The Low Energy Module (LEM): Development of a CubeSat spectrometer for sub-MeV particles and Gamma Ray Burst detection.

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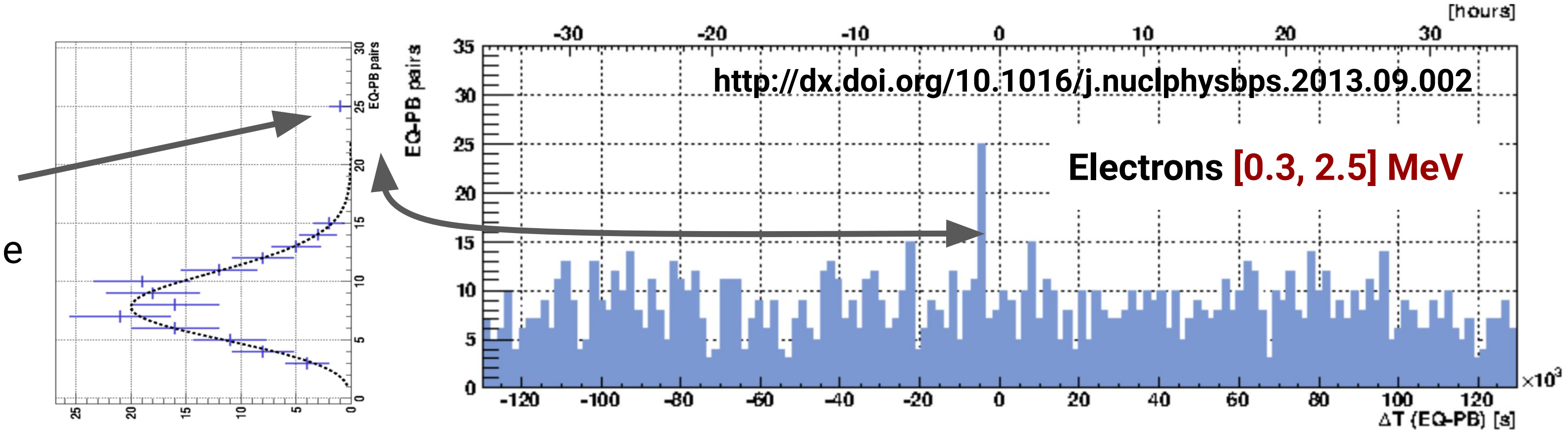
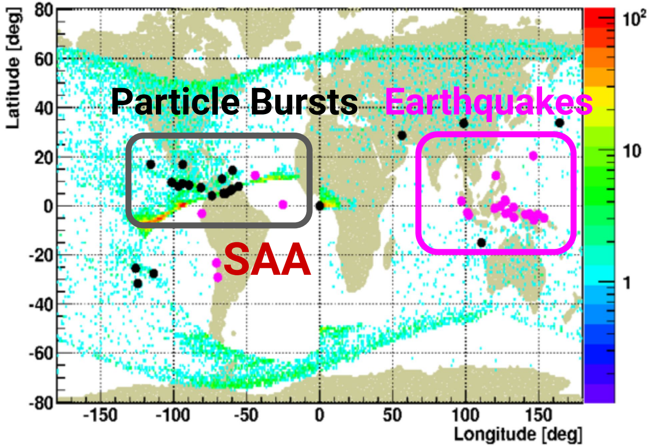
Physics Goals

Statistical correlation between PBs and seismic events

Excess incompatible with bkg.

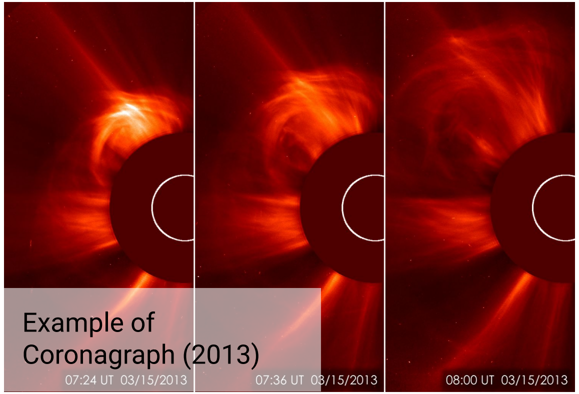




- <u>Time correlation</u> between Particle Bursts (**PBs**) and **earthquakes** (M > 5) in 13 years
- **Correlation found** observing **electrons** with energy in **[0.3, 2.5] MeV** (NOAA MEPED instr.)
- <u>**PBs** mostly generated by indonesian earthquakes but **detected near SAA**</u>

Space Weather investigation and GRB monitoring

CME example: Courtesy of NASA (SOHO)



- Severe **space weather** storms could cause <u>power outages</u> and <u>telecommunication alterations</u>
- the construction of new instruments to monitor and (possibly) to **predict** the effects of **solar activity** on Earth is crucial.
- Thanks to a CdZnTe mini-calorimeter, the LEM spectrometer also allows **photon detection** in the **sub-MeV range**, joining the quest for the investigation of the nature of **Gamma Ray Bursts**

Intense solar activities could cause increases of particle fluxes

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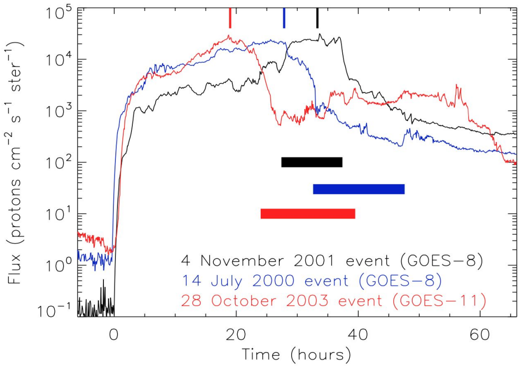

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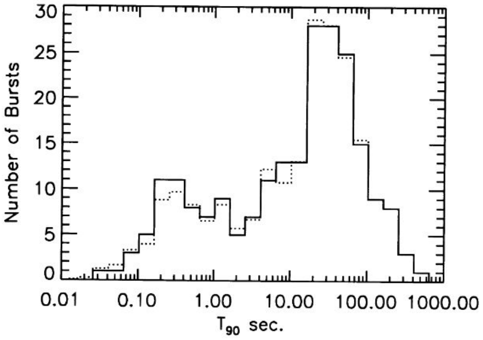
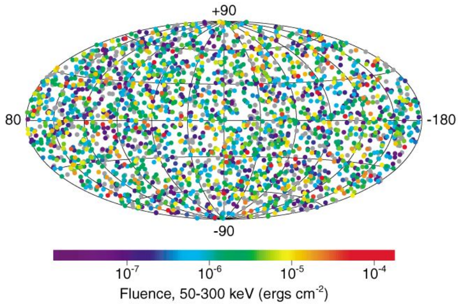


https://heasarc.gsfc.nasa.gov/docs/cgro/batse/

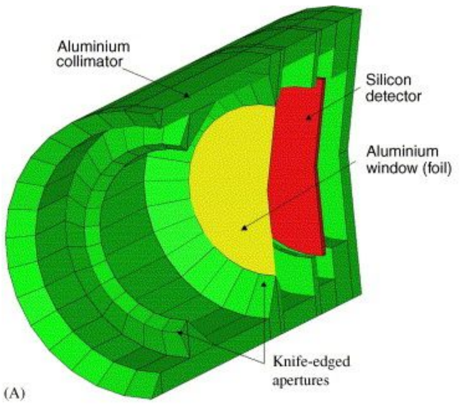
2704 BATSE Gamma-Ray Bursts



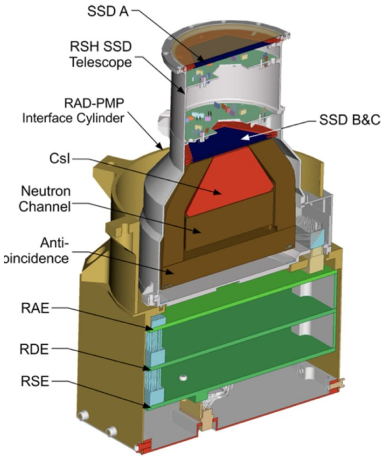
The Low Energy Module:

Geometry and Geant4 simulation

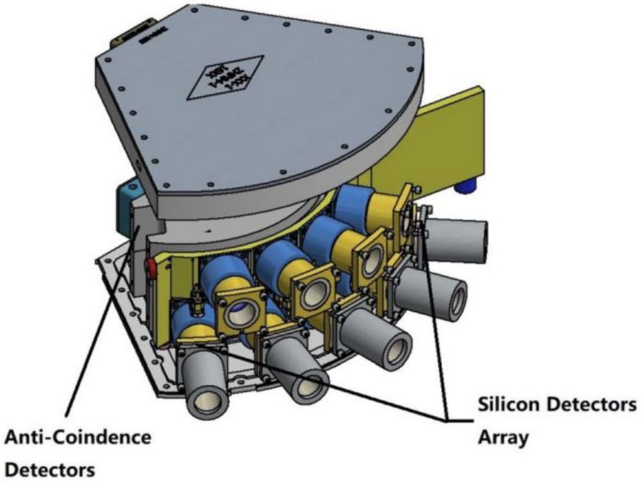
Past detectors design? Not suitable



doi:10.1016/j.pss.2005.10.019



DOI 10.1007/s11214-012-9913-1



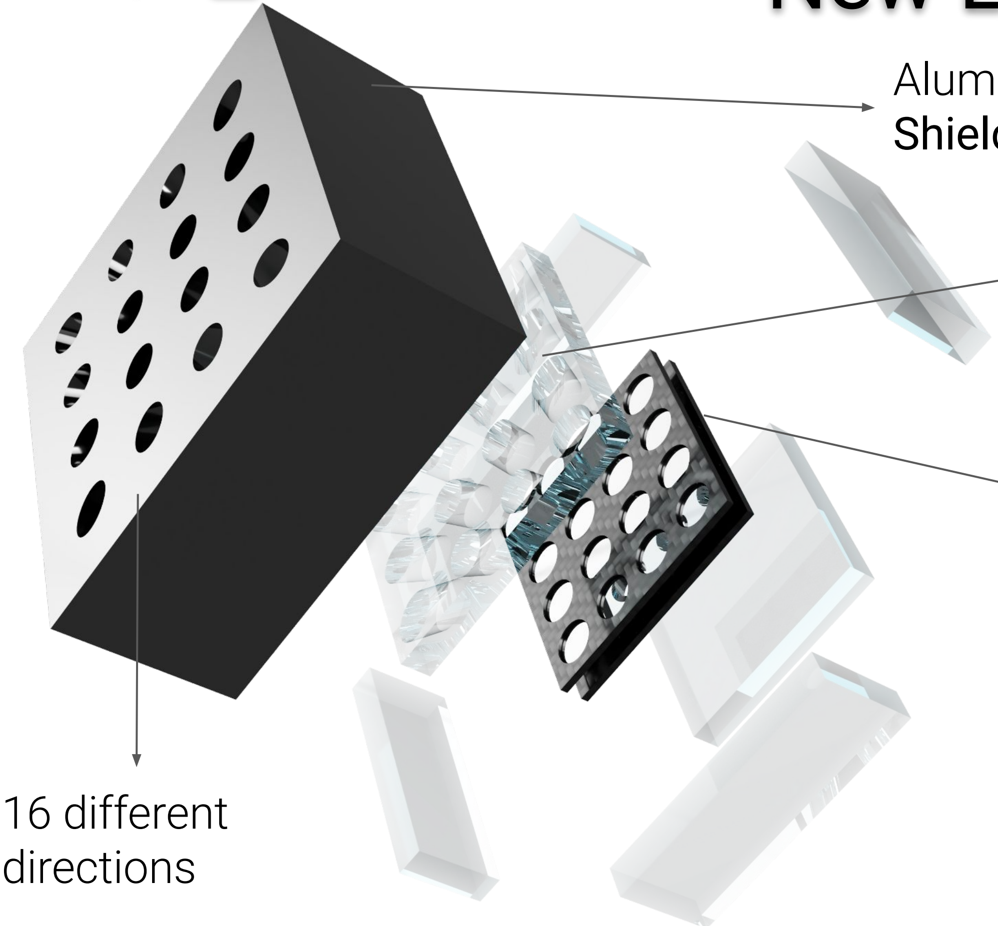
doi:10.1007/s41605-019-0101-7

DEMETER - IDP
- Light (~ 500 g)
- 1 direction monitored
- FOV 26°
- Electrons [0.07, 0.8] MeV
- **No PID**

RAD - Curiosity (Mars)
- Standard tracking (multiple scattering)
- **poor ang.res. @ Low E**
- CsI scintillators hygroscopic, fragile.

HEPP-L (CSES)
- bulky collimators
- Electrons **[0.1, 3] MeV**
- Protons [2, 20] MeV
- Only 9 directions monitored at same time

New LEM geometry concept



Aluminium mask (Thickness 0.8 cm)
Shielding of Trapped Electrons **BKG**

Active collimator (plastic scintillator, about 1 cm thick)

16 independent modules for PID
- Passivated Implanted Planar <u>Silicon</u> detectors **: 100 um**
- **<u>CZT detector : 1 mm</u>**

16 different directions

- Lateral plastic scintillator **veto**
- 1 bottom plastic scintillator **veto**

<u>Within 1U CubeSat frame</u> (10x10x10 cm^3)!

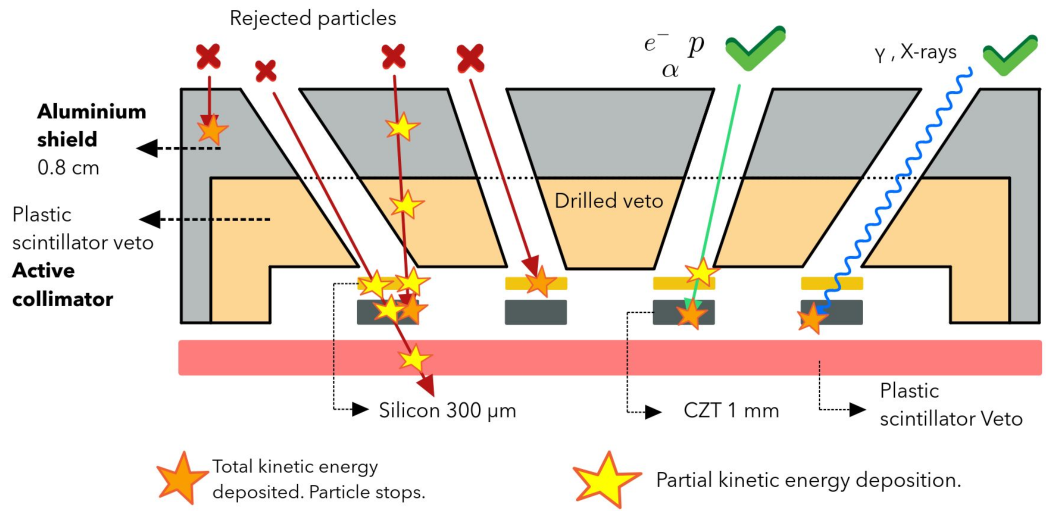
The detection concept

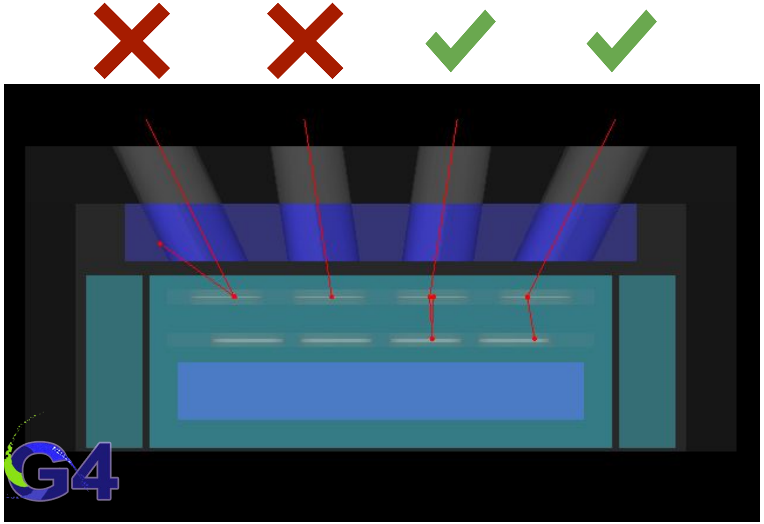
- Shielded by Aluminium
- or undefined direction
- Veto activated
- **Rejected**

- Energy is too low
- No PID
- Direction OK
- **not acquired (only rate meter)**

- Energy is too large (very difficult PID)
- Veto activated
- **Rejected (or prescaled)**

- Particle **confined** within the thin layer and the veto
- **Good events**





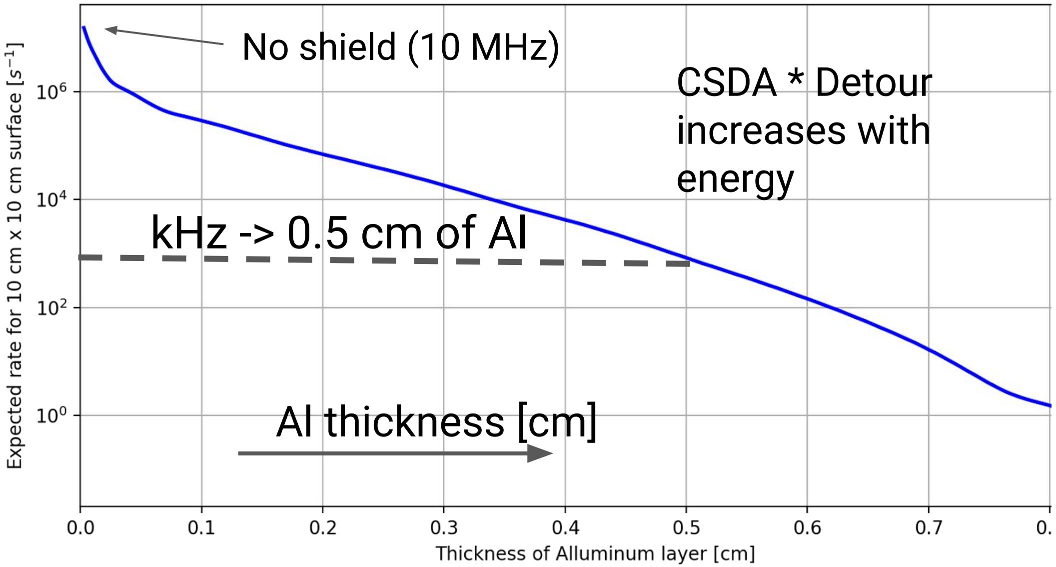
Aluminium shielding of trapped electrons

Energy [MeV]	Differential flux [MeV^{-1} cm^{-2} s^{-1}]	Integral flux [cm^{-2} s^{-1}]
0,04	1,96E+06	2,44E+05
0,1	1,25E+06	1,51E+05
0,25	3,20E+05	4,48E+04
0,5	4,35E+04	1,15E+04
0,75	1,32E+04	5,56E+03
1	6,21E+03	3,38E+03
1,5	2,44E+03	1,46E+03
2	1,03E+03	6,29E+02
2,5	4,99E+02	2,82E+02
3	2,09E+02	1,09E+02
3,5	8,56E+01	4,19E+01
4	3,23E+01	1,41E+01
4,5	1,05E+01	4,17E+00
5	3,06E+00	1,14E+00
5,5	6,87E-01	2,41E-01
6	1,09E-01	3,17E-02
6,5	1,57E-02	0,00E+00

Table 3.1-1 Trapped electron spectrum
Courtesy of TAS-I

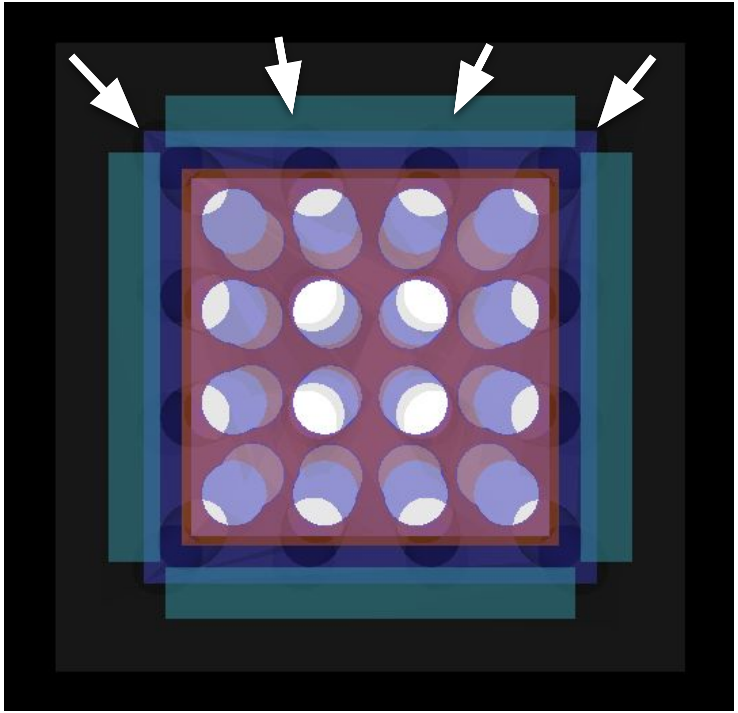
- **~0.5 cm** of **Aluminium** stop e- with energy below **3.5 MeV**
- Surviving flux **~20 cm^{-2} s^{-1}**
- Expected **Veto rate ~10 kHz**
- Expected **Event rate ~1-10 kHz** (trapped electrons)

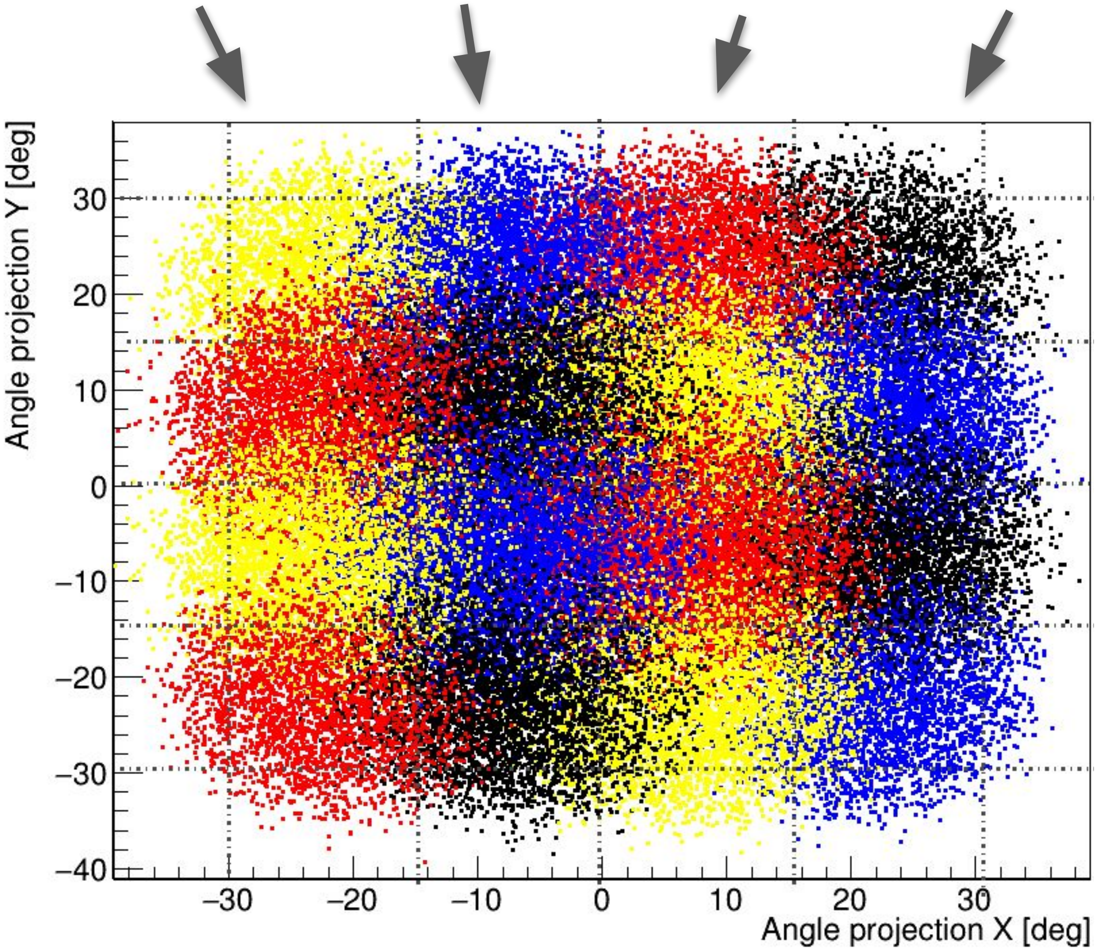
Al -> Shielding trapped electrons



Angular Resolution

- Large FOV (60° x 60°)
- Resolution of about **~7 degs (rms)**





Study of the Energy Deposition

Some definitions:

ΔE Energy in 100 um Si (Thin)

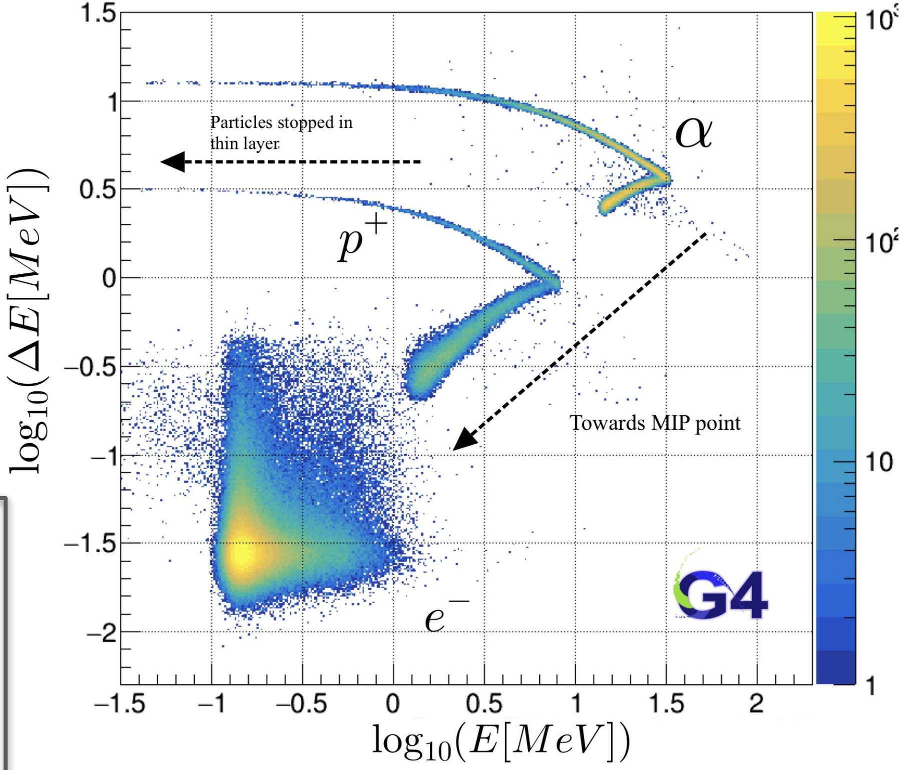
E Energy in 500 um Si (or eventually 1mm CZT)

$$\Delta E \propto \frac{z^2}{\beta^2} \qquad E_{tot} \simeq \frac{1}{2} m \beta^2$$

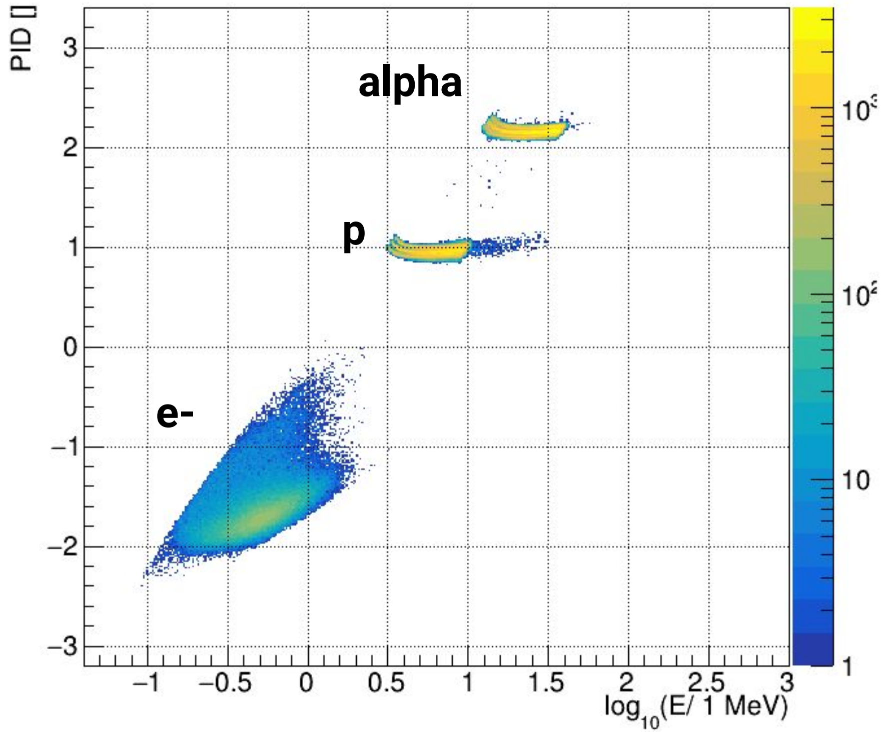
$$E_{tot} = E + \Delta E$$

$$PID_{\text{proxy}} = \log_{10}\left(\frac{\Delta E}{1\ \text{MeV}} \frac{E_{tot}}{1\ \text{MeV}}\right)$$

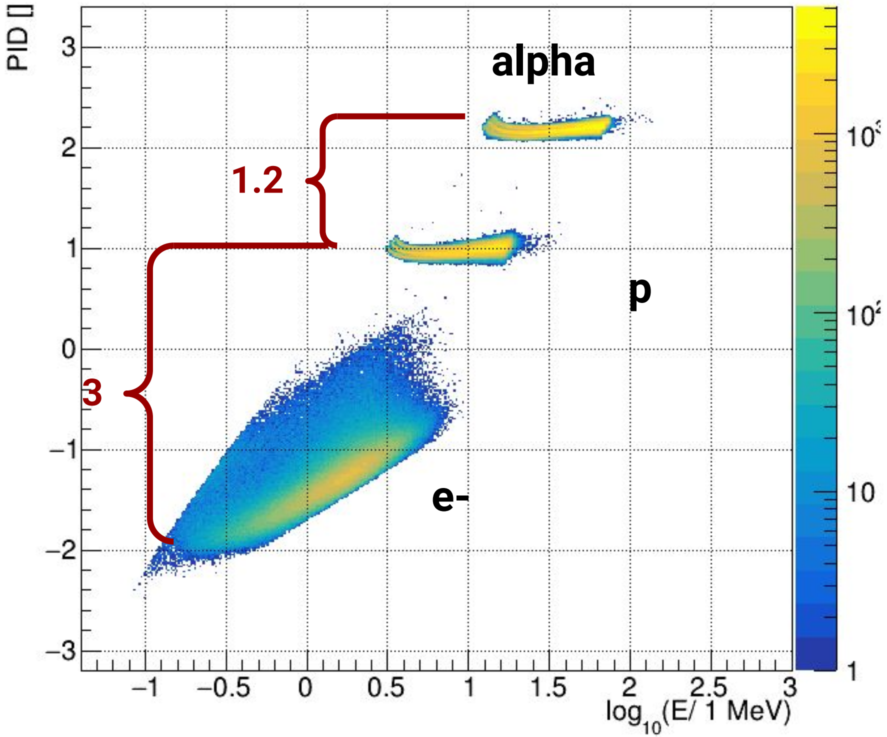
$$\simeq \log_{10} \frac{z^2}{\beta^2} \frac{\beta^2 m}{2} = \boxed{\log_{10} z^2 m} + \text{const.}$$



ΔE : Si 100 µm | E : Si 500 µm



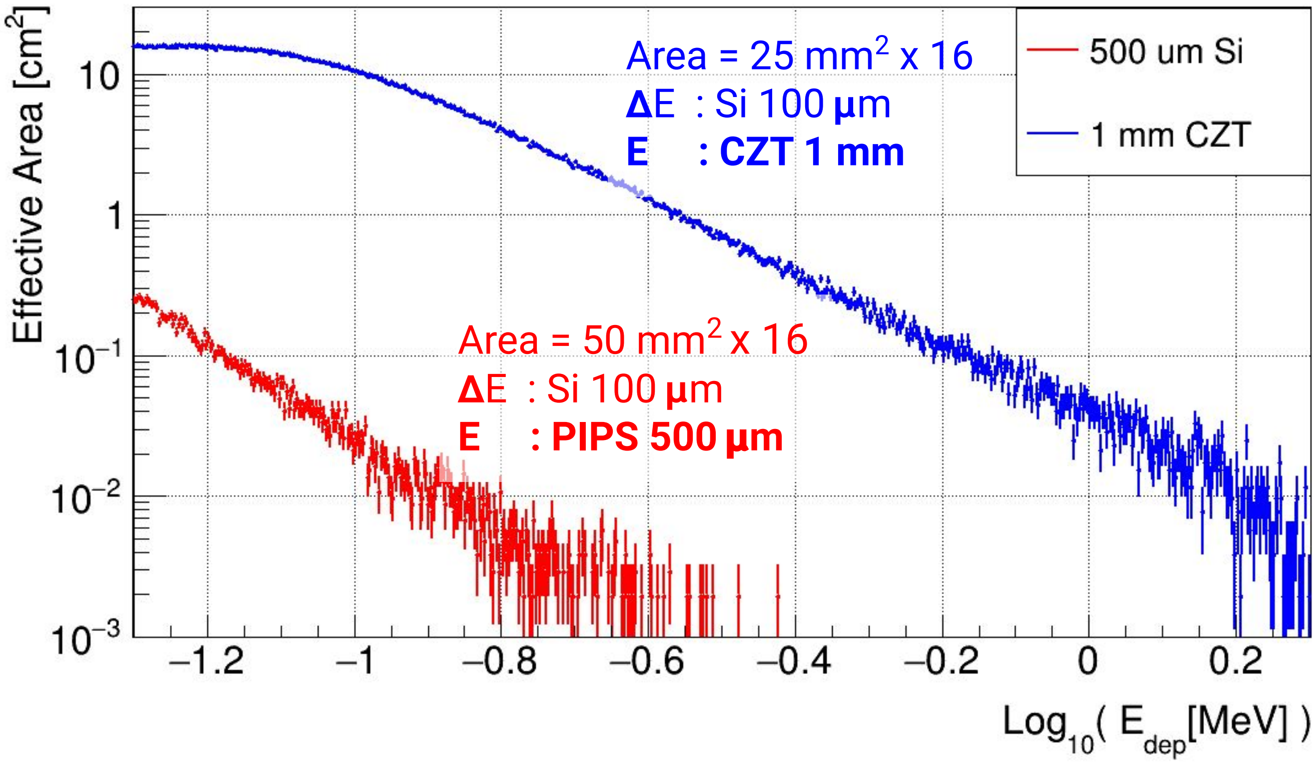
ΔE : Si 100 µm | E : CZT 1 mm



$$\mathrm{PID}_{\mathrm{proxy}} \simeq \log_{10} m z^2 + \mathrm{const.}$$

- Δ PID (e-, p+) ~ $\mathrm{Log}_{10}(938/0.511)$~**3**
- Δ PID (p+, alpha) ~ $\mathrm{Log}_{10}(2^2 * 4)$ ~ **1.2**

Effective area for gamma: Silicon vs. CdZnTe (CZT)



CZT properties:

Density 5.7 g cm^{-3}
Z(**Cd**) = **48**
Z(**Te**) = **52**

High voltage required

$$\sigma_{\mathrm{Ph.\ E.}} \sim Z^{4-5}$$

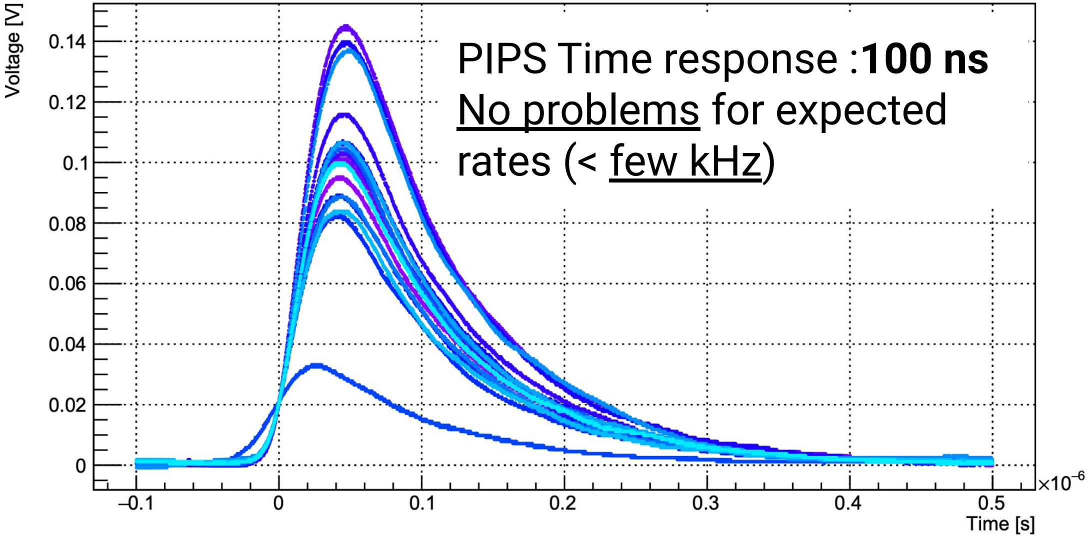
Detection Yield for Silicon is **low**

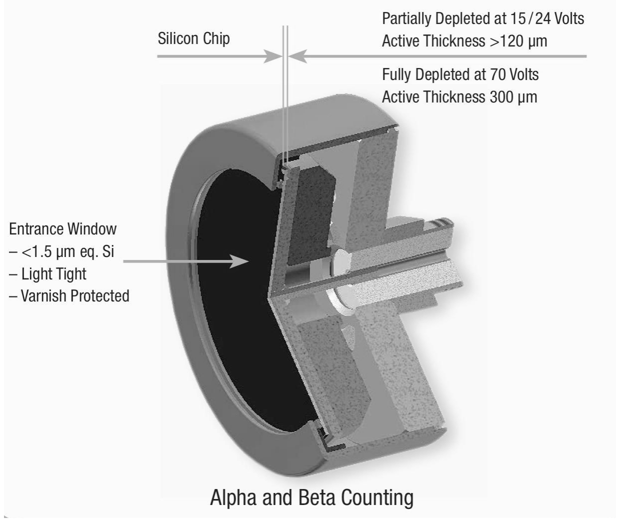
Improved Detection Yield for photons with CZT!!

Silicon detector characterisation at TIFPA (Trento INFN)

Passivated Implanted Planar Silicon

- Particle generates **electron-hole** pairs
- Electron - hole pairs separated by **electric field**
- **Charge** collected **proportional** to **energy**



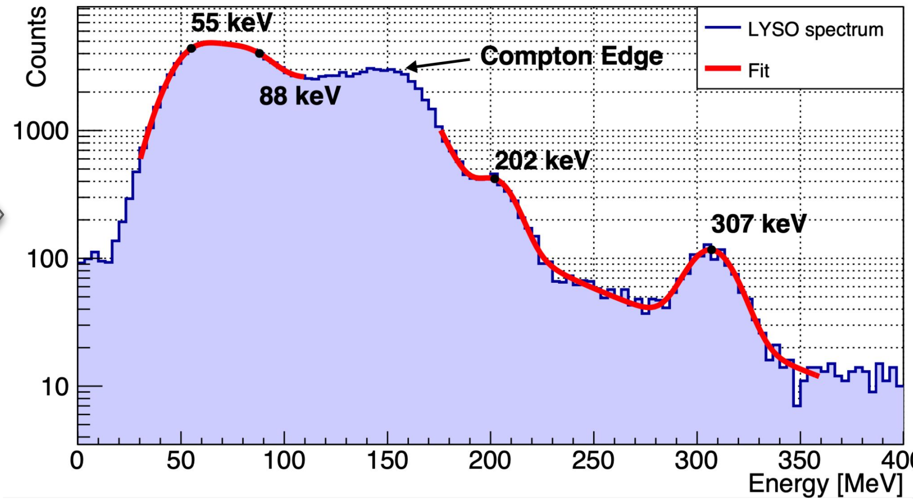


Calibration with γ

$$K_{cal} = 36.7(3)\ \mathrm{mV/MeV}$$
$$\sigma = 11.1(4)\ \mathrm{keV}$$

^{176}Lu

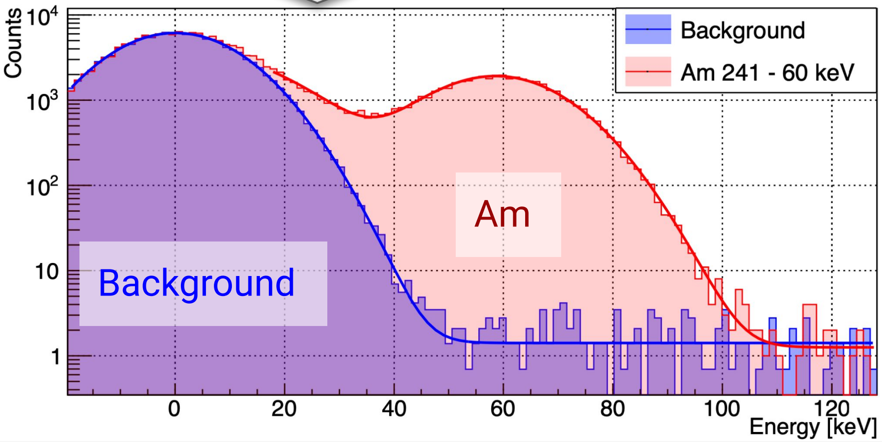
In PIPS

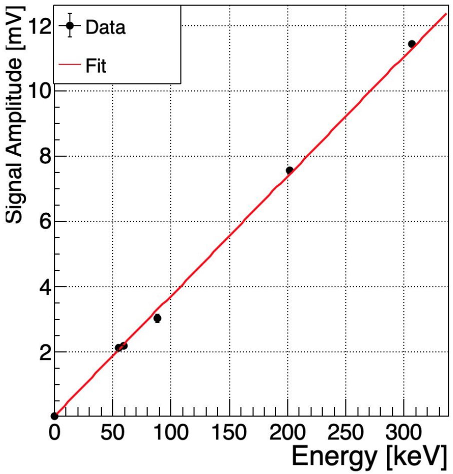


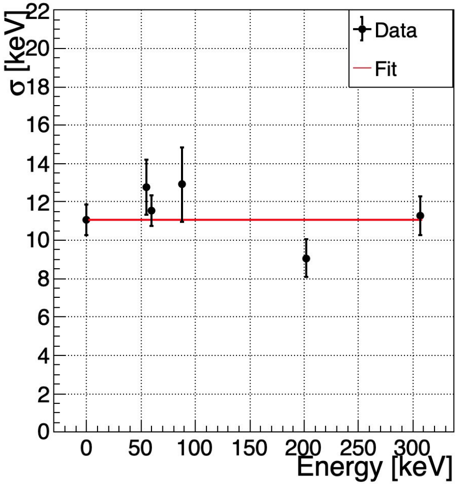
^{241}Am

In PIPS

Calibration
Resolution





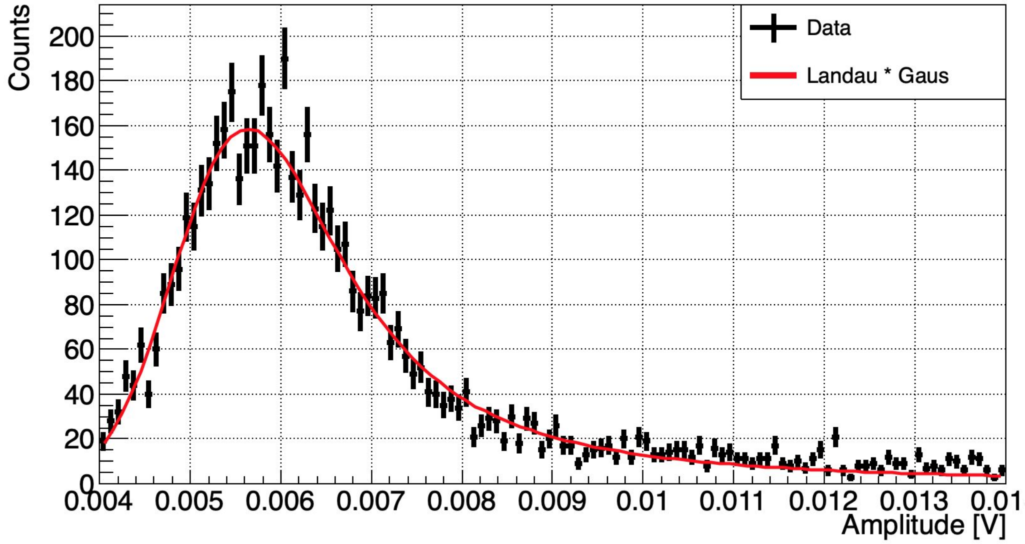


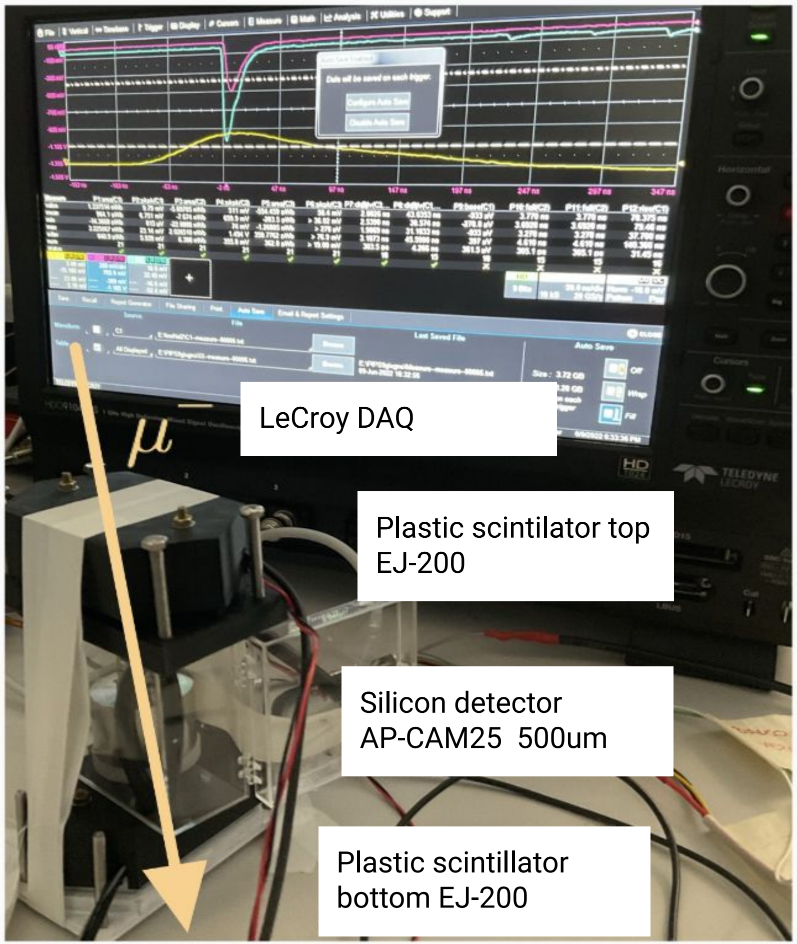
Calibration with muons

- MIP atmospheric muons
- MPV measurement :

$$K_{cal} = (37.2 \pm 0.1^{\text{stat}} \pm 0.3^{\text{syst}})\ \text{mV/MeV}$$

- Design performance is verified





Conclusions and outlooks

- PIPS characterised and **Monte-Carlo** simulation **validated**

- Current efforts on the development of **read-out for 300 um PIPS** (Mirion)

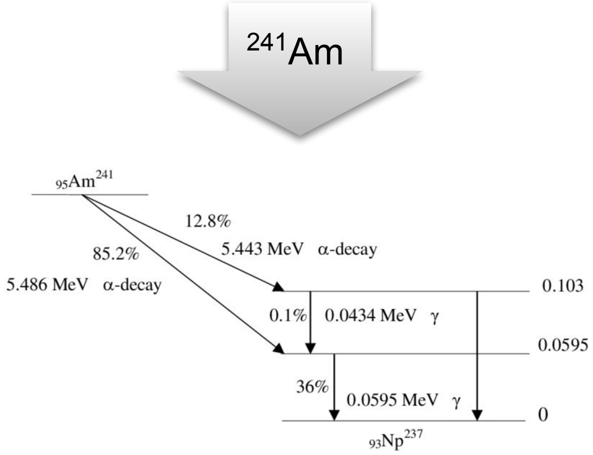
- Future efforts on the testing/characterisation of Ion implanted Silicon Detectors **100 um** thick and **CZT detectors**

- **LEM is under construction** …
  Test on sensor prototypes are ongoing at INFN-TIFPA and FBK laboratories

Backup

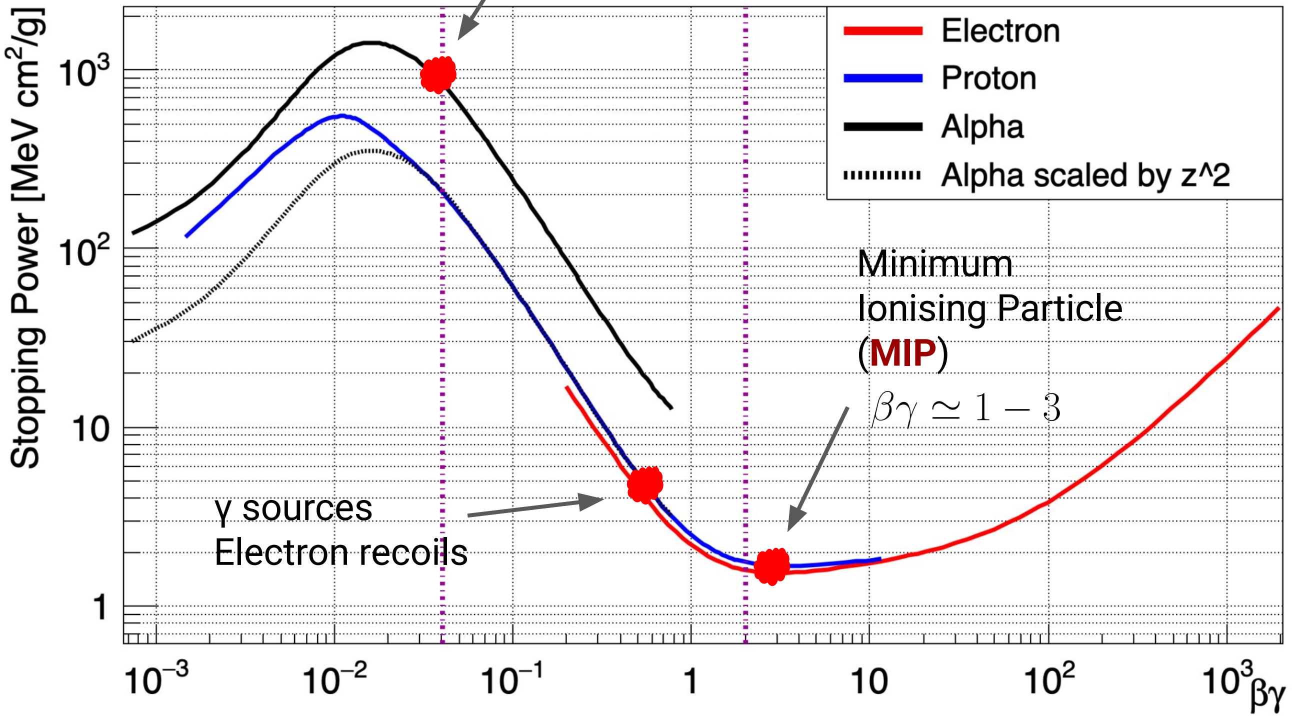
Characterisation with highly ionising particles

- **Alpha** Stopping power is ~ **500** times **larger** than **MIP**s
- Important to verify if the **detector's response is linear** with the **energy deposition** per unit length



For a 3-5 MeV **alpha**, $\beta\gamma \simeq 10^{-2} - 10^{-1}$

https://dx.doi.org/10.18434/T4NC7P

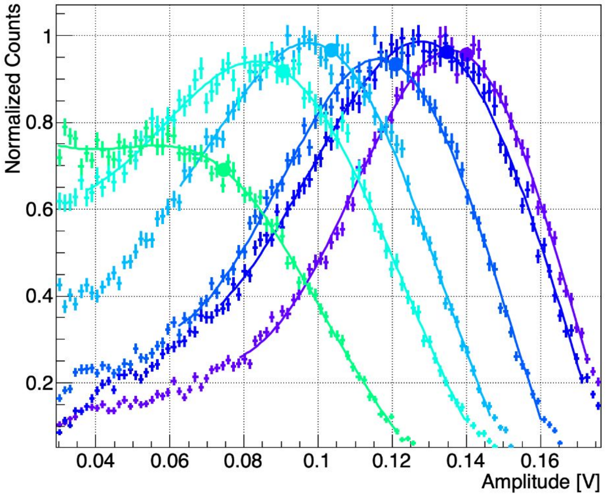


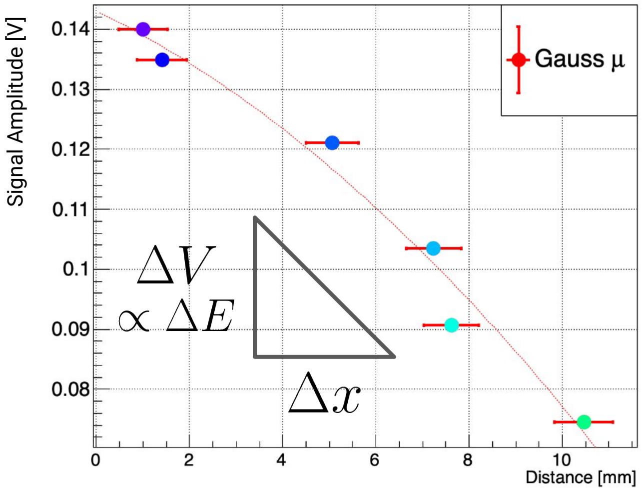
Characterisation with alpha particles

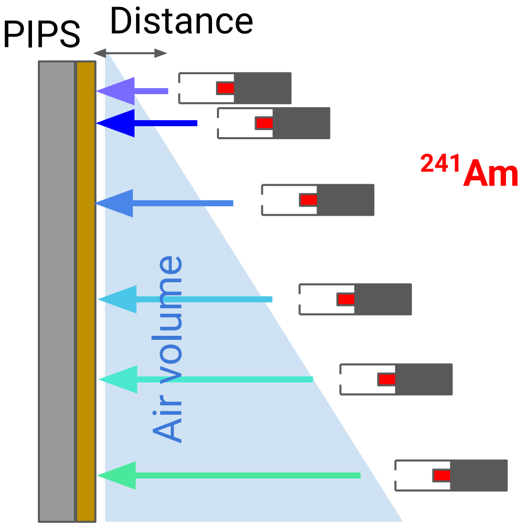
- 5.4-5.44-5.49 MeV α produced by ^{241}Am decay
- Energy loss: ~ **<u>1 MeV/cm</u>** in **Air** (degraded to 2-3 MeV)
- Measured energy distributions for different path lengths
- Estimation of $\partial V/\partial x$, proportional to $\partial E/\partial x$

To **remove** the **dependence** on the **calibration constant** we compute

$$\frac{1}{\langle V\rangle}\frac{\partial V}{\partial x} = \frac{1}{\langle E\rangle}\frac{\partial E}{\partial x}$$







Characterisation with alpha particles

$$\frac{1}{\langle V \rangle}\frac{\partial V}{\partial x} = \frac{1}{\langle E \rangle}\frac{\partial E}{\partial x} \quad (*)$$

- Experimental data $(*)$ compared with **Monte-Carlo** simulations (**GEANT4**)
- $\mathbf{K_{cal}}$ in **agreement** with previous calibration (37 mV/MeV)