A Novel Electromagnetic Calorimeter for a Balloon Borne Spectrometer

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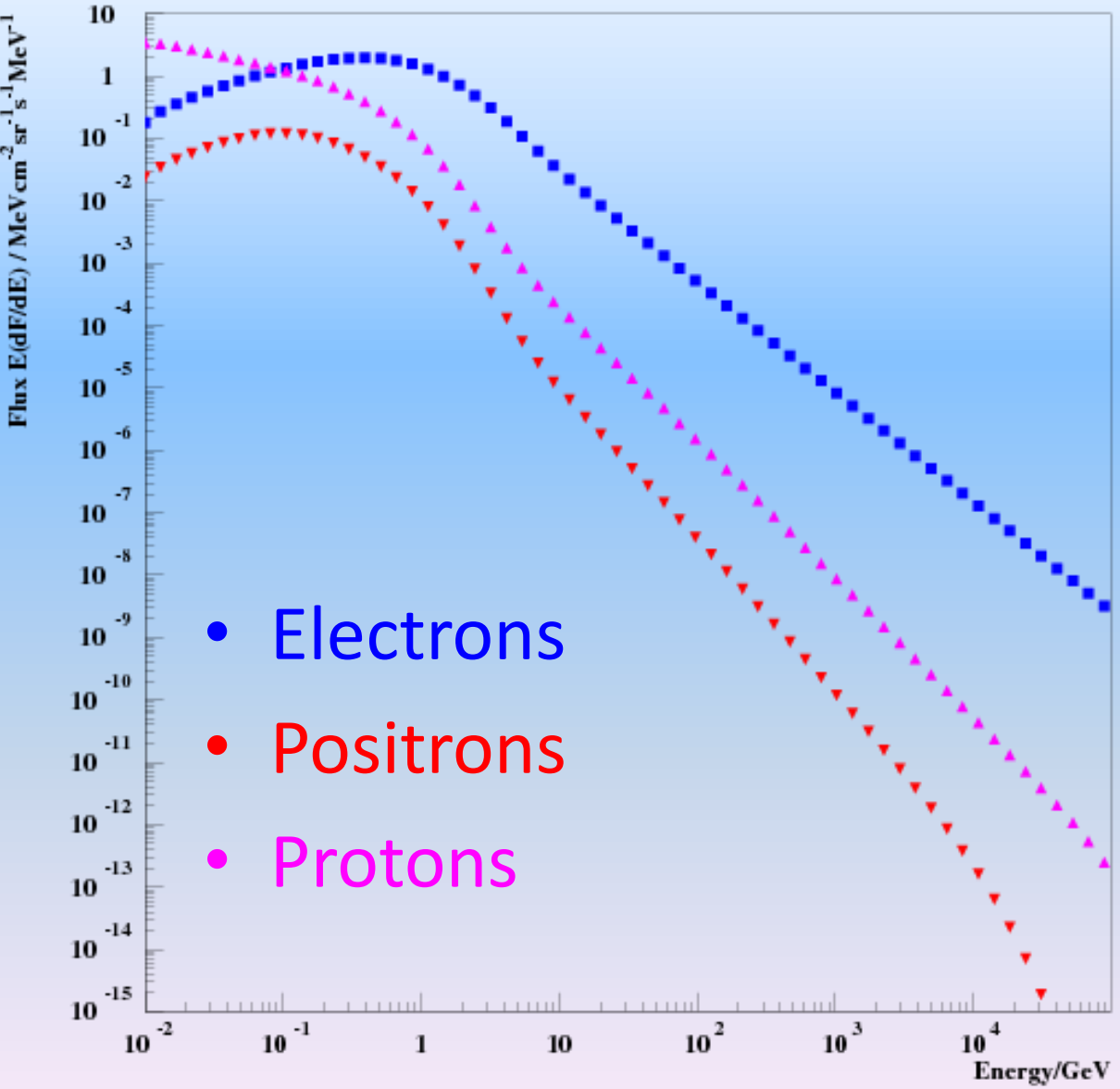
Overview

1. Why measure positrons up to 1 TeV (or beyond)?
2. PEBS concept
3. Electromagnetic Calorimeter
4. Design performance
5. Testbeam 2010
6. Novel SiPM read-out
7. Characterisation of new prototype
8. Summary and Conclusions

Our Understanding (GALPROP)

- GALPROP is a numerical code for calculating the propagation of relativistic charged particles and the diffuse emissions produced during their propagation. The GALPROP code incorporates as much realistic astrophysical input as possible together with latest theoretical developments.
- http://galprop.stanford.edu/

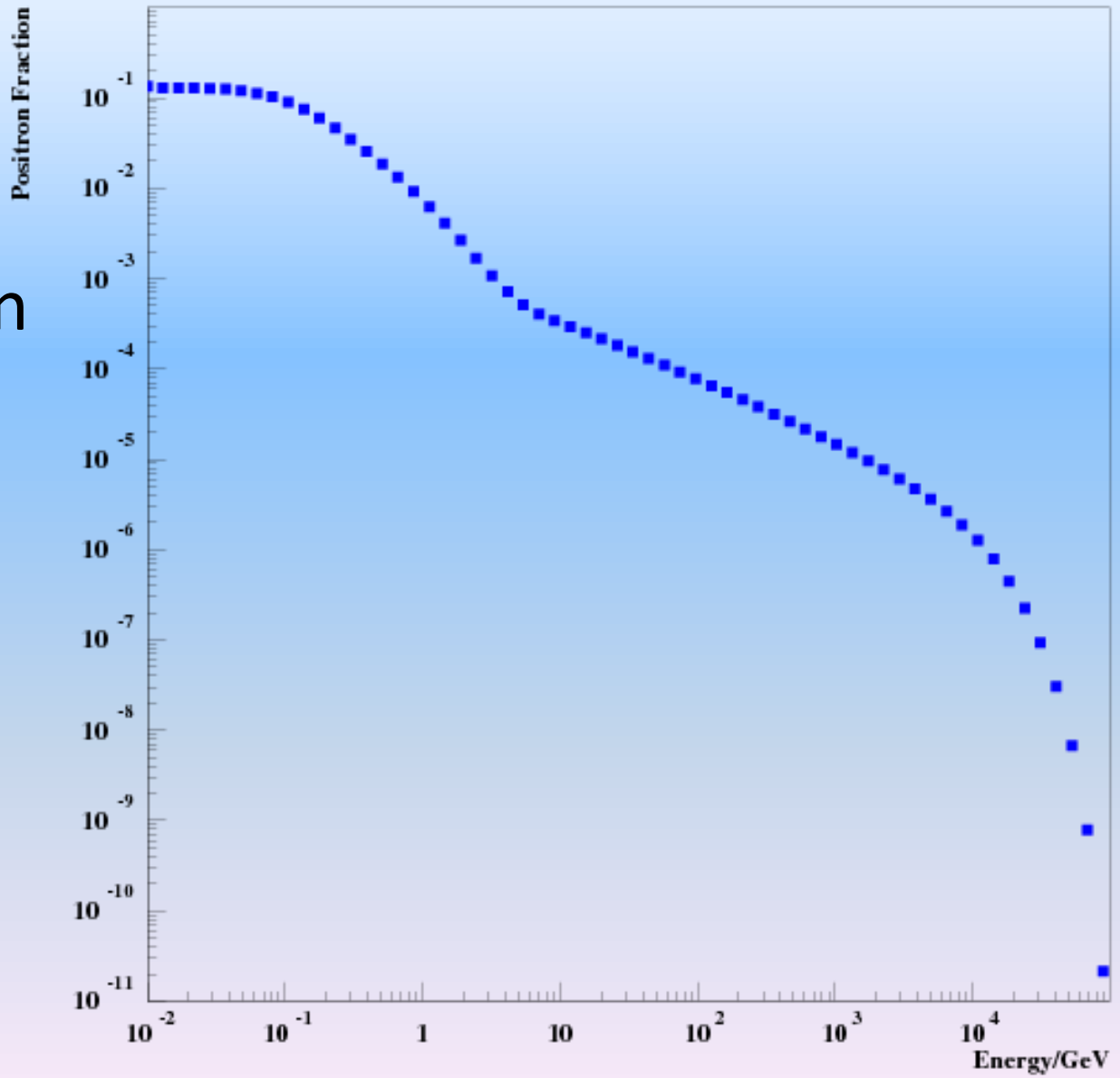
GALPROP: Cosmic Ray Fluxes



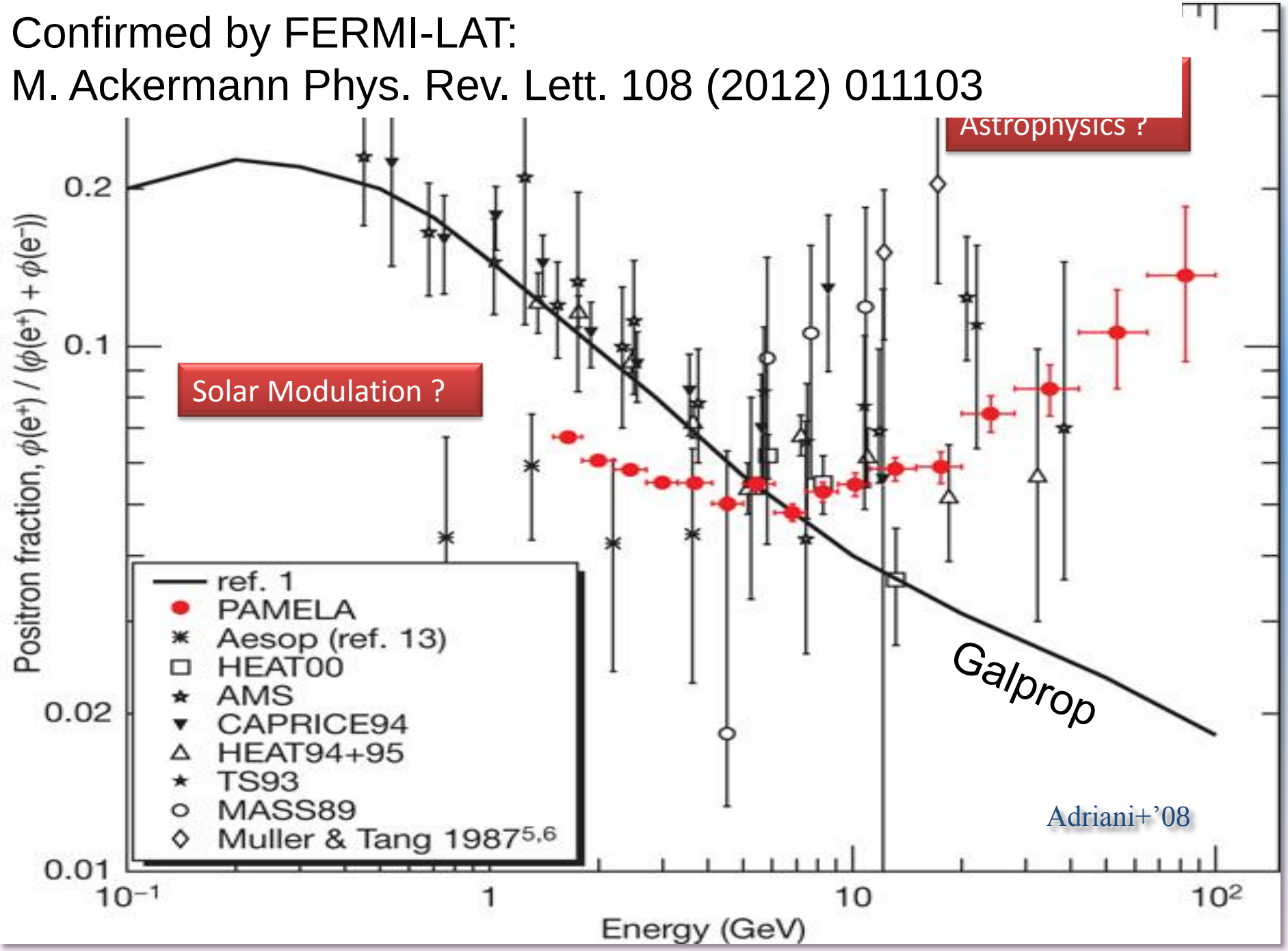
Spectra drop steeply with increasing energy

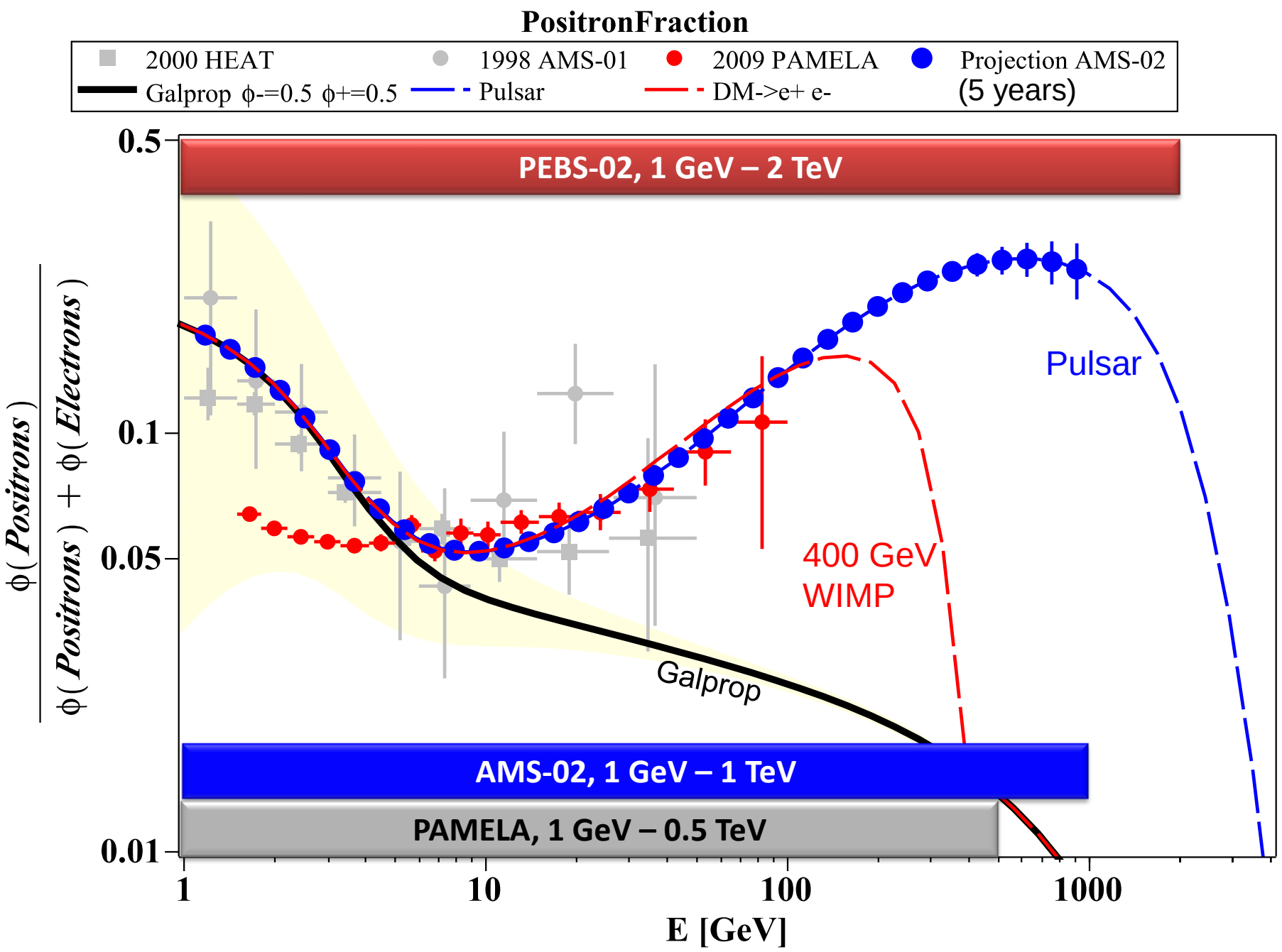
Positron Fraction

- Positron fraction decreases even more rapidly

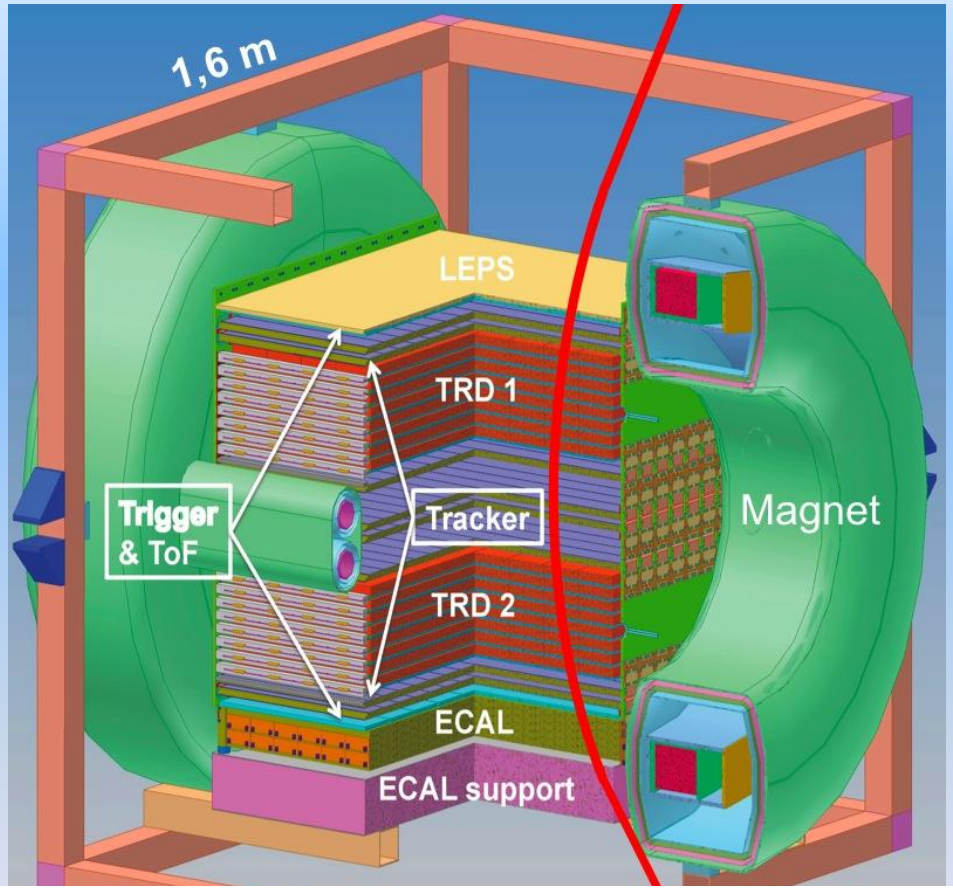


Confirmed by FERMI-LAT:
M. Ackermann Phys. Rev. Lett. 108 (2012) 011103

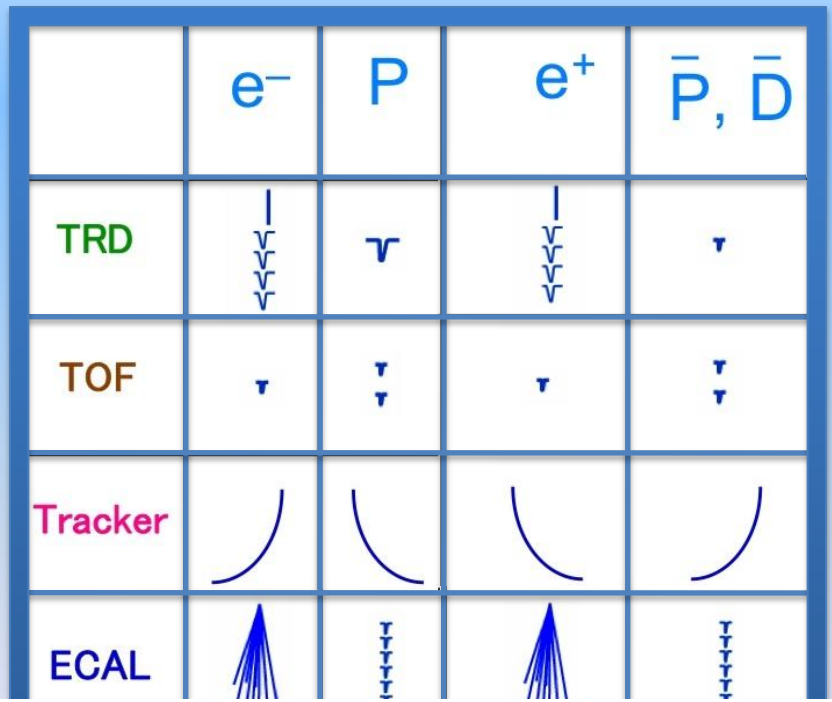



PositronFraction
2000 HEAT
1998 AMS-01
2009 PAMELA
Projection AMS-02
(5 years)
Galprop ϕ-=0.5 ϕ+=0.5
Pulsar
DM->e+ e-
PEBS-02, 1 GeV – 2 TeV
AMS-02, 1 GeV – 1 TeV
PAMELA, 1 GeV – 0.5 TeV
Pulsar
400 GeV
WIMP
Galprop
0.5
0.1
0.05
0.01
1
10
100
1000
E [GeV]
ϕ(Positrons) / ϕ(Positrons) + ϕ(Electrons)

PEBS Experiment



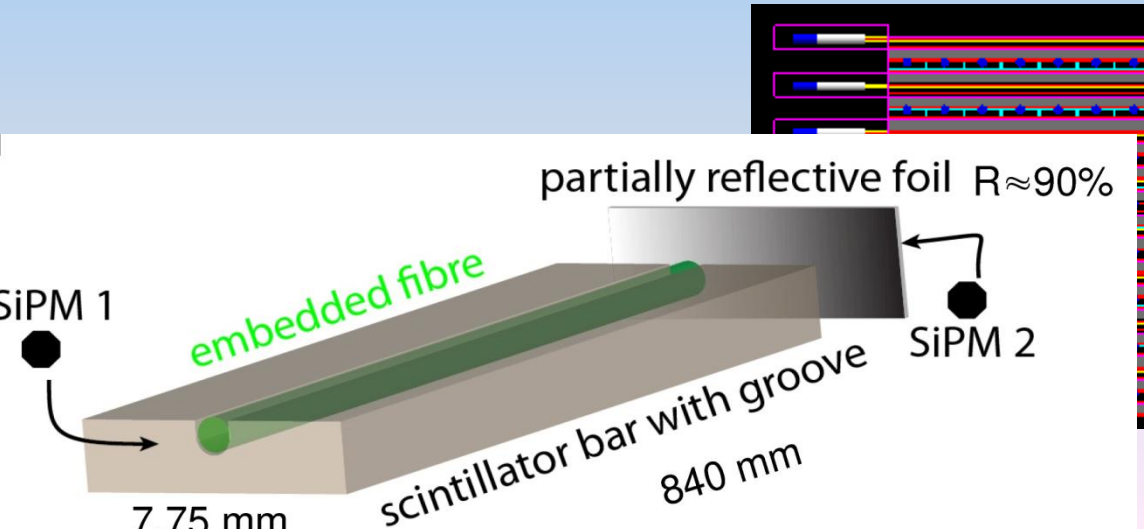
The overall height, including the lower crush pads, is 2.7 m and the overall width is 3.3 m. The total weight of the instrument is 2000 kg.

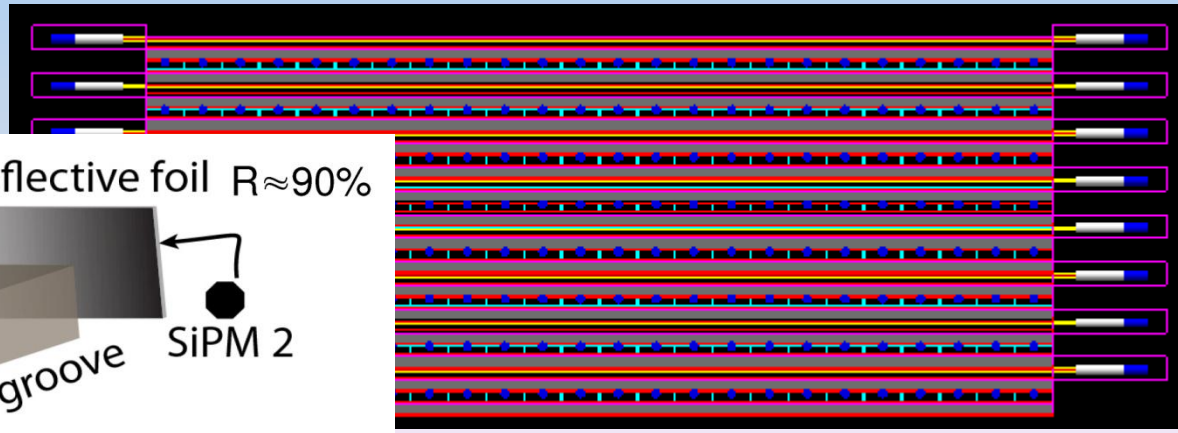


Tracker, magnet, TRD→ 10^3 proton rejection
ECAL → 10^3 proton rejection at high energy
Superconducting magnet – Charge measurement > TeV (e^+/e^-)

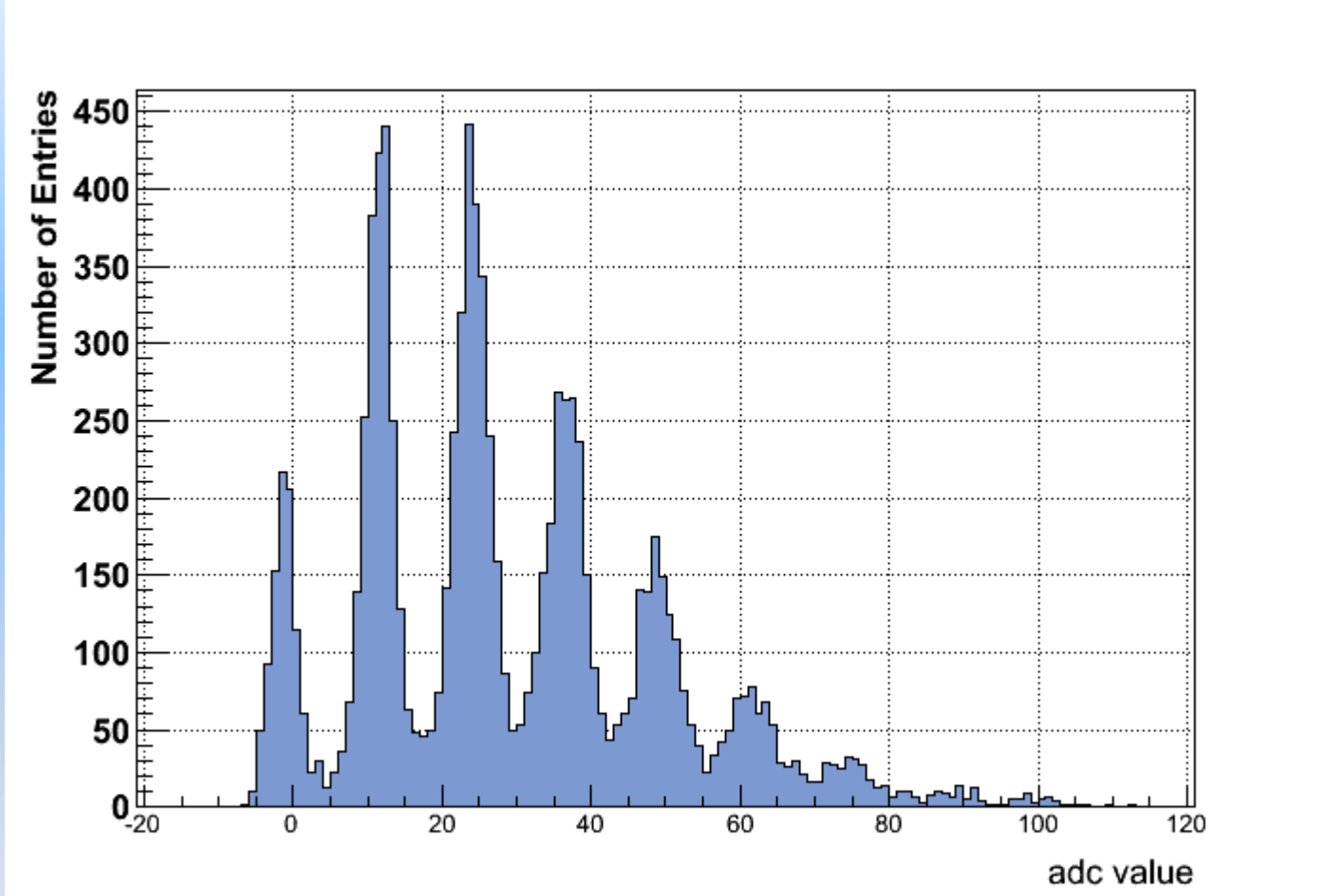
Electromagnetic Calorimeter

- Crucial to measuring the high energy positron spectrum is to reject significant background from protons (>10^3 suppression)
- A lead-scintillator sampling calorimeter with 6mm Pb, 4mm Sci
- Scintillator read-out with embedded wavelength shifting fibres
  - Improves homogeneity and shower shape reconstruction
- Read-out with novel SiPMs
- Dynamic range needs to be from MIPs to ~3000 MIPs
  - Split gains, different read-out on each end of the fibre

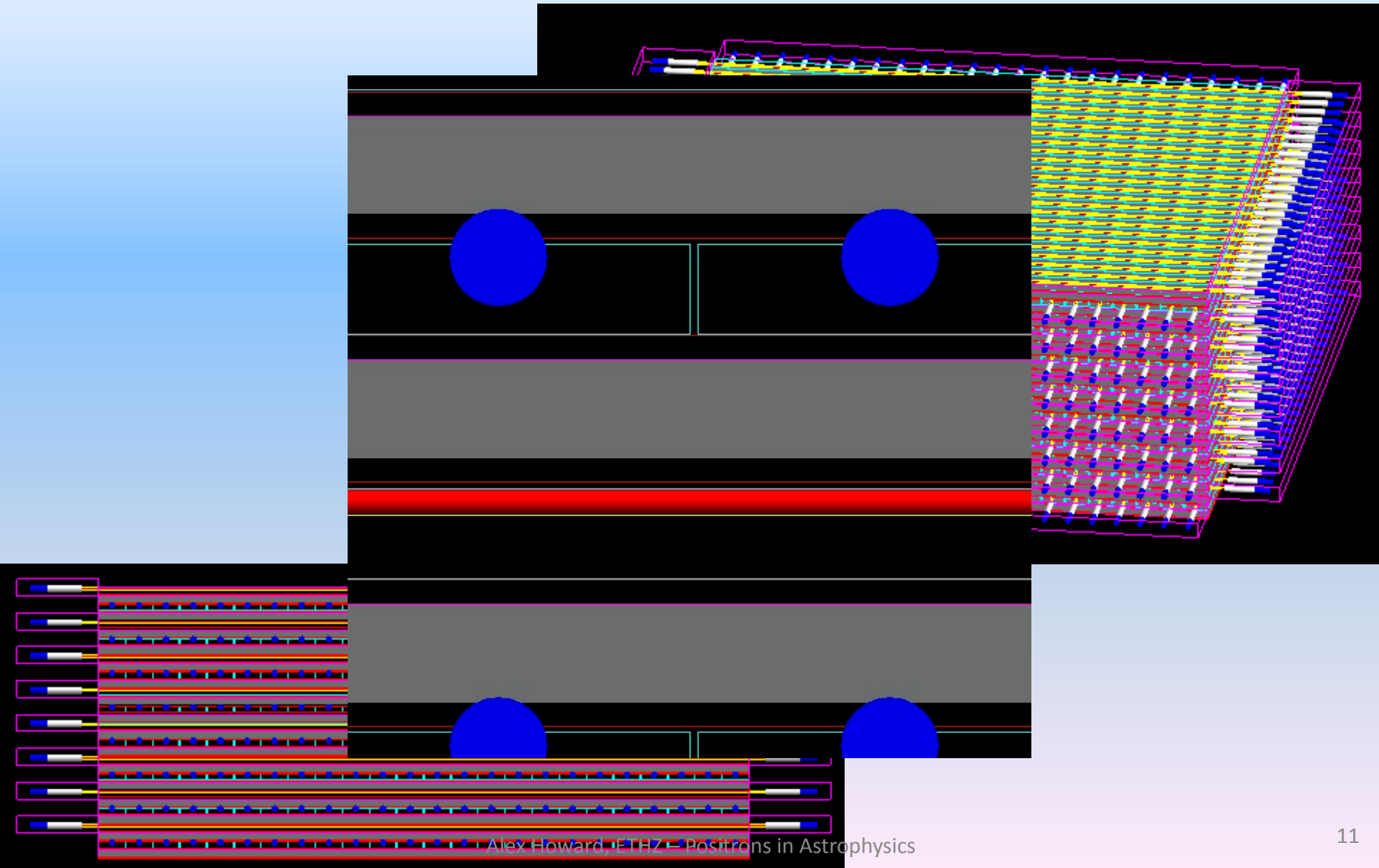




Single Photoelectron Resolution



Geant4 – Full Prototype



Rejection Factors

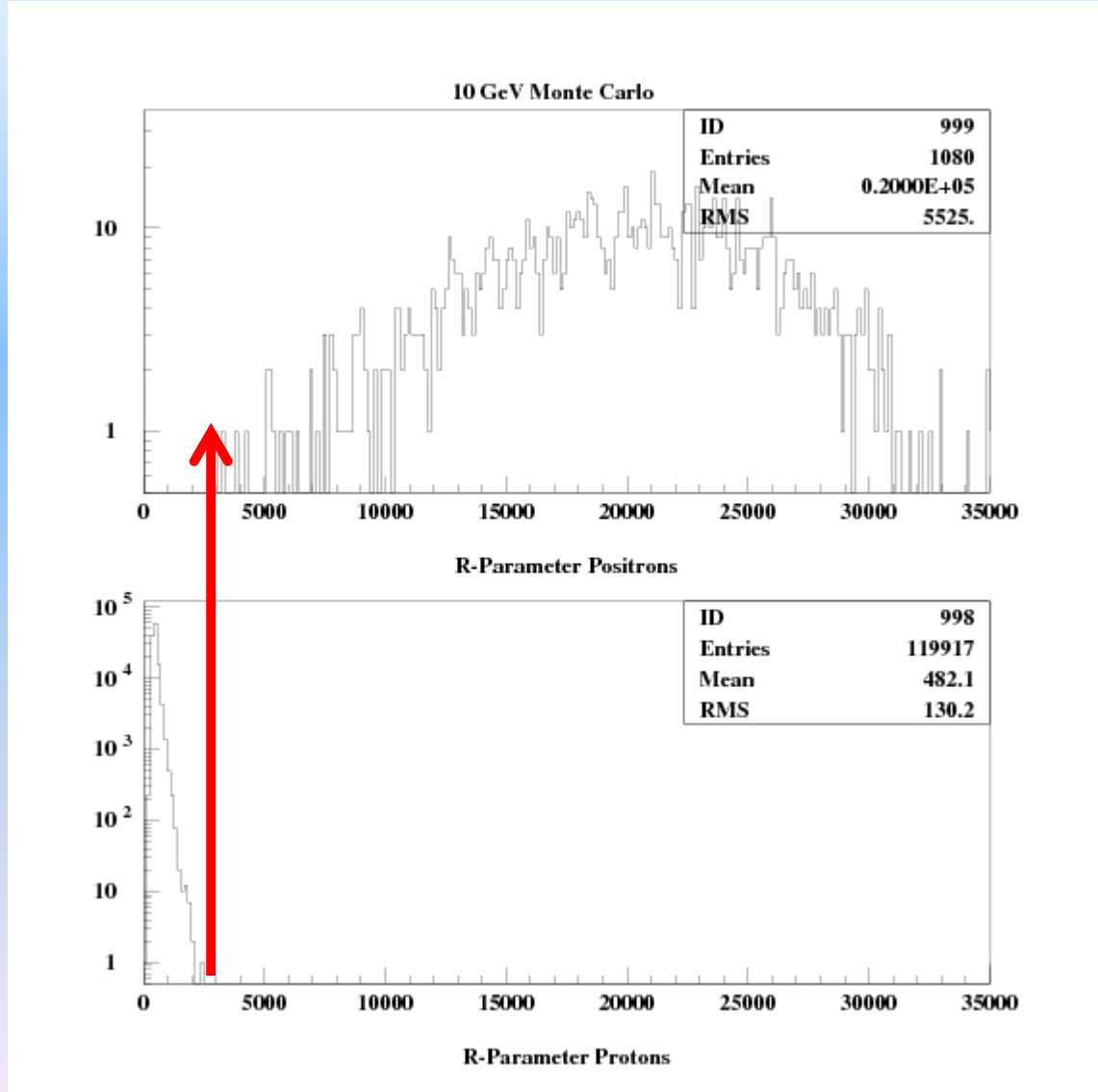
- R-parameter:

  $\sum$ (bar_signal x layer)

  within two Moliere radii and up to the shower maximum
- PAMELA used this approach

M/C Positrons vs. Protons

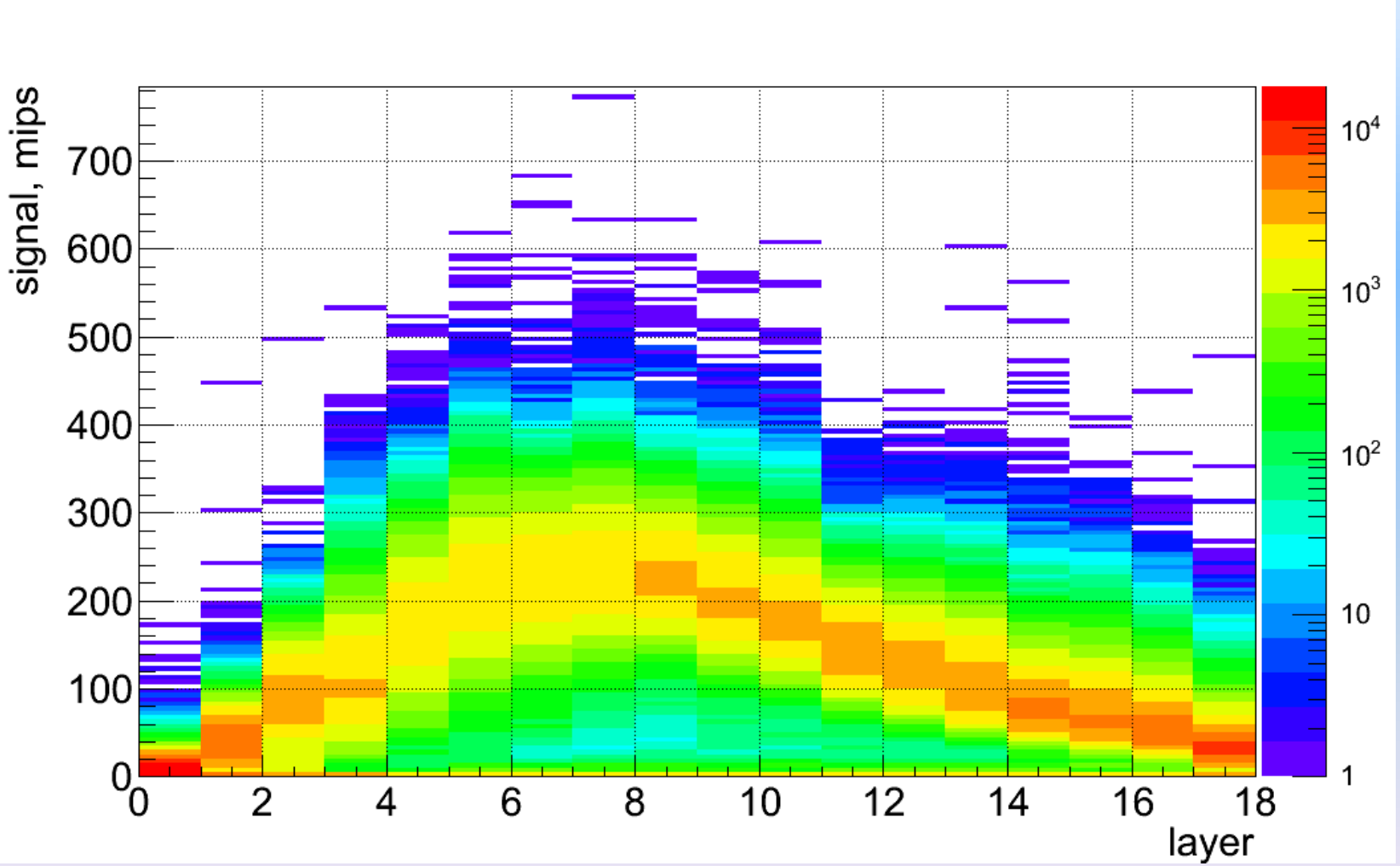
- Recent Monte Carlo of test beam set-up
- 120000 protons do not give an electron-like signal
- @10 GeV
- High energy data in progress



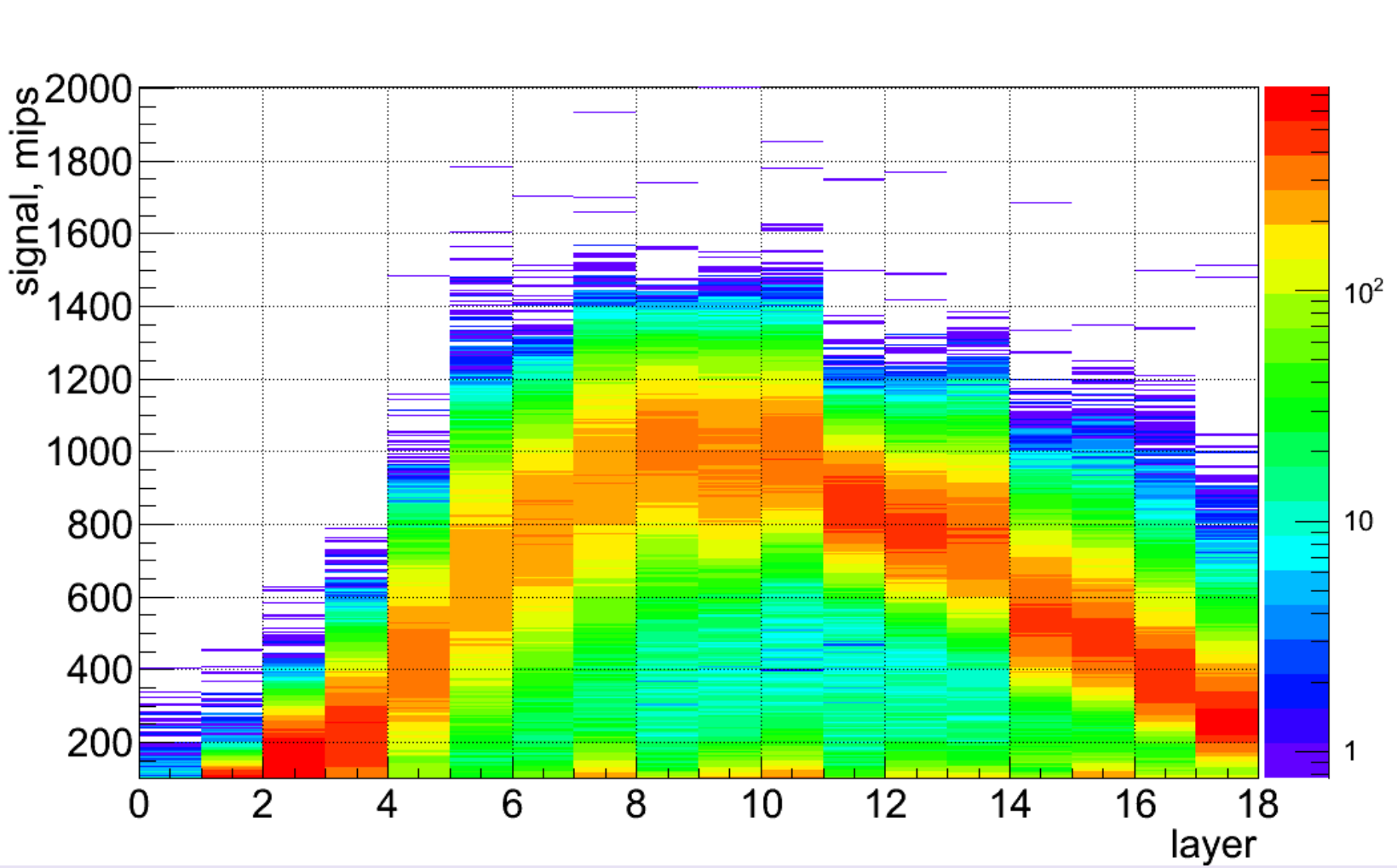
Testbeam'10

- One type of SiPM (Hamamatsu)
- Proton contamination in the beam above 50 GeV
- Change of read-out electronics (SPIROC)
- Attenuated filters introduced on one side
  - Split gain
  - Four options of read-out range
  - Unfortunately cross-talk and non-linearity when high gain channel saturated
  - Analysis hard…

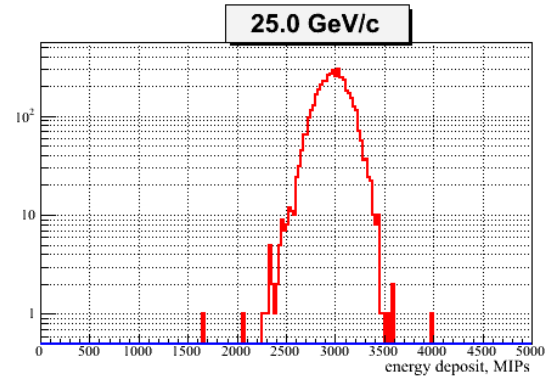
Shower Profile 25 GeV Positrons

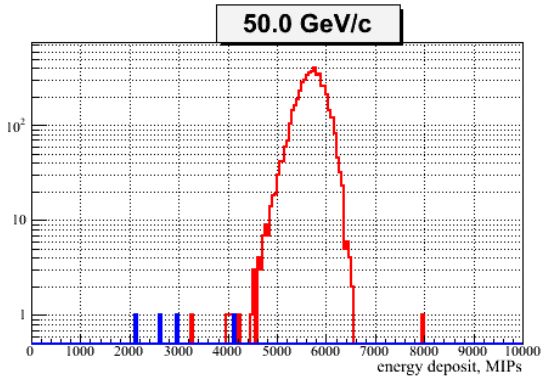


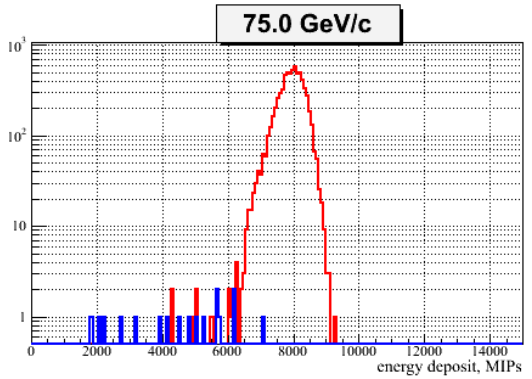
Shower Profile 125 GeV Positrons

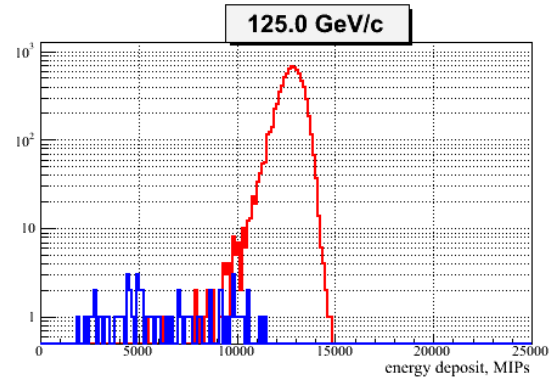


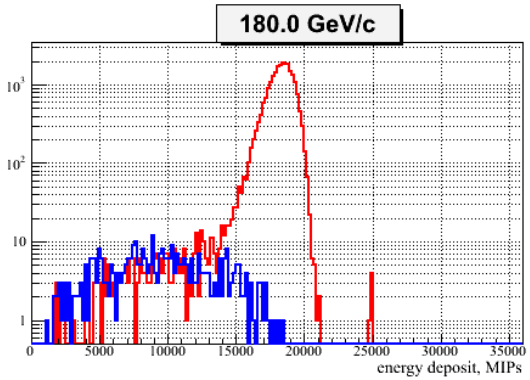
Beam Contamination



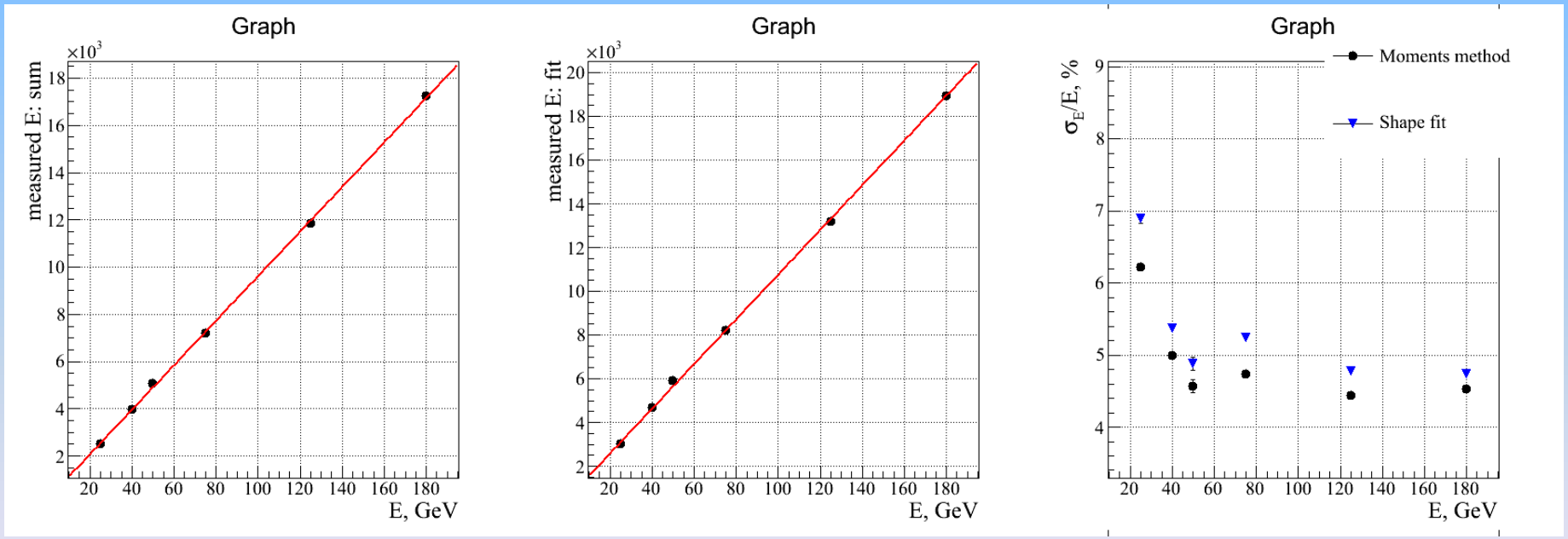






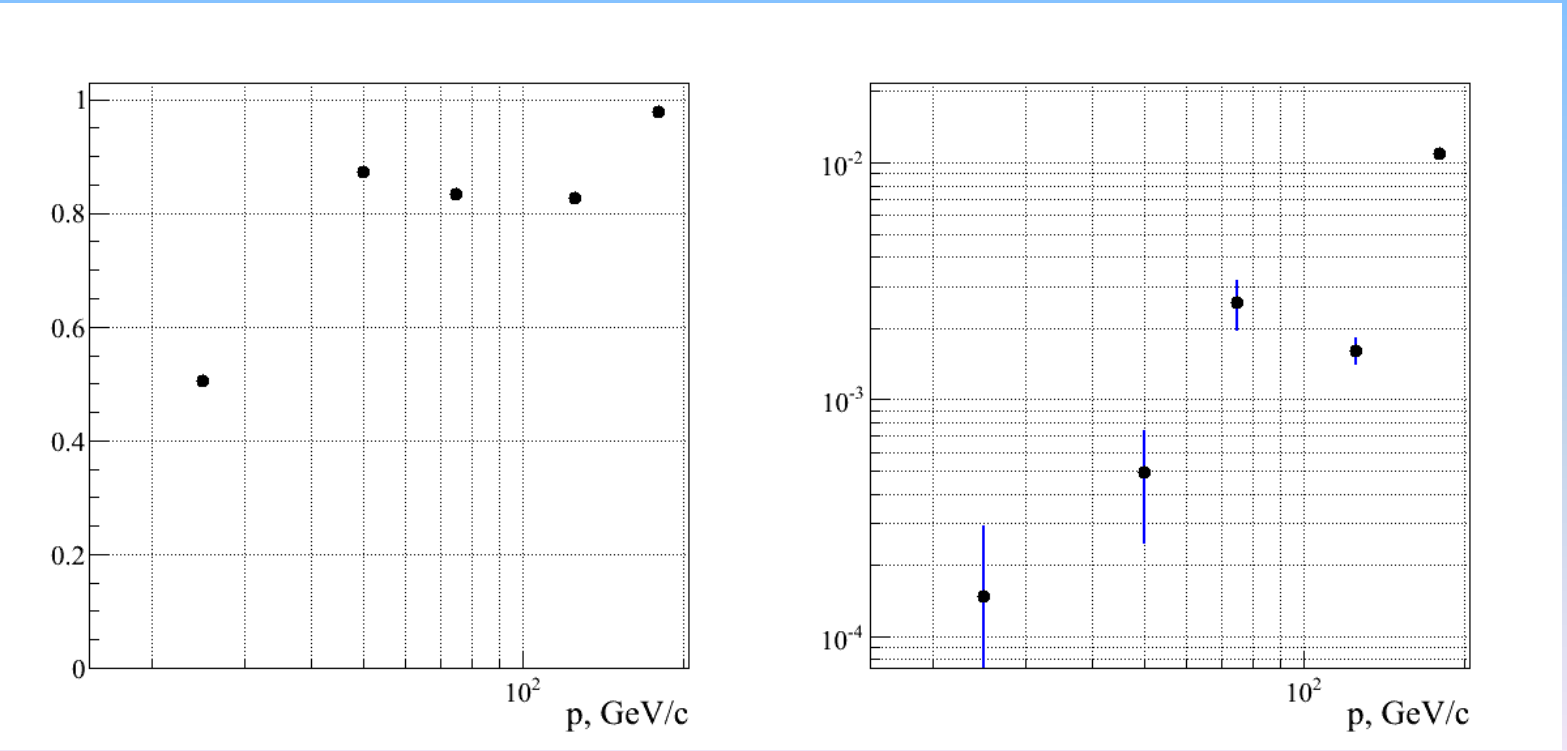


Energy Linearity and Resolution



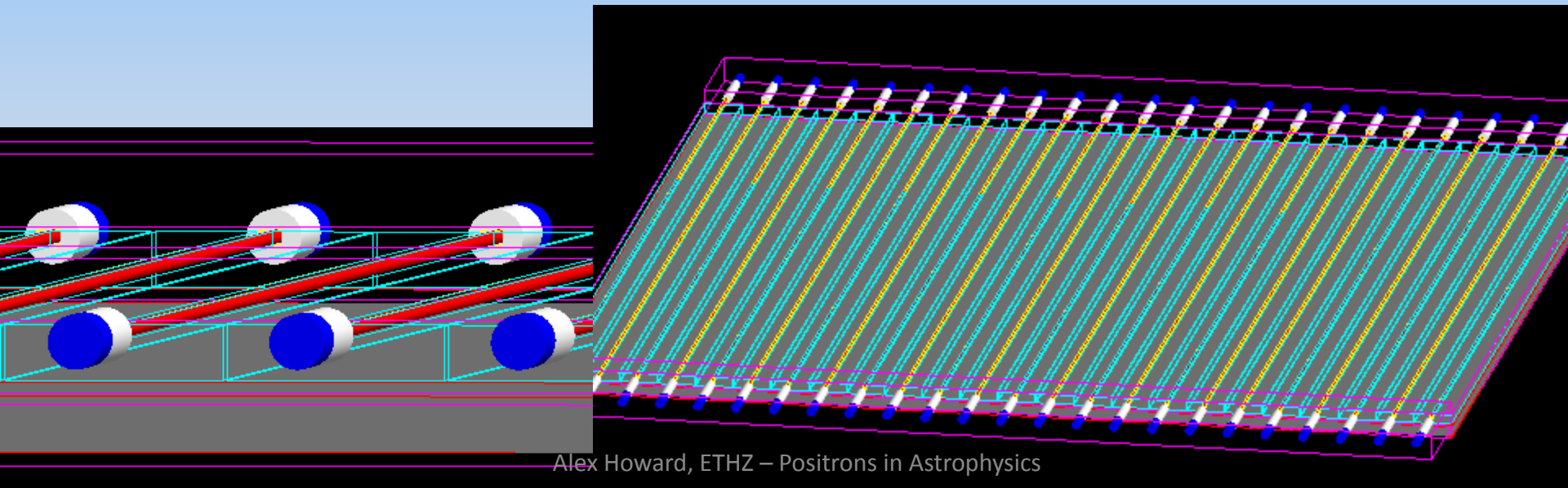
Proton Rejection

- Positron efficiency and proton rejection factors
- Up to 50 GeV rejection is better than 10^{-3}



ECAL Prototype 2012

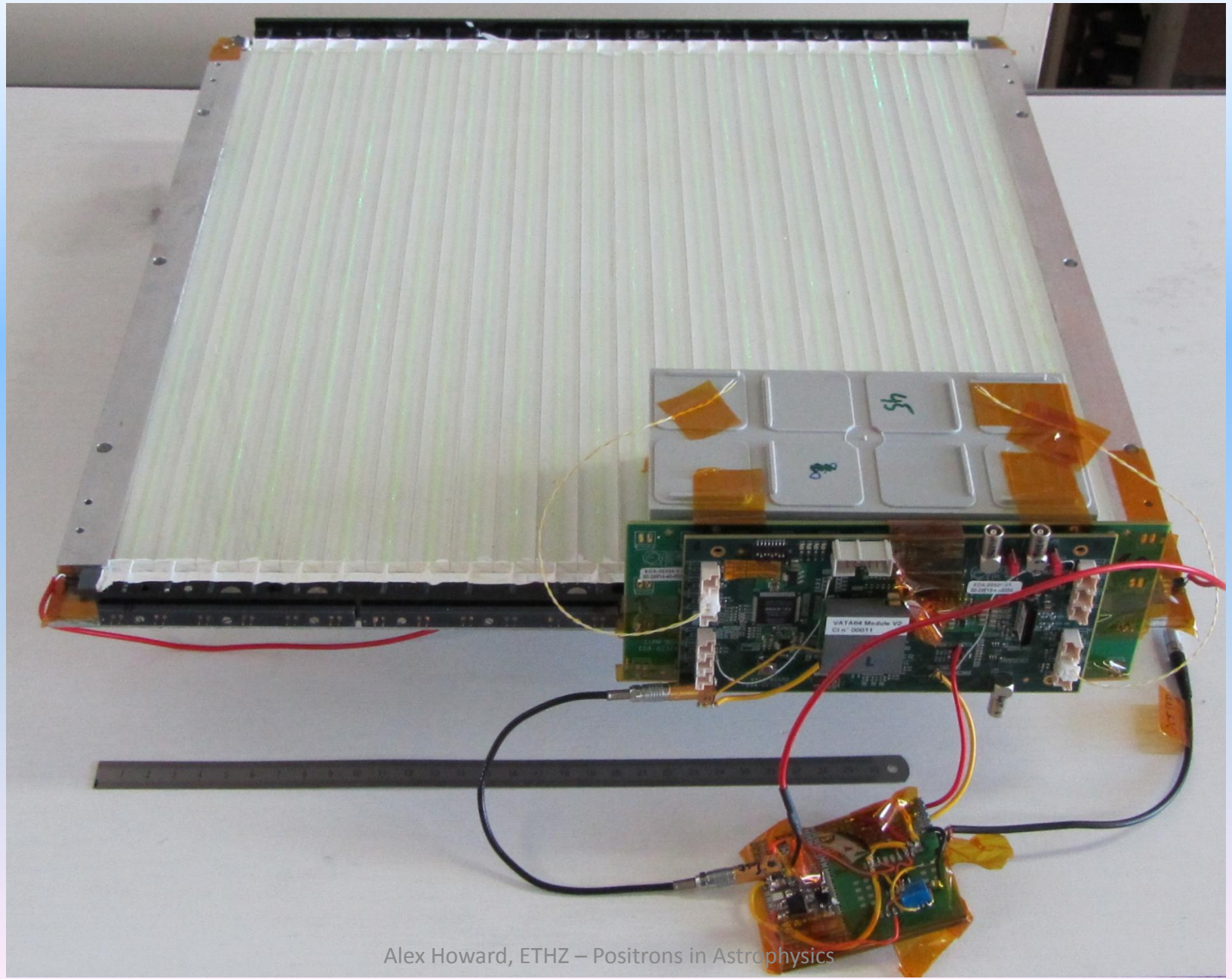
- New ECAL being constructed
  - Larger (384mm x 384mm)
  - 16 layers
  - Single electronics (IDEAS VATA-64)
  - Two types of SiPMs for read-out → two gains
  - Test of slow scintillator → could reduce saturation



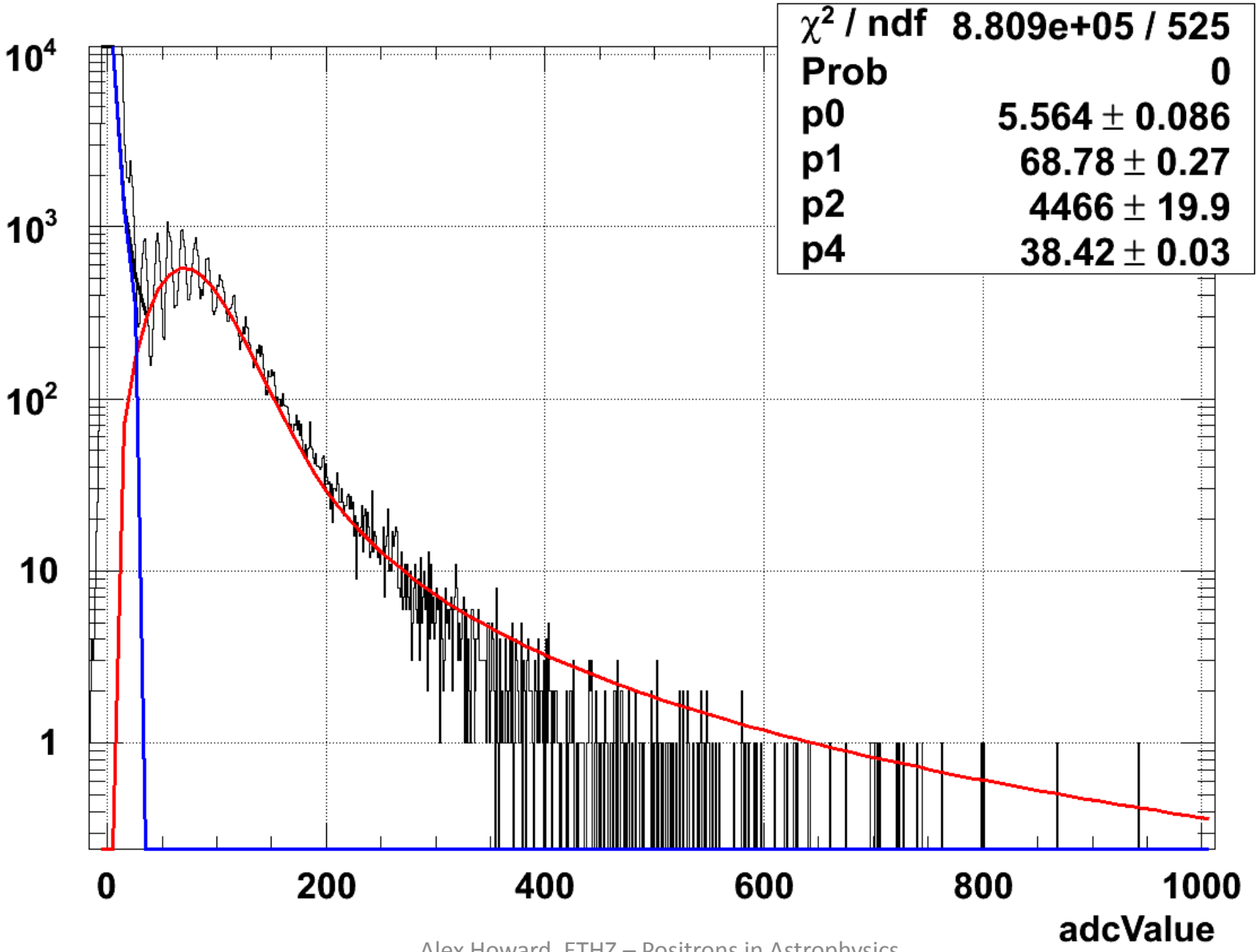
Two Type of SiPMs

- Each end of the wavelength shifting fibre is read-out with different SiPMs
- One side is “standard” MPPC from Hamamatsu (3000 pixels/mm^2) - G = 5x10^5
- Second side is using Zecotek MAPDs - G = 5x10^4
  - New device
  - 15000 pixels/mm^2
  - Much higher saturation, lower gain
  - Unfortunately also higher noise

Cosmic Muon Test

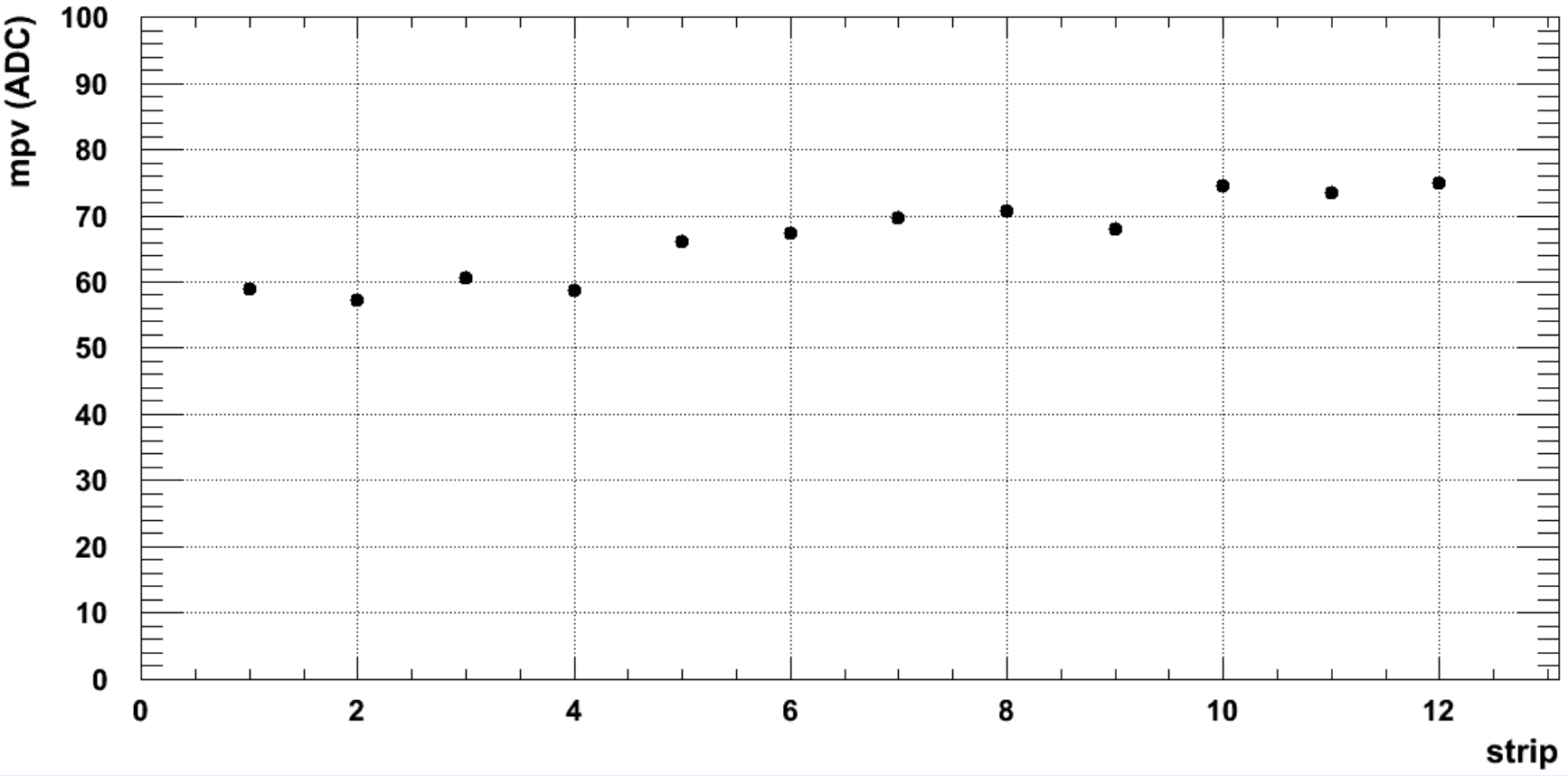


Landau distribution from muons



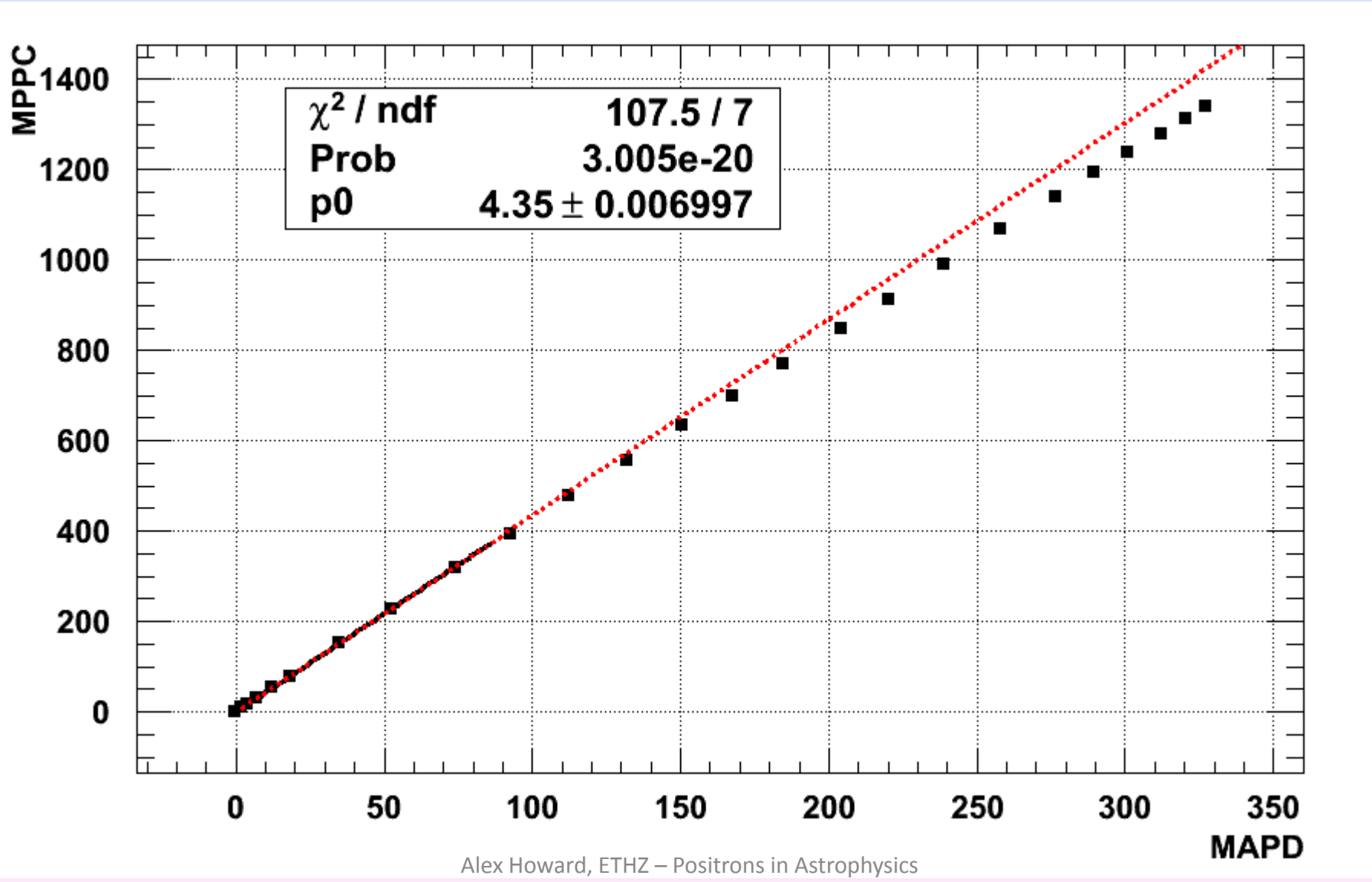
Uniformity Across Read-out Plate

- Most probable value of Landau distribution from cosmic muons



MPPC vs. MAPD

- MAPD does not saturate compared to MPPC

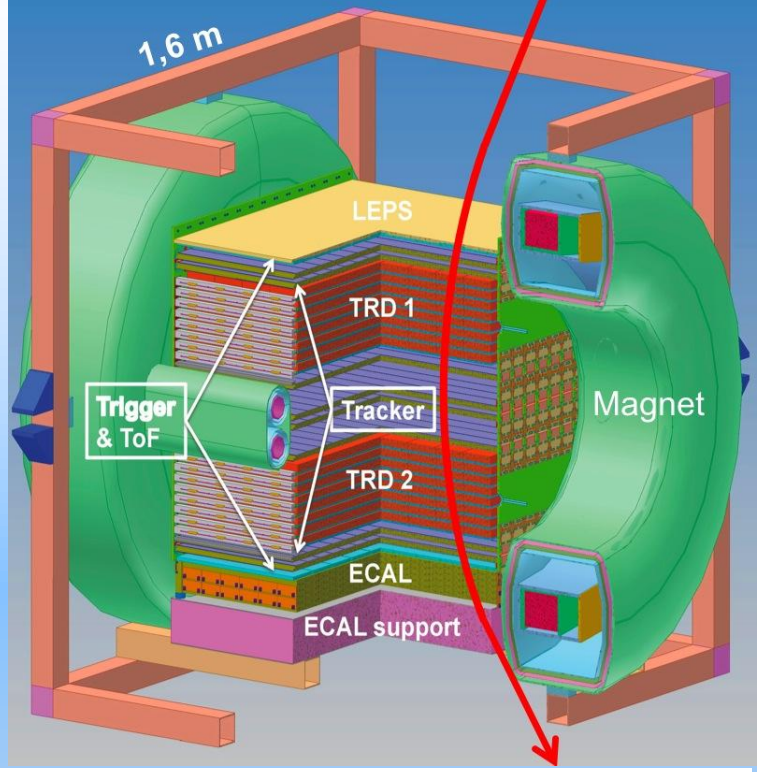


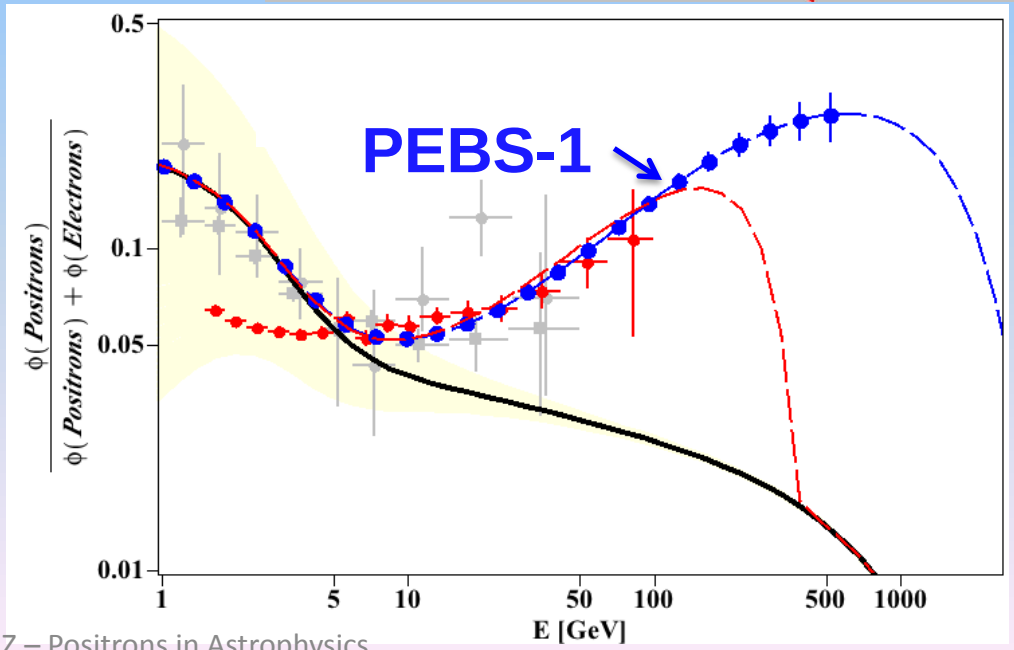
ECAL future

- We are currently on schedule to produce the full prototype for summer testbeam
- Uniformity, Noise and Linearity appear to be under control
- Temperature stability will also be tested
- Proton rejection should exceed 10^4 (M/C)
- Energy resolution of 15%/√E (GeV)
- Two SiPM read-out gives full dynamic range from MIPs up to several thousand

PEBS Summary

- A dedicated balloon experiment could provide a competitive measurement of the cosmic ray electron & positron flux.
- The spectrometer is based on a scintillating fiber tracker with SiPM readout and a permanent magnet.
- The proton rejection of ~10^6 can be achieved by a combination of ToF, TRD, ECAL and Tracker.
- Key parameters:
  Acceptance: ~1200 cm^2 sr
  Weight: ~2000 kg
  Power: ~900 Watt
- R&D Phase:
  ongoing – testbeam this summer
- Construction Phase: Could start now!
- First PEBS Flight: 201?





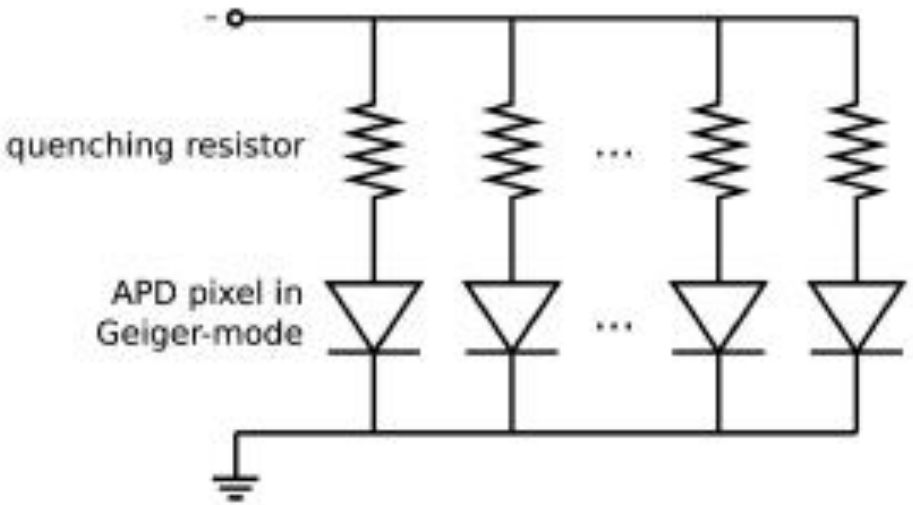
Conclusions

- PAMELA first measured a discrepancy in the positron fraction at high energy and confirmed by FERMI-LAT
- Interest in being able to measure the positron fraction up to (and beyond the TeV) scale
- The ability to reject significant proton backgrounds is important – ECAL offers this possibility
- A novel ECAL is being developed using two types of SiPMs is being developed
- Combination with tracker and superconducting magnet would allow precise measurements up to the TeV scale

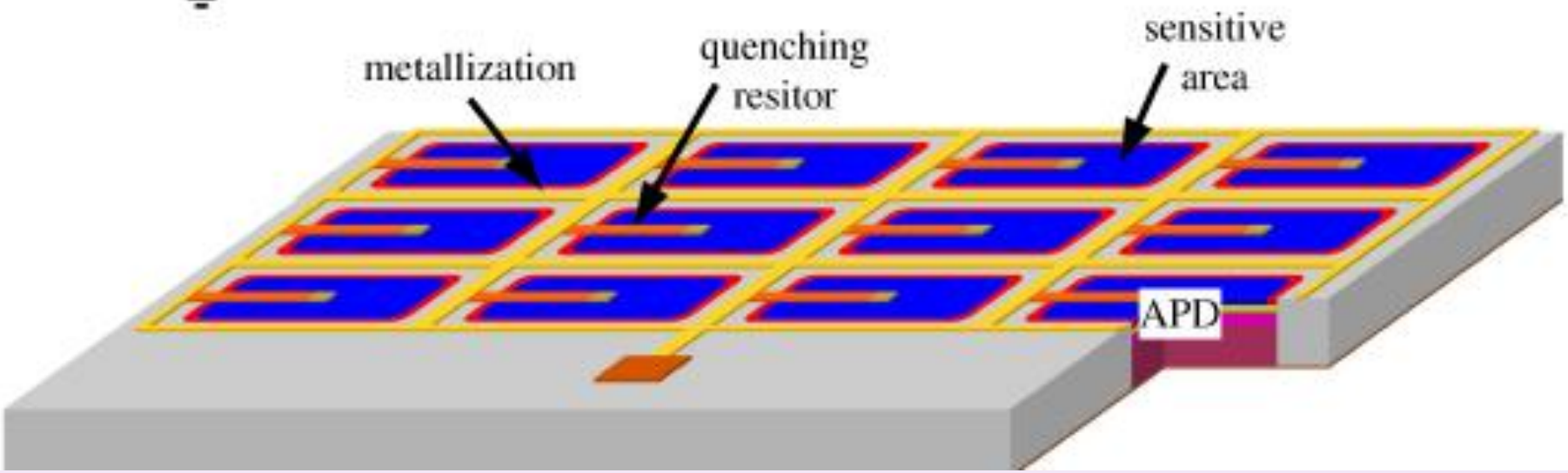
Thank you!

BACK UP SLIDES

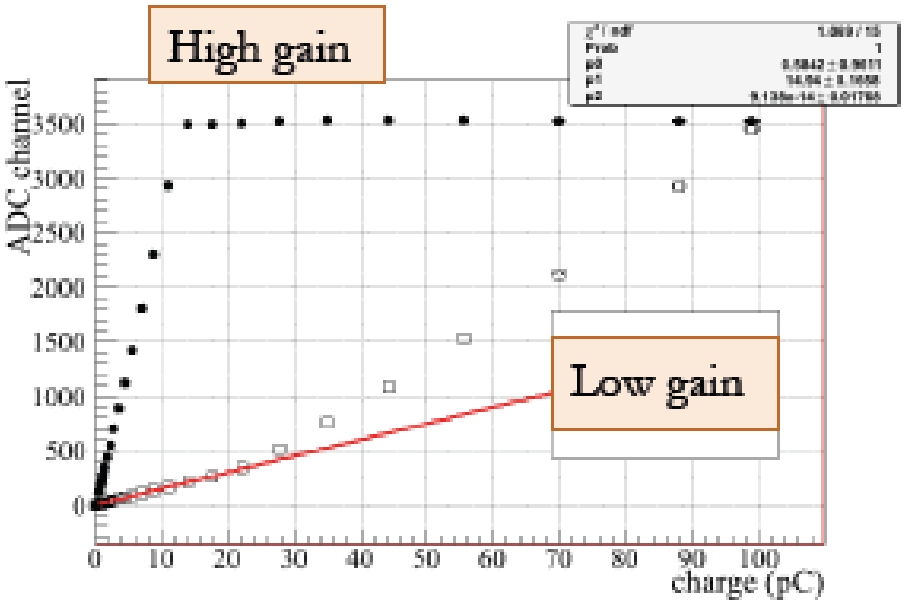
Silicon Photomultipliers (Geiger-mode APD)

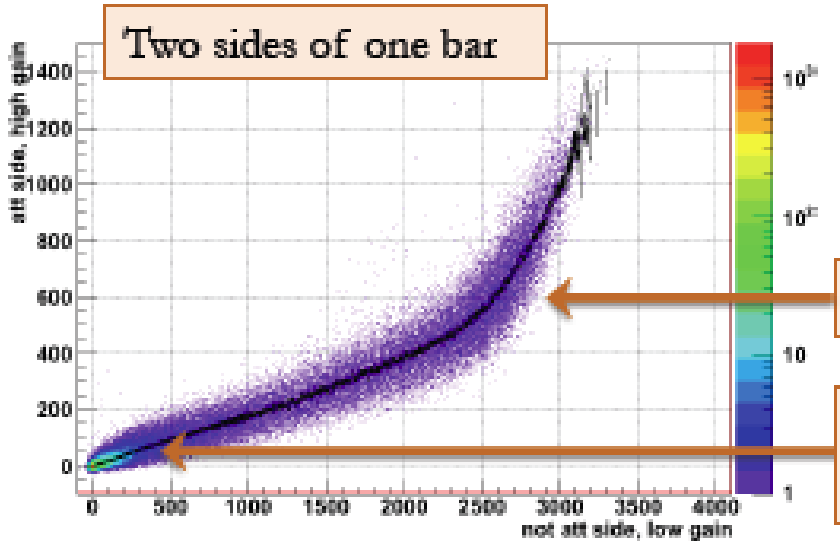


- avalanche photo diodes (APD) operated in Geiger mode
- internal gain ~10^6, compact in dimension, insensitive to magnetic fields, low bias voltage (<100 V)
- noise is an issue



Challenges of SPIROC Read-out





- ✓ 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

SiPM saturation visible at ~2500

Start of electronics non-linearity