ECOS 2012 - 18, 21 June Villa Vigoni, Menaggio, Italy

Isospin Effects on Heavy Ion reactions studied with stable beams in the range of Energy 10-30 AMeV.

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Outline

- Physic case
- Selected recent results from HIC by Stable beams & Chimera detector at E = 10 – 35 AMeV
- Conclusions
- Perspectives

Physics Case

ISOSPIN – ***quantum number to express symmetry property of the total wave function of a nucleus.***

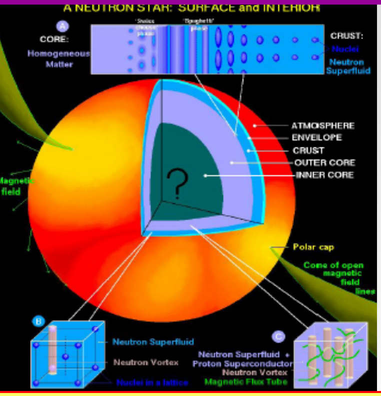
The 3° component of the isospin for a nucleus is

$$T_3 = (Z - N)/2 = Z\,(1 - N/Z)/2$$

I = N/Z **Experimental Observable**

The hypotesis is that *"the effective nuclear forces have a no trivial dependence on isospin, and both nuclear structure and cohesion vary with the isospin"*

Physics Case



NEOS & Simmetry Energy

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

$$\delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p} = \frac{N-Z}{A}$$

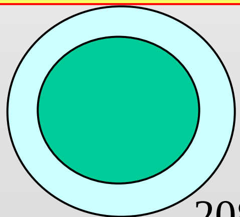
$$\rho = \rho_n + \rho_p$$

$$\rho_0 = 0.16\ fm^{-3}$$

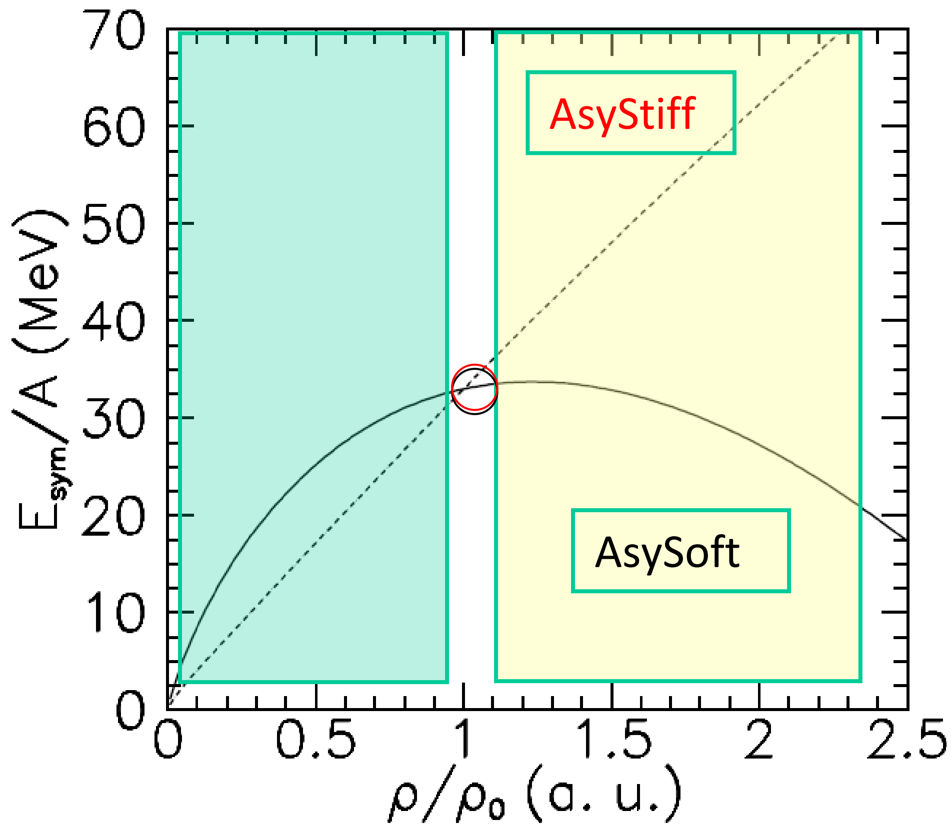
$\rho \leq \rho_0$

HIC- Fermi energy (15-20 AMeV)

- **isoscaling**
- **isospin diffusion**
- **collective excitations**
- **surface phenomena**
- **phase transitions**



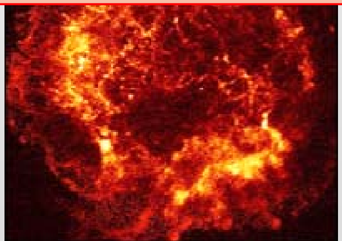
^{208}Pb



$\rho \leq \rho_0$

Relativisti HIC

- **differential flow**
- **n/p, ratios**
- **pions ratios**
- **kaon ratios**
- **neutron stars**



Physics Case

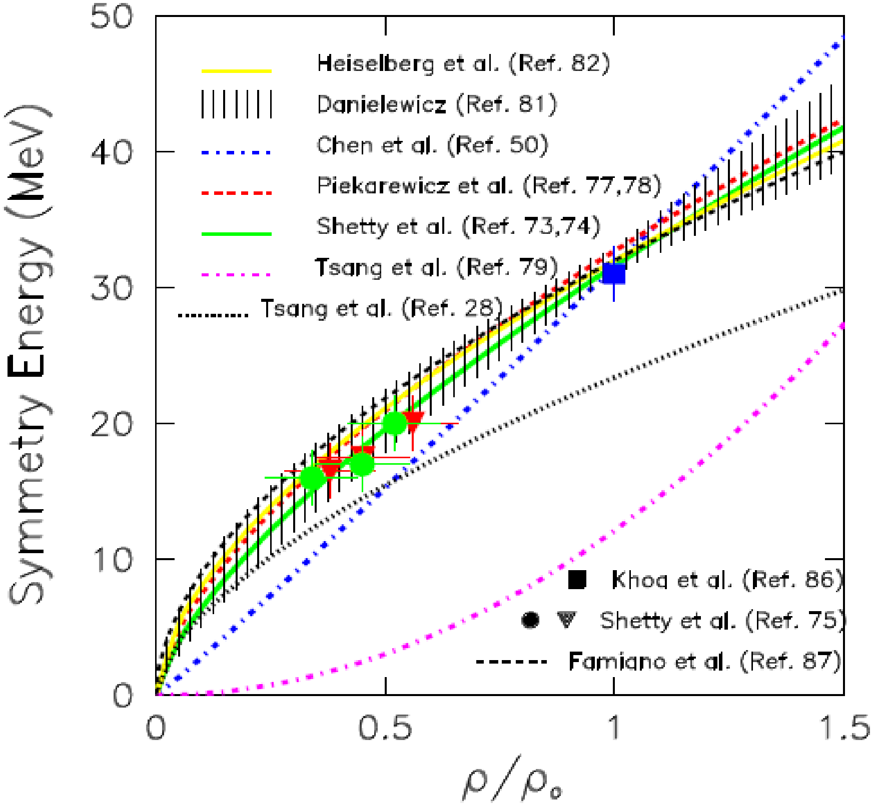
NEOS & Simmetry Energy

$\rho \leq \rho_0$

Many experiment were done in the Fermi Energy regime

Ganil, GSI, LNL, LNS, MSU, TAMU

It needs new data to verify and to refine the results



$\rho \geq \rho_0$

Very few data!

It needs systematics at high energy with different systems and probes

$$E_{sym}(\rho) = E_{sym}(\rho_0)\,(\rho/\rho_0)^{\gamma}$$

$E_{sym}(\rho_0) = 31 \div 33$ MeV

$\gamma = 0.69 \div 1.05$ *ASYSTIFF*

Physics Case

Selected recent results from HIC by

Stable Beams in low density region

E= 10 – 35 AMeV

ISOSPIN effects correlated to:

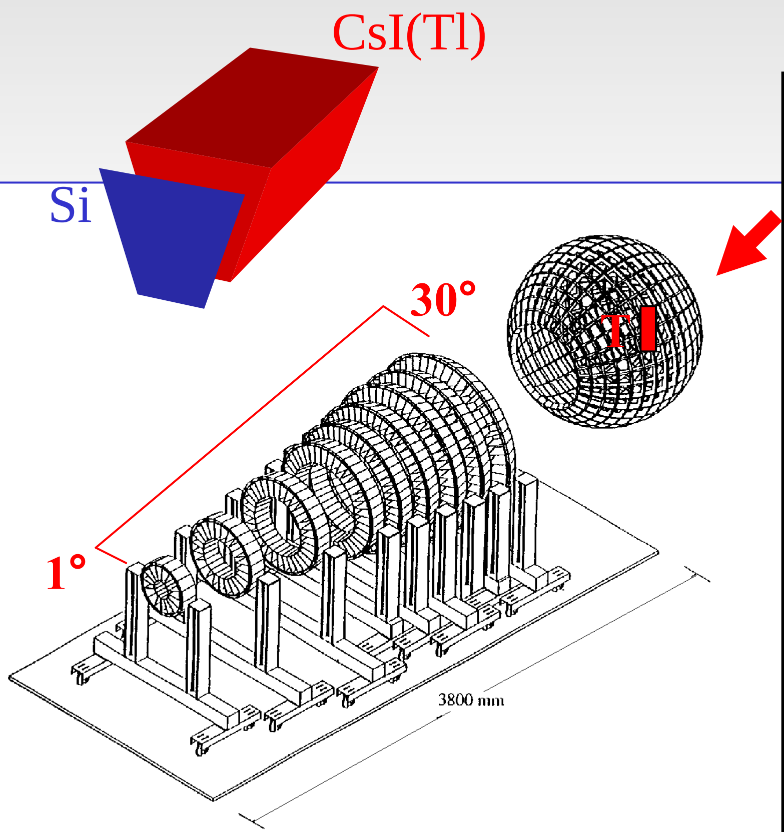
Dynamical evolution of the reaction mechanism
(ex:Correlation between fragments emission timescale and isospin dynamics at intermediate energy)

Formation and decay of composite system
(ex:Influence of the isospin on the reaction mechanism and emission process at lower energy)

CHIMERA@LNS

CHIMERA

Charge Heavy Ion Mass and Energy Resolving Array



Granularity	1192 telescopes Si (300μm) +CsI(Tl)
Geometry	RINGS: 688 telescopes 100-350 cm SPHERE: 504 telescopes 40 cm
Angular range	RINGS: $1° < \theta < 30°$ SPHERE: $30° < \theta < 176°$ 94% of 4π
Identification method	ΔE-E E-TOF PSD in CsI(Tl) PSD in Si (upgrade 2008)
Experimental observables and performances	TOF $\delta t < 1$ ns $\delta E/E$ LCP (Light Charge Particles) ≈ 2% $\delta E/E$ HI (Heavy Ions) ≤ 1% Energy, Velocity, A, Z, angular distributions
Detection threshold	≈ 1 MeV/A for H.I. ≈ 2 MeV/A for LCP

Dynamical evolution of the reaction mechanism

Correlations between fragment emission timescale and isospin dynamics at intermediate energy

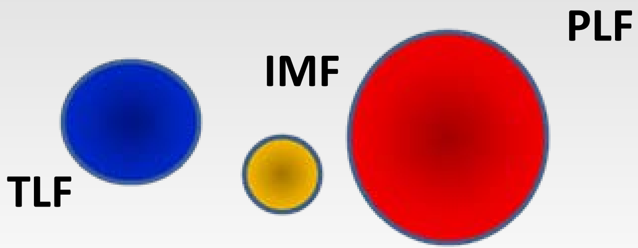
$^{112}Sn + ^{58}Ni$ (n-poor), $^{124}Sn + ^{64}Ni$ (n-rich)@ 35 AMeV

(TIMESCALE)

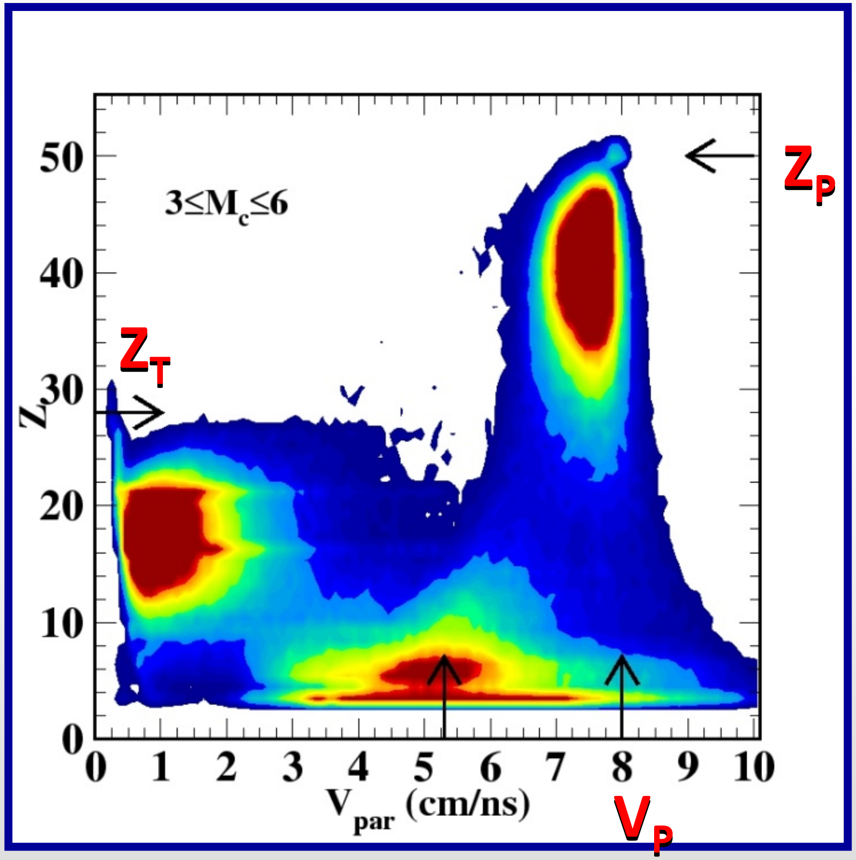
Ternary and semiperipheral events selection

$^{124,112}Sn + ^{58,64}Ni$ @ 35 AMeV

Tipical 3-body analisys

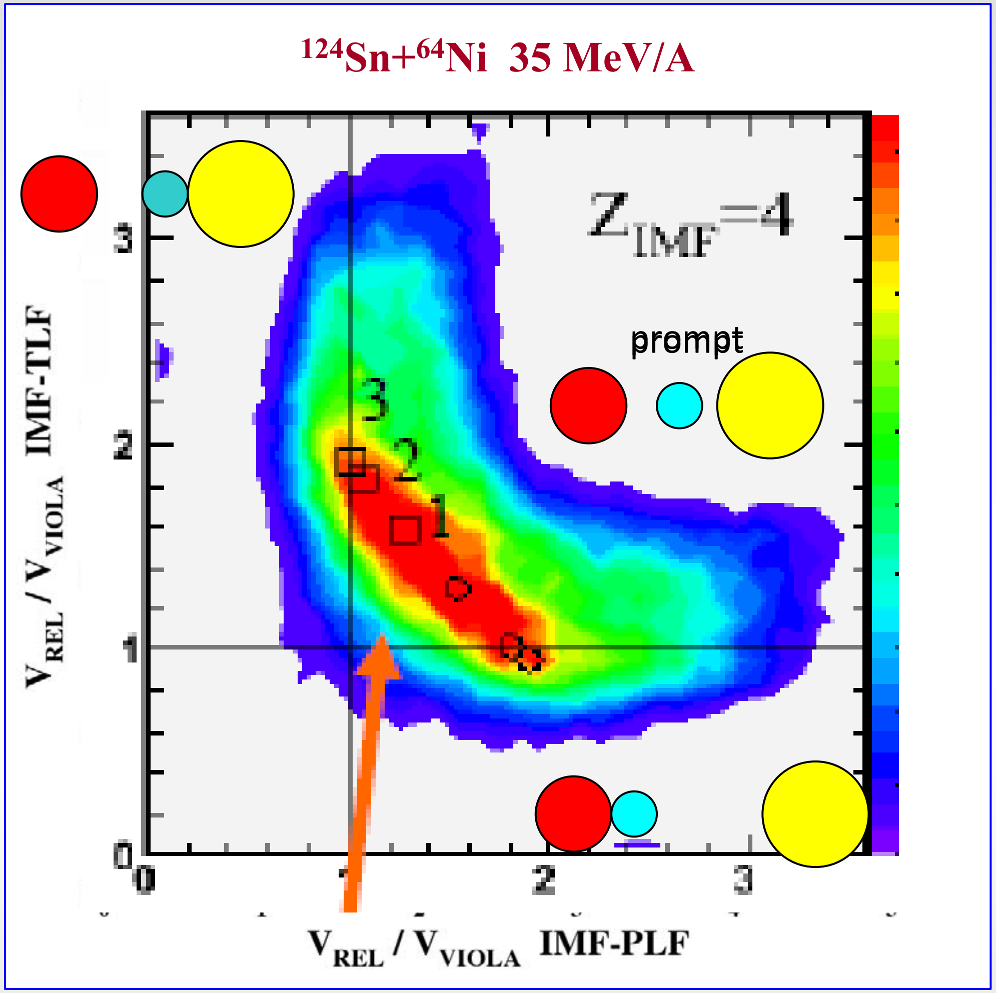


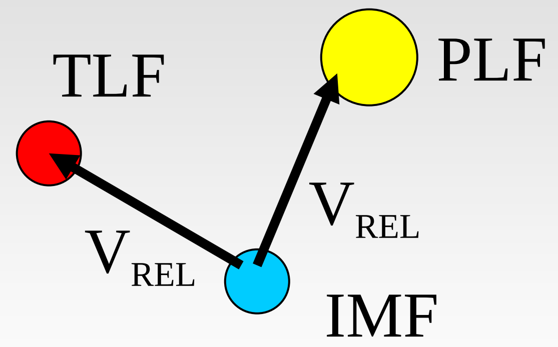
IMF , Z ≥ 3



E.De Filippo et al. PRC71,44602 (2005)

TIME SCALE: Emission Chronology by velocity correlation





Relative velocities are expressed in relationship with the Viola velocity (pure Coulomb repulsion)

Viola et al Nucl. Phys. A472, 318 (1987)

E.De Filippo et al. PRC71,44602 (2005)

v_{rel}/v_{viola} =1 SEQUENTIAL DECAY OF IMF FROM PLF (or TLF), t ~ 120 fm/c (3)

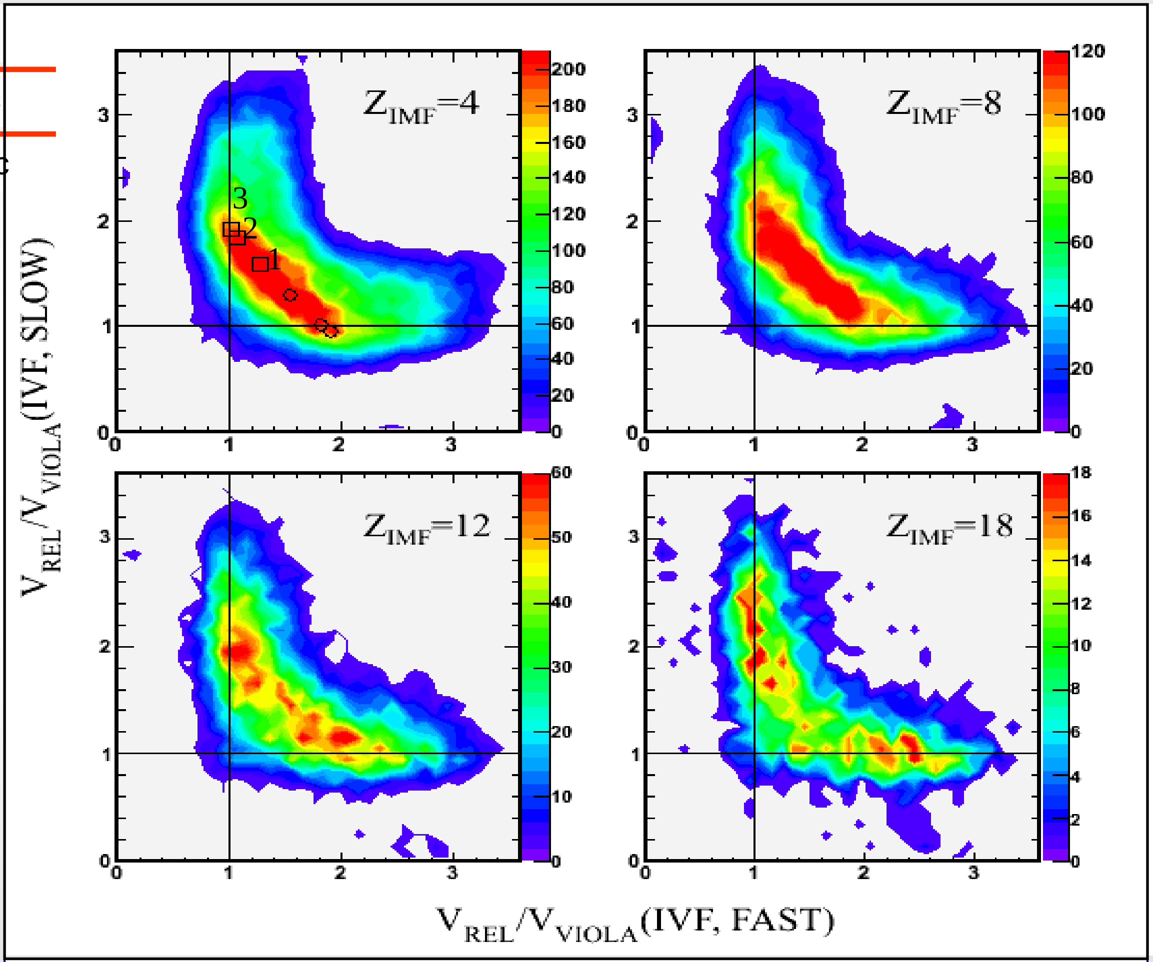
$v_{rel}/v_{viola} \neq 1$ NON-STATISTICAL EMISSION OF IMF , t ~ 40 fm/c (1)

TIME SCALE: Emission Chronology by velocity correlation

IMF

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

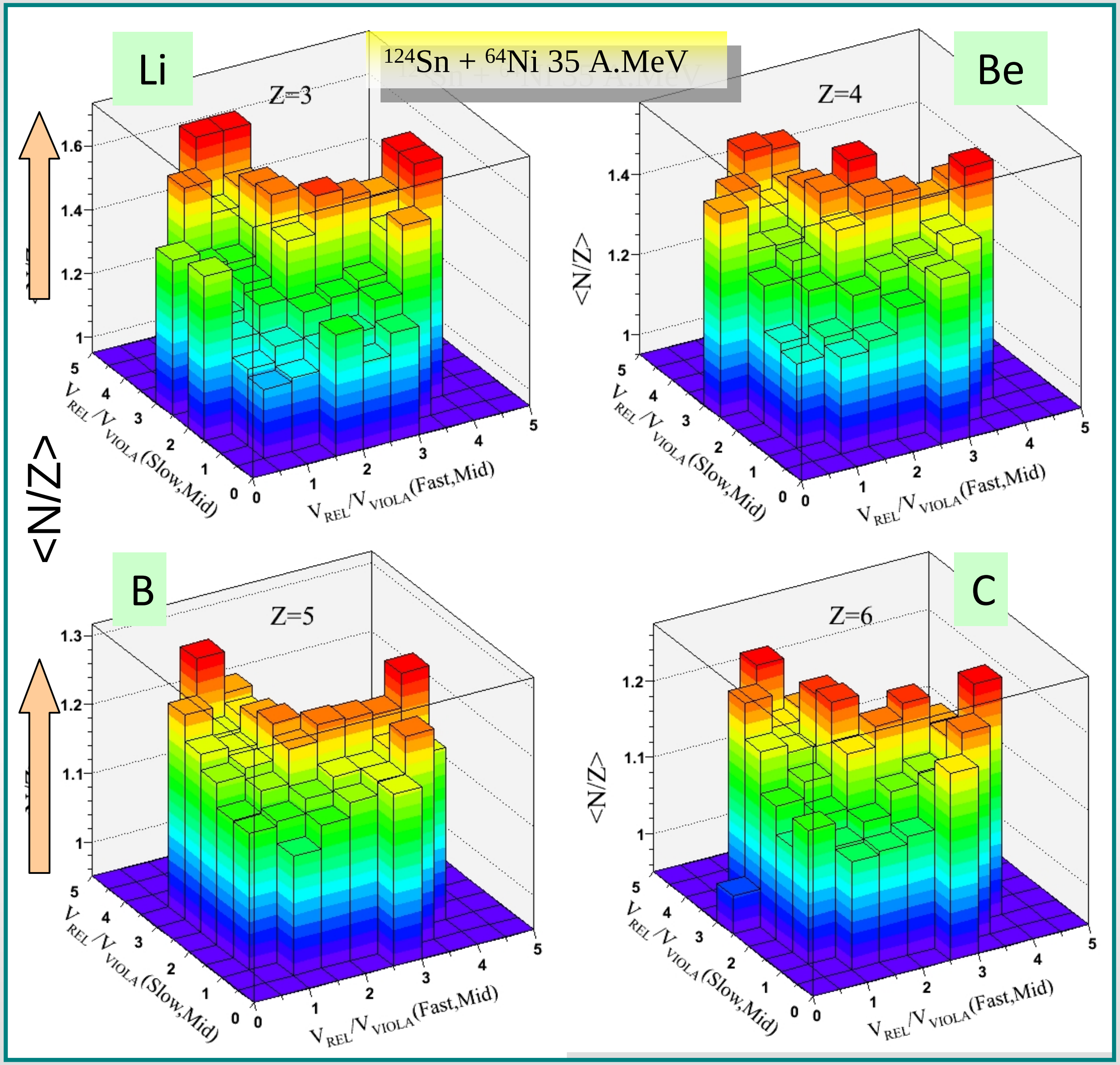
1	40 fm/c
2	80 fm/c
3	120 fm/c



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

E.De Filippo et al, in press PRC 2012

Correlations with IMFs isotopic properties



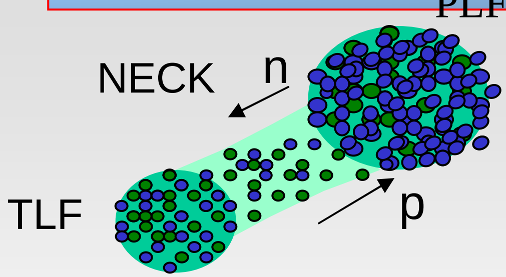
The correlation shows that the greatest **neutron enrichment is** linked to greater deviations from Viola systematics, that is to **fast prompt emission** of IMF.

We can select

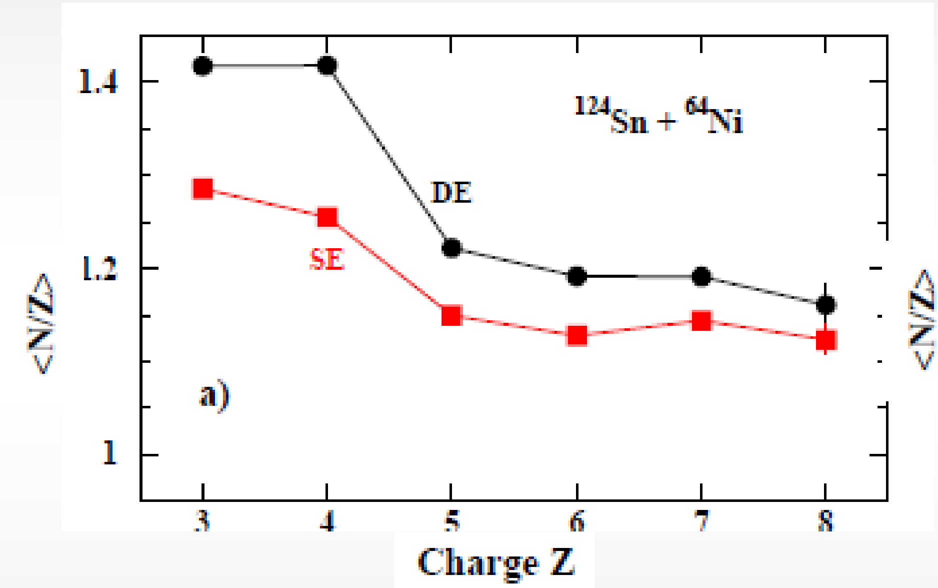
Dynamical emission

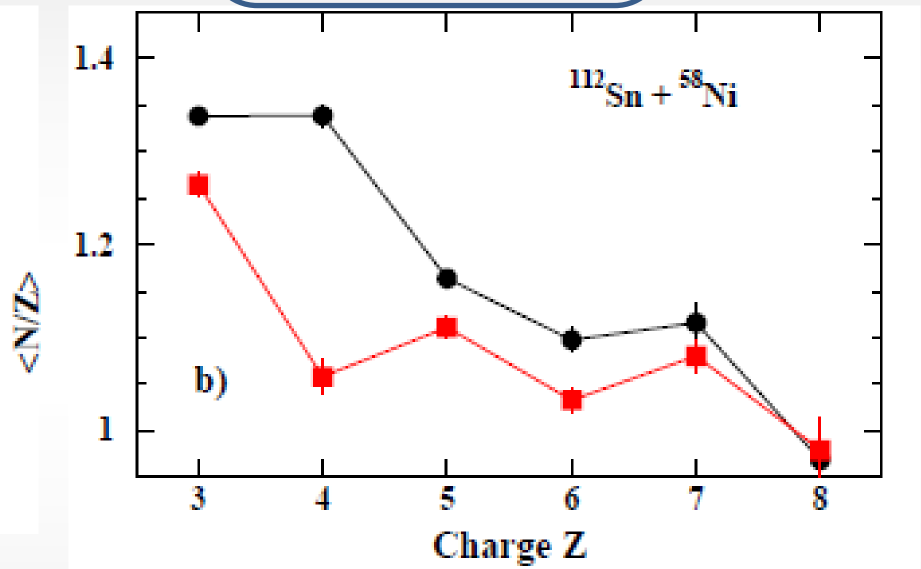
Statistical emission

Dynamical and Sequenzial emission of IMF



- Dynamically emitted particles
- Statistically emitted particles





Neutron rich system

Neutron poor system

n-rich system

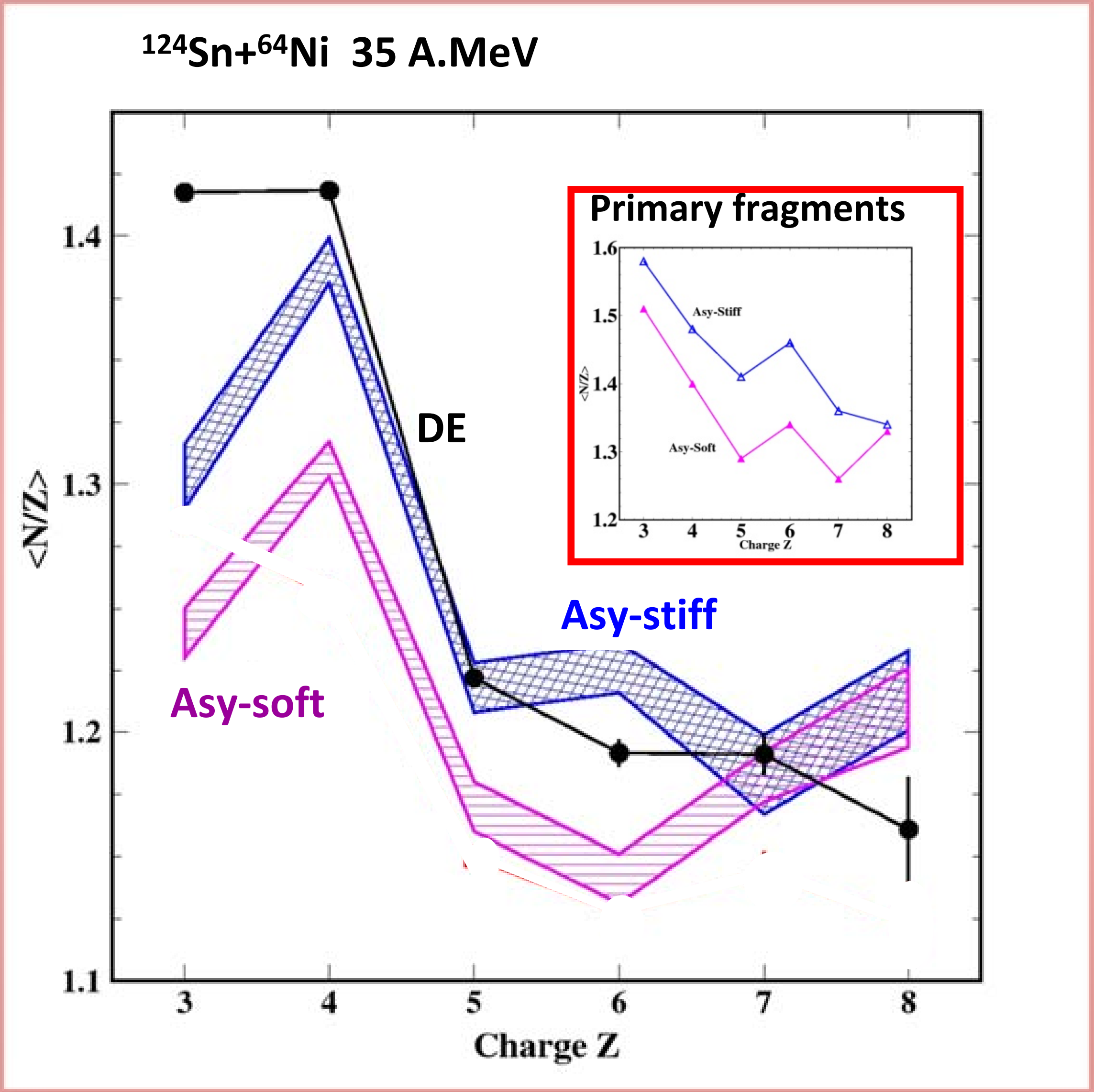
- Entrance channel memory effect

- Reduction in staggering effect

E.De Filippo et al,

in press PRC 2012

Stochastic Mean Field (SMF) + GEMINI calculation



SMF - microscopic approach that describe the evolution of systems by Boltzmann-Nordheim-Vlasov transport equation.
The model includes nuclear mean field dynamics and effect of fluctuations.

V. Baran et al. Nucl. Phys. A730 329 (2004).

● Dynamically emitted particles

E.De Filippo et al, in press PRC 2012

Formation and decay of composite system

N/Z effects on reaction mechanism and fragment production

$^{40,48}Ca + ^{48,40}Ca$ @ 25 AMeV

(LIMITING)

Study of N/Z effects on reaction mechanism and fragment production in central and semiperipheral collision at 25 AMeV (near multifragmentation trheshold)

$^{40}Ca + ^{40}Ca$ $N/Z_{tot} = 1.0$

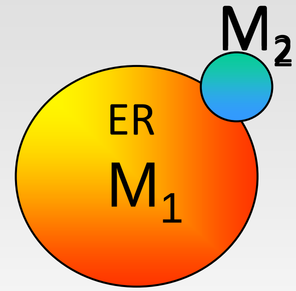
$^{40}Ca + ^{46}Ti$ $N/Z_{tot} = 1.05$

$^{40}Ca + ^{48}Ca$ $N/Z_{tot} = 1.2$

$^{48}Ca + ^{48}Ca$ $N/Z_{tot} = 1.4$

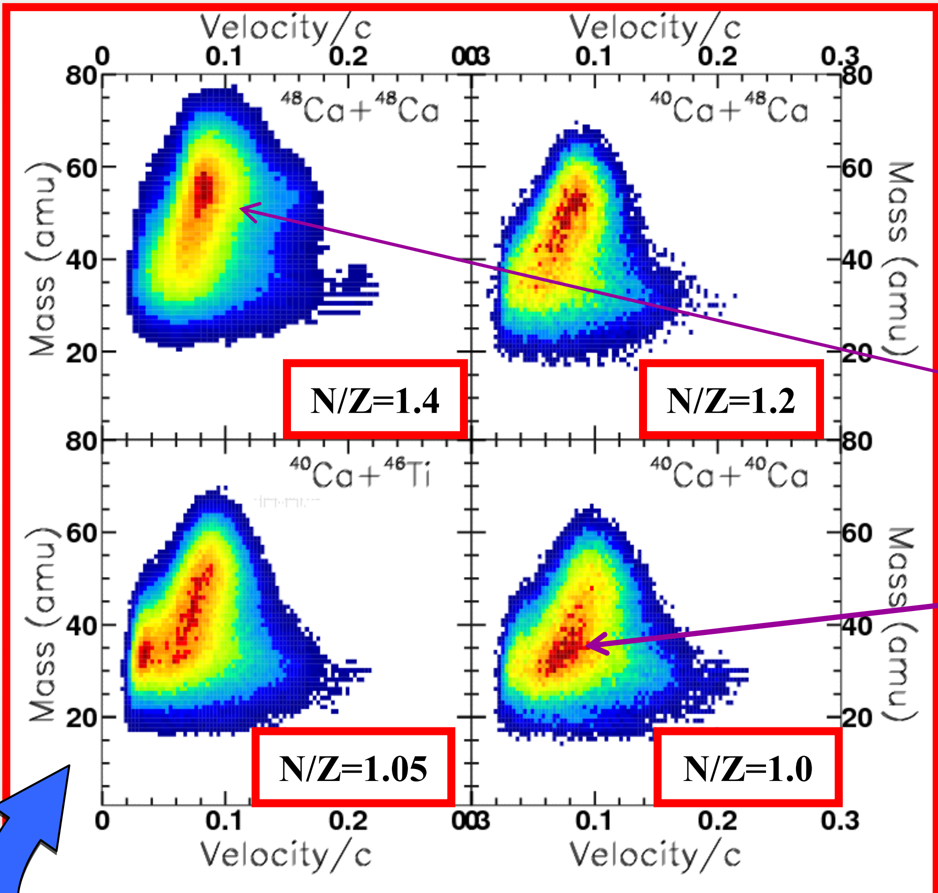
N/Z influence on Reaction Mechanism in semipheriperal collisions

$^{48}Ca + ^{48}Ca$, $^{40}Ca + ^{48}Ca$ @25 A.MeV
$^{40}Ca + ^{46}Ti$, $^{40}Ca + ^{40}Ca$



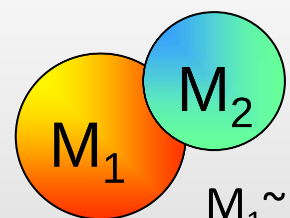
CF-ICF fusion

$M_1 > M_2$



The N/Z degree of freedom strongly influences the *reaction mechanism*

- Larger N/Z → one massive fragment emission as in CF -ICF events (ER) $M_1 > M_2$
- Lower N/Z → lighter and faster mass emission as in binary-like events (BL) $M_1 \sim M_2$



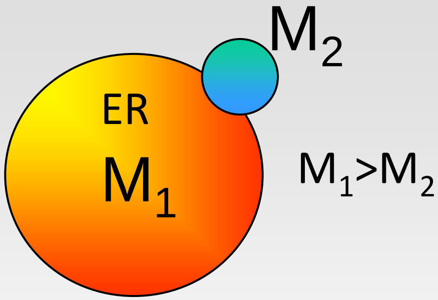
$M_1 \sim M_2$

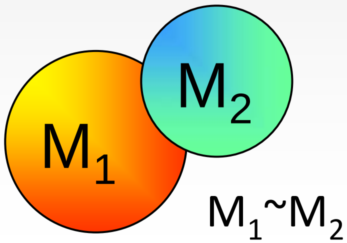
Binary reaction

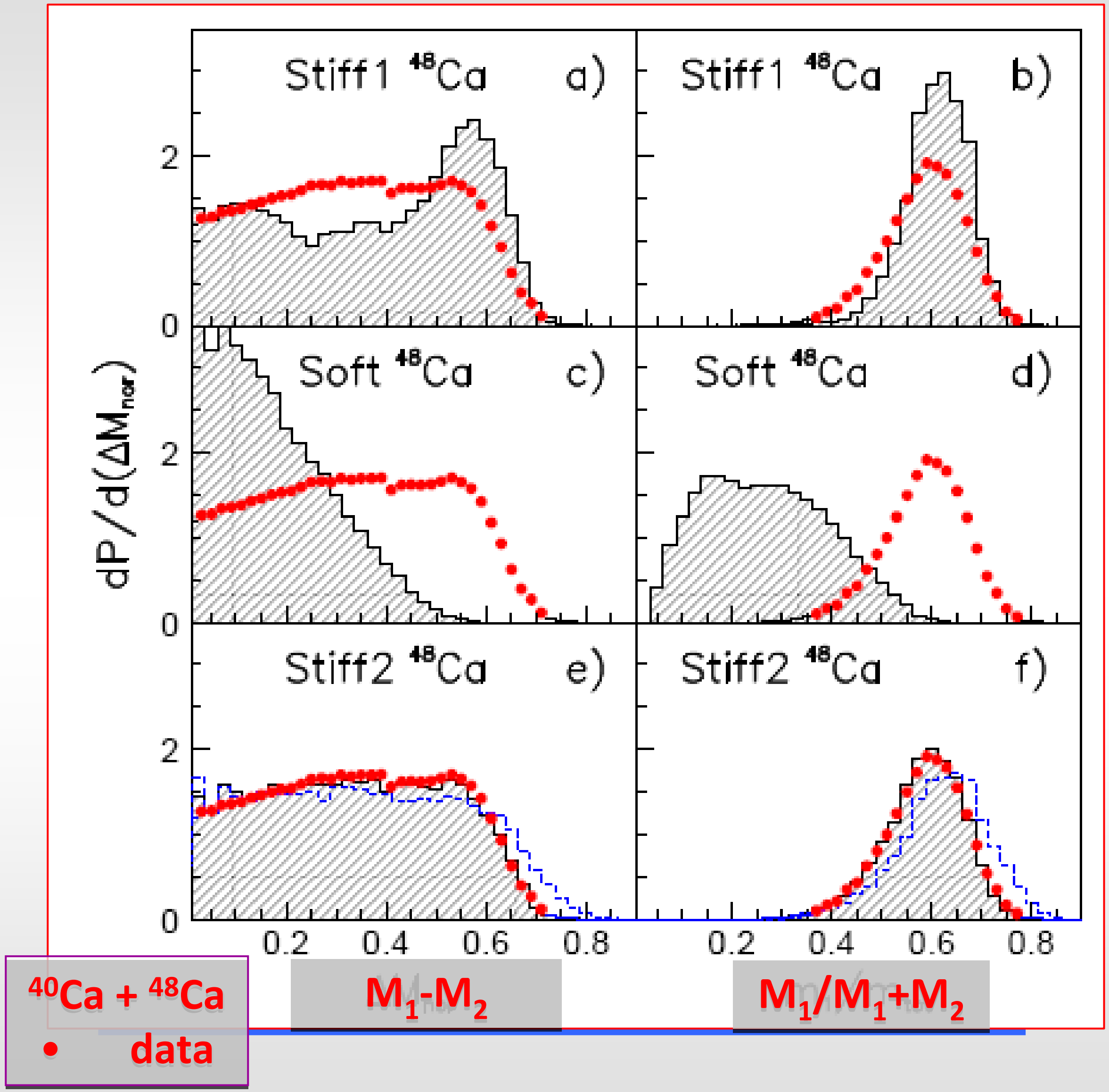
Mass of heaviest fragment

I.Lombardo et al. PRC in press 2012

Comparison with Co MD (Constrained Molecular Dynamics) II + Gemini



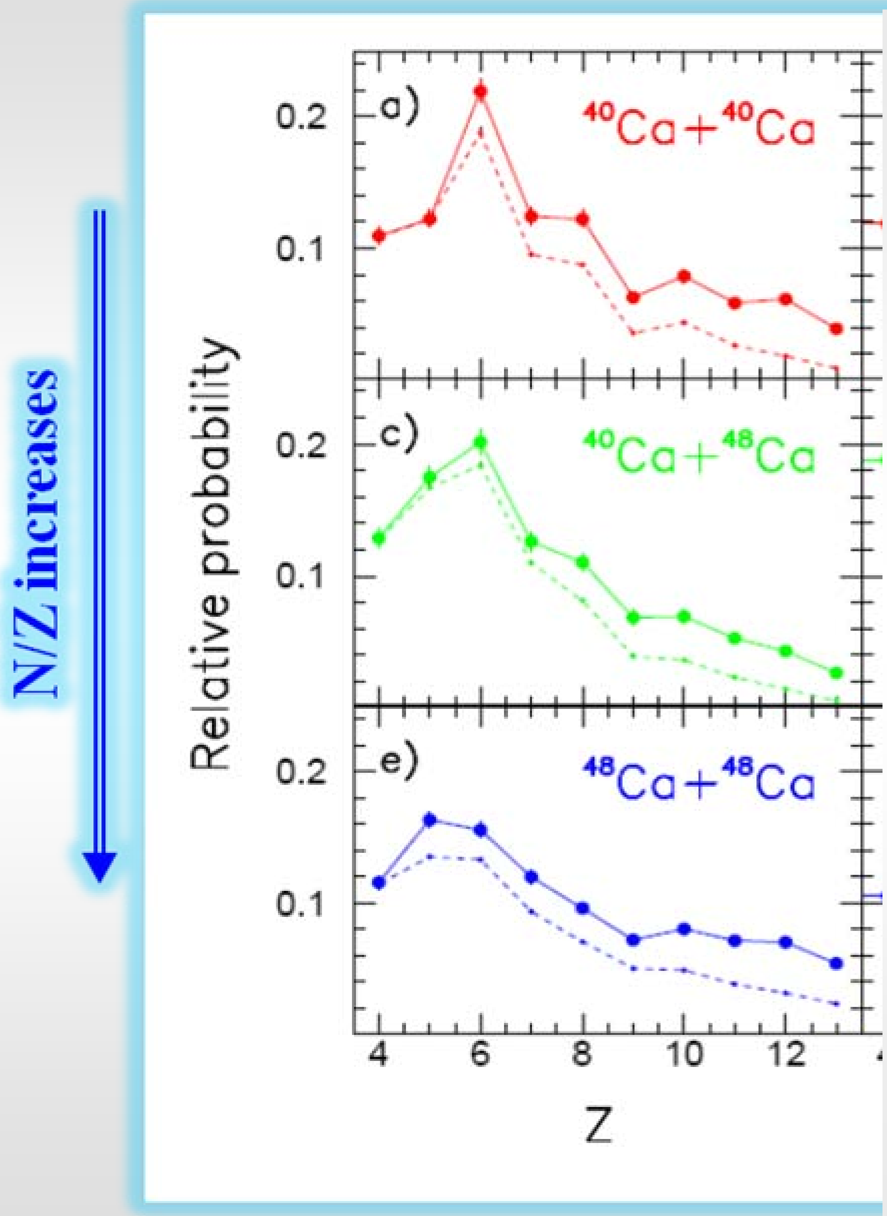




Comparisons with CoMD-II model indicates a sensitivity of the reaction mechanism to the asy-EOS : the best agreement is with a slightly stiff (γ=1) symmetry term

F. Amorini et al., Phys. Rev Lett. 102 112701 (2009)
I.Lombardo et al., Phys. Rev. C82 014608 (2010)
M. Papa and G. Giuliani, EPJ A39 (2009)

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



^{40}Ca + ^{40}Ca, ^{40}Ca + ^{48}Ca, ^{48}Ca + ^{48}Ca 25 A.MeV

n-rich system

- Reduction in staggering effect

I. Lombardo et al. Phys. Rev. C84 024613 (2011).

Formation and decay of composite system

Isospin influence on the emission mechanism of complex fragments (Z≥3)

$^{78,86}Kr + ^{40,48}Ca$ @10 AMeV

(ISODEC preliminary results)

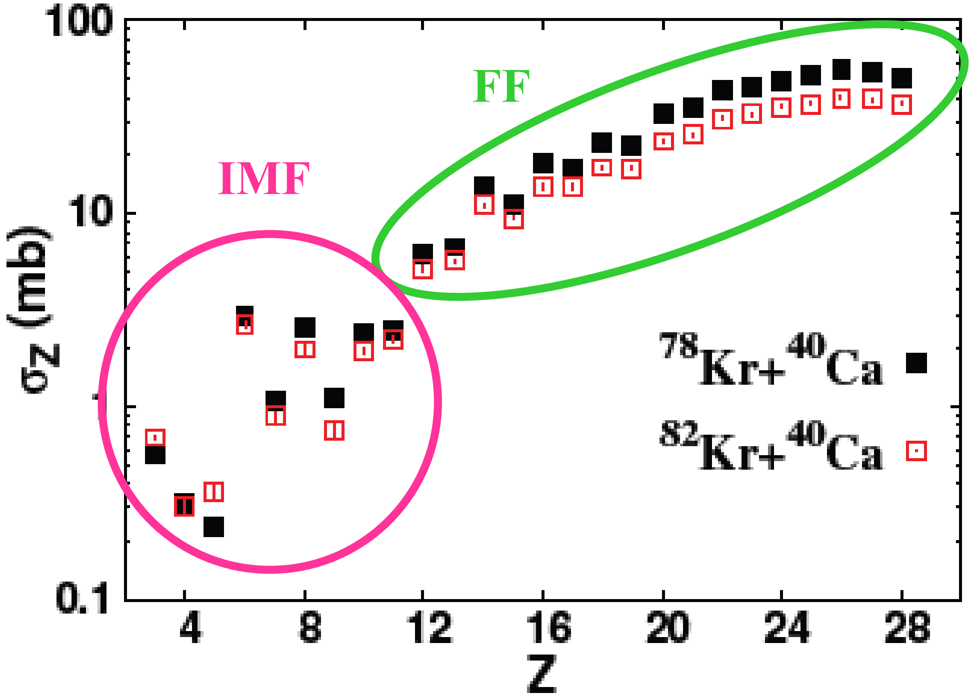
The isospin (N/Z) influence on the emission mechanism of complex fragments (IMF, Z≥3), to extract information on:

- **level density parameter, (thermal properties, E*, $m_{effective}$)**
- **fission barrier, (Symmetry, congruence and Wigner E terms)**
- **viscosity, (coupling collective – intrinsic modes, Fermi level)**

Crucial for the modelizations of the
nuclear collisions and of the de-excitation process

E475S INDRA @GANIL E = 5.5 AMeV

^{78,82}Kr + ^{40}Ca → ^{118,122}Ba* (~ 100 MeV)



3≤ θ ≤ 44° IC-Si-CsI

forward part

- Energy, ang. Distr. RP
- Charge distribution
- Cross section decay mode

CN neutron rich (o)

- 30% less fission (Z ≥ 14)
- Less even-odd staggering of IMF (6 ≤ Z ≤ 12)

G. Ademard et al. PRC 83 (2011) 054619

ISODEC CHIMERA@LNS E = 10 AMeV

$^{78}Kr + ^{40}Ca \longrightarrow ^{118}Ba$

$^{86}Kr + ^{48}Ca \longrightarrow ^{134}Ba$

- **Higher energy**

  Influence on the amplitude of the staggering, on the temperature of the emitting system.

- **Isotopic separation of IMF**

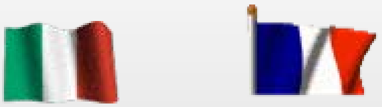
  to investigate the staggering effects looking at the isotopic distribution of IMF.

- **Exploration of a larger domain in N/Z of the system (stable beam!)**

  to study the dependence from the N/Z on the mechanism of complex fragment emission from CN

- **Exclusive measurements in a large angular range**

CN	^{118}Ba	^{134}Ba
E*(MeV)	215	270
V_B(MeV)	90	87
E_{CM}/V_B	2.9	3.5
$(N/Z)_{tot}$	1.11	1.39

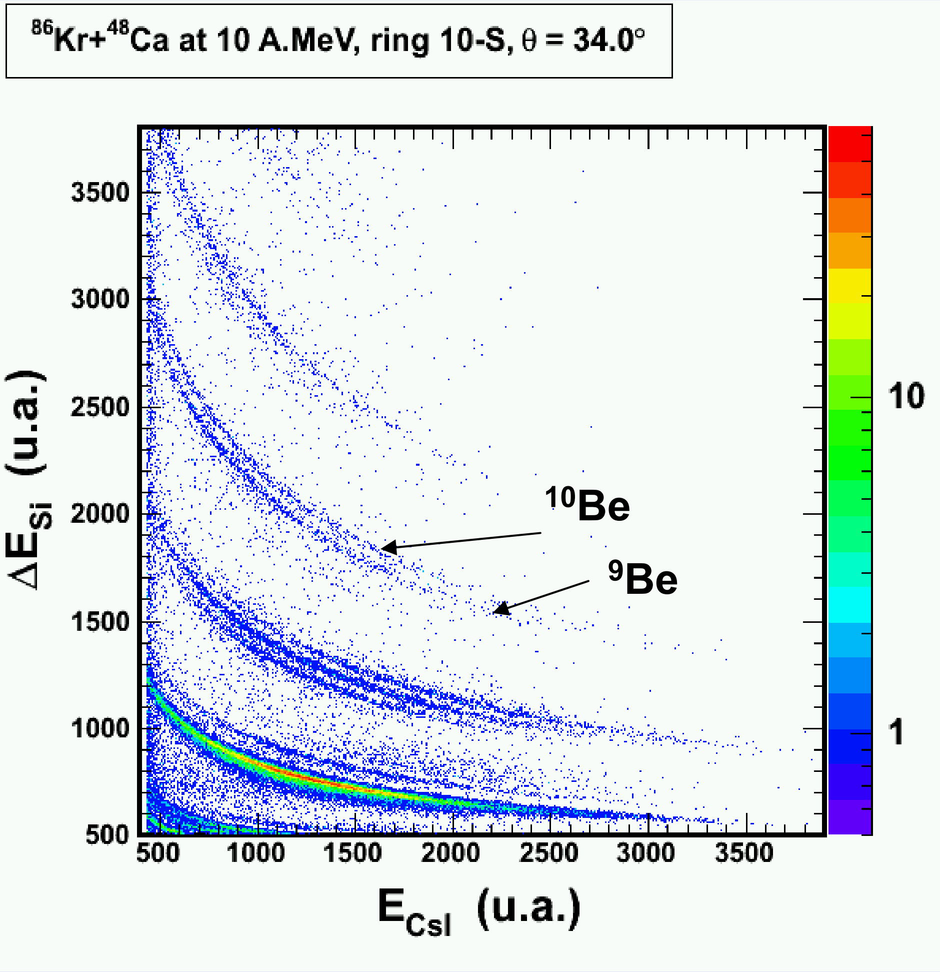


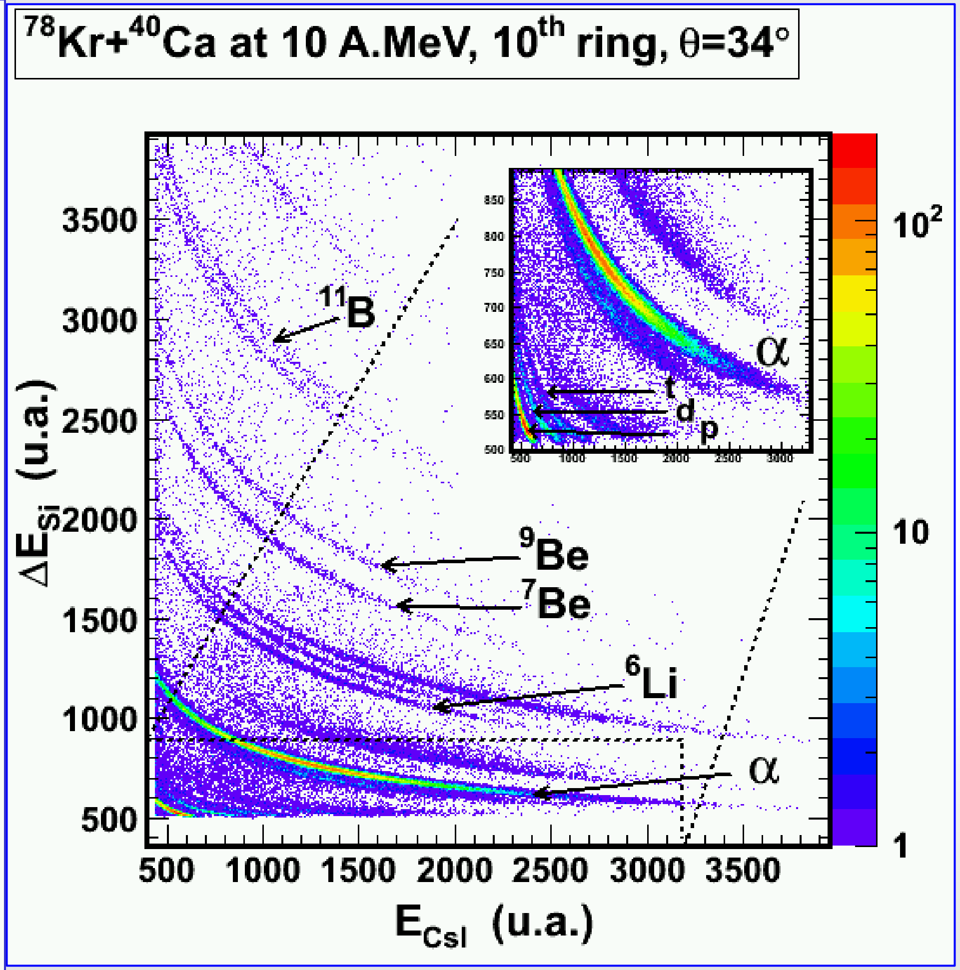
ITA-FRA Collaboration

LEA COLLIGA agreement (GANIL & INFN LNL-LNS)

IMF Isotopic Identification

ΔE-E , Si-CsI(Tl)





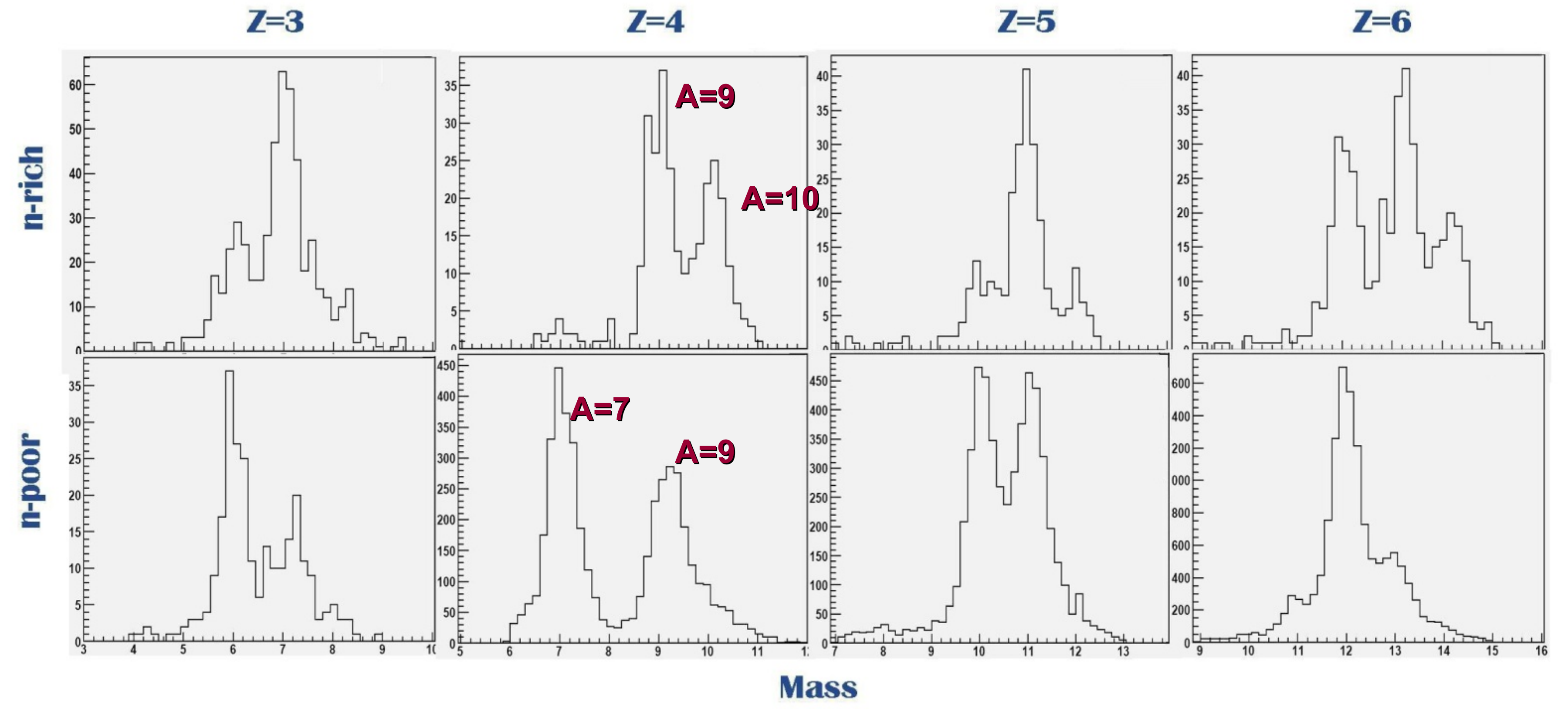
n-rich

n-poor

S.P. et al., EPJ Web of Conf. 17,16010 (2011)

IMF Mass Identification

Li **Be** **B** **C**



n-rich	$^{86}Kr + ^{48}Ca$	10 AMeV, ϑ=12°
n-poor	$^{78}Kr + ^{40}Ca$	

S.P. et al., EPJ Web of Conf. 17,16010 (2011) ,G.Politi et al, EPJ Web of Conf. 21 (2012) 02003
M.La Commara et al., Proc.of the IWM2011, GANIL,Caen, France (in press) 2012

IMF Energy Spectra (CM)

ϑ=12°

Variation in yield, width, center position and asymmetry of the IMF Energy Spectra are connected to:

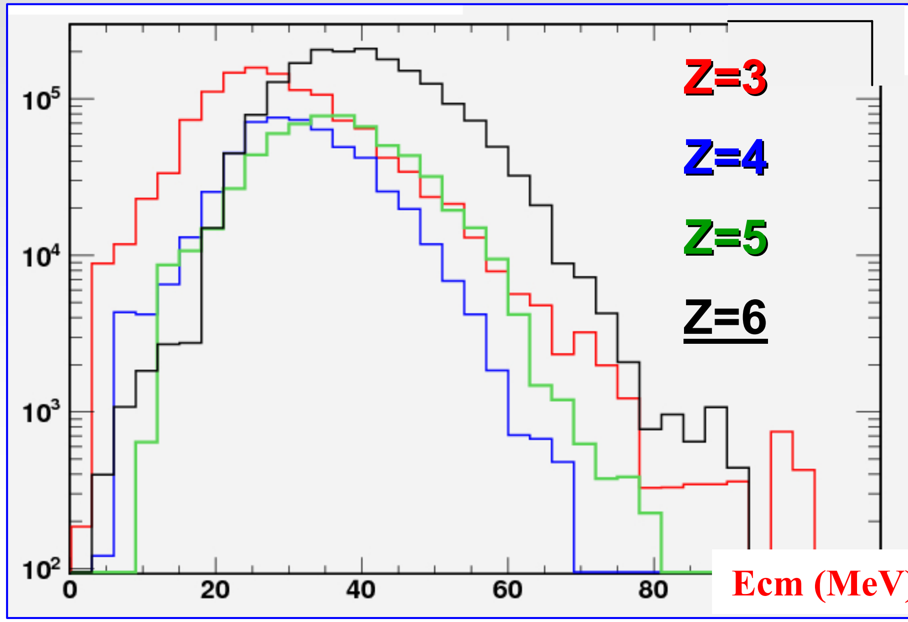
-different sources decay

-presence of different masses for Z

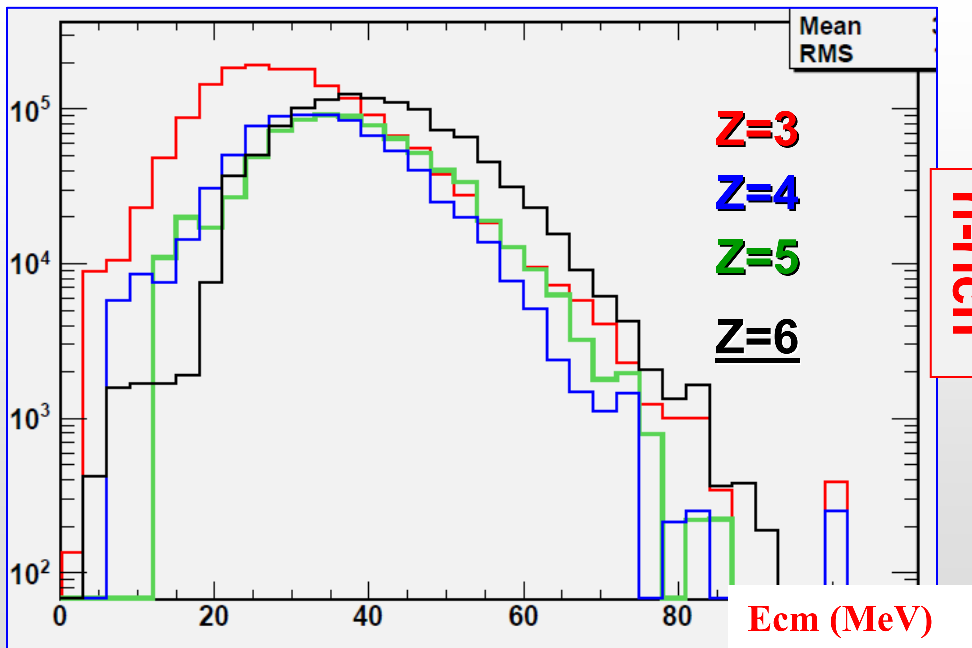
-influence of nuclear pairing forces

-influence of symmetry energy term

To be studied also by looking at the isotopic composition



n-poor



n-rich

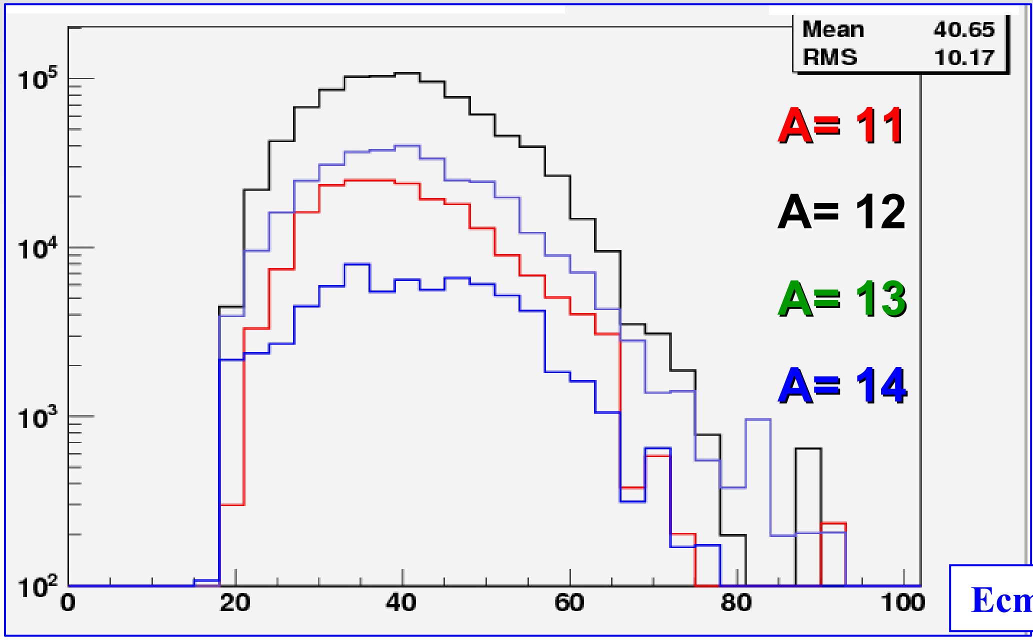
Preliminary Results

EURORIB12

Carbon Isotopes Energy Spectra (CM)

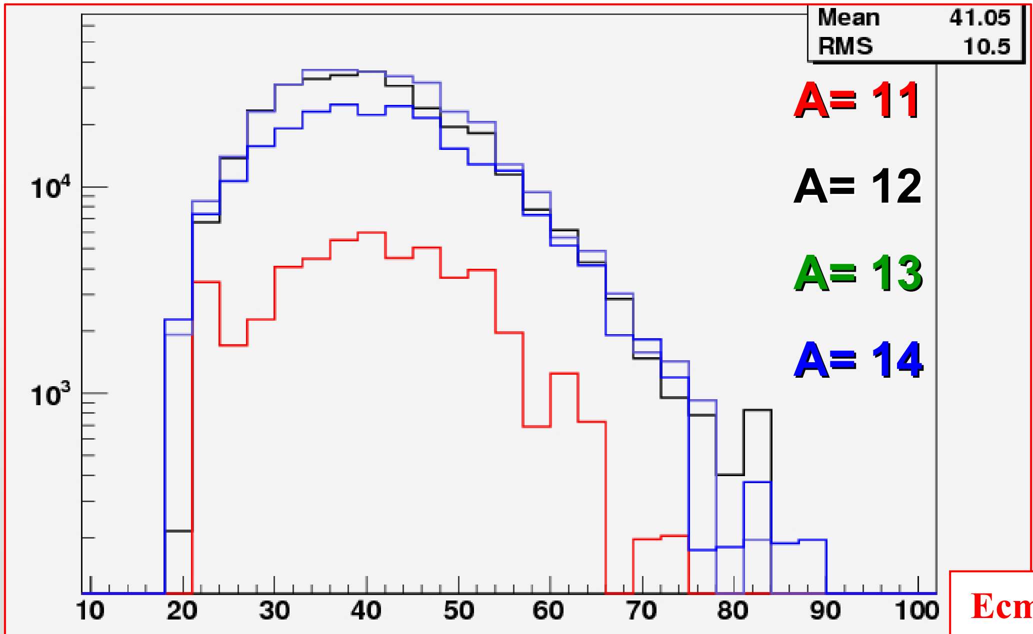
ϑ=12°

n-poor



Ecm (MeV)

n-rich



Ecm (MeV)

Preliminary Results

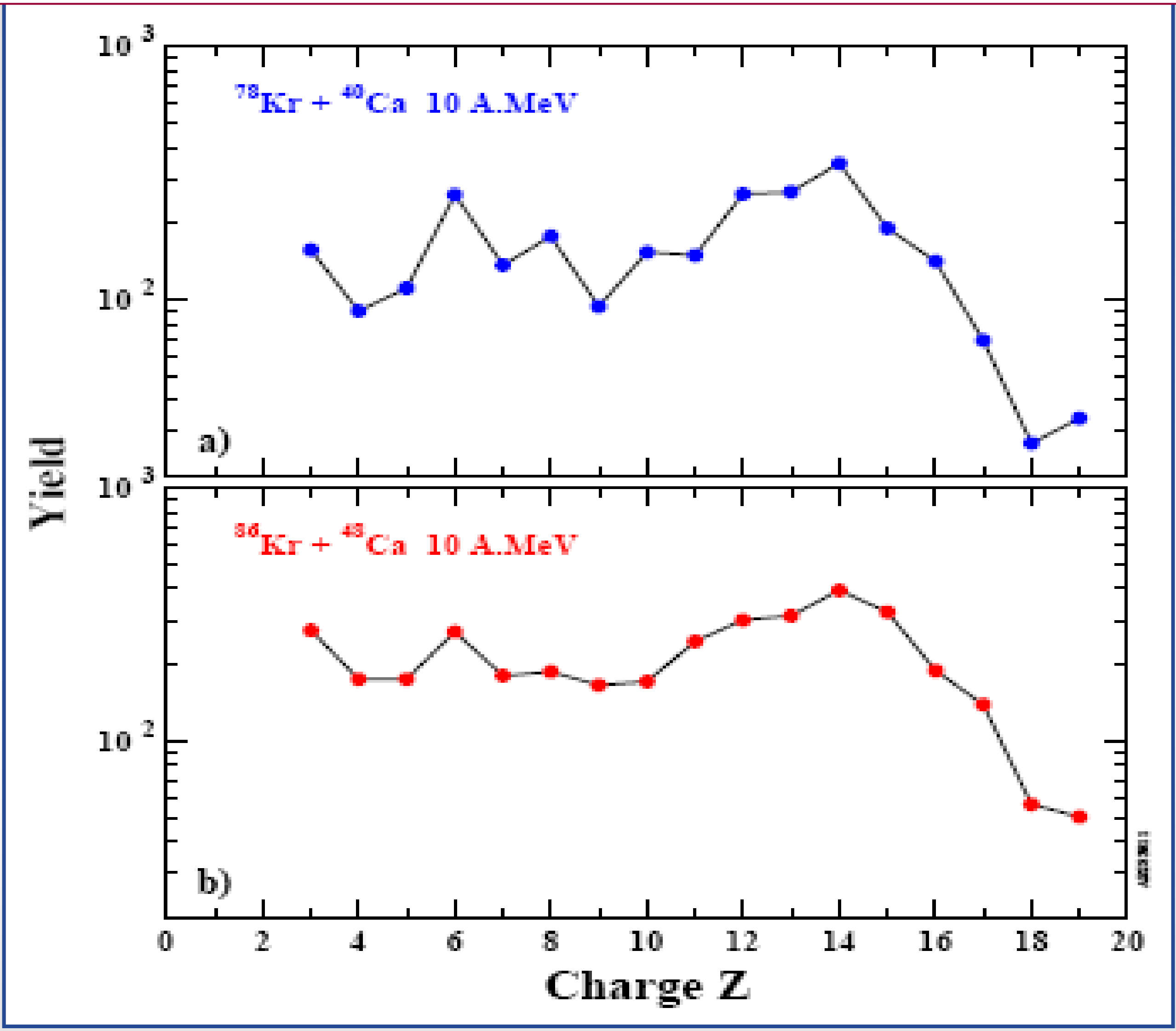
EURORIB12

Charge Distribution

n-poor

n-rich

ϑ=12°



Staggering of IMF decreases for n-rich systems

-the influence of **nuclear pairing forces**

-**structure effects** (*M. D'Agostino et al., NPA 861 (2011) 47*)

S.P. et al., EPJ Web of Conf. 17, (2011) ,
G.Politi et al, EPJ Web of Conf. 21 (2012)
M.La Commara et al., Proc.of the IWM2011, GANIL (in press) 2012

Conclusion

Experimental results from HI reactions realized with the 4π CHIMERA detector in the range 10-35 AMeV were presented.

We put in light as reaction mechanism, i.e. decay and emission processes, dynamics, time scale and composition of the produced fragments, are dependent from the influence the ISOSPIN on the effective nuclear interaction.

Stable beams, in a large range of mass and energy and the development of detectors at high specialization, (as well as neutron detectors and correlators), will make possible to refine and to improve our knowledge.