Observational capabilities and techniques for the study of Light-Nuclei in Cosmic Rays with the PAMELA experiment.

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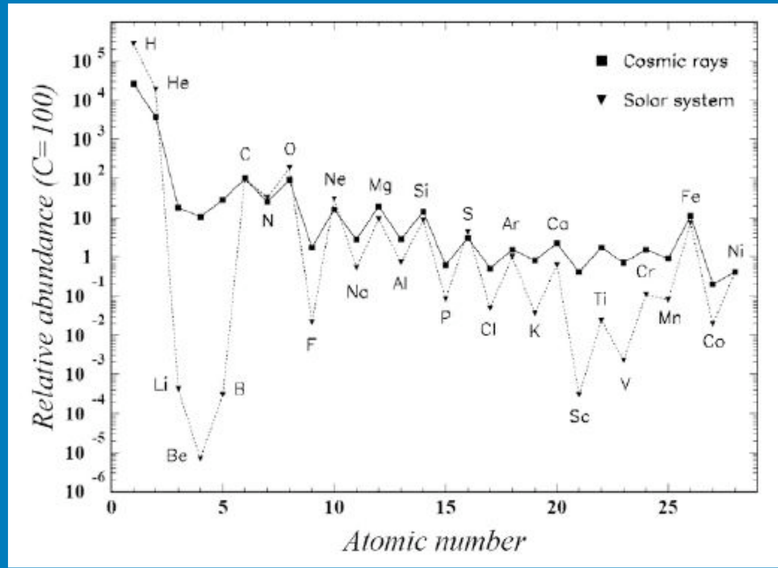
Summary

- Physical reasons to study the nuclear component of CR
- The PAMELA experiment
- How to use sub-detectors to identify nuclei
- Charge calibration and resolution for PAMELA sub-detectors

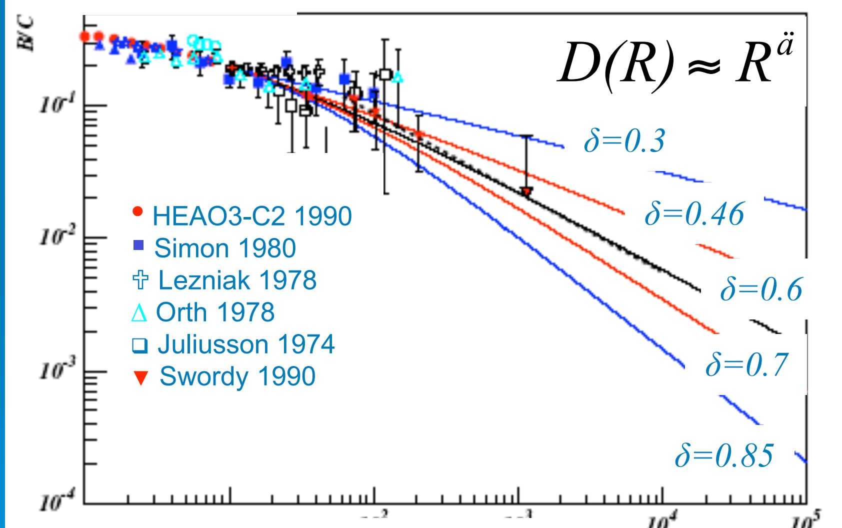
The chemical composition of cosmic rays is a crucial piece of information and is becoming well determined at energies below the knee, where direct measurements can still be carried out, while it is more uncertain and model dependent at higher energies.

The composition of low energy cosmic rays provides important hints to the acceleration processes and the propagation of cosmic rays through the interstellar medium (ISM).

Especially important in this respect are the abundances and spectra of elements produced as secondaries of primary cosmic rays.



B/C ratio



A. Castellina, F. Donato 2005

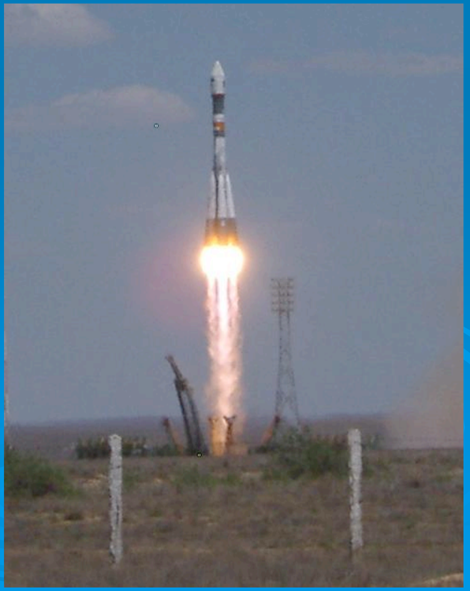
Elements such as Boron, Beryllium and Lithium, which are mainly produced as secondaries of primary cosmic rays,can be very useful..

The ratio of secondary to primary (for instance B/C) cosmic ray fluxes provides a unique tool to characterize the diffusion properties of the ISM. Existing measurements of this ratio as a function of energy suggest that the diffusion coefficient scales with energy as $D(E) \sim E^{\alpha}$, with $\alpha \sim 0.6$, at least at rigidities below 10 GV, while it is not clear whether at higher energies the slope remains constant or there is a flattening.

The PAMELA experiment

- Search for antimatter
- Search for dark matter
- Study of cosmic-ray propagation
- Study solar physics and solar modulation
- Study of electron spectrum
- Study terrestrial magnetosphere

- First switch-on on June 21th 2006
- Continuous data taking mode since 11th July 2006
- Mission extended till December 2011



Launched on June 15th 2006

PAMELA apparatus

Main requirements: high-sensitivity particle identification, precise momentum measure.

Time-Of-Flight

plastic scintillator strips + PMT:

⇒ trigger, albedo rejection;

⇒ mass identification up to E ~ 1 GeV;

⇒ charge identification from dE/dX.

Magnetic spectrometer

with microstrip Si tracker:

⇒ charge sign and momentum from the curvature;

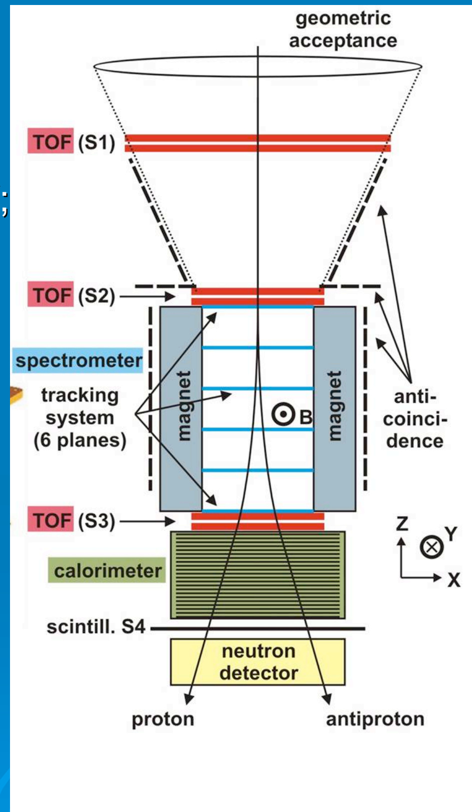
⇒ charge identification from dE/dX.

Electromagnetic calorimeter

W/Si sampling; 16.3 X0:

⇒ discrimination e^+ / p, e^- / p^- from shower topology;

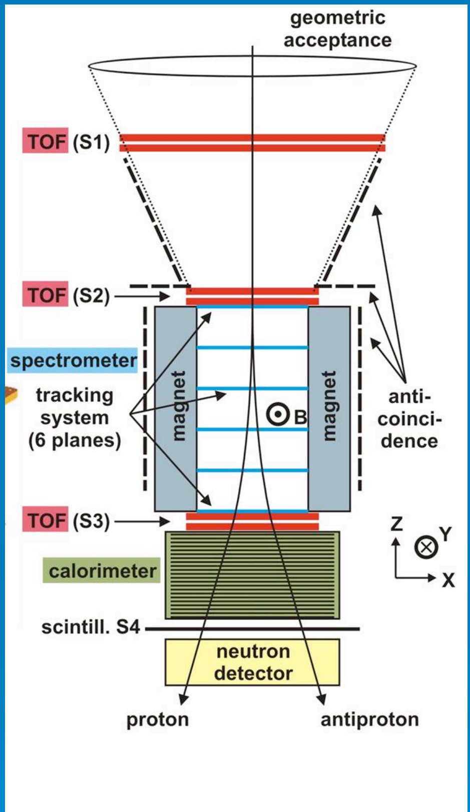
⇒ direct E measurement for e-.



Charge identification

$$-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

Bethe Bloch
ionization energy-loss of heavy (M>>me) charged particles



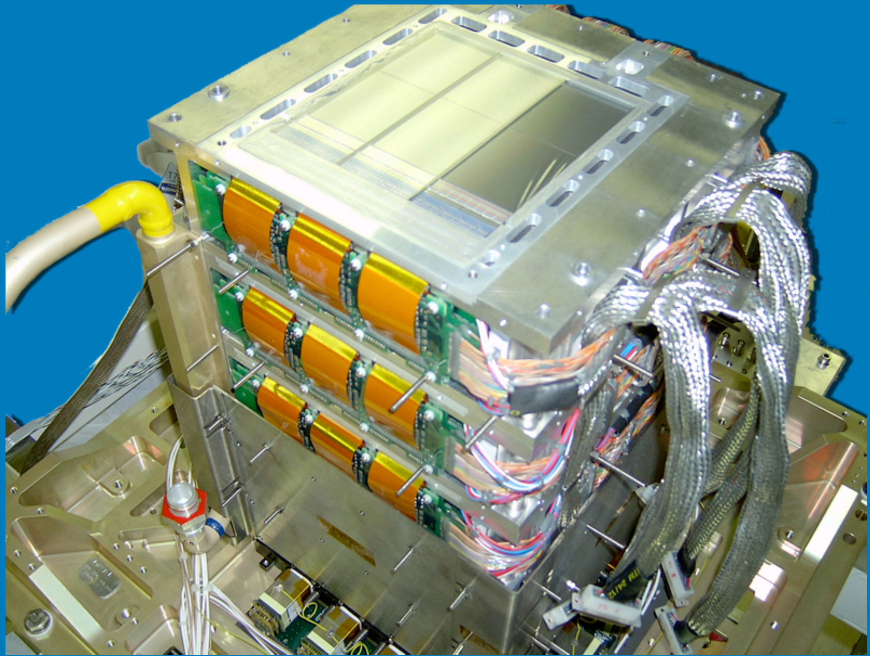
A particle traversing the PAMELA instrument crosses:
- six layers of plastic scintillators (ToF),
- six silicon tracker layers (Tracker)
- at least, the first silicon plane of the calorimeter (Calo)

13 independent measurements of the dE/dx to evaluate the Z of the particle*.
3 charge determining detectors ToF, Tracker, Calorimeter

Z_{ToF} Z_{trk} Z_{Calo}

*Particles that do not undergo charge-changing interactions

PAMELA Tracker system



Characteristics:

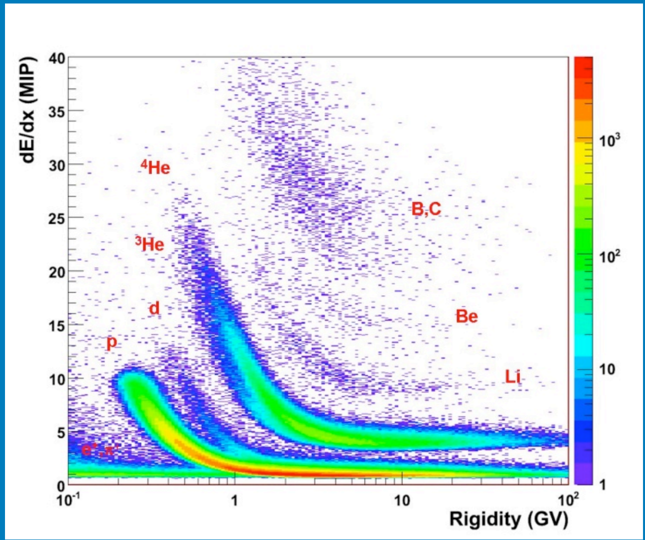
- 6 planes double-side (x&y view) microstrip Si sensors
- 36864 channels

Performances:

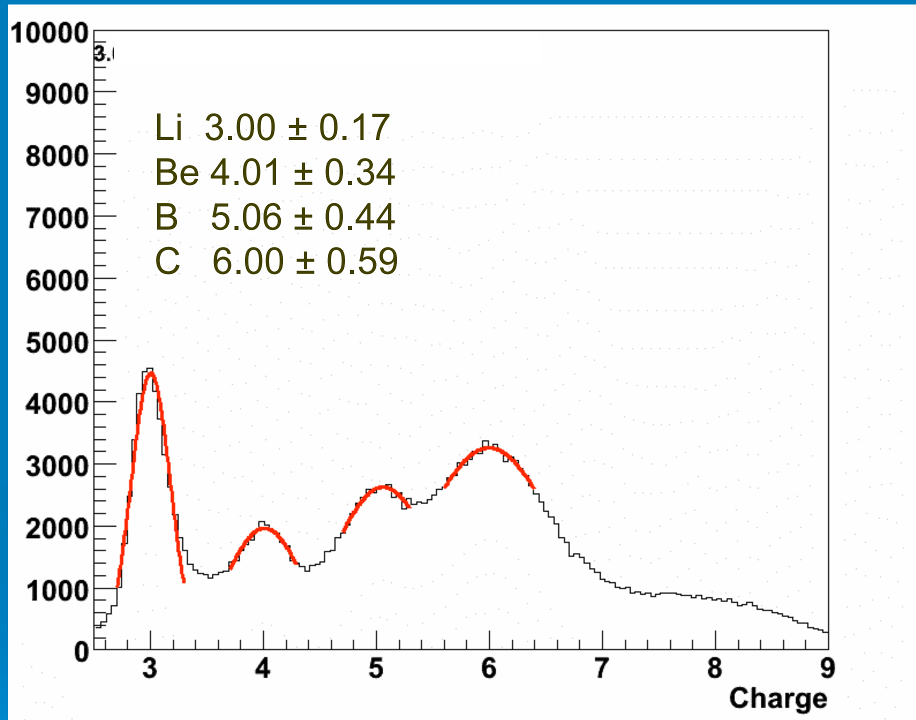
- Spatial resolution: 3-4μm
- MDR ~1TV (from test beam data)
- Dynamic range Z = 1 to Z = 4

Charge signal due to ionization losses inside Si, integrated on clusters of strips, is converted into dE/dx measurement by means of a linear scale; each plane has been calibrated independently.

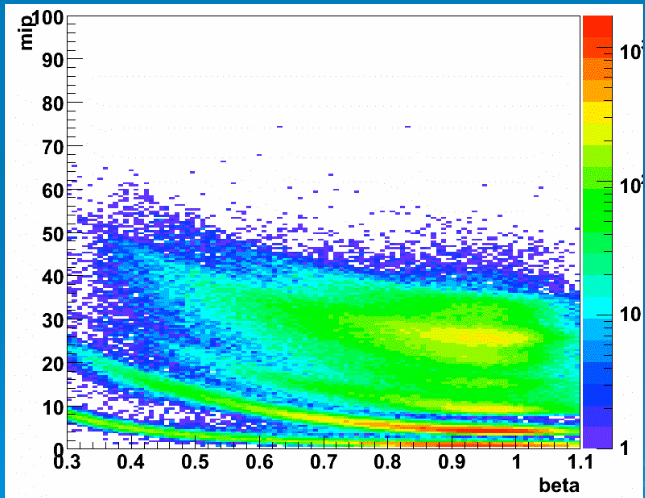
Charge measurements with tracker



Mean of six ionization losses vs rigidity

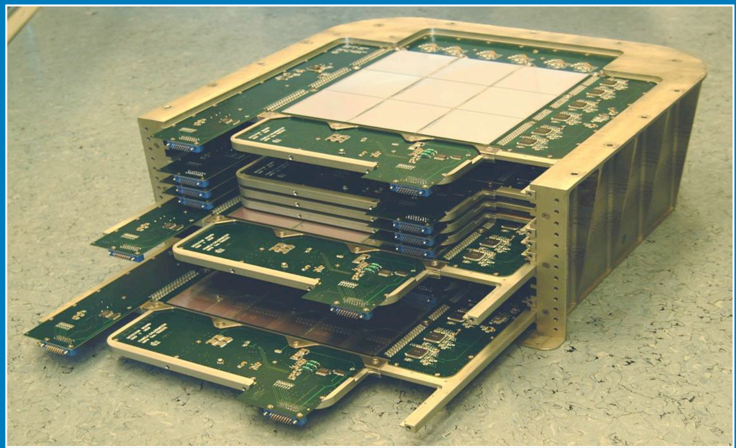


Z measured in a layer of the tracker



Ionization loss in a layer vs beta

PAMELA Calorimeter



Characteristics:

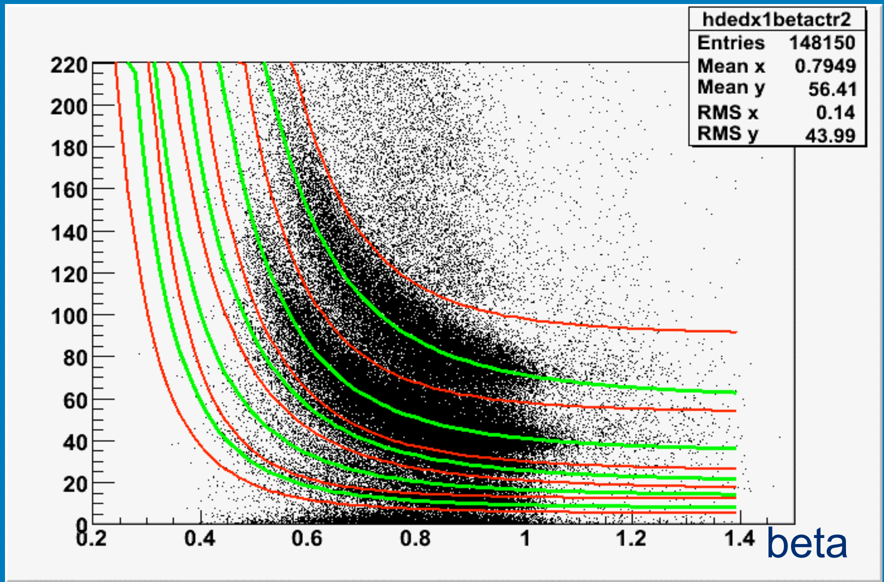
- 44 Si layers (X/Y) +22 W planes
- 16.3 X_o / 0.6 l_0
- 4224 channels
- Dynamic range 1400 mip
- Self-trigger mode (> 300 GeV GF~600 cm^2 sr)

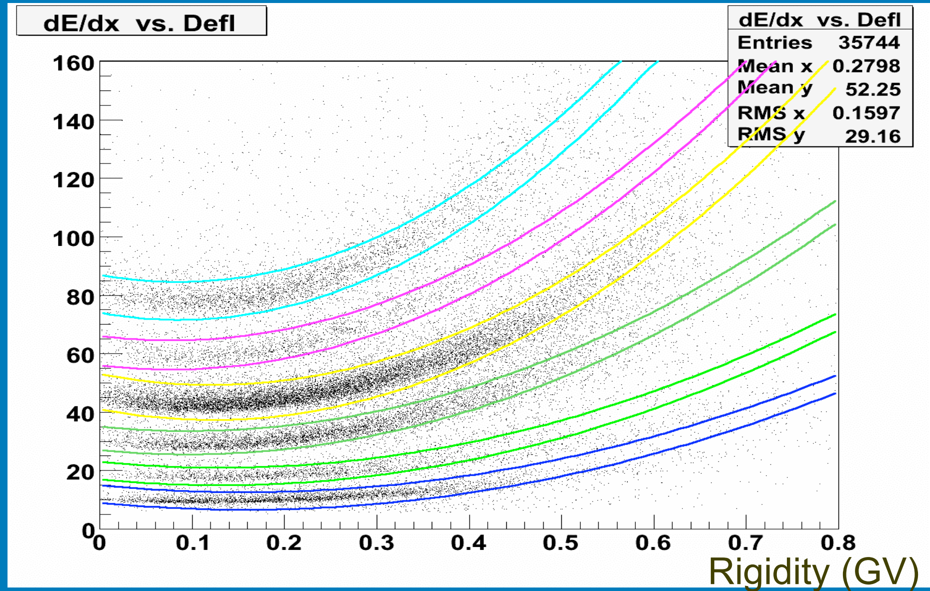
Performances:

- p-bar and e^+ selection efficiency ~ 90%
- p rejection factor $>10^5$
- e^- rejection factor $> 10^4$
- Energy resolution ~5% @200GeV

Also in this case a linear scaling function was calculated to convert charge signal into dE/dx for each layer.

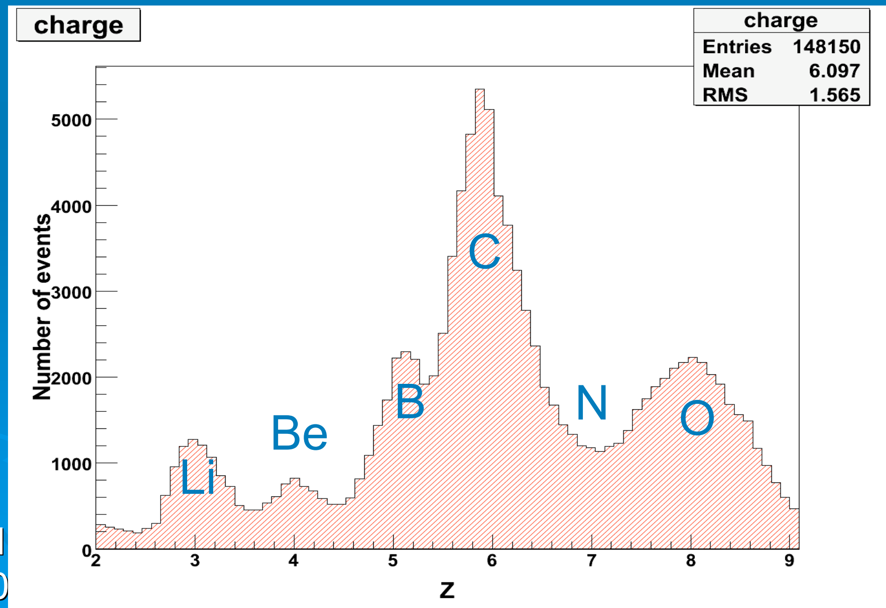
Charge measurements with Calorimeter





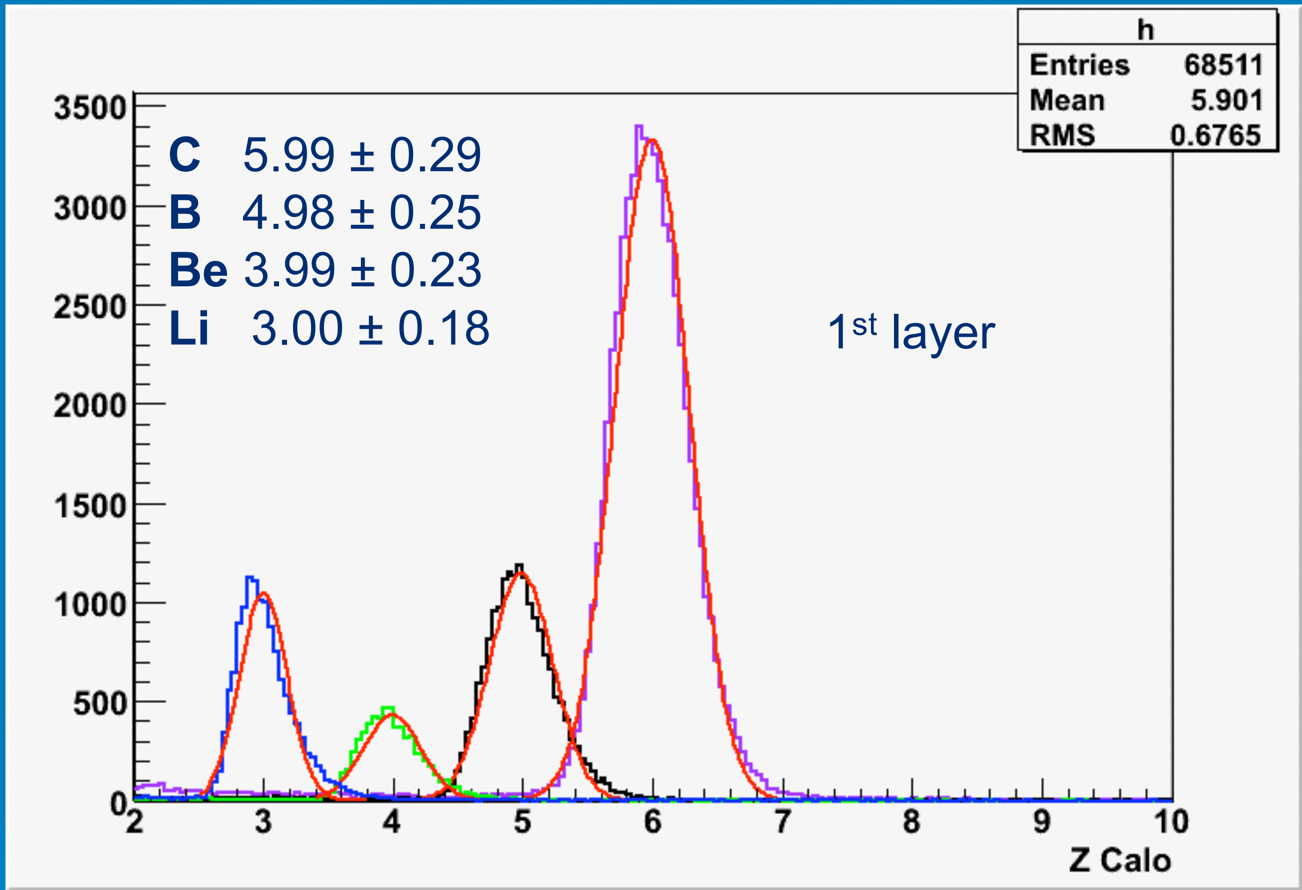
Fitting different charge bands

Z distribution



First layer only is used

Charge measurements with Calorimeter



Charge separation of the Calorimeter for nuclei pre-selected by the ToF

PAMELA ToF system

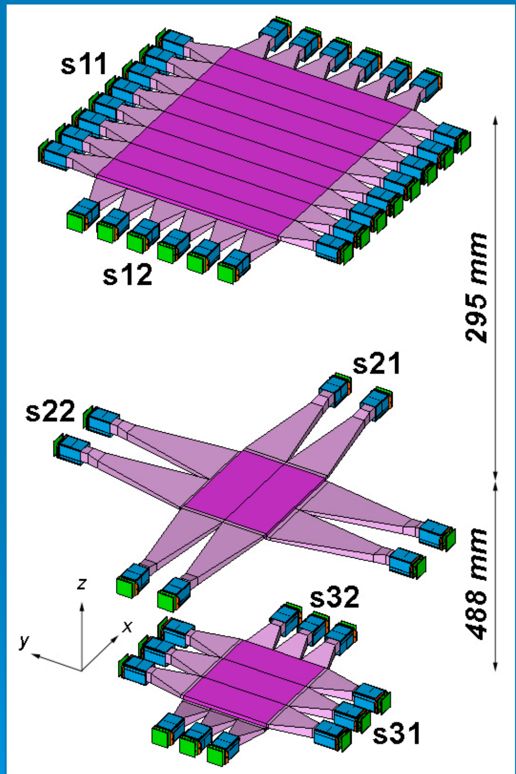
Characteristics:

- 6 layers (3 planes, double view) of BC404 plastic scintillator
- 24 paddles
- 48 photomultipliers

Performances:

- Time resolution:
  - 250 ps protons
  - 70 ps Carbon
- Dynamic range
  Z = 1 to Z = 8*

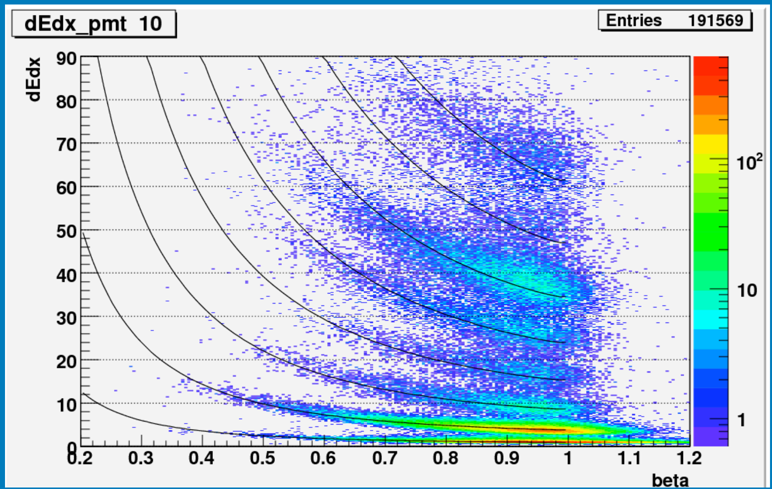
* Only relativistic Oxygen



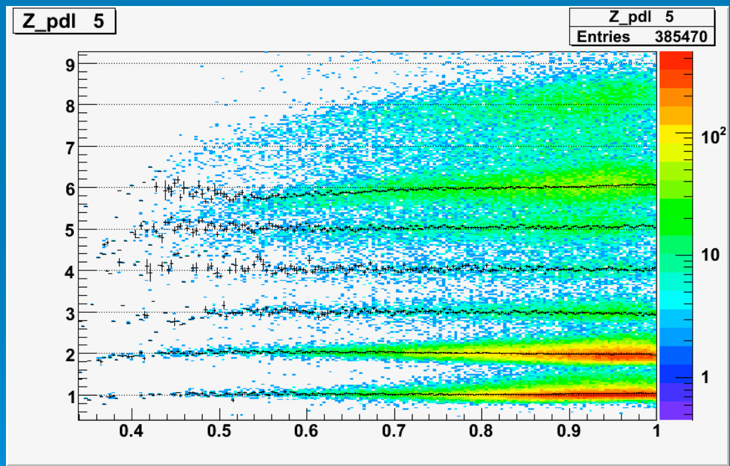
A very complicated charge calibration:

- 6 different groups of scintillators + 48 different PMTs → 48 independent scaling procedure
- Loss of linearity of the instrument due to Birks'saturation of scintillators and loss of gain of PMTs at high values of charge deposits → scaling functions from ADC signal to dE/dx measurement are not linear.

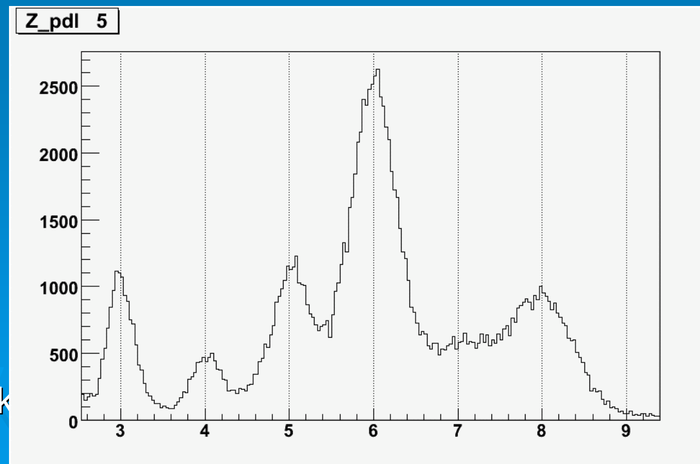
Charge measurements in a ToF paddle



dE/dx vs. β distribution in a paddle (after corrections for attenuation, gain variation and non linearity)

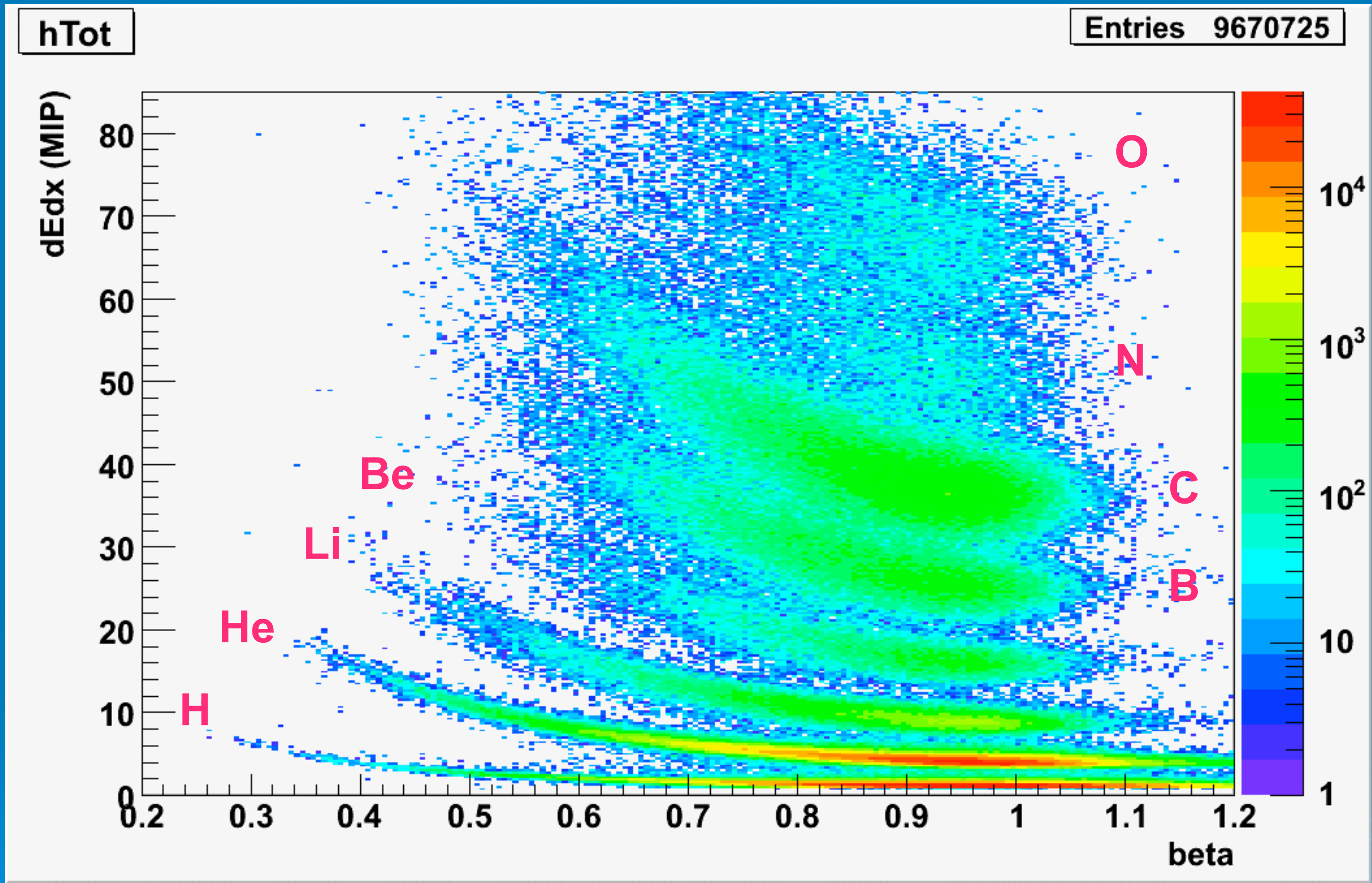


scaling for a Bethe-Block function



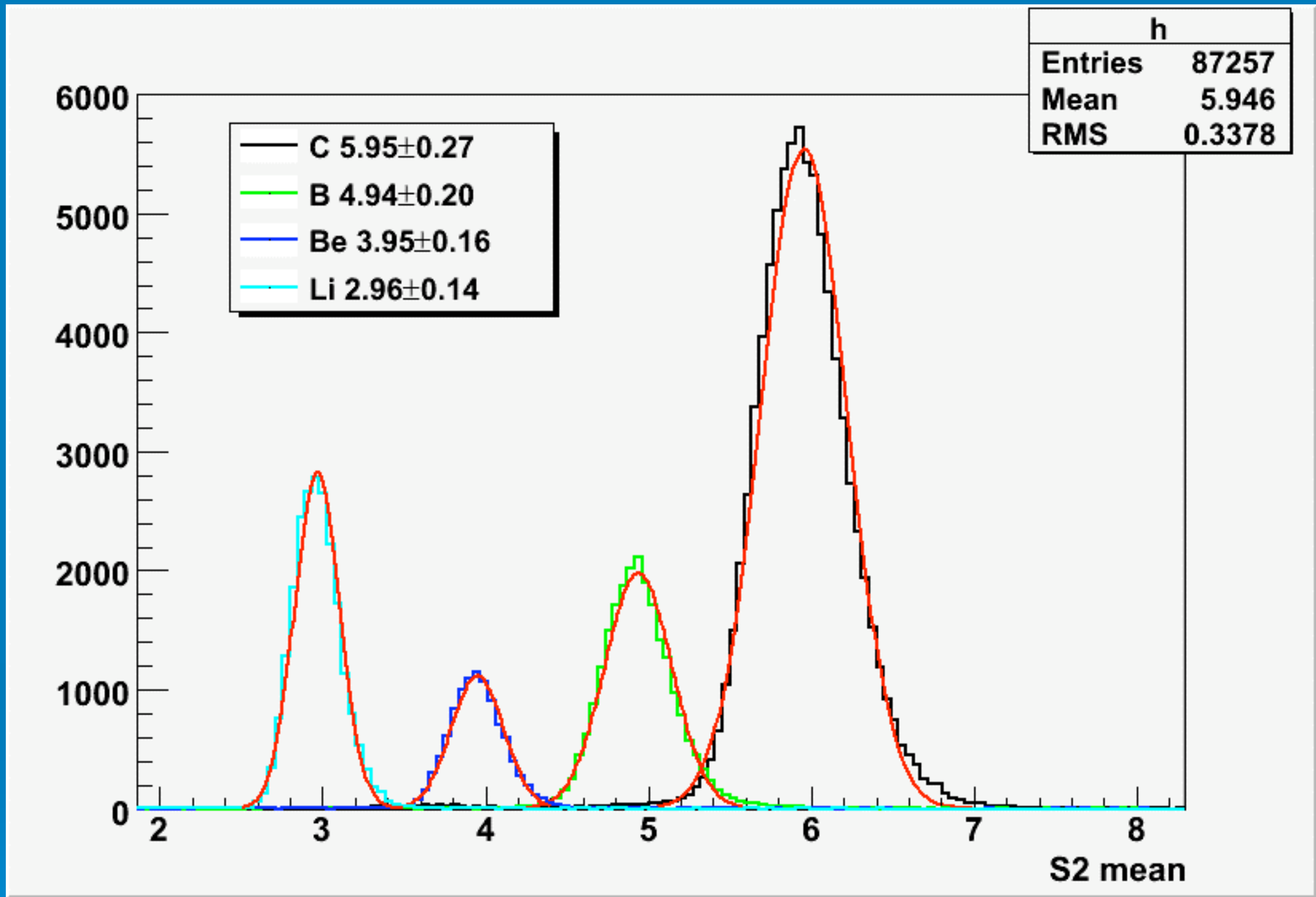
Z measured in a paddle

All ToF dEdx



hTot
Entries 9670725
dEdx (MIP)
0
10
20
30
40
50
60
70
80
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
beta
1
10
10^2
10^3
10^4
O
N
C
B
Be
Li
He
H

Charge identification in a TOF plane



Sample of nuclei selected by requiring charge consistency between Calorimeter and S11 ToF layer

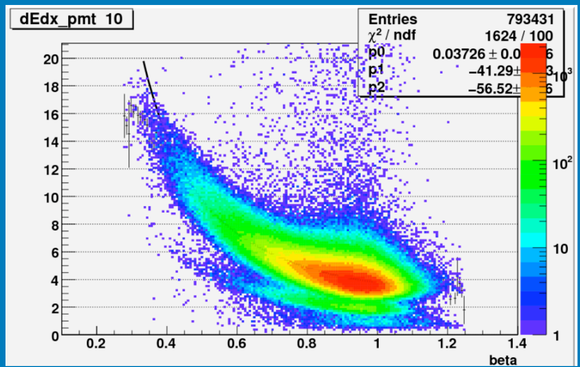
Charge identification

For nuclei analysis:

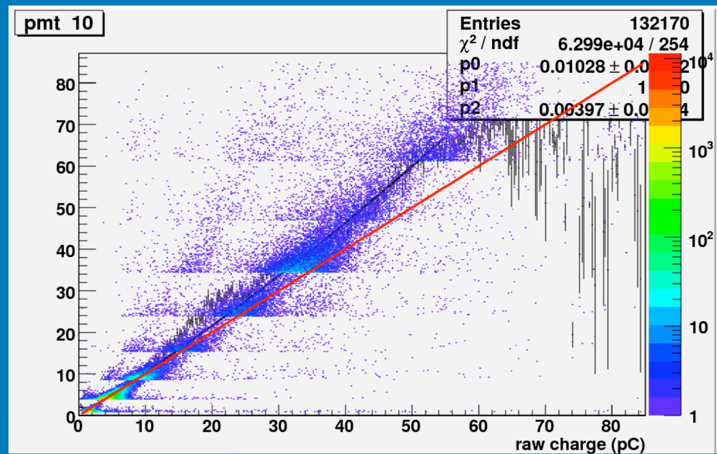
- ToF system is used as main charge detector
- Z_{trk} *is* used to select heavier nuclei in the 'background' of protons and helium
- Z_{calo} *is used* to study the efficiency of the selection cuts.

For details concerning selection criteria and scientific results see poster presented by **L. Marcelli**

Step 3: compensation of saturation respect to the Bethe-Block



Fit of Bethe-Block function on He bands



- Scatterplot of dEdx after step 2 vs expected one, which is the value from Bethe-Block for associated Z, from calorimeter and β, from ToF
- Fit of the trend using a pol2 function (higher plot on the right)