NUSYM 2017

7th international symposium on nuclear symmetry energy
SEPTEMBER 4TH - 7TH / GANIL, CAEN, FRANCE

TOPICS

- progress in experimental investigations of the nuclear EoS,
- status of theories of the nuclear reactions and of the asymmetric nuclear matter,
- influence of the symmetry term on the structure of objects and processes in the Femto and astro scales,
- correlations and clusterization in dense, normal and dilute nuclear matter,
- new facilities and new instruments.

Density and time scale determinations in Heavy Ion collisions at medium energies(*)

Angelo Pagano
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LOCAL ORGANIZING COMMITTEE

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Sabrina Lecerf-Rossard (GANIL)
Administrative secretary

Thanks a lot

(*) principal investigators: E.De Filippo, A.P., Paolo Russotto
In papers presented in many int. Workshops a and Pubblications (2004-2017)
REVERSE/ISOSPIN/EXOCHIM/NewCHIM coll.

Out line of the talk:

-Introduction (some general observations)

-The Time-scale determination with CHIMERA detector
(brief review historical of the Wp2 et al. method in (~) ternary reactions)

- Density (tentative) determination in neck fragmentation (physics case)

- Conclusions

Ideally connected with E.De Flippo
Talks given at :

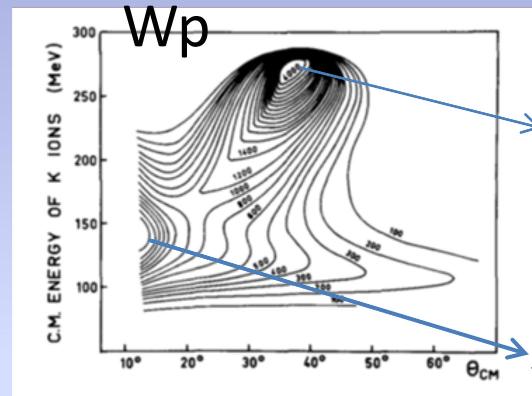
Nu YM14
7-9 July 2014
University of Liverpool (UK)

Transport 2017 - MSU

Introduction:

The study of the reaction mechanism in heavy ion collisions at coulomb energies could be understood in the frame of two main approaches:

-The correlation of measured quantities is understood over the time -Diachronic (*)- (Movie)



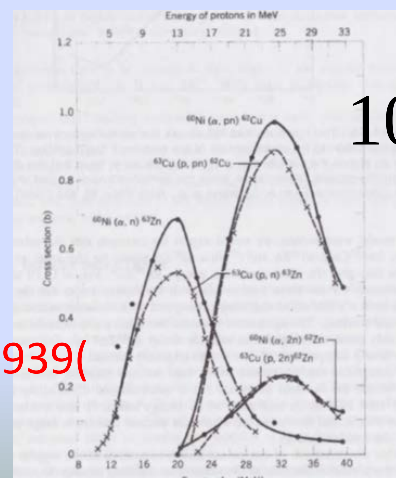
Time scale is linked to energy dissipation:

$10^{-23}s$

$10^{-20}s$

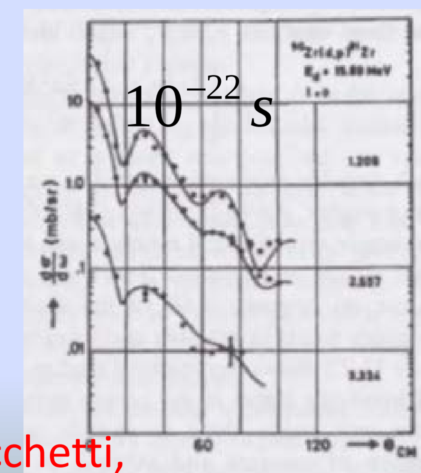
Semiclassical – deflection function + dissipation

-Quantities are correlated without relation with the time -Synchronic- (photo)



$10^{-16}s$

S.N.Goshal, phys.Rev.80,939(1950)



$10^{-22}s$

F.D.Becchetti, et al.Phys.Rev.182,1190(1969)

(*) diachronic
adjective /ˌdaɪ.əˈkrɒn.ɪk/ /ˌdaɪ.əˈkrɑː.nɪk/
relating to the changes in observables , especially a language, that happen over time

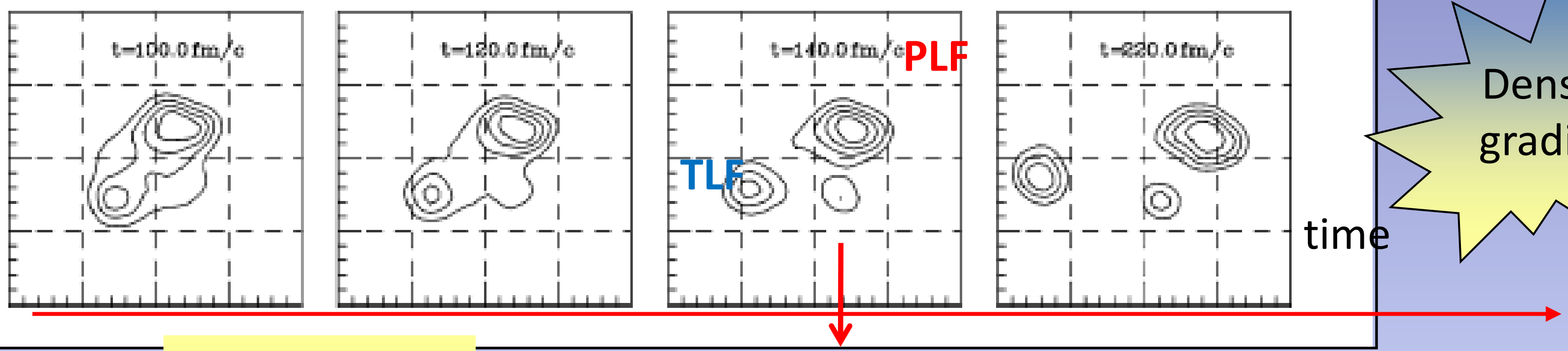
With the increase of the collision energy such a schematic approach is faced with the extreme evolving (with the time) character of the nuclear density(not present at coulomb energies)

Short summary :

a) At Fermi energy (≈ 50 MeV/nucleon) Characteristic sub-saturation density in both peripheral and central collisions have been (indirectly) evaluated and supported by transport theory

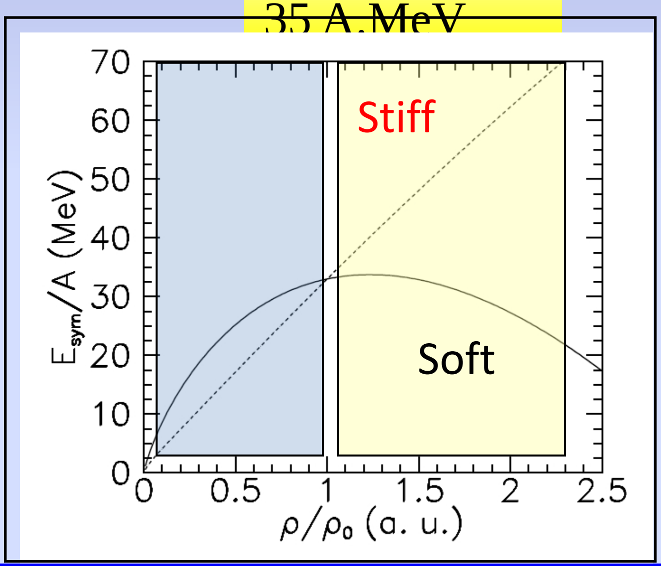
b) At Medium energy (> 200MeV/nucleon) large supra-saturation density in semi-central (participants) and central collisions of short duration(< 50fm/c) have been also predicted (and, e.g., large radial flow have been measured)

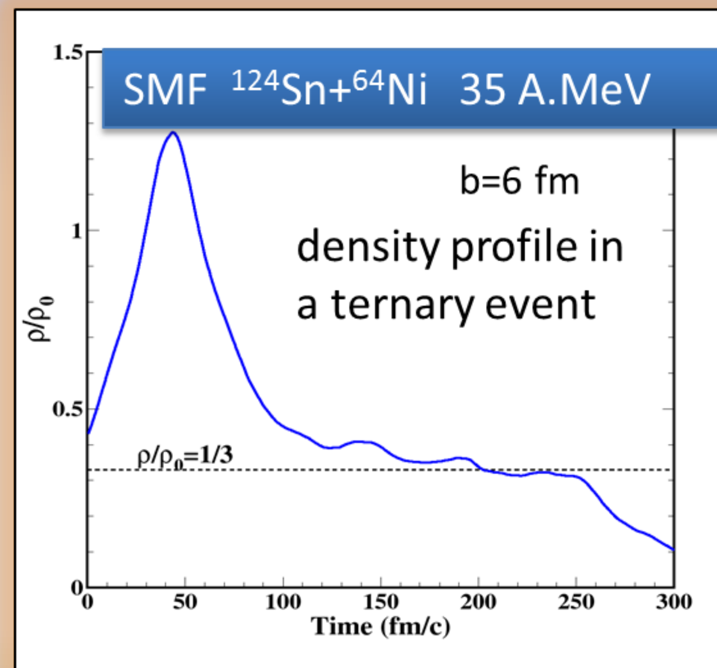
a) Fermi Energy: Sub-saturation density in peripheral collisions: **Midvelocity NECK emission: Isospin drift:Diffusion-Migration (basic phenomenology)**



Density gradient

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





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

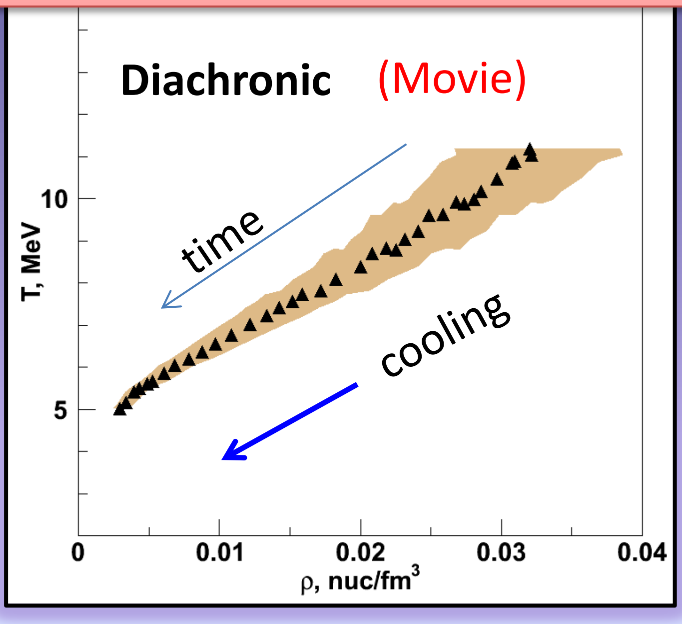
Diffusion Migration

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

a) Fermi Energy- Semi central and central collisions: Nuclear matter symmetry energy at low density ($\rho/\rho_0 \leq 0.2$)

Temperature and density determination from intermediate velocity source in ^{40}Ar,^{64}Zn + ^{112,124}Sn at 47 A.MeV

NIMROD@TAMU



R. Wada et al., PRC85, 064618 (2012)

-> …''nascent fireball in interaction zone. The expansion and cooling of this zone leads to a correlated evolution of density and temperature.''

Examples:

Formation of light clusters at very low densities

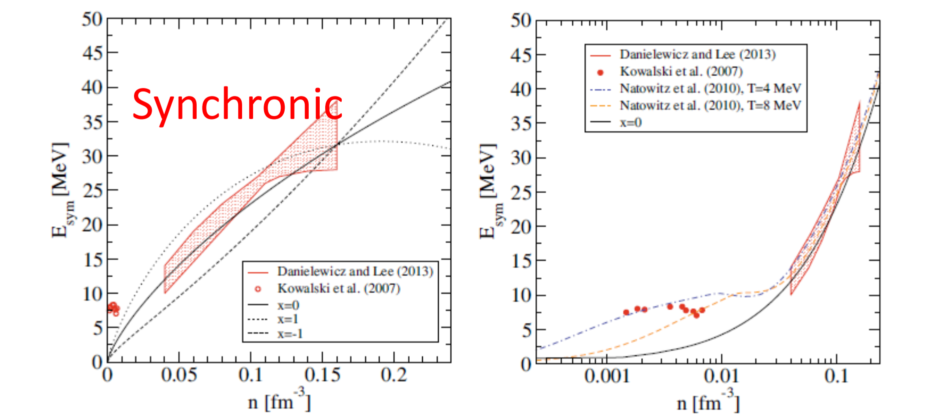


Fig. 9. Symmetry energy as a function of density, linear scale (left) and logarithmic scale (right). Experiment [5] compared with predictions according to the MDI parametrization of Chen *et al.* [90,91] with different parameter values x and the QS model [43]. The hatched area shows constraints obtained from Isobaric Analog States (IAS) of Danielewicz and Lee [92]. Courtesy of David Blaschke.

K. Hagel et al., EPJA 50:39 (2014)

Also:

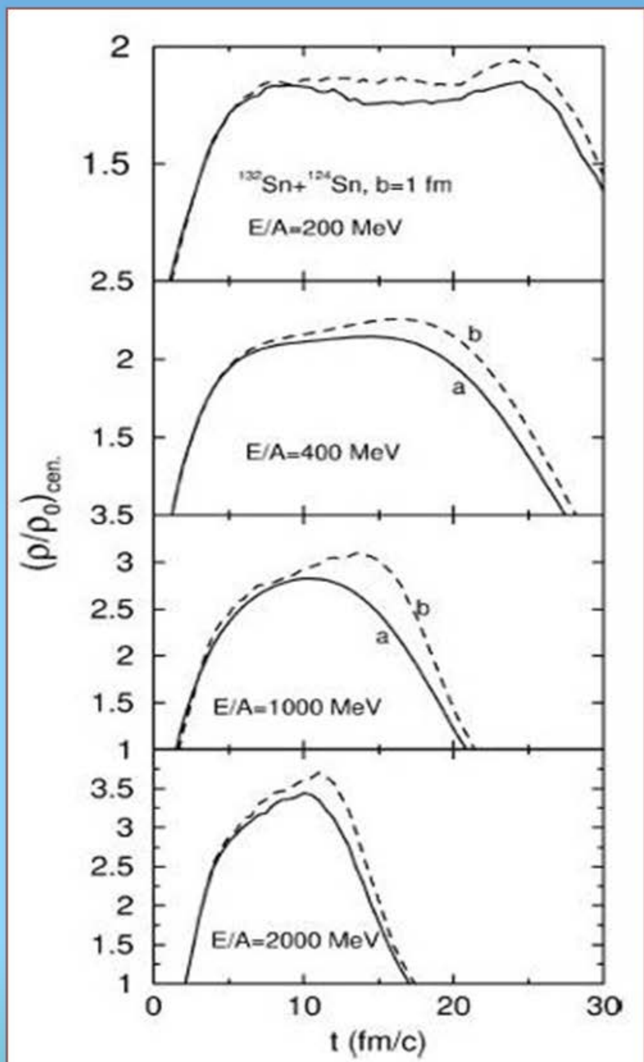
J.B. Natowitz et al., PRL 104 202501 (2010)

Lee G. Sobotka, Physics 3, 42 (2010)

QS = Quantum Statistical model including clusterization by Typel, Roepke et al.,

RMF = Relativistic mean field approaches

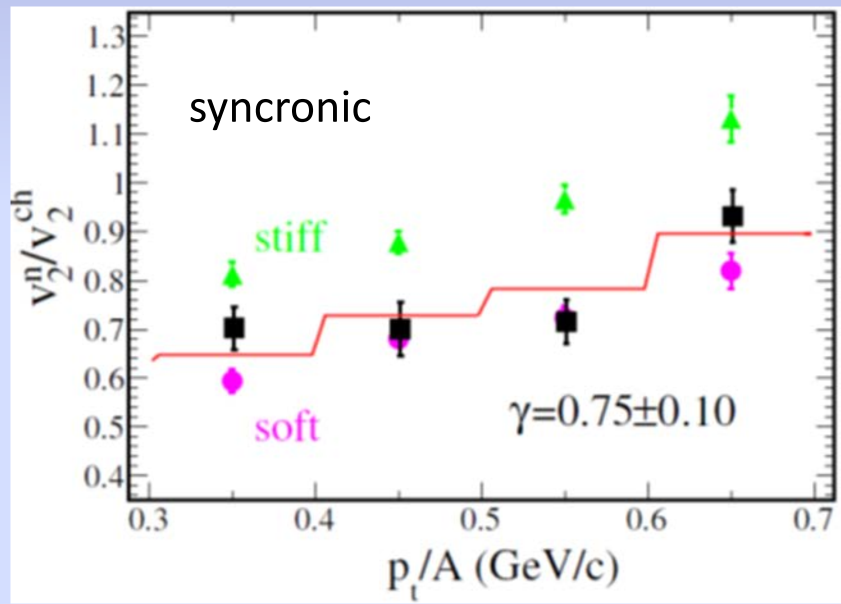
b) Medium energy: Suprasaturation density : Flow measurements



Bao-An Li, NPA 708 365 (2002)

$$V_2(y, p_t) = \left\langle \frac{p_x^2 - p_y^2}{p_t^2} \right\rangle$$

See P. Russotto talk Nusym2017
For perspectives



ASY-EOS DATA: P. Russotto et al., PRC 94, 034608 (2016)
γ = 0.72± 0.19 ; L=72□13

TIME-SCALE method- is based on the CHIMERA characteristics to measure TLF (large coverage)

Analysis based on fragment (IMF) – measurements . LCP are essentially used to estimate impact parameters b.

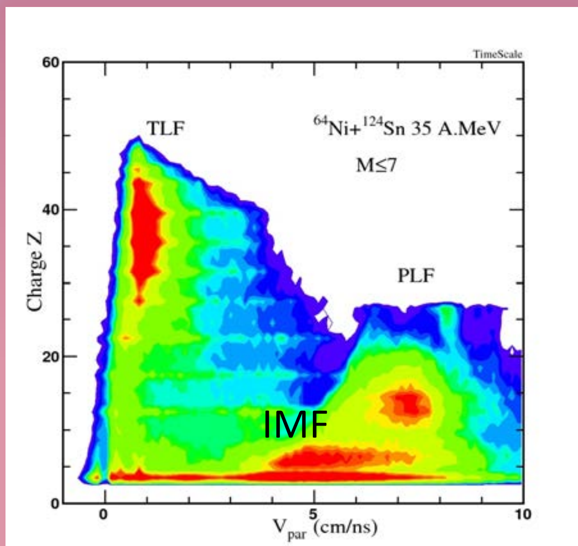
Almost complete events:

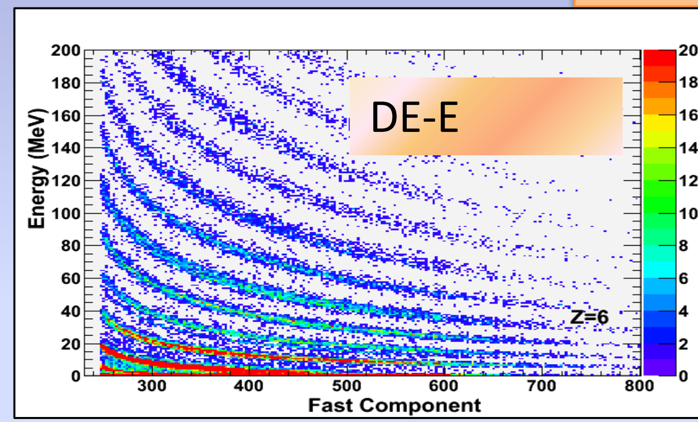
$p/p_{tot} > 60\%$

$Z/Z_{tot} > 60\%$

$M_{tot} \leq 7$ *(peripheral)*

FRAGMENTS:

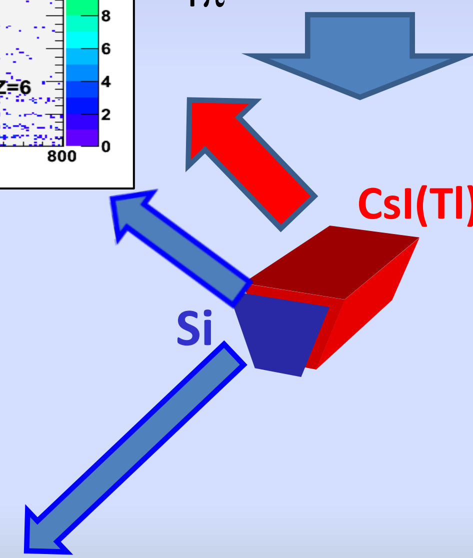


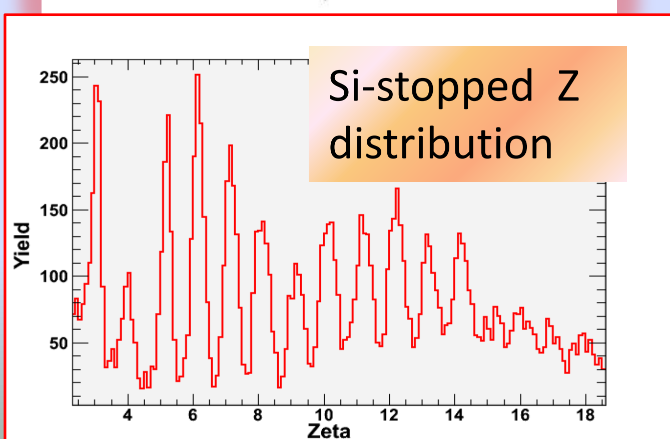


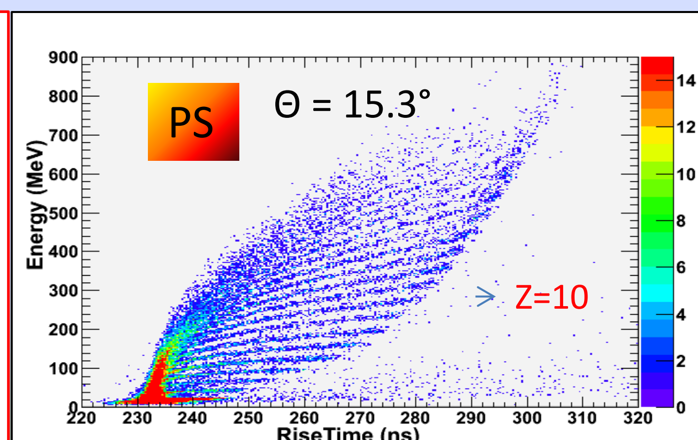
1200

Telescopes

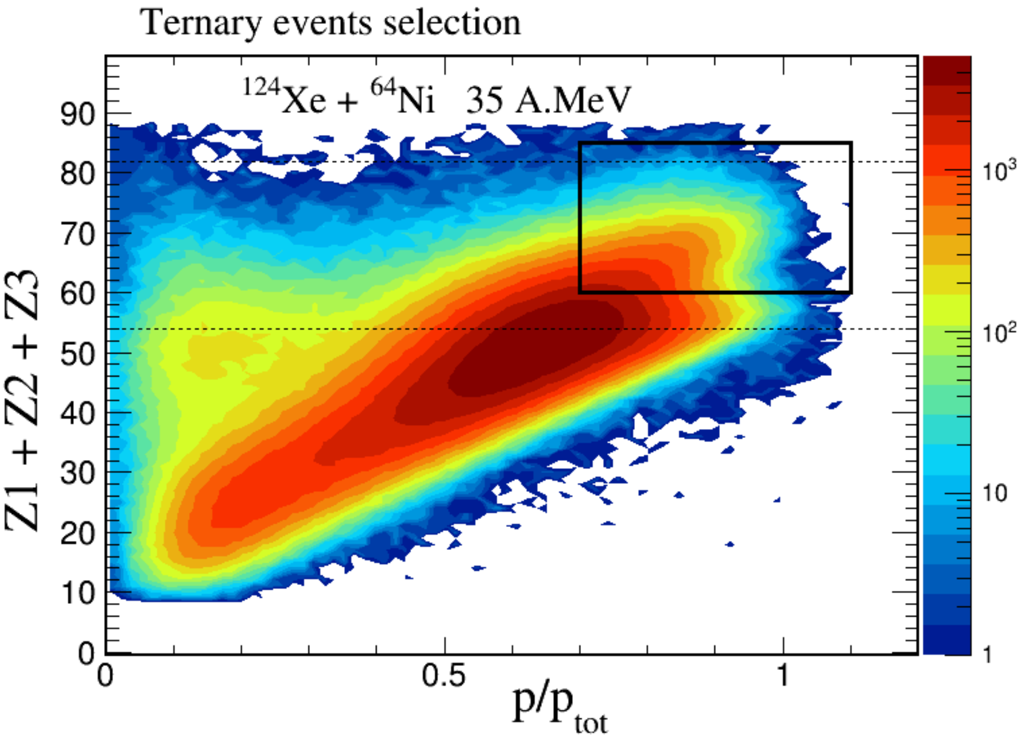
4π

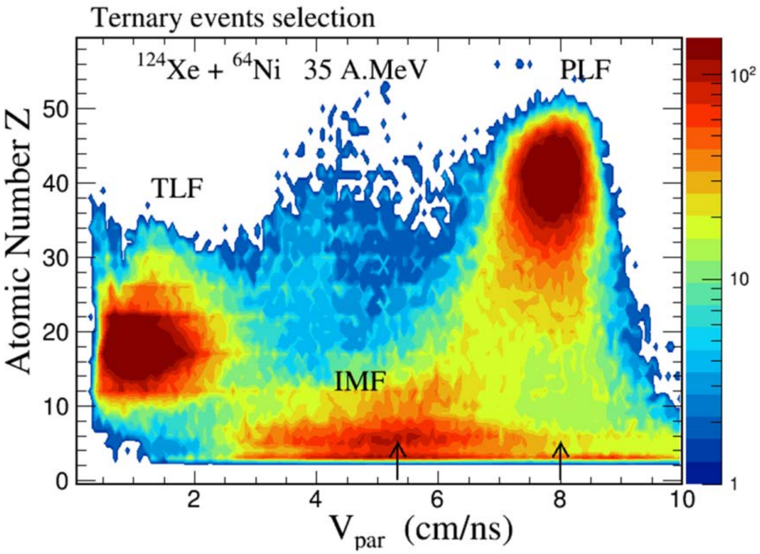






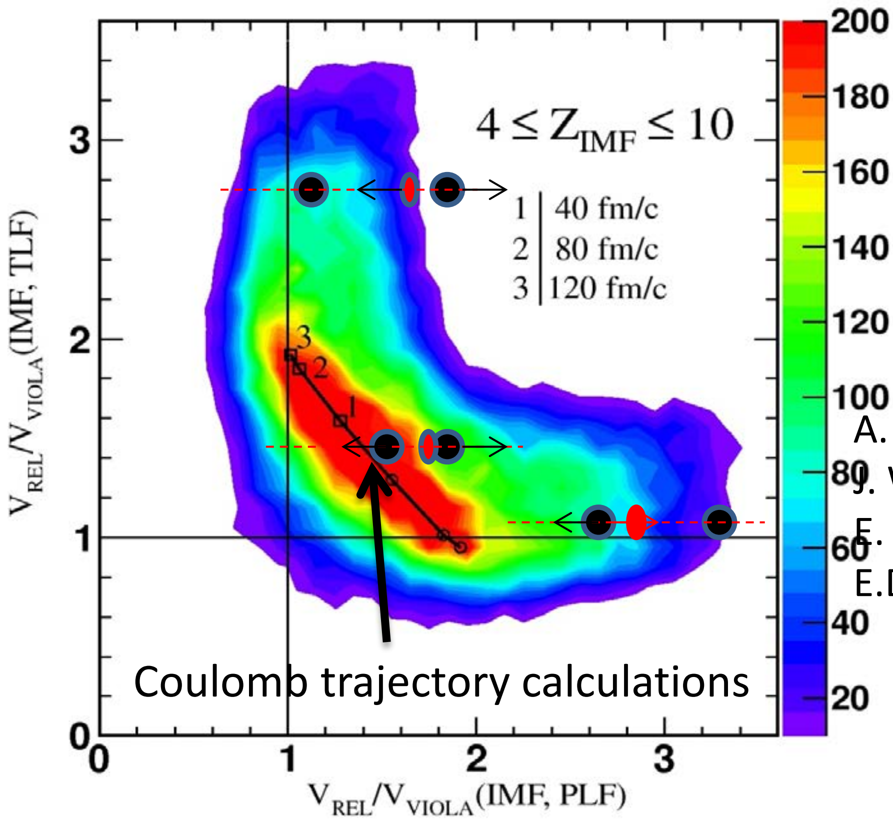
Method calibrated for peripheral three body reactions:

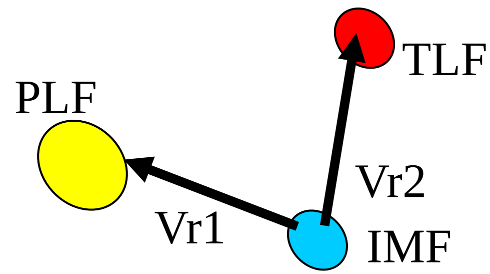




The time scale calibration (for light fragments Z < 15) was firstly applied to the reaction $^{124}Sn+^{64}Ni$, at $E_{lab}(^{124}Sn)/A$=35 MeV/nucleon. Very briefly, the experimental relative velocities of IMFs with respect to PLFs and TLFs, V_{REL} (IMF,PLF) and V_{REL} (IMF,TLF), respectively, are divided by the relative velocity V_{VIOLA} , corresponding to the released kinetic energy, determined by the Coulomb repulsion for the binary splitting of the two sub-systems (IMF,PLF) and (IMF,TLF), as given by the Viola systematic .

The wilczy’nski Plot 2

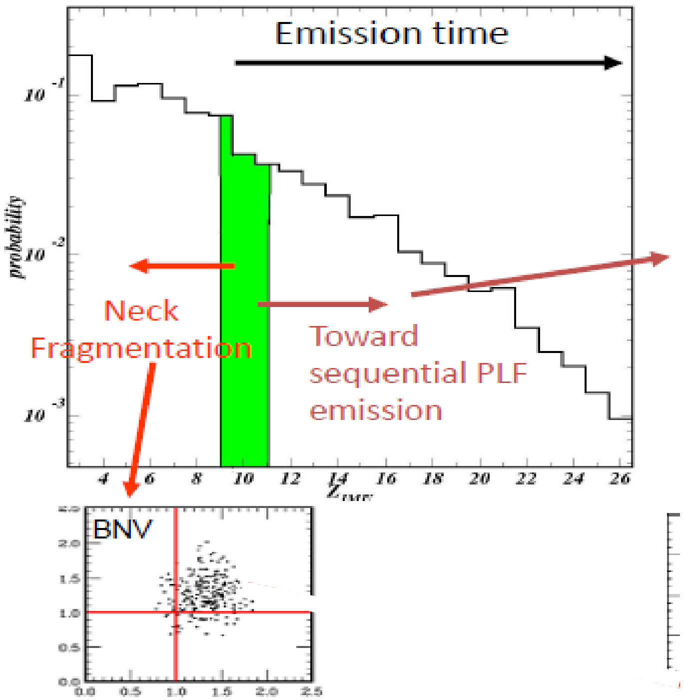




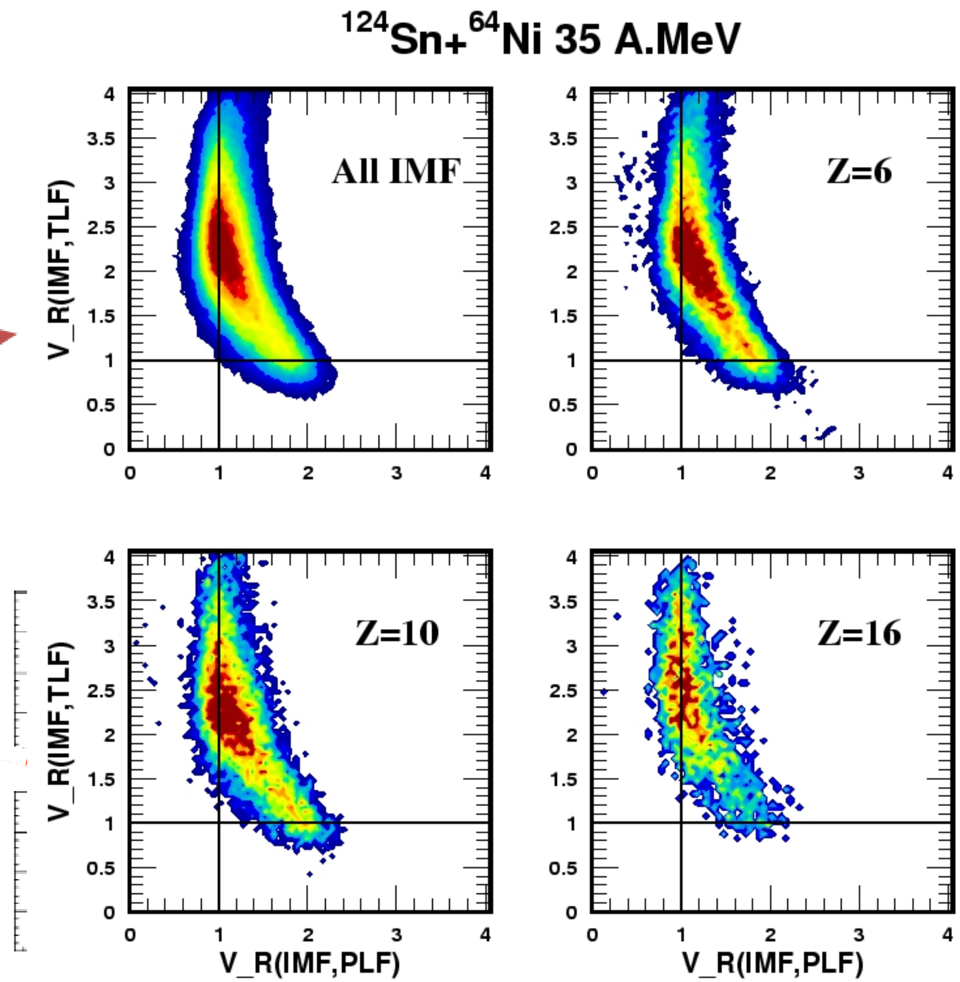
$$E_{viola} = (0.755\frac{Z_1 Z_2}{A_1^{1/3} + A_2^{1/3}} + 7.3)MeV$$

A. Pagano et al., Nucl. Phys. A 734, 504 (2004)
J. Wilczynski et al., Int. J. Mod. Phys. E14, 353 (2005)
E. De Filippo et al., Phys. Rev. C 71, 044602 (2005)
E.De Filippo et al., Phys. Rev. C 86,014610 (2012)

Important hierarchy effects in IMF emission time: It has been observed that with increasing the charge of the IMF fragments, the corresponding emission time increases up to large values of the order of 300 fm /c . Such fragments predominantly undergo an asymmetric (fission) fragmentation of a primary PLF in two massive fragments



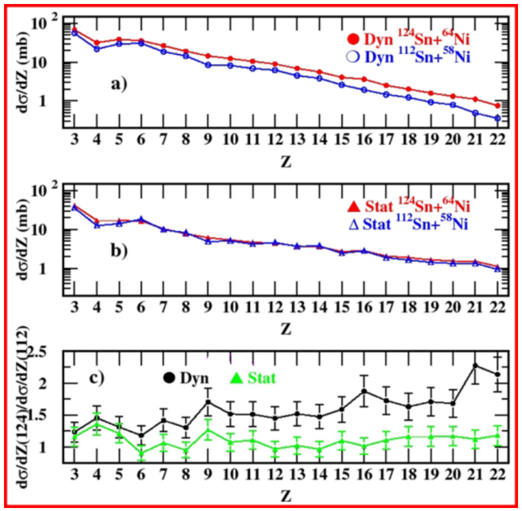
Dynamical transport BNV simulation BNV model accounts only for the "prompt" light component of IMF's (V. Baran et al. Nucl. Phys. A730 329, 2004).



Enhanced contribution of dynamical component in binary projectile break-up (dynamical fission) for neutron rich system

P.Russotto et al coll. (sub. to PRC)

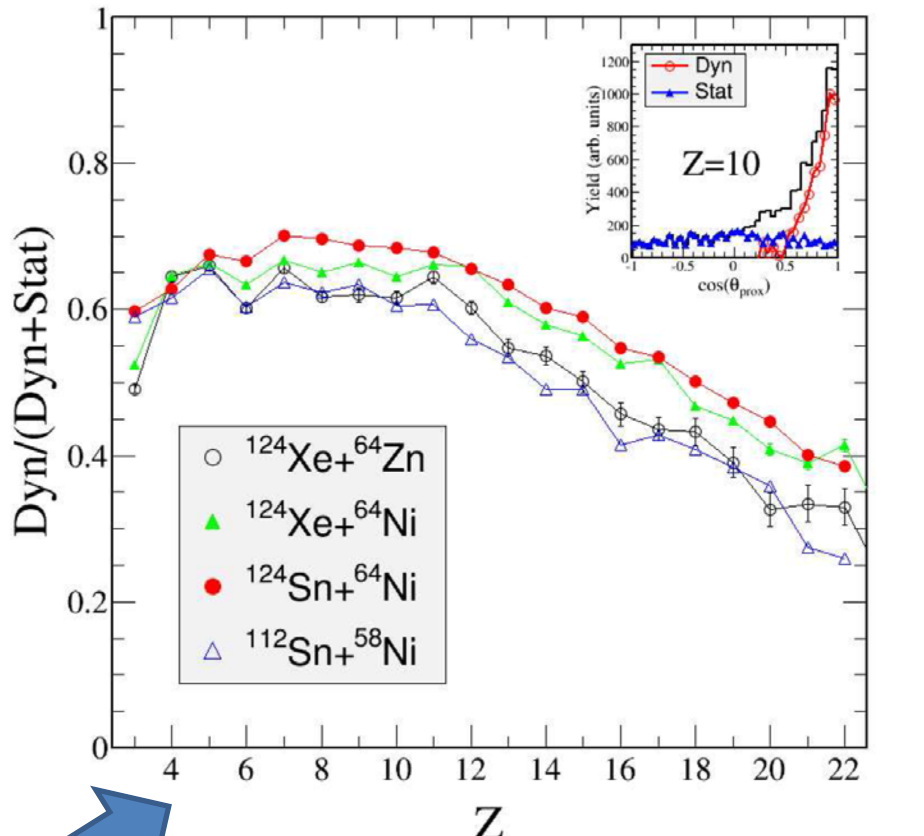
35MeV/nucleon



P. Russotto et al., Phys. Rev. C 91, 014610 (2015).

TABLE I. Isospin (N/Z) of the systems investigated in the REVERSE and InKiIsSy experiments

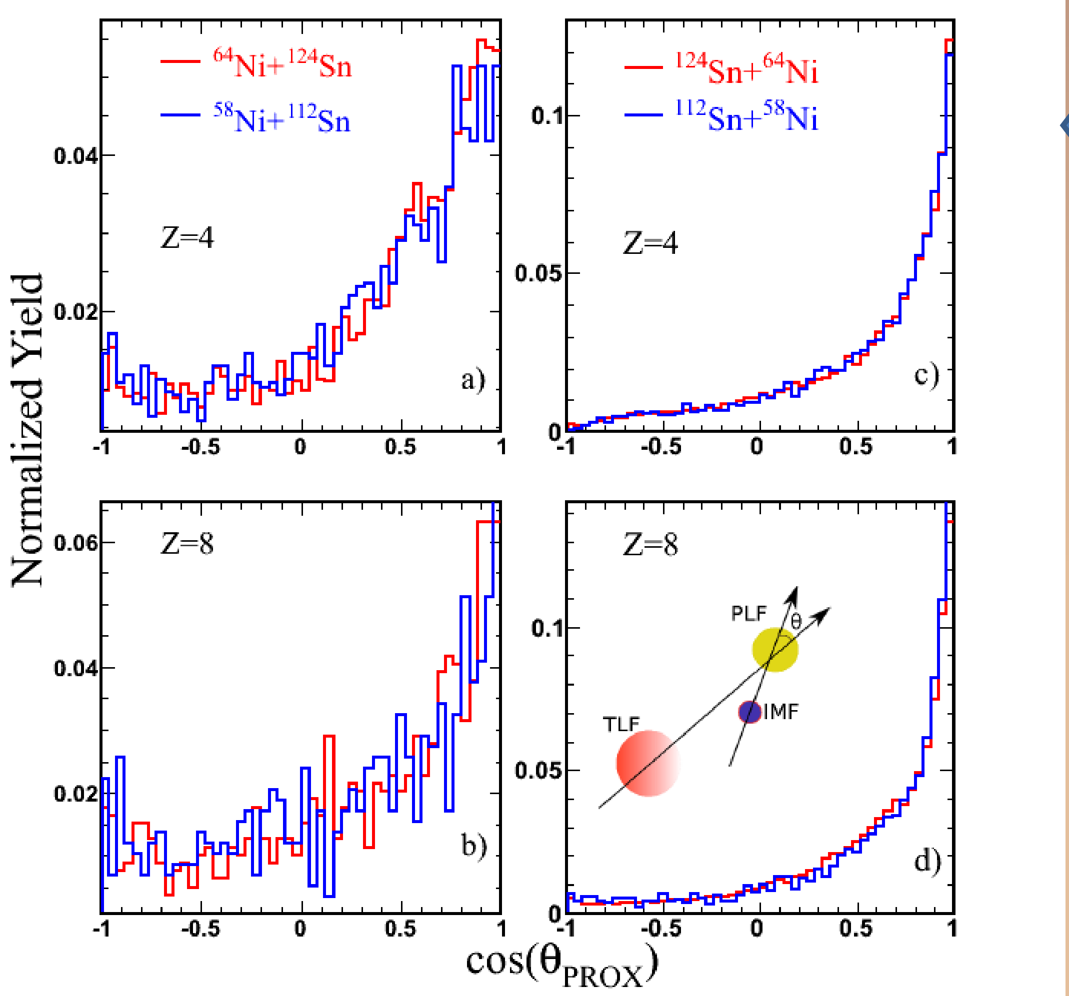
System	N/Z Projectile	N/Z Target	N/Z Composite
$^{124}Sn+^{64}Ni$	1.48	1.29	1.41
$^{112}Sn+^{58}Ni$	1.24	1.07	1.18
$^{124}Xe+^{64}Zn$	1.30	1.13	1.24
$^{124}Xe+^{64}Ni$	1.30	1.29	1.29



...or online) Ratio of the dynamical component to the total (dynamical+statistical) value plotted as a function of ... atomic number Z, for the ^{124}Xe+^{64}Zn (empty circles) and ^{124}Xe+^{64}Ni (full triangles) systems; for comparison, also ...ata of the ^{124}Sn+^{64}Ni (full circles) and ^{112}Sn+^{58}Ni (empty triangles) systems are shown. The inset shows an example ...f the $\cos(\theta_{prox})$ for IMFs of Z=10 (black line). The statistical contribution (full triangles) is obtained symmetrizing around $\cos(\theta_{prox}) = 0$ the "forward emission", i.e., the $\cos(\theta_{prox}) < 0$ part; the Dynamical contribution (empty circles) is then obtained by subtracting the statistical contribution from the total one, as described in [12].

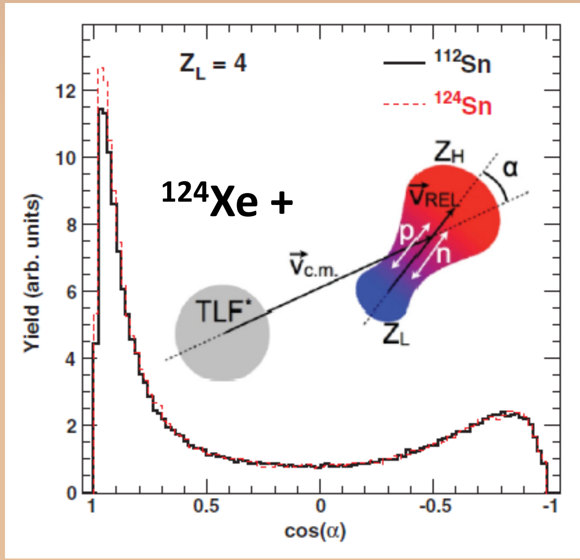
Strong alignement : PLF break-up in **direct** kinematics (left) and **reverse** kinematics (right)

At the same bombarding energy (35MeV/nucleon @lns)



Enhancement of backward DYNA) fragment yield relative to the forward component (STAT)

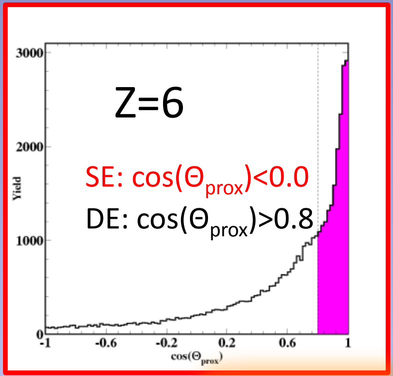
Similar results:



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

presented by E. De Filippo et al, NN2012 Conference Proceedings, S. Antonio (Texas, USA), May 27-June 1 2012 Jour. Phys. CS 420 (2013).

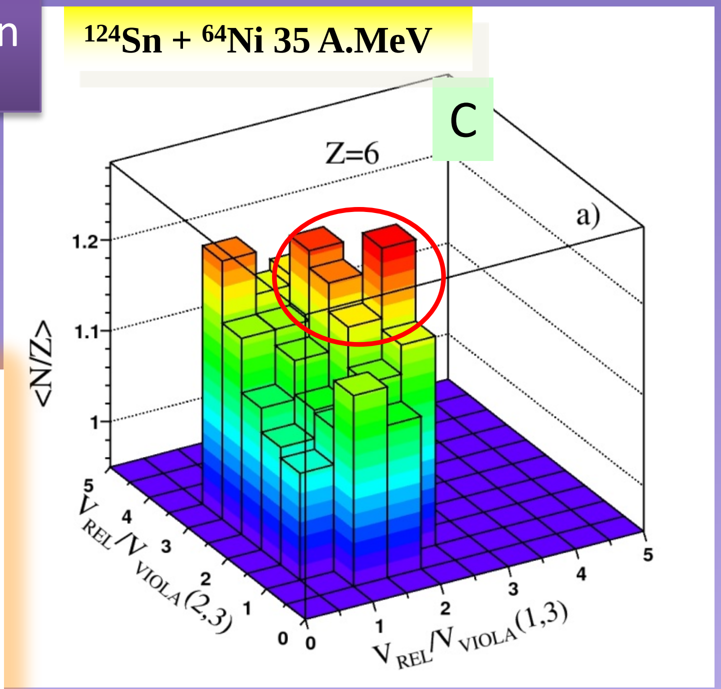
Neck neutron enrichment; reduction of "staggering" odd-even effects

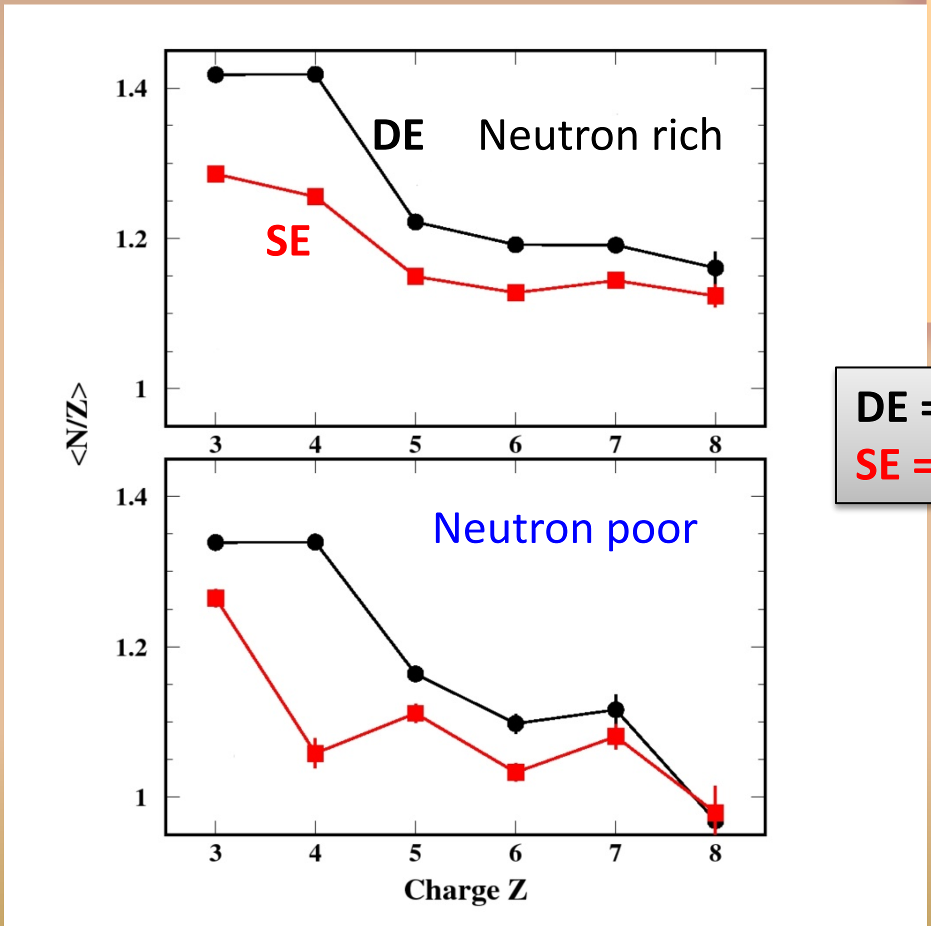


(1) Condition on cos(Θ_{prox})

+

(2) Condition on V_{rel} plot





DE = Dynamical emitted
SE = Statistical emitted

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

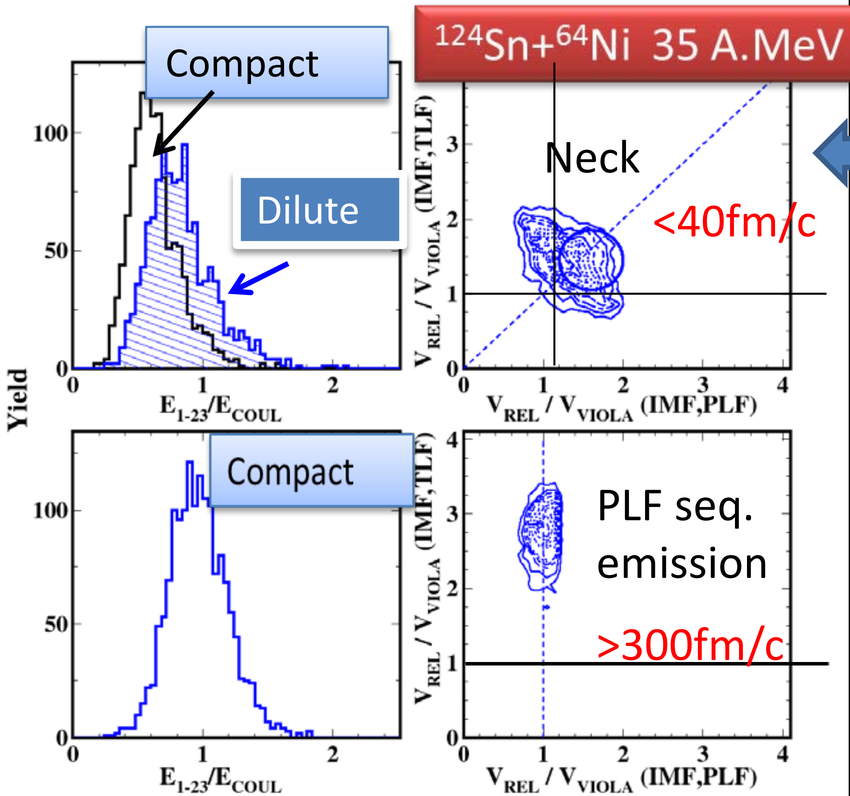
Experimental remark (motivation)

Normal density of nuclei was measured by diffusion experiments and/or deviation of elastic Scattering by Rutherford diffusion and nuclear mass evaluation (semi empirical mass formula with 5 parameters). The summary of all these evaluations is represented by LDM description of the nucleus over a large scale phenomenology.

From experimental point of view is highly desirable that density far for normal saturation value , as the one predicted by modern reactions theory, could be measured with methods as much as possible independent by theoretical calculations .

In the following i present to your attention (and consideration) a method that could be valuable for Density determination of the participant region undergoing clusterisation In the early phase of the reaction (dynamical emission)

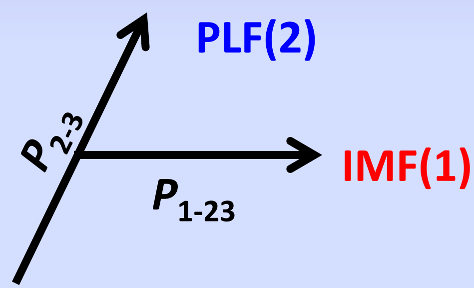
Density determination: the three body analysis



Preliminary analysis was presented at INPC(2013)- by E. De Filippo et al.

Assumption: complete aligned configuration:

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



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

NUCLEAR INSTRUMENTS AND METHODS 37 (1965) 240–248; © NORTH-HOLLAND PUBLISHING CO.

KINEMATIC RELATIONS IN REACTIONS OF THE FORM A + B ⟶ C + D + E

G. G. OHLSEN*

Research School of Physical Sciences, Australian National University, Canberra, Australia

Received 24 May 1965

The ratio $E_{1-23}/E_{COULOMB}$ is calculated considering for the IMFs a compact or Diluite configurations (see Figure on the right)
(filled histogram corresponding to about ρ= 0.05 1/fm^3) resulting from average values of SMF predictions (ρ=0.05-0.06 1/fm^3) 30% of normal dens.

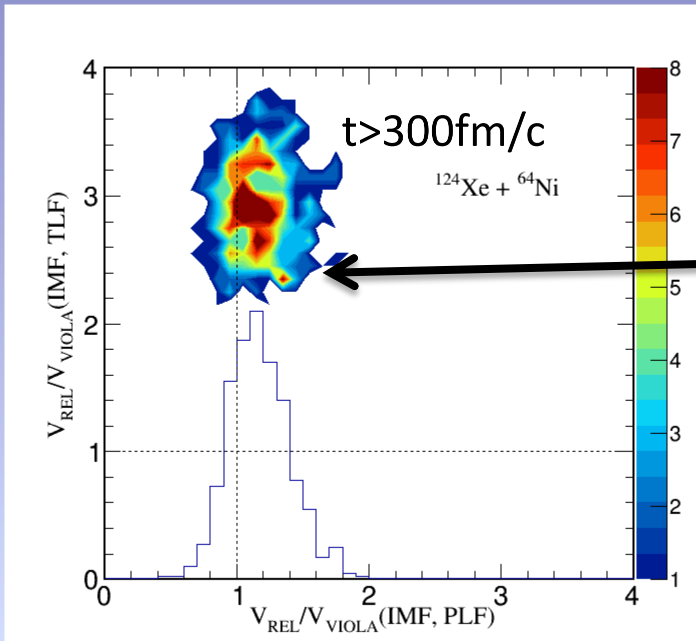
Recently we have applied the method to different reactions and colliding systems at the same bombarding energy (35MeV/nucleon) with the aim to measure correlations among different observables at short time scale:

112,124Sn+ 58,64Ni (direct and inverse kinematics) : Reverse and Time Scale experiments + More recent InKiIsSy :

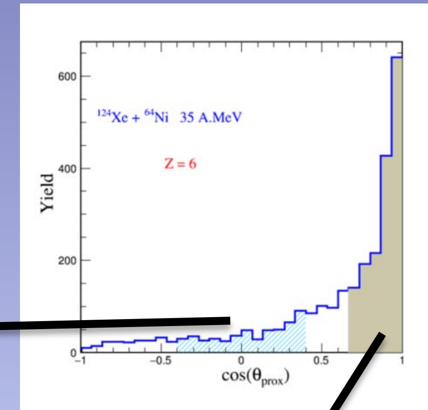
System	N/Z Projectile	N/Z Target	N/Z Composite
$^{124}Sn+^{64}Ni$	1.48	1.29	1.41
$^{112}Sn+^{58}Ni$	1.24	1.07	1.18
$^{124}Xe+^{64}Zn$	1.30	1.13	1.24
$^{124}Xe+^{64}Ni$	1.30	1.29	1.29

Few examples are shown in the presentation

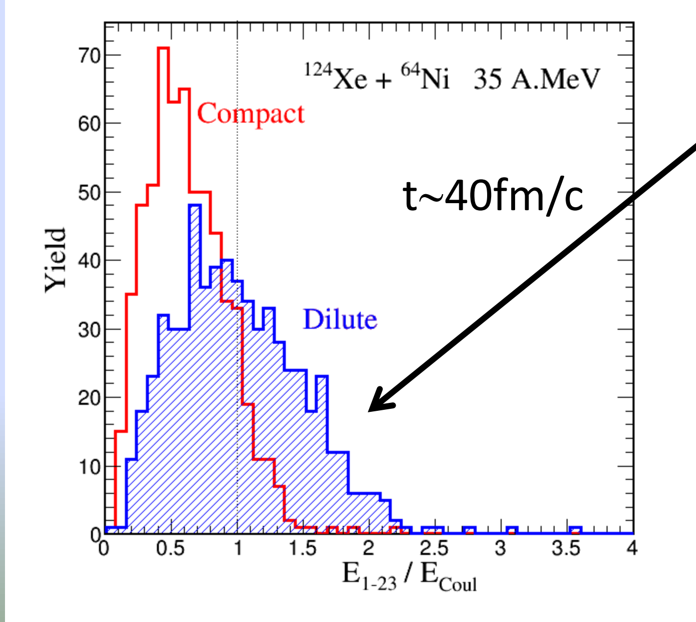
STATISTICAL (sequential Decay)

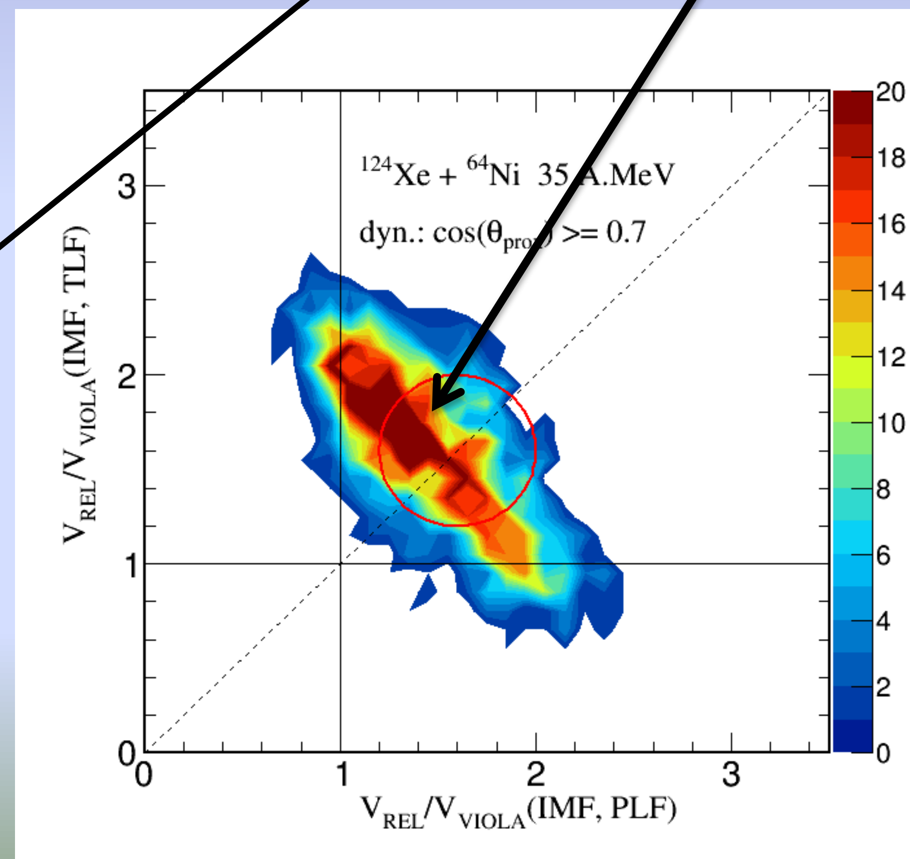


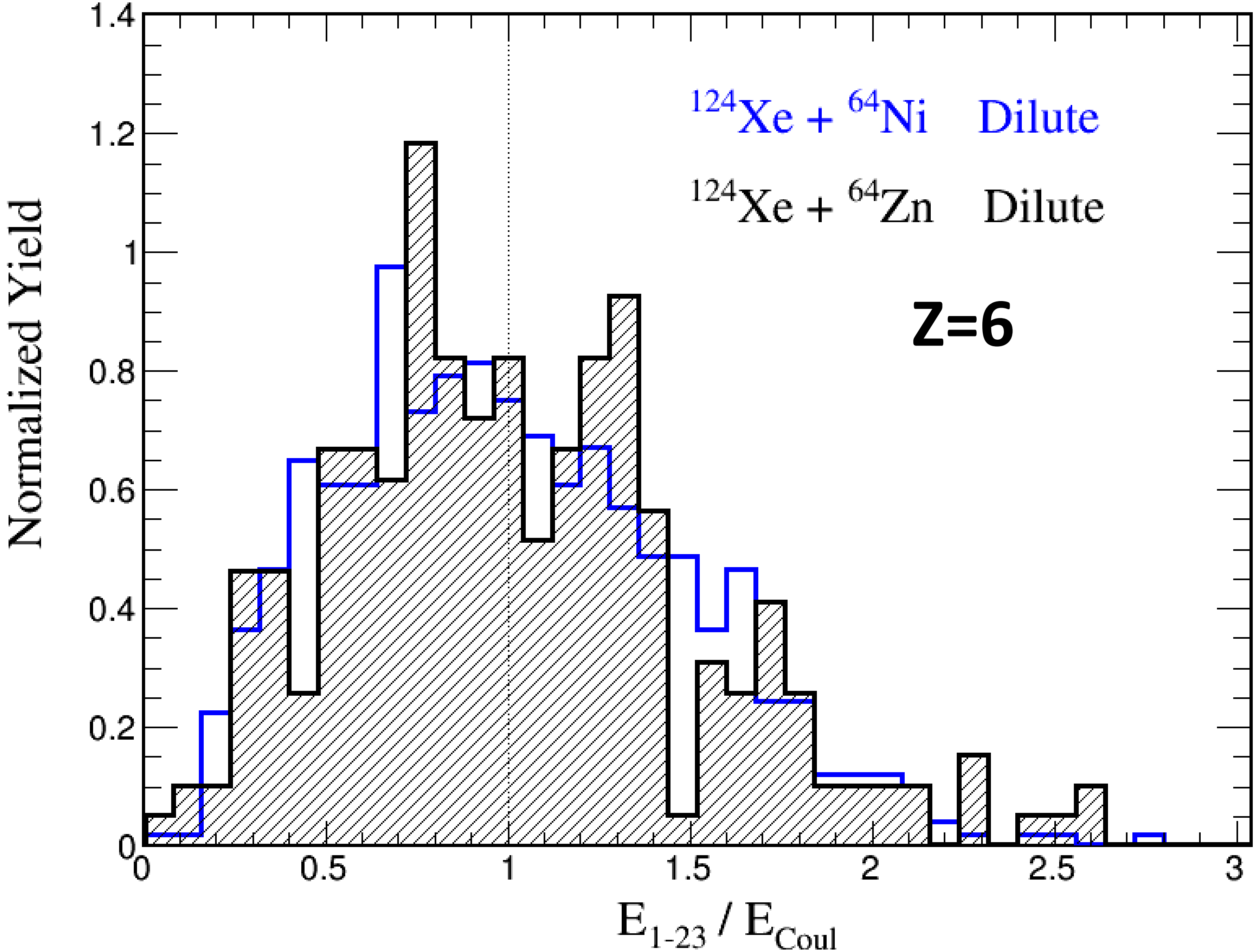
Z=6



DYNAMICAL(prompt-aligned)

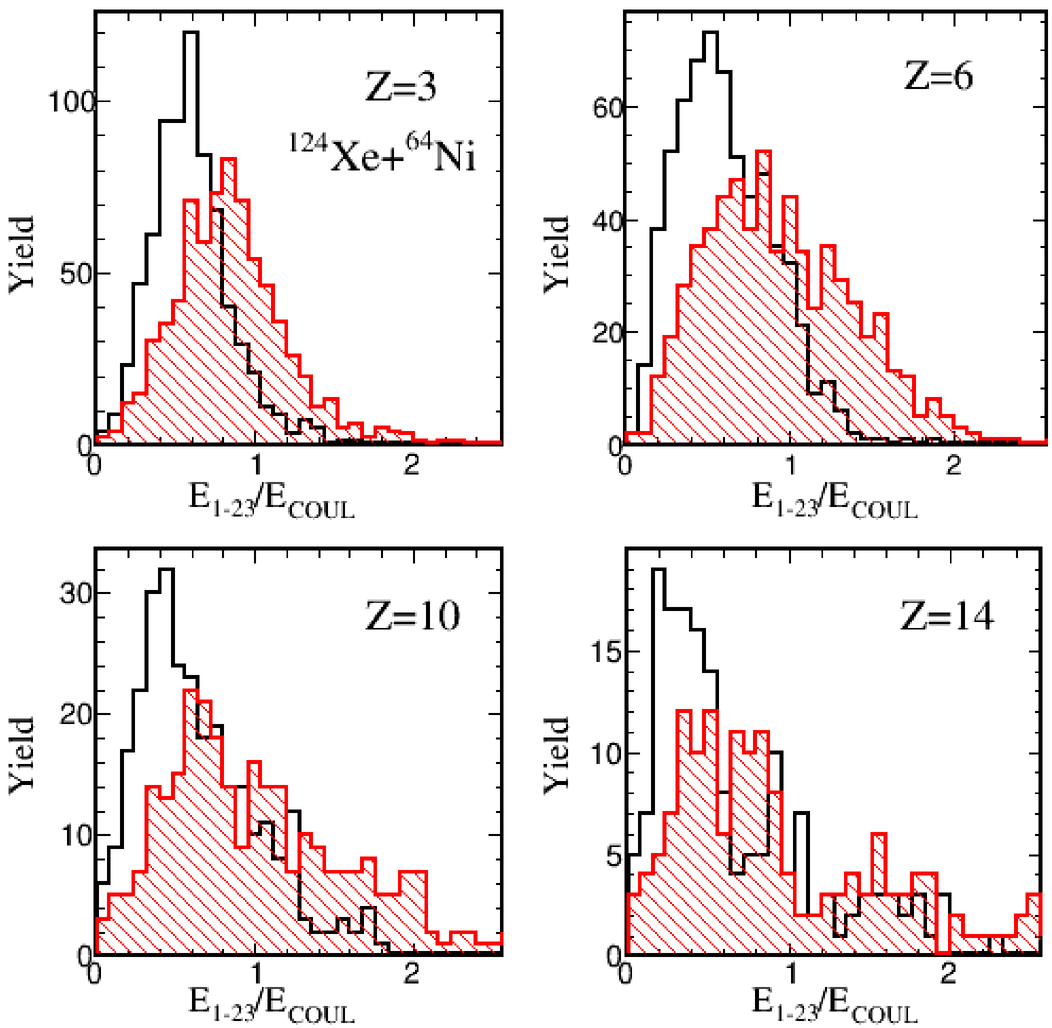




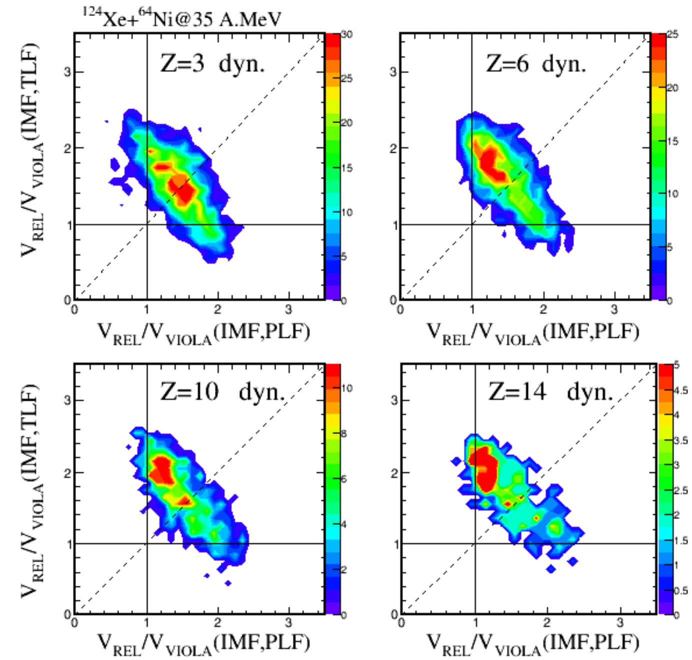


^{124}Xe + ^{64}Ni Dilute
^{124}Xe + ^{64}Zn Dilute
Z=6
Normalized Yield
E_{1-23} / E_{Coul}
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
0.5
1
1.5
2
2.5
3

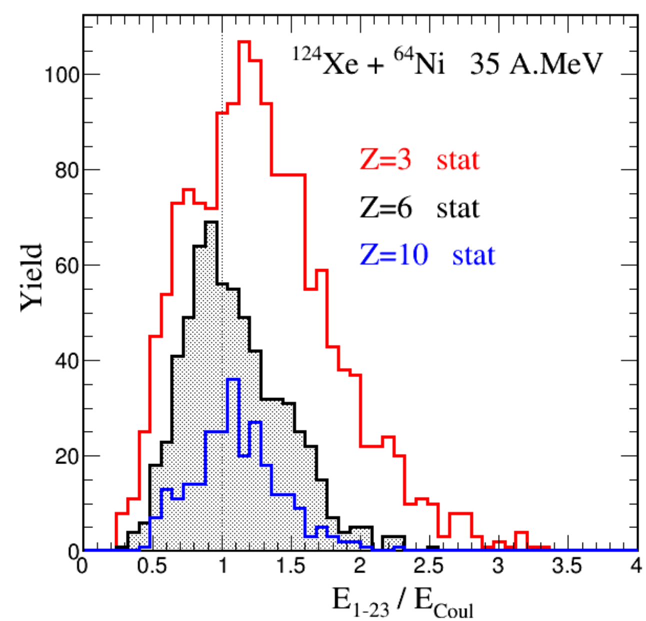
Dynamical



Z=3
^{124}Xe+^{64}Ni
Z=6
Z=10
Z=14
Yield
E_{1-23}/E_{COUL}

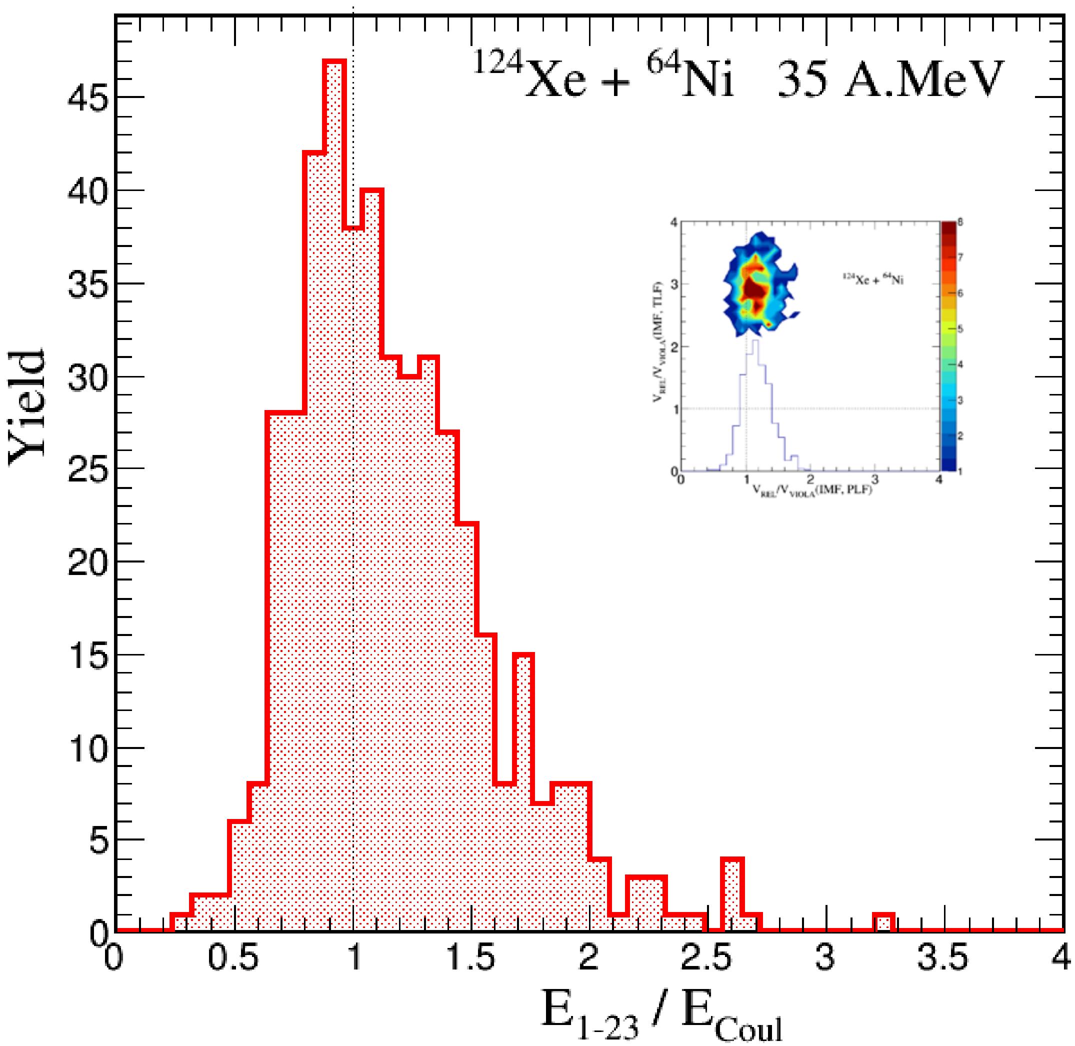


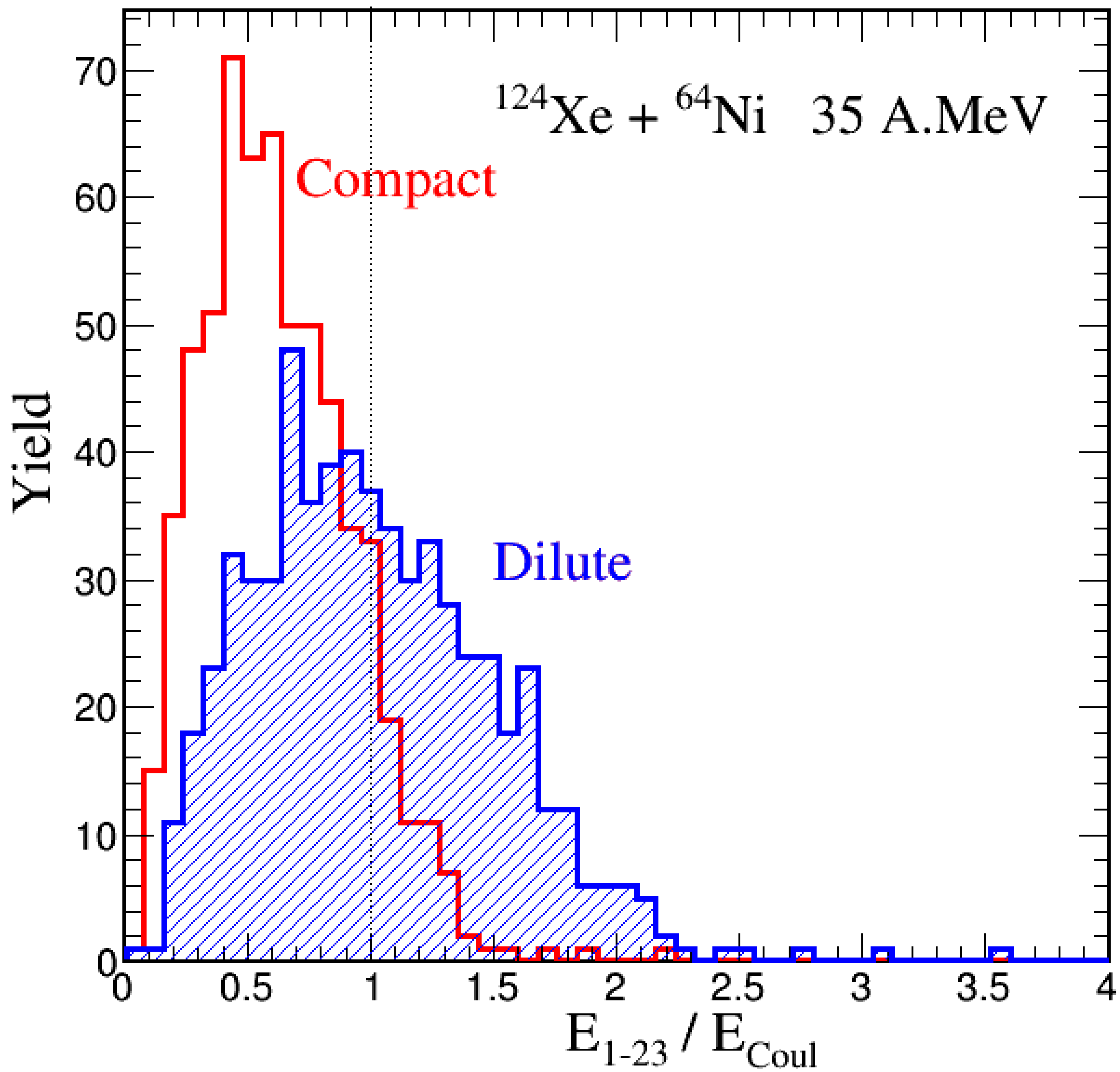
^{124}Xe+^{64}Ni@35 A.MeV
Z=3 dyn.
Z=6 dyn.
Z=10 dyn.
Z=14 dyn.
V_{REL}/V_{VIOLA}(IMF,TLF)
V_{REL}/V_{VIOLA}(IMF,PLF)



^{124}Xe + ^{64}Ni 35 A.MeV
Z=3 stat
Z=6 stat
Z=10 stat
Yield
E_{1-23} / E_{Coul}

Sequential, dilute,   d=1.2 fm





^{124}Xe + ^{64}Ni 35 A.MeV
Compact
Dilute
Yield
0
10
20
30
40
50
60
70
0
0.5
1
1.5
2
2.5
3
3.5
4
E_{1-23} / E_{Coul}

Conclusions

In Heavy Ion physics at Fermi and medium energies the reaction mechanism is dominated by a clear dynamical phase of short time scales (~ 100fm/c) characterised by rapid changing in the baryonic density leading to the formation of clusters of nuclear matter in a freeze-out configurations and then to a sequential decay.
Signature of this evolutionary phase are still persistent (against sequential decay) in the kinematical properties of the detected fragments and light particles. Different observables are particularly sensitive to this early phase of the reactions (Isoscaling , Flow, …..). Among them , in this paper we discussed the relevant role of the relative kinetic energy, as a signature of the expanding nature of the participant nucleons of the reaction allowing for direct determination of both time scale and density.

I am grateful to my friends of the Chimera Working and theorists in Catania for the decisive help in my more recent activity.