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

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.

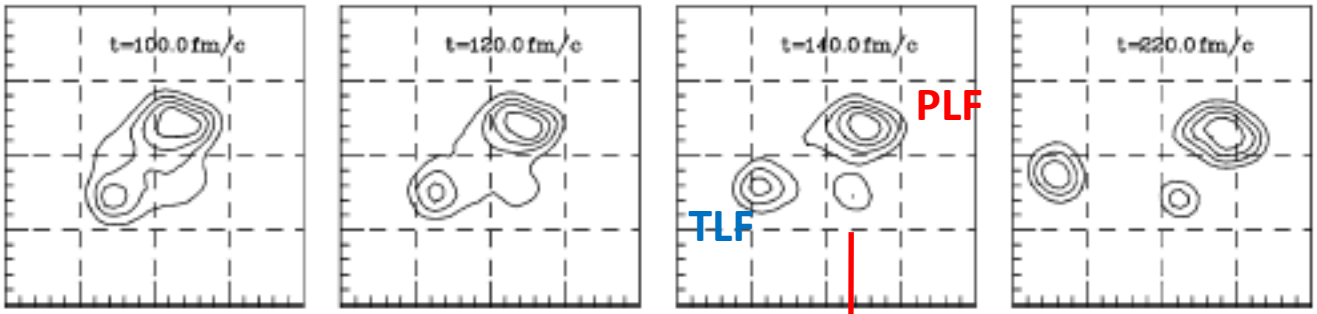
Does "neck" region really explore a low density asymmetric nuclear matter ? *An experimental survey.*

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

New prospectives for the future with the Chimera

INPC 2013

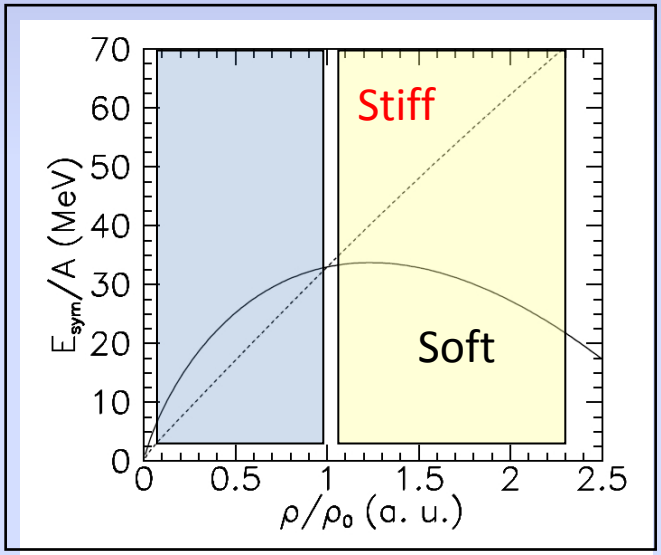
Midvelocity emission: NECK emission and Isospin drift

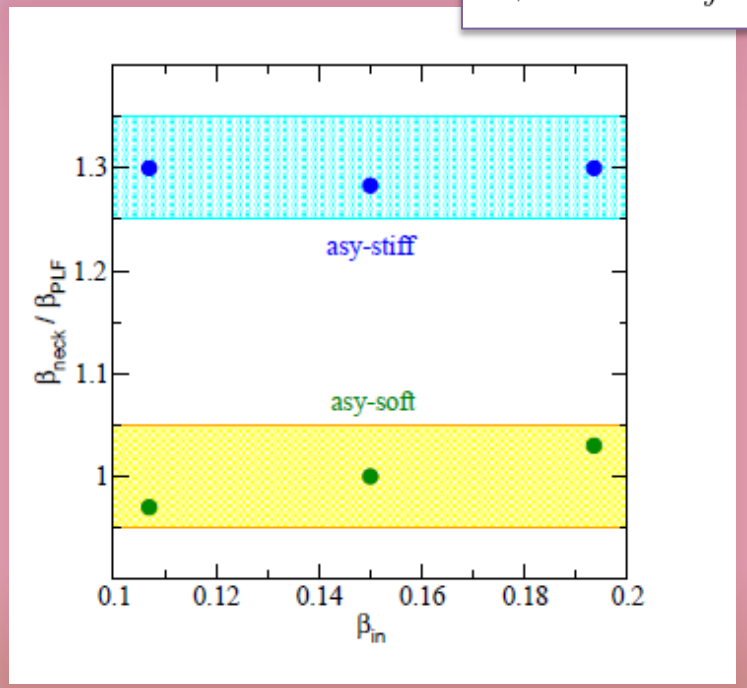


Density gradient

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

$$\frac{\beta_{IMF}}{\beta_{res}} = \frac{E_{sym}(\rho_R)}{E_{sym}(\rho_I)}$$



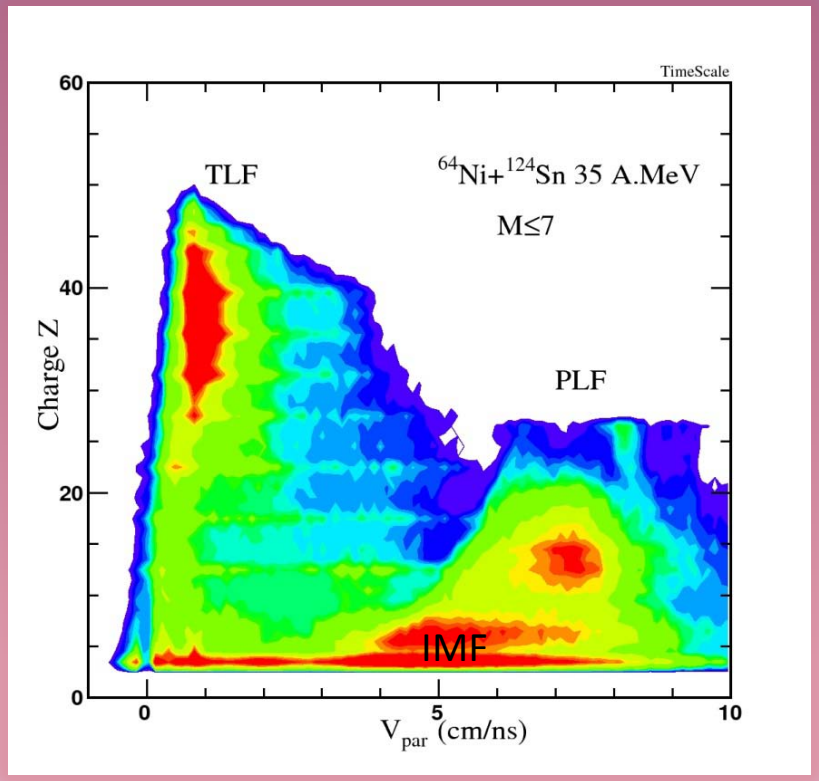


$$j_n - j_p \propto E_{sym}(\rho)\nabla I + \frac{\partial E_{sym}(\rho)}{\partial \rho} I \nabla \rho$$

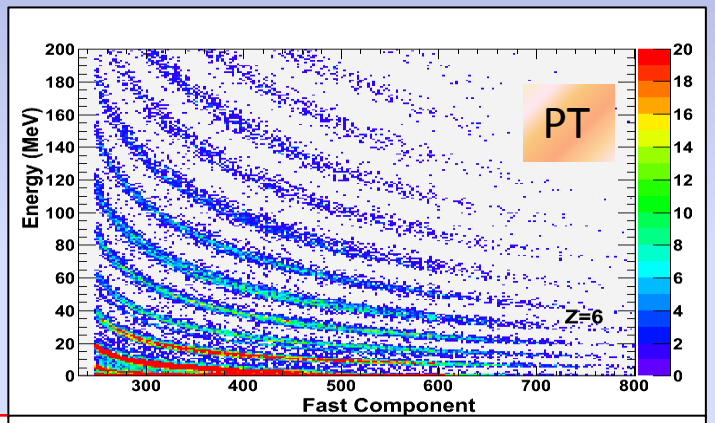
Diffusion Migration

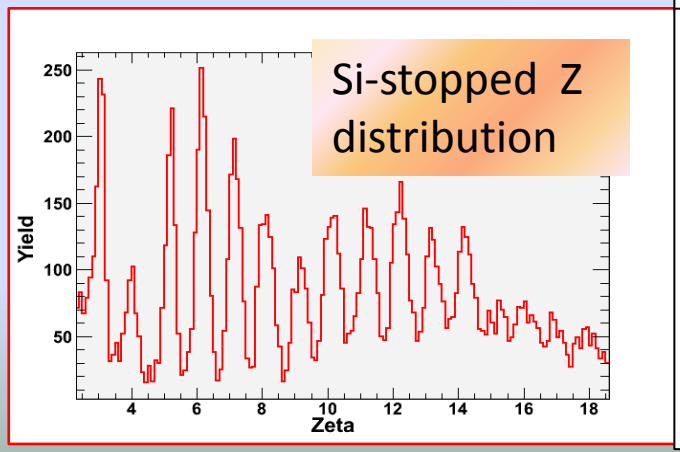
M. Colonna et al., J. Phys. CS, 413, 012018 (2013)

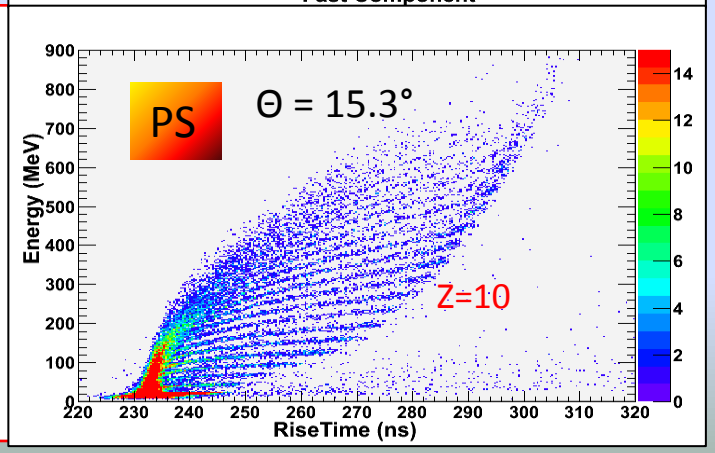
TimeScale experiment: 35 A.MeV ^{64}Ni + ^{124}Sn and ^{58}Ni + ^{112}Sn in direct kinematics

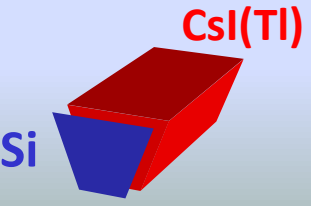


Almost complete events:
p/p_{tot}> 60%
Z/Z_{tot}> 60%
M_{tot}≤7









Correlation between Isospin Dynamics and emission Time-scale

- Disentangling dynamic and statistical emission: space-time characterization and correlations.

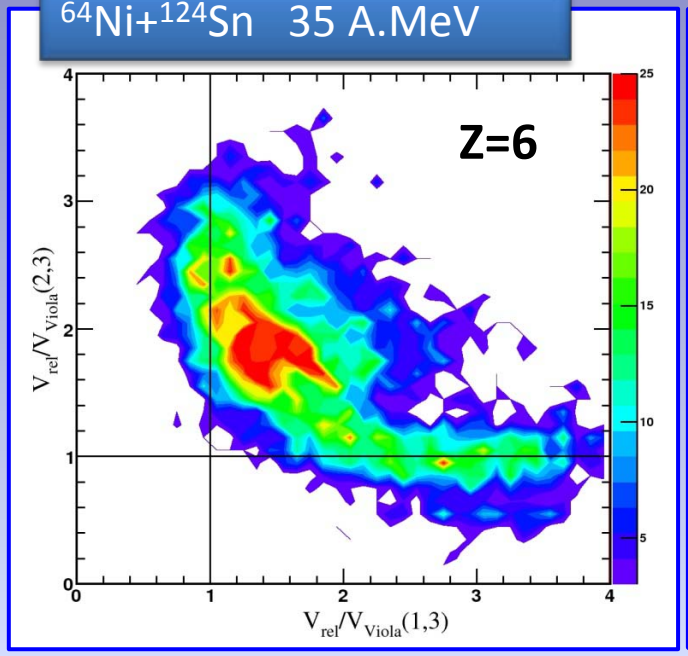
- Study of isotopic composition of fragments: isospin migration, neutron enrichment.

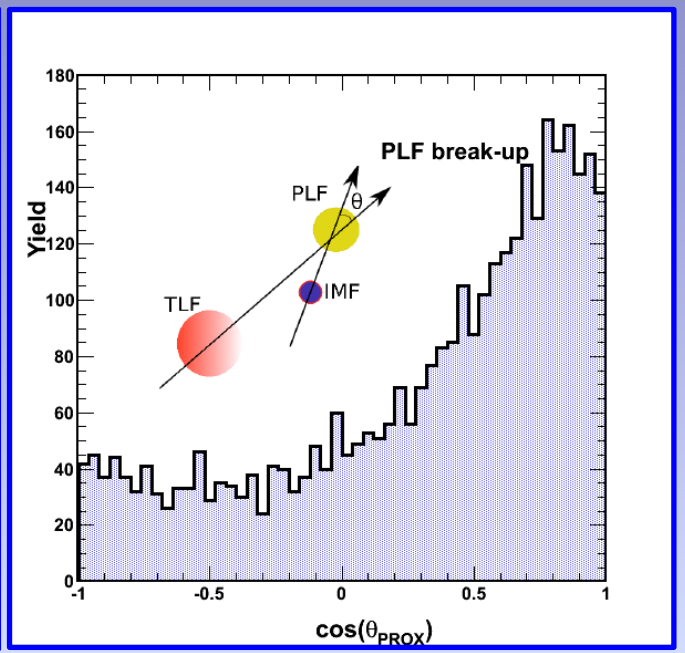
- Calculations: probing the density dependency of the symmetry energy using these new observables

Disentangling dynamical vs. statistical emission in ternary events

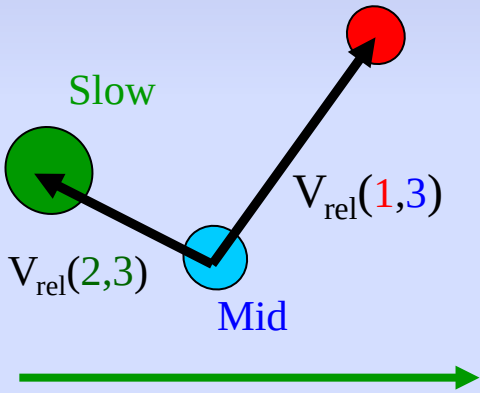
preliminary

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





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

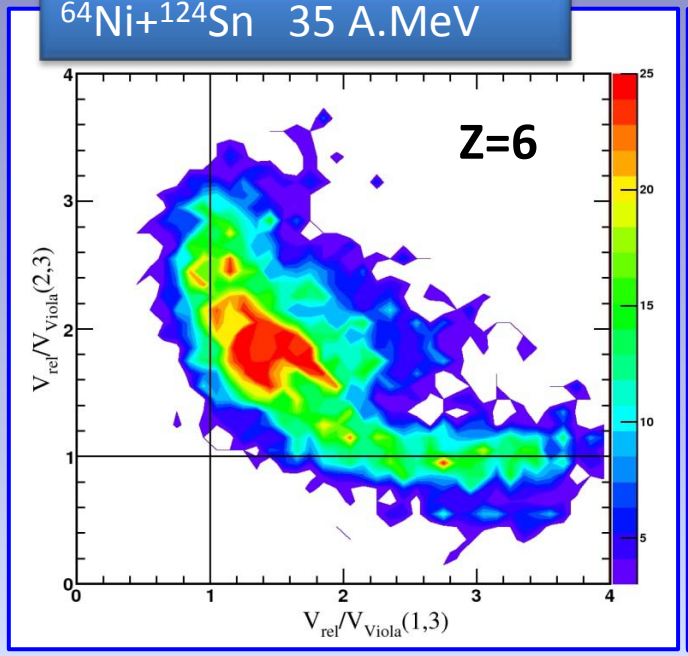


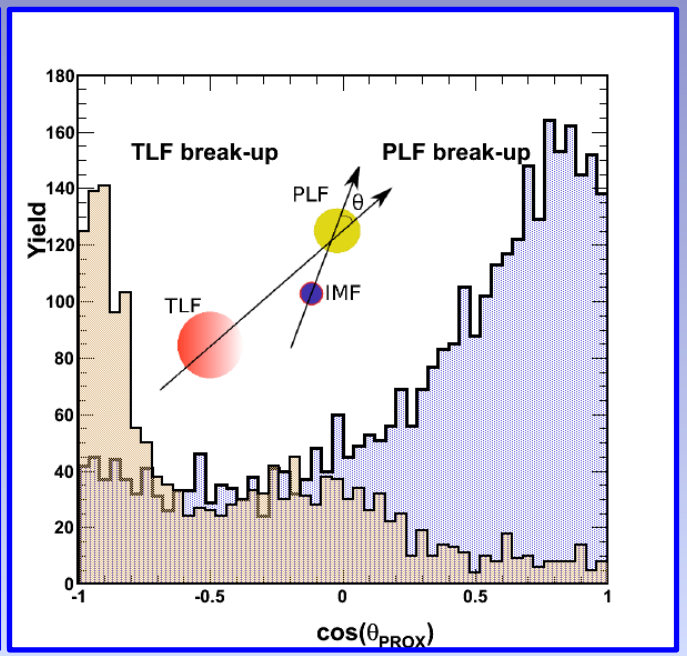
The three heaviest fragments are ordered according to decreasing value of parallel velocity.

Disentangling dynamical vs. statistical emission in ternary events

preliminary

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





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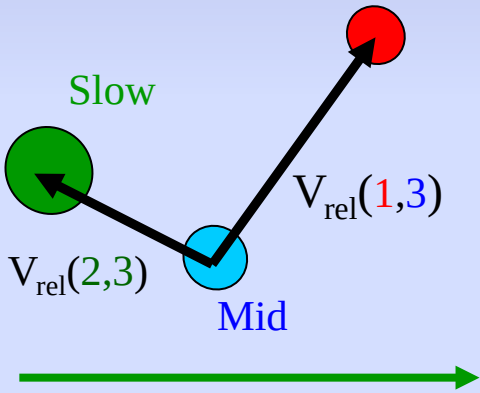
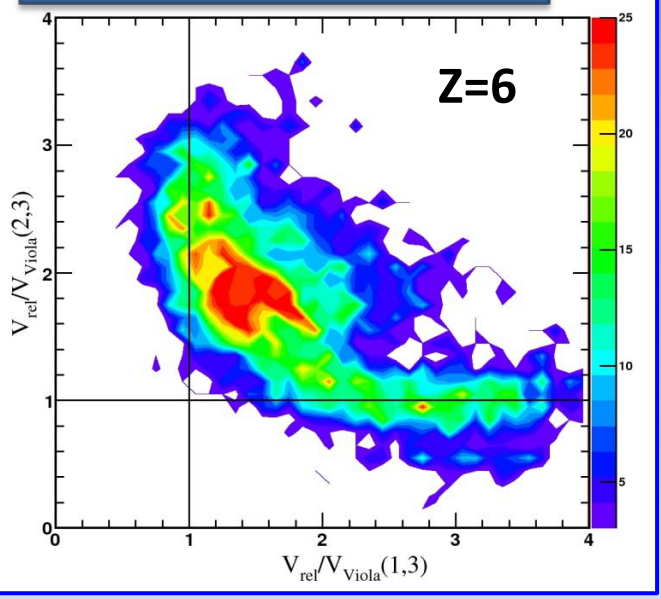


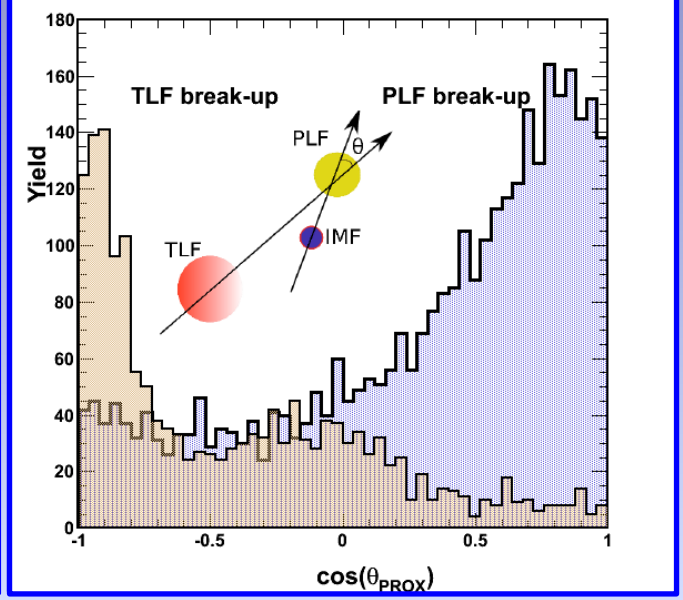
The three heaviest fragments are ordered according to decreasing value of parallel velocity.

Disentangling dynamical vs. statistical emission in ternary events

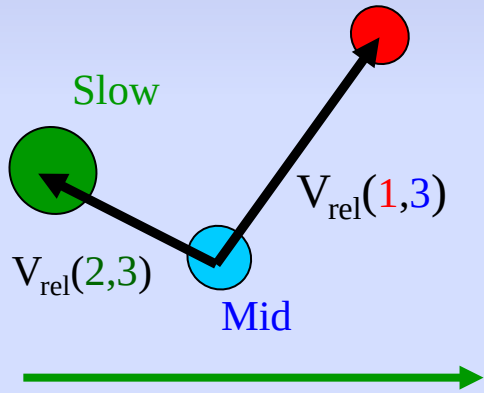
preliminary

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

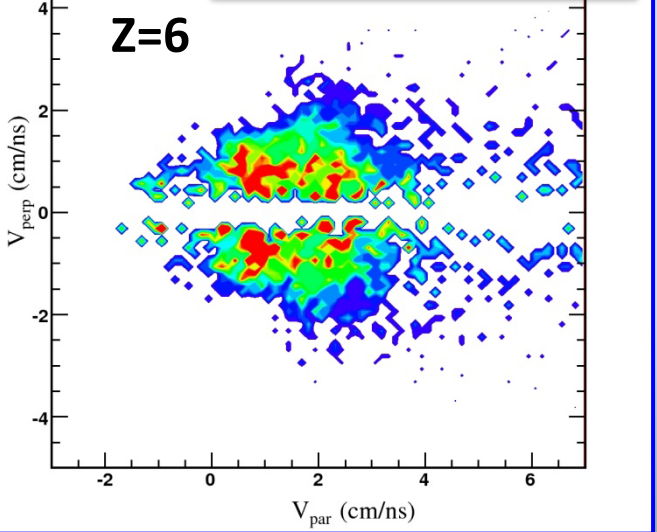


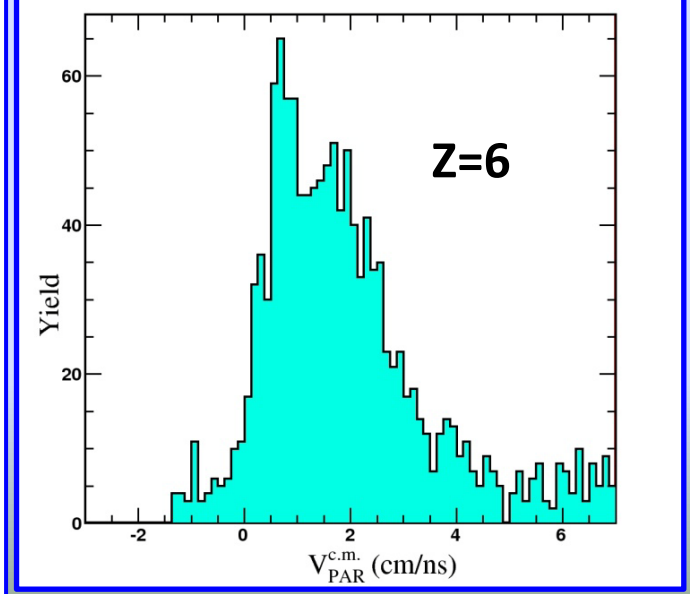


cos(θ)≈±1
aligned emission of the lighter fragment in the backward emisphere of **PLF** (+1) and **TLF** (-1) towards midrapidity



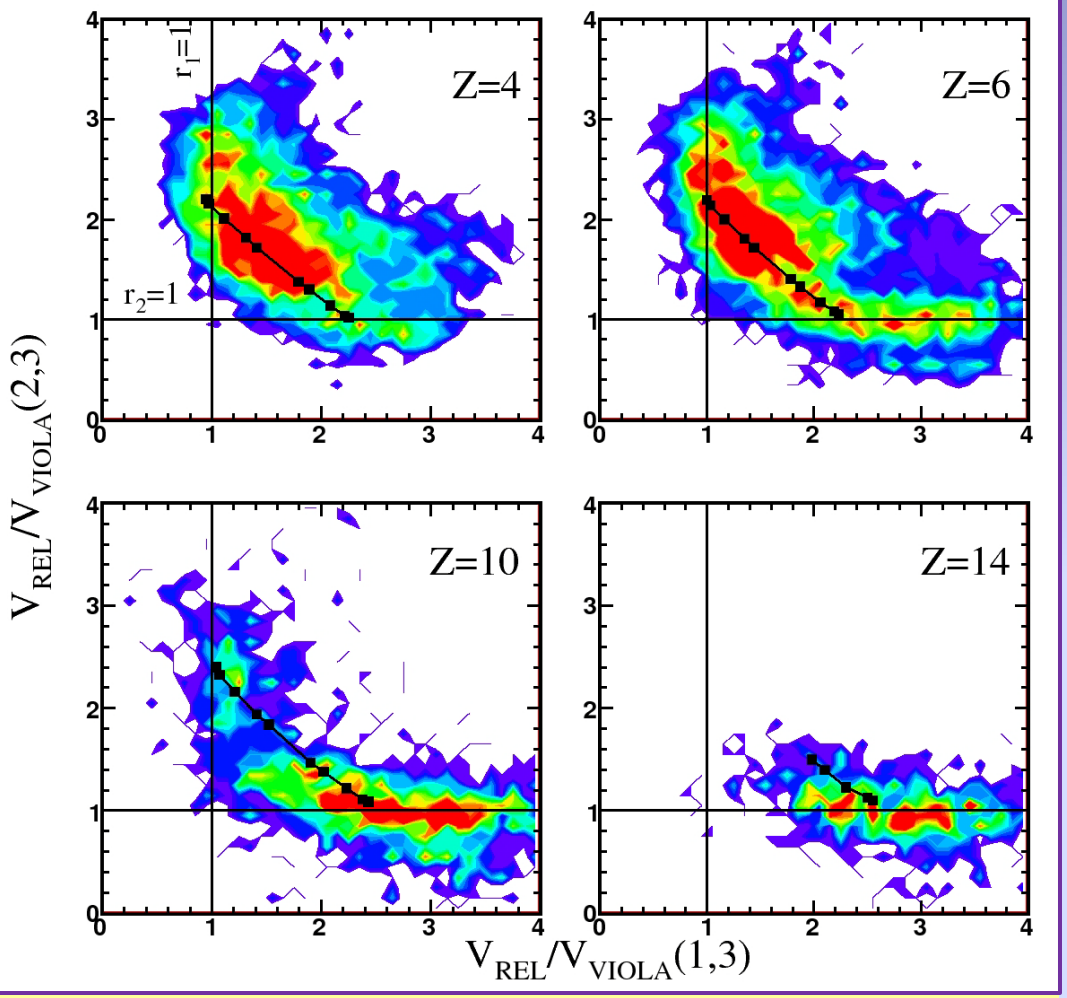
abs(cos(θ_{PROX})>0.8



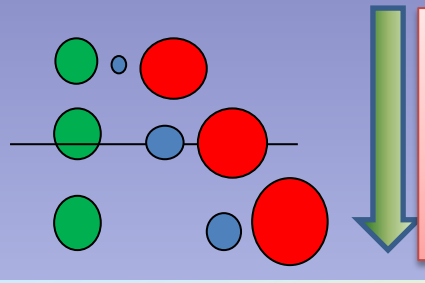


The three heaviest fragments are ordered according to decreasing value of parallel velocity.

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

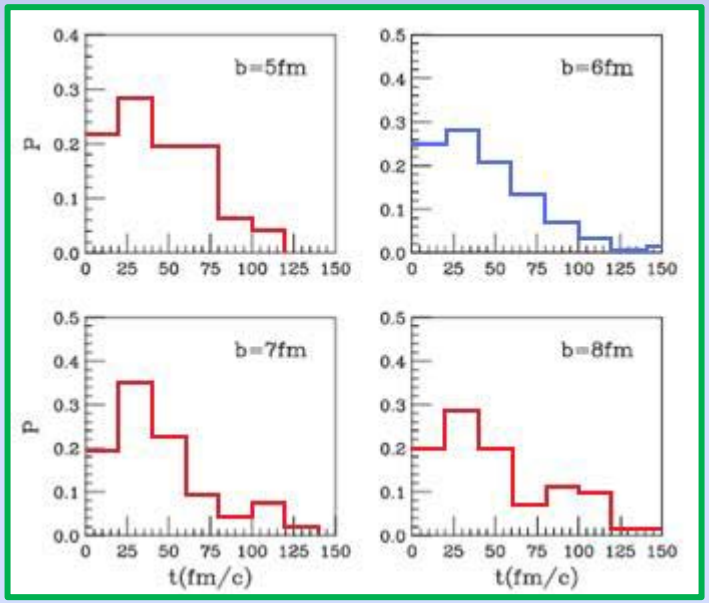


Relative velocities are expressed in units of the velocity corresponding to the Coulomb repulsion energy of a given subsystem according to the Viola systematics.



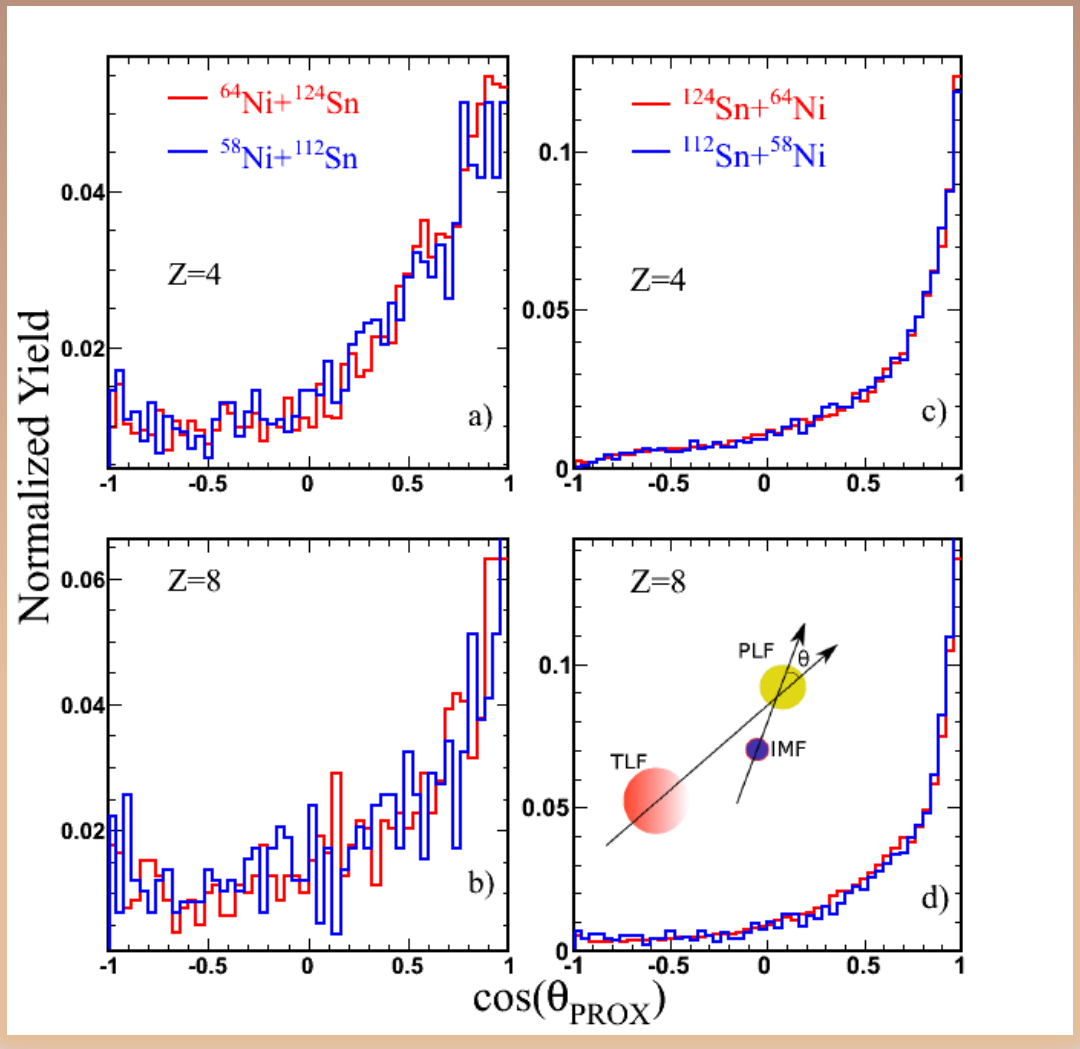
30 fm/c
.....
80 fm/c
120 fm/c

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

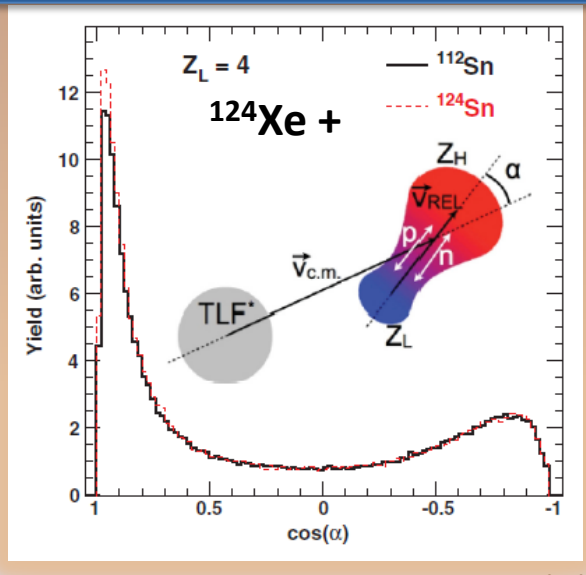


SMF: $^{124}Sn + ^{64}Ni$ probability of scission-to-scission time in neck fragmentation. *V. Baran et al. Phys. Rep 410, 335 (2005)*

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



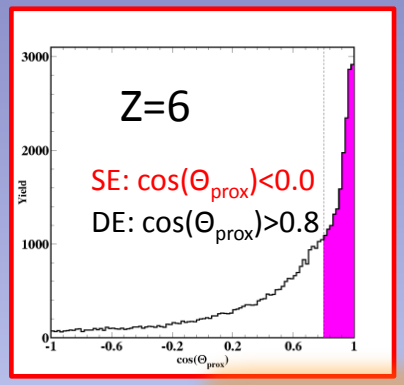
Enhancement of backward fragment yield relative to the forward component



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

See E.d.F. et al, NN2012 Conference Proceedings, S. Antonio (Texas, USA), May 27-June 1 2012 Jour. Phys. CS 420 (2013).

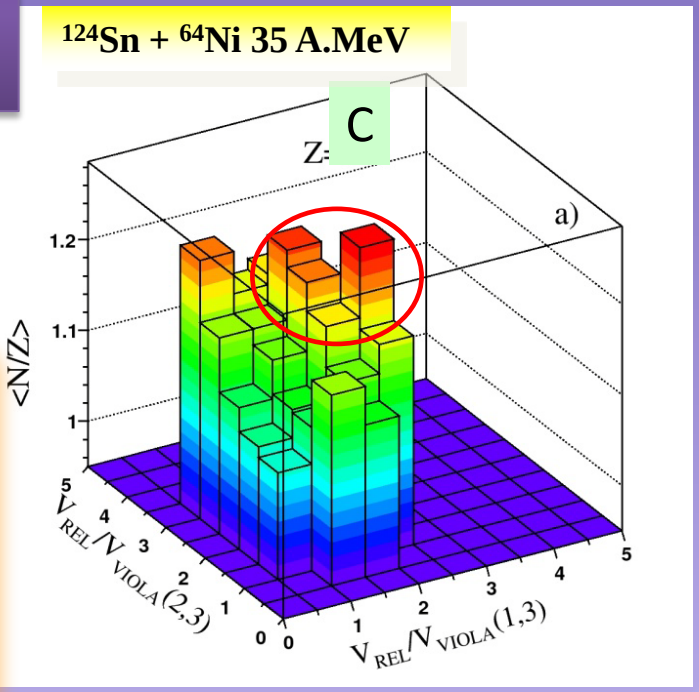
Neck neutron enrichment; reduction of "staggering" odd-even effects

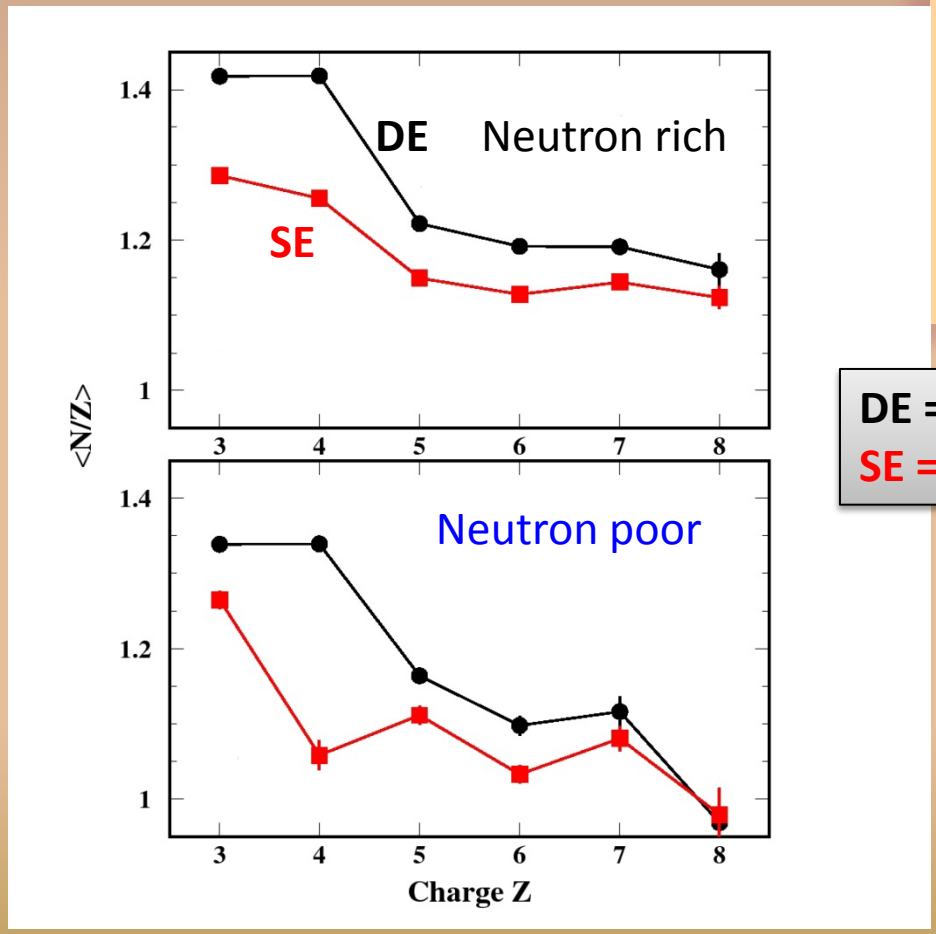


(1) Condition on $\cos(\Theta_{prox})$

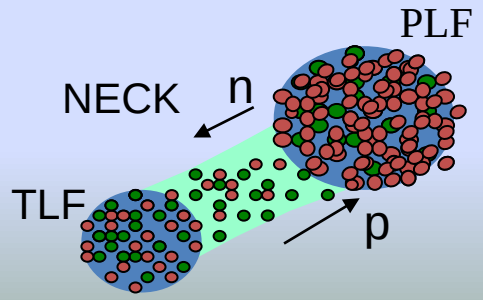
+

(2) Condition on V_{rel} plot

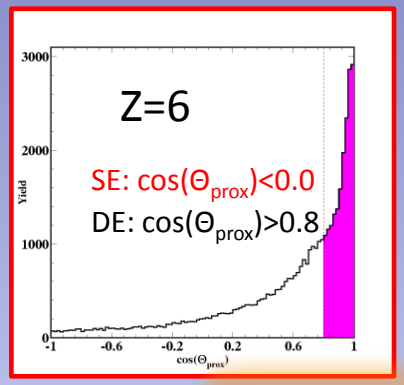




DE = Dynamical emitted
SE = Statistical emitted



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



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

+

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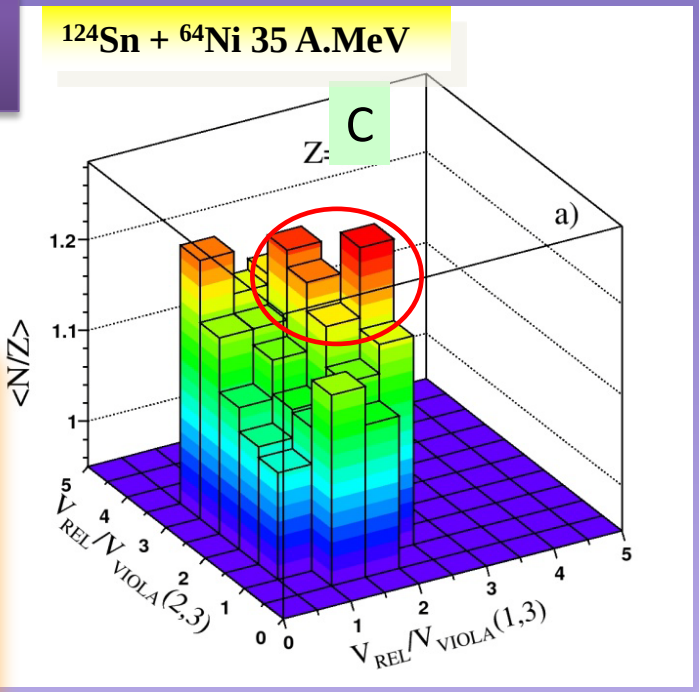
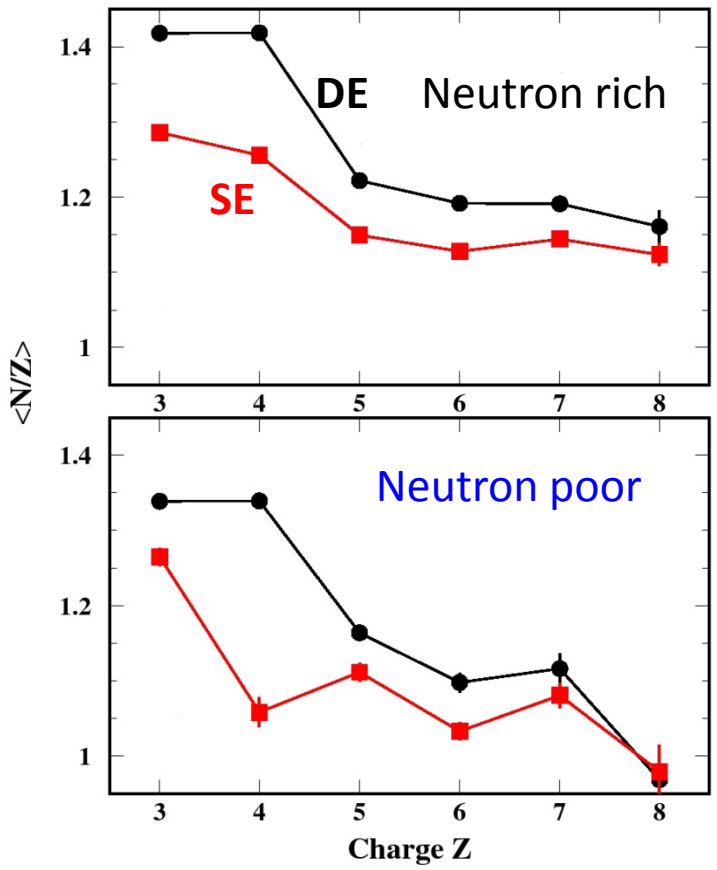


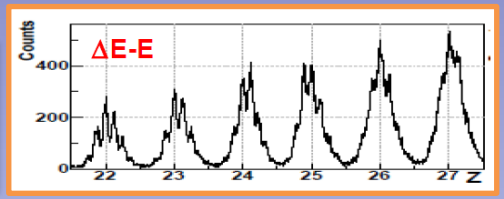


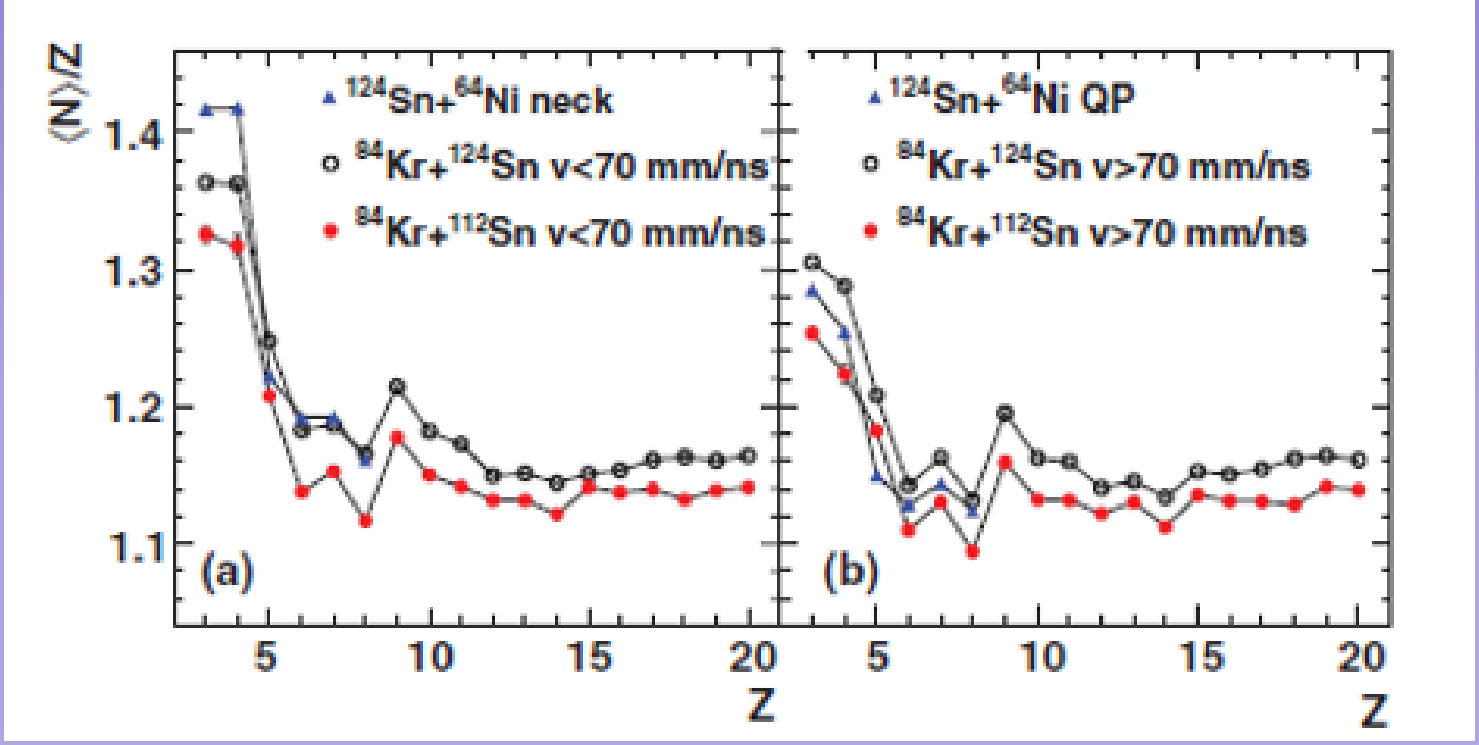
DE = Dynamical emitted
SE = Statistical emitted

The correlation shows that the greatest neutron enrichment is linked to the largest deviations from Viola systematics.

Comparison with FAZIA data ^{84}Kr + ^{112,124}Sn data 35 A.MeV

FAZIA data: **^{84}Kr+^{112,124}Sn**
Selection based on particles velocity





S. Barlini et al., Phys. Rev. C87, 054607 (2013)
S. Piantelli poster NR160

Chimera data (**triangles**): **^{124}Sn+^{64}Ni**
Selection based on angular correlations

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

$$L = 3\rho_0 \left(\frac{dE_{sym}(\rho)}{d\rho} \right)_{\rho=\rho_0} =$$

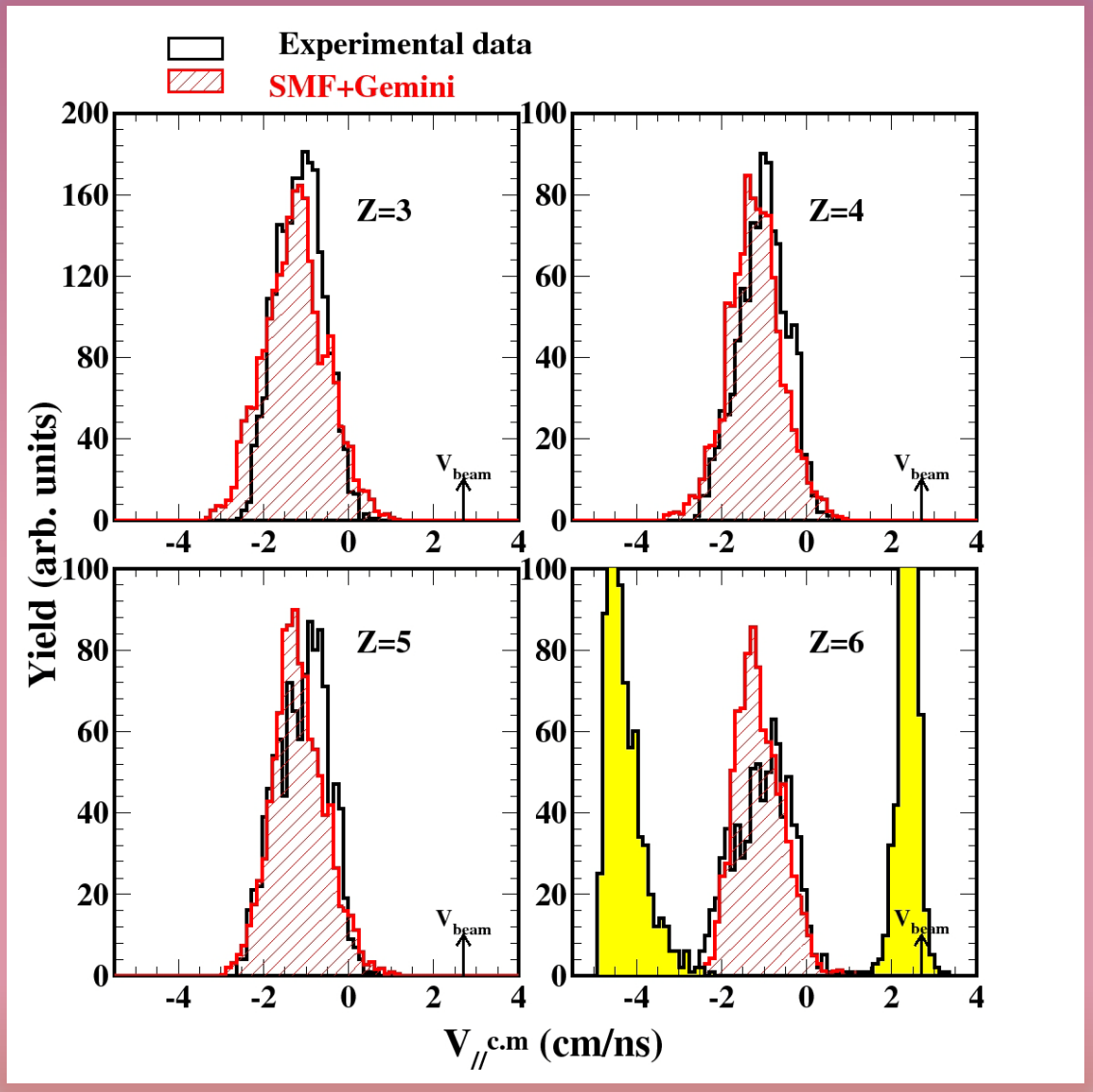
≈ 80 MeV for the asy-stiff

≈ 25 MeV for the asy-soft

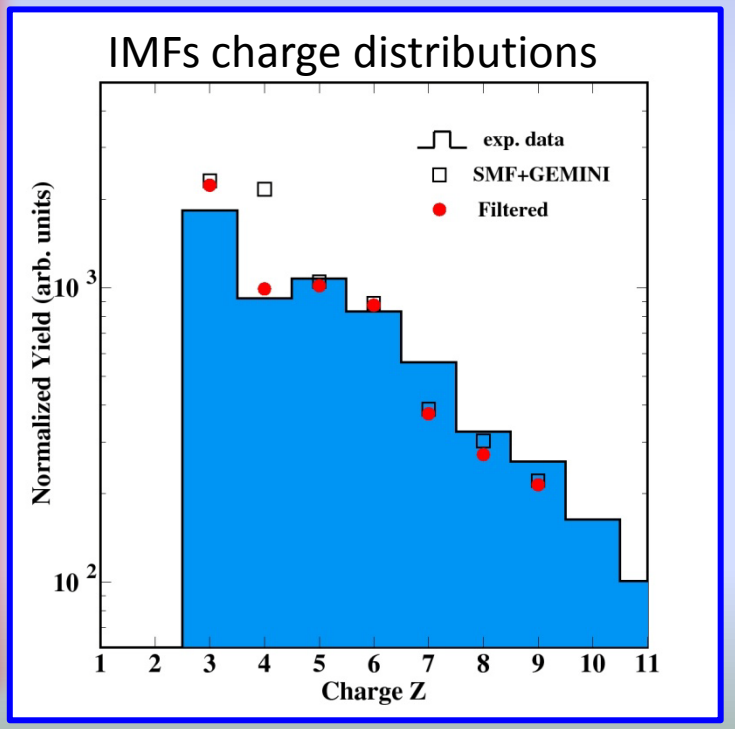
$$S_0 \approx 30 MeV$$

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

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

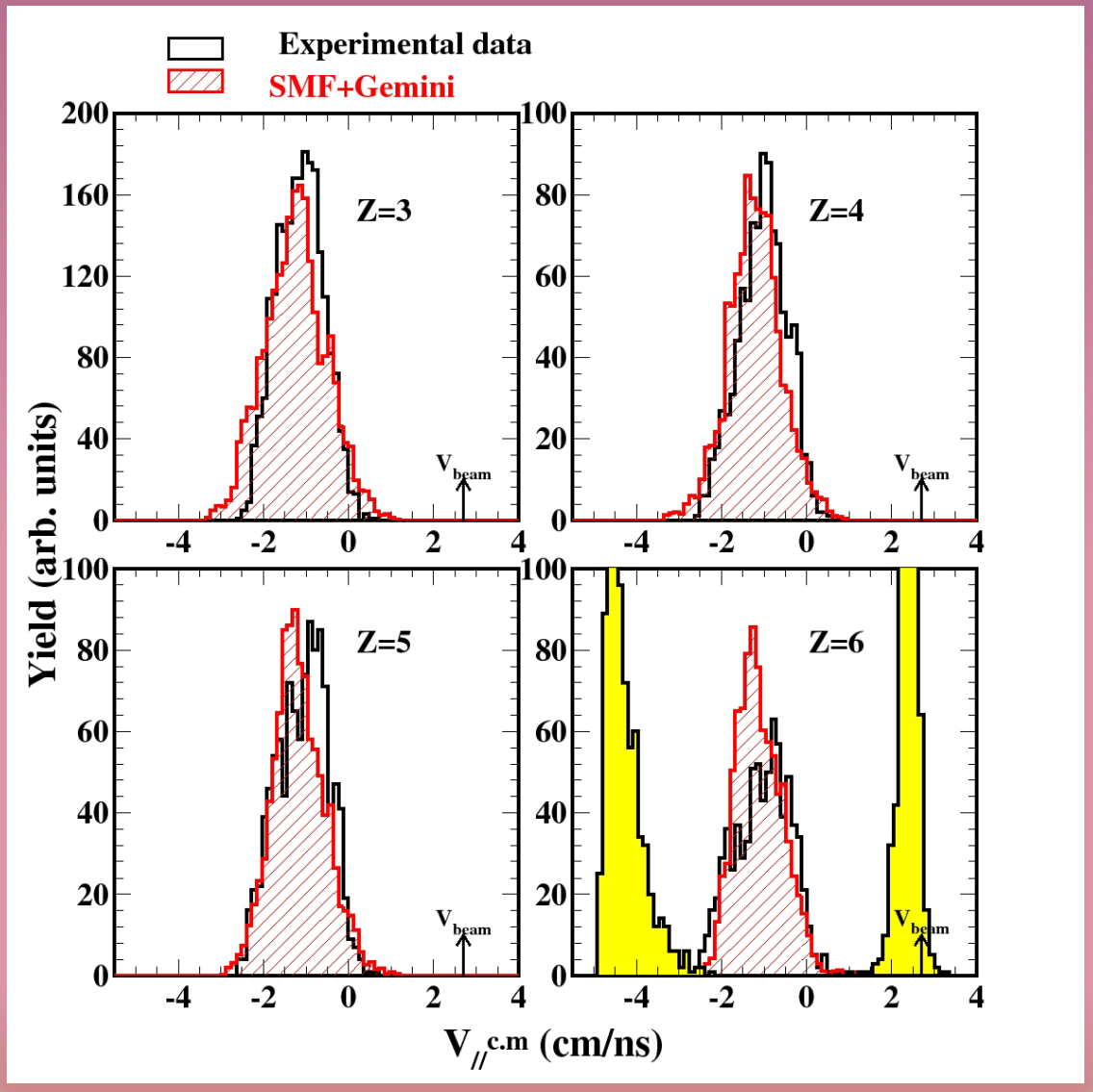


Calculated distributions are filtered by detectors acceptance, thresholds, time-of-flight experimental resolution.



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

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



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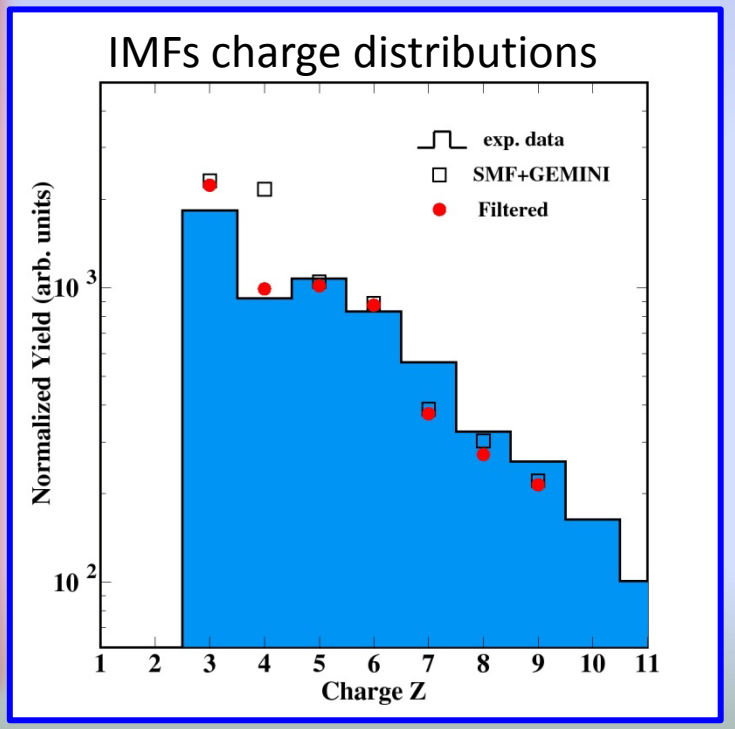
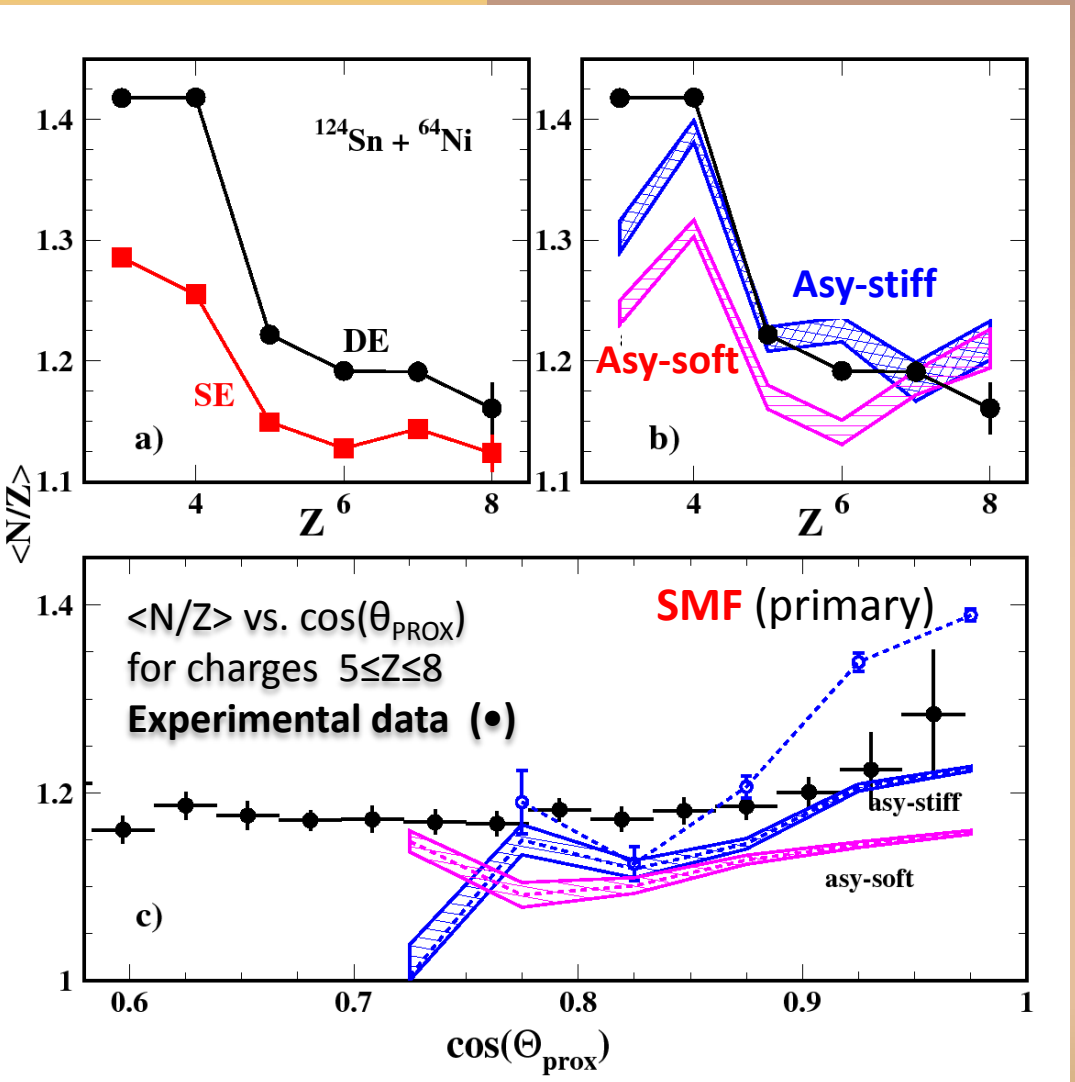


Phys. Rev. C ***86*** *014610 (2012)*

Stochastic Mean Field (SMF) + GEMINI calculation

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



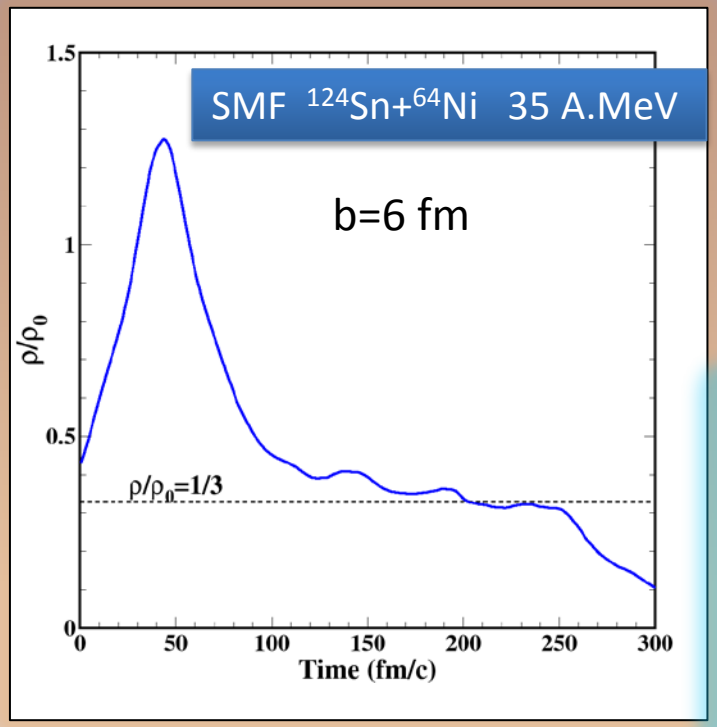
Phys. Rev. C ***86*** *014610 (2012)*

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

- Dynamically emitted particles
- Statistically emitted particles

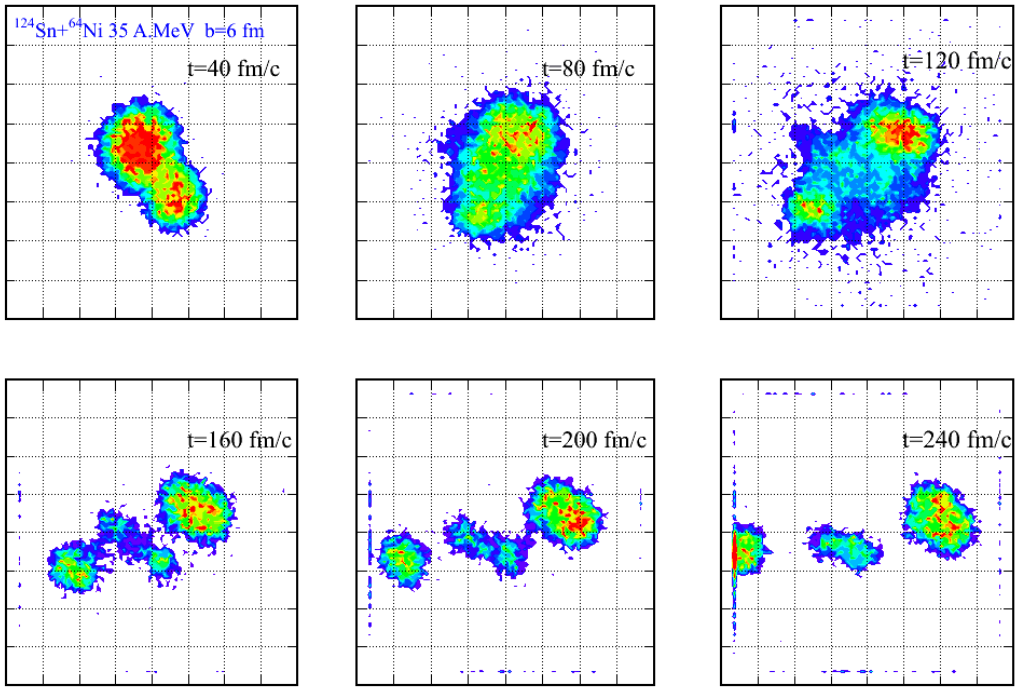
See also: S. Hudan et al., PRC **86** 021603(R).
K. Brown et al., arXiv:1305.1320 (2013)

Density: a three body analysis using SMF data in ternary events



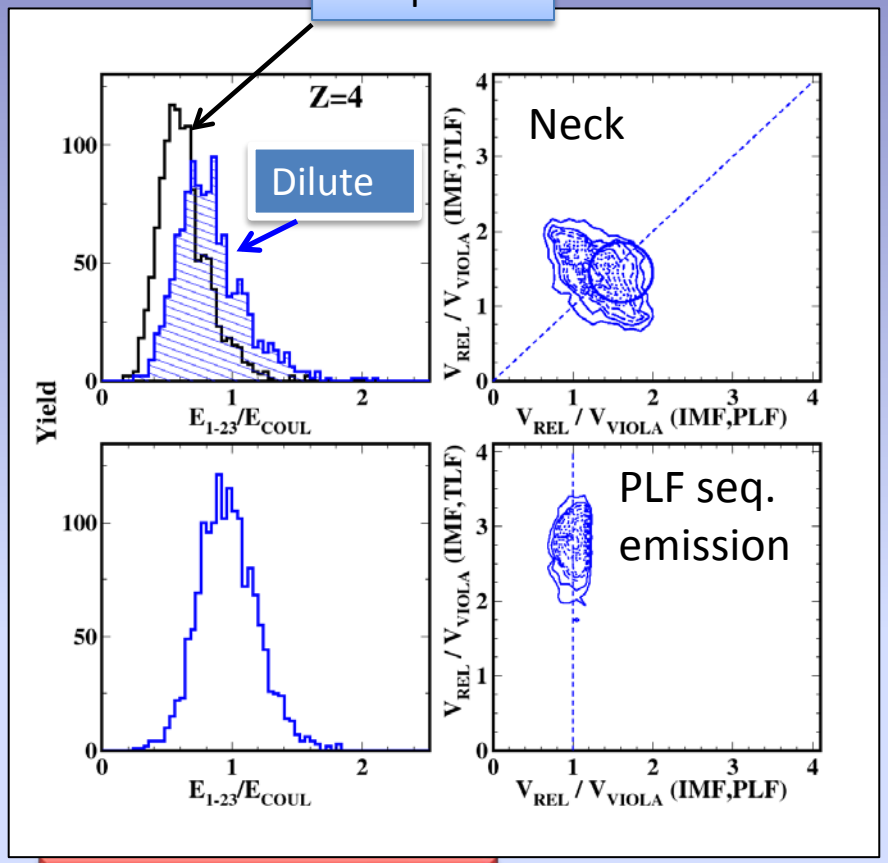
Time evolution of density at b=6 fm for the same event.

Time evolution of the density in the reaction plane in a ternary event at 6 fm. The density is shown at every 40 fm/c.



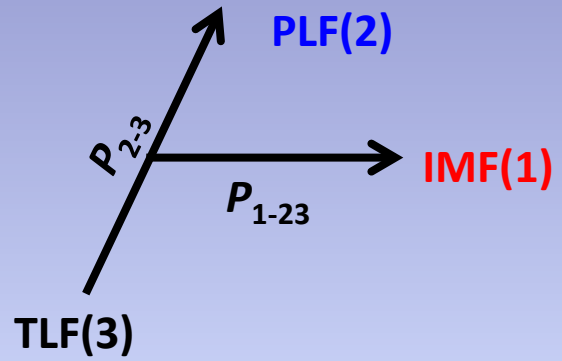
Density: the three body analysis in the experimental data

Preliminary



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

In the 3-bodies center-of-mass system:



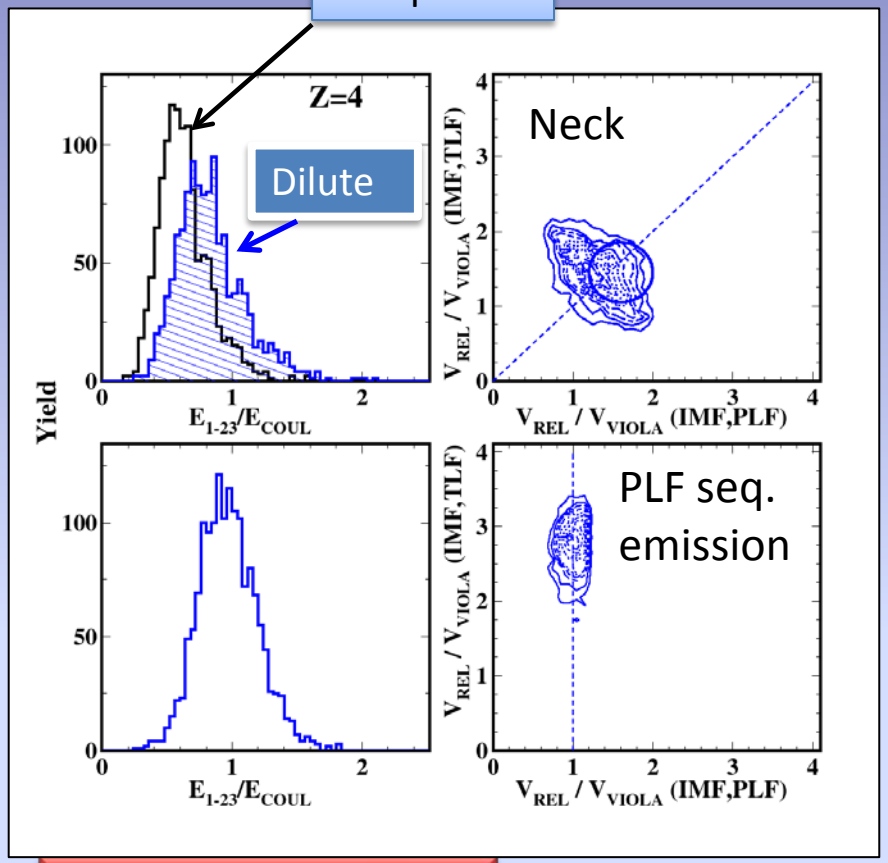
$$E_{TOT}^{c.m.} = E_1 + E_2 + E_3 = \frac{p_{1-23}^2}{\mu_{1-23}} + \frac{p_{23}^2}{\mu_{23}} = E_{1-23} + E_{23}$$

The ratio $E_{1\text{-}23}/E_{COULOMB}$ is calculated considering for the IMFs a dilute configuration with $r_0=1.8A^{1/3}$ fm (filled histogram corresponding to about 0.05 ρ_0) resulting from average values of SMF calculation (ρ=0.05-0.06 1/fm^3)

Density: the three body analysis in the experimental data

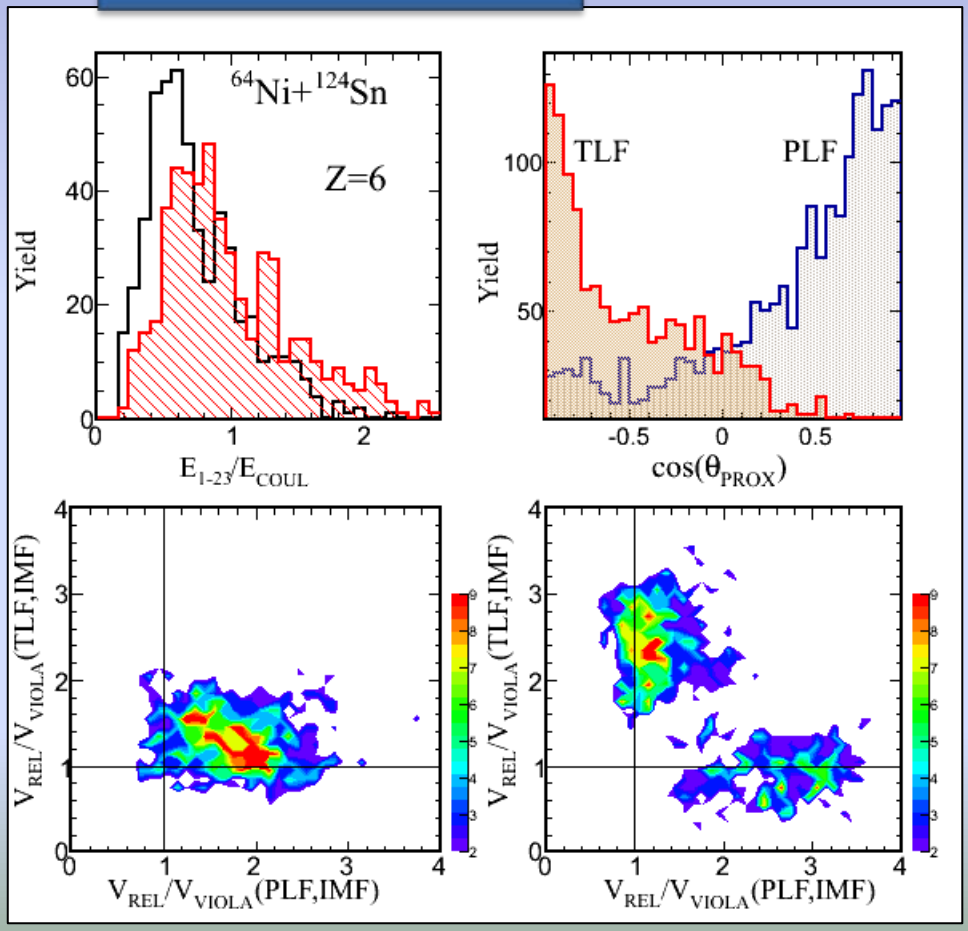
Preliminary

Compact



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

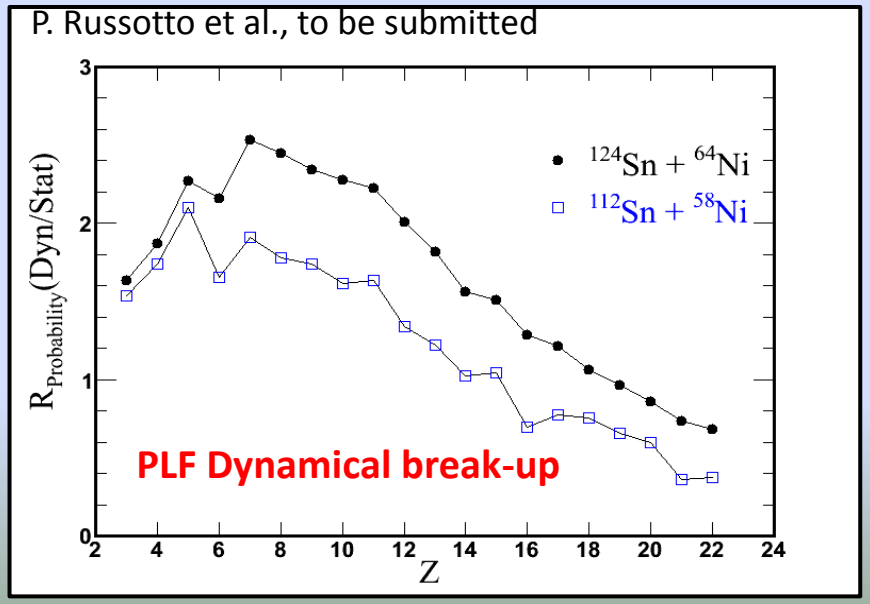
$^{64}Ni + ^{124}Sn$ 35 A.MeV

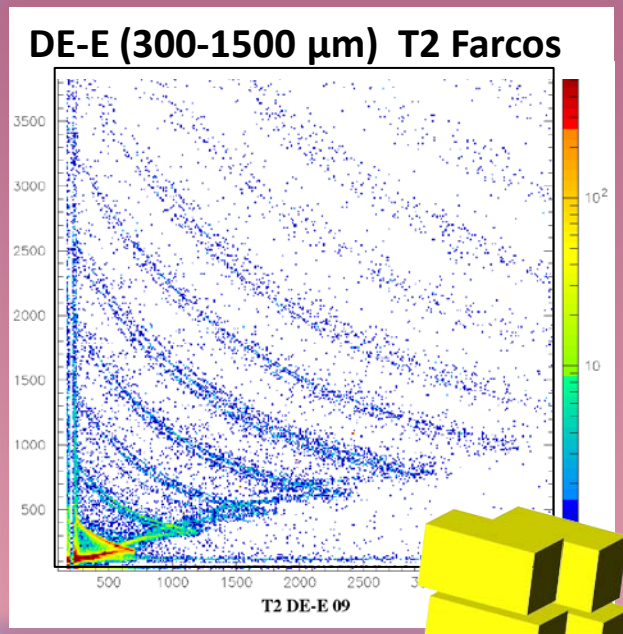


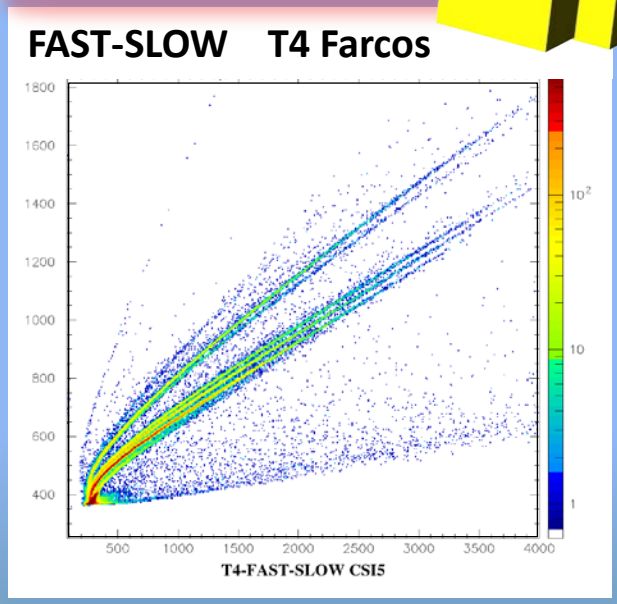
The INKIISSY (INverse KInematics ISobaric SYstems) $^{124}Xe + {}^{64}Zn$ (April 2013)

Study of Mass vs Isospin effects with the $^{124}Xe+^{64}Zn$ and $^{124}Sn+^{64}Ni$ reactions

This study 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 4 telescopes of FARCOS array.





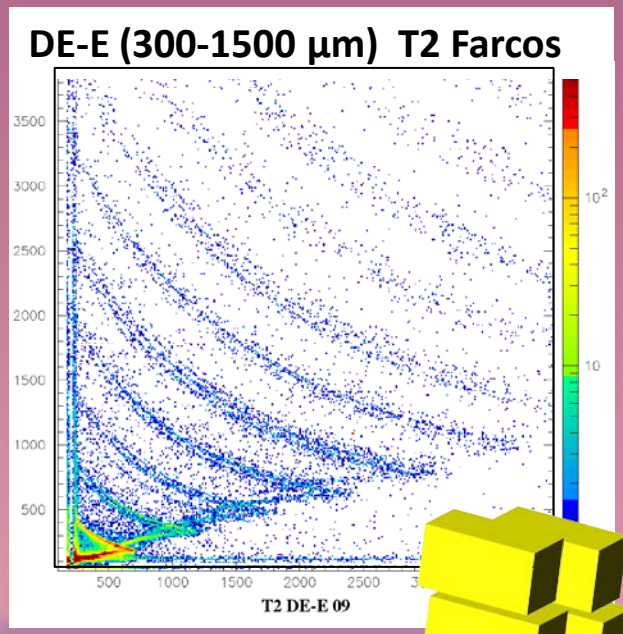


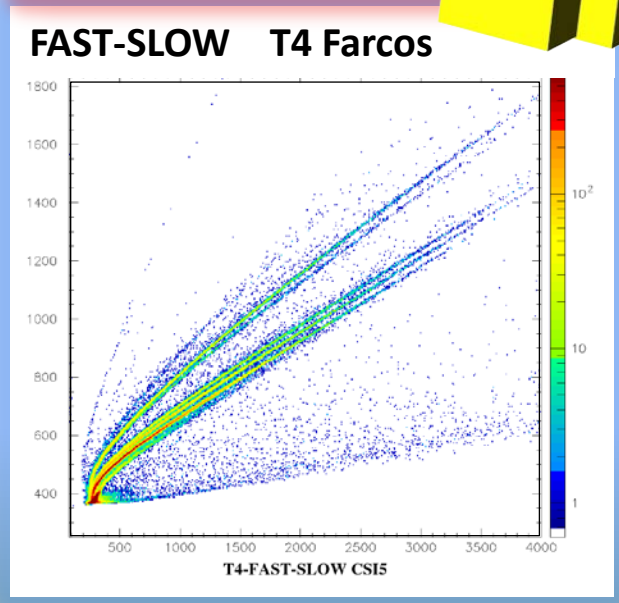
see poster session NF001,NR153

The INKIISSY (INverse KInematics ISobaric SYstems) $^{124}Xe + {}^{64}Zn$ (April 2013)

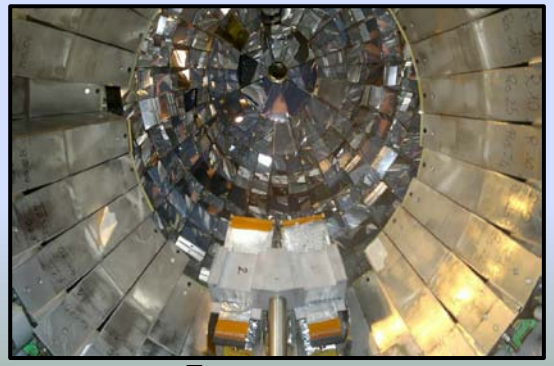
Study of Mass vs Isospin effects with the $^{124}Xe+^{64}Zn$ and $^{124}Sn+^{64}Ni$ reactions

This study 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 4 telescopes of FARCOS array.





CHIMERA backward sphere

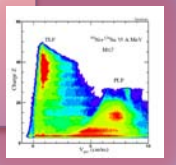


Farcos compact module

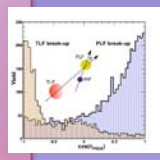
see poster session NF001,NR153

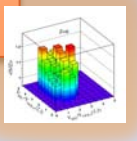
SUMMARY

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)

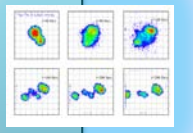


We have introduced a method to disentangle sequential from dynamically emitted particles at midrapidity and we have correlated the isotopic composition of Intermediate mass fragments with their emission timescale. Dynamically emitted IMF shows larger values of <N/Z> isospin asymmetry and stronger angular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

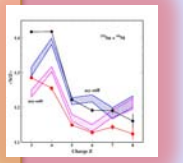




We have started a phenomenological estimation of the density in ternary neck events in order to probe that, as stated by transport model calculations, neck fragments are formed in presence of a density gradient



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.



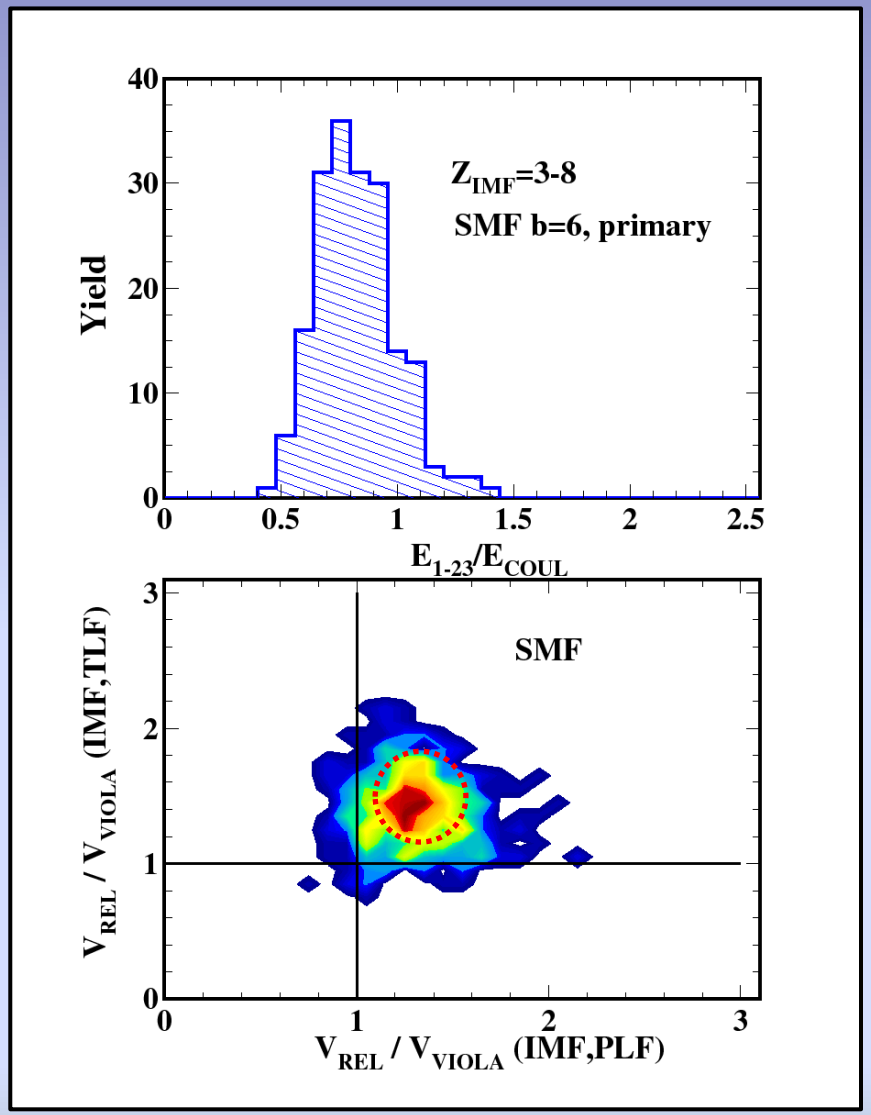
New experiment al INFN_LNS: **^{124}Xe+^{64}Zn** as compared with **^{124}Sn+^{64}Ni** at 35 A.MeV; Study of Mass vs. Isospin effects with Chimera+Farcos prototype.

This is a collective work of CHIMERA and EXOCHIM collaborations.

In particular all people of TIMESCALE , TIMESCALEZn and INKIISSY 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, R. Planeta, S. Pirrone, G. Politi, A. Pop, F. Porto, L. Quattrocchi, F. Rizzo, E. Rosato, P. Russotto, S. Santoro, K. Siwek-Wilczynska, I. Skwira, A. Trifirò, M. Trimarchi, G. Verde, M. Vigilante, J. Wilczyński, L. Zetta.

Density: a three body analysis using SMF data in ternary events



Preliminary

Qualitatively there is a good agreement, for the the dilute configuration, between data and simulations.

The ratio $E_{1-23}/E_{COULOMB}$ is calculated considering for the IMFs a dilute configuration with $r_0=1.8A^{1/3}$ fm (filled histogram corresponding to about 0.05 ρ_0) resulting from average values of SMF calculation (ρ=0.05-0.06 1/fm^3)