

AMS-02: TRDTN1

**Straw Module System (QM)
(Straw Modul, UTE, UHVD, UFE)**

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Aachen, 19th February 2009**

Mechanical Stiffness and Eigenfrequencies, Temperature Ranges (Table 1), Gas Tightness, Gas Gain Performance

TRD Component Temperature Range

Item	Experim. Setup	Quantity tested	Temperature Range [°C]	Operative	Survival (no damage)	Comment
DOR-Connector	LN ₂ (15 min)	8	-77	No	Yes	
DOR-Connector	TVT AC	20	T<-20	No	Yes	
			-20<T<+40	Yes	Yes	
Manifold FVs unswitched	TVT AC	1 x 5 channels potted, no Stycast	-20<T<+40	Yes	Yes	
			-25<T<-20	-	Yes	
FV Operation	TVT AC	2 x 2 FV	0<T<+40	Yes	Yes	
			-25<T<0	No	Yes	No switching
TRD Straw Module	TVT AC	4 SQ-Modules	-20<T<+45	Yes	Yes	With (Gas, HV, Power)
	TVT MPE		-45<T<+60	-	Yes	No (Gas, HV, Power)
UFE	TVT AC	82 FM(+19 FS)	-20<T<+50	Yes	Yes	
			-35<T<-20	-	Yes	
			+50<T<+80	-	Yes	
UHVD	TVT AC	5 QM	-45<T<+63	-	Yes	

TRD Requirements	ICD 27.01.2006
Non Operative (Survival)	-20<T<40°C
Operative	-10<T<40°C

TRD Component Space Qualification:	
Non Operative (Survival)	-25<T<40°C
Operative	-20<T<40°C

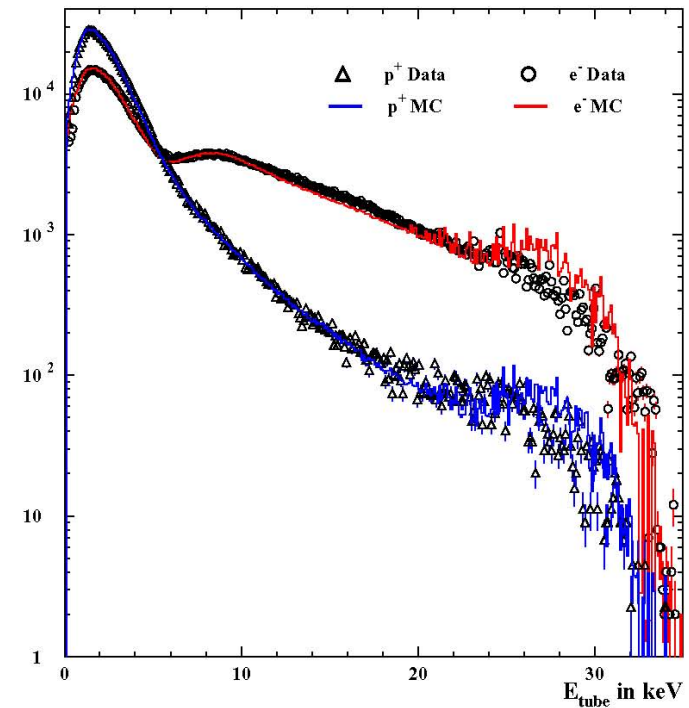
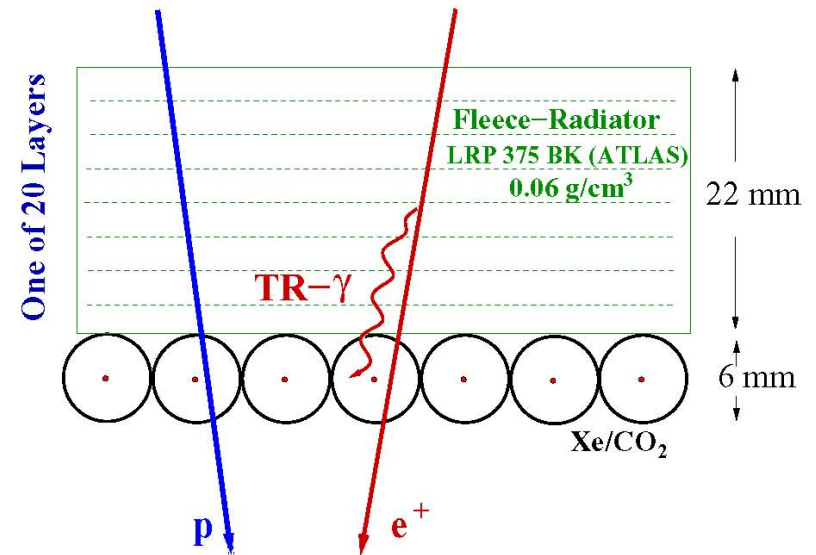
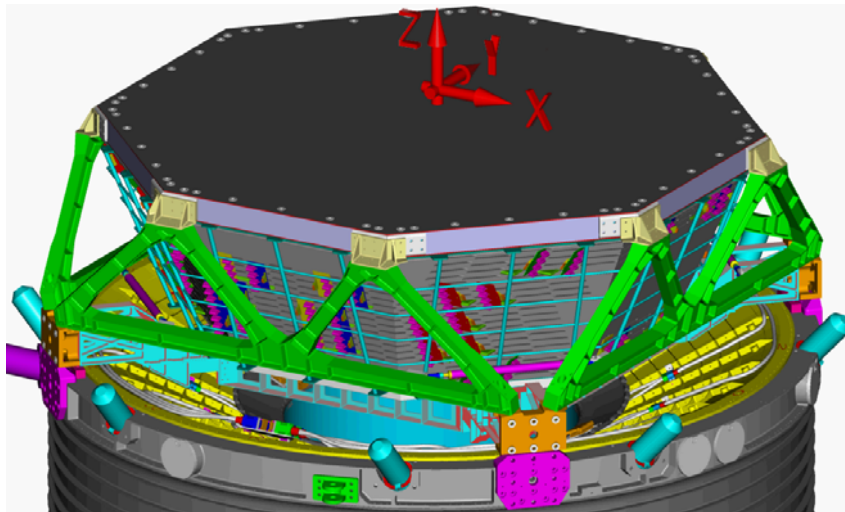
AMS-02 – TRD: Principle

p^+ rejection $>10^2$ 1-300 GeV $0.5\text{m}^2\text{sr}$

Chosen configuration for 60 cm height:

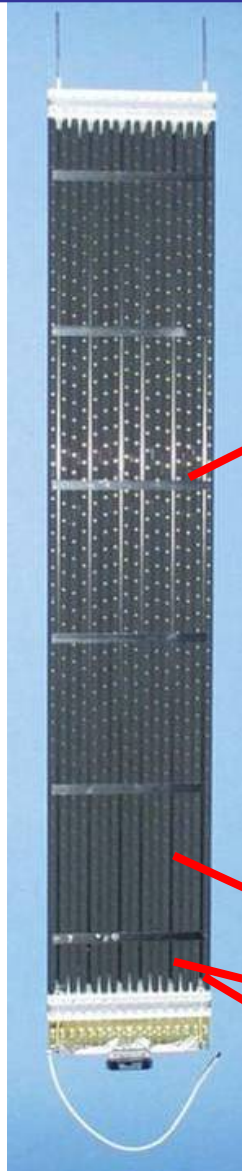
20 Layers each existing of:

- 22 mm fibre fleece
- \varnothing 6 mm straw tubes (Xe/CO₂ 80%/20%)

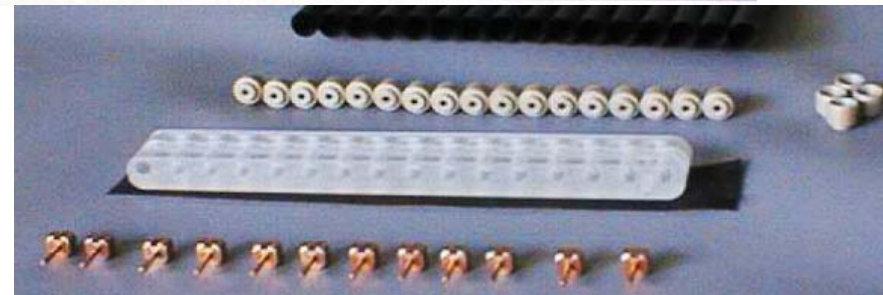
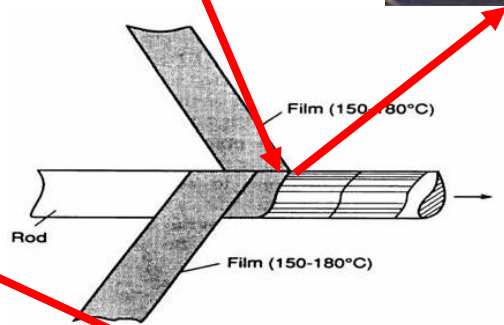
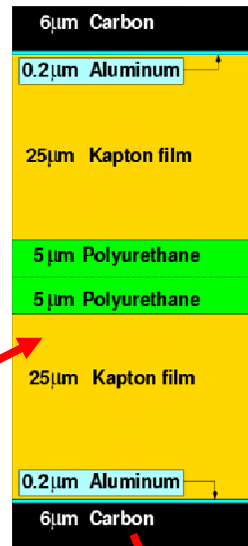


AMS-02 – TRD: Straw Modules

- Straw tubes: $72 \mu\text{m}$ multilayer aluminium kapton foil, $\text{Ø } 6 \text{ mm}$, $0.8 \div 2.0 \text{ m}$ length
- Wire: tungsten anode wire, $30 \mu\text{m}$ Ø , tension $\approx 100 \text{ g}$
- Gas mixture: Xe / CO_2 (80% / 20%)
- Operating HV $\sim 1460 \text{ V} \rightarrow$ Gasgain of ~ 3000
- 1 Module $\rightarrow 16$ Straws, $100 \mu\text{m}$ mechanical accuracy
- 328 Modules $\rightarrow 5248$ Straws



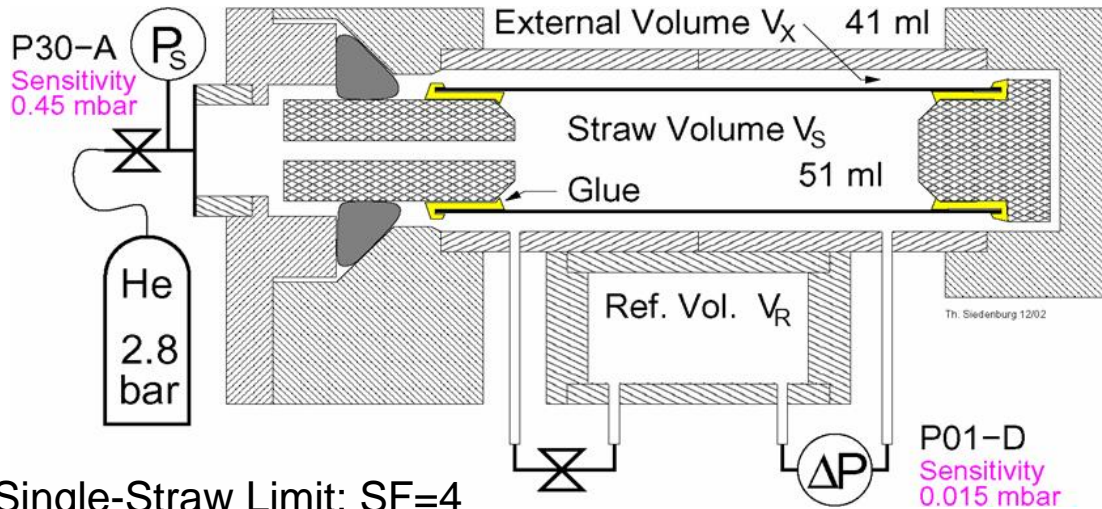
TRDTN 1



6 longitudinal stiffeners

Strips across every 10 cm

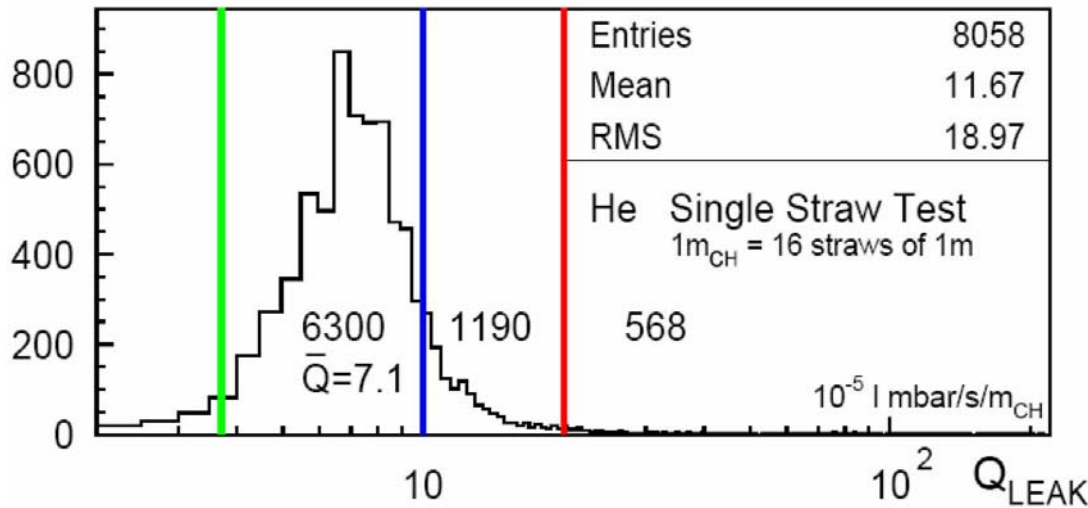
AMS-02 – TRD: Single Straw Test



Single-Straw Limit: SF=4

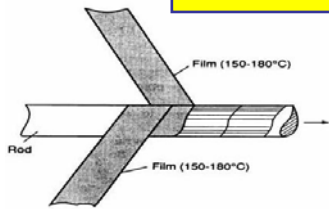
He $q_{PV} < 1 \cdot 10^{-5}$ l mbar/s/m

The gastightness of each individual straw tube was measured with the single straw teststand. 5248 straws out of 6300 gastight straws have been selected for the 328 flight straw modules after the results of QM MOD04

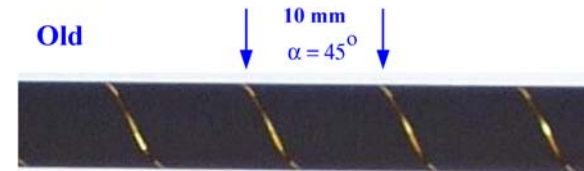


MOD04
**Mechanical Stiffness and Eigenfrequencies,
Gas Gain & Gas Tightness**

Vibrationtest @ RWTH-Aachen: 4-Layer Test Jigg MOD 04



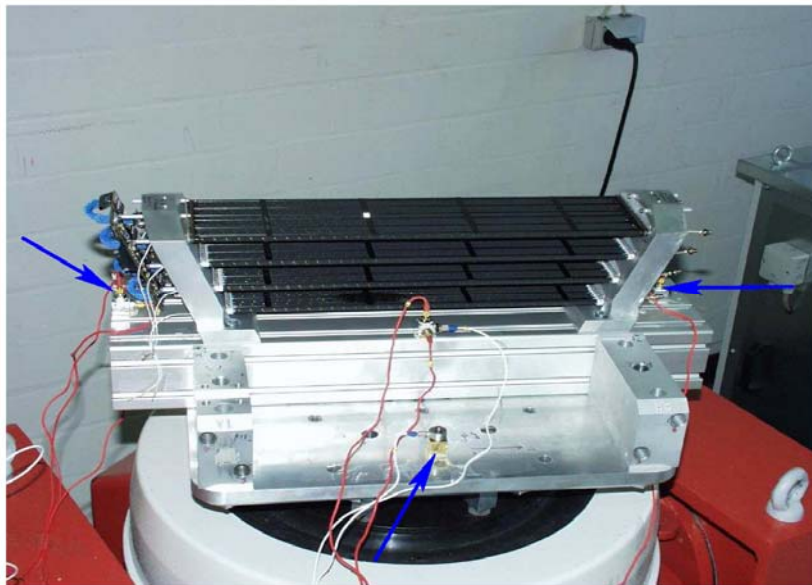
Straw tubes produced with a winding angle of 45° resulting in a pitch of 10 mm



Vibration-Test-Cycle:

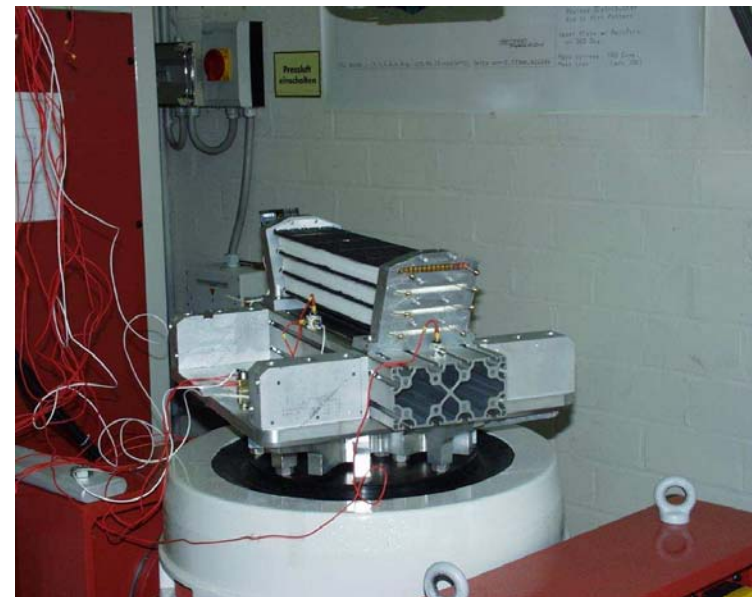
- Sine Sweep 0.5 g (10-2000 Hz)
- Random spectrum $a_{RMS} = 6.8$ g
- Sine Sweep 0.5 g (10-2000 Hz)

Z-direction without Radiator



TRDTN 1

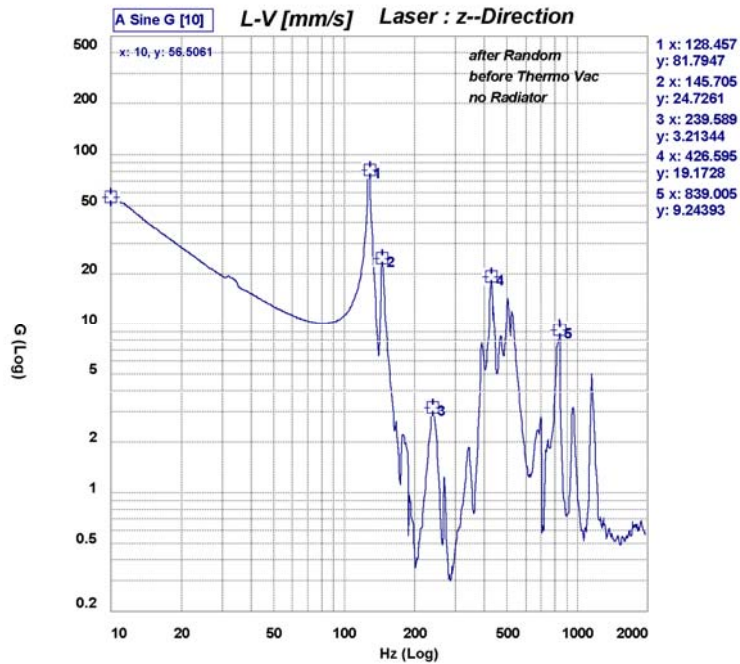
Z-direction with Radiator



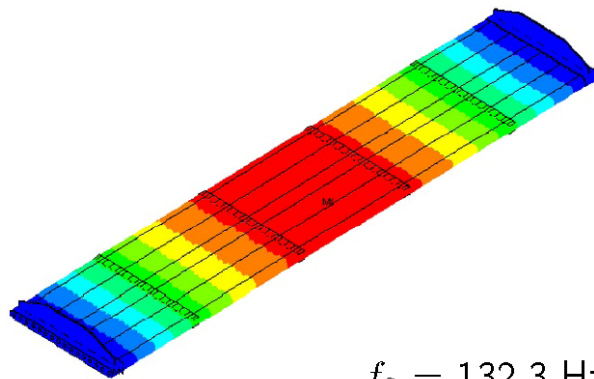
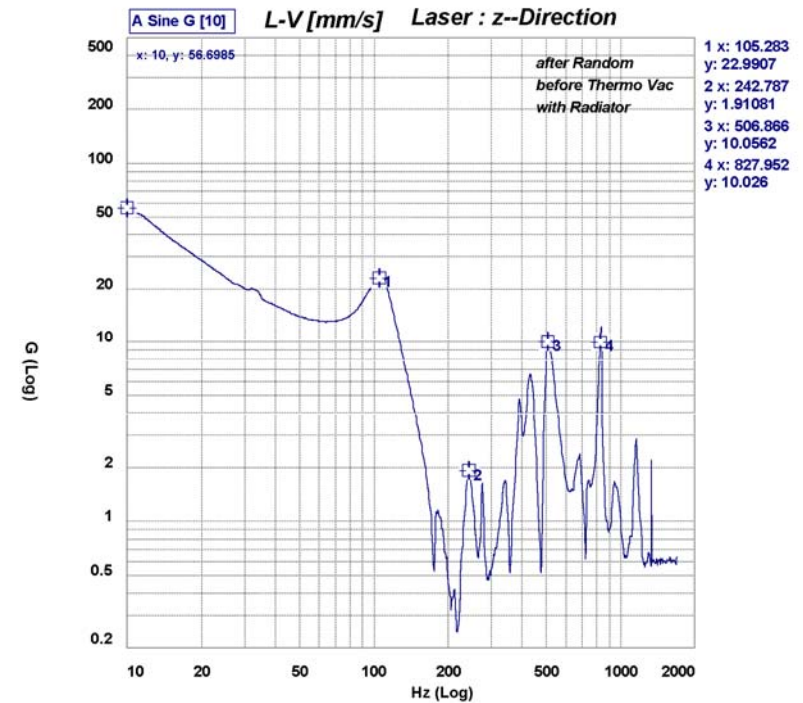
Aachen, 19th February 2009

Vibrationtest @ RWTH-Aachen: 4-Layer Test Jigg MOD 04

Z-direction without Radiator



Z-direction with Radiator



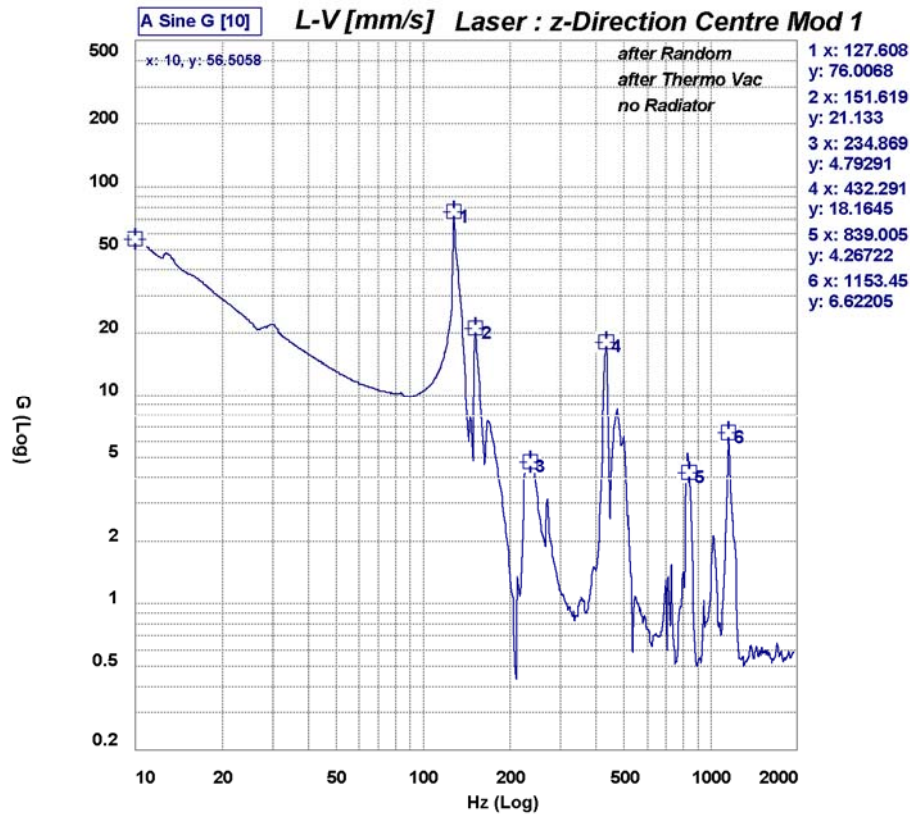
$$f_0 = 132.3 \text{ Hz}$$

132.319
UY
TOP
RSYS=0
DMX =1
SMN =. 02192
SMX =1
-. 02192
. 091626
. 205173
. 31872
. 432267
. 545813
. 65936
. 772907
. 886453
1

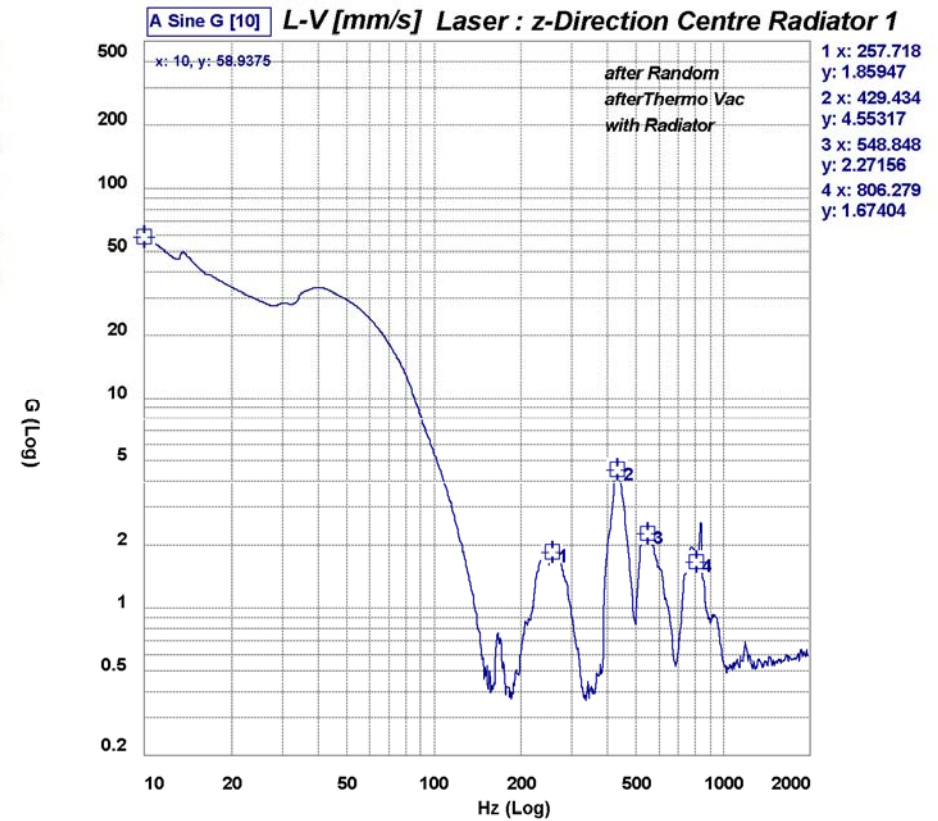
AMS TRD Modul
Length 450 mm
Support Dist. 450 mm
16 Tubes,
Diameter 6.0 mm

Vibrationtest @ RWTH-Aachen: 4-Layer Test Jigg MOD 04 after Thermovacuum Test

Z-direction without Radiator



Z-direction with Radiator

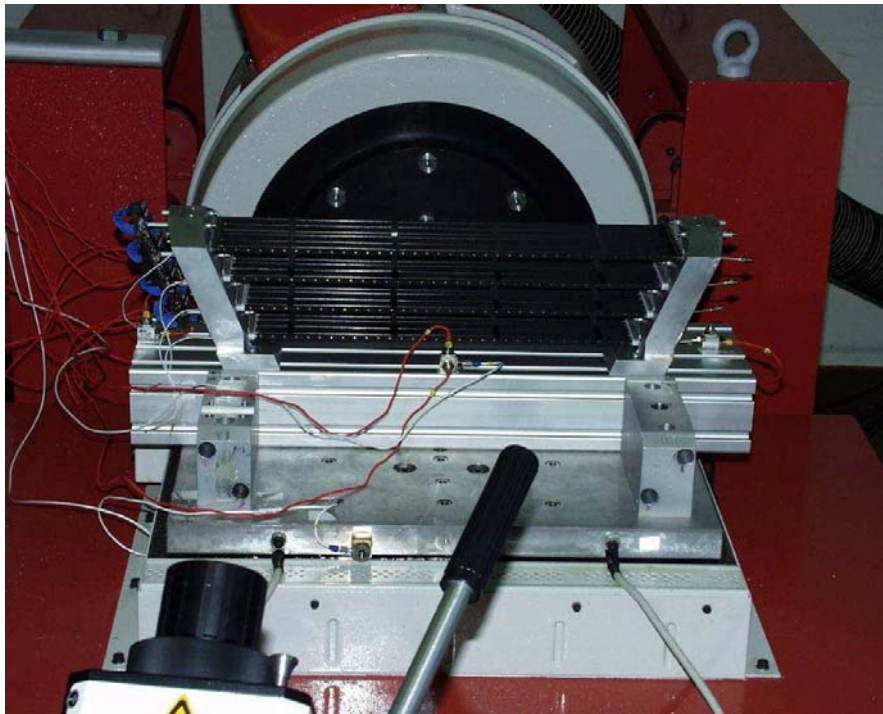


Vibrationtest @ RWTH-Aachen: 4-Layer Test Jigg MOD 04

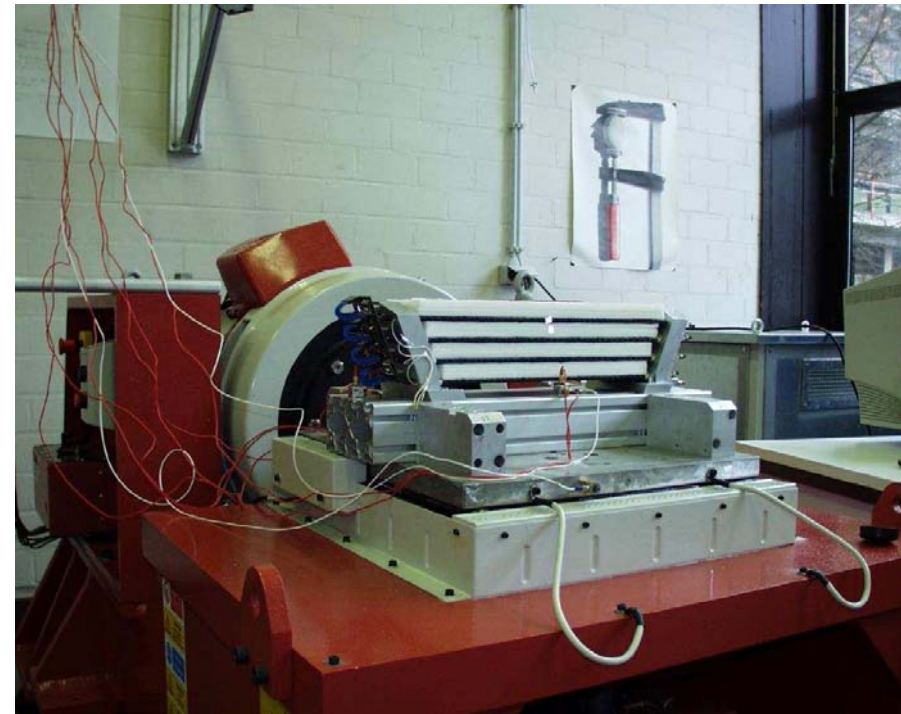
Vibration-Test-Cycle:

- Sine Sweep 0.5 g (10-2000 Hz)
- Random spectrum $a_{RMS} = 6.8$ g
- Sine Sweep 0.5 g (10-2000 Hz)

Y-direction without Radiator

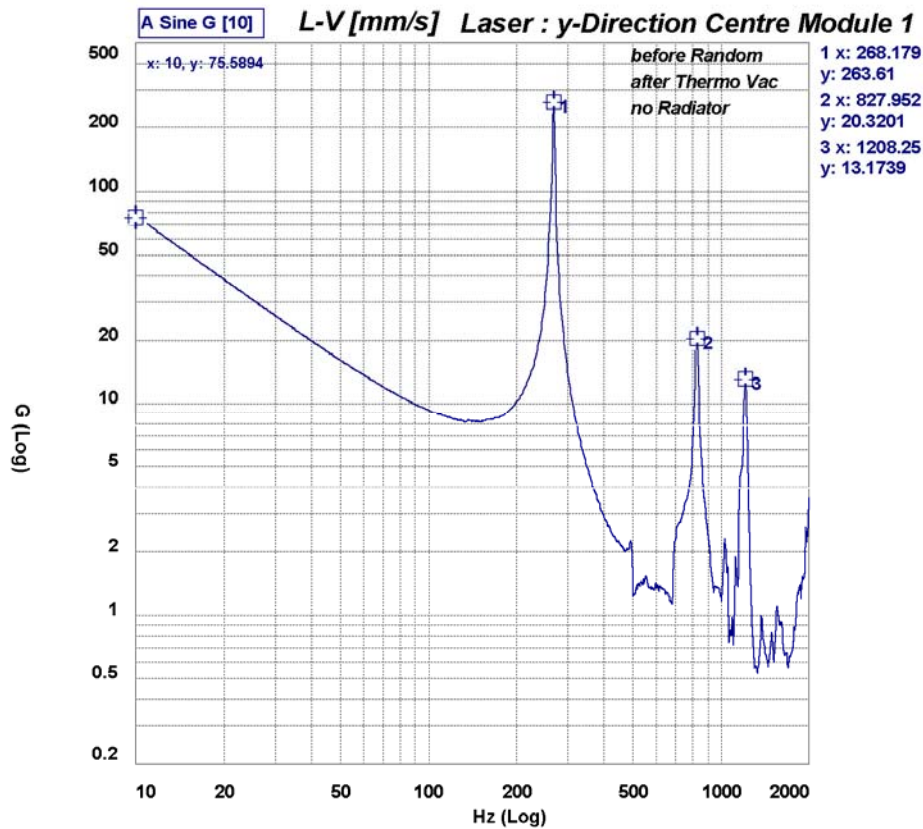


Y-direction with Radiator

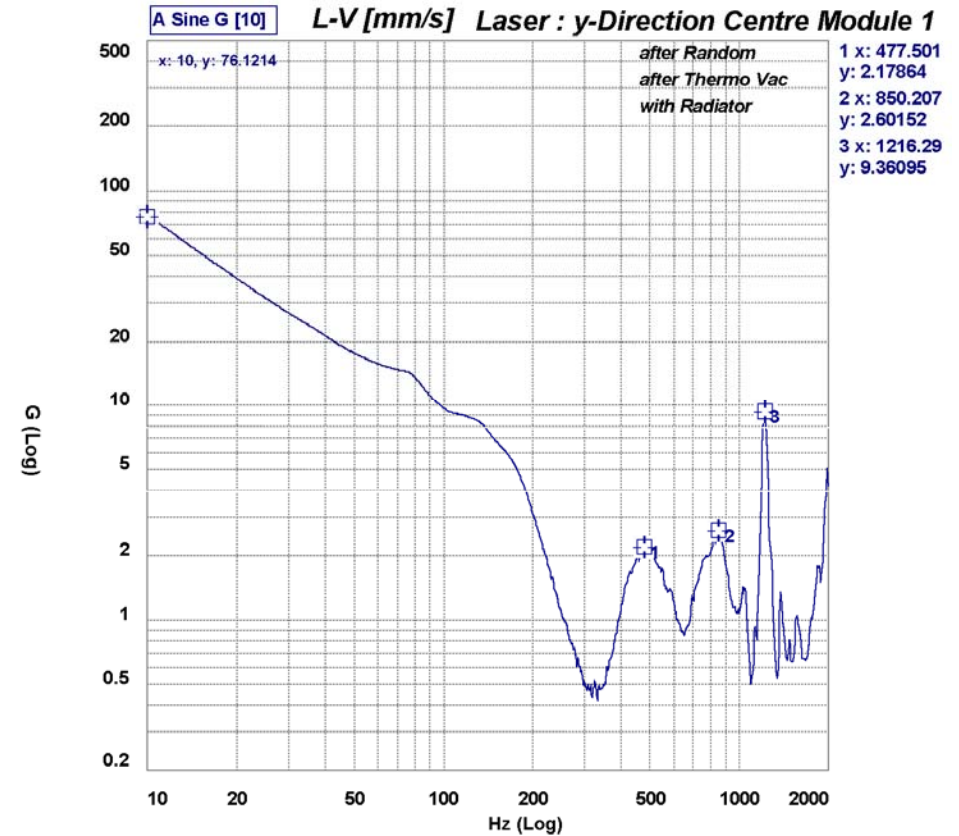


Vibrationtest @ RWTH-Aachen: 4-Layer Test Jigg MOD 04 after Thermovacuum Test

Y-direction without Radiator



Y-direction with Radiator

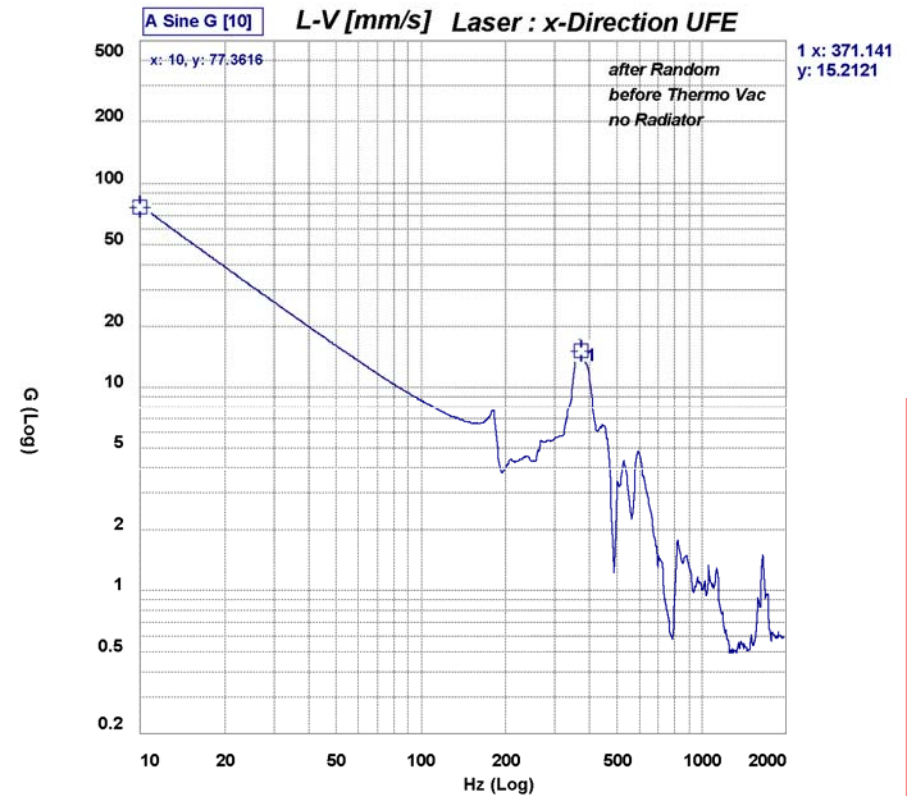
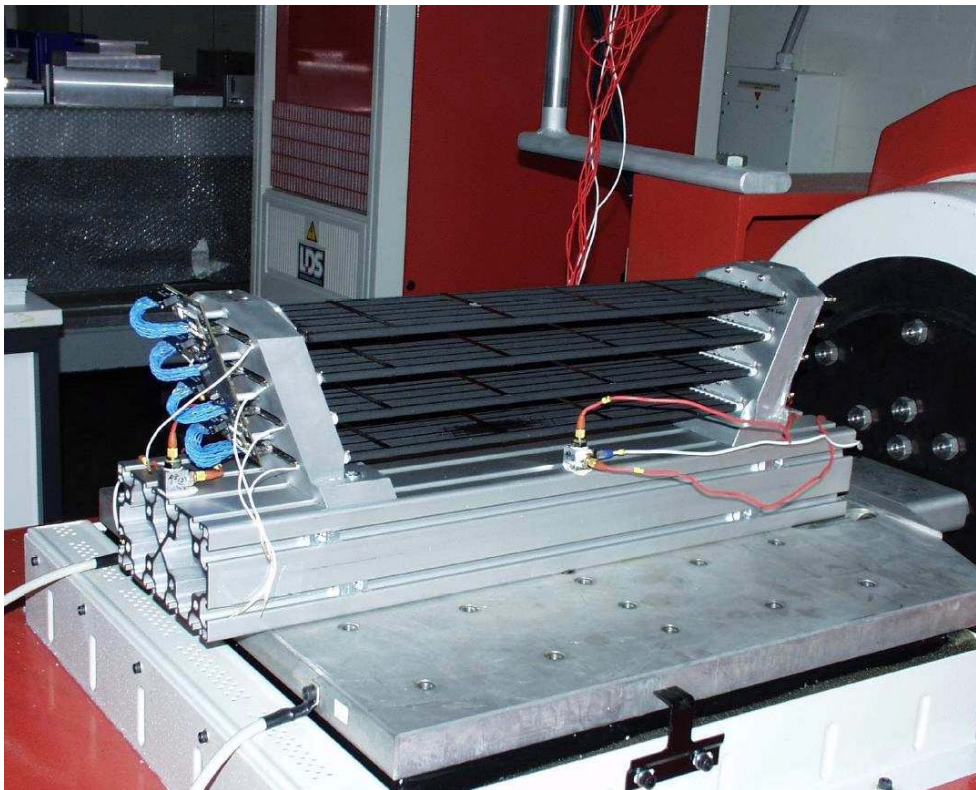


Vibrationtest @ RWTH-Aachen: 4-Layer Test Jigg MOD 04

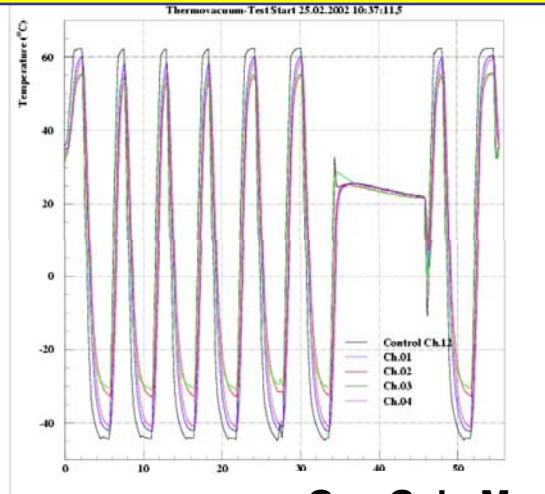
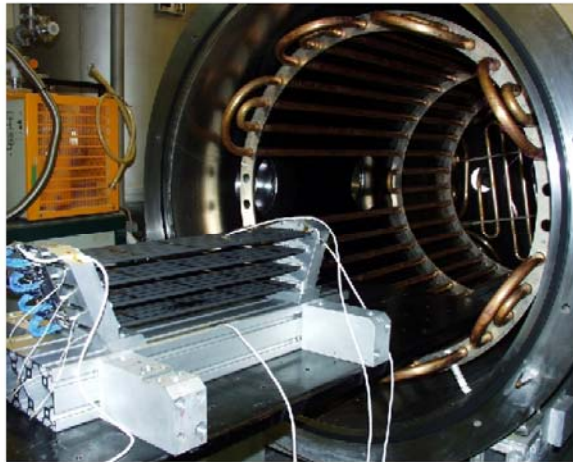
Vibration-Test-Cycle:

- Sine Sweep 0.5 g (10-2000 Hz)
- Random spectrum $a_{RMS} = 6.8$ g
- Sine Sweep 0.5 g (10-2000 Hz)

X-direction without Radiator

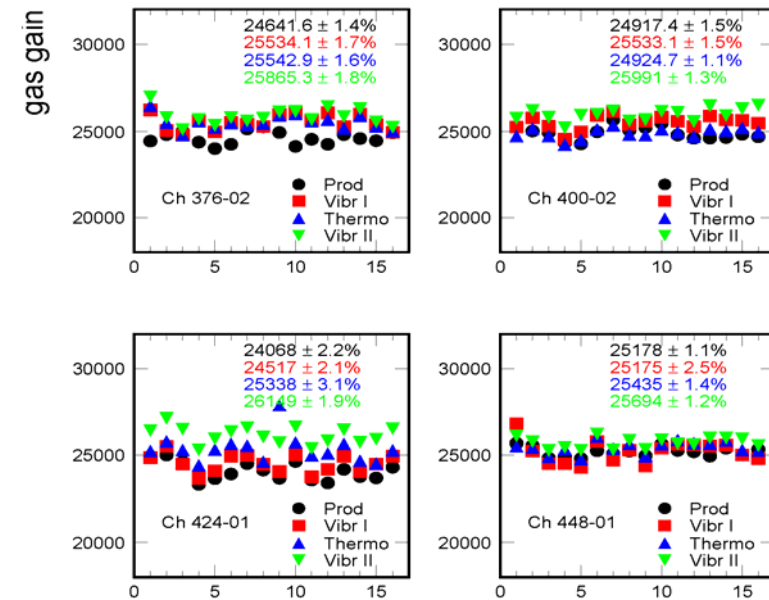


Thermovacuum-Test @ MPE: 4-Layer Test Jigg MOD 04



Module	Produktion	Vibration I	Thermo-Vakuum	Vibration II
Straw Länge L [mm]	Leckrate q (He) [$\cdot 10^{-4} \frac{\text{mbar}}{\text{s}}$]	Leckrate q (He) [$\cdot 10^{-4} \frac{\text{mbar}}{\text{s}}$]	Leckrate q (He) [$\cdot 10^{-4} \frac{\text{mbar}}{\text{s}}$]	Leckrate q (He) [$\cdot 10^{-4} \frac{\text{mbar}}{\text{s}}$]
448	2.2	2.7	39.6	20.0
424	1.8	3.1	3.8	3.8
400	1.9	2.8	2.4	2.6
376	1.7	12.1	2.0	11.9

Gas Gain Measurement with Ar/CO2



Due to this measured gas untightness, development of single straw teststand and gas tightness test of each individual straw before straw module production!

MOD1282

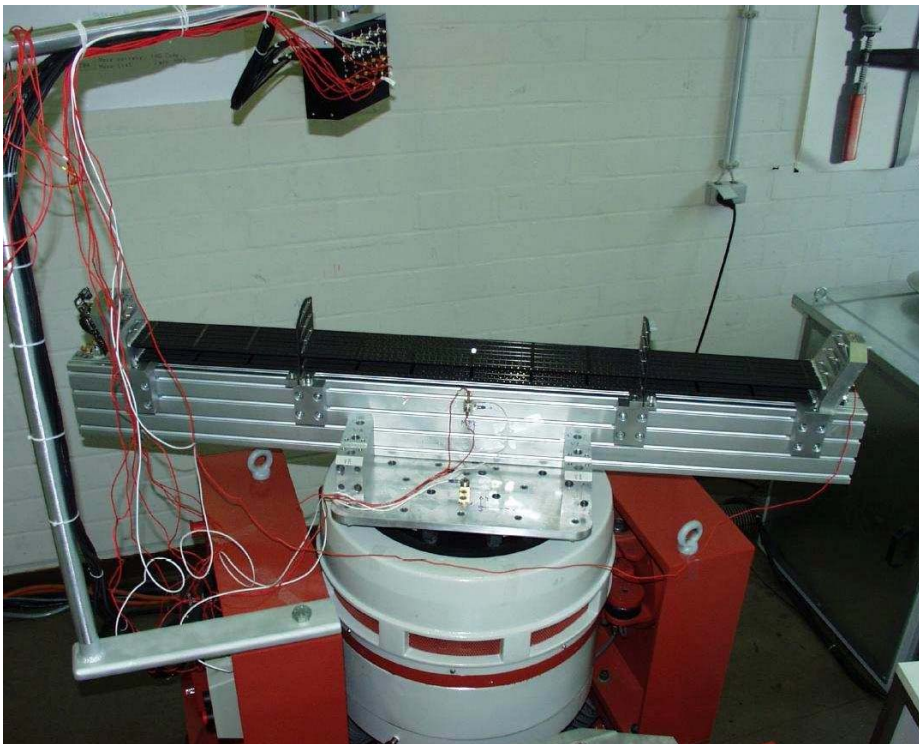
Mechanical Stiffness and Eigenfrequencies

Vibrationtest @ RWTH-Aachen: 2-Layer Test Jigg MOD 1282

Vibration-Test-Cycle:

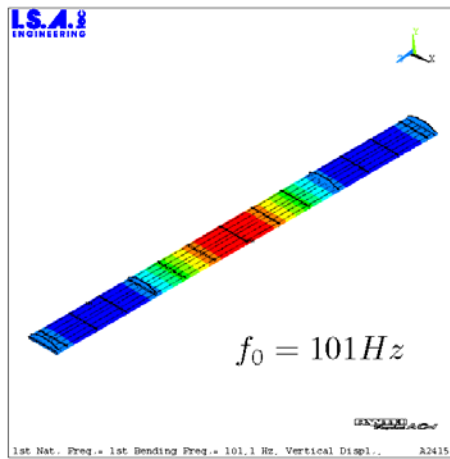
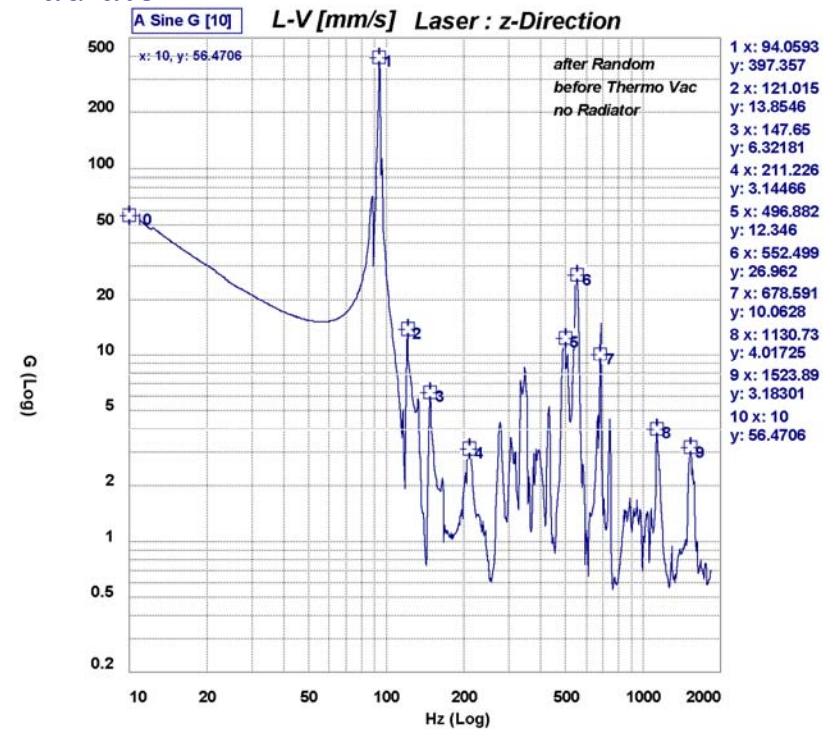
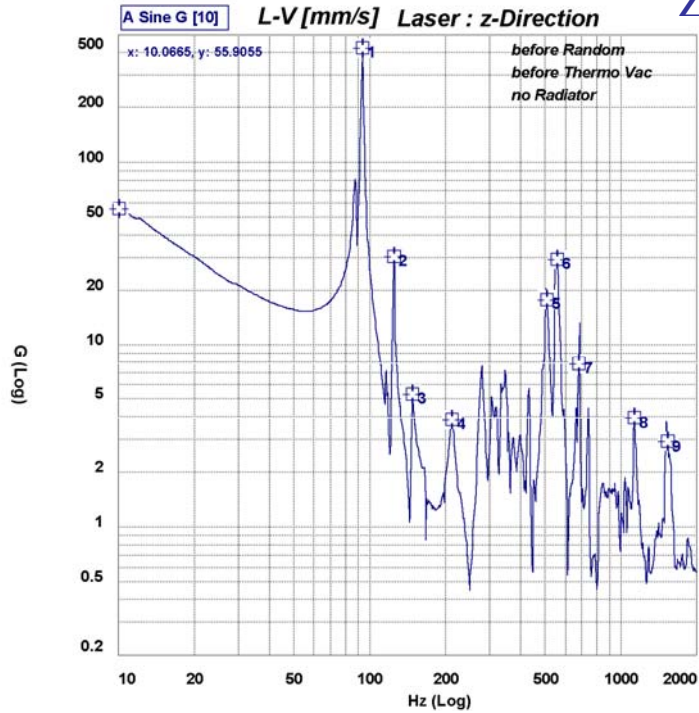
- Sine Sweep 0.5 g (10-2000 Hz)
- Random spectrum $a_{RMS} = 6.8$ g
- Sine Sweep 0.5 g (10-2000 Hz)

Z-direction without Radiator



Vibrationtest @ RWTH-Aachen: 2-Layer Test Jigg MOD 1282

Z-direction without Radiator

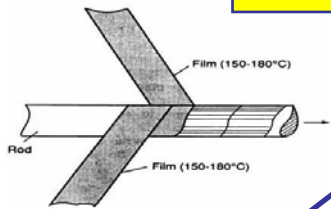


ANSYS TRD Test Chamber
Corresp. ans02-1215

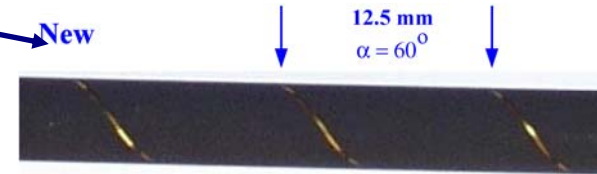
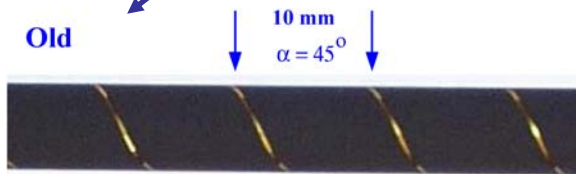
Chamber Length 1282 mm
Support Dist. 1272 mm
16 Tabs
Diameter 6.0 mm
Thickness 0.078 mm
E-Modulus 2760 MPa
6 Longitud. Stiffeners
Double-T-Shape
Thickness 0.3/0.9 mm
E-Modulus 178 GPa

MOD06 & MOD07
Mechanical Stiffness and Eigenfrequencies,
Temperature Ranges (Thermovacuum Test),
Gas Tightness, Gas Gain Performance

4-Layer Test Jiggs MOD06 & MOD07



Straw tubes produced with a winding angle of 45° resulting in a pitch of 10 mm, new straw material with a winding angle of 60° resulting in a pitch of 12.5 mm

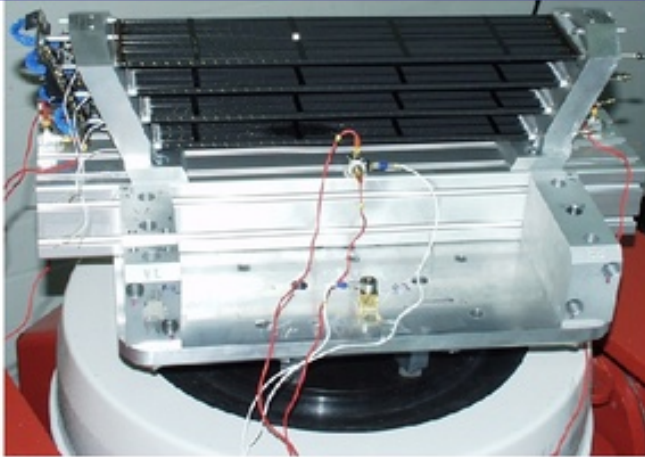


MOD 06 Length <i>mm</i>	Air q_{He} $10^{-5} \frac{l \cdot mbar}{s}$	Vacuum Safety Factor CO ₂
587	5.7	4.1
611	7.0	4.2
635	4.5	5.6
659	3.8	5.9
Σ	20.9	

MOD 07 Length <i>mm</i>	Air q_{He} $10^{-5} \frac{l \cdot mbar}{s}$	Vacuum Safety Factor CO ₂
587	2.6	5.1
611	2.7	5.8
635	8.3	3.5
659	4.0	5.0
Σ	17.6	

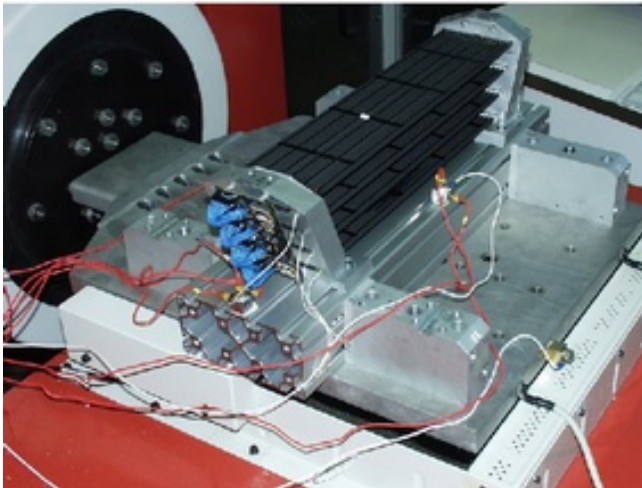
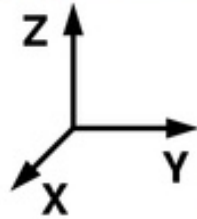
Vibrationtest, Thermovacuumtest → eigenfrequencies, gas tightness, gas gain

Vibrationtest @ RWTH-Aachen: 4-Layer Test Jiggs MOD06 & MOD07



Vibration-Test-Cycle:

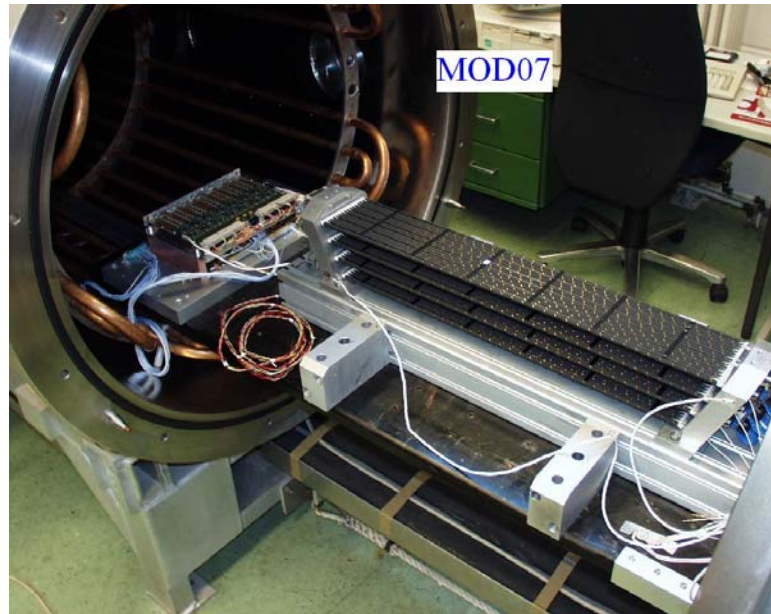
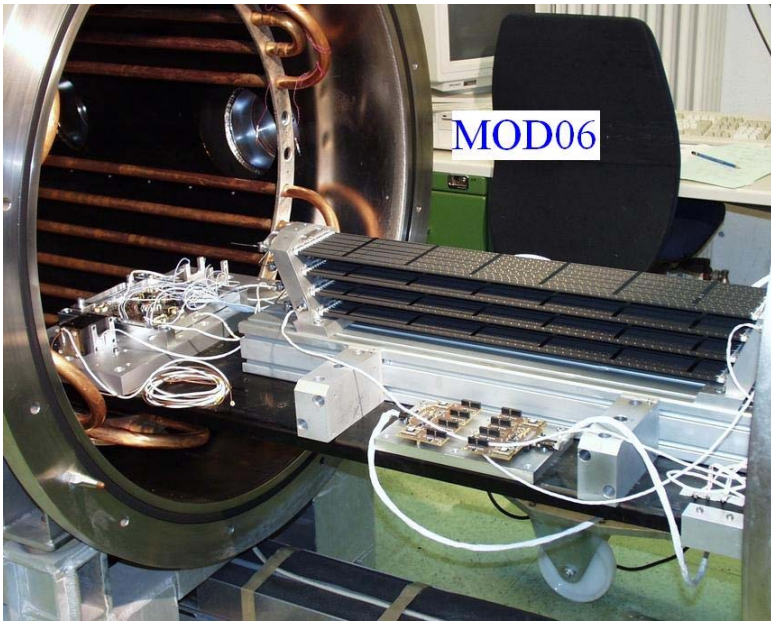
- Sine Sweep 0.5 g (10-2000 Hz)
- Random spectrum $a_{RMS} = 6.8$ g
- Sine Sweep 0.5 g (10-2000 Hz)



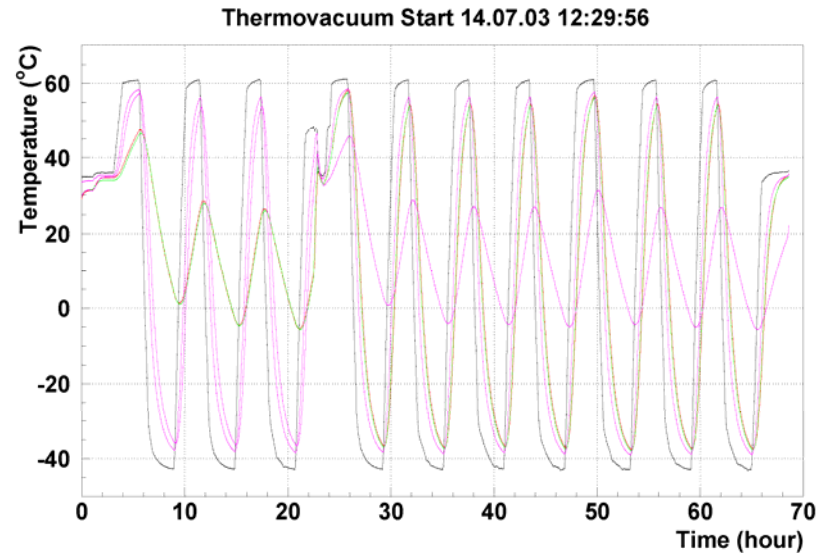
TRDTN 1

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Thermovacuum-Test @ MPE: 4-Layer Test Jiggs MOD06 & MOD07



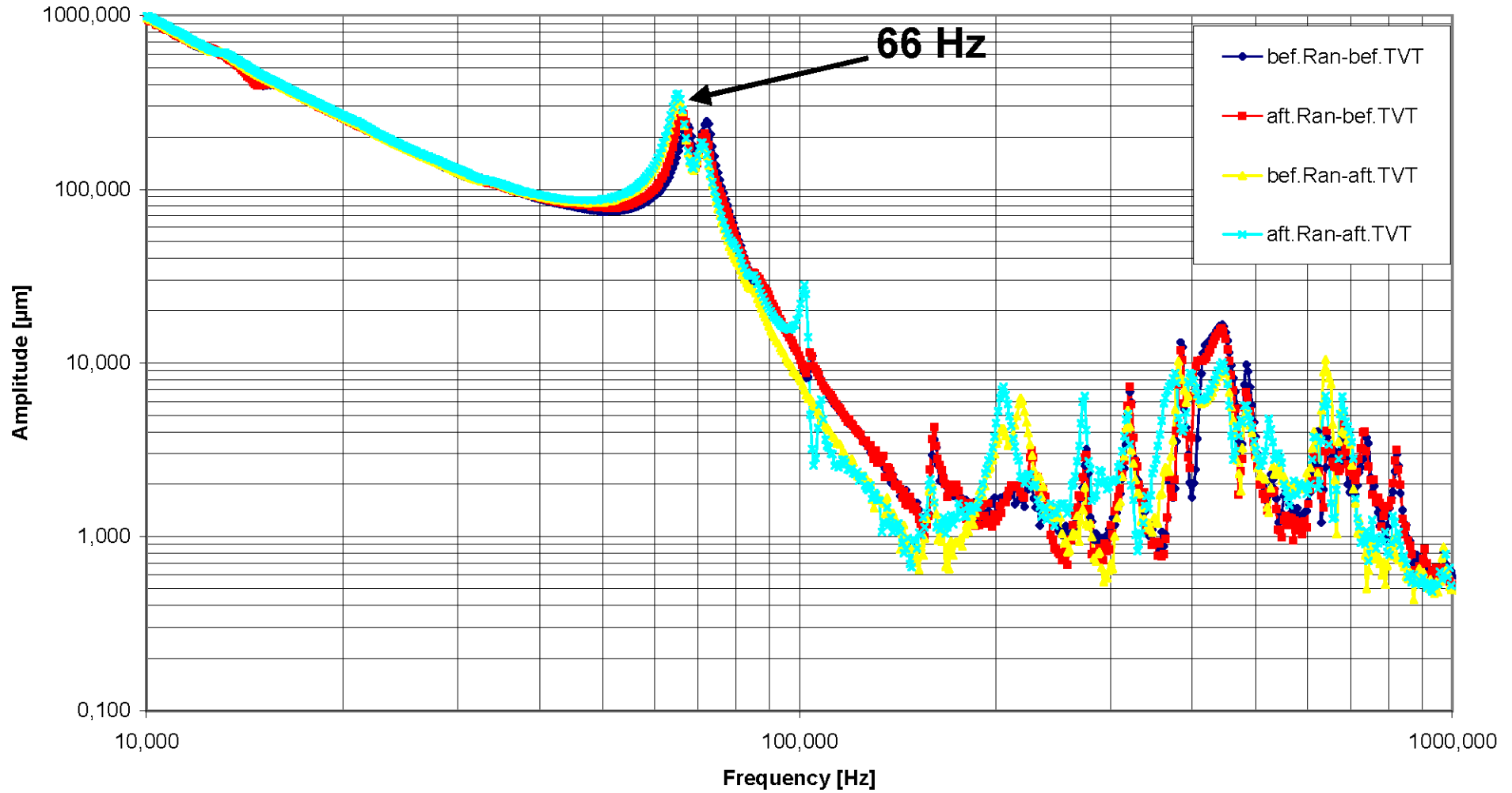
TRDTN 1



Aachen, 19th February 2009

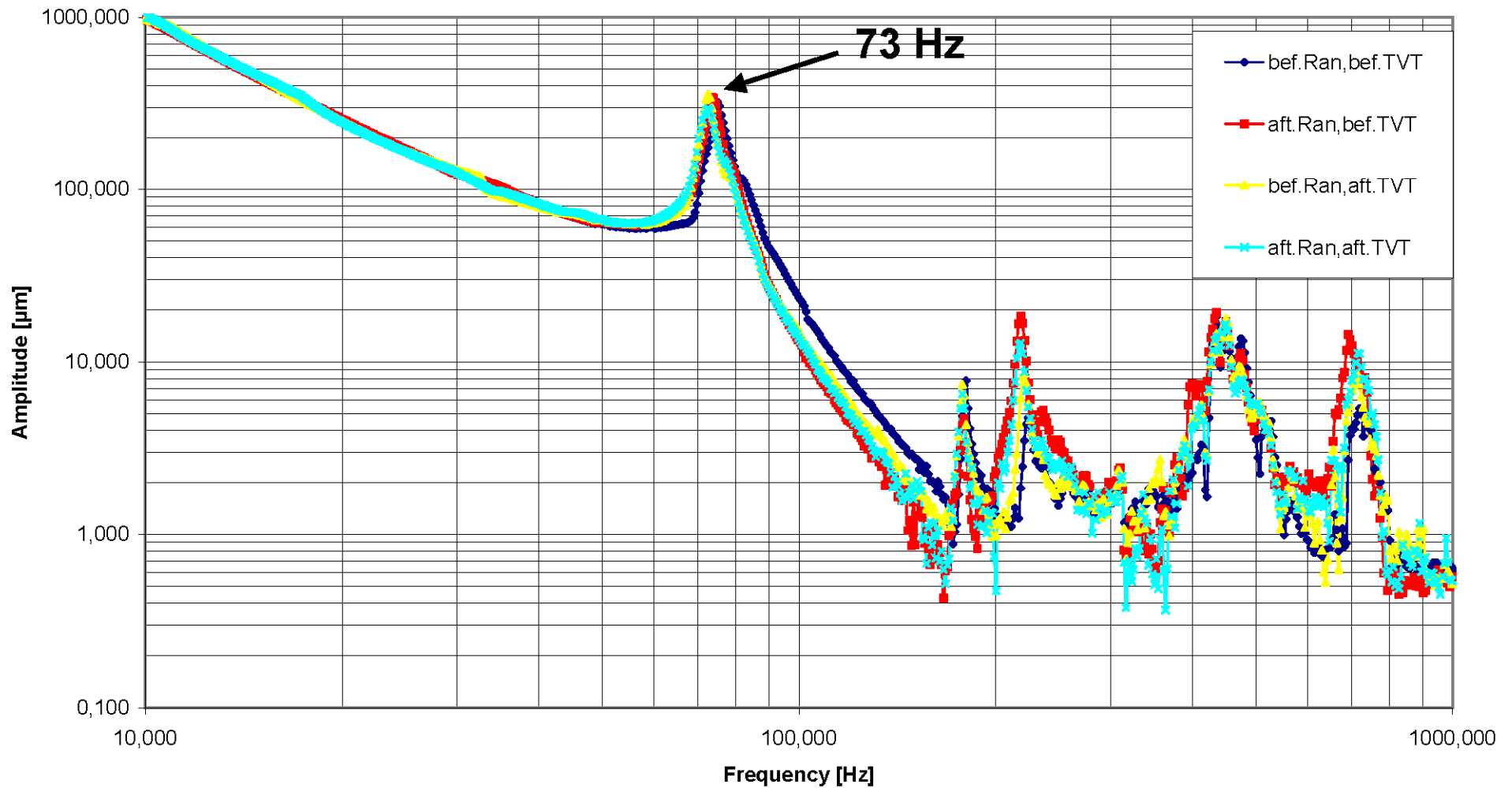
Vibrationtest @ RWTH-Aachen, MOD06 Eigenfrequencies

AMS-02 TRD MOD-06



Vibrationtest @ RWTH-Aachen, MOD07 Eigenfrequencies

AMS-02 TRD MOD-07



Gas Tightness MOD06 & MOD07

Mod. No.	$q_{He,Air}$ $10^{-5} \frac{l \cdot mbar}{s}$			
	before SQ	Vib I	TVT	Vib II

MOD06: Old Straw Material

587	5.7			5.2
611	7.0			6.1
635	4.5			3.7
659	3.8			3.5
Jigg06	21.5	19.9	22.4	19.4

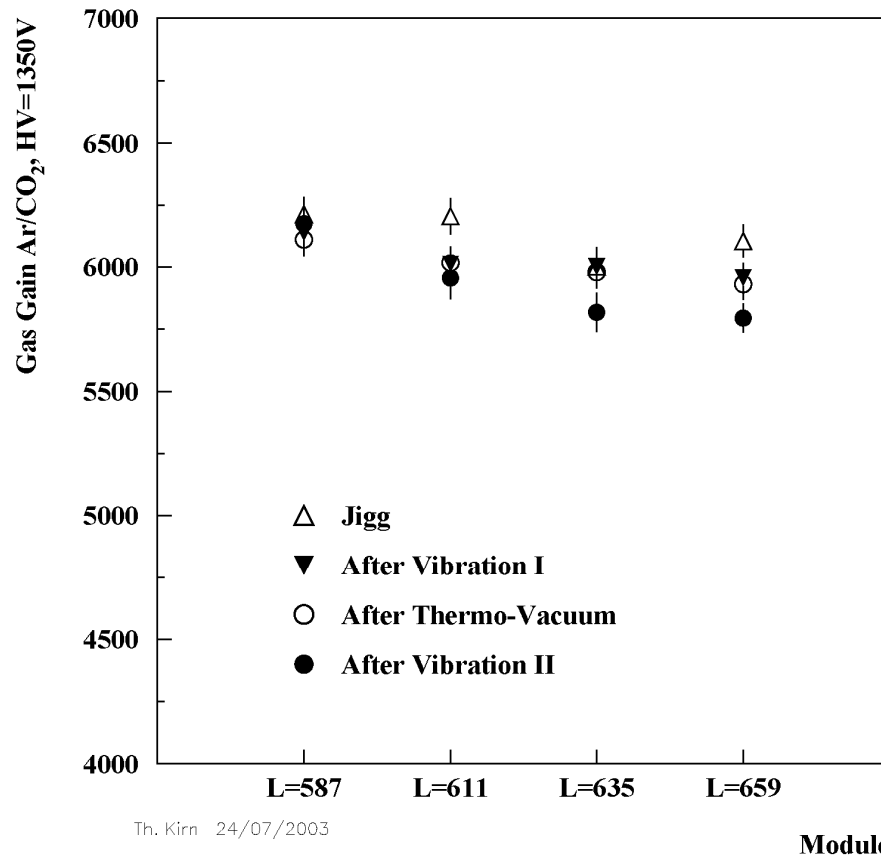
MOD07: New Straw Material

587	2.6			
611	2.7			
635	8.3			
659	4.0			
Jigg07	13.5	12.7	18.4	14.0

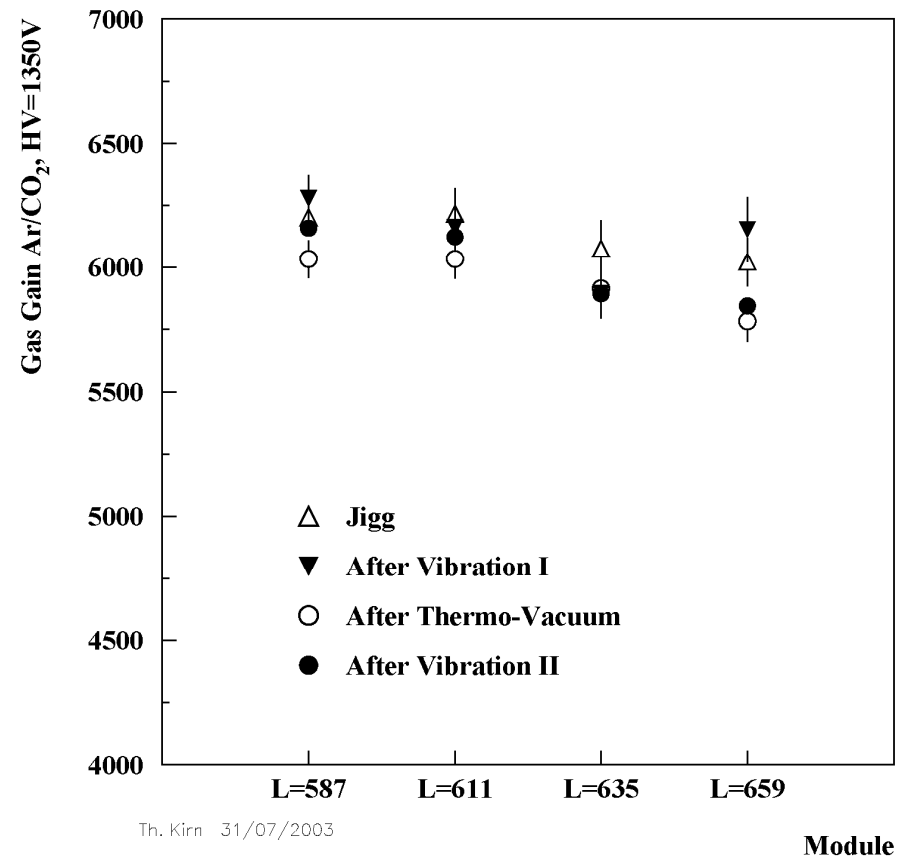
Gas Tightness of 4-Layer Jiggs MOD06 & MOD07 okay

Gas Gain MOD06 & MOD07

MOD 06



MOD 07



Gas Gain of 4-Layer Jiggs MOD06 & MOD07 okay

**MOD06 & MOD07 Result: No significant changes in gas tightness and gas gain
 → straw modules + UTE + UHVD + UFE-board + gas tubing are space qualified**

Longterm Vacuum Test

Gas Tightness, Gas Gain Performance

Longterm Test



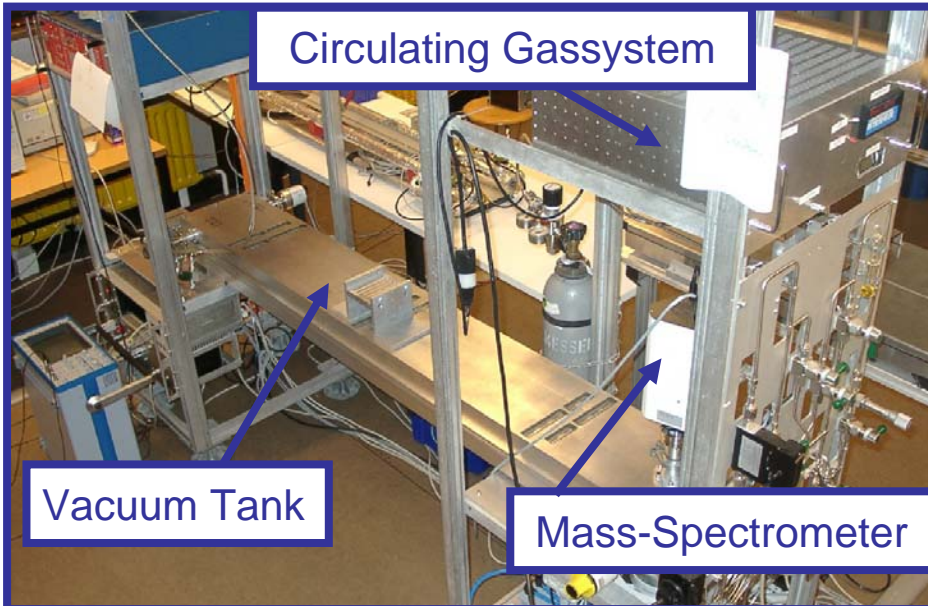
1 Gasgroup → 8 Modules

Fe^{55} – Monitoring

Pressure-Drop Measurements

Mass-Spectrometer Measurements

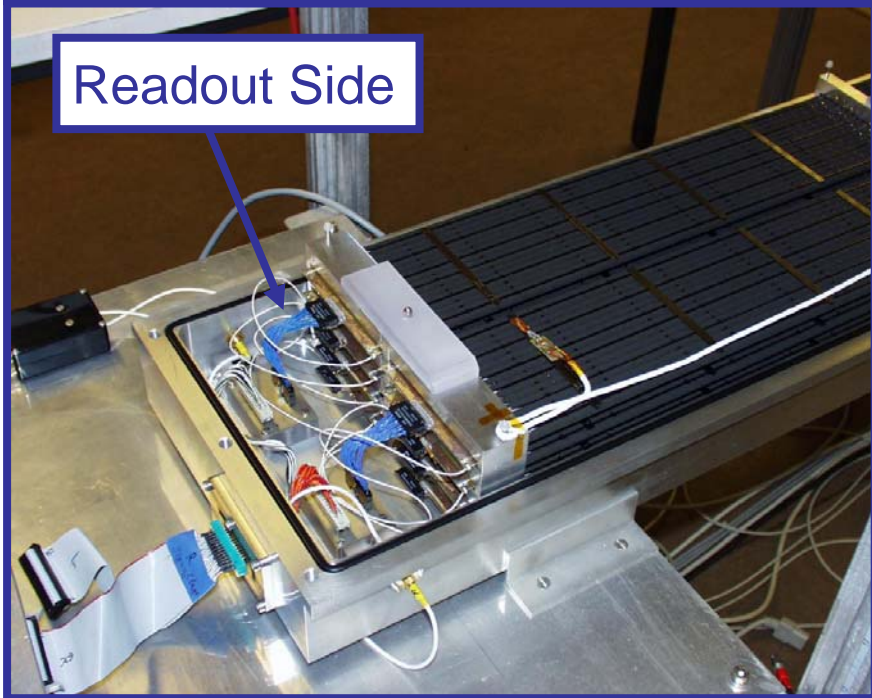
Mod. No.	Length [mm]	Air q_{He} $[10^{-5} \frac{l \cdot mbar}{s}]$	Vacuum Safety- Factor CO_2	Gas Gain $ArCO_2$ U = 1350V	
				Mean	RMS [%]
LZT I	1534.61	6.0	7.40	6018.6	1.65
LZT II	1534.61	5.7	7.8	5922.2	1.82
LZT III	1534.61	5.2	7.2	5891.4	1.70
LZT IV	1534.61	5.8	7.5	5756.6	2.17
LZT V	1534.61	6.3	6.9	5902.3	1.64
LZT VI	1534.61	5.1	7.7	5737.9	1.11
LZT VII	1534.61	4.7	7.9	5906.7	1.99
LZT VIII	1534.61	5.5	7.7	5867.4	1.25



Longterm Test

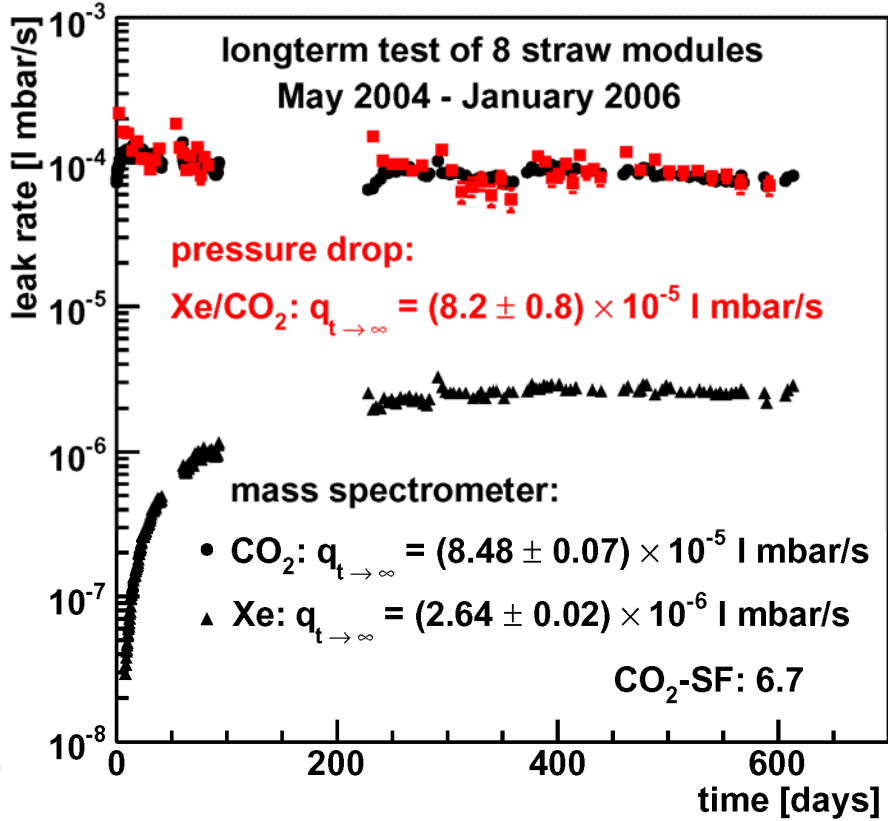
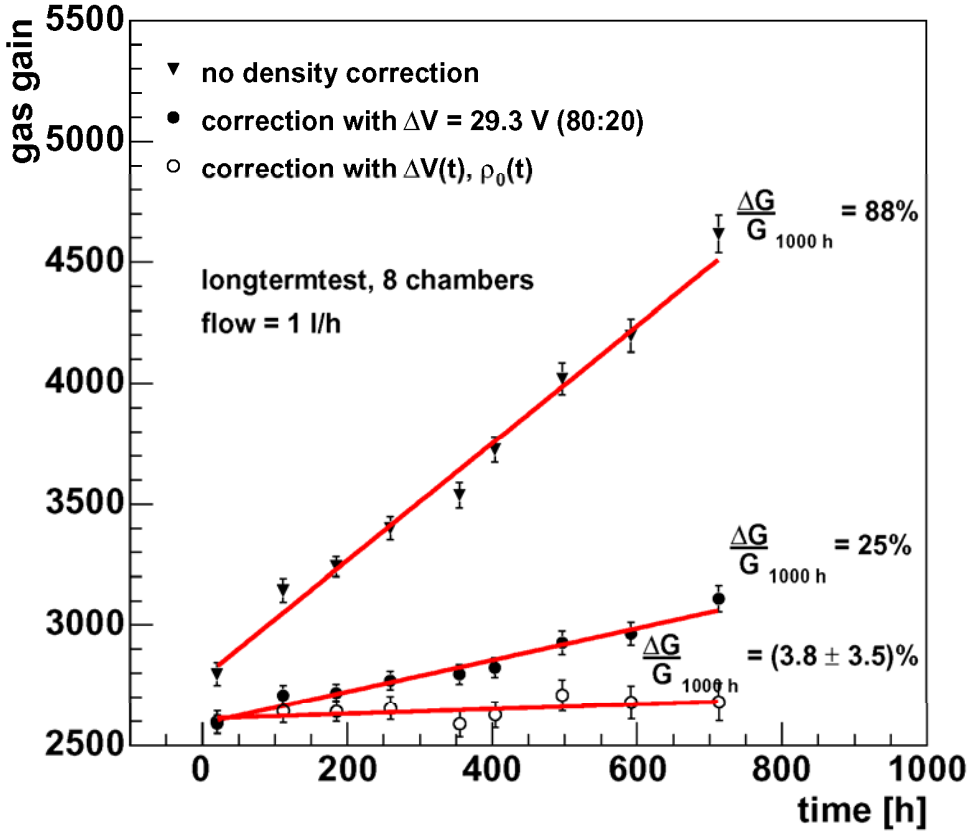
Stable Operation for 1.75 year

- 1 Gasgroup → 8 Modules
- Fe⁵⁵ – Monitoring
- Pressure-Drop Measurements
- Mass-Spectrometer Measurements

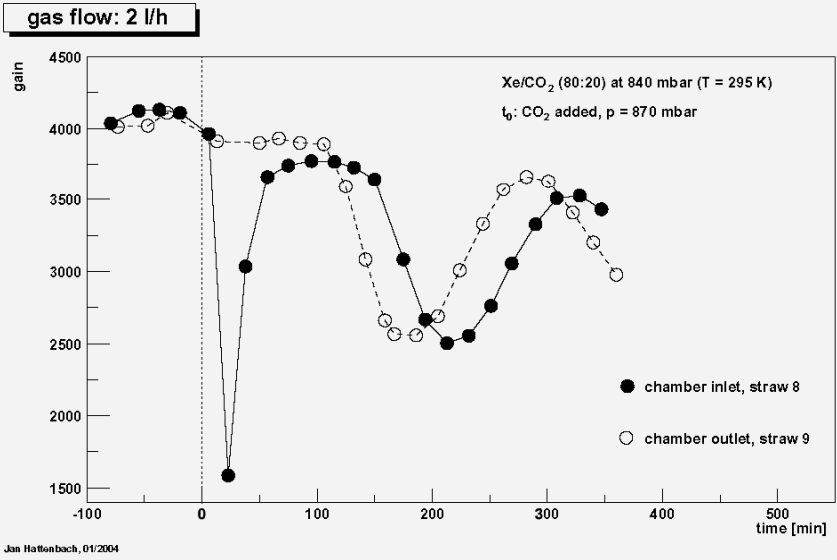
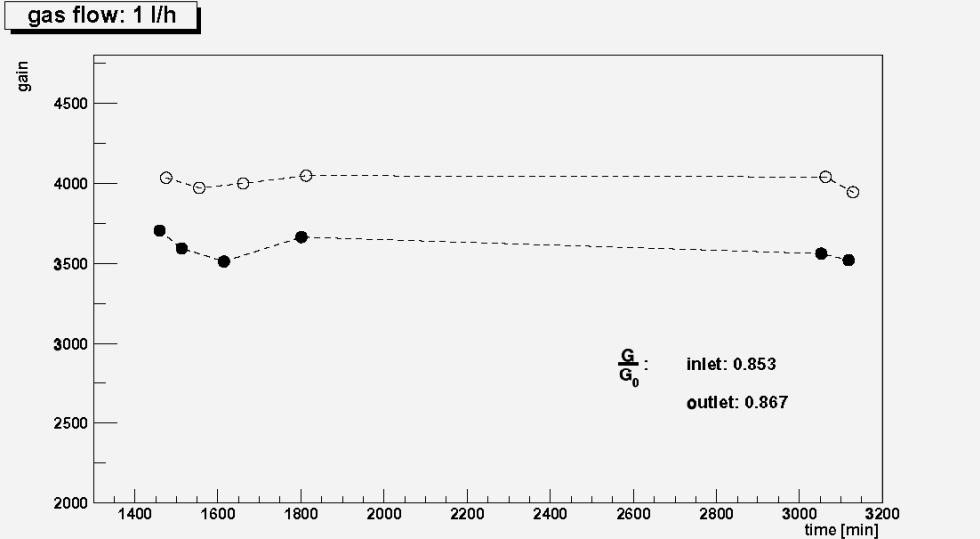
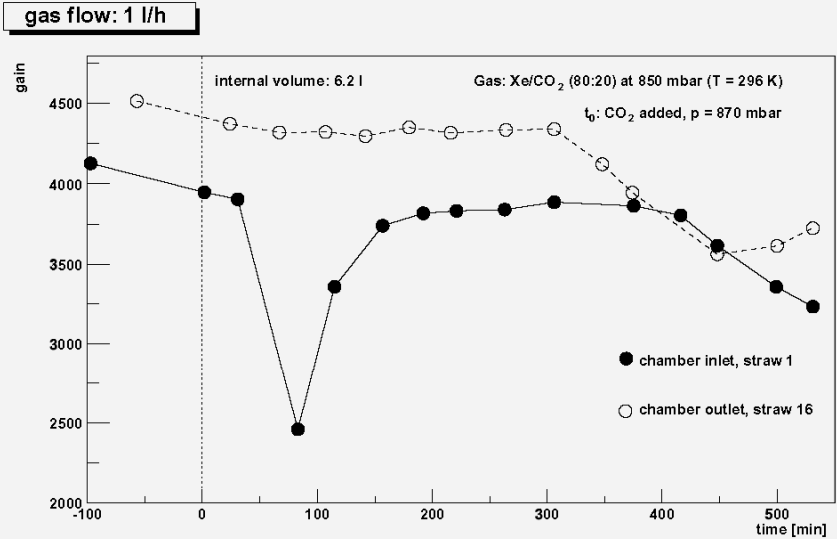


Longterm Test

Stable Operation for 1.75 year



Longterm Test – Gas Refreshment



ElectroMagnetic Interference Test

FE & DAQ EMI-Test



EMI Test @KMW Co. Munchen

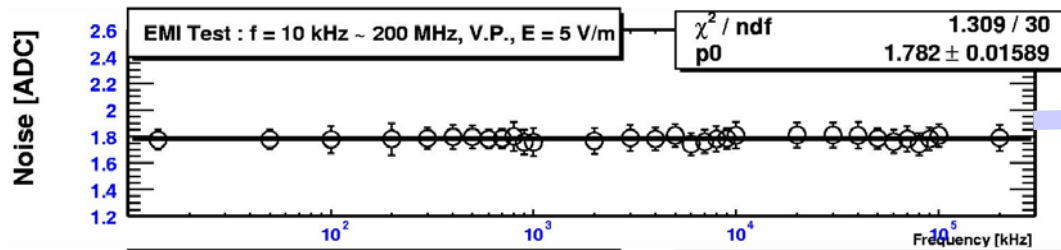
According to
“Space Station Electromagnetic Emission and
Susceptibility Requirements for the Electromagnetic
Compatibility”

SSP30237 paragraphs RS02, RS03, and RE02

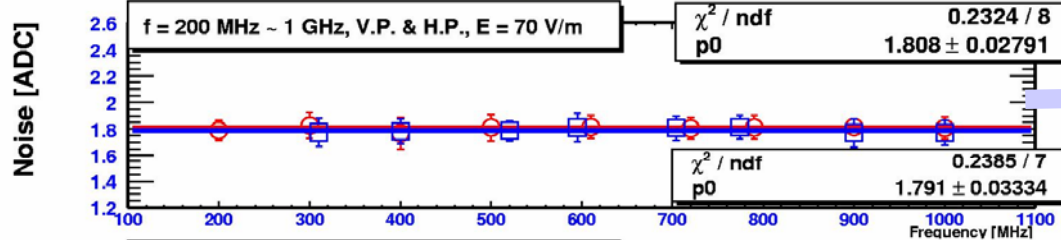


Wave : Horizontal / Vertical Polar.
Frequency range : 10 kHz ~ 1 GHz
Electric Field : 5 ~ 100 [V/ m]

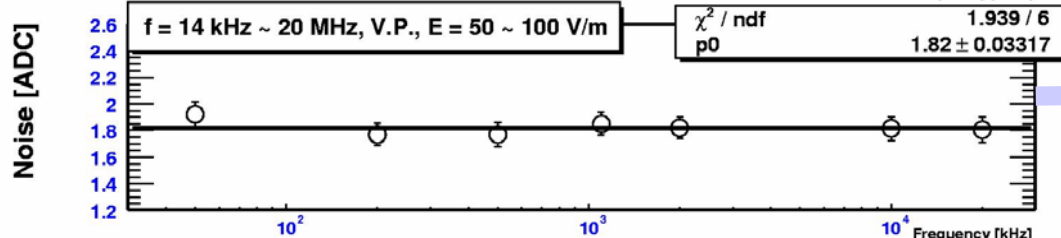
EMC Test : Susceptibility



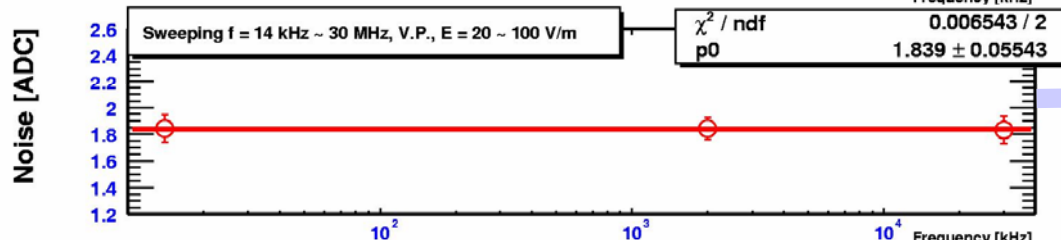
Freq. = 10 kHz ~ 200MHz
 $|E|_{\text{rms}} = 5 \text{ [V/m]}$ w. V.P.
Noise VP = 1.782 +/- 0.0159[ADC]



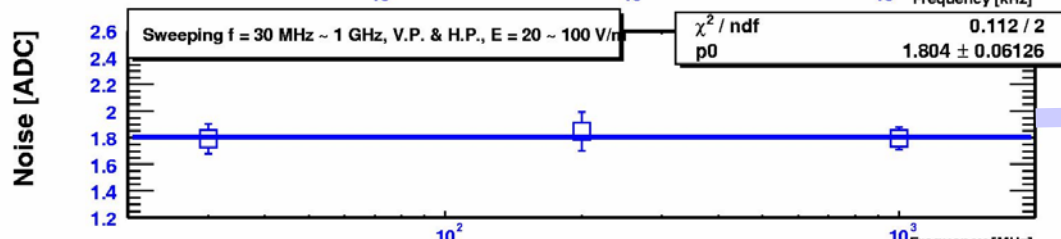
200MHz ~ 1GHz, 70 [V/m]
Noise VP = 1.808 +/- 0.0279[ADC]
Noise HP = 1.781 +/- 0.0333[ADC]



14kHz ~ 20MHz, 50~100[V/m]
Noise VP = 1.82 +/- 0.0332[ADC]

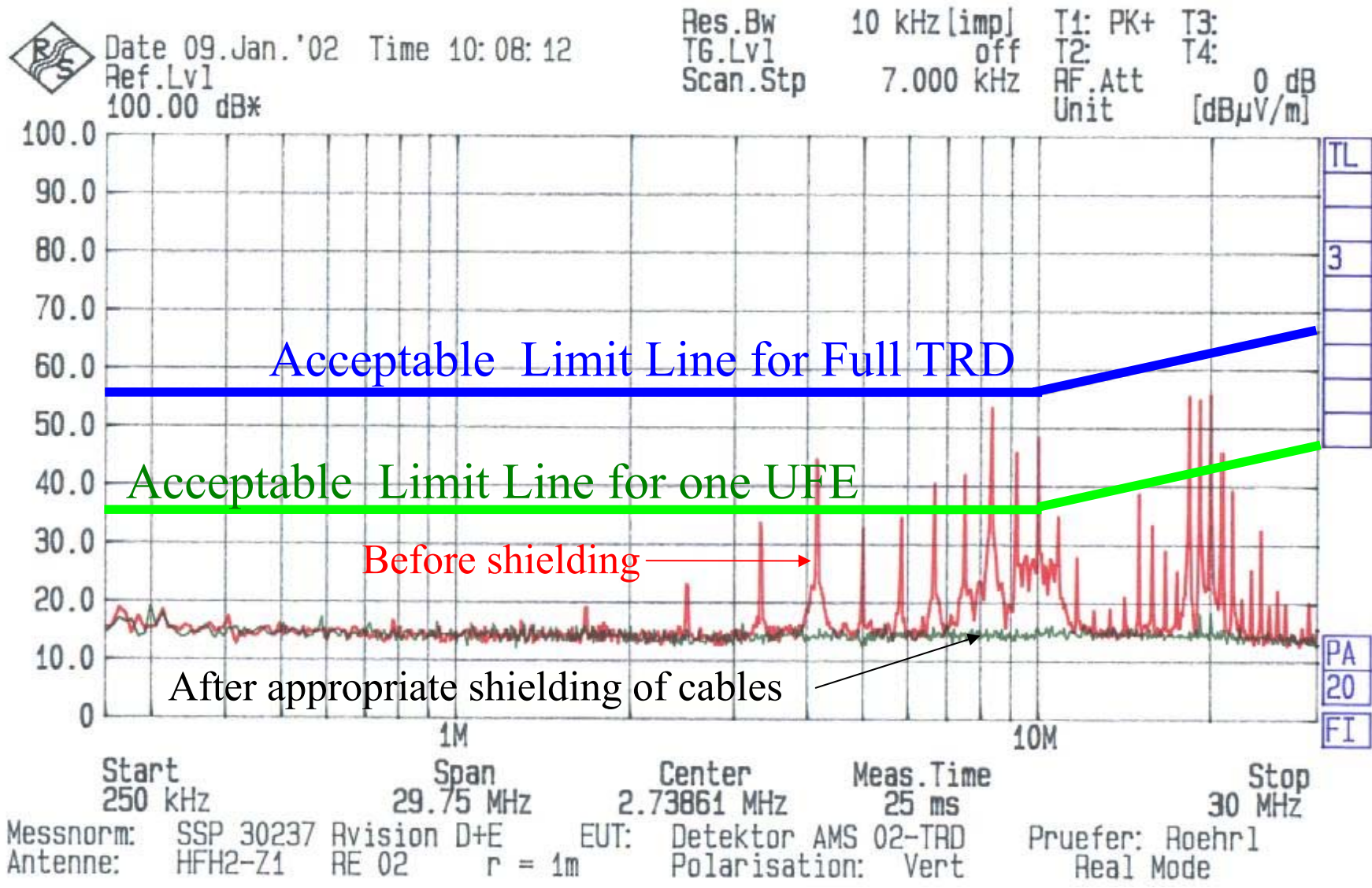


Sweeping Freq. = 14 kHz ~ 30MHz
 $|E|_{\text{rms}} = 20 \sim 100 \text{ [V/m]}$ w. V.P.
Noise VP = 1.839 +/- 0.0554[ADC]



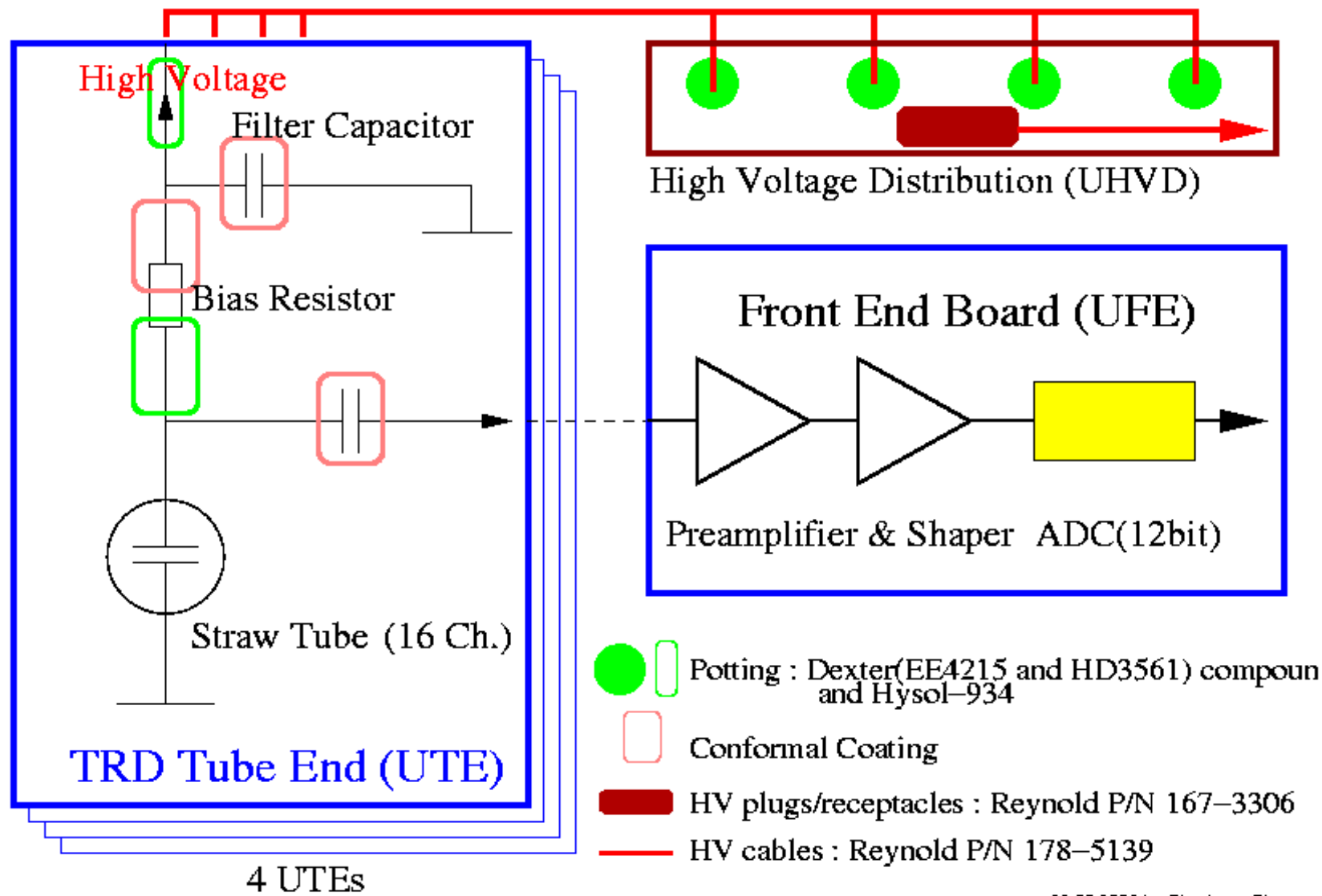
Sweeping Freq. = 30MHz ~ 1GHz
 $|E|_{\text{rms}} = 20 \sim 100 \text{ [V/m]}$ w. V(H).P.
Noise V&H = 1.804 +/- 0.0613[ADC]

EMC Test : Emission from one TRD UFE board



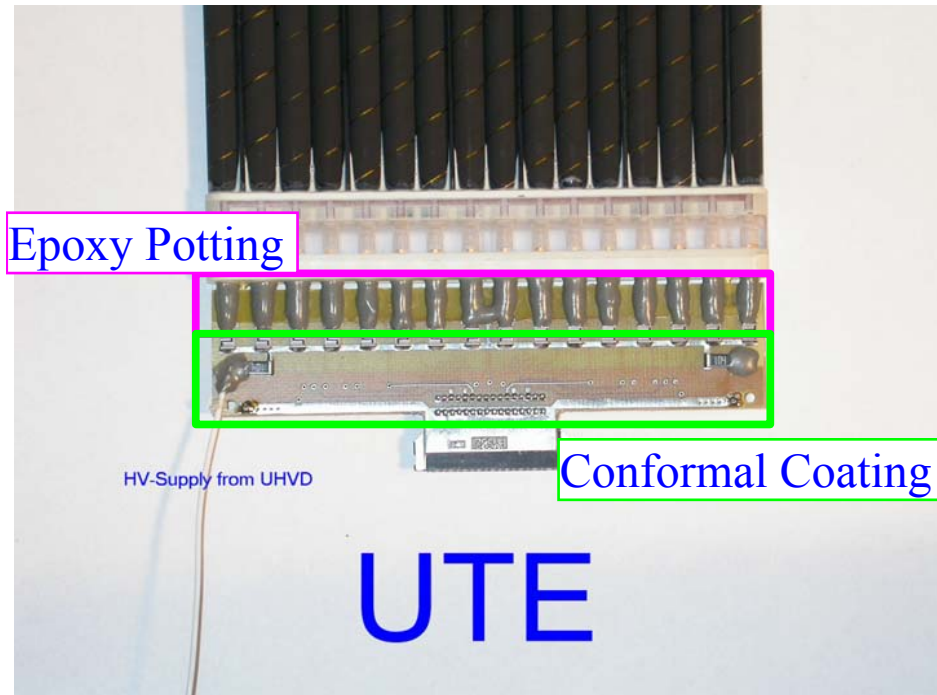
Corona (Local Discharge) Test

Layout of TRD HV components

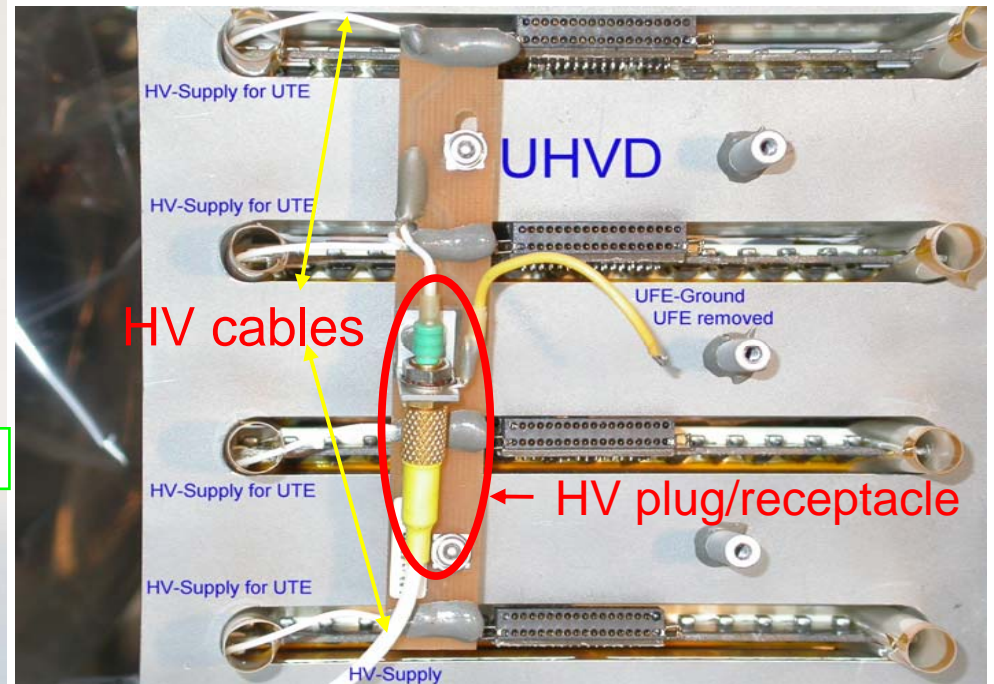


29.03.2005 by Chanhoon Chung

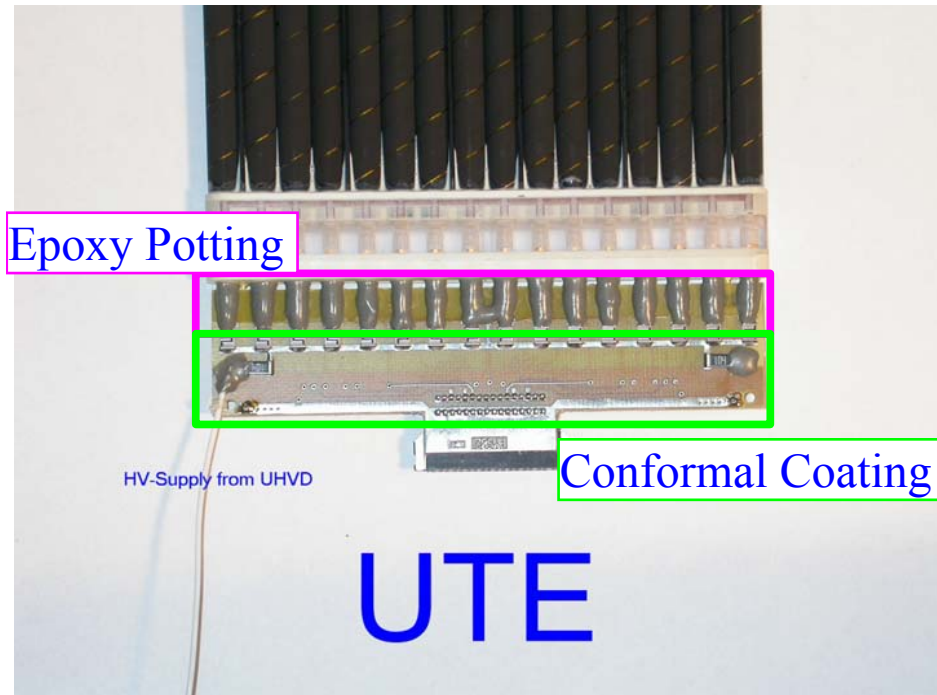
Straw Module UTE-board



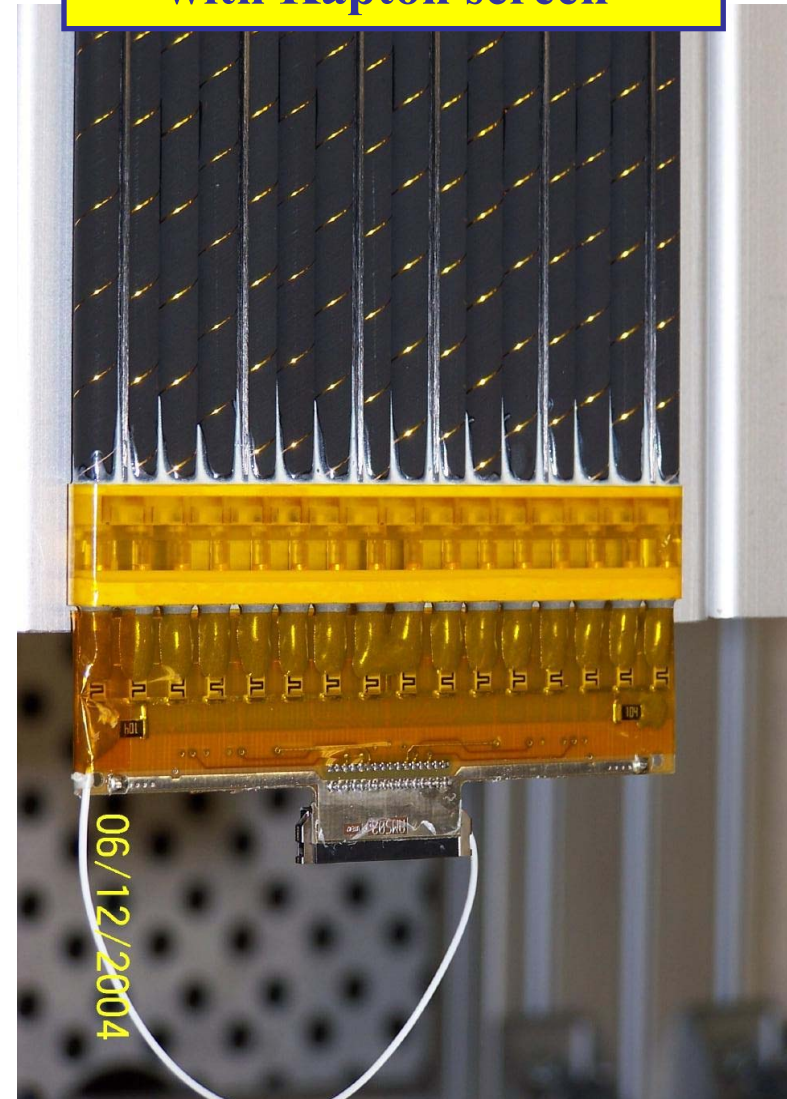
HV-Distribution (UHVD) board



Straw Module UTE-board

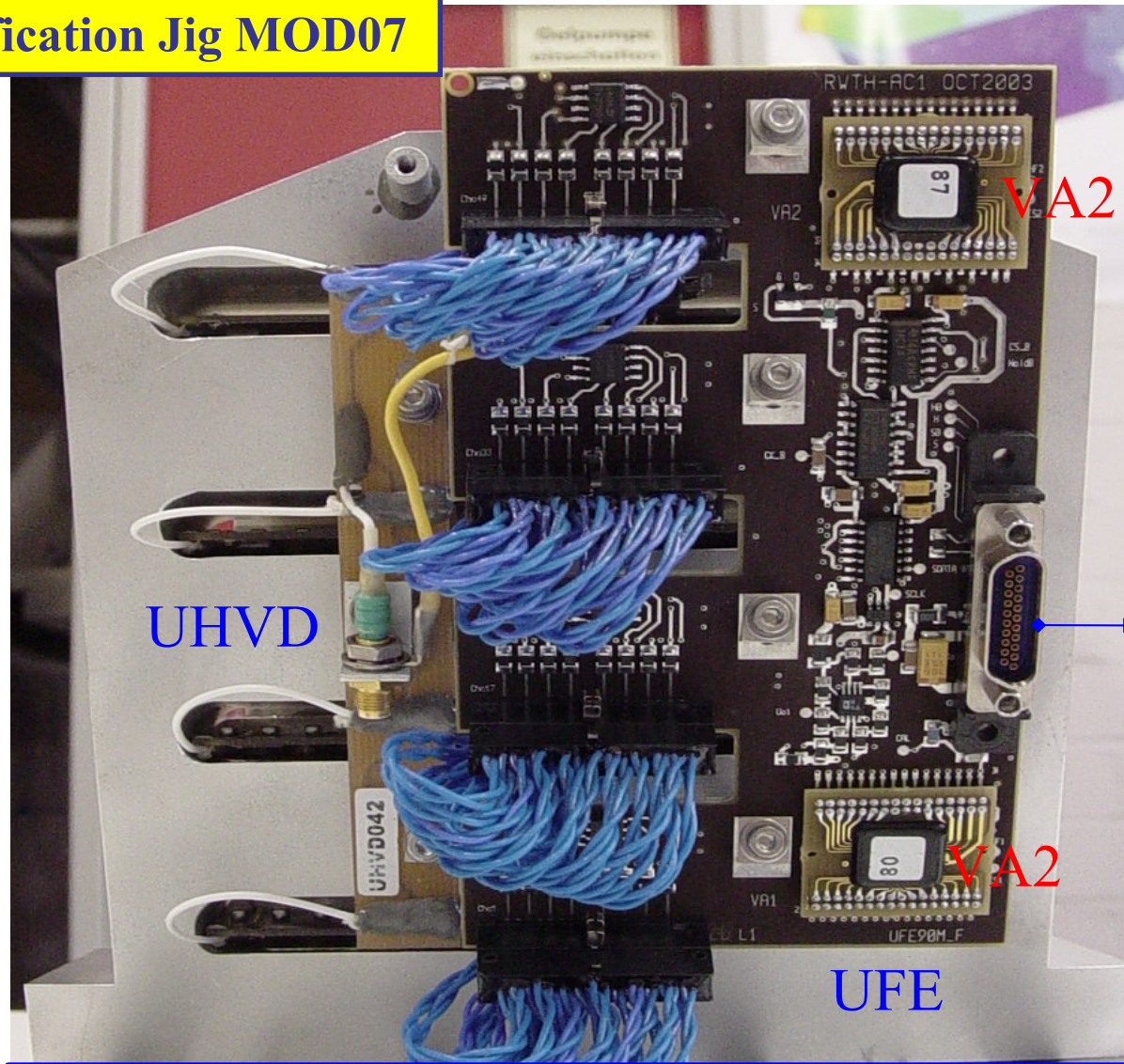


Straw Module UTE-board with Kapton screen



Space Qualification Jig MOD07

Octagonl-Like Al. Panel



UHVVD

VA2

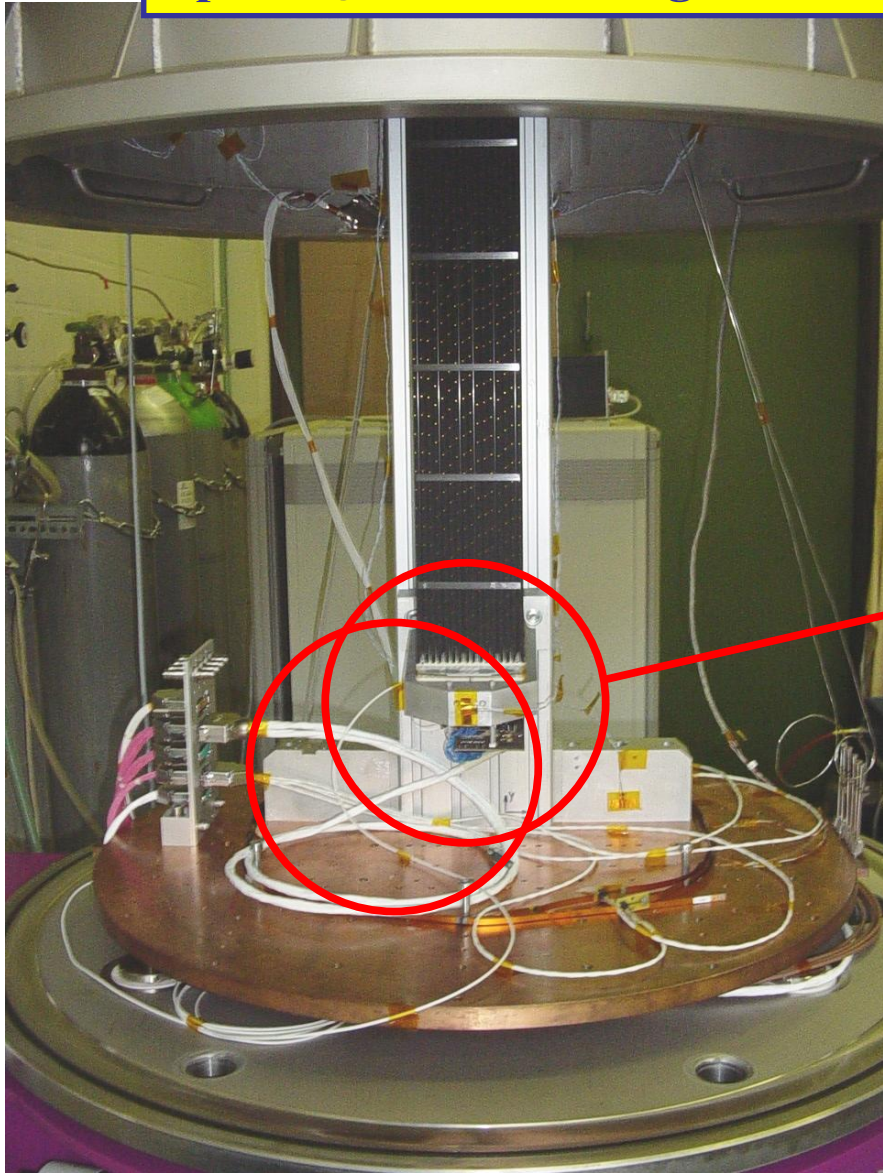
To UDR2

VA2

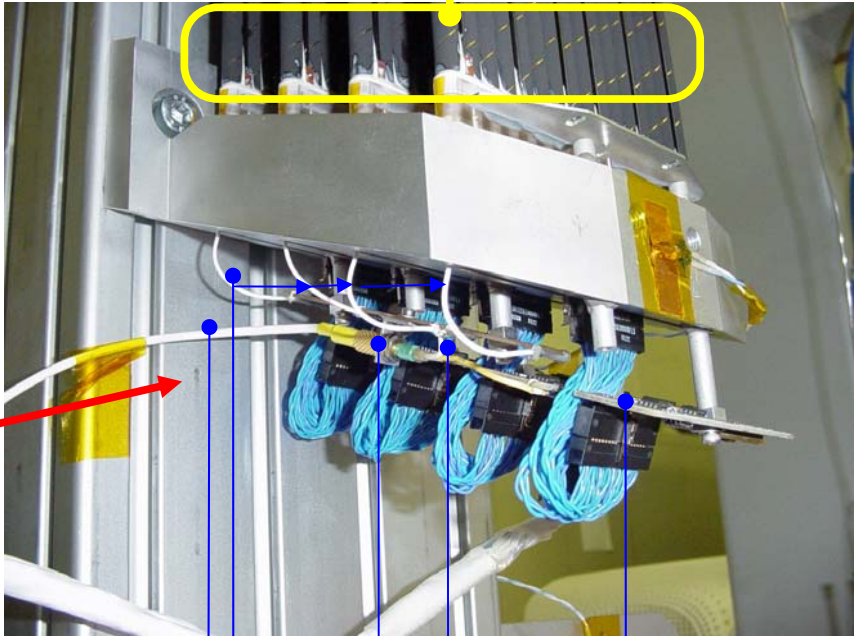
UFE

Complete Single HV & Readout Unit

Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

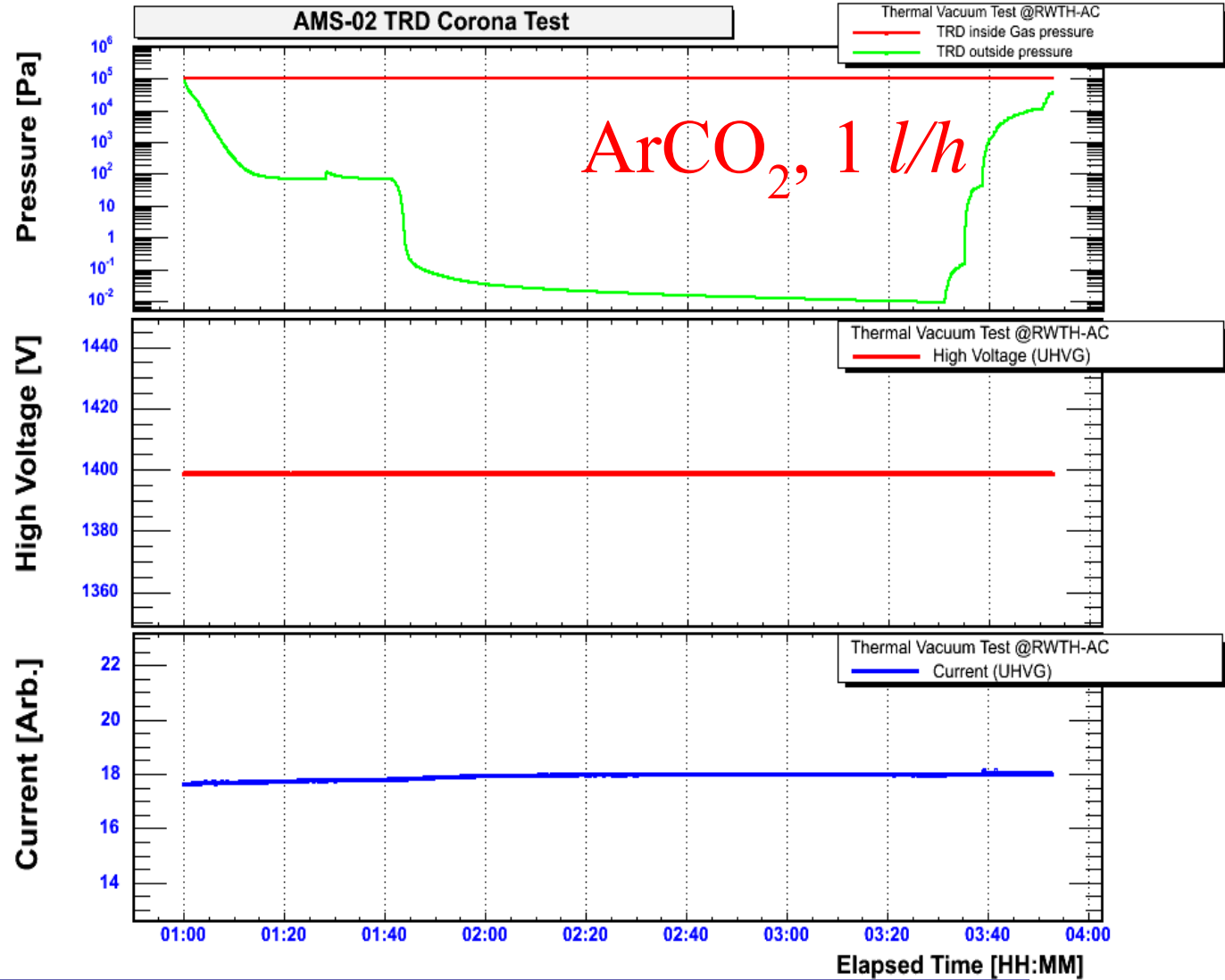


TRD 4 layers straw modules



HV Cables
HV Plug/Receptacle
UHVD^{UFE}

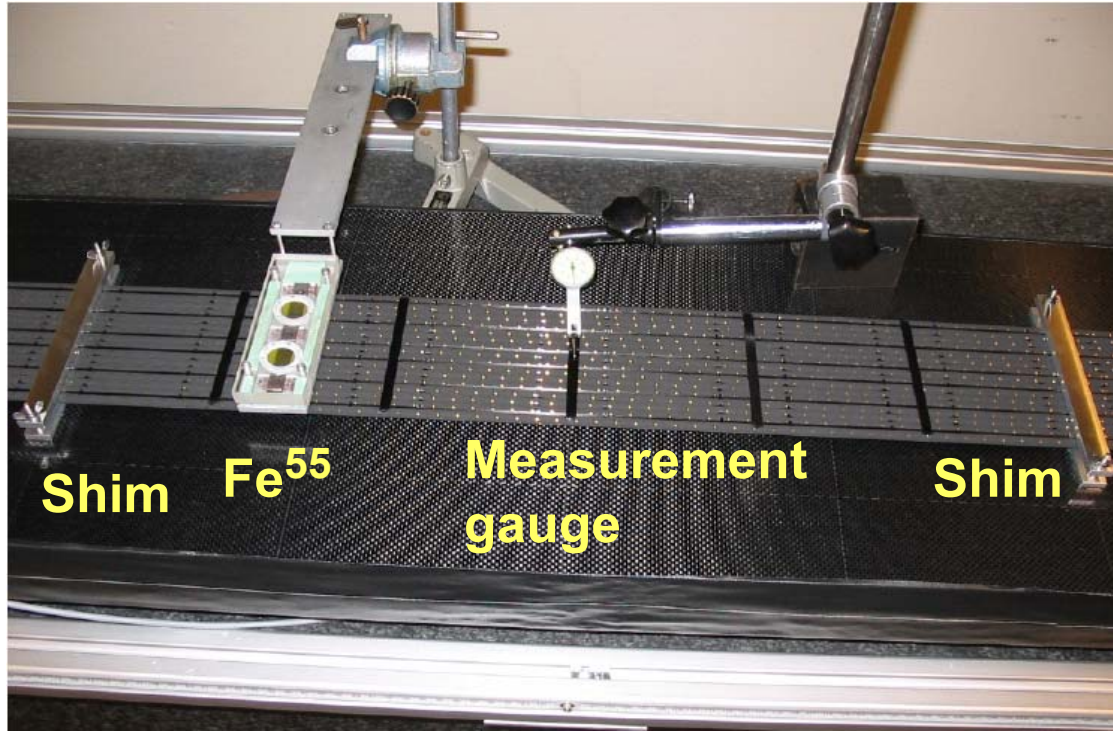
Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen



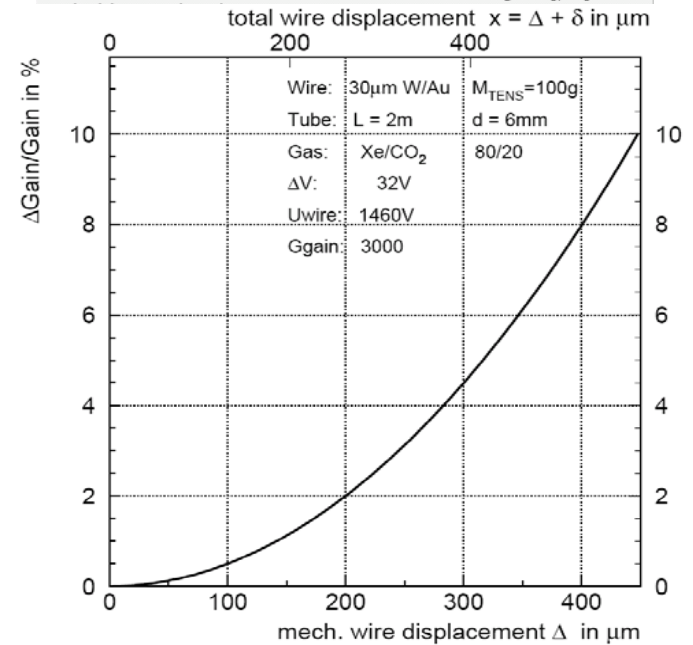
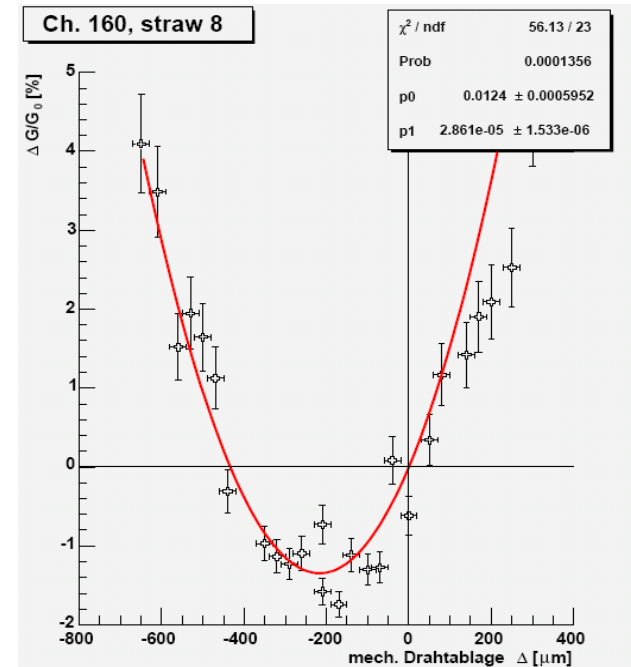
With Kapton Screening of UTE-boards no Corona discharges observed!

Controlled Module-Shimming Test Comparison of Gasgain Measurement and X-Ray Tomography

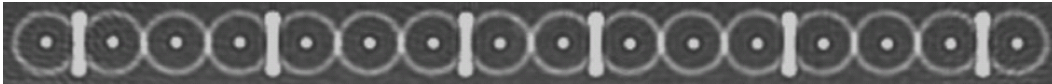
Fe⁵⁵ – Gasgain-Measurement for wire displacement detection



Controlled Modul-Shimming



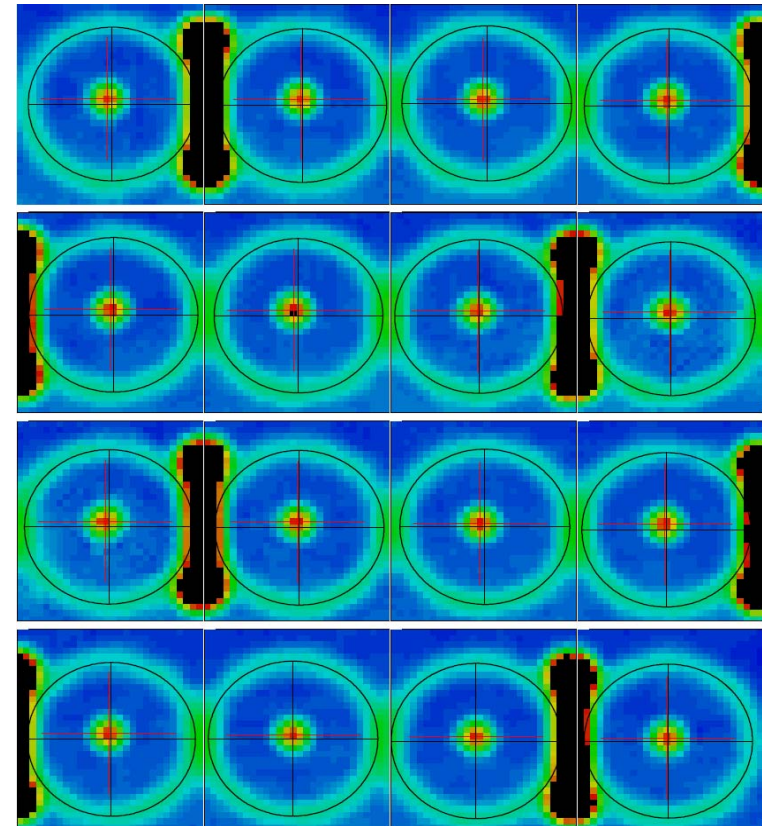
Computer Tomography X-ray for wire displacement detection



Dicom Image File



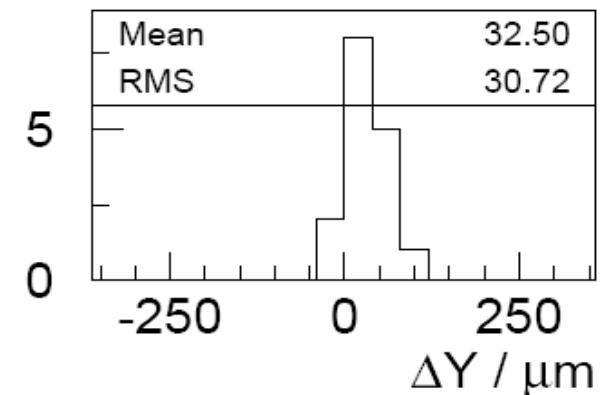
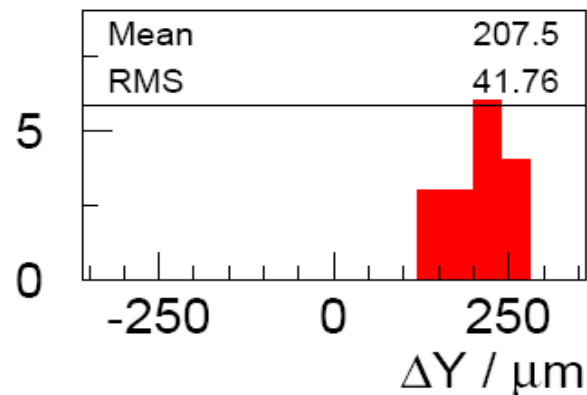
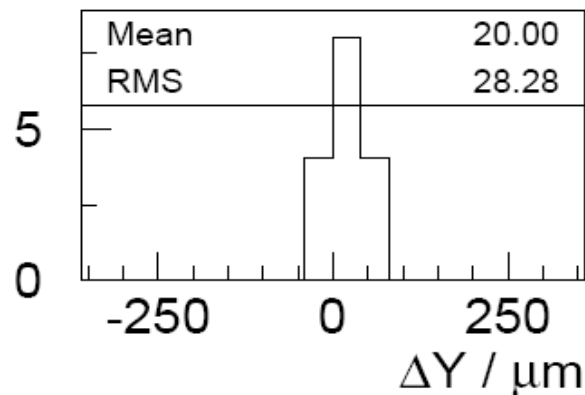
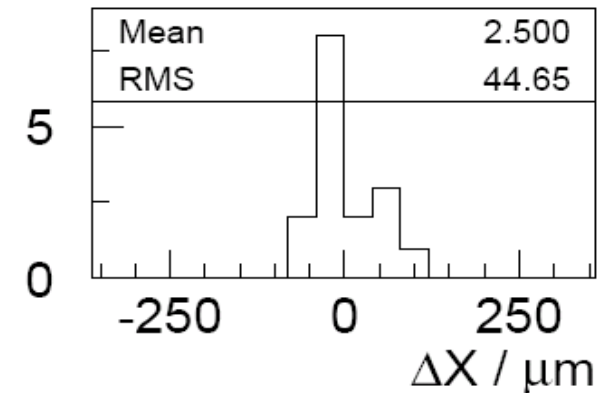
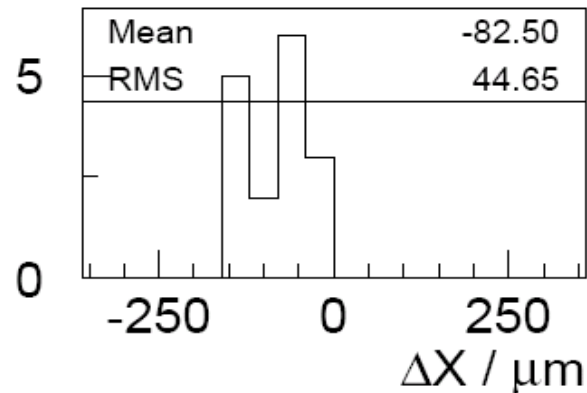
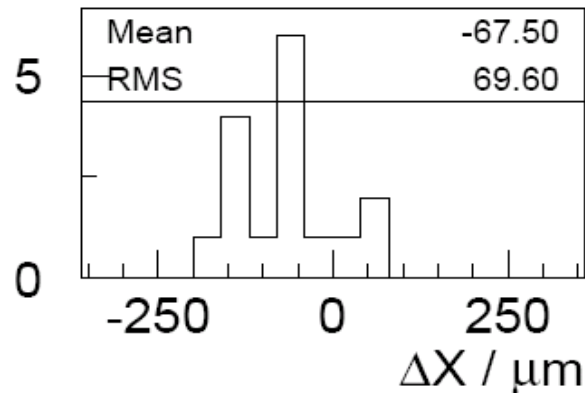
Luisenhospital Aachen (GE 16-Channel CT)



Wire- and Tube-xy-Fit ($\sigma \approx 10 \mu\text{m}$)

Computer Tomography X-Ray for wire displacement detection

Controlled Shimming of +200 μm y-direction in middle of module



GAS-SIDE

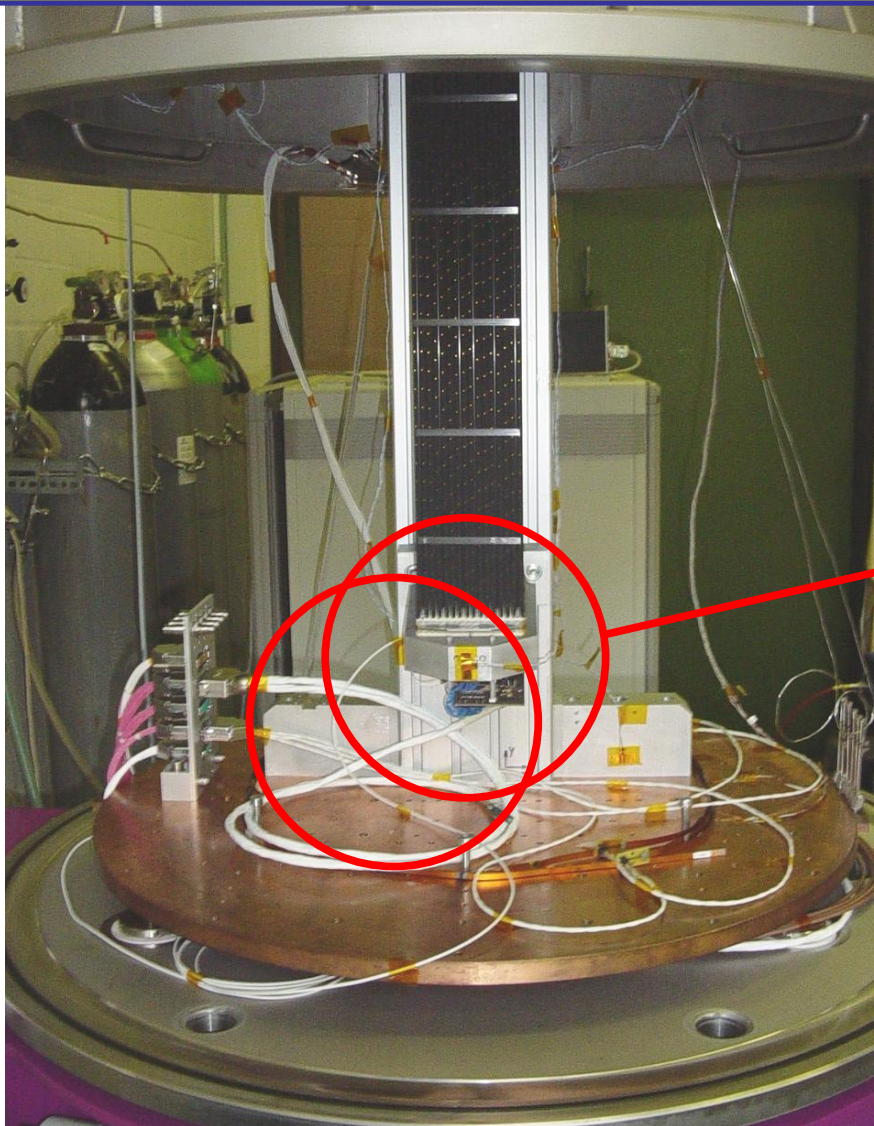
CENTER

READOUT-SIDE

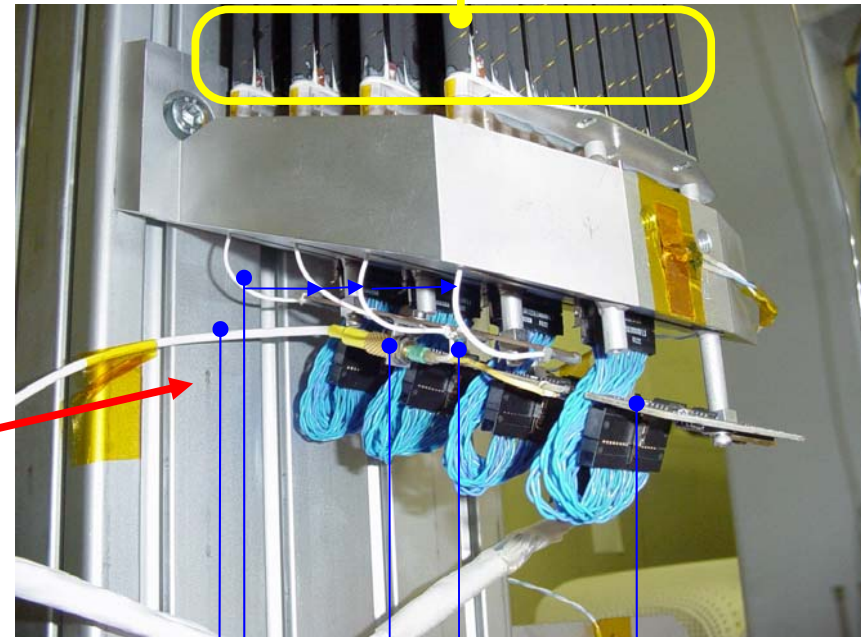
Operation of 4 TRD Modules (MOD07) in TVT

- **Experimental Setup**
- **Gain (Temperature)**
- **Temperature Cycles for functional tests**
- **Characteristics of pedestal and noise**
- **Gas-tightness Measurements**
- **Gain (HV)**

Space Qualification Jig MOD07 mounted on CFC
@ TVT Teststand RWTH Aachen

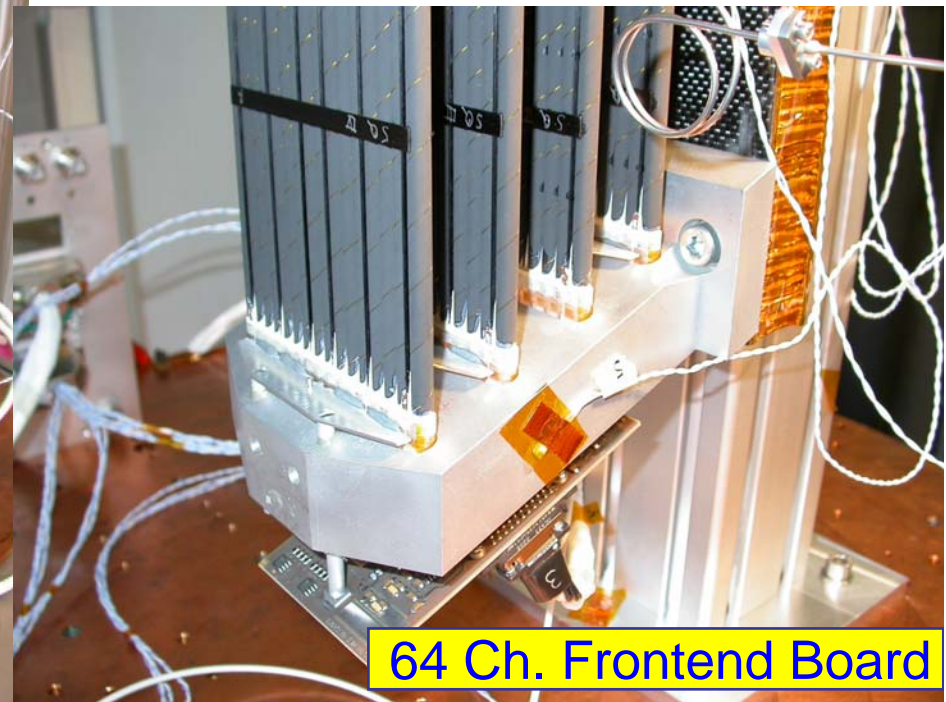
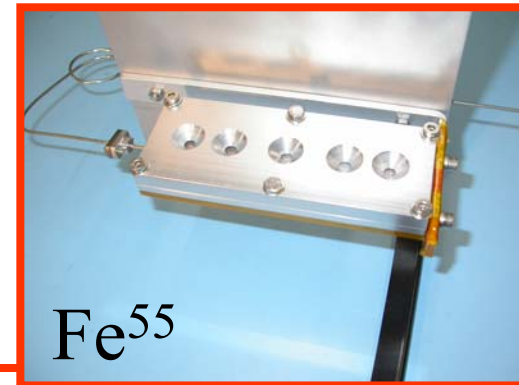
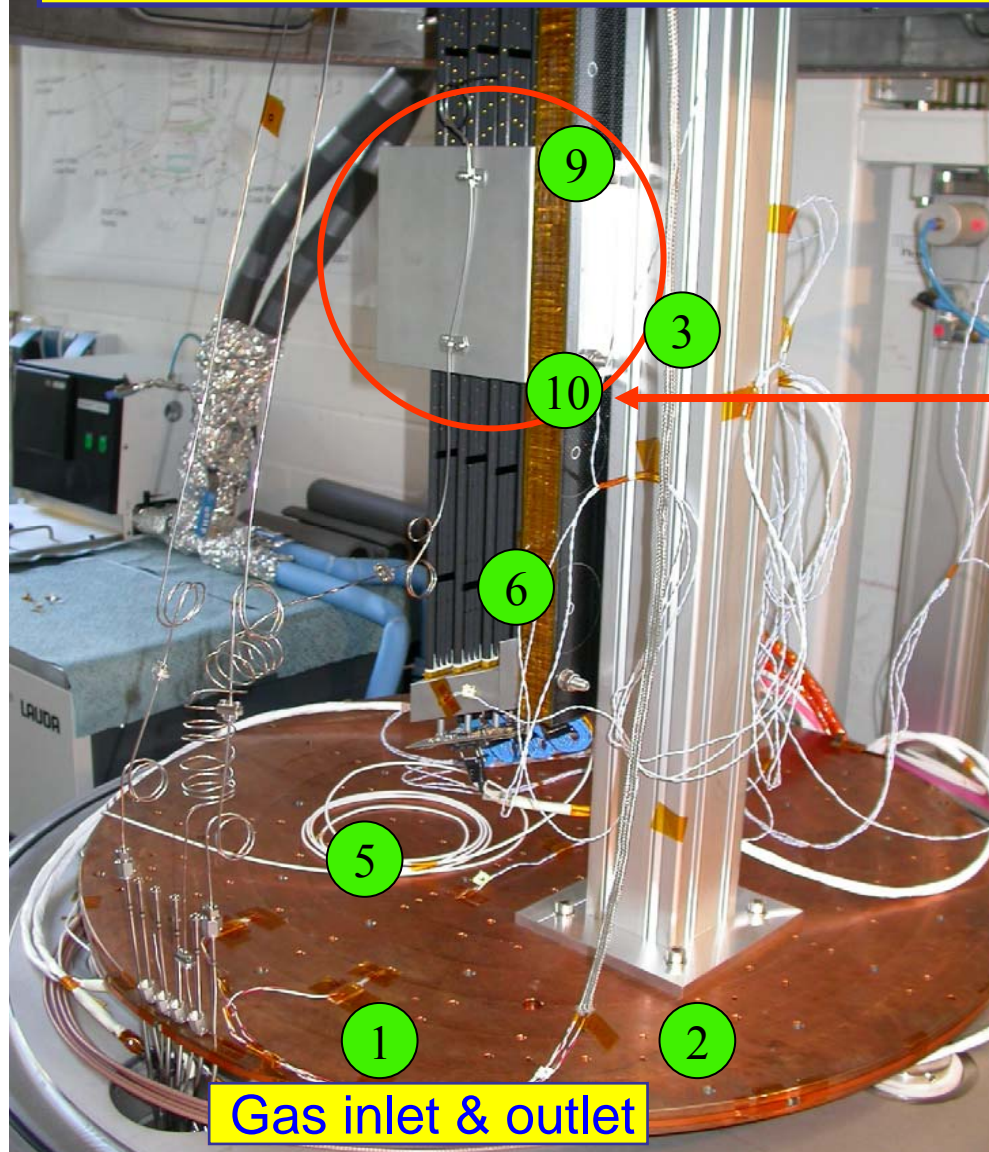


TRD 4 layers straw modules



HV Cables
HV Plug/Receptacle
UHVD^{UFE}

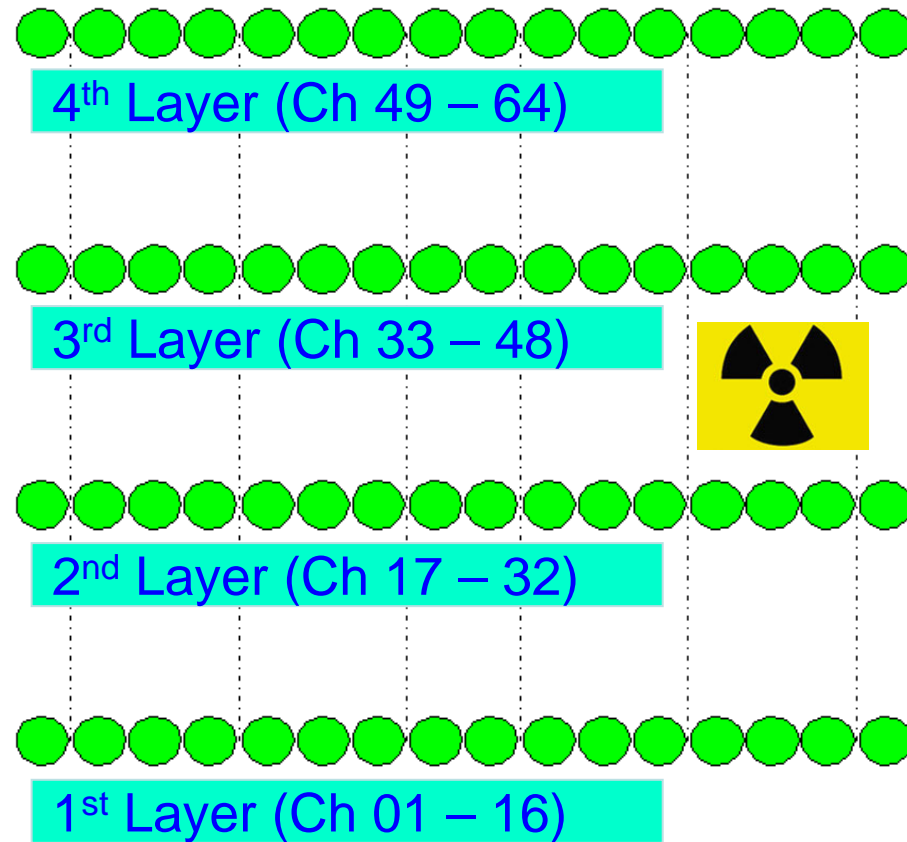
Space Qualification Jig MOD07 mounted on CFC @ TVT Teststand RWTH Aachen



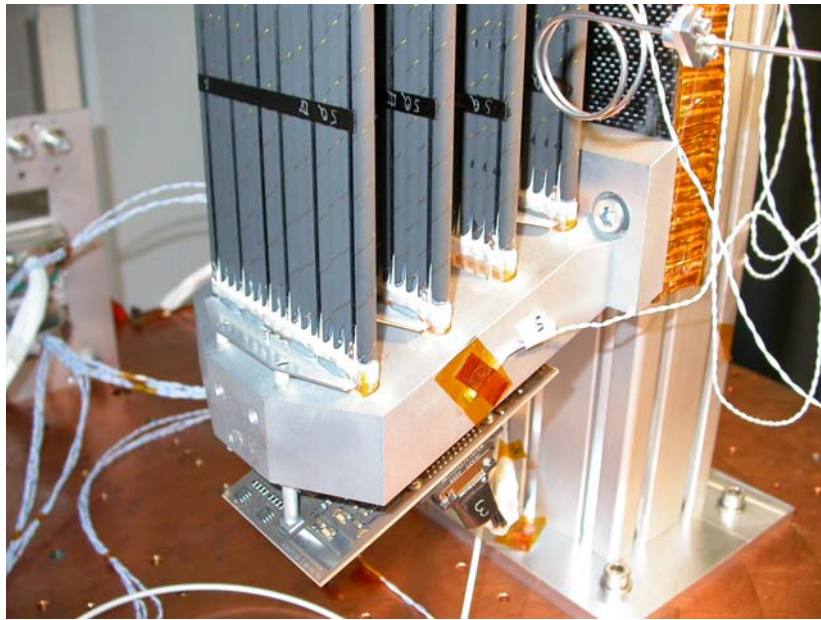
TRDTN 1

Aachen, 19th February 2009

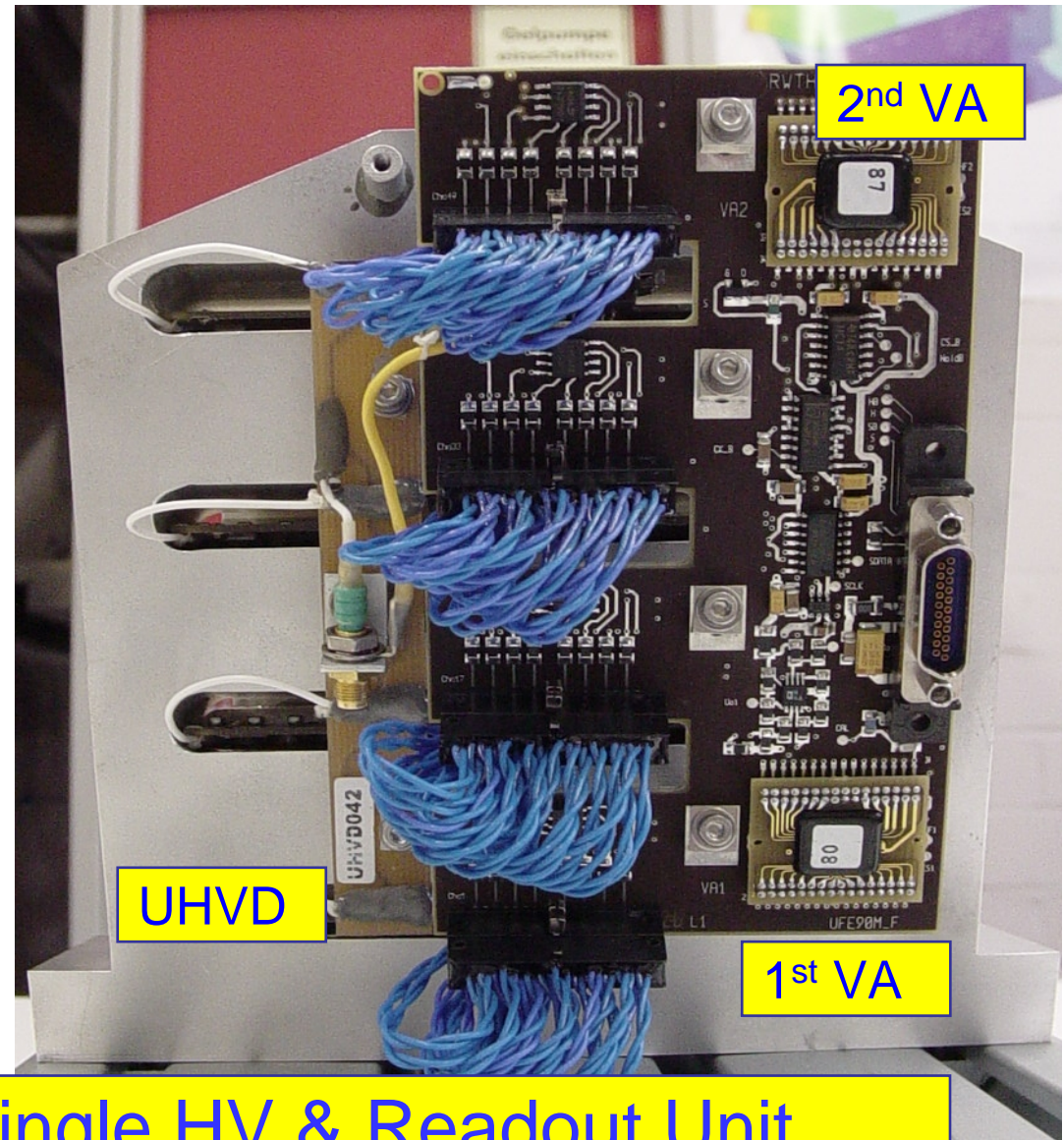
Space Qualification Jig MOD07 mounted on CFC @ TVT Teststand RWTH Aachen



Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen DAQ

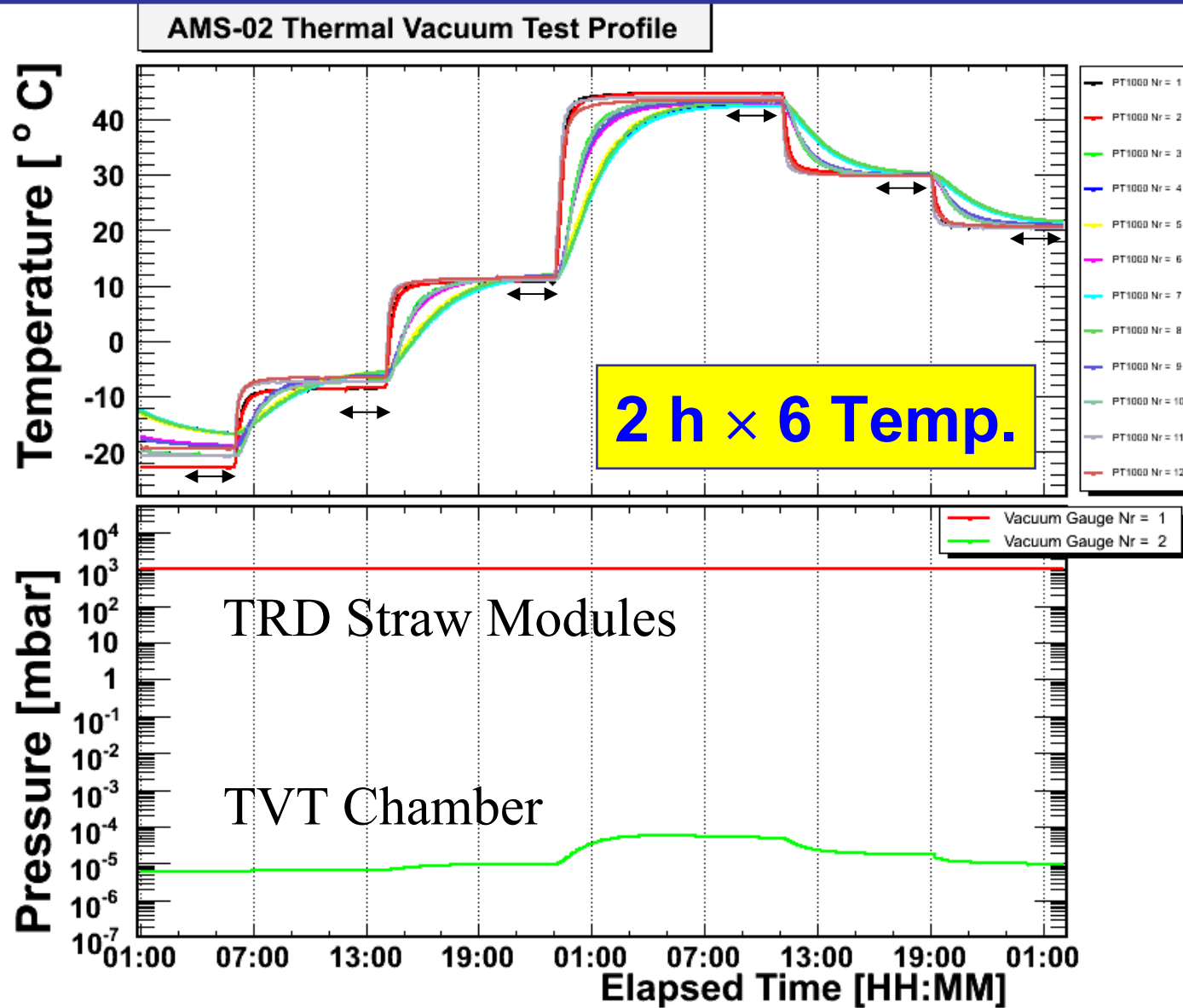


64 Ch. Front-End Board (UFE)



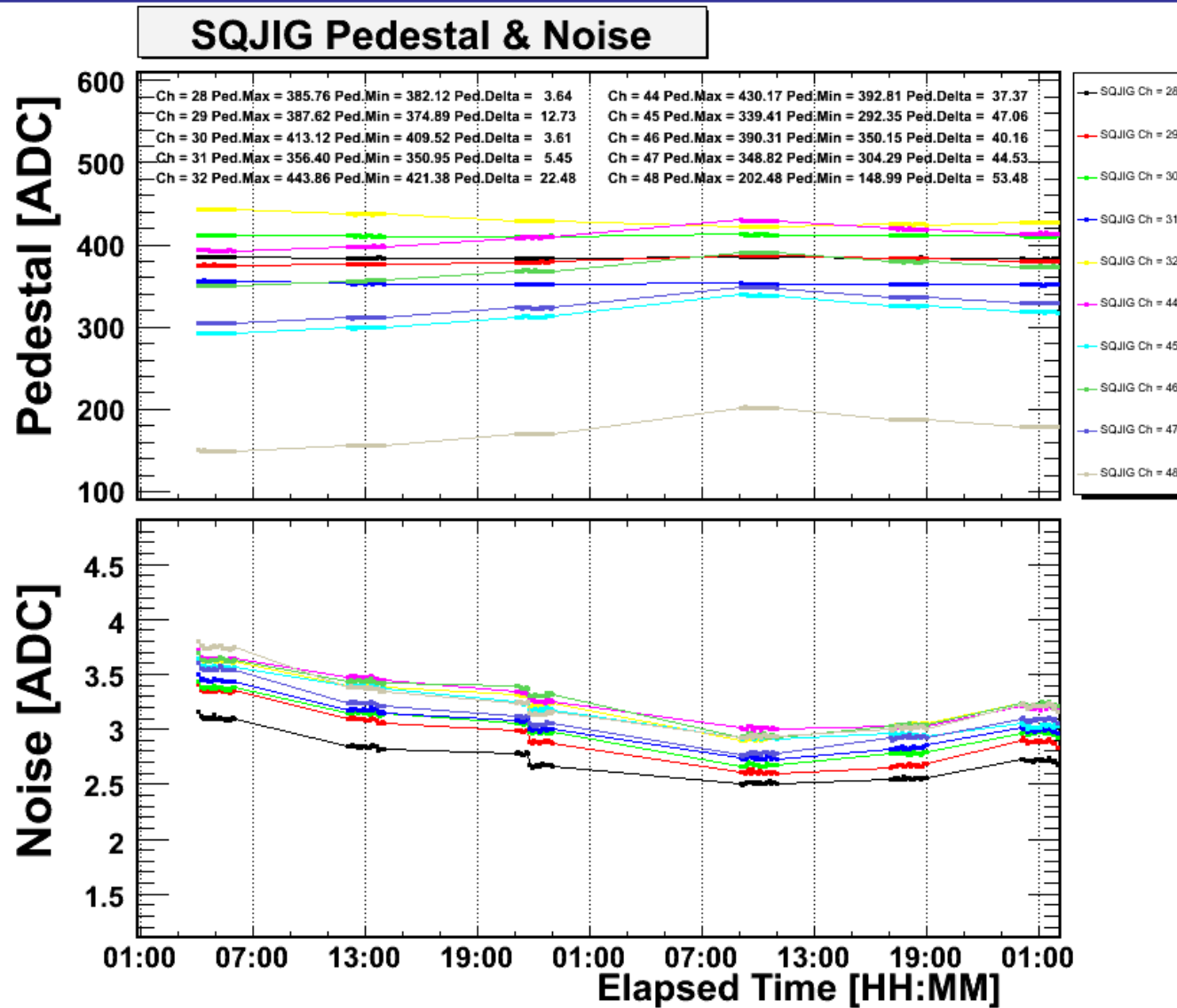
TRD Complete Single HV & Readout Unit

Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen Cycles



Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

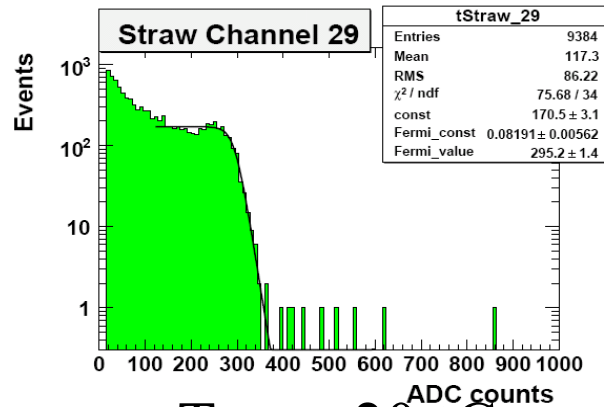
Pedestal and Noise



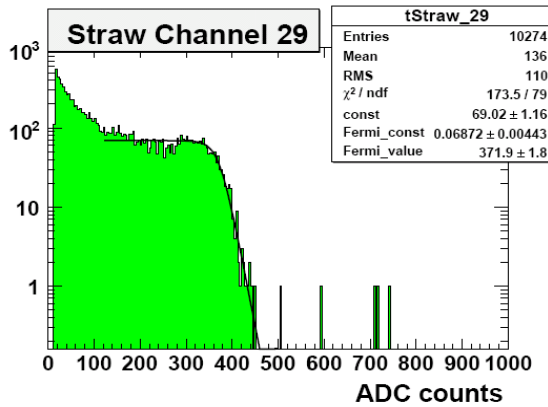
Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Fe55 Signals

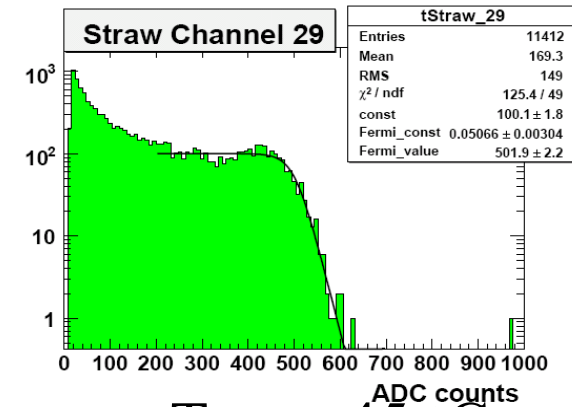
$T_s = -25\text{ }^\circ\text{C}$



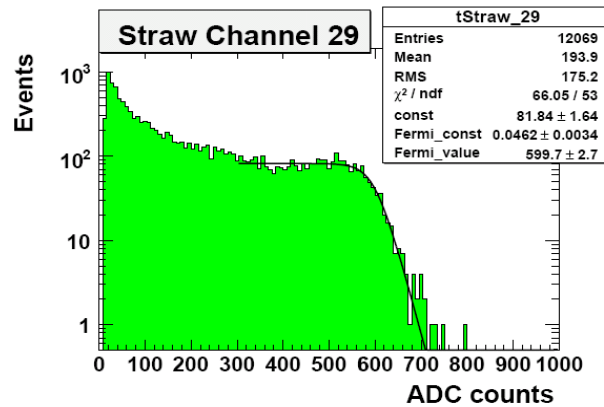
$T_s = -10\text{ }^\circ\text{C}$



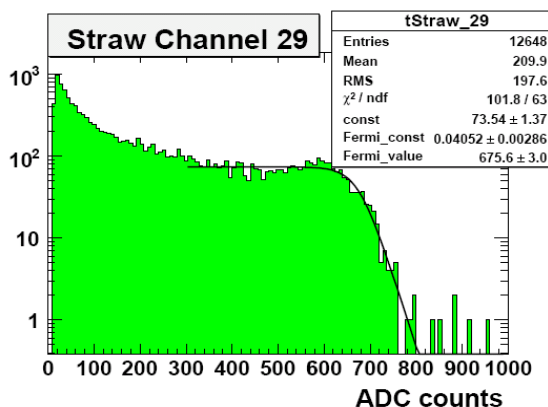
$T_s = +10\text{ }^\circ\text{C}$



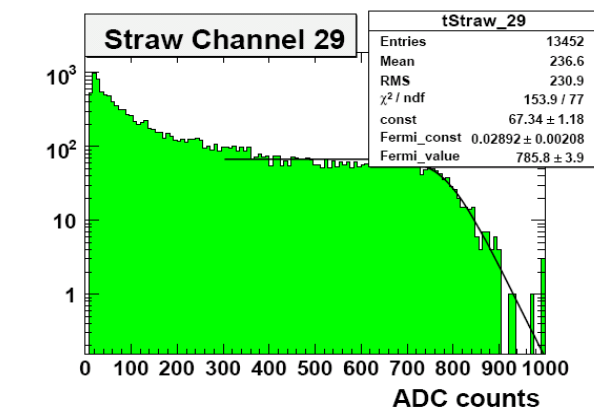
$T_s = +20\text{ }^\circ\text{C}$



$T_s = +30\text{ }^\circ\text{C}$



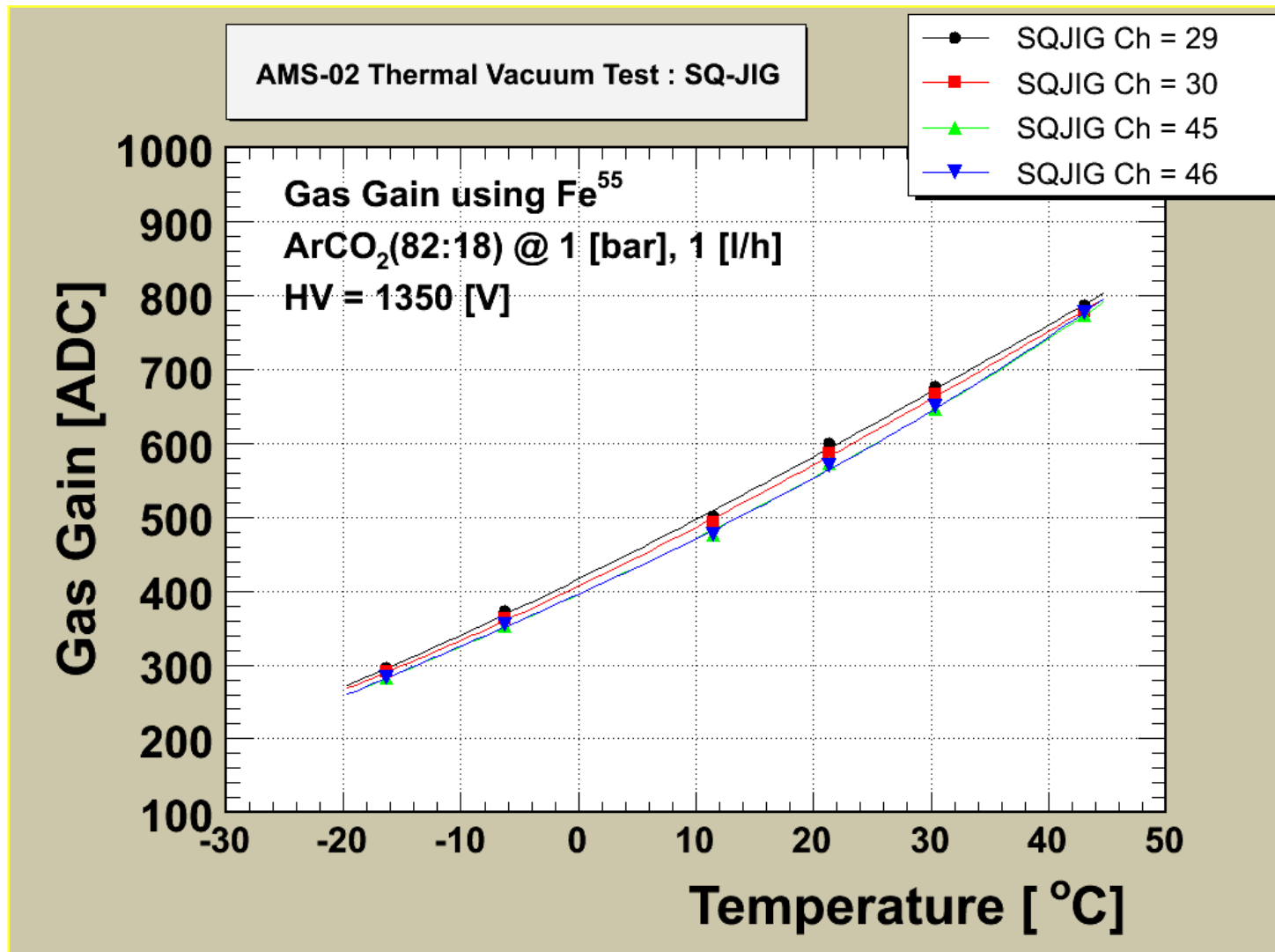
$T_s = +45\text{ }^\circ\text{C}$



Fermi Function Used to Fit : $F(x) = a / [e^{b(x-c)} + 1]$

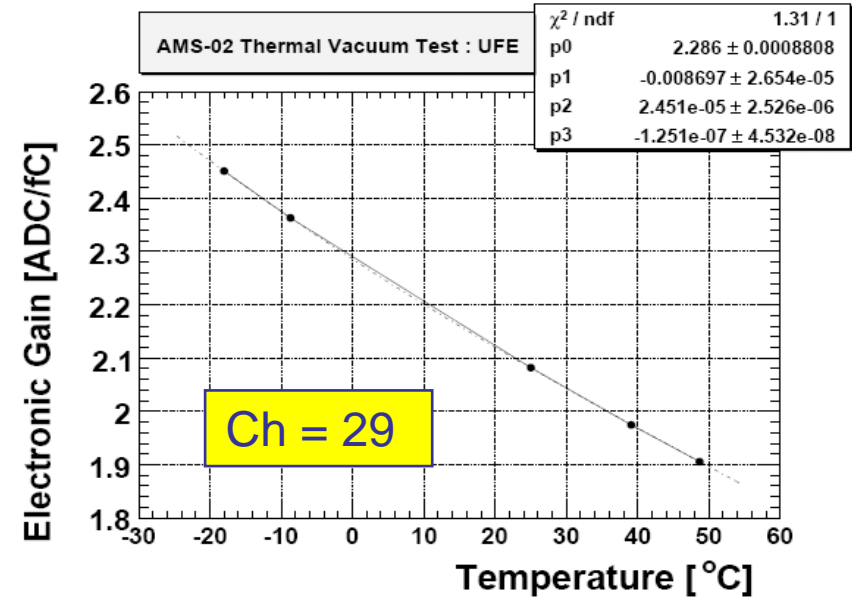
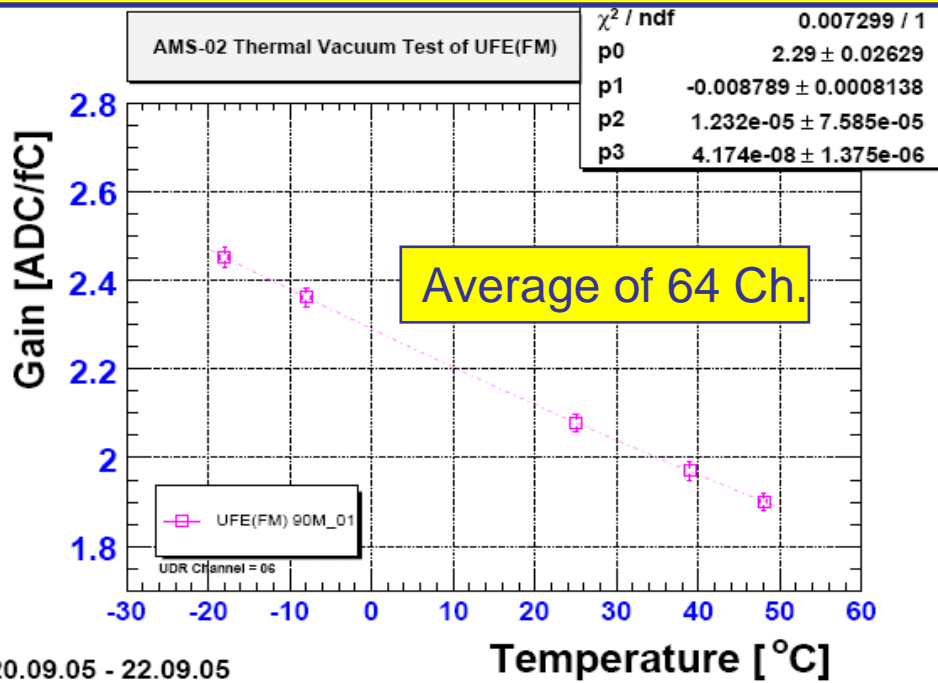
Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Gas Gain vs Temperature

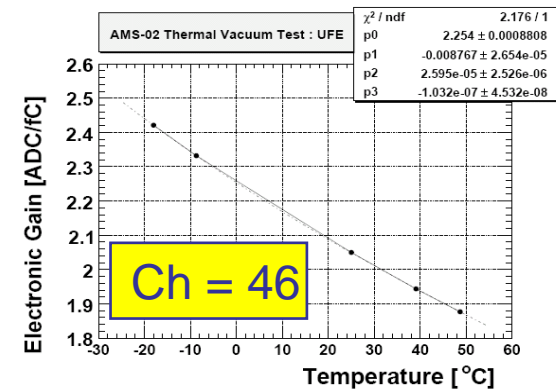
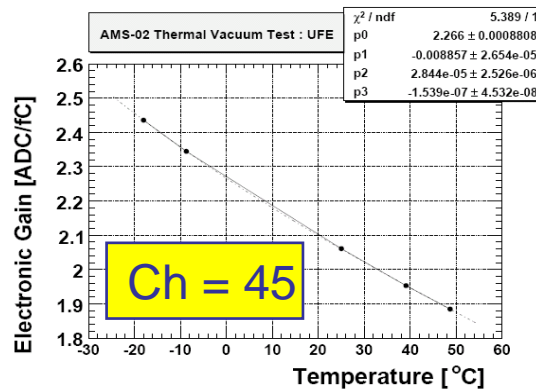
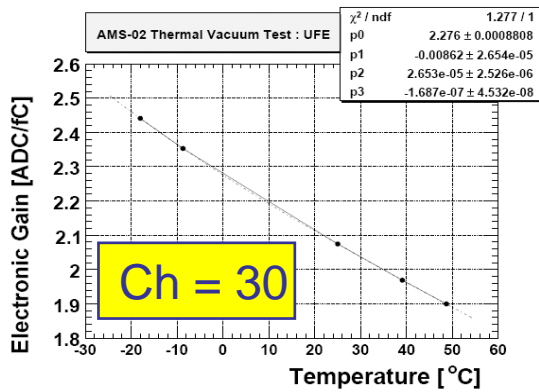


Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

UFE: Gain Correction



20.09.05 - 22.09.05



TRDTN 1

Aachen, 19th February 2009

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Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Diethorn Formula

$$\ln G = \frac{\ln 2 \times V}{\ln(b/a) \times \Delta V} \ln \left(\frac{V}{\ln(b/a) \times a \times E_{\min} \times (\rho / \rho_0)} \right)$$

Using $\rho = \rho_0 \times p_r / T_r$: $p_r = \frac{p}{p_0}$, $T_r = \frac{T}{T_0}$

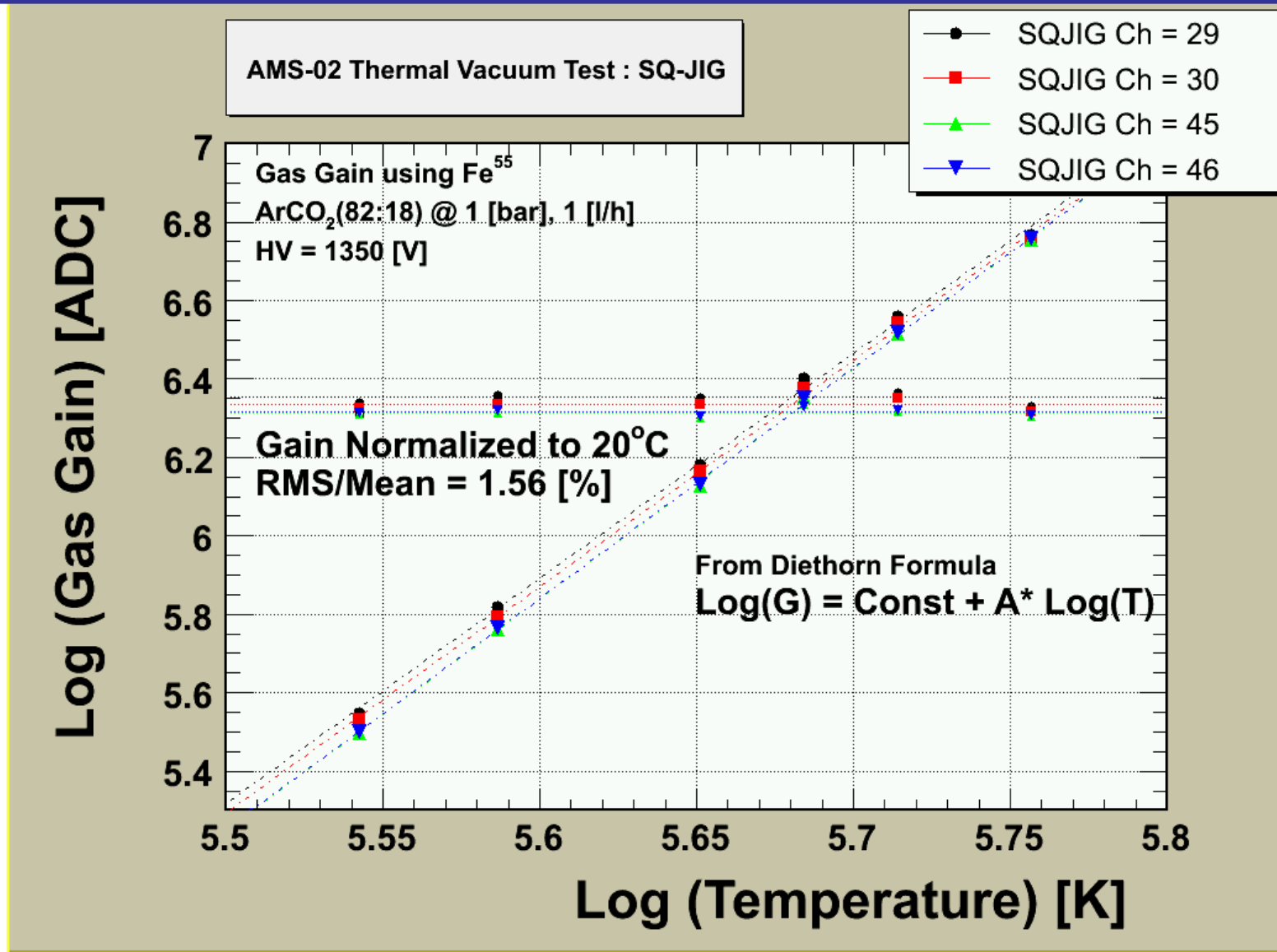
$$\frac{\ln G \times \ln(b/a)}{V} = \frac{\ln 2}{\Delta V} \times \ln \left(\frac{V}{\ln(b/a) a p_r / T_r} \right) - \frac{\ln 2}{\Delta V} \ln(E_{\min})$$

a : anode wire radius b : cathode inner radius T : temperature ($T_0 = 273.15\text{K}$)
 V : applied voltage ρ : gas density p : gas pressure ($p_0 = 1.013 \times 10^5 \text{ Pa}$)

ΔV : average potential required to produce one more electrons in the gas
 E_{\min} : minimal field needed for electron to be multiplied

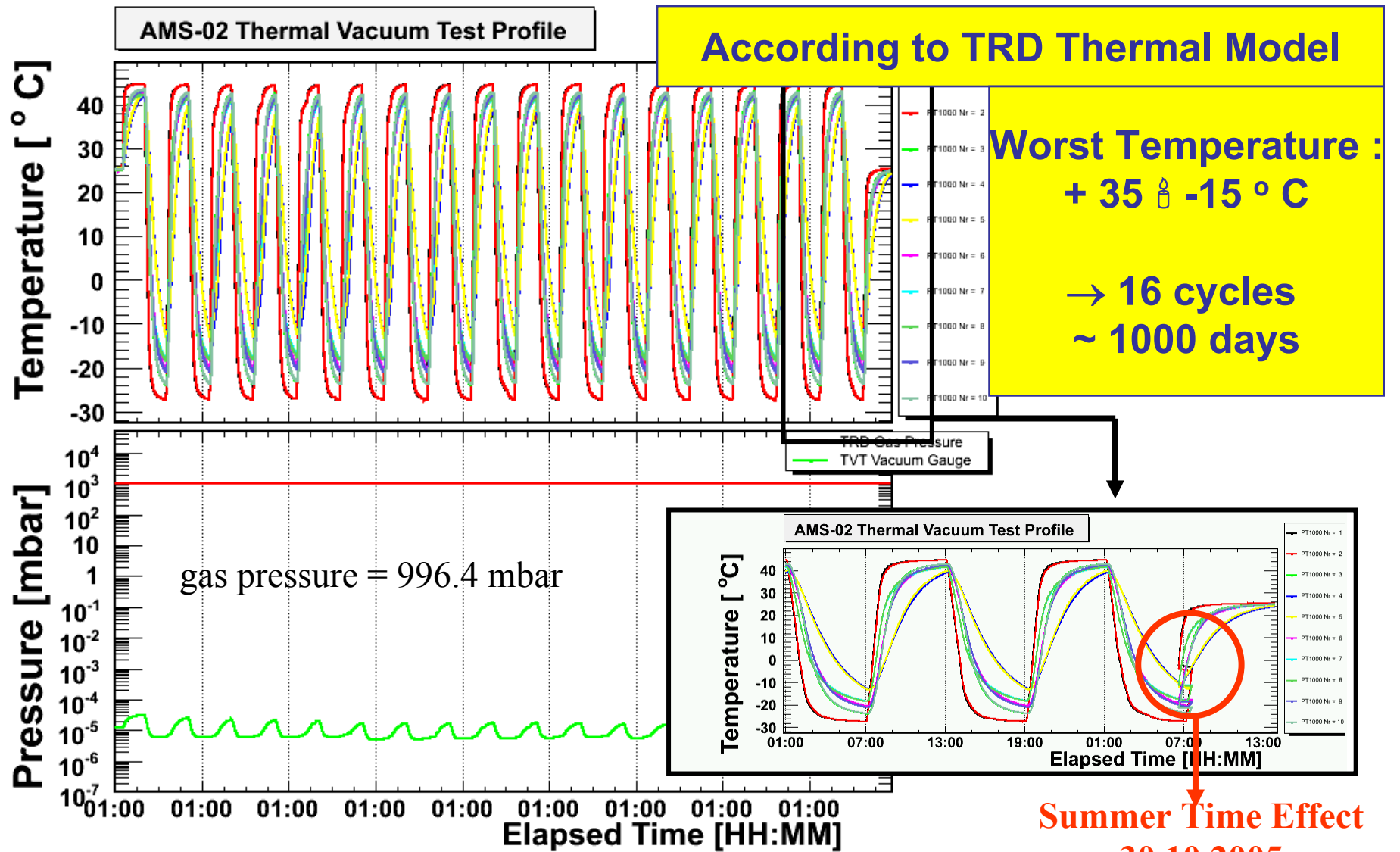
Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Gas Gain vs Temperature



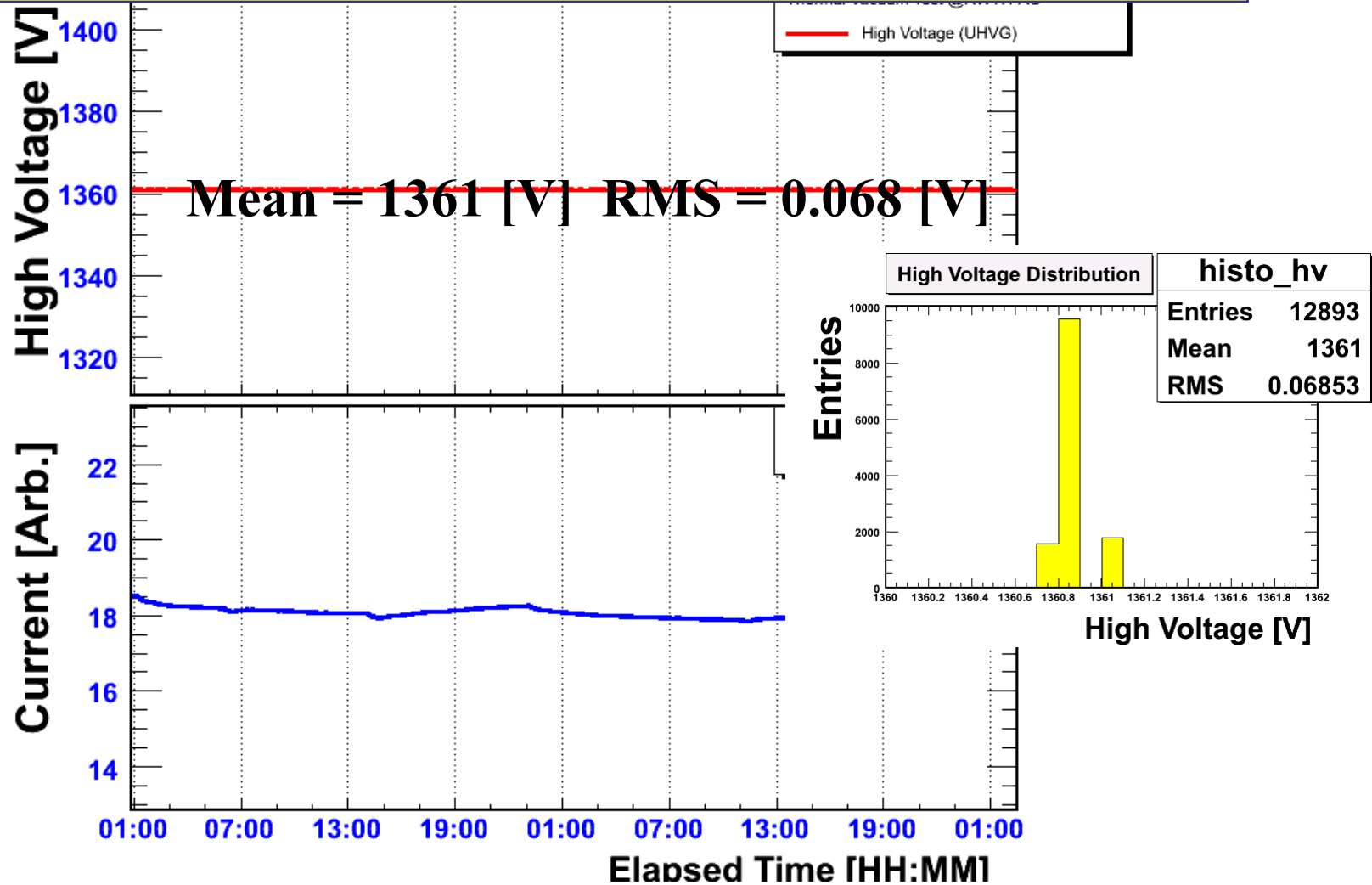
Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

TVT 16 Cycles



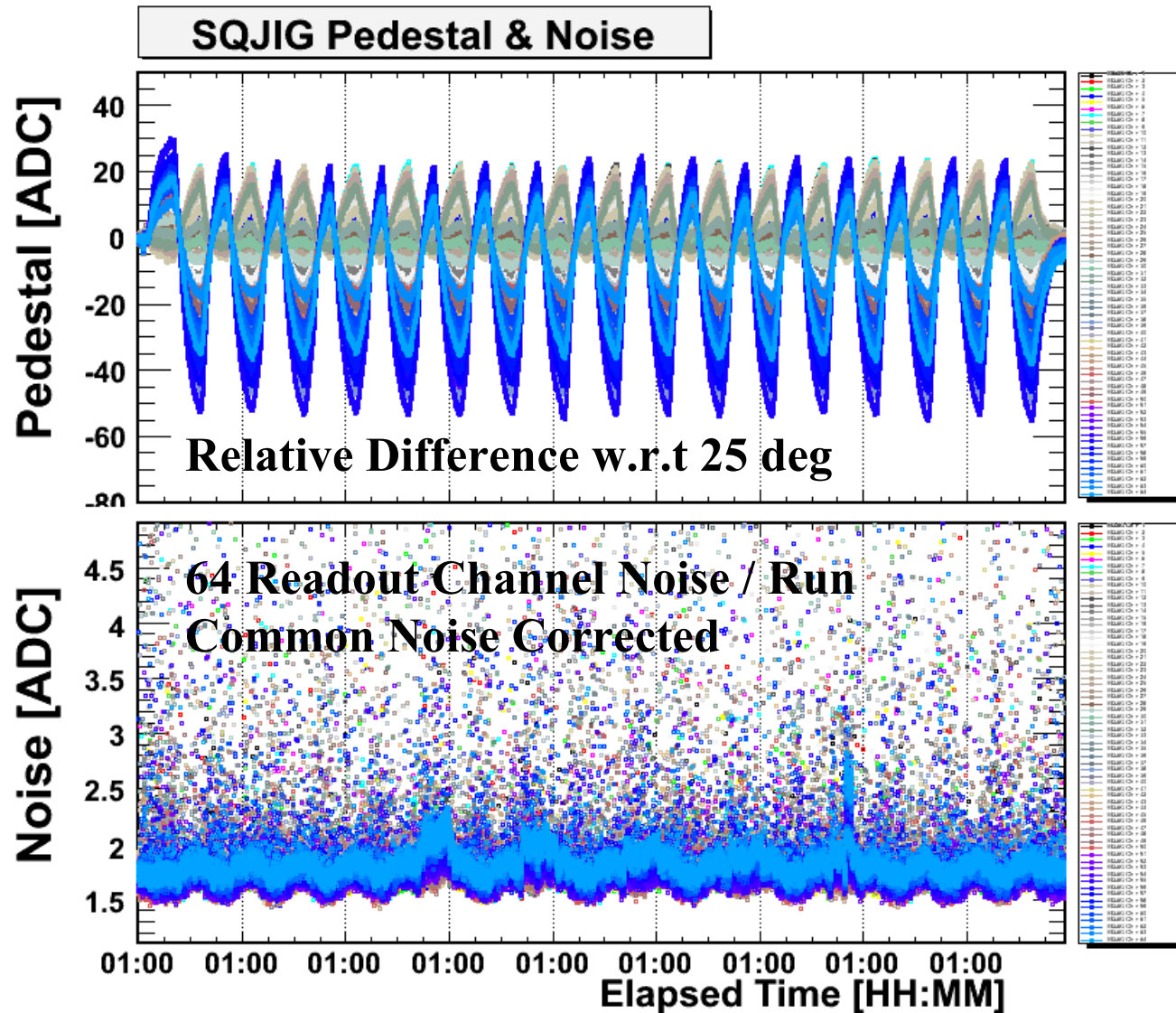
Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

TRD Requirements : Extremely Stable Voltage Supplies
To prevent gain changes during operations : $G \propto \exp(V)$



Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Pedestal & Noise

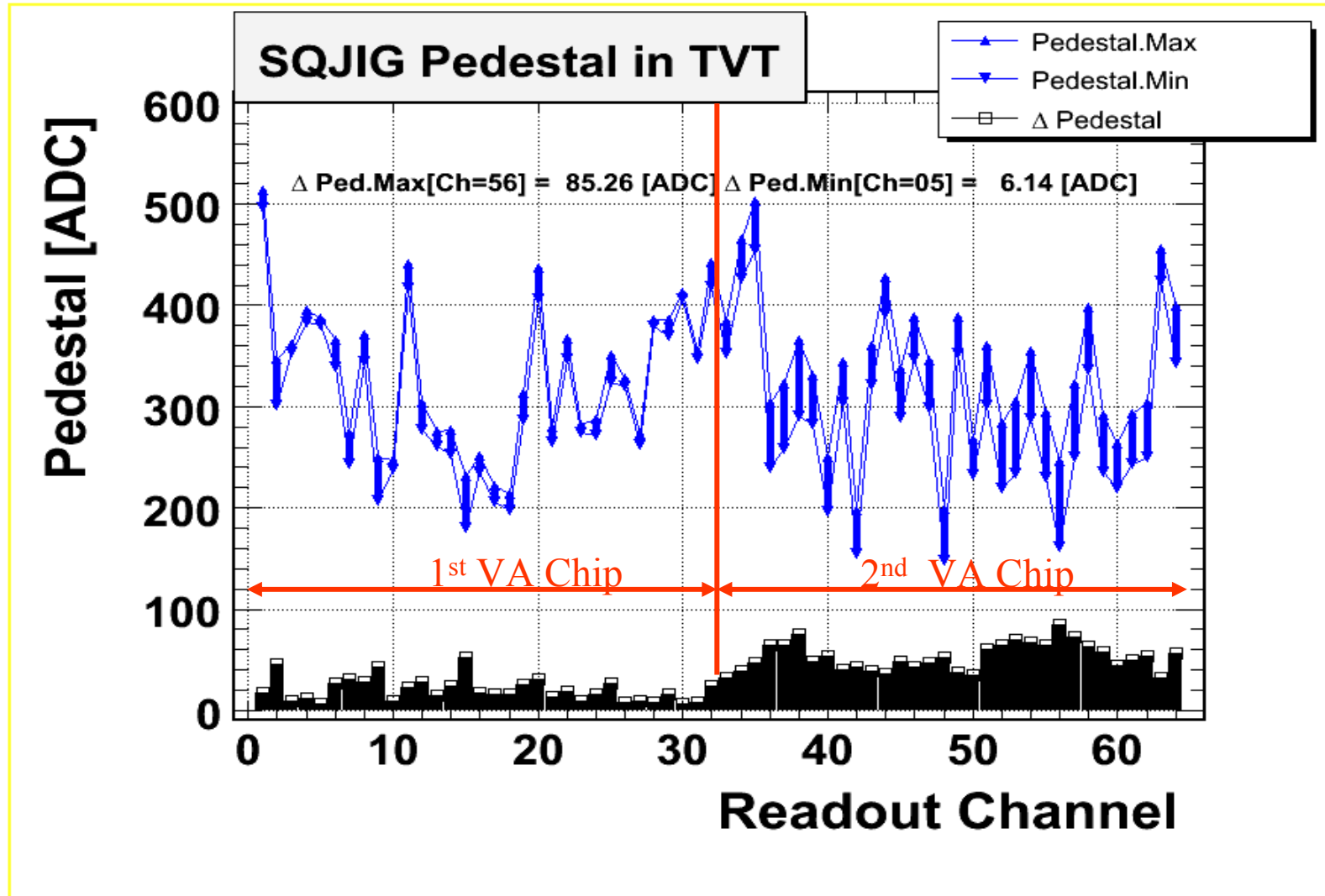


Total Time =
12874 min

Total Runs =
12874

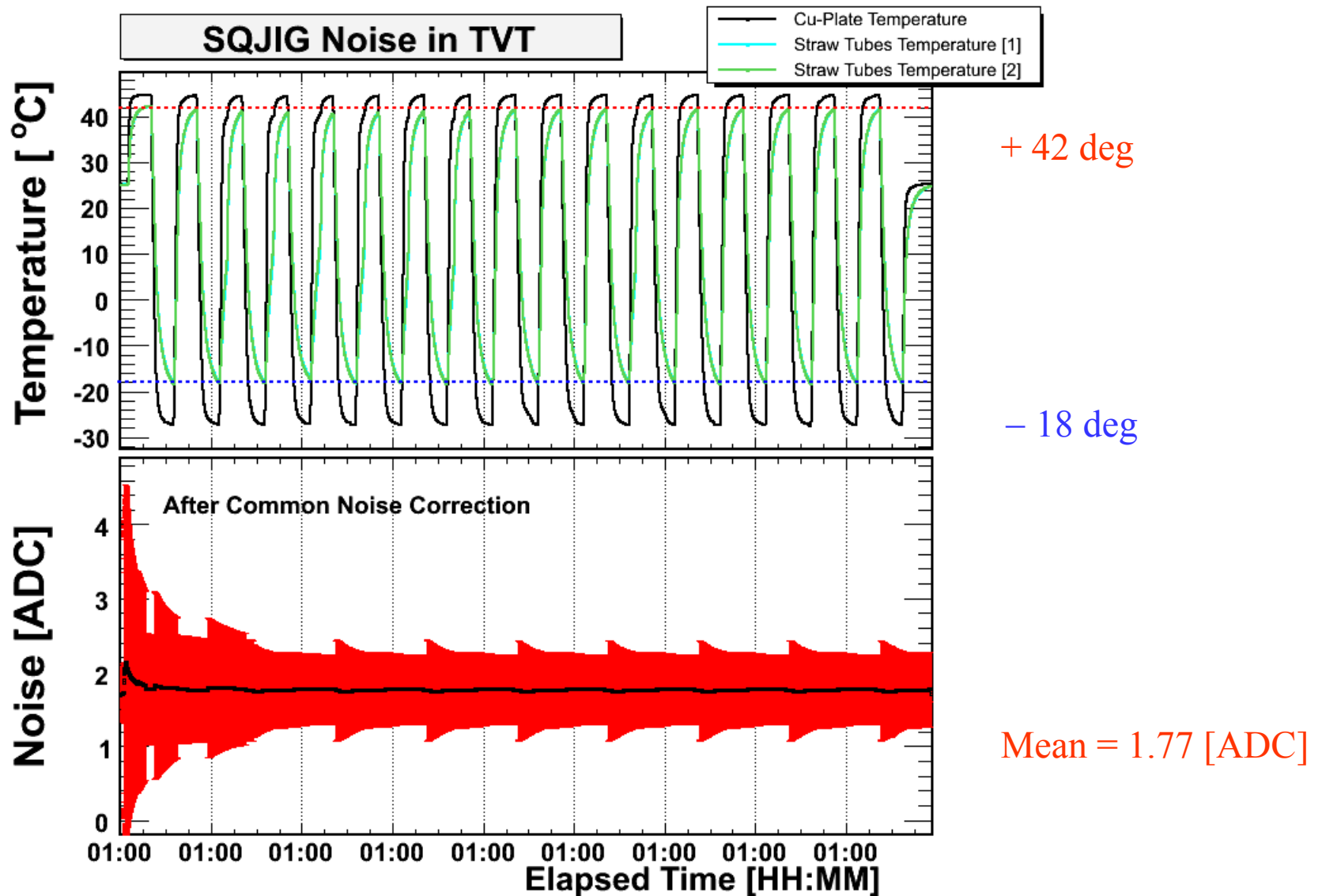
Entries =
12874×64

Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen Pedestal & Noise



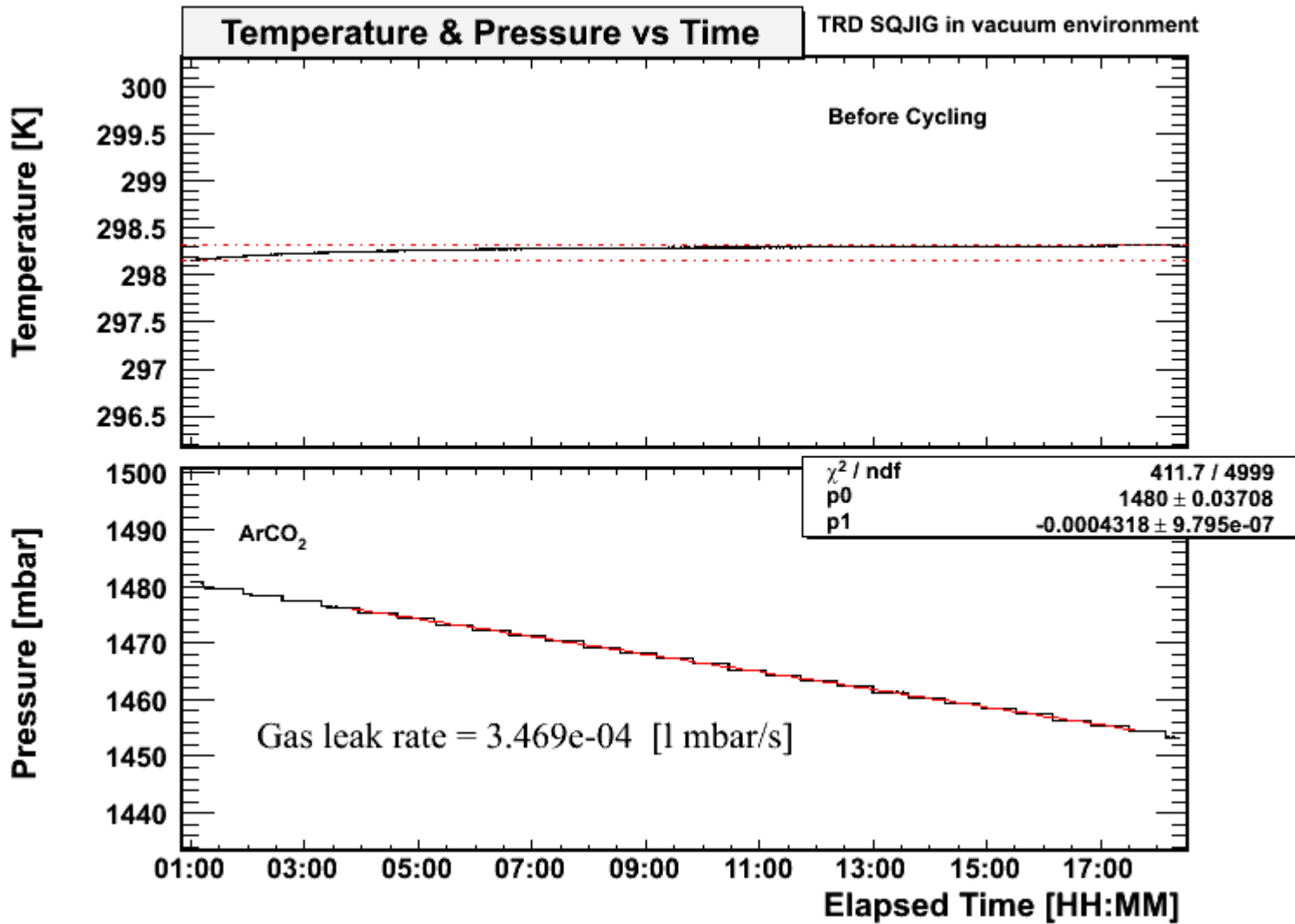
Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Noise vs Temperature



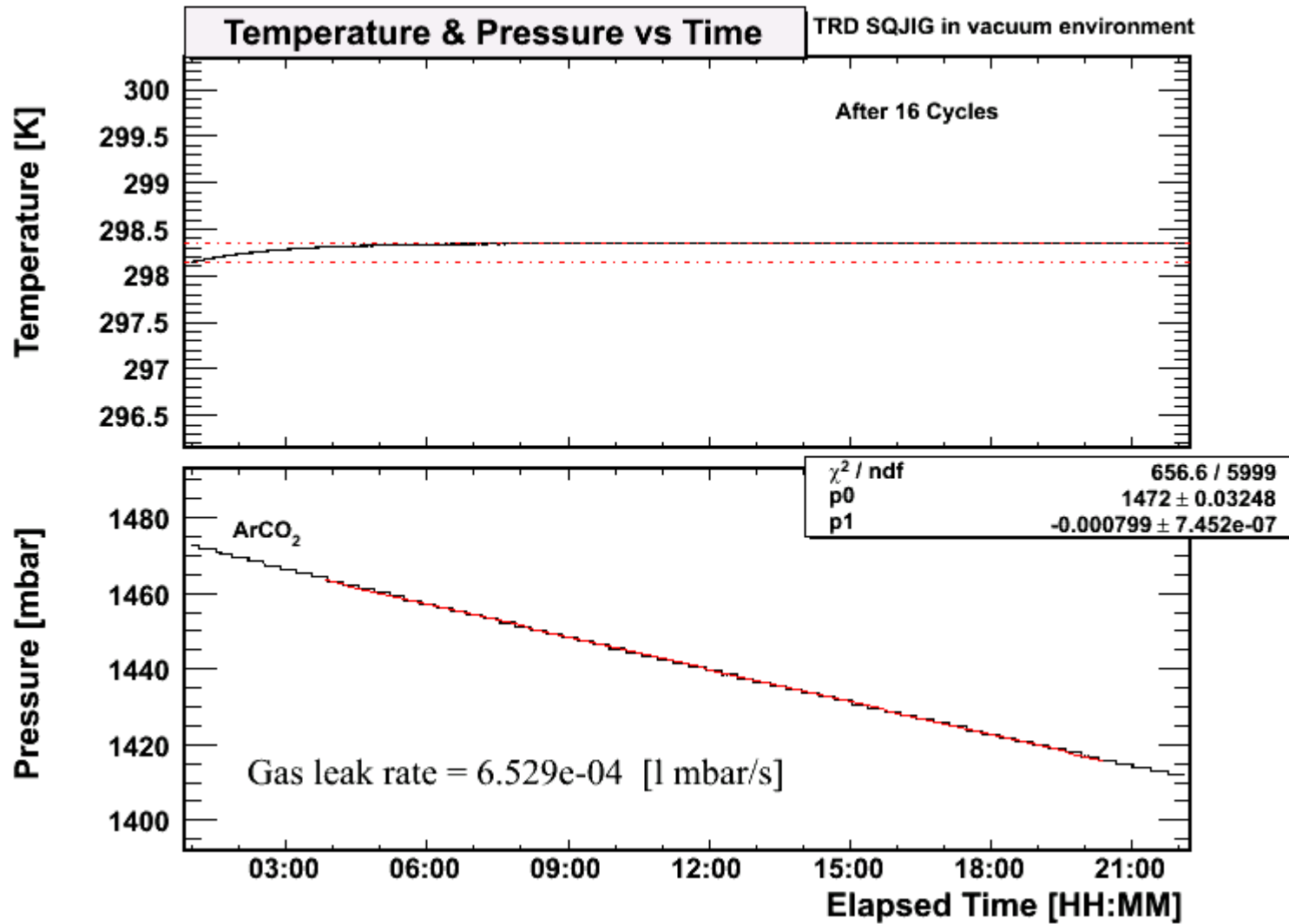
Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Gastightness before TVT



Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Gastightness after TVT



Space Qualification Jig MOD07 @ TVT Teststand RWTH Aachen

Gas Gain (HV)

Environments : +20 deg, +40 deg, -20 deg

