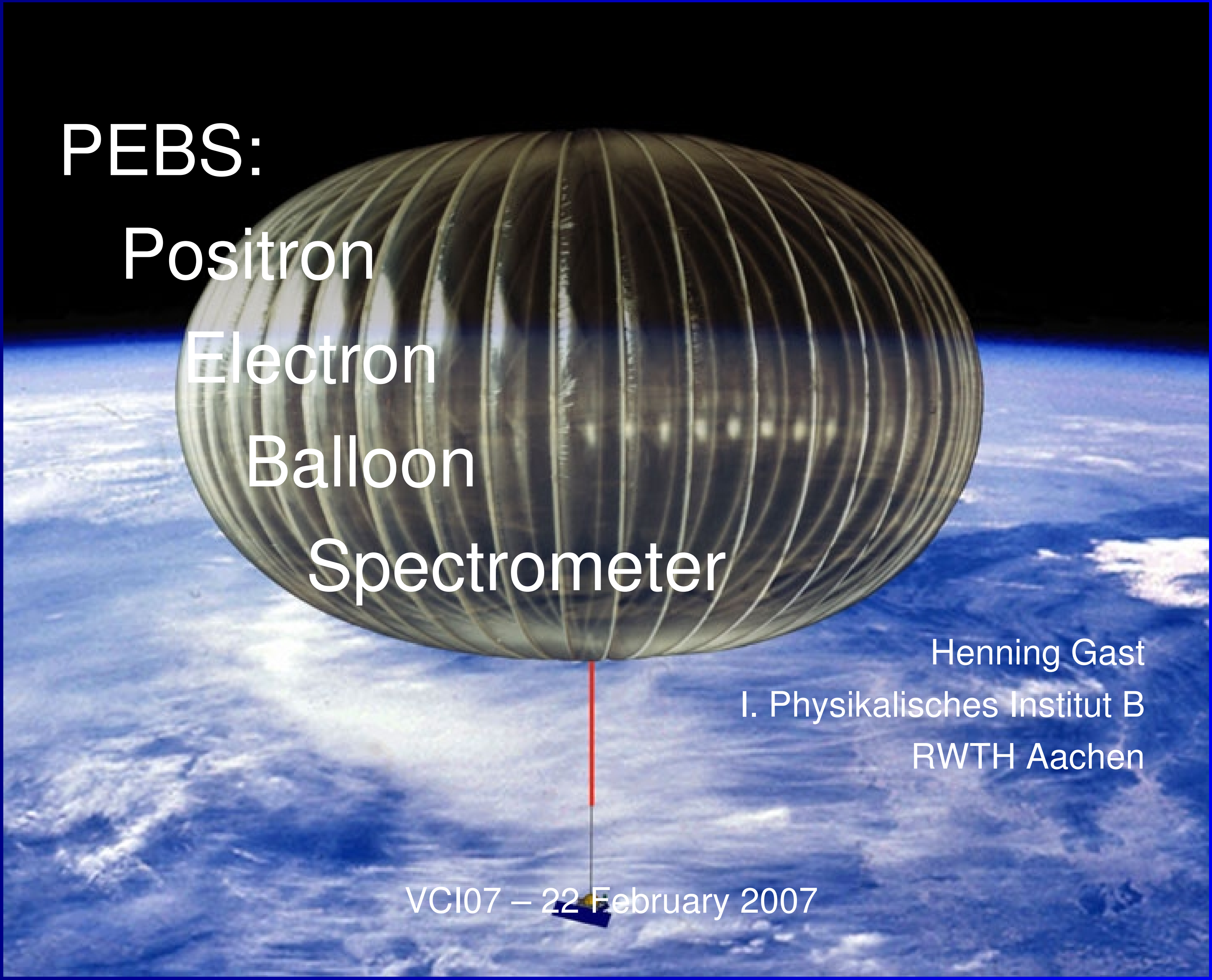

PEBS: Positron Electron Balloon Spectrometer

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I. Physikalisches Institut B
RWTH Aachen

VCI07 – 22 February 2007

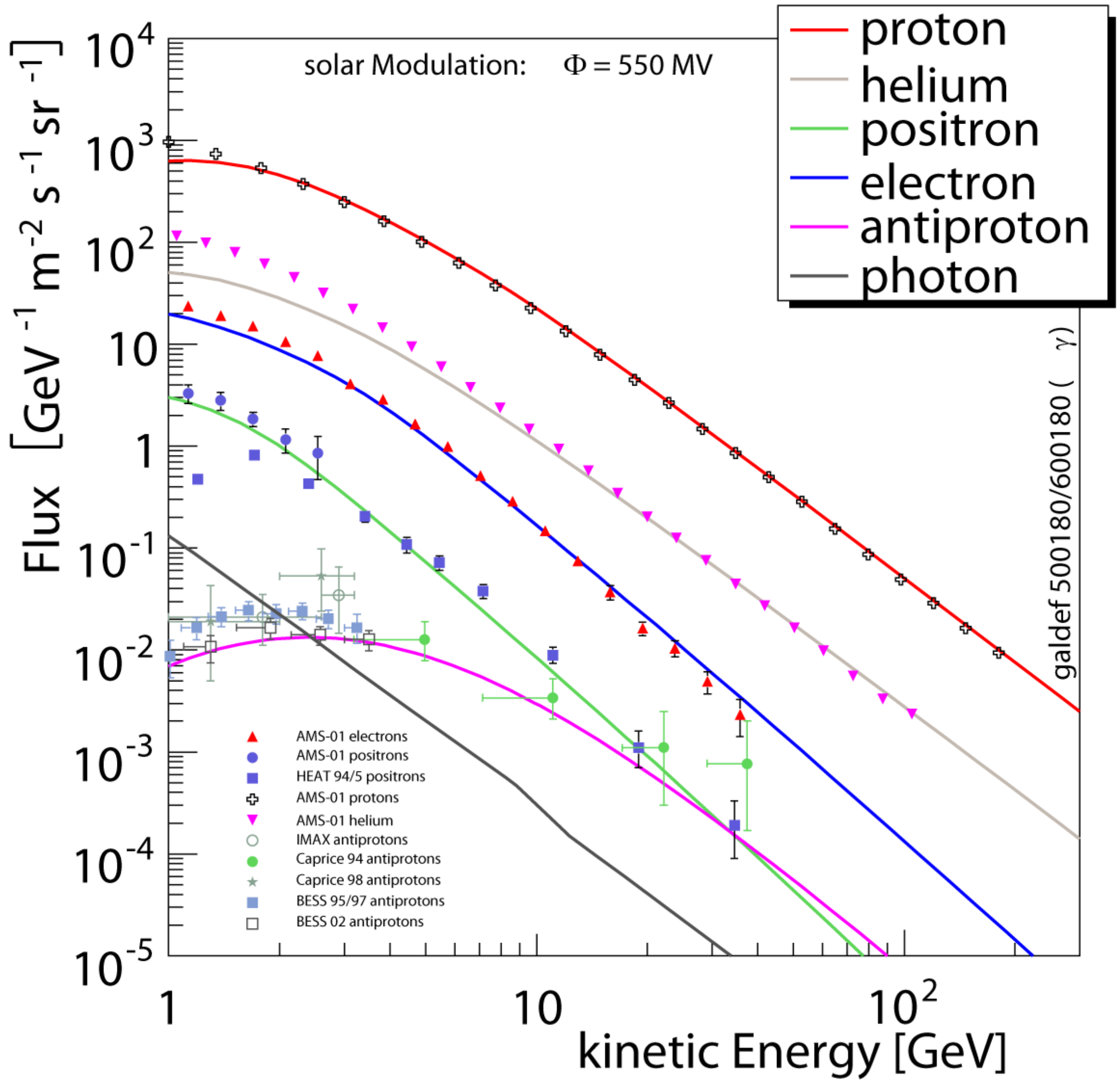
Introduction

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 0.25m^{2}sr = 43 e$^+$/GeV

Prospective performance of PEBS detector

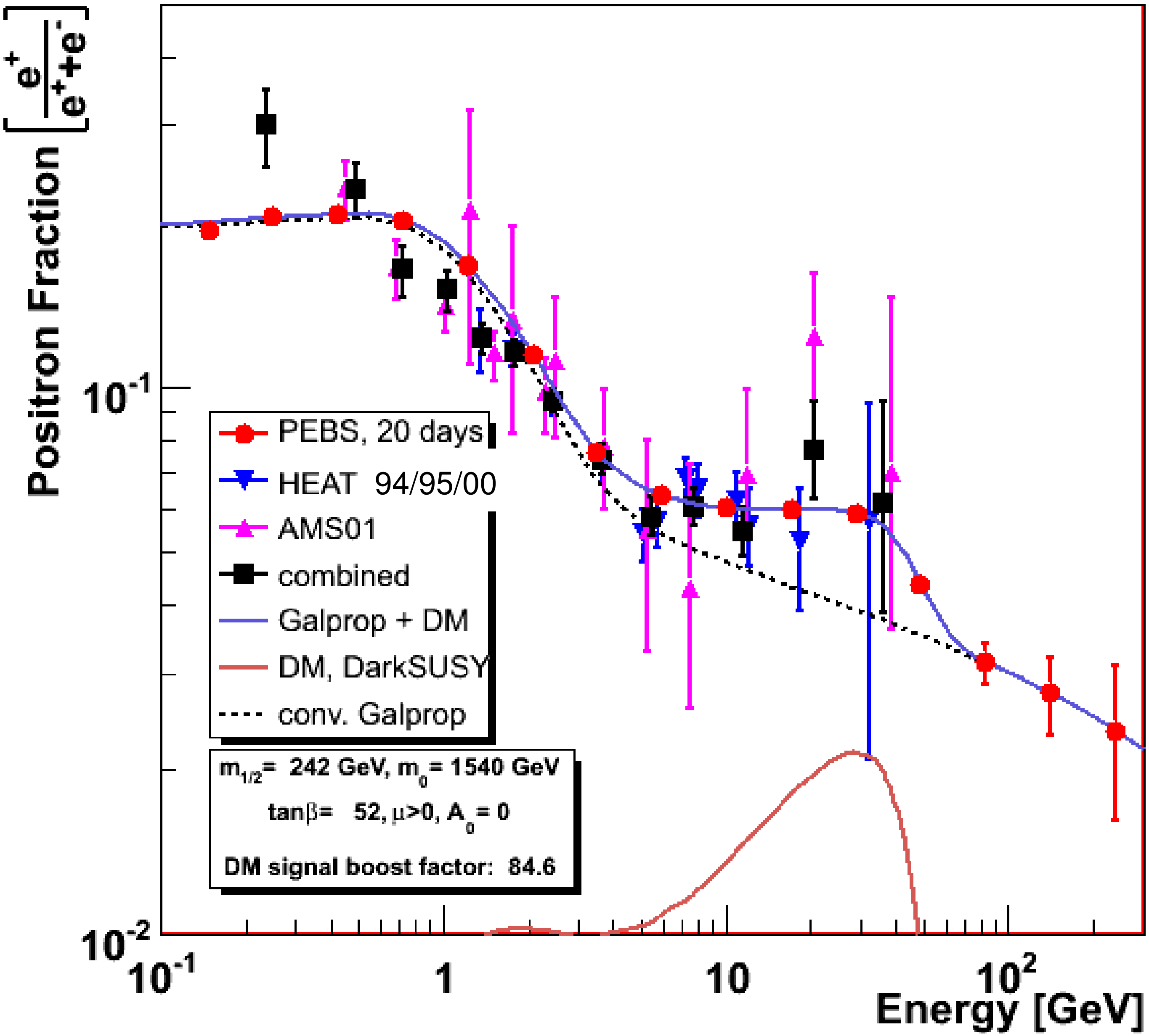
acceptance @100GeV
and mission duration

PEBS 2500 cm²sr
20 days

AMS02 500 cm²sr
1000 days

PAMELA 20 cm²sr
1000 days

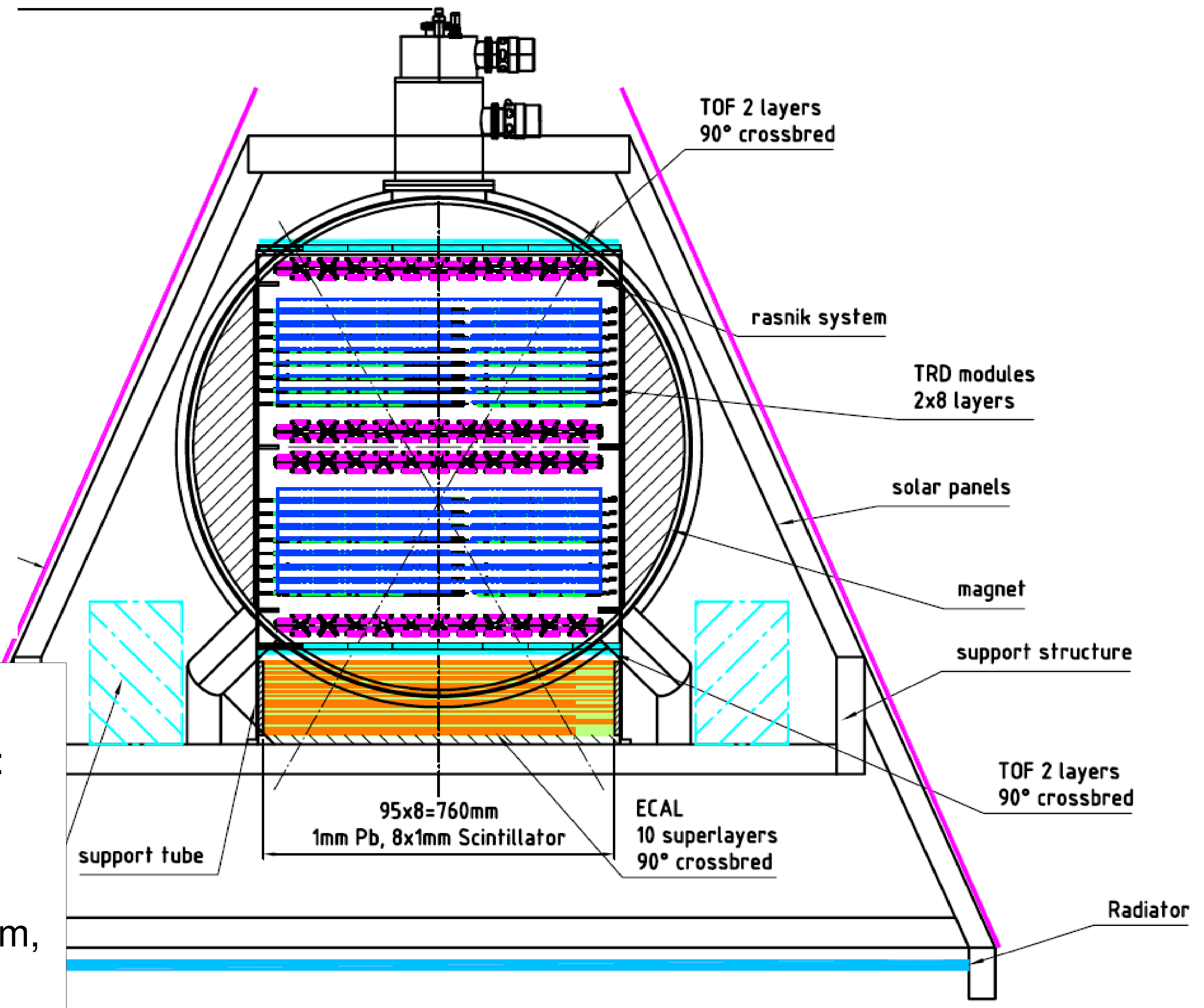
20 days PEBS=
100 days AMS02
7 years PAMELA



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



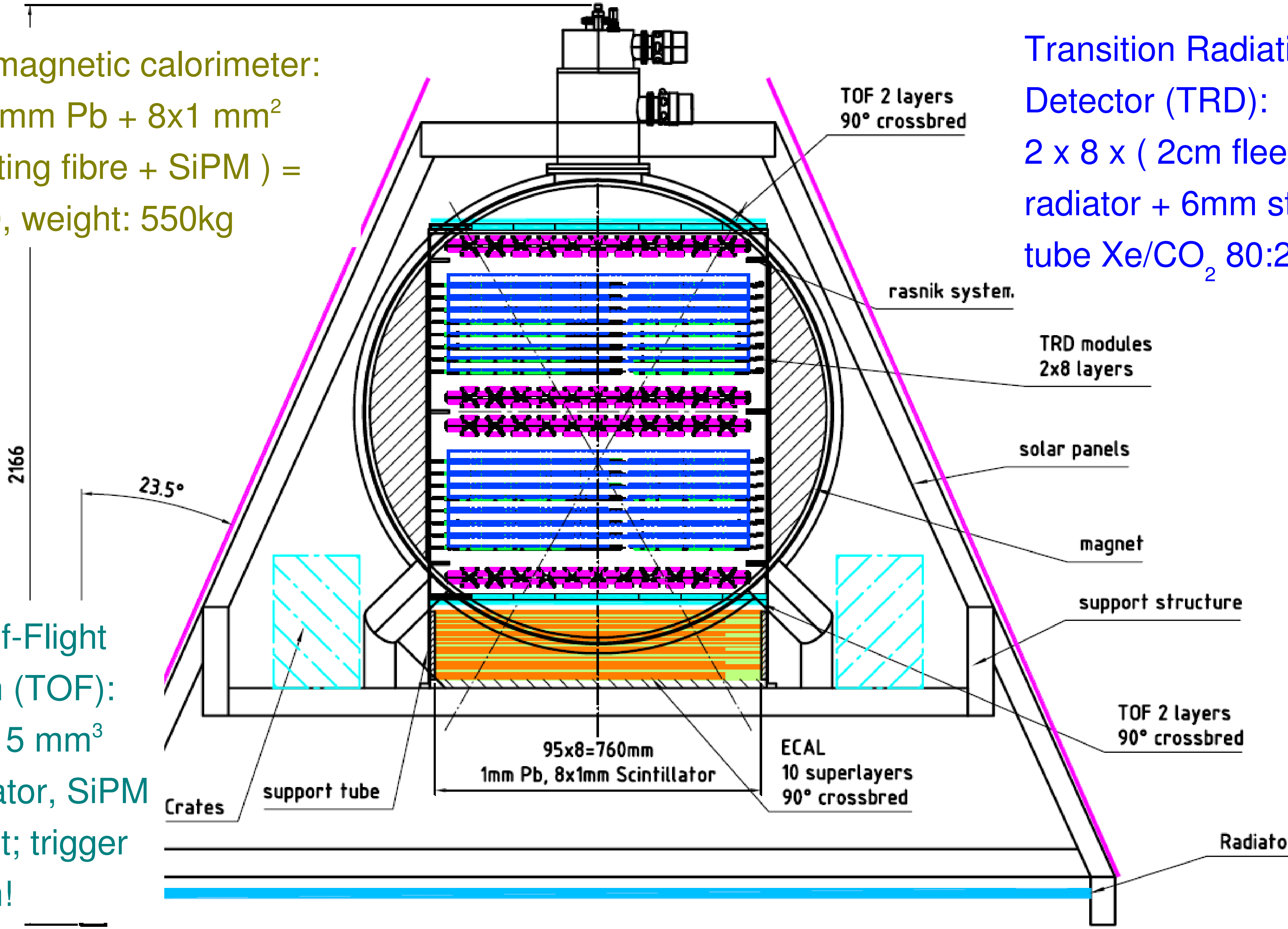
Magnet acceptance (width=0.8m, length=0.8m): 4000 cm^2sr
Positron acceptance (tracker+ECAL; width=0.76m, length=1m): 2500 cm^2sr

PEBS design overview

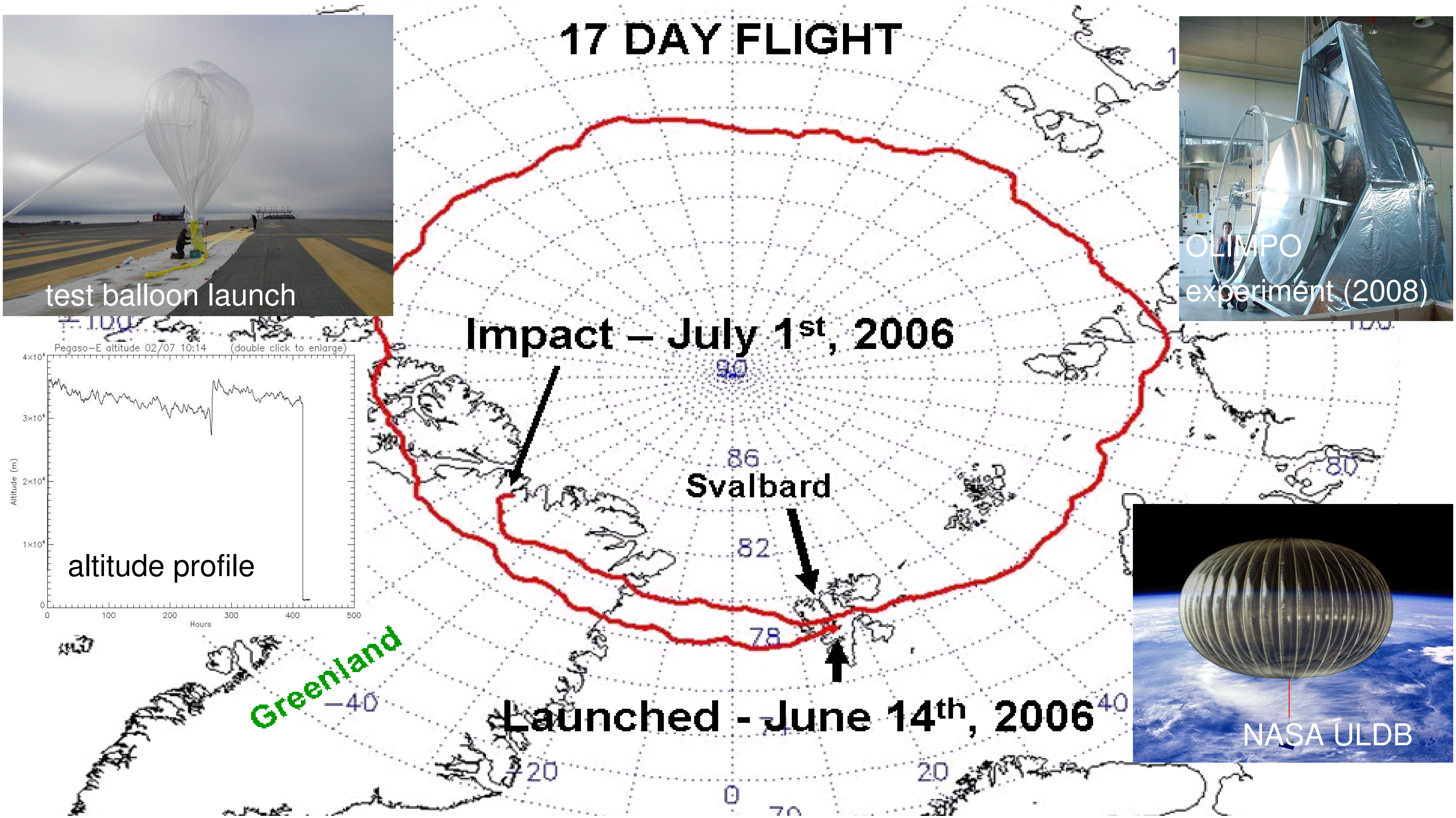
Electromagnetic calorimeter:
80 x (1mm Pb + 8x1 mm^2 scintillating fibre + SiPM) = 14.3 X0, weight: 550kg

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!



Balloons

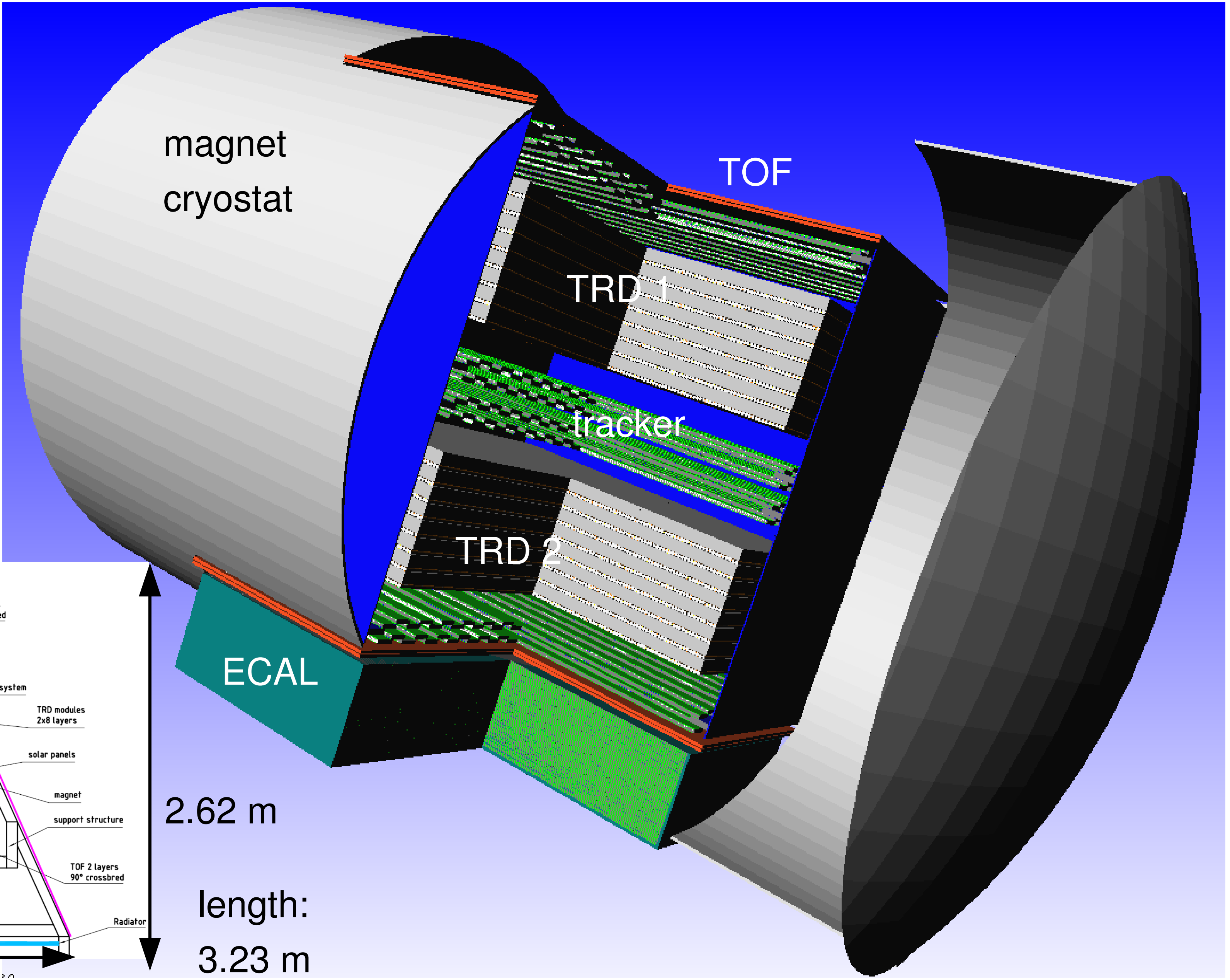


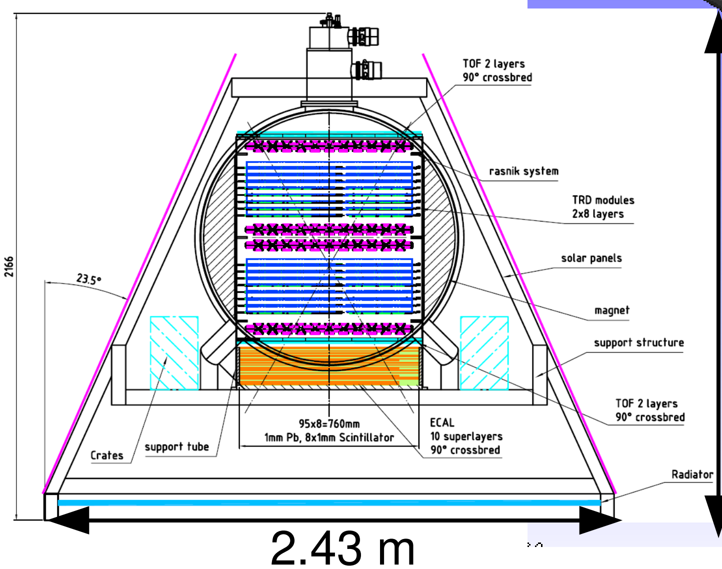
High-altitude (~40km), long-duration (~20 days) balloon flights from Svalbard ballonport (ASI)

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

PEBS detector components

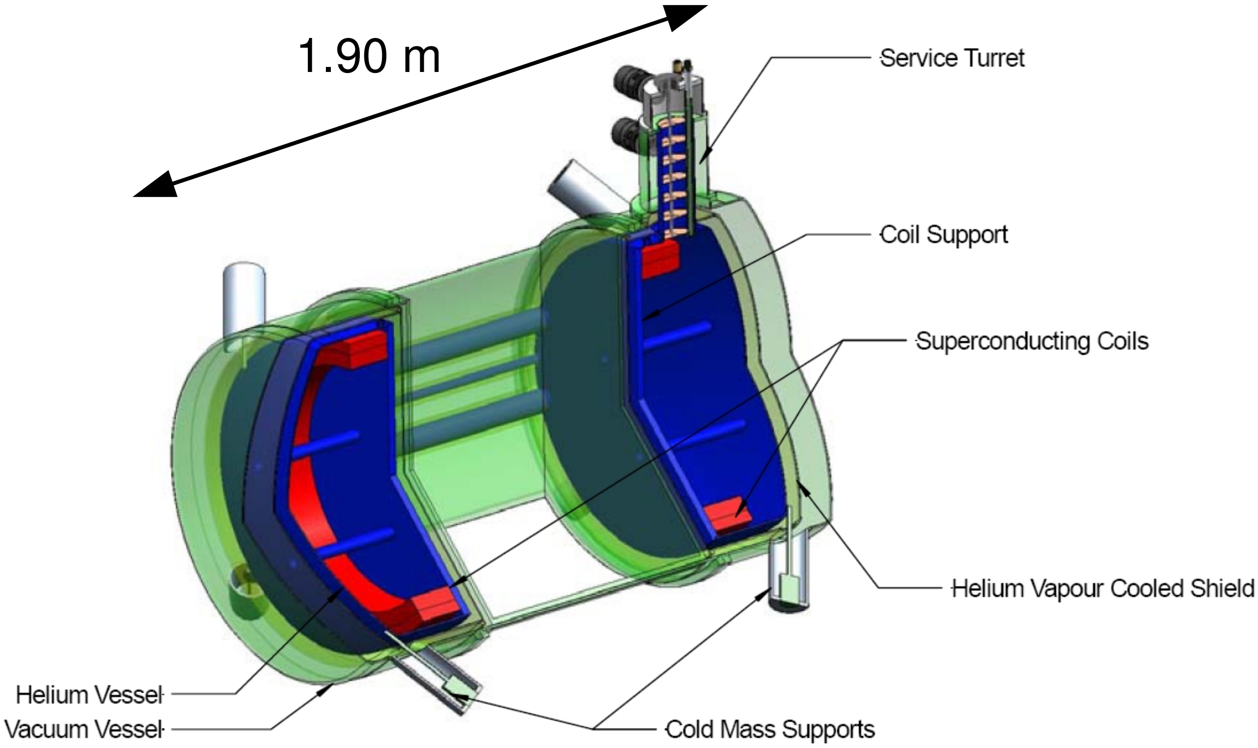
Full Geant4
detector simulation
available





Magnet design

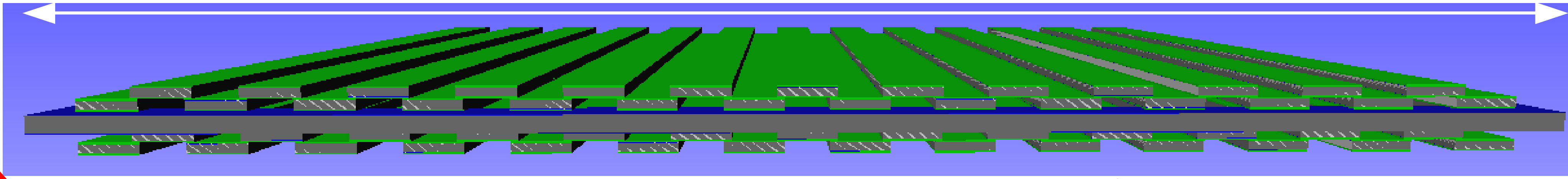
ISOMAX magnet (1998) flown on high-altitude balloon

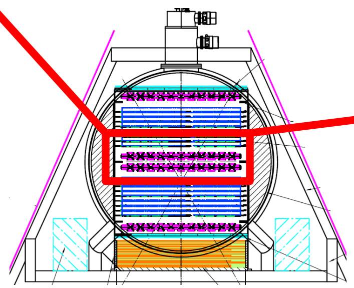


Concept Cryostat View for Vapour Cooled Shield and Coil Design 5.

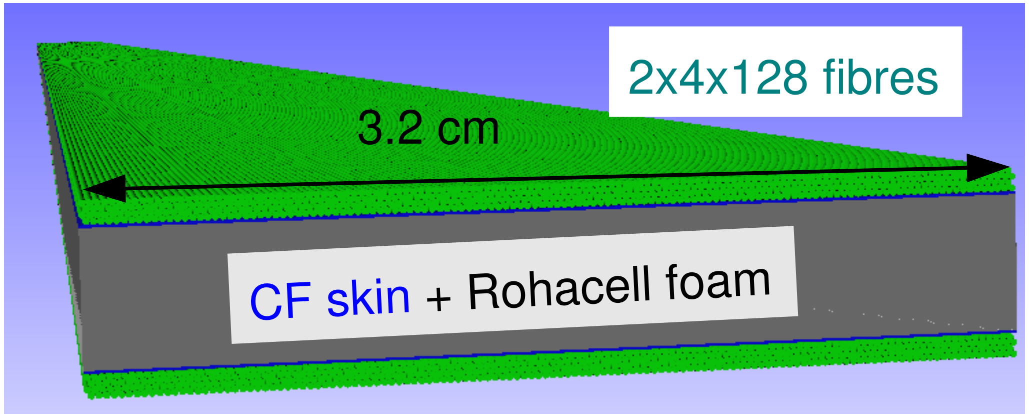
Magnet design by Scientific Magnetics for superconducting pair of Helmholtz coils in He cryostat, mean field 1 Tesla, opening 80x80x80 cm^3, weight: 850kg

Tracker layout





tracker superlayer

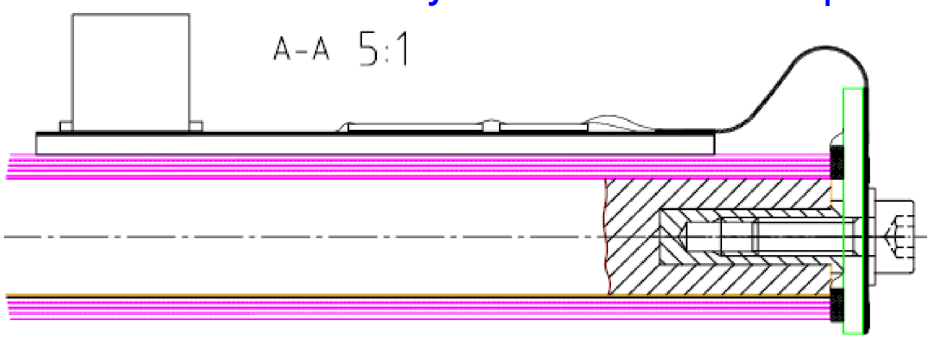


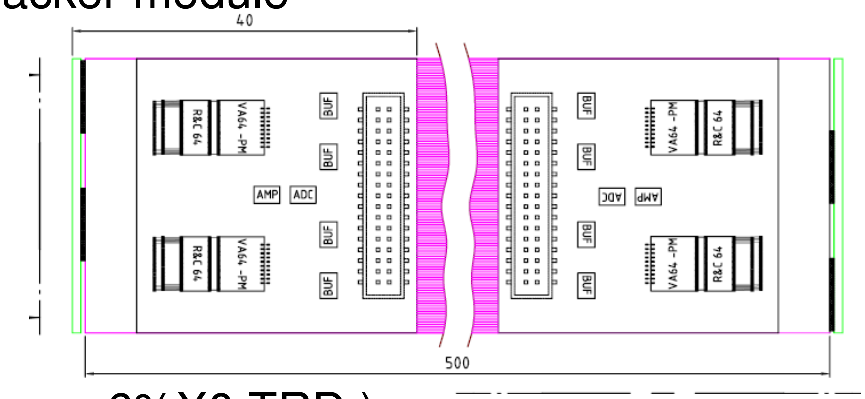
tracker module

4 superlayers of 2 layers of double-layered modules of scintillating fibres, d=250 μm

stack of fibres accumulates light on SiPM

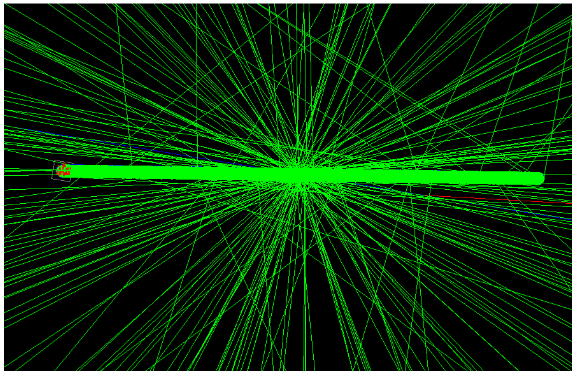
readout of SiPMs by dedicated VA chip



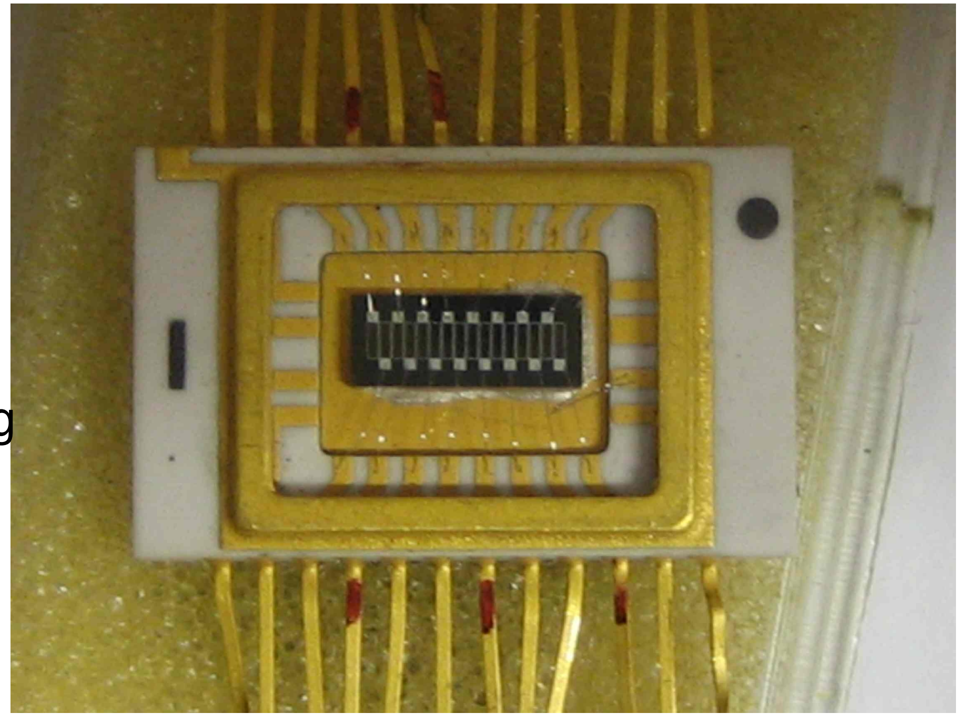


material budget: 12% X0 (6% X0 tracker + 6%X0 TRD)

Tracker readout scheme

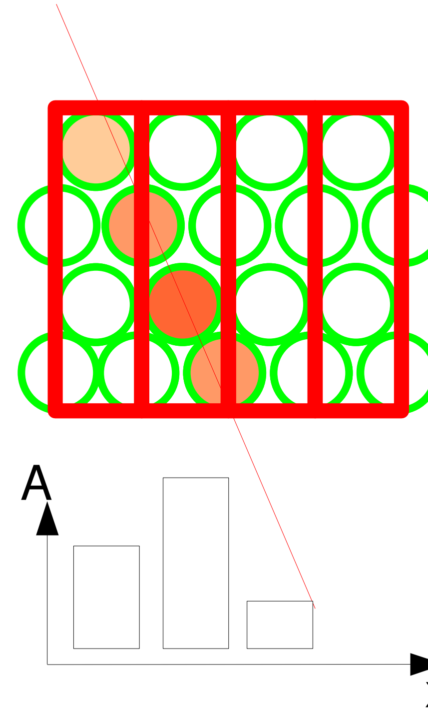


light collection in scintillating fibre in Geant4 simulation



16x1 silicon photomultiplier, strip width 380 µm

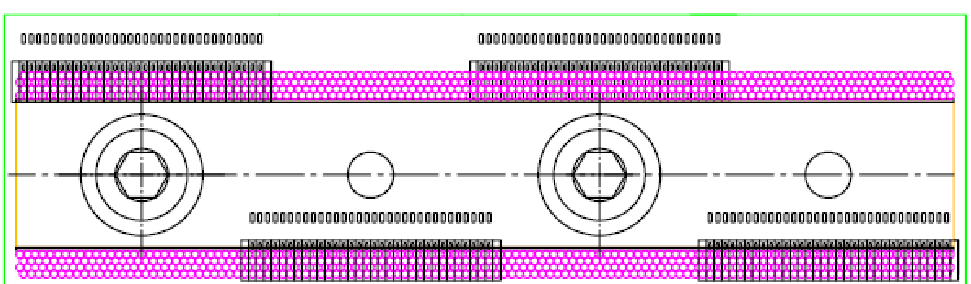
need 32x1, 250µm strip width



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

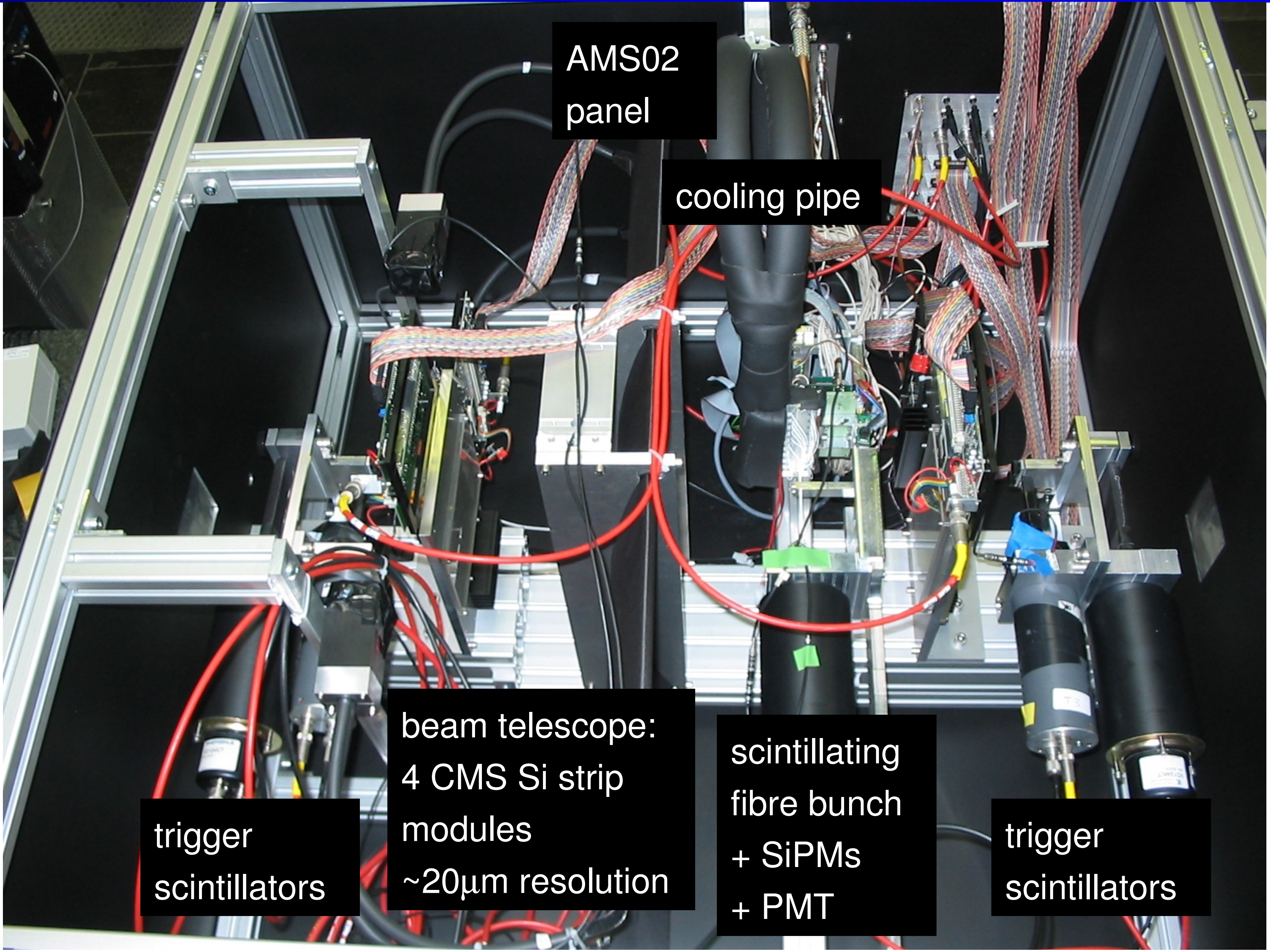
better spatial resolution than pitch/√12 , depending on p.e. yield

fibre module front view, with SiPM arrays on alternating sides

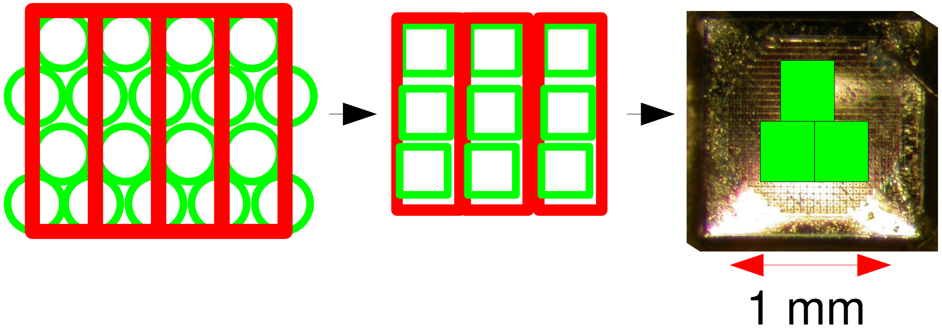


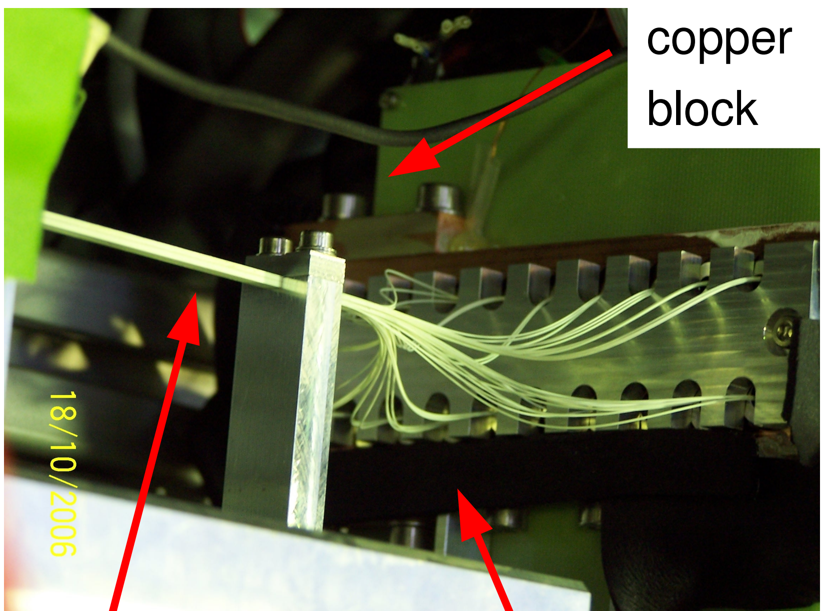
total power consumption (~50000 channels) of tracker: 260 W

PEBS fibre tracker testbeam setup



PEBS testbeam MC

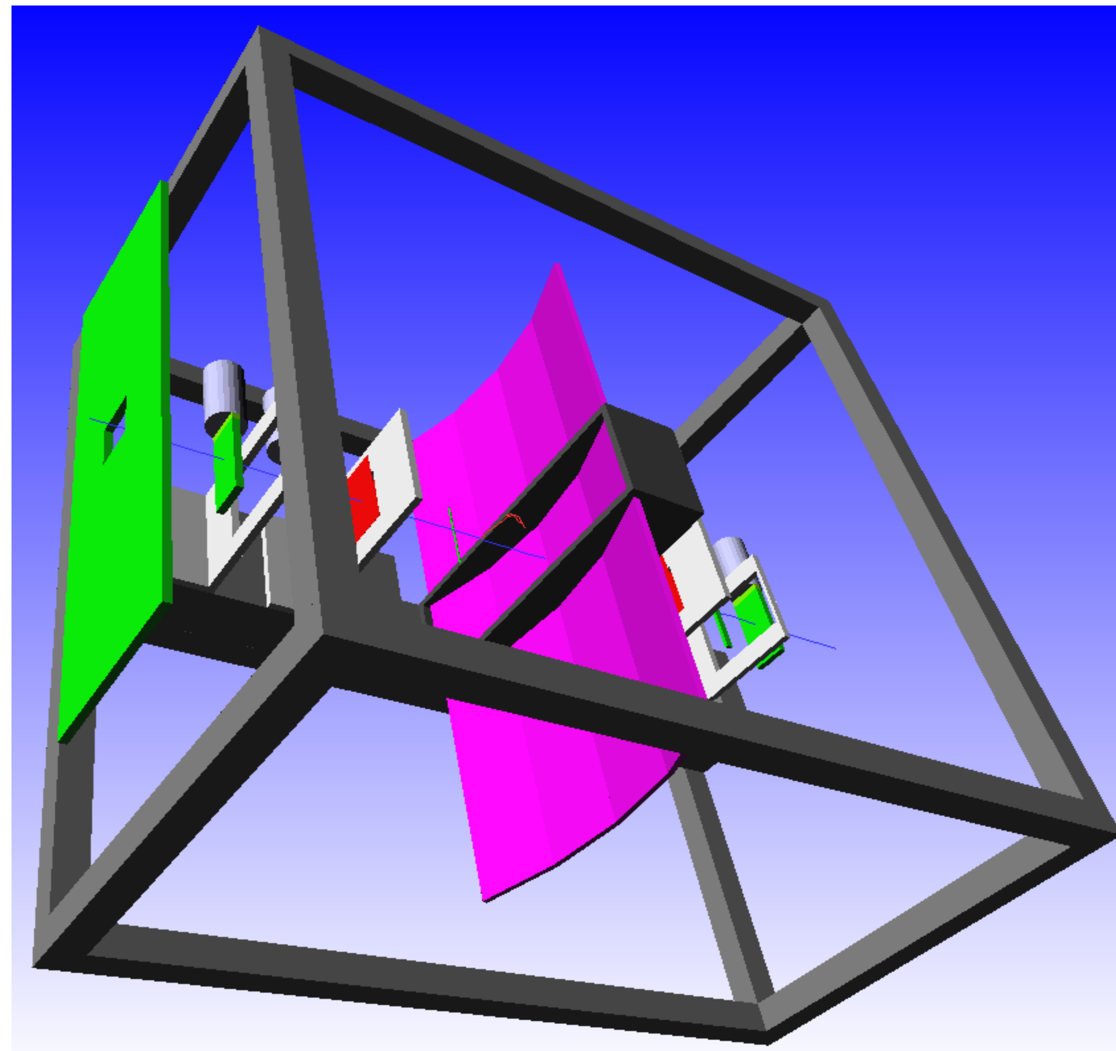




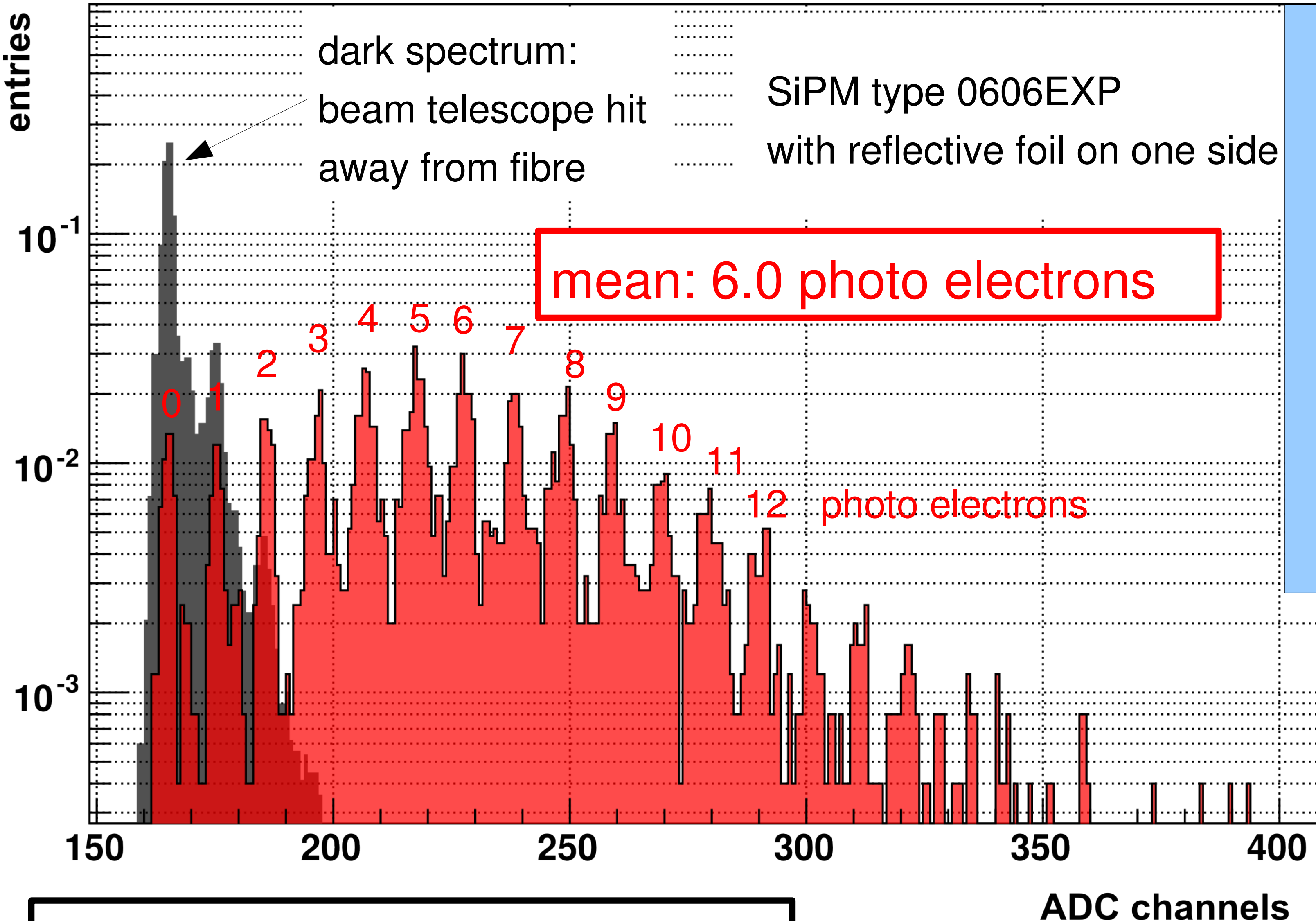
copper block

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

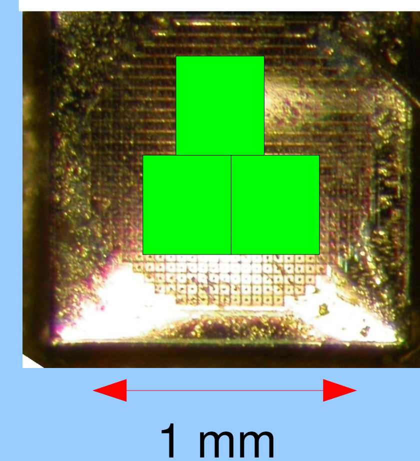
3 fibres each to SiPM in copper block



SiPM: example of a MIP spectrum



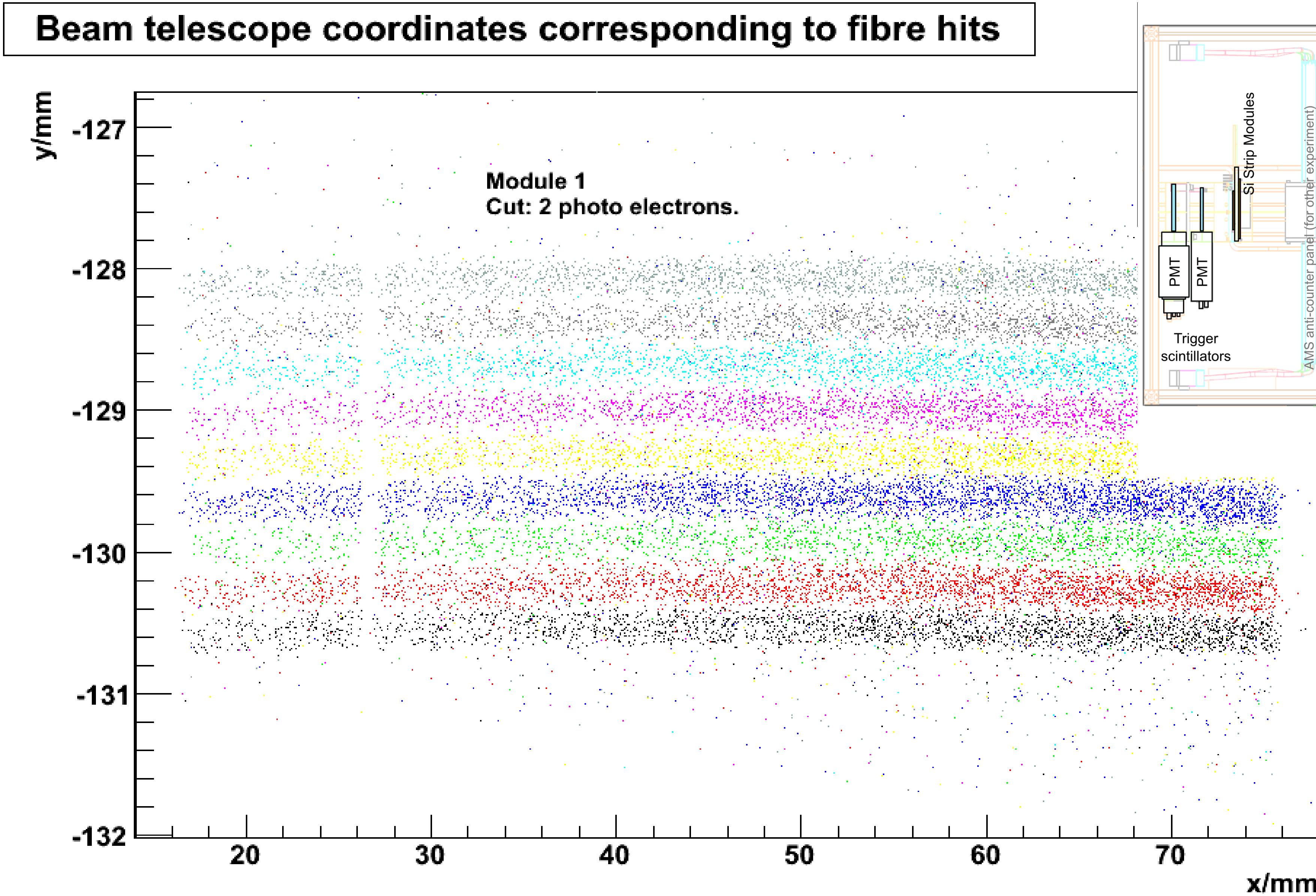
excess noise:
fibre area =
0.27 x SiPM area

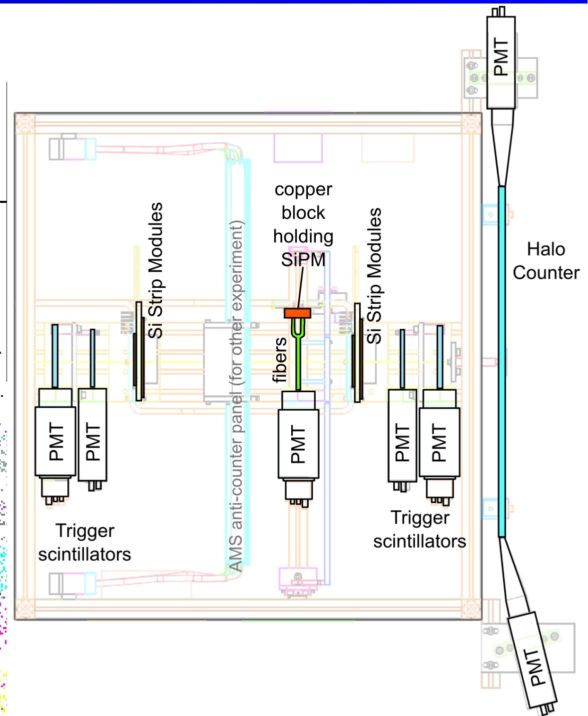


Photonique
SSPM 0606 EXP
S/N=20,
eff(0.5pe)=96%
SSPM 050701GR
S/N=100,
eff(0.5pe)=91%

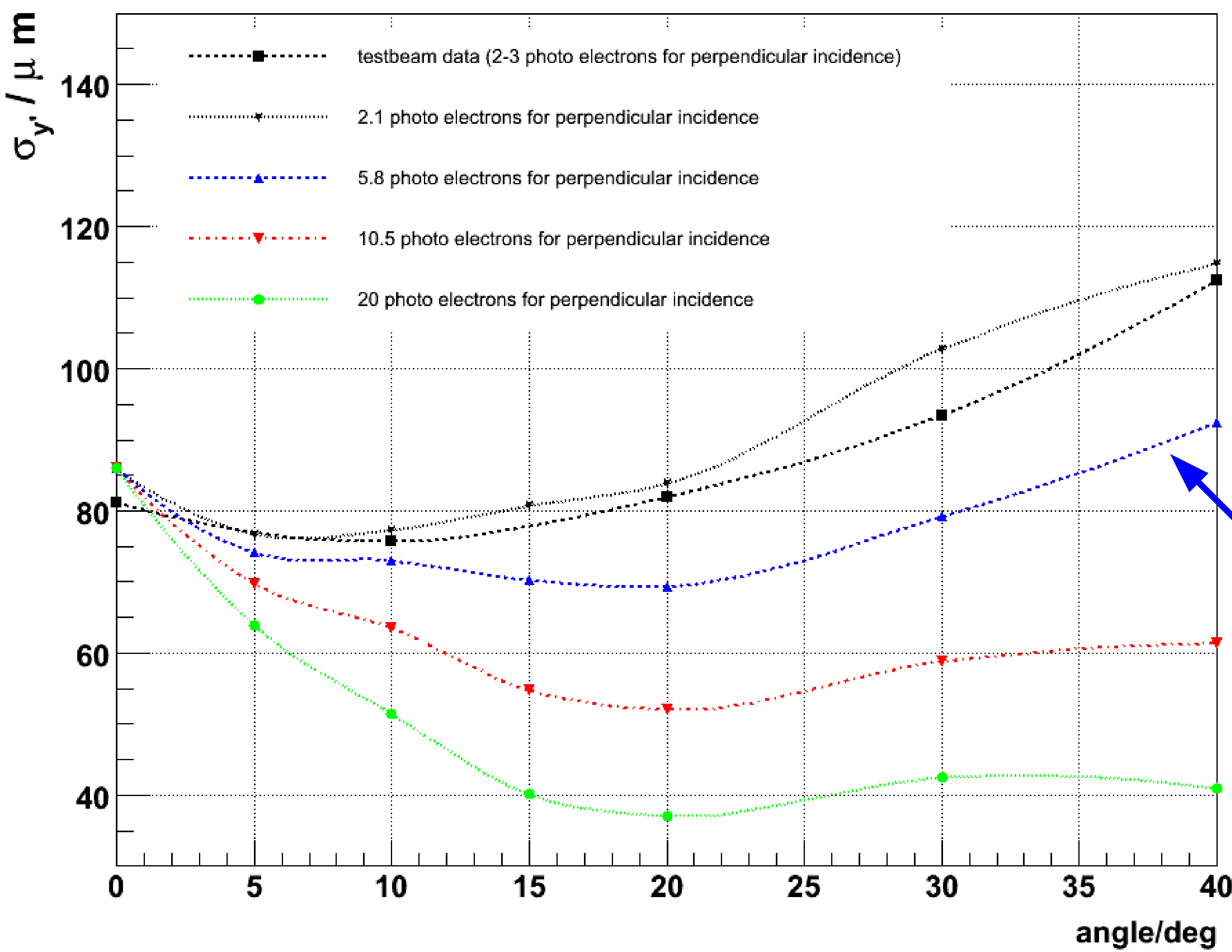
for details see poster by Gregorio Roper

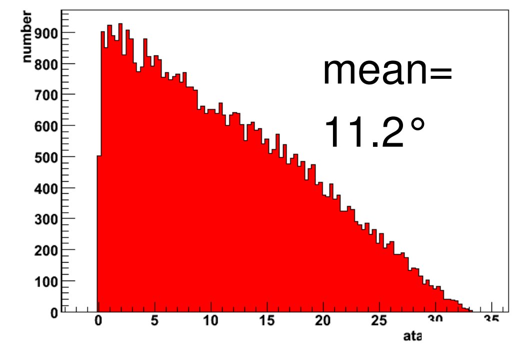
Fibre coordinates in beam telescope





Spatial resolution vs angle of incidence

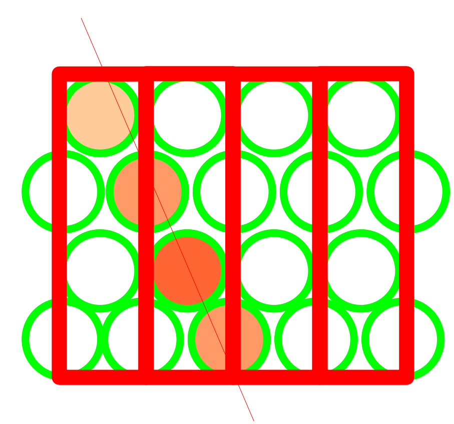




35°

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

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

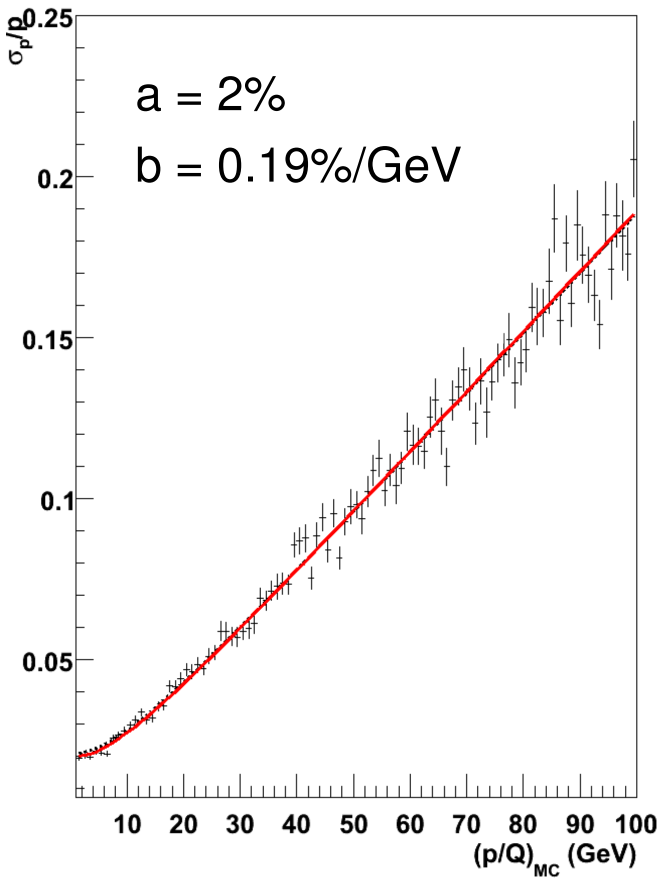


Tracker performance: Momentum resolution

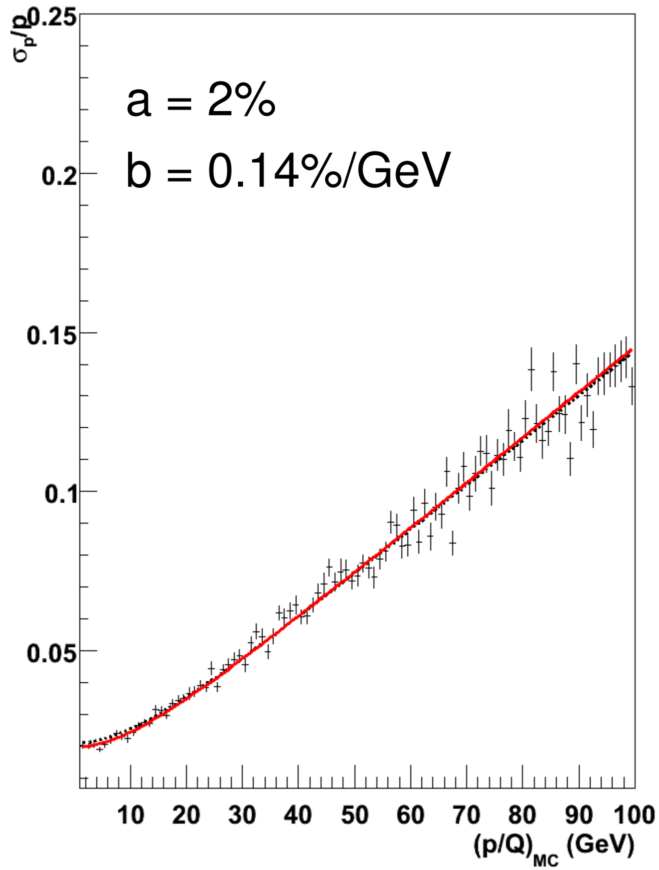
Muon momentum resolution from G4 simulation using testbeam parameters, d = 250µm, B=1T

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

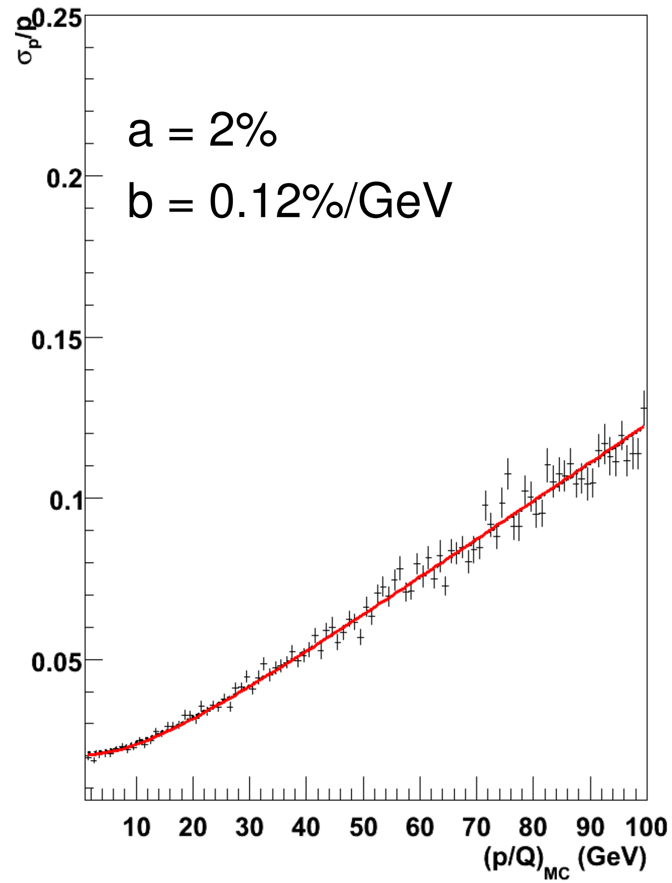
p.e. efficiency = 1 x testbeam efficiency



p.e. efficiency = 1.5 x testbeam efficiency



p.e. efficiency = 2 x testbeam efficiency



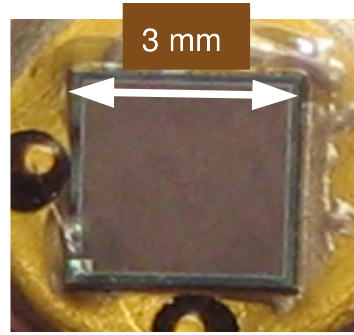
ECAL layout

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

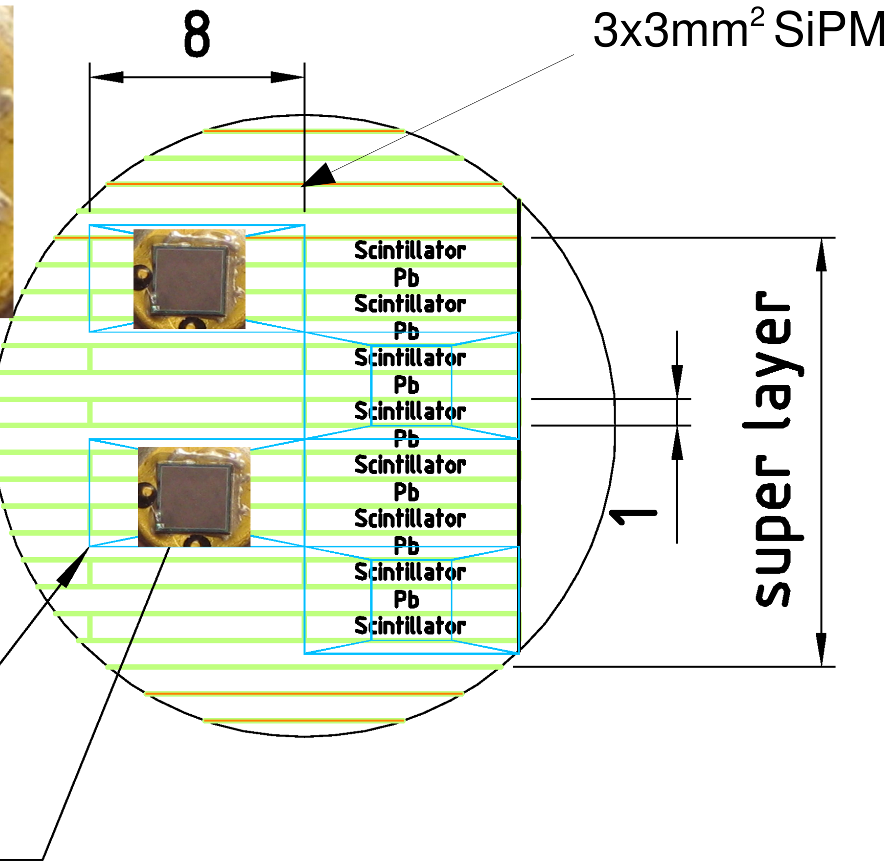
1mm lead

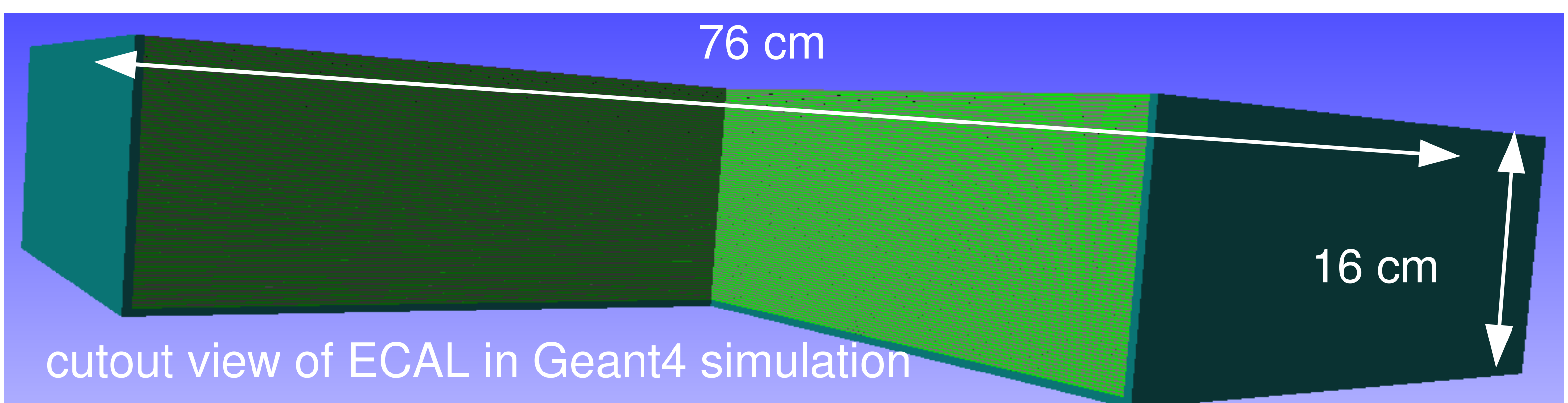
fibre: 1mm height, 8mm width, read out by SiPMs

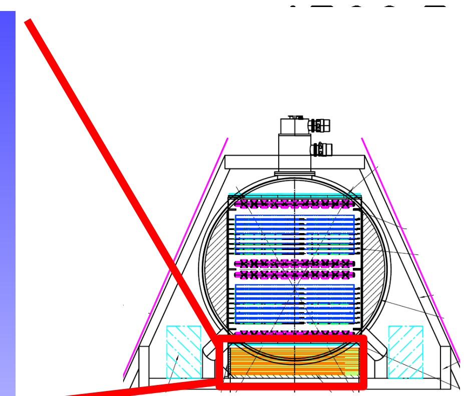
14.3 X0 in total, ECAL weight: 550 kg



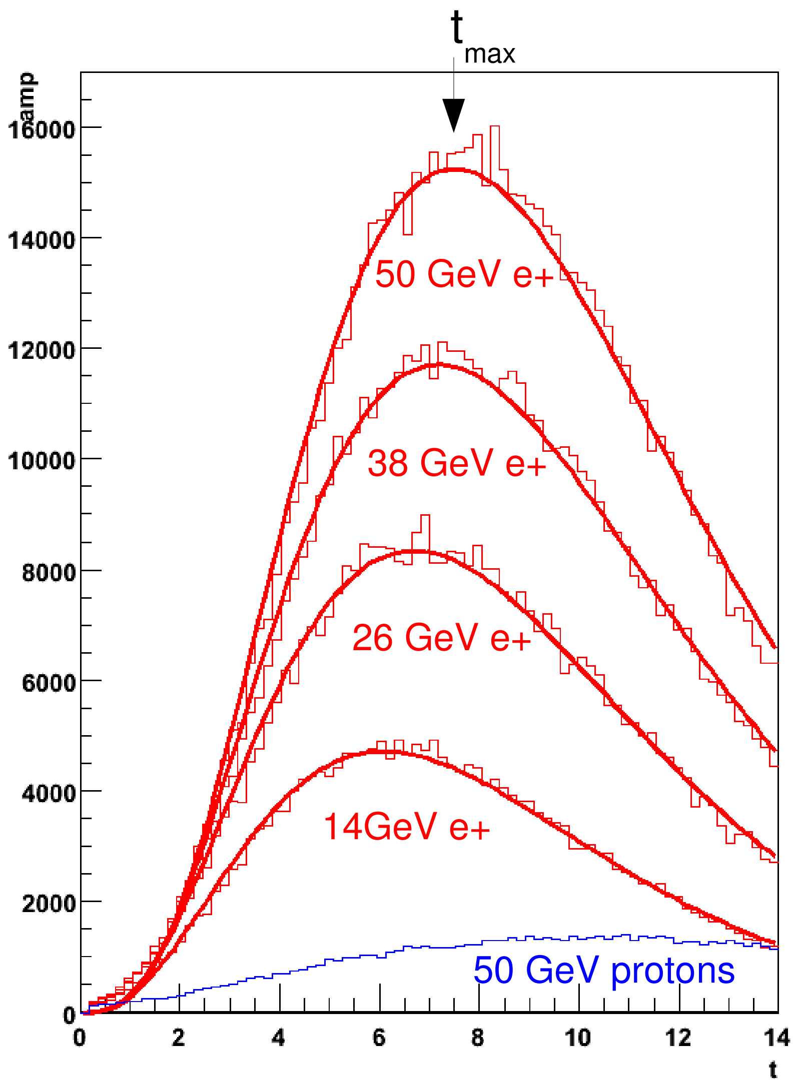
3x3 mm array:
8100 pixel





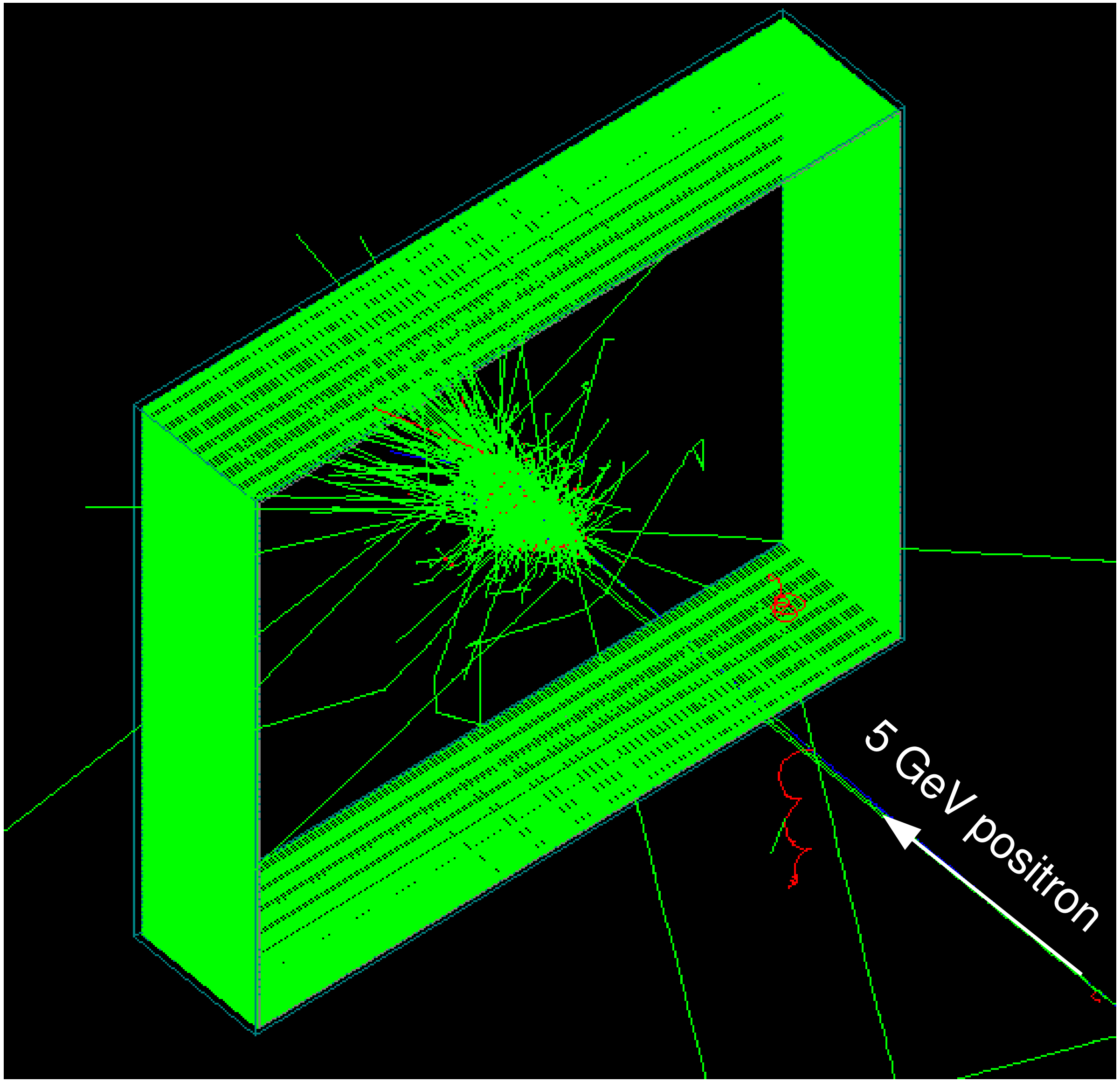


ECAL shower



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

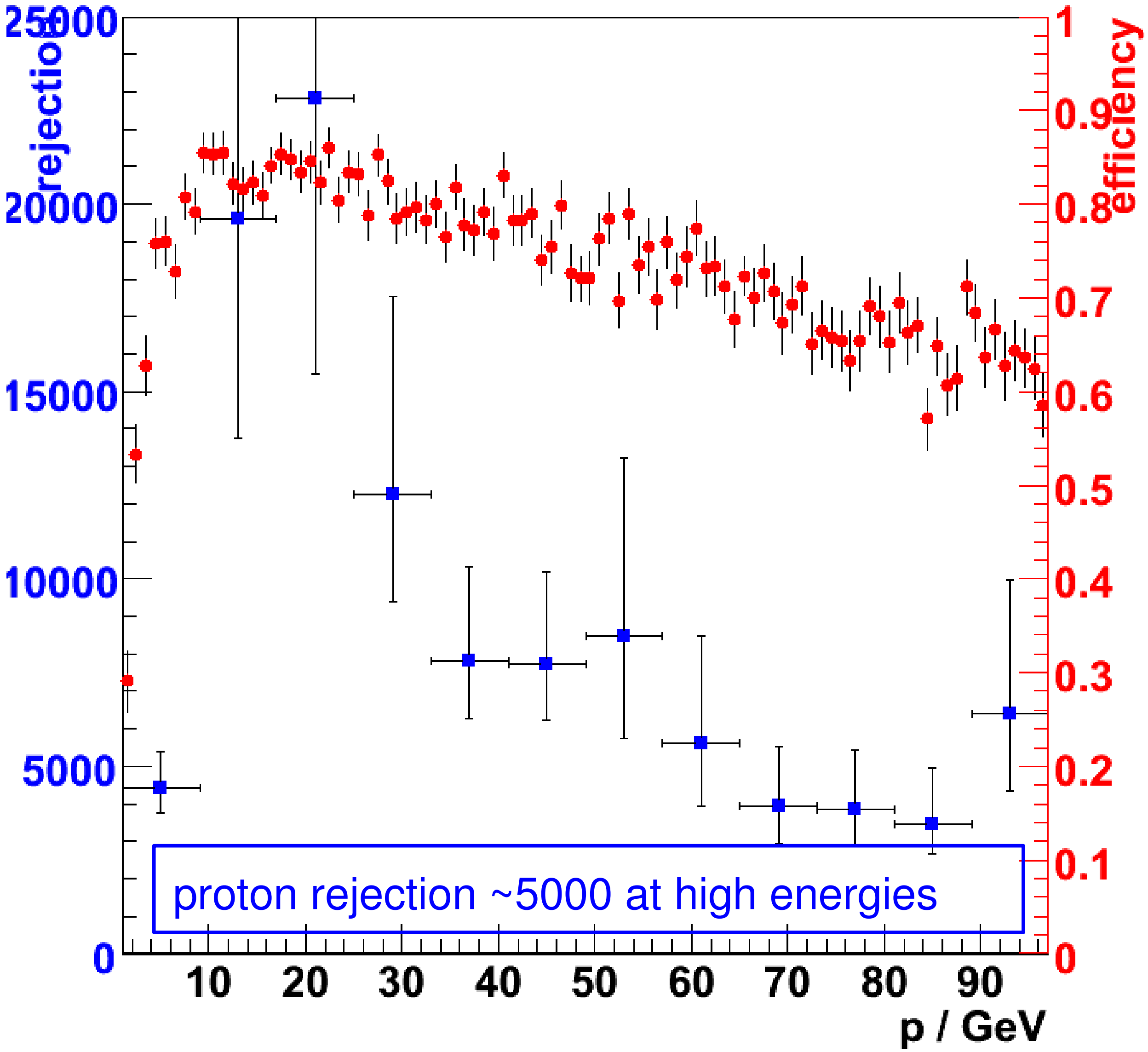
longitudinal shower profiles

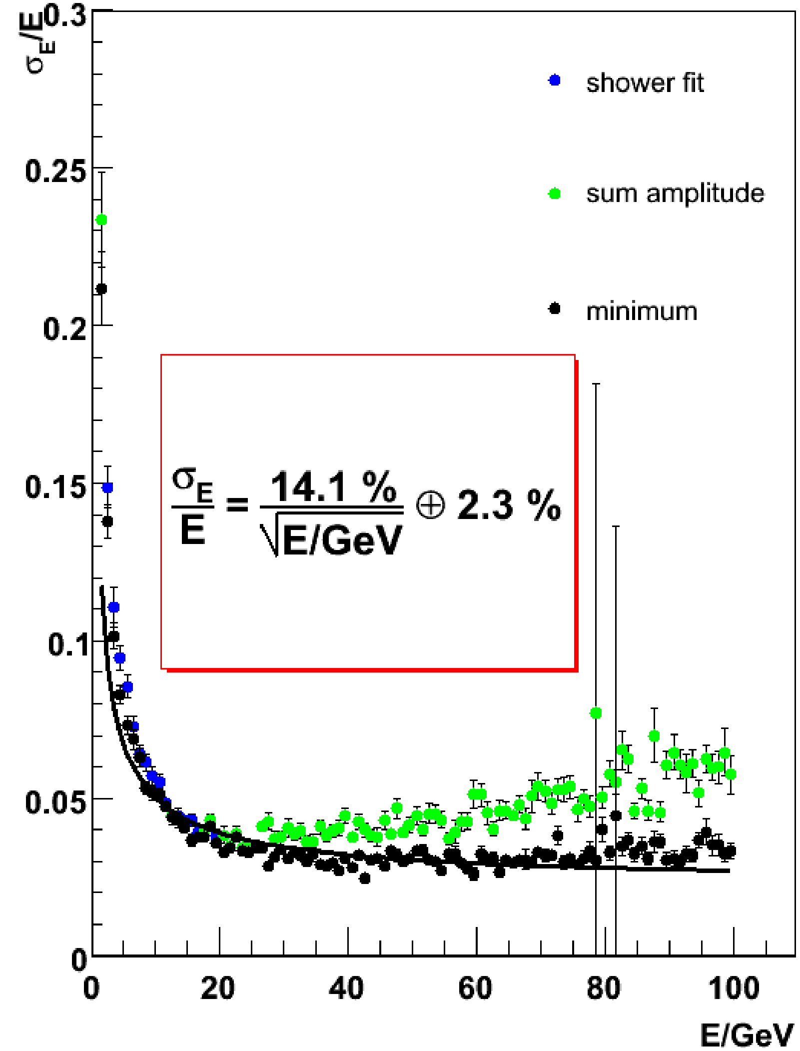


ECAL shower in Geant4 simulation

ECAL proton rejection and energy resolution

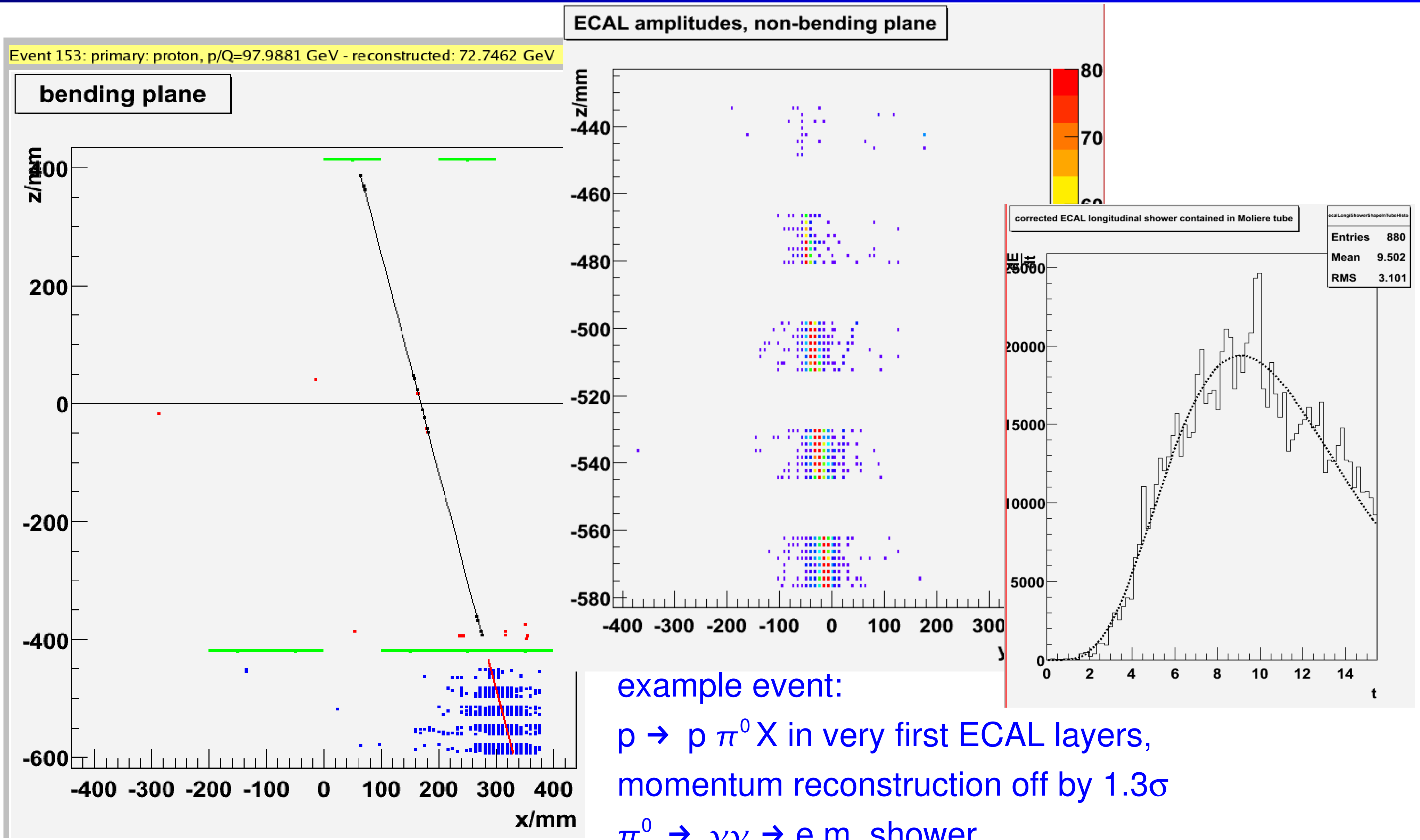
Simulated 40000 positrons and 1700000 protons





ECAL energy resolution

Intrinsic limits on rejection



example event:

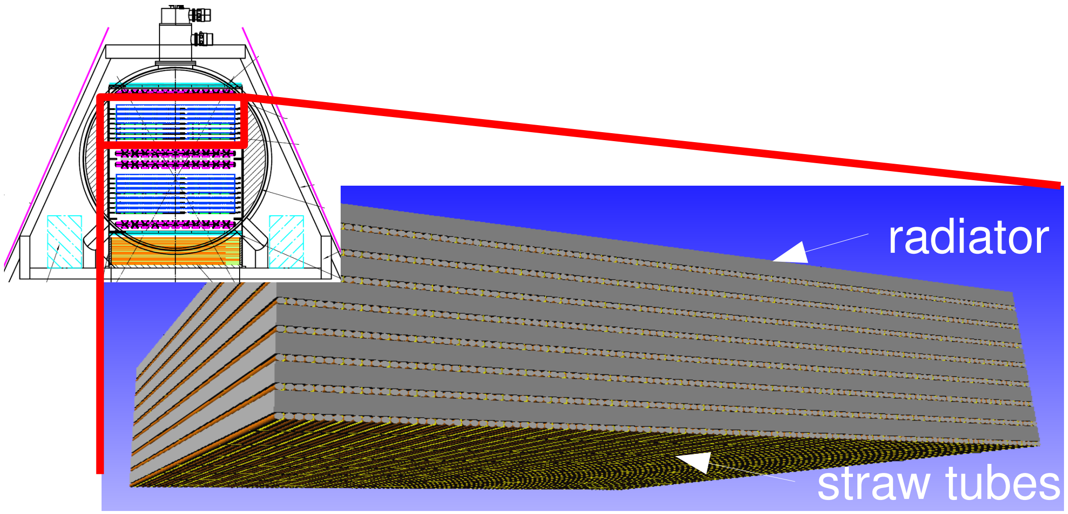
p → p π^0 X in very first ECAL layers,

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

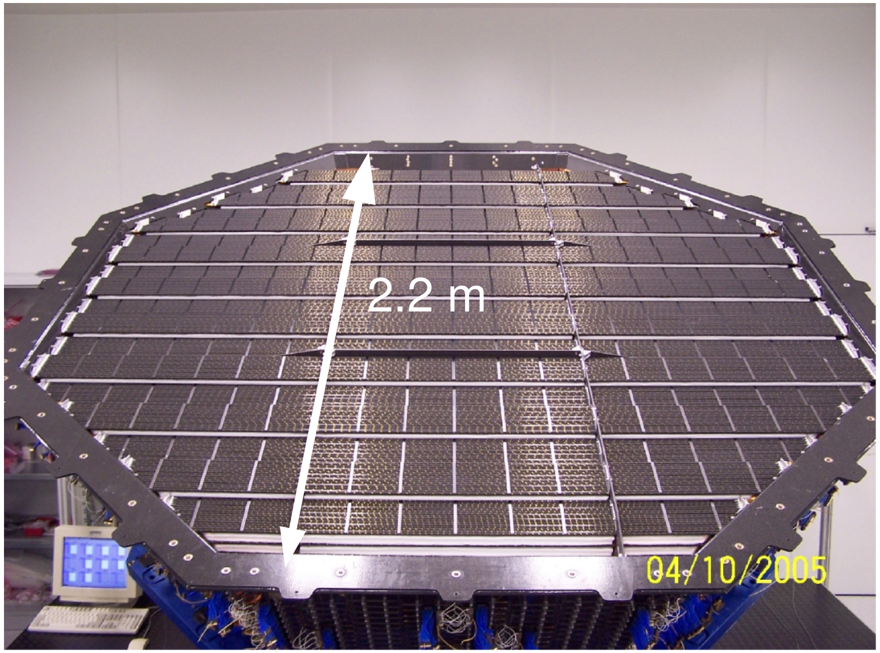
TRD design



TRD superlayer in G4 simulation

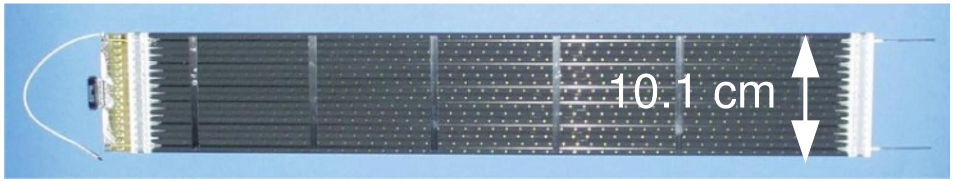
2 x 8 layers of fleece radiator,
TR x-ray photons absorbed by Xe/CO2 mixture (80:20), in 6mm straw tubes with 30 μm tungsten wire

Design equivalent to AMS02 space experiment



AMS02 TRD octagon integrated at RWTH Aachen workshop

Tasks: proton suppression and tracking in non-bending plane

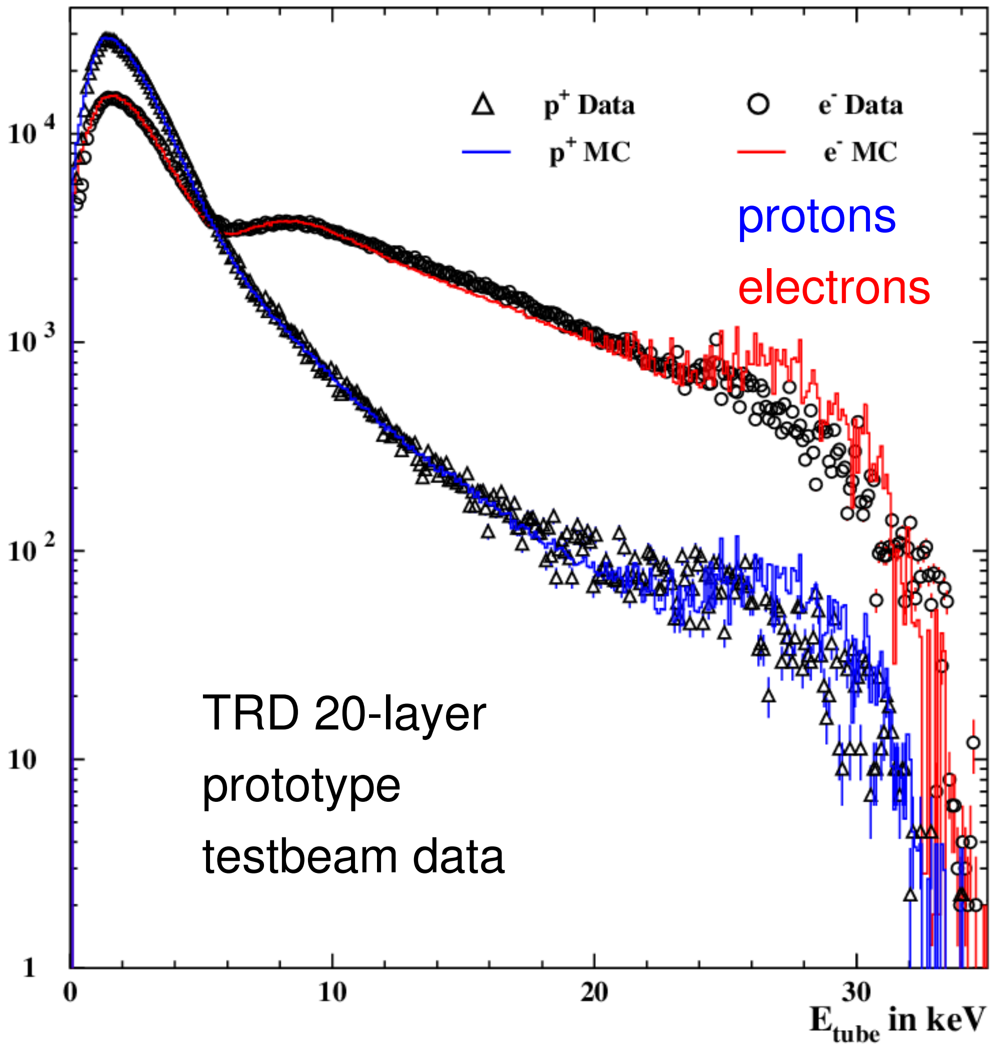


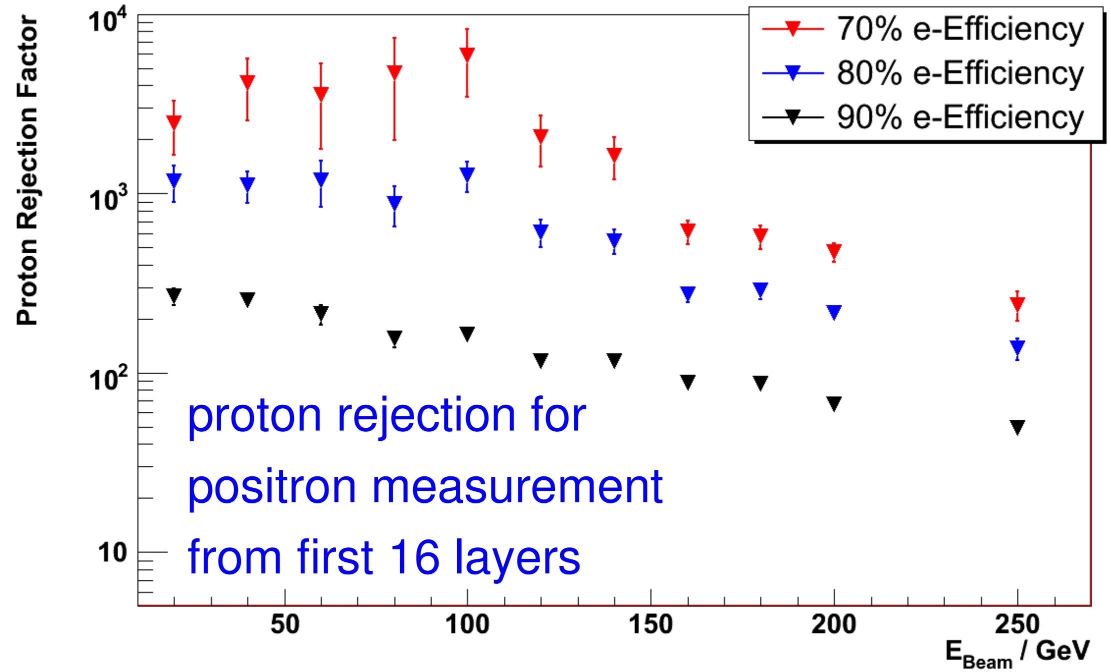
single TRD module

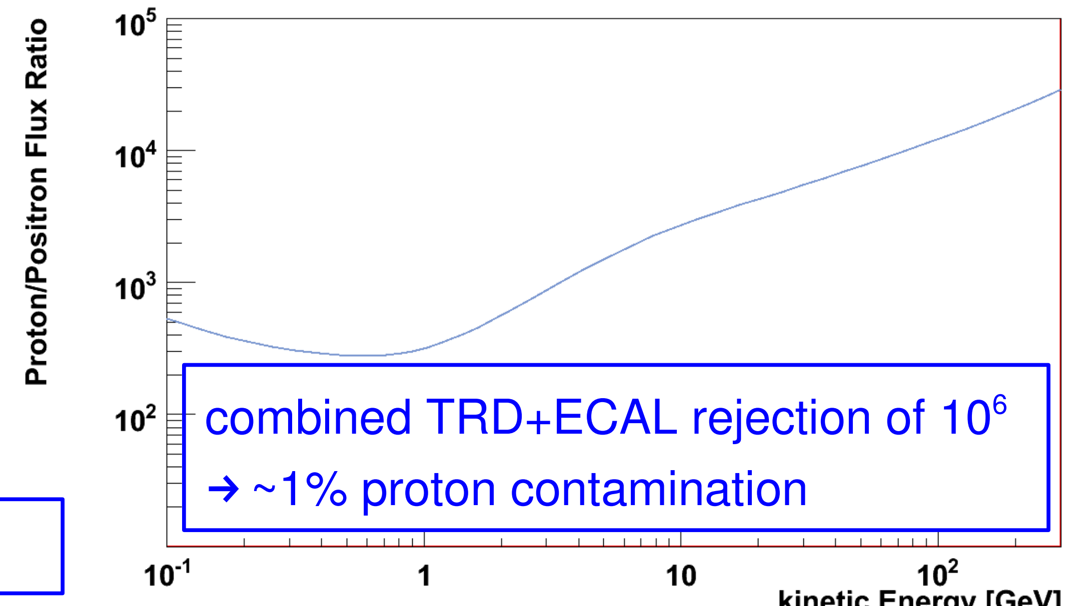
for details see poster by Thomas Kirn

TRD performance: positron/proton separation

Analysis of TRD prototype testbeam data







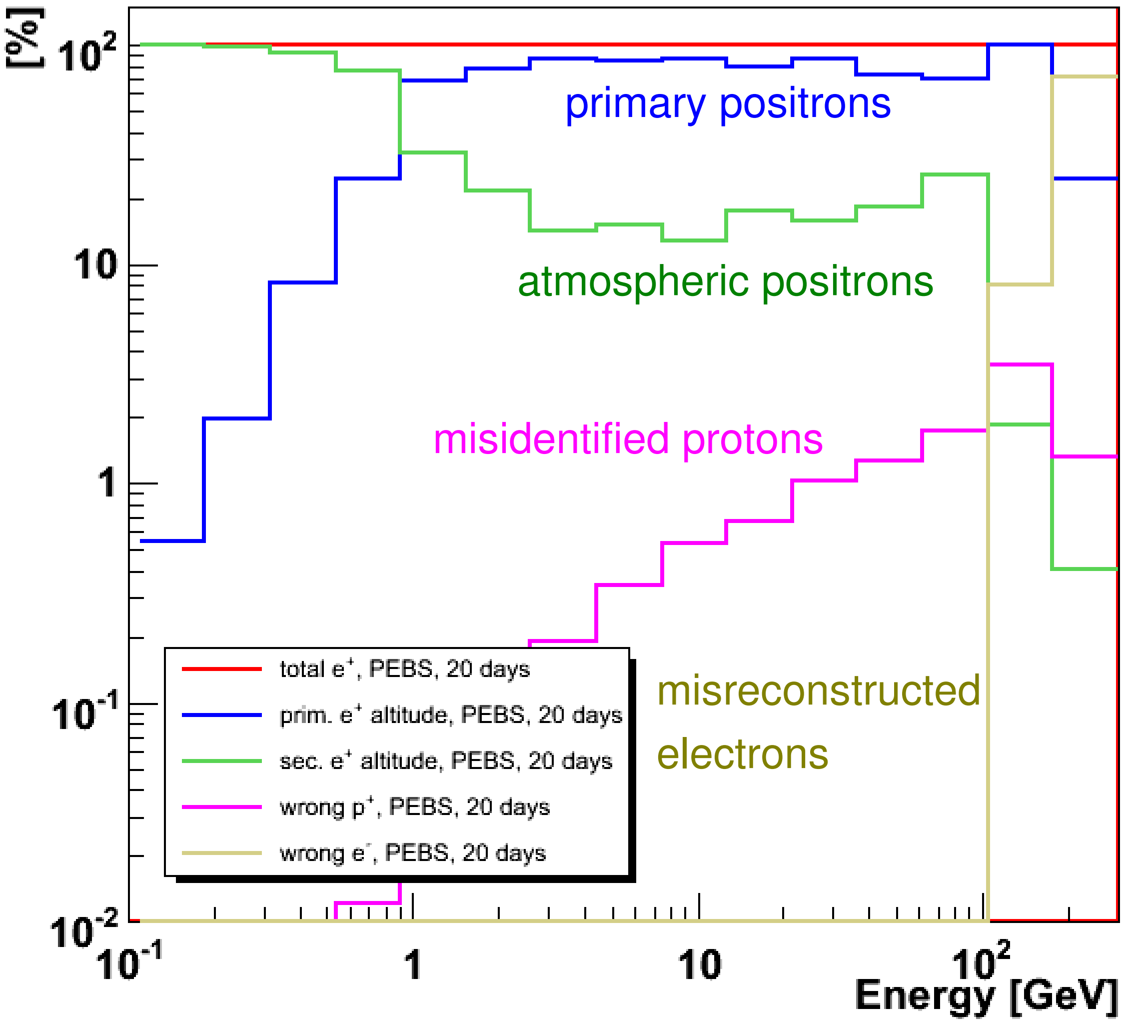
proton rejection ~1000

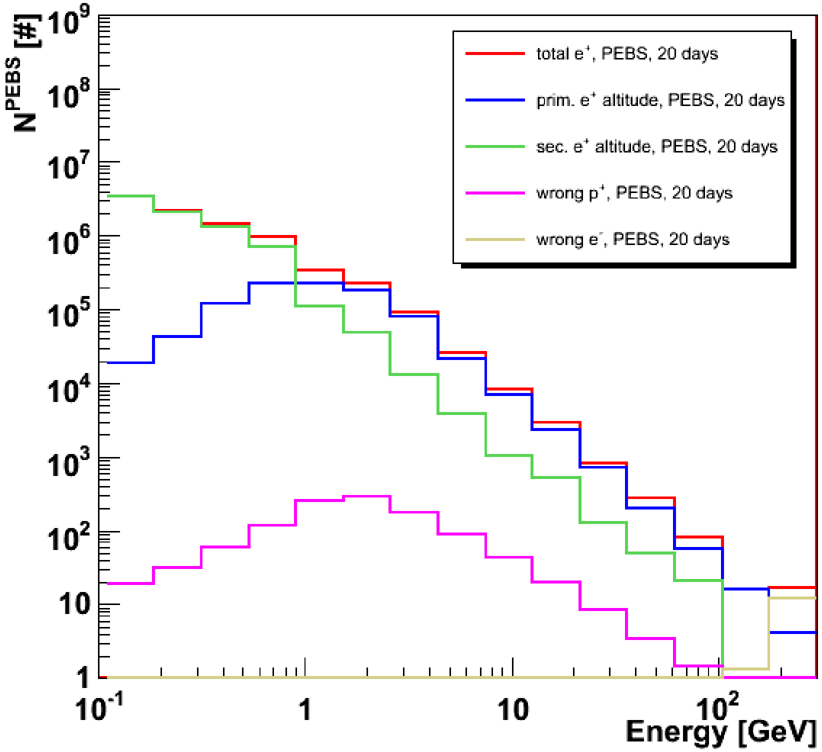
Conclusion

- 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
- 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

Background contributions

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

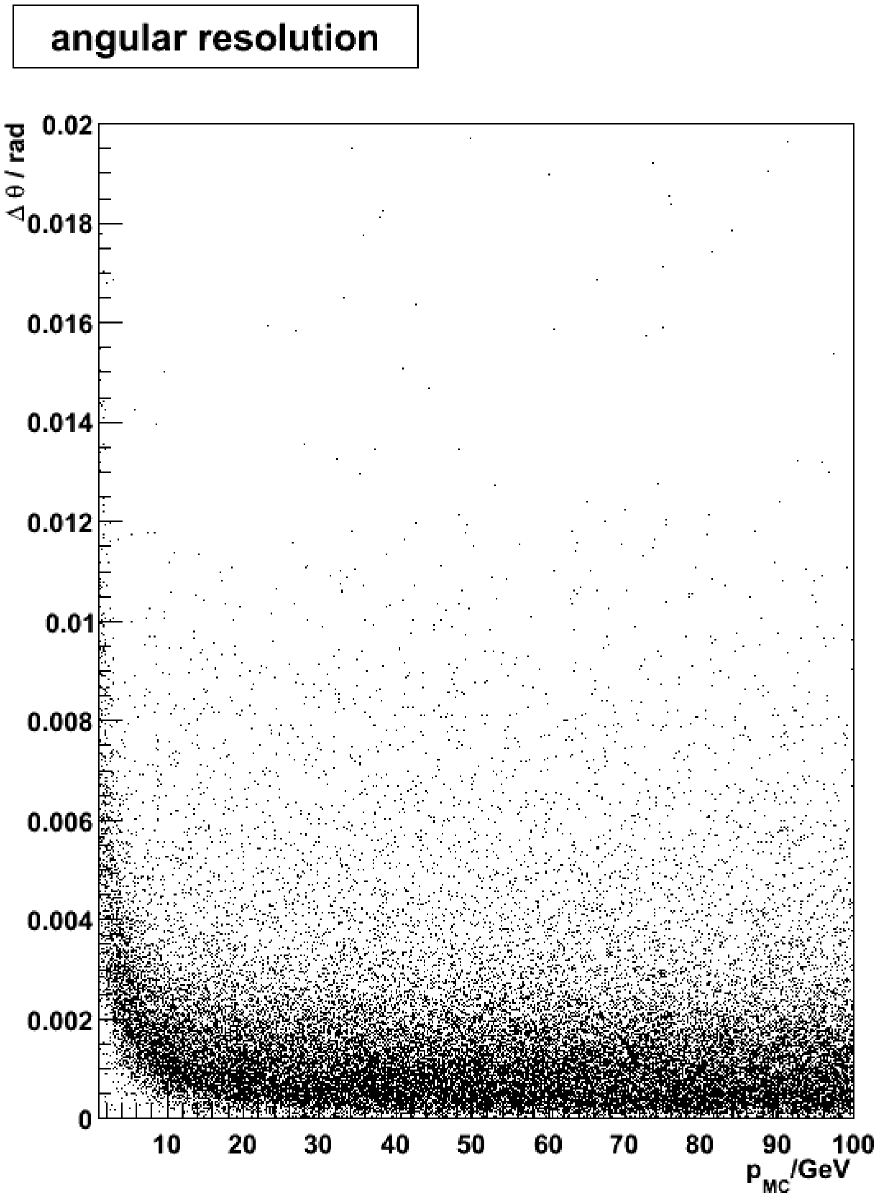


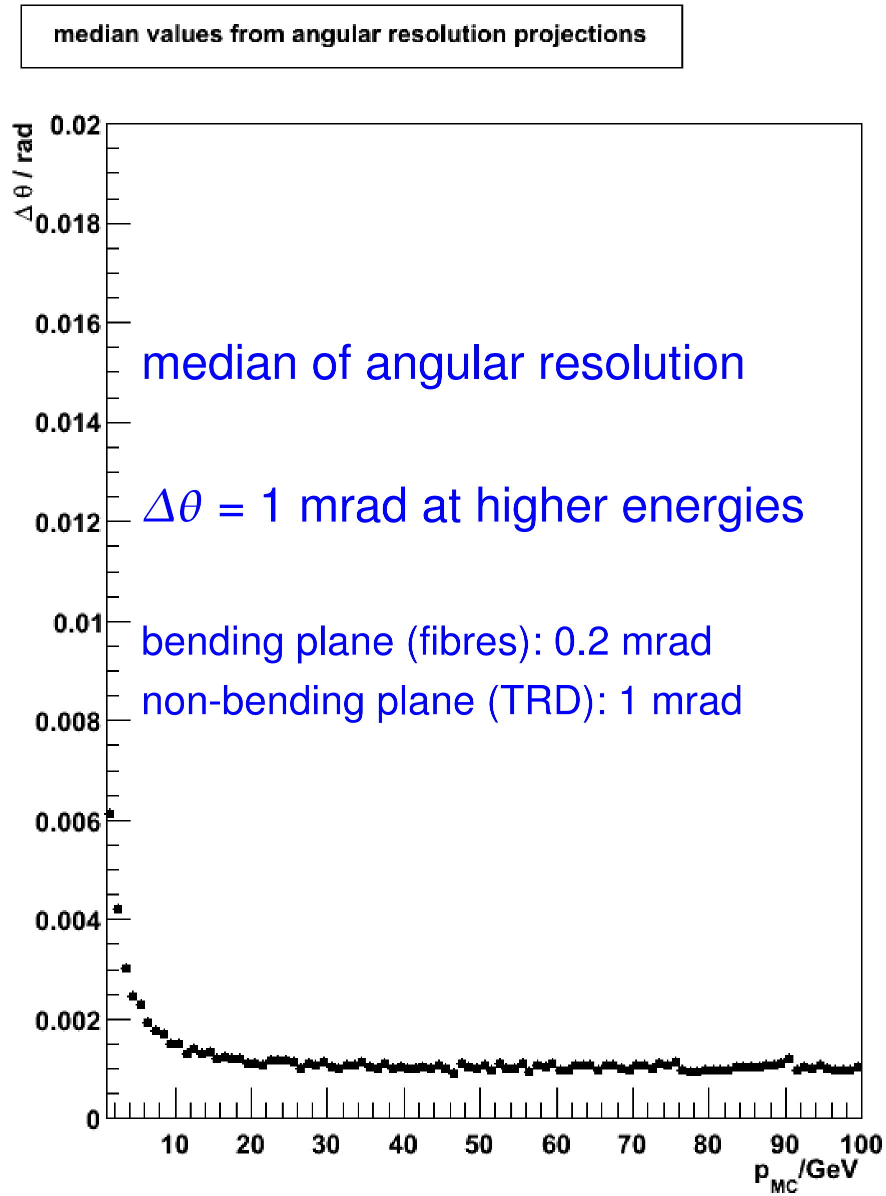


contributions in absolute numbers for 20-day flight for efficiency = 50%

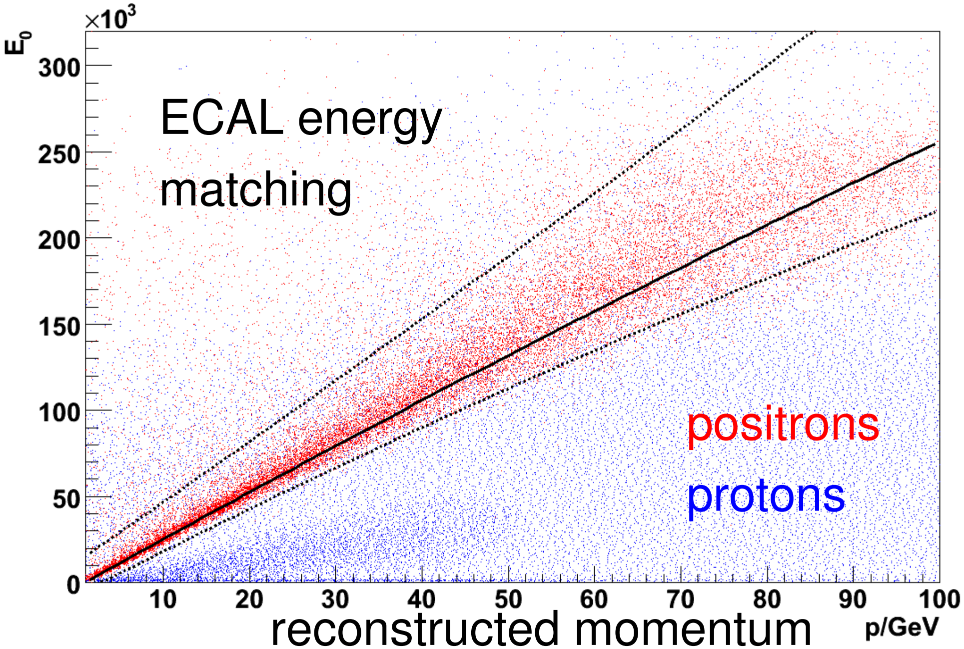
composition of positron component according to PLANETOCOSMICS simulation of atmospheric background and contributions from p/e- misidentification

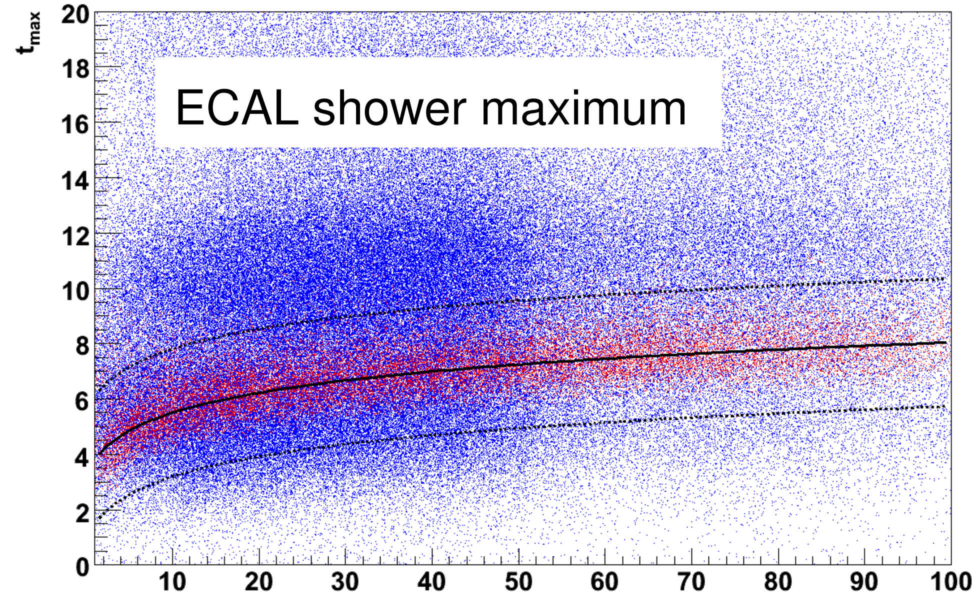
Tracker performance: Angular resolution

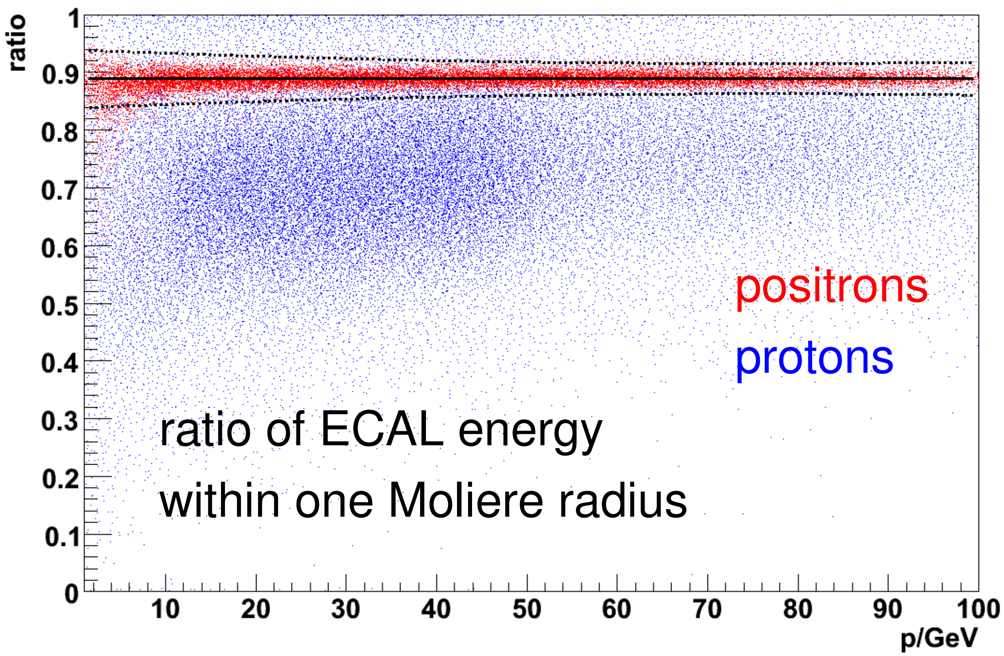


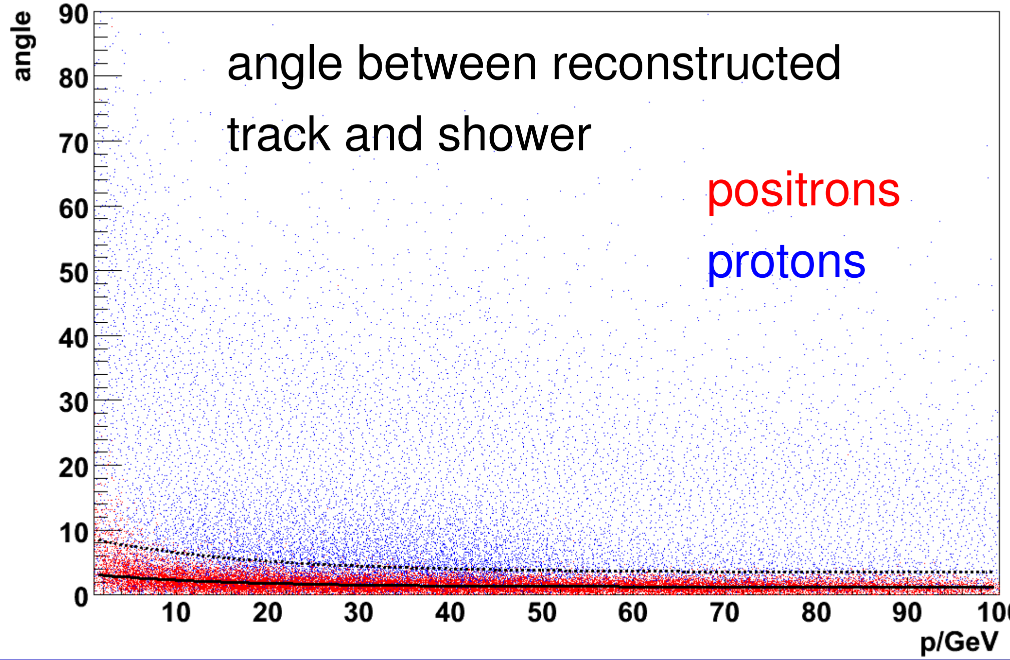


ECAL performance



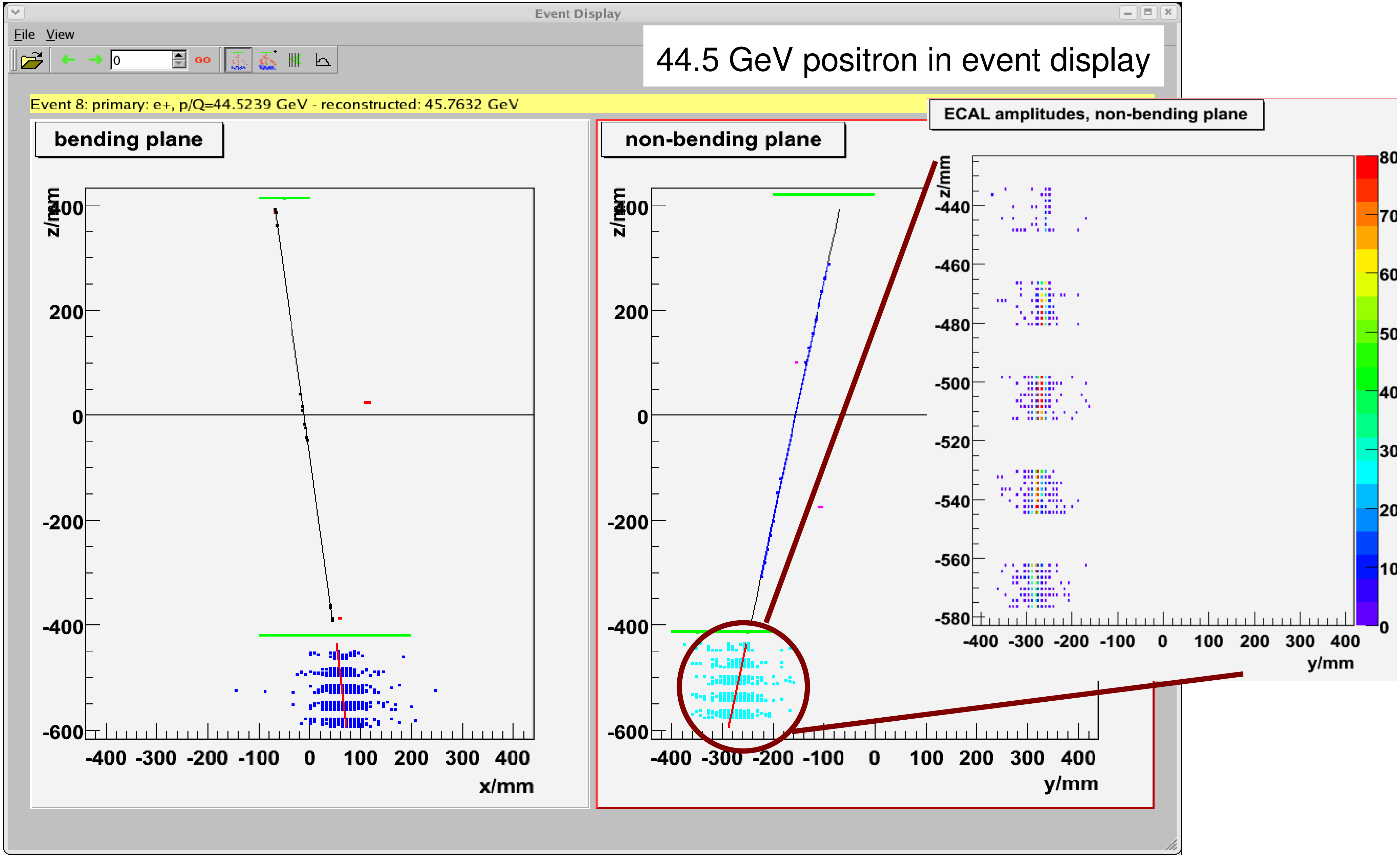




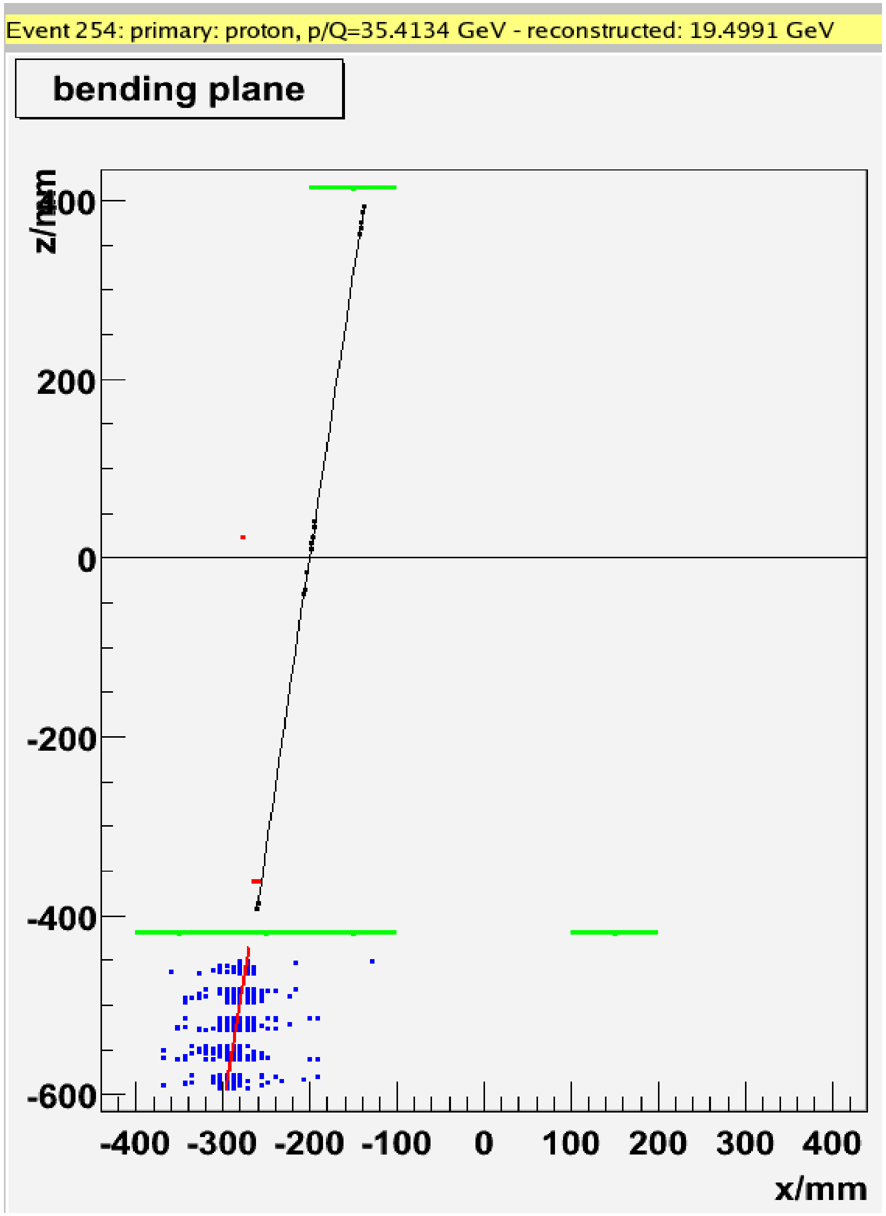


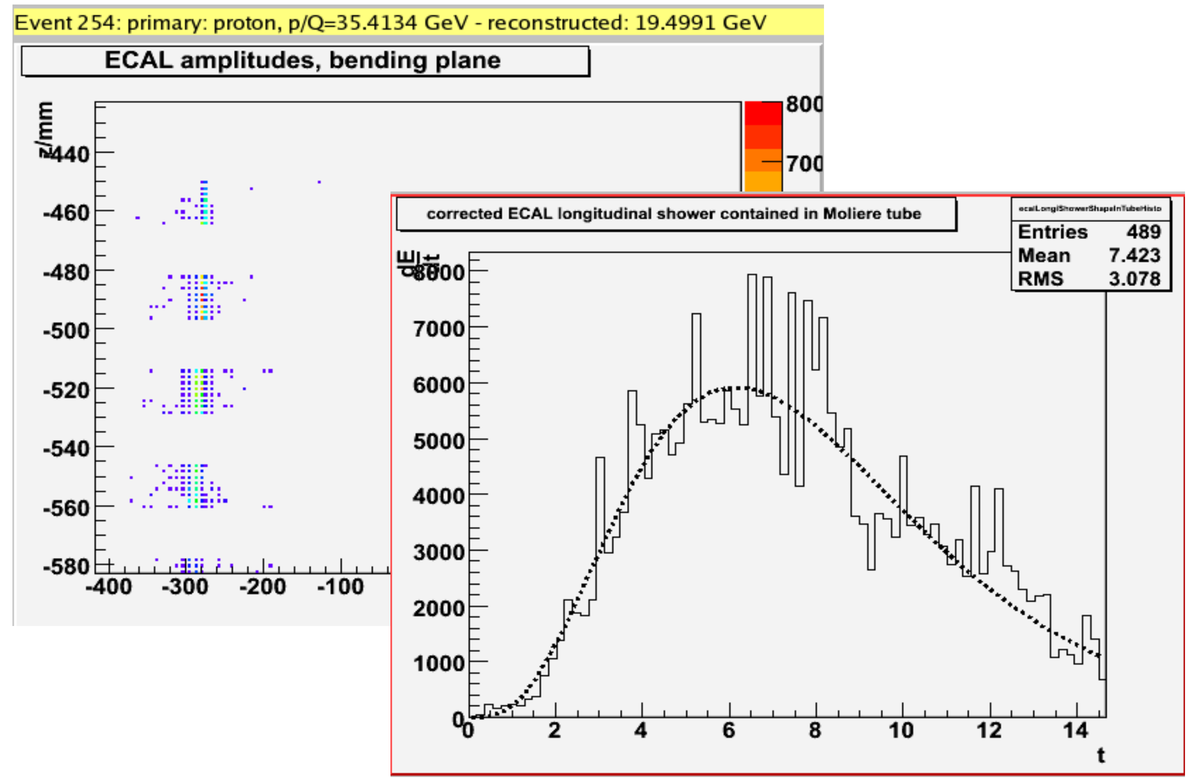
Example event

44.5 GeV positron in event display



Intrinsic limits on rejection (2nd example)





example event:

p →p π^0 X before last tracker layer

generated: p_{gen}=35.4 GeV

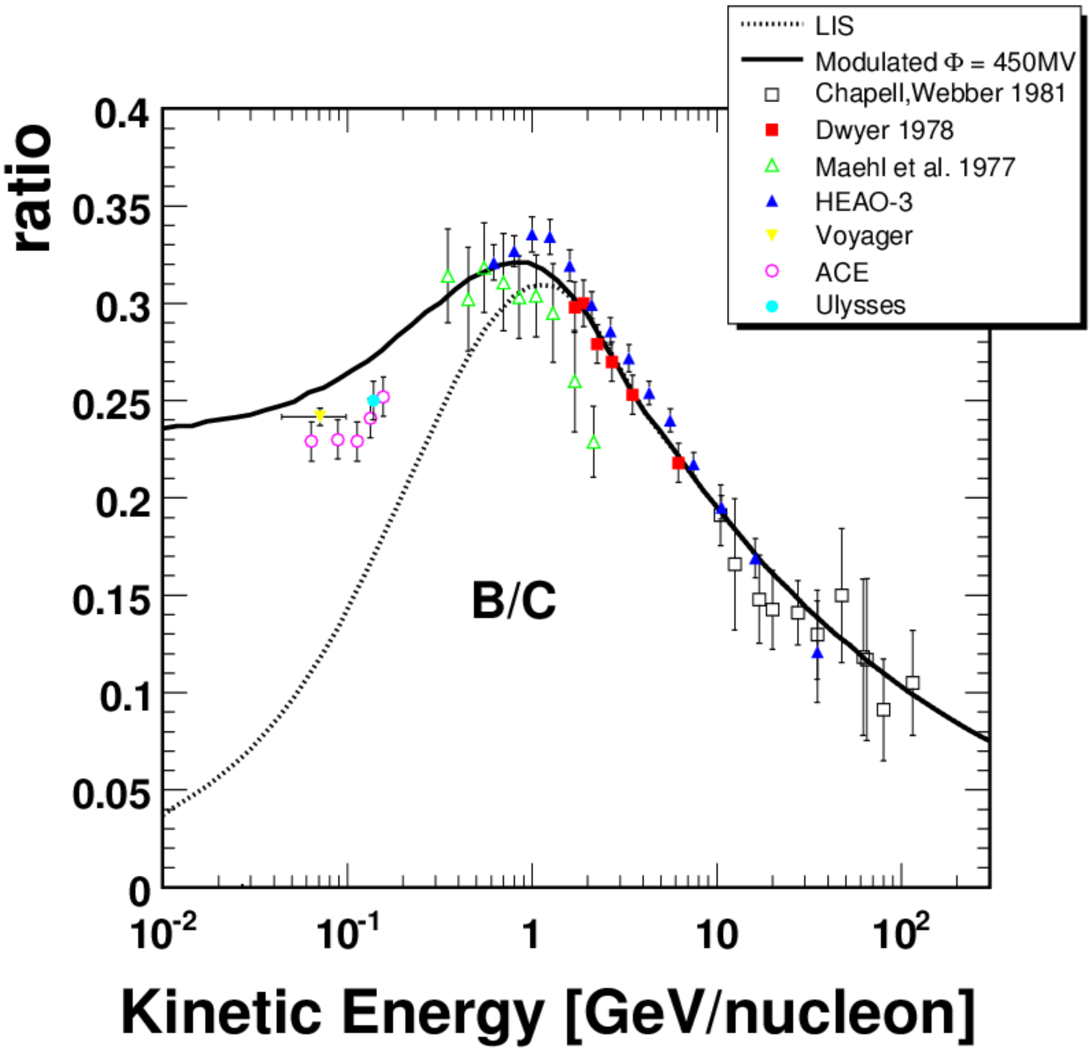
π^0 momentum: 18.9 GeV → $\gamma\gamma$ → e.m. shower

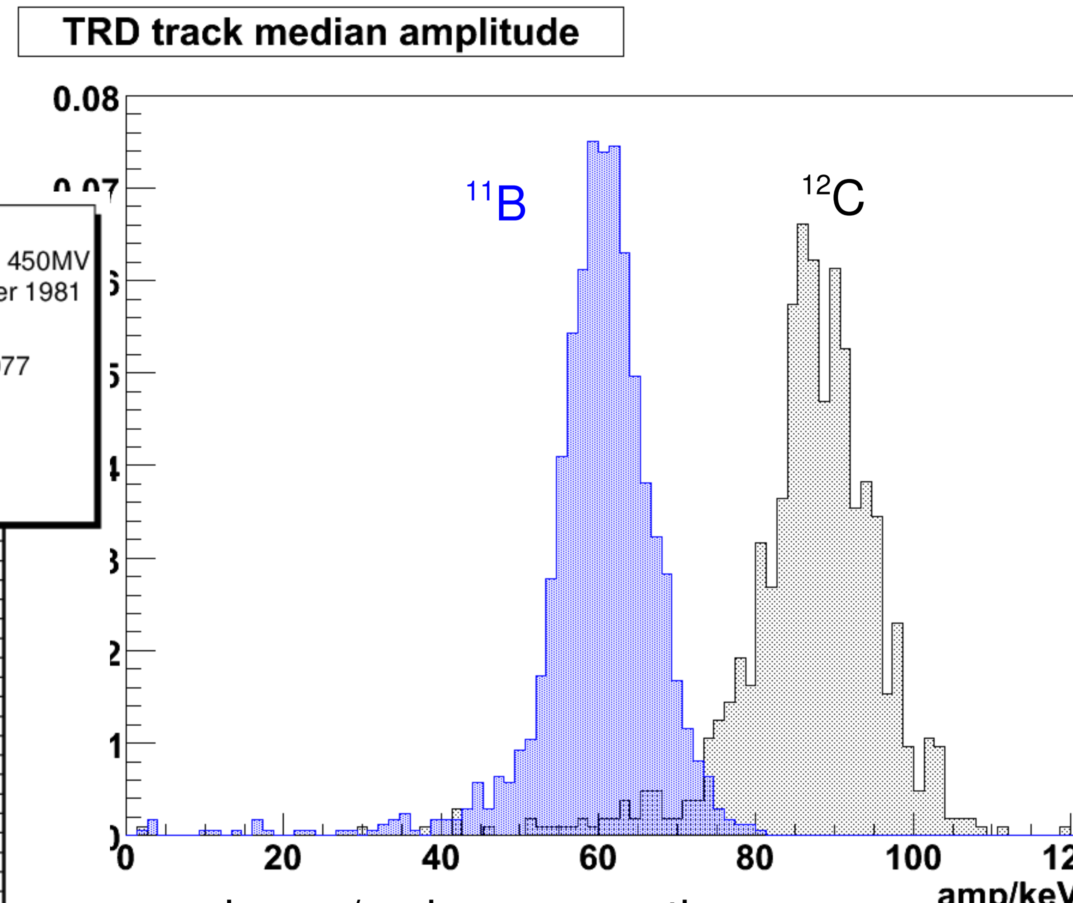
reconstructed: p_{reco}=19.5 GeV

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