The High Energy Particle Detector of the CSES mission

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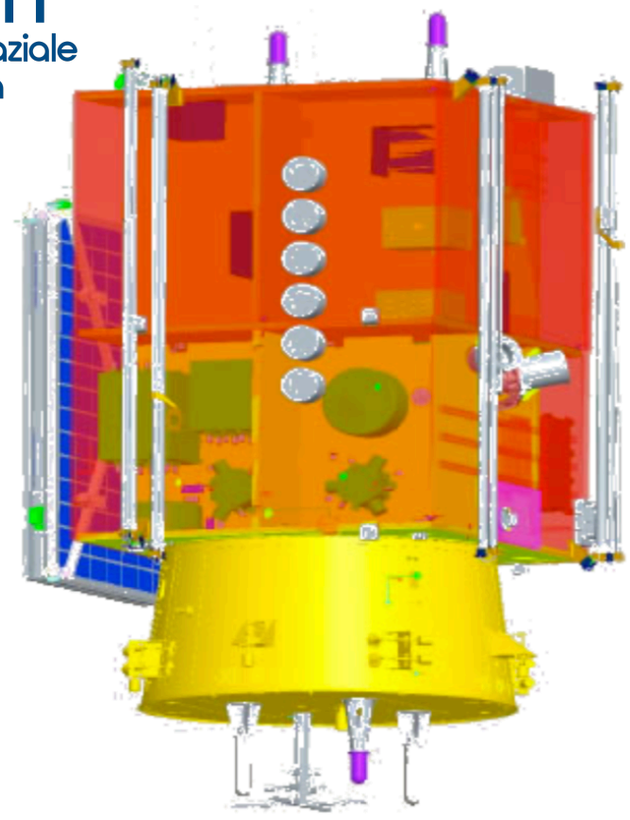
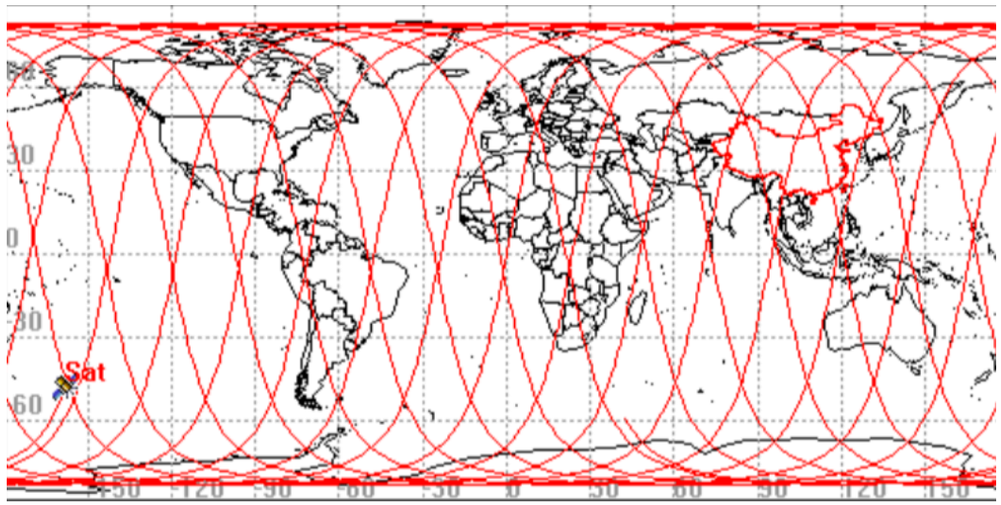
The CSES Mission

The CSES (China Seismo-Electromagnetic Satellite) mission is a sophisticated multi-channel space observatory for seismic phenomena. Many agencies, universities and research institutes are involved:

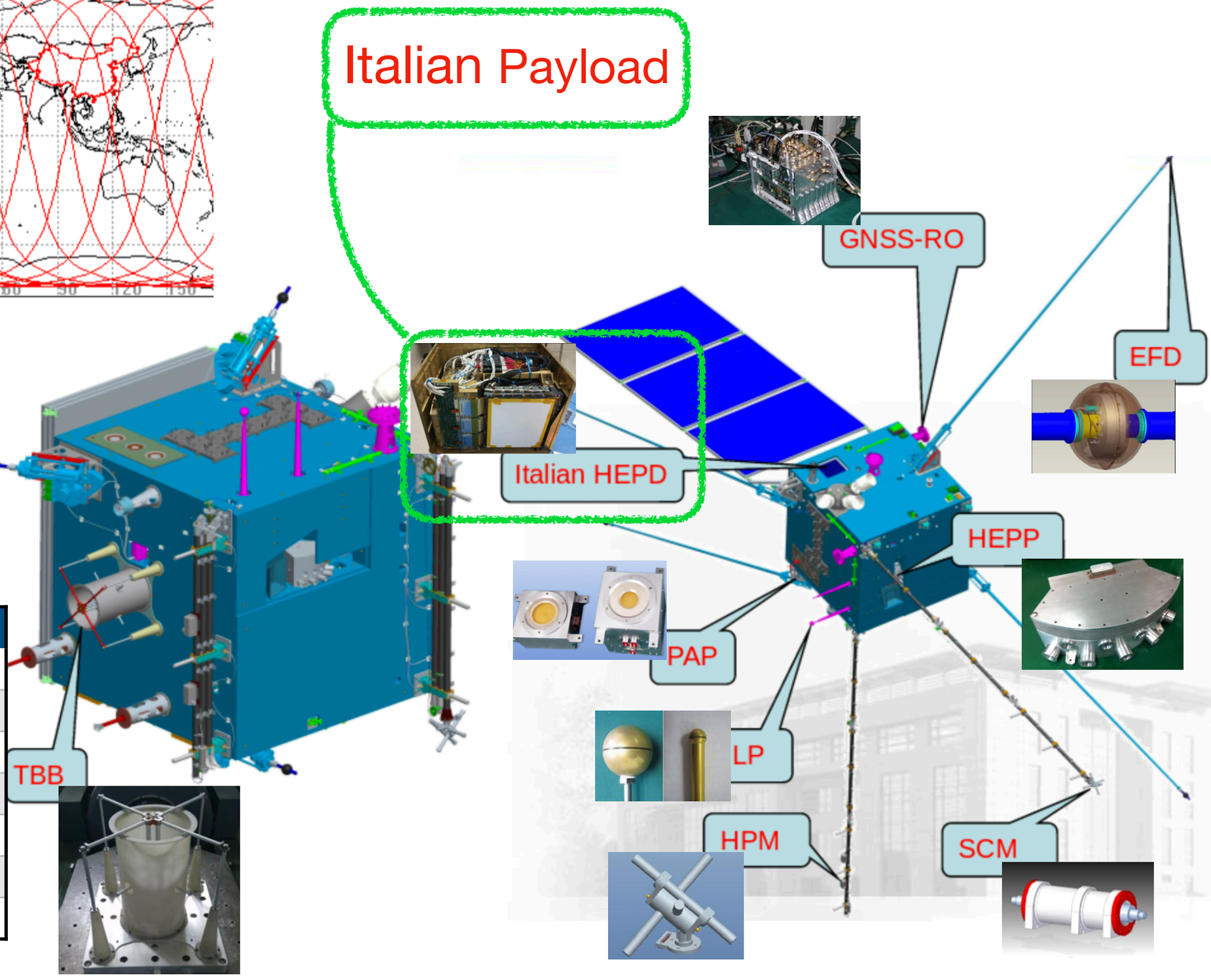


- CNSA (China National Space Agency) and CEA (China Earthquake Administration);
- ASI (Agenzia Spaziale Italiana), INFN (Istituto Nazionale di Fisica Nucleare), INGV and IAPS;
- University of Trento, Rome Tor Vergata, Bologna, Naples, Perugia, Beijing, Nettuno.

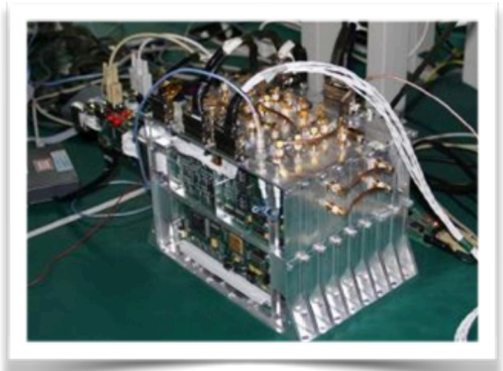
CSES and the payloads



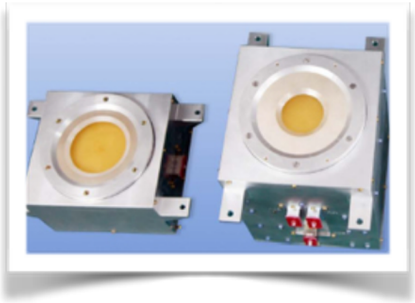
Item	Parameter
Orbit type	Sun-Synchronous
Mass	~ 730 kg
Orbit altitude	506.991 km
Orbit Inclination	97.424°
Orbit period	94.61 min
Circles per day	15+1/5
Recursive Period	5 days



The payloads

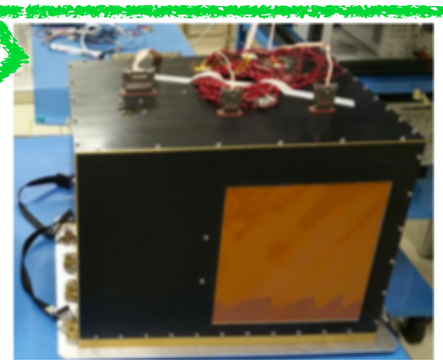


The **GNSS (Global Navigation Satellite Systems) Occultation Receiver** is used to measure the total electron content (TEC) and to obtain **vertical electron density**.



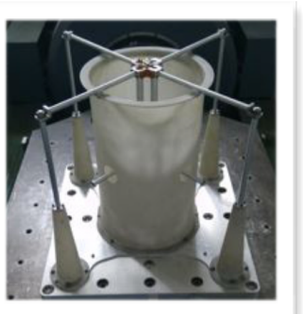
The **Plasma Analyser** measures the plasma parameters, **including ion density**, **ion composition** and **ion density fluctuation.**

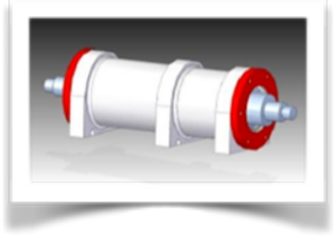
ITALIAN



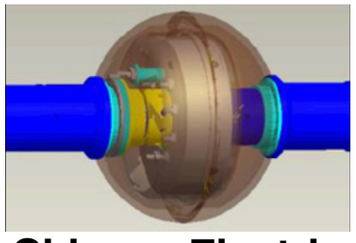
The **High Energy Particle Detector (HEPD)** developed by the Italian Collaboration, detects electrons, protons and light nuclei.

The primary objective of the **Tri-Band beacon** is to study the **electron density in the ionosphere** and to produce 2-D maps or 1-D profiles.

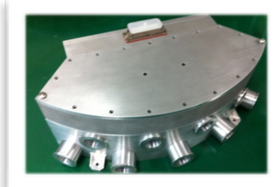




The **High-Precision Magnetometer** is an optically-pumped absolute scalar **magnetometer.**



The **Chinese Electric Field Detector (EFD)** has been realized in two Models (Qualification and Flight) by the Lazhou Institute of Physics (LIP)



HEPP: Low energy particle detector
Energy range:
e: 2-50 MeV
p: 15-200 MeV

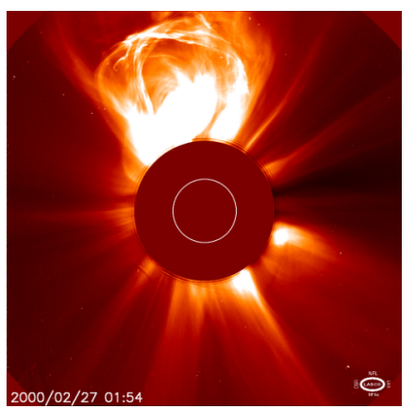
The **Langmuir Probe** allows to monitor the global parameters of the ionosphere in situ and to study the **coupling between lithosphere and ionosphere** before, during and after earthquakes.

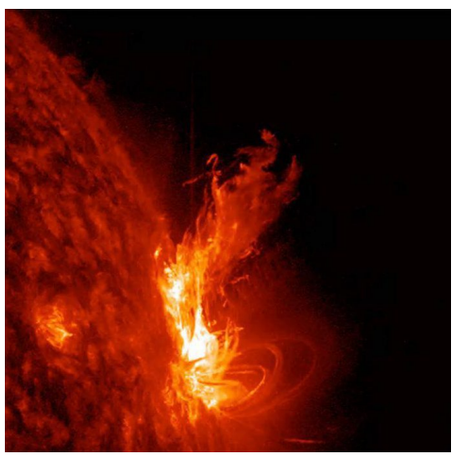
The **Search-Coil Magnetometer (SCM)** measures **magnetic field fluctuations** in ionosphere.

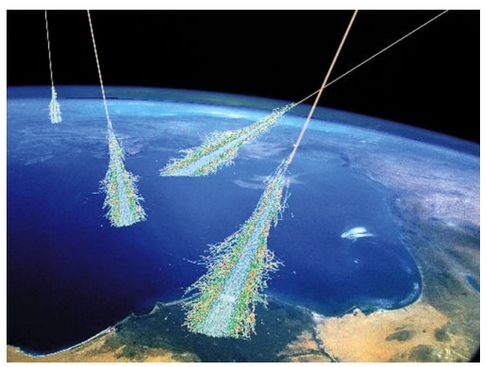
CSES - Scientific Objectives

CSES is the first satellite of a space monitoring system designed to investigate the topside ionosphere and to gather world-wide data of the near-Earth electromagnetic environment:

- Monitor the **electromagnetic field** and **waves**;
- Measure the particles and plasma **perturbations of the atmosphere**, ionosphere and magnetosphere induced by natural sources and anthropic emitters;
- Study their correlation with **seismic events**;
- Study **solar-terrestrial interactions** and phenomena of solar physics, namely Coronal Mass Ejections (CMEs), solar flares and cosmic ray solar modulation.



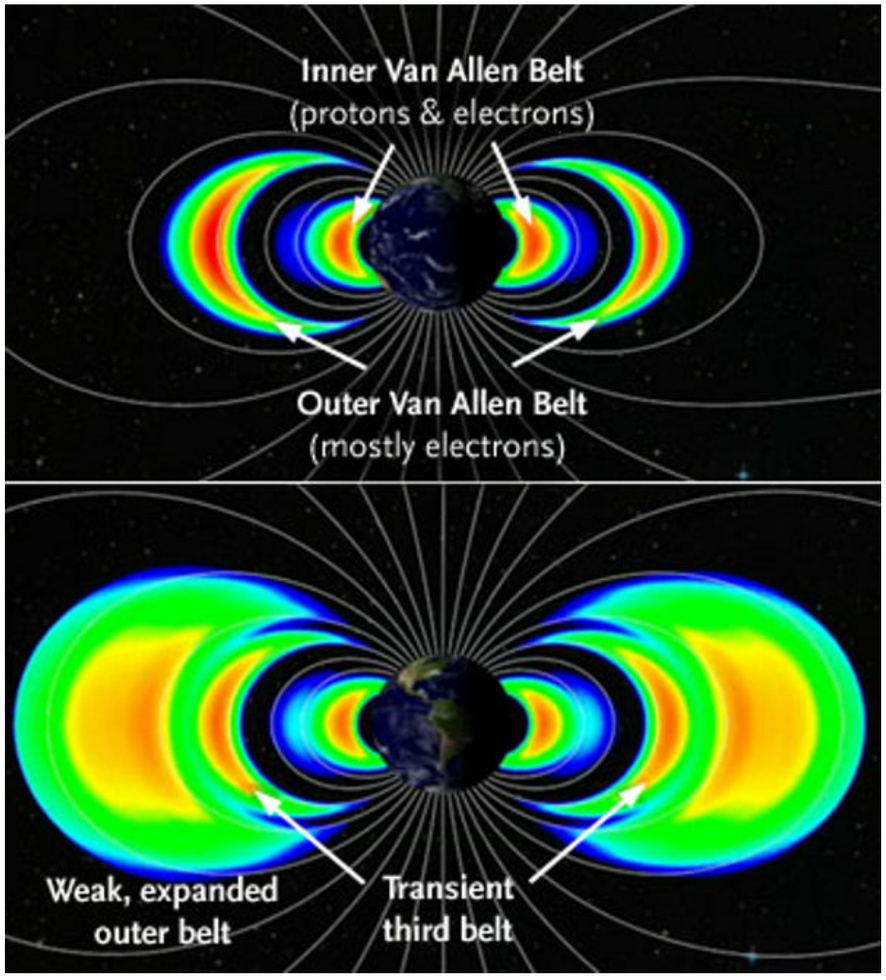


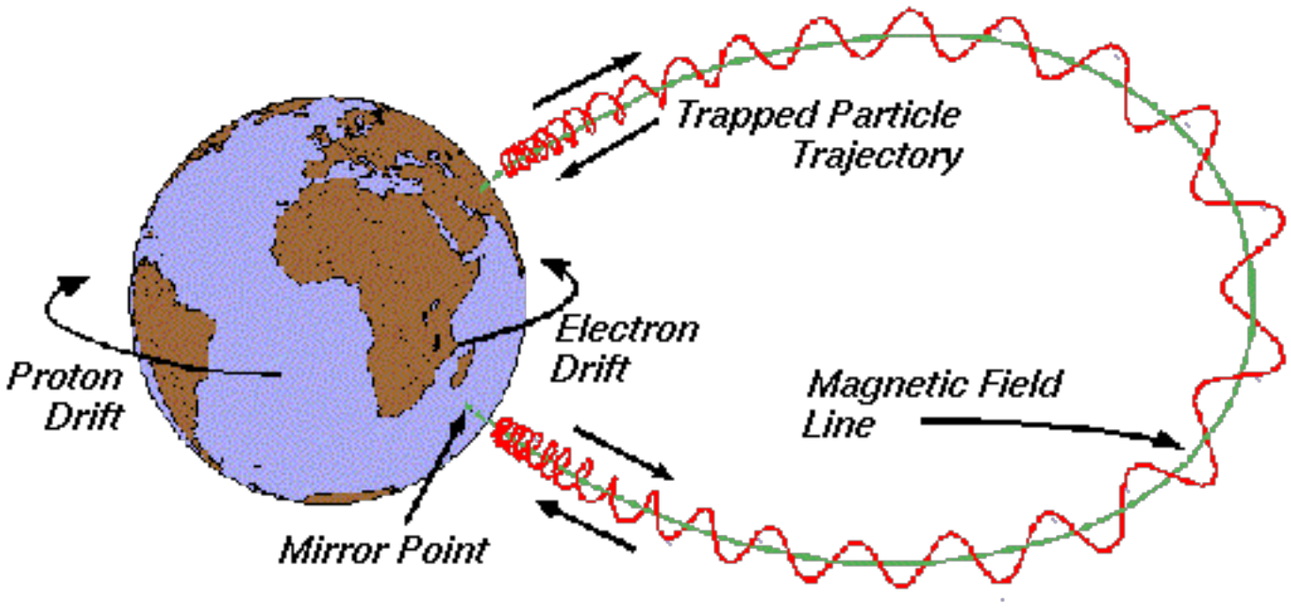


Van Allen belts - Trapped particles

The Van Allen belts are toroidal regions of charged energetic particles trapped by the geomagnetic field. They are mainly formed by solar wind and cosmic rays particles :

- The “inner” belt extends from 0.2-2 Earth radii (1<L<3). It is formed by **protons (100 keV - 50 MeV)** and **electrons (1-10 MeV)** ;
- The “outer” belt (3-10 Earth radii) is essentially formed by **electrons (40 keV-5 MeV)** ;
- Occasionally a “transient” belt can arise correspondingly to intense solar activity.





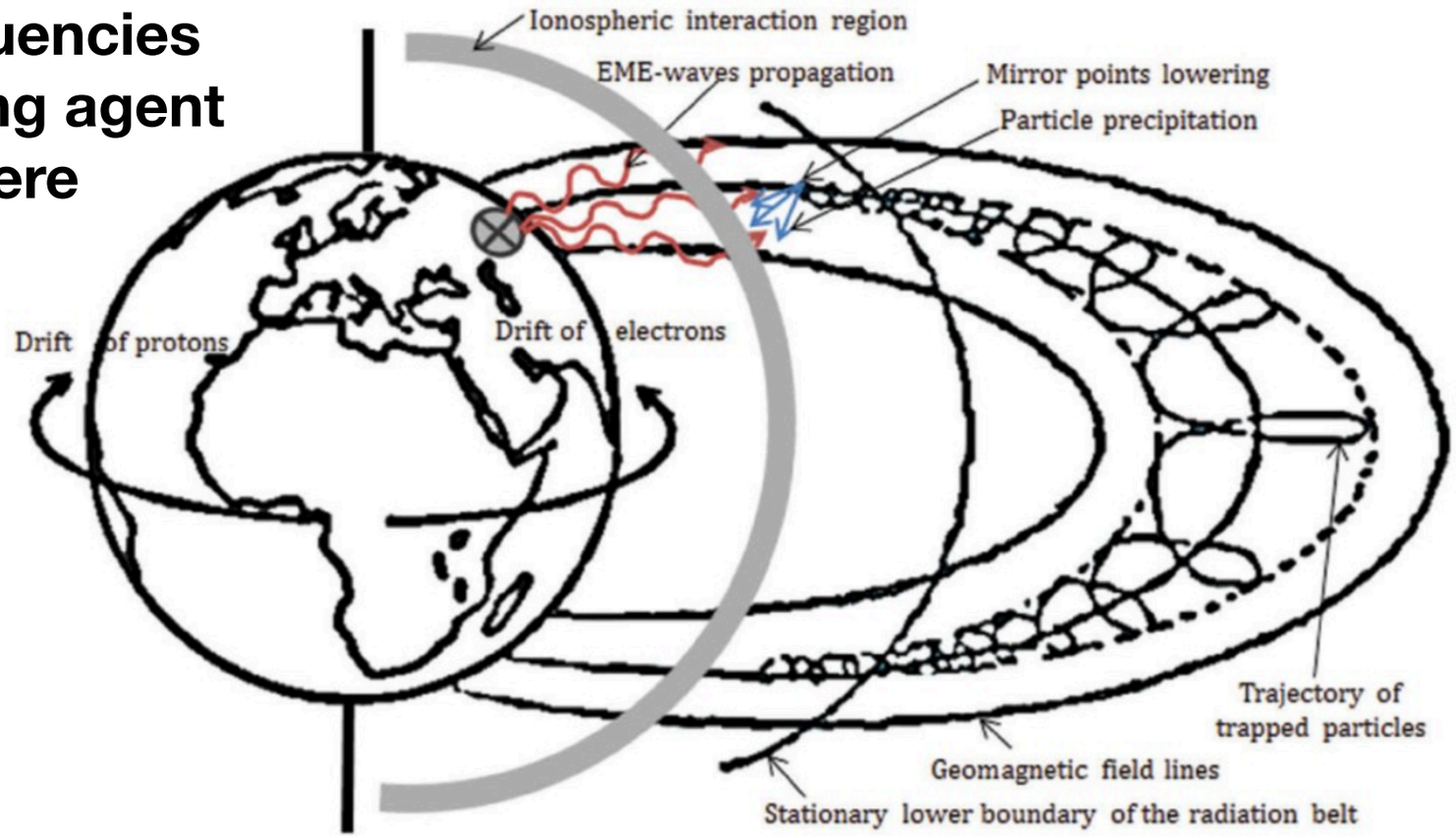
The motion of trapped particles is described by the following quantities :

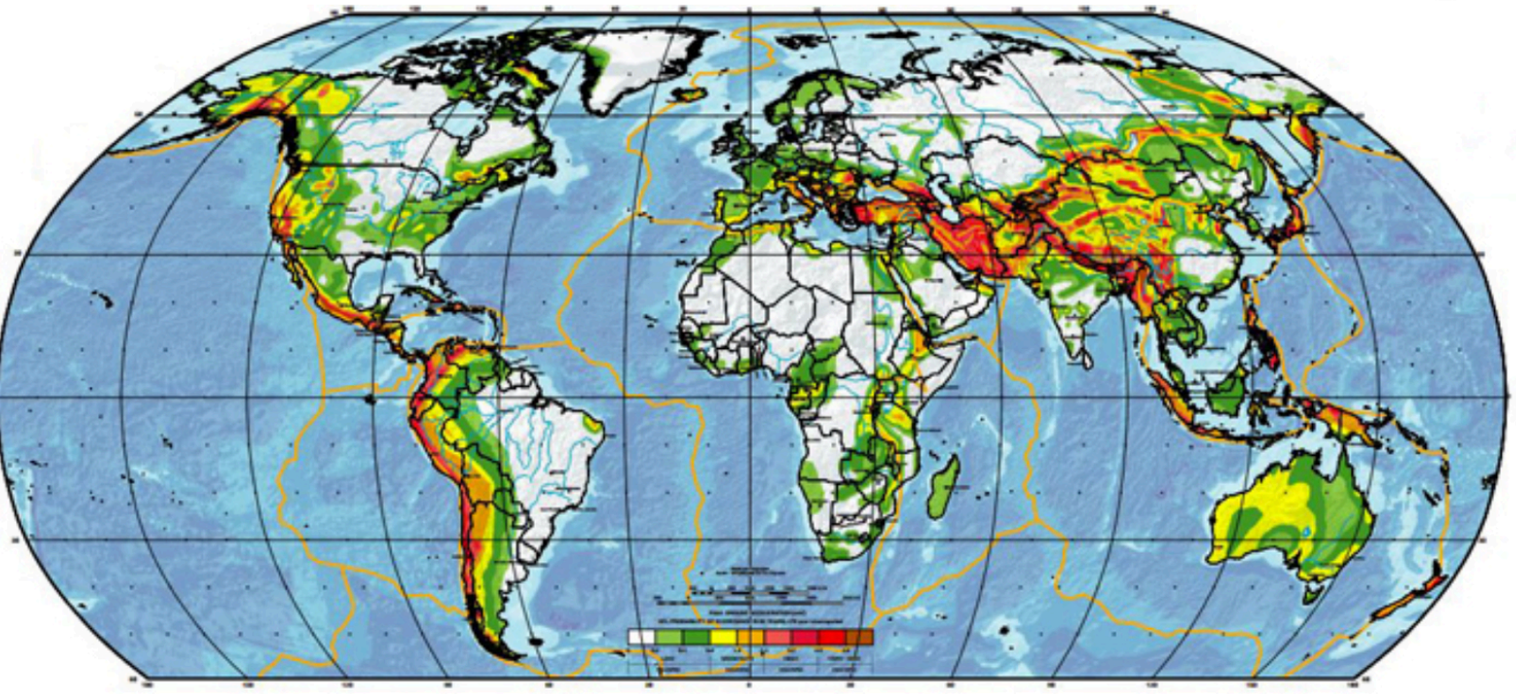
- Adiabatic invariants (if energy variation is slow): **gyration**, **bouncing** and **drift**;
- The **mirror point** and the **pitch angle**.

Earthquakes from space

If an earthquake produces low frequencies e.m. waves, these can be the coupling agent between litho and magnetosphere

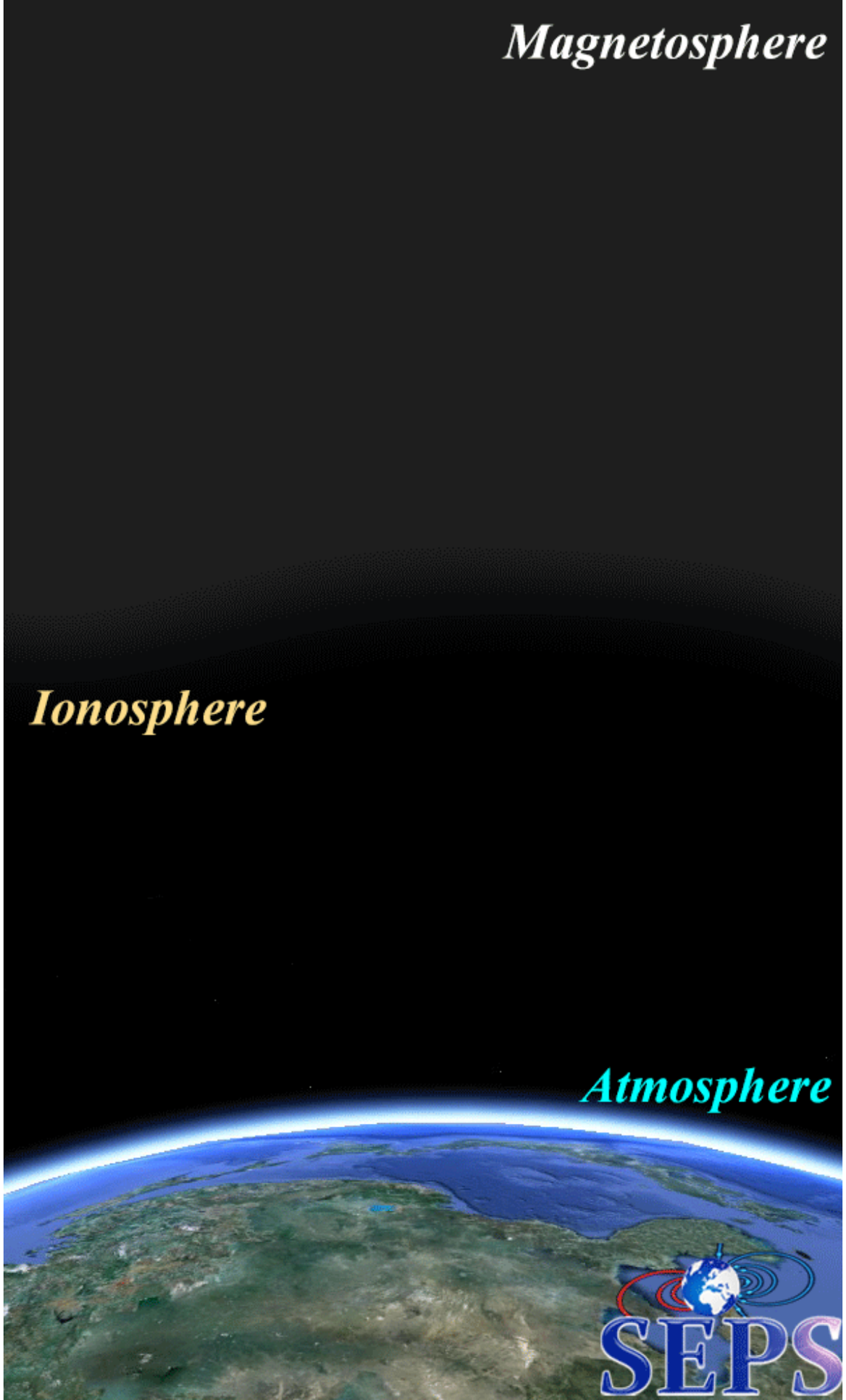
- These e.m waves can lower the mirror points by perturbing the lower ionosphere;
- Produce a **particle precipitation** from the inner radiation belt **(1 MeV electrons)**;
- **Large background**, many e.m waves emitters.





Once recorded the electron burst with the satellite, it can be correlated with seismic events:

- Energy and angles measured by the satellite;
- High-precision back tracing algorithm like the one used by PAMELA.

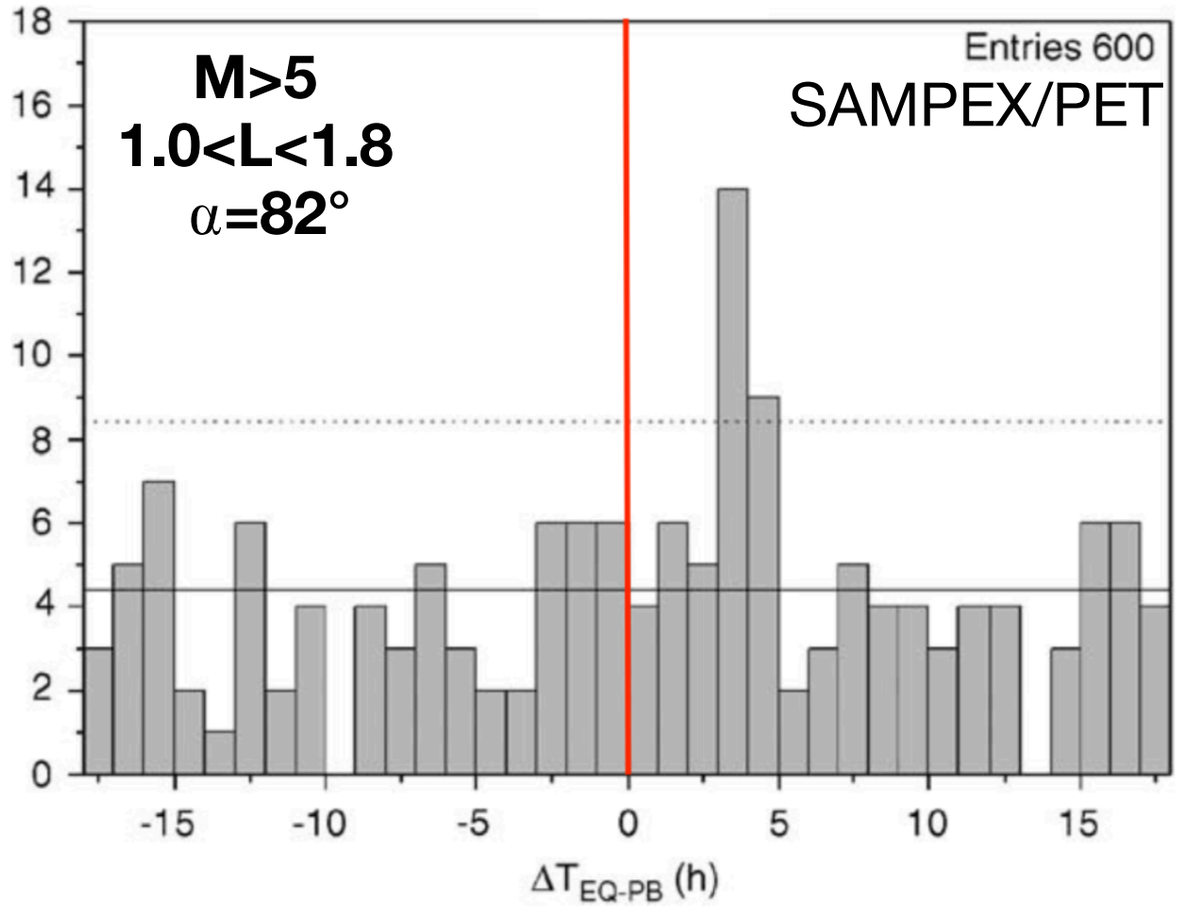

Magnetosphere
Ionosphere
Atmosphere
SEPS

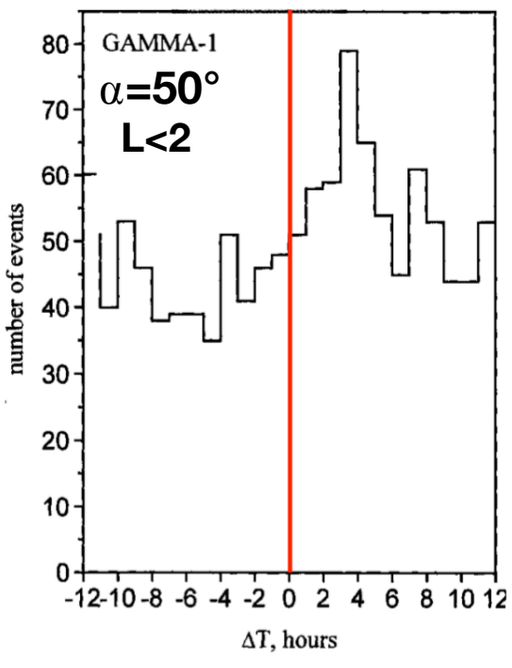
Heritage

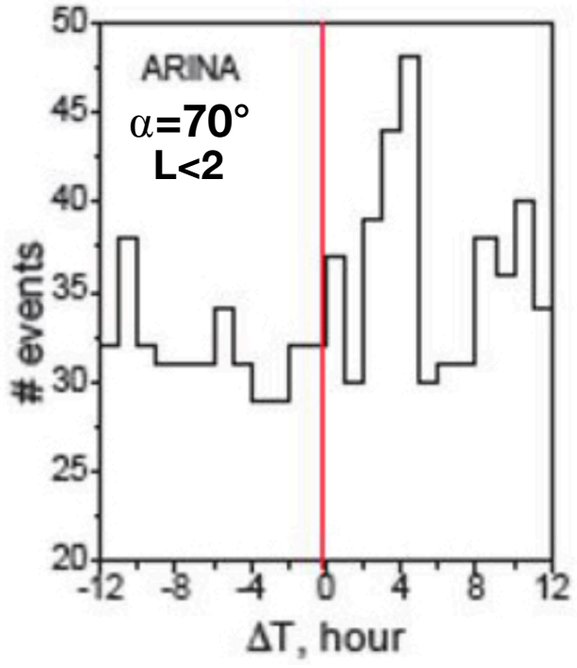
The insight of the correlation between strong EQ and PB is not so new as it may appears:

- **"High- energy charged particle bursts in the near-Earth space as earthquake precursors"**(Aleksandrin et al. in 2003) and **"Correlations between earthquakes and anomalous particle bursts from SAMPEX/PET satellite observations"** (V. Sgrigna et al. in 2005);

- SAMPEX/PET, GAMMA-1, ARINA data were used crossing them with strong earthquakes time and location.







The selection on the data used for this correlation study is based on:

- The magnitude M of the earthquake (usually M>=4) and the depth of the hypocenter < 100 km;

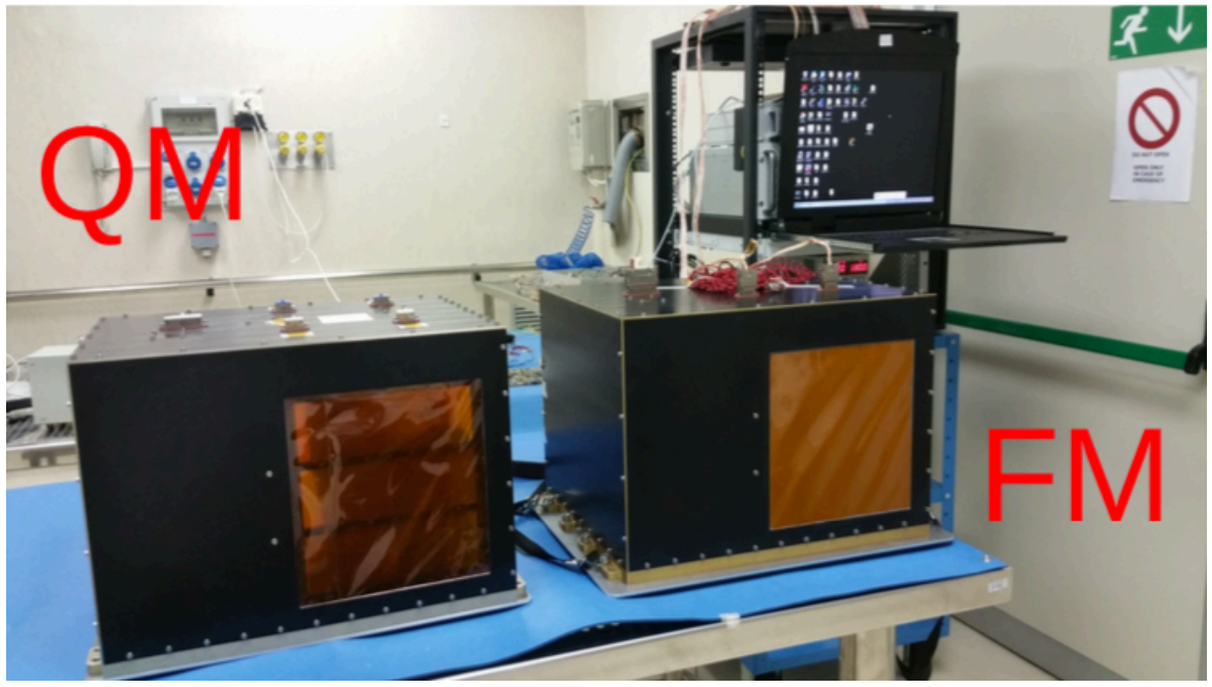
- The L-shell and the orbit inclination.

The Limadou project - HEPD

The Italian collaboration in the CSES mission is named as "Limadou project":

- "Limadou" is the Chinese transliteration for Matteo ("Madou") Ricci ("Li");

- He was a jesuit priest from Italy. He lived between 1552 and 1610 and spent 30 years of his life in China, teaching math, physics, astronomy and christian religion to the local populations.



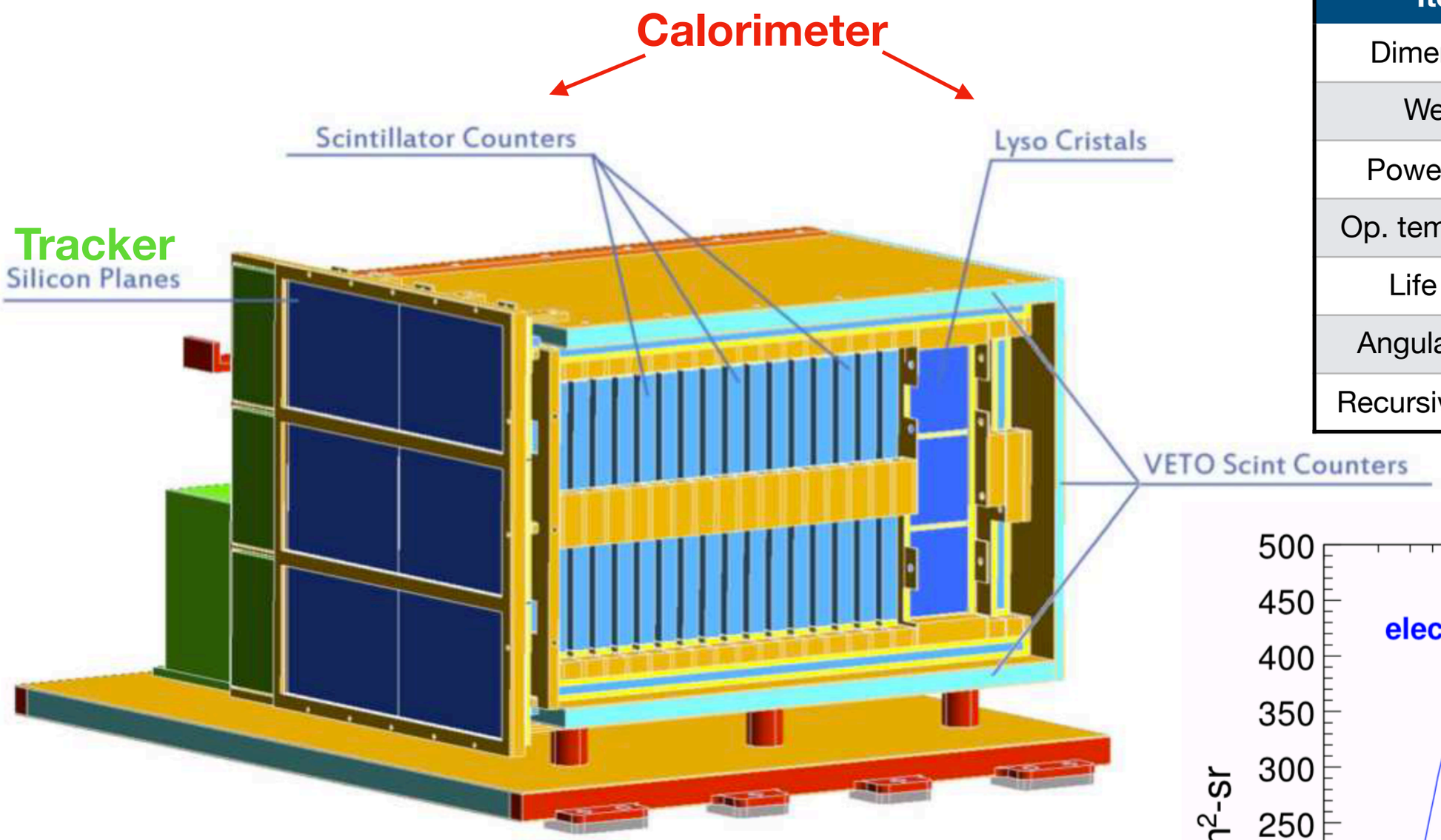
The HEPD (High Energy Particle Detector) is the detector sensitive to charged particles:

- It detects electrons in the energy range 10-150 MeV and nuclei in the energy range 30-300 MeV;

- It was realized in 4 different models:
  - **Electrical Model** (EM)
  - **Structural and Thermal model** (STM)
  - **Qualification Model** (QM)
  - **Flight Model** (FM)

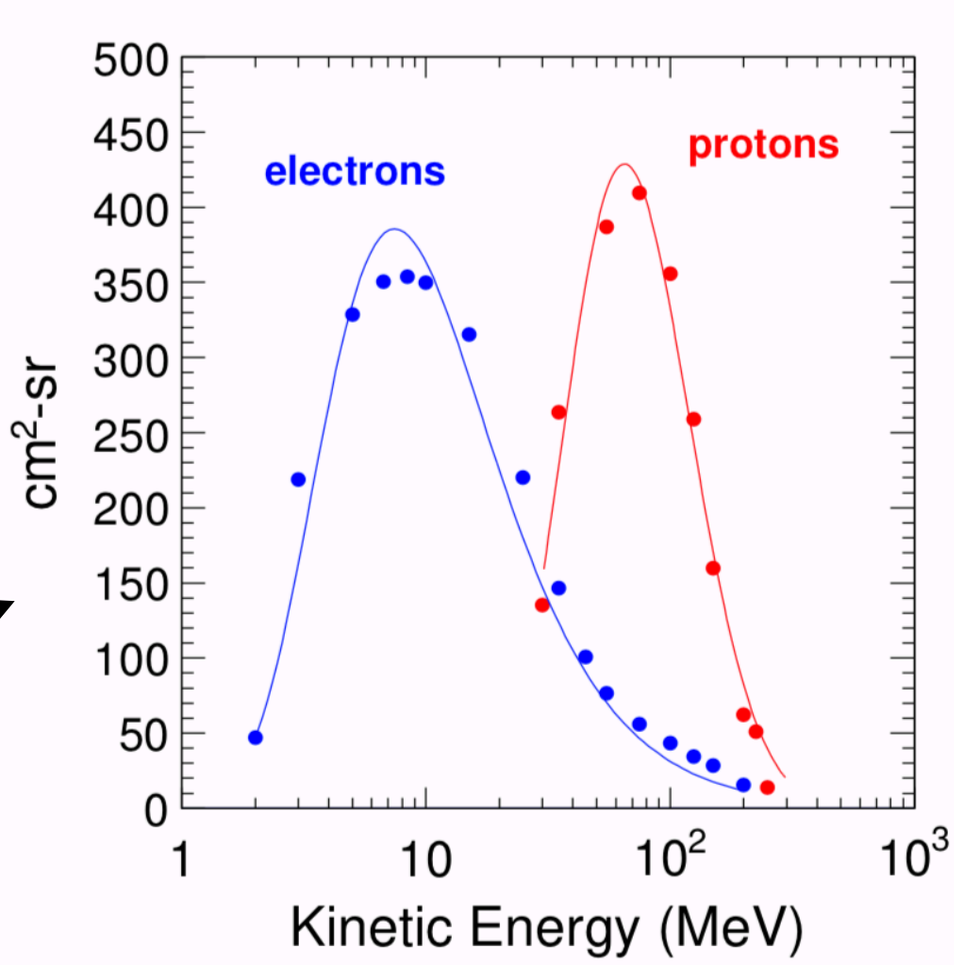
LIMADOU 利玛窦

The Limadou HEPD

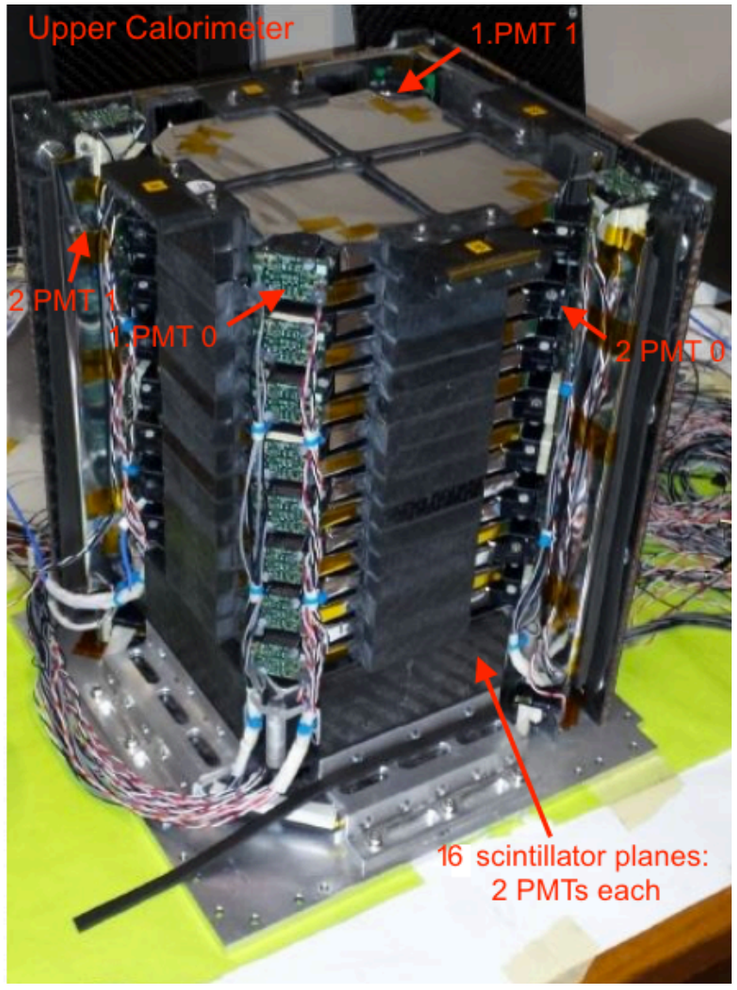


Item	Values
Dimensions	20x20x40 cm^3
Weight	~ 43 kg
Power cons.	< 43 W
Op. temperature	-10 °C - 34 °C
Life span	5 years
Angular resol.	8° @ 5 MeV
Recursive Period	5 days

Electron and **proton** estimated acceptances



The Limadou HEPD

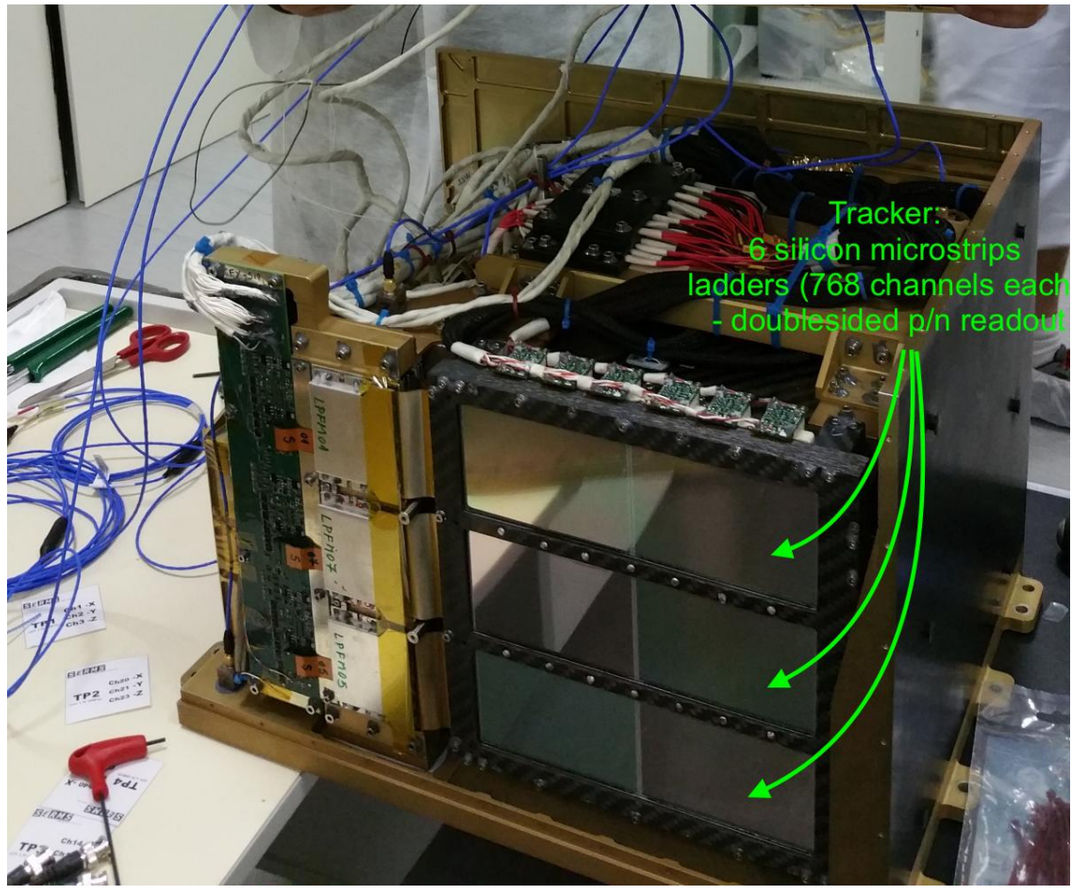


Calorimeter and Trigger

- a **trigger plane made of plastic scintillator**, segmented into 6 paddles, each one read by two PMTs;
- a calorimeter, for the energy reconstruction, composed by:
  - **16 planes of plastic scintillator (15 x 15 x 1 cm^3)**, each one readout by two PMTs;
  - a **3 x 3 matrix** of an **inorganic scintillator** (LYSO crystal);
- a **veto system** which consists of **5 plastic scintillators** (four lateral and one at the bottom of the instrument).

Tracker

- **2 planes of silicon microstrip detectors (300 µm)** divided in 6 ladders 768 strips each (**4608** in total), double sided readout;
- Alternated **floating and readout strips** with a pitch of 182 µm;
- The tracker is used for measuring the **arrival direction** and to **identify particles (measuring dE/dx)**



Pre-Flight Test on the FM

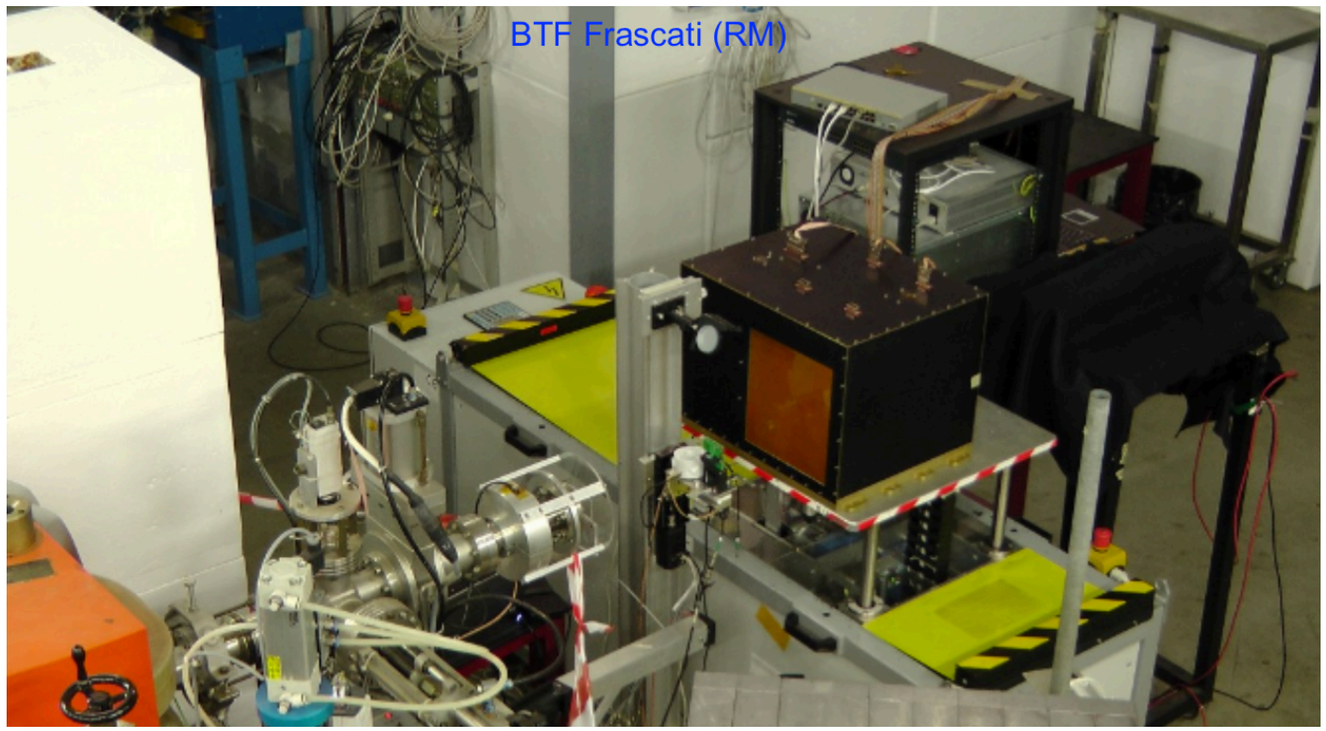
Different facilities have been exploited to provide different particle at different energies:

- **Beam Test Facility (BTF of Frascati)** on October 2016, **electrons** in the energy range from 30-120 MeV;

- **Agenzia Provinciale Servizi Sanitari (APSS of Trento)** on November 2016, **protons** with energy 37-228 MeV;

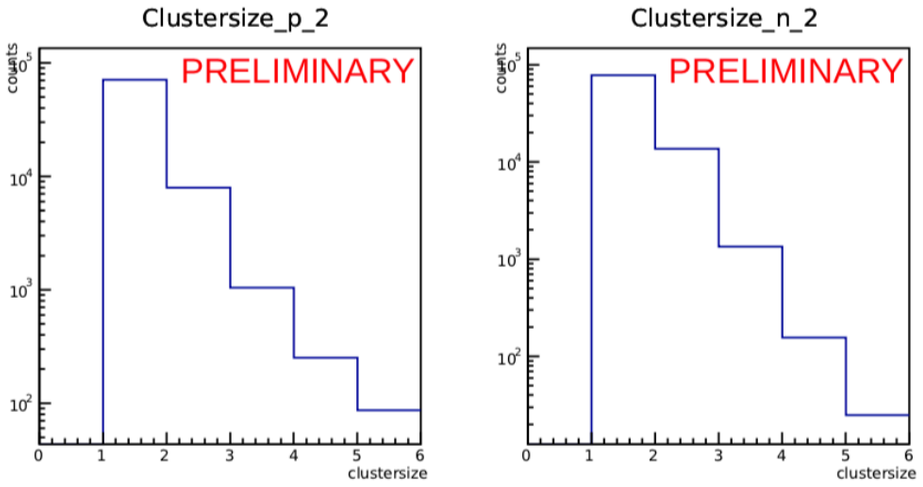
- **Atmospheric muons** taken in different places (China and Italy) with energy ~ 4 GeV.

All detector subsystems were evaluated with these tests. We will focus mainly on the **Tracker** and on the **Calorimeter**.

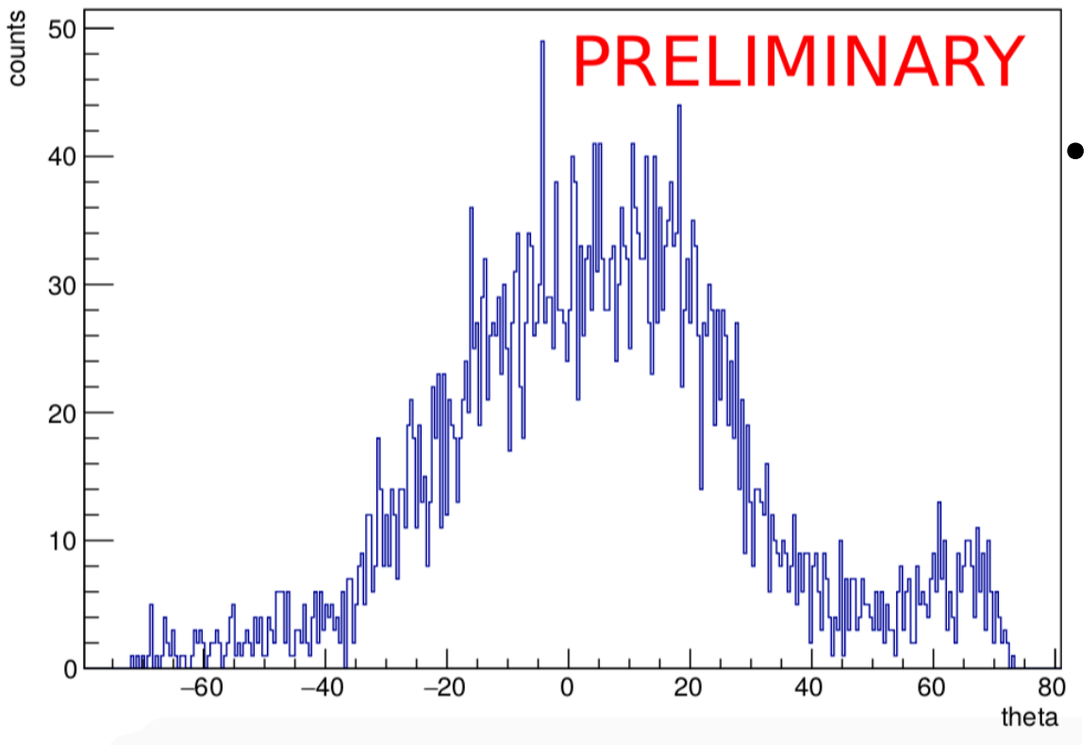


Tracker performance - 1/2

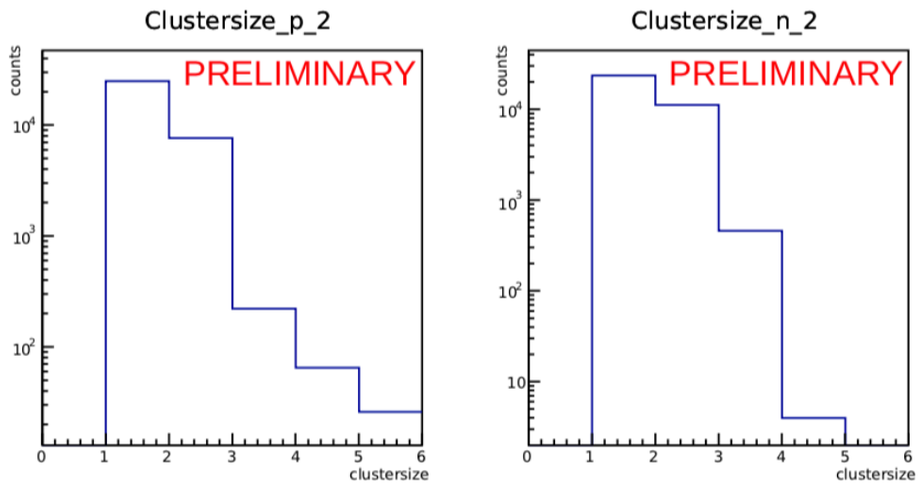
Muons ~ 4 GeV, ladder 2 side p/n.
Characterization for MIP particles.



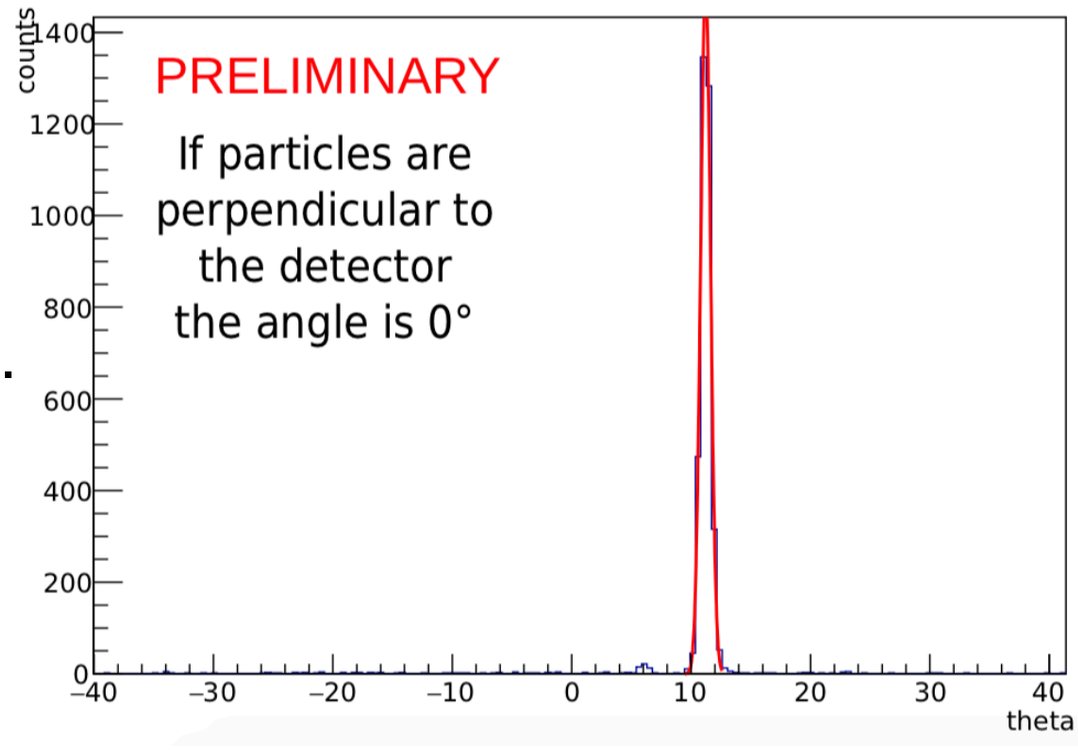
theta_central_ladder_p



- A cluster is a **group of activated** strips, which have a S/N>3;
- tracker **cluster size (CS)** is an important characterization.
- Angle reconstructed with **2 consecutive ladder;**



theta_central_ladder_n

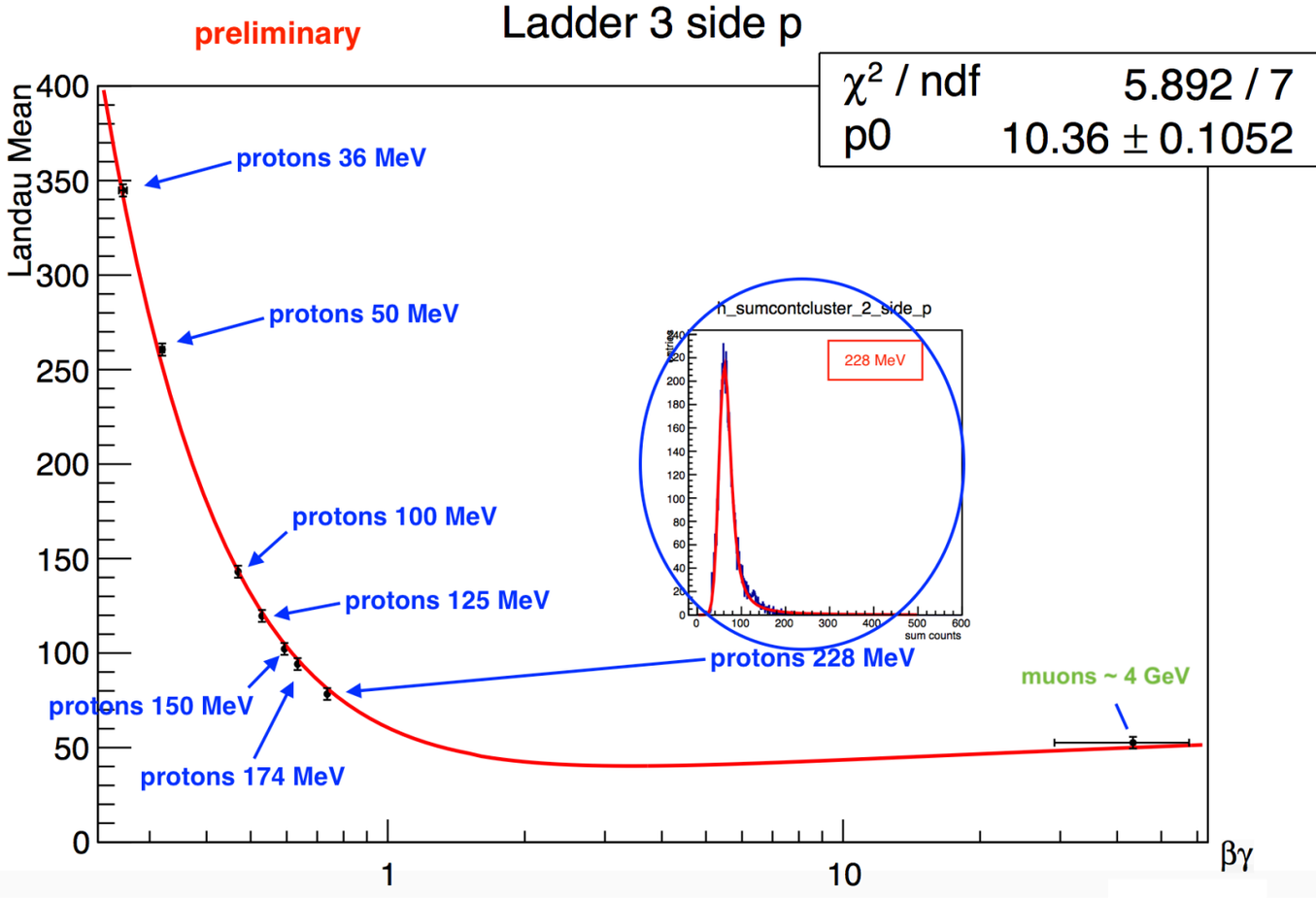


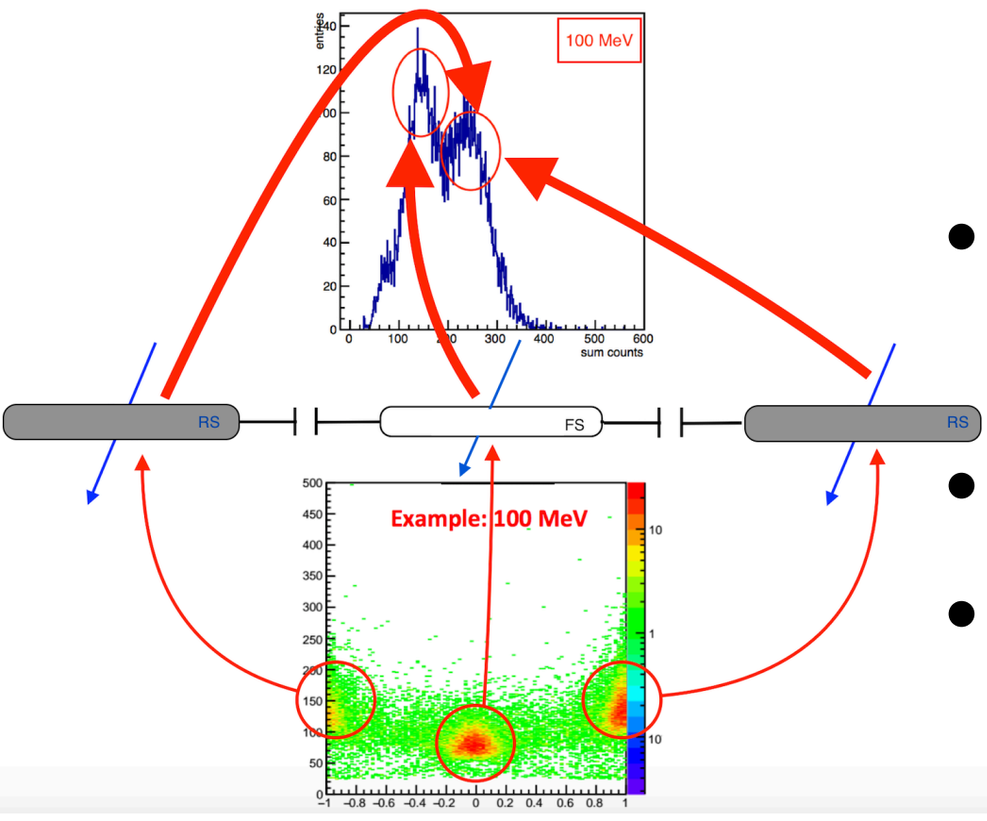
Protons 70 MeV, ladder 2 side p/n.
Characterization for highly ionizing particles. Beam tilted 12°

Tracker performance - 2/2

When a particle passes trough the tracker planes, it deposits energy:

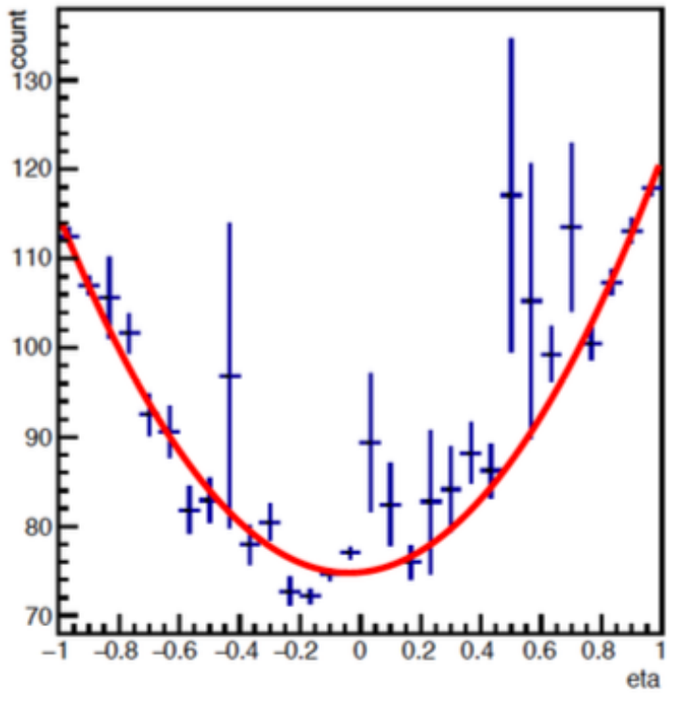
- ADC count distribution is a Landau convoluted with a gaussian and we extract the mean from it;
- by using the test beam data we know the energy of the incident particle;
- then we fit the point with a Bethe curve, leaving a free scale parameter;
- we obtain the ADC->KeV conversion factor (**p0/300µm**).





An important part of the analysis deals with the charge sharing:

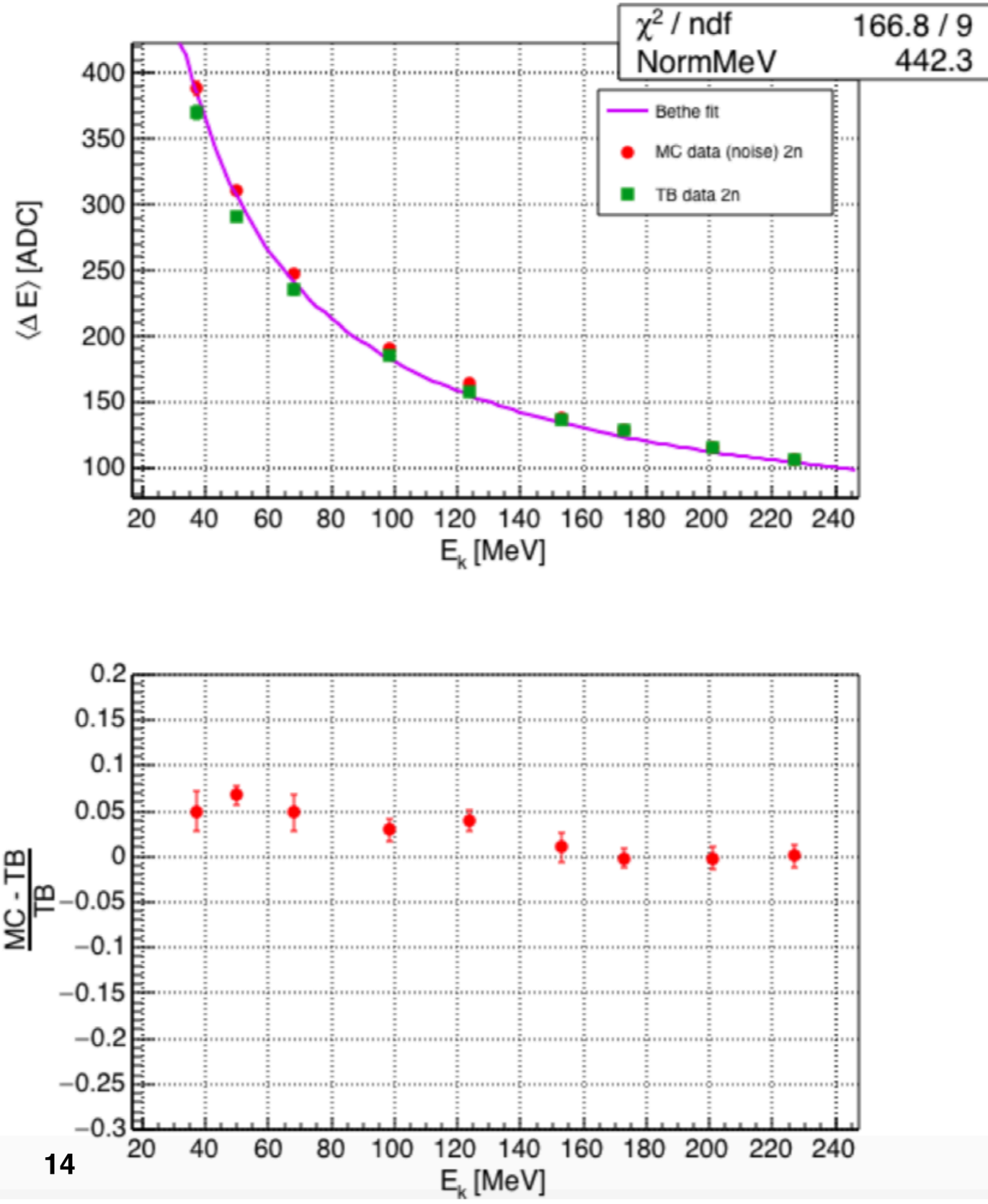
- Since we have a floating strip between two readout ones we have charge sharing;
- $$\eta = \frac{ADC_R}{ADC_L + ADC_R} \quad ;$$
- We fit the points with a parabola and we correct the counts for $0 < \eta < 1$.



TB Data vs Monte Carlo

We compared the test beam point with MC:

- The tracker has been simulated with GEANT4;
- Energy loss in the air between beam exit and detector window included in the simulation;
- The χ^2 test is computed for the MC against the Bethe best fit to data;
- Good agreement (within 5%) between TB and MC;

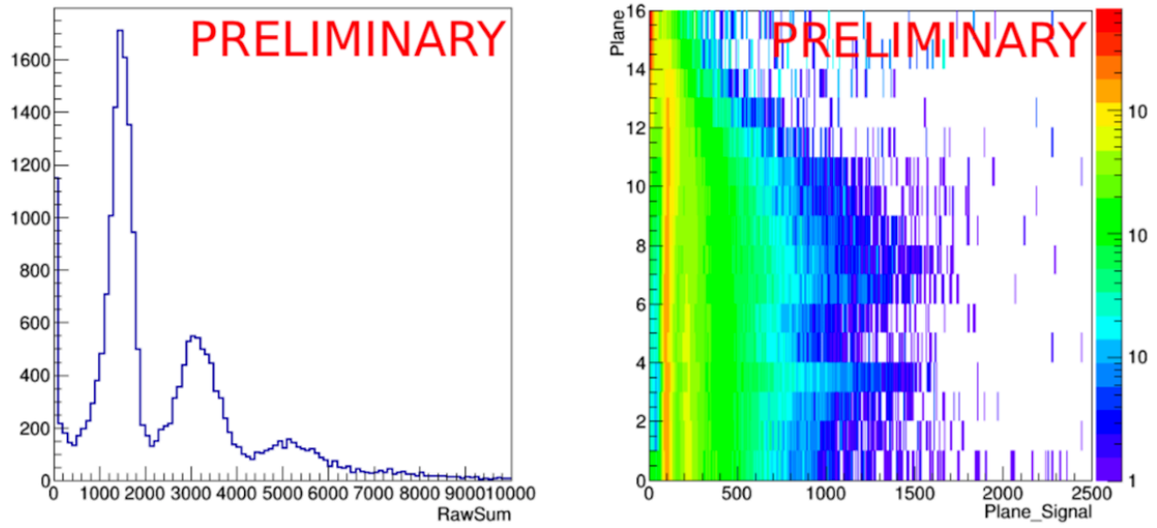


Calorimeter performance - 1/2

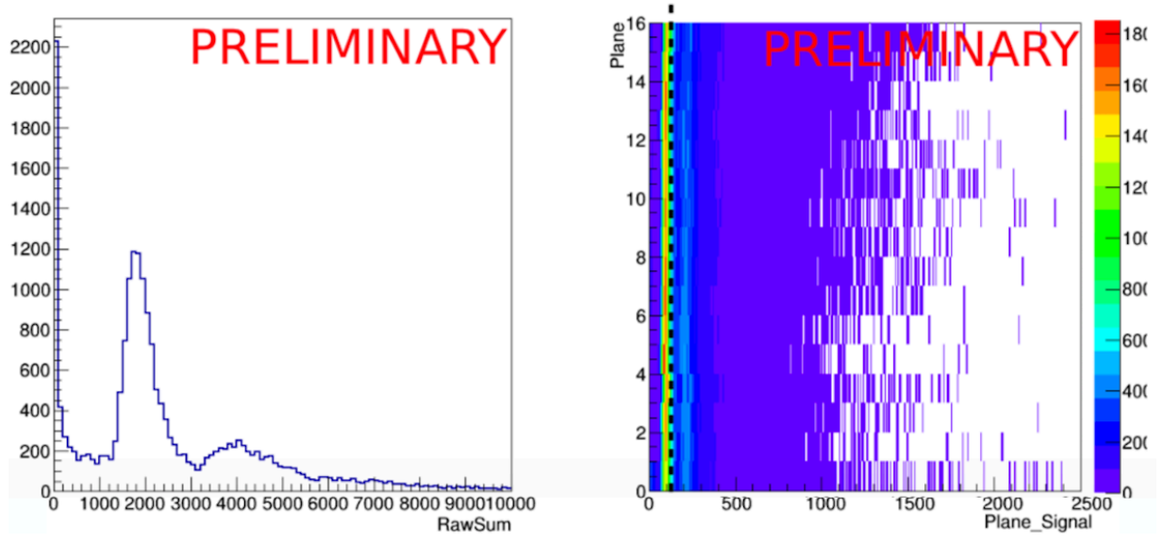
The HEPD calorimeter has been tested with electrons and protons:

- 30 MeV electrons are almost contained in the upper calorimeter (16 scint. planes);
- 90 MeV electrons go trough all the 16 scint. planes and are stopped by the lyso;
- **Multiple peaks** correspond to higher electron **multiplicity**;

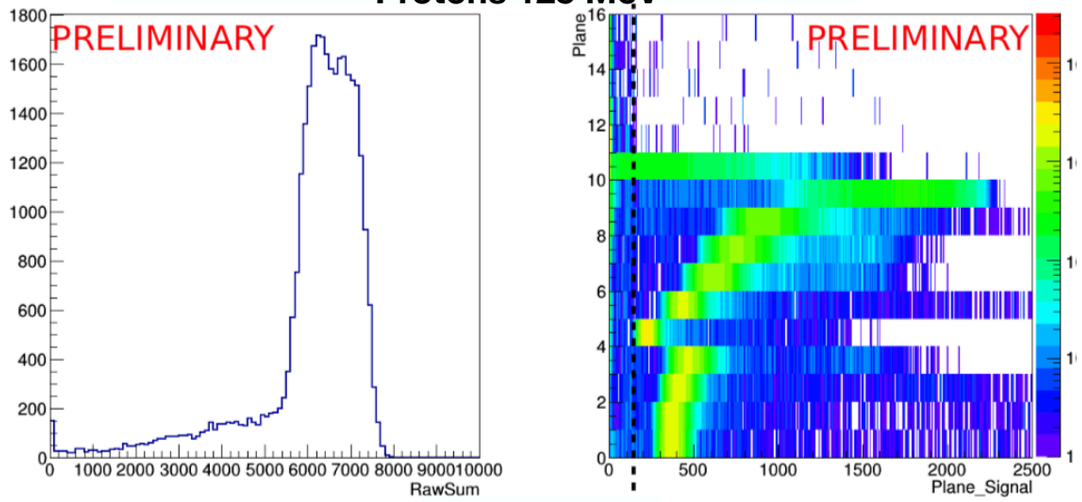
Electrons 30 MeV



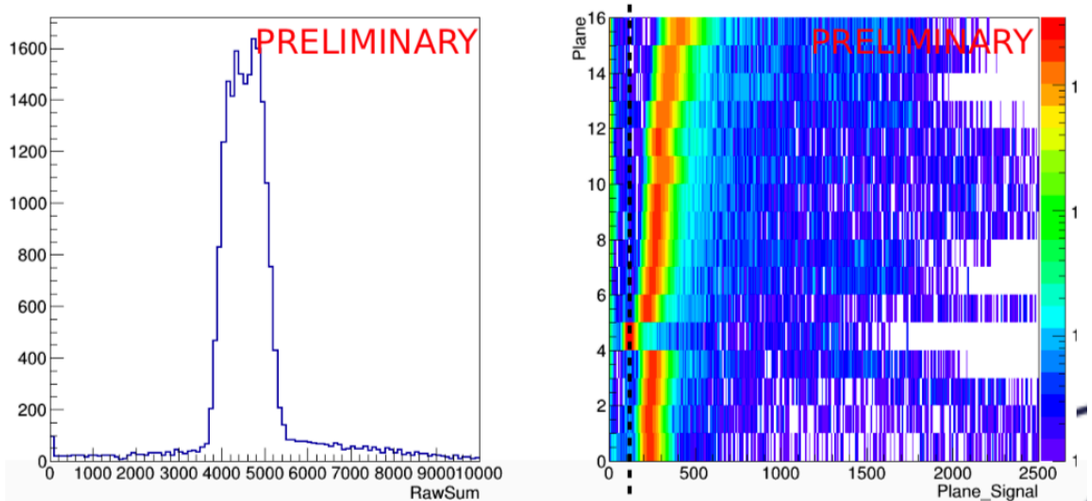
Electrons 90 MeV



Protons 125 MeV



Protons 228 MeV

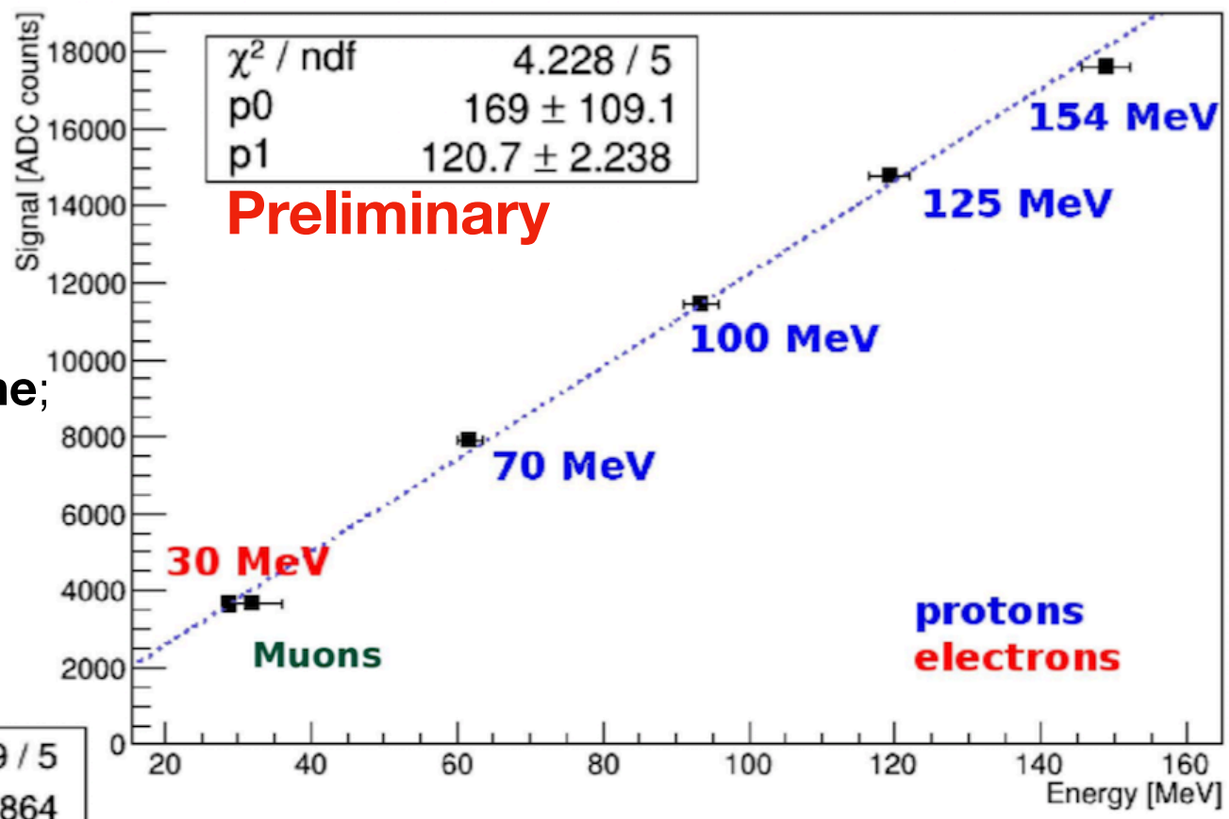


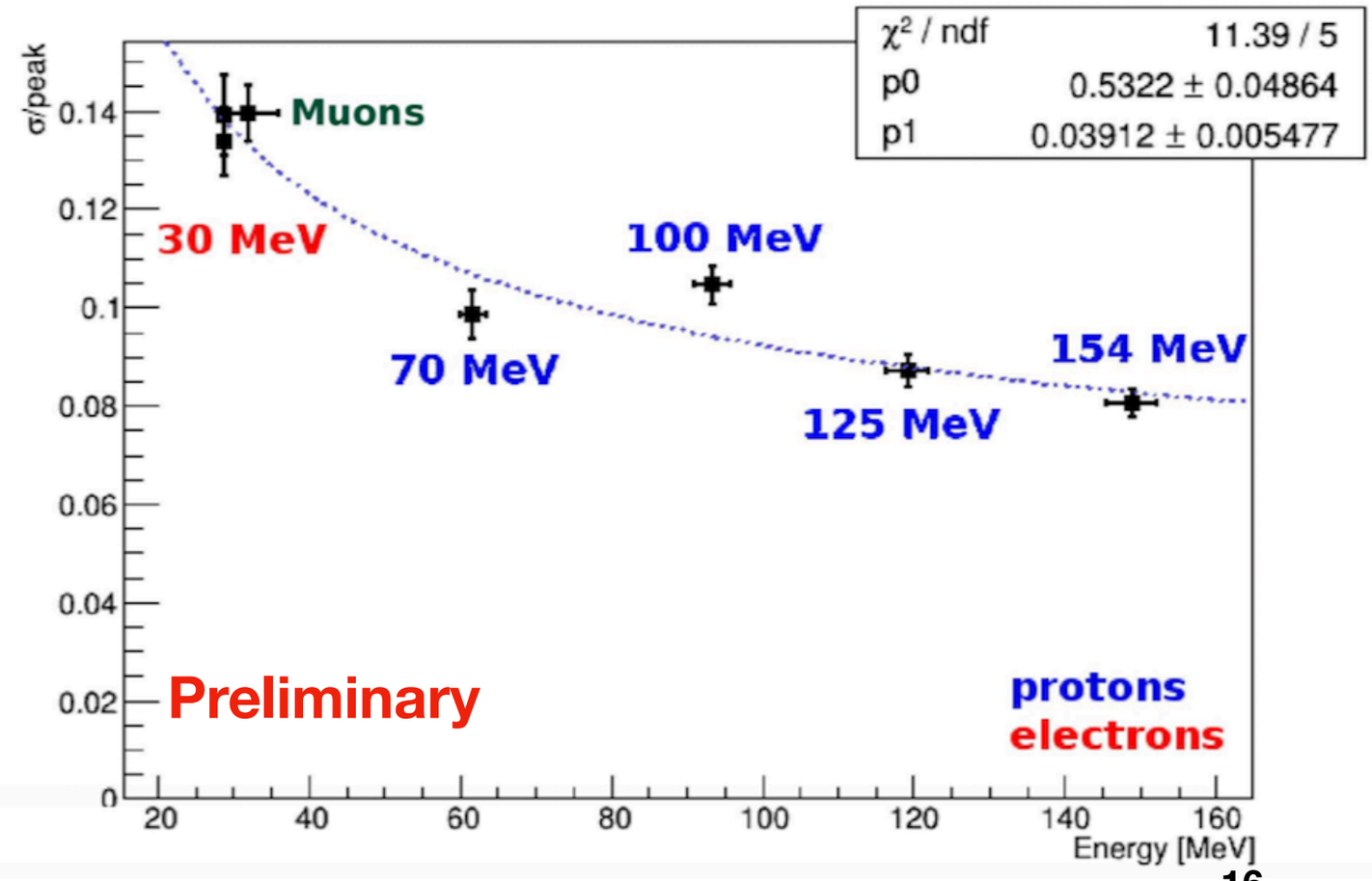
- 125 MeV protons are stopped in the calorimeter distribution (the **Brag peak** is visible);
- 228 MeV protons go trough all the scintillators;
- Scintillator for all particles are **equalized**.

Calorimeter performance - 2/2

Calibration and conversion factor have been obtained also for the calorimeter:

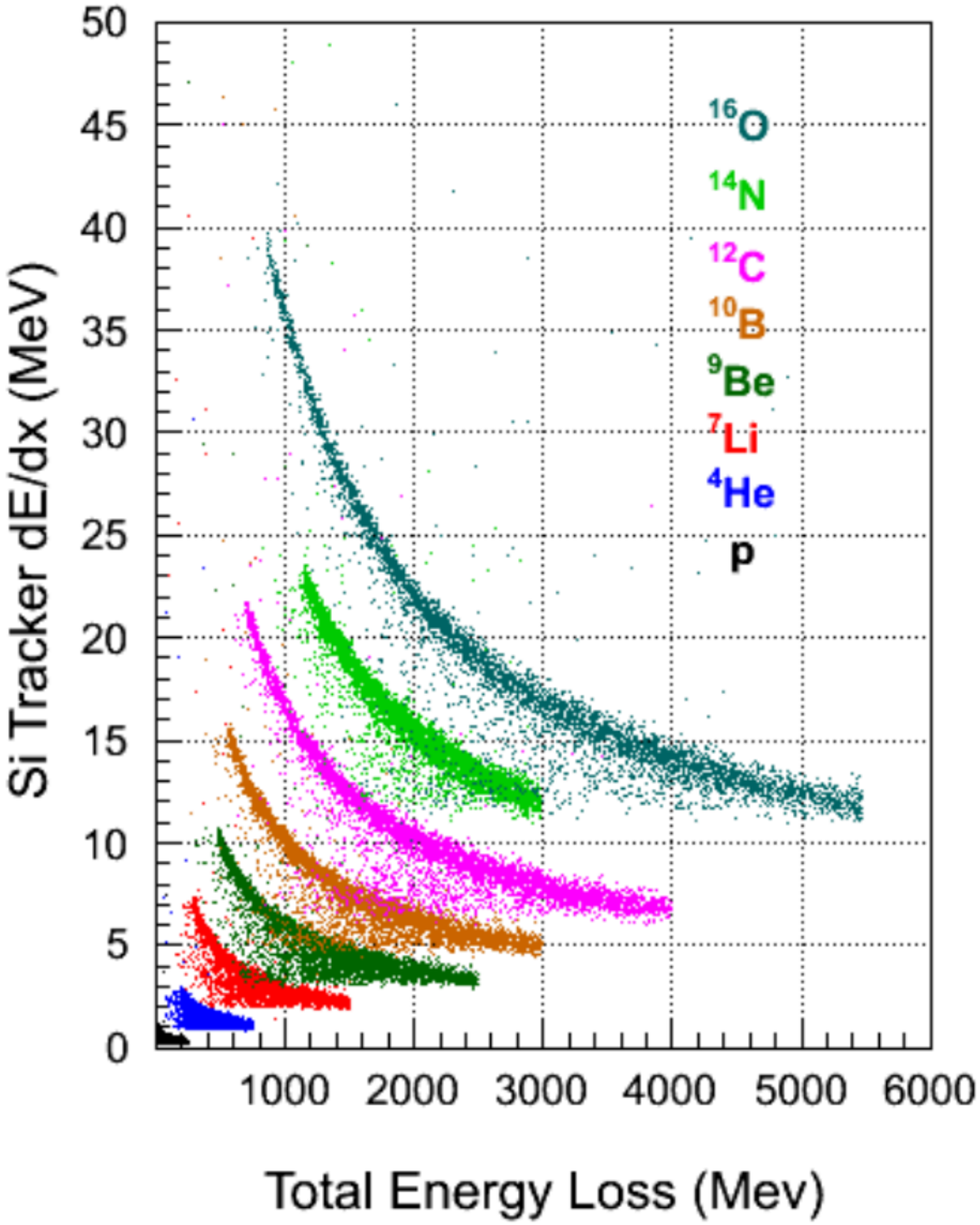
- **Electron** and **protons** used to perform the energy calibration of the calorimeter;
- Subtraction of **Eloss in Silicon Tracker** and **Trigger plane**;
- **Gaussian-convoluted Landau fit distribution**: mean E total energy loss <ADC>;
- **Conversion ADC/MeV** exacted from the fit.

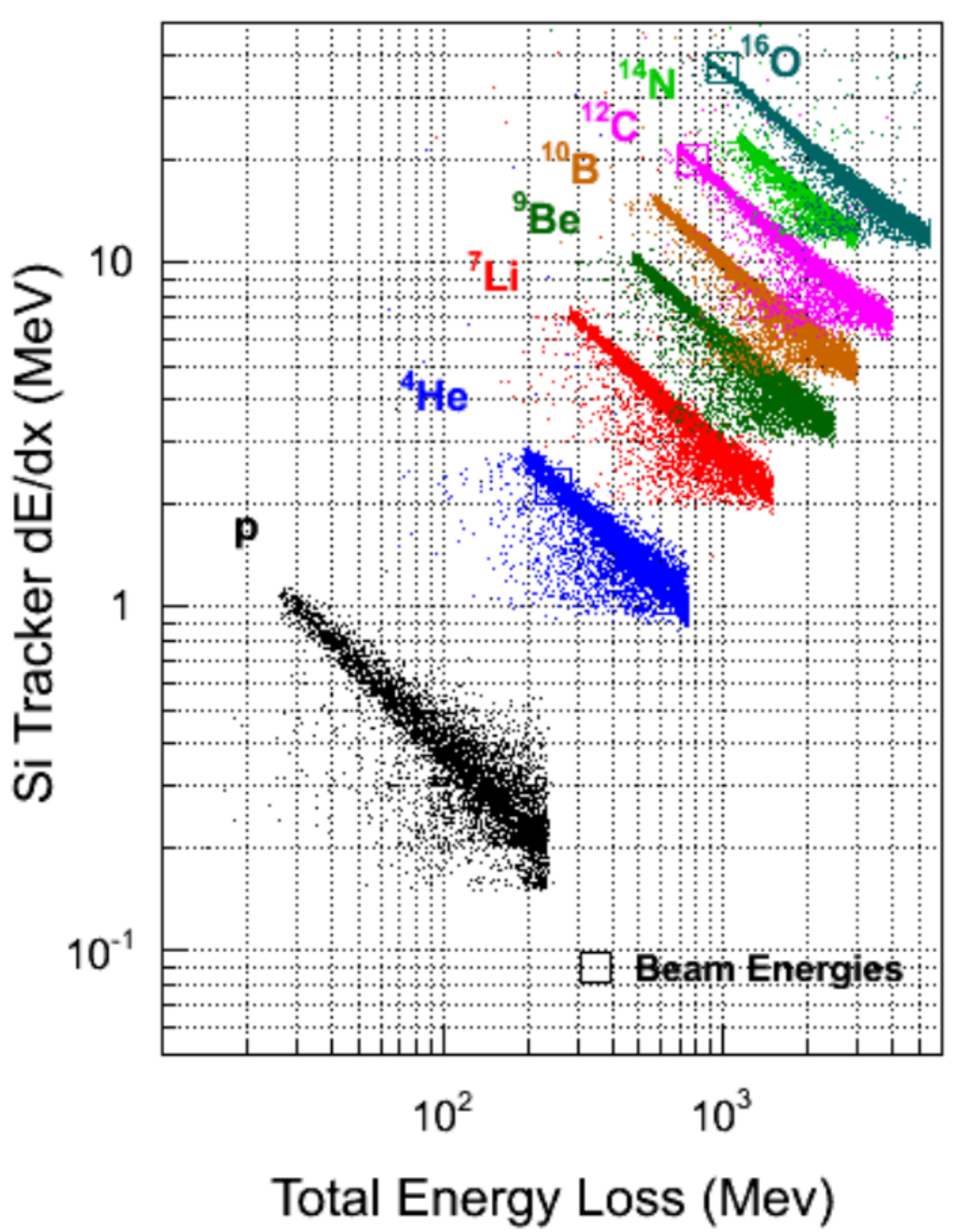




- Energy resolution curve;
- **Fully contained** protons and electrons have been used for this study;
- Muon point correspond to **atmospheric muons**;

Simulation PID for nuclei





Conclusions and future events

During the pre-launch test sessions we characterized the detector subsystems:

- Tracker:
  - Tracks and angles reconstruction;
  - dE/dx calibration;

- Calorimeter
  - using the test beam data the calo has been calibrated;
  - E reconstruction validated with different energies and particles.

Past/Future Activities (FM):

- October-November 2016: Test Beam Campaign;

- shipped 16th December 2016, delivered to DFH Satellite Co. 30th December 2016;

- **Launch scheduled for 2nd February 2018;**

- **3 months of commissioning phase;**