FATA2025

FAst Timing Applications for Nuclear Physics and Medical Imaging

Catania - Italy, 8th - 10th October 2025

The second edition of FATA will be held in memory of Angelo Pagano, chair of the previous editions.

Università di Catania

INFN LNS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Sud

Centro Siciliano di Fisica Nucleare e Struttura della Materia

Dipartimento di Fisica e Astronomia "Ettore Majorana"

The "pixelation technique" in the Timing Analysis of the data collected by the FARCOS correlator in the CHIFAR experiment

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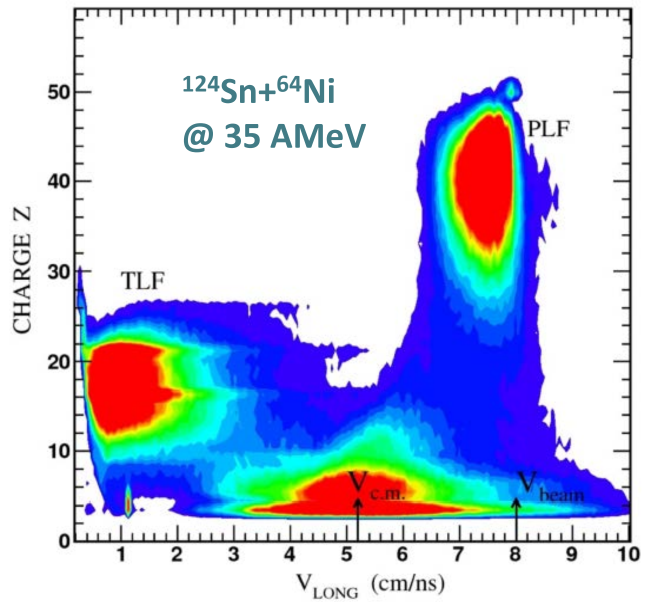
Heavy Ion collisions at Fermi energy regime

$[10\ MeV/A < E/A < 100\ MeV/A]$

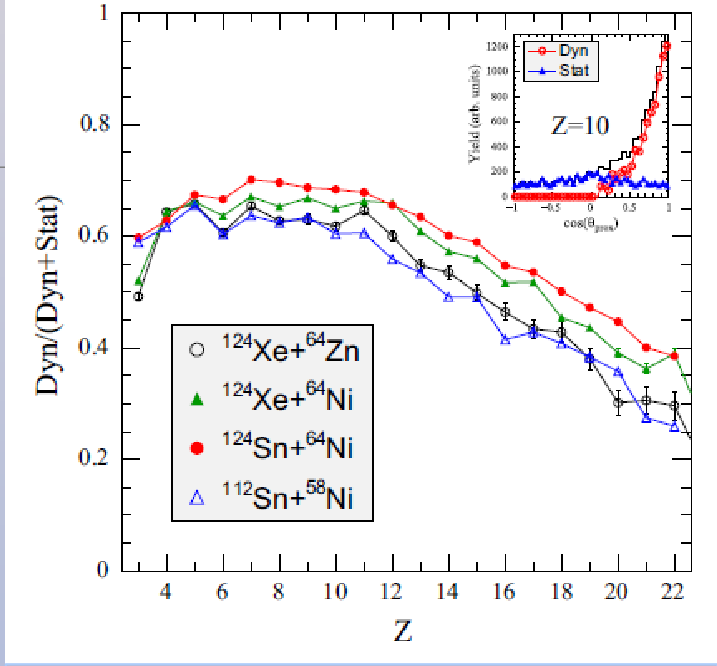
From REVERSE and InKiIsSy experiments…

Ternary events detected with CHIMERA:

- PLF + TLF + IMF



E. De Filippo *et al.*, Phys. Rev. C **71**, 044602 (2005).



P. Russotto *et al.*, Eur. Phys. J. A. **56**, 12 (2020).

Dynamical emission of IMFs:

- Light IMFs ($Z \lesssim 8$) are emitted in fast neck emission process within $100 - 120\ fm/c$ after reseparation between PLF and TLF;

- Heavier IMFs ($Z \gtrsim 9$) are emitted in a fast-dynamical splitting (fission-like) of the PLF in a time ($\lesssim 500\ fm/c$) shorter than the one typical of statistical emission;

Enhancement of dynamical emission probability in neutron rich system:

influence of isospin content (N/Z) on dynamical effects!

CHIFAR experiment @ LNS-INFN

"neutron rich" system: **$^{124}Sn+^{64}Ni$** *(1.48+1.29)*

"neutron poor" system: **$^{112}Sn+^{58}Ni$** *(1.24+1.07)*

"isobaric" system: **$^{124}Xe+^{64}Zn$** *(1.30+1.13)*

$$I = \frac{N_P}{Z_P} + \frac{N_T}{Z_T}$$

$^{124}Sn+^{64}Zn$ *(1.48+1.13)*

$^{112}Sn+^{64}Ni$ *(1.24+1.29)*

$^{124}Xe+^{64}Ni$ *(1.30+1.29)*

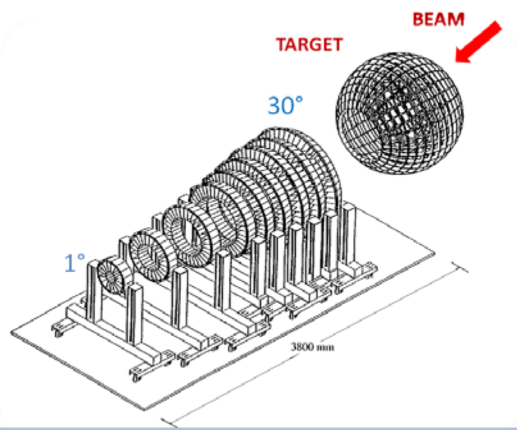
Experimental goals at lower energy [**20 AMeV**] with respect to the previous experiments:

- Study of emission mechanism: dynamical/statistical;
- IMFs production;
- Isospin role in HI collisions;

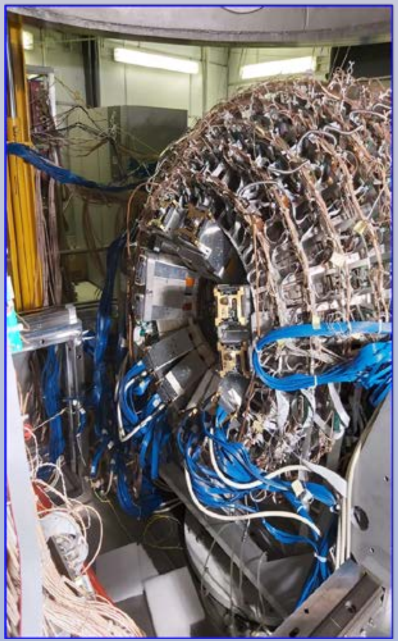
➢CHIFAR experiment @ LNS-INFN: experimental setup

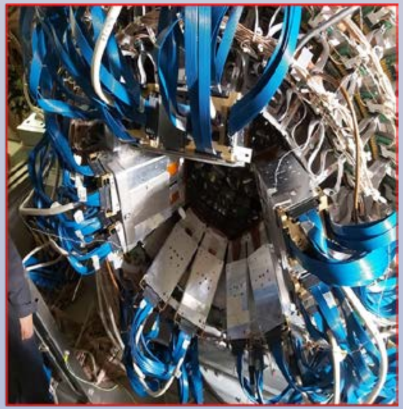
CHIMERA ✚ FARCOS

- **C**harged **H**eavy **I**on **M**ass and **E**nergy **R**esolving **A**rray;
- 4π multi-detector;
- 1192 telescopes (35 rings): each one has Si-detector and CsI(Tl) scintillator.

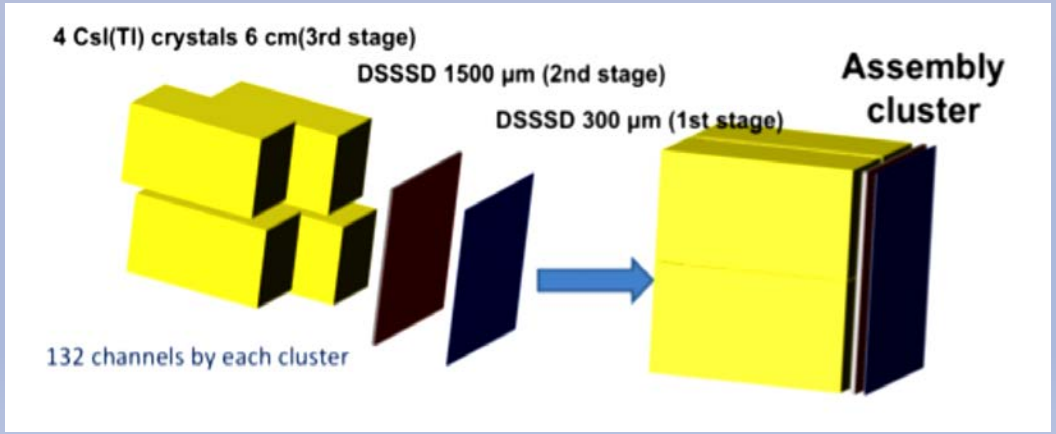


Pagano A. *et al.*, Eur. Phys. J. A 56, 102 (2020)





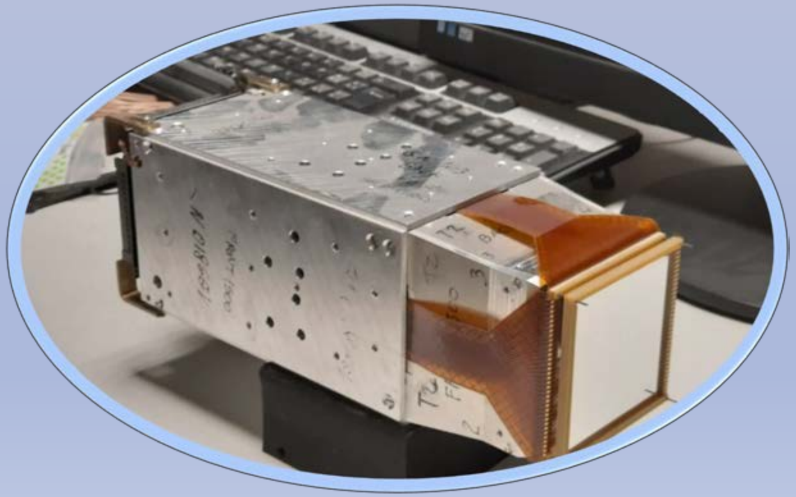
- **F**emtoscope **AR**ray for **CO**rrelation and **S**pectroscopy;
- High energy and angular resolution;
- Modular array of 20 telescopes: each one has 6 detectors: 2 DSSSDs + 4CsI(Tl).
- Angular range: 13°-30° (lab. system)

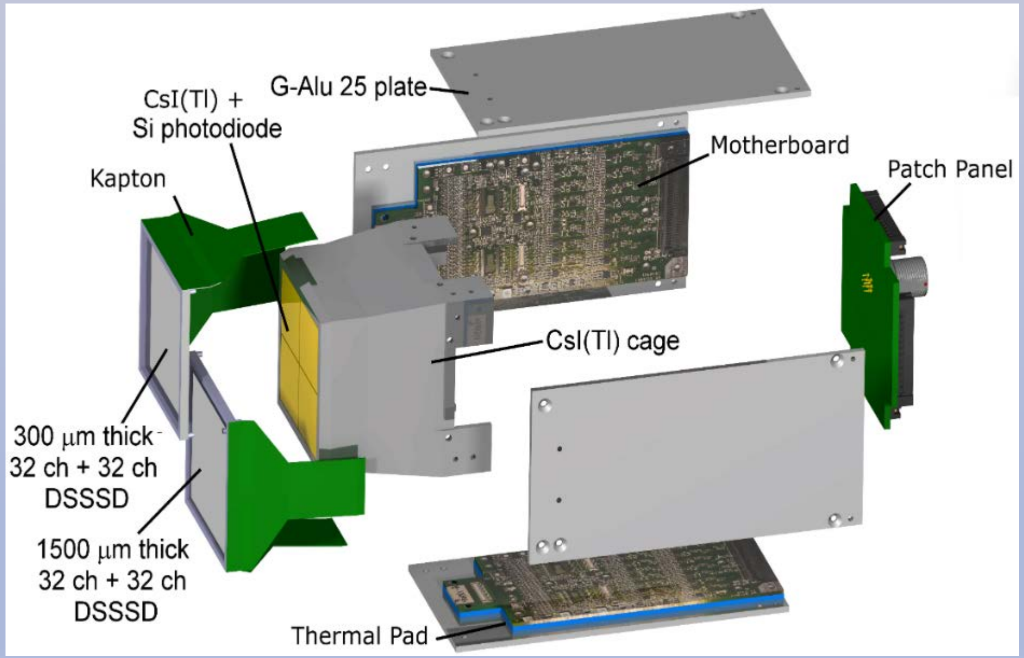


Pagano E.V. *et al.*, EPJ Web of Conferences (2016) 117:10008

➢CHIFAR experimental setup: array structure of each FARCOS correlator telescope

- 10 telescopes employed in the CHIFAR experiment;
- 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

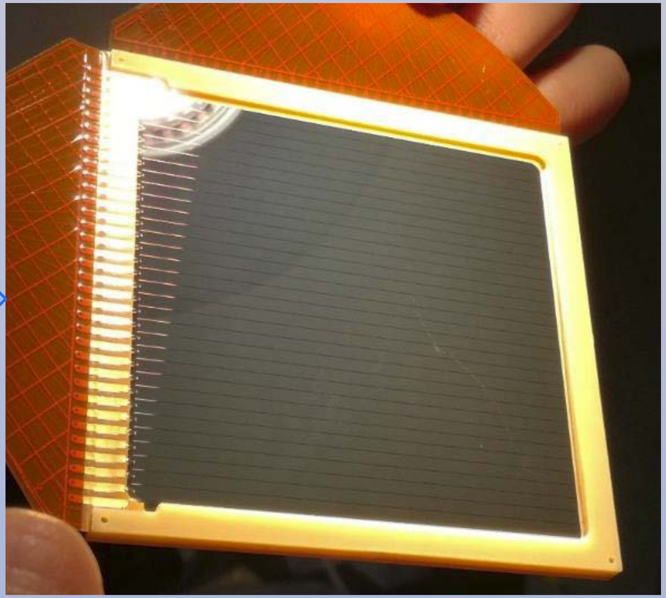


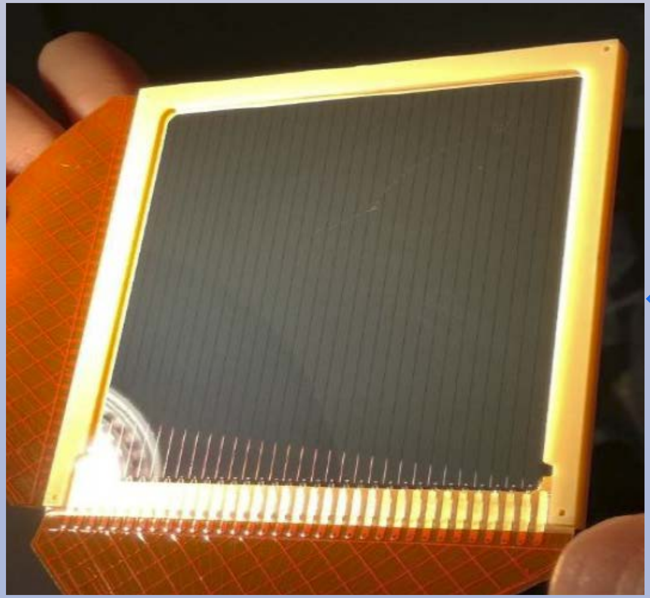


➢FARCOS correlator in CHIFAR experiment: DSSSD for the "pixelation technique"…

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





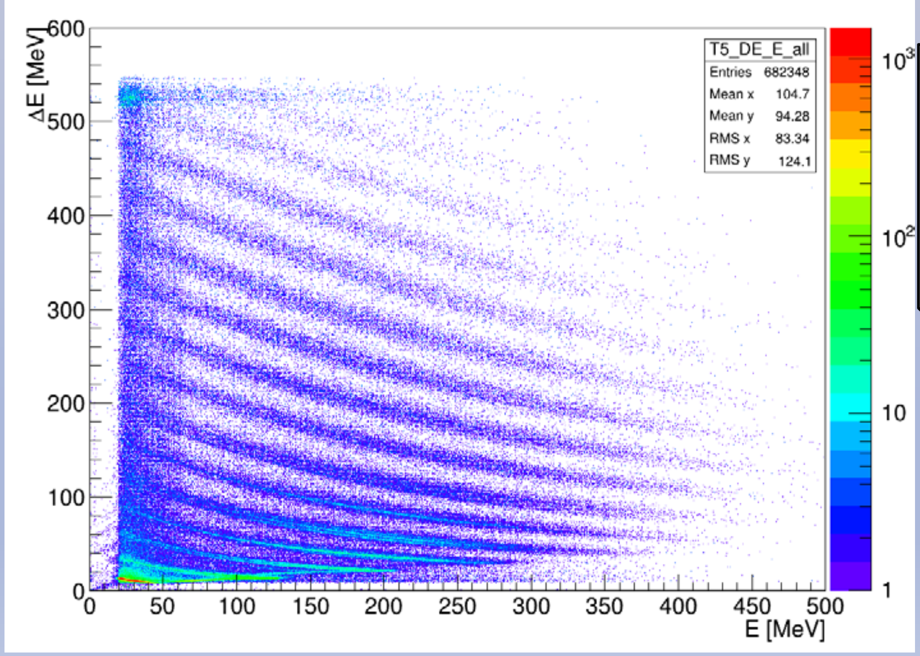
Back side of a DSSSD, with 32 vertical strips

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"

the assignment of the **position** to **each particle** detected by FARCOS, in terms of its coordinates:

from the crossing of a fired strip of the front side and the one of the back side of the first DSSSD (300 μm thick), the pair of the **polar angle θ** and the **azimuthal angle ϕ** determine a unique spatial position for the particle



For each FARCOS telescope, the ΔE-E matrices include all experimental events, without discrimination about noise, electronic inductions, interstrip events...

A selection of the events was mandatory!

The procedure works step by step…

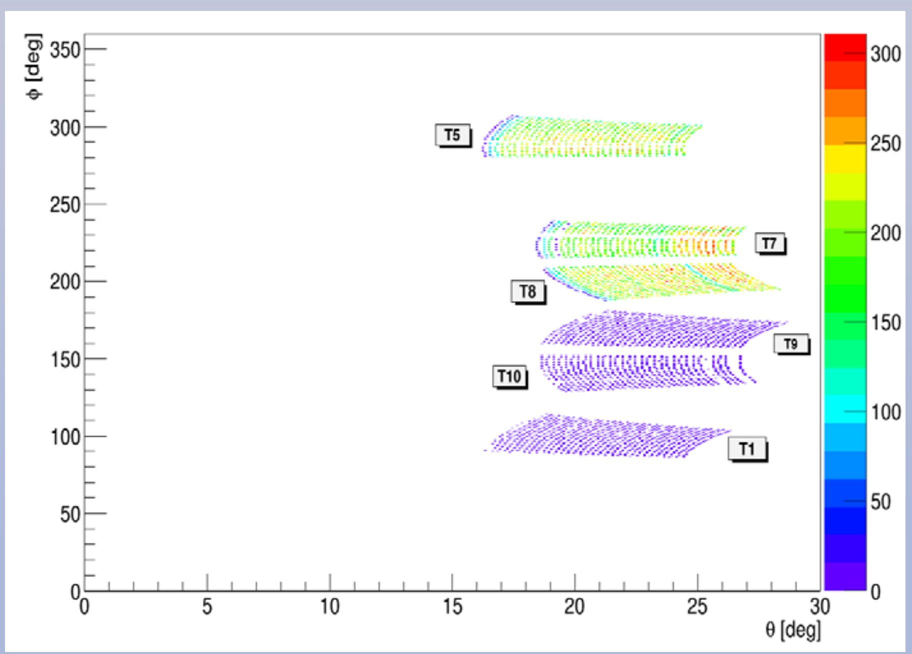
FARCOS correlator in CHIFAR experiment: the "pixelation technique"

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

1st STEP

Experimental constraints to select only "true particles":

- particle multiplicity
  - = 1 for Si−300 μm, front and back;
  - = 1 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) or N_{strip} (300 μm) = N_{strip} (1500 μm) ±1



For a **single** particle detected by a FARCOS telescope, a **good assignment** of its position was achieved without ambiguity…

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

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

2nd STEP

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% $\Delta E_{back} < \Delta E_{front} < 115\% \, \Delta E_{back}$ (7σ)
- N_{strip} (300 μm) = N_{strip} (1500 μm) || N_{strip} (300 μm) = N_{strip} (1500 μm) ±1

	ΔE_front [MeV]	ΔE_back [MeV]	E_front [MeV]	Nstrip_300_front	Nstrip_300_back	Nstrip_1500_front
#1	51,6344	51,8097	79,8859	29	13	29
			148,723			30
			228,6089	**Position ambiguity resolved:** this is an **interstrip event in DSSSD_1500µm** (ambiguity in energy only)		
#2	12,9576	12,9558	22,1211	4	0	4
	118,8961	120,4121	180,1131	13	25	13
	Unresolved ambiguity: are these **2 particles?** Could we assign their **position** using the **TIME VARIABLE**?					
#3	12,0703	12,3186	24,9049	29	29	30
	114,9052	116,9252		30	18	
	126,9753			**Unresolved ambiguity:** this is an interstrip event in DSSSD_300µm; Could we assign its position using the **TIME VARIABLE**?		

Unfortunately, simply comparing the **energies** lost was **no longer enough** to classify all the events: it cannot discriminate between interstrip, electronic induction or spurious events...

Some **ambiguities** have been observed...

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

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

3rd STEP

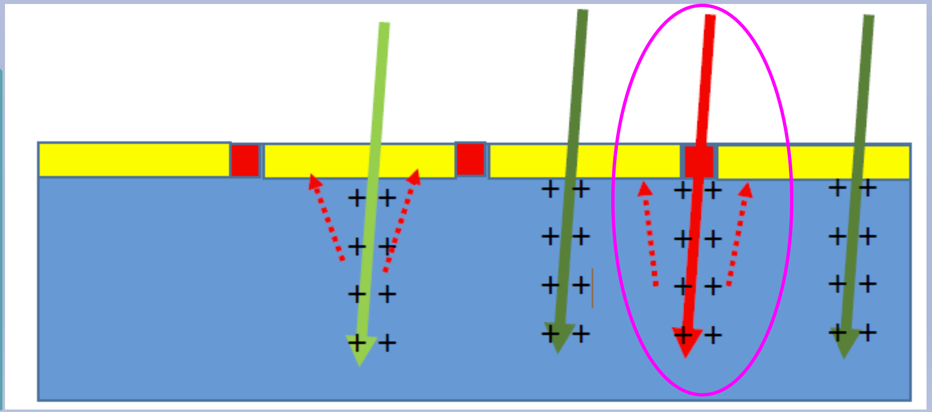
Experimental constraints to select only "true particles":

- 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

INTERSTRIP event:

If a particle is collected into the very slight region between 2 adjacent strips, its energy is shared between them

- the real reconstruction of the event is given by the sum of the two values of the energy released in each strip



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

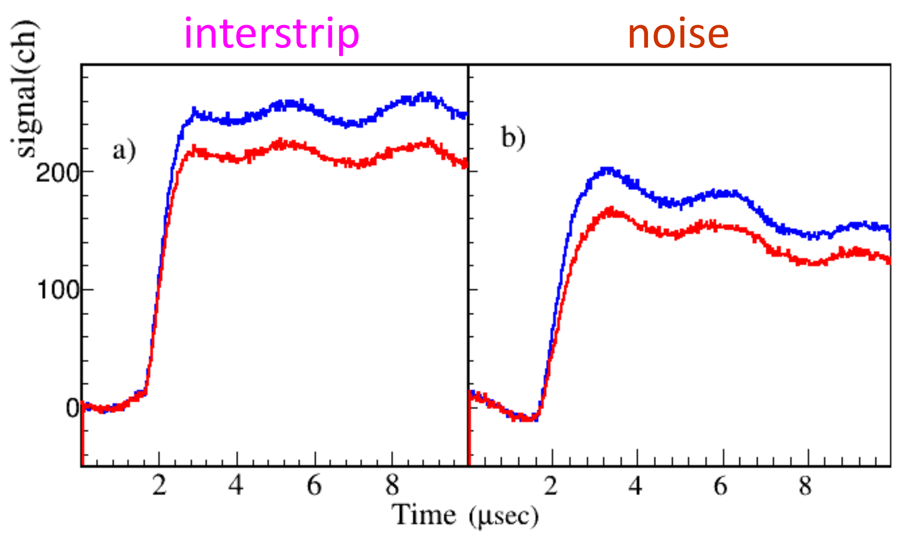
assignment for each detected particle of its position in the DSSSD (300 µm thick)

4th STEP

Experimental constraints to select only "true particles":

- particle multiplicity $\begin{cases} = 2 \text{ for Si–300 µm, front and back;} \\ = 2 \text{ for Si–1500 µm, front;} \\ < 4 \text{ for Si–1500 µm, back;} \\ = 0 \text{ for CsI(Tl)} \end{cases}$
- 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:
time in which the signal reaches 10% of its amplitude, after the subtraction of the baseline



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

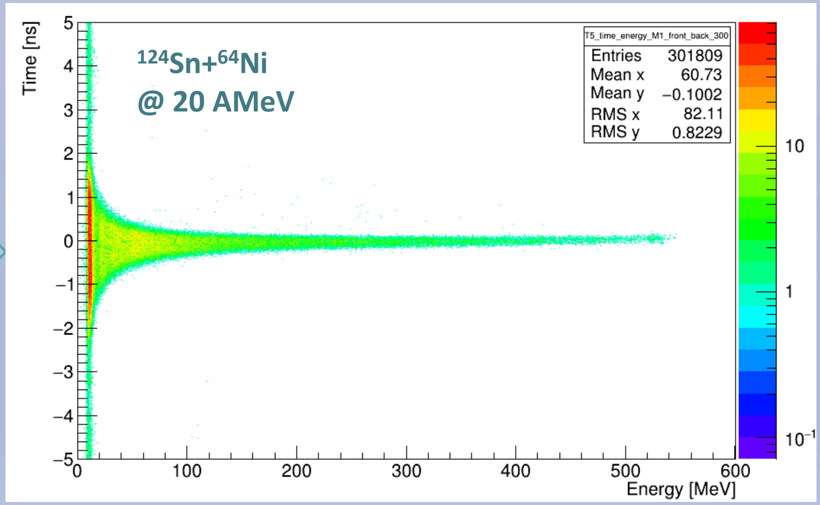
assignment for each detected particle of its position in the DSSSD (300 μm thick)

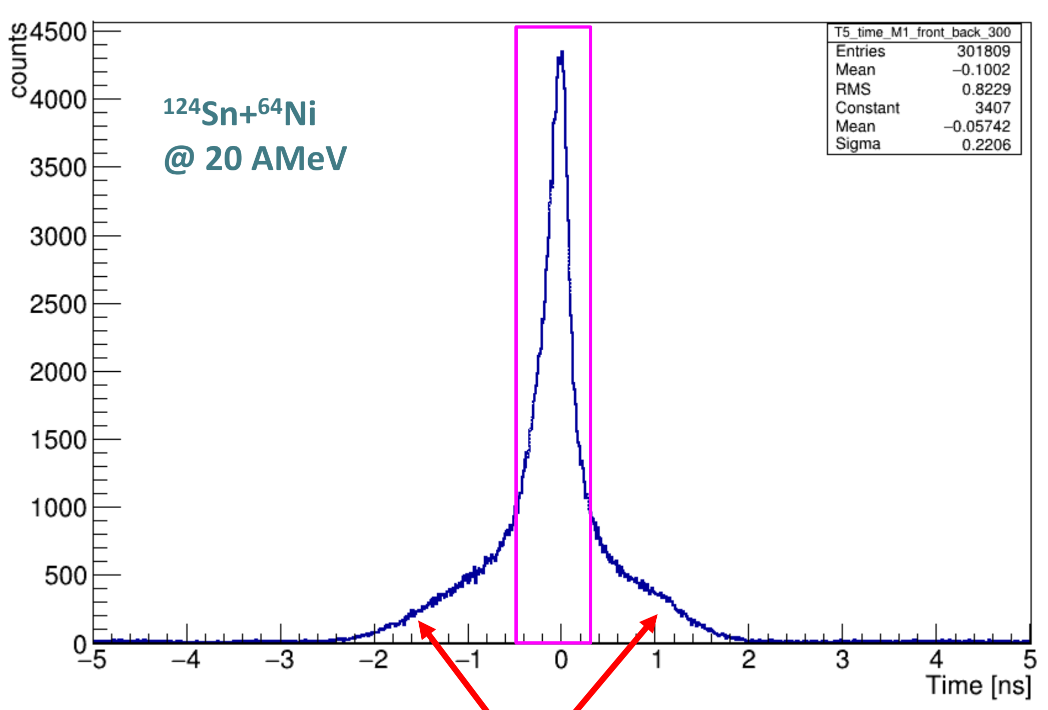
4th STEP

Experimental constraints to select only "true particles":

- particle multiplicity $\begin{cases} = 2 \text{ for Si–300 μm, front and back;} \\ = 2 \text{ for Si–1500 μm, front;} \\ < 4 \text{ for Si–1500 μm, back;} \\ = 0 \text{ for CsI(Tl)} \end{cases}$
- 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:

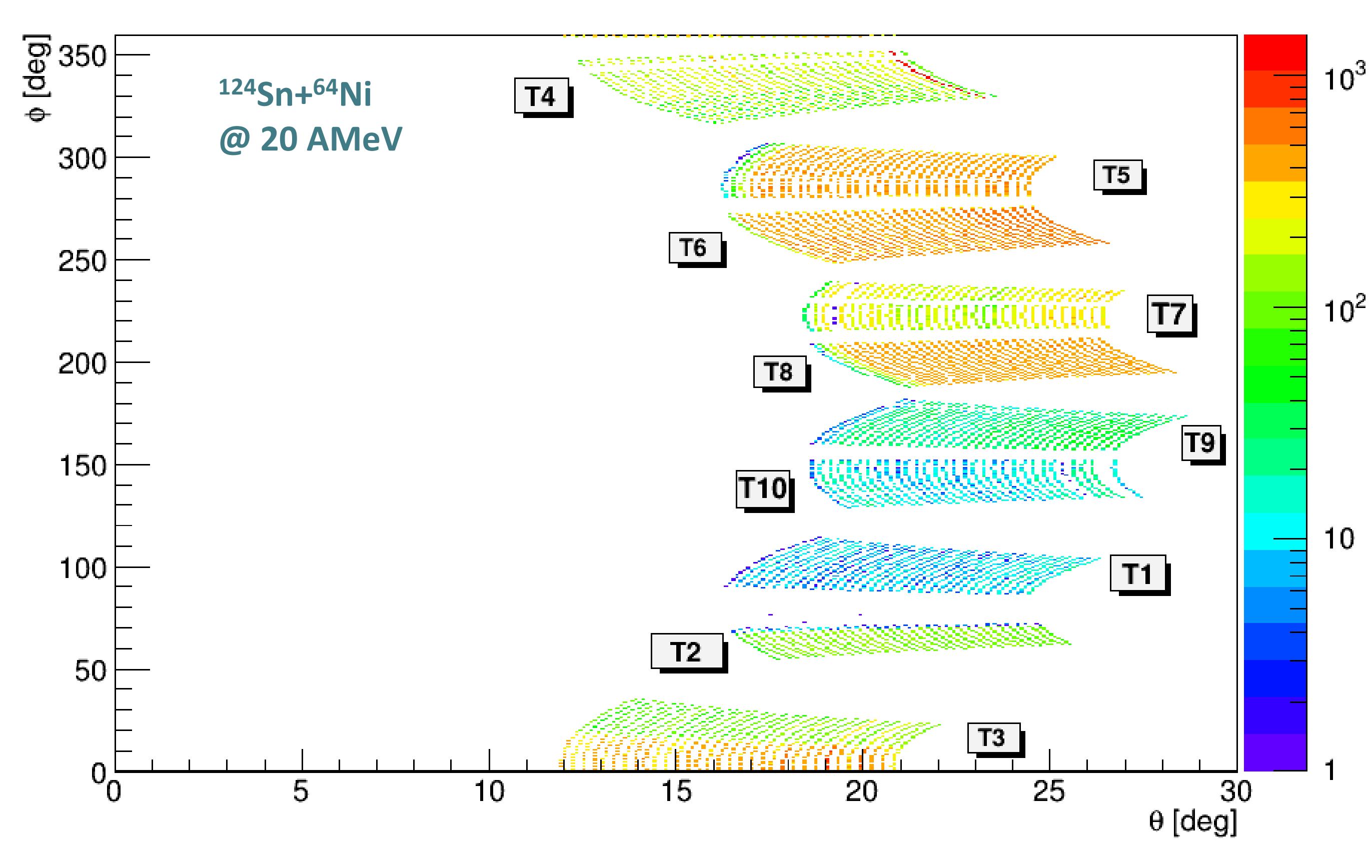




unphysical events (noise, spurious coincidences) are excluded thanks to the timing analysis

FARCOS correlator in CHIFAR experiment: the "pixelation technique"

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



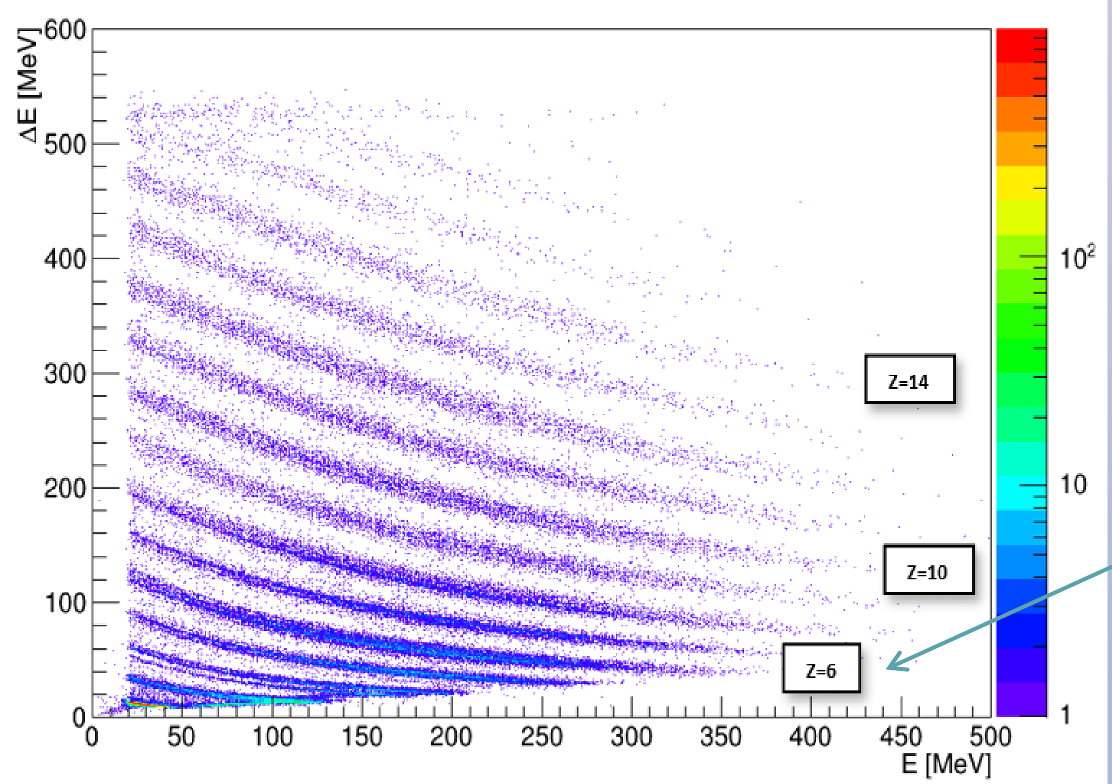
Experimental constraints to select only "true particles":

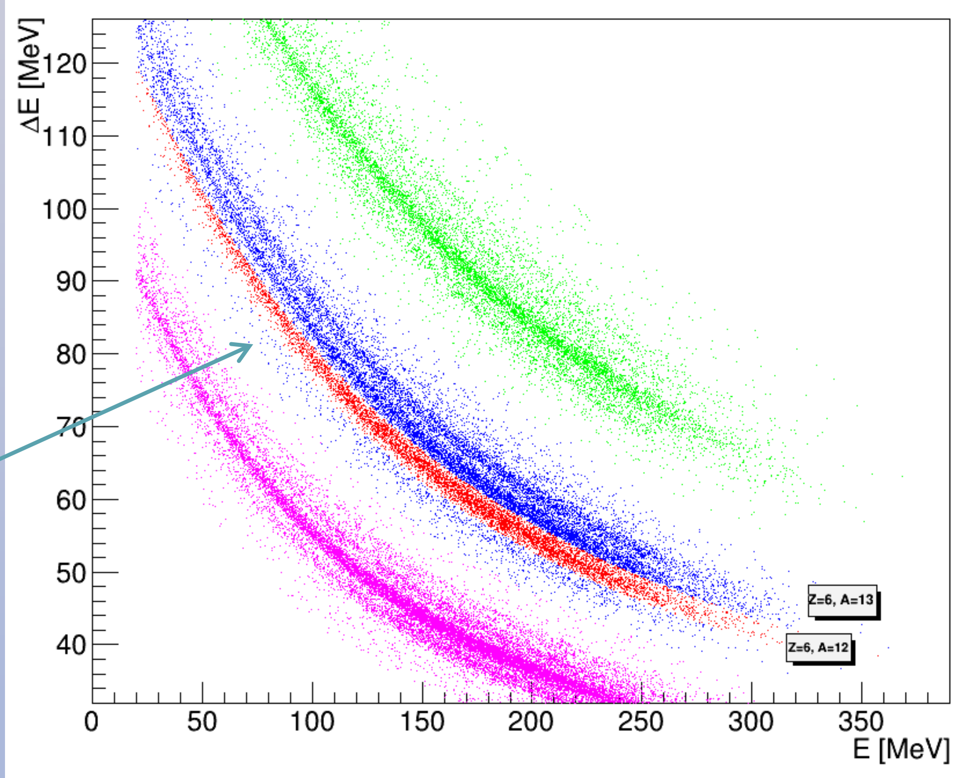
- particle multiplicity
  - = 1 for Si–300 μm, front and back;
  - = 1 for Si–1500 μm, front;
  - < 4 for Si–1500 μm, back;
  - = 0 for CsI(Tl)
- 85% $\Delta E_{back} < \Delta E_{front} <$ 115% ΔE_{back} (7σ)
- N_{strip} (300 μm) = N_{strip} (1500 μm) or N_{strip} (300 μm) = N_{strip} (1500 μm) ±1
- particle multiplicity = 2
  - interstrip events reconstructed
  - unphysical events excluded (timing analysis)

FARCOS telescopes covered polar angles between 13° and 30° (azimuthal coverage of 2π)

There is no ambiguity in the assignment of the position!

➢FARCOS correlator in CHIFAR experiment: particle identification

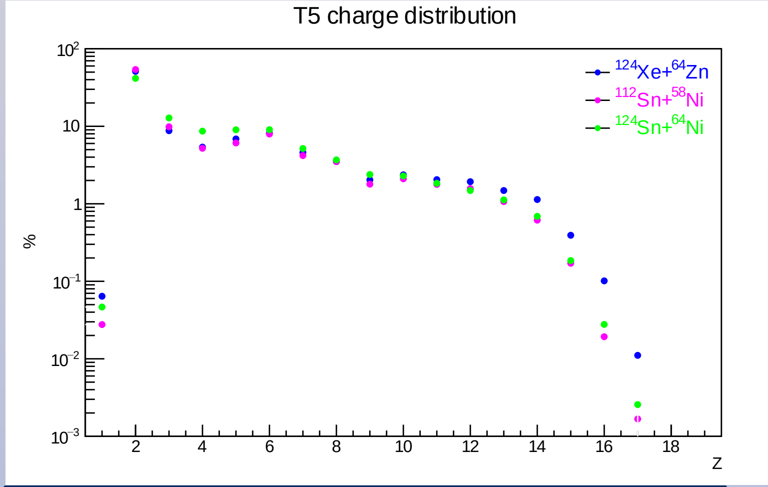




obtained by an identification algorithm developed by the CHIMERA collaboration

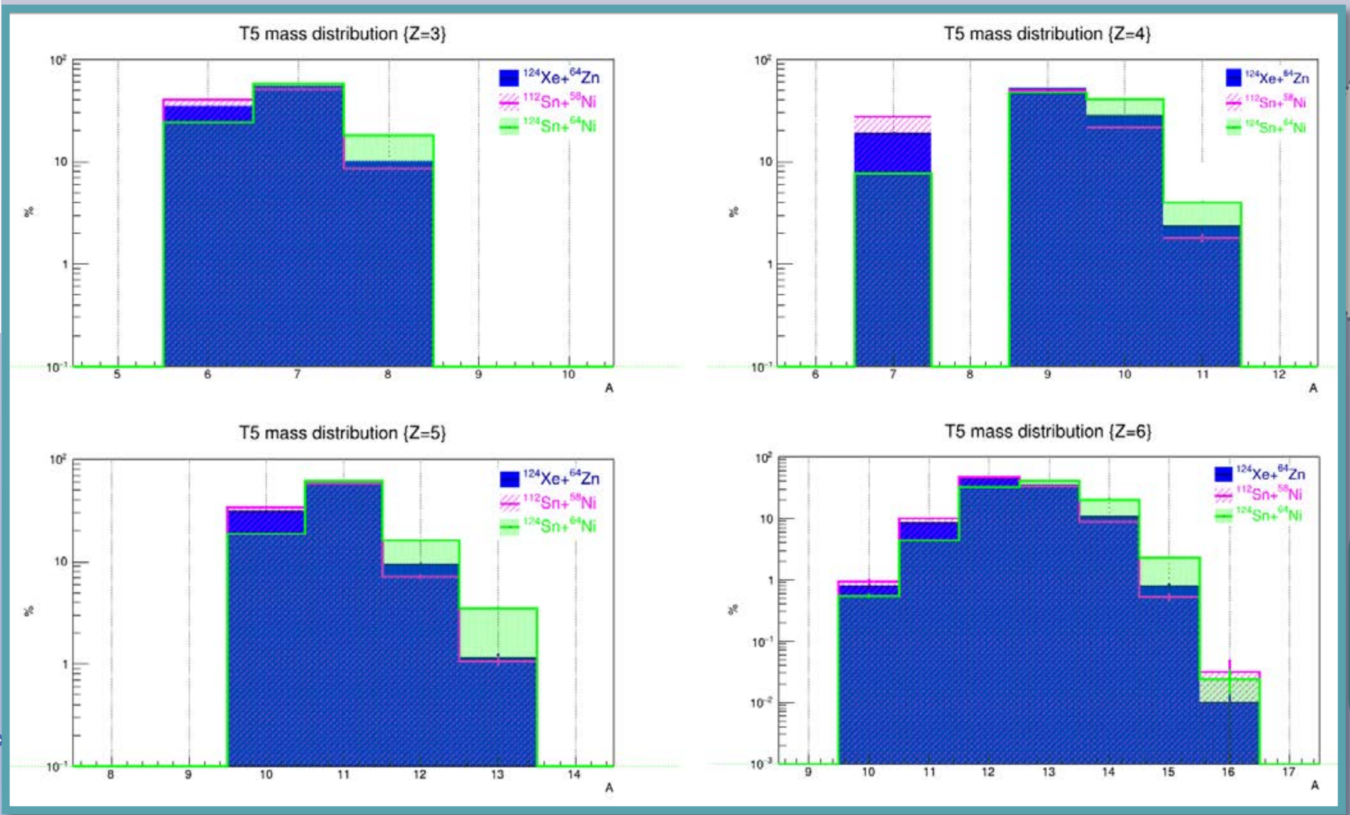
- Identification in charge up to $Z \approx 16$;
- Isotopic identification of IMFs up to $Z \approx 9$ and $A \approx 20$;

➢FARCOS correlator in CHIFAR experiment: Isospin role in HI collisions



IMFs isospin distribution follows initial Isospin content: memory of initial conditions is not lost

Preliminary analysis!



- "isobaric" system: $I = N/Z = 1.24$
- "neutron poor" system: $I = N/Z = 1.18$
- "neutron rich" system: $I = N/Z = 1.41$

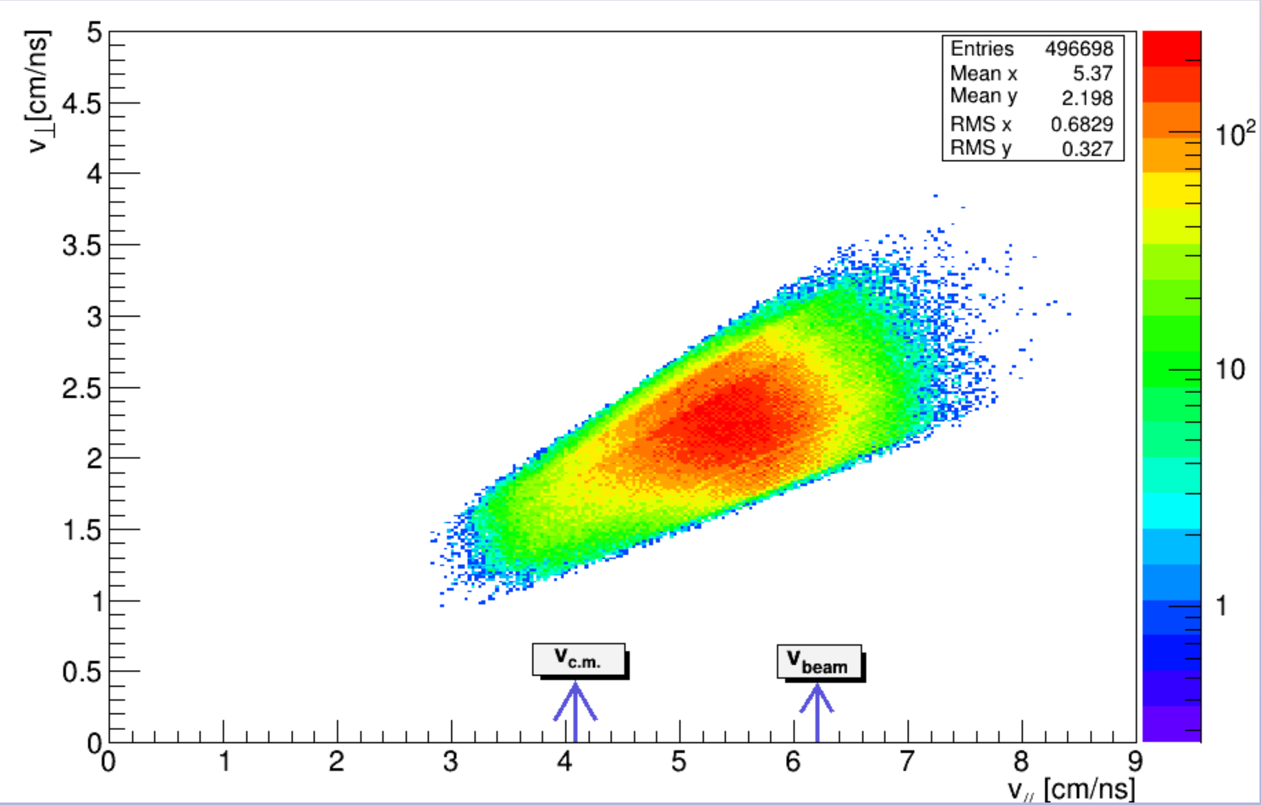
<u>preliminary</u> observations:
1)Enhanced light IMFs emission in the neutron rich reaction
2)The isobaric system (high-fissility) presents a stronger emission of heavier IMFs

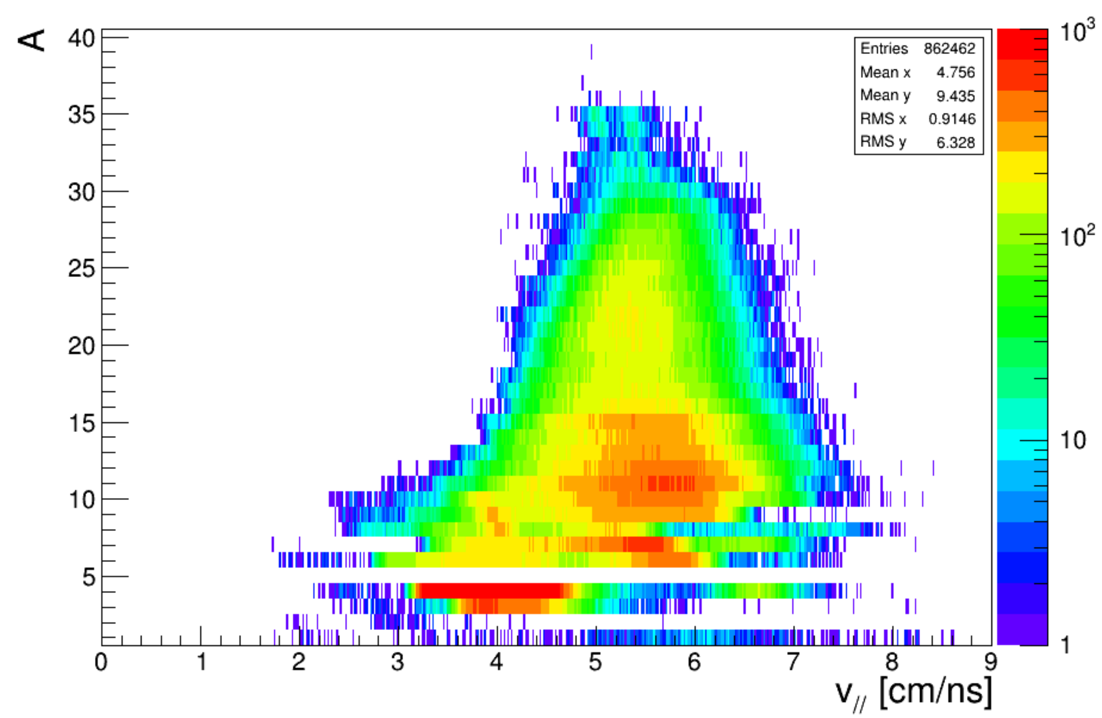
effect of neutrons enrichment for neutron rich system!

Preliminary analysis from FARCOS data, without CHIMERA data!

➢Preliminary results about physics cases of the experiment

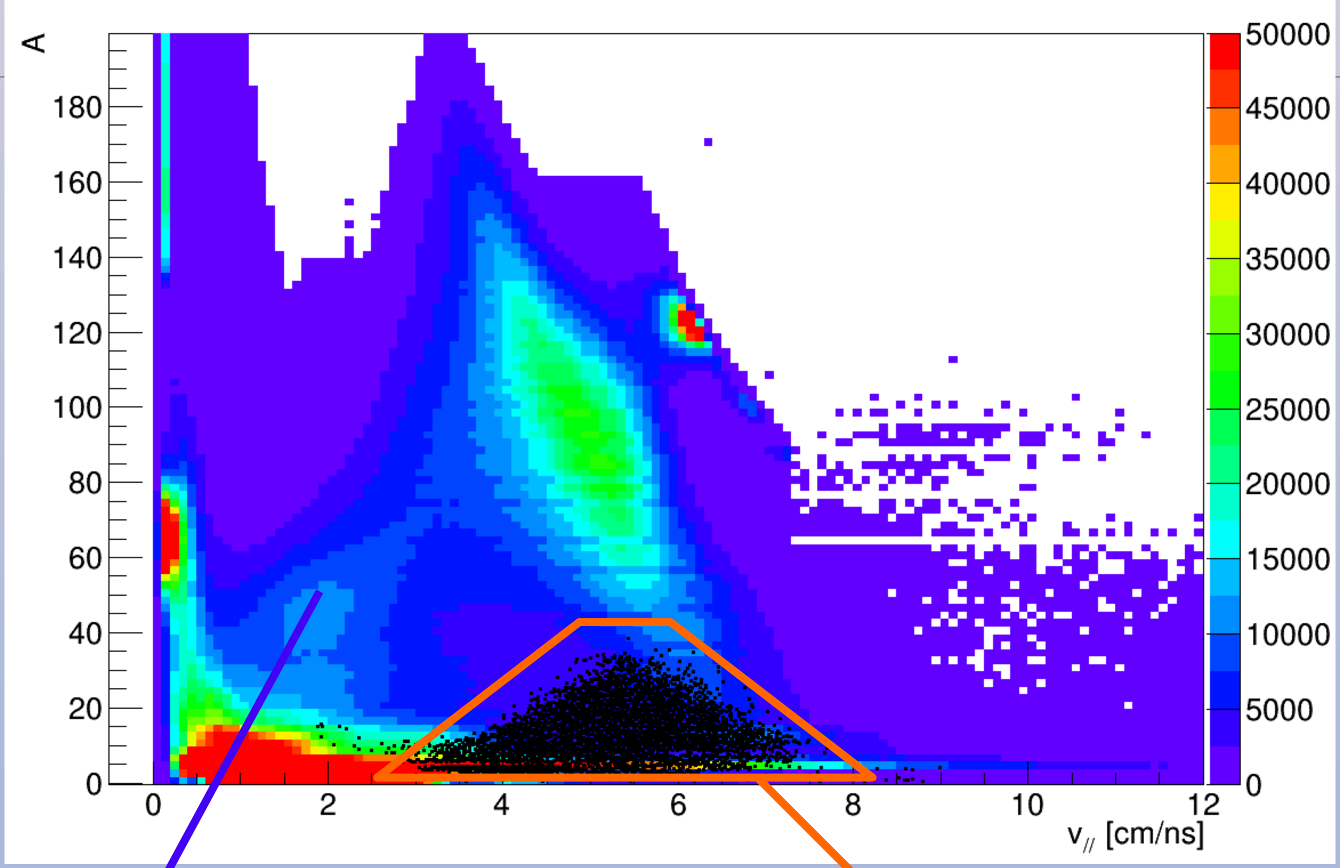
From FARCOS data analysis, on the identified IMFs having 2<Z<16:





❖ Velocity distribution is centred on v_{PLF}, towards the midvelocity (lab. system).

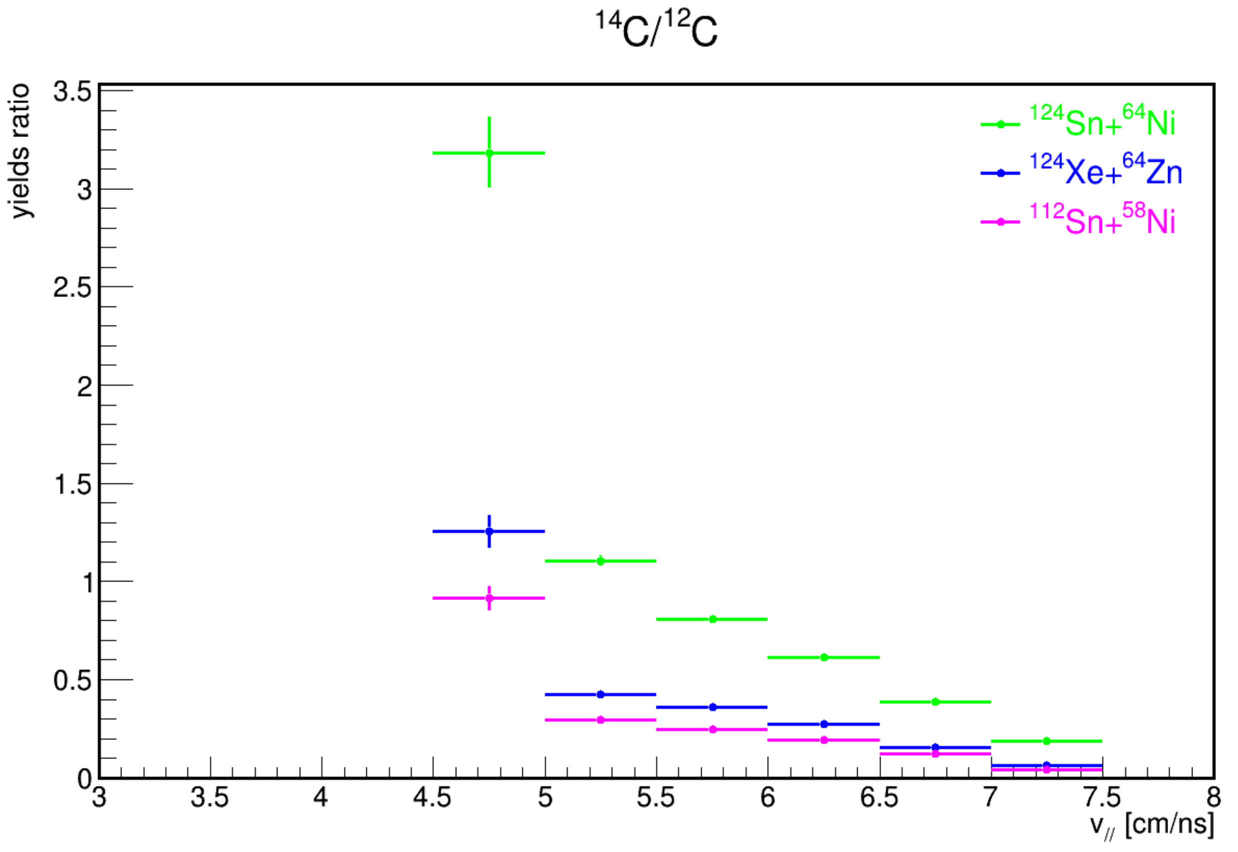
➢Preliminary results about physics cases of the experiment



❖ **CHIMERA** data (colour scale) and events identified by **FARCOS** (black dots):

➢ good identification of the phase space up to $A \lesssim 35$.

➢Preliminary results about physics cases of the experiment



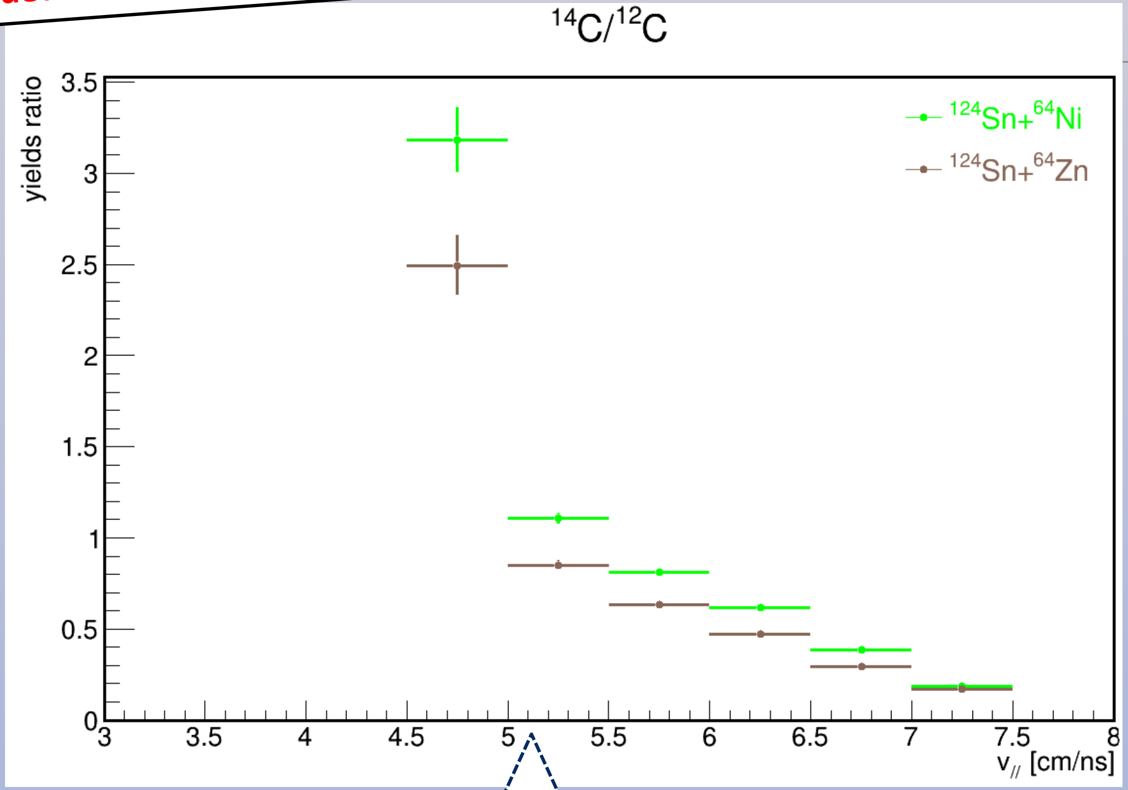
PRELIMINARY RESULTS from raw data:
detector response is not included, high thresholds for detected particles within the two stages for DSSSDs (ΔE-E method);

- **"neutron rich" system: $I = N/Z = 1.38$**
- **"isobaric" system: $I = N/Z = 1.21$**
- **"neutron poor" system: $I = N/Z = 1.16$**

❖ *N/Z* distributions as a function of $v_{//}$ follow initial Isospin content:
  - ➢ punctual memory of initial conditions is not lost;
  - ➢ effect of neutron enrichment, according to the isospin ratio of each reaction.

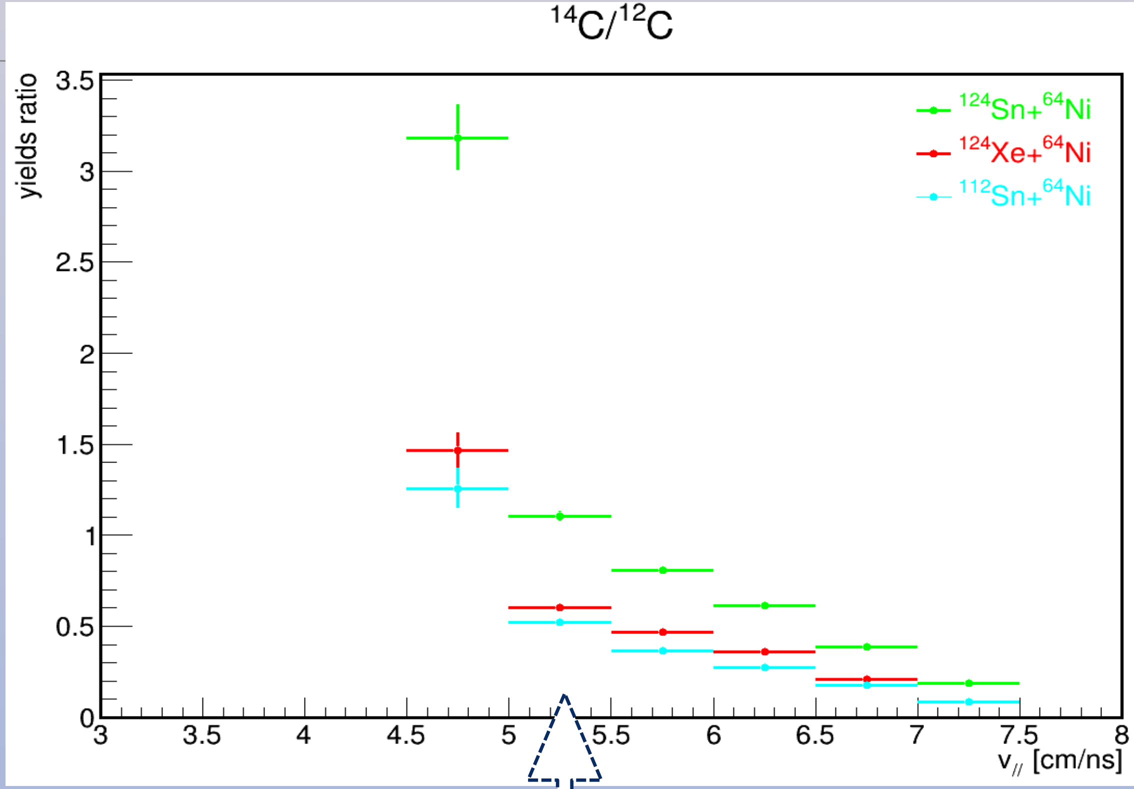
➢Preliminary results about physics cases of the experiment

raw data
(detector response not included)



For same projectile ^{124}Sn…

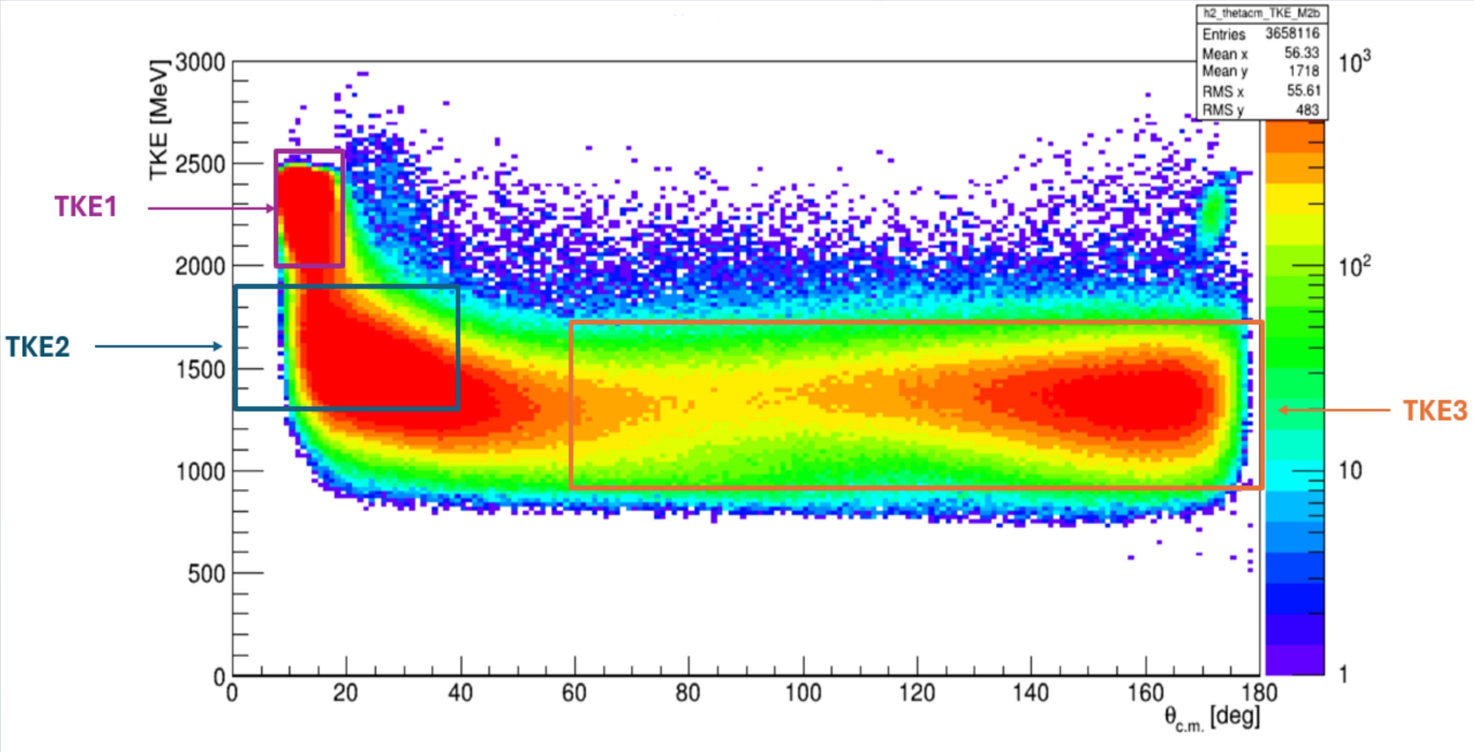
- $I = 1.38$
- $I = 1.31$



..and for same target ^{64}Ni

- $I = 1.38$
- $I = 1.29$
- $I = 1.26$

➢ Preliminary results about physics cases of the experiment



TKE1: quasi-elastic emission;

TKE2: deep-inelastic mechanism with the possible rupture of the PLF;

TKE3: fission/fusion

The ranges of the TKE vs. $\theta_{c.m.}$ variables will be useful to impose constraints in future data analyses…

- Merging of FARCOS and CHIMERA data is mandatory to select some global variables (*i.e.* total charged particles multiplicity, reaction plane, impact parameter, etc.) for the characterization of the reaction mechanism and the IMFs emission process;
- N/Z distributions with specific constraints (TKE - $\theta_{c.m.}$, global variables using the CHIMERA multi-detector);
- Results will be compared with some theoretical models…

Thanks for your attention!