CIEMAT MEETING 19/04/2016

CaloCube: Test Beam Prototype

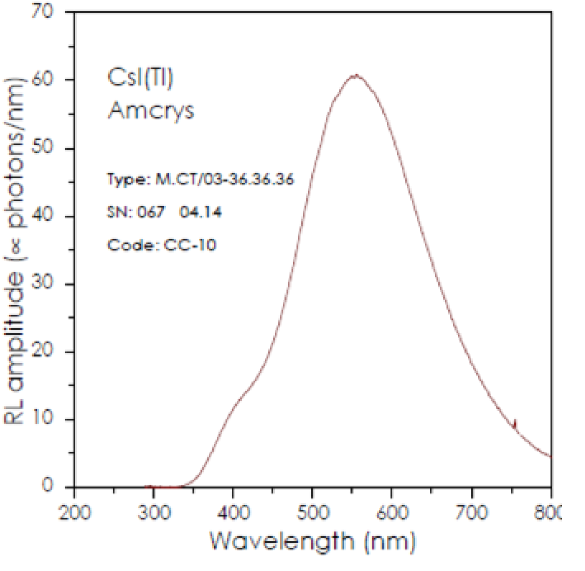
Raffaello D'Alessandro
Elena Vannuccini, Miriam Olmi (Data Analysis)

Scintillating material

- **CsI(Tl)** crystals

Density	**4.51 g/cm^3**
Wavelength @max	**550 nm**
Light output	**54 ph/keV** (45 % of NaI(Tl))
Primary decay time	**1 ms**

  - Produced by **Amcrys**
  - **3.6 cm** side (~ 1 Molière radius)

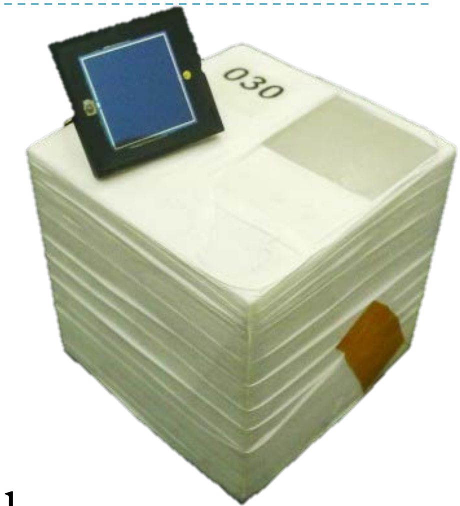


- Expected optical signal
  - 1MIP → ~ 20 MeV ~ 10^6 ph/facet
  - (assuming 80% collection efficiency on one facet from ray-tracing simulation with diffusive surface)

Sensors

- Detector requirements:
  - Sensible to MIPs
  - Shower reconstruction capabilities up to 1PeV
    - From MC, up to 10% of incident energy deposited on a single crystal

→ Dynamic range ($0.5 \div 5 \cdot 10^6$ MIP)

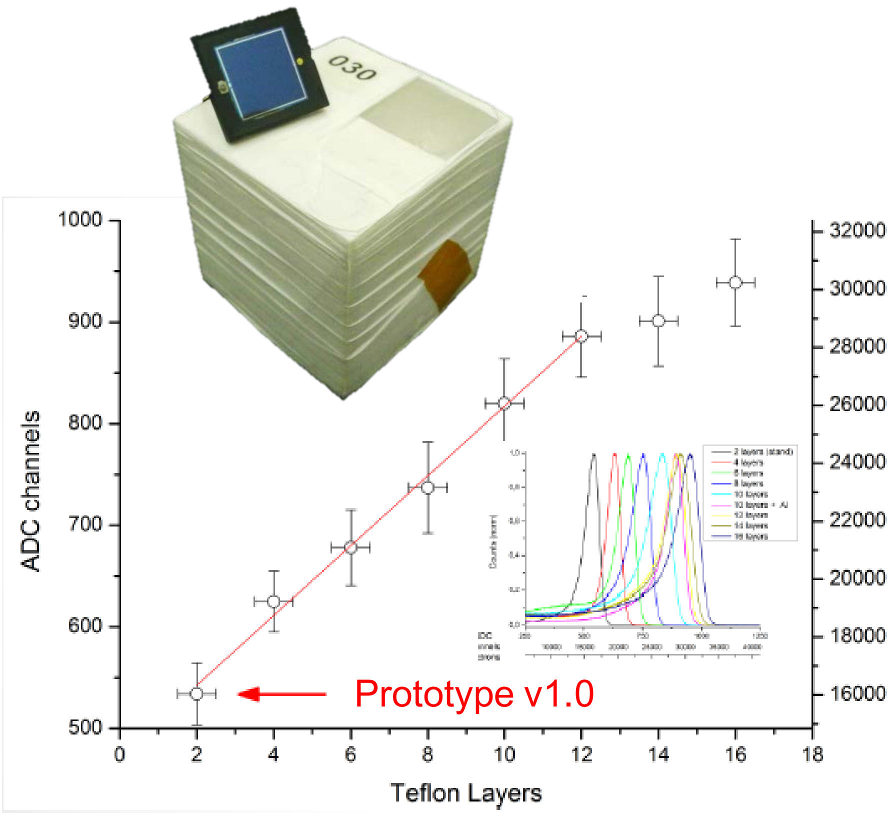


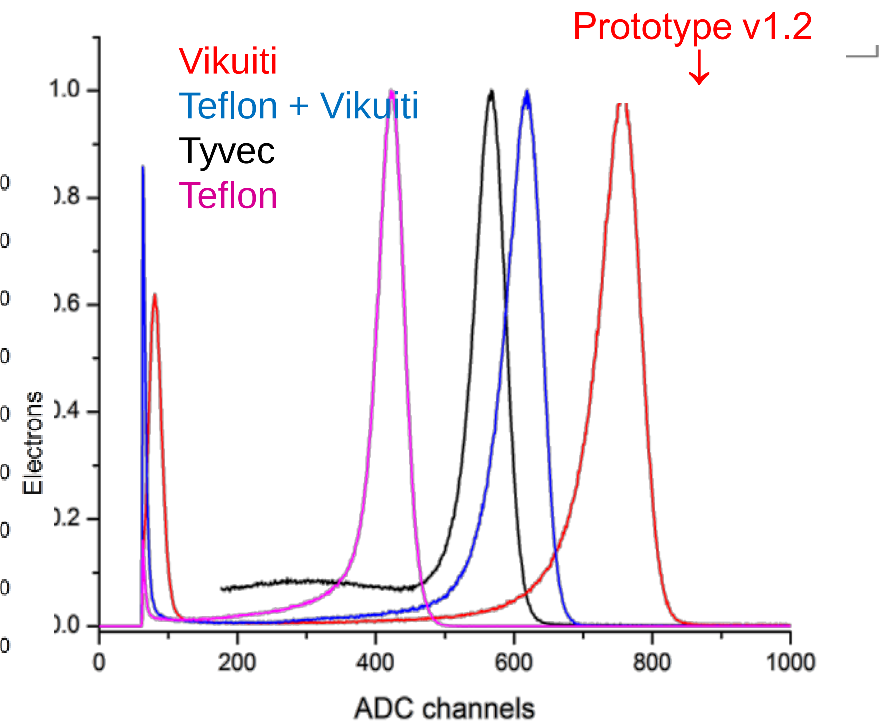
- At least 2 Photo Diodes necessary for each crystal
  - Large-area PD for small signals
    - VTH2090 (Excelitas)
    - Expected electrical signal
      - 1MIP ~ $4 \cdot 10^4$ e^- ~ 7 fC
      - Max signal ~ $2 \cdot 10^{11}$ e^- ~ 30nC
  - Small-area PD for large signals
    - T.b.d. (VTP9412H, VTP3310H,…)
    - With GF ~ 600 times lower → Max.signal ~ 50pC

	VTH2090
Active area	84.6 mm^2
Q.E. @CsI(Tl) peak	75%
C_J	70pF @30V

Light-collection optimization

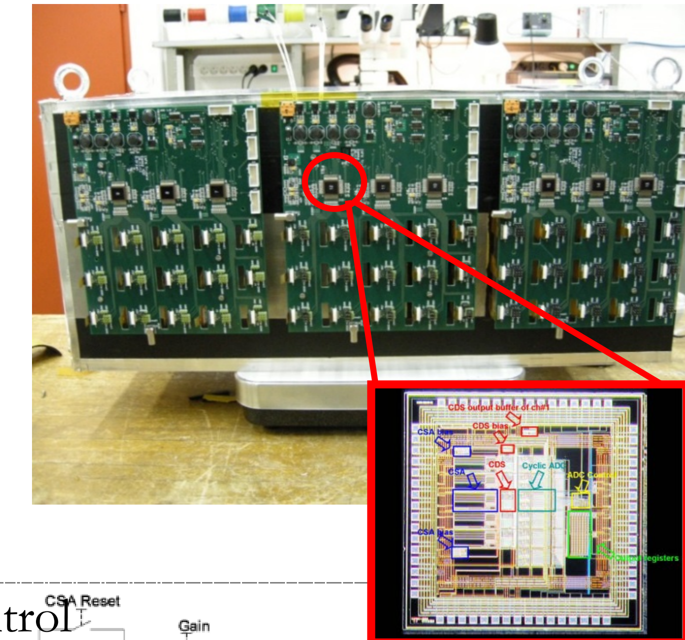
- Studied with signal induced by 5,5 MeV α from Am source
- Setup:
  - single cube (matte) coupled to VTH2090 PD
  - Readout by commercial CSA and DPA modules (Amptek)

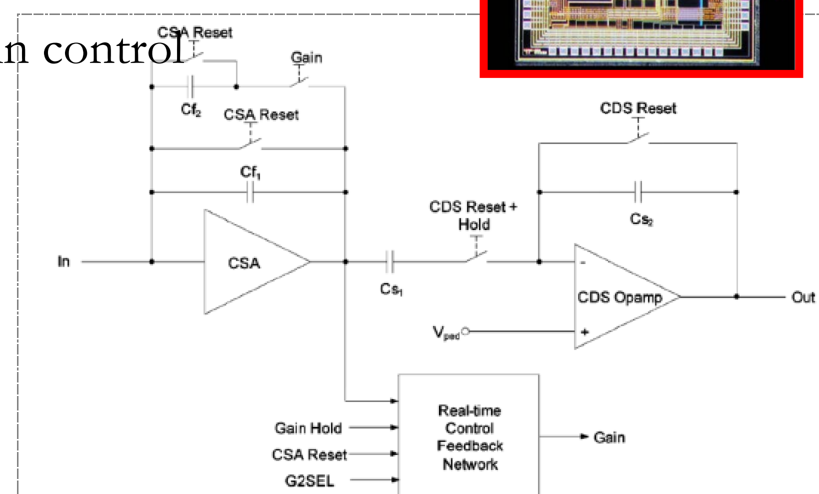




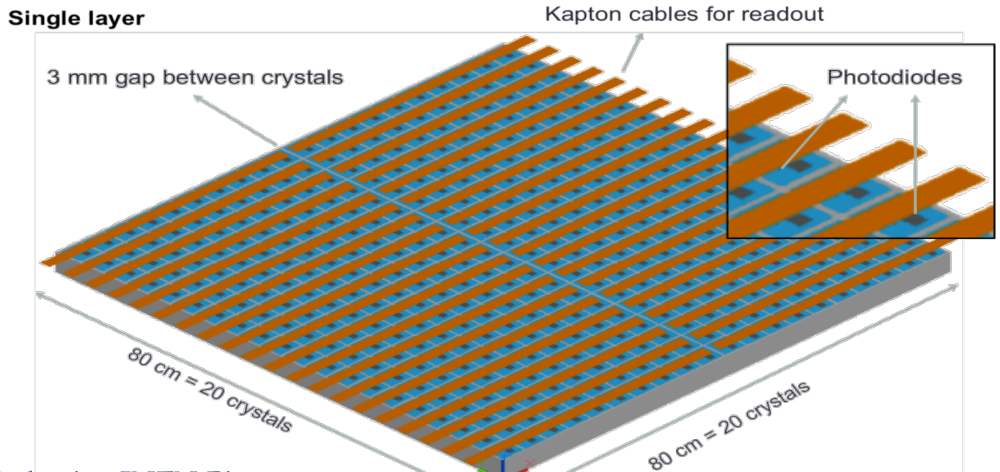
Front-end electronics

- CASIS chip (V1.1)
  - R&D project by INFN
  - Developed by INFN-Ts
  - Designed for Si-calorimetry in space
  - 16 independent analog channels
    - CSA
    - Correlated double sampling system
    - Double gain (1:20) with automatic gain control
  - Characteristics:
    - Dynamic range ~ 52.2 pC
    - ENC ~ 2280e$^-$ + 7.6e$^-$/pF
    - 2.8 mW/ch



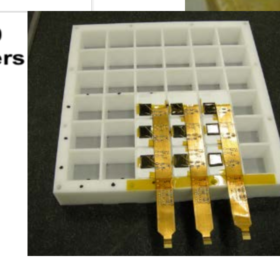


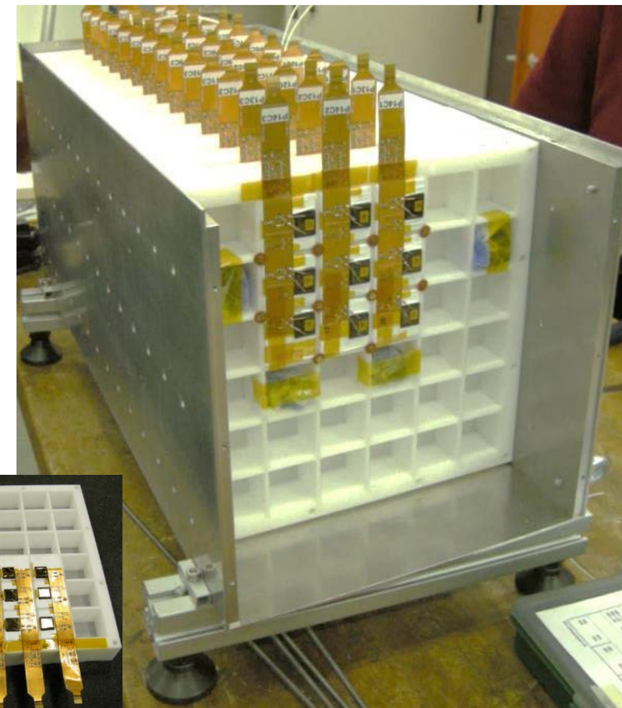
The prototype calorimeter assembly



- Mechanics: INFN Pisa
- FE electronics: INFN Trieste
- Crystals, PDs, DAQ, assembly: INFN Firenze

x 20 layers

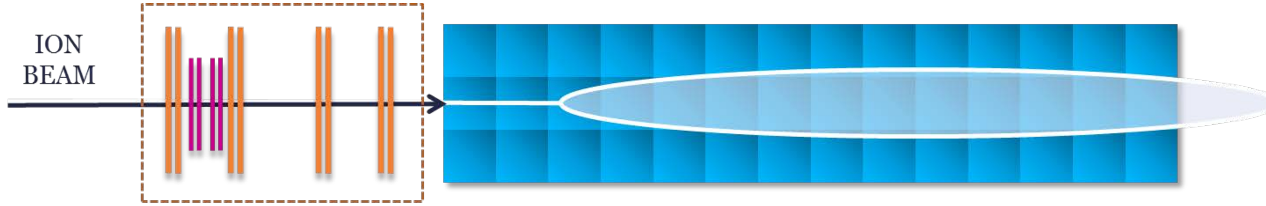




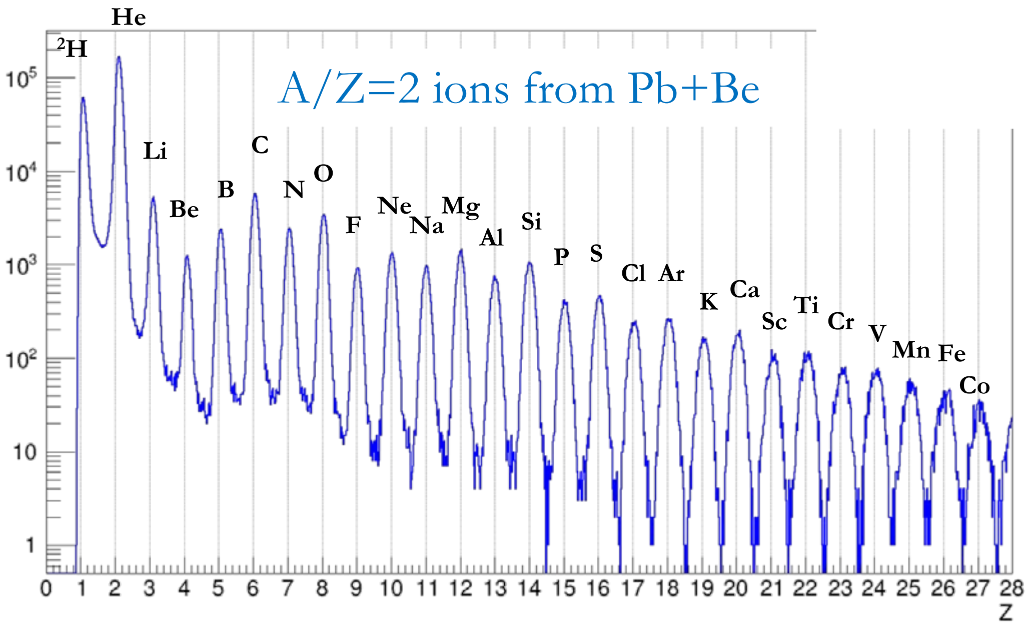
- **4mm** gap between active elements
- 3×3 elements for each plane
  - ~ **1.5 R_M** shower containment
- Up to 15 layers
  - active depth **28.4 X_0 → 1.35 λ_I**
- Three upgrades (v1.0-1-2), tested with particle beams

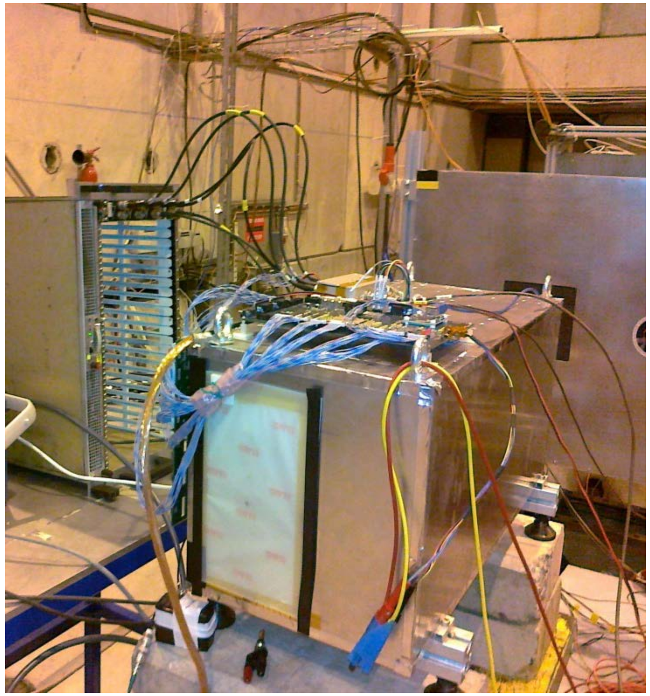
Feb 2013	v1.0	Ions Pb+Be 13-30 GeV/u
Mar 2015	v1.1	Ions Ar+Poly 19-30 GeV/u
Aug/Sep 2015	v1.2	μ,π,e 50-75-150-180 GeV

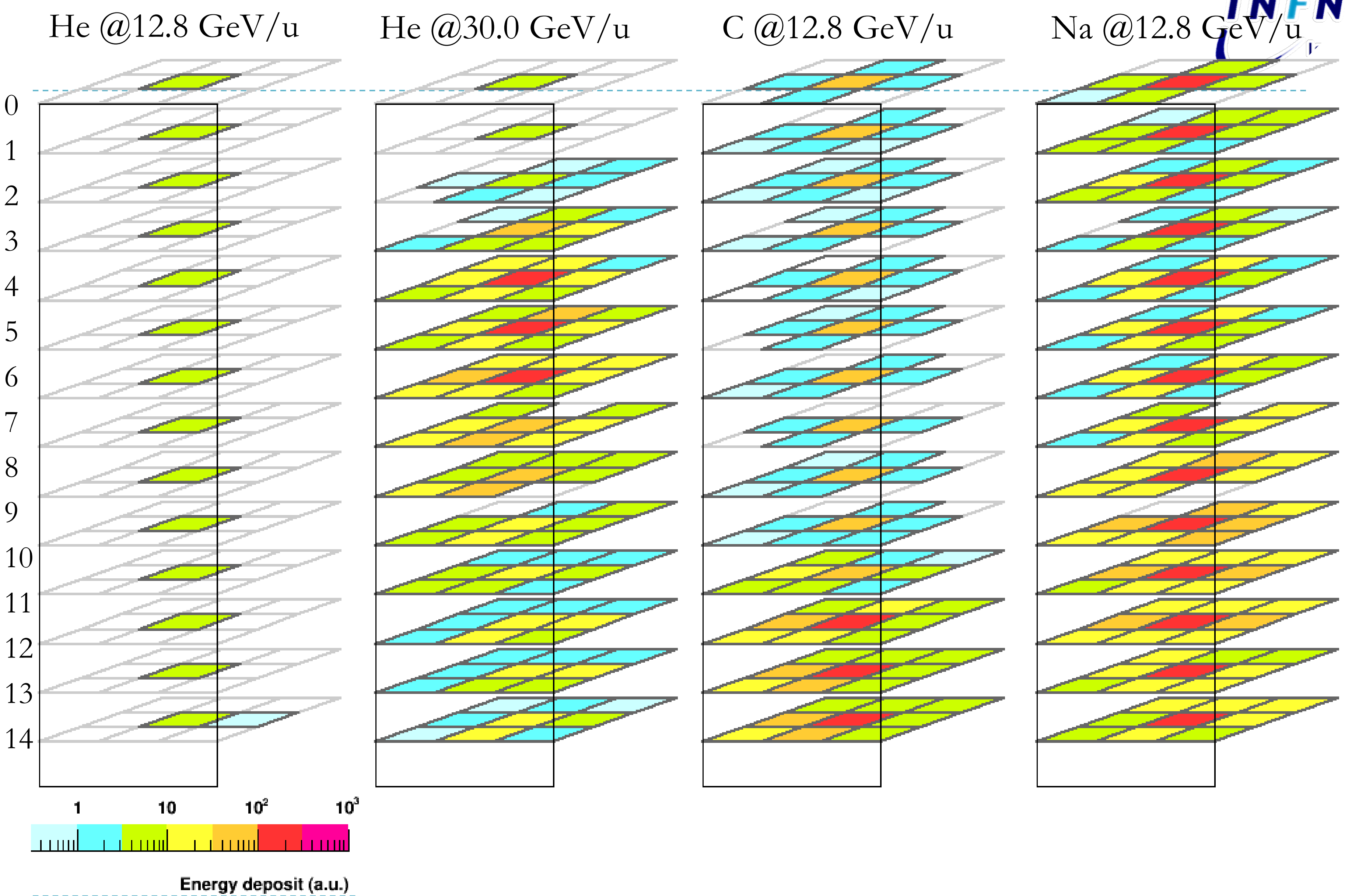
Test with ion-beam



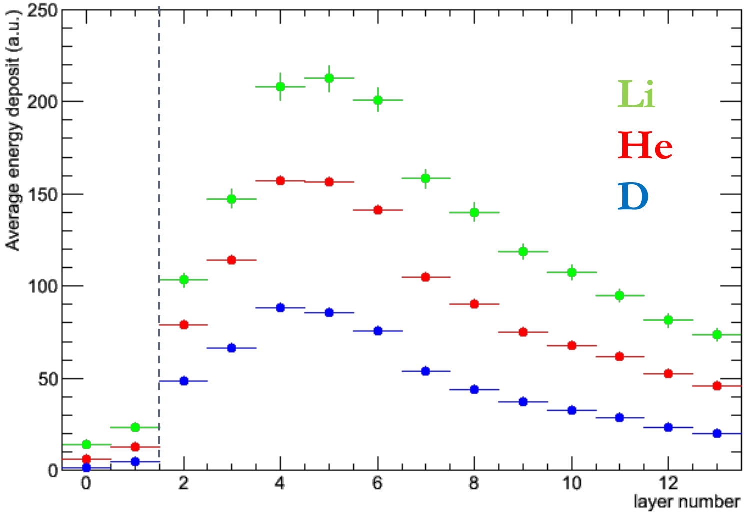
Precise beam position & Z-tagging from BT (INFN Pisa/Siena)

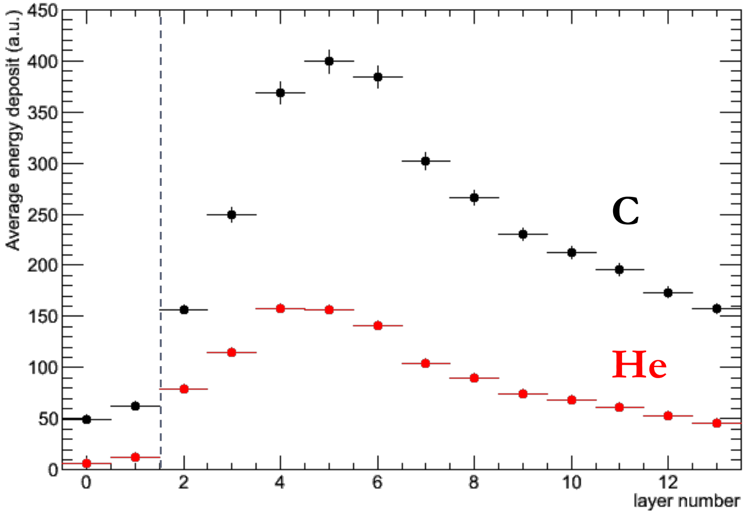


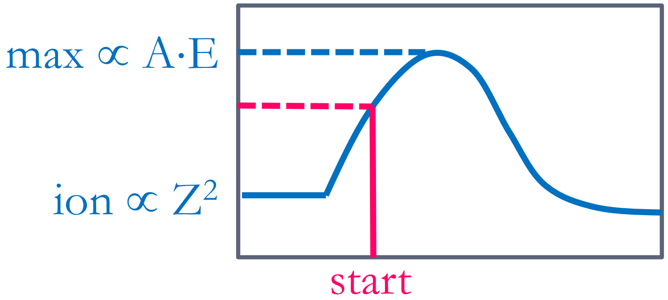



He @12.8 GeV/u
He @30.0 GeV/u
C @12.8 GeV/u
Na @12.8 GeV/u
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
1
10
10^2
10^3
Energy deposit (a.u.)

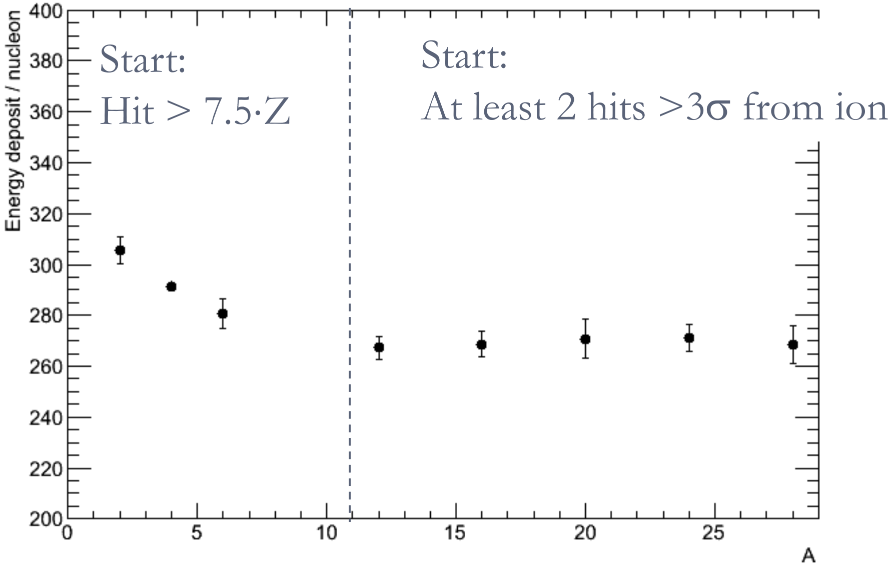
Shower profile







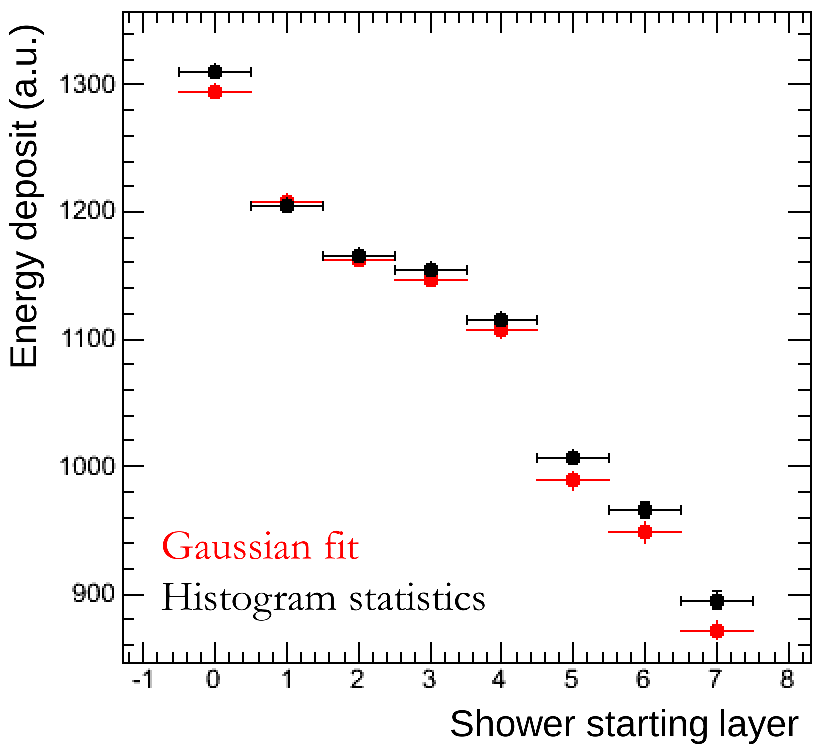
Shower start on layer 2

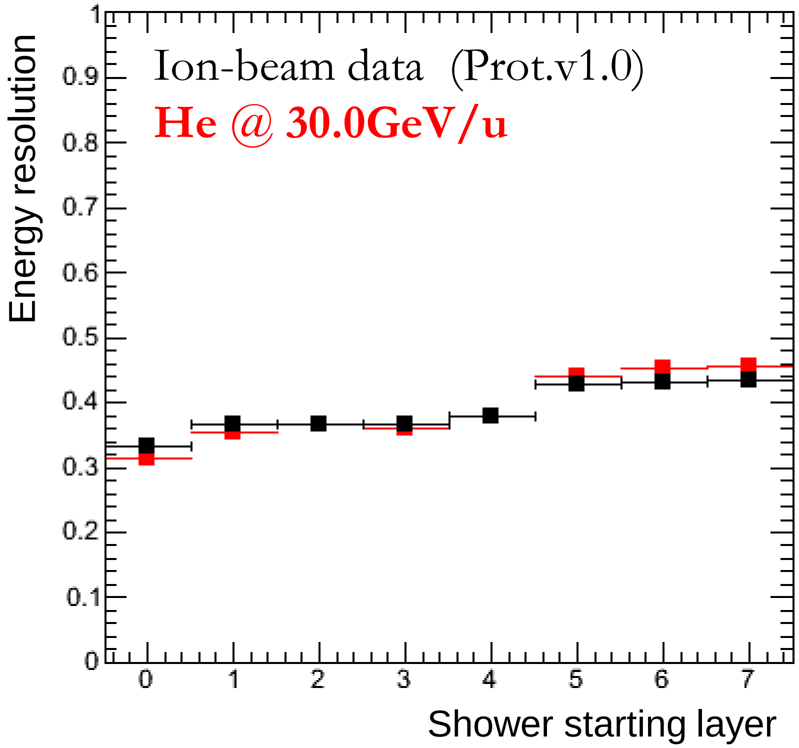


Ions @ 30.0GeV/u

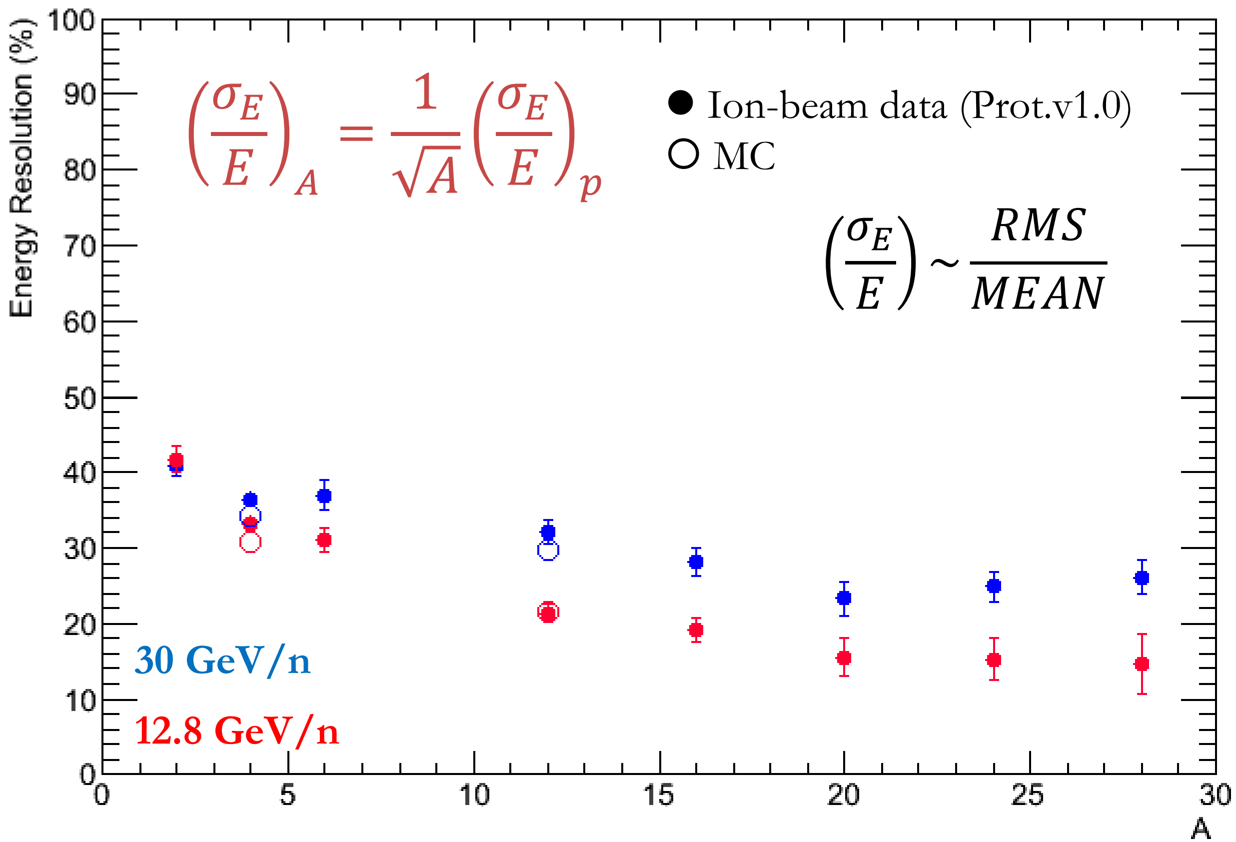
Prototype v1.0

Energy resolution –vs– shower containment





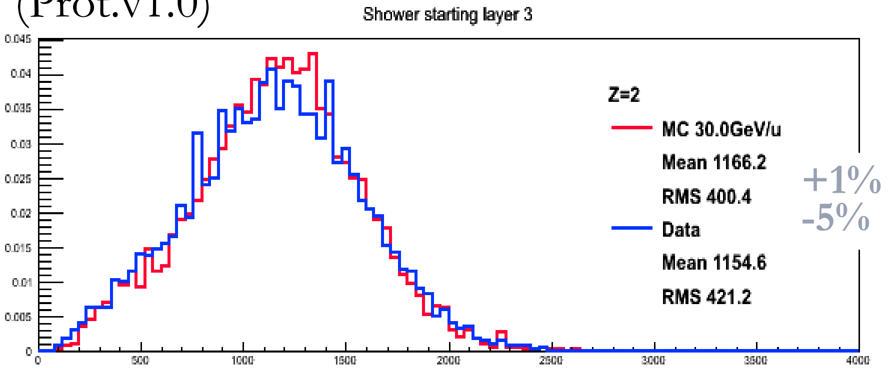
Energy resolution –vs– A

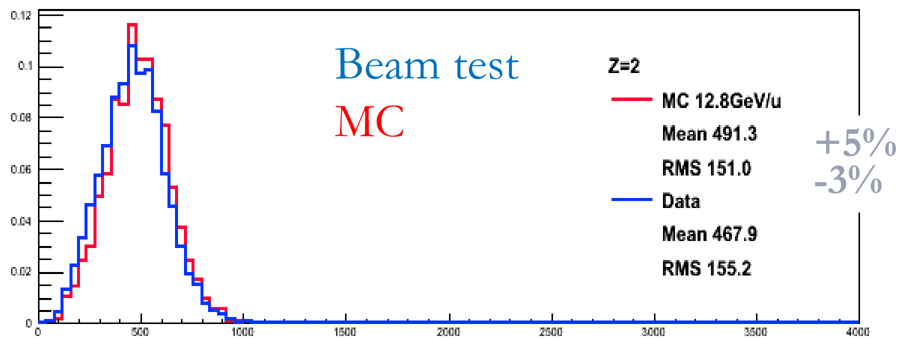


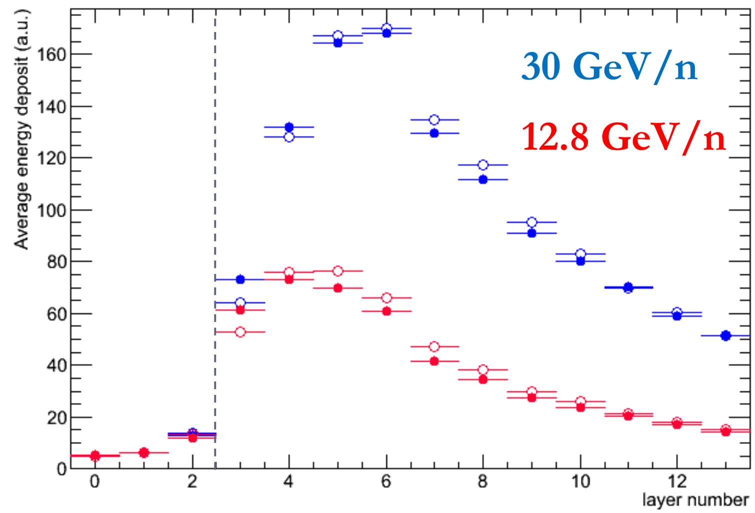
Showers starting on layer 3

Beam-test –vs– MC data

(Prot.v1.0)

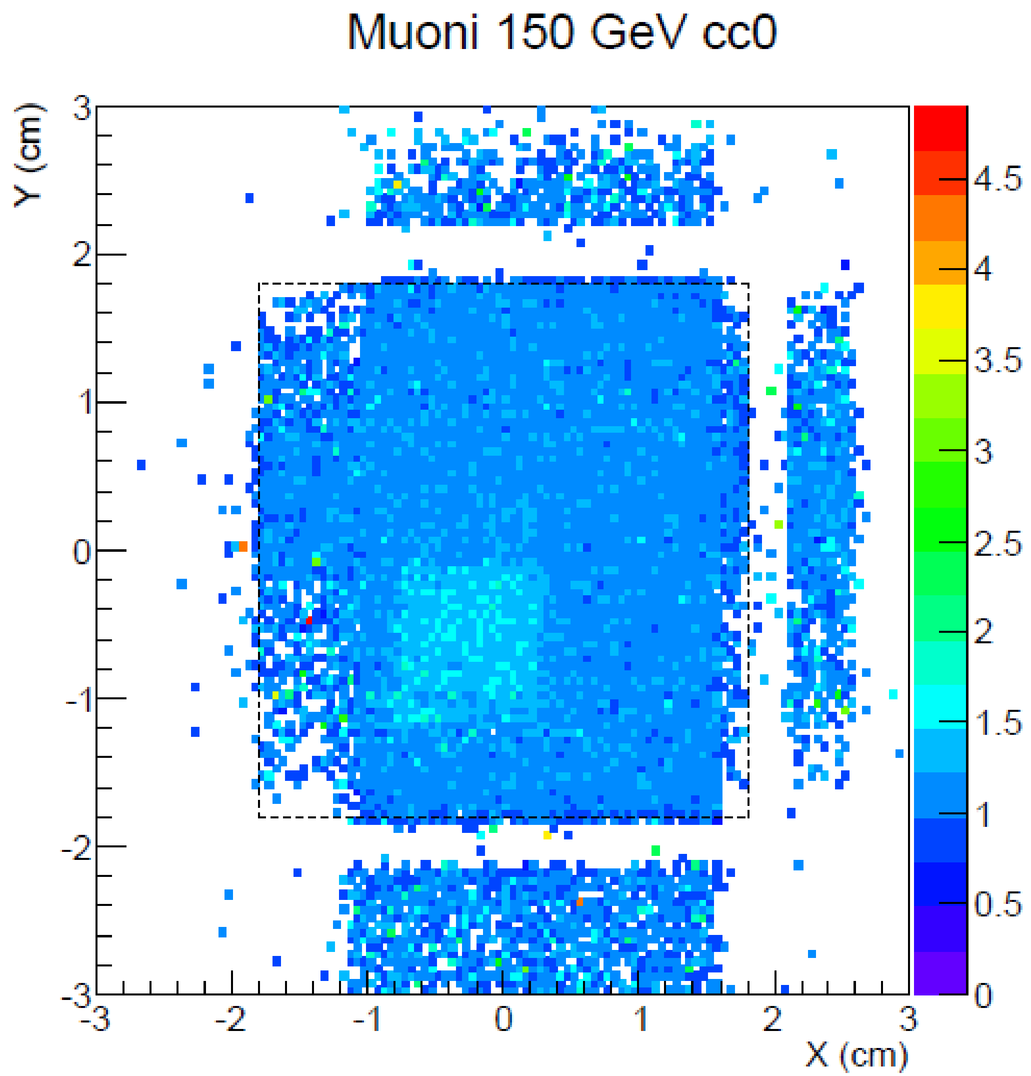






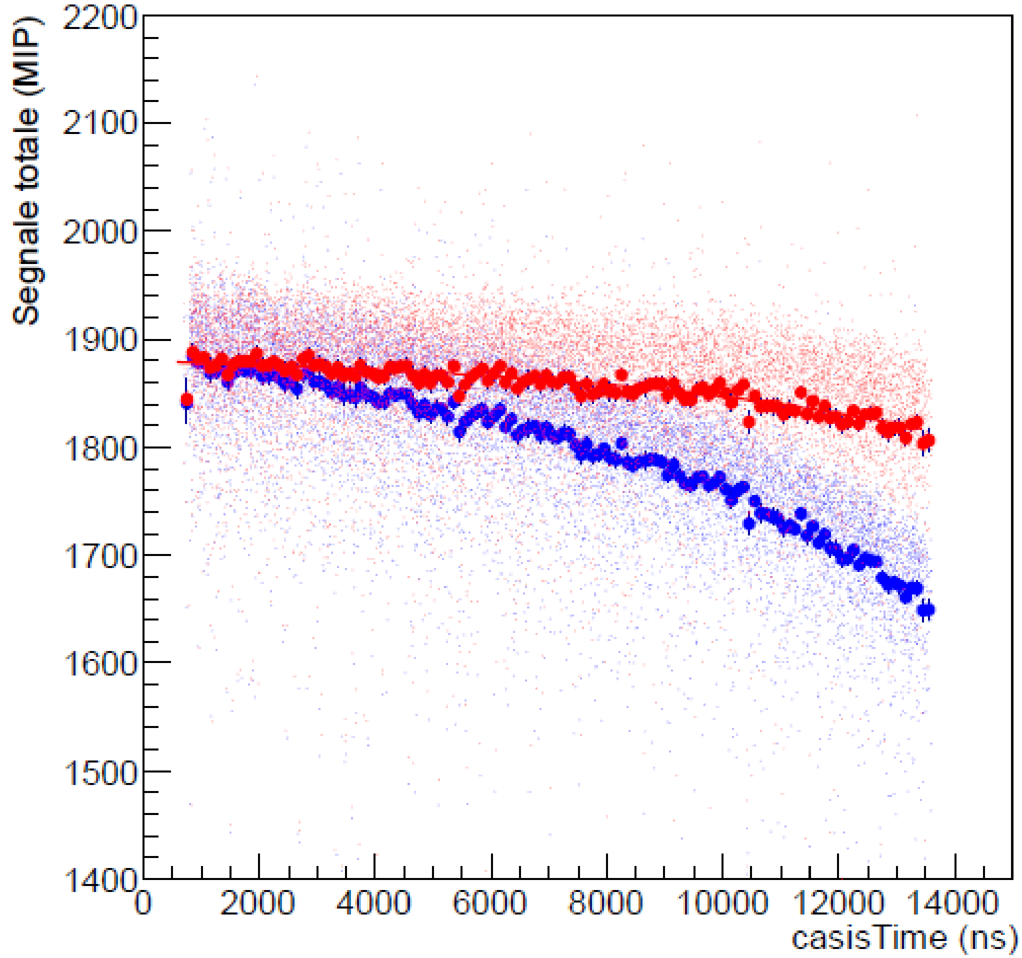
- Prot. v1.0 affected by instrumental effects → MC fine tuning:
  - 14% optical cross talk
  - 4.5% additional gaussian spread to single-crystal signal

- Agreement with MC prediction at few % level
- Measured energy resolution systematically worse than expected
- Improved performances expected for v1.1 (analysis underway)



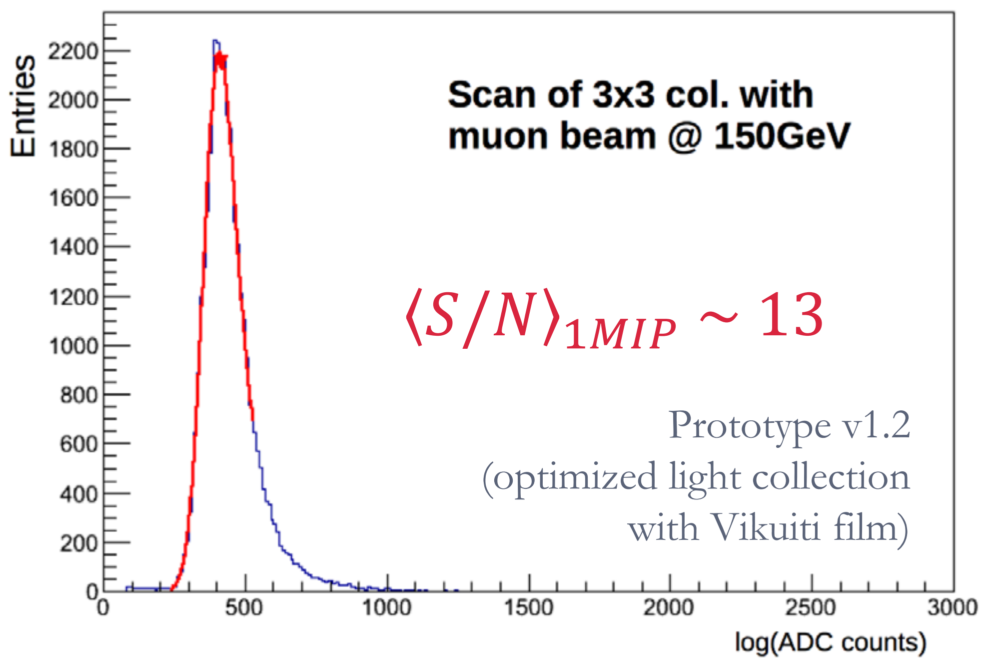
Muoni 150 GeV cc0
Y (cm)
X (cm)
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

Elettroni 50 GeV/c

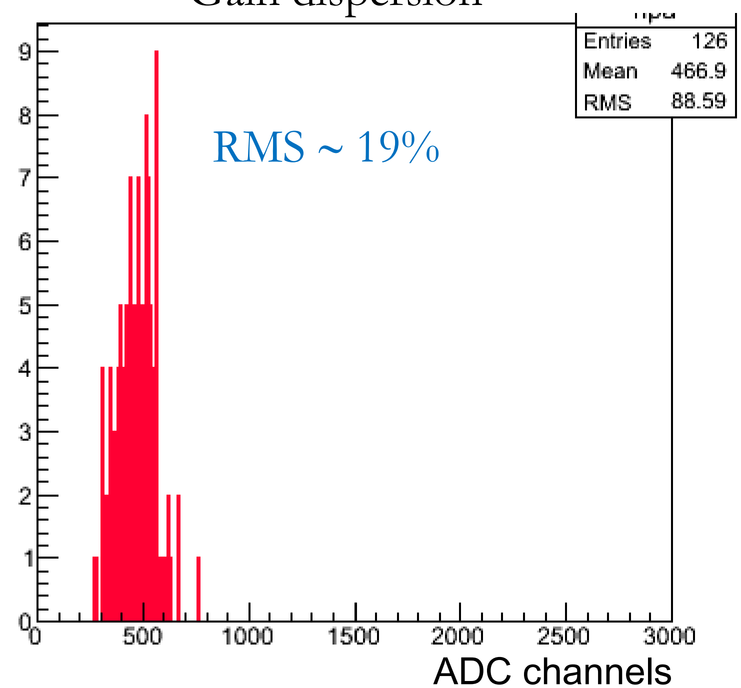


Single-crystal calibration

First crystal along the beam direction

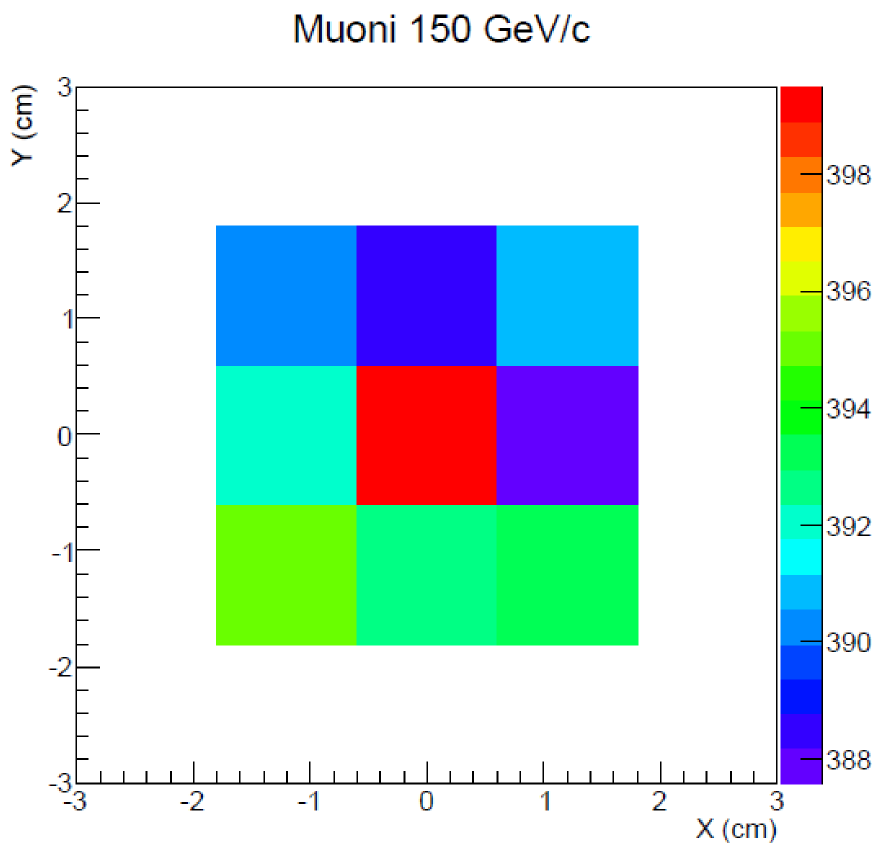


Gain dispersion

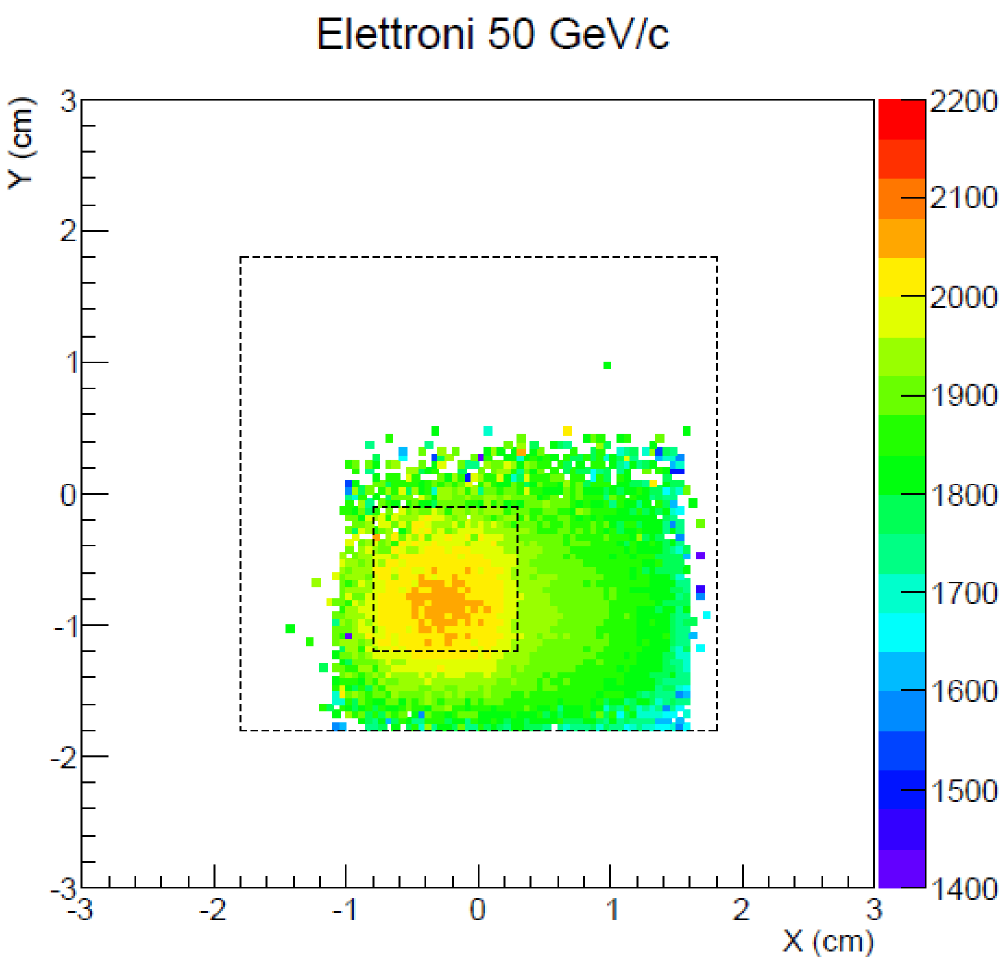


- Signal induced by MIPs used to equalize crystal responses

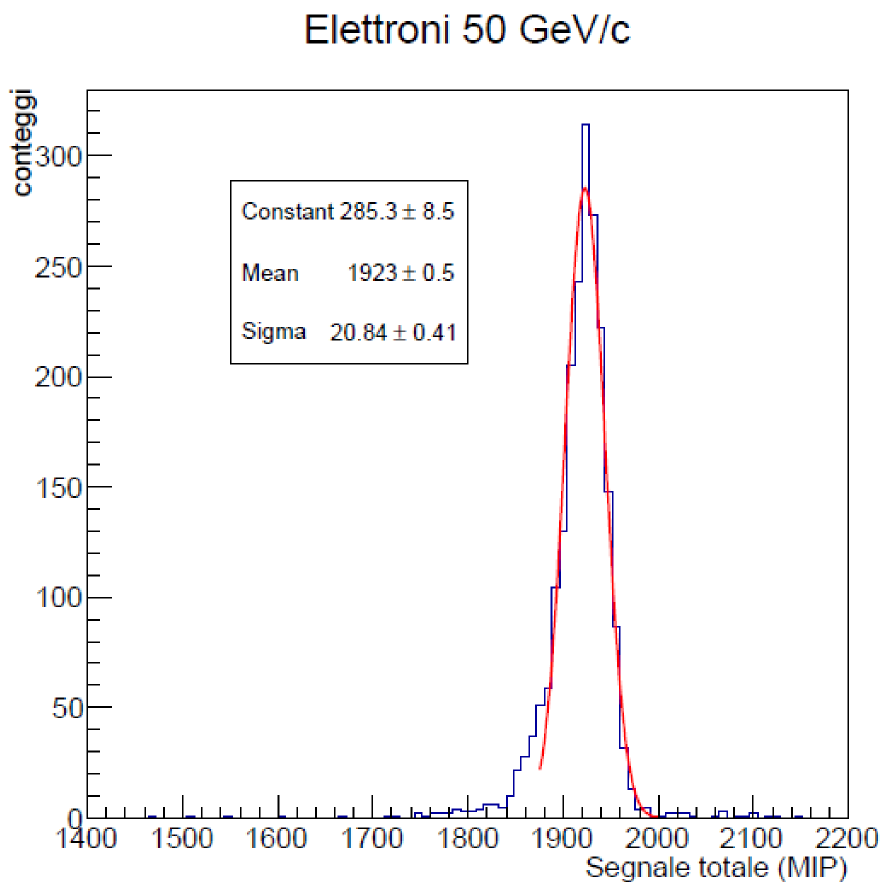
Muon calibration (PD and CASIS corrected)

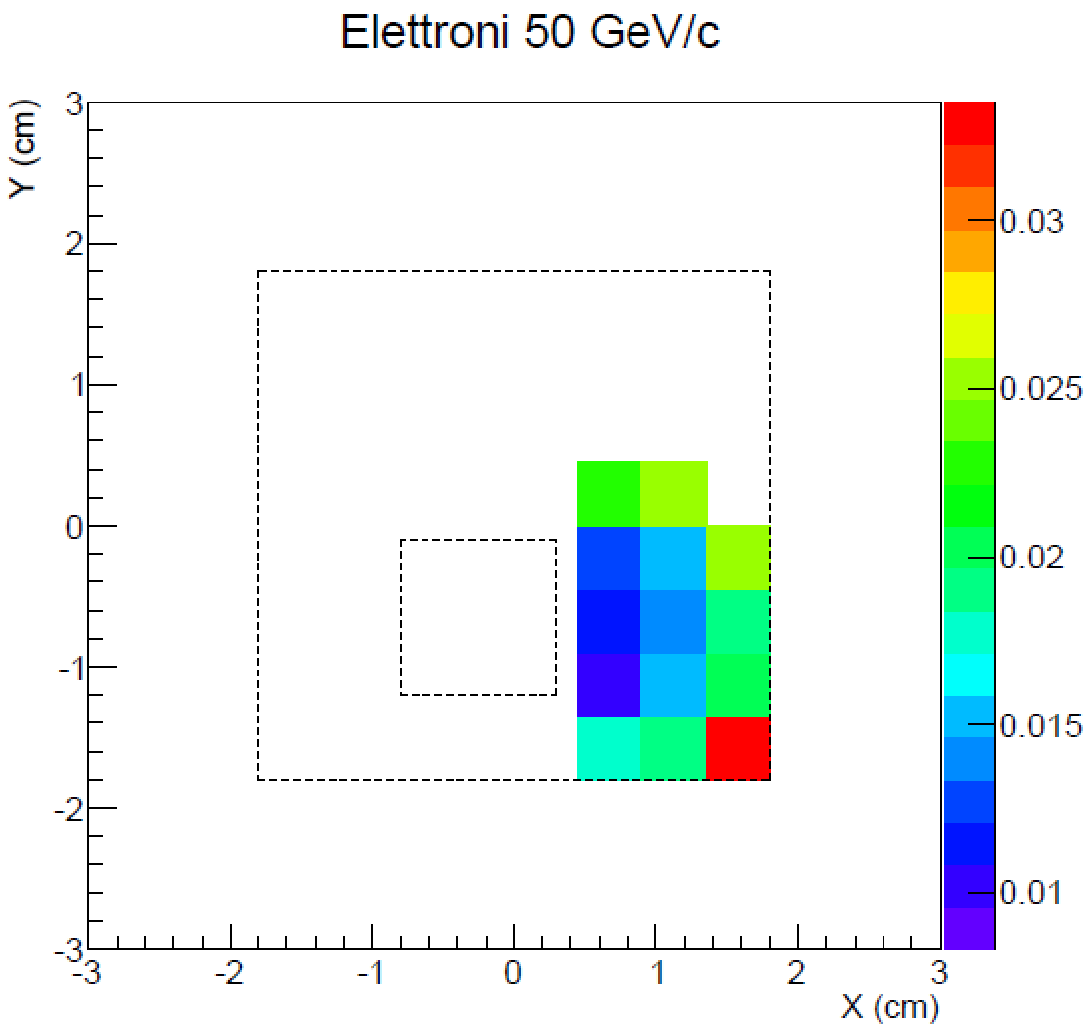


390	388	391
392	399	387
395	393	393


Elettroni 50 GeV/c
Y (cm)
X (cm)
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3
2200
2100
2000
1900
1800
1700
1600
1500
1400

Down to business!

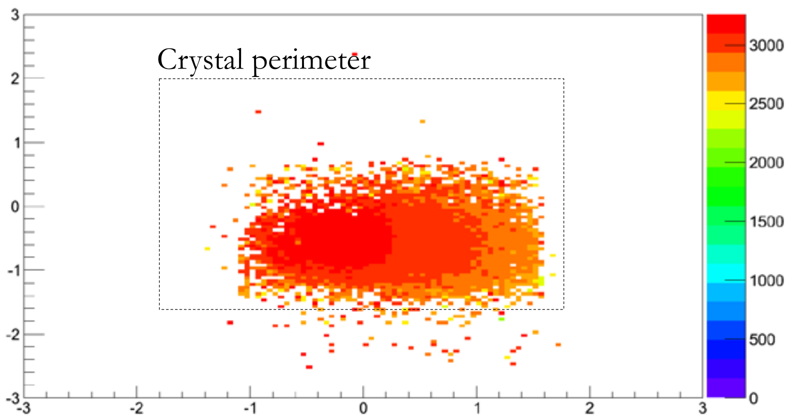


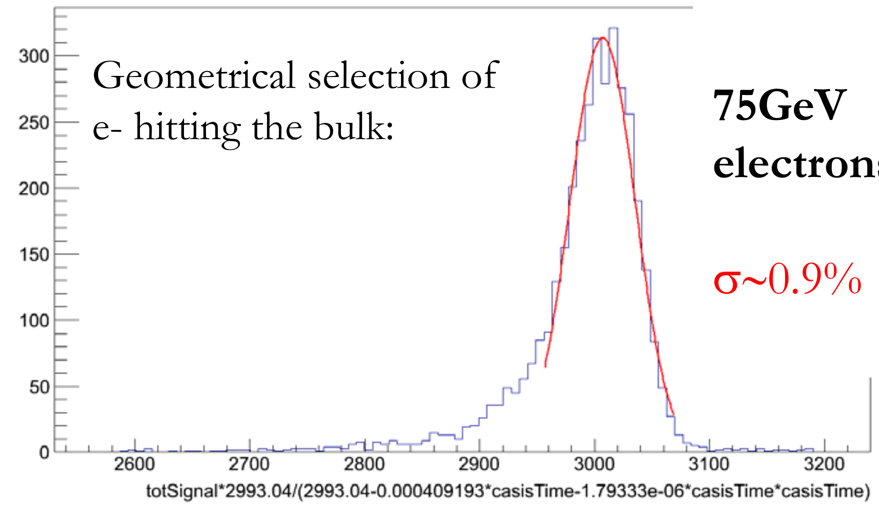


Elettroni 50 GeV/c
Y (cm)
X (cm)
3
2
1
0
-1
-2
-3
0.03
0.025
0.02
0.015
0.01

Electron-beam test

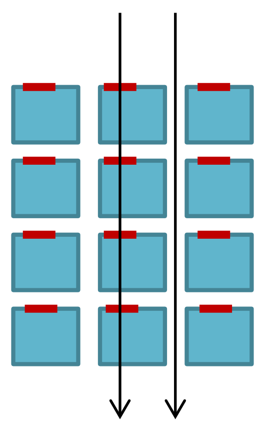
Prototype v1.2 (preliminary)

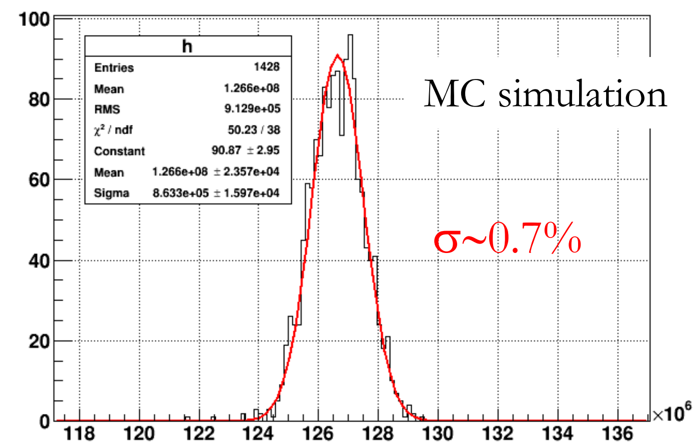




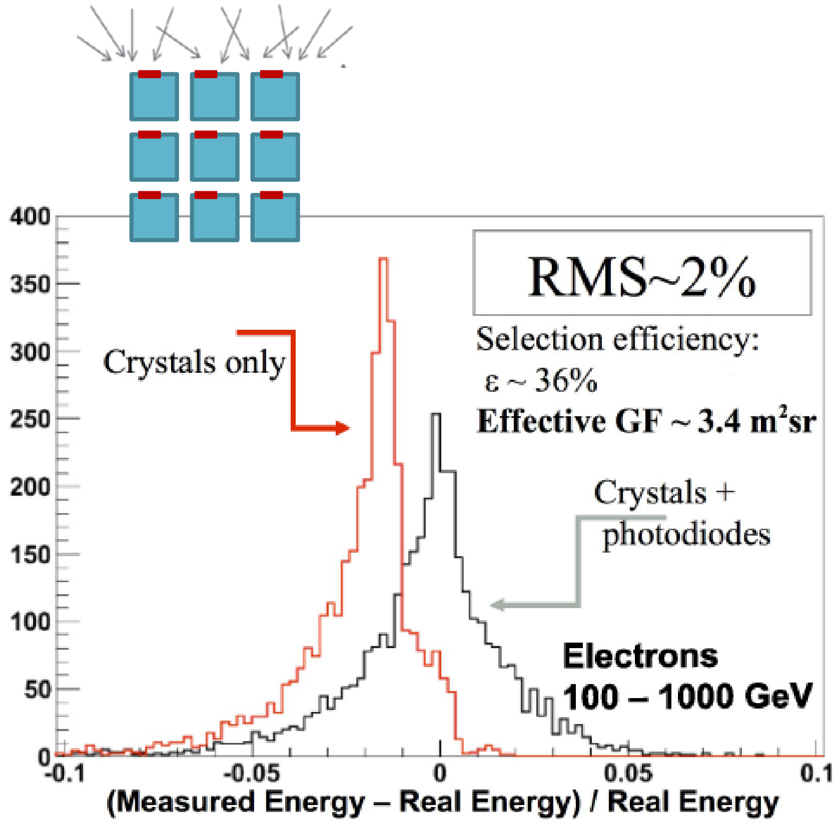
- Large variations (~10%) on the collected energy depending on inpact position: crystal bulk, sensor, borders (known geometrical effect, not a surprise)

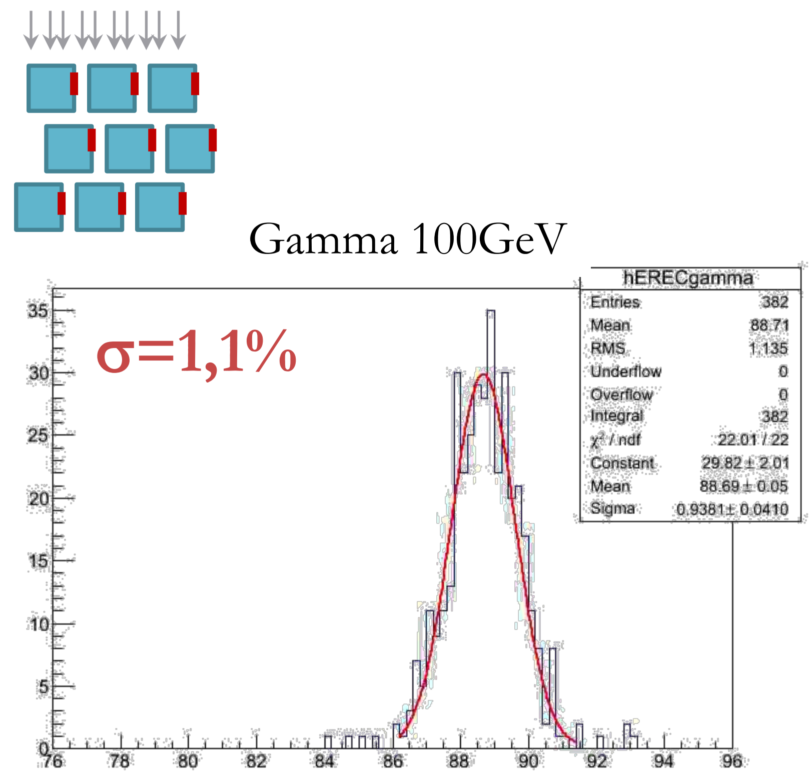
- Good resolution, but still discrepancies with MC, to be undertood





Expected CaloCube performances for e.m.-showers





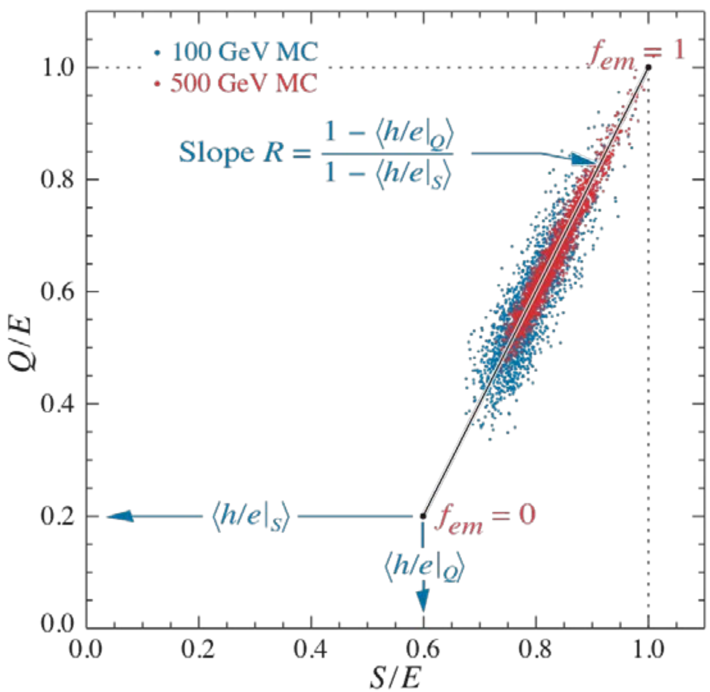
- CaloCube baseline design (CsI 20×20×20)
- Isotropic flux of electrons 100GeV÷1TeV (CR-like)

- CaloCube design optimized for gamma detection

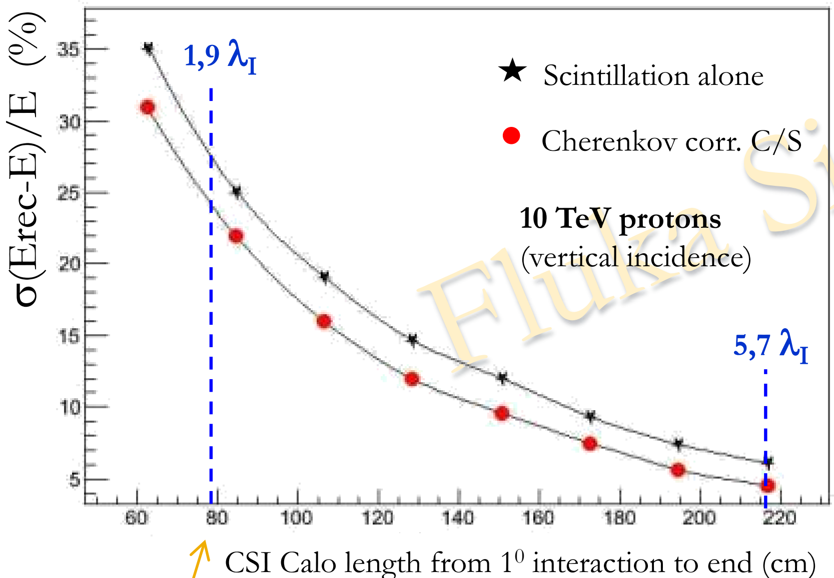
Dual readout (P. Lenzi, O. Starodubtsev BTF Tbeam)

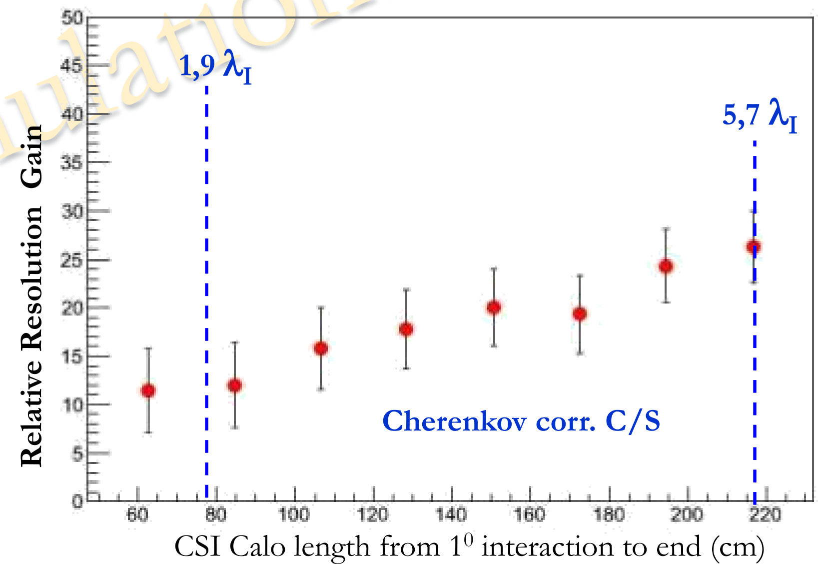
- Simultaneous detection of Cherenkov and scintillation light useful to increase performance
  - Event-by-event correction for fluctuations in shower e.m.-fraction
  - Significant improovements in total absorption calotrimeters
- CaloCube ?
  - Thin calorimeter → resolution dominated by leakage
  - Cherenkov signal extraction from CsI(Tl) crystals

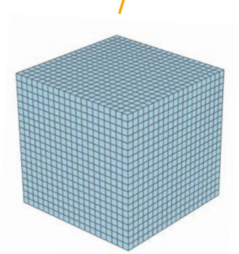
(Groom, JP, 2012)



Dual readout applied to CaloCube geometry





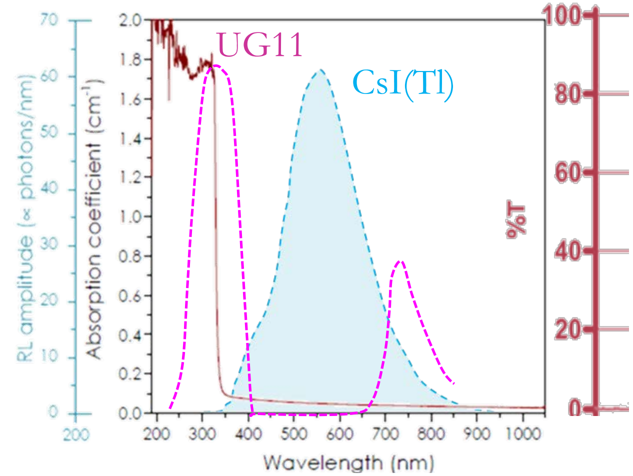


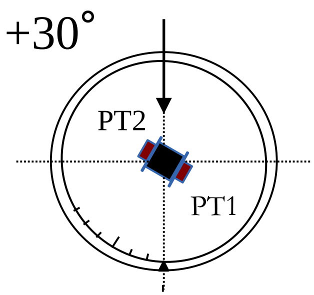
Baseline design
CsI(Tl)
20×20×20

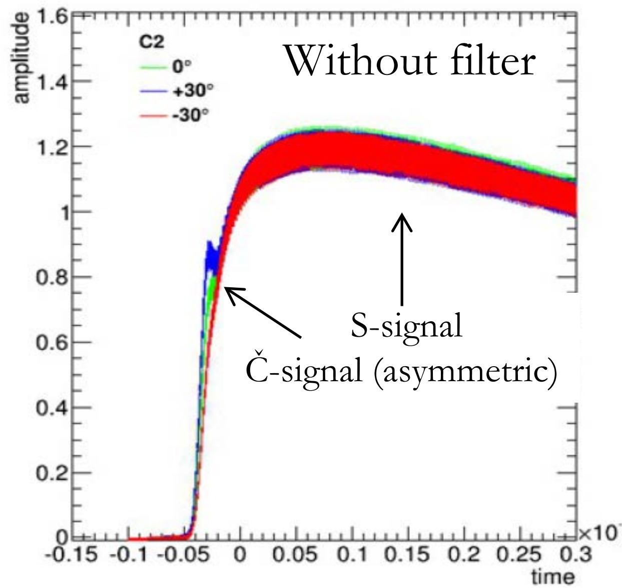
- Dual readout applied to 60×60×60 CsI crystals 0.3mm gap
  - Selection of progressively contained shower
- Moderate resolution improvement, increasing for increasing depth
- From the space point of view
  - Equivalent to saving 3 layers (~ 0.3t weight)
  - Could provide cross-calibration and cross-linearity check ??
  - …as far as it is technologically feasible

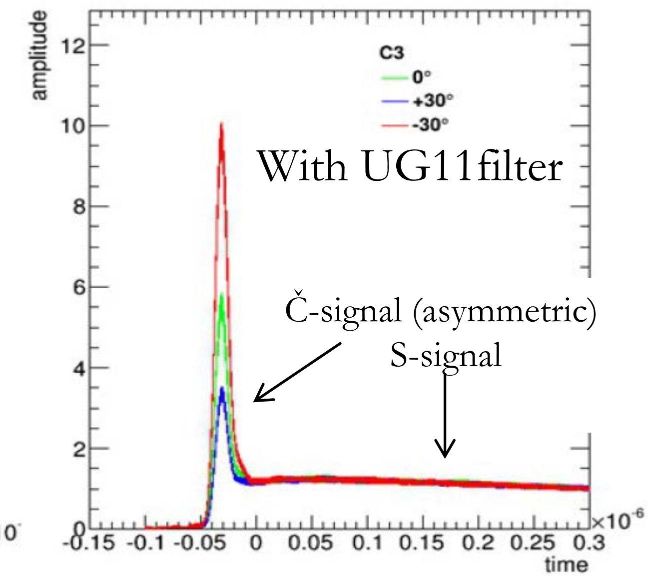
Cherenkov signal in CsI(Tl)

- CsI(Tl) transparent down to 340 nm
- Separation based on <u>timing</u> (promt-vs-delayed) and <u>wavelength</u> (uv-vs-green)
- Test @BTF with 460MeV e^-
  - Absorber wrapping (to keep Č directionality)
  - Two PMTs on opposite side, readout by oscilloscope



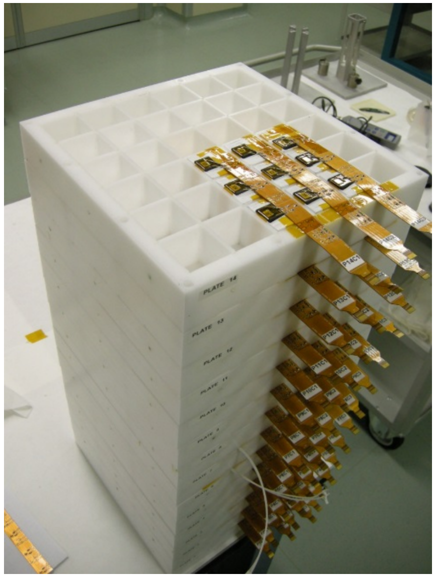


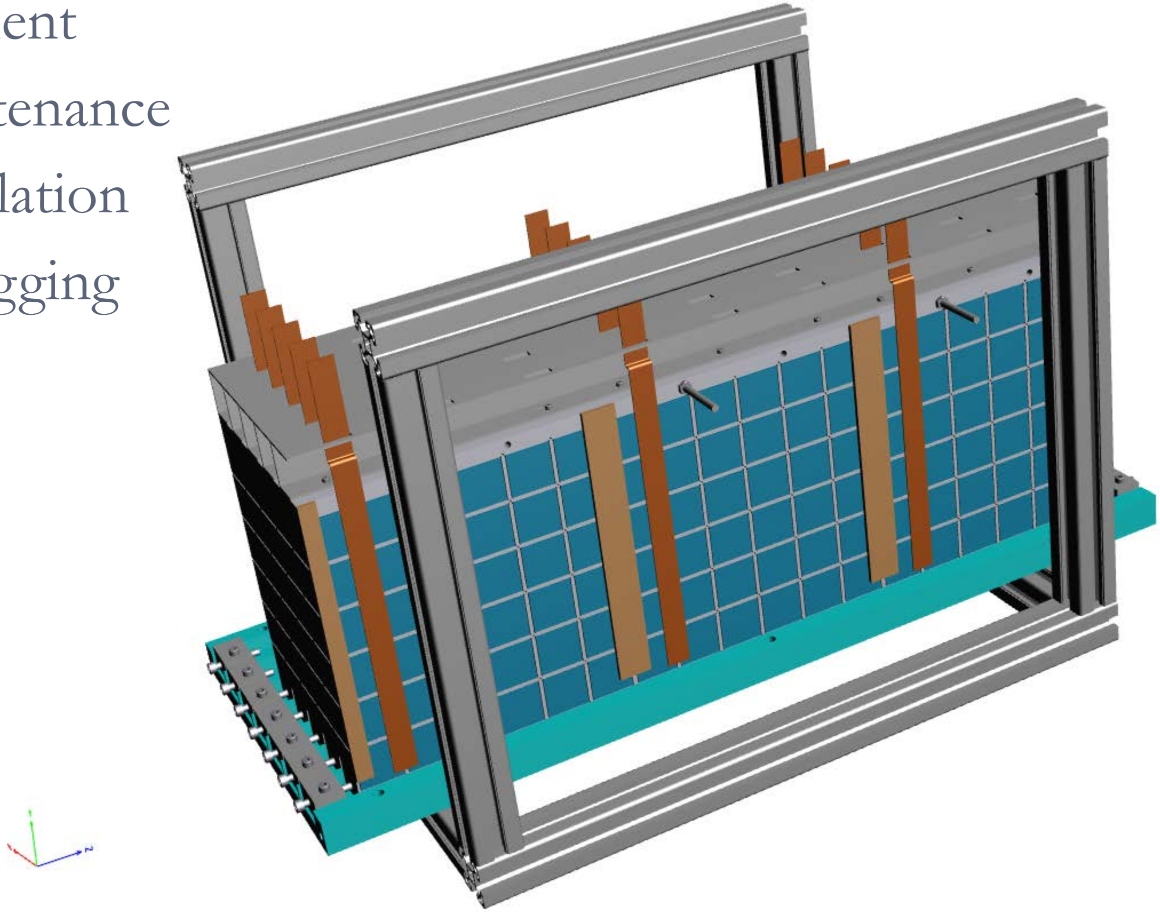




Prototype mechanics 2.0 (A. Basti)

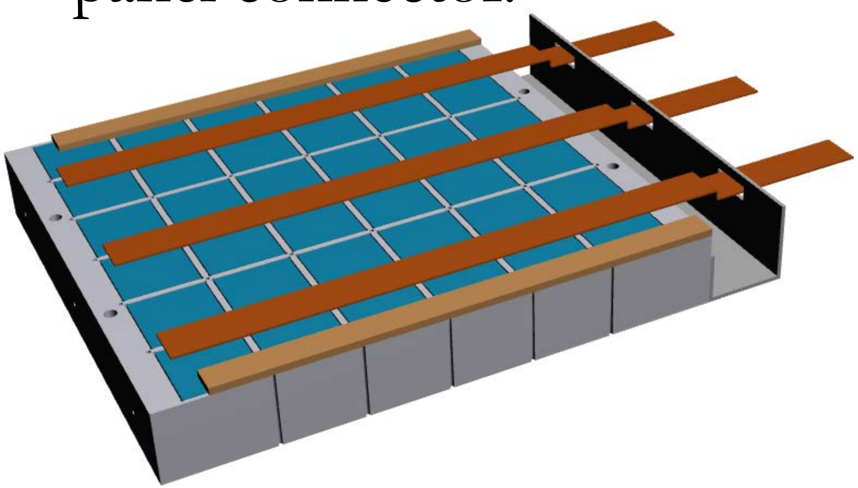
- Addresses some of the issues we had at past Test Beams.
  - Diode placement
  - Ease of maintenance
  - Ease of installation
  - Ease of debugging

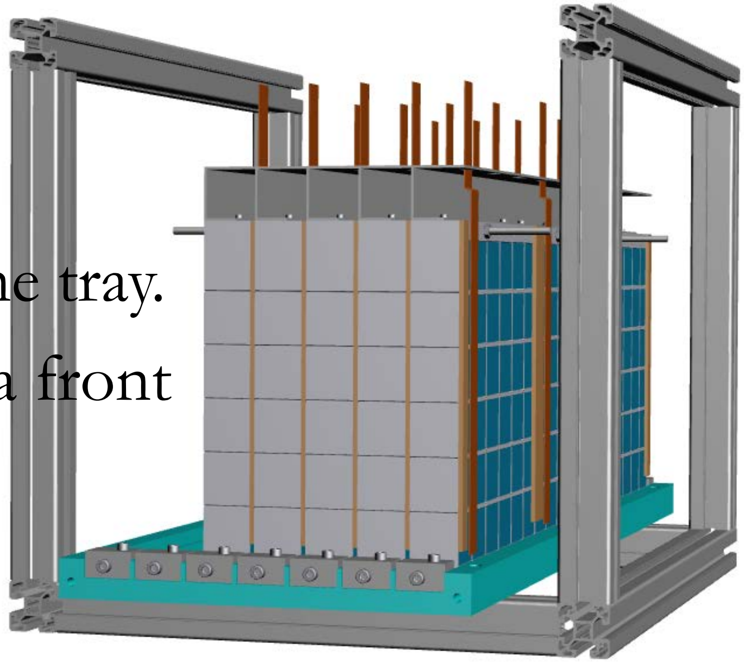




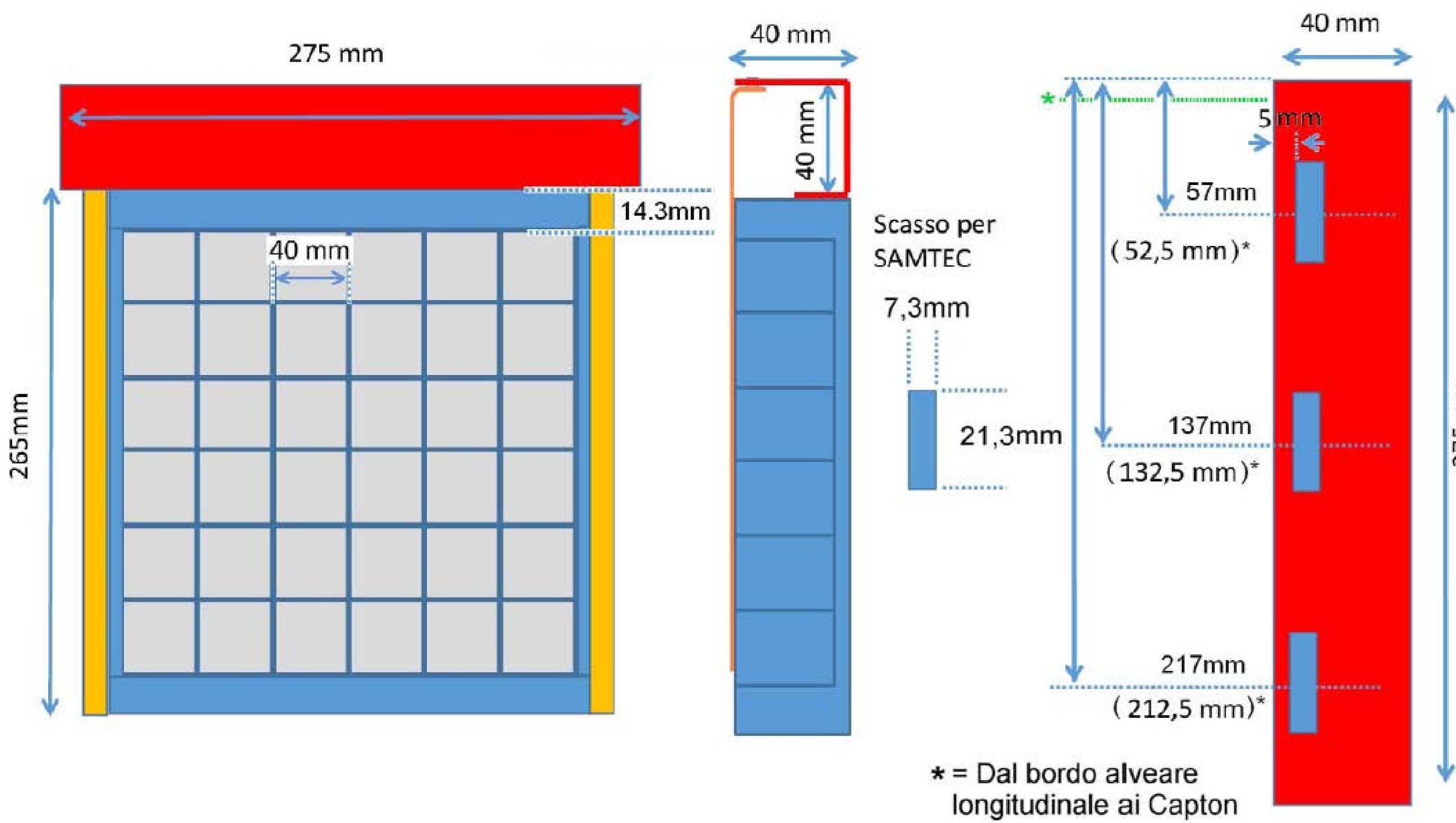
Prototype mechanics 2.0

- 36 crystals per tray
- 18 trays , 648 crystals
- Each tray is mounted sideways !
- Each F.E. board serves ONLY one tray.
- Inside cable is rigidly attached to a front panel connector.



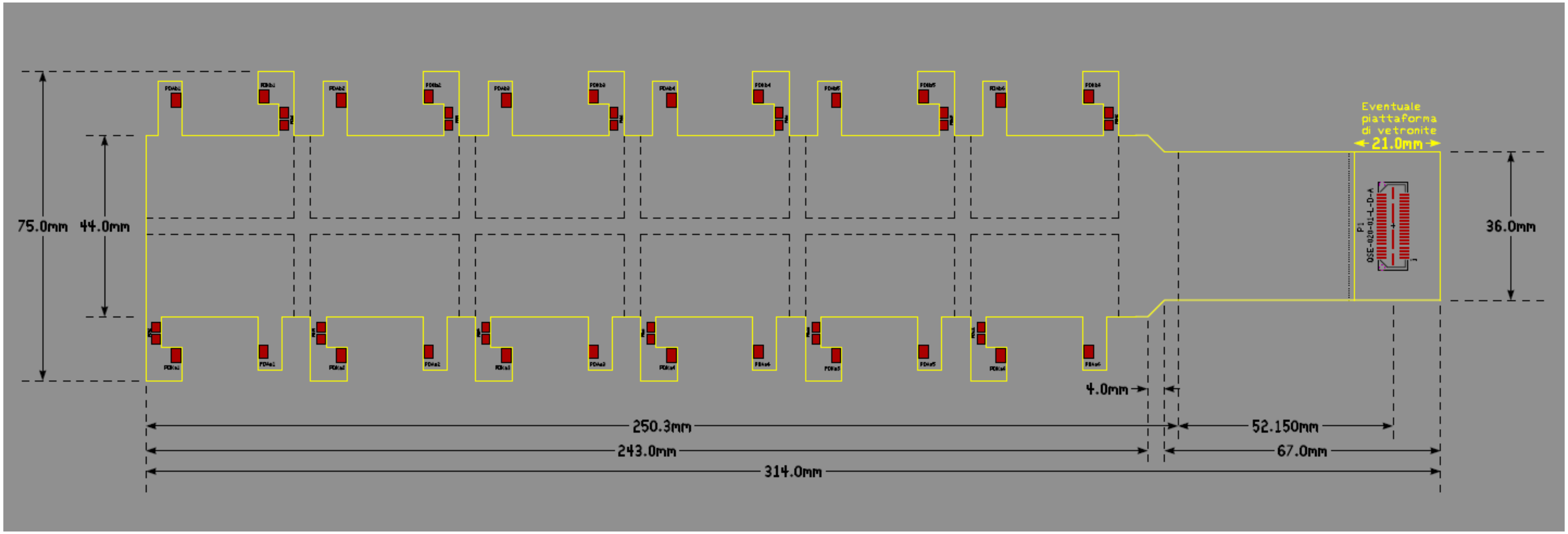


Modified Crystal Tray

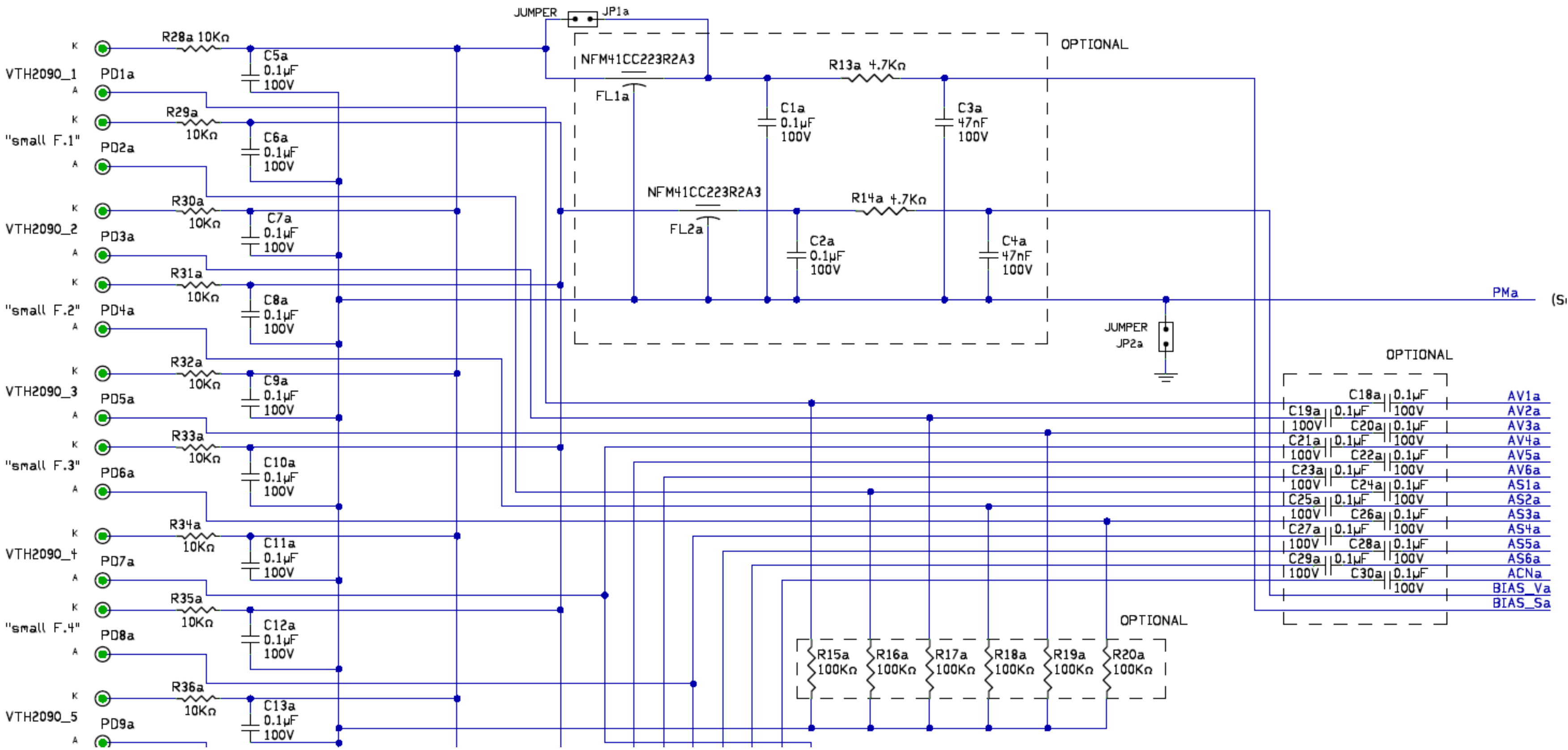


Inner Cable (Scolopendra by S. Detti)

- Connects the photodiodes to the outside world.
  - Each one services two rows of crystals (12 x 2 PDs)
  - Provide decoupling and has biasing network
  - Common return can be refrred to GND or Vcc (FE dependent)
  - Output connector fixed to tray front panel.

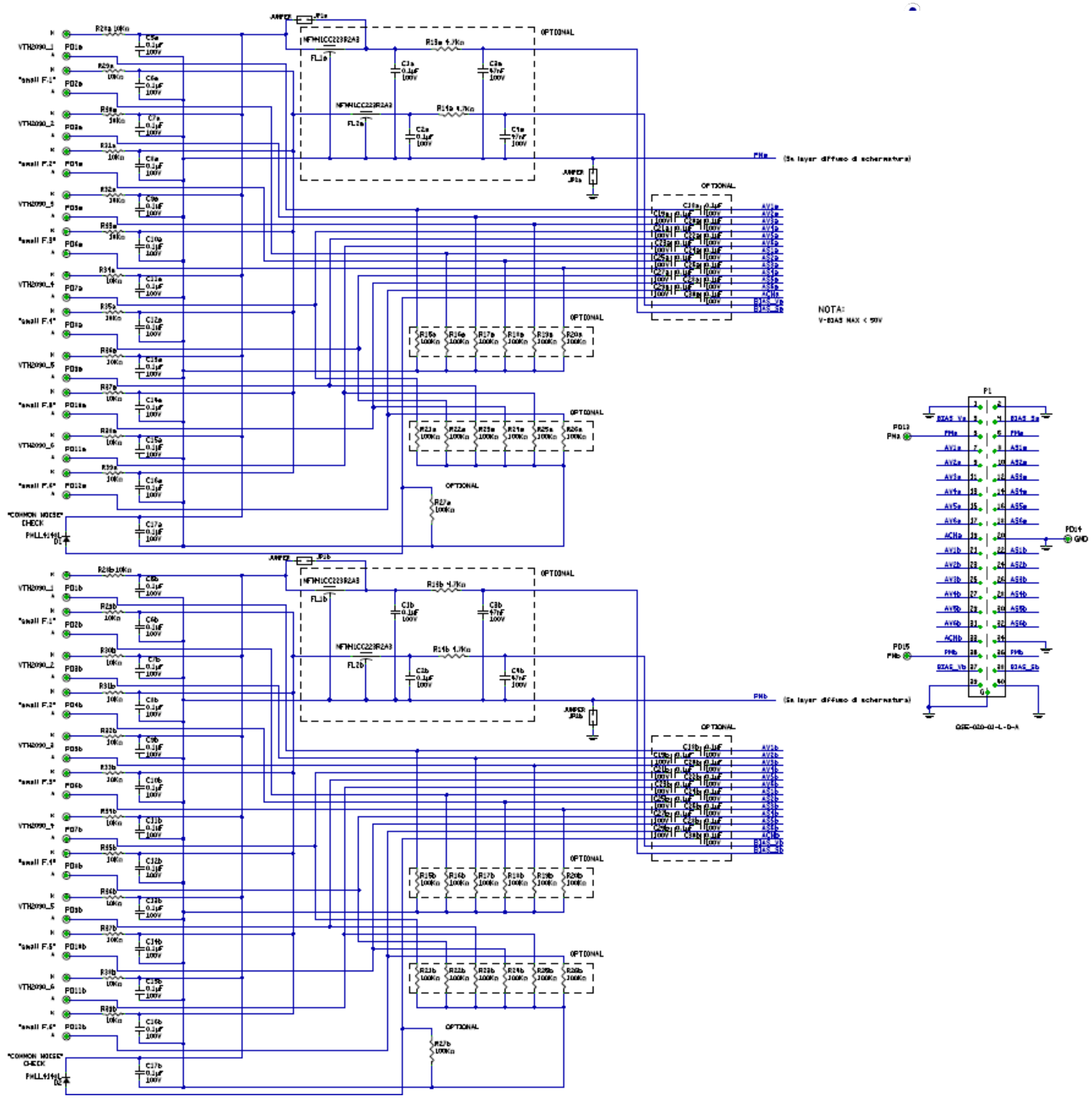


Electrical layout of the Scolopendra



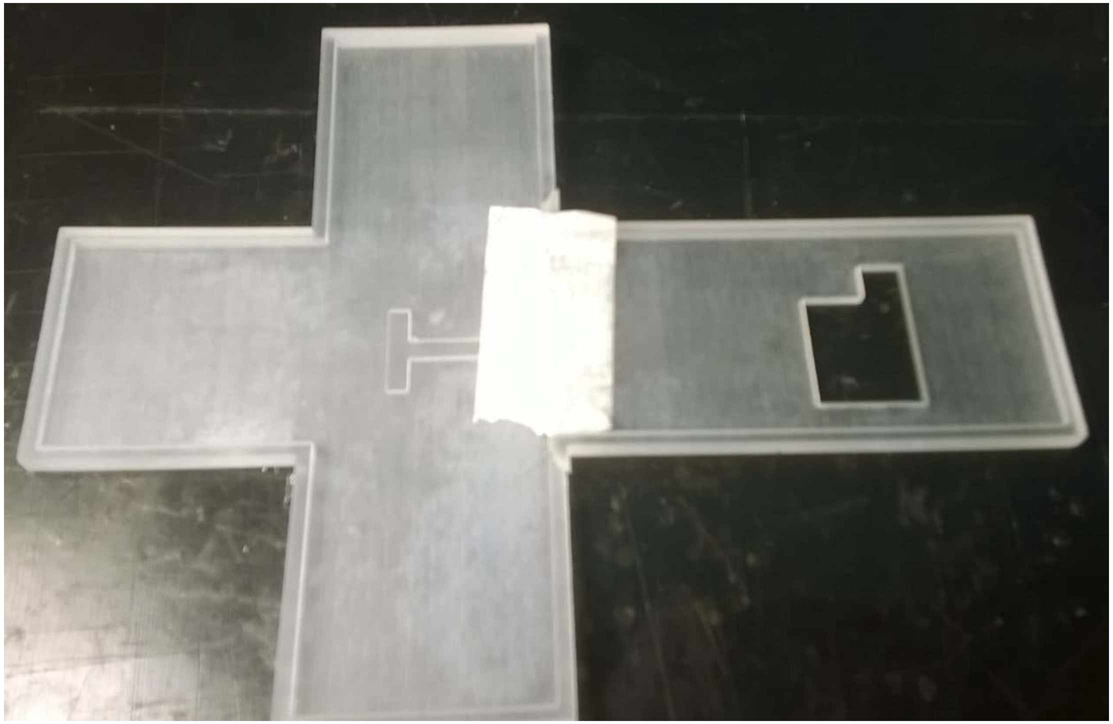
Scolopendra (2)

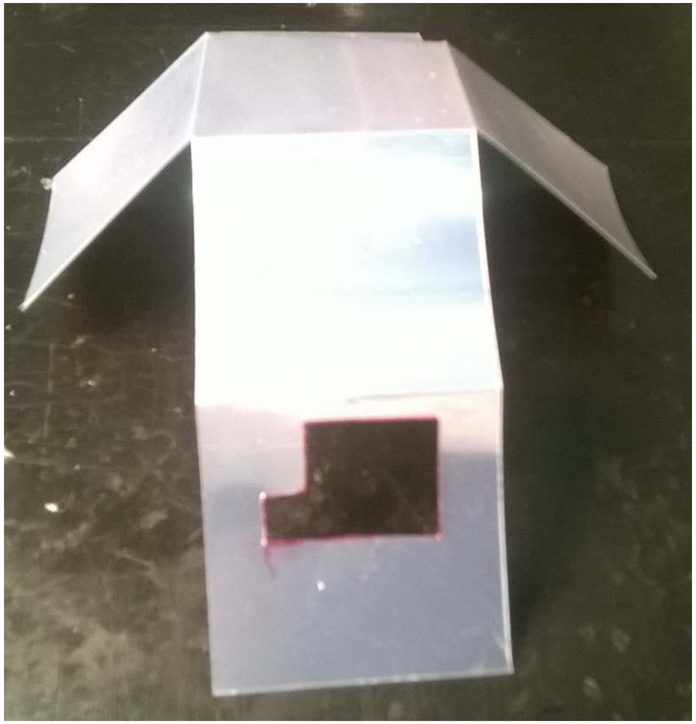
- 2 Sections
- 6 Crystals each
- 2 PDs per Crystal
- SAMTEC Conn.



New wrapping and new PDs layout

- Use Vikuiti (much more efficient)
- Cut out from A4 sheets
- Using a plastic template (3D print)





Photodiodes

- Large area and small area
- Excelitas VTH2090 ~85 mm^2
- Excelitas VTP9412H 1.6 mm^2
- Use a plastic template (3D print) to position them precisely and glue them to the crystal.

Studies on the Carbon Fibre Structure

- One prototype tray was also made in Carbon Fibre

- First trial before assembling a full size tray (28x28 Crystals).
- Vibration tests.

Main resonances Z axis

- From simulations 800 Hz (unloaded)
- We verified this (S. Ricciarini) two months ago.

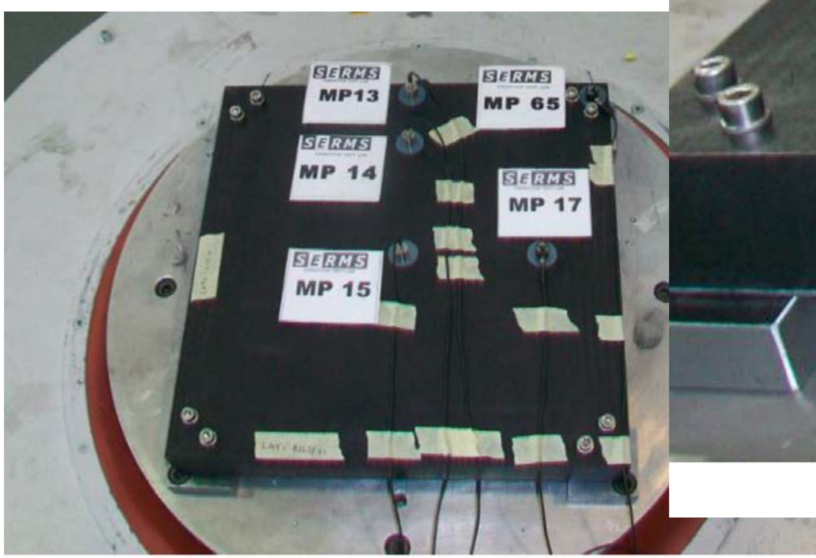


Figure 1: Z DIRECTION - TEST SETUP AND SENSOR LAYOUT

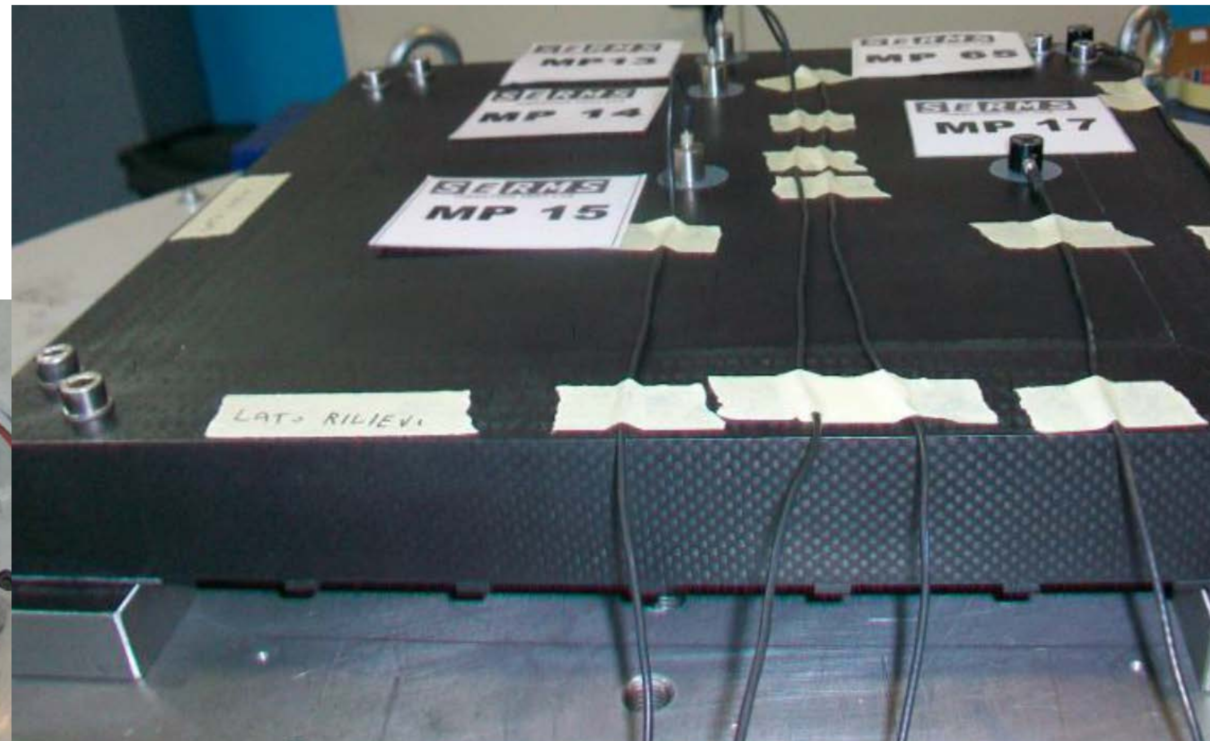


Figure 2: Z DIRECTION - TEST SETUP AND SENSOR LAYOUT

Vibrational Resonances (Stimulus 2g)

- 1 KHz first resonance
- Phase -180º

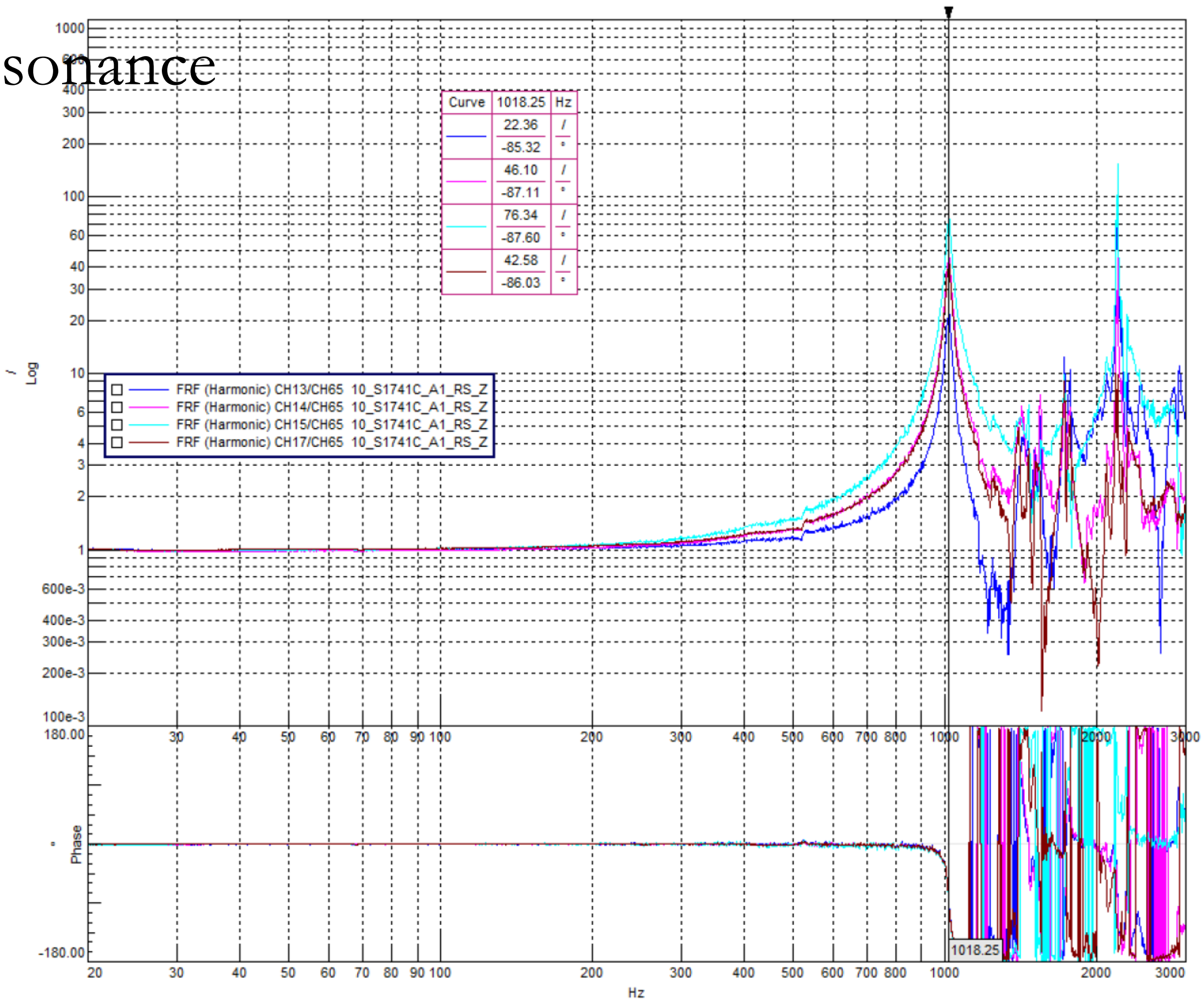


Figure 7: Resonance Search; Z direction

Future

- Calocube 2.0
- Do we still try to optimize for gammas ?
- Mechanics (C.F. ?)
- Different crystal ?
- Different readout ? Dual readout ?
- Different F.E. ?
- Trigger implementation !
- …and consequently DAQ !

The CaloCube collaboration

- R&D project financed by INFN for 3 years (end 2016)
  - Design and optimization of a calorimeter for measurements of high-energy cosmic rays in space

- Participants:
  - INFN: Catania/Messina, Florence,
    Milano (Bicocca), Pisa, Pavia, Trieste/Udine
  - CNR-IMM-MATIS Catania (dichroic filter deposition)
  - IMCB-CNR Napoli (Surface treatments and WLS deposition)
  - Contacts with CNR Firenze