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science, technology & innovation

Department: Science, Technology and Innovation REPUBLIC OF SOUTH AFRICA

NRF National Research Foundation

iThemba LABS Laboratory for Accelerator Based Sciences

The African Nuclear Physics Conference 2025 (ANPC 2025)

INFN

Istituto Nazionale di Fisica Nucleare

Results on the CROSSTEST@LNL experiment for NArCoS: the Cross-talk problem

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CHIRONE Coll.

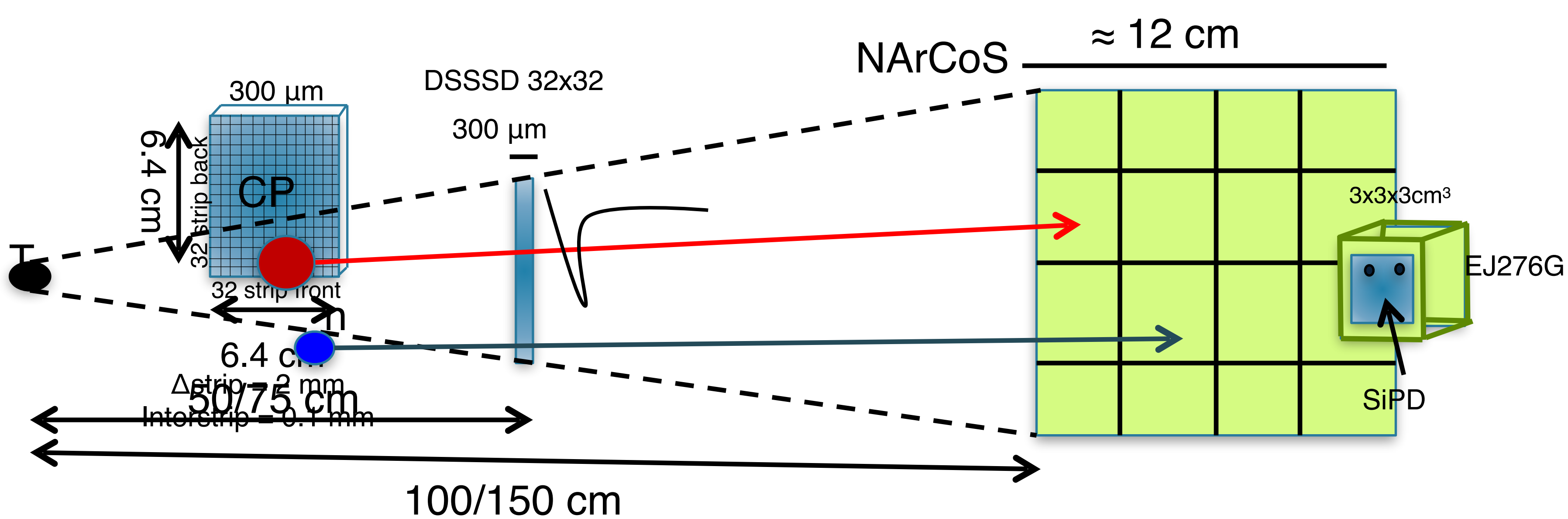
NArCoS

IDEA

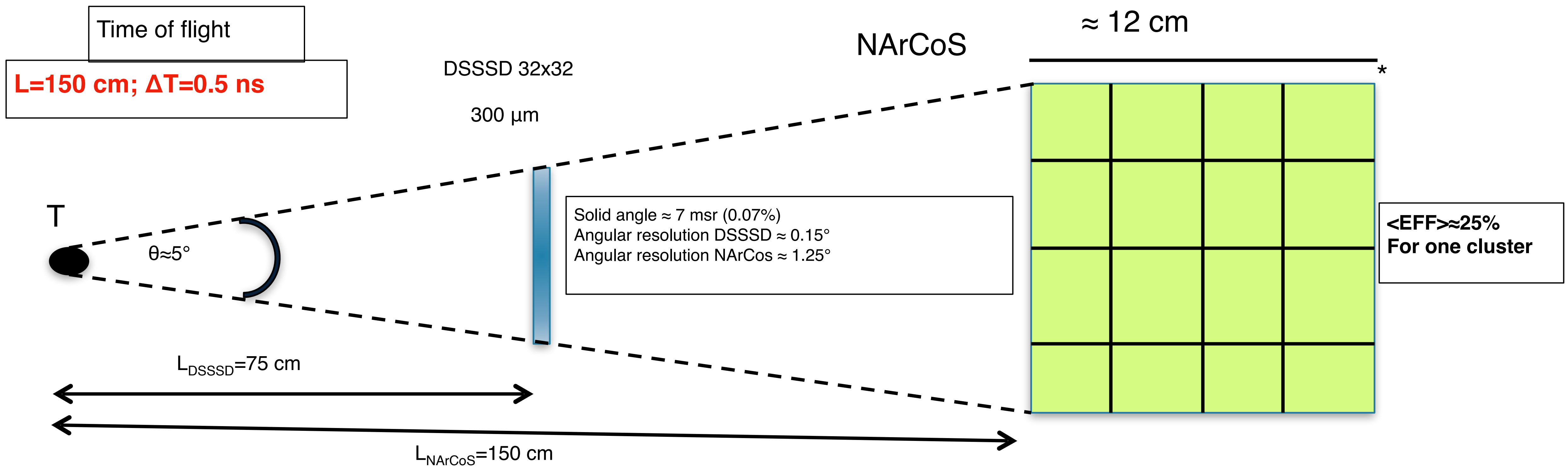
To realize a prototype of detector able to detect at the same time charged particles and neutrons with high energy and angular resolution for reaction studies and applications

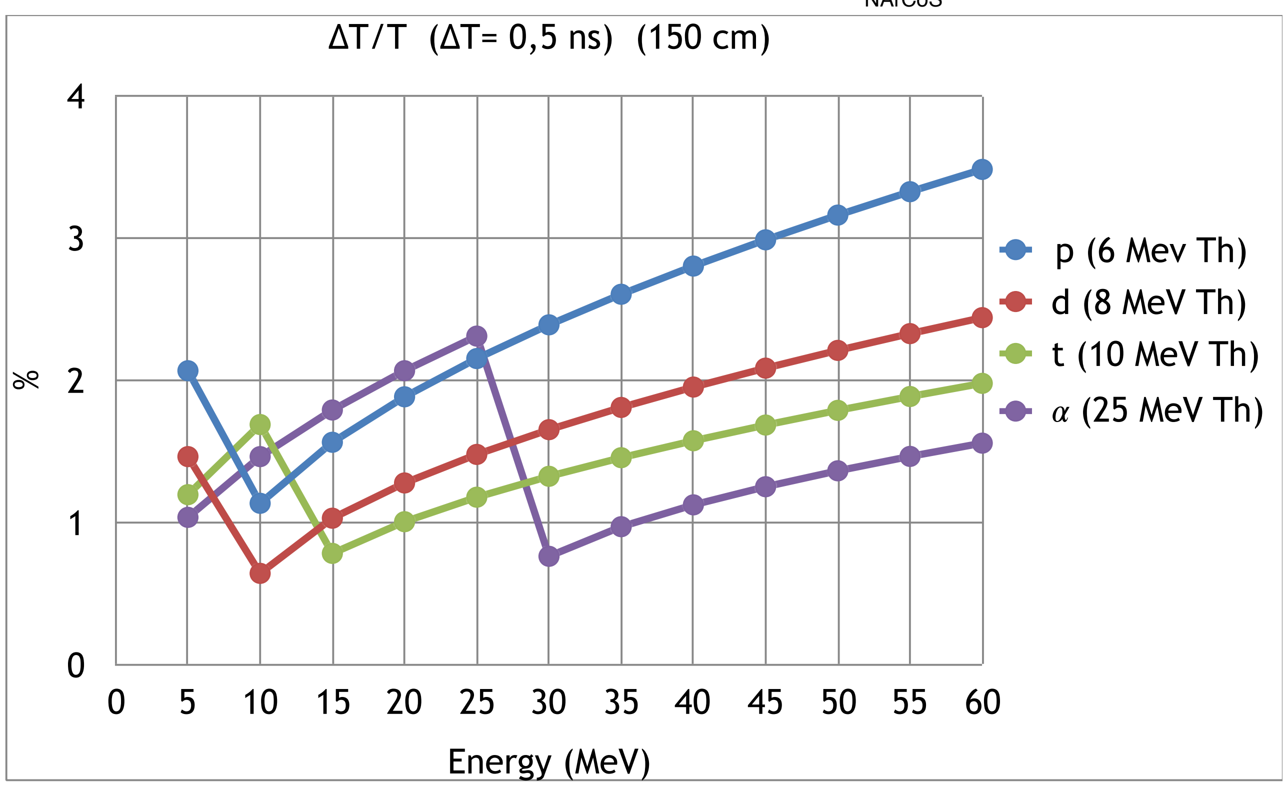
- Candidate: The plastic scintillator EJ276-Green Type (ex EJ299-33) ($3x3x3cm^3$)
- 1 cluster: 4 consecutively cubes -> $3x3x12\ cm^3$
- Reading the light signal: SiPM and digitalization
- Neutron detection efficiency ≈ 50% for the prototype (16 clusters)
- Modular, reconfigurable (in mechanic and electronic)
- 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)

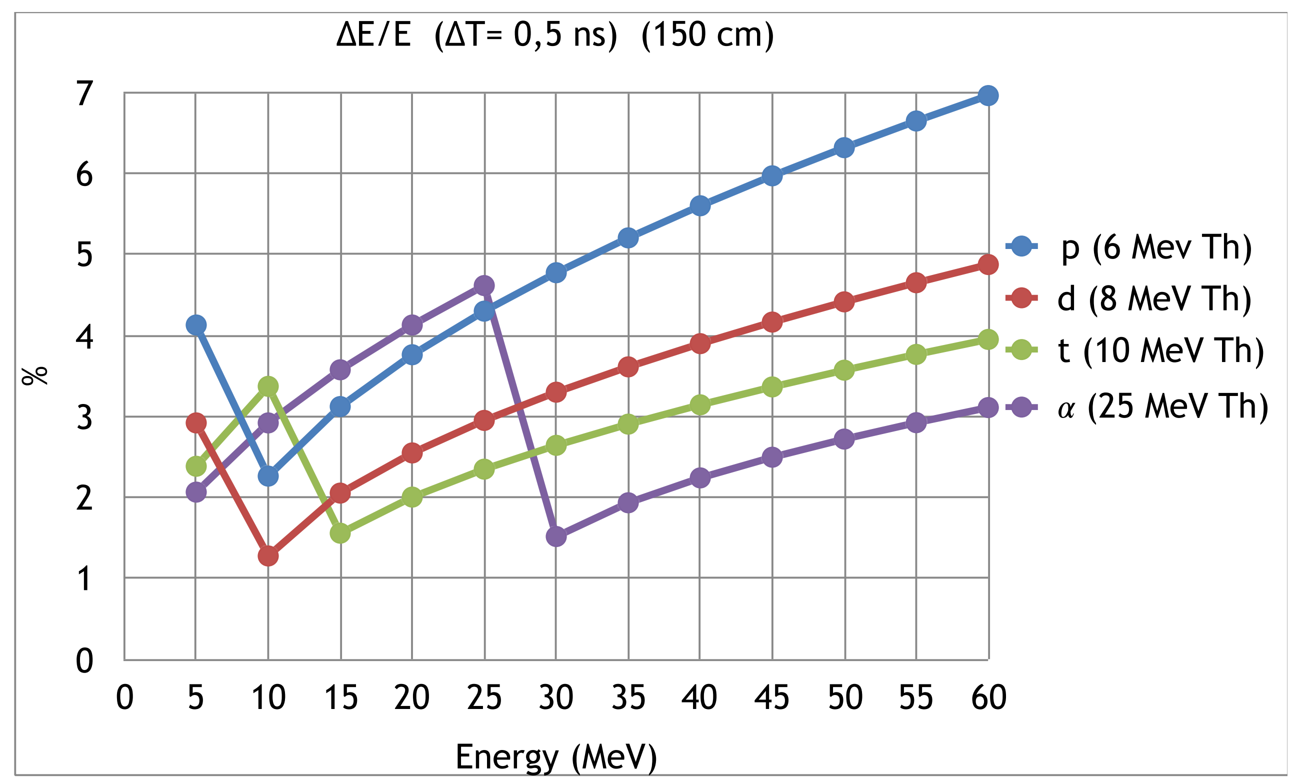
  TOF measured using the RF of the CS or with an ancillary MCP (low intensity exotic beams)



Expected performances

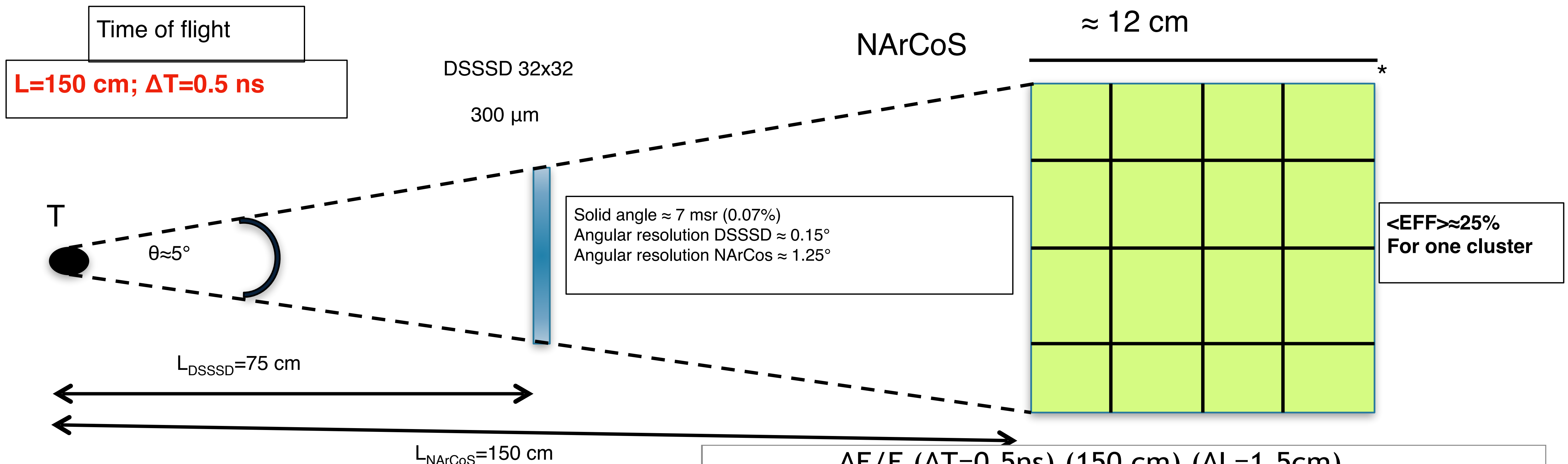


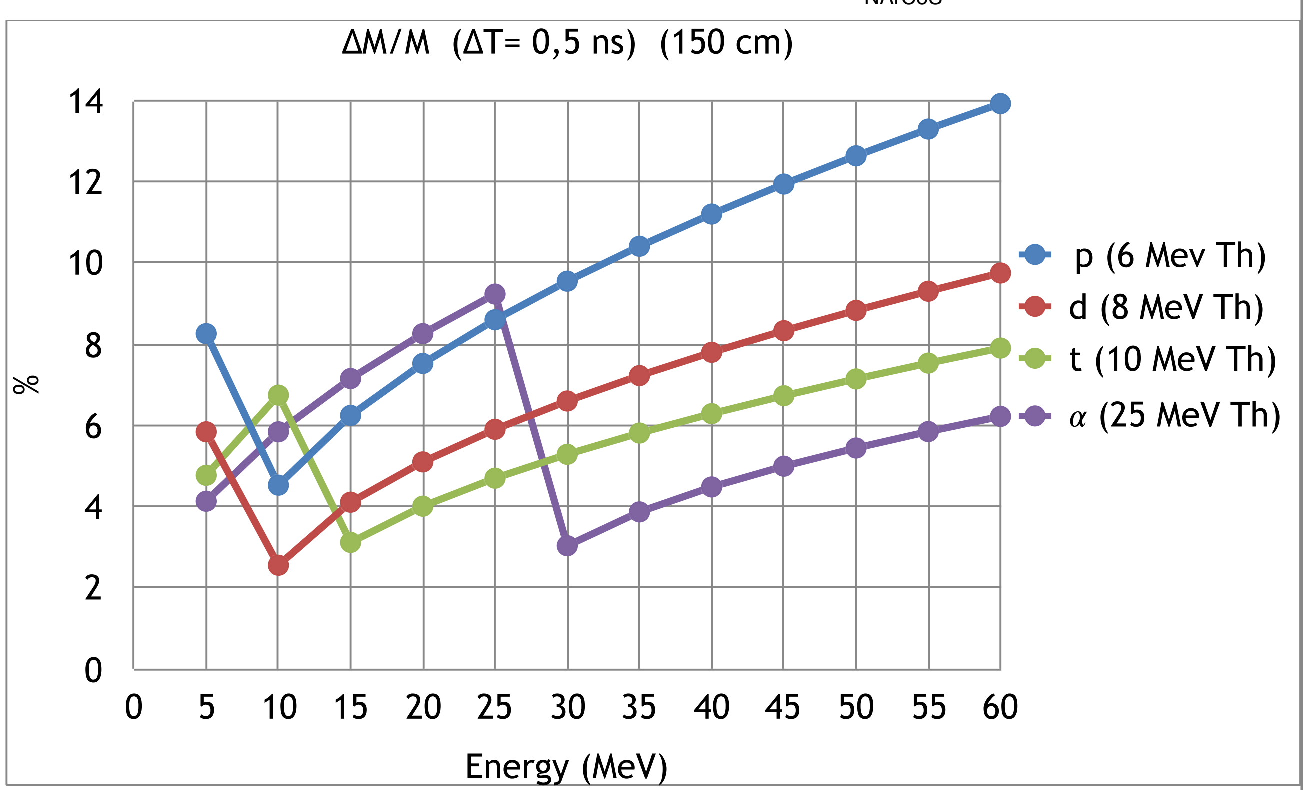


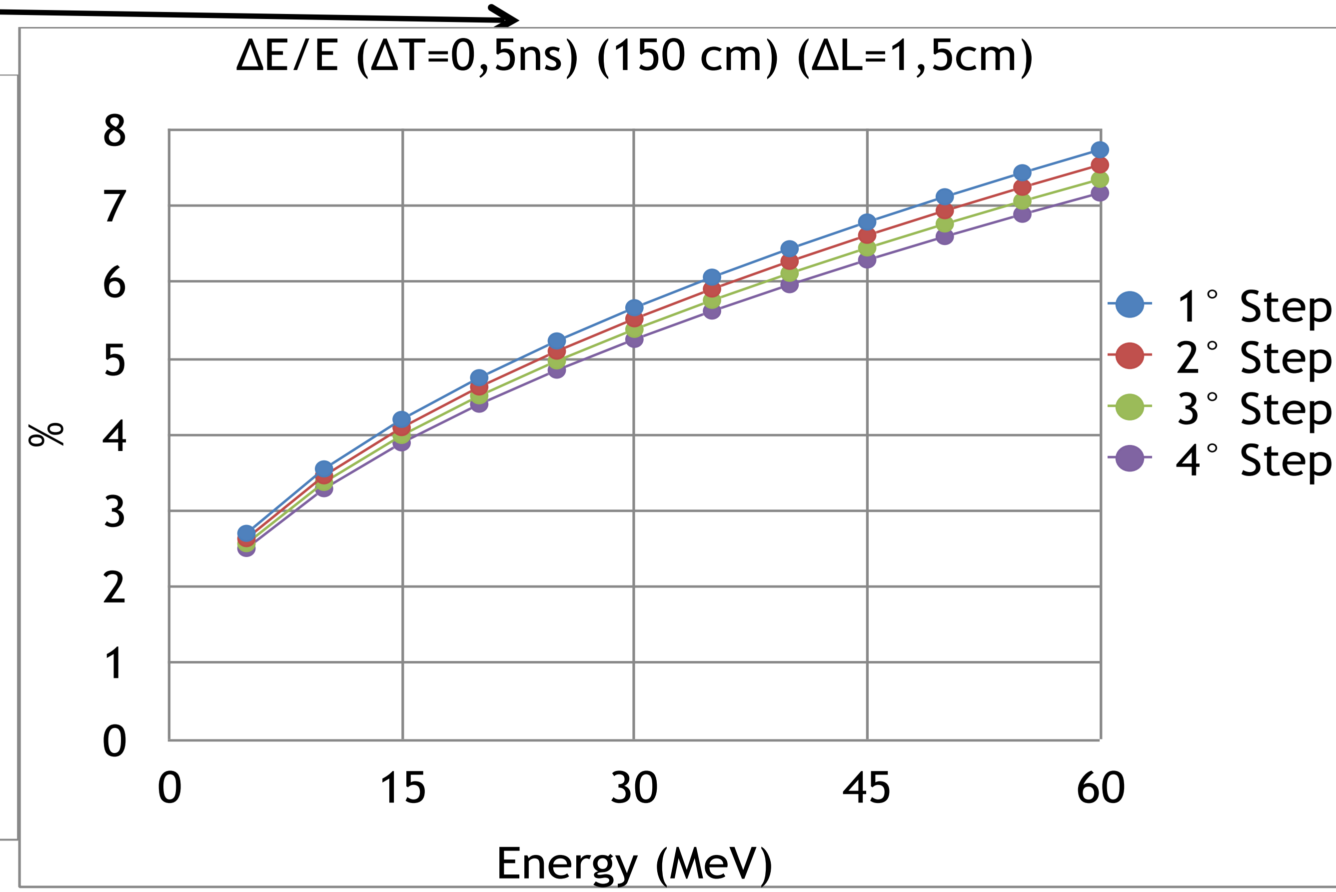


*the mechanical structure will have the possibility of an angular movimentation

Expected performances







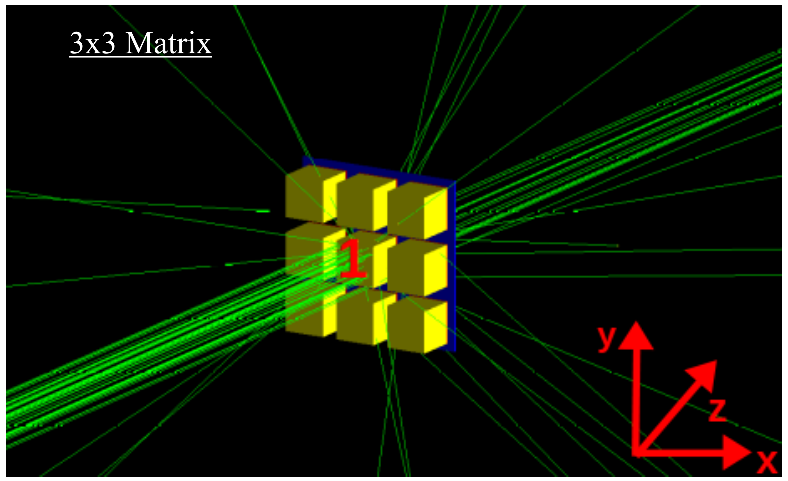
*the mechanical structure will have the possibility of an angular movimentation

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)

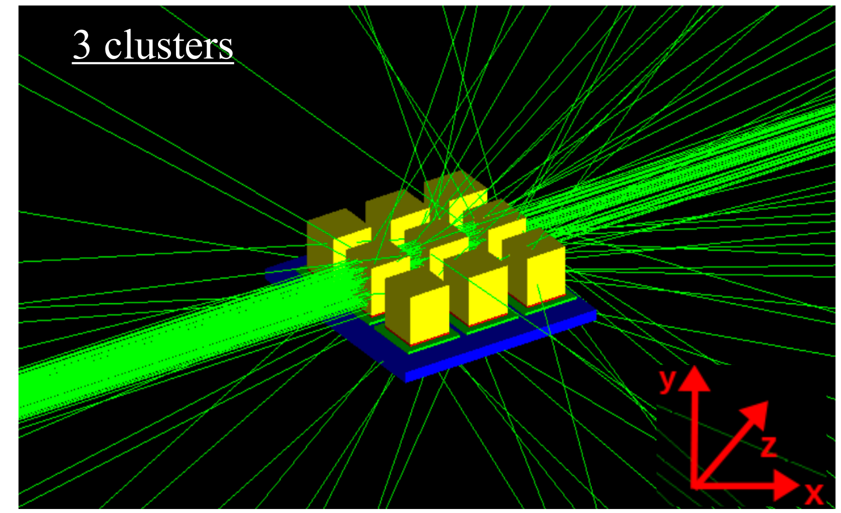


Two configurations was tested

Main reaction for neutrons

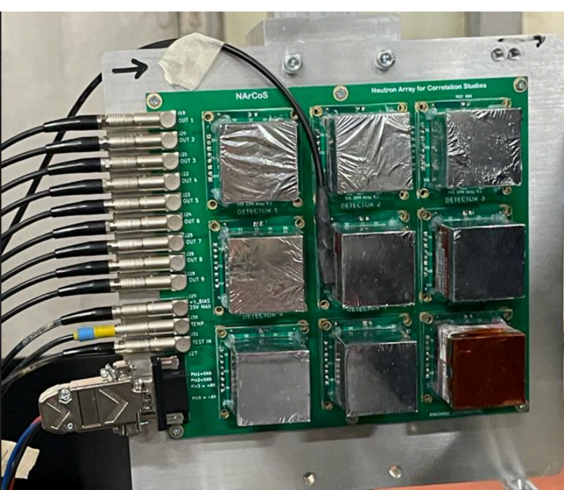
$p + {}^{7}Li \longrightarrow {}^{7}Be + n$

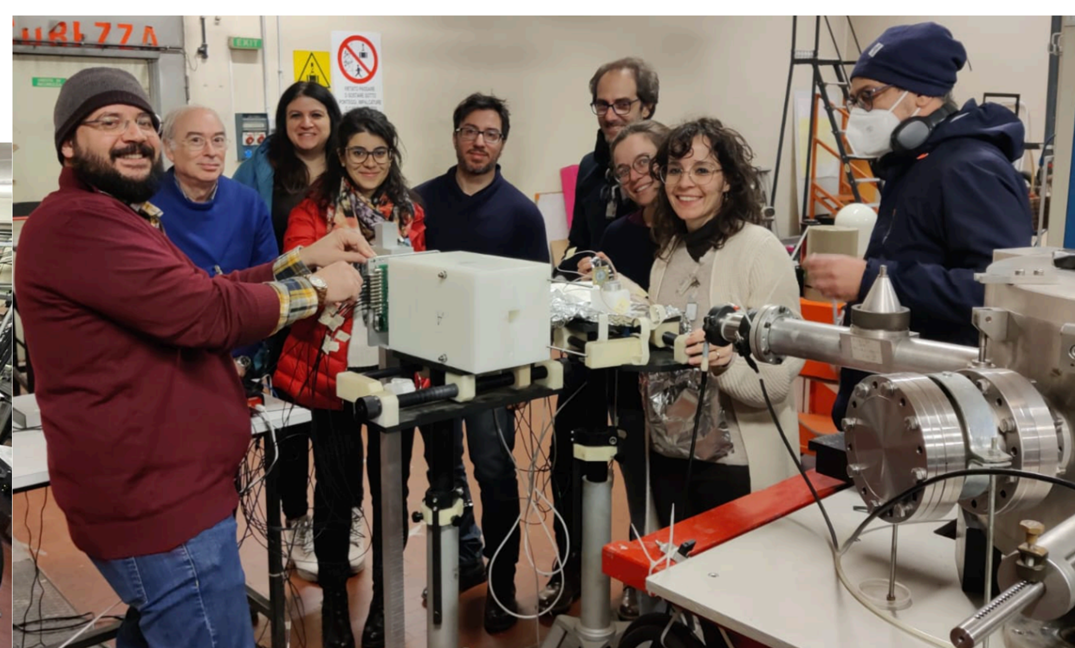
The 3 clusters (linear crosstalk)



The experiment was performed at CN accelerator of INFN-LNL laboratory using a proton beam of 5 MeV on a LiF target producing a neutron beam having energy En < 5 MeV (neutron experimental threshold 1.5 MeV)

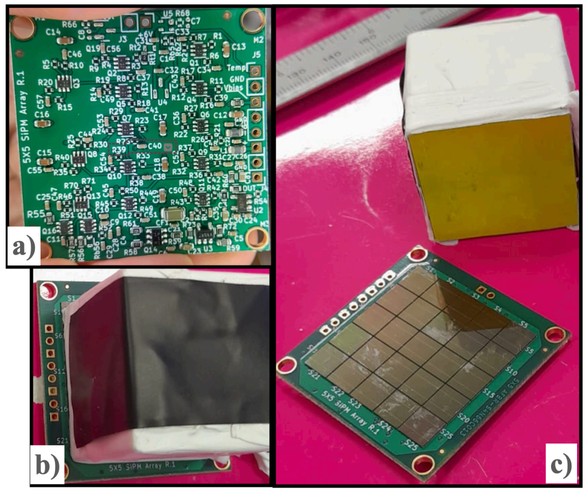
Experimental Setup





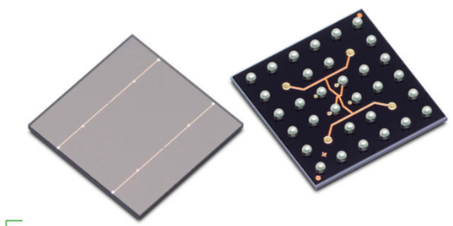
Preliminary results of CROSSTEST exp. @LNL (end of 2023)

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 (≈ 40k microcells). The SiPM matrix is coupled with the plastic having theirs PAC and bias/ temperature compensation circuit



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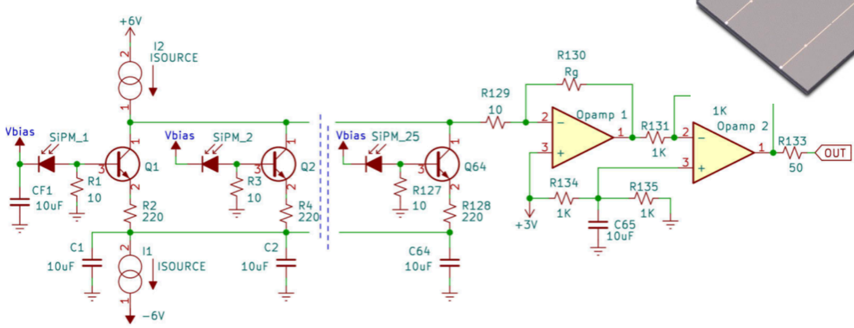
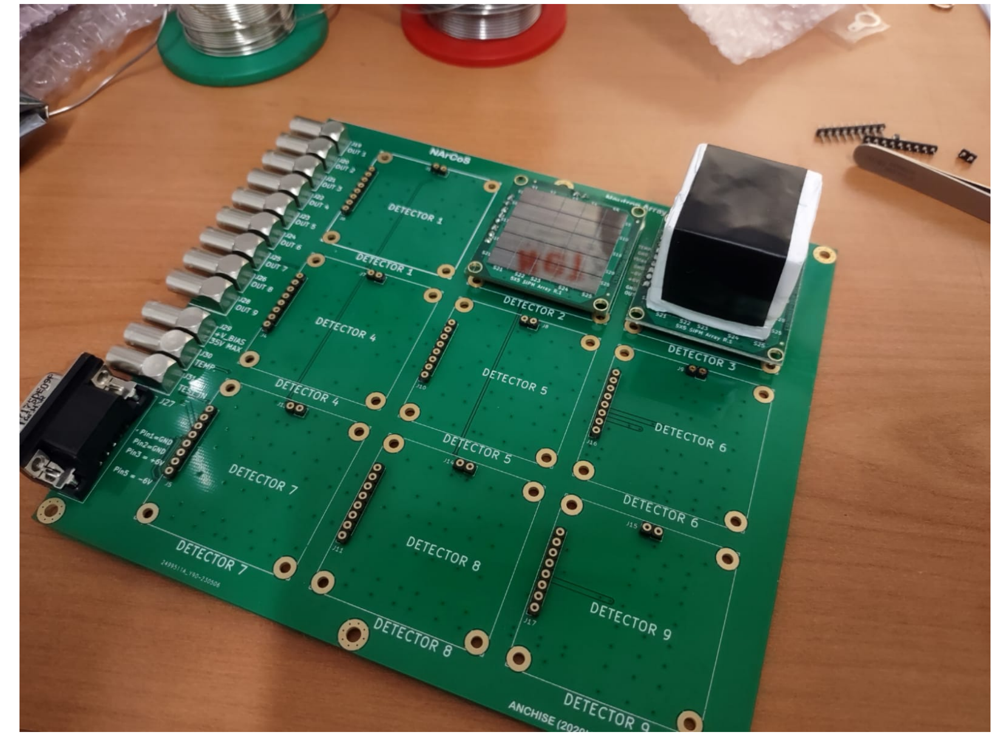
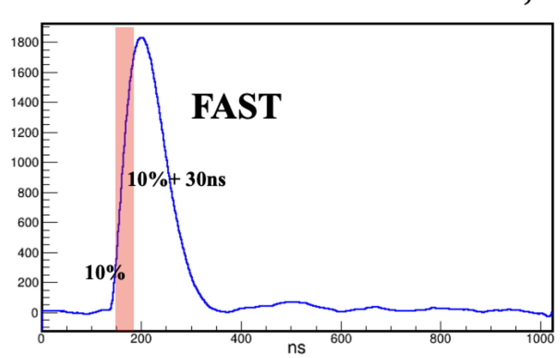
AFBR-S4N66C013

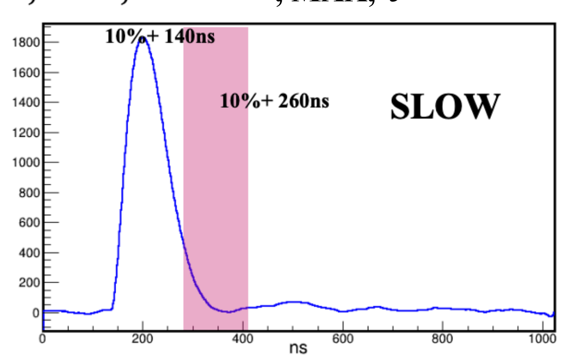


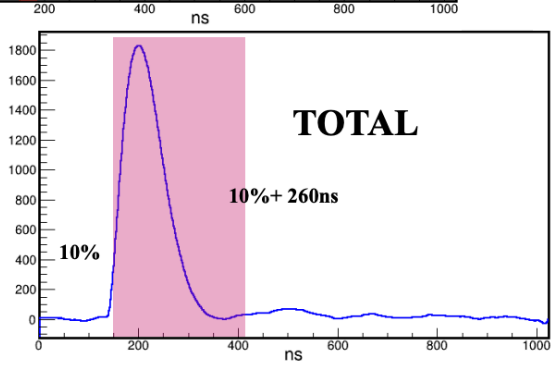
Electronic Board for housing the 9 elementary cells with its electronic readout boards, with the out of the signals, test ingress, temperature monitoring and bias ingress



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*

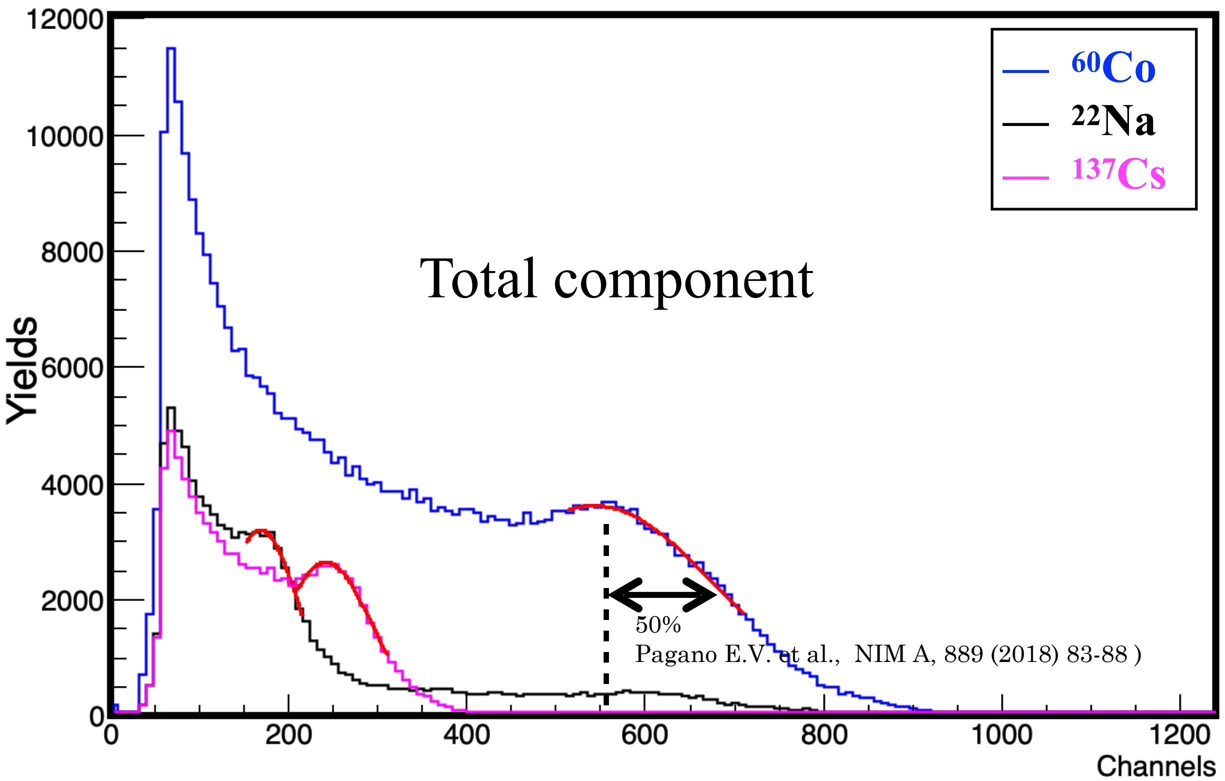
Sampling frequency: 1 Gs/s
Trigger: internal (only the central plastic detector)

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

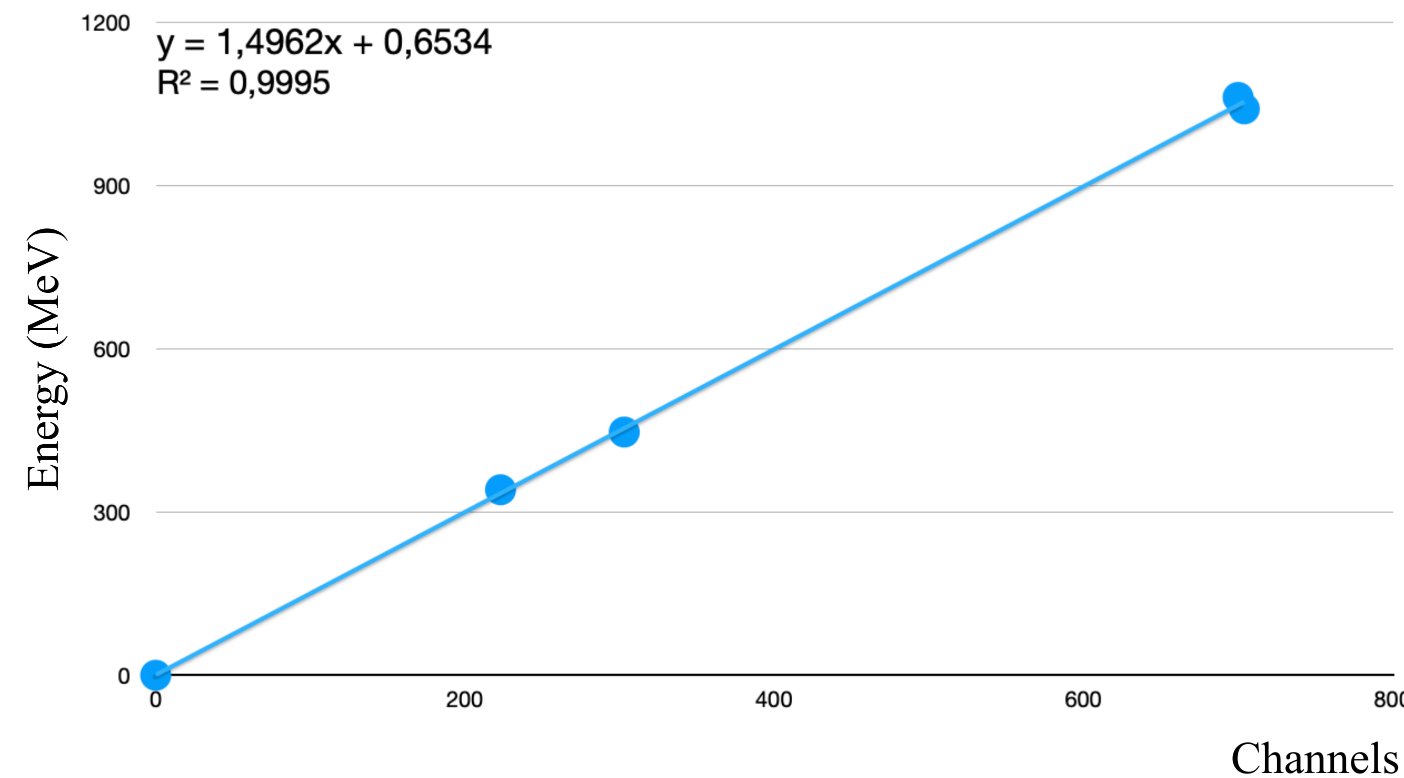
Preliminary results of CROSSTEST exp. @LNL (end of 2023)

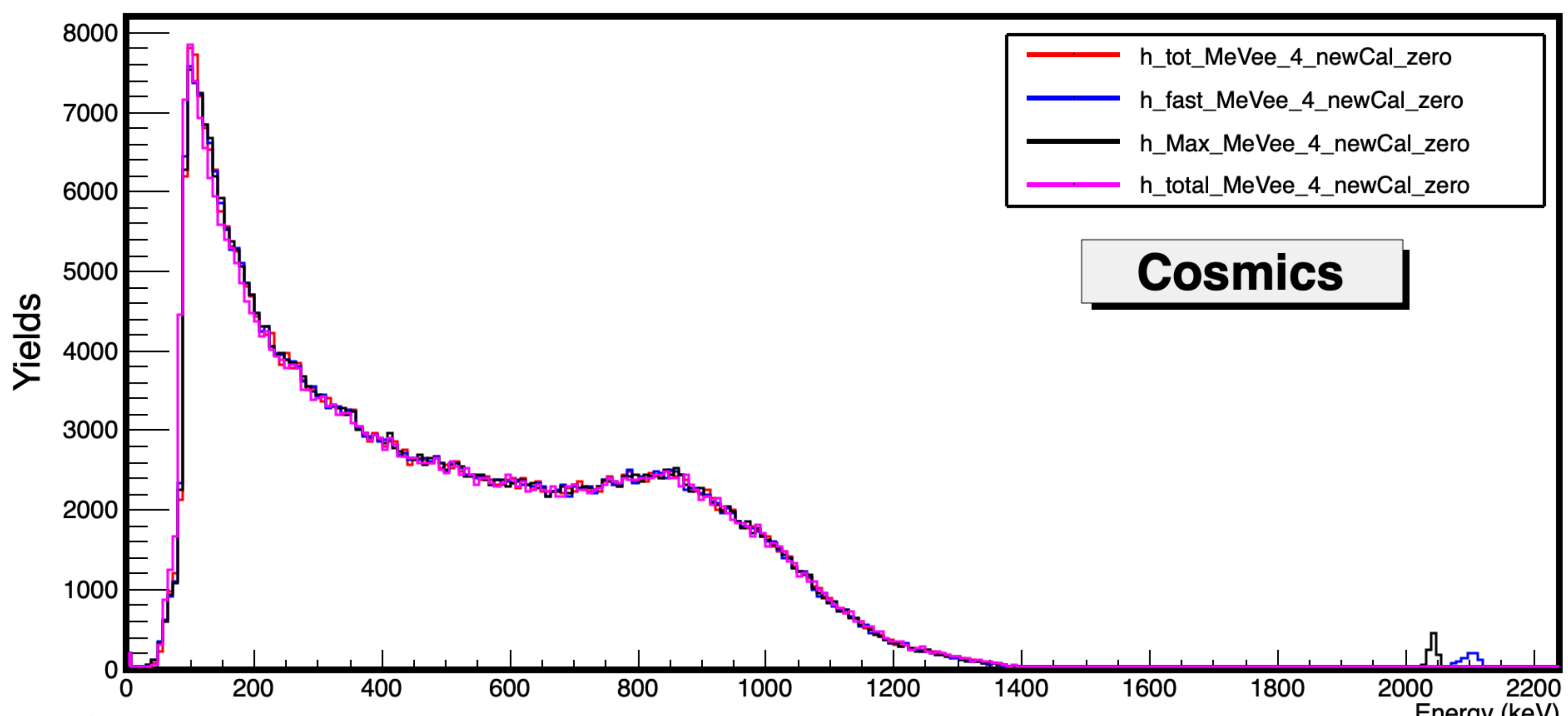
Detectors energy calibration

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



Central plastic



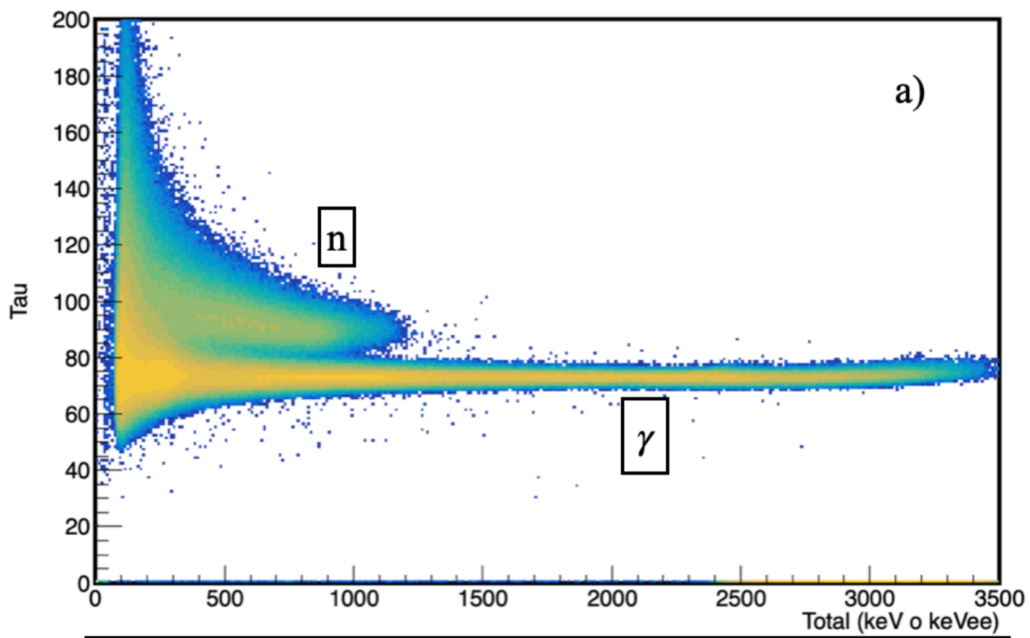


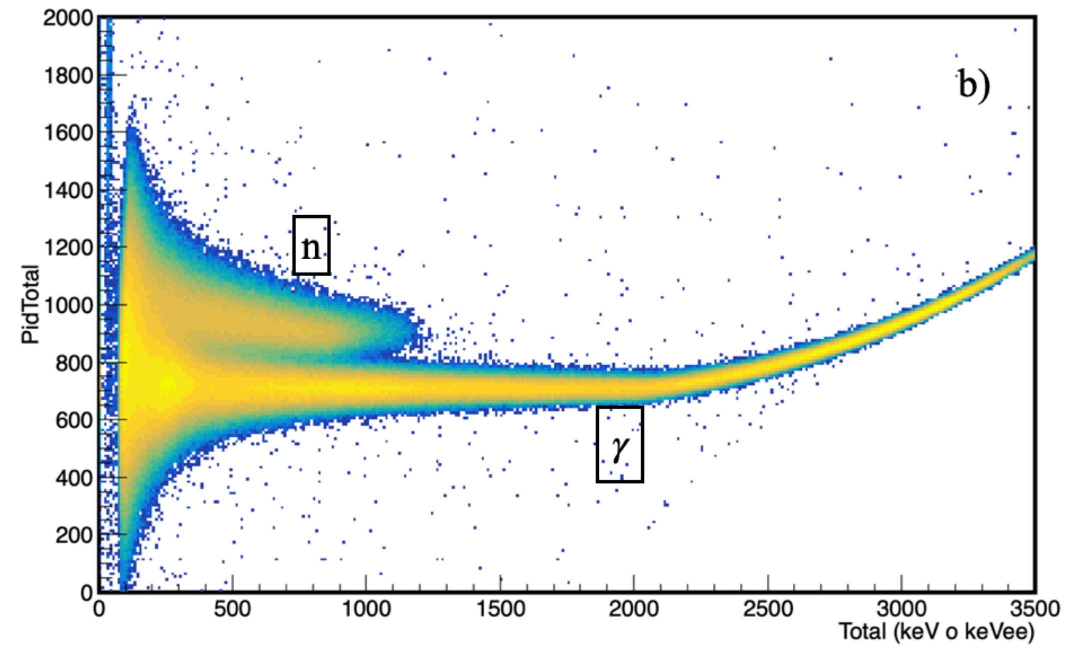
Good energy linearity

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)

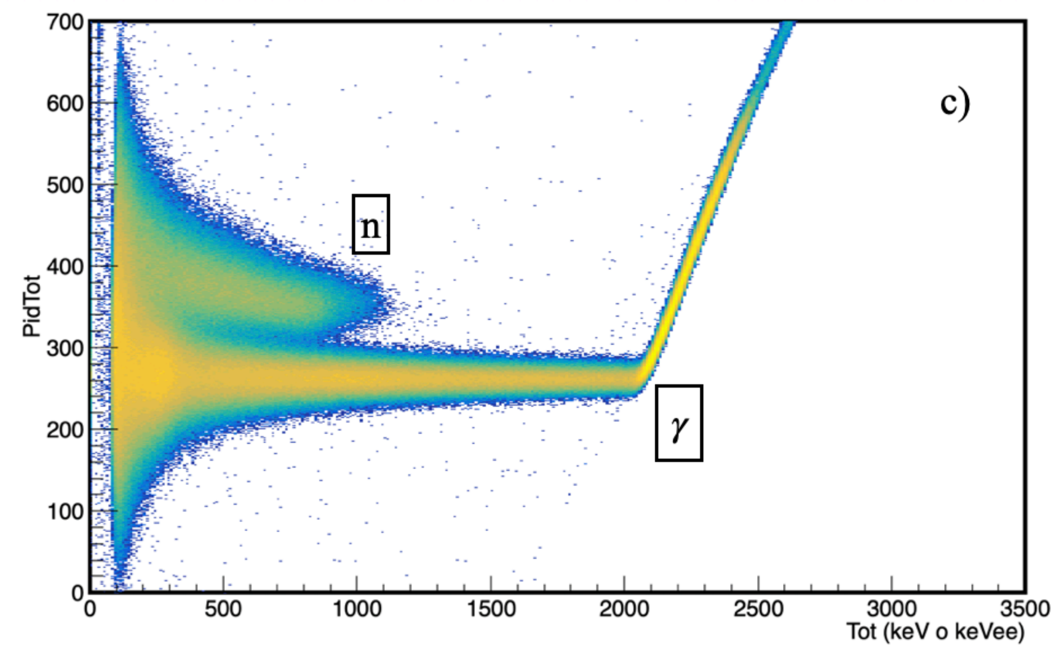
b) PidTotal VS Total (keV)

c) PidTot Vs Tot (keV)

Tau: fit esponenziale nella parte decrescente del segnale

PidTotal: Slow/Total*

PidTot: Slow/Tot*

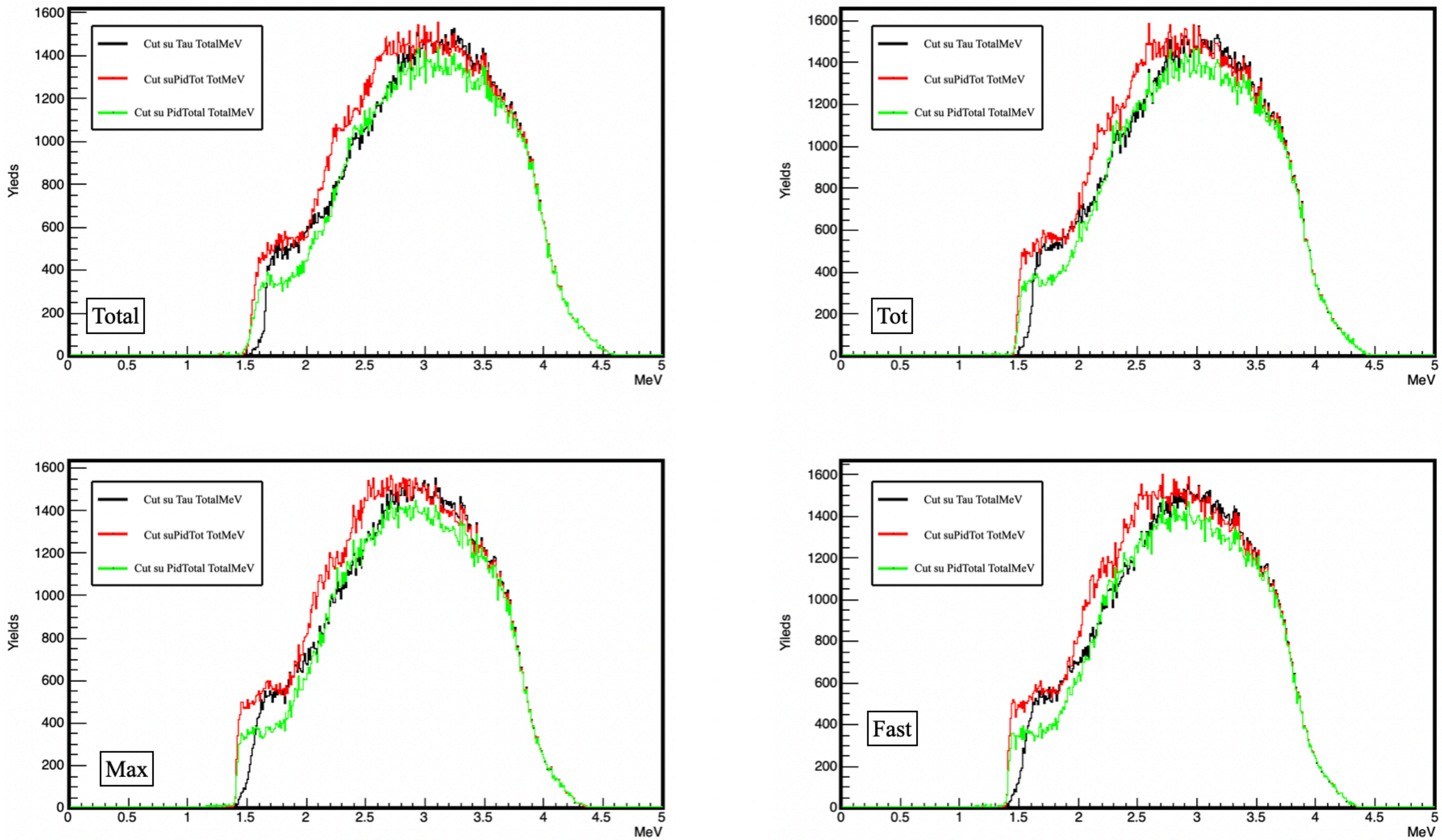


Central plastic

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:

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

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

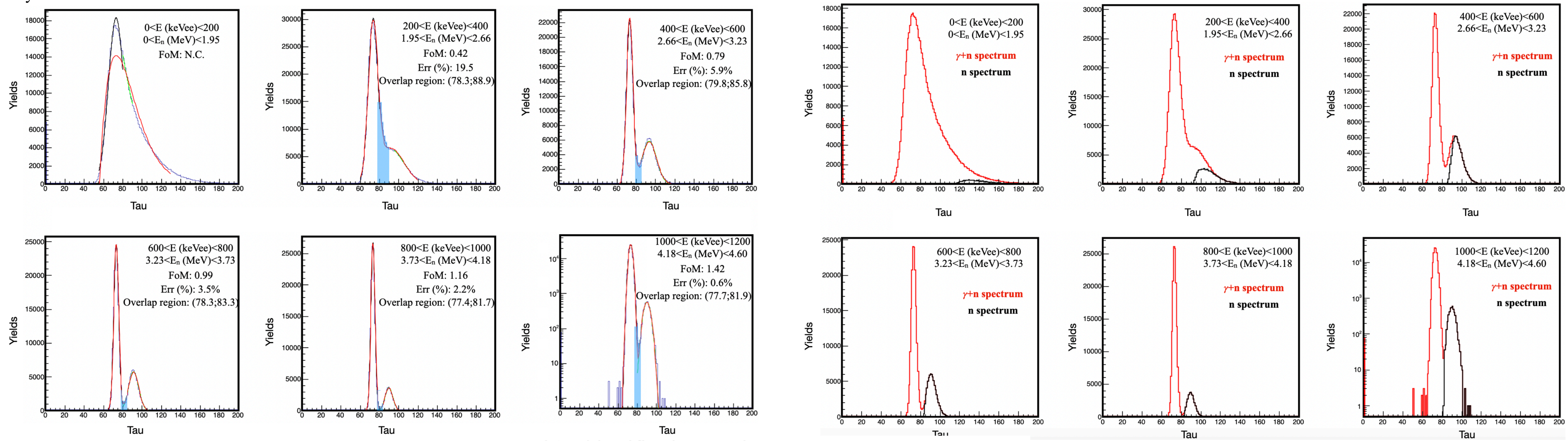
a = 0.8 MeVee*MeV^{-1}
b = 0.39MeVee
c = 0.22 MeV
L_{out} in MeVee
E_{dep} in MeV

Reasonable neutron energy spectra (neutron beam maximum energy 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

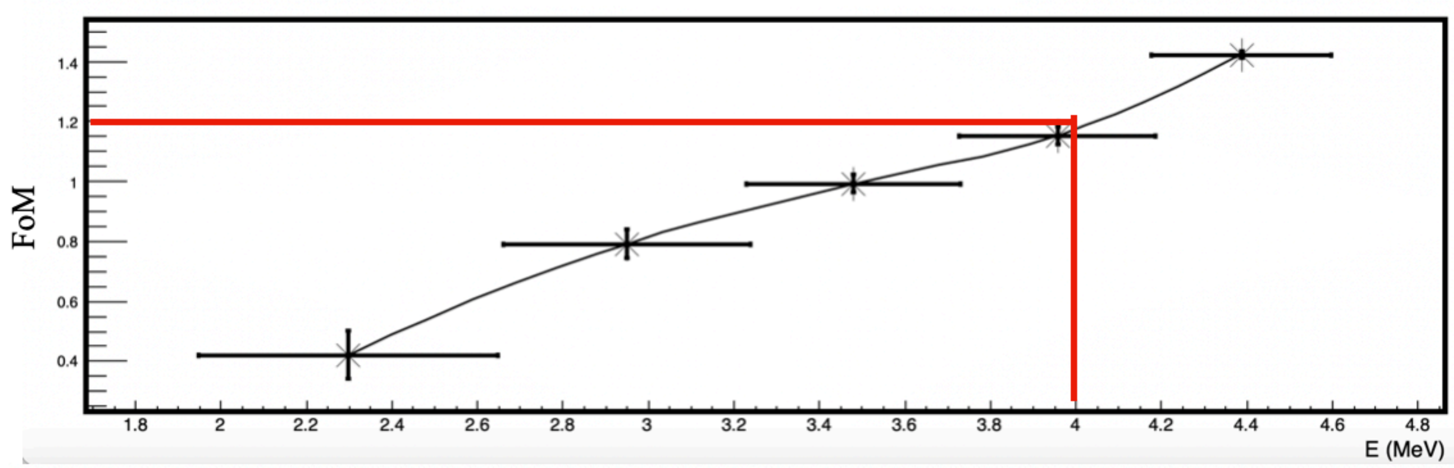
Preliminary results of CROSSTEST exp. @LNL (end of 2023)

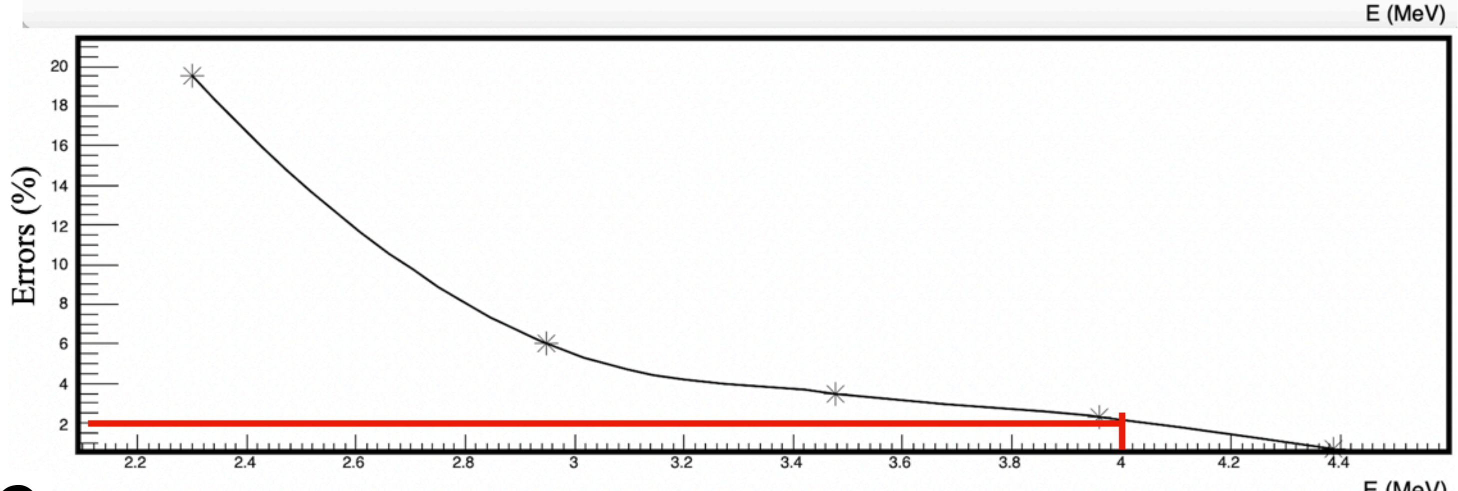
FoM and Errors estimations

Very close results for the others 2D Identification Matrix



Tau Vs Total 2D identification matrix



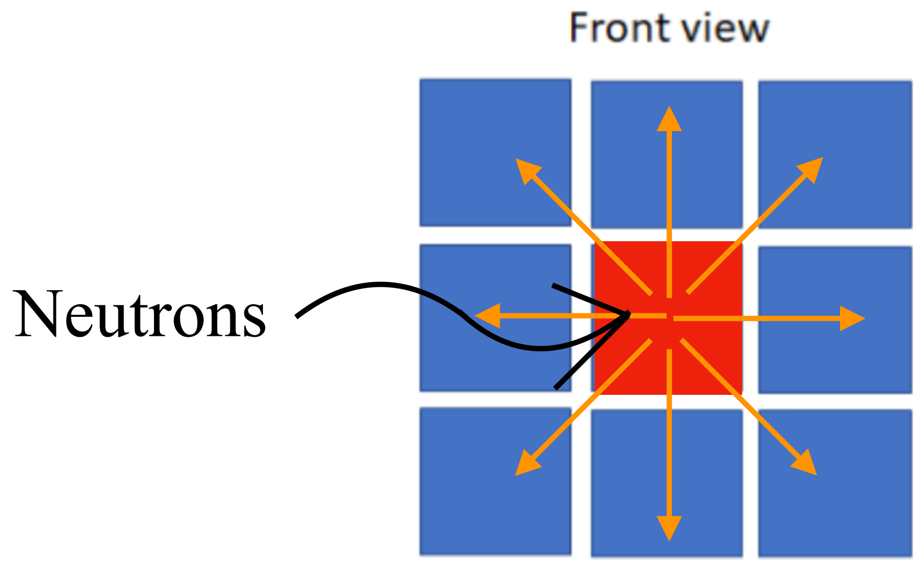


At about 4 MeV of neuters we obtain a value of 1.2 of FoM generally considered as "good". At this value the corrispondi errors in the neutron identification is about 2%

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

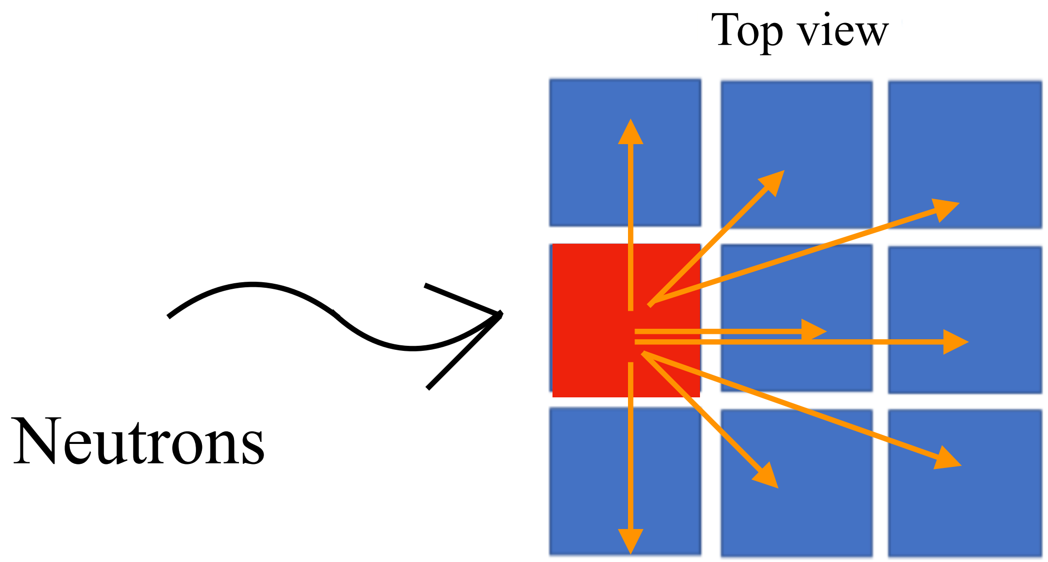
$$P\,(\%)\ =\ prob\,(\%)\ \pm\ Er_{ass}\,(\%)\ =\ (0.117\ \pm\ 0.008)\ \%$$

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

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

Crosstalk Measurement for 4.5 MeV of neutrons

Cluster configuration (linear crosstalk)



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

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

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

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

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

Crosstalk Measurement and comparison with MC based simulation

The simulated value was obtained form GEAN4 toolkit simulation (G. Santagati and L. Quattrocchi)

And from MCNPX toolkit simulation (L. Quattrocchi)

The two simulation software were in good agreement

Value for Neutrons of 5 MeV

Conf.	Measured crosstalk Probability	Measured Error	Measured Error (%)	GEANT4 crosstalk Probability	GEANT4 error	GEANT4 error (%)	Difference
MATRICE	0,117	0,008	7	0,45	0,06	13	0,333
CLUSTER	0,163	0,005	3	1,37	0,07	5	1,207

The difference from measured to the respect of the simulated values are not so big in absolute value but large un relative!

A factor 4 in for the matrix configuration

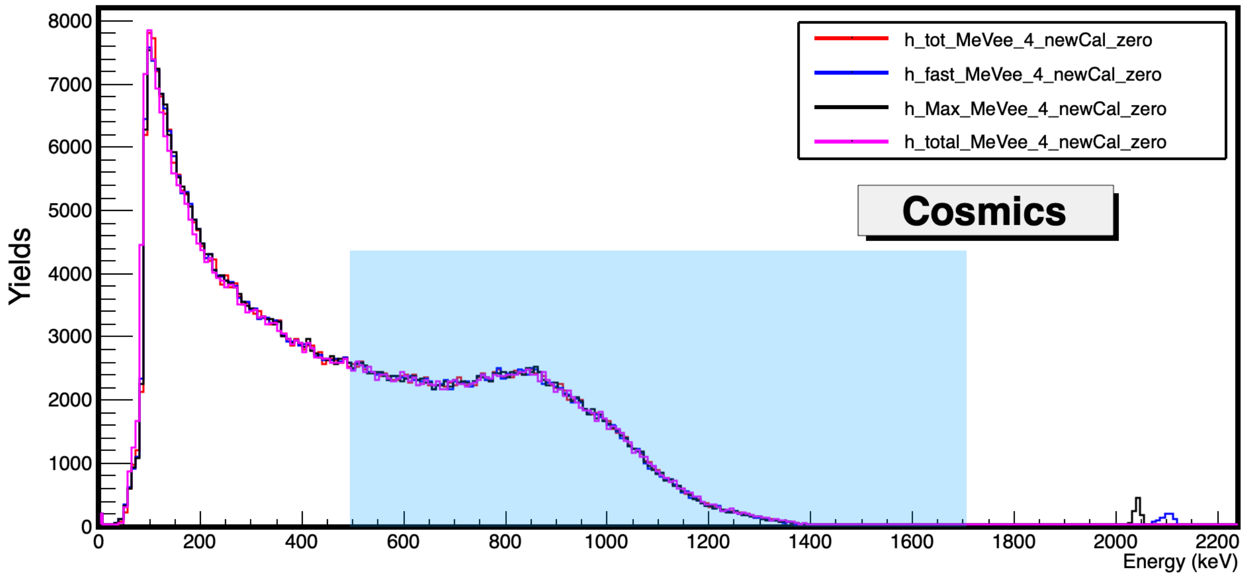
An order of magnitude for the cluster configuration

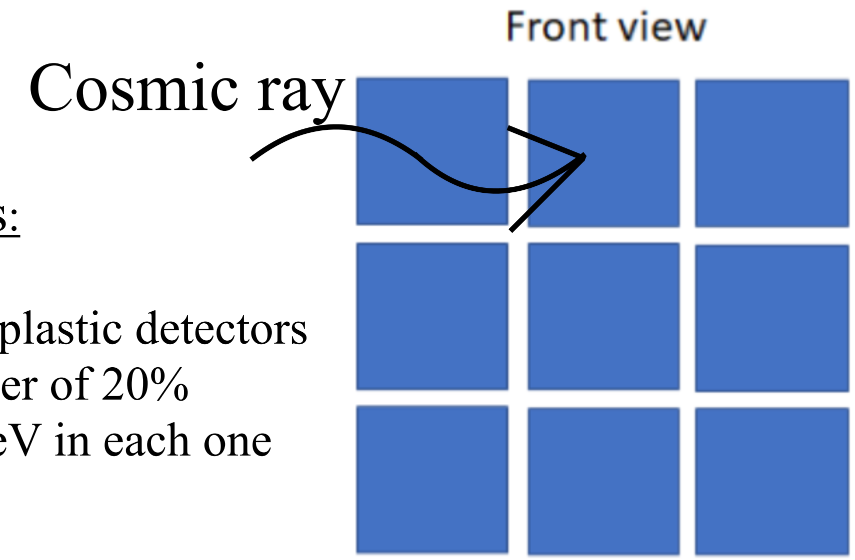
More investigation are needed

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

Time resolution

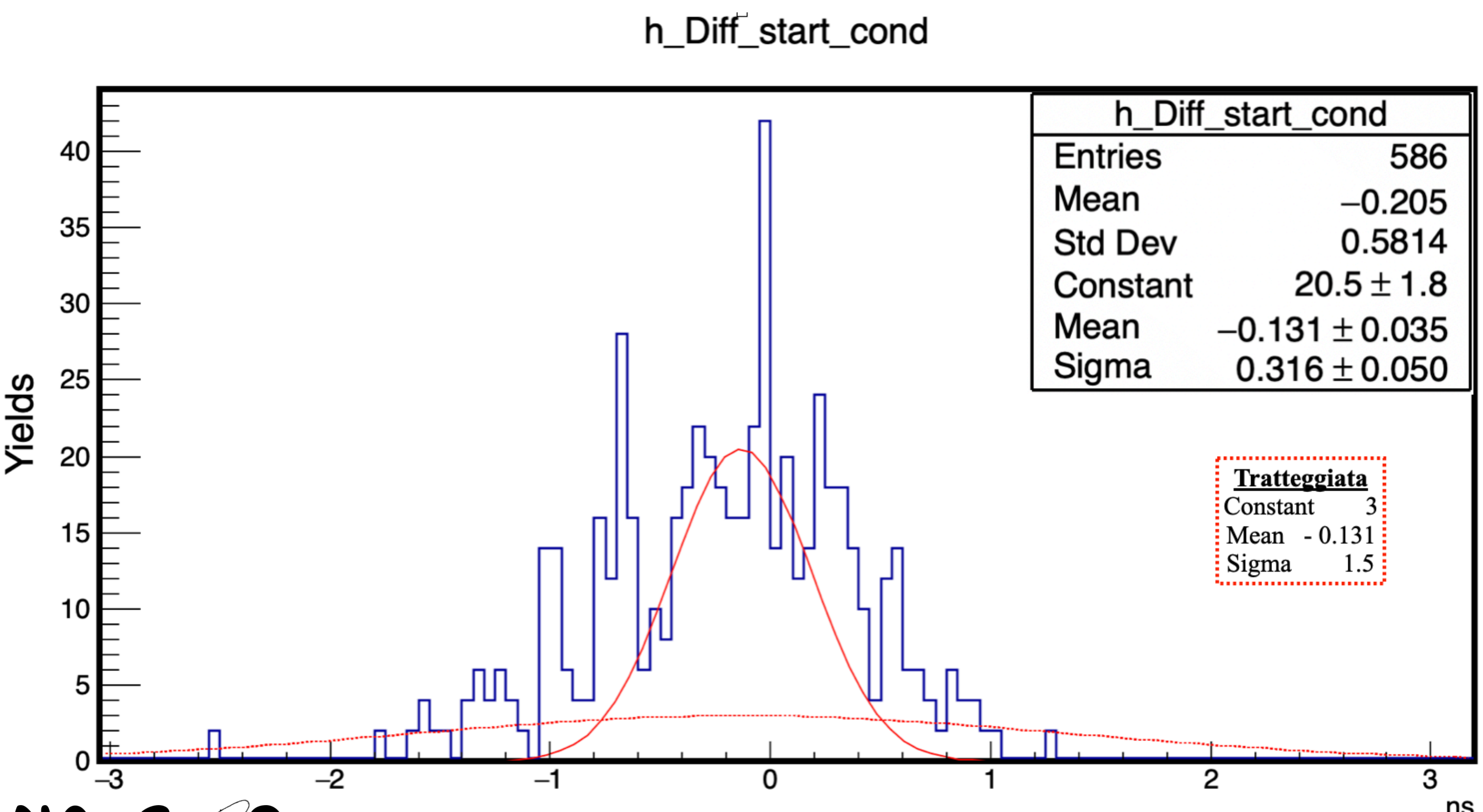
evaluated with a cosmic ray detected in coincidence between two plastic scintillator





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

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

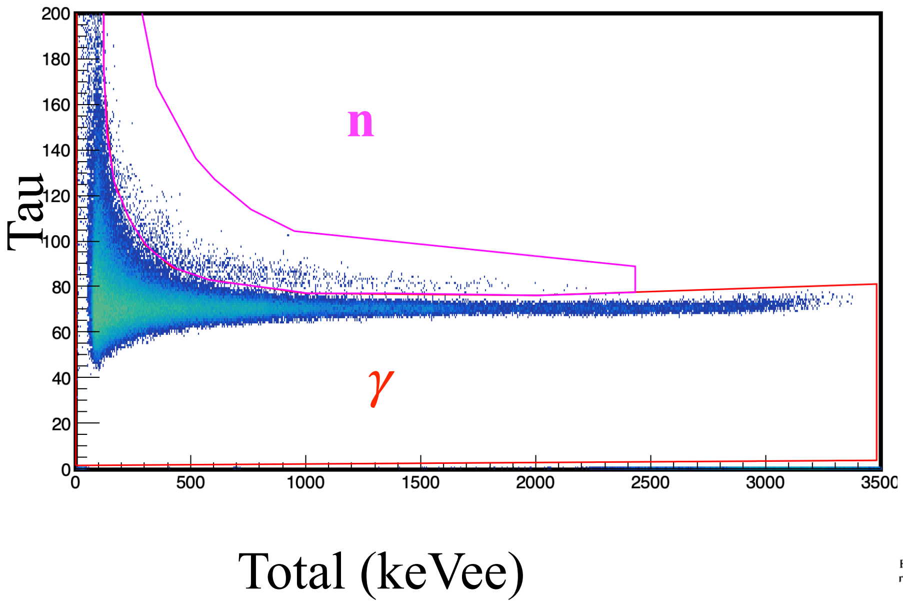
$$\sigma_{el} \approx 100\ ps$$

Neutron Energy from ToF Measurement

Test @LNS with AmBe radioactive Source

$^{9}Be + \alpha \longrightarrow {}^{12}C^{*} + n \longrightarrow {}^{12}C + \gamma(4.44) + n$

F. De Guarrini et al., NIM 92 (1971) 277-284



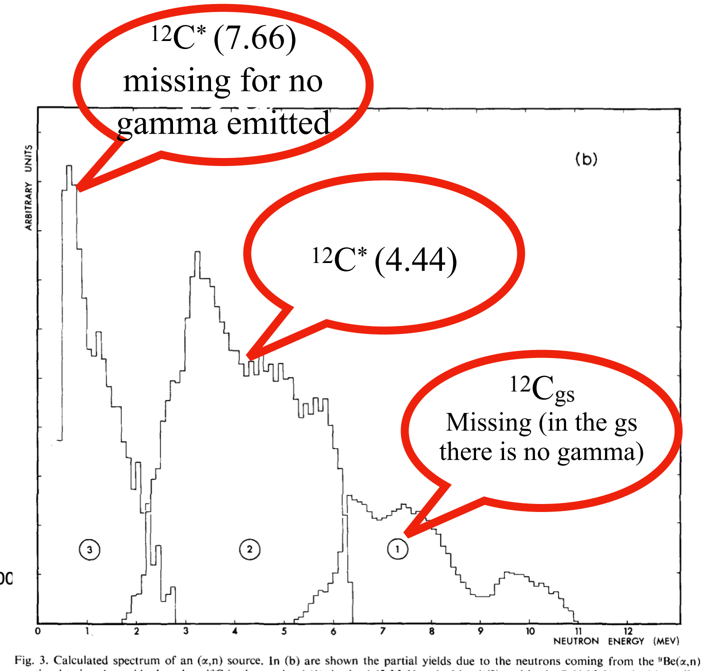
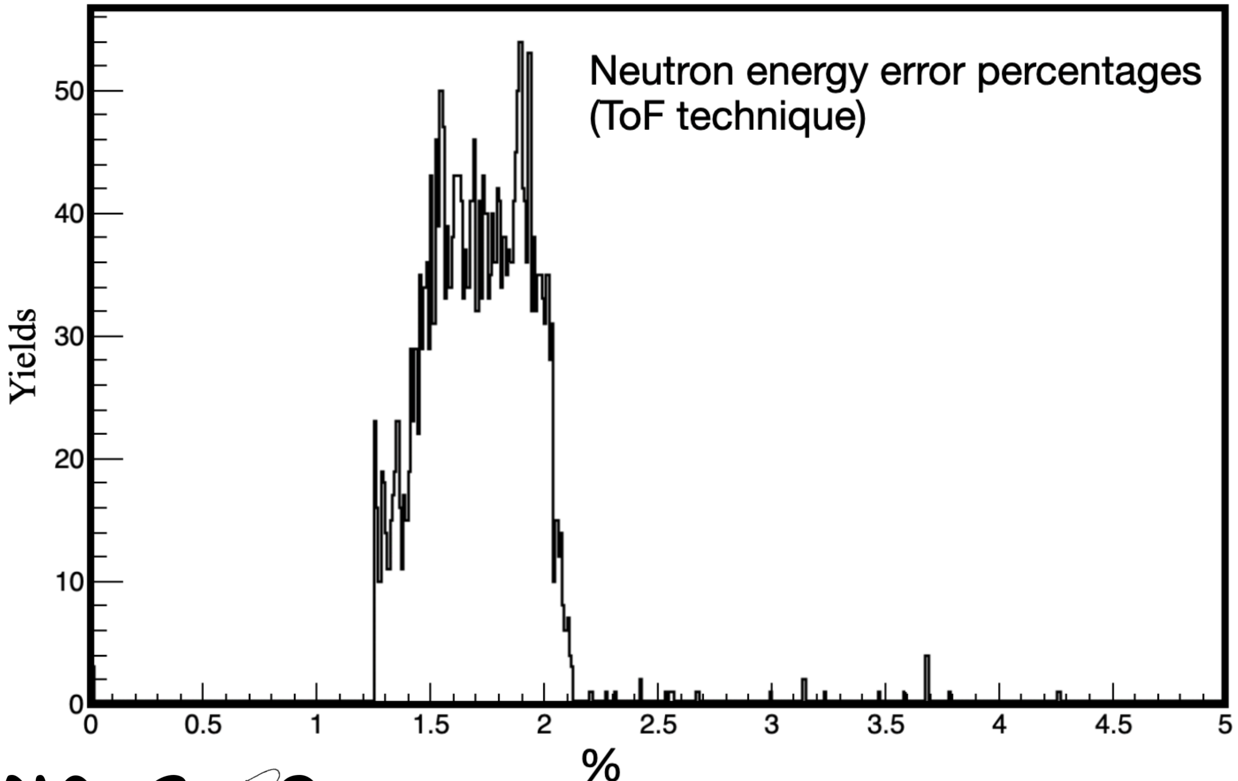
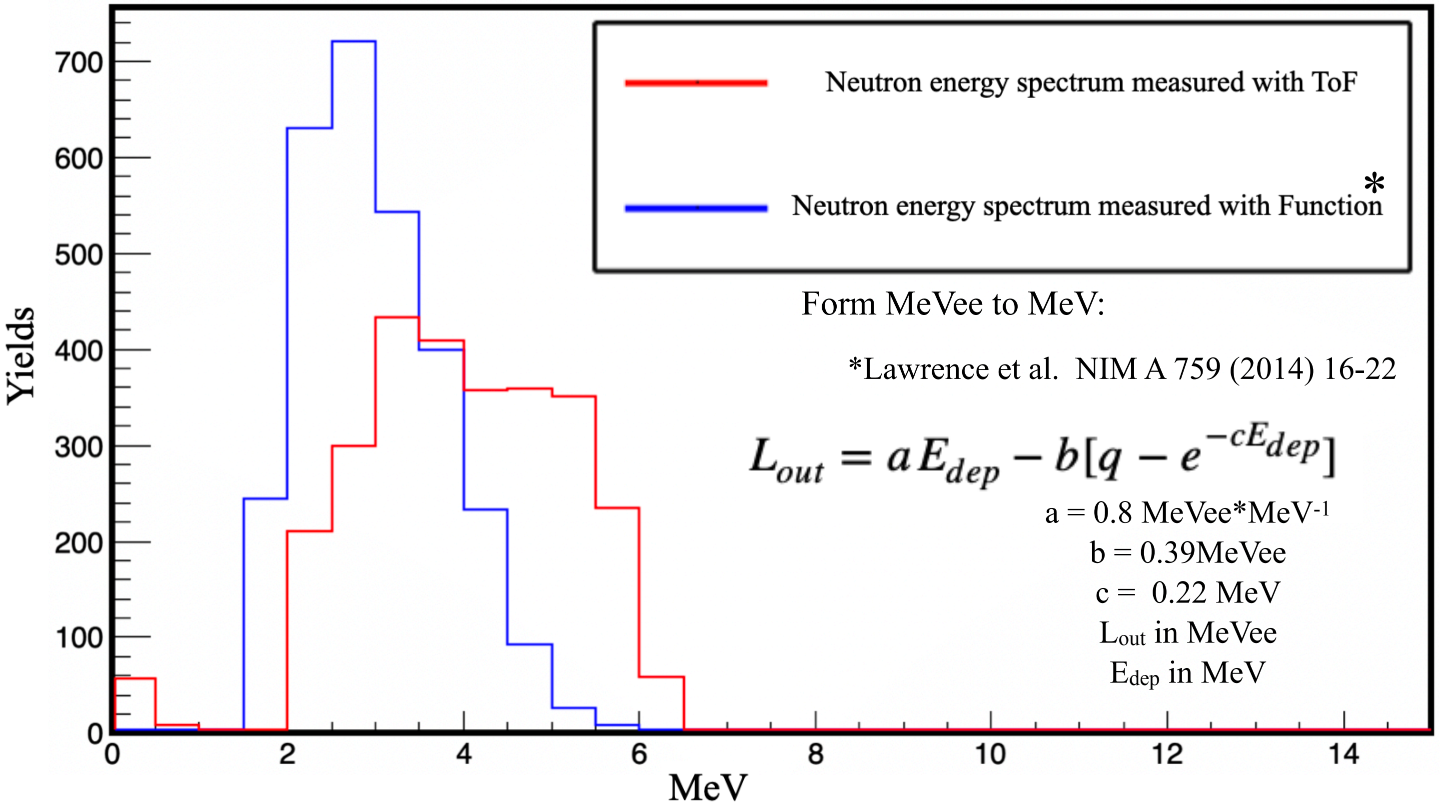


Fig. 3. Calculated spectrum of an (α,n) source. In (b) are shown the partial yields due to the neutrons coming from the ⁹Be(α,n) reaction leaving the residual nucleus ¹²C in the g.s. level (1), in the 4.42 MeV excited level (2) and in the 7.66 MeV excited level (3).





Form MeVee to MeV:

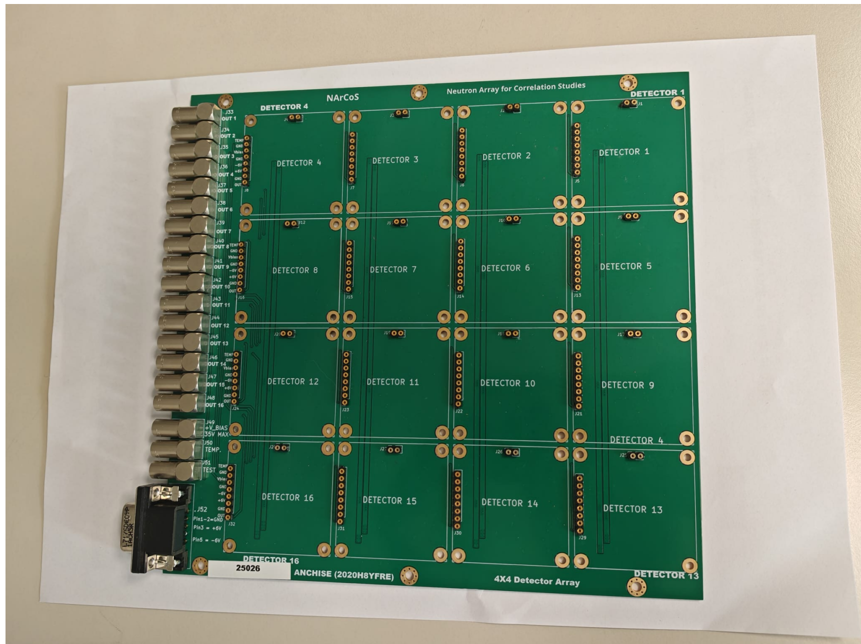
*Lawrence et al. NIM A 759 (2014) 16-22

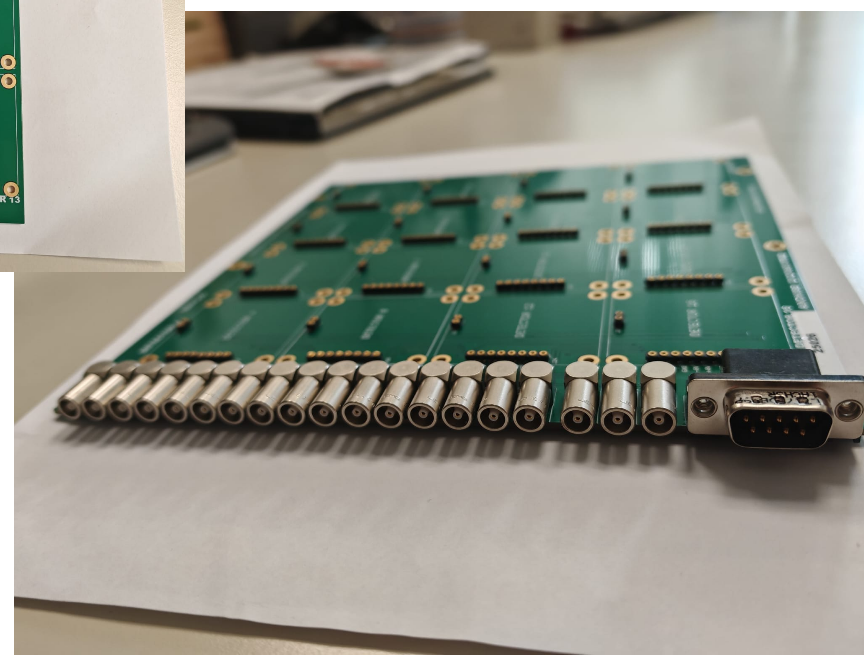
$$L_{out} = aE_{dep} - b[q - e^{-cE_{dep}}]$$

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

What we have now

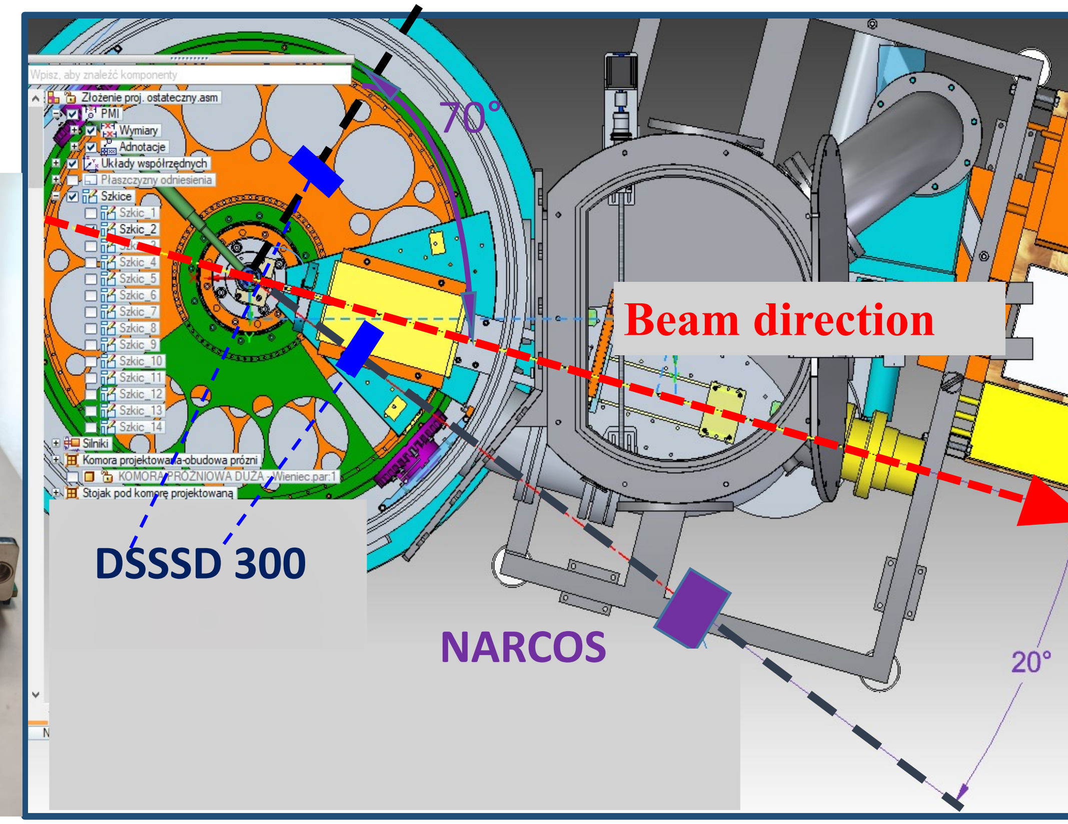
4X4 board



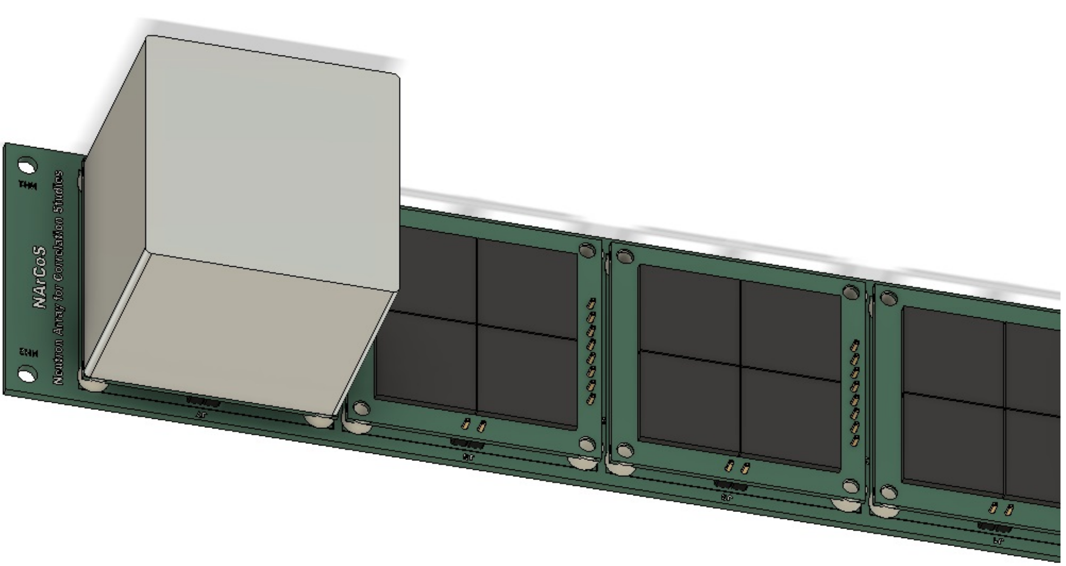


MoReNA Exp. (HIL Warsaw spring 2026)

13C + 12C → 13C* + 12C → 12C + n +12C

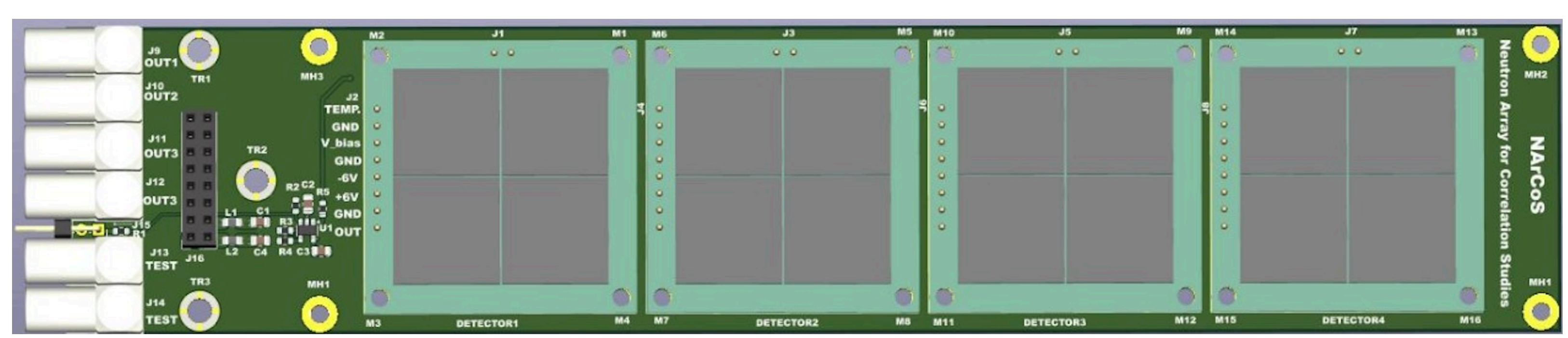


Already developed the Cluster Board (expect to arrive in the next months 16 clusters)



New Si-PM

BROADCOM AFBR-S4N44P164M 4x4 NUV-MT



Conclusions and perspectives

The CROSSTEST experiment was performed in November 2023 at the CN accelerator at LNL-INFN using a neutron beam of 4.5 MeV of maximum energy from a proton primary beam of 4.5 MeV impinging on a LiF target.

The prototypal electronics of readout able to read a matrix of 25 SiPM for each plastic scintillator (EJ276G) worked with good performances.

The preliminary results obtained so far are encouraging: a very good and linear energy calibration of several variable acquired was obtained, good separation between neutron and gamma with a FoM of 1.2 at 4 MeV of neutrons with three different 2D identification matrix, a neutron threshold of 1.5 MeV, a gamma threshold of 70 keV and a time resolution of 320 ps was achieved for 2 plastic scintillator and the electronics (assumable 220 ps for one scintillator and the electronics).

The crosstalk valute at 5 MeV of neutrons was measured for the matrix configuration is about P(%) = 0.1% and for the cluster configuration is about P(%) = 0.2%.

Thees value are relatively far from the MC based simulation (GEANT4 and MCMPX) or the matrix configuration is about P(%) = 0.5% and for the cluster configuration is about P(%) = 1.4%.

New test was performed at LNS-INFN in order to measure the time resolution and the possible time delay between the two versions of the plastic scintillators (EJ276G and EJ276).

New experiments have to be performed in order to test the crosstalk at higher neutron energies in Catania at LNS-INFN and in Legnaro at LNL-INFN.

The study of the mechanical configuration of the NArCoS prototype is completed.

An extension of the study for the efficiency and for the crosstalk problem for the prototype in its final configuration has to be done by means of GEANT4 and MCNPX

For more info see :

1) Pagano E.V. et al., N.S., Nucl. Instrum. Methods A, 889 (2018) 83-88
2) Pagano E.V. et al., N.S., Nucl. Instrum. Methods A, 905 (2018) 47-52
3) Pagano E.V. et al., IL NUOVO CIMENTO 41 C (2018) 181
4) Pagano E.V. et al., JPS Conf. Proc. 32, 010096 (2020)
5) Pagano E.V. et al., IL NUOVO CIMENTO 43 C (2020) 12
6) Pagano E.V. et al., J. Phys.: Conf. Ser. 1643 (2020) 012037
7) Pagano E.V. et al., IL NUOVO CIMENTO 45 C (2022) 64
8) Pagano E.V. et al., Front. Phys. 10:1051058
9) Pagano E.V. et al., LNS Report (2022)
10) Pagano E.V., G. Politi, A. Simancas et al., Nucl. Instrum. Methods A 1064 (2024) 169425
11) Santagati G., Pagano E.V. et al., RAD Conference Proceedings, vol. 7, pp. 52-58, 2023
12) Santagati G., Pagano E.V. et al., IL NUOVO CIMENTO C, vol. 48, (2025) 13
13) Pagano E.V. et al., IL NUOVO CIMENTO C, vol. 48, (2025) 12
14) Quattrocchi L., Gnoffo B., Pagano E.V. et al., (Proceedings of the International Conference Applied Nuclear Physics 2024 to be published)
15) Gnoffo B., Pagano E.V. et al., on timing performances in preparations
16) Pagano E.V. et al., on croostalk al 5 MeV neutron in preparation

Thanks for the attention