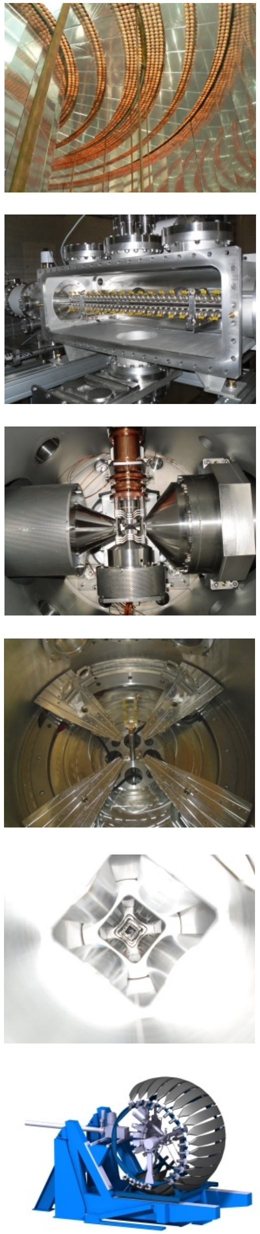
lpc caen
Laboratoire de physique corpusculaire



Latest results from **INDRA** and the new **INDRA+FAZIA** scientific program at **GANIL**

Olivier LOPEZ, LPC Caen, France
(INDRA-FAZIA)

XXth Colloque GANIL, Amboise

cnrs dépasser les frontières
IN2P3
Les deux infinis

ENSI CAEN
ÉCOLE PUBLIQUE D'INGÉNIEURS
CENTRE DE RECHERCHE

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CAEN
NORMANDIE

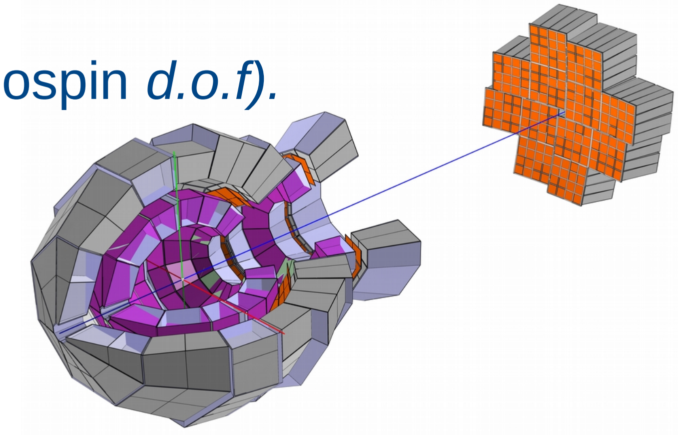
Normandie Université

Outlines

Latest results from INDRA

- Isospin diffusion *vs* chemical equilibrium
- Transport properties above E_{Fermi} : σ_{NN}^{*} and *N/Z* equilibration
- Fragment formation dynamics : spinodal instabilities in asymm. matter
- Improving INDRA identification : yes we can...

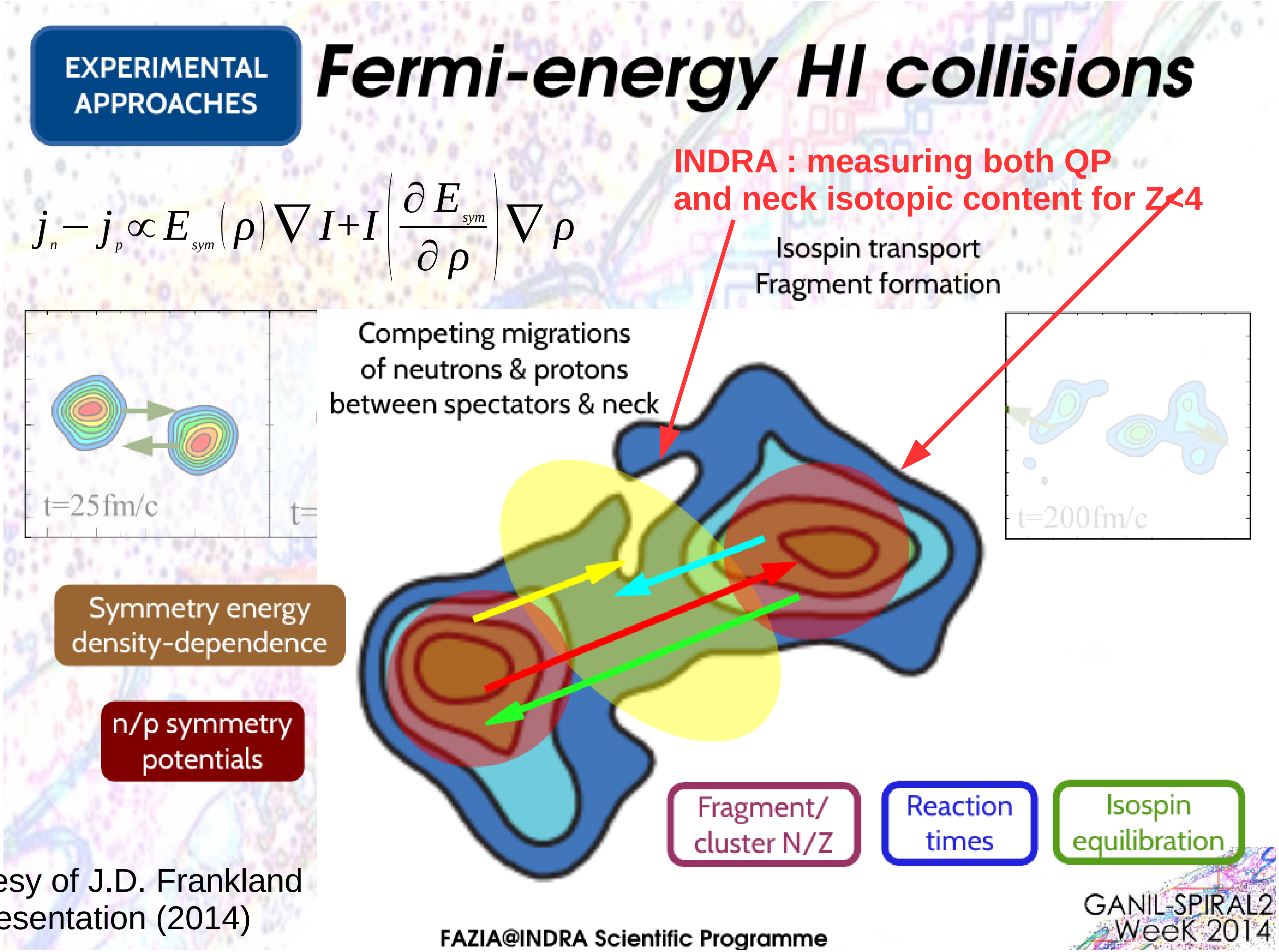
INDRA+FAZIA experimental program @ GANIL



- Thermo. : Phase diagram for asymmetric matter (isospin *d.o.f).*
- EOS : Density dependence of SE (status 2017)
- Transport : Isovector properties of *NN* interaction

Latest results from INDRA

Density Dependence of Symmetry Energy



EXPERIMENTAL APPROACHES

Fermi-energy HI collisions

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

INDRA : measuring both QP and neck isotopic content for Z<4

Isospin transport
Fragment formation

Competing migrations
of neutrons & protons
between spectators & neck

Symmetry energy density-dependence

n/p symmetry potentials

Fragment/ cluster N/Z

Reaction times

Isospin equilibration

FAZIA@INDRA Scientific Programme

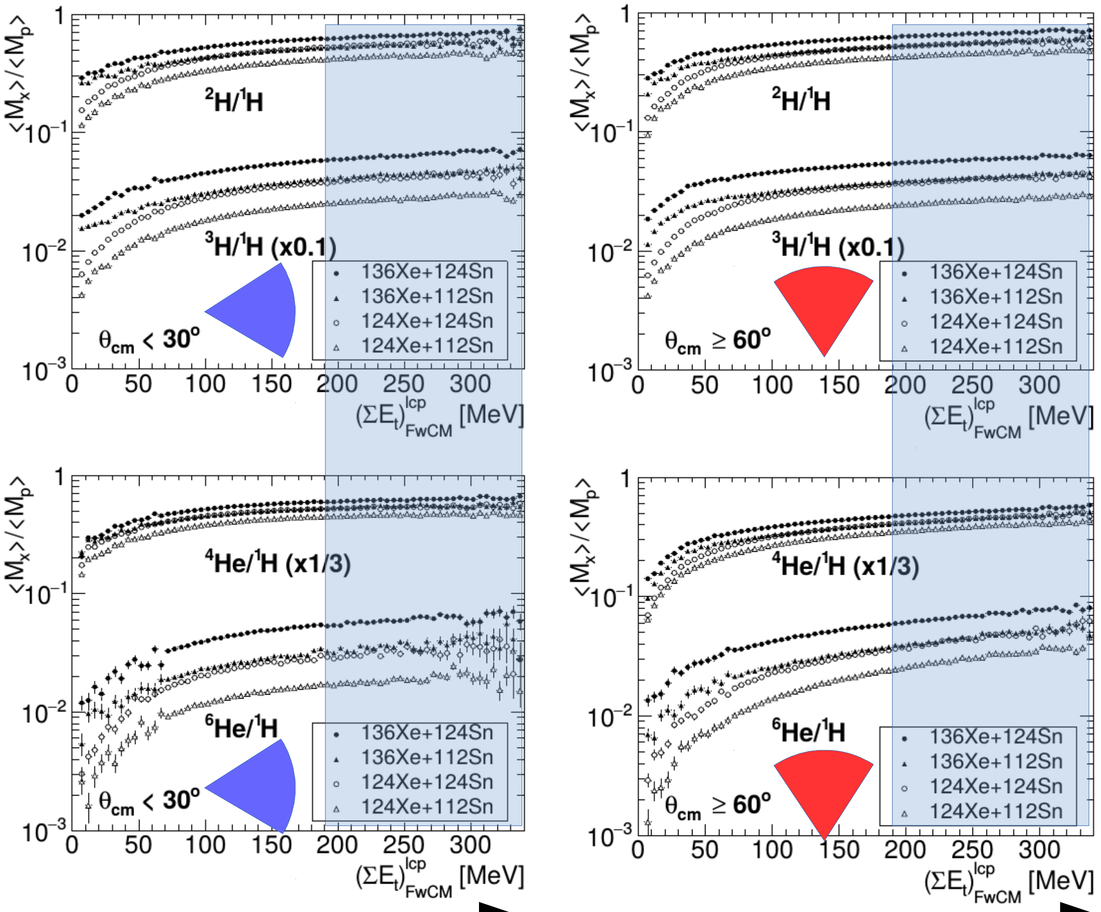
GANIL-SPIRAL2 Week 2014

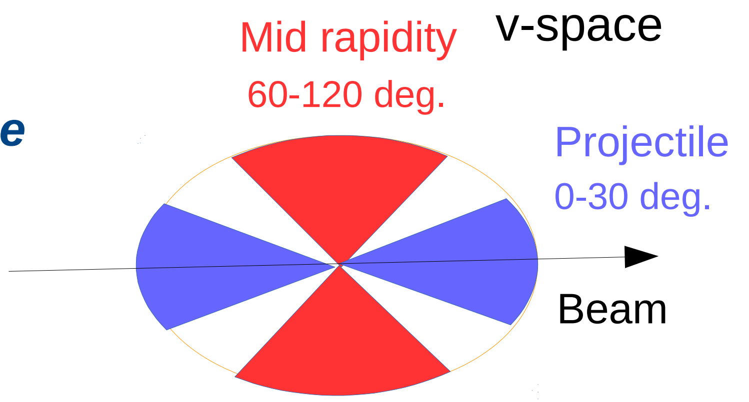
Courtesy of J.D. Frankland
SC presentation (2014)

Chemical equilibration : Isospin diffusion and migration

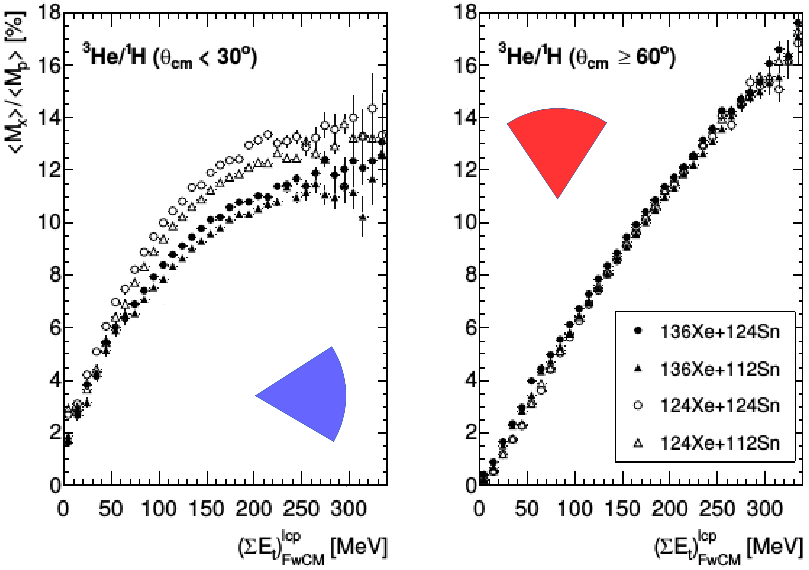
$^{124/136}$Xe + $^{112/124}$Sn at 32A MeV : INDRA data

Abundance ratios for small clusters/lcp : *d,t,^{3}He,α, ^{6}He*




Mid rapidity
60-120 deg.
v-space
Projectile
0-30 deg.
Beam

R. Bougault *et al*, arXiv:1703.03694



centrality

centrality

centrality

- **Chemical equilibrium** for *d,t,^{3}He,α,^{6}He* in central collisions
  but *^{3}He* ratios are **different** and never show chem. equilibrium

^{136}Xe+^{112}Sn ≡ ^{124}Xe+^{124}Sn

Transport properties : in-medium *NN* cross section (I)

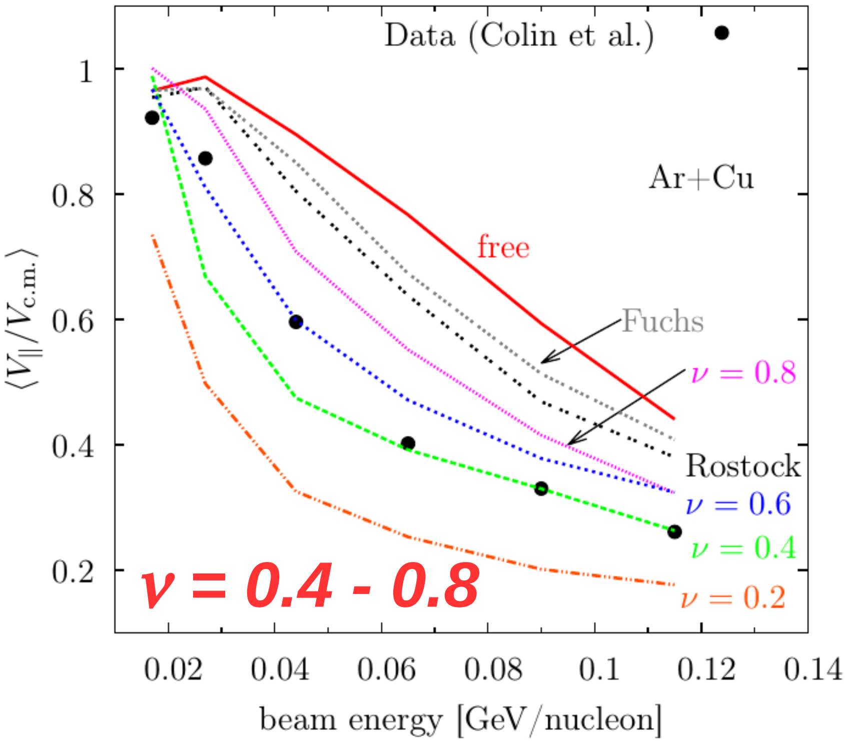
Best param. in the Fermi energy domain : *P. Danielewicz, Acta. Phys. Pol. B* ***33****, 45 (2002)*
Tempered cross section from unitarity limit σ_0

$$\sigma_{NN}^* = \sigma_0 \tanh(\sigma_{NN}^{free} / \sigma_0)$$

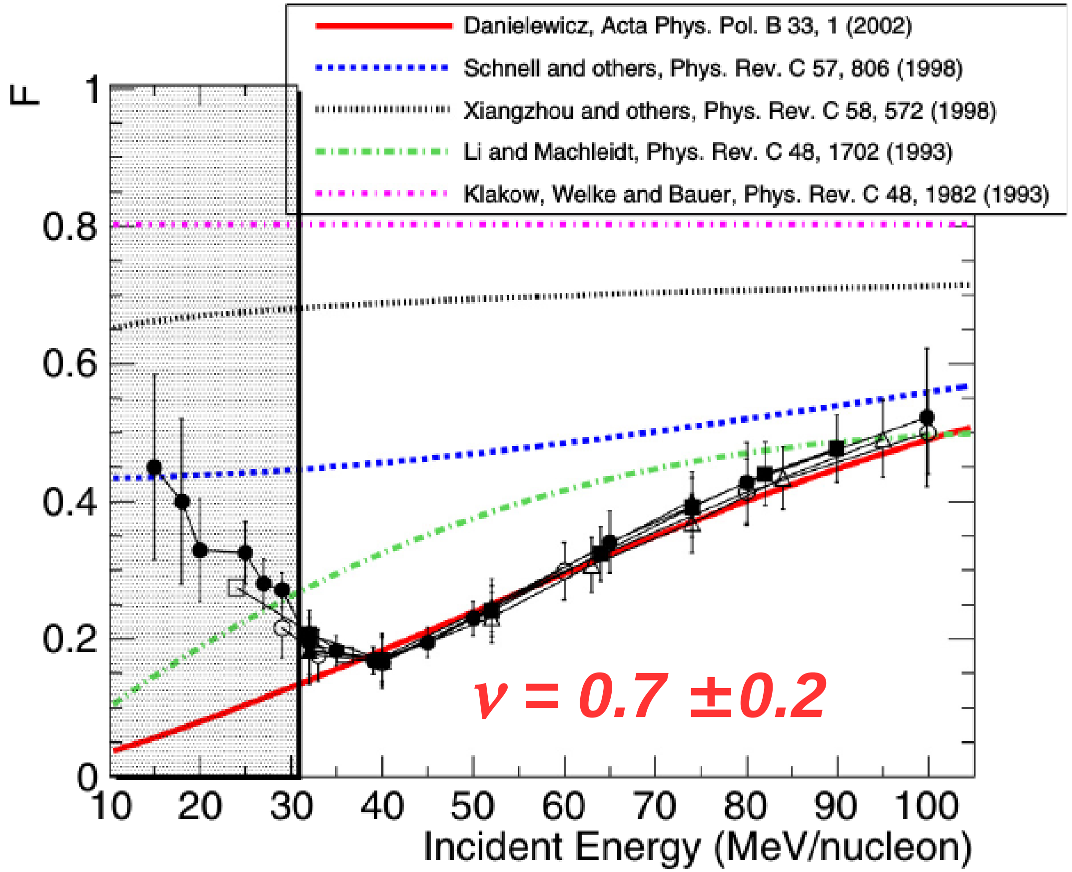
with : $\sigma_0 = \nu \rho^{-2/3}$ and : $\nu = 0.4 – 0.8$

INDRA meta-analysis for symmetric systems between *30A – 100A MeV*
O. Lopez et al., PRC ***90****, 064602 (2014)*

MSU analysis on asymmetric systems :
LMT between 20A – 120A MeV
E . Colin et al., PRC ***57****, R1032 (1998)*



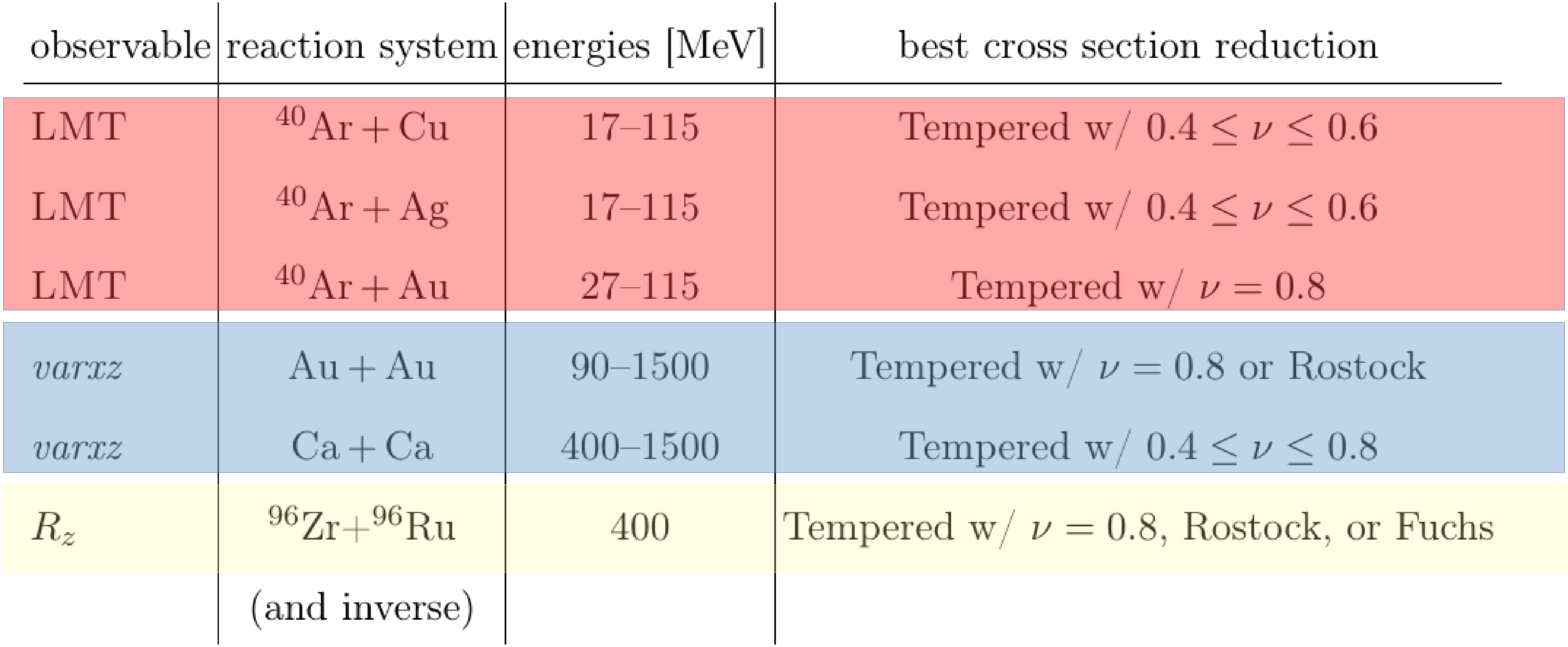
ν = 0.4 - 0.8



ν = 0.7 ±0.2

In-medium *NN* cross section (II)

B. Brent and P. Danielewicz, [nucl-th] arxiv:1612.04874v1 (2016)



observable	reaction system	energies [MeV]	best cross section reduction
LMT	$^{40}\mathrm{Ar}+\mathrm{Cu}$	17–115	Tempered w/ $0.4 \le \nu \le 0.6$
LMT	$^{40}\mathrm{Ar}+\mathrm{Ag}$	17–115	Tempered w/ $0.4 \le \nu \le 0.6$
LMT	$^{40}\mathrm{Ar}+\mathrm{Au}$	27–115	Tempered w/ $\nu = 0.8$
varxz	Au + Au	90–1500	Tempered w/ $\nu = 0.8$ or Rostock
varxz	Ca + Ca	400–1500	Tempered w/ $0.4 \le \nu \le 0.8$
R_z	$^{96}\mathrm{Zr}+^{96}\mathrm{Ru}$	400	Tempered w/ $\nu = 0.8$, Rostock, or Fuchs
	(and inverse)		

Recoil velocity (E,A)

$$\mathrm{LMT} = \left\langle \frac{v_\parallel}{v_{\mathrm{c.m.}}} \right\rangle$$

Rapidity variances (E,A)

$$varxz = \frac{\Delta y_x}{\Delta y_z},$$

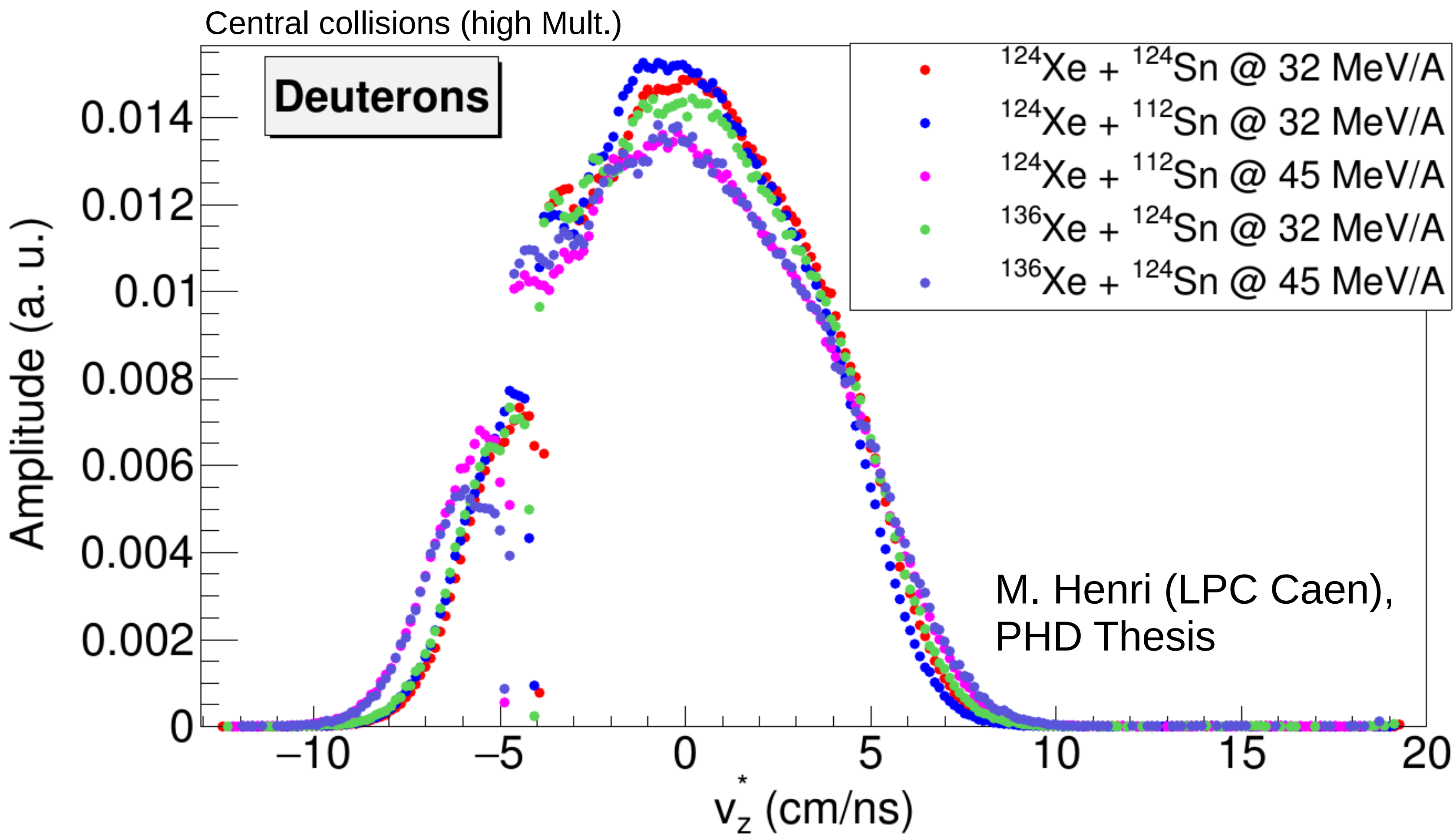
Isospin tracer (Z,A)

$$R_Z = \frac{2 \times Z - Z^{\mathrm{Zr}} - Z^{\mathrm{Ru}}}{Z^{\mathrm{Zr}} - Z^{\mathrm{Ru}}}$$

INDRA

INDRA+FAZIA

In-medium *NN* cross section (II)



M. Henri (LPC Caen), PHD Thesis

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)

$$\mathrm{LMT} = \left\langle \frac{v_{\parallel}}{v_{\mathrm{c.m.}}} \right\rangle$$

$$varxz = \frac{\Delta y_x}{\Delta y_z},$$

$$R_Z = \frac{2 \times Z - Z^{\mathrm{Zr}} - Z^{\mathrm{Ru}}}{Z^{\mathrm{Zr}} - Z^{\mathrm{Ru}}}$$

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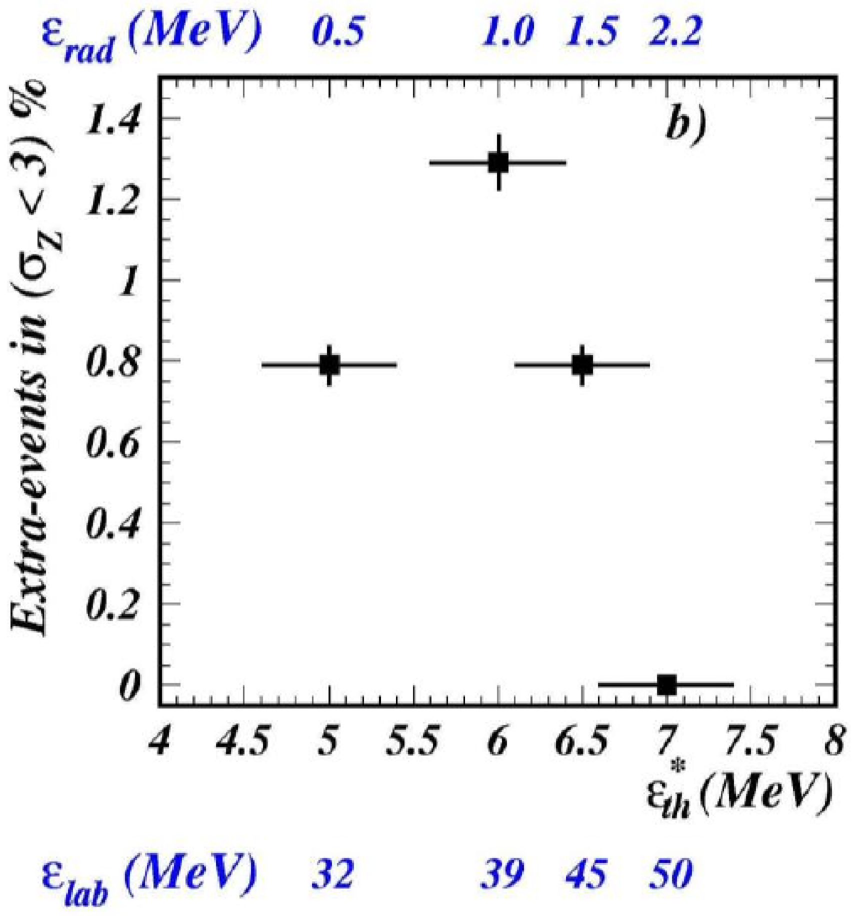
Spinodal decomposition: isoscalar *vs* isovector instabilities

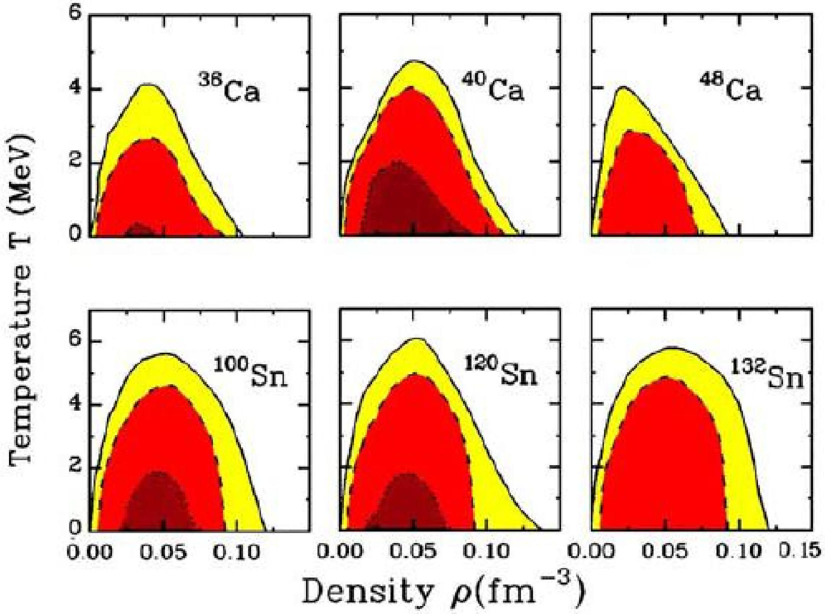
Spinodal decomposition and dynamics of fragmentation

High-order correlations in charge : ^{129}Xe+^{nat}Sn 32A-50A MeV



B. Borderie et al., **PRL 86 (2001)**

Spinodal region is reduced ► N/Z



M. Colonna *et al.*, PRL 88 (2002)

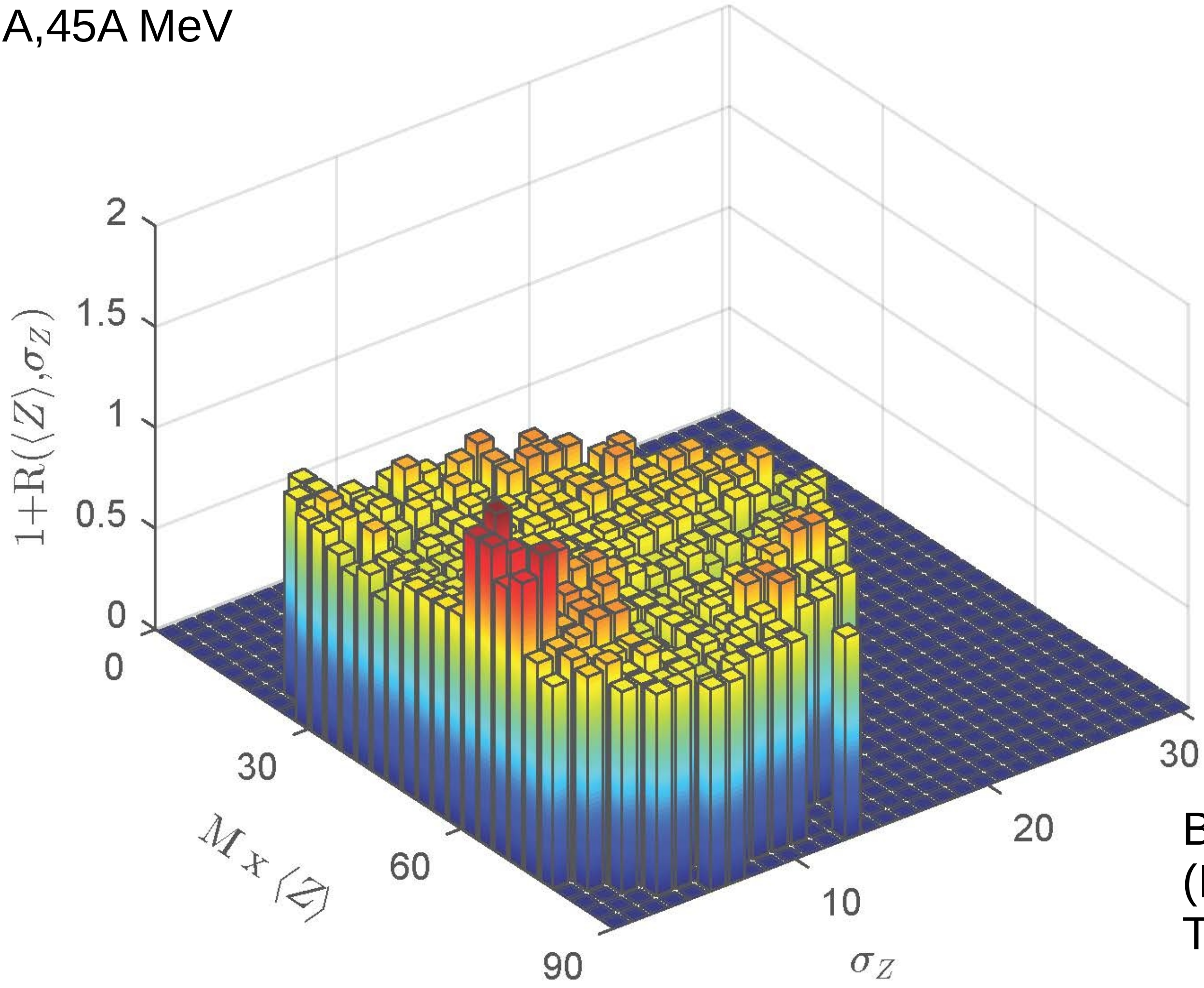
stability growth time dashed lines 100 fm/c
dotted lines 50 fm/c

- Isospin dependence of the phase diagram ?
- Correlations with masses (isocalar) and isospin (isovector)

Spinodal decomposition: isoscalar *vs* isovector instabilities

Same analysis done for QF events
^{124}Xe+^{112}Sn @ 32A,45A MeV
^{136}Xe+^{124}Sn @ 32A,45A MeV

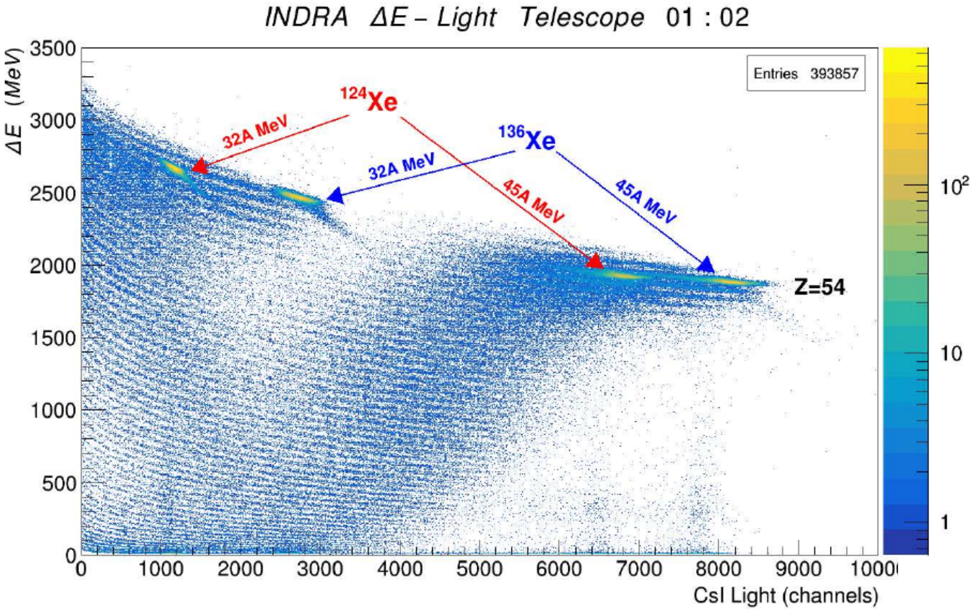
Spinodal instabilities are indeed reduced in neutron-rich matter ...



B. Borderie *et al.*
(INDRA Coll.)
To be submitted

- Equal-sized fragments are **over-produced**
- Statistical confidence is **largely enhanced** (10x statistics) to overcome the **5σ limit** ...

Improving isotopic identification for INDRA Si-CsI telescopes ...

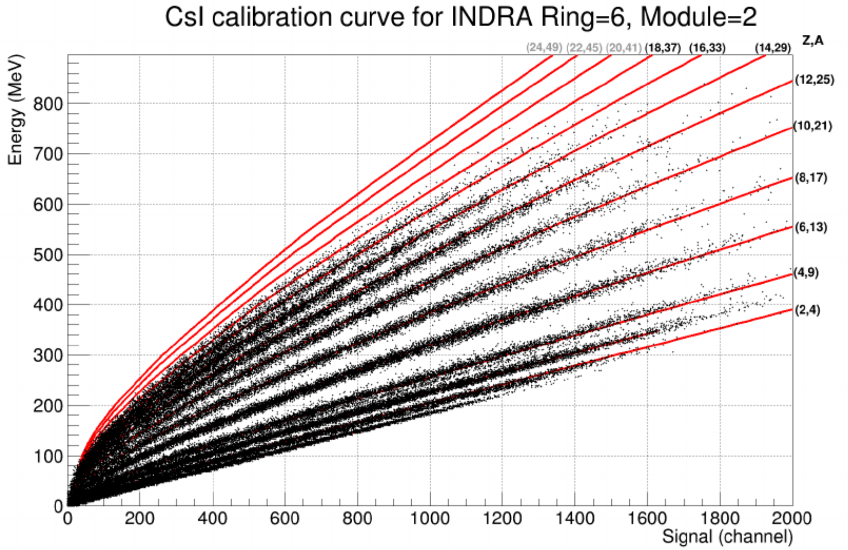


From Si-CsI raw matrices, get ***Z*** (grid) and
From CsI light output integration, get L_{exp}

- Start with an initial A_0 value (mass tables)
- From the calibrated ΔE silicon and $A \to E_{csI,0}$
- From Light-Energy formula*, then estimate L_0
- Iterate on $A \to E_{CsI,i} \to L_i$ until $L_i = L_{exp}$

Isotopic identification Z<12
Isotopic estimation (±3) up to Z=54 ...

+



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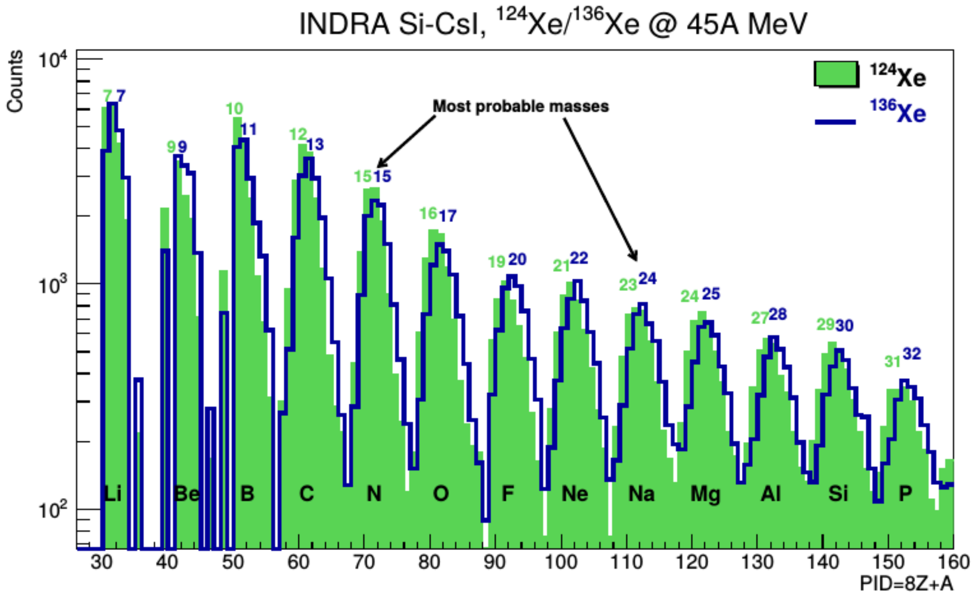
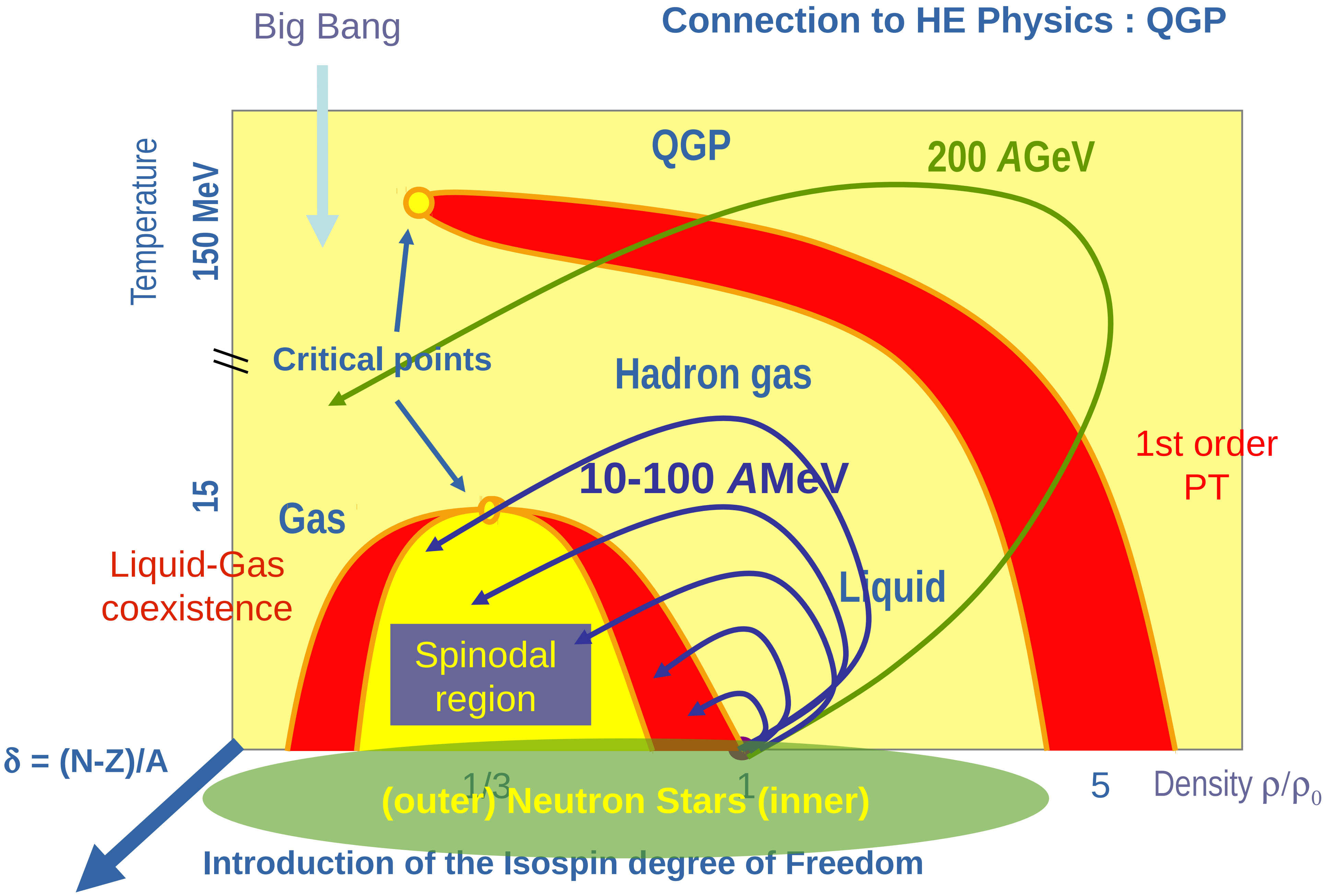


O. Lopez *et al*, *arXiv:1707.08863*
Submitted to NIM A

$$^{*}\mathcal{L}(E_0) = a_1 E_0 \left[1 - a_2 \frac{AZ^2}{E_0} \ln\left(1 + \frac{1}{a_2 AZ^2/E_0}\right) + a_2 a_4 \frac{AZ^2}{E_0} \ln\left(\frac{E_0 + a_2 AZ^2}{a_3 A + a_2 AZ^2}\right) \right]$$

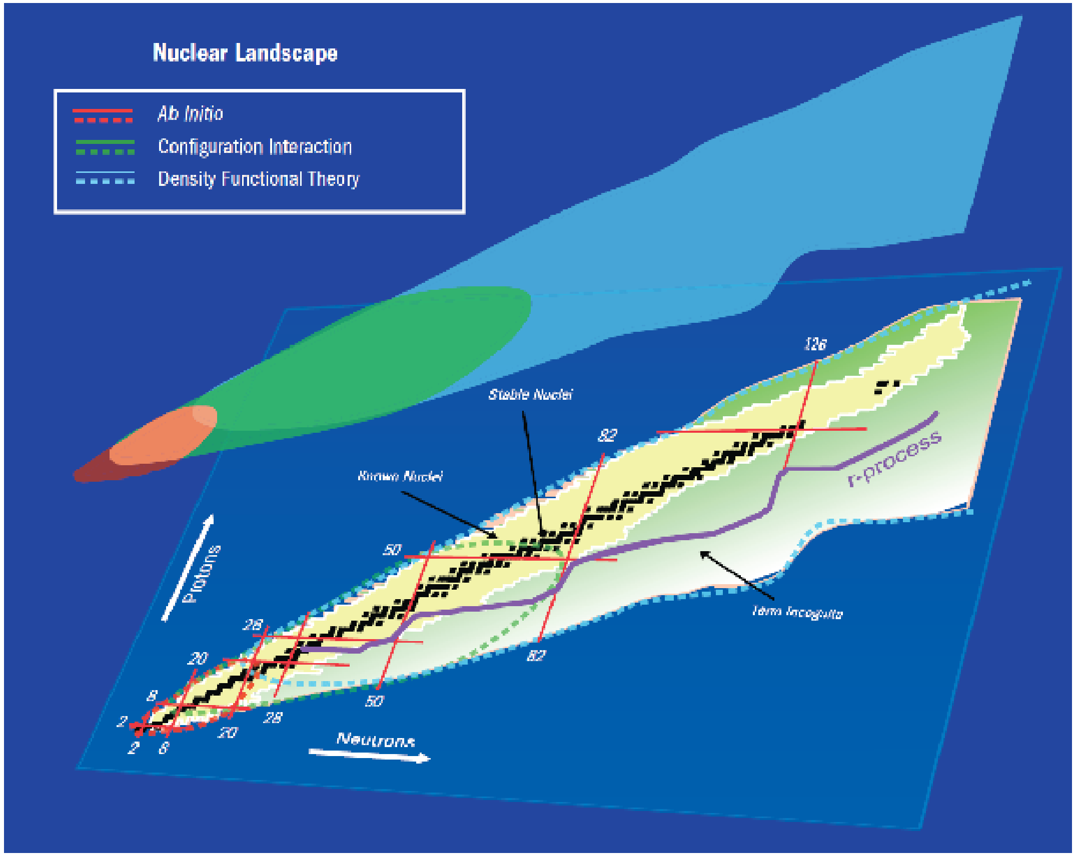
INDRA + FAZIA
Experimental program at GANIL

Phase diagram of Nuclear Matter



Microscopic Description of Nuclei

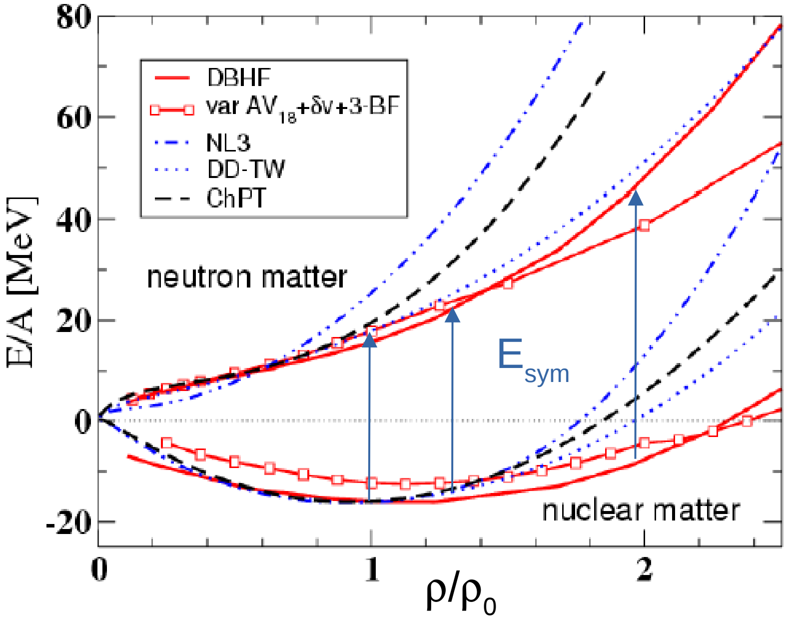
Self-consistent Mean-Field calculations are probably the only possible framework to understand the structure of medium and heavy nuclei.



$$E = \langle \psi \,|\, H \,|\, \psi \rangle$$
$$H = \langle \varphi \,|\, H_{eff} \,|\, \varphi \rangle$$

$$H = E[\rho]$$

Energy-Density Functionals



Direct link to EOS and Symmetry Energy

Symmetry Energy around ρ_0

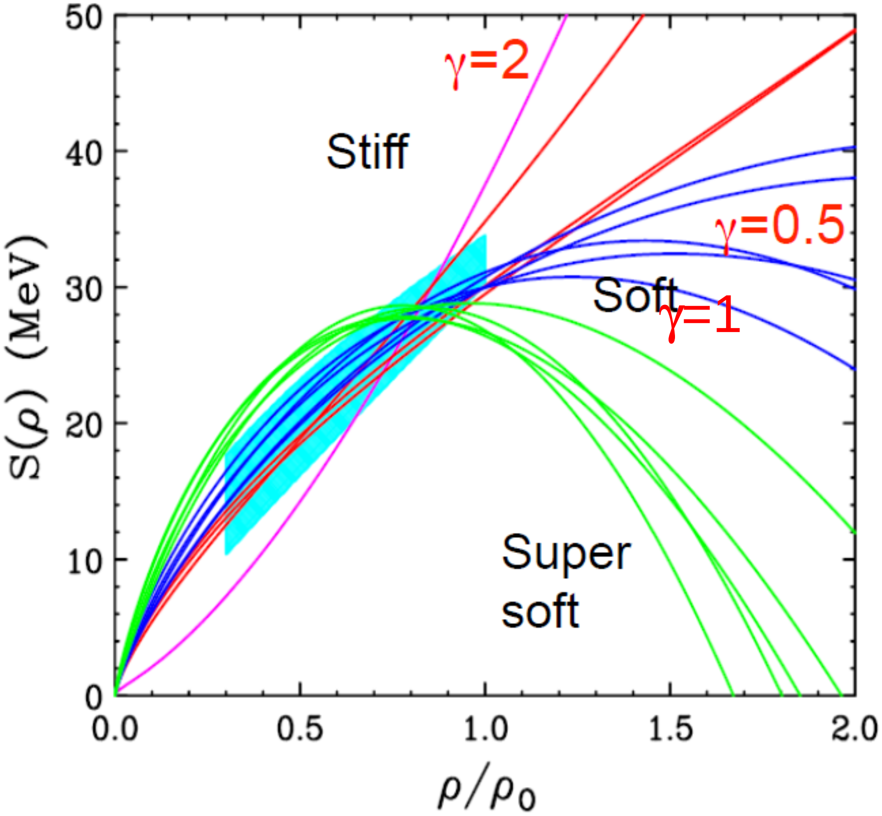
$$E/A\,(\rho,\delta) = E/A\,(\rho,0) + \delta^2 \cdot S(\rho)$$

$$\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p) = (N-Z)/A$$

- Constraints for **Astrophysics** (NS) and for laboratory experiments
- Needed for **transport models** and nuclear matter studies (Thermodyn.)
- Link to the ***NN* interaction** (isovector) in the nuclear medium ($m^*_{n,p}$)

Density dependence for SE

M.B. Tsang, Prog. Part.Nucl.Phys. 66, 400 (2011)
Brown, Phys. Rev. Lett. 85, 5296 (2001)



$$S(\rho) = S_k(\rho/\rho_0)^{2/3} + S_i(\rho/\rho_0)^{\gamma}$$

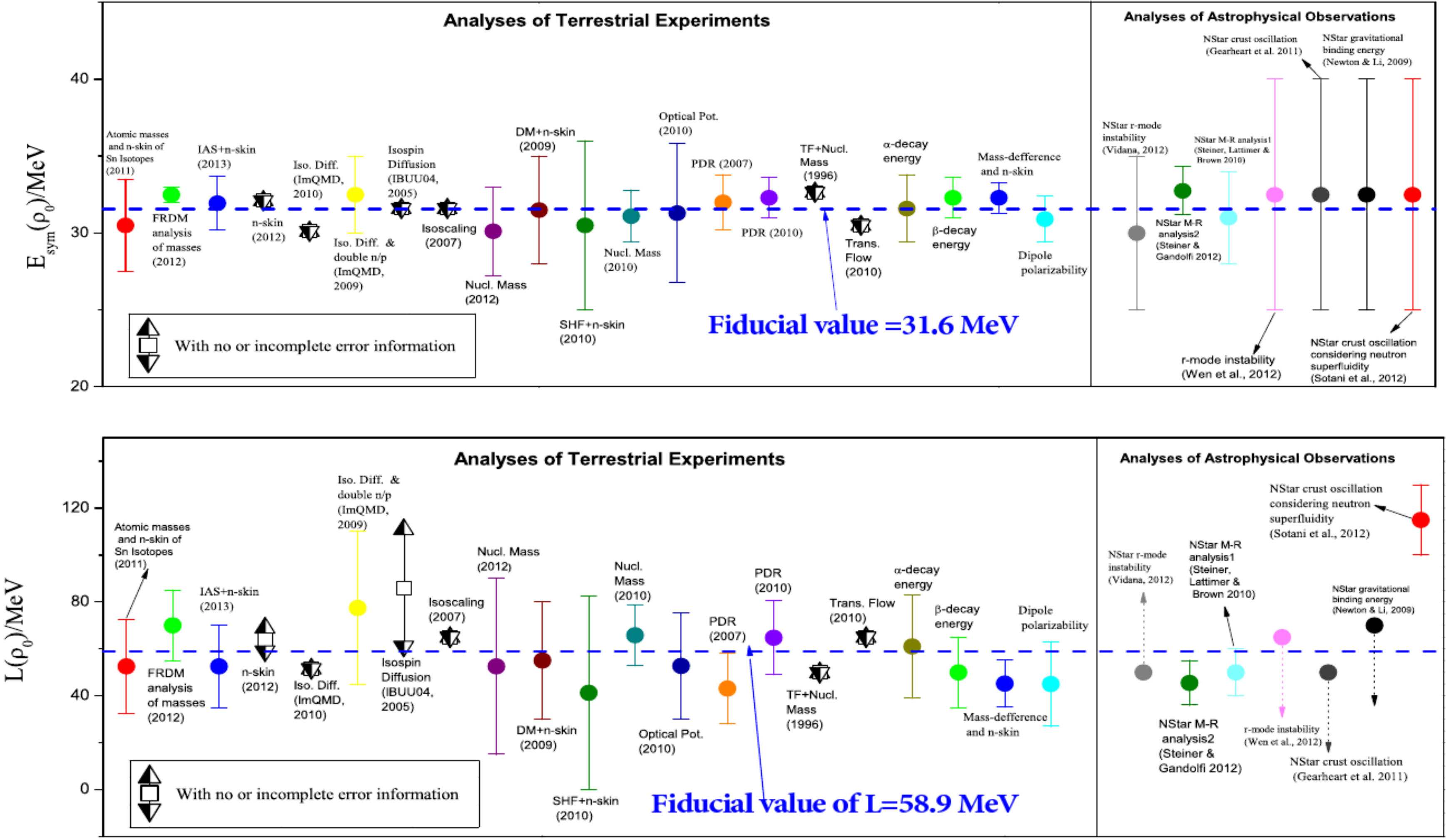
$$L(\rho) = 3\rho\,\frac{\partial S(\rho)}{\partial \rho}$$

$$K_{sym}(\rho) = 9\rho^2\,\frac{\partial^2 S(\rho)}{\partial \rho^2}$$

Symmetry Energy around ρ_0 (II)

Latest evaluation for $E_{sym}(\rho_0)$ and slope $L(\rho_0)$

B.A. Li and X. Han, Phys. Lett. B727 (2013) 276

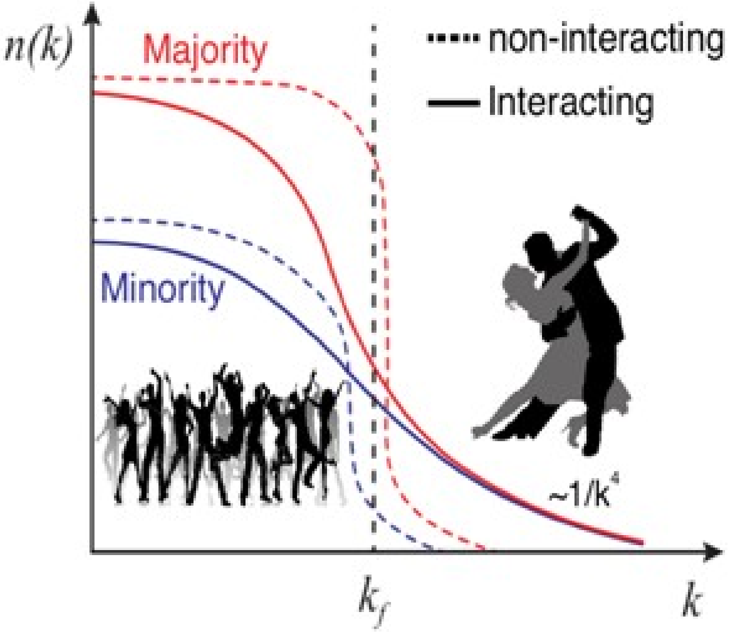


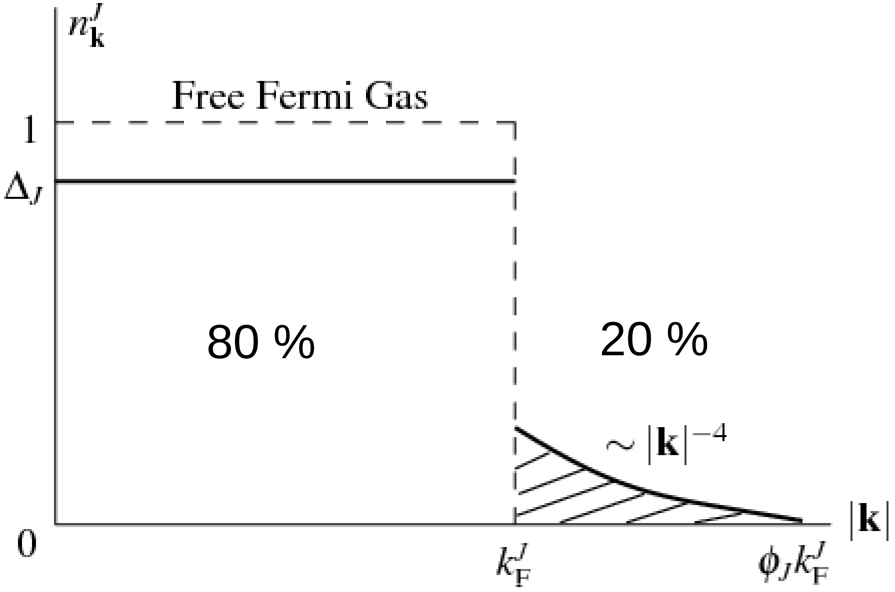
Today (2017) : $E_{sym}(\rho_0) = 31.9 \pm 2.5$ MeV → **8%** uncertainty

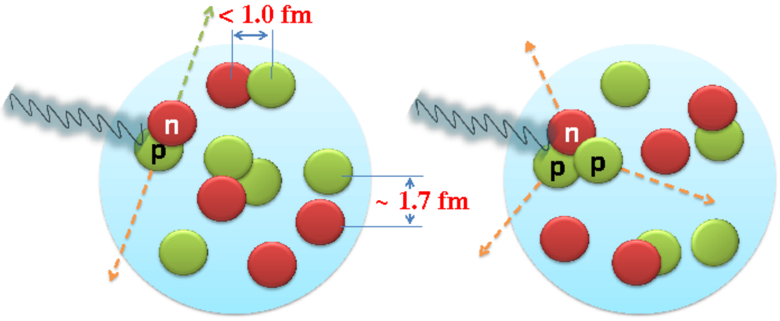
$L(\rho_0) = 55.3 \pm 28.1$ MeV → **51%** uncertainty

$K_{sym}(\rho_0)$ not constrained at all

Tensor effects : SRC in ground state nuclei







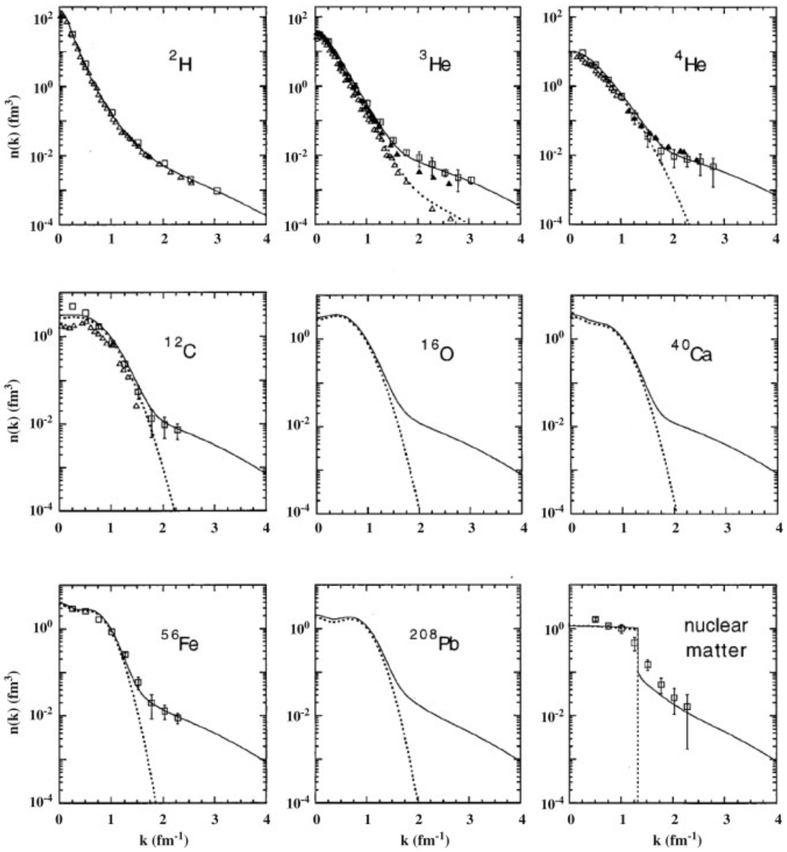
(a) **2N-SRC** (b) **3N-SRC**

- due to the tensor component
- mainly *p-n* SRC (> 90%)
- SRC are ehanced in *N=Z* nuclei

Short-Range Correlations in nuclei

- *SRC* is the result of the **tensor part** of the ***NN* interaction**
- Nucleon momentum distribution at high *p* present **a tail α $1/p^4$**
- Mainly **proton distribution** are affected by this effect, **20 times more** than neutrons
- **20 % of protons** in nuclei experience SRC
- Modify the uncorrelated Fermi gas picture, in terms of **Fermi energy for protons/neutrons**

C. Ciofi degli Atti, *et al.*,
PRC 53, 1689 (1996)



- Change the **sharing between kinetic and potential parts** of the symmetry energy

Uncorrelated (no SRC)

$E_{sym}^{kin} \approx 12\ (\rho/\rho_0)^{2/3}$

$E_{sym}^{pot} \approx 20\ (\rho/\rho_0)^{\gamma}$ **with** $\gamma = 0.6\text{-}1$

$E_{sym}(\rho_0) \approx 32$ **MeV**

$L_{sym}(\rho_0) \approx 50 - 70$ **MeV**

Soften DDSE ...

O . Hen et al.,
PRC 91, 025803 (2015)

Correlated (SRC)

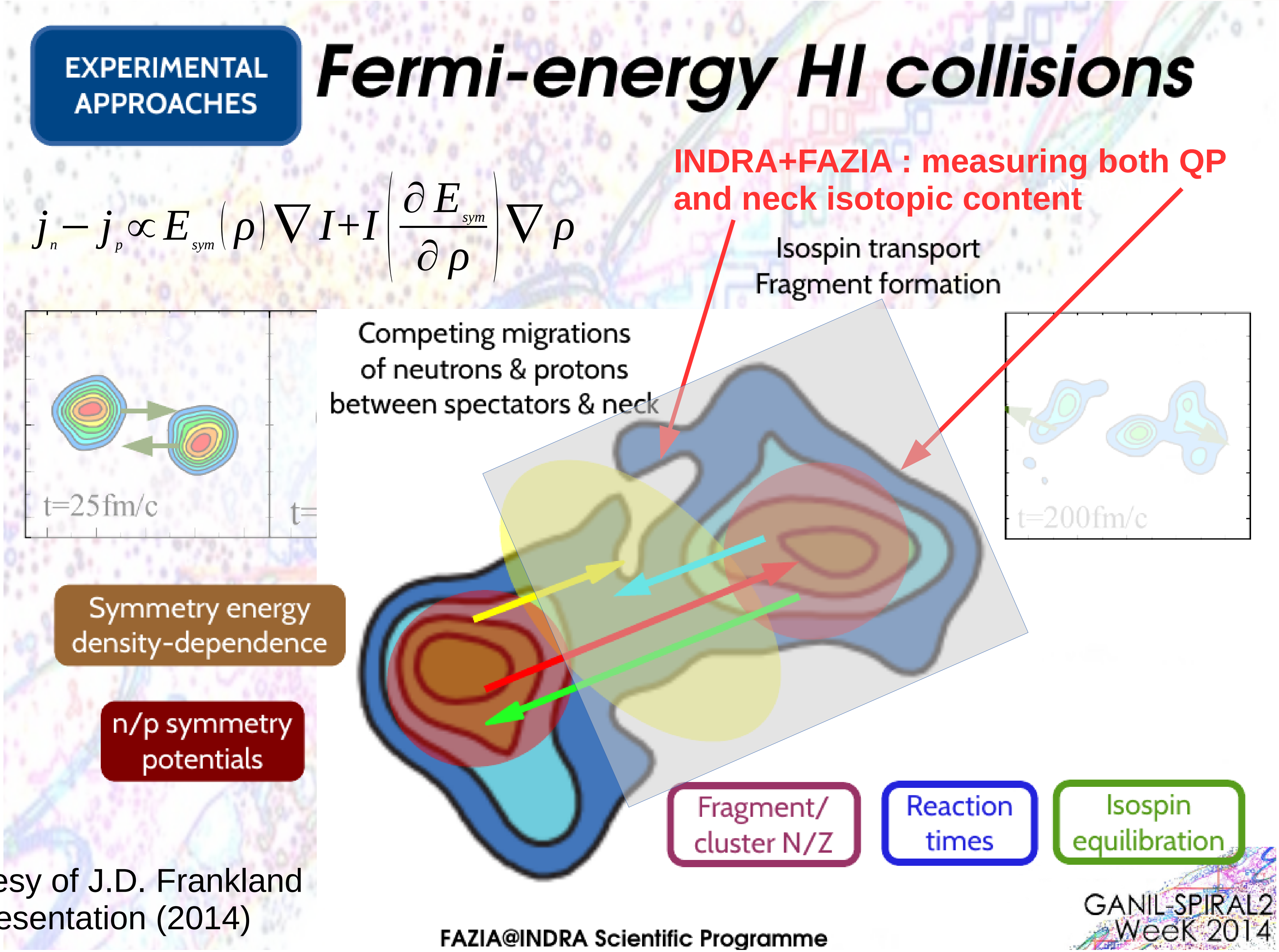
$E_{sym}^{kin} \approx -5\ (\rho/\rho_0)^{2/3}$

$E_{sym}^{pot} \approx 37\ (\rho/\rho_0)^{\gamma}$ **with** $\gamma = 0.35\text{-}0.6$

$E_{sym}(\rho_0) \approx 32$ **MeV**

$L_{sym}(\rho_0) \approx 30 - 55$ **MeV**

Density Dependence of Symmetry Energy : neck + QP



EXPERIMENTAL APPROACHES

Fermi-energy HI collisions

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

Isospin transport
Fragment formation

Competing migrations
of neutrons & protons
between spectators & neck

Symmetry energy density-dependence

n/p symmetry potentials

Fragment/ cluster N/Z

Reaction times

Isospin equilibration

FAZIA@INDRA Scientific Programme

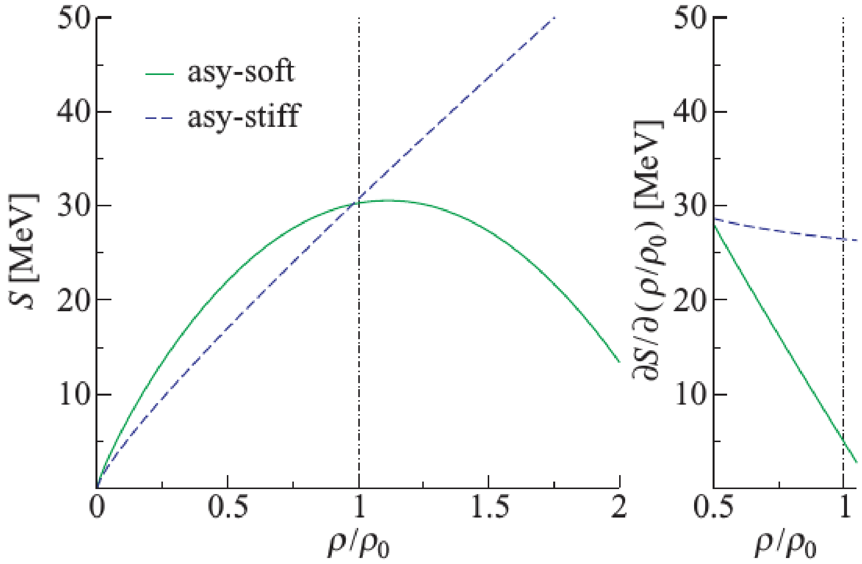
GANIL-SPIRAL2 Week 2014

INDRA+FAZIA : measuring both QP and neck isotopic content

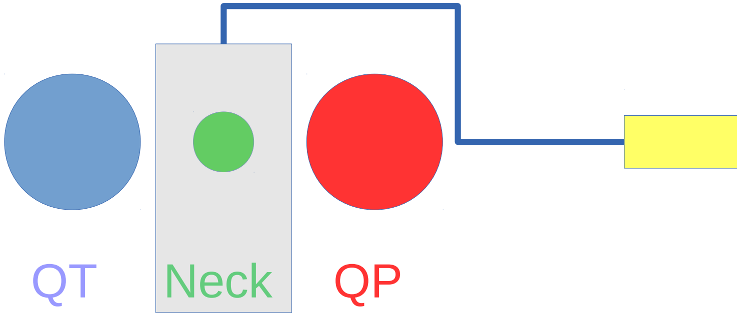
Courtesy of J.D. Frankland
SC presentation (2014)

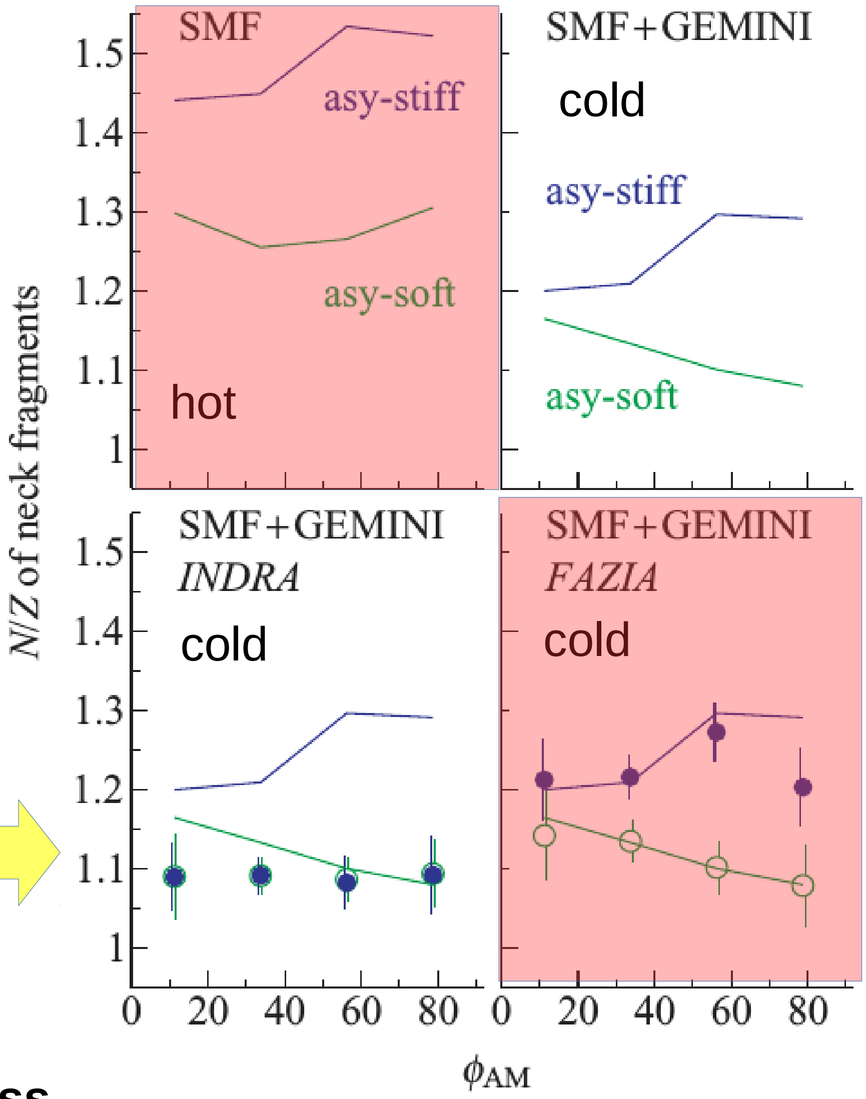
Density Dependence of Symmetry Energy : neck

SMF simulations $^{58/68}$*Ni*+$^{58/68}$*Ni 15A*, *40A* MeV
P. Napolitani et al., PRC ***81****, 044619 (2010)*



Ternary events for ^{68}*Ni*+^{68}*Ni* at *40A MeV*
1 QT + *1 neck IMF* + *1QP*
0.45 < b_{red} < 0.75





FAZIA data could be sensitive to E_{sym} stiffness ...

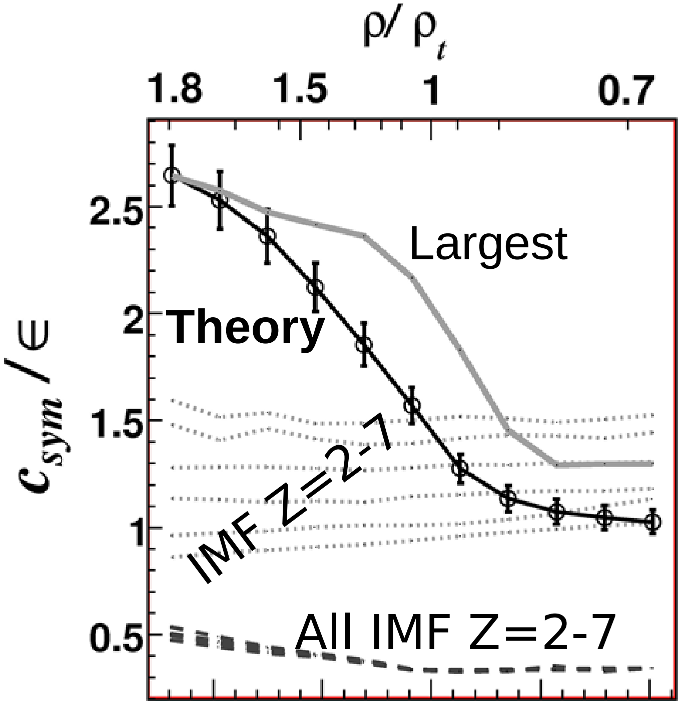
Density Dependence of Symmetry Energy : QP

- **Isoscaling:** observed scaling law of fragment (*N*,*Z*) production for two reactions involving different isotopes (ex. $^{40/48}$*Ca*,$^{124/136}$*Xe*)
- **Isoscaling**: can be related to the symmetry energy
- **Relationship**: different parametrizations from macro/microscopic approaches

3D Lattice-Gas Model: the isotopic distribution of the largest cluster in each event is more sensitive to the symmetry energy of the fragmenting system as compared to previous studies using mostly Light or Intermediate Mass Fragments (*Z*=*1*-*8*)

Example : ^{40,48}*Ca*+^{40}*Ca @ 35A - 50A* MeV

- Measure the **isoscaling law** of the **largest fragments** for selected impact parameters
- Measure the density of the fragmenting system through **fragment-fragment correlations**
- Extract the **density dependence** of the symmetry energy as presented here

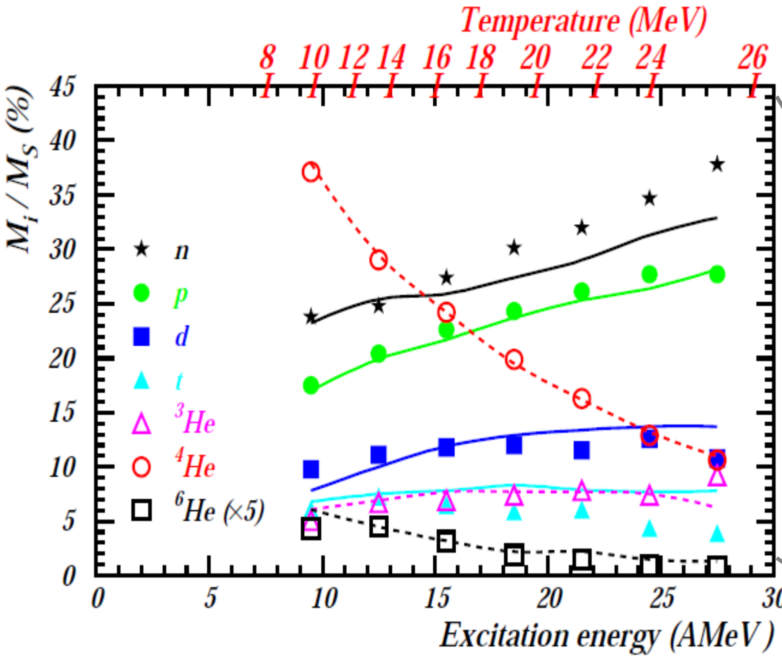


G. Lehaut *et al.* (INDRA coll.), *Phys. Rev Lett.* **102**, 142503 (2009)

Symmetry Energy for $\rho \ll \rho_0$

Vaporization : a bridge between nuclear physics and astrophysics

Described by a **weakly-interacting quantum gas of nuclear species in thermal and chemical equilibrium**



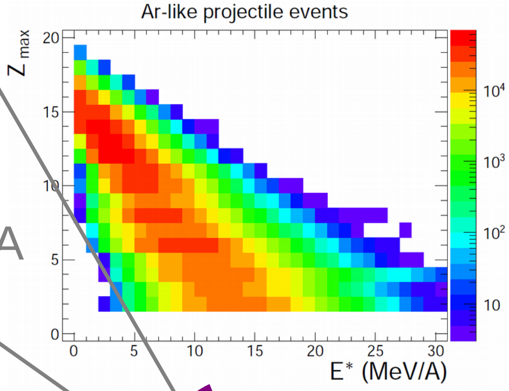
B. Borderie et al., (INDRA collaboration) EPJ A 6 (1999)
F. Gulminelli et al., NPA 615 (1997).

Done with INDRA

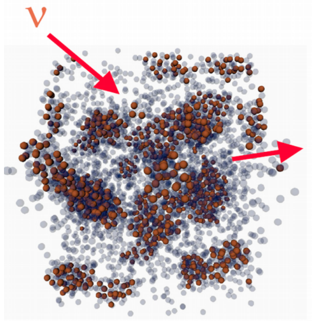
The neutrino-sphere, where the last scattering of neutrinos occurs during the collapse of the supernovae core, is a warm low-density neutron-rich matter. The energetics of these low density neutron-rich matter is determined by the **symmetry free energy far from saturation which is poorly known.**

Vaporization events of ^{40,48}Ca-like projectiles with FAZIA

- Evolution of the **cluster mixing** among **nucleon-gas**
- Including isotopes heavier than helium
- **In-medium properties** of clusters
- Exploring **densities, temperatures and N/Z** on the path from multifragmentation to vaporization



To be done with FAZIA



P. Papakonstantinou et al., Phys. Rev. C 88 (2013) 045805.
Ad. R. Raduta et al., Eur. Phys. J. A (2014) 50:24.

Example : ^{58,64}Ni + ^{58,64}Ni 50A -90A MeV

Unique set of experimental data to constrain theoretical descriptions. Dedicated calculations will be done with the recently proposed extended NSE model, which is optimized to study equilibrium properties of subsaturation exotic matter to constrain the symmetry free energy far from saturation ($\rho \ll \rho_0$)

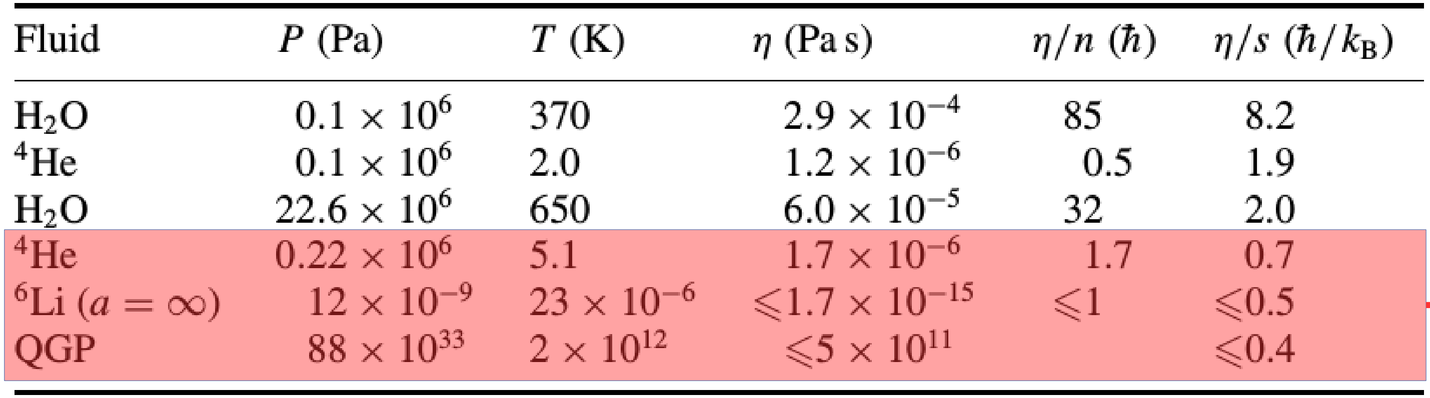
Shear viscosity and transport quantities : *perfect fluid limit*

The **shear viscosity η** measures the **amount of dissipation** in a fluid ; in Kinetic Theory, it is related to the **rate of momentum transport** by quasi-particles in the medium.

Classically, it is defined in terms of the **friction force** per unit area S created by a **shear flow** characterized by a **transverse flow gradient** ∇v_z : $\boldsymbol{F/S = \eta\ \nabla v_z}$

In Kinetic Theory, we have : $\eta = 1/3\ m\langle v\rangle\ \rho\ \lambda^*_{NN}$

Superfluidity when $\eta/s \ll 1$



Fluid	P (Pa)	T (K)	η (Pa s)	η/n ($\hbar$)	η/s ($\hbar/k_B$)
H_2O	0.1×10^6	370	2.9×10^{-4}	85	8.2
^{4}He	0.1×10^6	2.0	1.2×10^{-6}	0.5	1.9
H_2O	22.6×10^6	650	6.0×10^{-5}	32	2.0
^{4}He	0.22×10^6	5.1	1.7×10^{-6}	1.7	0.7
^{6}Li ($a = \infty$)	12×10^{-9}	23×10^{-6}	$\lesssim 1.7 \times 10^{-15}$	$\lesssim 1$	$\lesssim 0.5$
QGP	88×10^{33}	2×10^{12}	$\lesssim 5 \times 10^{11}$		$\lesssim 0.4$

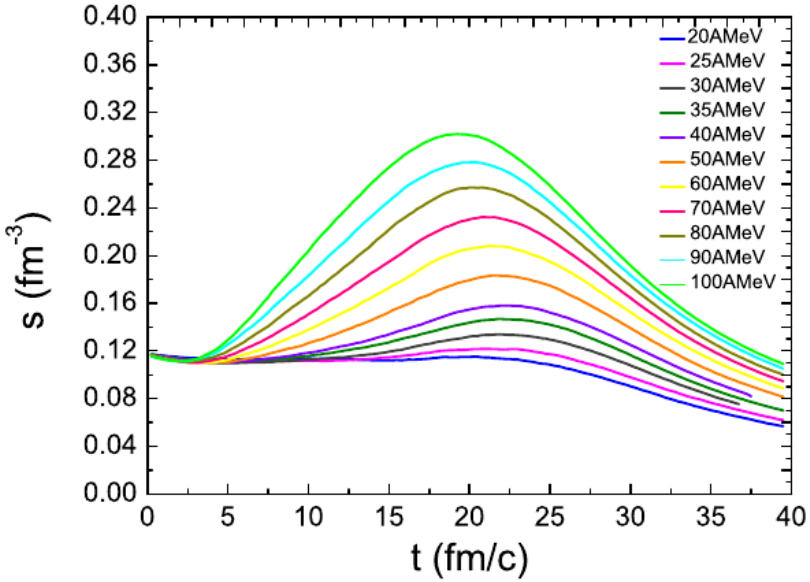
T. Schäfer and D. Teaney, *Rep. Prog. Phys.* ***72****, 126001 (2009)*
«Nearly perfect fluidity : from cold atomic gases to hot quark gluon plasmas »

η/s is limited at low values (most perfect fluid) by the **quantum universal ratio limit *η/s = 1/4π***

What is the viscosity of the nuclear matter in the Fermi energy domain ?
Can it be used to probe the LG phase transition ?

Shear viscosity in nuclear matter : how far from the *perfect fluid ?*

IQMD calc. for ^{129}Xe+^{119}Sn central collisions :
Entropy density with momentum-dependent
Skyrme interaction (*K=220 MeV*)



H. L. Liu, Y. G. Ma, A. Bonasera, X. G. Deng,
O. Lopez, and M. Veselsky,
To be published in PRC

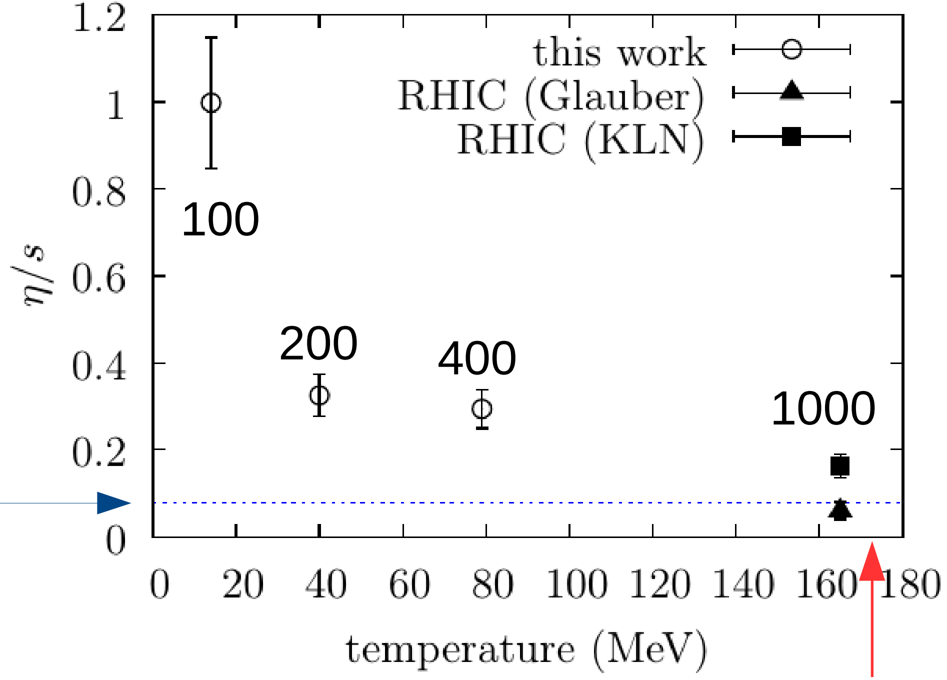
η is contrained by INDRA data from stopping

Universal lower limit 1/4π →

Boltzmann-Uehling-Uhlenbeck simulations
RHIC energies : *Glauber MC* model

B. Brent and P. Danielewicz,
[nucl-th] arxiv:1612.04874v1 (2016)

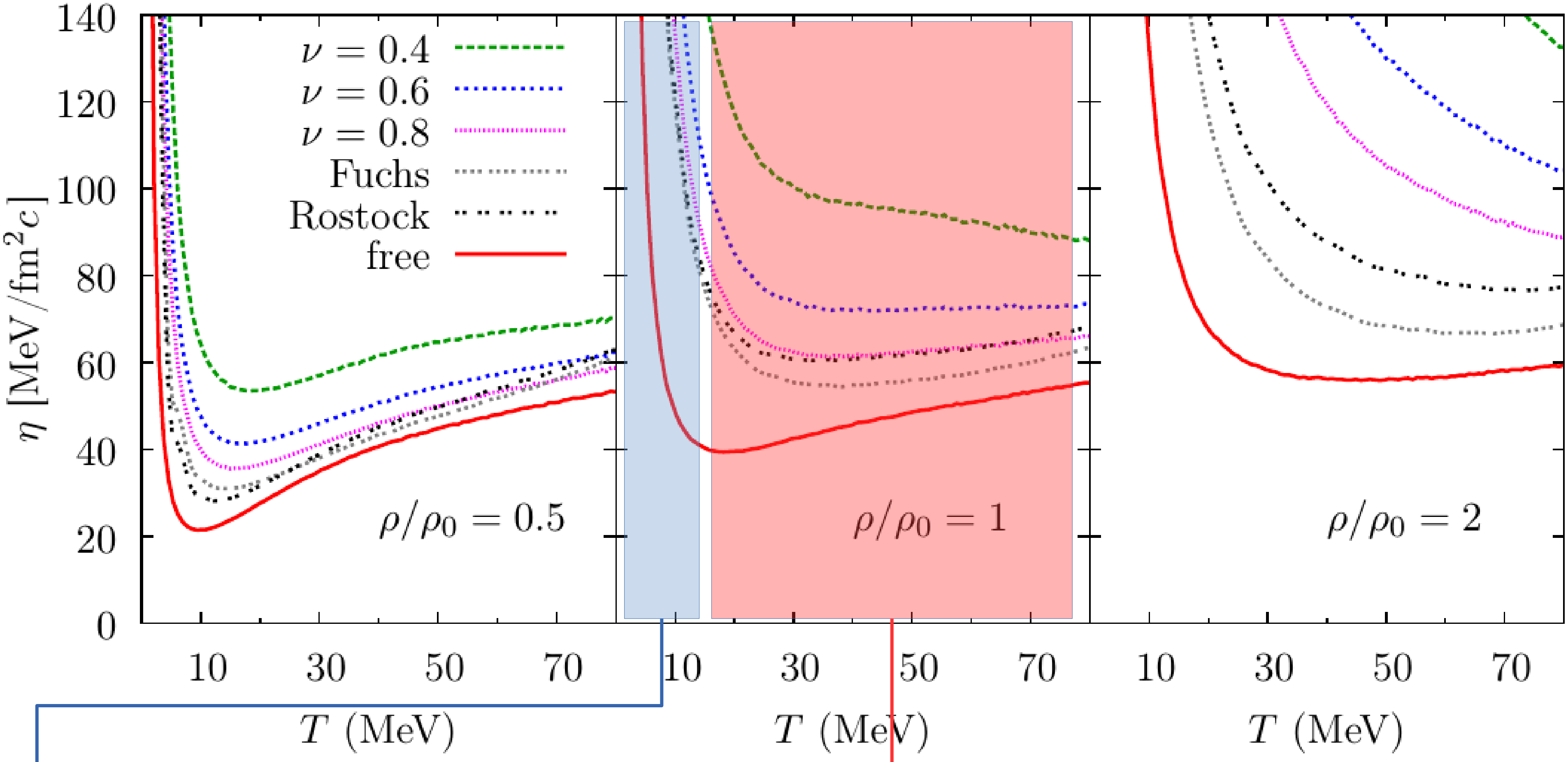
Au+Au central collisions (b<1.5 fm)



Critical Temperature ~ 170 MeV

Shear viscosity and phase transition

B. Brent and P. Danielewicz, [nucl-th] arxiv:1612.04874v1 (2016)



Degenerate Fermi fluid at low *T* : due to Pauli exclusion principle

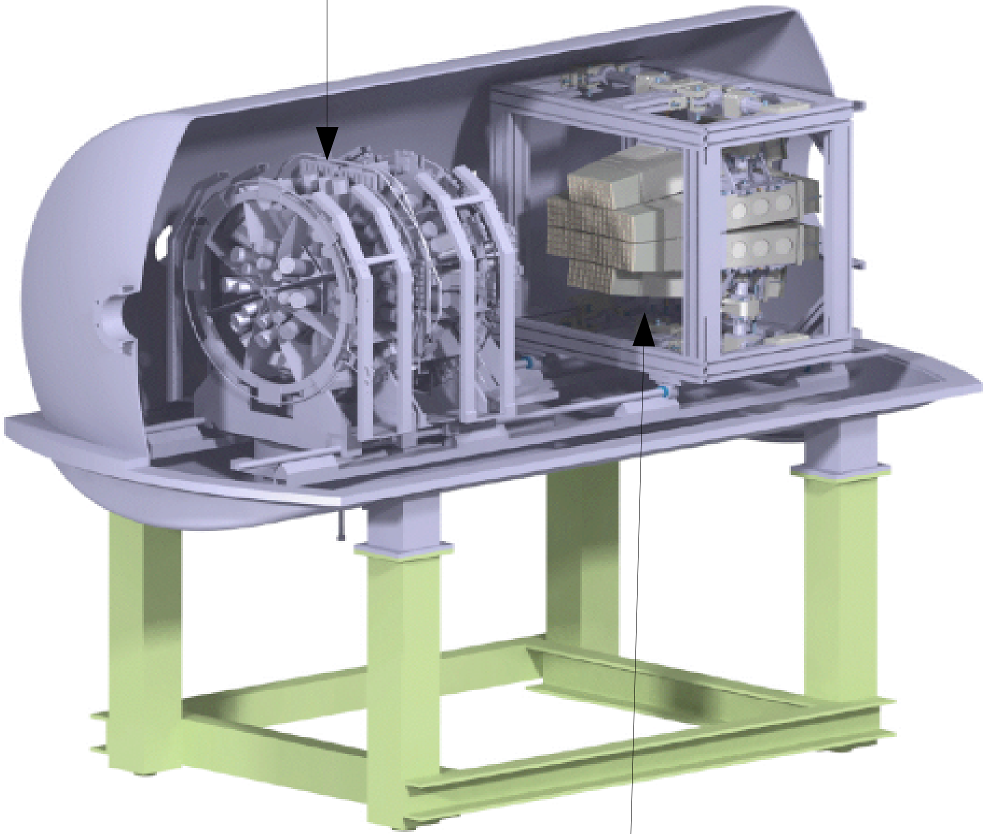
Lack of collisions → **High viscosity,** η goes as *1/T*

Classical (nucleon) gas at high *T* : η goes as $\sqrt{T}$

Phase transition...

Coupling FAZIA demonstrator with INDRA

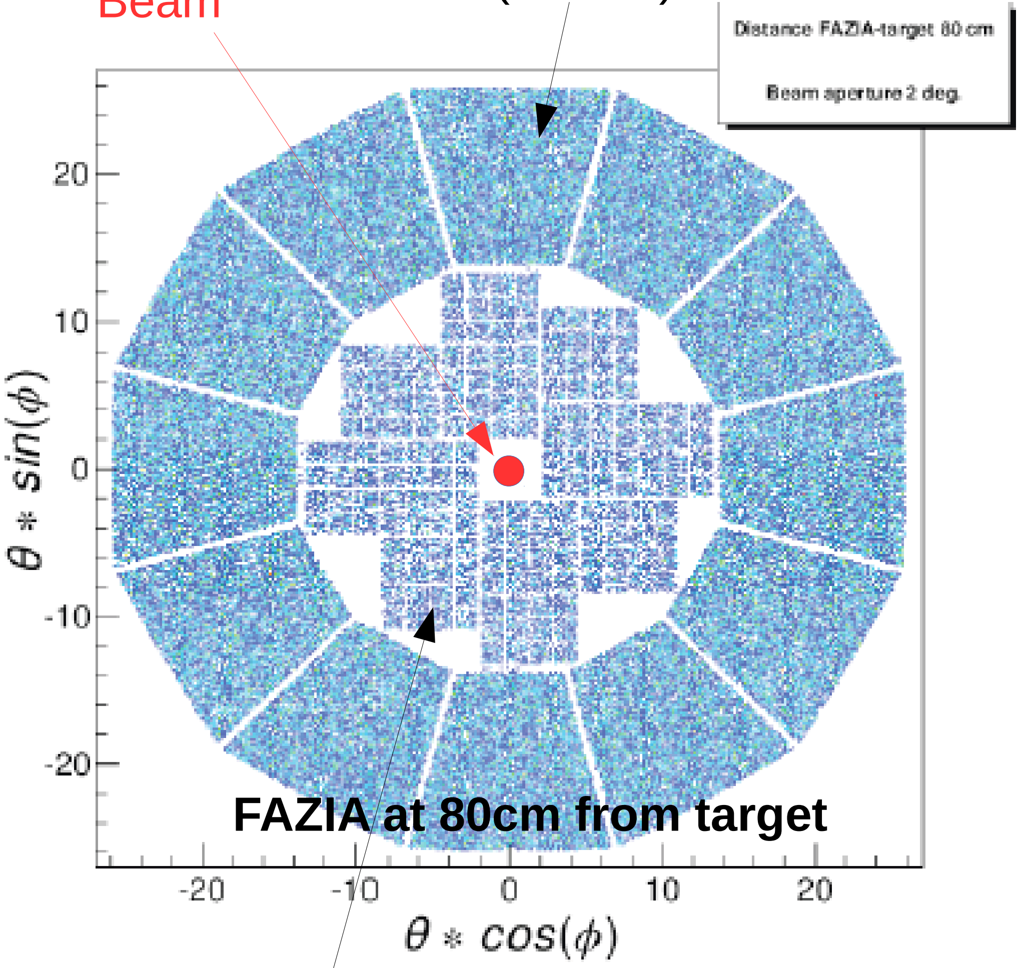
INDRA (rings 1,2/3,4/5 removed)



FAZIA demonstrator (est. 2016), 12 blocks :
192 20x20mm^2 high-quality *Si-Si-CsI* telescopes
from 2 to 14 deg. + customized full digital electronics

Beam

Ring 6/7
(INDRA)



FAZIA at 80cm from target

Transverse plane

Between 2-14 deg.
FAZIA geom. acceptance 82% (90%)
Granularity x2 as compared to *INDRA*

INDRA + FAZIA scientific program at GANIL

Isovector dependence of the nuclear interaction and EOS

- **In-medium properties of clusters** : clustering @ low density (i.e. α–Hoyle states), cluster emission in n-rich/poor systems

- Study of **EOS at low density** : vaporization and cluster mixing with nucleon gas

- **Density dependence of Symmetry Energy**: isospin diffusion in *DIC*, isoscaling using the largest fragment, neutron enrichment in the neck (migration/diffusion)

- **Transport properties** @ Fermi energy : *NN* collisions in the isovector sector, isospin tracer, short-range correlations in nuclei, effective masses, and also : radial flow, viscosity ...

The End ?

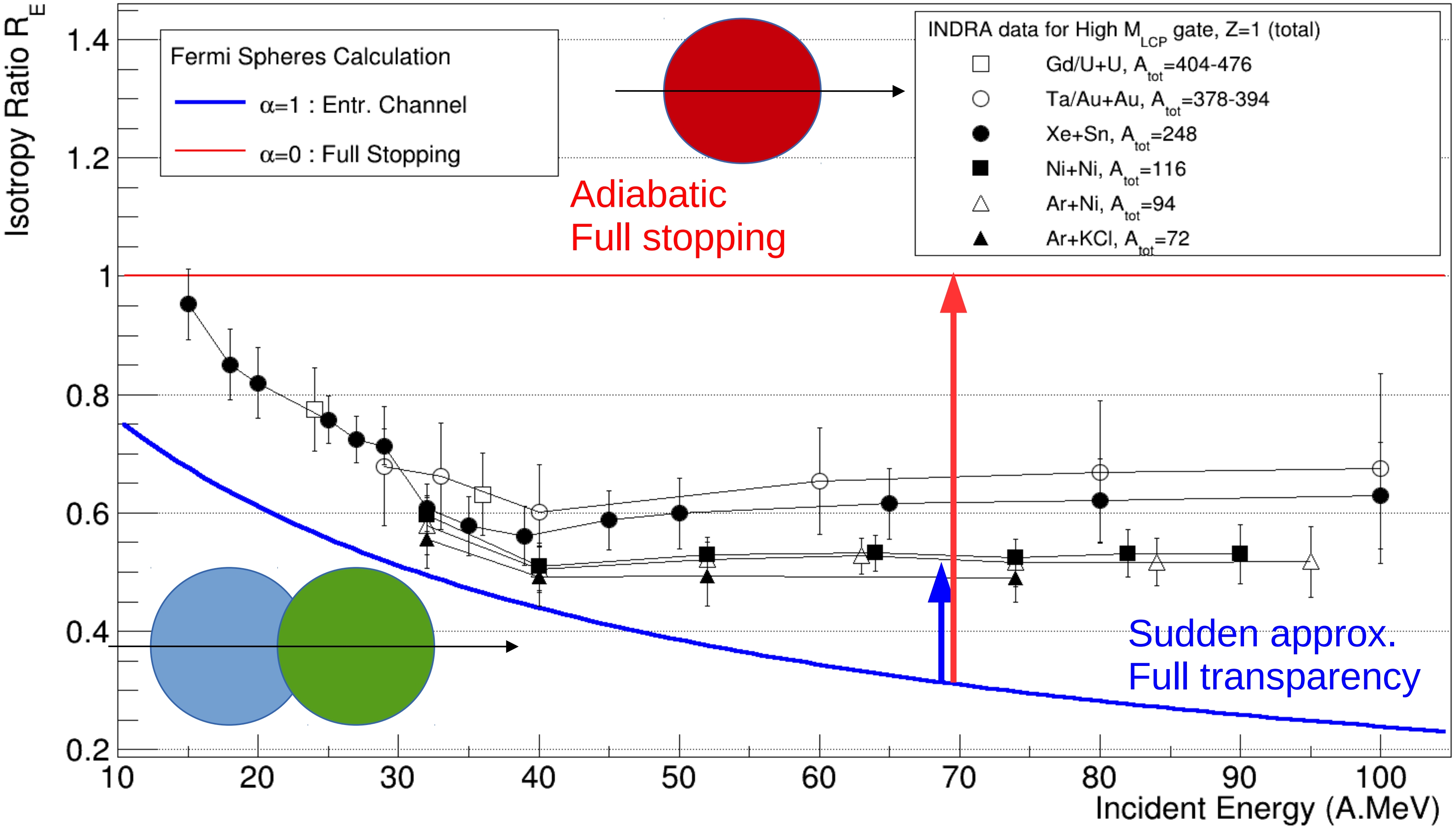
The Beginning !

Stopping power in central HIC

42 (quasi)-symmetric systems,
Only protons for $<R_E>$...

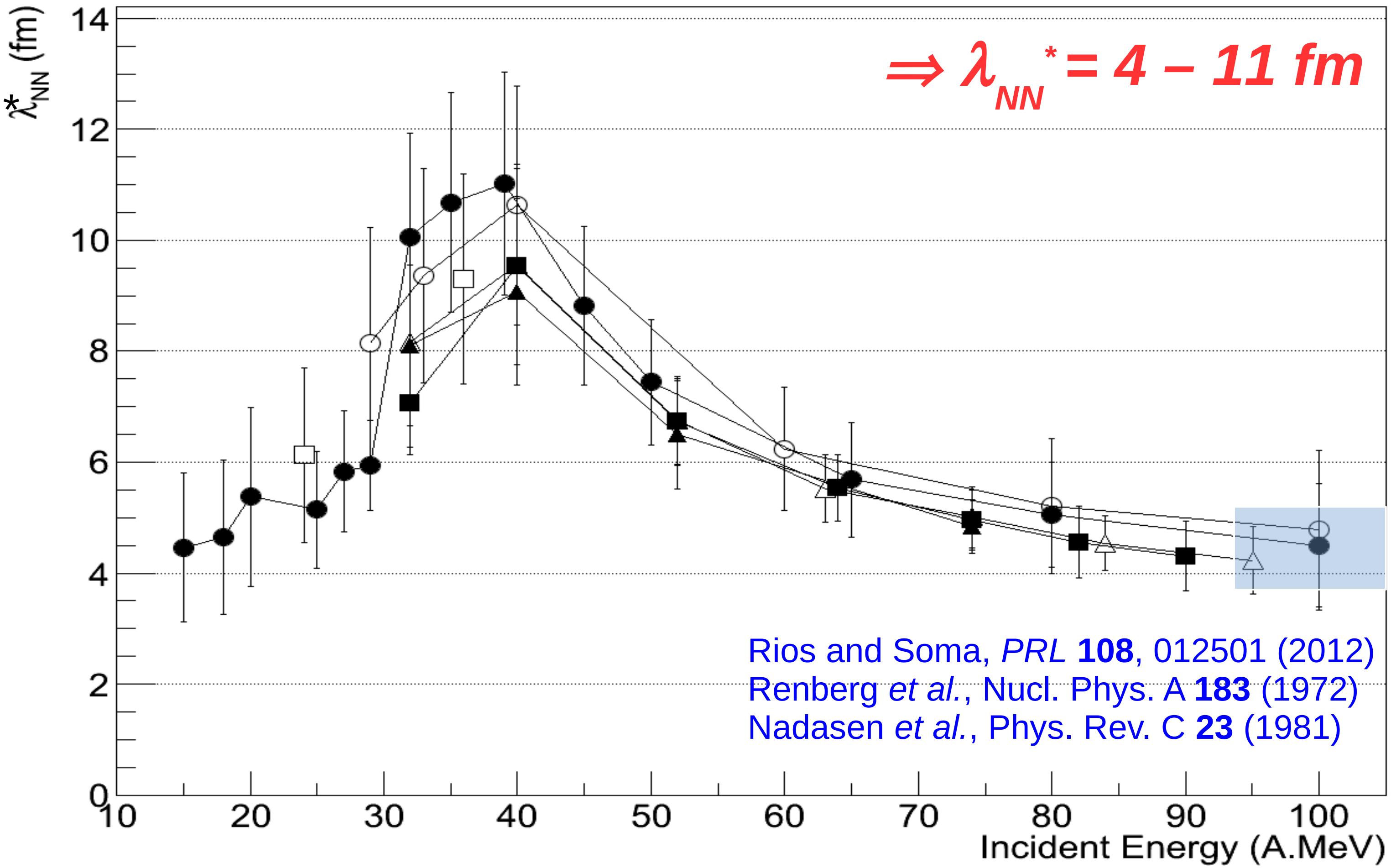
Nuclear Stopping

$$R_E(\alpha) = \frac{1}{1+5(\alpha P_{rel}/P_{Fermi})^2}$$



Nucleon mean free path in nuclear medium

Assuming: $<\lambda_{NN}^{*}> = L/d$



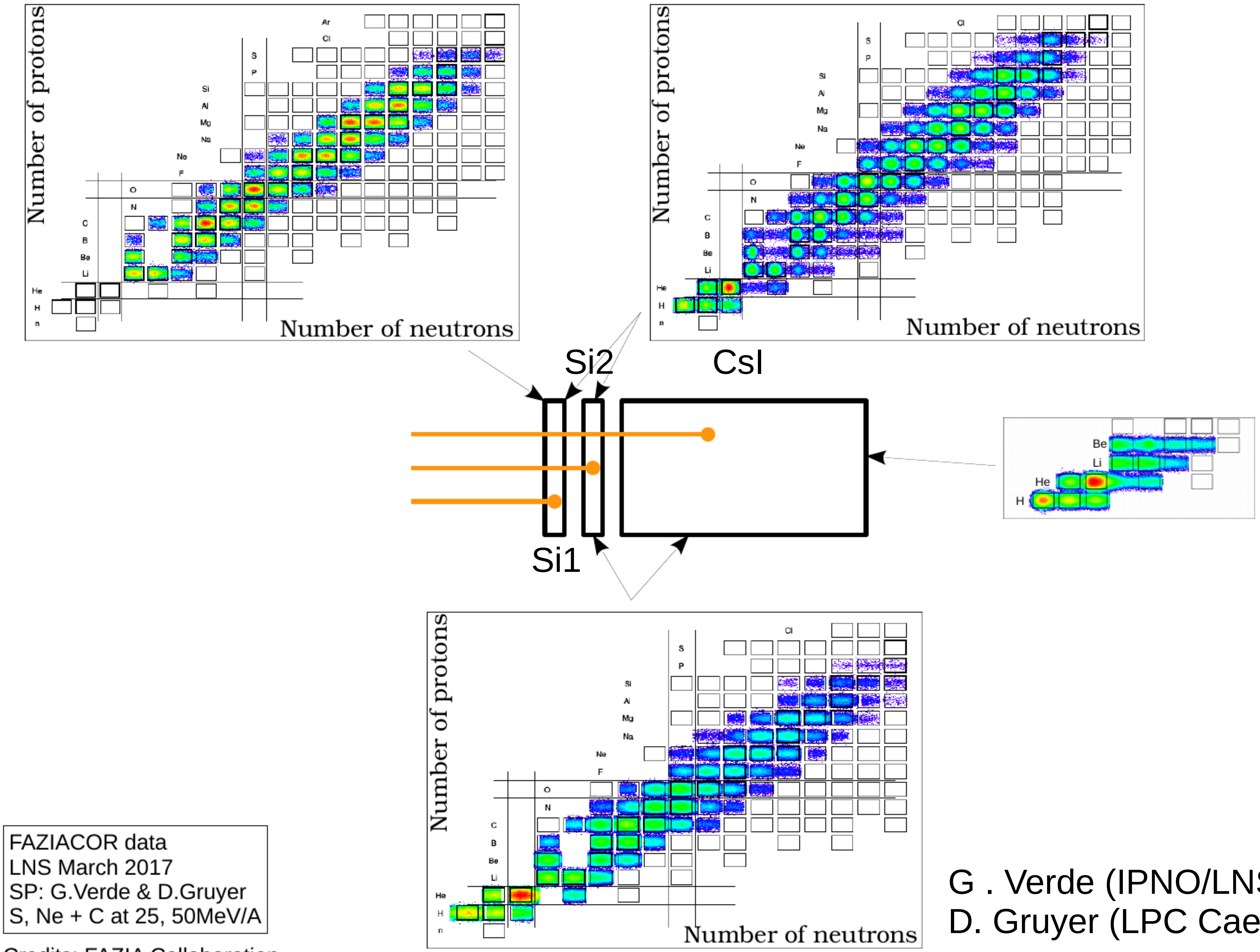
$\Rightarrow \lambda_{NN}^{*} = 4 – 11$ fm

$\lambda_{NN}^{*} = 4\text{-}5$ fm

Rios and Soma, *PRL* **108**, 012501 (2012)
Renberg *et al.*, Nucl. Phys. A **183** (1972)
Nadasen *et al.*, Phys. Rev. C **23** (1981)

- **$\lambda_{NN} \geq R$: complete stopping and thermalization not achieved...**
  J. Su and F.S. Zhang, PRC 87, 017602 (2013) [AMD]
- Contradictory findings with *SMF* by E. Bonnet, *et al.*, PRC 89, 034608 (2014)

FAZIACor status for Identification



FAZIACOR data
LNS March 2017
SP: G.Verde & D.Gruyer
S, Ne + C at 25, 50MeV/A

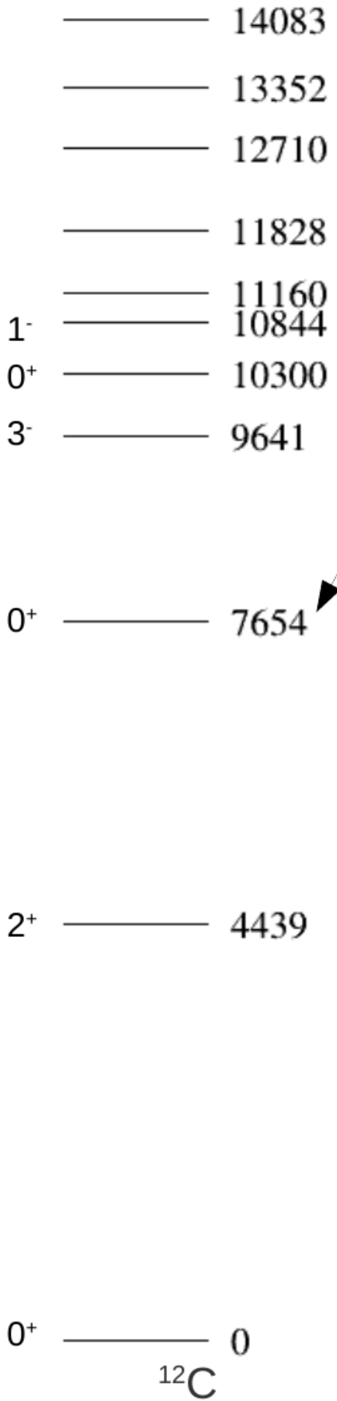
Credits: FAZIA Collaboration

G . Verde (IPNO/LNS Catania)
D. Gruyer (LPC Caen)

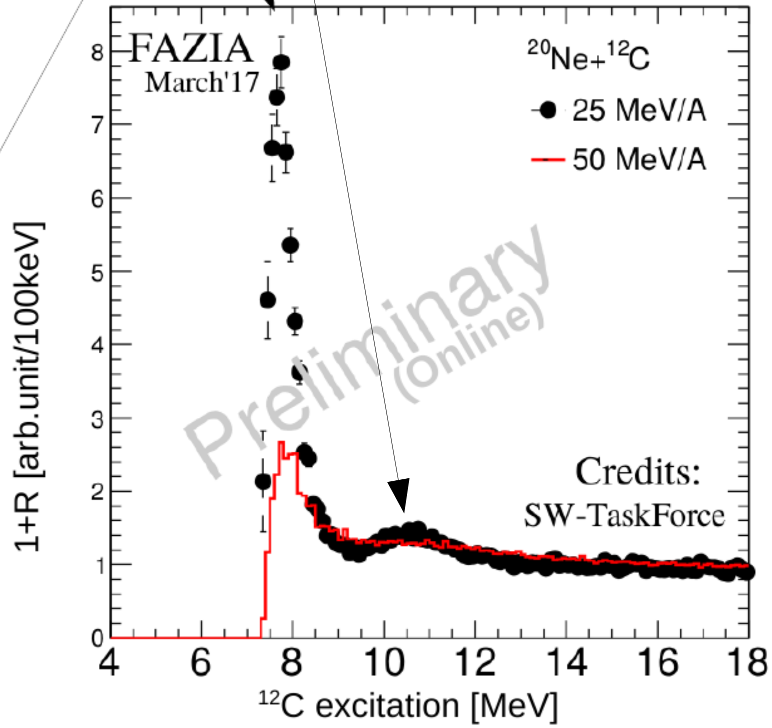
FAZIACor : in-medium cluster correlations

Very preliminary results (online)

From E. Bonnet (GANIL)

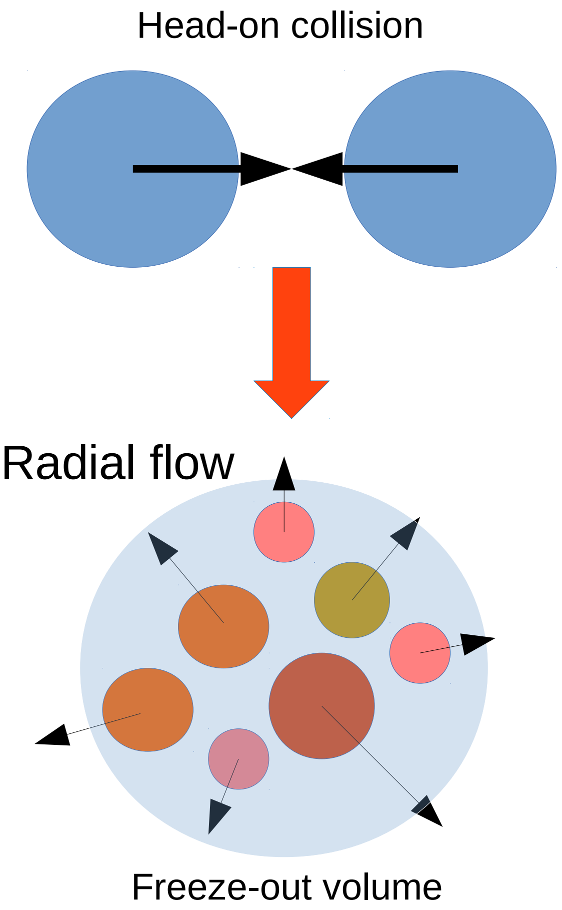


Hoyle state

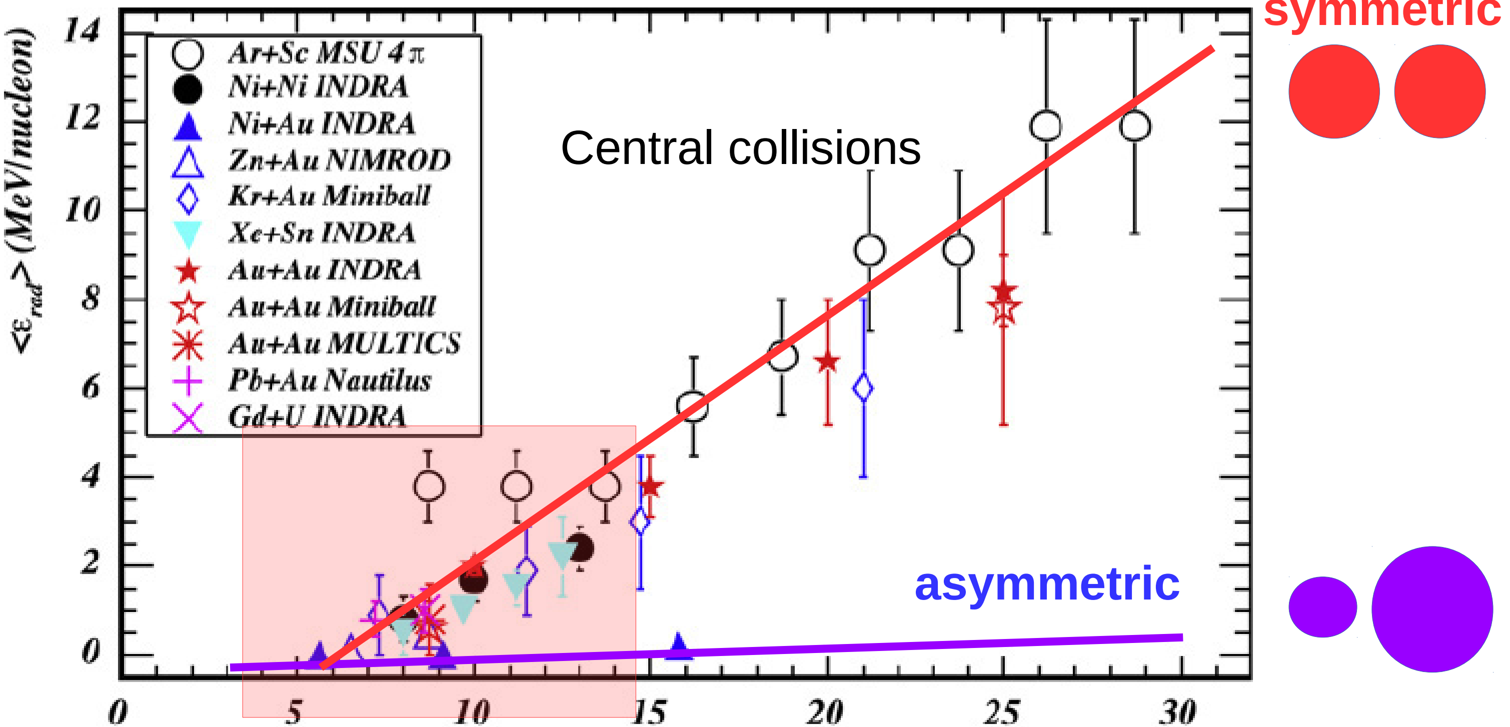


Online results are promising : in-medium clustering for light nuclei, here ^{20}Ne and ^{32}S with 3-α correlation (^{12}C*)

Radial Flow systematics



B. Borderie *et al.*, *Prog. In Part. Sci. And Nucl. Phys.* **61**, 551 (2008)



Available range at GANIL (CSS2)
$3 < E_{cm}/A < 15$ MeV

- **Linear behavior** as a function of E_{cm} : *at $E_{cm}/A=10$ MeV, we get :* $\boldsymbol{\varepsilon_{rad}=1.5\text{-}2}$ ***AMeV***
  but **some discrepancies** appear ...

- Radial flow is obtained from **multifragmentation models** (SMM-like) : **freeze-out volume**

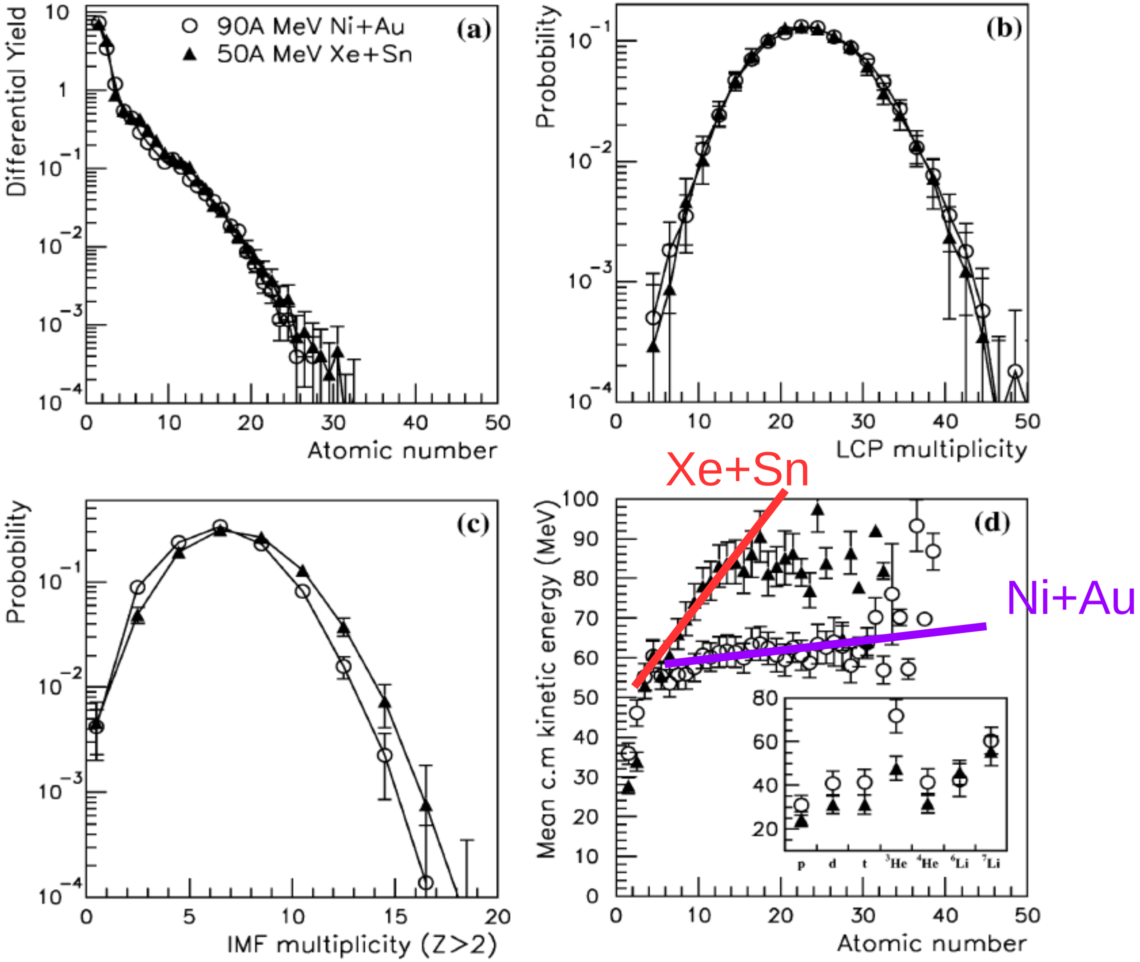
→ model-independent estimation for radial flow is needed...

Radial flow : toward an experimental determination

From **central collisions** at same ***E**** or ***T*** :

- Same fragmentation pattern:
  Partitions and multiplicities are similar
- Differences for the Kinetics :
  - → **Radial flow ε_{rad}**
  - → **Experimental determination of ε_{rad} for *Z>4* with isotopic resolution (A)**

N. Bellaize *et al.* (INDRA coll.), Nucl. Phys. A **709**, 367 (2002)



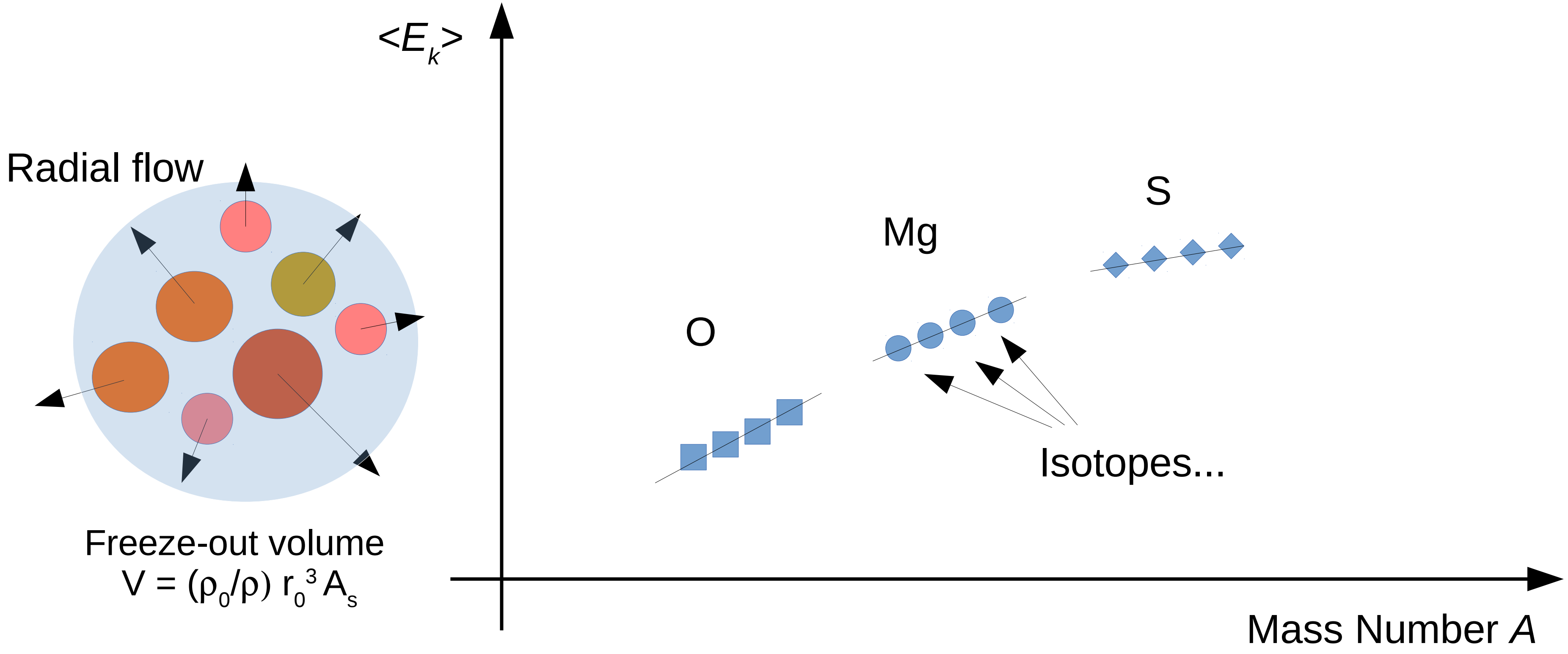
Proposed experiment

- Cover the Fermi energy domain
- Benefit from the maximal *N/Z* with stable beams at E_{fermi}
- Also study the **isospin diffusion/migration** in dissipative collisions

^{124,129,136}Xe @ 30, 39, 50 AMeV on ^{40,48}Ca and ^{nat}Sn targets

Radial flow : toward an experimental determination

3 components for E_k : $\langle E_k \rangle = \langle E_{coul}(Z) \rangle + \langle T \rangle + \langle E_{rad}(A) \rangle$



- Coulomb : $\langle E_{coul}(Z) \rangle \;\alpha\; Z\,(Z_s - Z_0)\,(\rho/\rho_0)^{1/3}$

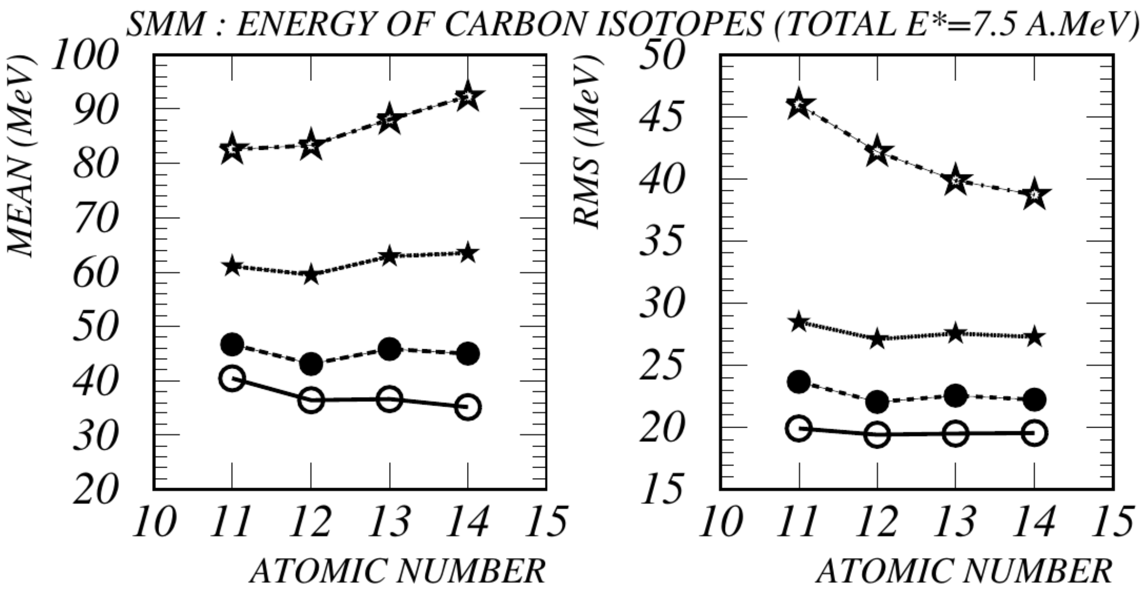
- Thermal : **<*T*>** : thermal component, no dep.

- Radial : $\langle E_{rad}\,(A) \rangle = \langle \varepsilon_0 \rangle \,.\, A$ where $\langle \varepsilon_0 \rangle$ is the average radial flow component

Radial flow : toward an experimental determination

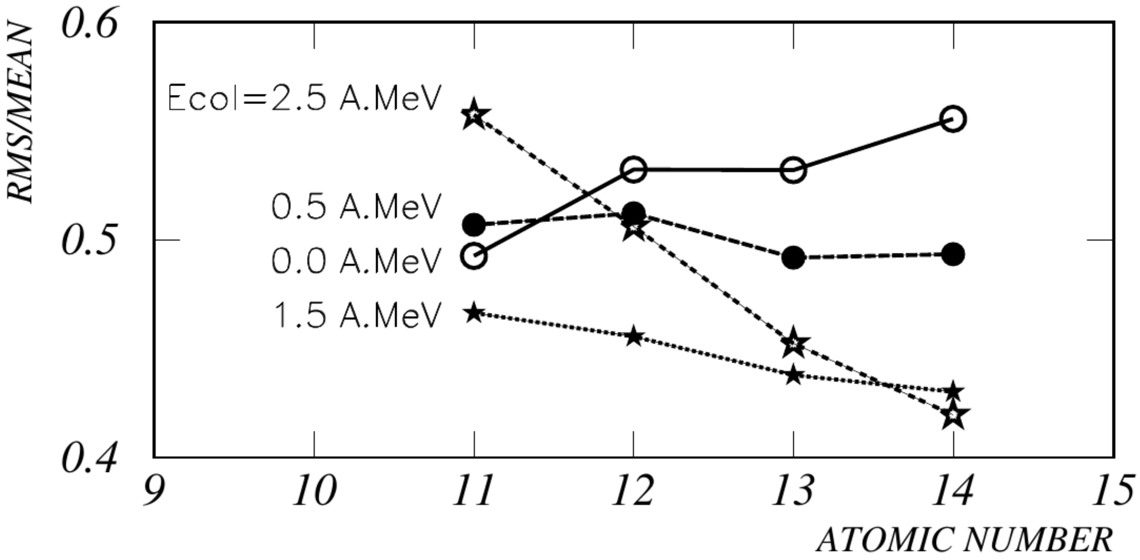
SMM Calculations

Z=90, E*/A=7.5 MeV
$\rho = \rho_0/3$



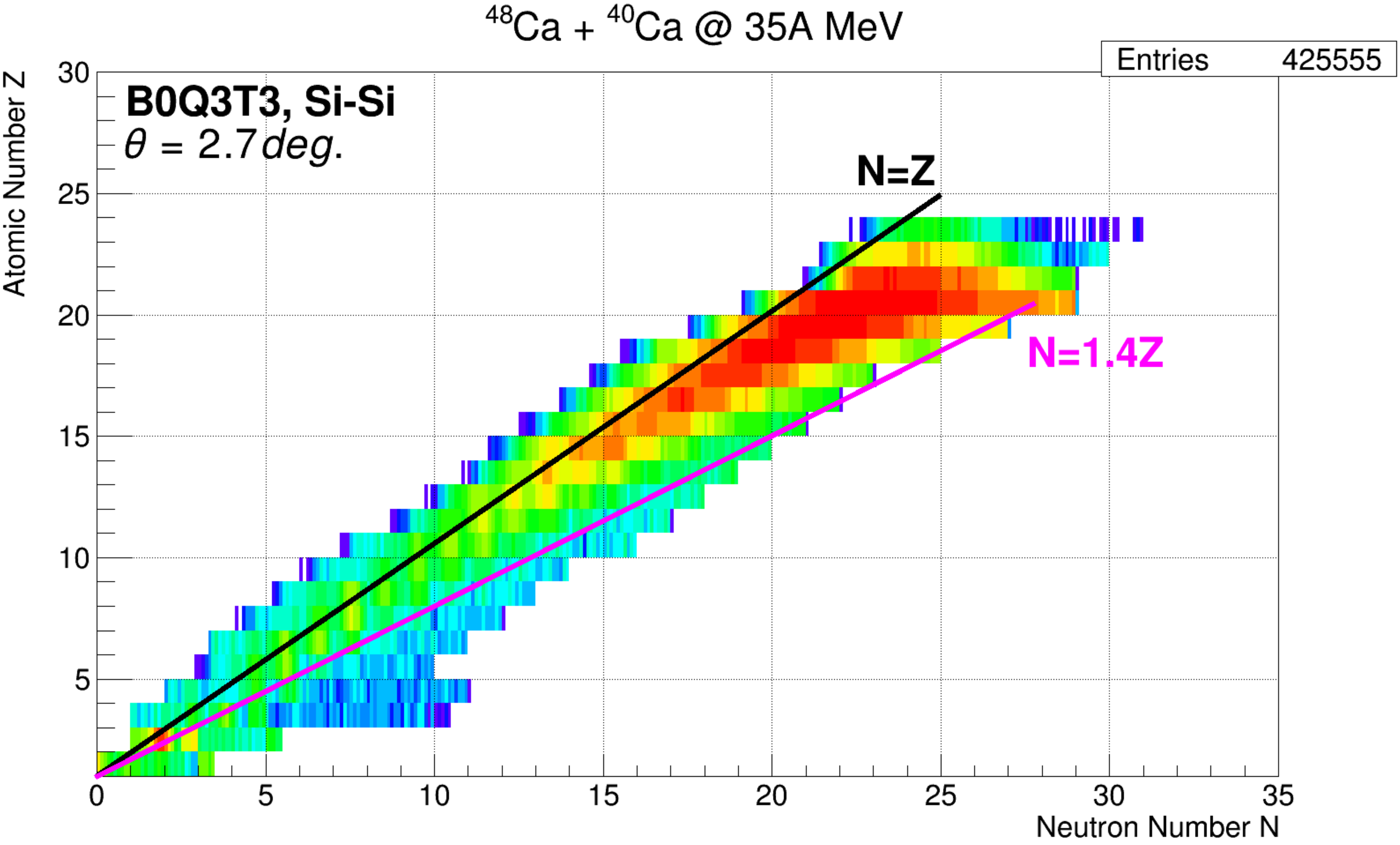
Carbon isotopes

Even better for higher species ?...



Courtesy of R. Bougault

FAZIASym : Isospin diffusion for ^{48}Ca QP



Only inclusive events … preliminary !

FAZIASYM @ LNS
Dec. 9-20 2015

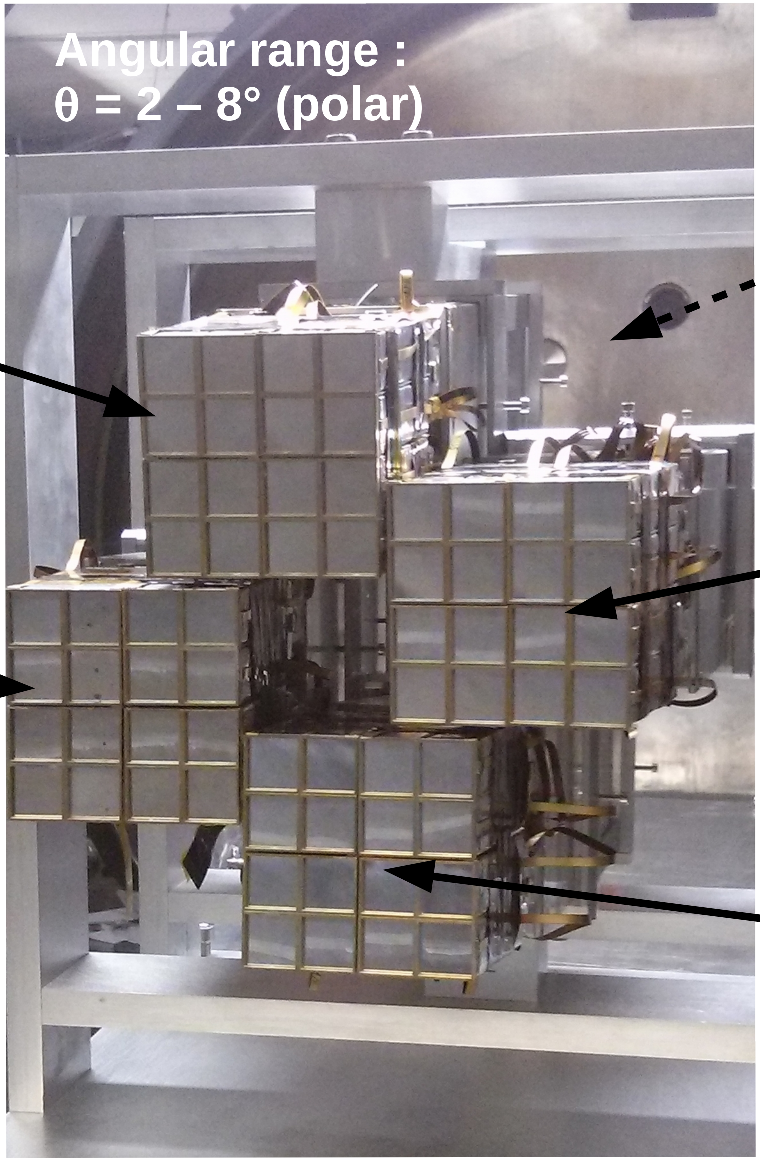
^{40}*Ca* + ^{40,48}*Ca* (+ *C* layer)
^{48}*Ca* + ^{40,48}*Ca* (+ *C* layer)
@ 35A MeV

$\theta_{grazing}$ (^{40}Ca) = 1.93°
$\theta_{grazing}$ (^{48}Ca) = 1.85°

1 Block =
16 telescopes *Si-Si-CsI*

- Si(NTD) : 300 μm thick.
- Si(NTD) : 500 mm thick.
- CsI(Tl) : 10 cm thick.

Q,I readout from PACI
In-vacuum Front-End Electronics
Sampling at 250 MhZ, 14 bits



Angular range :
θ = 2 – 8° (polar)

Block 0

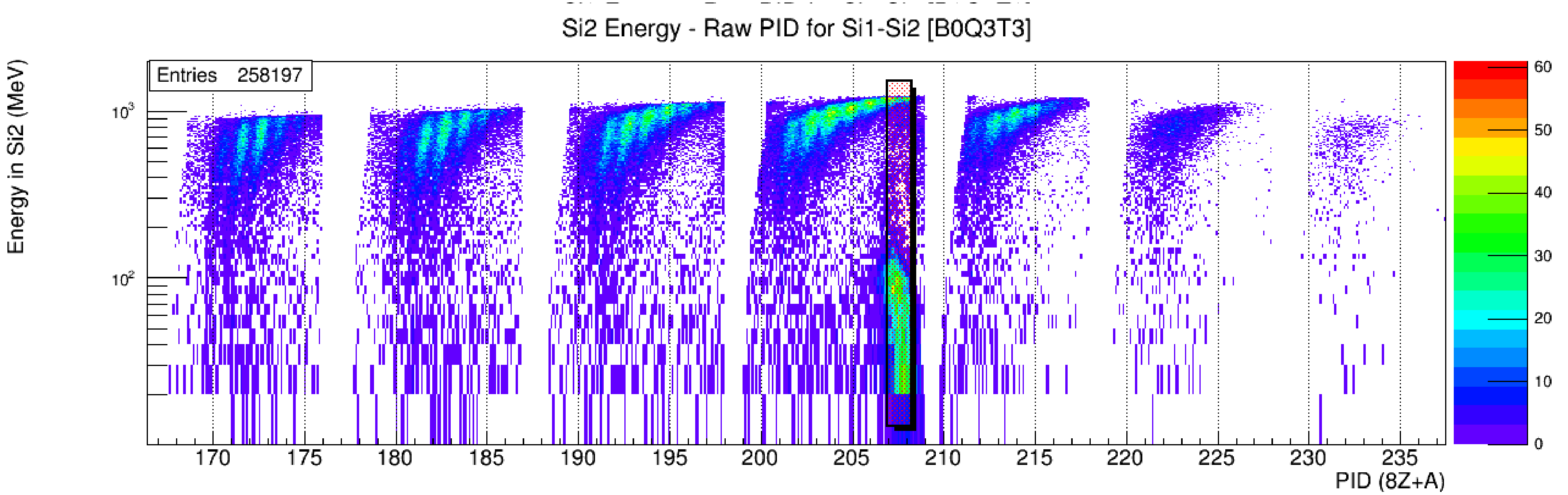
Downstream
Telescope
for Rutherford
scattering (B4)

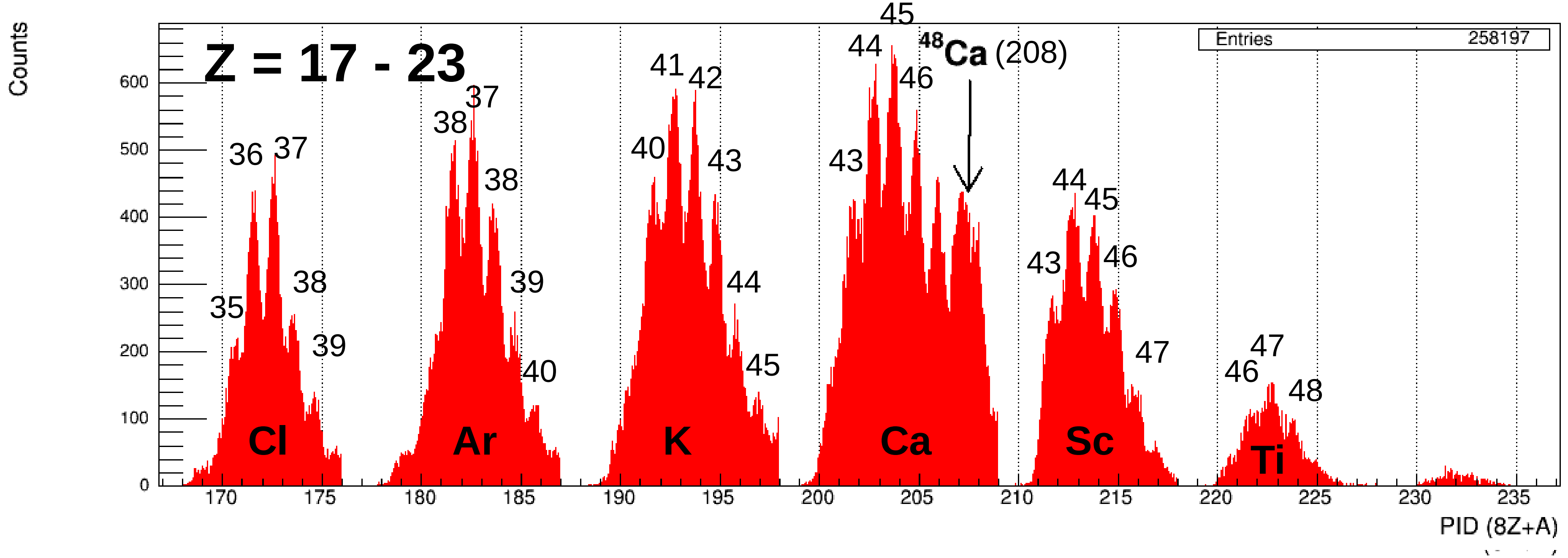
Block 3

Block 1

Block 2

FAZIASym : Identification using AMI grid (II)

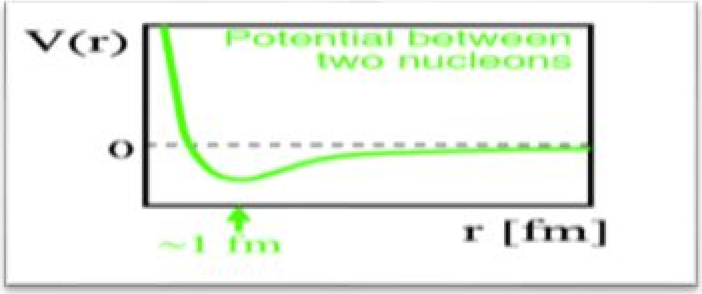




Isotopic Identification is OK up to Z=20, even for ^{48}Ca combining *PSA* + *E-ΔE*

Short Range Correlations

- **Features of SRC:**



- Nucleons can stay at closer distance (*<1 fm*

  Strong attraction and repulsion

- Nucleons can carry much higher momenta

  Exceed the limit of IPSM – k>k_F

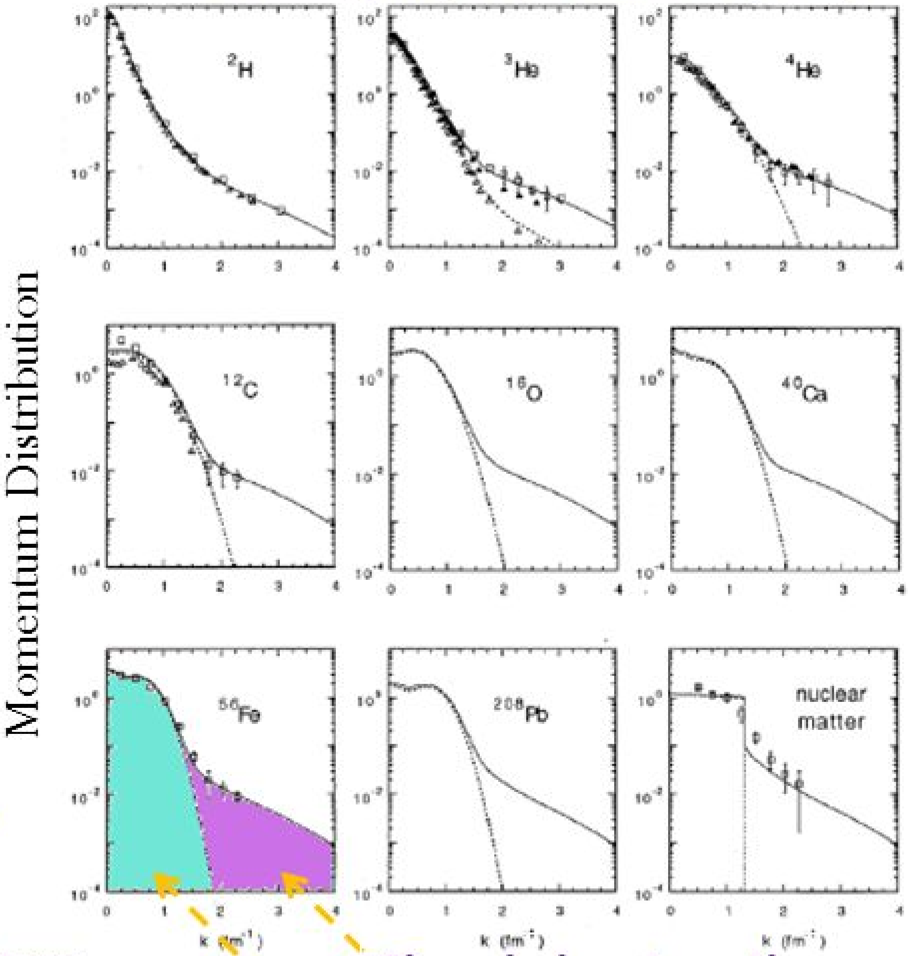
- Zero total momentum:

  A real ground state, not an excited state.

- Break-up these correlated nucleons:

  Detect a nucleon with much higher momentum;

C. Ciofi degli Atti, et al, PRC 53 1689 (1996)



The missing strength

Mean Field Prediction

Momentum distribution: → **All possible momentum values that nucleons carry inside the nucleus.**