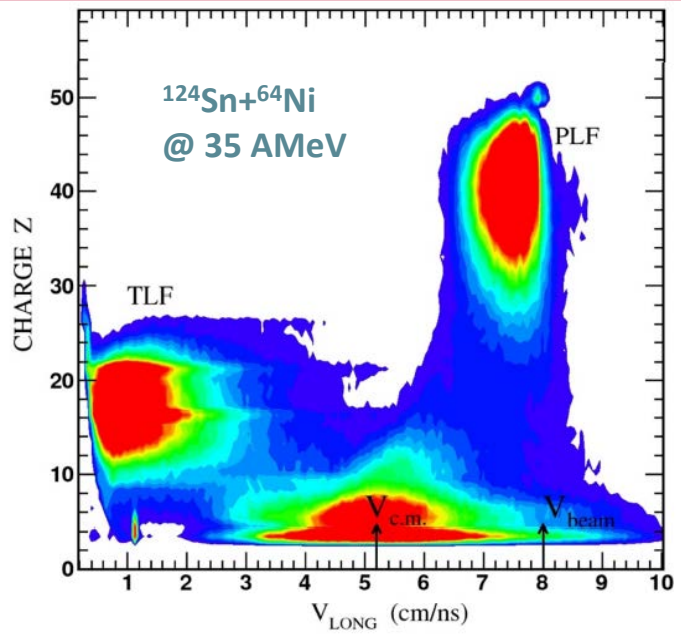
FARCOS correlator in the CHIFAR experiment: latest results from particle correlation studies

C. Zagami[(1)(2)(3)], E.V. Pagano[(2)], P. Russotto[(2)], E. De Filippo[(4)], L. Acosta[(5)(6)], T. Cap[(7)], G. Cardella[(4)], F. Fichera[(4)], E. Geraci[(1)(4)(3)], B. Gnoffo[(1)(4)], C. Guazzoni[(8)(9)], G. Lanzalone[(10)(2)], C. Maiolino[(2)], N.S. Martorana[(4)], T. Matulewicz[(11)], A. Pagano[(4)], M. Papa[(4)], K. Piasecki[(11)], S. Pirrone[(4)], M. Piscopo[(2)], R. Planeta[(12)], G. Politi[(1)(4)], F. Risitano[(13)(4)], F. Rizzo[(1)(2)(3)], G. Saccà[(4)], G. Santagati[(4)], K. Siwek-Wilczynska[(11)], I. Skwira-Chalot[(11)] e M. Trimarchi[(13)(4)]

(1) Dipartimento di Fisica e Astronomia ”Ettore Majorana”, Università di Catania, Italy (2) INFN, Laboratori Nazionali del Sud - Catania, Italy (3) CSFNSM-Centro Siciliano di Fisica Nucleare e Struttura della Materia, Catania, Italy (4) INFN, Sezione di Catania, Italy (5) Instituto de Física. Universidad Nacional Autónoma de México, Mexico (6) Instituto de Estructura de la Materia, CSIC, Spain (7) National Centre for Nuclear Research, Poland (8) Dip. di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Italy (9) INFN, Sezione di Milano, Italy (10) Facoltà di Ingegneria e Architettura, Università Kore, Italy (11) Faculty of Physics, University of Warsaw, Warsaw, Poland (12) M. Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland (13) Dipartimento di Scienze MIFT, Univ. di Messina, Messina, Italy

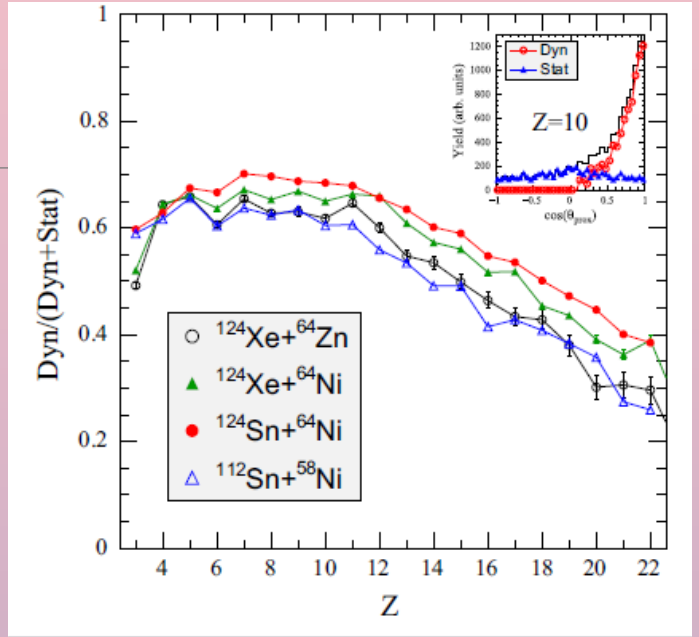
Heavy Ion collisions at Fermi energy regime

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



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

- Ternary events detected with CHIMERA: PLF + TLF + IMF



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)

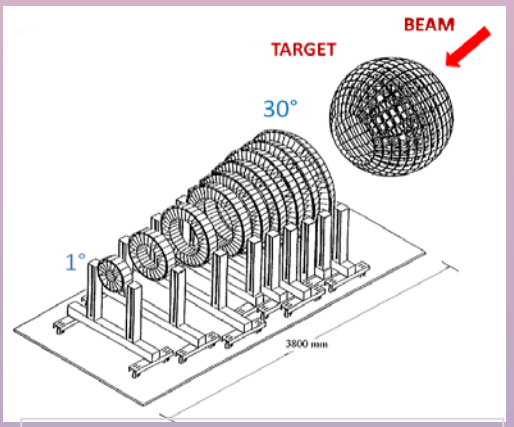
Experimental goals at lower energy [**20 AMeV**] with respect to the previous experiments:

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

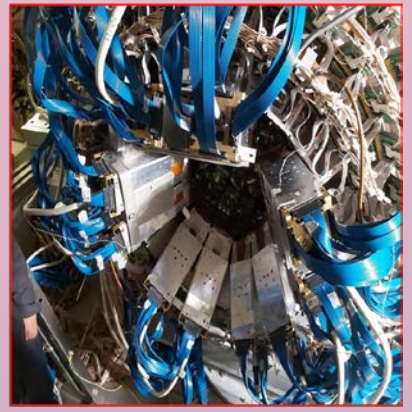
➢CHIFAR experiment @ LNS-INFN: experimental setup

CHIMERA

- **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.

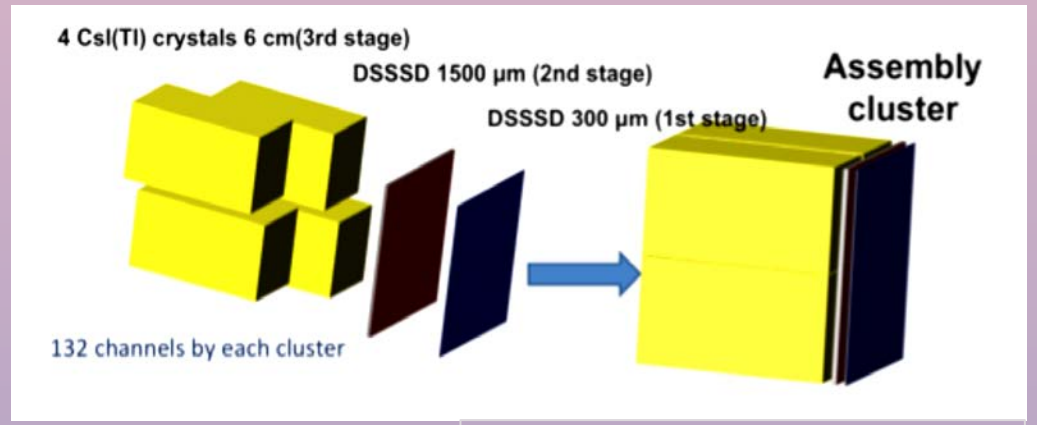


Pagano A. *et al.*, Eur. Phys. J. A 56, 102 (2020)



FARCOS

- **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 experiment @ LNS-INFN:
developments on the data collected by FARCOS correlator

Steps of the data analysis:

I. Energy calibration of DSSSDs;

II. Evaluation of the energy resolution, for front and back sides;

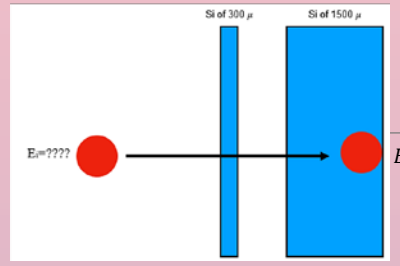
III. IMFs production: particle identification;

IV. Application of the “pixelation technique”;

V. Preliminary study of the Isospin role in HI collisions;

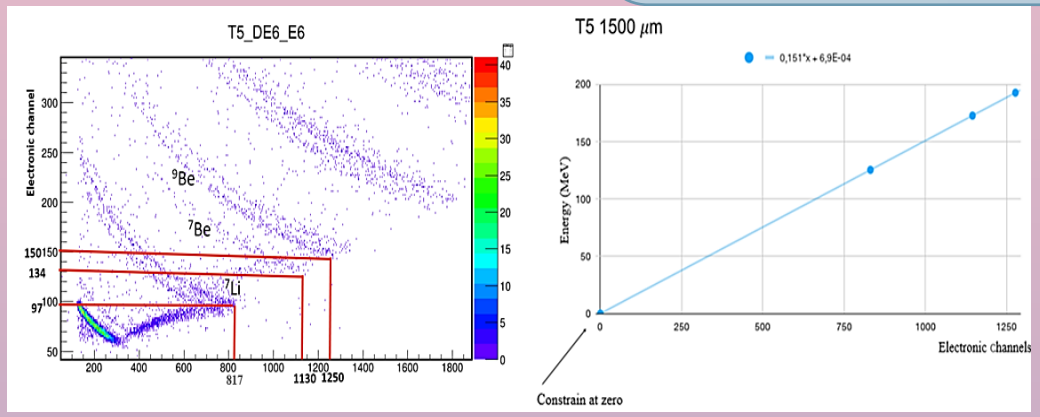
VI. Study of some physics cases of the experiment and preliminary results

➢FARCOS correlator in CHIFAR experiment: I. energy calibration of DSSSDs

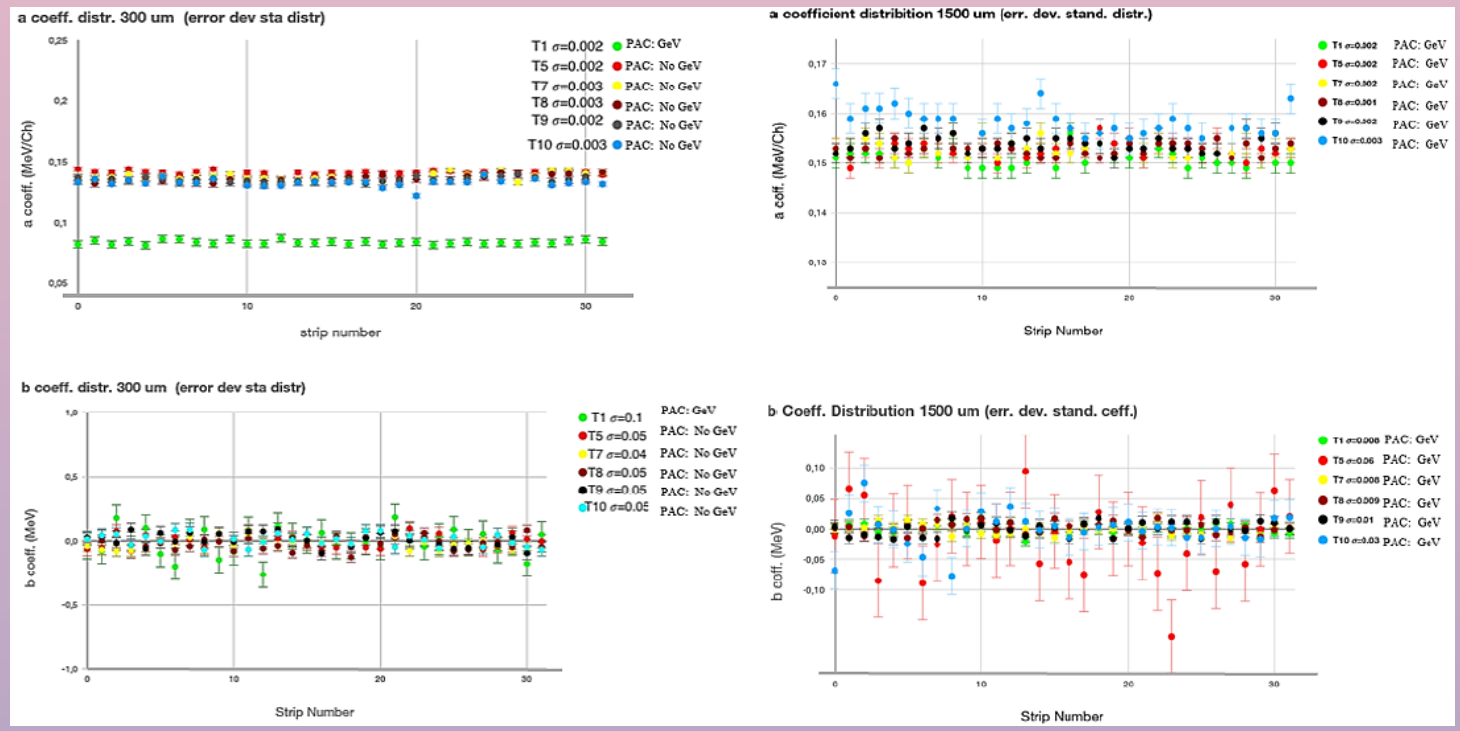


Punching through technique:

In the ΔE-E identification matrix (Si-Si), the tails at the end of each hyperbolic curve are generated by the particles that are in transmission also in the second Si stage and lose completely their energy in the CsI(Tl) stage. Choosing the very initial point (where we can assume particles arrested in 1800 μm of Si) of the tails of ^{7}Li – ^{7}Be – ^{9}Be and using LISE++ software, the initial energy E_i was reconstructed, by setting $E_f = 0\ MeV$ at the end of 1800 μm; the energy lost in each of the two Si-detectors was obtained by the difference.



Particle	Energy lost in Si-300 μm	Energy lost in Si-1500 μm	Total kinetic energy released
^{7}Li	13,52 MeV	125,43 MeV	138,95 MeV
^{7}Be	18,45 MeV	172,75 MeV	191,20 MeV
^{9}Be	20,74 MeV	192,76 MeV	213,50 MeV



➢FARCOS correlator in CHIFAR experiment: II. energy resolution of DSSSDs (front side)

For each Si-telescope (300 μm) was taken into account all 32 strips front, except the first one (n° 0) and the last one (n°31), and not working strips, in coincidence with four sets of 8 back strips.

T1: 300μm all working

T5: 300μm all working

T7: 300μm 3 strips not work (n°18, n°19, n°20)

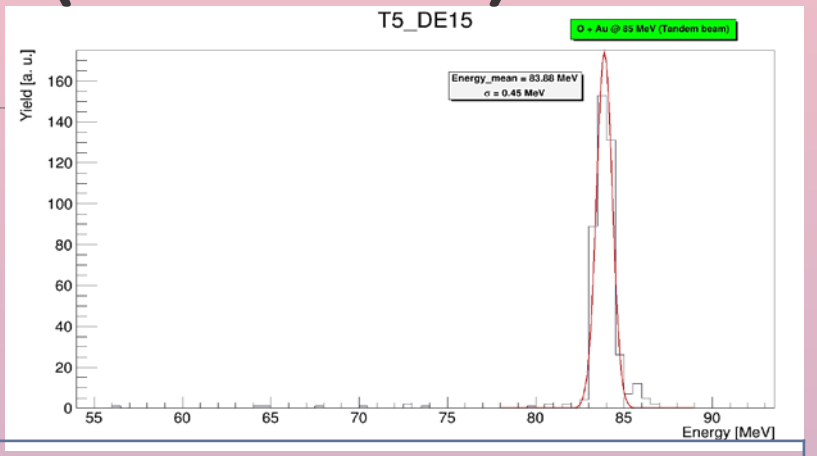
T8: 300μm all working

T9: 300μm all working

T10: 300μm 2 strips not work (n°9, n°26)

Evaluation through elastic scattering:

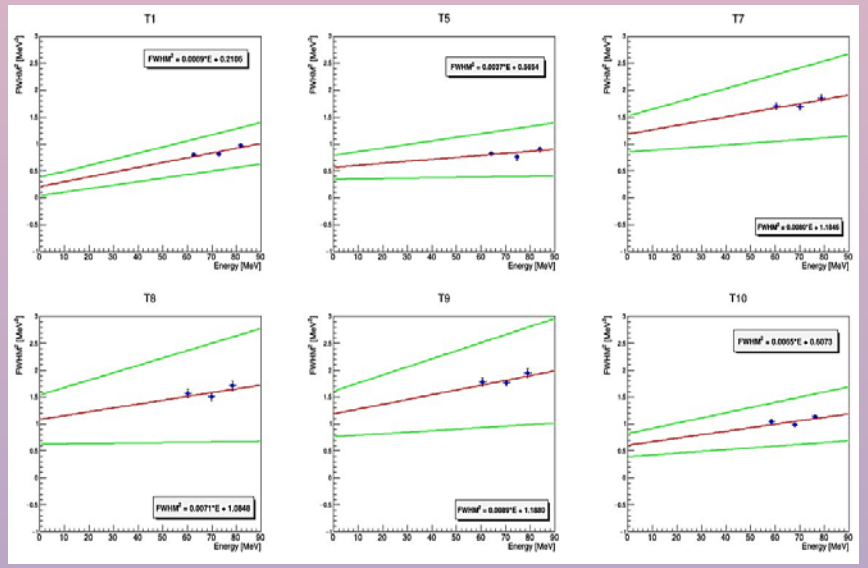
1. O + Au @ 85 MeV (Tandem beam)
2. C + Au @ 75 MeV (Tandem beam)
3. C + Au @ 65 MeV (Tandem beam)



$$FWHM^2 = a \cdot E + b$$

with:

- E = mean value for each telescope
- a = differential increasing of *FMWH* as function of E
- b = square of electronic error for each telescope

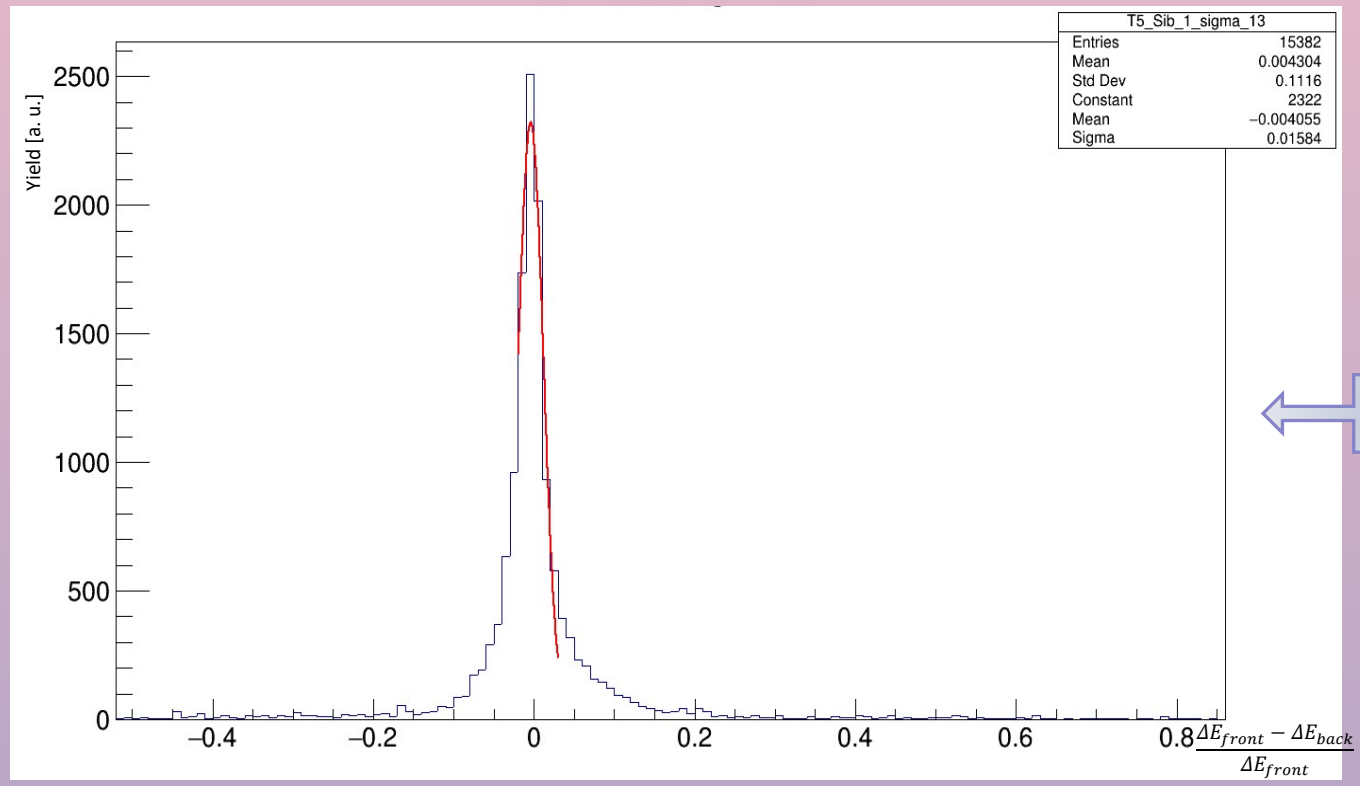


Elastic scattering: O + Au @ 85 MeV							
Telescope	Energy mean [MeV]	FWHM (total error) [MeV]	Resolution [%]	Electronic error [keV]	Electronic error [%]	Detector error [keV]	Detector error [%]
T1	81,80 ± 0,99	0,99 ± 0,02	1,2	459 ± 187	47	528 ± 202	53
T5	83,81 ± 0,95	0,95 ± 0,02	1,1	752 ± 149	79	196 ± 171	21
T7	78,81 ± 1,36	1,36 ± 0,02	1,7	1088 ± 154	80	271 ± 176	20
T8	78,43 ± 1,31	1,31 ± 0,03	1,7	1042 ± 220	80	266 ± 253	20
T9	78,92 ± 1,40	1,40 ± 0,03	1,8	1090 ± 195	78	306 ± 224	22
T10	76,11 ± 1,07	1,07 ± 0,02	1,4	779 ± 140	73	286 ± 156	27

≈0.5% (RMS)

➢ FARCOS correlator in CHIFAR experiment: II. energy resolution of DSSSDs (back side)

For each DSSSD (300 μm), the ratio $\frac{\Delta E_{front} - \Delta E_{back}}{\Delta E_{front}}$ was evaluated, for each front strip in coincidence with all 32 back strips



≈1.6% (RMS)

➢ FARCOS correlator in CHIFAR experiment: III. particle identification

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

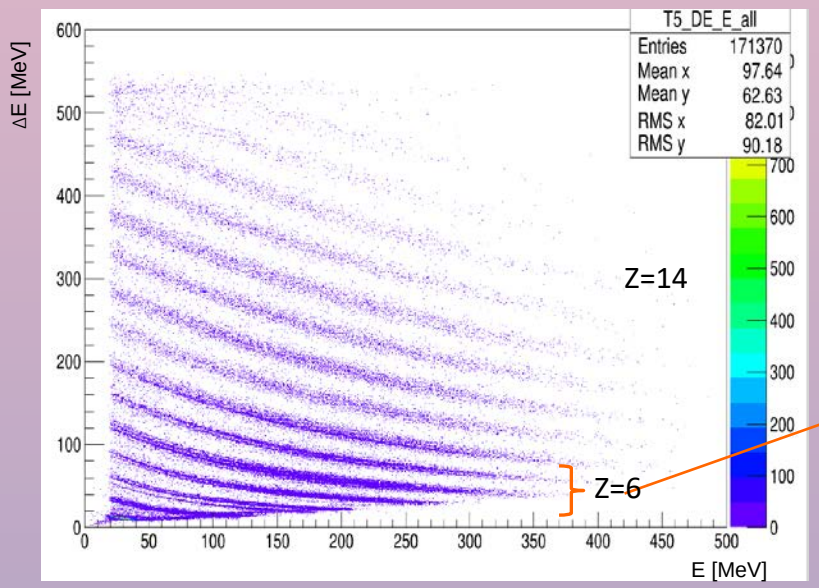
ΔE-E technique

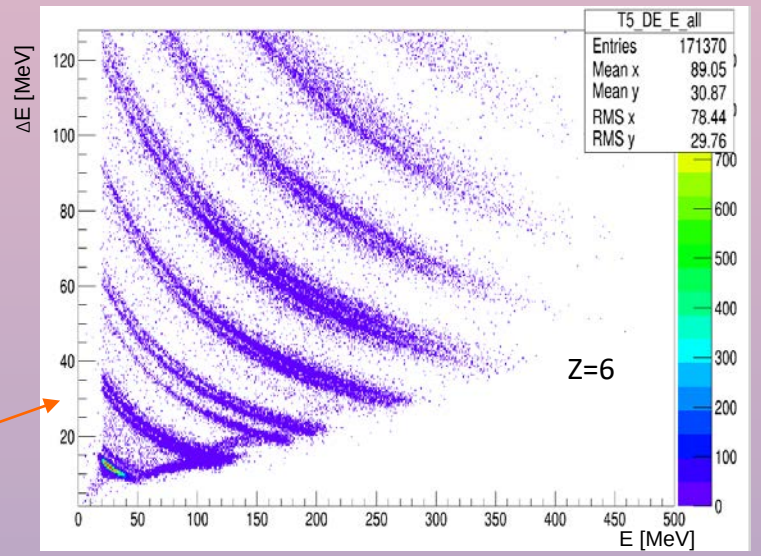
applied to DSSSDs (300 µm – 1500 µm):

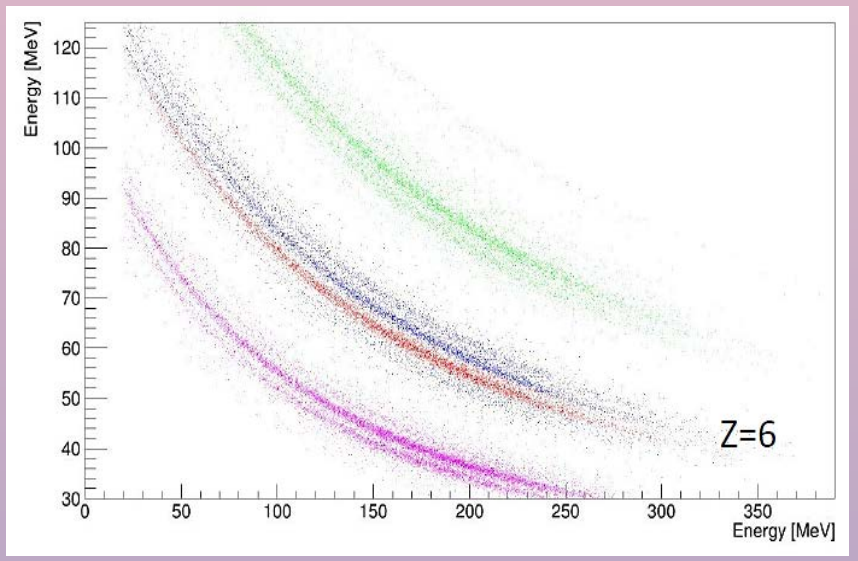
$\Delta E * E \propto z^2 * m$

(Bethe-Bloch formula)

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



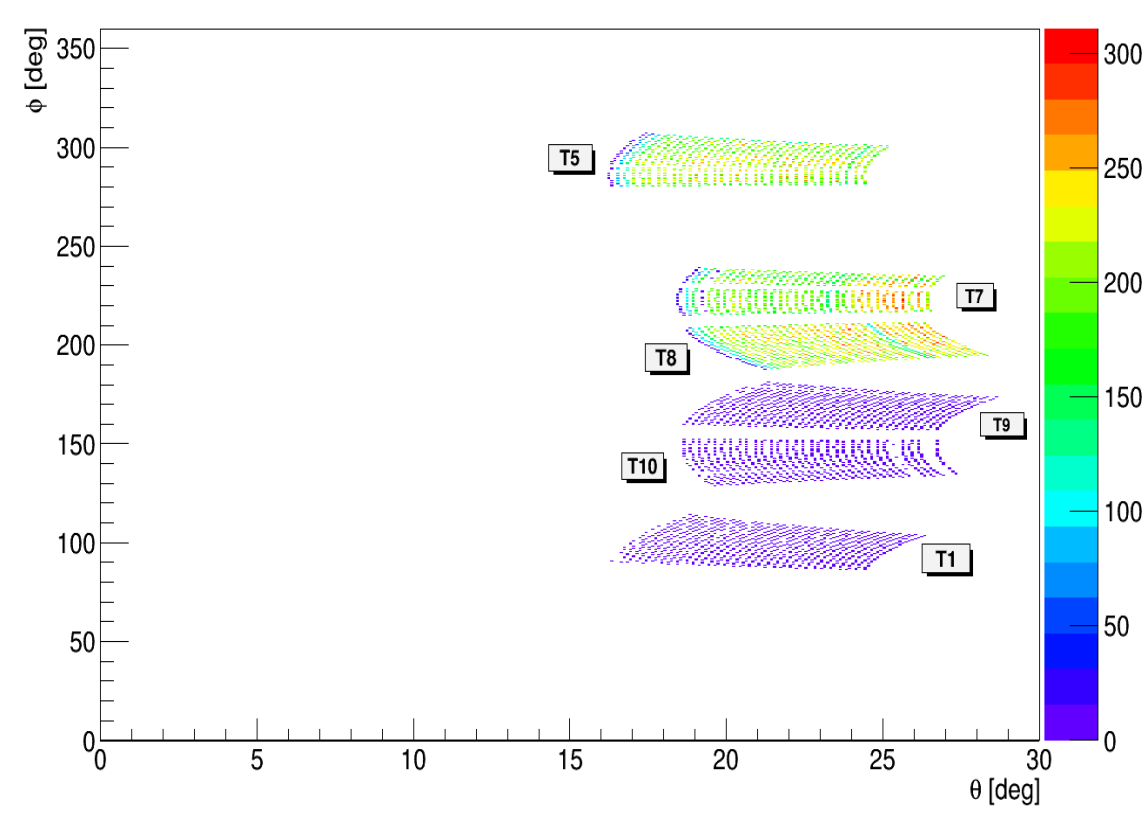




obtained by an automatic algorithm developed by the CHIMERA collaboration

➢ FARCOS correlator in CHIFAR experiment: IV. the “pixelation technique”

assignment for each detected particle of its position in the DSSSD:
assignment of the coordinate, the polar angle θ and the azimuthal angle ϕ for each detected particle from the analysis of the fired strip of the front side and the one of the back side of the DSSSDs



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

FARCOS telescopes covered polar angles between 16° and 29°

There is no ambiguity in the assignment of the position!

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

assignment for each detected particle of its position in the DSSSD

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

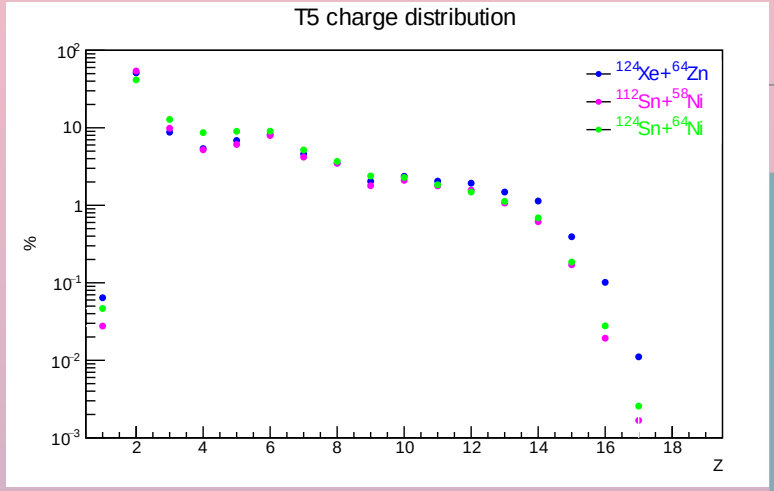
G. Cardella, N. S. Martorana et al., submitted to Nucl. Instr. and Meth. A

There are some **ambiguities** regarding the assignment of the position of the detected particle…

WORK IN PROGRESS…

	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 [1]	13 [1]	29 [0]
			148,723			30 [1]
			228,6089	Solved ambiguity in position: it is an Interstrip event in DSSSD_1500µm, (ambiguity only in energy)		
#2	12,9576	12,9558	22,1211	4 [0]	0 [0]	4 [0]
	118,896	120,412	180,113	13 [1]	25 [1]	13 [1]
	Unsolved ambiguity: are they 2 different particles?? Could we assign the position using the TIME VARIABLE??					
#3	12,0703	12,3186	24,9049	29 [0]	29 [1]	30 [1]
	114,905	116,925		30 [1]	18 [0]	
	126,9753			Unsolved ambiguity: it is an Interstrip event in DSSSD_300µm; Could we assign the position using the TIME VARIABLE?? -> next step…		

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



preliminary observations:

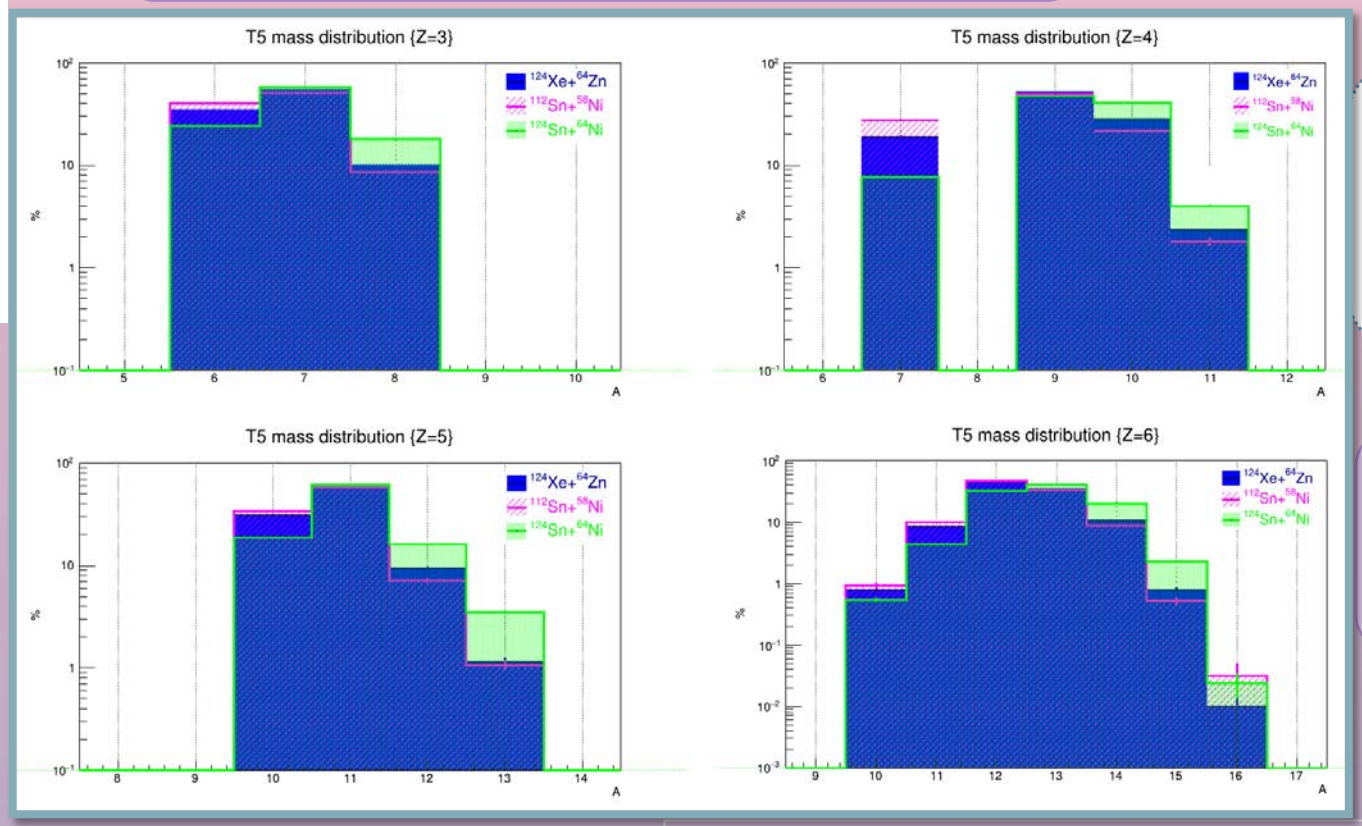
1)Enhanced light IMFs emission in the neutron rich reaction

2)The isobaric system (high-fissility) presents a stronger emission of heavier IMFs

Preliminary analysis from FARCOS data, without CHIMERA data!

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

Preliminary analysis!

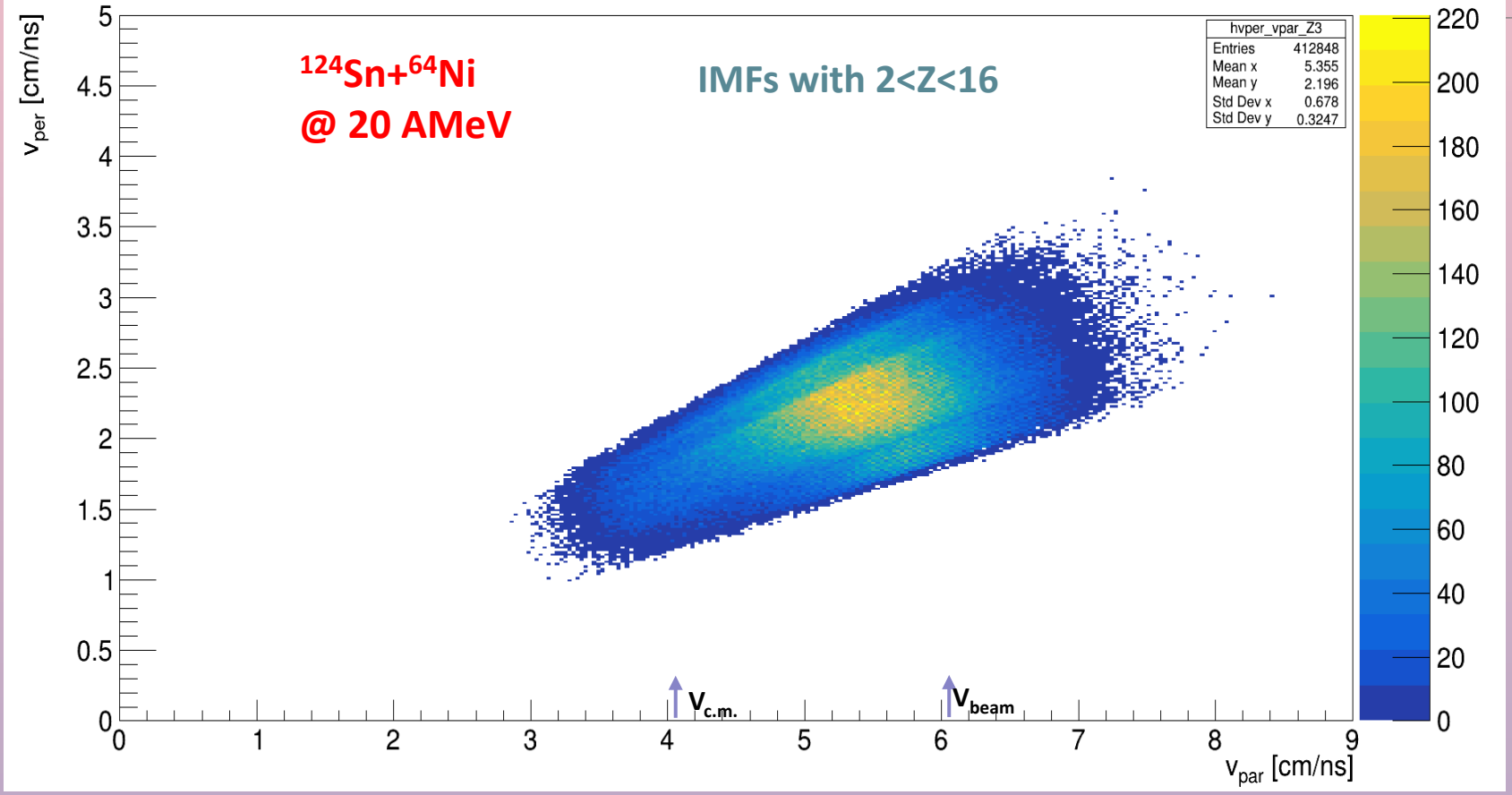


- "isobaric" system: $I = N/Z = 1.24$
- "neutron poor" system: $I = N/Z = 1.18$
- "neutron rich" system: $I = N/Z = 1.41$

effect of neutrons enrichment for neutron rich system!

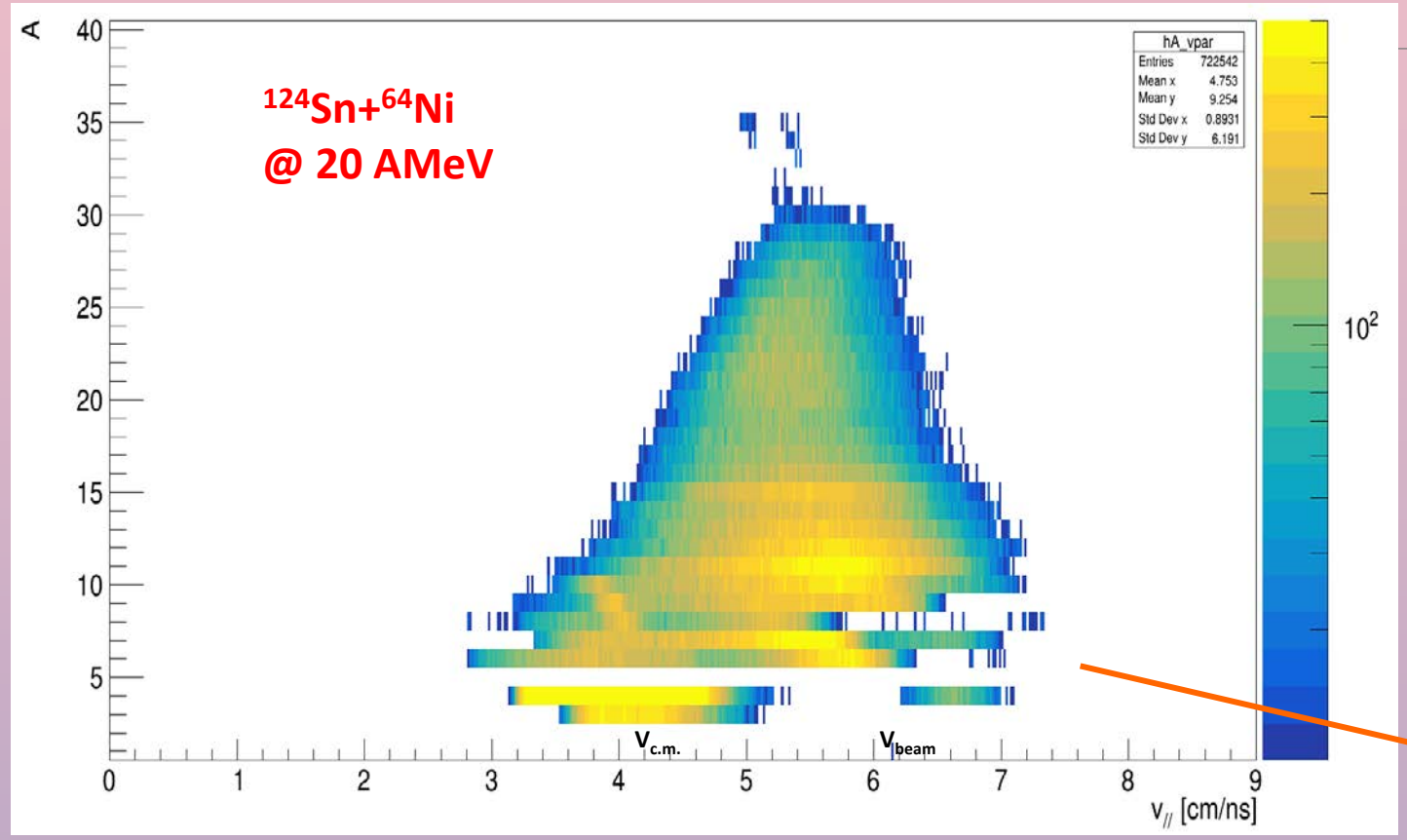
obtained by an automatic algorithm developed by the CHIMERA collaboration

➢ Preliminary results:
VI. study of physics cases of the experiment



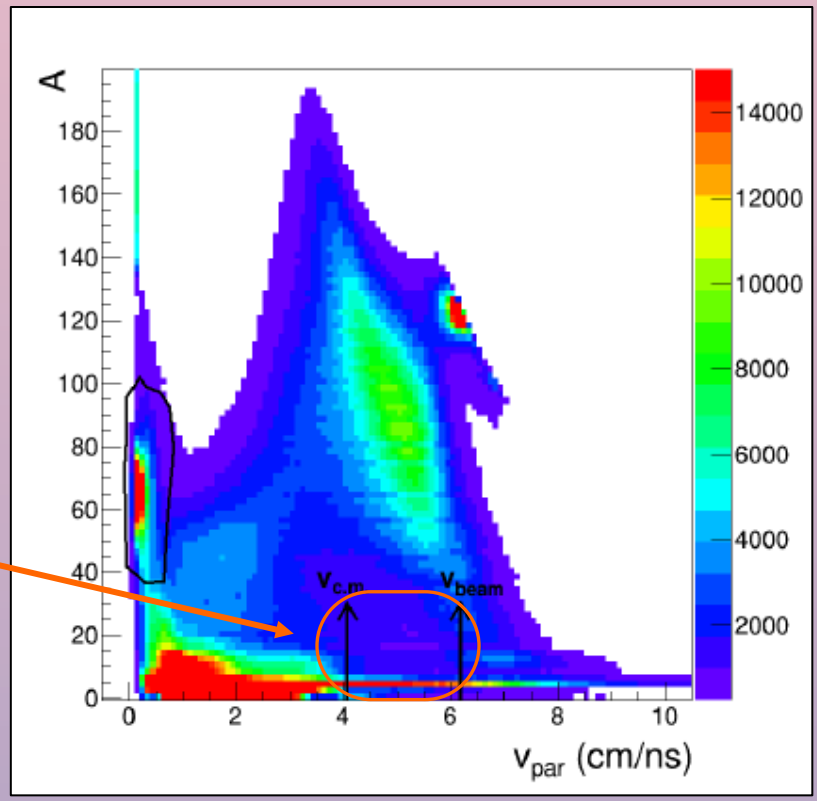
- velocity distribution centred on v_{PLF} (lab. system)

➢ Preliminary results
VI. study of physics cases of the experiment

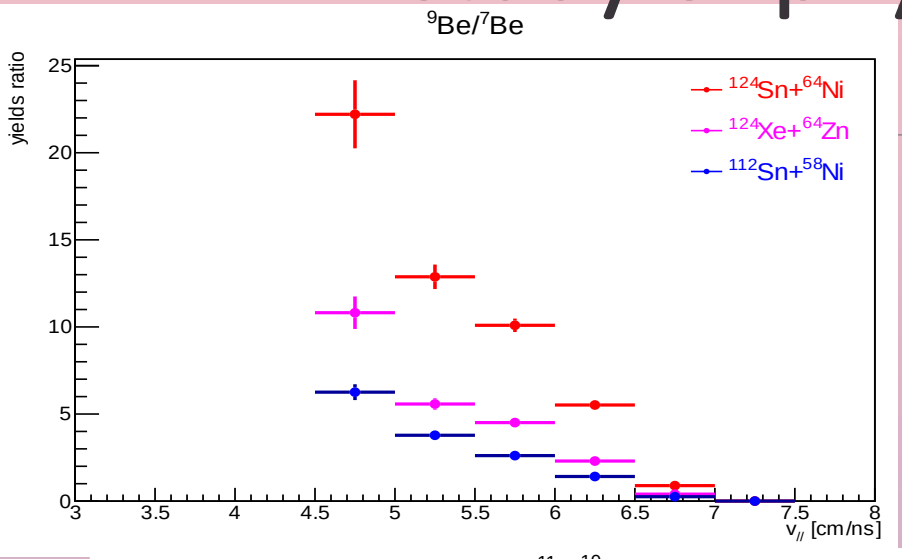


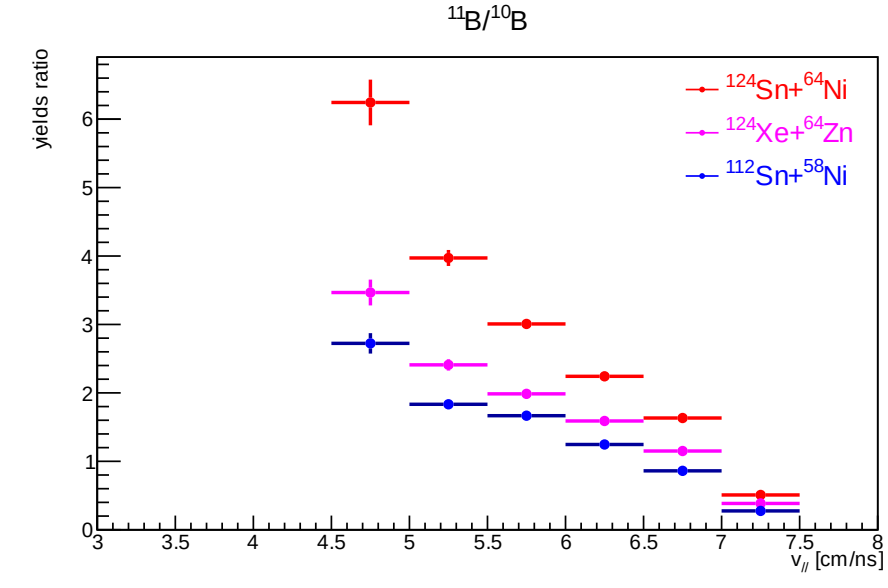
particle multiplicity = 1

Results in agreement with the analysis of the data collected by CHIMERA



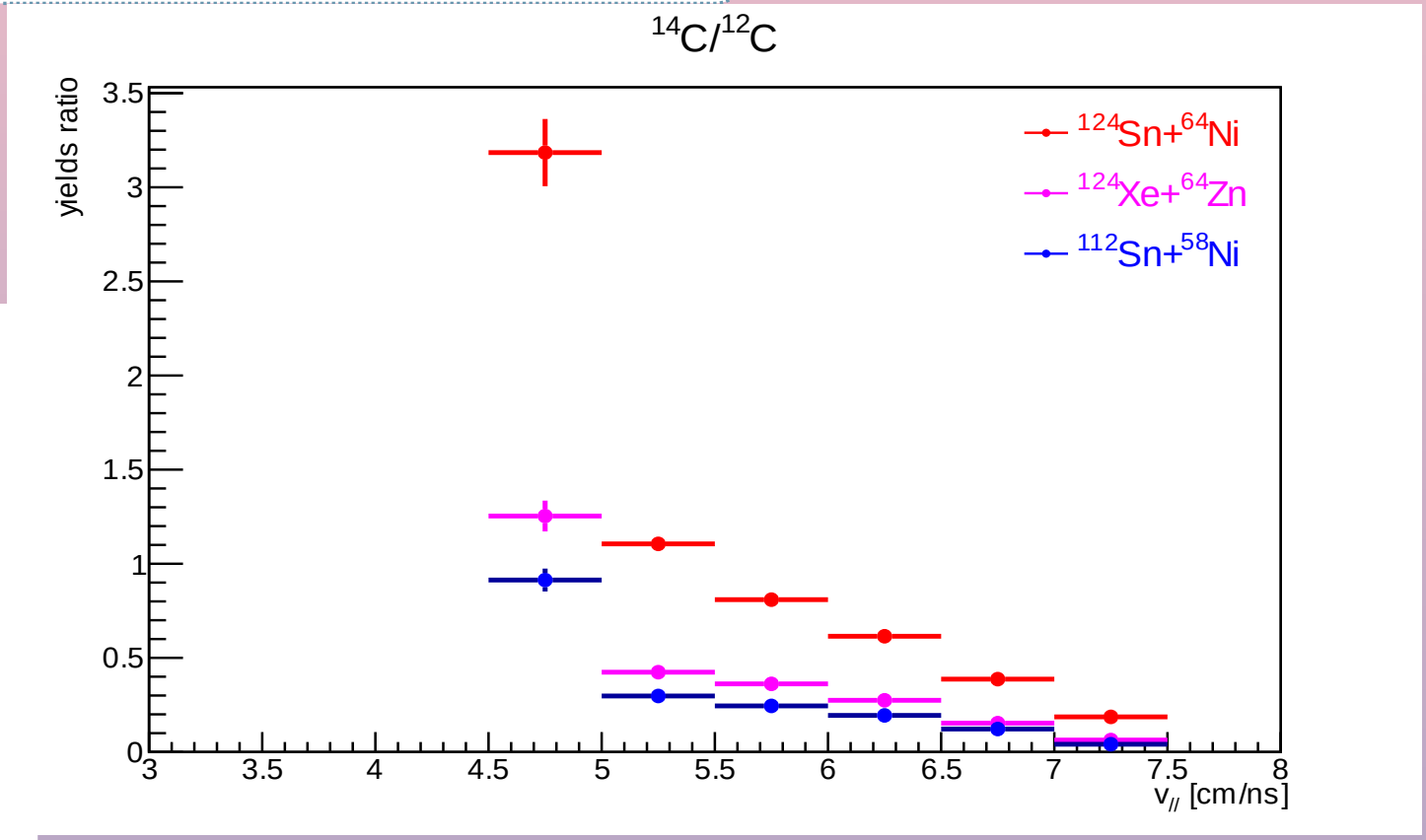
➢Preliminary results
VI. study of physics cases of the experiment





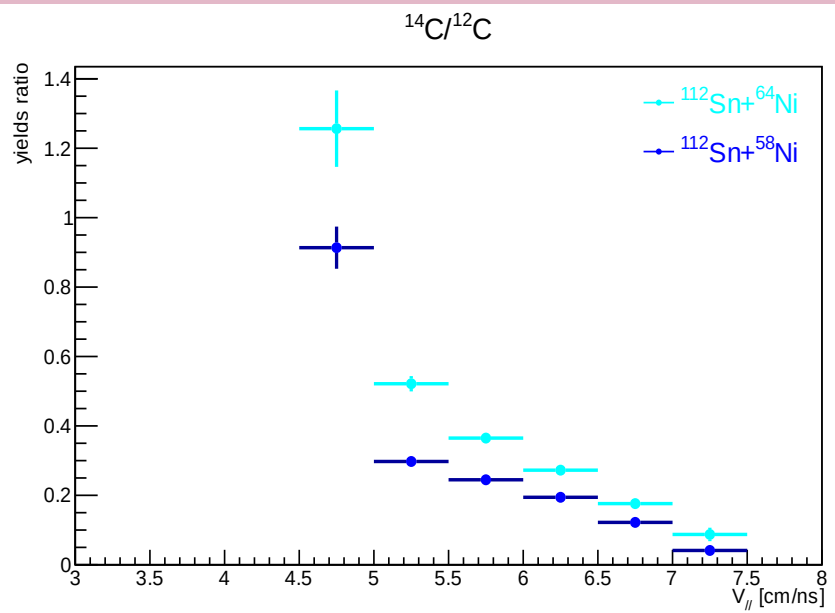
- "neutron rich" system: $I = N/Z = 1.38$
- "isobaric" system: $I = N/Z = 1.21$
- "neutron poor" system: $I = N/Z = 1.16$

raw data (detector response not included)

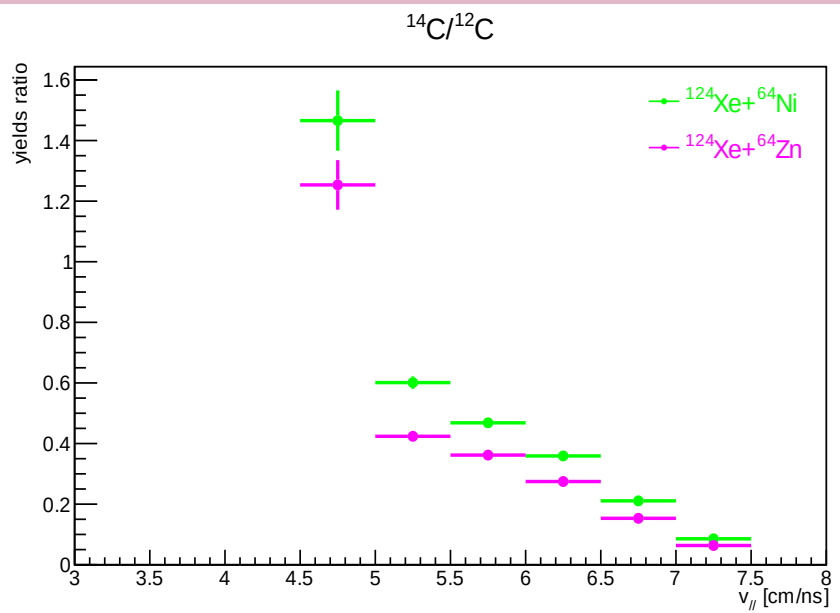


➢Preliminary results:
VI. study of physics cases of the experiment

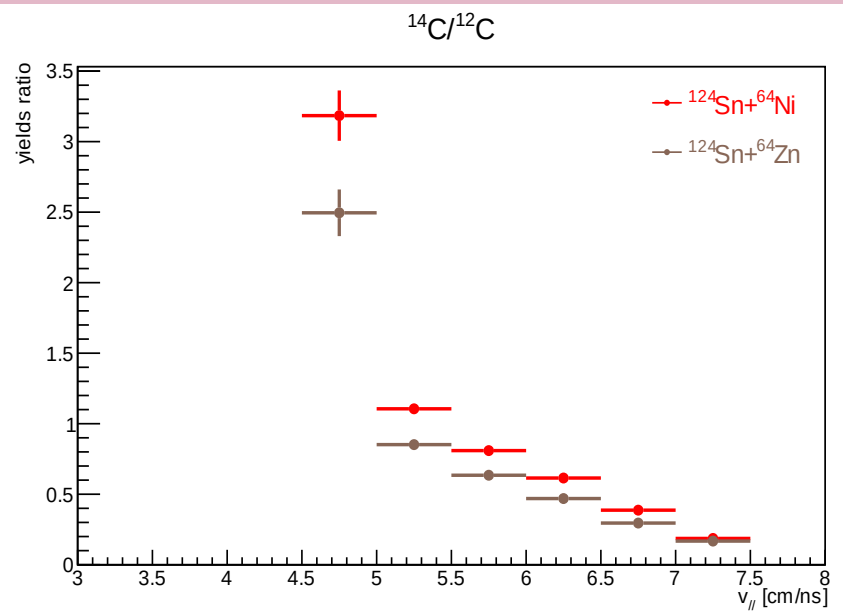
raw data (detector response not included)



- $I = 1.26$
- $I = 1.16$



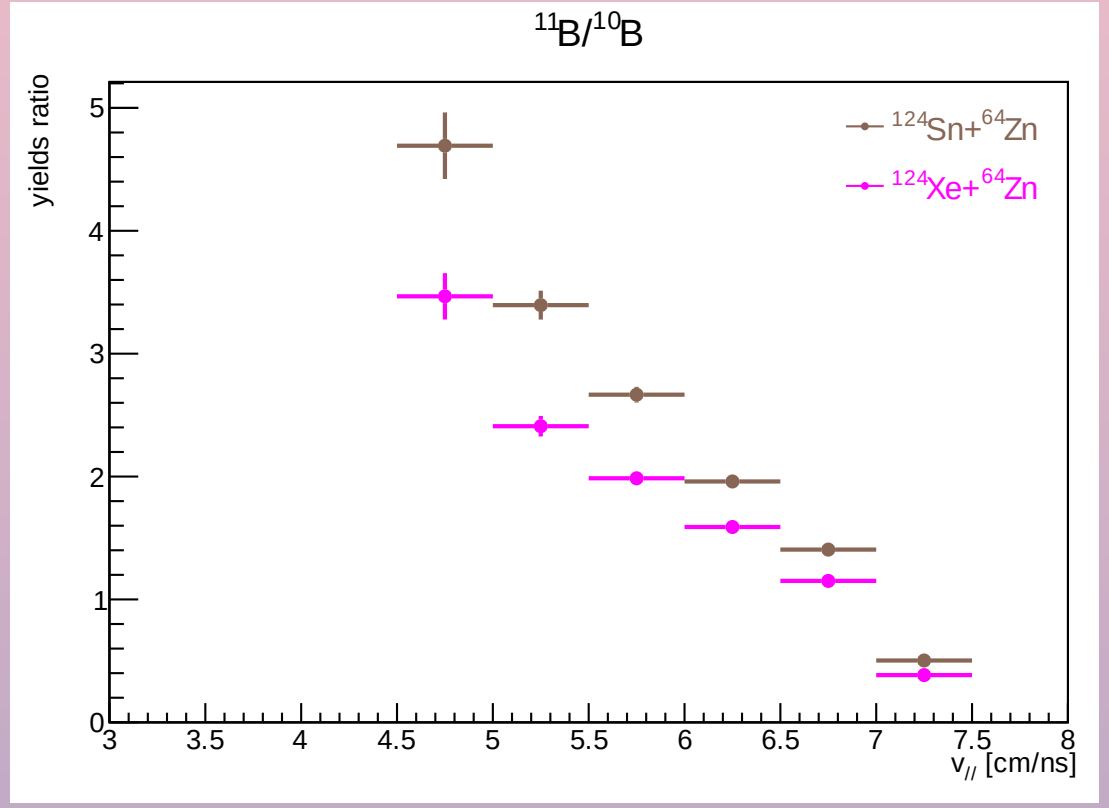
- $I = 1.29$
- $I = 1.21$



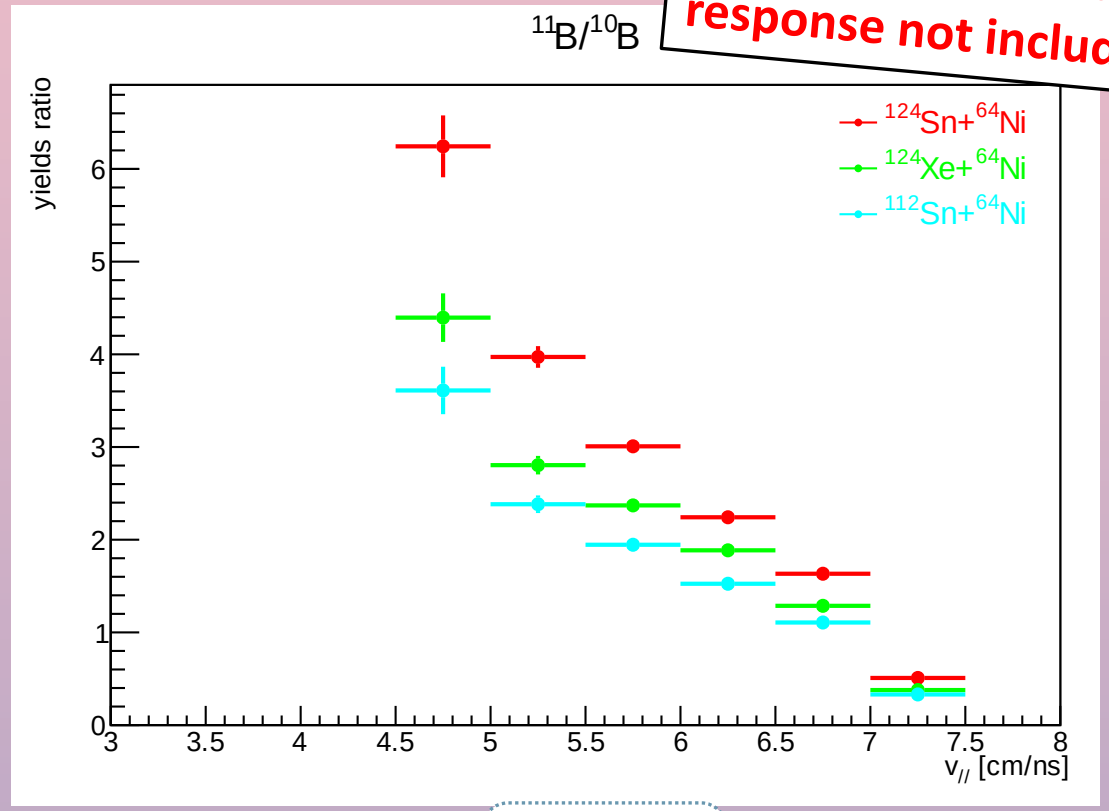
- $I = 1.38$
- $I = 1.31$

➢ Preliminary results:
VI. study of physics cases of the experiment

raw data (detector response not included)



- $I = 1.31$
- $I = 1.21$



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

➢ Preliminary results about physics cases of the experiment

From (only) FARCOS data analysis

- Preliminary results from raw data (detector response is not included): particle multiplicity is equal to 1, high thresholds for detected particles within the two stages for DSSSDs (ΔE-E method);
- *N/Z* distributions as a function of $v_{//}$ follow initial Isospin content: punctual memory of initial conditions is not lost;
- *N/Z* distributions as a function of $v_{//}$ reflect the effect of neutron enrichment, according to the isospin ratio of each reaction;
- Velocity distribution is centred on v_{PLF}, towards the midvelocity;
- IMFs' identification in the portion of the phase space between $Z = 2$ and $Z = 15$;
- Preliminary analysis from FARCOS data, for IMFs detected by DSSSDs: LCPs will be identified by CsI (next step of analysis)…
- Preliminary analysis from FARCOS data, without CHIMERA data, and so without selection of global variables mandatory for the characterization of the reaction mechanism (total charged particles multiplicity, reaction plane, etc); data will be filtered with the experimental setup (next steps of analysis)…
- Results will be compared with some theoretical models (next step)…

Thanks for your attention!