DEVELOPMENT OF A HOMOGENEOUS, ISOTROPIC AND HIGH DYNAMIC RANGE CALORIMETER FOR THE STUDY OF PRIMARY COSMIC RAYS IN SPACE EXPERIMENTS

- MODERN SPACE EXPERIMENTS, POINT OF INTERESTS. REQUIREMENTS
- CONSTRUCTION STUDYING, DEVELOPMENT AND OPTIMIZATION
- BUILDING
- TESTS RESULTS

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POINTS OF INTERESTS

- **Knee region >10^{15} eV**

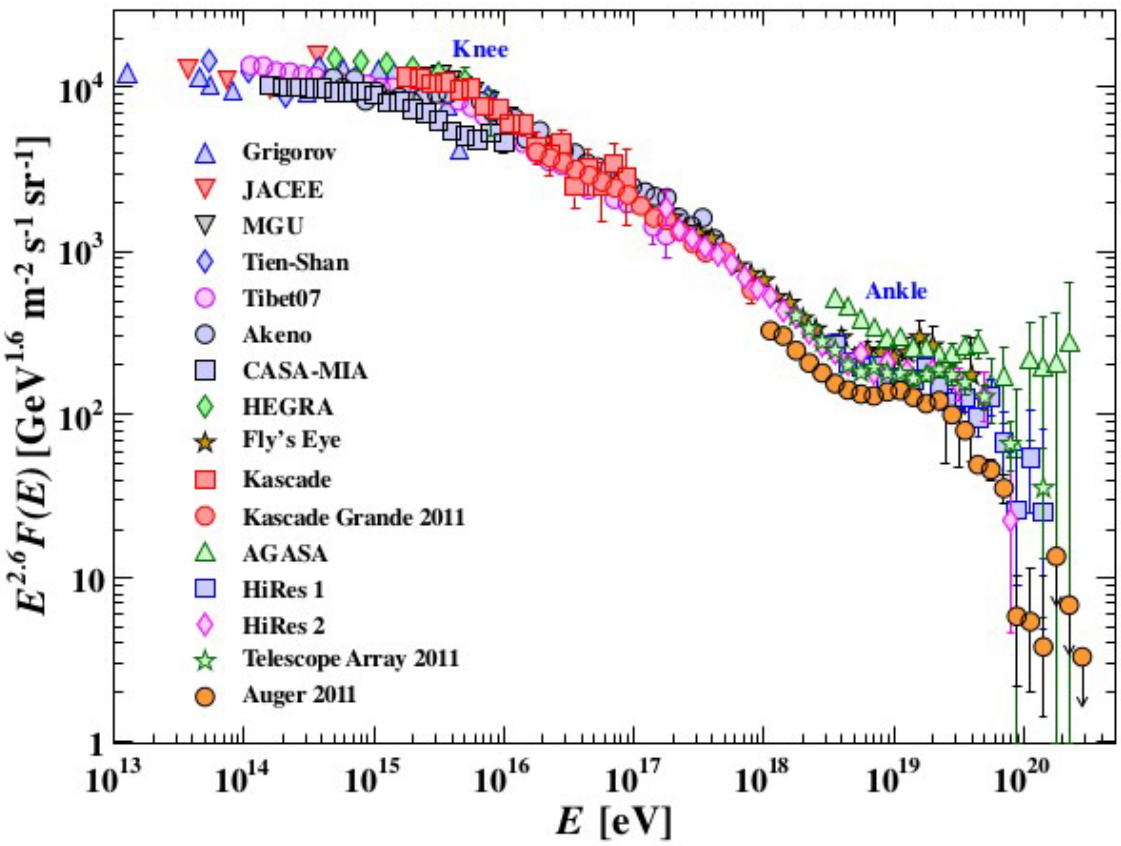
Provides information about the physics of acceleration and propagation of cosmic rays

Problems:

Until now have been studied by ground-based experiments

Space experiments are limited by exposure time and small geometrical factor

Dominant proton background

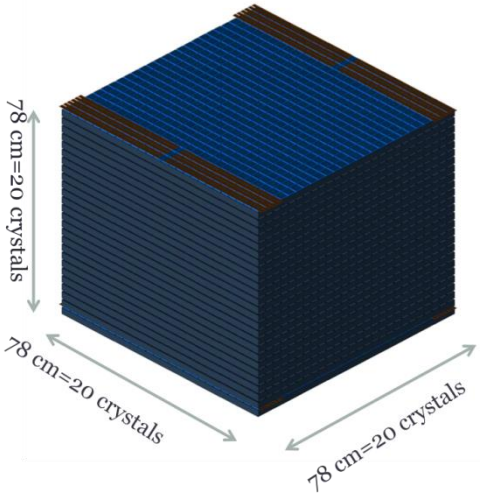


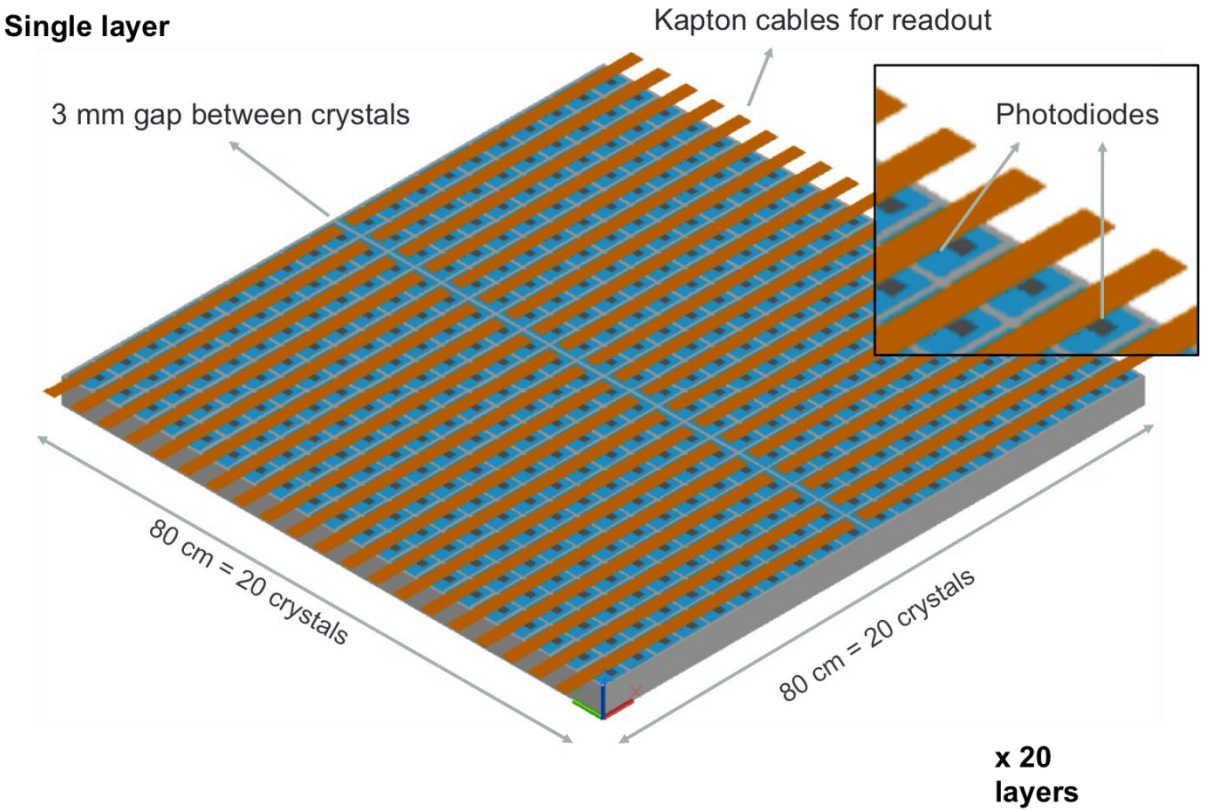
REQUIREMENTS

- High dynamic range: 0,5 – 10^7MIP
- Isotropy
- Homogeneity
- Geometric factor of at least a few m^2 sr
- Energy resolution for hadrons of 40% or better
- Energy resolution of 1-2% for electrons
- Rejection power h/e > 10^5
- Limited mass and power budget

CONSTRUCTION

Cubic device designed as a 3D mesh of small cubic scintillating crystals is proposed. The cubes are separated by a small gap.





CONSTRUCTION

Tallium-doped cesium iodide (CsI(Tl))

Crystal size of 1 Moliere radius

The calorimeter is very deep in terms of both radiation and interaction lengths, and features a planar geometric factor of (1:91*5) = 9.55 m^2 sr.

Two photodiodes coupled to each crystal: a large area photodiode for small signals and a small area one for large signals

High dynamic range readout electronics (CAIS)

Signals are extracted by means of kapton cables.

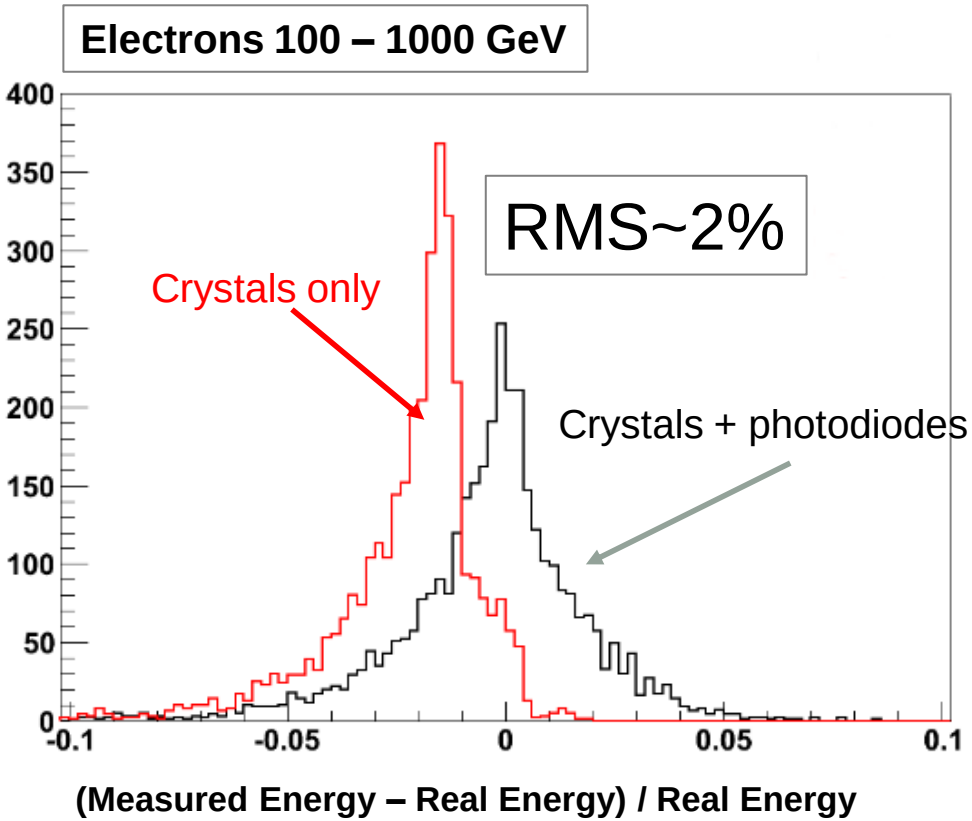
	Cubes
N×N×N	**20×20×20**
L of small cube (cm)	3.6*
Crystal volume (cm^3)	46.7
Gap (cm)	**0.3**
Mass (Kg)	1683
N.Crystals	8000
Size (cm^3)	78.0×78.0×78.0
Depth (R.L.) “ (I.L.)	39×39×39 1.8×1.8×1.8
Planar GF (m^2sr) **	1.91

(* one Moliere radius)
(** GF for only one face)

SIMULATIONS

- FLUKA based simulation
- Planar generation surface on one of the 5 faces
- Results valid also for the other faces!
- Carbon fiber in between crystals (3 mm gaps)
- Large photodiode is inserted on the crystal in the simulation
  - We take into account also the energy release in the Photodiode itself!
  - Light collection efficiency and PD quantum efficiency are included in the simulation
- Electrons: 100 GeV – 1 TeV range
- Protons: 100 GeV – 100 TeV range
- ~ 100 – 10.000 events for each energy
- No mis-calibration effects are included in the simulation
- For the moment we have very low statistics for high energy particles (huge computing time is necessary….)

SIMULATIONS



Containment criteria for electrons requires the impact point to be at least 2 crystals away from the border of the calorimeter and shower length to be at least 21 X_0. The efficiency of the selection is 36%, which gives an overall effective geometric factor GF_{eff} = 3.4 m^2 sr.

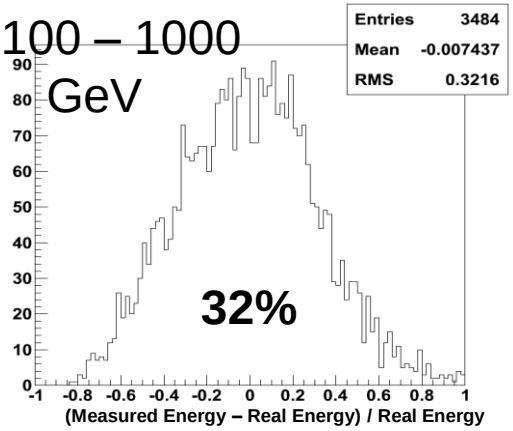
Non-gaussian tails due to leakages and to energy losses in carbon fiber material

<u>Ionization effect on PD: 1.7%</u>

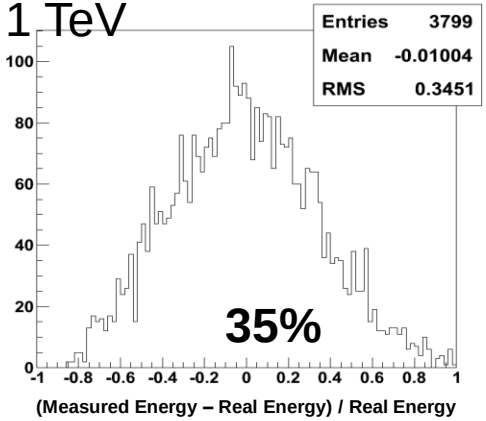
SIMULATIONS

Protons

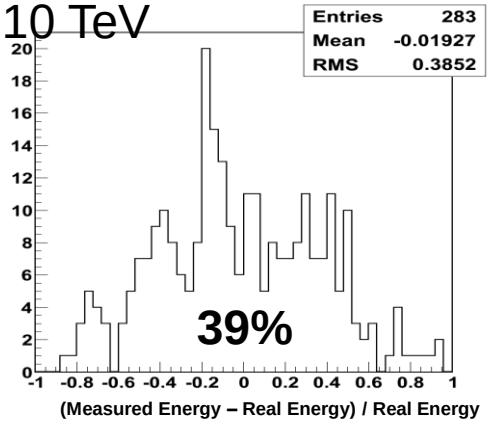
100 – 1000 GeV



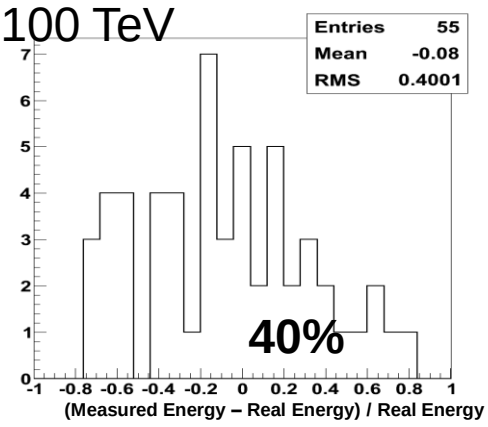
1 TeV



10 TeV



100 TeV



Selection efficiencies:

$\varepsilon^{0.1\text{-}1TeV} \sim 35\%$

$\varepsilon^{1TeV} \sim 41\%$

$\varepsilon^{10TeV} \sim 47\%$

$GF_{eff}^{0.1\text{-}1TeV} \sim 3.3\ m^2sr$

$GF_{eff}^{1TeV} \sim 3.9\ m^2sr$

$GF_{eff}^{10TeV} \sim 4.5\ m^2sr$

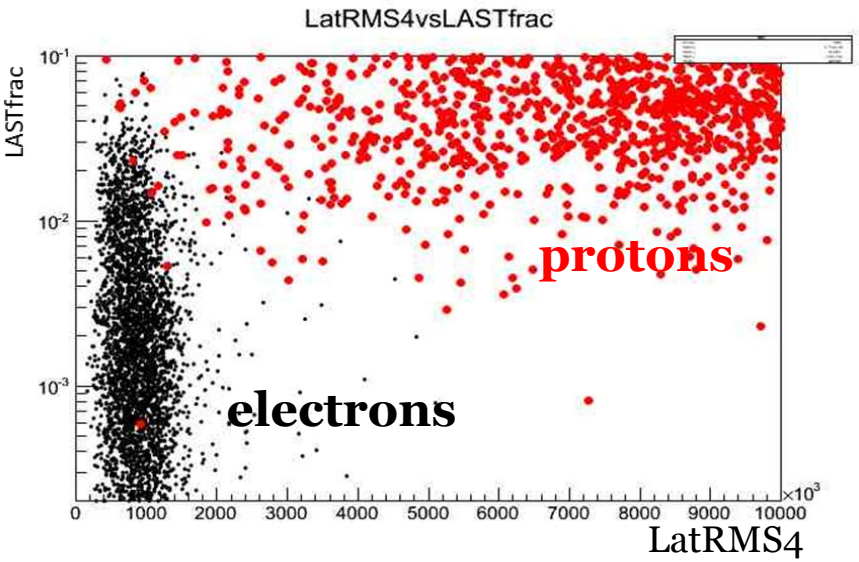
SIMULATIONS

Proton rejection factor

Montecarlo study of proton contamination using CALORIMETER INFORMATIONS ONLY

- **PARTICLES propagation & detector response simulated with FLUKA**
- **Geometrical cuts for shower containment**
- **Cuts based on longitudinal and lateral development**

LONGITUDINAL



LATERAL

- 155.000 protons simulated at 1 TeV : only 1 survive the cuts
- The corresponding electron efficiency is 37% and almost constant with energy above 500gev

STUDY ON THE CRYSTALS AND PHOTODIODES

- CsI(Tl) generates 54000 photons/MeV
- 1 MIP (3,6x3,6x3,6 cm^3) ≈ 20 MeV ≈ 1 080 000 photons
- Two crystals with different size have been studied (cubes with side of 2,5 and 3,6 cm)
- VTH 2090 photodiode have been used
- The single channel high precision DAQ system by Amptek has been used. This system includes charge sensitive preamplifier A250 and digital pulse analyzer PX5.
- Spectral measurements with Am 241 gamma source have been done to calibrate the diode and DAQ system.
- For the next step the Scintillator-photodiode module has been studied using calibrated DAQ and Am 241 α line (~5,5 MeV).

STUDY ON THE CRYSTALS AND PHOTODIODES

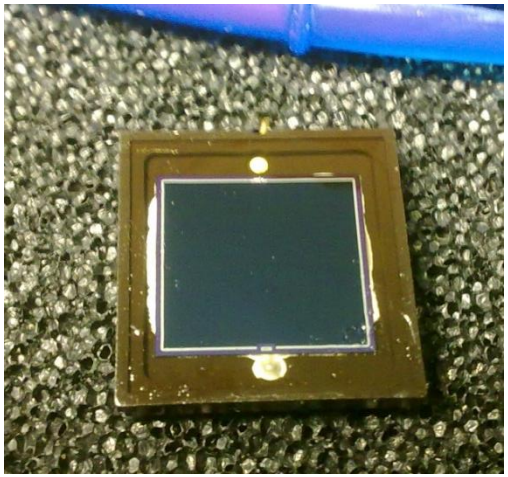
- VTH 2090

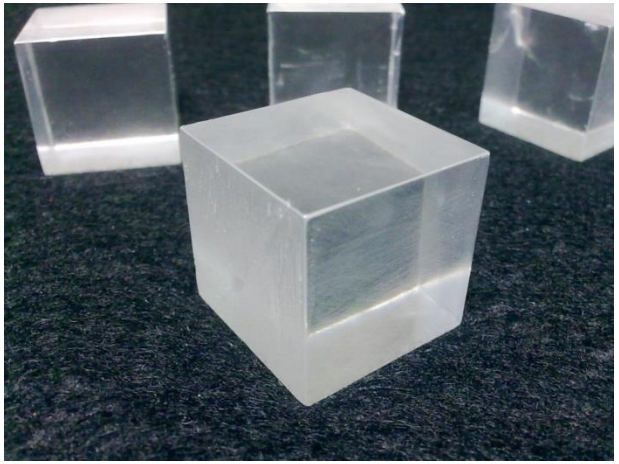
Manufacturer – Excelitas

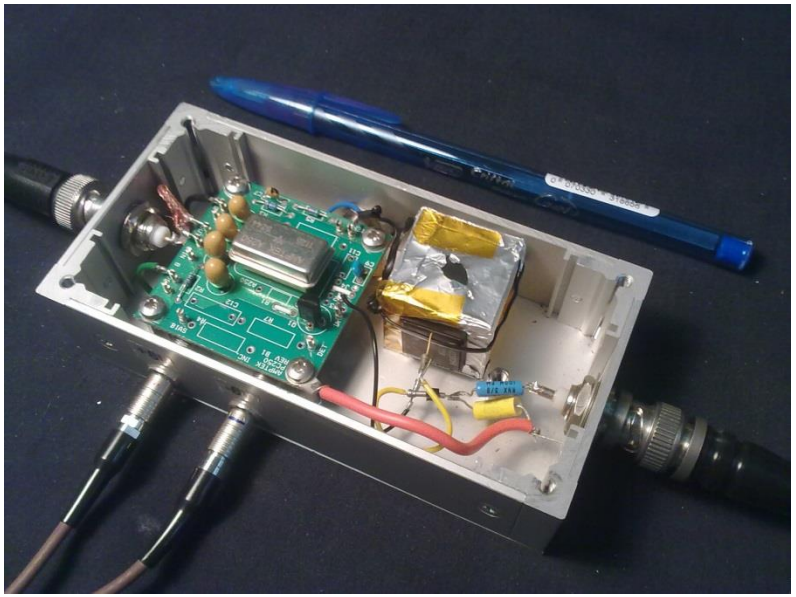
Size - 9,2x9,2 mm^2

V_{op}= 45V

PDE (550 nm)= 0,68







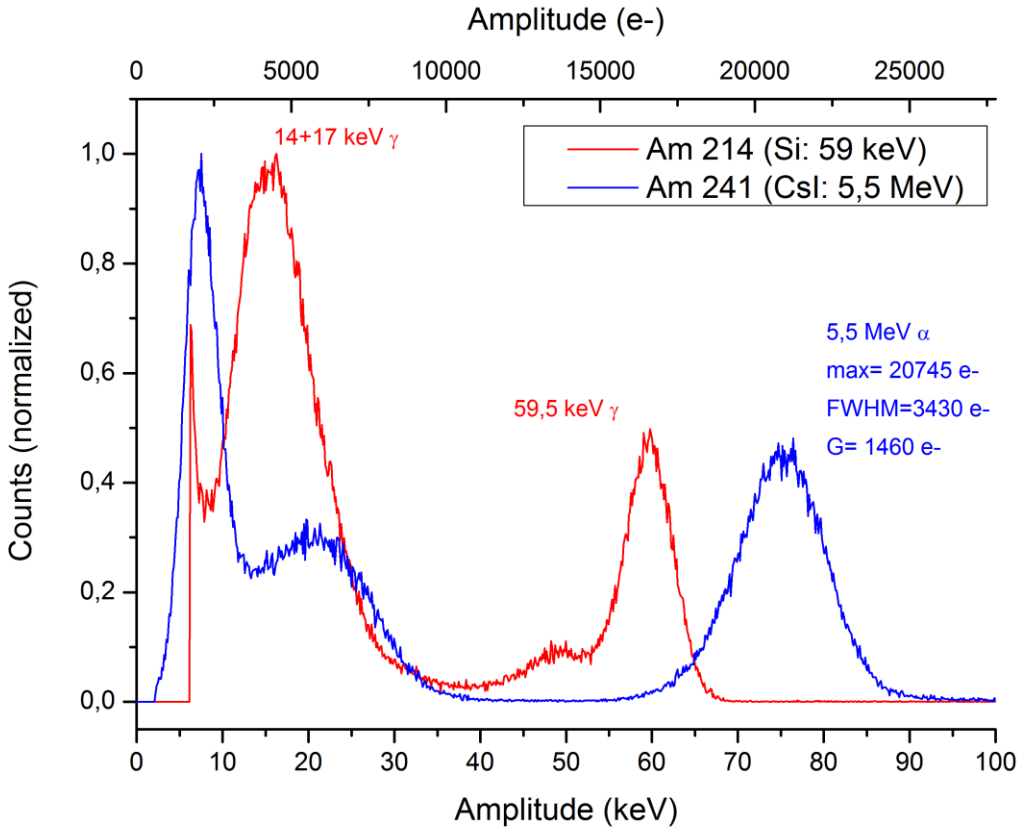
STUDY ON THE CRYSTALS AND PHOTODIODES

CsI(Tl) light yield is 54000 photons/MeV => 5.5 MeV*54000=297 000 photons.
Light collection efficiency = 0.8
Geometry factor = 0.1354
Photodiode PDE efficiency = 0.68

Calculated signal = 297000*0.8*0.1354*0.65 = 21880 electrons

Measured signal = 20745 electrons

S/N = 15



BUILDING

- **Two prototypes have been built at INFN Florence, with the help of INFN Trieste, INFN Pisa and University of Siena.**

- **A small, so called “pre-prototype”, made of 4 layers with 3 crystals each**
  - 12 CsI(Tl) crystals, 2.5x2.5x2.5 cm^3

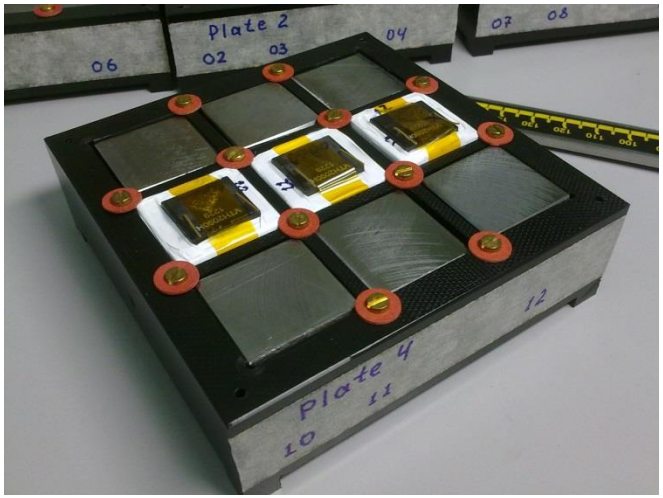
- **A bigger, properly called “prototype”, made of 14 layers with 9 crystals each**
  - 126 CsI(Tl) crystals, 3.6x3.6x3.6 cm^3

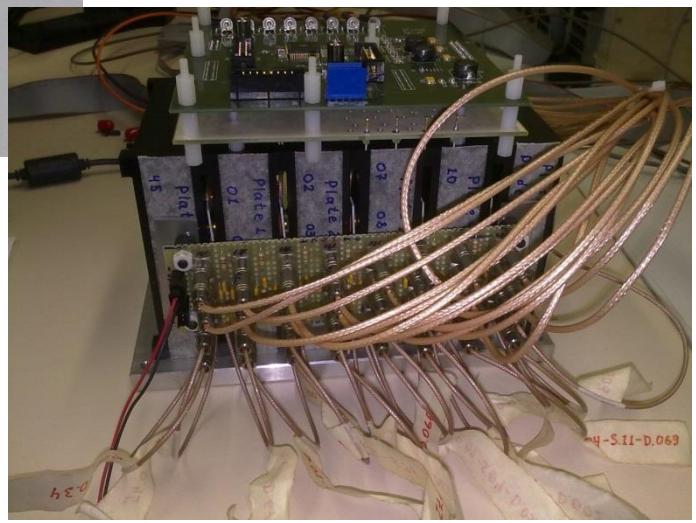
- **CASIS chip has been used to read both devices**

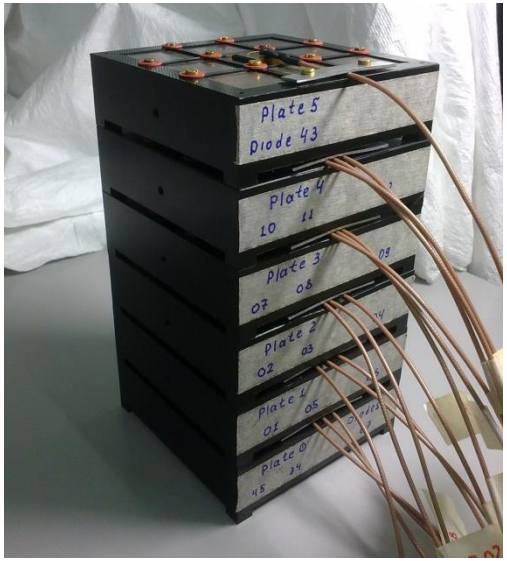
BUILDING

Pre-prototype

- 12 CsI(Tl) crystals, 2.5x2.5x2.5 cm^3
- 4 layers with 3 crystals each
- 1 CASIS, 16 channels

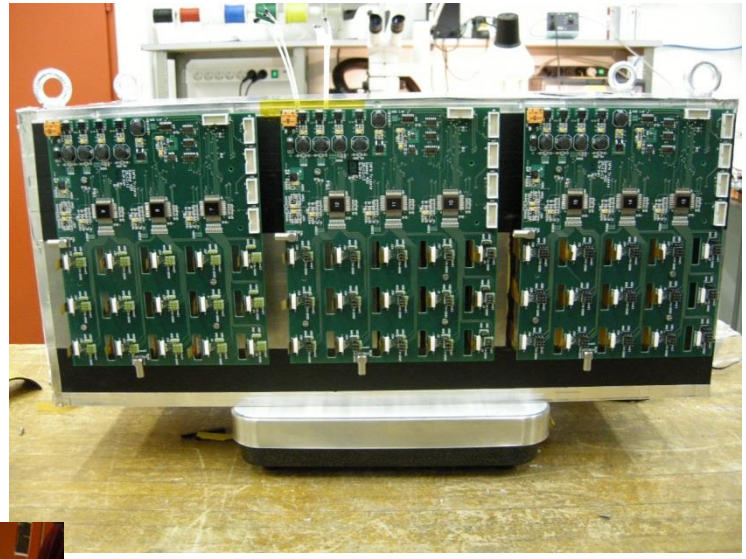


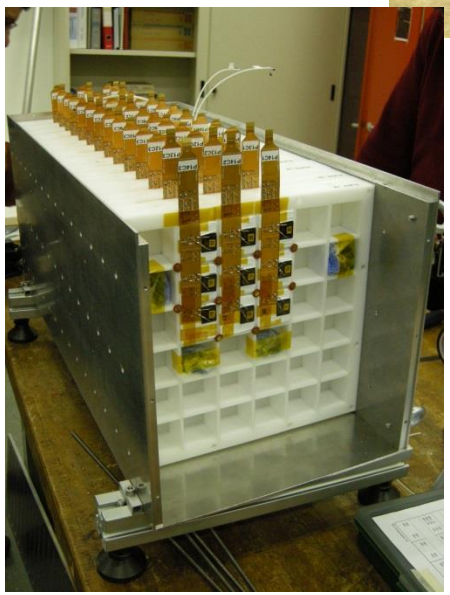


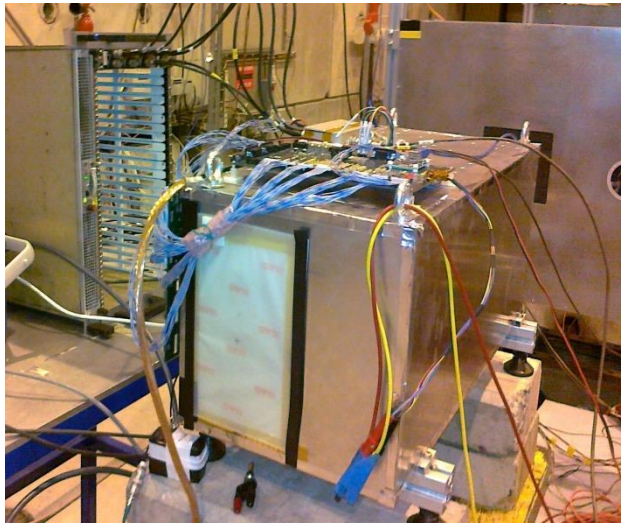


BUILDING

- **Prototype**
  - 126 CsI(Tl) crystals, 3.6x3.6x3.6 cm^3
  - 14 layers with 9 crystals each
  - 9 CASIS, 144 channels







- **CASIS**

High dynamic range preamplifier developed by INFN Trieste

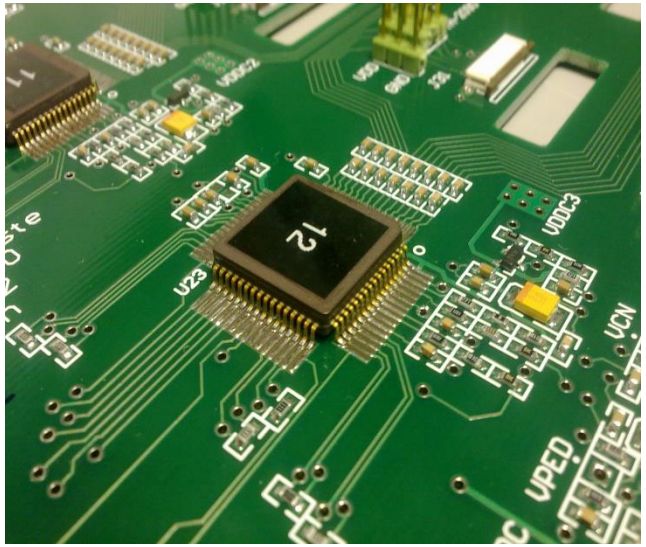
Charge sensitive preamplifier with double sampling correlated circuit

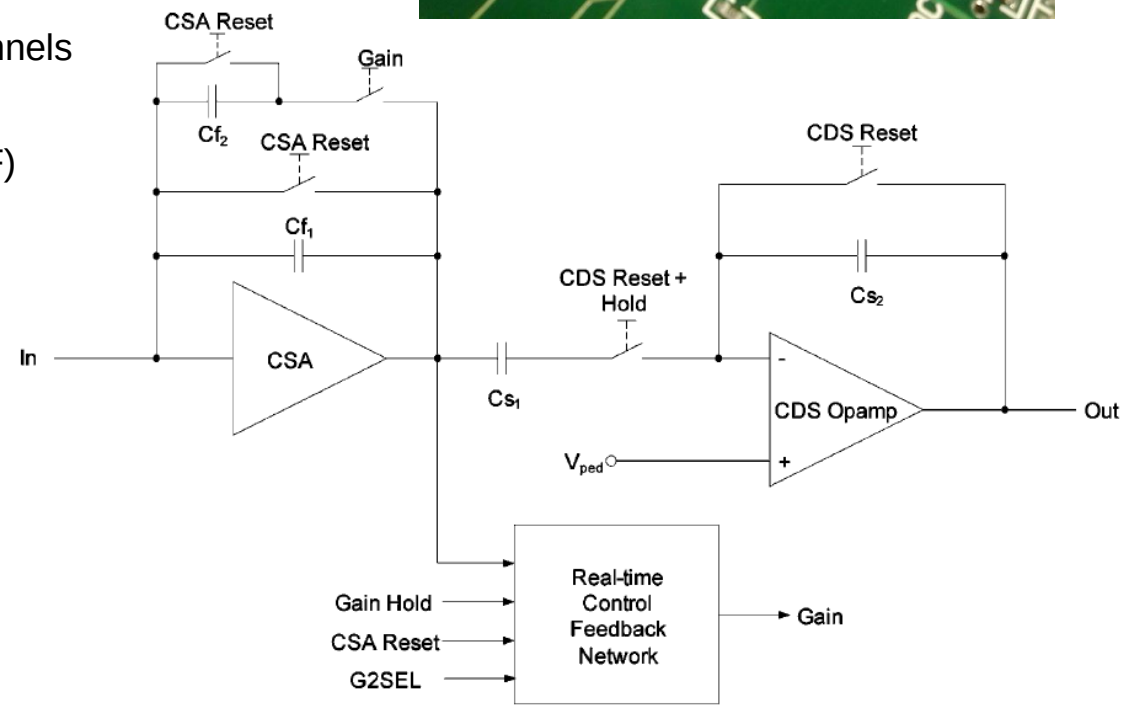
Number of channels 16

Dynamic range (pC) 52

Shift register for multiplexing 16 channels to single out line

Noise (e-) 2840 e^- +9.75 e^-/pF *C (pF)





RESULTS

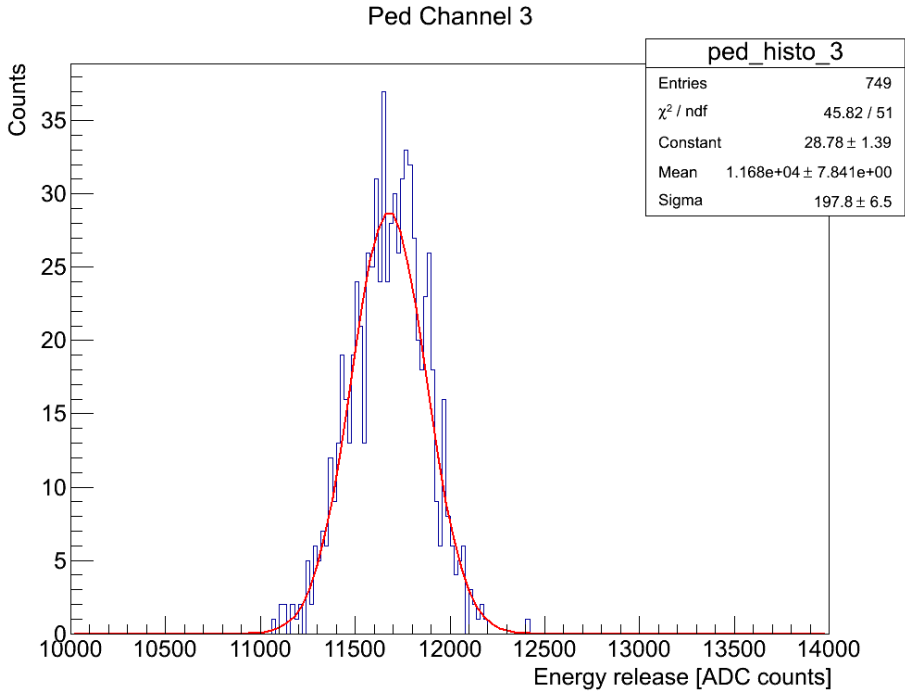
Both devices have been tested at CERN SPS

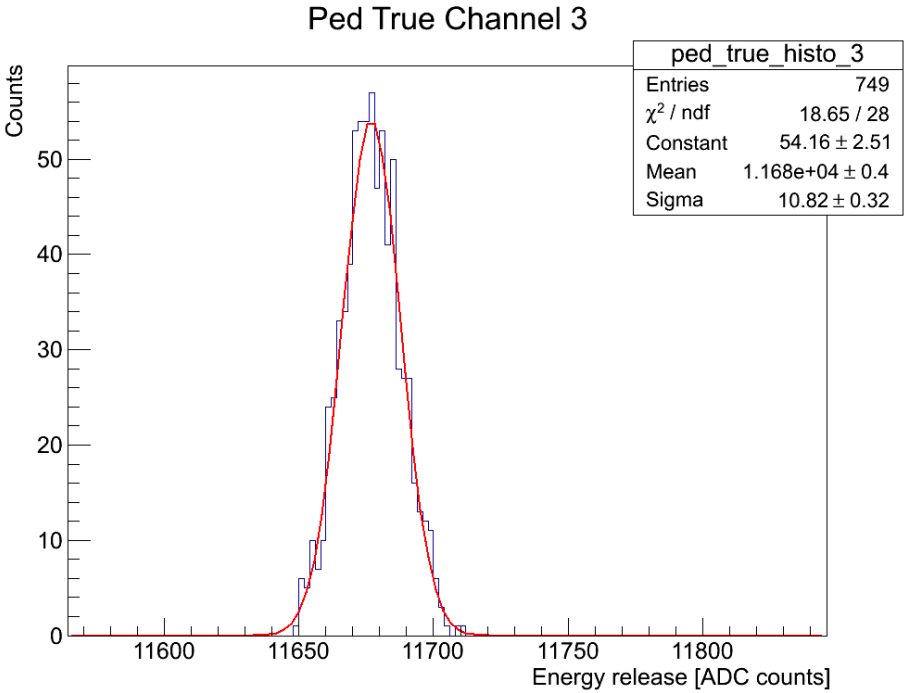
The two calorimeters have been tested in October 2012 and February 2013, respectively.

A muon beam of 150 GeV/c has been used for the pre-prototype.

Ions with A/Z=2 at 30 GeV/n and 12 GeV/n have been used for the prototype.

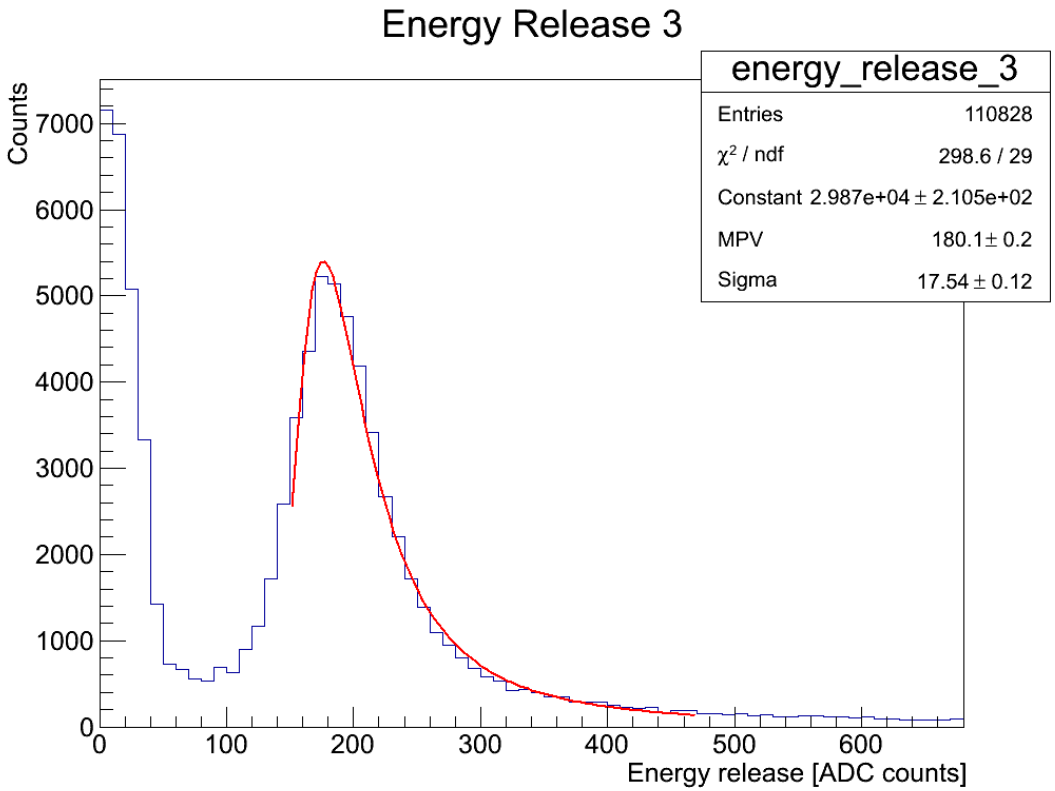
RESULTS. PRE-PROTOTYPE





Pedestal distribution for one channel without and with common noise substraction

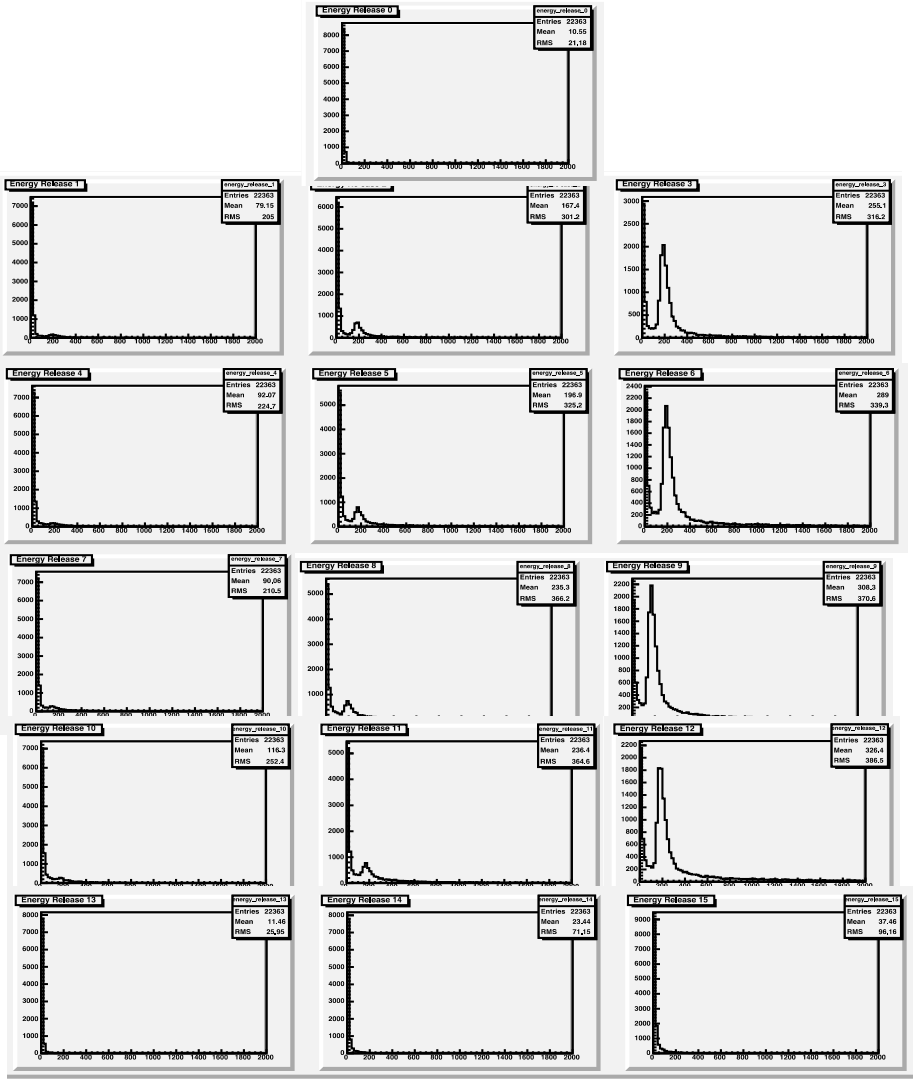
RESULTS . PRE-PROTOTYPE



Muons signal. Channel 3.

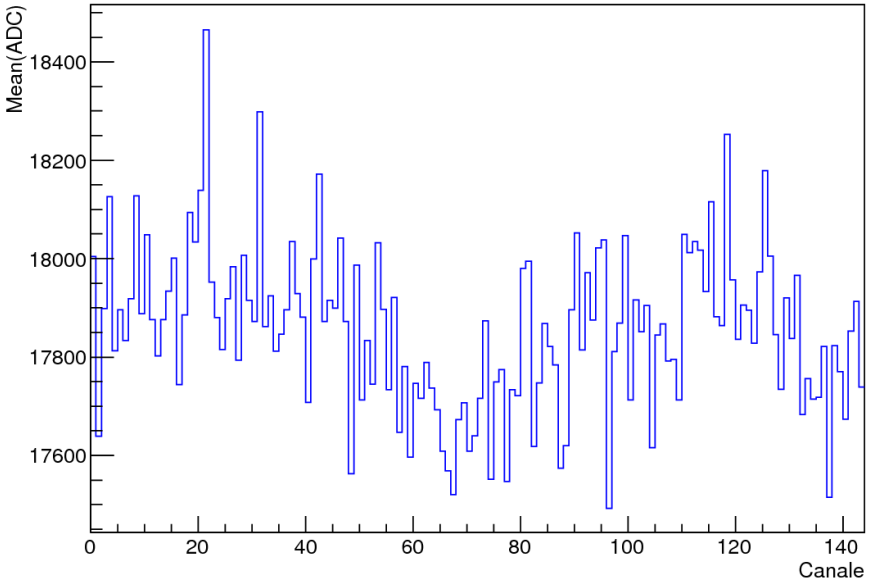
Chann.	PED σ	MPV	S/N
1	10.4	194.9	19.3
2	10.8	183.3	18.1
3	10.7	180.1	17.8
4	10.4	190.5	18.9
5	10.7	172.5	17
6	11.1	182.7	16.5
7	10.2	144.4	14.4
8	10.2	195	19.4
9	10	164.9	16.4
10	10.3	171.8	17
11	10.5	170.8	16.9
12	10.2	183.7	18.3

A spot on the pre-prototype test beam (μ^- beam)

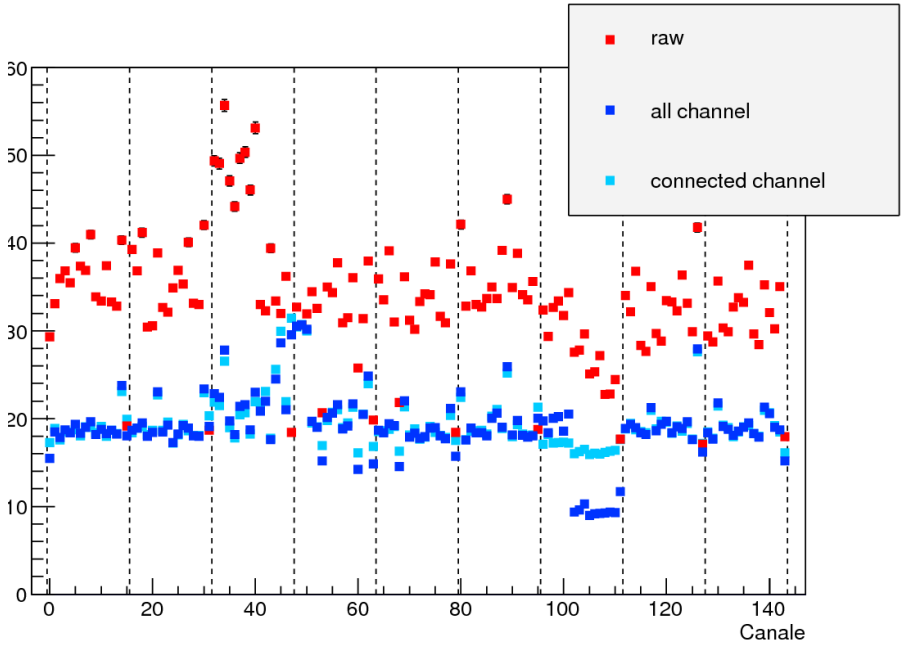


RESULTS . PROTOTYPE

Pedestals



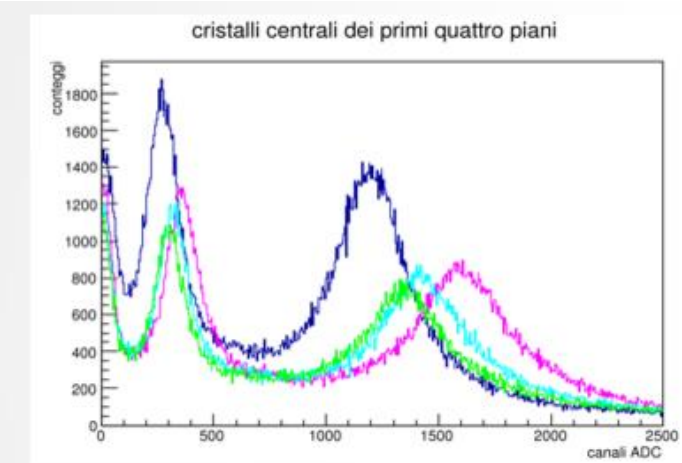
Mean value distribution

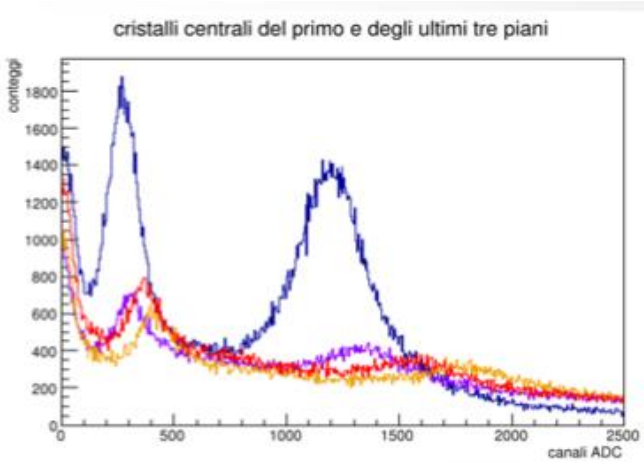


RMS distribution with different models of CN subtraction

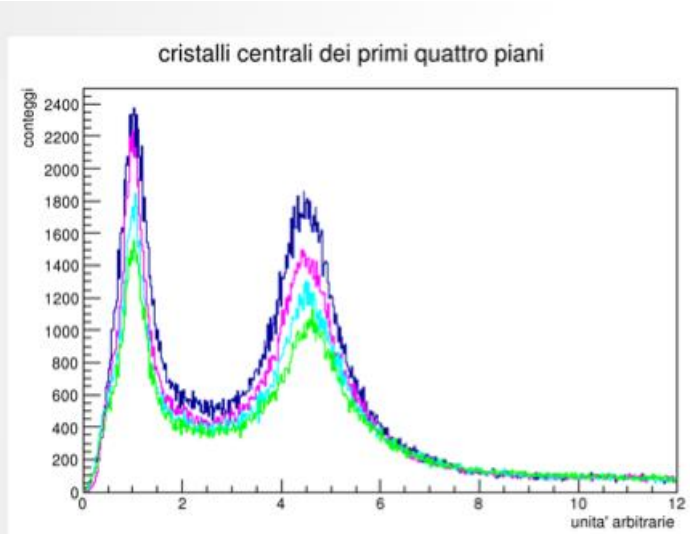
RESULTS . PROTOTYPE

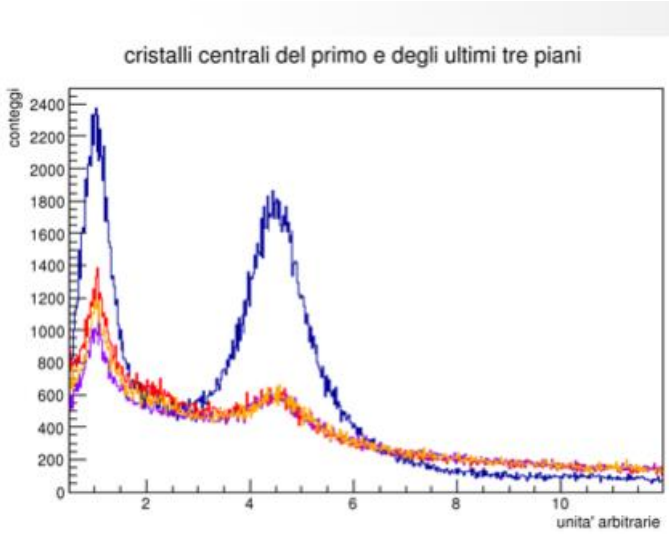
Before calibration





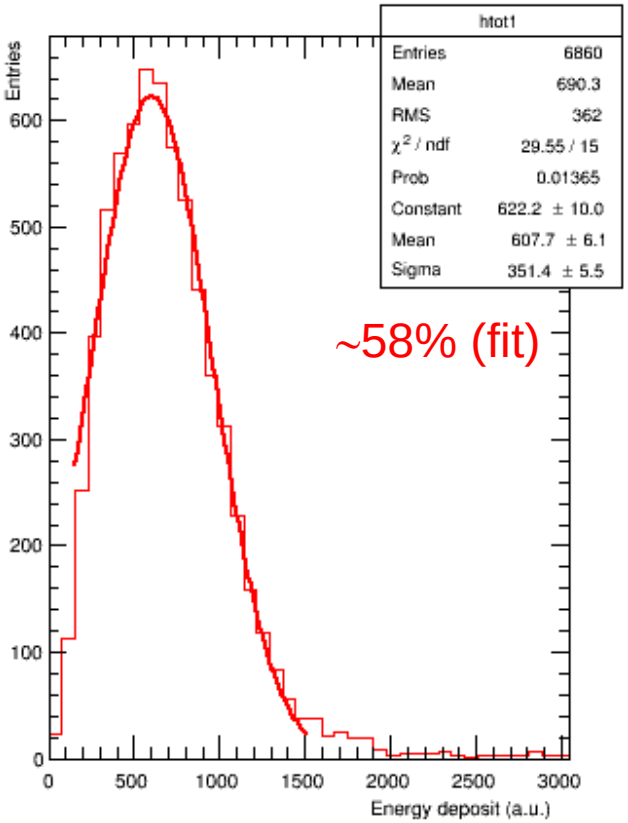
After calibration

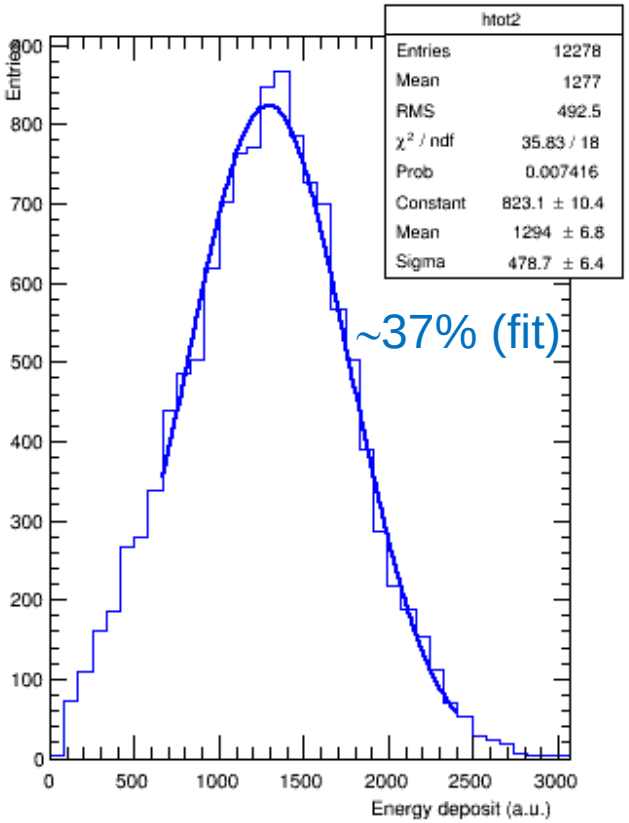




RESULTS . PROTOTYPE

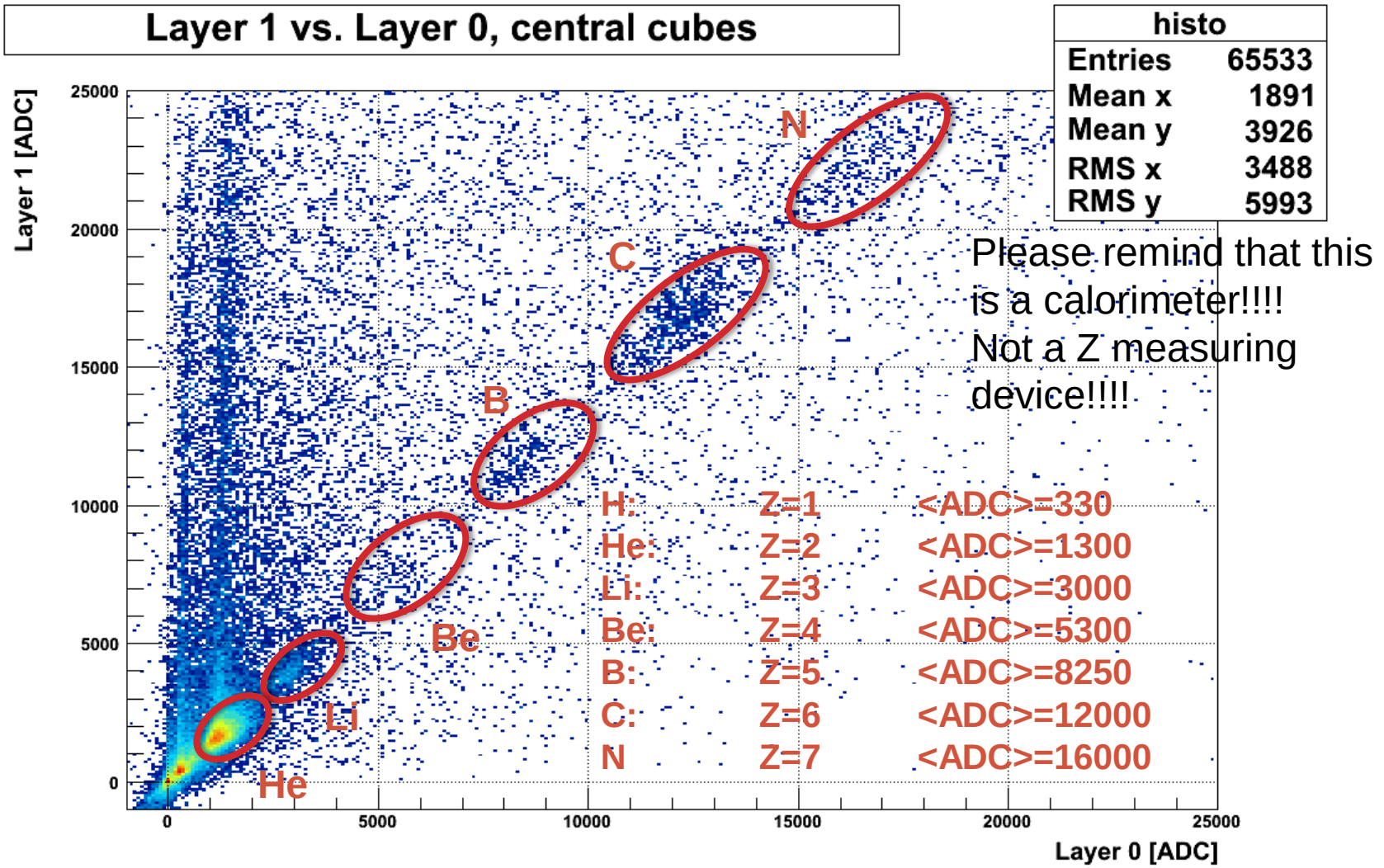
Energy resolution





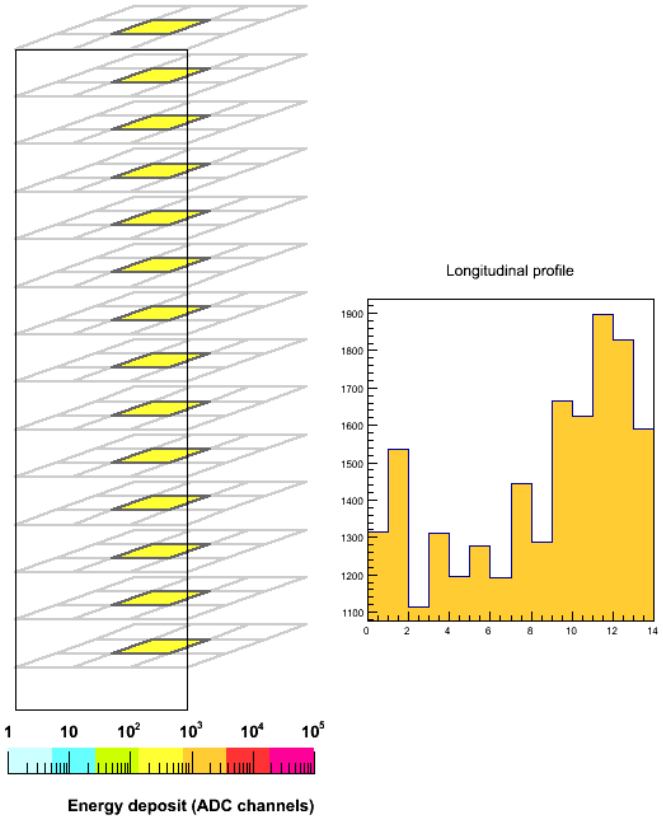
Z=2
Z=1
30 GV
Starting-layer ==2

Scatter plot

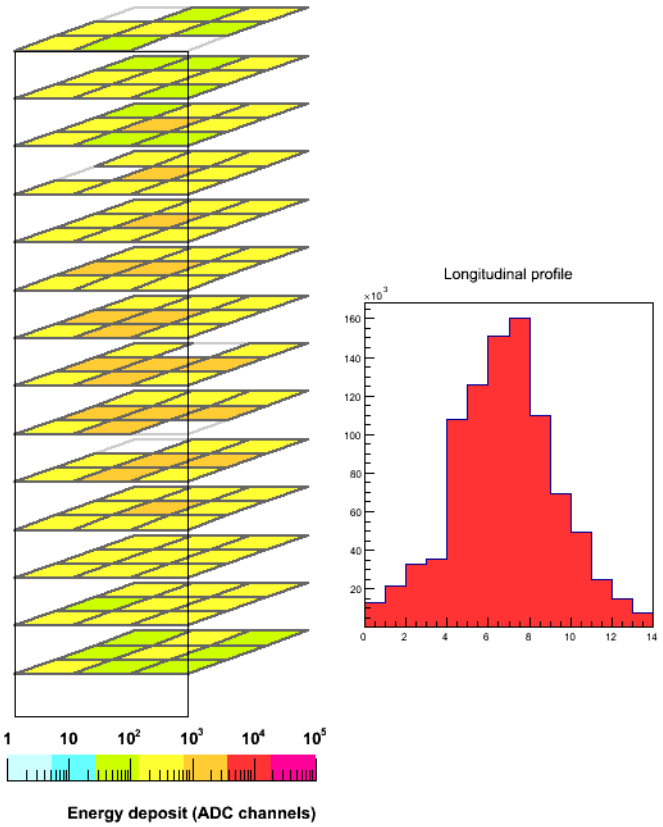


RESULTS . PROTOTYPE

Shower profiles



MIP



Hadronic shower

CONCLUSIONS

The proposed homogeneous and isotropic calorimeter has been carefully designed to maximize acceptance within the constrained framework of a space mission, with a good energy resolution to detect the knee of cosmic-ray spectrum and to resolve possible structures in the electron+positron component.

MonteCarlo simulations show that a geometric factor of 3 - 4 m^2sr can be achieved by detecting particles impinging on 5 sides of the cube, with 2% energy resolution for electrons and 30-40% for protons.

Proton rejection power h/e > 10^5 can be obtained.

Two prototypes have been built and tested at CERN SPS to demonstrate the measurement principle. Test beam data analysis is ongoing, together with MonteCarlo simulation runs and electron/proton rejection studies. The possibility to instrument each crystal with a SiPM to read the Cerenkov light in order to perform hadronic shower compensation is being investigated as well.

BACKUP

$GF_{eff} = \varepsilon * GF_{singleface} * 5 = \varepsilon * 9{,}55 m^2 sr$