Experimental observations of isospin effects:

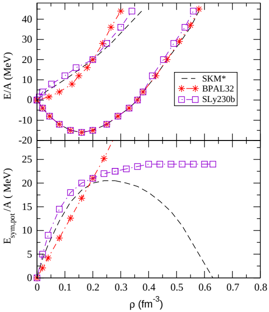
isospin diffusion - multifragmentation

M. F. Rivet
Institut de Physique Nucléaire, Orsay, France
INDRA Collaboration

Fluctuations and temporal evolution in heavy-ion collisions
10/05/2012

Outline

Introduction



V. Baran et al., Phys. Rep. 410 (2005) 335.

$$\frac{E}{A}(\rho, I) = \frac{E}{A}(\rho) + \frac{E_{sym}}{A}(\rho) \times I^2$$

symmetric matter

with $I = \frac{\rho_n - \rho_p}{\rho} = \frac{N-Z}{A}$

EOS using different effective interactions may present the same saturation properties for symmetric nuclear matter, but very different symmetry energy contributions.

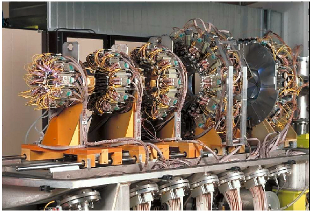
Introduction

We present experimental observables that are isospin sensitive, and examine whether they can help in constraining the EOS.

1. Isospin diffusion in semi-peripheral ^{58}Ni+^{58}Ni and ^{58}Ni+^{197}Au collisions at 52 and 74 AMeV, studied as a function of the dissipation (or impact parameter).
2. Isospin effects in multifragmentation of quasi-fusion sources in ^{124,136}Xe+^{112,124}Sn collisions at 32 and 45 AMeV.
3. Information on the symmetry energy term of the EOS will be derived through comparisons with the Stochastic Mean Field model from Catania (M. Colonna *et al.* NPA642 (1998) 449.)

Experiments performed with INDRA

Experiments were performed at GANIL. Charged reaction products were detected by the 4π INDRA array. (90% geometrical coverage)

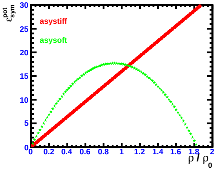


INDRA allows to work with complete events : more than 80% of the charge is detected (of total system for central collisions, of projectile in the forward c.m. hemisphere for semi-peripheral collisions. We call

- fragments : $Z \geq 5$
- particles : $Z \leq 4$
- light charged particles lcp : H, He isotopes

- Skyrme interaction. Soft isoscalar EOS : K_∞=200 MeV.

2 prescriptions for the symmetry energy :



- free σ_{NN} with its angular, energy and isospin dependences (upper limited to 50 mb).
- 50 or 30 test particles/nucleon
- hot fragments de-excited while propagating using the SIMON code.

The Stochastic Mean Field model

M. Colonna et al. NPA 642 (1998) 449

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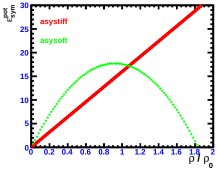

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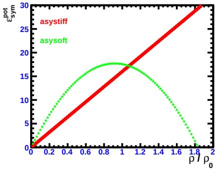

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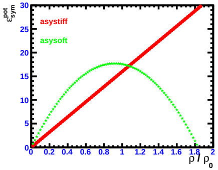

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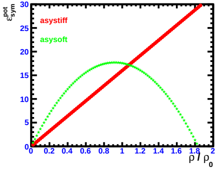

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Isospin diffusion : the studied systems

Same projectile, two targets

^{58}Ni + ^{58}Ni

^{58}Ni + ^{197}Au

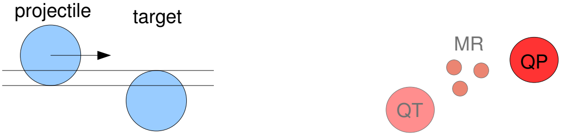
at 52A and 74A MeV.

Ni+Ni is used as a reference system because, in a first approximation, we expect no isospin change, but those due to preequilibrium

For Ni+Au we expect PE + isospin transport effects

Experimental Selections I

- We select semiperipheral collisions, with two main products in the exit channel (b∼ 4 fm up to b_{max}).



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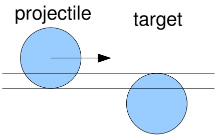

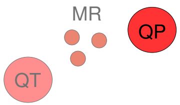

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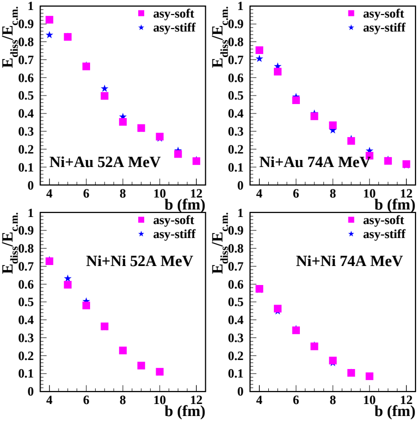
The sorting variable: the energy dissipation



$$E_{\rm diss} = E_{\rm c.m.} - \frac{1}{2}\mu V_{\rm rel}^2$$

with

$$V_{\rm rel} = V_{\rm QP}^{\rm rec} \times \frac{A_{\rm tot}}{A_{\rm target}}$$

$V_{\rm QP}^{\rm rec}$ obtained from selected fragments

SMF shows that this variable well correlates with the impact parameter.

The experimental isospin variable: $(\langle N\rangle/\langle Z\rangle)_{CP}$

E. Galichet et al., Phys. Rev. C 79 064614

Definition

$$(\langle N\rangle/\langle Z\rangle)_{CP} = \sum_{N_{evts}} \sum_{\nu} N_{\nu} / \sum_{N_{evts}} \sum_{\nu} P_{\nu}$$

N_{ν} and P_{ν} are the numbers of neutrons and protons bound in particle ν, forward emitted in the NN or QP frame.
ν = d, t, ^{3}He, α, ^{6}He, ^{6}Li, ^{7}Li, ^{8}Li, ^{9}Li, ^{7}Be, ^{9}Be, ^{10}Be
free protons are excluded, as neutrons are not measured.

Experimental selection

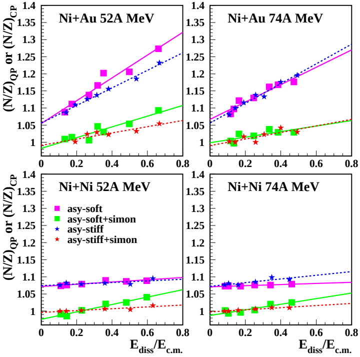
for comparison with SMF

In SMF we cannot “identify” MR fragments/particles. We can construct $(\langle N \rangle / \langle Z \rangle)_{CP}$ only with the de-excitation products of the QP.

I shall present here $(\langle N \rangle / \langle Z \rangle)_{CP}$ using only particles forward emitted in the QP frame.

The ideal isospin variable: $(\langle N\rangle/\langle Z\rangle)_{QP}$
sorting with E_{diss}

SMF results : N/Z of QP* when QP, QT re-separate.



Periph. $\longrightarrow$ central

- Small increase of $(\langle N\rangle/\langle Z\rangle)_{QP}$ with dissipation for Ni+Ni, stronger with asy-stiff (more preequilibrium *p* emission)
- Ni+Au: N/Z higher for asy-soft, more dissipative. N/Z diffusion related to degree of dissipation and driving force provided by E_{sym}

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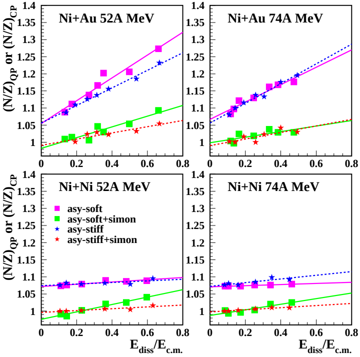

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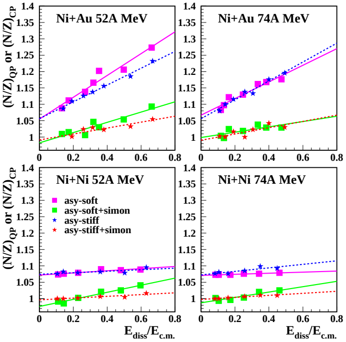
QP* de-excited with the help of the SIMON code.

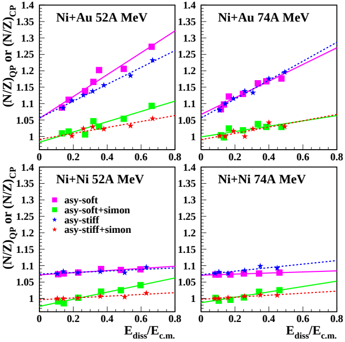


- De-excitation ⇒ $(\langle N\rangle/\langle Z\rangle)_{CP} < (\langle N\rangle/\langle Z\rangle)_{QP}$; smaller slopes.
- Differences with asy-EOS still present, even increased at 52A MeV (due to larger E* with asy-soft -> more emission of n-rich nuclei)

The ideal isospin variable

sorting with E_{diss} - effect of de-excitation

QP* de-excited with the help of the SIMON code.



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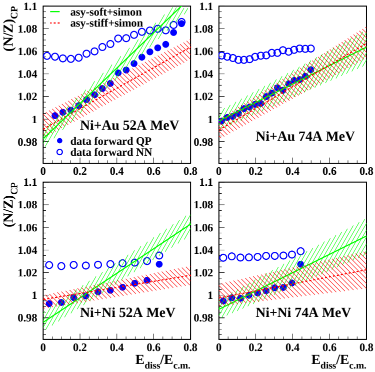
Comparison experimental data - SMF

E. Galichet et al., Phys. Rev. C 79 064615

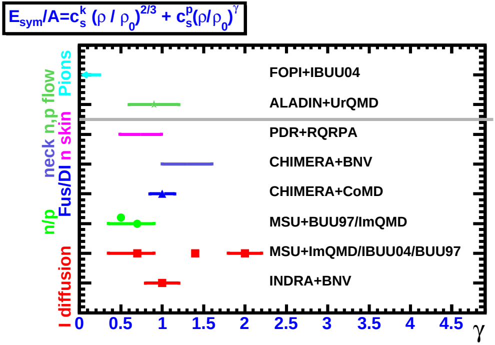


A better overall agreement is obtained with the asy-stiff EOS,

in which the potential part of the symmetry energy varies linearly with the density.

Data around the world

up to 05/2010



Shape of E_{sym} still data and model dependent.

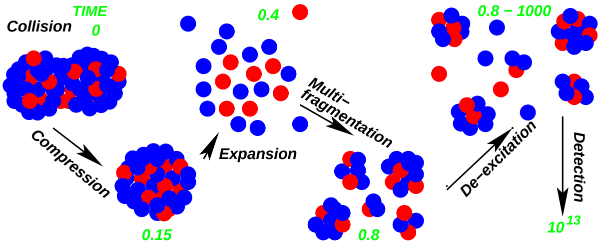
E_{proj}/A = 32 MeV

^{124}Xe+^{112}Sn
^{124}Xe+^{124}Sn
^{136}Xe+^{112}Sn
^{136}Xe+^{124}Sn

E_{proj}/A = 45 MeV

^{124}Xe+^{112}Sn

^{136}Xe+^{112}Sn
^{136}Xe+^{124}Sn



time unit 10^{-21} s

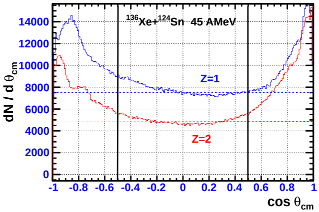
Freeze-Out

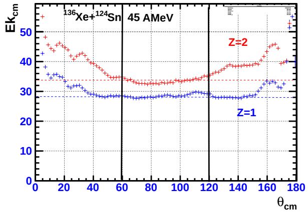
Experimental systems and selections

$Z_{tot} \geq 80$ and $\theta_{flot} \geq 60^o$

Select compact shape events from central collisions (quasi-fusion)

- Fragment c.m. angular and energy distributions $\sim$ isotropic
- Also Particles $\in [60 - 120^o]$



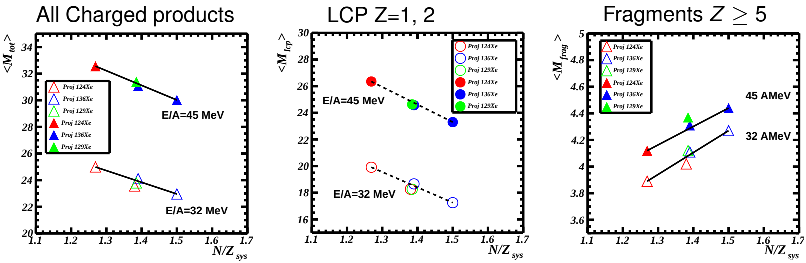


We assume those belong to the multifragmenting source.

Experimental observables

Multiplicities vs (N/Z)$_{sys}$

(F. Gagnon-Moisan PhD thesis and FGM et al. to be published)

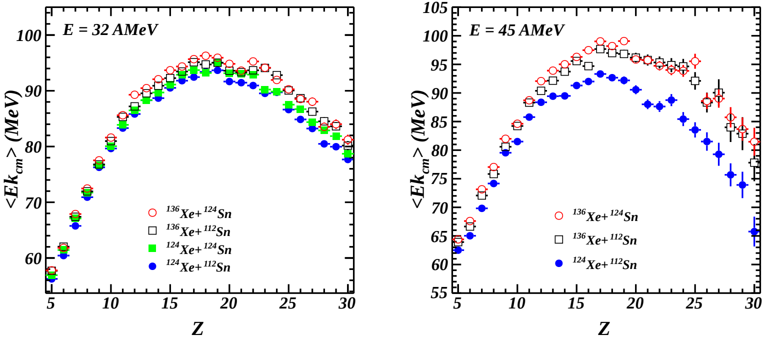


Multiplicities depend on N/Z_{sys}, the N/Z of the total system.
Entrance channel mass asymmetry does not play any role for these central collisions.

Effect of primary process or of evaporation ?

Experimental observables

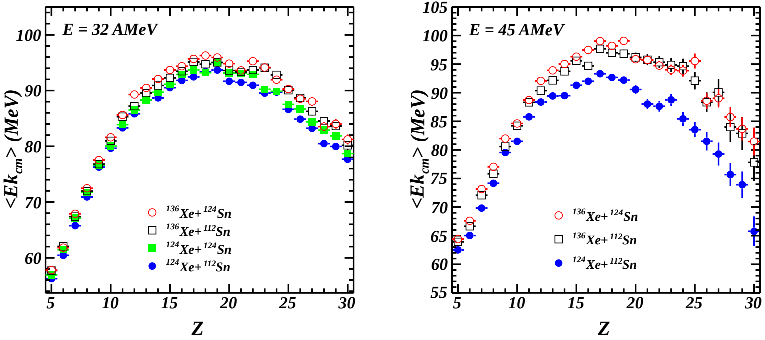
Fragment kinetic energies



- For each system $Ek_{cm}(45) > Ek_{cm}(32)$
- At a given incident energy, higher energies for neutron-rich system.
- Can be explained by different expansion energy due to larger PRIMARY fragment masses.

Experimental observables

Fragment kinetic energies



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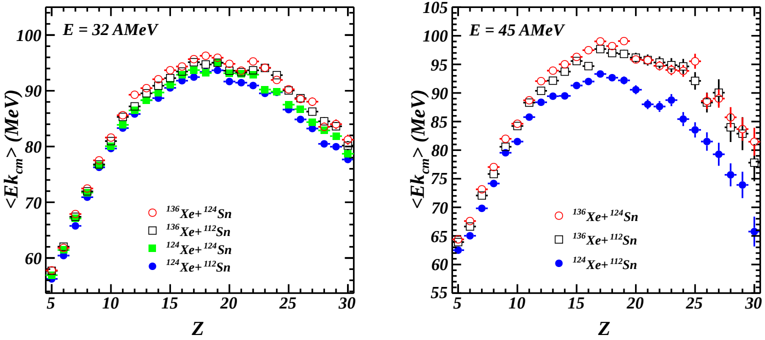

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Simulations

- Simulations at b = 0, 1, 2, 4 fm for times up to 300 fm/c
- At 45 AMeV, two main outgoing fragments for b>1 fm. For b=0, a single source multifragments.
  1. 120 fm/c Source (big residue) + preequilibrium
  2. 300 fm/c Primary fragments + free nucleons
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Avoid filtering for data-SMF comparison?

Preliminary analysis

- no small clusters produced (spinodal) or recognized (clustering algorithm) in SMF ⇒ they only come from de-excitation of fragments (Z≥5). Those are not produced through evaporation.
- preequilibrium/multifragmentation nucleons “lost” (not input to SIMON)
- a try: extrapolate experimental data to full detection, Z_{tot}=104, for multiplicities (M_{lcp}, M_{frag}) and different Z_{bound}

Experiment

$Z_{lcp} = \sum_{Z=1,2}$
$Z_{bound_5} = \sum_{Z\geq 5}$

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$Z_{lcp} = 104 - \sum_{Z\geq 3}$
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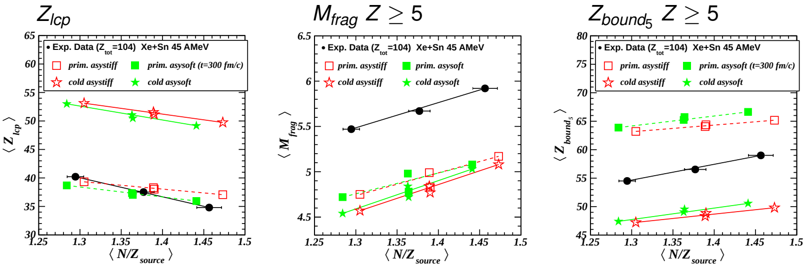
Simulation vs Experiment

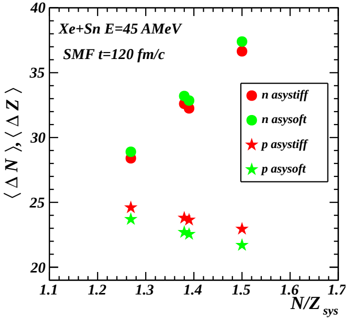
Multiplicities, Z_{bound} vs $\langle N/Z \rangle_{Source}$



Experimental trends already exist at 300 fm/c : isospin effect largely comes from the dynamics, not from evaporation.
In simulation
Z_{lcp} too large, Z_{bound_5} and M_{frag} underestimated,
and smaller differences between the n-richer and n-poorer systems

SMF

$(\Delta Z = Z_{sys} - Z_S)$



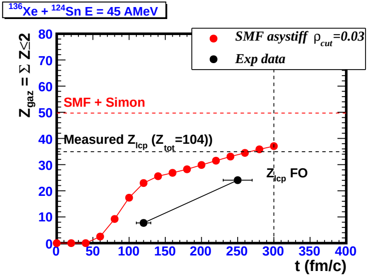
In low density region, E_{sym}^{pot} more repulsive for n, more attractive for p when asysoft.

In experiment

$Z^{preeq} = Z_{lcp}^{preeq} + Z_{3,4}^{preeq} =$
$104 - \sum_{Z \geq 5} - 2 \times \sum_{Z \leq 4}^{60-120^o}$
(anisotropic part)

Simulation vs Experiment

Time sequence (speculative)



Using previous studies

we deconvolve

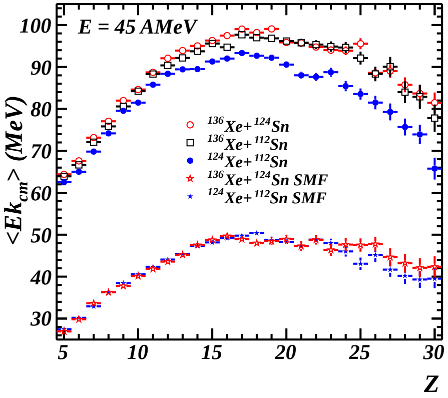
$$2 \times Z_{lcp}^{60-120^o} = Z_{lcp}^{FO} + Z_{lcp}^{evap} :$$

60% + 40 %

(Piantelli NPA809, Hudan PRC67)

The difference between experiment and simulation seems to be built at early times: too much preequilibrium in simulations.

Simulation vs Experiment
Fragment kinetic energies



Conclusions:
semi-peripheral collisions

1. $(\langle N\rangle/\langle Z\rangle)_{CP}$ is a good probe of isospin diffusion for Ni+Au.
2. In dynamical simulations differences between asy-EOS are present, and persist after secondary decay.
3. A better global agreement for the 4 studied cases is obtained in the asy-stiff case ($E_{sym}(\rho) \propto (\rho/\rho_0)$).

Conclusions:

Xe+Sn central collisions at 45 AMeV

1. Larger multiplicities and kinetic energies fof fragments observed for neutron-rich system
2. SMF allows to attribute a large part of the effect, for multiplicities, to the preequilibrium/multifragmentation stage
3. Too much preequilibrium, not enough fragments in the simulation
4. Fragment kinetic energy largely underestimated in SMF
5. Difficult to test EOS asystiffness with these observables

For the future

BLOB (Maria and Paolo)

DYWAN (Nantes team)