PEBS: Positron-Electron Balloon Spectrometer

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On behalf of PEBS collaboration:
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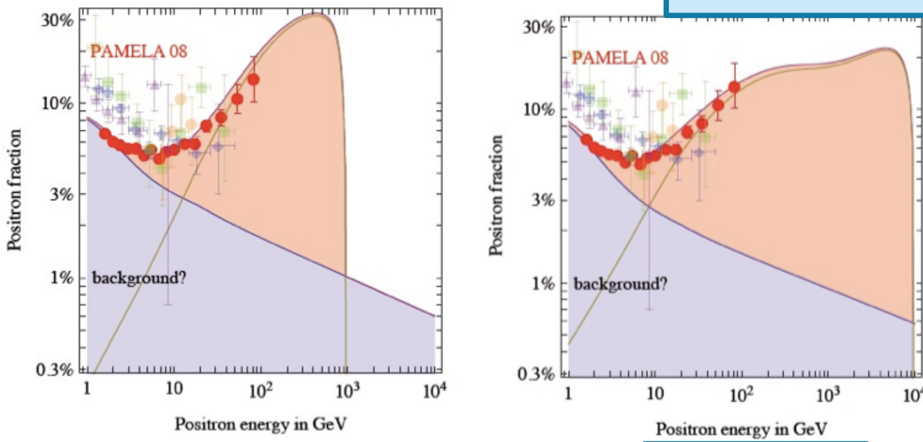
Tsinghua University

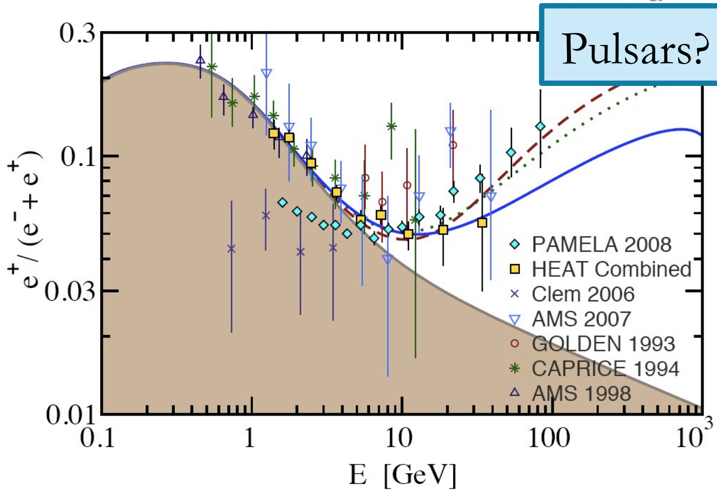
e^+ fraction in cosmic rays

M. Cirelli et al, arXiv:0809.2409v3

Dark Matter?



Pulsars?



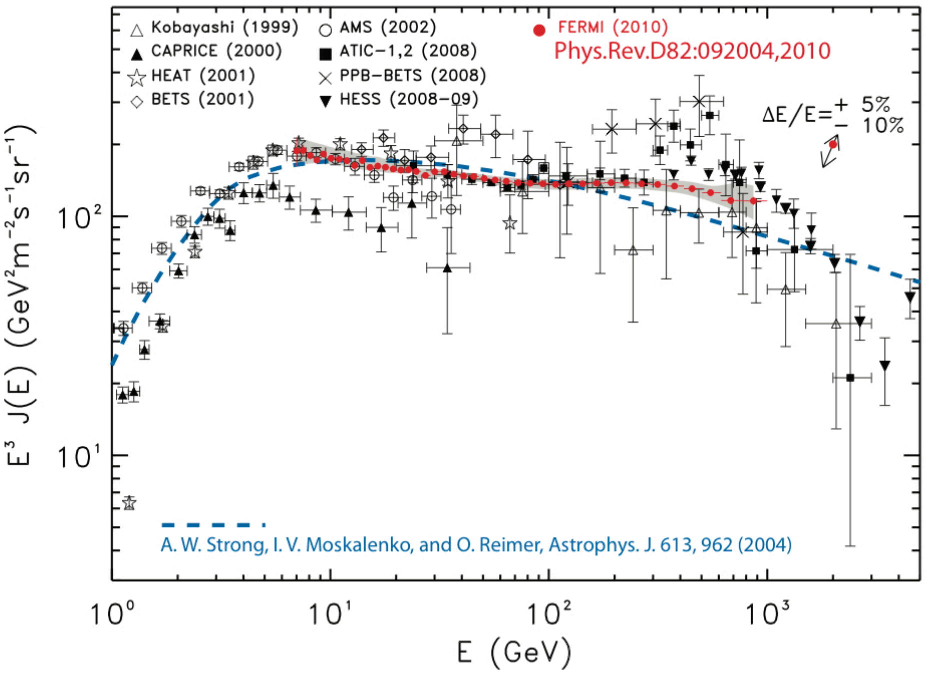
H. Yuksel et al, arXiv:0810.2784v4

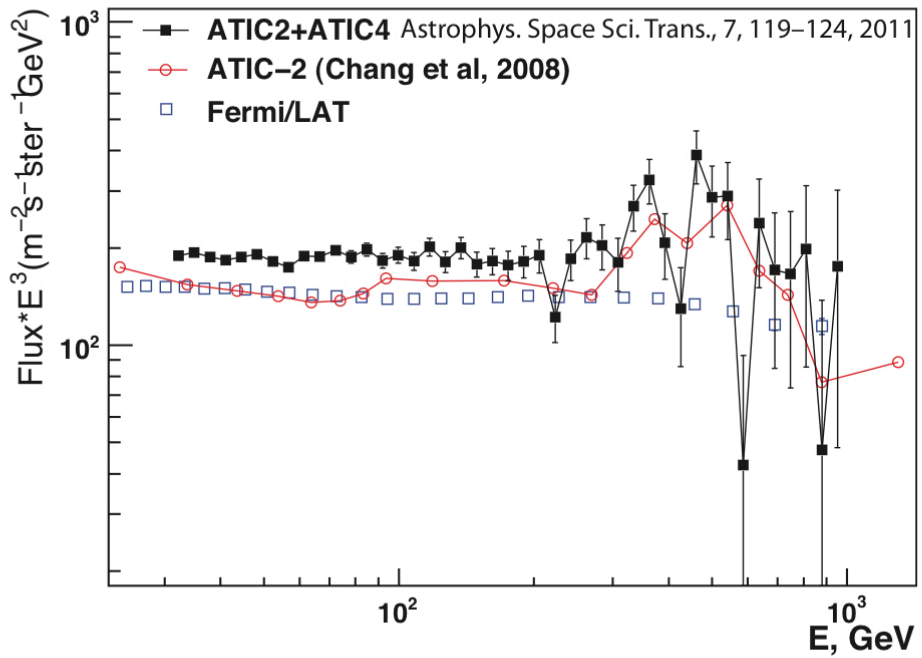
- High energy region:
  - dark matter signature?
  - nearby pulsars?
  - ➢ needs measurement to higher energies and complementary information from antiproton fraction
- Low energy region:
  - charge-sign dependent solar modulation
- ATIC, FERMI and HESS also see features in total $e^+ + e^-$ flux

Total e^{+}+e^{-} flux in cosmic rays

- Recent observations of primary cosmic $e^{+}+e^{-}$ flux shows an interesting deviation from the expected shape at high energies, above 100 GeV

$e^{+}+e^{-}$ flux





PEBS (I and II phases) characteristics

Positron-Electron Balloon Spectrometer designed for precise measurement of charged cosmic rays:

- 1st phase:
  - positron fraction up to 600 GeV
  - total $e^+ + e^-$ spectrum up to 2 TeV
- 2nd phase:
  - e^+ up to 1.8 TeV
  - antiprotons and He^3/He^4 up to 100 GeV/N

Acceptance: spectrometer 1000 cm^2sr (PAMELA: 21.5 cm^2sr), ECAL+TRD 7500 cm^2sr

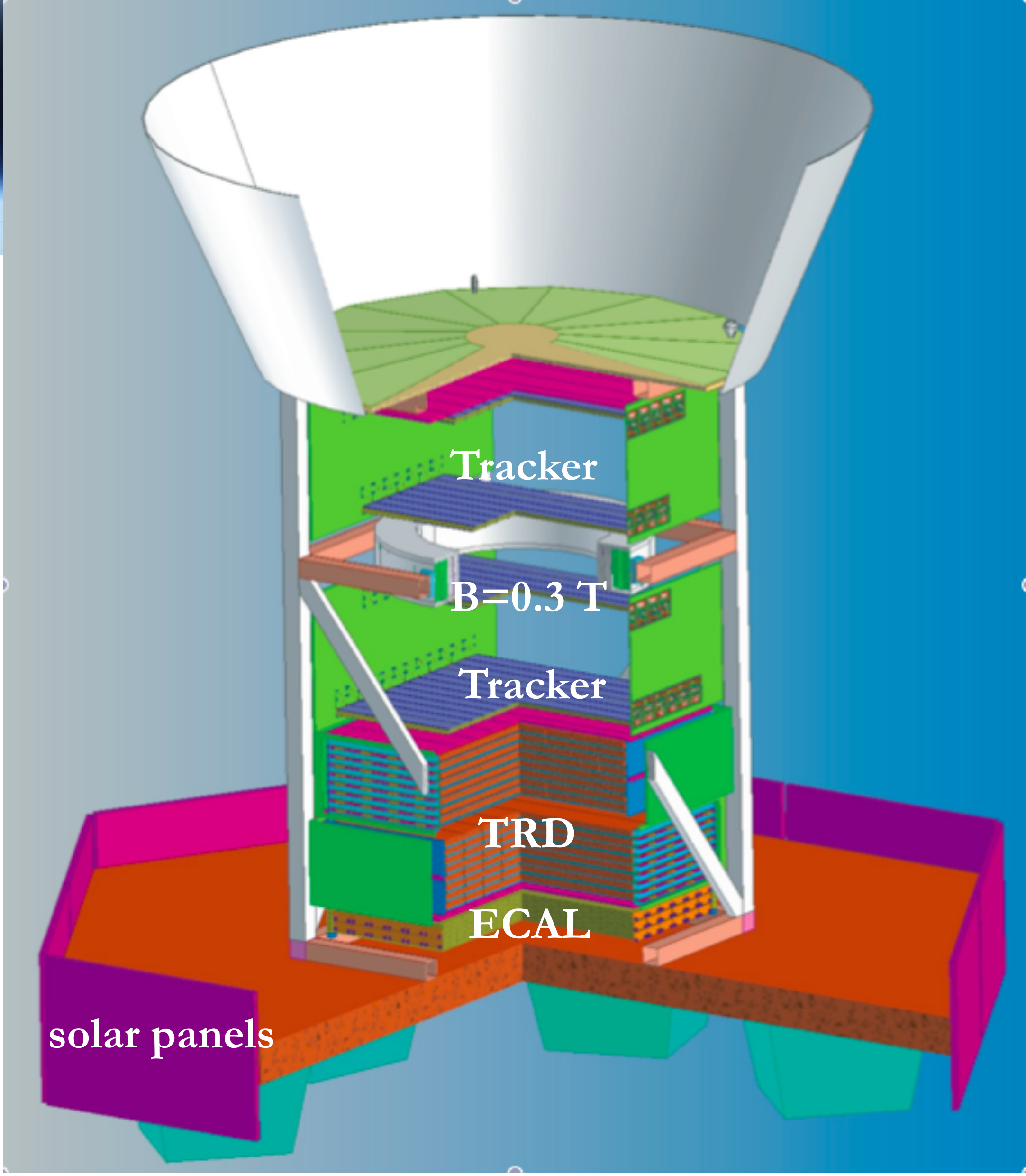
Magnetic field: 0.34 T (1st phase) and 0.8 T (2nd phase, superconducting magnet)

Tracker: point resolution 50 μm

ECAL: sandwich calorimeter with 18 X_0, e/p separation: p rejection up to 10^4 at 80% electron efficiency.

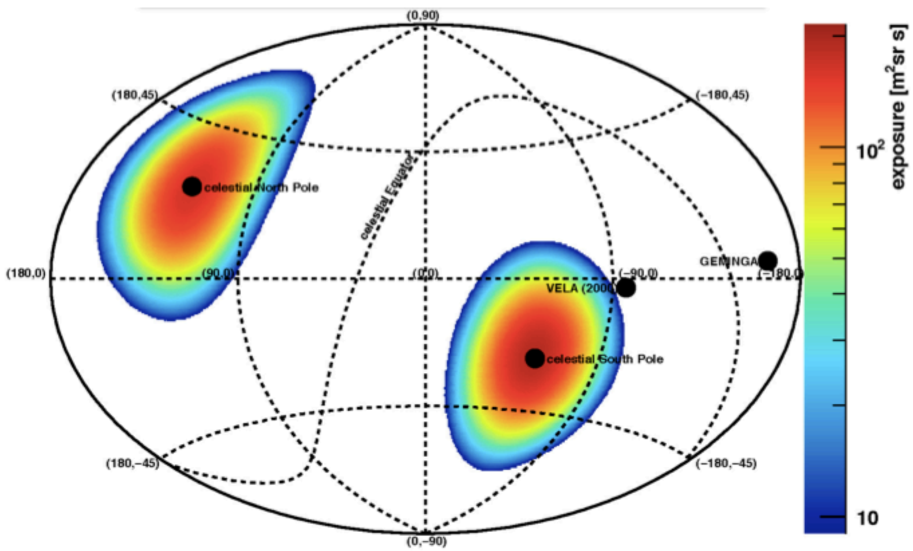
TRD: p rejection 2000-20 in a range 10 GeV – 1 TeV

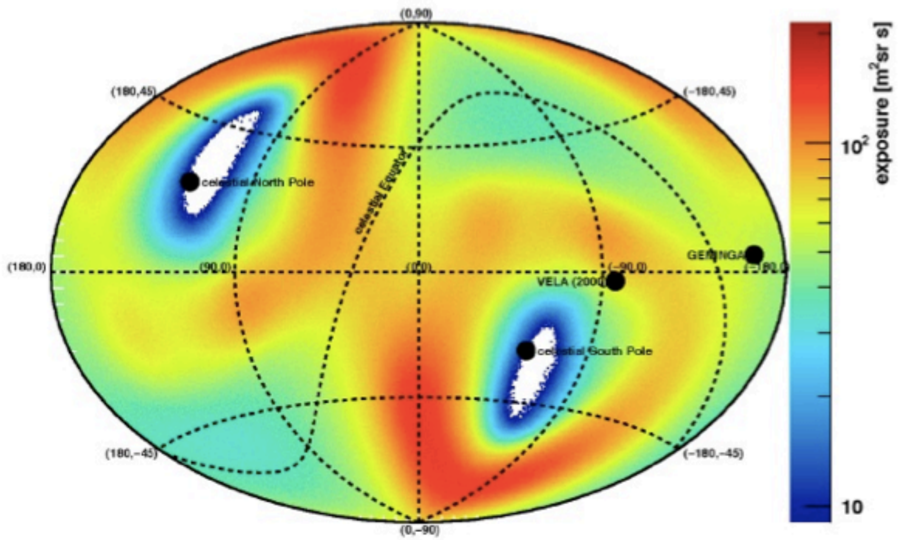
RICH: 2nd phase only, allows p measurement in 100 GeV region



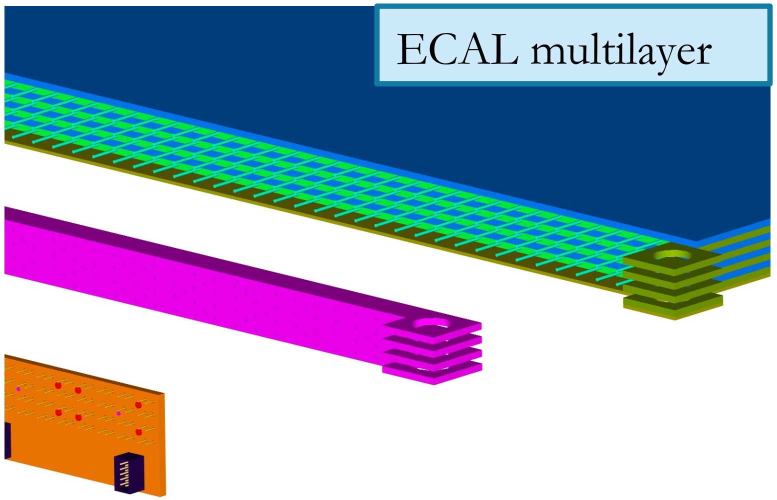
PEBS vs. AMS-2

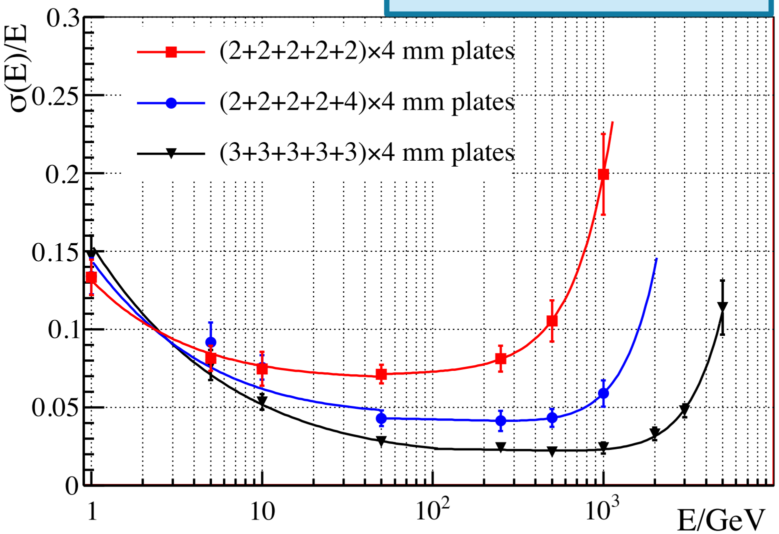
Sky coverage of the two experiments





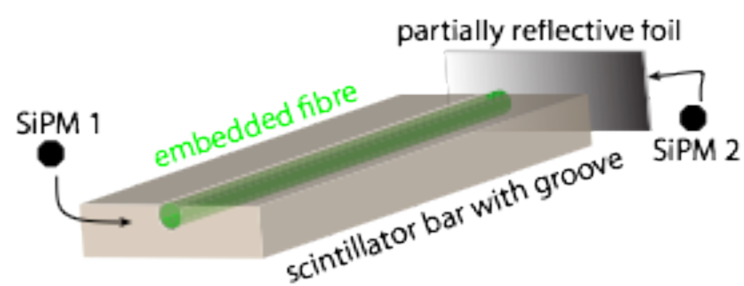
ECAL specifications


ECAL multilayer

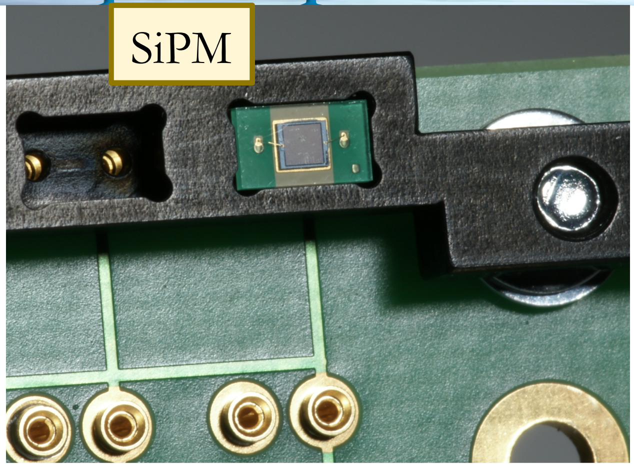
Geant4 simulation


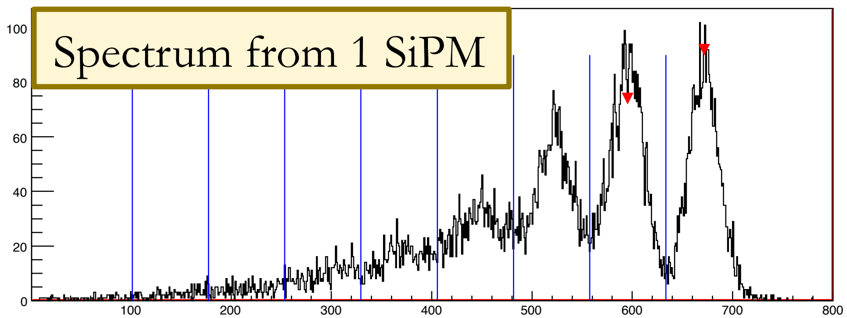
Sandwich calorimeter:

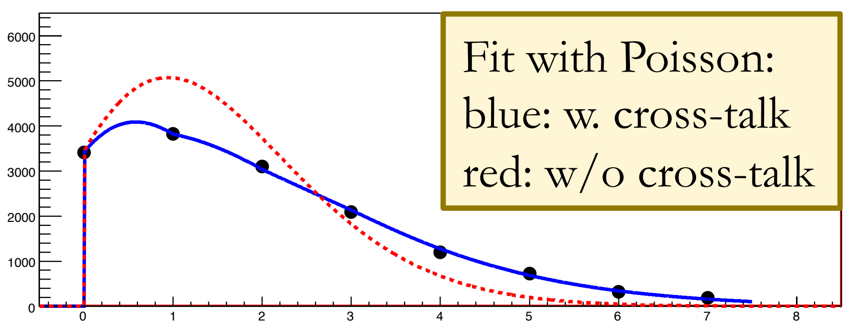
- 21 layer alternatively placed in x- and y-direction: 3D shower reconstruction
- Tungsten absorber plates 3 mm
- Scintillating bars 3×7.35×837 mm^3
- Embedded ø1 mm WLS fibers
- Equivalent to 18 X_0
- "4 gains" readout system:
  - double side readout with SiPMs (MPPC from Hamamatsu)
  - and 2 gain SPIROC chip, a different chip being investigated as well
  - required dynamic range:
    - For 1TeV e^+ ~40k photons at shower maximum
    - For MIPs (i.e. muons) ~10 photons
  - SiPM+WLS fiber system provides 10-2000 p.e.
  - ➢ one side is optically attenuated by factor 40



Silicon Photomultiplier: Multi-pixel photon counter







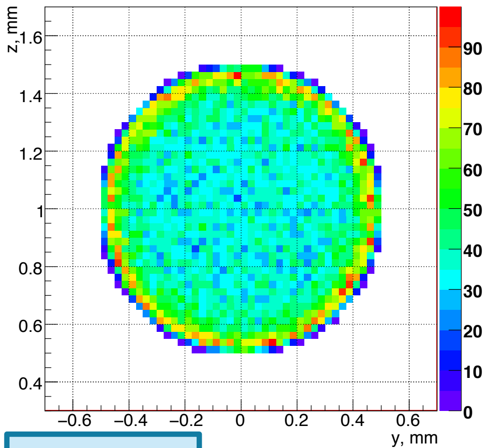
Operational principle

- array of avalanche photodiodes on common Si substrate.
- operation in Geiger mode: one full micro-pixel discharge – 1 p.e.
- high micro-pixel density: 100-1600/mm^2: can measure $O(1) – O(10^3)$ photons
- low breakdown voltage (~70 V)
- high photo-detection efficiency (PDE): 30-70%
- can operate in magnetic field
- characteristics depend on the temperature: breakdown voltage, PDE, cross-talk rate

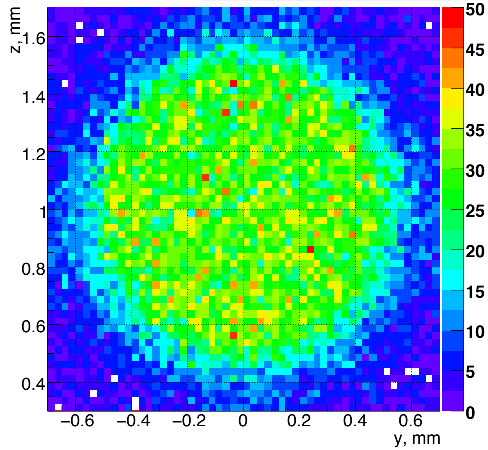
Exploring SiPM Saturation

GEANT4

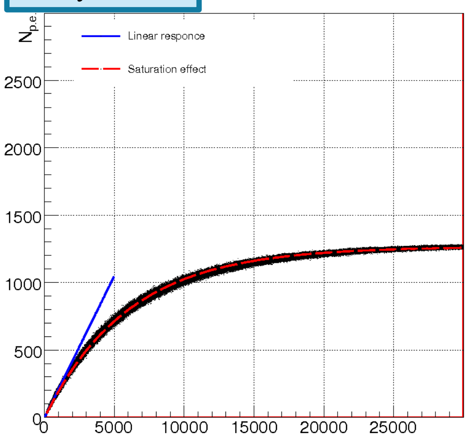
No epoxy



With epoxy

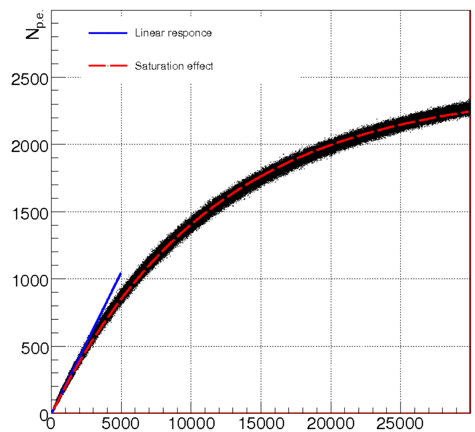


Toy MC



Nγ incident

N fired pixels



Nγ incident

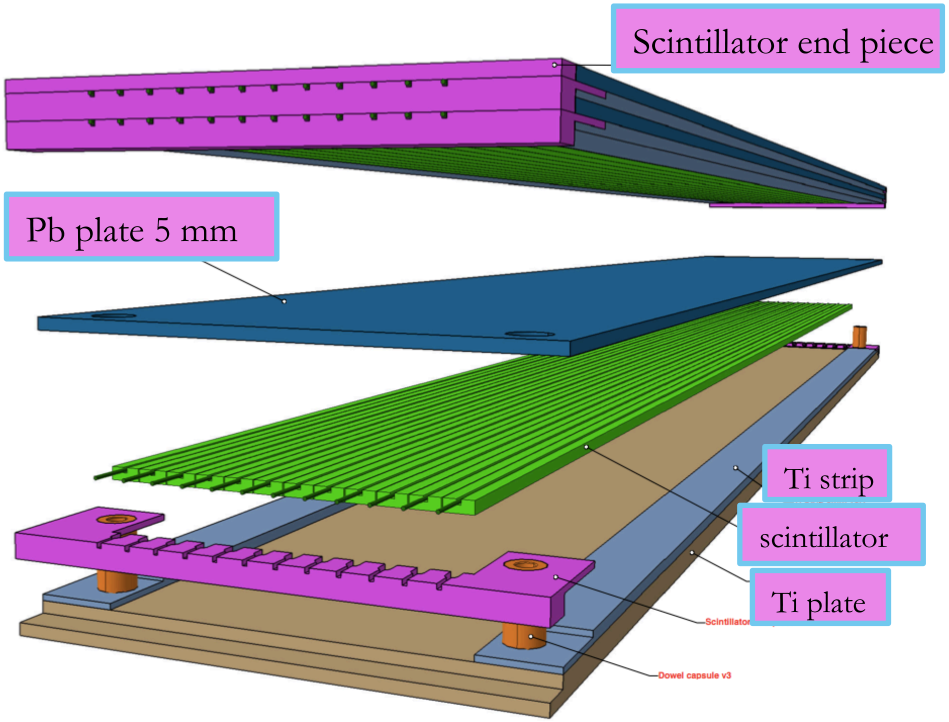
Full optical simulation

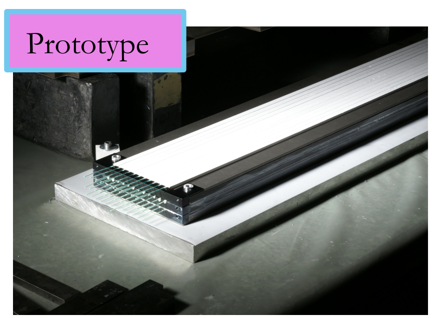
- One scintillating bar with embedded WLS fiber
- SiPM: 1.4×1.4 mm^2 surface, 25×25 μm^2 pixel size
- 2 configurations of SiPM surface:
  - direct contact with fiber
  - with epoxy layer protection 250 μm
- Light is created by MIPs passing uniformly through the bar.
- Spatial, time and spectral characteristics of the photons incident on SiPM are obtained.

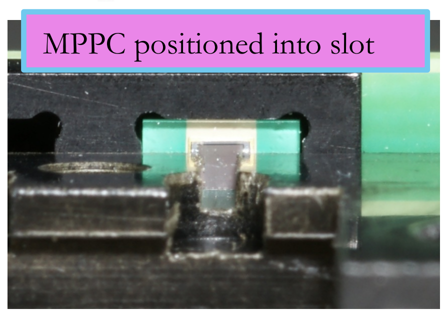
Toy Monte Carlo

- Number of photons is varied from 1 to 30k with 10 experiments for each.
- Number of fired micropixels is counted.
- Obtained effective number of micropixels is ~1300 (geometrical coverage) and ~2500 in two cases.

Prototype I assembly





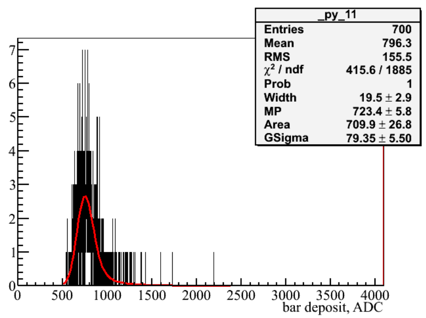


- Prepared for the PS beam: μ, e, π with energies 1-6 GeV
- 3 layers: lead absorber plates 5 mm and long scintillating bars
- Embedded ø1 mm Y11(200) Kuraray WLS fibers
- White BC-620 TiO_2 paint to avoid optical cross-talk and increase light collection
- Double readout with SiPMs:
  - factor 12 light attenuation at one side (low energies – less light)
- 3.2 X_0 and removable additional lead layers which could be put in front of the prototype

Intercalibration of all channels

Not attenuated side: 4 GeV μ

Fit with a convolution of Gaussian and Landau distributions



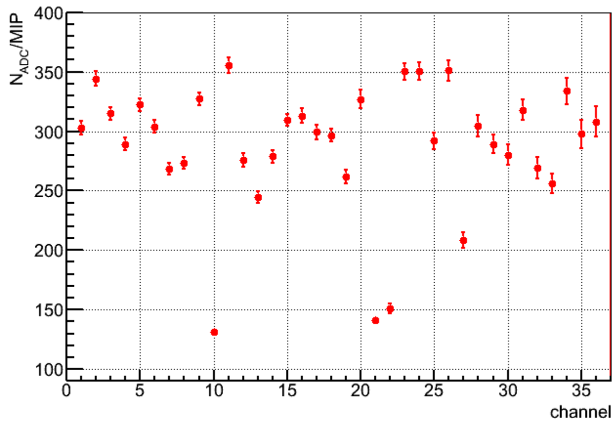
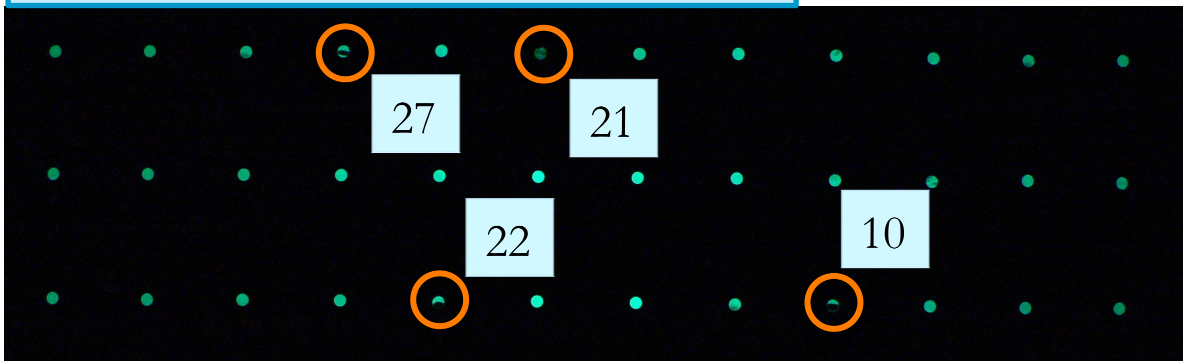
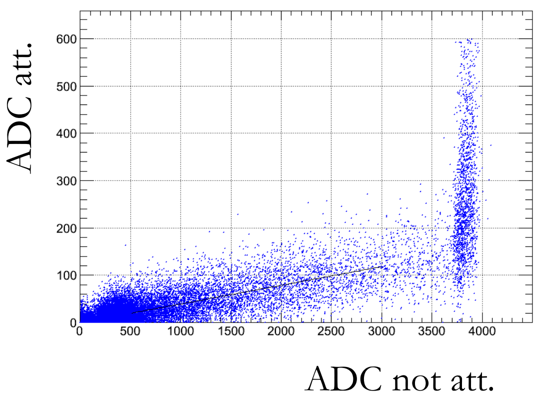


Photo of prototype: broken WLS fibers



Attenuated side: e^- data

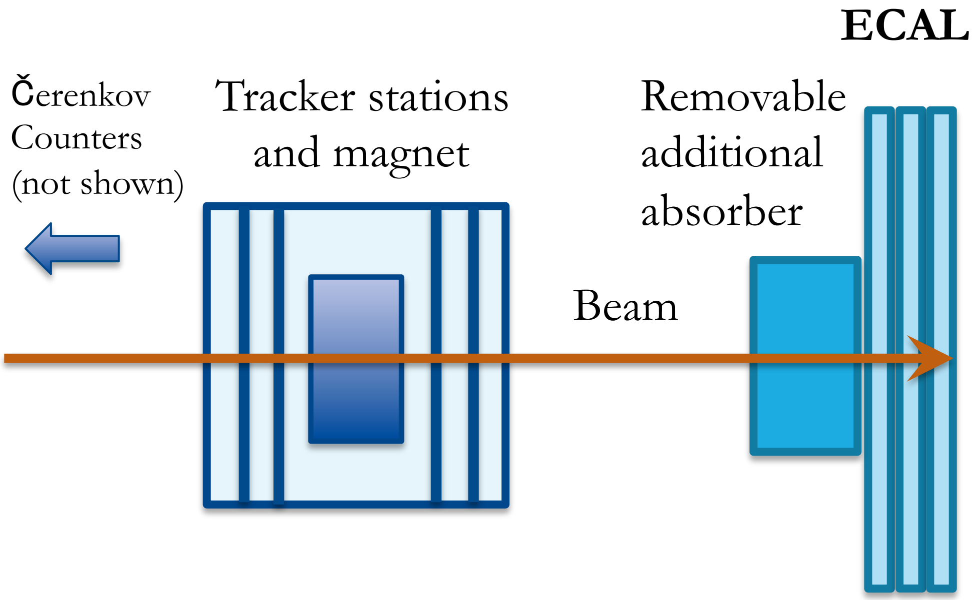
- Attenuated vs not attenuated side: one bar

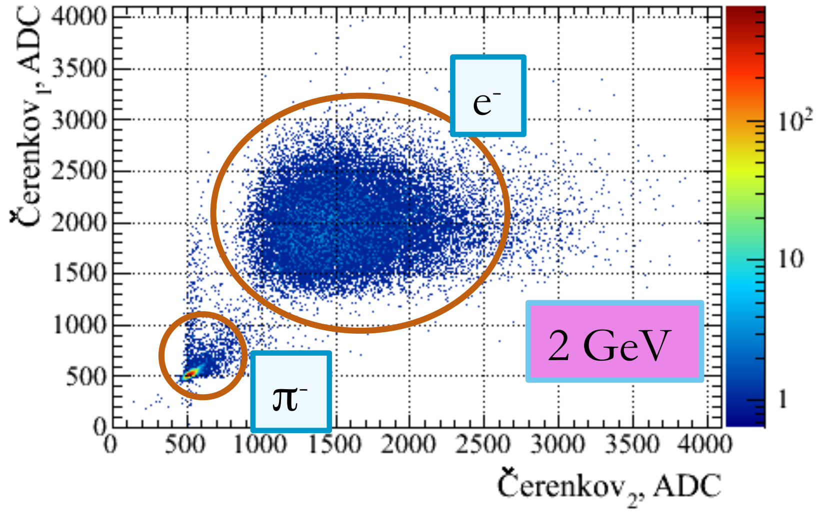


- Information from the attenuated side used only when the not att. side is saturated

Event selection

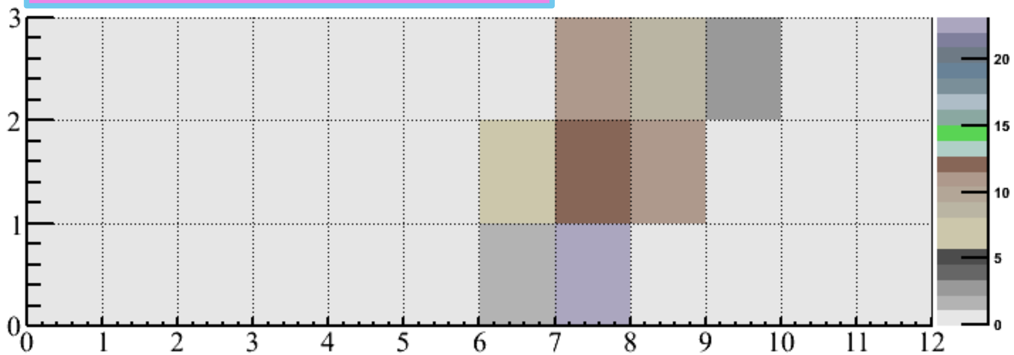
Testbeam setup, top view





- Two threshold Čerenkov counters used to select electrons from the beam

Event display: 2 GeV e$^-$

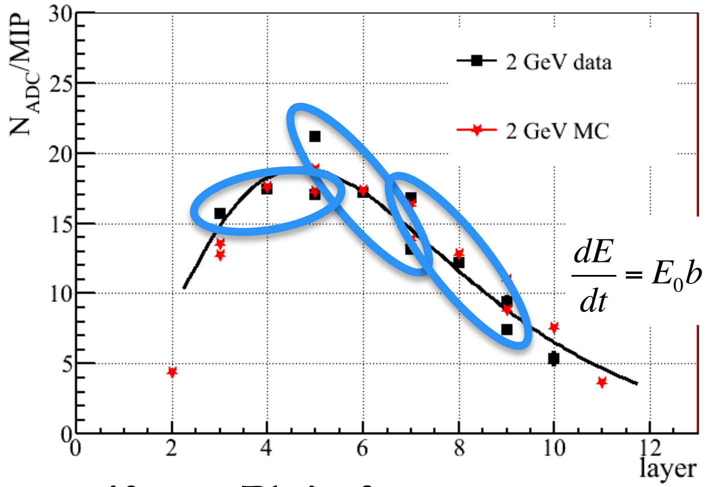


Cluster definition:

- 1st bar: deposit > 1 MIP
- Adjacent added if > 0.2 MIP
- Procedure repeated when no more fired neighboring bars
- Lateral shower containment cut is applied (<10% of the energy deposit on the edge)

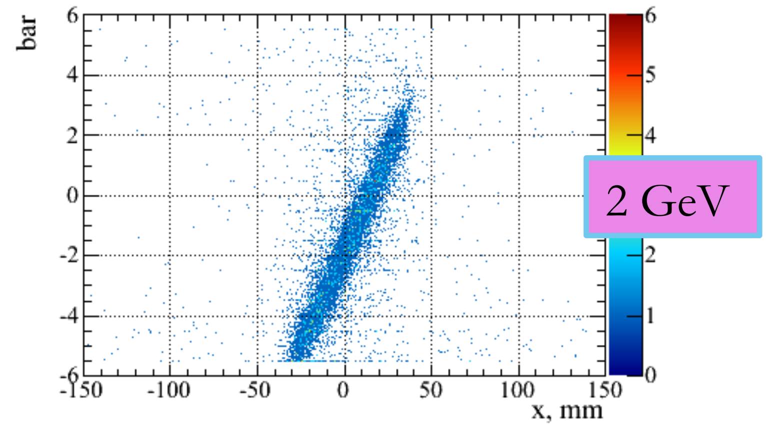
2 GeV shower development

2 GeV data vs MC



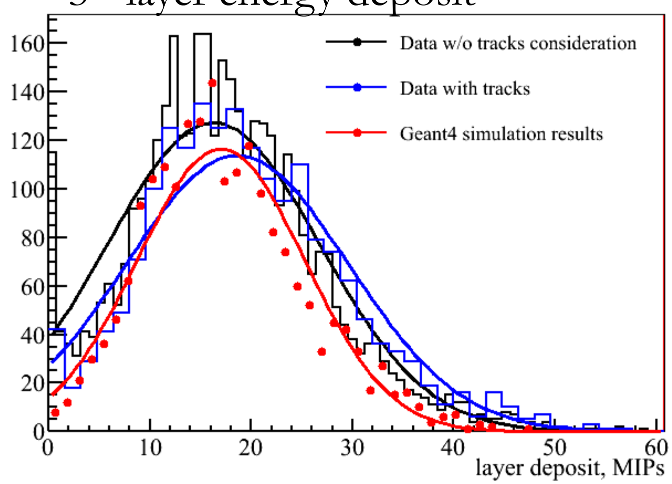
$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

Center of the cluster vs track coordinate

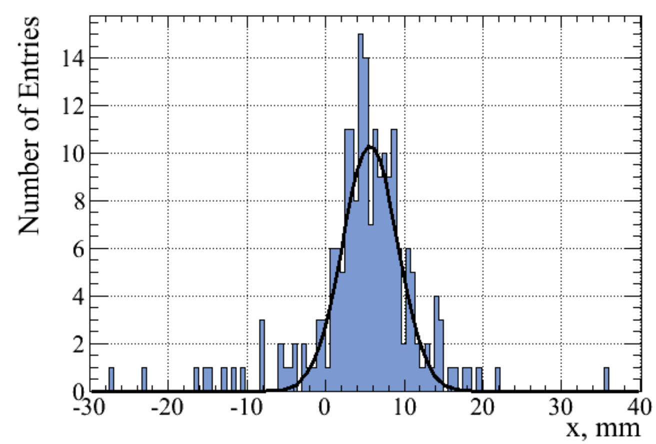


10 mm Pb in front

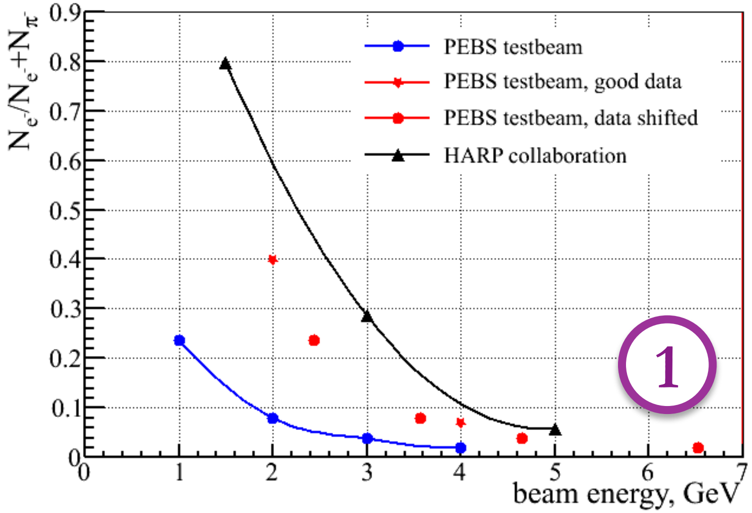
3rd layer energy deposit

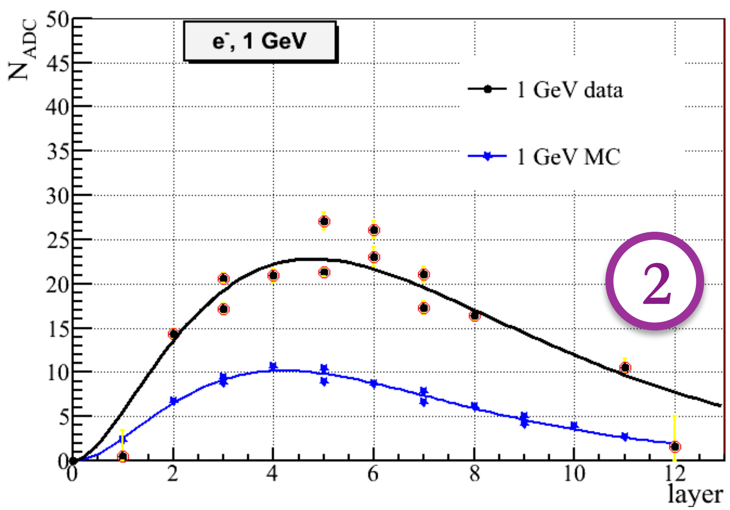


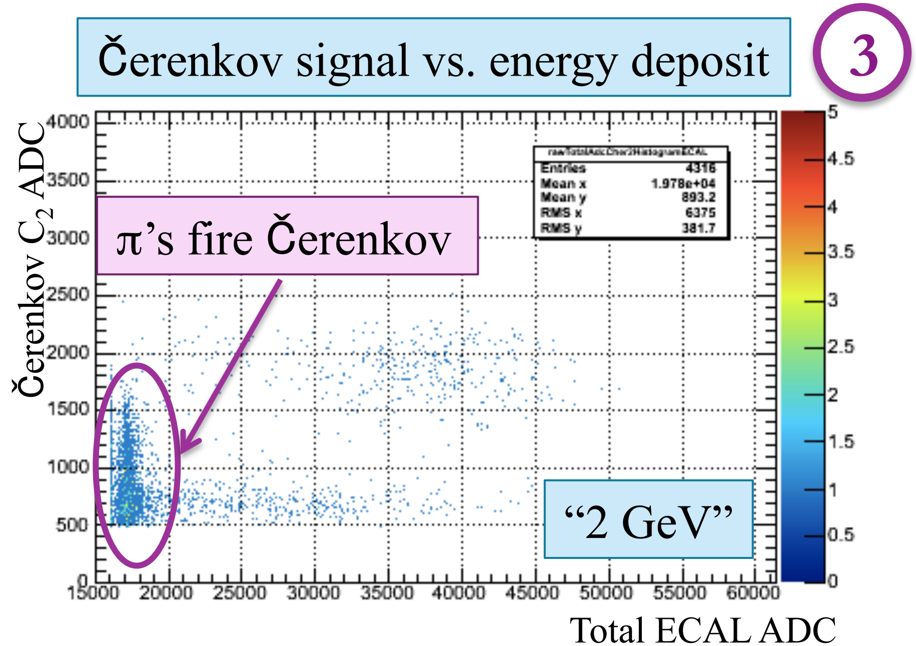
Resolution of the cluster center position vs tracker σ=3.5±0.3 mm



Puzzle with sets of 1-5 GeV: Solved!







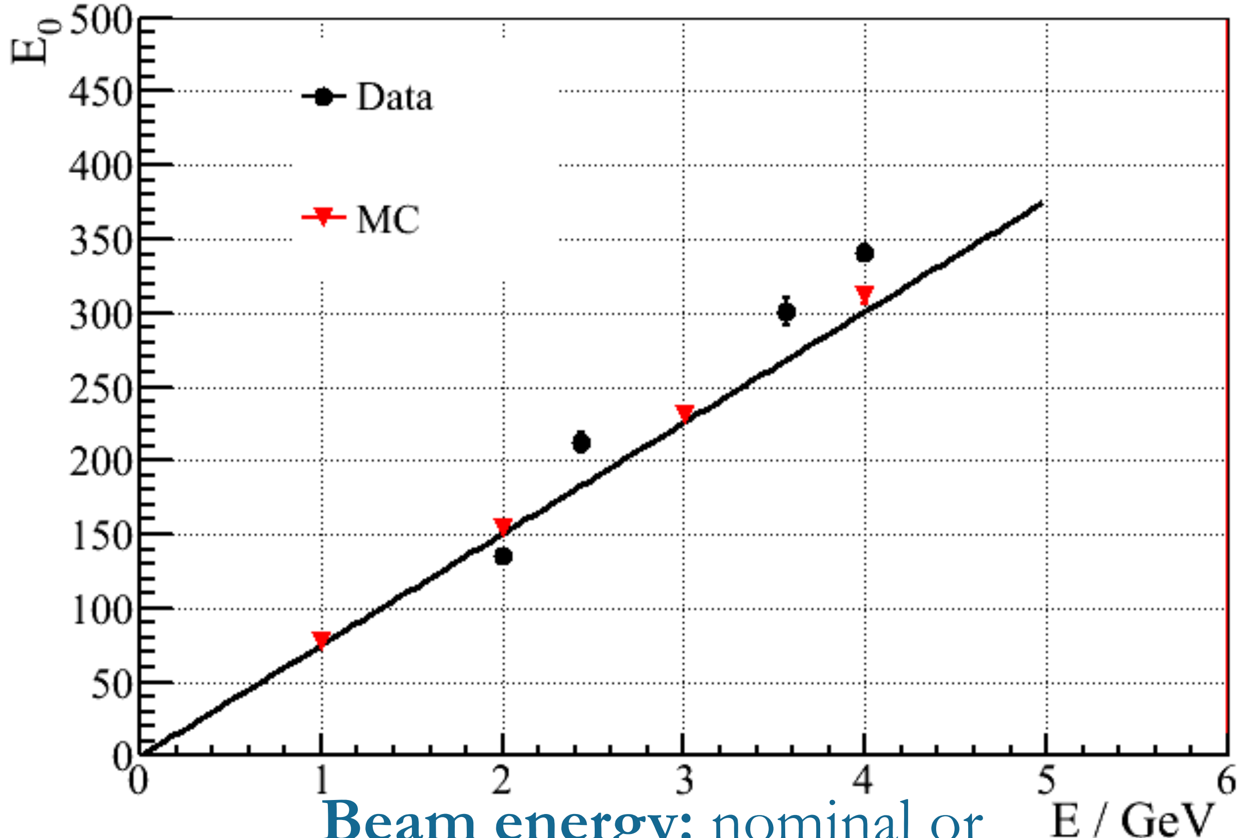
① Electron abundance in the beam much lower than nominal for given energy

② Over threshold Čerenkov signal for hadrons

③ Shower development vs. MC

Linearity of ECAL response

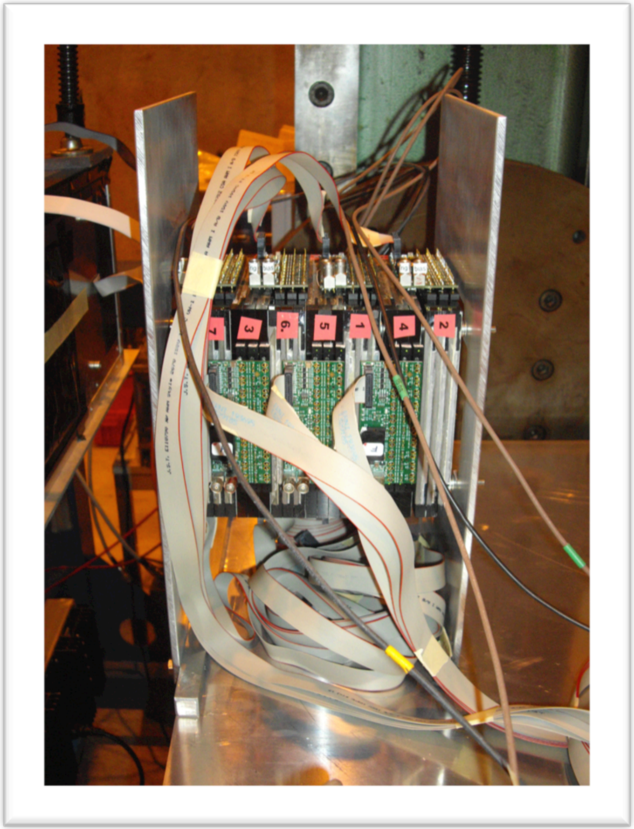
Fitted parameter:
from the shower shape

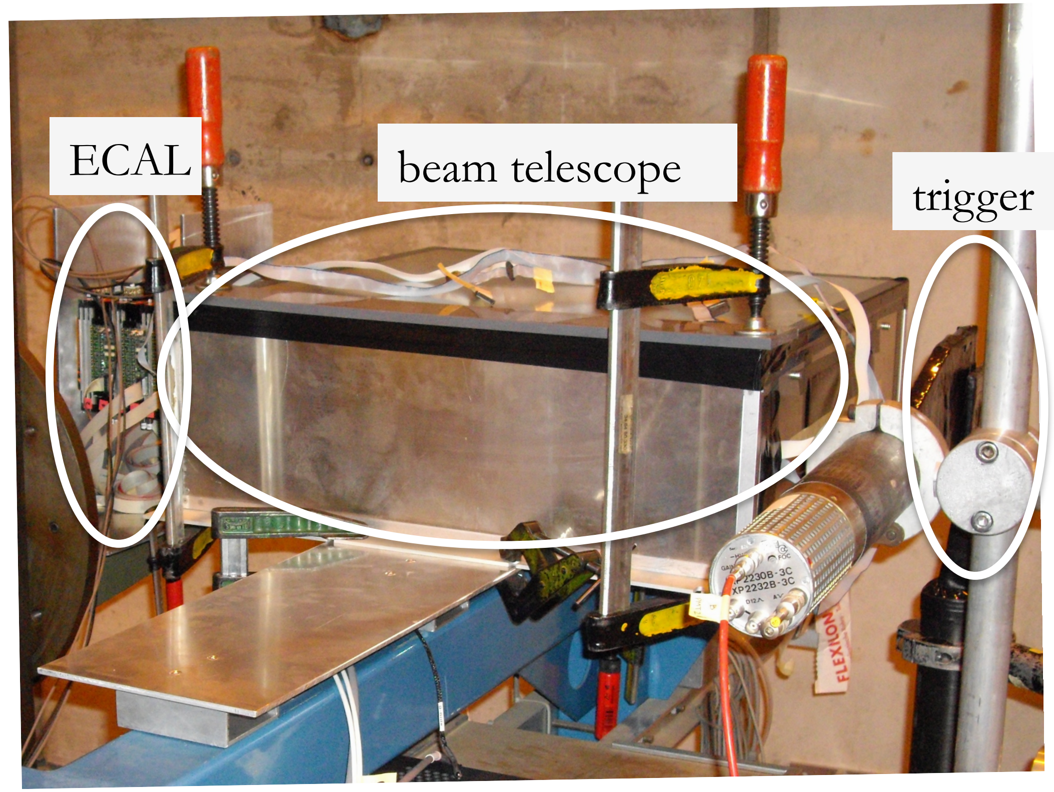


Beam energy: nominal or reconstructed with tracker

Prototype II: peculiarities

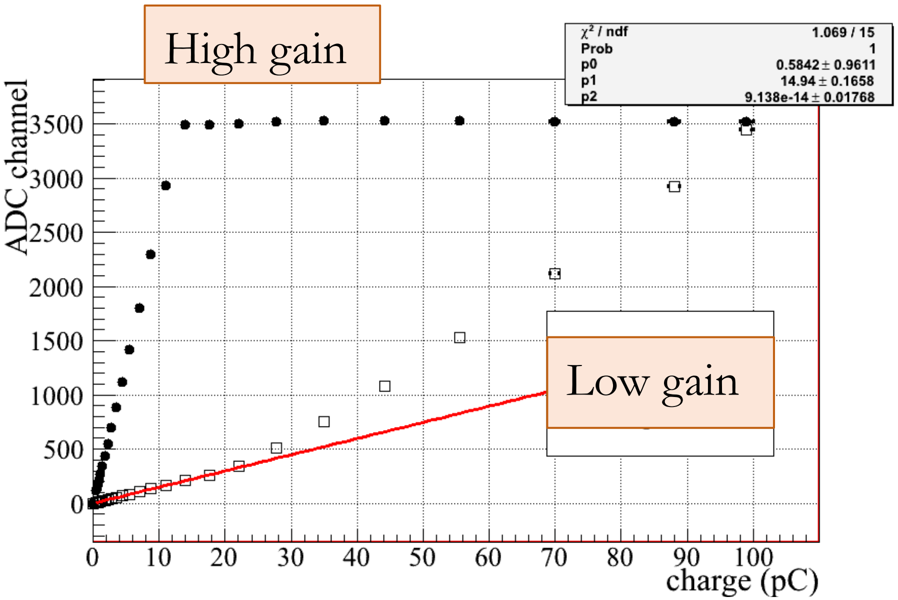
- **Testbeam setup:** prototype, beam telescope, 2 scintillators used for trigger

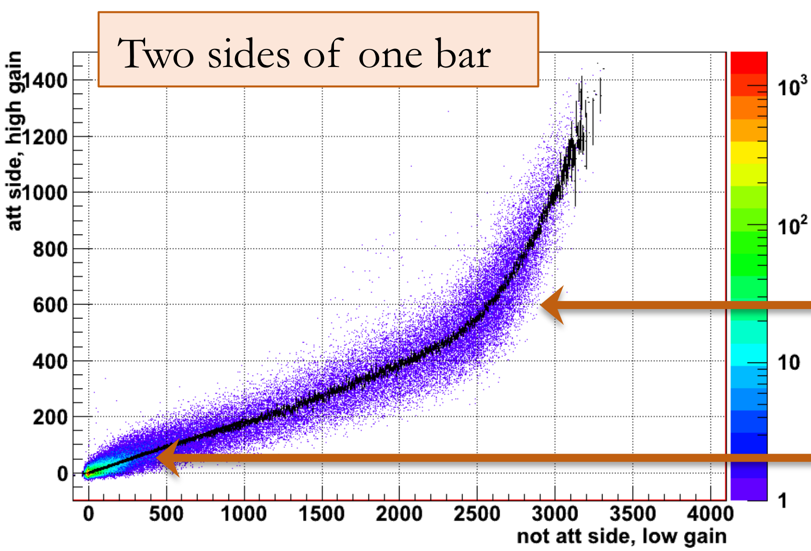




- **Prototype:** short bars ($3 \times 7.35 \times 114$ mm^3), W absorber, 21 layer, 18 X_0
- **Readout:** Signal from each SiPM digitized with 2 parallel outputs:
  - High gain: noise 7 ADC
  - Low gain: attenuation by factor ~17, noise 4 ADC
  - ➔4 readouts with gain ratio: 1:~1/17:~1/5:~1/17 (counting from the previous)

Challenges of the SPIROC readout





SiPM saturation visible at ~2500

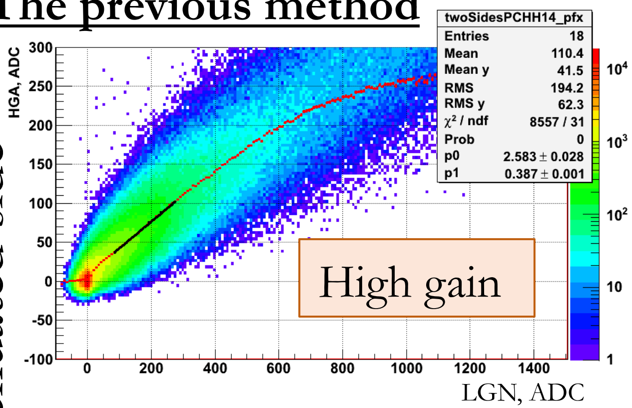
Start of electronics non-linearity

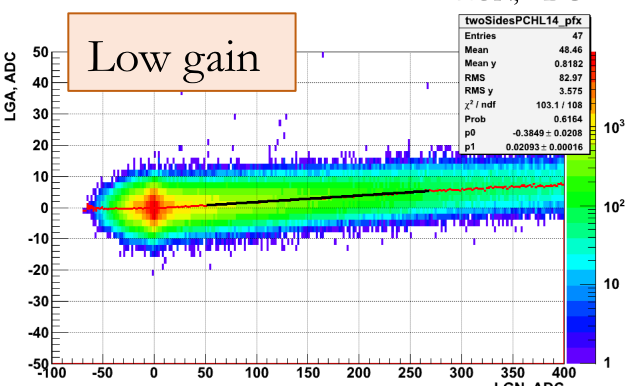
- ✓ Baseline shift with RMS = 20 ADC in high gain: non-trivial correction for events occupying more than 60% of ECAL
- ❑ After the high gain saturation the low gain response is non-linear:
  - ❑ This region coincides with the SiPM non-linearity
  - ❑ Those non-linearities are opposite in sign!
- ✓ When subjected to the intensive high charge injection high gain exhibits disproportional (smaller) signal or stops working

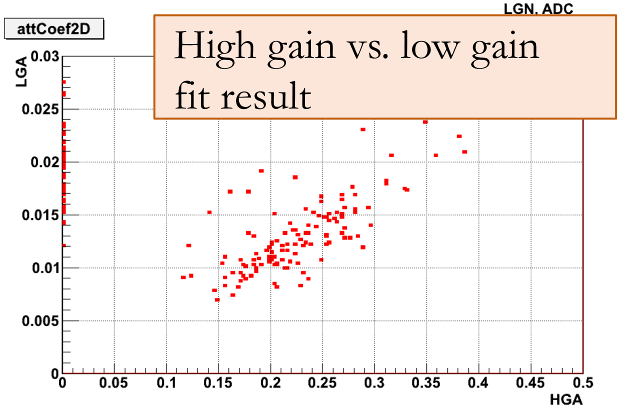
ECAL intercalibration II

The previous method

Attenuated side

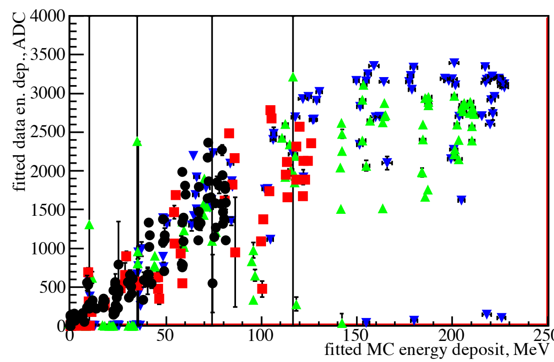




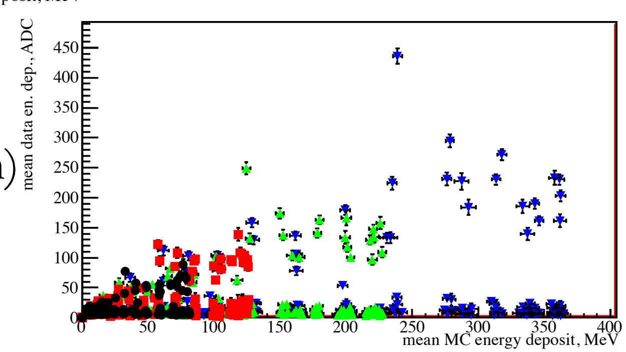


The new method tested:

- allows to parameterize all non-linearities
- uses GEANT4 description of the prototype
- energy deposit in each bar left by a particle passing through its central part is fitted with Gaussian for a range of energies and compared with MC result.



- Each color corresponds to e^- beam energy:
  - 25, 40, 75, 125 GeV
- Each point represents one channel



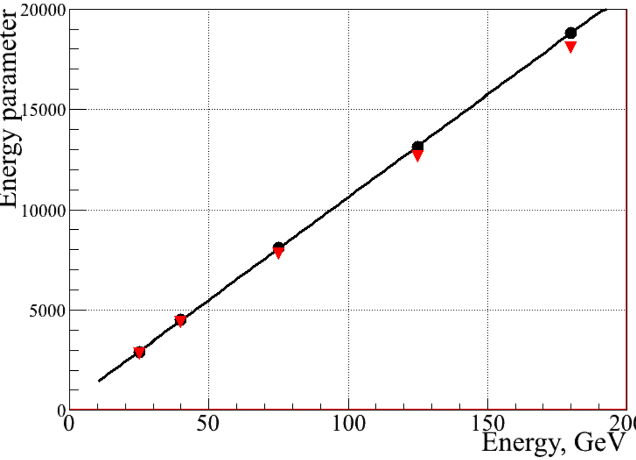
- Not attenuated side (up)
- Attenuated side (bottom)

ECAL performance

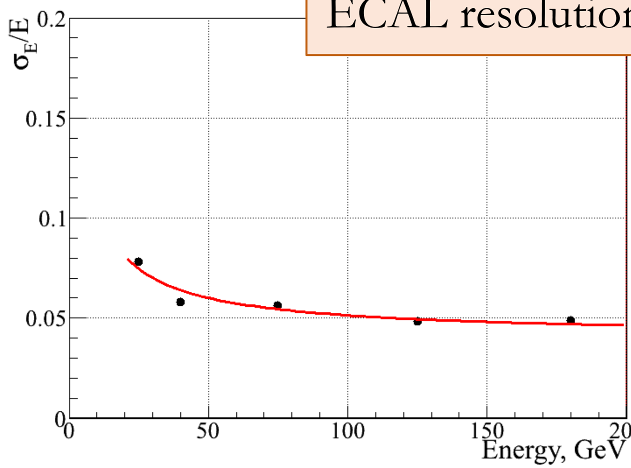
- Effectively 18 layers

Position resolution

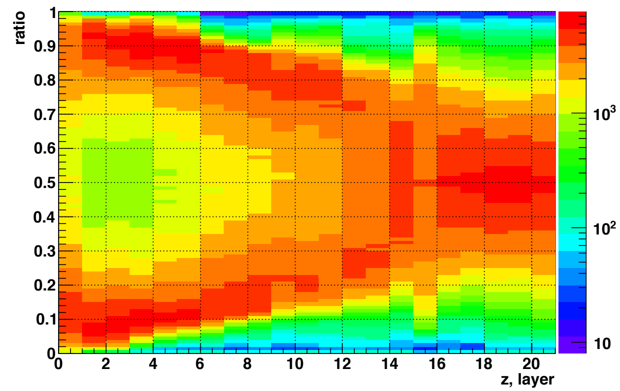
ECAL energy scale



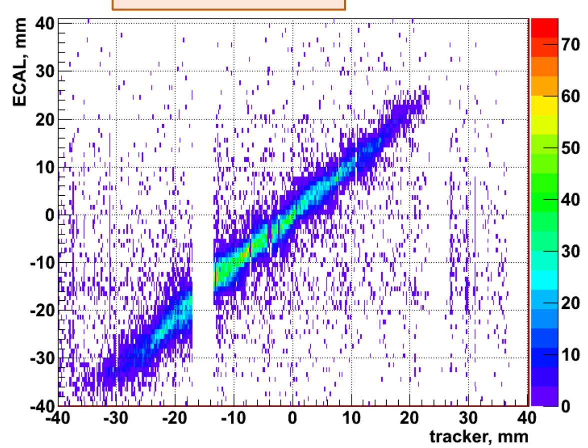
ECAL resolution



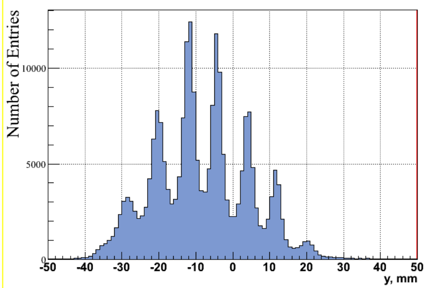
Ratio of signal in bars in cluster

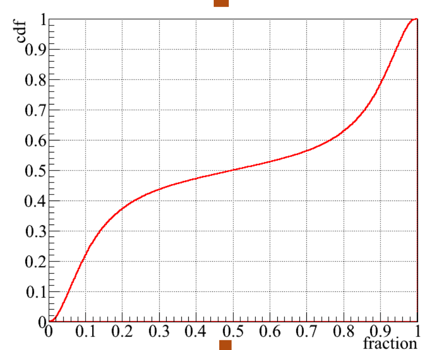


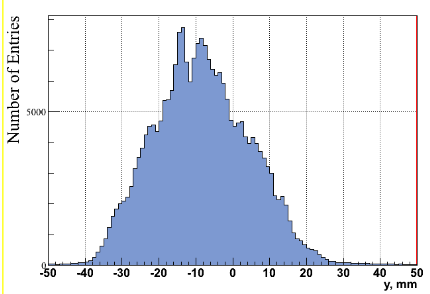
$\sigma \cong 2$ mm



2[nd] layer position

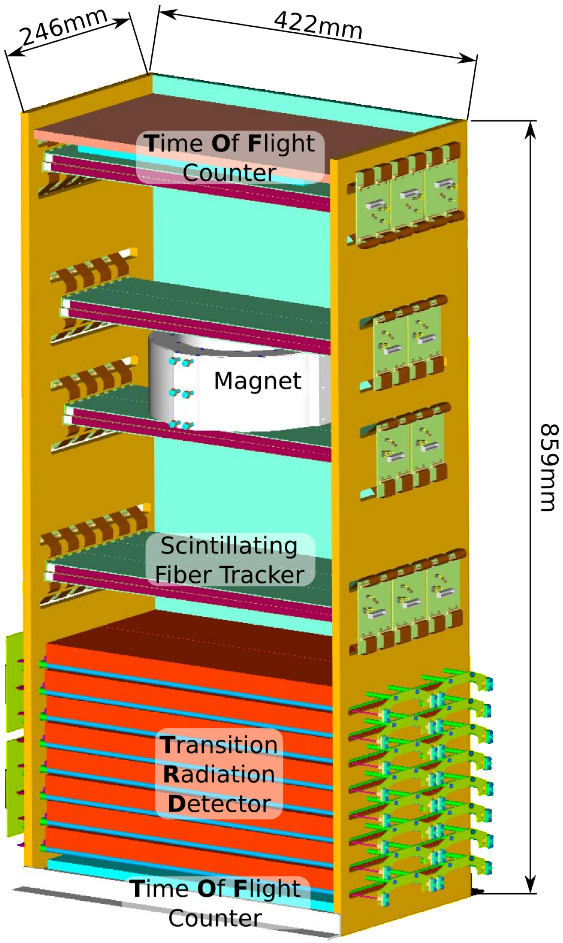




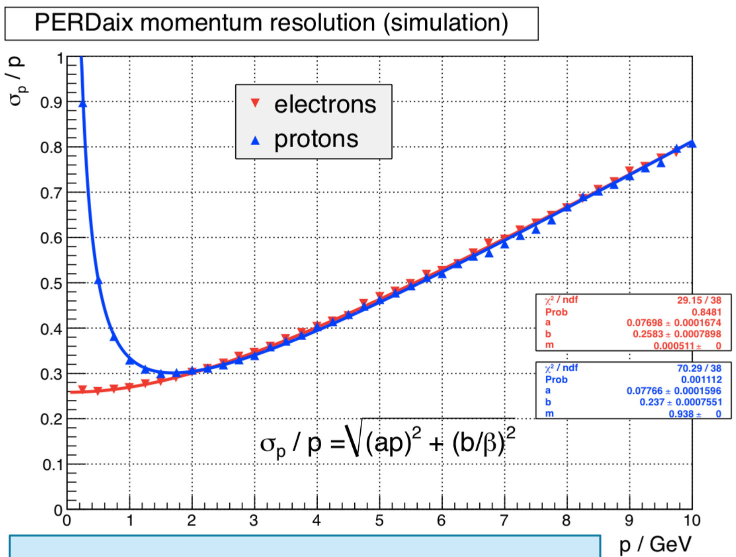


PERDaix project:
Proton Electron Radiation Detector Aix-la-Chapelle

- designed and built mainly by RWTH Aachen students
- electronics is provided by EPFL
- balloon-borne spectrometer
- goal range 0.5-5 GeV (maximal detectable rigidity 9.6 GV)
- can separate e^+, e^-, p, He
- acceptance is 58.7 cm^2 sr
- data taking for 2 hours at 33 km height
- the analysis of solar modulation of charged cosmic particles: fluxes are affected up to 10 GeV
- launch in November 2010 with the German-Swedish Balloon-borne Experiments for University Students (BEXUS) program
- PS T9 line testbeam in May 2011

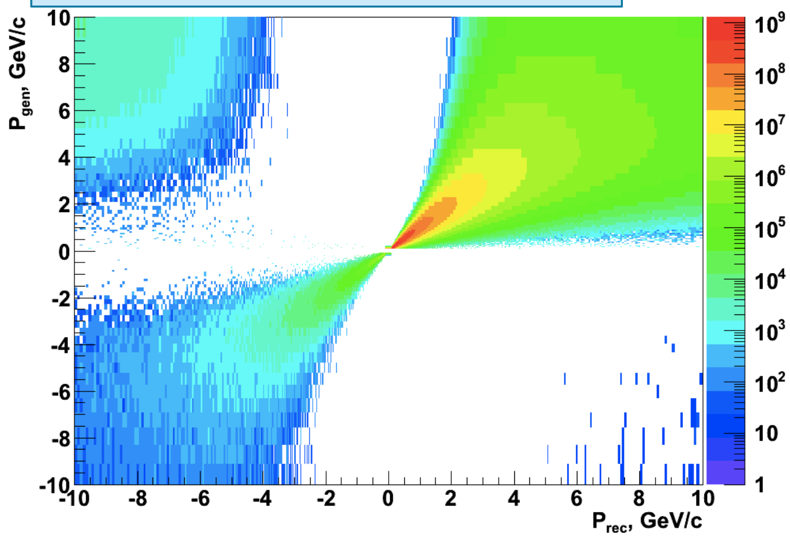


Study of the Unfolding option

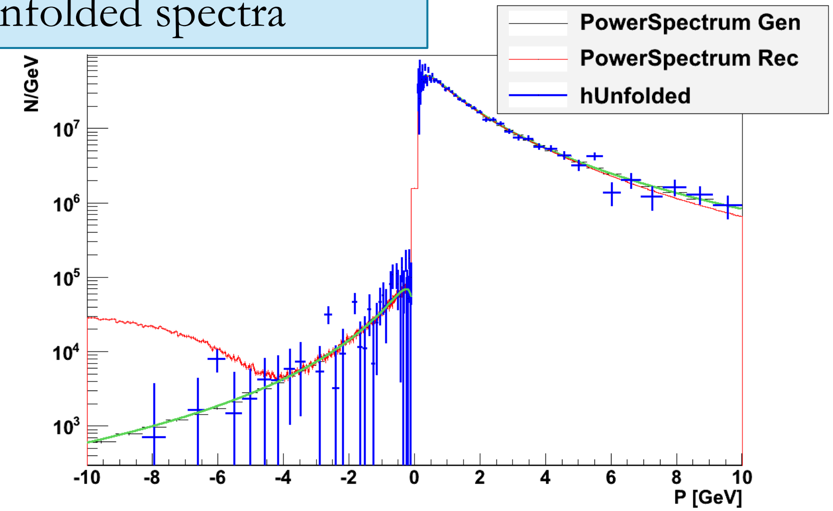


- main goal - cosmic ray spectra free from detector effects
- migration matrix common for p and e^-
- having correct migration matrix and e^-/p ratio it's possible to statistically correct final spectra w/o additional PID
- is under study

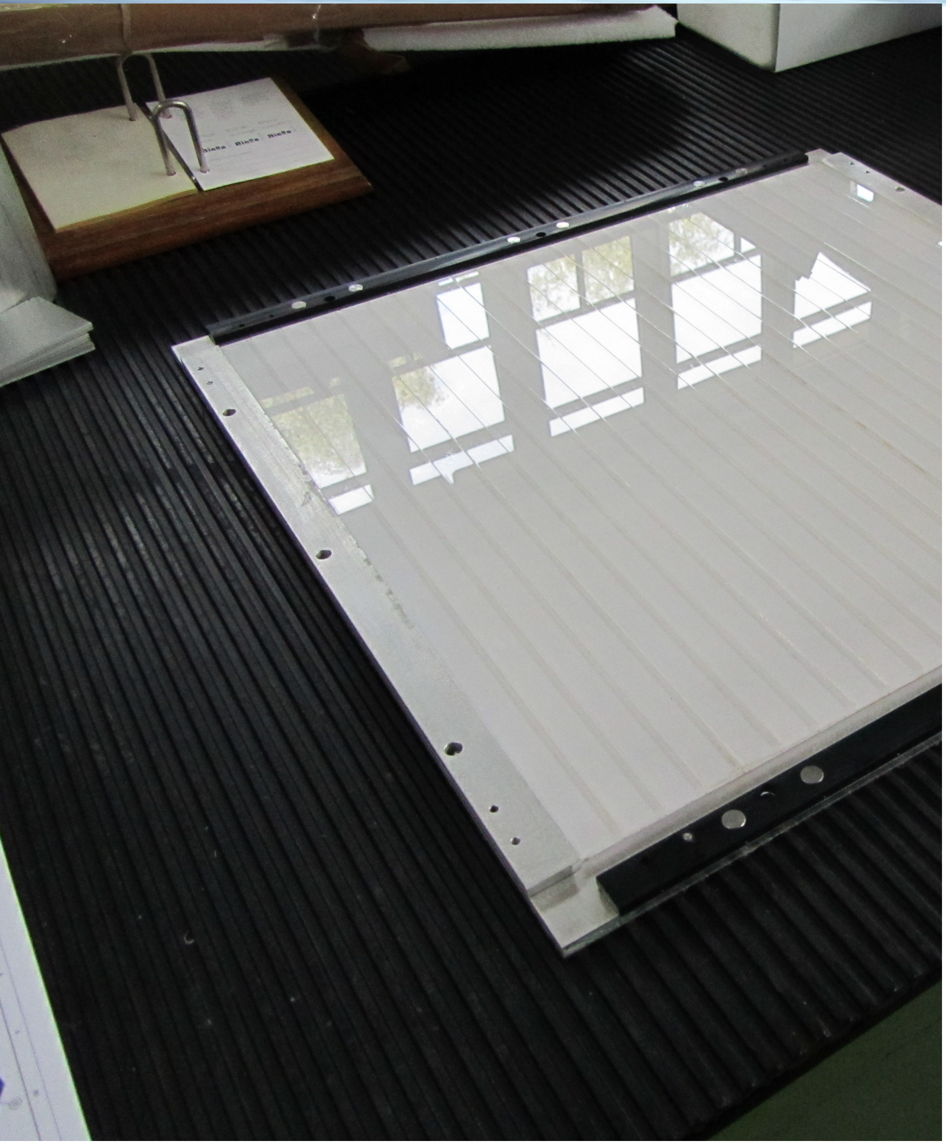
Migration matrix for p and e^-



MC for measured and unfolded spectra

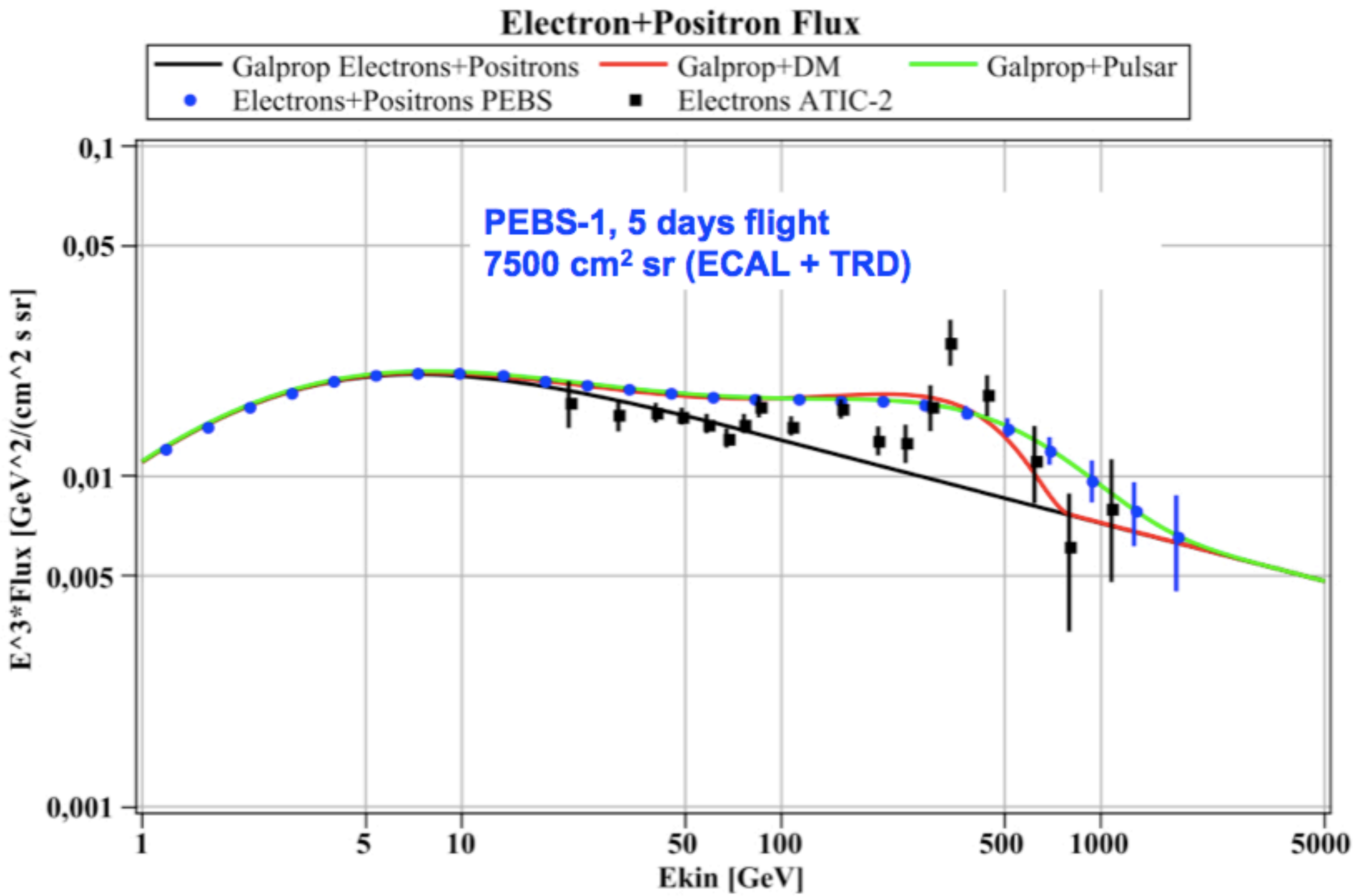


Conclusions and next steps



- Concept of the SiPMs and double-side readout is proved to be viable for PEBS ECAL
- SiPMs with larger dynamic range might replace "SiPM+light attenuation" system on one side
- The new electronics will be used with further prototypes
- Also intercalibration with the MC is tested and to be used along with the one presented here
- The e/p separation is studied with MC and being verified with the available data
- The next generation ECAL prototype is now in construction for the testbeam and then balloon flight in summer 2012:
  - ◆Active area 38.4×38.4 cm^2◆Pb absorber (4 mm)◆16 layers◆11.4X_0

BACK-UP SLIDES

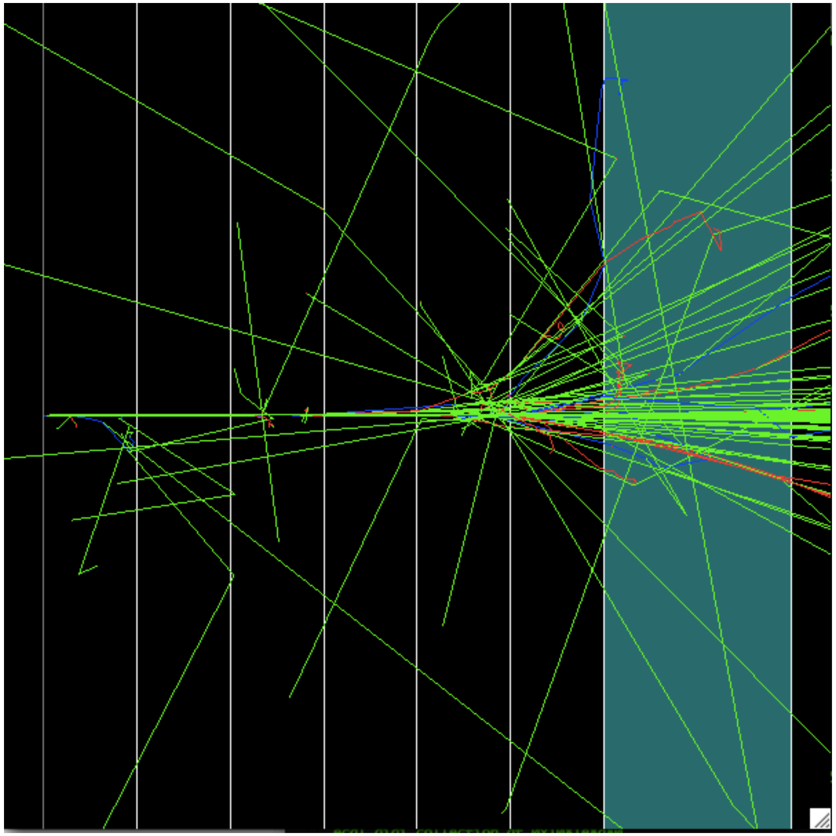


PEBS-1 potential

- e^+ and e^- separation up to 600 GeV (2nd phase up to 1.8 TeV)
- total e^++e^- spectrum up to 2 TeV (w/o charge sign identification)
- 2nd phase: antiprotons and He^3/He^4 up to 100 GeV/n

Shift between 2 same layer points

Titanium ($^{48}Ti_{22}$), X_0=3.56 cm



Tungsten ($^{184}W_{74}$), X_0=0.35 cm