PEBS:
Positron Electron Balloon Spectrometer

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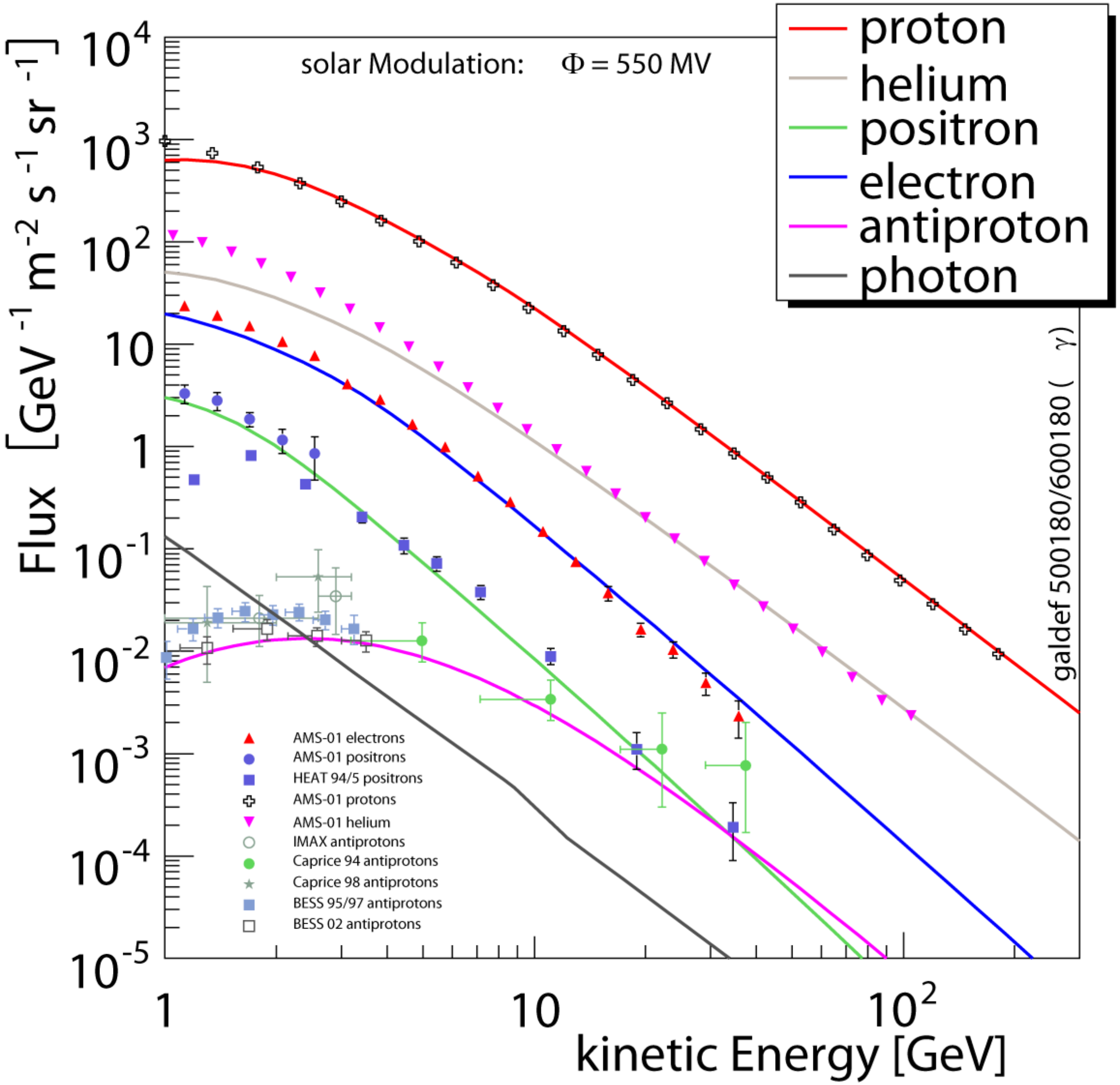
Introduction

Goal: Measure the cosmic-ray positron fraction with a balloon-borne spectrometer.

Motivation: Indirect search for dark matter.

Requirements:

- Large geometrical acceptance:
  >1000 $cm^2 sr$ for 20-day campaign
- Excellent proton suppression of $O(10^6)$
- Good charge separation
- Payload weight < 2t
- Power consumption < 1000W



e.g. at 40 GeV: $10^{-4} GeV^{-1} m^{-2} sr^{-1} s^{-1}$ x (20x24x3600)s x 0.25$m^2 sr$ = 43 e^+/GeV

Prospective performance of PEBS detector

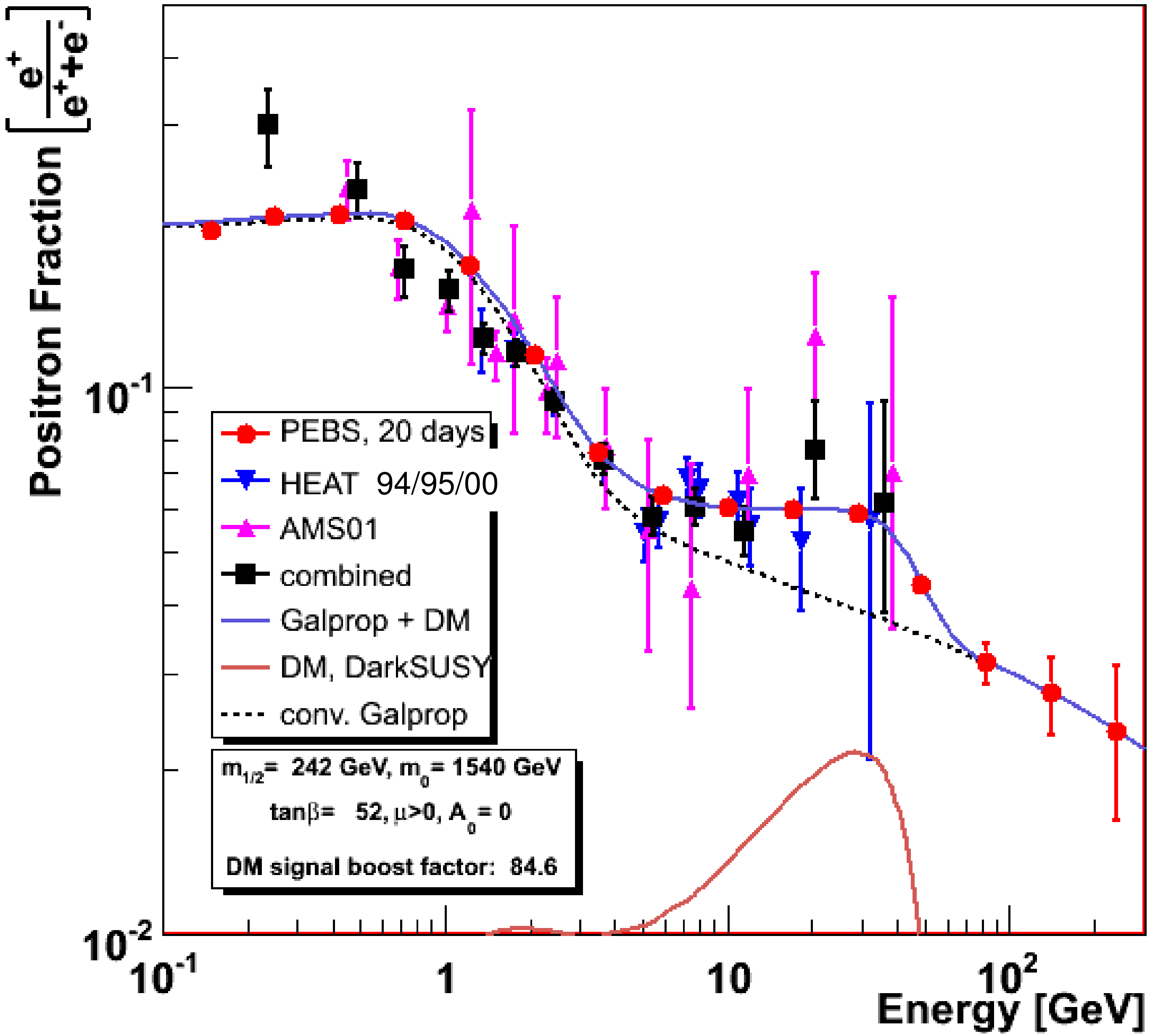
acceptance @100GeV
and mission duration

PEBS 2500 cm²sr
20 days

AMS02 500 cm²sr
1000 days

PAMELA 20 cm²sr
1000 days

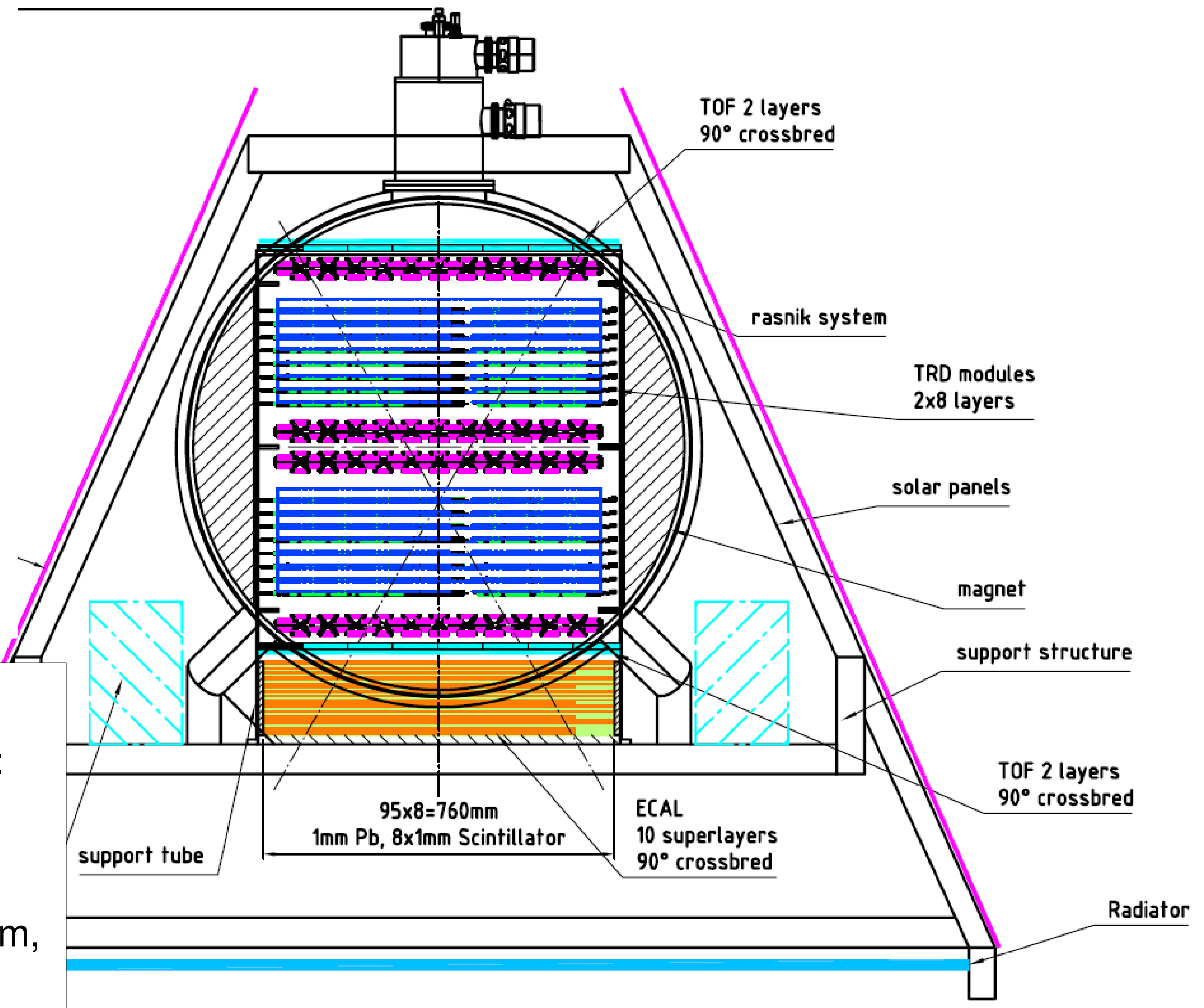
20 days PEBS=
100 days AMS02
7 years PAMELA



PEBS design overview

Tracker:
Scintillating fibres (d=250 μm) with Silicon Photo-Multiplier (SiPM) readout; power: 260W

Magnet:
Pair of superconducting Helmholtz coils, Helium cryostat, mean B = 1T, weight: 850kg



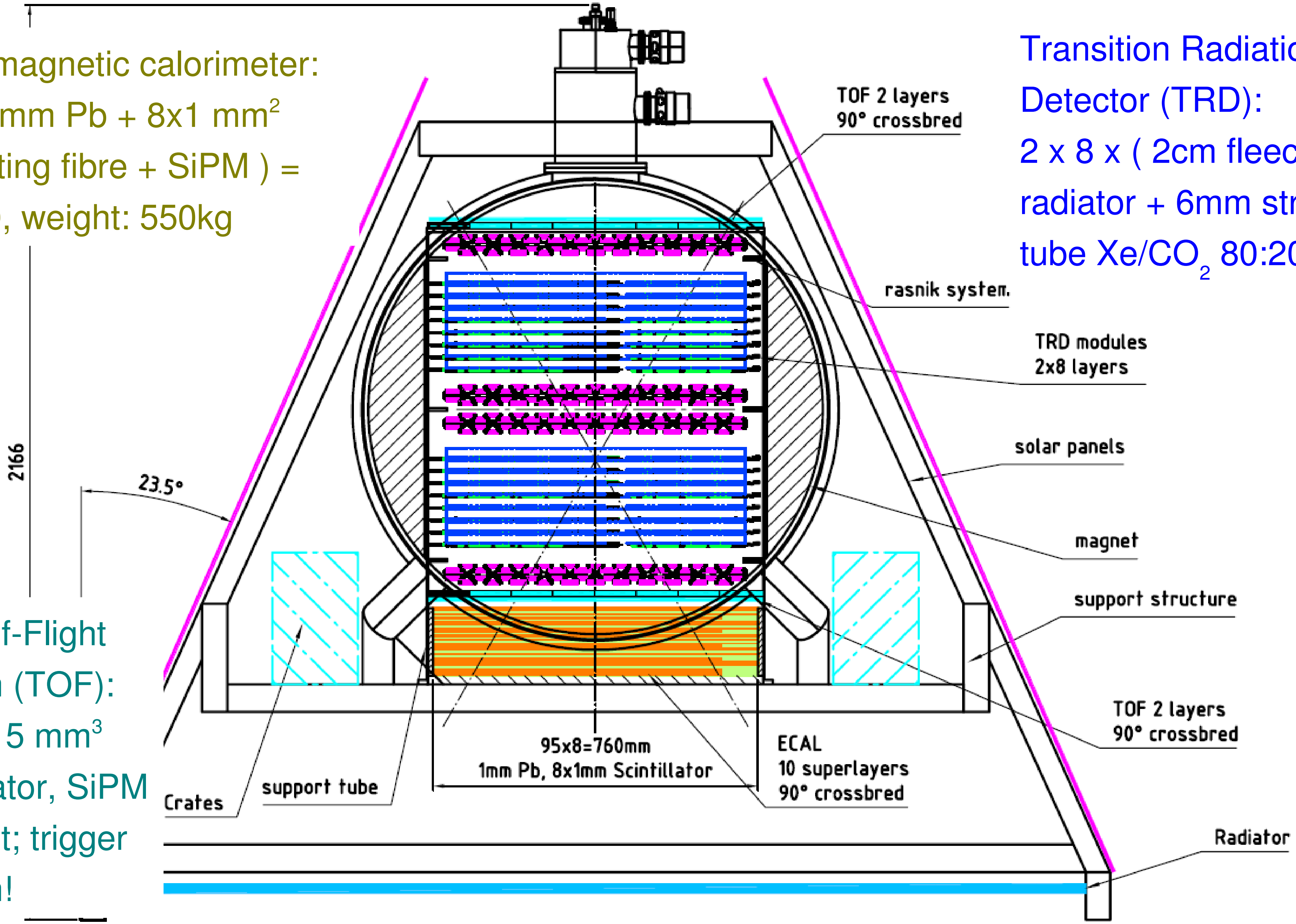
Magnet acceptance (width=0.8m, length=0.8m): 4000 cm^{2}sr
Positron acceptance (tracker+ECAL; width=0.76m, length=1m): 2500 cm^{2}sr

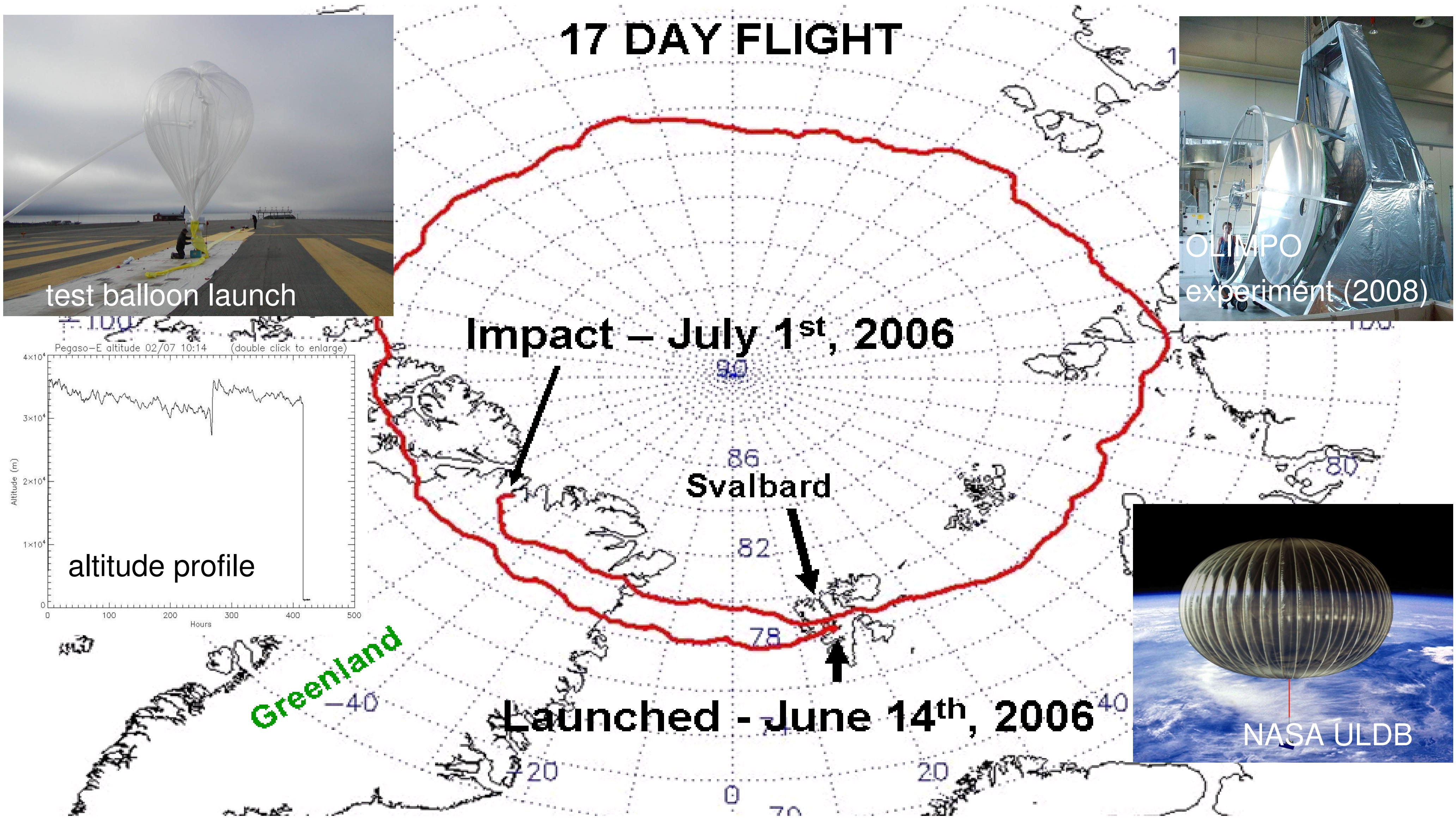
PEBS design overview

Electromagnetic calorimeter:
80 x (1mm Pb + 8x1 mm^2 scintillating fibre + SiPM) = 14.3 X0, weight: 550kg

Transition Radiation Detector (TRD):
2 x 8 x (2cm fleece radiator + 6mm straw tube Xe/CO_2 80:20)

Time-of-Flight system (TOF):
2 x 2 x 5 mm^3 scintillator, SiPM readout; trigger system!



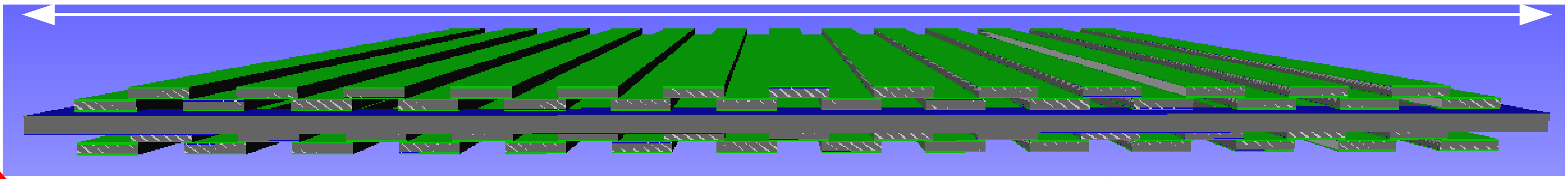


High-altitude (~40km), long-duration (~20 days) balloon flights from Svalbard ballonport (ASI)

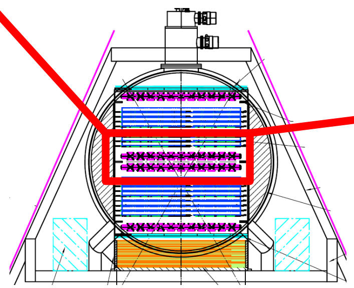
Interesting alternative to space, allows recalibration of experiment as well as multiple journeys

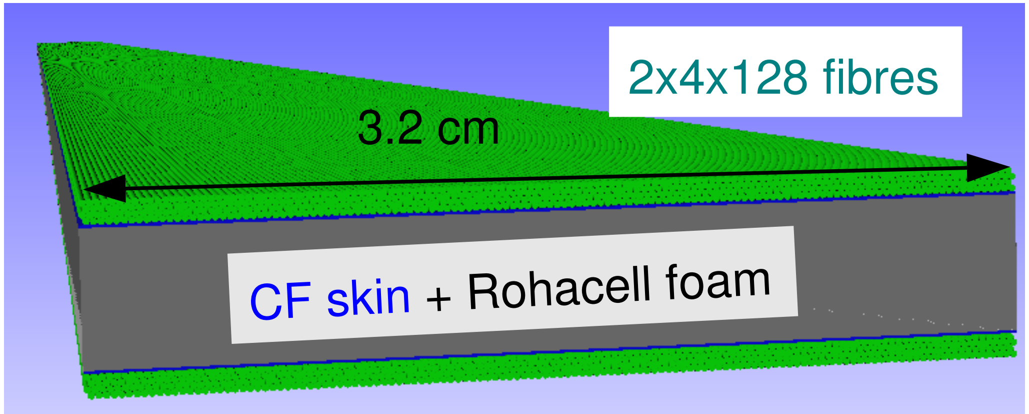
Tracker layout

0.80 m



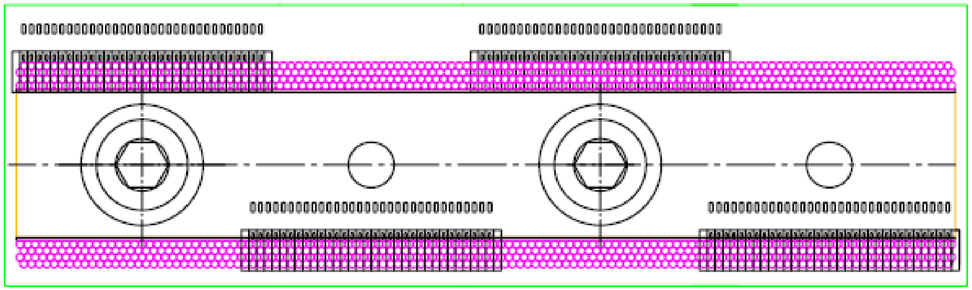
tracker superlayer

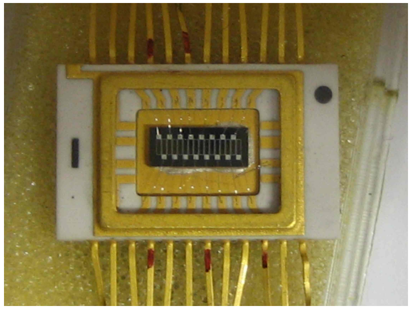




tracker module

4 superlayers of 2 layers of double-layered modules of scintillating fibres, d=250 μm
stack of fibres accumulates light on SiPM
readout of SiPMs by dedicated VA chip

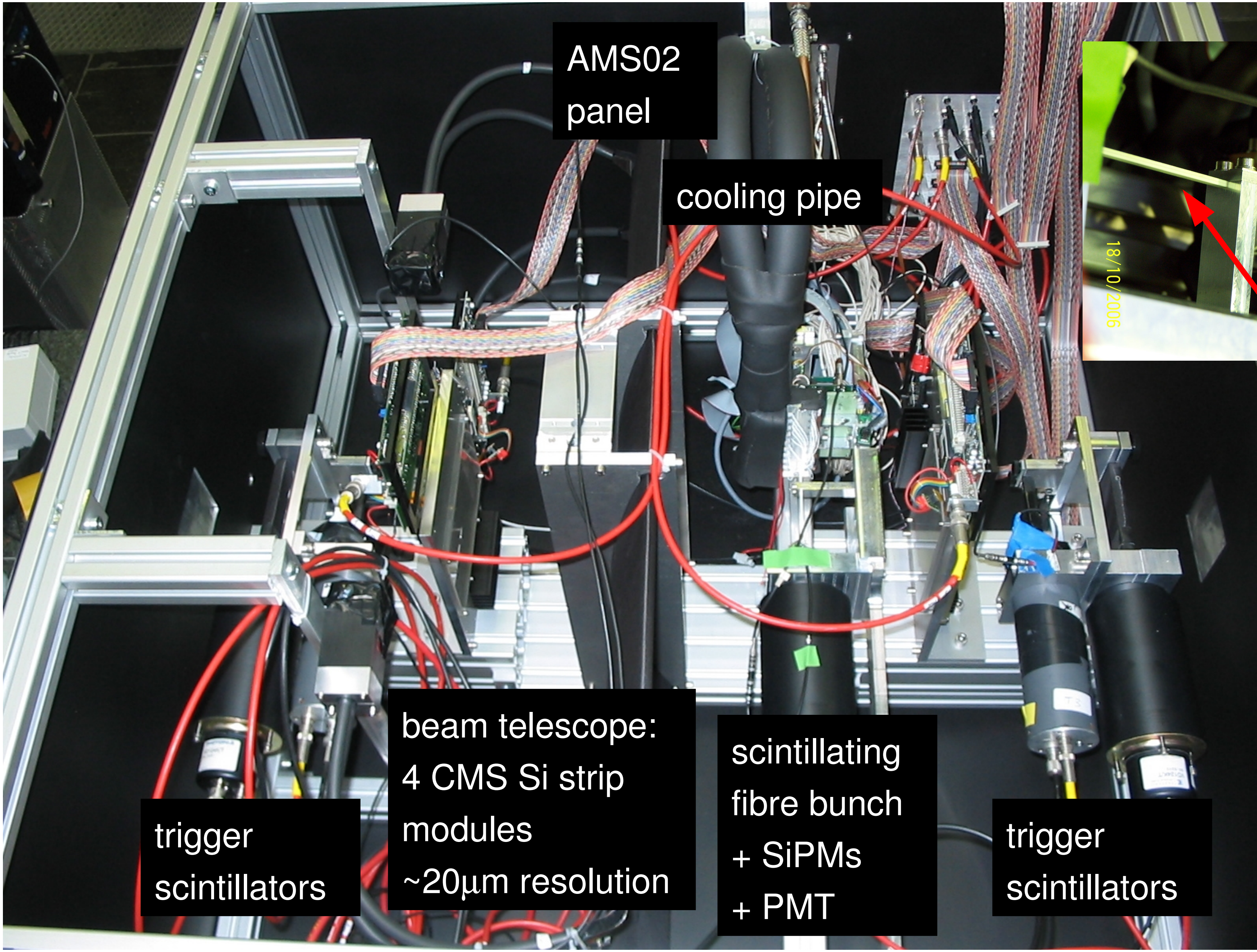


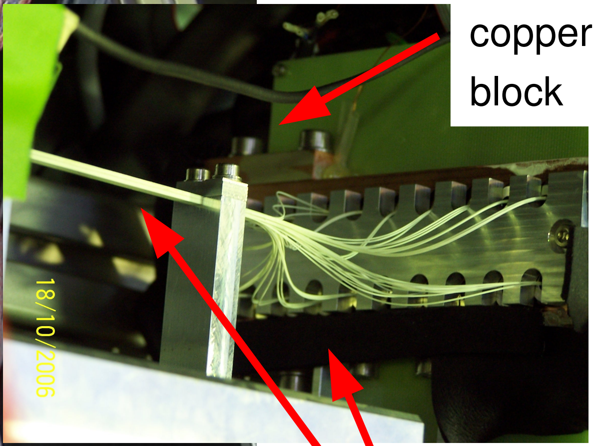


16x1 silicon photomultiplier, strip width 380 µm
need 32x1, 250µm strip width

material budget: 12% X0 (6% X0 tracker + 6%X0 TRD)

PEBS fibre tracker testbeam setup

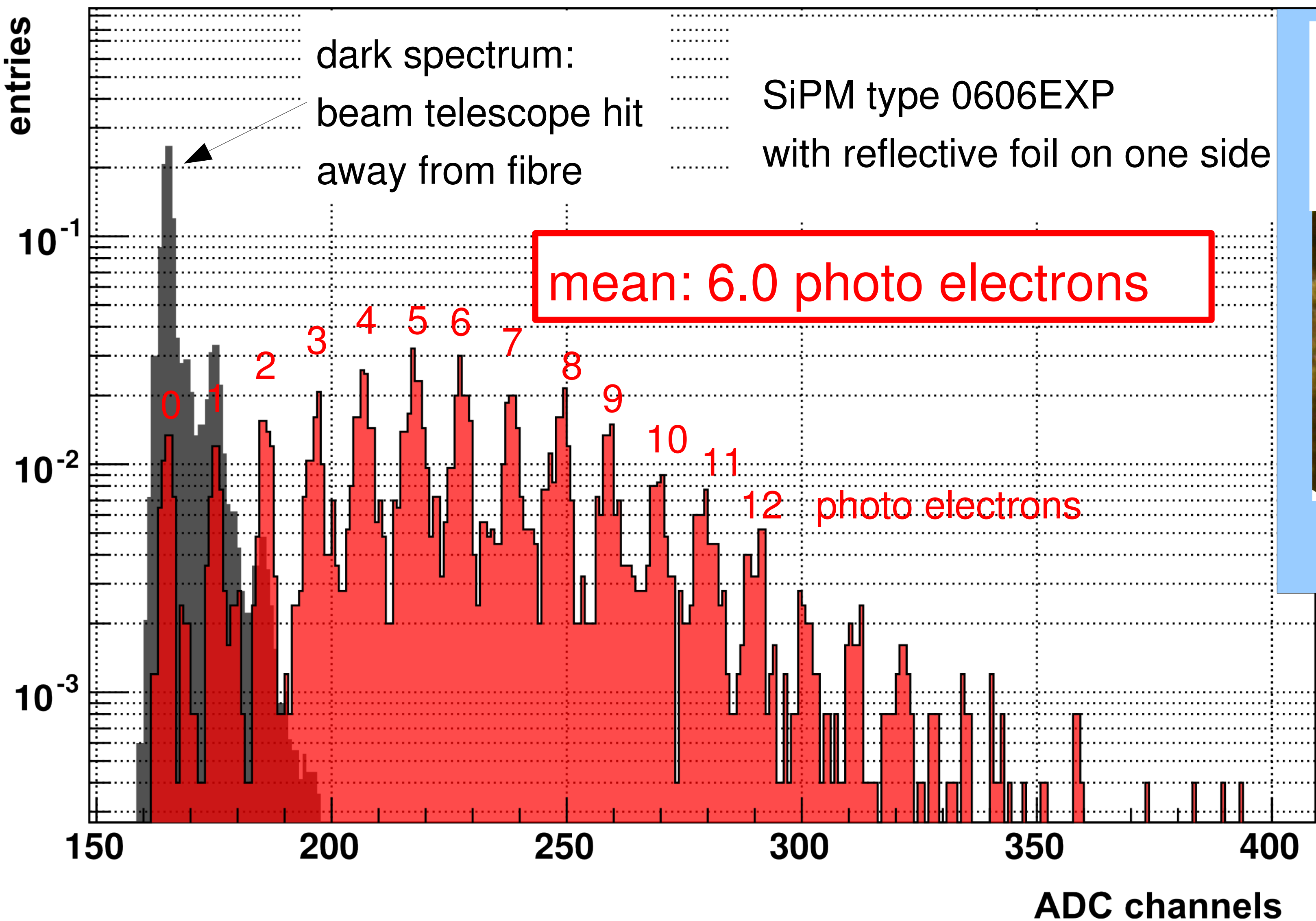




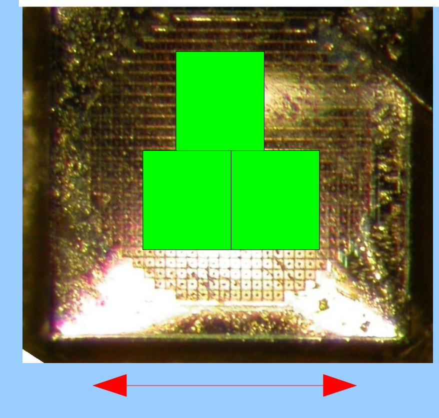
2 fibre bunches: 3x10 square fibres, d=300 μm

3 fibres each to SiPM in copper block

SiPM: example of a MIP spectrum

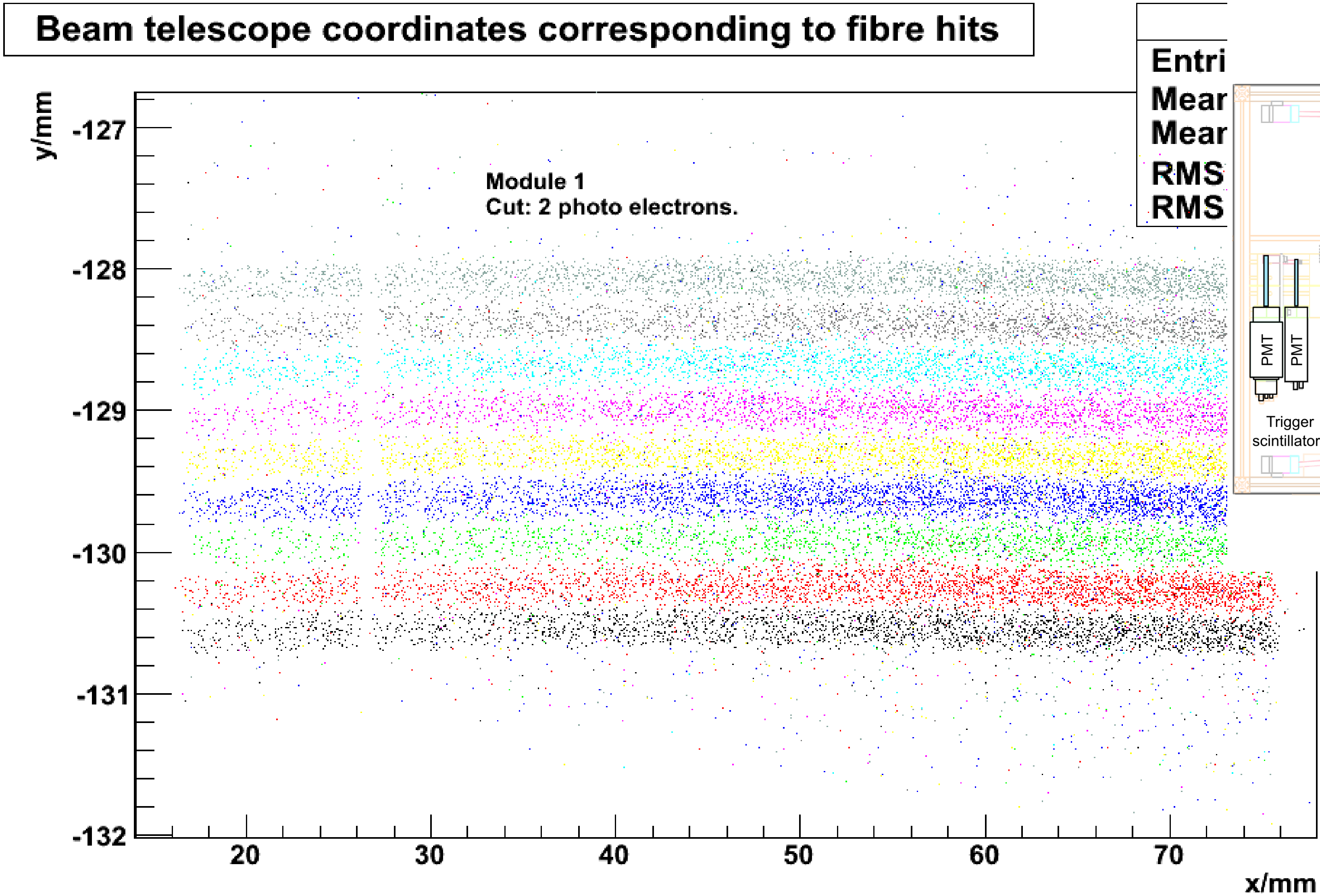


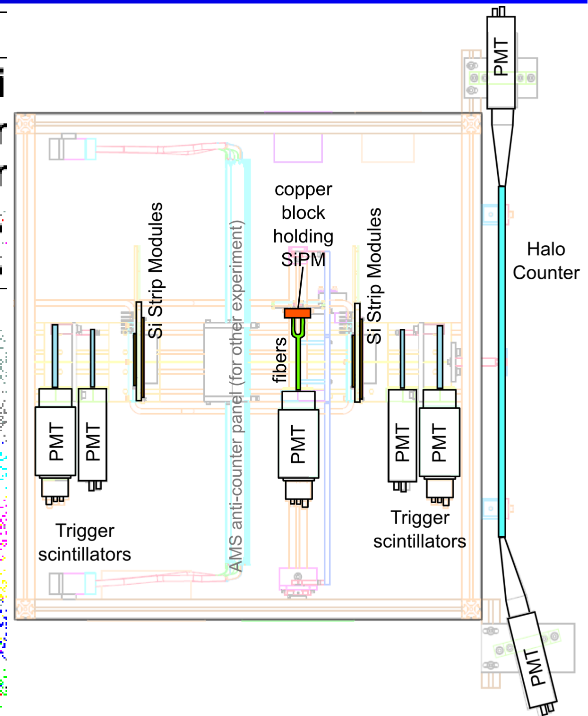
excess noise:
fibre area =
0.27 x SiPM area



Photonique
SSPM 0606 EXP
S/N=20,
eff(0.5pe)=96%
SSPM 050701GR
S/N=100,
eff(0.5pe)=91%

Fibre coordinates in beam telescope

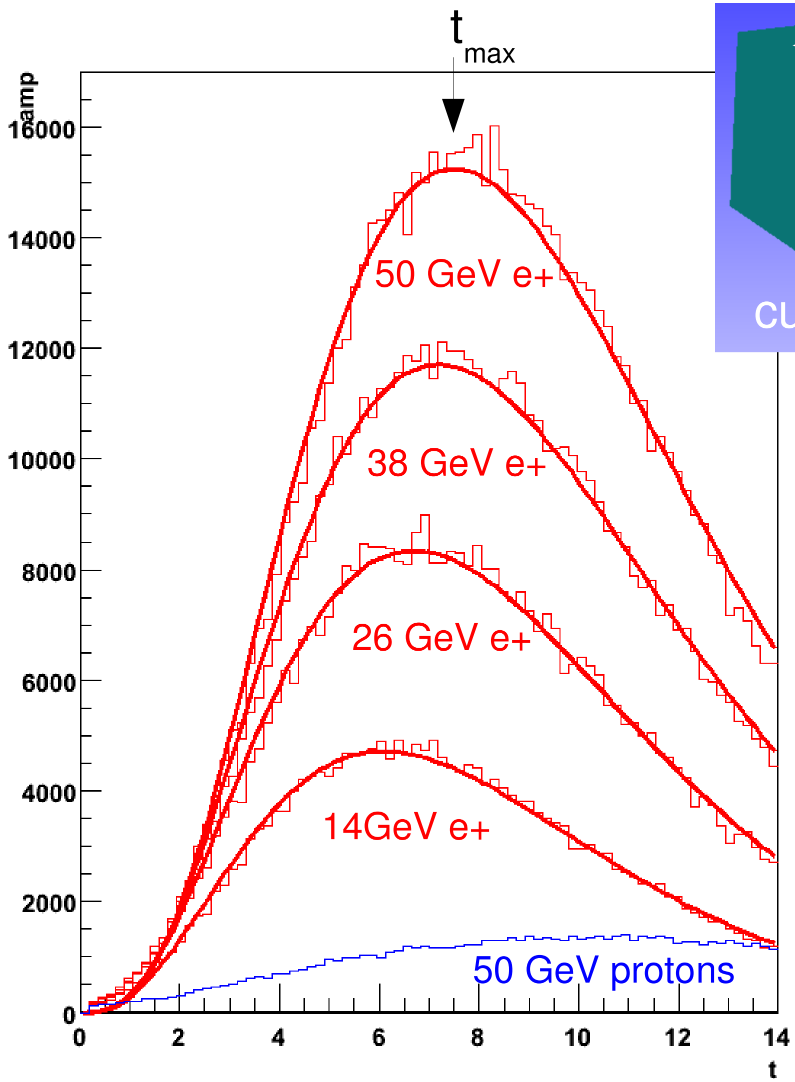




Testbeam results → PEBS MC simulation → muon momentum resolution: a=2%, b=0.19%/GeV

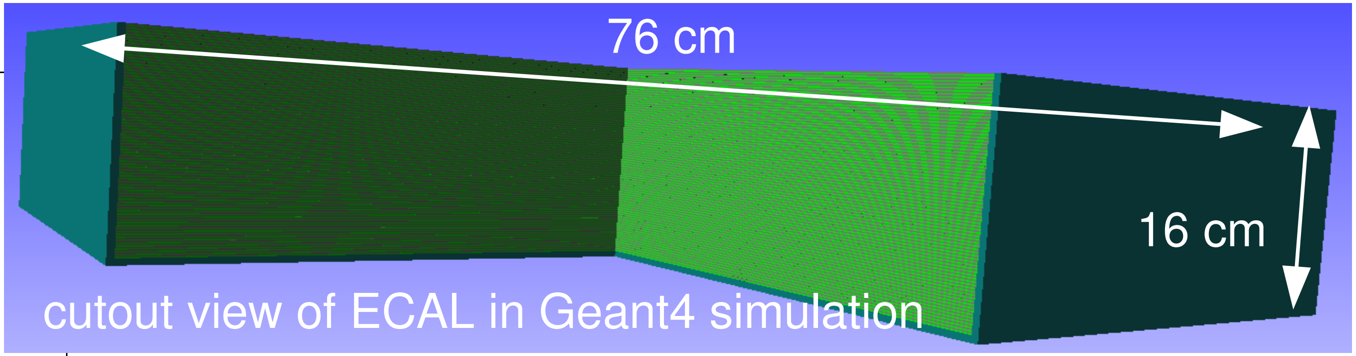
$$\frac{\sigma_p}{p} = \sqrt{a^2 + (b \cdot p)^2}$$

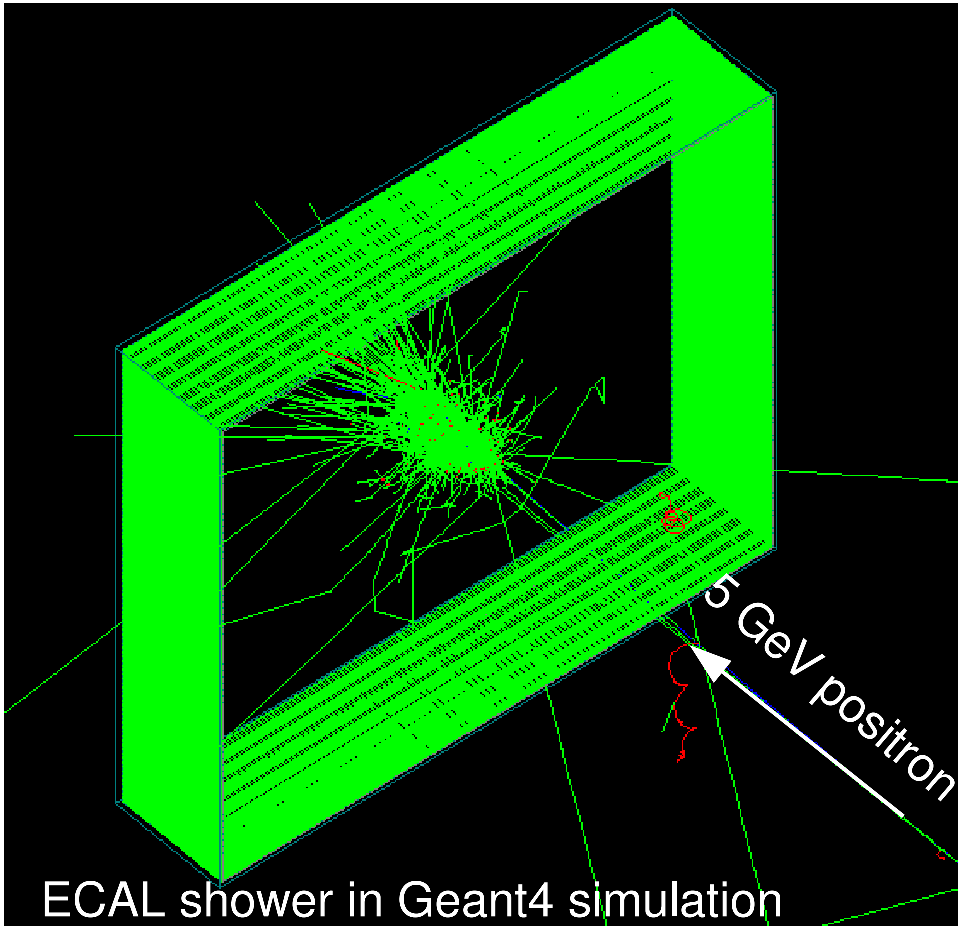
ECAL shower



$$\frac{dE}{dt} = E_0 \frac{b^{\alpha+1}}{\Gamma(\alpha+1)} t^{\alpha} e^{-bt} \qquad t = x/X_0$$

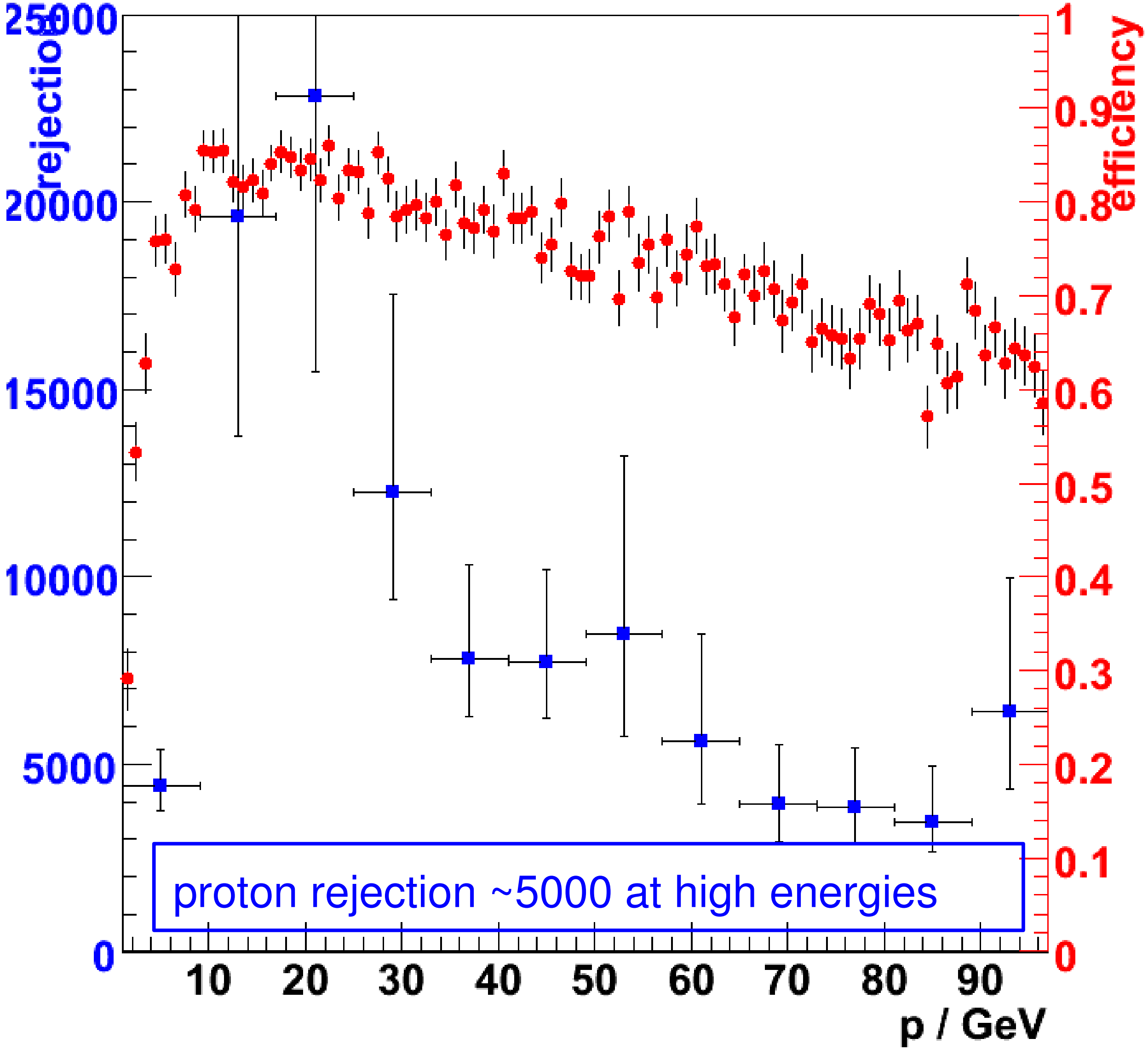
longitudinal shower profiles

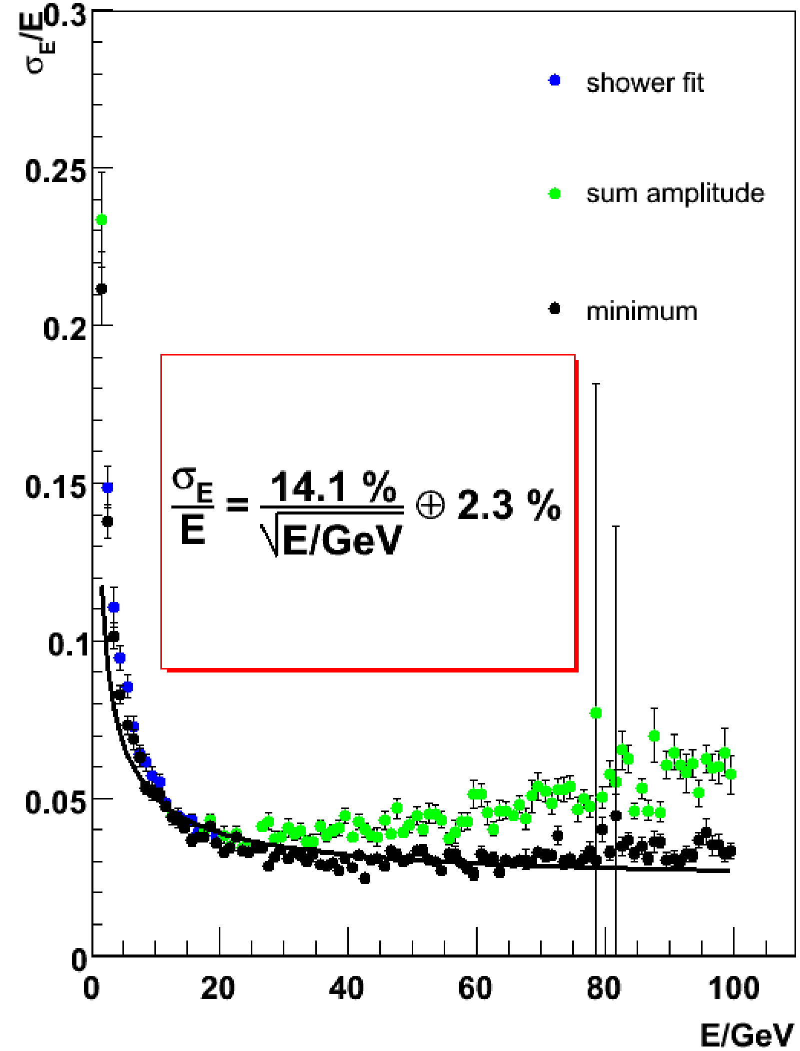




ECAL proton rejection and energy resolution

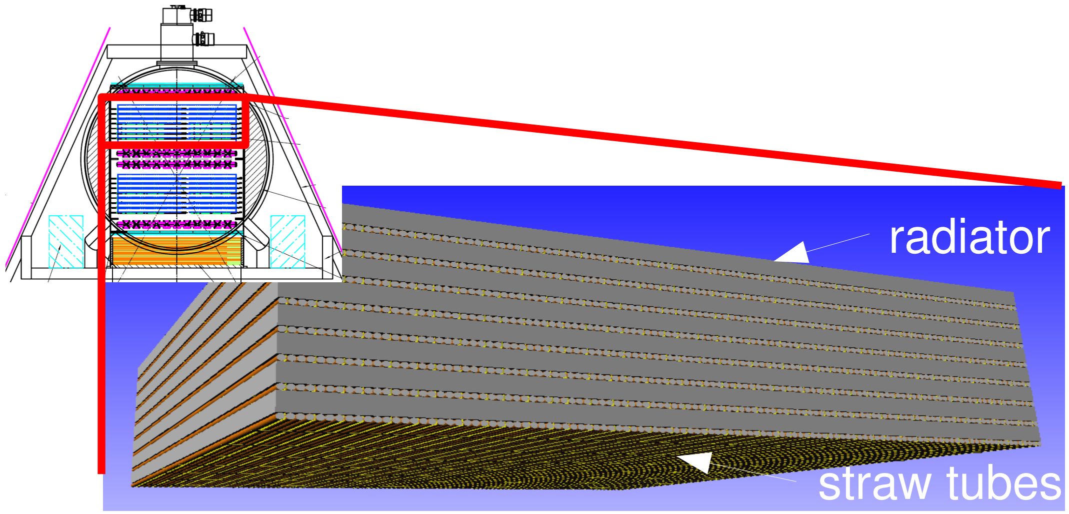
Simulated 40000 positrons and 1700000 protons





ECAL energy resolution

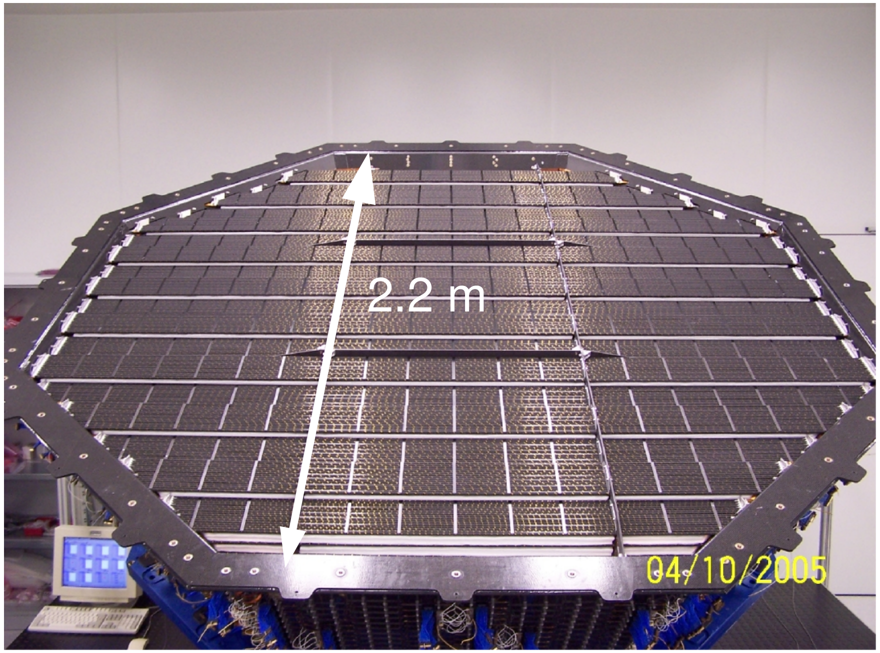
TRD design



TRD superlayer in G4 simulation

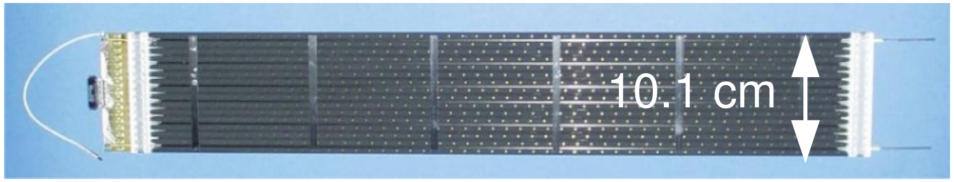
2 x 8 layers of fleece radiator,
TR x-ray photons absorbed by Xe/CO2 mixture (80:20), in 6mm straw tubes with 30 μm tungsten wire

Design equivalent to AMS02 space experiment



AMS02 TRD octagon integrated at RWTH Aachen workshop

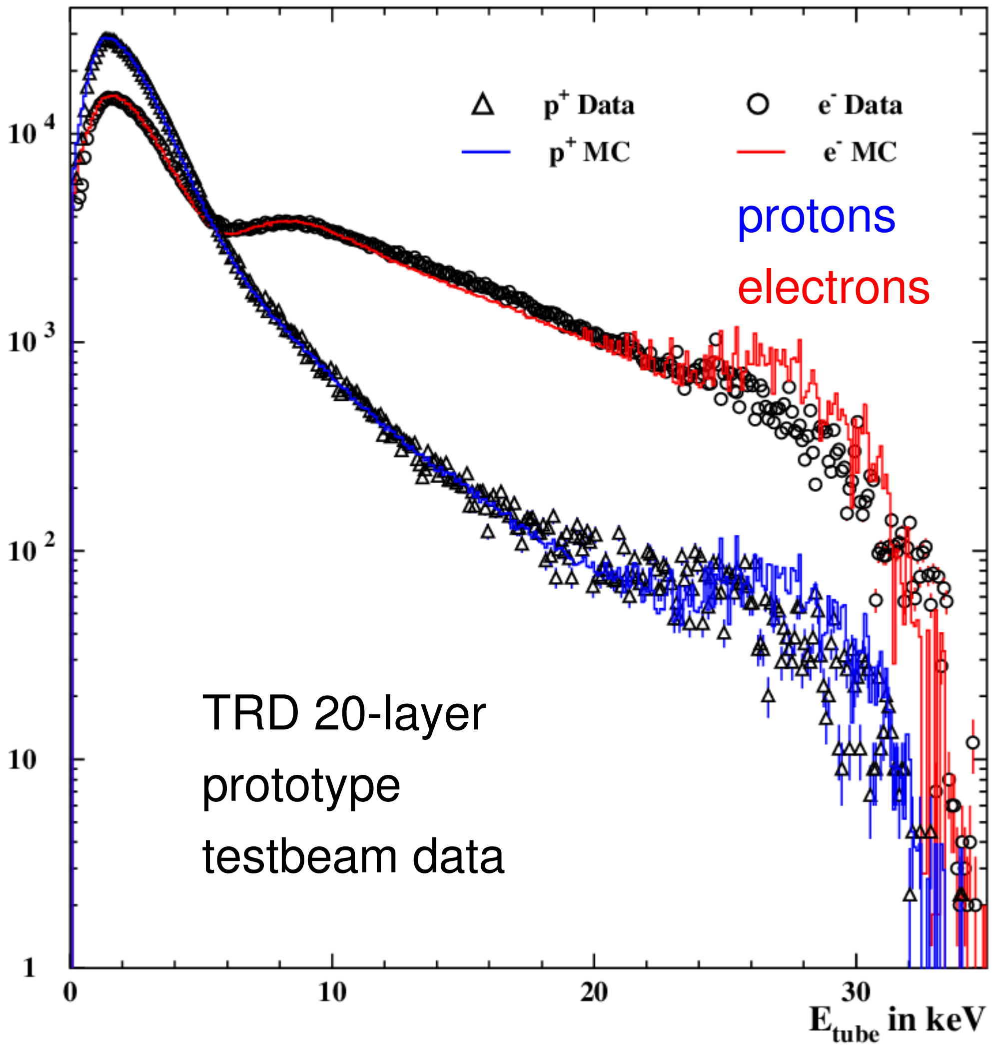
Tasks: proton suppression and tracking in non-bending plane

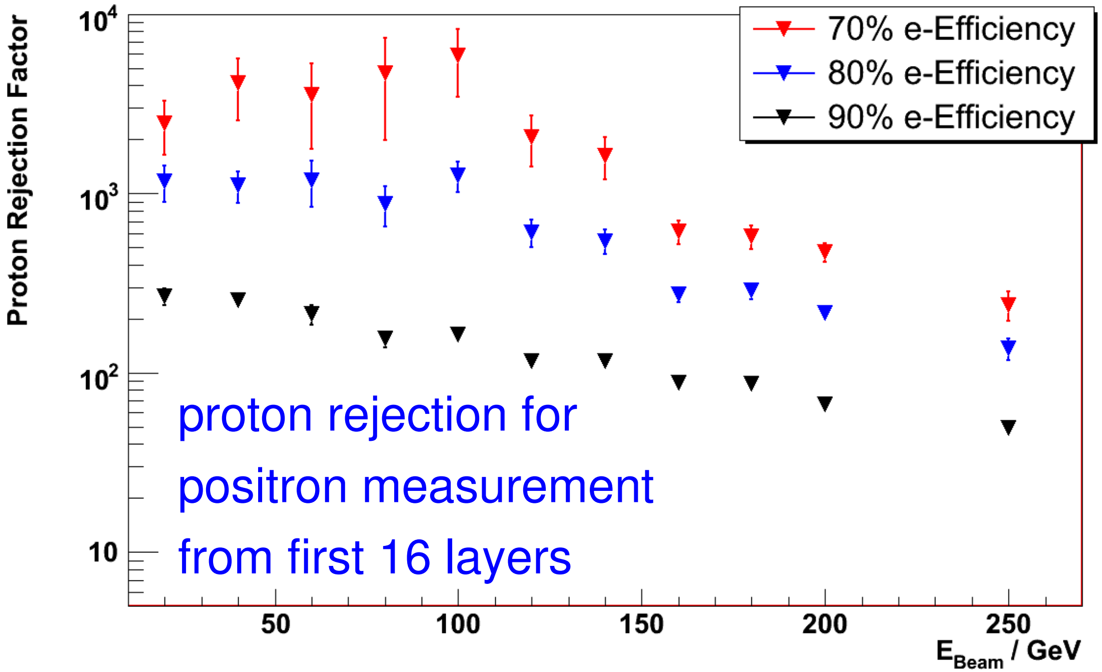


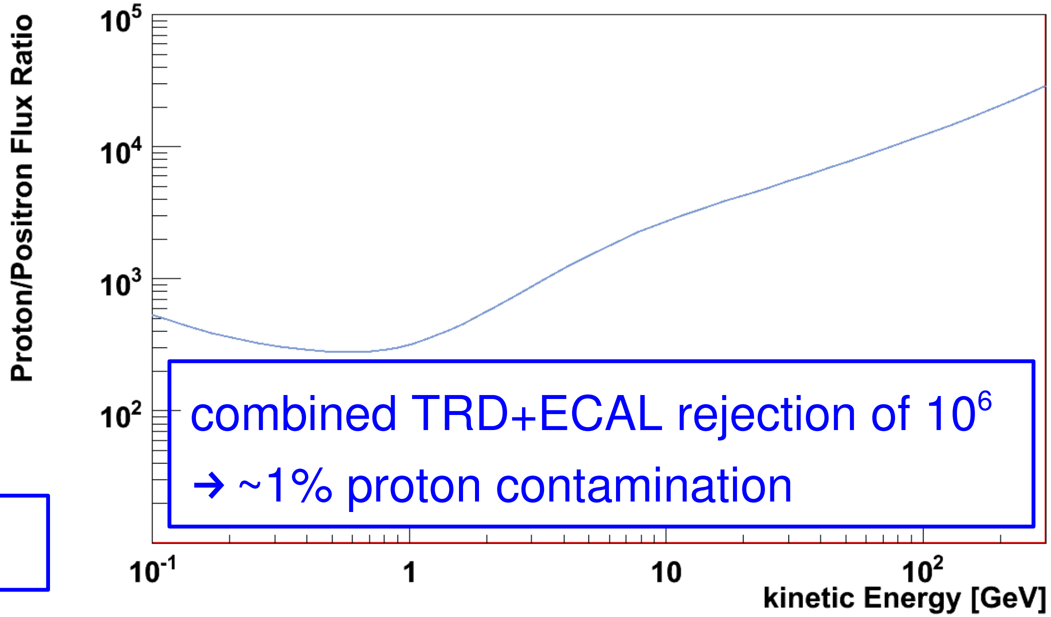
single TRD module

TRD performance: positron/proton separation

Analysis of TRD prototype testbeam data





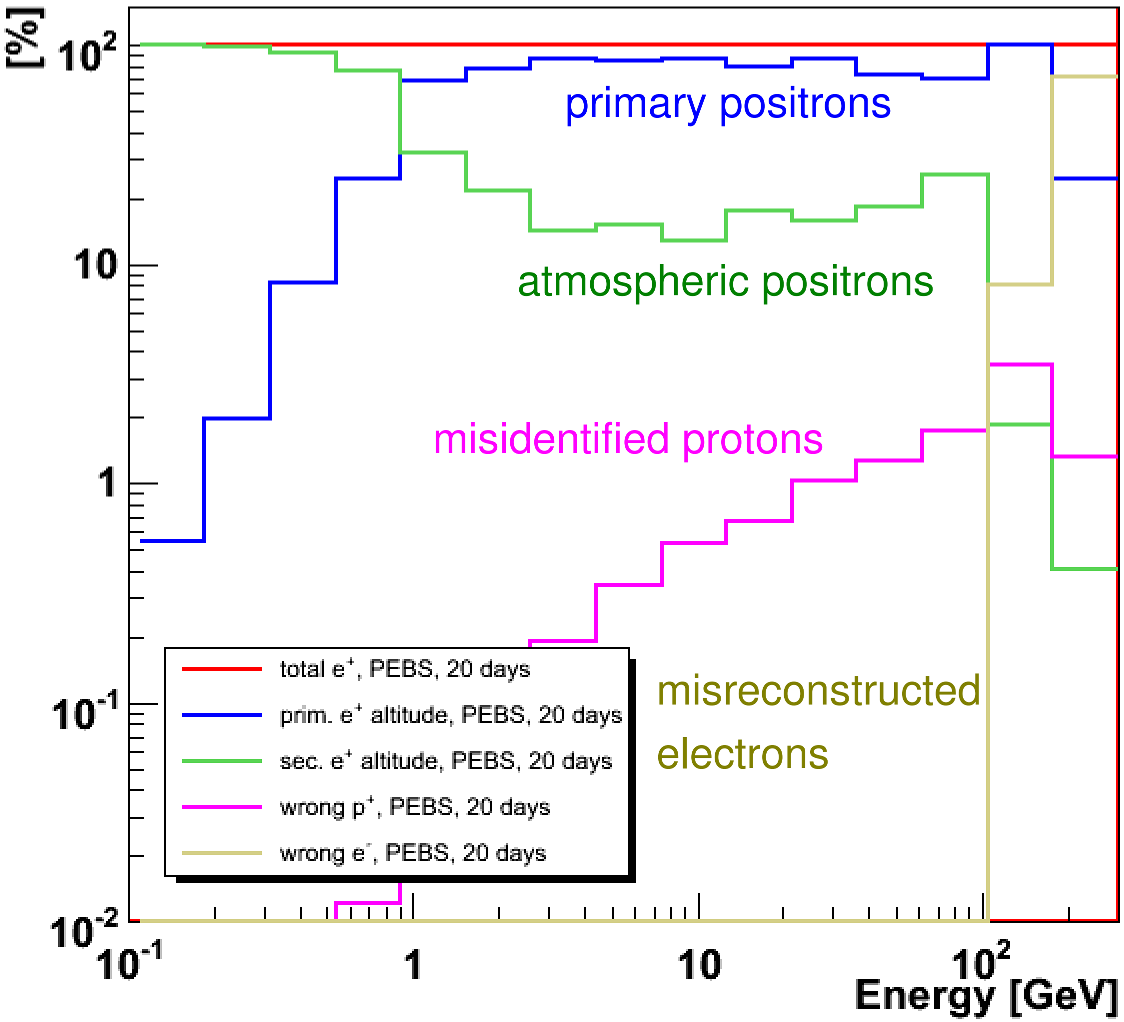


combined TRD+ECAL rejection of 10^6
→ ~1% proton contamination

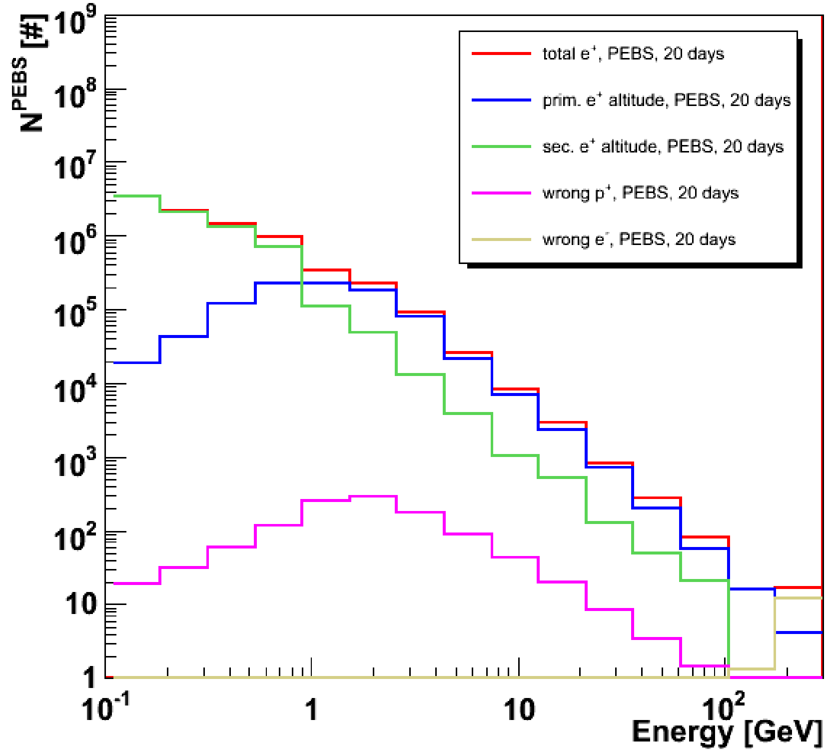
proton rejection ~1000

Background contributions

40 km altitude: 3.7 g/cm^2 remaining atmosphere



composition of positron component according to PLANETOCOSMICS simulation of atmospheric background and contributions from p/e- misidentification



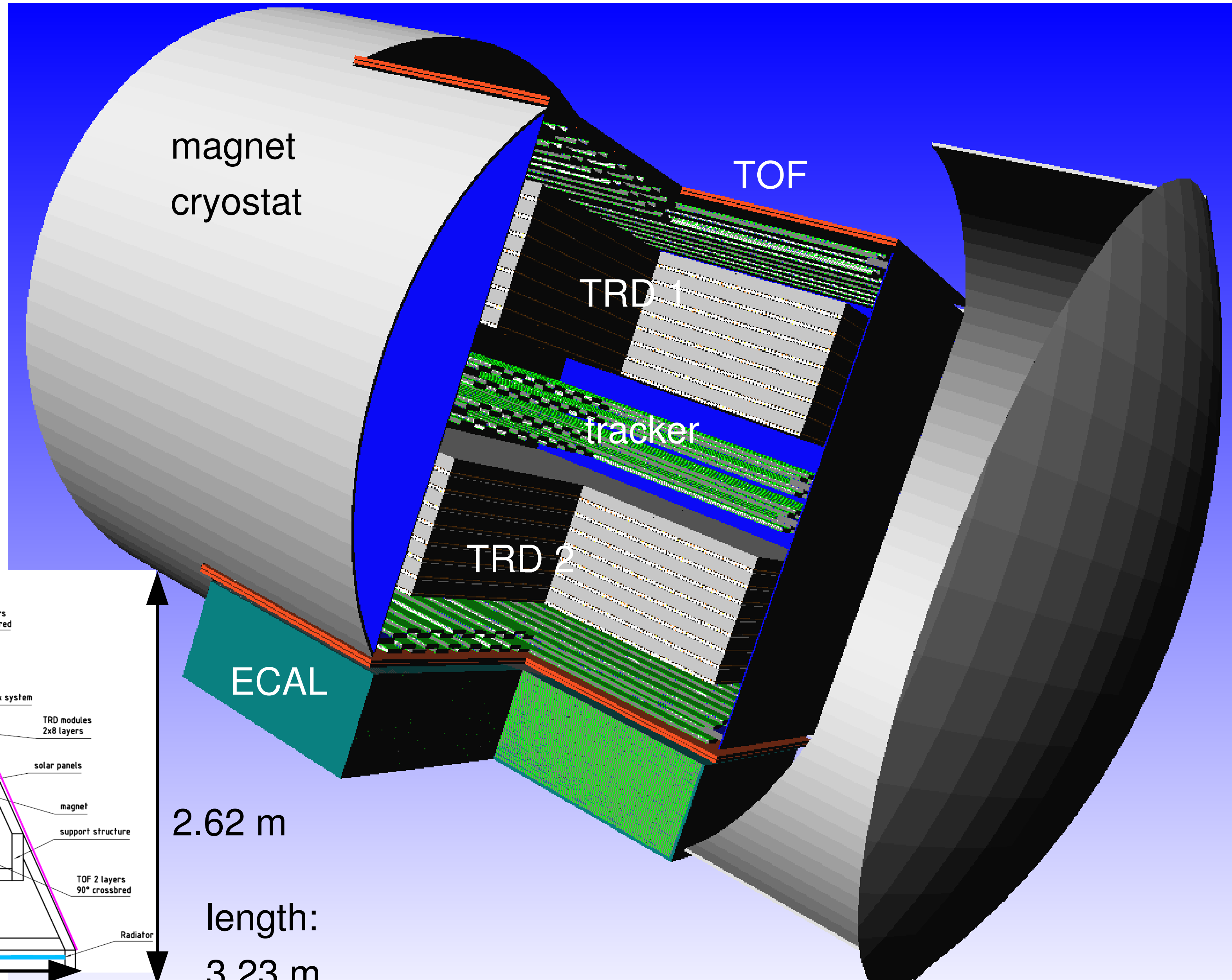
contributions in absolute numbers for 20-day flight for efficiency = 50%

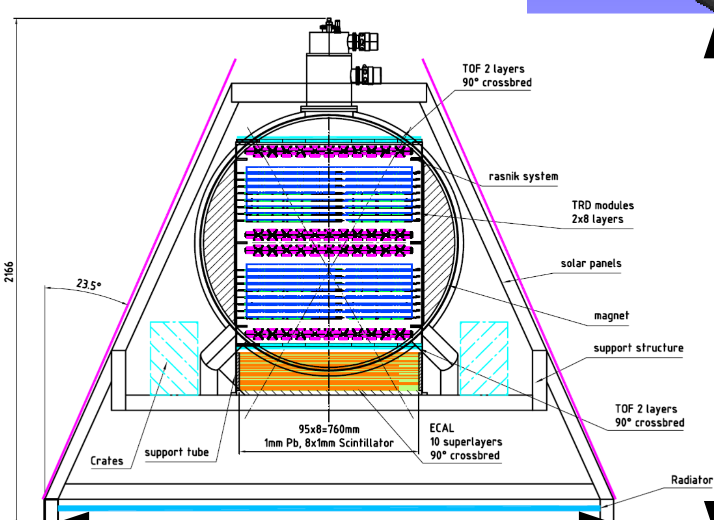
Conclusion

- Design study to build a balloon-borne spectrometer to measure the cosmic-ray positron fraction, in the context of indirect search for dark matter
- Scintillating fibres with SiPM readout as key components, proof of principle established in testbeam at CERN in October 2006
- Proton rejection of O(1,000,000) can be achieved with ECAL and TRD
- Design study with large acceptance to increase existing data by two orders of magnitude
- Expected amount of data from running experiments can be exceeded by an order of magnitude

PEBS detector components

Full Geant4 detector simulation available





2.62 m

length:
3.23 m

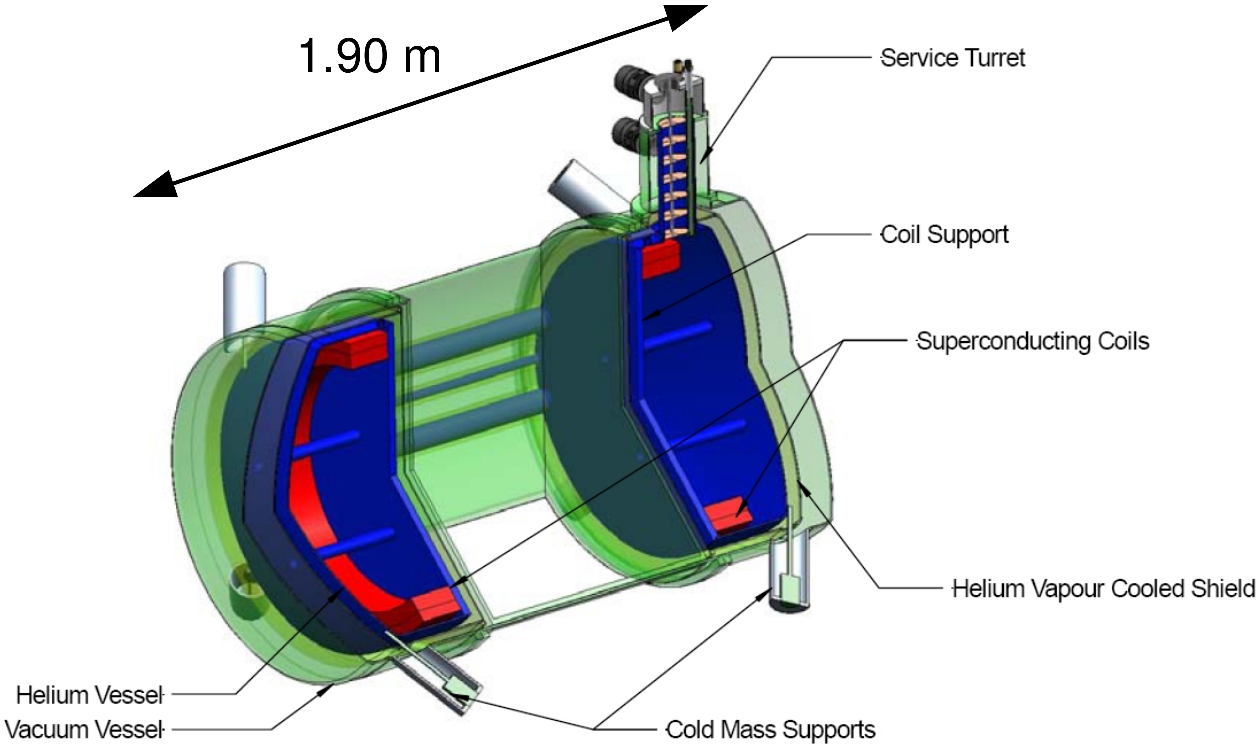
2.43 m

Magnet design

Rectangular area
for detectors with
axis perpendicular
to the magnetic field

Helmholtz coils
inside here

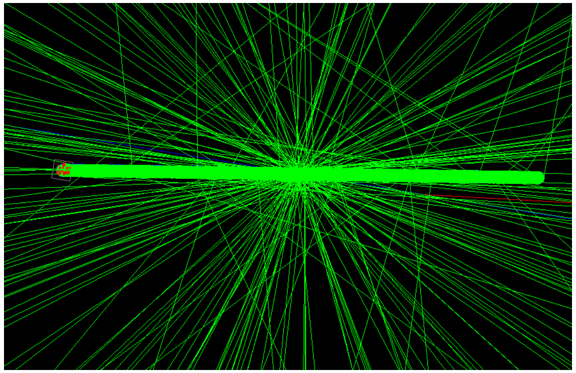
ISOMAX magnet (1998) flown on high-altitude balloon



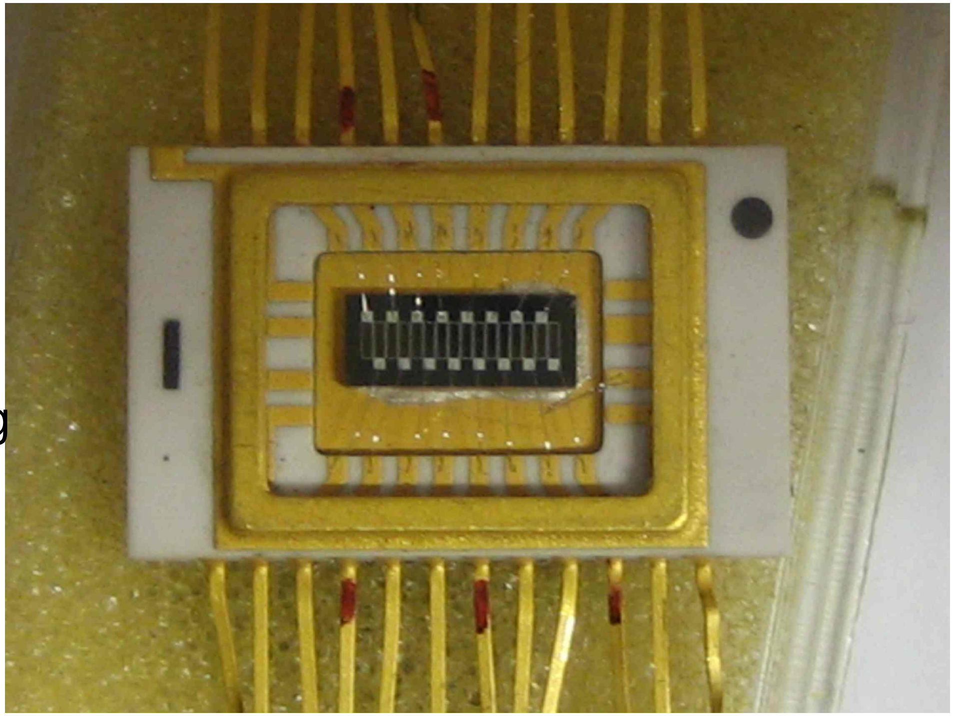
Concept Cryostat View for Vapour Cooled Shield and Coil Design 5.

Magnet design by Scientific Magnetics for superconducting pair of Helmholtz coils in He cryostat, mean field 1 Tesla, opening 80x80x80 cm^3, weight: 850kg

Tracker readout scheme

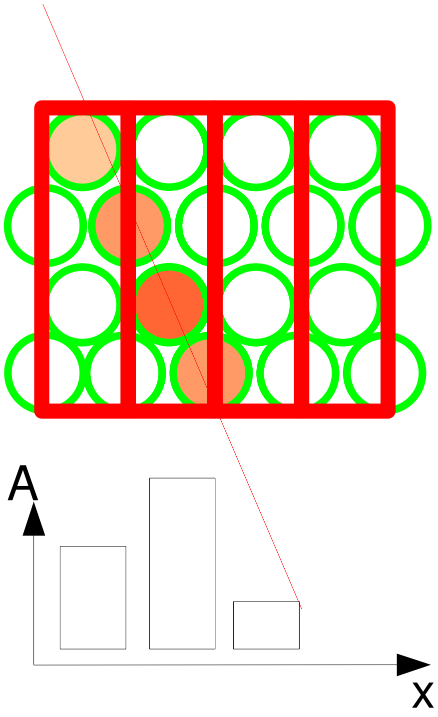


light collection in scintillating fibre in Geant4 simulation



16x1 silicon photomultiplier, strip width 380 µm

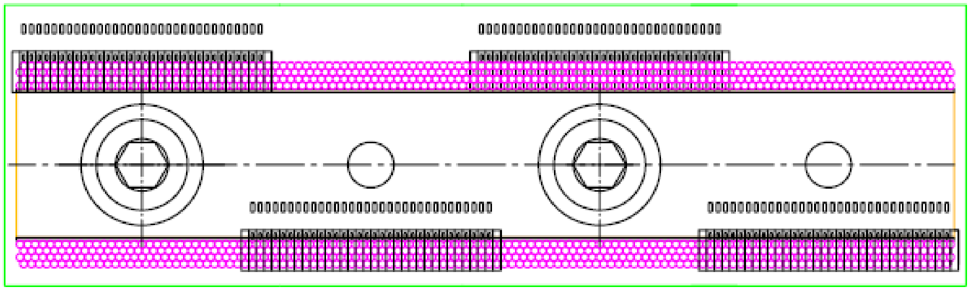
need 32x1, 250µm strip width



4x1 readout scheme (column-wise) with weighted cluster mean

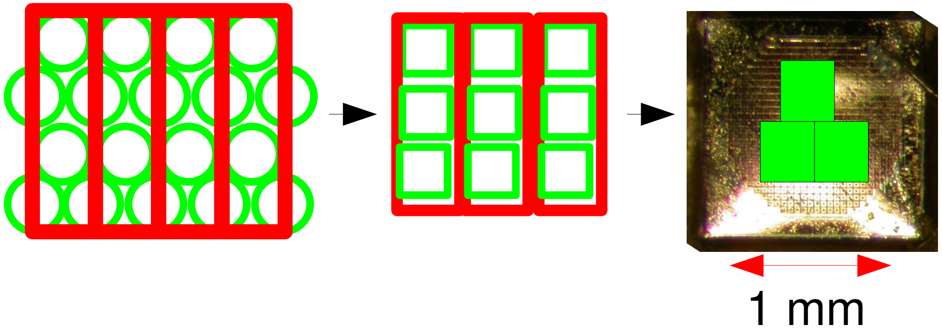
better spatial resolution than pitch/√12 , depending on p.e. yield

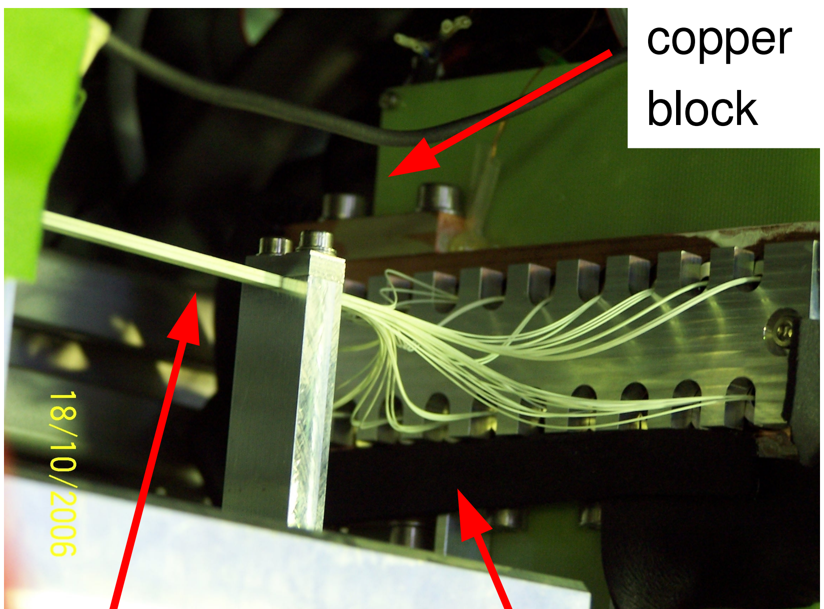
fibre module front view, with SiPM arrays on alternating sides



total power consumption (~50000 channels) of tracker: 260 W

PEBS testbeam MC

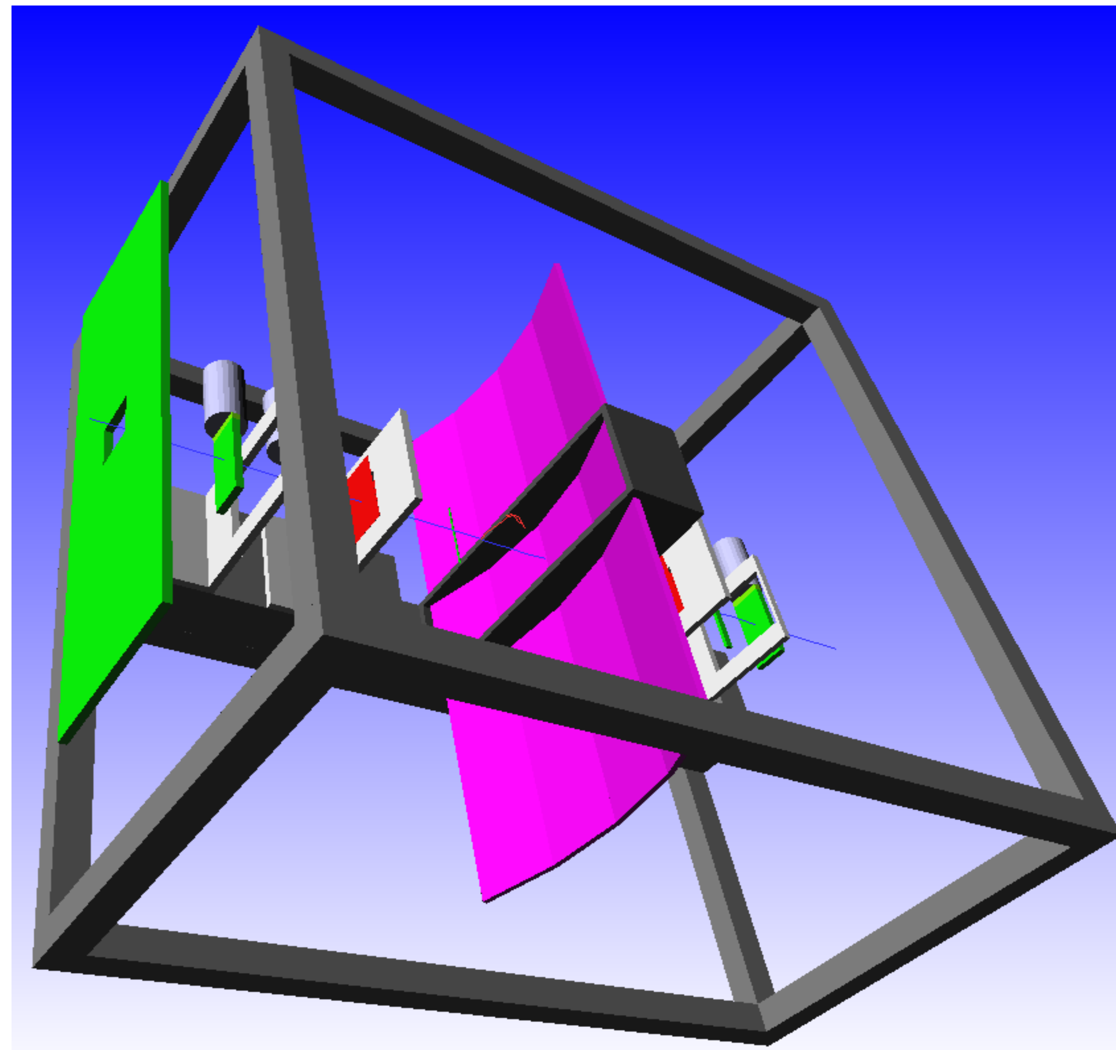




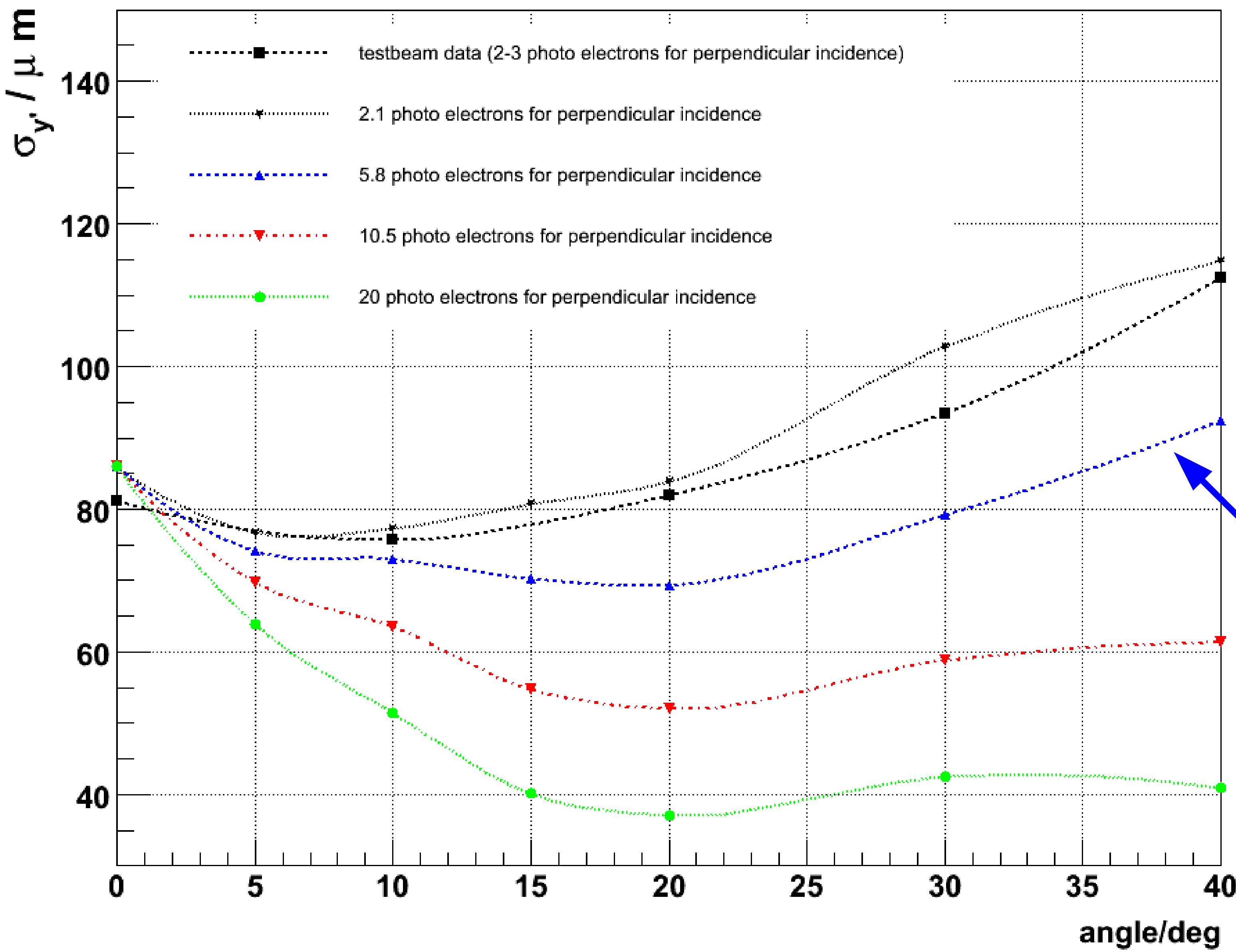
copper block

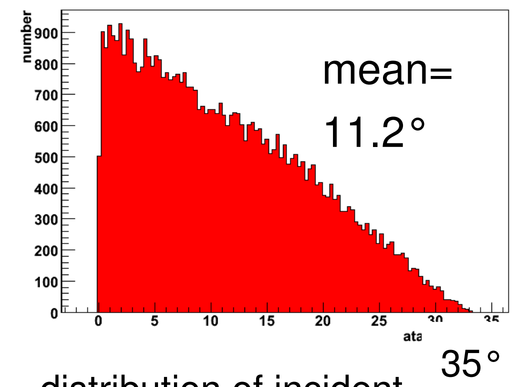
2 fibre bunches: 3x10 square fibres, d=300 μm

3 fibres each to SiPM in copper block



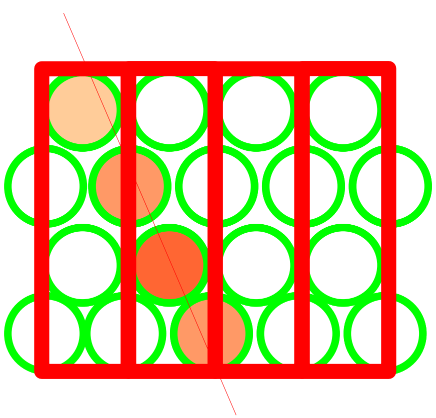
Spatial resolution vs angle of incidence





distribution of incident angle projected to bending-plane for PEBS detector

p.e. yield of testbeam fibre stack with reflective foil

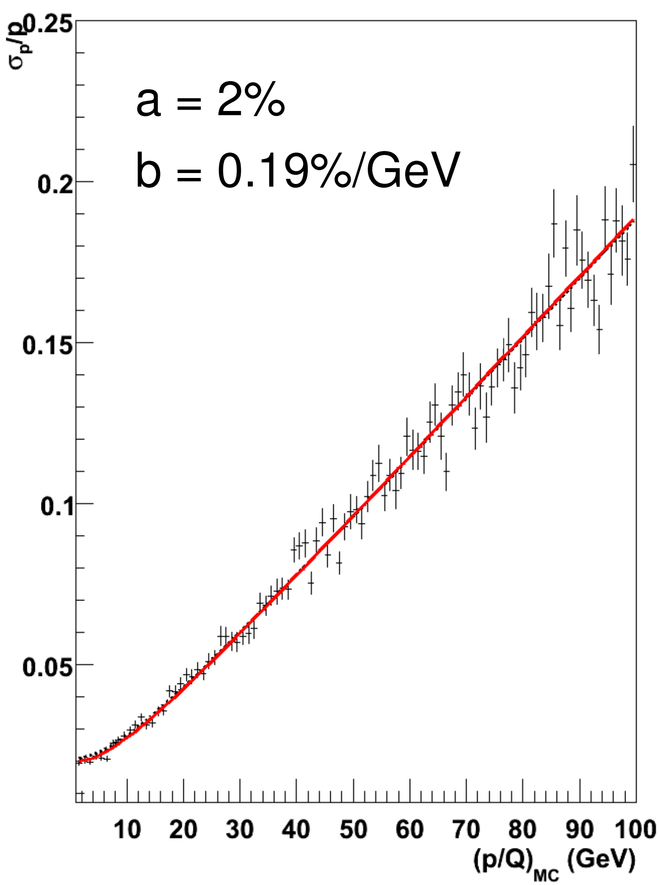


Tracker performance: Momentum resolution

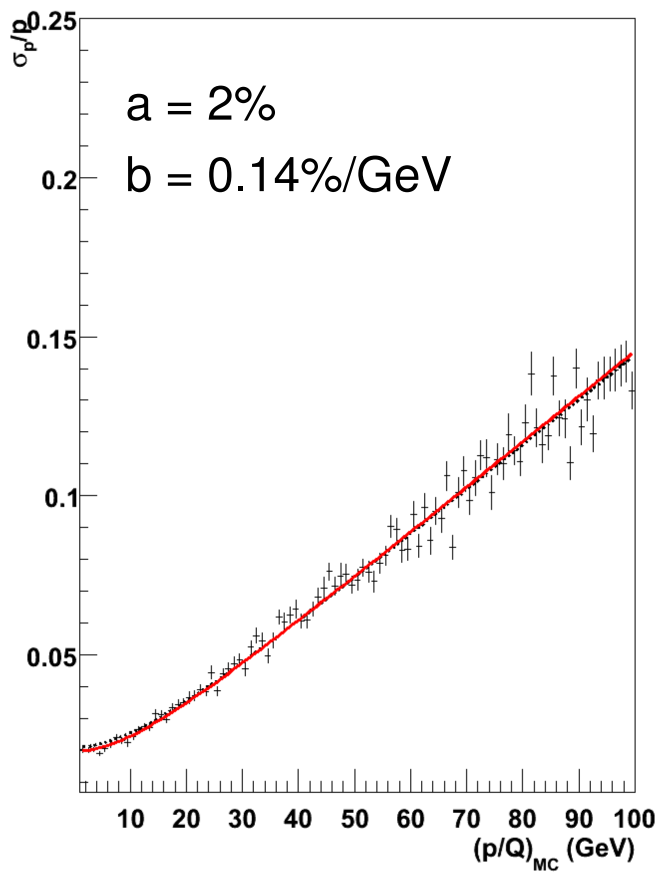
Muon momentum resolution from G4 simulation
using testbeam parameters, d = 250µm, B=1T

$$\frac{\sigma_p}{p} = \sqrt{a^2 + (b \cdot p)^2}$$

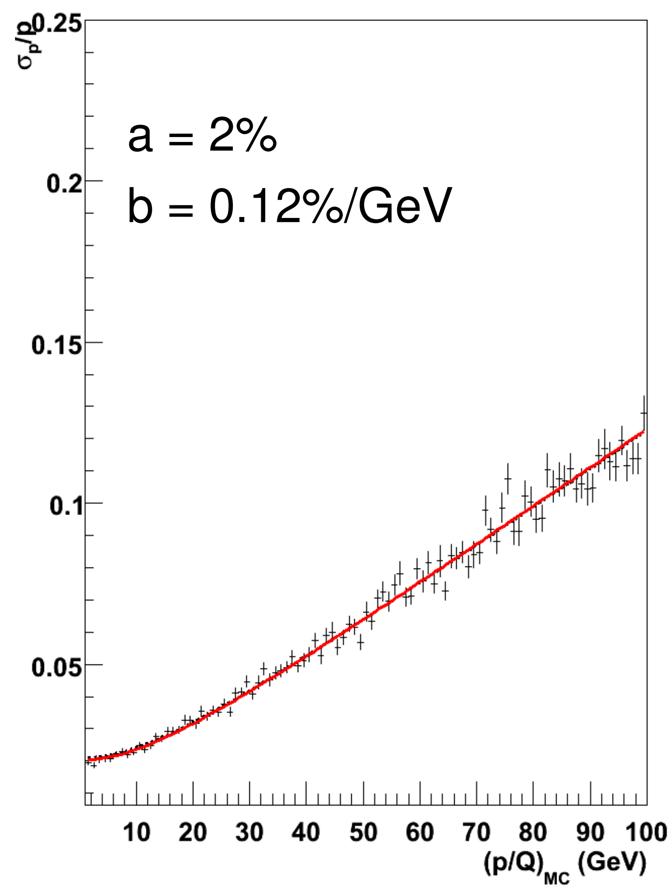
p.e. efficiency = 1 x
testbeam efficiency



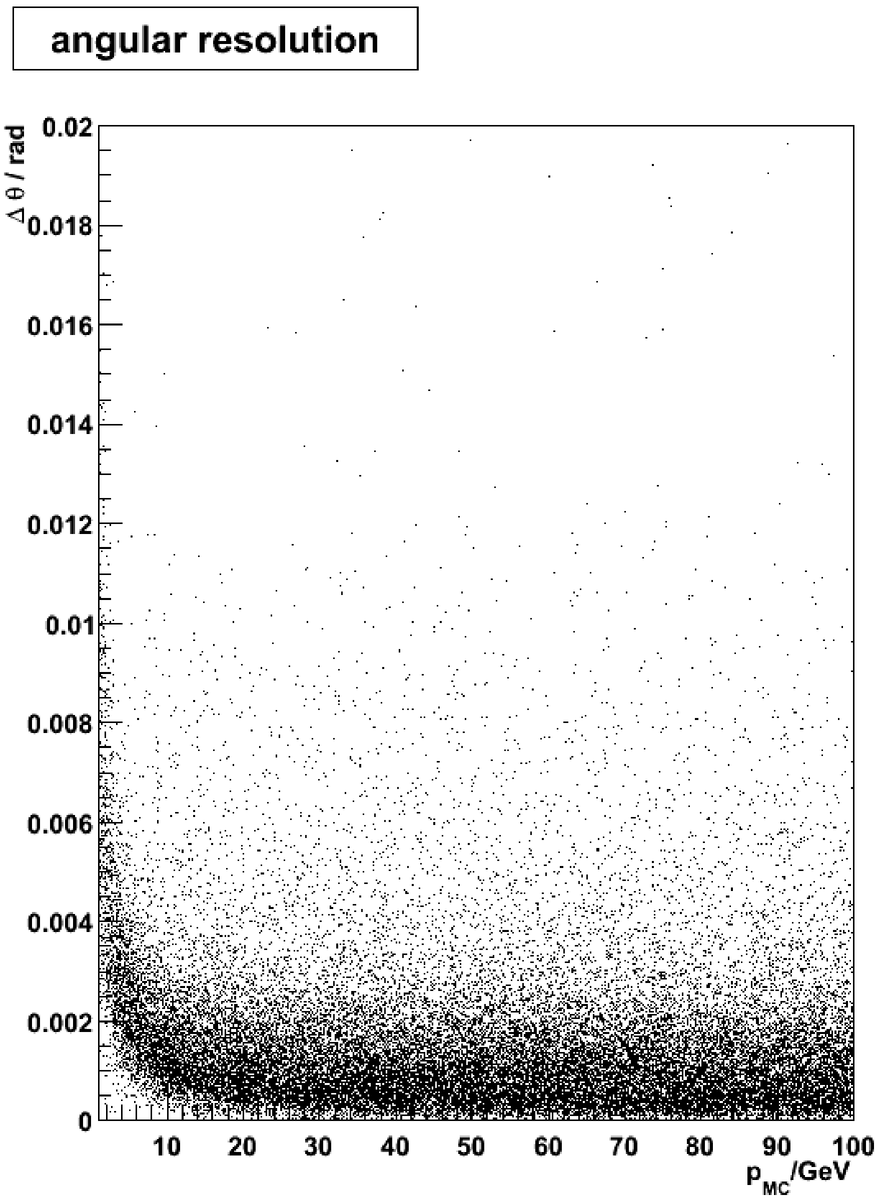
p.e. efficiency = 1.5 x
testbeam efficiency

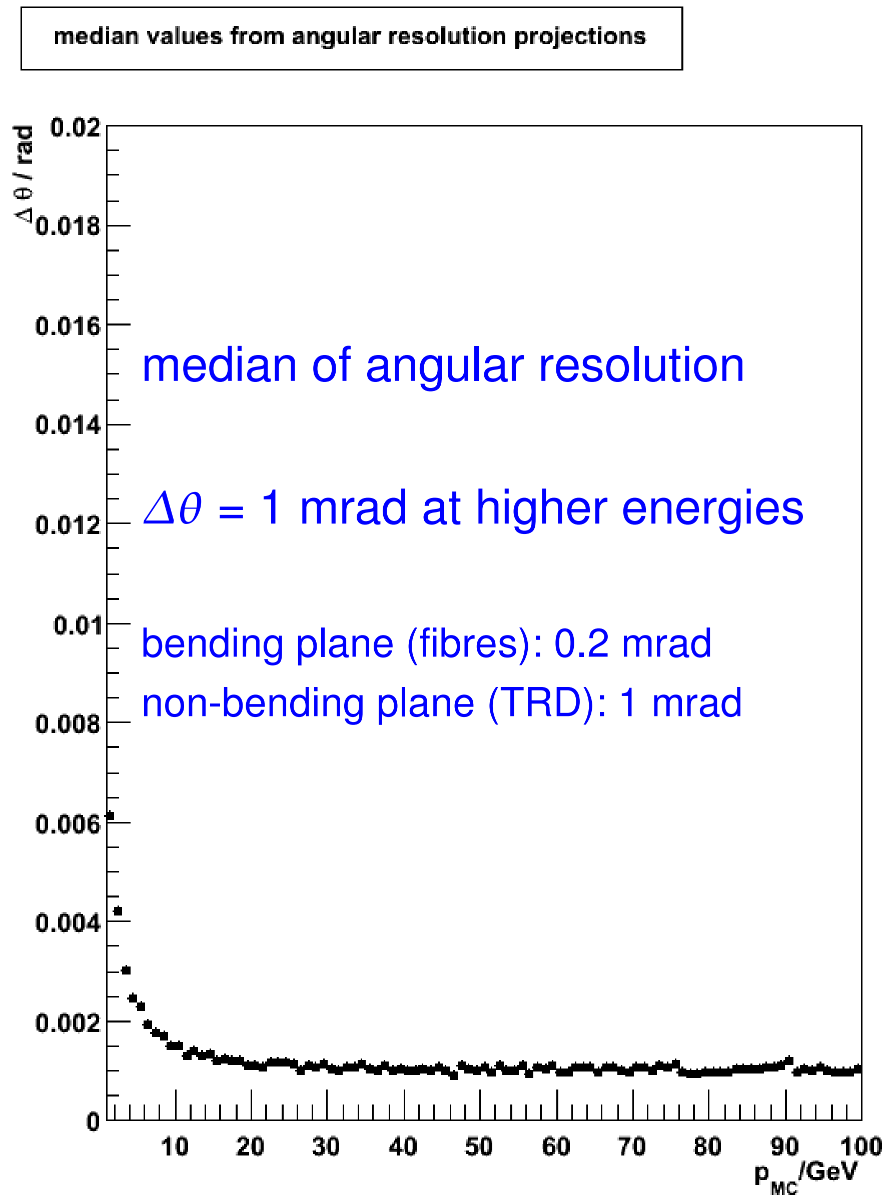


p.e. efficiency = 2 x
testbeam efficiency



Tracker performance: Angular resolution





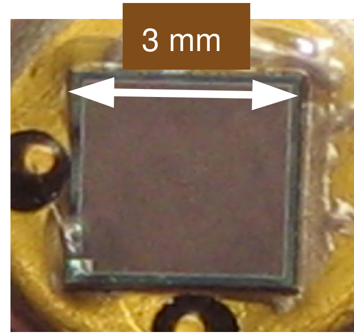
ECAL layout

8 superlayers of ten layers of lead-scintillating fibre sandwich, with alternating orientation

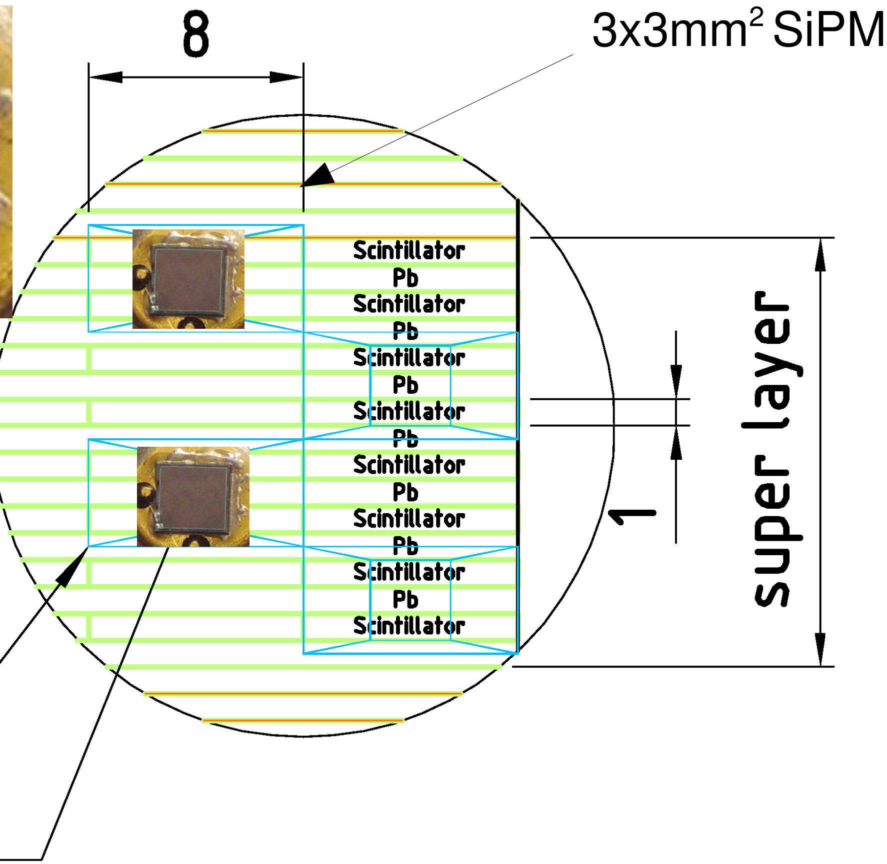
1mm lead

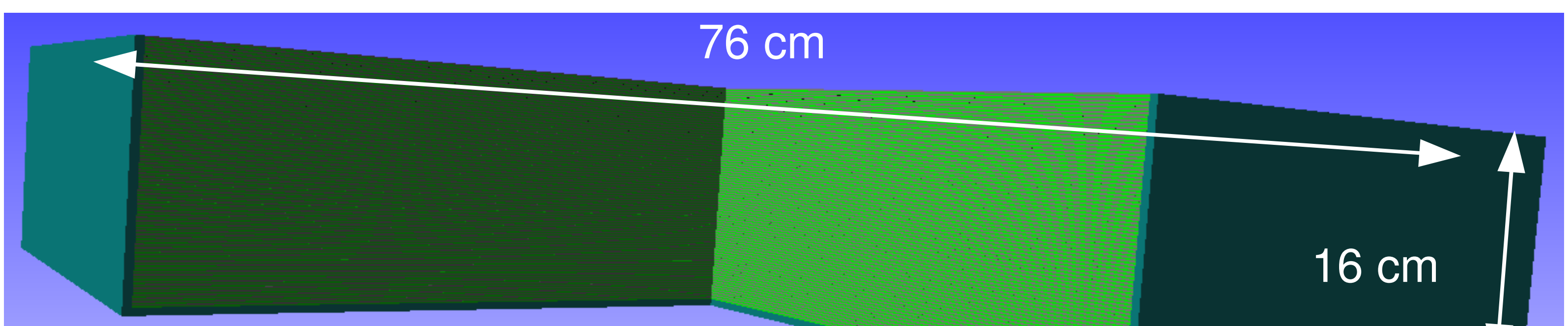
fibre: 1mm height, 8mm width, read out by SiPMs

14.3 X0 in total, ECAL weight: 550 kg

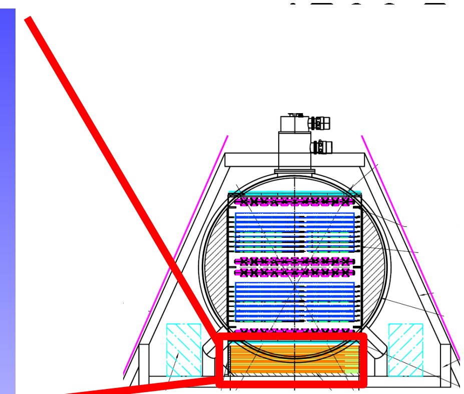


3x3 mm array:
8100 pixel

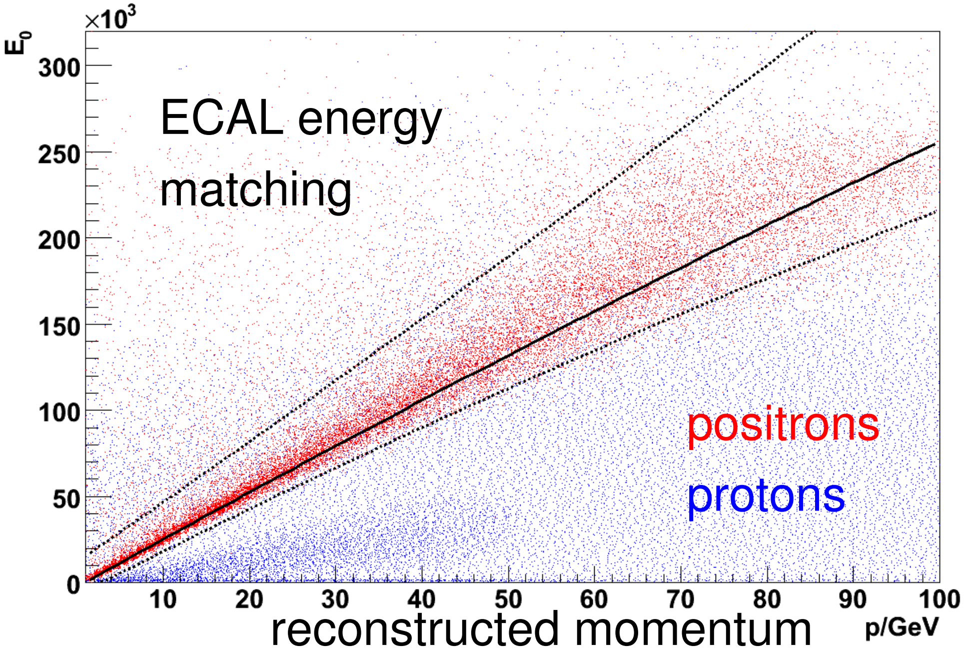


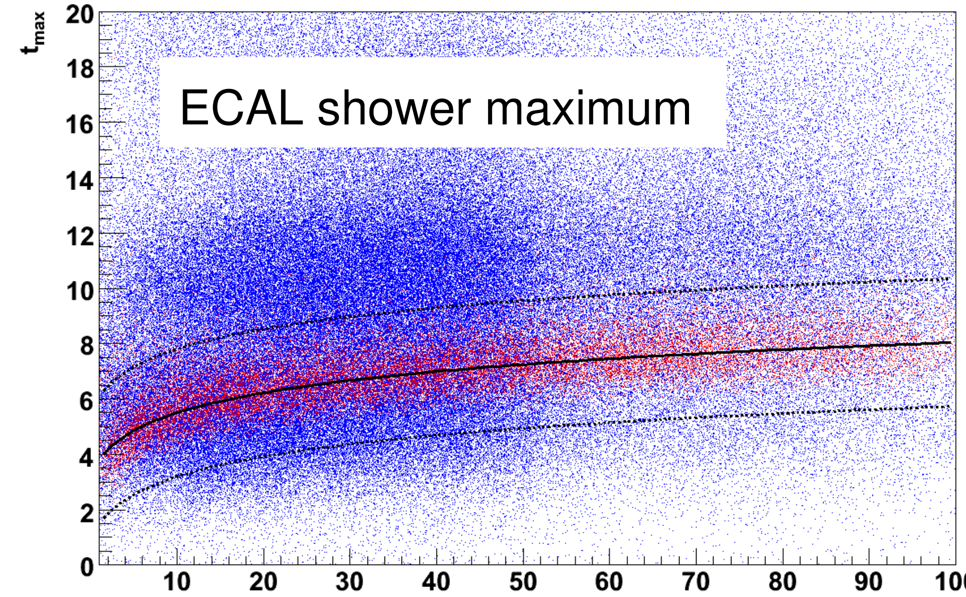


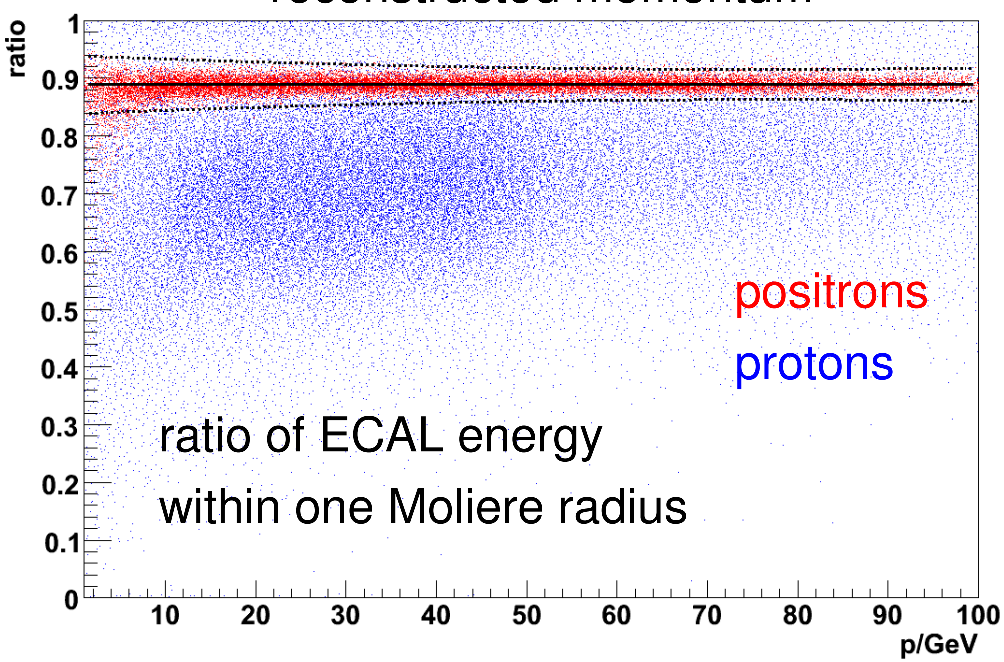
cutout view of ECAL in Geant4 simulation

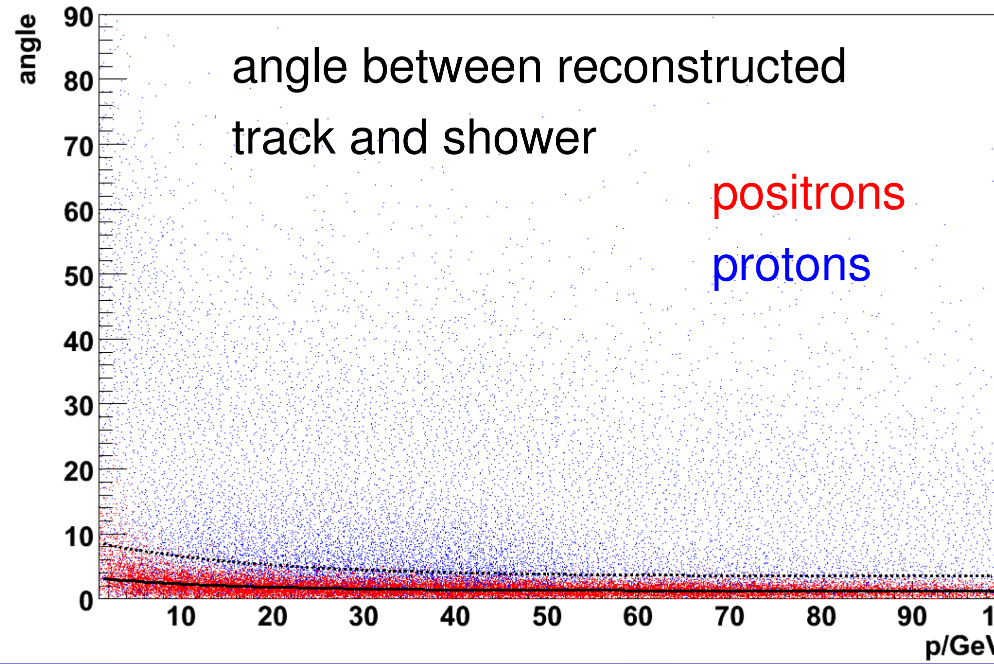


ECAL performance

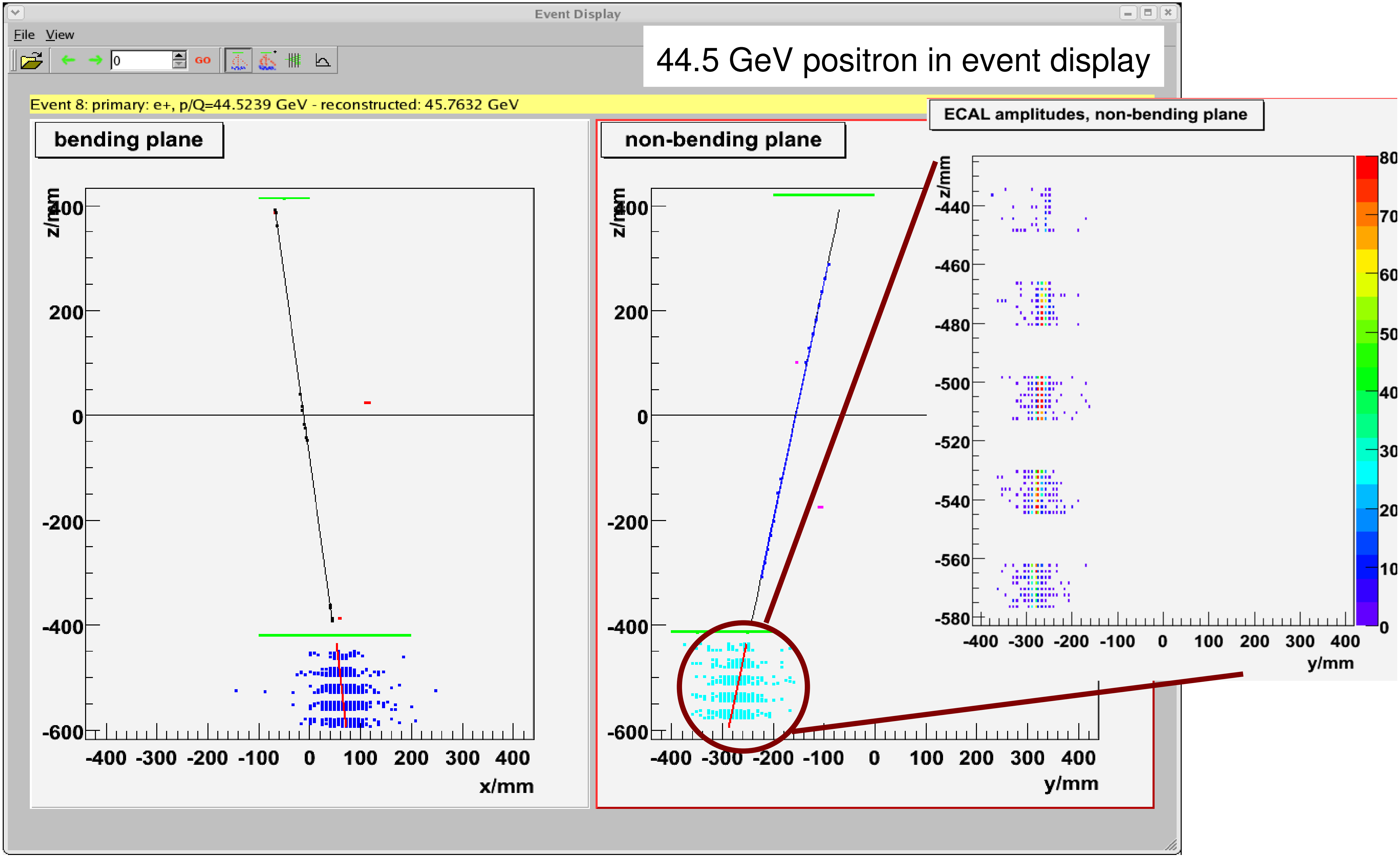




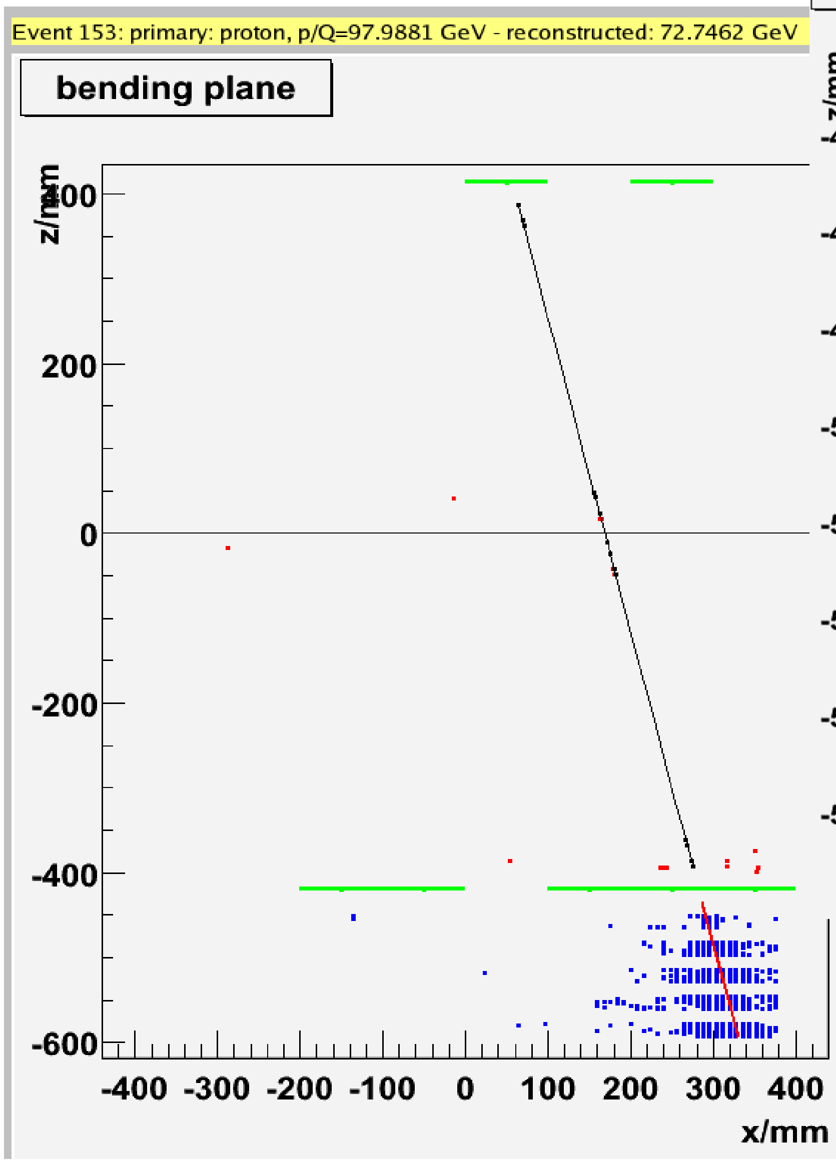


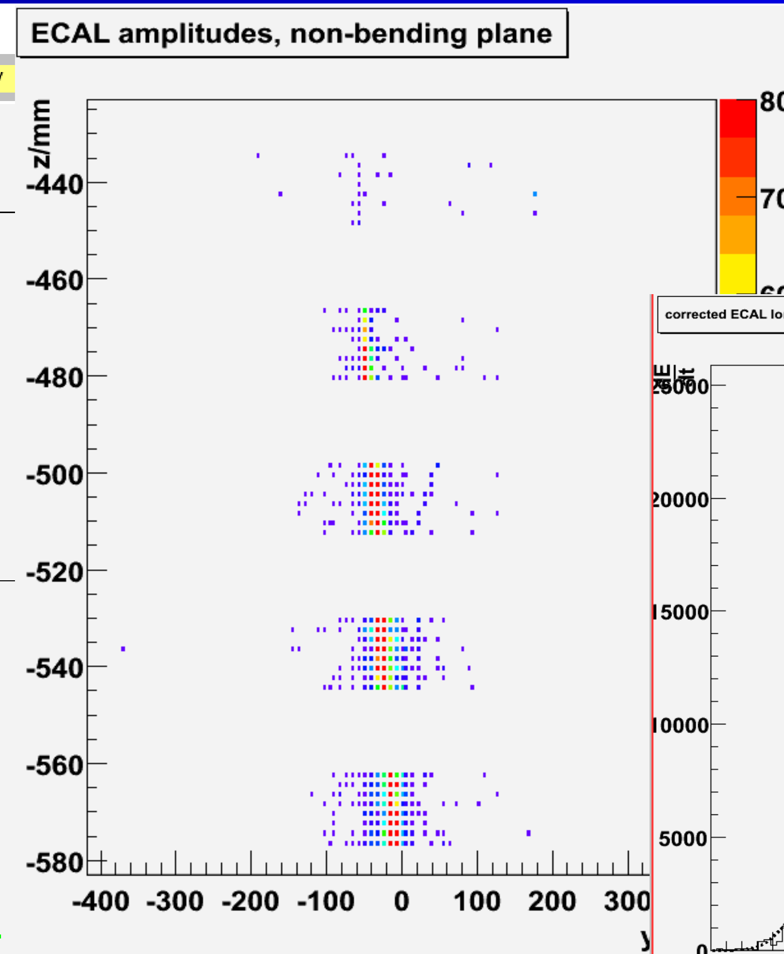


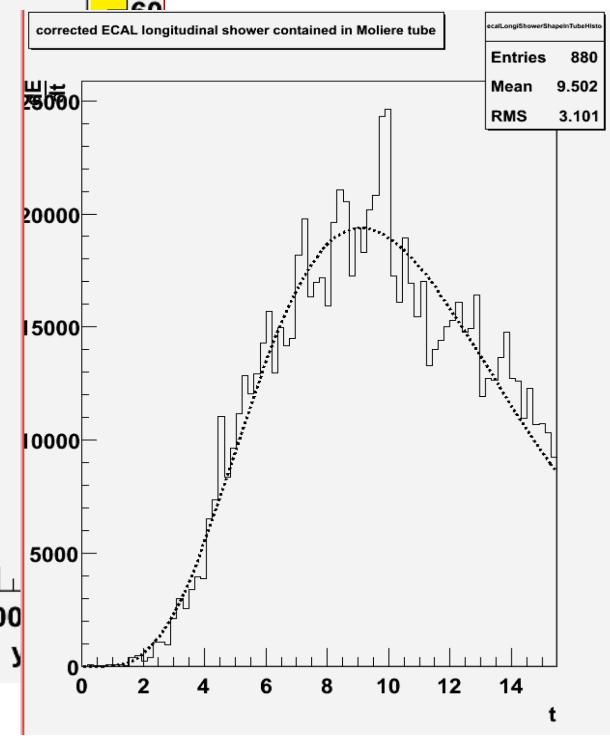
Example event



Intrinsic limits on rejection







example event:

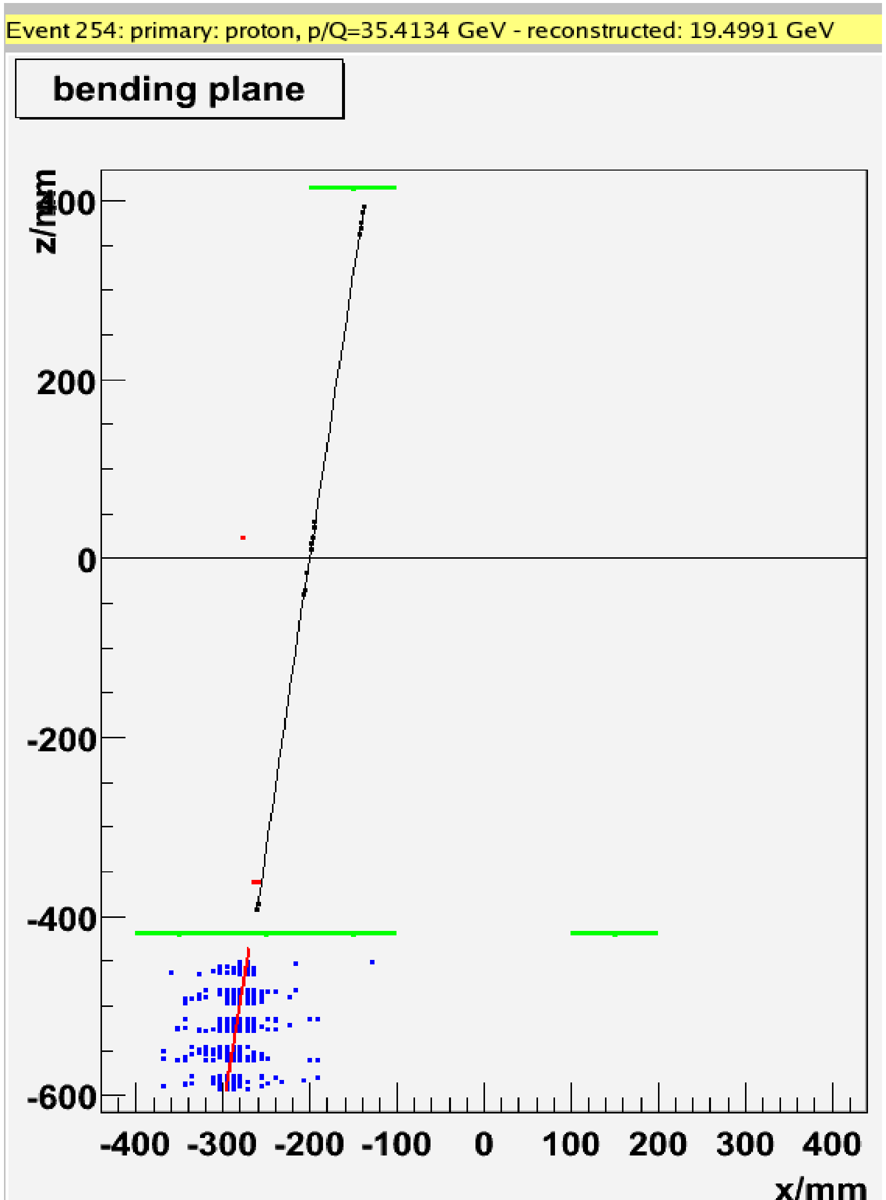
p → p π^0 X in very first ECAL layers,

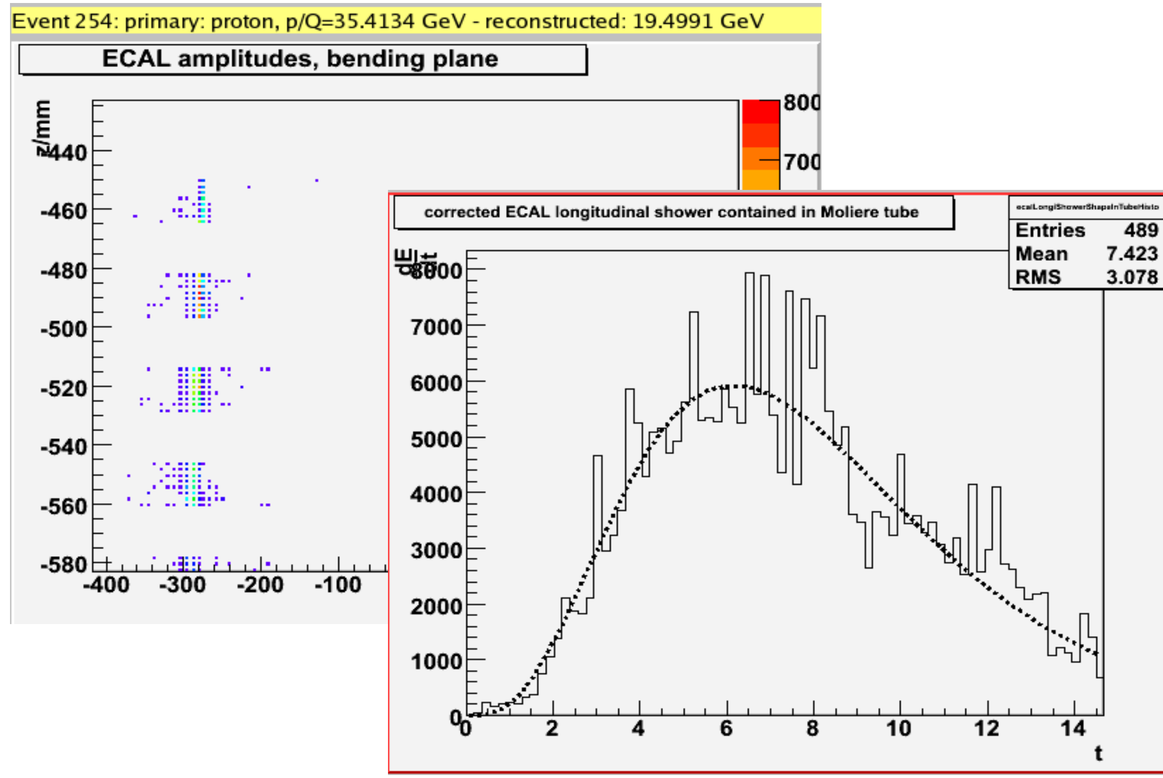
momentum reconstruction off by 1.3σ

π^0 → $\gamma\gamma$ → e.m. shower

intrinsic resolution limited by high-energy π^0 production in front of or in first layers of ECAL

Intrinsic limits on rejection (2^{nd} example)





example event:

p → p π^0 X before last tracker layer

generated: p_{gen}=35.4 GeV

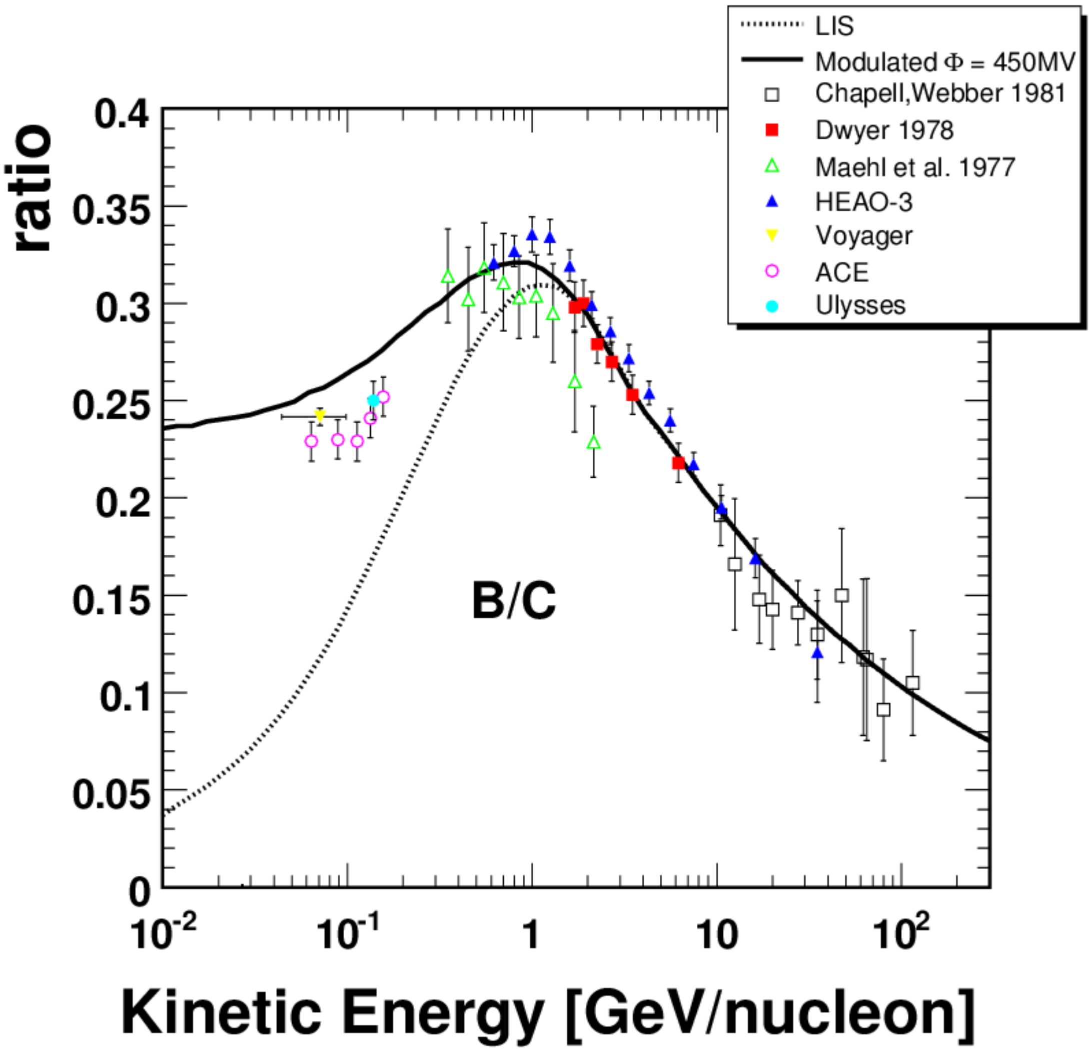
π^0 momentum: 18.9 GeV → $\gamma\gamma$ → e.m. shower

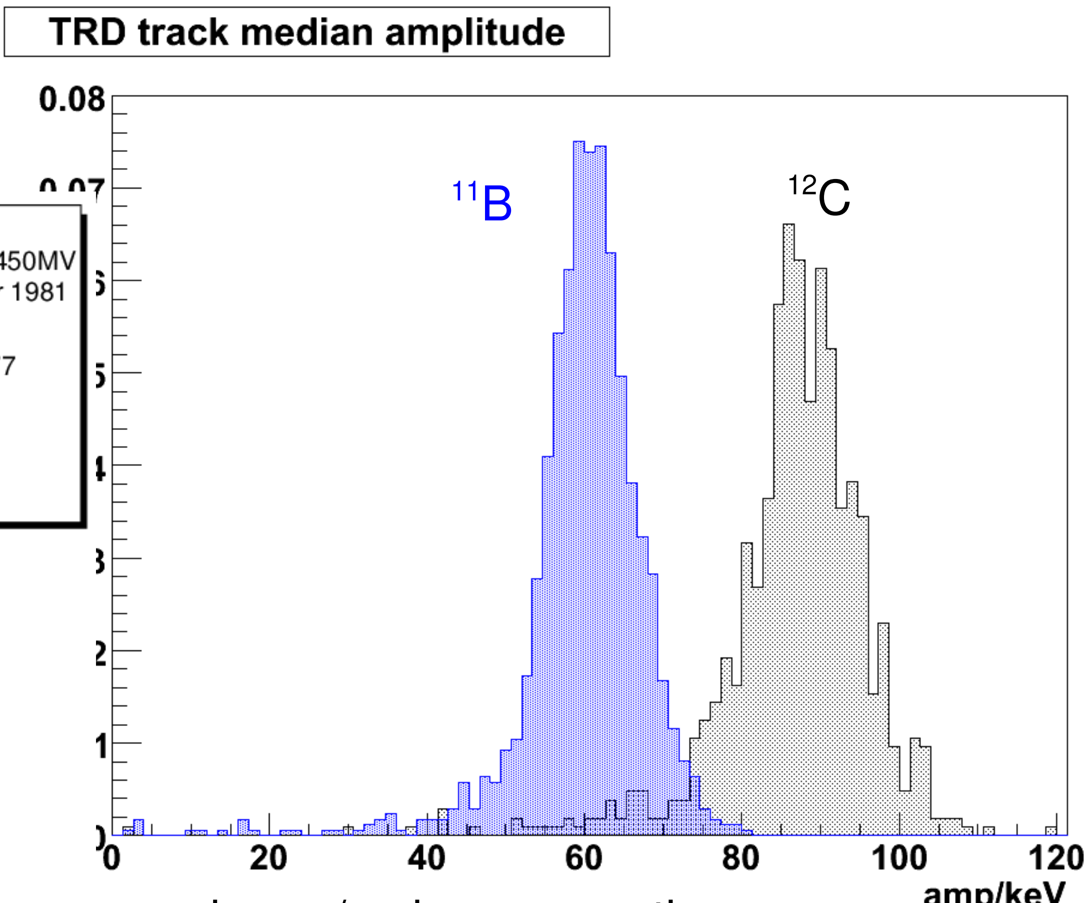
reconstructed: p_{reco}=19.5 GeV

intrinsic resolution limited by high-energy π^0 production in front of or in first layers of ECAL

TRD performance: boron / carbon

compilation of B/C measurements and GALPROP prediction





boron/carbon separation at 5 GeV/n in Geant4 simulation

needs to be studied in more detail

TRD performance: antiproton/electron separation

Analysis of TRD prototype testbeam data