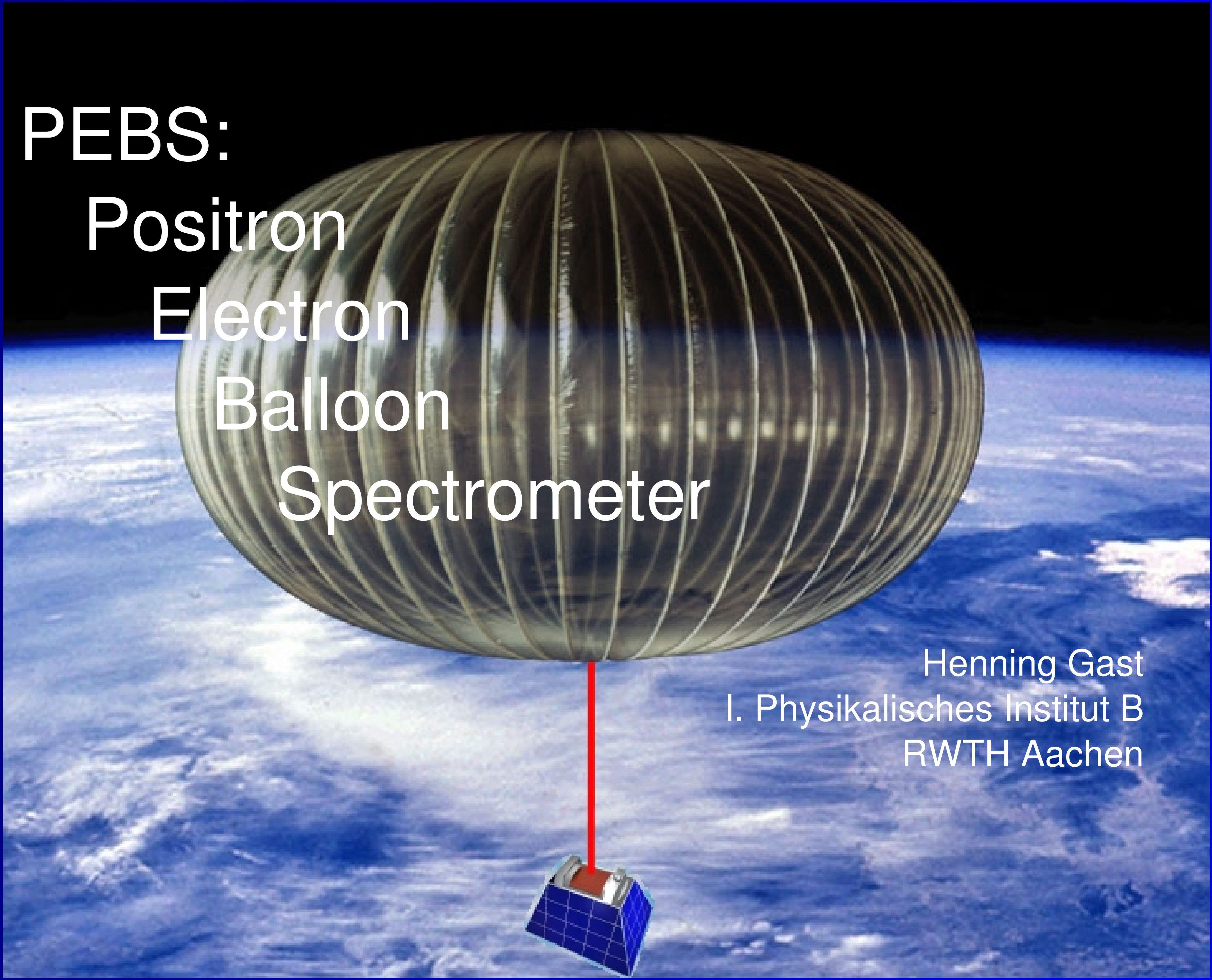


# PEBS:
# Positron Electron Balloon Spectrometer

Henning Gast
I. Physikalisches Institut B
RWTH Aachen

$30^{th}$ International Cosmic Ray Conference – Merida, Mexico

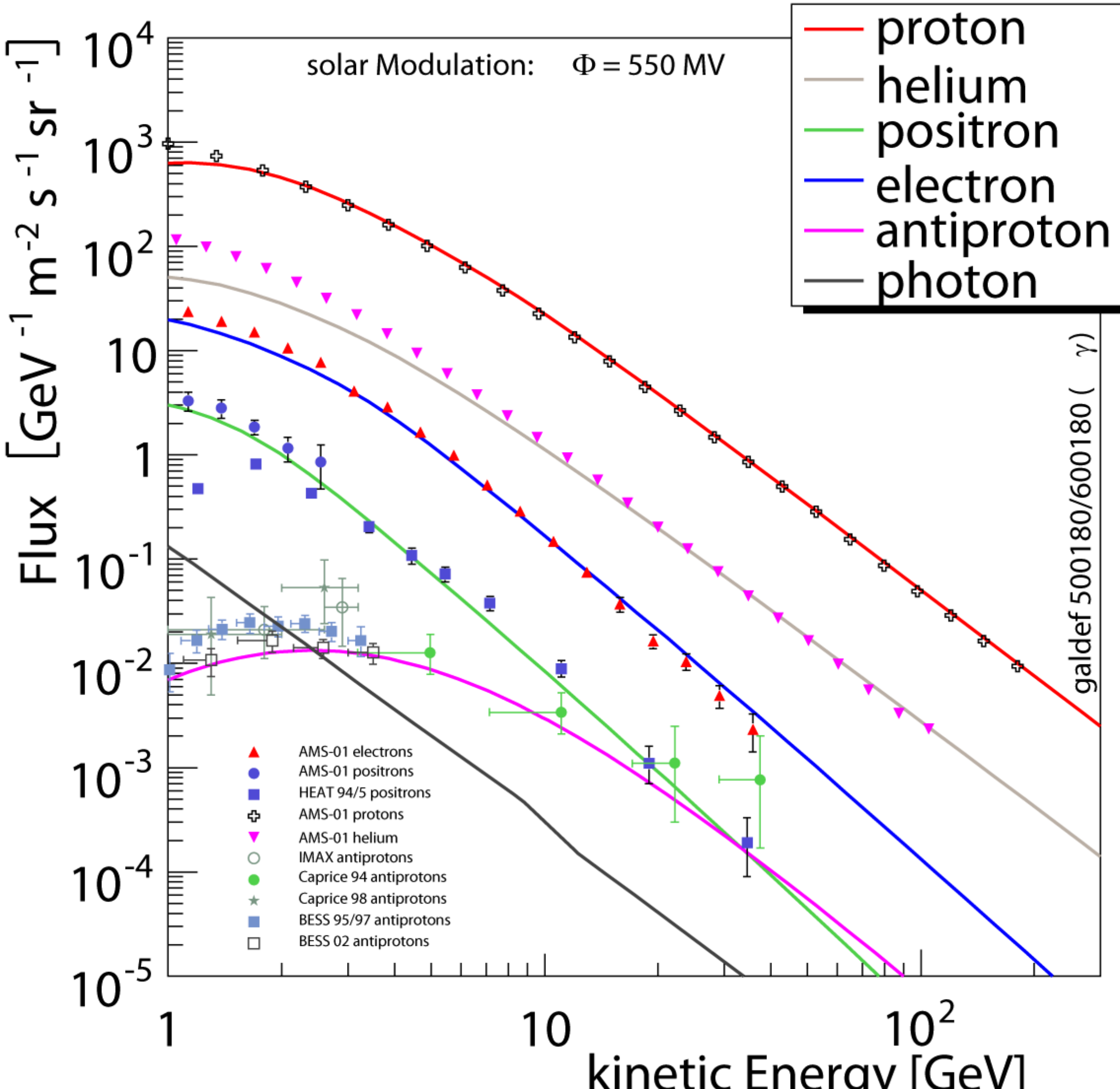
# Introduction

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 (100x24x3600)s x 0.4 $m^2 sr$ = 344 $e^+$/GeV

# Prospective performance of PEBS detector

*acceptance @100GeV and mission duration*

PEBS 4000 cm²sr, 100 days

AMS02 800 cm²sr, 1000 days

PAMELA 20 cm²sr, 1000 days

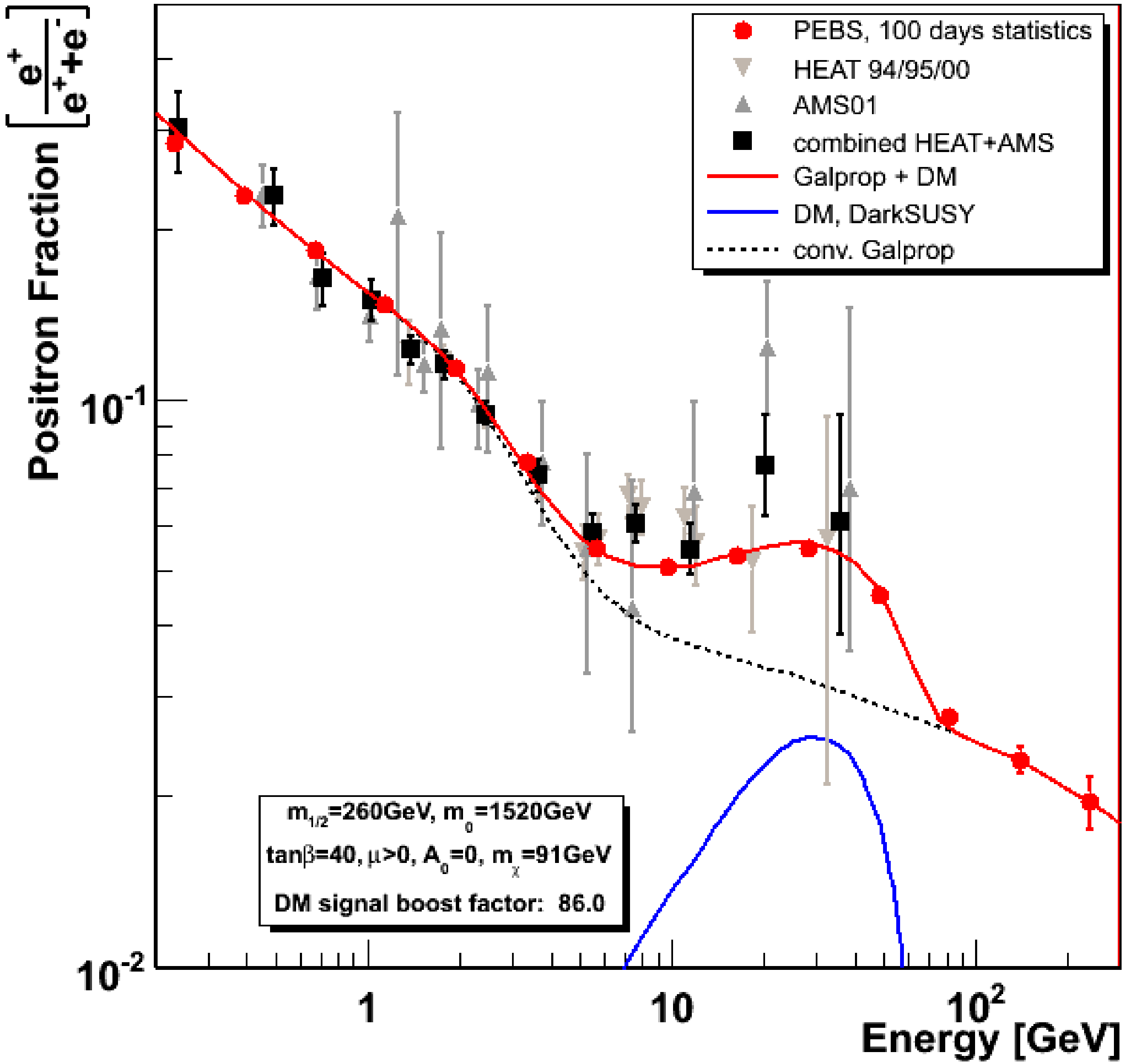
PEBS schedule

2010 20 days

2011 40 days

2012 40 days

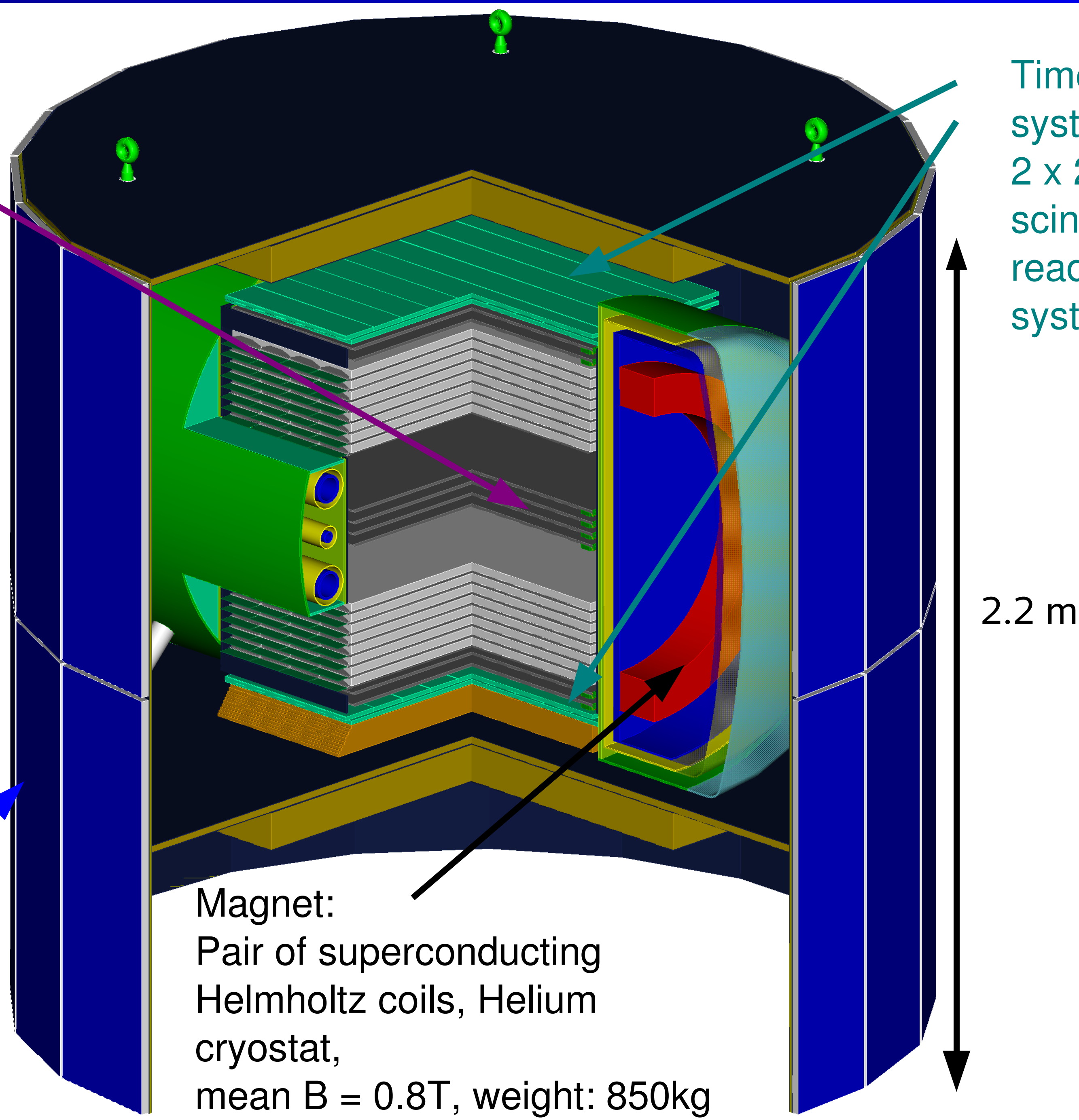
100 days PEBS=
1.4 years AMS02
55 years PAMELA



# PEBS design overview

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

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

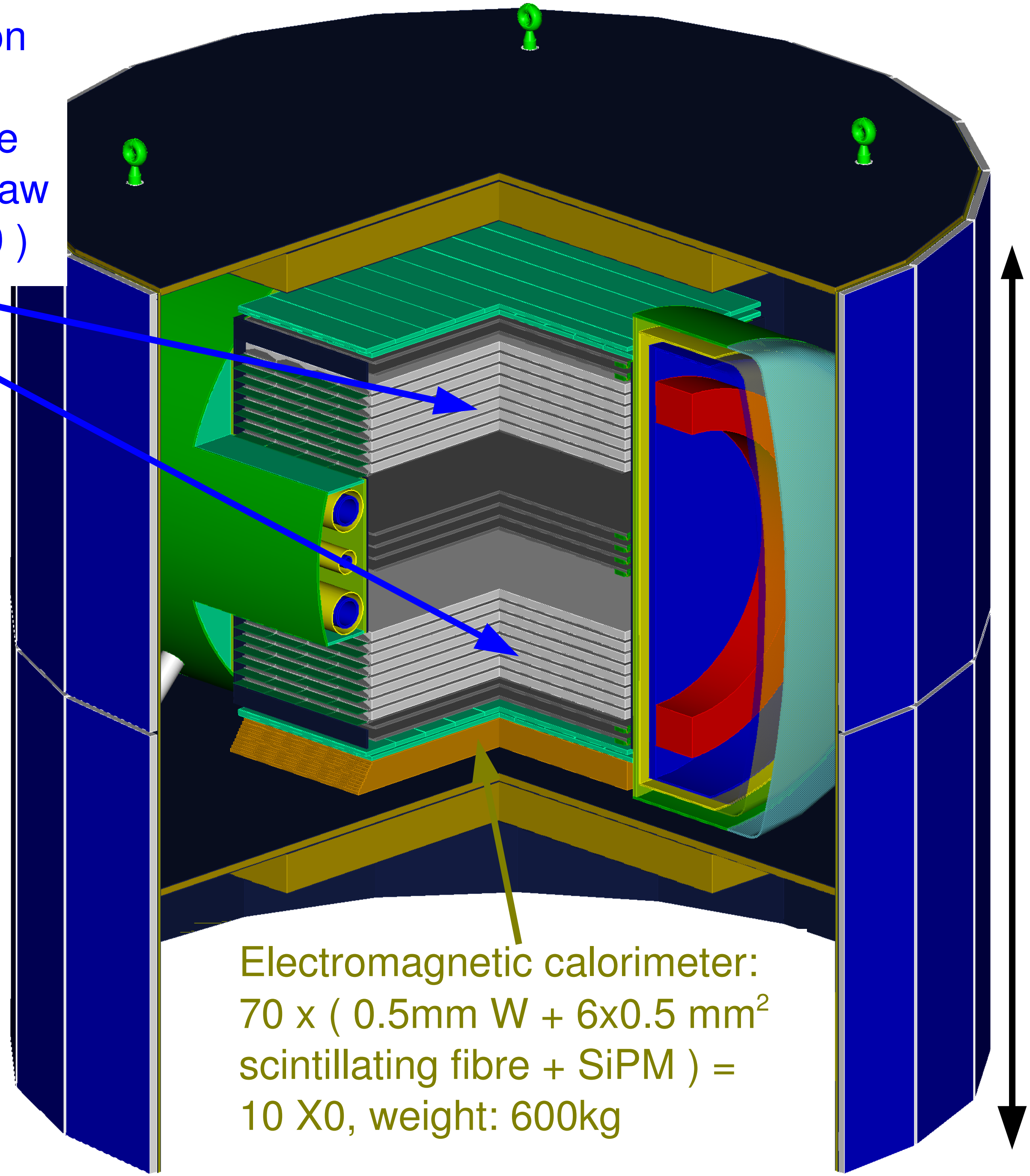



Solar panels:
power for subdetectors, communications, data handling
~600 W

Magnet:
Pair of superconducting Helmholtz coils, Helium cryostat,
mean B = 0.8T, weight: 850kg

# PEBS design overview

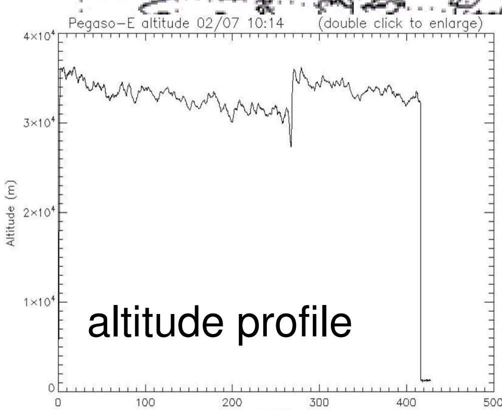
Transition Radiation Detector (TRD):
2 x 8 x ( 2cm fleece radiator + 6mm straw tube $Xe/CO_2$ 80:20 )

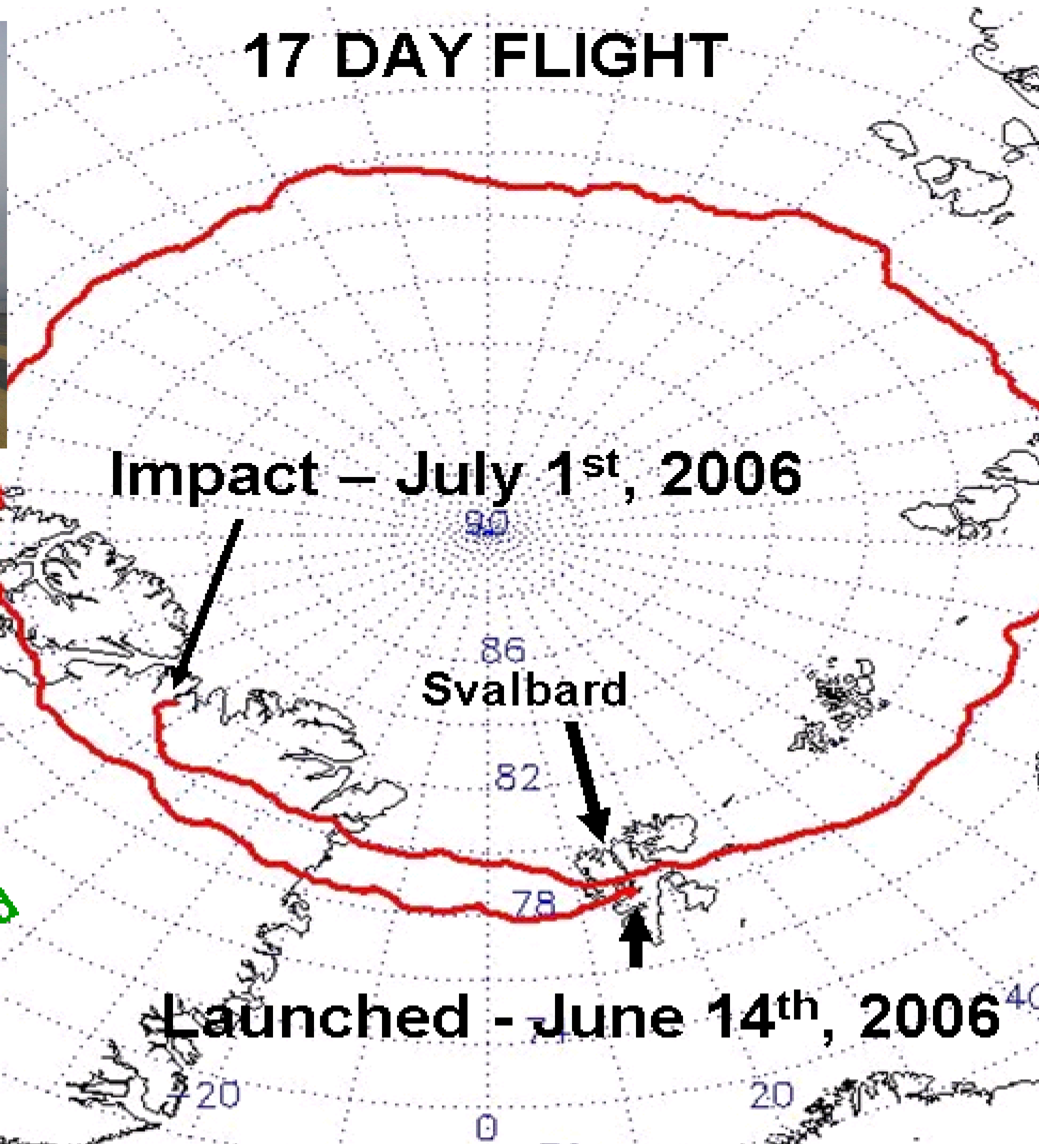



Positron acceptance: 4000 $cm^2sr$

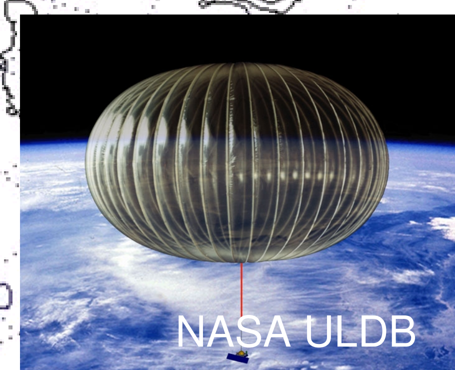
Electromagnetic calorimeter:
70 x ( 0.5mm W + 6x0.5 $mm^2$ scintillating fibre + SiPM ) = 10 X0, weight: 600kg

# Balloons

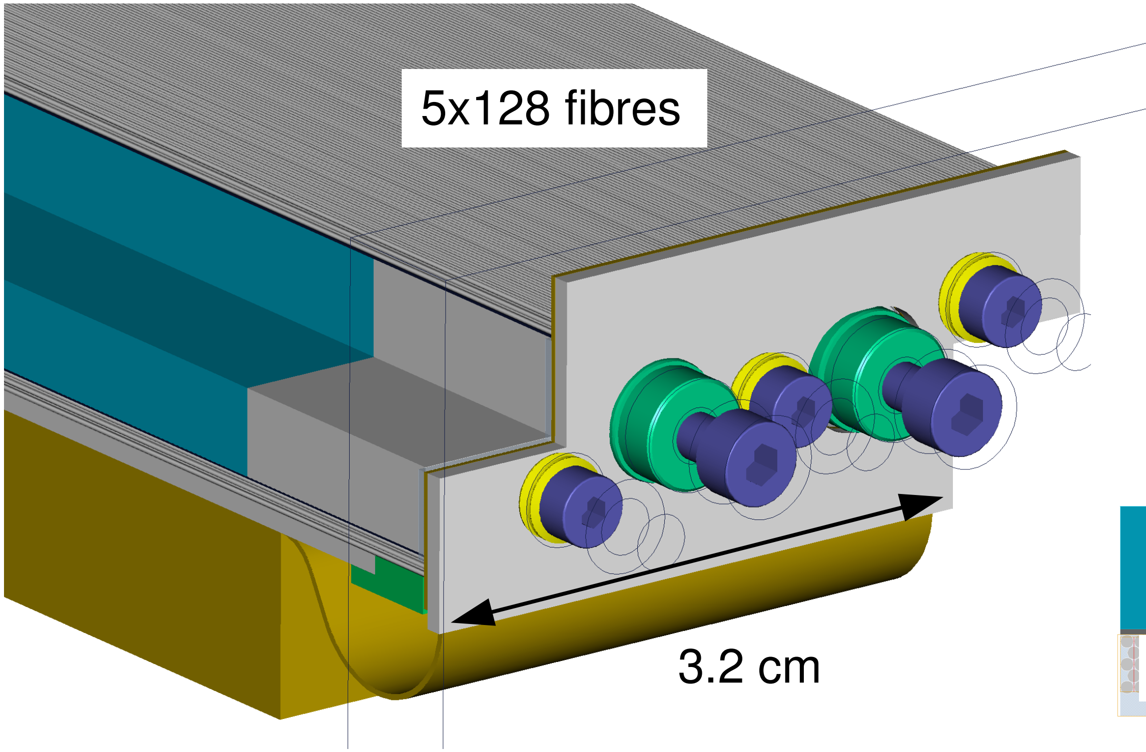


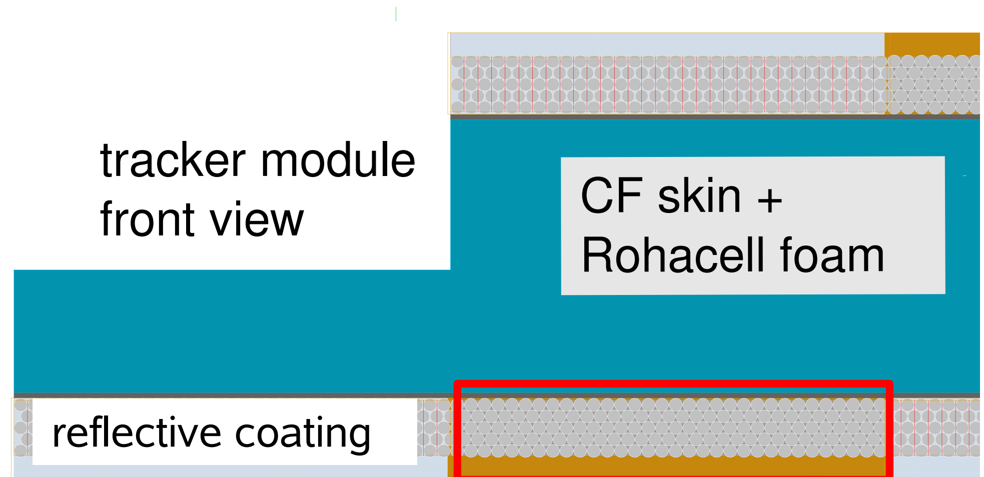


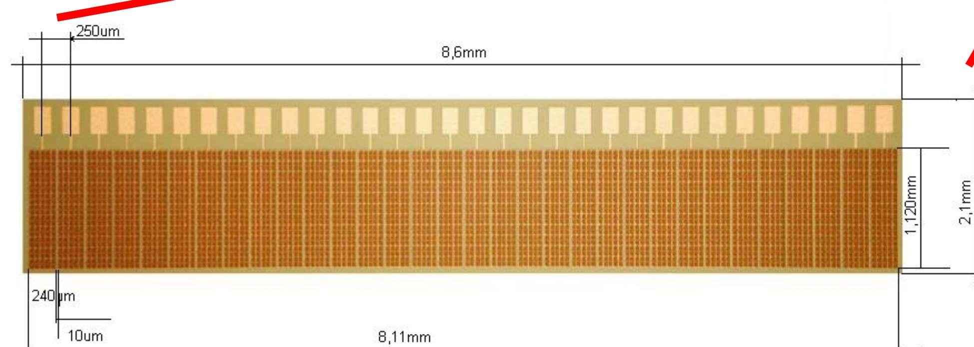

High-altitude (~40km), long-duration (~20 days) balloon flights from Svalbard ballonport (ASI)

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

# Tracker modules

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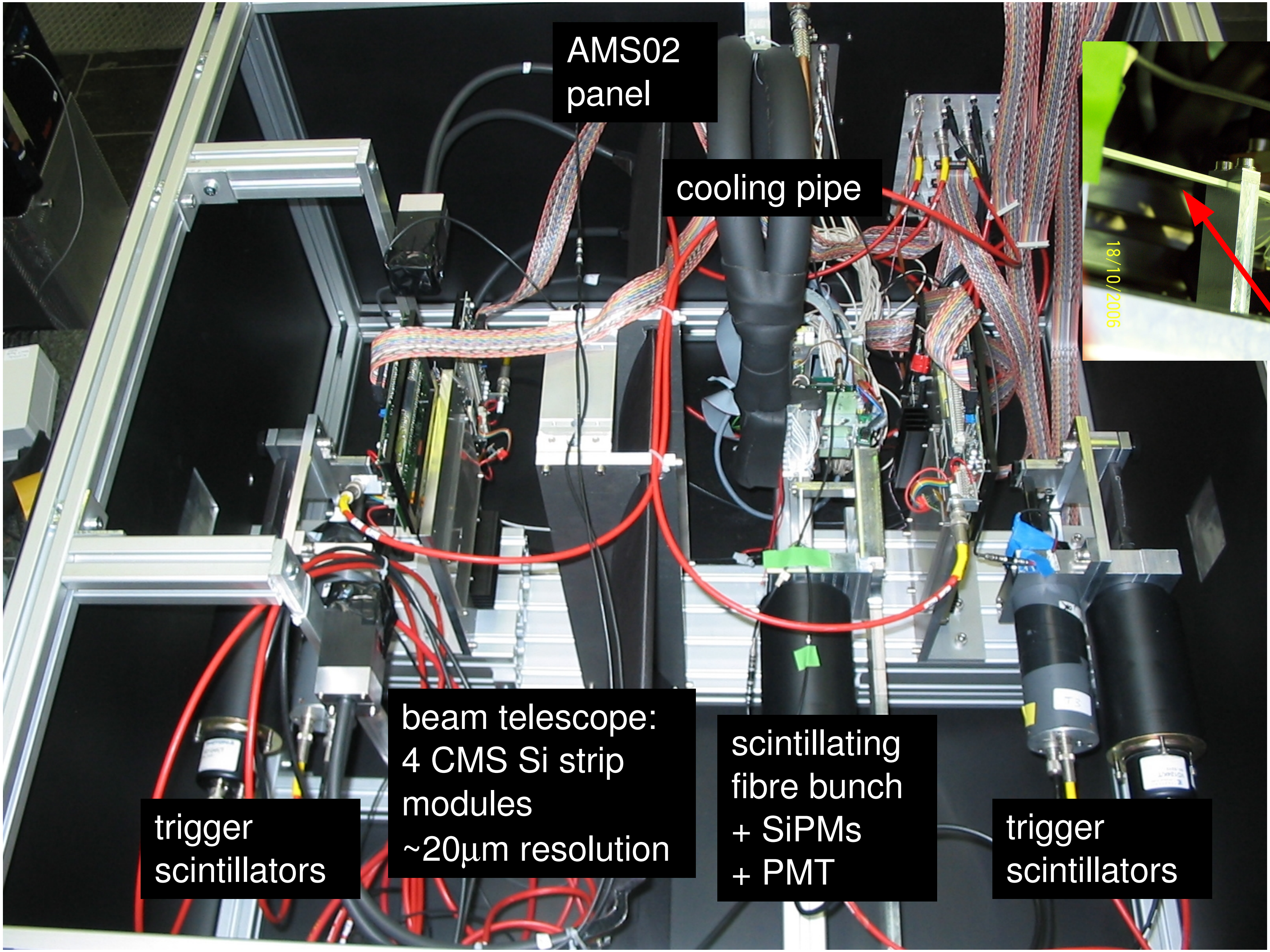
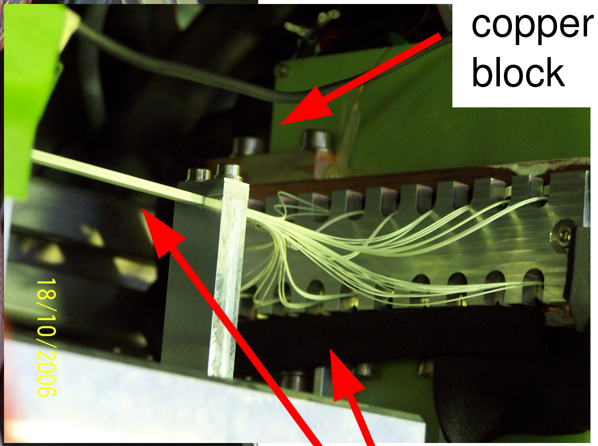
8 superlayers of 25 double-layered modules of scintillating fibres, d=250 $\mu$m, stack of fibres accumulates light on SiPM readout of SiPMs by dedicated VA chip

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

32x1 silicon photomultiplier
250µm strip width, 100 pixels/SiPM

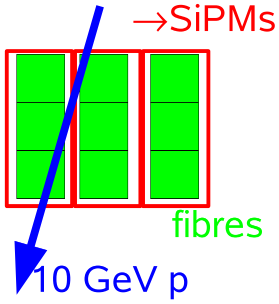
# PEBS fibre tracker testbeam setup



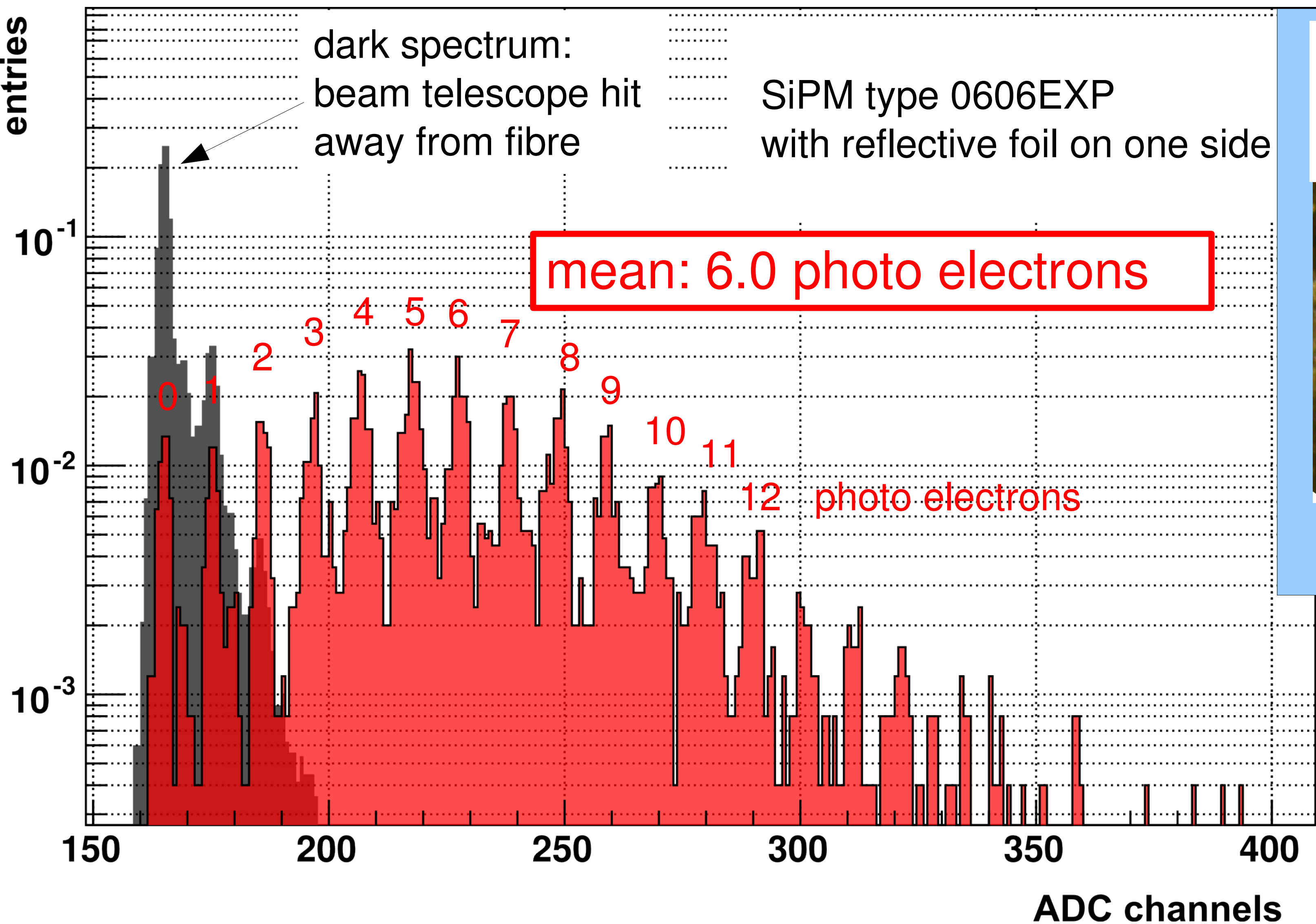



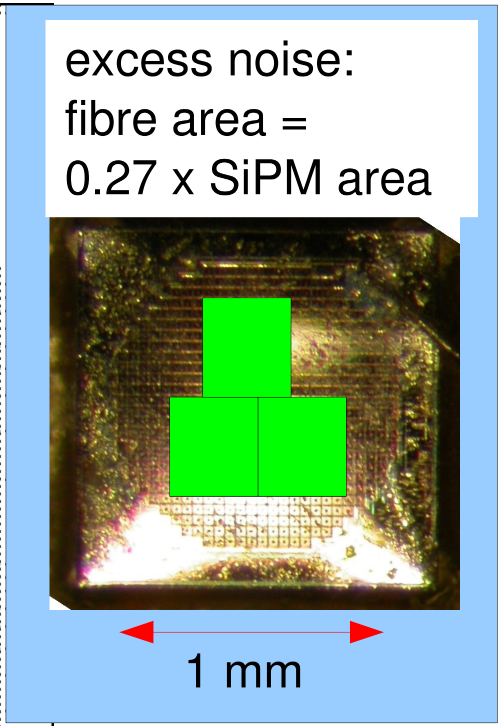

copper block

2 fibre bunches:
3x10 square fibres, d=300 $\mu$m
3 fibres each to SiPM in copper block



# SiPM: example of a MIP spectrum



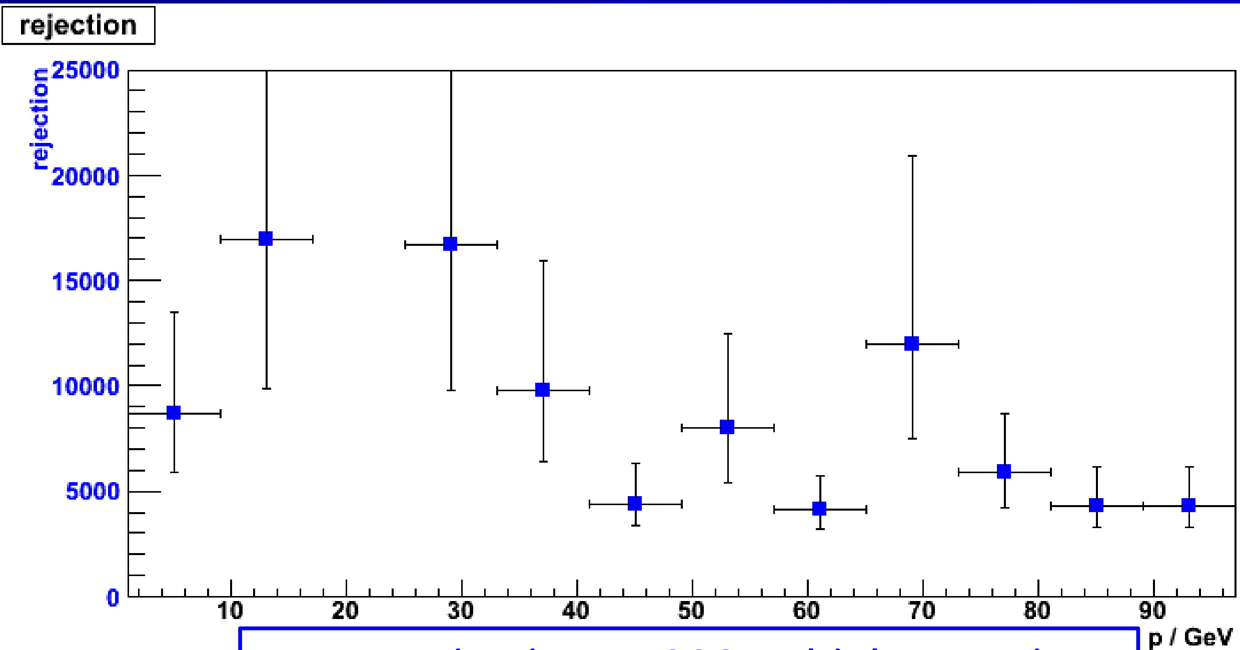




Photonique
SSPM 0606 EXP
S/N=20,
eff(0.5pe)=96%
SSPM 050701GR
S/N=100,
eff(0.5pe)=91%

Testbeam results → PEBS MC simulation → muon momentum resolution: a=2.3%, b=0.194%/GeV

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

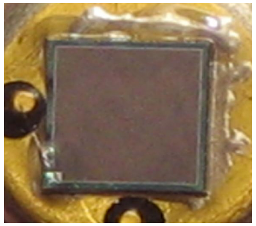
# ECAL proton rejection and energy resolution



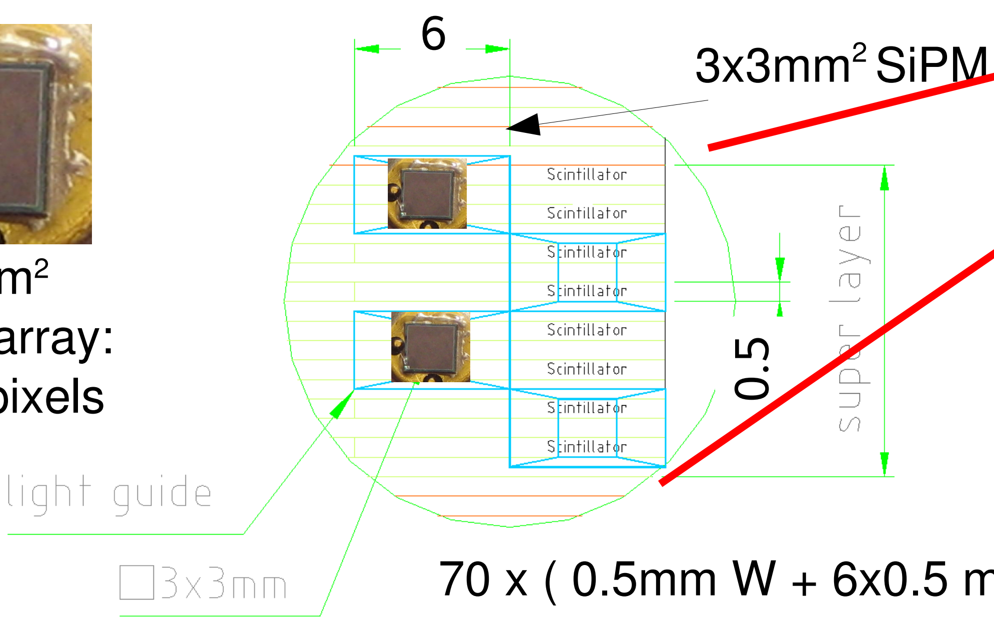

proton rejection ~5000 at high energies
(electron efficiency ~65%)

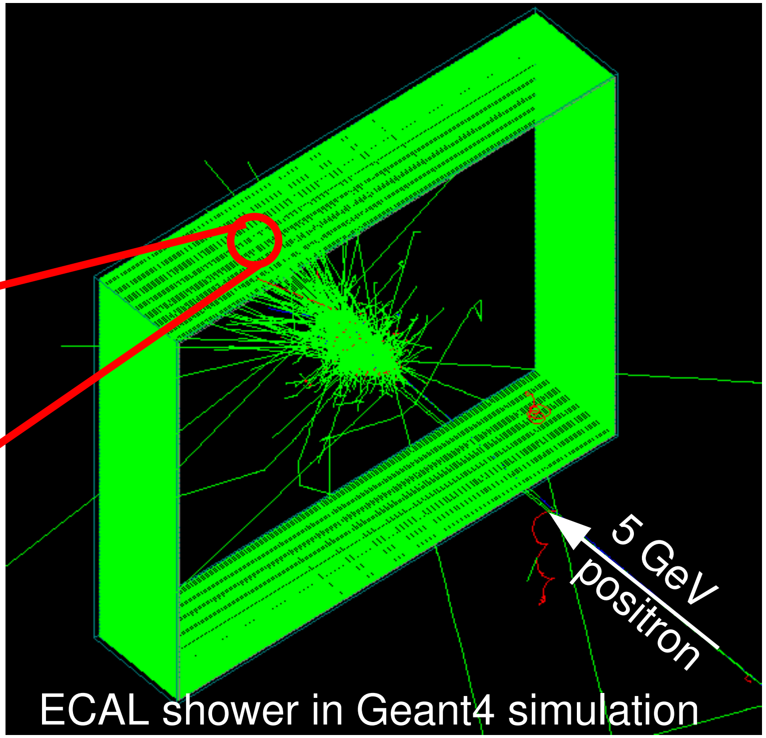
Simulated 40,000 positrons and
1,000,000 protons

ECAL energy resolution
~10%
dominated by leakage
effect



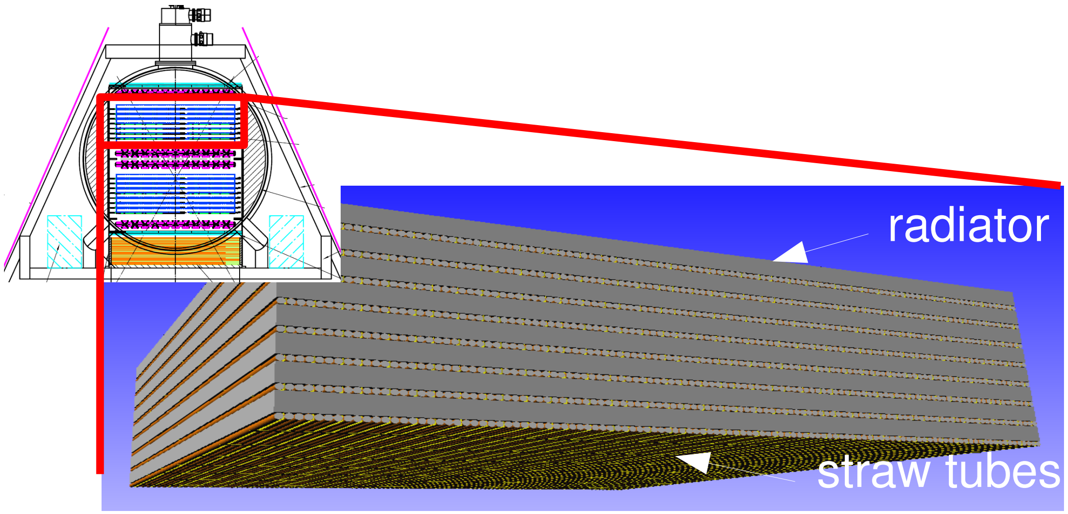
3x3 mm² SiPM array:
8100 pixels




70 x ( 0.5mm W + 6x0.5 mm² scintillating fibre + SiPM ) = 10 $X_0$

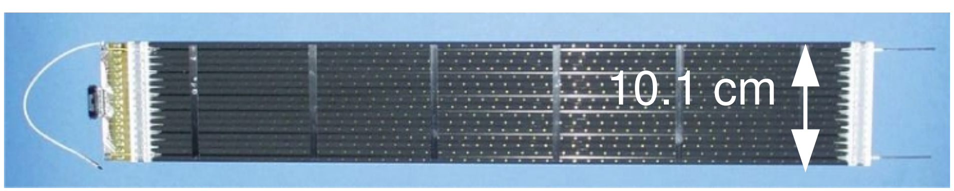
# TRD design



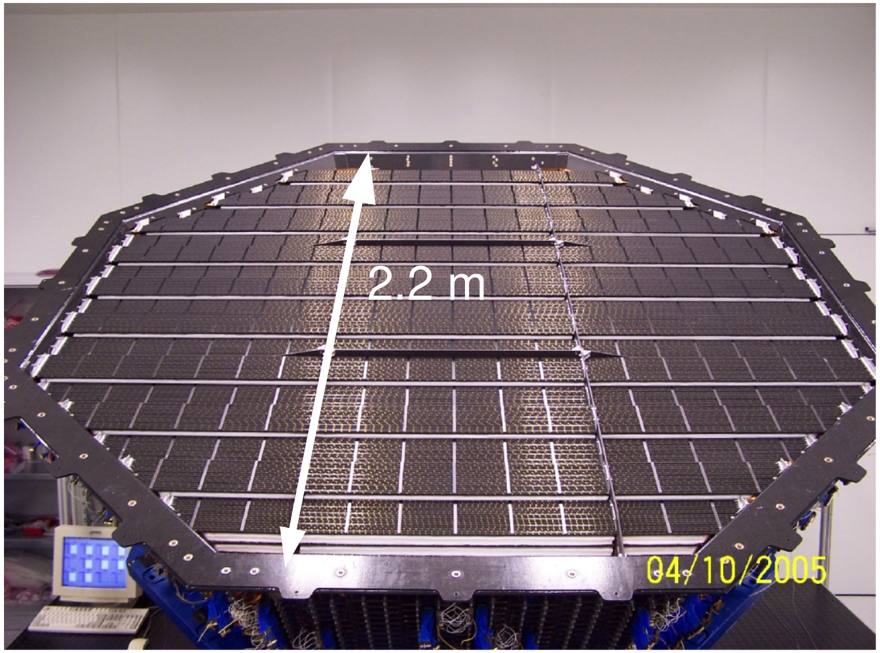

TRD superlayer in G4 simulation

2 x 8 layers of fleece radiator,
TR x-ray photons absorbed by Xe/CO2 mixture (80:20), in 6mm straw tubes with 30 $\mu$m tungsten wire
Design equivalent to AMS02 space experiment

Tasks: proton suppression and tracking in non-bending plane



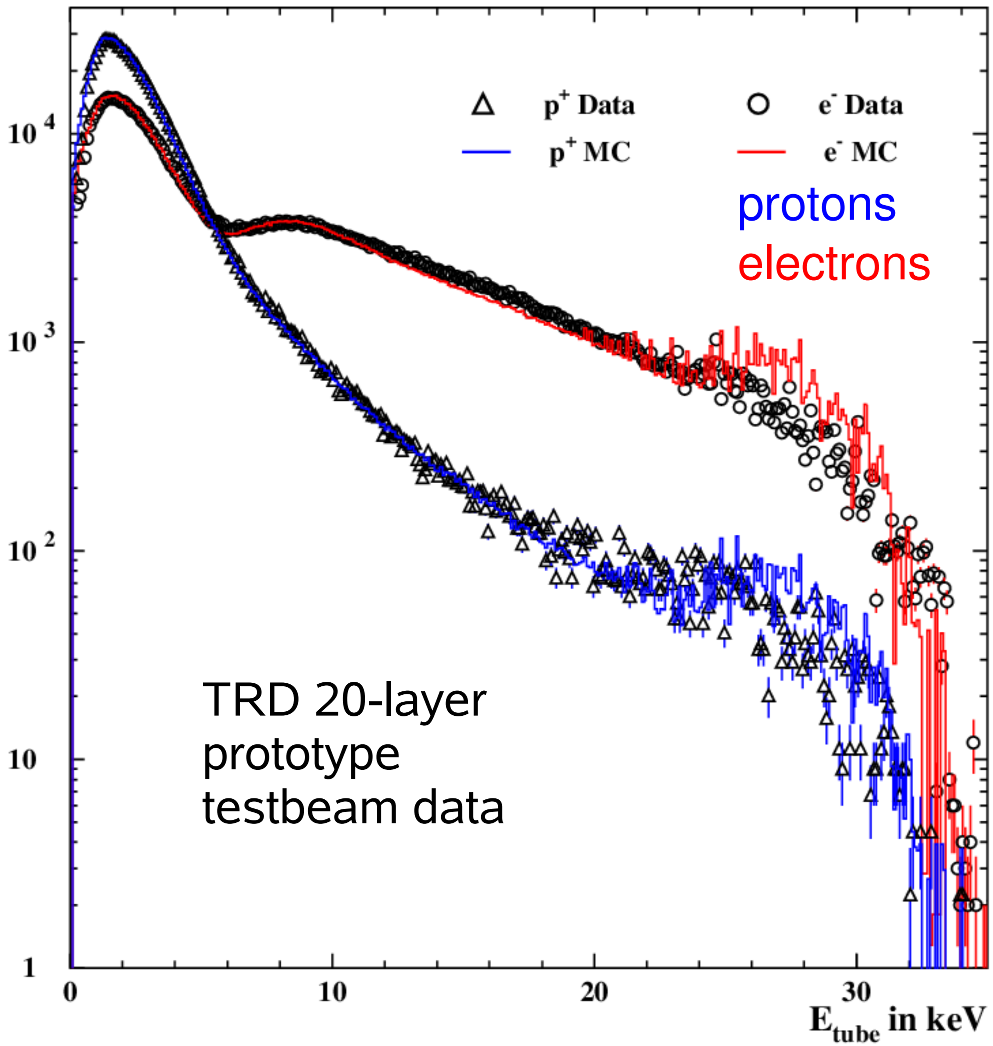

single TRD module



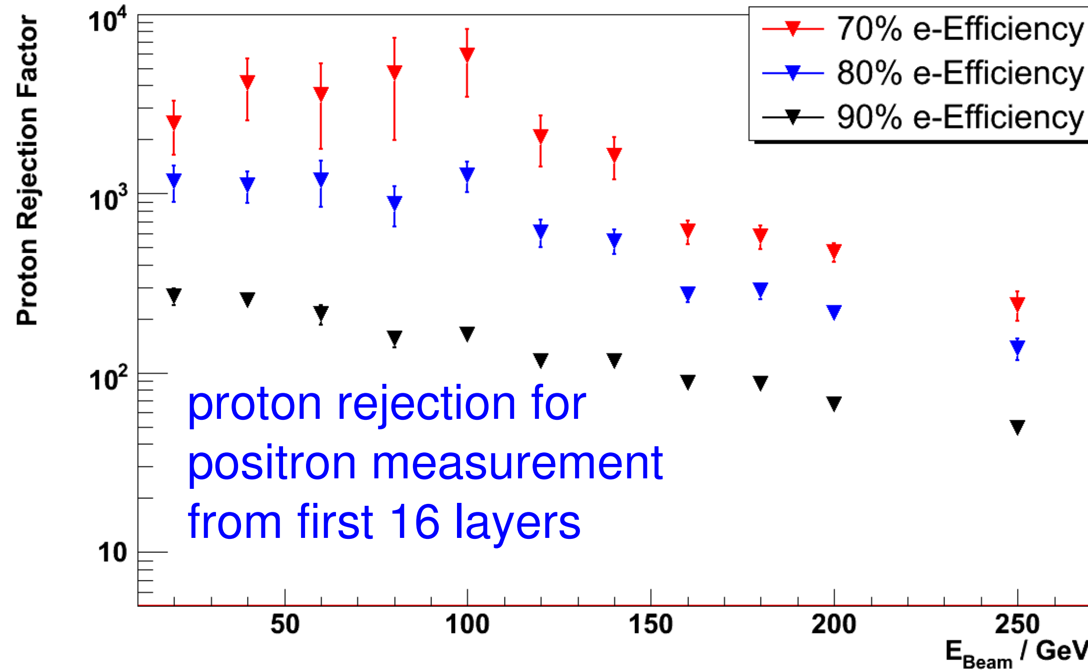

AMS02 TRD octagon integrated at RWTH Aachen workshop

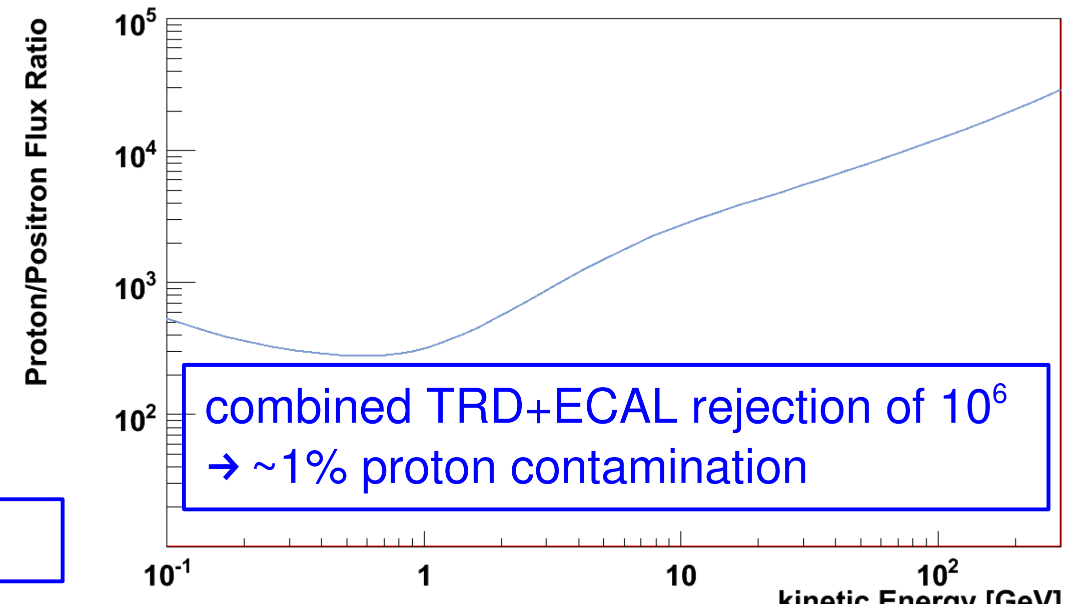
# TRD performance: positron/proton separation

Analysis of TRD prototype testbeam data

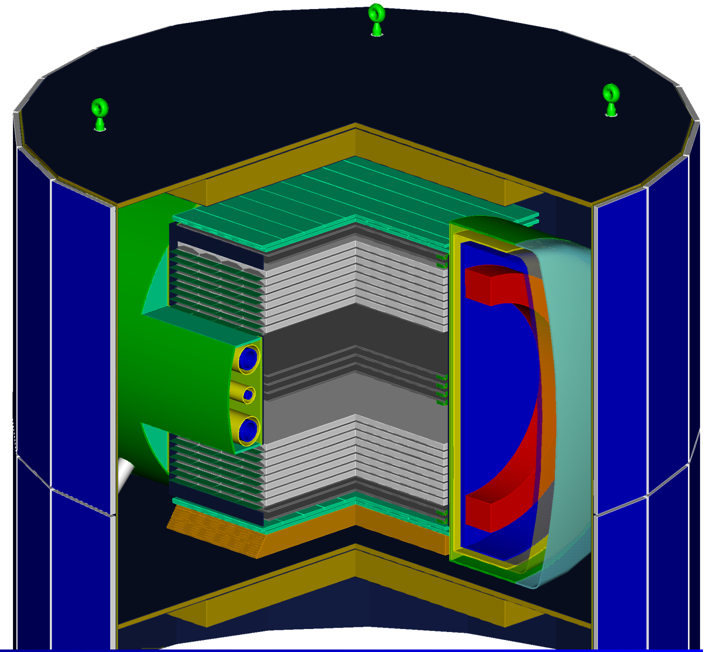



proton rejection ~1000



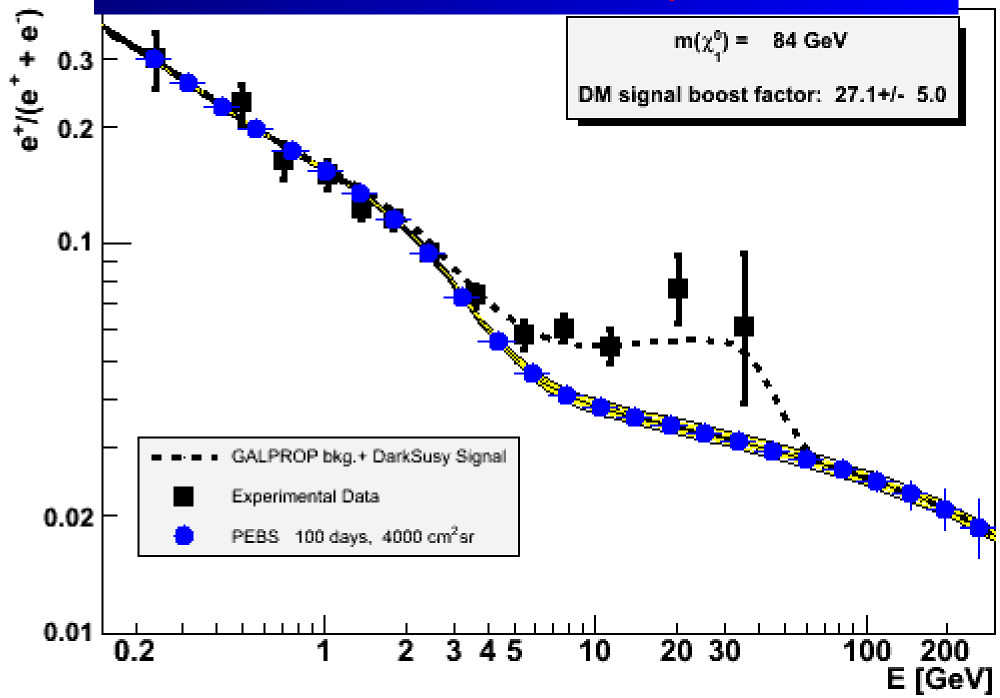



# Conclusion



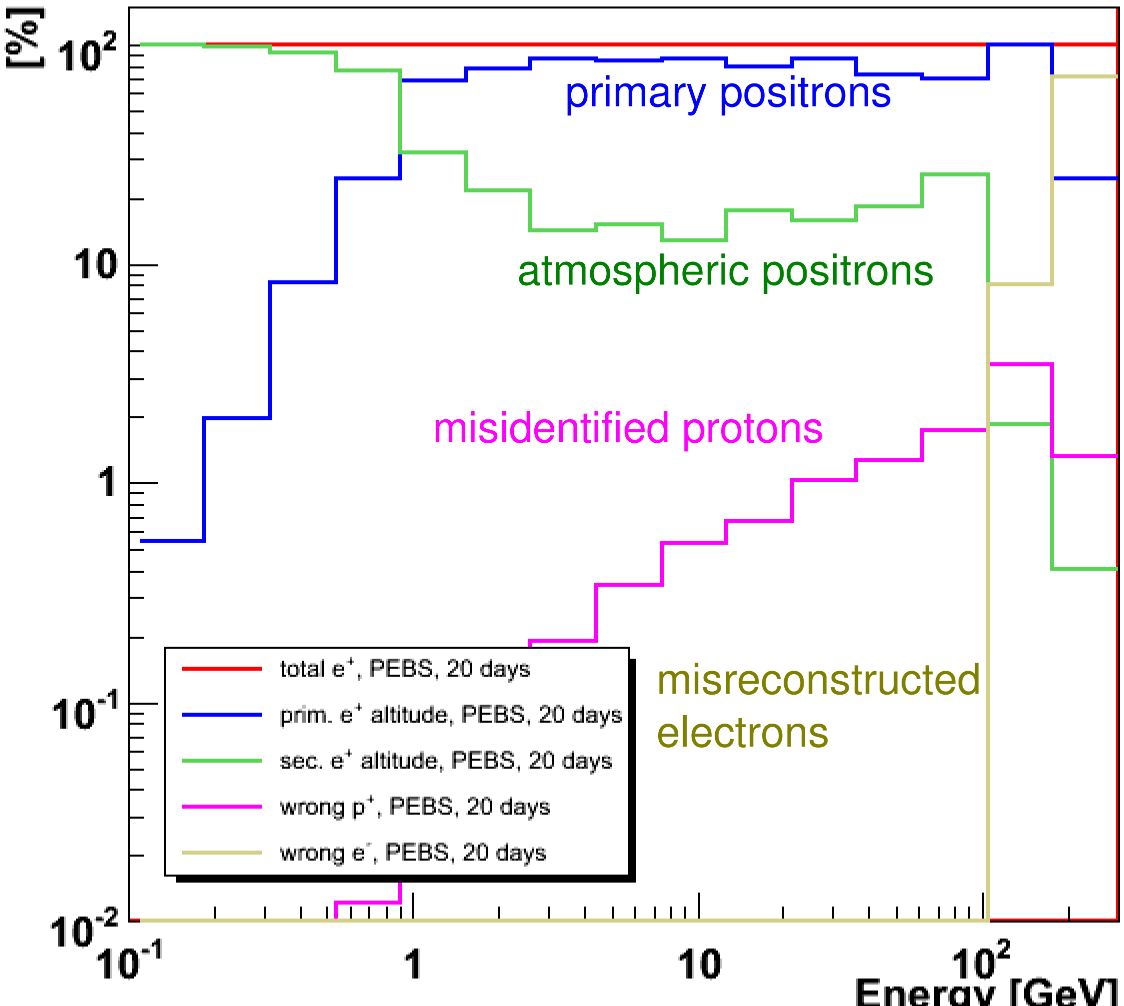
- Design study to build a balloon-borne spectrometer to measure the cosmic-ray positron fraction, in the context of indirect search for dark matter
- Scintillating fibres with SiPM readout as key components, proof of principle established in testbeam at CERN in October 2006
- Proton rejection of O(1,000,000) can be achieved with ECAL and TRD
- Study of physics program ongoing (antiprotons, B/C, ...)

Anomaly in the positron spectrum?
PEBS can answer the question!

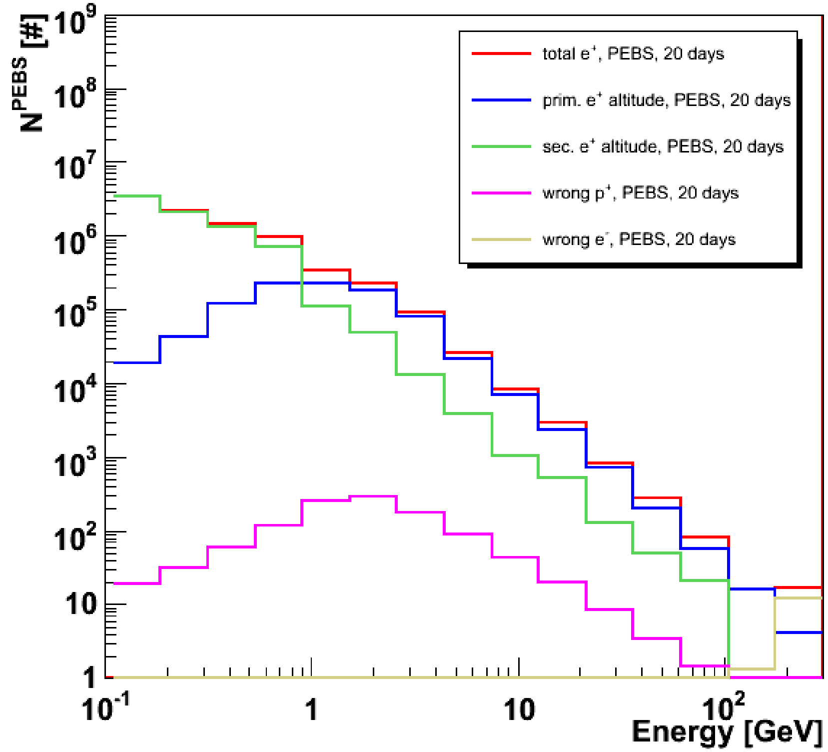


# Background contributions

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



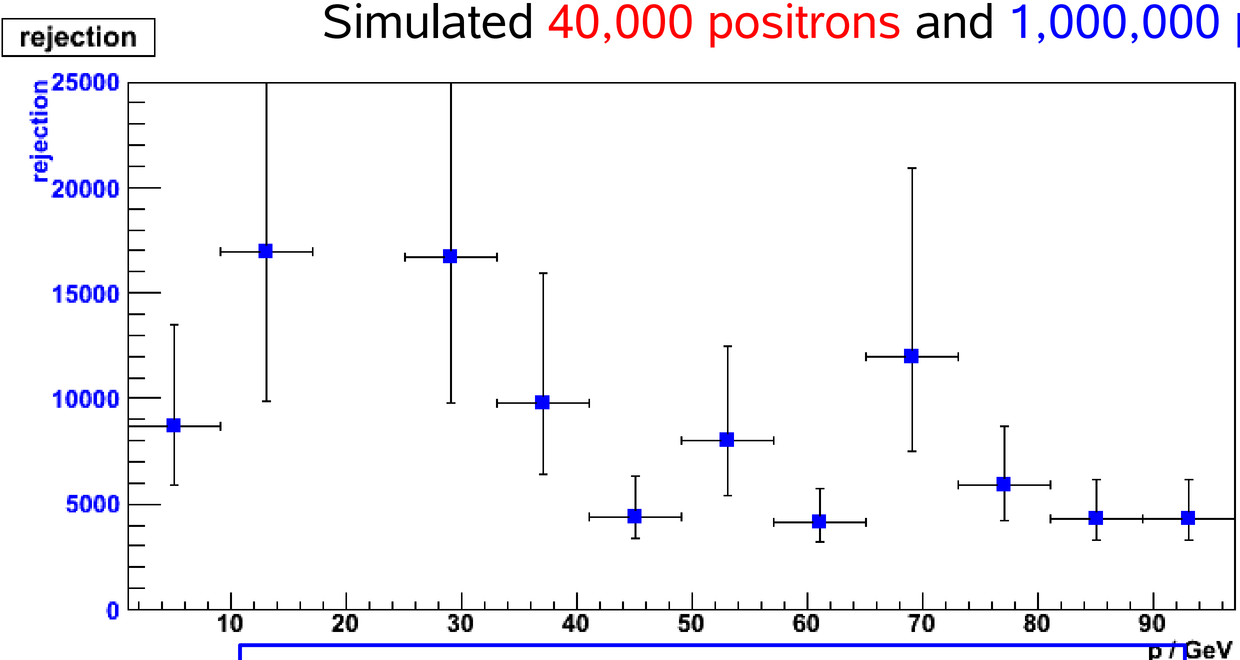

composition of positron component according to PLANETOCOSMICS simulation of atmospheric background and contributions from p/e- misidentification



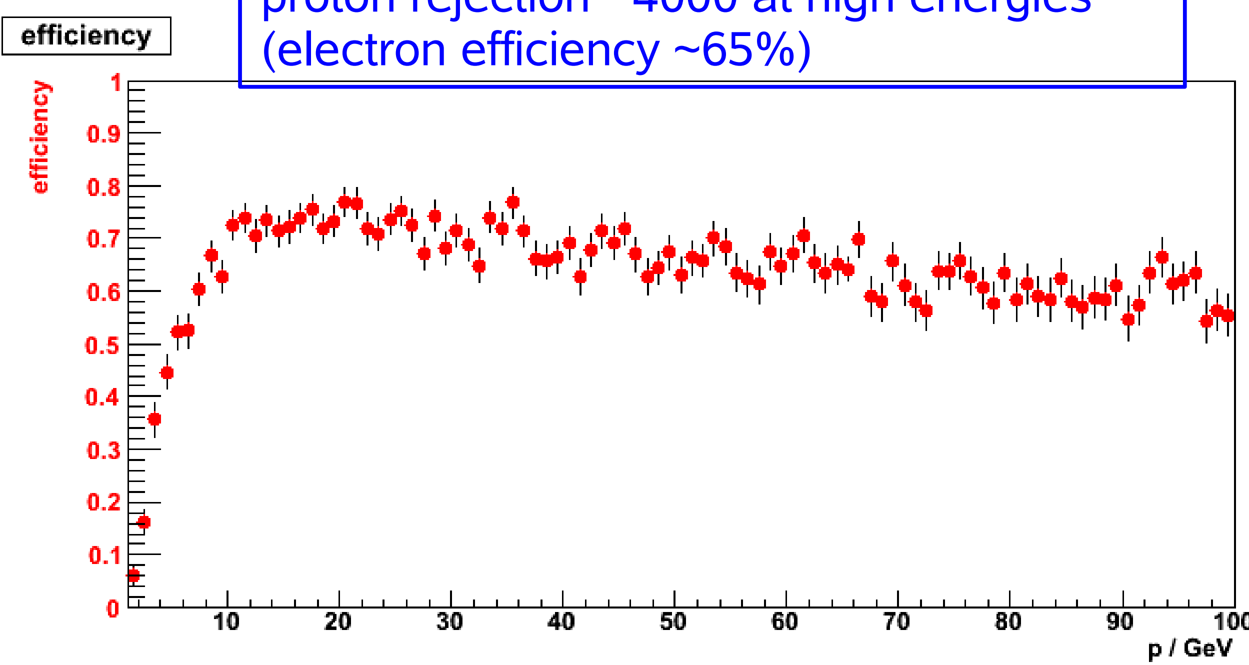

contributions in absolute numbers for 20-day flight for efficiency = 50%

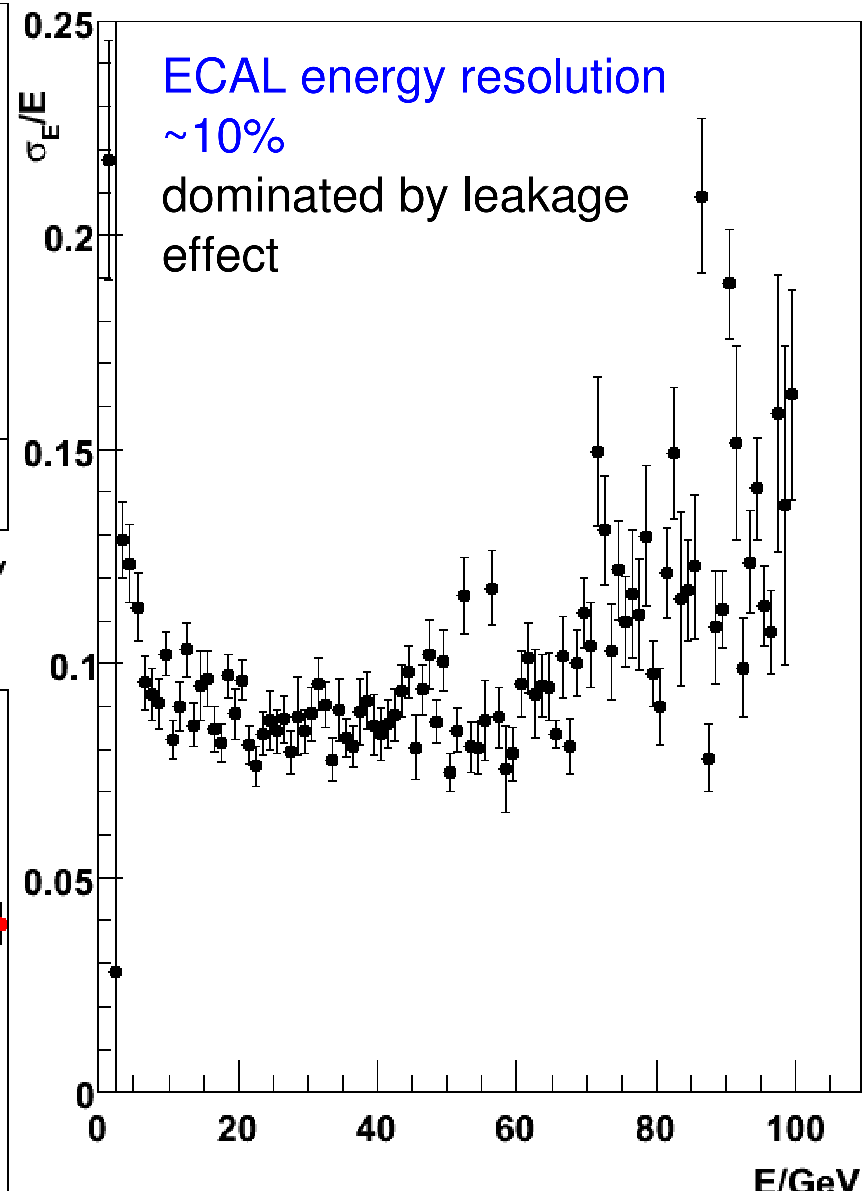
# ECAL proton rejection and energy resolution

Simulated 40,000 positrons and 1,000,000 protons



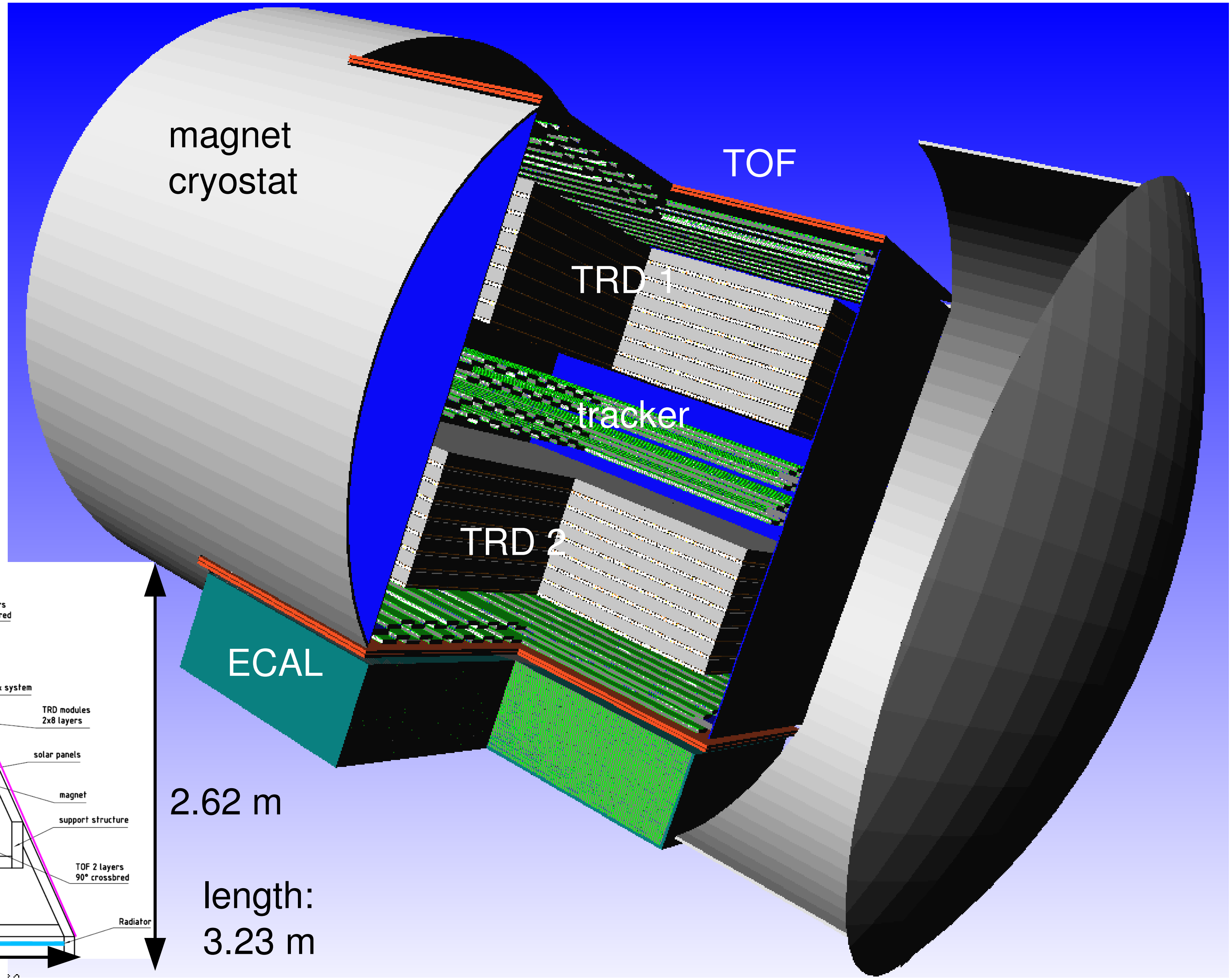

proton rejection ~4000 at high energies
(electron efficiency ~65%)

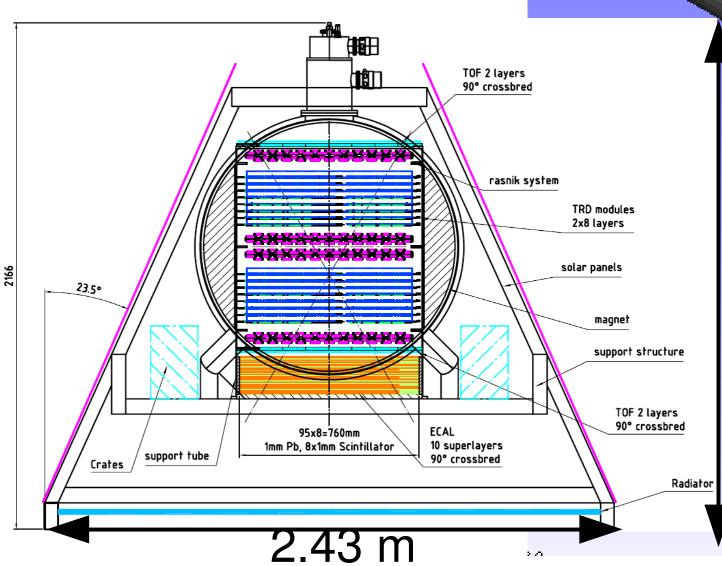


# PEBS detector components

Full Geant4
detector simulation
available



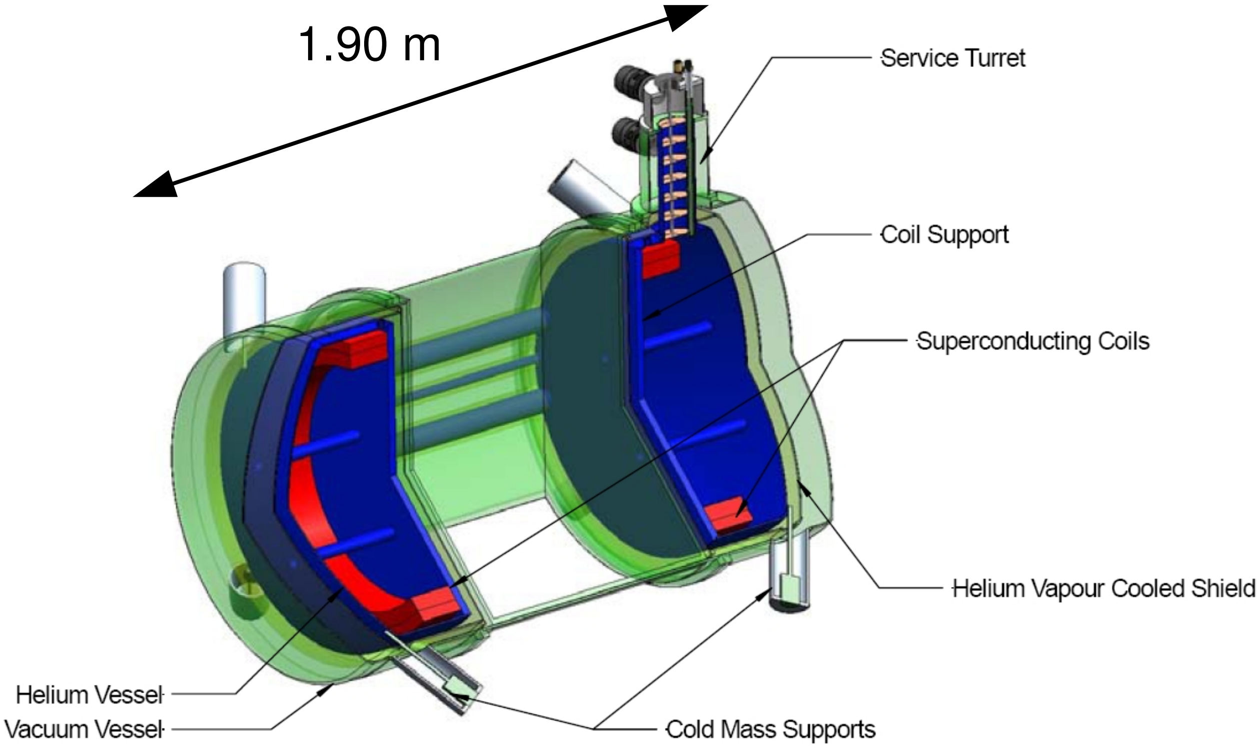



# Magnet design

Rectangular area
for detectors with
axis perpendicular
to the magnetic field

Helmholtz coils
inside here

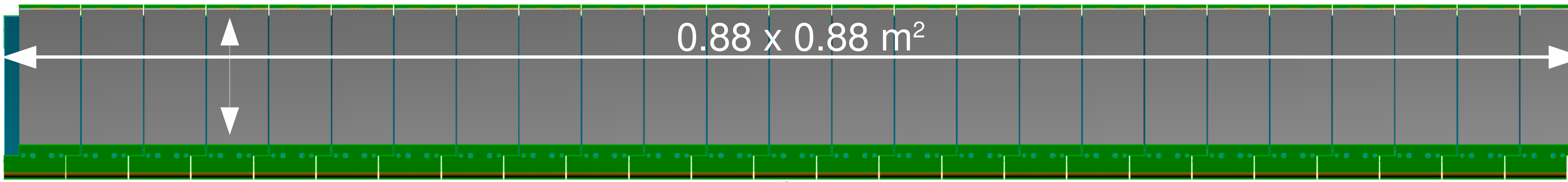
ISOMAX magnet (1998) flown on
high-altitude balloon



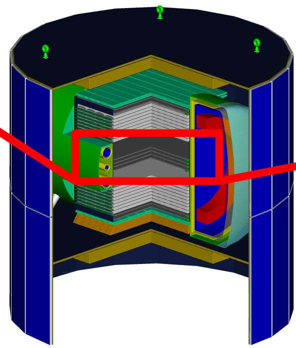

Concept Cryostat View for Vapour Cooled Shield and Coil Design 5.

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

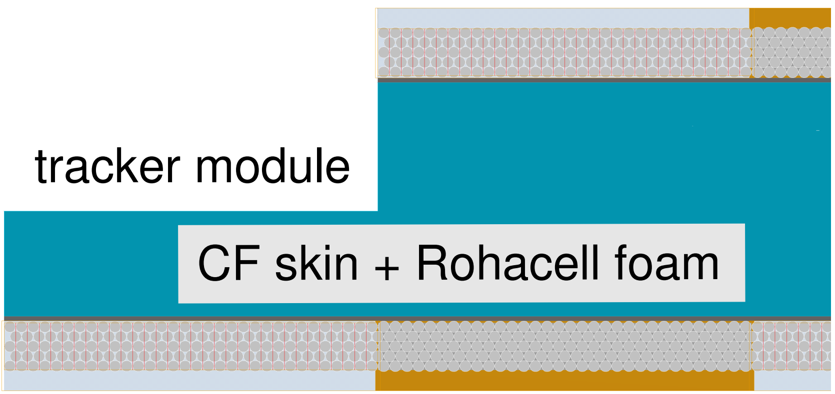
# Tracker layout




tracker superlayer

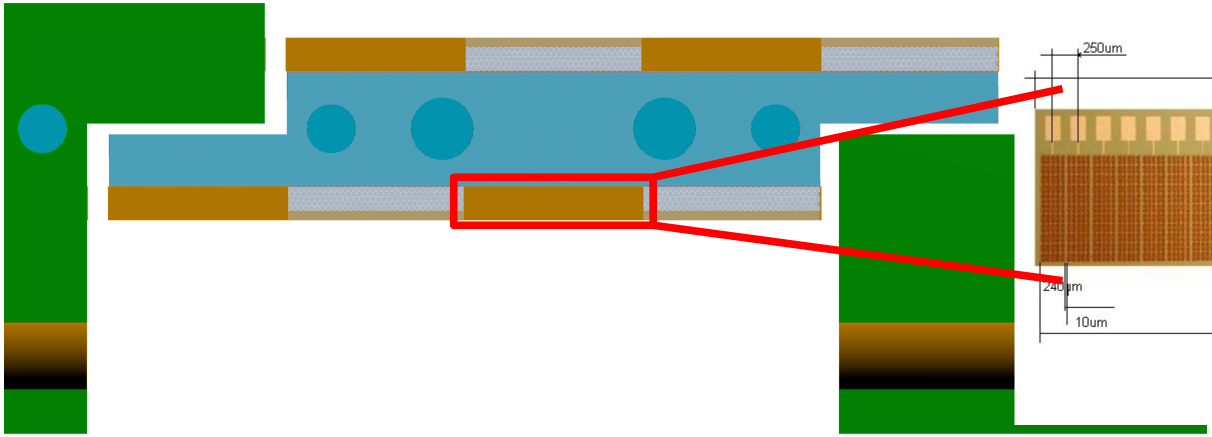


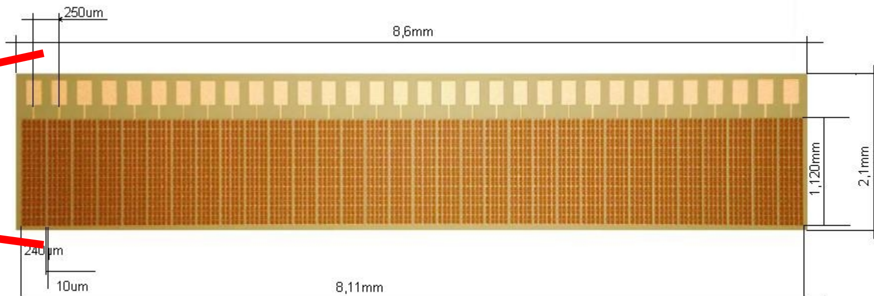
2x5x128 fibres




tracker module

8 superlayers of double-layered modules
of scintillating fibres, d=250 $\mu$m
stack of fibres accumulates light on SiPM
readout of SiPMs by dedicated VA chip



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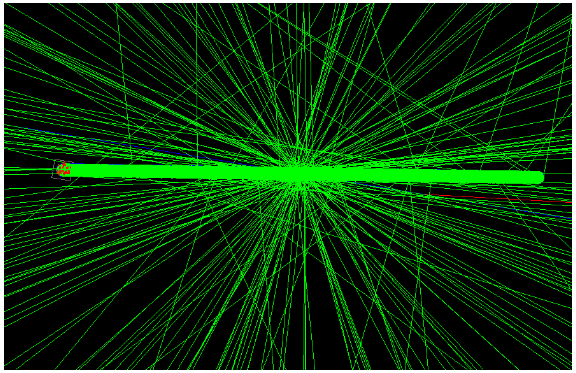
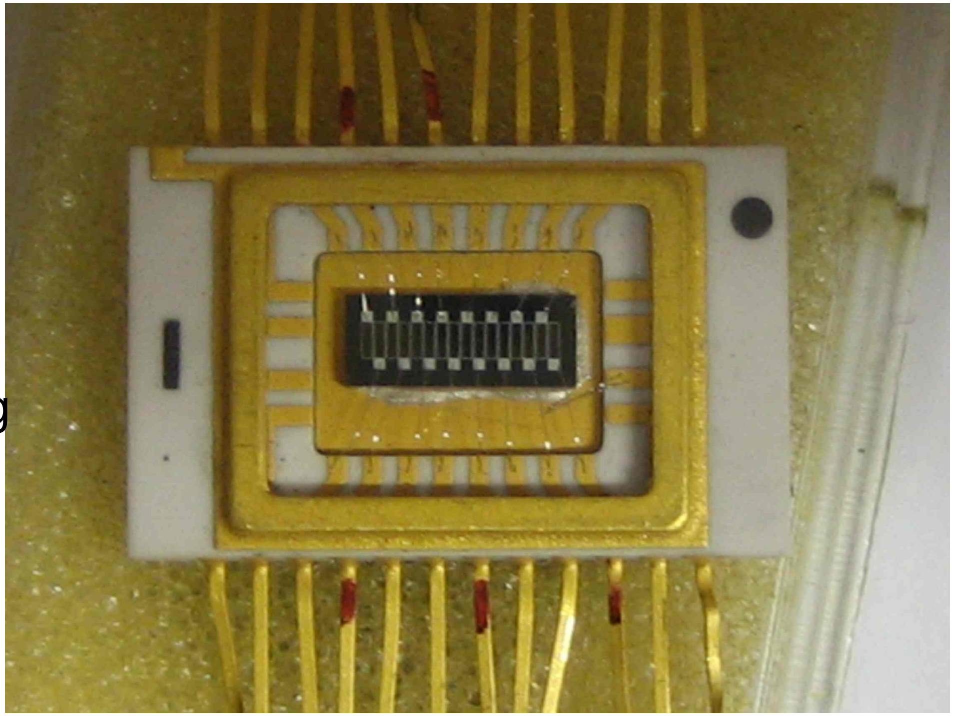
32x1 silicon photomultiplier
250µm strip width, 100 pixels/SiPM

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

# Tracker readout scheme

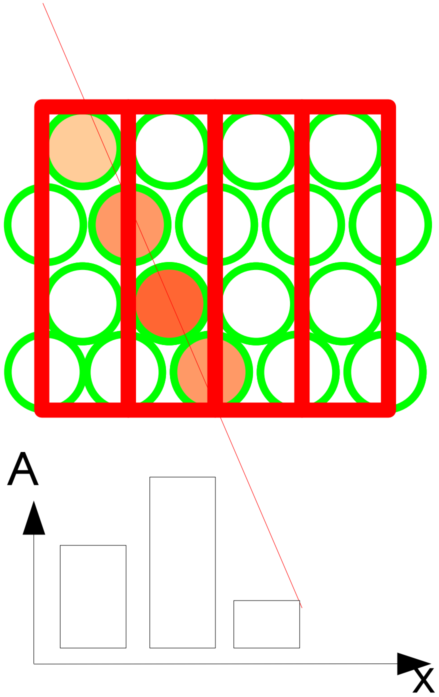


light collection in scintillating fibre in Geant4 simulation



16x1 silicon photomultiplier, strip width 380 µm

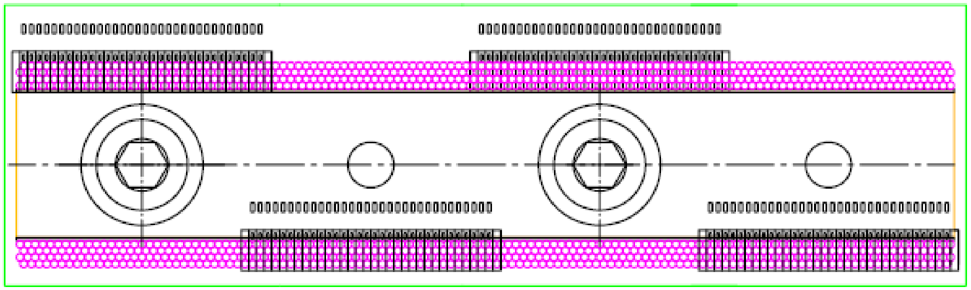
need 32x1, 250µm strip width




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

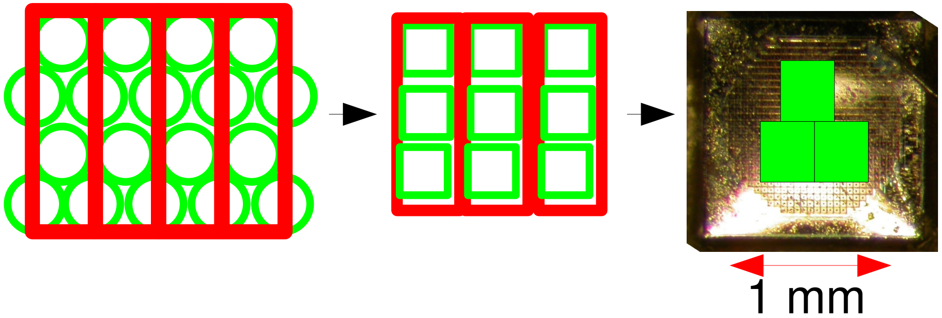
better spatial resolution than pitch/√12 , depending on p.e. yield

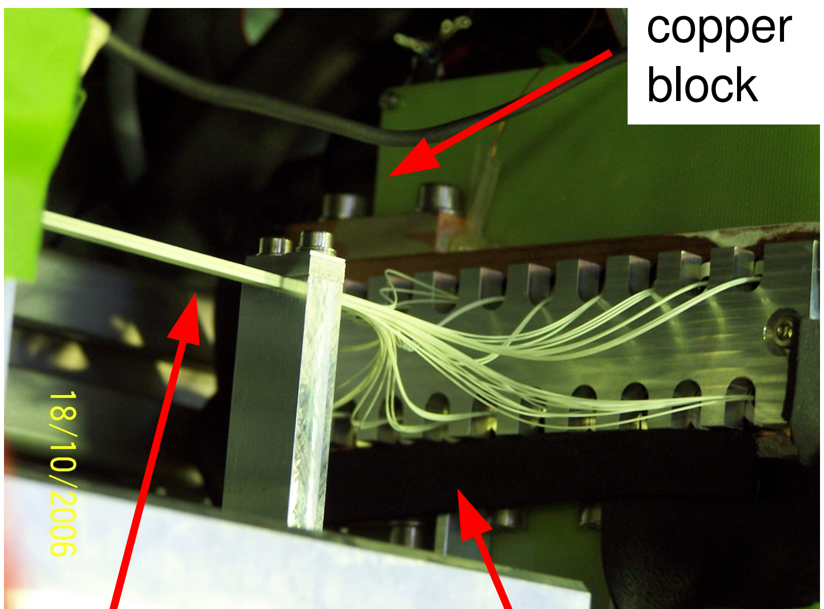
fibre module front view, with SiPM arrays on alternating sides



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

# PEBS testbeam MC

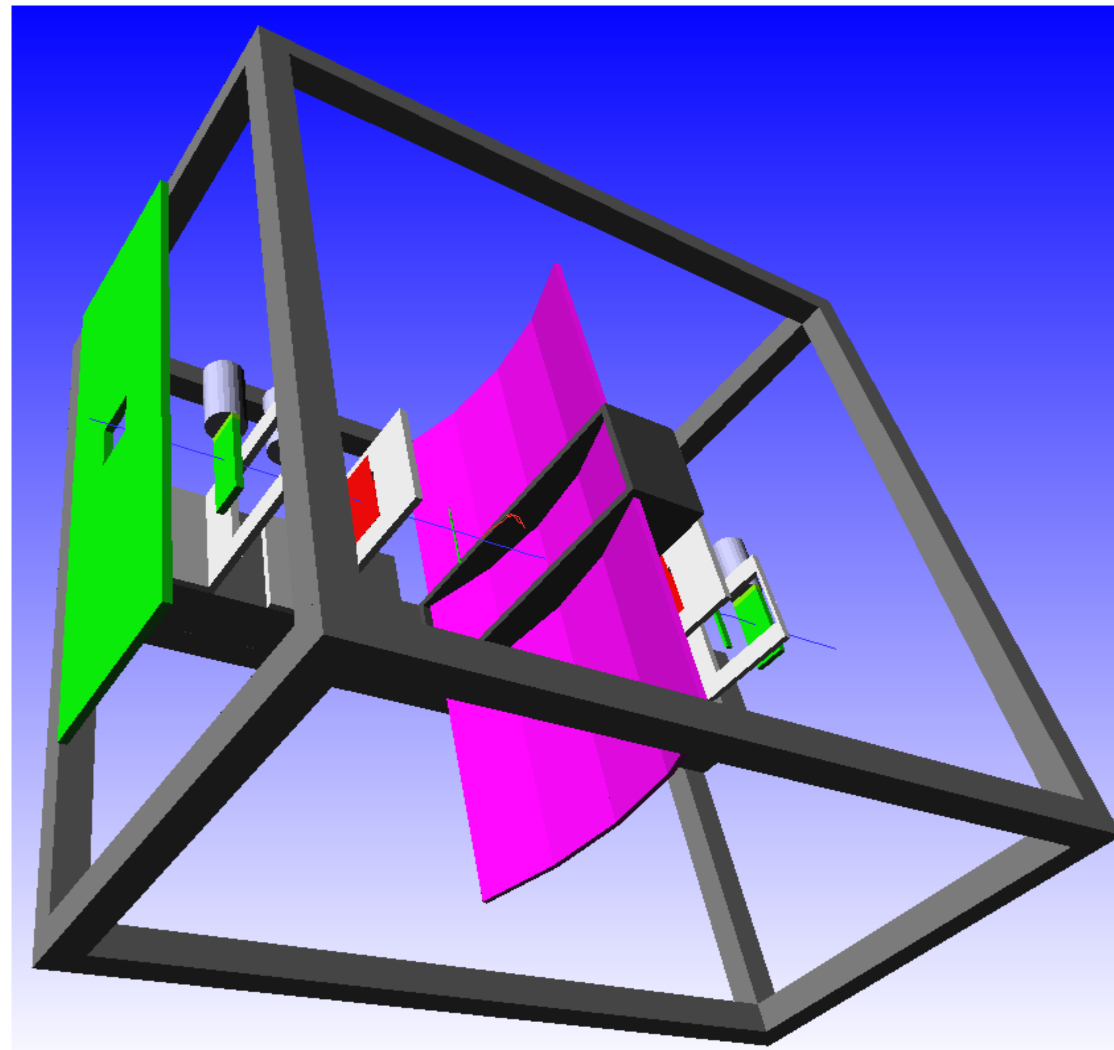


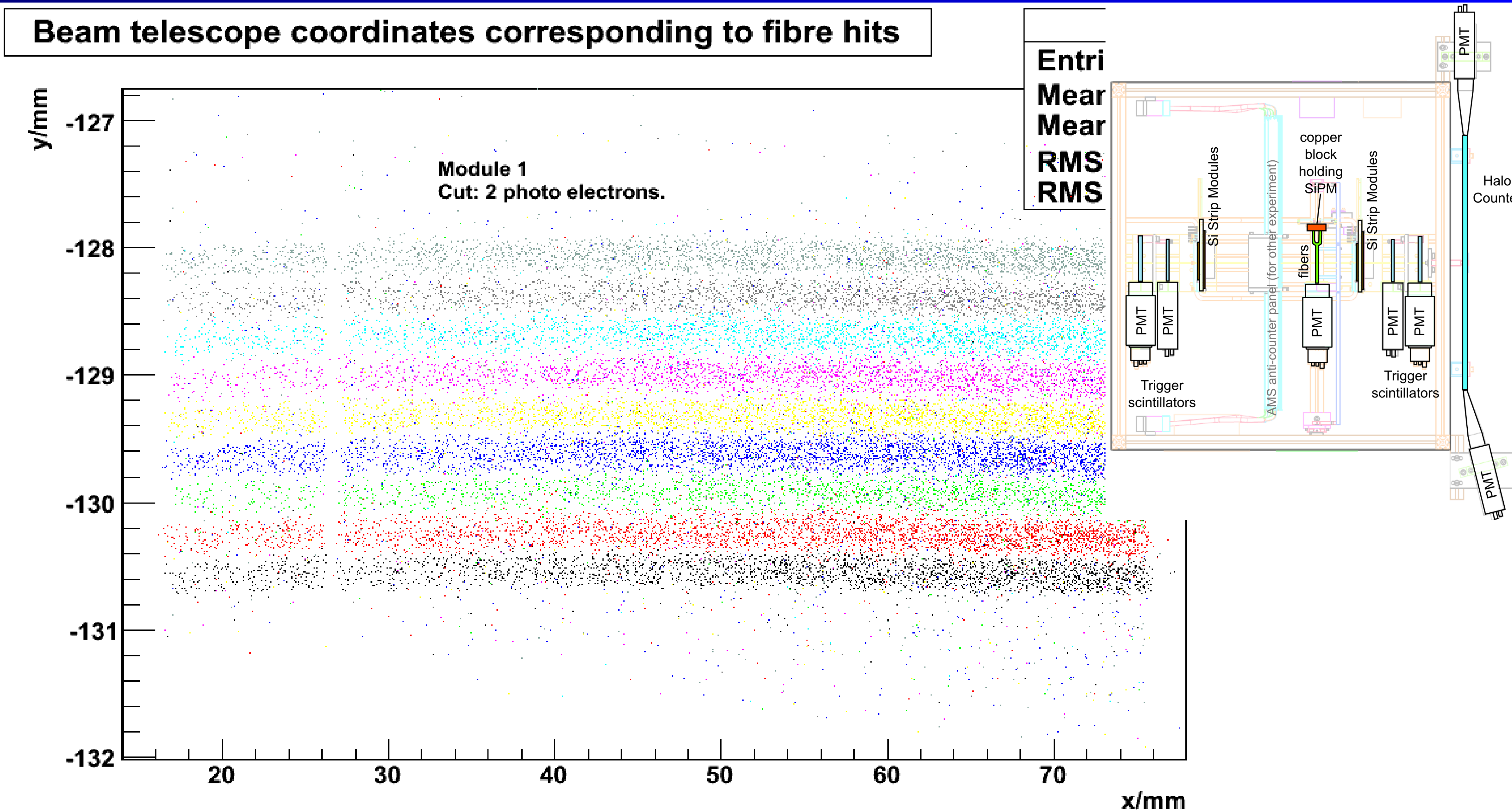

copper block

2 fibre bunches: 3x10 square fibres, d=300 $\mu$m

3 fibres each to SiPM in copper block



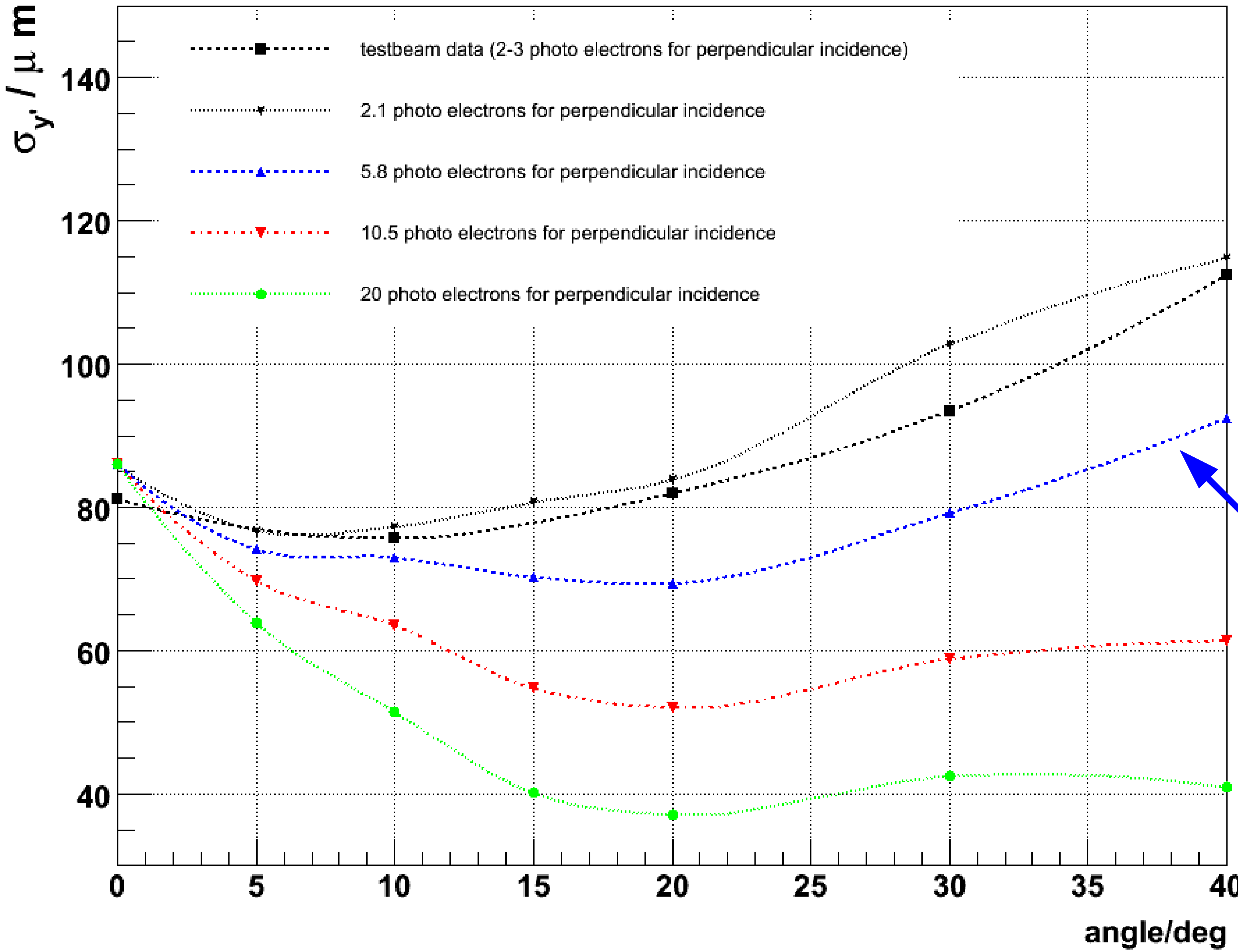
# Fibre coordinates in beam telescope

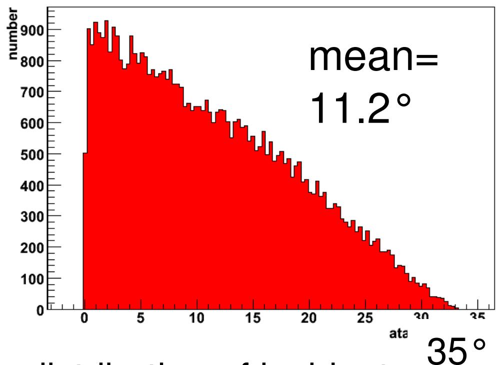



Testbeam results → PEBS MC simulation → muon momentum resolution: a=2%, b=0.19%/GeV

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

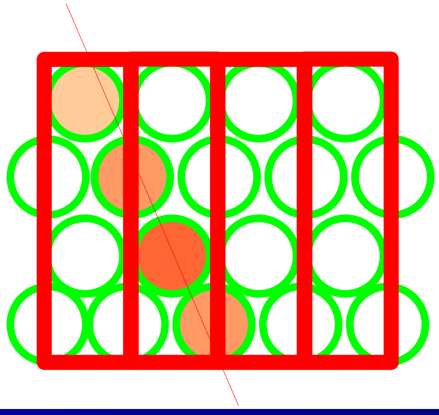
# Spatial resolution vs angle of incidence




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

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

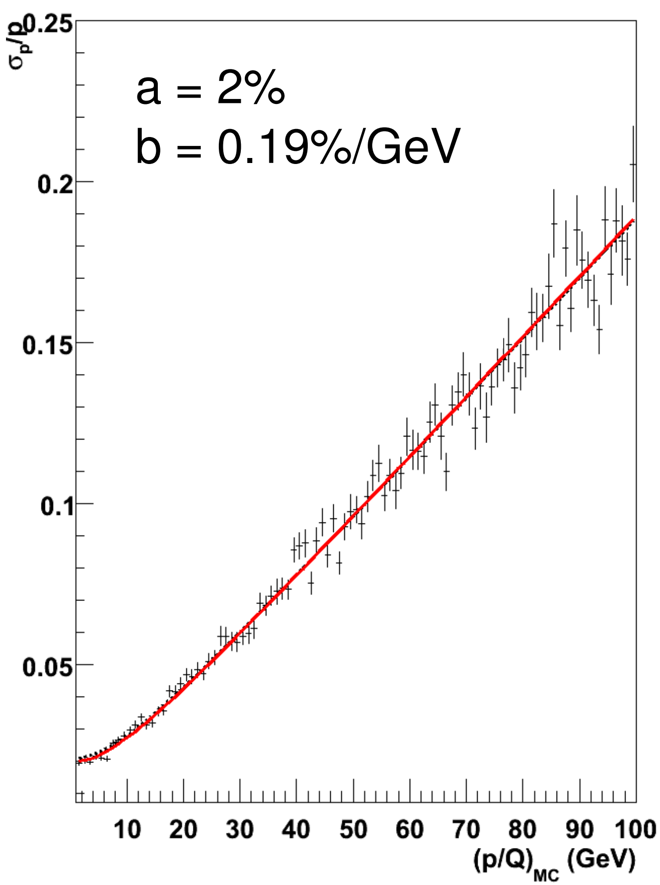


# Tracker performance: Momentum resolution

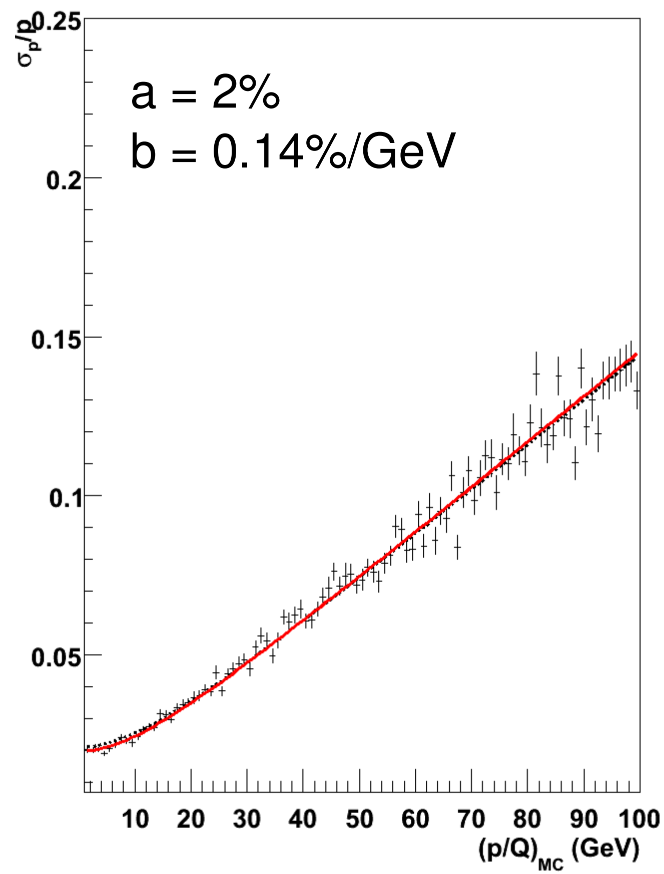
Muon momentum resolution from G4 simulation
using testbeam parameters, d = 250µm, B=1T

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

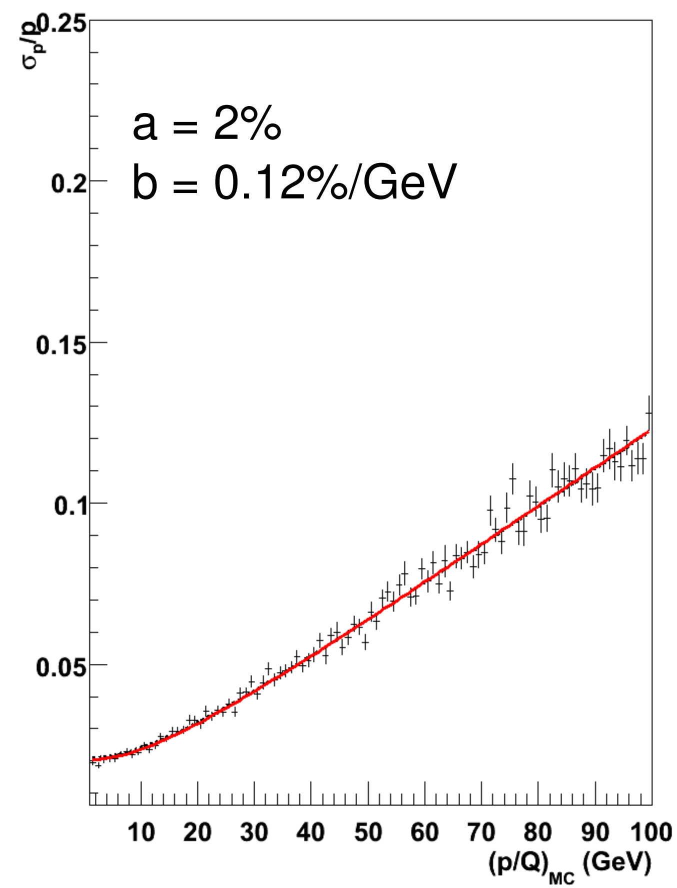
p.e. efficiency = 1 x
testbeam efficiency



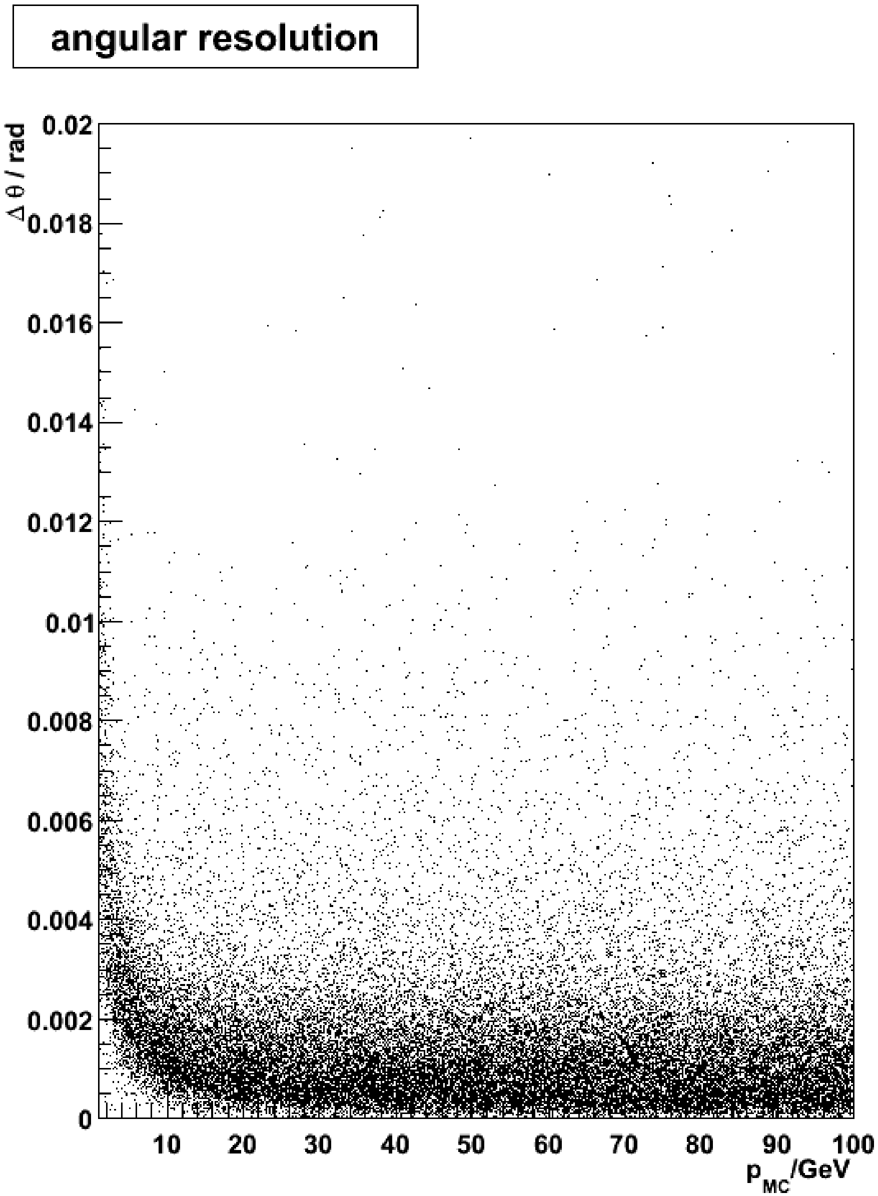

p.e. efficiency = 1.5 x
testbeam efficiency

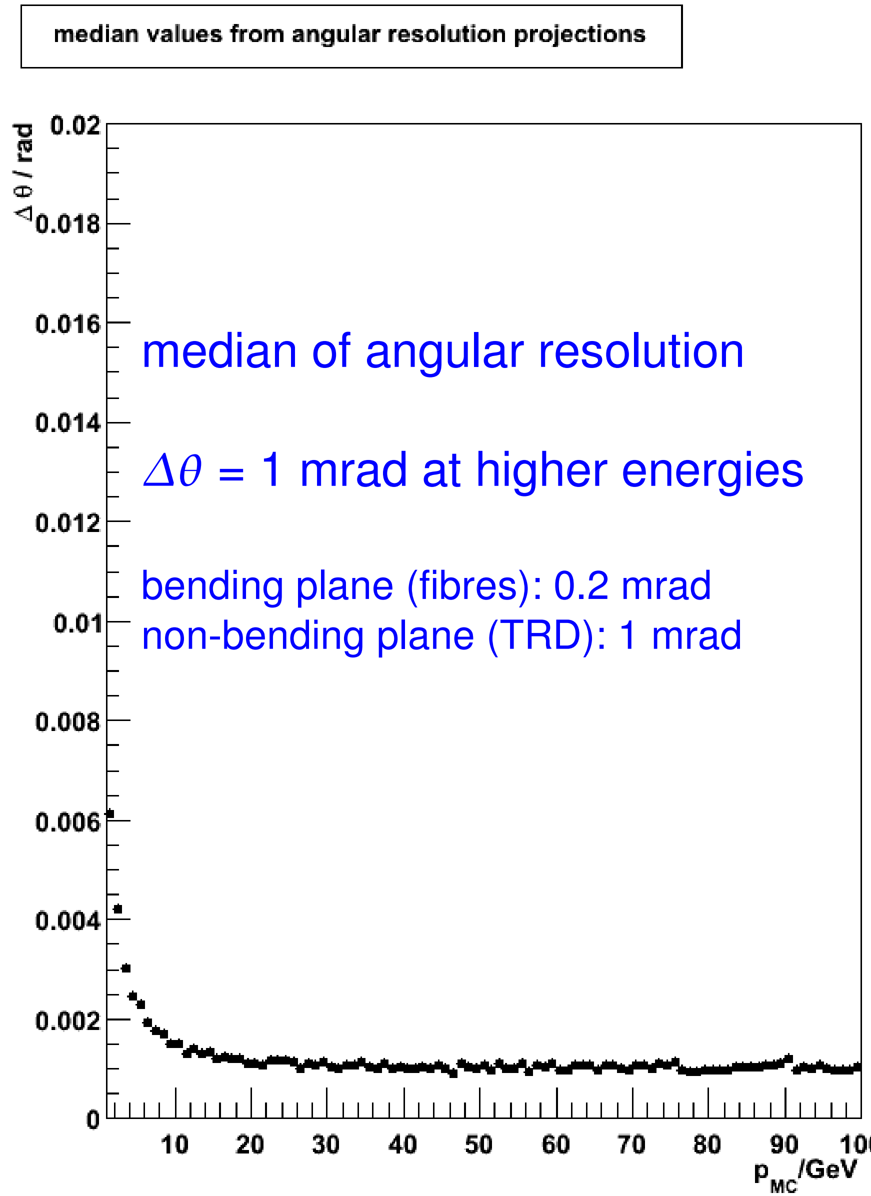



p.e. efficiency = 2 x
testbeam efficiency



# Tracker performance: Angular resolution



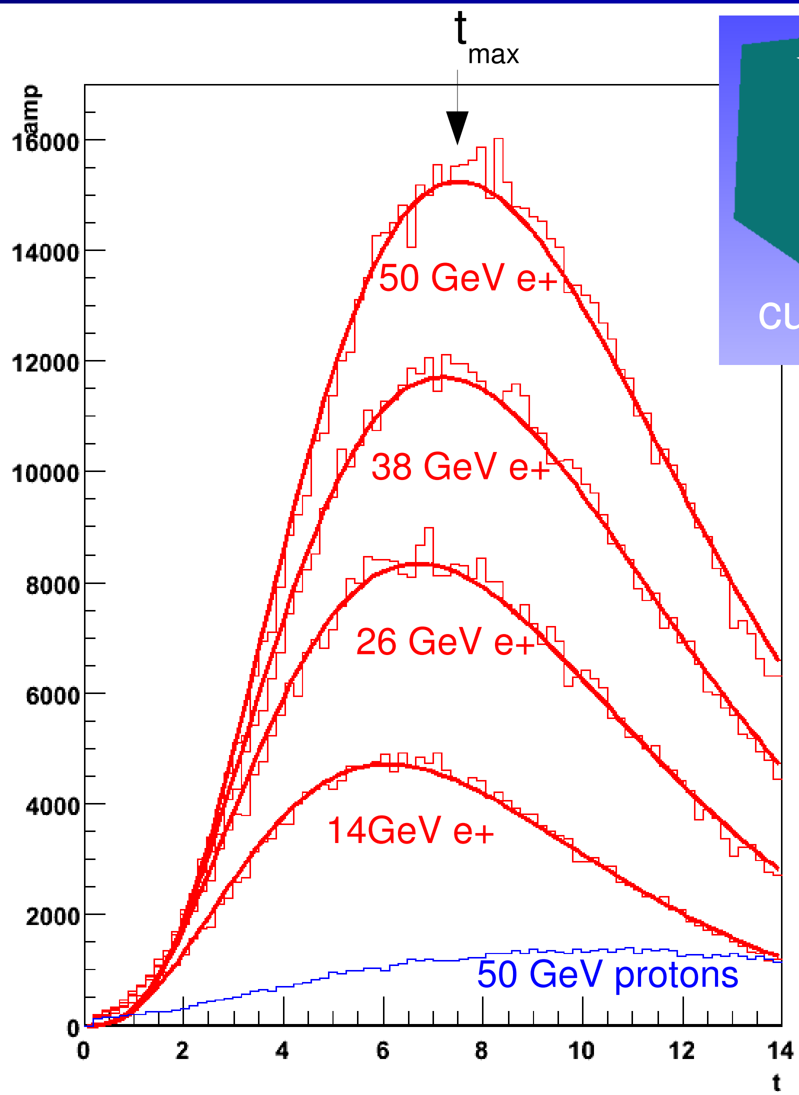



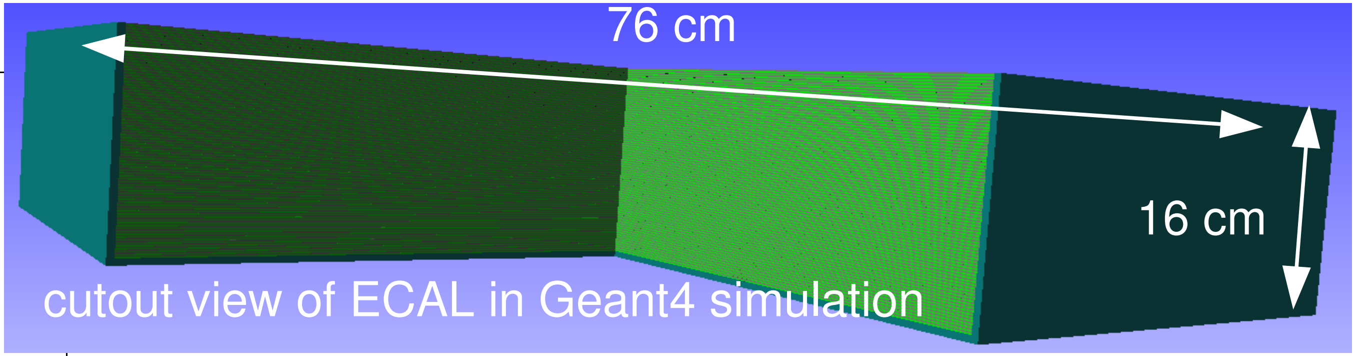

median of angular resolution

$\Delta\theta$ = 1 mrad at higher energies

bending plane (fibres): 0.2 mrad
non-bending plane (TRD): 1 mrad

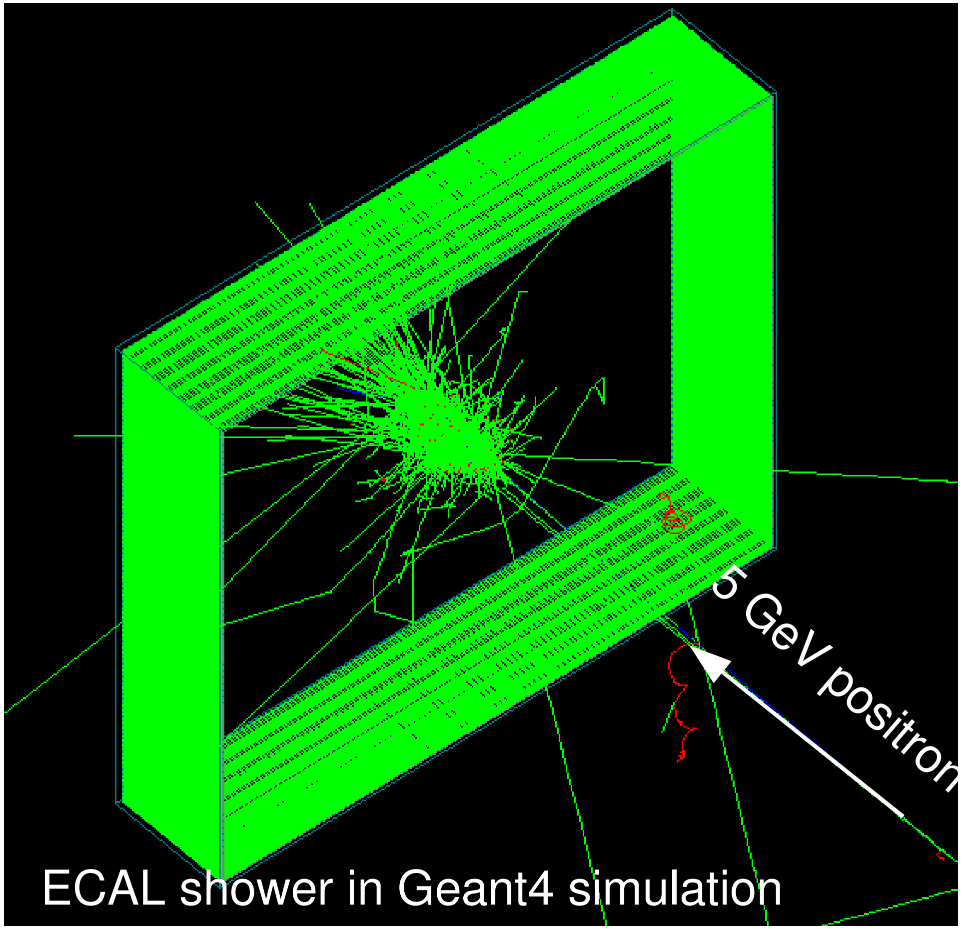
# ECAL shower



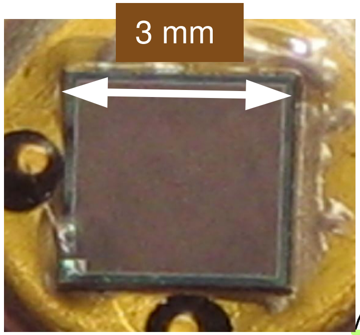

$$\frac{dE}{dt} = E_0 \frac{b^{\alpha+1}}{\Gamma(\alpha+1)} t^{\alpha} e^{-bt} \qquad t = x/X_0$$

longitudinal shower profiles

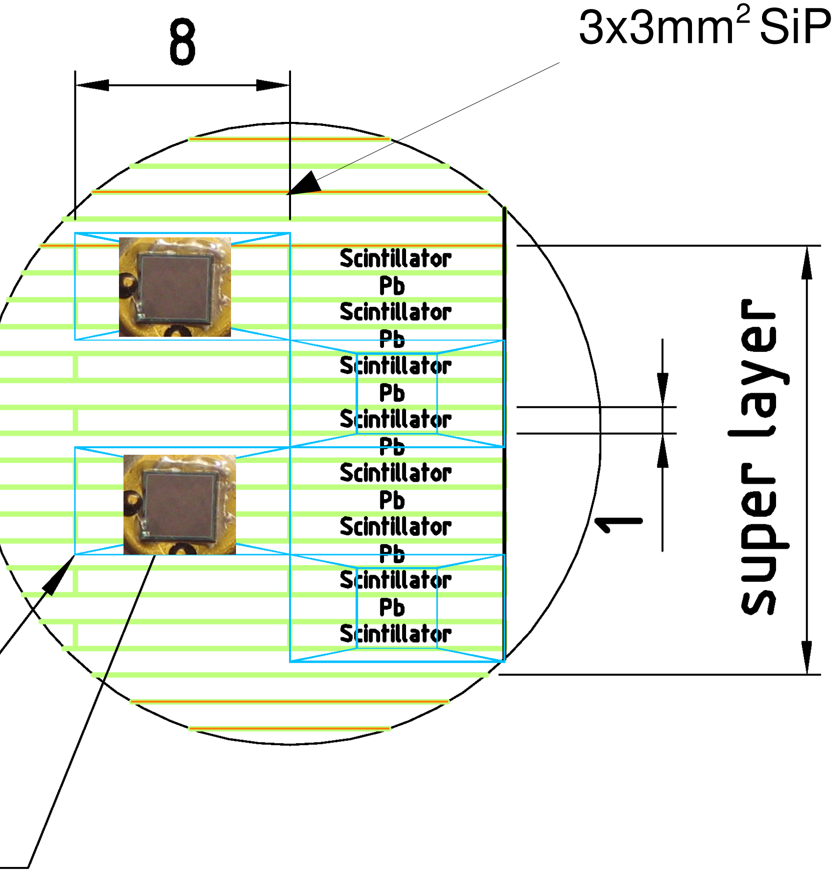


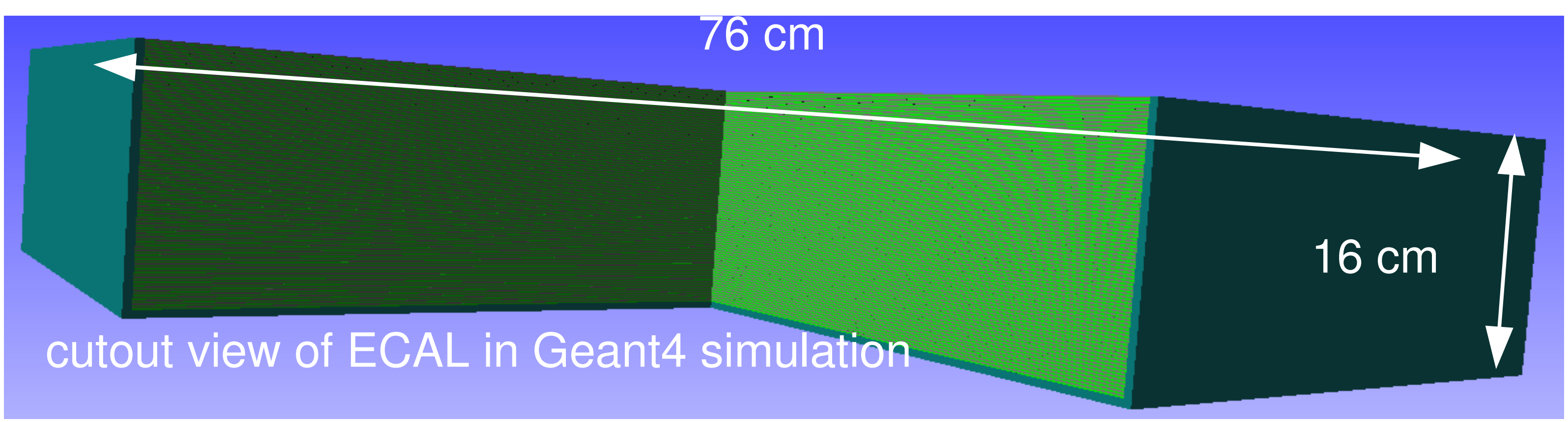
# ECAL layout

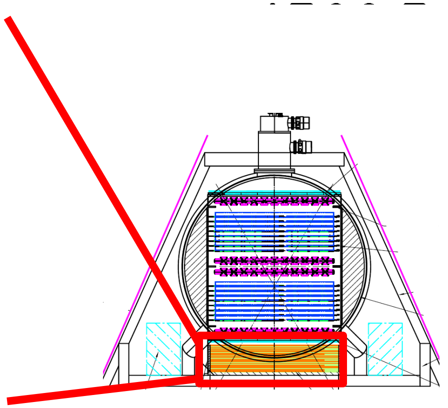
8 superlayers of ten layers of lead-scintillating fibre sandwich, with alternating orientation
1mm lead
fibre: 1mm height, 8mm width, read out by SiPMs
14.3 X0 in total, ECAL weight: 550 kg



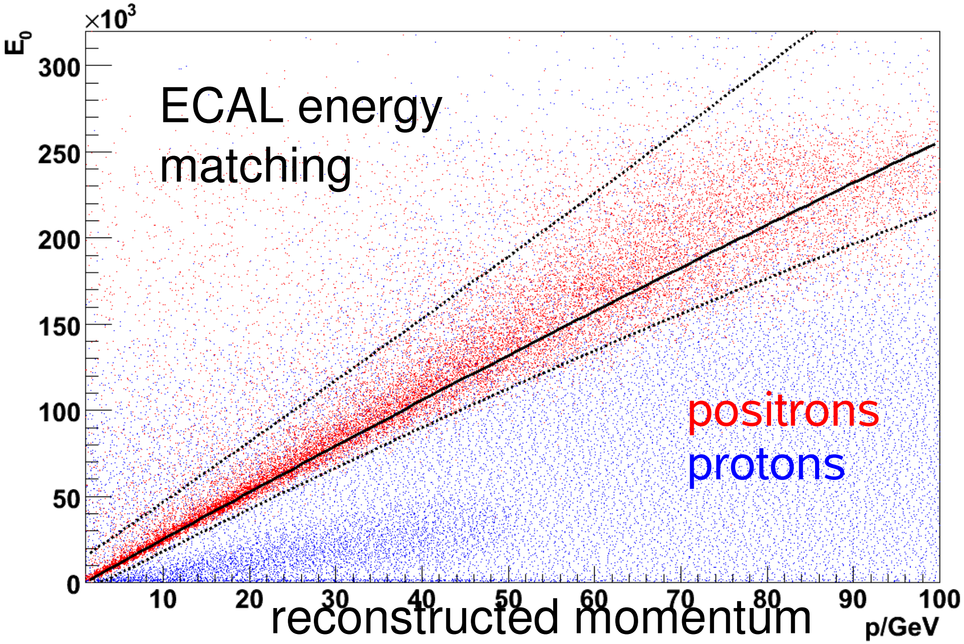

3x3 mm array:
8100 pixel

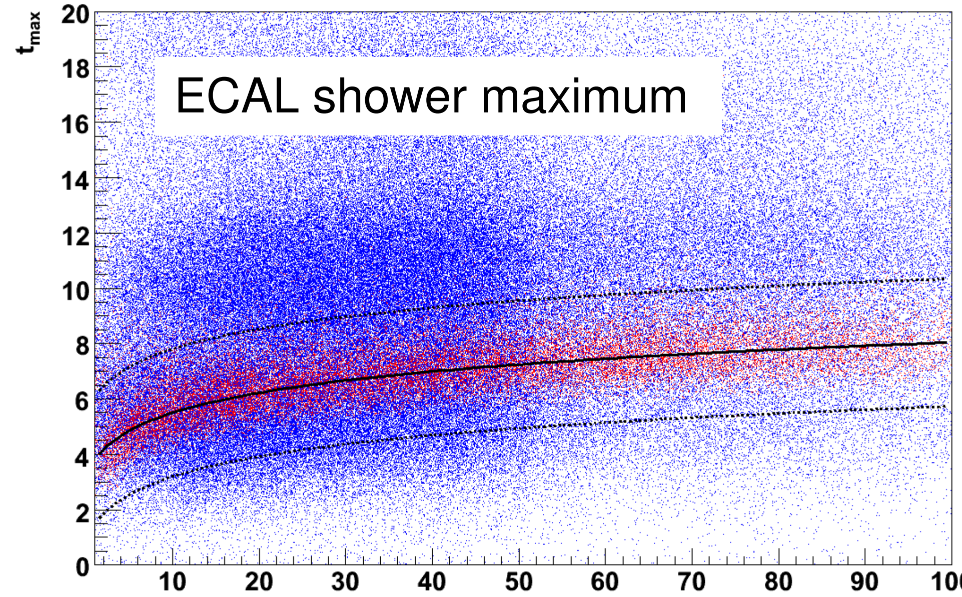


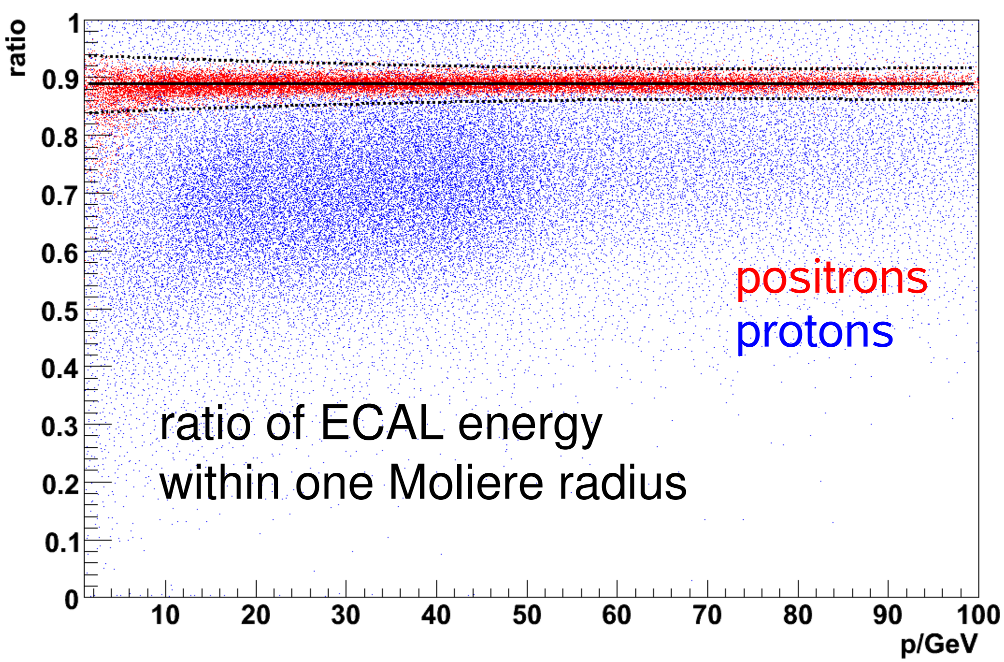



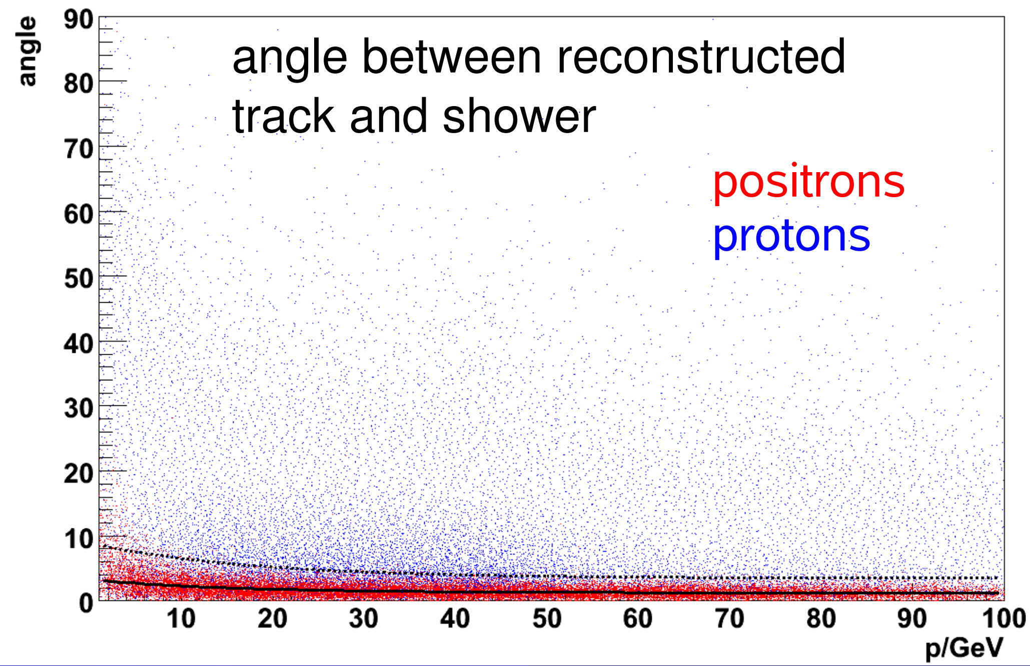



# ECAL performance

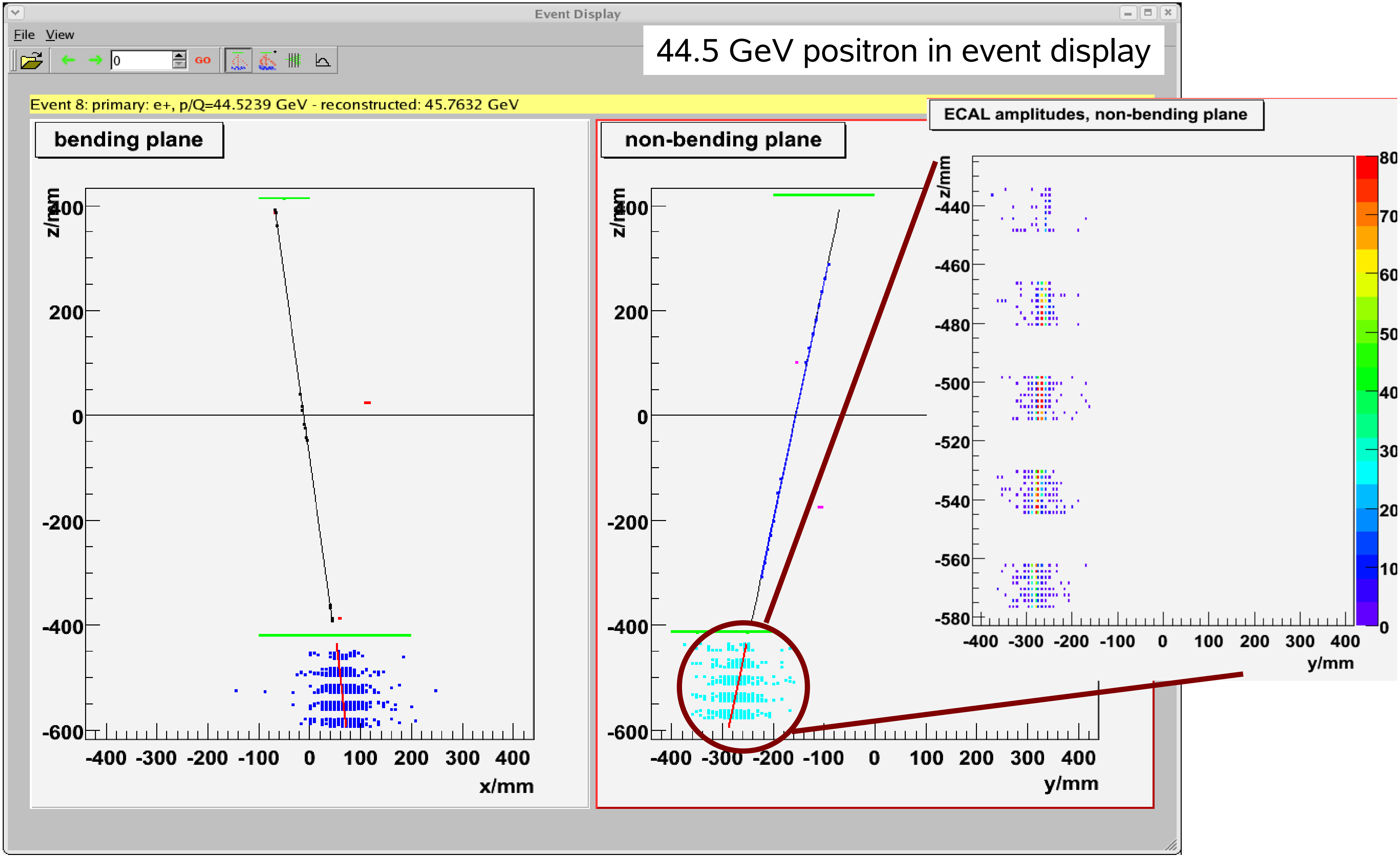


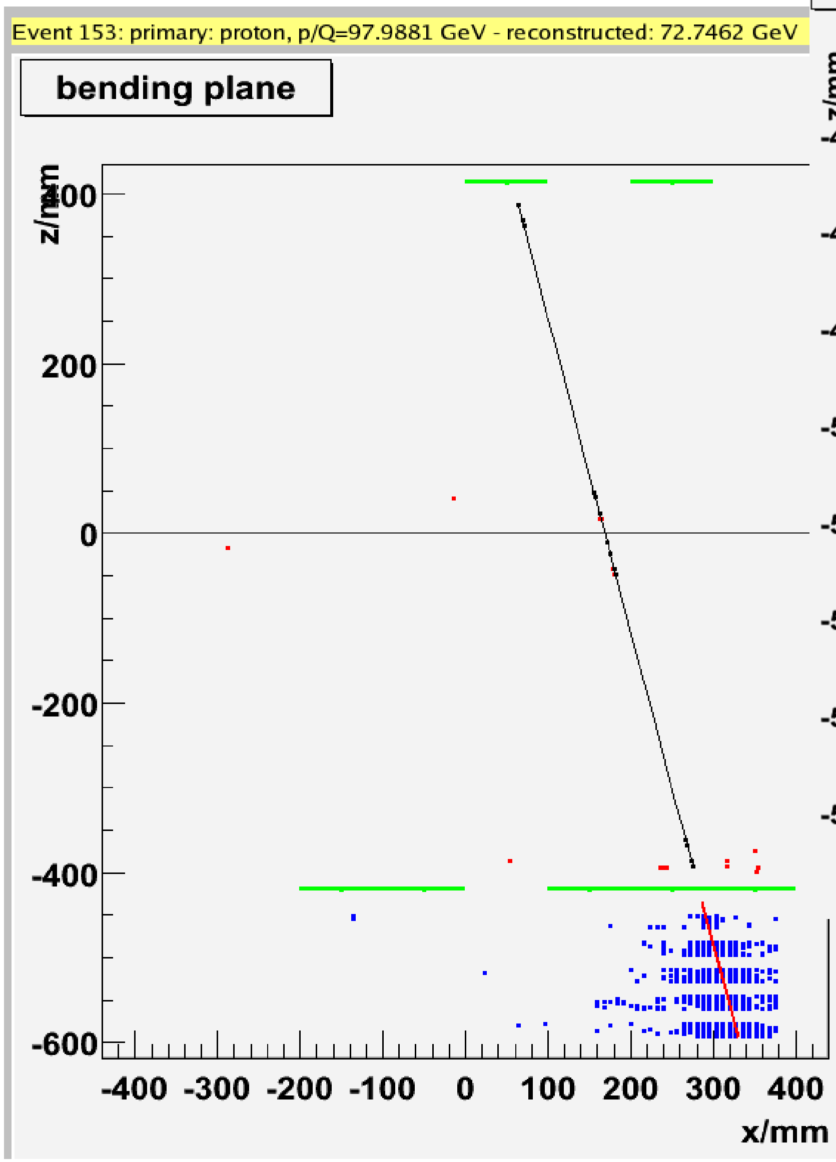



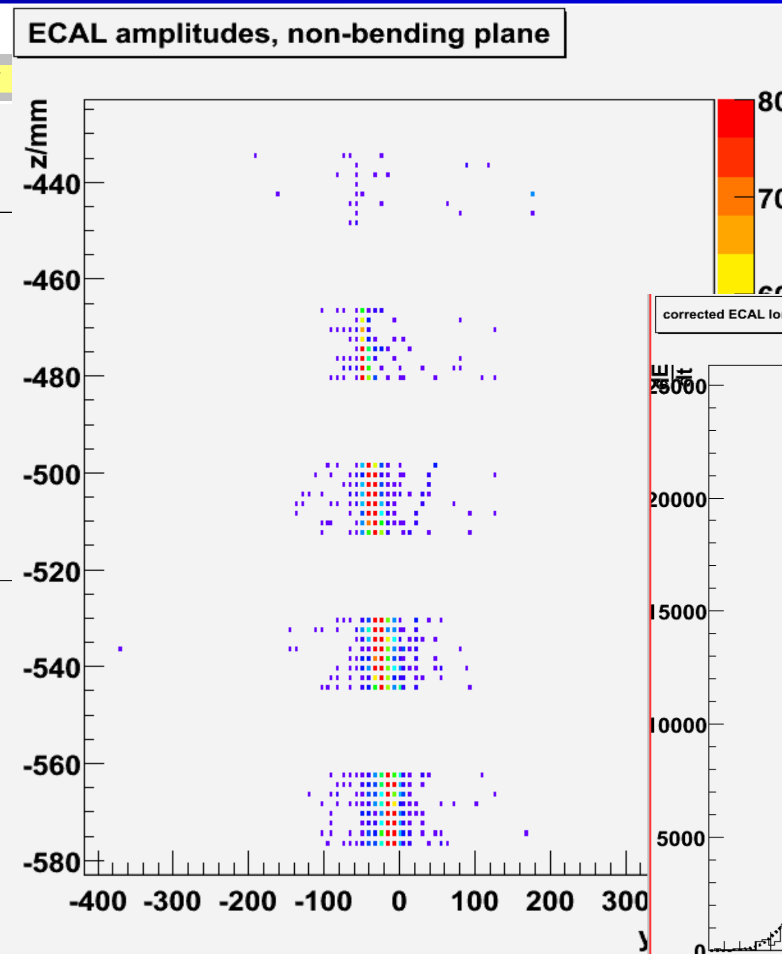



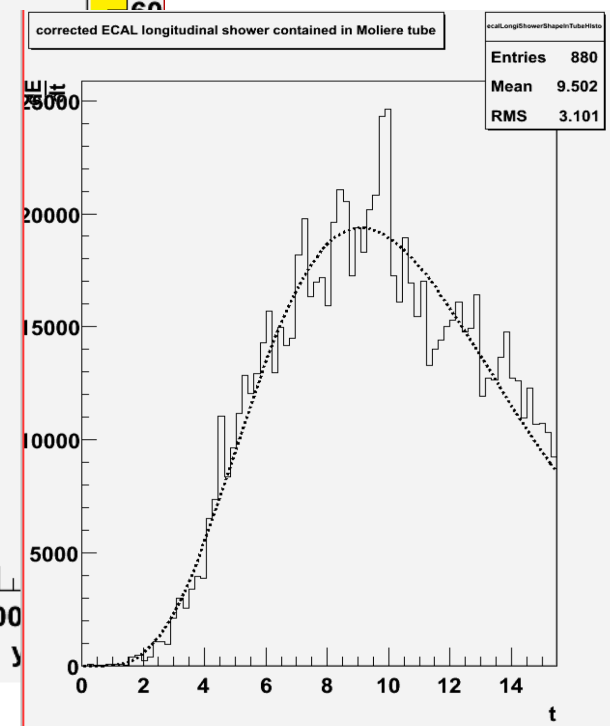
# Example event



# Intrinsic limits on rejection




example event:

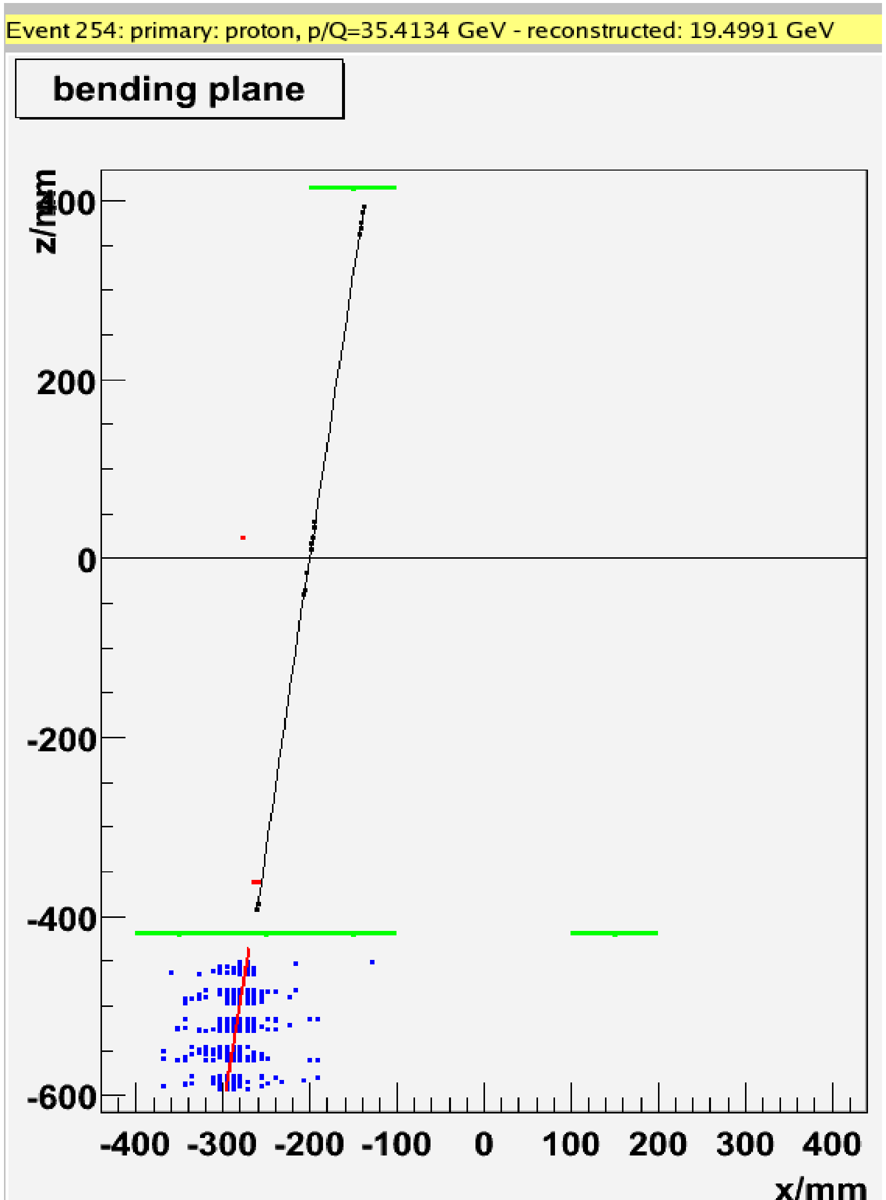
p → p $\pi^0$ X in very first ECAL layers,

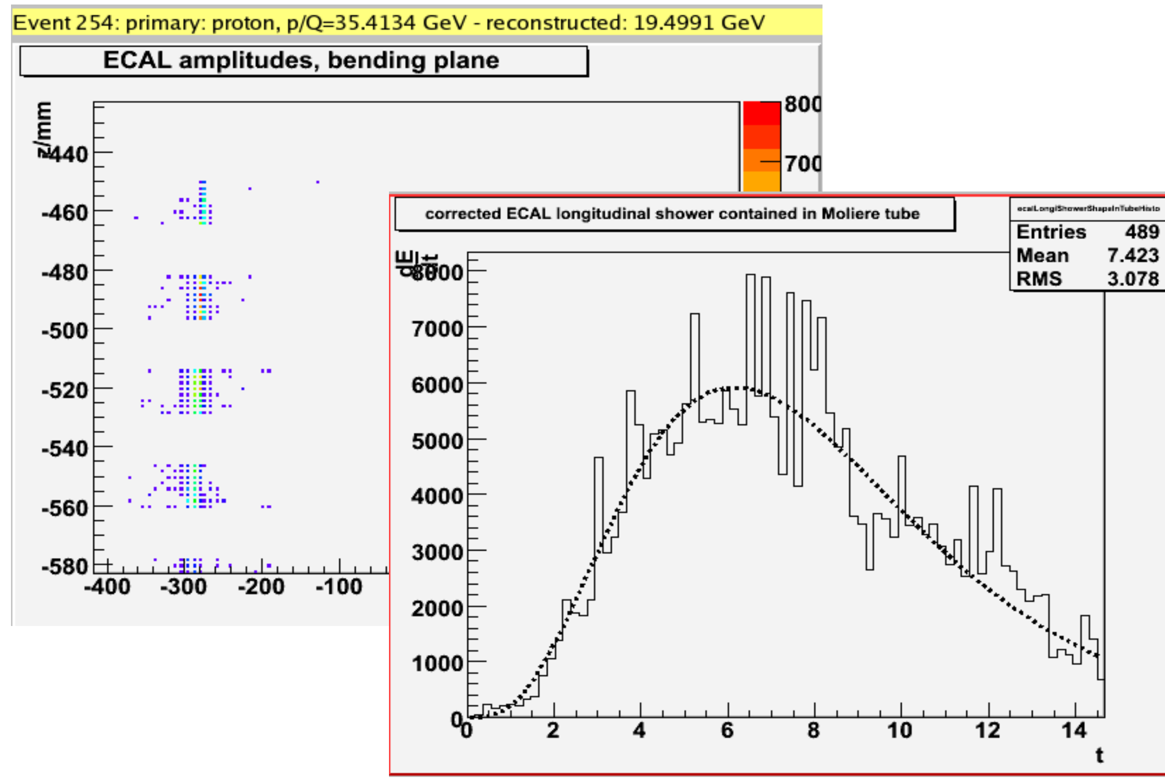
momentum reconstruction off by 1.3σ

$\pi^0$ → $\gamma\gamma$ → e.m. shower

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

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




example event:

p → p $\pi^0$ X before last tracker layer

generated: $p_{gen}$=35.4 GeV

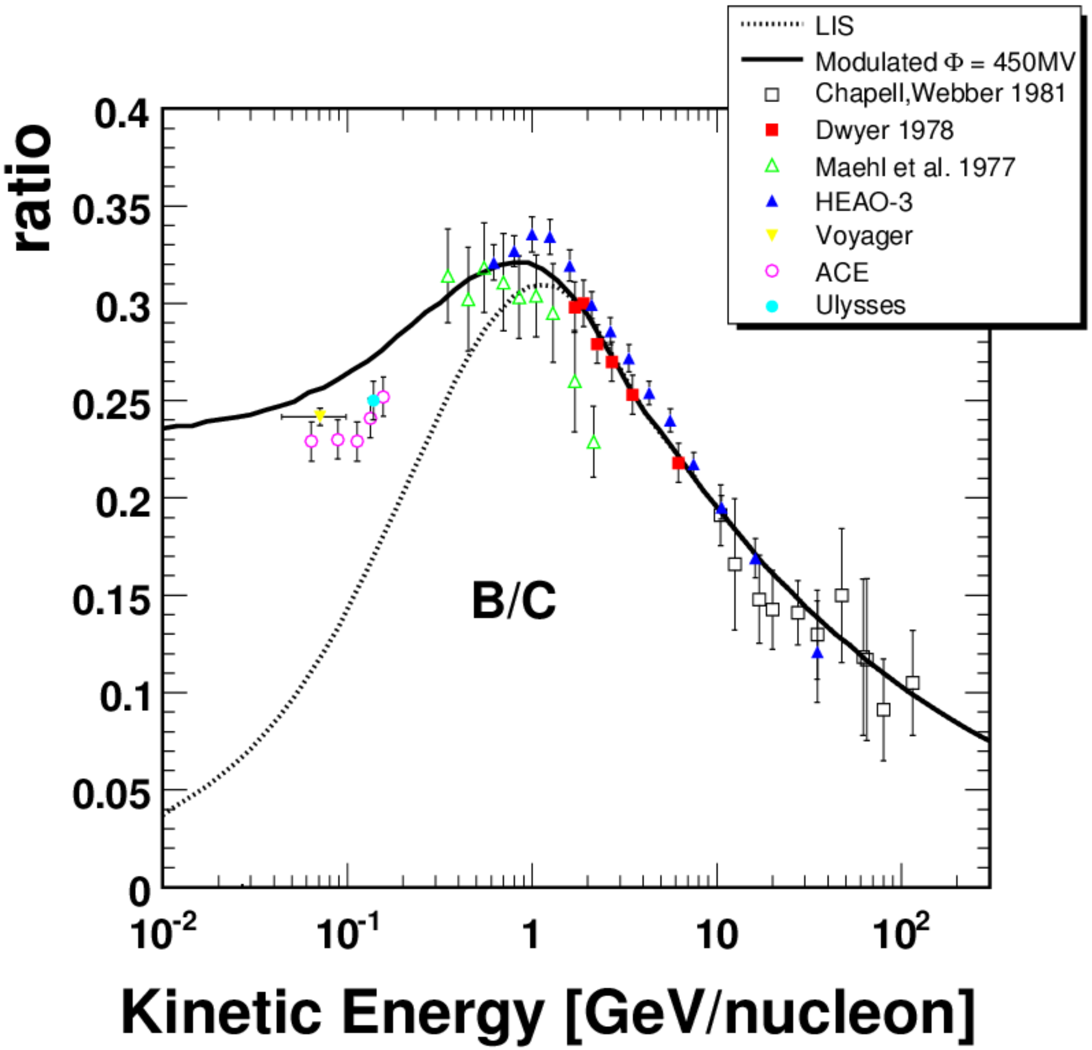
$\pi^0$ momentum: 18.9 GeV → $\gamma\gamma$ → e.m. shower

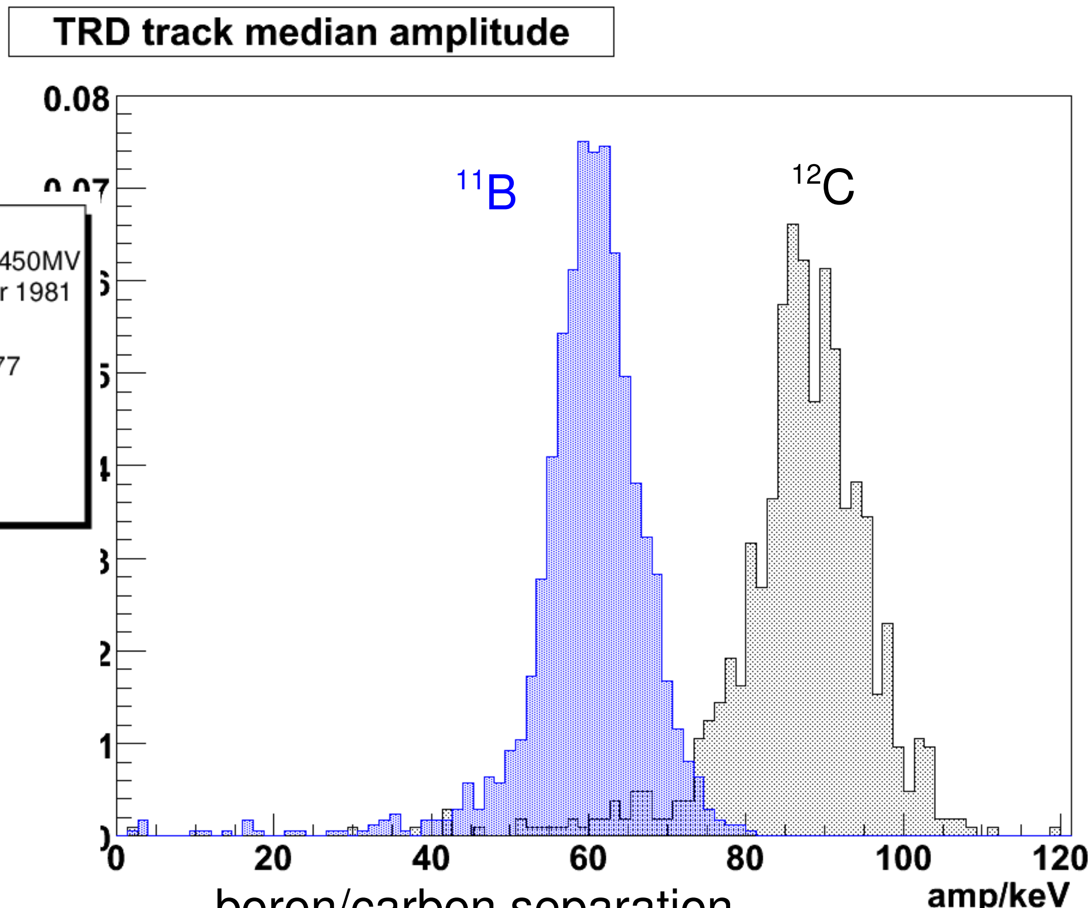
reconstructed: $p_{reco}$=19.5 GeV

intrinsic resolution limited by high-energy $\pi^0$ 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