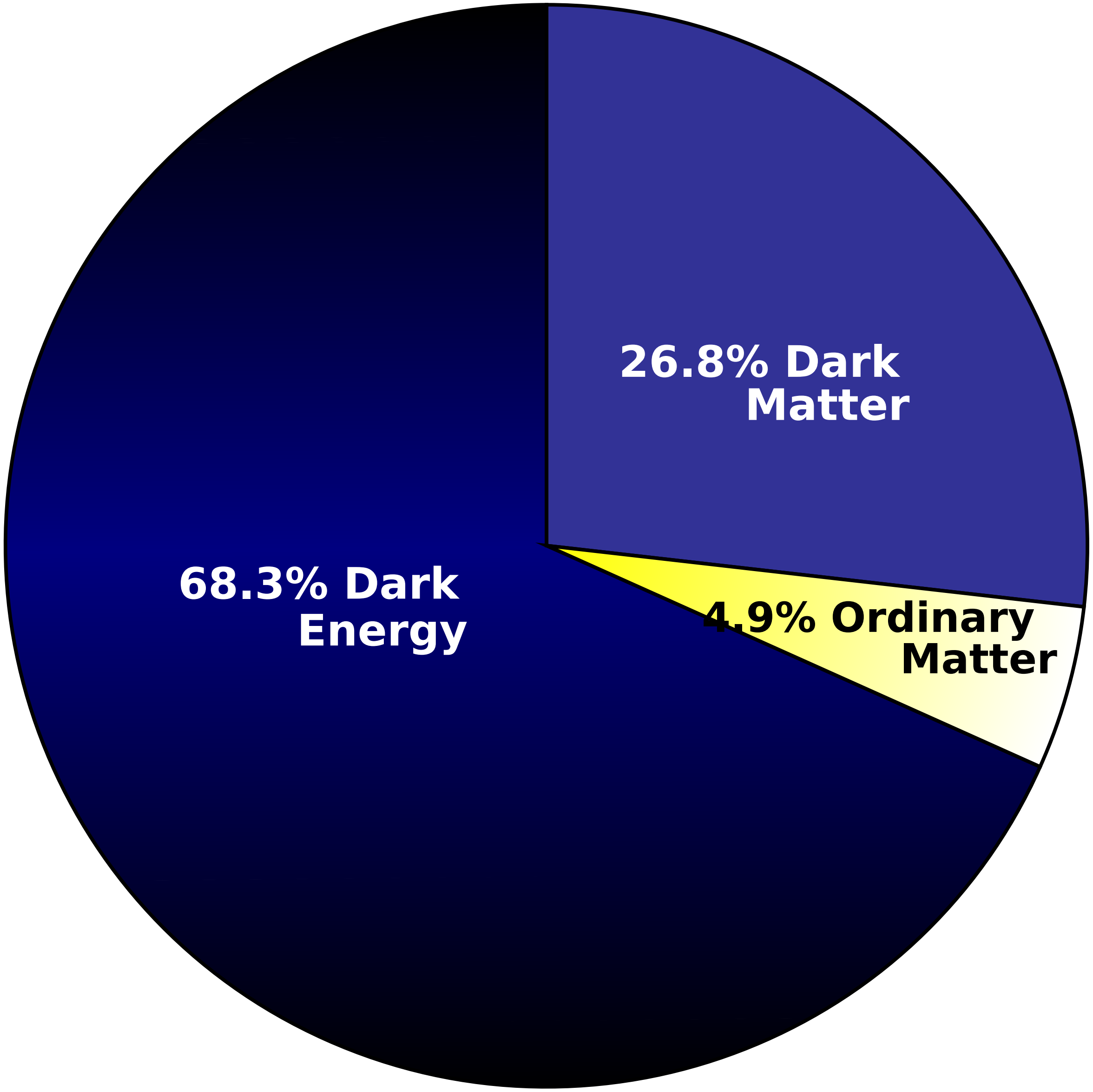
Performance of the Electromagnetic CALorimeter of the AMS-02 experiment on the International Space Station and measurement of the positron fraction in the 1.5 – 350 GeV energy range

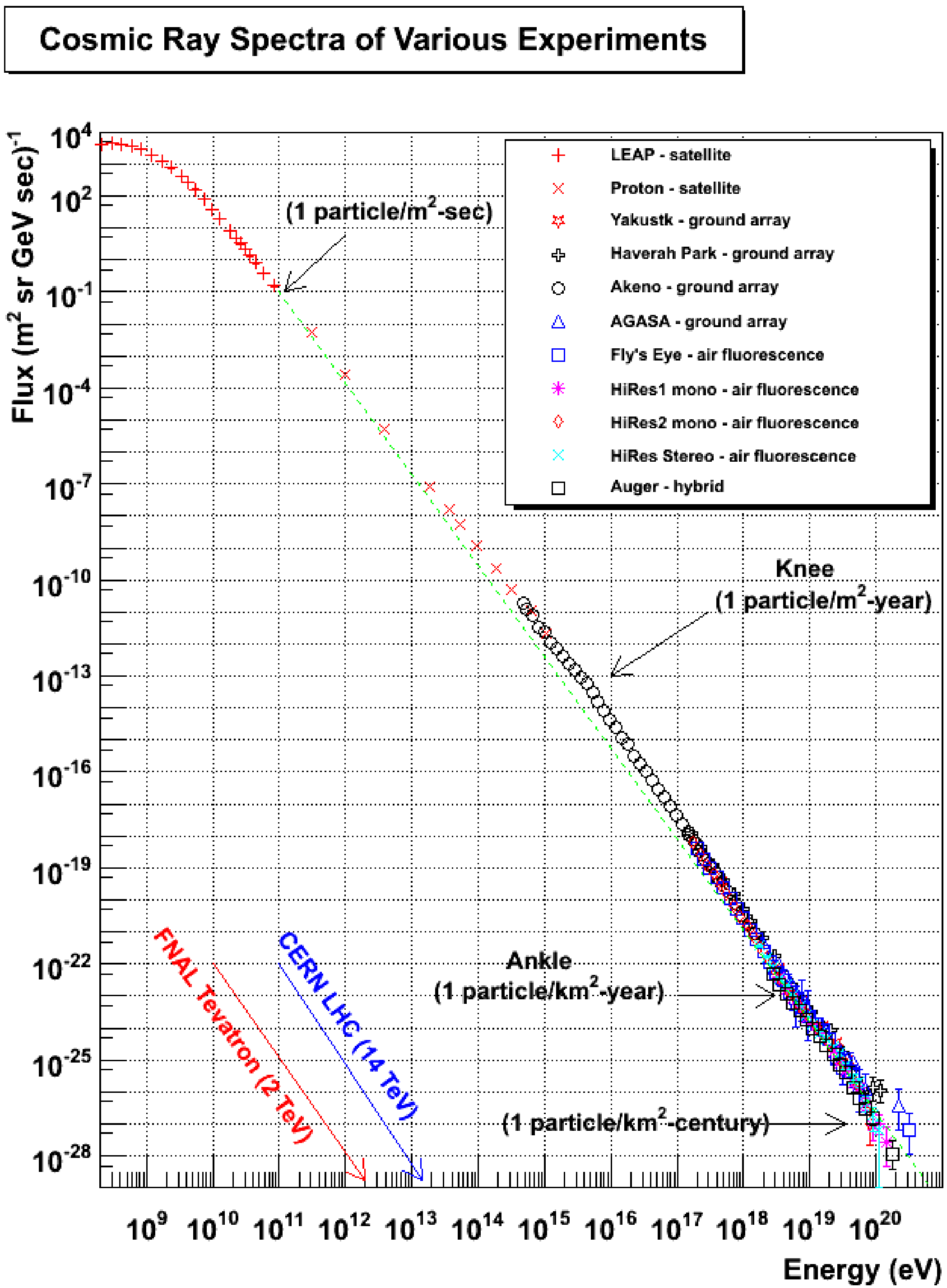
Laurent Basara

Overview

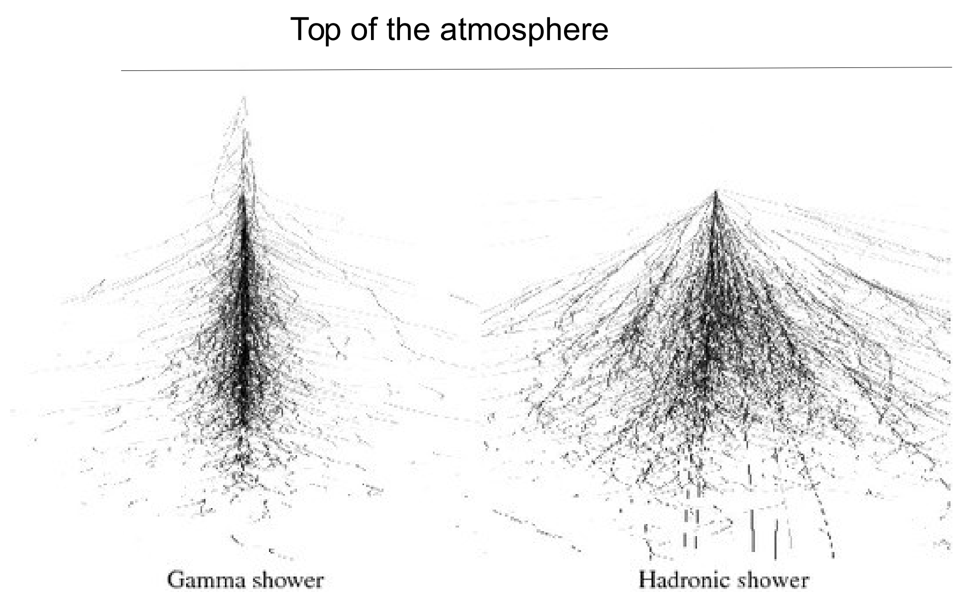
- Performances of the AMS-02 detector
- Lepton / proton discrimination
- Positron fraction

What is the Universe made of?

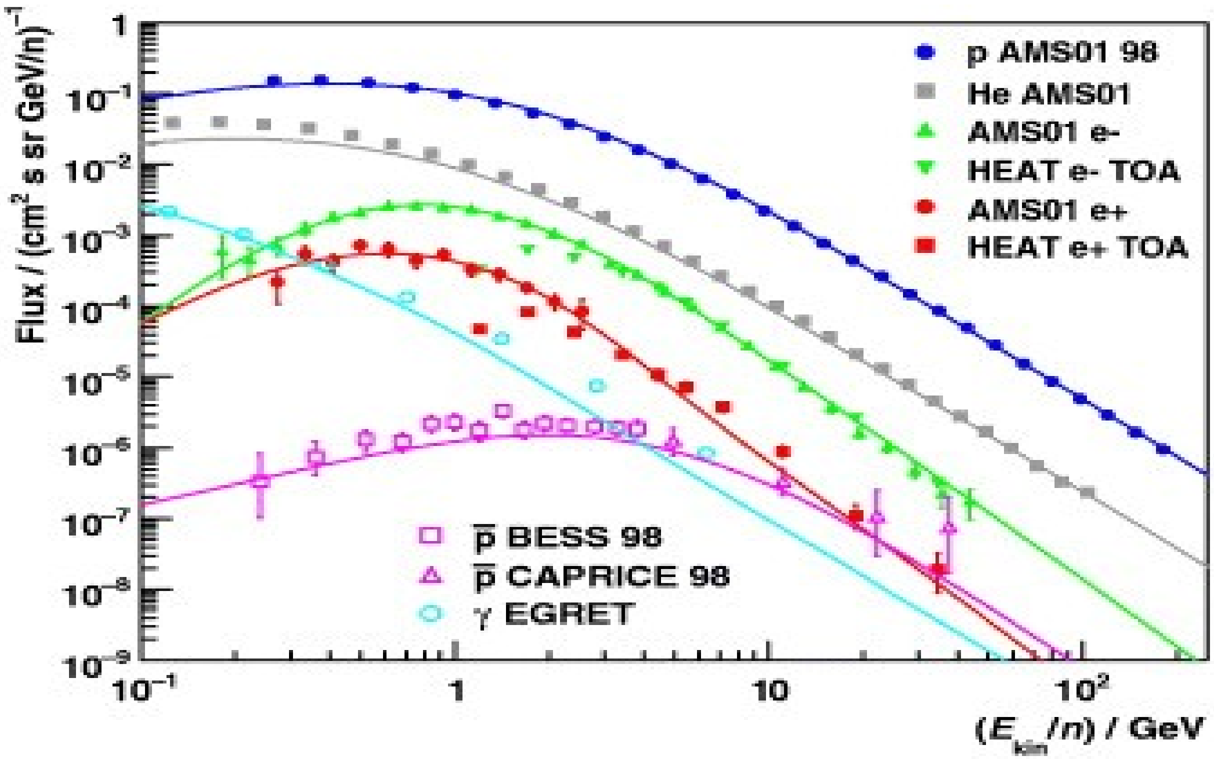


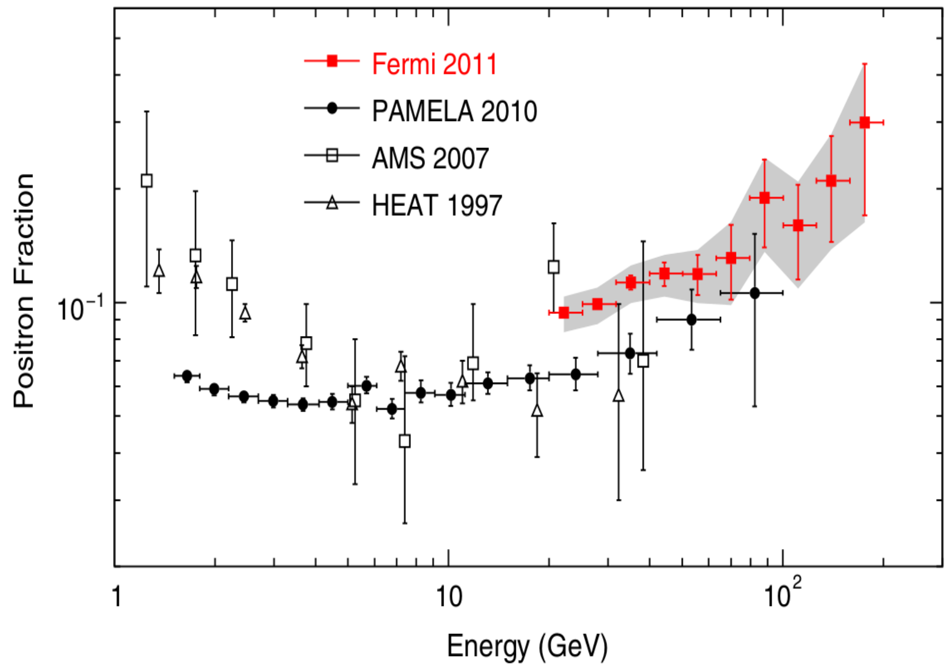


Standard matter and cosmic-ray spectrum



Composition of cosmic rays

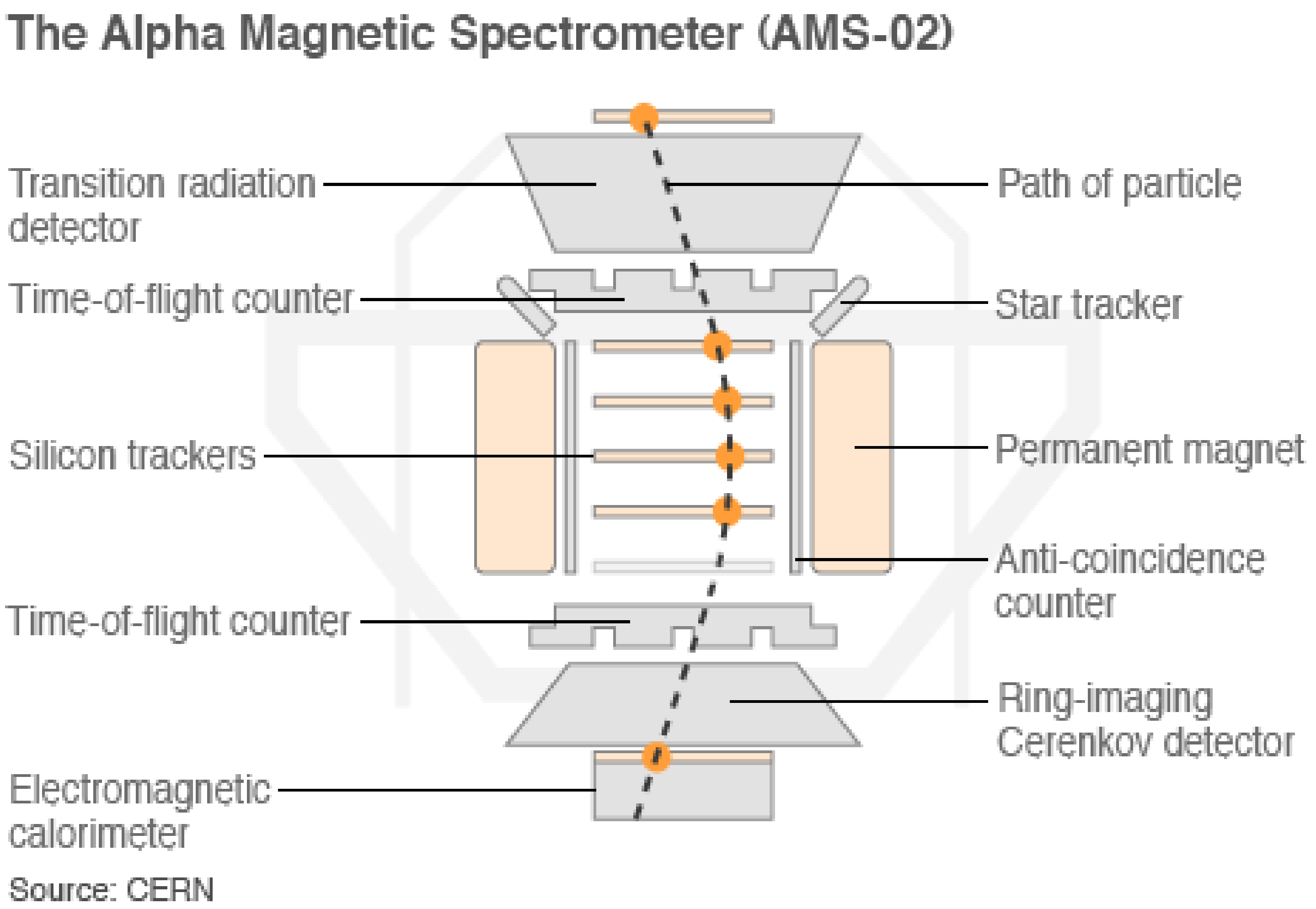




- Mainly protons, then He, e-, e+…
- Expected types of particles
  - Primary : protons, electrons, …
  - Secondary : positrons
- $e^+ / (e^+ + e^-)$: expected to decrease
  - Fermi, PAMELA, … : increases
  - Primary source of antiparticles ?

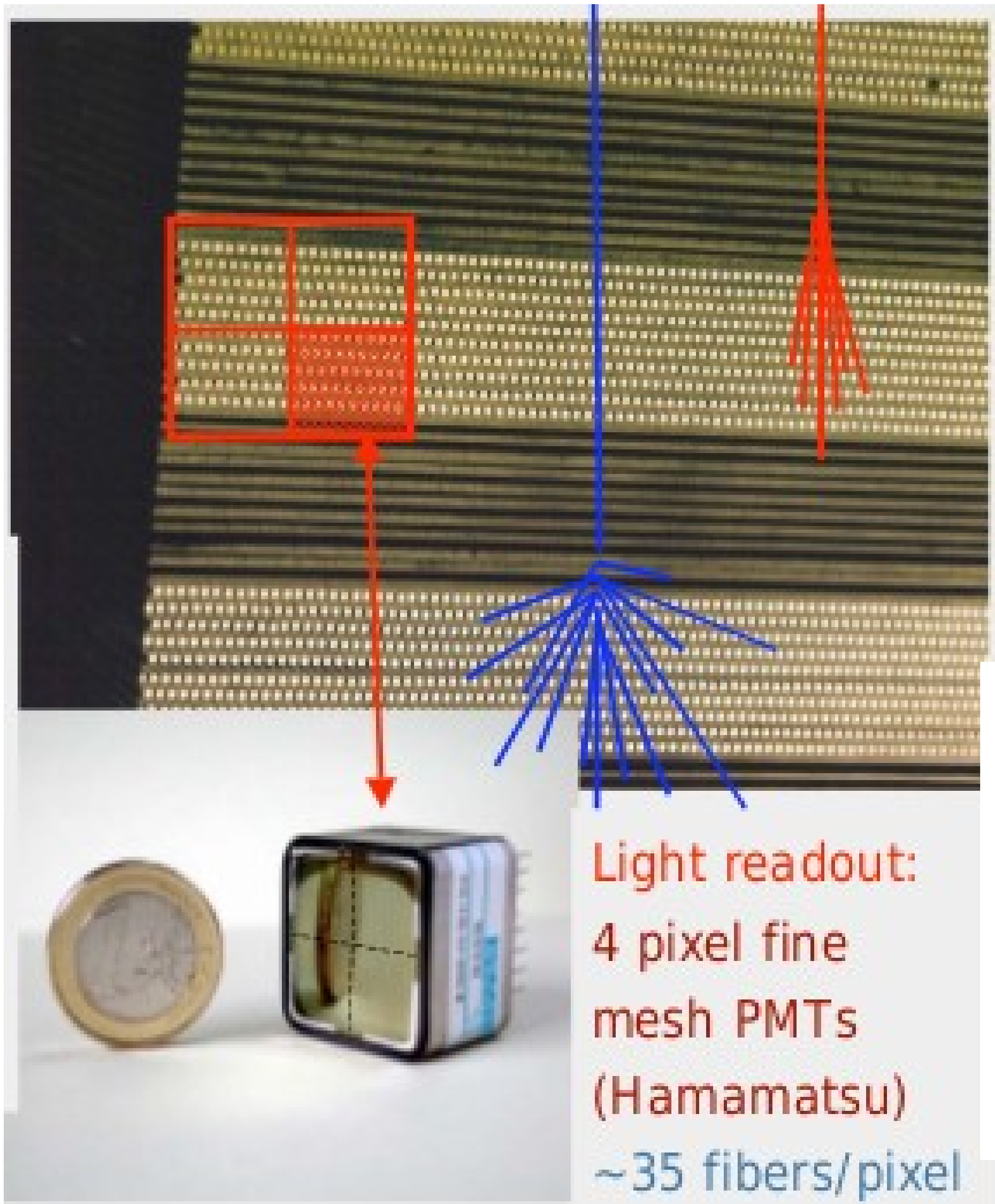
Part I
The AMS-02 detector

The AMS-02 experiment

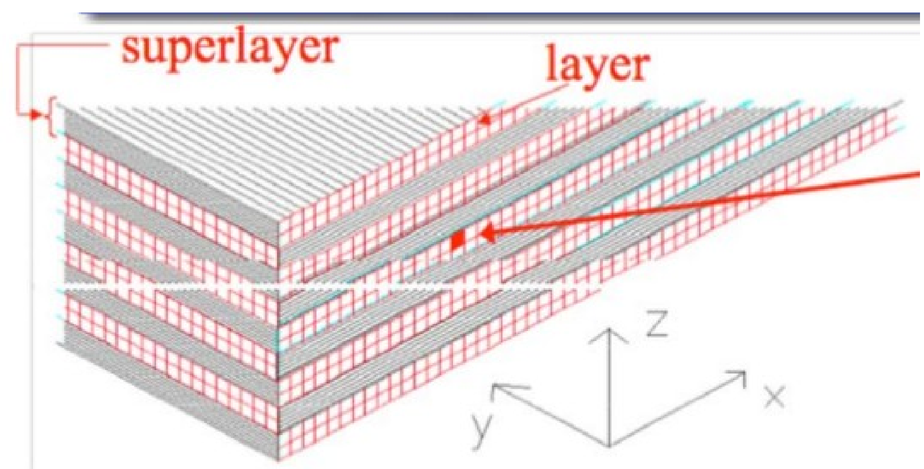


- Magnetic spectrometer
- GeV to TeV (anti)particles,
- 17.10^9 particles / year
- Objectives :
  - Dark matter studies
  - Primordial antimatter
  - Production / propagation models

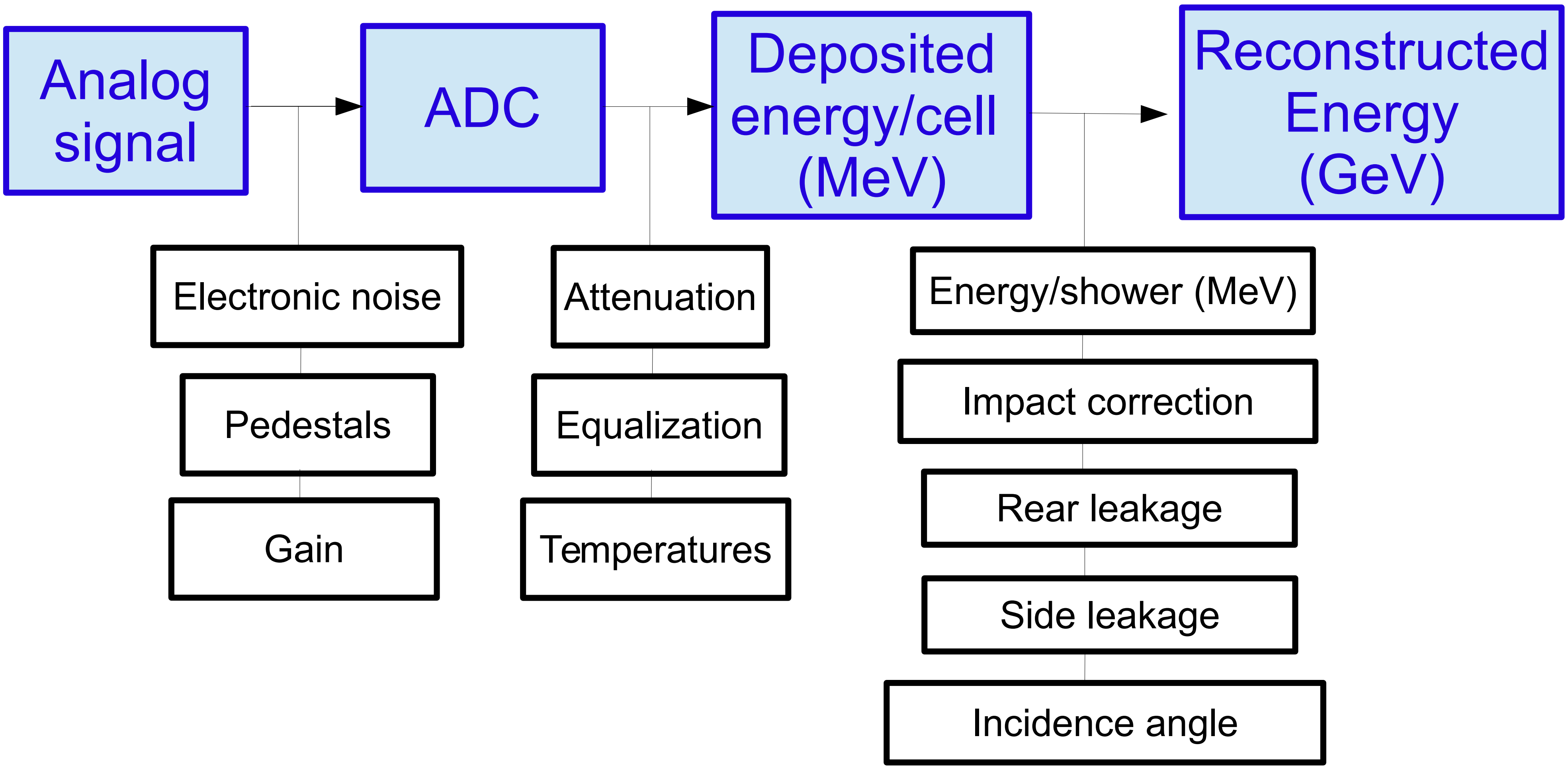
Electromagnetic CALorimeter (ECAL)



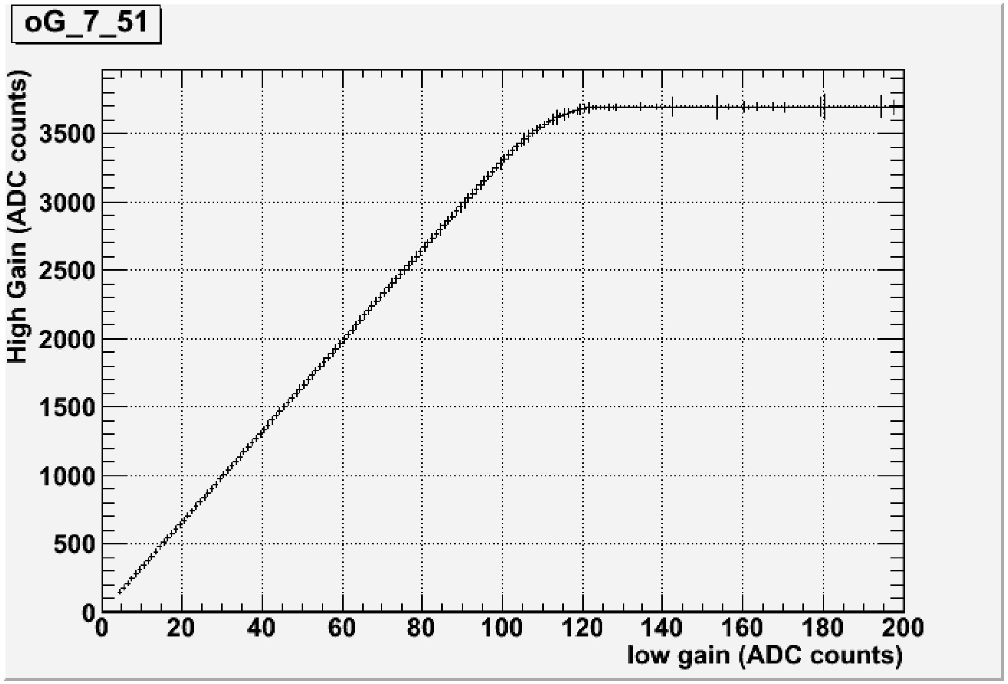
- 3D imaging, sandwich of 9 superlayers of 36 PMTs
- Energy measurement
- Leptons / hadrons discrimination

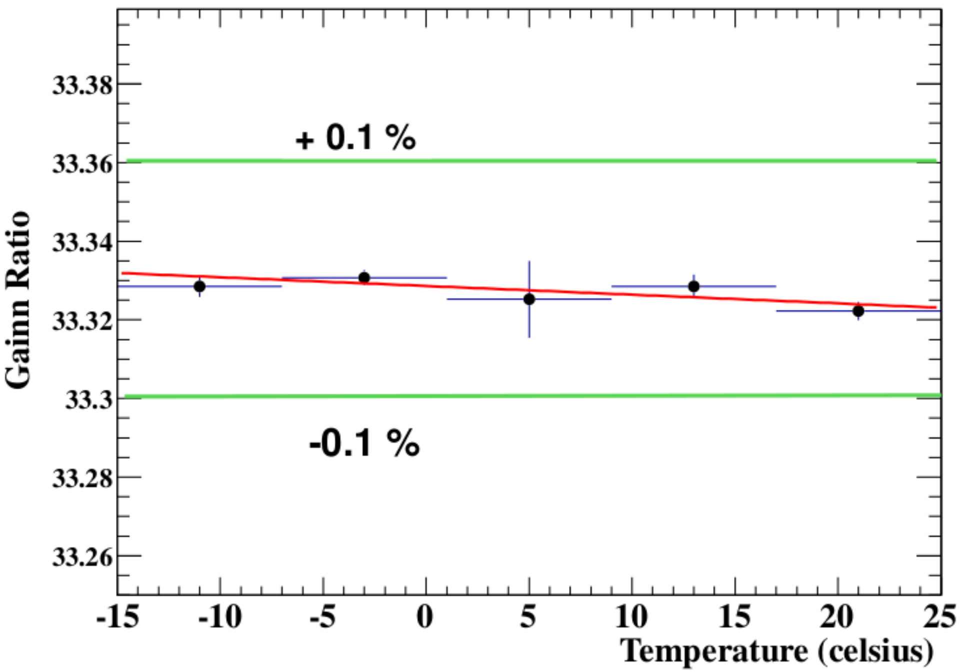


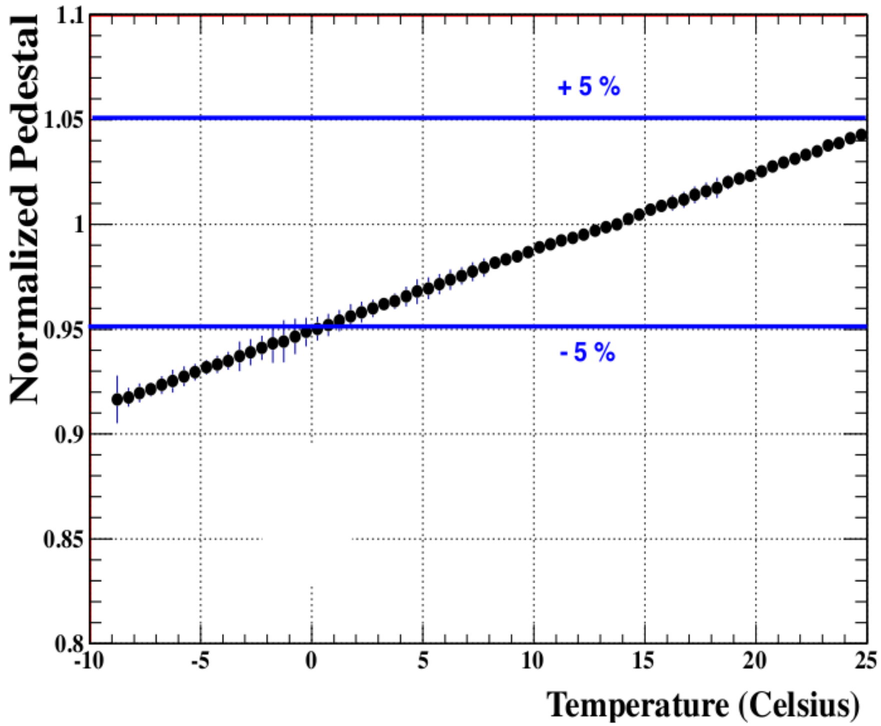
Energy reconstruction in the ECAL



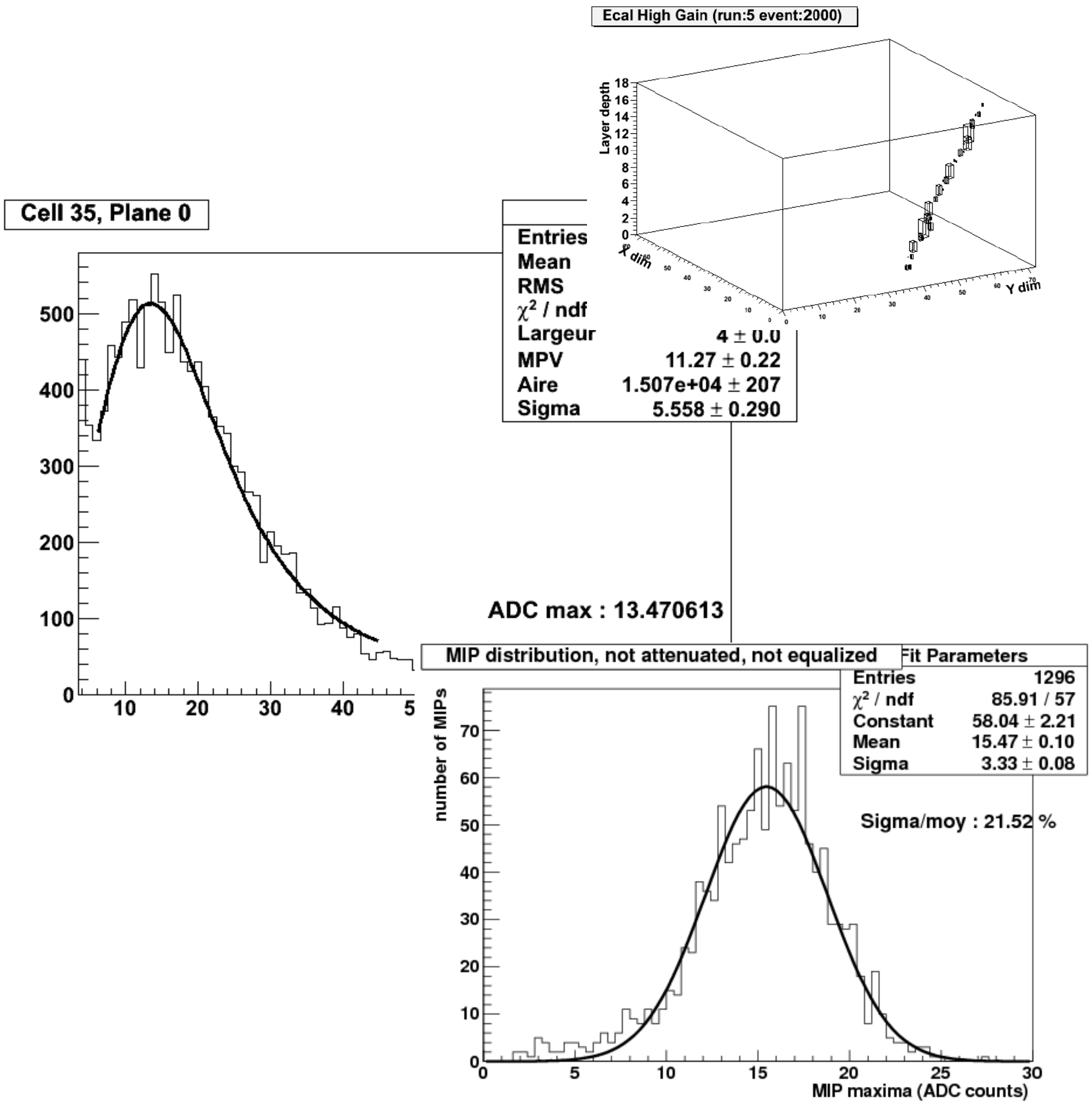
Electronic readout of THE ECAL





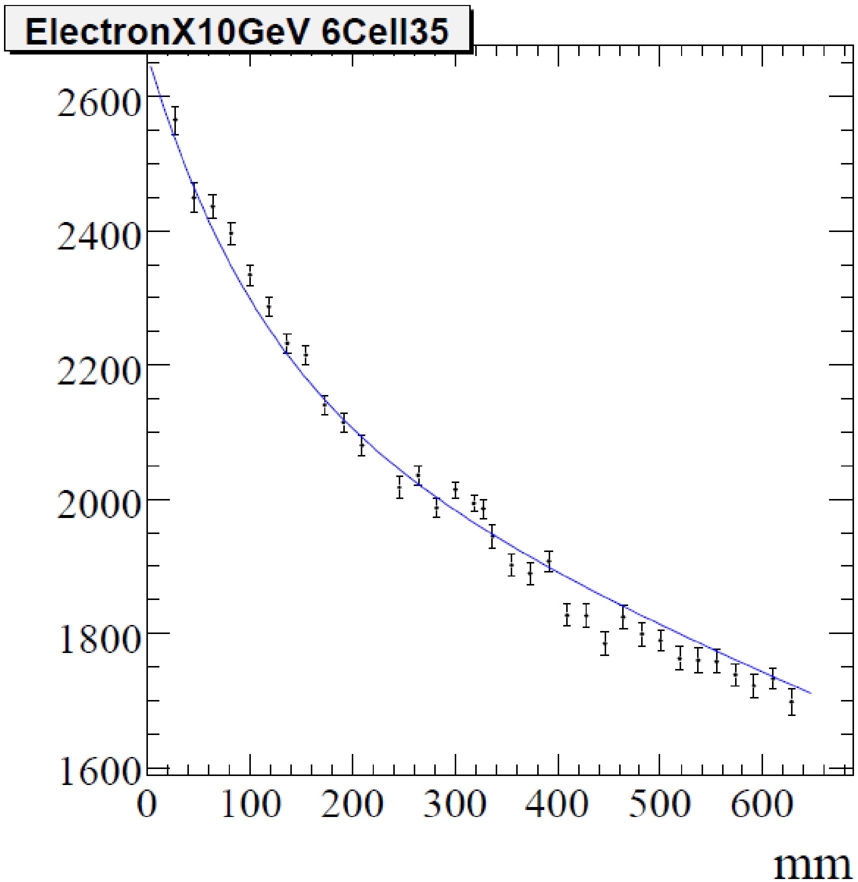


Interaction of particles in the ECAL



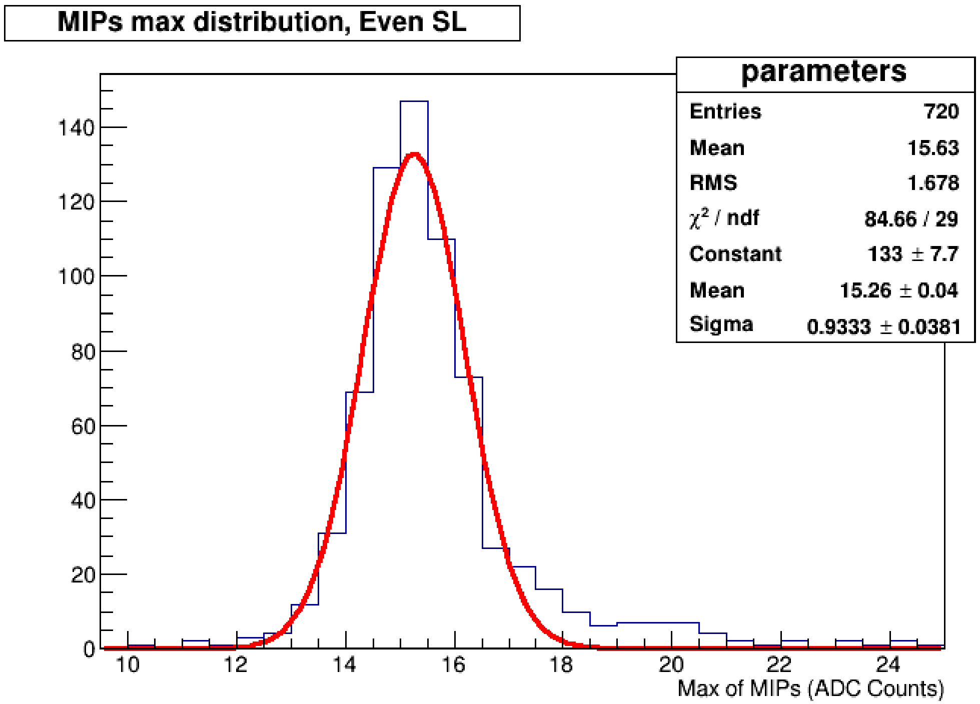
- Shower development :
  - Leptons almost contained.
  - Protons:
    - Rear leakage
    - 50 % MIPs
- MIP Distribution
  - Landau x Gaussian fitted
  - Distribution of maxima : gaussian
  - Reduce Gaussian spread (sigma/mean)

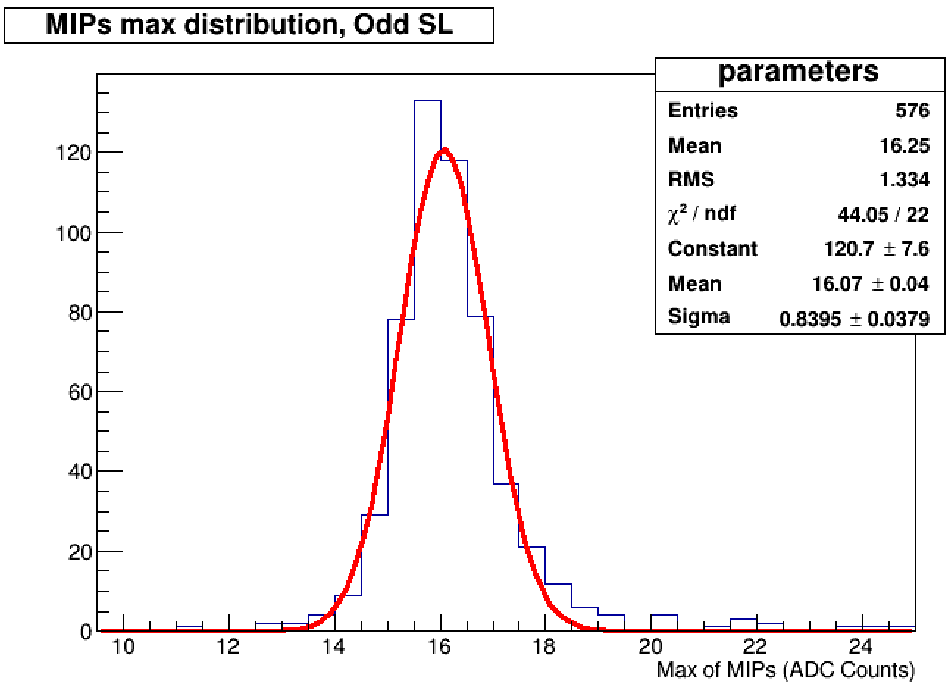
Attenuation



- Inside cells : fibers
- Energy attenuated along length of fibers
- Scanned in BT, assumed homogeneous for all cells
- Direct collection (fast) + reflexion on other end (slow):

$$\mathsf{AttCor}(x) = N\left[k\exp\left(-\frac{\lambda_{\mathsf{fast}}}{X}\right) + (1-k)\exp\left(-\frac{\lambda_{\mathsf{slow}}}{X}\right)\right]$$

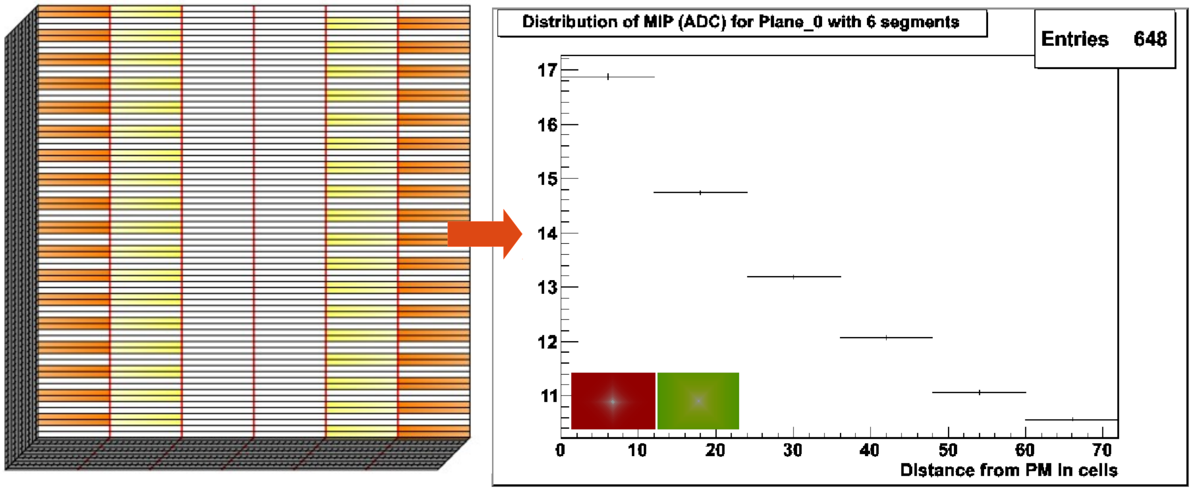


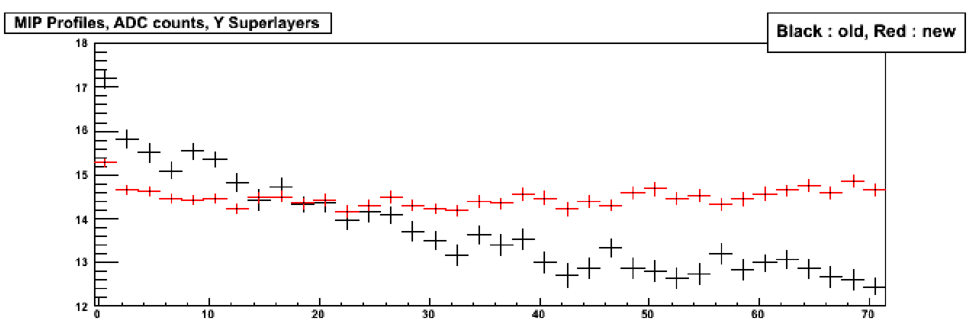


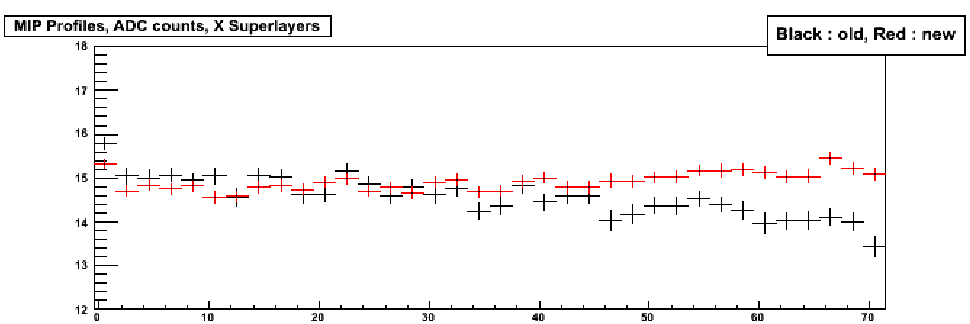
X and Y fit

- Homogeneity probed against the direction of the cells.
- Sigma/mean of 5.2 % in X, 6.1 % in Y.
- Do certain directions / layers / cells behave differently ?

Cell binning

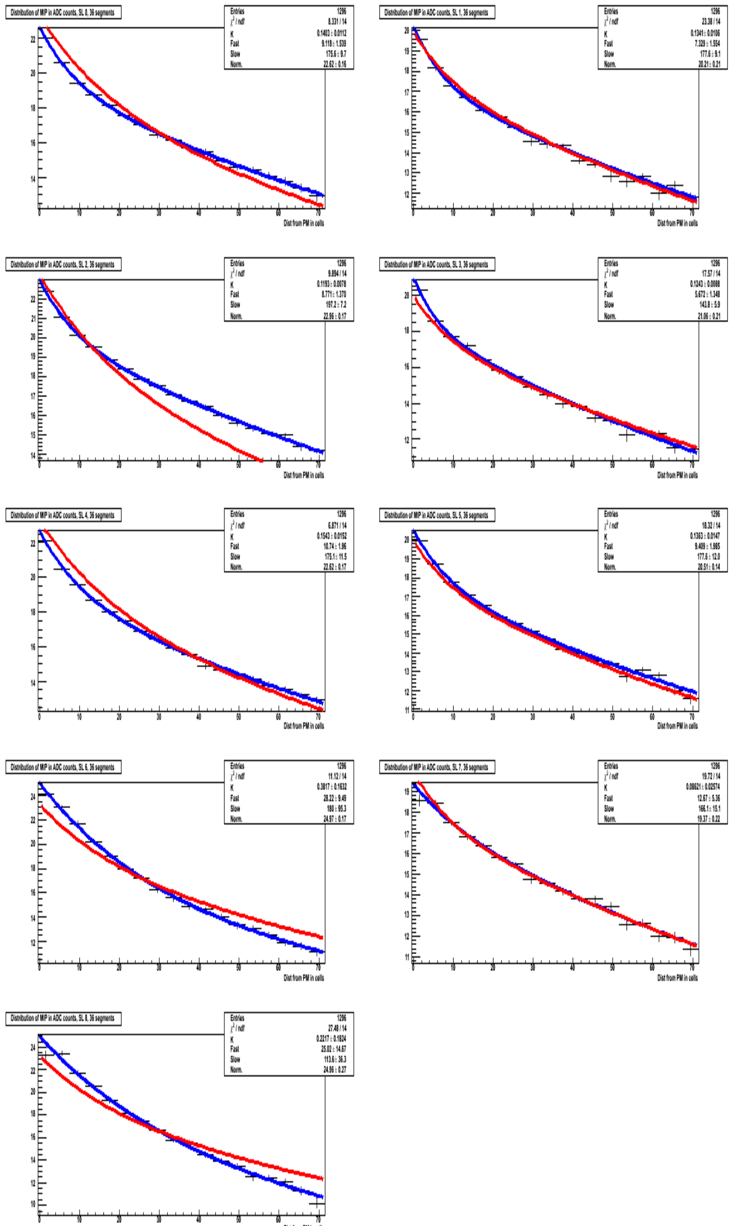




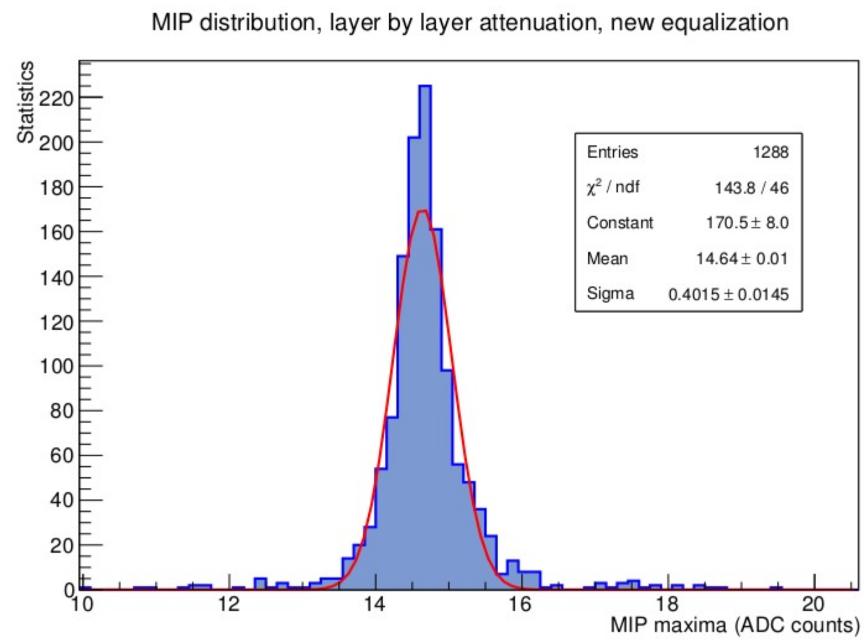


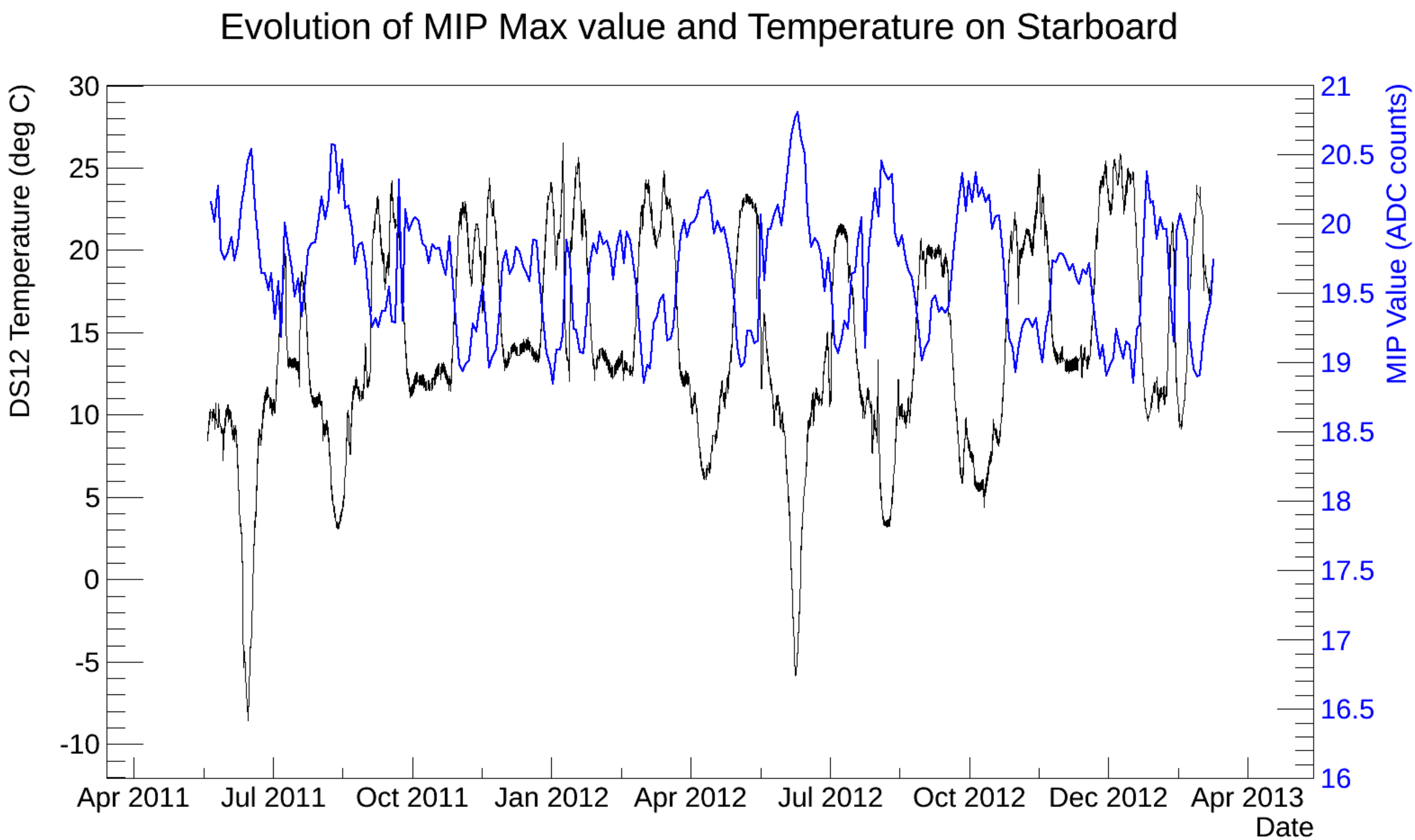
- For each cell, interpolation to estimate hit position
- Binning along the fiber
- Summed according to direction and fit for each bin
- Difference for the two directions

Equalization

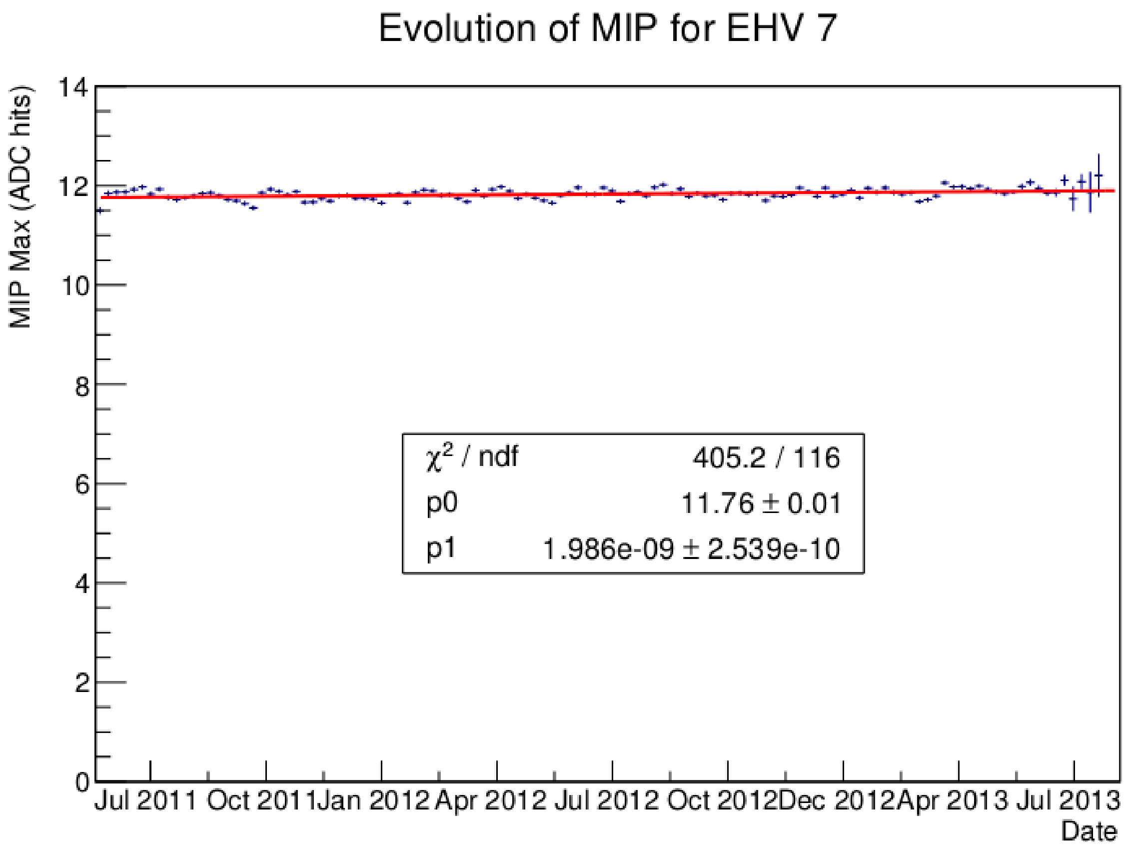


- Finally done for each superlayer → differences
- New intercell equalization
- After the equalization new spread of 2.7 % (8 % before)
- Could the differences found be due to aging effects ?
- Monitor MIP evolution through time



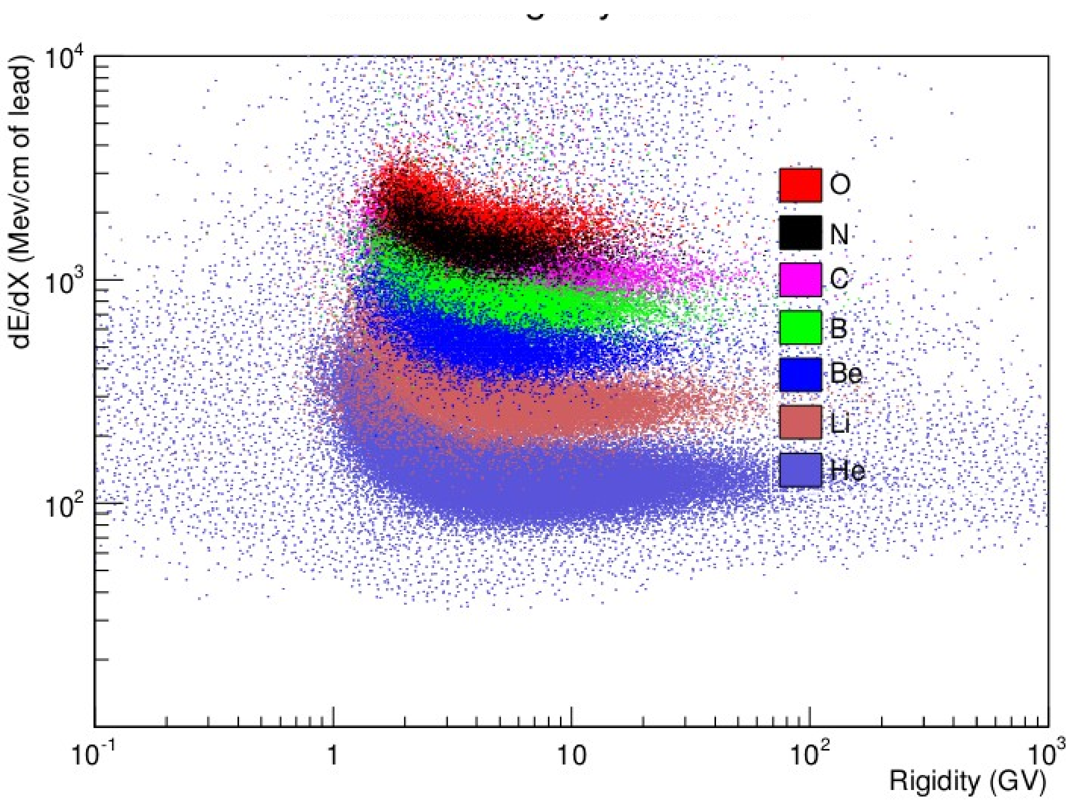

Evolution of MIP Max value and Temperature on Starboard
DS12 Temperature (deg C)
30
25
20
15
10
5
0
-5
-10
21
20.5
20
19.5
19
18.5
18
17.5
17
16.5
16
MIP Value (ADC counts)
Apr 2011
Jul 2011
Oct 2011
Jan 2012
Apr 2012
Jul 2012
Oct 2012
Dec 2012
Apr 2013
Date

MIP evolution



- MIP decorrelated wrt EHV temperature
- No aging
- Performances ok for ~ 6 MeV
- Higher energies ?

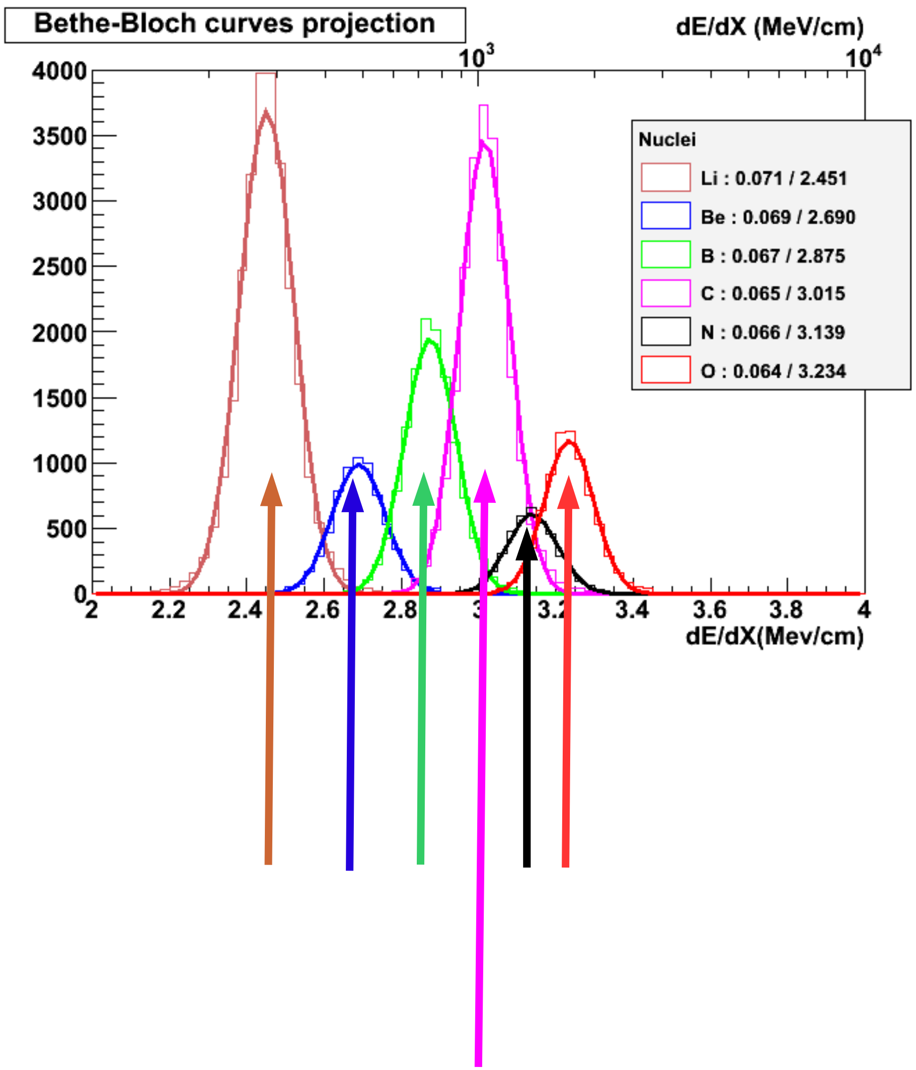
Bethe–Bloch formula



- For ionization losses :

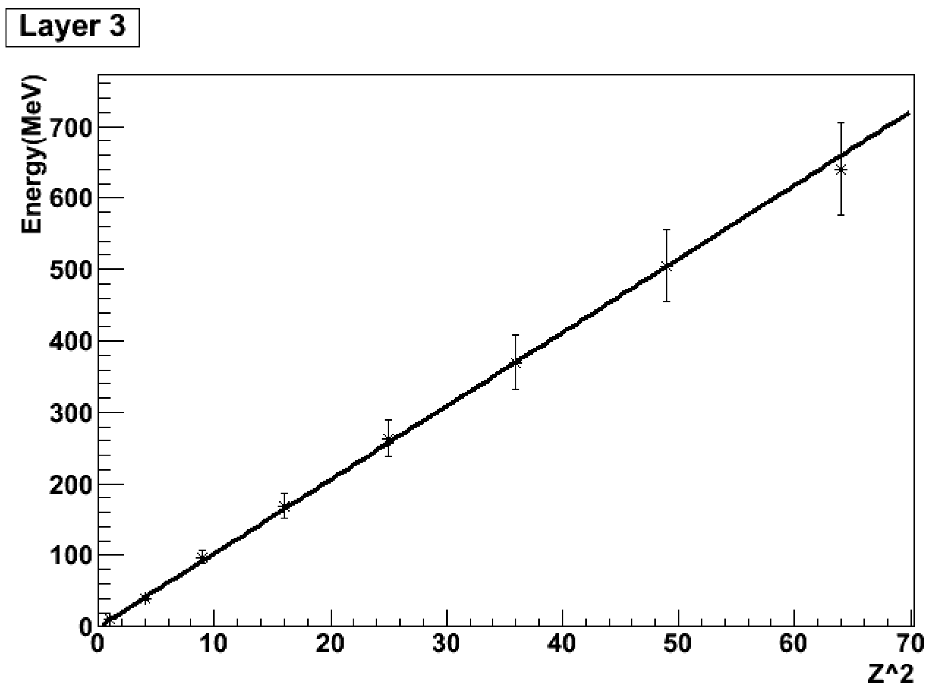
$$-\frac{dE}{d\xi} = z^2 f(v) \frac{Z}{m}$$

- Rigidity + Energy known: single point (z^2)
- Tracker used to :
  - Identify nuclei
  - Compute rigidity
- dE/dX from ECAL ; allow to identify charge ?



Bethe-Bloch curves projection
dE/dX (MeV/cm)
10^3
10^4
4000
3500
3000
2500
2000
1500
1000
500
0
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
dE/dX(Mev/cm)
Nuclei
Li : 0.071 / 2.451
Be : 0.069 / 2.690
B : 0.067 / 2.875
C : 0.065 / 3.015
N : 0.066 / 3.139
O : 0.064 / 3.234

Linearity for most abundant nuclei



- Nuclei up to Z=8 (O) more abundant
- Excellent linearity up to Z=7
- Drop for Z=8 ?

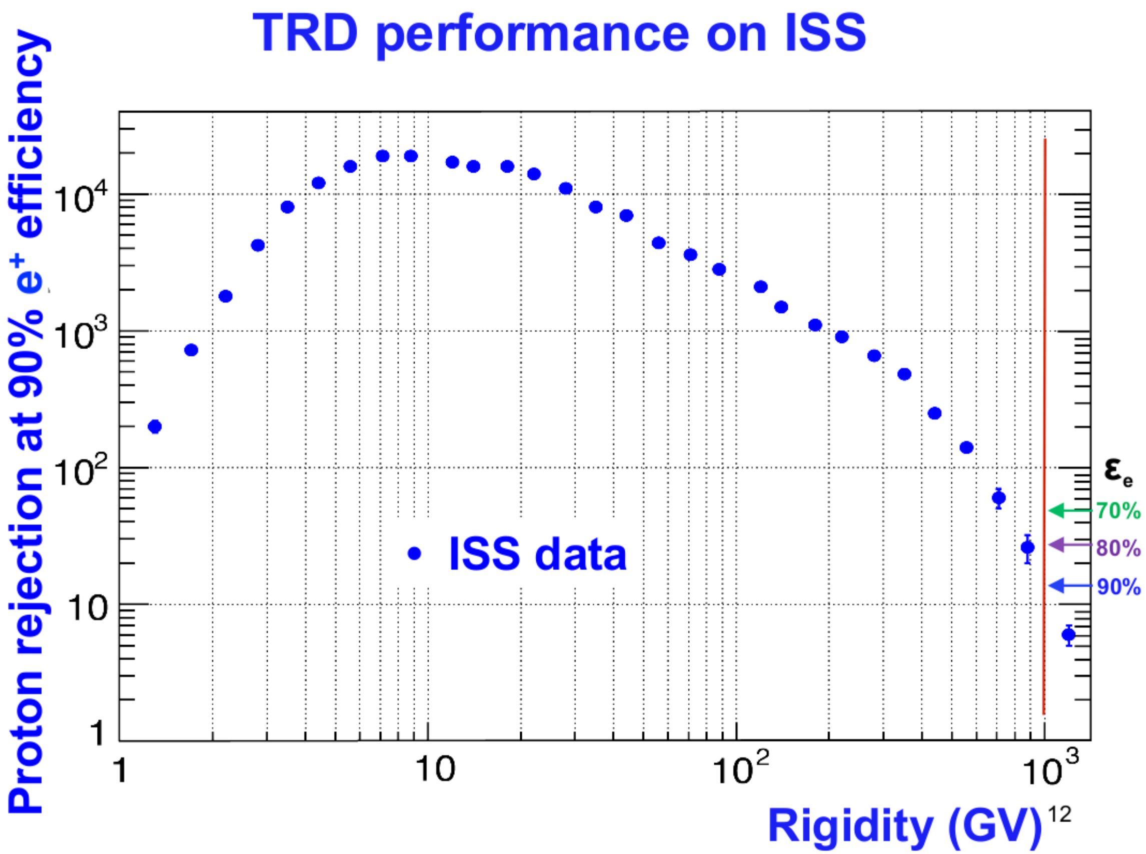
Conclusions on the performances of the detector

- Global AMS-02 performances as expected
- For ECAL :
  - Excellent electronic performances.
  - Stable through time.
  - Stable in energy up to GeV.

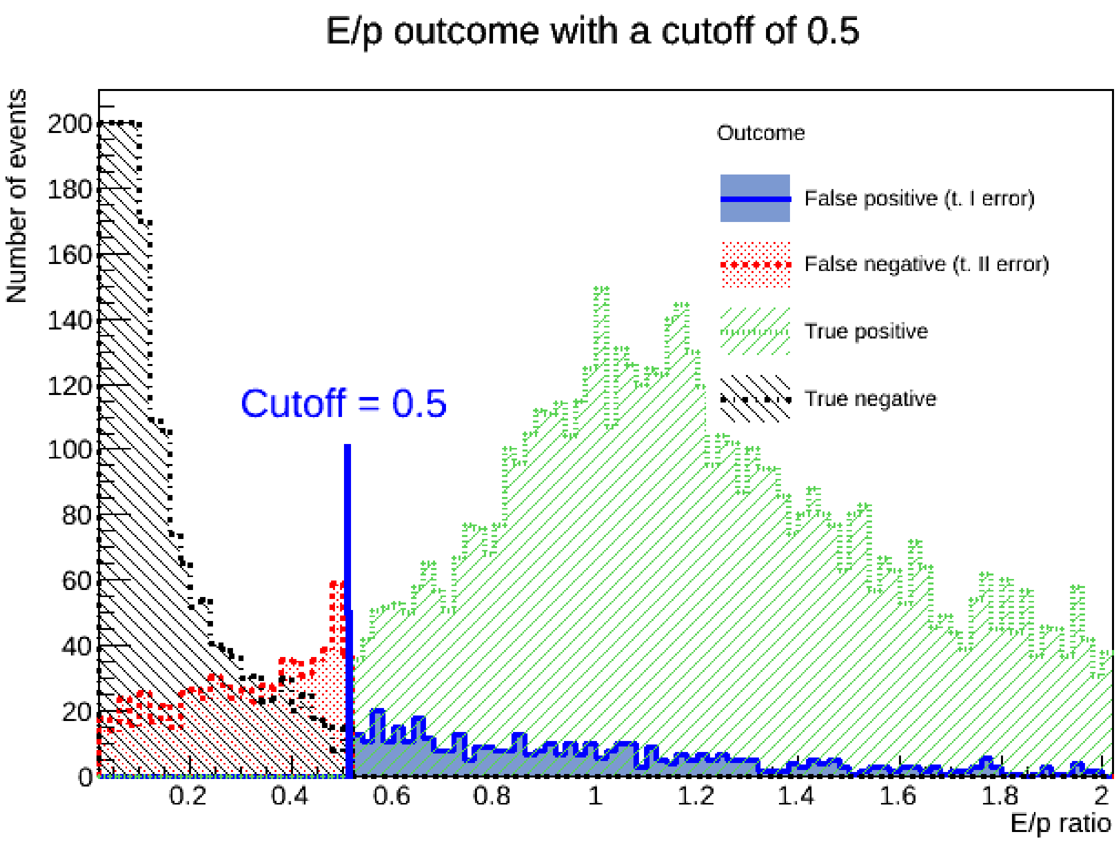
Part II.
Leptonic / hadronic discrimination

Objectives

- e+ / e+e- ratio
  - Select leptons
  - Protons large background
- TRD up to ~ 100 GeV, above: ECAL



Another estimator: E/P ratio

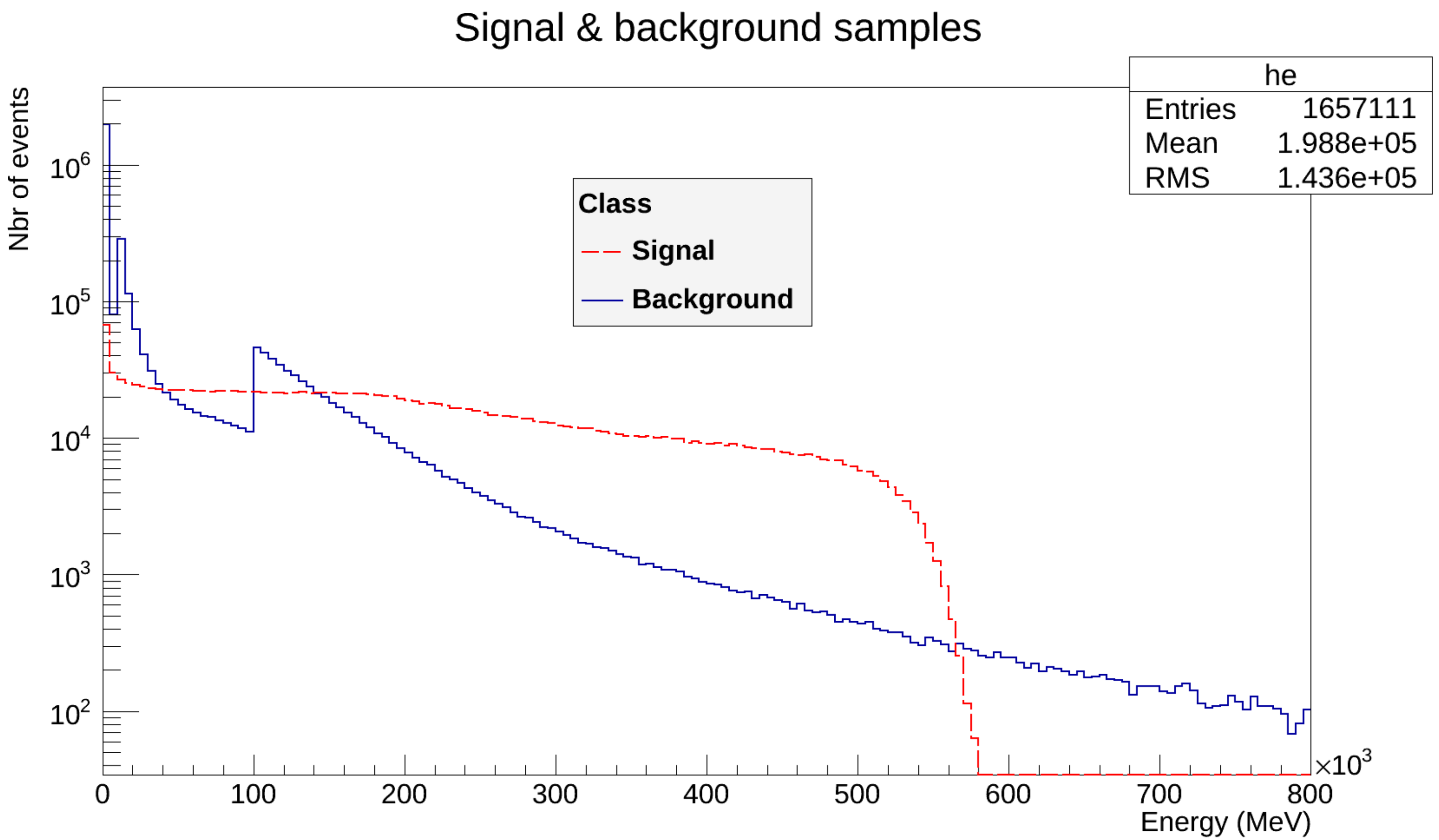


- E/P discrimination
  - For β = 1: E=P, for Z=1: R=P
  - Electromagnetic showers: E=P(=R)
  - Hadronic showers: E<P(=R)
  - Compare R with E
- Discrimination quantification:
  - *Efficiency*
  - *Rejection*

Multivariate analysis

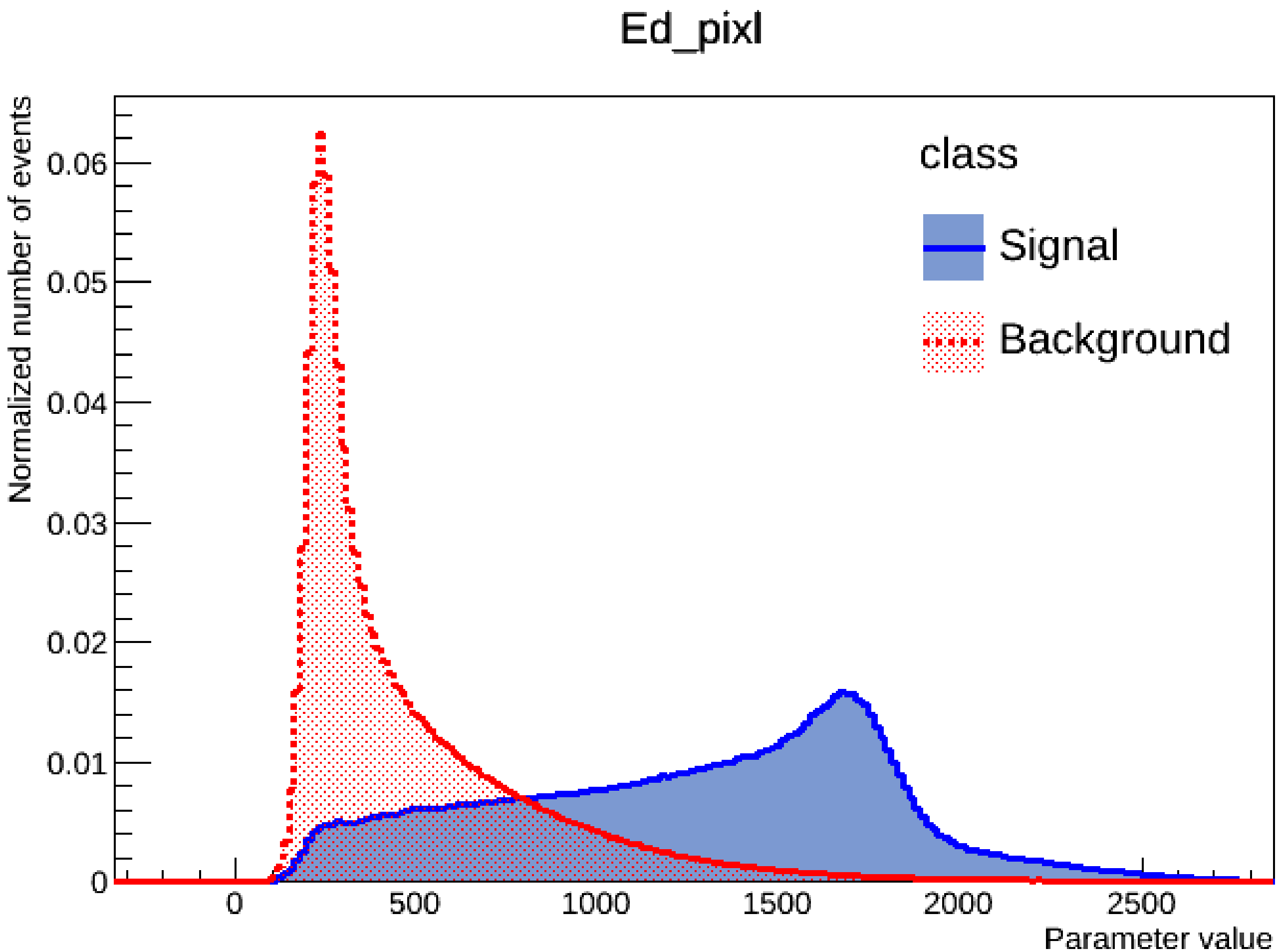
- Get pure samples
- Identify variables
- Optimally combinate them
- Assess performance
- Estimate nature given the variables

Get "pure" samples



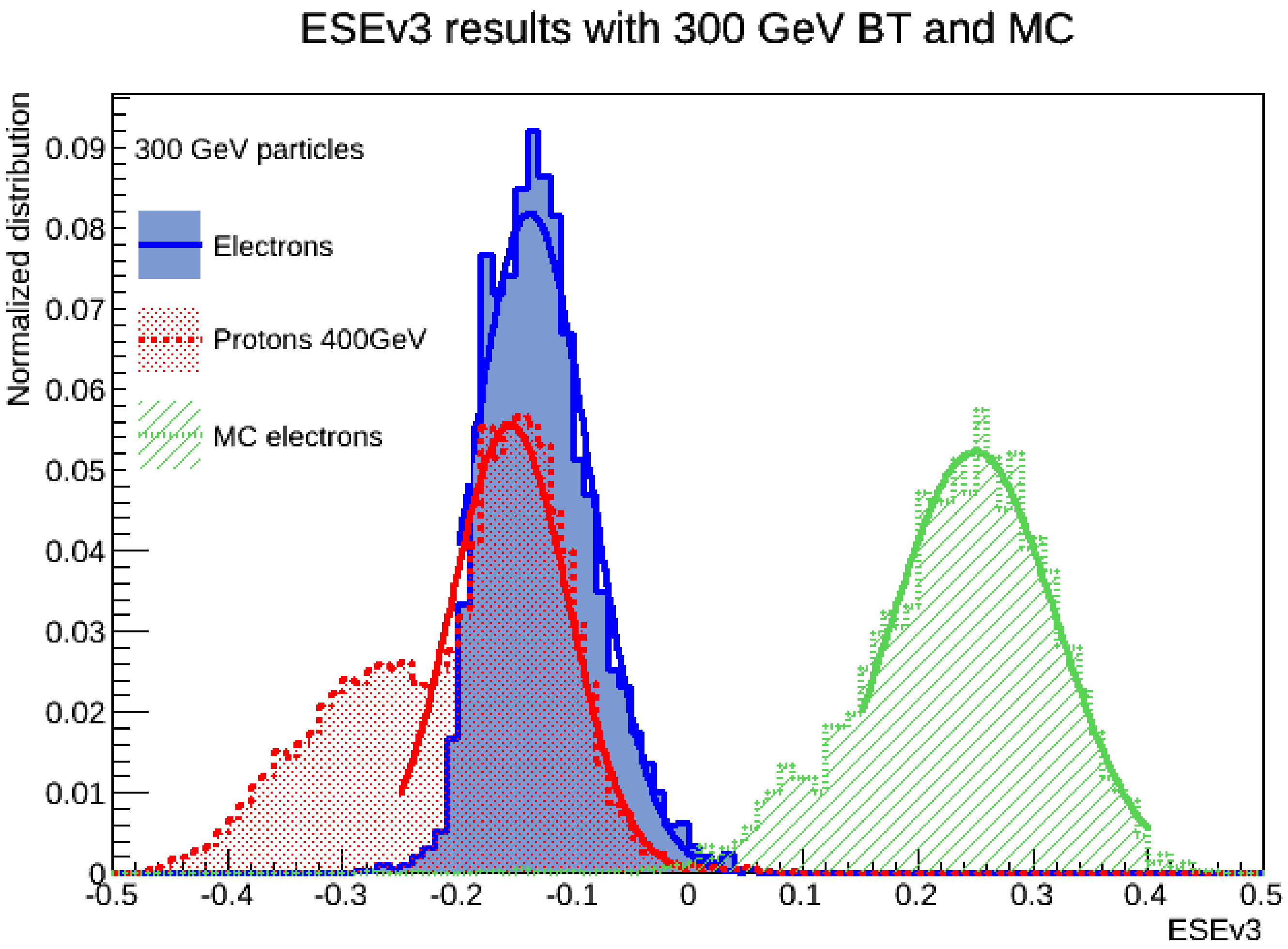
- Beam tests
- Monte-Carlo simulations
- ISS Data (selected by TRD, E/P...)

Which variables ?



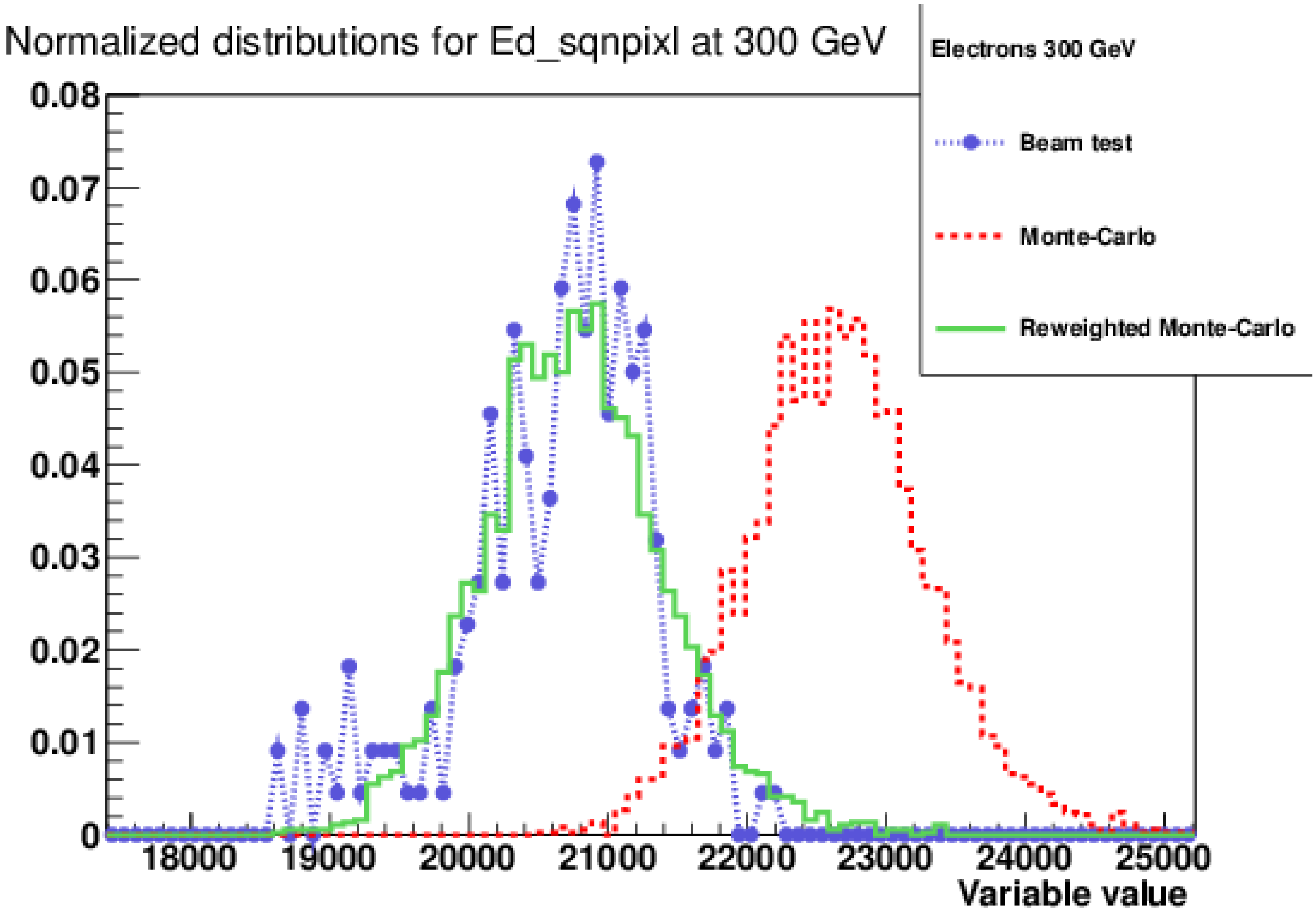
- Shape-related variables
- Fit to the longitudinal profile
- Energy-deposited variables

First results



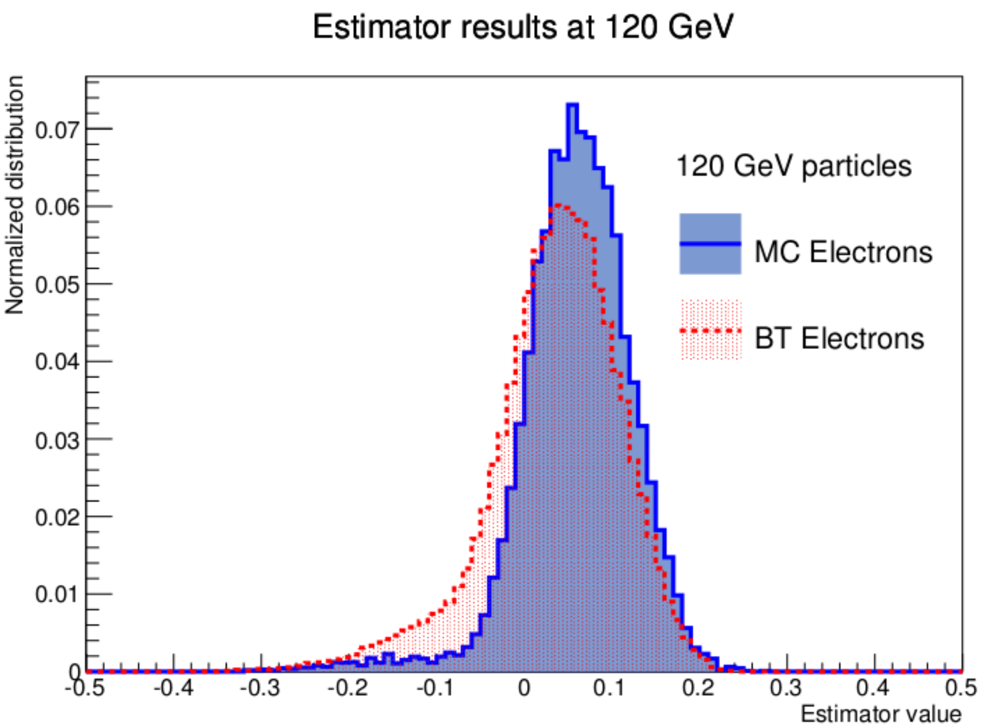
Adjust simulation to data ?

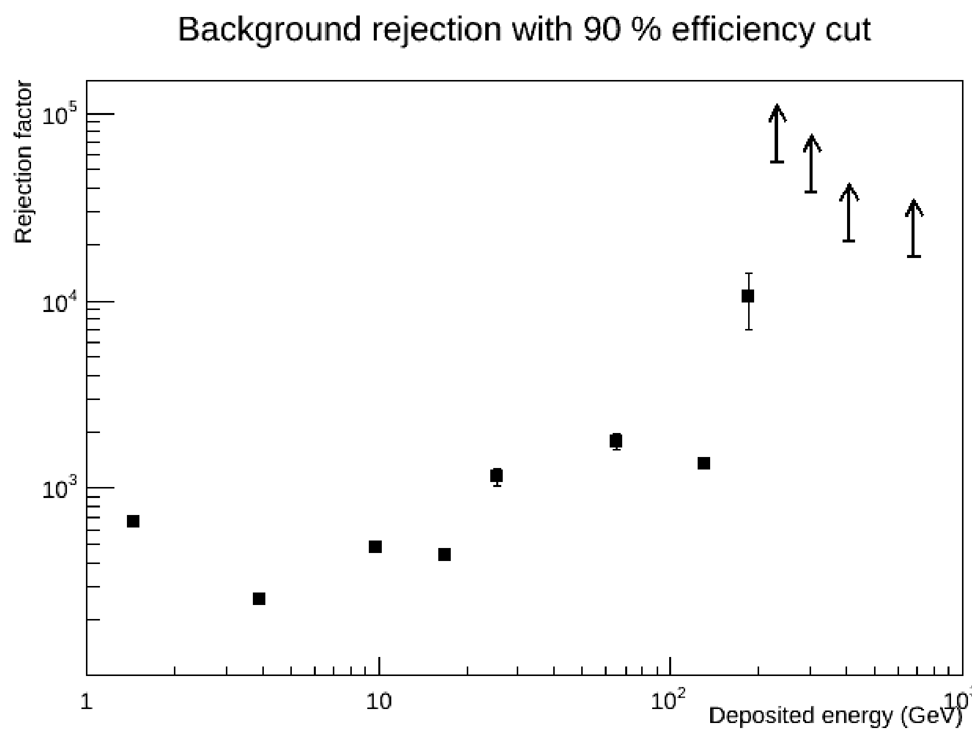
Smearing



- Differences MC/BT at the variables level
- Compare variables distributions
- Smear the variables

Results after smearing





- For a 90 % efficiency, increases with energy
- $>10^4$ above 200 GeV

Conclusions on part II

- A Leptons / hadrons estimator was built
- Only ECAL variables
- Combined (E/P + MIPs + Estimator) rejection of 10^4 obtained for a 90 % efficiency above 200 GeV
- → Compute the positron fraction

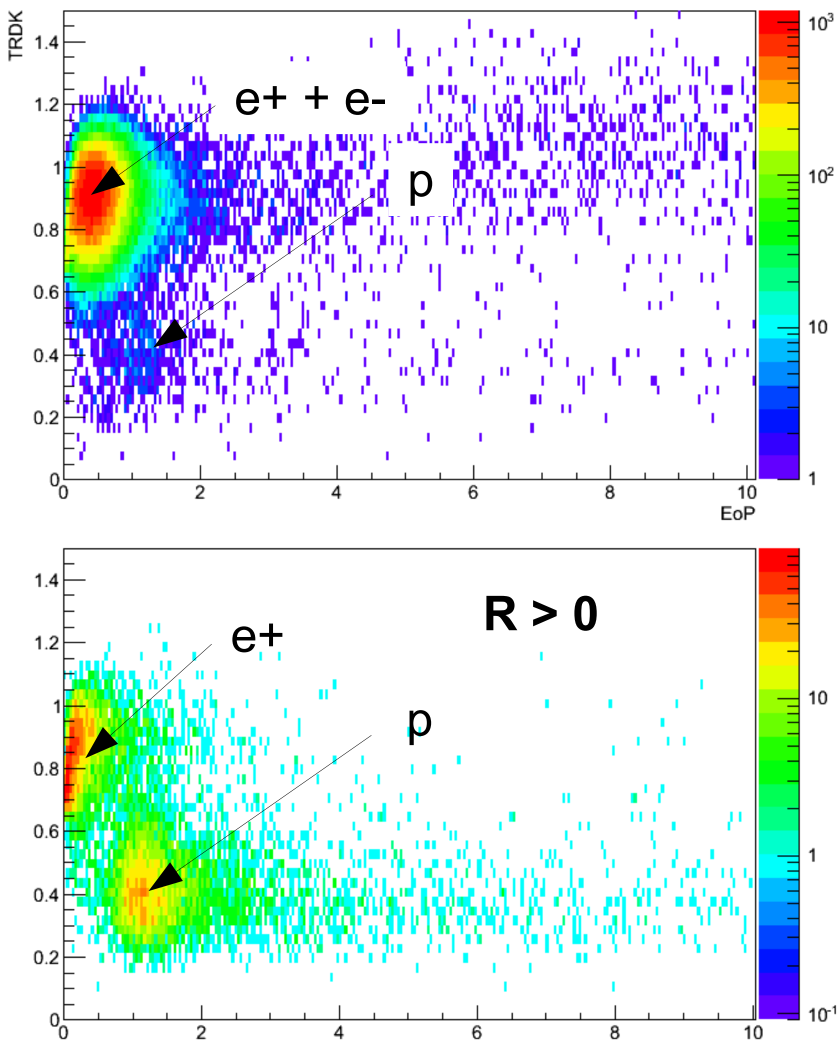
Part III.
The positron fraction

Definition of the positron fraction

$$R \equiv \frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}} \approx \frac{n_{e^+}}{n_{e^+} + n_{e^-}}$$

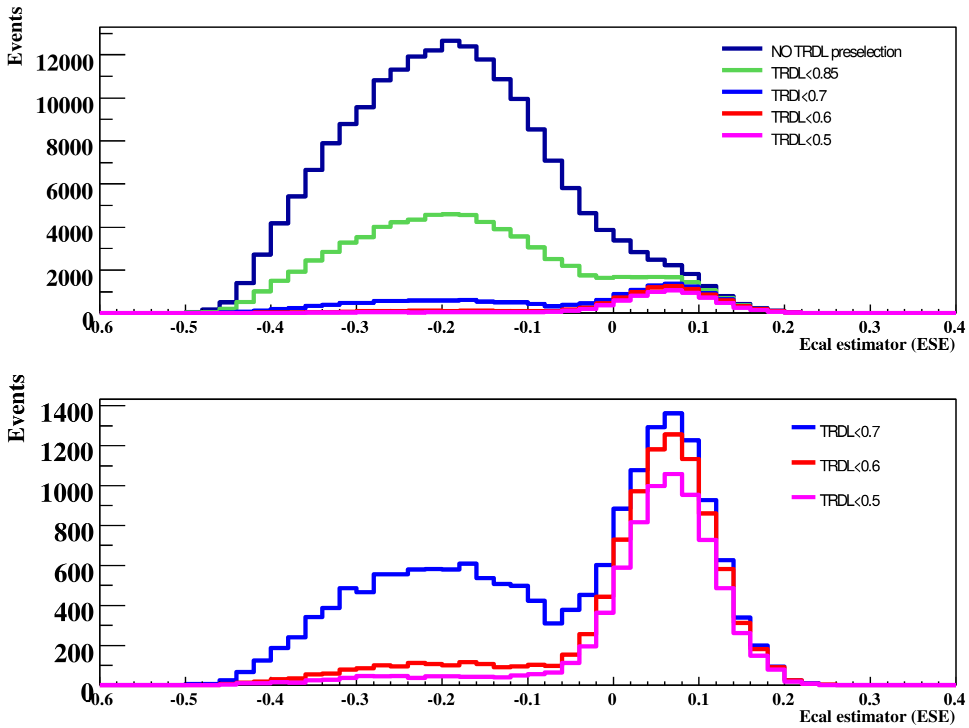
- The positron fraction
  - Independent on acceptance
  - Direct ratio of the number of particles
- Methodology
  - Only keep leptons
  - Estimate their charge

Leptons selection



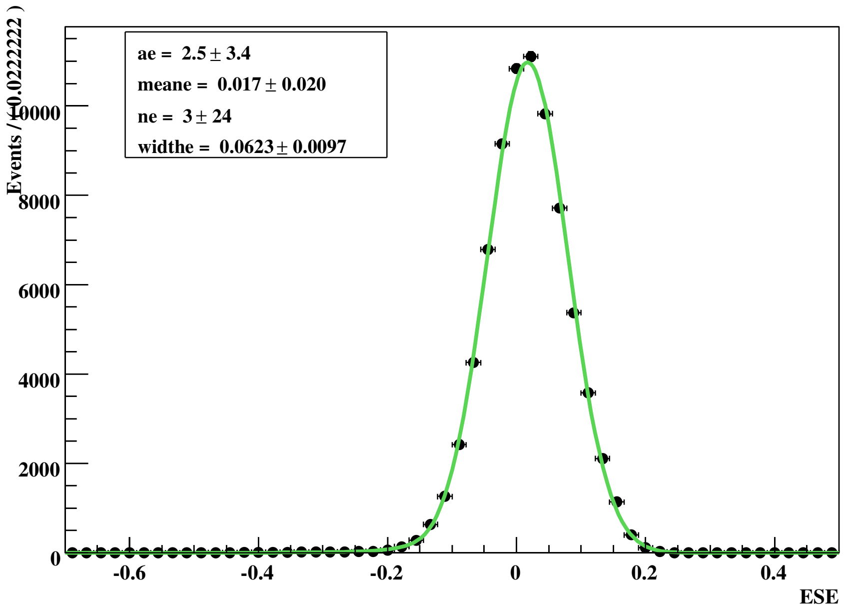
- 65 energy bins from 1.5 to 350 GeV
- Events selection: primary events, track quality, particle estimators...
- 3 estimators:
  - TRD log-likelihood
  - E/P rejection
  - ECAL Estimator
- Use the first two to select pure samples
- Determine the shape of the third on those samples

Lepton selection 2



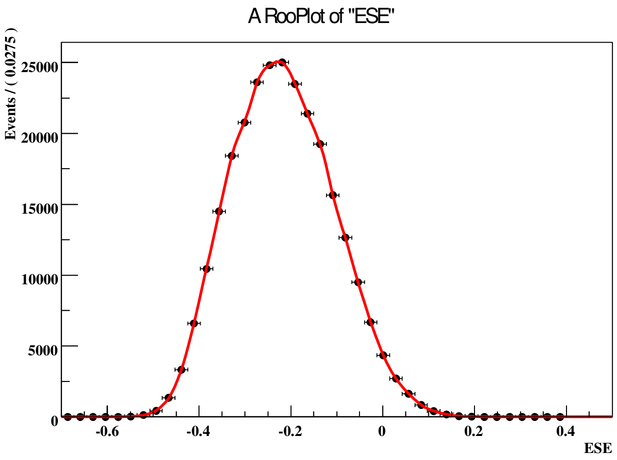
- Effect of various TRD cuts on ESE around 100 GeV
- Discard hadrons while keeping leptons.
- Done for all energies.
- Optimal selections

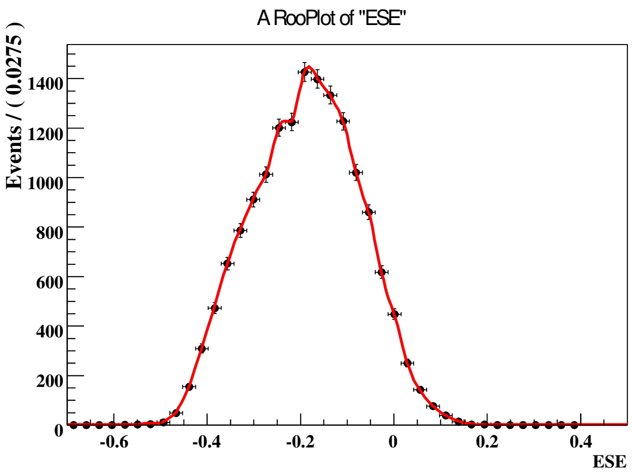
Leptons templates



- Preselection
  - R<0
  - E/P>0.9
  - TRDL<0.45
- Good fit through analytical function
  - Crystal Ball
  - Gaussian core portion
  - Power law low-end tail

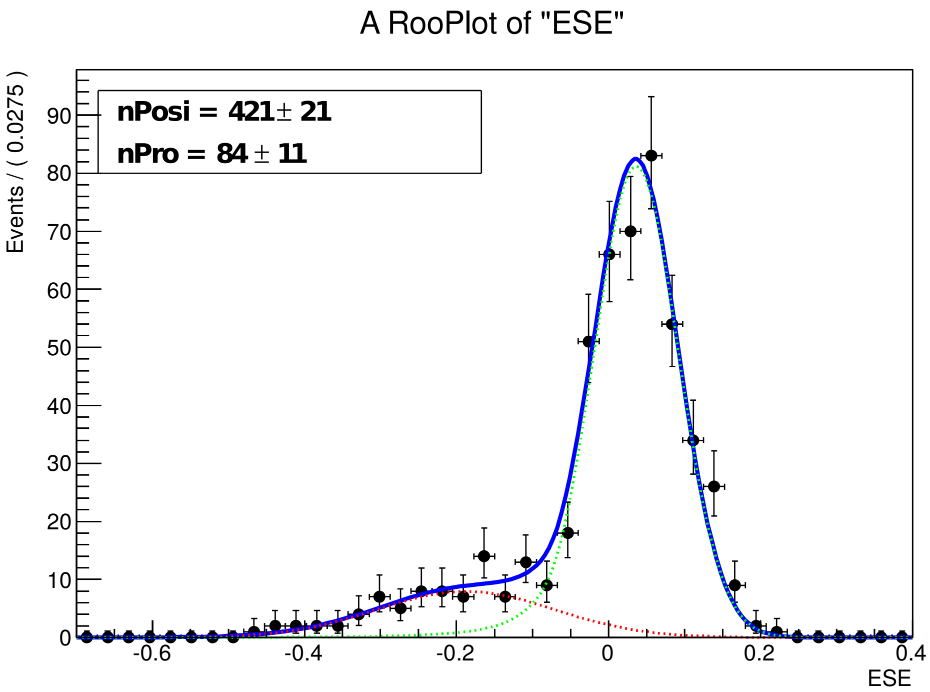
Protons templates





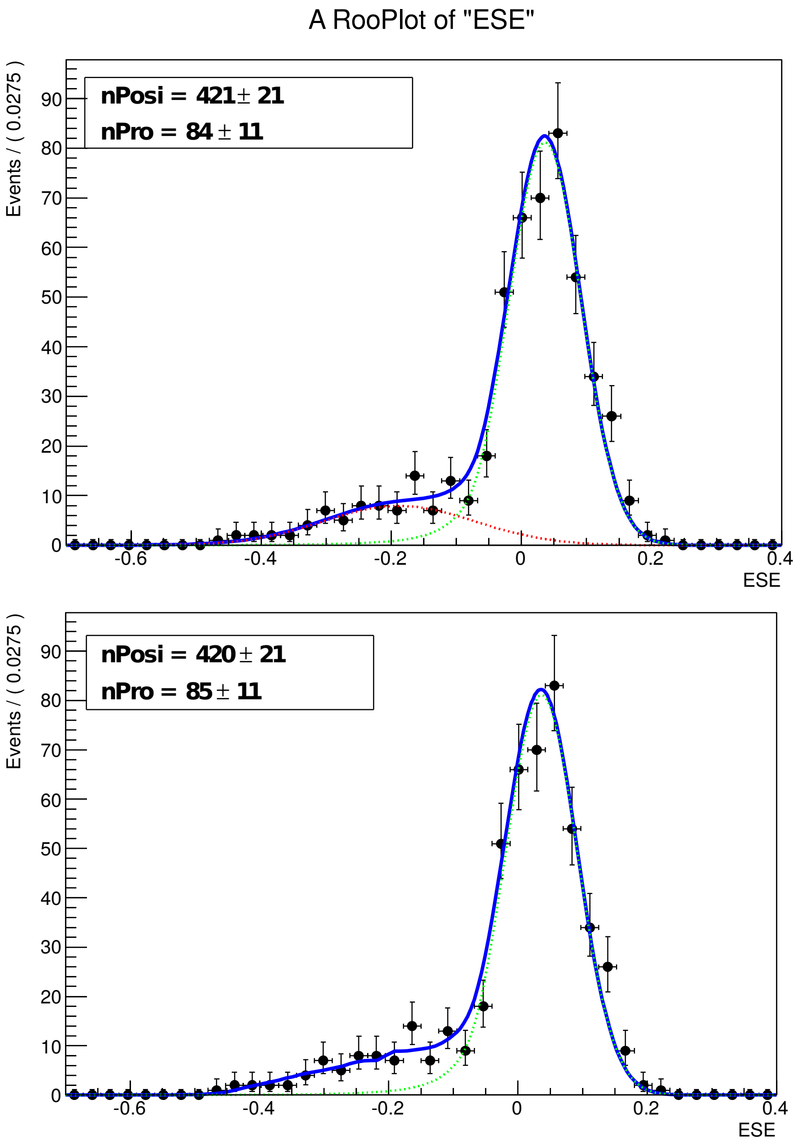
- Preselection :
  - R > 0
  - E/P < 0.4
  - TRD > 0.9 for E<115GeV, 0.85 above.
- Crystal ball does not reproduce well data
  - Novosibirsk (analytical)
  - Histograms (direct) fits

Application of the templates



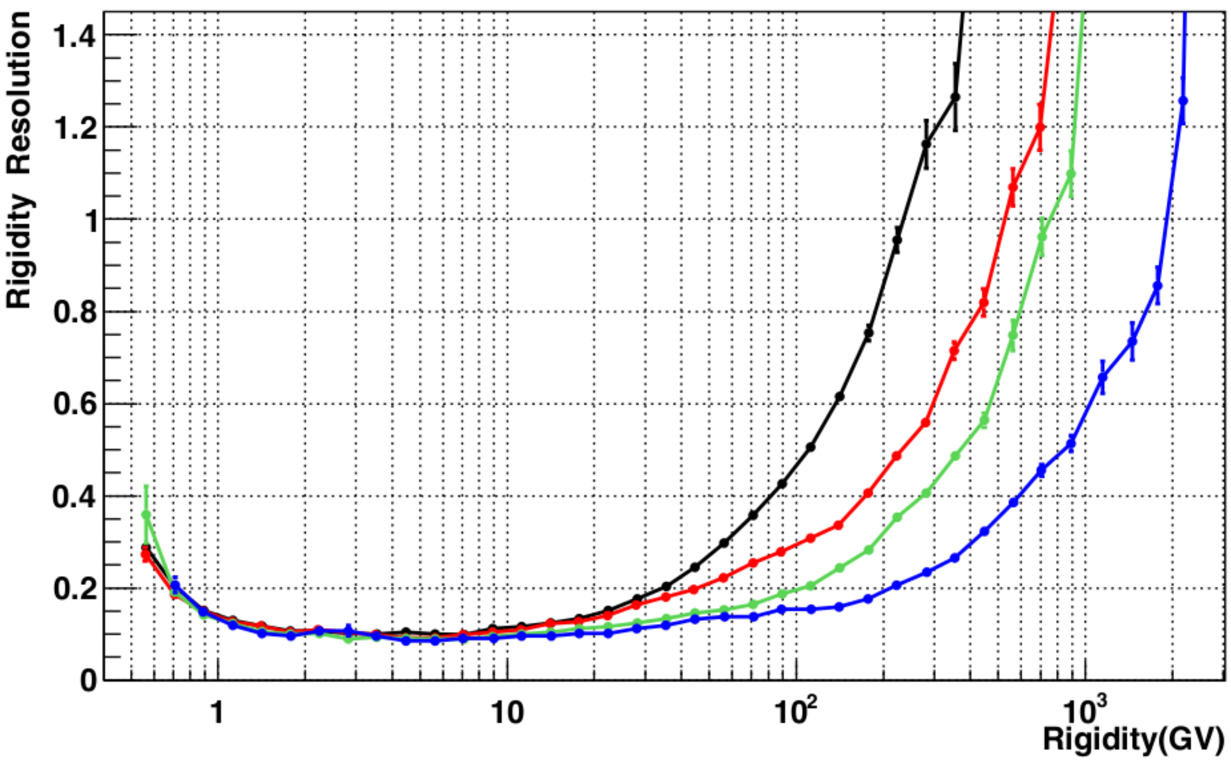
- Apply to preselected "real" data for each bin
- A histogram = a unique linear combination of leptons and protons template.
- Area = number of each species
- Done for all events ($e^+ + e^-$) and ones with positive rigidities (e^+).

Comparison between proton templates



- Top: Novosibirsk, bottom: histograms
- Differ only by one event
- Seen for all bins of high energies
- Histograms taken for all bins

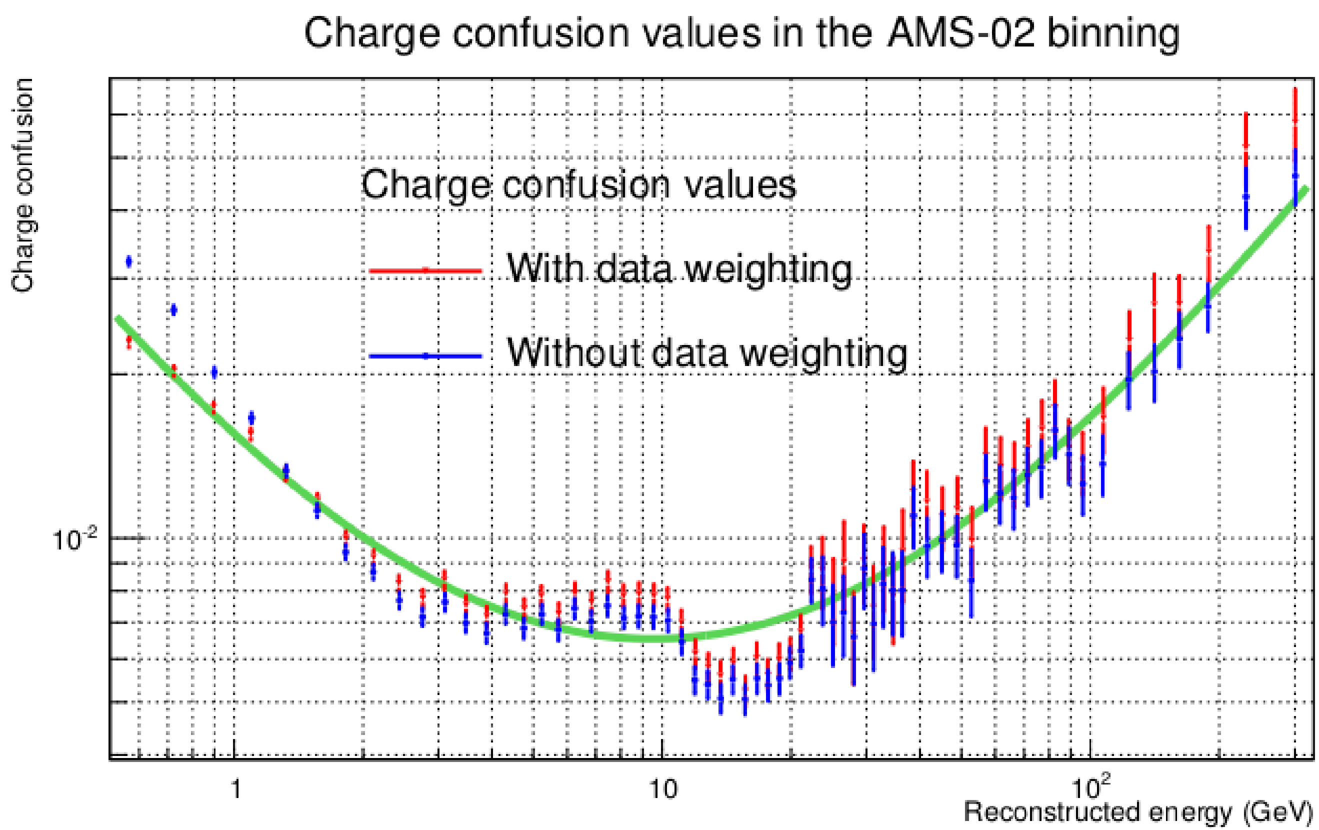
Charge confusion



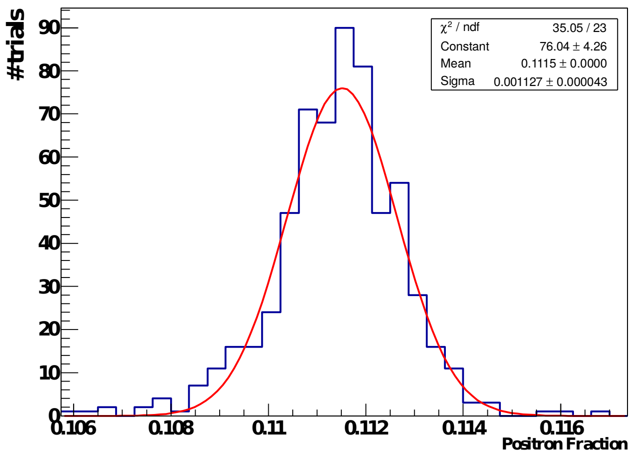
- Sign of charge: only given through magnet + tracker
- Limited granularity
  - Maximum detectable rigidity 2TV
  - Some charge signs are wrong
- Estimate the fraction of charge misidentified (charge confusion)
- Monte-Carlo simulations

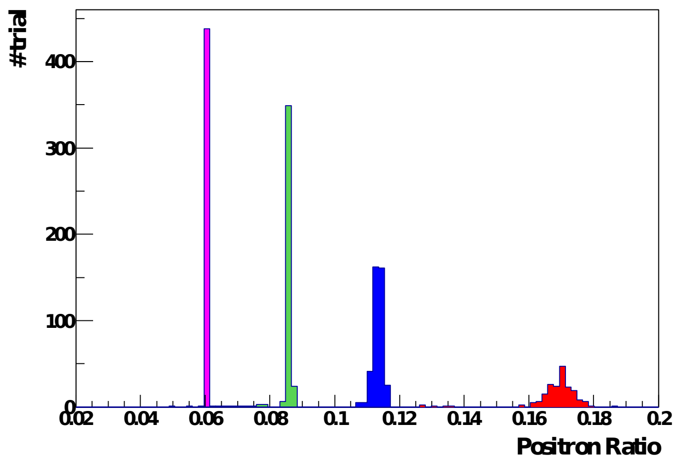
Assessing the charge confusion

$$f_{cc} \equiv \frac{n_{cc}}{n_{e^-}} \qquad R = \frac{1}{1-2f_{cc}}\left(\frac{n_+}{n_+ + n_-} - f_{cc}\right)$$



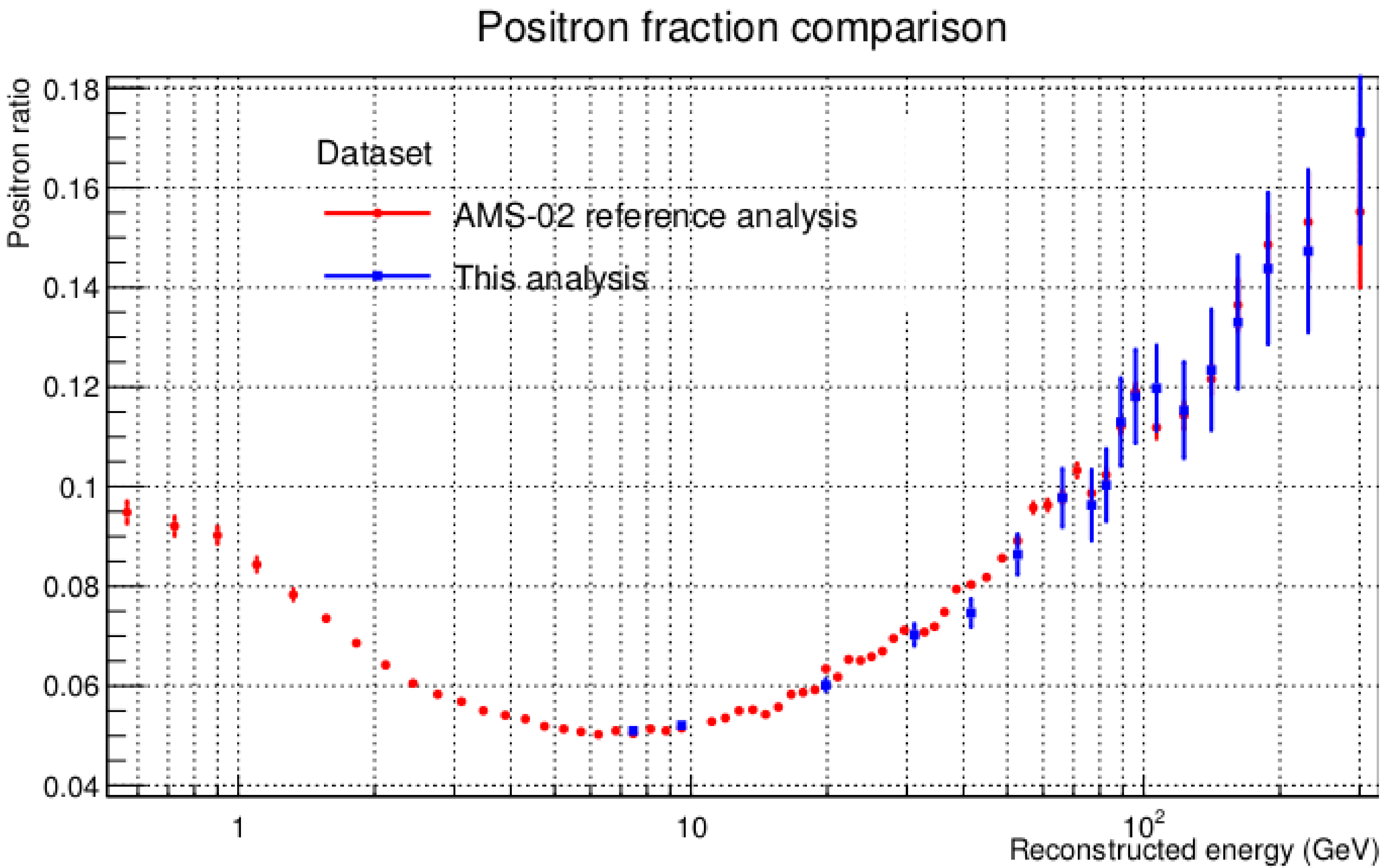
Uncertainty sources





- Acceptance asymmetry (neglected)
- Bin-to-bin migration (neglected)
- Charge confusion (stat.)
- Reference spectra (seen)
- Effect of the number of leptons selected by TRDL, E/P on ratio
- Added in squares to give the squared total uncertainty

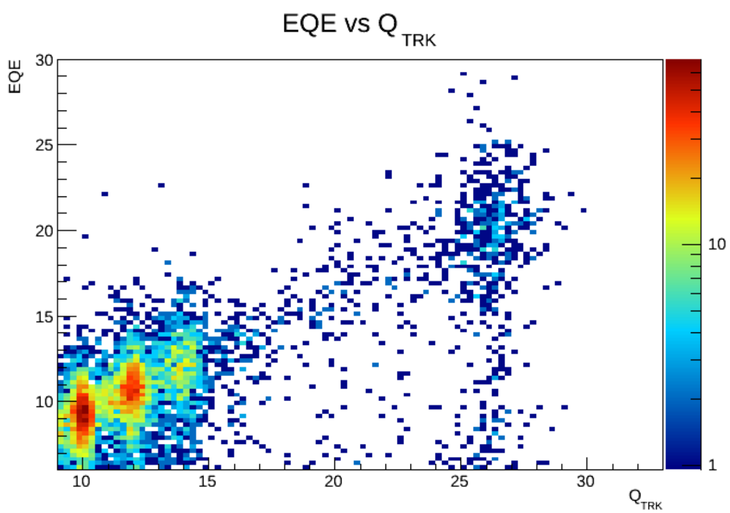
Final positron ratio

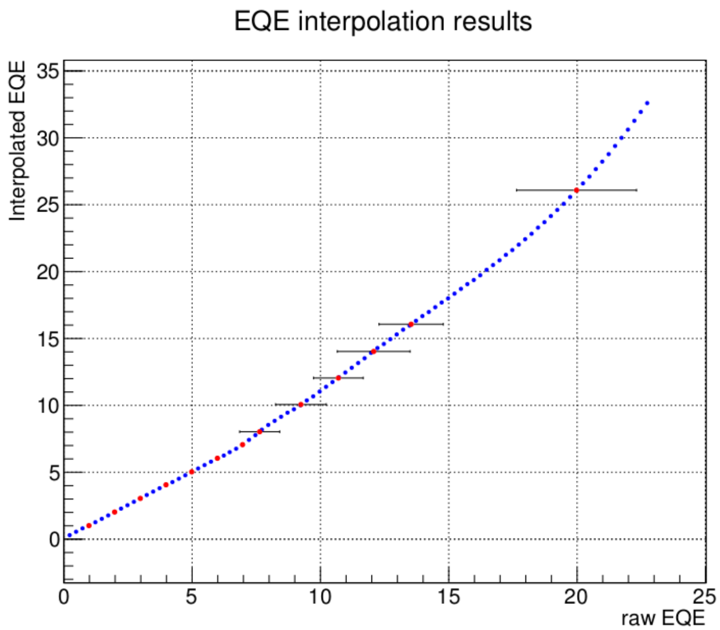


Conclusions and prospectives

- Results from the paper are reproduced, using different method and estimator
- Crucial point: what happens after 350 GeV (plateau ? stiff drop?)
- More statistics ($\sqrt{t}$)
- Improve ESEv3
  - New MC simulations
  - More smeared variables
  - More ISS Data
- 2D fits
- Other spectra from AMS-02
- Other experiments
  - ISS-CREAM
  - CALET

Nuclei of higher charge





- Drop, and the re-increase
- Known effects (GLAST, ToF...)
  - Quenching
  - Antiquenching
- Effect due to nuclei charge, not lack of linearity.
- Use of splines between Z=8 and Z=26
- Implemented in the software