CHI-NEXT (2026-2028) Collaboration

SYMEOS - A Trip to FRIB with FARCOS and NARCOS

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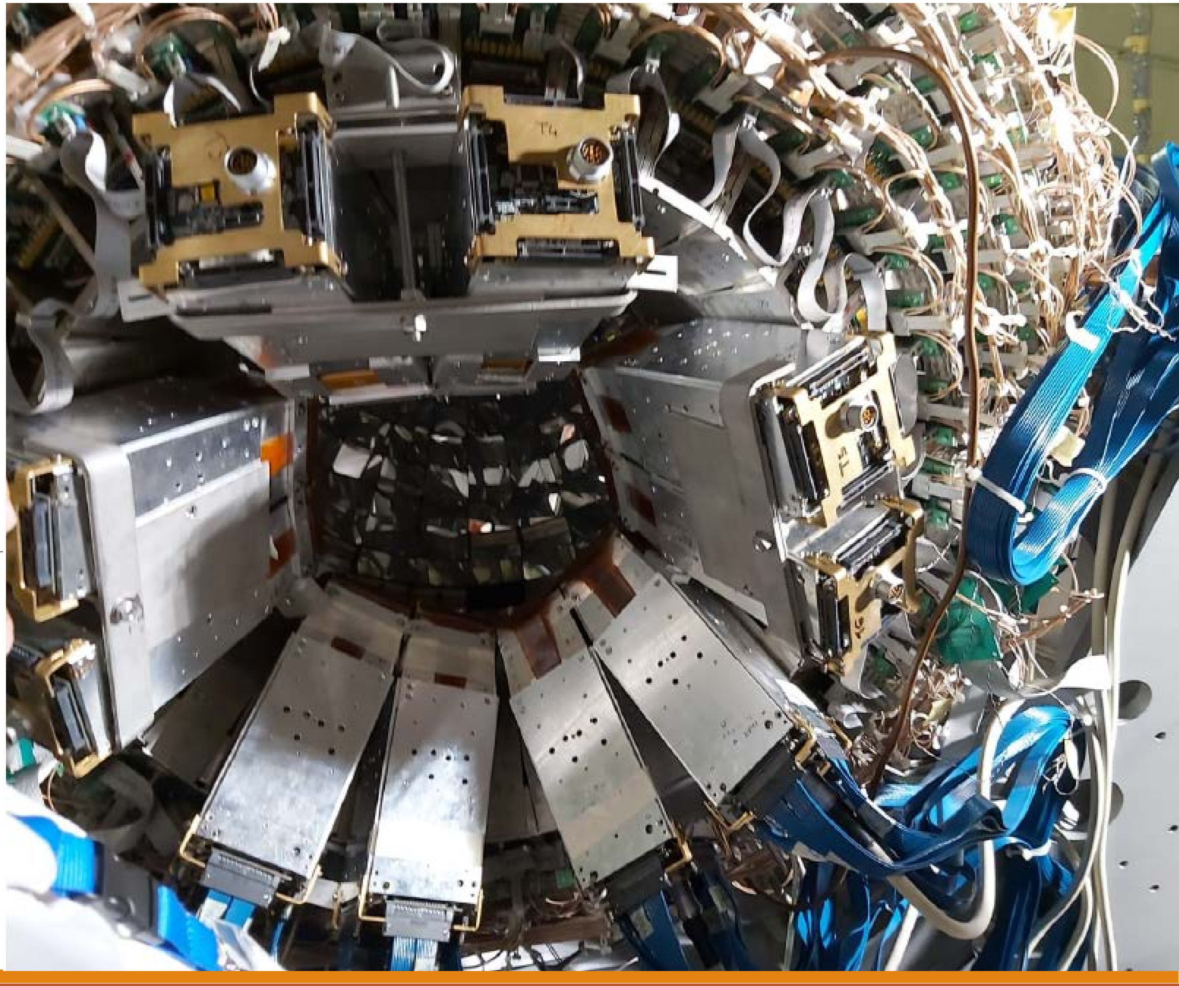
NUSDAF 2025

1st Collaboration Meeting on NUclear Structure, Dynamics and Astrophysics at FRIB

FARCOS

Femtoscope ARray for COrrelation and Spectrosopy



FARCOS detection system: a new correlator for spectroscopy and nuclear reactions

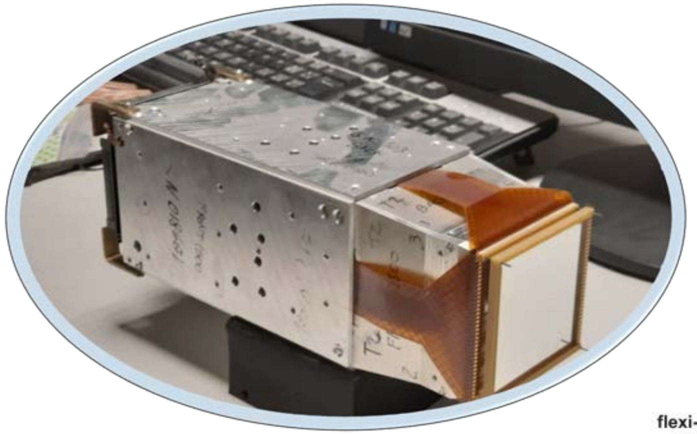
HICs at intermediate energy regime $[10\ MeV/A < E/A < 100]$: open questions in nuclear physics..?!?

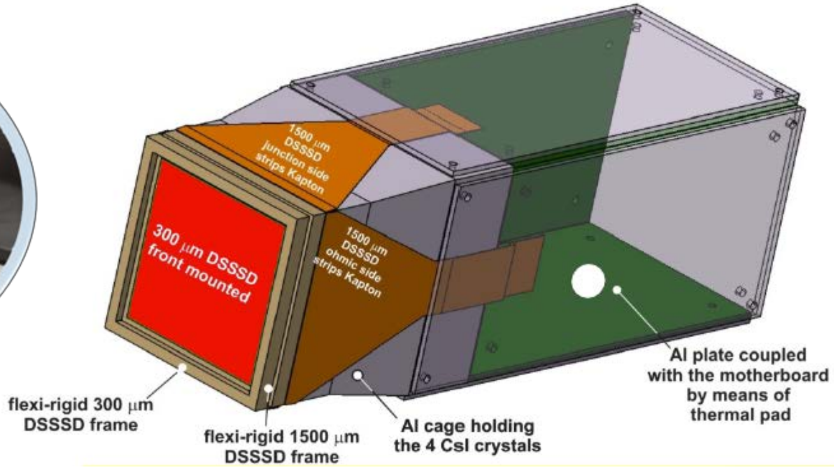
- the study of the **density dependence** of the symmetry energy, for the **Equation of State** of the nuclear matter
- **two-particle correlations** at low and intermediate energies, to investigate the emission times of particles and size of an emitting source with large isospin N/Z asymmetries
- **Nuclear structure and reaction mechanism**: **exotic nuclei** are also produced in the HICs; the measurements of observables, such as **linear momentum and energy**, of the detected particles permit to reconstruct the parent nucleus and its spectroscopic features, in areas of interest also common to nuclear astrophysics.
- **Direct reactions** with stable and radioactive beams, to probe exotic nuclei in inverse kinematics.
- **Bose condensate states** in nuclei, which can be identified by the emission of alpha particles.

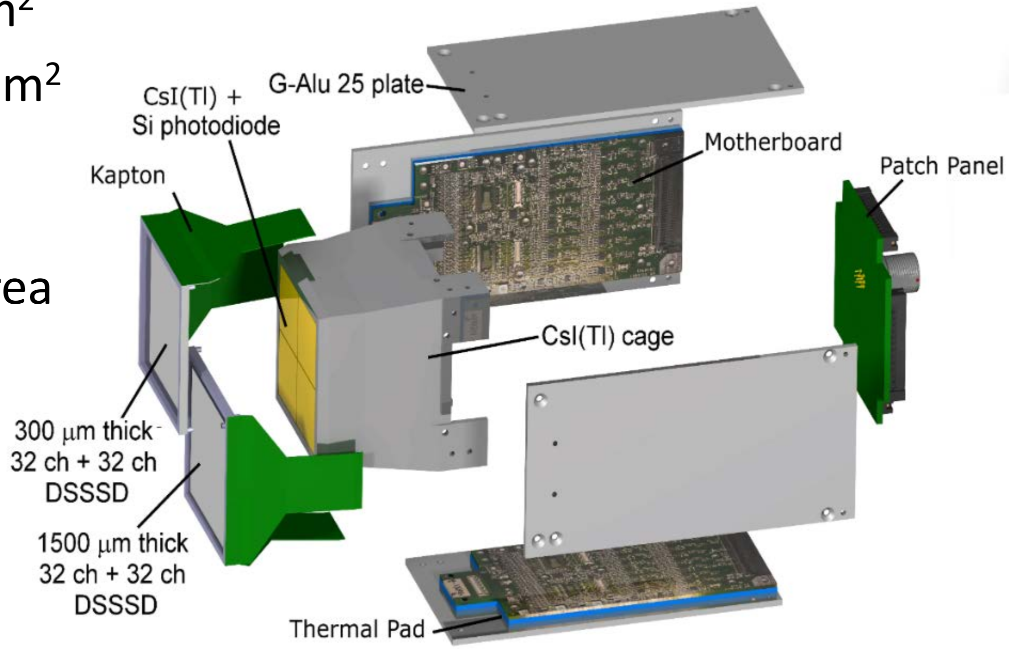
FARCOS detection system: a new correlator for spectroscopy and nuclear reactions

- modular structure of each telescope, with 3 detection stages:
  - ➢ DSSSD (32 x 32 strips), 300 μm thick, active area of 6.4 x 6.4 cm^2
  - ➢ DSSSD (32 x 32 strips), 1500 μm thick, active area of 6.4 x 6.4 cm^2
  - ➢ 4 CsI(Tl) scintillators, 6 cm thick, active area of 3.2 x 3.2 cm^2

  - ❖ output electronic signal read by Si photodiode, 18 x 18 mm^2 area

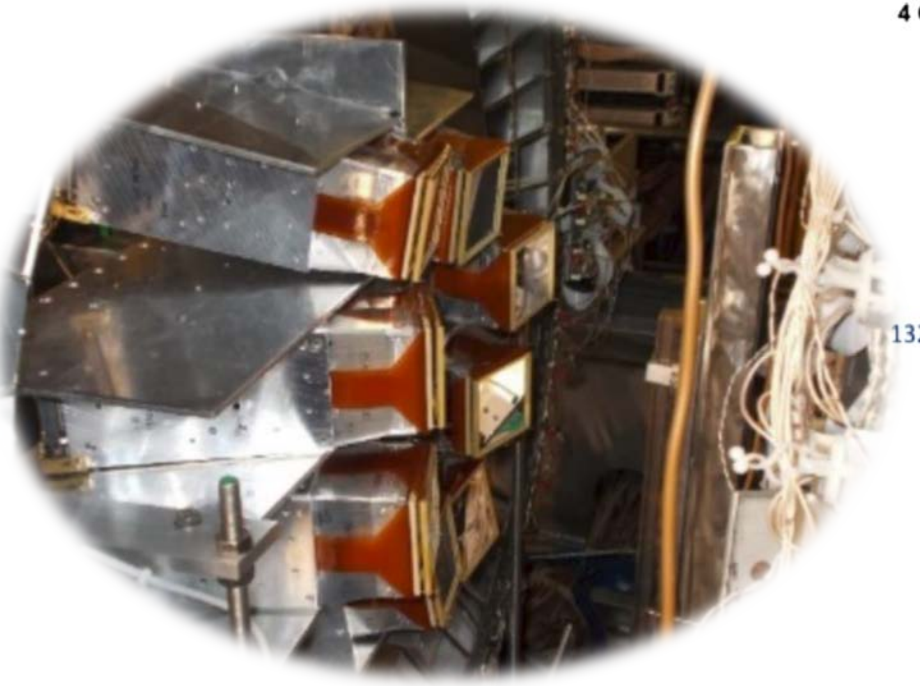


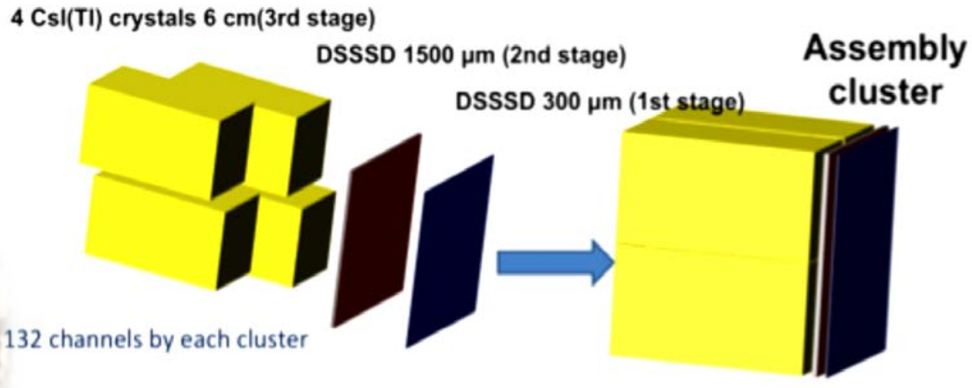


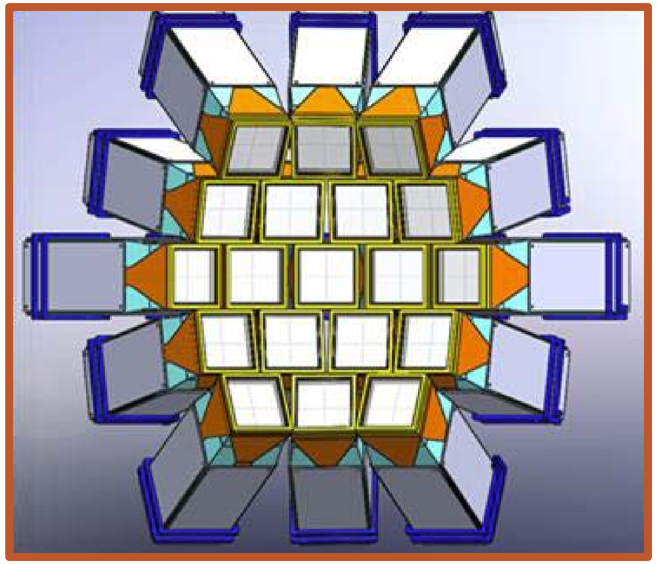


L. Acosta *et al.*, 2017 IEEE Nuclear Science Symposium (NSS) and Medical Imaging Conference (MIC), pp. 1– 4 (2017)

FARCOS detection system: a new correlator for spectroscopy and nuclear reactions







- 20 telescopes in its final configuration:

✓ high **energy** and **angular resolution**

✓ high **portability**, couplable with other 4π detectors such as CHIMERA

✓ designed to investigate two/multi-particle and Intermediate Mass Fragments (IMFs) correlations in HICs at Fermi energies

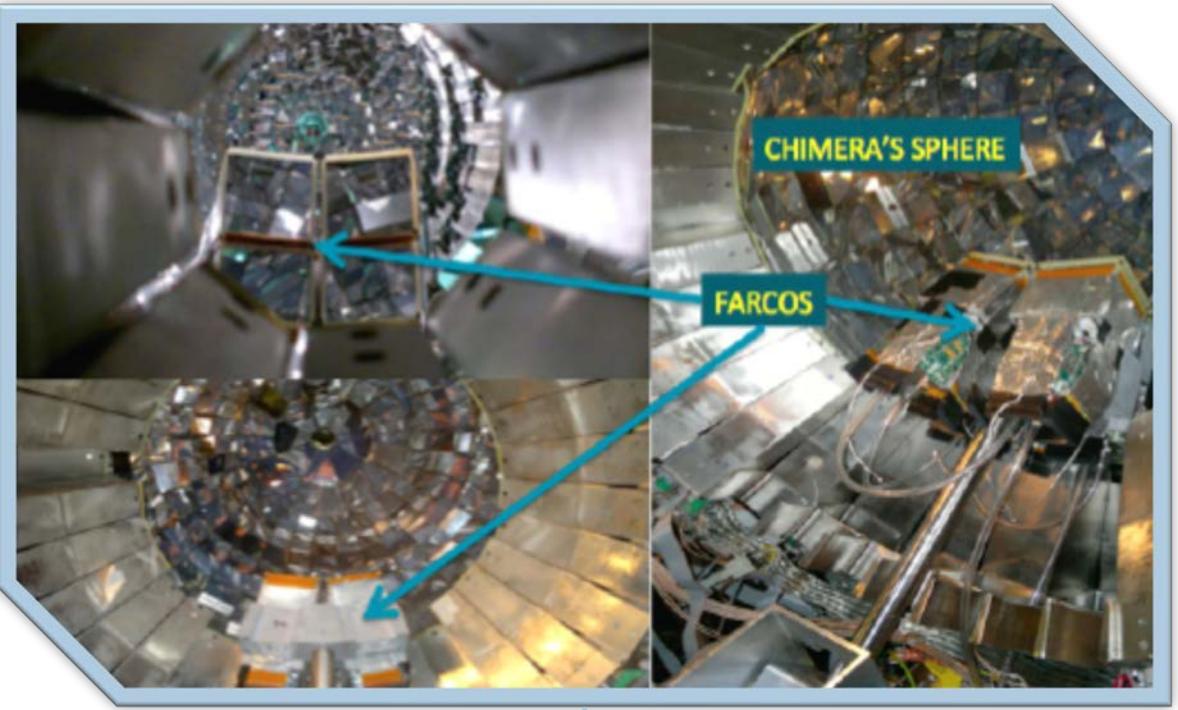
INFN LNS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Sud

INFN CATANIA Istituto Nazionale di Fisica Nucleare Sezione di Catania

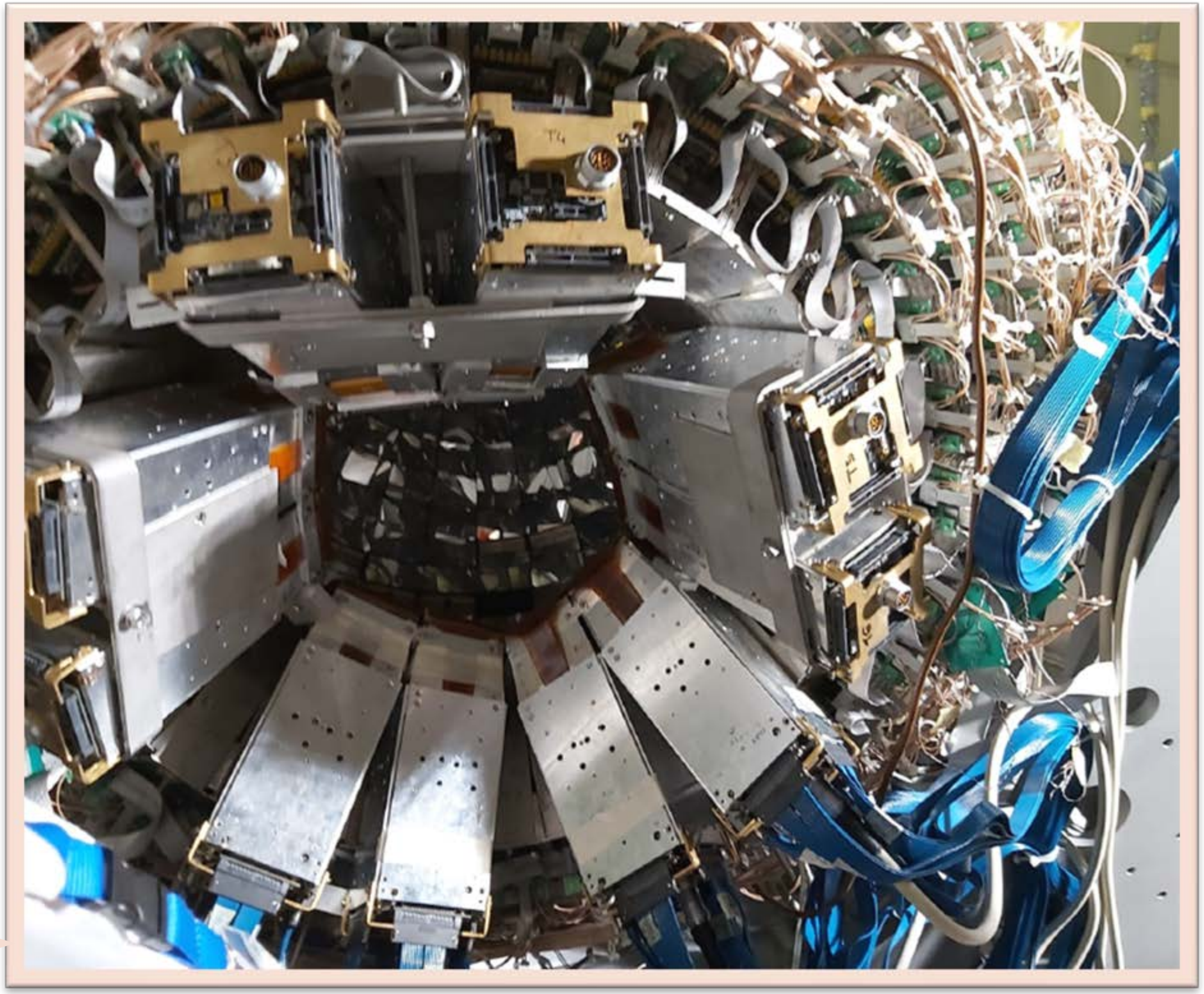
INFN MILANO Istituto Nazionale di Fisica Nucleare Sezione di Milano

FARCOS detection system: a new correlator for spectroscopy and nuclear reactions

E.V. Pagano *et al.*, EPJ Web of Conferences (2016) 117:10008



4 FARCOS telescopes used in the InKiIsSy experiment

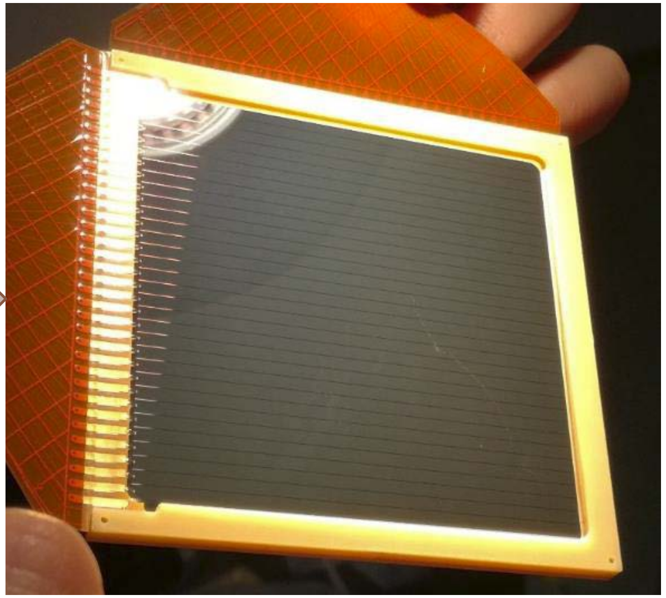


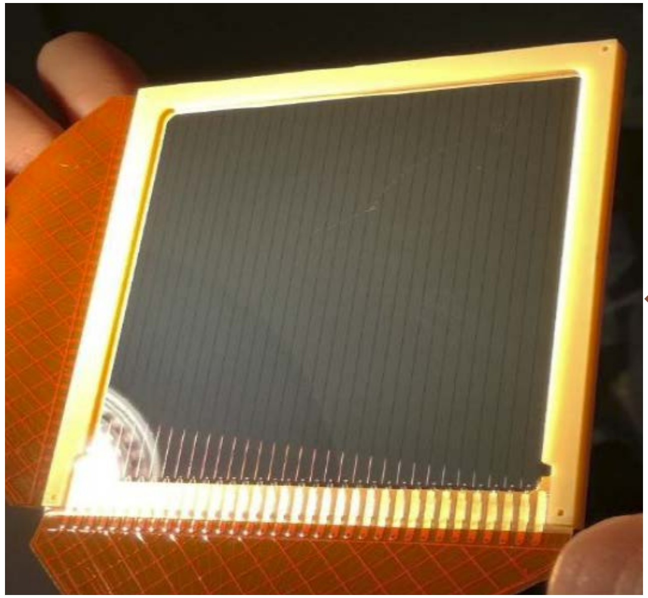
10 FARCOS telescopes used in the CHIFAR experiment

➢FARCOS correlator in the experimental setup: DSSSDs for the "pixelation technique"...

Double **S**ided **S**ilicon **S**trip **D**etector (DSSSD), featuring strips on both sides, enables **precise particle positioning** while significantly reducing the required number of readout electronics channels.

Front side of a DSSSD, with 32 horizontal strips





Back side of a DSSSD, with 32 vertical strips

DSSSDs have become excellent instruments capable of collecting particles with very high energy and angular resolution, thanks to their segmentation into strips.

➢ FARCOS correlator in CHIFAR experiment: the "pixelation technique"

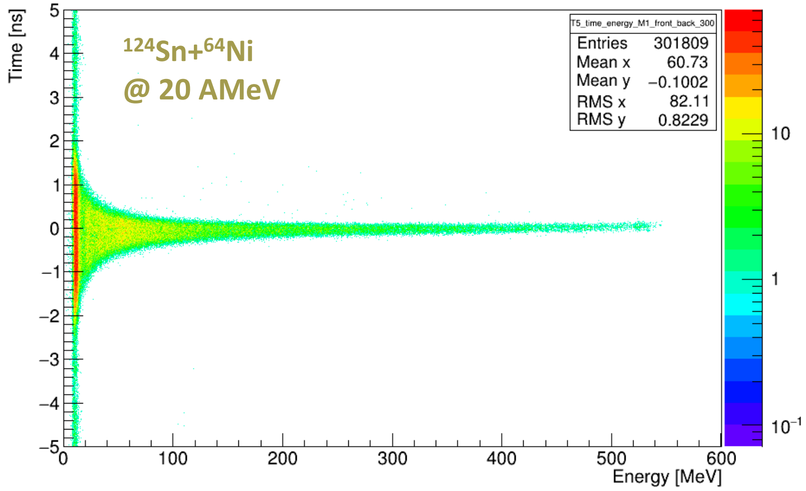
PRELIMINARY ANALYSIS

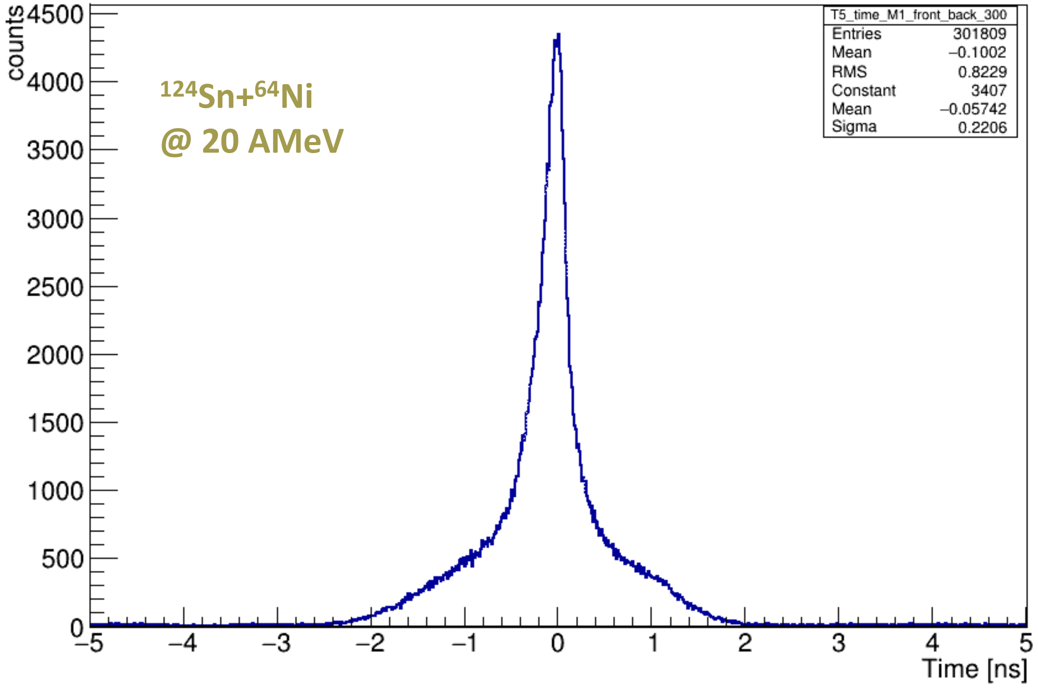
assignment for each detected particle of its position in the DSSSD (300 μm thick)

Experimental constraints to select only "true particles":

- particle multiplicity
  - **≤ 2** for Si−300 μm, front and back;
  - **≤ 2** for Si−1500 μm, front;
  - < 4 for Si−1500 μm, back;
  - = 0 for CsI(Tl)
- 85% $\Delta E_{back} < \Delta E_{front} <$ 115% ΔE_{back} (7σ)
- N_{strip} (300 μm) = N_{strip} (1500 μm) || N_{strip} (300 μm) = N_{strip} (1500 μm) ±1

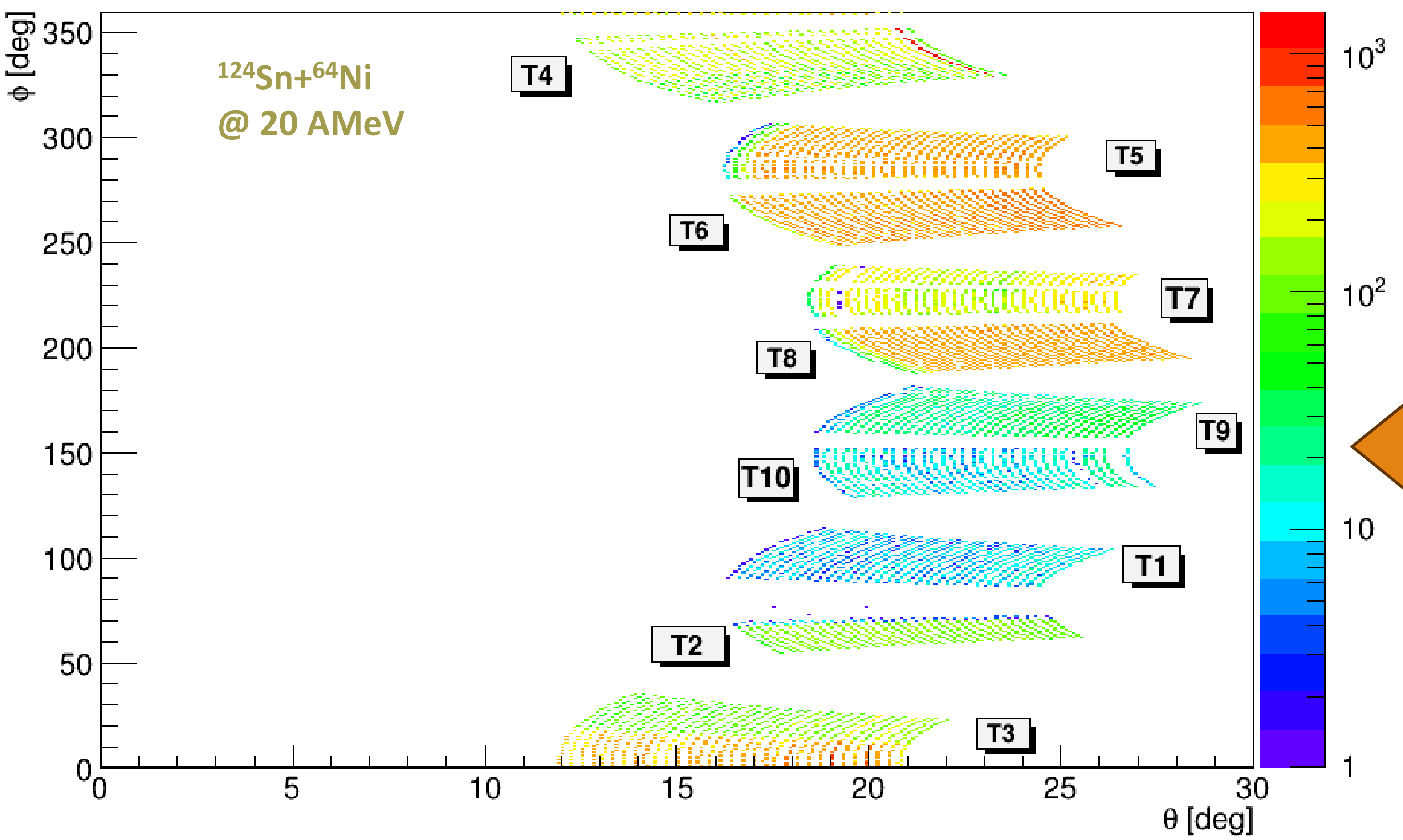
«DETECTION TIME» variable:





unphysical events (noise, spurious coincidences) are excluded thanks to the timing analysis

➢FARCOS correlator in the experimental setup: DSSSDs for the "pixelation technique"…

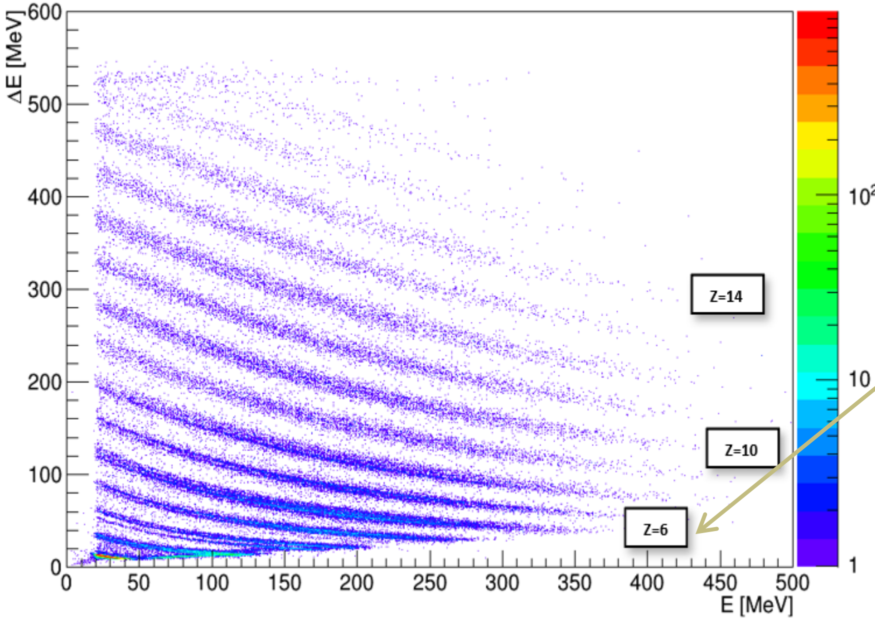


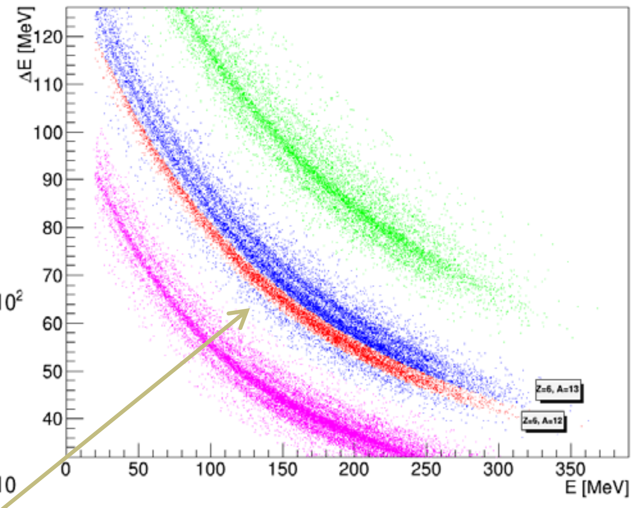
assignment for each detected particle of its position in the DSSSD (300 μm thick)

10 FARCOS telescopes used in the CHIFAR experimental setup:

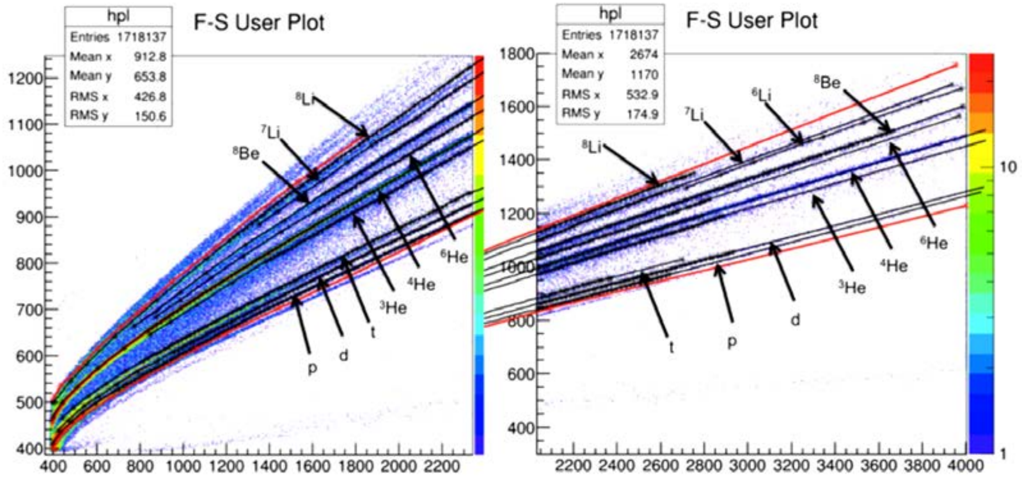
- ✓ polar coverage between 13° and 30°
- ✓ azimuthal coverage of 2π

➢FARCOS correlator in the experimental setup : particle identification





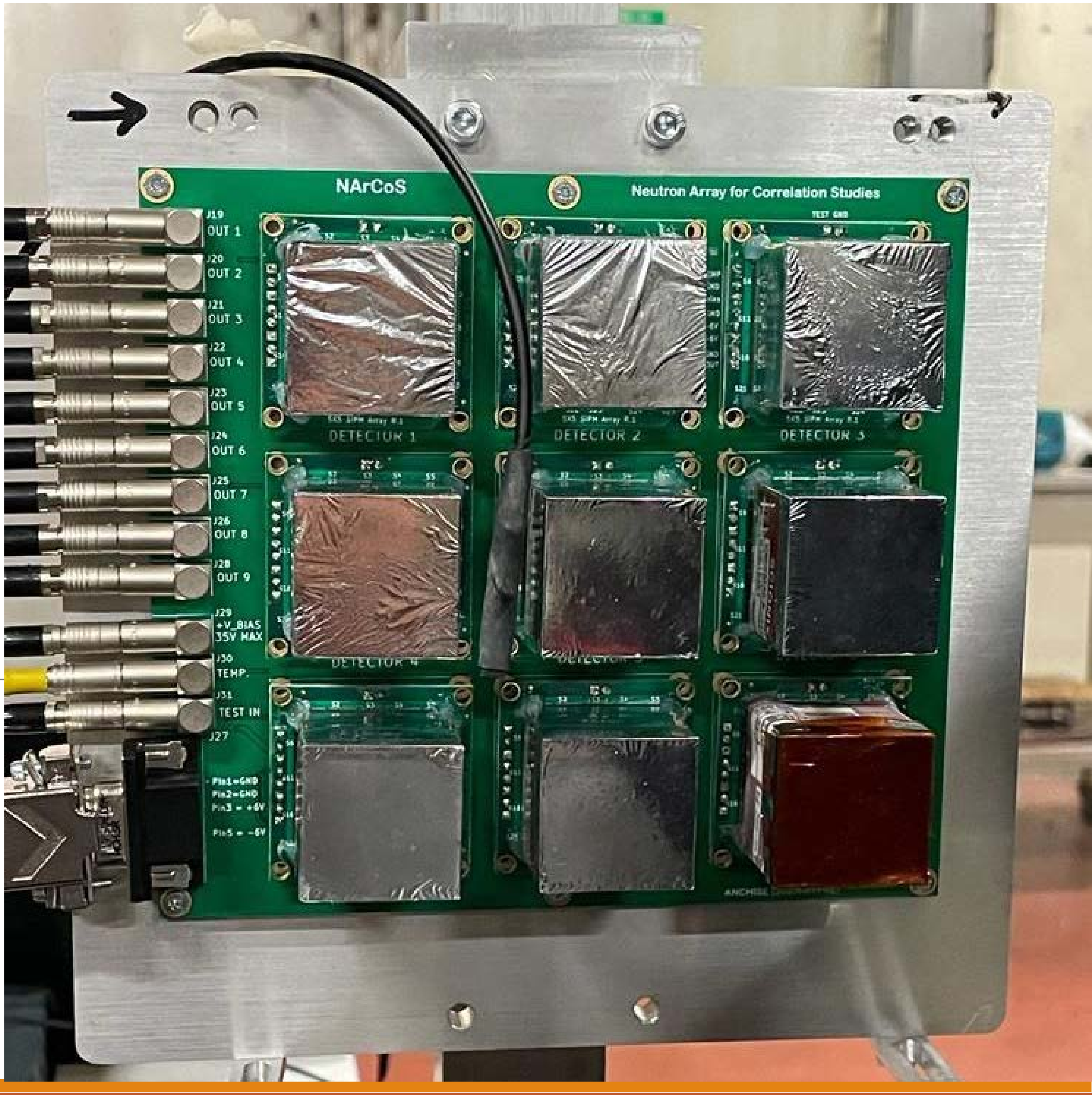
PSD identification in a CsI(Tl) crystal, from the analysis of the InKiIsSy experiment



ΔE-E method in DSSSDs, from the analysis of the CHIFAR experiment

NArCoS

Neutron Aray for Correlation Studies

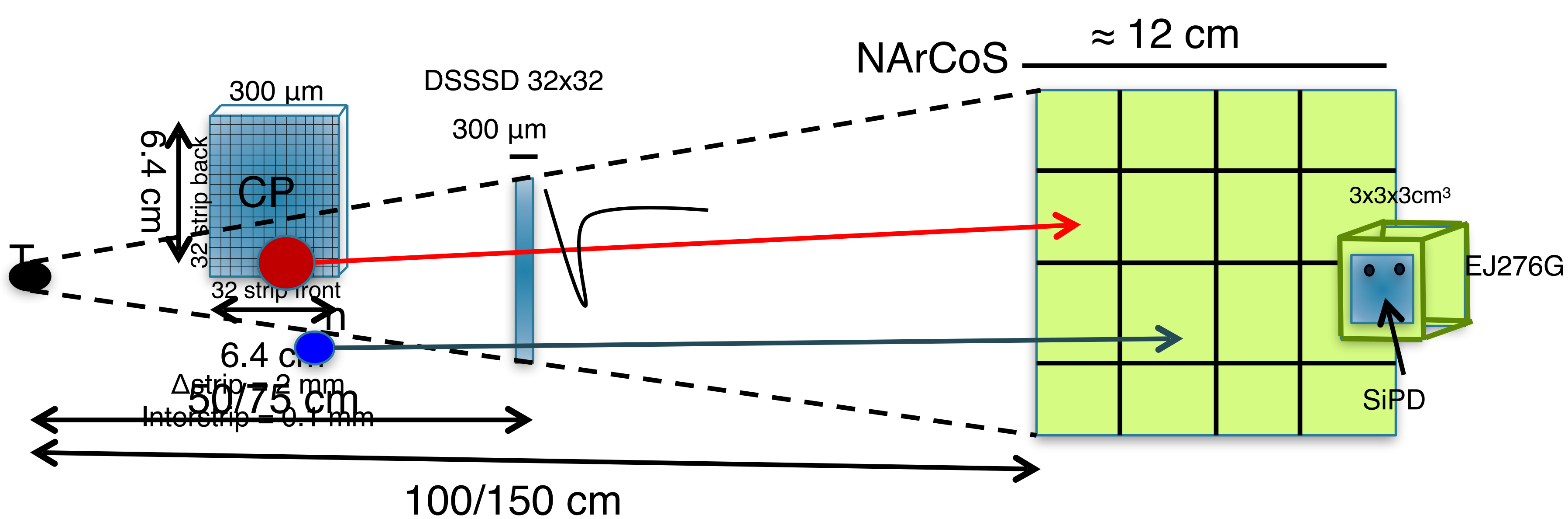


IDEA

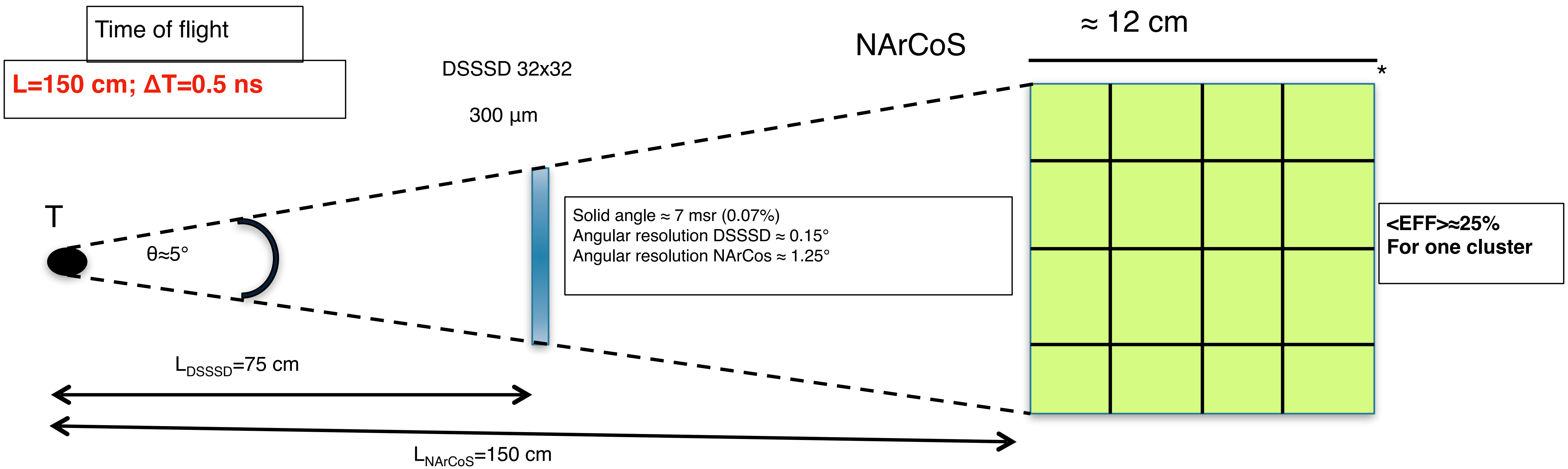
To realize a prototype of detector able to detect at the same time charged particles and neutrons with high energy and angular resolution for reaction studies and applications

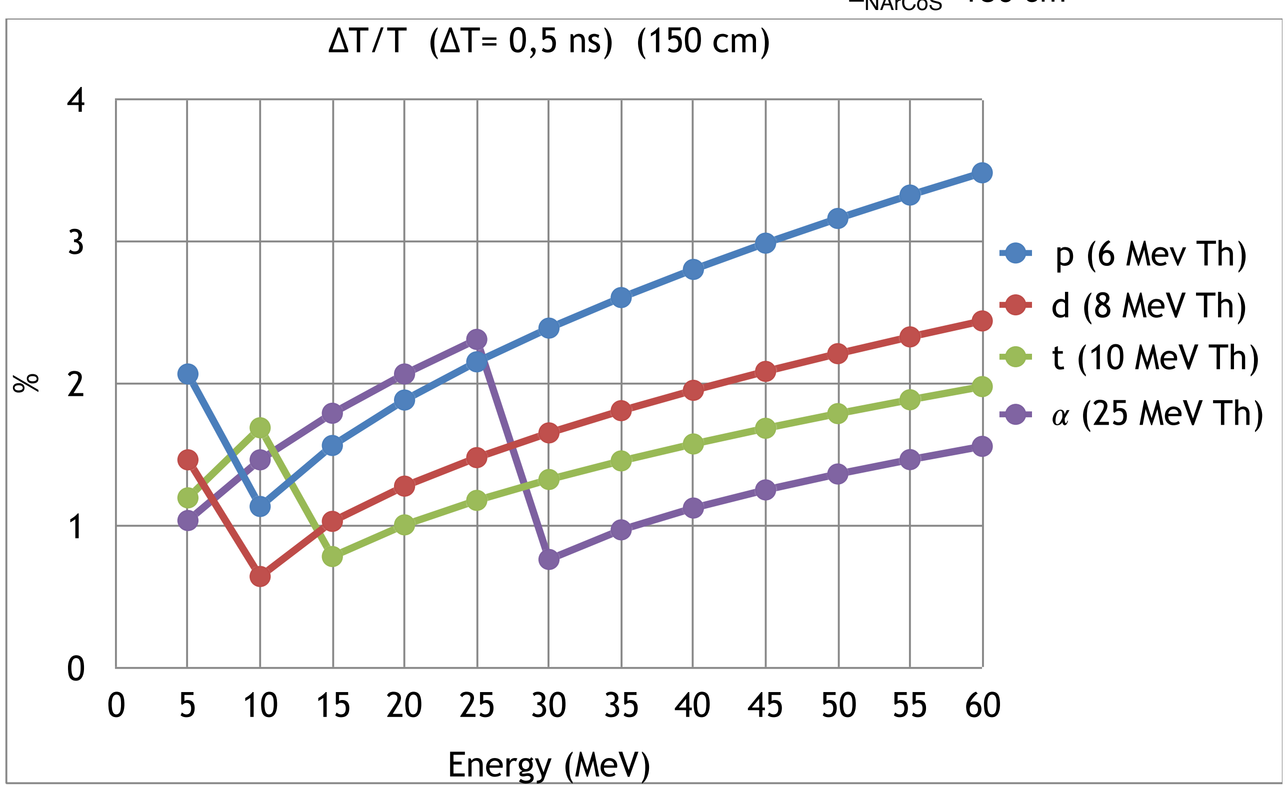
- Candidate: The plastic scintillator EJ276-Green Type (ex EJ299-33) ($3x3x3 cm^3$)
- 1 cluster: 4 consecutively cubes -> $3x3x12\ cm^3$
- Reading the light signal: SiPM and digitalization
- Neutron detection efficiency ≈ 50% for the prototype (16 clusters)
- Modular, reconfigurable (in mechanic and electronic)
- Discrimination of n/γ from PSD (but also light charged particles)
- Energy measurement from ToF ($\Delta t \leq 0.5$ ns with $L_{ToF} \approx 1 \div 1.5$m)

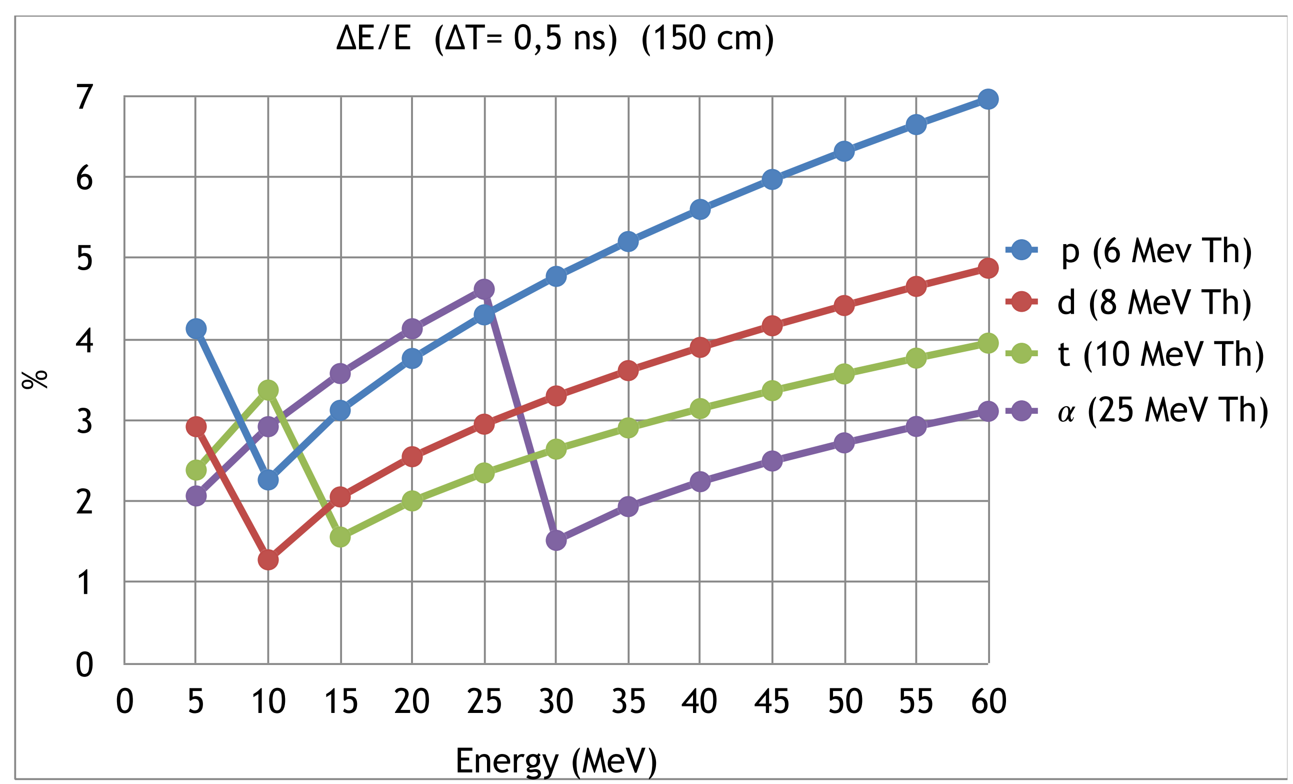
  TOF measured using the RF of the CS or with an ancillary MCP (low intensity exotic beams)



Expected performances

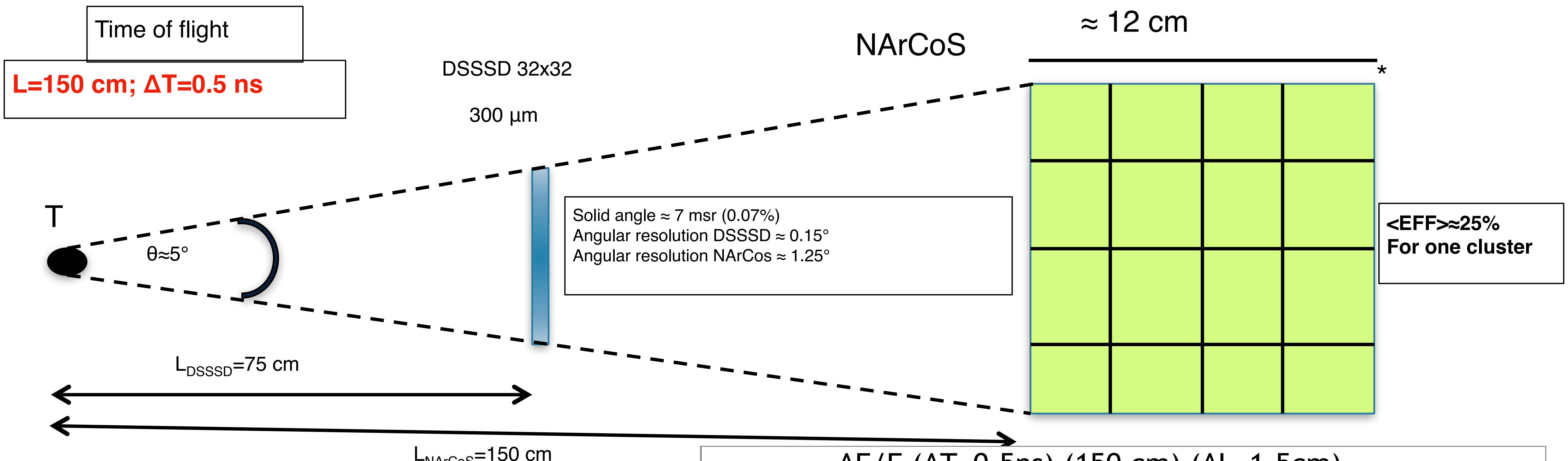


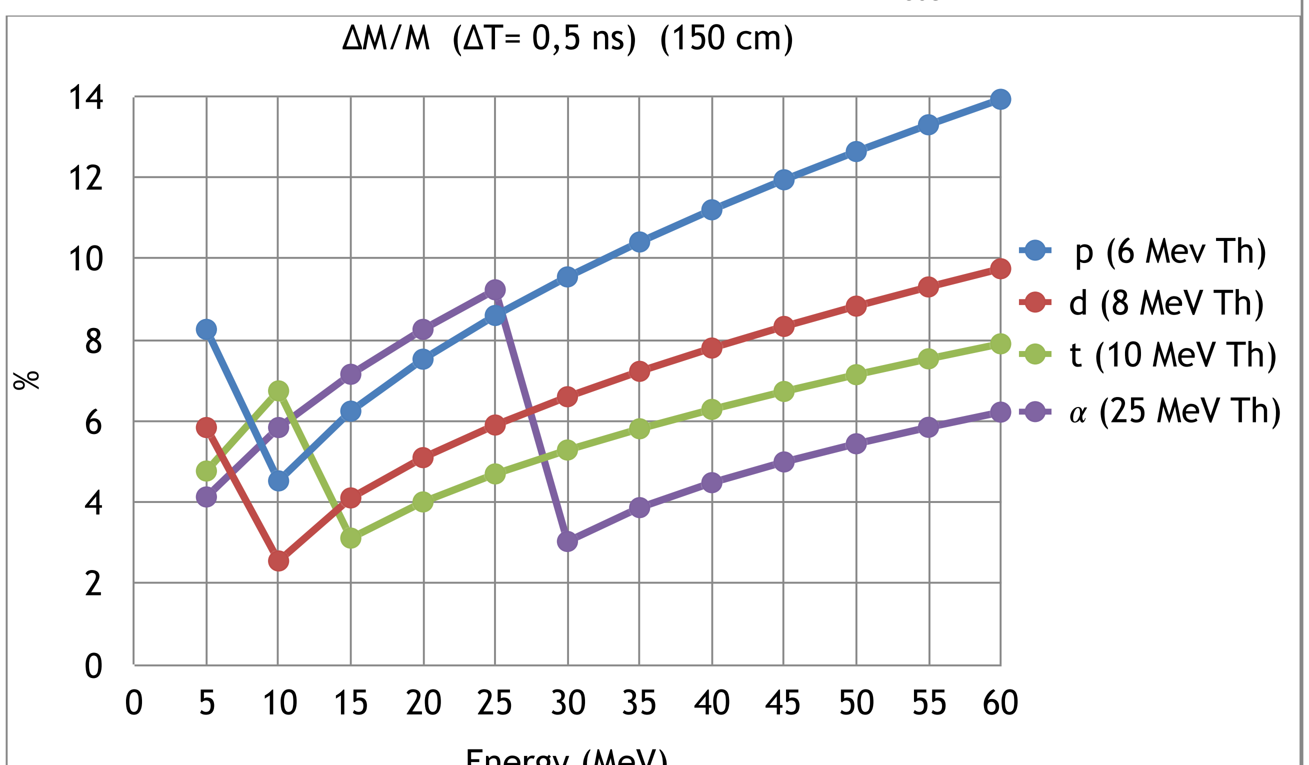


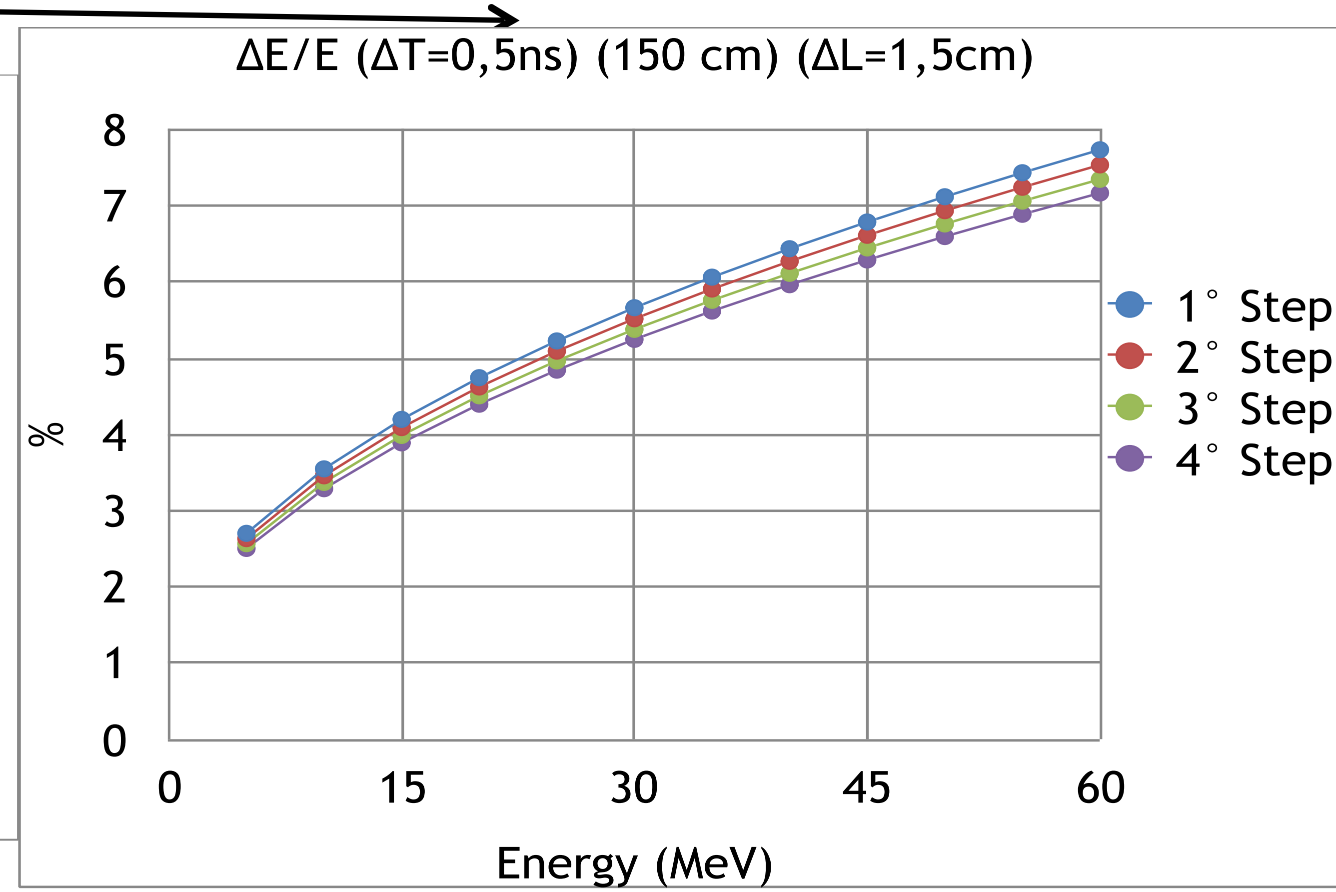


*the mechanical structure will have the possibility of an angular movimentation

Expected performances







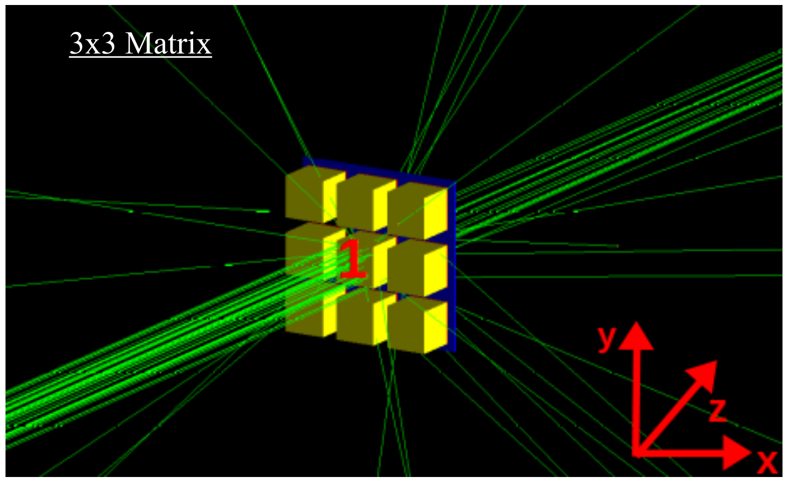
*the mechanical structure will have the possibility of an angular movimentation

Preliminary results of CROSSTEST exp. @LNL (end of 2023)

One of the main problem is to manage the cross-talk among the elementary cells

Spokesperson(s): E.V. Pagano, G. Politi, P. Russotto, T. Marchi

The 3x3 Matrix (surface crosstalk)

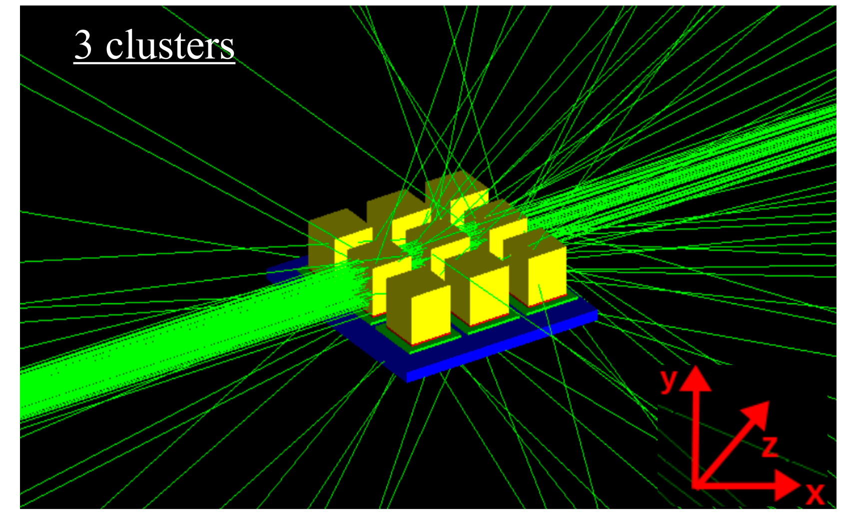


Two configurations was tested

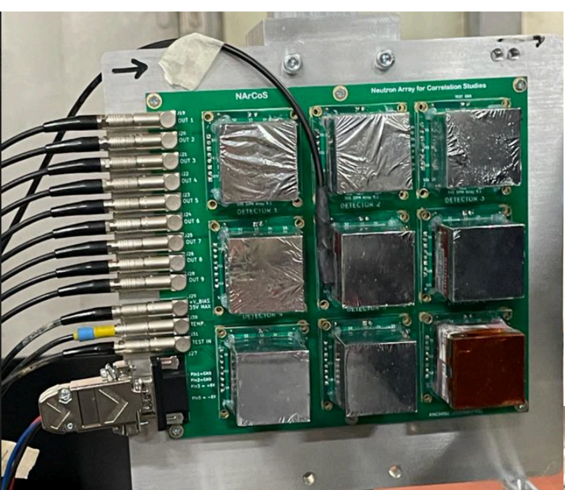
Main reaction for neutrons

$p + {}^{7}Li \longrightarrow {}^{7}Be + n$

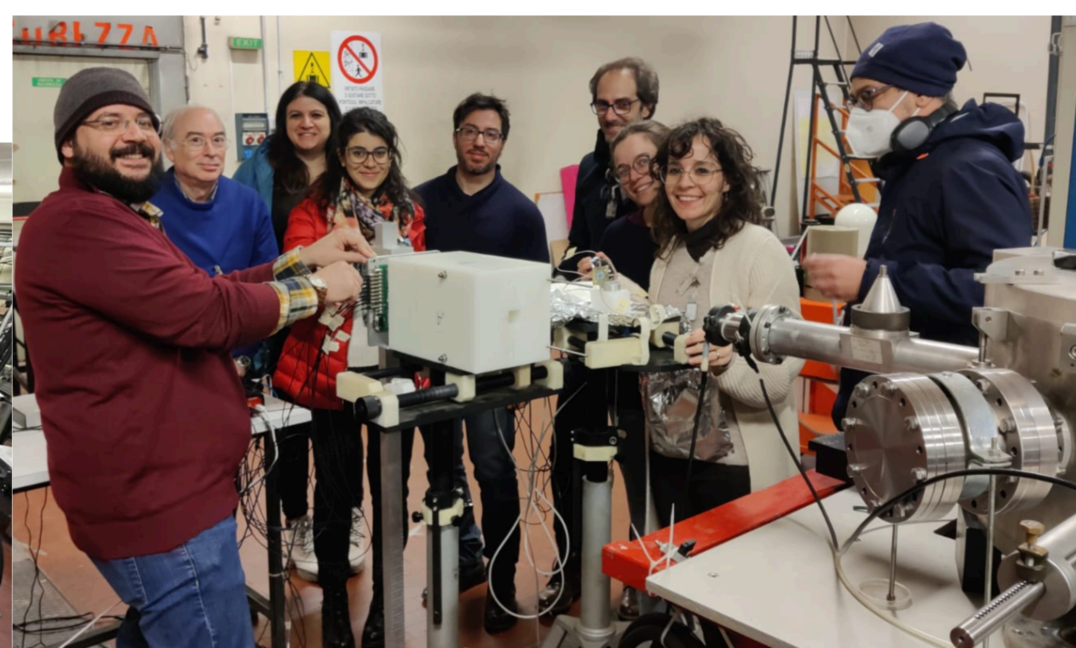
The 3 clusters (linear crosstalk)



The experiment was performed at CN accelerator of INFN-LNL laboratory using a proton beam of 4.5 MeV on a LiF target producing a neutron beam having energy En < 4.5 MeV (neutron experimental threshold 1.5 MeV)



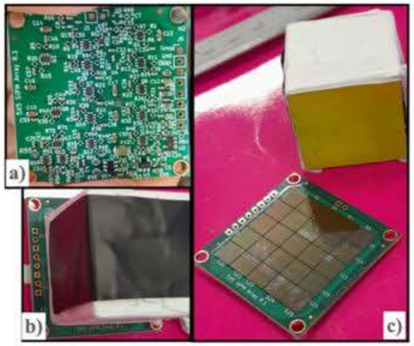
Experimental Setup



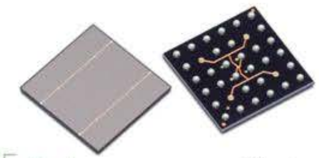
Preliminary results of CROSSTEST exp. @LNL (end of 2023)

Prototypal readout electronic

in coll. with INFN-MI (C. Boiano)



Each elementary cell of EJ276G (3x3x3 cm^3) is equipped with a matrix of 25 SiPM (6x6 mm^2) of 30 μm of thickness ($\approx$ 40k microcells). The SiPM matrix is coupled with the plastic having theirs PAC and bias/ temperature compensation circuit



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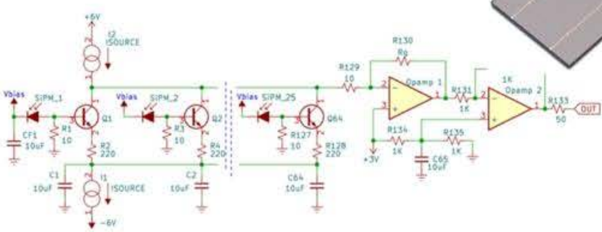
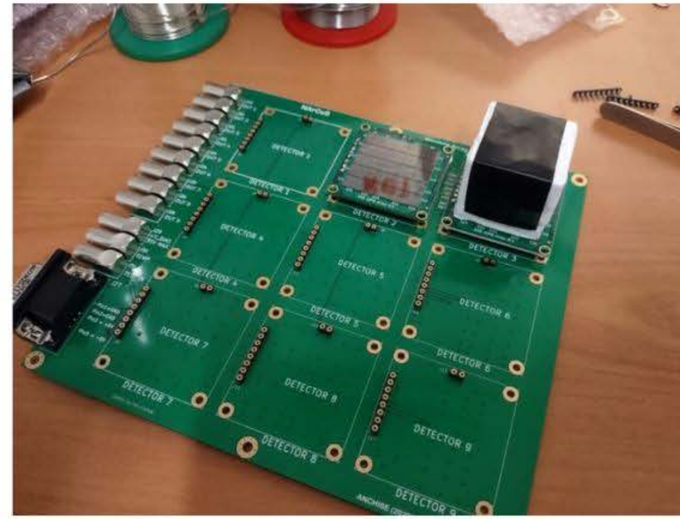
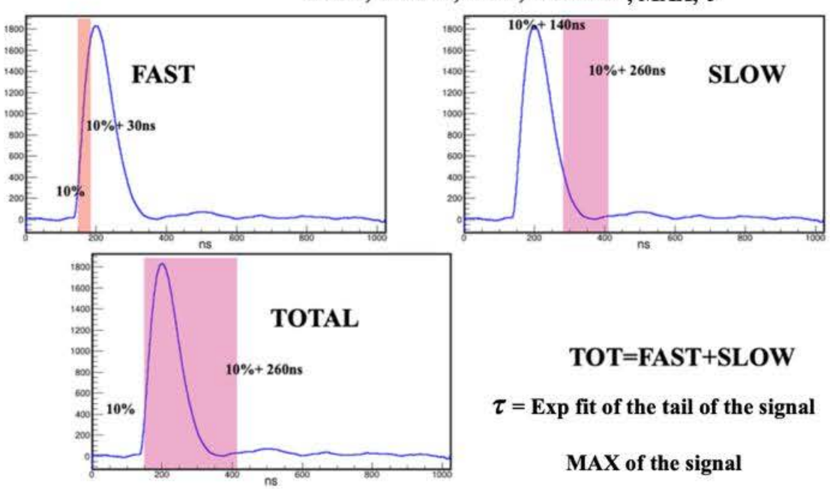




Electronic Board for housing the 9 elementary cells with its electronic readout boards, with the out of the signals, test ingress, temperature monitoring and bias ingress

FAST, SLOW, TOT, TOTAL , MAX, τ



TOT=FAST+SLOW

τ = Exp fit of the tail of the signal

MAX of the signal

Caen digitizer DT5742B*

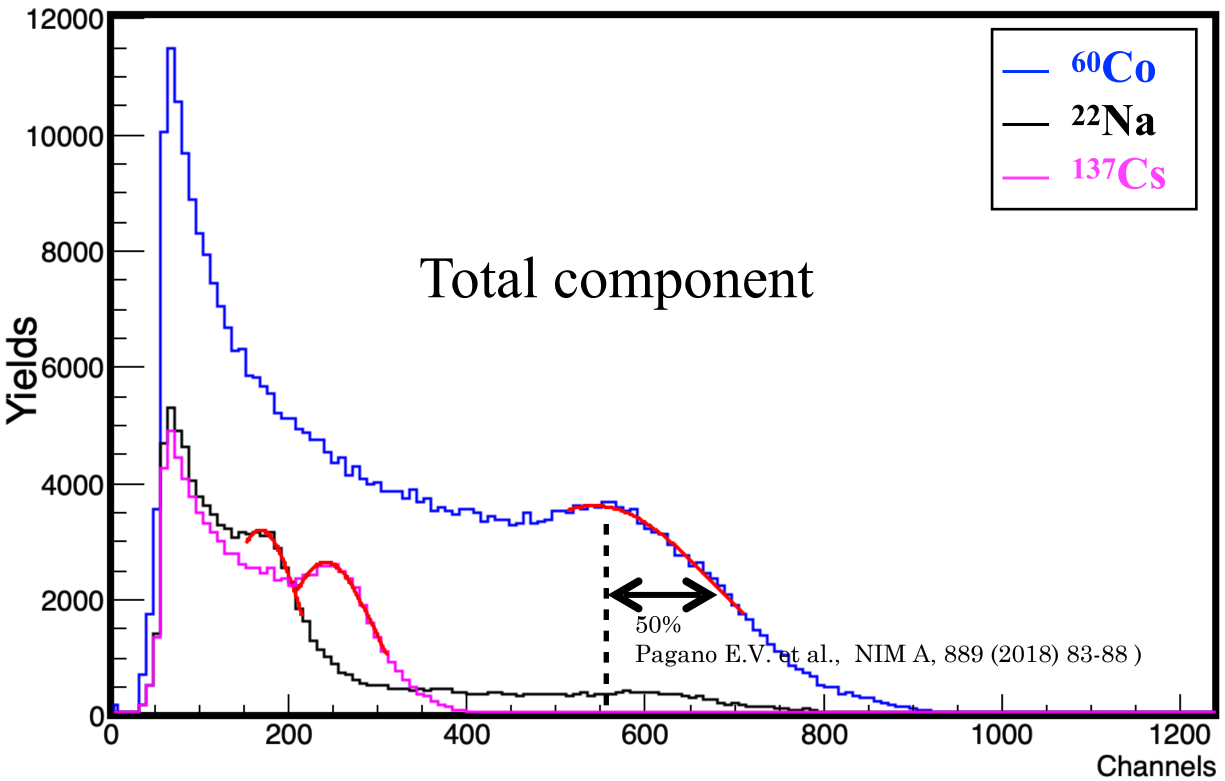
Sampling frequency: 1 Gs/s
Trigger: internal (only the central plastic detector)

* https://www.caen.it/products/dt5742/

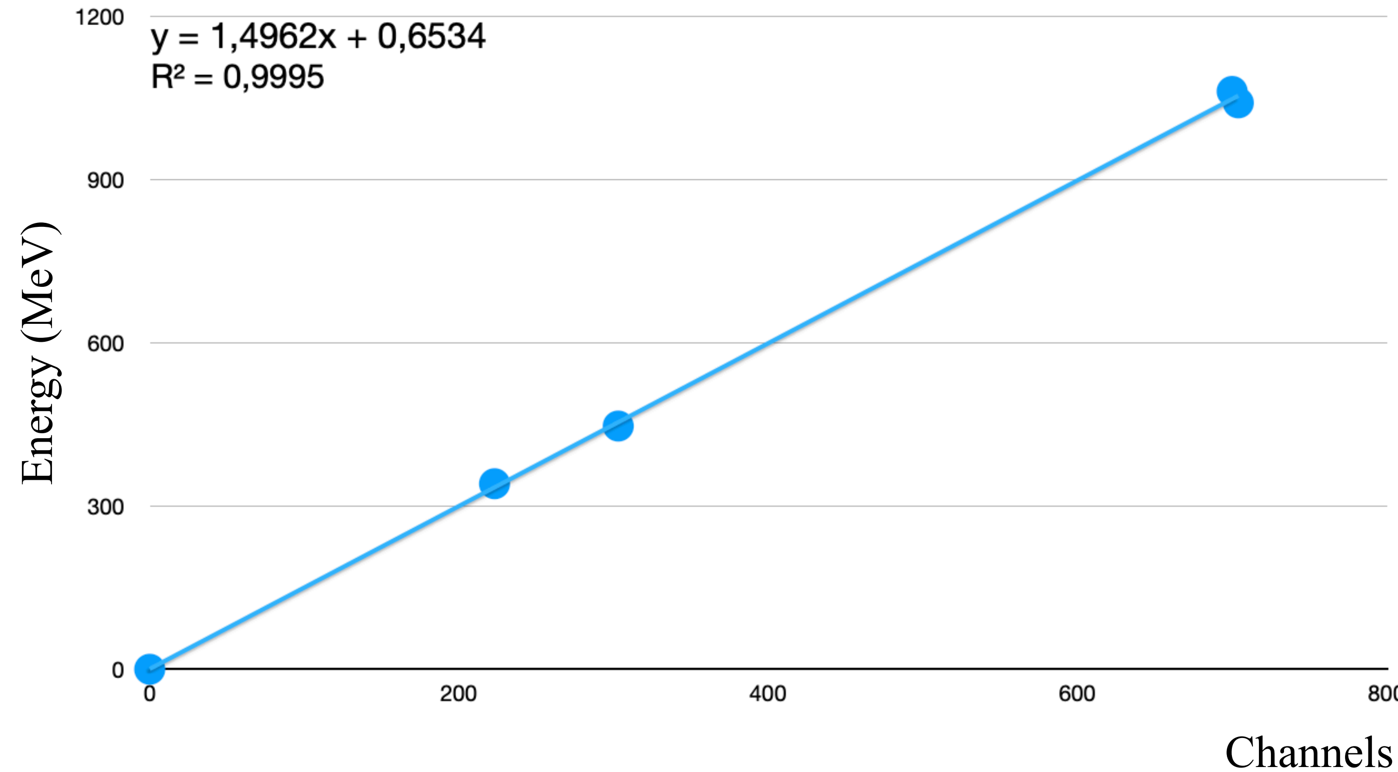
Preliminary results of CROSSTEST exp. @LNL (end of 2023)

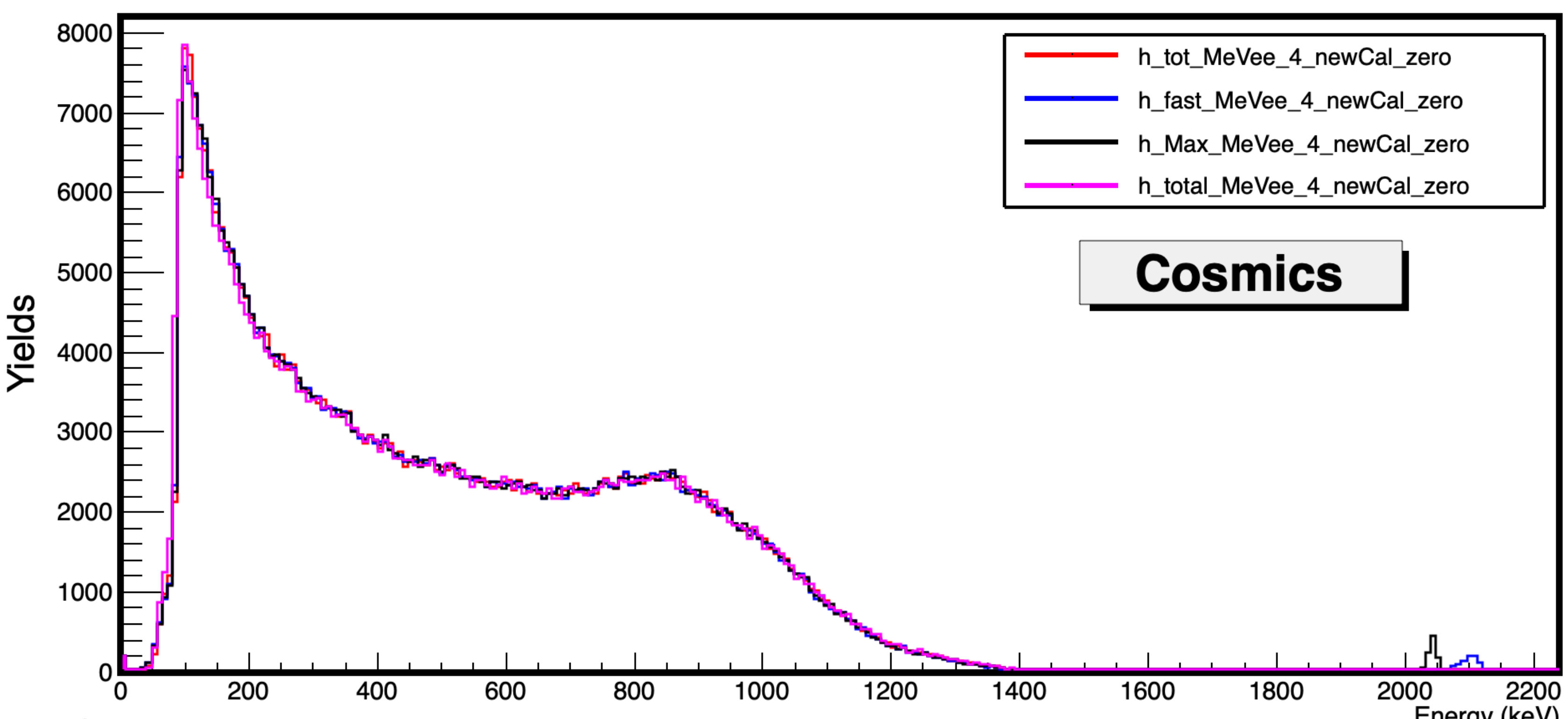
Detectors energy calibration

Calibration sources: ^{22}Na, ^{60}Co, ^{137}Cs,



Central plastic



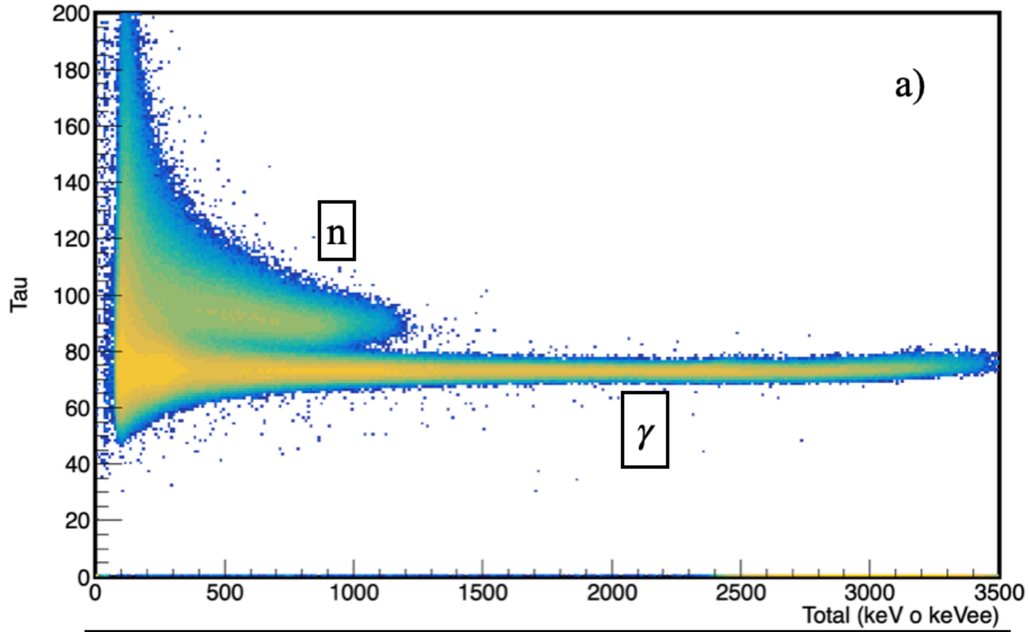


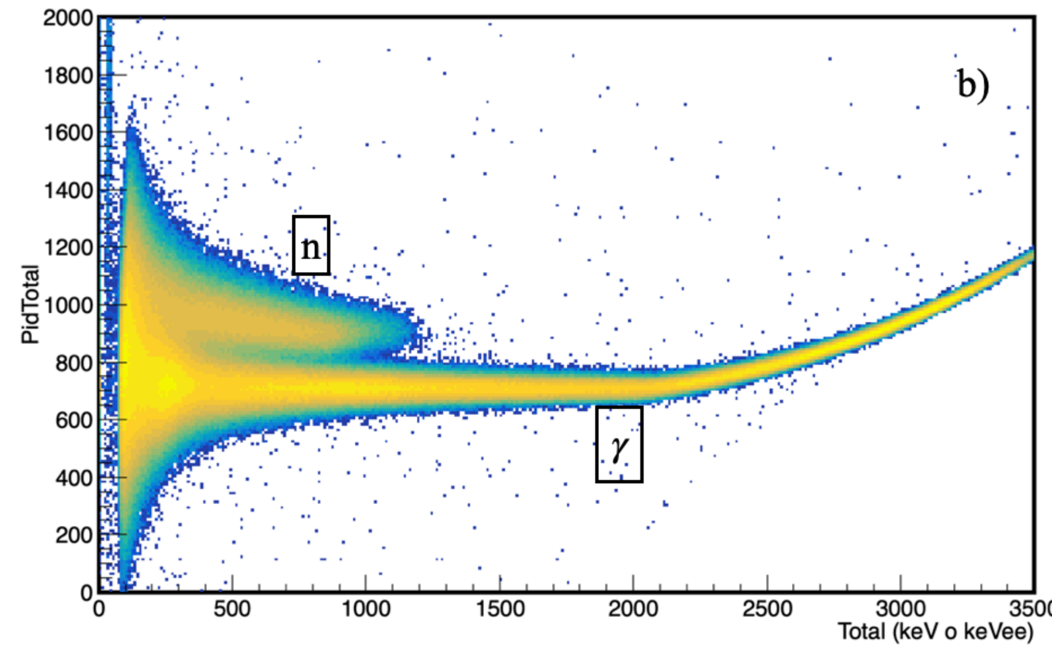
Good energy linearity

Gamma rays energy threshold ≈ 70 keV

Preliminary results of CROSSTEST exp. @LNL (end of 2023)

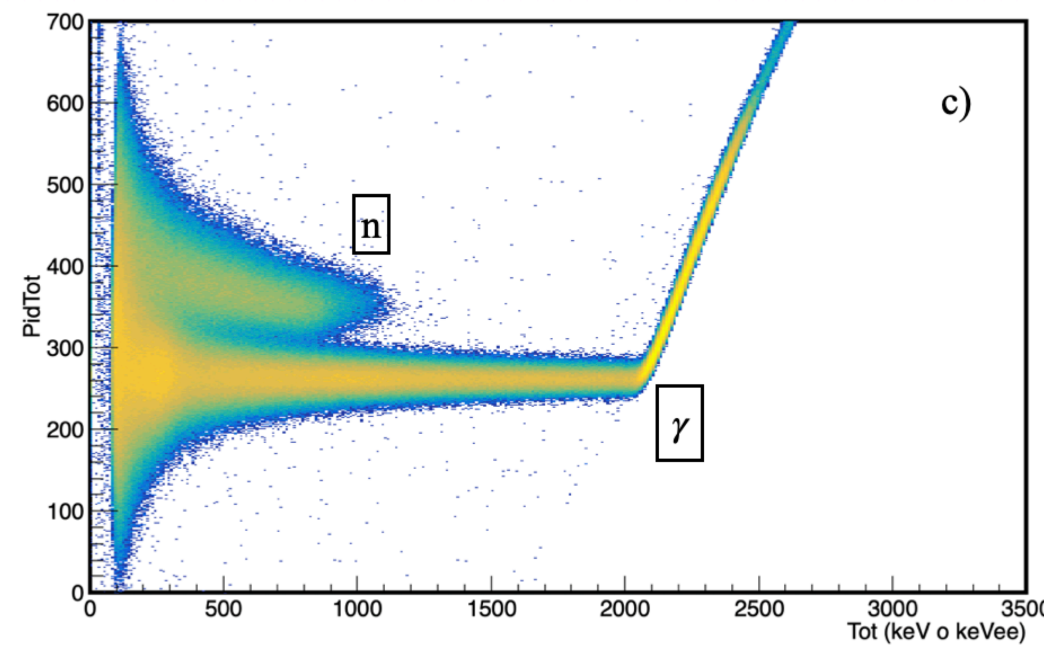
2D identification matrix





Matrici di identificazione 2D ottenute dal plastico centrale nella "schedona" posta a conf. a matrice
a) Tau Vs del Total (keV)
b) PidTotal VS Total (keV)
c) PidTot Vs Tot (keV)

Tau: fit esponenziale nella parte decrescente del segnale
PidTotal: Slow/Total*
PidTot: Slow/Tot*

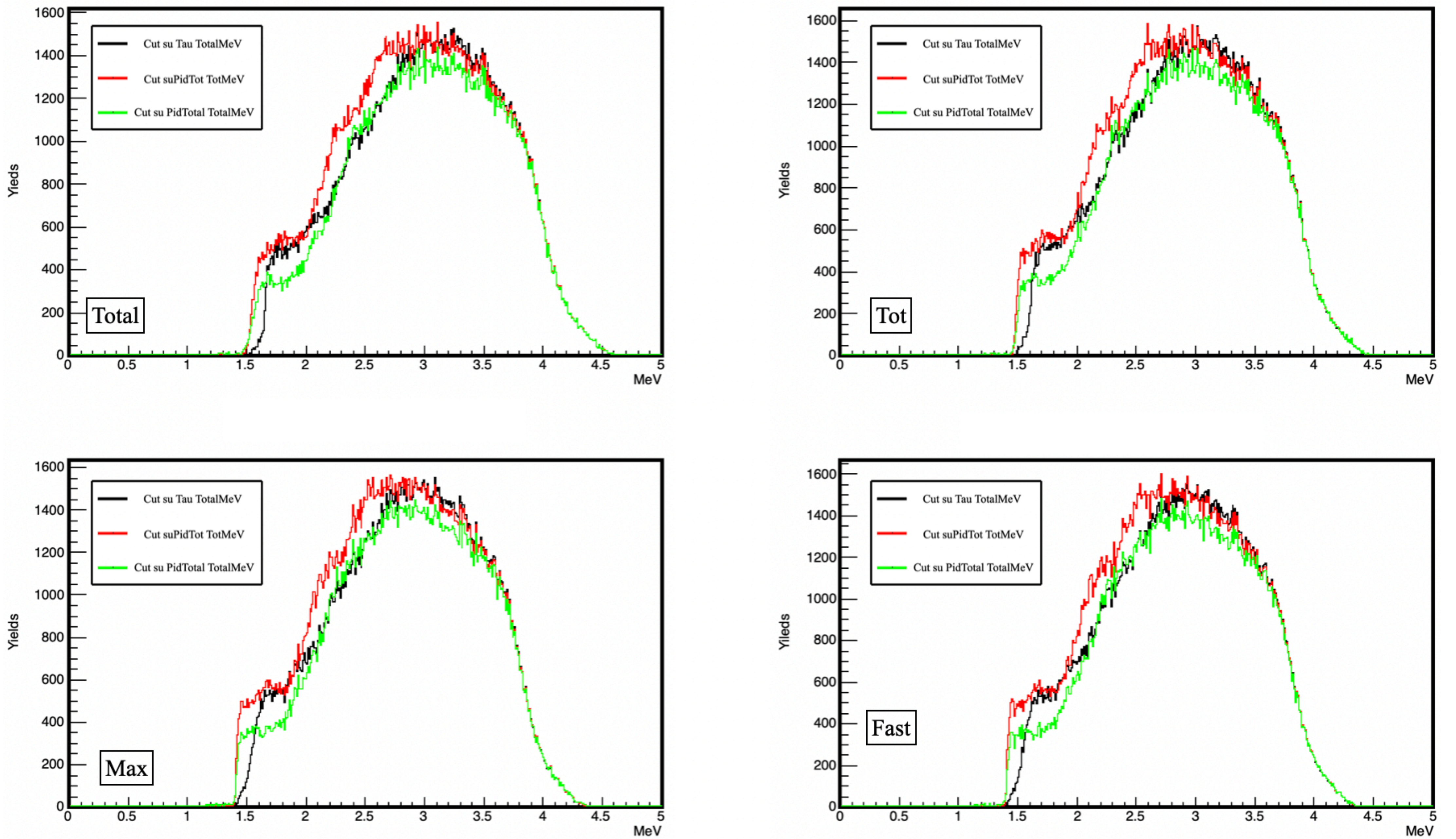


Central plastic

Three different 2D identification matrix was analyzed in order to study the detector performances

Preliminary results of CROSSTEST exp. @LNL (end of 2023)

Neutron spectra



Form MeVee to MeV:

$$L_{out} = a E_{dep} - b[q - e^{-cE_{dep}}]^*$$

a = 0.8 MeVee*MeV^{-1}
b = 0.39MeVee
c = 0.22 MeV
L_{out} in MeVee
E_{dep} in MeV

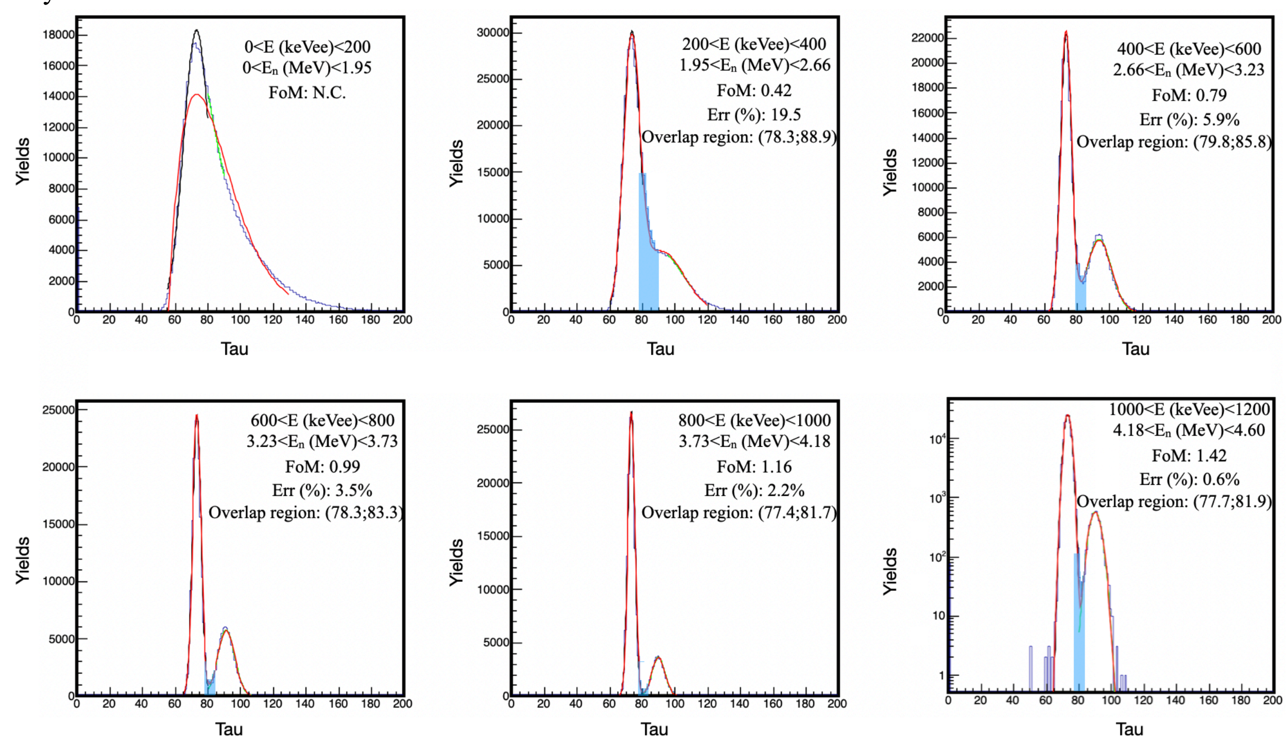
*Lawrence et al. NIM A 759 (2014) 16-22

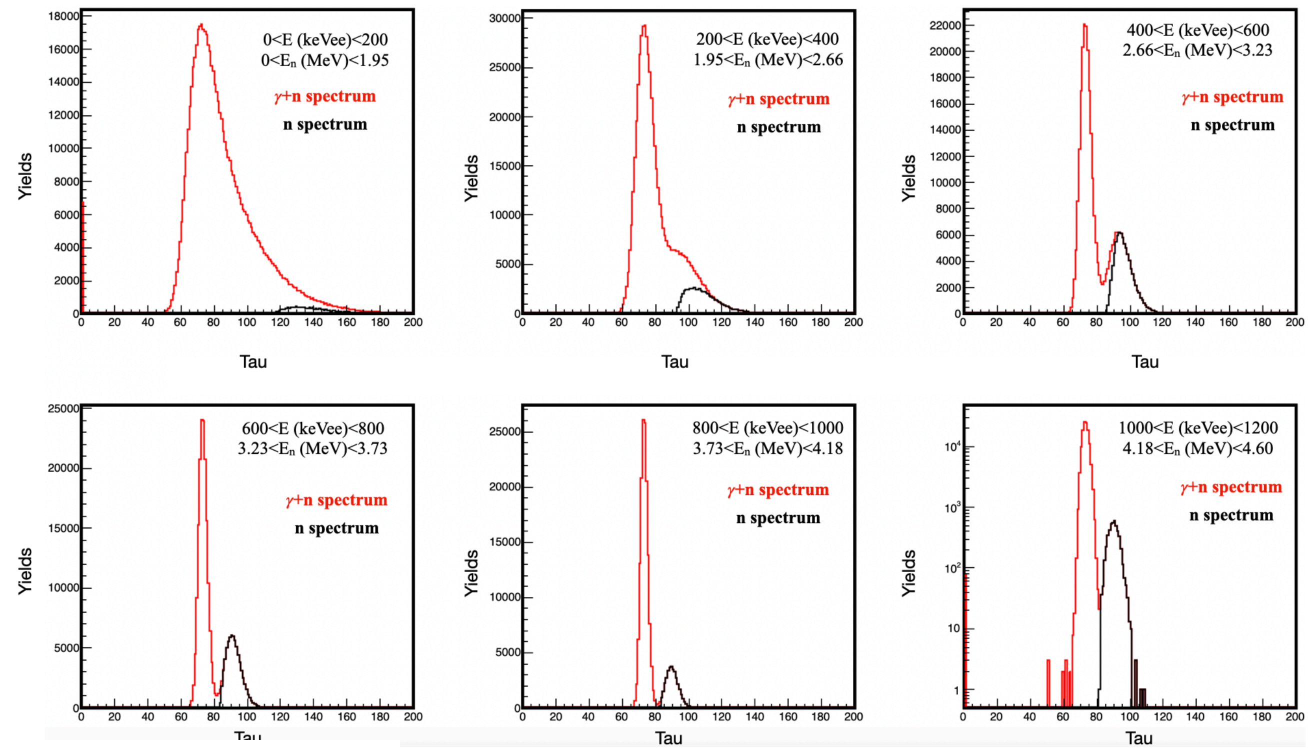
Reasonable neutron energy spectra (neutron beam maximum energy 4.5MeV), robust energy calibration as a function of the variable, robust neutron selection as a function of the three 2D identification matrix, about 1.5 MeV of neutron energy threshold

Preliminary results of CROSSTEST exp. @LNL (end of 2023)

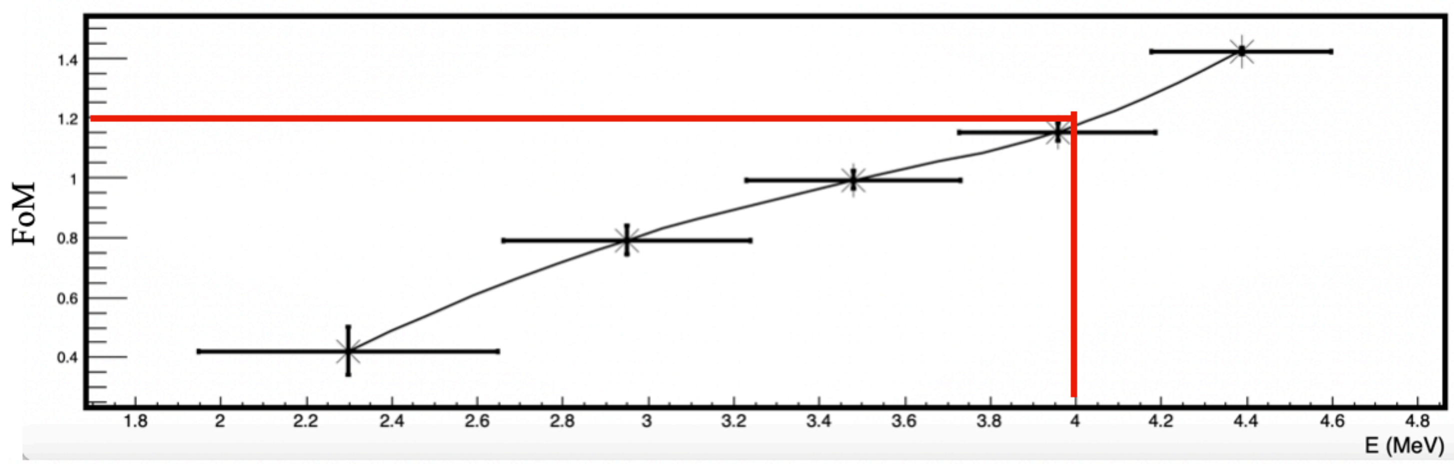
FoM and Errors estimations

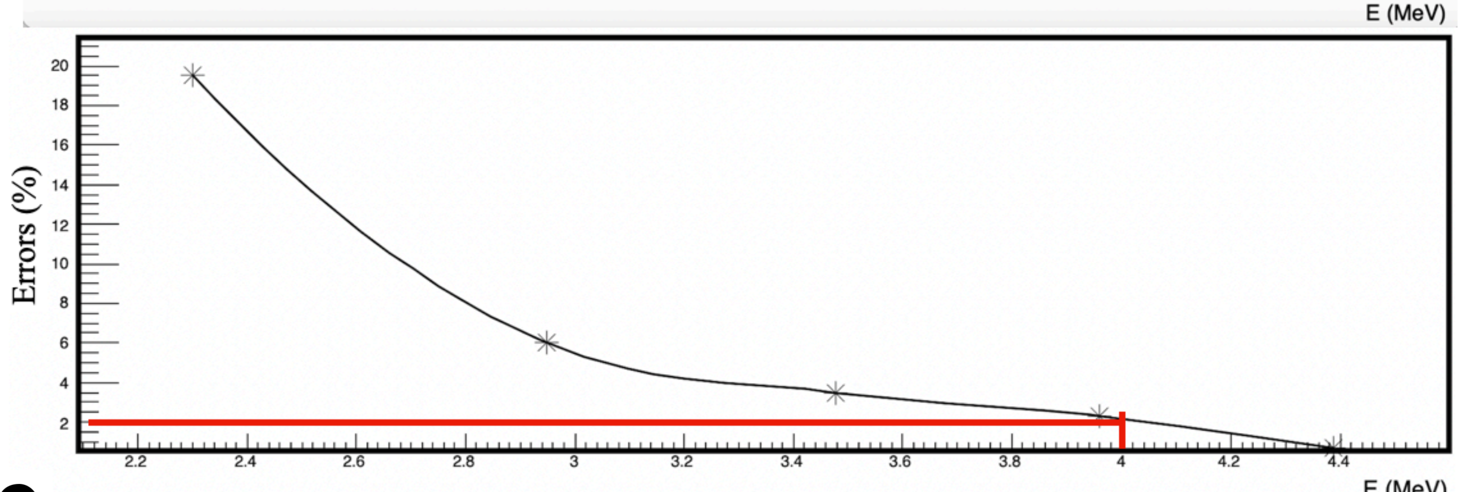
Very close results for the others 2D Identification Matrix





Tau Vs Total 2D identification matrix



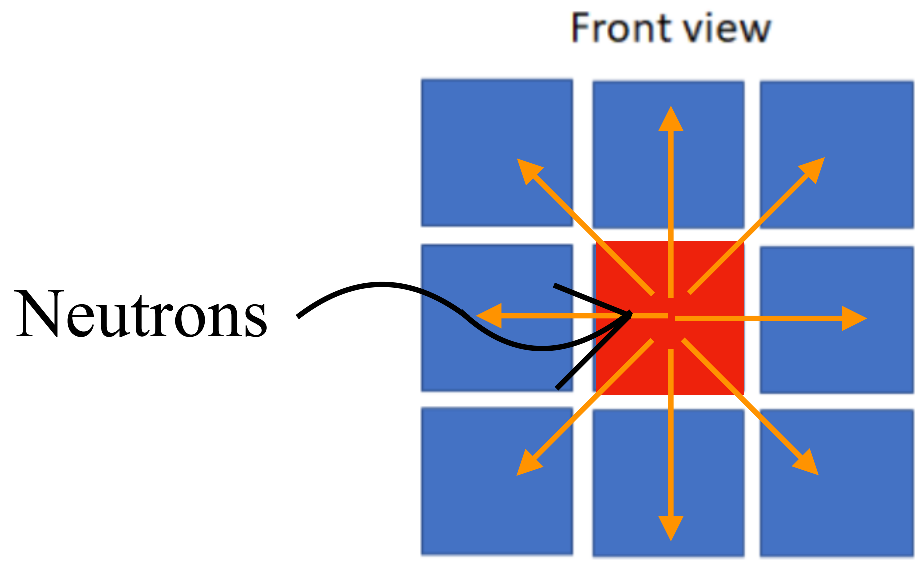


At about 4 MeV of neuters we obtain a value of 1.2 of FoM generally considered as “good”. At this value the corrispondi errors in the neutron identification is about 2%

Preliminary results of CROSSTEST exp. @LNL (end of 2023)

Crosstalk Measurement for 4.5 MeV of neutrons

Matrix configuration (surface crosstalk)



Only the central plastic scintillator was in trigger

Neutrons in other plastics in the same event (with multiplicity equal to 2) are crosstalk (or background)

Crosstalk probability: $$\frac{number\ of\ neutrons\ non\ in\ trigger}{number\ of\ neutron\ in\ trigger\ (central)}\ x\ 100\ \%$$

$$P\ (\%)\ =\ prob\ (\%)\ \pm\ Er_{ass}\ (\%)\ =\ (0.117\ \pm\ 0.008)\ \%$$

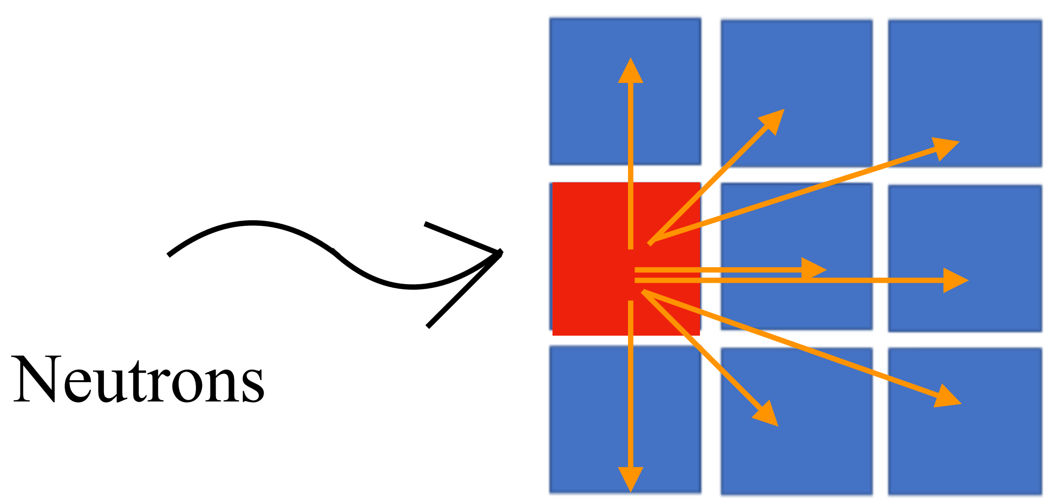
$$P\ (\%)\ \approx\ 0.1\ \%$$

Preliminary results of CROSSTEST exp. @LNL (end of 2023)

Crosstalk Measurement for 4.5 MeV of neutrons

Cluster configuration (linear crosstalk)

Top view



Only the central plastic scintillato

Neutrons in other plastics in t
multiplicity equal to 2) are cros

Crosstalk probability: $$\frac{number\ of\ neutrons\ non\ in\ trigger}{number\ of\ neutron\ in\ trigger\ (central)}\ x\ 100\ \%$$

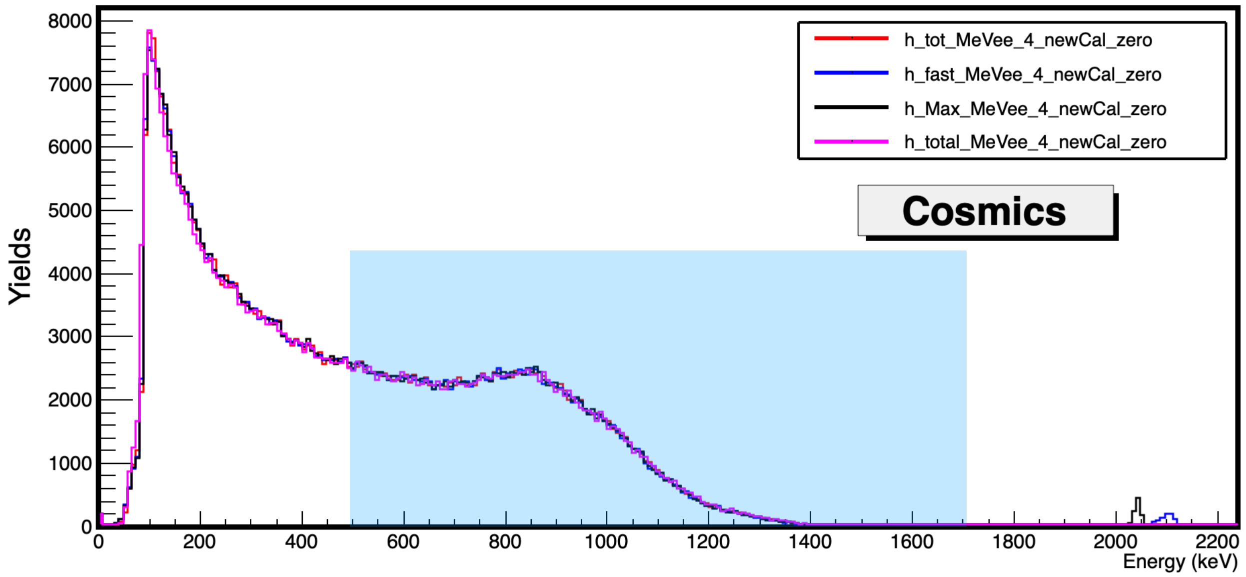
$$P\,(\%) \;=\; prob\,(\%) \;\pm\; Er_{ass}\,(\%) \;=\; (0.163 \;\pm\; 0.005)\ \%$$

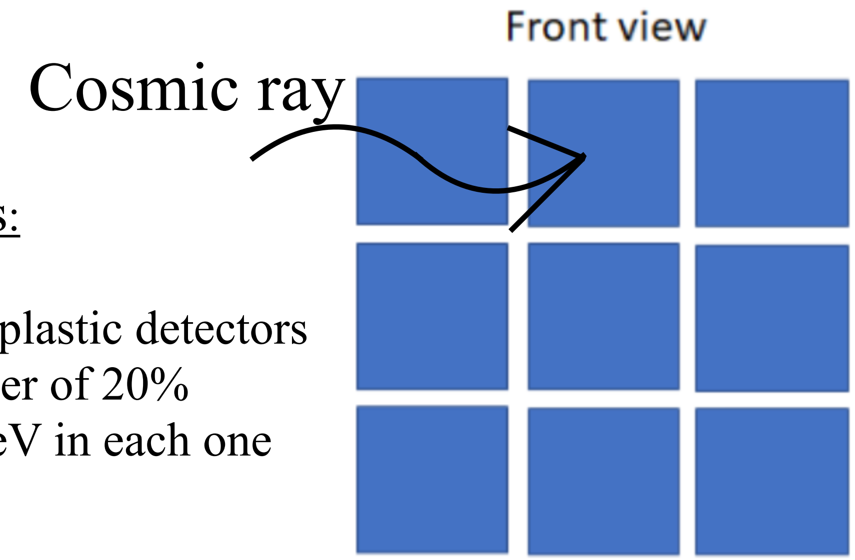
$$P\,(\%) \;\approx\; 0.2\ \%$$

Preliminary results of CROSSTEST exp. @LNL (end of 2023)

Time resolution

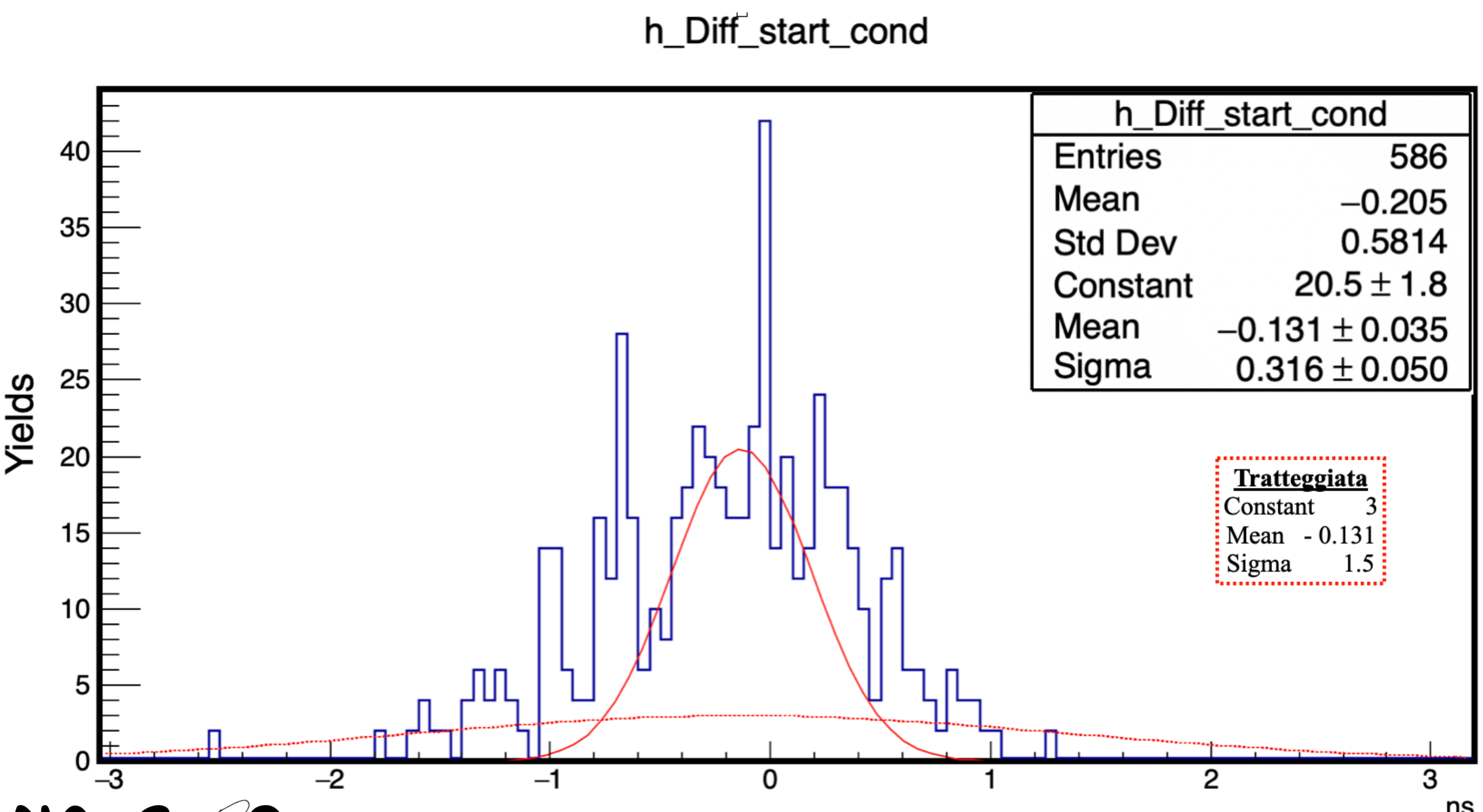
evaluated with a cosmic ray detected in coincidence between two plastic scintillator





Experimental conditions:

- Multiplicity = 2;
- Contiguity of the two hit plastic detectors
- Energy difference no larger of 20%
- Energy larger than 500 keV in each one



Two component in the spectrum

One real coincidence with a $\sigma \approx 320$ ps and another of spurious coincidence corresponding to about 10% of the selected events

Time resolution of one single green plastic

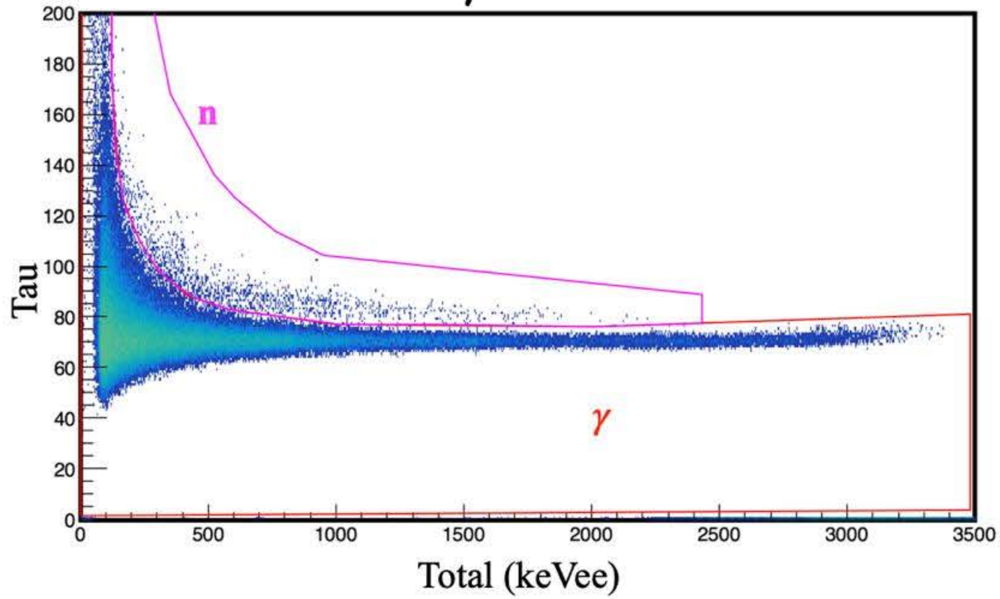
$$\sigma_{tot}^2 = 2\sigma_{green}^2 + \sigma_{el}^2 -> \sigma_{green} = \sqrt{\frac{\sigma_{tot}^2 - \sigma_{el}^2}{2}} \approx 215\ ps$$

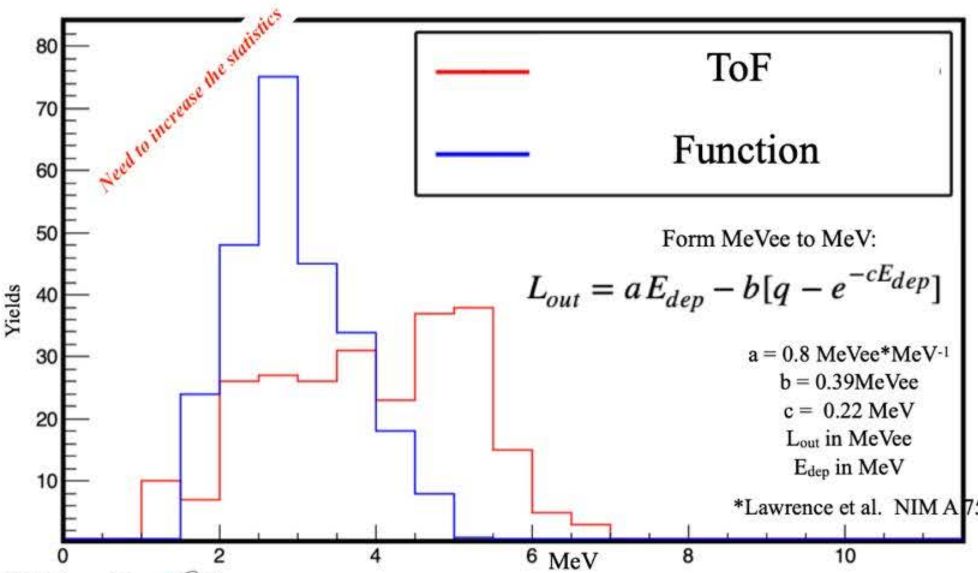
$$\sigma_{el} \approx 100\ ps$$

Neutron Energy from ToF Measurement

Test @LNS with AmBe radioactive Source

$^{9}Be + \alpha \longrightarrow {}^{12}C^{*} + n \longrightarrow {}^{12}C + \gamma + n$





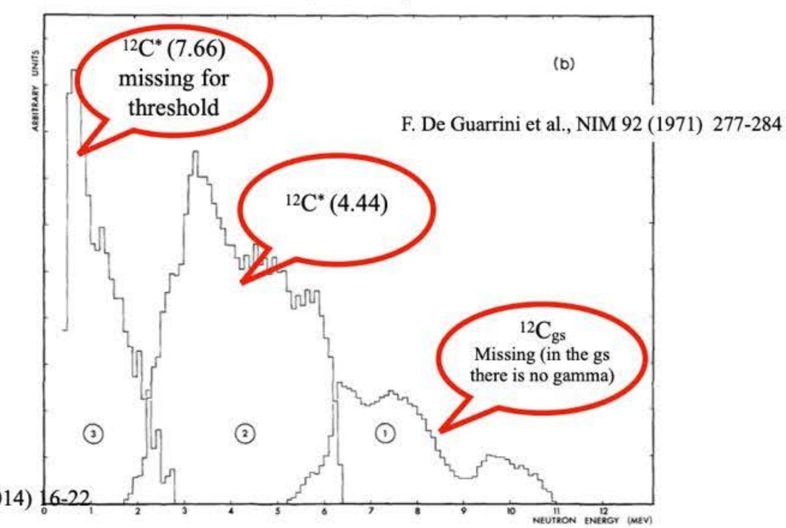
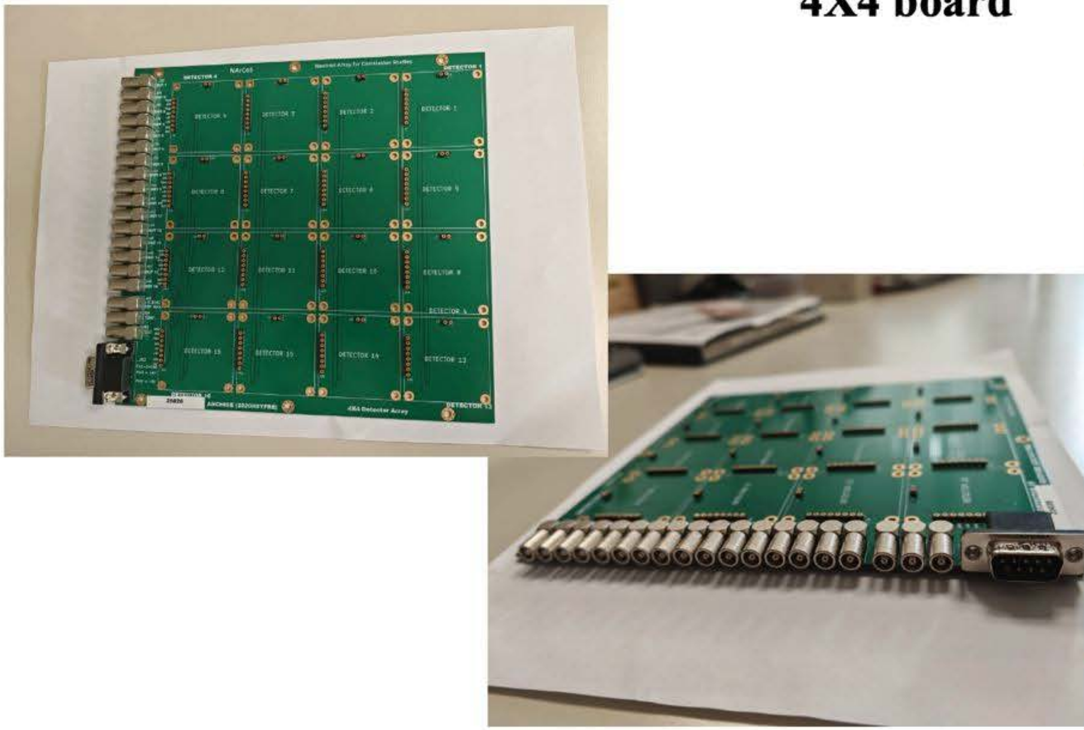


Fig. 3. Calculated spectrum of an (α,n) source. In (b) are shown the partial yields due to the neutrons coming from the $^{9}Be(\alpha,n)$ reaction leaving the residual nucleus ^{12}C in the g.s. level (1), in the 4.42 MeV excited level (2) and in the 7.66 MeV excited level (3).

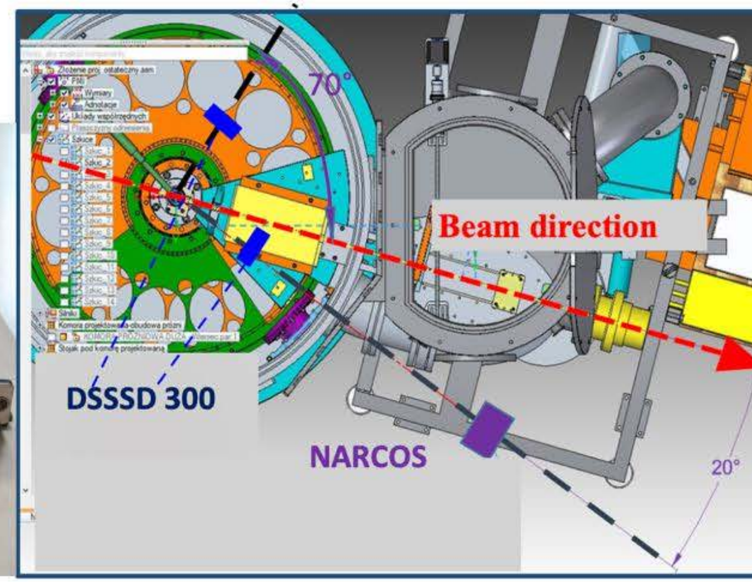
What we have now

4X4 board

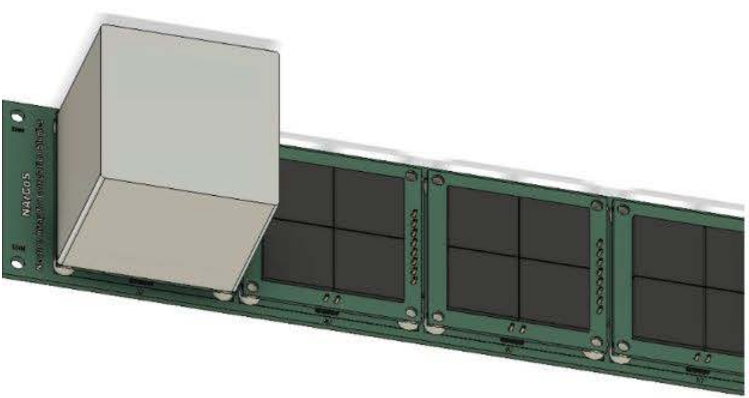


MoReNA Exp. (HIL Warsaw spring 2026)

13C + 12C → 13C* + 12C → 12C + n +12C

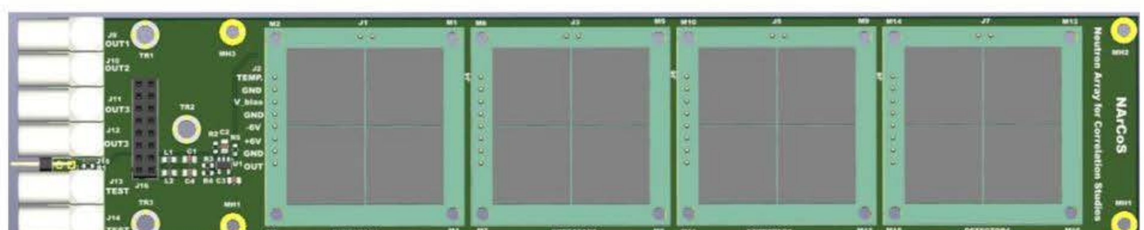


Already developed the Cluster Board (expect to arrive in the next months 16 clusters)



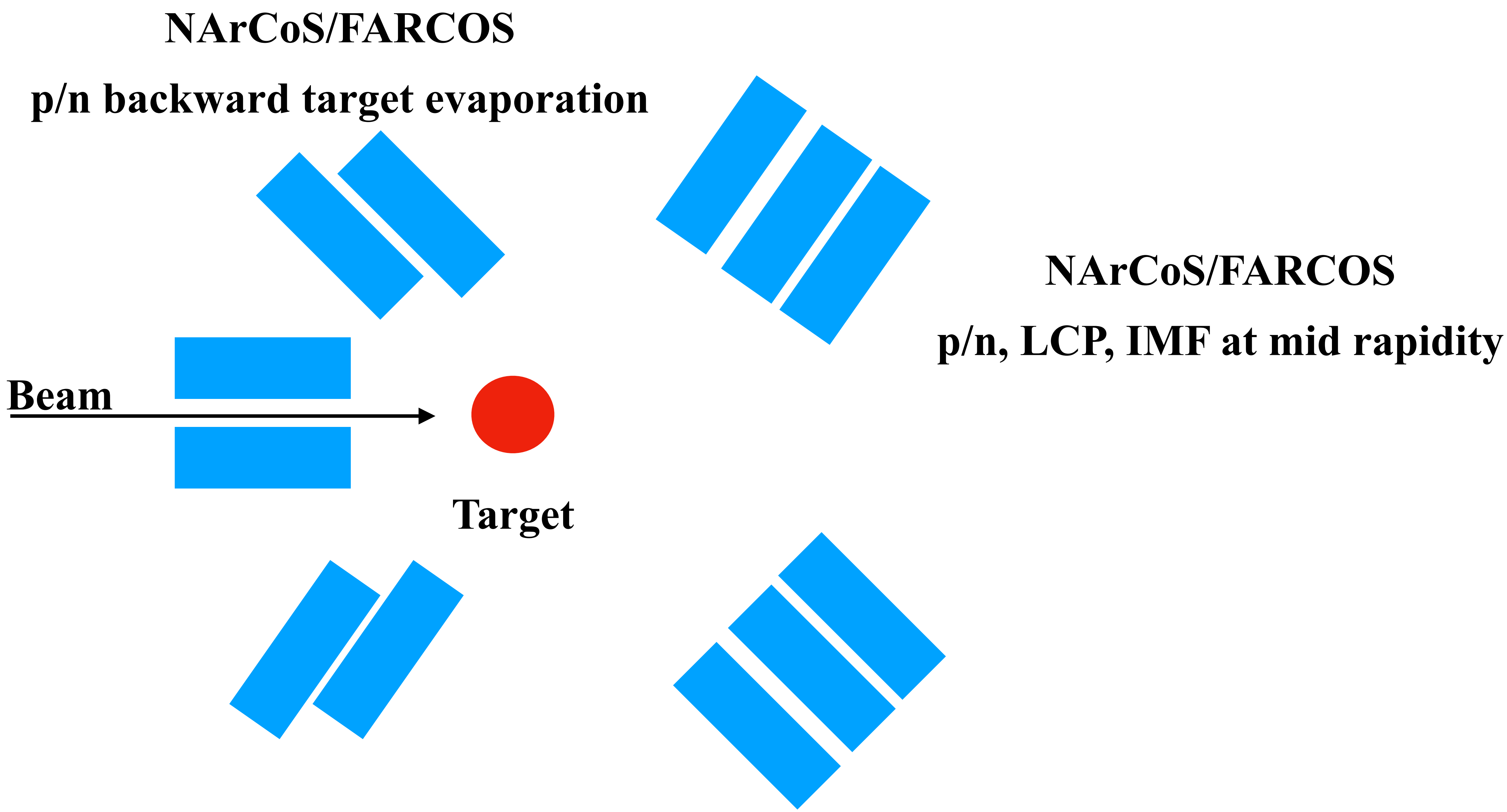
New Si-PM

BROADCOM AFBR-S4N44P164M 4x4 NUV-MT



Useful at FRIB?

Example of experimental setup



Let to discuss together about the scientific program