FATA 2025: Fast Timing Applications for nuclear physics and medical imaging
8–10 October 2025

Fast Timing with SiC detector arrays for high-intensity Radioactive Ion Beam experiments

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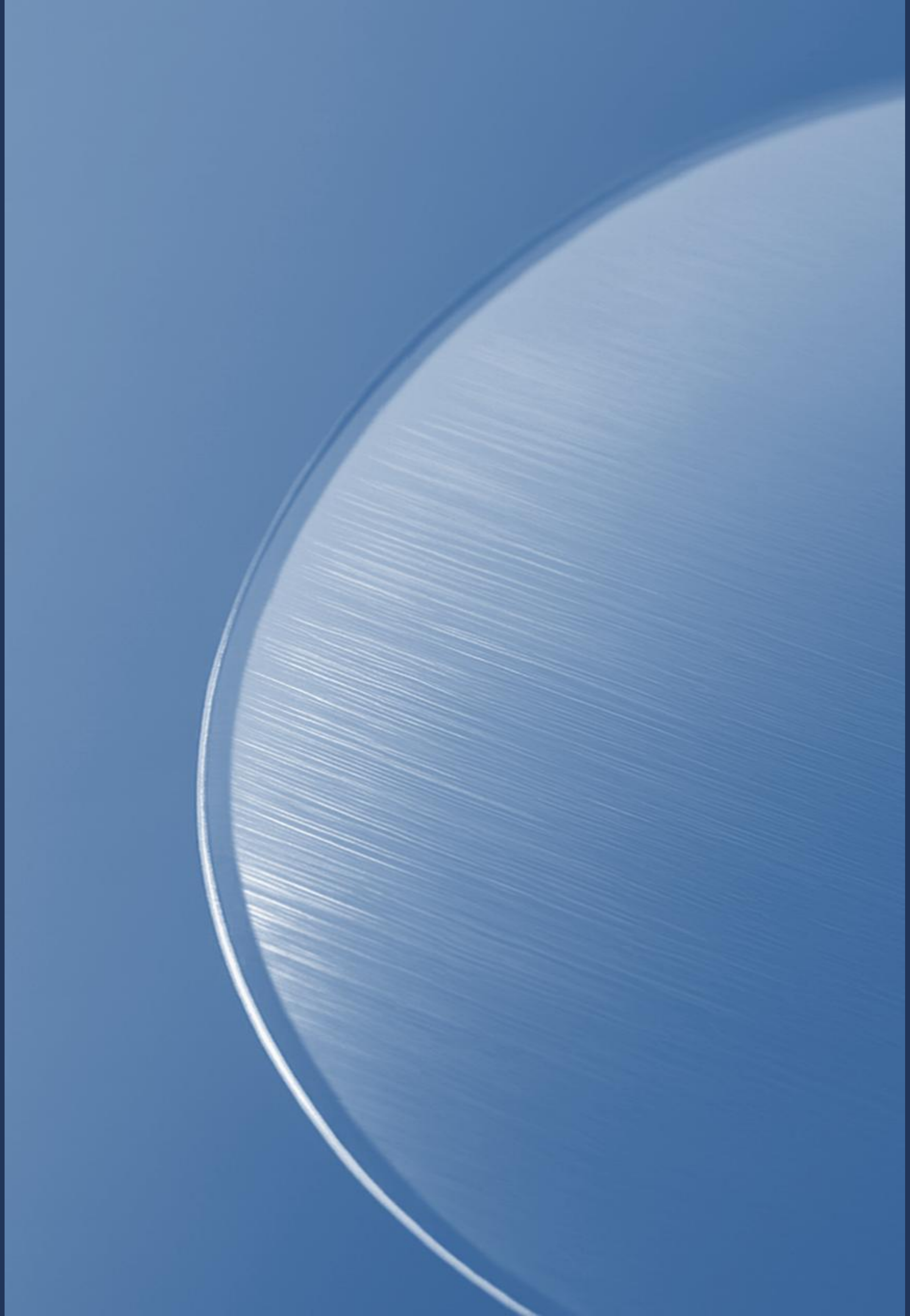
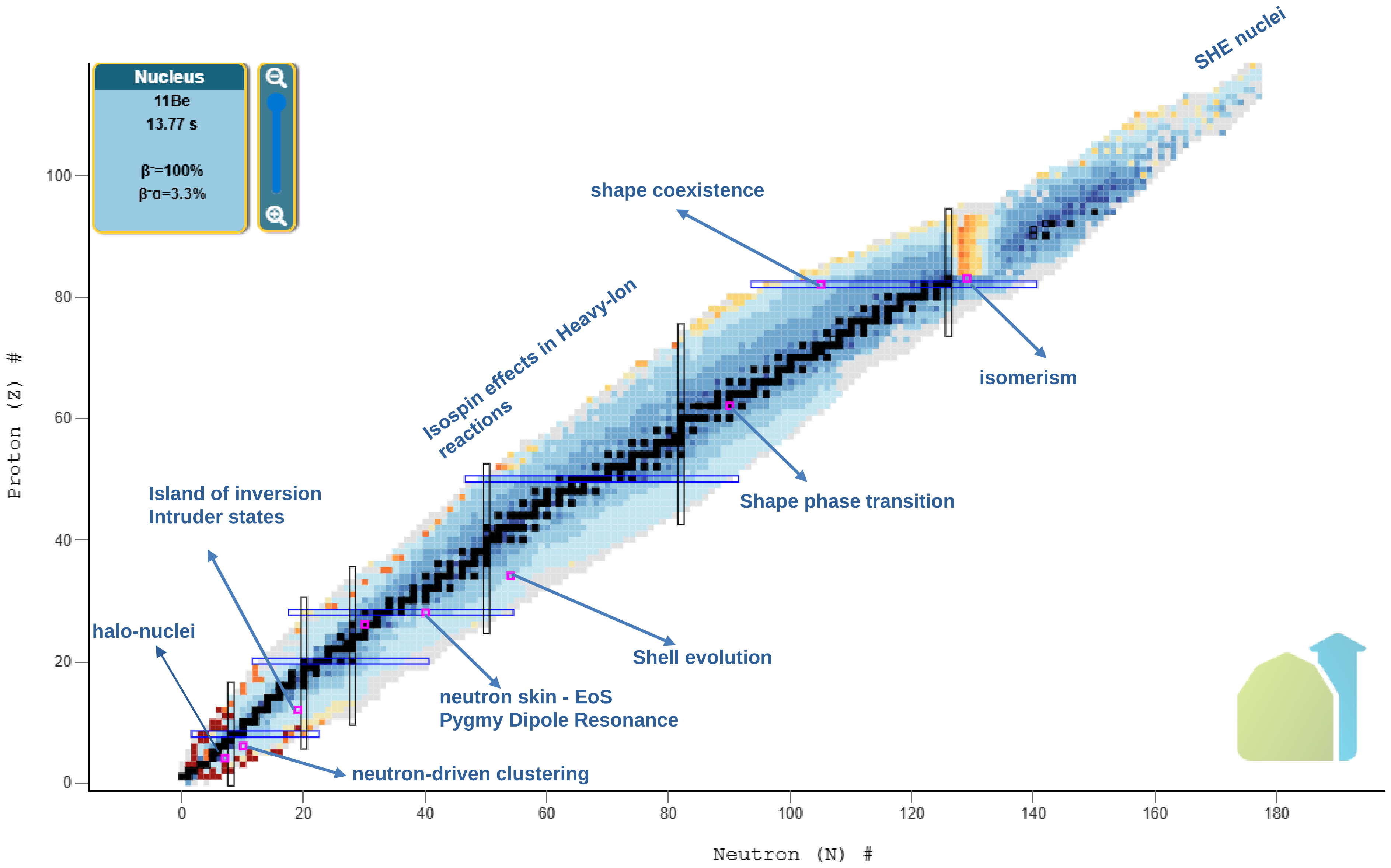
INFN-Sezione di Catania

SAMOTHRACE & CHIRONE collaboration



Contents



https://www.nndc.bnl.gov/nudat3/

Stable isotope	Positron-emitting isotopes	Half-life
^{12}C	^{11}C	20.33 min
	^{10}C	19.3 s
^{14}N	^{13}N	9.97 min
	^{12}N	11.0 ms
^{16}O	^{15}O	2.04 min
	^{14}O	1.17 min
^{19}F	^{18}F	1.83 h
	^{17}F	1.07 min
^{20}Ne	^{19}Ne	17.26 s
	^{18}Ne	1.66 s

M. Durante and K. Parodi, Frontiers in Physics 8, (2020)

nature physics

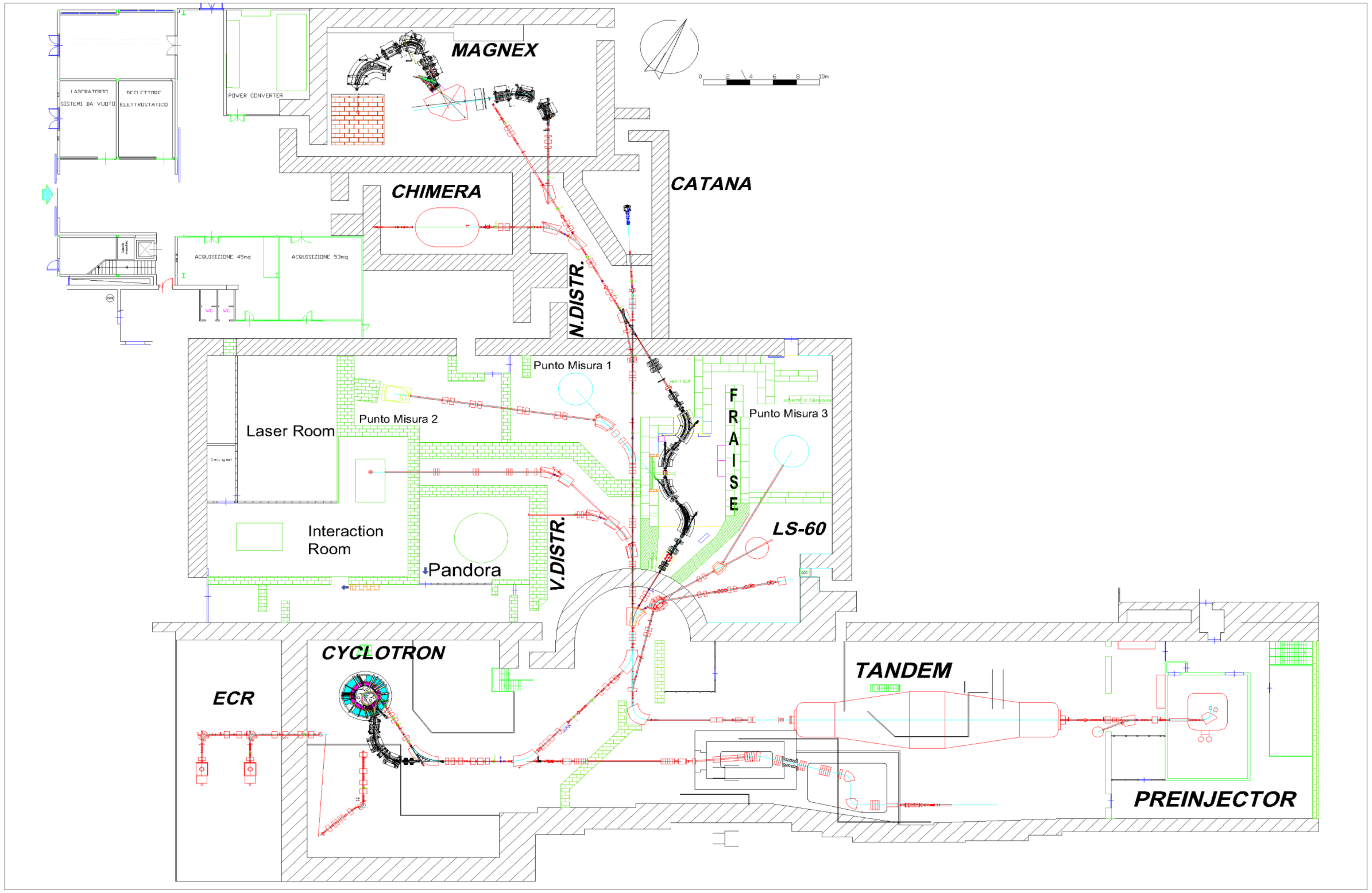
Article https://doi.org/10.1038/s41567-025-02993-8

Image-guided treatment of mouse tumours with radioactive ion beams

Boscolo, D., et al. Image-guided treatment of mouse tumours with radioactive ion beams. Nat. Phys. (2025) https://doi.org/10.1038/s41567-025-02993-8

RIB are generally acknowledged as the main tool to address the most important modern questions in nuclear physics, as they allow the study of nuclei at extreme conditions[12–14]. In cancer radiotherapy, RIB have the same biological effectiveness as the corresponding stable ion beams[15,16] but increase the PET signal-to-noise ratio by approximately an order of magnitude, reduce the shift between the activity and dose peaks, and mitigate the washout image blur with short-lived isotopes (for example, ^{10}C) and online acquisition[17,18].

The FRAISE (Fragment In- Flight Separator) @INFN-LNS facility



Primary beams:

- He- Zn
- beam power up to 3 kW
- Factor 20 in intensity over the past

RIBs

- ^{6}He-^{68}Ni
- 10^4-10^8 pps
- Energy ≈ 30-50 AMeV

RIBs selection:

- fragment separator → presence of cocktail beam
- PID: ΔE-TOF

Russo A et al., NIM B 463 (2020) 359 418 – 420
Russotto P. et al., J. Physics: Conf. Ser., 1014 (2018) 012016
Martorana N.S. et al., Frontiers in Physics, 10 (2022)

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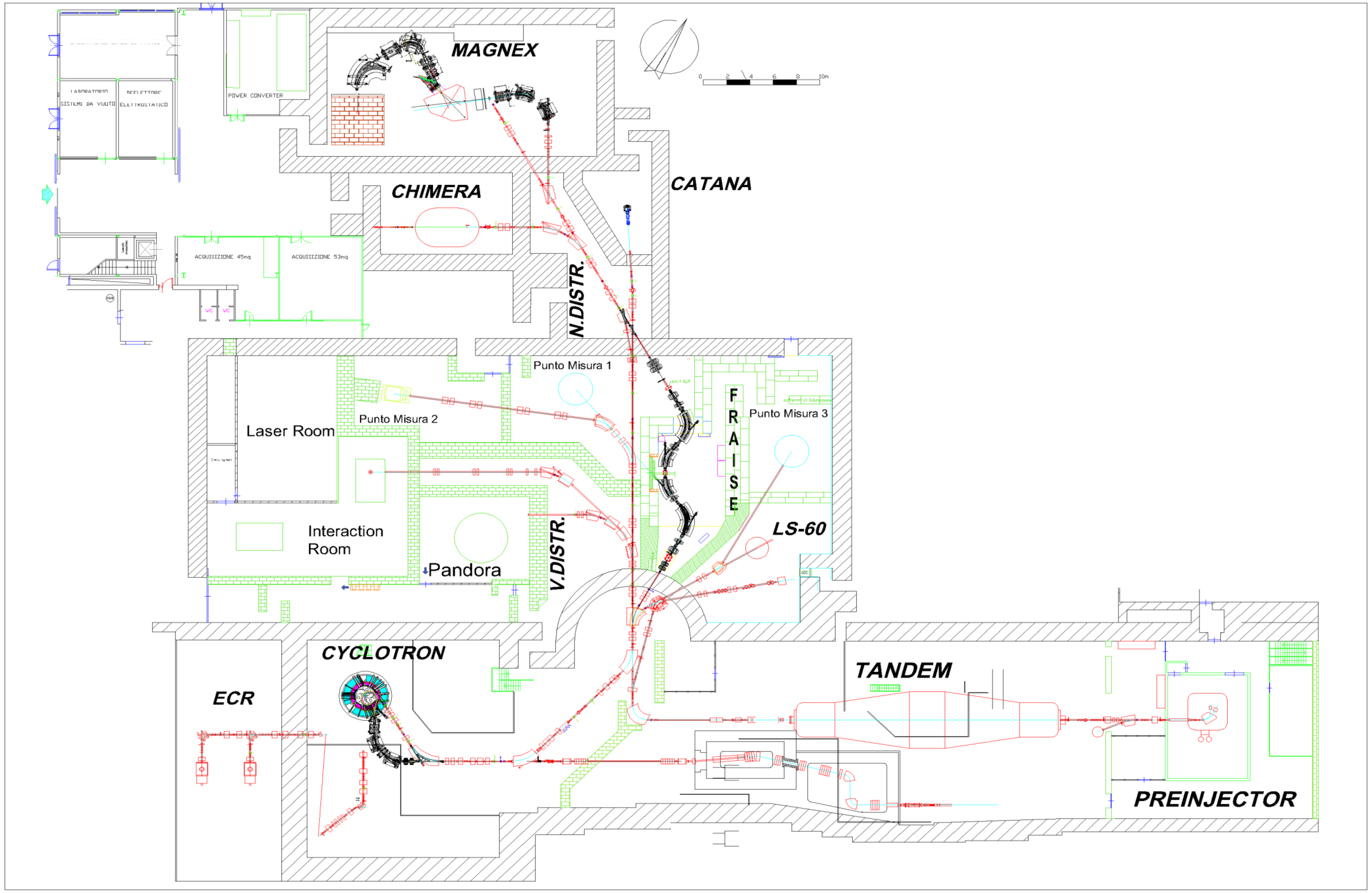

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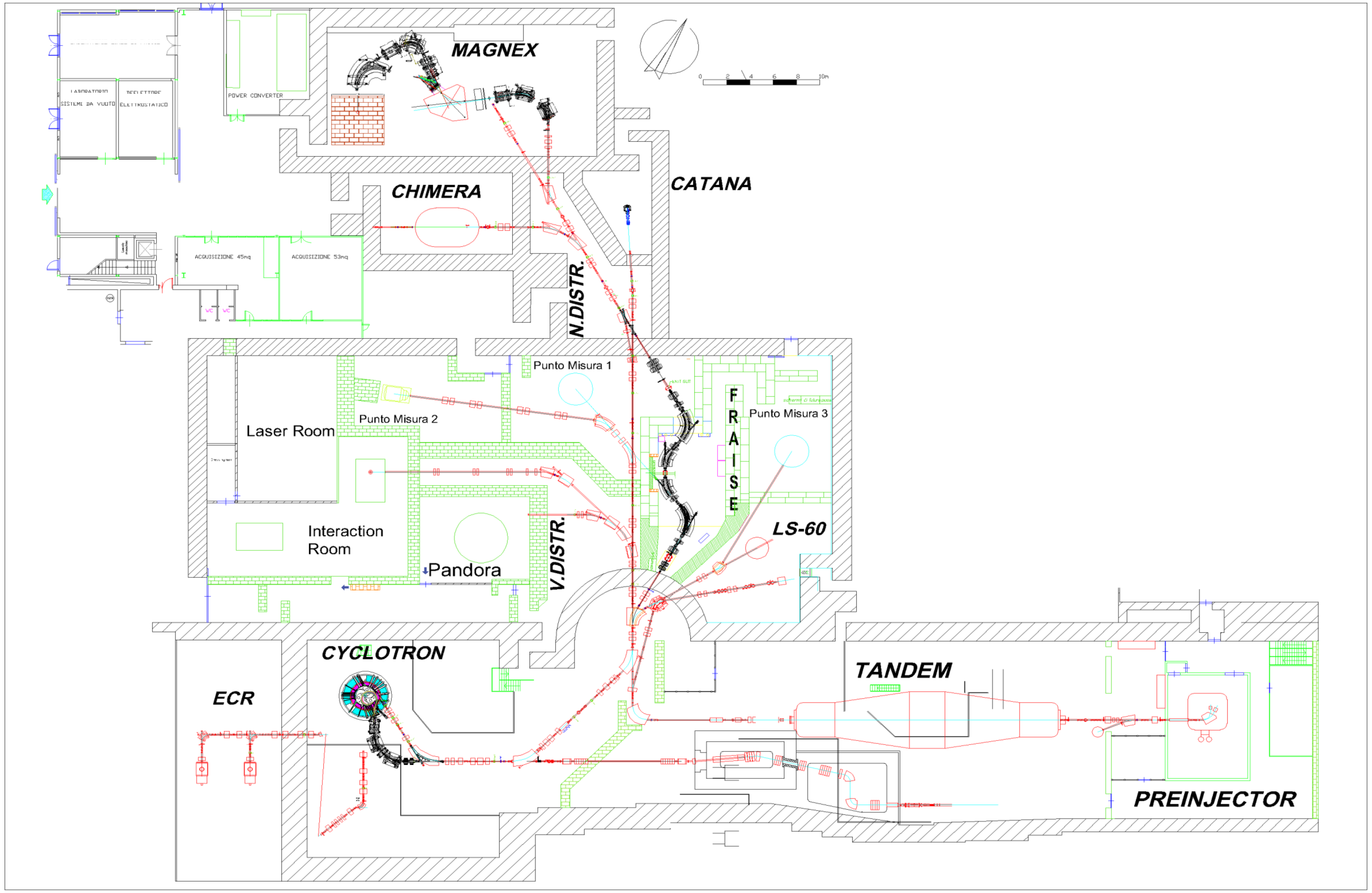

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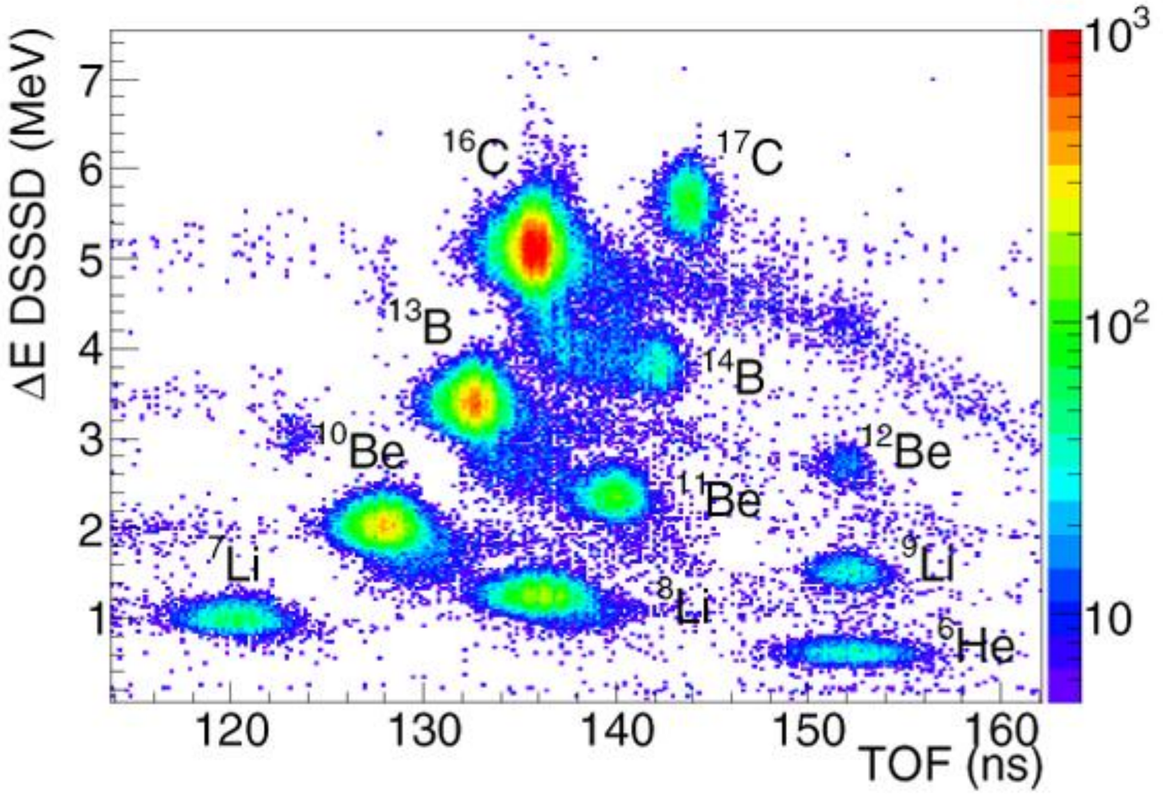
ΔE-ToF plot for the cocktail beam produced by ^{18}O beam of 55 AMeV on a 1500 µm thick ^{9}Be target obtained with the FRIBs facility at INFN-LNS (2001-2019)



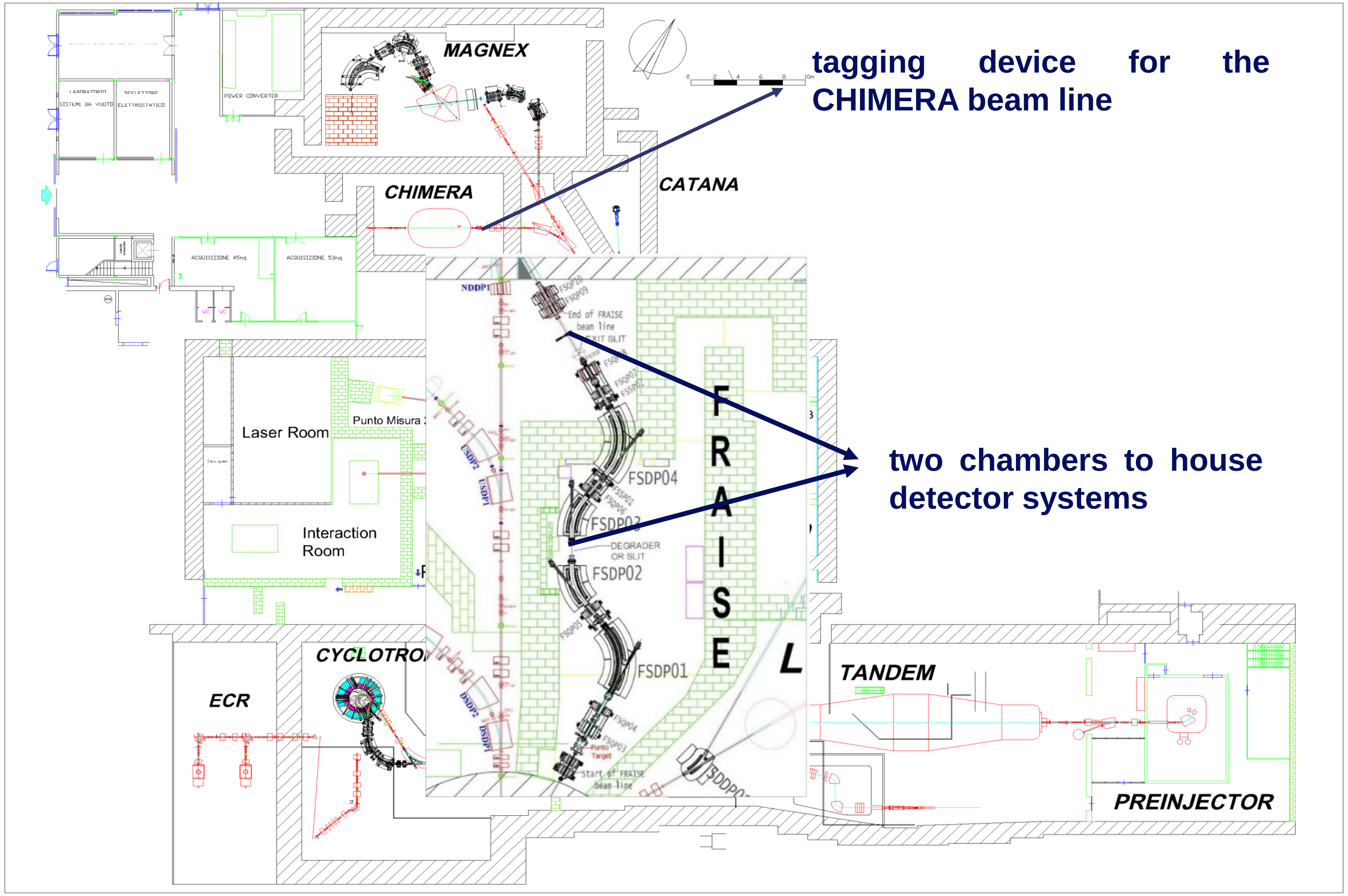
Dell'Aquila D et al 2016 Phys. Rev. C 93 024611

Start of ToF→ **MCP (43 mm x 63 mm)** 13 m away from the **DSSSD**
Stop & ΔE → **DSSSD (32 x 32 strips, 2 mm wide, 100-150 µm)** 2 m upstream of the reaction target

Limitation:

MCP: up to 10^6 pps, Δt ≈ 300-400 ps
DSSSD:max rate 200 kHz, but worsening of performances in ≈1 week with medium mass beam, as ^{68}Ni, at 30 kHz; Overall Δt <≈1 ns

Key Points



tagging device for the CHIMERA beam line

two chambers to house detector systems

Arrays of radiation-hard SiC detectors equipped with optimized fast front-end electronics able to provide:

1. Spatial distribution of the ions
2. ΔE of ions passing through the detection systems
3. ToF between two SiC systems or with respect the CS RF
4. System versatile to be used in several facilities

Identification via ΔE-ToF (points 2 and 3)

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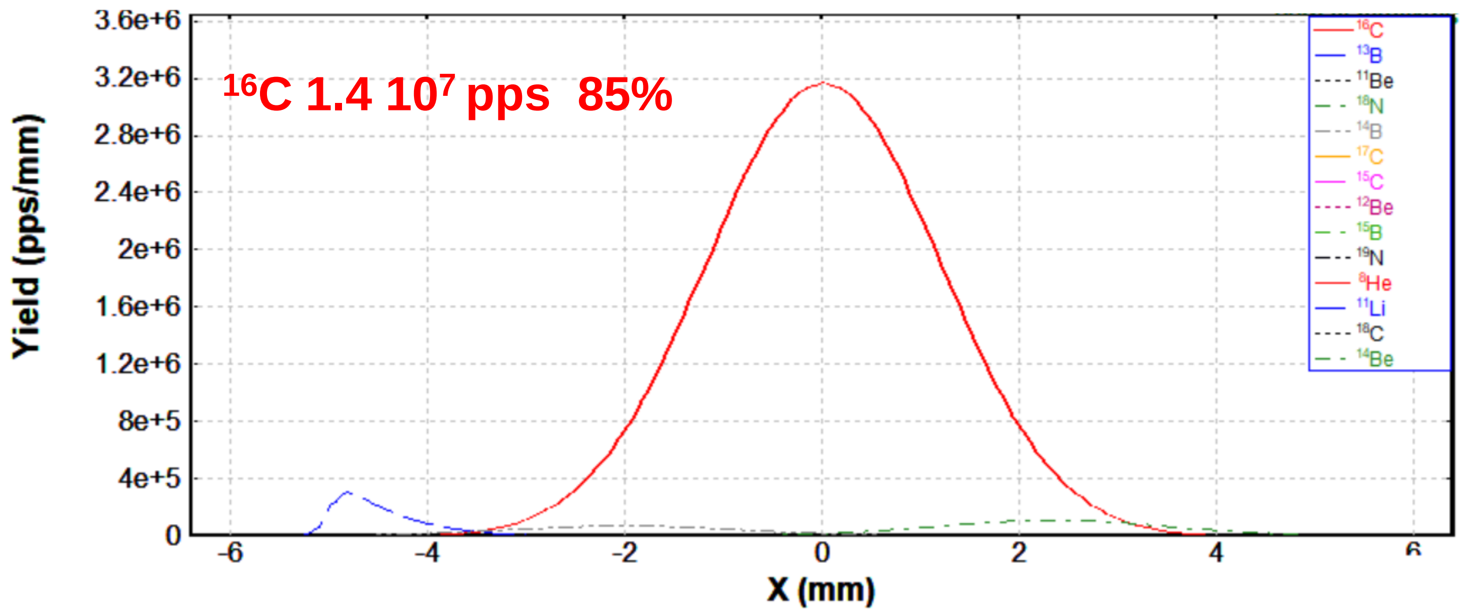
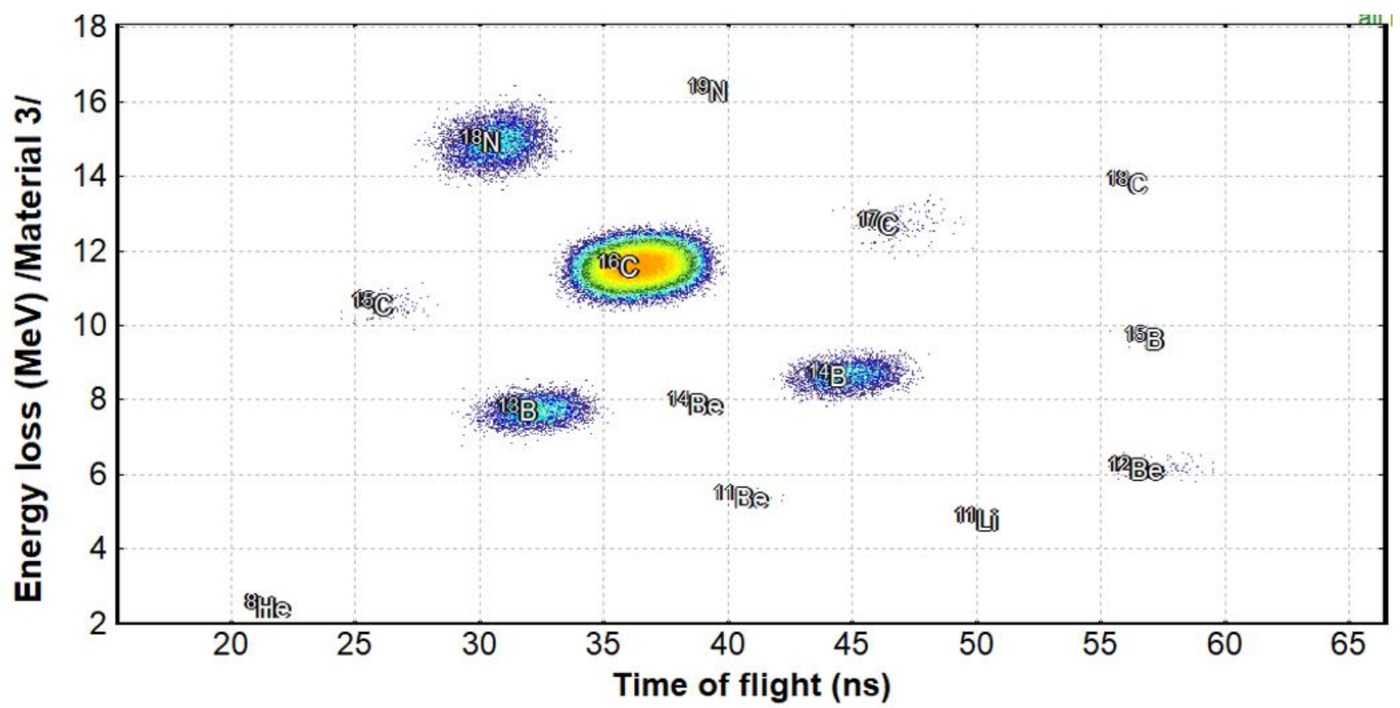
Russotto P. et al., J. Physics: Conf. Ser., 1014 (2018) 012016
Martorana N.S. et al., Frontiers in Physics, 10 (2022)

Key Points

- **Simulation of spatial distribution of beam components and ΔE-ToF plot using a SiC detector placed after the FraISe exit slit**





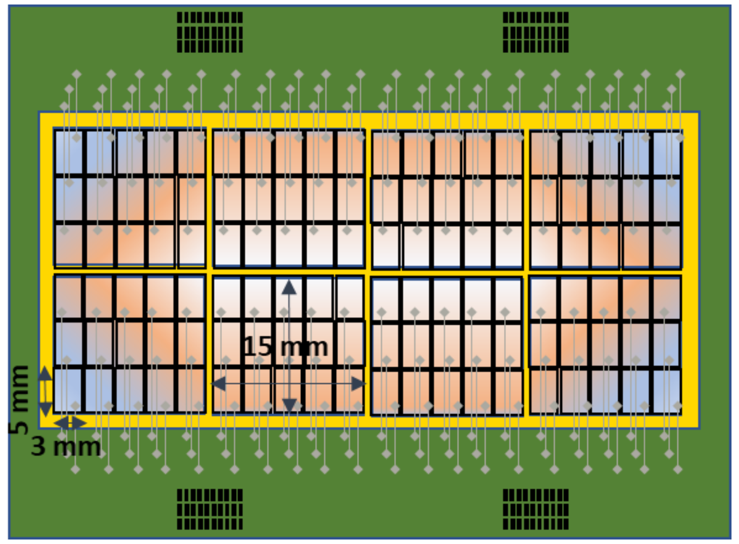
Primary Beam	RIB at the FRS exit	Pps at the exit slit	ΔE on 100 μm SiC
^{12}C (60 MeV/A)	^{10}Be (50 MeV/A)	≈ 2 10^7	≈ 6 MeV
^{12}C (60 MeV/A)	^{11}C (45 MeV/A)	≈ 2 10^8	≈ 6 MeV
^{18}O (70 MeV/A)	^{13}B (58 MeV/A)	≈ 7 10^6	≈ 8 MeV
^{40}Ar (60 MeV/A)	^{38}S (48 MeV/A)	≈ 2 10^7	≈ 80 MeV

Some RIBs foreseen with FraISe*

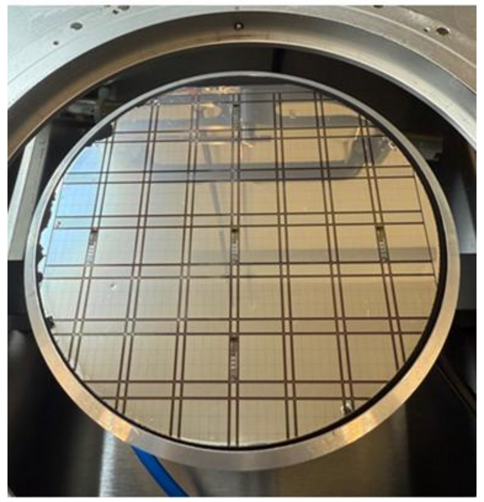
*** simulation studies reported in Martorana N.S. et al., Frontiers in Physics, 10 (2022)**

Key Points

- Arrays of SiC pixels of 3 mm × 5 mm - 180 µm → will be covered an area of ≈ 60×30 mm^2 → segmentation able to sustain ≈ 10^7 pps



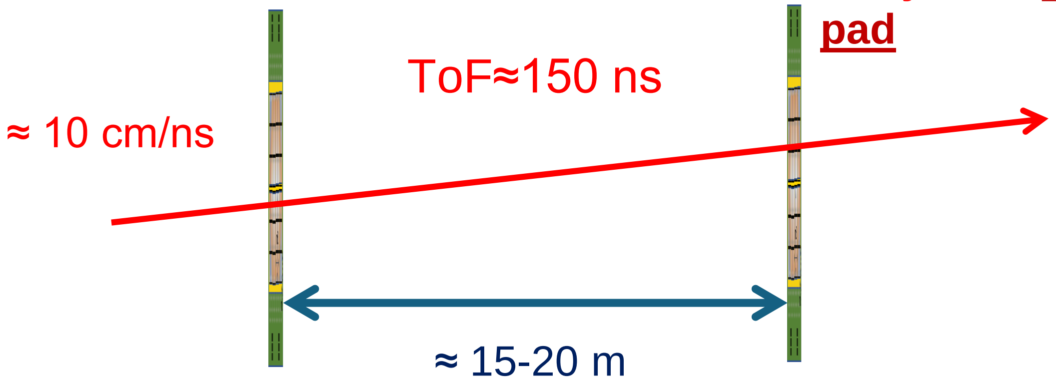
Courtesy of C. Guazzoni



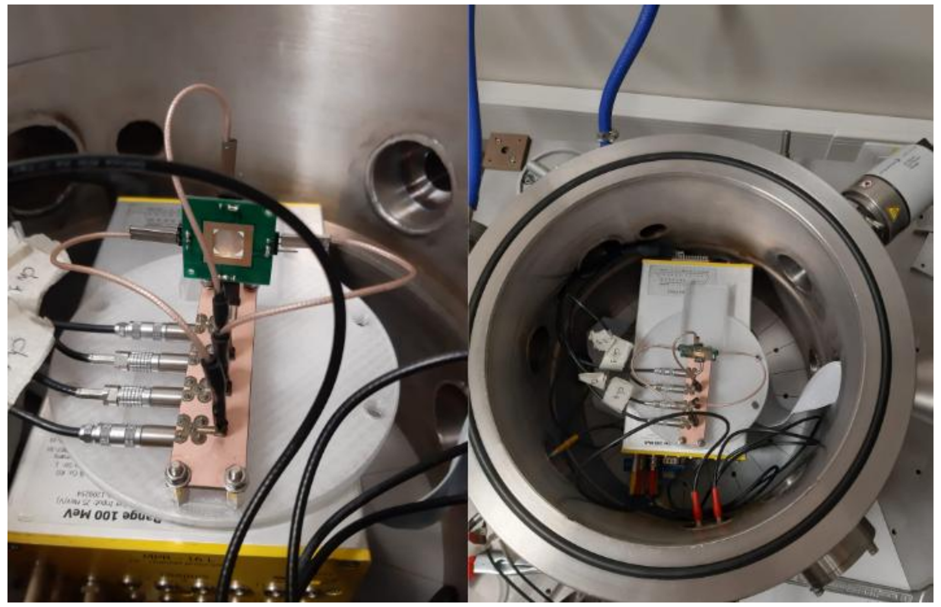
Courtesy of G. Cardella

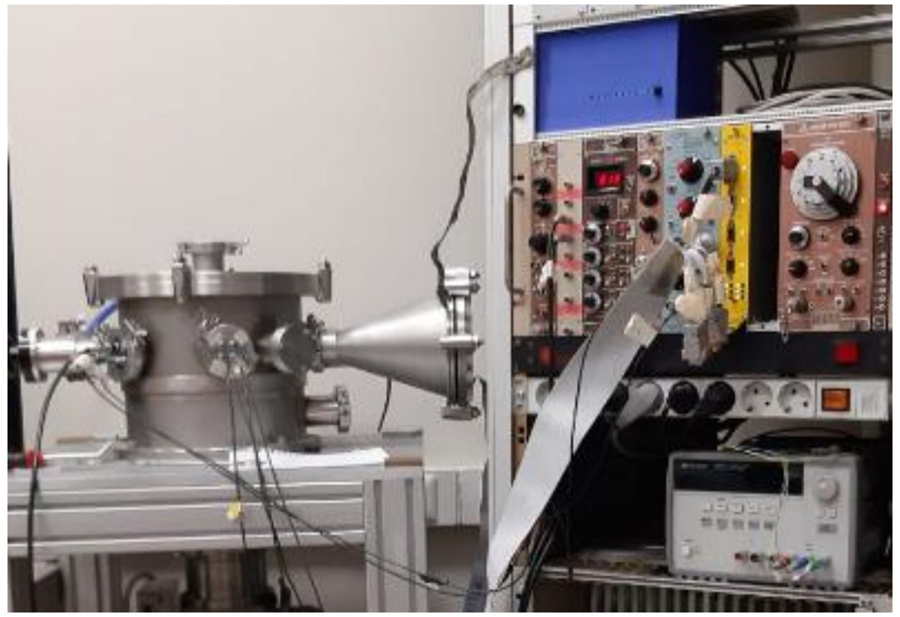
A typical issue of fragmentation beams is ΔE/E ≈2 %→ uncertainty for a beam of 50 MeV/A is ≈ 1 MeV/A

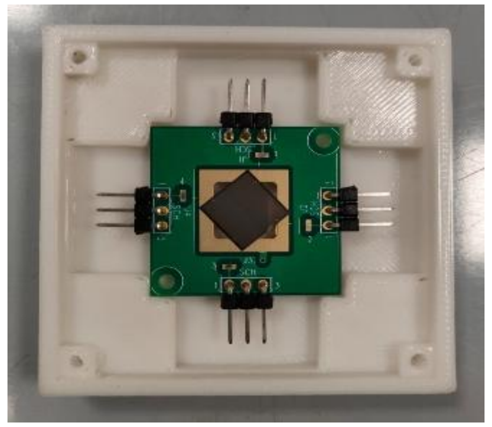
in order to provide RIBs with ΔE/E ≈ 0.5 % we can use the ToF measurement between two SiC arrays → <u>100 ps for each SiC pad</u>



- **Characterization of SiC prototypes**







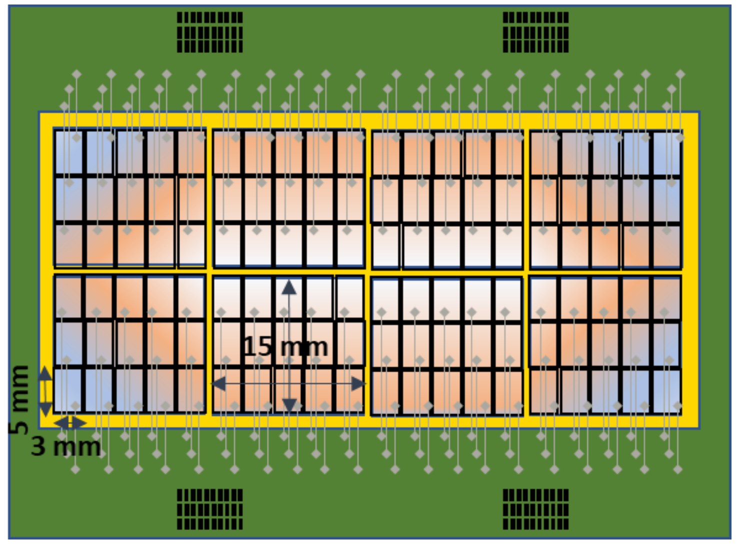
2x2 pixels SiC detector (100 µm- 1 cm^2)

Commercial electronics:

- Mesytec MPR-16 preamplifier
- CAEN DGT DT5742 16 ch, 1 GHz
- Analyses on waveform and applied filter

N.S. Martorana et al., NIMA, under review

- **Arrays of SiC pixels of 3 mm × 5 mm - 180 μm → will be covered an area of ≈ 60×30 mm² → segmentation able to sustain ≈ 10^7 pps**



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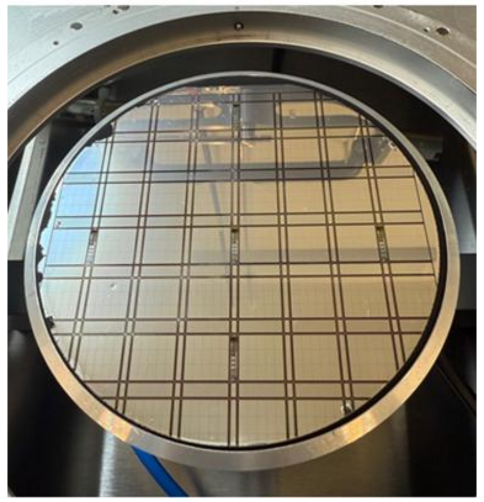

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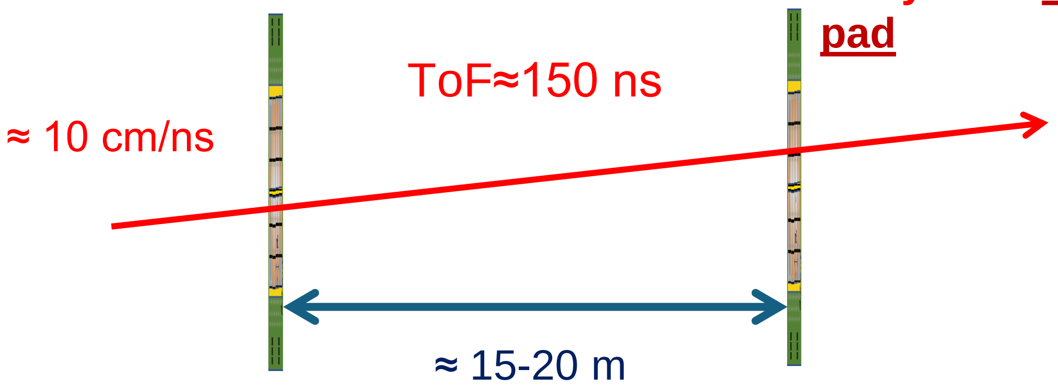
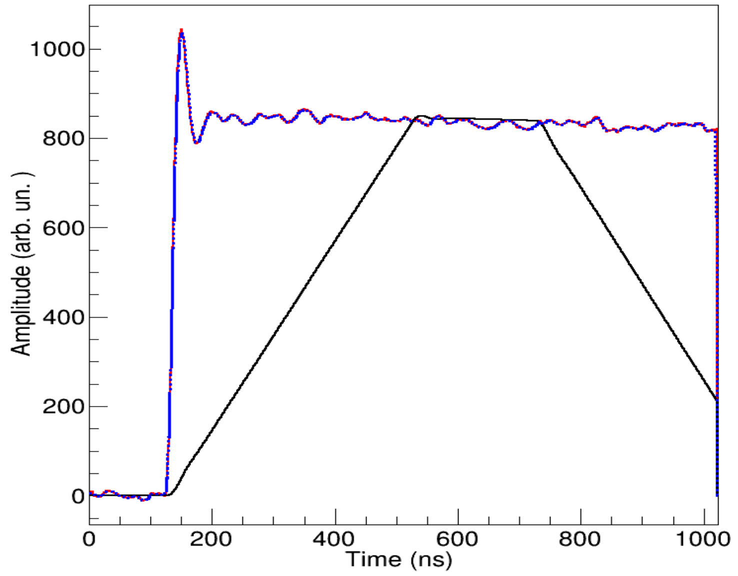
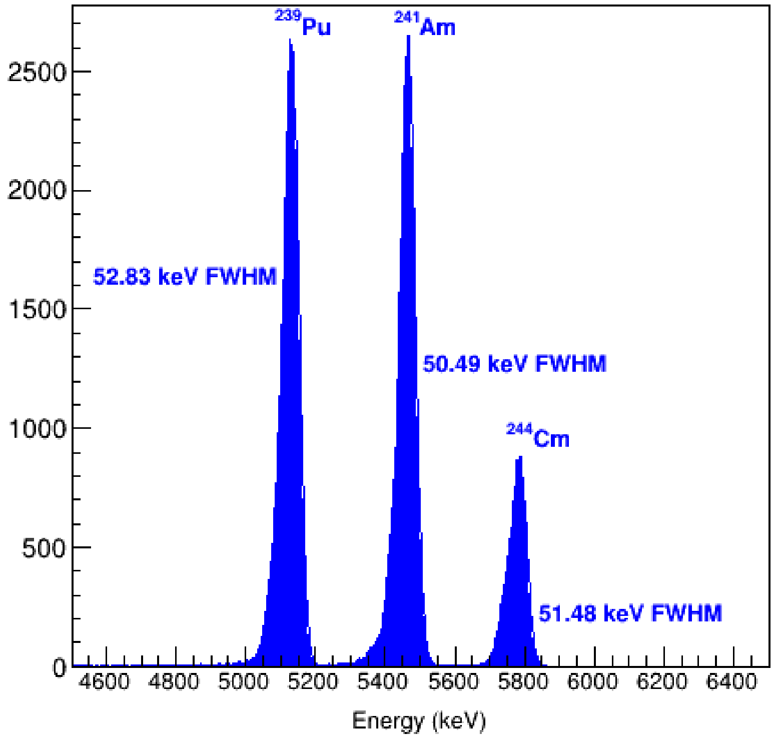


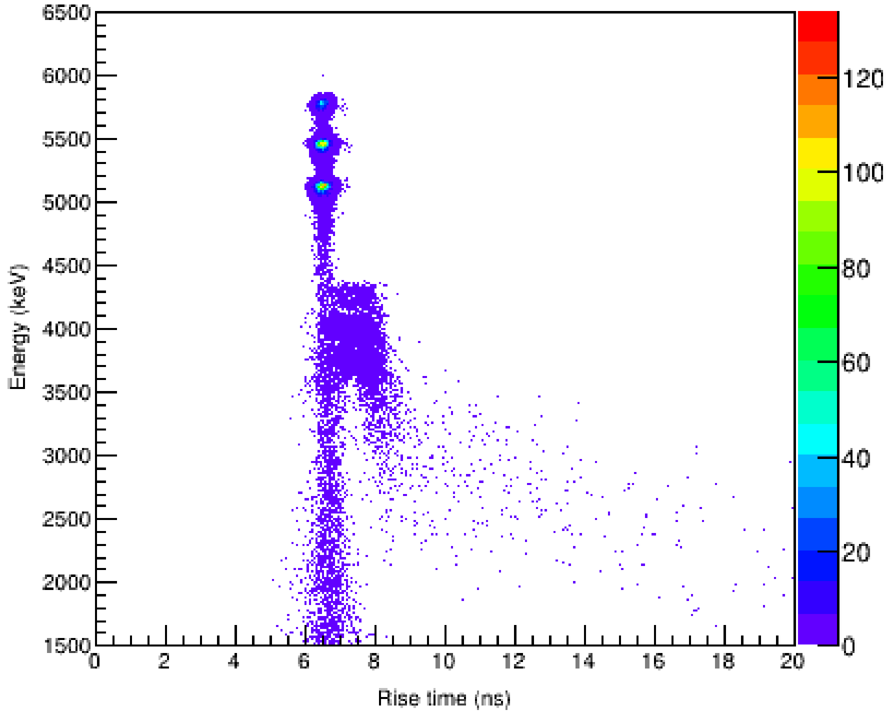
- **Characterization of SiC prototypes**

- **SiC waveform**
- **Signal after the trapezoidal filter**
- **Blue dashed line→ smoothing to extract the timing**

maximum→ energy information
start time → a fraction % of the extracted maximum







Energy spectrum and energy vs rise time plot obtained for one pixel, using ^{239}Pu, ^{241}Am, ^{244}Cm α radioactive source

N.S. Martorana et al., NIMA, under review

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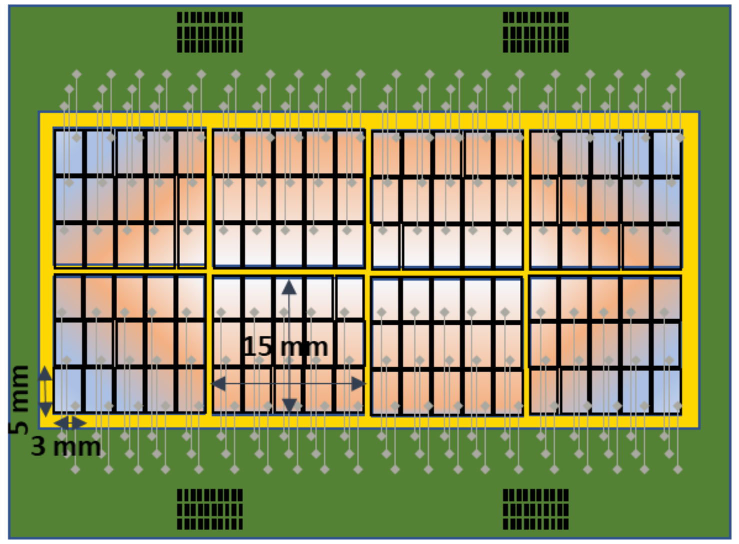

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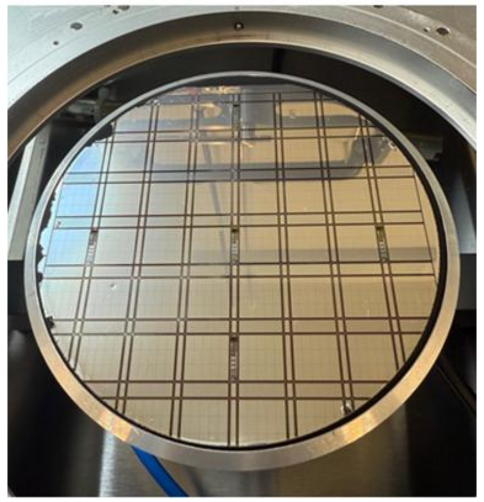
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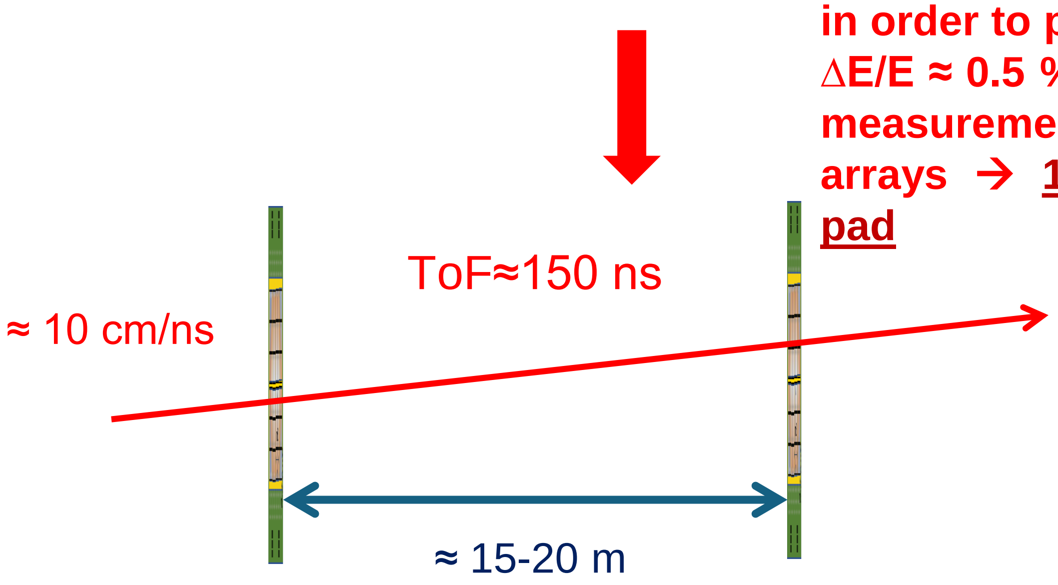

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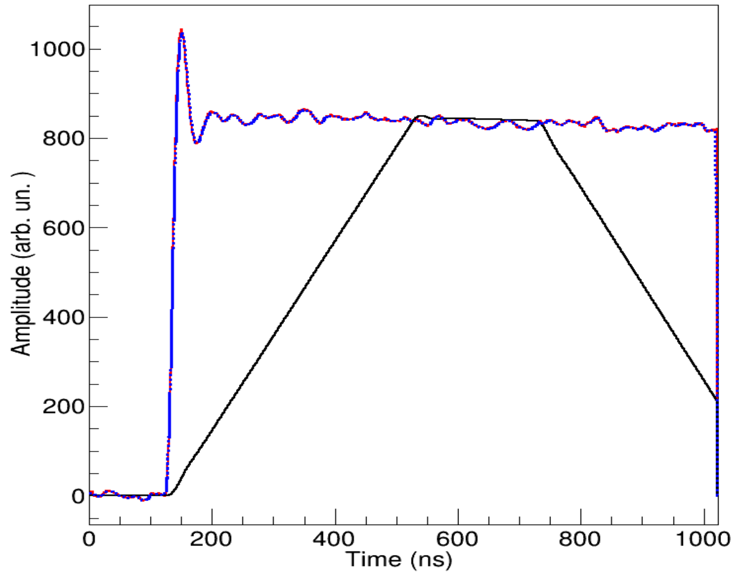

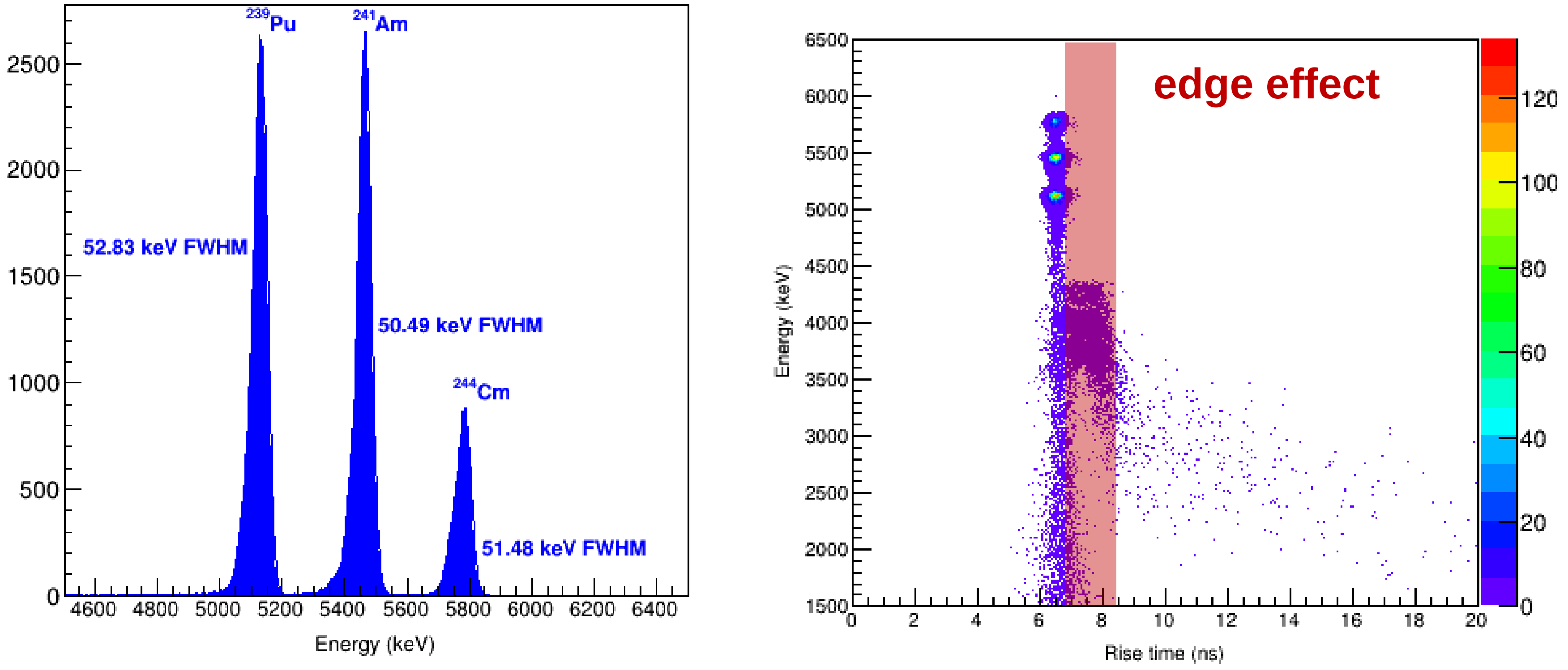

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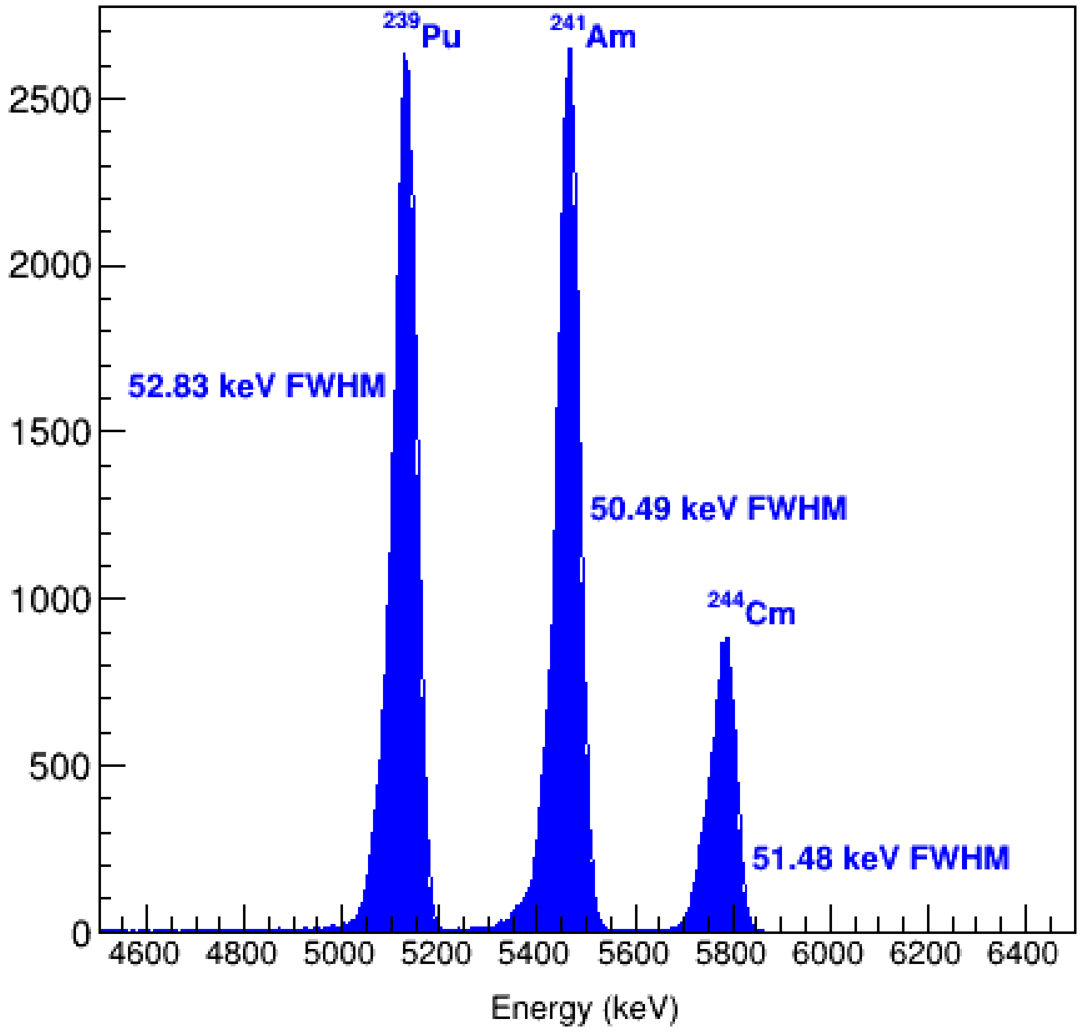
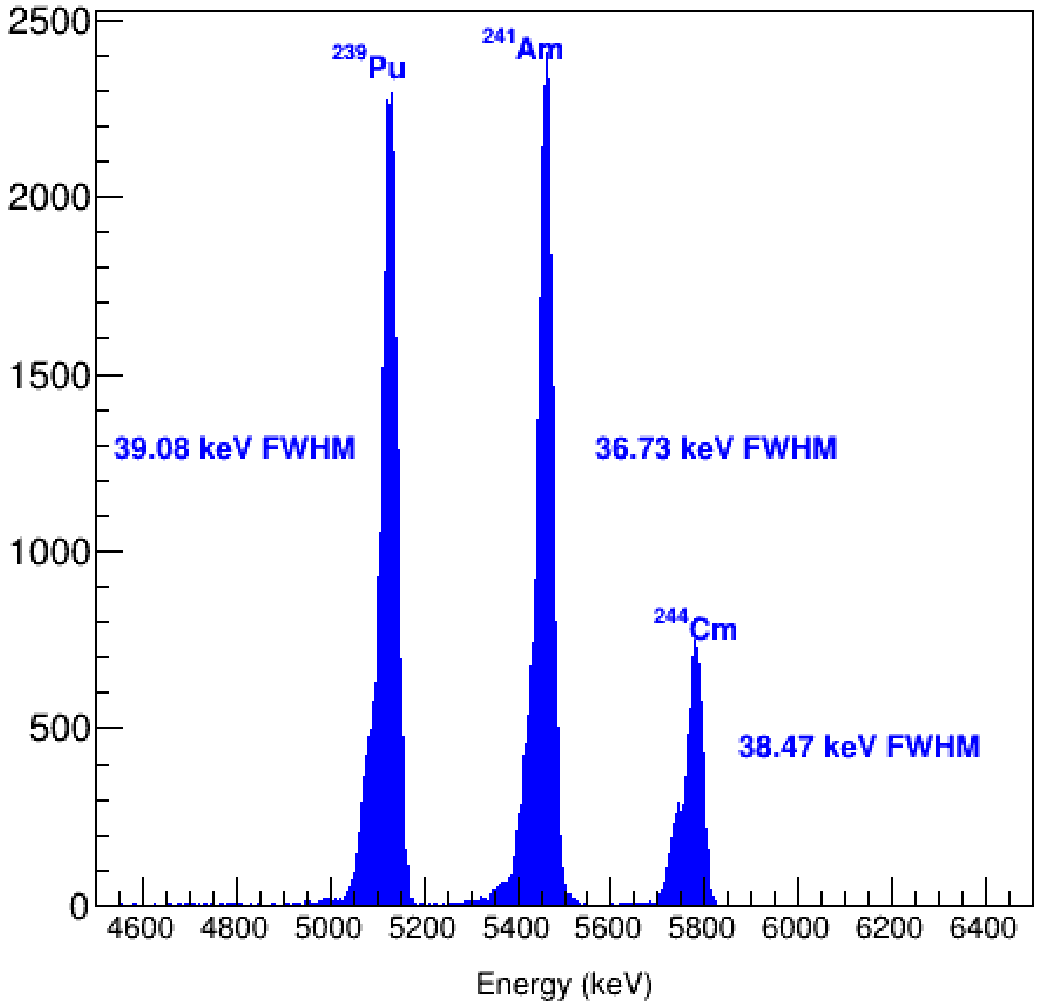
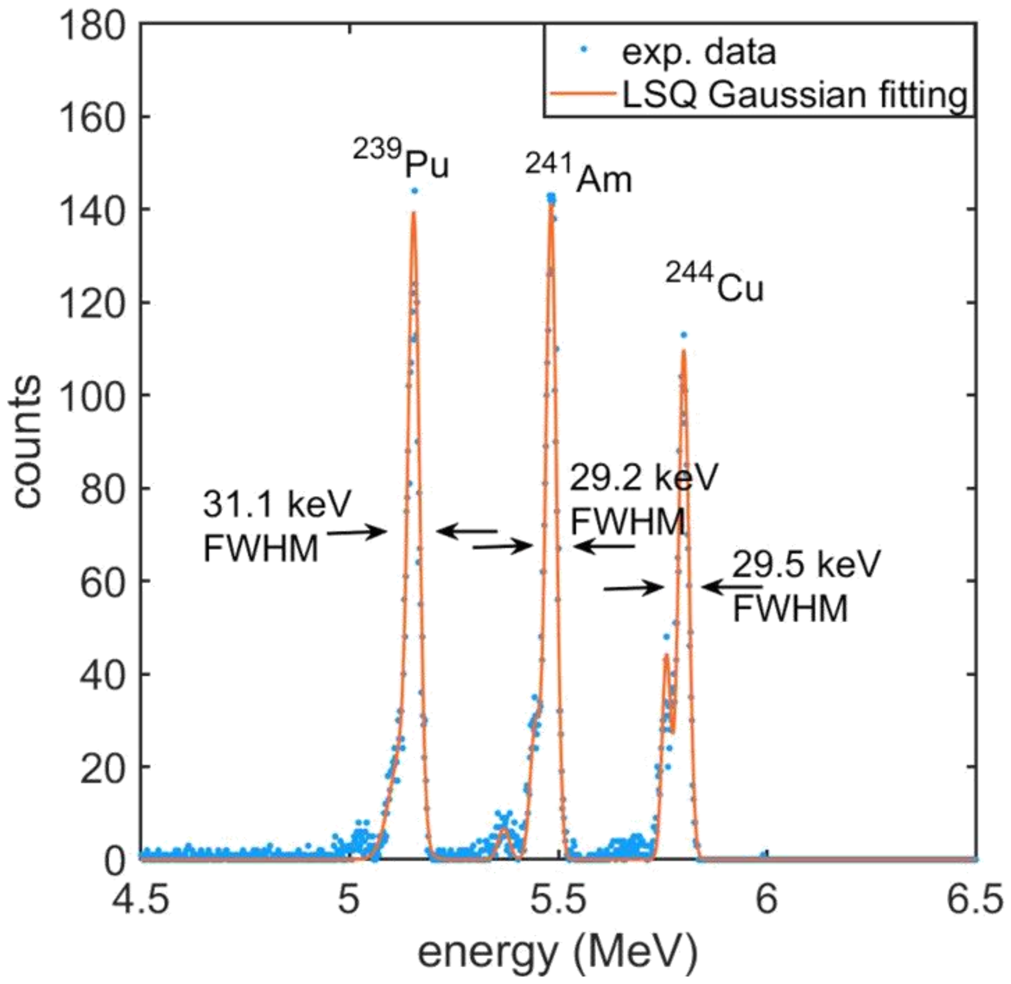


Energy spectrum obtained with ^{239}Pu, ^{241}Am, ^{244}Cm α source for a SiC pixel, mesytec preamplifer and CAEN DGT



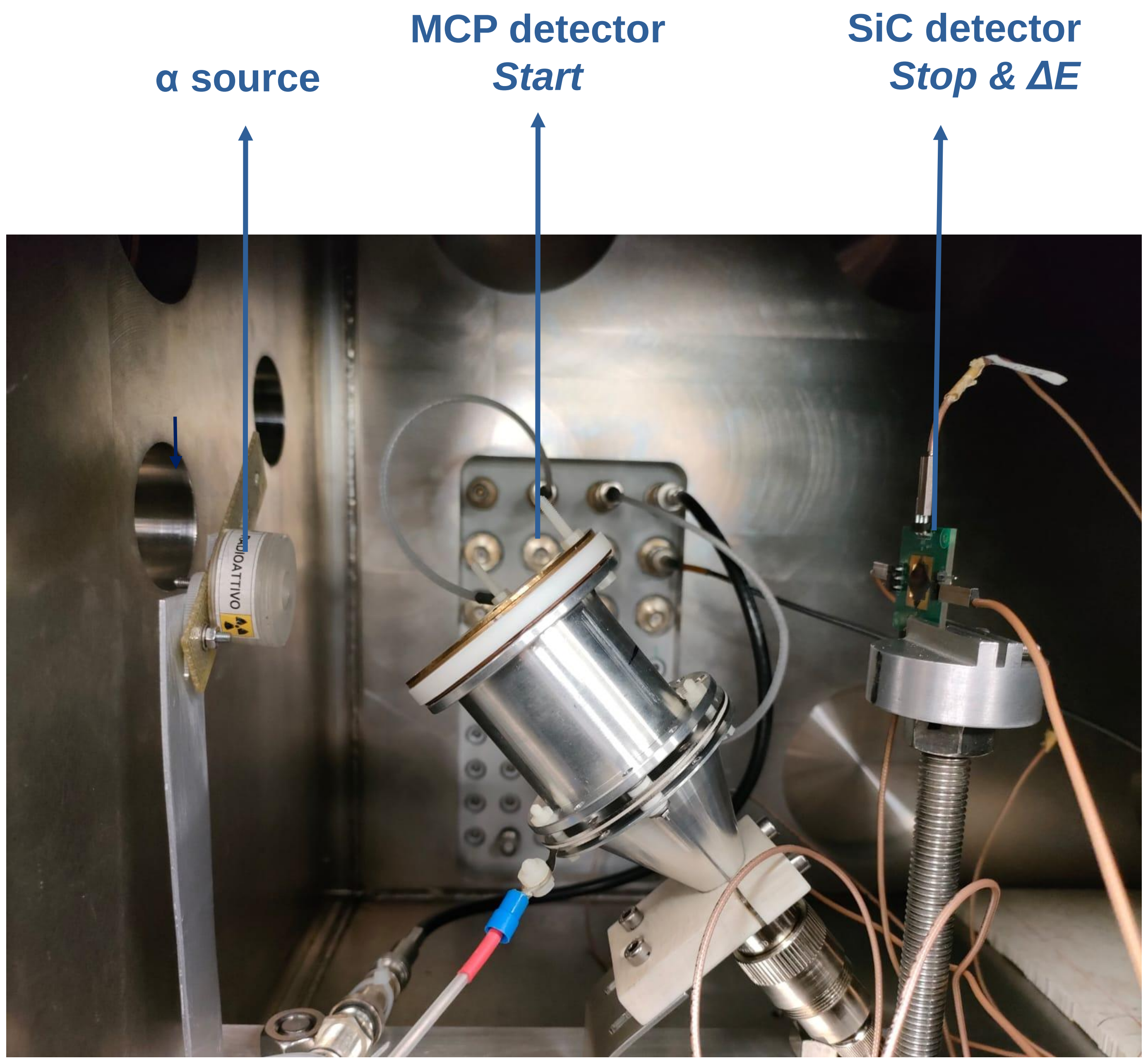
Energy spectrum obtained with ^{239}Pu, ^{241}Am, ^{244}Cm α source for a SiC pad, mesytec preamplifer, ORTEC amplifier and MCA acquisition

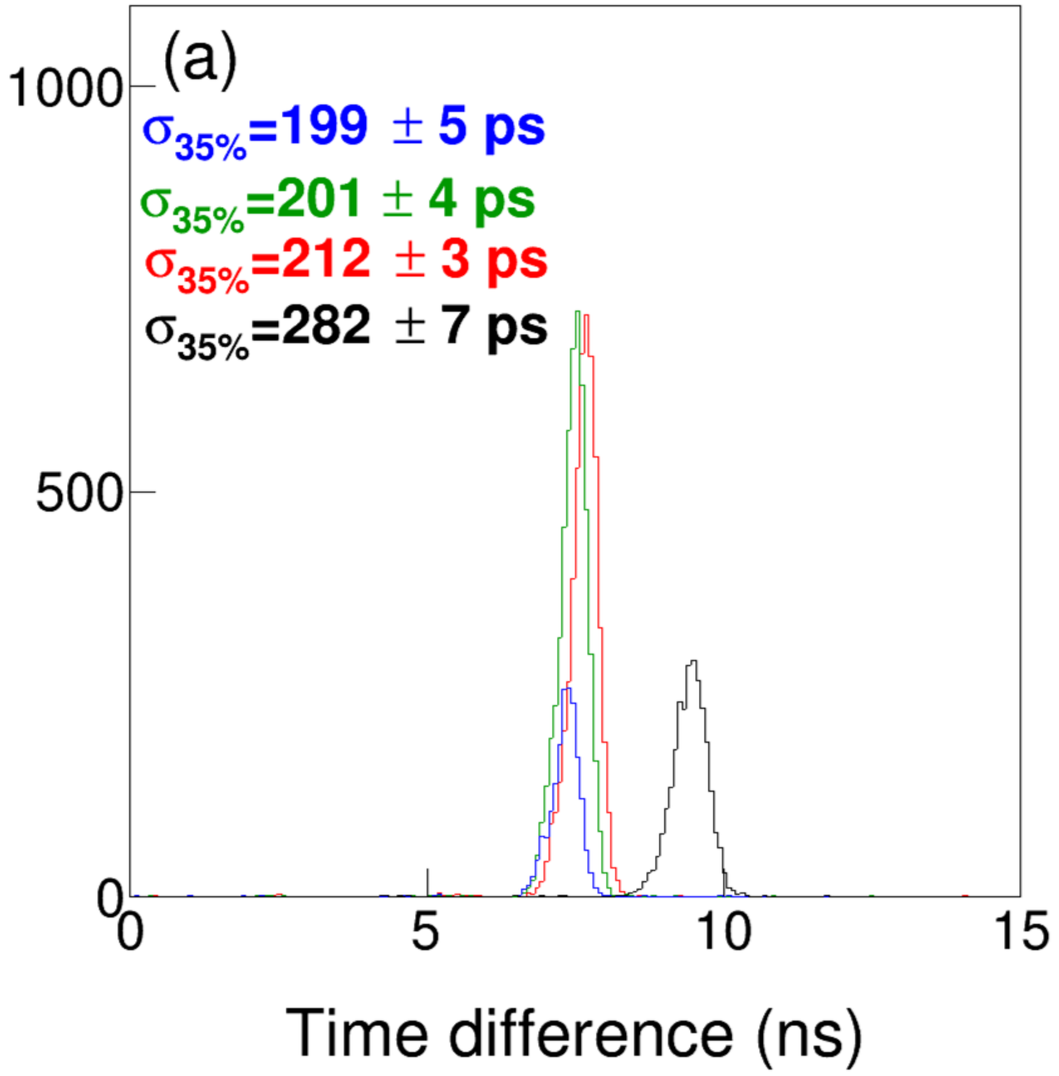


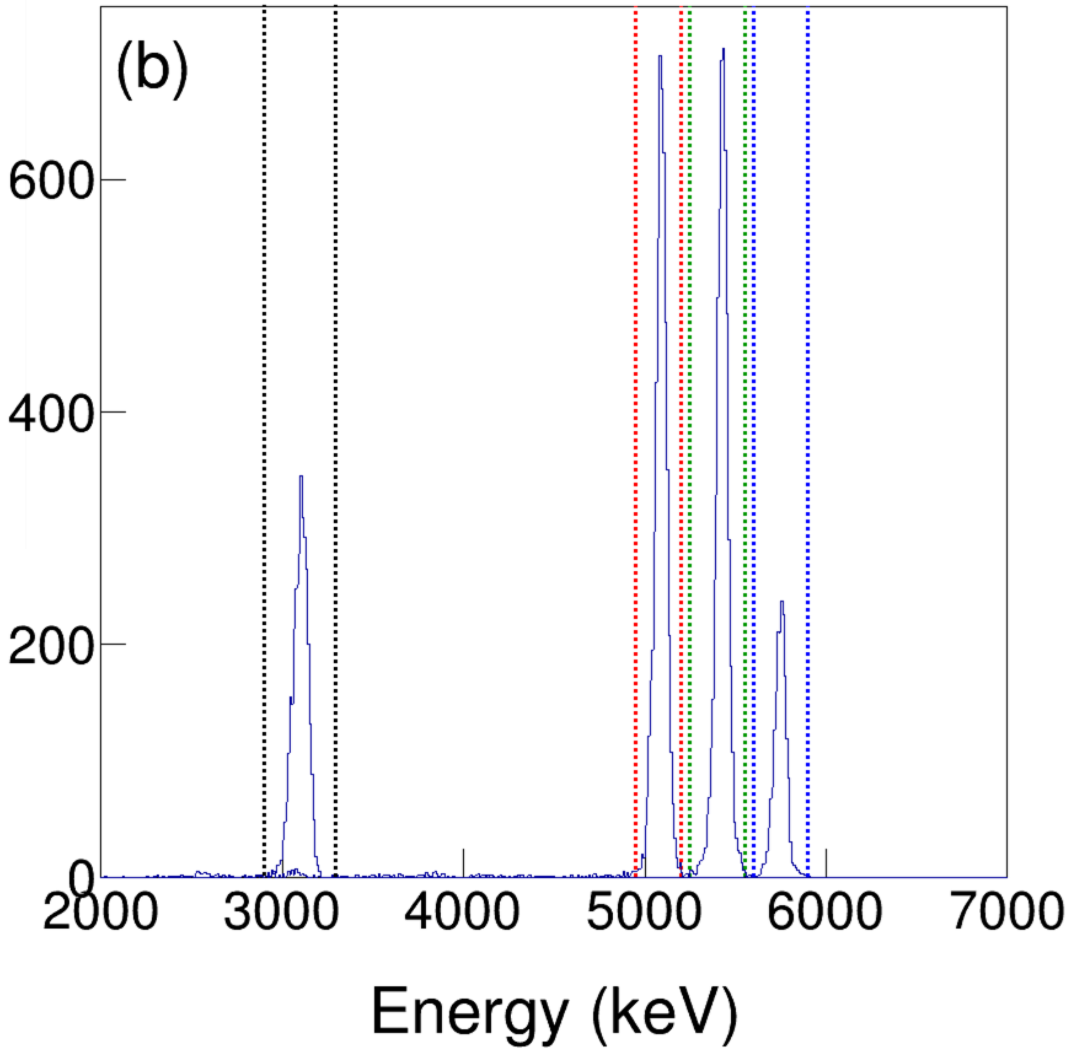
Energy spectrum obtained with ^{239}Pu, ^{241}Am, ^{244}Cm α source for a SiC pad and ASIC preamplifier (courtesy of C. Guazzoni)

N.S. Martorana et al., NIMA, under review

Test performed at INFN-LNS using a MCP as start signal and 2x2 SiC as stop signal over a base flight of ≈ 11 cm





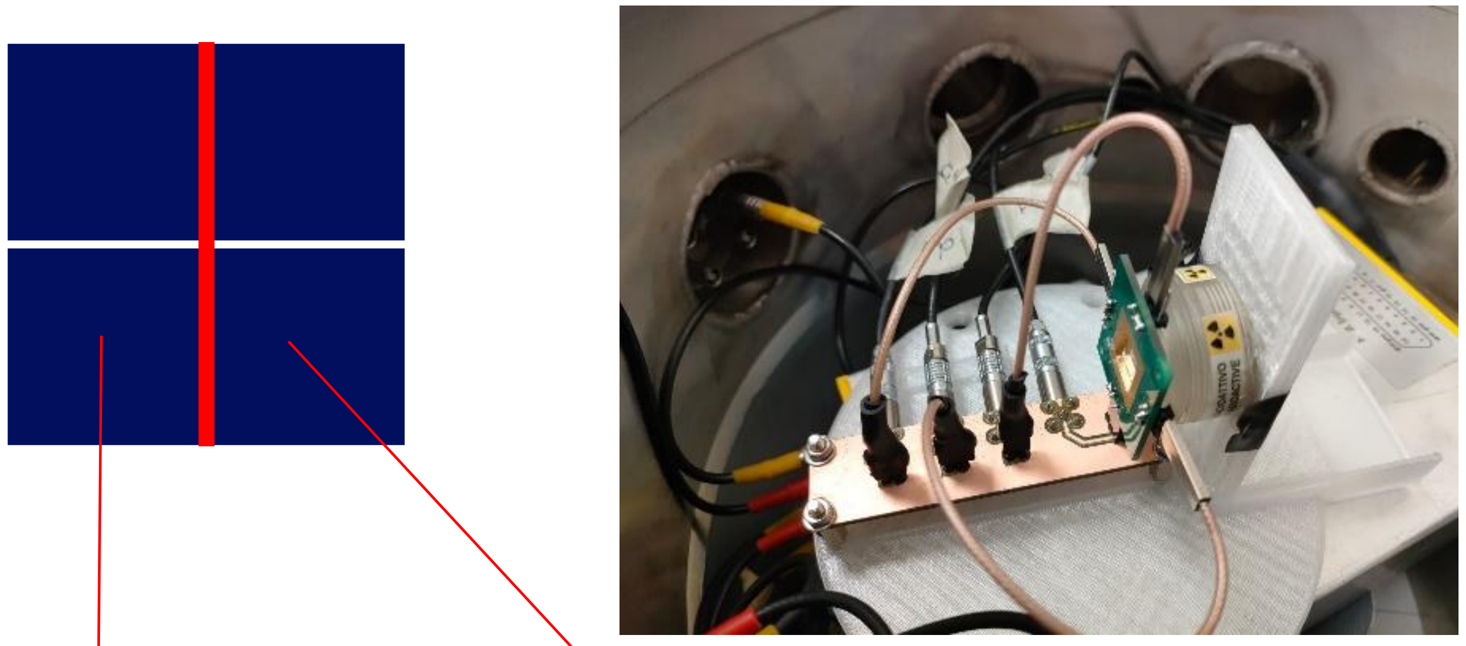


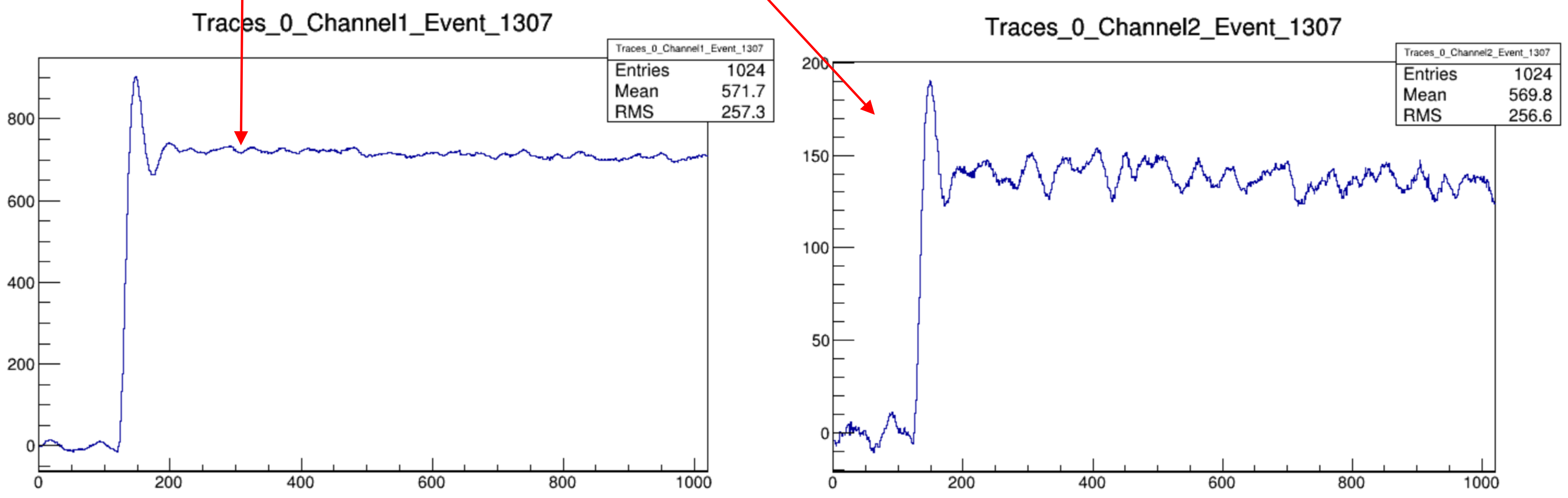
- Standard mixed α source $\rightarrow$ $\sigma_{MCP+SiC} \approx$ 200 ps
- ^{148}Gd α source $\rightarrow \sigma_{MCP+SiC} \approx$ 300 ps

N.S. Martorana et al., NIMA, under review

To obtain the information on the timing performance of a single SiC pixel→ data analysis looking at the sharing of the signals; namely signals in events in which two adjacent pixels are in coincidence

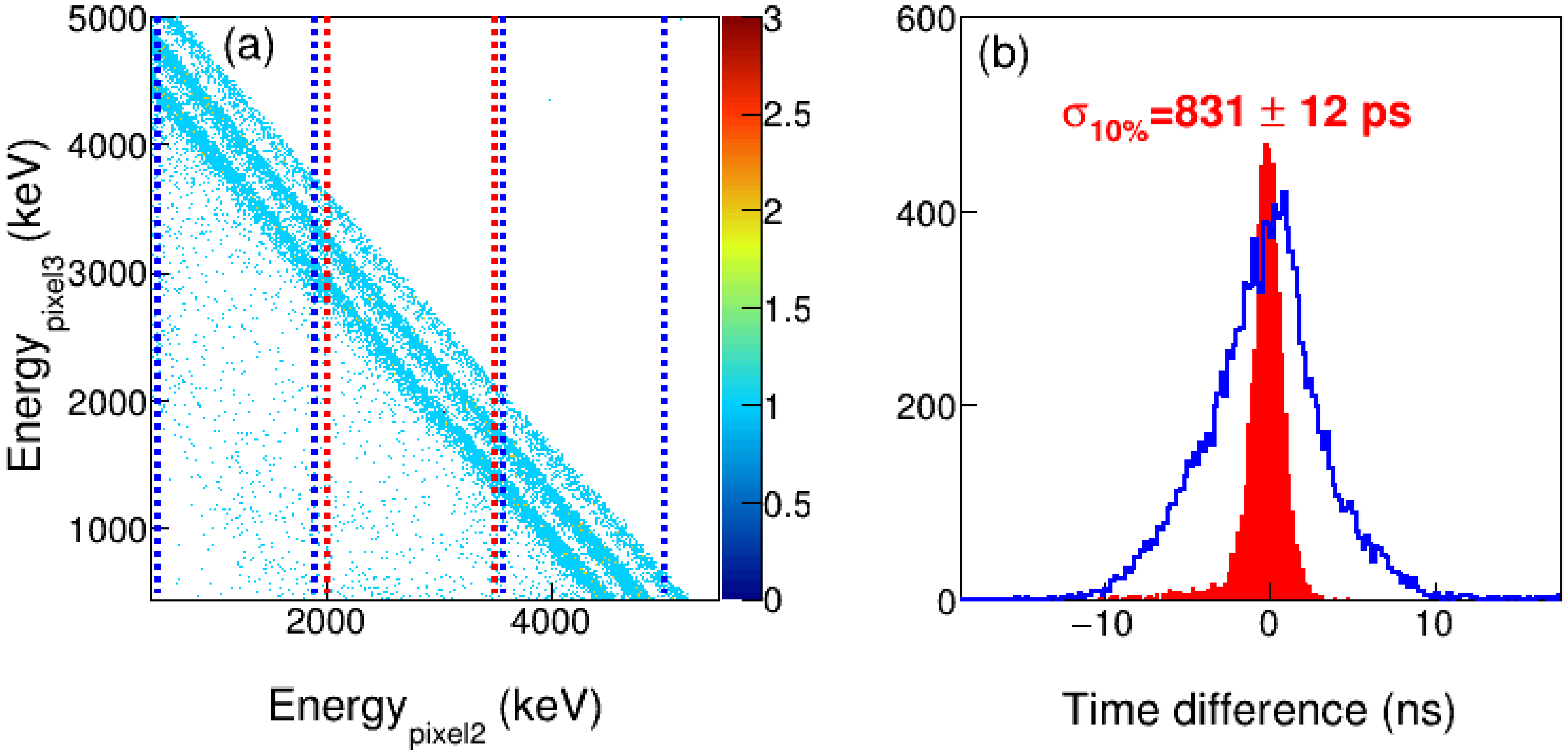
Mixed α source→ a particle impinges on the interpixel region→ signals detected by two adjacent pixels





Waveforms in a coincidence event

N.S. Martorana et al., NIMA, under review



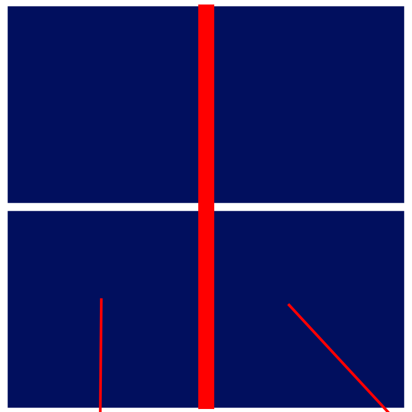
- ✓ **Start/crossing time has been evaluated at the 10% of the extracted maximum**
- ✓ **Time difference: difference between the start/crossing time signals of two adjacent pixels in coincidence events**

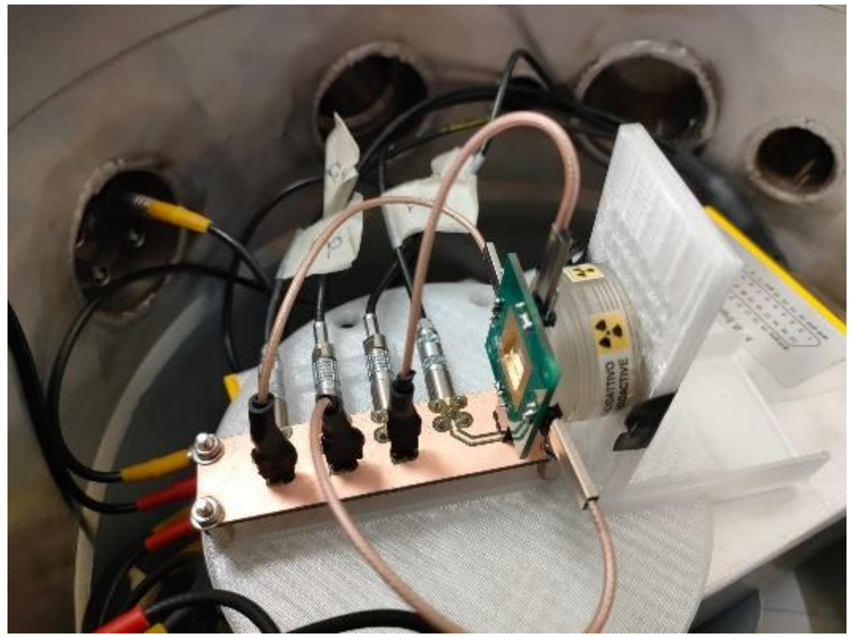
Time difference = $Start_{SiCx} - Start_{SiCy}$

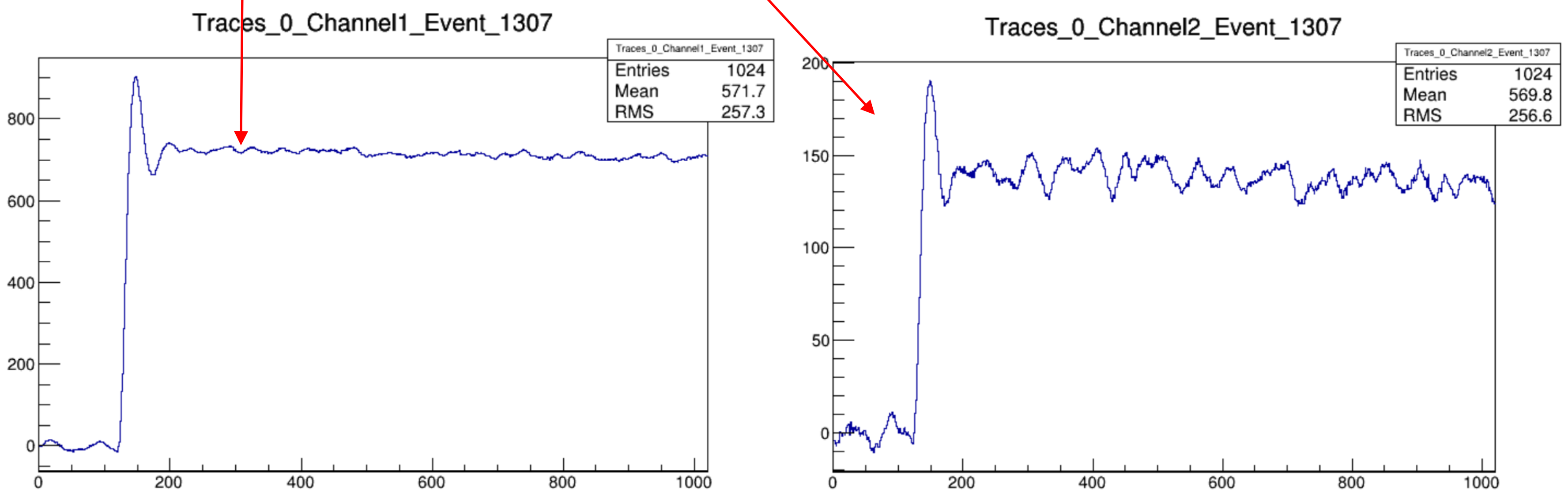
- ✓ **Time difference in coincidence events with energy cuts→ σ ≈ 800 ps**

To obtain the information on the timing performance of a single SiC pixel→ data analysis looking at the sharing of the signals; namely signals in events in which two adjacent pixels are in coincidence

Mixed α source→ a particle impinges on the interpixel region→ signals detected by two adjacent pixels







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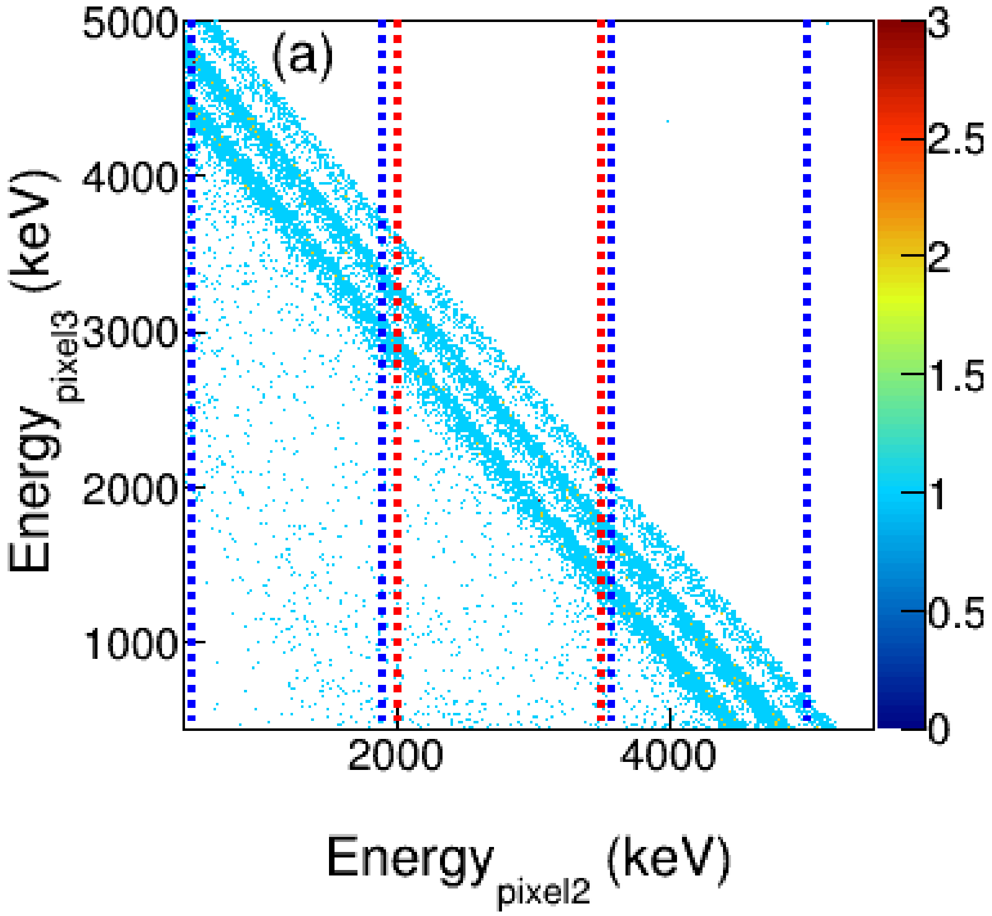
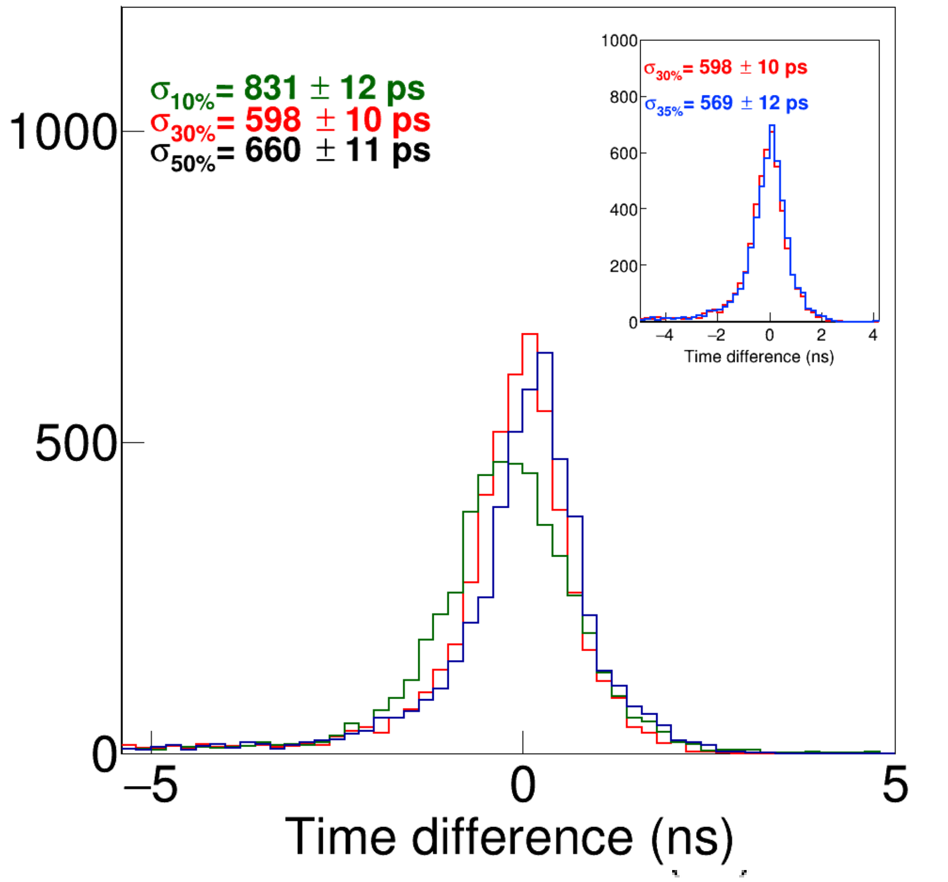




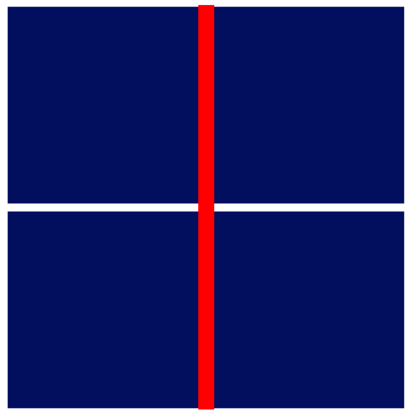
- ✓ **Start/crossing time has been evaluated at the 10% of the extracted maximum**
- ✓ **Time difference: difference between the start/crossing time signals of two adjacent pixels in coincidence events**

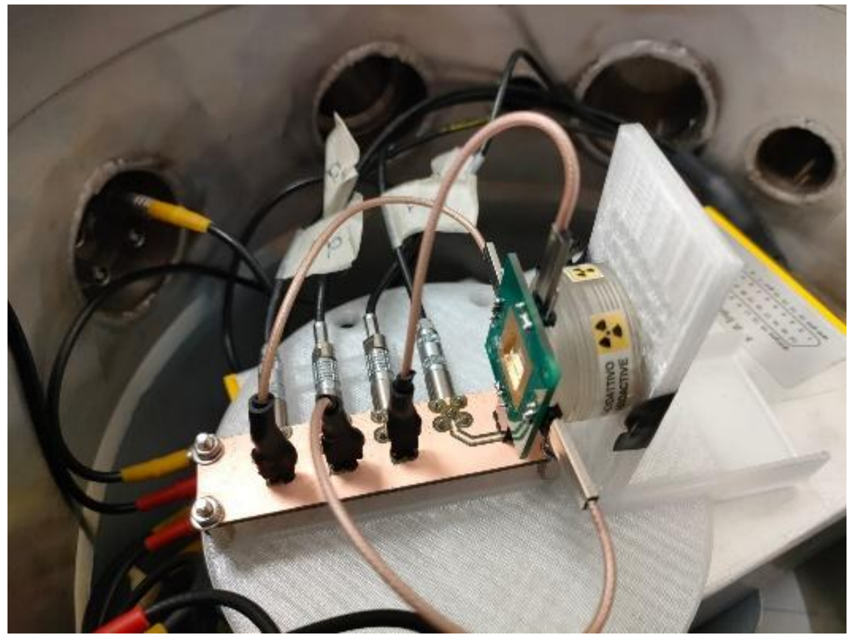
$$\text{Time difference} = Start_{SiCx} - Start_{SiCy}$$

- ✓ **Time difference in coincidence events with energy cuts→ σ ≈ 800 ps**
- ✓ **Analysis on the crossing time to optimize the sigma value→ 35% crossing time minimize the sigma value**

To obtain the information on the timing performance of a single SiC pixel→ data analysis looking at the sharing of the signals; namely signals in events in which two adjacent pixels are in coincidence

Mixed α source→ a particle impinges on the interpixel region→ signals detected by two adjacent pixels



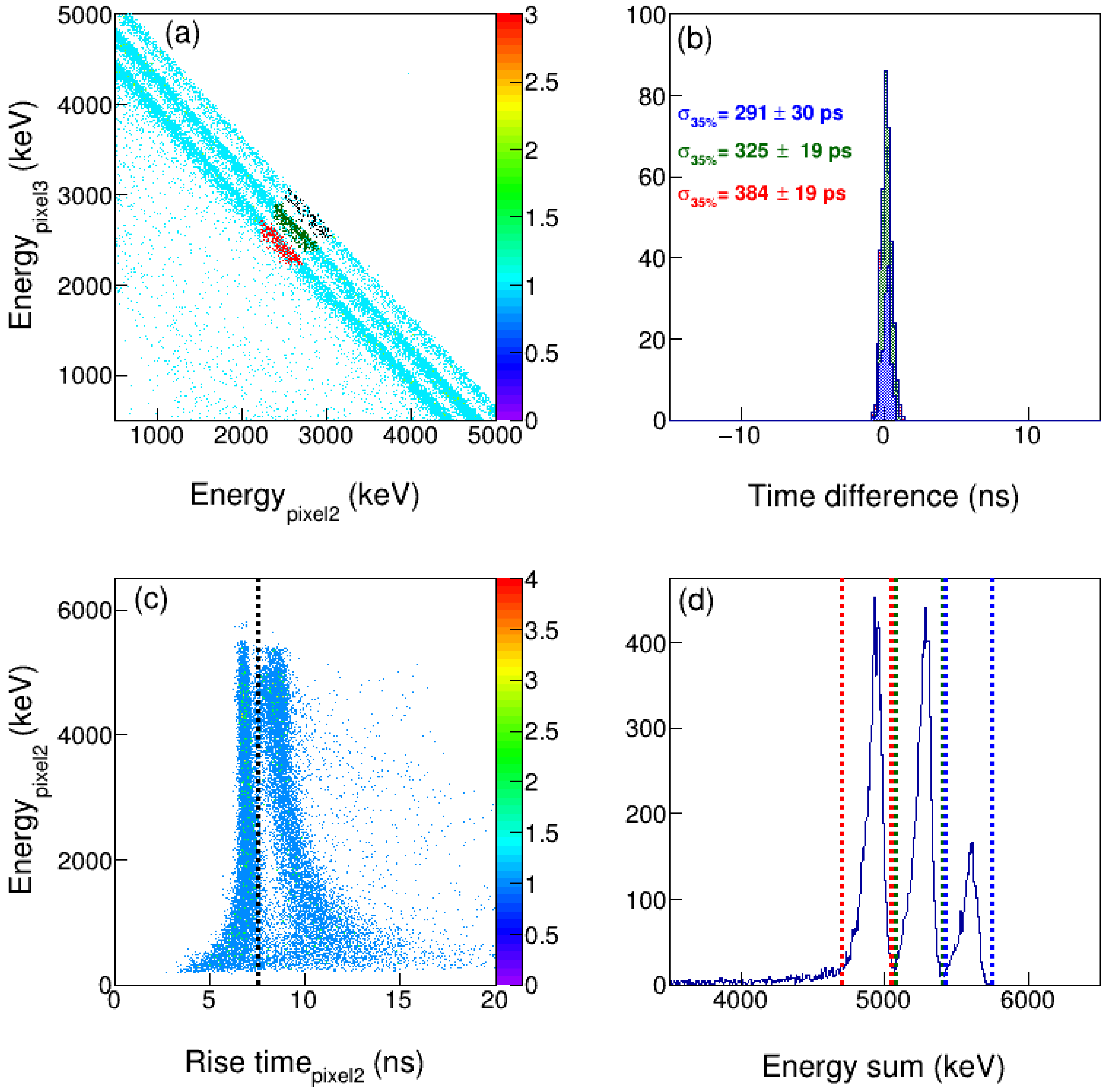


To obtain the energy dependence of the time resolution, more strict conditions were included in the analysis:

i) a rise-time < 7.5 ns to remove edge effect
ii) a constraint upon the sum of the two pixels energies
iii) a cut on the energies of two adjacent pixel

Having the pixels, in this region, the same energy range, one can assume that the pixels response is the same →

$$\sigma = \sqrt{\sigma^2_{pixel2} + \sigma^2_{pixel3}} \rightarrow \sigma_{pixel} = \frac{\sigma}{\sqrt{2}}$$



Same method applied also for the Gd α source

N.S. Martorana et al., NIMA, under review

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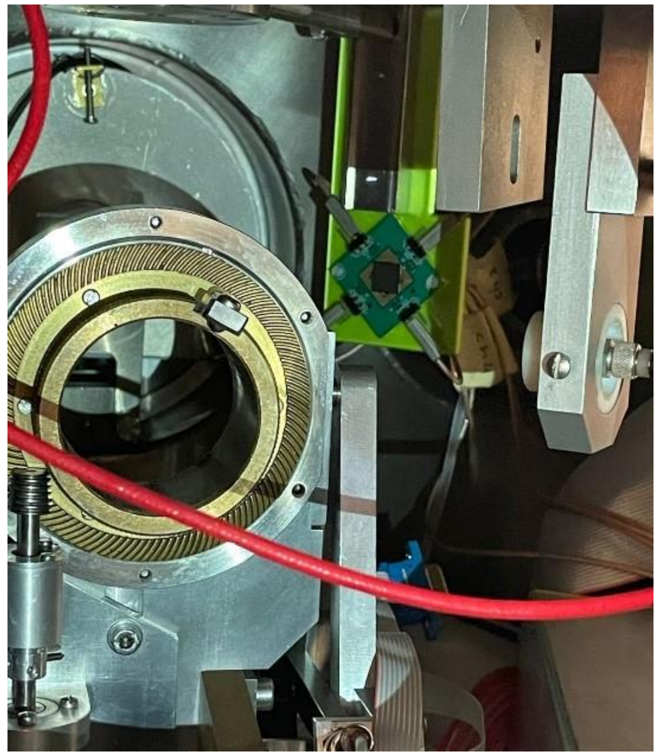
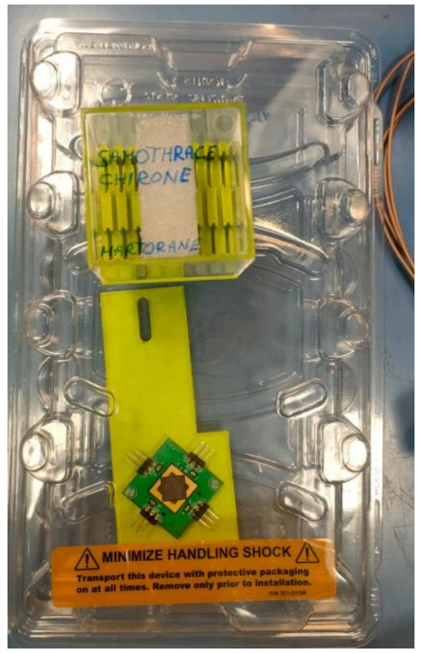
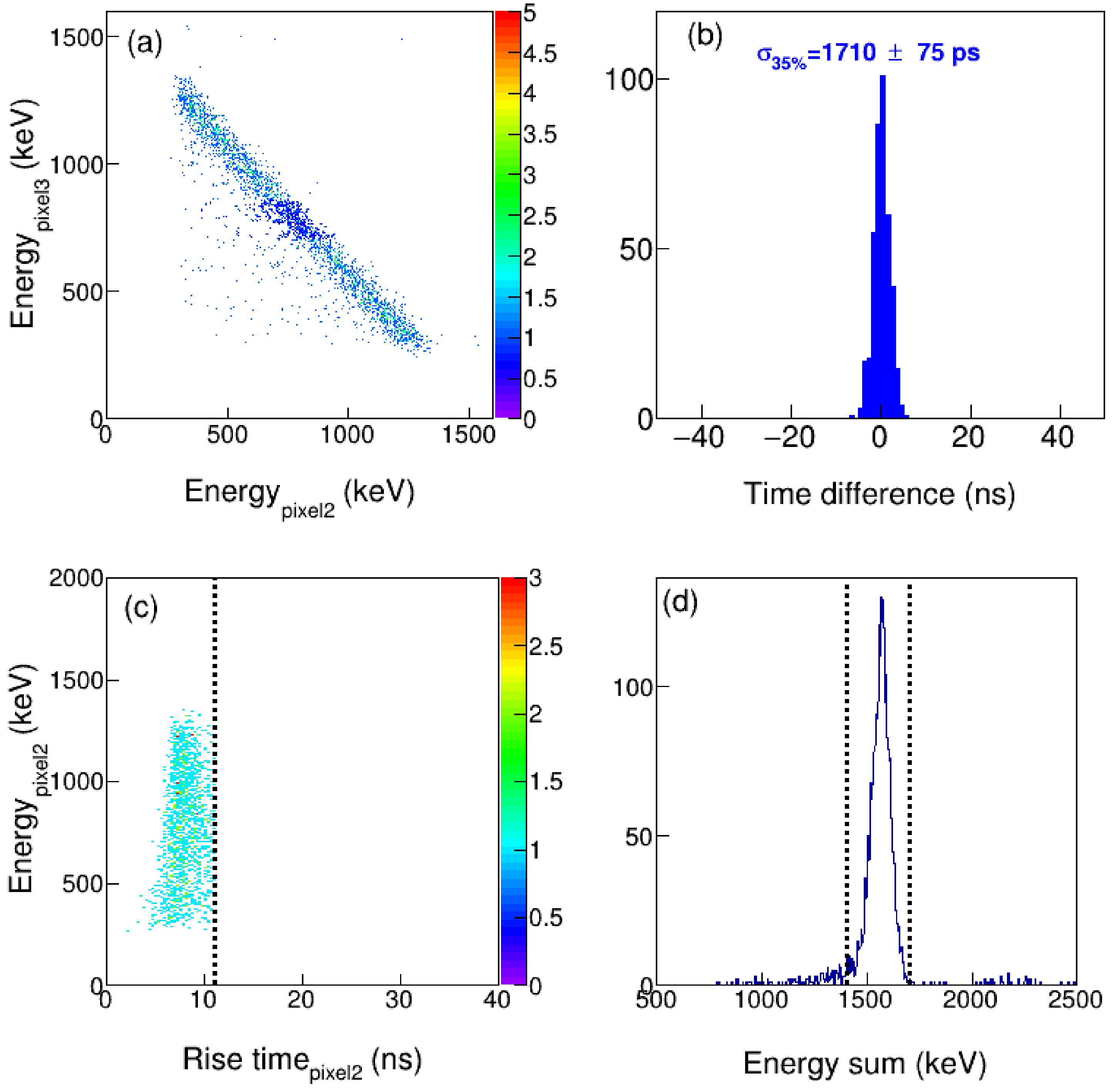




- 100 μm SiC detector at θ≈150° in the laboratory frame, and inside a vacuum chamber
- carbon target with an evaporated Au layer ≈ 20 μg/cm^2 was used

Measurement conducted at Dipartimento di Fisica e Astronomia «Ettore Majorana» using the Singletron accelerator with low energy α and proton beams

Timing response using the sharing method with 2 MeV α beams



Same method applied for the 1 MeV proton beams

N.S. Martorana et al., NIMA, under review

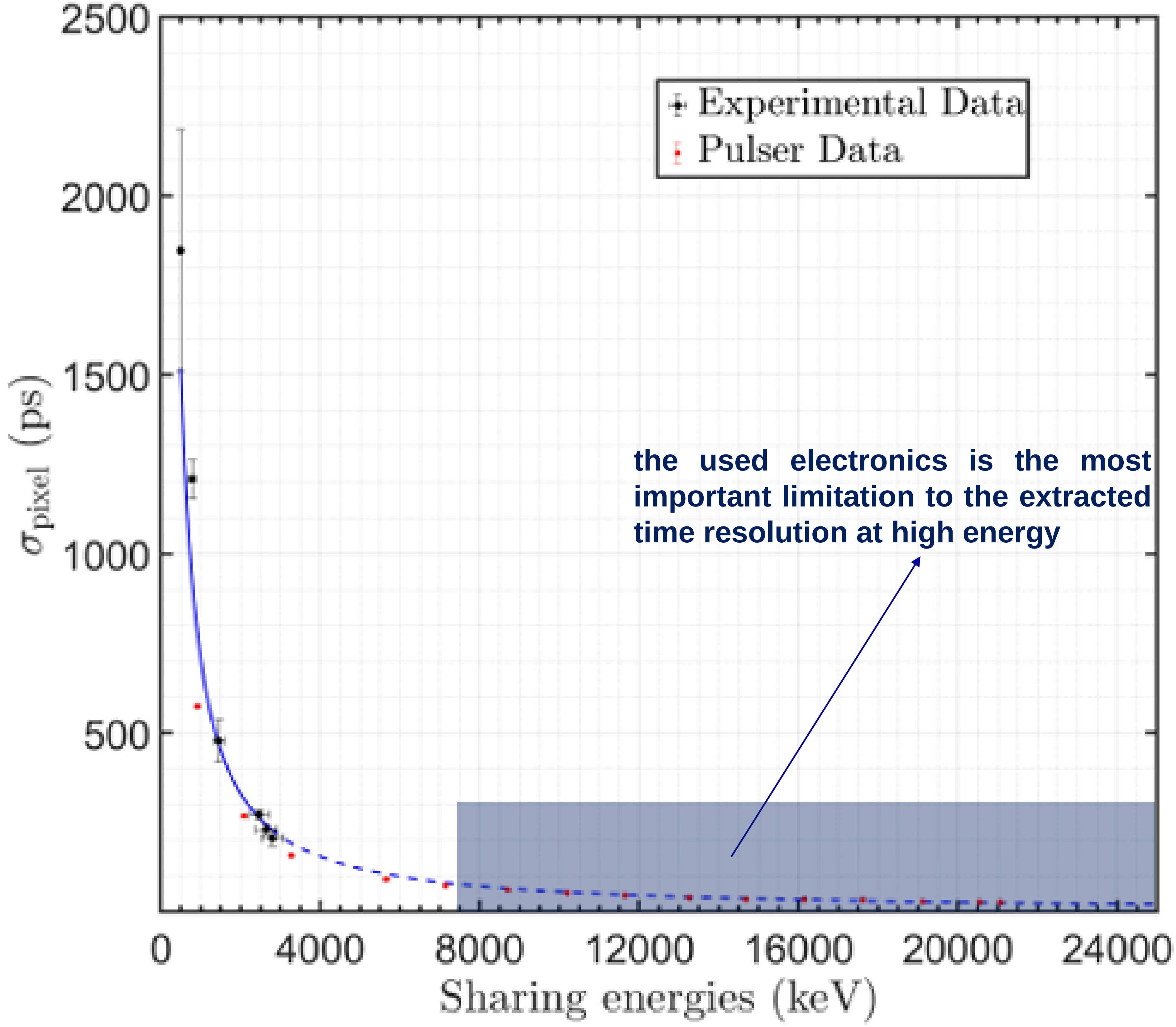
To obtain the information on the timing performance of a single SiC pixel→ data analysis looking at the sharing of the signals; namely signals in events in which two adjacent pixels are in coincidence

Black point:

- ✓ experimental data: mixed α source; Gd source, low energy proton and α beams

Red point:

- ✓ Pulser data sent to the Mesytec preamplifier



N.S. Martorana et al., NIMA, under review

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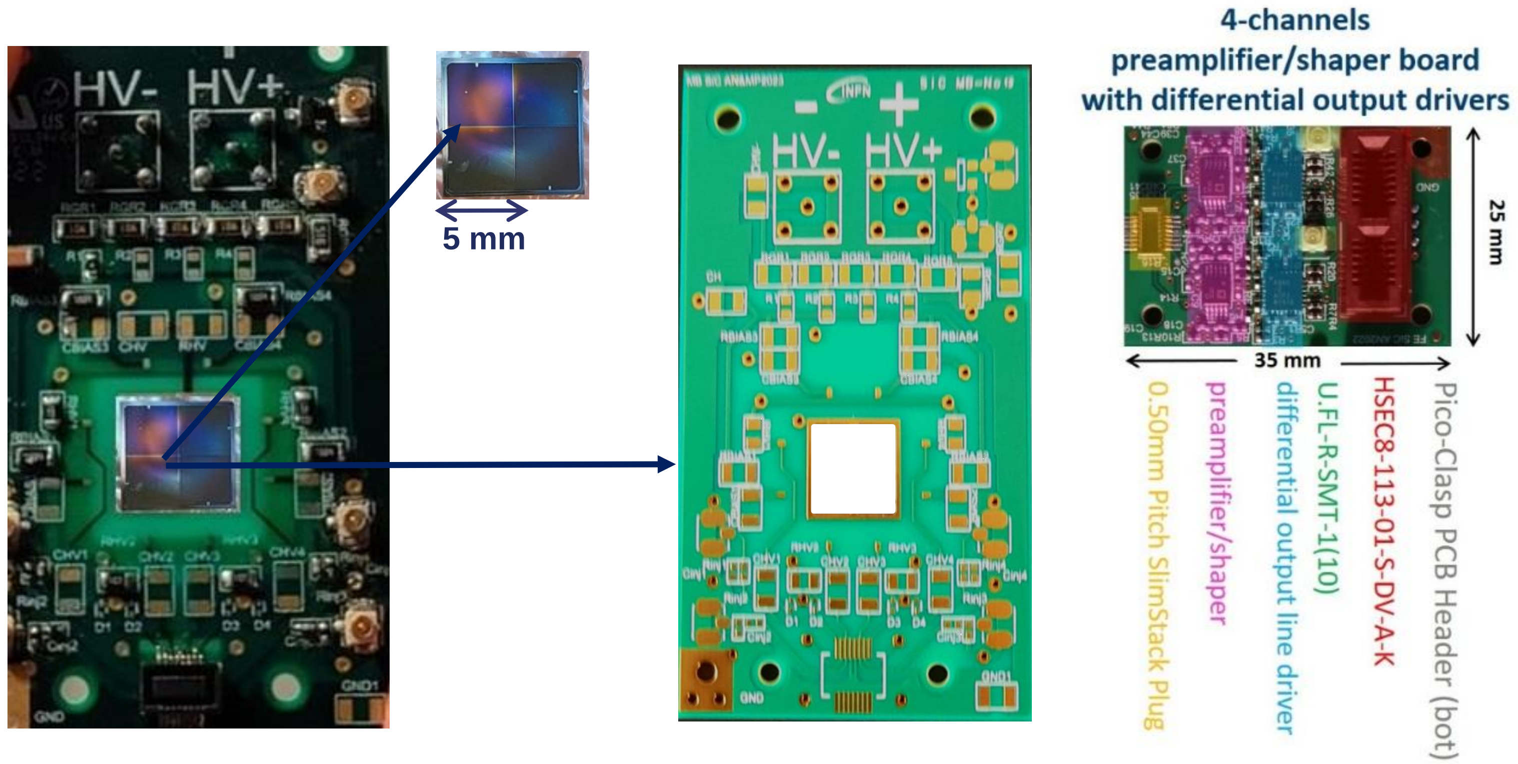
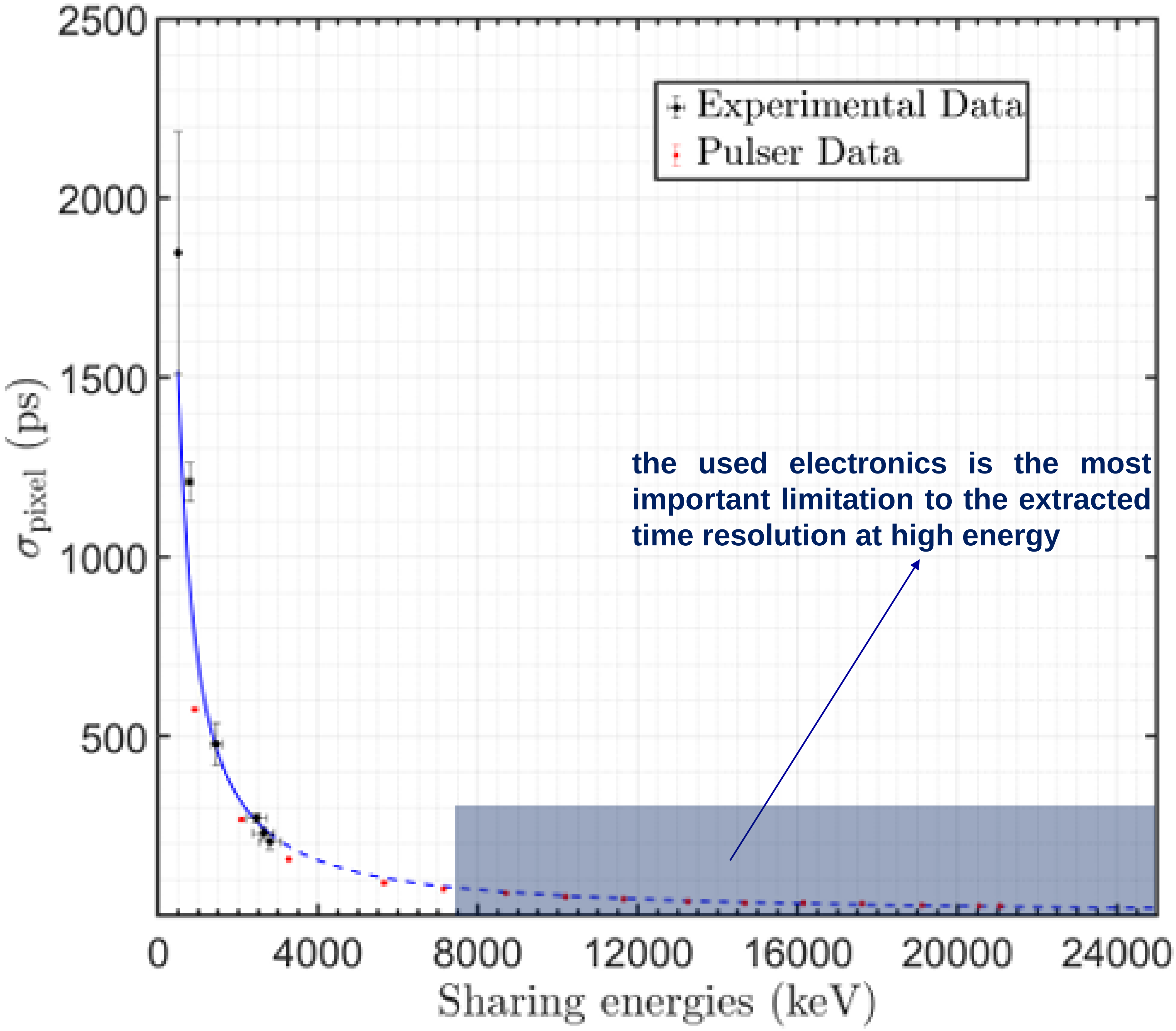
Pictures of a 2x2 SiC array mounted on a PCB and 4-channels preamplifier developed at INFN and Politecnico di Milano for 1 cm^2 detector carrier in full transmission mode (courtesy of C. Guazzoni)



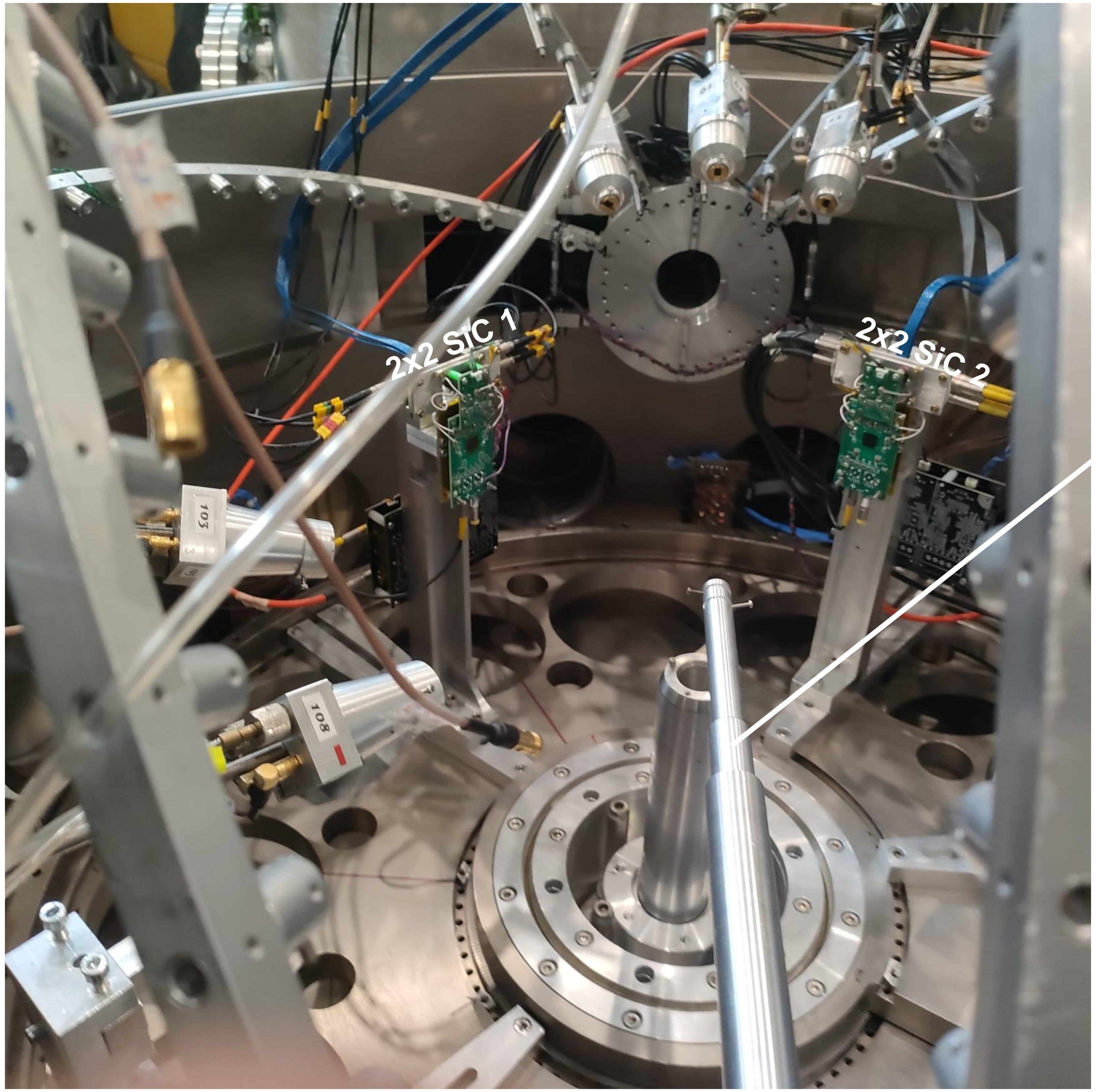
Altana C et al., IEEE Nuclear Science Symposium and Medical Imaging Conference 390 (NSS/MIC) (2021), 1–4

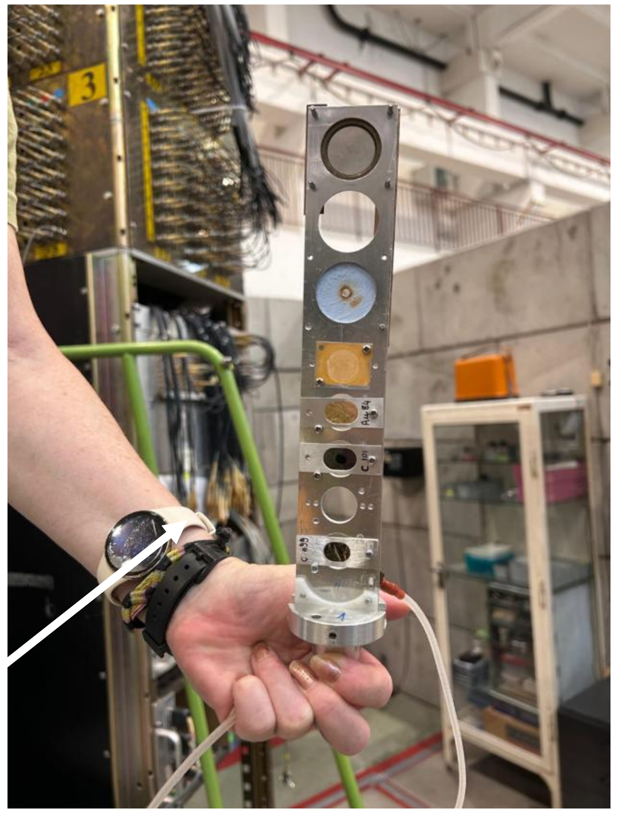


the used electronics is the most important limitation to the extracted time resolution at high energy

N.S. Martorana et al., NIMA, under review

T-INSIDE experiment→ June 2025

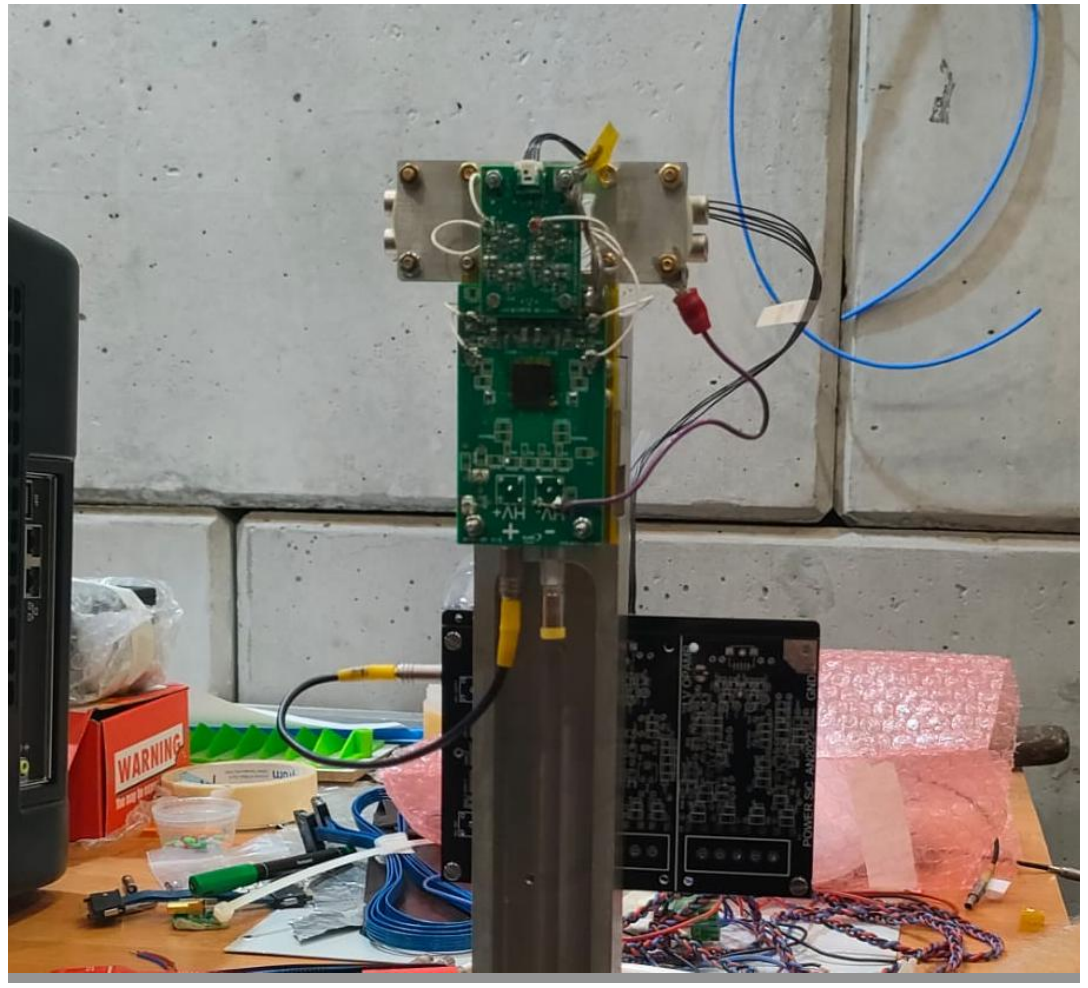




$^{12}C + ^{12}C$ (0.1 mg/cm^2) @73 MeV

Detector arrangement:

ICARE chamber placing two SiC 2x2 detectors at different angles <u>in order to extract the time resolution as a function of fragments energy</u>



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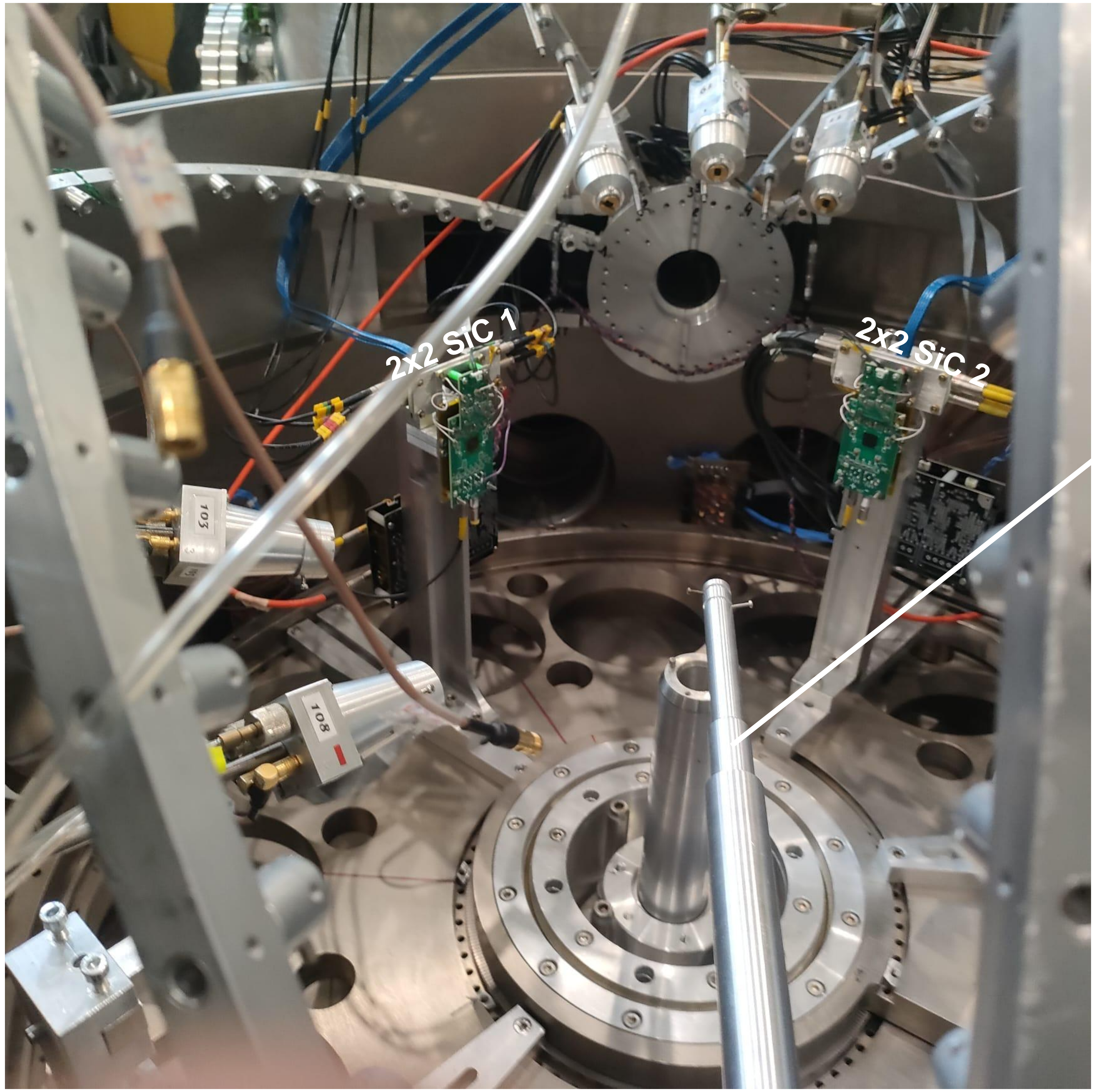

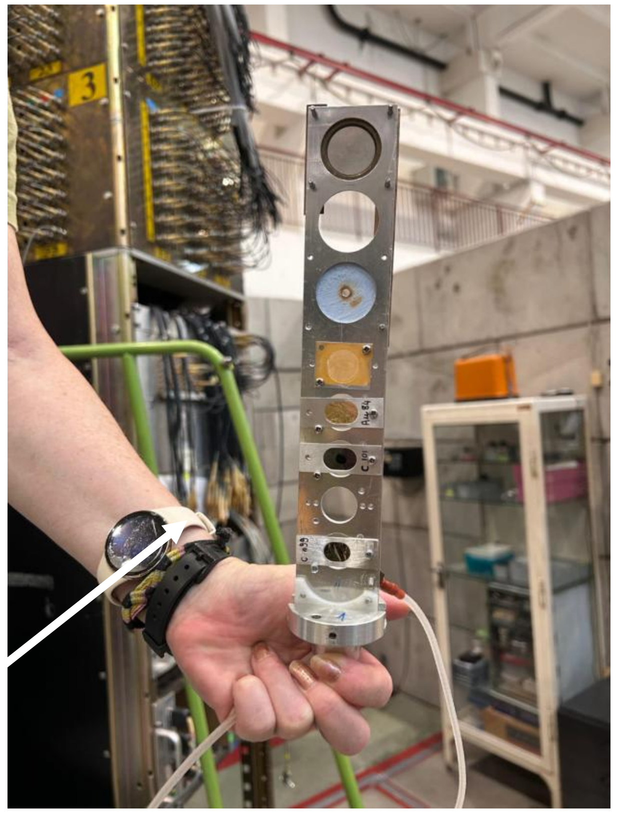

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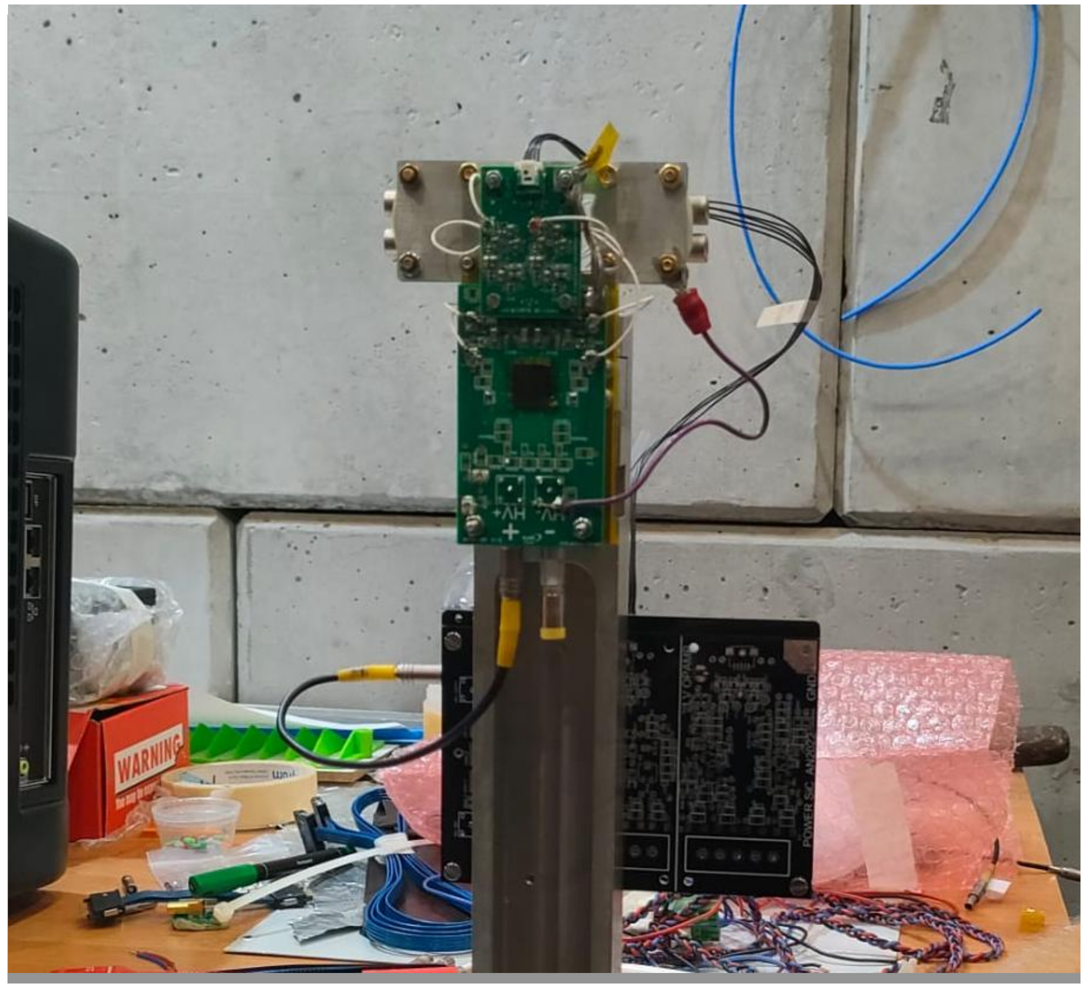

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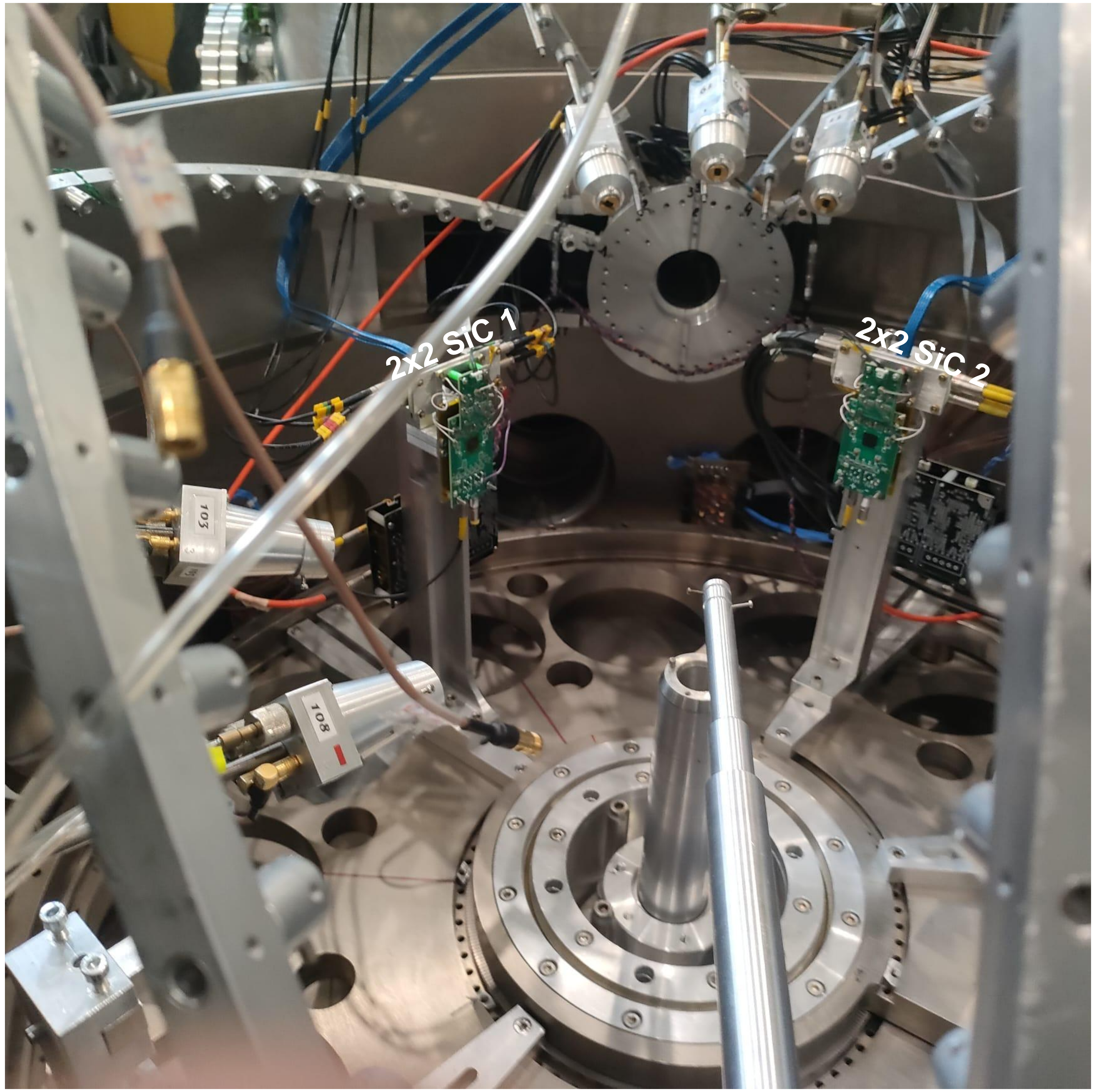

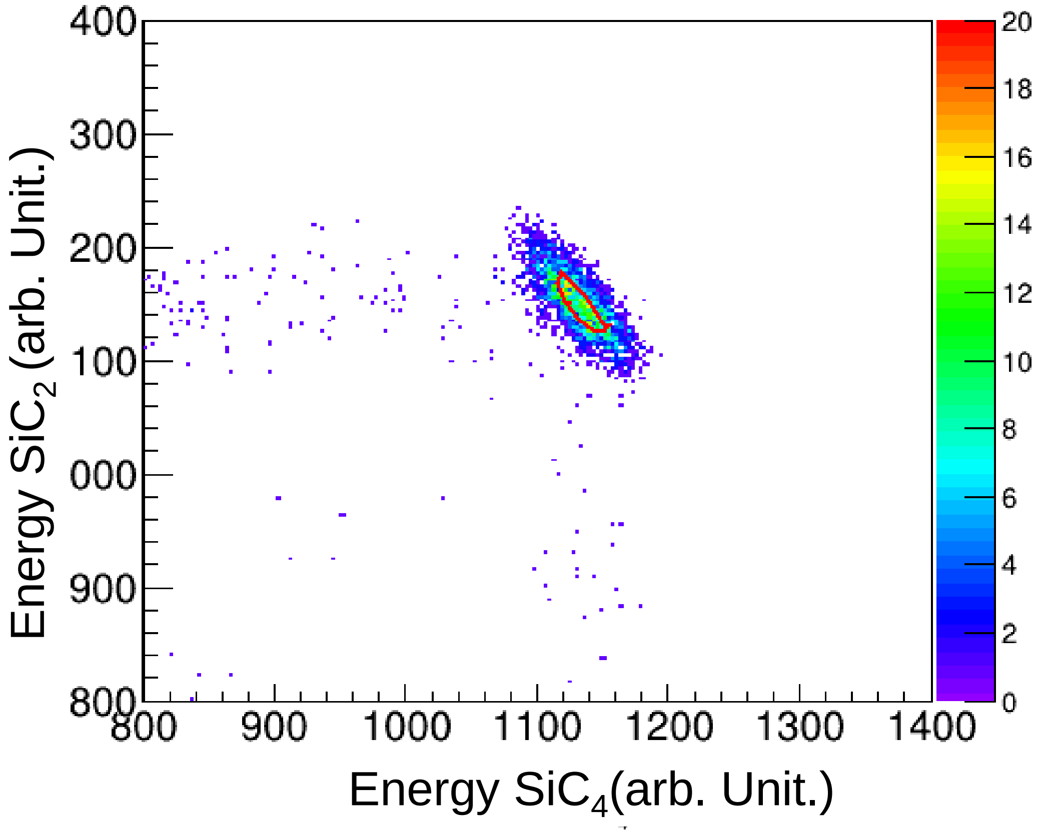

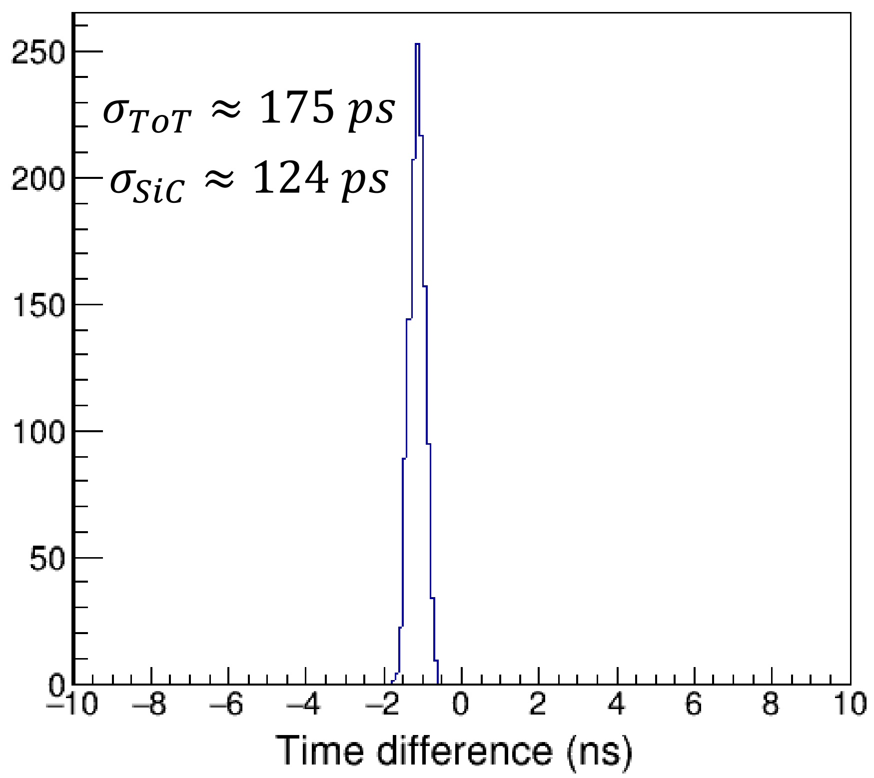

Population of 4.44 MeV in ^{12}C	$\vartheta_{SiC_1} \approx 43°$ $Ene\ loss_{SiC_1}$ 34 MeV	$\vartheta_{SiC_2} \approx 43°$ $Ene\ loss_{SiC_2}$ 34 MeV

Conclusions and future plans

- Development of SiC arrays
- Results obtained with α sources (ΔE/E < 1%)
- Results obtained with sources (sharing and ToF methods) show a σ_t<300 ps at 5 MeV
- Preliminary results with carbon coincidence shows a σ_t ≈125 ps at 34 MeV
- Further data analysis and simulations are ongoing
- Further steps will concern the production of SiC arrays and commissioning of the whole setup

To learn more:

- N.S. Martorana et al., 2025 JINST 20 C07064
- A. Barbon et al., 2025 JINST 20 C07058
- G. D'Agata et al., 2025 JINST 20 C09015
- G. D’Agata et al., IL NUOVO CIMENTO 48 C (2025) 72
- A. Barbon et al., IL NUOVO CIMENTO 48 C (2025) 72
- N.S. Martorana et al., IL NUOVO CIMENTO 48 C (2025) 62
- N.S. Martorana et al., IL NUOVO CIMENTO 47 C (2024) 56
- Martorana N.S. et al., Frontiers in Physics, 10 (2022)
- F. Risitano, IL NUOVO CIMENTO 45 C (2022) 68
- L. Acosta et al., 2022 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), Italy, 2022, pp. 1-4
- Martorana N.S. et al., Il Nuovo Cimento 45 C (2022) 63
- Martorana N.S., Il Nuovo Cimento 44 (2021) 1
- Altana C et al., IEEE Nuclear Science Symposium and Medical Imaging Conference 390 (NSS/MIC) (2021), 1–4
- Russo A et al., NIM B 463 (2020) 359 418 – 420
- Russotto P. et al., J. Physics: Conf. Ser., 1014 (2018) 012016

THANK YOU FOR THE ATTENTION

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