



IWM-EC 2021

International Workshop on Multi-facets of EOS and Clustering

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GANIL, Caen

Europe/Paris timezone



Istituto Nazionale di Fisica Nucleare

Recent results on the construction of a new correlator for neutrons and charged particles

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⁽¹⁾ INFN, Laboratori Nazionali del Sud, Catania, Italy



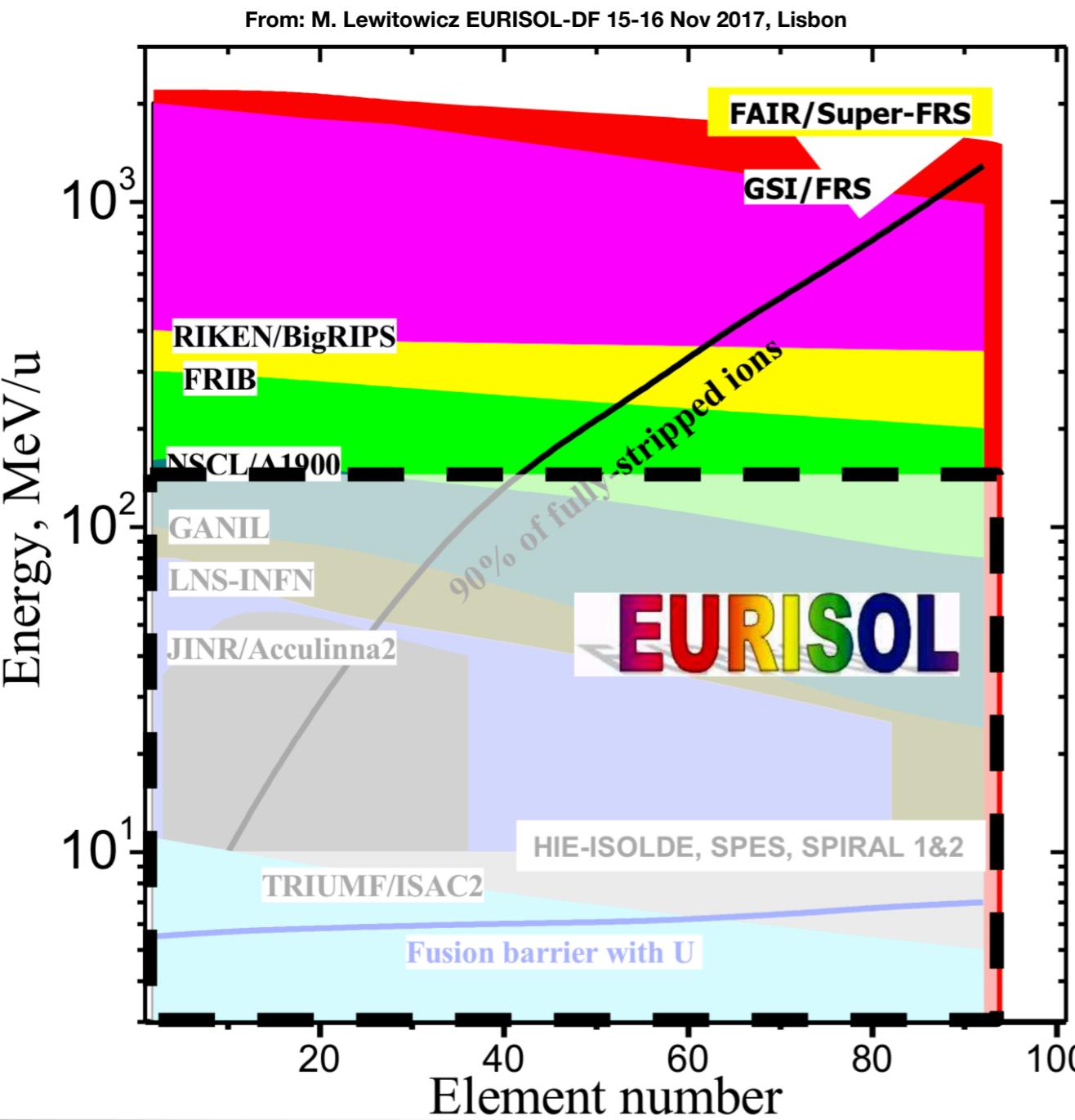
NARCOS

Project's motivations

The advent of the new facility for Radioactive Ion Beams (RIBs)
in particular for the n-rich ones

“The RIBs are an important opportunity”

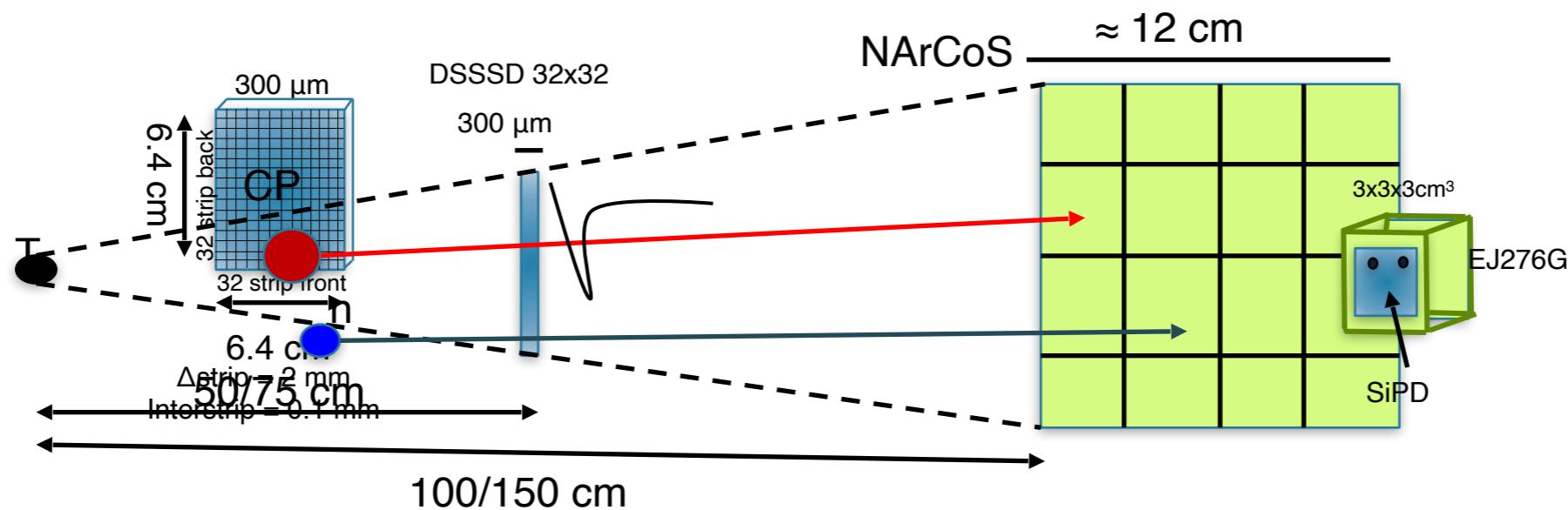
(C. Horovitz)



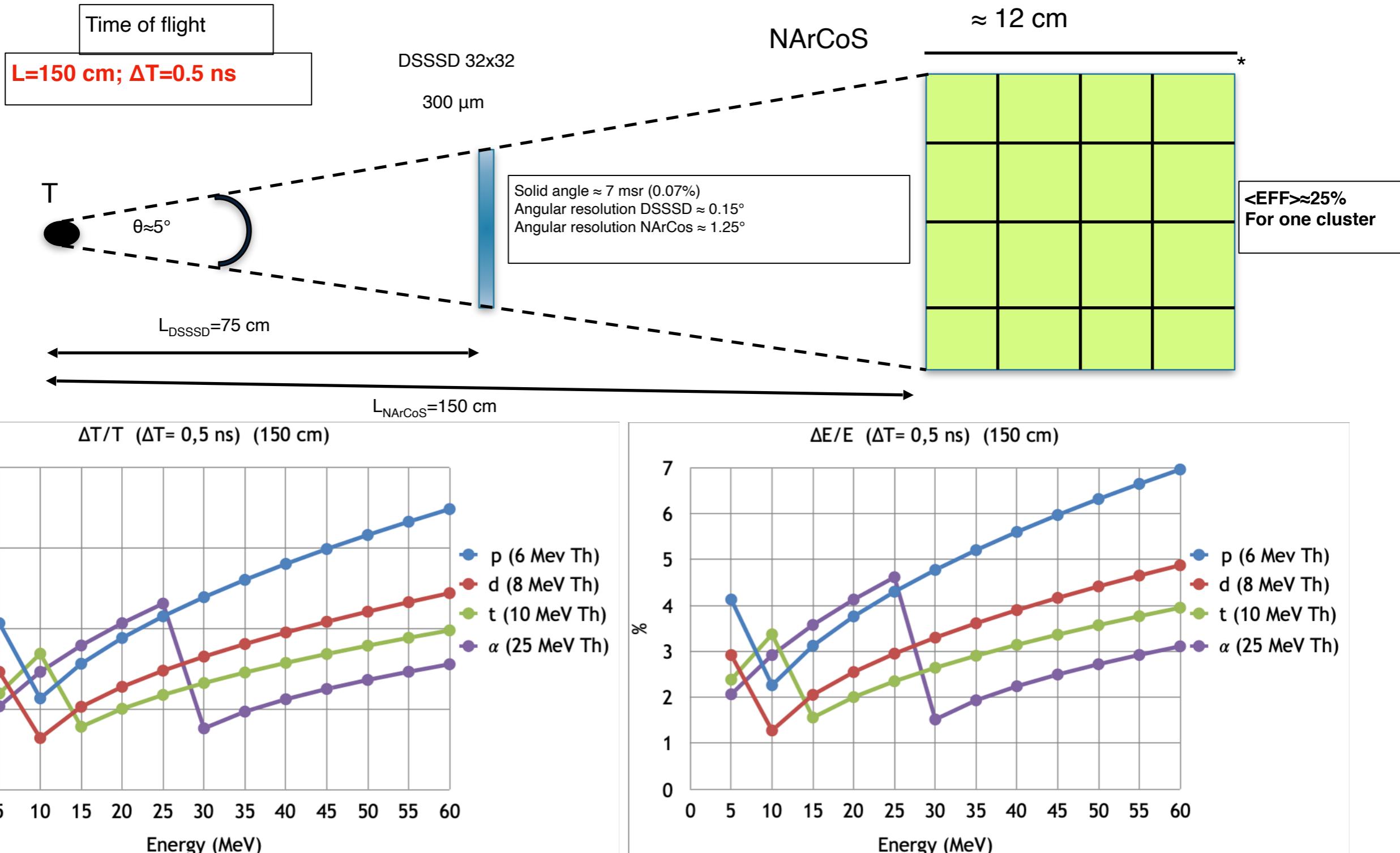
IDEA

To realize a prototype of detector able to detect at the same time charged particles and neutrons with high energy and angular resolution for reaction studies and applications

- Candidate: The plastic scintillator EJ276-Green Type (ex EJ299-33) ($3 \times 3 \times 3 \text{ cm}^3$)
- 1 cluster: 4 consecutively cubes $\rightarrow 3 \times 3 \times 12 \text{ cm}^3$
- Reading the light signal: Si-PM and digitalization
- Modular, reconfigurable (in mechanic and electronic)
- Discrimination of n/γ from PSD (but also light charged particles)
- Energy measurement from ToF ($\Delta t \leq 1 \text{ ns}$ with $L_{\text{ToF}} \approx 1 \div 1.5 \text{ m}$)
TOF measured using the RF of the CS or with an ancillary MCP (low intensity exotic beams)

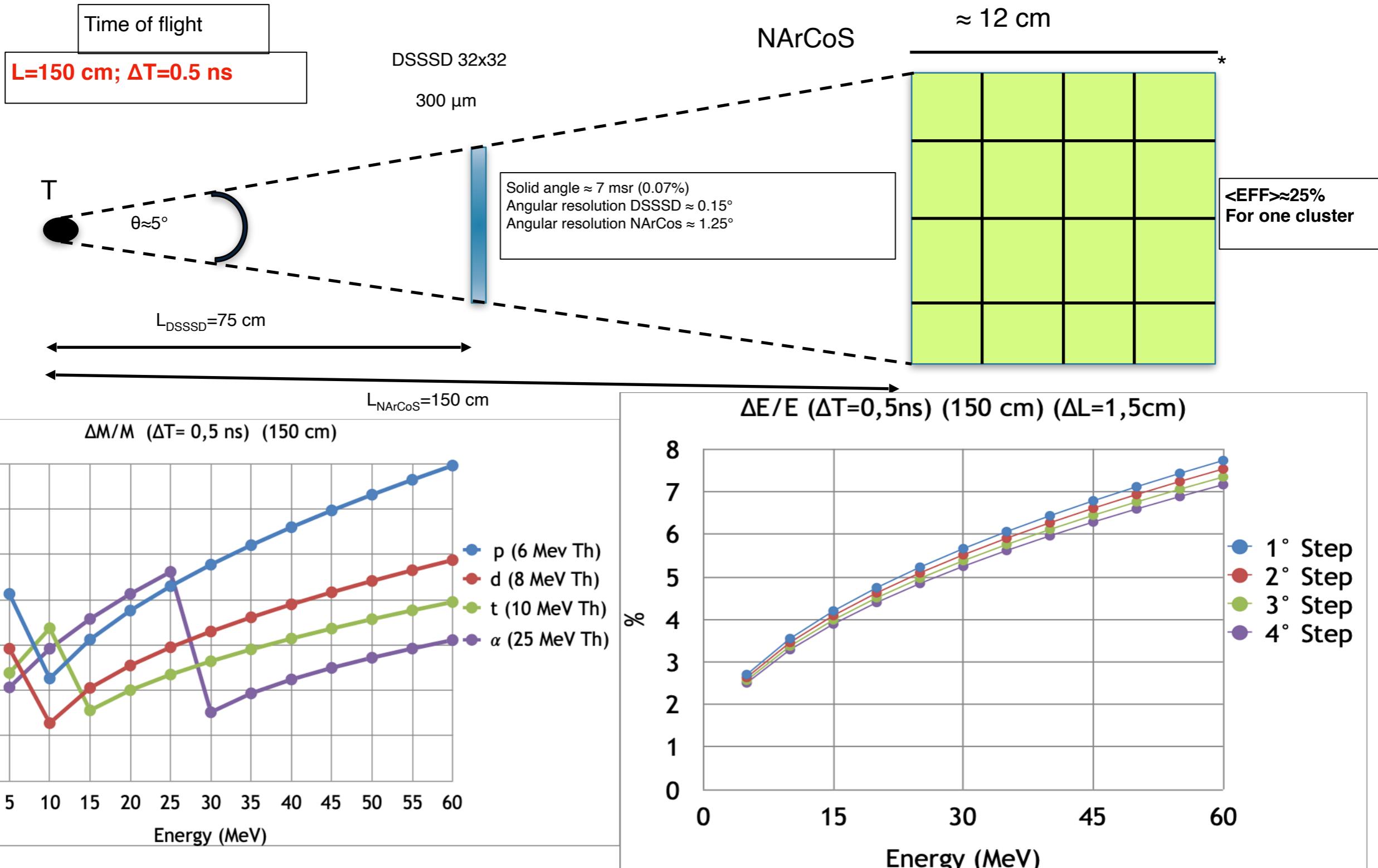


Just few numbers



*the mechanical structure will have the possibility of an angular movimentation

Just few numbers

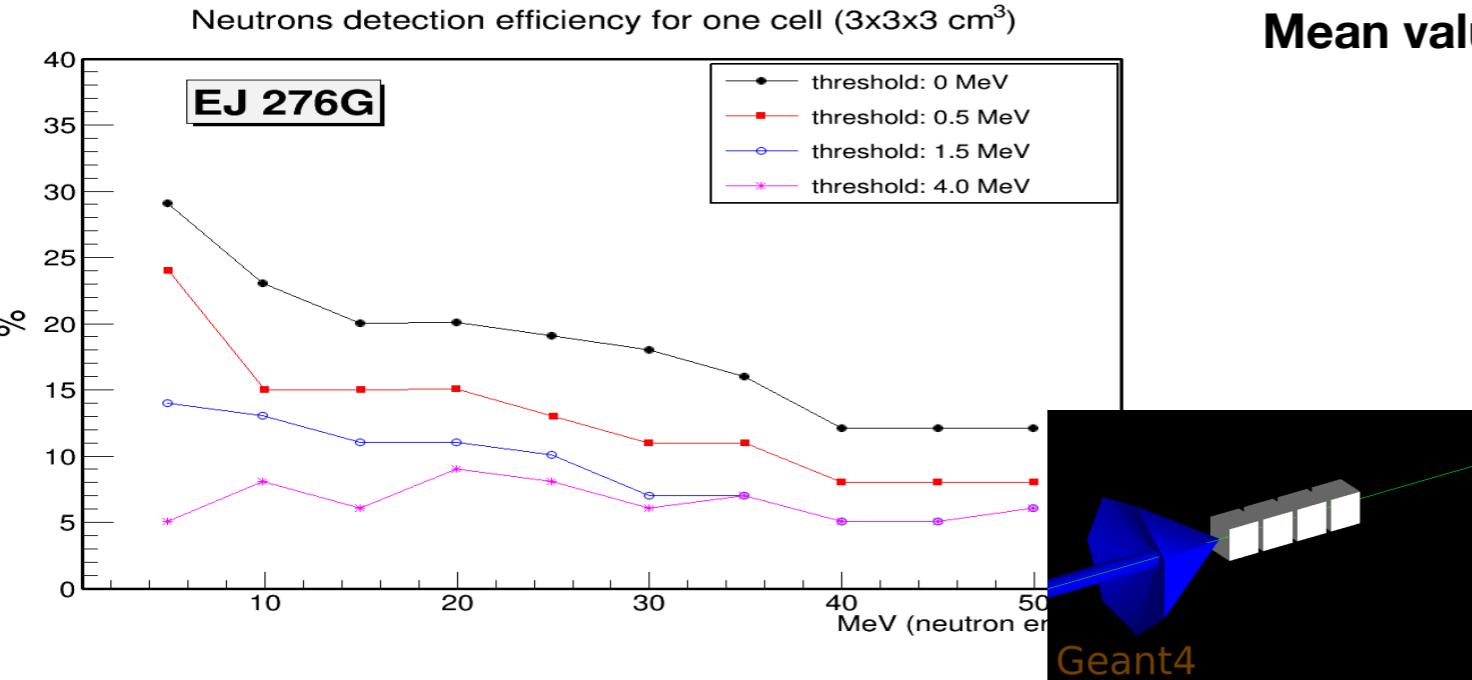


*the mechanical structure will have the possibility of an angular movimentation

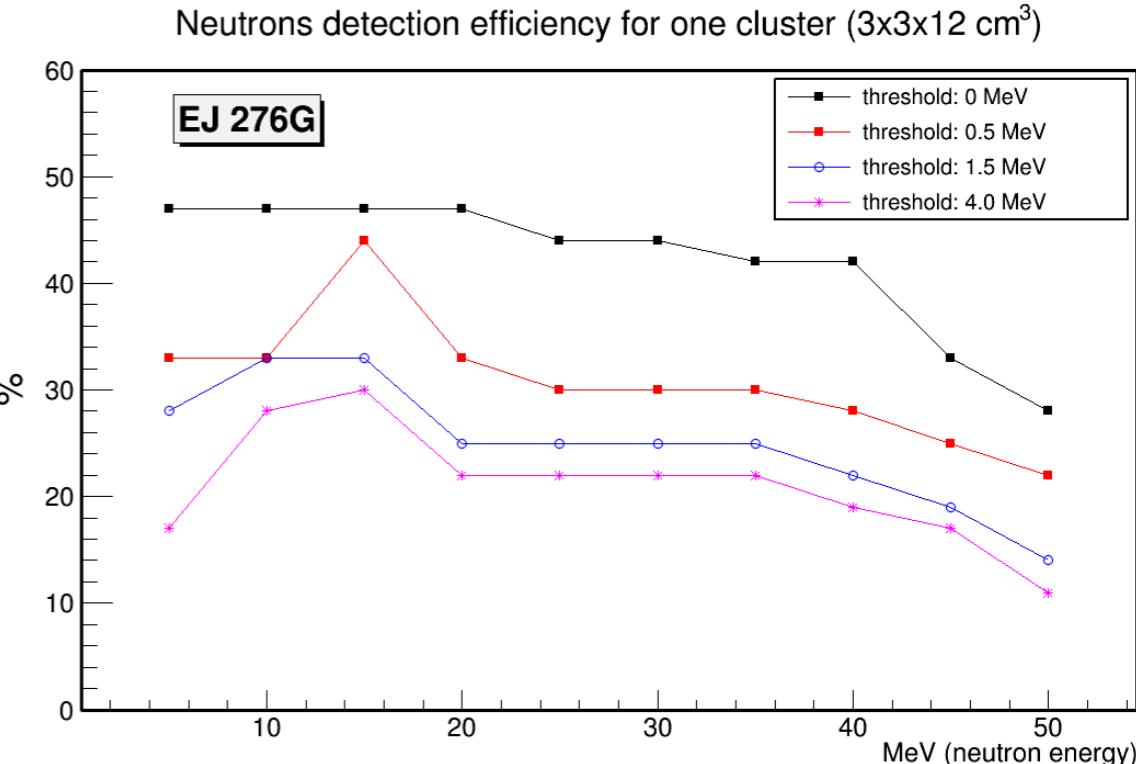
What about the neutron detection efficiency?

GEANT 4 simulation in order to estimate the neutron detection efficiency

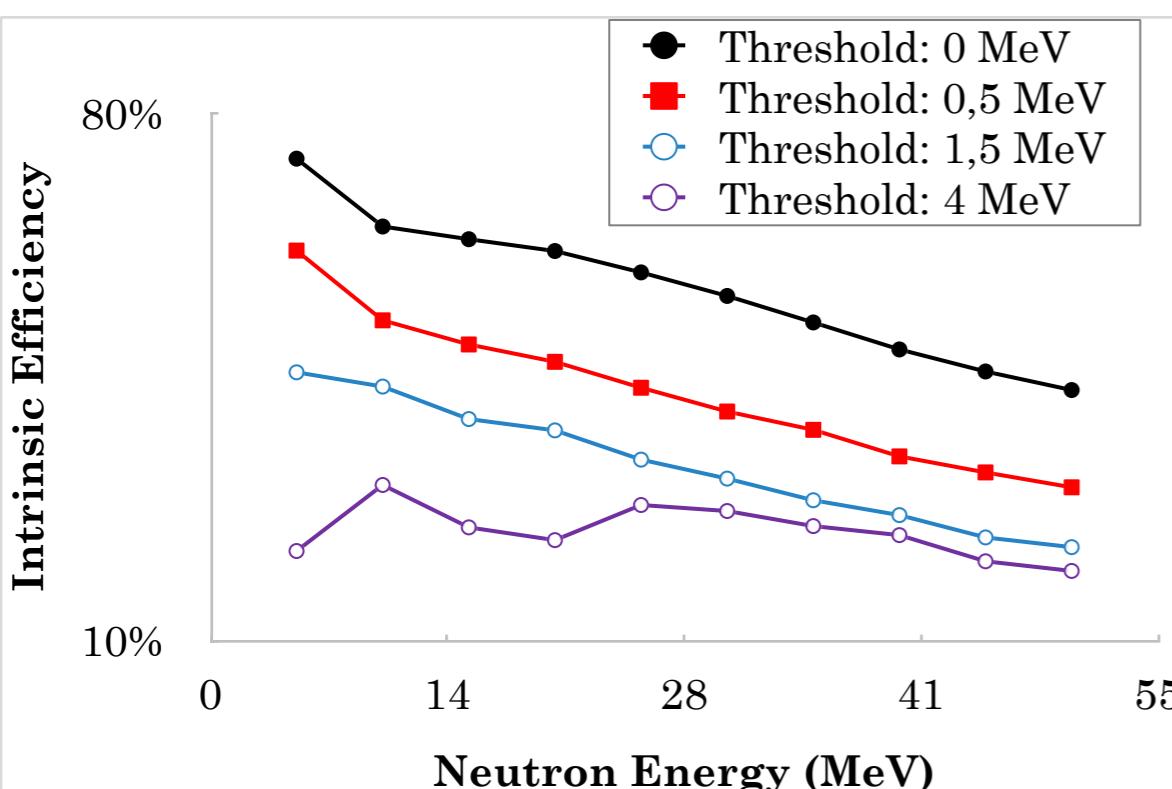
Mean value for one detection cell ($3 \times 3 \times 3 \text{ cm}^3$) $\approx 9\%$



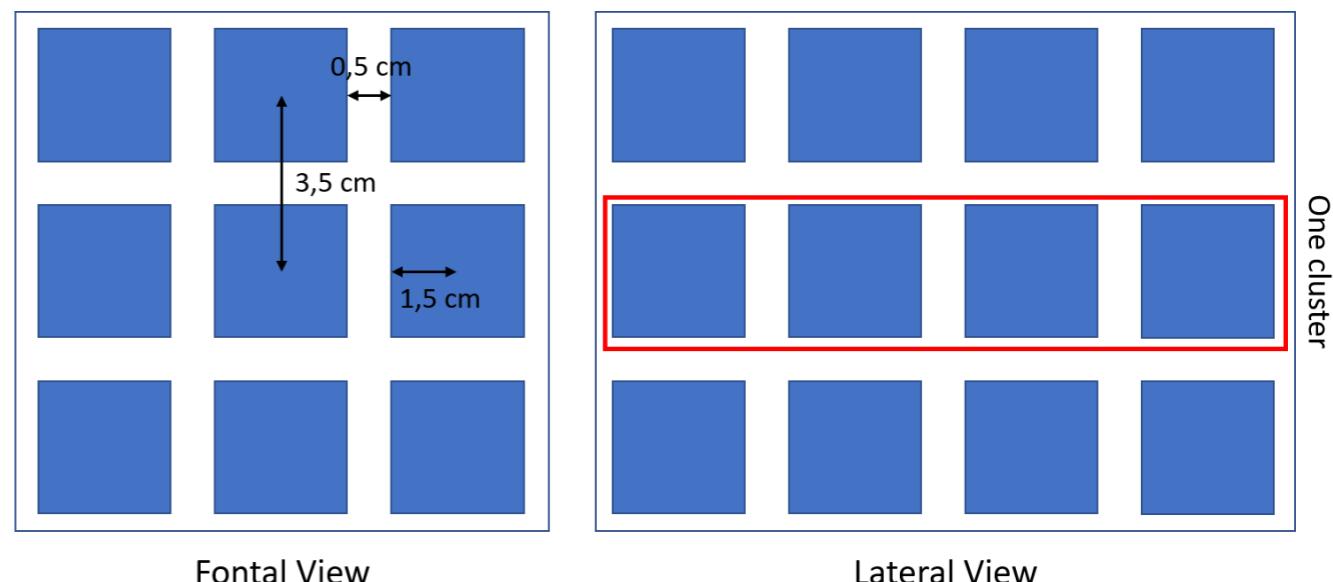
Mean value for one detection cluster ($3 \times 3 \times 12 \text{ cm}^3$) $\approx 25\%$



Mean value for a 36-cell array ($9 \times 9 \times 12 \text{ cm}^3$) $\approx 33\%$



Scheme of Simulation Geometry:
36 (3 x 3 x 4) cell array



Latest results: tests by using the SiPM (i-Spector CAEN)

The test was done during the master thesis work of A. Simancas in Catania (EVP tutor)

➤ Detector Configurations:

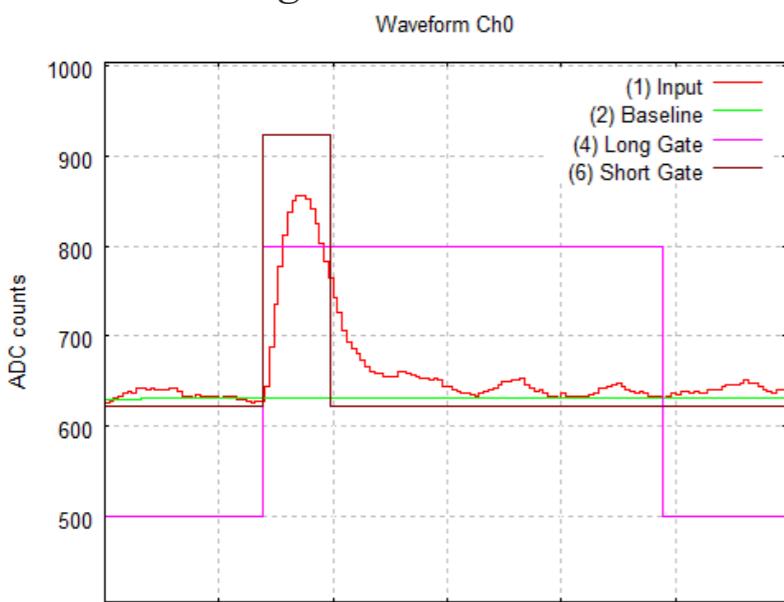
- EJ-276G + PMT
- EJ-276 + i-Spector
- EJ-276G + i-Spector

➤ Lab measurements with radioactive sources:

- Vacuum Chamber
- Pb shield
- Gamma sources: ^{133}Ba , ^{137}Cs , ^{60}Co , ^{152}Eu
- Alpha source: ^{241}Am
- Digitizer from CAEN

➤ Data analysis of heavy ion reactions:

- CHIMERA scattering chamber (LNS)
- Detector at 11° in lab frame
- Beam: ^{124}Sn at 20 MeV/A (CHIFAR experiment)
- Targets: ^{64}Zn and ^{64}Ni
- GET digital electronics



Example of signal and integration windows

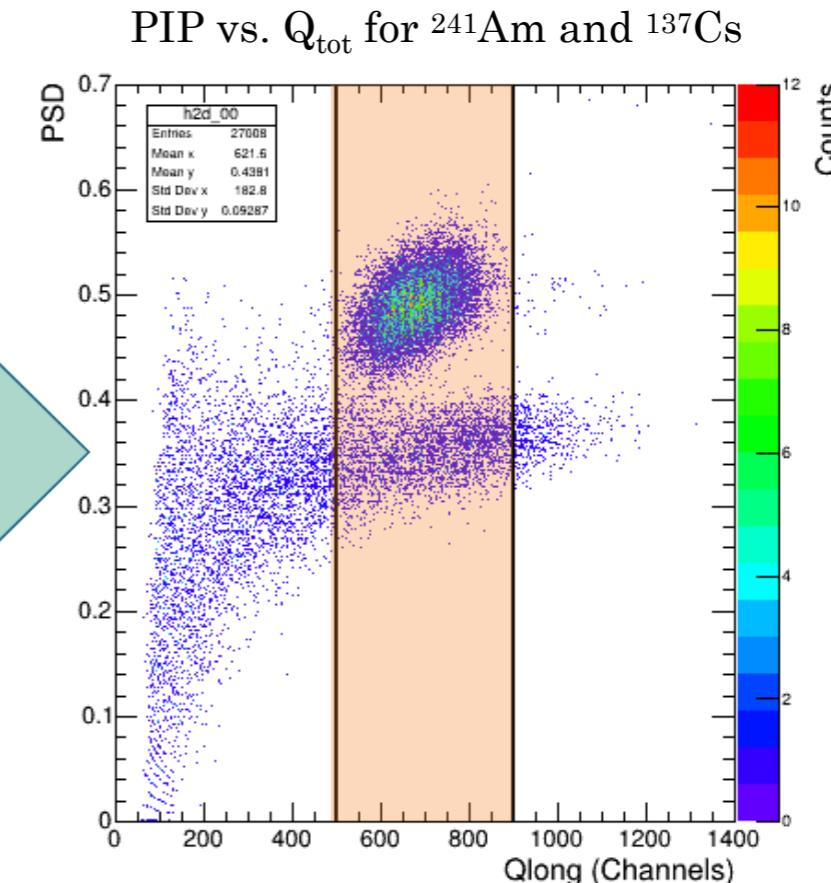
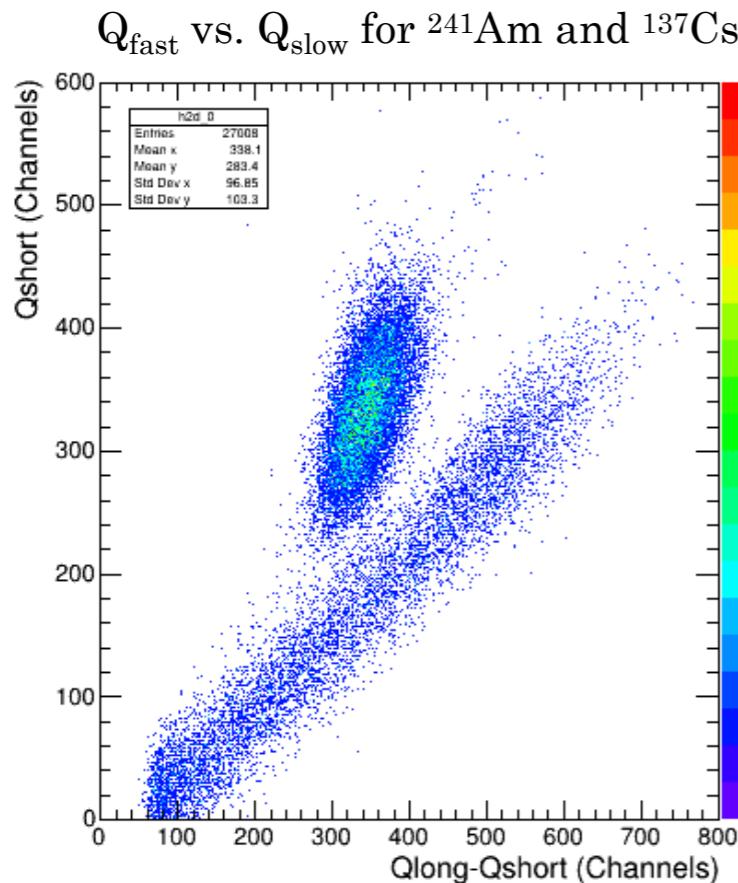
E.V.Pagano, G. Politi, A. Simancas et al., in preparation



i-Spector from CAEN
(3x3 cm SiPM and
electronics)



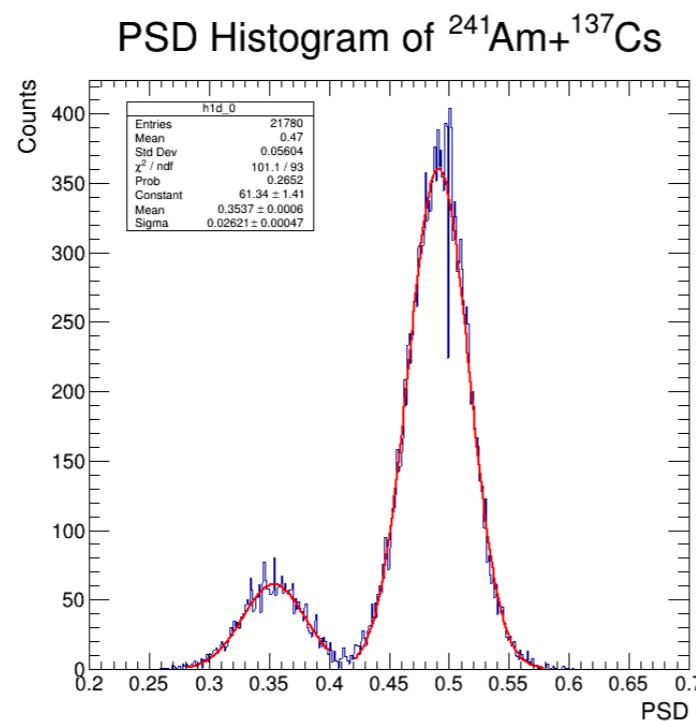
Example of PSD plots



$$PIP = 1 - \frac{Q_{\text{fast}}}{Q_{\text{tot}}} = \frac{Q_{\text{slow}}}{Q_{\text{tot}}}$$

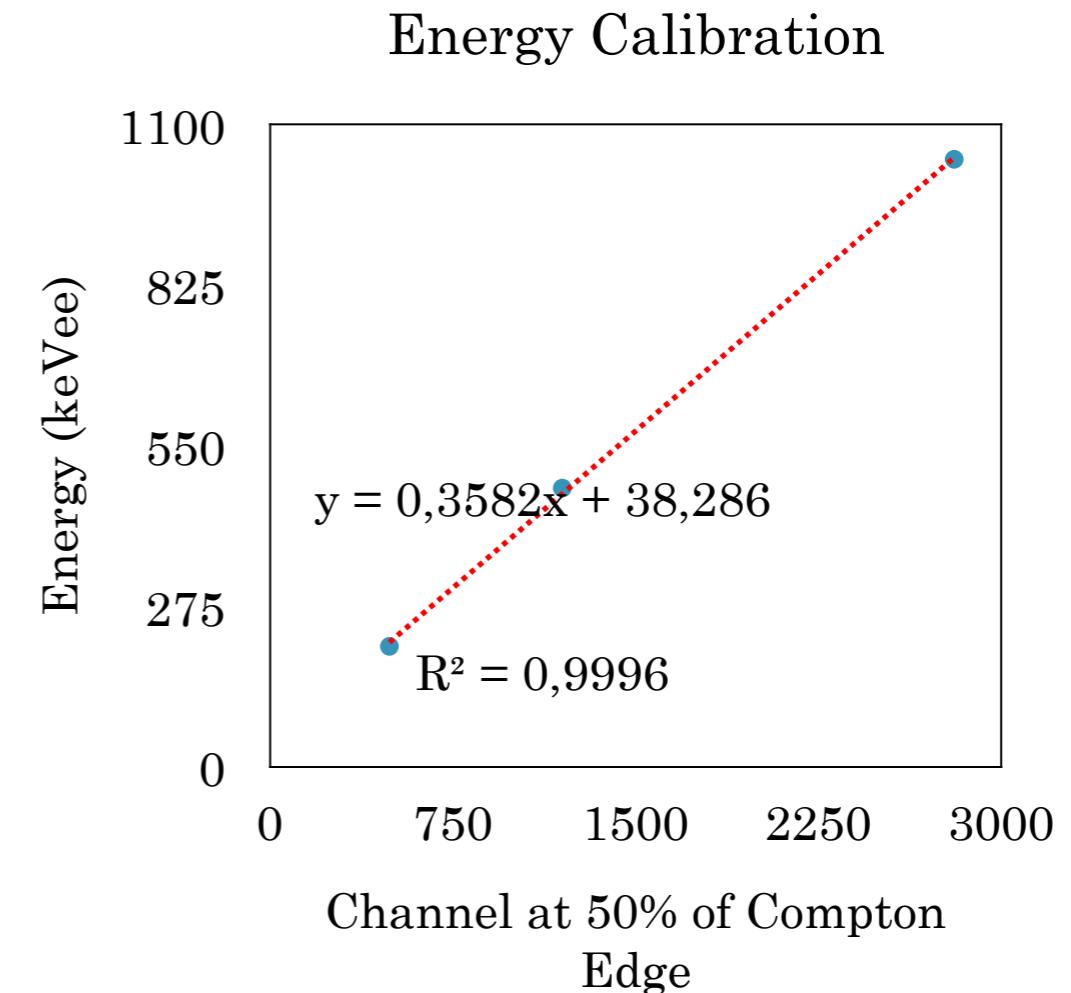
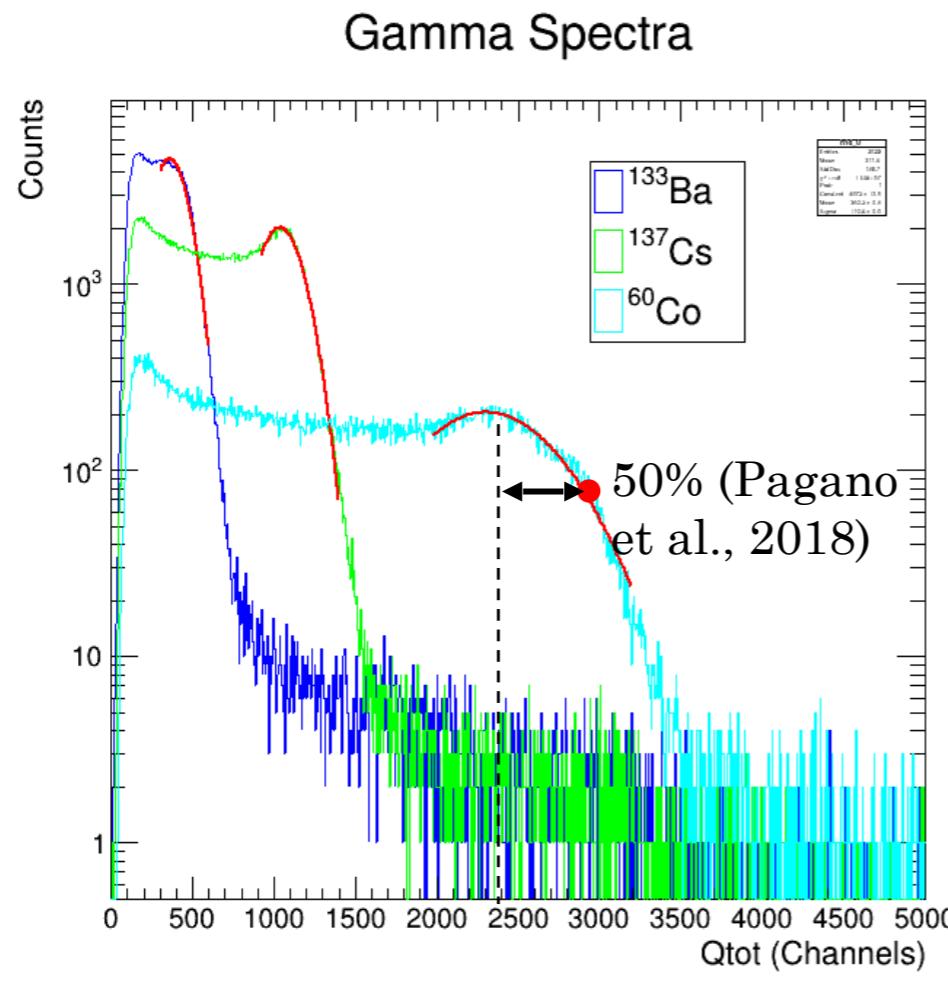
EJ-276 + i-Spector

PIP = Particle Identification Parameter

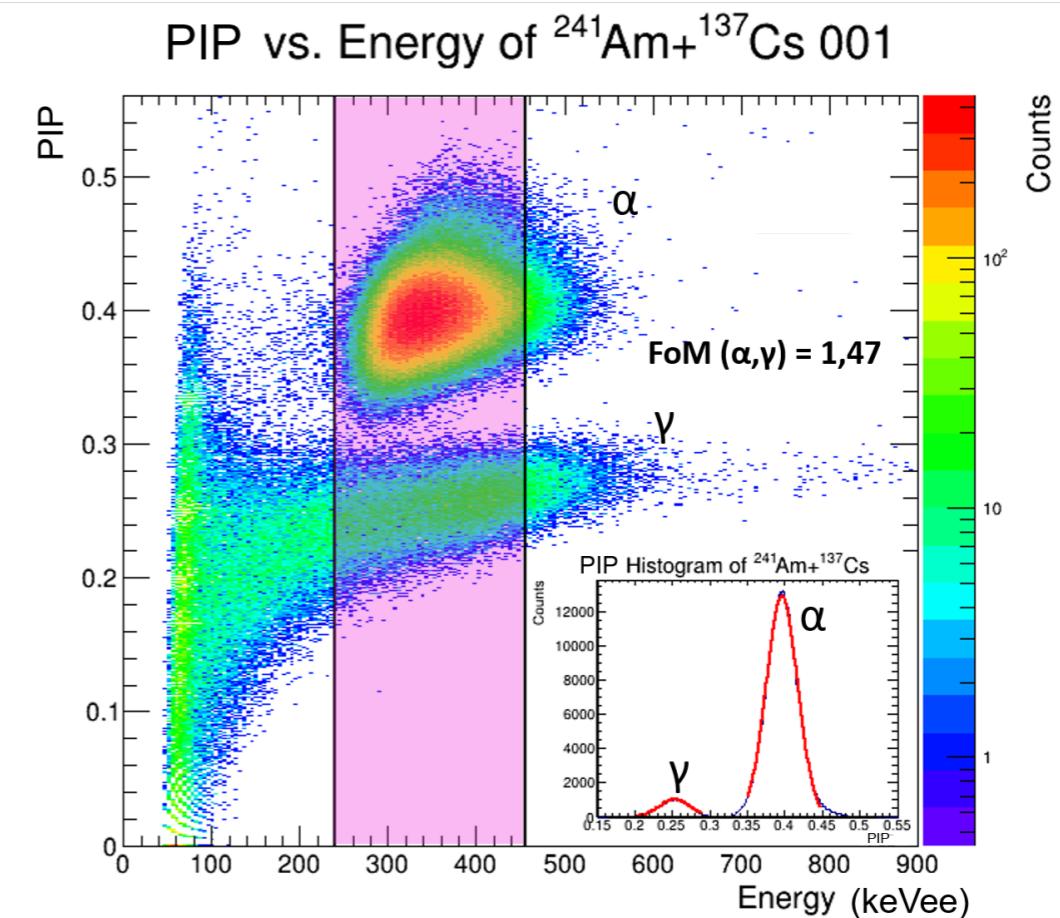
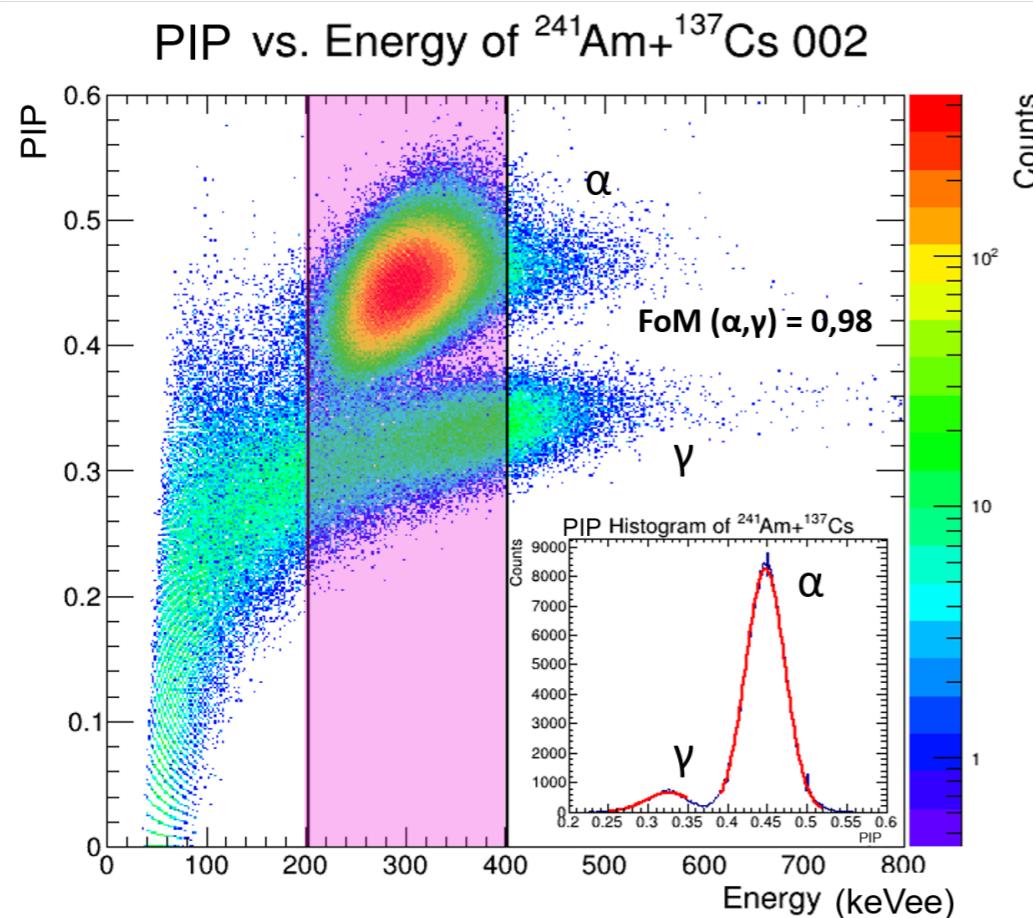


Projection in PIP axis

Example Gamma spectra



PSD studies using sources



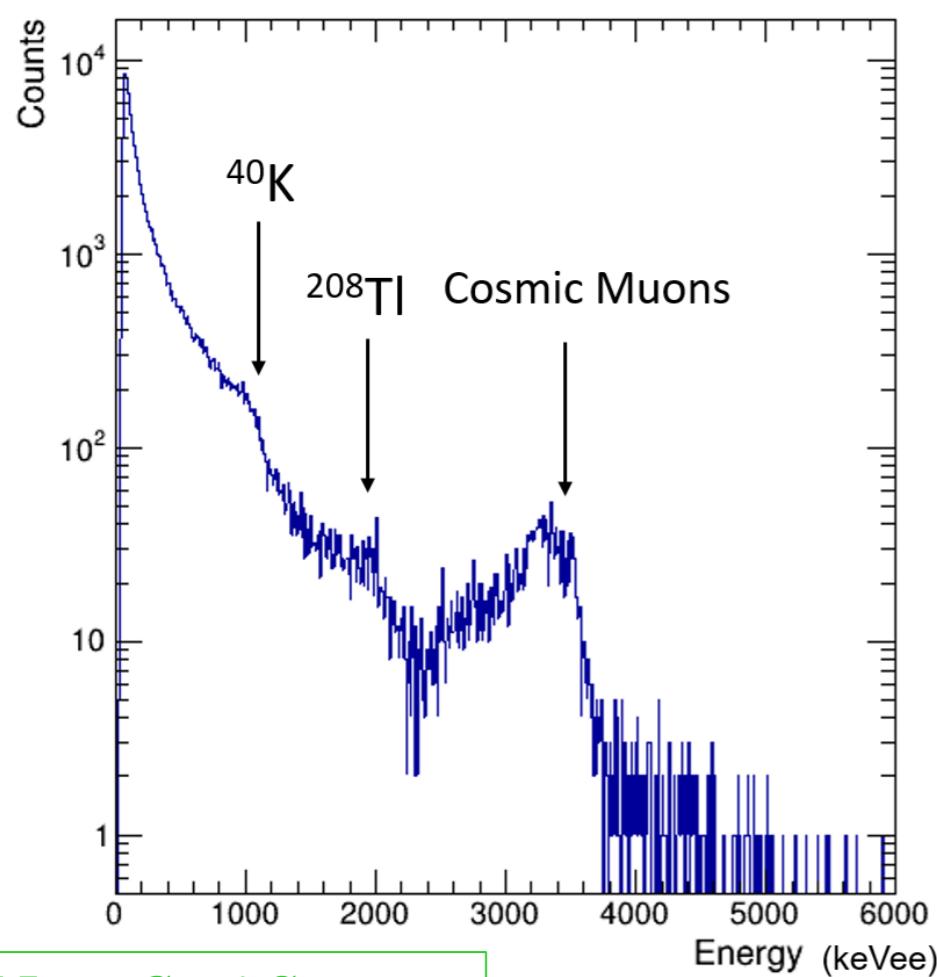
EJ-276 + i-Spector

EJ-276G + i-Spector

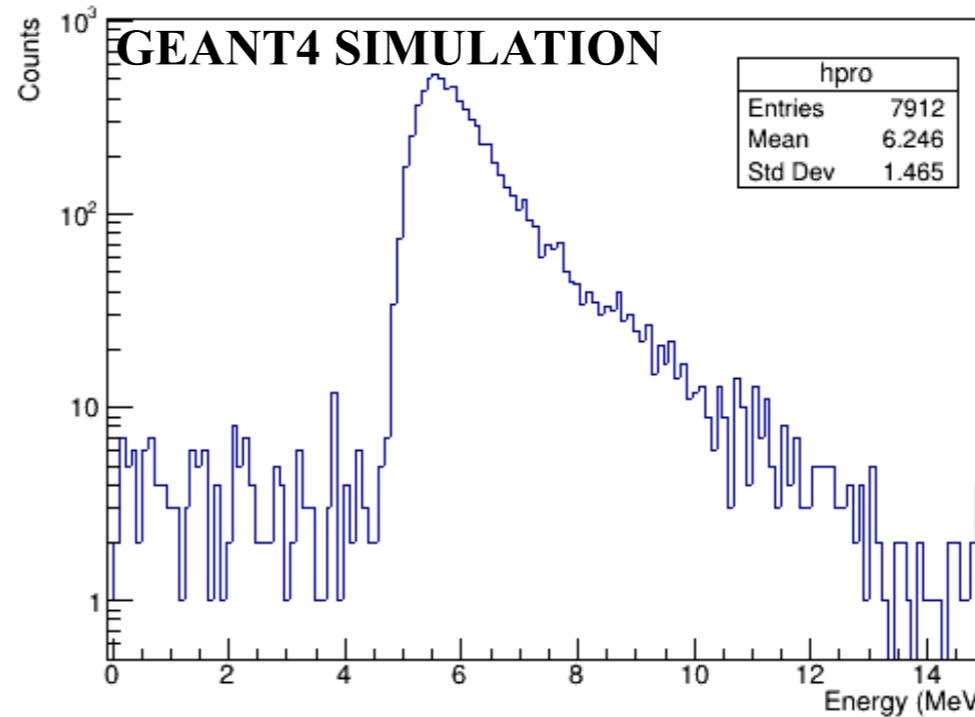
| Detector | FoM |
|---------------------|------|
| i-Spector + EJ-276 | 0.98 |
| i-Spector + EJ-276G | 1.47 |
| PMT + EJ-276G | 1.03 |

Background without Lead Shielding

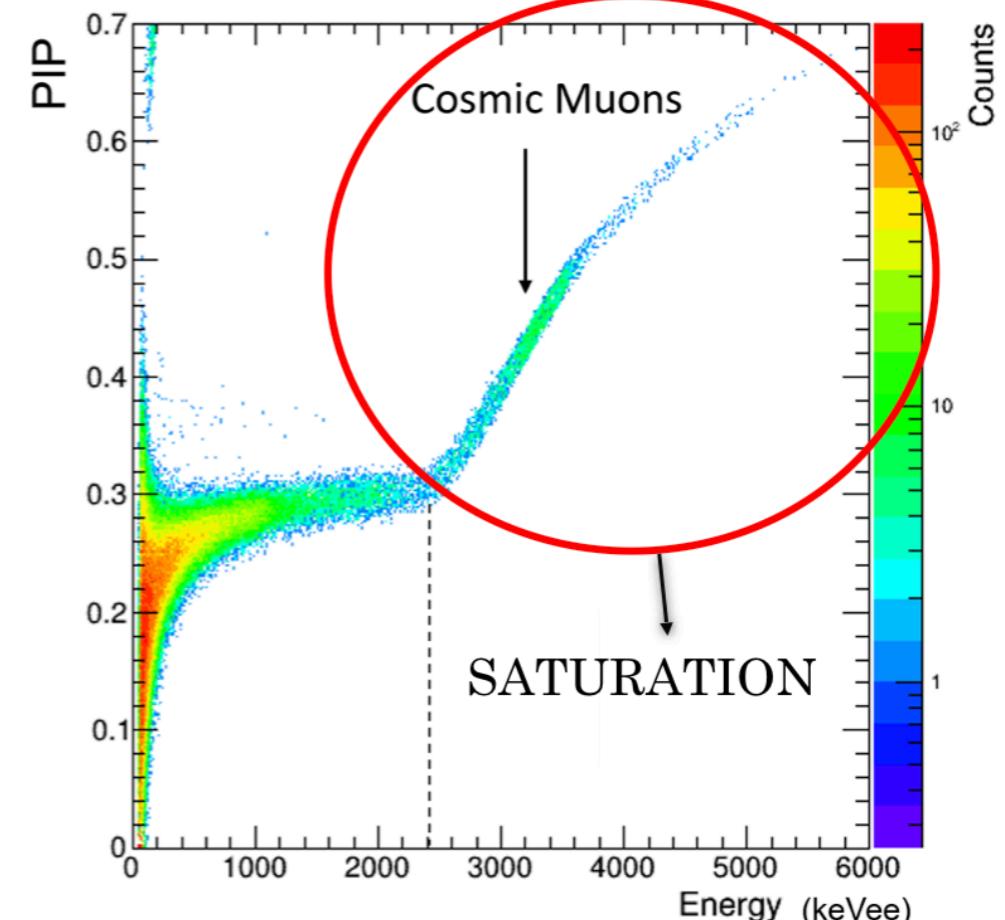
Background Histogram



Cosmic Muons Spectrum



PIP vs. Energy of Background

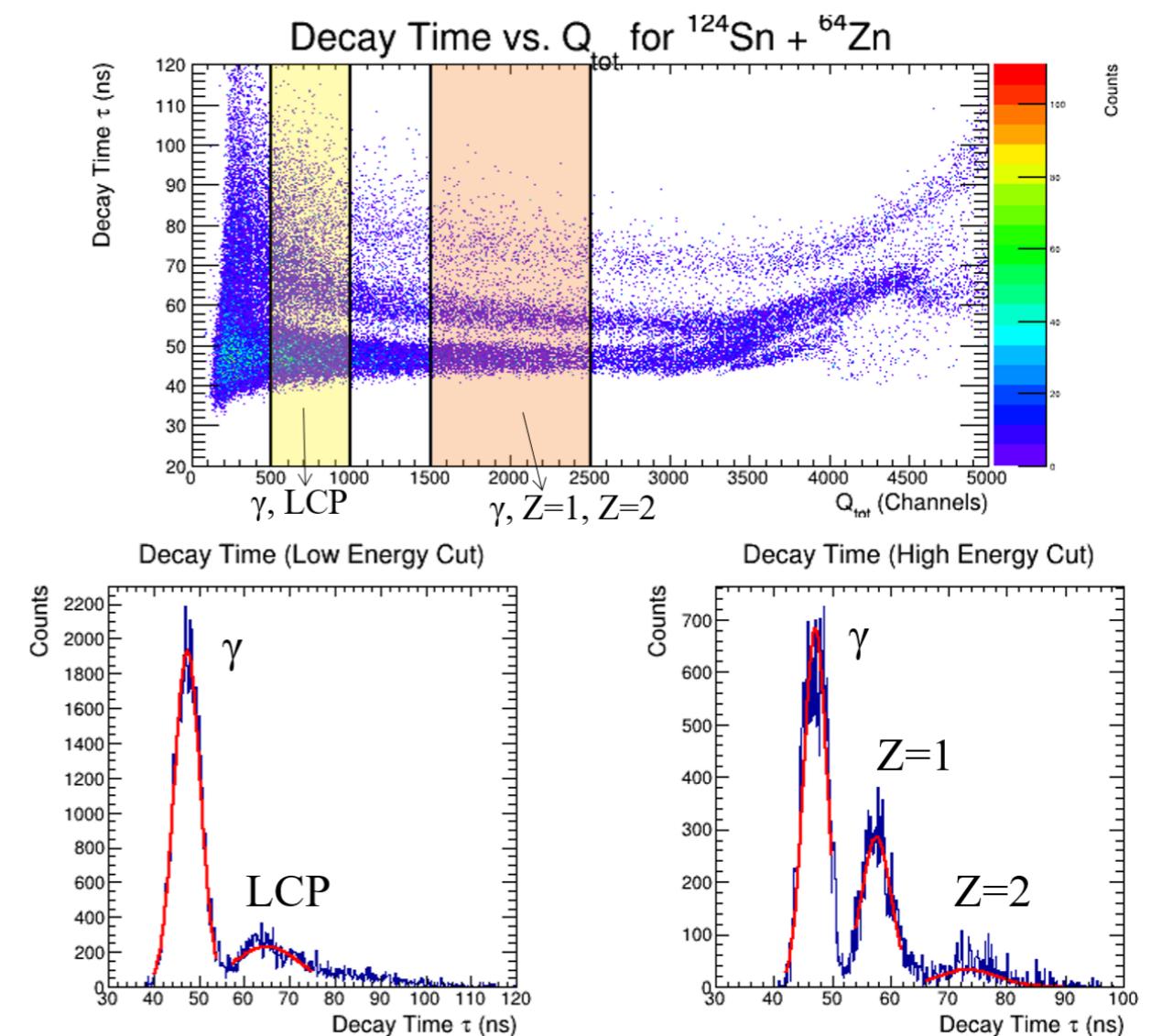
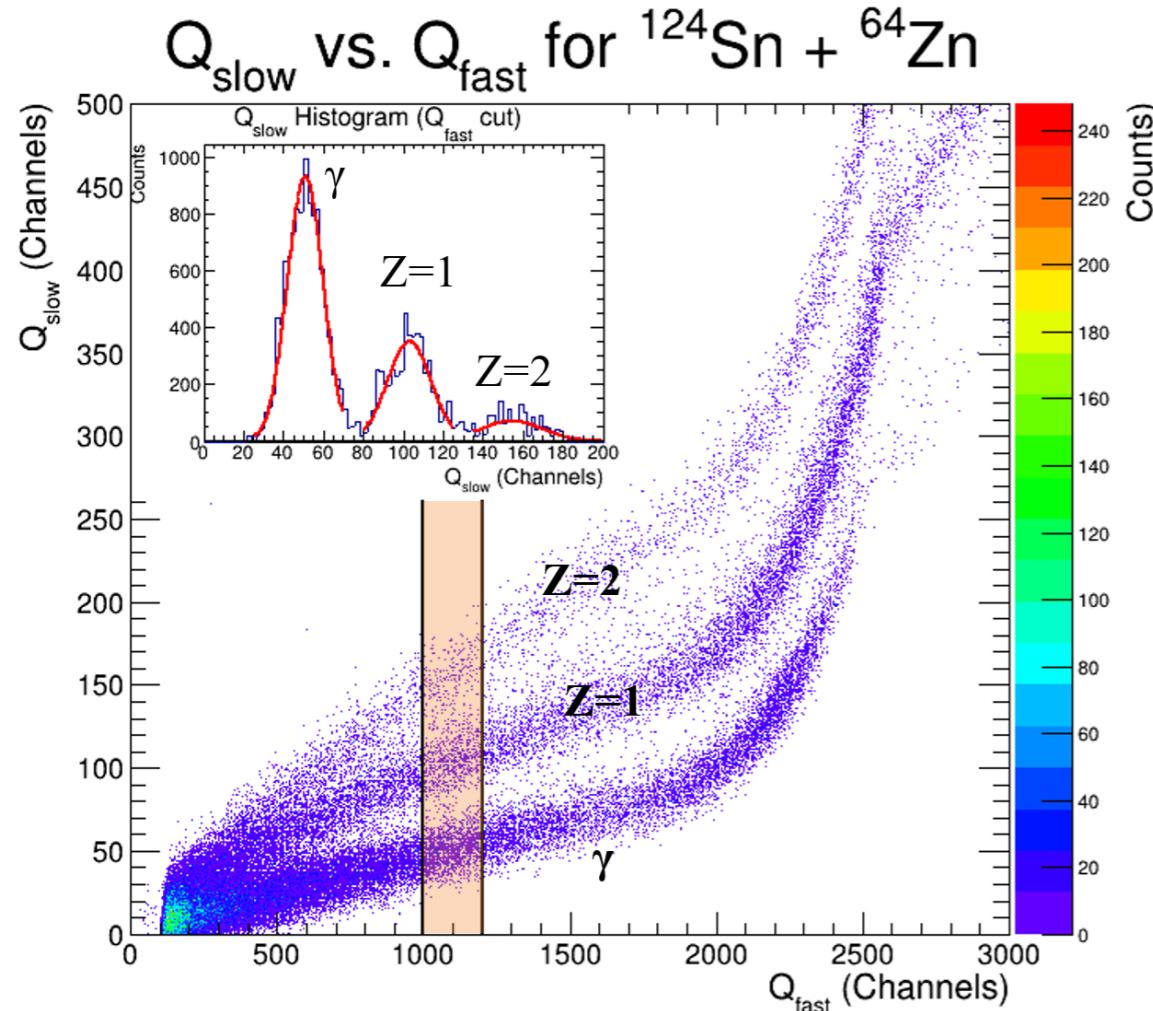


The saturation is due the
The electronic of the i-Spector
That is done for
low energy gamma particles

PSD studies using beams

CHIFAR exp @Ins (spokesperson: EVP, E. De Filippo, P. Russotto)

EJ-276 + i-Spector



| PSD Method | FoM(γ , Z=1) | FoM(Z=1, Z=2) | FoM(γ , LCP) |
|-------------|----------------------|---------------|----------------------|
| Integration | 1.08 | 0.78 | - |
| Decay Time | 0.95 | 0.87 | 0.71 |

**LCP = Light Charged Particles
Neutrons included in Z=1**

Conclusions 1

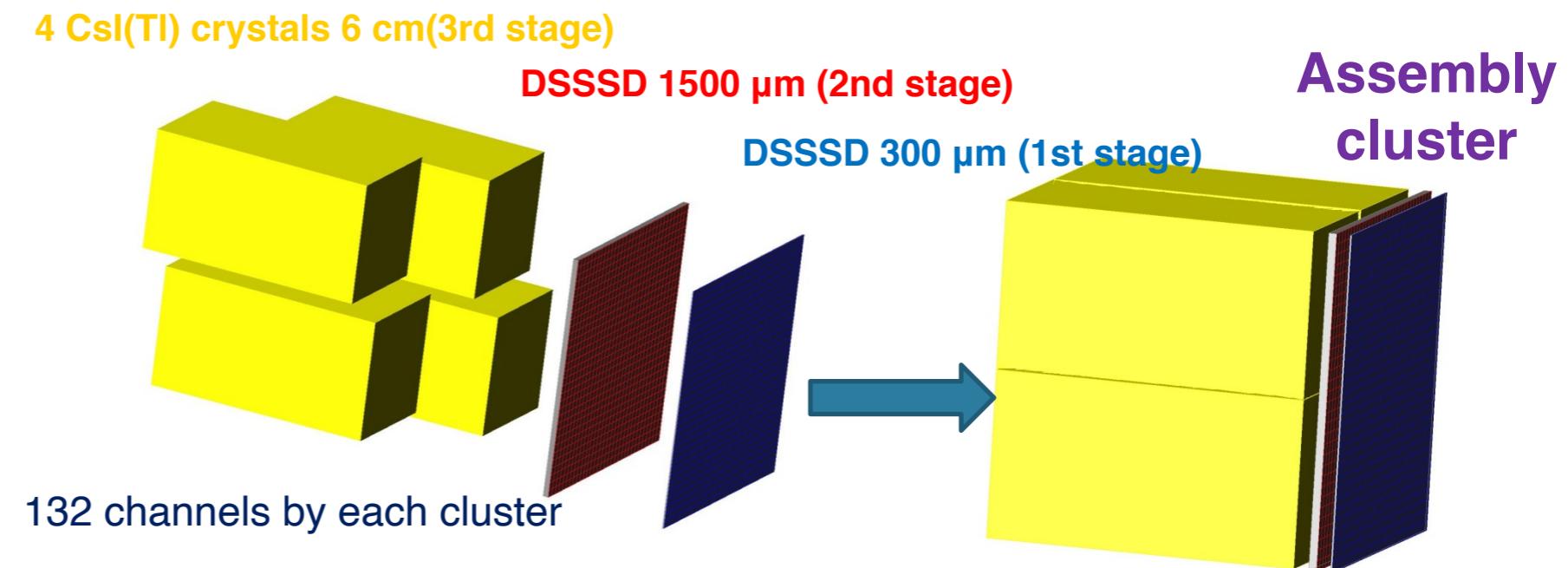
- Studied response of detector configurations:
- Lab experiment with radioactive sources (low background):
 - Good linearity in light output between 207 - 1041 keVee
 - Good quality of PSD, specially for **EJ-276G + i-Spector** with $\text{FoM}(\alpha,\gamma) = 1.47$
 - Pulse saturation due to signal processing electronics
- Data analysis of heavy ion reactions (high background):
 - Good PSD capabilities studied through two techniques
- GEANT4 Simulation: ~33% neutron efficiency for 36-cell array at 1.5 MeV threshold

FARCOS

(Femtoscope ARray for COrrelations and Spectroscopy)

Strips calibration for CHIFAR experiment (spokes (EVP, E. De Filippo, P Russotto))

- Based on (62x64x64 mm³) clusters
- 1 square (0.3x64x64 mm³) DSSSD 32+32 strips
- 1 square (1.5x64x64 mm³) DSSSD 32+32 strips
- 4 60x32x32 mm³ CsI(Tl) crystals



- Modular array of telescopes
- High energy and angular resolution
- $\Delta E/E$ discrimination, pulse-shape discrimination and possible TOF discrimination like in 4pi CHIMERA
- Digitization (GET Electronics)
- DSSSD(Double-Sided Silicon Strip Detector) each with 32 strips, both in vertical and in a horizontal and 4 crystals of CsI(Tl).
- Portability and modularity to be coupled to 4 π detectors as CHIMERA or magnetic spectrometers
- Integrated and reconfigurable electronics
- Possibility of updating and upgrades

Calibration FARCOS's silicon strips in the CHIFAR EXP

CHIFAR experiment:

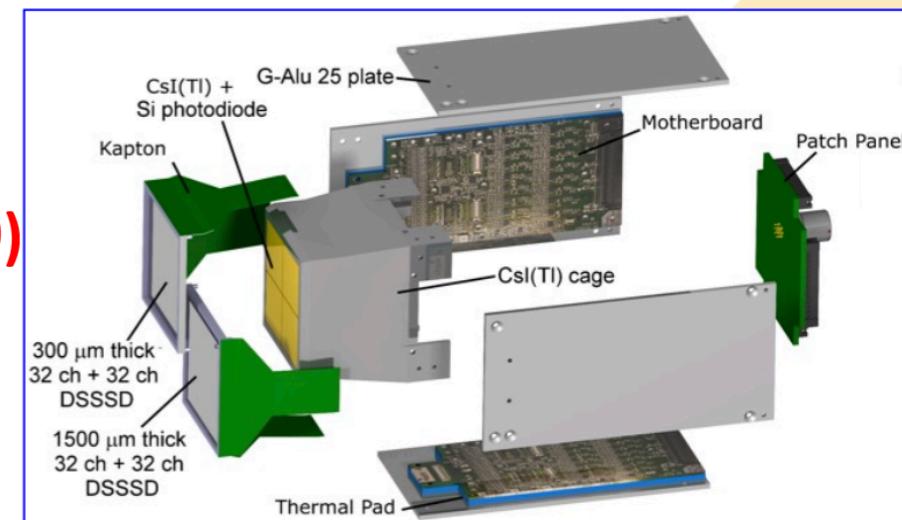
Study of the dynamical and statistical PLF break-up @20 MeV/A

$^{124}\text{Sn}+^{64}\text{Ni}$, $^{112}\text{Sn}+^{58}\text{Ni}$ and $^{124}\text{Xe}+^{64}\text{Zn}$ at 20 A MeV (November 2019)

Spokes: E.V. Pagano, E. De Filippo, P. Russotto et al.

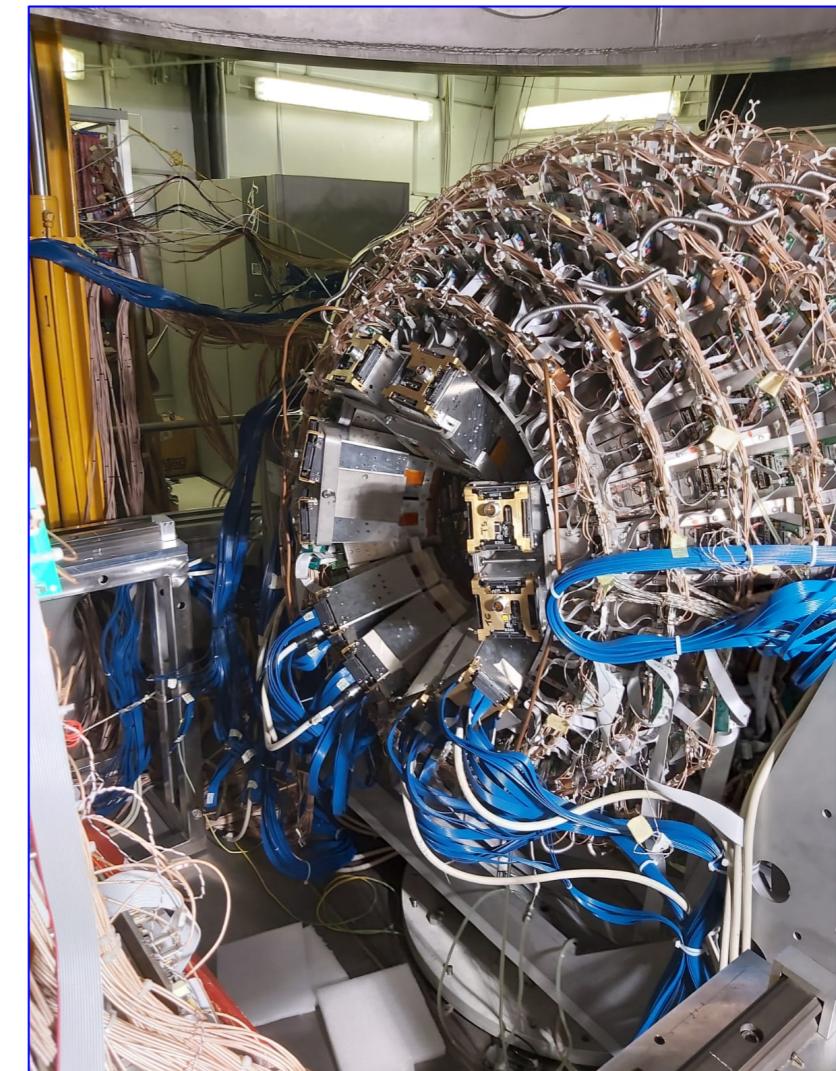
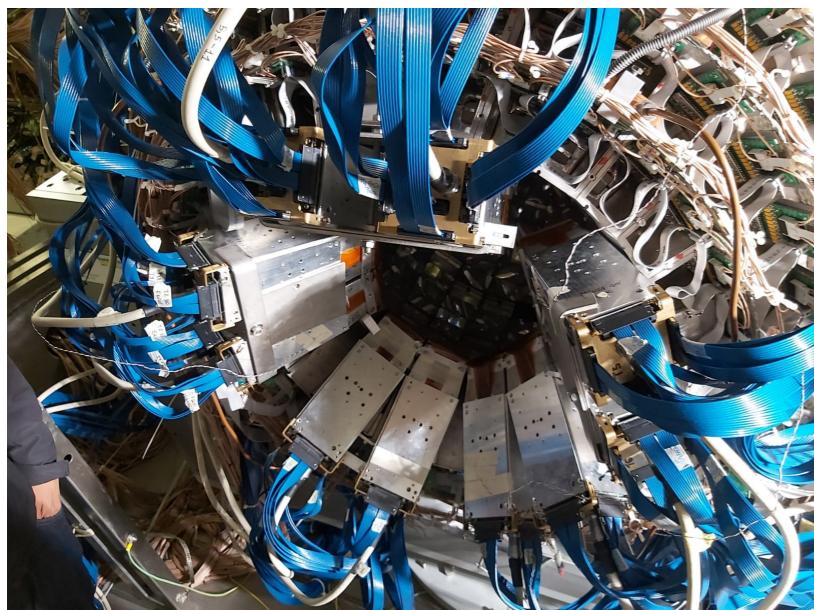
For the CHIMERA analysis P. Russotto talk

**CHIMERA + 10 FARCOS telescopes in a
“quasi”- ring configuration**



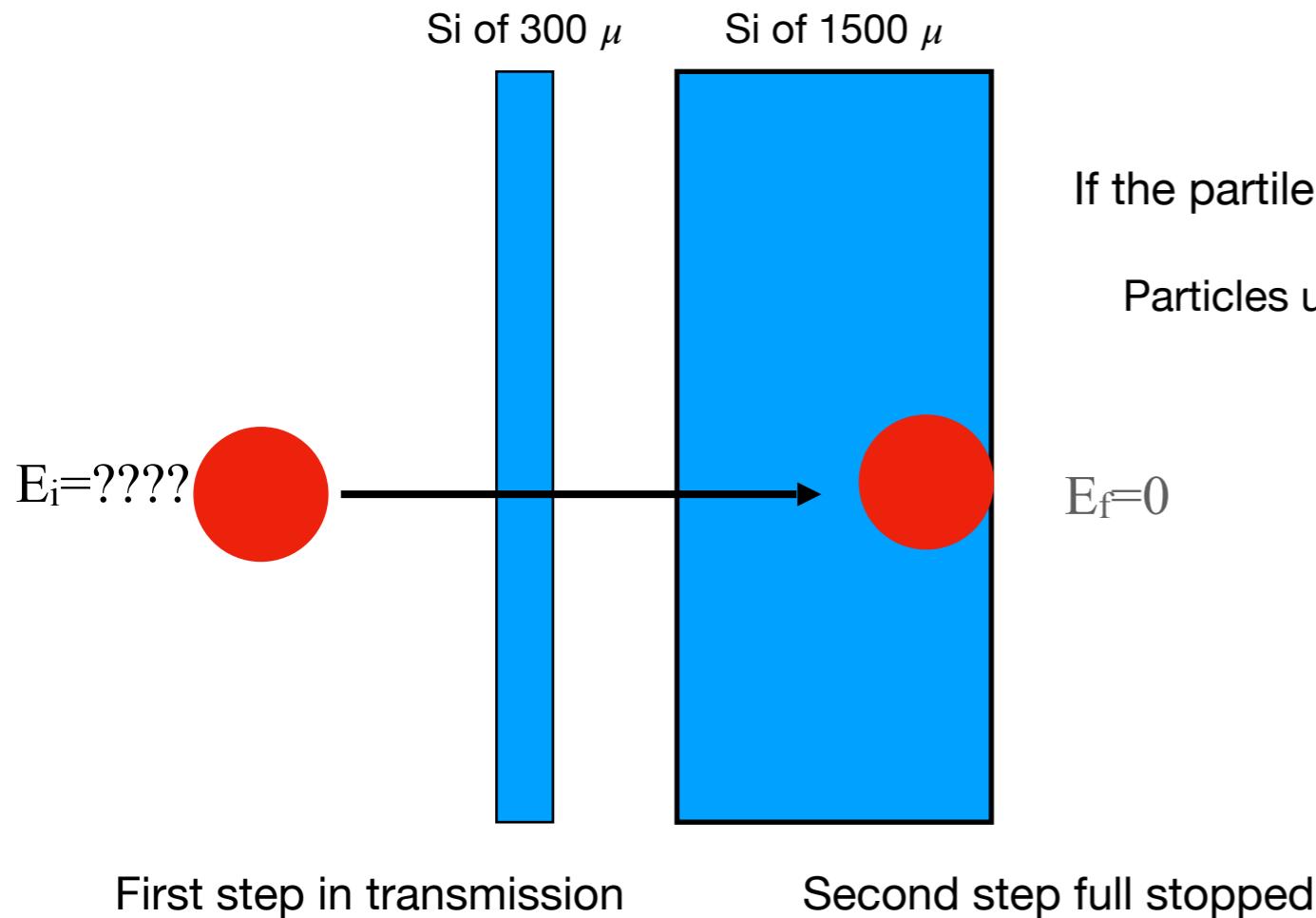
FARCOS arranged in a ring structure with $16 < \vartheta < 30$ polar angle

Only 6 analyzed for the present work



Calibration FARCOS's silicon strips in the CHIFAR EXP

Technique used: Punch Through



If the particle is arrested in $1800\ \mu$ of Silicon the initial energy E_i is known

Particles used for the calibration and their energies calculated by LISE++*

| Particle | $300\ \mu$ (MeV) | $1500\ \mu$ (MeV) | $1800\ \mu$ (MeV) |
|---------------|---------------------|----------------------|----------------------|
| ^7Li | 13,57 | 125,38 | 138,95 |
| ^7Be | 18,52 | 172,68 | 191,2 |
| ^9Be | 20,82 | 192,68 | 213,5 |

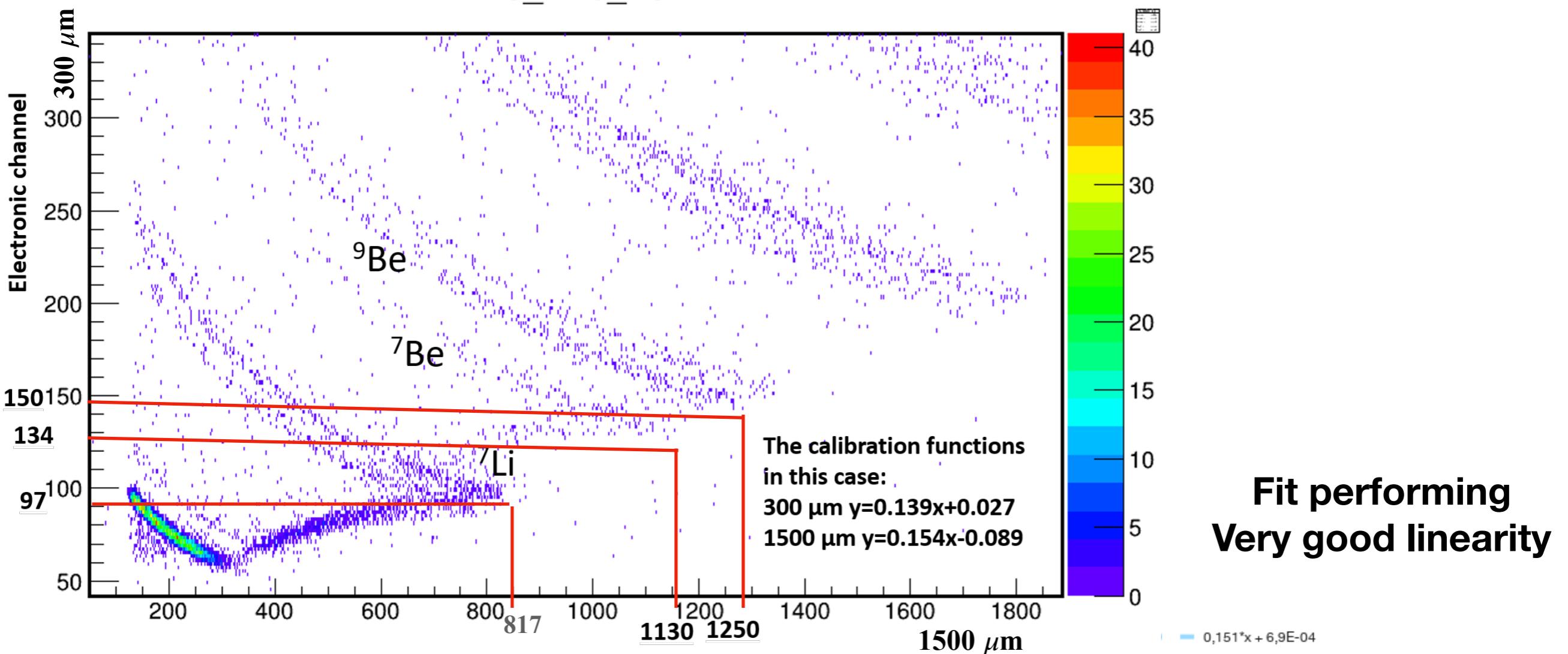
*<http://lise.nscl.msu.edu/lise.html>

1

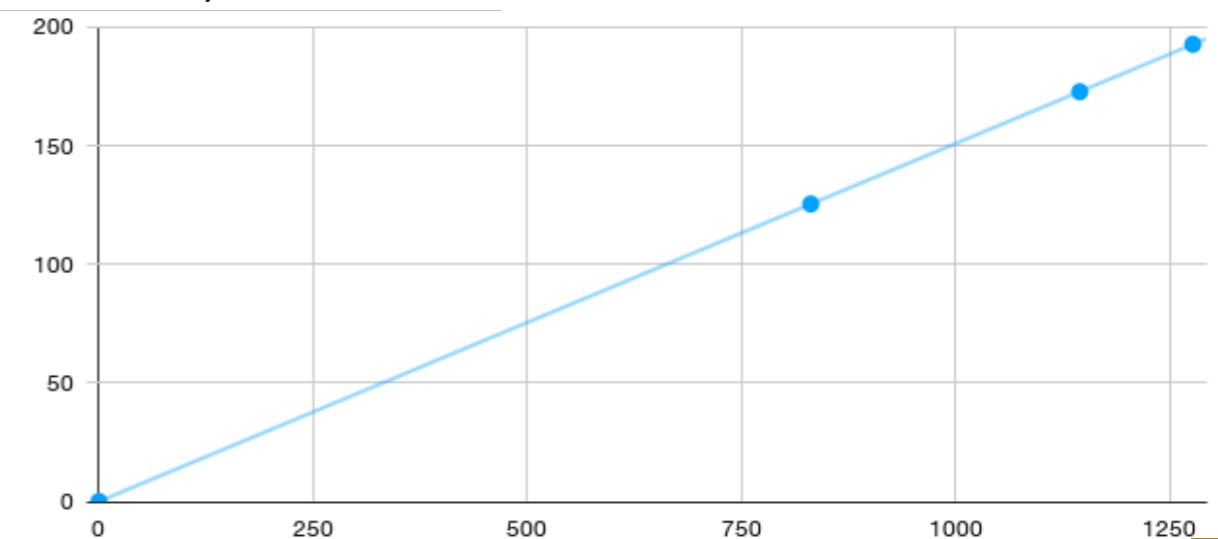
Calibration FARCOS's silicon strips in the CHIFAR EXP

Telescopes of FARCOS good and calibrated : T1, T5, T7, T8, T9, T10

T5_DE6_E6

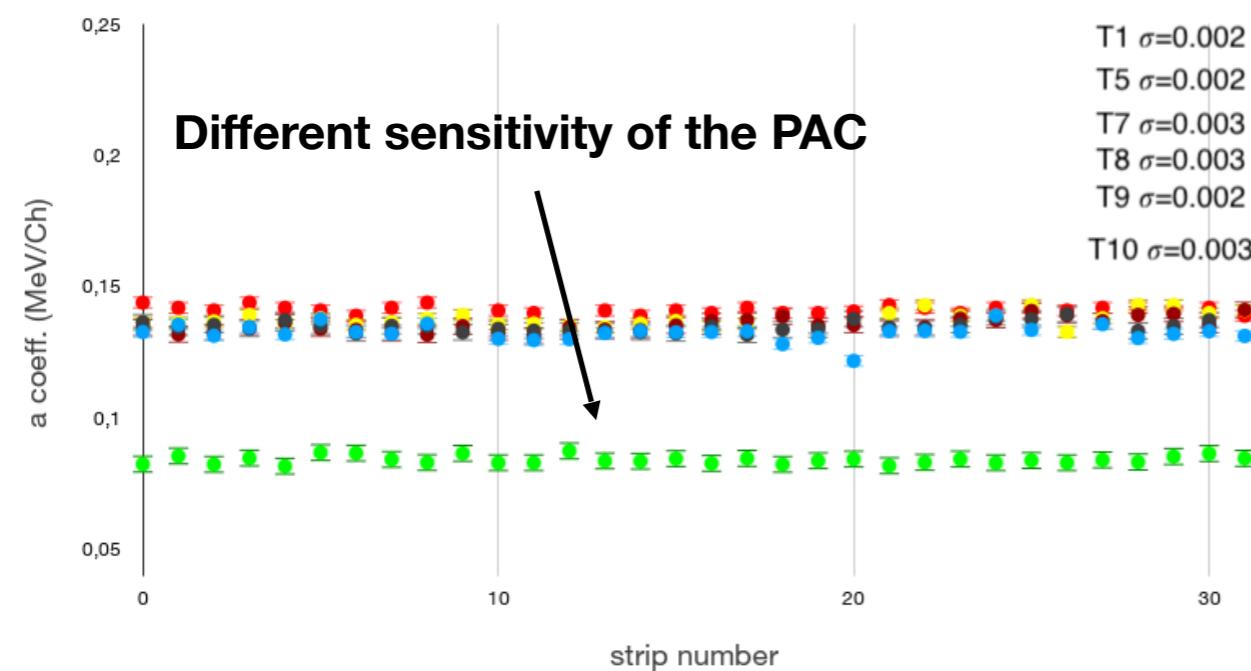


Electronic channel

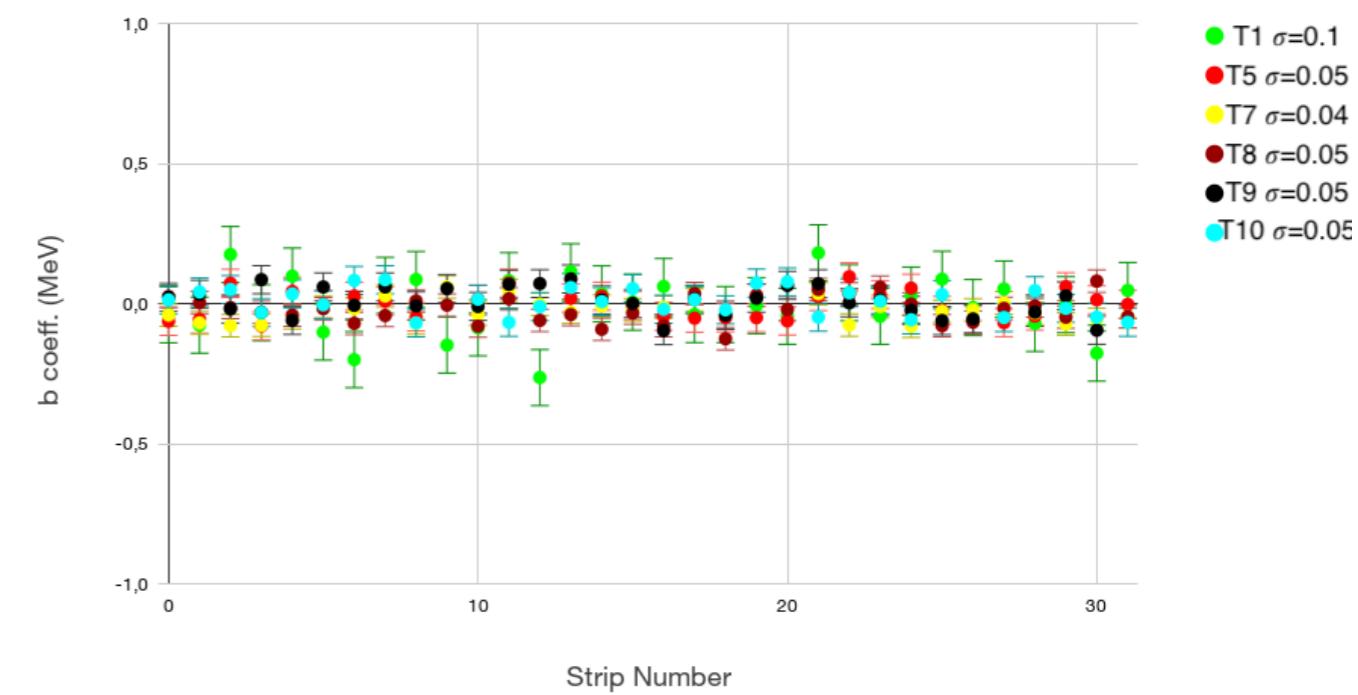


Calibration FARCOS's silicon strips in the CHIFAR EXP

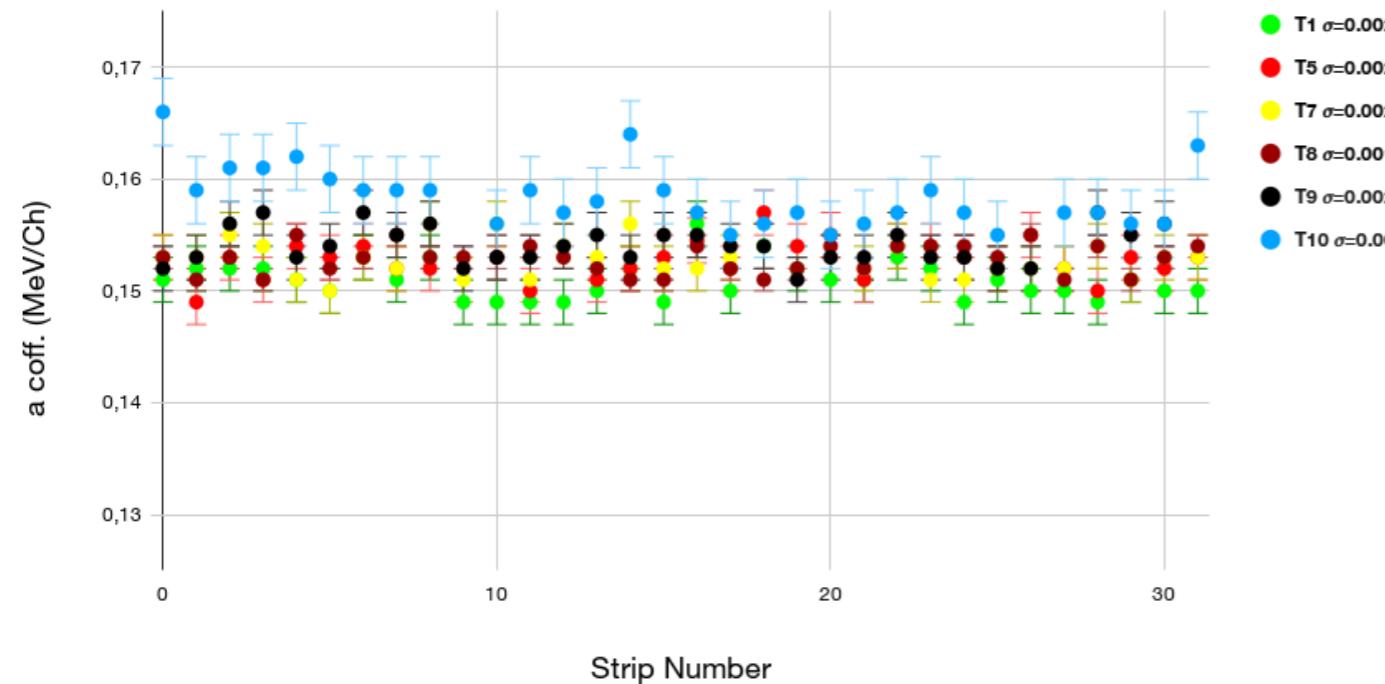
a coeff. distr. 300 um (error dev sta distr)



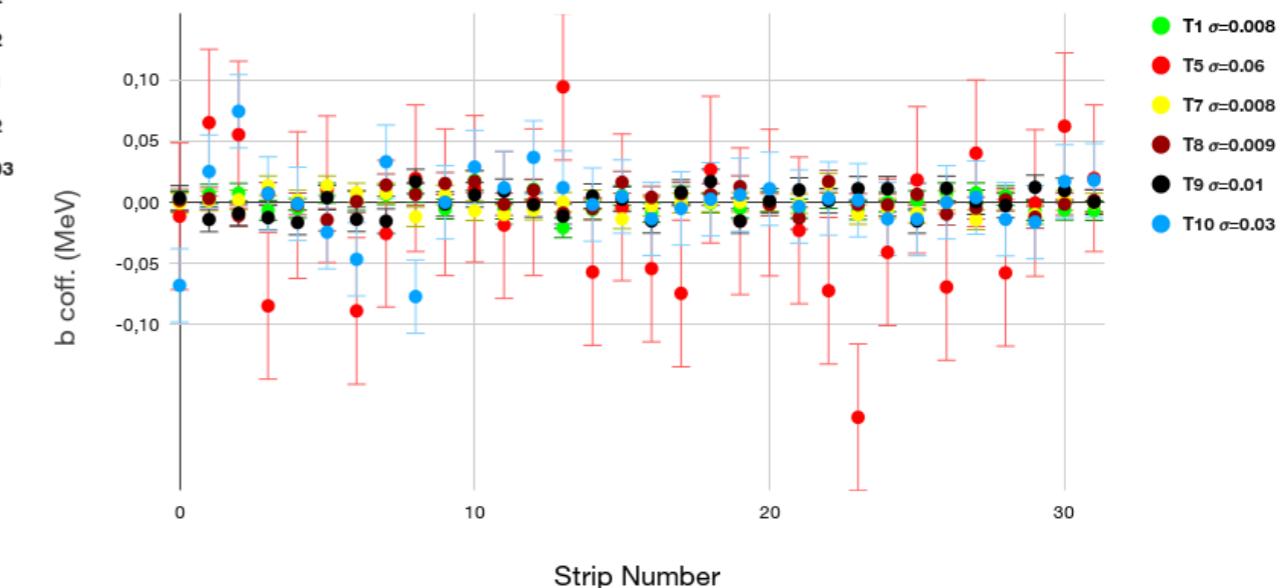
b coeff. distr. 300 um (error dev sta distr)



a coefficient distribution 1500 um (err. dev. stand. distr.)



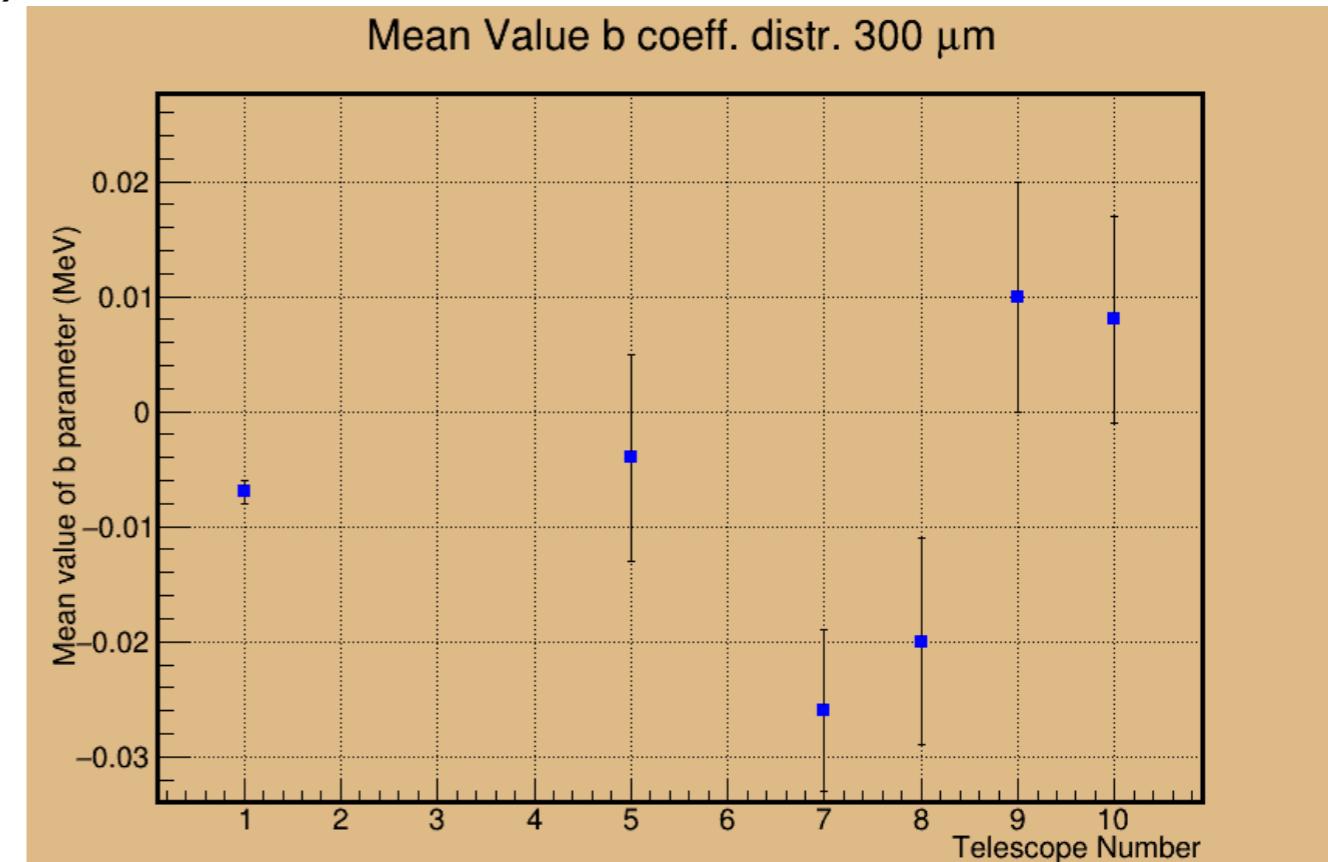
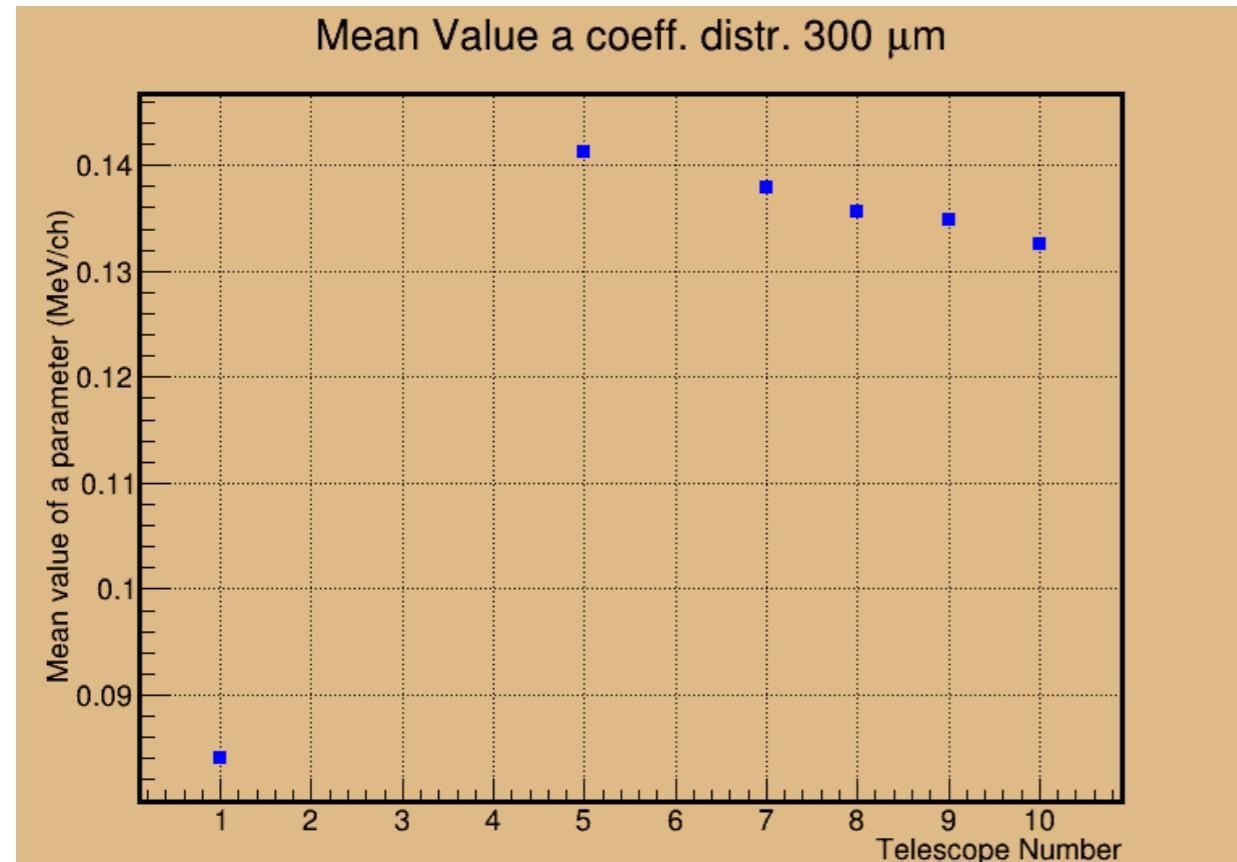
b Coeff. Distribution 1500 um (err. dev. stand. ceff.)



Calibration FARCOM's silicon strips in the CHIFAR EXP

Some global information for each telescope
Mean parameters value distribution

300 μm



| Telescope | T1 | T5 | T7 | T8 | T9 | T10 |
|---------------------|------|-------|-------|-------|-------|-------|
| Mean Value (keV/ch) | 84,1 | 141,3 | 137,9 | 135,6 | 134,8 | 132,5 |
| Error (kev/ch) | 0,3 | 0,3 | 0,3 | 0,5 | 0,4 | 0,6 |
| Error (%) | 0,36 | 0,21 | 0,22 | 0,37 | 0,30 | 0,45 |

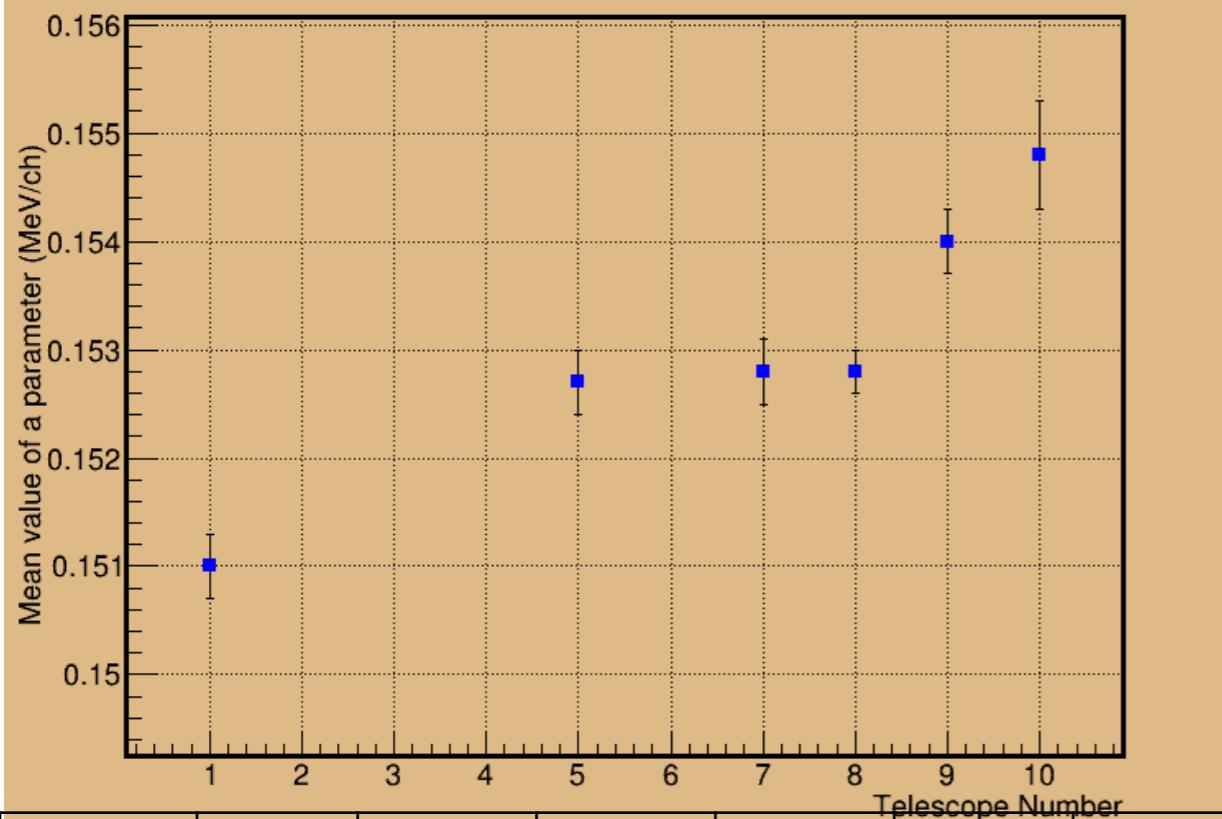
| Telescope | T1 | T5 | T7 | T8 | T9 | T10 |
|------------------|----|-----|-----|-----|-----|-----|
| Mean Value (keV) | -7 | -4 | -26 | -21 | 10 | 8 |
| Error (kev) | 1 | 9 | 7 | 9 | 10 | 9 |
| Error (%) | 14 | 225 | 27 | 43 | 100 | 112 |

Calibration FARCOM's silicon strips in the CHIFAR EXP

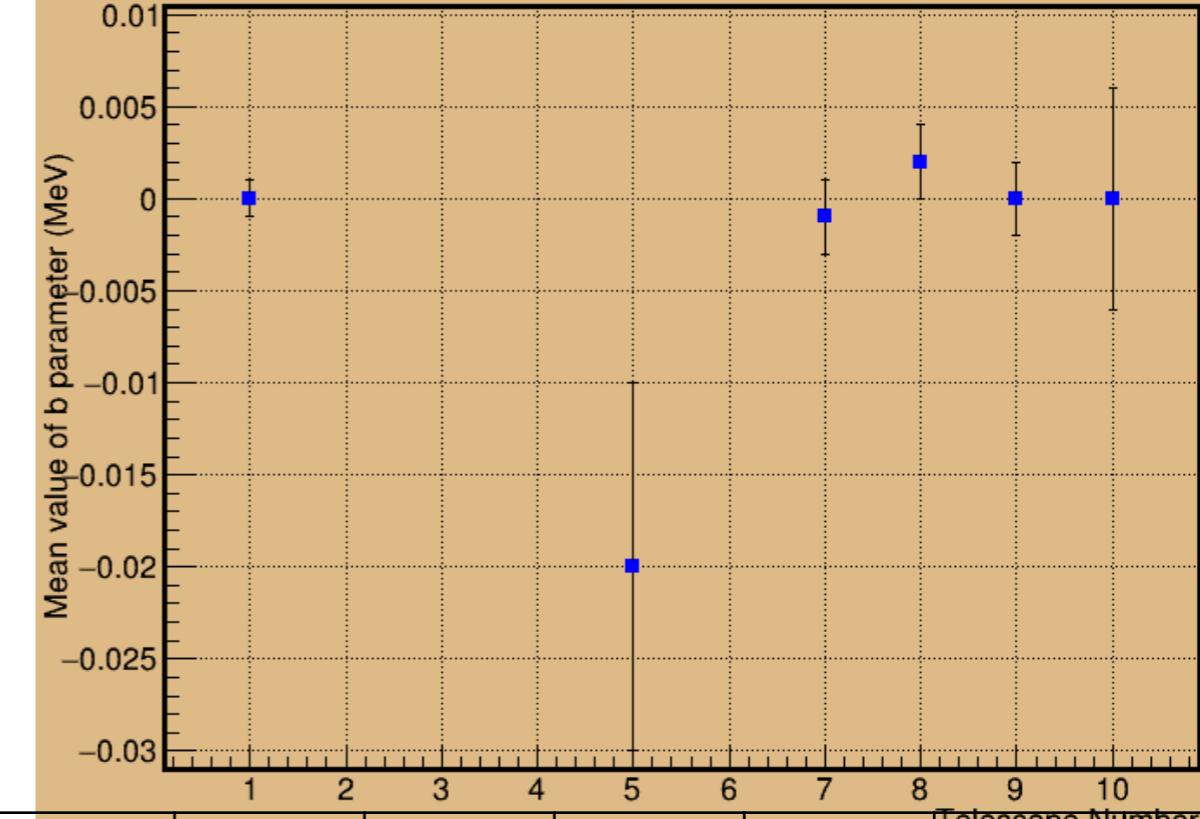
Some global information for each telescope
Mean parameters value distribution

1500 μm

Mean Value a coeff. distr. 1500 μm



Mean Value b coeff. distr. 1500 μm



| Telescope | T1 | T5 | T7 | T8 | T9 | T10 |
|------------------|-------|-------|-------|-------|-------|-------|
| Mean Value (keV) | 151,0 | 152,7 | 152,8 | 152,8 | 154,0 | 158,4 |
| Error (kev) | 0,3 | 0,3 | 0,3 | 0,2 | 0,3 | 0,5 |
| Error (%) | 0,2 | 0,2 | 0,2 | 0,1 | 0,2 | 0,3 |

| Telescope | T1 | T5 | T7 | T8 | T9 | T10 |
|------------------|----|-----|-----|-----|----|-----|
| Mean Value (keV) | 0 | -20 | -1 | -2 | 0 | 0 |
| Error (kev) | 1 | 10 | 2 | 2 | 2 | 6 |
| Error (%) | / | 50 | 200 | 100 | / | / |

Calibration FARCOS's silicon strips in the CHIFAR EXP

Some global information for each telescope

PAC sensitivity of $300 \mu\text{m}$ and $1500 \mu\text{m}$

$300 \mu\text{m}$

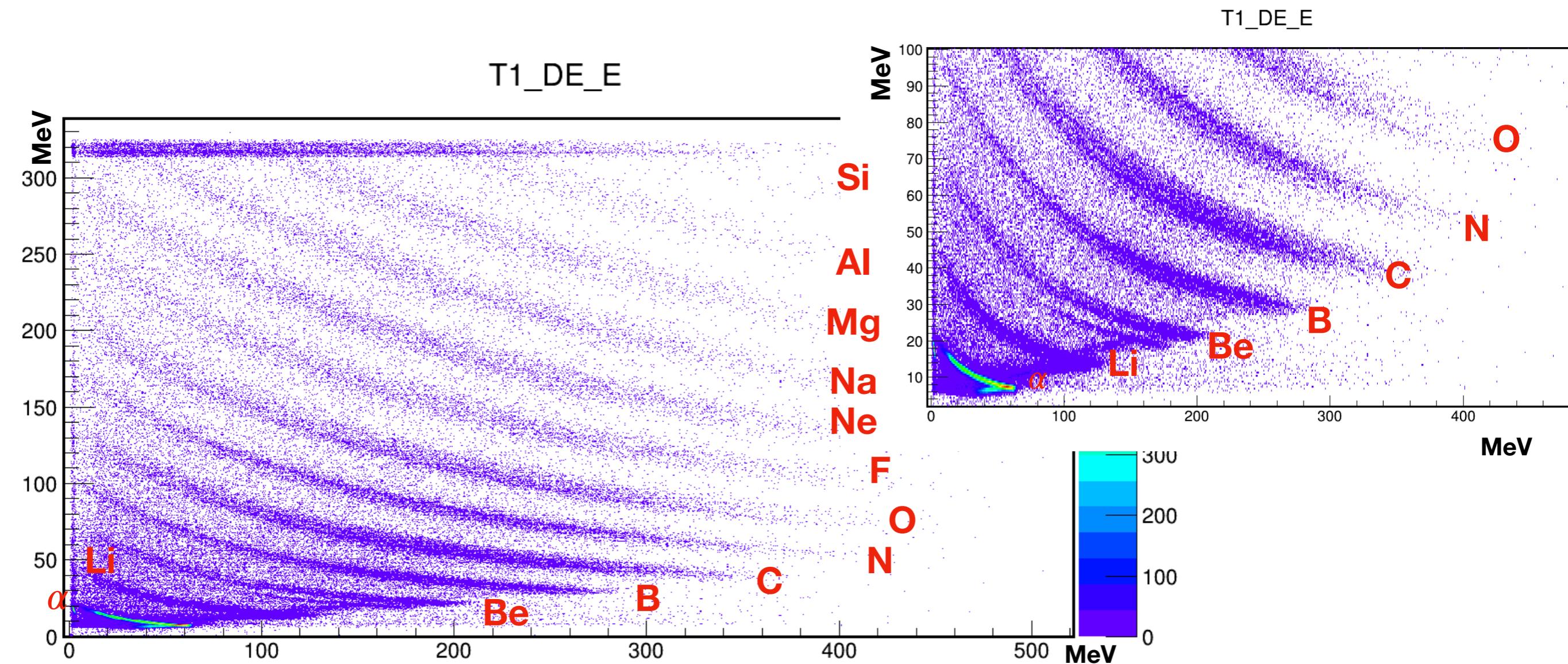
$1500 \mu\text{m}$

| Telescope | Nominal sensitivity (keV/ch) | Nominal max (MeV) | Exp. sensitivity (keV/ch) | Exp. max (MeV) |
|-----------|------------------------------|-------------------|---------------------------|----------------|
| T1 | 61 | 250 | 84,1 | 345 |
| T5 | 122 | 500 | 141,3 | 579 |
| T7 | 122 | 500 | 137,9 | 565 |
| T8 | 122 | 500 | 135,6 | 555 |
| T9 | 122 | 500 | 134,8 | 552 |
| T10 | 122 | 500 | 132,5 | 543 |

| Telescope | Nominal sensitivity (keV/ch) | Nominal max (MeV) | Exp. sensitivity (keV/ch) | Exp. max (MeV) |
|-----------|------------------------------|-------------------|---------------------------|----------------|
| T1 | 122 | 500 | 151 | 619 |
| T5 | 122 | 500 | 152,7 | 626 |
| T7 | 122 | 500 | 152,8 | 626 |
| T8 | 122 | 500 | 152,8 | 626 |
| T9 | 122 | 500 | 154 | 631 |
| T10 | 122 | 500 | 158,4 | 649 |

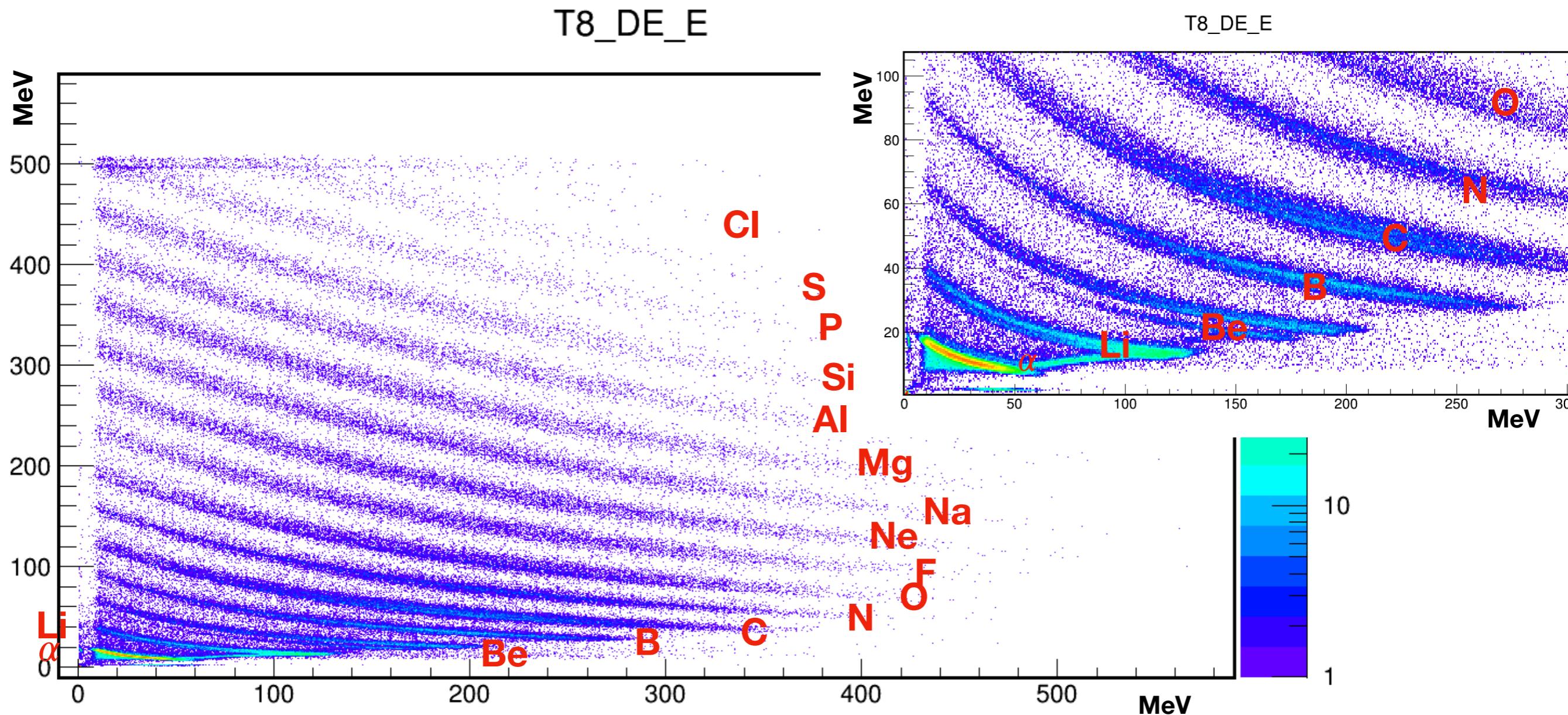
Calibration FARCOS's silicon strips in the CHIFAR EXP

All the strips of the T1 except n° 0 and n°31



Calibration FARCOS's silicon strips in the CHIFAR EXP

All the strips of the T8 except n° 0 and n°31



Calibration FARCOS's silicon strips in the CHIFAR EXP

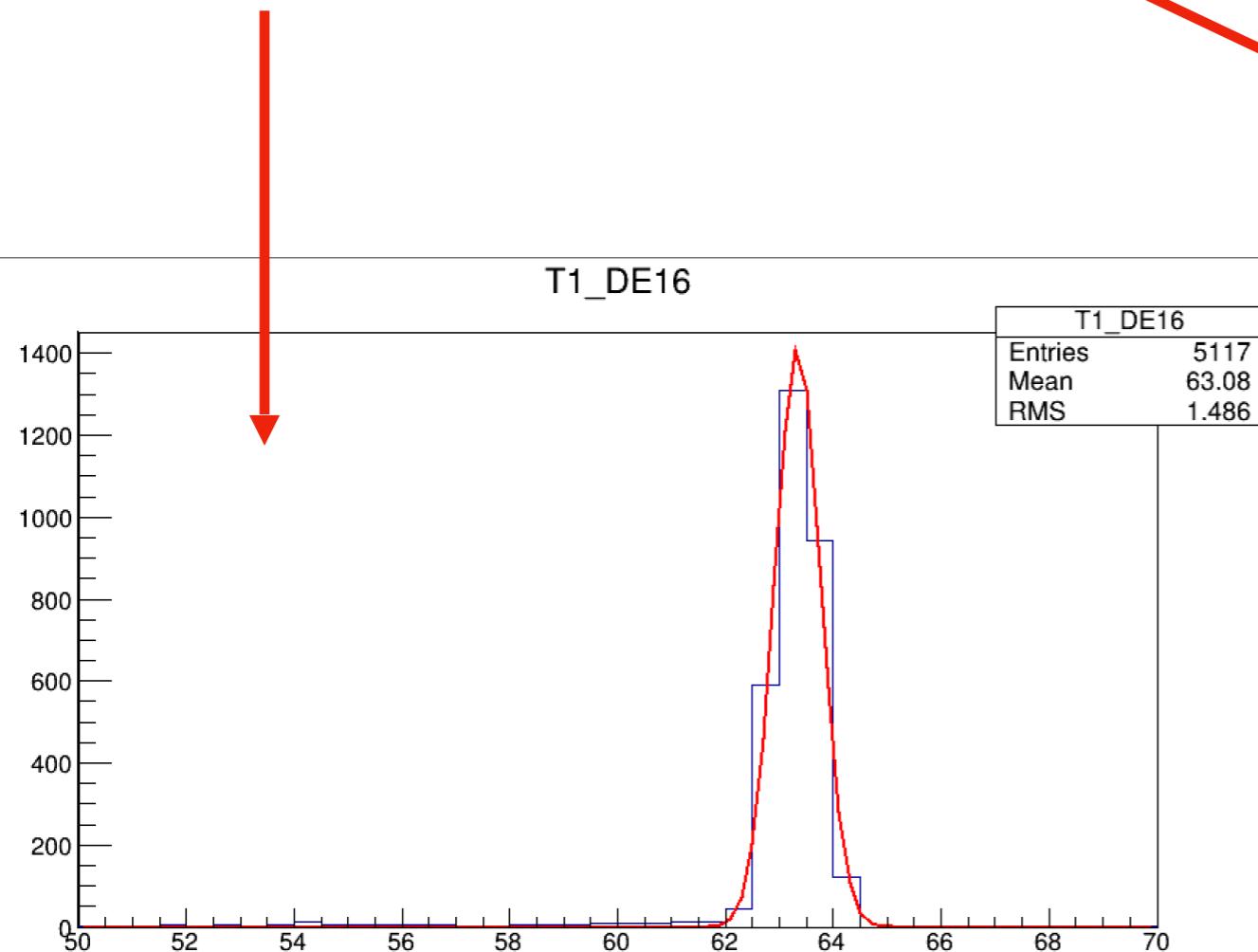
Energy resolution evaluated on elastic scattering for the $300\mu\text{m}$
For each telescope was take into account four strips (4,16,22,29).

O + Au @ 85 MeV (Tandem beam)

C + Au @ 75 MeV (Tandem beam)

C + Au @ 65 MeV (Tandem beam)

preliminary



| Telescope | Mean (MeV) | σ (MeV) | FWHM (MeV) | Risolution of FWHM (%) |
|-----------|------------|----------------|------------|------------------------|
| T1 | 62,9 | 0,4 | 1 | 1,6 |
| T5 | 64,4 | 0,5 | 1,17 | 1,8 |
| T7 | 60,7 | 0,65 | 1,5 | 2,5 |
| T8 | 60 | 0,58 | 1,37 | 2,3 |
| T9 | 60,9 | 0,61 | 1,44 | 2,4 |
| T10 | 58,7 | 0,47 | 1,11 | 1,9 |

Calibration FARCOS's silicon strips in the CHIFAR EXP

Energy resolution evaluated on elastic scattering for the $300\mu\text{m}$

For each telescope was take into account four strips (4,16,22,29).

Estimation of electronic error in FWHM

$$\text{FWHM}^2 = a * E + b$$

preliminary

Where

FWHM: is the mean value of the telescope

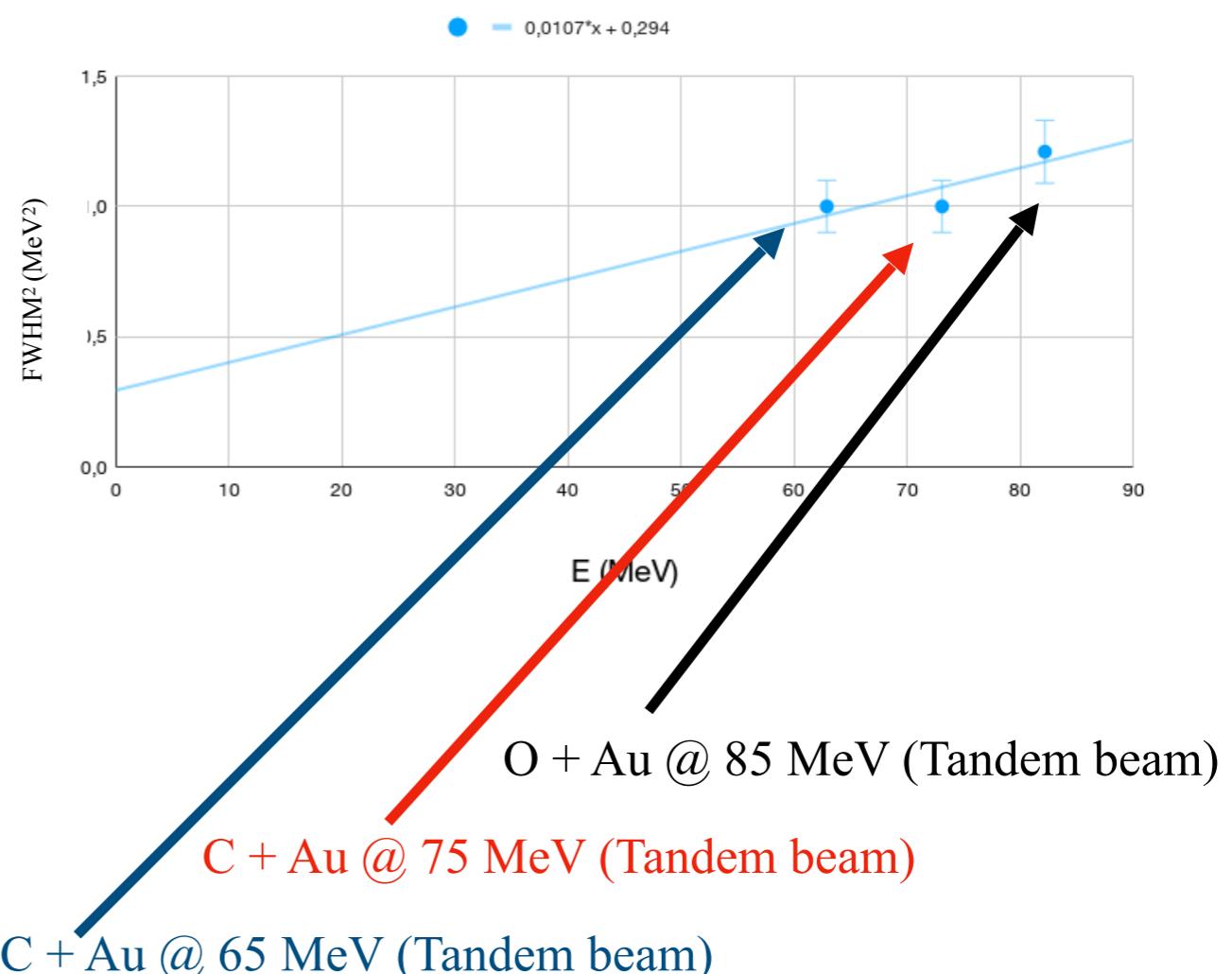
E: energy mean value of the telescope

Parameter a: differential increasing of FWHM
as a function of E

Parameter b: Square of the electronic error
of the telescope calculated on FWHM

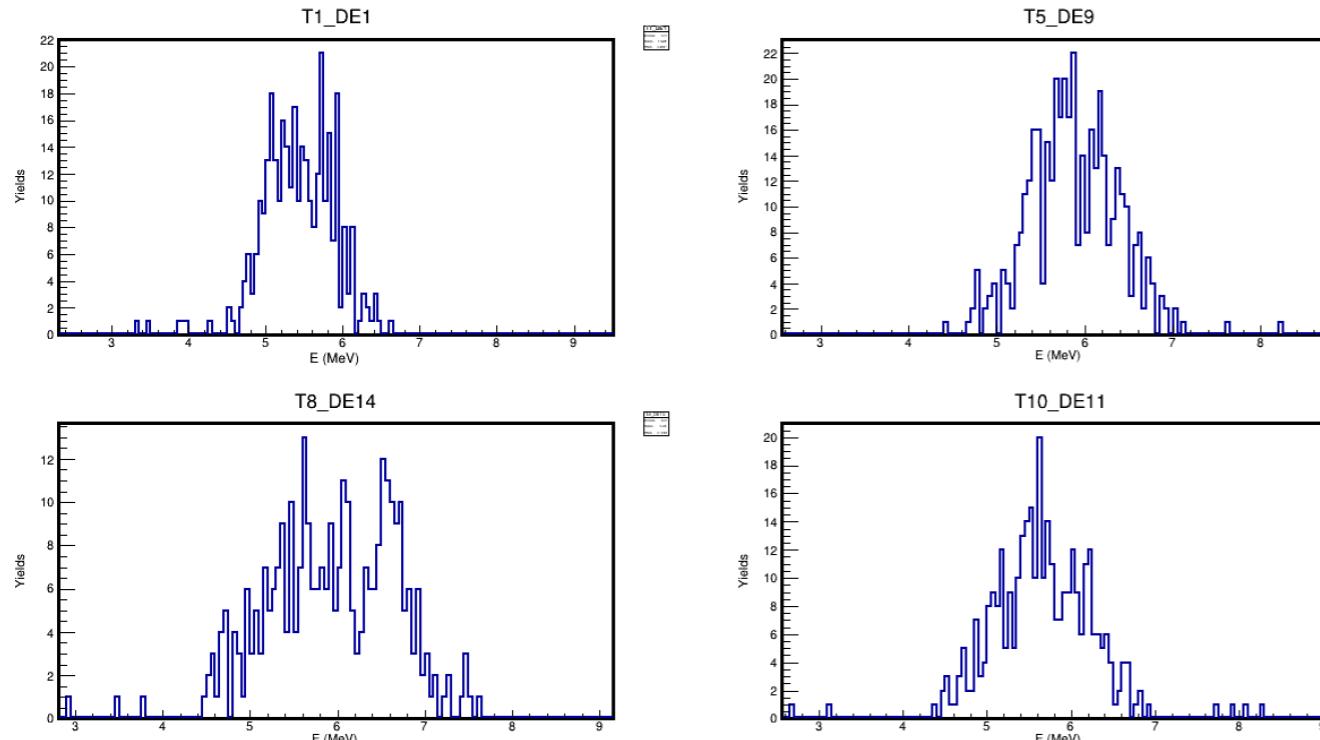
| Telescope | Electron error (keV) | $\partial(\text{FWHM})/\partial E$ (keV) |
|-----------|----------------------|--|
| T1 | 540 | 10,7 |
| T5 | 854 | 9,4 |
| T7 | 1200 | 17,1 |
| T8 | 799 | 20,1 |
| T9 | 711 | 26,9 |
| T10 | 693 | 11 |

T1 Experimental curve of FWHM^2 as a function of E



Calibration FARCOS's silicon strips in the CHIFAR EXP

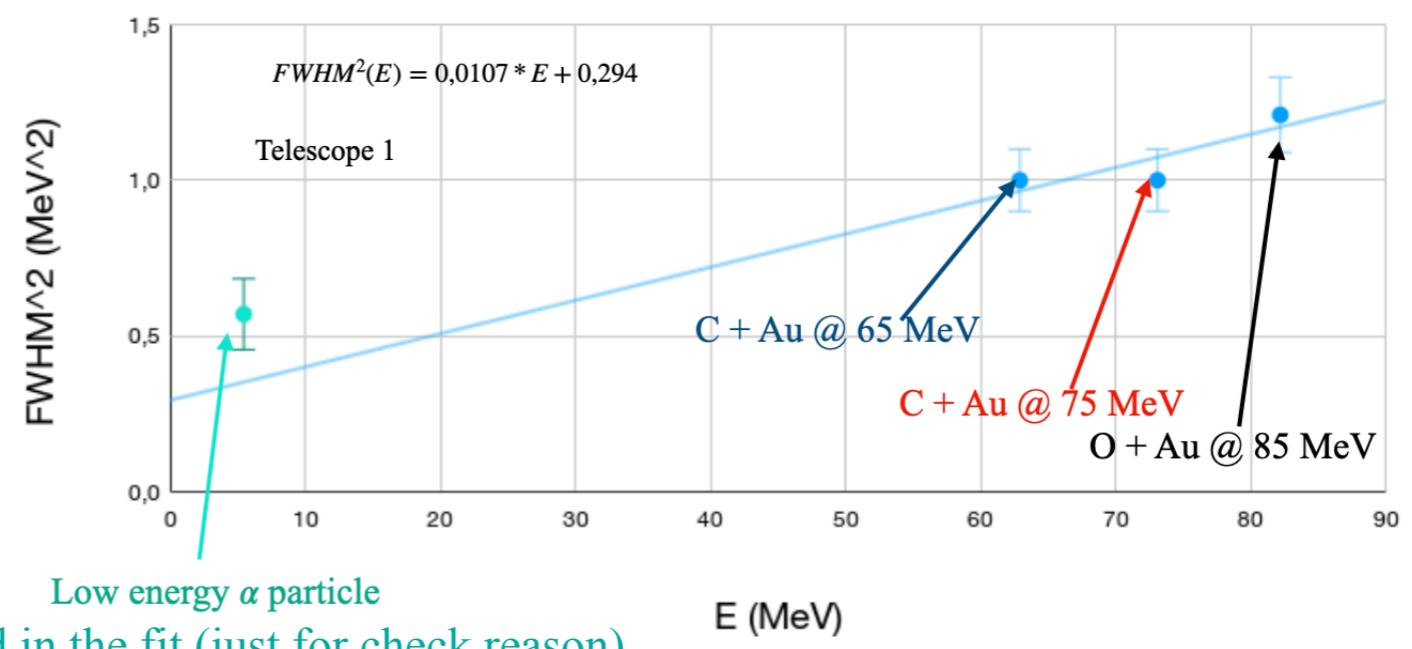
Calibration check and Energy resolution evaluated on alpha particles
300 μ m



preliminary

Due to the PAC sensitivity we can only detect
a convolution of the three alpha picks

5.156 MeV
5.586 MeV
5.902 MeV



Conclusions 2

- Studied the calibration of the DSSSD of FARCOS in final configuration:
 - Good linearity in energy calibration and possible to add all the strips in one identification matrix
 - The DSSSD total resolution is between 1 and 2 MeV (1.5 - 2.5% FWHM) evaluated only in the 300 μm
 - In the most of the case the resolution is equal shared between the detector and the electronic
- The PAC sensitivity not allow to resolve the three alpha source picks but we can say that:
 - the convoluted energy spectra is in the energy right place
 - There are not systematic errors in the energy calibration
 - The resolution at low channels is dramatic dominated by the electronic (with sensitivity used in CHIFAR exp)

What next

- Identification of the particles
- Pixelatation (determination of the position of the particles)
- Calibrations and identification of light particles in the CsI(Tl)
- Integration of the FARCOS data with the CHIMERA ones

Thanks for the attention