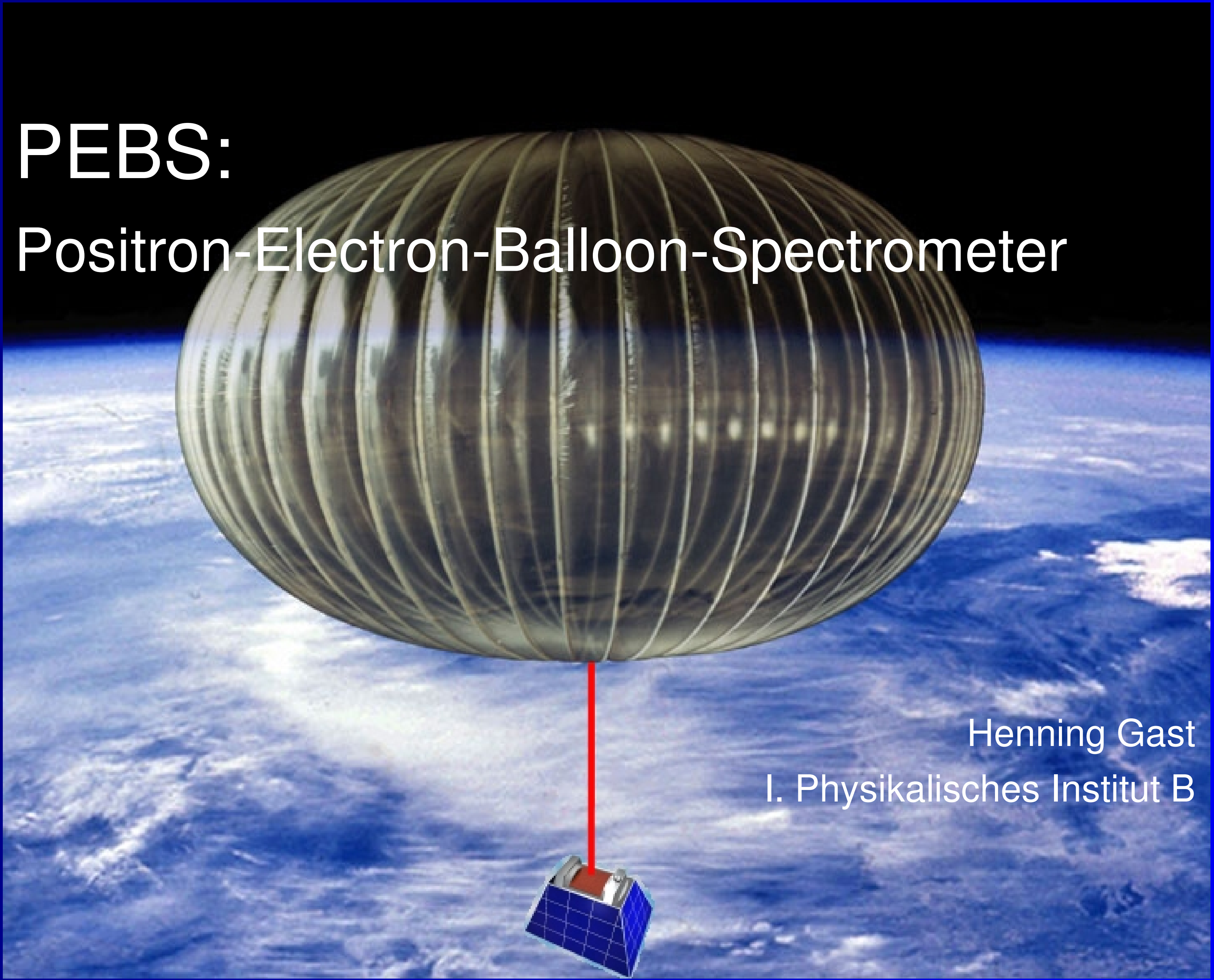
PEBS:

Positron-Electron-Balloon-Spectrometer



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I. Physikalisches Institut B

Berichtswoche zum GK “Elementarteilchenphysik an der TeV-Skala” - Bad Honnef, 27. August 2007

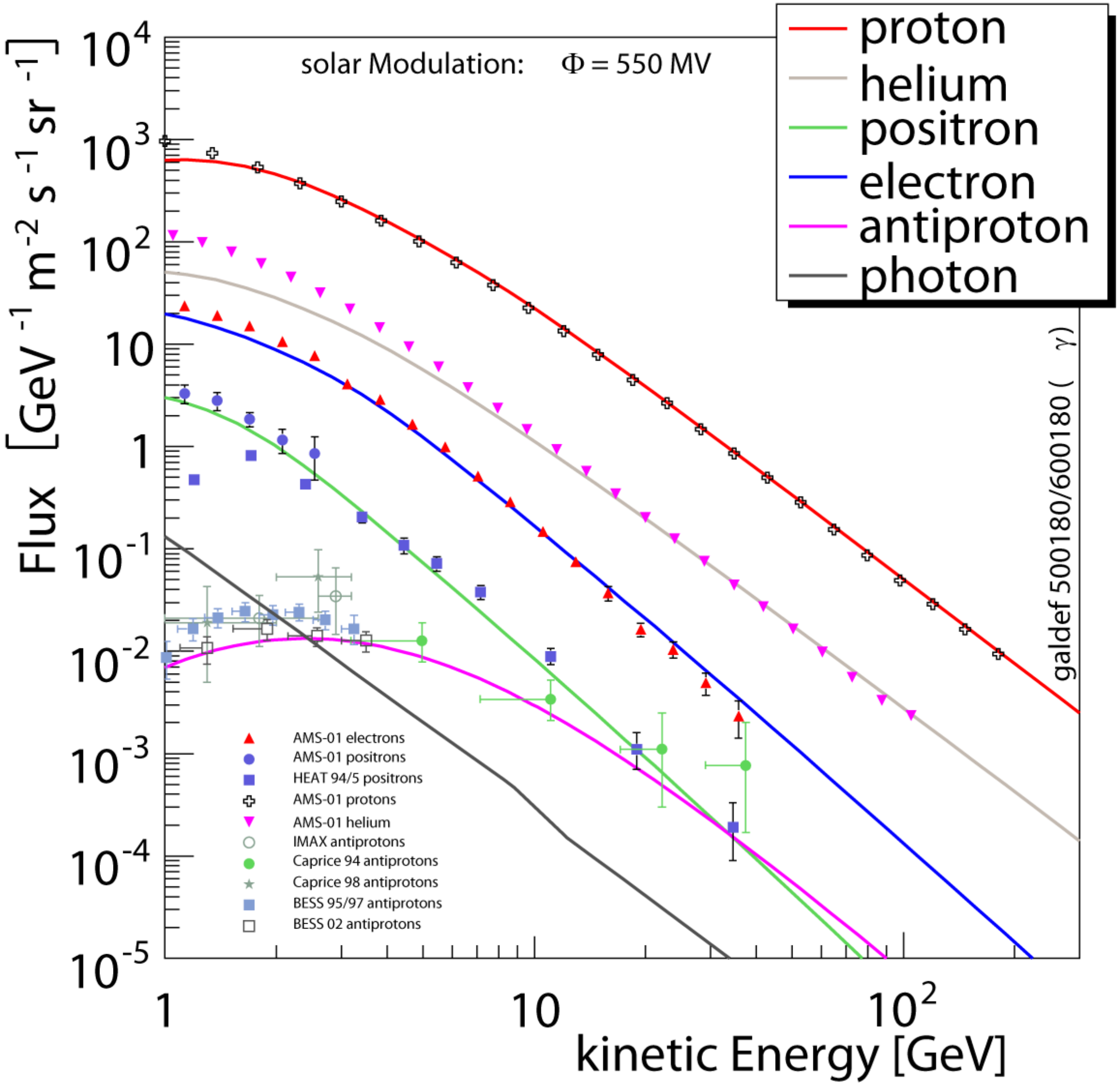
Introduction

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

Motivation: Indirect search for dark matter.

Requirements:

- Large geometrical acceptance:
  >1000 cm^2sr 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^2sr = 344 e^+/GeV

Prospective performance of PEBS detector

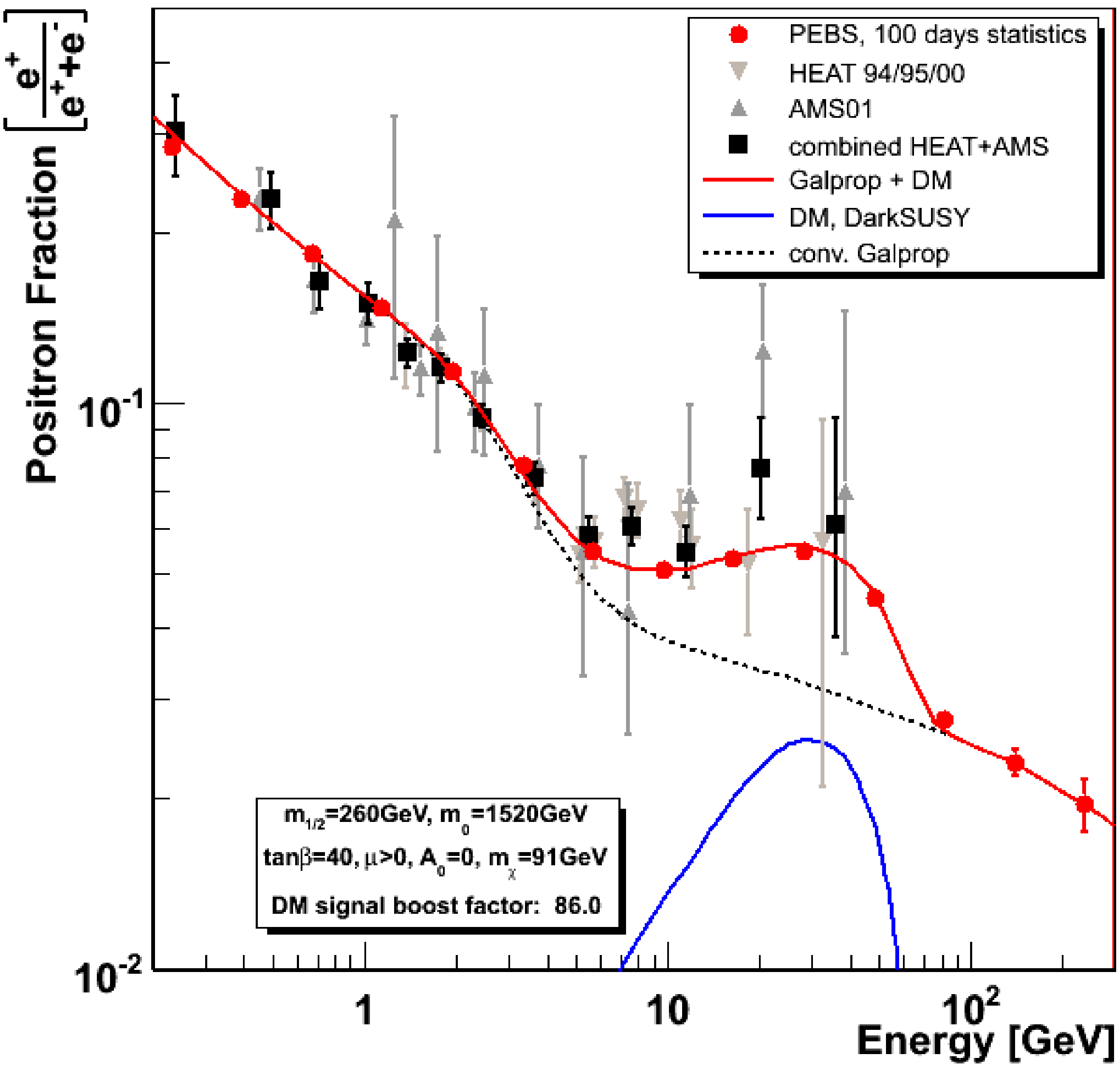
acceptance @100GeV and mission duration

PEBS	4000 cm²sr
	100 days
AMS02	800 cm²sr
	1000 days
PAMELA	20 cm²sr
	1000 days

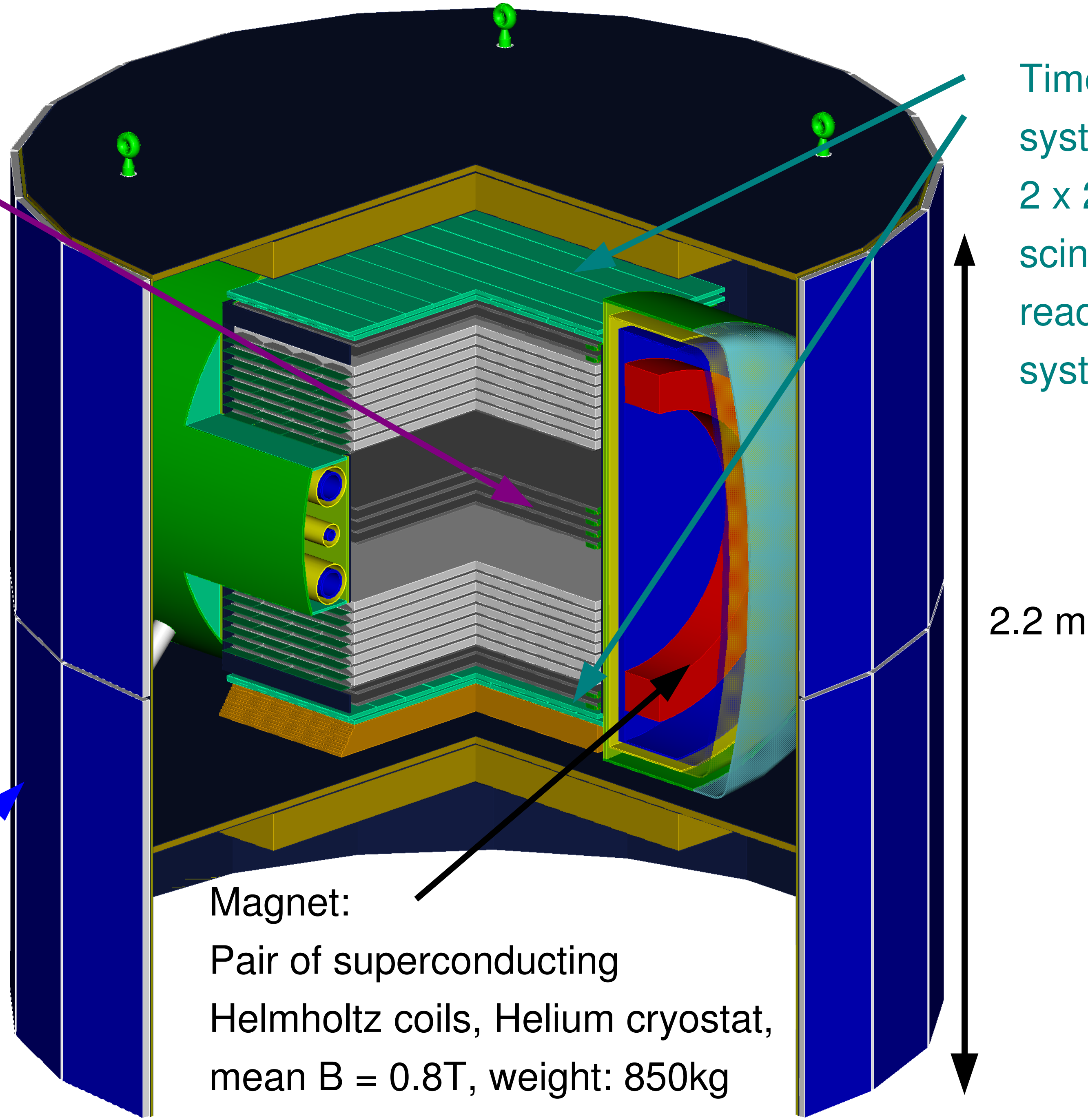
PEBS schedule

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 μm) with Silicon Photo-Multiplier (SiPM) readout; power: 260W

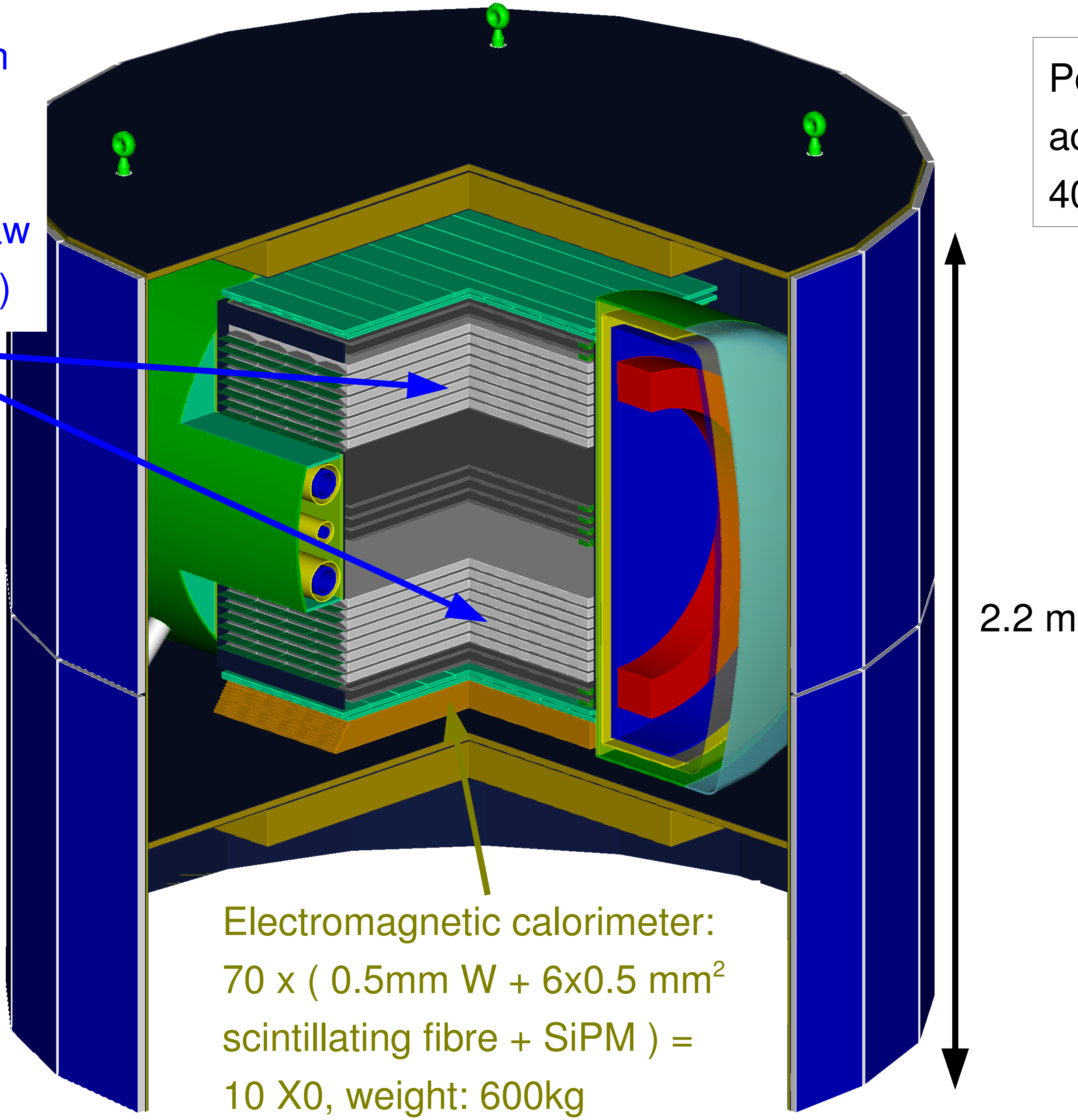
Time-of-Flight system (TOF):
2 x 2 x 5 mm scintillator, SiPM readout; trigger system!

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

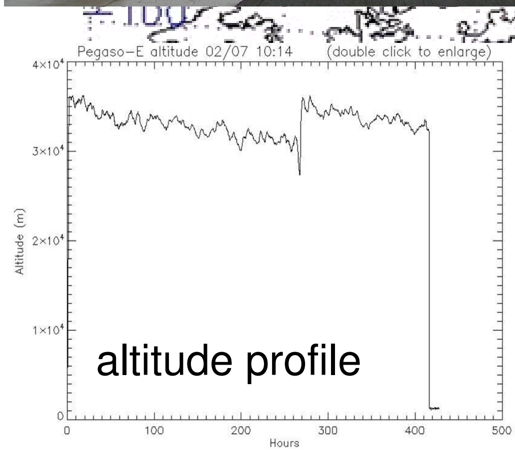
Transition Radiation Detector (TRD):
2 x 8 x (2cm fleece radiator + 6mm straw tube Xe/CO_2 80:20)

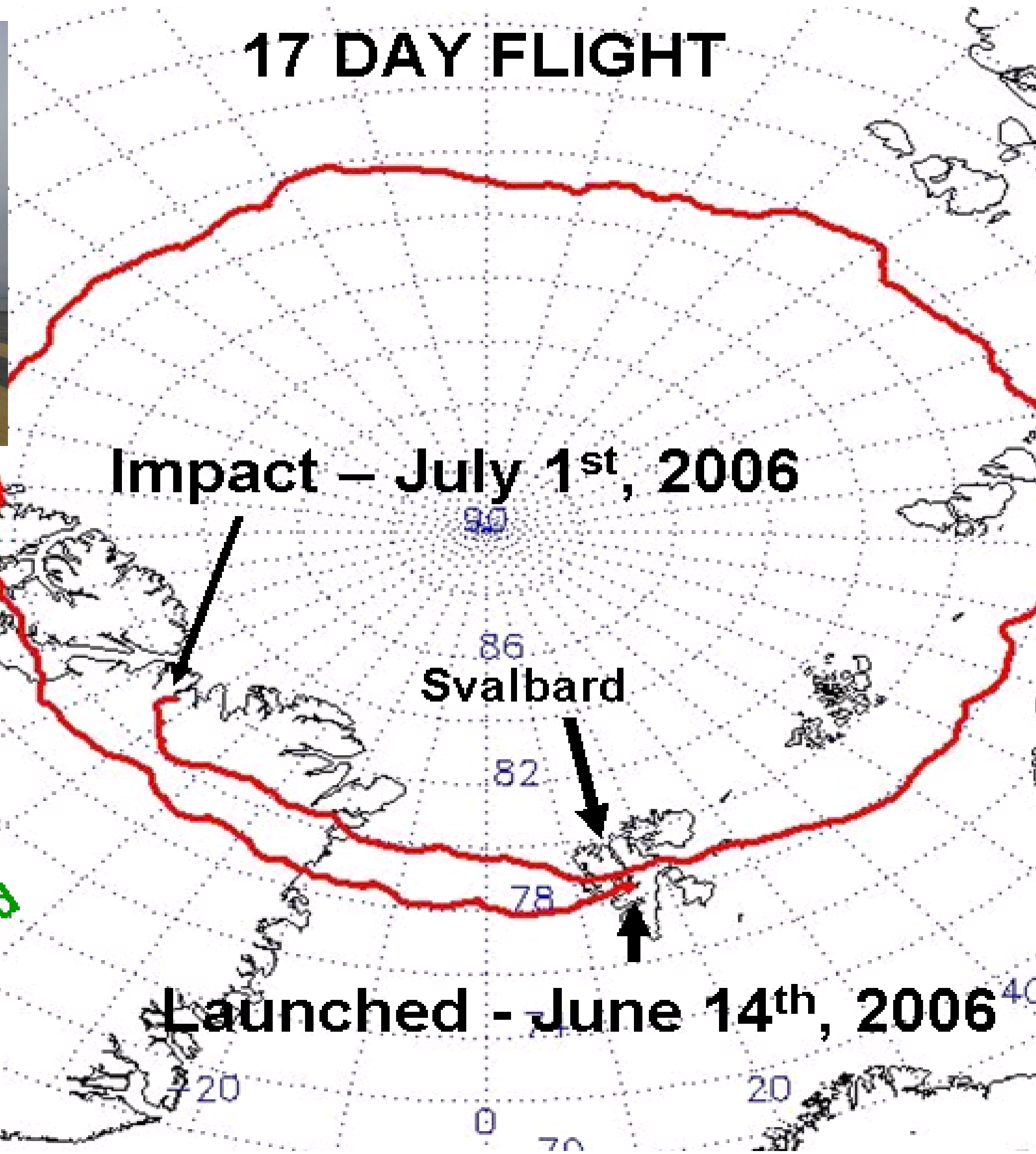


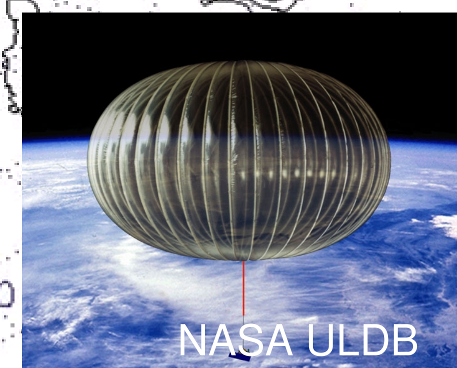
Positron acceptance:
4000 cm^2sr

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

Balloons



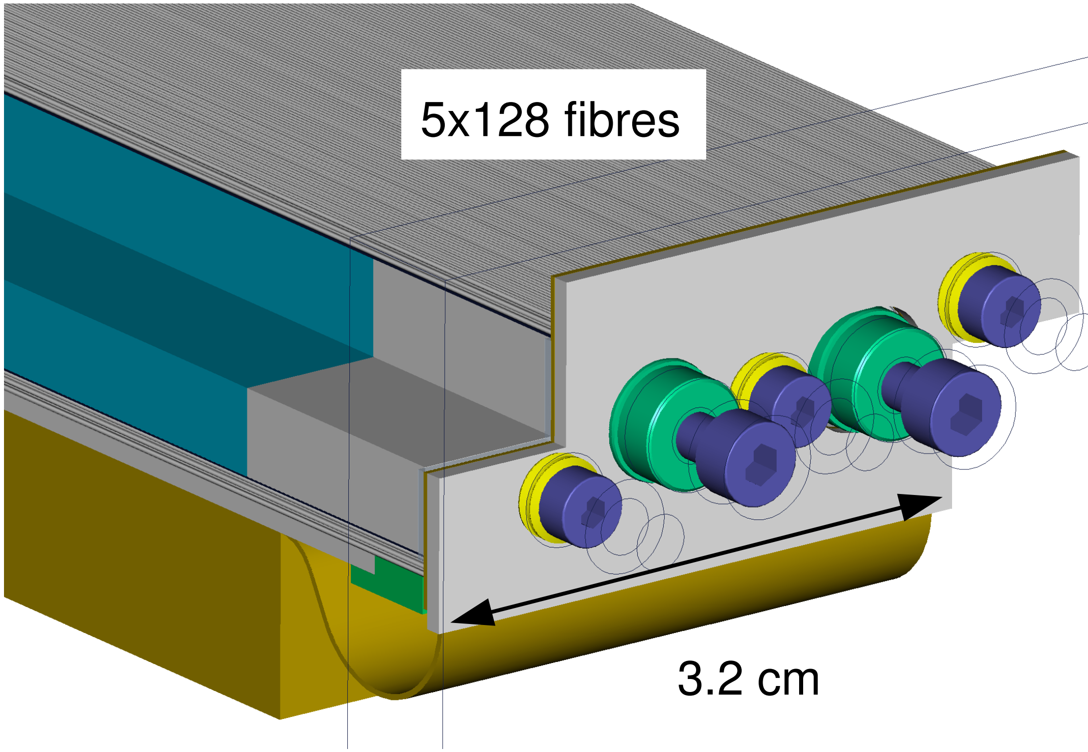


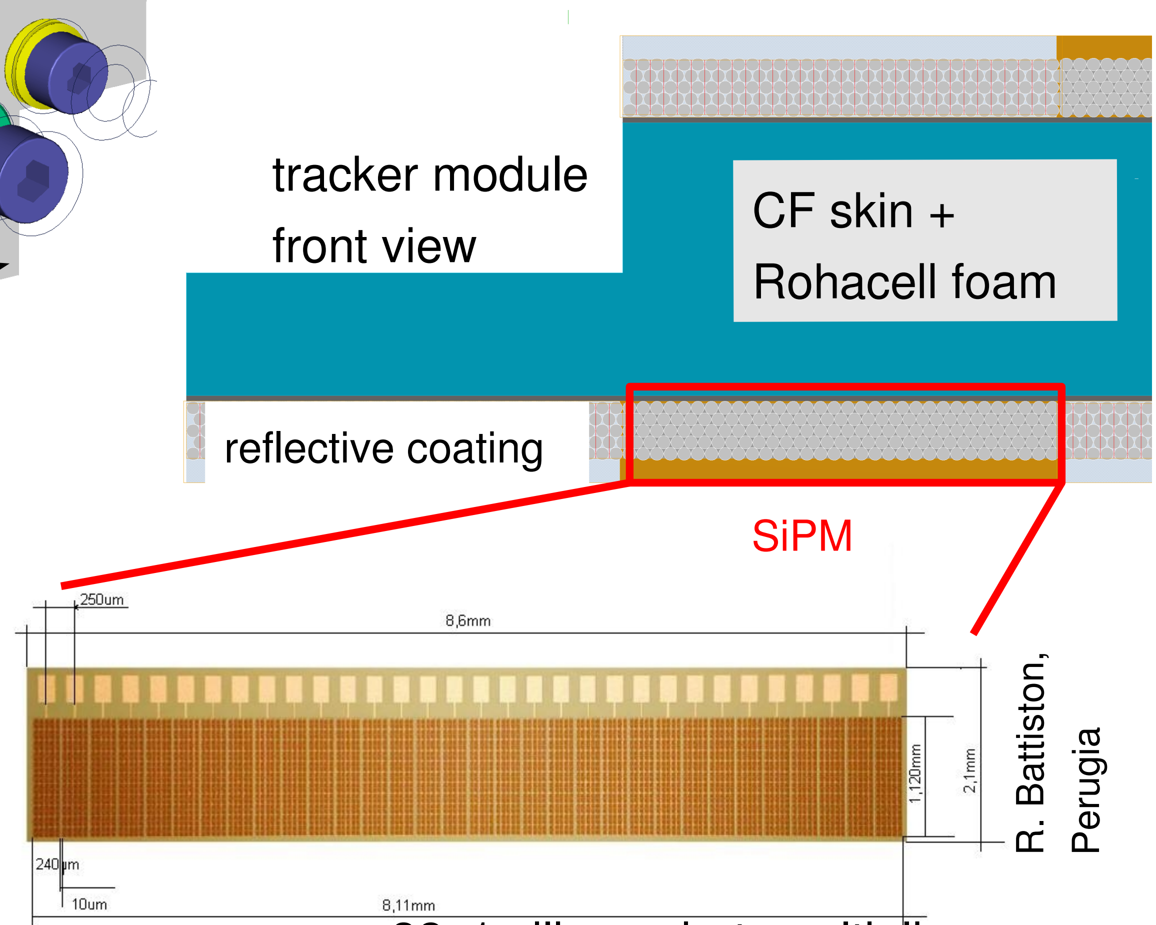


High-altitude (~40km), long-duration (~20 days) balloon flights from Svalbard ballonport (ASI)

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

Tracker modules





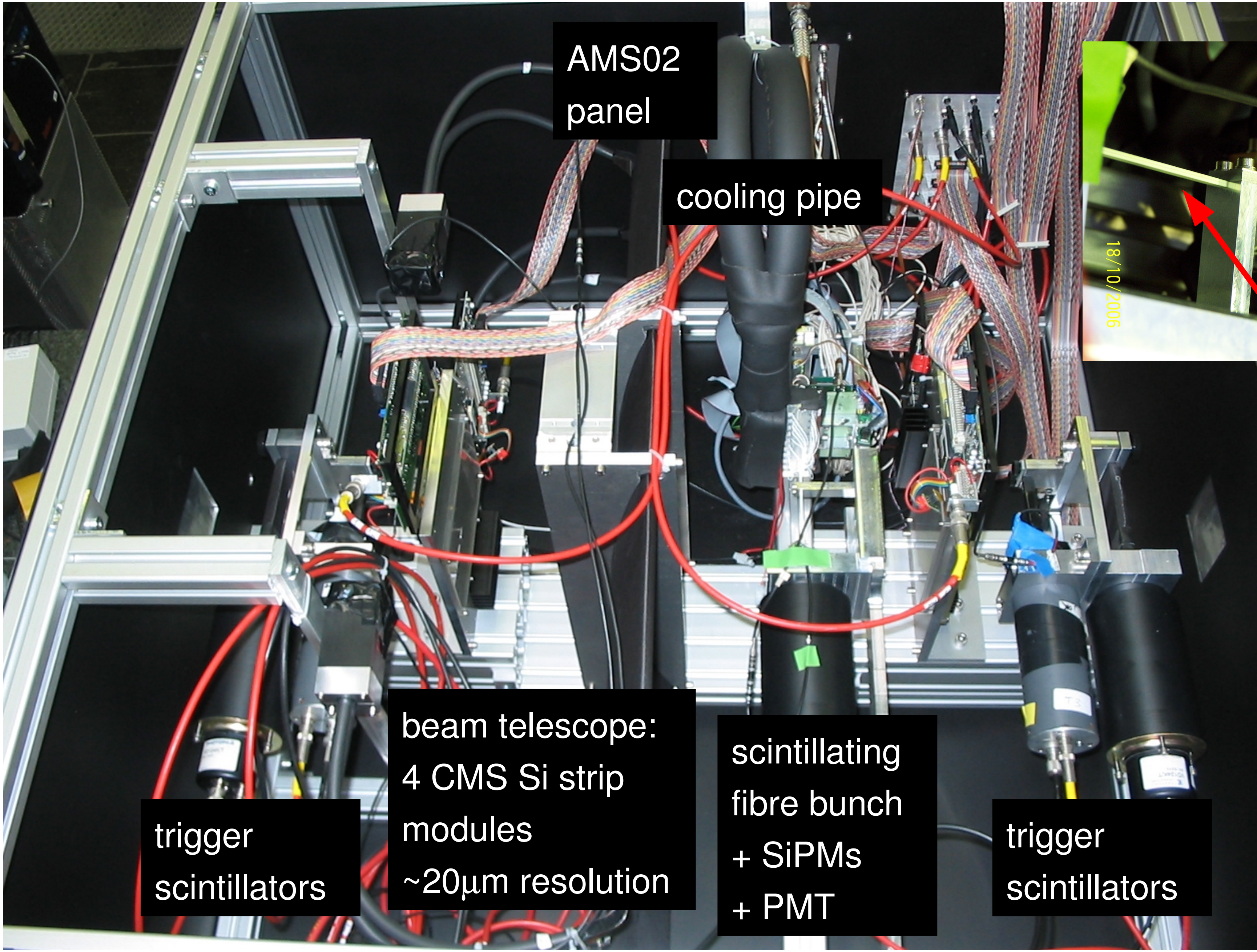
32x1 silicon photomultiplier

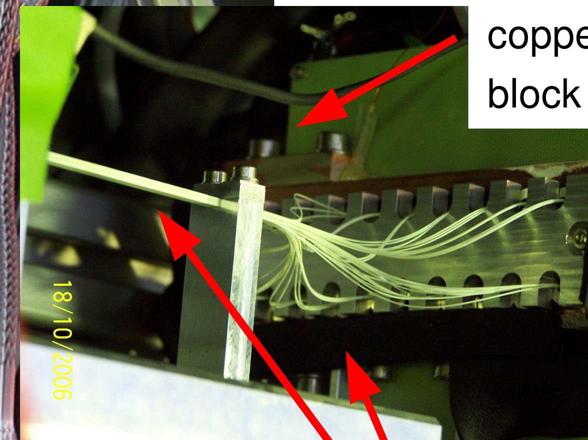
250µm strip width, 100 pixels/SiPM

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

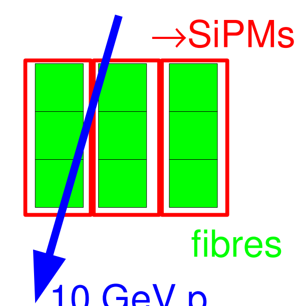
material budget: 12% X0
(6% X0 tracker + 6% X0 TRD)

PEBS fibre tracker testbeam setup

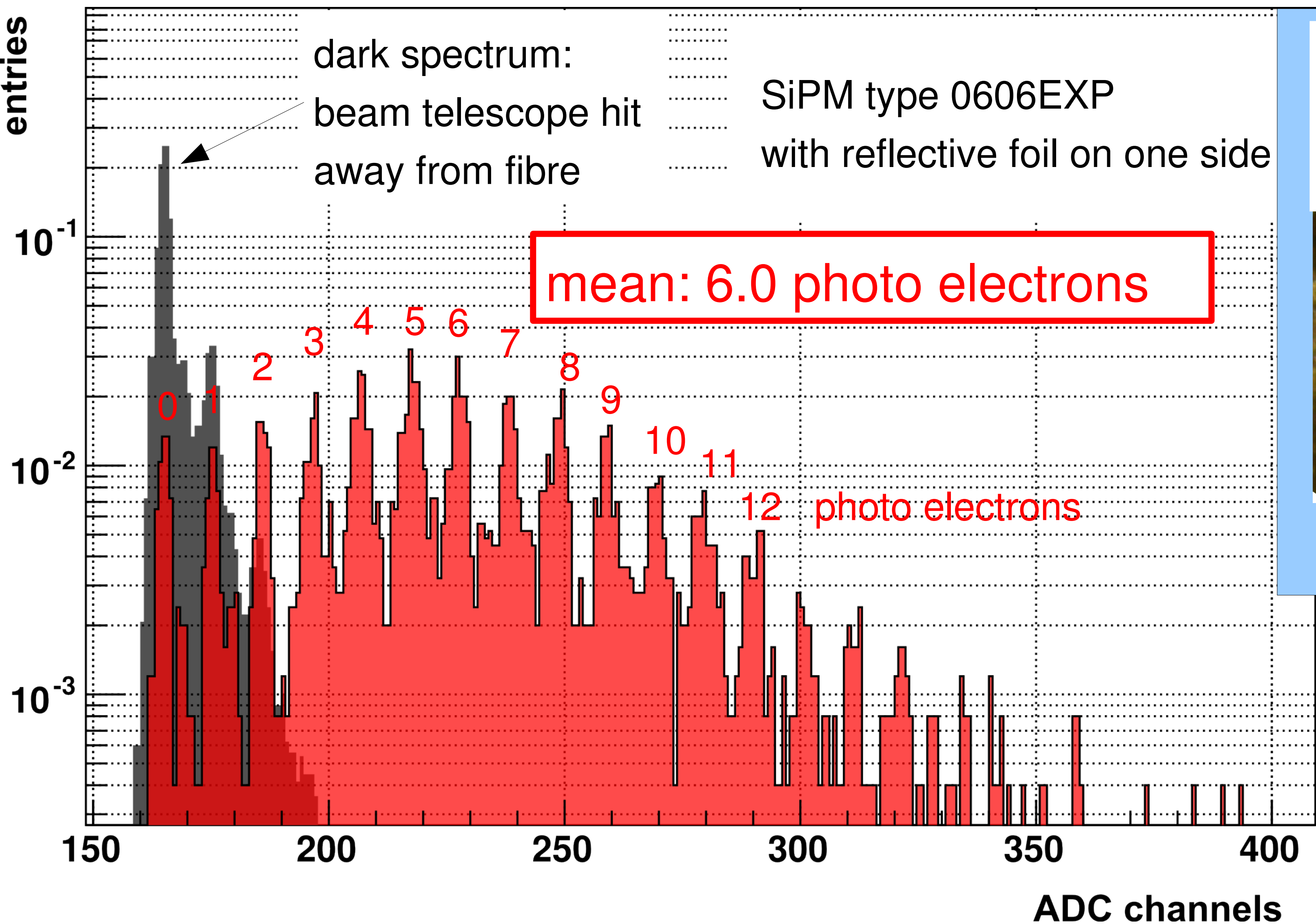


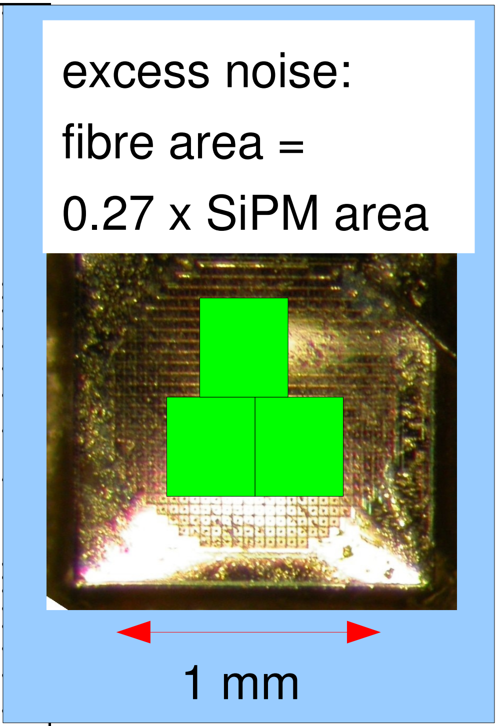


2 fibre bunches:
3x10 square fibres,
d=300 μm
3 fibres each to
SiPM in copper
block



SiPM: example of a MIP spectrum



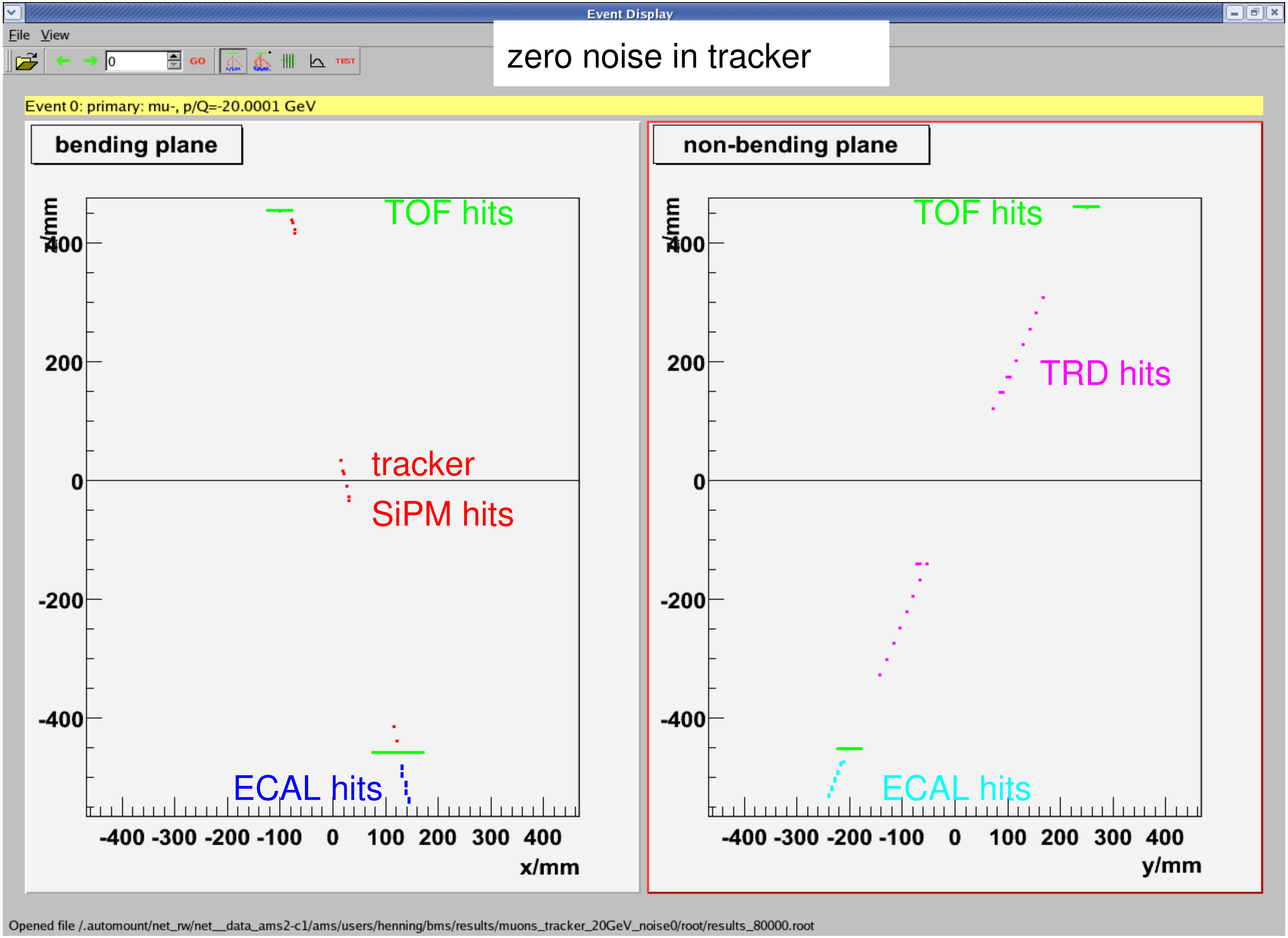


Photonique
SSPM 0606 EXP
S/N=20,
eff(0.5pe)=96%
SSPM 050701GR
S/N=100,
eff(0.5pe)=91%

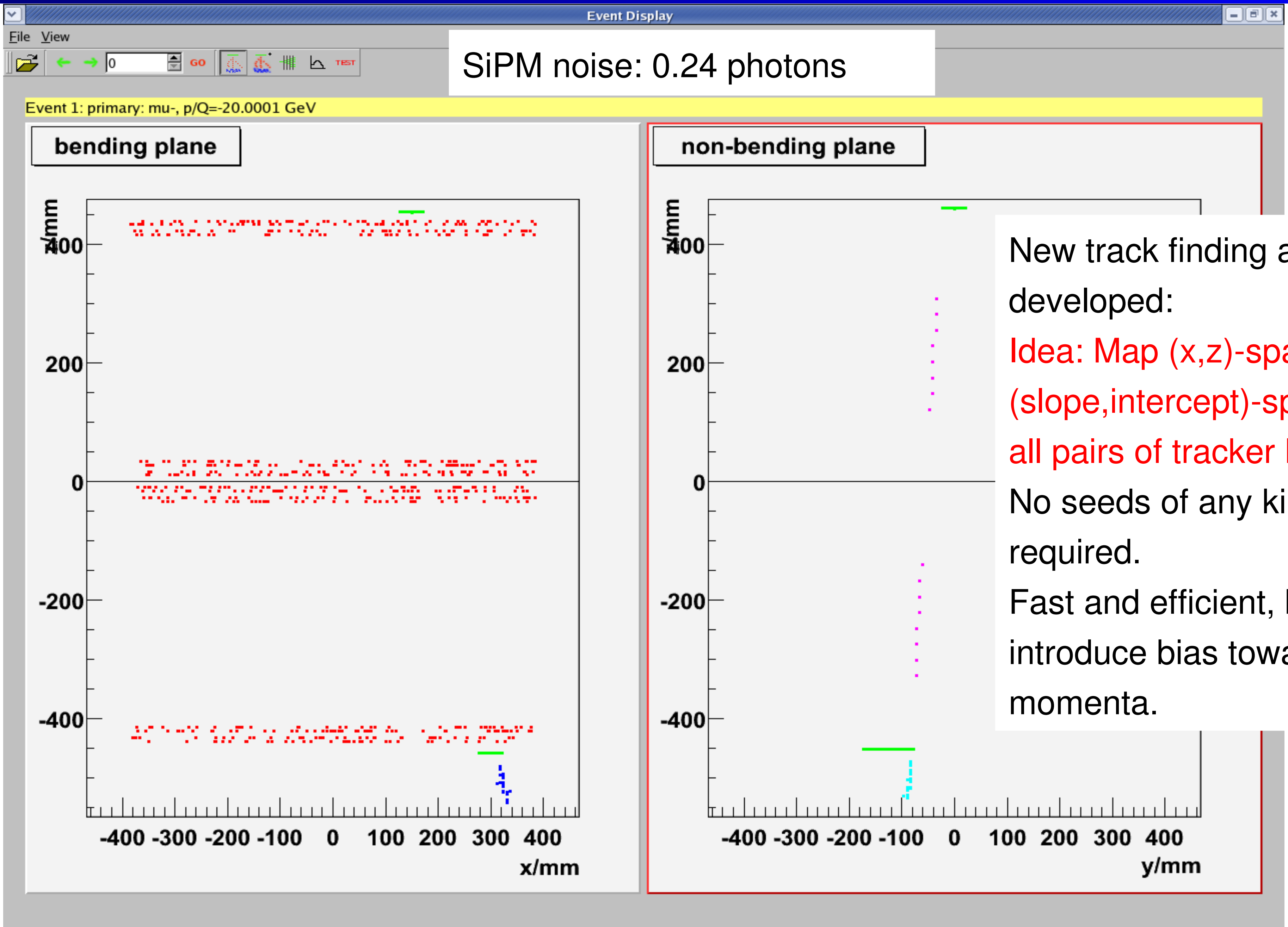
Testbeam results → PEBS MC simulation → muon momentum resolution: a=2.3%, b=0.194%/GeV

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

Problem: Track finding under SiPM noise conditions



Moderate SiPM noise



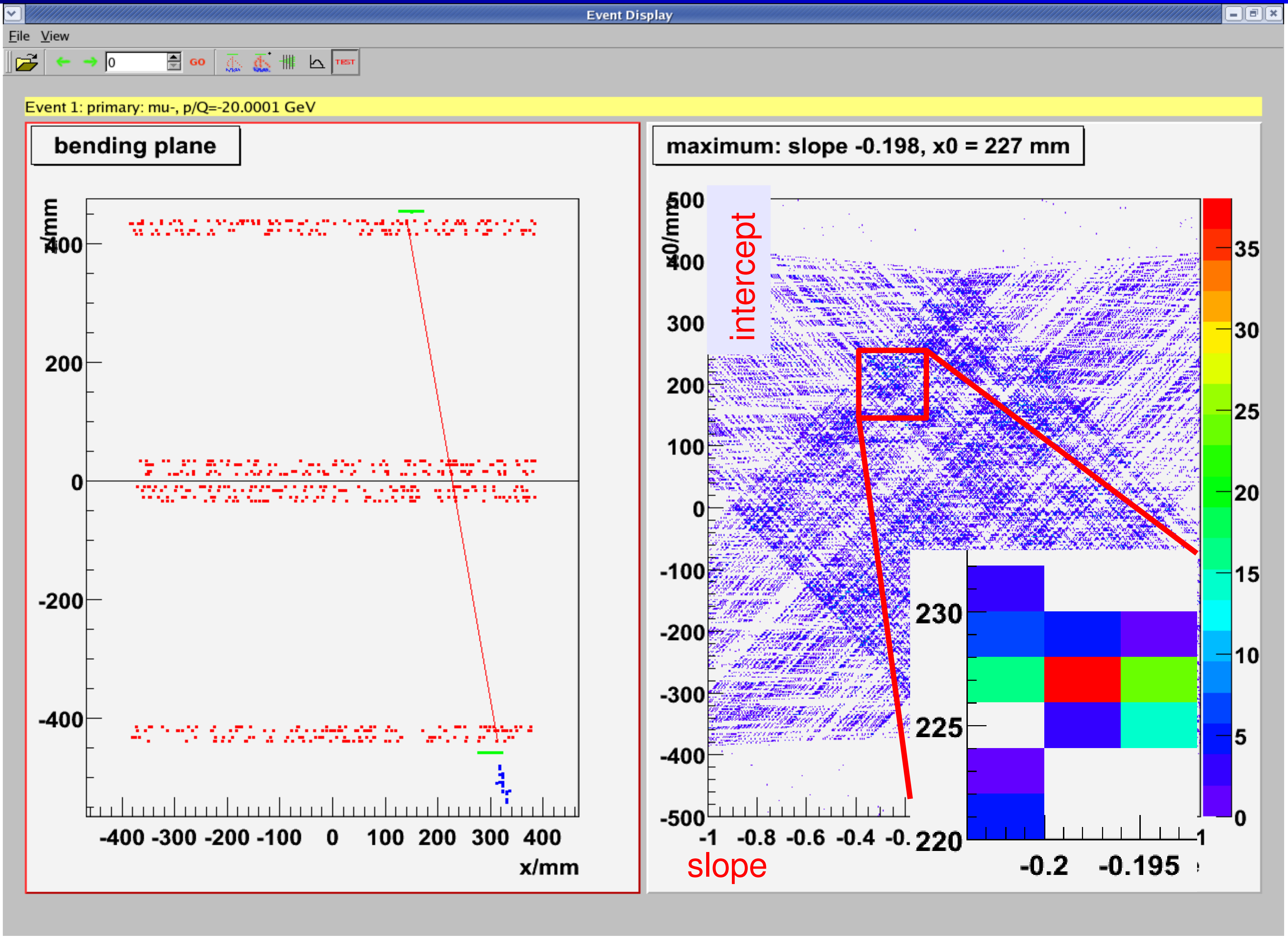
New track finding algorithm developed:

Idea: Map (x,z)-space to (slope,intercept)-space using all pairs of tracker hits.

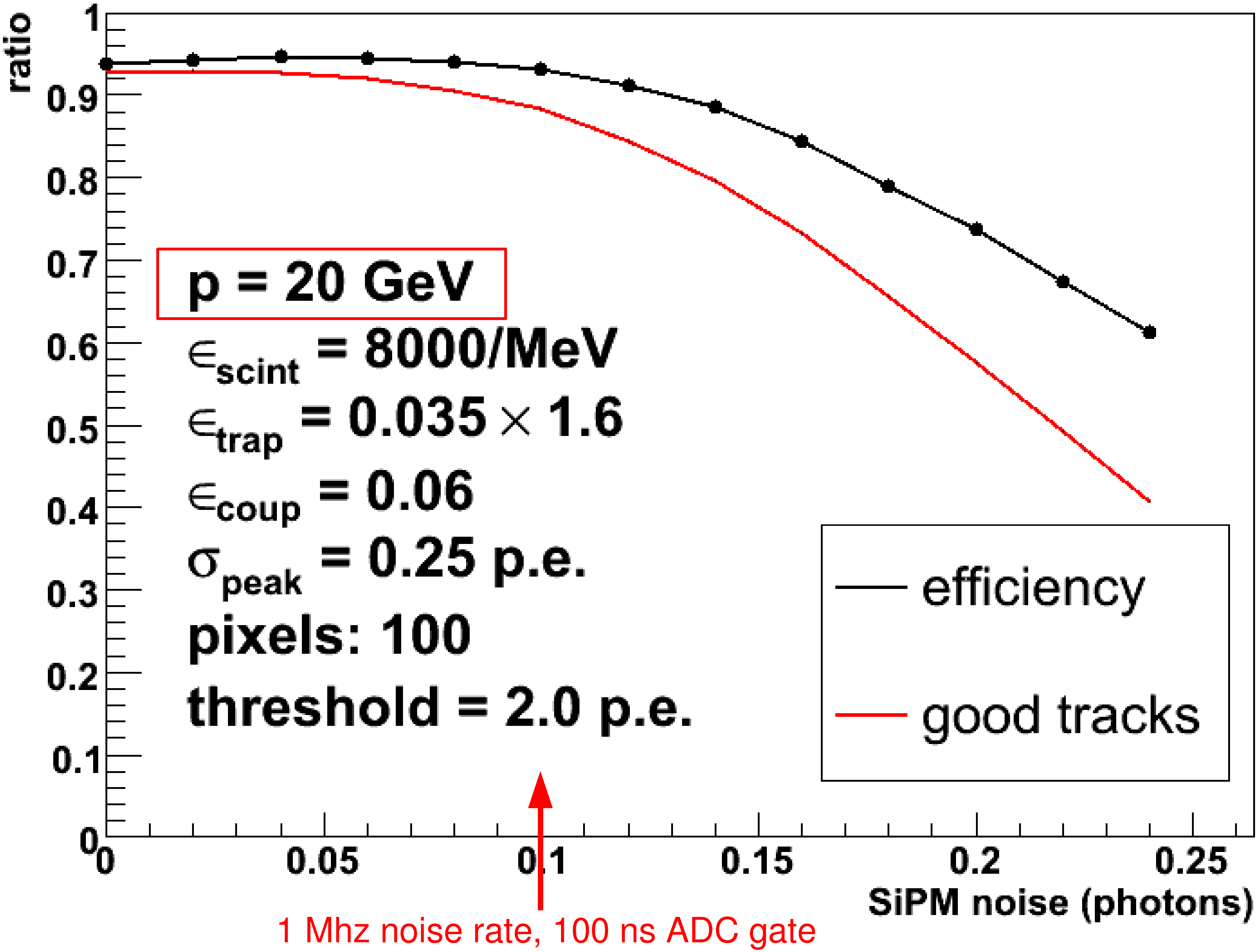
No seeds of any kind required.

Fast and efficient, but may introduce bias towards high momenta.

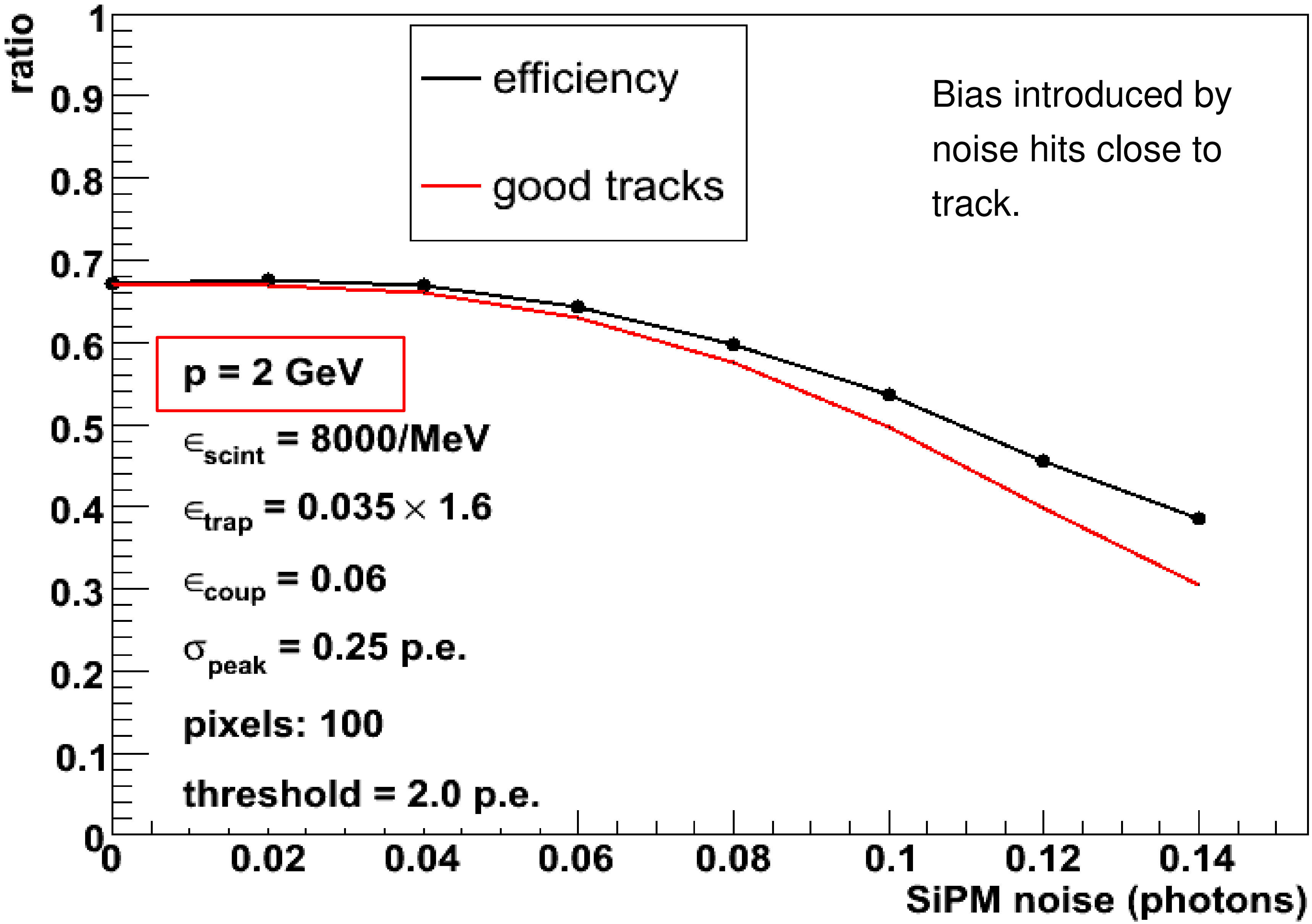
New seedless track finding algorithm



Track finding efficiency and fake rate

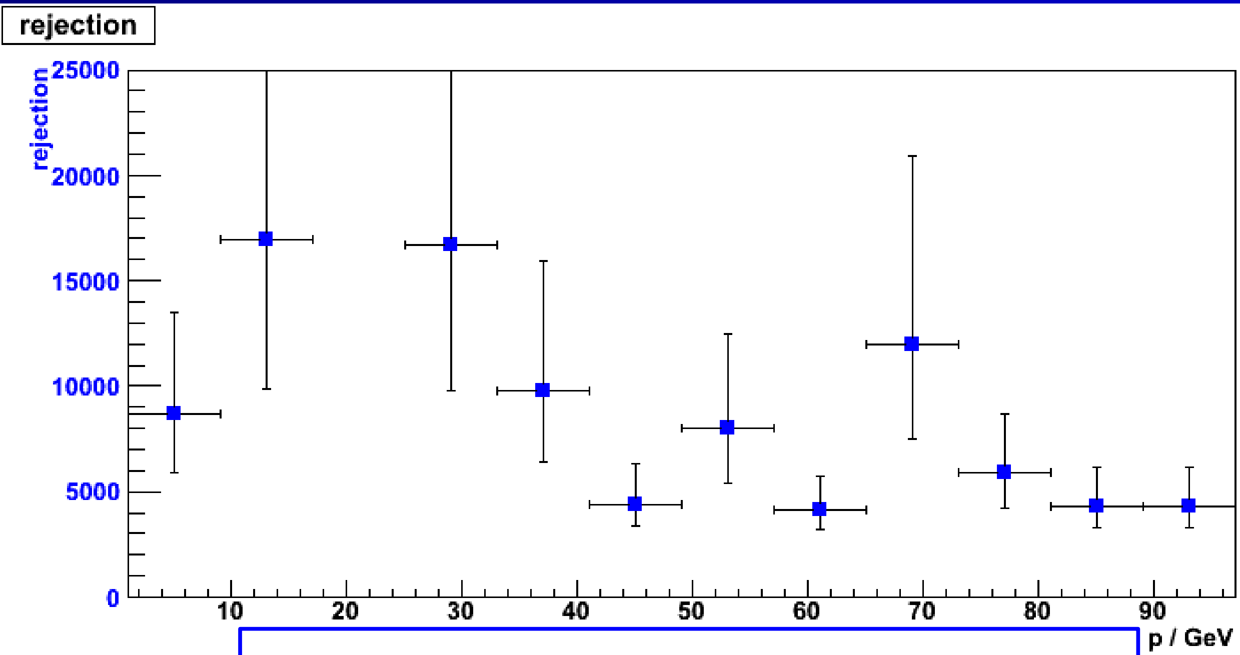


Low energy behaviour



Bias introduced by noise hits close to track.

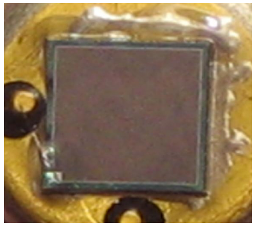
ECAL proton rejection and energy resolution



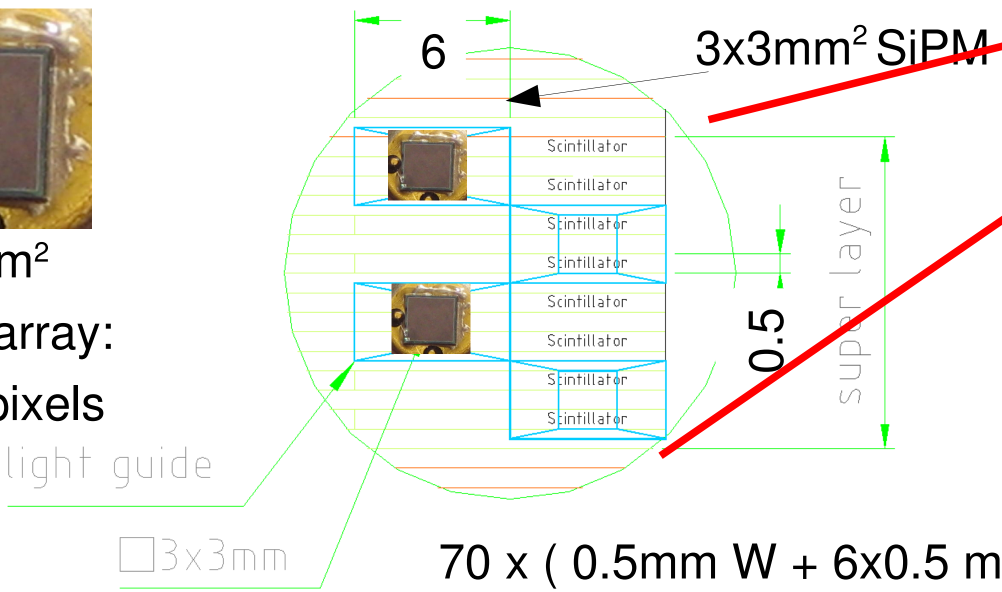
proton rejection ~5000 at high energies
(electron efficiency ~65%)

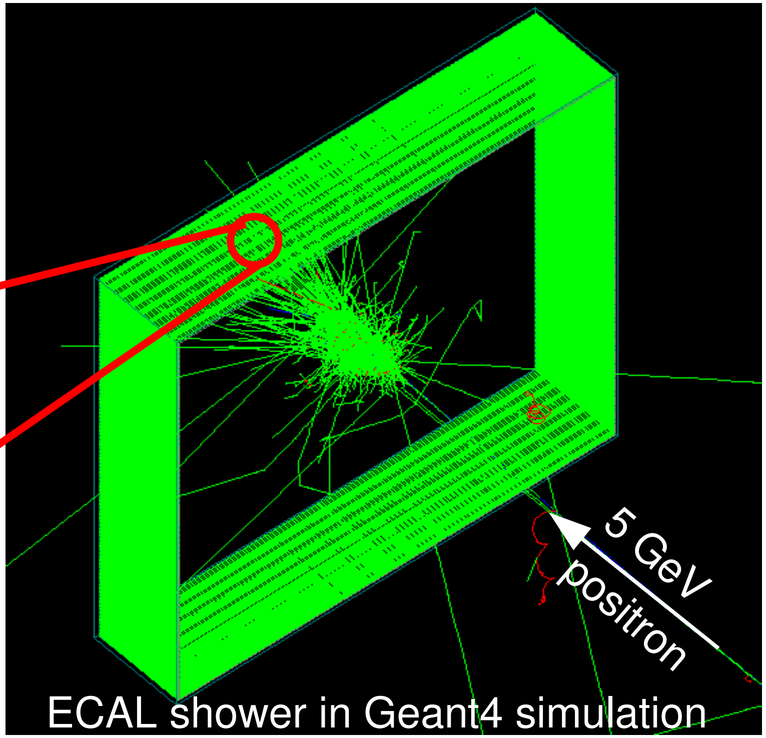
Simulated 40,000 positrons and
1,000,000 protons

ECAL energy resolution
~10%
dominated by leakage
effect



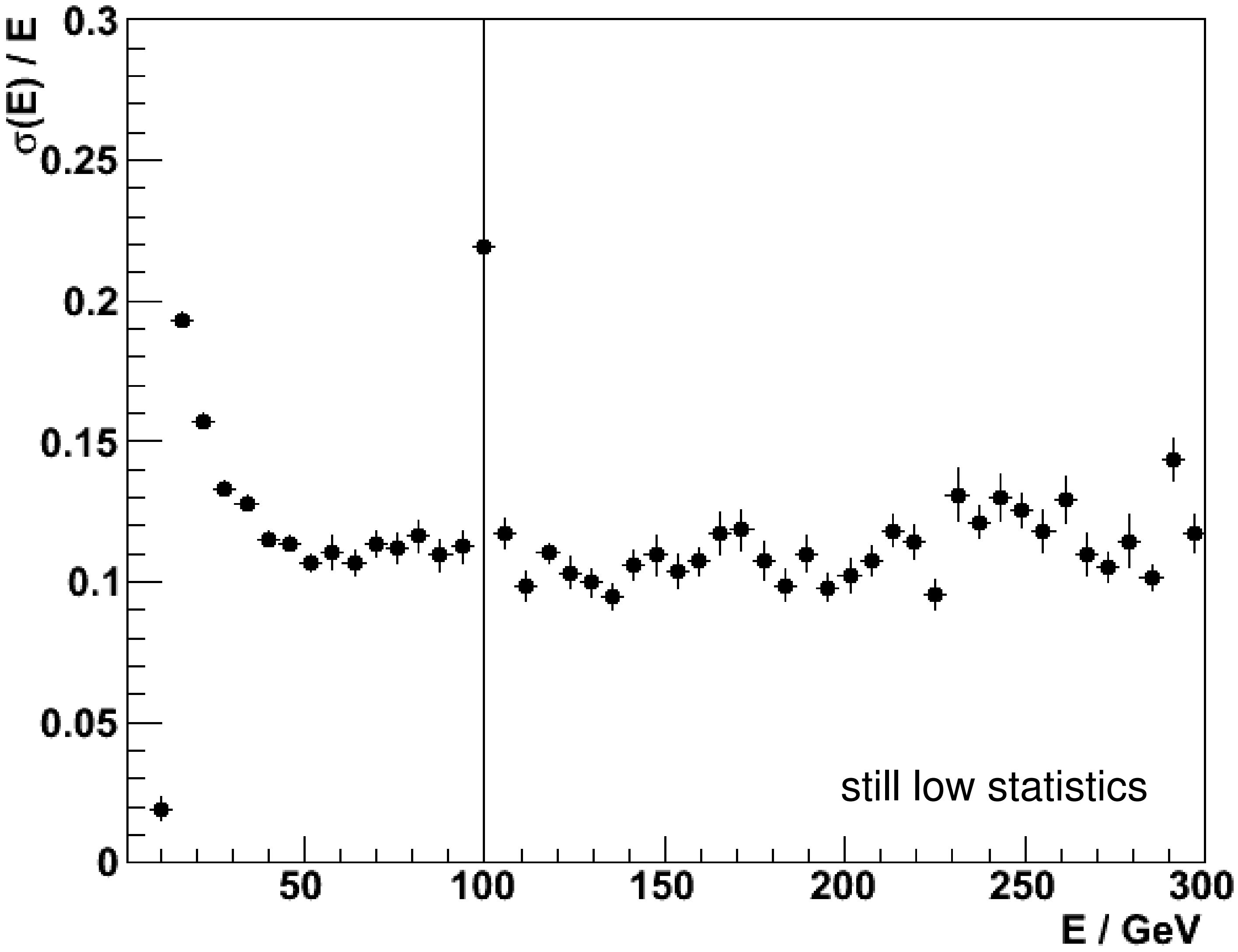
3x3 mm^2
SiPM array:
3600 pixels





70 x (0.5mm W + 6x0.5 mm^2 scintillating fibre + SiPM) = 10 X_0

ECAL energy resolution at high energies

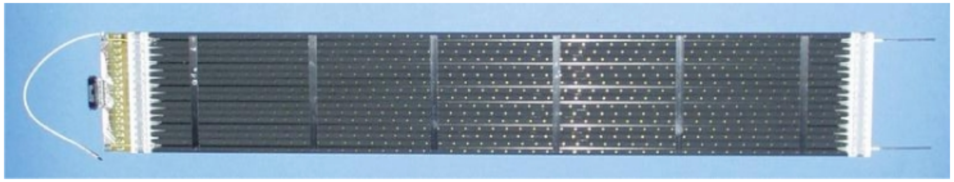


ECAL energy resolution at higher energies limited by:

- leakage effect
- limited number of pixels in SiPM: non-linearity and saturation effects

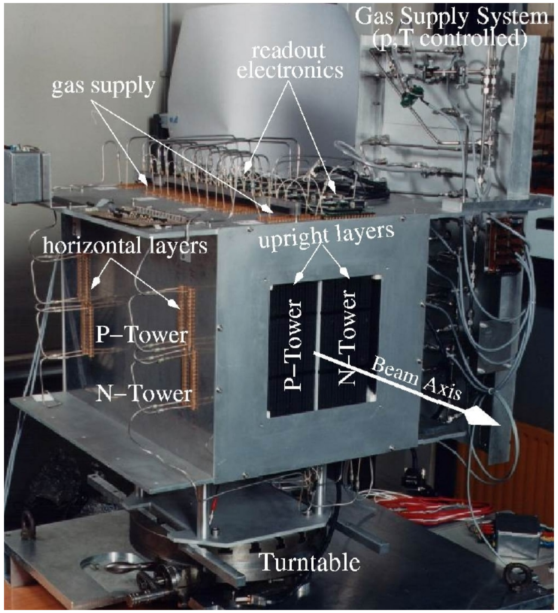
Investigating possibility to measure electron spectrum in TeV range...

TRD design



single TRD module

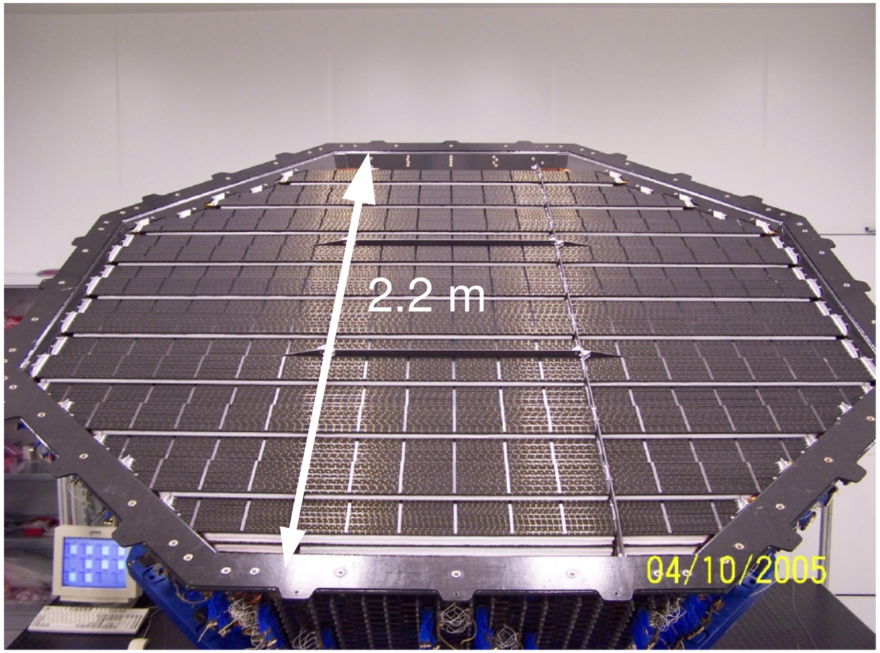
Tasks: proton suppression and tracking in non-bending plane



TRD prototype prepared for testbeam (2000)

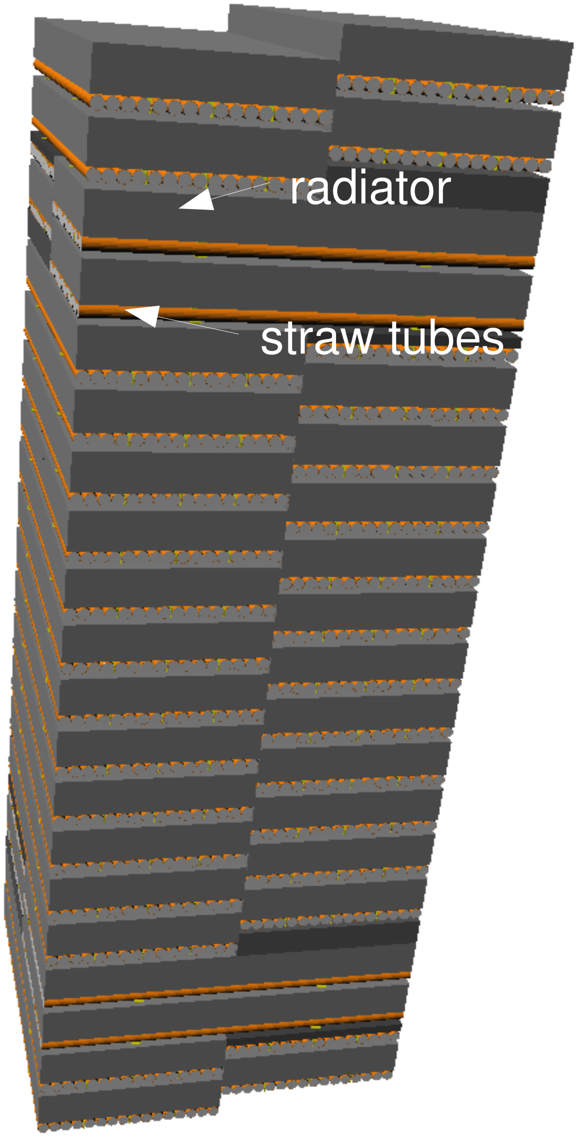
2 x 8 layers of fleece radiator, TR x-ray photons absorbed by Xe/CO2 mixture (80:20), in 6mm straw tubes with 30 μm tungsten wire

Design equivalent to AMS02 space experiment

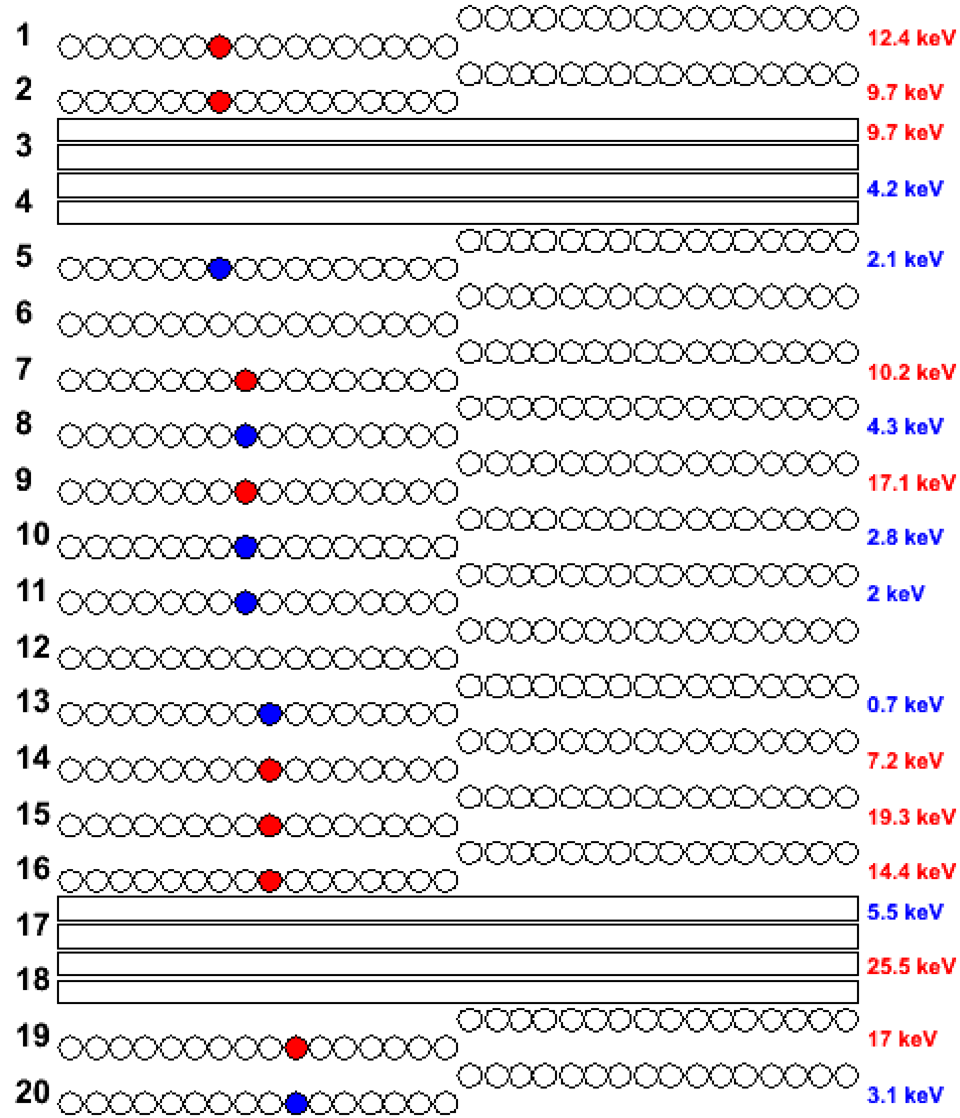


AMS02 TRD octagon integrated at RWTH Aachen workshop

Geant4 simulation of TRD testbeam (2000)



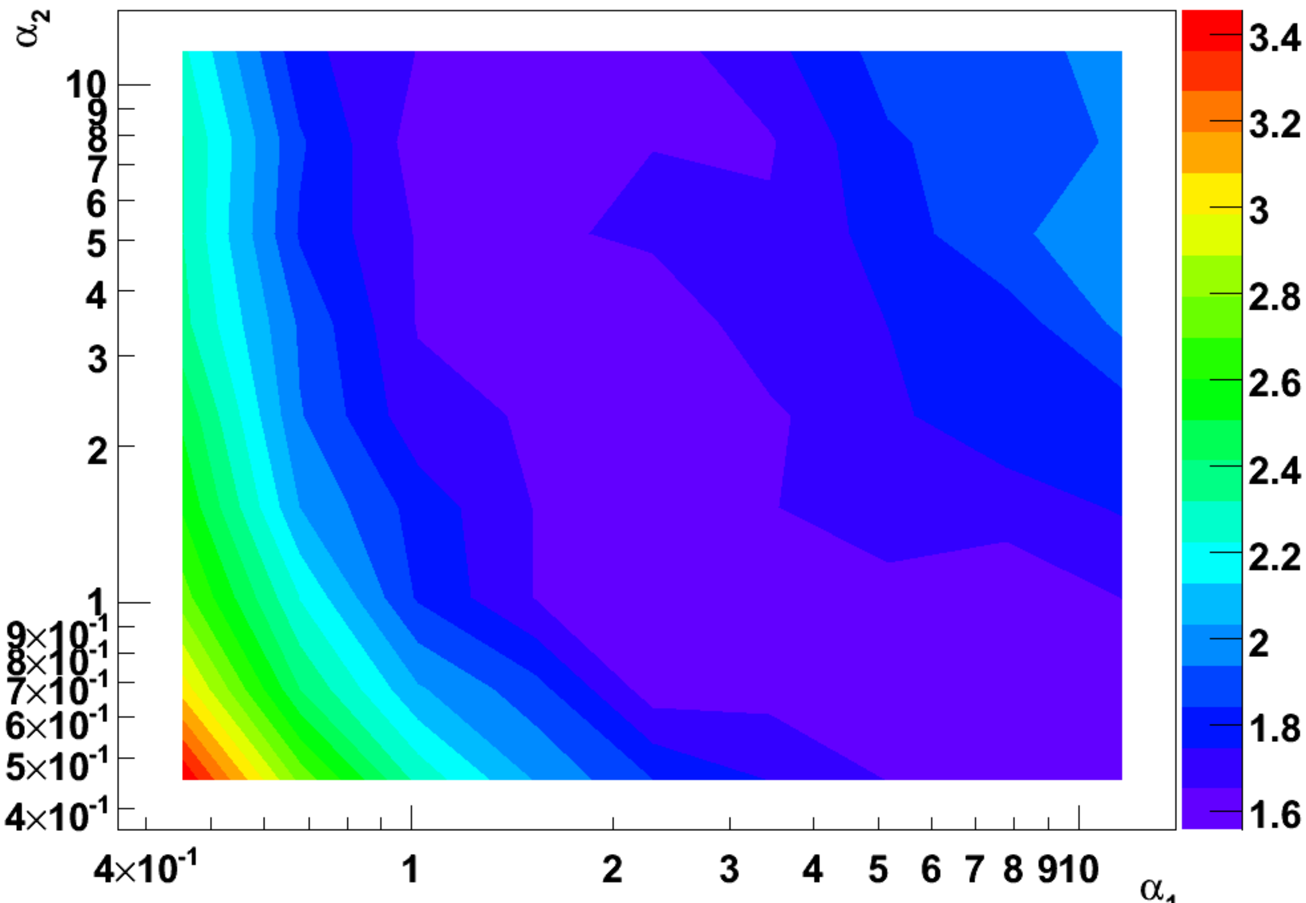
SPRONG

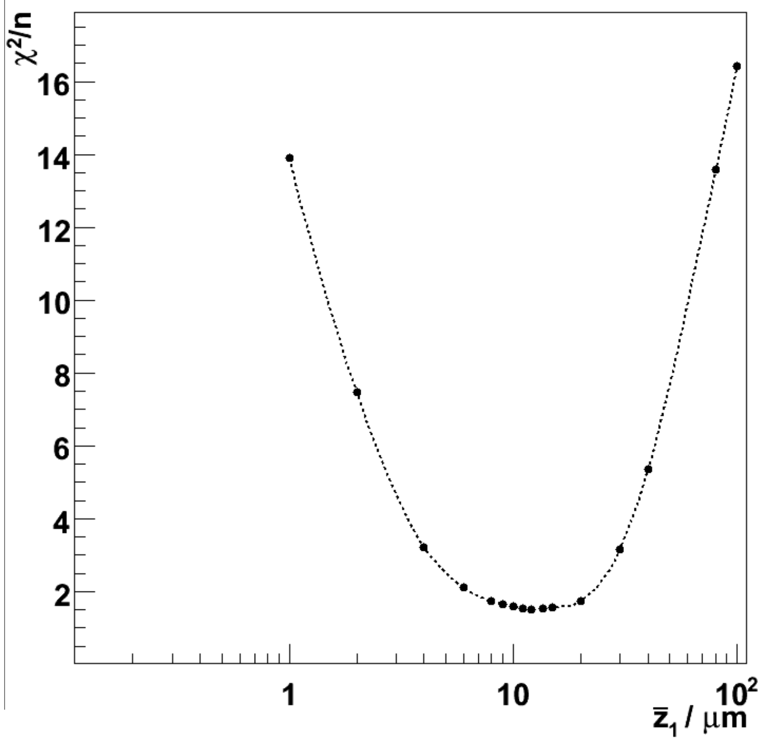


20-layer TRD prototype subjected to 20 GeV electron and 20-200 GeV proton beams at CERN

Question: What is the reliability of the TR and energy loss simulation in Geant4?

Adjustment of simulation parameters





TR yield depends on radiator structure. Here, fiber and gas thicknesses assumed to vary according to

$$p_j(z) = \left(\frac{\alpha_j}{\bar{z}_j}\right)^{\alpha_j} \cdot \frac{z^{\alpha_j - 1}}{\Gamma(\alpha_j)} \cdot \exp\left(-\frac{\alpha_j z}{\bar{z}_j}\right)$$

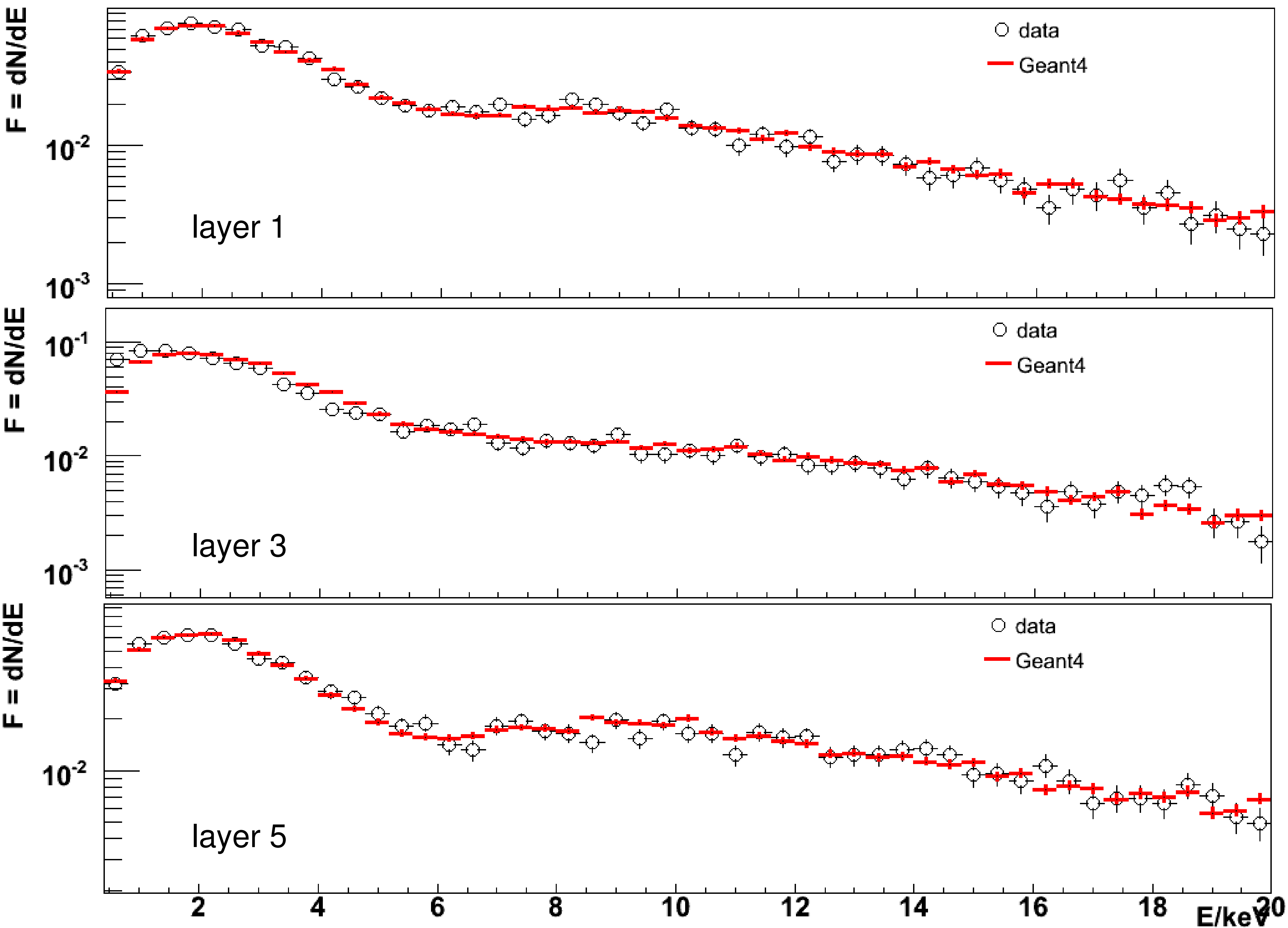
Adjustment of parameters using suitable χ^2/n as a measure for deviations of simulation from testbeam data.

α_1 fleece thickness fluctuation parameter

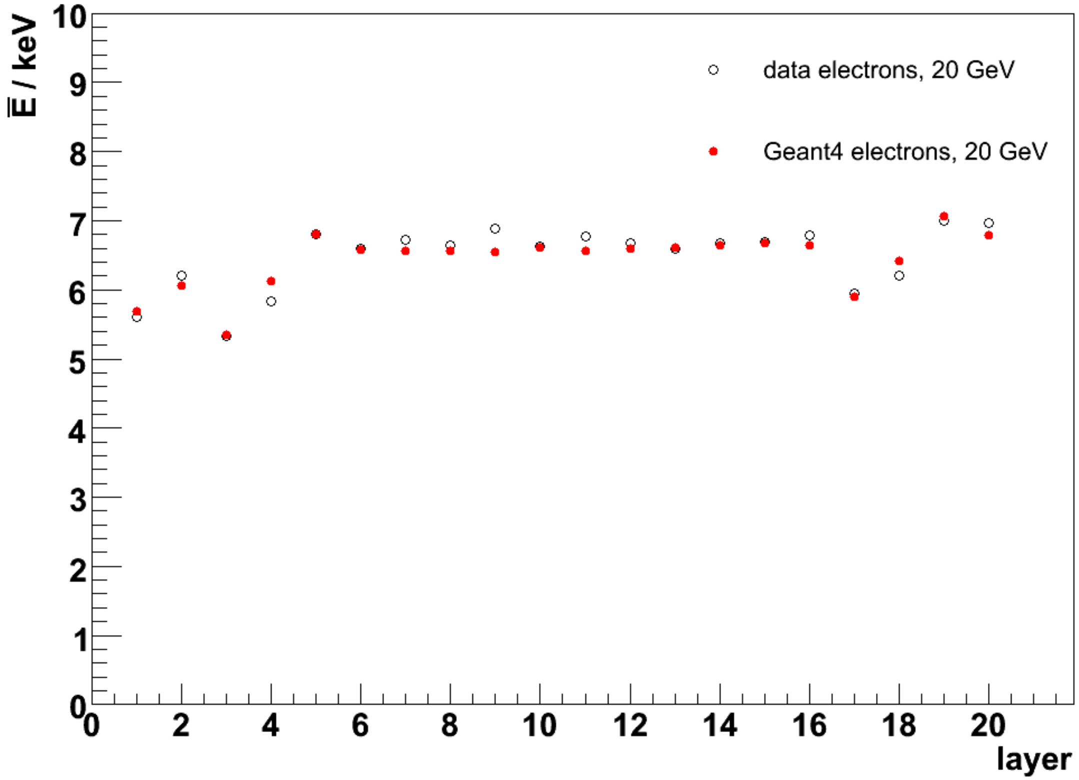
α_2 gas thickness fluctuation parameter

$\bar{z}_1$ mean fiber thickness, nominal value: 10 µm

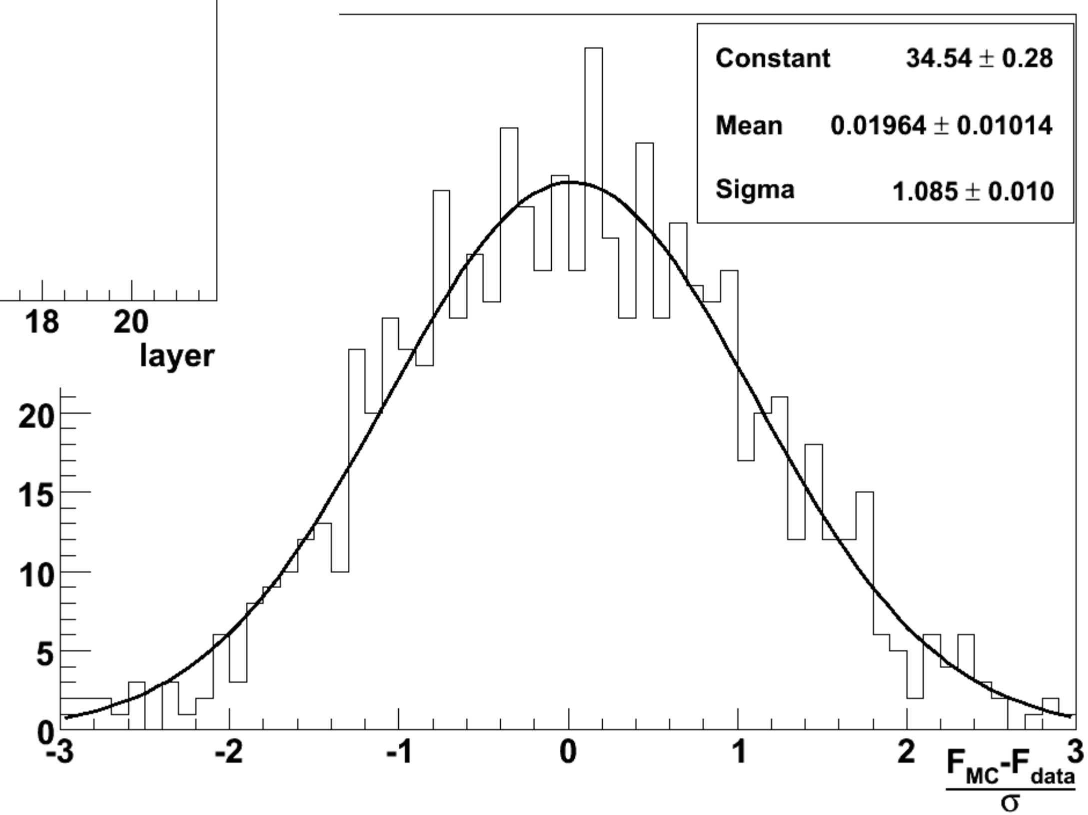
Electron spectra at different layers



Mean energy depositions

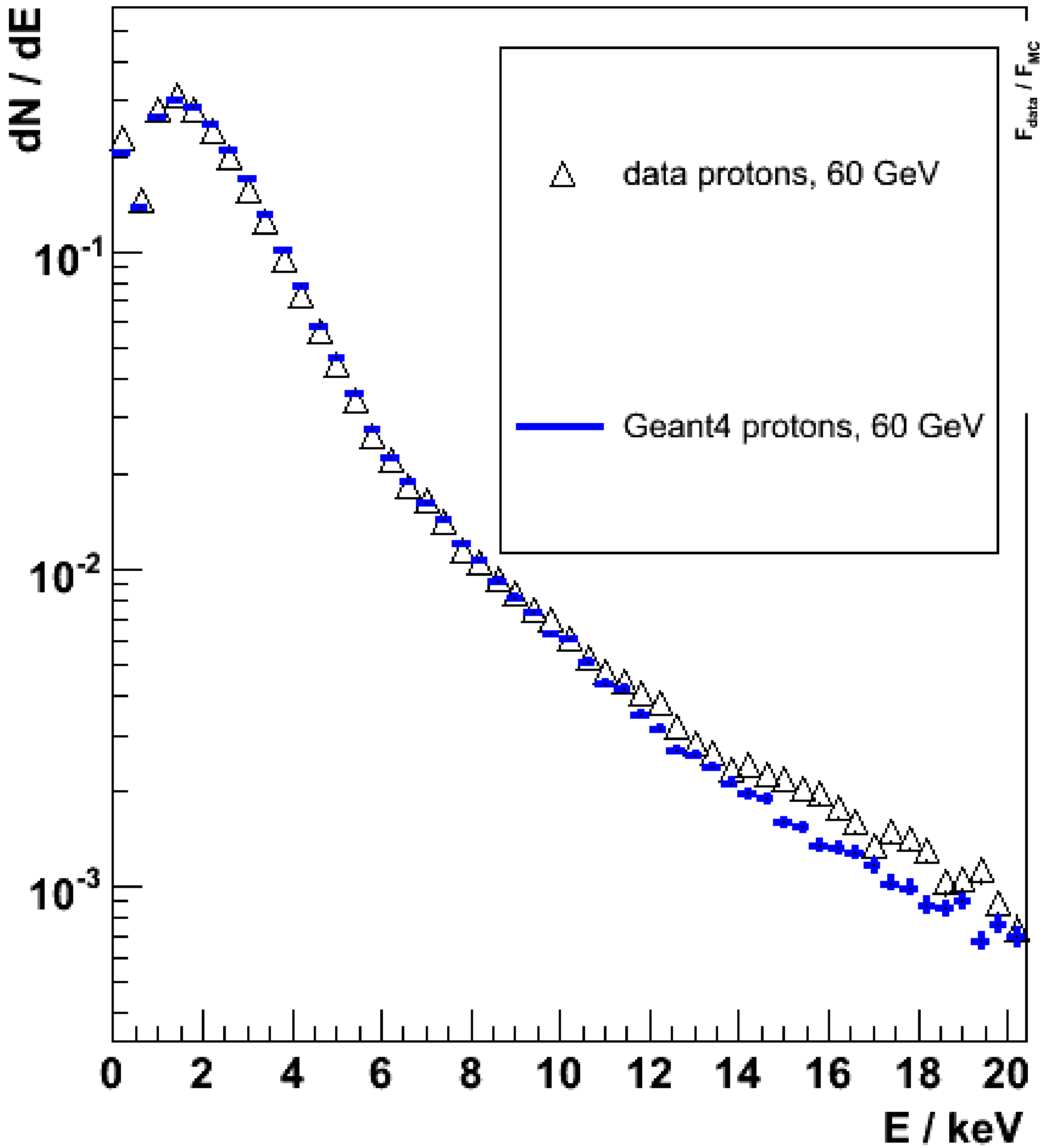


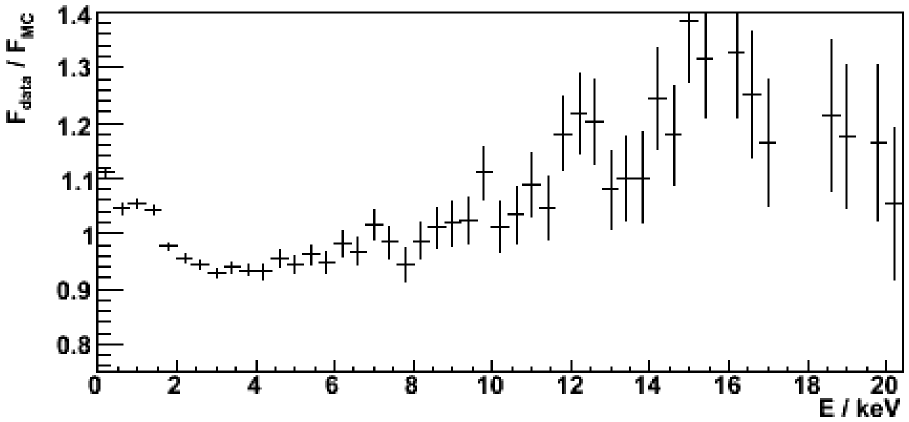
Residuals distribution has mean 0 and standard deviation 1.1



Effect of different amounts of radiator in front of certain layers reproduced.
Deviation from data smaller than layer-to-layer variation.

Slight deviations in proton spectra

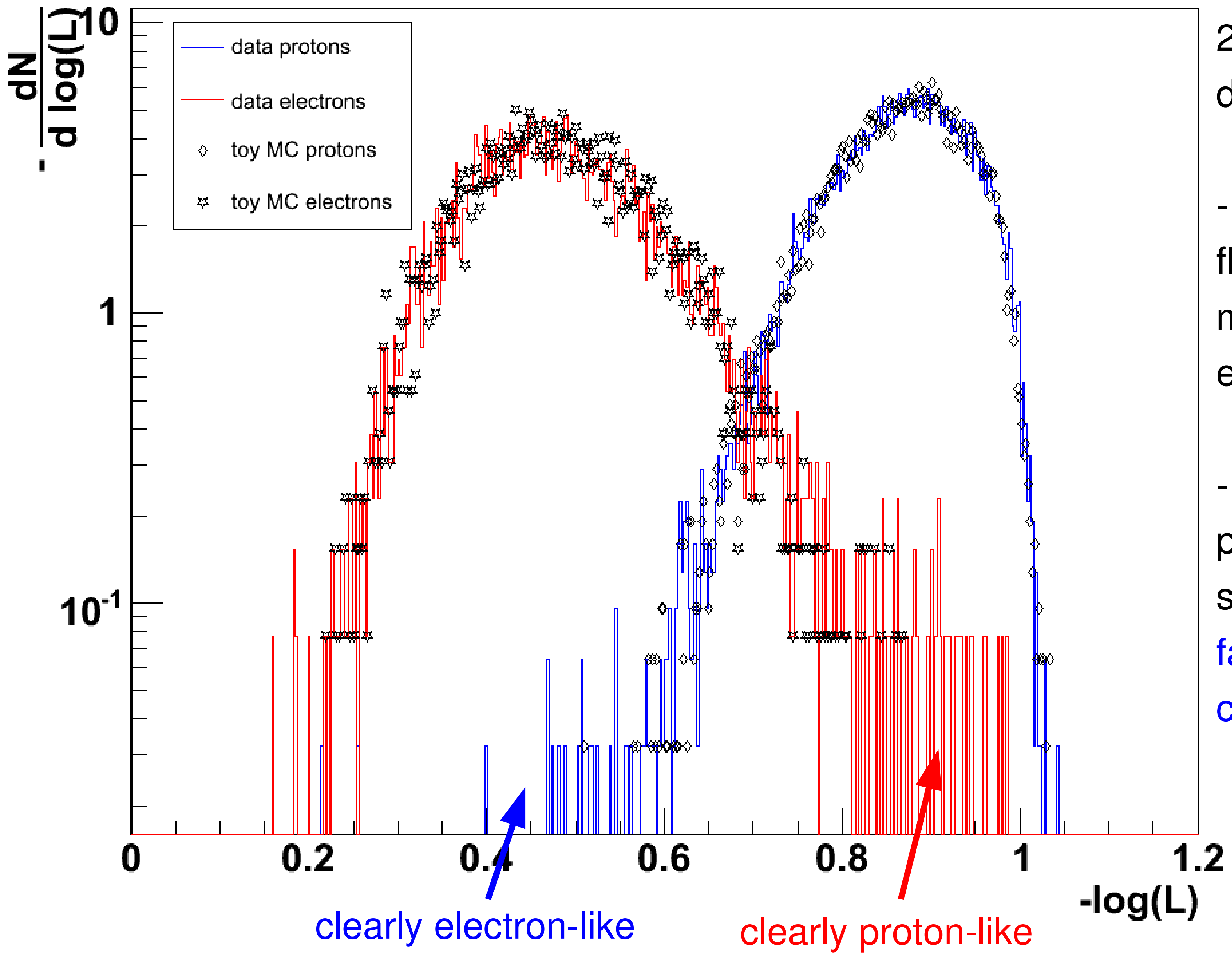




Small deviations in tails of proton dE/dx distributions.

Evaluate effect on estimated rejection using “toy MC”: randomly generate 20 energy depositions according to the simulation and data distributions.

Toy MC study to evaluate effect of deviations

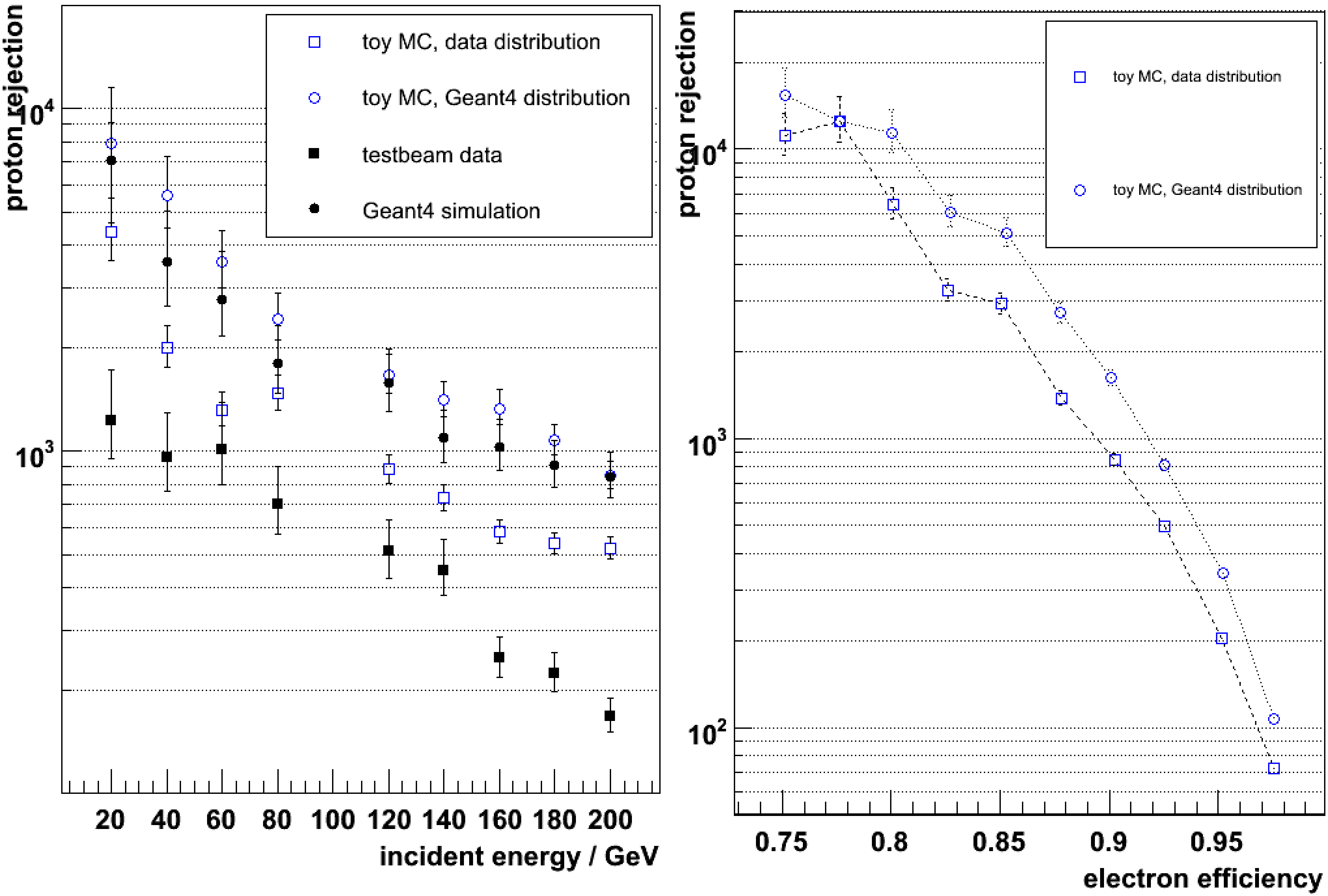


2 kinds of proton events determine rejection:

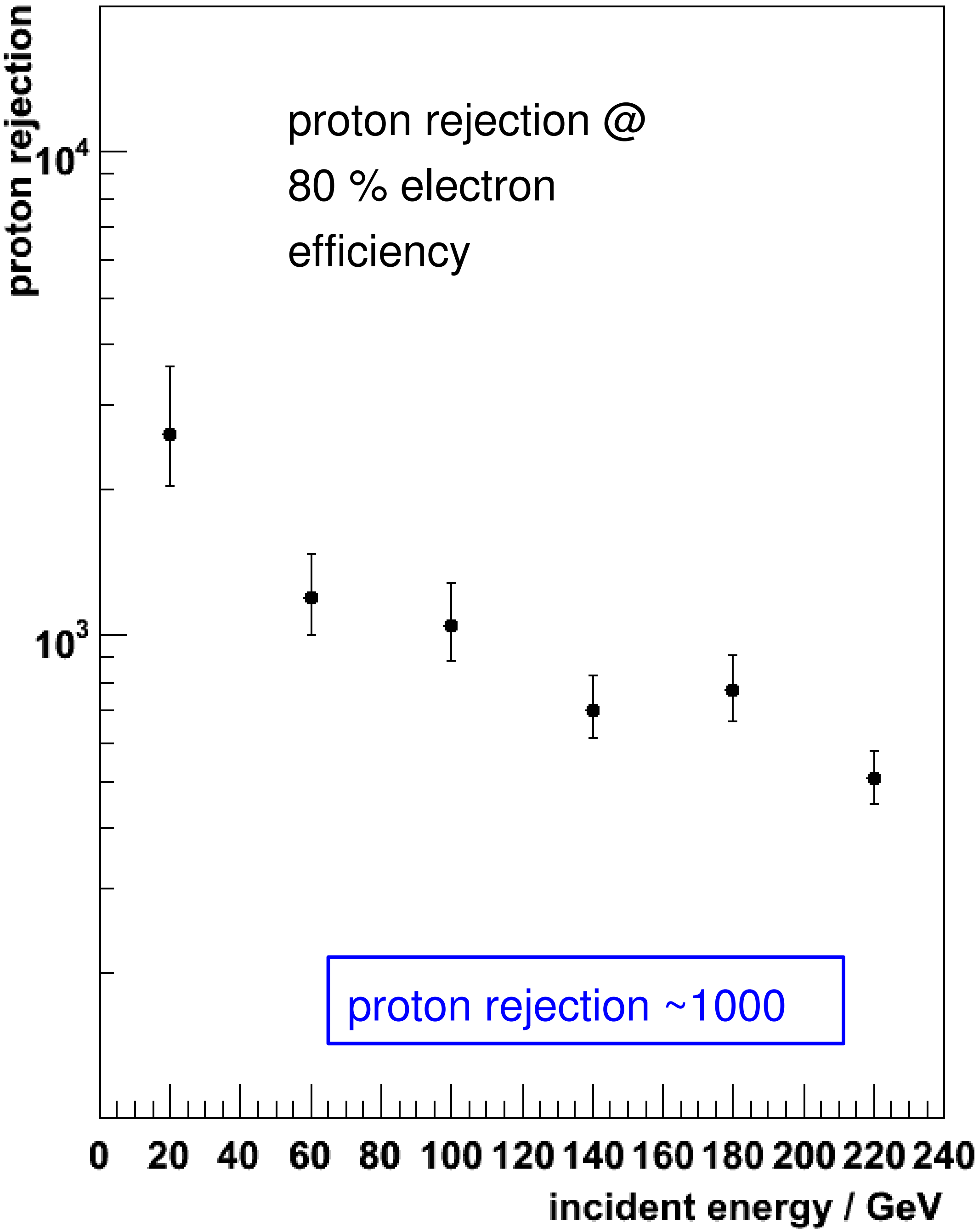
- events with statistical fluctuations leading to many tubes with high energies (→ toy MC)

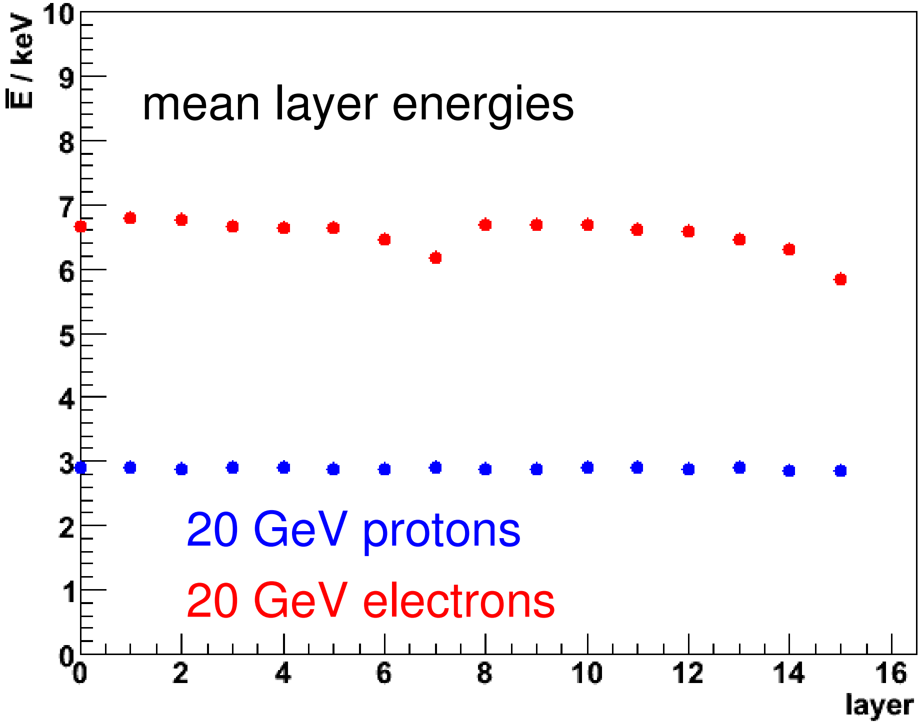
- events with electron or pion creation (diffractive scattering, π^0 events), faked by beam contamination

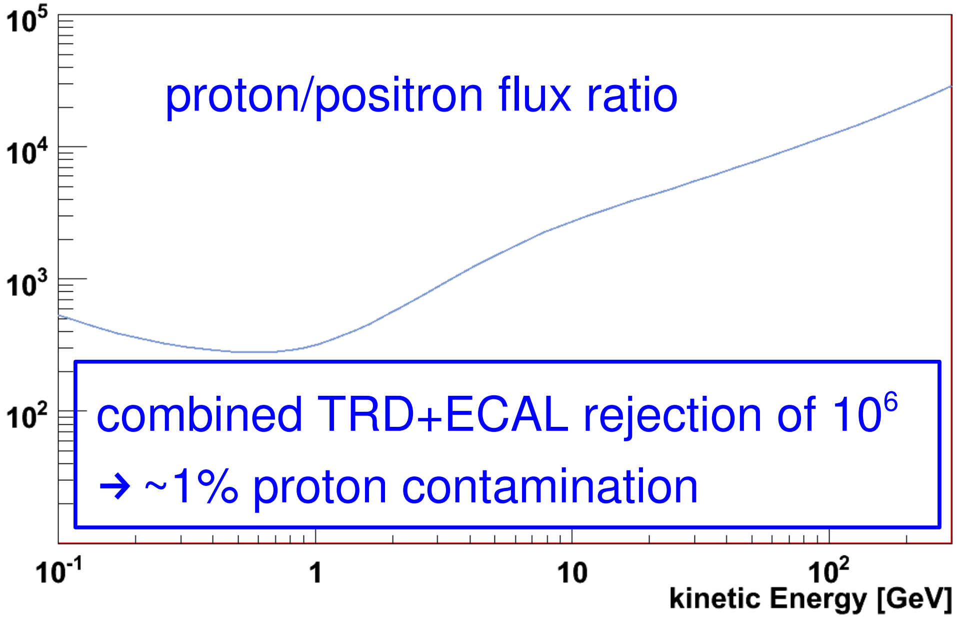
Proton rejection and electron efficiency



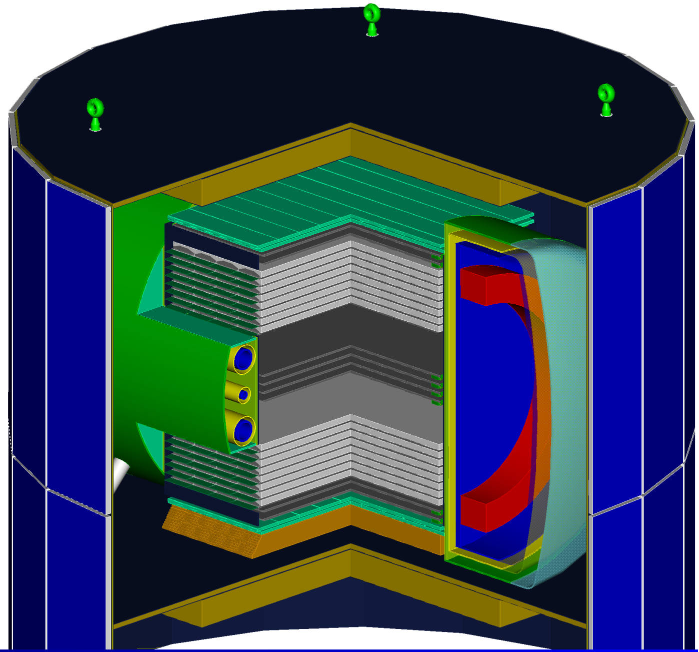
Projected performance of PEBS-TRD







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!