E. De Filippo (INFN Catania) for the EXOCHIM collaboration

INFN Istituto Nazionale di Fisica Nucleare

Probing the symmetry energy at low density using observables from neck fragmentation mechanism

The TimeScale experiments in direct ^{64,58}Ni + ^{124,112}Sn and reverse ^{124,112}Sn+^{64,58}Ni kinematics at 35 A.MeV

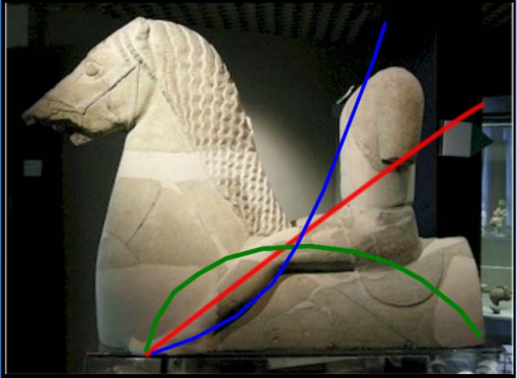
Time scale sequence in midvelocity fragments emission: correlations with the isospin dynamics.

Even-odd effects in light fragments for different production mechanisms

Comparisons with SMF+GEMINI calculations. Probing the symmetry energy term of EOS.

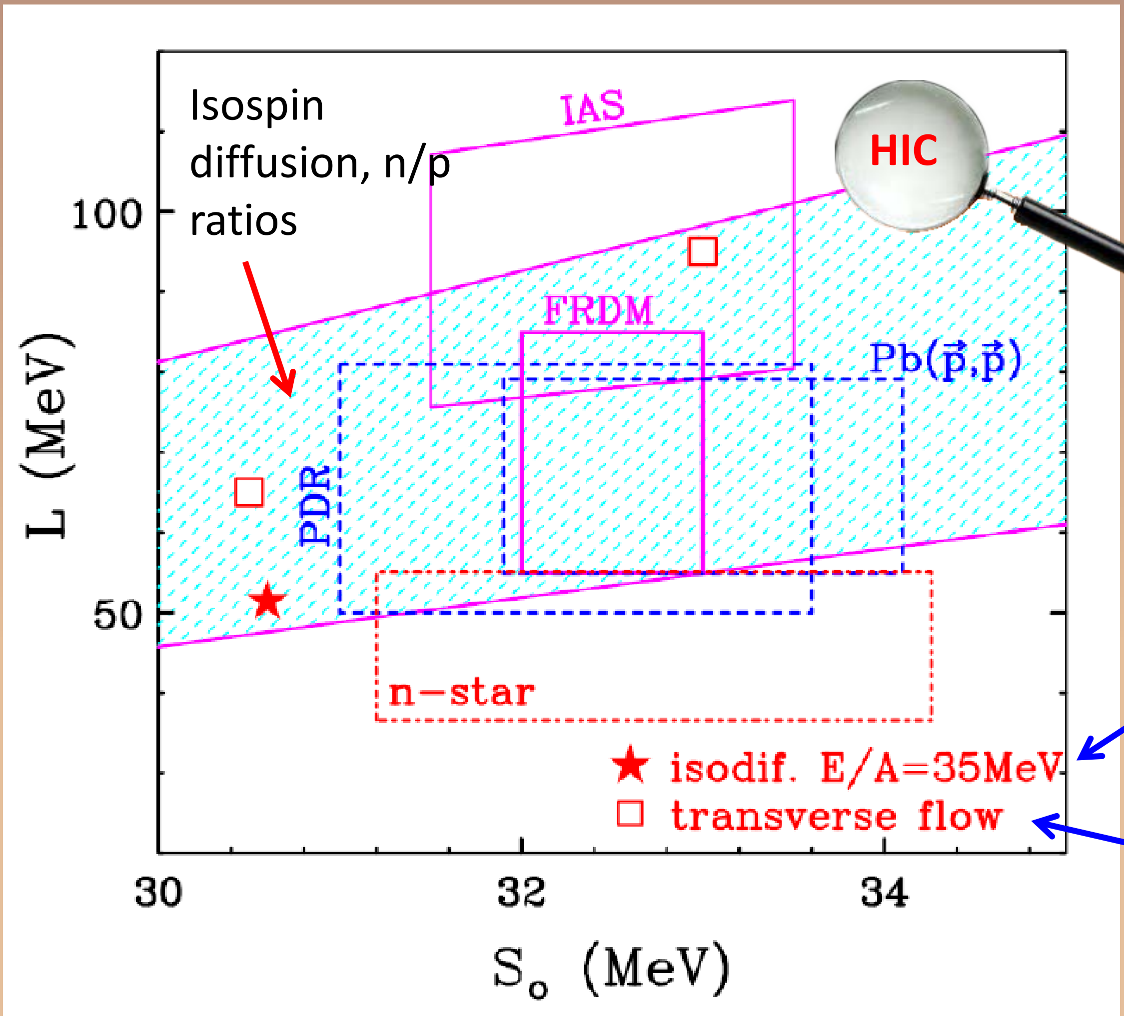
New prospectives and plans for the future with the Chimera + Farcos device.

AsyEoS SIRACUSA



September 4-6 2012

Constraining the symmetry energy around and below normal nuclear density



M.B. Tsang et al, Phys. Rev. C86, 015893 (2012)

$$E(\rho,\delta) = E(\rho,\delta=0) + E_{sym}(\rho)\delta^2$$

$$\delta = \frac{\rho_n - \rho_p}{\rho}$$ **isospin asymmetry**

$$L = 3\rho_0 \frac{dE_{sym}(\rho)}{d\rho}$$ Slope

$S_0 = E_{sym}(\rho_0)$ Strenght

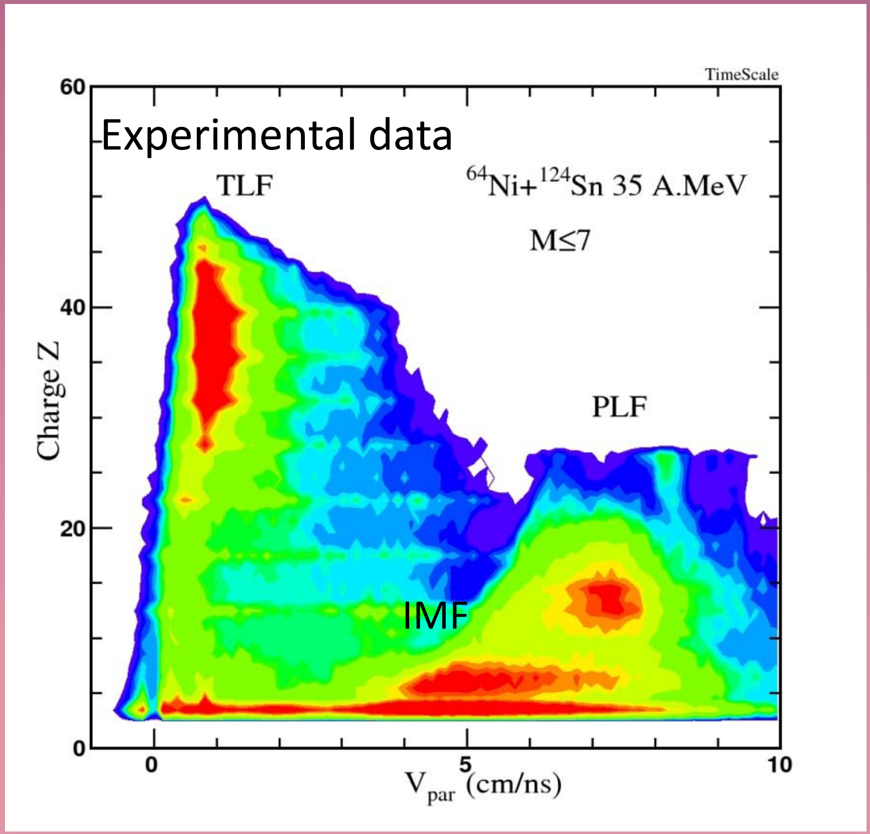
MSU-Chimera data: Z.Y. Sun et al. PRC 82 051603(R) 2010

Texas A&M data, Z. Kohley et al., PRC 83, 044601 (2011)

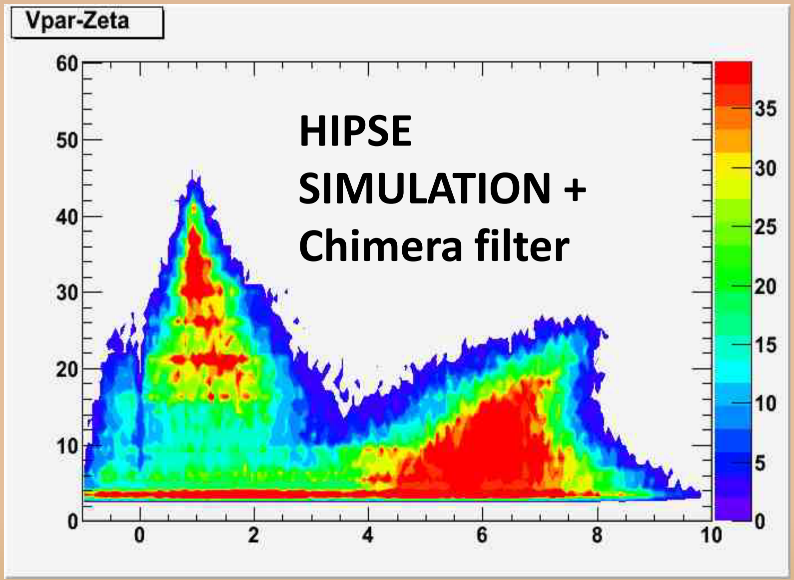
IAS = Isobaric Analog States (Danielewicz/Lee)
PDR = Pygmy dipole resonance (Klimkiewicz et al.)
FRDM = Finite Range Droplet Model (Moller et al.)

$$S(\rho) = S_0 + \frac{L}{3}\left(\frac{\rho-\rho_0}{\rho_0}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho_0}\right)^2 + ...$$

TimeScale experiment: 35 A.MeV $^{64}Ni + ^{124}Sn$ and $^{58}Ni + ^{112}Sn$ in direct kinematics

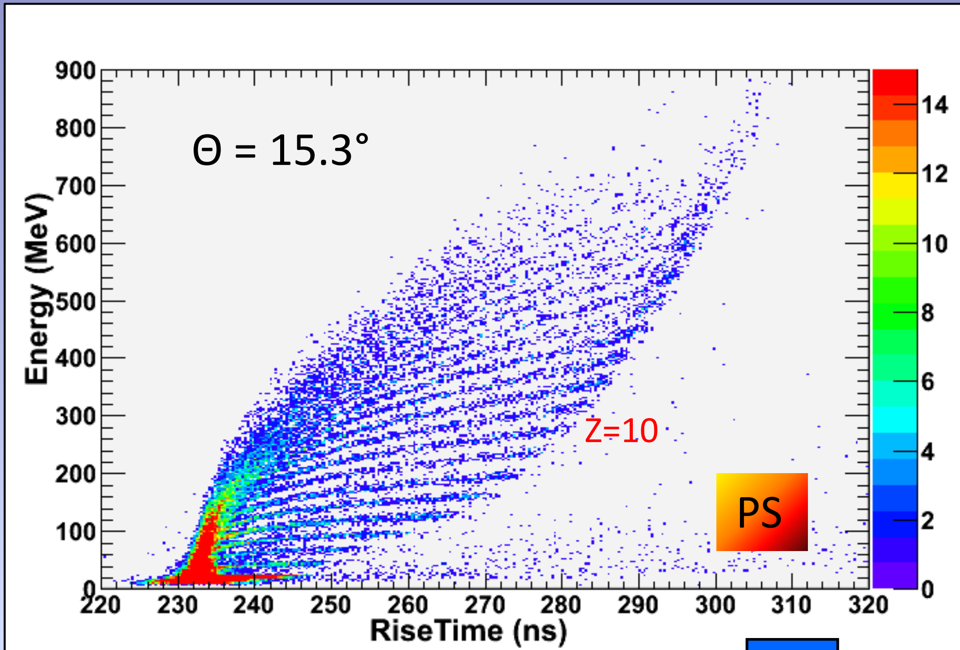


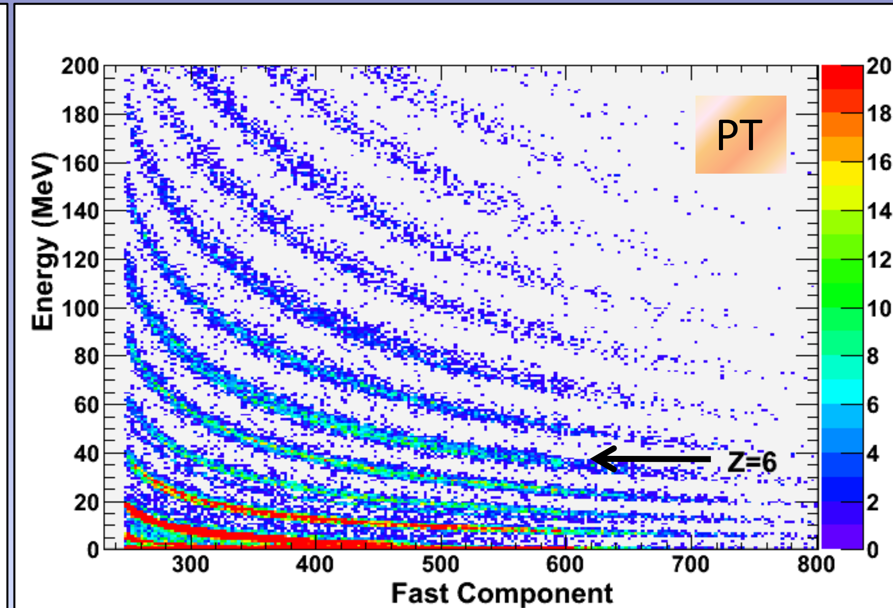
Almost complete events:
$p/p_{tot} > 60\%$ $Z/Z_{tot} > 60\%$
$M_{tot} \leq 7$

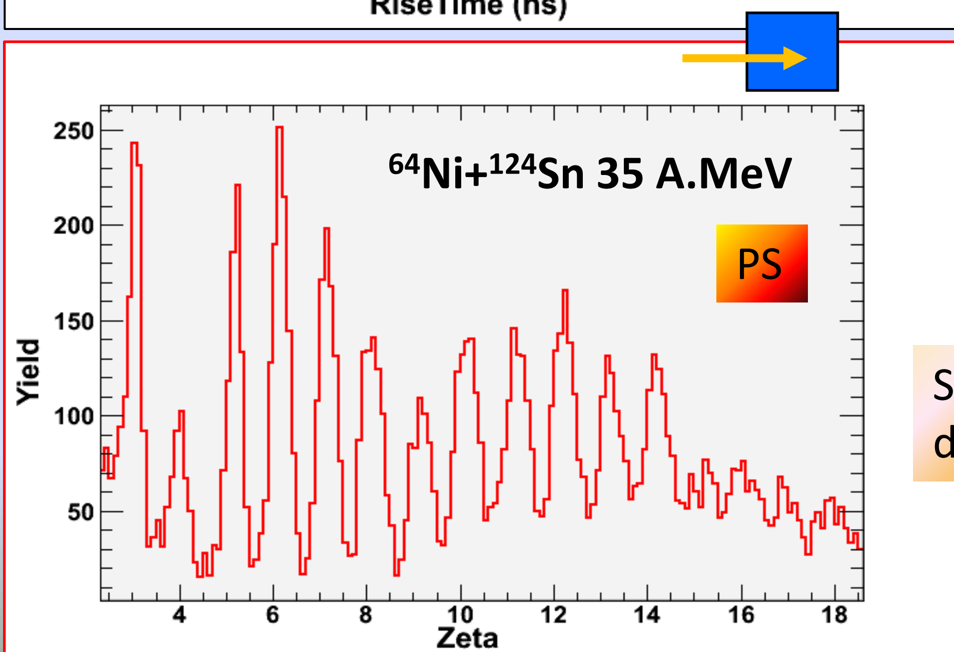


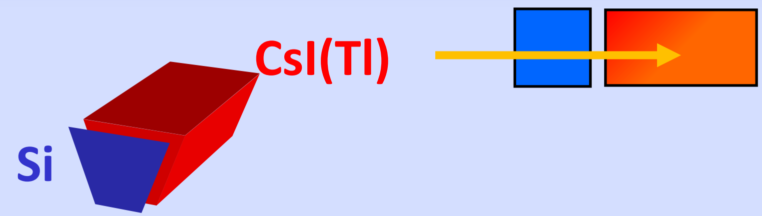
See also: E.d.F. et al., NN2012 *Conference Proceedings*, S. Antonio (Texas, USA), May 27-June 1 2012, to appear in JPCS.
R. Gianì, *Master thesis* (2012).

PulseShape Analysis in TimeScale experiment









Si-stopped Z distribution

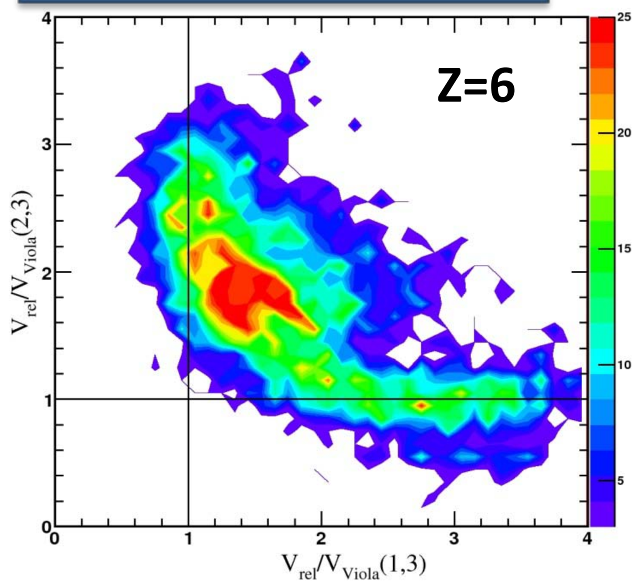
Correlation between Isospin Dynamics and emission Time-scale

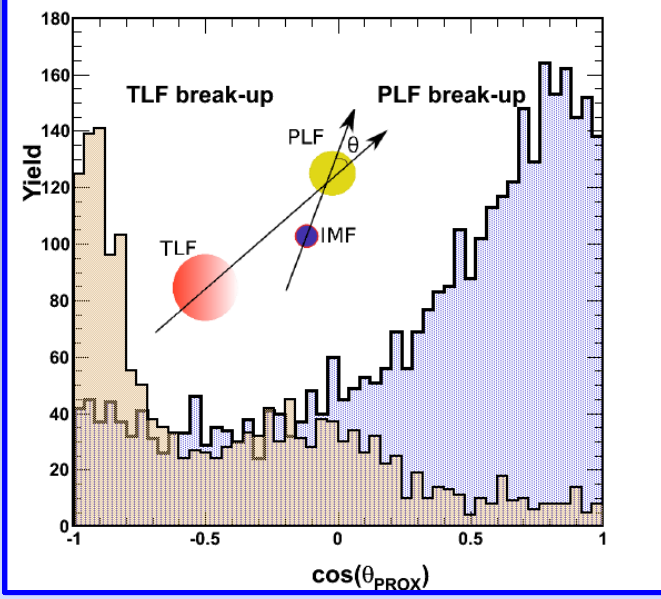
- ❑ Disentangling dynamic and statistical emission: space-time characterization and correlations.
- ❑ Study of isotopic composition of fragments: isospin migration, neutron enrichment.
- ❑ Calculations: probing the density dependency of the symmetry energy using these new observables

Disentangling dynamical vs. statistical emission in ternary events

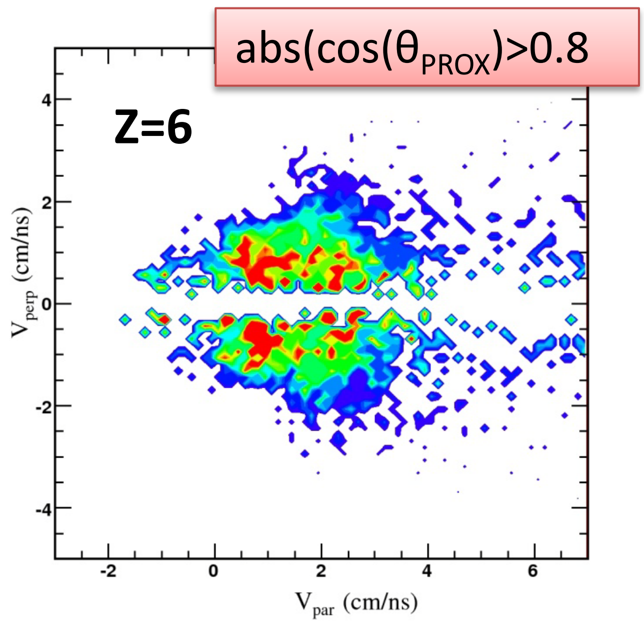
$^{64}Ni+^{124}Sn$ 35 A.MeV

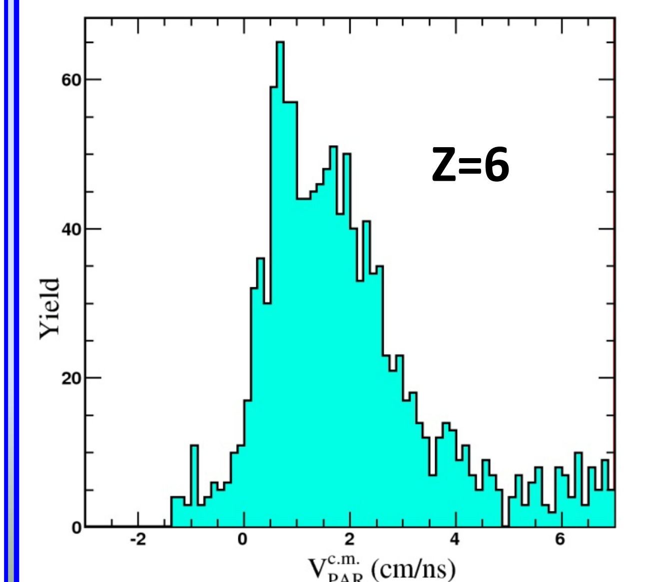
preliminary

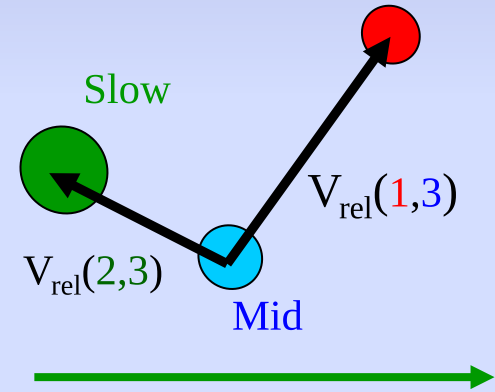




cos(θ)≈±1
aligned emission of the lighter fragment in the backward emisphere of **PLF** (+1) and **TLF** (-1) towards midrapidity



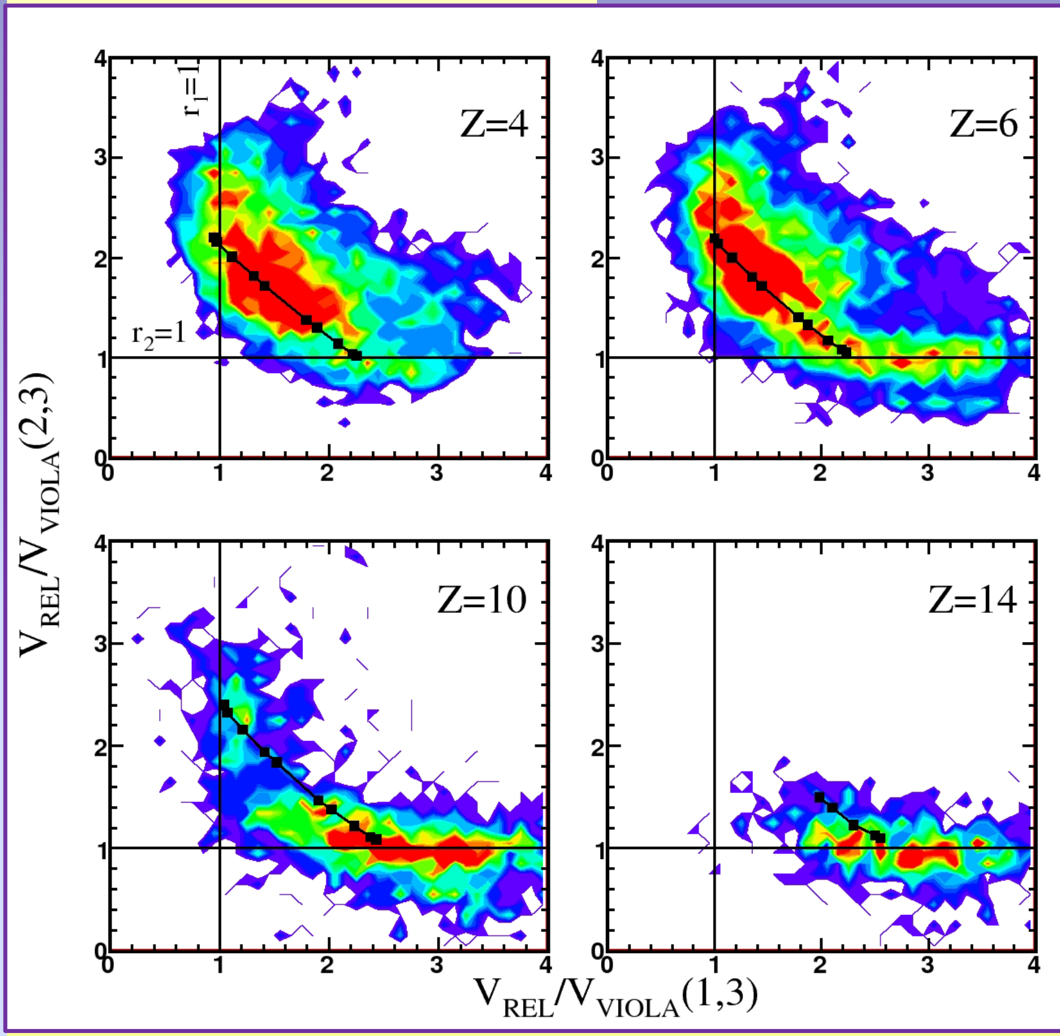


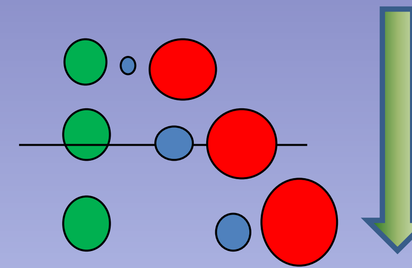


The three heaviest fragments are ordered according to decreasing value of parallel velocity.

3-BODY CORRELATIONS IN TERNARY EVENTS

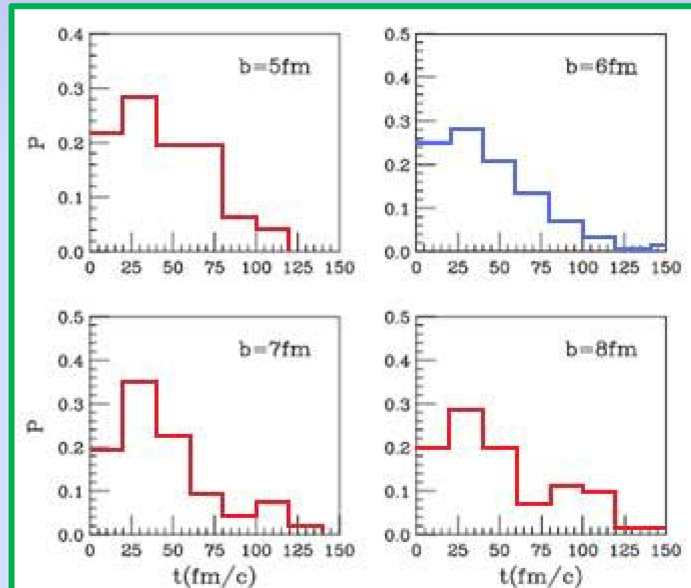
^{64}Ni+ ^{124}Sn + 35 A.MeV





30 fm/c
……
80 fm/c
120 fm/c

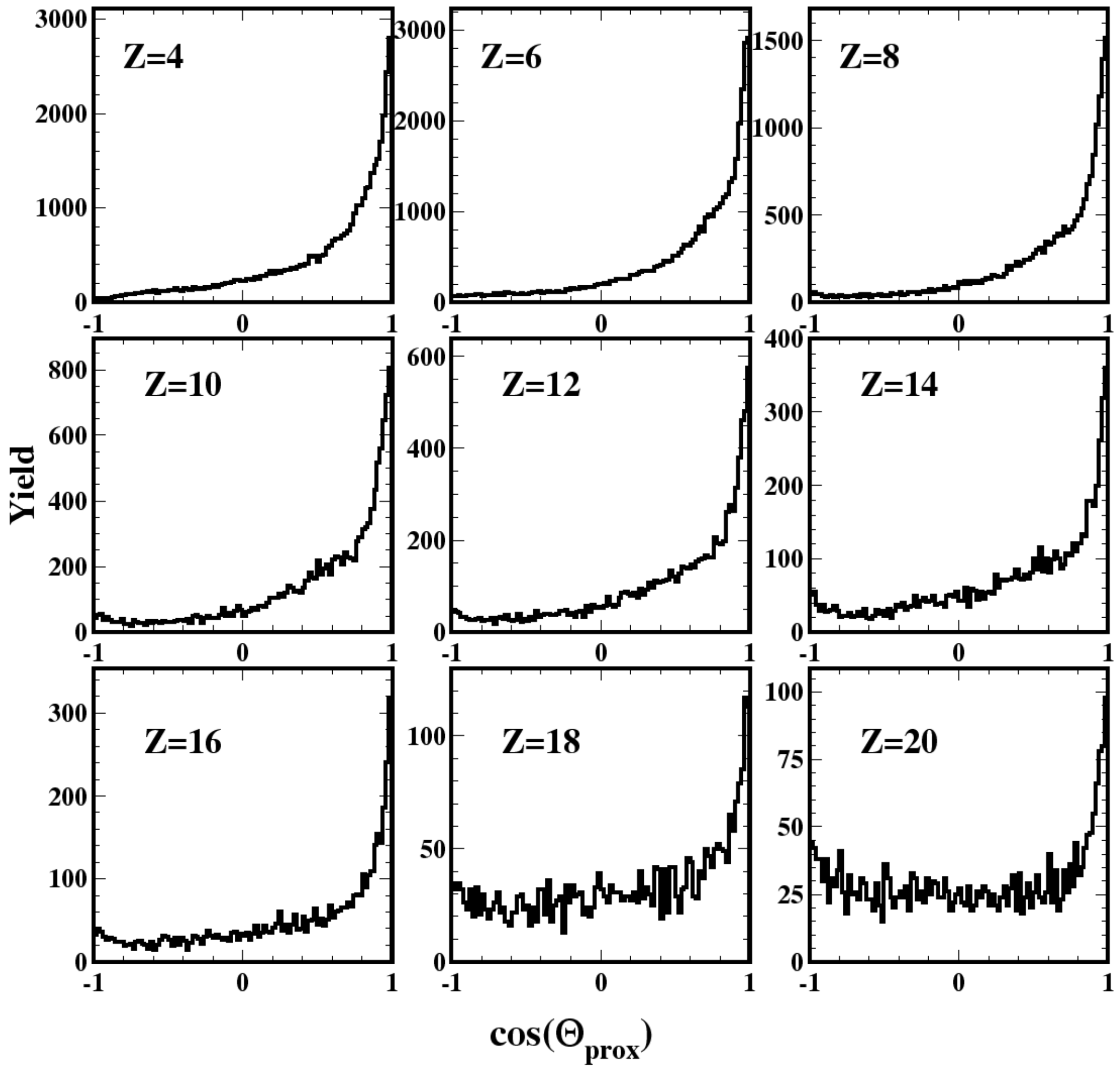
Emission cronology: light fragments are produced earlier (~40 fm/c) than heavier ones (~120 fm/c)



Relative velocities are expressed in units of the velocity corresponding to the Coulomb repulsion energy of a given subsystem according to the Viola systematics (Nucl. Phys. A472, 318 (1987).

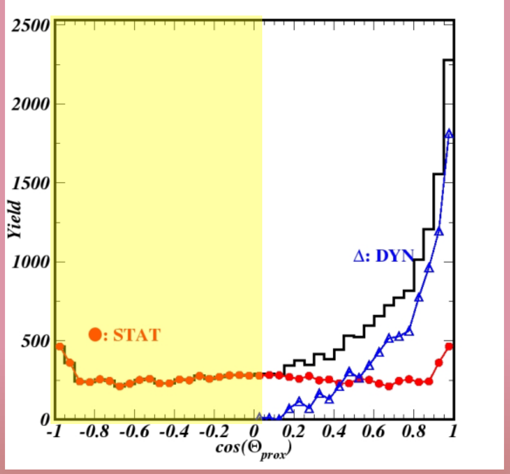
SMF: ^{124}Sn+^{64}Ni probability of scission-to-scission time in neck fragmentation. *V. Baran et al. Phys. Rep 410, 335 (2005)*

Angular distributions: Reverse kinematics experiment

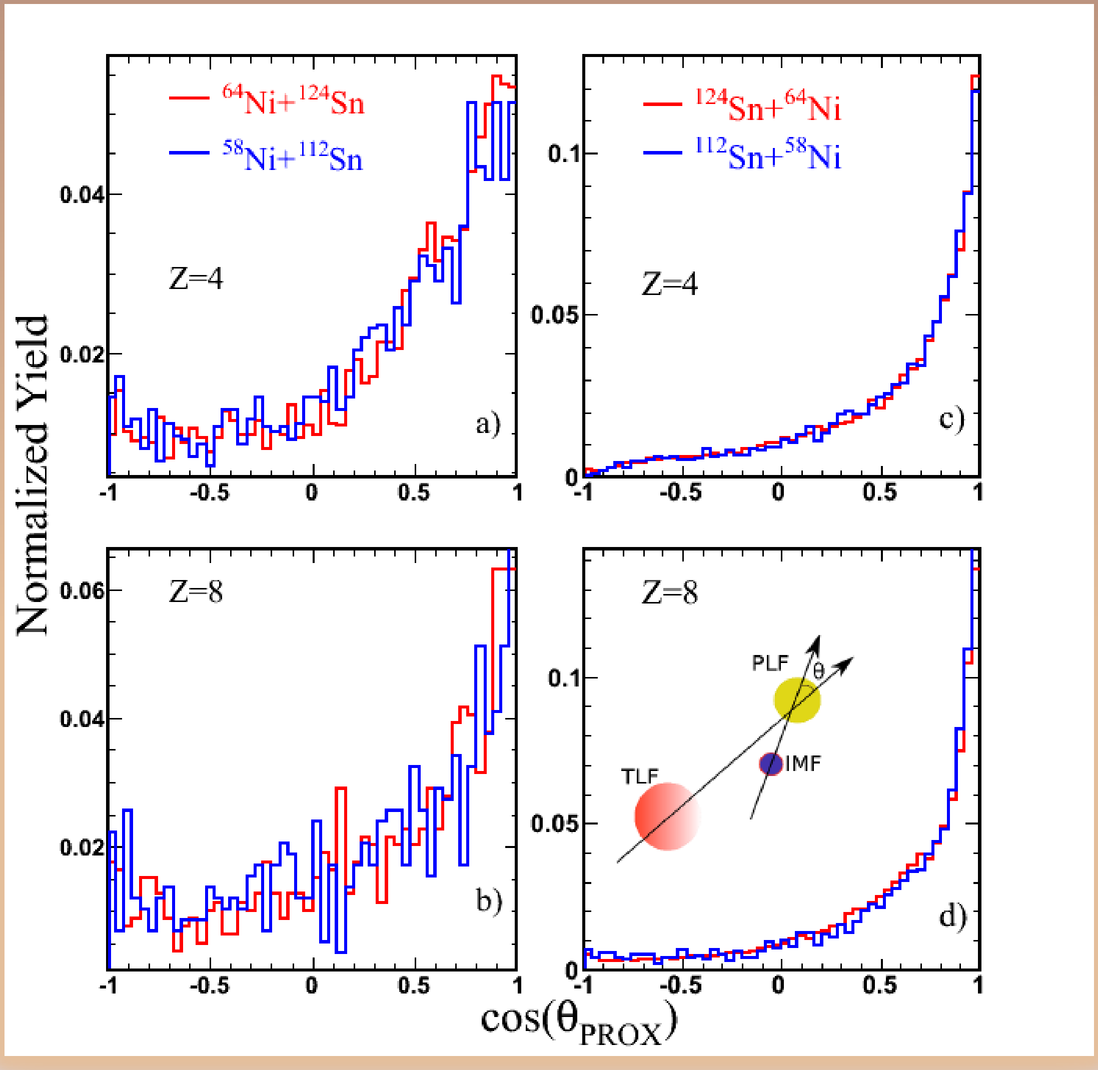


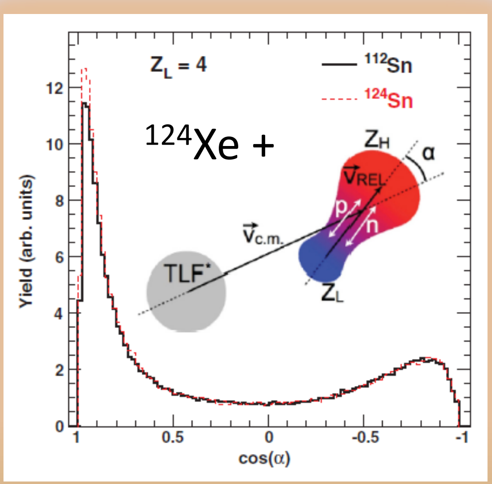
cos(Θ_{prox}) distribution for different IMFs.

They can be seen as a superposition of a forward/backward symmetric distribution and an asymmetric one.



Angular distributions: PLF break-up in **direct** (left) and **reverse** (right) kinematics



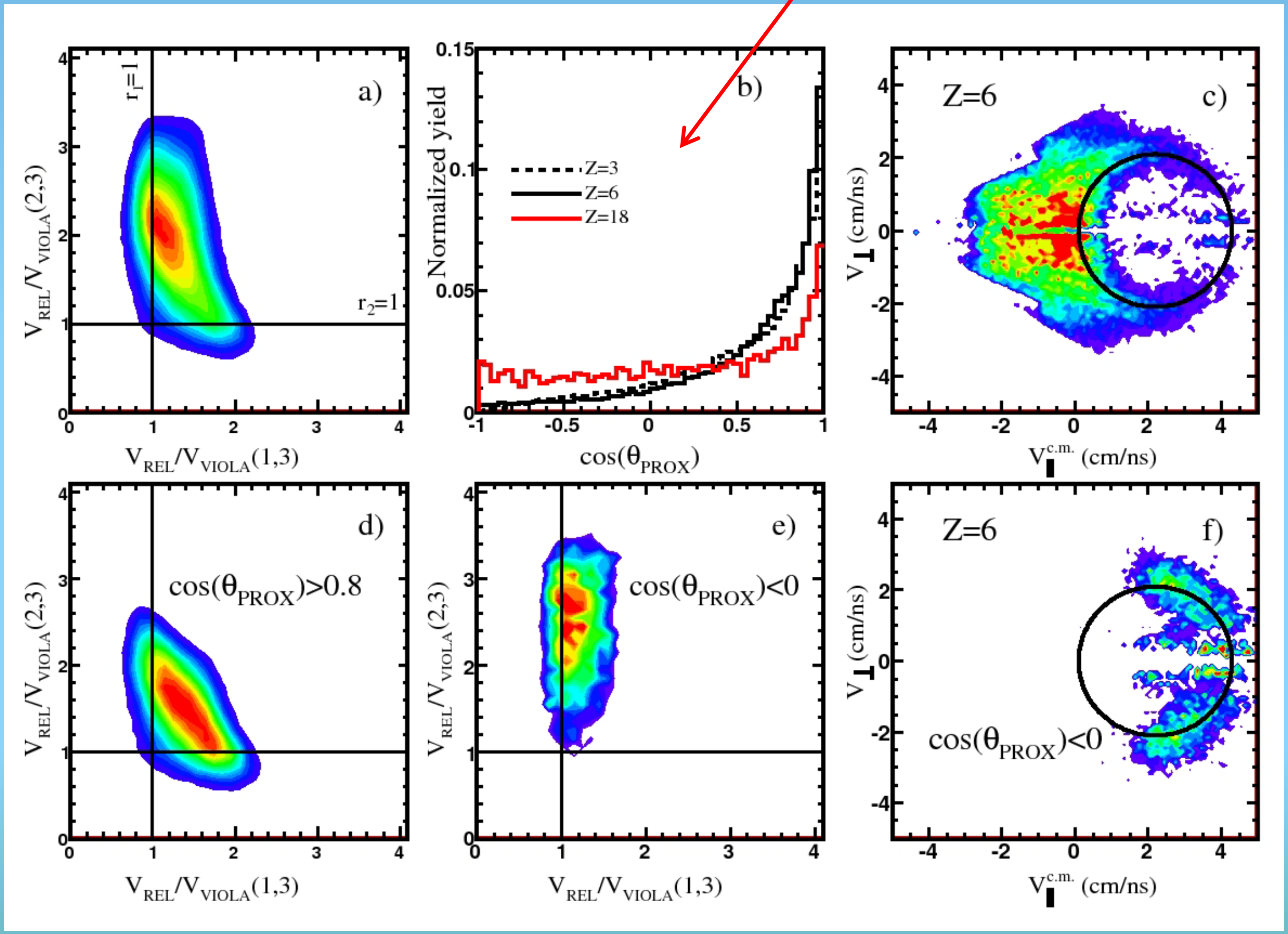


See E.d.F. et al, NN2012 Conference Proceedings, S. Antonio (Texas, USA), May 27-June 1 2012, to appear in JPCS.

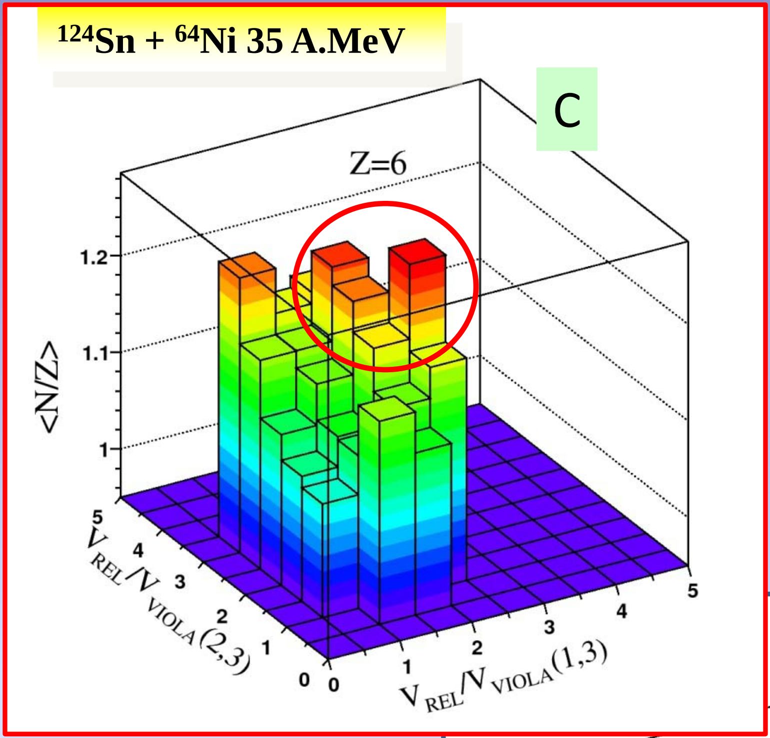
S. Hudan et al., PRC **86** 021603(R)

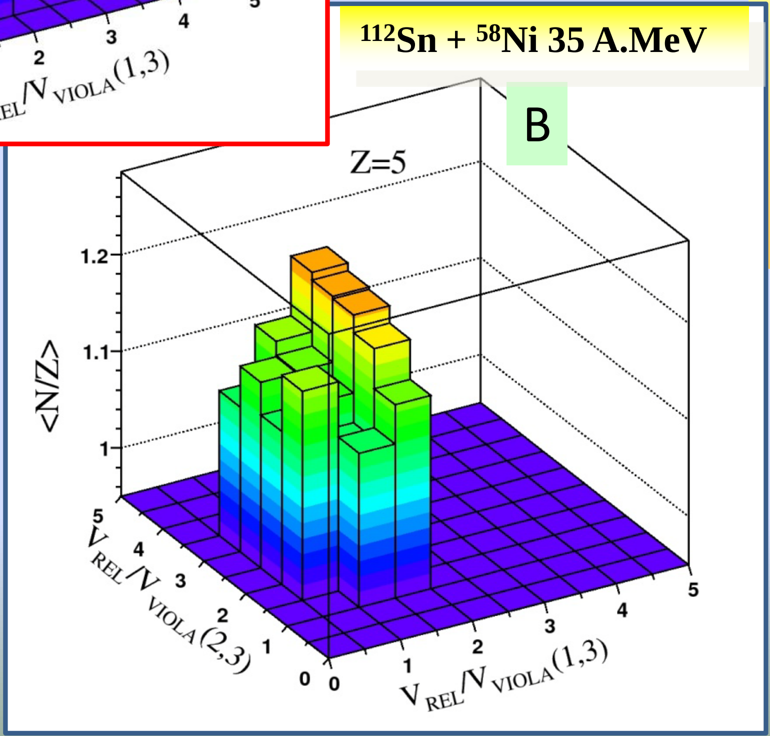
Experimental method: Data Analysis on $^{124}Sn+^{64}Ni$ at 35 A.MeV

θ_{prox}: angle between the direction of the PLF velocity and the breakup axis.



Correlations with IMFs isotopic properties

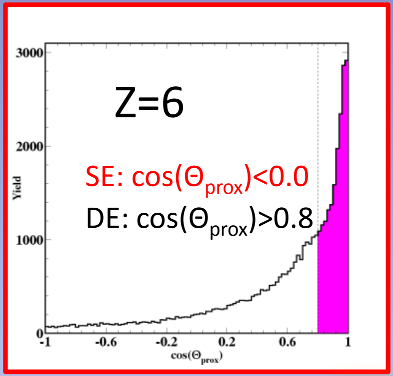




In order to study correlations between fragments formation dynamics and fragments isotopic composition we have plotted <N/Z> for different bins in the V_{rel}/V_{viola}(PLF-IMF) – V_{rel}/V_{viola}(TLF-IMF) plane

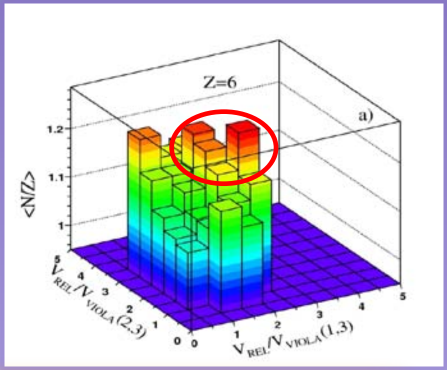
The correlation shows for both the system studied that the greatest neutron enrichment is linked to greater deviations from Viola systematics.

Neck neutron enrichment; reduction of "staggering" odd-even effects

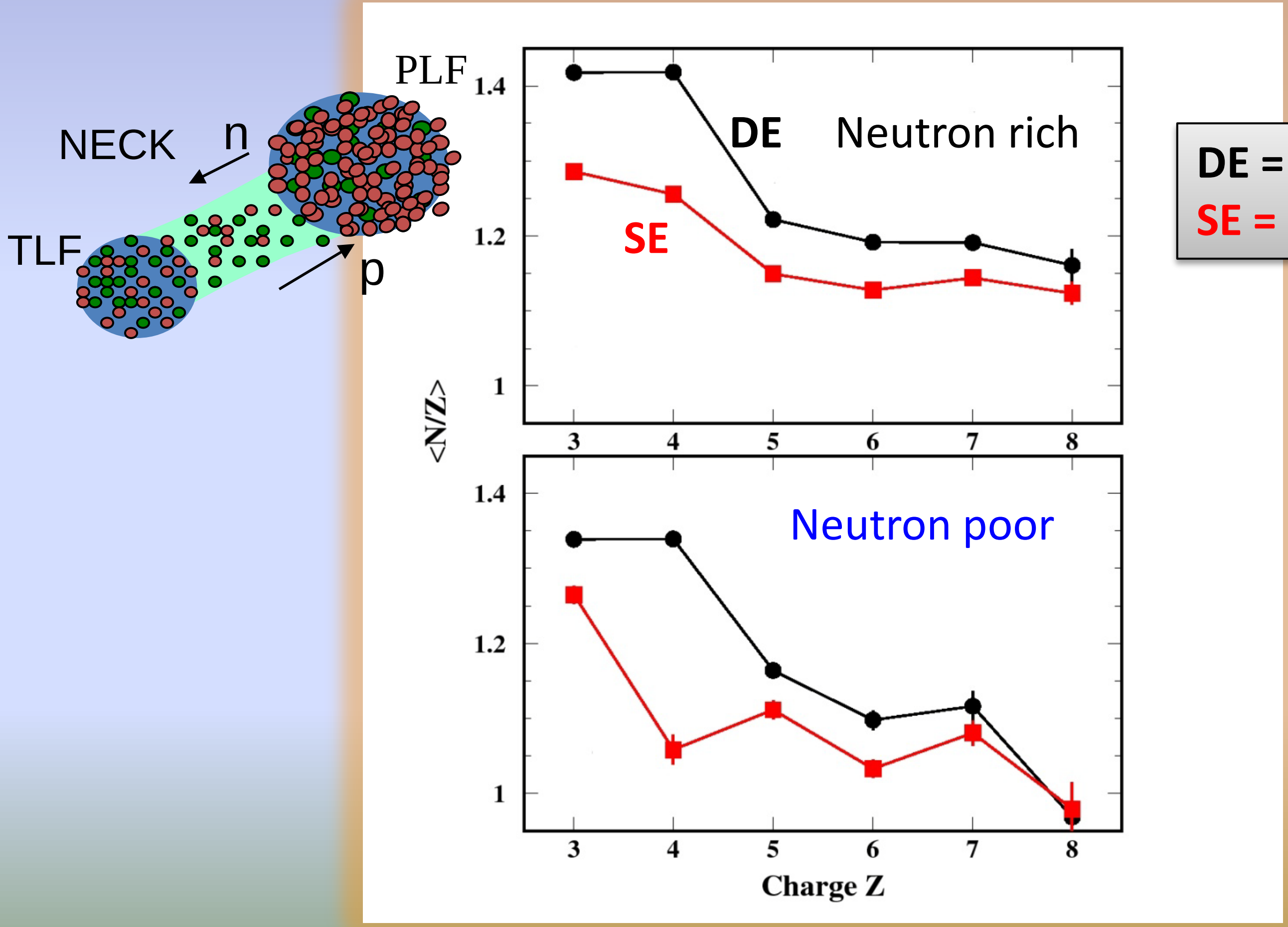


(1) Condition on $\cos(\Theta_{prox})$

+



(2) Condition on V_{rel} plot

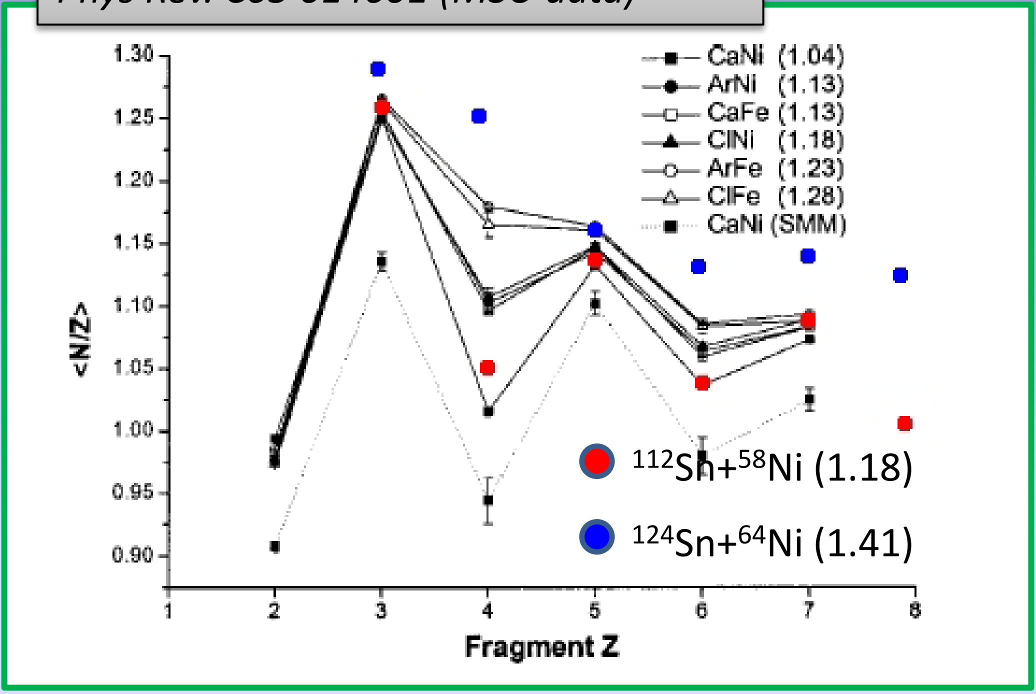


DE = Dynamical emitted

SE = Statistical emitted

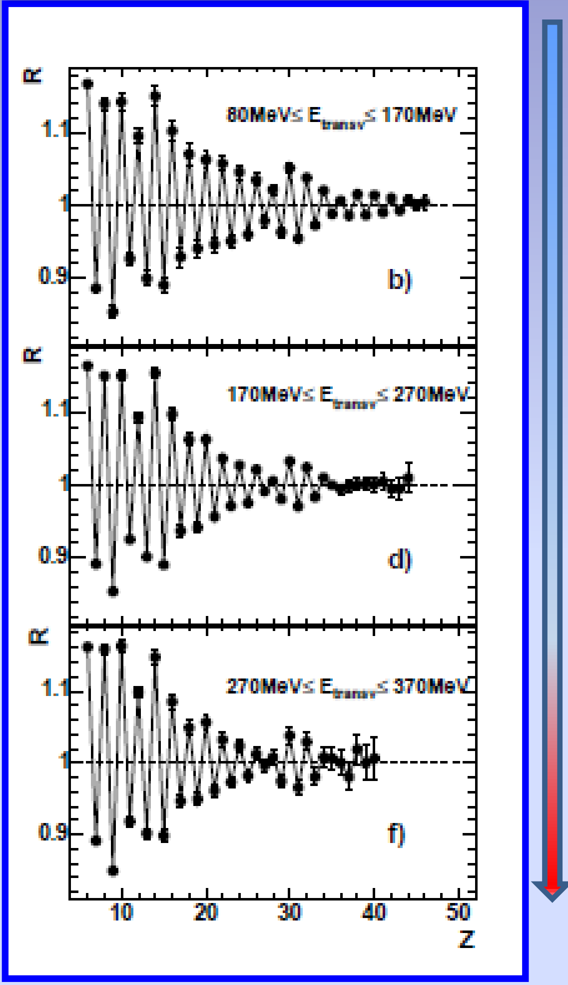
Even-odd effects on Z and N distributions of light fragments

Adapted from E.M. Winchester et al.
Phys Rev. C63 014601 (MSU data)



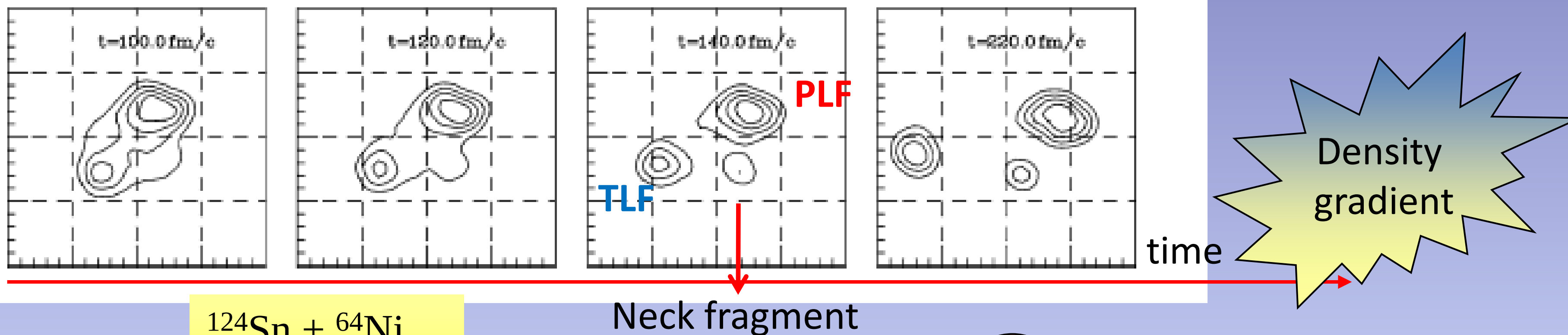
See M. D'agostino et al. Nucl. Phys. A861 (2011) 47.
I. Lombardo et al. (EXOCHIM collaboration) Phys. Rev. C84 024613 (2011).
M.V. Ricciardi et al., Nucl. Phys. A733, 299 (2004).

^{112}Sn + ^{58}Ni   35 A.MeV

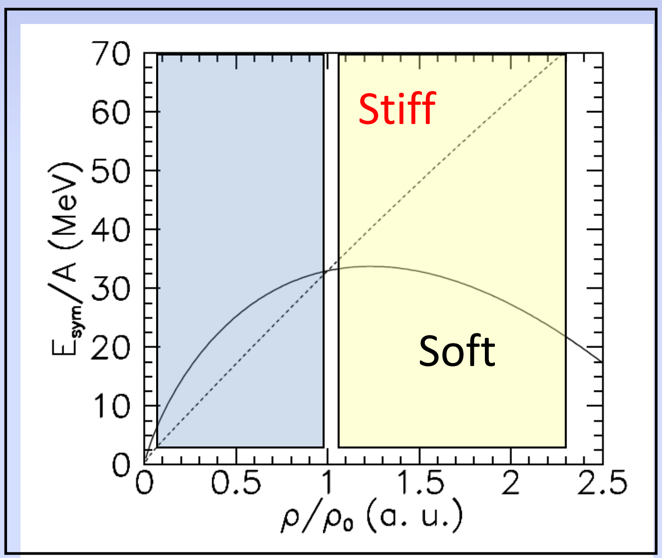


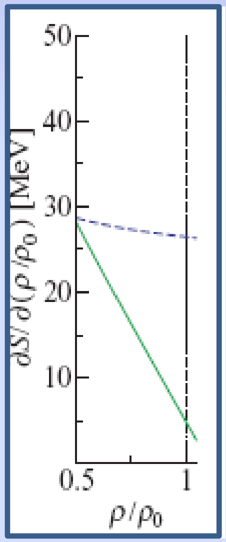
*G. Casini et al. Phys Rev C**86** 011602(R) 2012 (Chimera-Nuclex collaboration)*

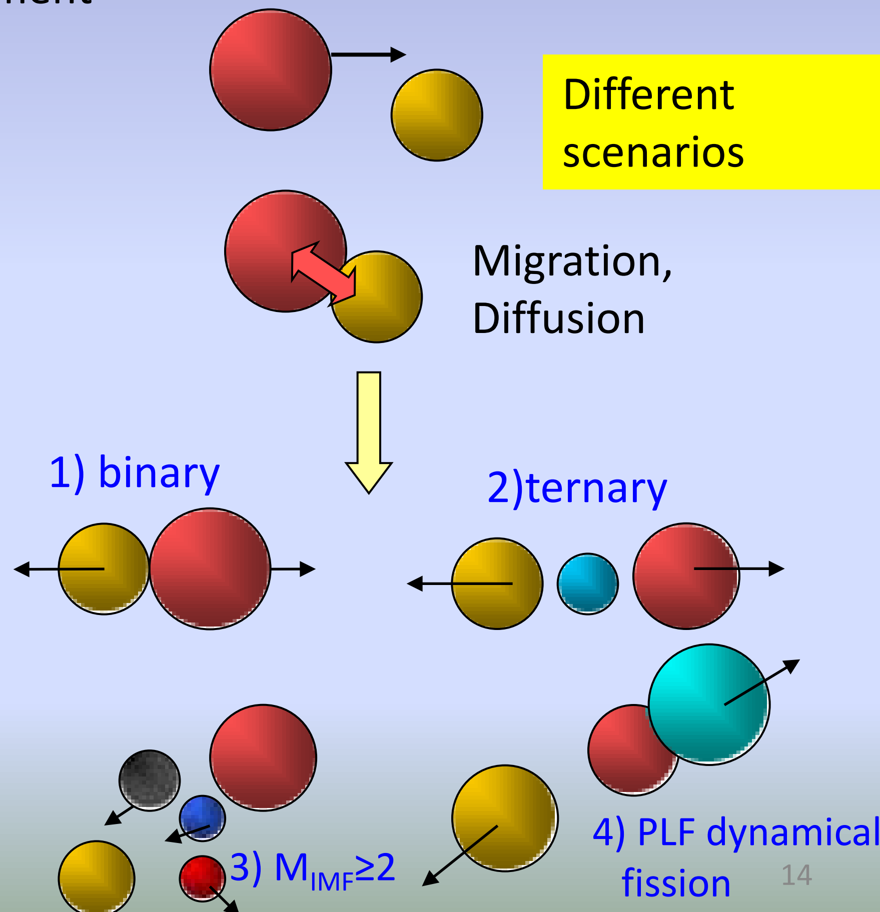
Midvelocity emission: NECK emission and Isospin drift



$^{124}Sn + {}^{64}Ni$
35 A.MeV



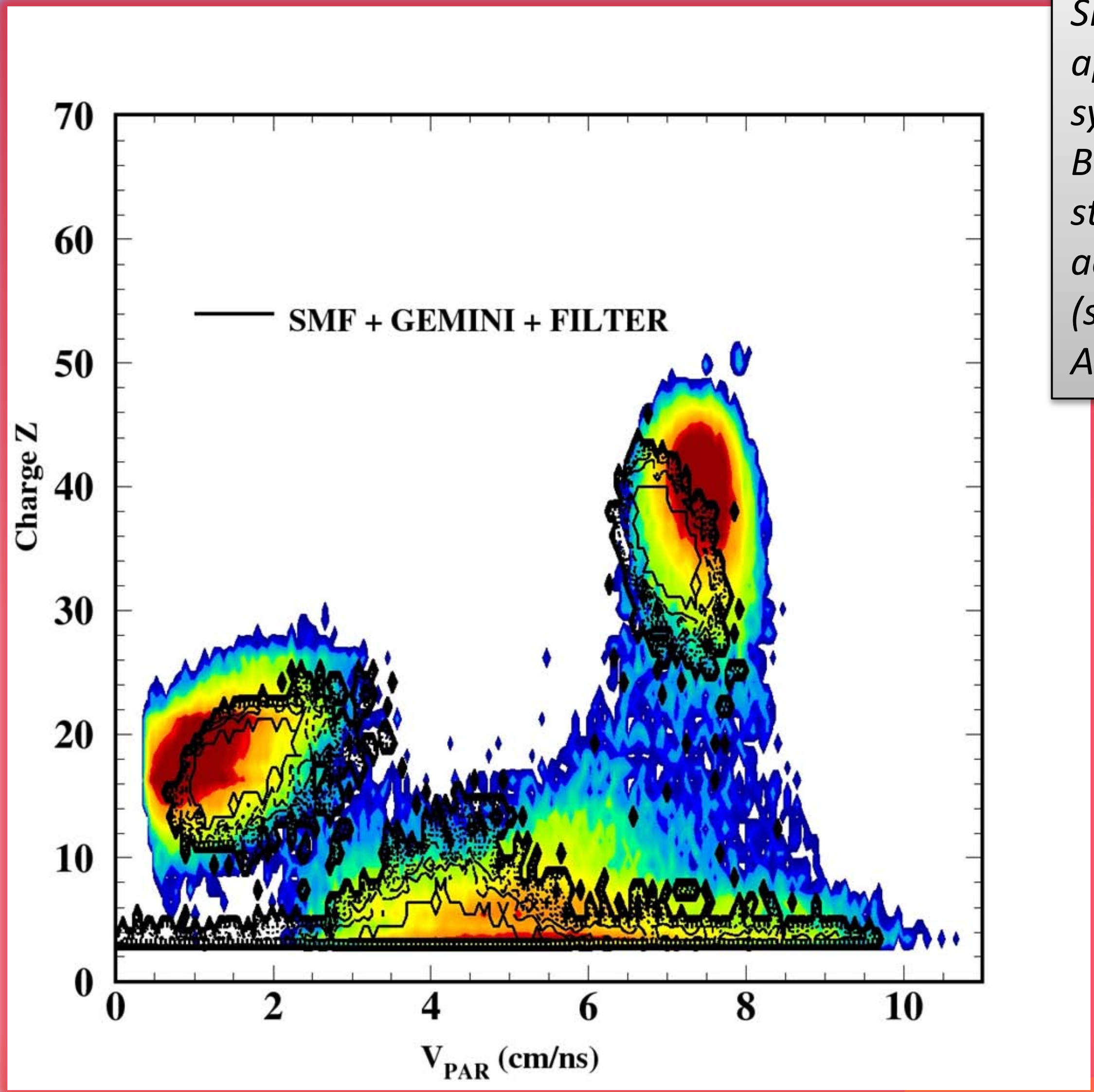




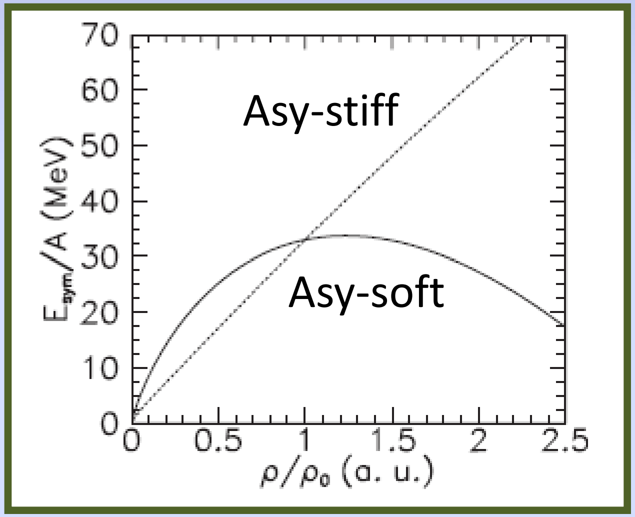
$$j_n - j_p \propto E_{sym}(\rho)\nabla I + \frac{\partial E_{sym}(\rho)}{\partial \rho} I \nabla \rho$$

diffusion migration

Stochastic Mean Field (SMF) + GEMINI

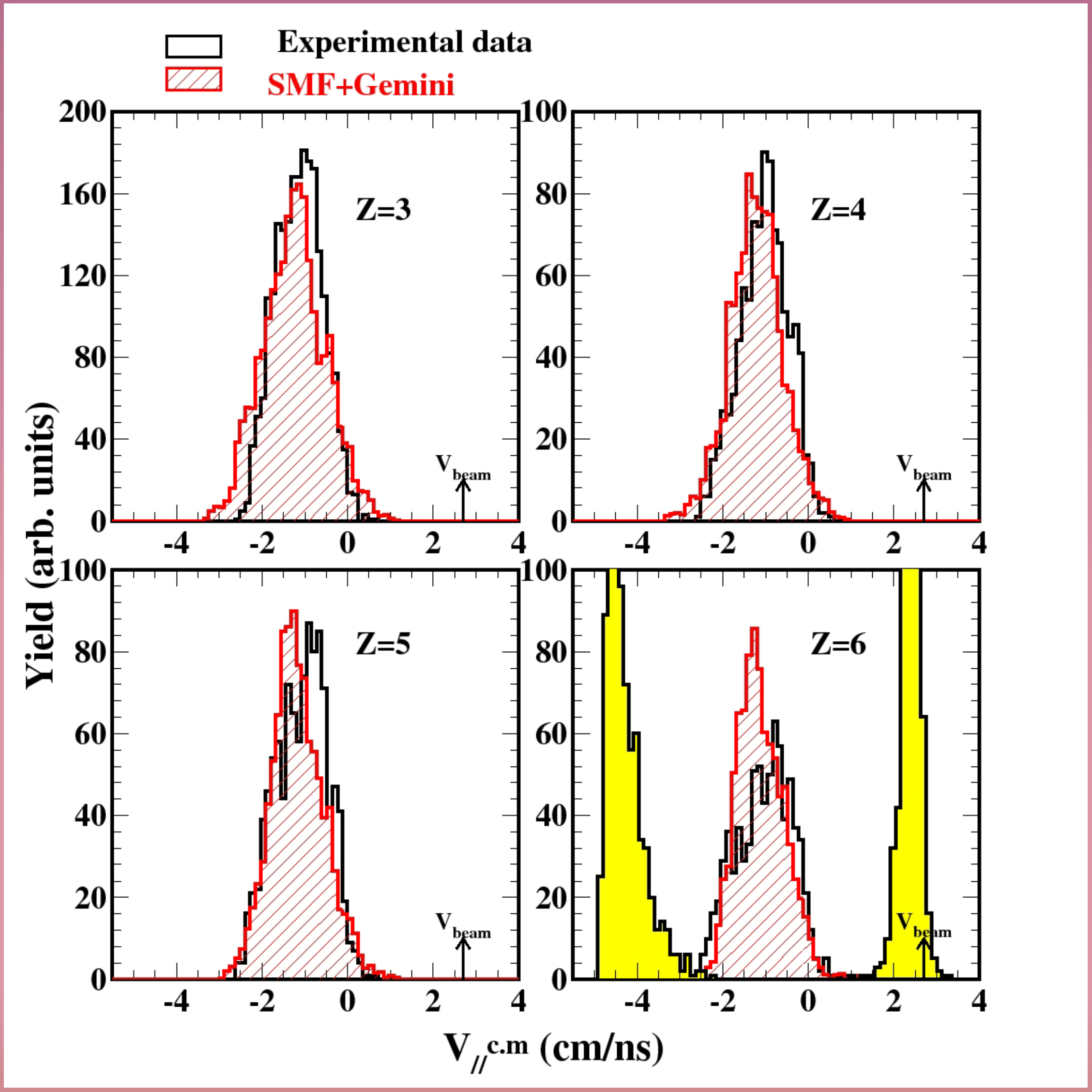


SMF is a stochastic mean field microscopic approach that describe the evolution of systems via a transport equation (of the Boltzmann-Nordheim-Vlasov type) with a stochastic fluctuating term that takes into account the dynamics of fluctuations. (see for example V. Baran et al. Nucl. Phys. A730 329 (2004).



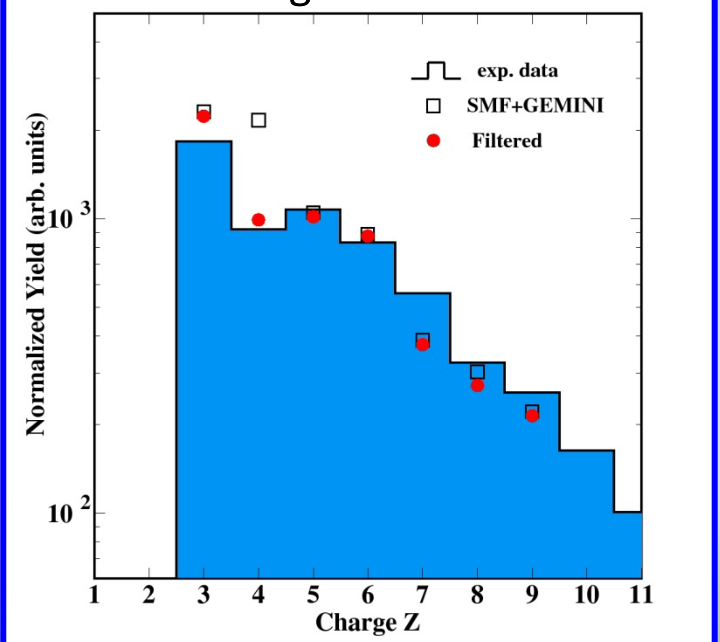
In these calculations: $L = 3\rho_0 \left(\frac{dE_{sym}(\rho)}{d\rho} \right)_{\rho=\rho_0} =$ ≈ 80 MeV for the asy-stiff; ≈ 25 MeV for the asy-soft

Stochastic Mean Field (SMF) + GEMINI: IMFs $V_{//}$ spectra



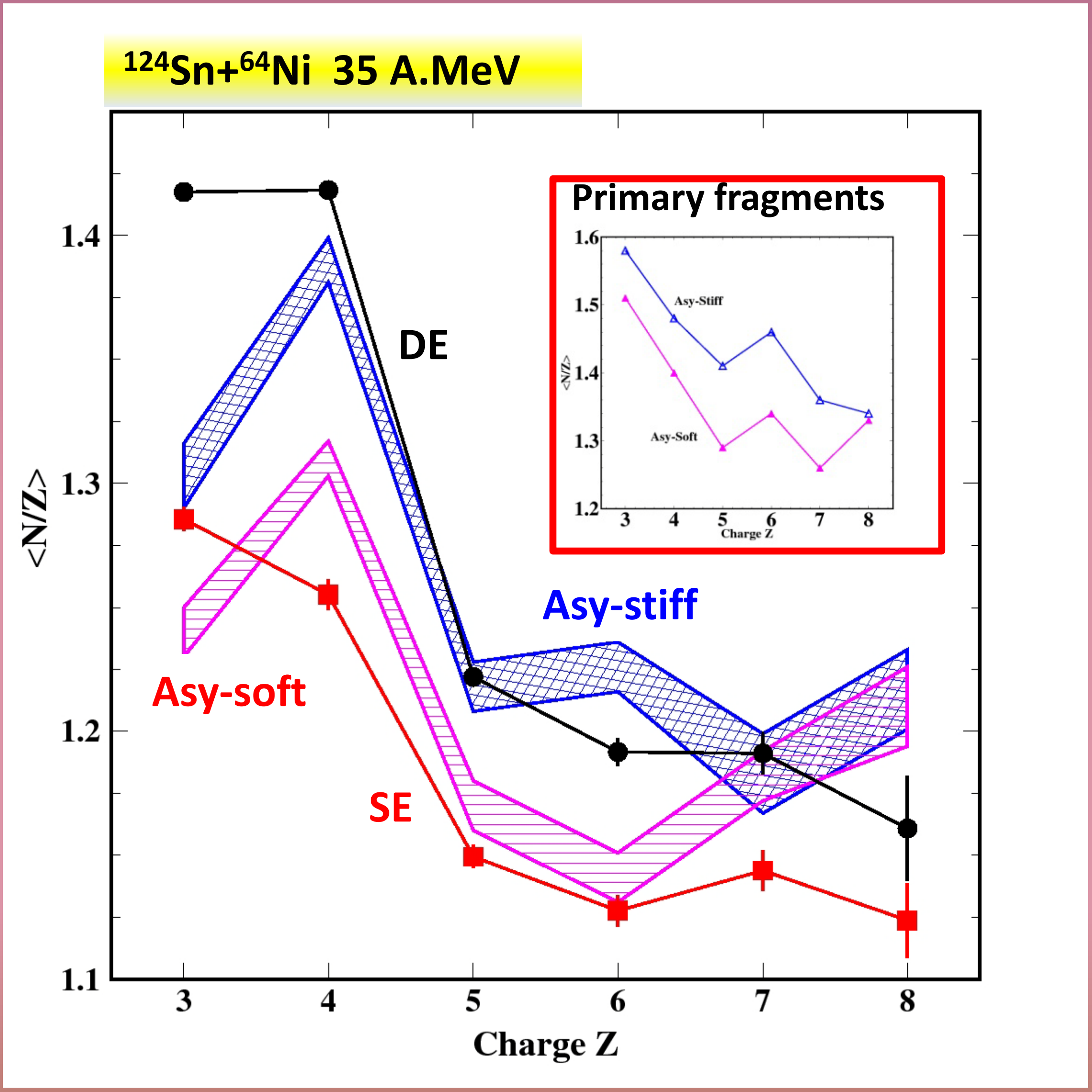
Calculated distributions are filtered by detectors acceptance, thresholds, time-of-flight experimental resolution.

IMFs charge distributions



Phys. Rev. C ***86*** *014610 (2012)*

Stochastic Mean Field (SMF) + GEMINI calculation

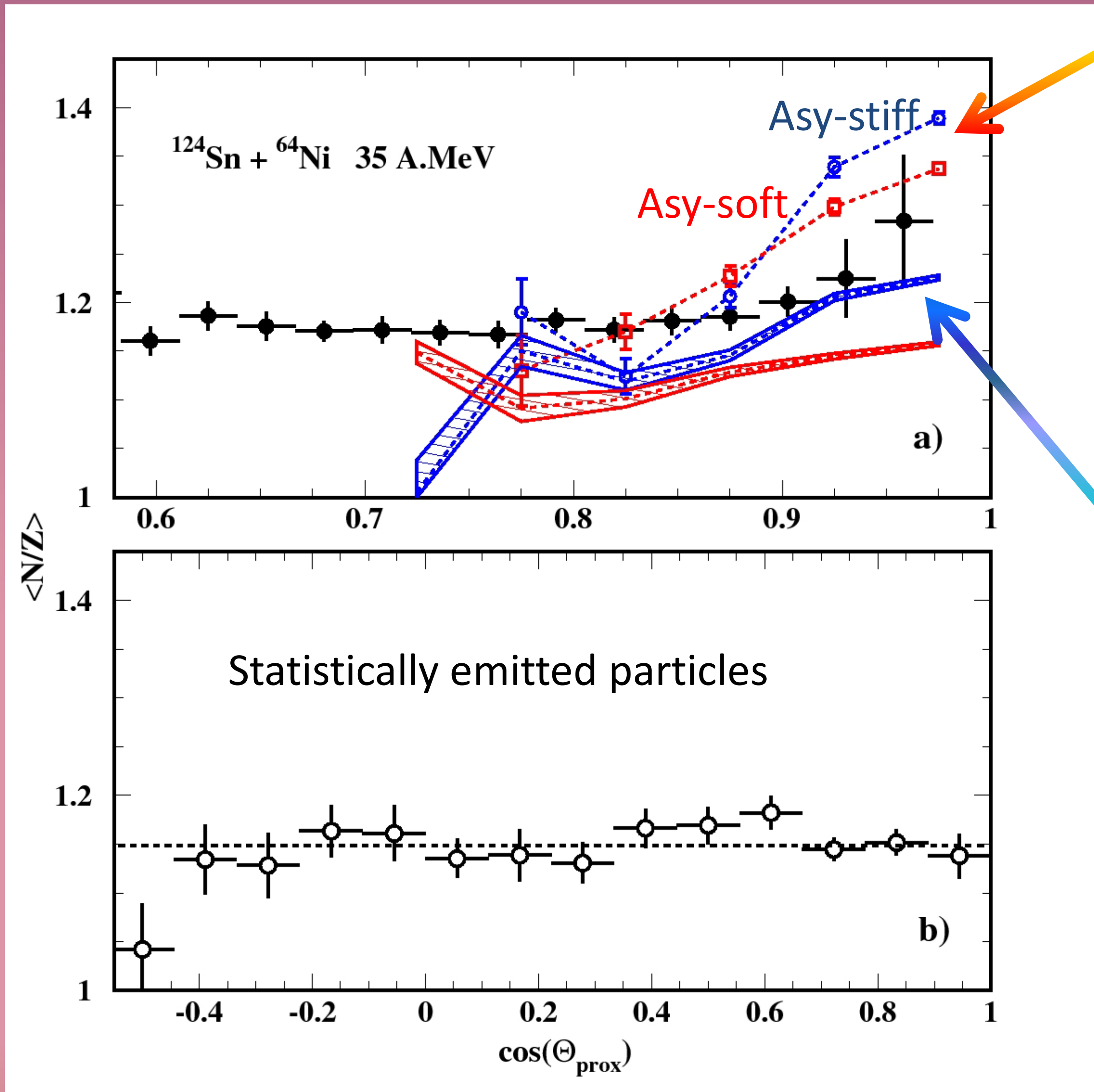


Experimental <N/Z> distribution of IMFs as a function of their atomic number compared with results of SMF (insert) and SMF+GEMINI calculations (hatchad area) for two different parametrizations of the symmetry potential (asy-soft and asy-stiff)

- Dynamically emitted particles
- Statistically emitted particles

Phys. Rev. C ***86*** *014610 (2012)*

Correlations between "isotopic" and "kinematical" observables



SMF (primary)

<N/Z> as a function of cos(θ_{PROX}) for charges 5≤Z≤8

Experimental data (●)

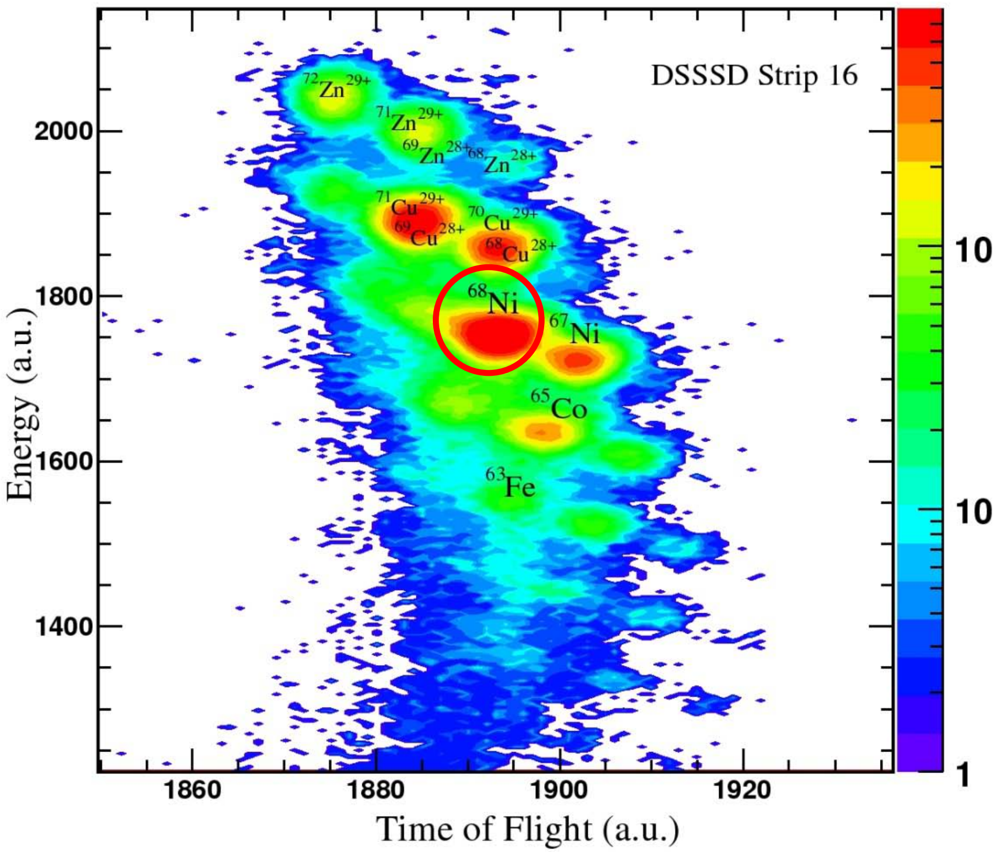
SMF + GEMINI

Phys. Rev. C ***86*** *014610 (2012)*

See also: S. Hudan et al., PRC **86** 021603(R).

Exotic beams: ^{68}Ni production with ^{70}Zn primary beam

Outlook I



Production of a ≈30 A.MeV ^{68}Ni beam at LNS (TimeScaleZn test)

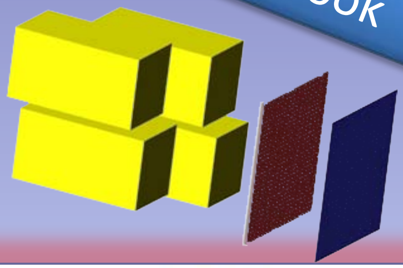
We used a $^{70}Zn^{19+}$ (40 A.MeV) primary beam impinging on a 250 µm ^{9}Be target. The maximum intensity obtained for the primary beam was ≈300 enA (0.03 kW)

Beams identification was obtained using the CHIMERA-IFEB tagging system constituted by a large surface MicroChannel plate followed by a Double Side 32x32 Silicon Strip Detector (DSSSD)

The production rate was 7 KHz / 30 Watt; reaching 100 Watt of primary beam current, we could obtain $2x10^4$ pps rate (Lise++ prediction is $5x10^4$ pps / 0.1 kW)

The Farcos correlator

Outlook II



Physics case: dynamics and spectroscopy

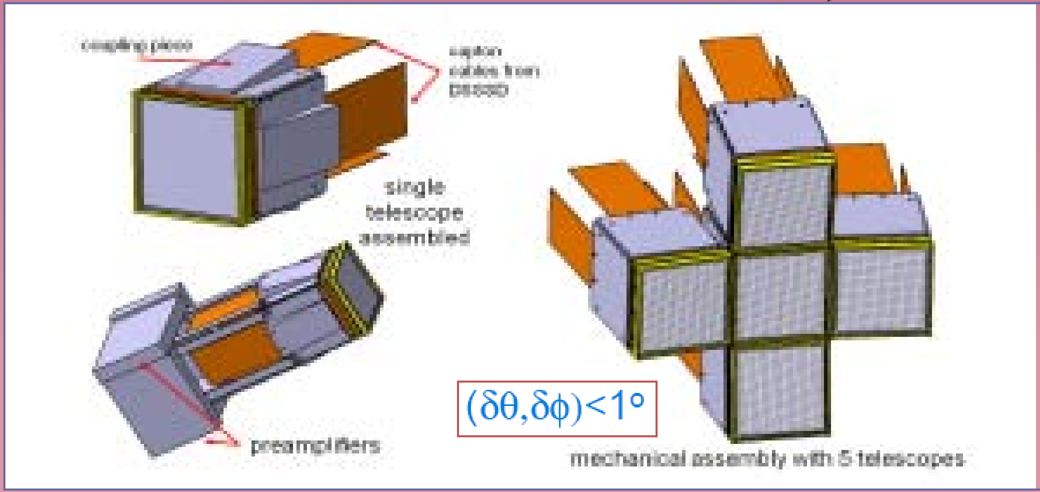
Correlation and "Imaging" in heavy-ion collisions-

(intermediate and relativistic energy)

Space-time characterization

Sizes, lifetimes, volumes, densities

Probing the symmetry energy



Spectroscopy of exotic nuclei

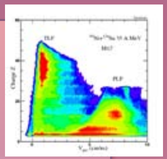
Direct and break-up reactions

MPCS: Multi-Particle Correlation Spectroscopy

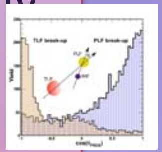
Event characterization required ==> mandatory coupling to 4π

FARCOS demostrator 3 clusters (first experiments next year)
FARCOS final configuration 20 clusters

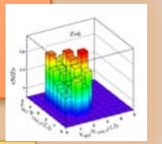
SUMMARY

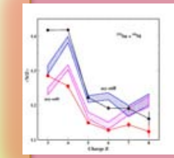


We have studied with the 4π detector CHIMERA the two reactions ^{64,58}Ni+^{124,112}Sn and ^{124,112}Sn + ^{64,58}Ni at the same energy of relative motion (35 A.MeV)



We have introduced a method to disentangle sequential from dynamically emitted particles at midrapidity and we have correlated the isotopic composition of Intermediate mass fragments with their emission timescale. Dynamically emitted IMF shows larger values of <N/Z> isospin asymmetry and stronger angular anysotropies supporting the concept of "*isospin migration*" in neck fragmentation mechanism.





We compared the data to a Stochastic Mean Field (SMF) simulation obtaining valuable constraints on the symmetry energy term of nuclear EOS at subsaturation densities. A stiff $E_{SYM}(\rho)$ behaviour with L≈80, corresponding to a linear density dependence,better reproduces the data.

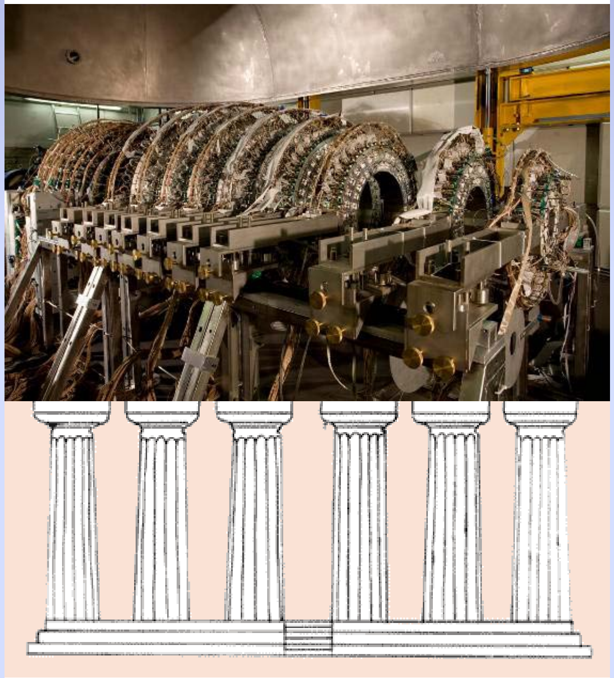
New experiment proposed to the next LNS PAC 2012: **^{124}Xe+^{64}Zn** as compared with **^{124}Sn+^{64}Ni** at 35 A.MeV; Study of Mass vs. Isospin effects with Chimera+Farcos prototype.

This is a collective work of CHIMERA and EXOCHIM collaborations.

In particular all people of TIMESCALE and TIMESCALEZn experiments listed below :

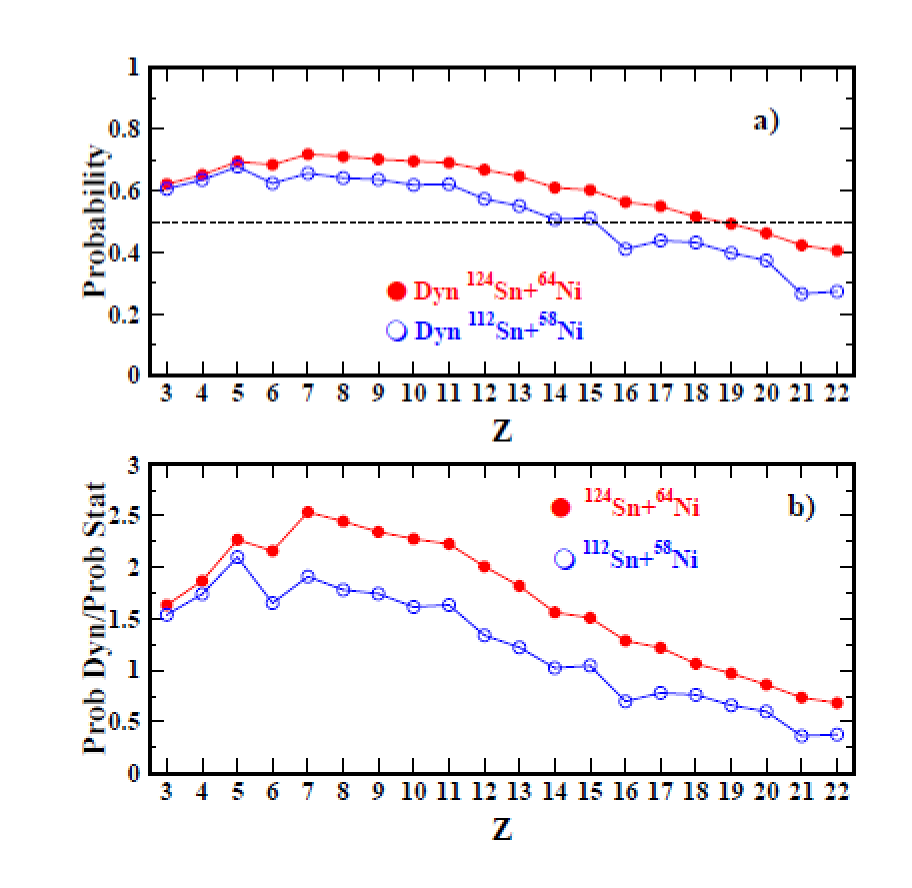
L. Acosta, C. Agodi, F. Amorini, L. Auditore, V. Baran, I. Berceanu, M. Buscemi, T. Cap, G. Cardella, M. Colonna, E. De Filippo, M. Di Toro, L. Francalanza, E. Geraci, S. Gianì, L. Grassi, A. Grzeszczuk, P. Guazzoni, J. Han, E. La Guidara, G. Lanzalone, I. Lombardo, C. Maiolino, T. Minniti, A. Pagano, E.V. Pagano, M. Papa, E. Piasecki, S. Pirrone, G. Politi, A. Pop, F. Porto, F. Rizzo, E. Rosato, P. Russotto, S. Santoro, A. Trifirò, M. Trimarchi, G. Verde, M. Vigilante, J. Wilczyński, L. Zetta.

CHIMERA, XXI century AC

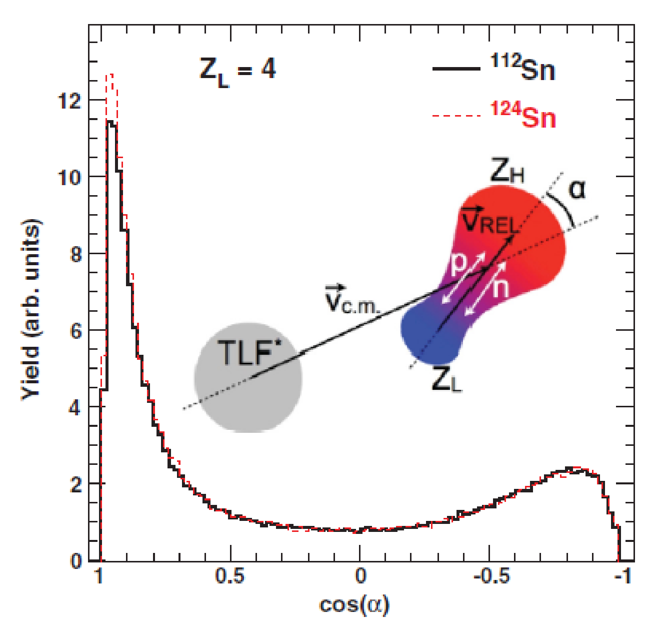


Apollonion, Siracusa, VI century BC

Probability associated to dynamical emission mechanism



Russotto et al. to be submitted to Phys. Rev C.



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