LHCb-SciFi-Fibre-Mat

Production Documentation

at RWTH Aachen University

Version 1

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Production Description

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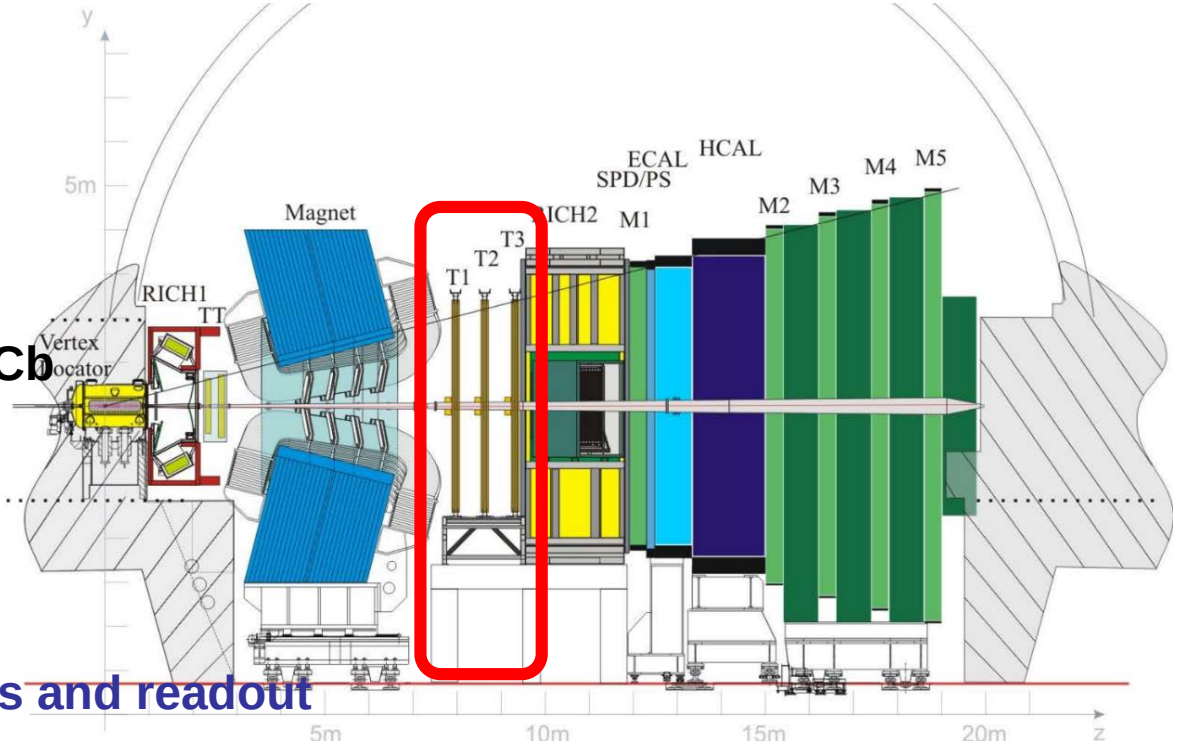
Introduction

LHCb Detector Upgrade

Motivation: Increase significantly the physics reach, especially for very rare decays

Limitations:
- **1MHz hardware trigger rate**
- **Detector occupancy**



Major tracking upgrade of LHCb (for after LS2, ≥2020, 50fb^{-1})

- **DAQ: a 40 MHz full readout**
- **New VELO**
- **RICH: new photon detectors and readout**
- **Calorimeters: remove SPD/PS and new readout**
- **Muon System: remove M1 and new readout**
- Tracking system: replace TT with new silicon strip detector (UT) and

  IT&OT with SciFi tracker (scintillating fibres with SiPM readout)

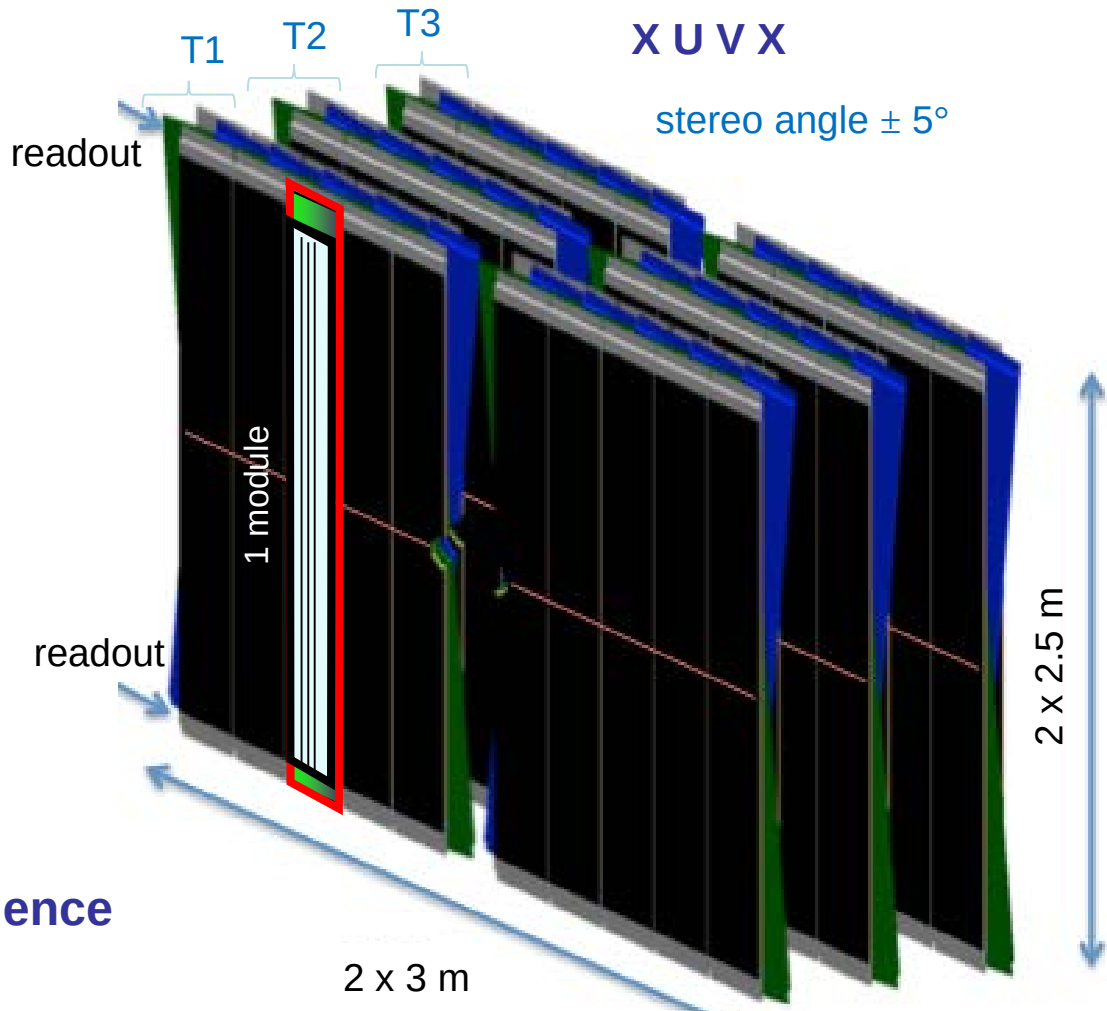
LHCb SciFi Tracker

General layout of the detector geometry:
3 stations with 4 planes each X-U-V-X (stereo angle 5°)

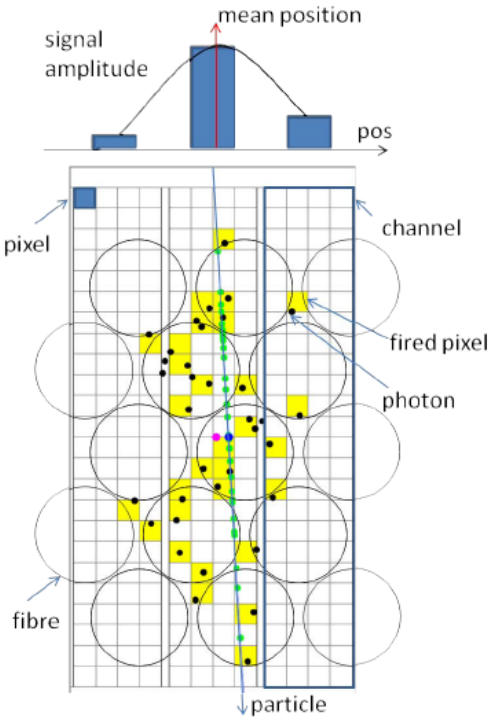
Requirements

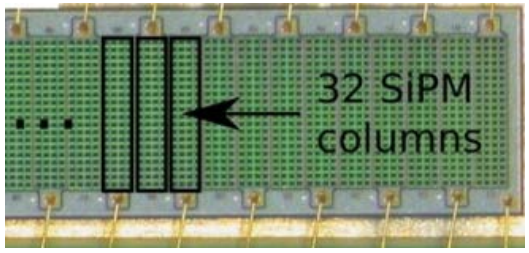
- **Hit detection efficiency:**
  single hits ~ 99%
- **Low material budget for single detector layer**
  ~1% X_0
- **Spatial resolution better:**
  100 µm in x-direction
- **40 MHz readout**
  without dead time
- **Radiation environment:**

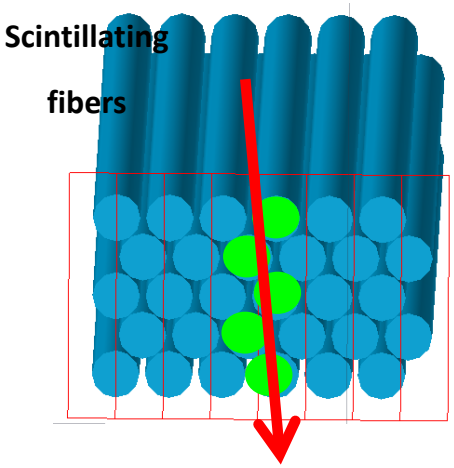
Fibres: up to 35 kGy,
SiPMs: approx. 1· 10^{12} n/cm^2 fluence
+ 100 Gy ionizing dose

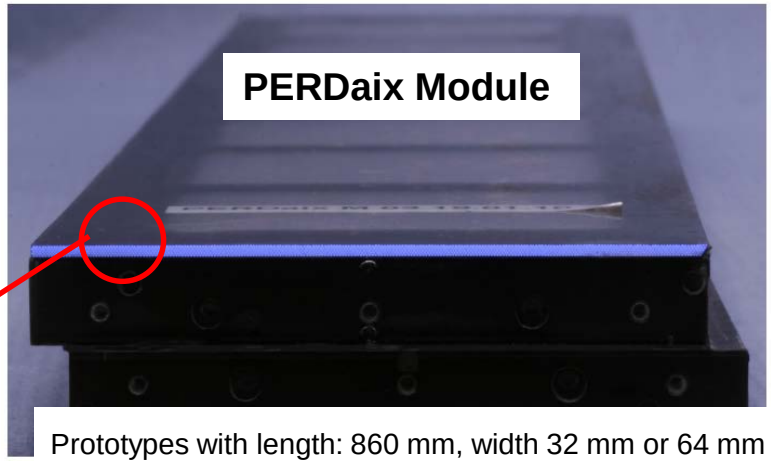


LHCb Scintillating Fibre Tracker: Principle

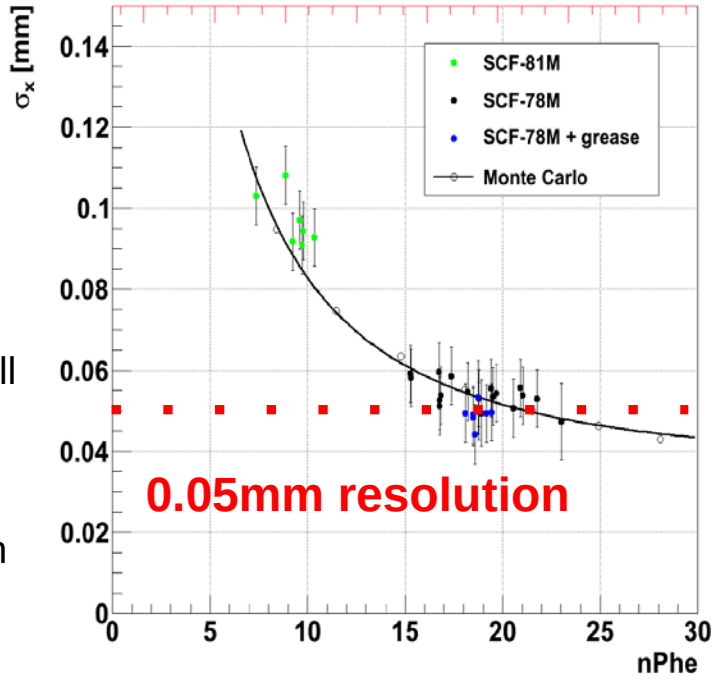








Prototypes with length: 860 mm, width 32 mm or 64 mm

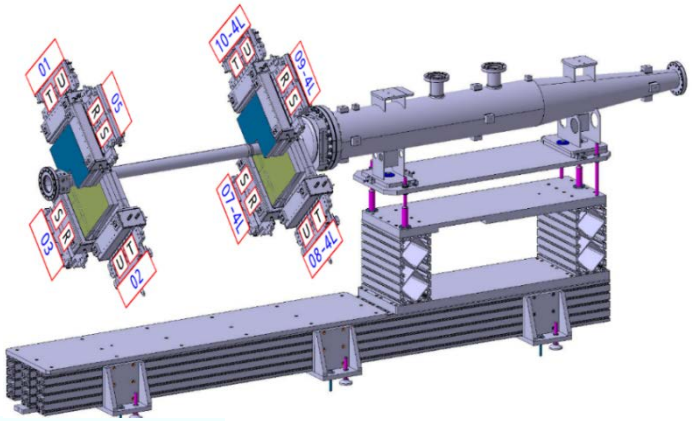


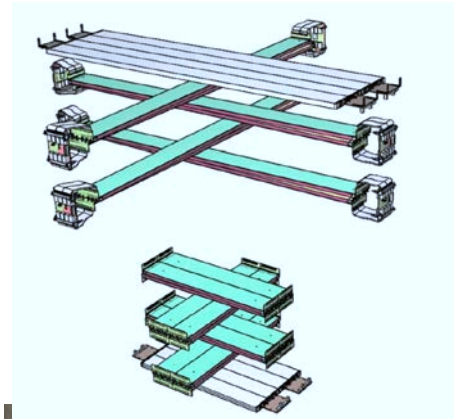
- Staggered layers of Ø250 μm fibres form a fibre mat
- Readout by arrays of SiPMs. 1 SiPM channel extends over the full height of the mat.
- Pitch of SiPM array should be similar to fibre pitch. Light is then spread over few SiPM channels. Centroiding can be used to push the resolution beyond p/sqrt(12).

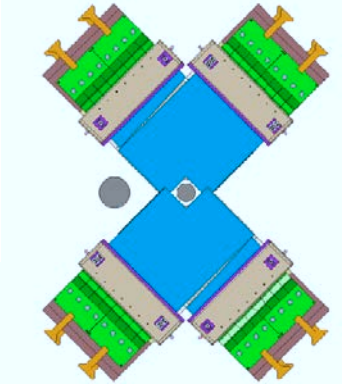
LHCb Scintillating Fibre Tracker: History

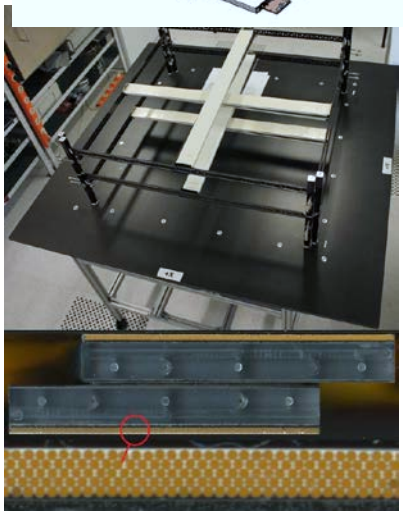
Scintillating Fibres and SiPMs as Photodetectors: The SciFi tracker is following the technology developed by the PERDaix detector (balloon experiment),

Beam Gas Vertex (BGV) Detector and a Muontomograph





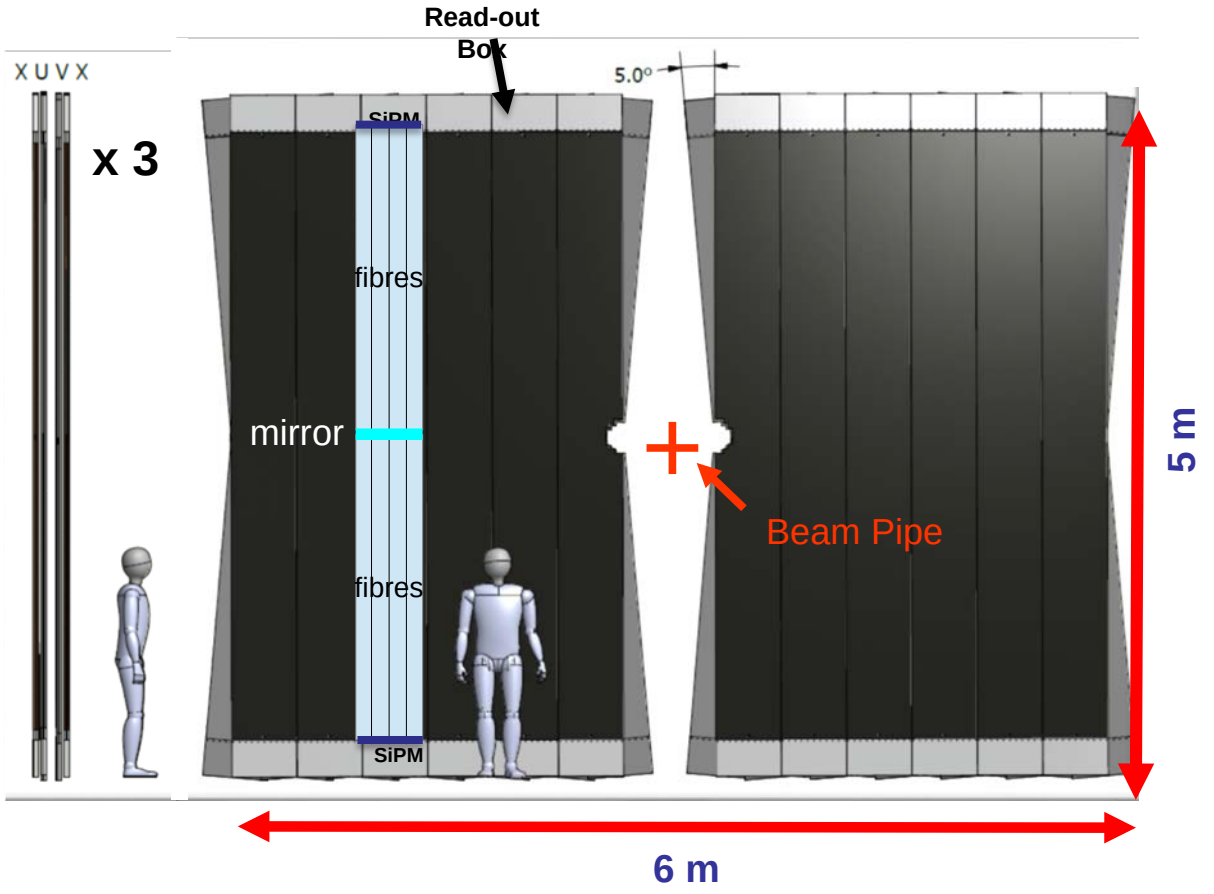




- Fibre Mats: Length: 30cm – 100cm, width: 32-64 mm, Layers:4-5

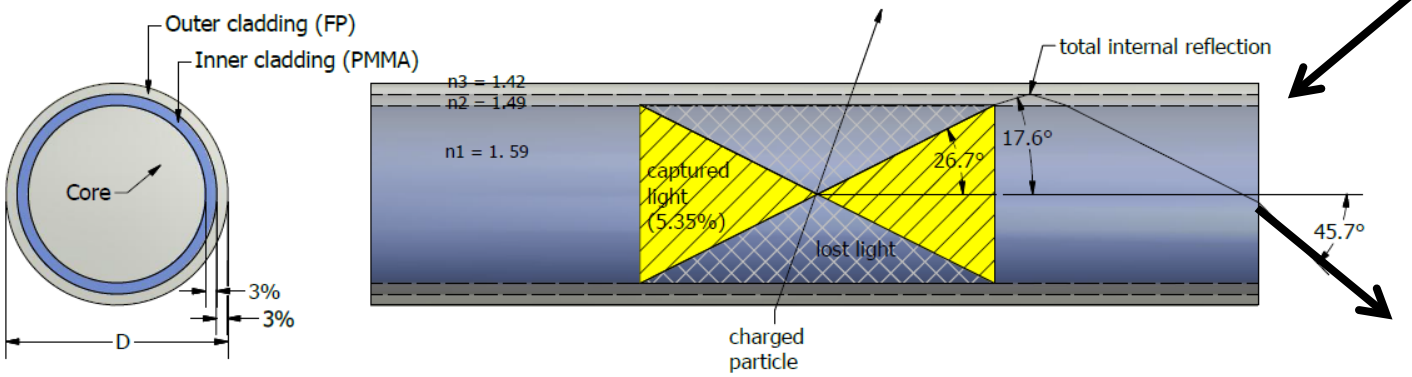
LHCb SciFi Tracker

- **144 modules** in 12 layers
- **360 m²** total area
- Module Carriers made out of CF skin and Nomex honeycomb
- **1 Module** consists of **8 fibre mats** (**1152 mats**)
- Fibre mats (**6 layers** per mat) run in vertical direction (L≈ 2 x 2.5m) sandwiched in module carriers (**1.1% X0**),
- Fibres: Ø 250µm, L=2.5m, **total length >10,000 km**)
- Fibres interrupted in mid-plane (y=0) and mirrored
- Read out at top and bottom with SiPM arrays (128 channels, 250 µm pitch)
- 590k SiPM channels
- SiPMs + FE electronics + services in a “Readout Box”



LHCb SciFi Tracker: Scintillating Fibres

Kuraray SCSF-78MJ fibres: Ø (250 ± 15) µm, 6 fibre layers per mat, each layer with 512 fibres with length 2.5m → 10,000 km fibres



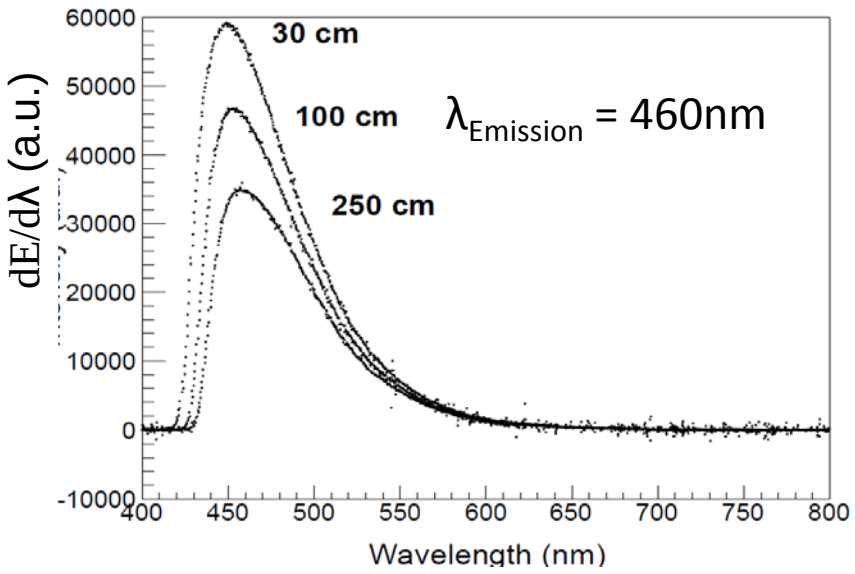
(Scintillator)

Polystyrene core with 2 dyes

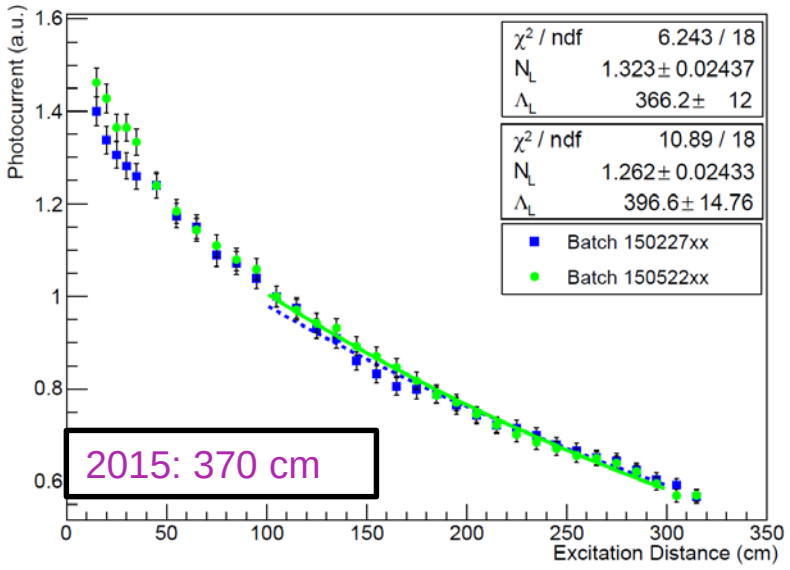
Only a few photons after 2.5m

300 photons per MIP produced (only 5% captured)

SCSF-78MJ



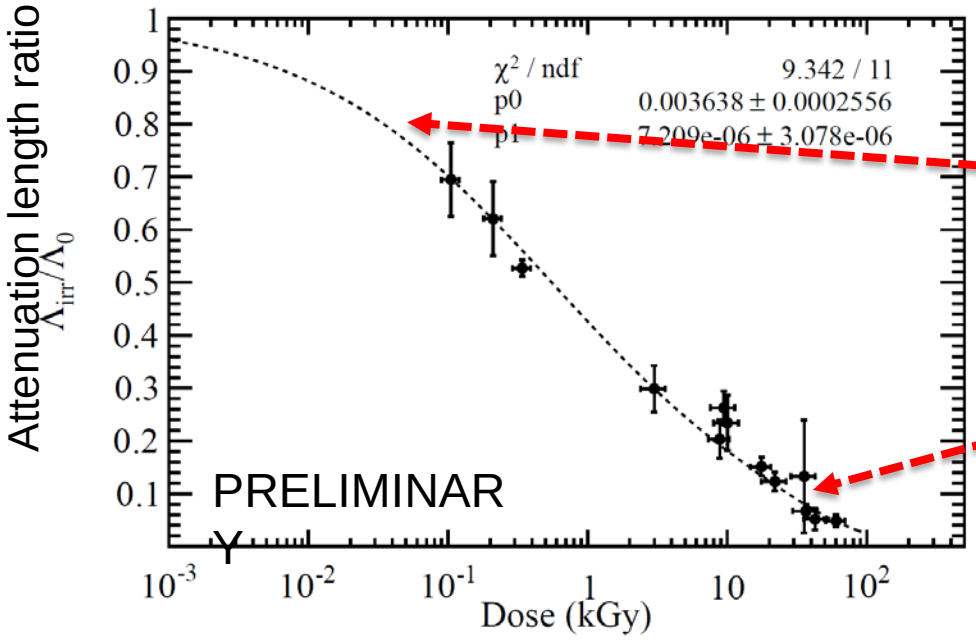
SCSF-78 (2015 fibres)



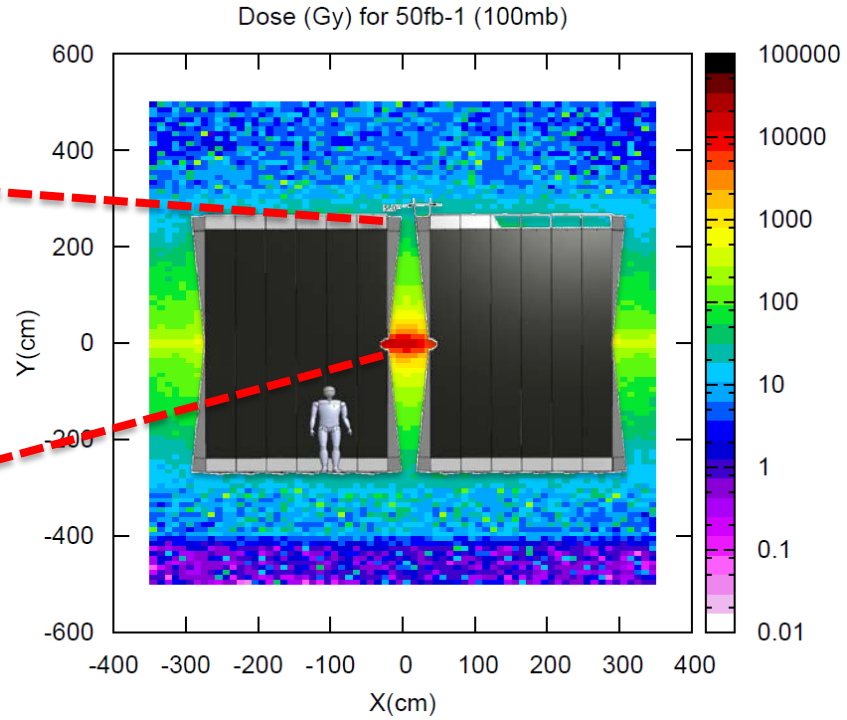
LHCb SciFi Tracker: Scintillating Fibres - Irradiation

Light transmission of scintillating fibre decreases under irradiation, (up to 35 kGy expected near the beam pipe over the upgrade lifetime)

A mix of low dose, low rate xray, gamma and high rate, high dose proton irradiations



Expected ionizing dose for LHCb Upgrade

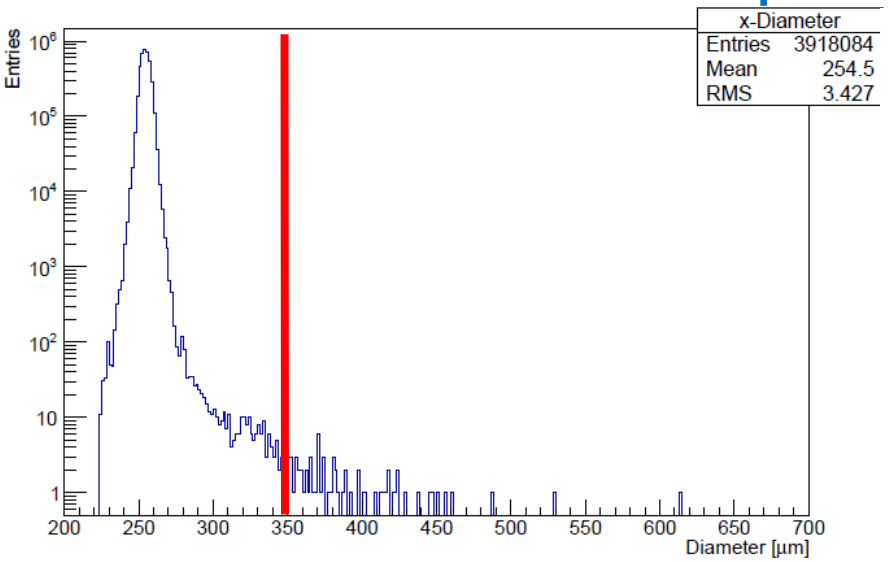


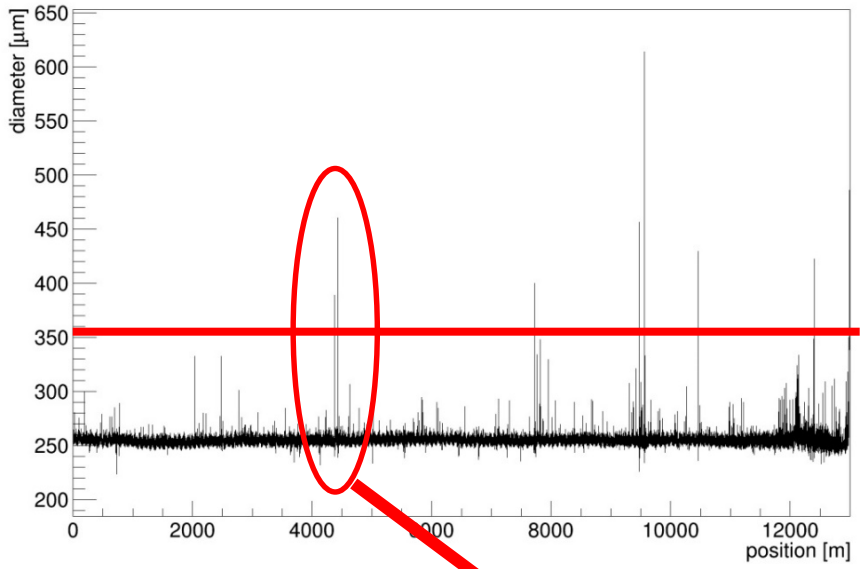
Up to 35 kGy near beam pipe, Down to 60 Gy in SiPM region

→ Expect a **40%** loss of transmitted light created near the beam pipe **after 10 years**

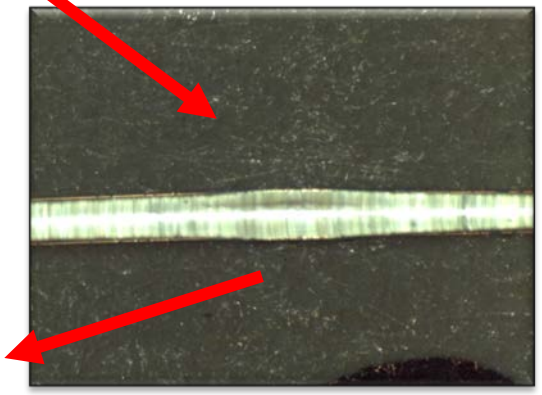
LHCb SciFi Tracker: Scintillating Fibres

Measurement of Fibre diameter profile (along fibre)

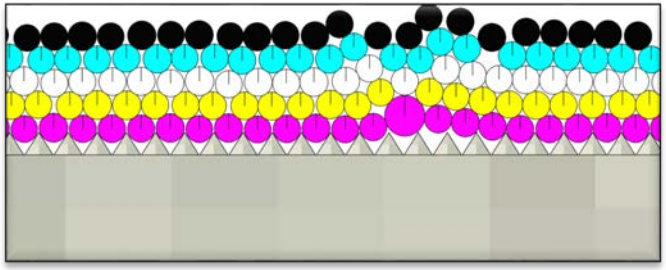




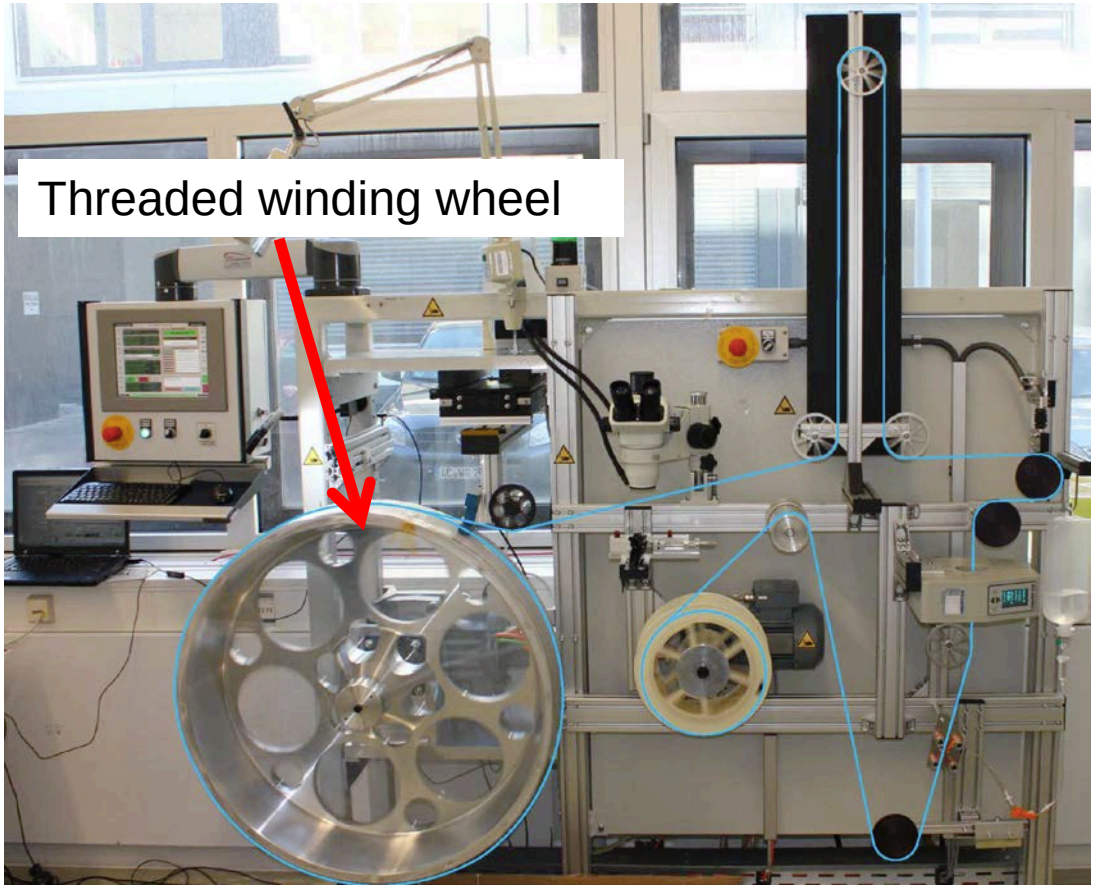
Fibre diameter (250 ± 7) µm,
But bumps appear (diameter >> 300 µm)
≈ 1 per km of fibre = 1 per layer of fibre mat.



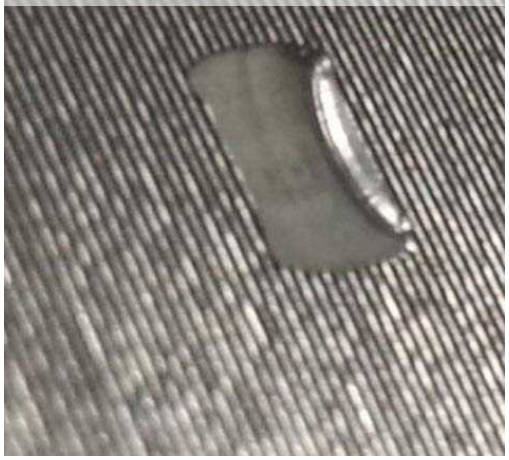
Possible to remove manually during winding process.

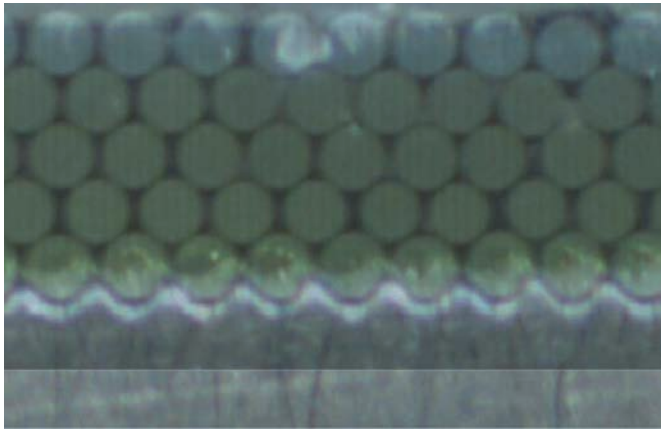


Principle of Fibre Mat Winding



Thread and hole for alignment pin





- First layer is directly wound onto hub,
- following layers are wound into groove-like depressions of preceding layers
- Need about 8km of fibre for one mat of 6 layers 2.5 meters long

→ 10,000 km of fibre in total

LHCb SciFi Tracker: Fibre Mats

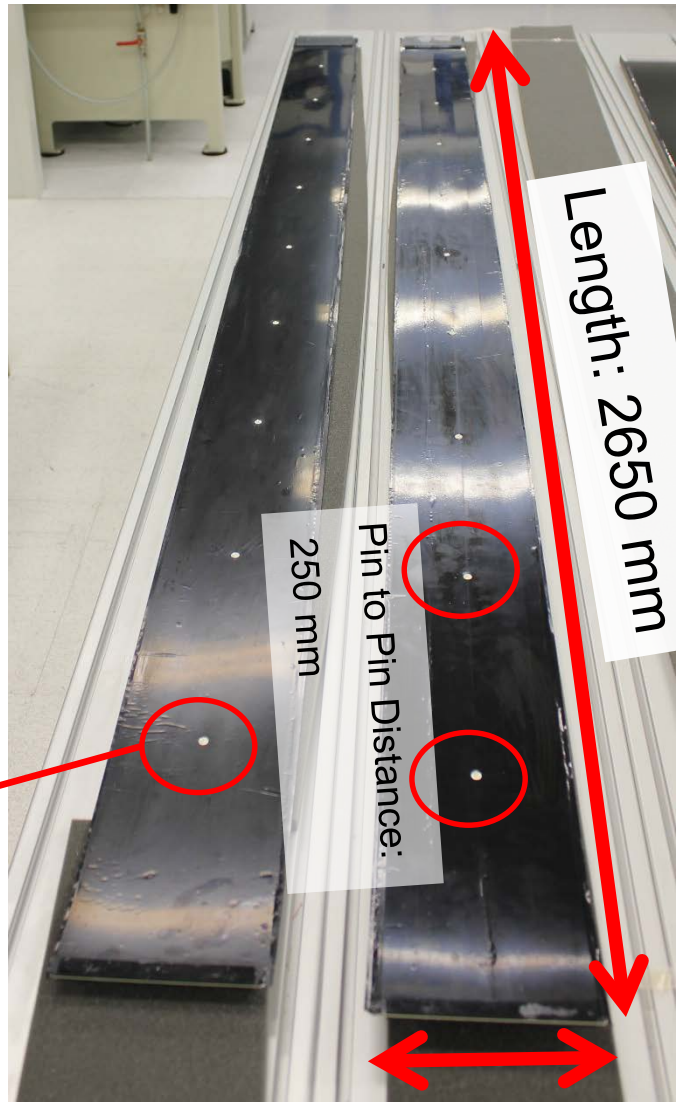
Foil lamination of SiFi mat is done to protect fibre mat and to make handling and shipping easier.

5 Production center for fibre mats:

2 in Russia (Kurchatov),

2 in Germany (RWTH Aachen, TU Dortmund)

and 1 in Switzerland (EPFL Lausanne)

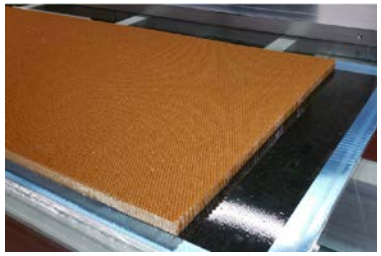


LHCb SciFi Tracker: Fibre Mat Modules:

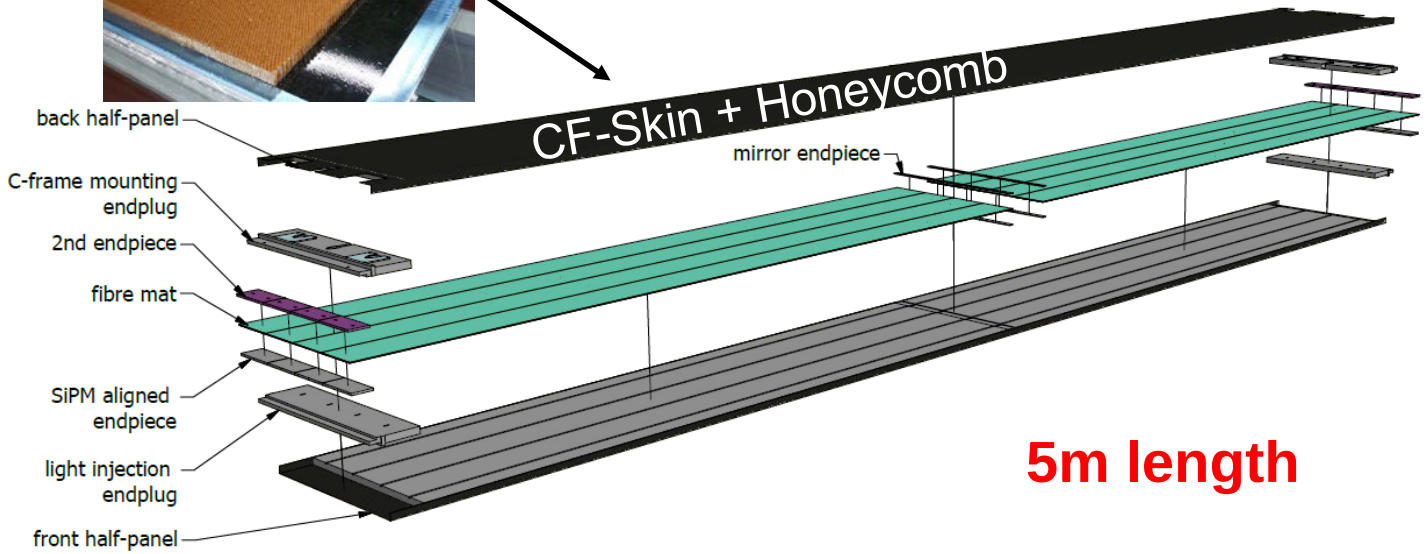
2 Module Center: Heidelberg Universität, NIKHEF Amsterdam

Fibre mats need to be assembled into a module that can be mounted and placed in the LHCb pit

- 8 mats aligned on a precision table
- Bond a carbon fibre + Nomex core structure to make a strong rigid object → Precision in time in z-direction better than 300 µm



144 Modules, 360 m² total area, 1152 SciFi mats



5m length

CFRP 200 µm
Epoxy 75 µm
Honeycomb 20 mm
Epoxy 75 µm
Foil 23 µm
Epoxy 27 µm
SciFi Mat
Epoxy 27 µm
Foil 23 µm
Epoxy 75 µm
Honeycomb 20 mm
Epoxy 75 µm
CFRP 200 µm

Material Budget:

1.1% X0

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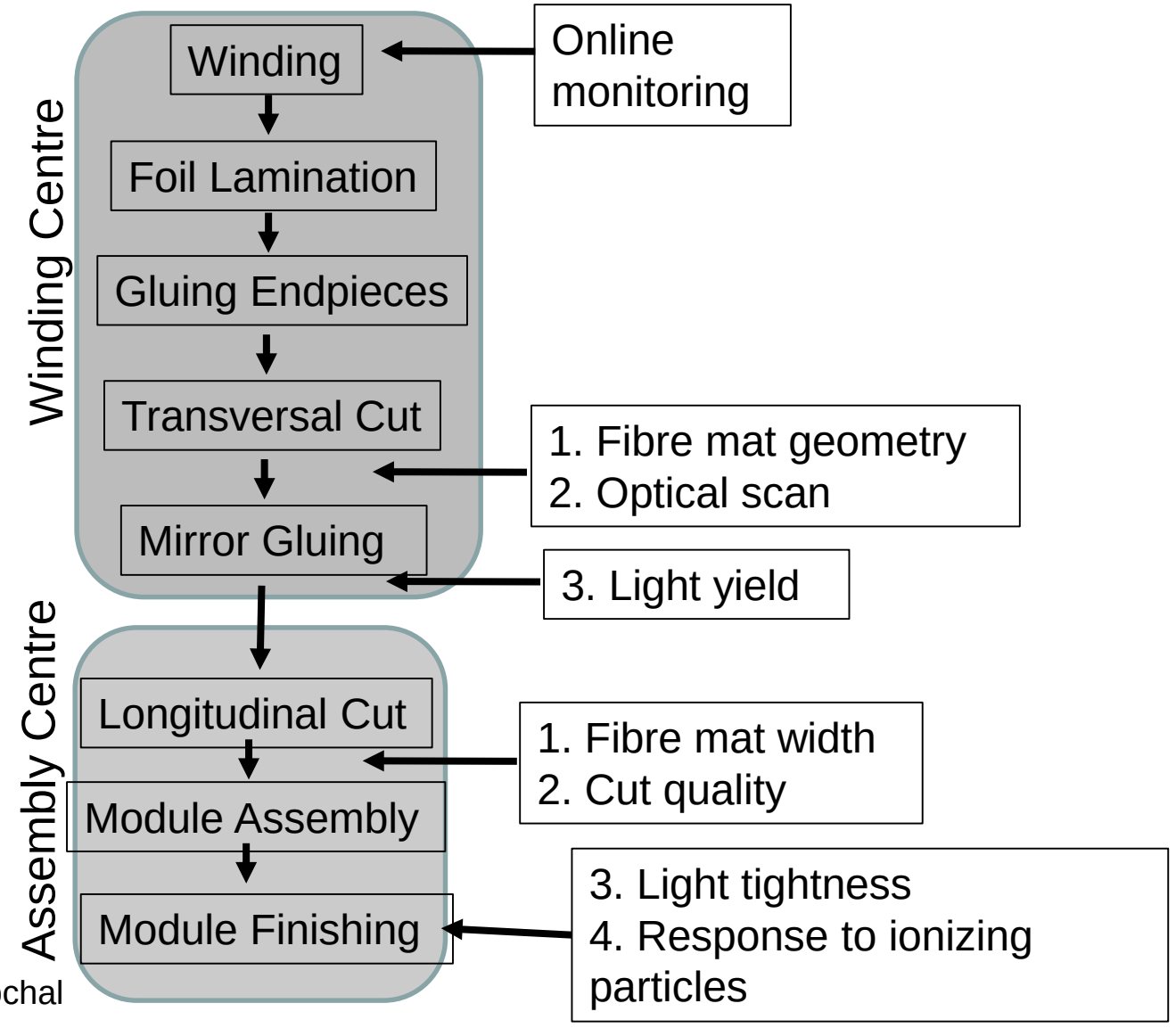
Production and Quality Control at Fibre Mat Winding Centres



Winding Process

Winding
Process Steps

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2. Mounting of winding wheel to winding machine 29
3. Preparation of winding machine 40
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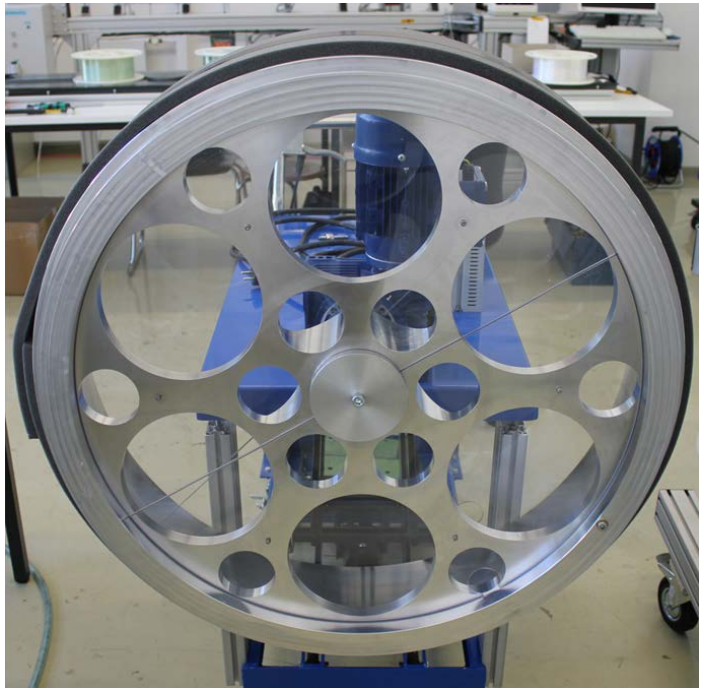
1. Preparation of Winding Wheel

1. Mount winding wheel on rotation cart 19
2. Cleaning of relevant surfaces for winding process like thread, pin-holes, cutting groove and all surfaces which could have contact with glue. 21
3. Apply Release Agent (Mikon 205) 3 times according to instruction manual 23
4. Follow supplier recommendation: Drying last layer of release agent overnight! 27

1. Preparation of Winding Wheel

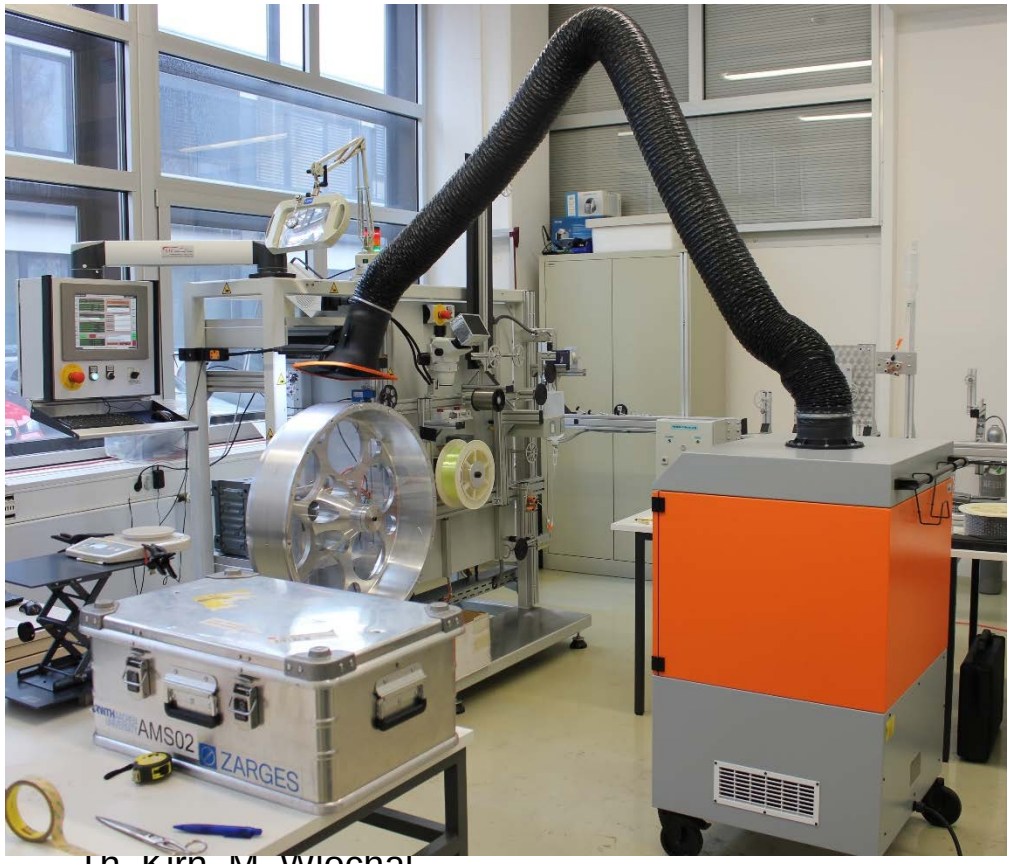
1. Mount winding wheel on rotation cart



1. Preparation of Winding Wheel

Attention: Respect Health and Safety Rules for steps 2, 3 and 4 !!!

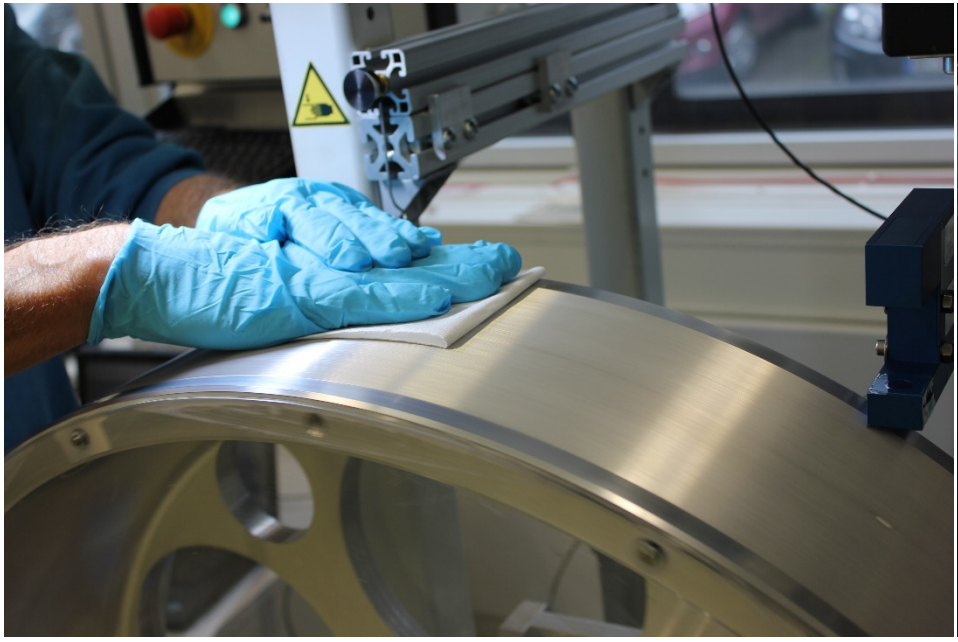
Do the next steps, cleaning of relevant surfaces, in a ventilated room or/and use in addition a vacuum exhauster and use a breathing mask

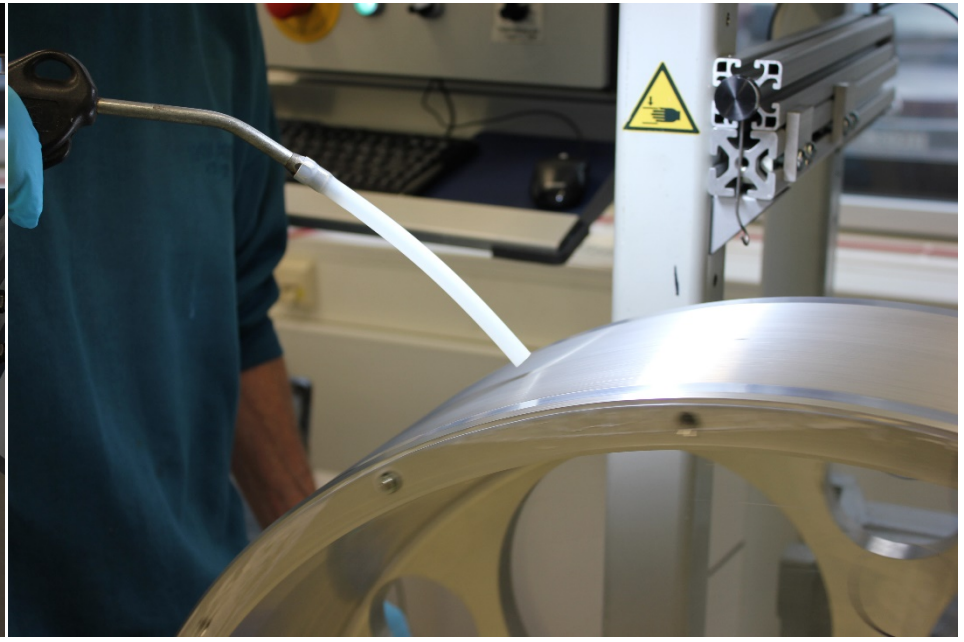


1. Preparation of Winding Wheel

2. Cleaning of relevant surfaces for winding process like thread, pin-holes, cutting groove and all surfaces which could have contact with glue. Cleaning agent: Zyvax Surface Cleaner, if necessary acetone and isopropanol

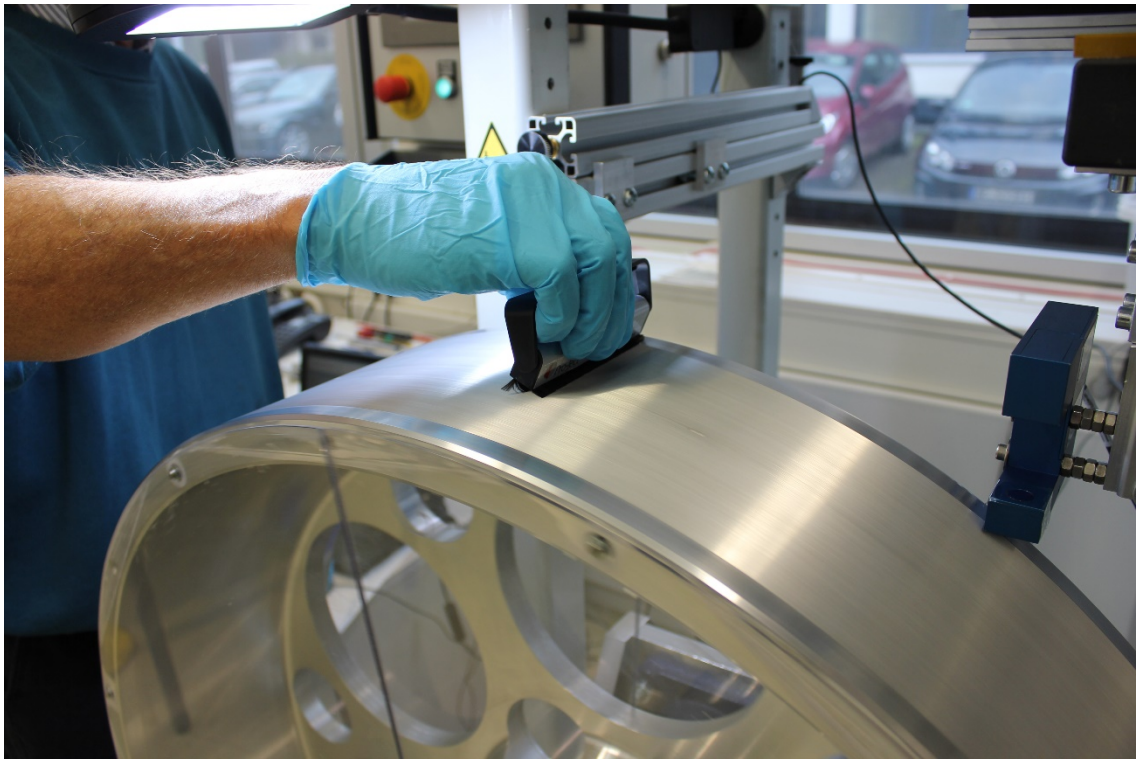
Use dry clean air to blow out pin-holes





1. Preparation of Winding Wheel

2. Cleaning of relevant surfaces for winding process like thread, pin-holes, cutting groove and all surfaces which could have contact with glue. Cleaning agent: Zyvax Surface Cleaner, if necessary acetone and isopropanol. Remove remaining dirt from wheel



1. Preparation of Winding Wheel

3. Apply Release Agent (Mikon 205) 3 times according to instruction manual.

Use a cloth to apply release agent to winding wheel

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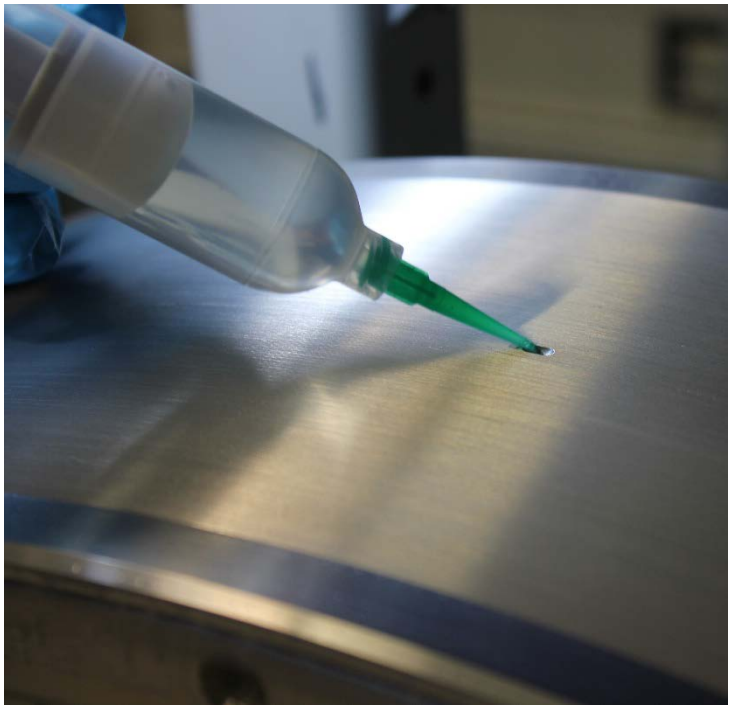
3. Apply Release Agent (Mikon 205) 3 times according to instruction manual

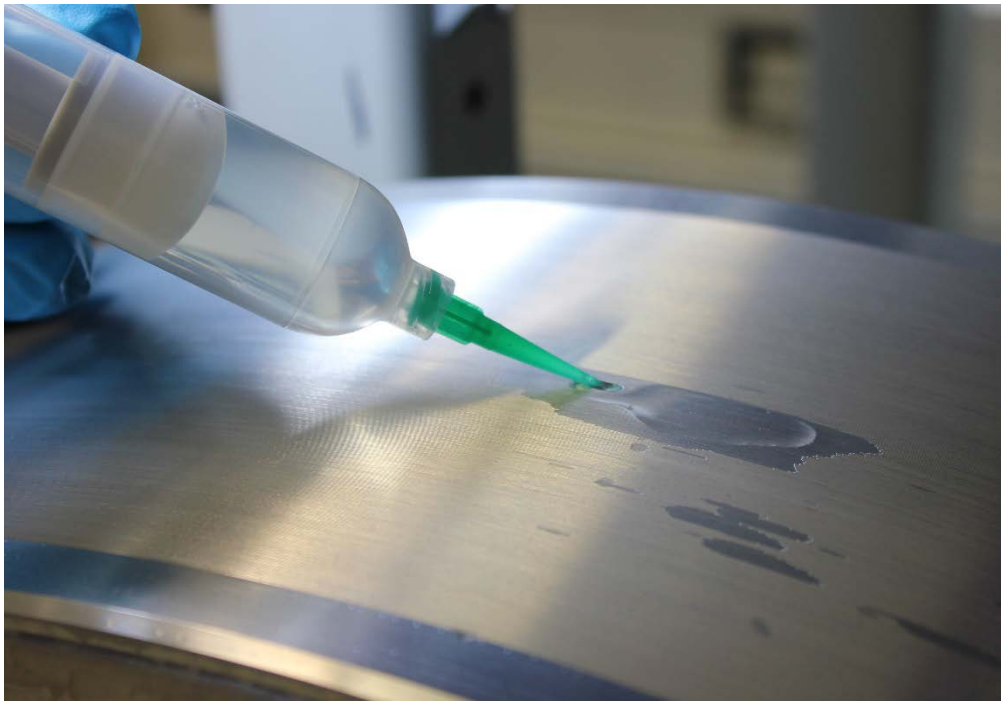
Use a cloth to apply release agent to winding wheel

1. Preparation of Winding Wheel

3. Apply Release Agent (Mikon 205) 3 times according to instruction manual

Fill release agent into cartridge, close cartridge with plug and mount it to cartridge gun

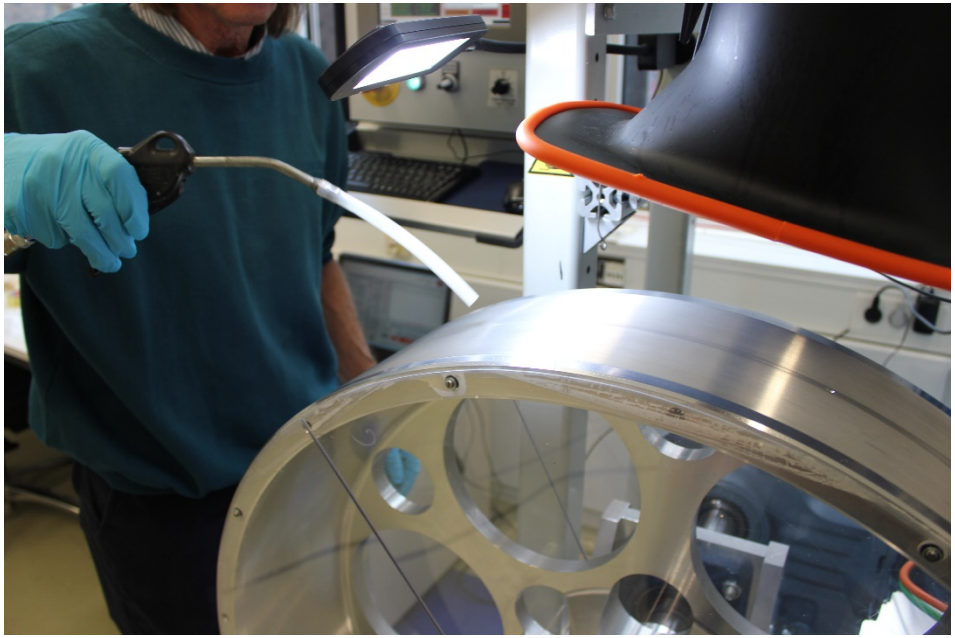




1. Preparation of Winding Wheel

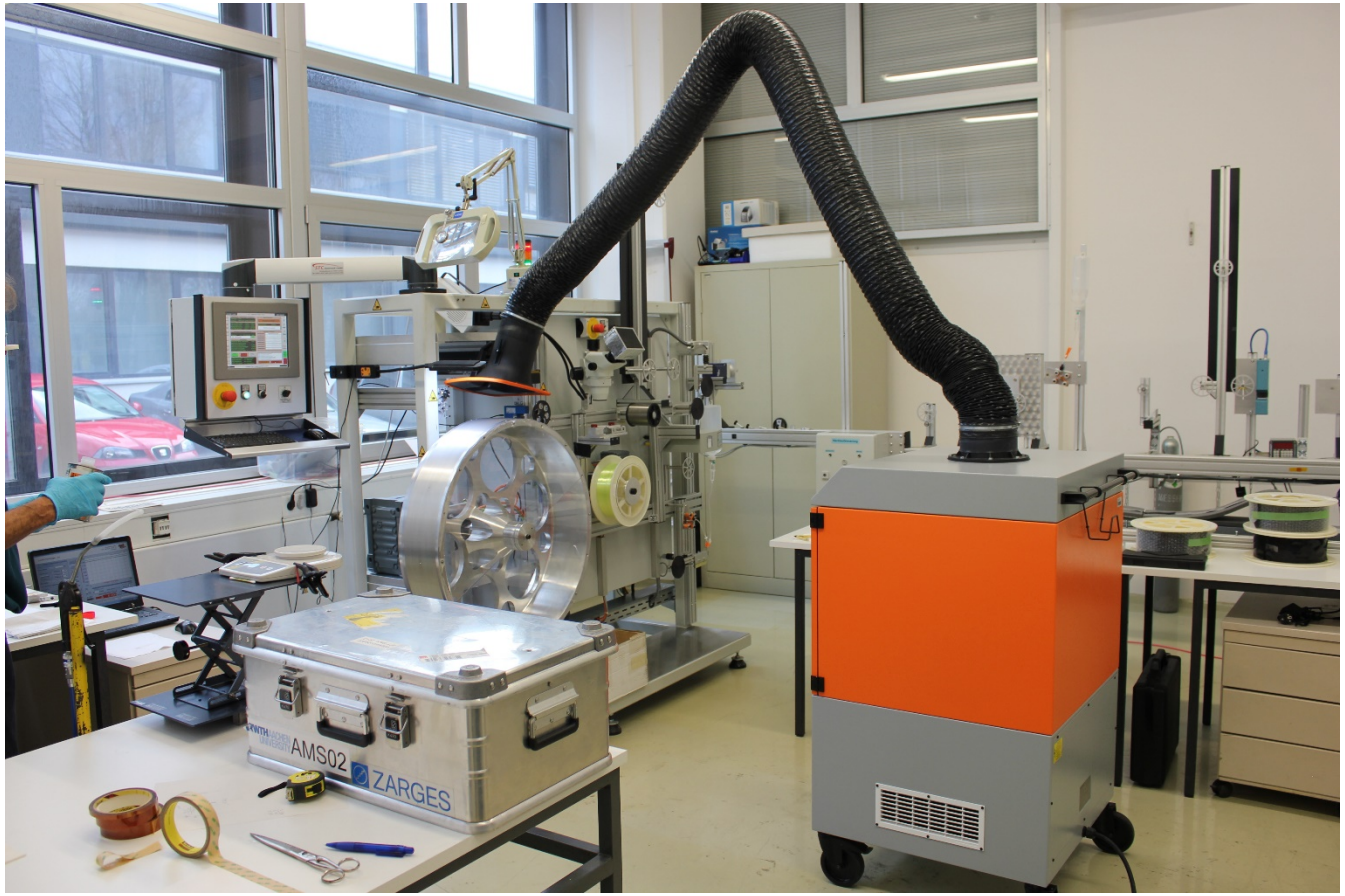
3. Apply Release Agent (Mikon 205) 3 times according to instruction manual

Continue distribution of release agent on wheel



1. Preparation of Winding Wheel

4. Follow supplier recommendation: Drying last layer of release agent overnight!



1. Preparation of Winding Wheel

With 1time applied Release Agent:

4 fiber mats can be produced, after each fiber mat winding wheel glue residuals need to be removed. Depending of the quality of the unforming one has to decide if a new additional layer of release agent is necessary!

After 4 fiber mats winding wheel must be cleaned completely and new portion of release agent is needed.

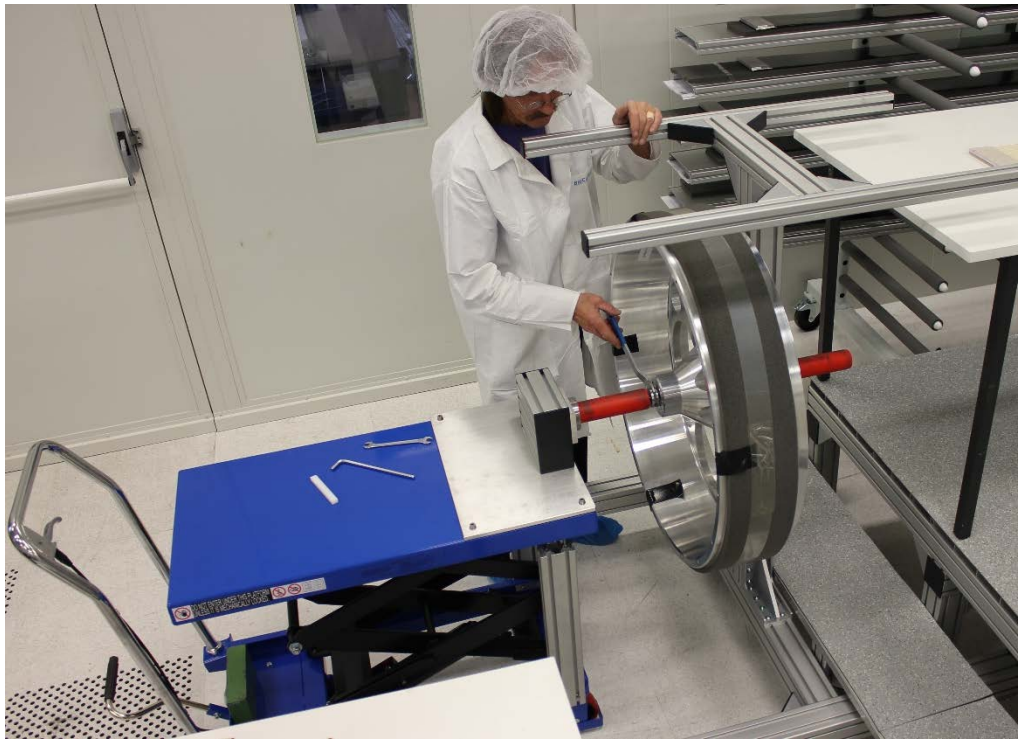
2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart 30
2. Drive wheel on handling cart to winding machine 35
3. Move wheel with crane in front of rotation axis of winding machine 36
4. Mount winding wheel on rotation axis 38
5. Mount wheel retainer with a screw to rotation axis. 39
6. Adjust start and stop parameters in STC software according to winding wheel parameters 39

2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart by

a) first screwing together axles from cart and storage rack using adapter.



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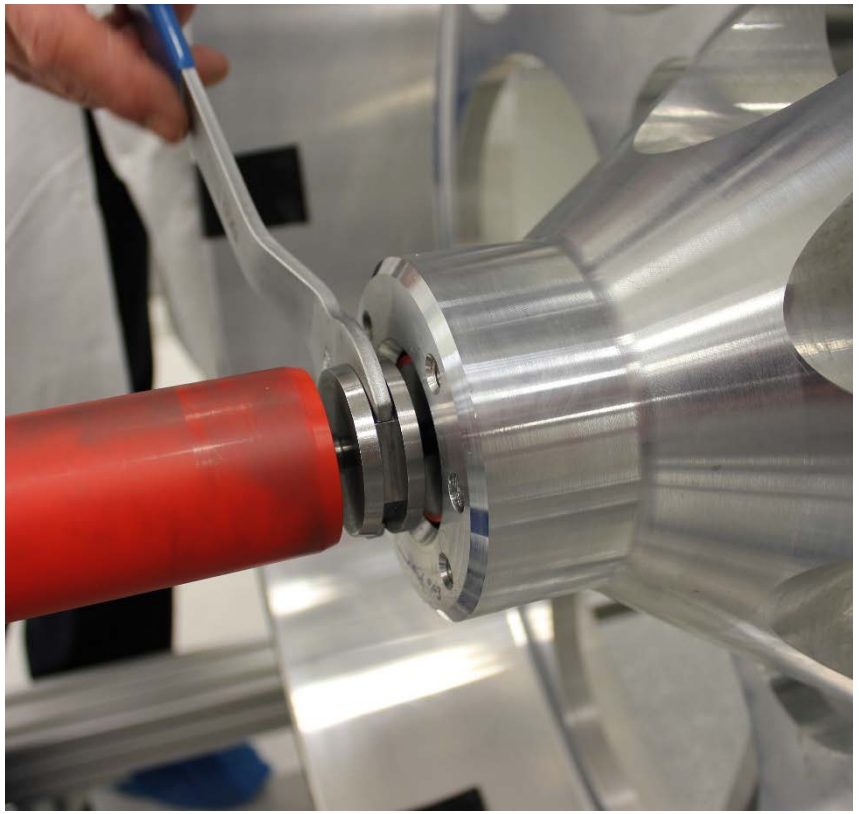

2. Mounting of winding wheel to winding machine

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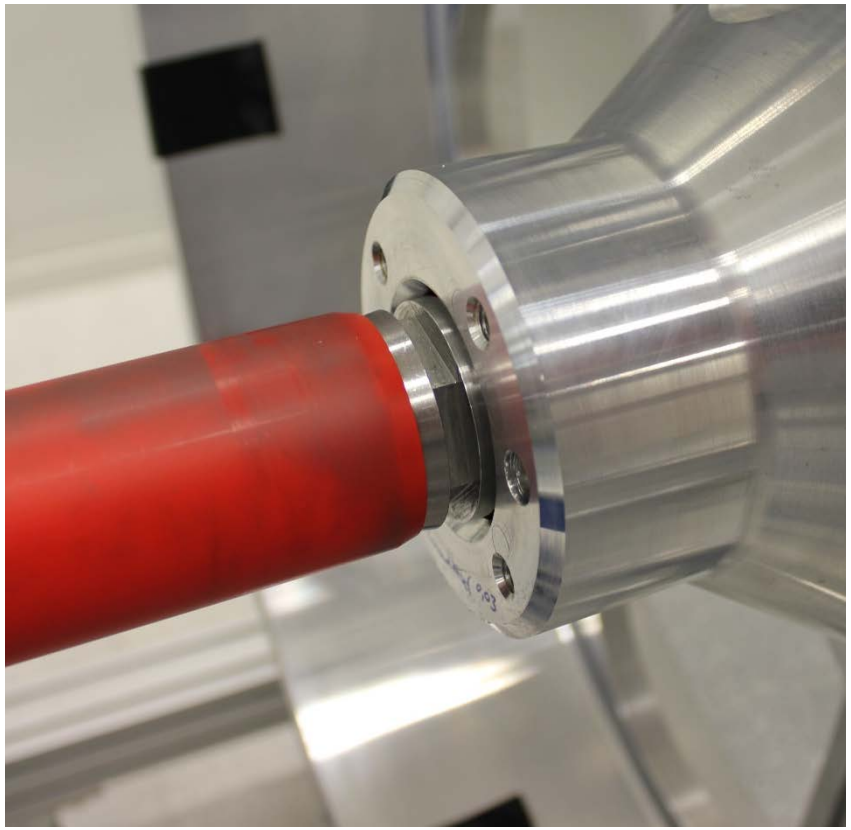
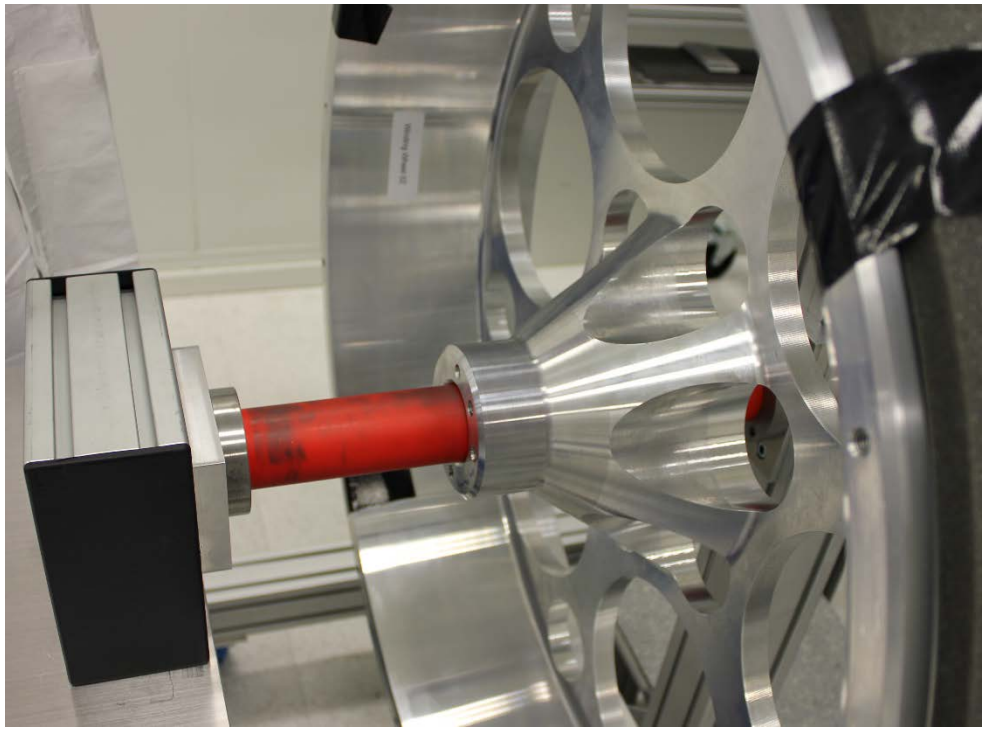
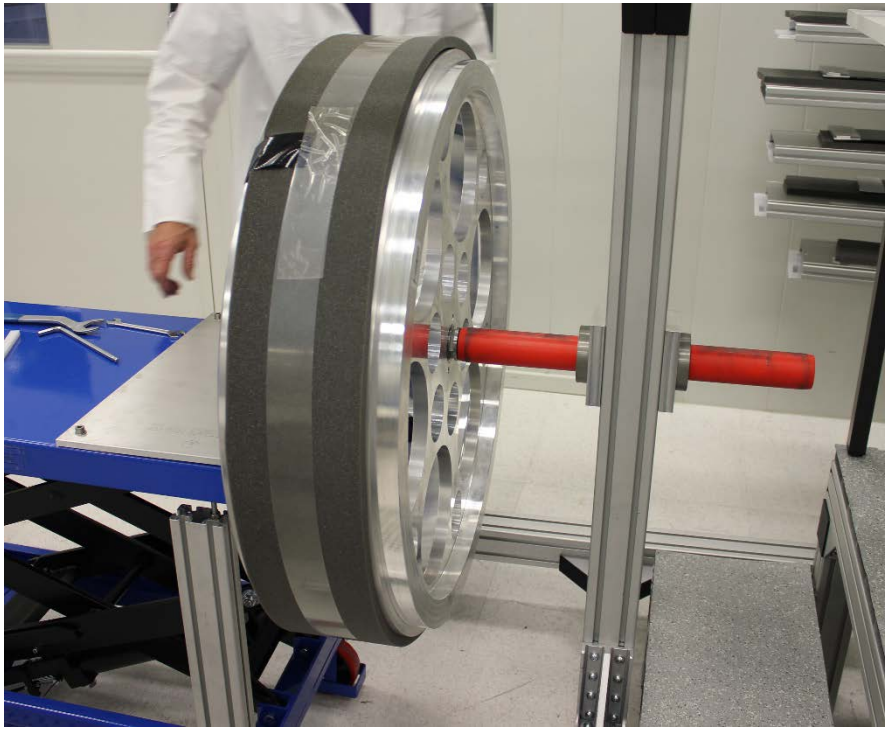


2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart by

b) sliding it.

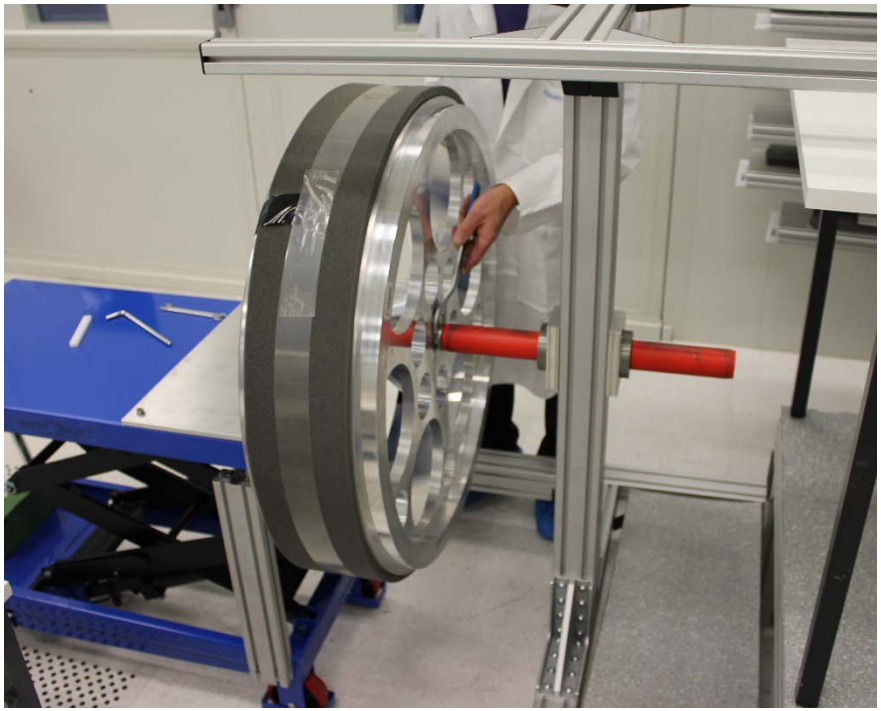




2. Mounting of winding wheel to winding machine

1. Transfer winding wheel from storage rack to handling cart

c) After the transfer unscrew axles again.



2. Mounting of winding wheel to winding machine

2. Drive wheel on handling cart to winding machine.

2. Mounting of winding wheel to winding machine

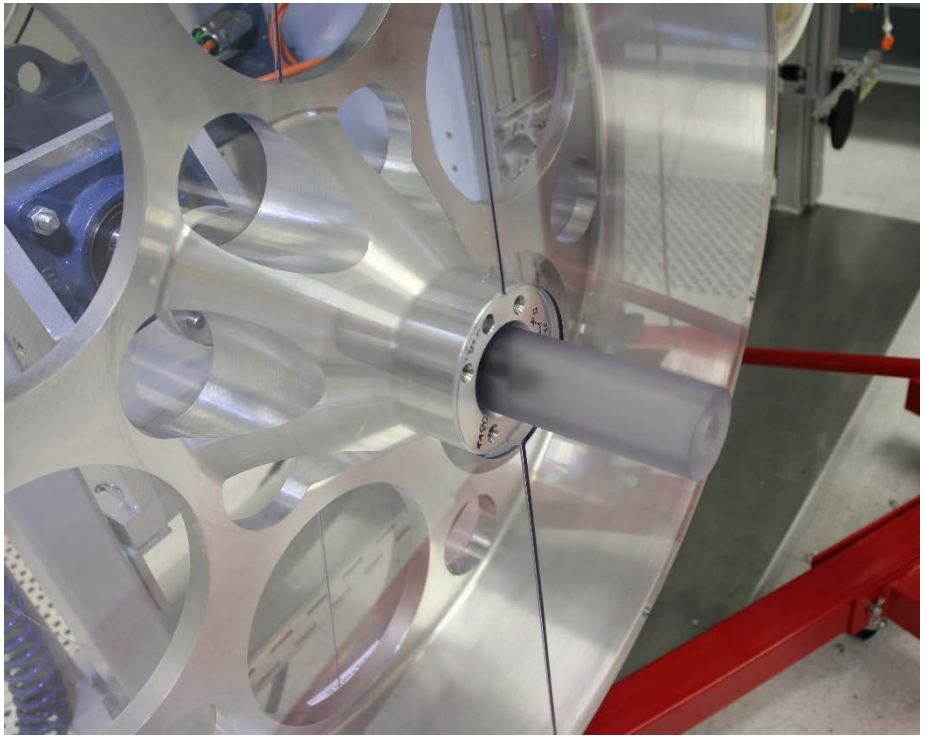
3. Move wheel with crane in front of rotation axis of winding machine

a) Mount wheel to crane

2. Mounting of winding wheel to winding machine

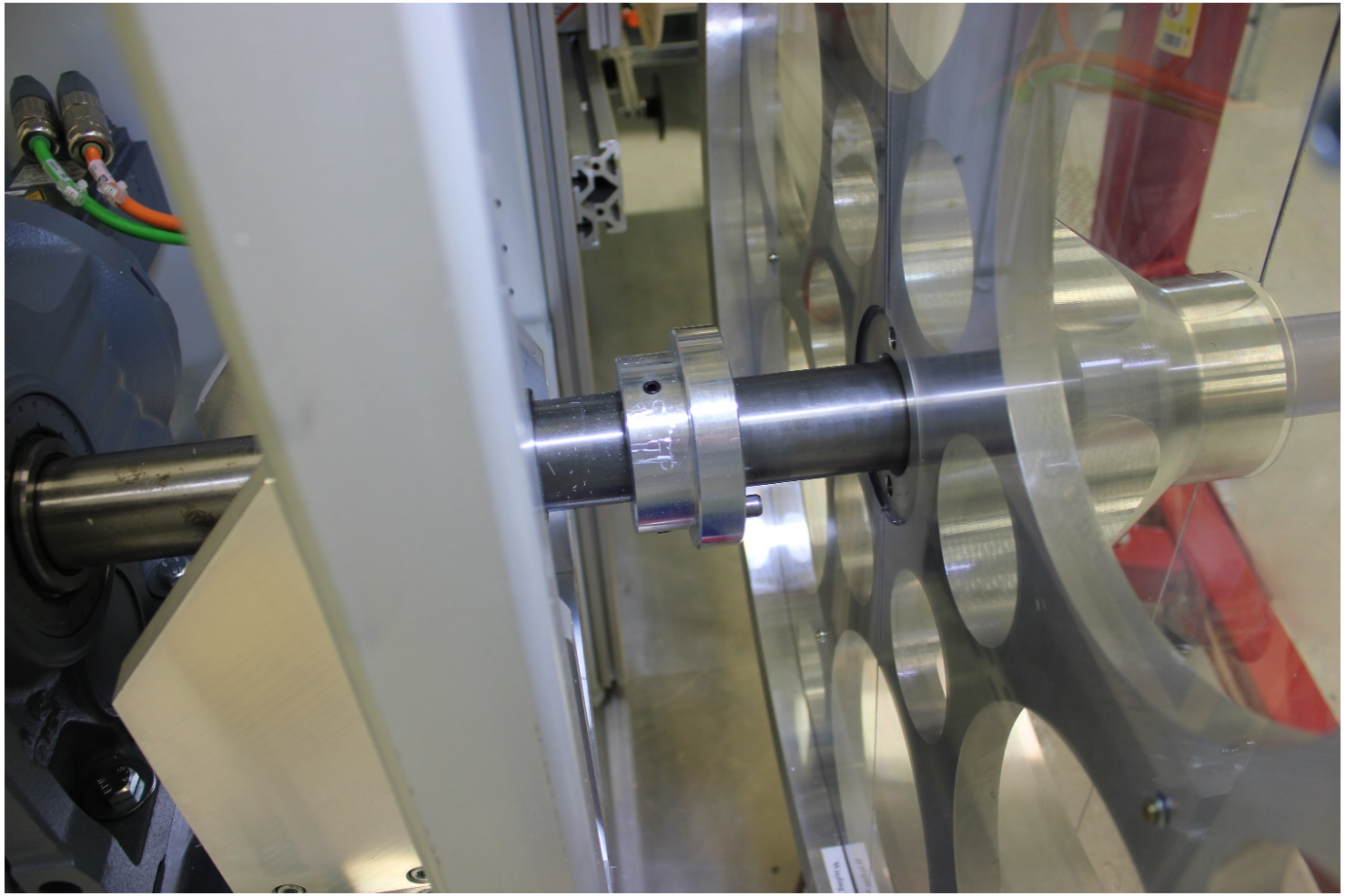
3. Move wheel with crane in front of rotation axis of winding machine

b) Move crane with wheel in front of rotation axis of winding motor. Transfer wheel to winding machine via adapter screwed to rotation axis of winding motor.



2. Mounting of winding wheel to winding machine

4. Mount winding wheel on rotation axis



2. Mounting of winding wheel to winding machine

5. Mount wheel retainer with a screw to rotation axis.

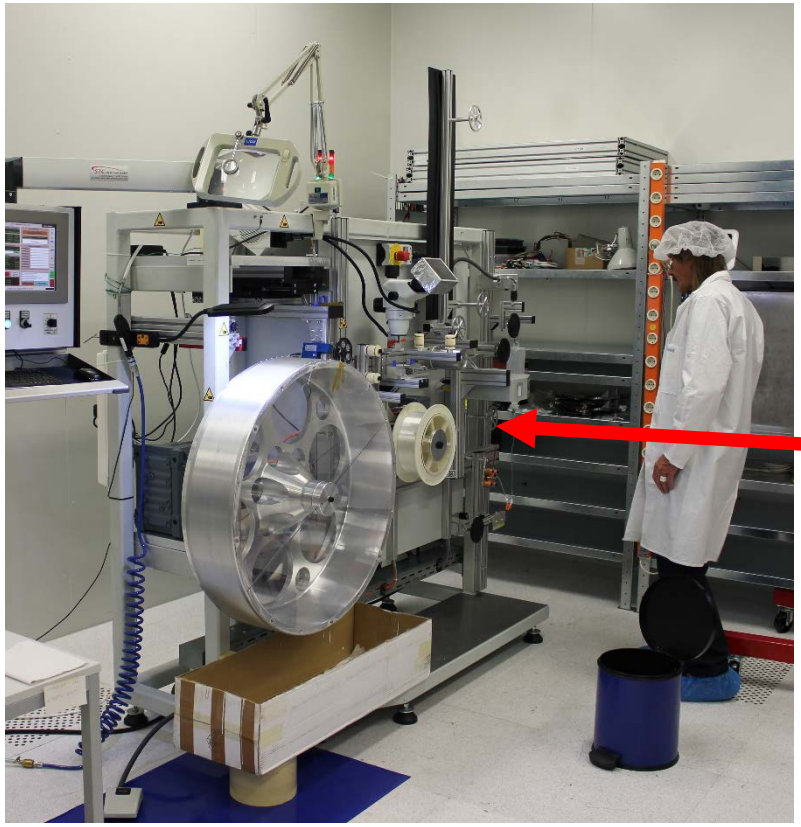
6. Adjust start and stop parameters in STC software according to winding wheel parameters.

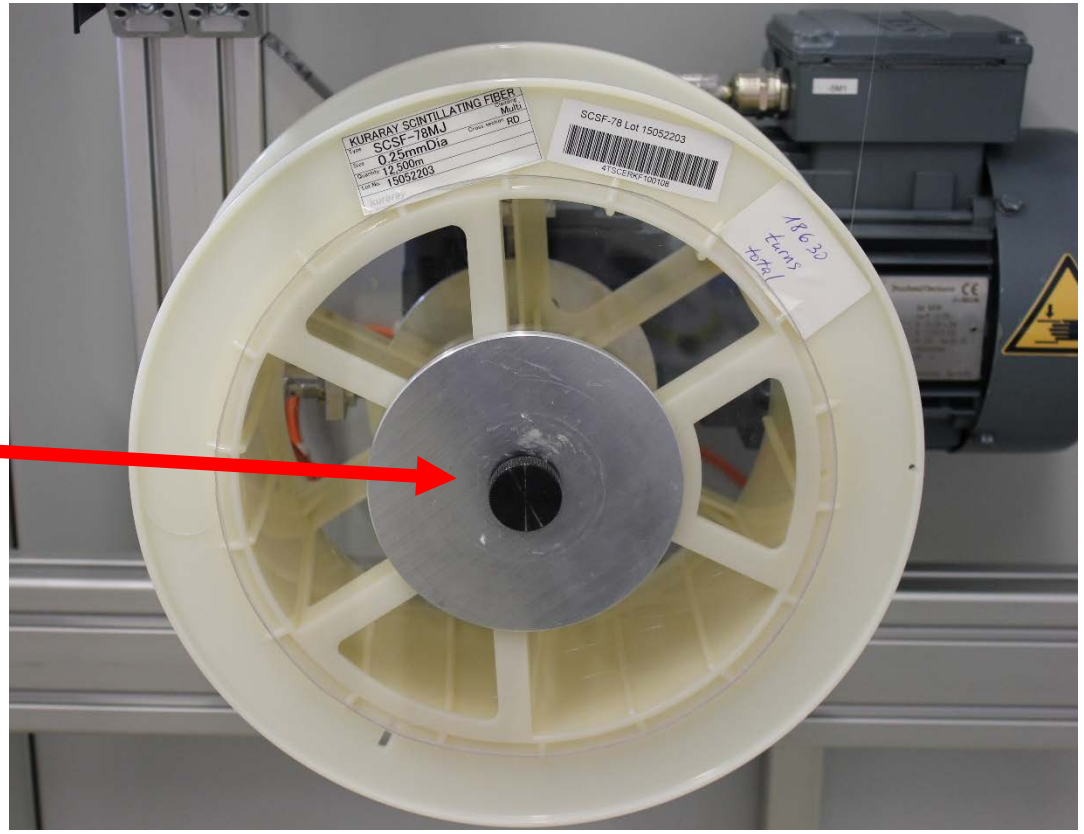
3. Preparation of winding machine

1. Mount Take-off spool with fibres to STC winding machine 40
2. Mount fibre to pulleys 41
3. Start up STC winding machine 41

3. Preparation of Winding Machine

1. Mount Take-off spool with fibres (delivered by Kuraray, tested by CERN) to STC winding machine

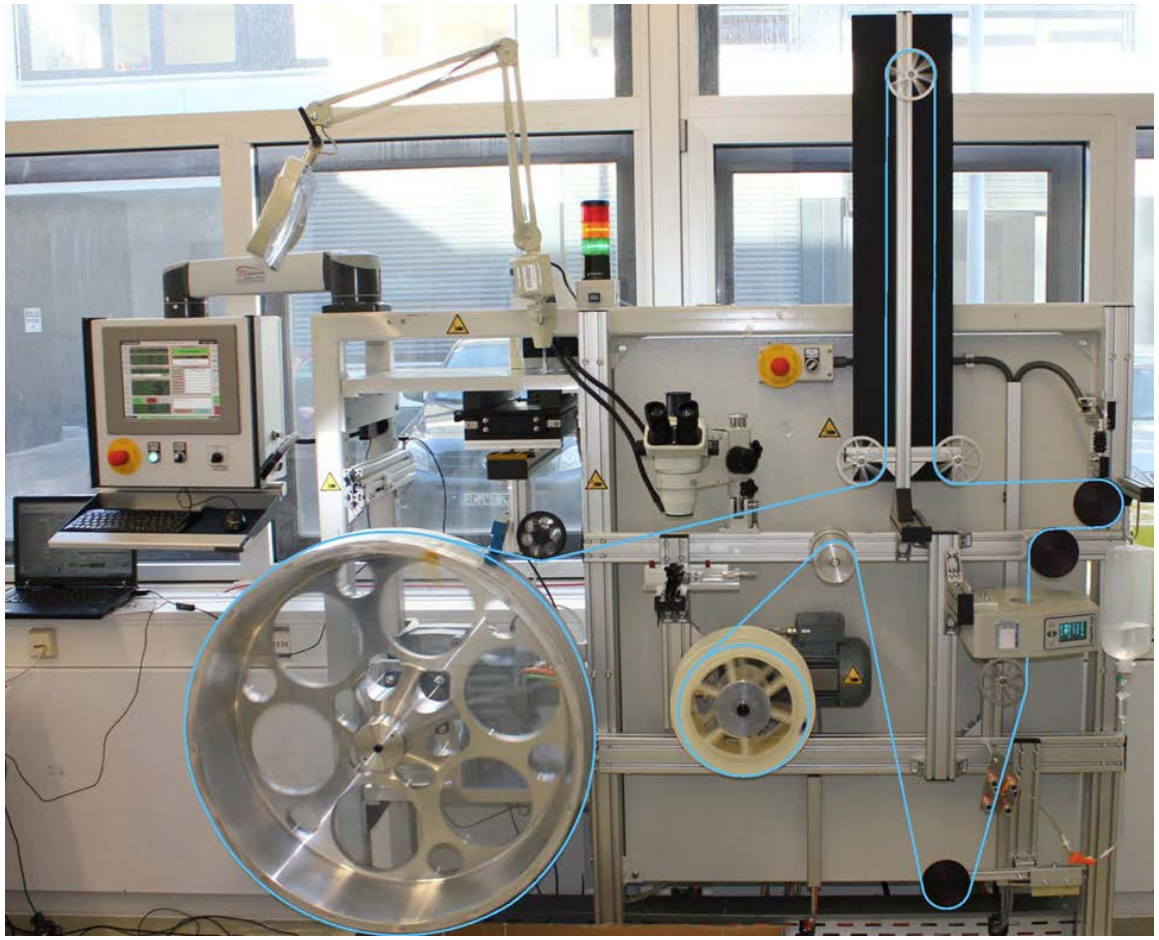




3. Preparation of Winding Machine

2. Mount fibre to pulleys as shown in photo

3. Start up STC winding machine



4. Winding of fibre mat

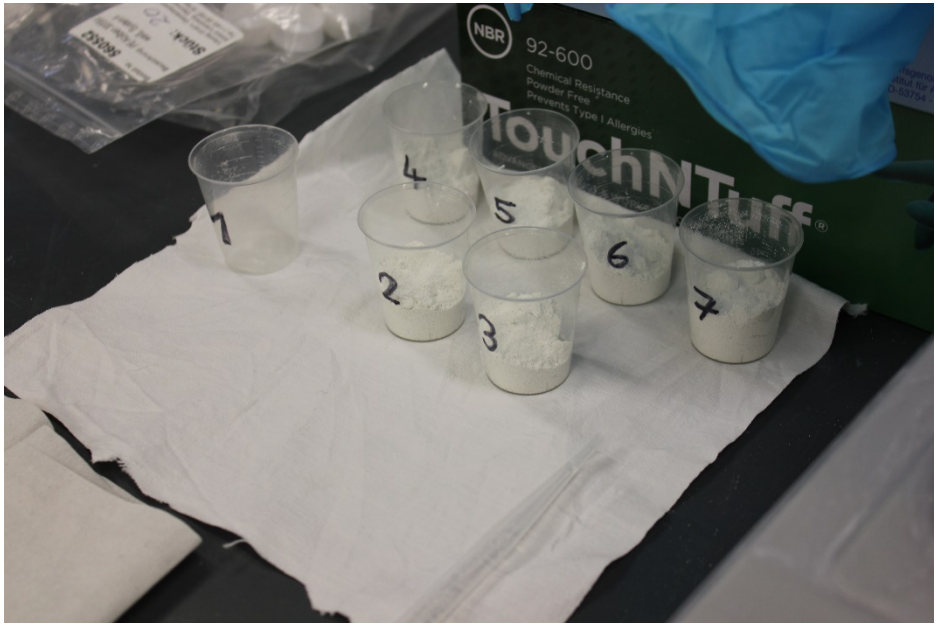
1. Prepare 7 portions of TiO_2 in measuring cups using a mesh to prevent clustering of TiO_2, protect cups against dust and humidity. 44
2. Cup 1: Fill Part A (binder) into cup with TiO_2 and premix by hand using a metallic spatulae; Prepare mixture of glue and TiO_2 (Epotek 301 -2 + 25% TiO_2) for layer 1 45
3. Prepare cartridge with a 0.5mm cone which is used to fill glue into pin holes of winding wheel. Fill glue mixture into cartridge, close cartridge with plug and mount it to cartridge gun 48
4. Apply mixed glue to wheel before first layer winding 49
5. Winding of first layer 58
6. Winding of layer 2 to 6 72

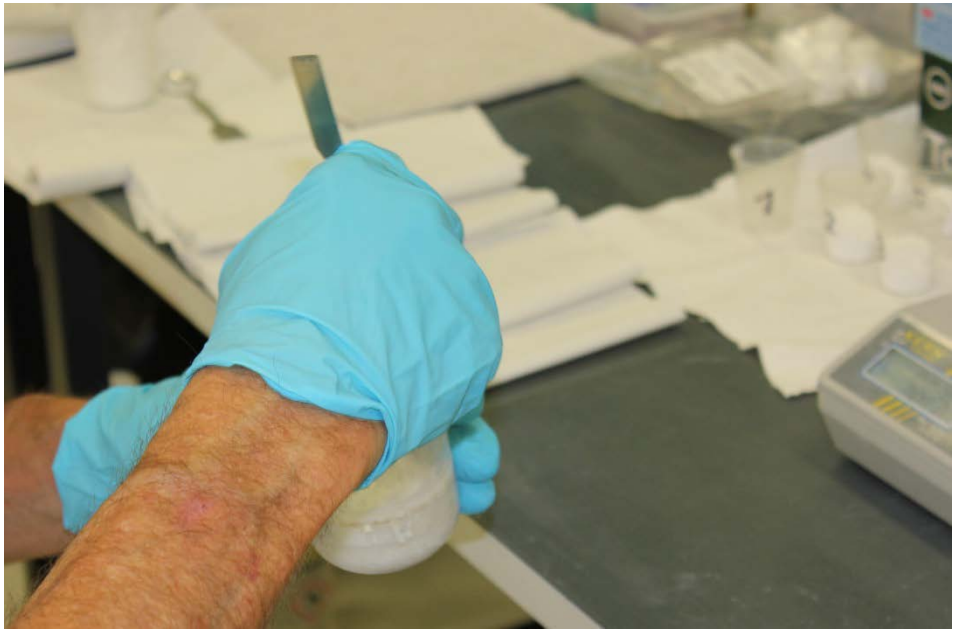
4. Winding of fibre mat

1. Prepare 7 portions of TiO_2 in measuring cups using a mesh to prevent clustering of TiO_2, protect cups against dust and humidity.

4. Winding of fibre mat

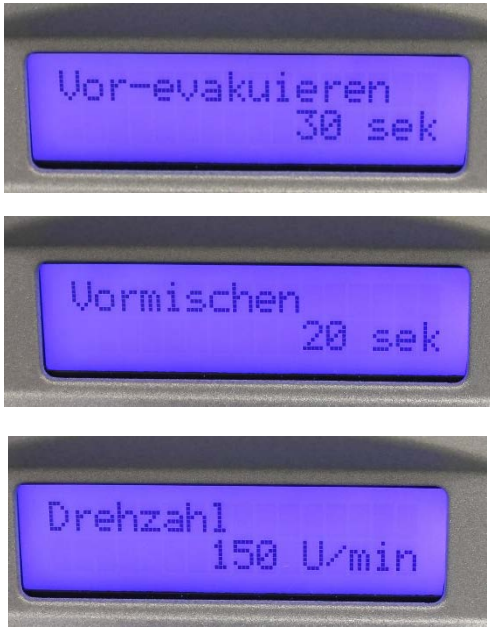
2. Cup 1: Fill Part A (binder) into cup with TiO_2 and premix by hand using a metallic spatulae

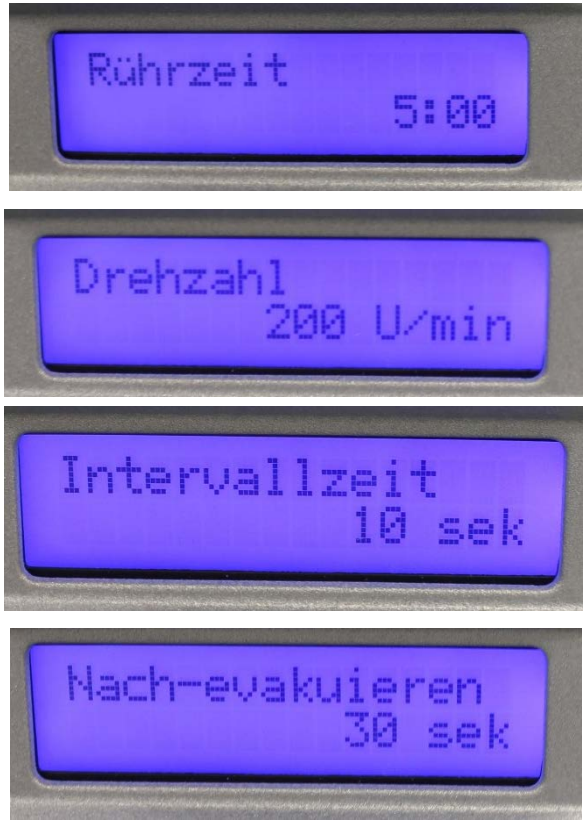




4. Winding of fibre mat

2. Cup 1: Prepare mixture of glue and TiO_2 (Epotek 301 -2 + 25% TiO_2) for layer 1 using a *smartmix X2* under vacuum, total mixture weight 31.25 g, Pre-evacuation: 30 sec, Pre-mixing time: 20 sec, Pre-Mixing speed: 150 U/min Mixing time: 5 min, Mixing speed: 200 U/min, Mixing direction change: 10 sec Post-evacuation: 30 sec





4. Winding of fibre mat

2. Cup 1: Prepare mixture of glue and TiO_2 (Epotek 301 -2 + 25% TiO_2) for layer 1 using a *smartmix X2* under vacuum, total mixture weight 31.25 g

4. Winding of fibre mat

3. Prepare cartridge with a 0.5mm cone which is used to fill glue into pin holes of winding wheel. Fill glue mixture into cartridge, close cartridge with plug and mount it to cartridge gun

4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:

a) Cover the transversal cutting groove on the wheel with kapton tape

b) Apply glue to pin holes of winding wheel with the cartridge gun

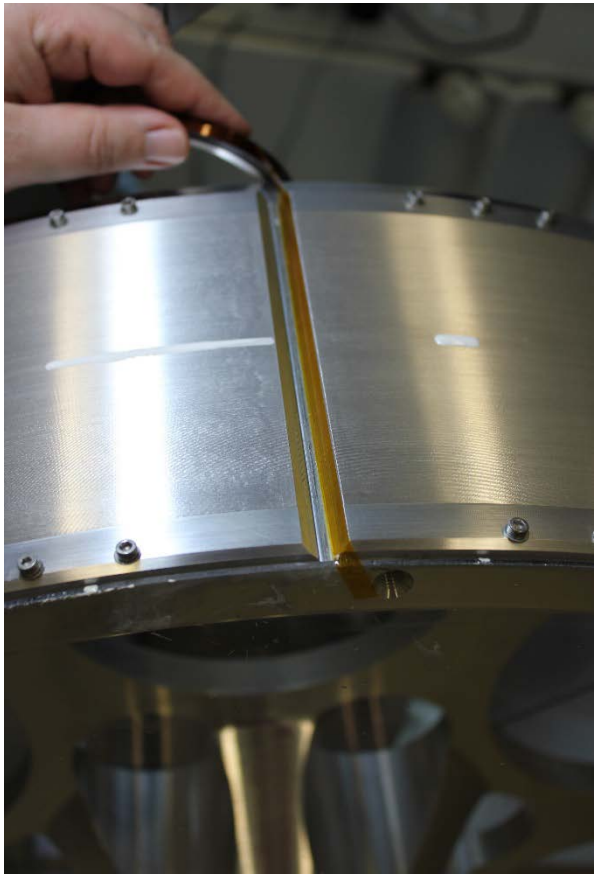
c) Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue

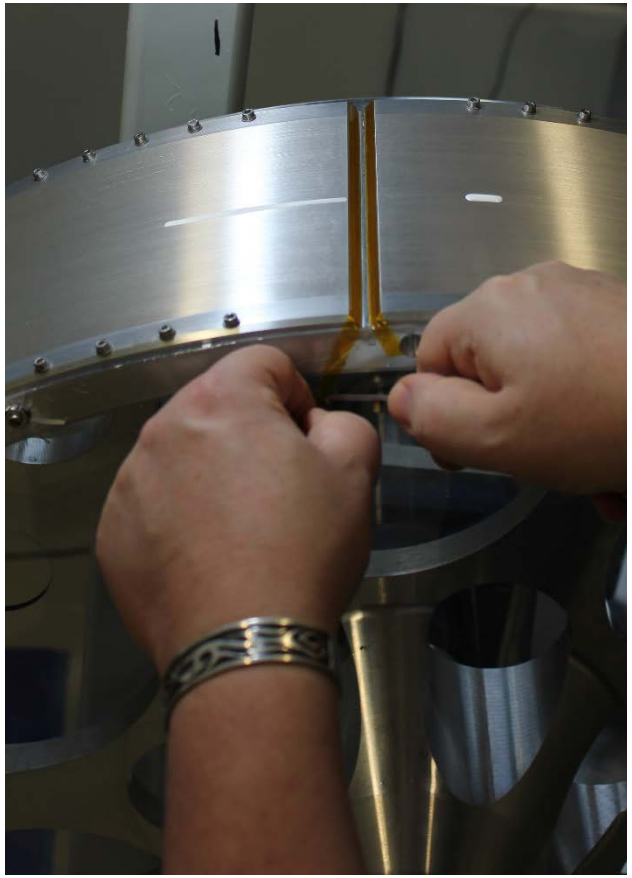
d) Apply glue to pin holes of winding wheel with the cartridge gun to refill pin holes

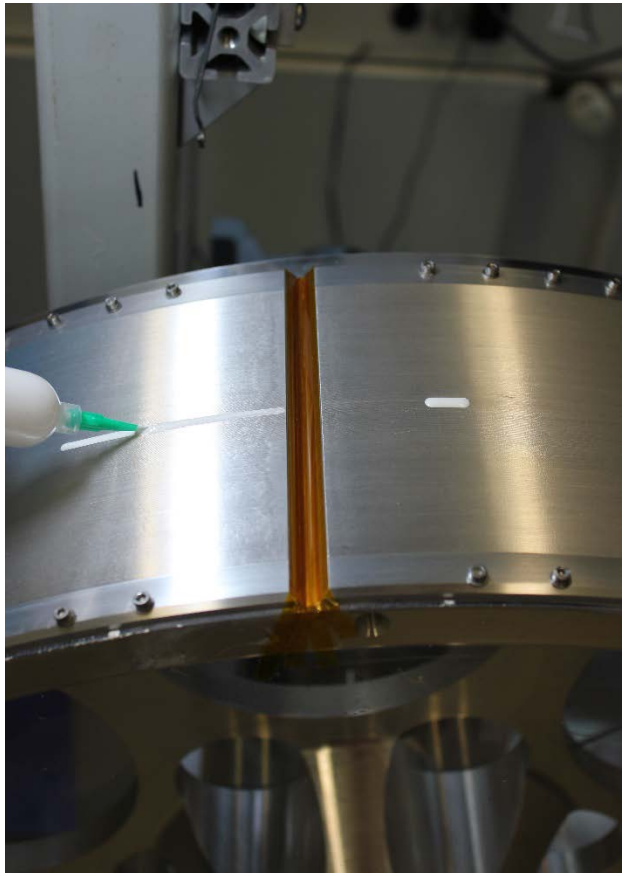
e) Clean transversal cutting groove

4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
a). Cover the transversal cutting groove on the wheel with kapton tape

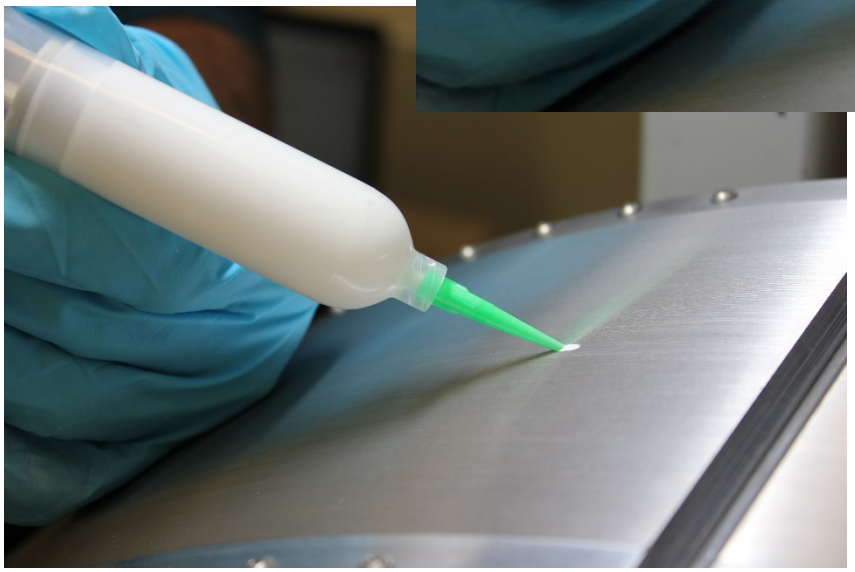


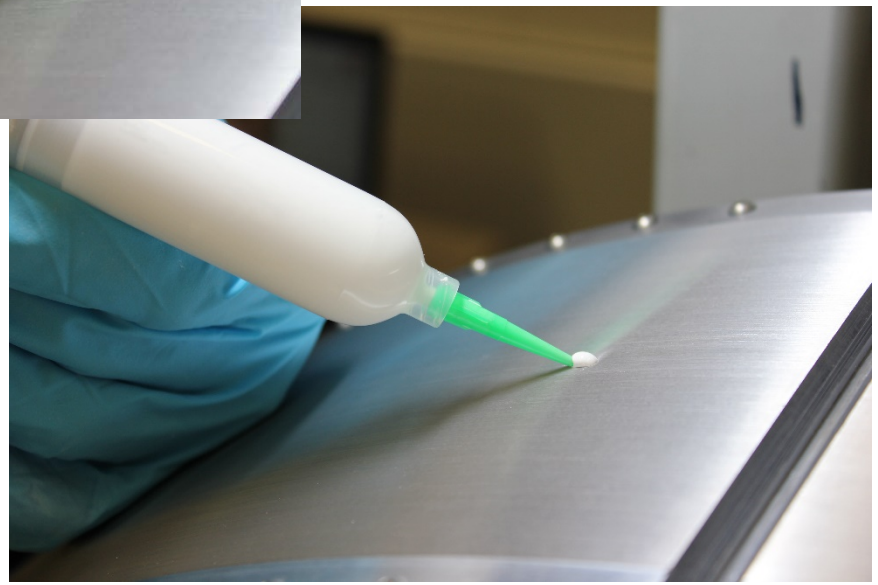




4. Winding of fibre mat

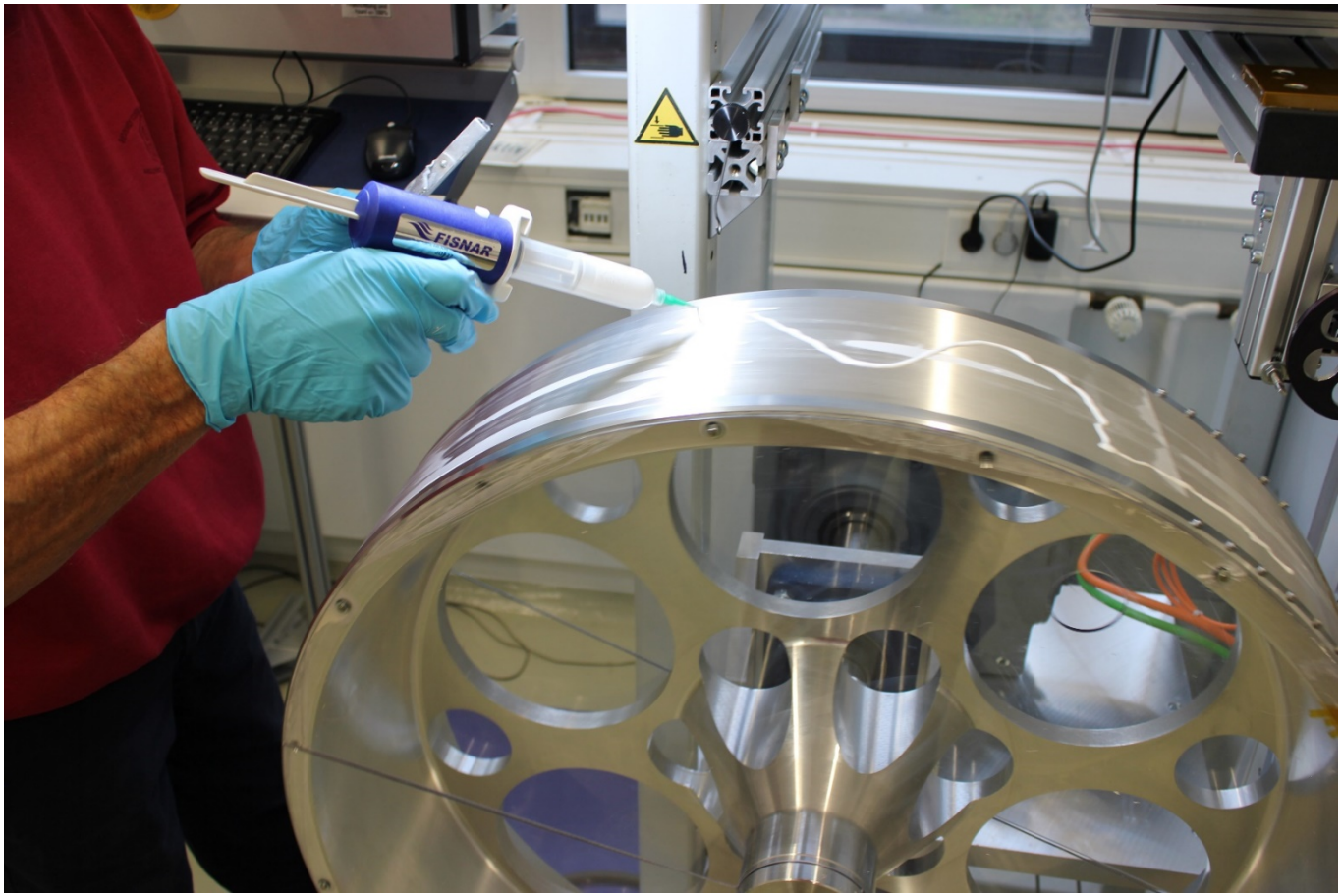
4. Apply mixed glue to wheel before first layer winding:
b) Apply glue to pin holes of winding wheel with the cartridge gun





4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
c). Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue

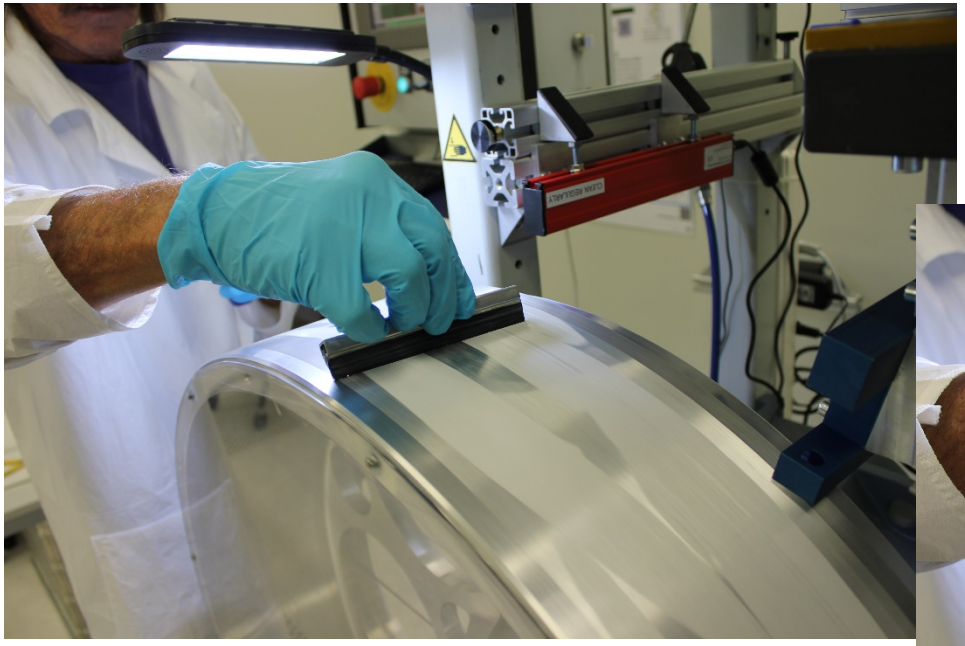


4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
c). Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue using a wiper

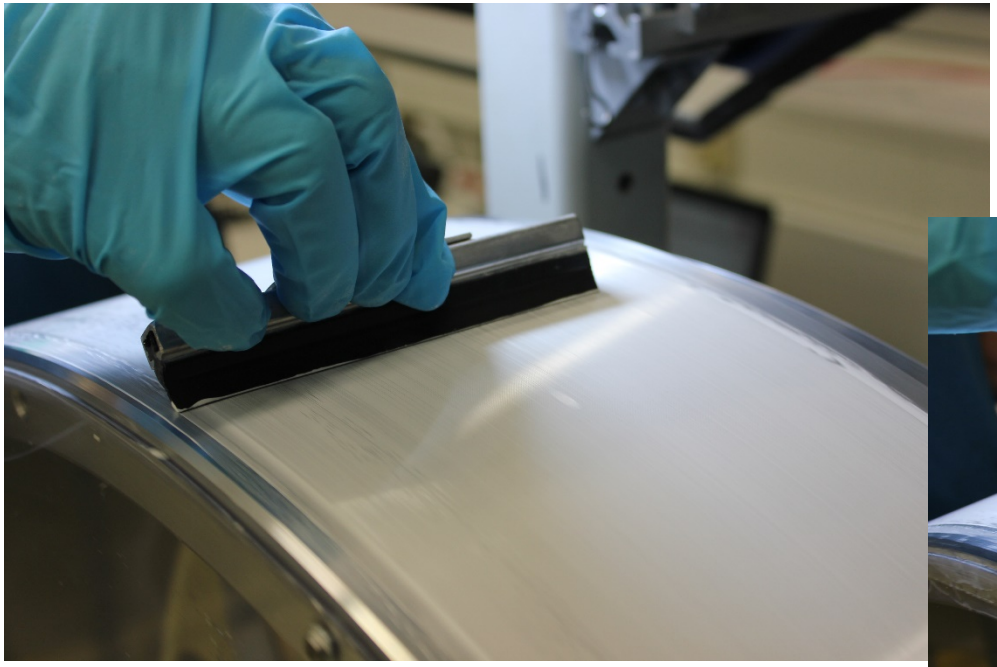
4. Winding of fibre mat

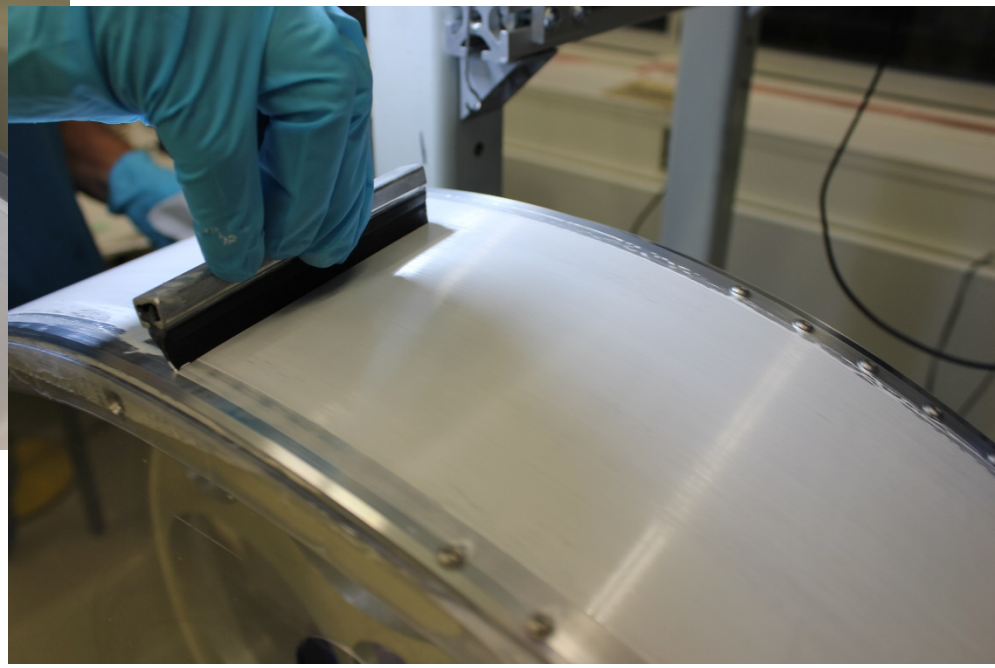
4. Apply mixed glue to wheel before first layer winding:
c). Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue using a wiper



4. Winding of fibre mat

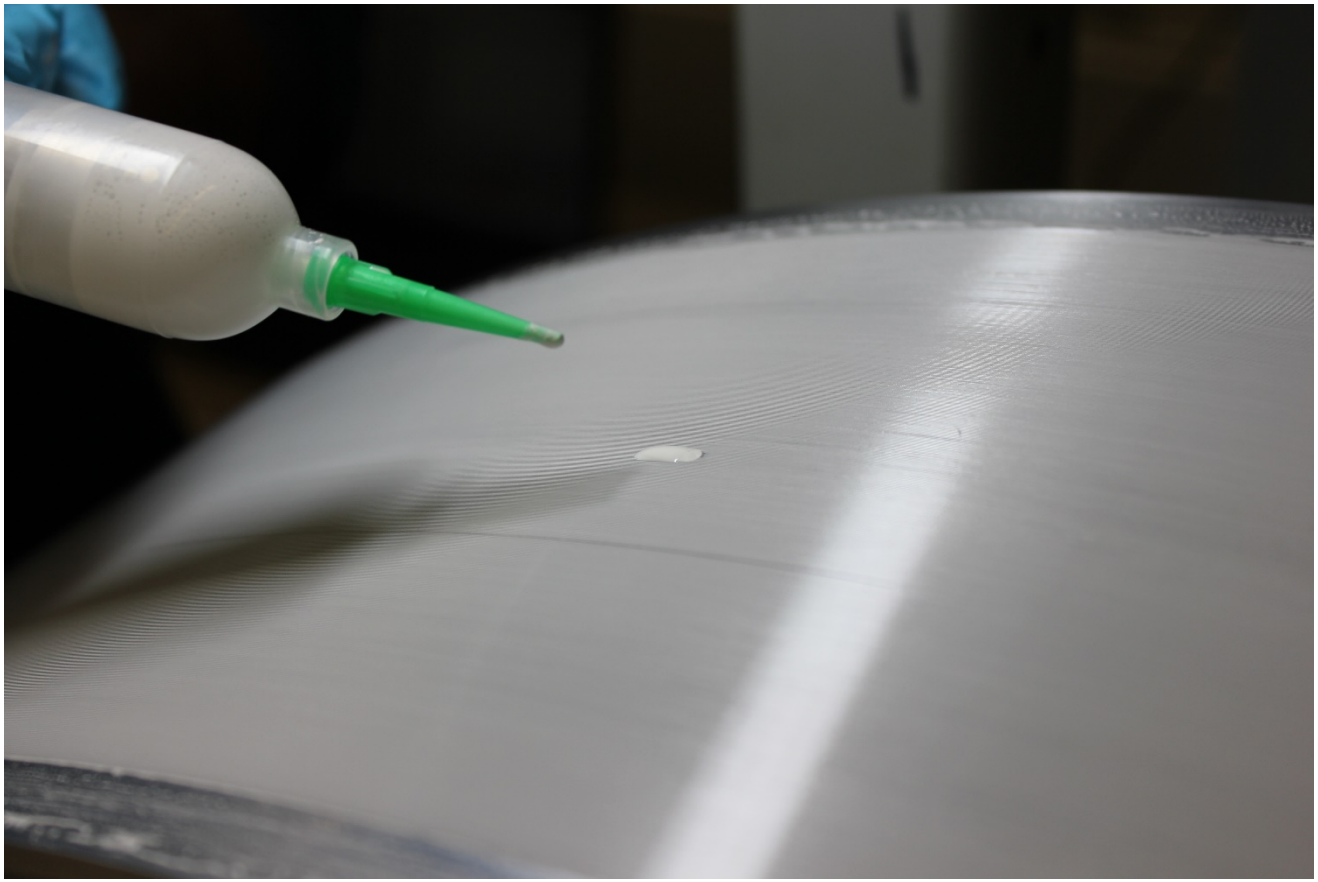
4. Apply mixed glue to wheel before first layer winding:
c). Apply glue to thread surface of winding wheel till whole surface of thread is covered with glue using a wiper





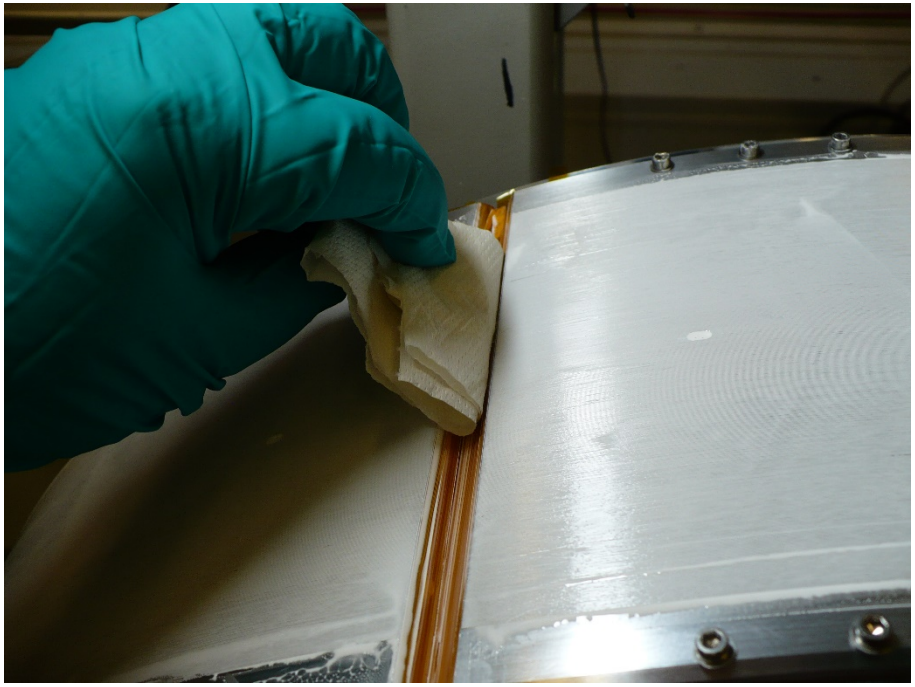
4. Winding of fibre mat

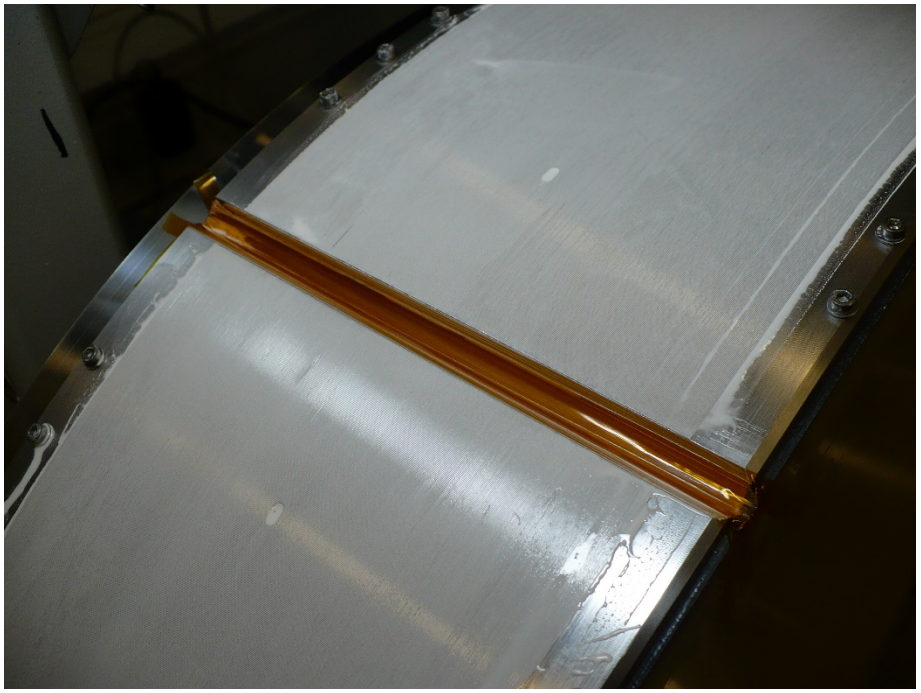
4. Apply mixed glue to wheel before first layer winding:
d). Apply glue to pin holes of winding wheel with the cartridge gun to refill pin holes if neccessary



4. Winding of fibre mat

4. Apply mixed glue to wheel before first layer winding:
e) Clean transversal cutting groove





4. Winding of fibre mat

5. Winding of first layer:

a) Fix the fibre with a screw on the edge of winding wheel outside the thread

b) Do the first 3 to 5 turns with lower speed. Use a magnifier to control that the fibres are placed in the right position in the thread.

c) If step b) is ok, increase the speed to full winding speed of 1.3m/s

d) If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station. If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding speed again. If the bump creates an error, wind the fibre back, clean it with isopropanol, and try to wind again. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 "***bump removal***") and start winding again.

4. Winding of fibre mat

5. Winding of first layer:

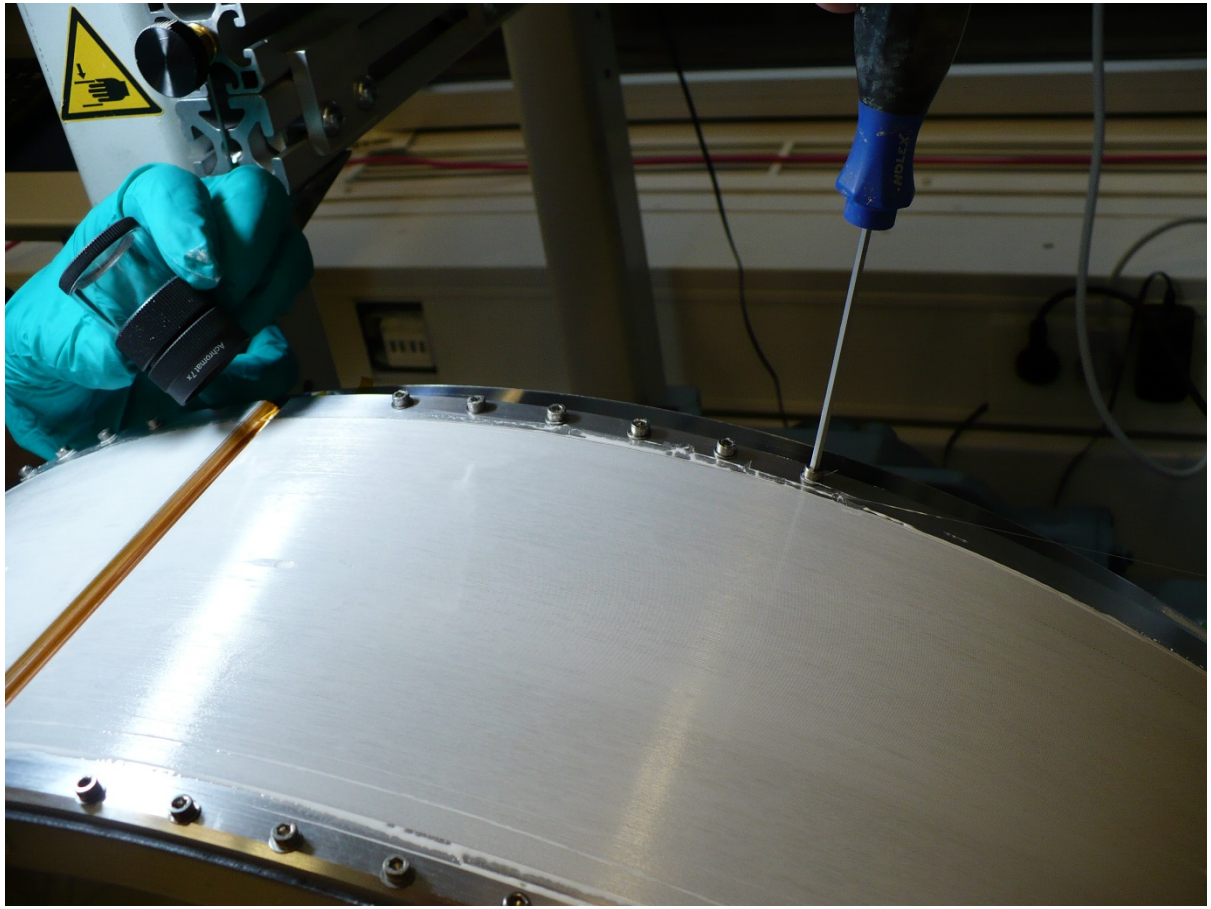
e) If no bump occurs and the winding is going smoothly you still have to watch continuously the winding to dectect winding errors. If you or your online monitoring system detects an error, stop the winding. Wind the fibre back, clean it with isopropanol, and try to wind it again on the thread. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 "***bump removal***") and start winding again.

f) At end of layer the fibre is fixed with a screw on the other edge of the winding wheel outside the thread and then cut the fibre.

4. Winding of fibre mat

5. Winding of first layer:

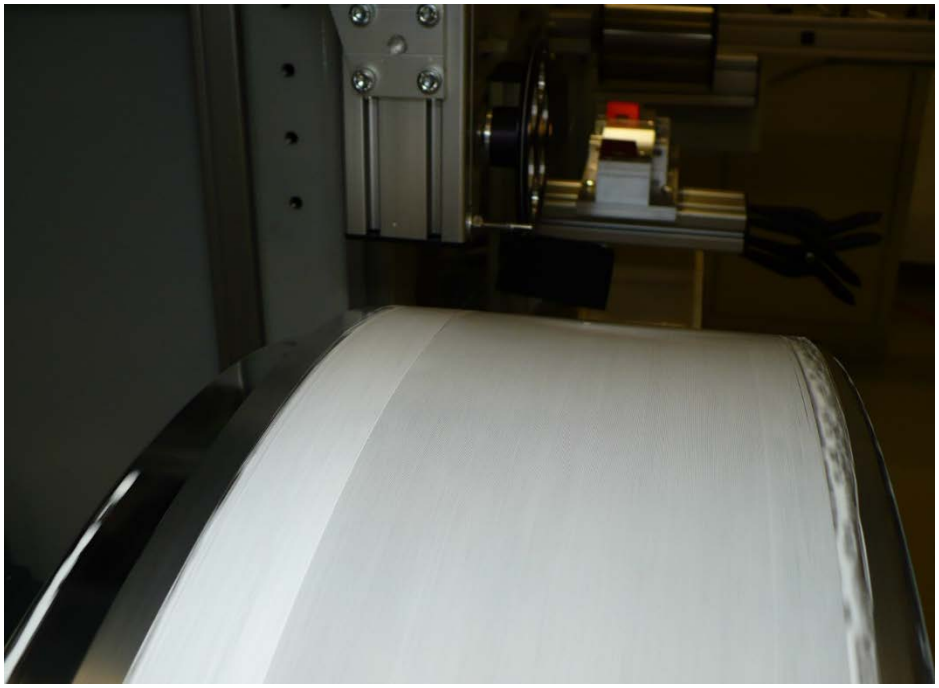
a) Fix the fibre with a screw on the edge of winding wheel outside the thread

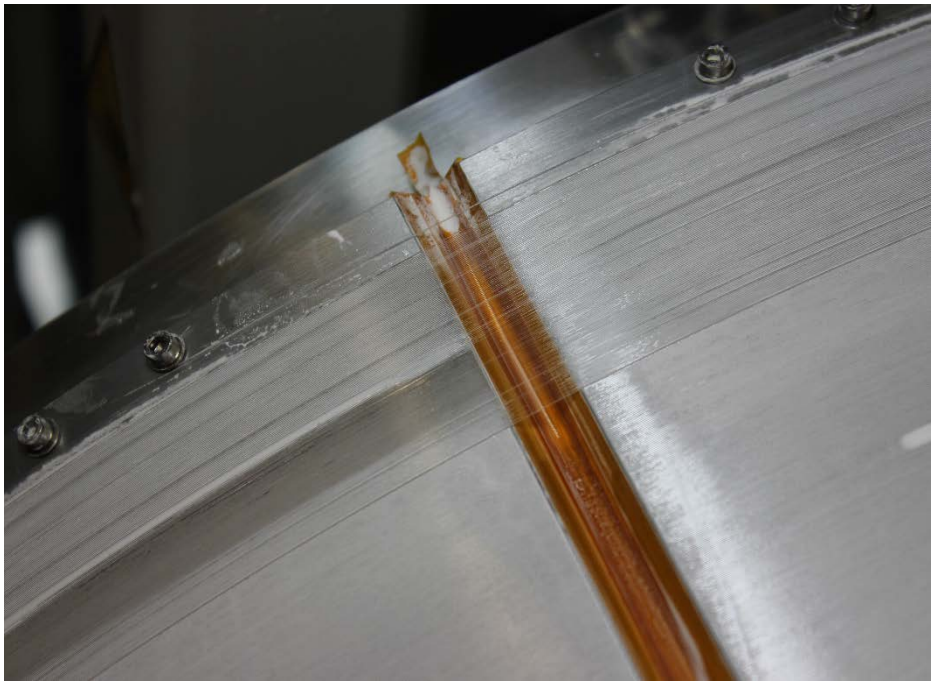


4. Winding of fibre mat

5. Winding of first layer:

b) Do the first 3 to 5 turns with lower speed. Use a magnifier to control that the fibres are placed in the right position in the thread.

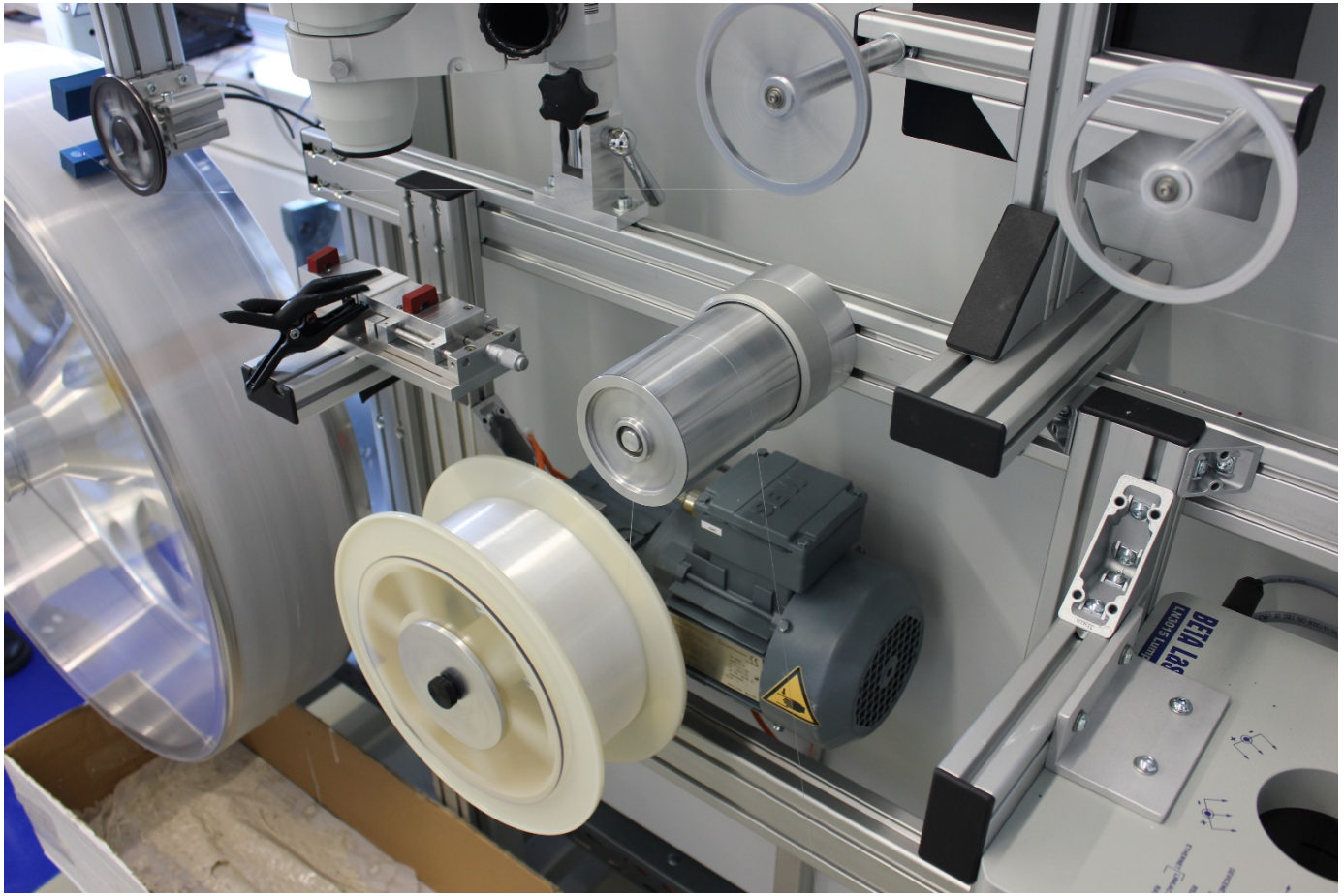




4. Winding of fibre mat

5. Winding of first layer:

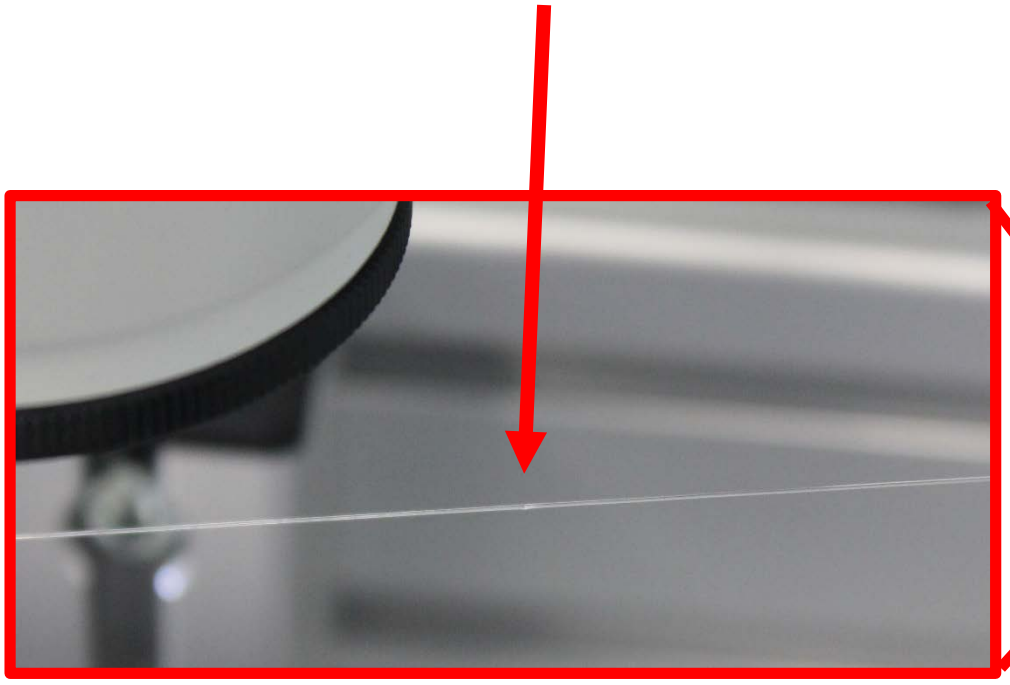
c) If step b) is ok, increase the speed to full winding speed of 1.3m/s



4. Winding of fibre mat

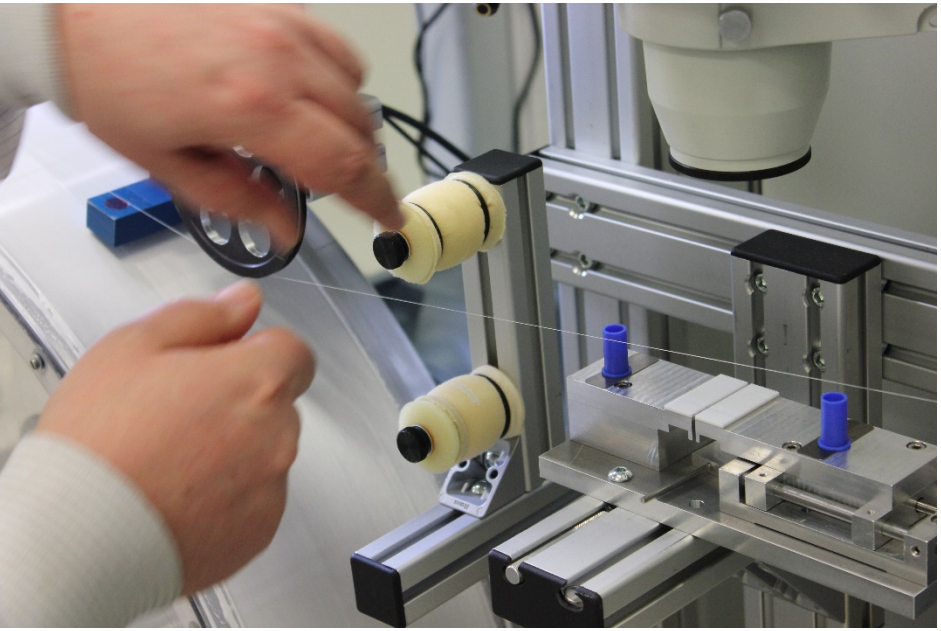
5. Winding of first layer:

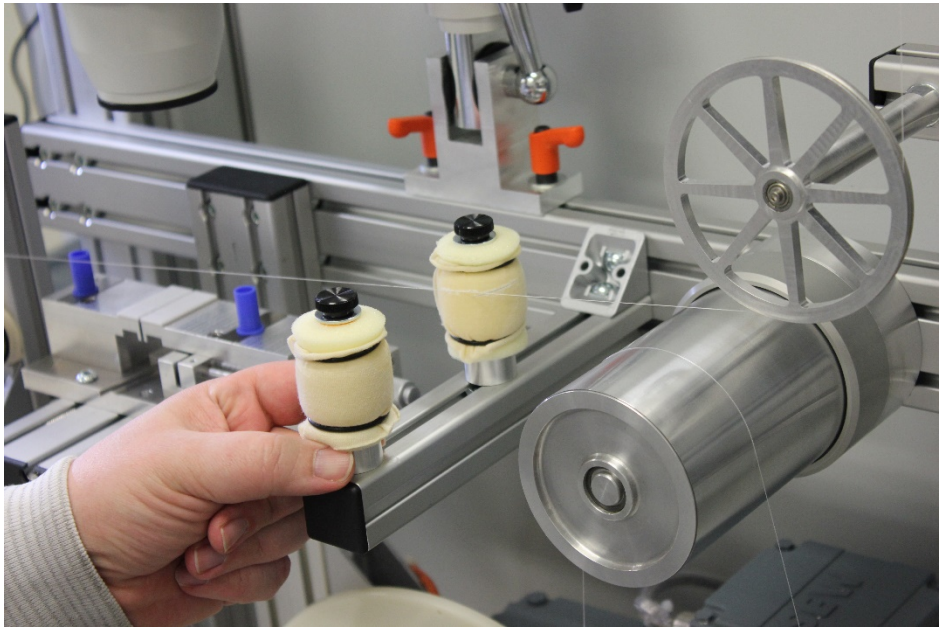
d) If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station.



4. Winding of fibre mat

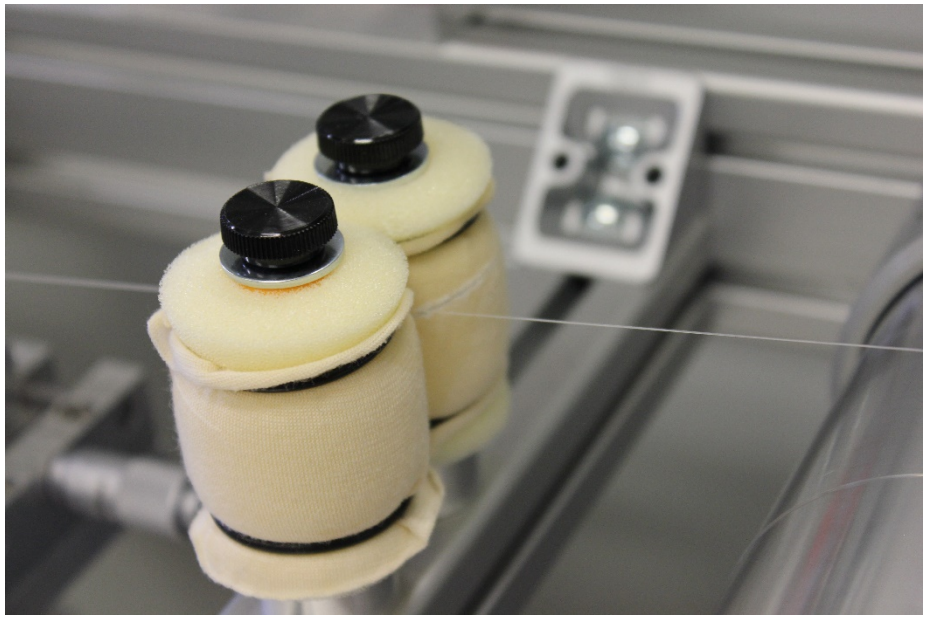
5. Winding of first layer:
d) cont.: If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding one again. If the bump creates an error, wind the fibre back by cleaning it with isopropanol and try to wind again.
Cleaning with isopropanol: a) “Close” wash up system

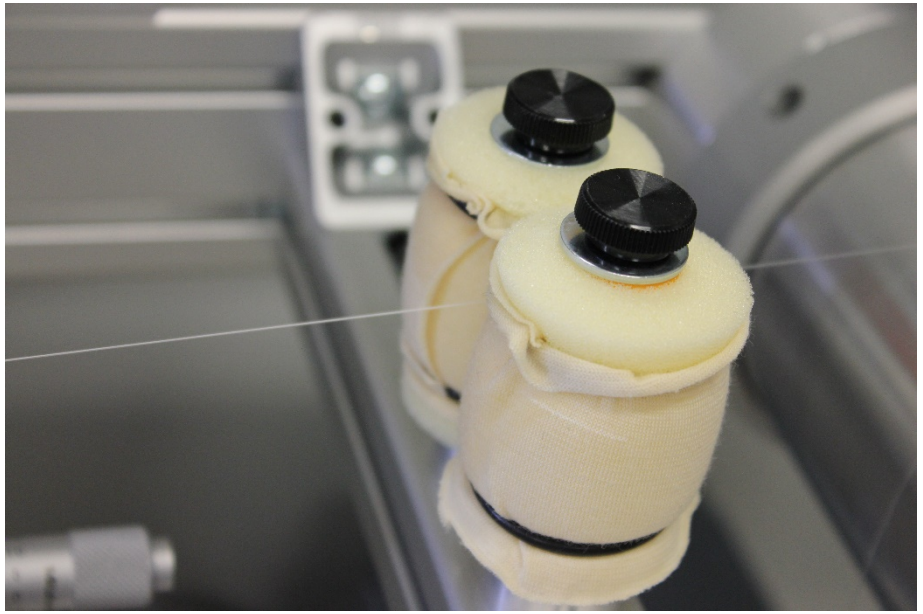




4. Winding of fibre mat

5. Winding of first layer:
d) cont.: If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding one again. If the bump creates an error, wind the fibre back by cleaning it with isopropanol and try to wind again.
Cleaning with isopropanol: a) “Close” wash up system



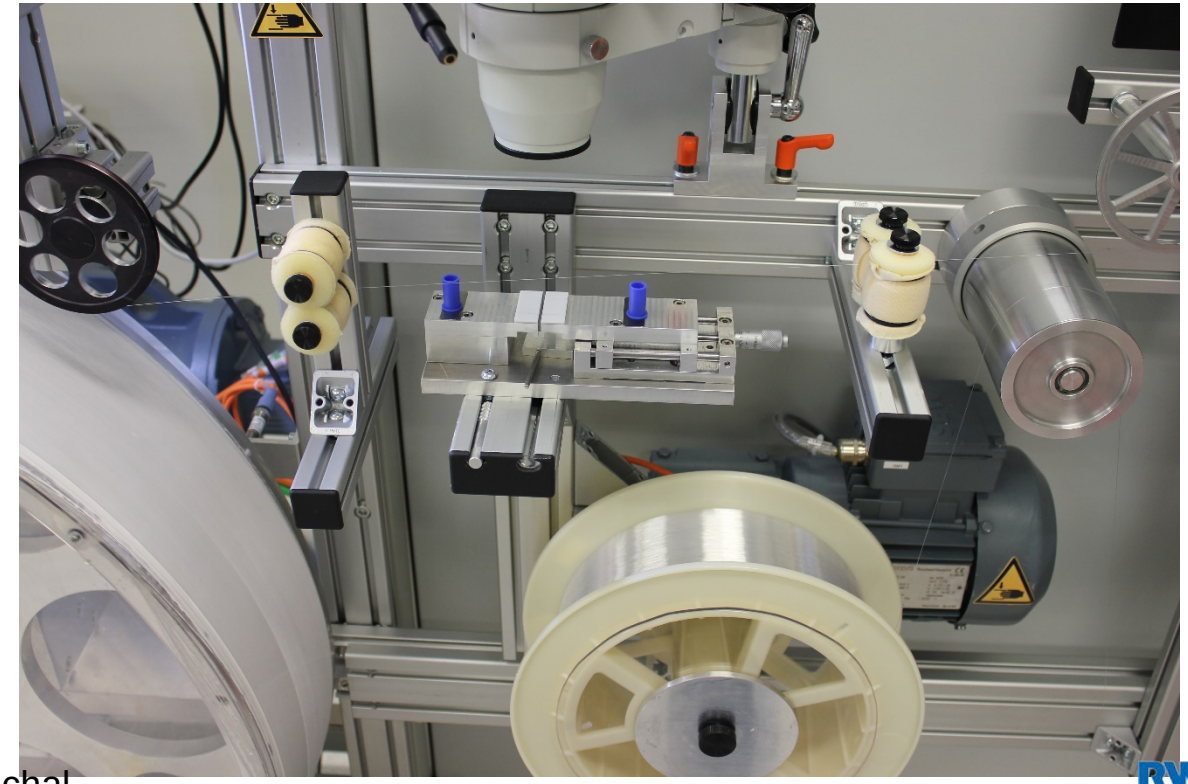


4. Winding of fibre mat

5. Winding of first layer:
d) cont.: If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding one again. If the bump creates an error, wind the fibre back by cleaning it with isopropanol and try to wind again.
Cleaning with isopropanol: b) Charge wash up system with isopropanol

4. Winding of fibre mat

5. Winding of first layer:
d) cont.: If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding one again. If the bump creates an error, wind the fibre back by cleaning it with isopropanol and try to wind again.
Cleaning with isopropanol: c) wind fibre back



4. Winding of fibre mat

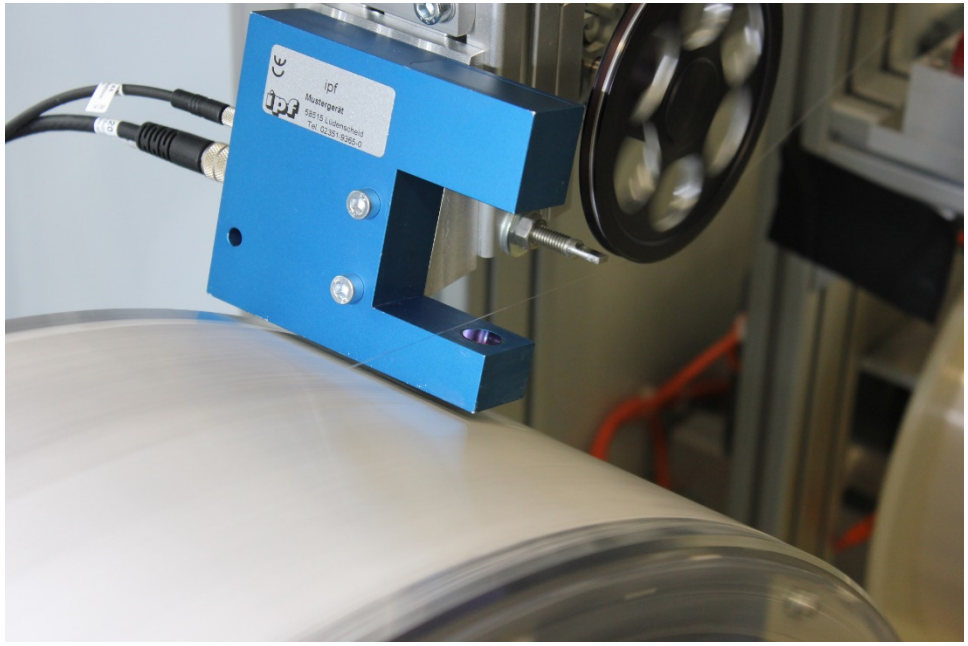
5. Winding of first layer:

d) cont.: If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 "***bump removal***") and start winding again.

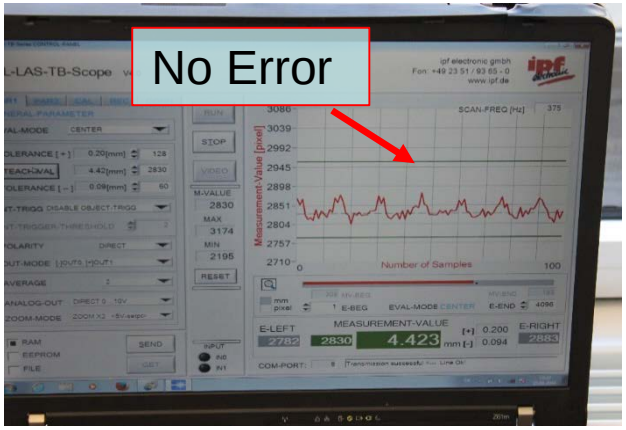
4. Winding of fibre mat

5. Winding of first layer:

e) If no bump occurs and the winding is going smoothly you still have to watch continuously the winding to detect winding errors. If you or your online monitoring system detects an error, stop the winding.



Laser Scope for error detection during winding of fibre mat

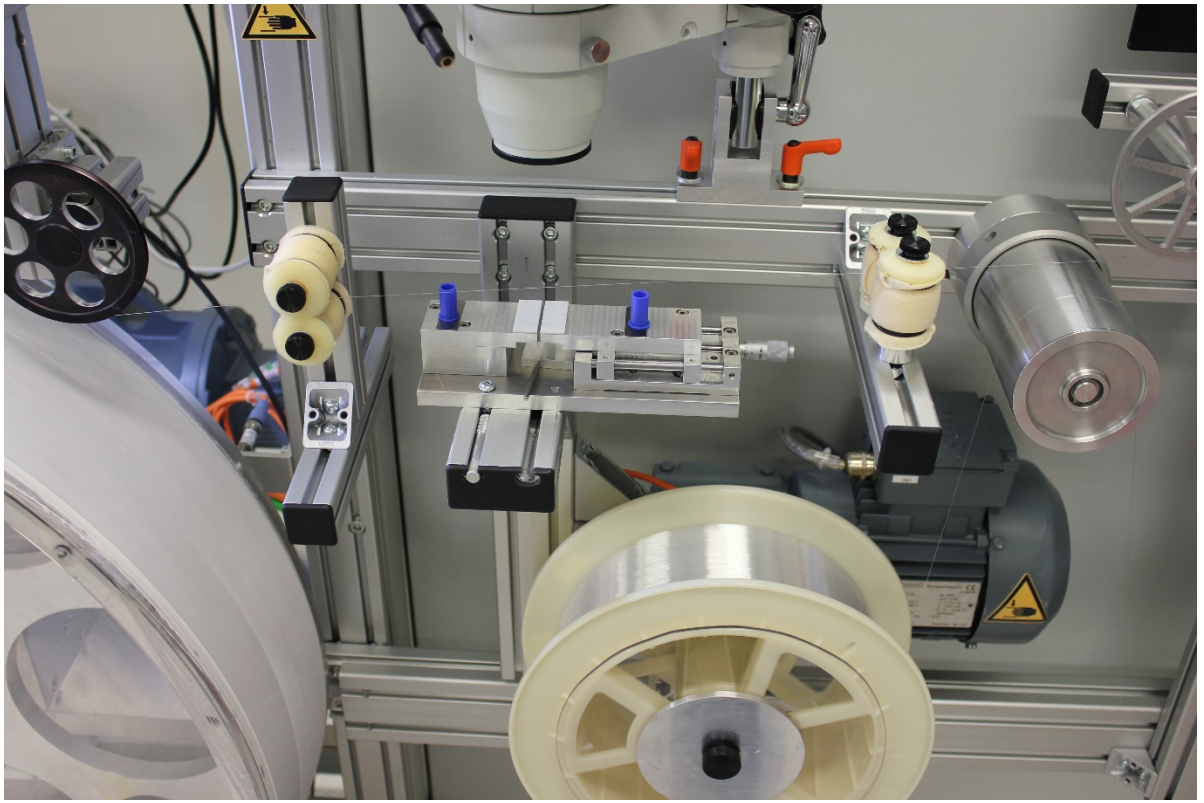


Detected Error → stopped winding

4. Winding of fibre mat

5. Winding of first layer:

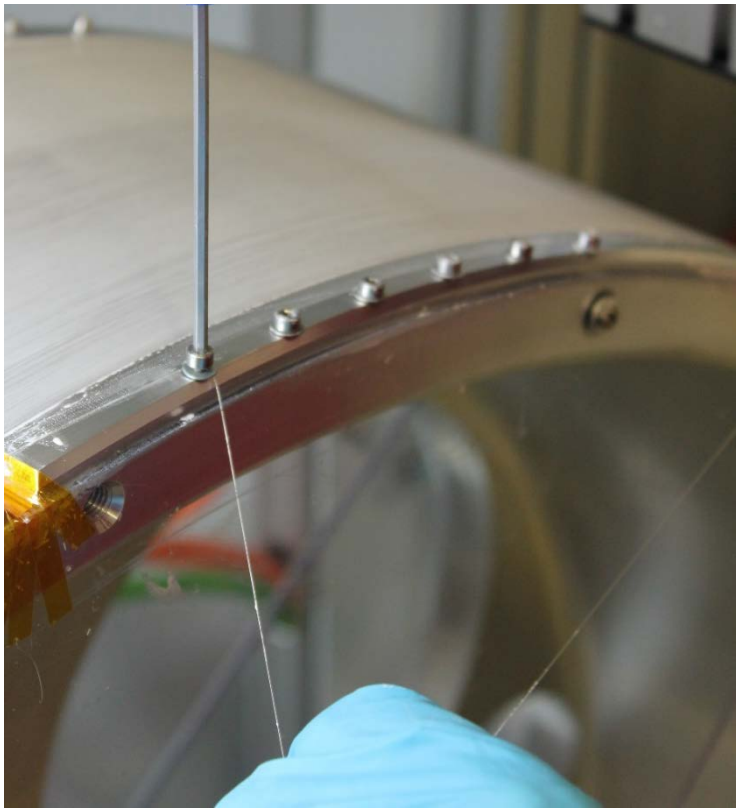
e) cont.: Wind the fibre back, clean it with isopropanol, and try to wind it again on the thread. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 "***bump removal***") and start winding again.

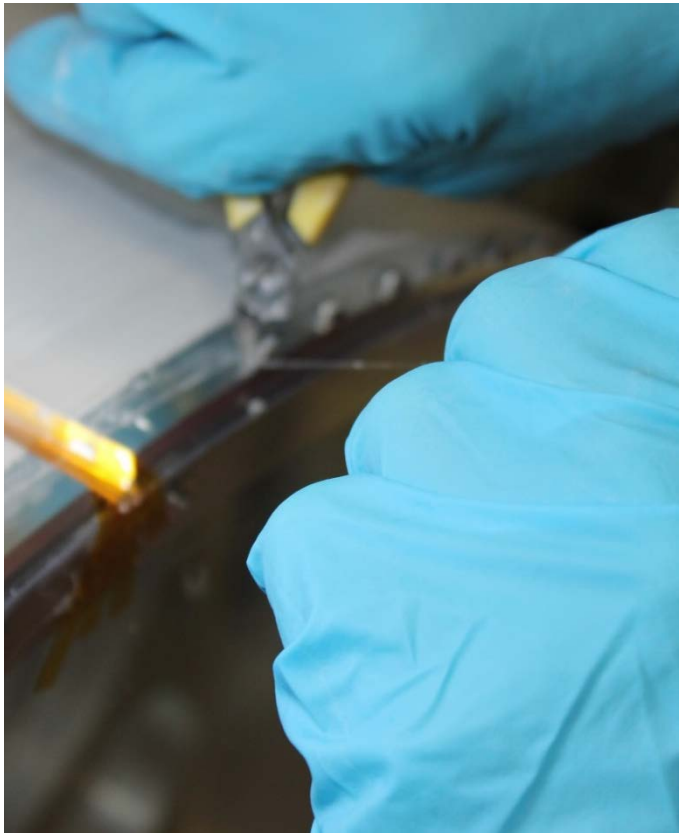


4. Winding of fibre mat

5. Winding of first layer:

f) At end of layer the fibre is fixed with a screw on the other edge of the winding wheel outside the thread and then cut the fibre.





4. Winding of fibre mat

6. Winding of layer 2 to 6:

a) First apply binder and second apply hardener to the next cup of glue.

b) Apply glue to surface of the previous wound layer.

c) Fix the fibre with a screw on the edge of winding wheel outside the thread

d) Do the first 3 to 5 turns with lower speed. Use a magnifier to control that the fibres are placed in the right position in the thread-like depressions created by the preceding layer.

e) If step d) is ok, increase the speed to full winding speed of 1.3 m/s

4. Winding of fibre mat

6. Winding of layer 2 to 6:

f) If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station. If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding speed again. If the bump creates an error, wind the fibre back, clean it with isopropanol, and try to wind again. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 "***bump removal***") and start winding again.

g) If no bump occurs and the winding is going smoothly you still have to watch continuously the winding to dectect winding errors. If you or your online monitoring system detects an error, stop the winding. Wind the fibre back, clean it with isopropanol, and try to wind it again on the thread. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 "***bump removal***") and start winding again.

4. Winding of fibre mat

6. Winding of layer 2 to 6:

h) At end of layer the fibre is fixed with a screw on the other edge of the winding wheel outside the thread and then cut the fibre.

i) Repeat these steps to the chosen amount of layers

j) Remove unnecessary glue on the side of winding wheel after the 6th wound layer

4. Winding of fibre mat

6. Winding of layer 2 to 6:

a) First apply binder and second apply hardener to the next cup of glue.

For Cup 2 to 5:

First: Fill Part A (binder) into cup with TiO_2 and premix by hand using a metallic spatulae;

Second: Prepare mixture of glue and TiO_2 (Epotek 301 -2 + 25% TiO_2) for layer 2 to 5 using a *smartmix X2* under vacuum, total mixture weight 21.88 g per layer

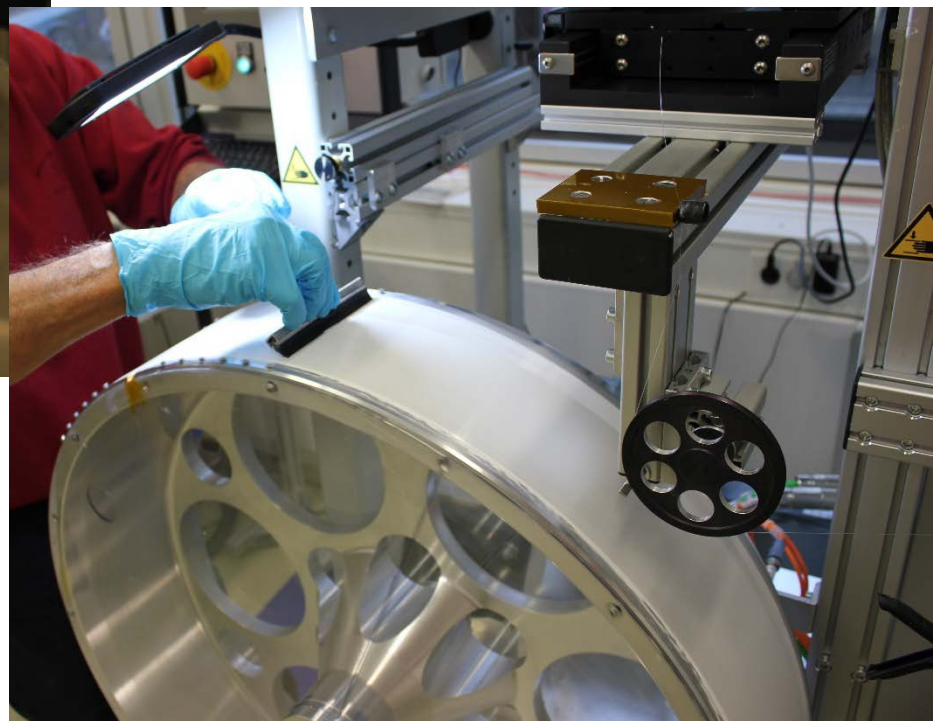
For Cup 6: Same procedure as before but total mixture weight 31.25 g

Cup 7: Spare

4. Winding of fibre mat

6. Winding of layer 2 to 6:

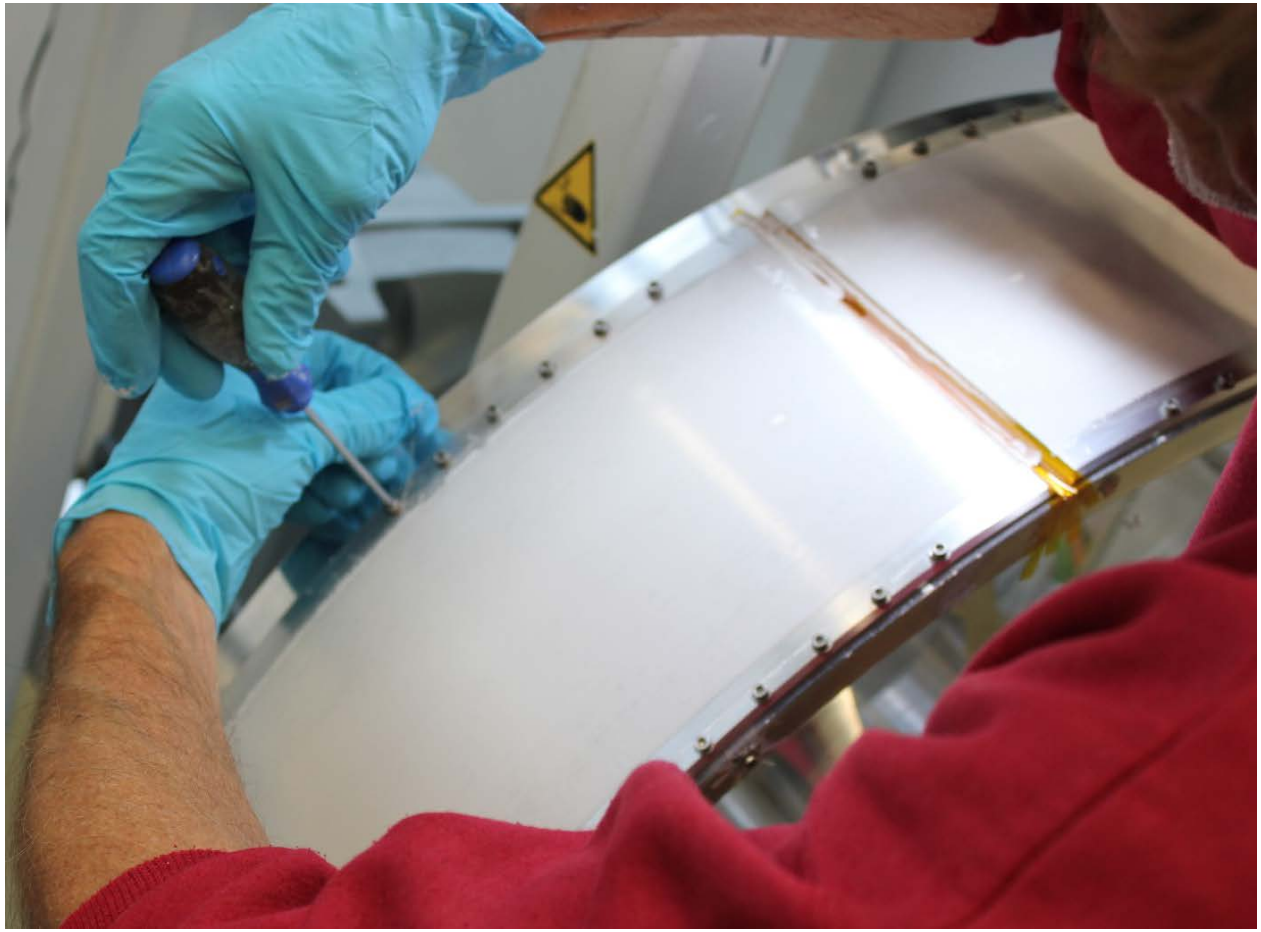
b) Apply glue to surface of the previous wound layer.



4. Winding of fibre mat

6. Winding of layer 2 to 6:

c) Fix the fibre with a screw on the edge of winding wheel outside the thread

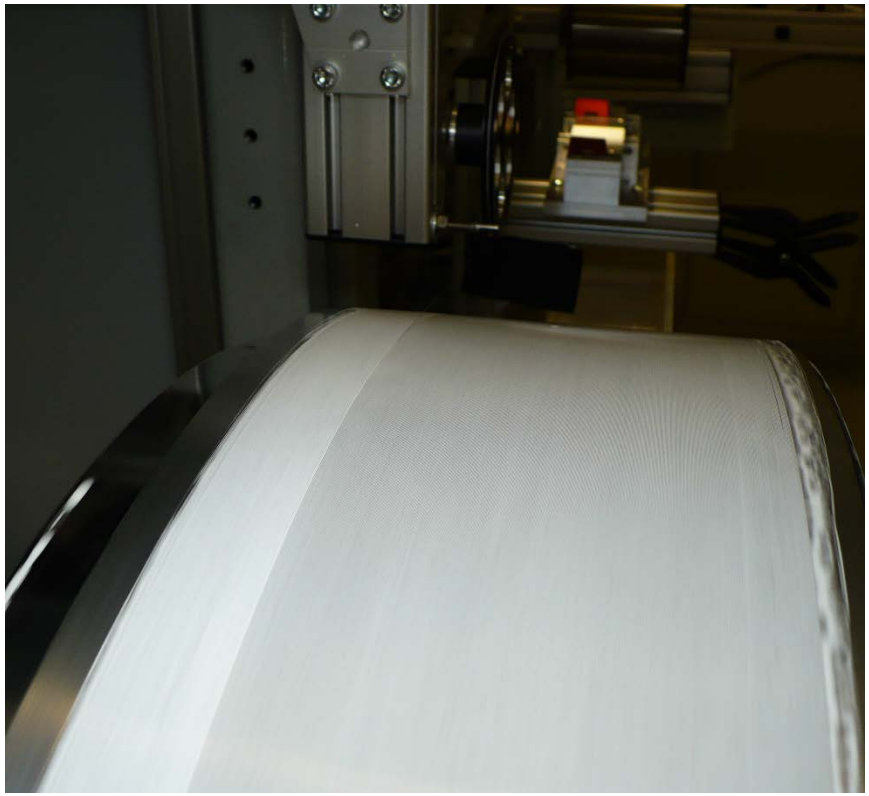


4. Winding of fibre mat

6. Winding of layer 2 to 6:

d) Do the first 3 to 5 turns with lower speed. Use a magnifier to control that the fibres are placed in the right position in the thread-like depressions created by the preceding layer.

e) If step d) is ok, increase the speed to full winding speed of 1.3 m/s

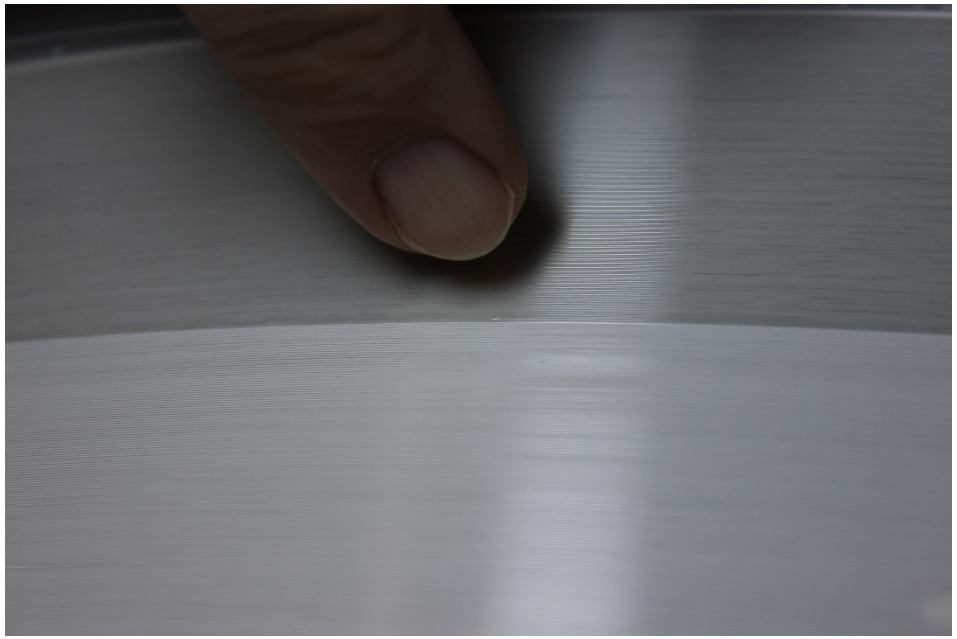


4. Winding of fibre mat

6. Winding of layer 2 to 6:

f) If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station. If the bump is ≤ 350 µm, continue the winding with very low speed. When the bump does not create an error during the next turns, increase the speed to the winding speed again. If the bump creates an error, wind the fibre back, clean it with isopropanol, and try to wind again.

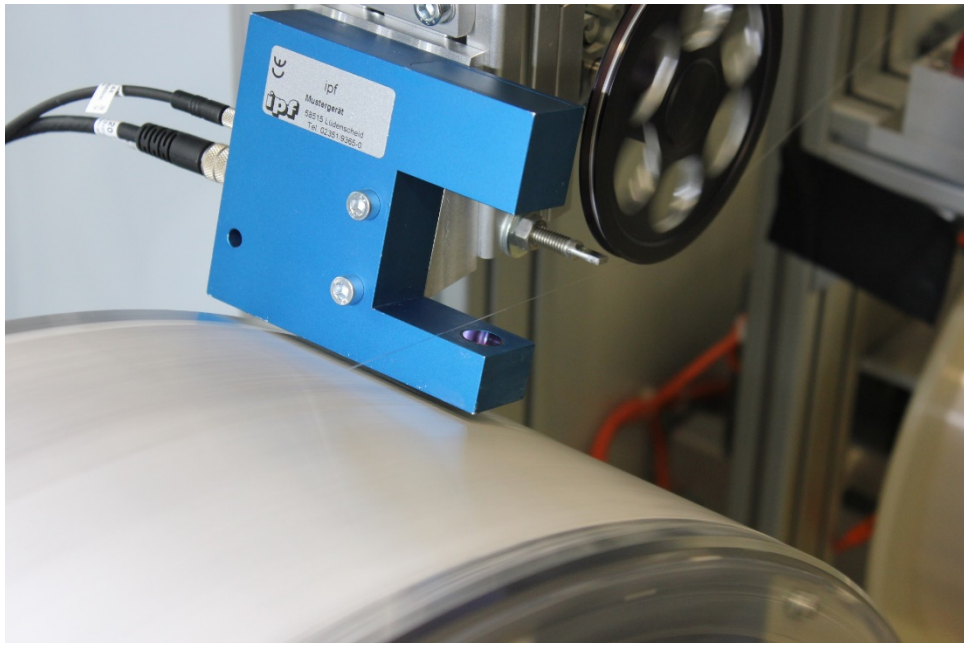
If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 "***bump removal***") and start winding again



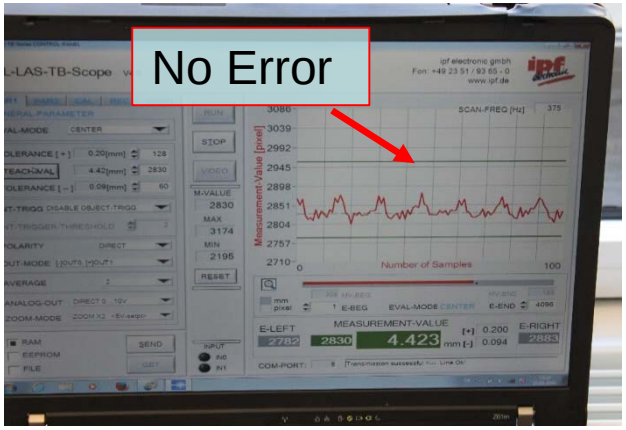
4. Winding of fibre mat

6. Winding of layer 2 - 6:

g) If no bump occurs and the winding is going smoothly you still have to watch continuously the winding process to dectect winding errors. If you or your online monitoring system detects an error, stop the winding.



Laser Scope for error detection during winding process

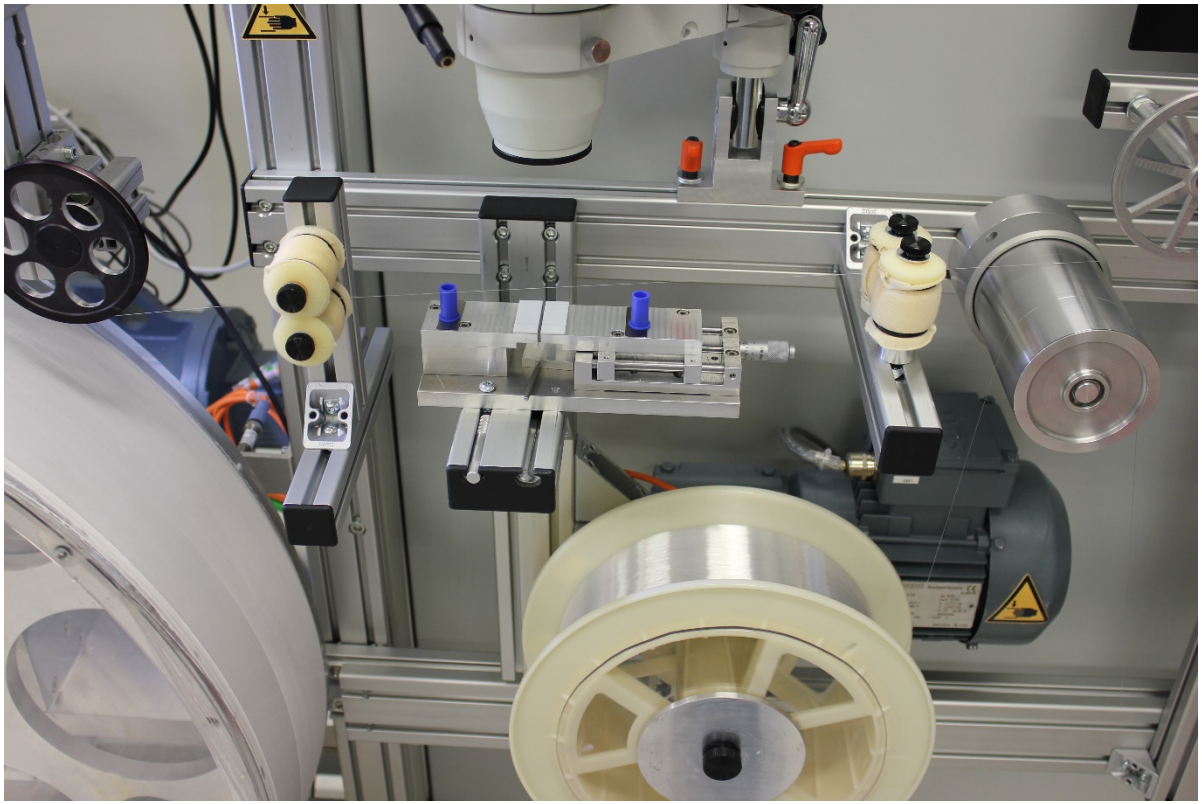


Detected Error → stopped winding

4. Winding of fibre mat

6. Winding of layer 2 - 6:

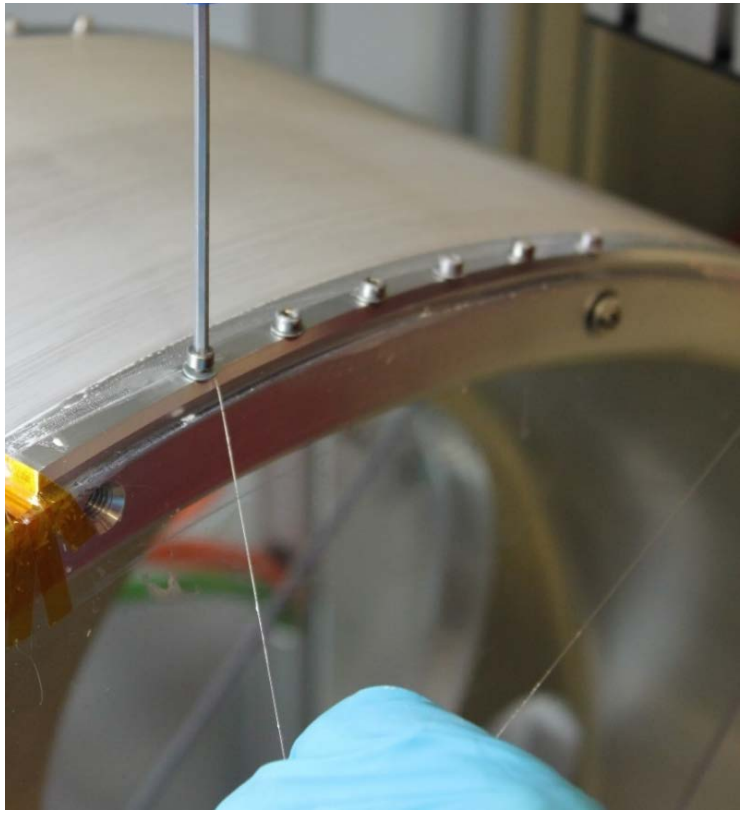
g) cont.: Wind the fibre back, clean it with isopropanol, and try to wind it again on the thread. If no error occurs now, increase the speed again to winding speed. If the bump still creates an error, wind the bump back to the bump removal station, remove the bump (see step 8 "***bump removal***") and start winding again.

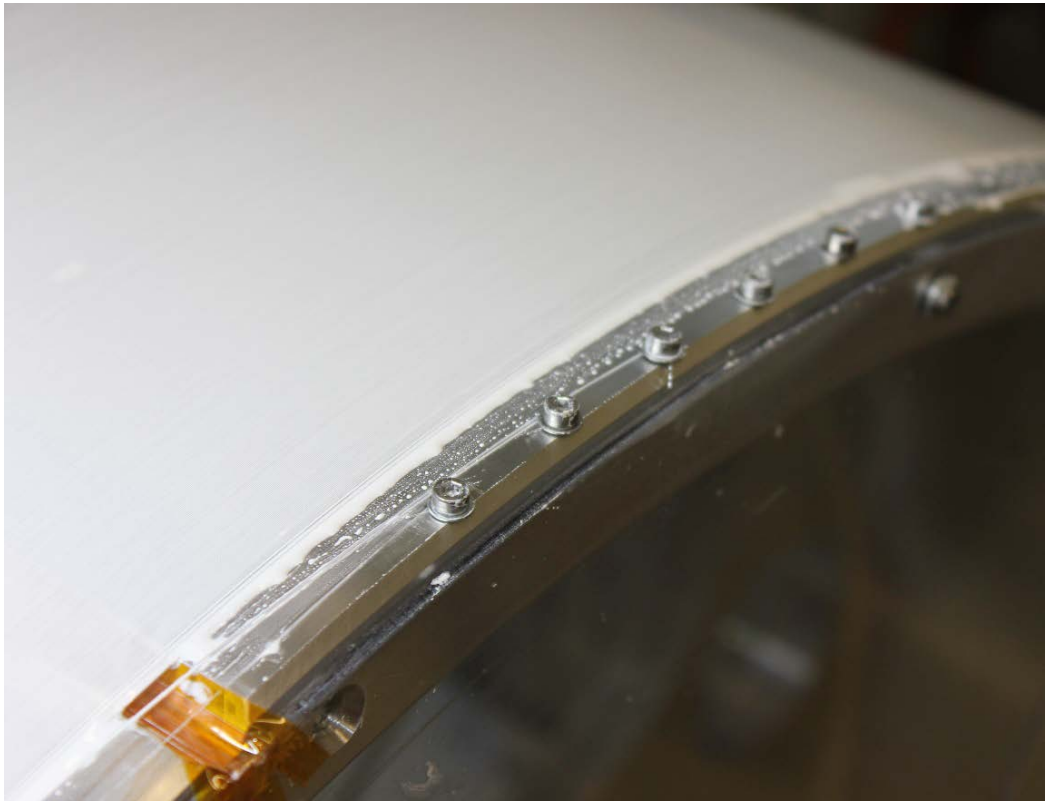


4. Winding of fibre mat

6. Winding of layer 2 to 6:

h) At end of layer the fibre is fixed with a screw on the other edge of the winding wheel outside the thread and then cut the fibre.



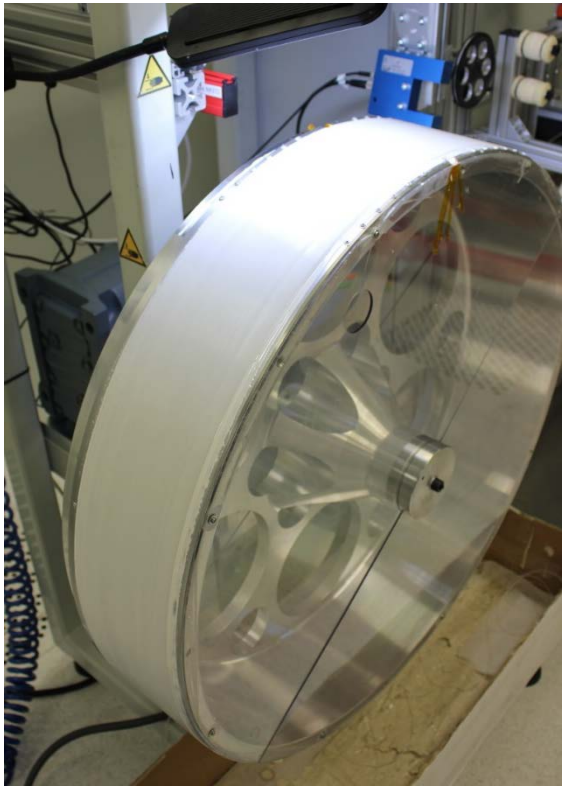


4. Winding of fibre mat

6. Winding of layer 2 to 6:

i) Repeat these steps to the chosen amount of layers

j) Remove unnecessary glue on the side of winding wheel after the 6th wound layer



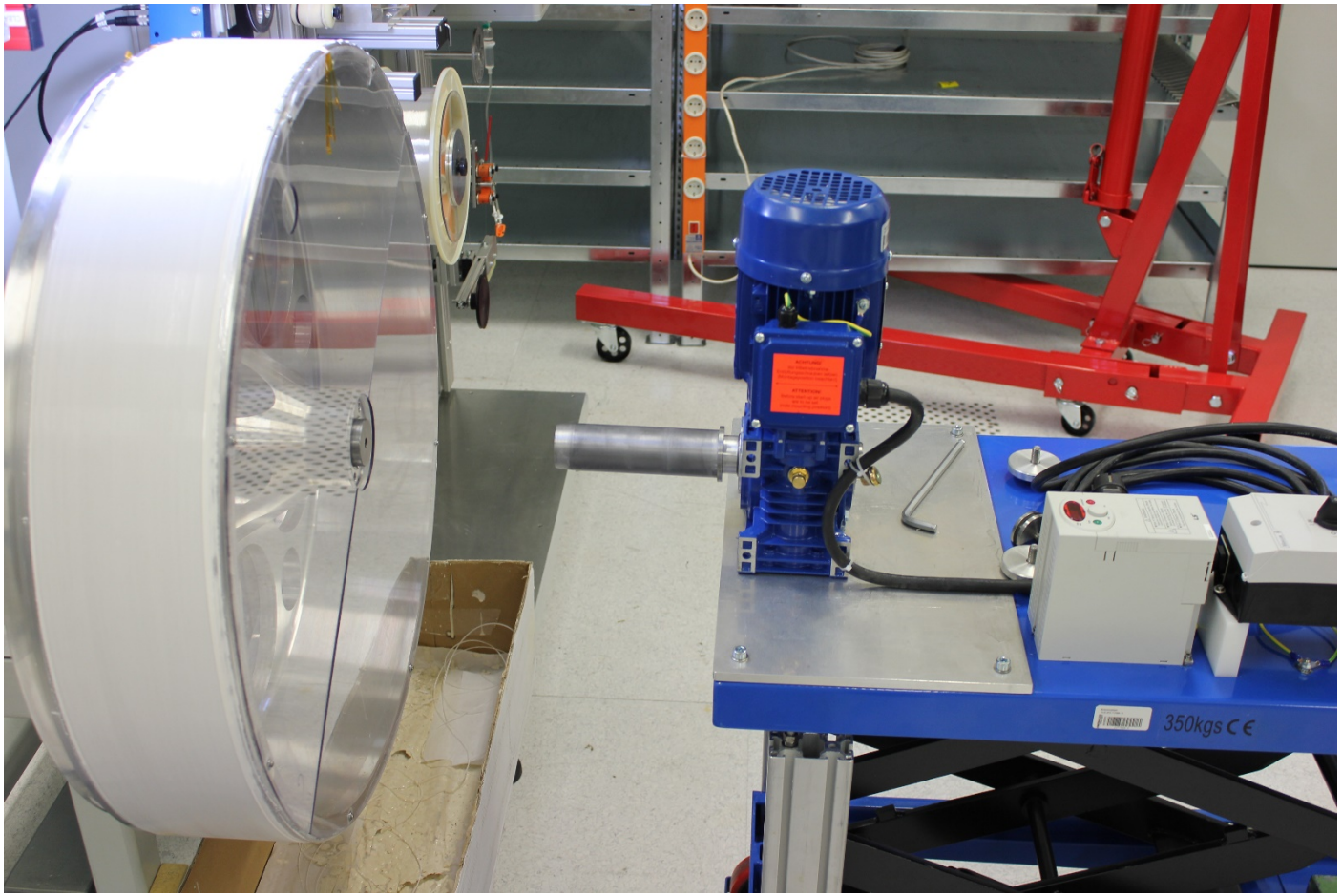
5. Curing of fibre mat

1. Mount winding wheel on rotation cart 85
2. Move rotation cart with winding wheel to parking position. 90
3. Keep winding wheel rotating on rotation cart for 12h till polymerisation is advanced and glue will not drop down of the wheel. 91
4. Move rotation cart to storage rack. 92
5. Dismount winding wheel and mount it to storage rack by screwing together again the axles using the adapter and sliding the wheel to the rack. 92
6. Keep curing of fibre mat on going till 48h are reached 94

5. Curing of fibre mat

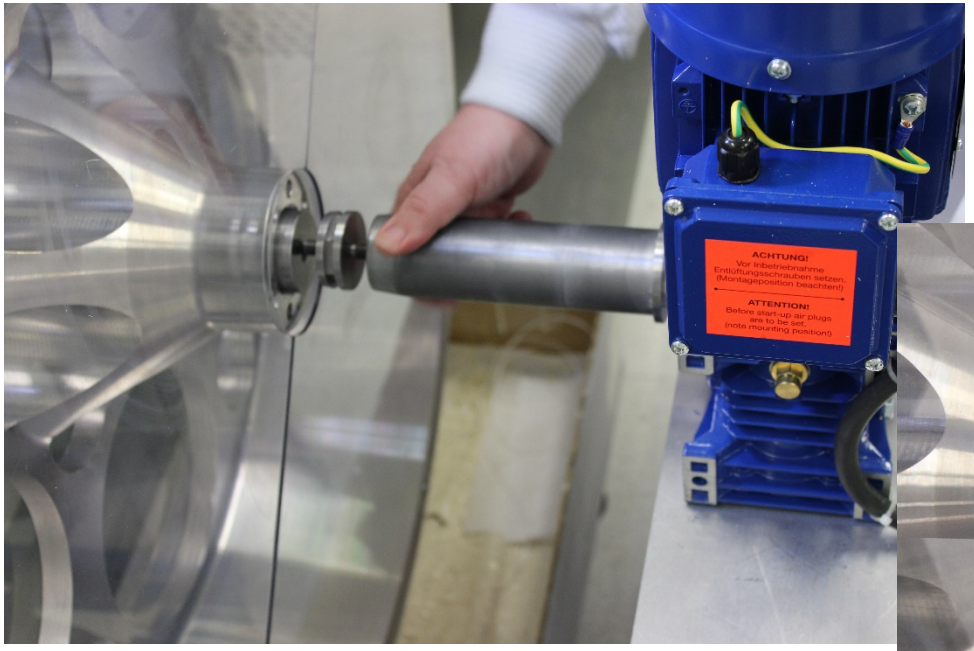
1. Mount winding wheel on rotation cart.

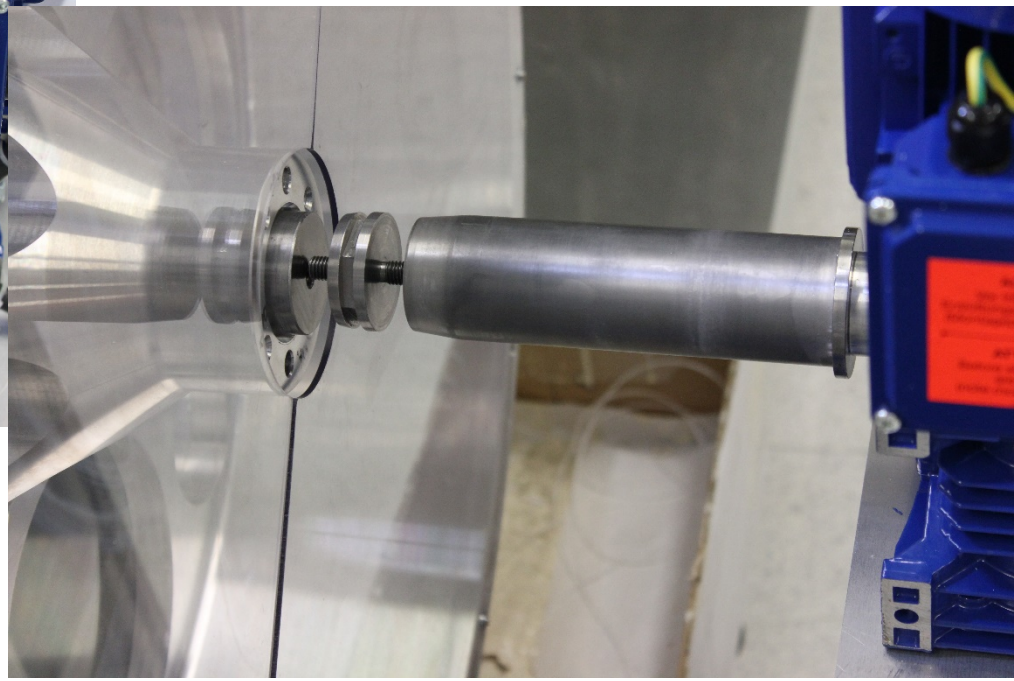
a) Move rotation cart in front of the winding wheel.



5. Curing of fibre mat

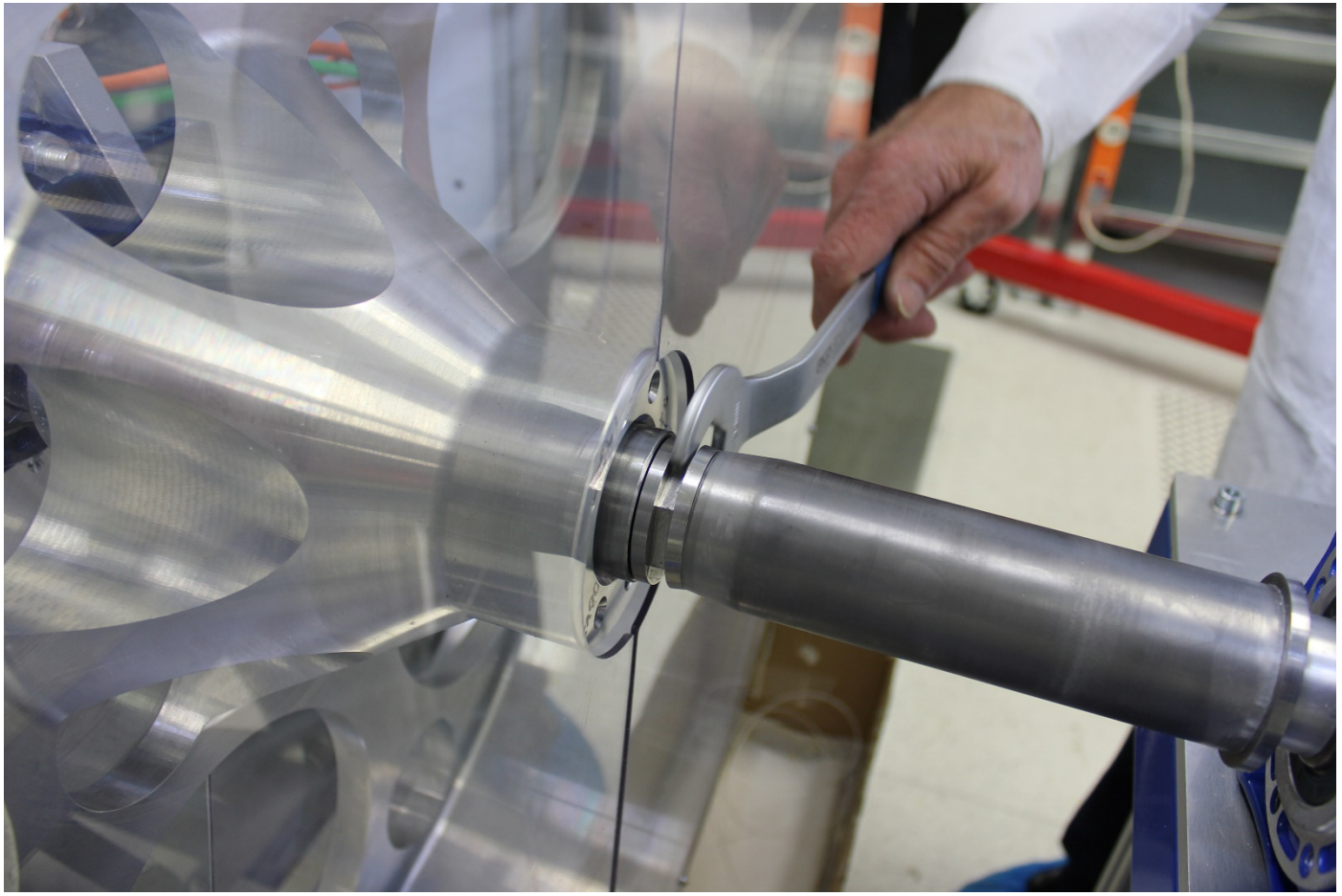
1. Mount winding wheel on rotation cart.
b) Screw axles of rotation cart and rotation motor of winding machine together using the adapter.





5. Curing of fibre mat

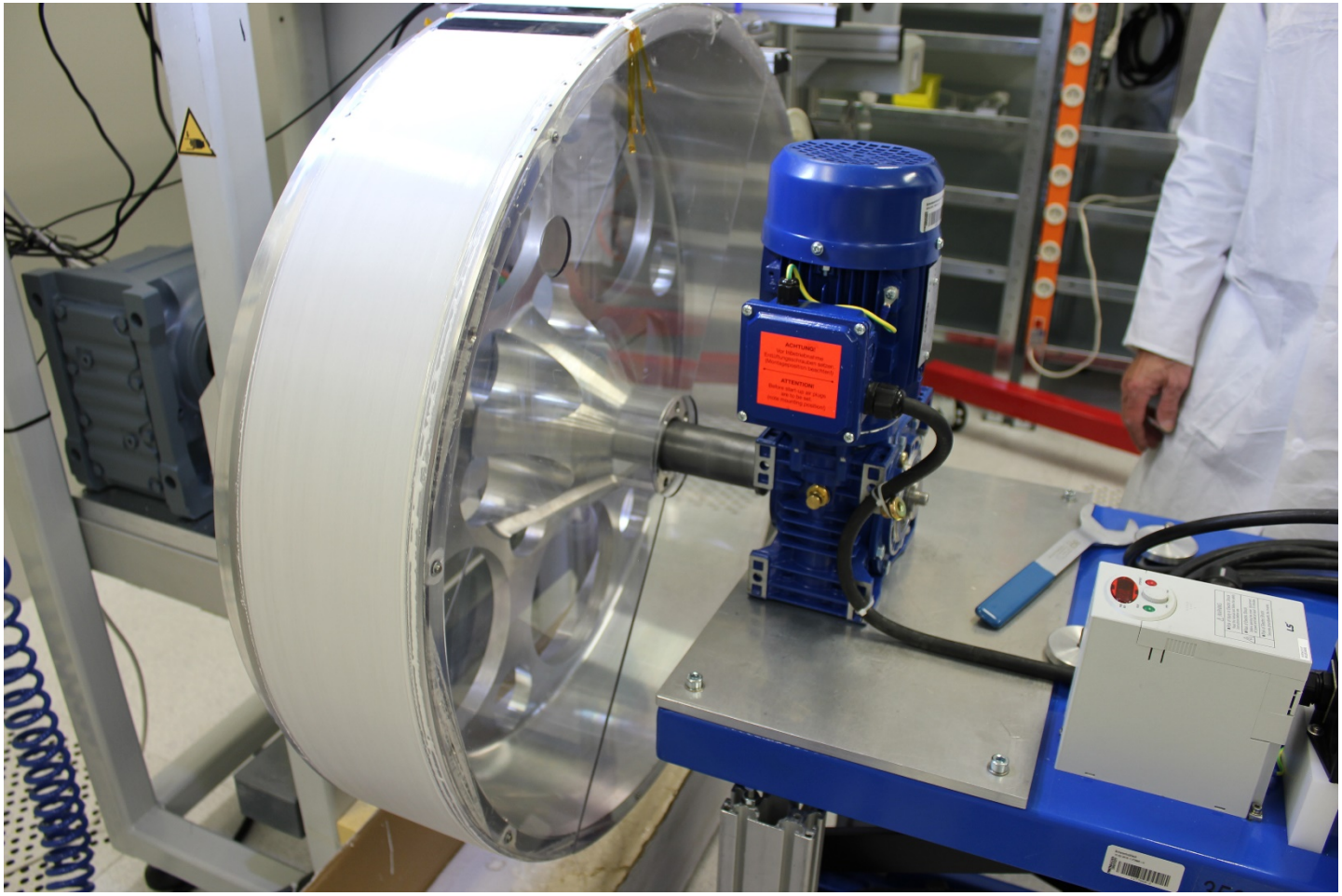
1. Mount winding wheel on rotation cart.
b) Screw axles of rotation cart and rotation motor of winding machine together using the adapter.



5. Curing of fibre mat

1. Mount winding wheel on rotation cart.

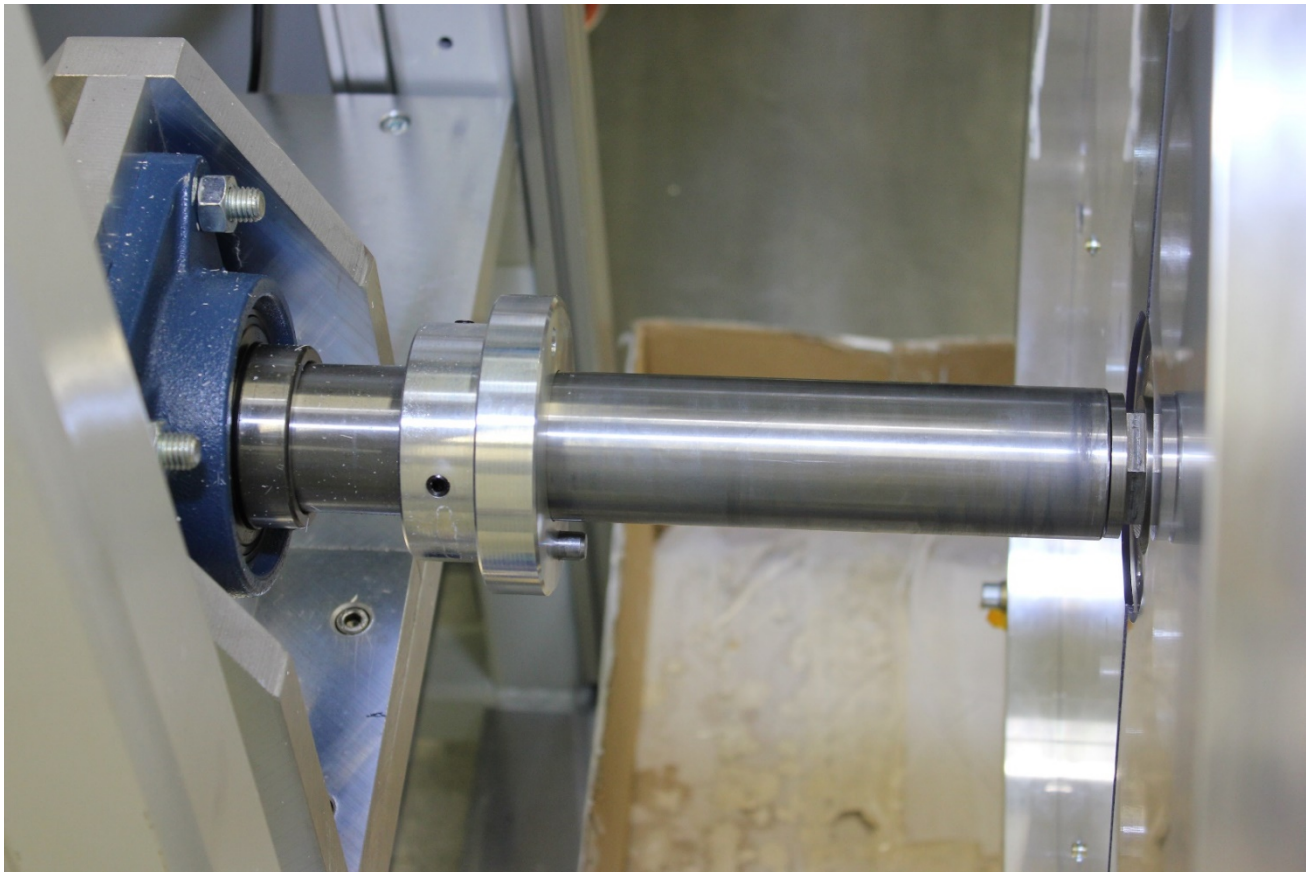
c) Slide wheel from winding machine over to rotation cart



5. Curing of fibre mat

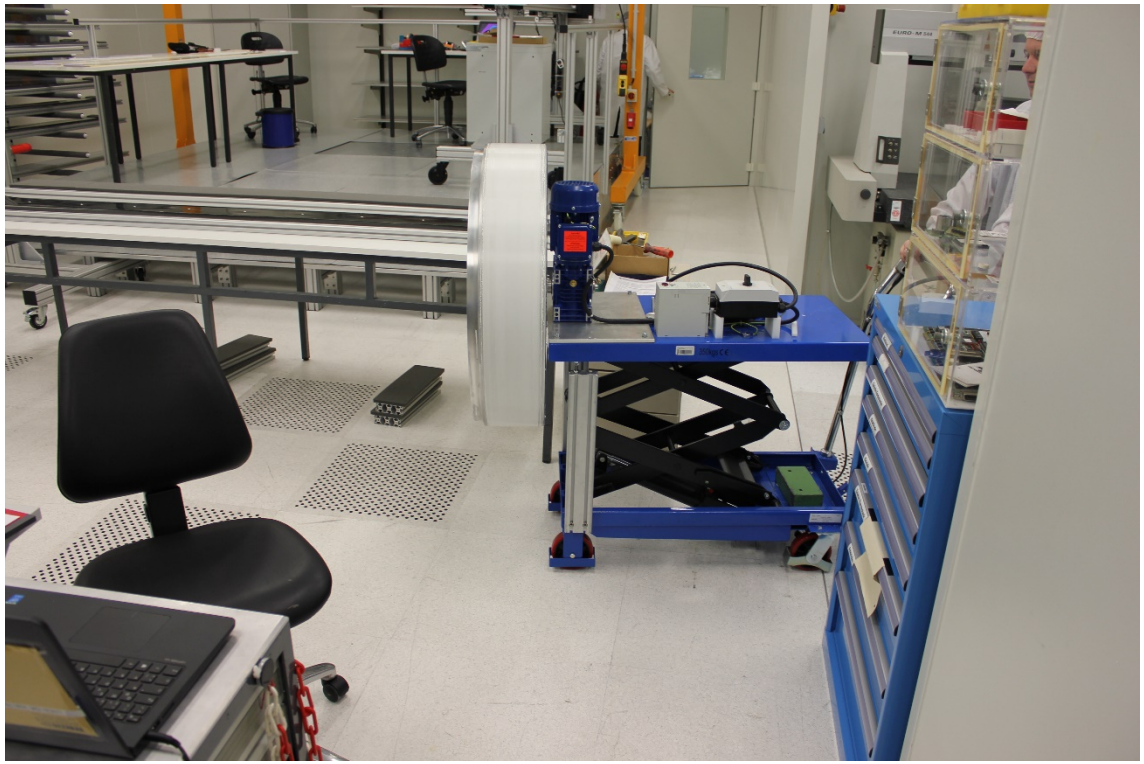
1. Mount winding wheel on rotation cart.

c) Slide wheel from winding machine over to rotation cart and unscrew the adapter



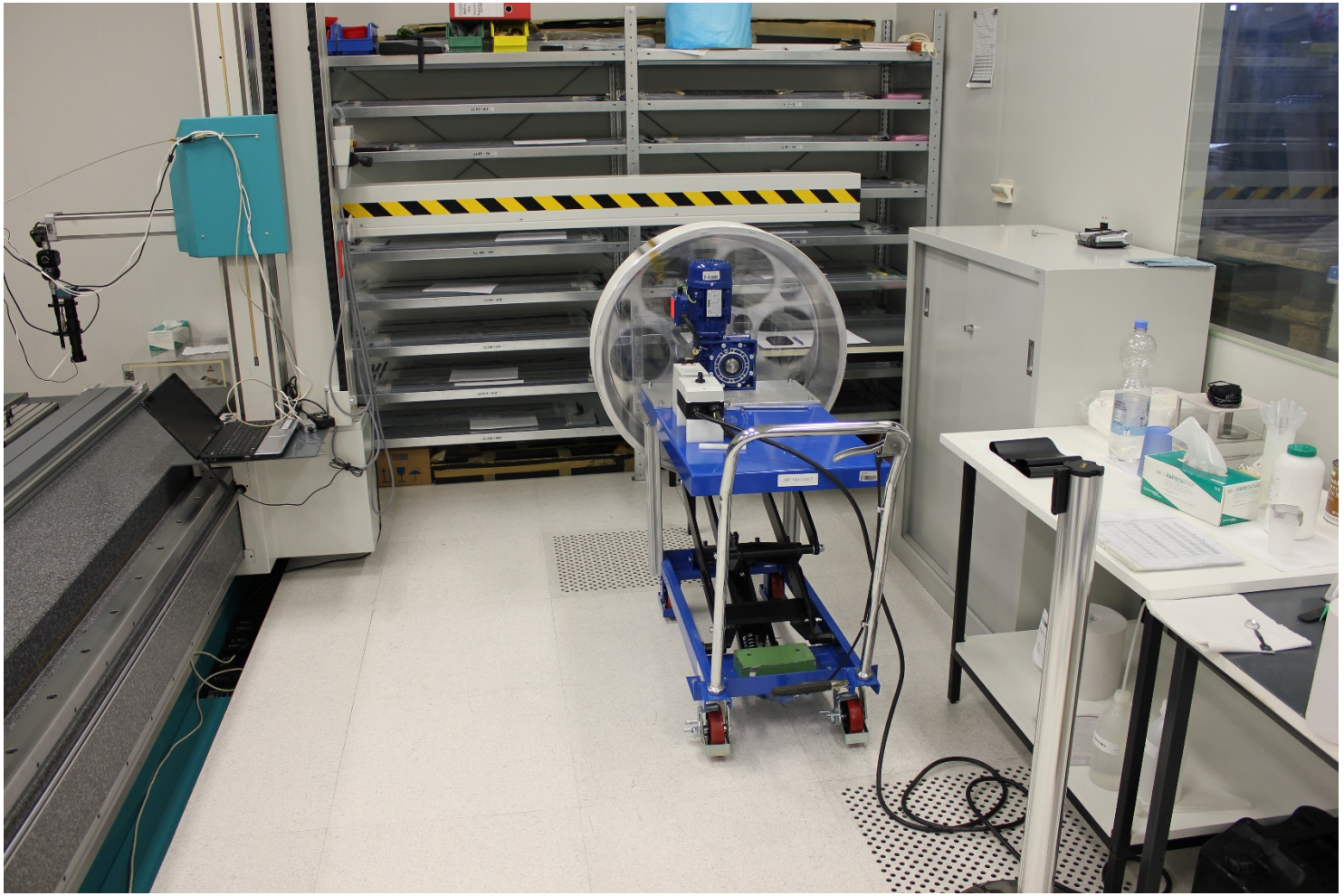
5. Curing of fibre mat

2. Move rotation cart with winding wheel to parking position.



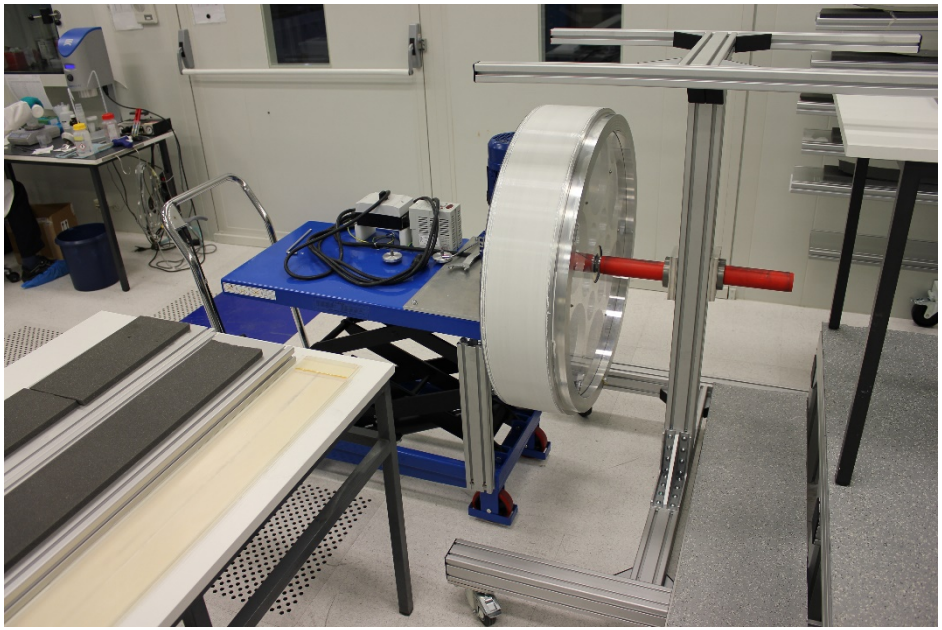
5. Curing of fibre mat

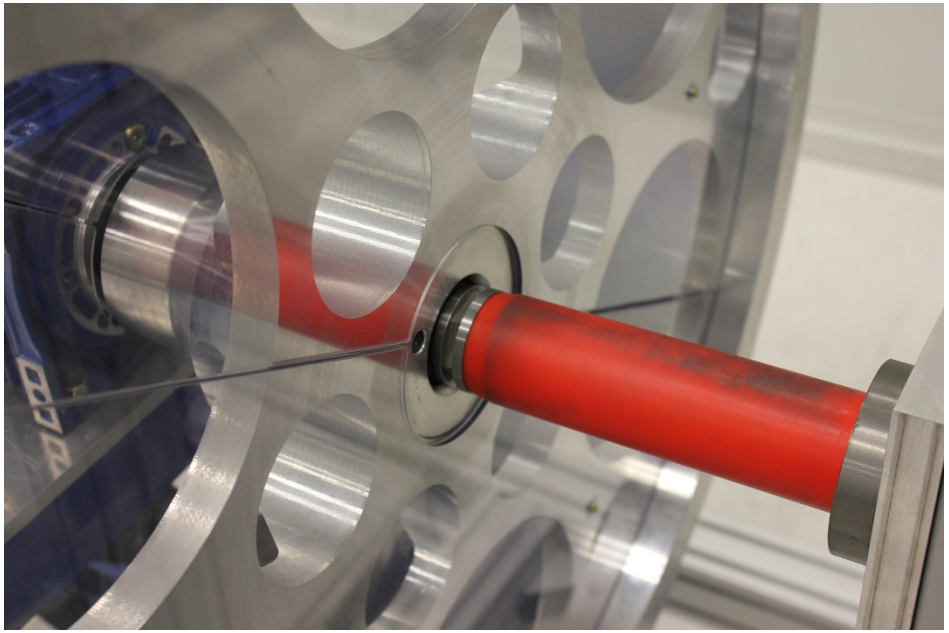
3. Keep winding wheel rotating on rotation cart for 12h till polymerisation is advanced and glue will not drop down of the wheel.



5. Curing of fibre mat

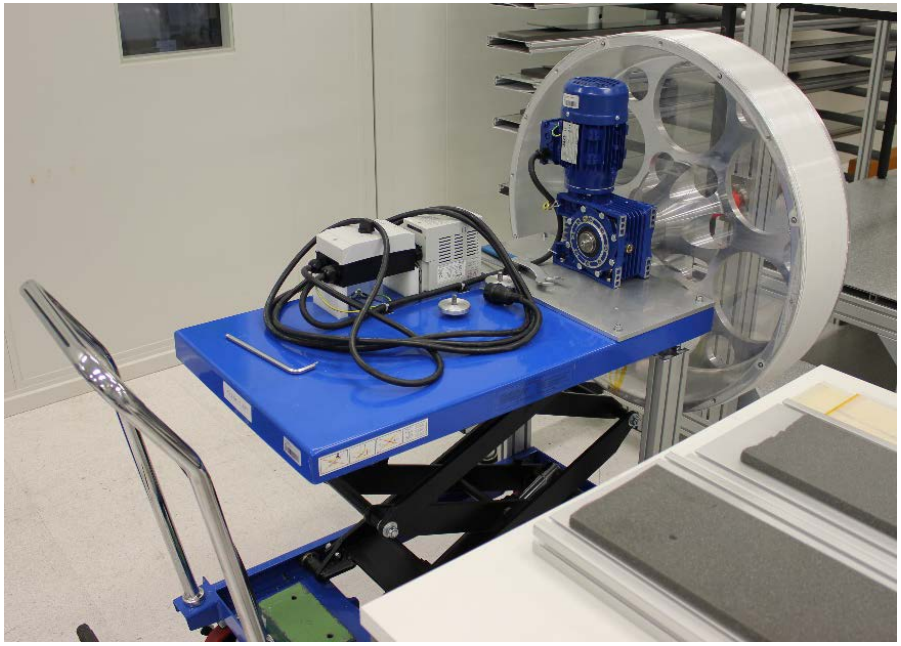
4. Move rotation cart to storage rack.
5. Dismount winding wheel and mount it to storage rack by screwing together again the axles using the adapter and sliding the wheel to the rack.

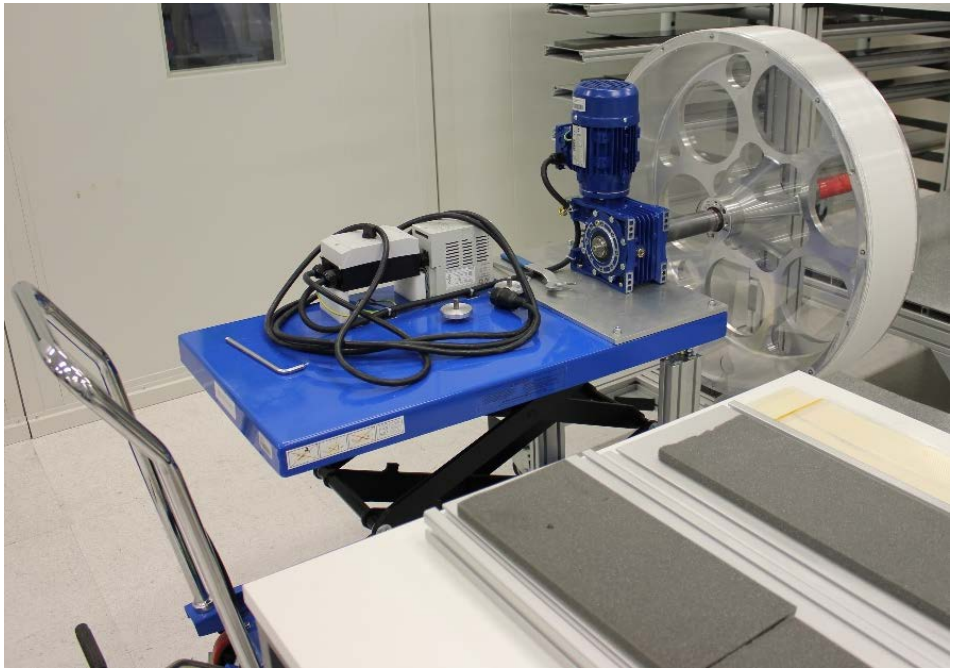




5. Curing of fibre mat

5. Dismount winding wheel and mount it to storage rack by screwing together again the axles using the adapter and sliding the wheel to the rack.

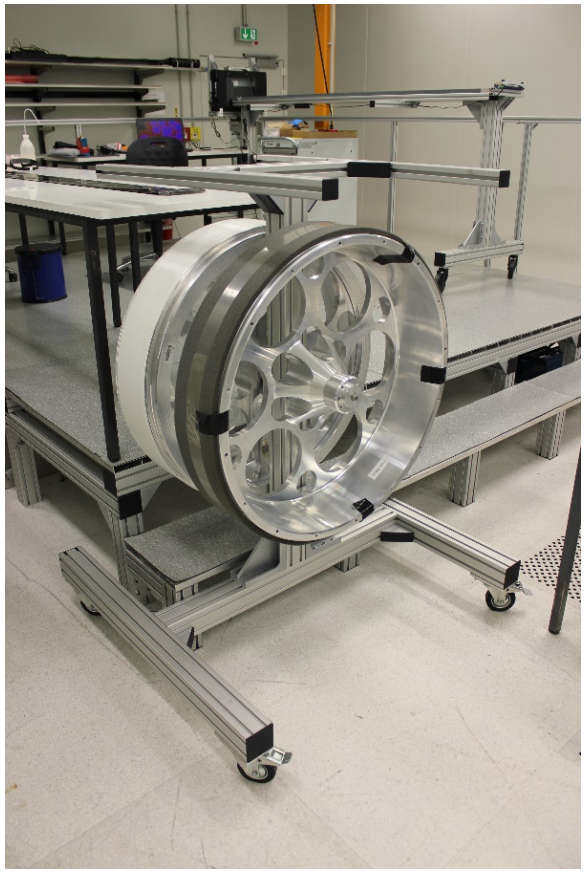


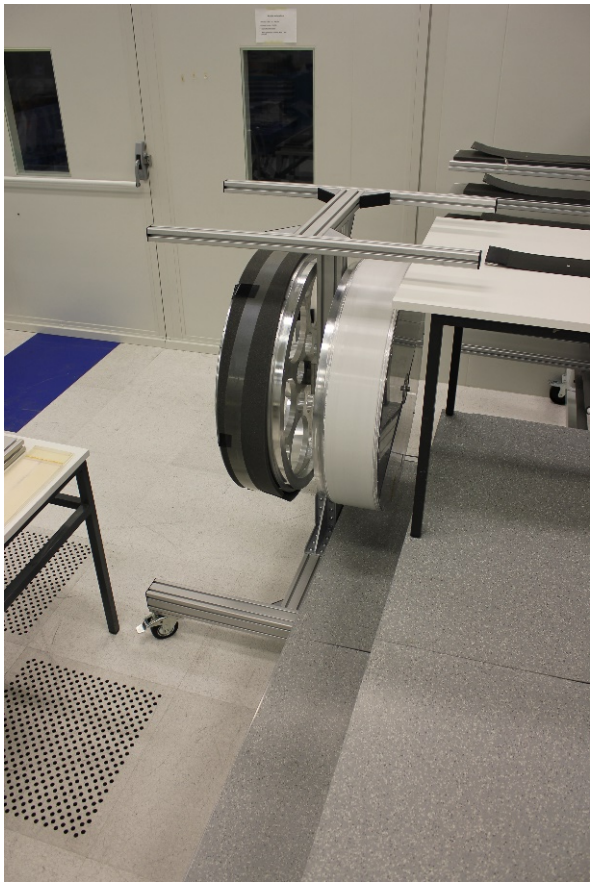


5. Curing of fibre mat

Curing of fibre mat for 48 h

6. Keep curing of fibre mat on going till 48 h are reached.





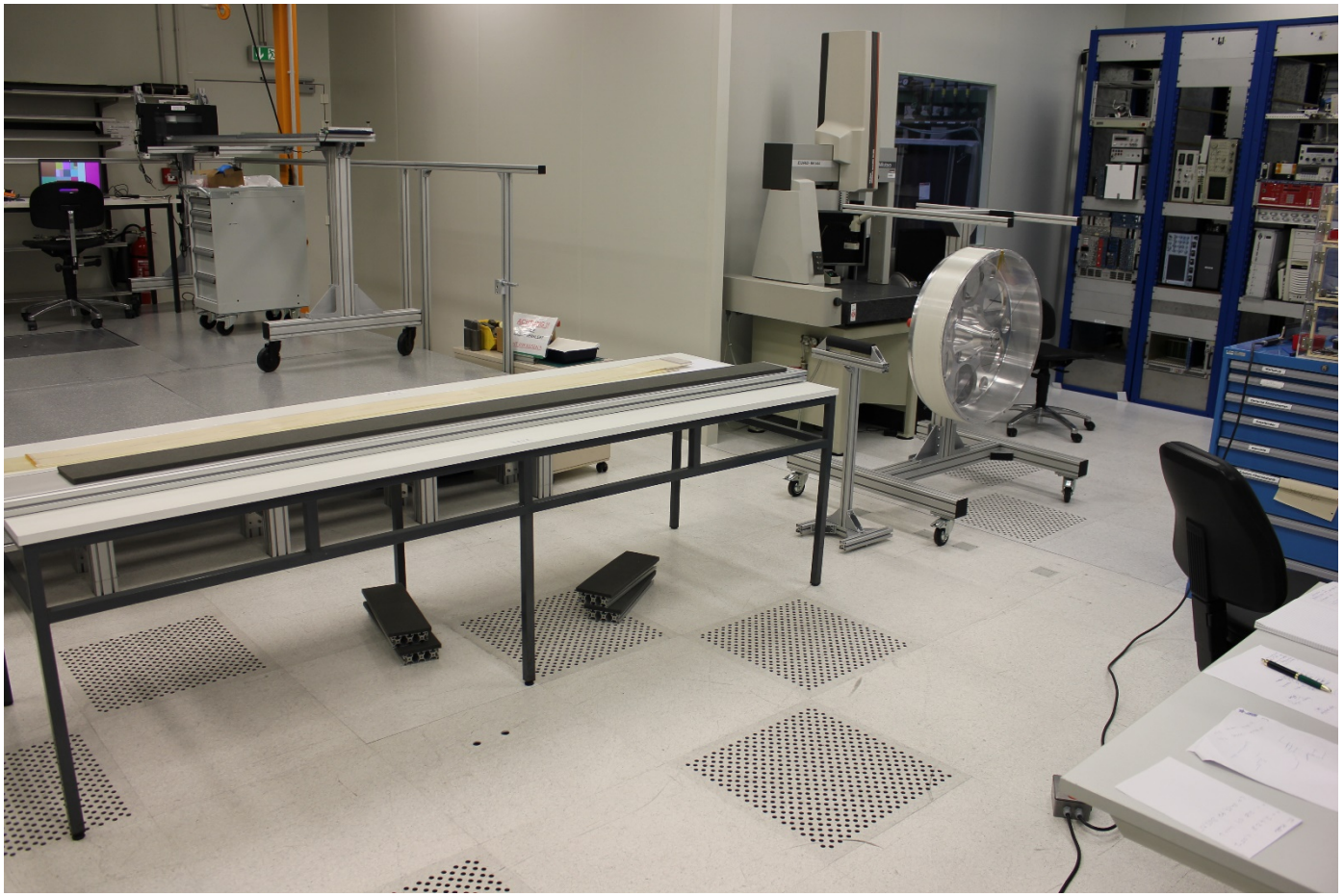
6. Unforming of fibre mat

1. Move storage jig with winding wheel and fibre mat to cutting position in front of long table. 96
2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel 97
3. Loosen fibre mat from winding wheel using a round plastic stick. Start loosening of the mat at the transversal cutting groove. 100
4. Guide fibre mat via a deviating roller on a shelf till end of fibre mat on wheel is reached. Loosen fibre mat from kapton tape. 105
5. Protect fibre mat using a foam. 107
6. Place shelf with protected fibre mat in storage rack where the mat is stored waiting for the next production step 110

6. Unforming of fibre mat

Unforming of fibre mat from winding wheel:

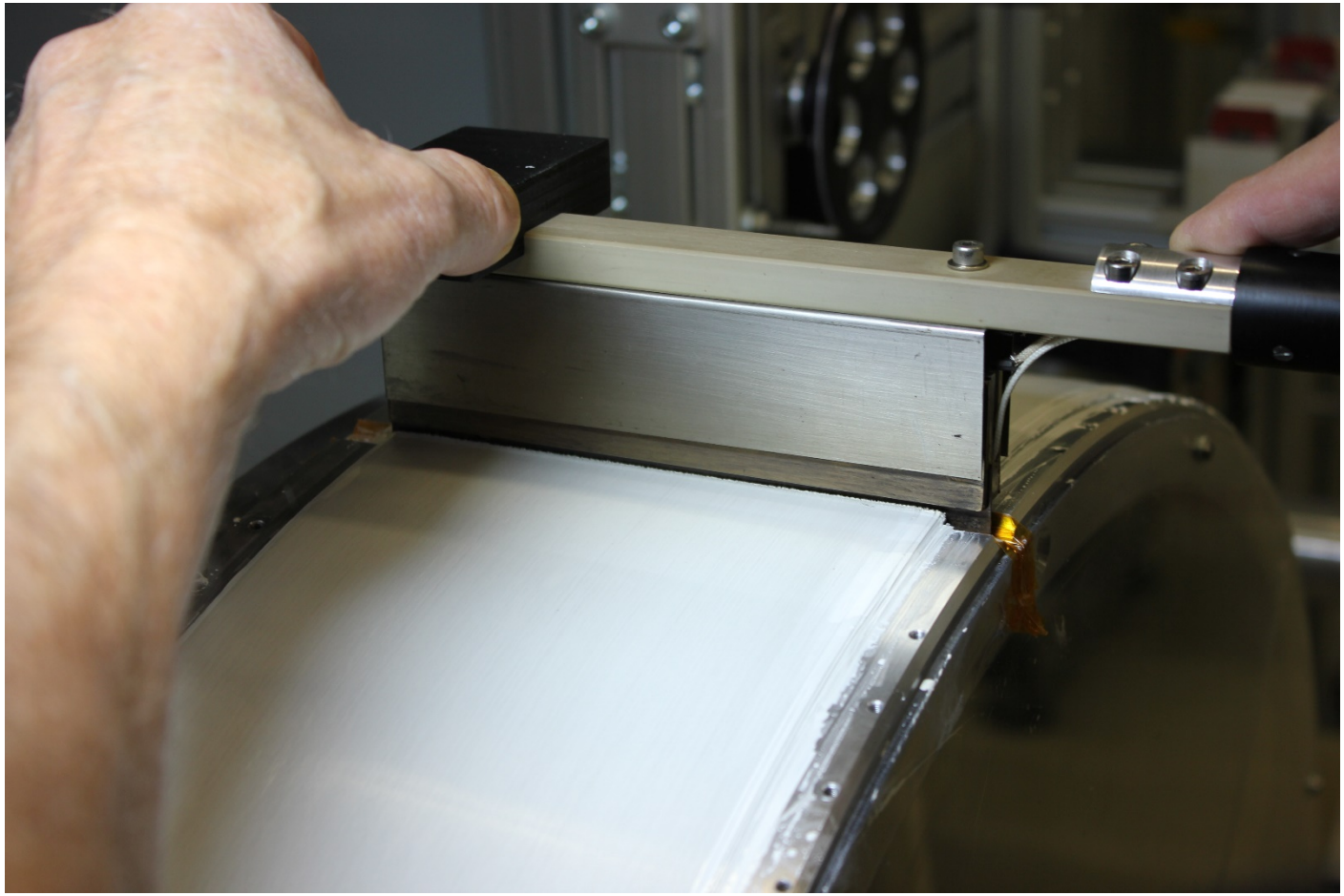
1. Move storage jig with winding wheel and fibre mat to cutting position in front of long table



6. Unforming of fibre mat

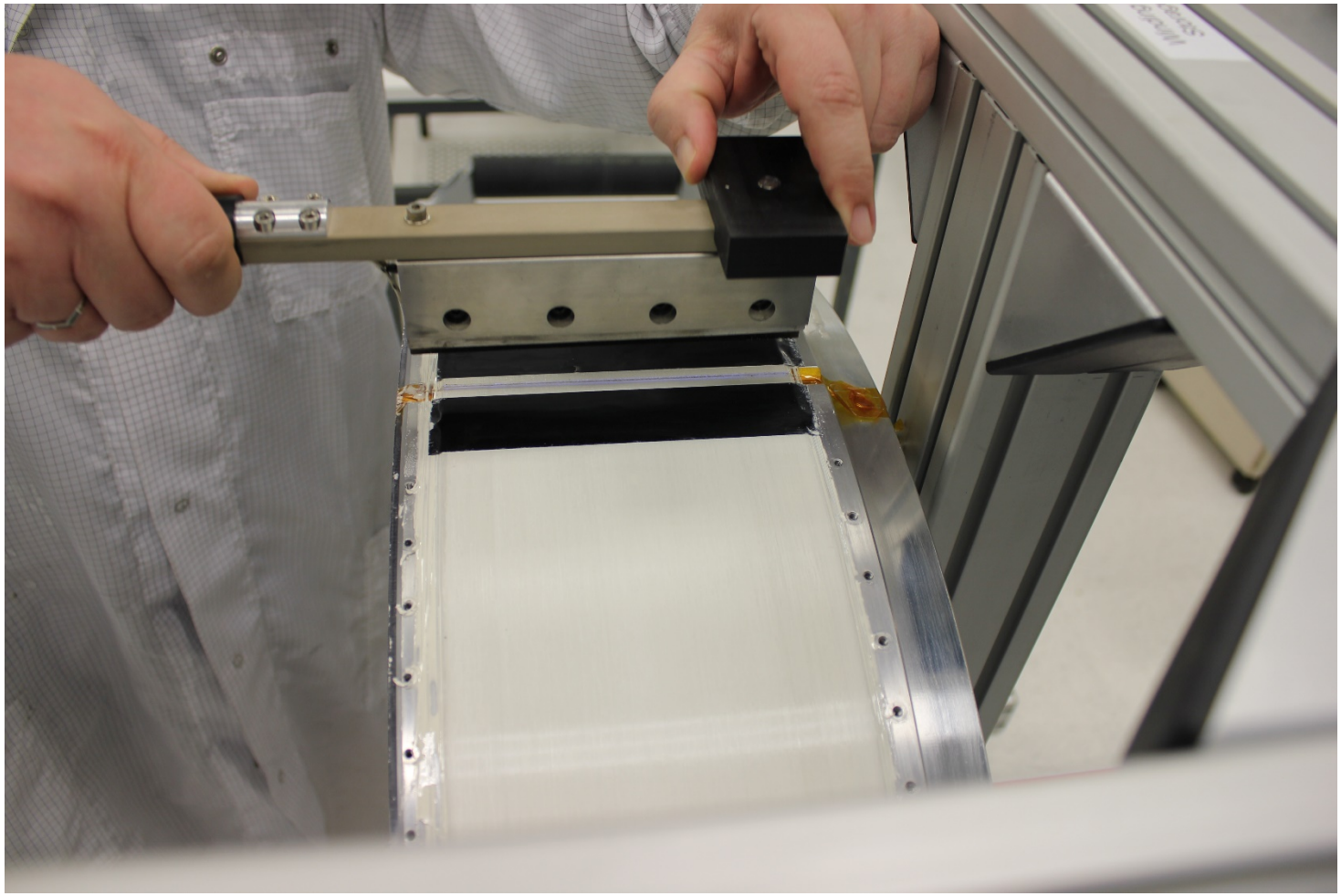
Unforming of fibre mat from winding wheel:

2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel



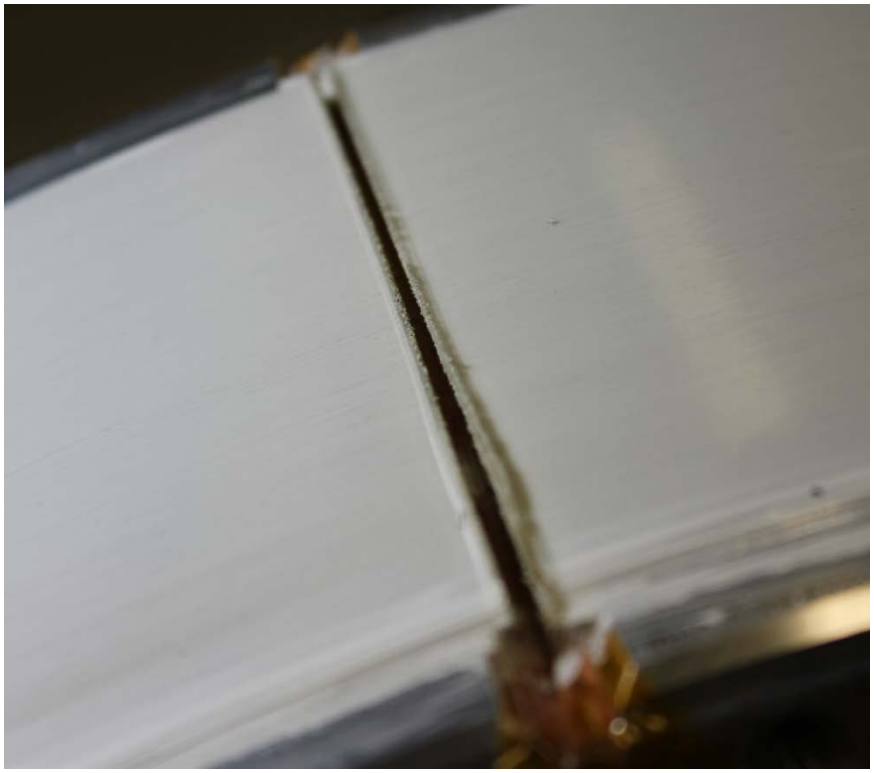
6. Unforming of fibre mat

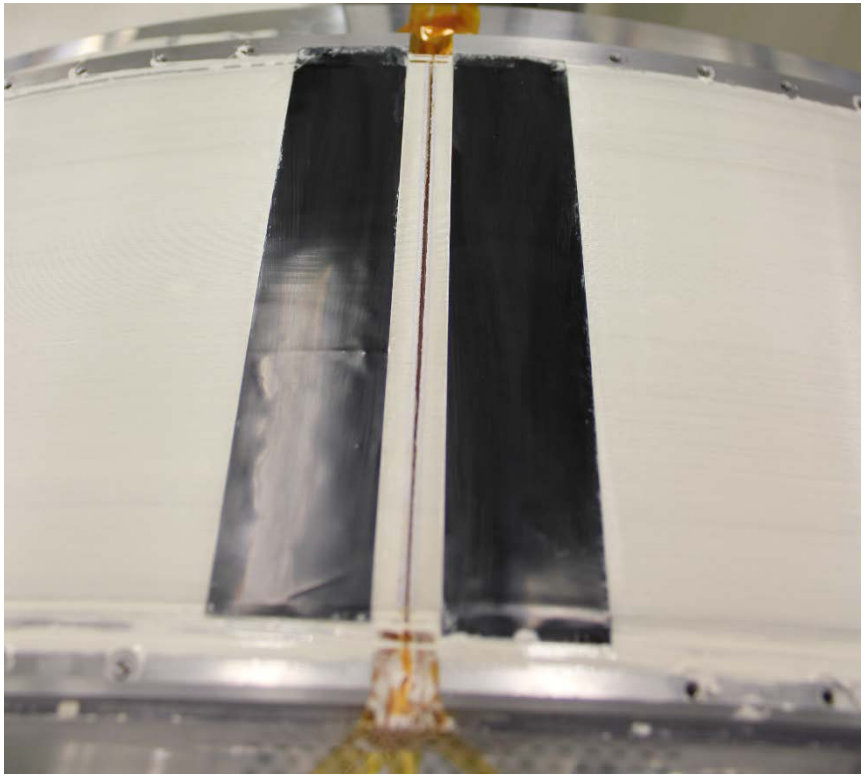
2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel



6. Unforming of fibre mat

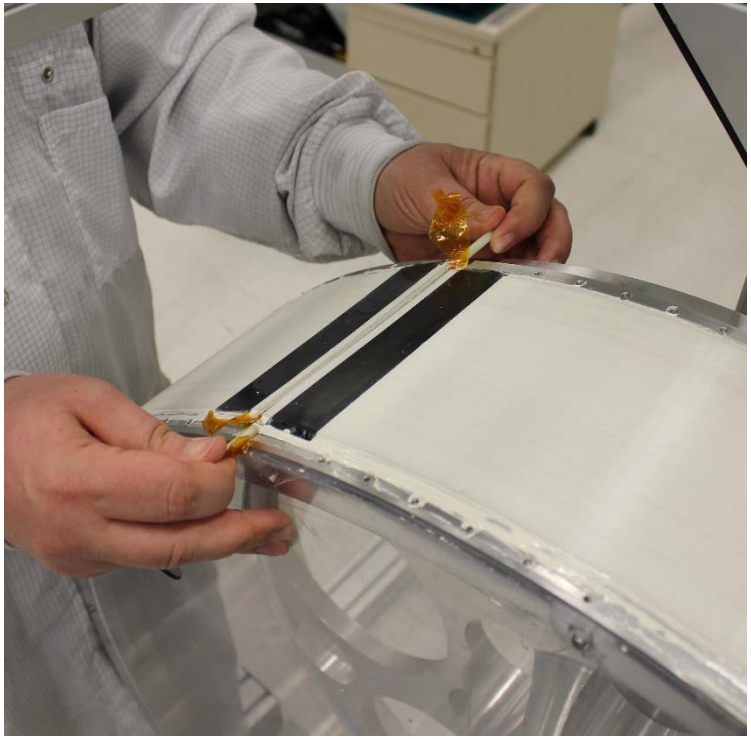
2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel

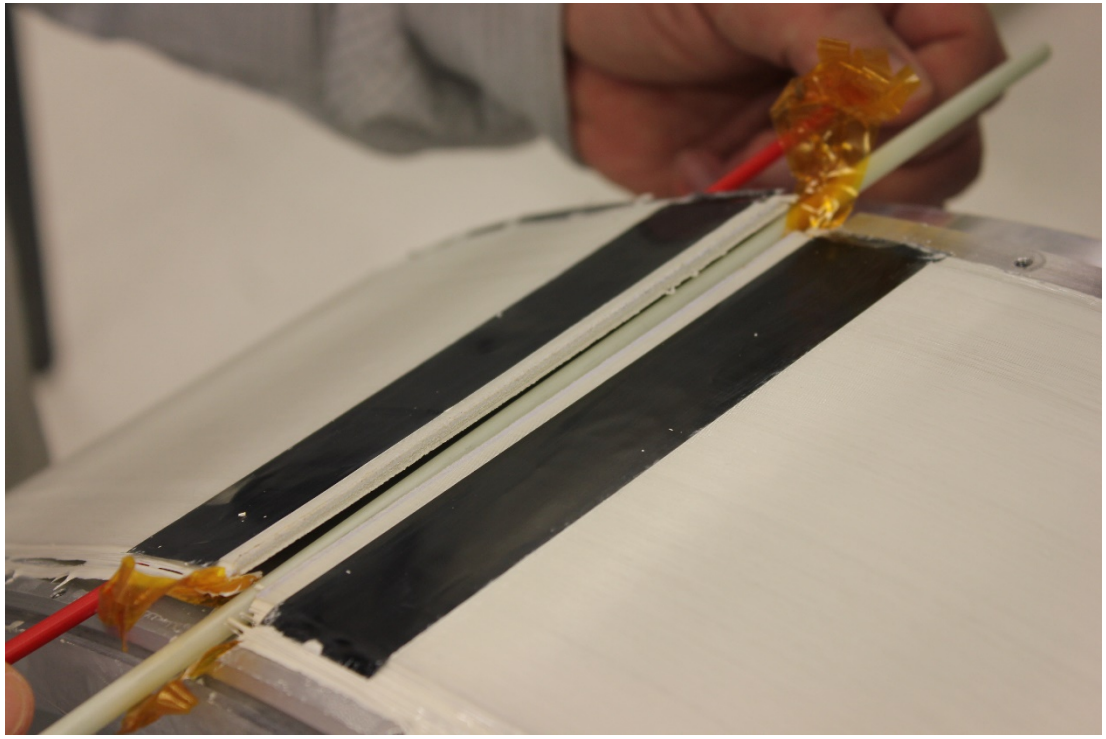




6. Unforming of fibre mat

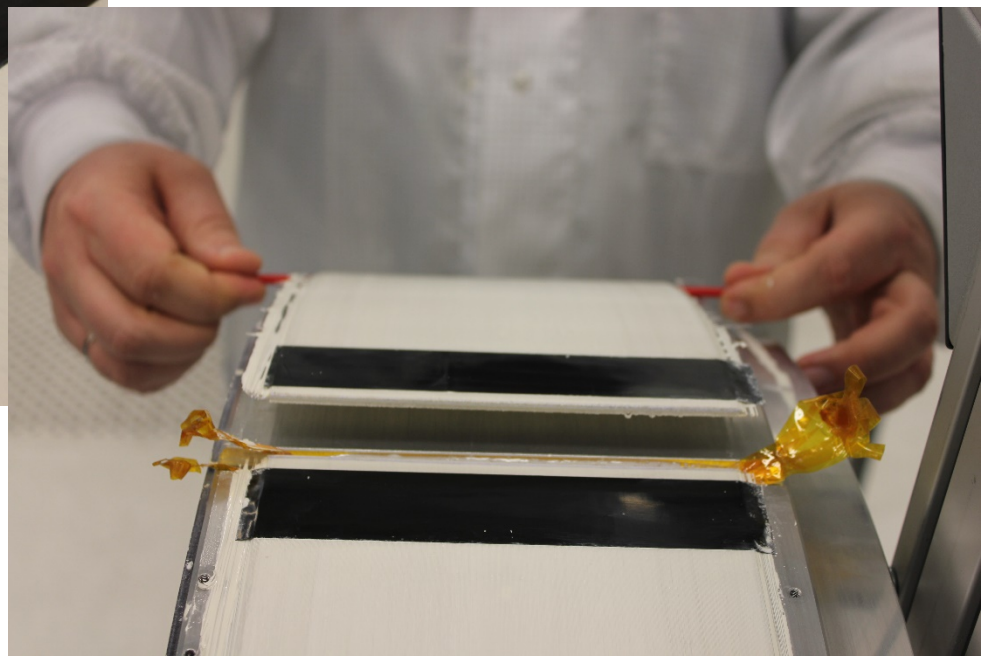
3. Loosen fibre mat from winding wheel using a round plastic stick. Start loosening of the mat at the transversal cutting groove.





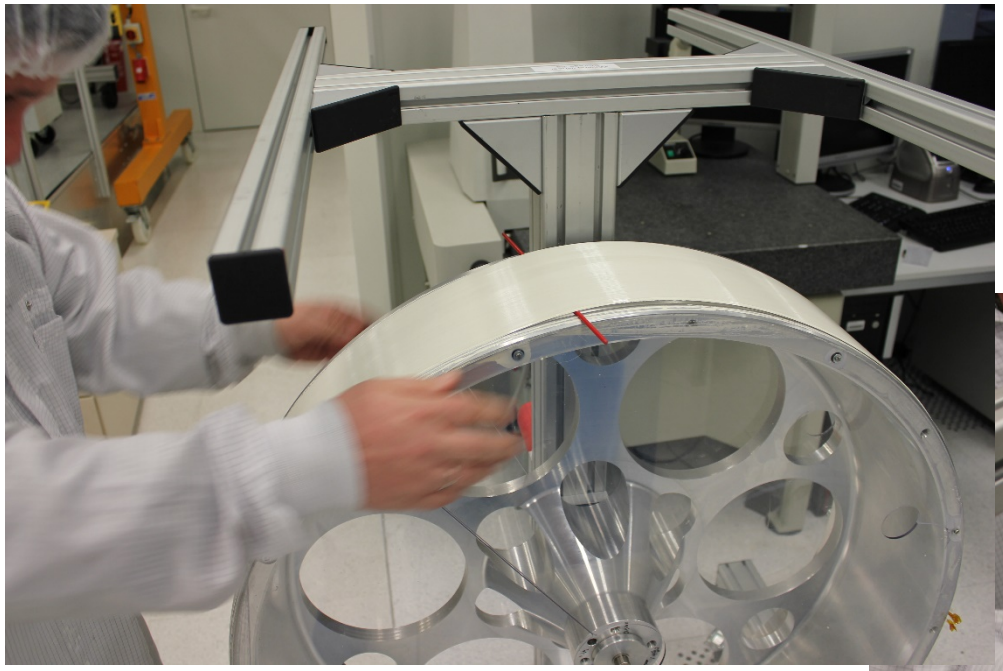
6. Unforming of fibre mat

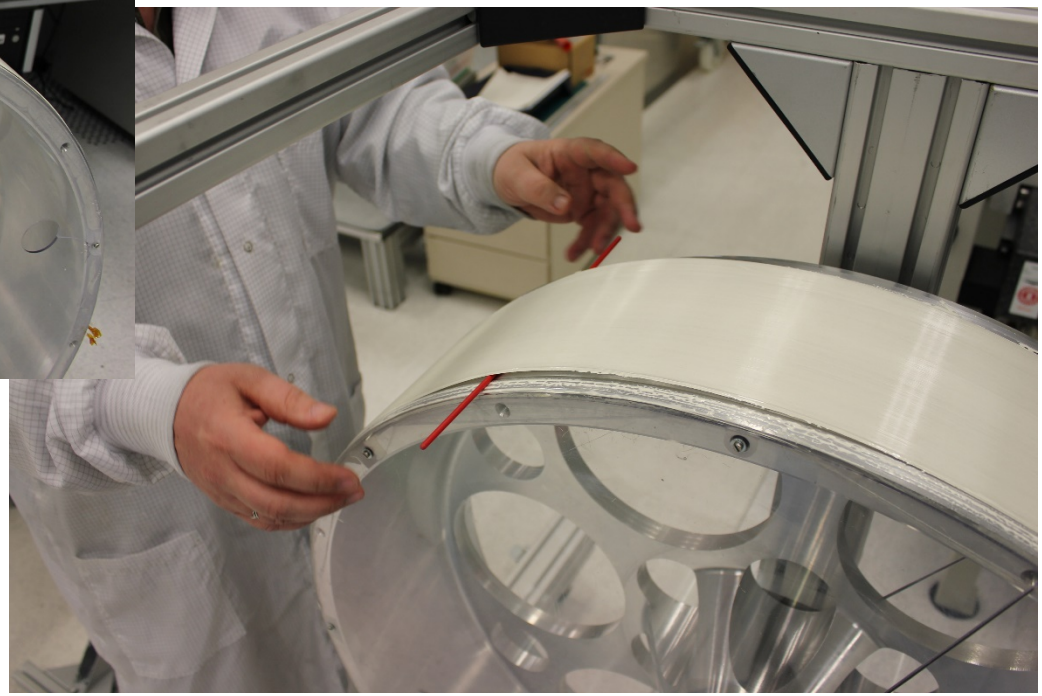
3. Loosen fibre mat from winding wheel using a round plastic stick. Start loosening of the mat at the transversal cutting groove.



6. Unforming of fibre mat

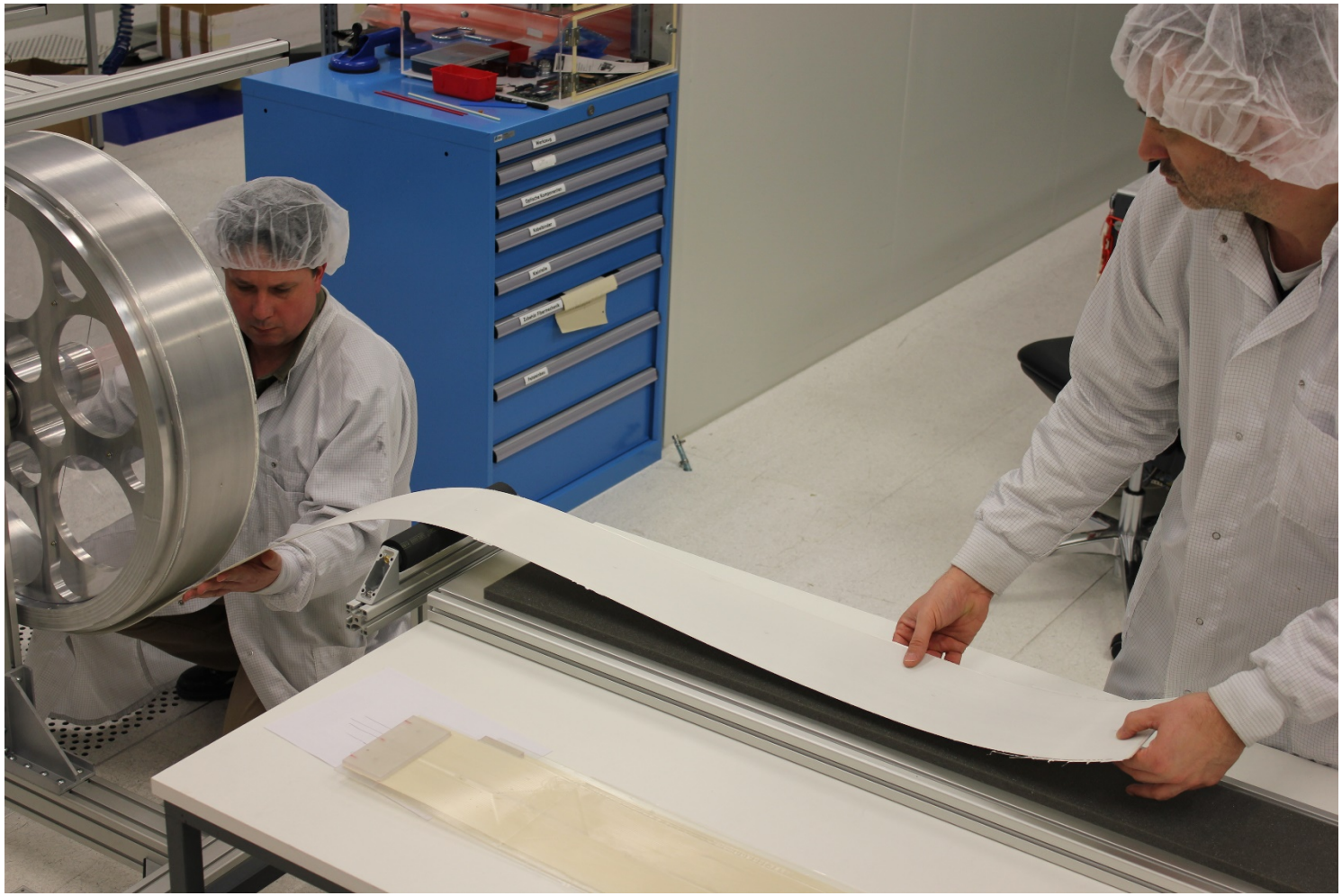
3. Loosen fibre mat from winding wheel using a round plastic stick. Continue loosening of the mat around the wheel.





6. Unforming of fibre mat

3. Continue loosening of the mat around the wheel. Guide fibre mat via a deviating roller on a shelf.

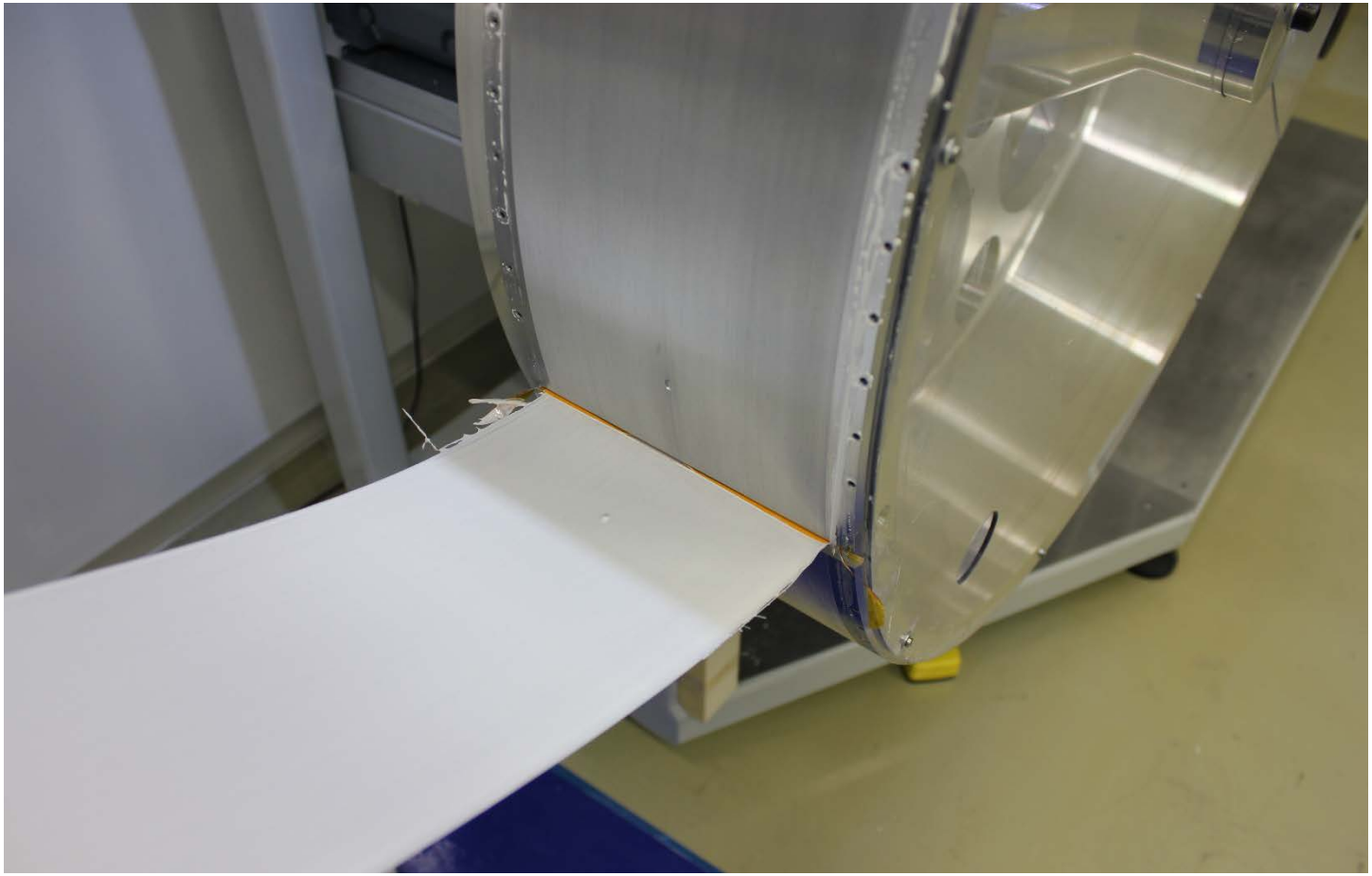


6. Unforming of fibre mat

3. Continue loosening of the mat around the wheel. Guide fibre mat via a deviating roller on a shelf.

6. Unforming of fibre mat

4. Guide fibre mat via a deviating roller on a shelf till end of fibre mat on wheel is reached. Loosen fibre mat from kapton tape.

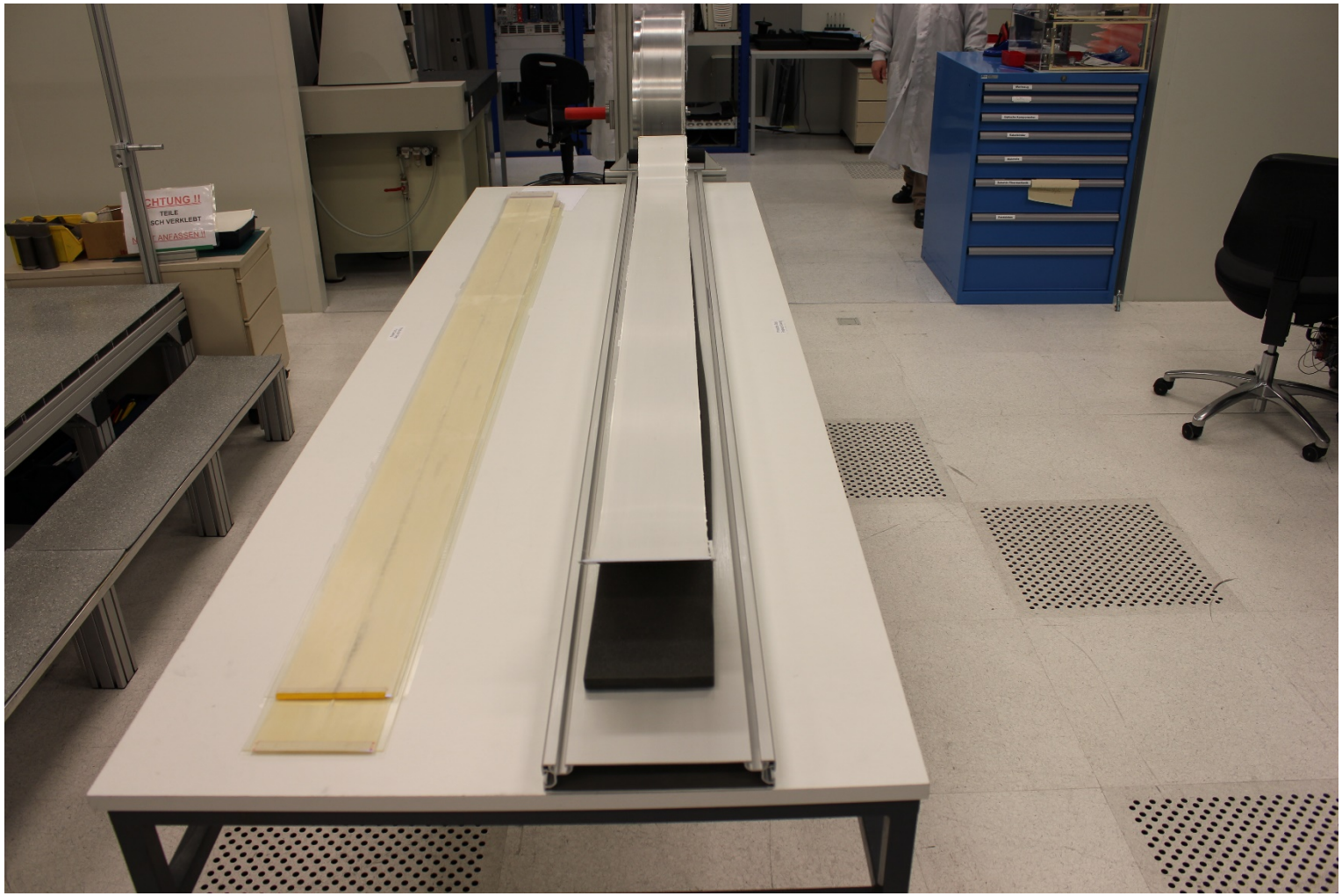


6. Unforming of fibre mat

4. Guide fibre mat via a deviating roller on a shelf till end of fibre mat on wheel is reached. Loosen fibre mat from kapton tape.

6. Unforming of fibre mat

5. Protect fibre mat using a foam.



6. Unforming of fibre mat

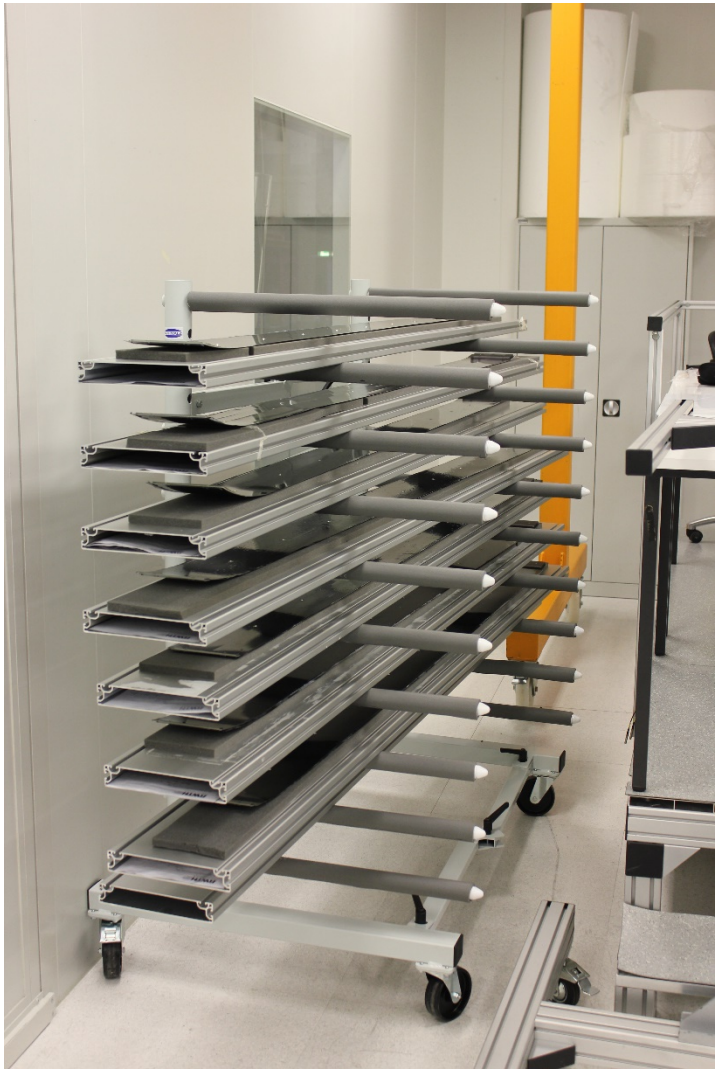
5. Protect fibre mat using a foam.

6. Unforming of fibre mat

5. Protect fibre mat using a foam. Fix foam to shelf using an adhesive tape.

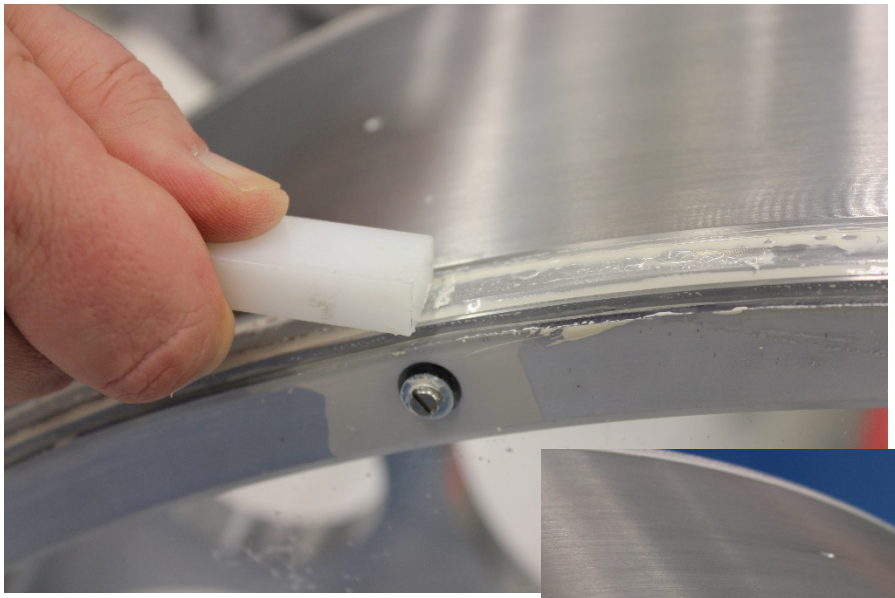
6. Unforming of fibre mat

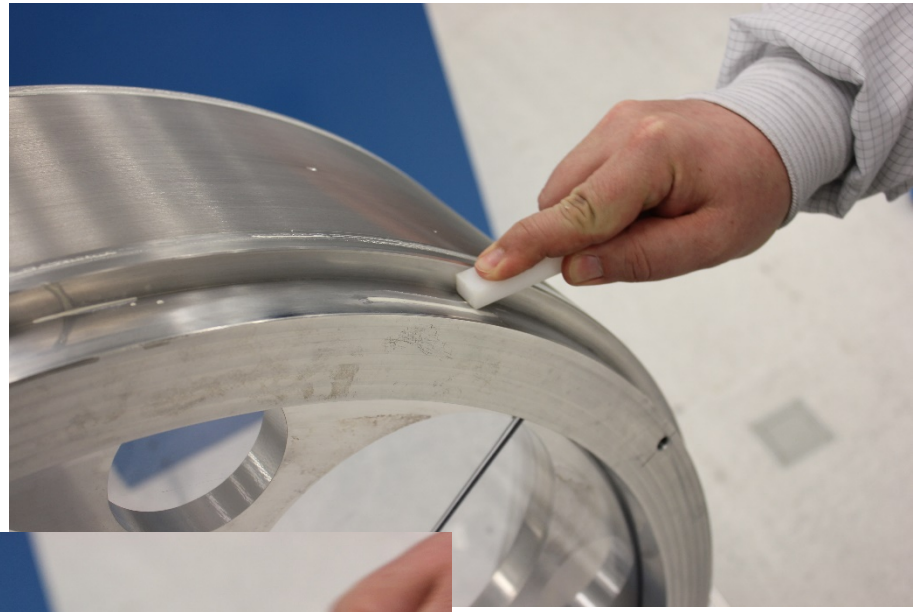
6. Place shelf with protected fibre mat in storage rack where the mat is stored waiting for the next production step

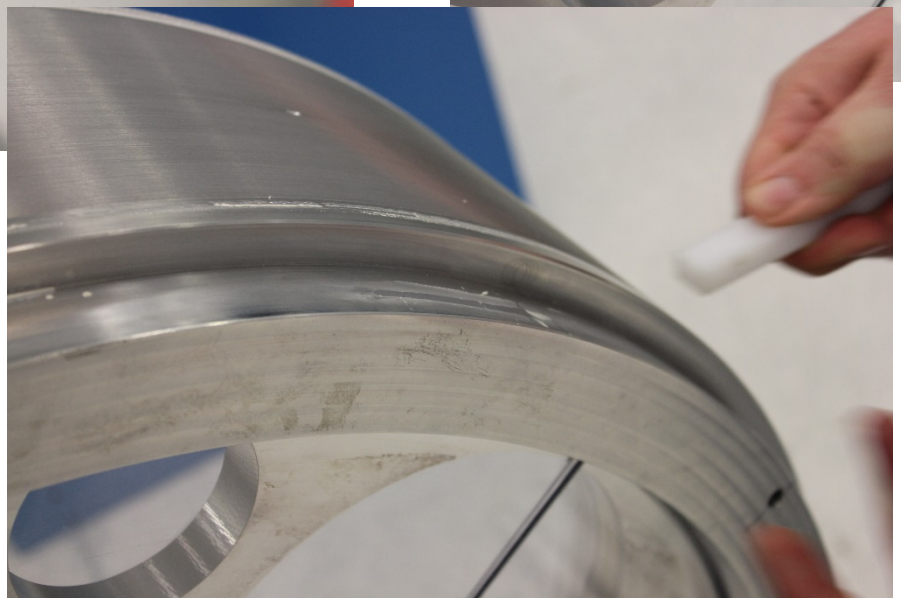


7. Reconditioning of fibre mat

1. Removal of glue residuals from winding wheel
2. Cleaning of winding wheel after production of 4 fiber mats, go to step 3.
   Preparation of Winding Wheel

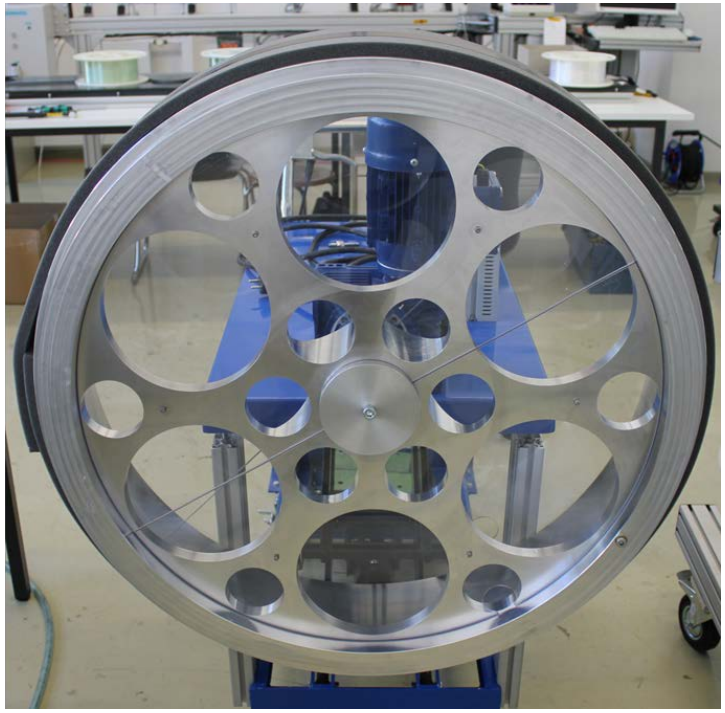






7. Reconditioning of winding wheel

1. Removal of glue residuals from winding wheel:
Use a nylon block, scotch brite and a brush to remove the glue residuals from winding wheel. If necessary apply release agent again.
2. Cleaning of winding wheel (similiar as cleaning of winding wheel in step 1: „Preparation of Winding Wheel“.
After production of 4 fiber mats the release agent has to be re-done, go to step 1 of Winding Process, “Preparation of Winding Wheel”.

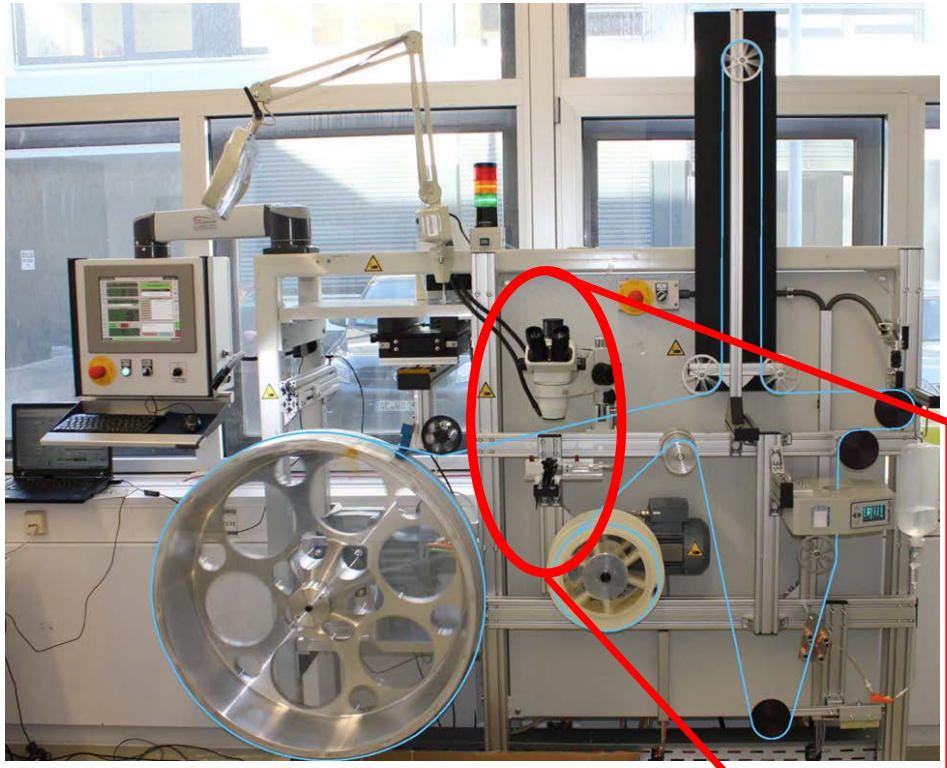


8. Bump Removal

1. If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station. 114
2. When the winding is continued and the bump creates an error, wind the fibre back by cleaning it with isopropanol. 115
3. Position and embed the fibre in the groove in the PTFE of the bump removal station. 116
4. Fix the fibre with magnets and clamps to cutting station 117
5. Place fibre into the groove above cutting piece which is clamped by linear slip table. 118
6. Cut bump out of fibre 119
7. Remove cutting block 121
8. Fibre glueing, which is an eye controlled process by stereo microscope 122

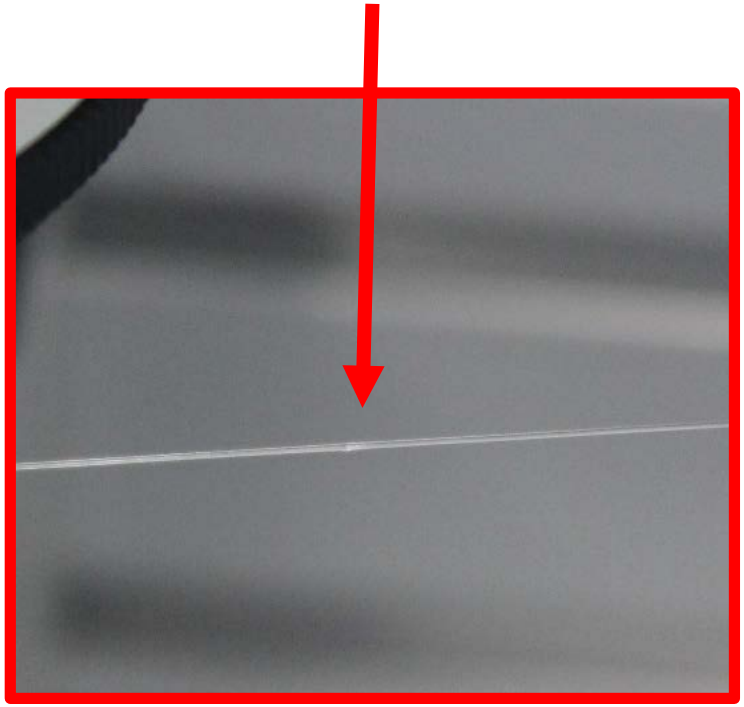
8. Bump Removal

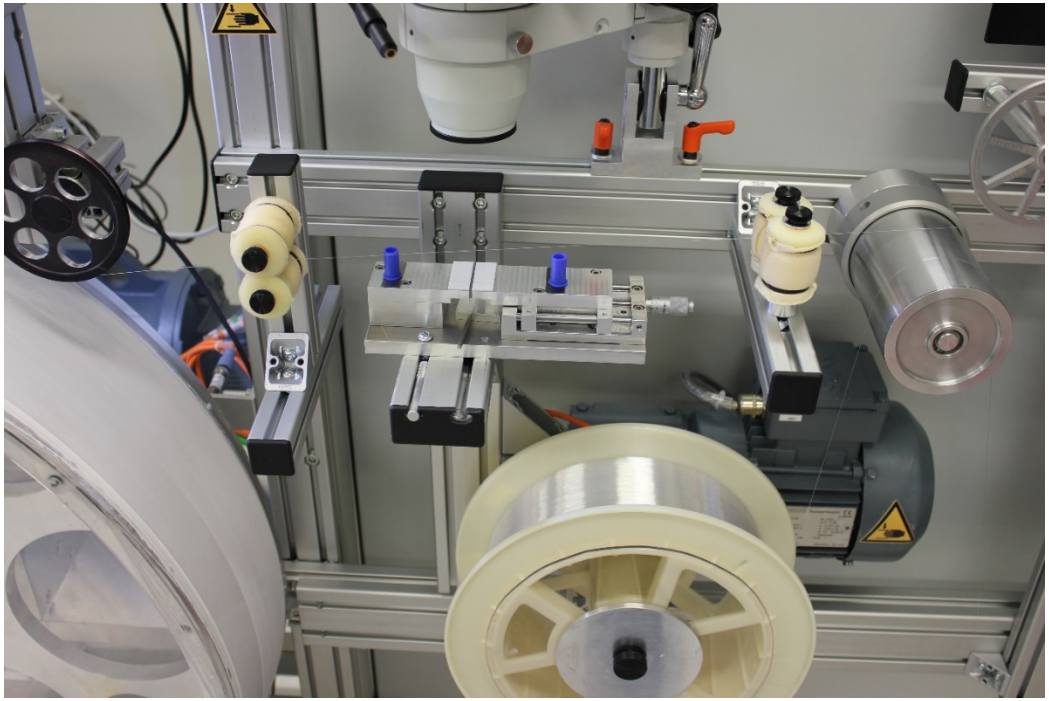
Removal of Bumps which create always errors during winding.



8. Bump Removal

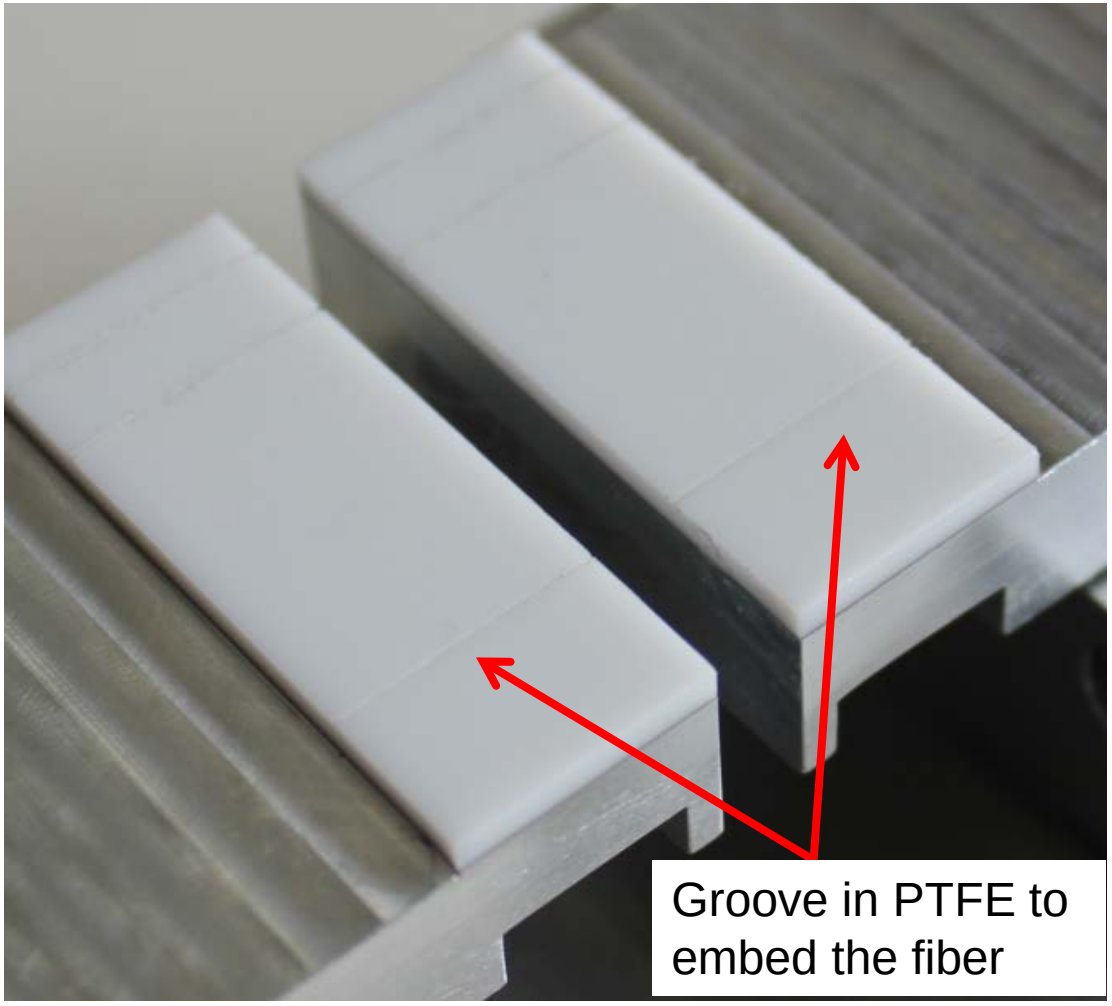
1. If the lump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station.
2. When the winding is continued and the bump creates an error, wind the fibre back by cleaning it with isopropanol.





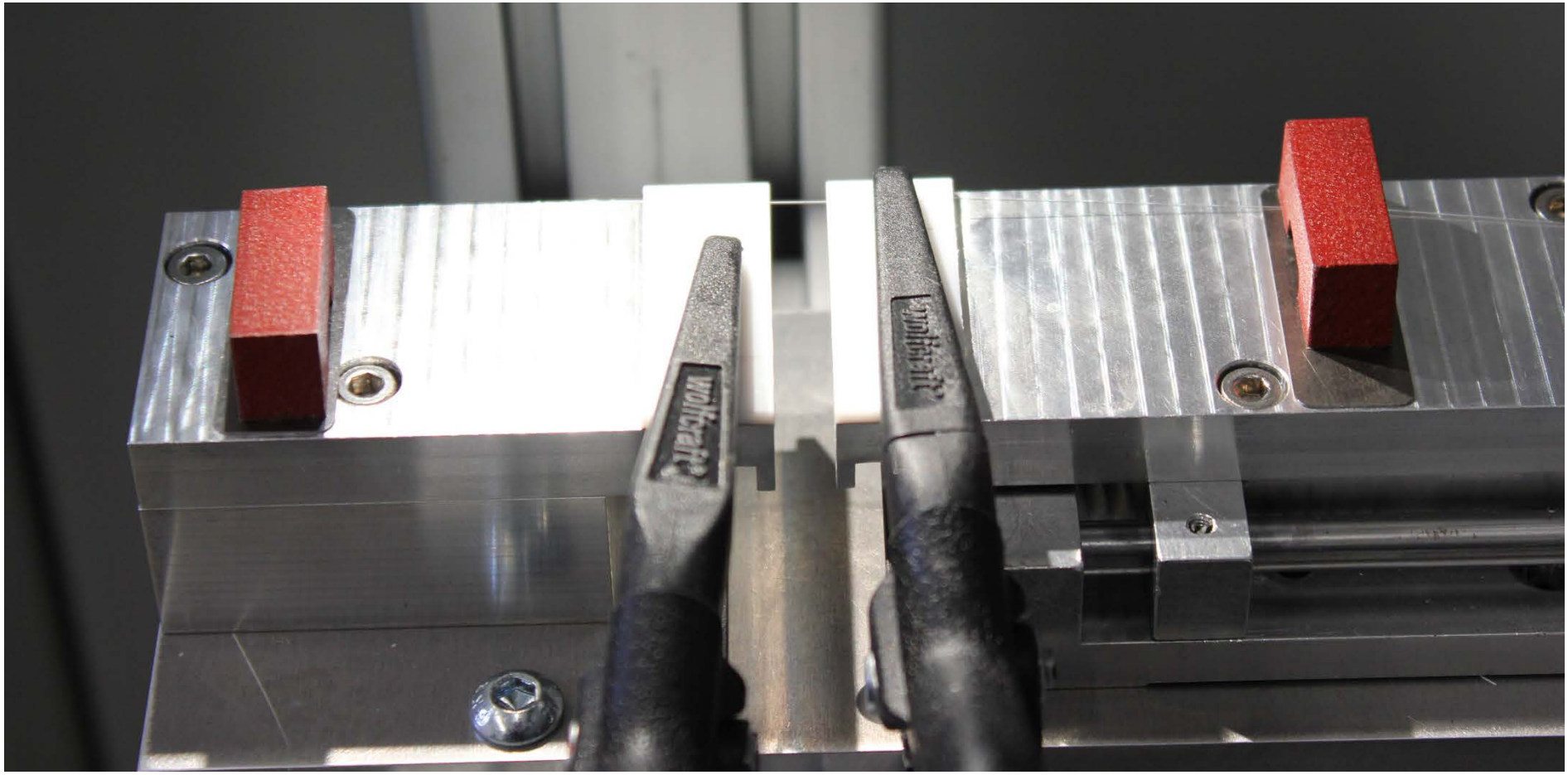
8. Bump Removal

3. Position and embed the fibre in the groove in the PTFE of the bump removal station.



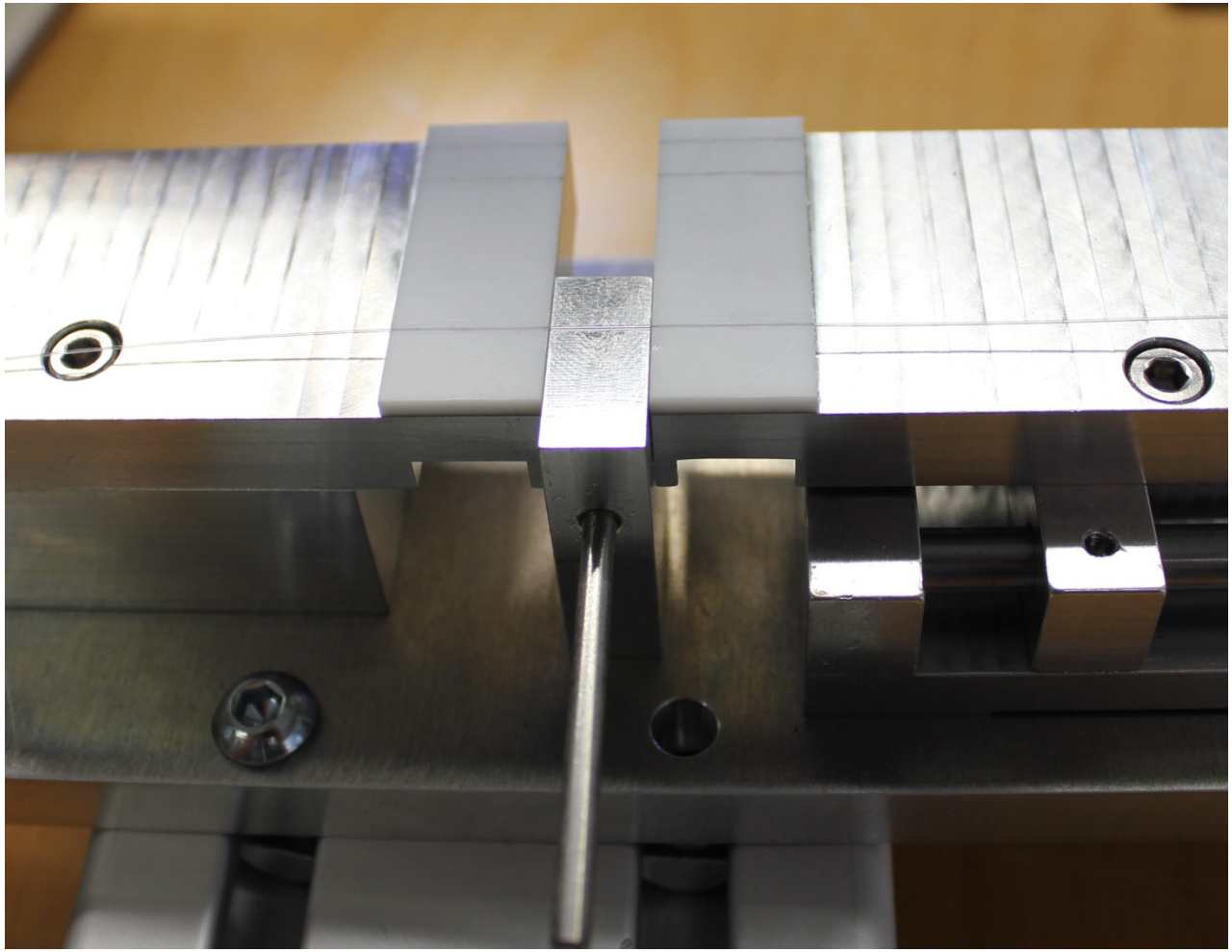
8. Bump Removal

4. Fix the fibre with magnets and clamps to cutting station



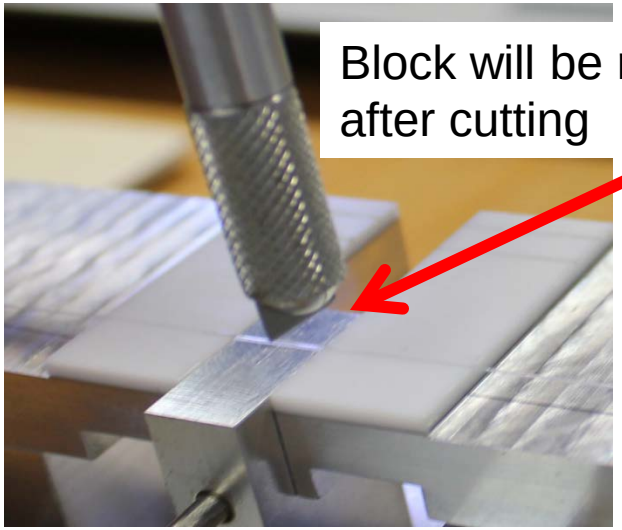
8. Bump Removal

5. Place fibre into the groove above cutting piece which is clamped by linear slip table. Use a head magnifying glass.



8. Bump Removal

6. Cut bump out of fibre.

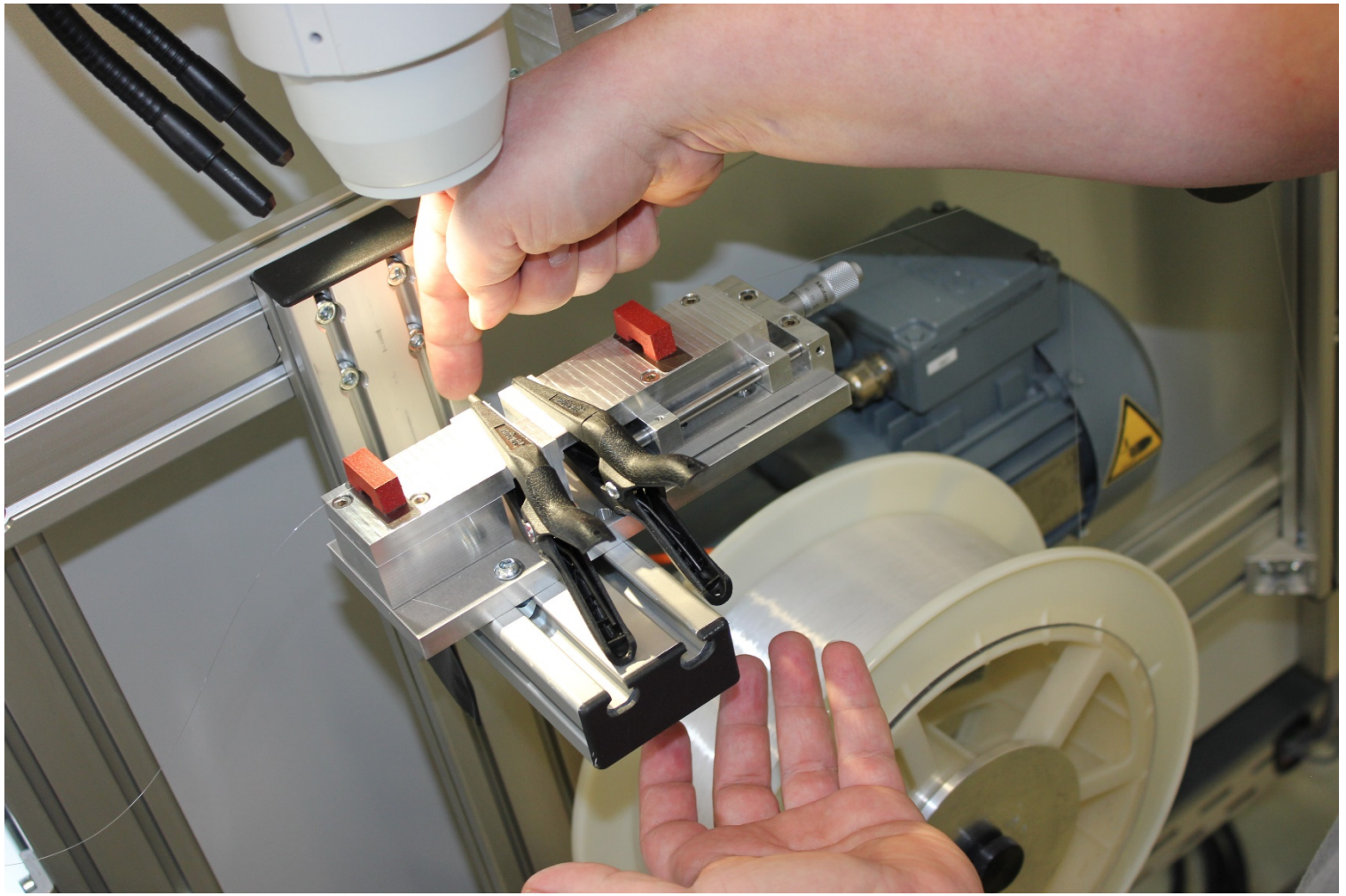


8. Bump Removal

6. Cut bump out of fibre.

8. Bump Removal

7. Remove cutting block



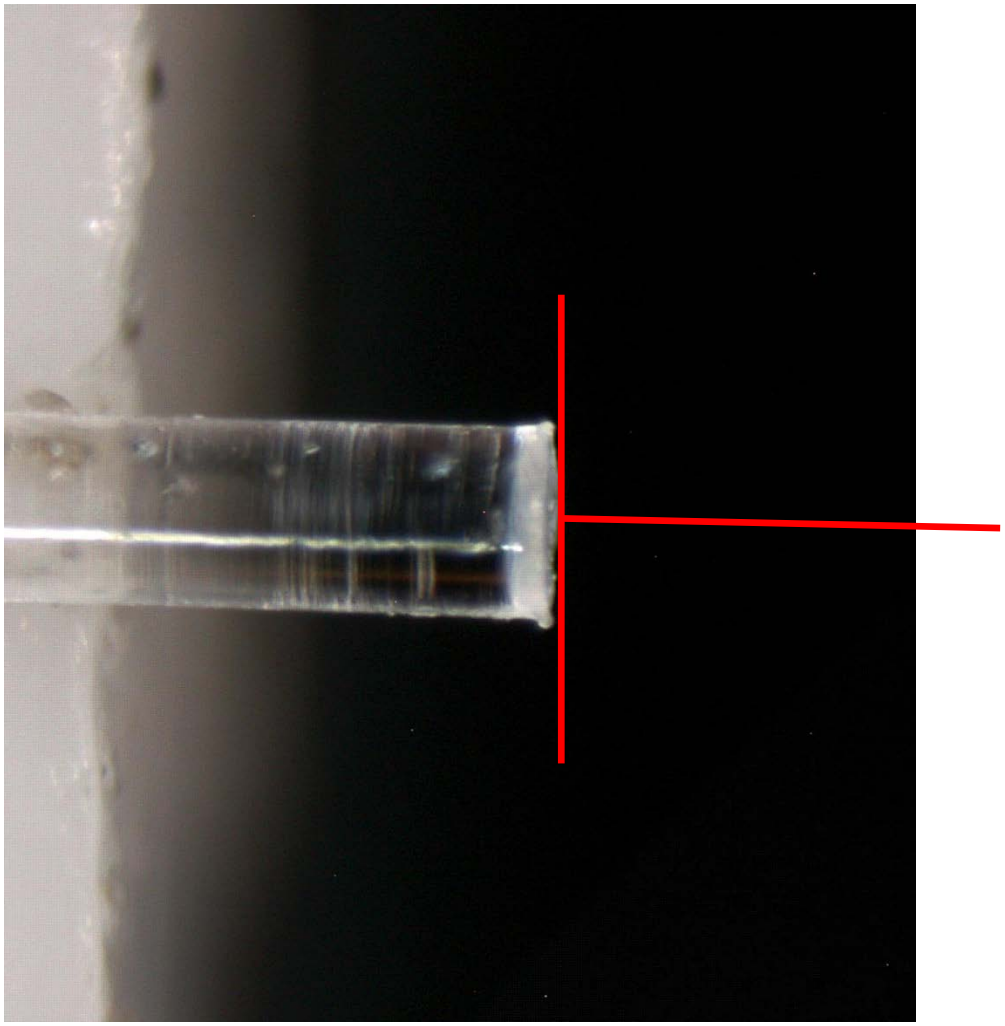
8. Bump Removal

8. Fibre glueing, which is an eye controlled process by stereo microscope

Magnification about 30X - 40X

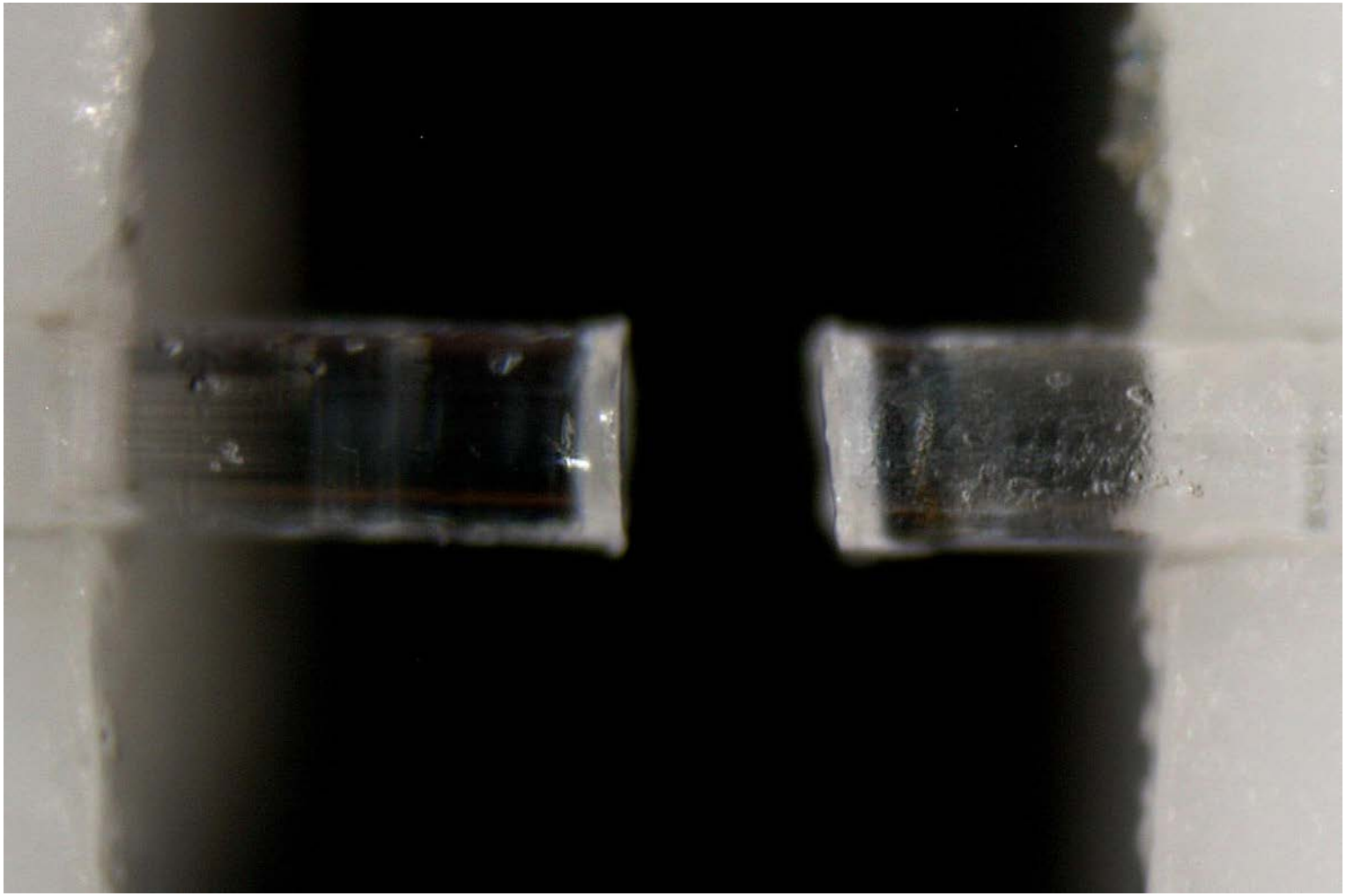
8. Bump Removal

8. Fibre glueing: a) check that cut is as rectangular as possible



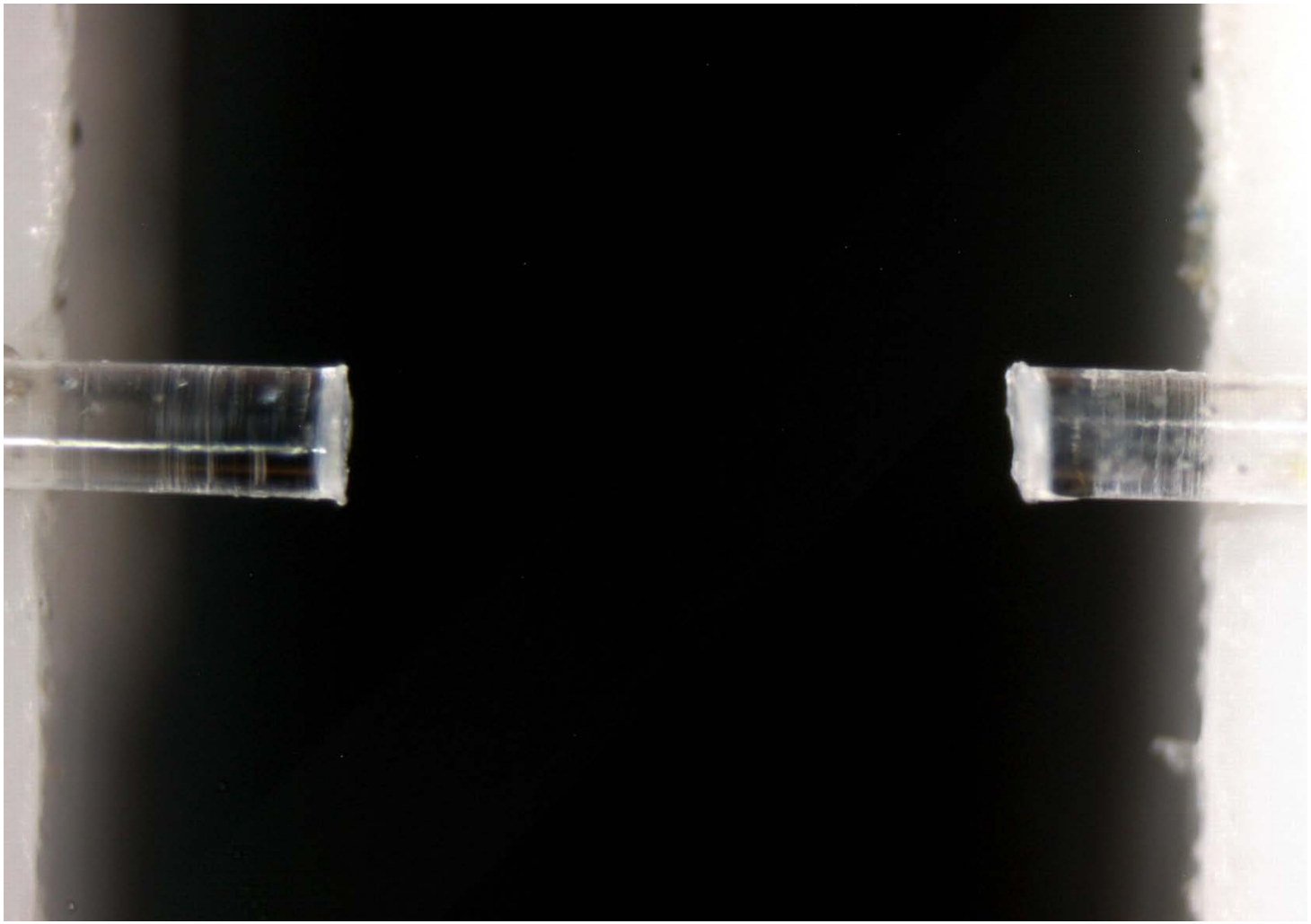
8. Bump Removal

8. Fibre glueing: b) Check alignment of the fibers in the jig



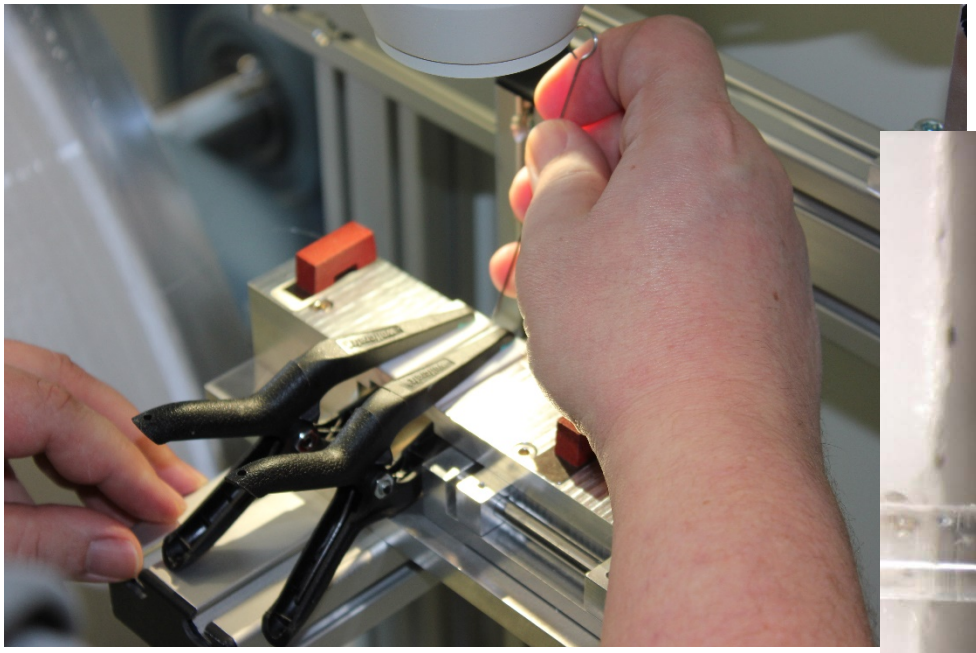
8. Bump Removal

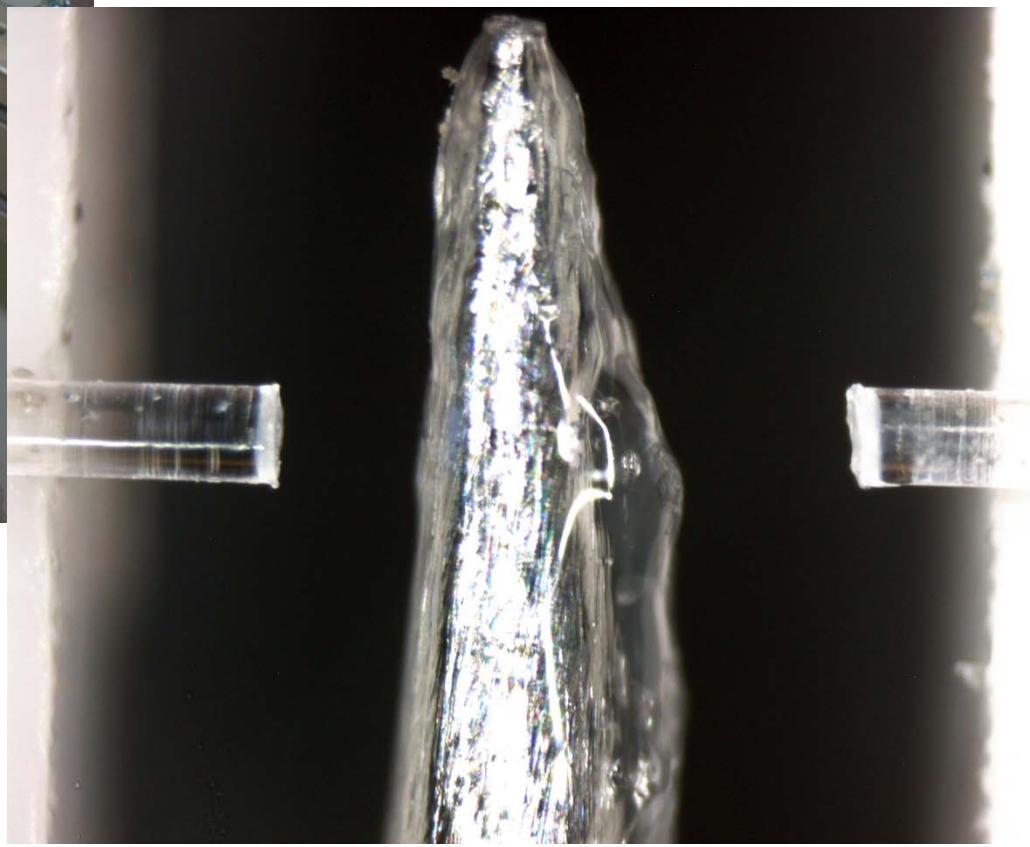
8. Fibre glueing: c) Open the distance of fiber ends to apply glue



8. Bump Removal

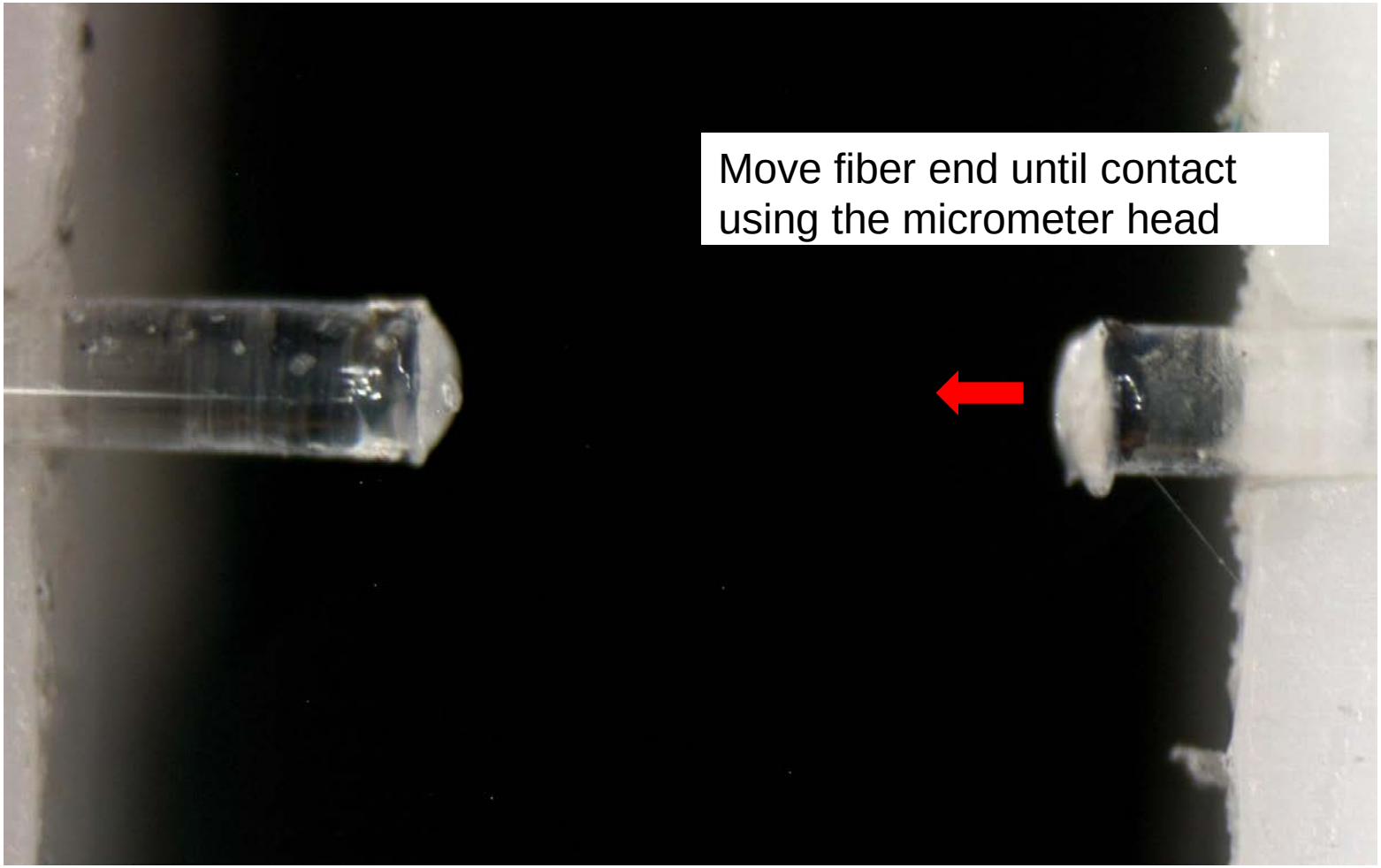
8. Fibre glueing: d) Applying glue with a needle tip





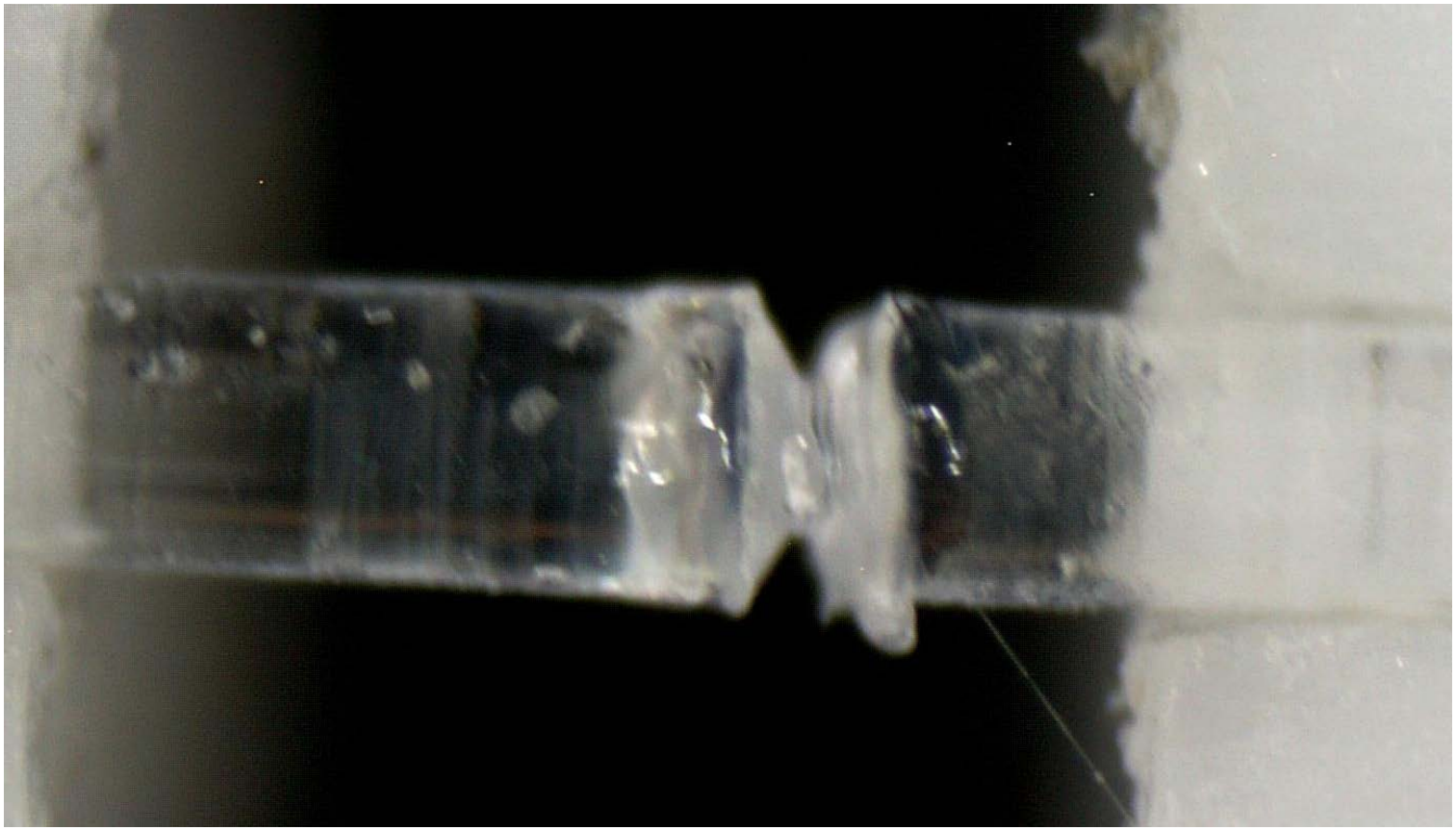
8. Bump Removal

8. Fibre glueing: e) Applied glue



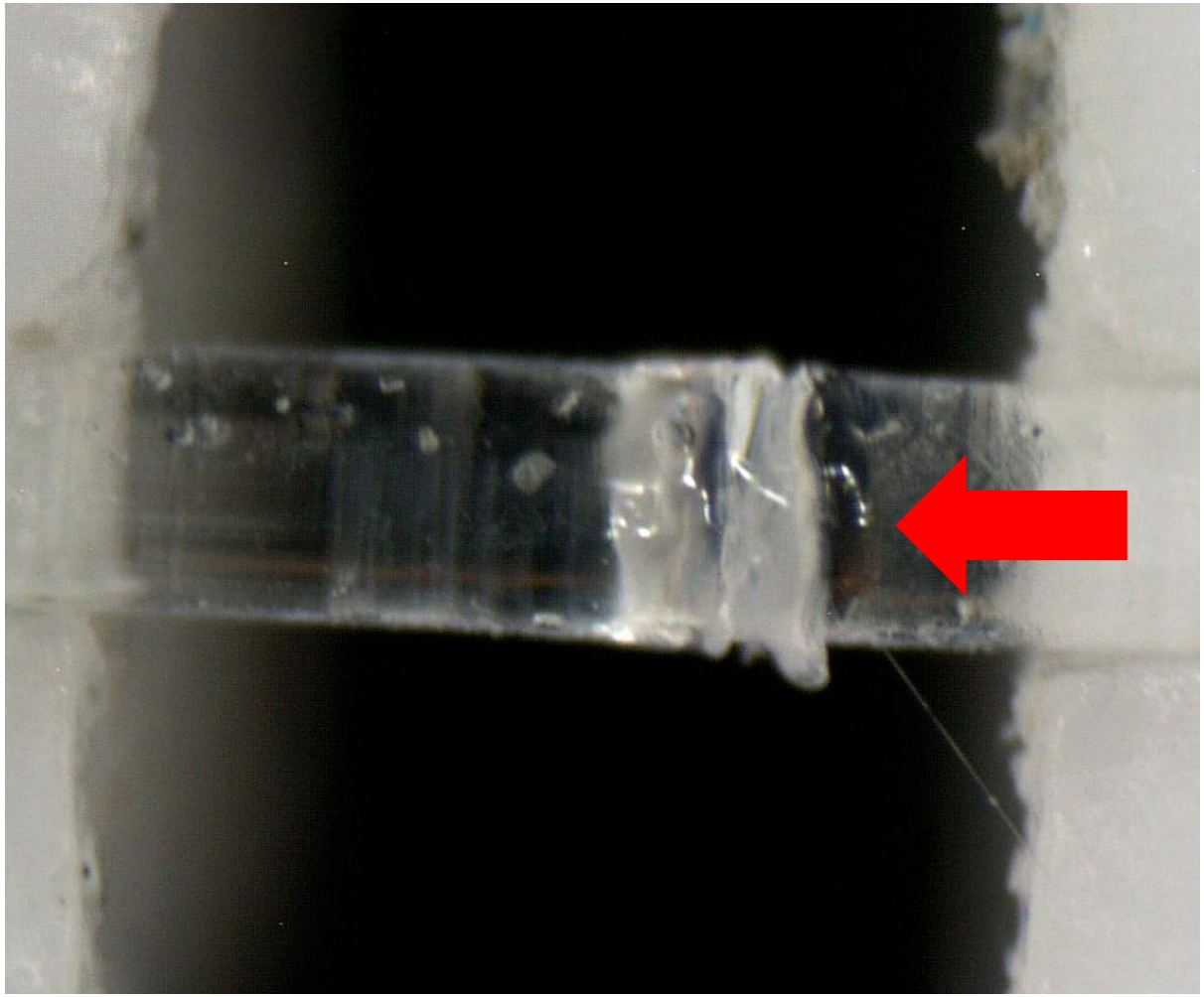
8. Bump Removal

8. Fibre glueing: f) Bring fibre ends in contact



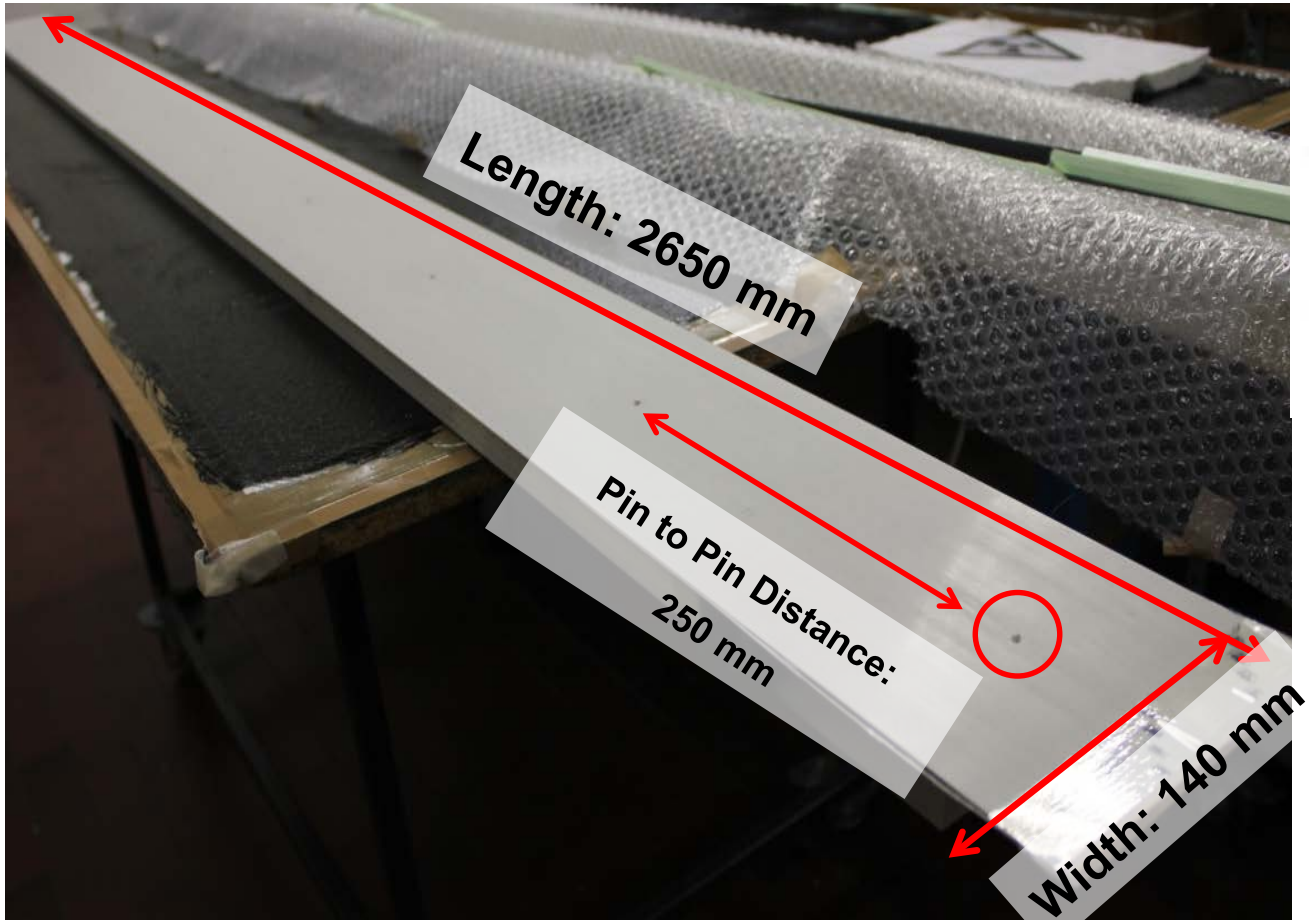
8. Bump Removal

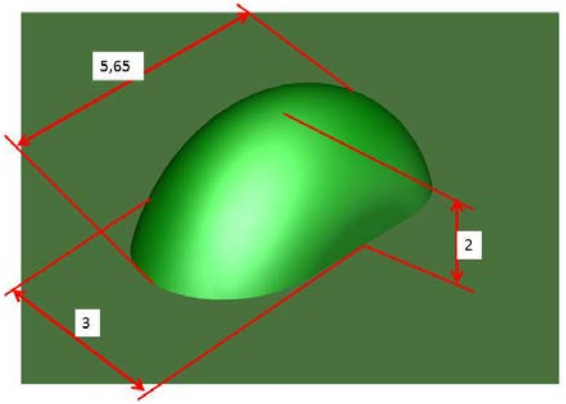
8. Fibre glueing: g) Adjusting the diameter by using the micrometer head



Result of Winding Process

Scintillating Fibre Mat: Dimensions: Length: 2650mm, Width approx. 140 mm





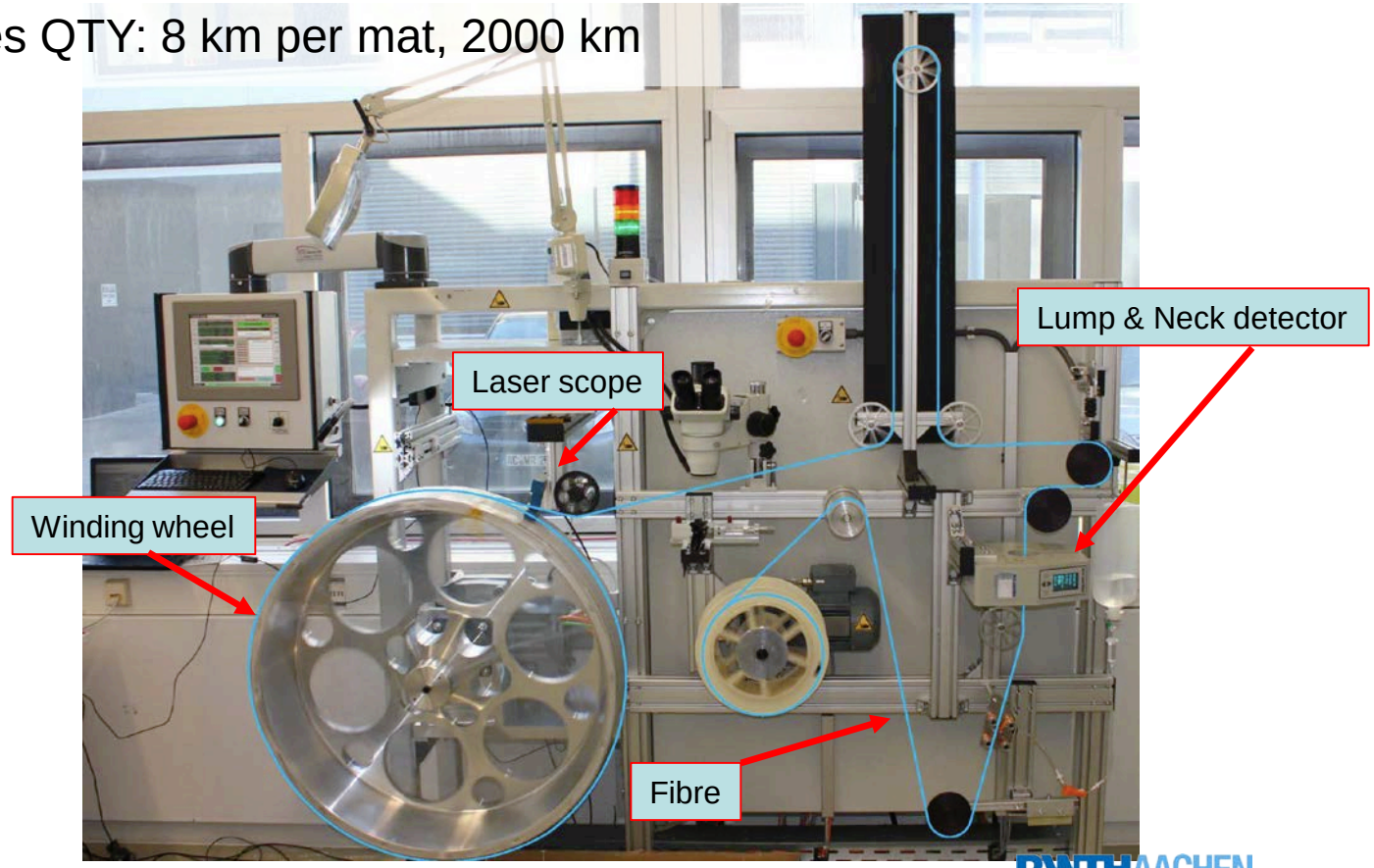
Winding Process: Tools

- Winding wheels, QTY 3 to 4

(Diameter 817 mm, width 140 mm, weight 64 kg, thread with 275 µm pitch)

Tools: Winding Machine

- STC Winding Machine QTY: 1
- Lump & Neck detector to detect bumps QTY: 1
- Laser Scope to detect errors during winding QTY:1
- Scintillating Fibres QTY: 8 km per mat, 2000 km



Winding Process: Tools

TOOLS:

- Glue mixer Smartmix X2 (Amman Girrbach GmbH, Dürrenweg 40, 75117 Pforzheim, Germany) QTY: 1
- Accuracy scale (0.01g sensitivity) QTY: 1
- Cartridge mastic gun Fisnar (Vieweg GmbH, Gewerbepark 13, 85402 Kranzberg, Germany) QTY: 1
- Squeegees with soft rubber egde ca. 150 mm wide QTY: 20
- Antistatic brush Pro-Ject (Audio Trade GmbH, Schenkendorfstrasse 29, 45472 Mülheim/Ruhr, Germany) QTY: 3
- Support for mat handling and transportation Item 240 mm wide, 2775 mm long, 40 mm high QTY: 15
- Breathing protection MSA 200 LS (MSA Deutschland GmbH, Thiemannstr. 1, 12059 Berlin, Germany) QTY: 1 per person

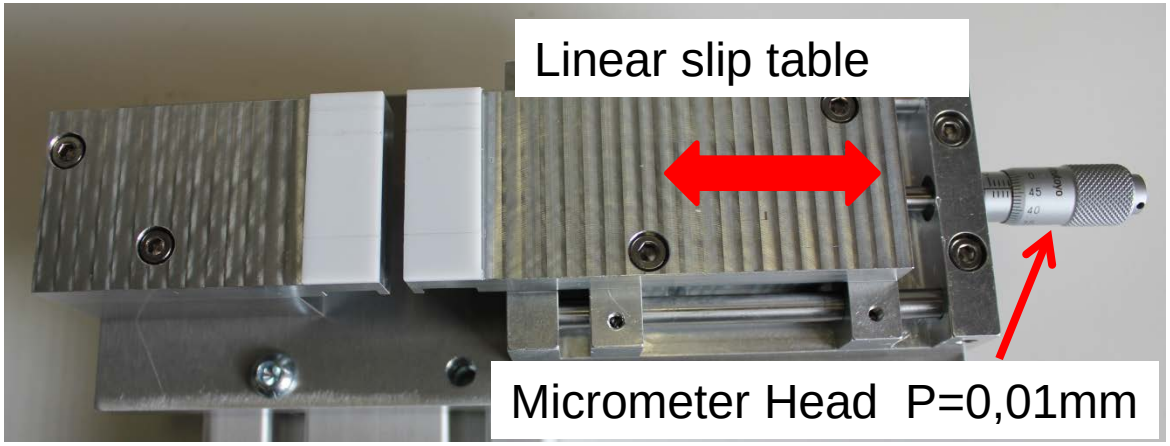
Winding Process: Tools

TOOLS:

- Safety glasses MSA Perspecta GH 3001 QTY: 1 per person
- Magnifying glasses for controlling the winding hub QTY: 2
- Tool for turning the winding wheel during curing, continuously adjustable in height and speed controlled (rotation cart) QTY: 1
- Tool for handling the winding wheel, continuously adjustable in height (handling cart) QTY: 1
- Storage rack for winding wheels QTY: 1
- Storage rack for fibre mats QTY: 2
- Handheld vacuum cleaner QTY: 1
- Small mobile crane for the handling of the winding hub (e.g. DEMA WK21HM) QTY:1
- Electrically heated blade QTY: 1

Winding Process: Tools

Tools for bump removal:



head magnifying glass

Tool with a standard piece of a razor blade

Stereo microscope
Magnification about 30X - 40X

Winding Process: Consumables

CONSUMABLES:

• Mixing tumblers for Smartmix X2	QTY: ≥ 5
• Single use protective gloves	QTY: 2500
• Cartridges, plugs for cartridge gun	QTY: 250
• Nozzles for cartridge gun	QTY: 250
• Plastic cups for glue or titanium oxide	QTY: 500
• Sifter for titanium oxide	QTY: 1
• Metallic spatulae	QTY: 5
• Paper towels for cleaning	QTY: 2500
• Dispenser for Tesa adhesive tape	QTY: 2
• Cotton cloth	QTY: 250

Winding Process: Consumables

CONSUMABLES:

- Small side cutter — QTY: 2
- Allen wrench with handgrip A/F 2.5 mm — QTY: 2
- Brass brushes for the cleaning of the winding hub — QTY: 25
- Lintless cloths for the cleaning of the winding hub — QTY: 500
- Cleaning agent Zyvax for the cleaning of the winding hub — QTY: 5l
- Release agent Mikon 205 (Lange & Ritter GmbH, Dieselstr. 25, 70839 Gerlingen, Germany) — QTY: 5l
- Disposable pipette, — QTY: 250
- Epoxy glue Epotek 301-2 — QTY: 50 kg (200g per mat)
- TiO2, — QTY: 12,5 kg
- Q-tips, — QTY: 500

Winding Process: Consumables

CONSUMABLES:

- Narrow roller, QTY: 500
- Wide roller, QTY: 100
- Isopropanol
- Acetone

Winding Process

Process/Step	Time	FTE
1. Wheel Preparation		
1. Mount winding wheel on rotation cart	10 min	1
2. Cleaning of wheel surface	30 min	1
3. Apply release agent 3 times	30 min	1
Wait in between	90 min	0
4. Drying of last layer release agent	12 hour	0
	Σ 70 min	**1**
	Σ 13.5 hour	**0**

Winding Process

Process/Step	Time	FTE
2. Mounting of winding wheel to winding machine		
1. Transfer winding wheel from storage rack to handling cart	10 min	1
2. Drive wheel on handling cart to winding machine	1 min	1
3. Move wheel with crane in front of rotation axis of winding machine	10 min	1
4. Mount winding wheel on rotation axis	1 min	1
5. Mount wheel retainer with a screw to rotation axis	1 min	1
6. Adjust start and stop parameters in STC software according to winding wheel parameters	5 min	1
	Σ 28 min	**1**

Winding Process

Process/Step	Time	FTE
3. Preparation of winding machine		
1. Mount Take-off spool with fibres to STC winding machine	1 min	1
2. Mount fibre to pulleys	5 min	1
3. Start up of STC winding machine	4 min	0
	Σ 6 min	**1**
	Σ 4 min	**0**

Winding Process

Process/Step	Time	FTE
4. Winding of fibre mat		
1. Preparation of 7 cups with TiO2	10 min	1
2. Prepare glue (cup 1-6)	42 min	1
3. Prepare cartridge (before layer 1)	5 min	1
4. Apply mixed glue to wheel before first layer winding	10 min	1
5. Winding of first layer	40 min	1
6. Winding of layer 2 to 6	200 min	1
	Σ 307 min	**1**

Winding Process

Process/Step	Time	FTE
5. Curing of fibre mat		
1. Mount winding wheel on rotation cart	10 min	1
2. Move rotation cart with winding wheel to parking position	1 min	1
3. Keep winding wheel rotating on rotation cart for 12h till polymerisation is advanced and glue will not drop down of the wheel	12 h	0
4. Move rotation cart to storage rack	1 min	1
5. Dismount winding wheel and mount it to storage rack by screwing together again the axles using the adapter and sliding the wheel to the rack	10 min	1
6. Keep curing of fibre mat on going till 48h are reached	36 h	0
	Σ 22 min	**1**
	Σ 48 h	**0**

Winding Process

Process/Step	Time	FTE
6. Unforming of fibre mat		
1. Move storage jig with winding wheel and fibre mat to cutting position in front of long table	1 min	1
2. Use a hot blade to cut the fibre mat at the position of the transversal cutting groove in the winding wheel	10 min	1
3. Loosen fibre mat from winding wheel	15 min	1
4. Guide fibre mat via a deviating roller on a shelf till end of fibre mat on wheel is reached. Loosen fibre mat from kapton tape	7 min	2
5. Protect fibre mat using a foam	1 min	1
6. Place shelf with fibre mat in storage rack	1 min	2
	Σ 27 min	**1**
	Σ 8 min	**2**

Winding Process

Process/Step	Time	FTE
7. Reconditioning of winding wheel		
1. Removal of glue residuals from winding wheel	20 min	1
2. Cleaning of winding wheel	30 min	1
	Σ 50 min	**1**

Winding Process

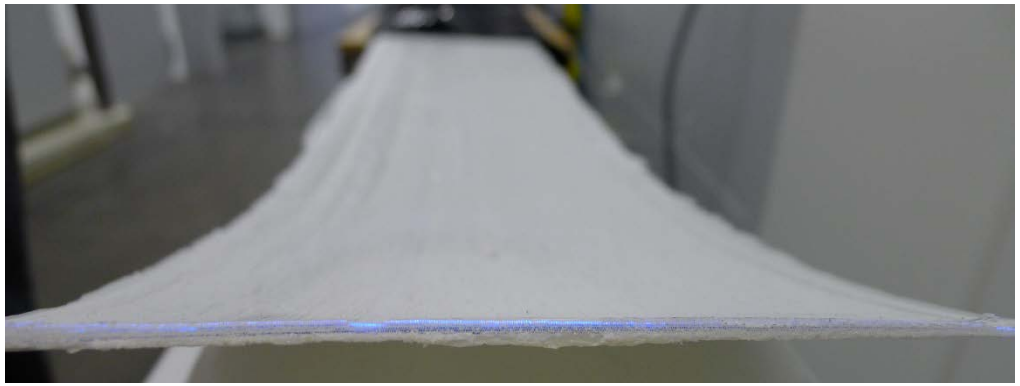
Process/Step	Time	FTE
8. Bump removal		
1. If bump and neck detector alerts due to a bump, the winding is stopped so that the bump will end in the area of the bump removal station.	1 min	0
2. When the winding is continued and the bump creates an error, wind the fibre back by cleaning it with isopropanol.	7 min	1
3. Position and embed the fibre in the groove in the PTFE of the bump removal station.	1 min	1
4. Fix the fibre with magnets and clamps to cutting station	1 min	1
5. Place fibre into the groove above cutting piece which is clamped by linear slip table.	1 min	1
6. Cut bump out of fibre	2 min	1
7. Remove cutting block	0 min	1
8. Fibre glueing, which is an eye controlled process by stereo microscope	3 min	1
9. Curing	5 min	0
	Σ 15 min	**1**
	Σ 6 min	**0**

Foil Lamination

and

Glueing of Endpieces

Foil Lamination



Raw fibre mats still fragile after unforming from winding wheel,

→ handling protection is needed to avoid damage to fibre mats

→ Foil lamination of SiFi mat is done to protect fibre mat and to make handling and shipping easier.

Foil Lamination and glueing of endpieces

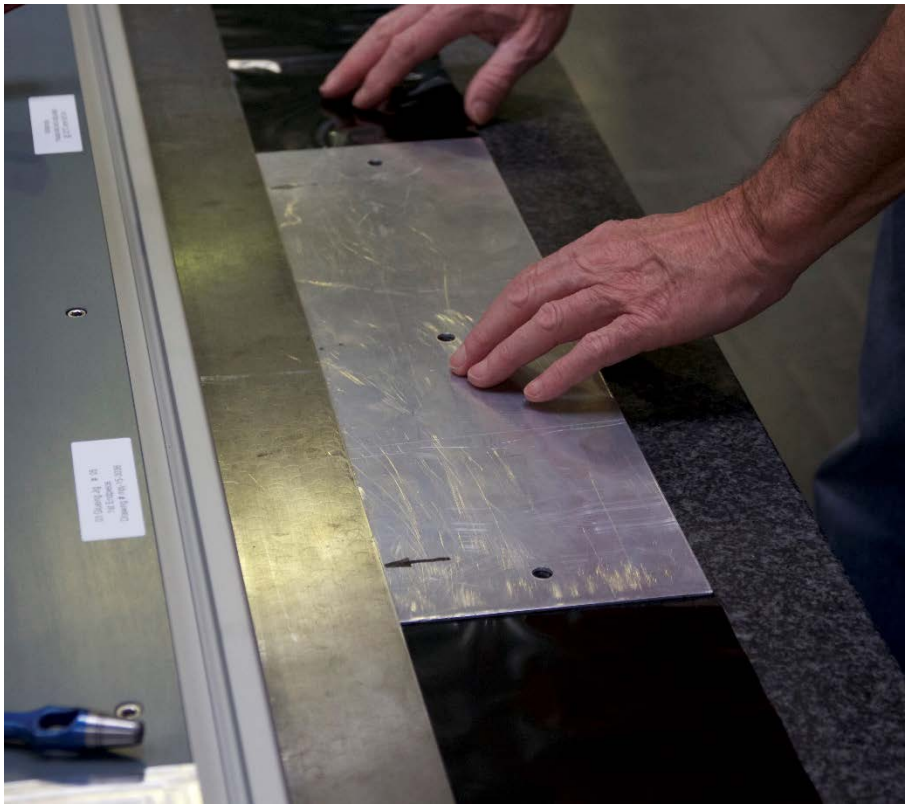
1. Lamination of fibre mat side with alignment pins 150
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and lower endpiece half mirror side. 168
3. Lamination of fibre mat side without alignment pins and glueing of upper endpiece half mirror side 173
4. Foil Lamination and Endpiece Glueing: Tools, Consumables, FTE 176

1. Lamination of fibre mat side with alignment pins

1. Prepare the foil for the fibre mat side with alignment pins
   - Prepare foil strip with overlength for the side of the fibre mat with alignment pins! Place foil straight on a flat surface, straightness can be reached by using a precision edge of a ruler

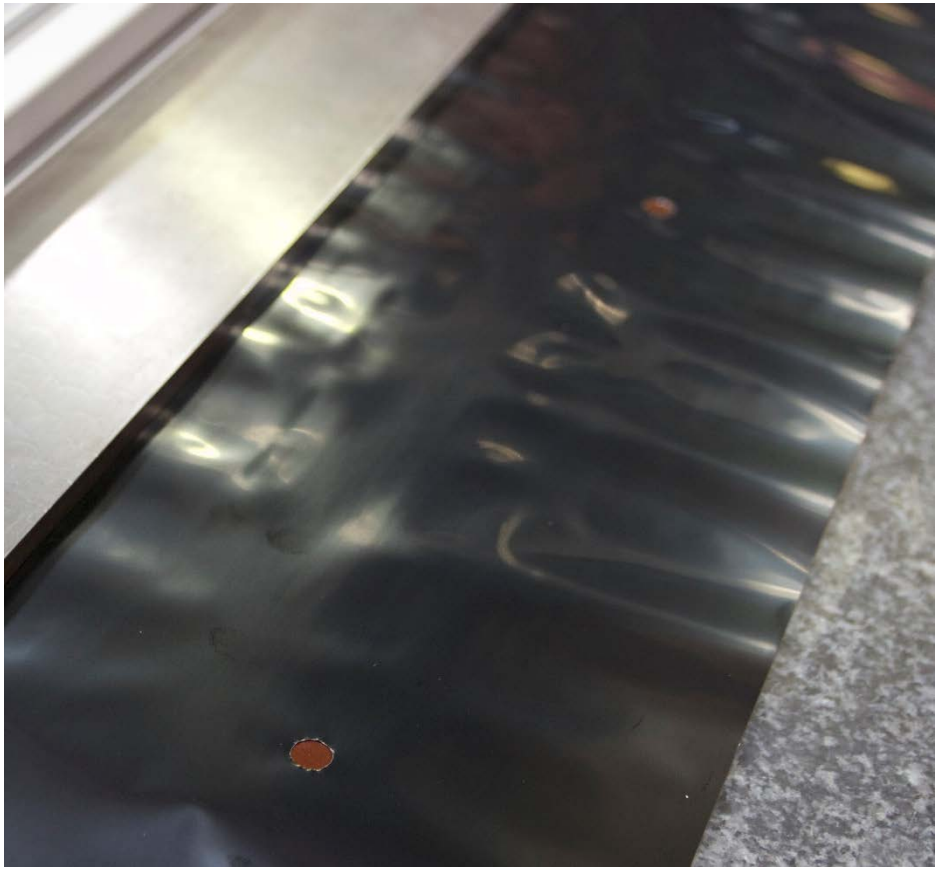
1. Lamination of fibre mat side with alignment pins

1. Prepare the foil for the fibre mat side with alignment pins:
   - Measure the position of the aperture plate with the holes for the alignment pins on the foil. Place the aperture plate on the foil.



1. Lamination of fibre mat side with alignment pins

1. Prepare the foil for the fibre mat side with alignment pins:
   - Punch holes for the alignment pins out of the foil



1. Lamination of fibre mat side with alignment pins

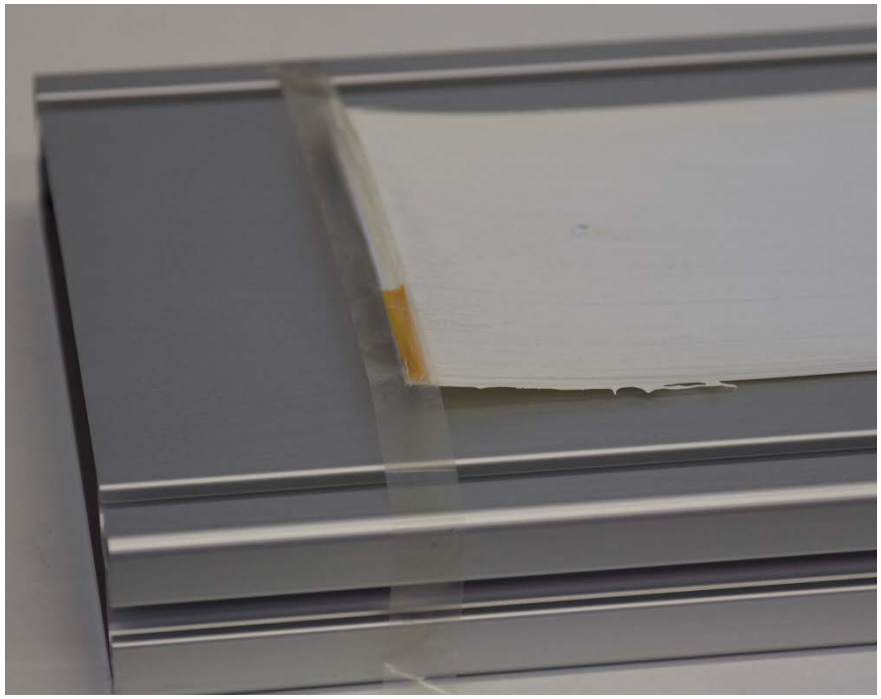
2. Prepare fibre mat side with alignment pins for foil lamination:
   - Take aluminium shelf with protected fibre mat out of storage shelf and place it on a table, remove protective foam

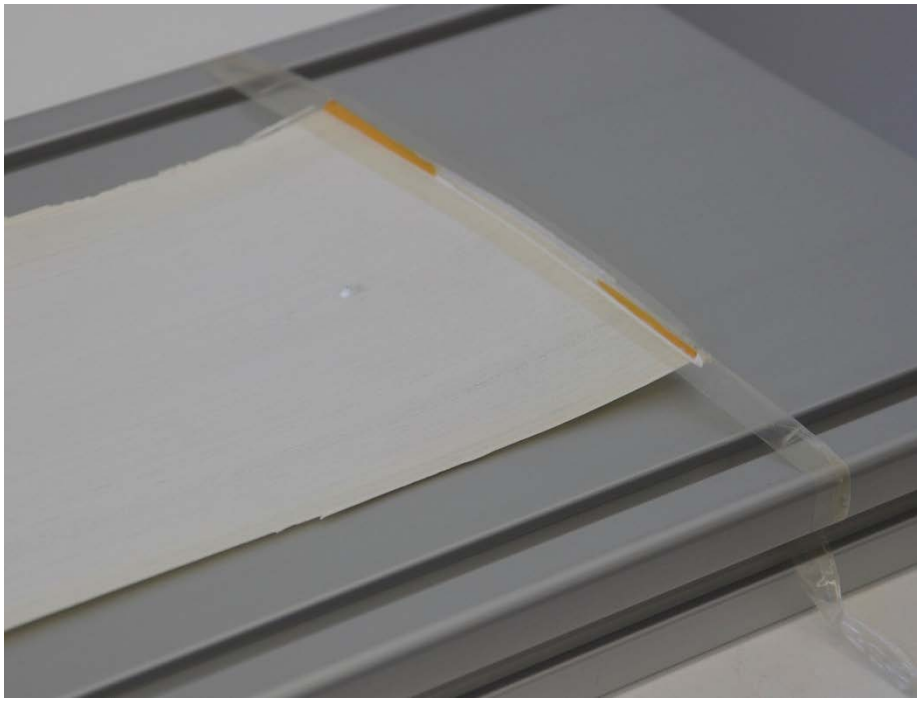
1. Lamination of fibre mat side with alignment pins

2. Prepare fibre mat side with alignment pins for foil lamination:
   - Place fibre mat on a clean aluminium shelf

1. Lamination of fibre mat side with alignment pins

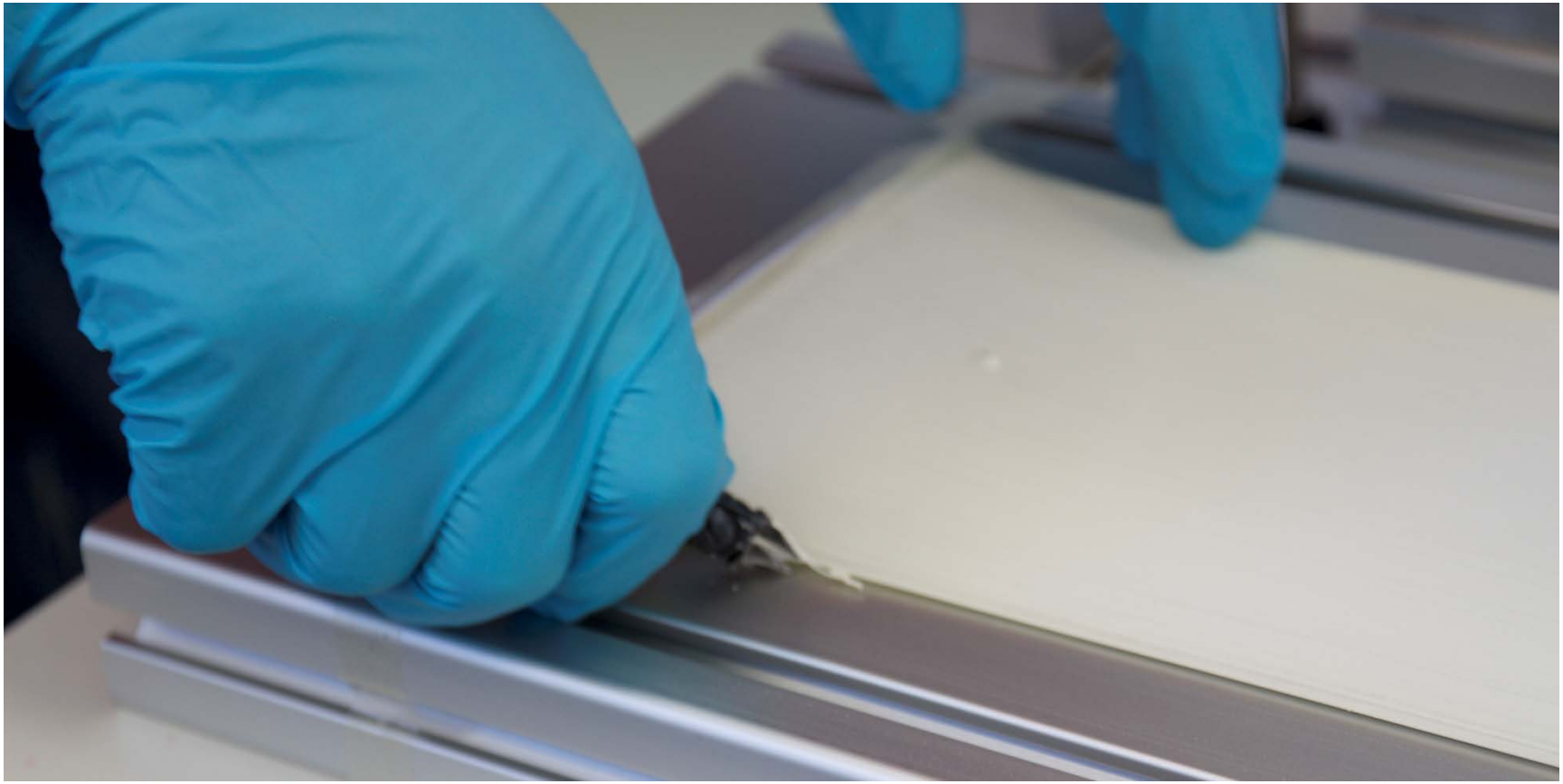
2. Prepare fibre mat side with alignment pins for foil lamination:
   - Fix fibre mat to aluminium shelf with adhesive tape on both end sides





1. Lamination of fibre mat side with alignment pins

2. Prepare fibre mat side with alignment pins for foil lamination:
   - Cut away glue residuals from the longitudinal sides of the fibre mat



1. Lamination of fibre mat side with alignment pins

2. Prepare fibre mat side with alignment pins for foil lamination:
   - Clean the fibre mat with isopropanol

1. Lamination of fibre mat side with alignment pins

3. Prepare the foil with the punched holes for the alignment pins of the fibre mat for lamination:

- Place foil on lamination table and fix it with an adhesive tape

1. Lamination of fibre mat side with alignment pins

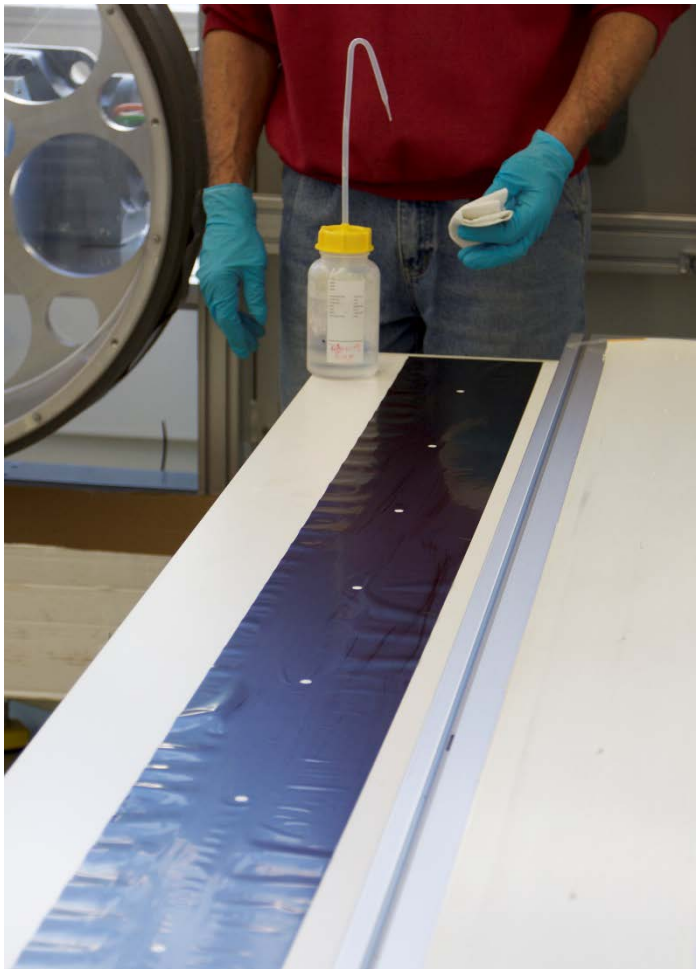
3. Prepare the foil with the punched holes for the alignment pins of the fibre mat for lamination:

- Roughen up the surface of the foil using a scotch brite (3M)

1. Lamination of fibre mat side with alignment pins

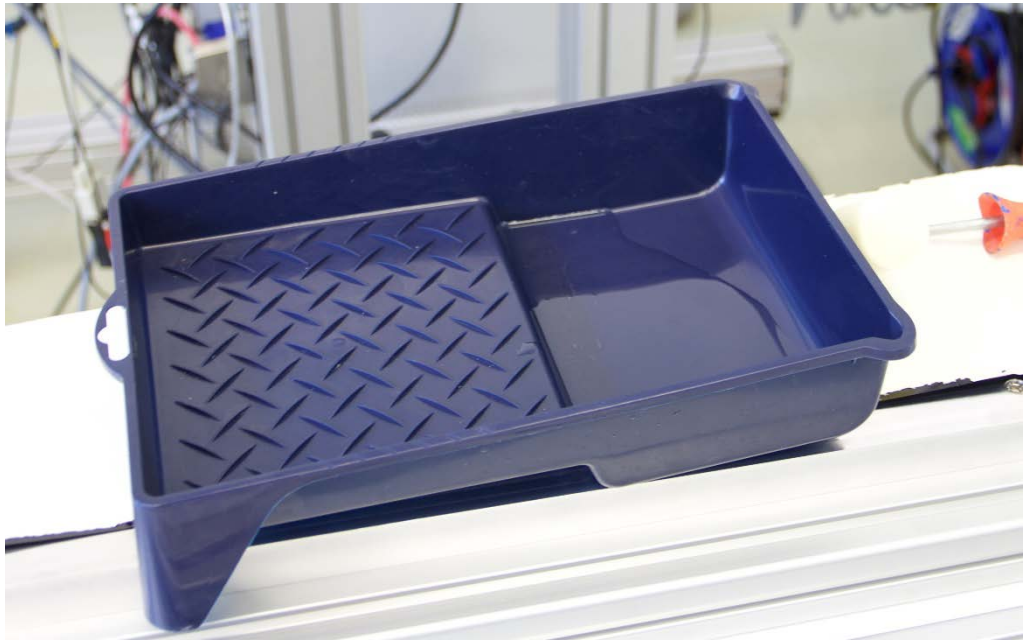
3. Prepare the foil with the punched holes for the alignment pins of the fibre mat for lamination:

- Clean foil quickly with acetone



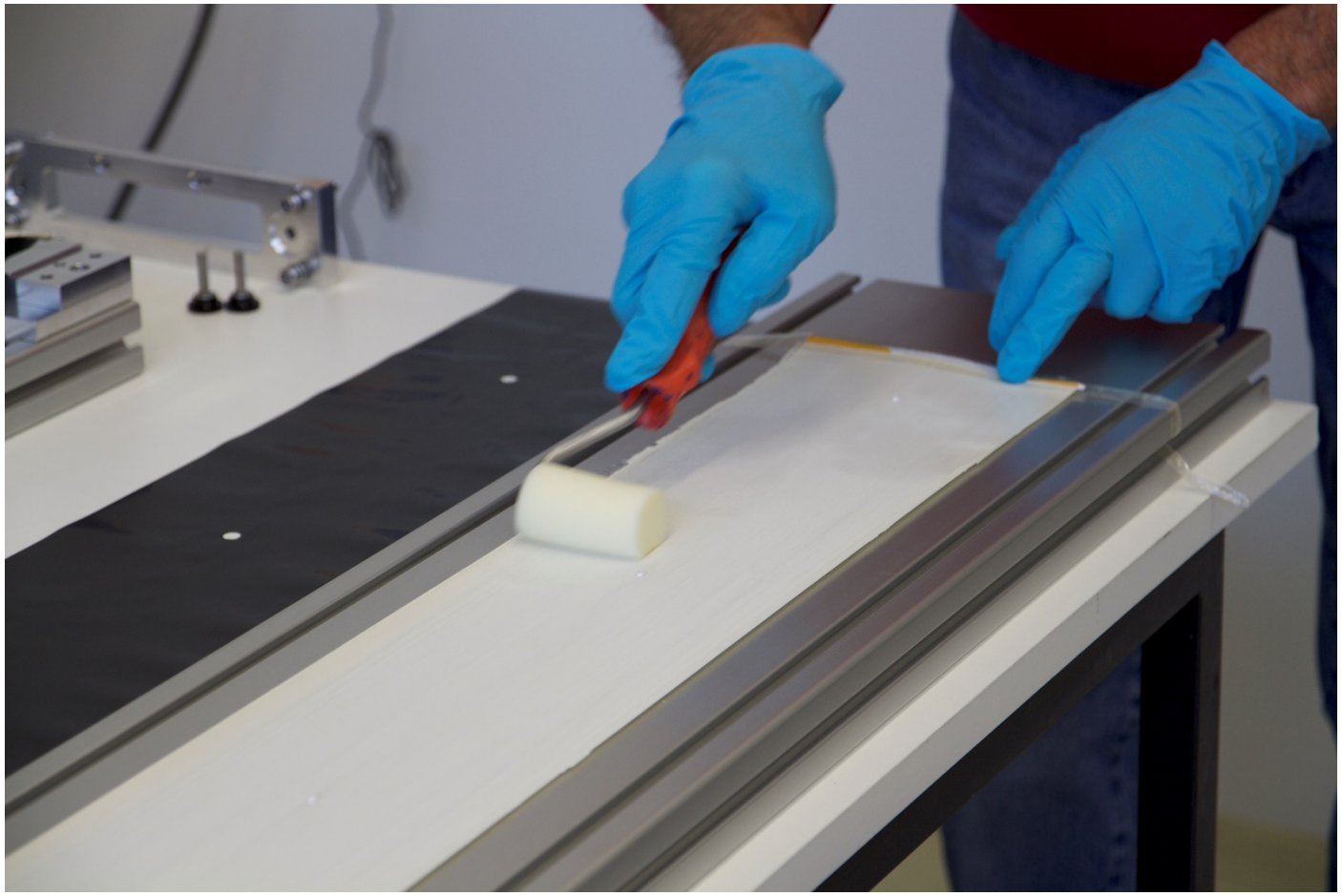
1. Lamination of fibre mat side with alignment pins

4. Prepare epotek glue 301 for the lamination (QTY: 20g)



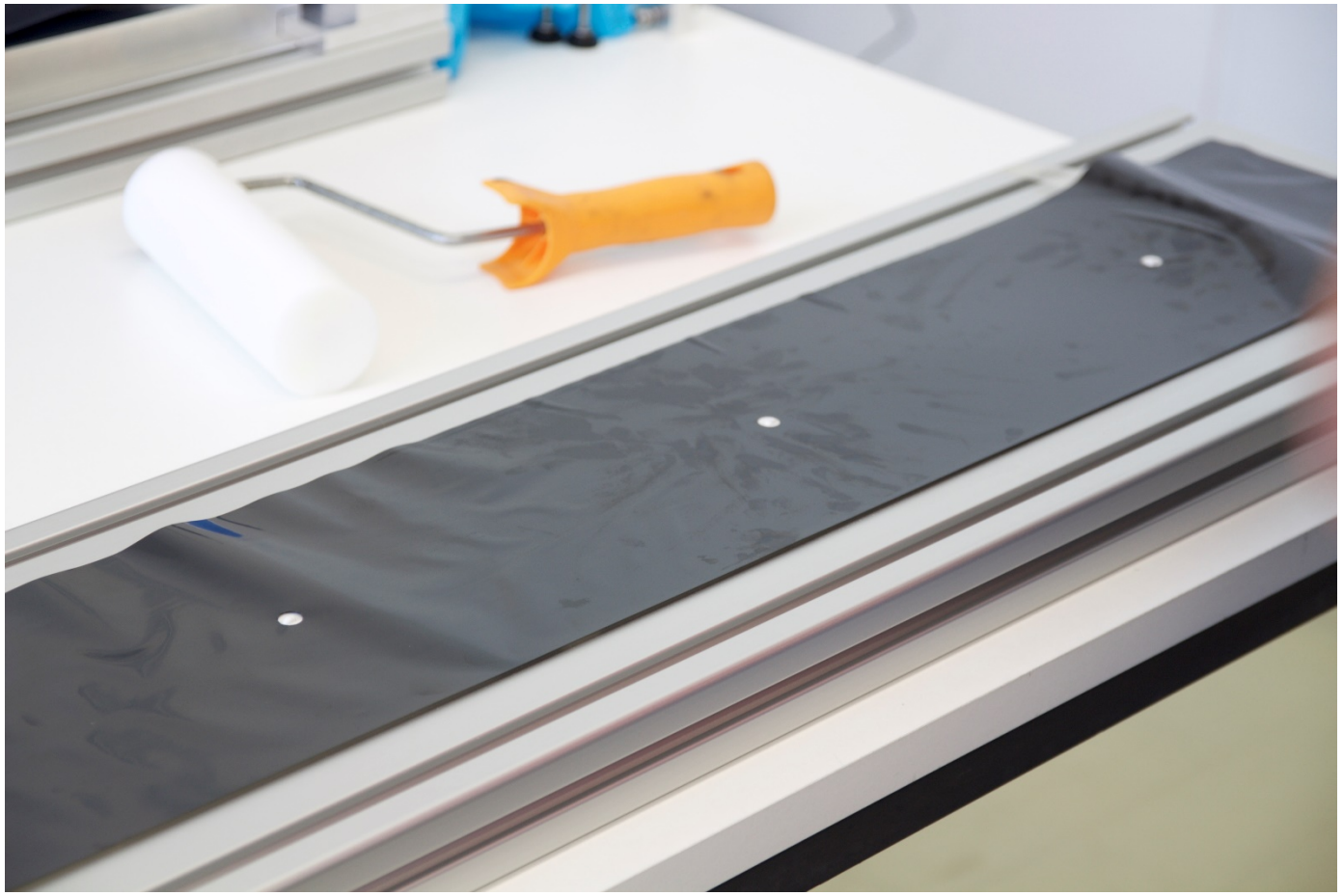
1. Lamination of fibre mat side with alignment pins

5. Apply epotek glue 301 on the face of the mat side with alignment pins!



1. Lamination of fibre mat side with alignment pins

6. Lay down the foil onto the glued surface and adjust it. Fasten the end of the foil onto the support.

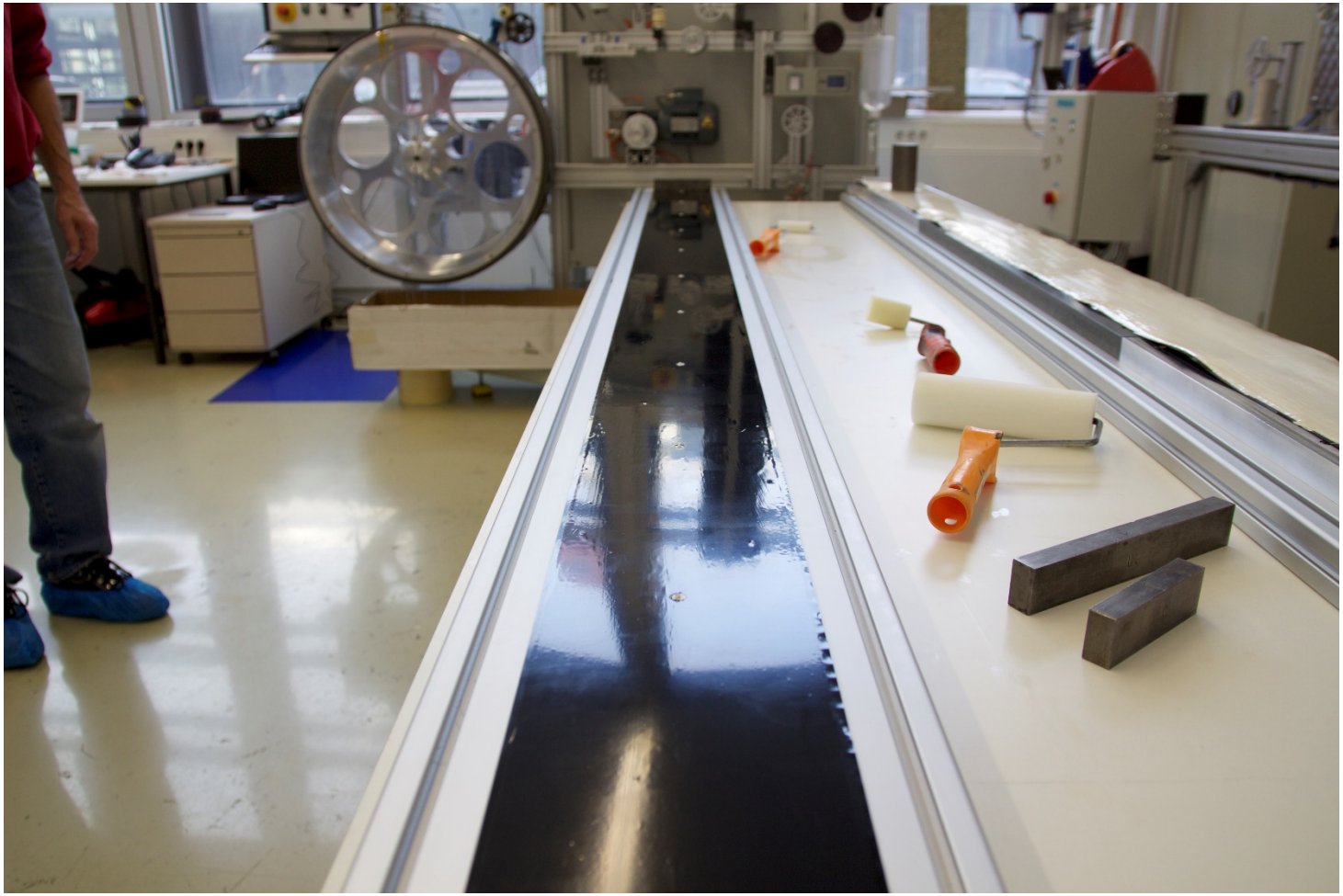


1. Lamination of fibre mat side with alignment pins

7. Continue applying epotek glue 301 to surface of fibre mat with alignment pins.

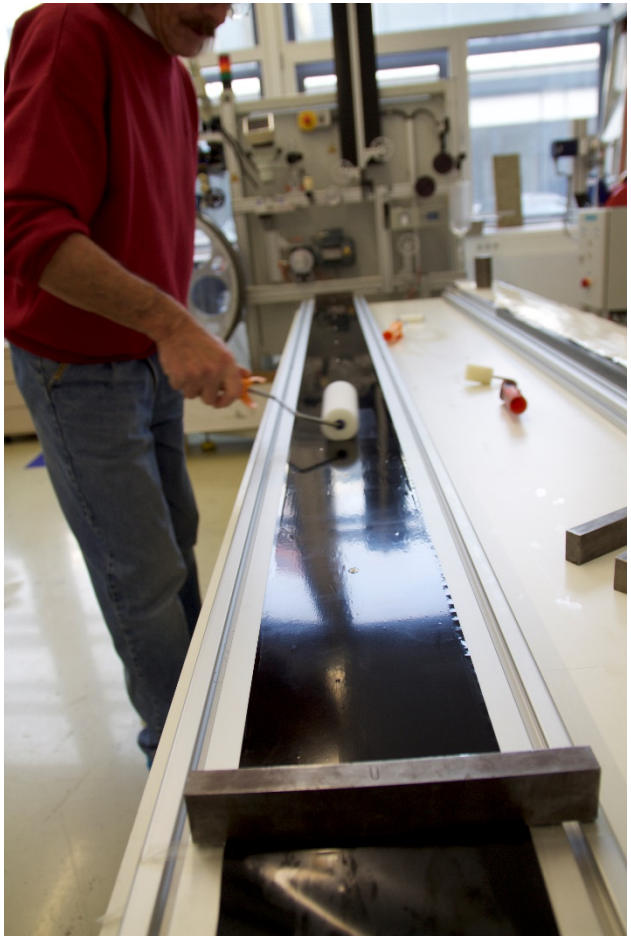
1. Lamination of fibre mat side with alignment pins

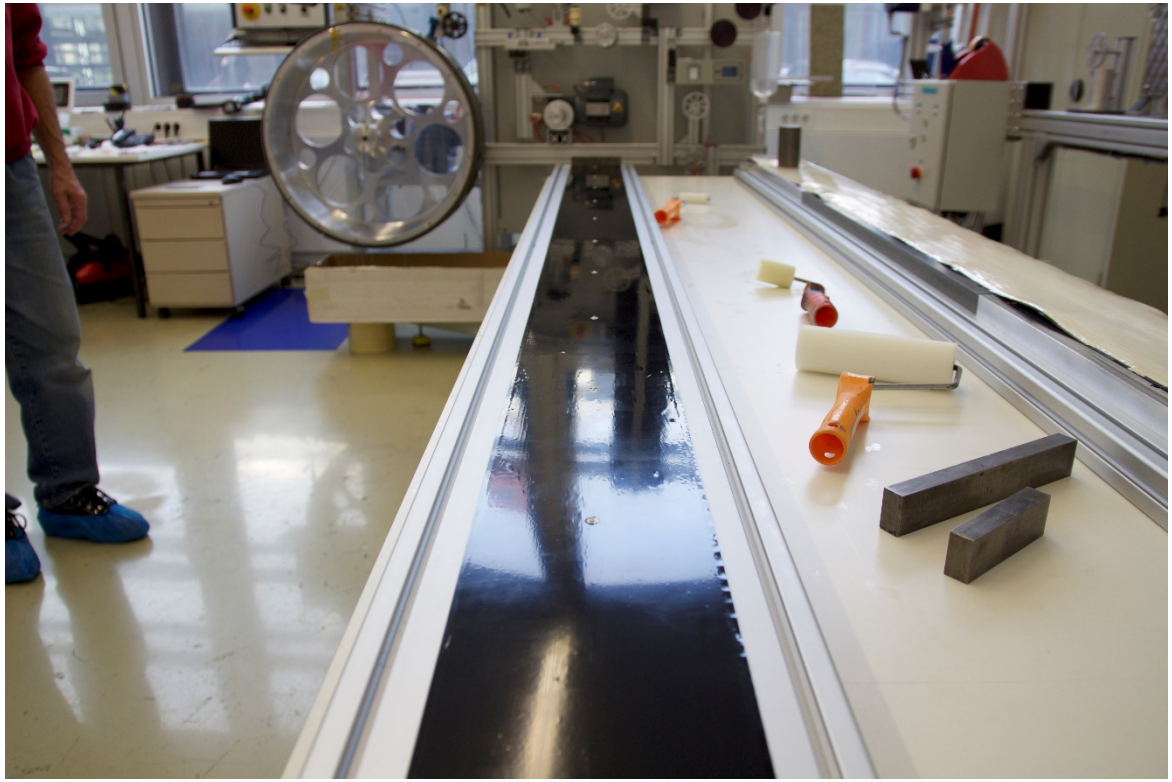
8. Continue adjusting the foil onto the glued surface.



1. Lamination of fibre mat side with alignment pins

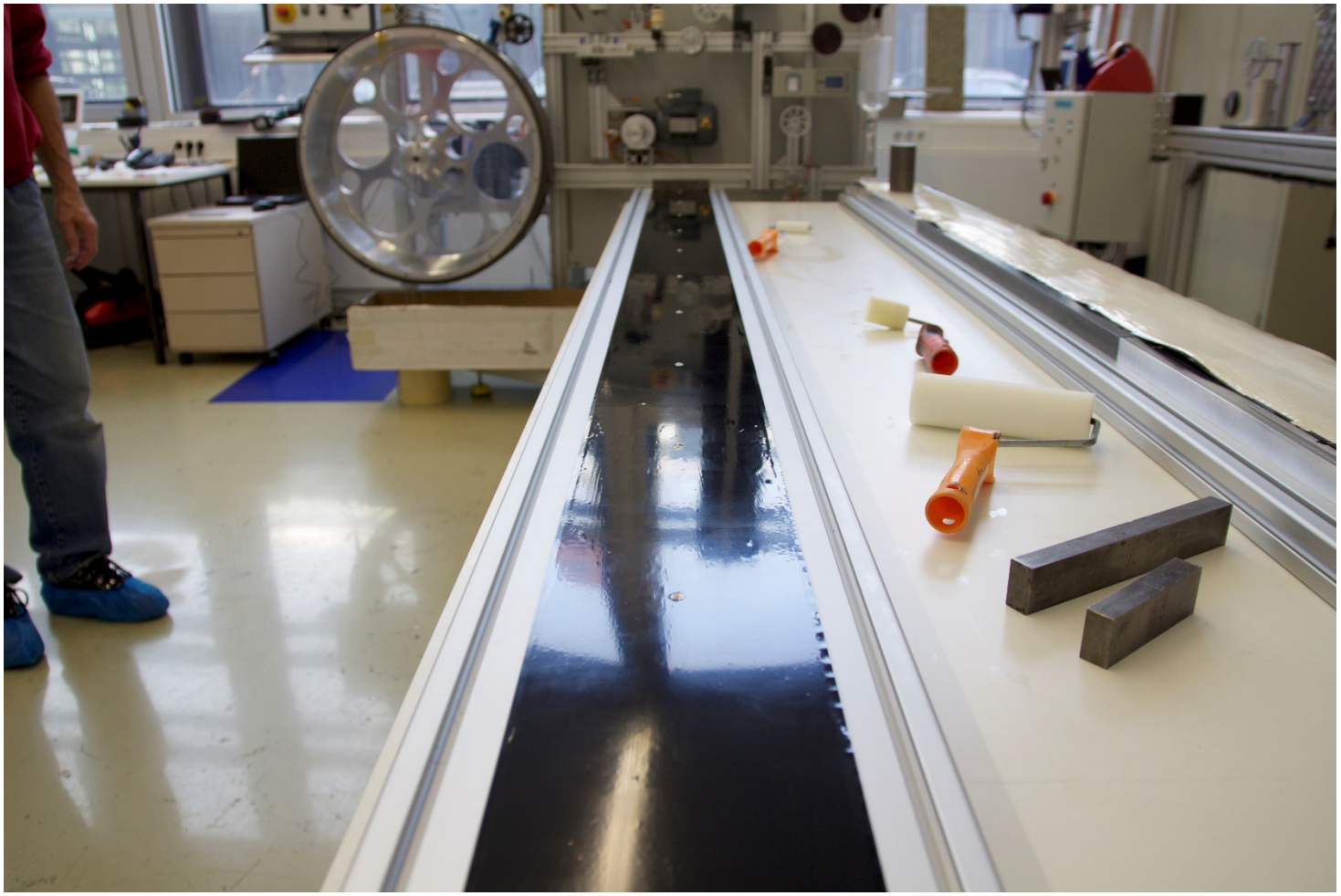
8. Continue laying down the foil onto the glued surface, adjust and apply moderate tension. Do the roller application to get rid of air bubbles.





1. Lamination of fibre mat side with alignment pins

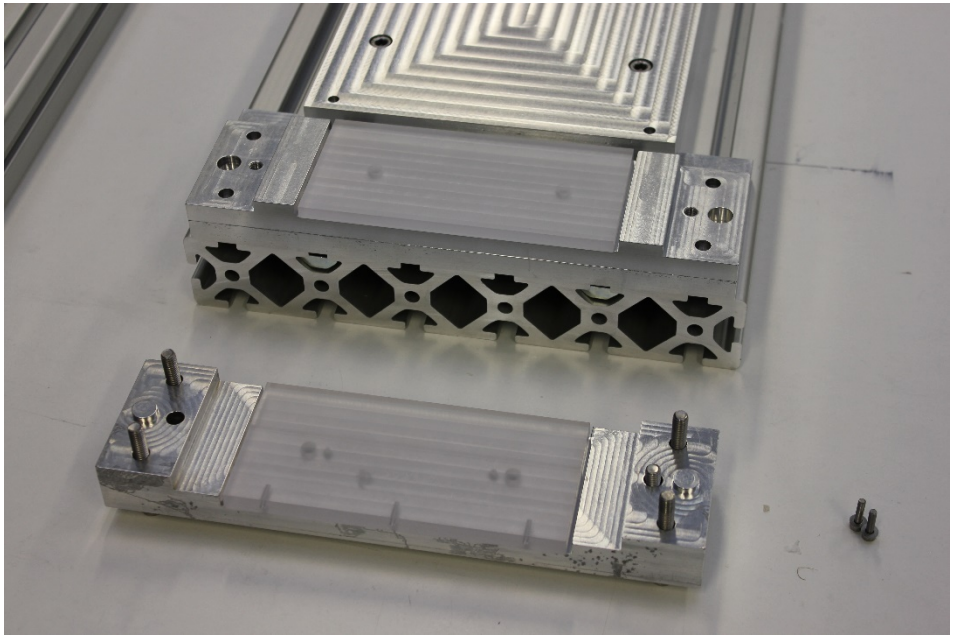
9. Cure over night, curing time minimum 12h

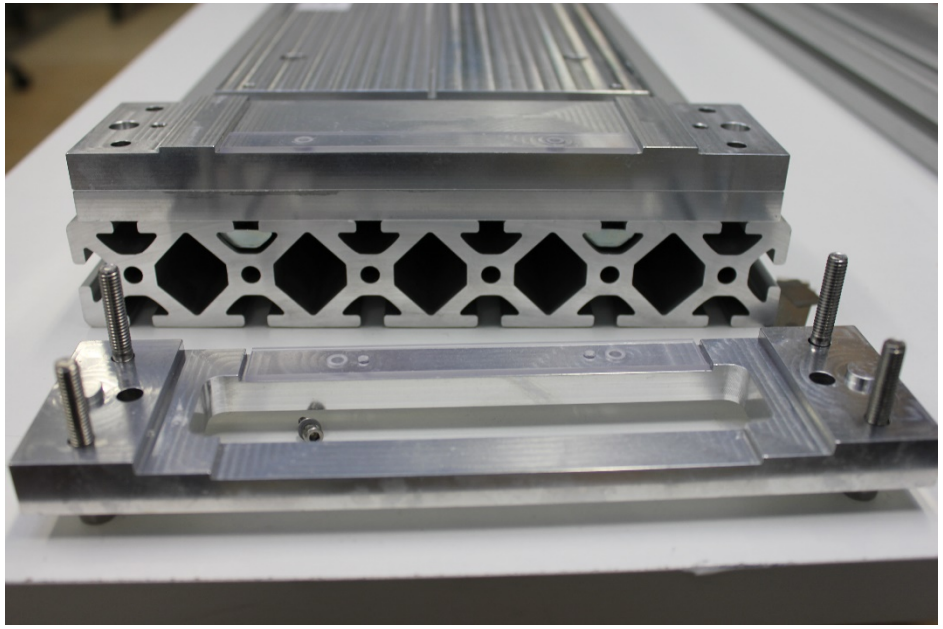


2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and lower endpiece half mirror side.

The glueing of the endpieces will be done in the foil lamination jig.

1. Prepare epoxy glue AW106. (QTY: 4g)
2. Apply epoxy glue AW106 onto the endpieces for the readout side and the lower half of the mirror side

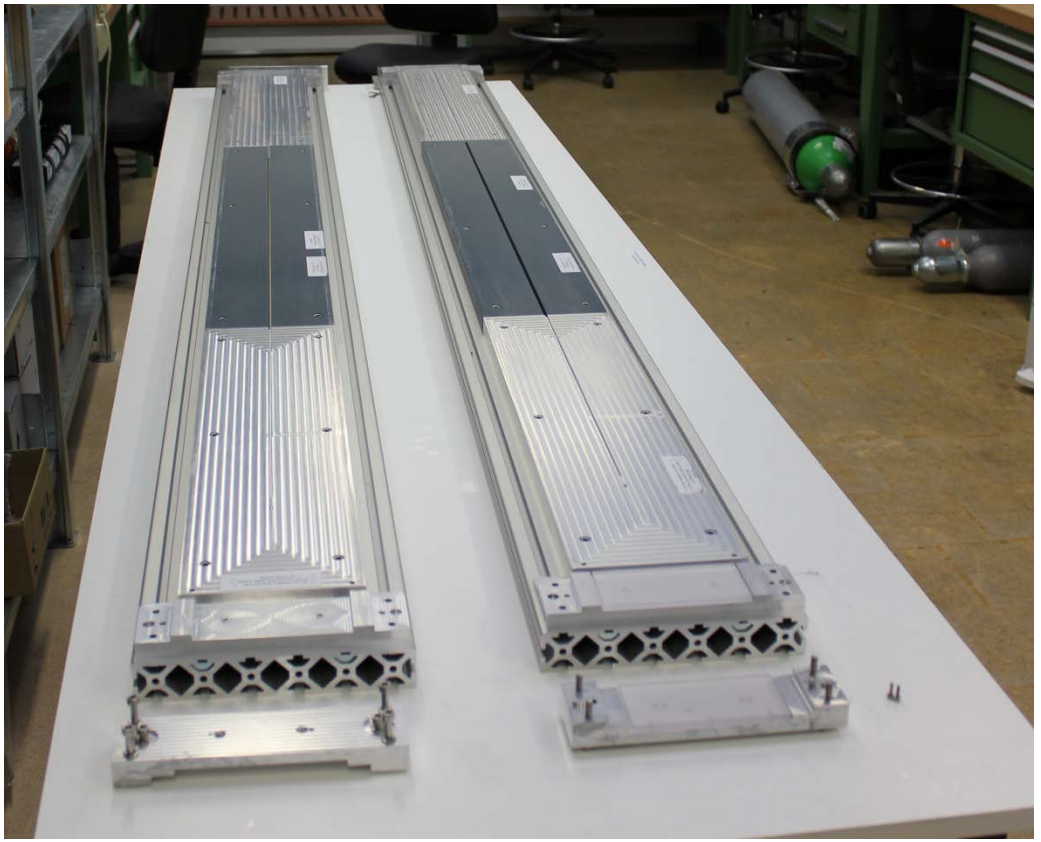




2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and lower endpiece half mirror side.

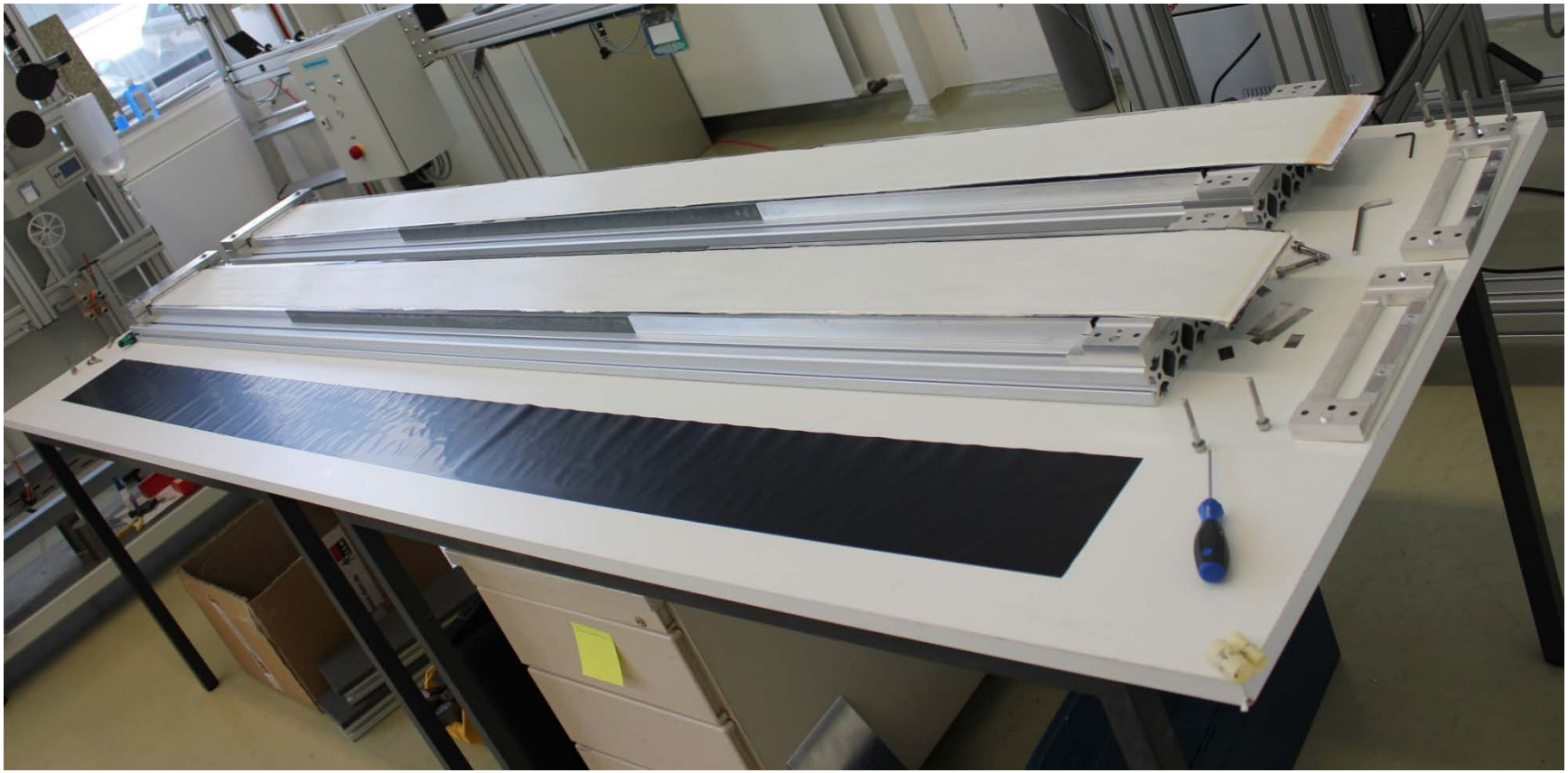
The glueing of the endpieces will be done in the foil lamination jig.

1. Prepare epoxy glue AW106. (QTY: 4g)
2. Apply epoxy glue AW106 onto the endpieces for the readout side and the lower half of the mirror side



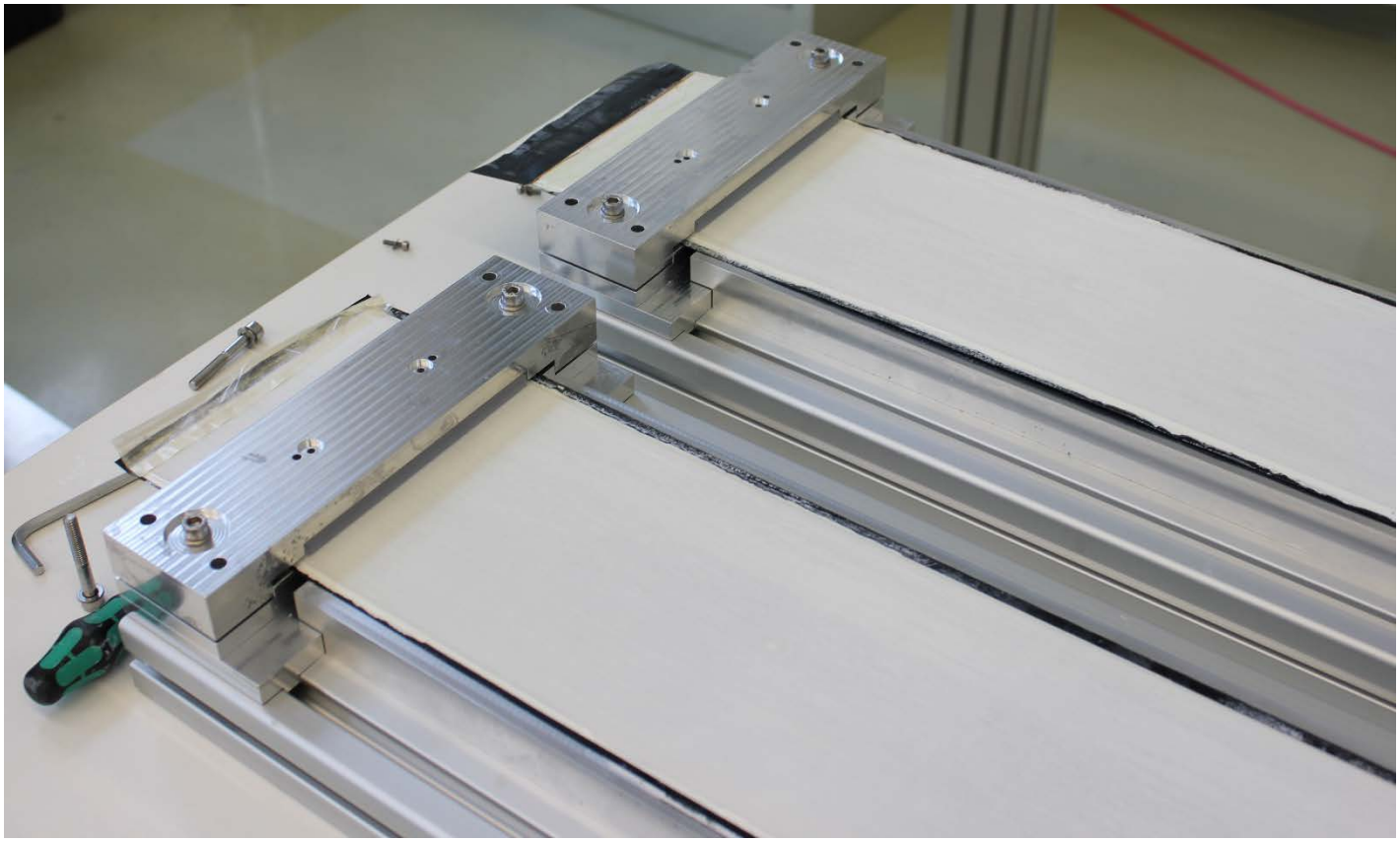
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and lower endpiece half mirror side.

3. Place and adjust the fibre mat in the jig with the alignment pins, screw in addition upper mirror endpiece half (without glue, just for tensioning), fix and screw the clamps for the endpieces together.



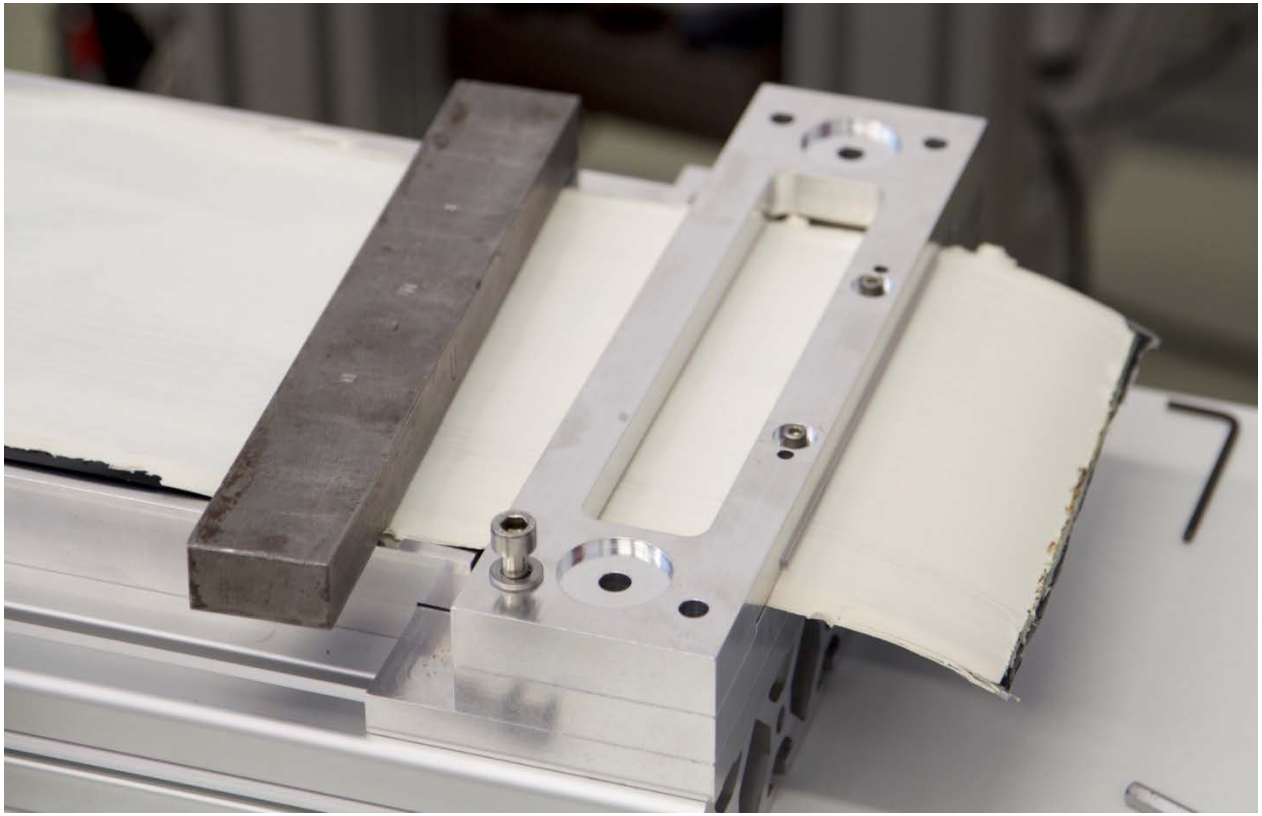
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and lower endpiece half mirror side.

3. Place and adjust the fibre mat in the jig with the alignment pins, fix and screw the clamps for the endpieces together.
4. Apply pressure, remove leaking glue



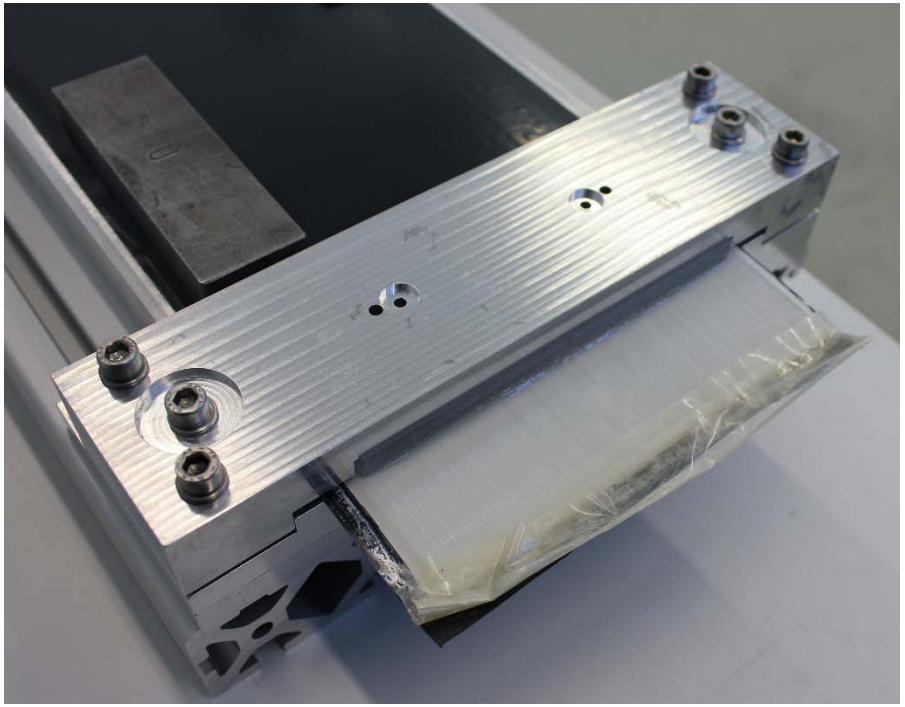
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and lower endpiece half mirror side

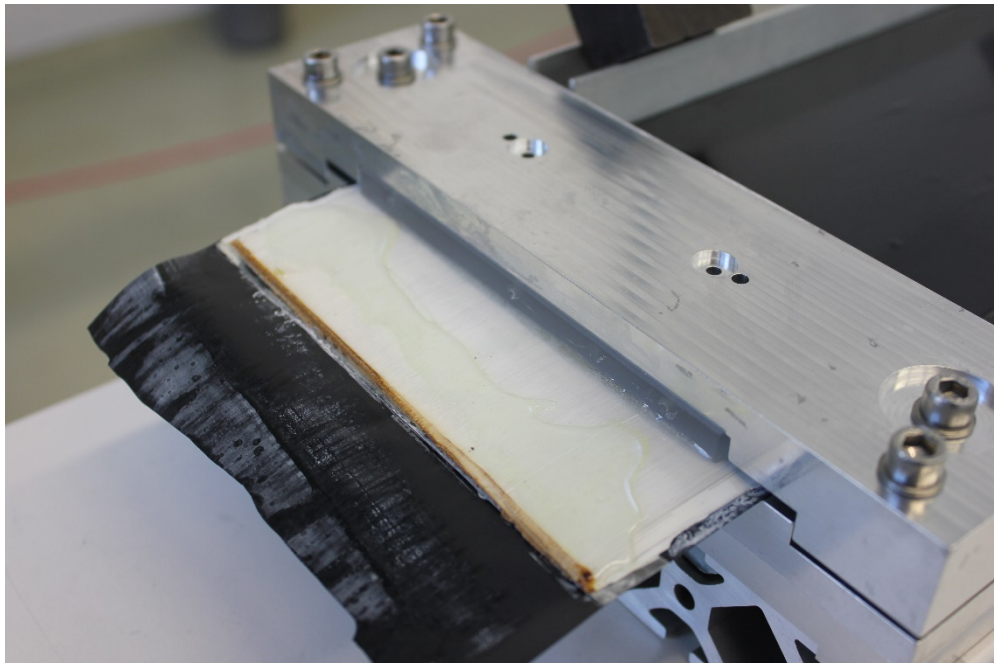
5. Screw in addition upper mirror endpiece half (without glue, just for tensioning), apply pressure, remove leaking glue
6. Cure over night, curing time minimum 12h



3. Lamination of fibre mat side without alignment pins and glueing of upper endpiece half mirror side

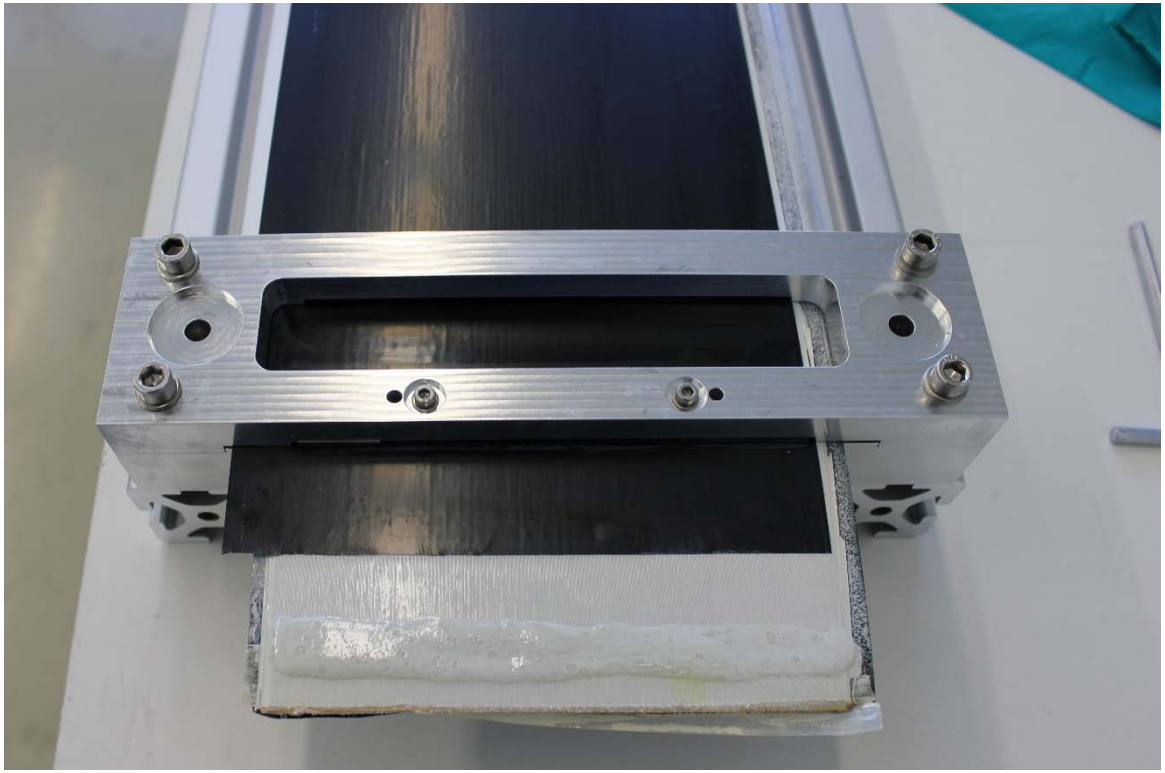
1. Prepare epoxy glues epotek 301 and AW106.
2. Apply epotek glue 301 on surface of the fibre mat side without alignment pins
3. Place and adjust foil on fibre mat against readout endpiece.





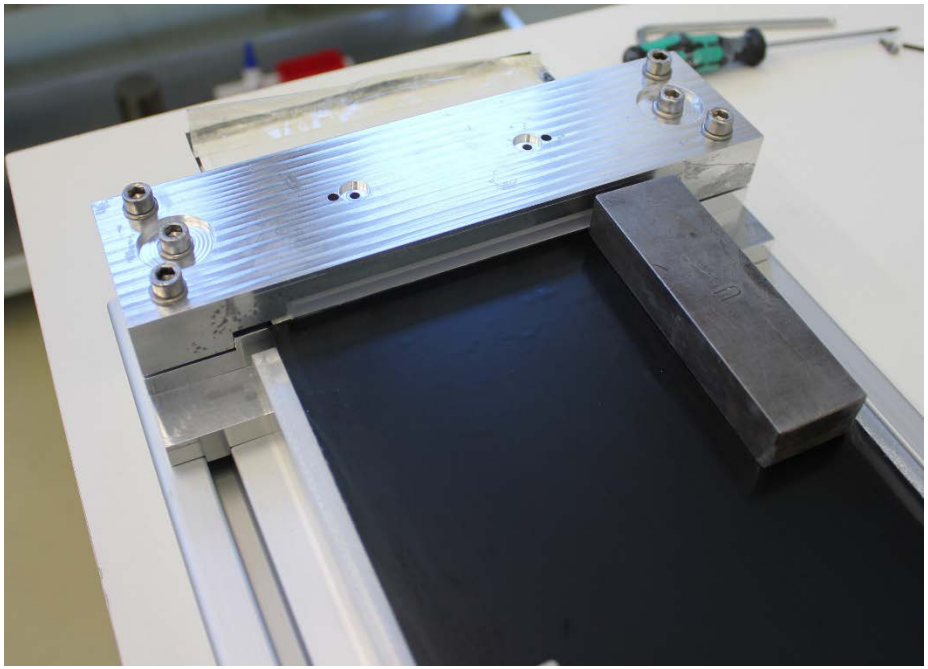
3. Lamination of fibre mat side without alignment pins and glueing of upper endpiece half mirror side

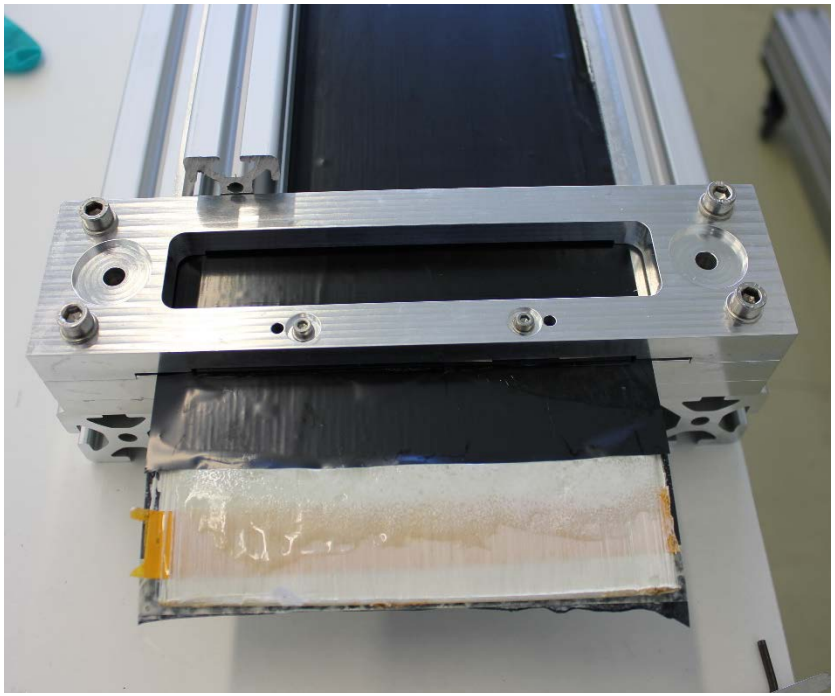
4. Lay down foil on glued surface of the fibre mat side without alignment pins over the end of the mirror side.
5. Apply glue AW106 on upper half of endpiece mirror side
6. Place, adjust and screw upper half of endpiece side clamp to lower side clamp
7. Apply pressure, remove leaking glue



3. Lamination of fibre mat side without alignment pins and glueing of upper endpiece half mirror side

8. Place weight on foil
9. Cure over night, curing time minimum 12h.





Foil Lamination and Endpiece Glueing: Tools

TOOLS:

- Multi purpose foil lamination and endpiece glueing jig, QTY: 1
- Narrow roller, QTY:1
- Wide roller used to push down the foil onto the mat, QTY:1
- Hole punch 10 mm to punch out the holes for the alignment pins QTY: 1
- Hammer and pad for the hole punch, QTY:1
- Aperture plate, QTY: 1
- Side cutter, QTY: 1

Foil Lamination and Endpiece Glueing Consumables

Consumables:

- Foil black 0.025 mm, QTY: 6m per mat, 1.5 km in total
- Adhesive tape to fix the foil, QTY: 105 m
- Scotch brite (3M), QTY: 10
- Epotek 301, QTY: 10 kg
- Disposable pipette, QTY: 250
- AW106 (Araldit), QTY: 1.5 kg
- Single use protective gloves, QTY: 250
- Roller, small ones QTY: 500, wide ones QTY: 100
- Isopropanol
- Acetone

Foil Lamination and Endpiece Glueing Consumables

Consumables:

- Upper Endpiece half readout side, QTY: 250
- Lower Endpiece half readout side, QTY: 250
- Upper Endpiece half mirror side, QTY: 250
- Lower Endpiece half mirror side, QTY: 250

Foil Lamination and Endpiece Glueing

Process/Step	Time	FTE
1. Lamination of fibre mat side with alignment pins		
1. Prepare the foil for the fibre mat side with alignment pins	20 min	1
2. Prepare fibre mat side with alignment pins for foil lamination	10 min	1
3. Prepare the foil with the punched holes for the alignment pins of the fibre mat for lamination	15 min	1
4. Prepare Epotek glue 301 for the lamination	7 min	1
5. Apply Epotek glue 301 on the face of the mat side with alignment pins	2 min	1
6. Lay down the foil onto the glued surface and adjust it. Fasten the end of the foil onto the support.	10 min	2
7. Continue applying epotek glue 301 to surface of fibre mat with alignment pins	5 min	1
8. Continue adjusting the foil onto the glued surface	5 min	1
9. Continue laying down the foil onto the glued surface, adjust and apply moderate tension. Do the roller application to get rid of air bubbles.	20 min	1
10. Cure over night, curing time minimum 12h	12 h	0
	Σ 84 min	**1**
	Σ 10 min	**2**

Foil Lamination and Endpiece Glueing

Process/Step	Time	FTE
2. Positioning of fibre mat on precision jig for glueing of lower and upper endpiece halves readout side and lower endpiece half mirror side		
1. Prepare epoxy glue AW106	7 min	1
2. Apply epoxy glue AW106 onto the endpieces for the readout side and the lower half of the mirror side	7 min	1
3. Place and adjust the fibre mat in the jig with alignment pins, screw in addition upper mirror endpiece half, fix and screw the clamps for the endpieces together.	5 min	2
4. Apply pressure, remove leaking glue	10 min	1
5. Screw in addition upper mirror endpiece half, apply pressure, remove leaking glue	10 min	1
6. Cure over night, curing time minimum 12h		
	Σ 34 min	**1**
	Σ 5 min	**2**

Foil Lamination and Endpiece Glueing

Process/Step	Time	FTE
3. Lamination of fibre mat side without alignment pins and glueing of upper endpiece half mirror side		
1. Prepare epoxy glues Epotek 301 and AW106	14 min	1
2. Apply glue Epotek 301 on surface of the fibre mat side without alignment pins	10 min	1
3. Place and adjust foil on fibre mat against readout endpiece	3 min	1
4. Lay down foil on glued surface of the fibre mat side without alignment pins over the end of the mirror side.	5 min	2
5. Apply glue AW106 on upper half of endpiece mirror side	1 min	1
6. Place, adjust and screw upper half of endpiece side clamp to lower side clamp	1 min	1
7. Apply pressure, remove leaking glue	10 min	1
8. Place weight on foil	2 min	1
9. Cure over night, curing time minimum 12h	12	0
	Σ 41 min	**1**
	Σ 5 min	**2**

Transverse Cut -

Optical Cut

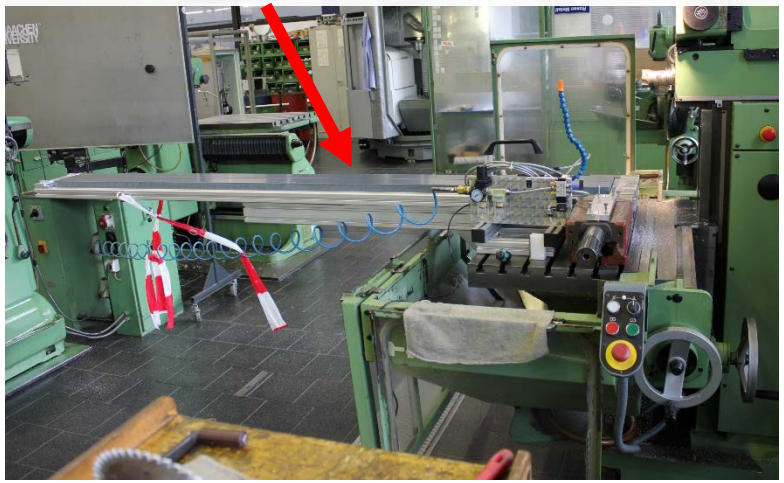
Transversal Cut – Optical Cut

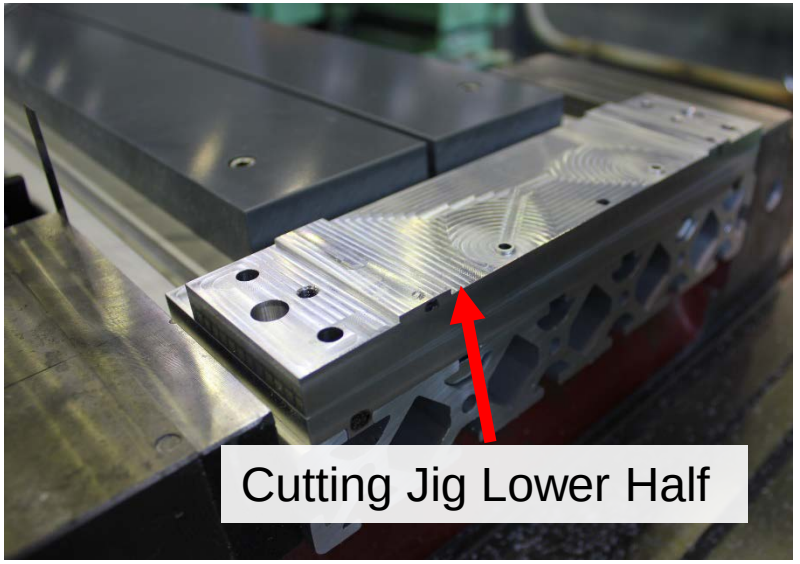
1. Position and align fibre mat on cutting jig 184
2. Pre-Cut on readout side using a saw blade to cut away overlength 185
3. Transversal Cut - Optical Cut on readout side using a diamond head 186
4. Repeat Pre-cut on mirror side 186
5. Repeat optical cut on mirror side 186
6. Acclimatisation and measurement of fibre mat length 187
7. Final optical cut mirror side 187
8. Transversal – Optical Cut: Tools, FTE 189

Optical Cut

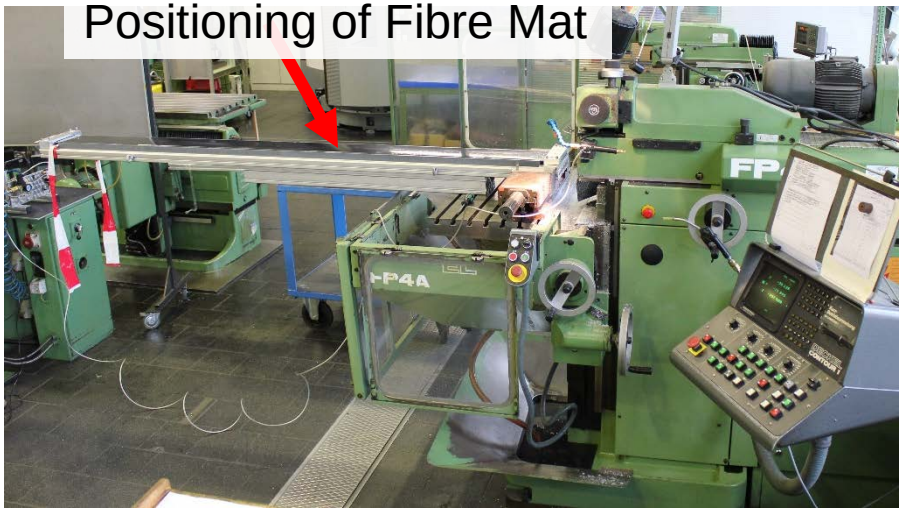
1. Position and align fibre mat on cutting jig

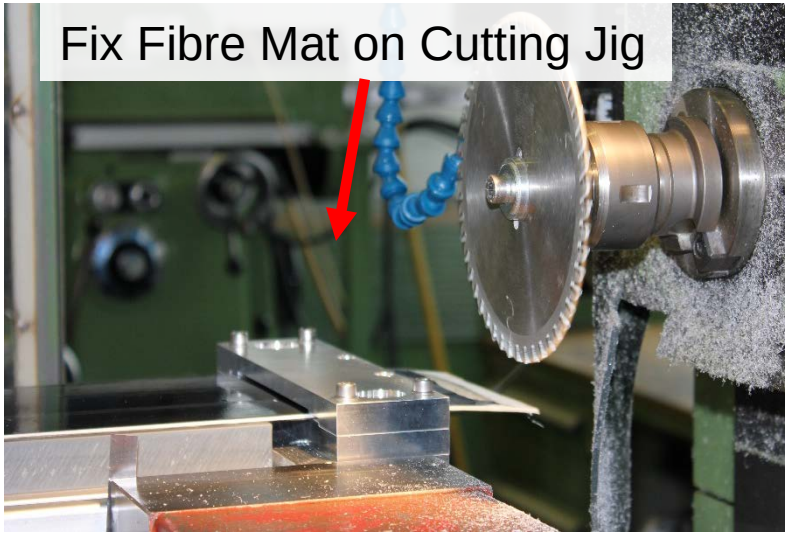
Multi Purpose Jig at Milling Machine





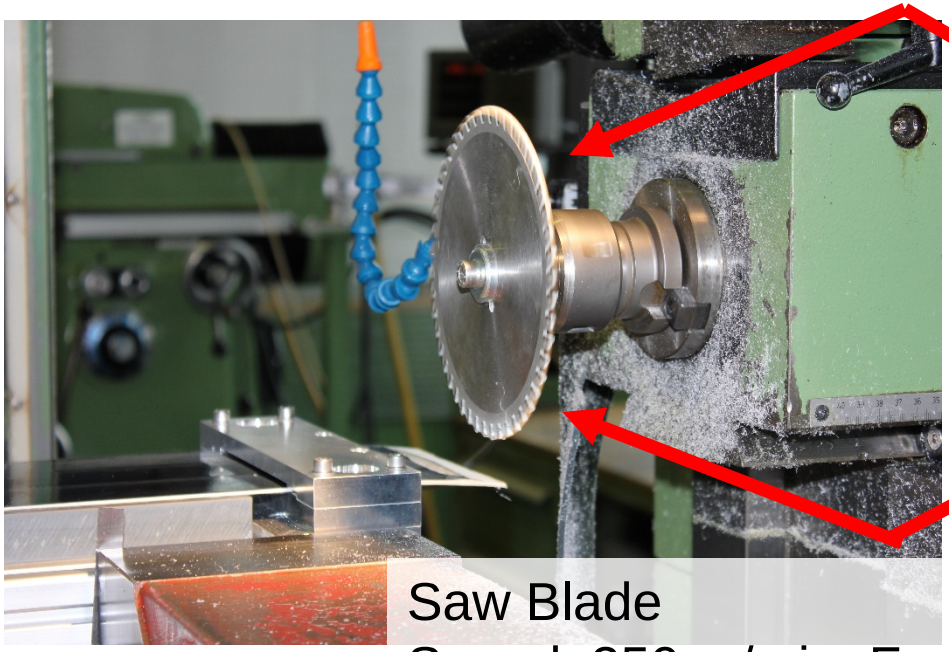
Positioning of Fibre Mat

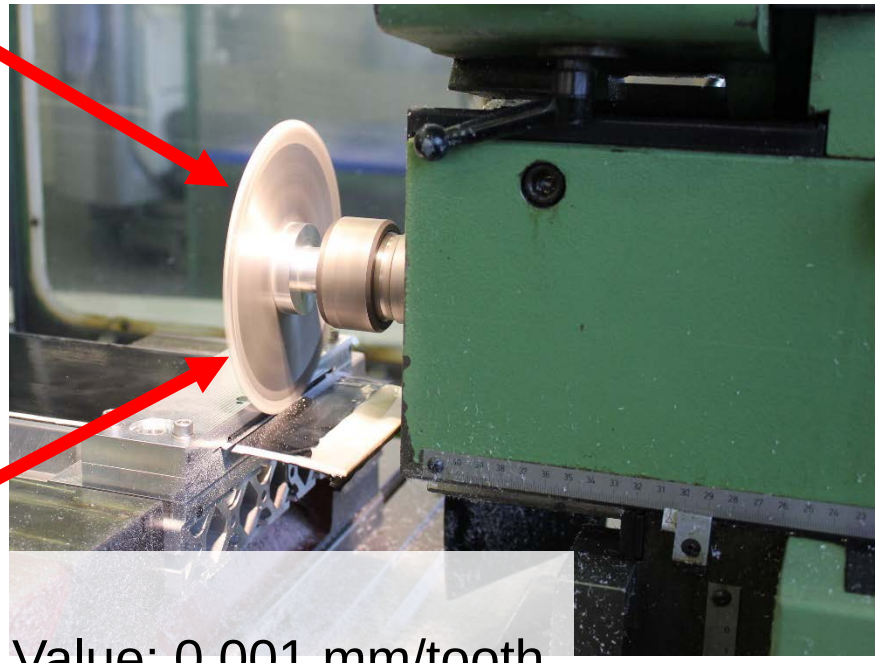




Optical Cut

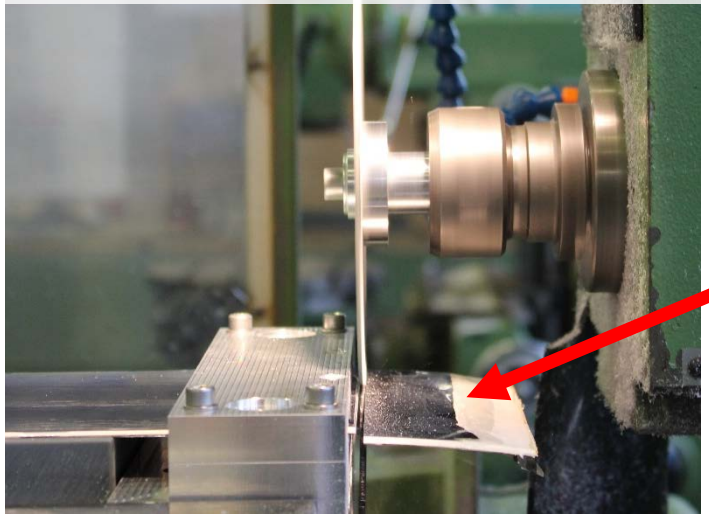
2: Pre-Cut on Readout Side using a Saw Blade to cut away overlength





Saw Blade

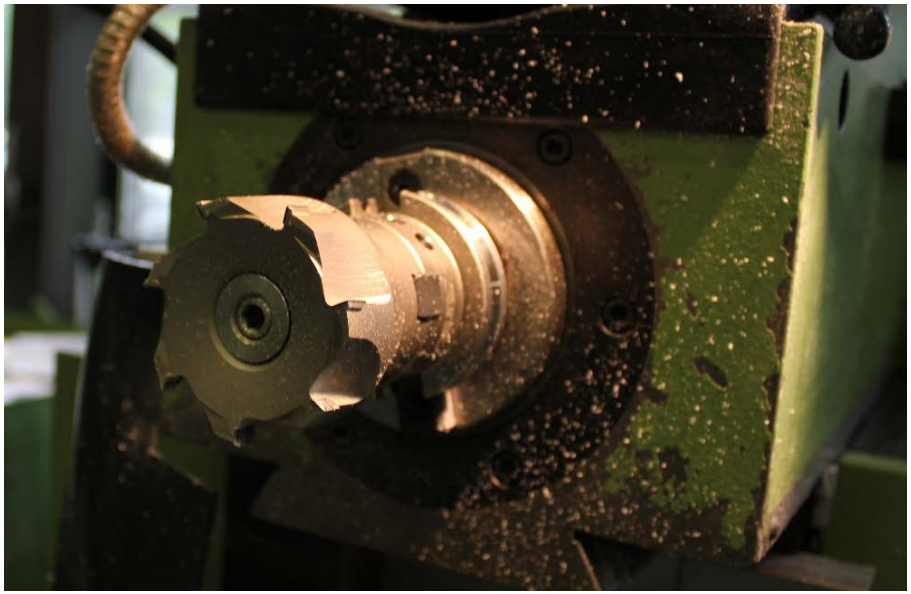
Speed: 250 m/min, Feed Value: 0.001 mm/tooth

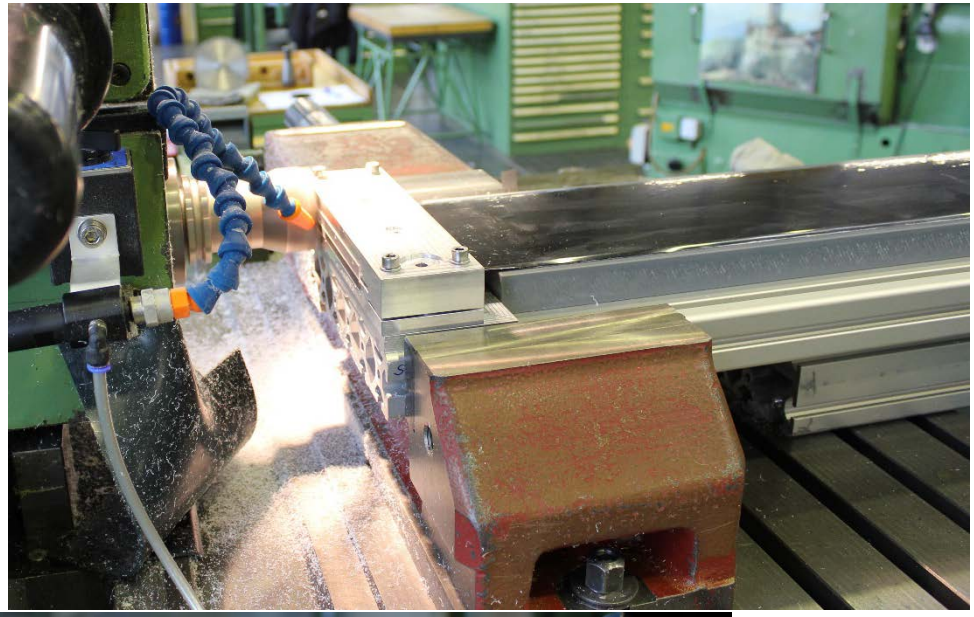


Overlength piece

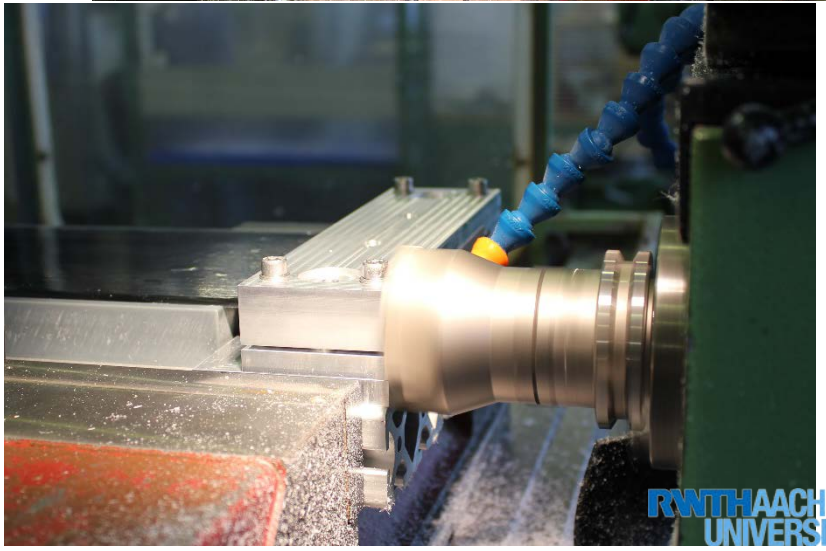
Optical Cut

3: Transversal Cut - Optical Cut on Readout Side using a diamond head





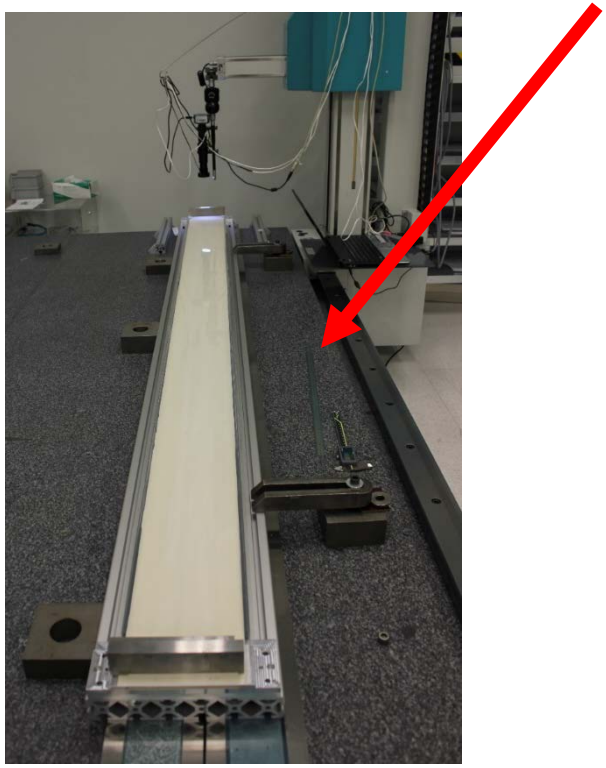
Diamond tip milling head
Speed: 200 m/min
Feed Value: 0.003 mm/tooth
Infeed Depth: 0.03 mm



Step 4 & 5: Repeat Pre-Cut and Optical Cut on Mirror Side

Optical Cut

6. Acclimatisation and Measurement of Fibre Mat Length



Gap between Fibre Mats at mirror positions: 2 mm

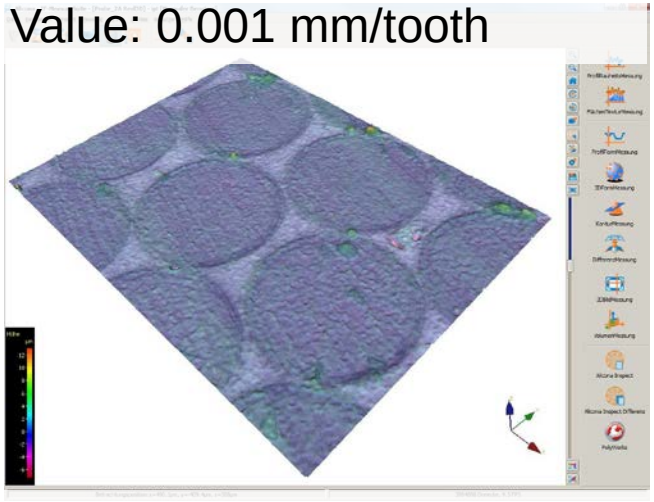
Nominal Length of Fibre Mat $(2424{,}0^{+0{,}1}_{-0{,}3})$ mm

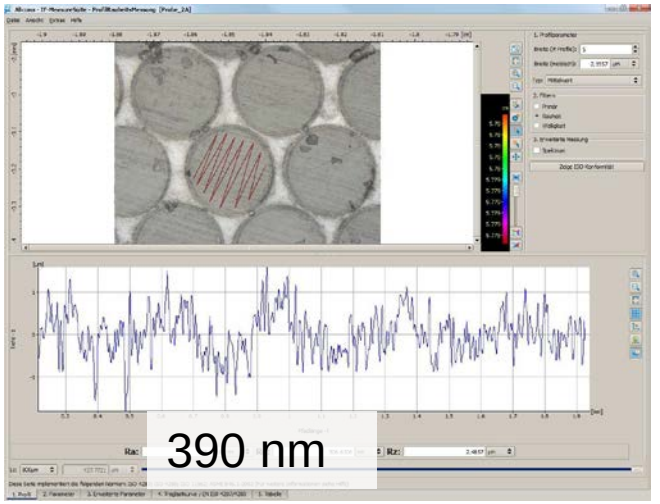
7. Final optical cut mirror side

Optical Cut - Quality

Saw Blade

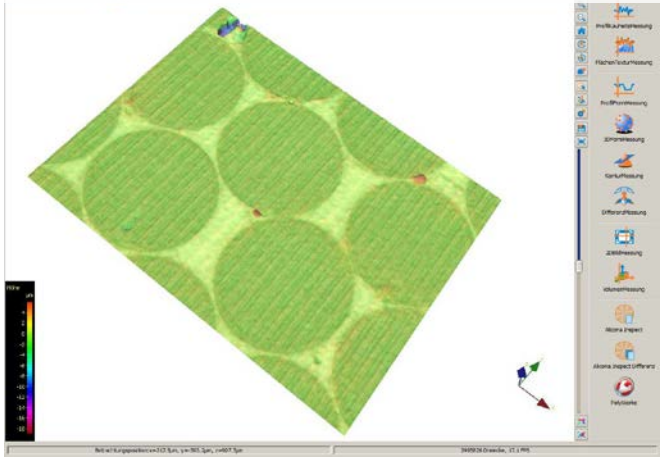
Speed: 250 m/min, Feed Value: 0.001 mm/tooth

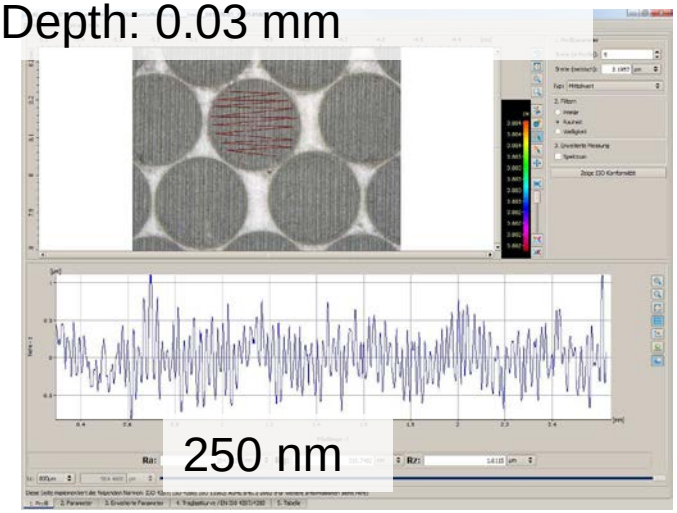




Diamond tip milling head

Speed: 200 m/min, Feed Value: 0.003 mm/tooth, Infeed Depth: 0.03 mm





Optical - Transversal Cut: Tools

TOOLS:

- Multi purpose jig for transversal cut, QTY: 1
- Saw blade, QTY:9
- Diamond head, QTY:2
- Geometry jig or 3d-measurement machine, QTY: 1

Optical - Transversal Cut

Process/Step	Time	FTE
1. Position and align fibre mat on cutting jig	5 min	2
2. Pre-Cut on readout side using a saw blade to cut away overlength	15 min	1
3. Transversal Cut - Optical Cut on readout side using a diamond head	40 min	1
4. Repeat Pre-cut on mirror side	15 min	1
5. Repeat optical cut on mirror side	40 min	1
6. Acclimatisation and measurement of fibre mat length	240 min 30 min	0 1
7. Final optical cut mirror side	40 min	1
	Σ 180 min	**1**
	Σ 5 min	**2**
	Σ 240 min	**0**

Mirror Glueing

Mirror Glueing

1. Place fibre mat and tools on a table. 194
2. Cleaning of fibre surface. 195
3. Glue two strips of double-sided adhesive tape to metal plate with respect to fibre mat width plus overlength. 195
4. Remove protective cover of double-sided adhesive tape 196
5. Glue two strips of Kapton tape on double-sided adhesive tape.The second strip is partial overlapping the first strip. 197
6. Glue mirror foil to second (upper) Kapton tape, position fibre mat over mirror. 198
7. Remove protective cover of mirror. 199
8. Prepare epoxy glue epotek 301 and apply it to mirror using a soft brush or Q-tip. 200
9. Cut Kapton tape to a length corresponding to width of fibre mat and loose tape from metal plate 201

Mirror Glueing

10. Fold Kapton tapes with mirror around the fibre mat. Glue lower and upper parts of Kapton tape to mirror endpiece 202
11. Remove lower part of Kapton tape from endpiece 203
12. Mount mirror glueing jig to mirror endpiece of fibre mat 204
13. Fix jig by clicking bushings into holes of mirror endpiece 205
14. Screw inner bar of jig against glued Kapton tape and mirror. 206
15. Curing time minimum 12h 207
16. After curing remove glueing jig 208
17. Cut Kapton tape on all sides to endpiece width with a reversed scalpel 209
18. Mirror Glueing: Tools, Consumables, FTE 210

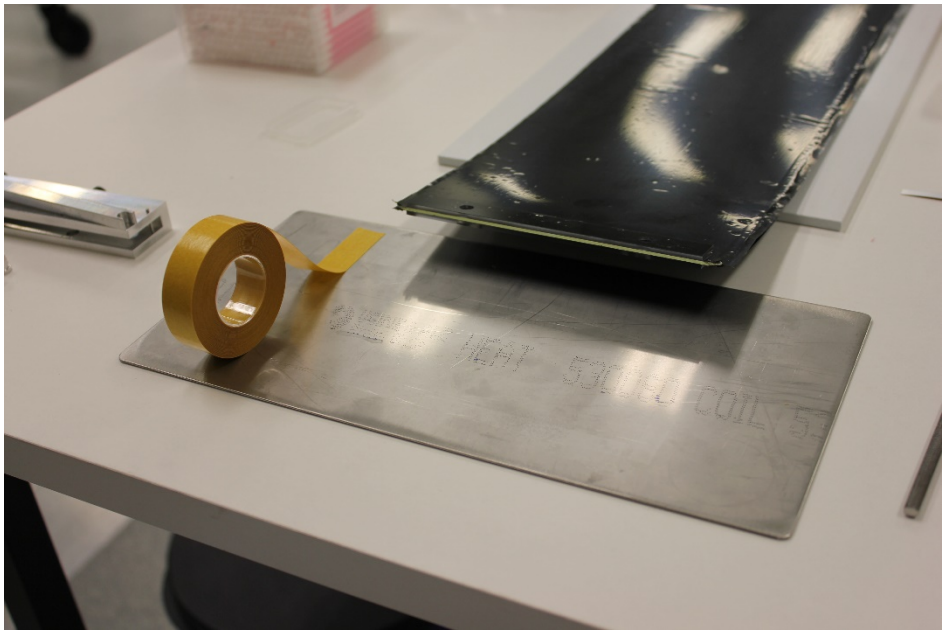
Mirror Glueing

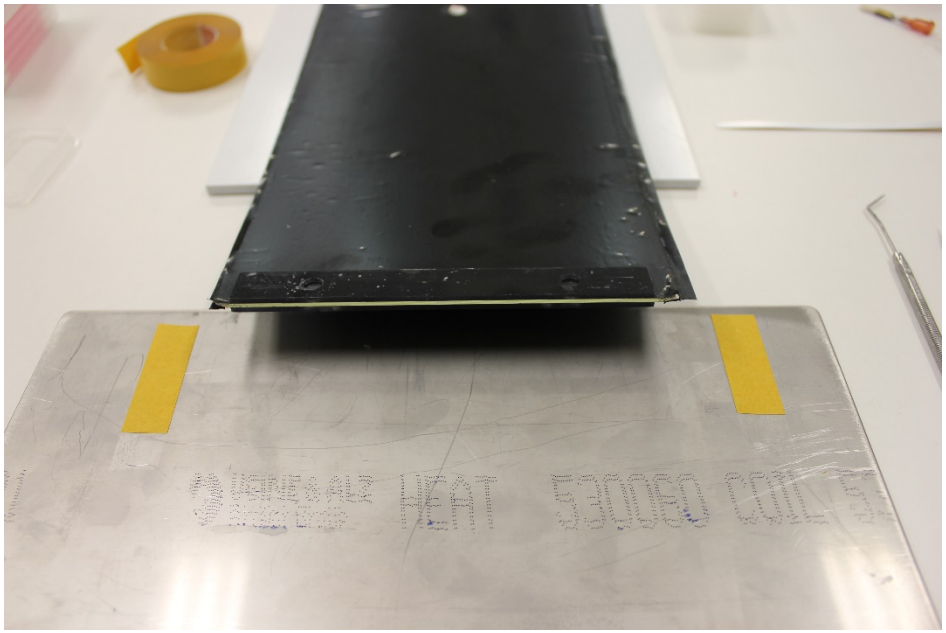
1. Place fibre mat and tools on a table.

Mirror Glueing

2. Cleaning of fibre surface.

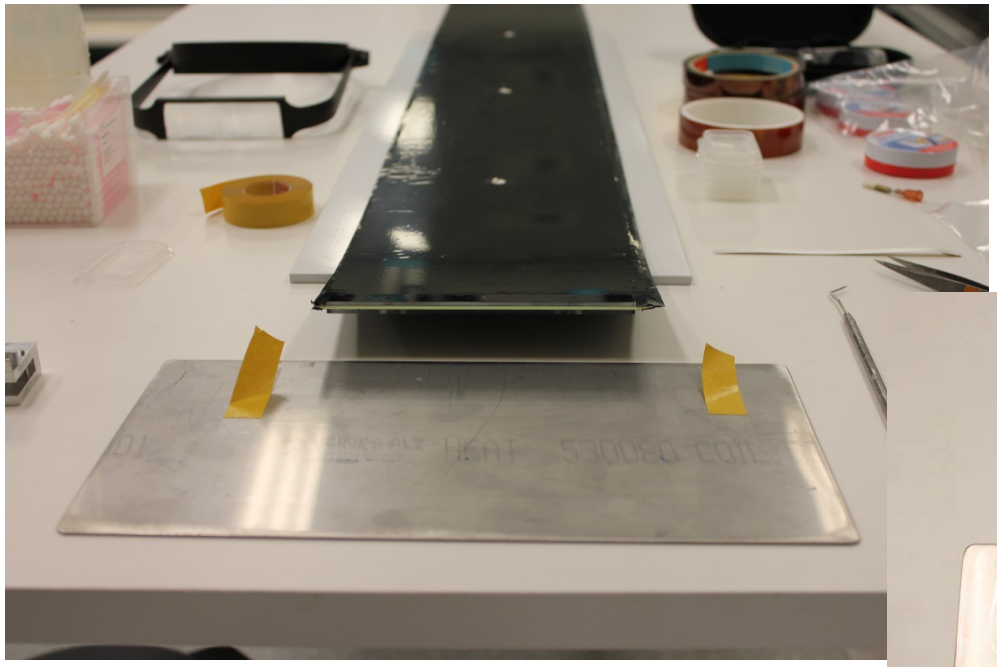
3. Glue two strips of double-sided adhesive tape to metal plate with respect to fibre mat width plus overlength.





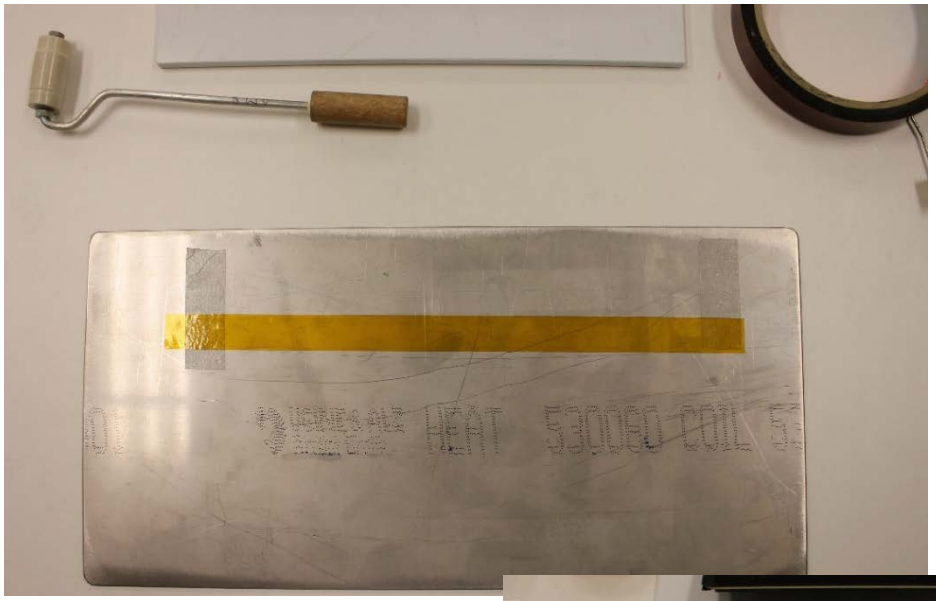
Mirror Glueing

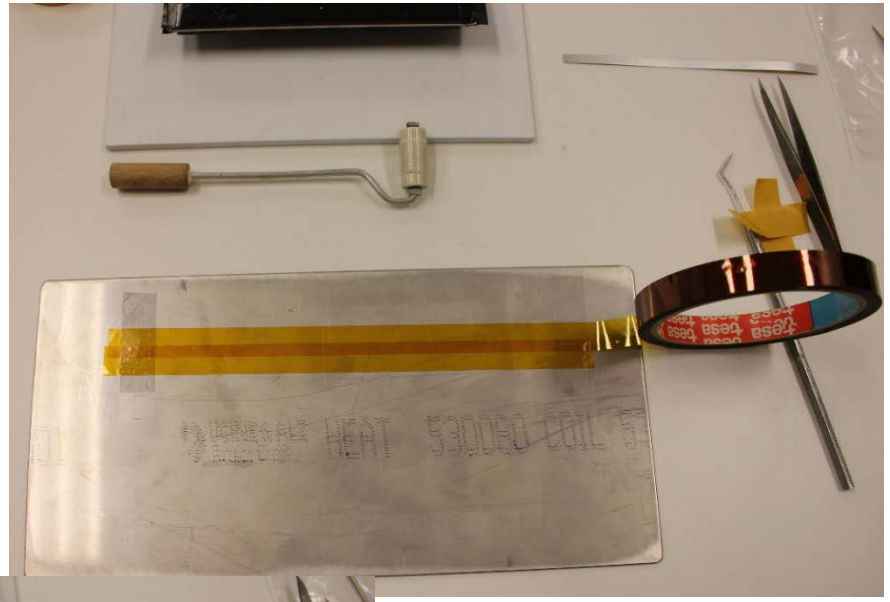
4. Remove protective cover of double-sided adhesive tape.



Mirror Glueing

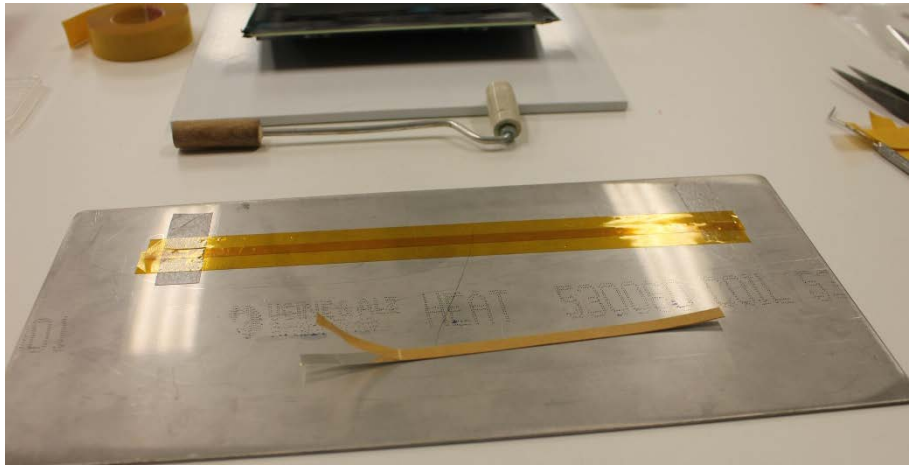
5. Glue two strips of Kapton tape on double-sided adhesive tape.The second strip is partial overlapping the first strip.

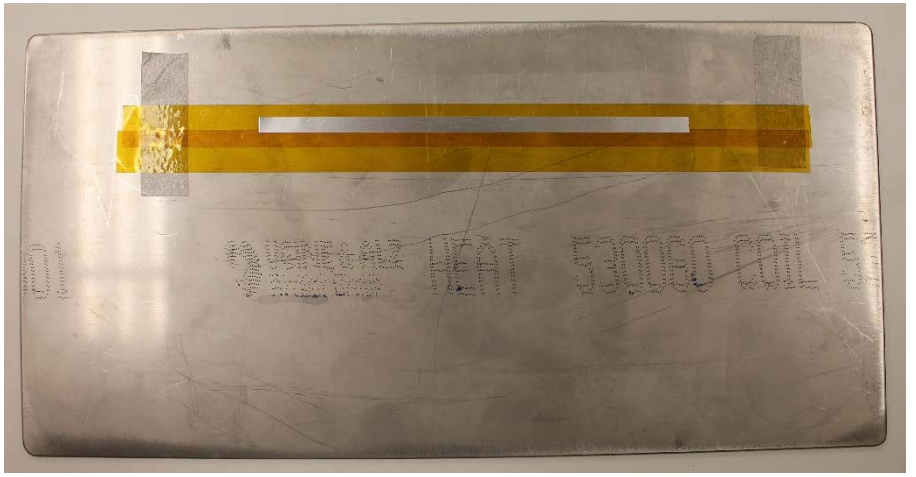


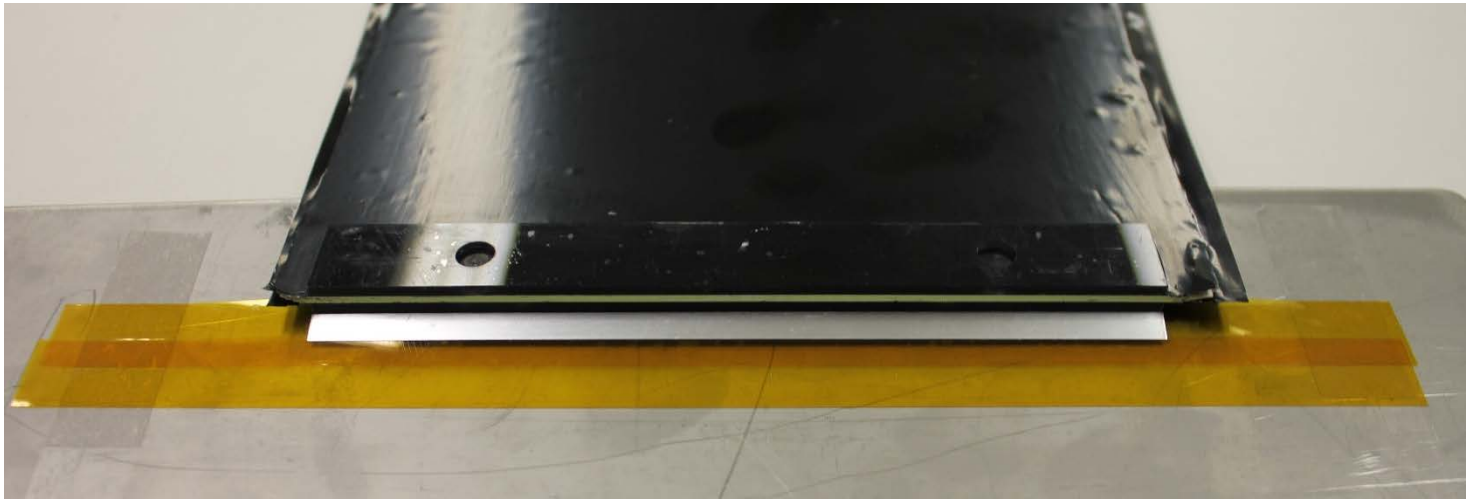


Mirror Glueing

6. Glue mirror foil to second (upper) Kapton tape, position fibre mat over mirror.

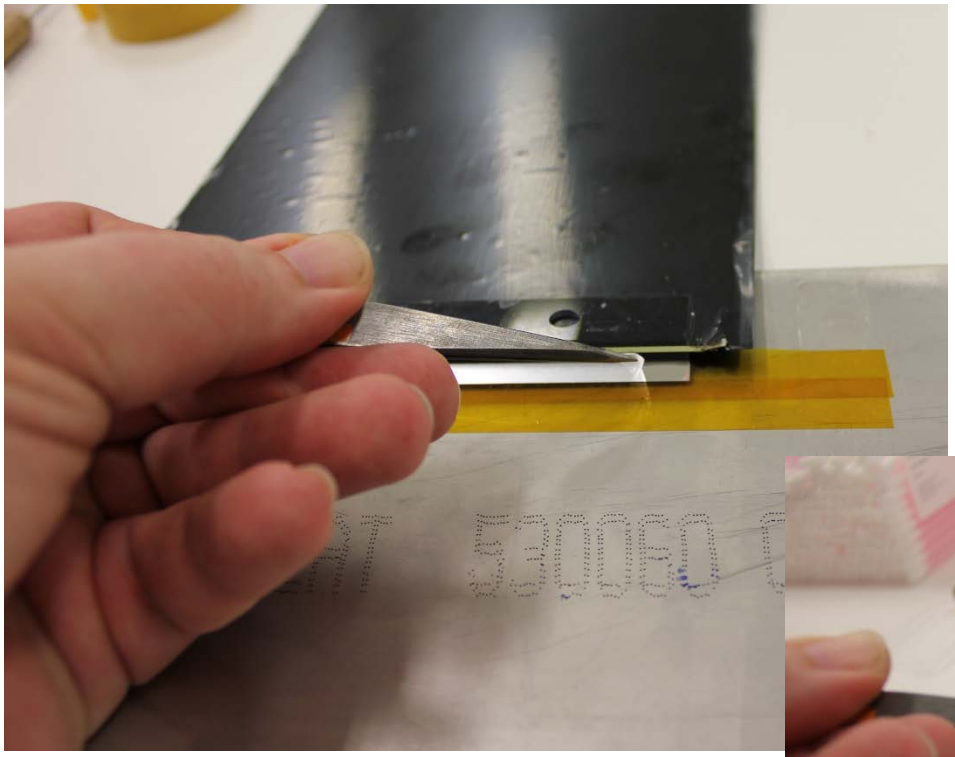


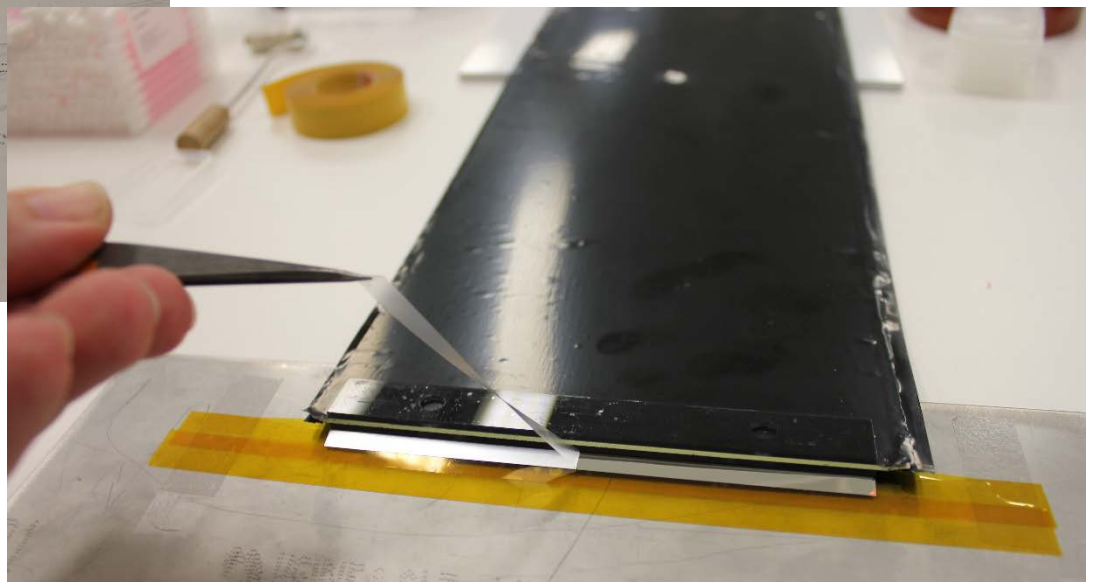




Mirror Glueing

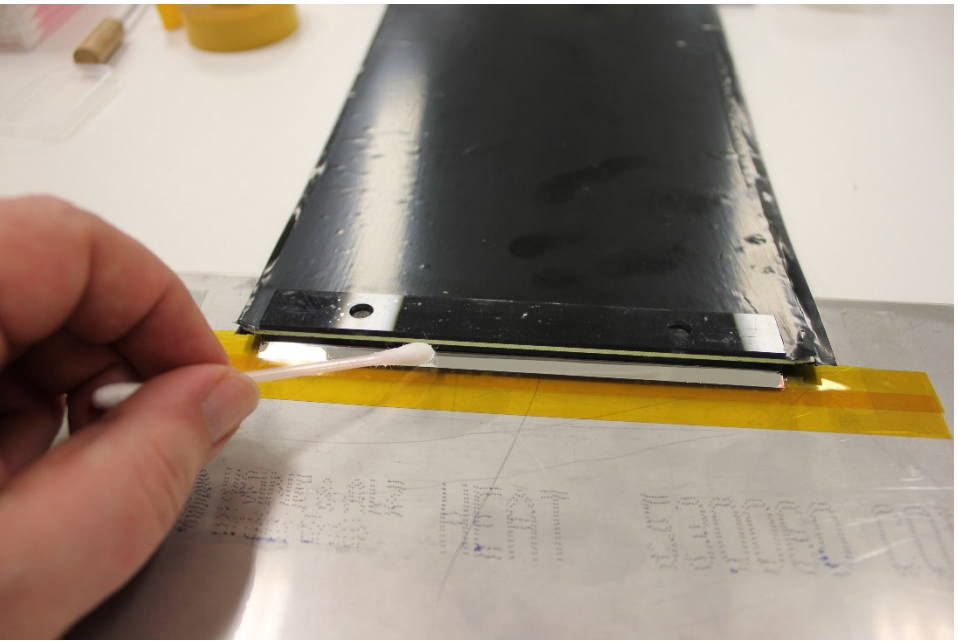
7. Remove protective cover of mirror.

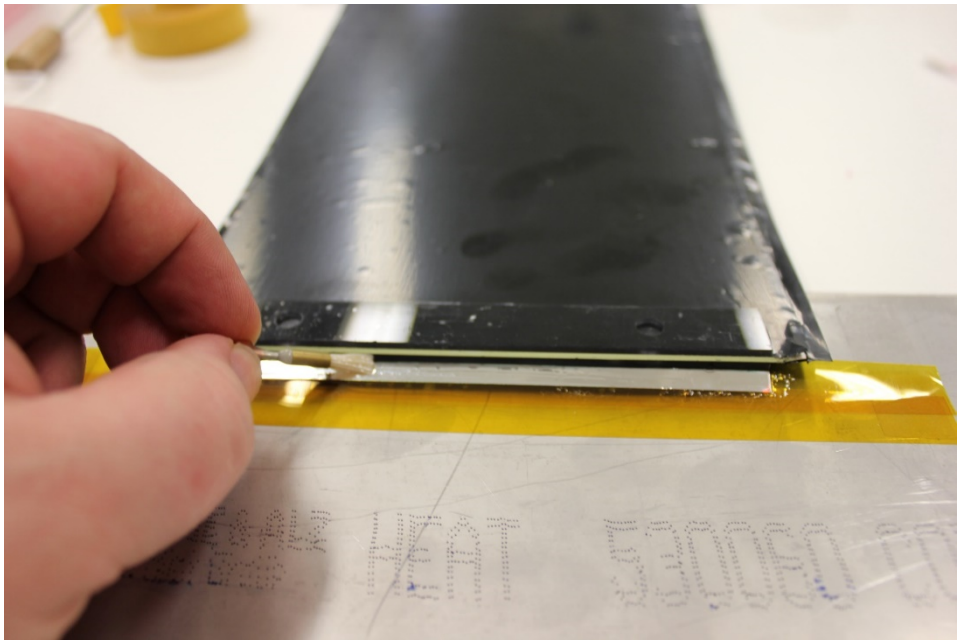




Mirror Glueing

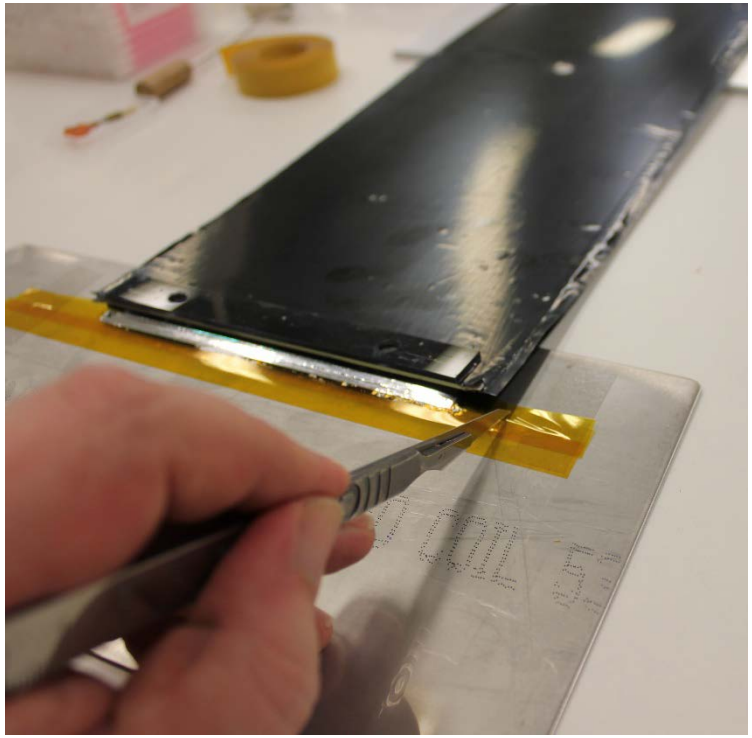
8. Prepare epoxy glue Epotek 301 (maximum 2g) and apply it to mirror using a soft brush or a Q-tip.

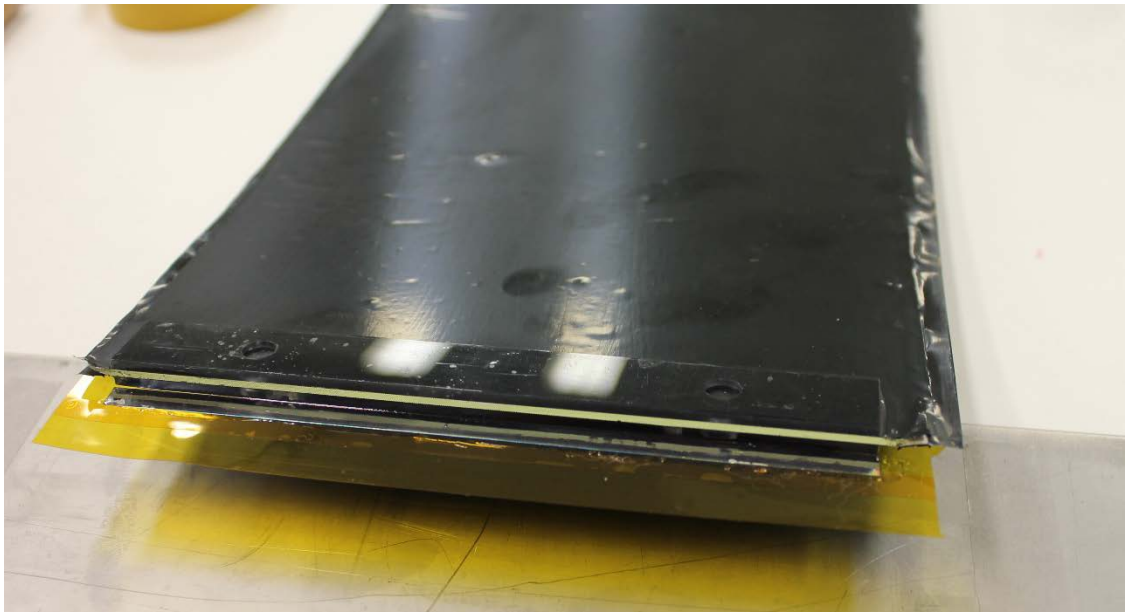




Mirror Glueing

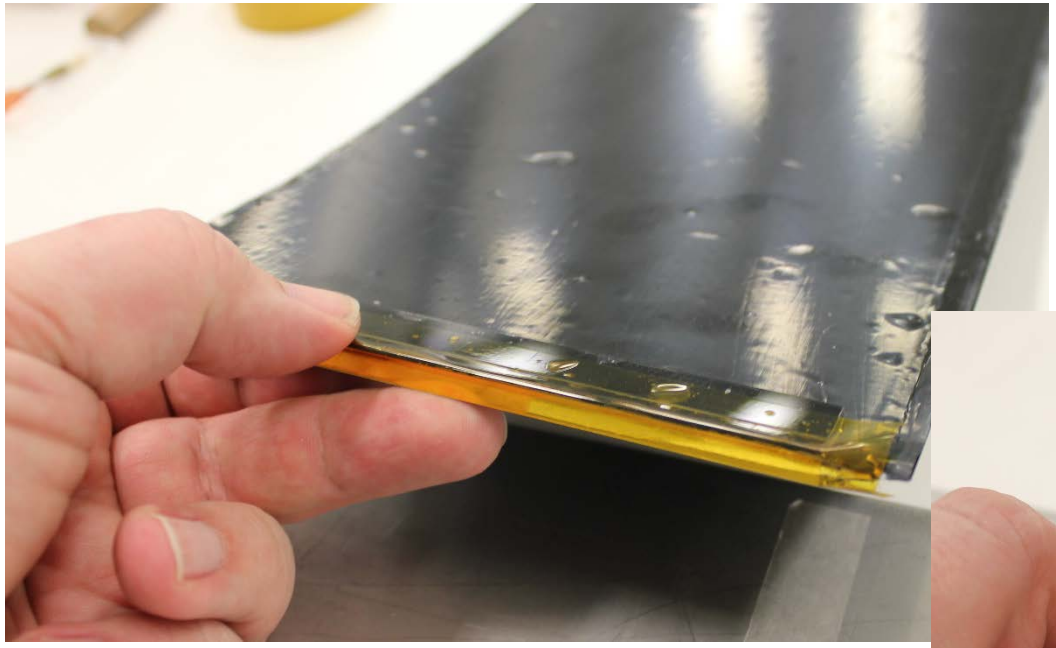
9. Cut Kapton tape to a length corresponding to width of fibre mat and loose tape from metal plate

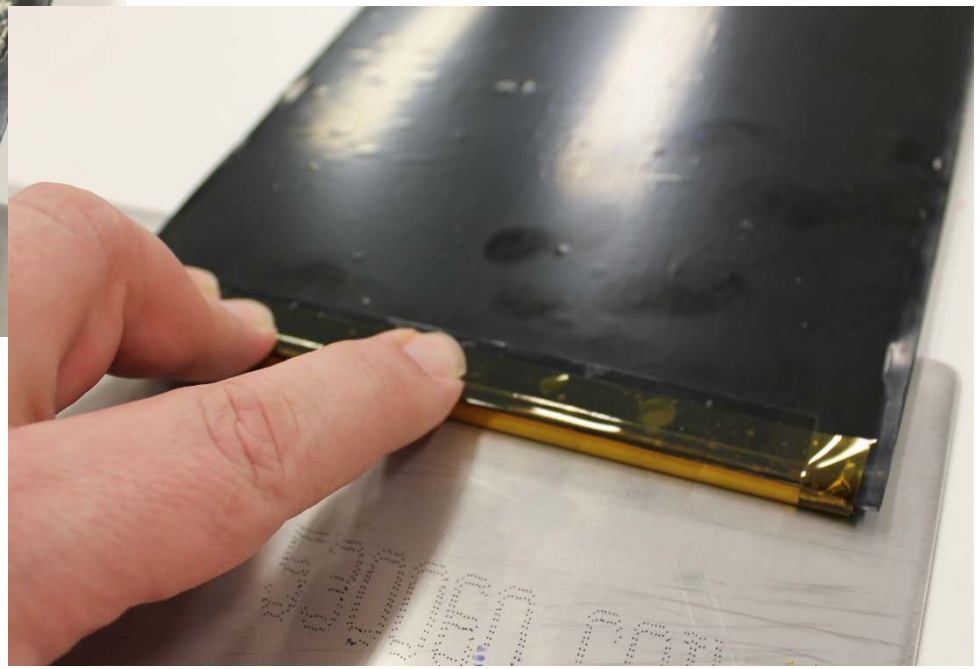




Mirror Glueing

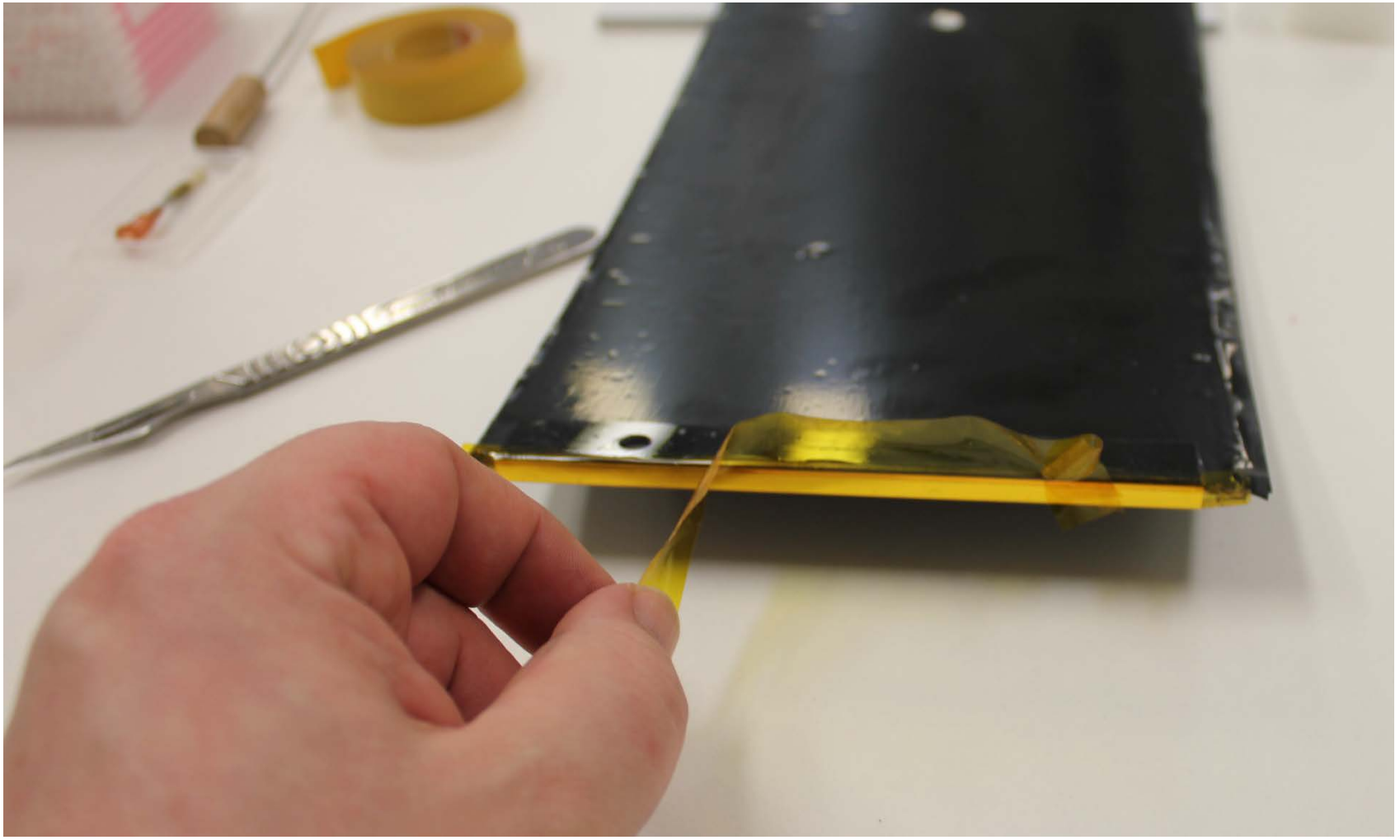
10. Fold Kapton tapes with mirror around the fibre mat. Glue lower and upper parts of Kapton tape to mirror endpiece.





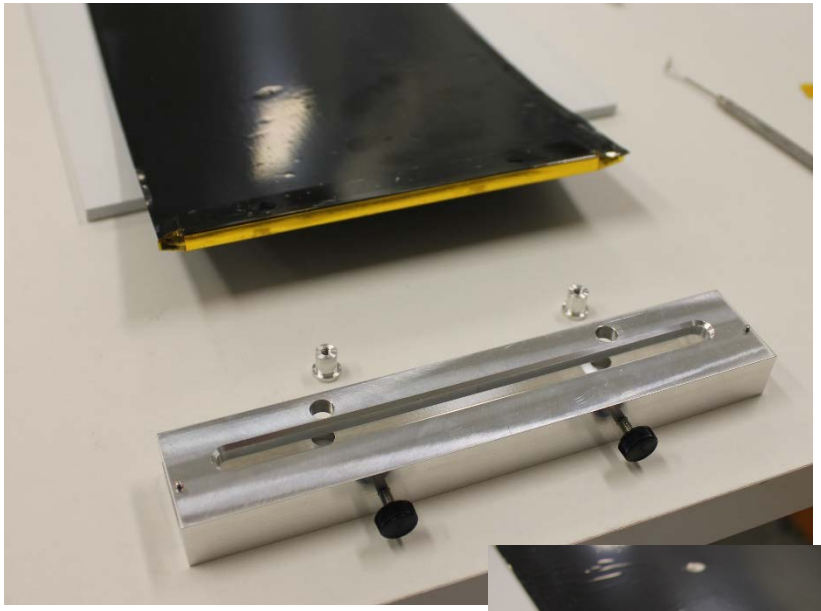
Mirror Glueing

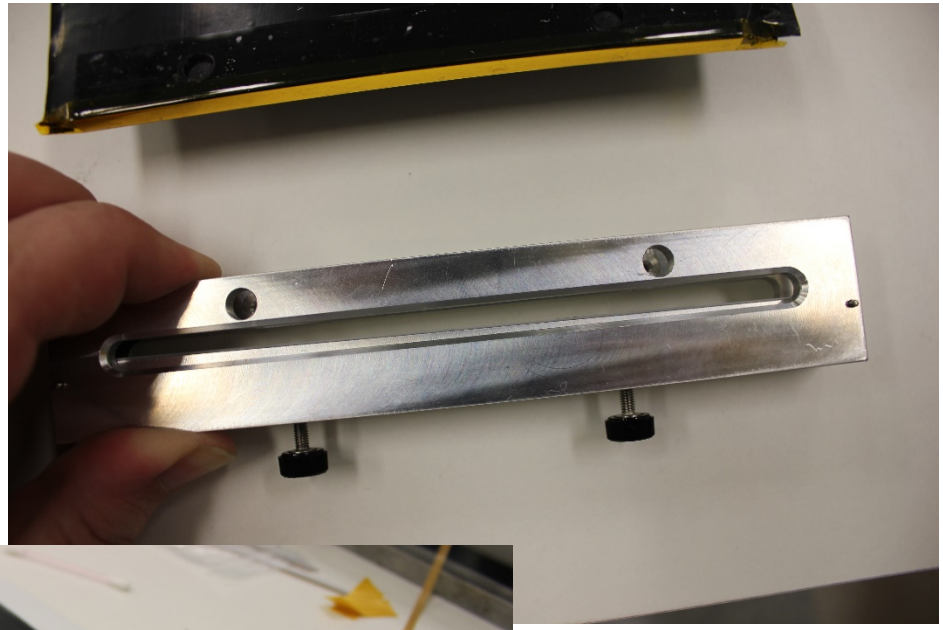
11. Remove lower part of Kapton tape from endpiece again

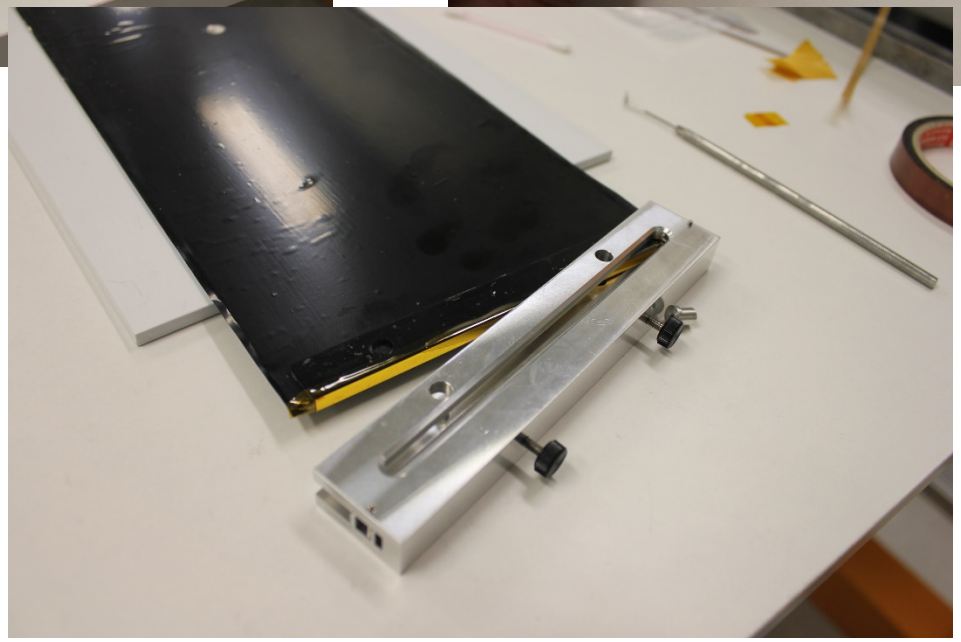


Mirror Glueing

12. Mount mirror glueing jig to mirror endpiece of fibre mat

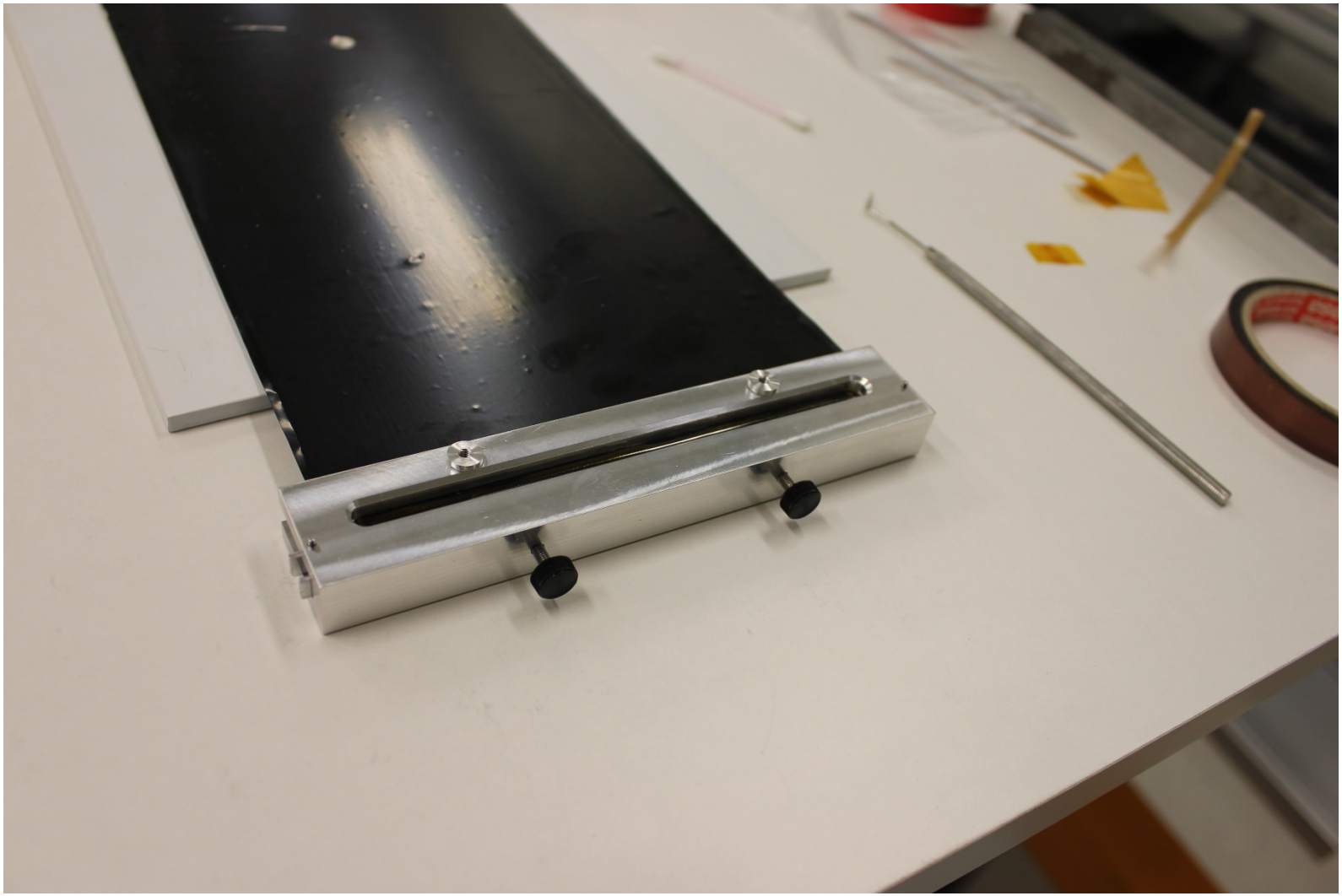






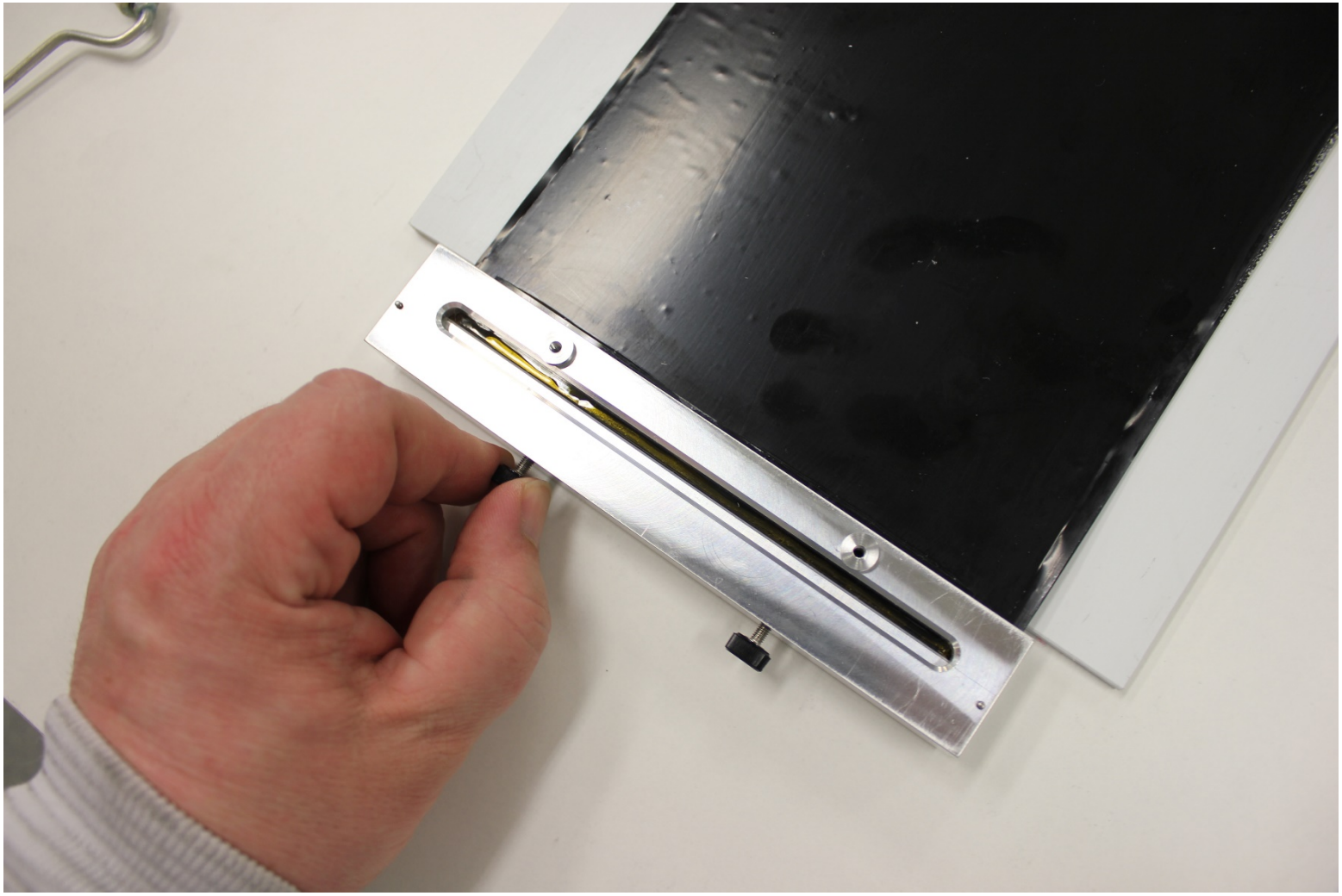
Mirror Glueing

13. Fix jig by clicking bushings into holes of mirror endpiece



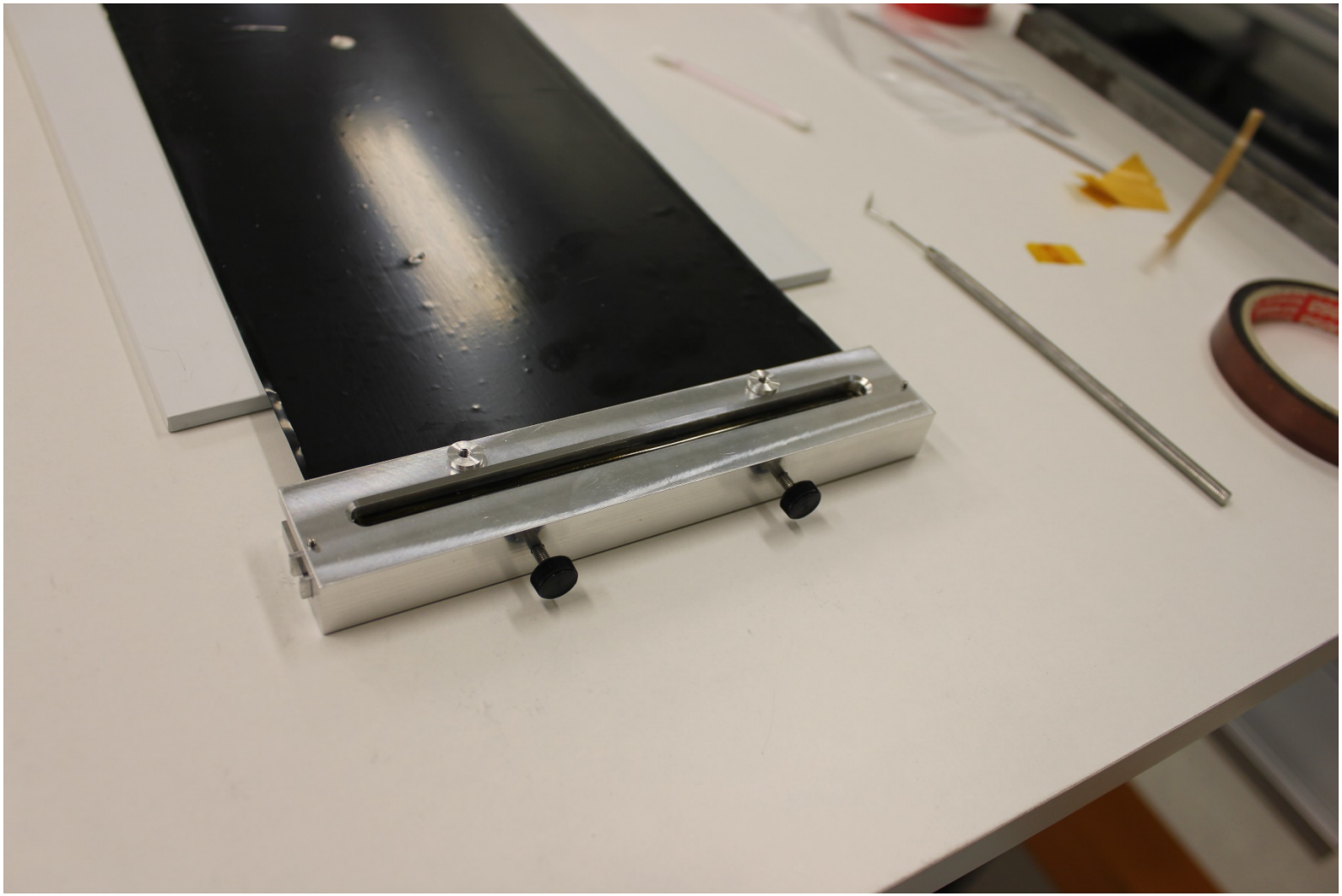
Mirror Glueing

14. Screw inner bar with a telfon cover against glued Kapton tape and mirror.



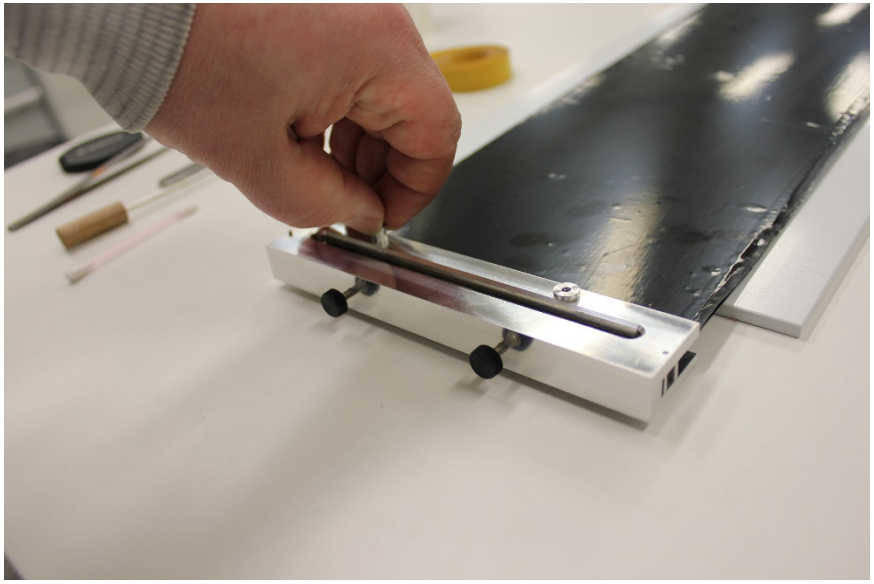
Mirror Glueing

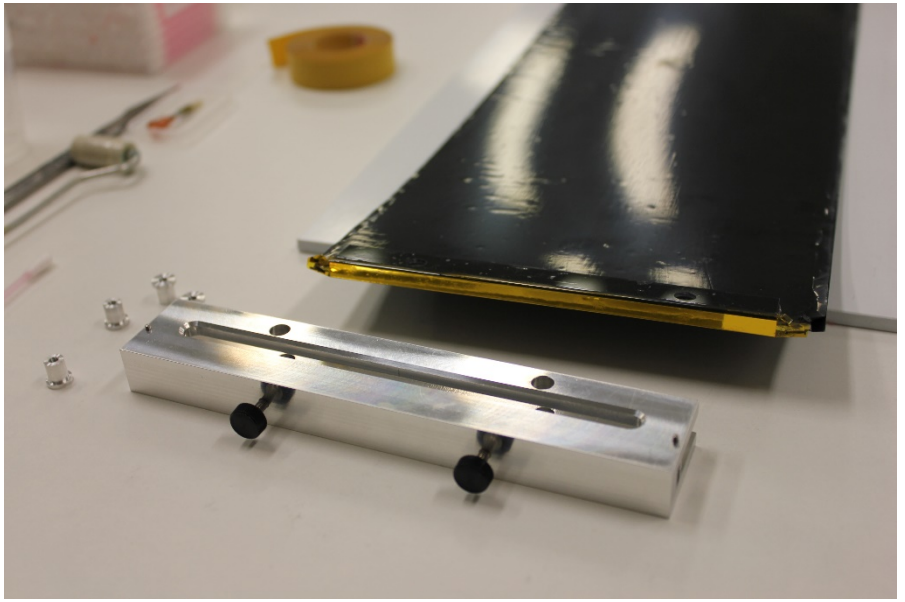
15. Curing time minimum 12h

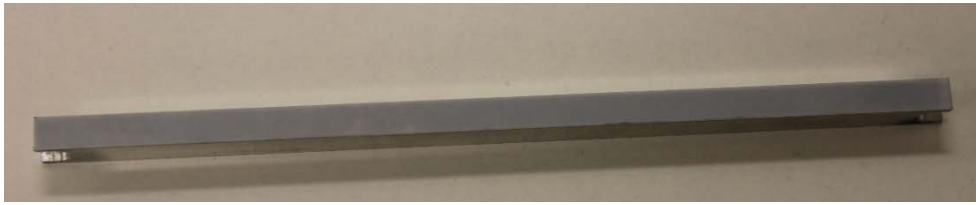


Mirror Glueing

16. After curing remove glueing jig

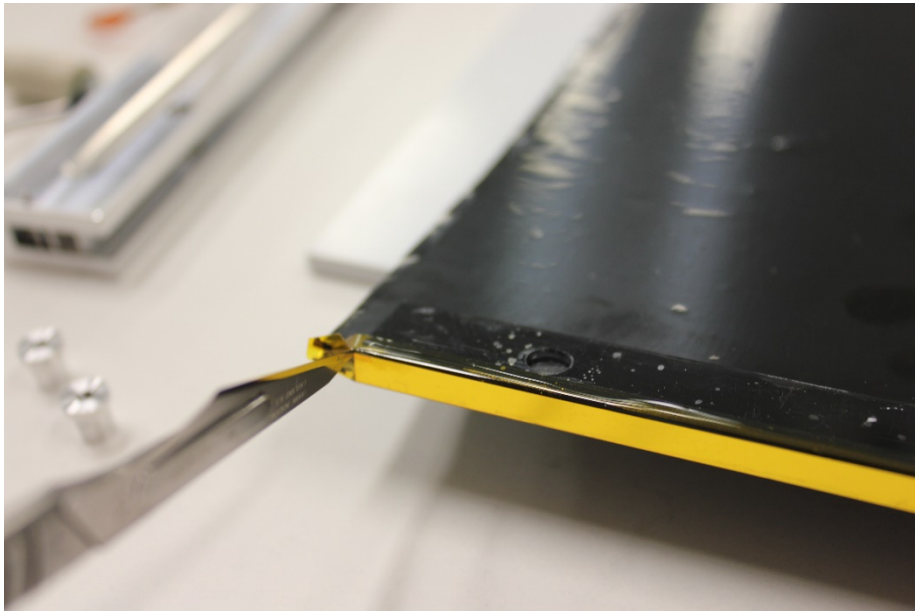


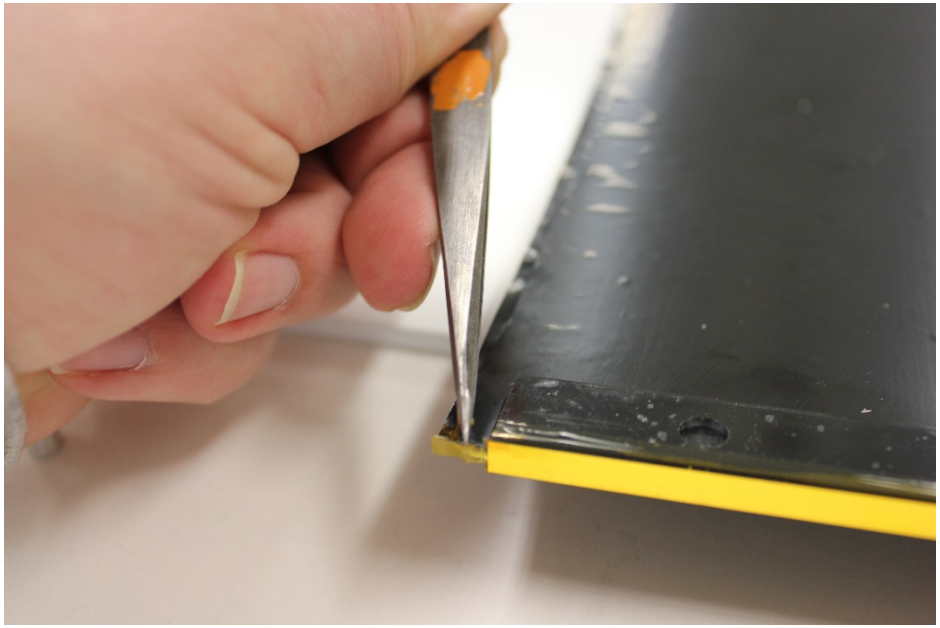




Mirror Glueing

17. Cut Kapton tape on all sides to endpiece width with a reversed scalpel





Mirror Glueing: Tools

1. Table, QTY:1
2. Metal plate, QTY: 1
3. Magnifying glass, QTY: 1
4. Forcipes, QTY: 1
5. Mirror glueing jig with an inner bar coated with teflon cover, QTY: 10
6. Pressure roller, QTY: 1
7. Plastic sheet (5mm thickness), QTY: 1

Mirror Glueing: Consumables

1. Scalpel / blade QTY: 1 / 50
2. Q-Tips, QTY: 250
3. Mirror Foil 3M (5mm height), QTY: 32 m
4. Kapton tape, QTY: 100 m
5. Double-sided adhesive tape, QTY: 10 m
6. Epotek 301, QTY: 0.5 kg

Mirror Glueing

Process/Step	Time	FTE
1. Place fibre mat and tools on a table	2 min	1
2. Cleaning of fibre surface	1 min	1
3. Glue double-sided adhesive tape to metal plate with respect to fibre mat width plus overlength	2 min	1
4. Remove protective cover of double-sided adhesive tape	1 min	1
5. Glue two strips of Kapton tape on double-sided adhesive tape.The second strip is partial overlapping the first strip	3 min	1
6. Glue mirror foil to second (upper) Kapton tape, position fibre mat over mirror	1 min	1
7. Remove protective cover of mirror	1 min	1
8. Prepare epoxy glue epotek 301 and apply it to mirror using a soft brush or a Q-tip	7 min	1

Mirror Glueing

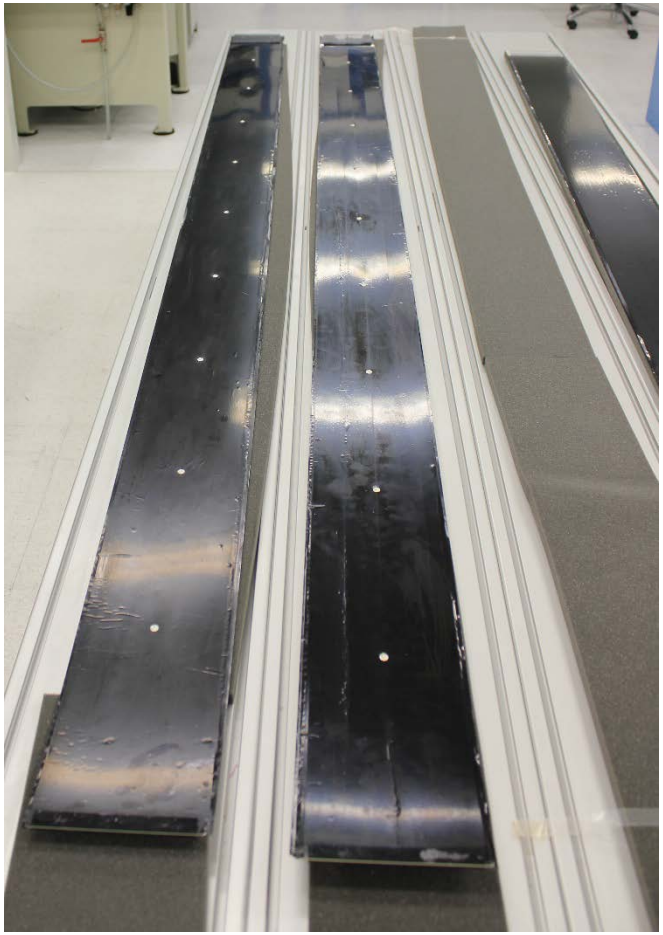
Process/Step	Time	FTE
9. Cut Kapton tape to a length corresponding to width of fibre mat and loose tape from metal plate	1 min	1
10. Fold Kapton tapes with mirror around the fibre mat. Glue lower and upper parts of Kapton tape to mirror endpiece	1 min	1
11. Remove lower part of Kapton tape from endpiece	1 min	1
12. Mount mirror glueing jig to mirror endpiece of fibre mat	1 min	1
13. Fix jig by clicking bushings into holes of mirror endpiece	2 min	1
14. Screw inner bar of jig against glued Kapton foil and mirror.	1 min	1
15. Curing time minimum 12h	12 h	0
16. After curing remove glueing jig	3 min	1
17. Cut Kapton tape on all sides to endpiece width with a reversed scalpel	7 min	1
	Σ 35 min	**1**
	Σ 12 h	**0**

Result of Fibre Mat Production Process

Result of Fibre Mat Production Process

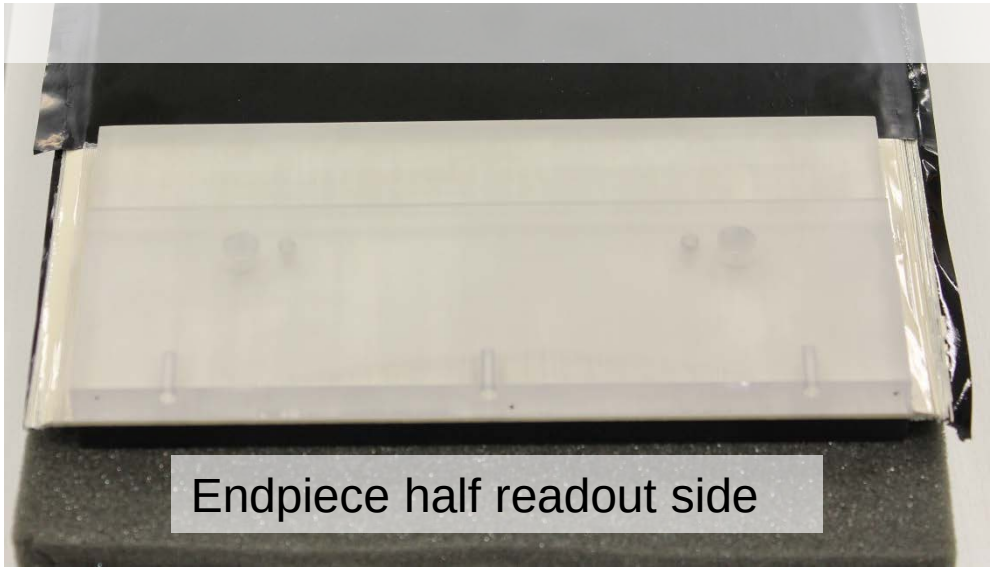
Scintillating Fibre Mat: Final Dimensions: Length: $(2424{,}0^{+0{,}1}_{-0{,}3})$ mm, Width: 140 mm

Scintillating Fibre Mat side with alignment pins.
On this side the lamination foil is below both endpiece halves (readout and mirror side)



Result of Fibre Mat Production Process

Scintillating Fibre Mat side without alignment pins.
On this side the lamination foil ends in front of readout endpiece half and runs below mirror endpiece half

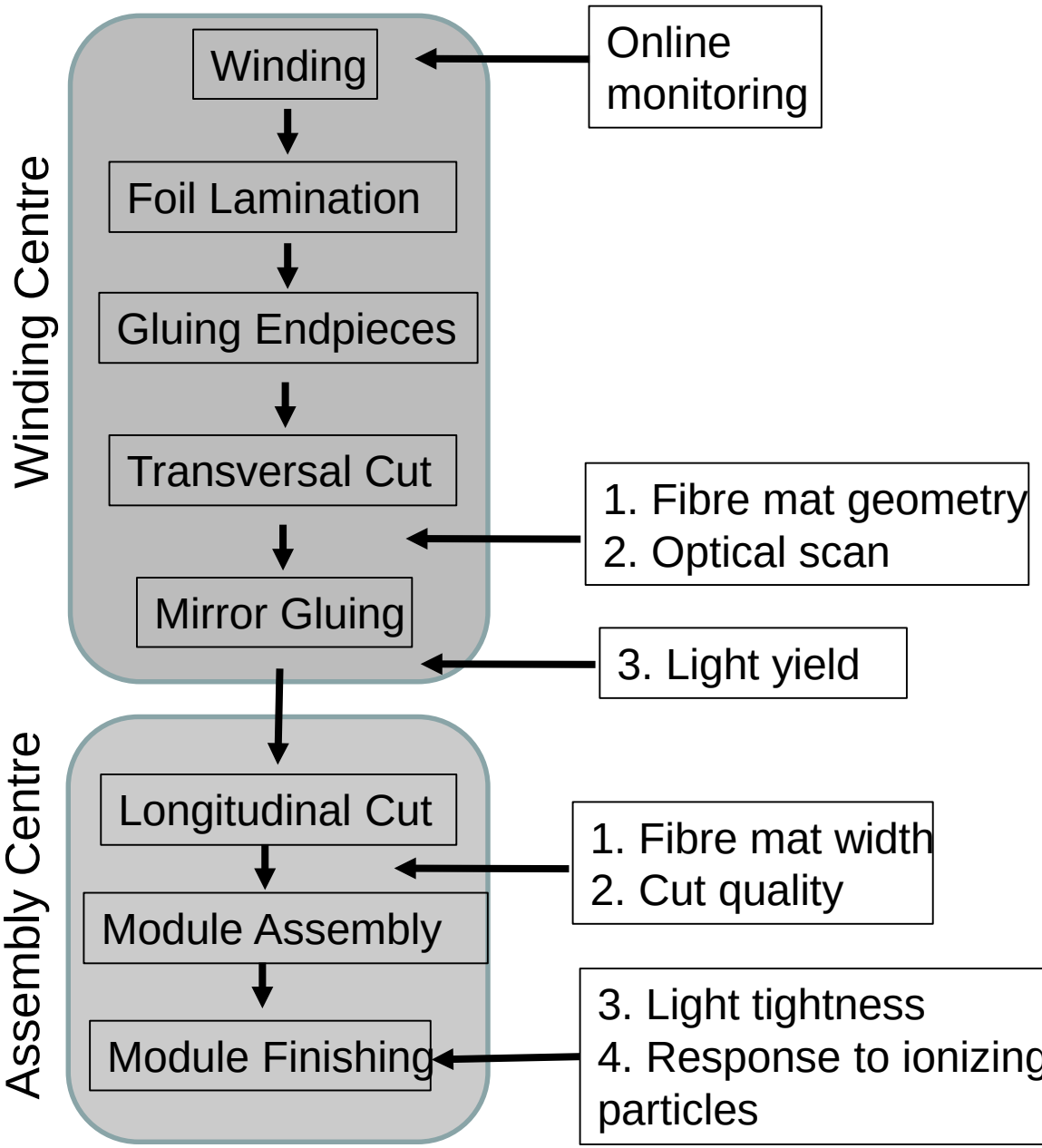


Quality Control

Quality Control

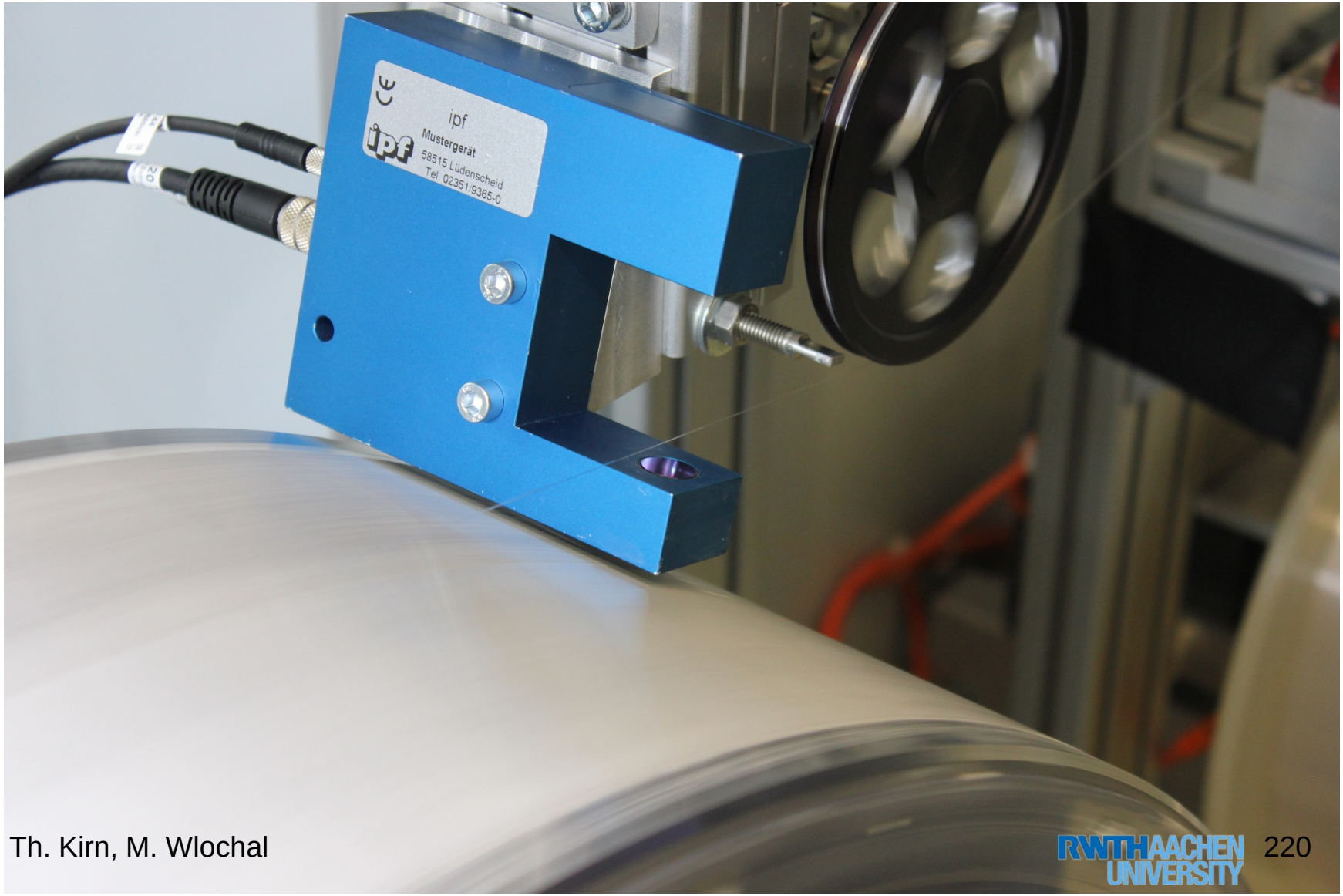
1. Principle of Fibre Mat Production and Quality Control 219
2. Online Monitoring during Winding 220
3. Optical Scan of Fibre Mat at readout and mirror side 223
4. Light Yield Measurement 231
5. Quality control of winding wheels 250

Quality Control



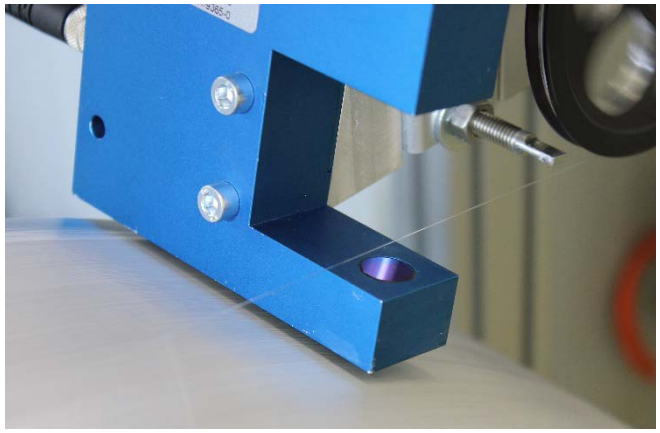
Online Monitoring during Winding

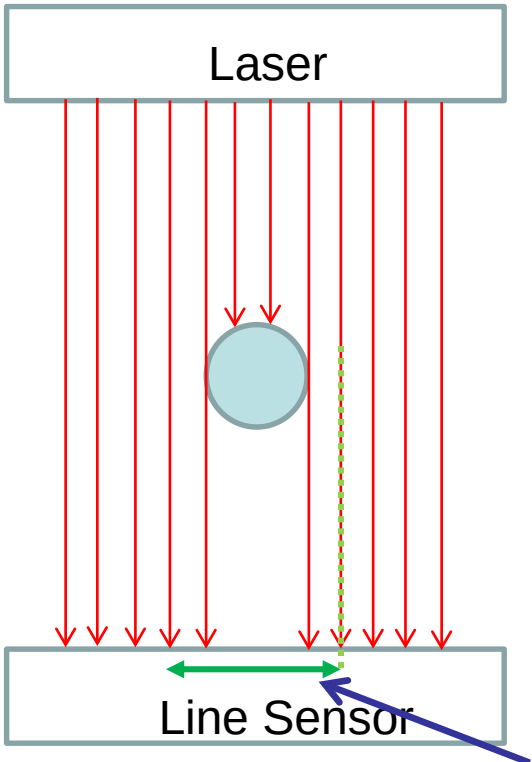
Laser Scope for error detection during winding process

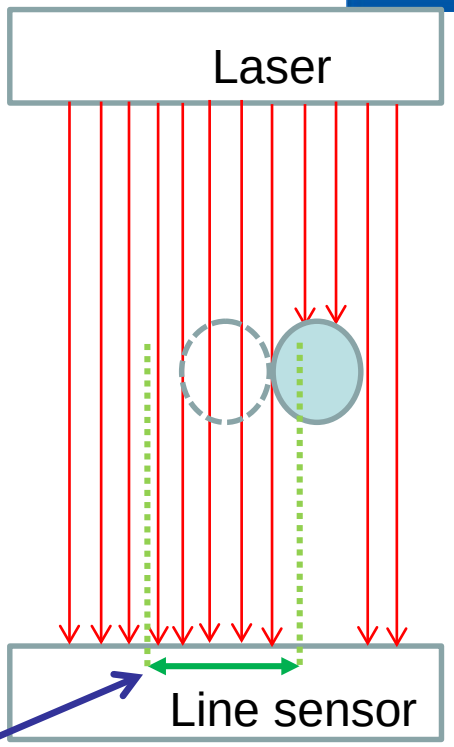


Laser Scope for online monitoring

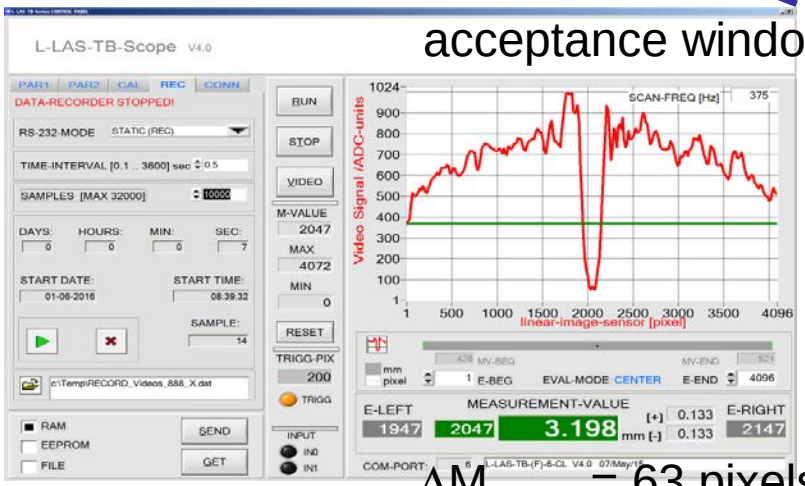
Measurement of fibre shadow position

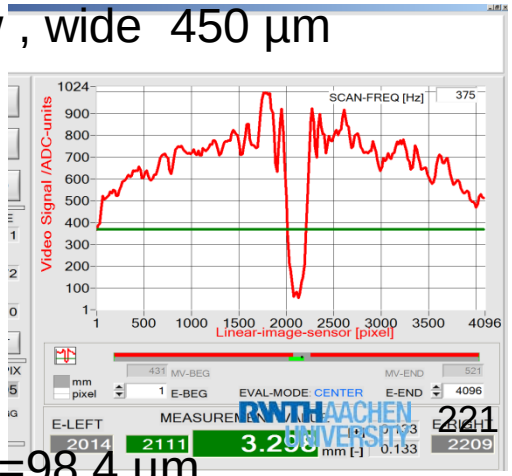






acceptance window , wide 450 µm

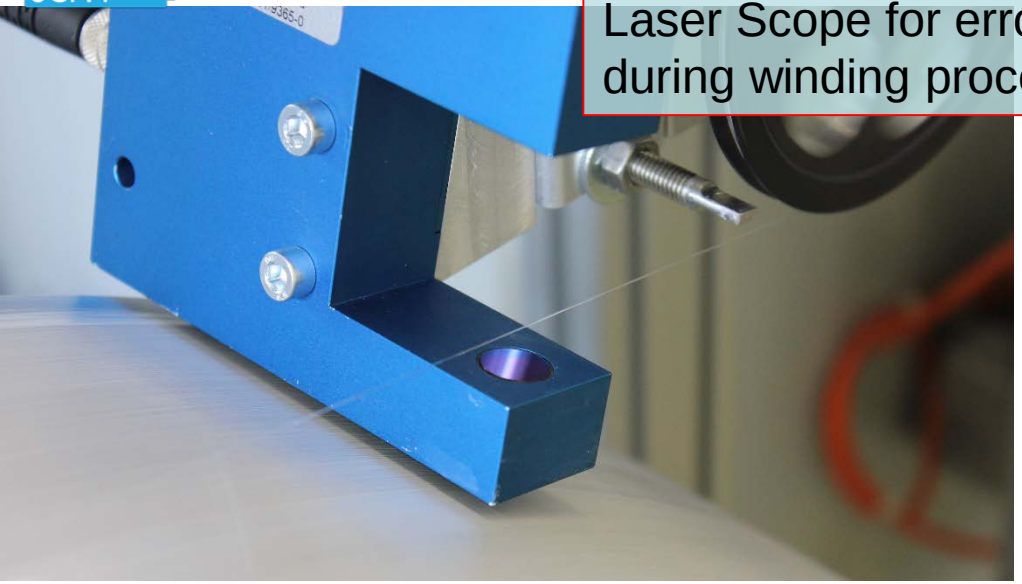


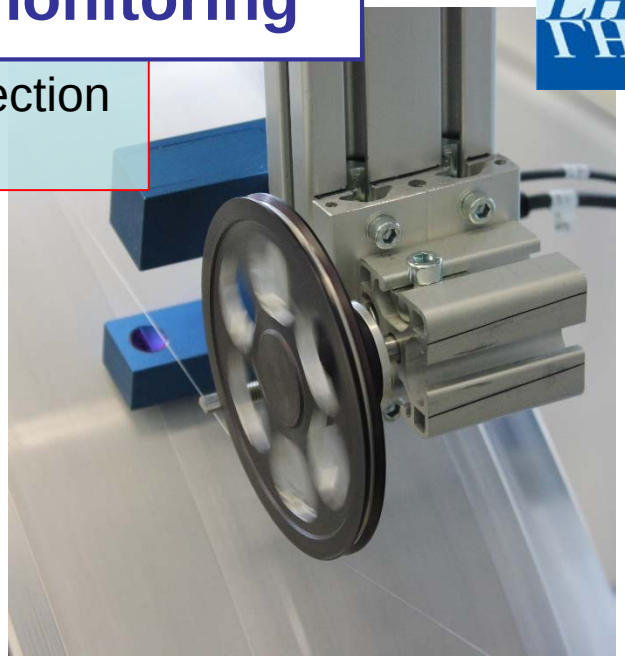


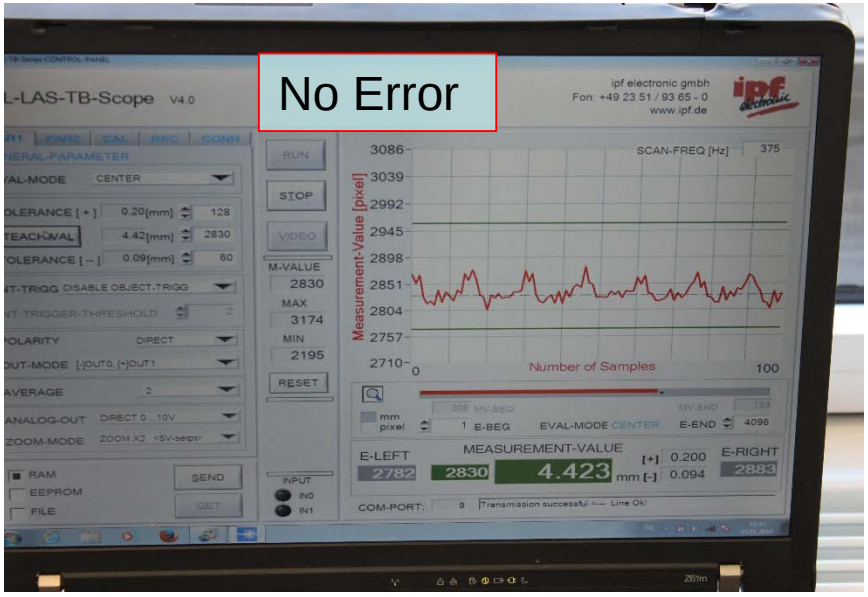
ΔM_{value} = 63 pixels =98.4 µm

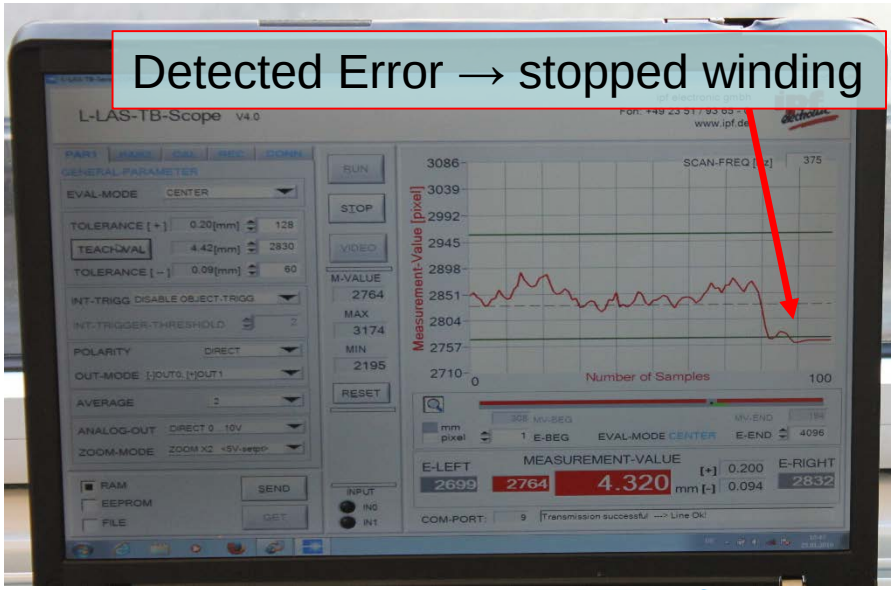
Laser Scope for online monitoring

Laser Scope for error detection during winding process



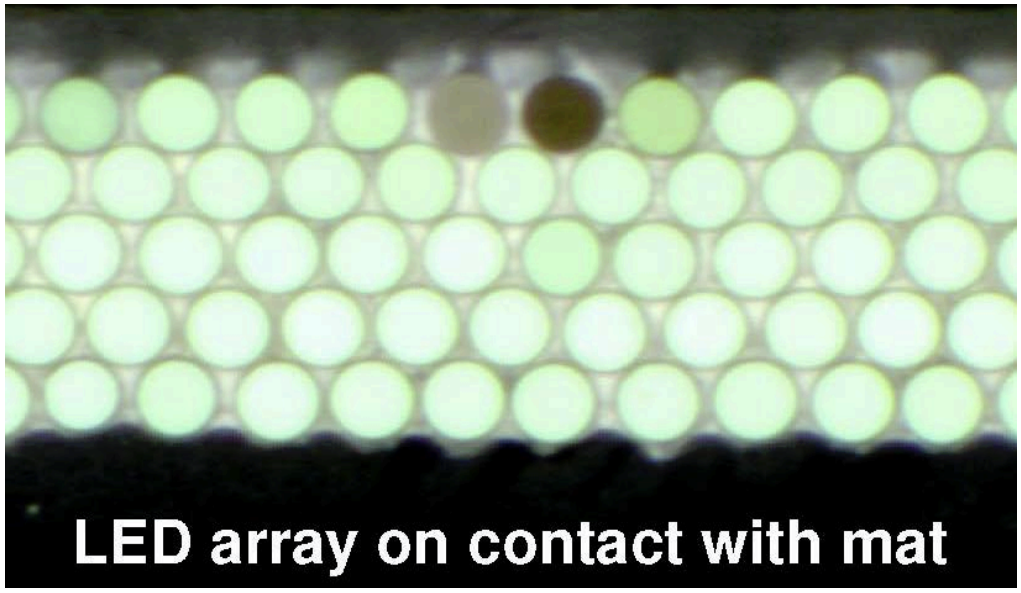






Optical Scan of fibre mat at readout and mirror side

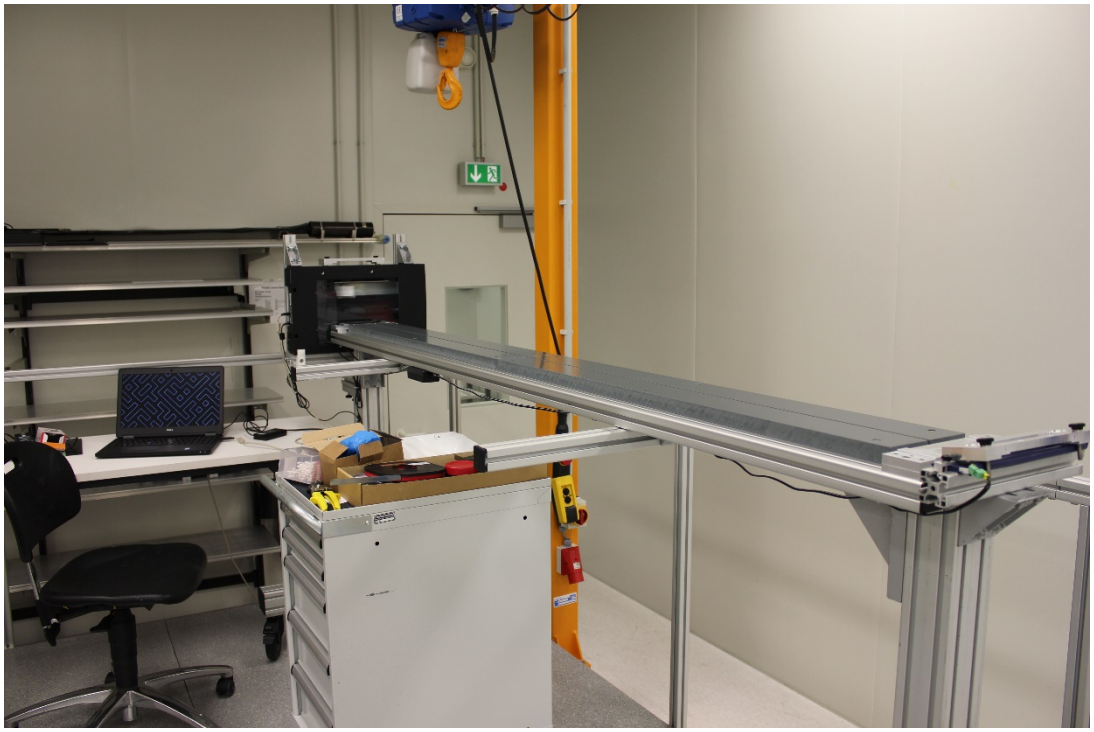
- The fibre mat sides (readout and mirror) are scanned to check the quality of the winding pattern of the fibre mat by using a commercial scanner in vertical scan mode.
- By scanning the mat irregularities, cracks and blind fibres can be detected.
- The mirror is glued to the mat after the optical scan.

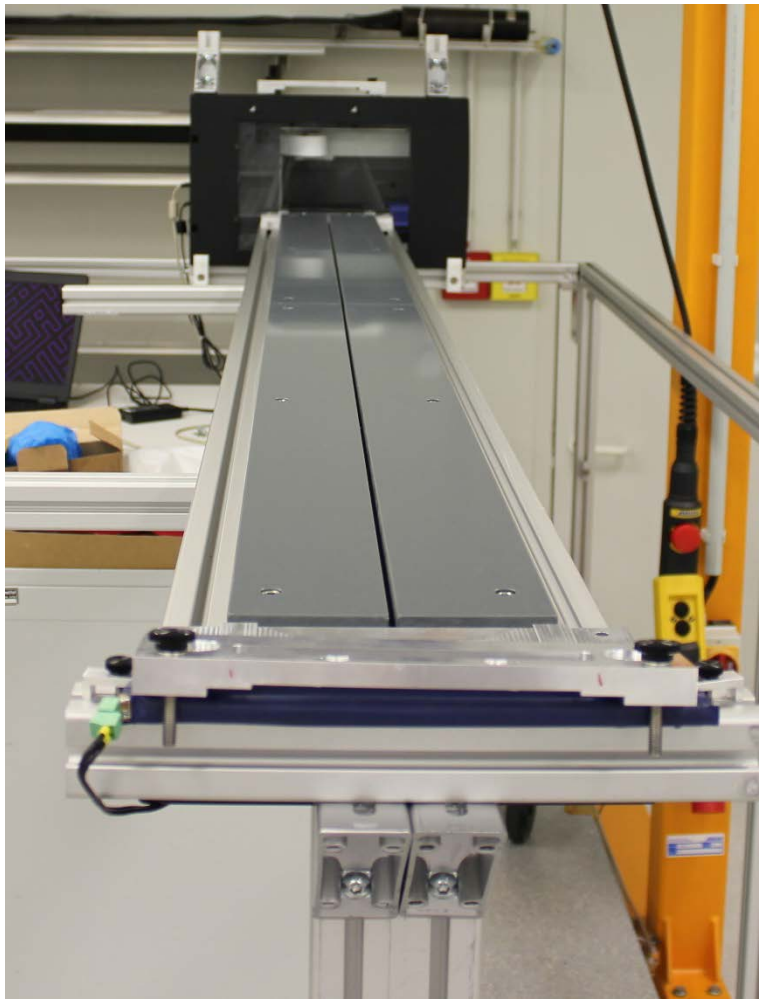


Optical Scan - setup

Setup consists of

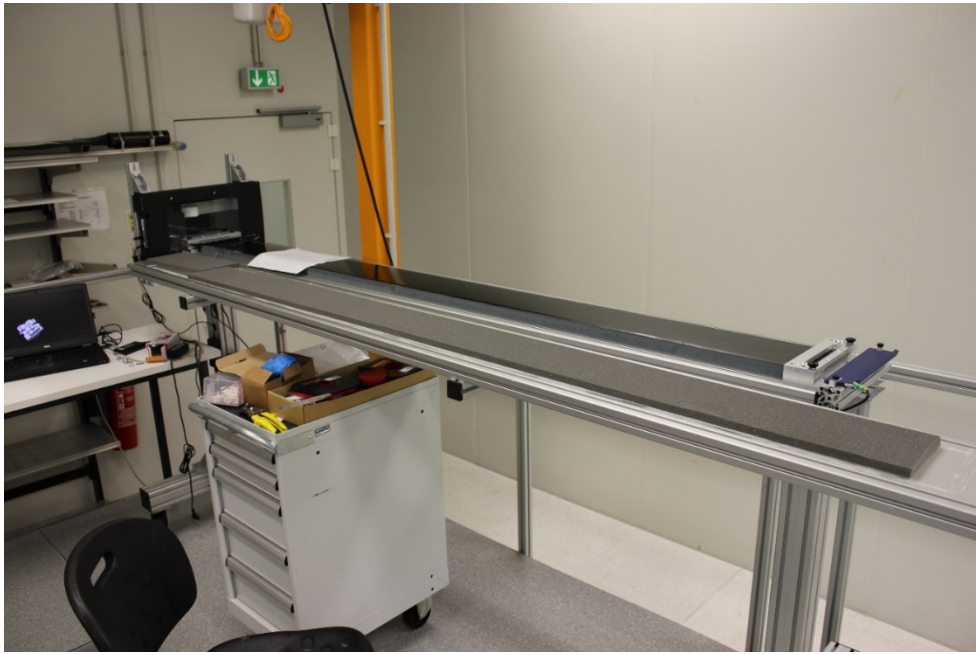
- multipurpose jig,
- commercial scanner,
- Laptop for readout of scanner
- LED-array to illuminate fibre mat from far end

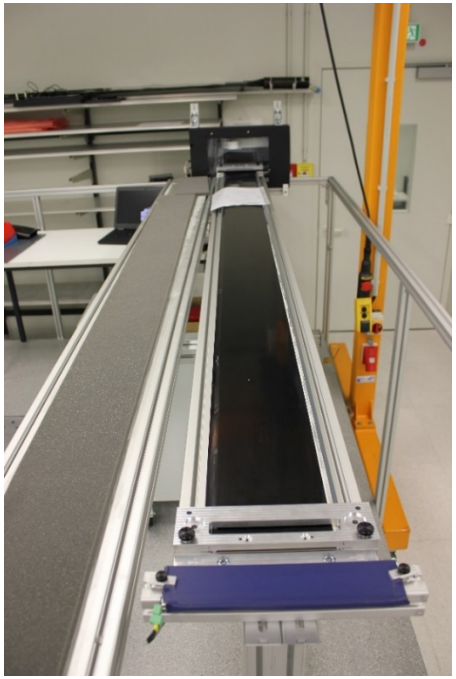




Optical Scan

1. Take fibre mat and place it on multipurpose jig of optical scanner setup
2. First fix position of mat close to scanner by screwing upper clamp against lower one.
3. Second fix position of mat at far end by screwing upper clamp against lower one
4. Move scanner towards face side of fibre mat using translation stage, stop on contact
5. Start scanning of the fibre mat face side.
6. Rotate mat after scanning, fix positions again and repeat scan of other face side
7. Start scanning of the fibre mat face side
8. Unmount fibre mat from scanner setup and place it in storage rack





Optical Scan

1. Take fibre mat and place it on multipurpose jig of optical scanner setup
2. First fix position of mat close to scanner by screwing upper clamp against lower one.
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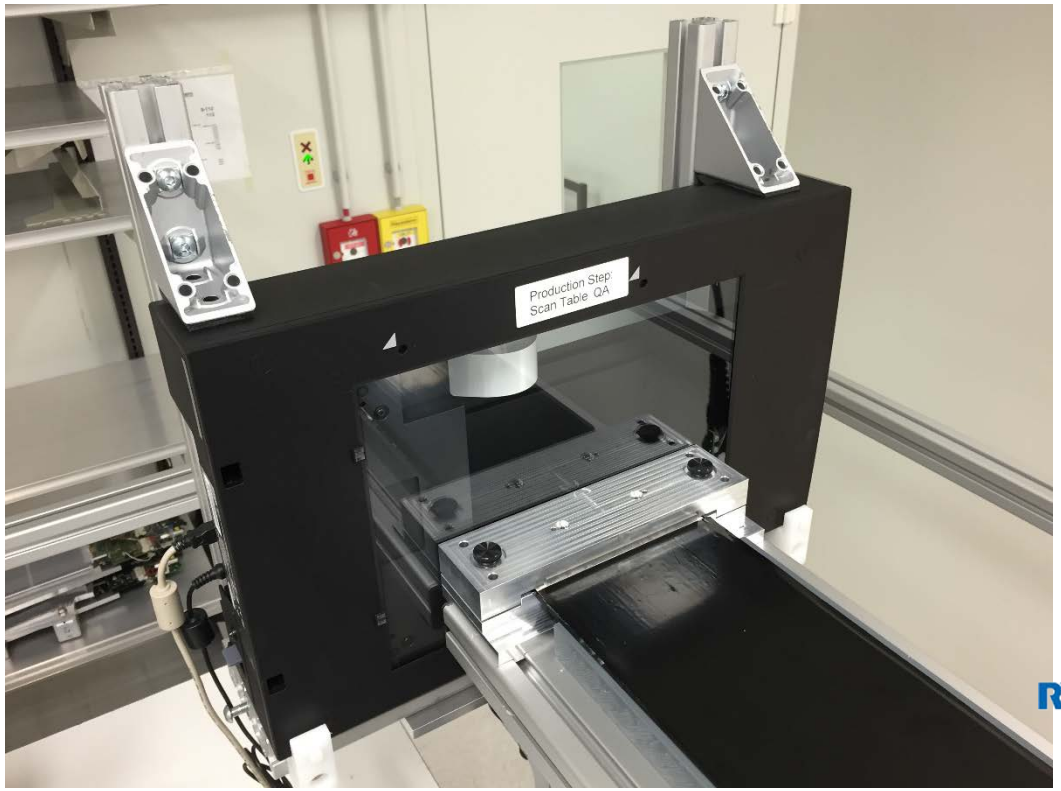
4. Move scanner towards face side of fibre mat using translation stage, stop on contact
5. Start scanning of the fibre mat face side.
6. Rotate mat after scanning, fix positions again and repeat scan of other face side
7. Start scanning of the fibre mat face side
8. Unmount fibre mat from scanner setup and place it in storage rack



Optical Scan

1. Take fibre mat and place it on multipurpose jig of optical scanner setup
2. First fix position of mat close to scanner by screwing upper clamp against lower one.
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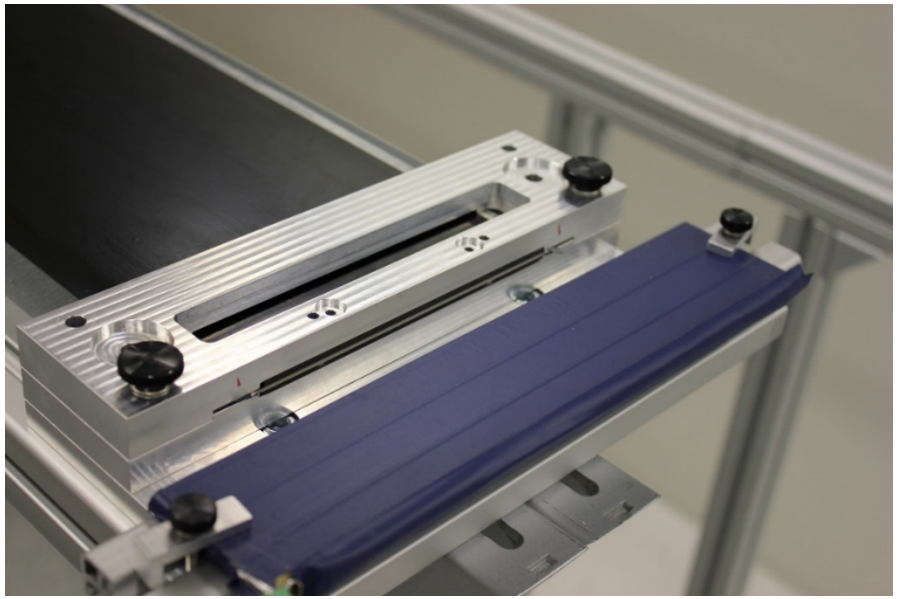
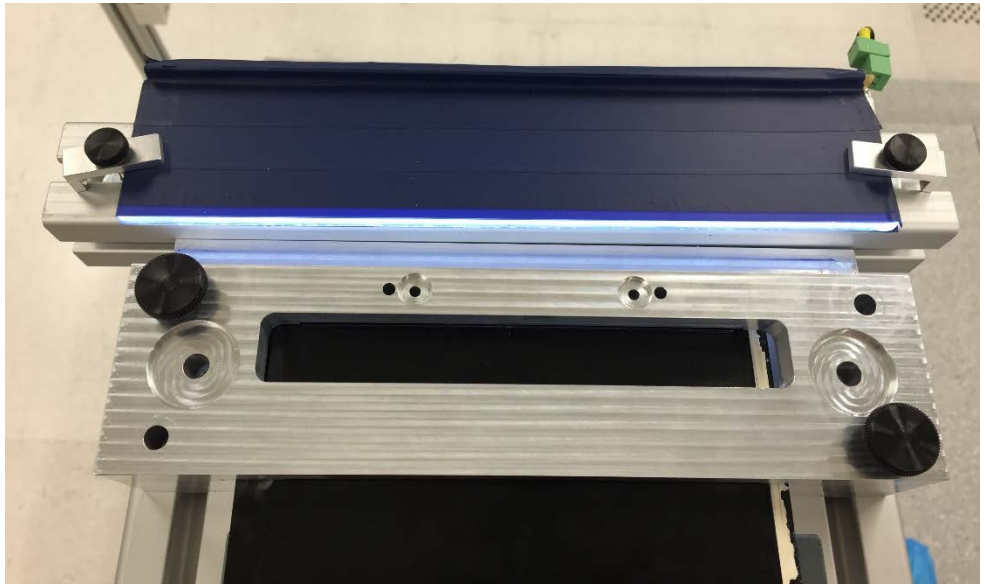
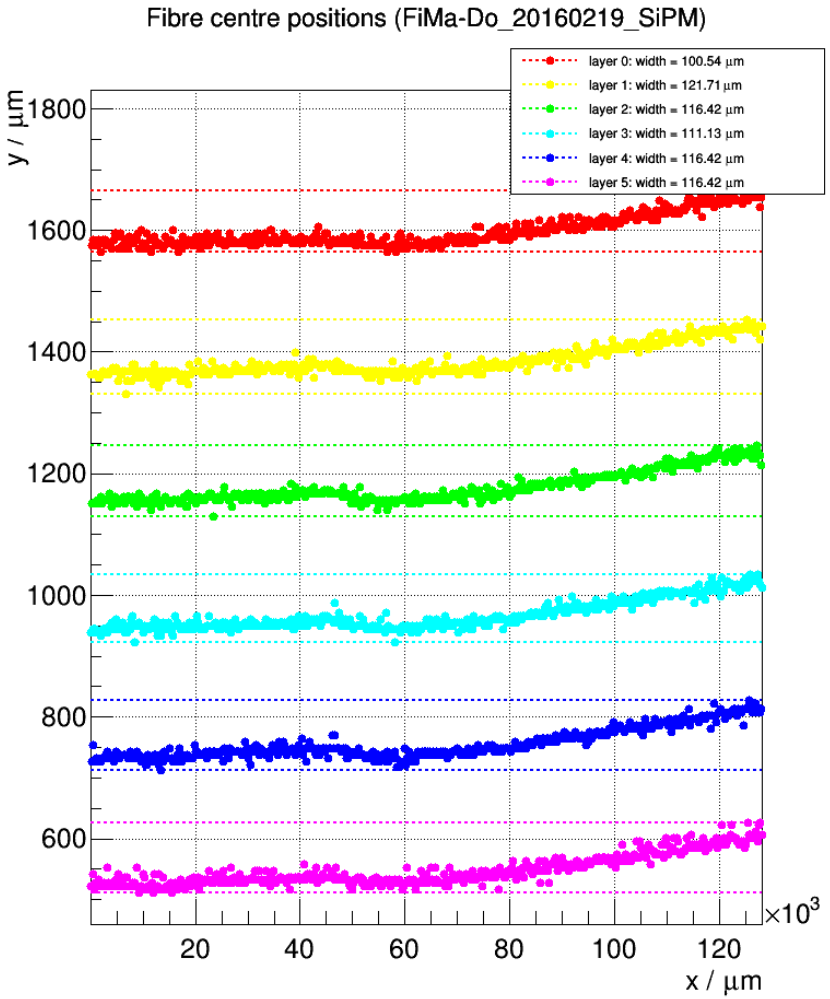
6. Rotate mat after scanning, fix positions again and repeat scan of other face side
7. Start scanning of the fibre mat face side
8. Unmount fibre mat from scanner setup and place it in storage rack

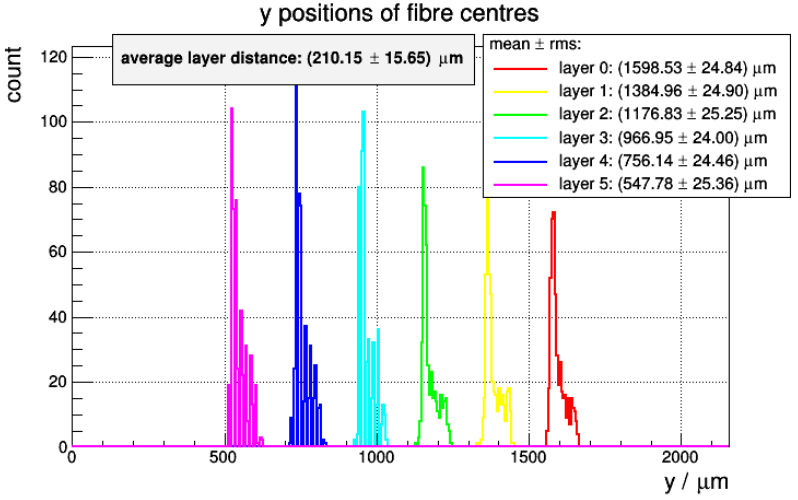


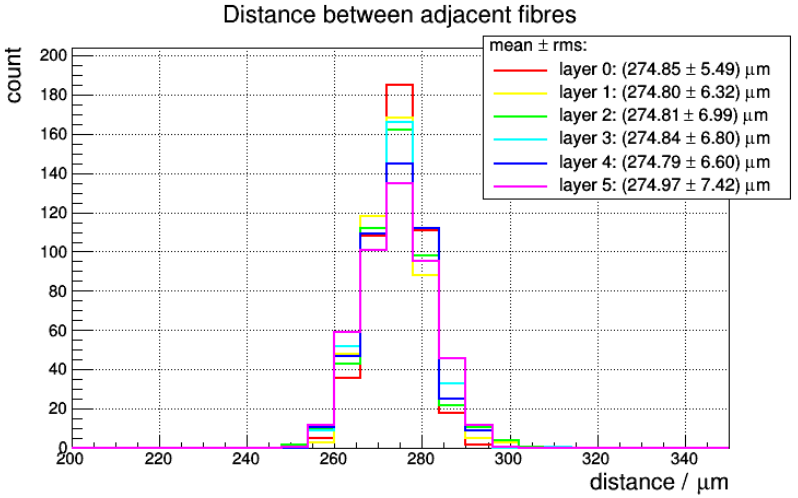


Optical Scan - Results

Scan – Results Readout Side:

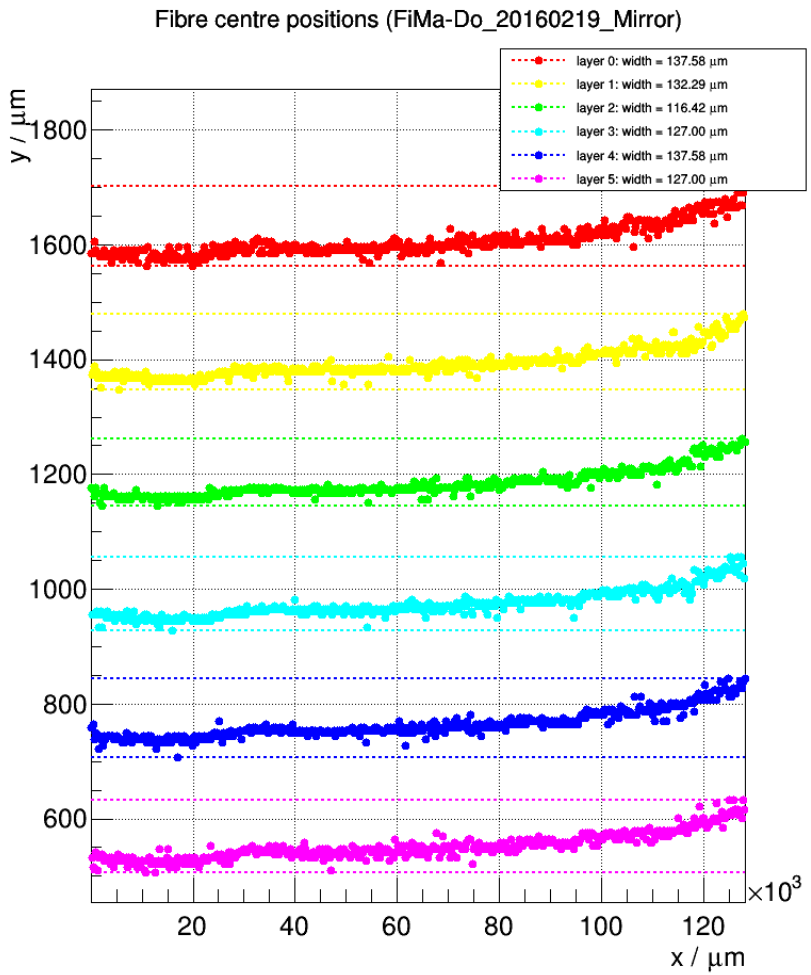


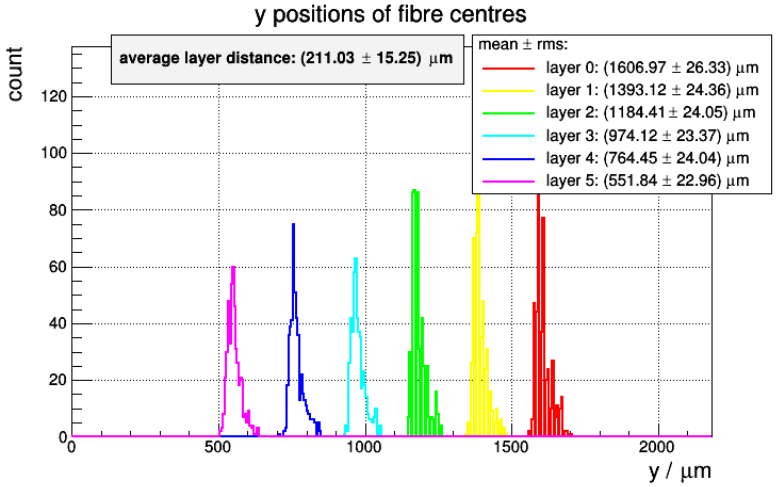


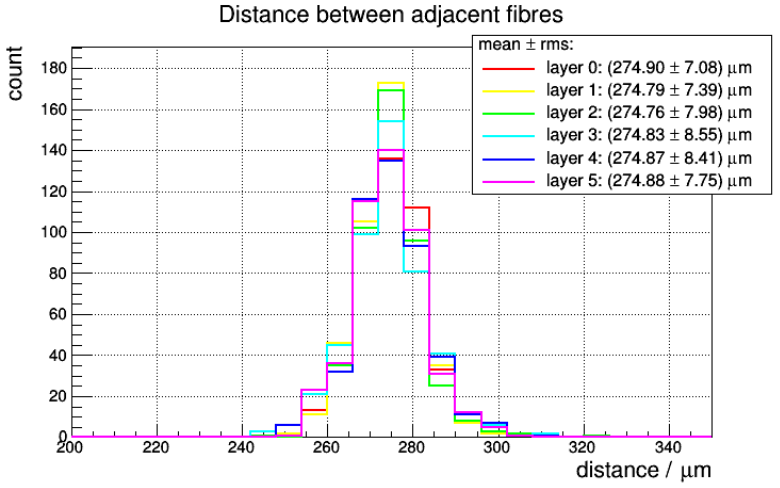


Optical Scan - Results

Scan – Results Mirror Side:







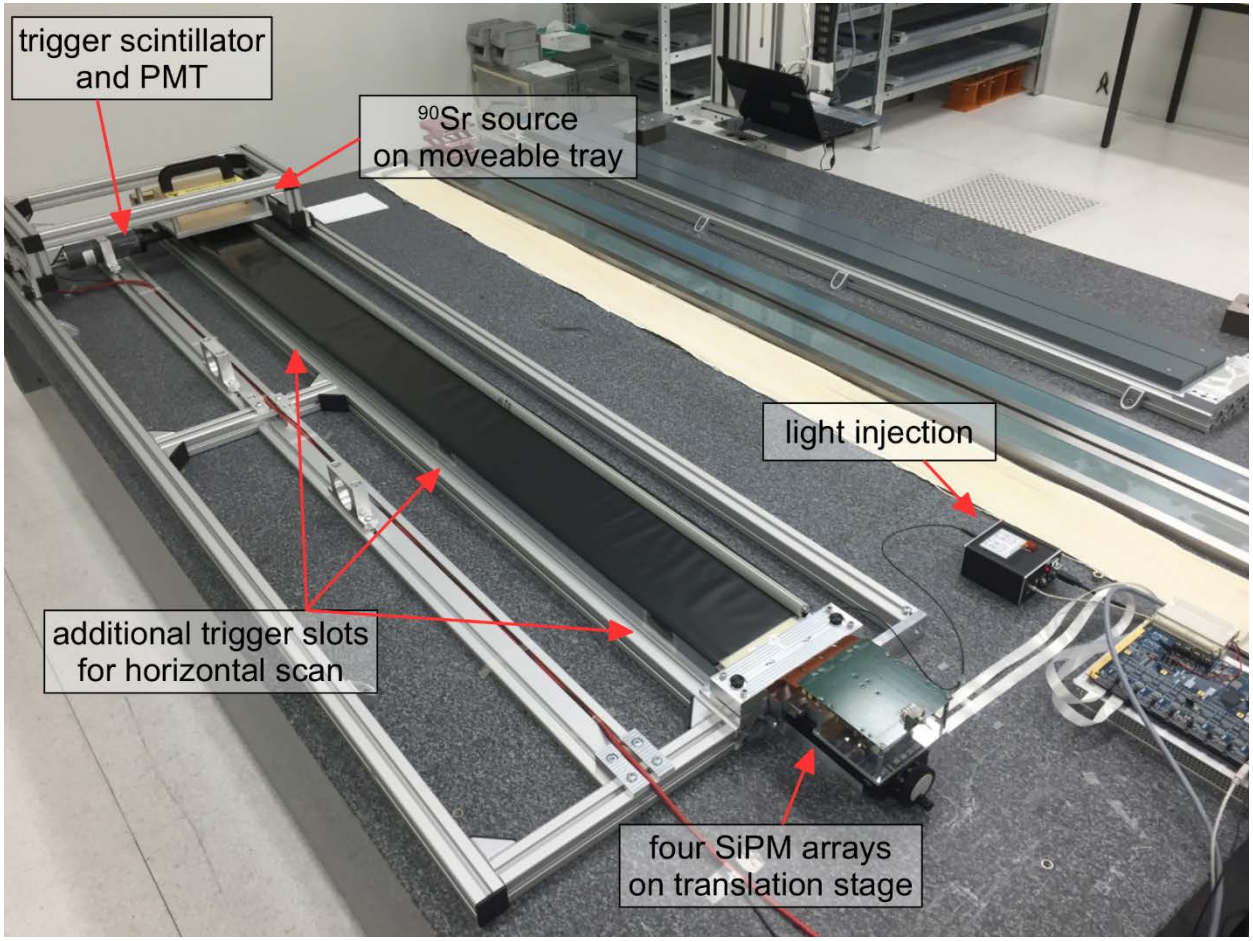
Optical Scan

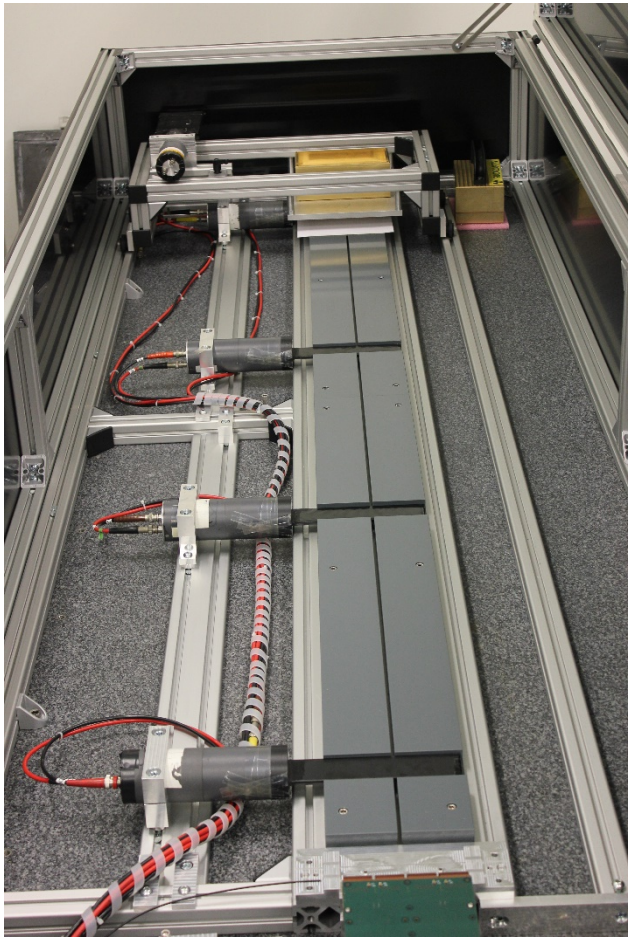
Process/Step	Time	FTE
1. Take fibre mat and place it on multipurpose jig of optical scanner setup	2 min	1
2. First fix position of mat close to scanner by screwing upper clamp against lower one	1 min	1
3. Second fix position of mat at far end by screwing upper clamp against lower one	2 min	1
4. Move scanner towards face side of fibre mat using translation stage, stop on contact	1 min	1
5. Start scanning of the fibre mat face side.	7 min	0
6. Rotate mat after scanning, fix positions again and repeat scan of other face side	5 min	1
7. Start scanning of the fibre mat face side	7 min	0
8. Unmount fibre mat from scanner setup and place it in storage rack	2 min	1
	Σ 13 min	**1**
	Σ 14 h	**0**

Light Yield Measurement – Sr^{90} - setup

- The scintillation fibre mats are excited by electrons from a radioactive Sr^{90} – source (endpoint energy of beta-spectrum is 2MeV) which are passing through the fibre mat and the trigger counters below the mat .
- The created light in the fibres is lead via total reflection to the readout end of the fibre mats. The light is detected by SiPM arrays, which are covering the full height and width of the mat.
- The signal of the SiPM-arrays are digitized by a front-end board with SPIROC-chips and a USB-board for the data acquisition.
- The full readout chain is calibrated by a light injection system similiar to the one used for the LHCb-SciFi-Modules where scratched fibres with a diameter of 1mm emit light which shines through the polycarbonate endpiece directly into the SiPM-arrays.
- The light yield is measured at the position close to the mirror for quality check, because this position is the most critical one in the LHCb SciFi tracker close to the beam pipe.
- The measurement of the light yield at three other positions along the fibre mat is possible to determine the attenuation length of the fibres .

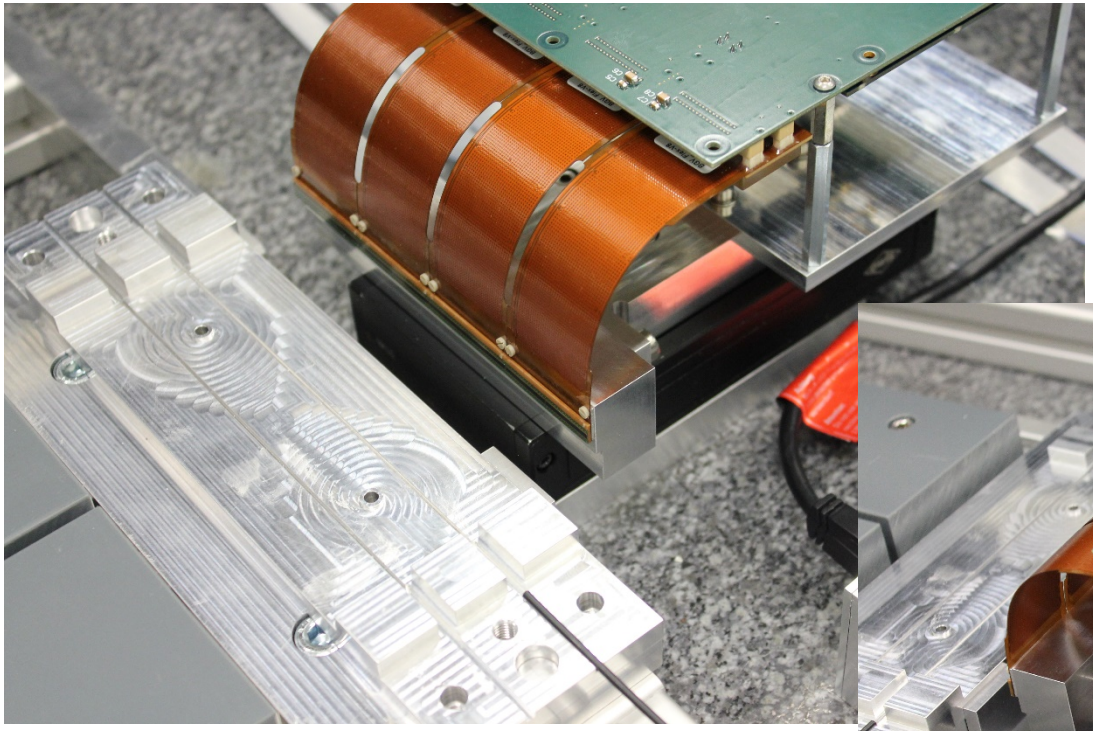
Light Yield Measurement – Sr90 setup

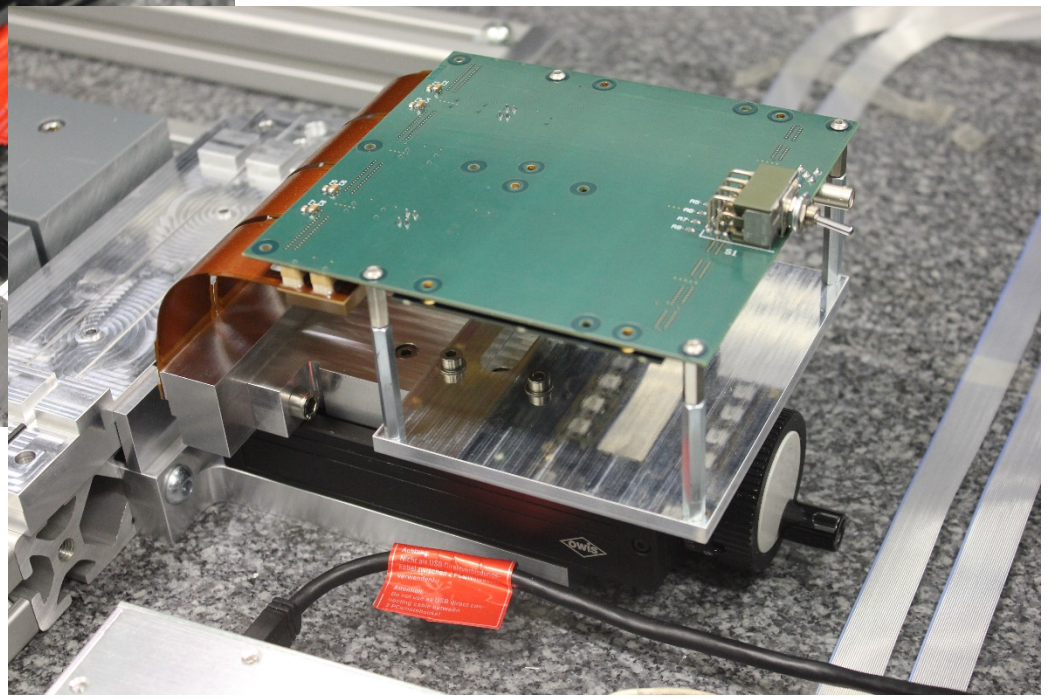




Light Yield Measurement

SiPM arrays are mounted on a translation stage and can be moved back and forth.
Between the fibre mat and the SiPM will always be a reproducible gap of 100 µm.





Light Yield Measurement

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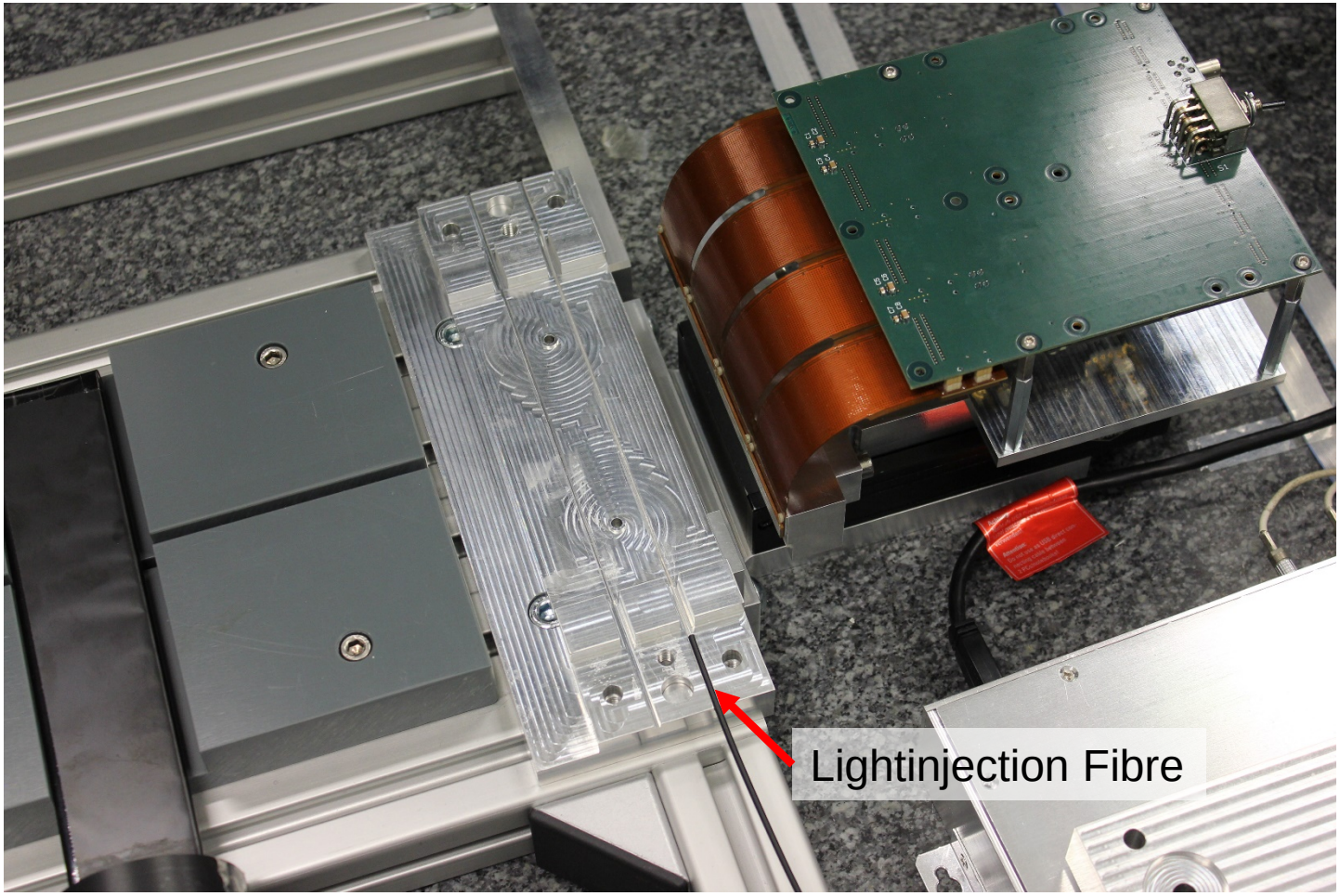
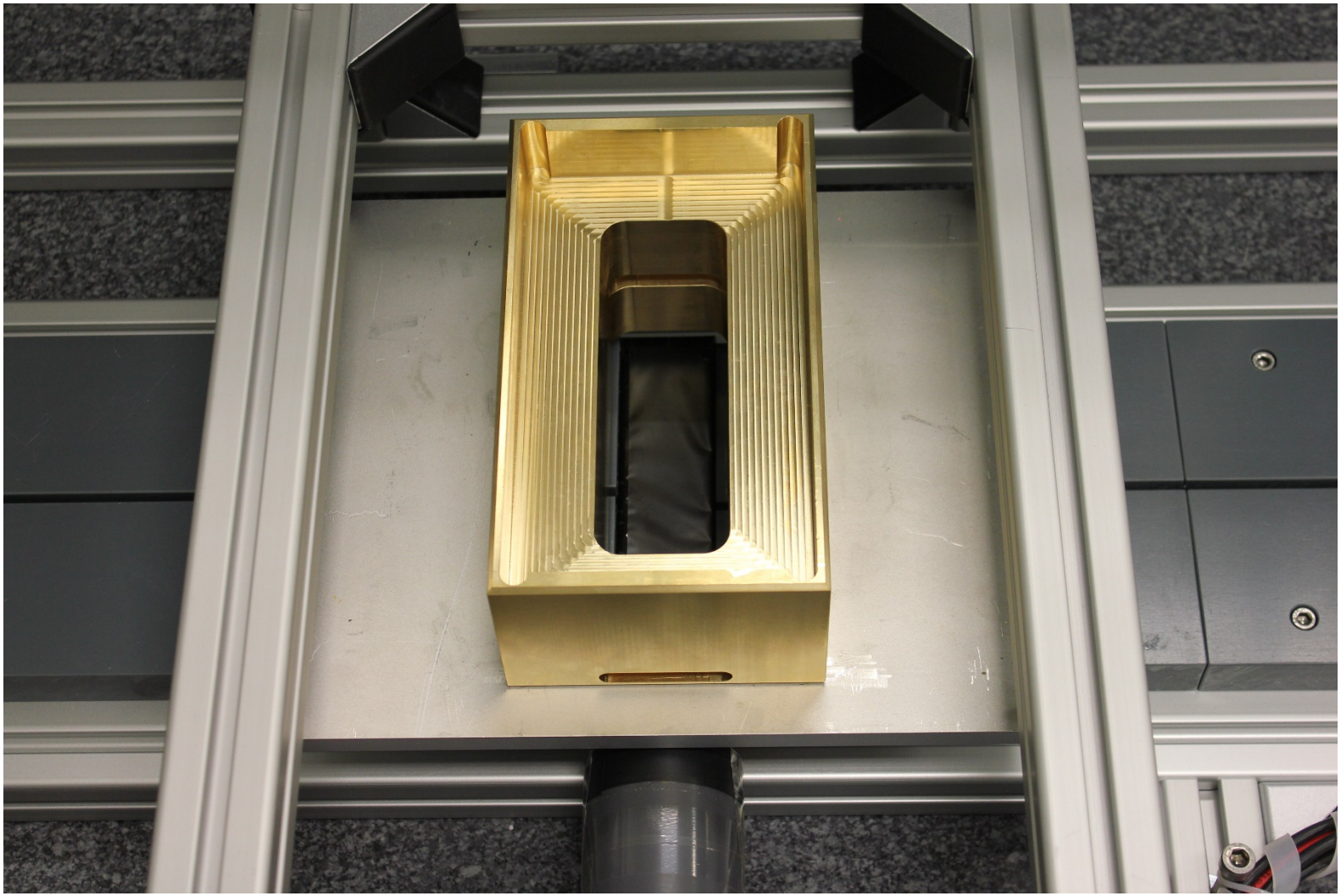
Between the fibre mat and the SiPM will always be a reproducible gap of 100 µm.



Light Yield Measurement

Moveable tray in which the Sr90-source can be placed.



Light Yield Measurement

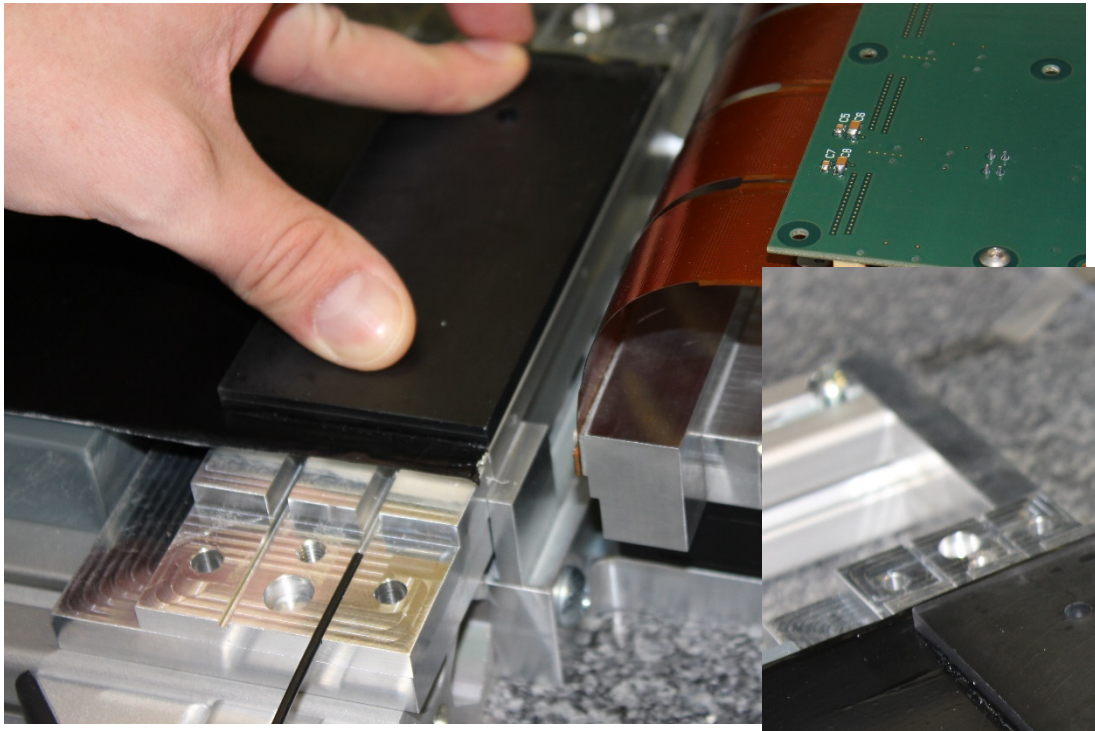
1. Take fibre mat and place it on multipurpose jig of Sr90-setup
2. Adjust fibre mat on readout position and fix position by screwing upper clamp to lower clamp at readout position
3. Fix position of fibre mat at mirror side by screwing upper clamp to lower clamp
4. Move SiPM array into measurement position
5. Place Sr90-source on moveable tray and move source to measurement position close to mirror side
6. Close lighttight box
7. Start measurement
8. Open lighttight box and put Place Sr90-source in lead bunker
9. Unmount fibre mat from multipurpose jig, take it out of lighttight box and put it back to storage rack

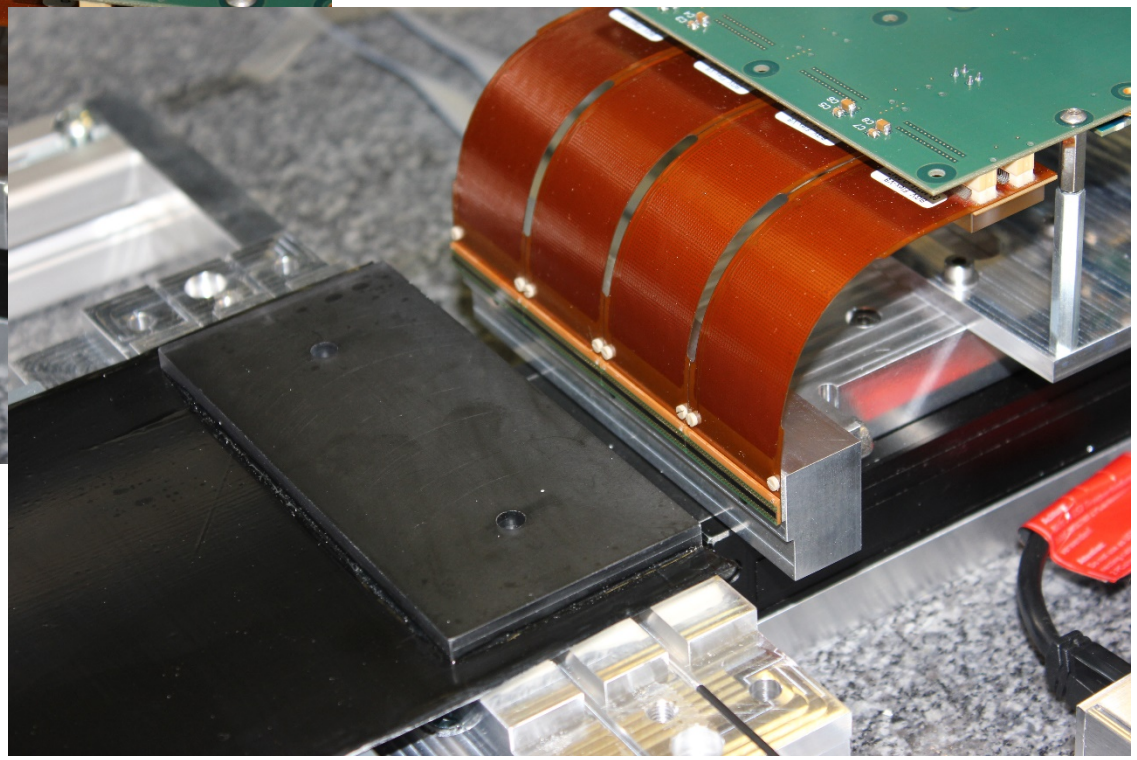
Light Yield Measurement

1. Take fibre mat and place it on multipurpose jig of Sr90-setup

Light Yield Measurement

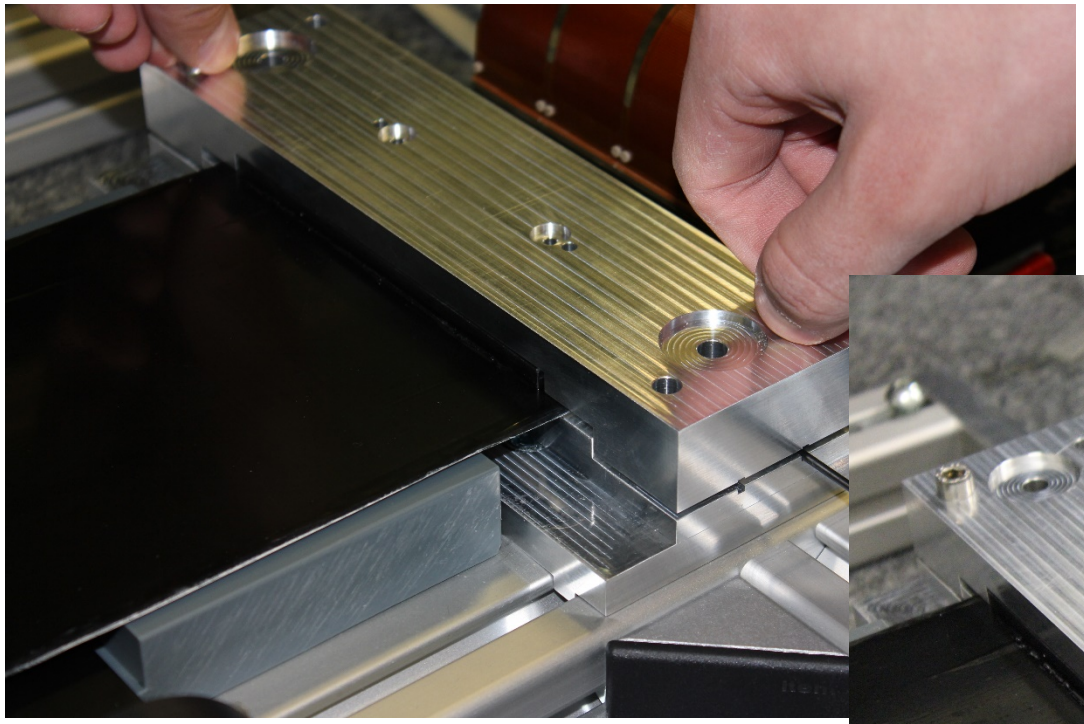
2.a Adjust fibre mat on readout position

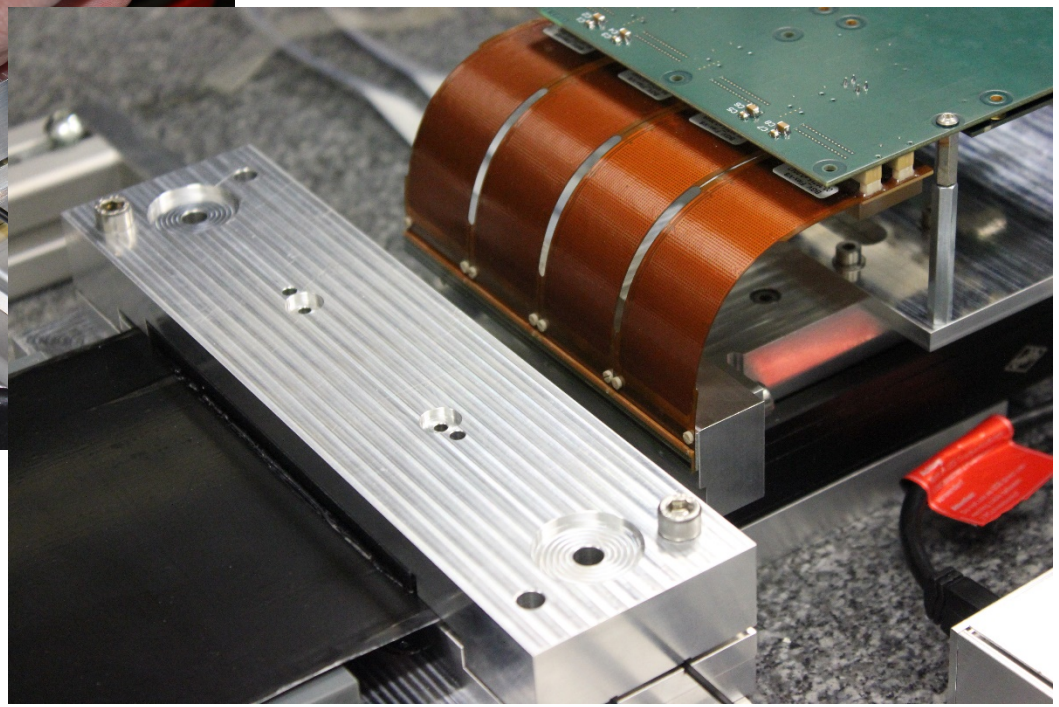




Light Yield Measurement

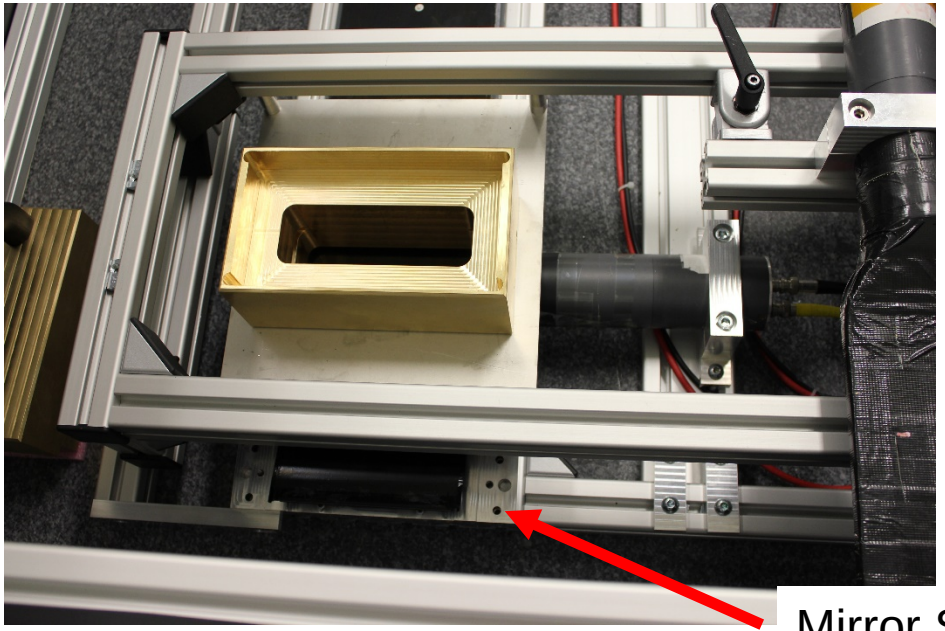
2.b Fix position by screwing upper clamp to lower clamp at readout position



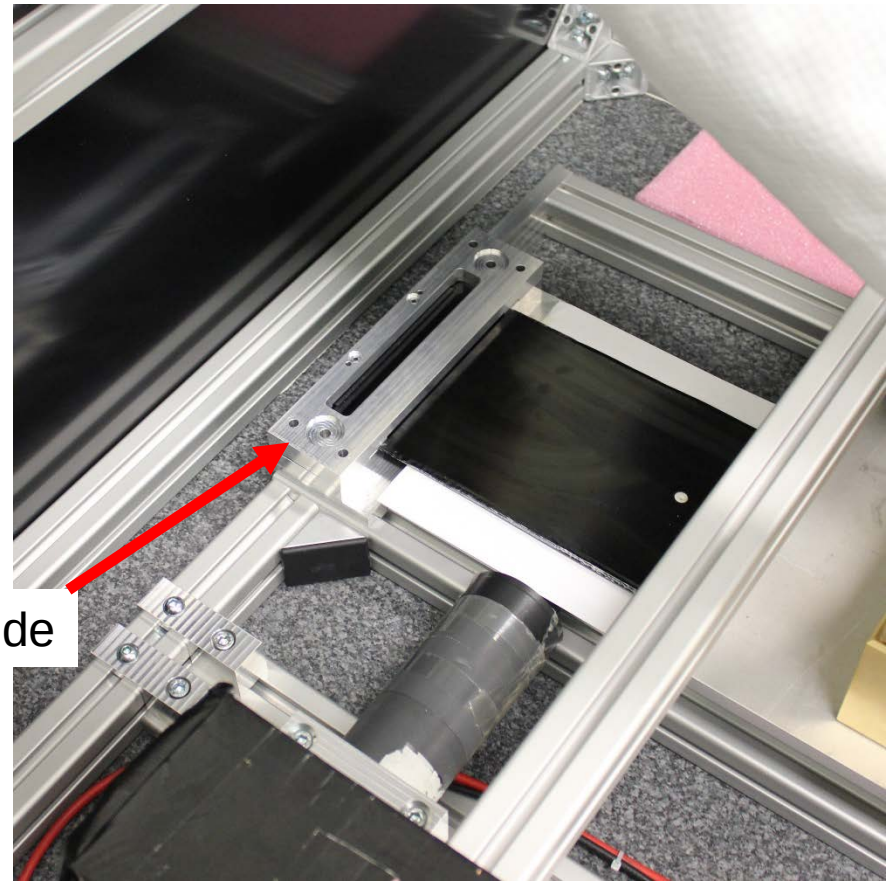


Light Yield Measurement

3. Fix position of fibre mat at mirror side by screwing upper clamp to lower clamp

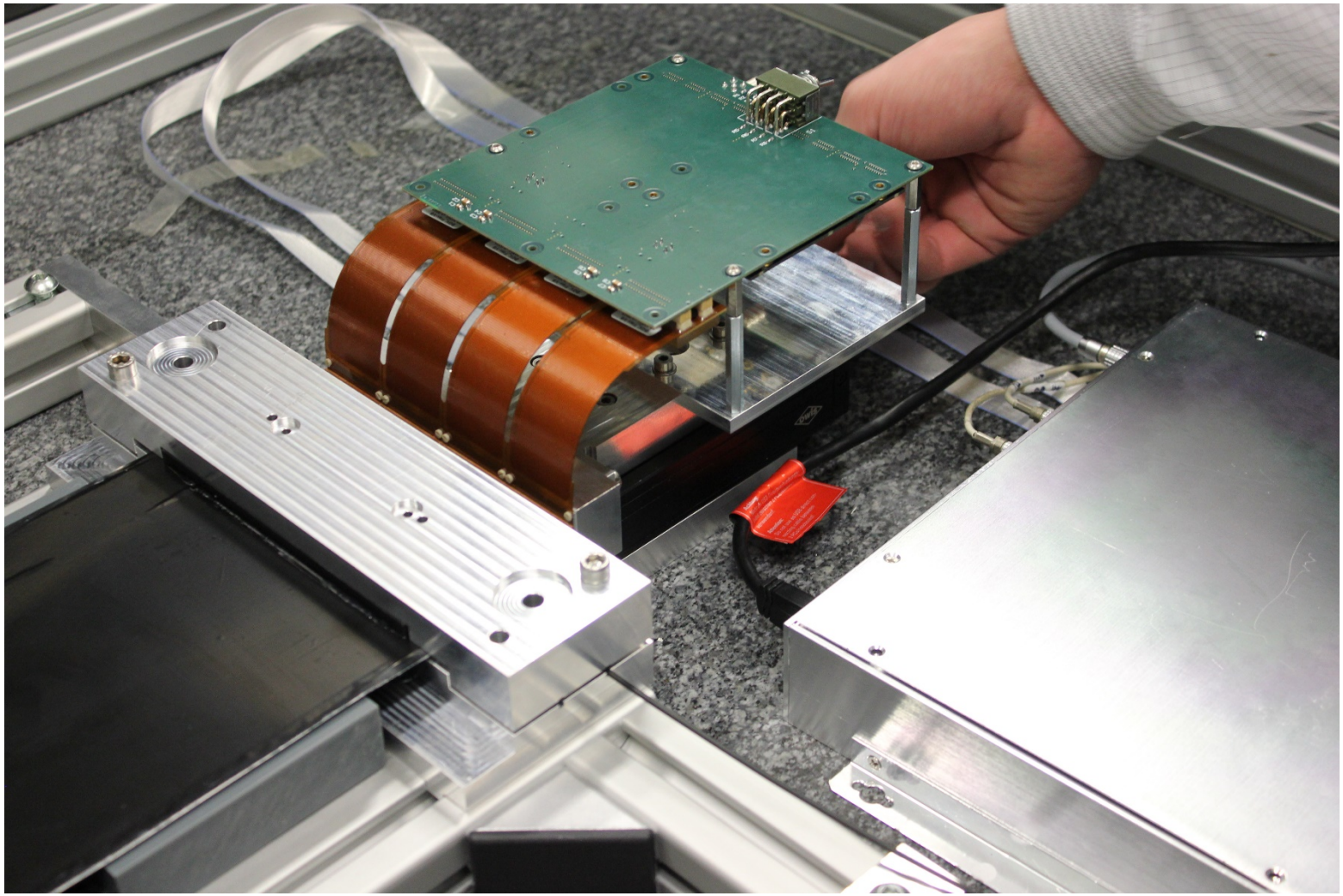


Mirror Side



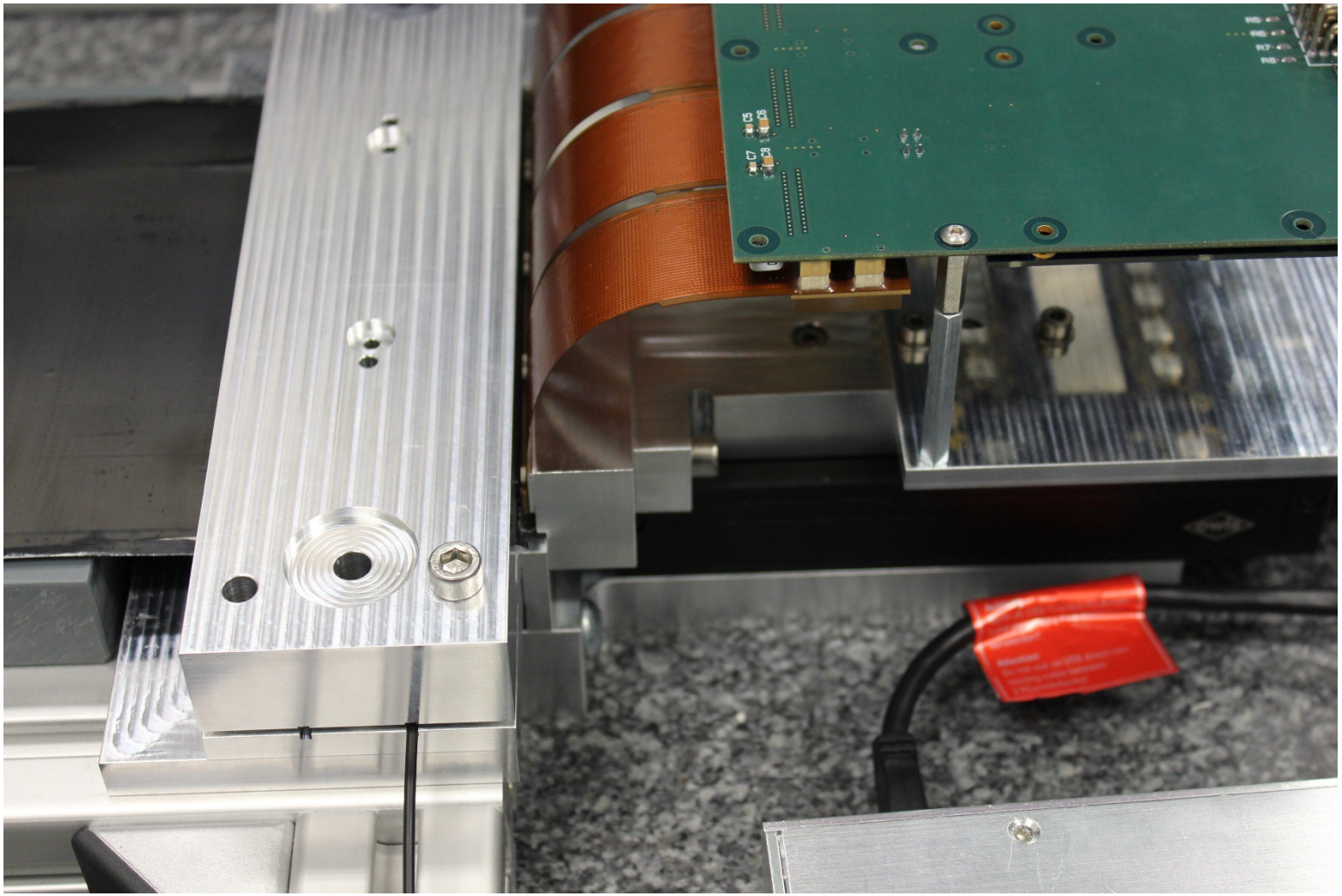
Light Yield Measurement

4. Move SiPM array into measurement position



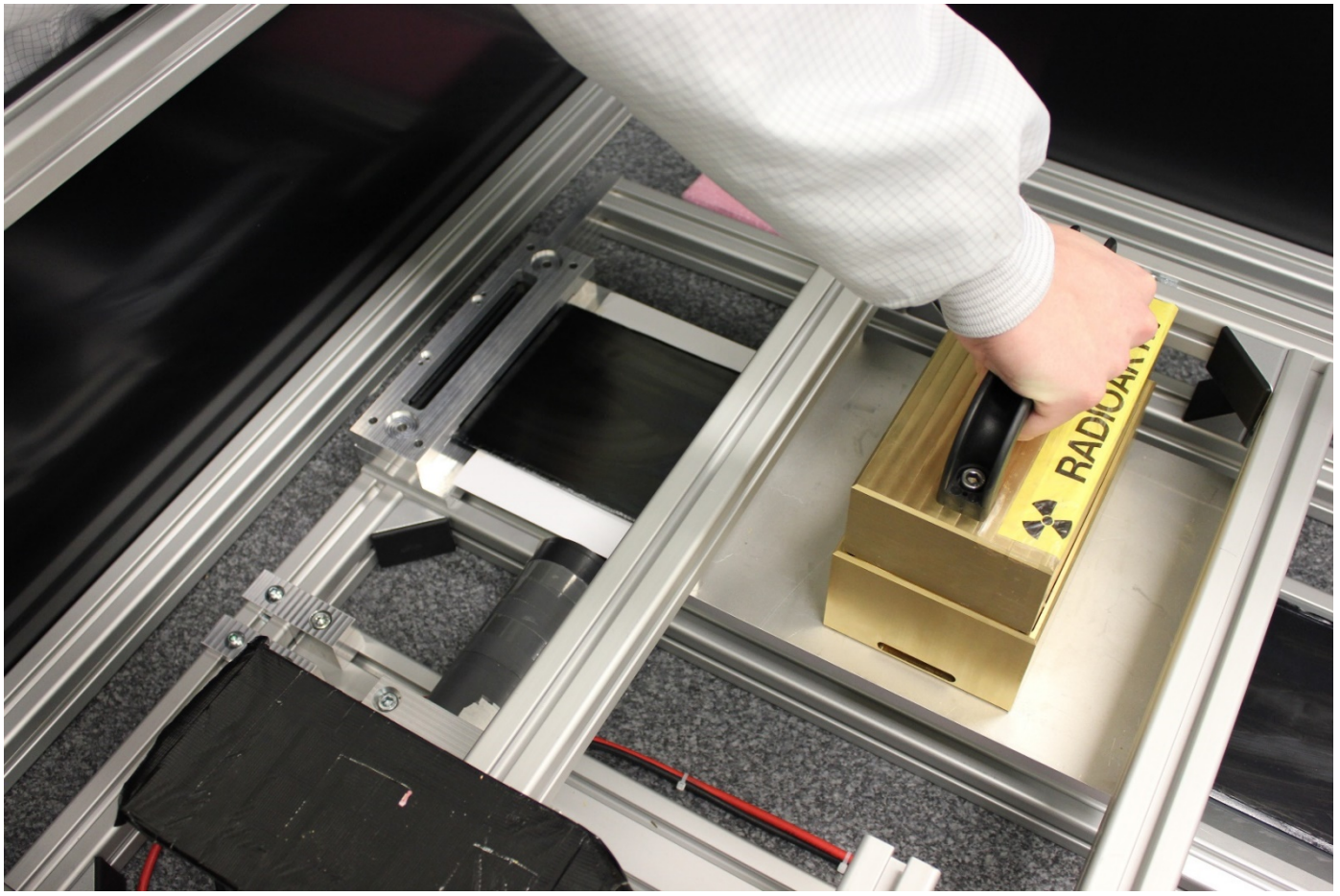
Light Yield Measurement

4. Move SiPM array into measurement position



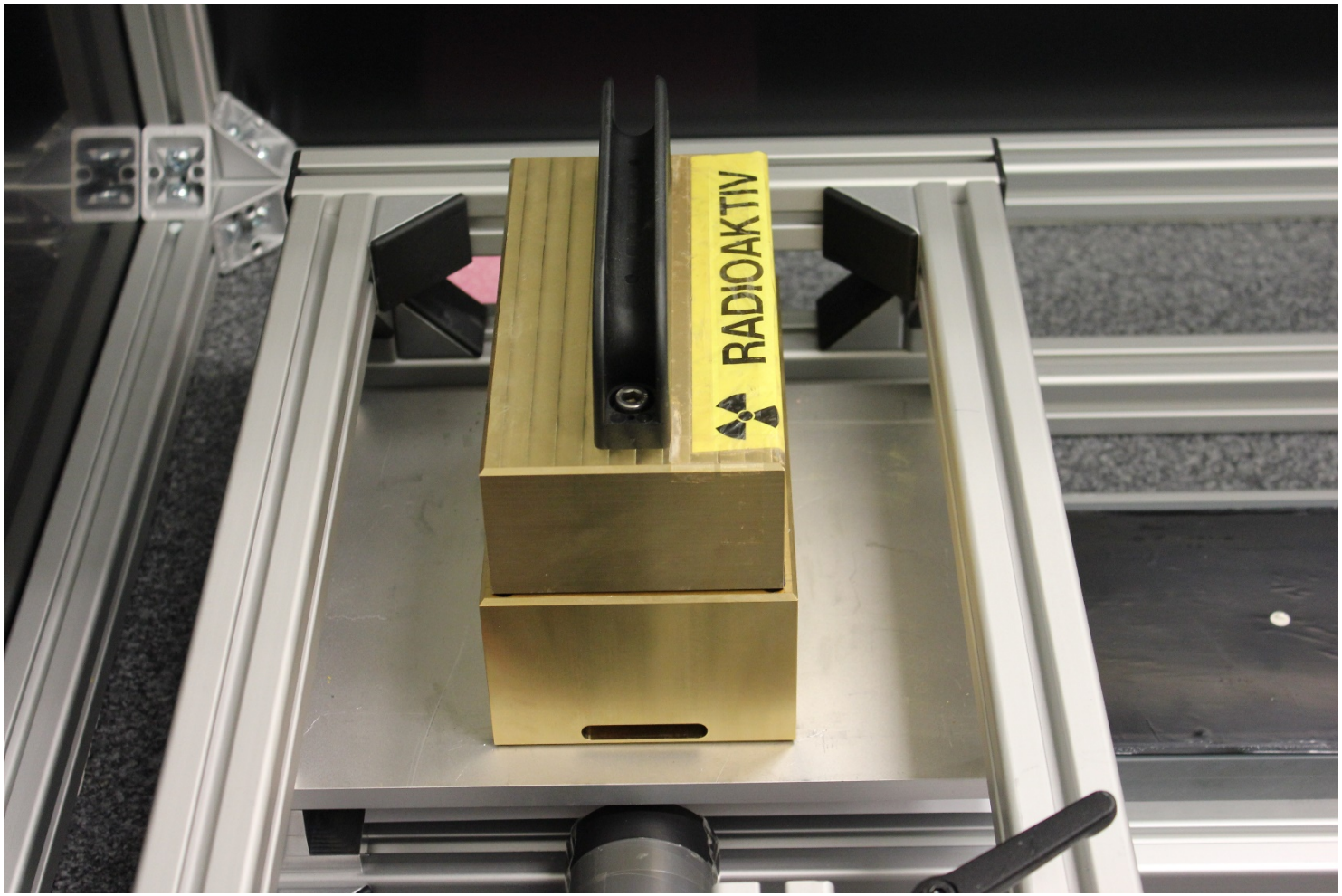
Light Yield Measurement

5. Place Sr90-source on moveable tray and move source to measurement position close to mirror side



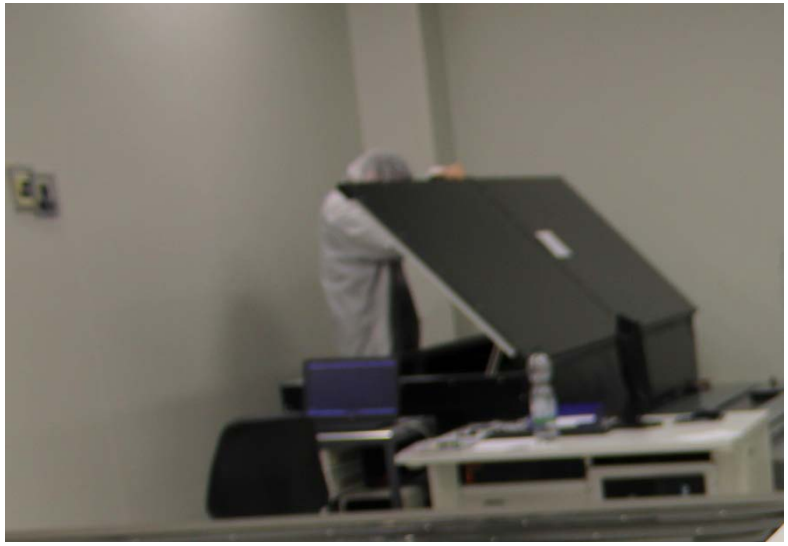
Light Yield Measurement

5. Place Sr90-source on moveable tray and move source to measurement position close to mirror side



Light Yield Measurement

6. Close lighttight box

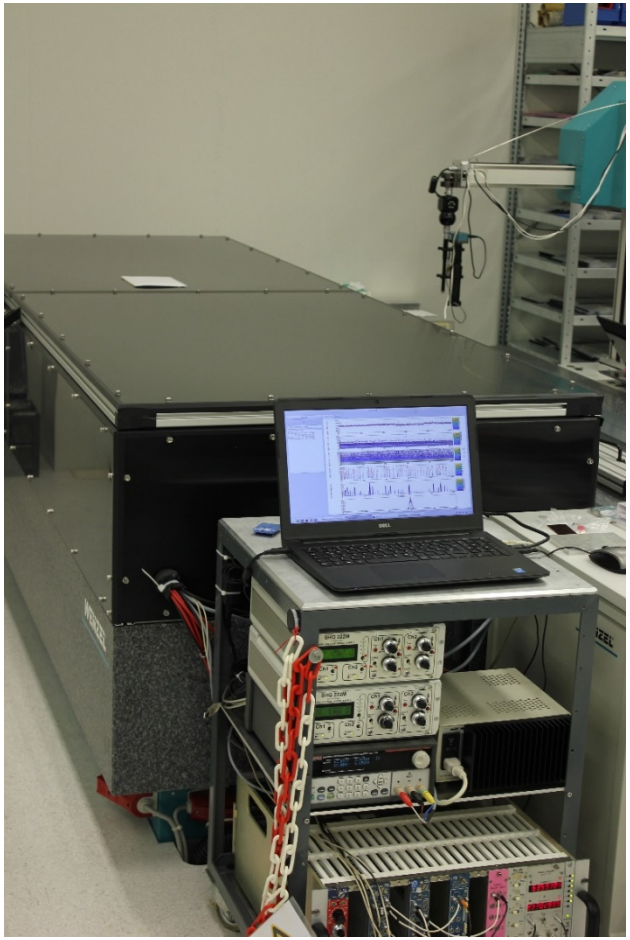


Light Yield Measurement

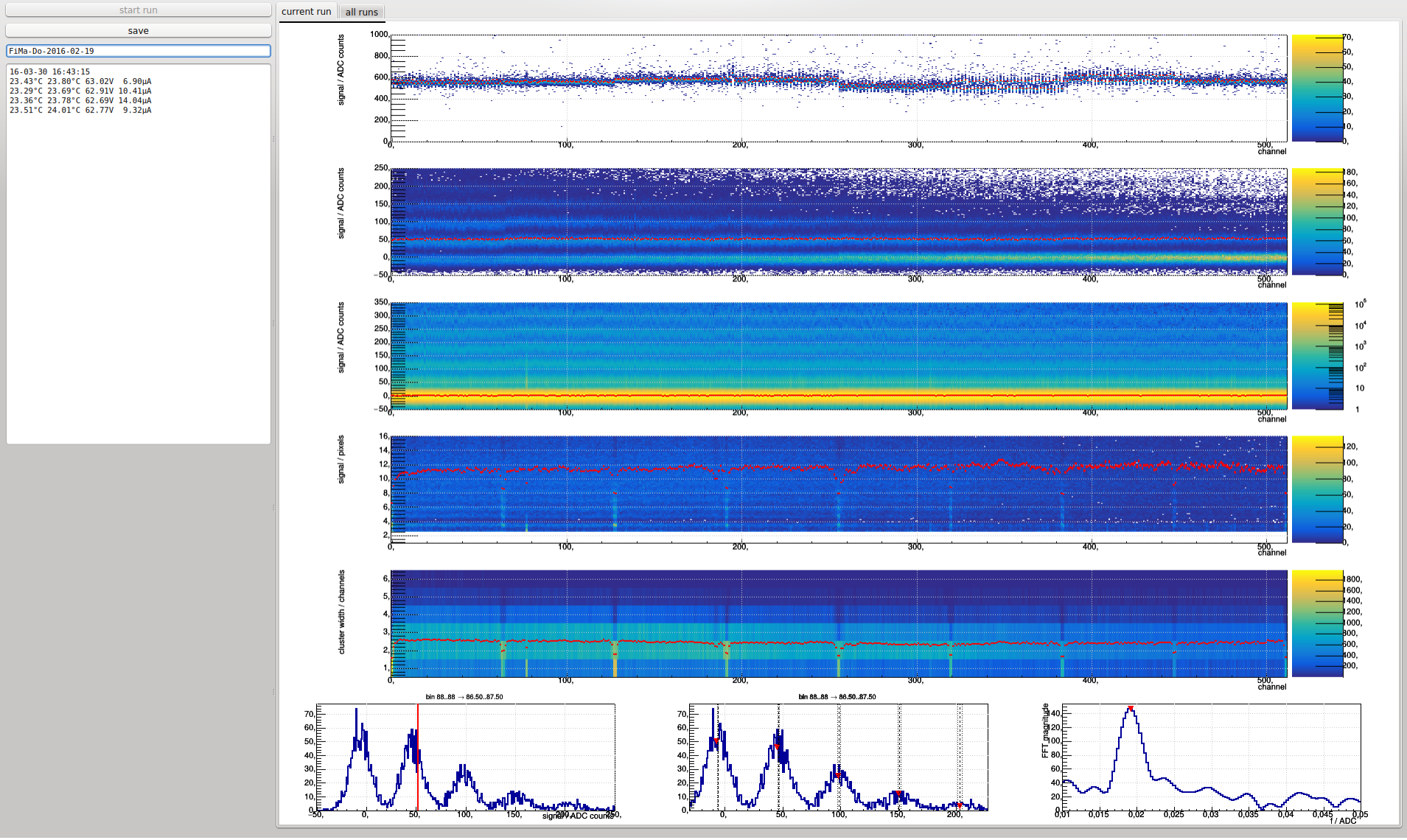
7. Start measurement

8. Open lighttight box and put Place Sr90-source in lead bunker

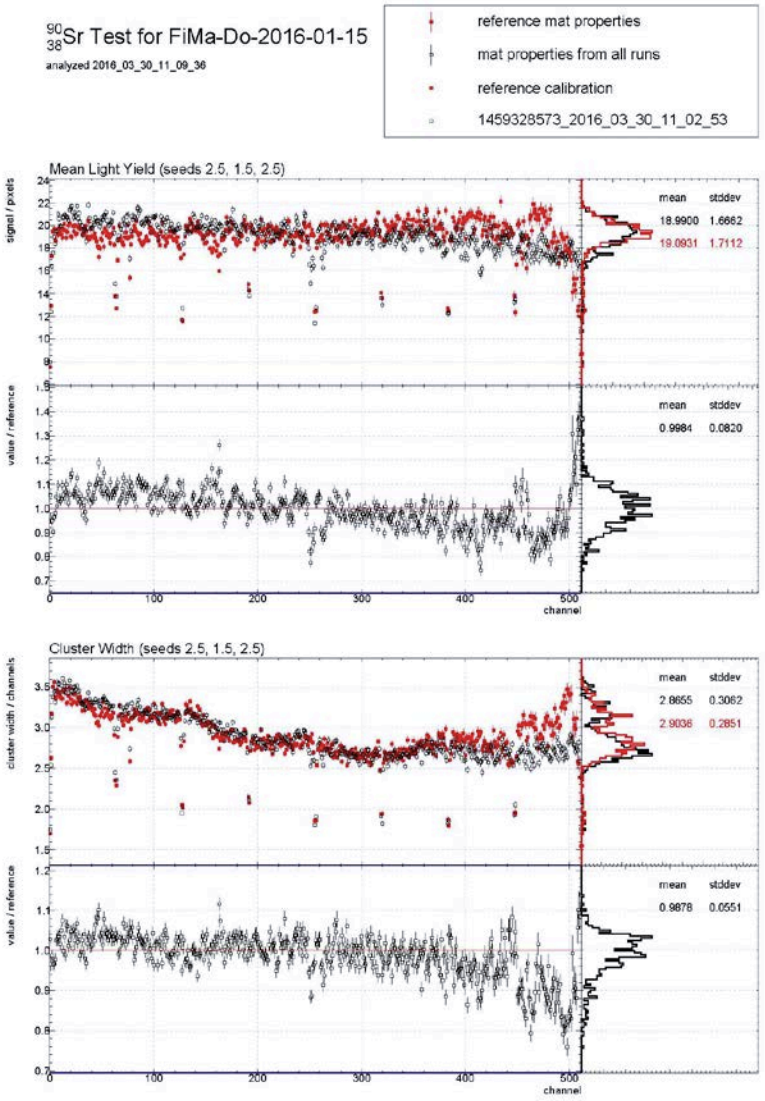
9. Unmount fibre mat from multipurpose jig, take it out of lighttight box and put it back to storage rack

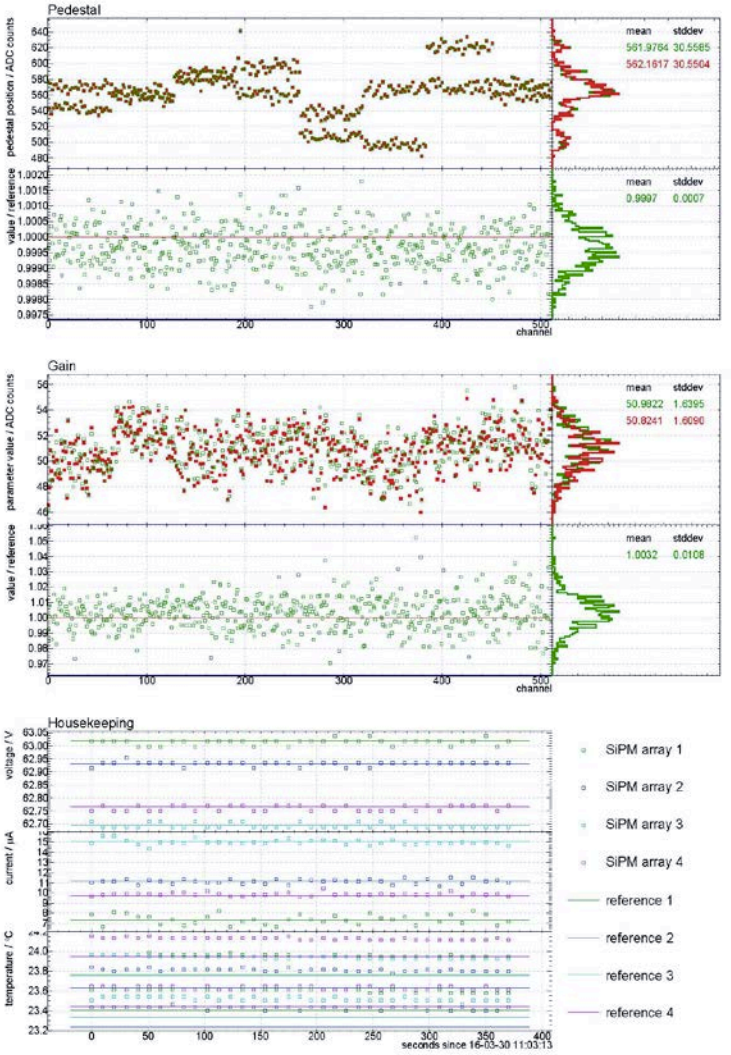


Light Yield Measurement Online Display



Light Yield Measurement Report





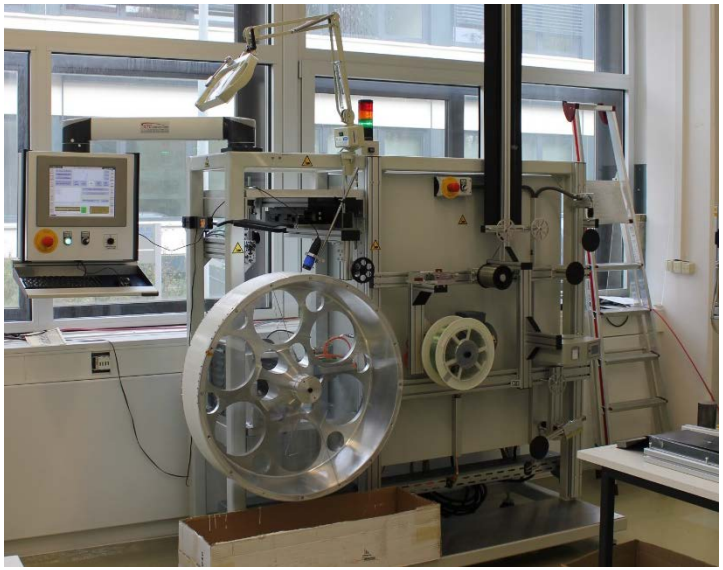
Light Yield Measurement

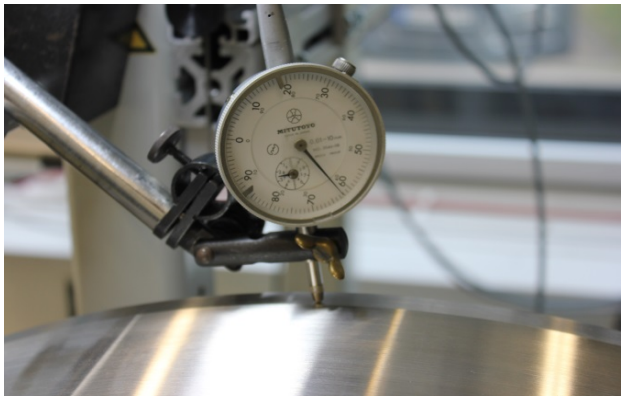
Process/Step	Time	FTE
1. Take fibre mat and place it on multipurpose jig of Sr90-setup	2 min	2
2. Adjust fibre mat on readout position and fix position by screwing upper clamp to lower clamp at readout position	1 min	1
3. Fix position of fibre mat at mirror side by screwing upper clamp to lower clamp	1 min	1
4. Move SiPM array into measurement position	1 min	1
5. Place Sr90-source on moveable tray and move source to measurement position close to mirror side	1 min	1
6. Close lighttight box	1 min	1
7. Start measurement	5 min	0
8. Open lighttight box and put Place Sr90-source in lead bunker	1 min	1
9. Unmount fibre mat from multipurpose jig, take it out of lighttight box and put it back to storage rack	2 min	2
	Σ 6 min	**1**
	Σ 4 min	**2**
	Σ 5 min	**0**

Quality control of winding wheels (for new or reworked wheels only)

1. Mount winding wheel to winding machine.
2. Measurement of radius, axial and radial runout.
3. Optical inspection of thread and pin-holes for burrs and sharp edges which can distort winding process or damage fibre during winding
4. If necessary remove burrs and edges with 3M-scotch brite

Quality Control of Winding Wheel





Quality Control of delivered wheel (new or after rework) before usage of it for fibre mat production:

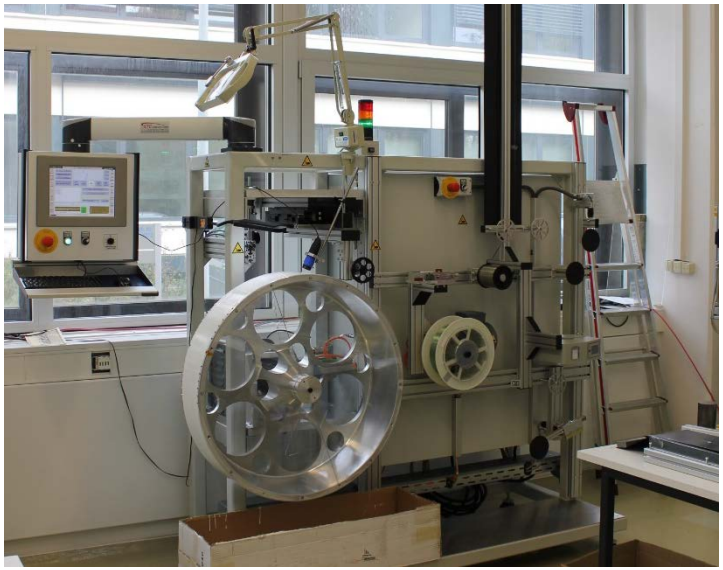
1. Mount winding wheel to winding machine.

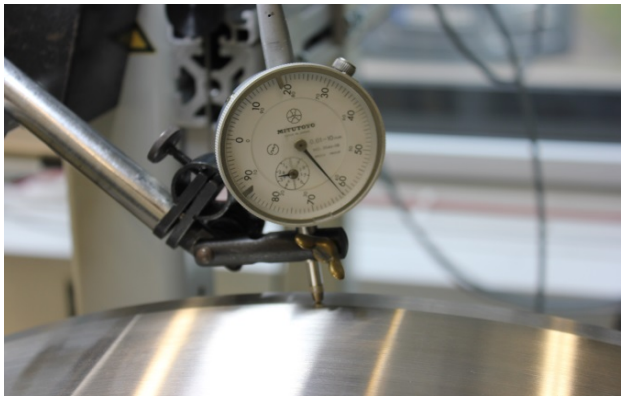
2. Measurement of radius, axial and radial runout.

Tolerances should be better than 100µm.

Diameter 817 mm, Thread-Width 140 mm

Quality Control of Winding Wheel





3. Optical inspection of thread and pin-holes for burrs and sharp edges which can distort winding process or damage fibre during winding

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