

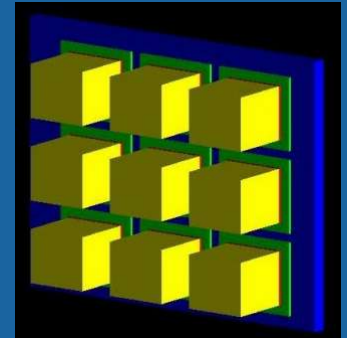
FATA2025: FAsT Timing Applications for nuclear physics and
medical imaging
8-10 October 2025
Catania



Timing characterization of the NArCoS apparatus

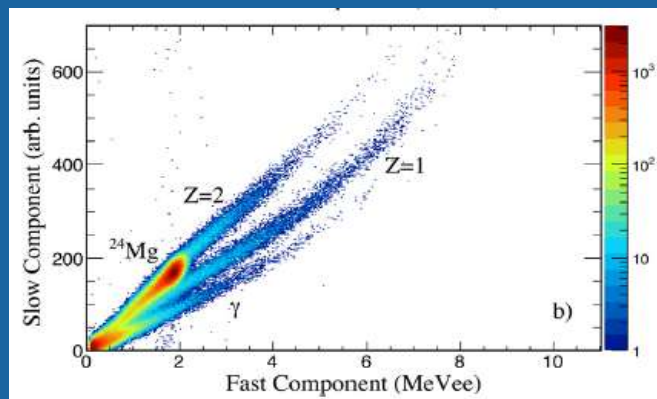
Outline

- Description of NArCoS
- Study of the identification capabilities
- Study of the timing characterization:
 - Time Resolution
 - Neutron Energy measured from ToF
- Conclusions and perspectives

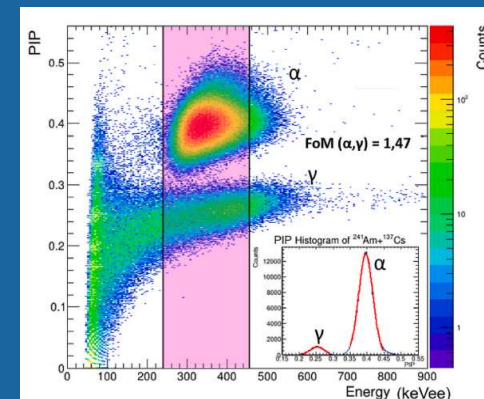


NARCOS: Neutron ARray for CORrelation Studies

NArCoS realized in Catania in the context of the ANCHISE (Array for Neutron and Charged particles with High linear momentum SElection) project, approved and financed by national PRIN2020 funding call and in the context of INFN-CSN3. A compact and segmented transportable apparatus → consisting of plastic scintillators → EJ276 (white) or EJ276G (green) ($3 \times 3 \times 3 \text{ cm}^3$)



Pagano E.V. et al., N.S., Nucl. Instrum. Methods A, 905 (2018) 47-52



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- Reading the light signal: Si-PM
- Modular, reconfigurable (in mechanic and electronic) → 64 detection cells
- Energy measurement from ToF ($\Delta t \leq 500 \text{ ps}$ and $L_{\text{ToF}} \approx 1 \text{ m}$) → TOF measured using the RF of the CS or with a MCP (in case of low intensity exotic beams) or kinematic coincidence
- Discrimination of n/ γ and light charged particles from PSD

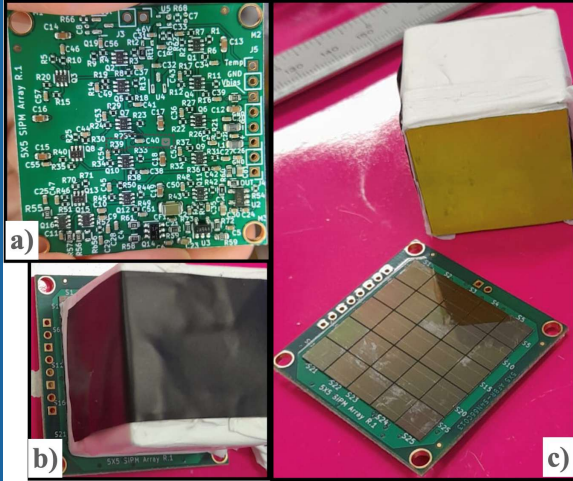
Results of CROSSTEST exp. @LNL (end of 2023)

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

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 $E_n < 4.5$ MeV (neutron experimental threshold 1.5 MeV) $\rightarrow p + {}^7\text{Li} \rightarrow {}^7\text{Be} + n$



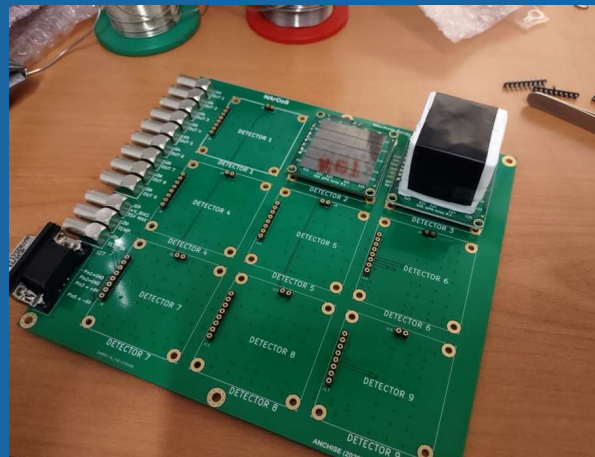
NArCoS: SiPM and mechanics



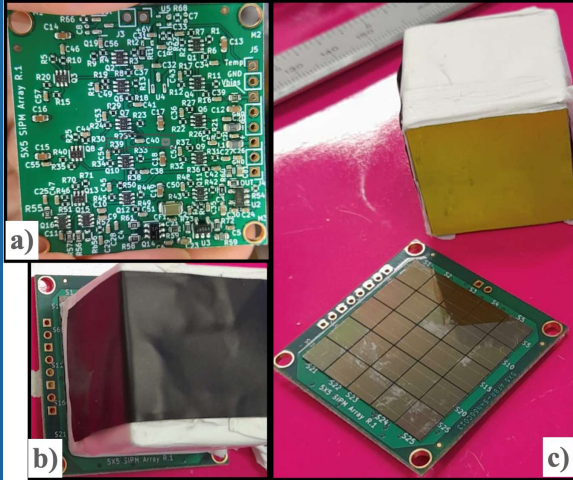
Prototype Electronic Board for housing the 9 elementary cells with their electronic readout boards, with the output of the signals, test inputs, temperature monitoring and bias input



Each elementary cell of EJ276G or EJ276 (3x3x3 cm³) is read with a matrix of 25 SiPM (6x6 mm²) of 30 μm of thickness ($\approx 40\text{k}$ microcells). The SiPM matrix is coupled with the plastic and provided of its PAC and bias/temperature compensation circuit



NArCoS: SiPM and mechanics



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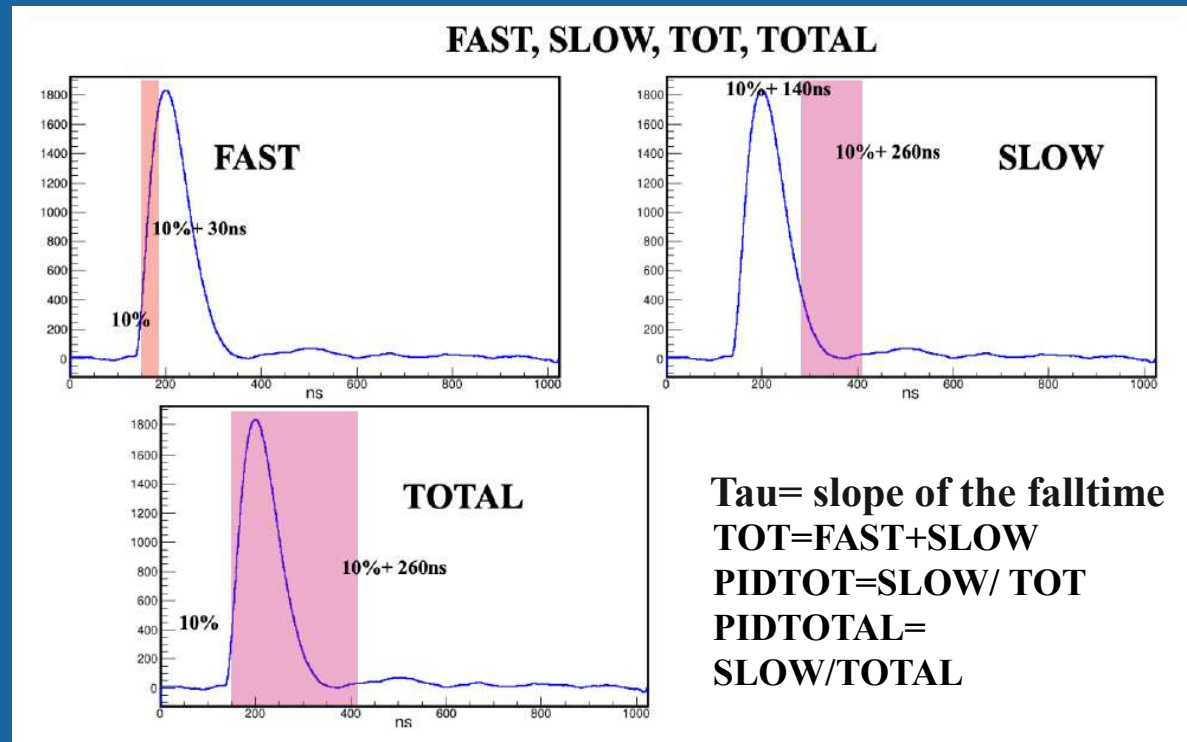
Sampling frequency: 1 GHz
Trigger: internal
(only the central plastic detector)

Variables used for the identification

10% of the Rise time $\leq$ FAST $\leq$ 10% of the Rise time+30 ns

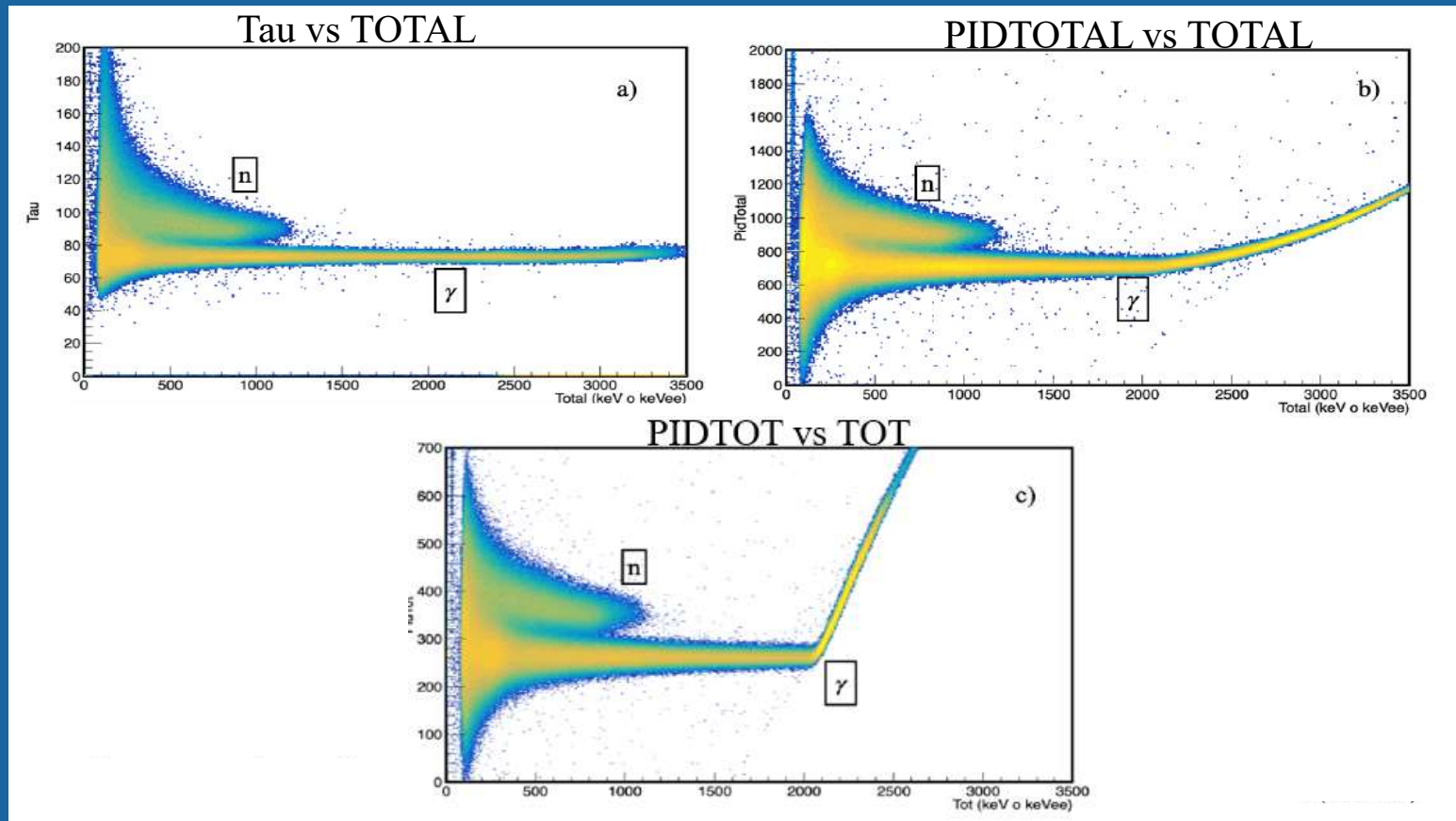
10% of the Rise time+140 ns $\leq$ SLOW $\leq$ 10% of the Rise time+260 ns

10% of the Rise time $\leq$ TOTAL $\leq$ 10% of the Rise time+260 ns



Identification matrices

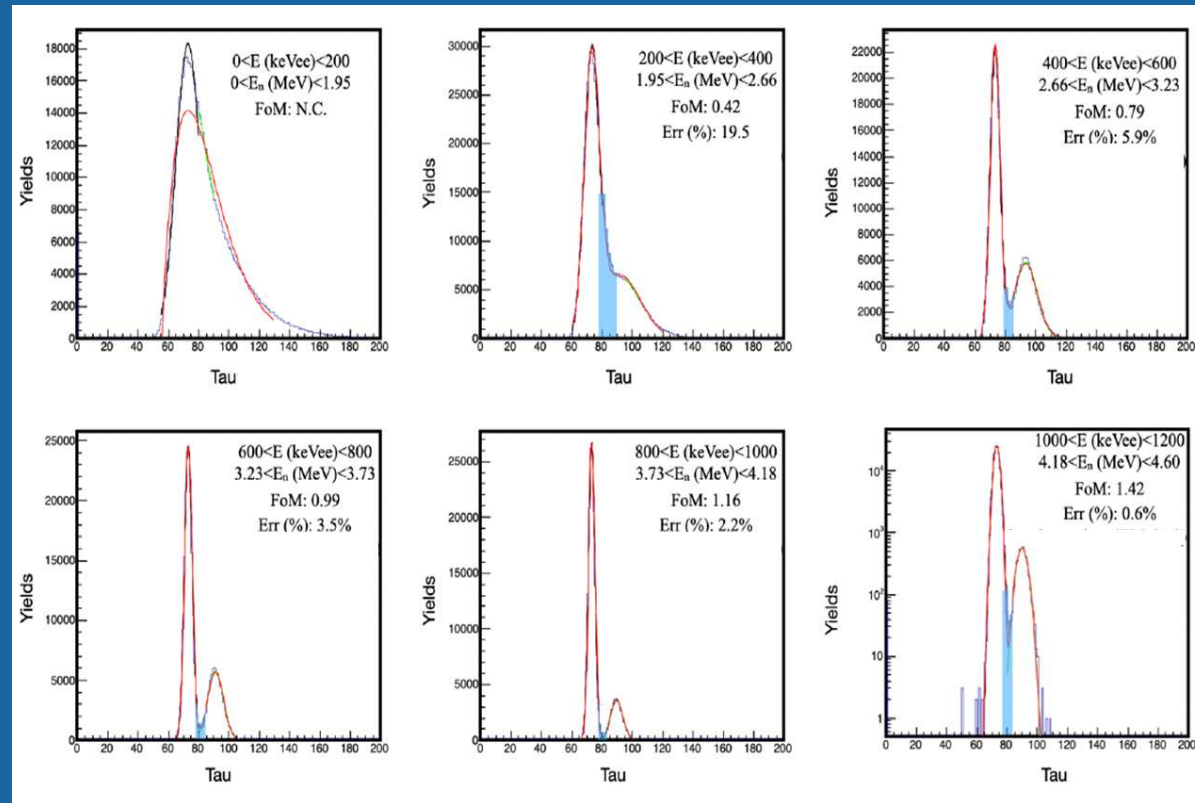
Pulse shape discrimination by using different variables, for one of the plastic detector.



Figures of merit, in different energy ranges, at slice of 200 KeVee for $0 < E < 1200$ KeVee

FoM (distance between the two peaks divided by the sum of the FWHMs of each peak)

6 projections of the 2D Tau Vs Total matrix on the Y axis (Tau) for each of the energy intervals of the Total component in keVee (0,200); (200,400); (400,600); (600,800); (800,1000); (1000,1200).

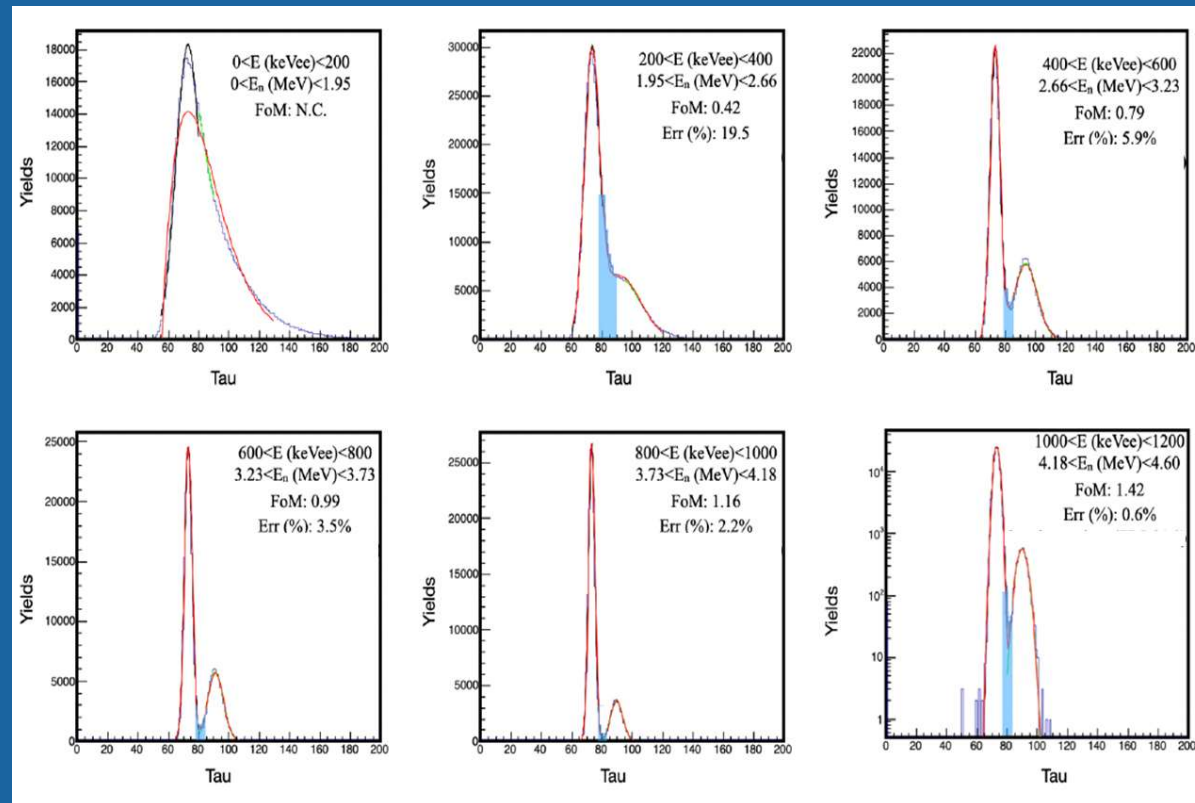


Gnoffo B., Pagano E.V. et al., IL NUOVO CIMENTO 48 C (2025) 12

Figures of merit, in different energy ranges, at slice of 200 KeVee for $0 < E < 1200$ KeVee

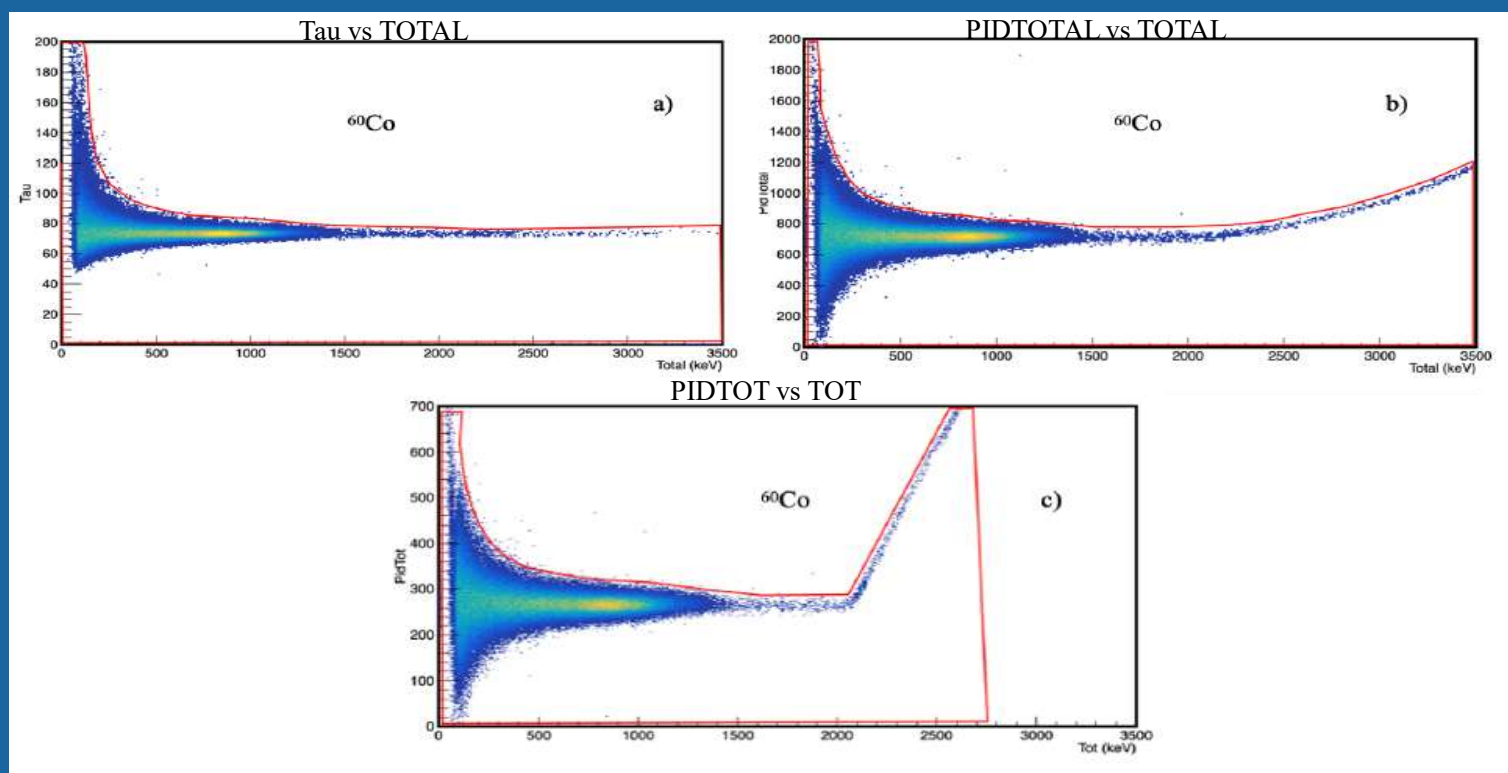
The value of the FoM is shown in each panel.

A good separation is obtained from 600 KeVee where the FoM is ≥ 1



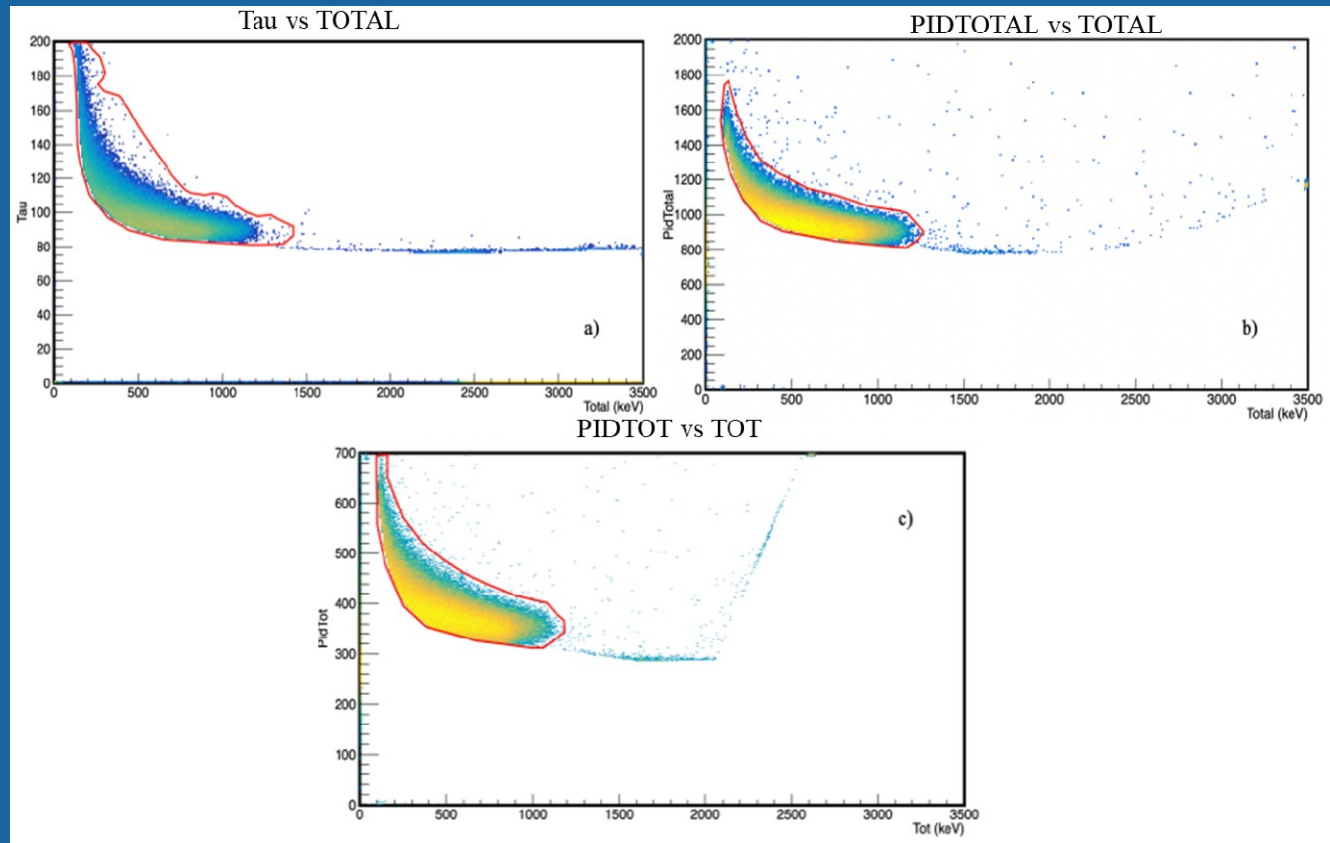
Gamma rays selection

To select gamma rays, a cut around the corresponding line was made in each of the bidimensional matrices obtained during the runs in which ^{60}Co source was used for the calibration.



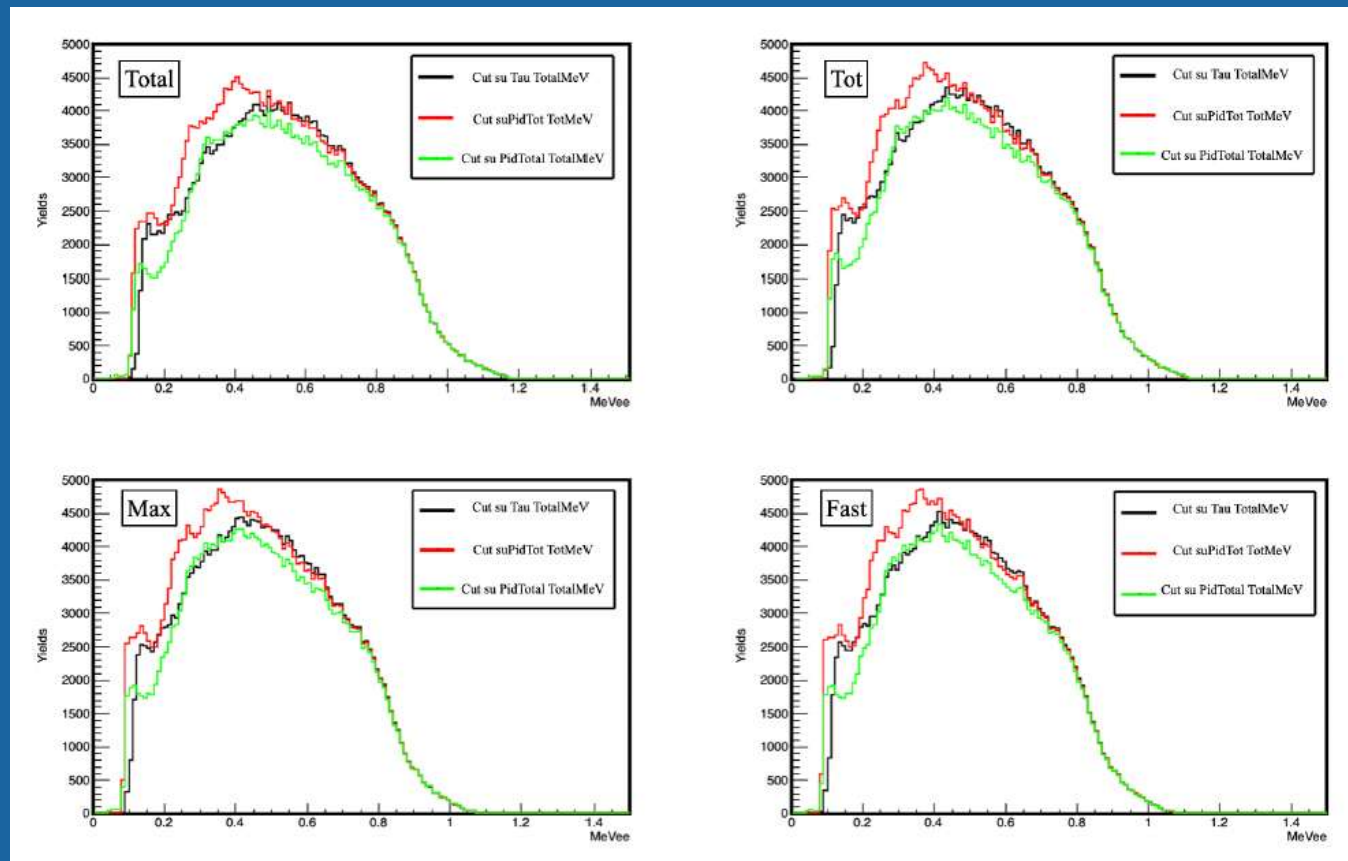
Neutron selection

In the beam runs, to select neutrons, a cut around the corresponding line was made in each of the bidimensional matrices obtained after the subtracted gamma band selected as described above.



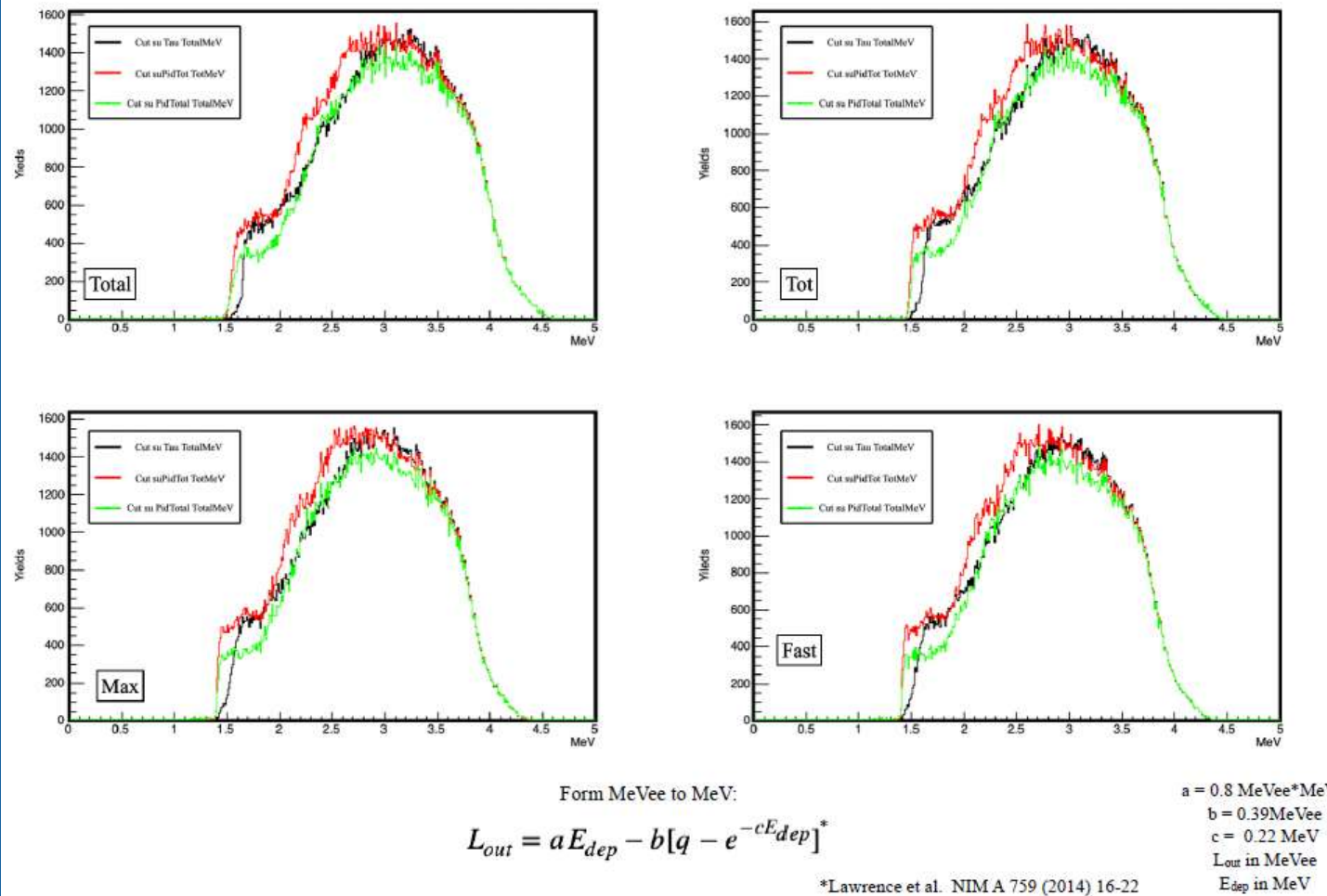
Neutron energy spectra

Energy spectra in MeVee, of neutrons selected as described above, shown in black when the selection was made from the 2d plot tau vs TOTAL, in red for the selection made from the Pidtot vs TOT matrix and in green for the selection from Pidtotal vs TOTAL.



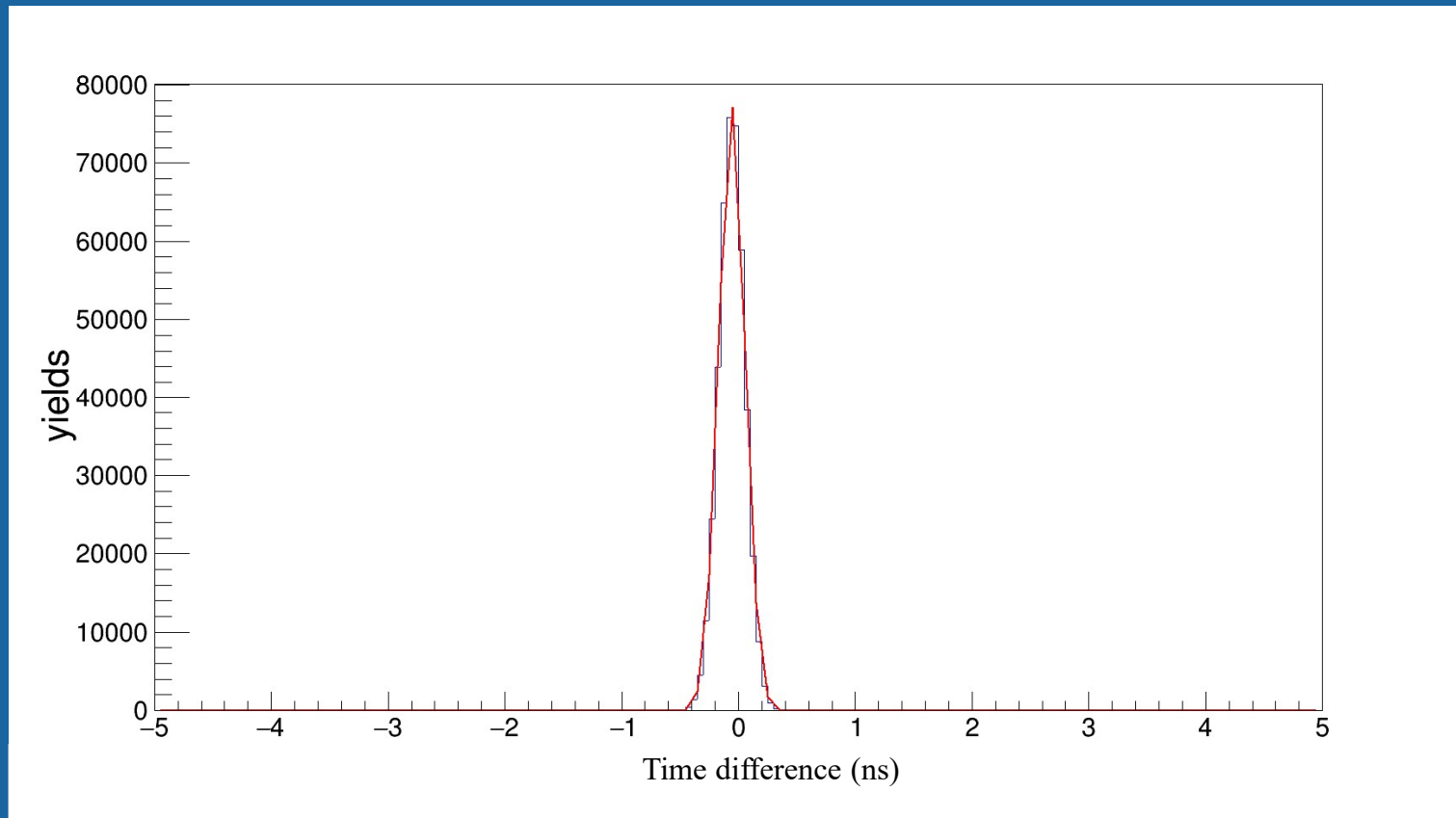
Neutron energy spectra

Energy spectra in MeV, of neutrons selected as described above, obtained by using the Lawrence formula



Electronic Time resolution

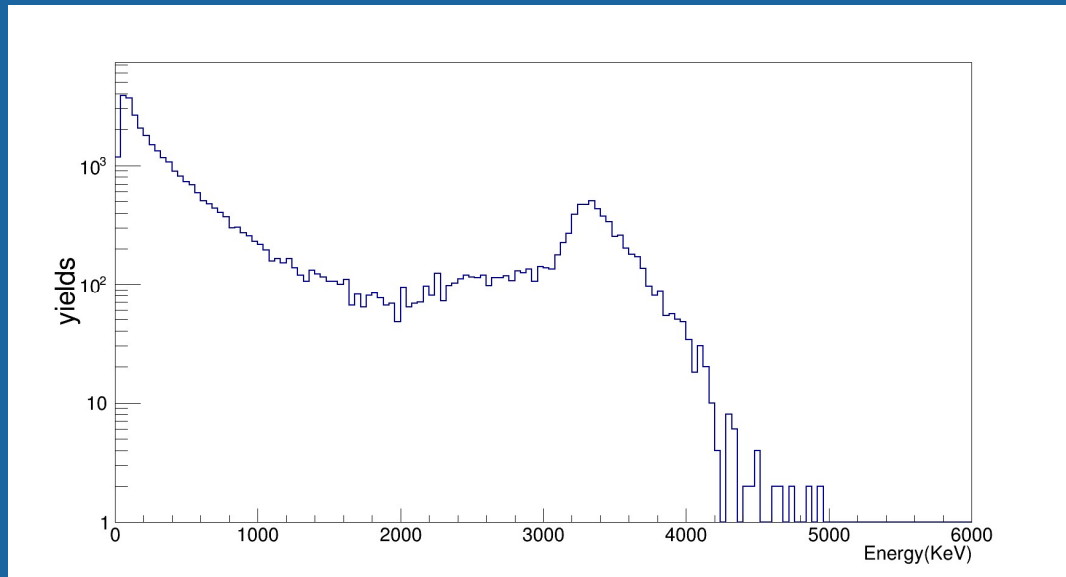
The electronic contribution to the time resolution was evaluated, by using the pulser and by considering the difference between the time signals of two different channels. The σ due just to the electronic board and digitizer is ≈ 100 ps



Global Time resolution

Study of the global time resolution, by using the difference between time signals of a cosmic ray punching through two contiguous detectors.

In the configuration, used for the test the first 8 position on the board are occupied by detectors of material EJ276-Green Type, while position number nine houses a detector of EJ276-White Type .



1	2	3
4	5	6
7	8	White type 9

We put the following conditions:

Multiplicity = 2;

contiguous detectors, in particular we only considered the pairs 6-9 and 3-6

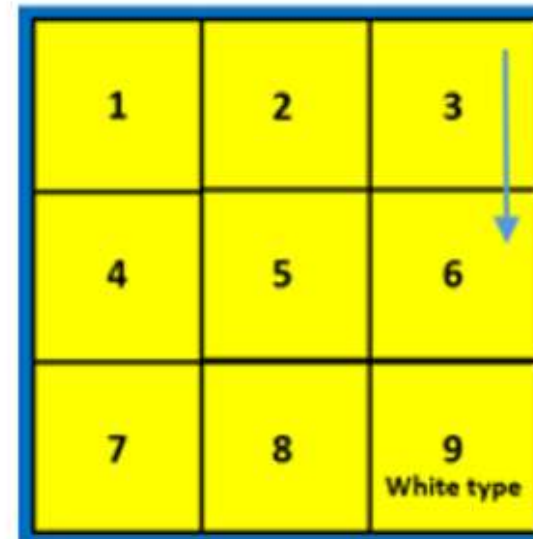
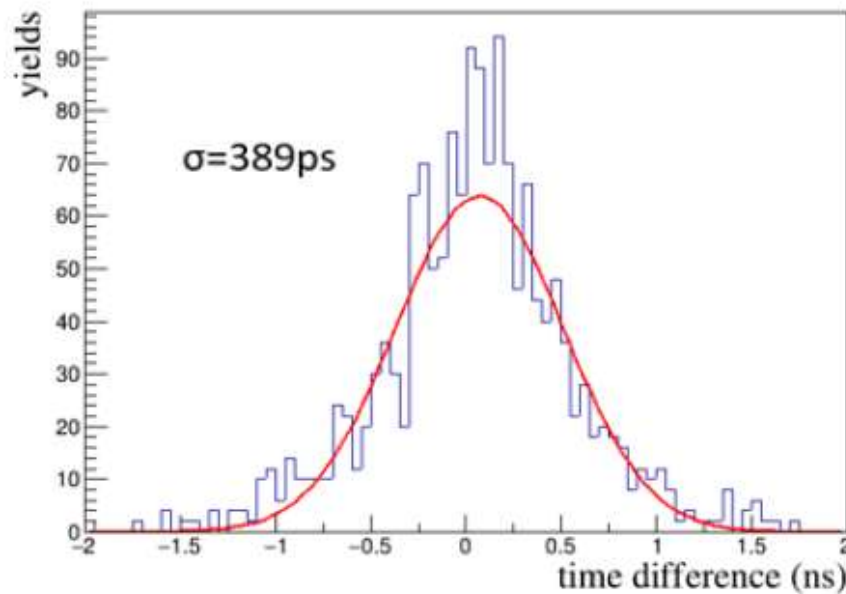
-> possible differences in time resolution between the two types of plastic materials

$E1 > 2\text{MeV}$ & $E2 > 2\text{MeV}$ -> just higher energetic cosmic rays are taken into account

Global Time resolution of EJ276 Green-Green Type

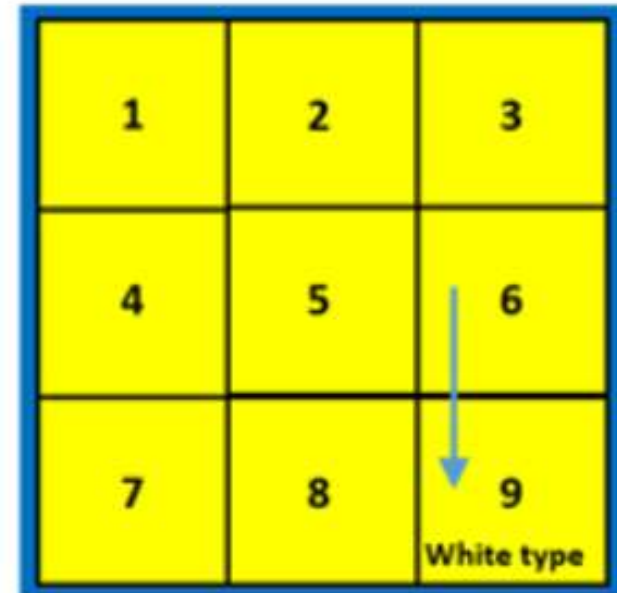
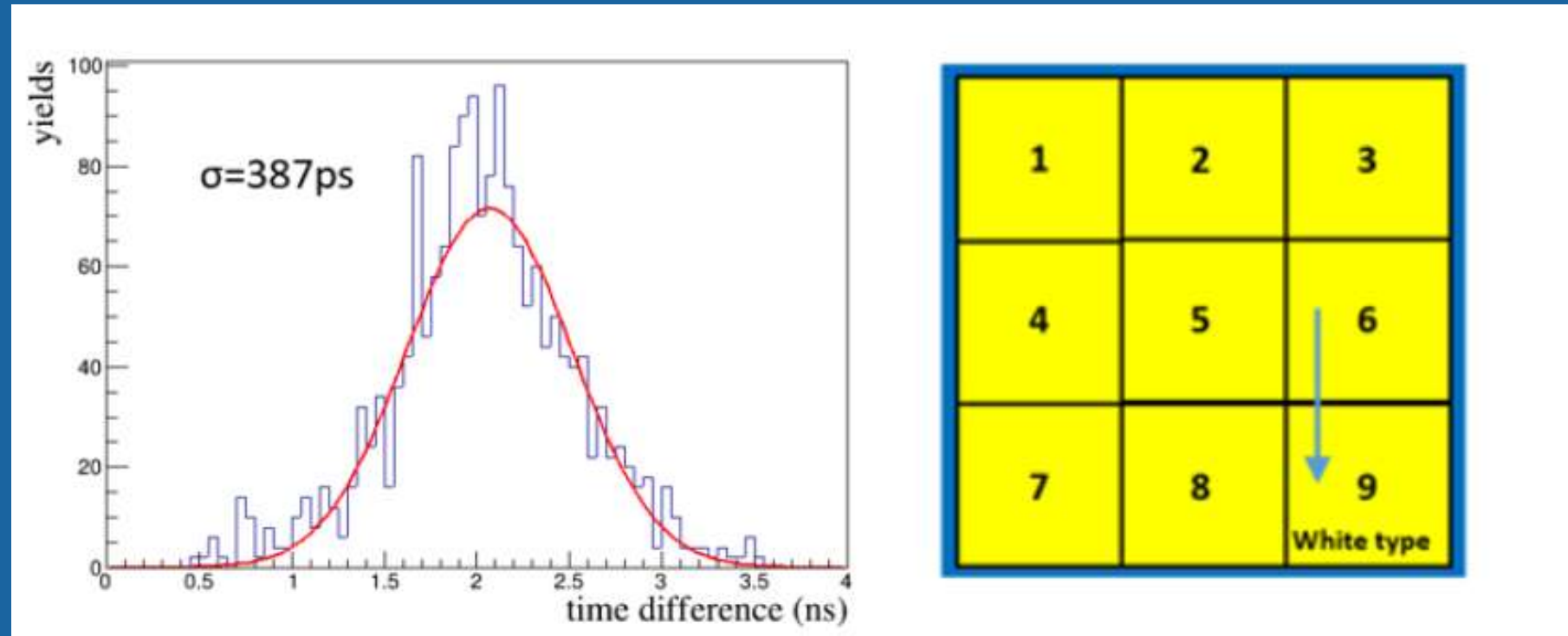
Global time resolution is evaluated by using the difference between time signals of a cosmic ray, punching through two contiguous detectors (3 and 6)

The detector pair 3 and 6 was chosen because the detector in position 6 was also used in the evaluation of the resolution of the EJ276 White Type



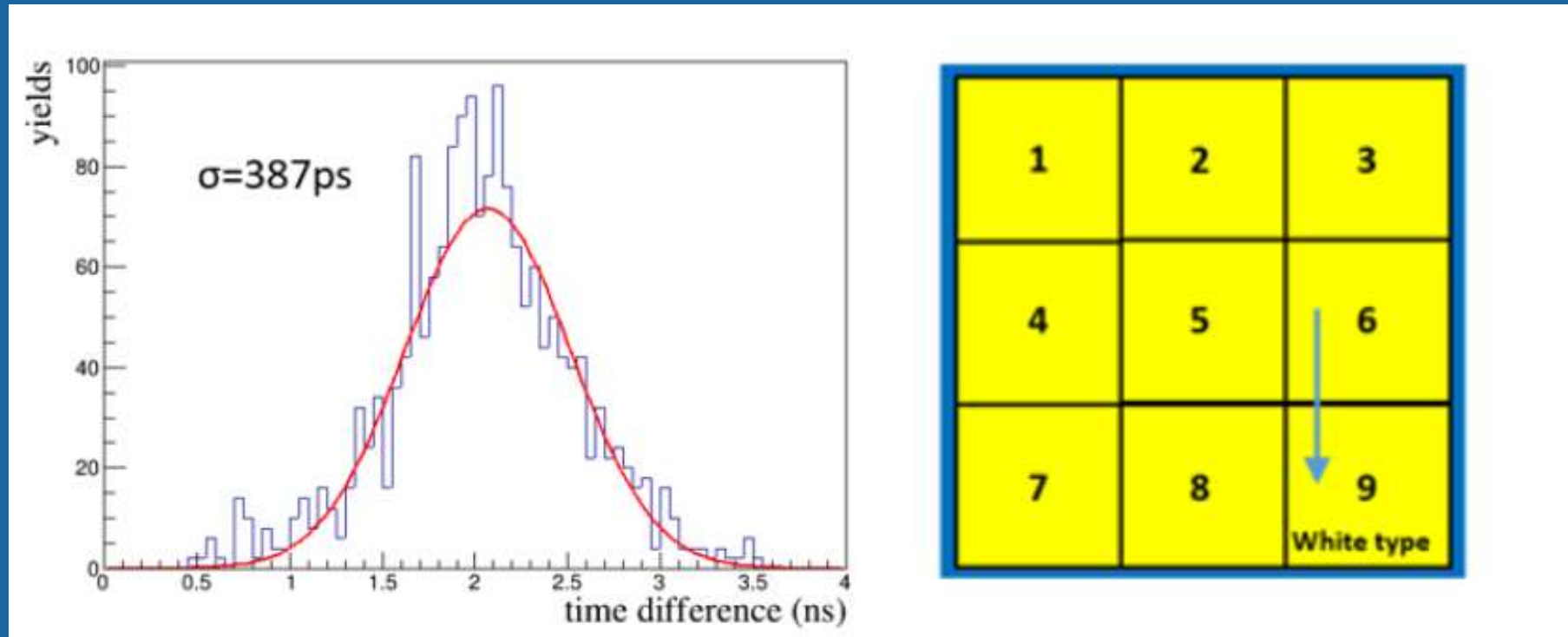
Global Time resolution of EJ276 Green-White Type

Global Time resolution is evaluated by using the difference between time of the signals of detectors 9 and 6



Global Time resolution of EJ276 Green-White Type

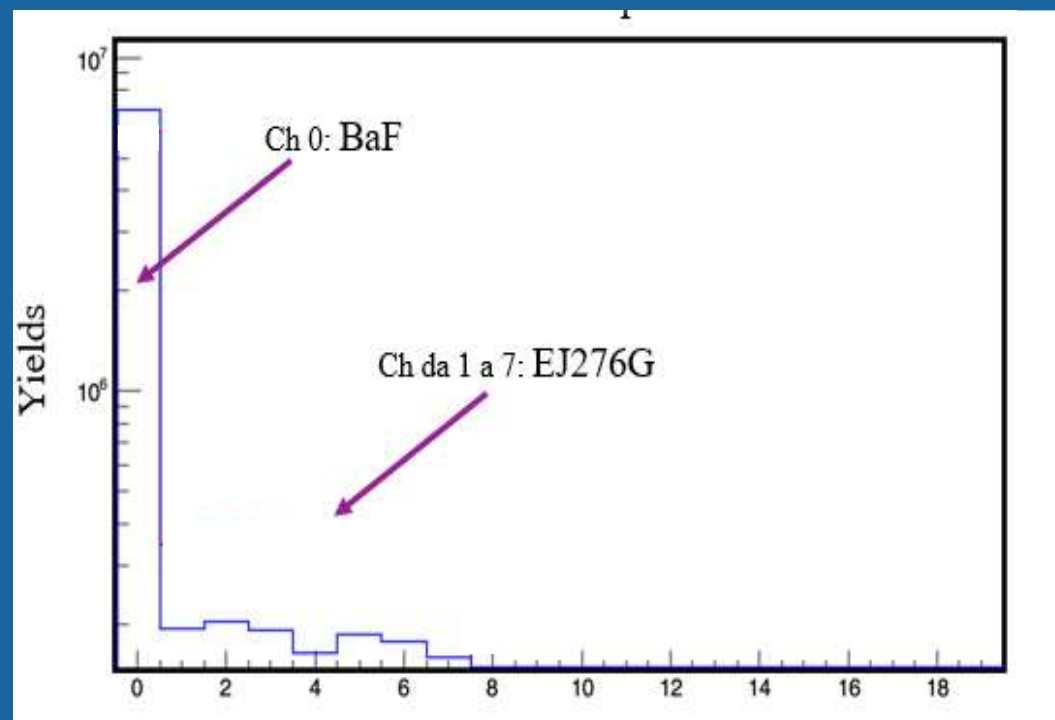
Global Time resolution is evaluated by using the difference between time of the signals of detectors 9 and 6



No appreciable differences are observed between the two types of material!!

Results of a test with AmBe source @LNS

The test was performed at LNS laboratory using an AmBe source for the measurement of neutron energy from Time of Flight. The apparatus consists of a BaF_2 scintillator and 7 plastic scintillator



Results of test with AmBe source @LNS

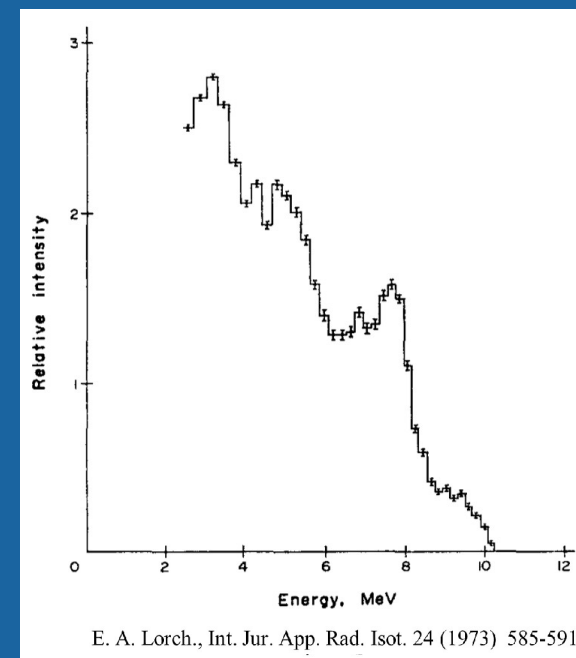
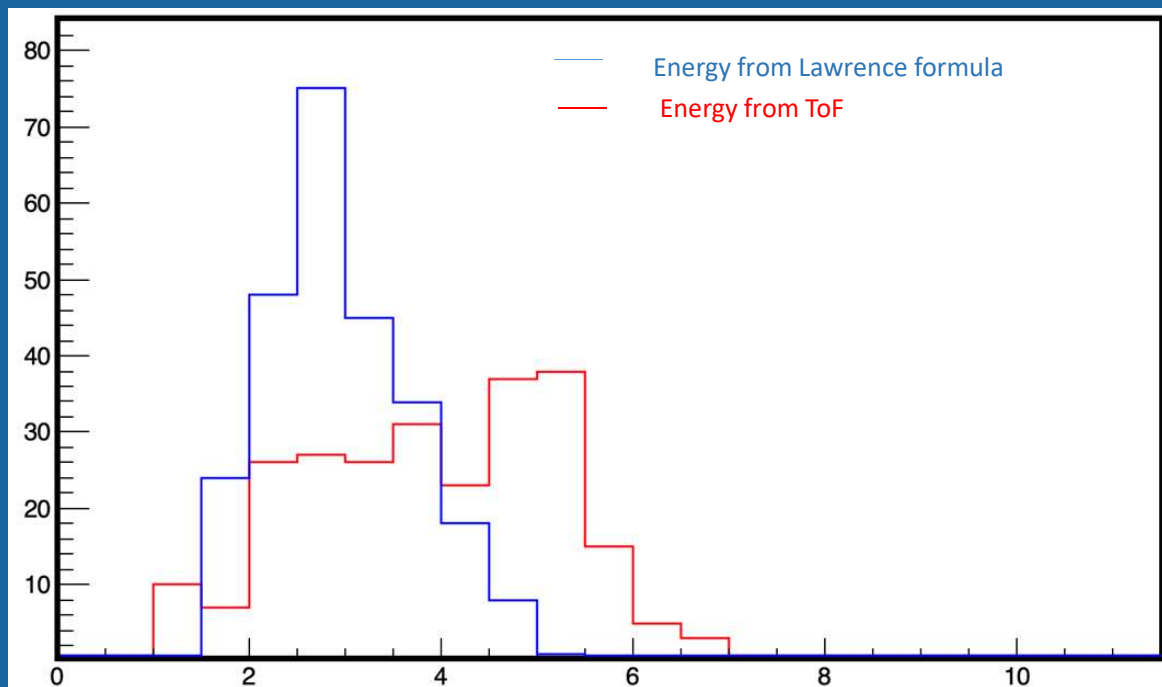
AmBe source $\rightarrow \alpha + {}^9\text{Be} \rightarrow {}^{13}\text{C}^* \rightarrow {}^{12}\text{C}^* + n \rightarrow \gamma + {}^{12}\text{C} + n$ for the measurement of neutron energy from Time of Flight. $\rightarrow \text{ToF} = t_{\text{Pla}} - t_{\text{BaF}} + t_0(\text{ns})$



Energy spectra of neutrons

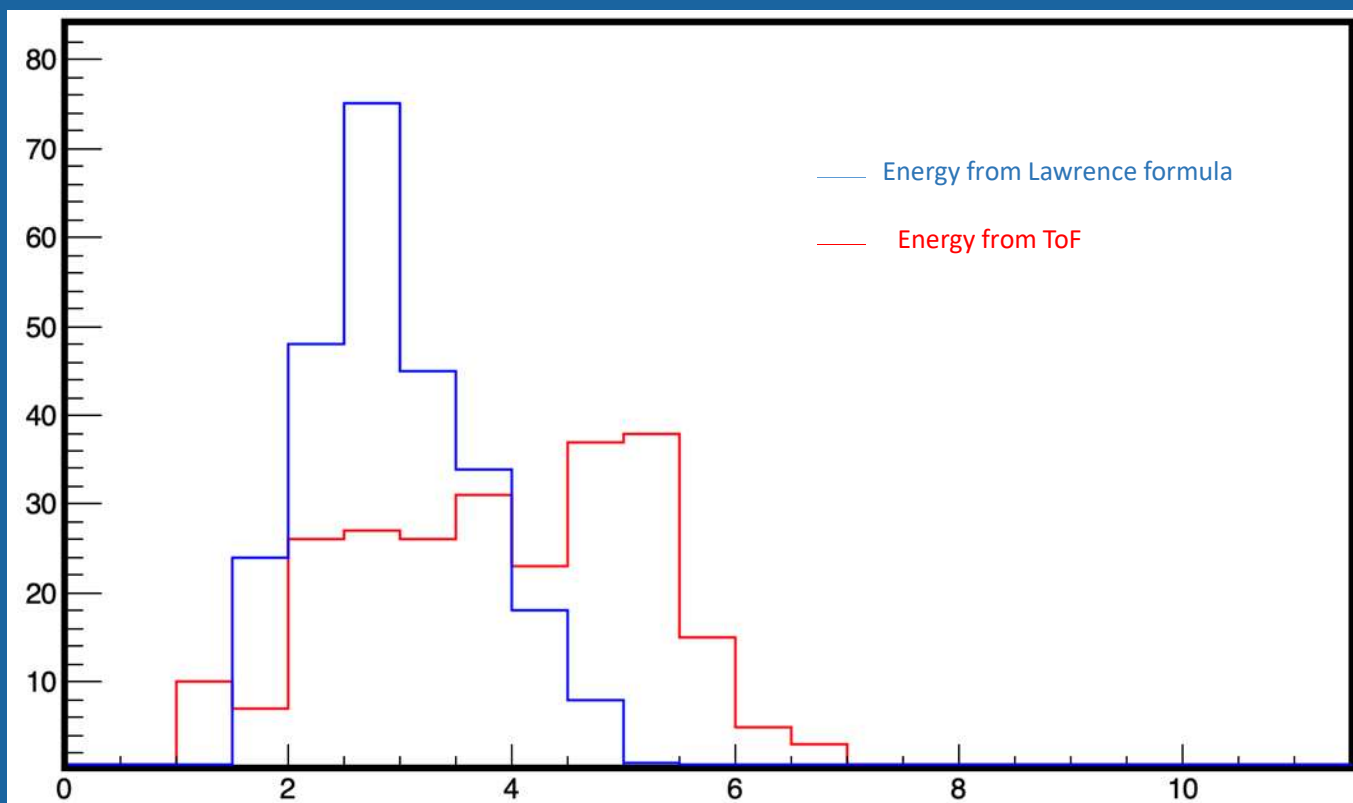
The neutron energy spectrum obtained from ToF is consistent with that reported in the literature using a stilbene detector.

The low-energy peak, corresponding to the neutron emitted with the 7.65 MeV Hoyle state of ^{12}C and similarly, the higher-energy peak, corresponding to neutron emission with the ground state of ^{12}C , are not observed since, in the absence of the γ -ray, no start signal is generated.



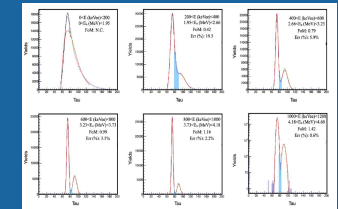
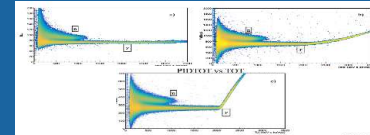
Energy spectra of neutrons

The two spectra obtained using the two methods (ToF and the Lawrence formula) differ because, in the spectrum derived from the Lawrence formula, the correction for the scattering angle is not taken into account. As a result, the spectrum is reasonably shifted toward lower energy values.

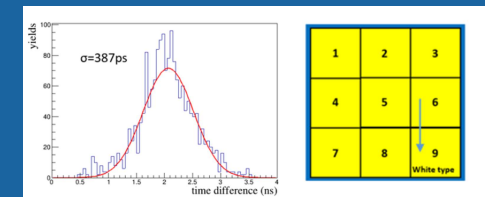
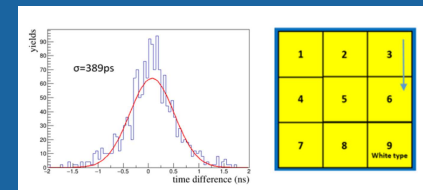


Conclusions and Perspectives

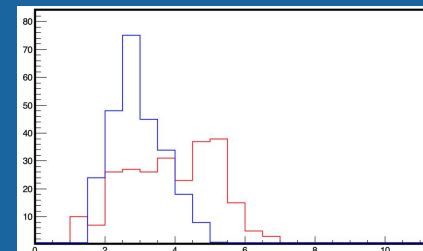
- A good separation between neutron and gamma with a FoM of 1.2 at 4 MeV of neutrons with three different 2D identification matrix,



- No appreciable differences in time resolution between the two types of materials!



- The neutron energy spectrum obtained from ToF is consistent with that reported in the literature using a stilbene detector.



Conclusions and Perspectives

- New tests are currently ongoing at LNS-INFN to improve the statistics of the neutron energy spectrum.
- 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.
- MoReNA experiment. The goal of the experiment is to test the feasibility of using NArCoS for the study of molecular states with low neutron multiplicity, focusing on the decay channel $^{13}\text{C} \rightarrow n + ^{12}\text{C}$
- In its final version, the demonstrator will include 16 clusters, each consisting of an array of 4 elementary cells arranged in line along the beam axis and mounted on a 4×1 PCB motherboard.



For more info see :

- 1) Pagano E.V. et al., N.S., Nucl. Instrum. Methods A, 889 (2018) 83-
- 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., IL NUOVO CIMENTO 48 C (2025) 12
- 16) Gnoffo B., Pagano E.V. et al., 2025 JINST 20
- 16) Gnoffo B., Pagano E.V. et al., on timing performances in preparations
- 17) Pagano E.V. et al., on croostalk al 4.5 MeV neutron in preparation

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