Istituto Nazionale
di Fisica Nucleare

Isospin effects in medium mass nuclear systems at 25 MeV/nucleon

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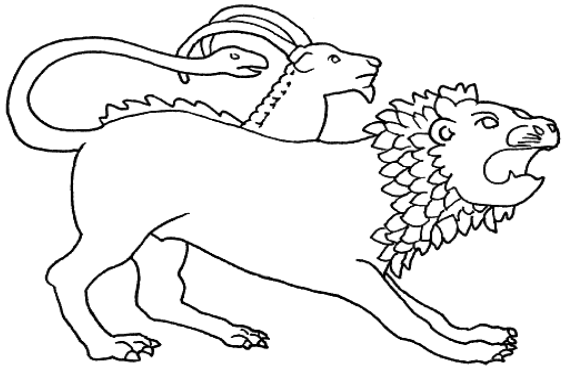

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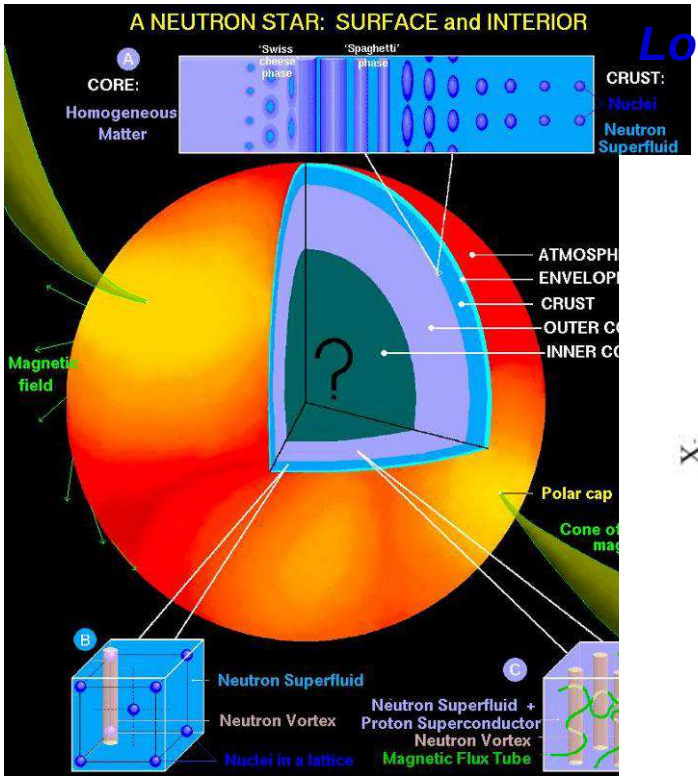
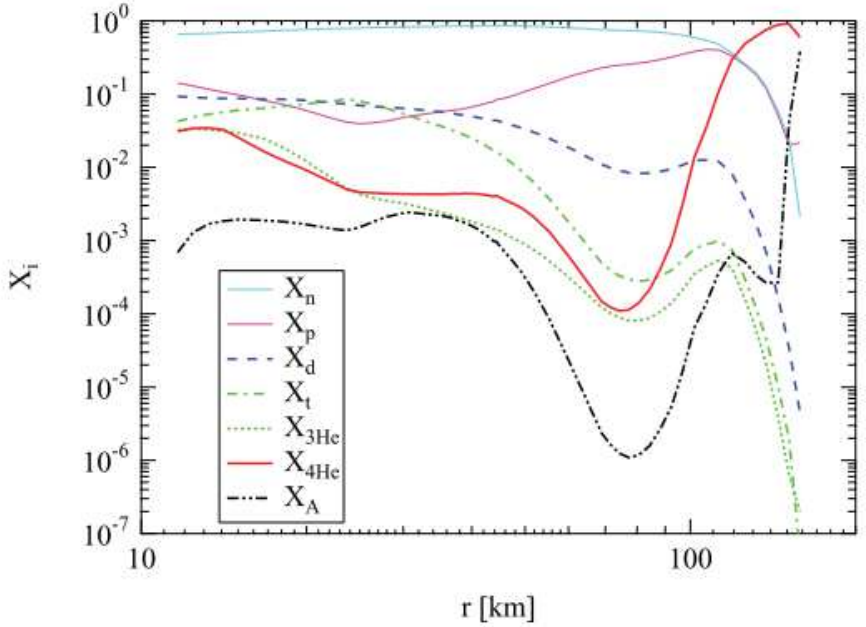
Equation of State **(EoS) of asymmetric NM ε (ρ, I)**
→ topics in nuclear *structure* and *dynamics*
→ relevant role also in *astrophysics*

High densities → *structure and stability* of Neutron Stars



Low **densities → *n-rich cluster* formation in *Supernovae* explosions**

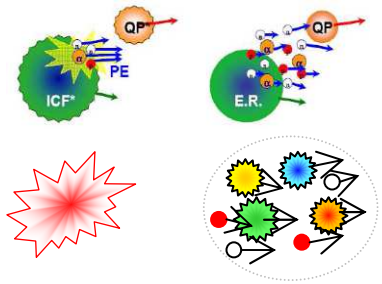


J.M. Lattimer and M.Prakash, *Science* 304 (2004) 536

K.Sumiyoshi and G.Ropke, *Phys. Rev.* C 77 (2008) 055804

How can we probe the (asy)- EoS?

Competition between reaction mechanisms at semi-central <b>

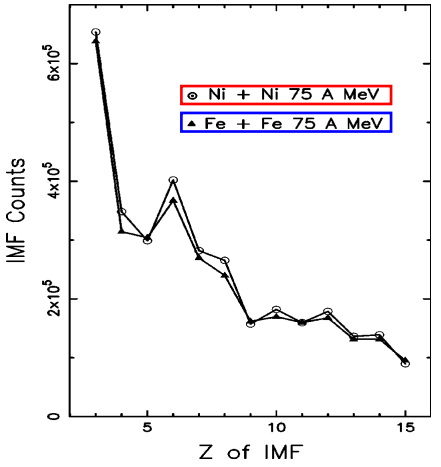


Evaporat. Residue Emission

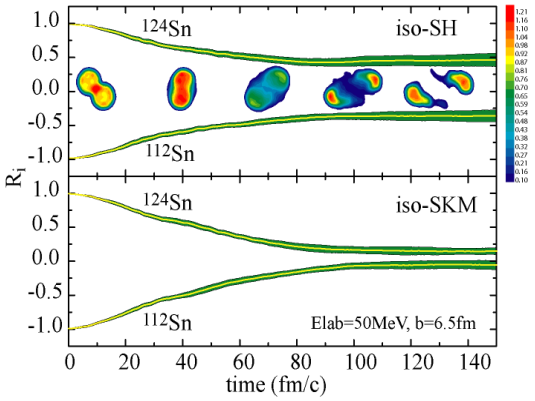
Fragment production

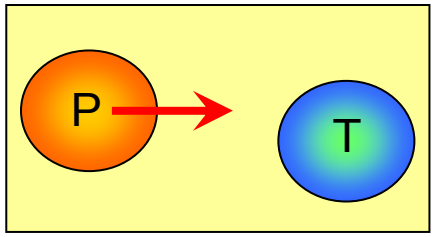
Neutron content of light isotopes

Amplitude of even-odd staggering on Charge and N distributions



Isospin transport process in peripheral collisions





Compare reactions having various:

- **N/Z of projectile**
- **N/Z of target**
- **N/Z of total system**

Explore the maximum range available (→ RIB)

Pre-equilibrium GDR emission

Pre-equilibrium n/p ratio

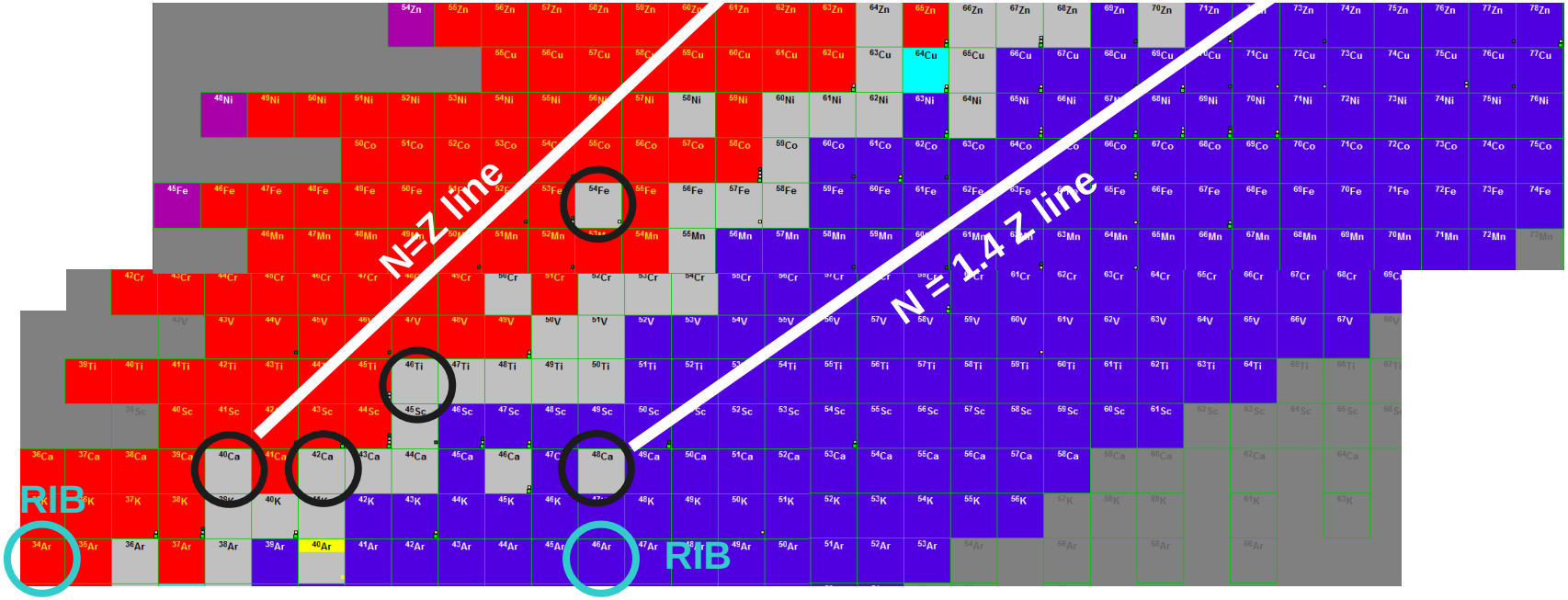
Pigmy Dipole Resonance

(A)Symmetry Term of Nuclear Equation of State

Review: M. Di Toro et al, JoP G 37 (2010)

Investigations in the region of *Ca*

The use of nuclides in the Ca region allows to investigate *n-rich* and *p-rich* systems

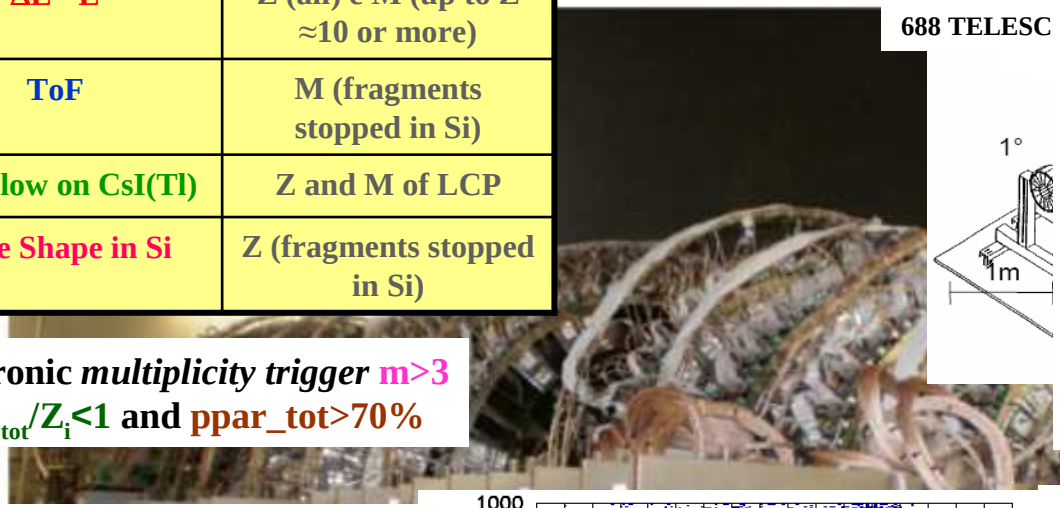


Two experimental campaigns at INFN-LNS:

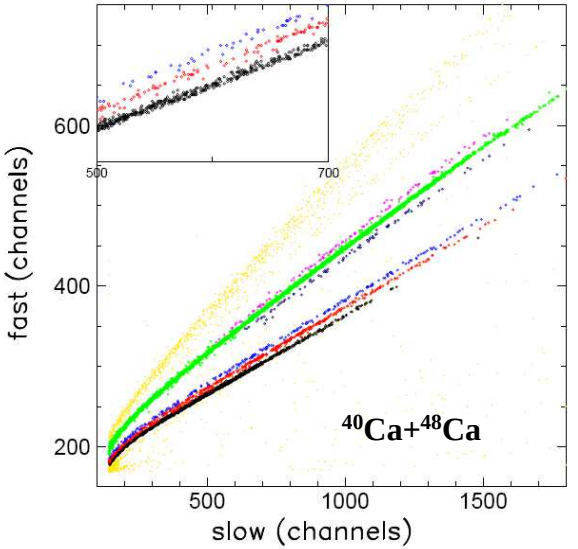
- **25 MeV/nucleon → *low* – *intermediate* energy reaction mechanisms**
- **^{40}Ca+^{40}Ca and ^{48}Ca+^{48}Ca → *extreme* N/Z values (1.0 – 1.4)**
- ***mixed* systems → isospin diffusion**
- **^{40}Ca+^{40,48}Ca and ^{40}Ca+^{46}Ti → *mass asymmetry* effects**
- **^{42}Ca+^{54}Fe *(preliminary)* and ^{48}Ca+^{48}Ca → *isospin vs mass* effects**

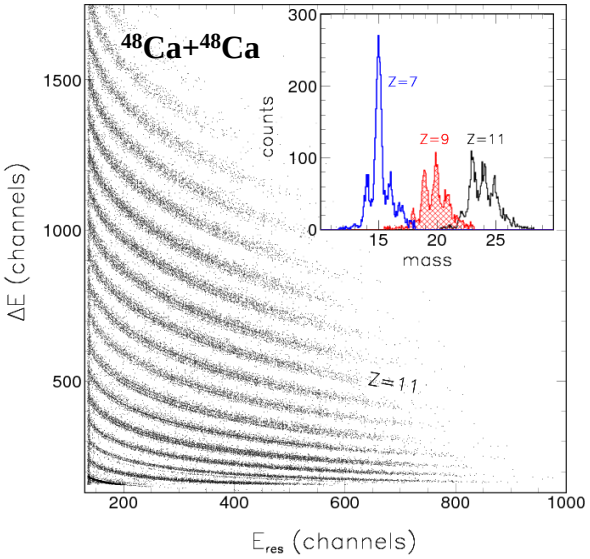
Perspectives with RIBs in the *Ar* region

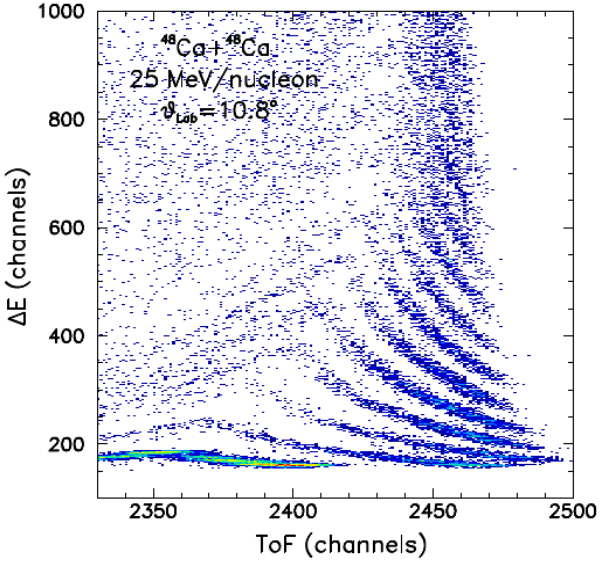
Exp. technique	Result:
ΔE - E	Z (all) e M (up to Z ≈10 or more)
ToF	M (fragments stopped in Si)
Fast-Slow on CsI(Tl)	Z and M of LCP
Pulse Shape in Si	Z (fragments stopped in Si)

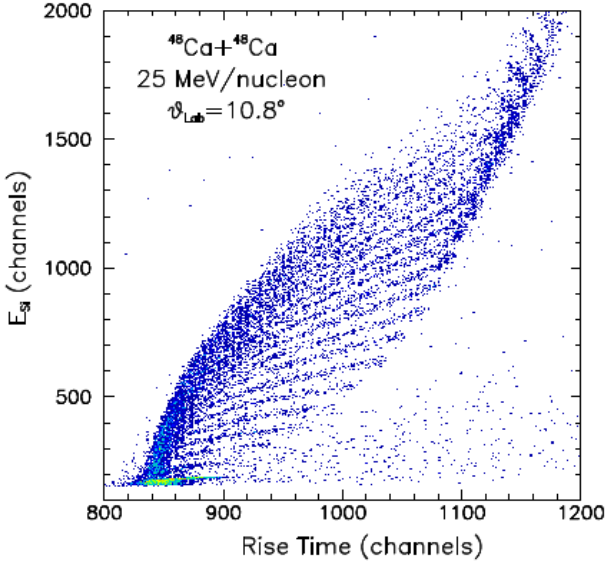


Electronic *multiplicity trigger* m>3
$0.8<Z_{tot}/Z_i<1$ and ppar_tot>70%









A. Pagano et al, Nucl. Phys. A 734 (2004) 504

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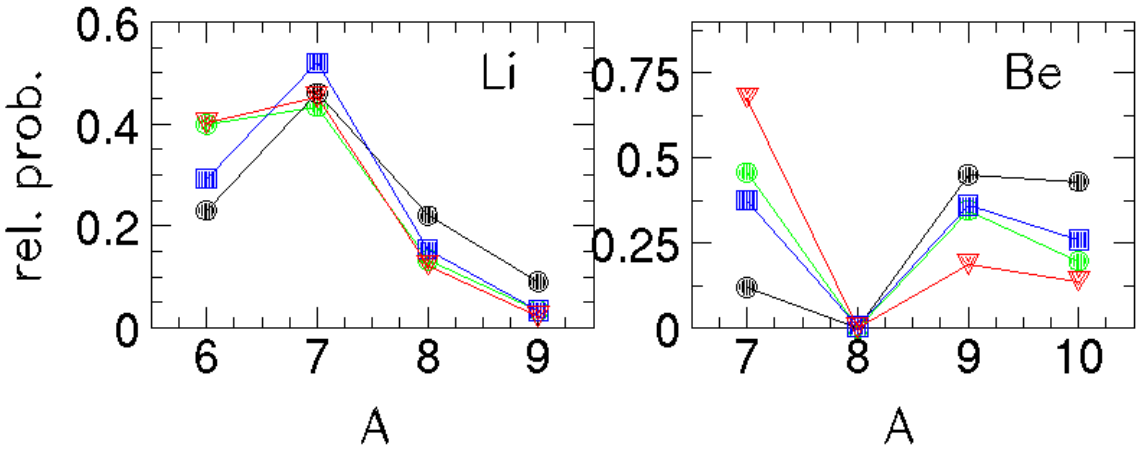
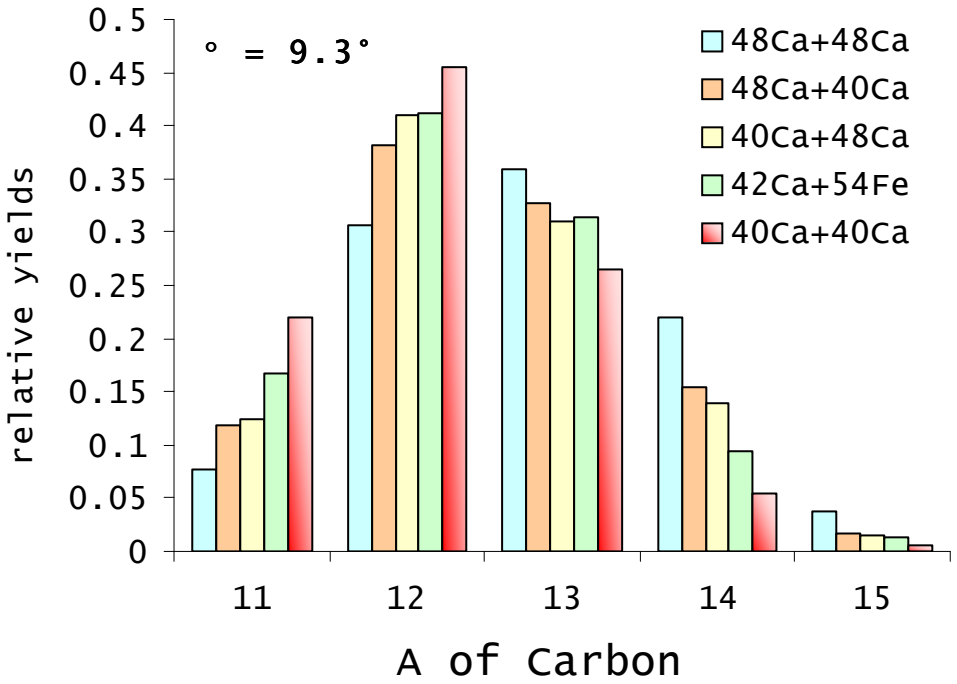


Forward* emission: *5.2° < θ < 15.3°

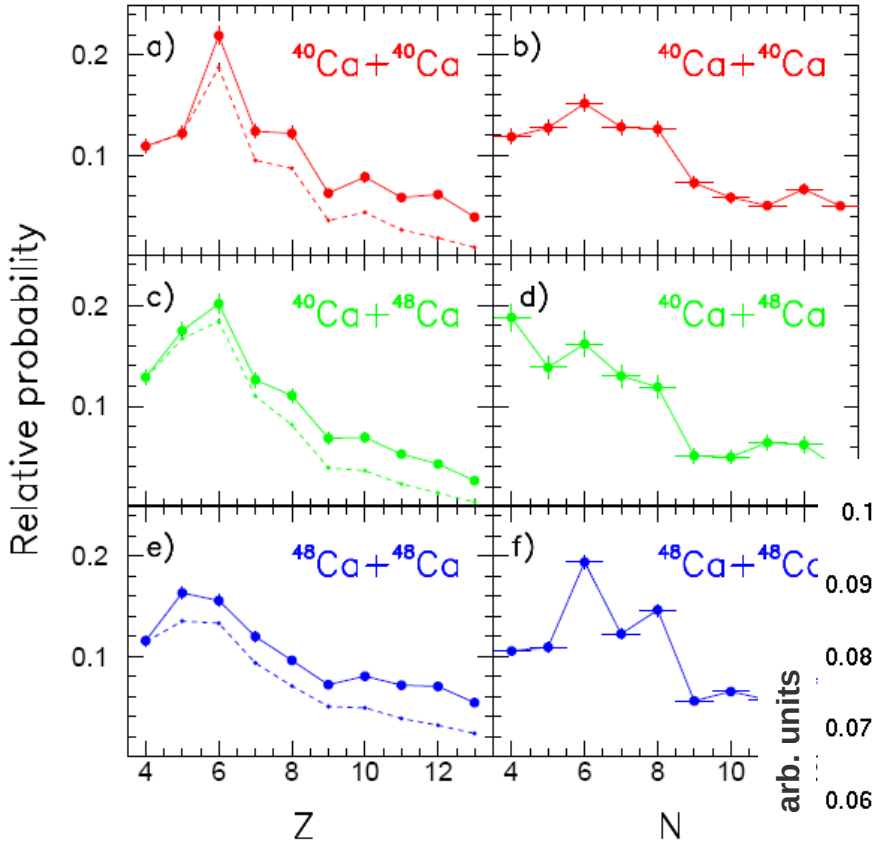
$^{48}Ca+^{48}Ca$	N/Z=1.4
$^{40}Ca+^{48}Ca$	N/Z=1.2
$^{42}Ca+^{54}Fe$	N/Z≈1.09
$^{40}Ca+^{40}Ca$	N/Z=1.0



strong isotopic effects

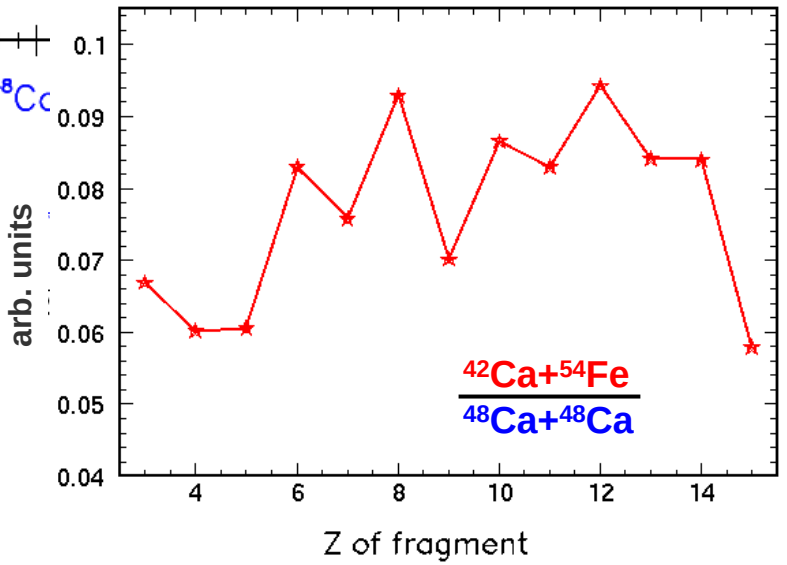
Inclusive emission of _light fragments_ at forward angles (_solid lines θ_{med}=11.5°_, _dashed lines θ_{med}=16.5°_) identifyed by means of ΔE-E: _even-odd_ effects on Z and N distributions

N/Z increases



I. Lombardo et al, PRC 84 (2011)

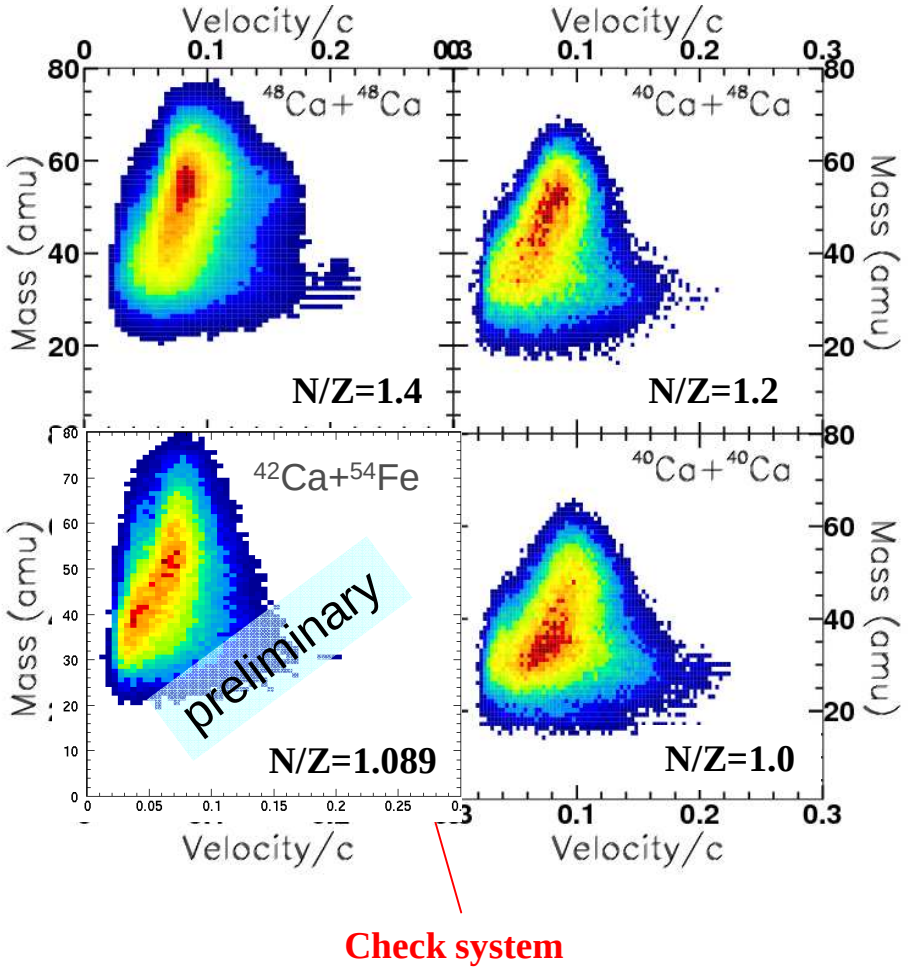
N/Z decrea



Even-odd effects:

B. Gatty et al, Nucl. Phys. A 253 (1975) 511
C. Beck et al, Zeit. Phys. A 343 (1992)
G. Lanzanò et al, Zeit. Phys. A 343 (1992) 429
Sl. Cavallaro et al, Phys. Rev. C 57 (1998) 731
K. X. Jing et al, Nucl. Phys. A 645 (1999) 203
L.B. Yang et al, Phys. Rev. C 60 (1999) 041602
E.M. Winchester et al, Phys. Rev. C 63 (2000)
E. Geraci et al, Nucl. Phys. A 734 (2004) 524
M.V. Ricciardi et al, Nucl. Phys. A 749 (2005)
Jun Su et al, Phys. Rev. C 83 (2011)
G. Ademard et al, Phys. Rev. C 83 (2011)
S. Pirrone et al, EPJ Web Conf. 17 (2011)

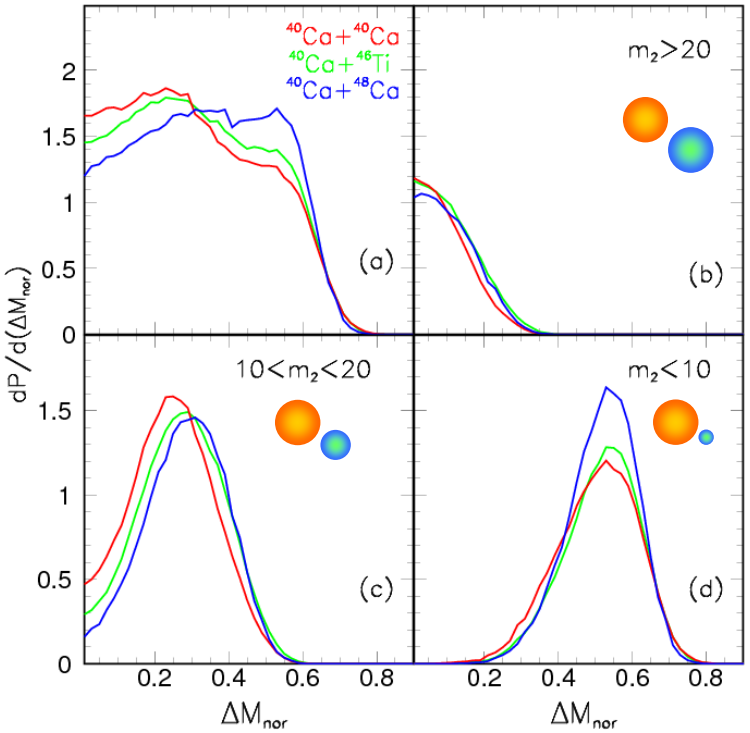
Central events ($m_{cp} \geq 5, 6$) **with the presence of a fast quasi-projectile** (v_2 or v_3>0.13c) (***massive transfer***). **Mass – velocity correlations of the *biggest* emitted fragment :**



The observed phenomenon *should not* be attributed to *mass asymmetry effects* → ^{48}Ca and ^{46}Ti have *similar m. a.*

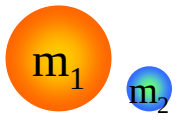
The N/Z degree of freedom strongly influences the *reaction mechanisms*:

- **Larger N/Z → larger heavy residue emission in Incomplete Fusion events**
- **Lower N/Z → binary-like, fusion-fission and IMF emission prevail**

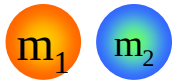


$$\Delta M_{nor} \equiv \frac{m_1 - m_2}{m_{tot}}$$

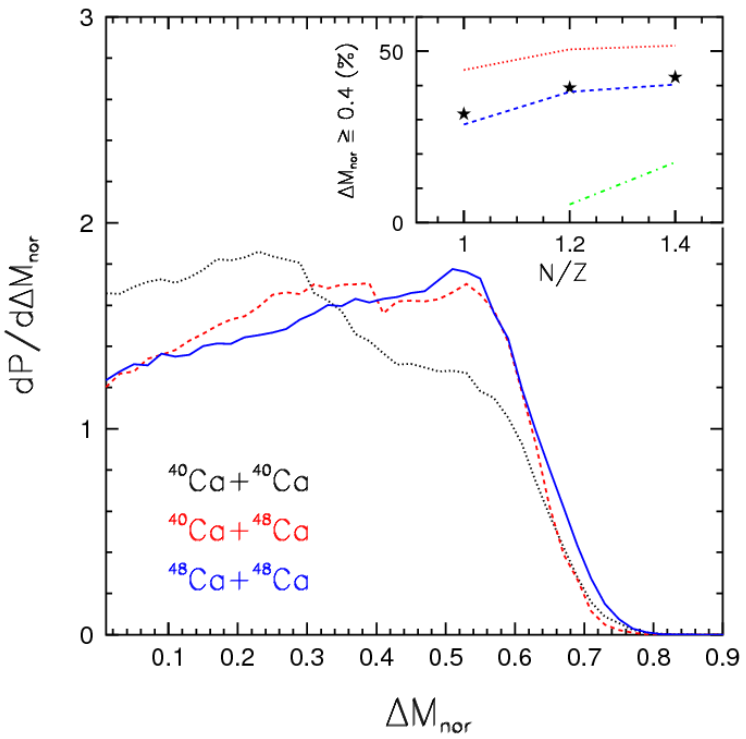
ΔM_{nor} analysis → disentangle the *competition* of various *mechanisms* in *central collisions*:



fusion-like → ***large ΔM_{nor}***



Binary-like
Multi-fragm.
Fusion-fission
→ ***low ΔM_{nor}***



***Percentage of* HR events by *integrating* $\Delta M_{nor} > 0.4$**

large N/Z → enhan. of HR

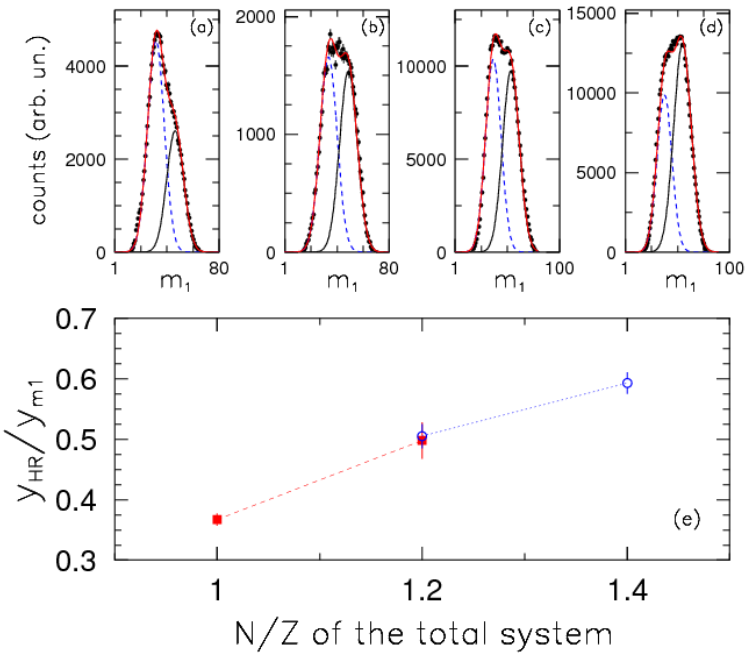
***symmetric* system → suppr. HR**

lines* in inset → CoMD-II model *calculations

Relative yields **of HR emission in** ***central collisions*** **by means of** ***two gaussian fit*** **of** ***experimental mass spectra:***

- **large N excess → HRs increase**
- **N ≈ Z → BL and IMF prevail**

This effect can be attributed to the ***interplay*** **between** ***Coulomb*** **and** ***Symmetry terms*** **→ nuclear dynamics**



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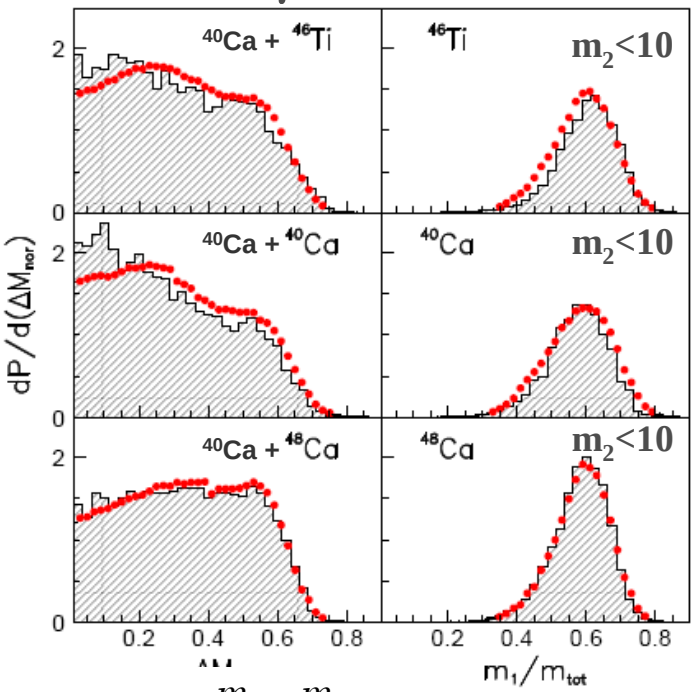
Stiff2 → γ=1



$$\Delta M_{nor} \equiv \frac{m_1 - m_2}{m_{tot}}$$

$$F\left(\frac{\rho}{\rho_0}\right)_{Soft} = \sqrt{\rho/\rho_0}$$

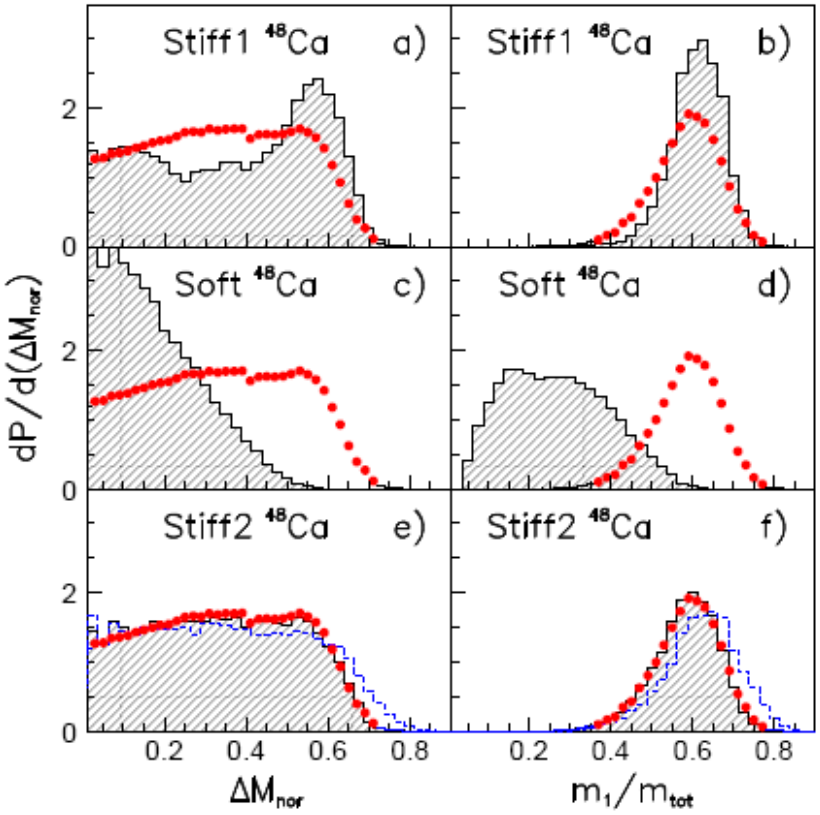
$$F\left(\frac{\rho}{\rho_0}\right)_{Stiff2} = \frac{\rho}{\rho_0}$$

$$F\left(\frac{\rho}{\rho_0}\right)_{Stiff1} = \frac{2(\rho/\rho_0)^2}{1+\rho/\rho_0}$$

Best agreement → Stiff2 option.
The GEMINI stage does not change the *overall shape* of spectra → dynamics

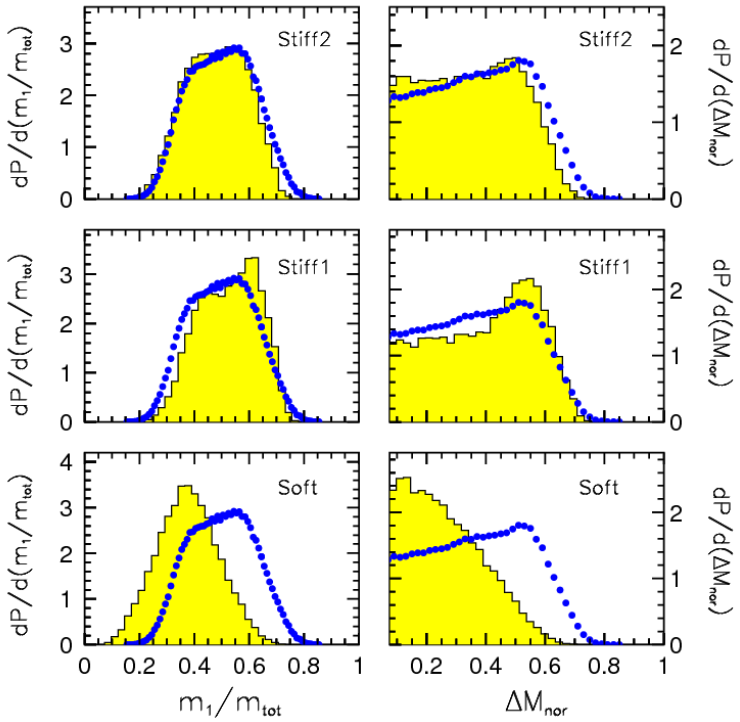
^{40}Ca + ^{40}Ca , ^{46}Ti , ^{48}Ca

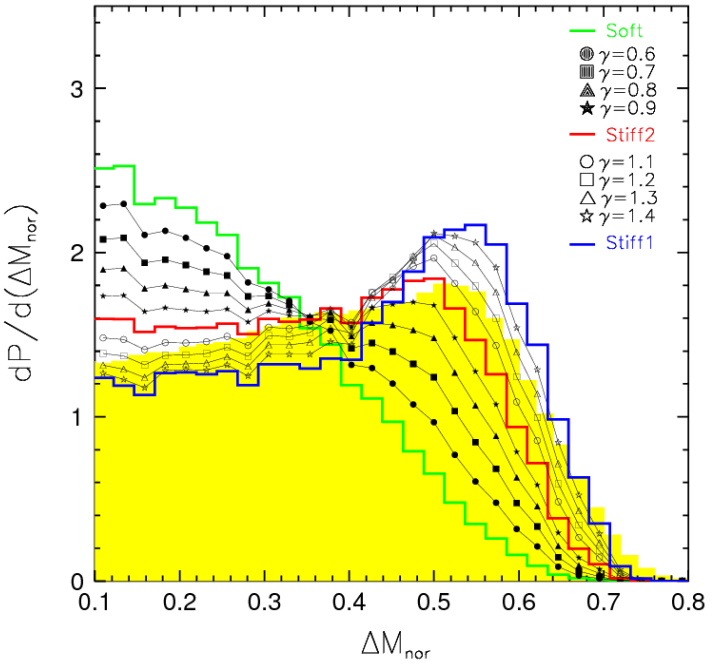
We compared experimental ΔM_{nor} distributions with CoMD-II (+GEMINI) model calculations → we adopted various *form factors* of $U_{sym}(\rho/\rho_0)$



Talk given by *M. Papa* this morning

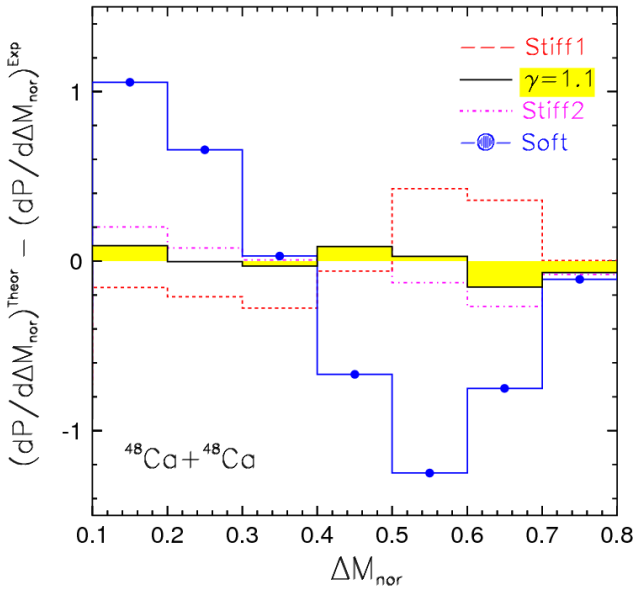
$^{48}Ca+^{48}Ca$ experiment





Good agreement with Stiff2 option (*linear*)

By interpolating **the three original options, we find** $\langle\gamma\rangle \approx 1.1$ → ***minimum deviation between exp. and calc.*** ΔM_{nor}



Moderately Stiff form factor

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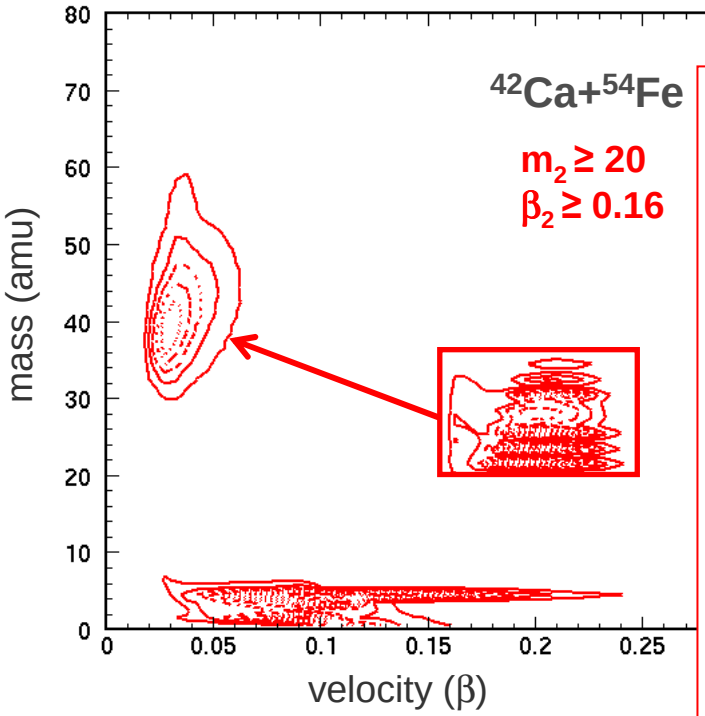
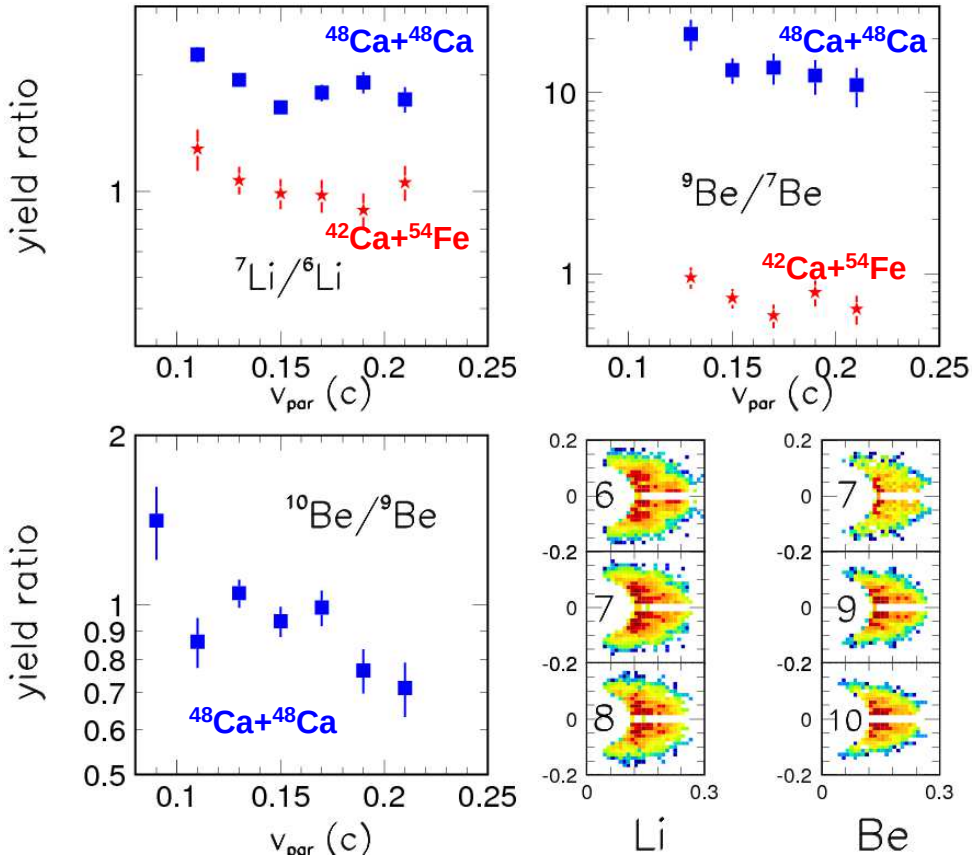
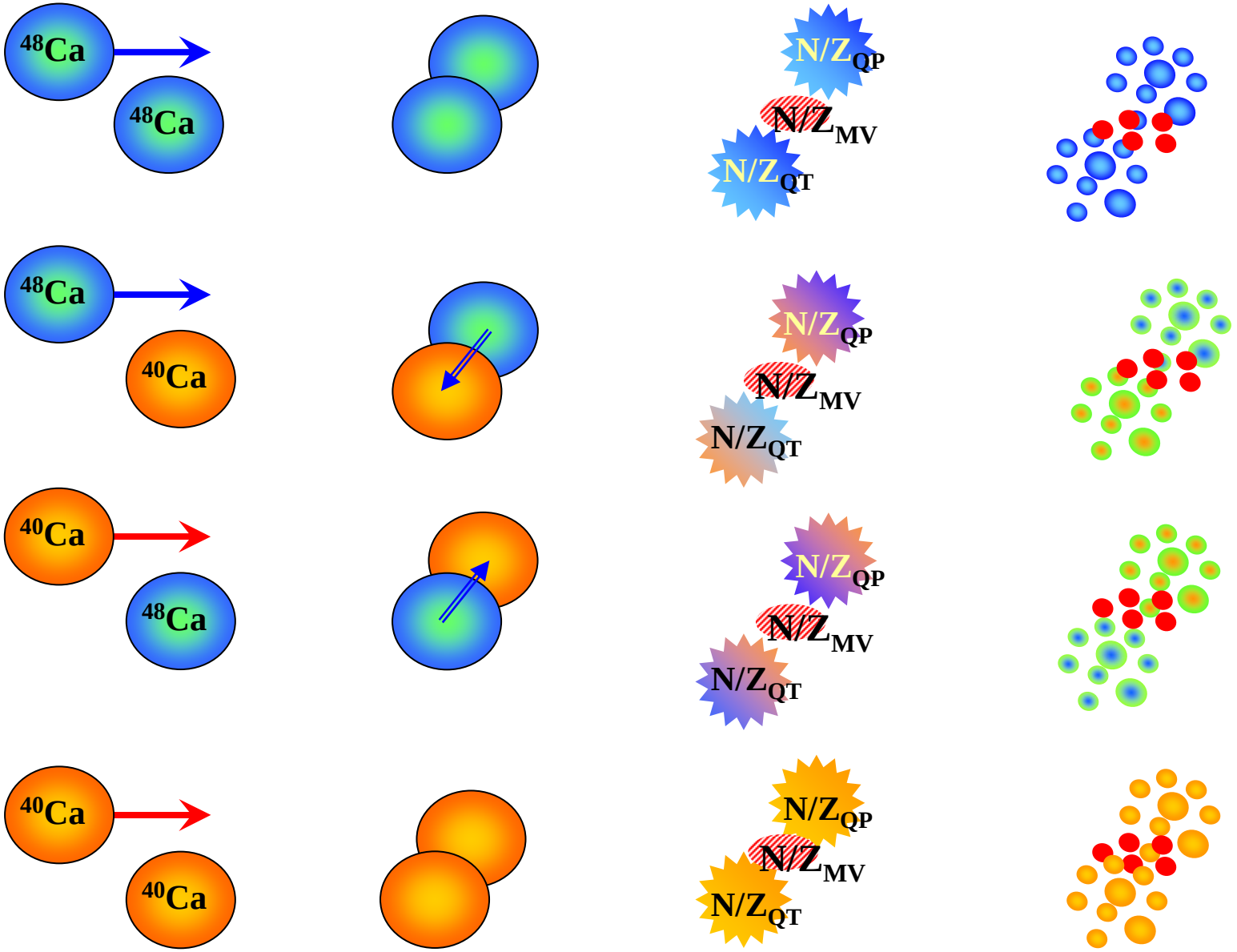
$^{42}Ca+^{54}Fe$: *binary* vs HR with *mass* and *velocity* selections



Binary dissipative selection

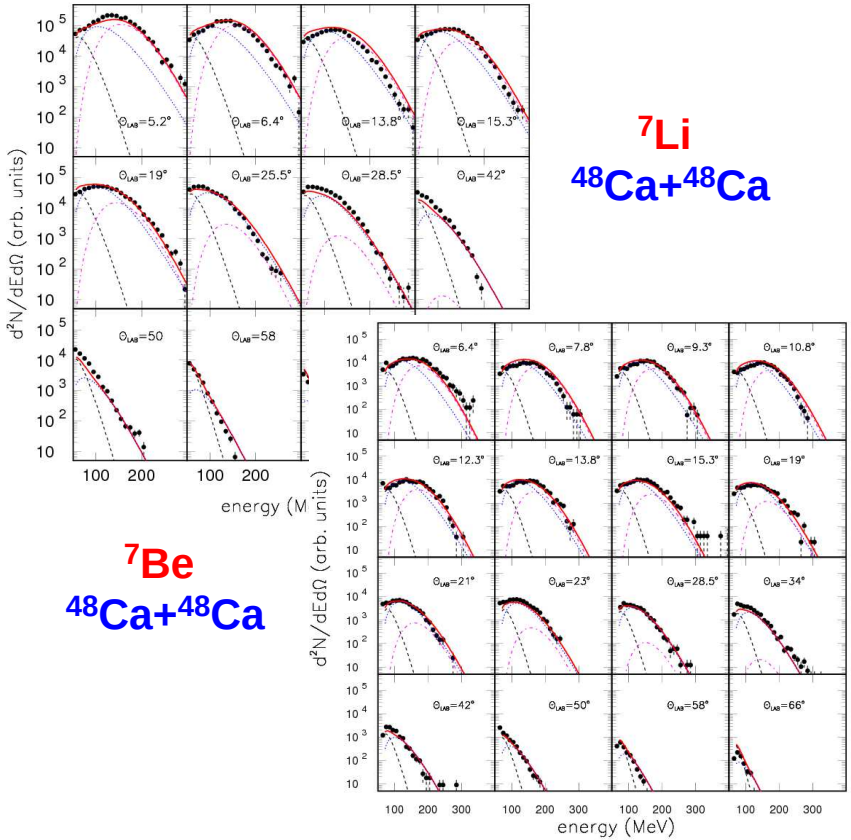


Semi-peripheral collisions: isospin diffusion



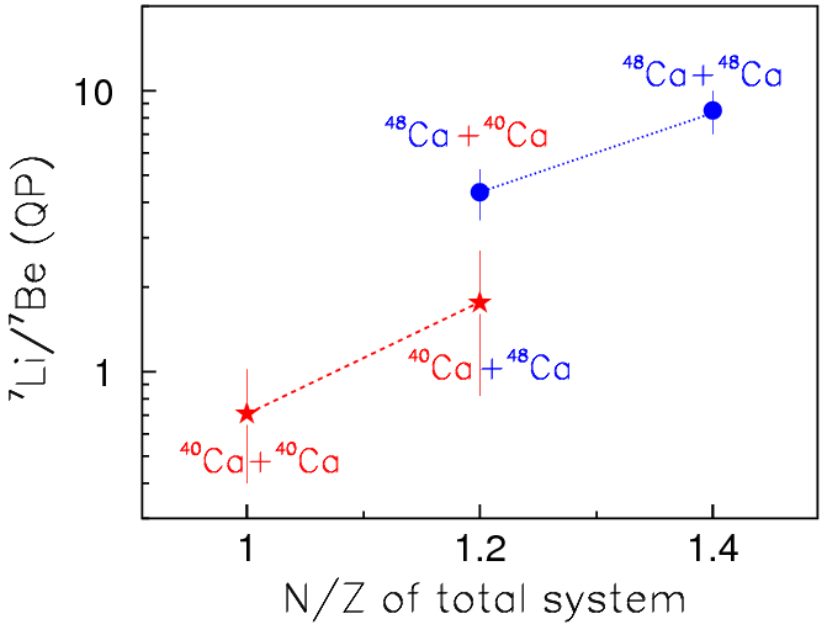
N/Z of QP and MV source → light isobars

N/Z of QP (and MV) → ^{7}Li/^{7}Be



^{7}Li
^{48}Ca+^{48}Ca

^{7}Be
^{48}Ca+^{48}Ca



^{7}Li and ^{7}Be emission yields by means of multi-component *moving source* fits.

Incomplete N/Z equilibrium

Following SM, we can assume:

$$\frac{Y_{^7Li}}{Y_{^7Be}} \propto \exp\frac{N}{Z}\Big|_{source}$$

and we can estimate (*roughly*) the degree of *N/Z equilibration*

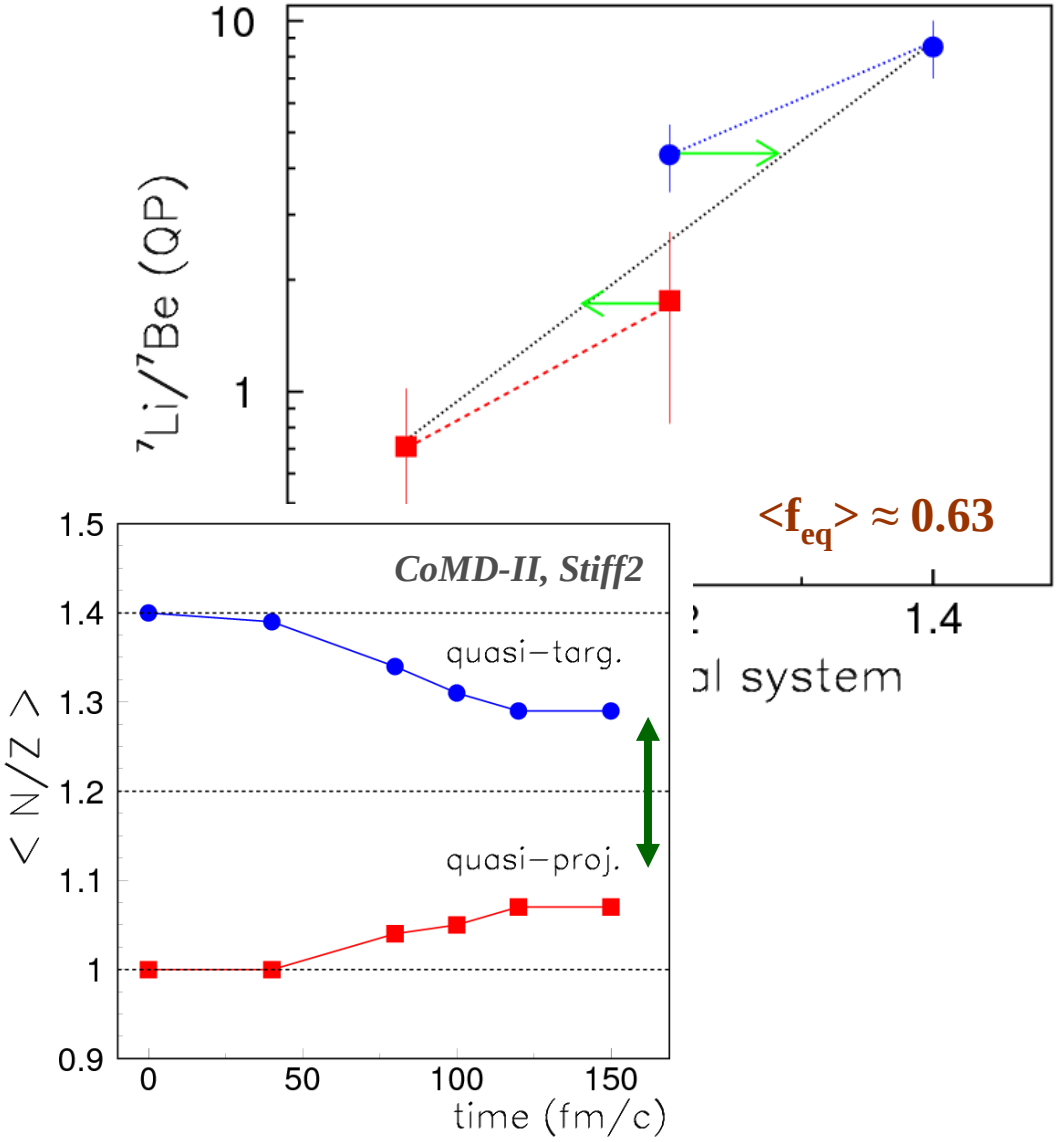
We can define the *fraction of equilibrium* as follows:

Keksis et al PRC 81 (2010)

$$f_{eq} \equiv \frac{\frac{N}{Z}_{QP} - \frac{N}{Z}_{P}}{\frac{N}{Z}_{TOT} - \frac{N}{Z}_{P}}$$

At *complete charge equilibrium* → f_{eq}=1

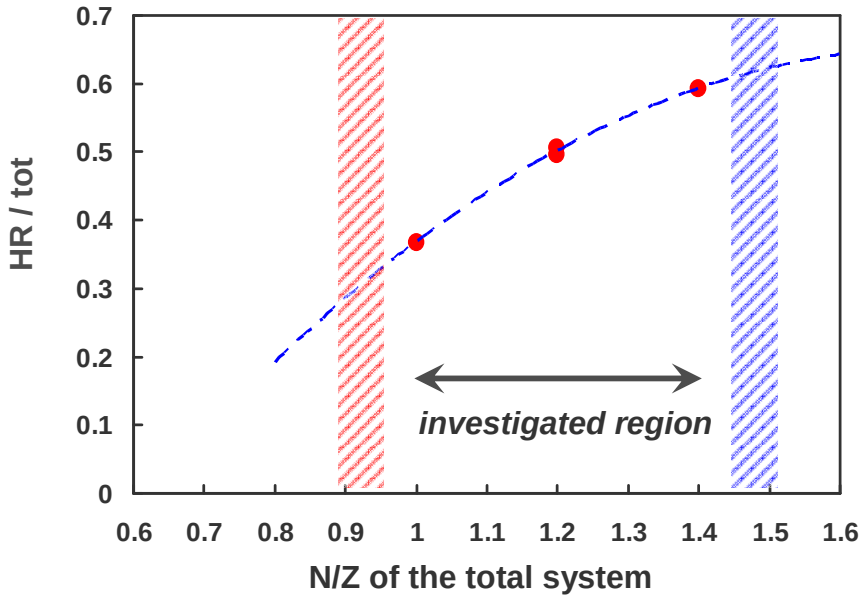
The *pure systems* → useful to plot the "*equilibrium line*"

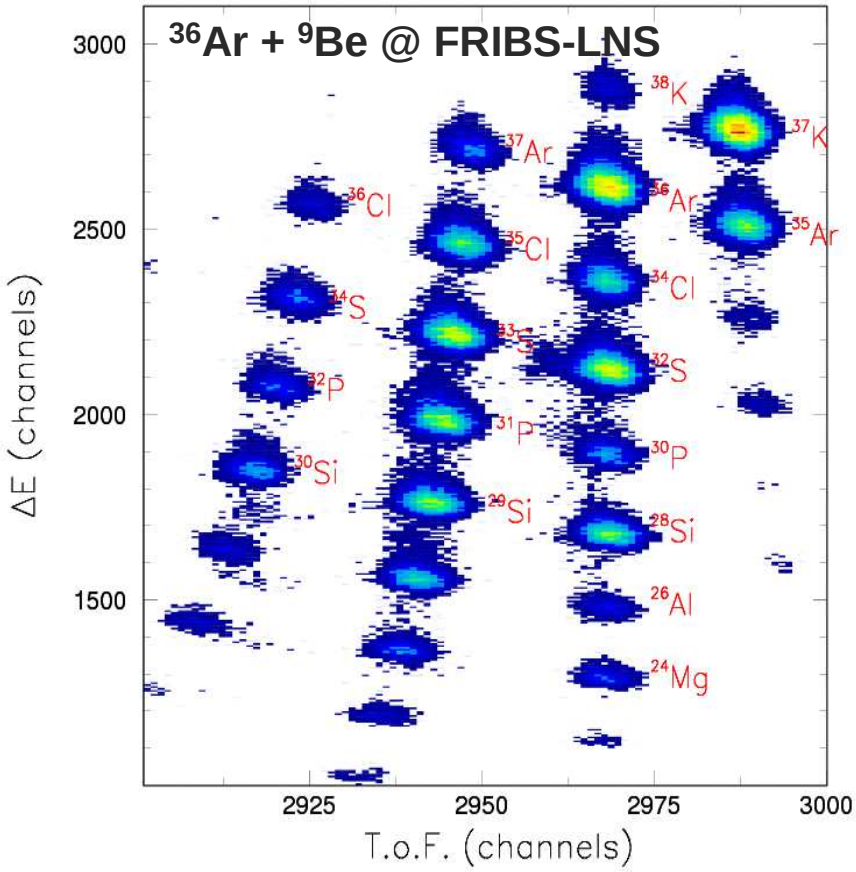


Competition between *reaction mechanisms* in central events (≈ 20 MeV/n)

$^{34}Ar+^{40}Ca$ (N/Z=0.947)

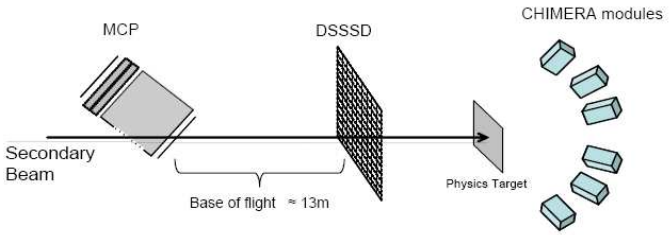
$^{46}Ar+^{48}Ca$ (N/Z=1.474)





We may also expect (*p-rich*):
→ very large *even-odd* effect on Z-distr.
→ enhancement of *fusion – fission*

p-rich collisions at ≈ 5 MeV/nucleon → behaviour of CN near/at the *proton drip line*



Thank you for the attention !

Exochim Collaboration

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