Enrico De Filippo (INFN Catania) for the NEWCHIM collaboration

*Sensitivity of N/Z ratio to **dynamical fission** of projectile in isobaric systems: a new probe for **symmetry energy** ?*

Physics case: competition between dynamical and statistical IMFs production

Influence of the N/Z ratio of the entrance channel in the dynamical fission of the quasi-projectile: enhanced cross-section for dynamical emission for the system with higher N/Z

The new data of InKiIsSy experiment (Inverse Kinematics Isobaric Systems), ^{124}Xe+^{64}Zn,^{64}Ni at 35 A.MeV complements the previous ones: TimeScale ^{64,58}Ni + ^{124,112}Sn (direct) and ^{124,112}Sn+^{64,58}Ni (inverse) kinematics .

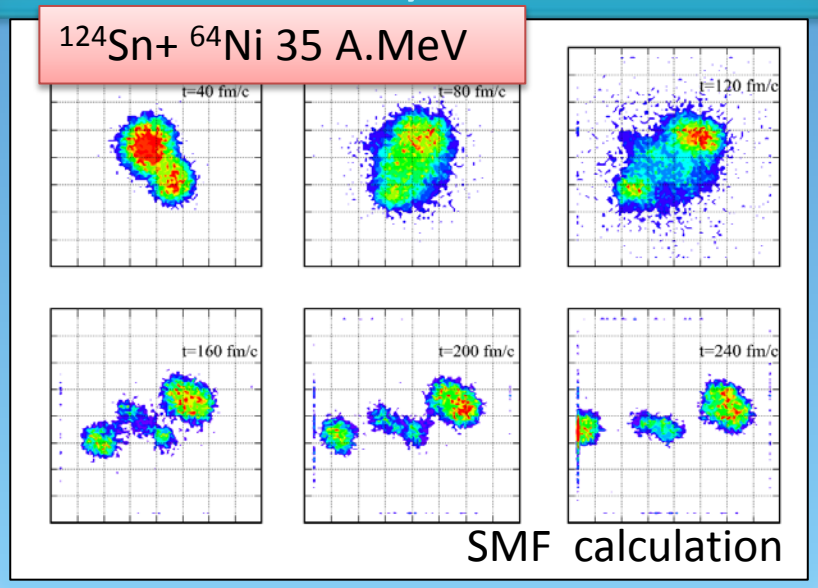
First "Inkiissy" experiment results

Constrained Molecular Dynamics (CoMD-3) simulations (preliminary)

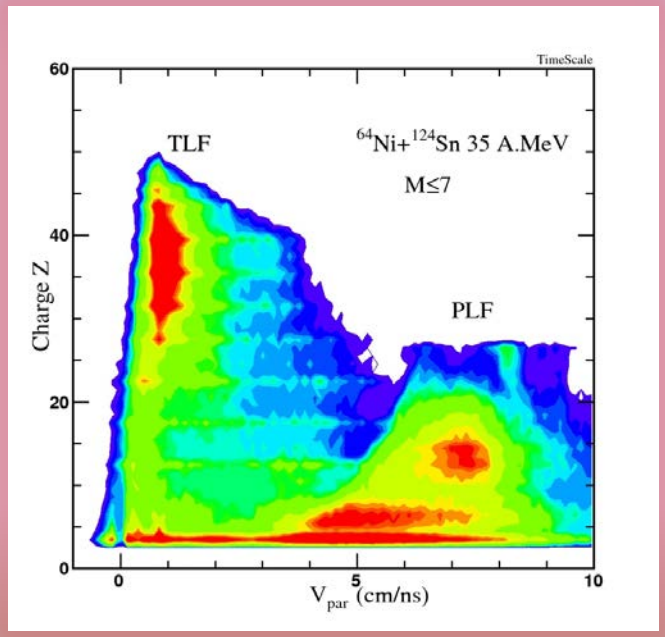
Perspectives with radioactive beams below Fermi energies (E/A<15 A.MeV) .

In “Timescale” and “Inkiissy” experiments we mainly look at:

1) The “**neck**” emission where light IMFs (Z<≈9) are produced at midrapidity due to the rupture of a piece of nuclear matter a low density (“neck”). This is generally a **FAST** process (<100 fm/c)



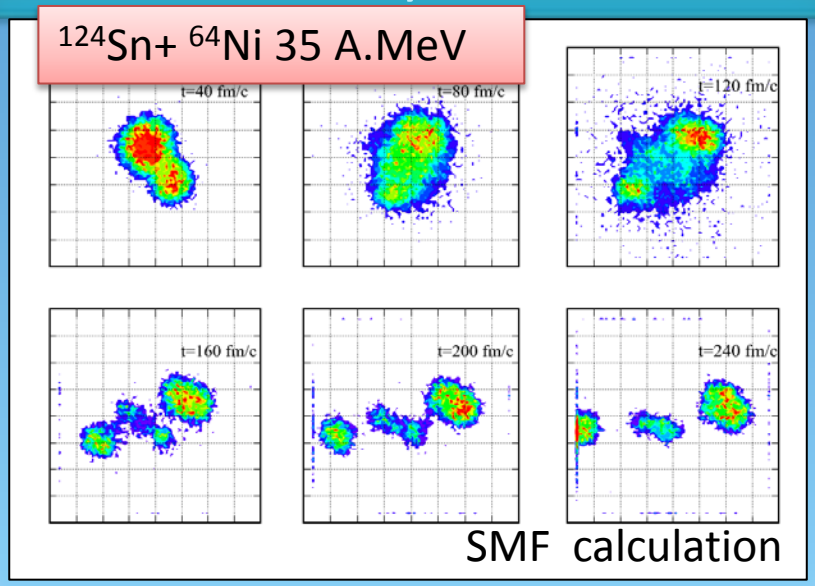
2) Excitation of a primary Projectile-like PLF* (TLF*) followed by its dynamical (non-equilibrated) asymmetrical splitting (**dynamical fission**). In this case emission of the **lighter IMF** is preferentially backwards in the PLF reference system.



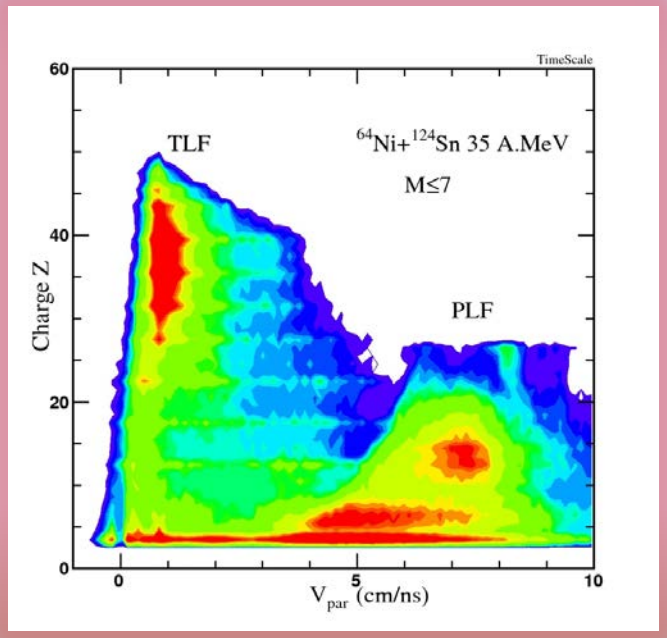
Role of **N/Z of entrance channel** in the reaction mechanisms

In “Timescale” and “Inkiissy” experiments we mainly look at:

1) The “**neck**” emission where light IMFs (Z<≈9) are produced at midrapidity due to the rupture of a piece of nuclear matter a low density (“neck”). This is generally a **FAST** process (<100 fm/c)



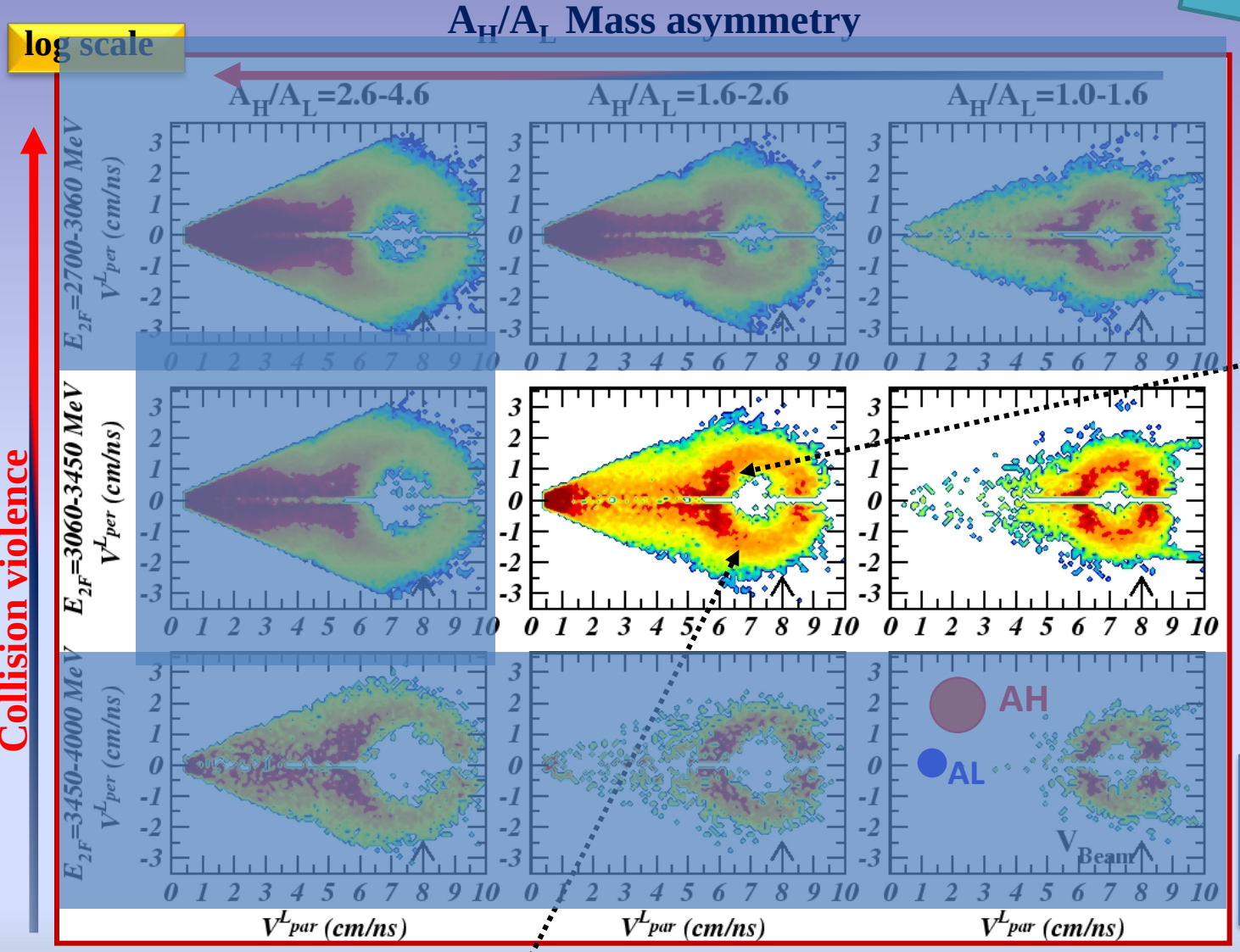
2) Excitation of a primary Projectile-like PLF* (TLF*) followed by its dynamical (non-equilibrated) asymmetrical splitting (**dynamical fission**). In this case emission of the **lighter IMF** is preferentially backwards in the PLF reference system.



Role of **N/Z of entrance channel** in the reaction mechanisms

The quasi-projectile break-up

$^{124}Sn+^{64}Ni$ 35 AMeV
Neutron rich



AH

AL

The lighter fragments are emitted preferentially backwards in the PLF reference system, i.e., towards the target nucleus:
Dynamical Fission
→ fast and non-equilibrated fission

E.De Filippo et al.,PRC 71 064604 (2005)
P. Russotto et al., PRC 81, 064605 (2010)

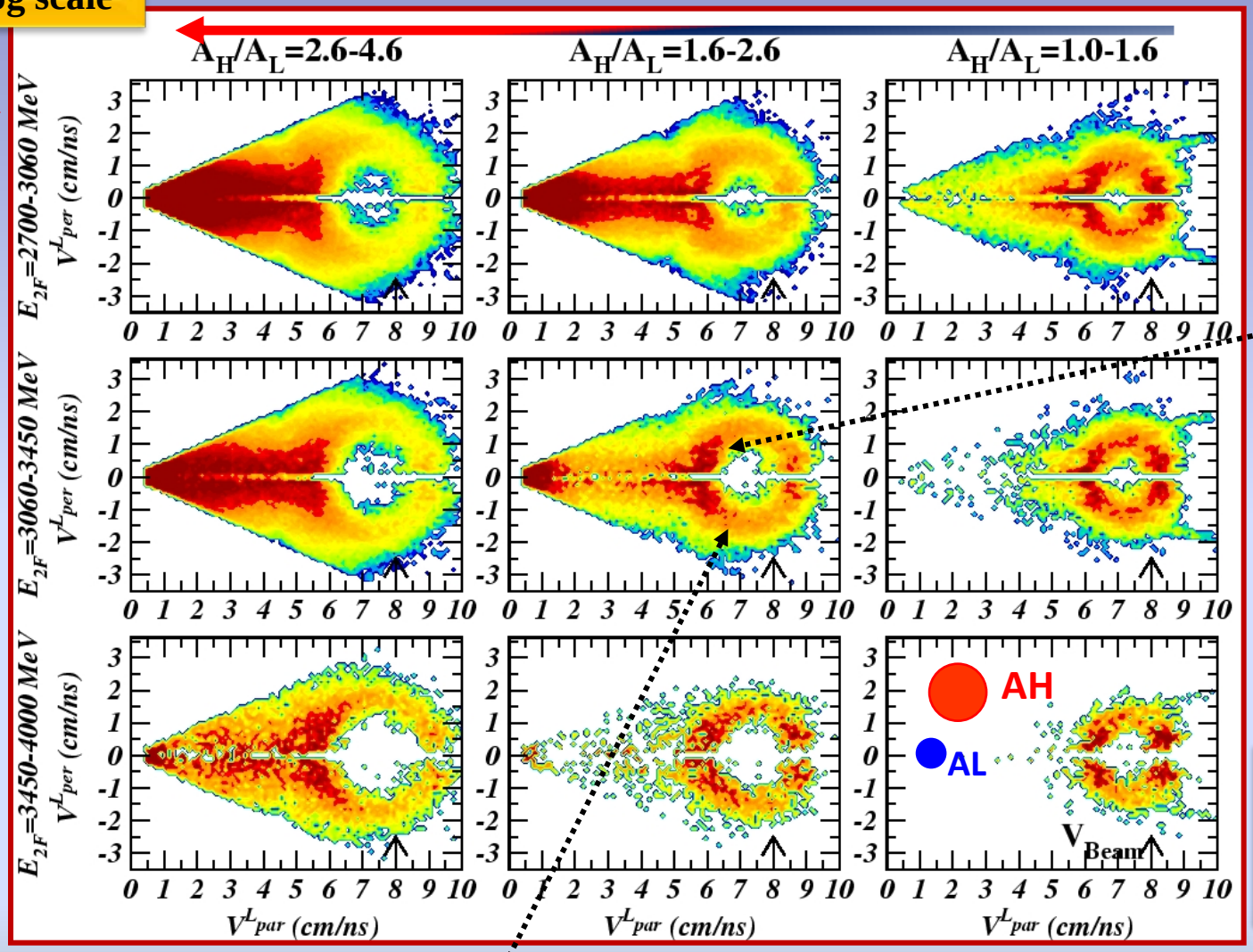
Coulomb ring 5<≈ V_{beam} = 8. cm/ns→ Well defined PLF source: scattering of PLF followed by its splitting in H&L fragments → sequential mechanism

The quasi-projectile break-up

$^{124}Sn+^{64}Ni$ 35 AMeV
Neutron rich

log scale

A_H/A_L Mass asymmetry



Collision violence

AH

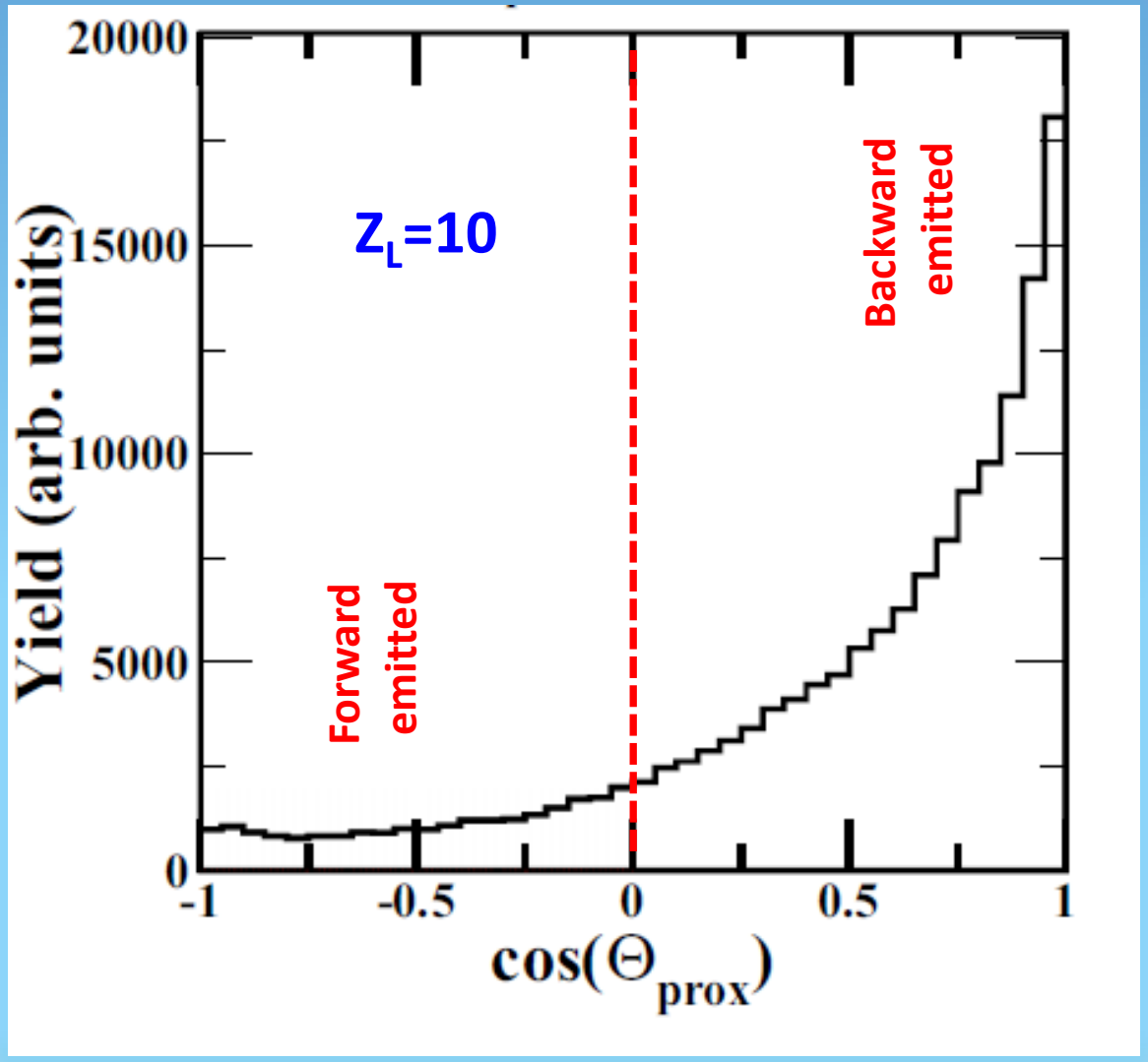
AL

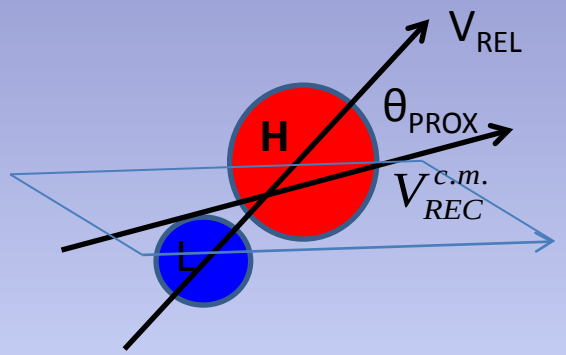
The lighter fragments are emitted preferentially backwards in the PLF reference system, i.e., towards the target nucleus:
Dynamical Fission
→ fast and non-equilibrated fission

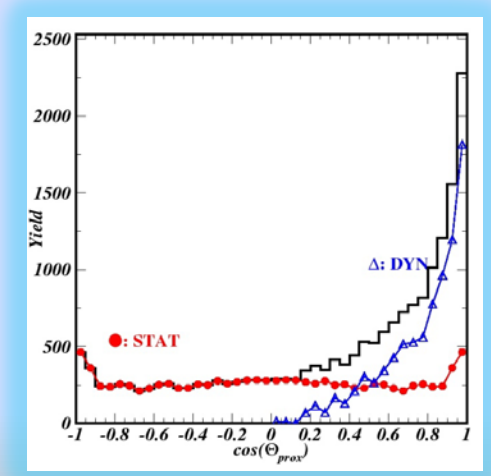
E.De Filippo et al.,PRC 71 064604 (2005)
P. Russotto et al., PRC 81, 064605 (2010)

Coulomb ring 5<≈ V_{beam} = 8. cm/ns→ Well defined PLF source: scattering of PLF followed by its splitting in H&L fragments → sequential mechanism

METHOD: disentangling dynamical vs. statistical emission: Angular Distributions



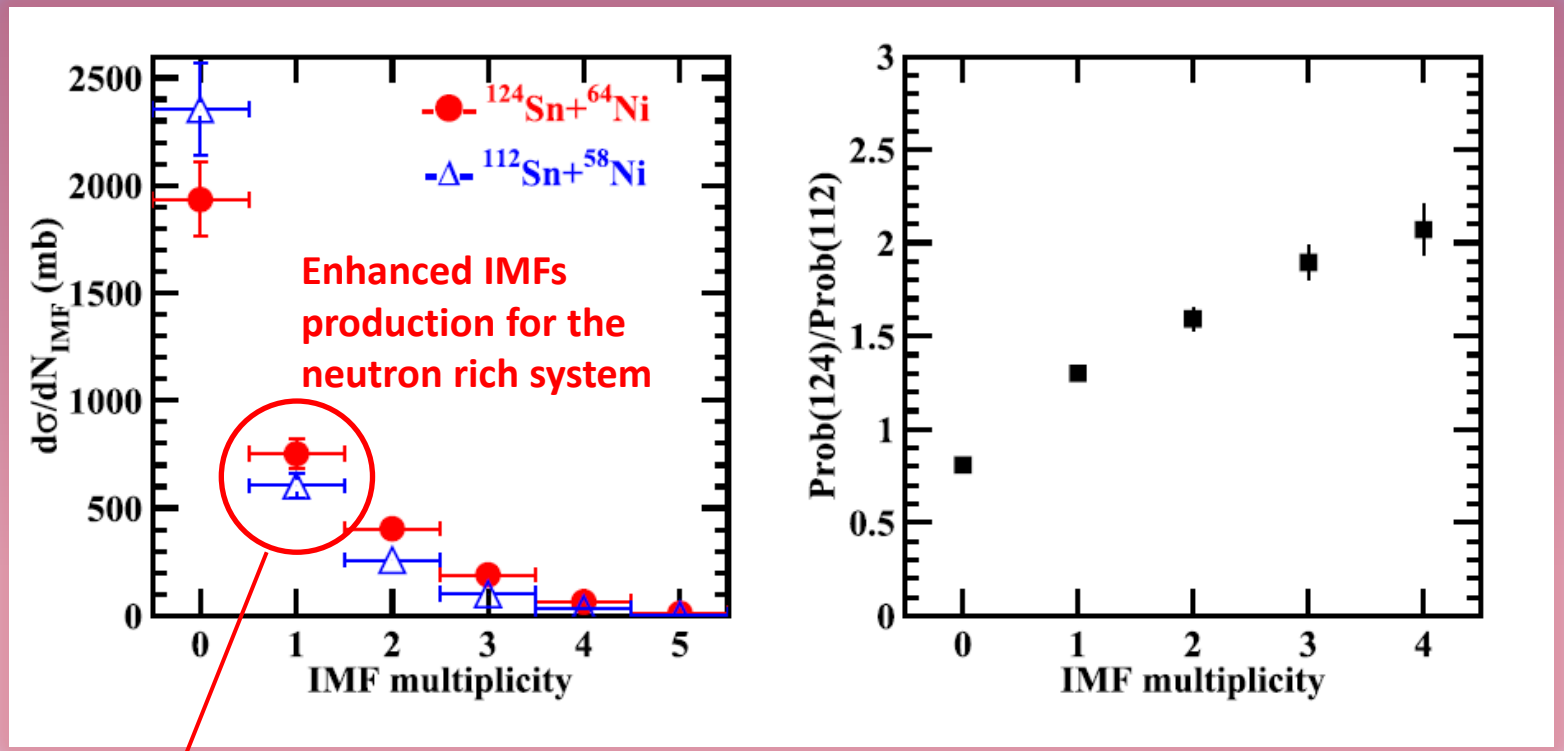




See also P. Russotto et l. PRC **91**, 014619 (2015)

S. Hudan et al., PRC **86** 021603(R) (2012)

Cross section as a function of the IMF multiplicity associated with PLF residue



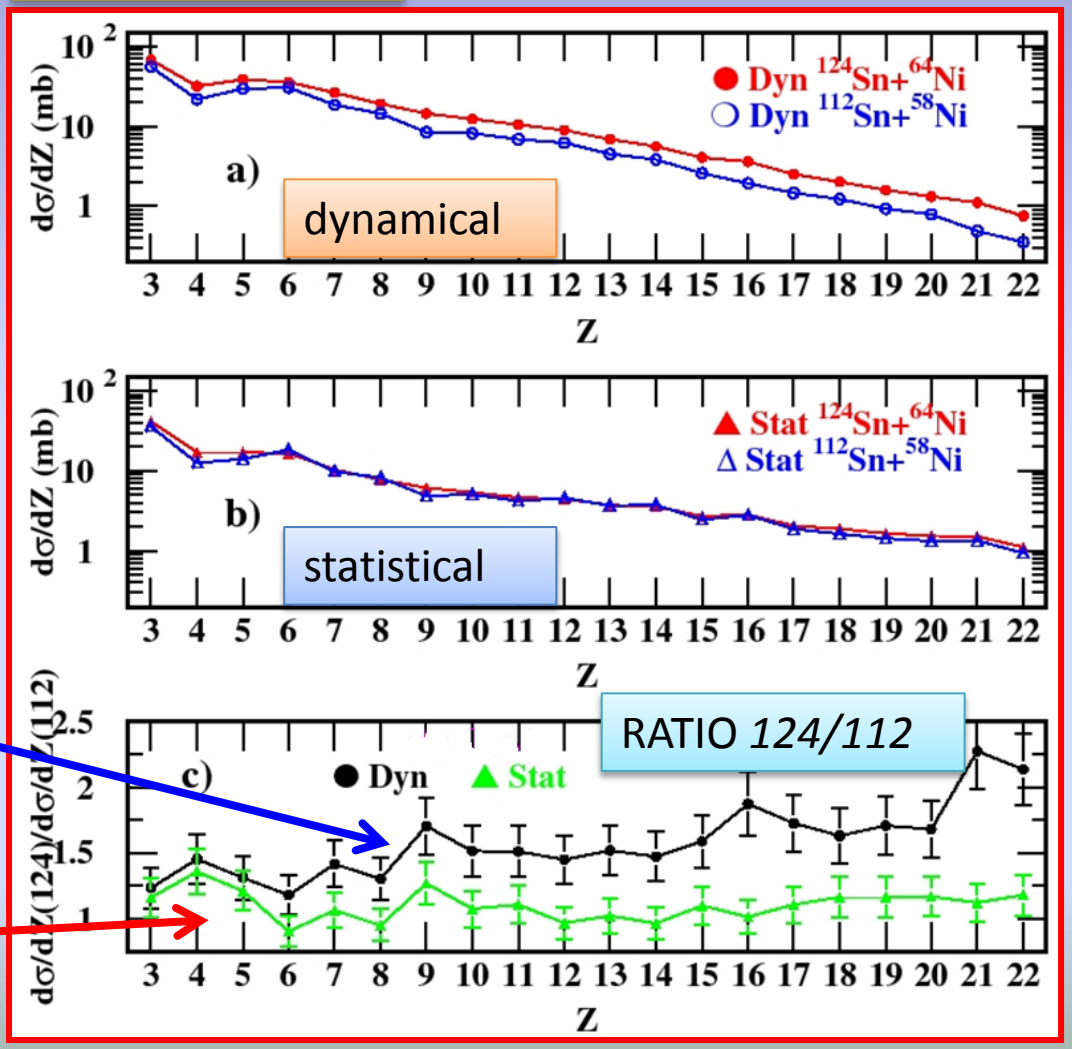
The analysis is done for M_{IMF}=1 events (ternary splitting). b/b_{max}>0.4

P. Russotto et al. , Phys. Rev. C91, 014610 (2015)

Comparison of IMFs cross sections for $^{124}Sn+^{64}Ni$ and $^{112}Sn+^{58}Ni$

P. Russotto et al. , Phys. Rev. C91, 014610 (2015)

Cross-sections

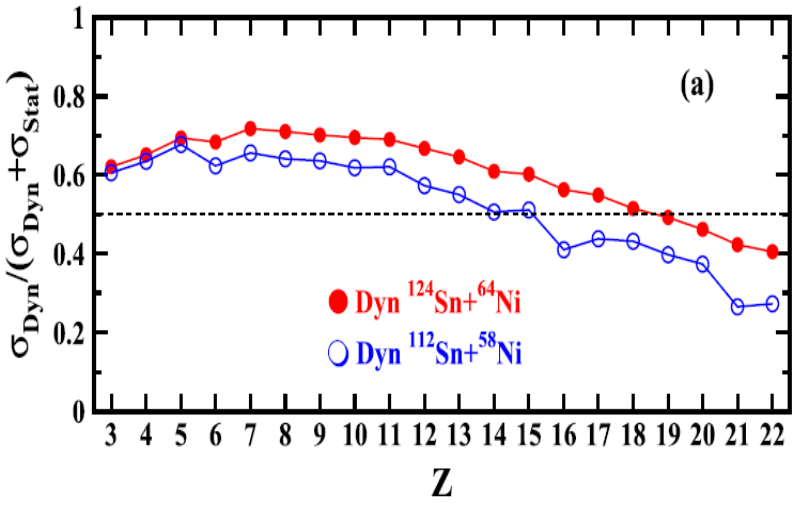


- **Dynamical component: enhanced for the neutron rich**
- **Statistical component: almost equal (A ratio: ~1.1 close to the mass ratio between the systems)**

see also A.B. McIntosh et al. PRC 81 034603 (2010)

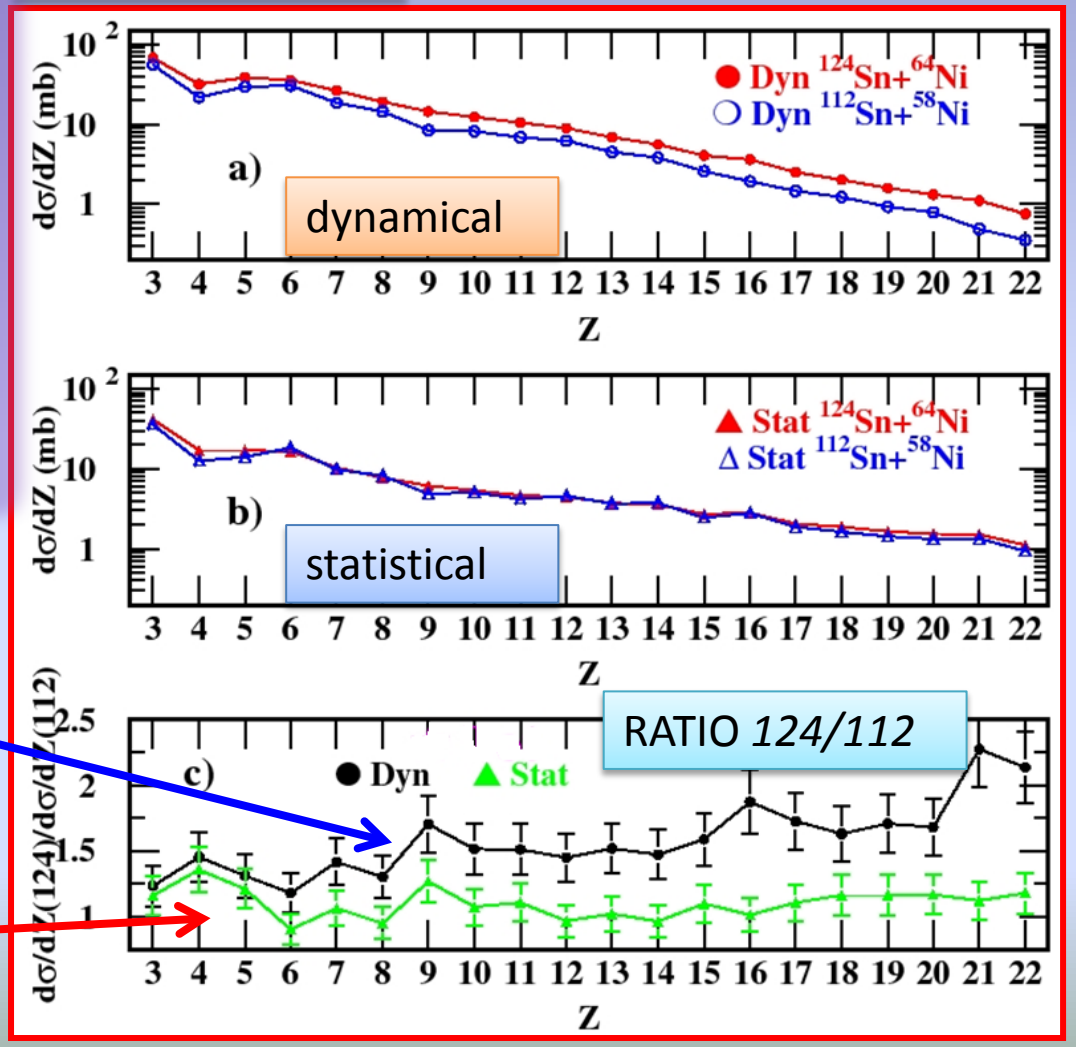
Comparison of IMFs cross sections for $^{124}Sn+^{64}Ni$ and $^{112}Sn+^{58}Ni$

Ratio of $\sigma_{dyn}/(\sigma_{dyn}+\sigma_{stat})$ as a function of IMFs charge Z for the two systems.



P. Russotto et al. , Phys. Rev. C91, 014610 (2015)

Cross-sections



- **Dynamical component: enhanced for the neutron rich**
- **Statistical component: almost equal (A ratio: ~1.1 close to the mass ratio between the systems)**

see also A.B. McIntosh et al. PRC 81 034603 (2010)

The INKIISSY EXPERIMENT $^{124}Xe + {}^{64}Zn, {}^{64}Ni$

Main experimental result: the dynamical component is enhanced for the neutron rich system.

Is it a **size (mass)** effect or **isospin** effect ?

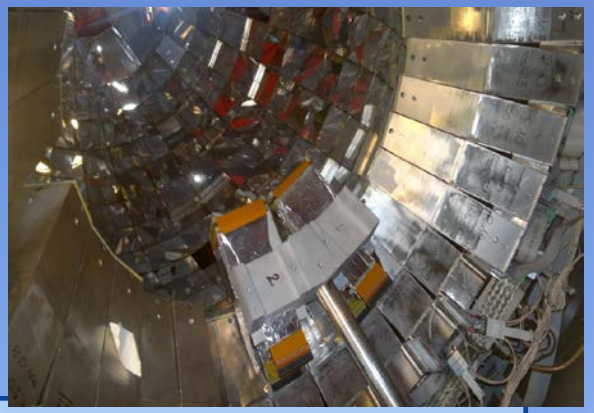
The idea is to use uses a projectile/target combination having the same mass of the neutron rich $^{124}Sn+{}^{64}Ni$ system and a N/Z $^{124}Xe+{}^{64}Zn$ as the neutron poor one $^{112}Sn+{}^{58}Ni$ at the same bombarding energy of 35 A.MeV using the 4π detector CHIMERA and the Farcos module prototype.

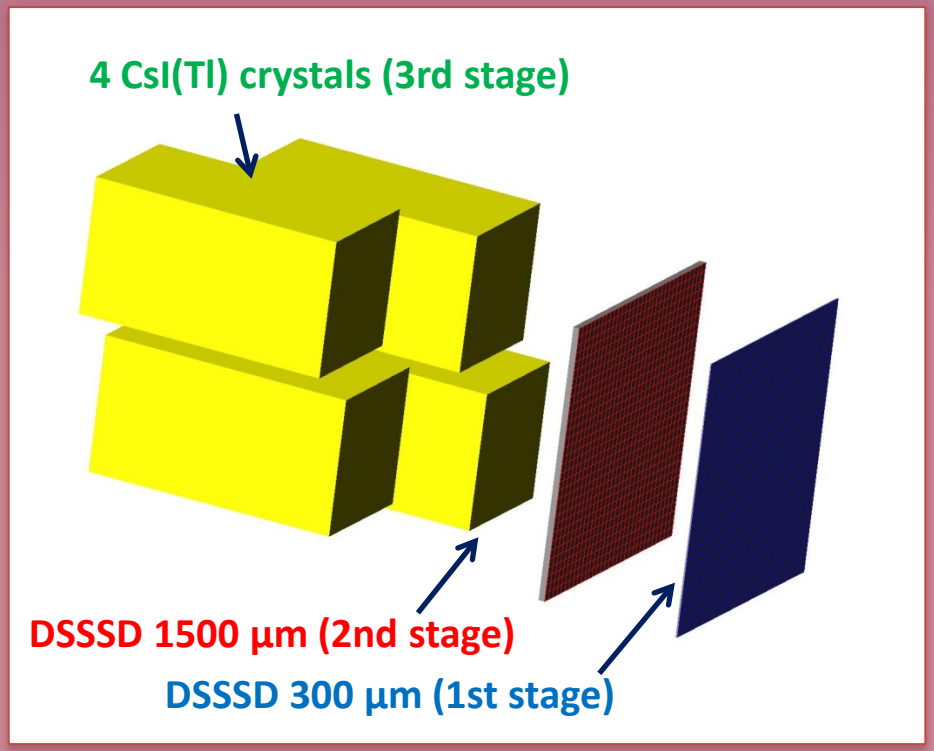
System	N/Z Projectile	N/Z target	N/Z compound
$^{124}Sn+{}^{64}Ni$	1.48	1.29	1.41
$^{124}Xe+{}^{64}Ni$	1.30	1.29	1.29
$^{124}Xe+{}^{64}Zn$	1.30	1.13	1.24
$^{112}Sn+{}^{58}Ni$	1.24	1.07	1.18

A new setup: the 4π CHIMERA + a module of FARCOS prototype

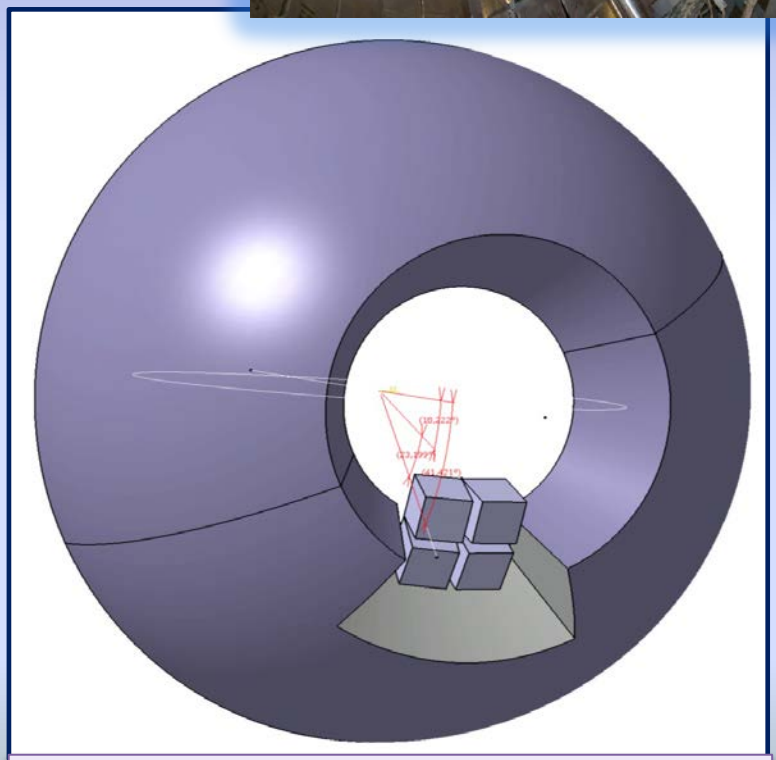
FARCOS: Femtoscope Array for COrrelations and Spectroscopy (INFN, Ganil, Huelva . . .)

- Based on (62x64x64 mm³) clusters
- 1 square (0.3x62x62 mm³) DSSSD 32+32 strips
- 1 square (1.5x62x62 mm³) DSSSD 32+32 strips
- 4 60x32x32 mm³ CsI(Tl) crystals





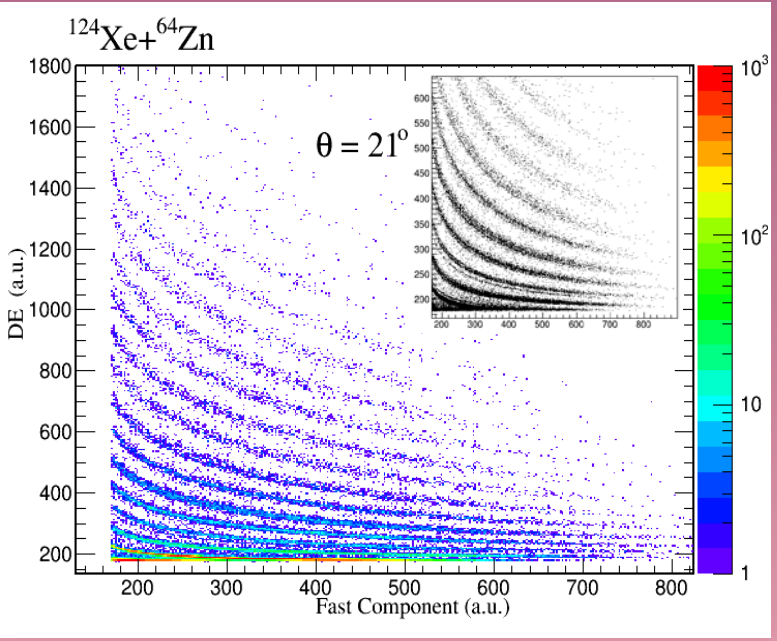
132 channels by each cluster



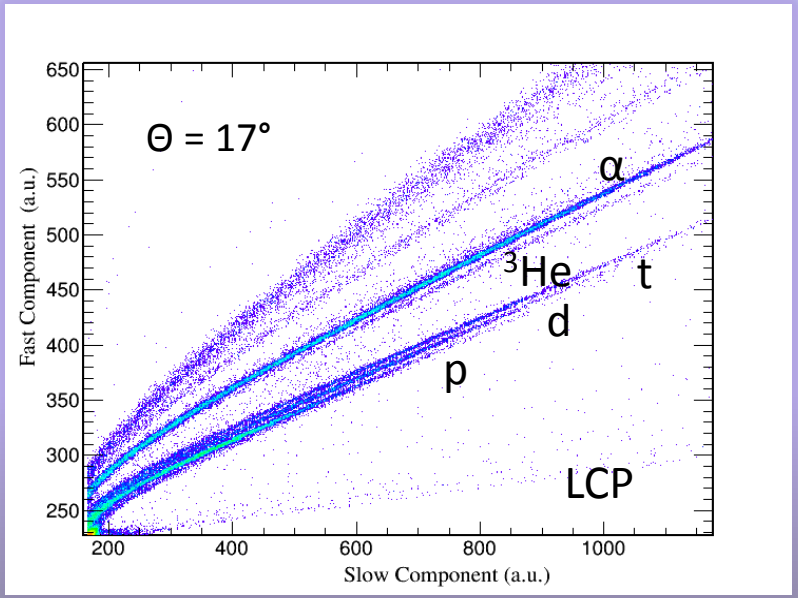
4 telescopes 25 cm from the target
θ_{lab} ~ 15-45 deg, $\Delta\phi$ ~ 75 deg

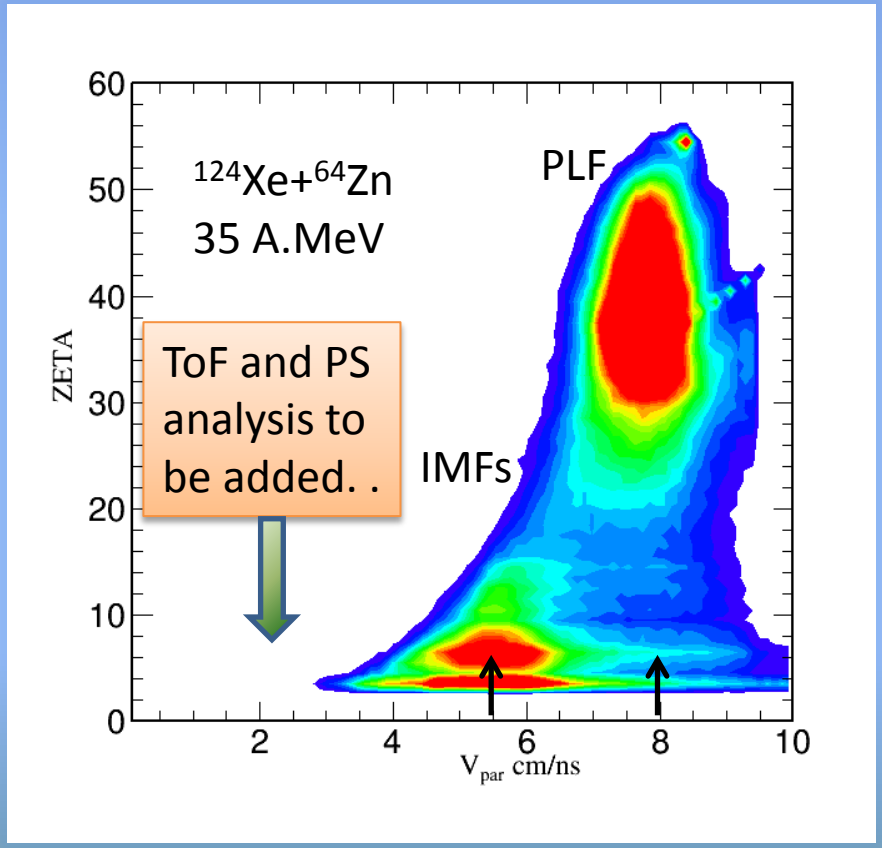
See: E.V. Pagano talk for FARCOS design presentation and results.

InKiIsSy: data analysis: first results

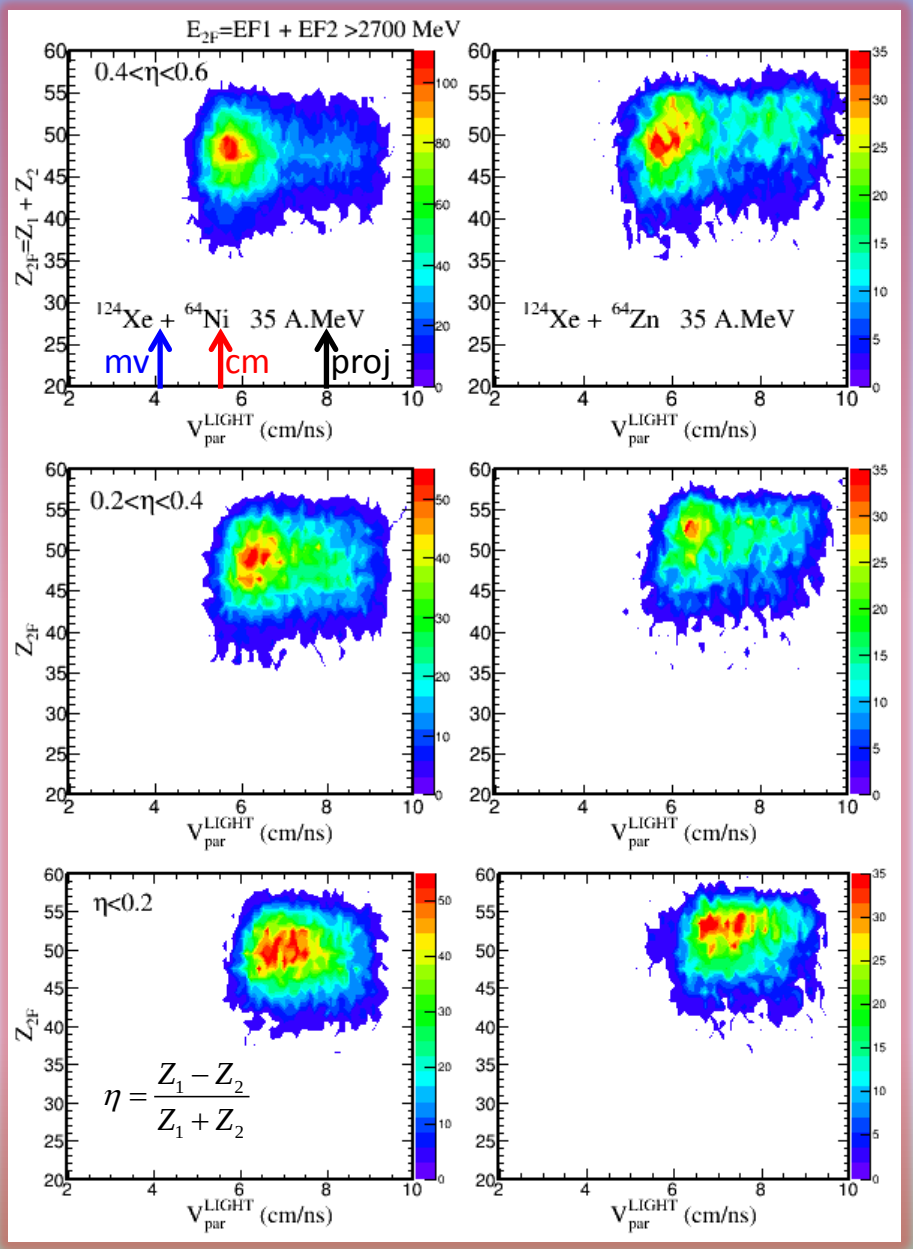


Data analysis (particle's calibration, identification) almost completed for particles punching-trough the 300 µm silicon detectors in the forward rings.





Analysis of the two largest fragments Z_1,Z_2 with V_{par}>4 cm/ns and M_{IMF}<=3, Z1+Z2>35

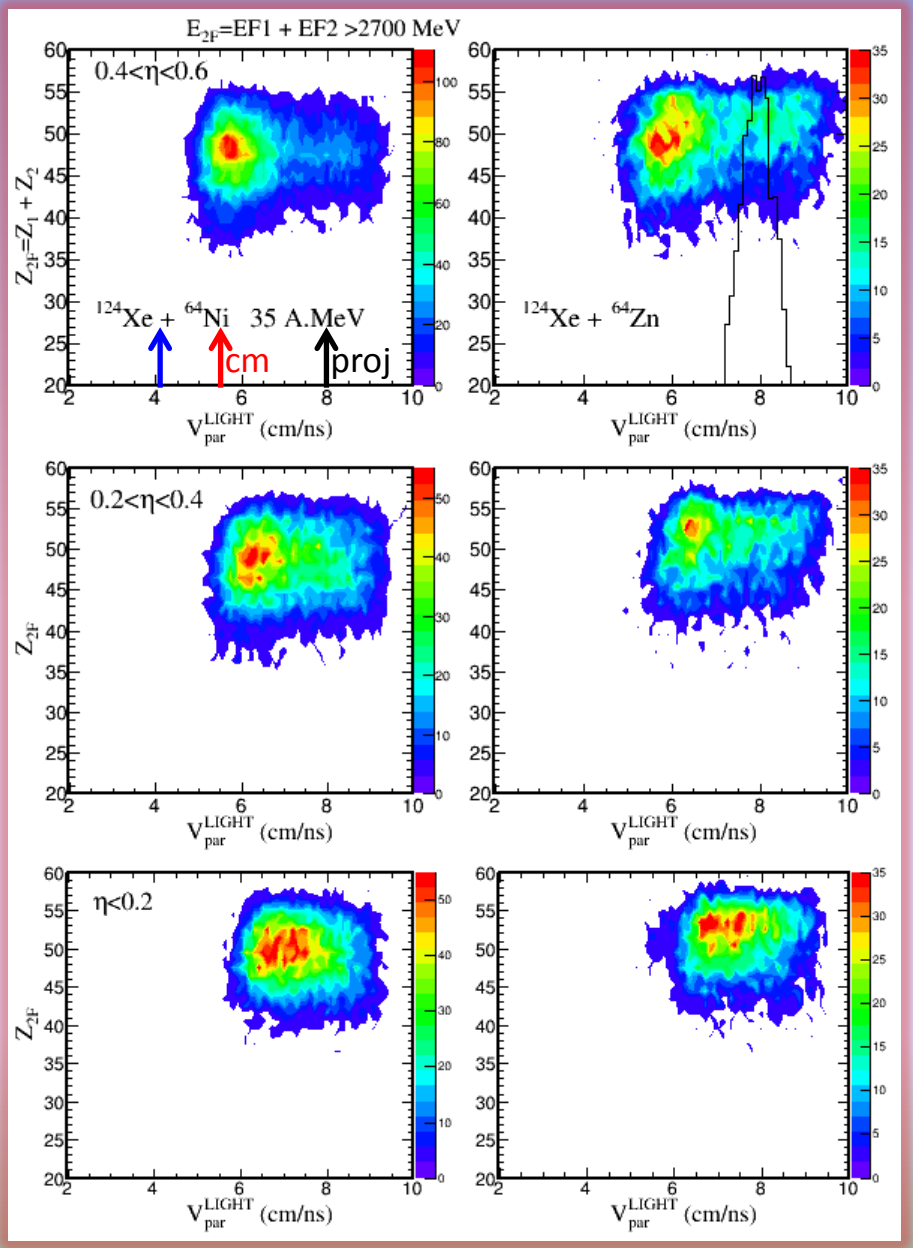


V_{PAR} ofLight fragment Z_2: two velocity components

PRELIMINARY Results

$$\eta = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

Analysis of the two largest fragments Z_1,Z_2 with V_{par}>4 cm/ns and M_{IMF}<=3, Z1+Z2>35

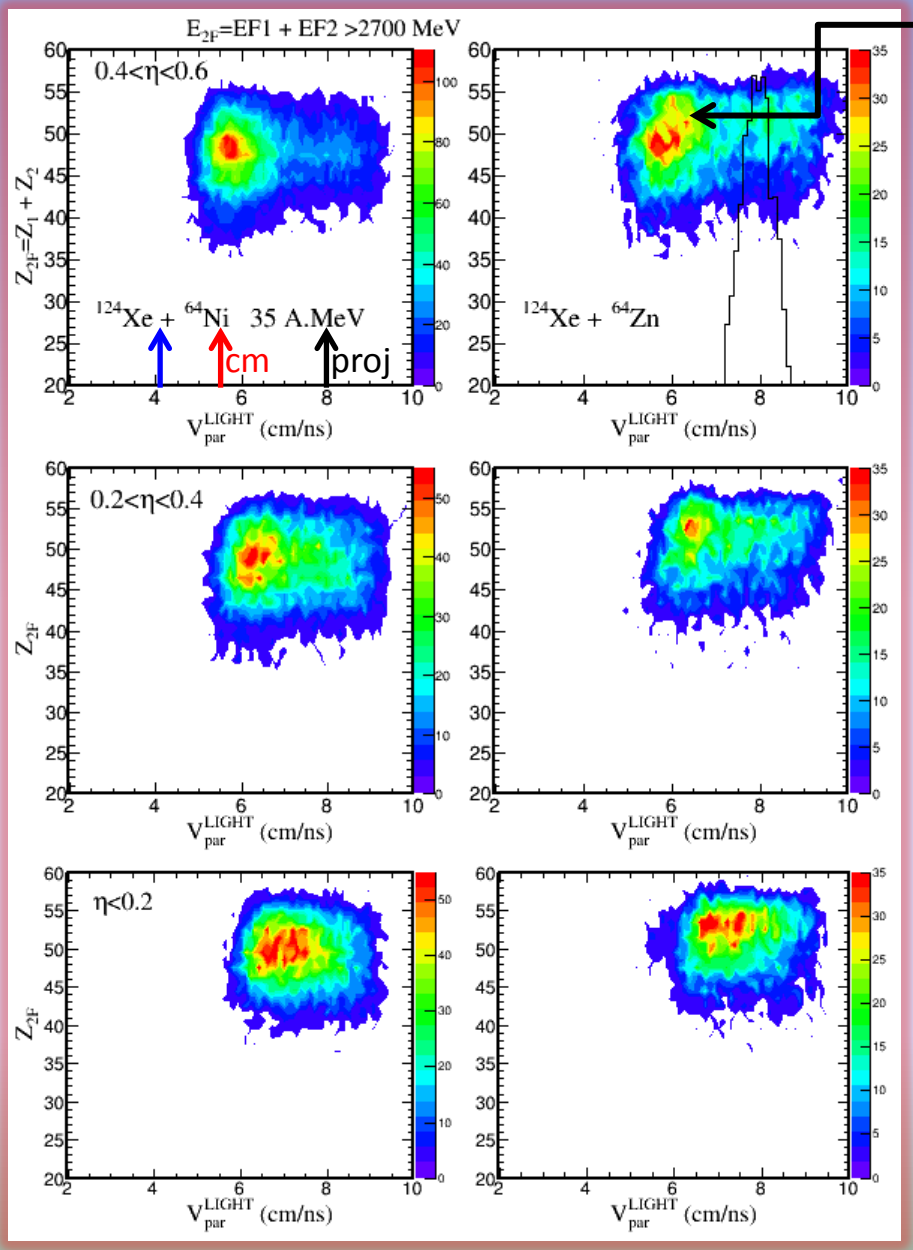


V_{PAR} ofLight fragment Z_2: two velocity components

PRELIMINARY Results

$$\eta = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

Analysis of the two largest fragments Z_1,Z_2 with V_{par}>4 cm/ns and M_{IMF}<=3, Z1+Z2>35

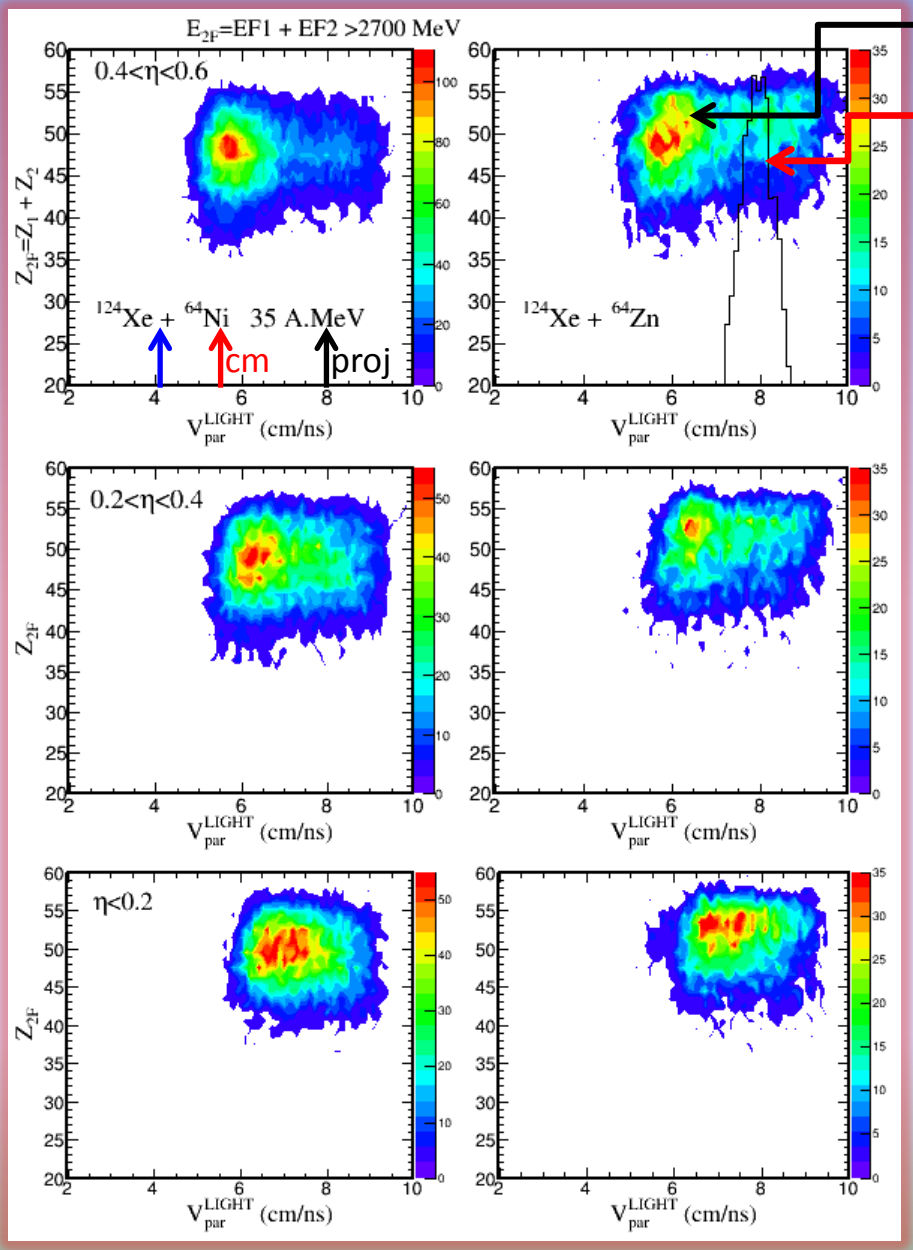


V_{PAR} ofLight fragment Z_2: two velocity components

PRELIMINARY Results

$$\eta = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

Analysis of the two largest fragments Z_1,Z_2 with V_{par}>4 cm/ns and M_{IMF}<=3, Z1+Z2>35

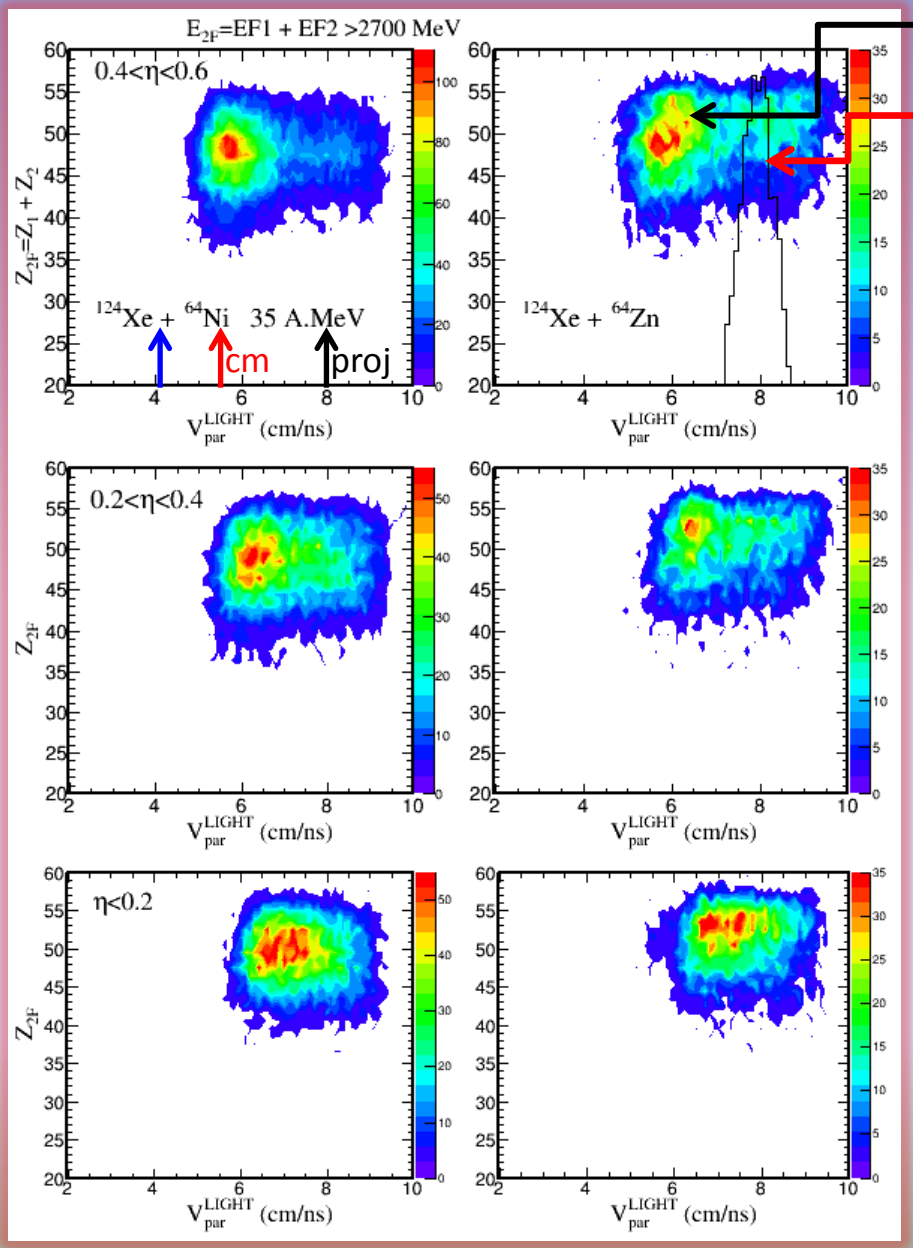


V_{PAR} ofLight fragment Z_2: two velocity components

PRELIMINARY Results

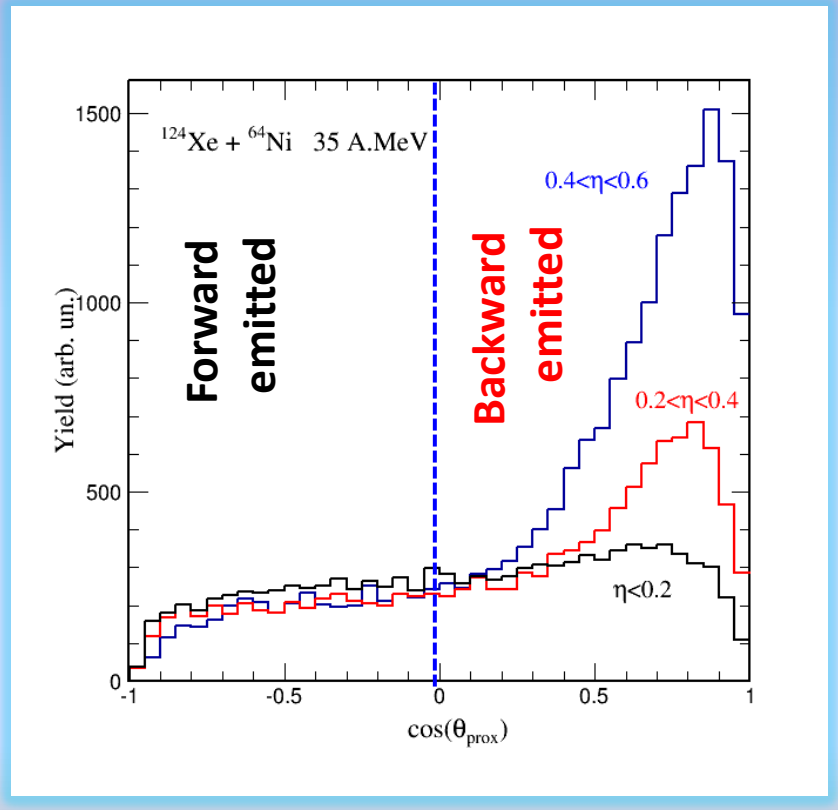
$$\eta = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

Analysis of the two largest fragments Z_1,Z_2 with V_{par}>4 cm/ns and M_{IMF}<=3, Z1+Z2>35



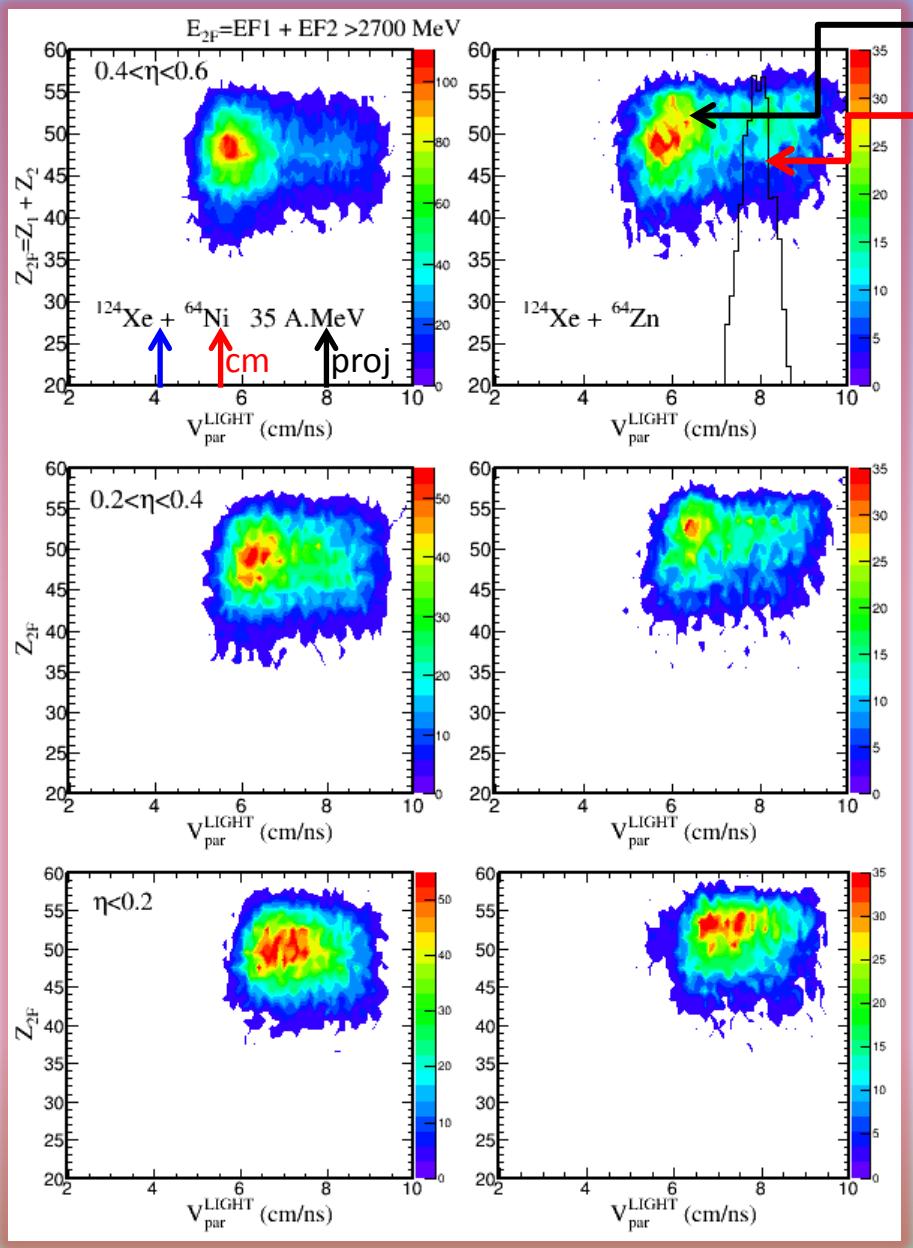
V_{PAR} ofLight fragment Z_2: two velocity components

PRELIMINARY Results



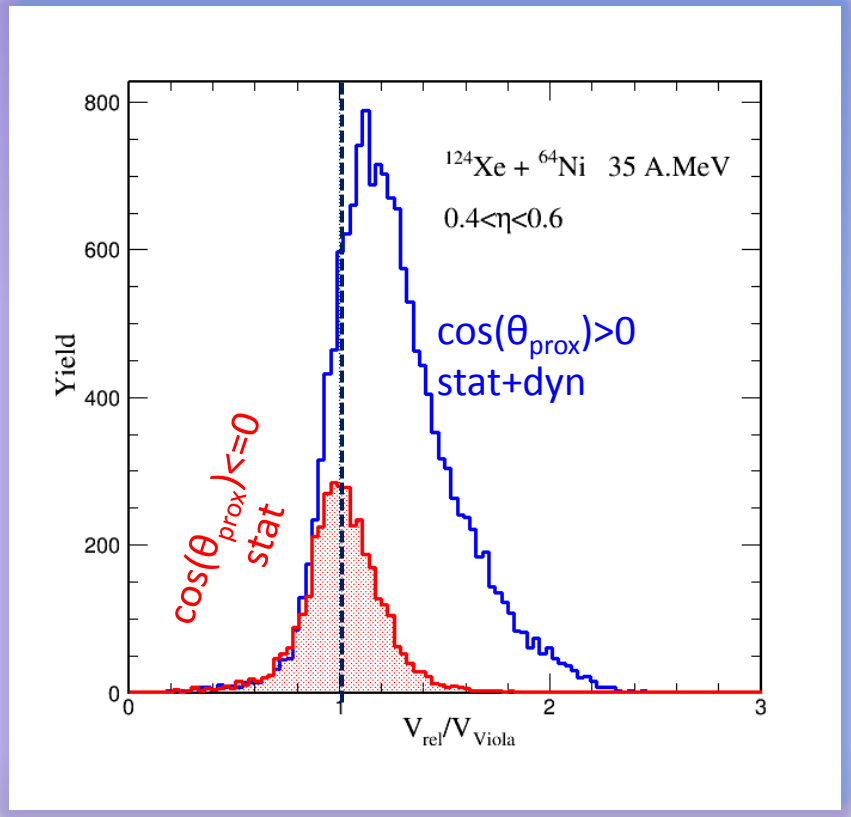
$$\eta = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

Analysis of the two largest fragments Z_1,Z_2 with V_{par}>4 cm/ns and M_{IMF}<=3, Z1+Z2>35



V_{PAR} ofLight fragment Z_2: two velocity components

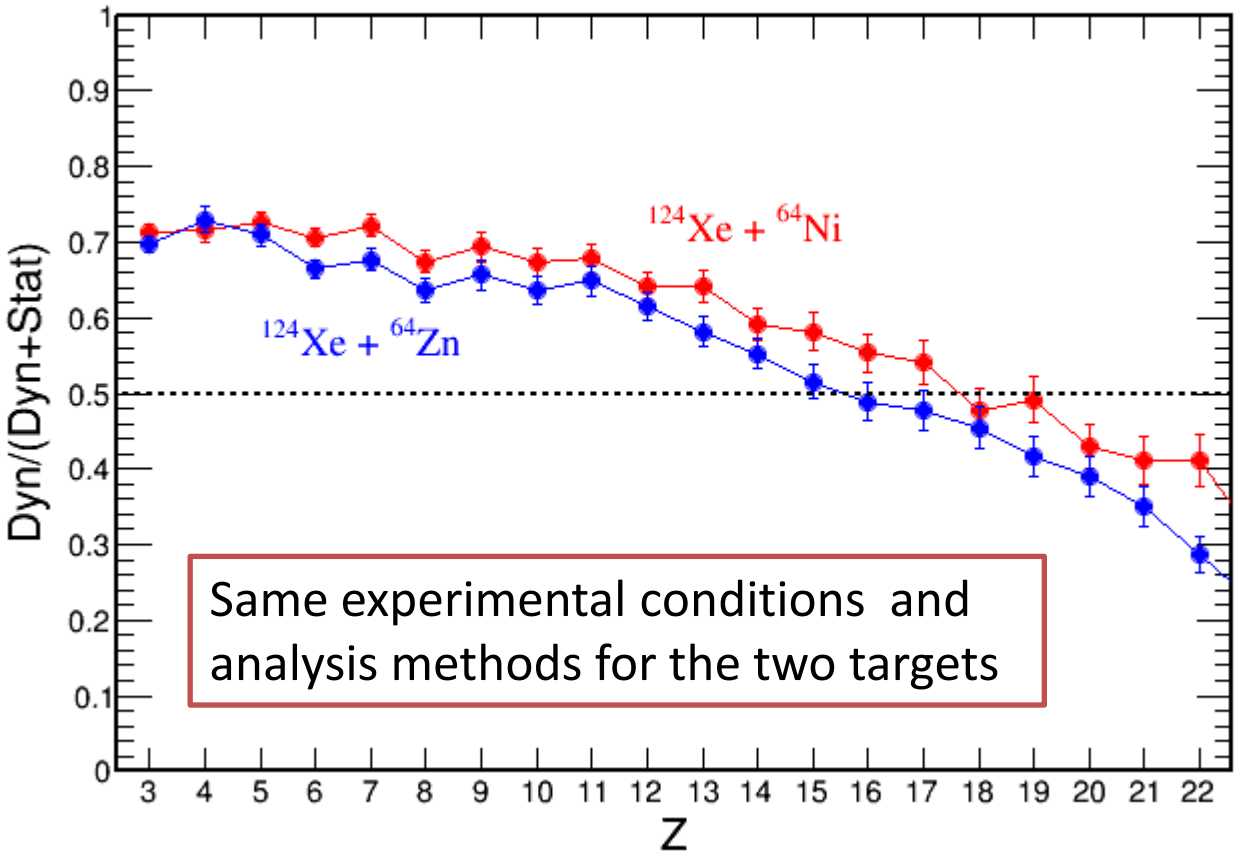
PRELIMINARY Results



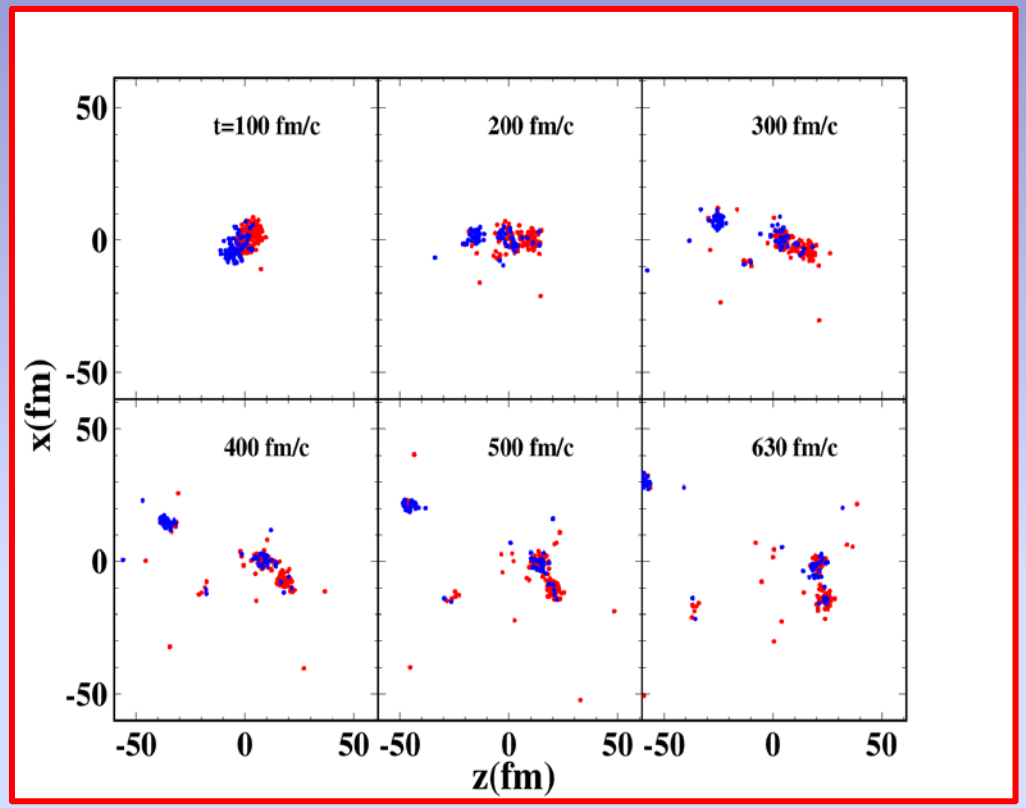
$$\eta = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

Analysis of new data with conditions as similar as possible to the previous Sn + Ni experiment as described in detail in Phys. Rev. C91, 014610 (2015).

PRELIMINARY Results



Constrained Molecular Dynamics simulation on Sn+Ni



CoMD-II time steps of one event leading to PLF fission in **^{124}Sn+^{64}Ni@35 A.MeV**

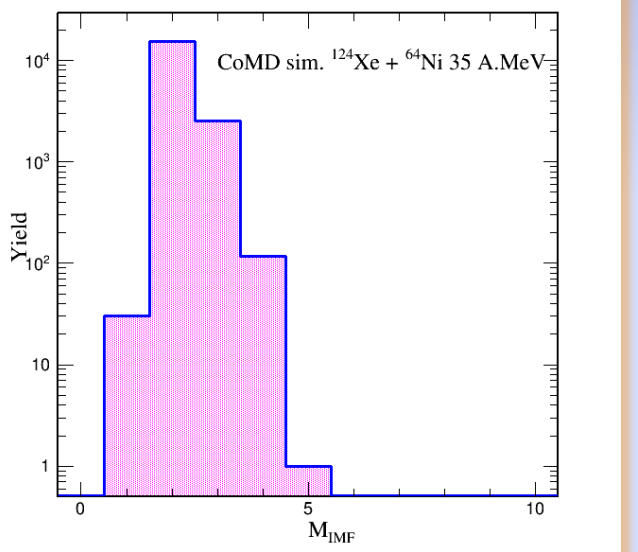
*M. Papa et al. (CHIMERA coll.), PRC **75**, 054616 (2007).*
E. De Filippo and A. Pagano EPJA 50, 32 (2015).

Constrained Molecular Dynamics simulation (CoMD-3)

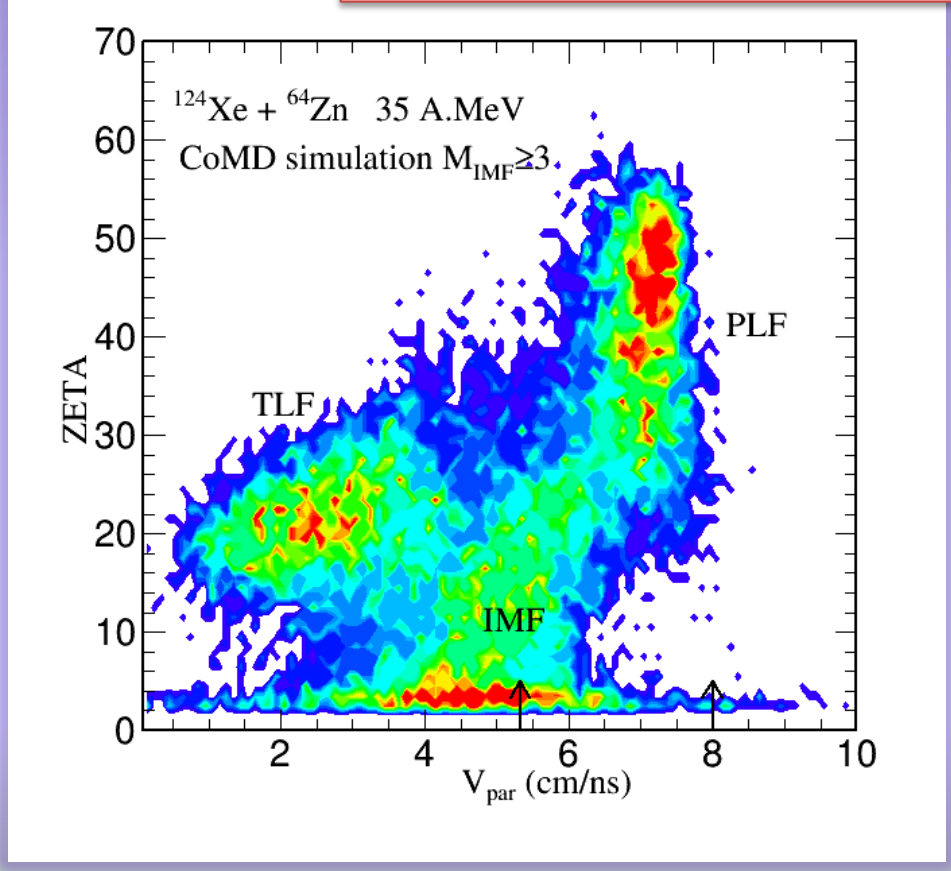
- ✓ 124Xe + 64 Zn @ 35 A.MeV
- ✓ **Preliminary** test at 650 fm/c and stiffness parameter on $E_{sym}(\rho)$, γ=1
- ✓ Checking for projectile break-up events

*Model → see M. Papa, Phys. Rev. **C87,** 014001 (2013) and refs therein*

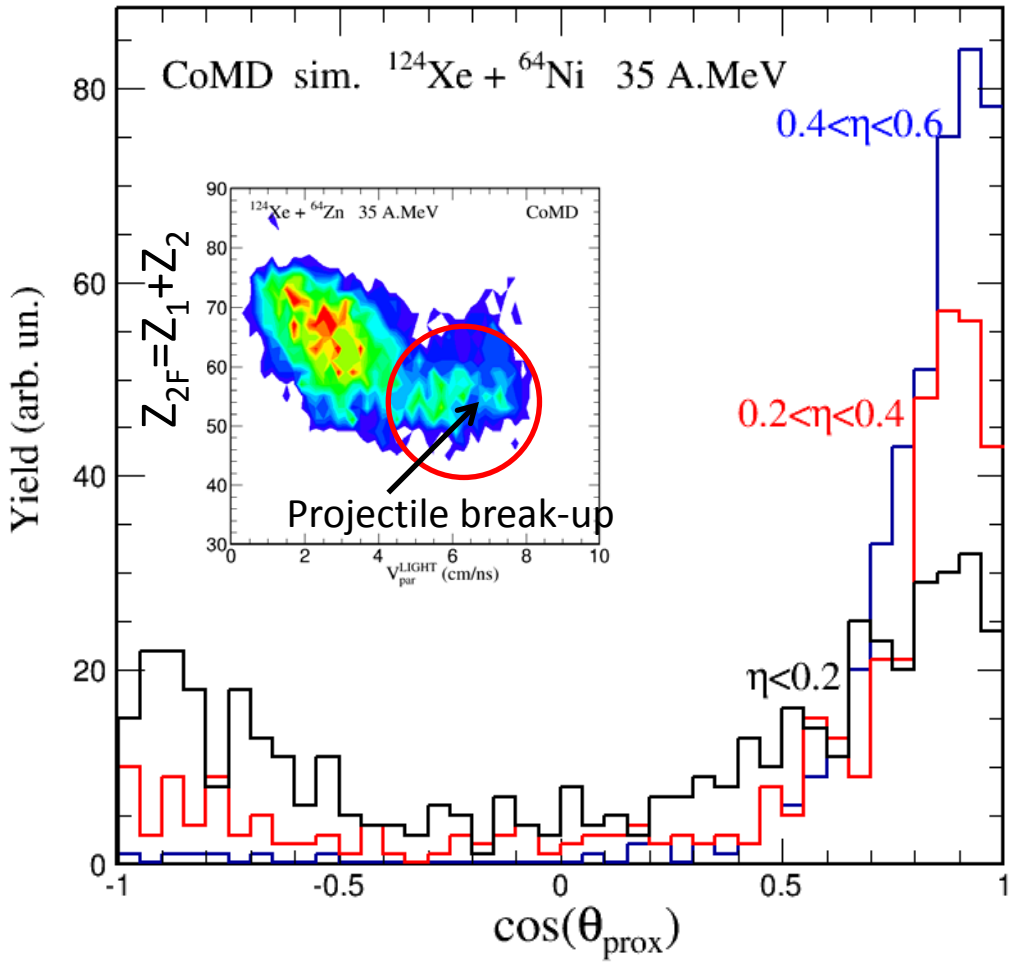
Selection: Three biggest fragments in events with $M_{IMF} \geq 3$

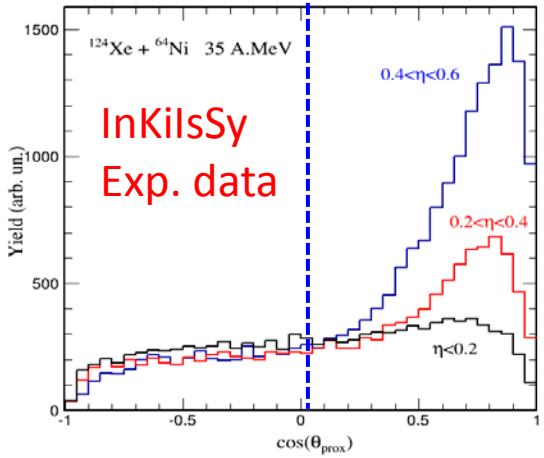


IMFs Multiplicity (b>4 fm)



Constrained Molecular Dynamics simulation (CoMD-3)



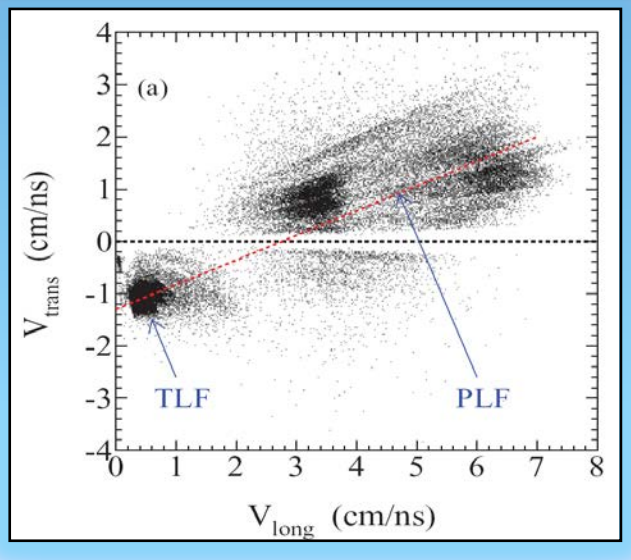


See also: CoMD-2 simulations in ^{64}Zn+^{64}Zn@45 A. MeV
*K. Stiefel, Z. Kohley et al., PRC**90**, 061605 (2014).*

Dynamical fission: interest to extend these studies at lower energies

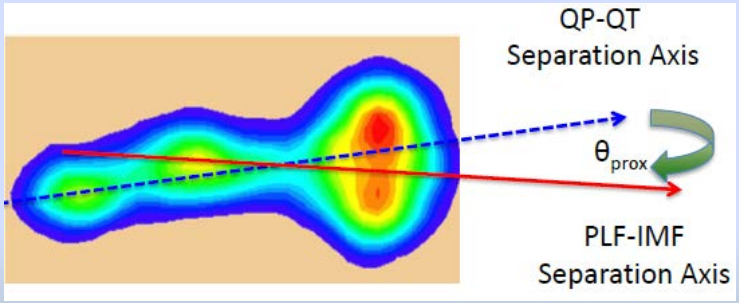
P. Glassel et al., *Zeit. Phys. A 310, 189 (1983)*
Study of ^{84}Kr+^{166}Er and ^{129}Xe+^{122}Sn at 12.5 AMeV. Strong Coulomb proximity effects observed for not fully equilibrated PLF fission.
A. Stefanini et al., ^{100}Mo+^{100}Mo, ^{120}Sn+^{120}Sn at 20 A.MeV, *Z. Phys. A351,167 (1995)*

OLD



Skwira et al. (CHIMERA collaboration)
Phys. Rev. Lett. 101, 262701 (2008)
J. Wilczynski et al., PRC 81, 024605 (2010)
C. Rizzo et al., PRC 90, 054618 (2014).
^{197}Au + ^{197}Au collisions have been studied at 15 AMeV and more recently at 23 A.MeV.
A new process of fast reseparation of this heavy system into three or four fragments of comparable size is observed

NEW



P. Cammarata et al., Texas A&M IWM-2014, *EPJ-WebOfConf vol. 88*
Study of three-body break-up mechanism in ^{136}Xe+^{64}Ni, ^{124}Xe+^{58}Ni, ^{124}Sn+^{64}Ni at 15 A.MeV with FAUST array

RECENT

SPES Letter Of Intent 2014.

1

SPES Letter Of Intent – March 2014

Isospin dependence of compound nucleus formation and decay

E.DeFilippo (INFN - Catania), J.D.Frankland (GANIL Caen), S.Pirrone (INFN - Catania), G.Politi (Univ. and INFN – Catania), Russotto (INFN-Catania)

G.Ademard (IN2P3 - IPN Orsay), L.Auditore (INFN – Gr. coll. and Univ. Messina), C.Beck (IN2P3 - IPHC Strasbourg), E.Bonnet (GANIL Caen), B.Borderie (IN2P3 - IPN Orsay), T.Cap (Univ. of Warsaw), G.Cardella (INFN – Sez. Catania), M.Colonna (INFN-LNS), E.DeFilippo (INFN – Sez. Catania), B.Gnoffo (Univ. di Catania), E.Henry (Univ. of Rochester, USA), M.La Commara (Univ. and INFN – Napoli), G.Lanzalone (INFN – LNS and Univ. Enna "Kore"), N.LeNeindre (IN2P3 - LPC Caen), I.Lombardo (INFN Sez. and Univ. di Napoli), T.Minniti (Univ.of Catania), S.Norella (INFN – Gr. coll. and Univ. Messina), A.Pagano (INFN- Sez. Catania), E.V.Pagano (INFN-LNS and Univ. Catania), M.Papa (INFN - Sez. Catania), E.Piasecki (Univ. of Warsaw), L.Quattrocchi (INFN – Gr. coll. and Univ. Messina), M.F.Rivet (IN2P3 – IPN Orsay), F.Rizzo (INFN – LNS and Univ. Catania), (Univ. of [illegible] Napoli), A.Trifirò (INFN – Gr. coll. and Univ. Messina), J.Toke (Univ. of Rochester, USA), M.Trimarchi (INFN – Gr. coll. and Univ. Messina), G.Verde (INFN -Sez. Catania), M.Vigilante (INFN and [illegible]

SPES letter of intent 2014

1) **The study of the isospin dependence on compound nucleus formation and decay (ISODEC scientific program, *see B. Gnoffo talk FF session*).**

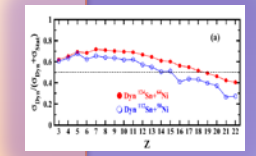
2) **The study of the influence of the isospin on the competition between Statistical and Dynamical Fission processes.**

Interest in the intermediate mass region: Kr, Sr, Sn beams on Ca, Ni

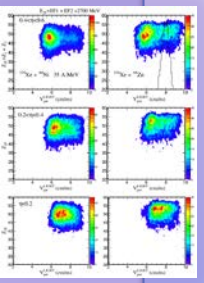
- $^{88\text{-}94}$Kr with 10^5 - 10^7 pps @ E/A = 10 - 12 MeV/A
- Sn or Cs exotic beams on target of Ca, Ni and Sn isotopes

Summary

The evaluation of cross-sections for dynamical and statistical IMFs emission has shown that the dynamical emission is enhanced for a neutron rich system while the statistical emission is equally probable for the two systems .

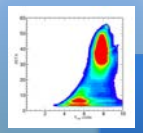


The dynamical IMF emission can be a good probe in order to contraint the density dependence of the symmetry energy but this need calculations following the full range of time-scales and IMF mass emission involved in PLF binary splitting. **Still a challenge for dynamical models (SMF, CoMD. . .).**



We have shown **first results of the Inkiissy** experiment, ^{124}**Xe+**^{64}**Zn,**^{64}**Ni** at 35 A.MeV using a system that is isobaric with the ^{124}**Sn+**^{64}**Ni** one. In this experiment a first prototype of a Farcos block (4 telescopes) was used coupled to the Chimera 4π detector. **IMF-IMF** correlations in Farcos will improve our capability to analyse events with $M_{IMF}>1$. As well Farcos will permit to study **p-p** correlations in more central collisions.

Sensitivity of N/Z ratio to dynamical fission: this effect could be new signature or probe of Isospin effect in reaction mechanisms.



Inkilssy data analysis …… continue

The INKIISSY experiment at LNS:

Spokes: P. Russotto, E. De Filippo, A. Pagano

L. Acosta, L. Auditore, V. Baran, T. Cap, G. Cardella, M. Colonna, E. De Filippo, L. Francalanza, B. Gnoffo, G. Lanzalone, I. Lombardo, C. Maiolino, T. Minniti, G. Marquinez-Durán, S. Norella, A. Pagano, E.V. Pagano, M. Papa, E. Piasecki, S. Pirrone, G. Politi, F. Porto, L. Quattrocchi, F. Rizzo, E. Rosato, P. Russotto, K. Siwek-Wilczynska, A. Trifirò, M. Trimarchi, G. Verde, M. Vigilante, J. Wilczyński