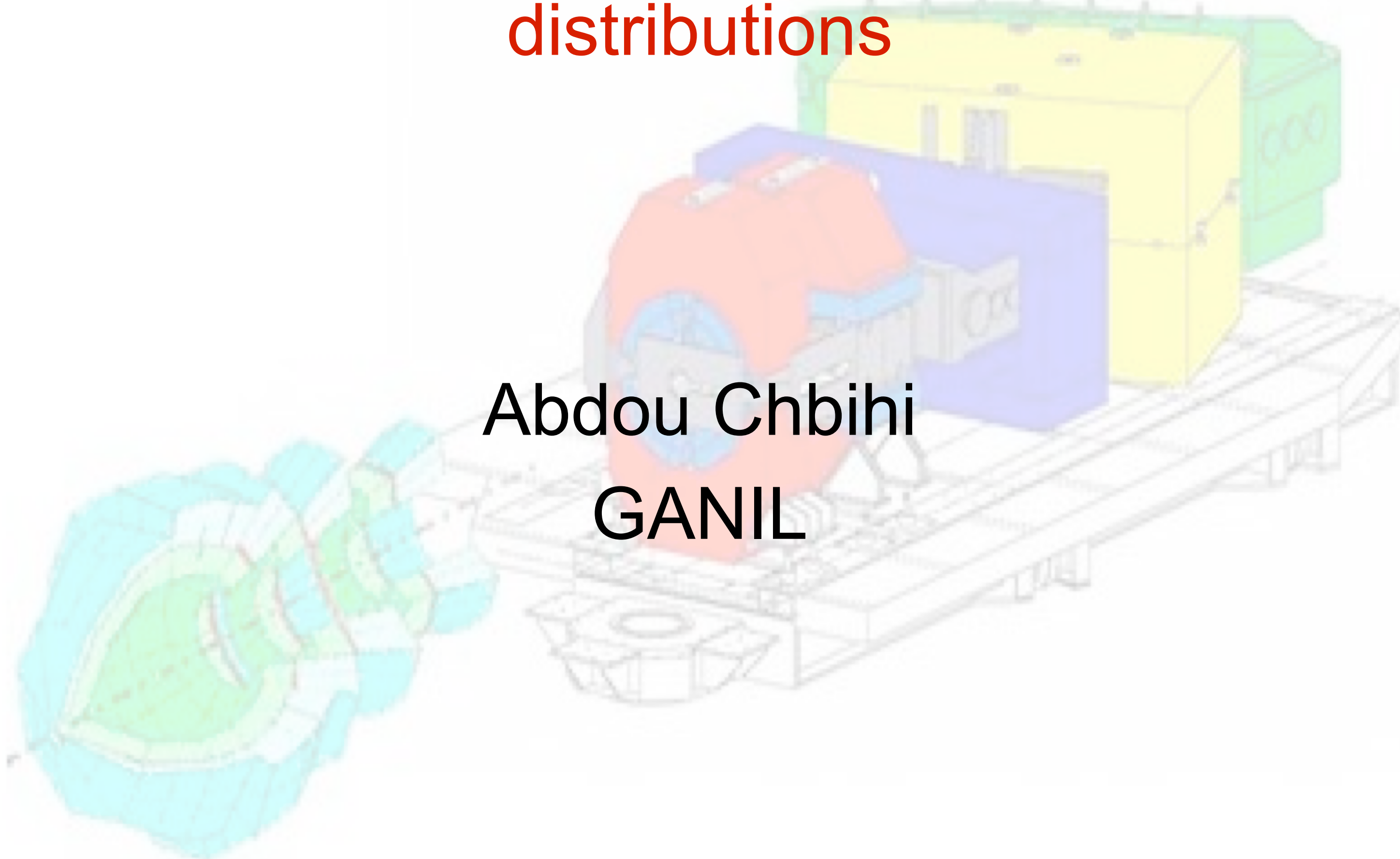
Study of the symmetry energy with isotopic distributions

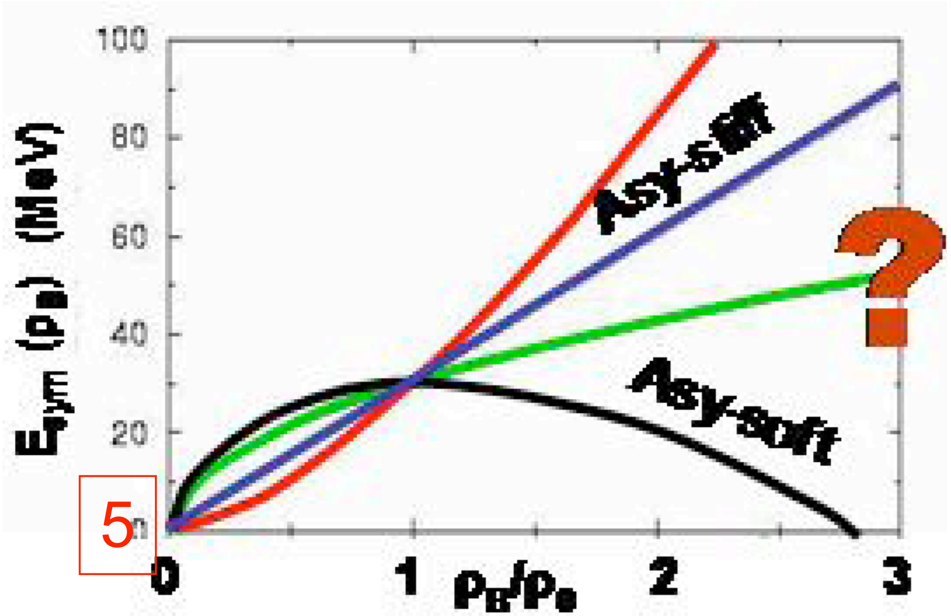


Abdou Chbihi

GANIL

exploring the density dependence of symmetry energy with heavy-ion collisions

Intermediate energies
Multifragmentation
subsaturation density

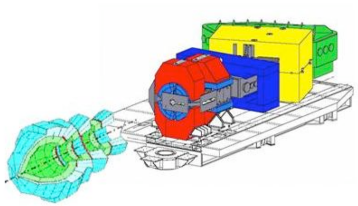


High energies
Suprasaturation density

GANIL

GSI

Eincident



^{124,129}Xe+^{112,124}Sn at E/A = 60-250 MeV
INDRA@GSI

^{40,48}Ca+^{40,48}Ca at E_{inc}/A=35 MeV

Probes of the density dependence of symmetry energy by studying heavy-ion collisions and N/Z d.o.f.

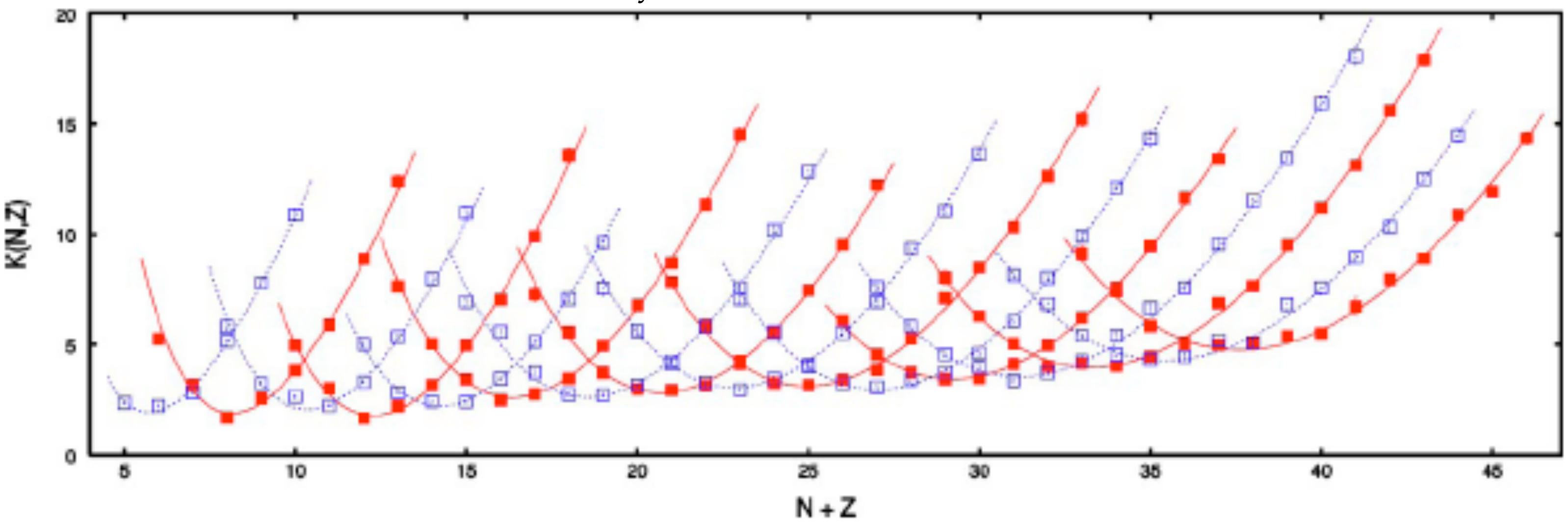
- Isoscaling of the nuclear multi-fragmentation
- Isospin diffusion
- Pre-equilibrium neutron/proton, (INDRA@GSI experiment)
    - Spectra of light cluster $^{3}H/^{3}He$
    - Spectra mirror nuclei $^{7}Li/^{7}Be$
    - Differential flow,
    - Correlation functions at low momentum (HBT)
- Isotopic distributions of complex fragments (GANIL experiment)

Accessing the symmetry energy

From isotopic distributions… ➡ …to the symmetry energy

AMD simulations: $^{40}Ca+^{40}Ca$, $^{48}Ca+^{48}Ca$, $^{60}Ca+^{60}Ca$, $^{46}Fe+^{46}Fe$
E/A=35 MeV and b=0 Primary fragment distributions

A. Ono et al., Phys. Rev. C70, 041604(R) (2004)



K(N,Z) : a global isotopic distribution constructed
by combining all yield of the frag. obtained in the 4 sys

$$K(N,Z) = \xi(Z)N + \eta(Z) + \zeta(Z)\frac{(N-Z)^2}{N+Z}$$

Accessing the symmetry energy

A. Ono et al., Phys. Rev. C70, 041604(R) (2004)

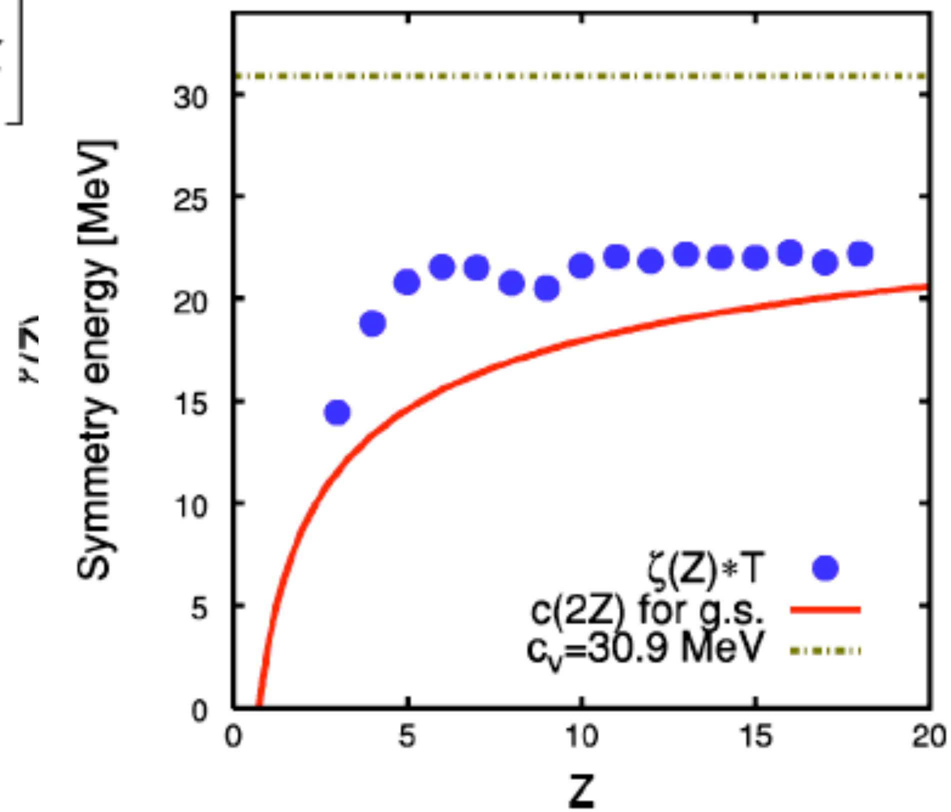
$$K(N,Z) = \xi(Z)N + \eta(Z) + \zeta(Z)\frac{(N-Z)^2}{N+Z}$$

$$Y(N,Z) \propto \exp\left[-\frac{G_{\rm nuc}(N,Z)}{T} + \frac{\mu_n}{T}N + \frac{\mu_p}{T}Z\right]$$

statistical treatment

$$\zeta(Z) = c(\overline{A}(Z))/T$$

$$k = -c_s/c_v$$

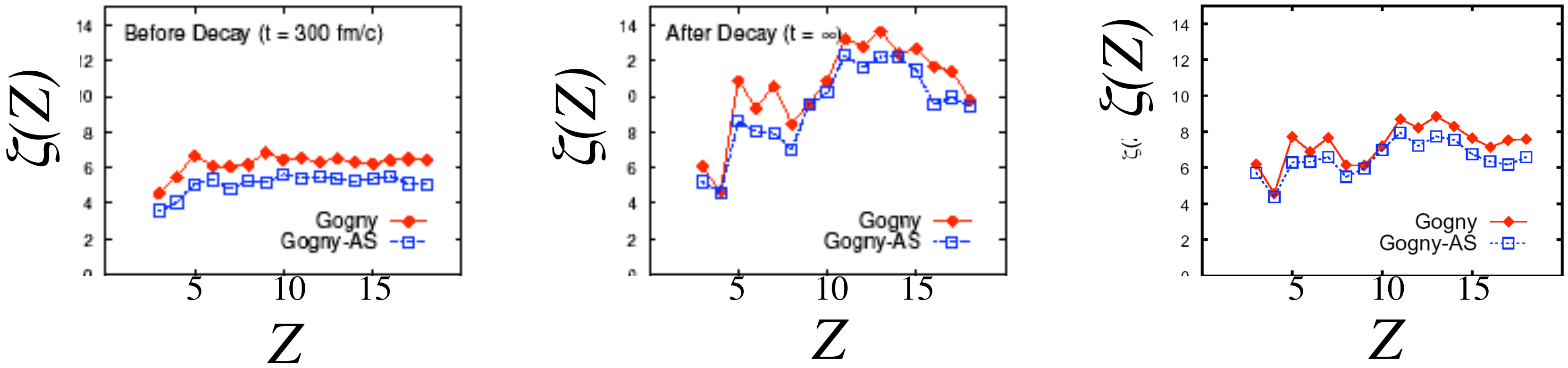


- $\zeta(Z)$ independent of Z (negligible surface effect) → symmetry energy of INM

- Probe density dependence of $C_{sym}(\rho)$ at subsaturation densities $\rho<\rho_0$

Effects of secondary decays

Primary Secondary a=A/8 Secondary a=A/16



A. Ono, *Acta Physica Hungarica A - Heavy Ion Physics*, in press

Secondary decays need to be taken into account for comparison to experimental data

Experiments coupling INDRA-VAMOS

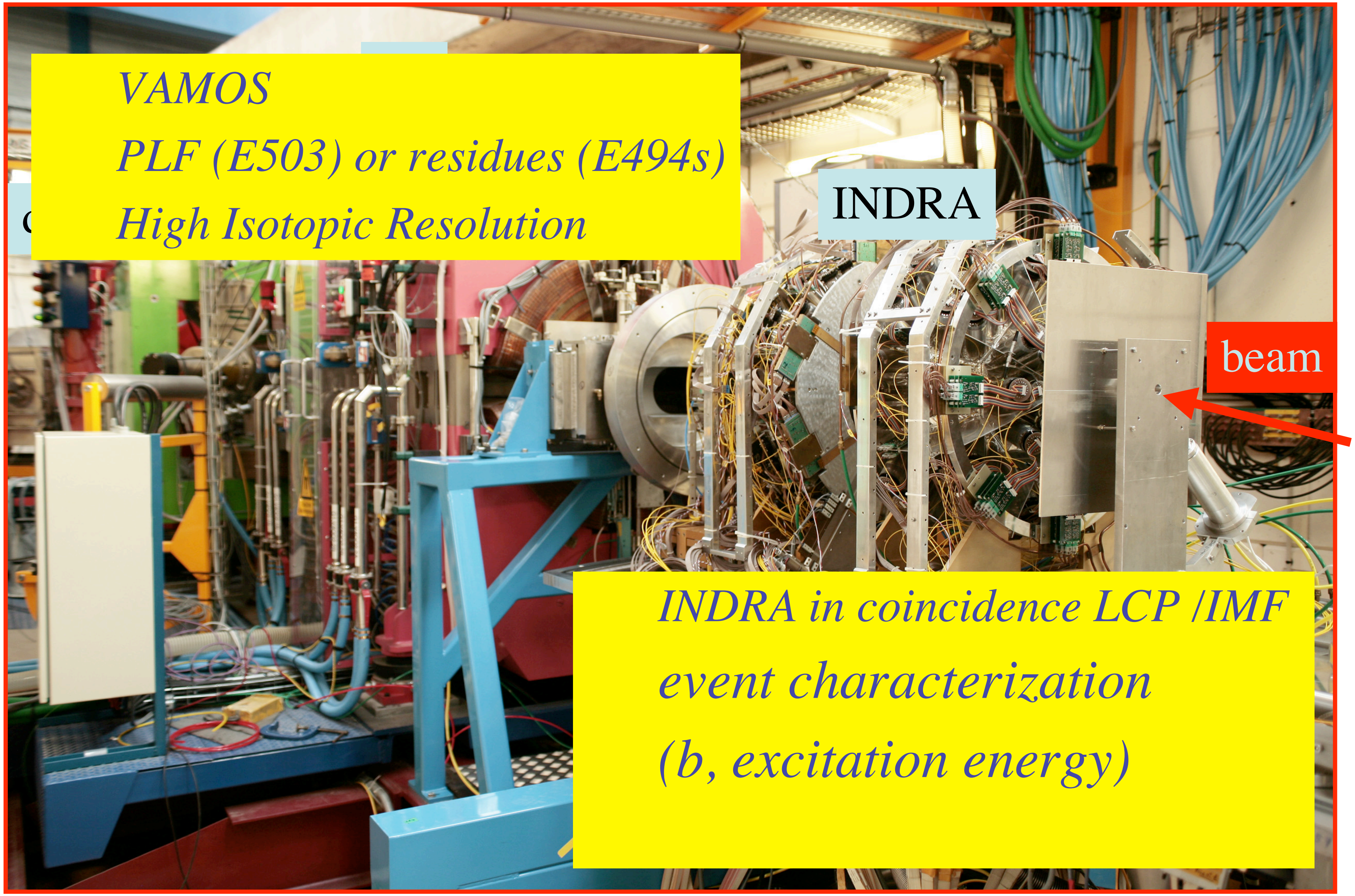
Symmetry energy experiments

- $^{40}Ca + ^{40}Ca$ @ E/A = 35 MeV
- $^{40}Ca + ^{48}Ca$ @ E/A = 35 MeV   isospin diffusion
- $^{48}Ca + ^{40}Ca$ @ E/A = 35 MeV   isospin diffusion
- $^{48}Ca + ^{48}Ca$ @ E/A = 35 MeV

For Bρ (Tm)= 2.2 , 2.12 , 1.957 , 1.80 , 1.656 , 1.523 , 1.401 , 1.289 , 1.186 , 1.091 , 1.004 , 0.923 , 0.849 , 0.782 , 0.719 , 0.661

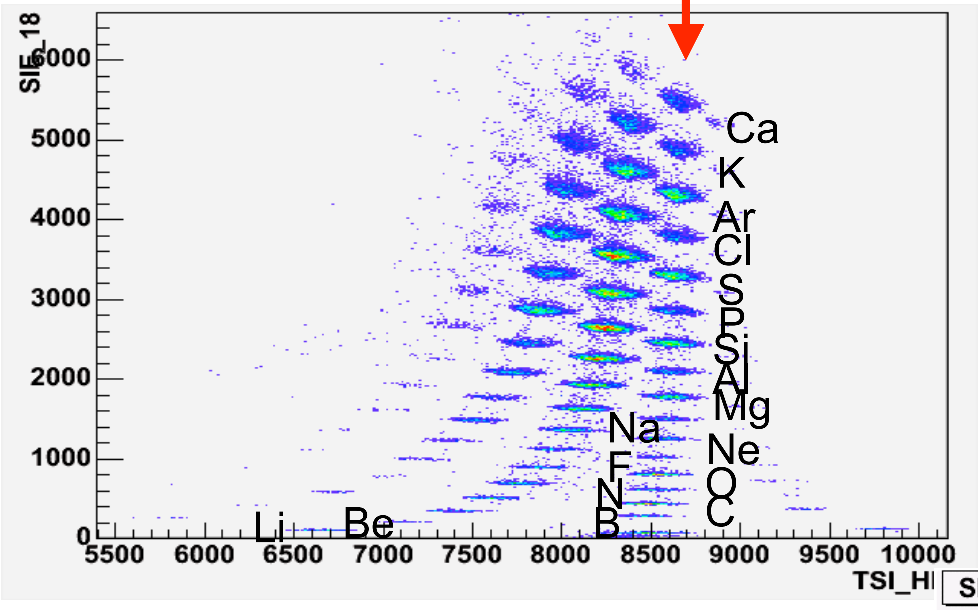
Isospin dependence of level density experiments (N. Le Neindre)

- $^{40}Ar + ^{64}Ni$ @ E/A = 12.7 MeV   (^{104}Pd)
- $^{40}Ar + ^{60}Ni$ @ E/A = 12.7 MeV   (^{100}Pd)
- $^{34}Ar + ^{58}Ni$ @ E/A = 13.5 MeV   (^{92}Pd)
- $^{36}Ar + ^{58}Ni$ @ E/A = 13.3 MeV   (^{94}Pd)
- $^{36}Ar + ^{60}Ni$ @ E/A = 13.3 MeV   (^{96}Pd)


VAMOS
PLF (E503) or residues (E494s)
High Isotopic Resolution
INDRA
beam
INDRA in coincidence LCP /IMF
event characterization
(b, excitation energy)

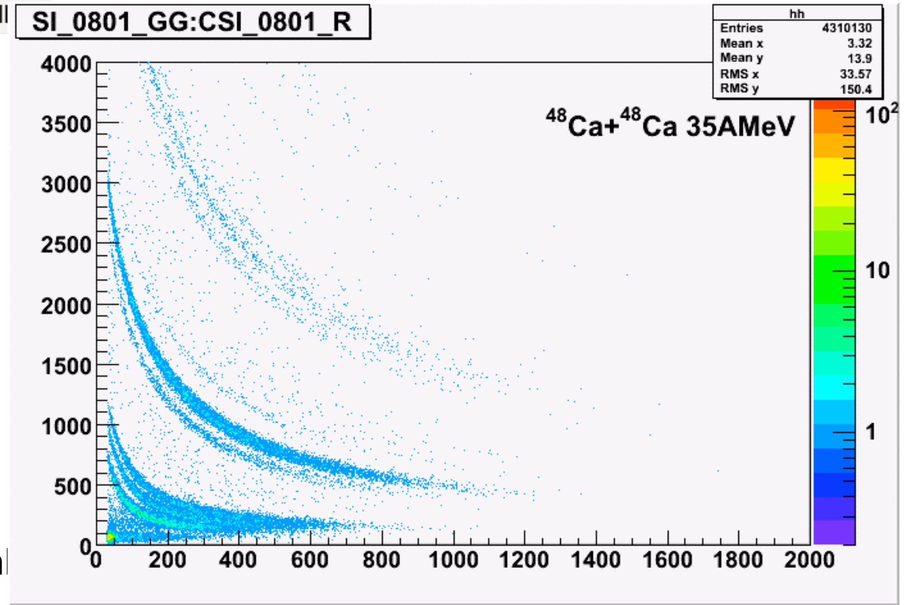
$^{40}Ca + ^{48}Ca$ @ 35 MeV/A

Result @ given Bρ
and for a given Si detector



INDRA

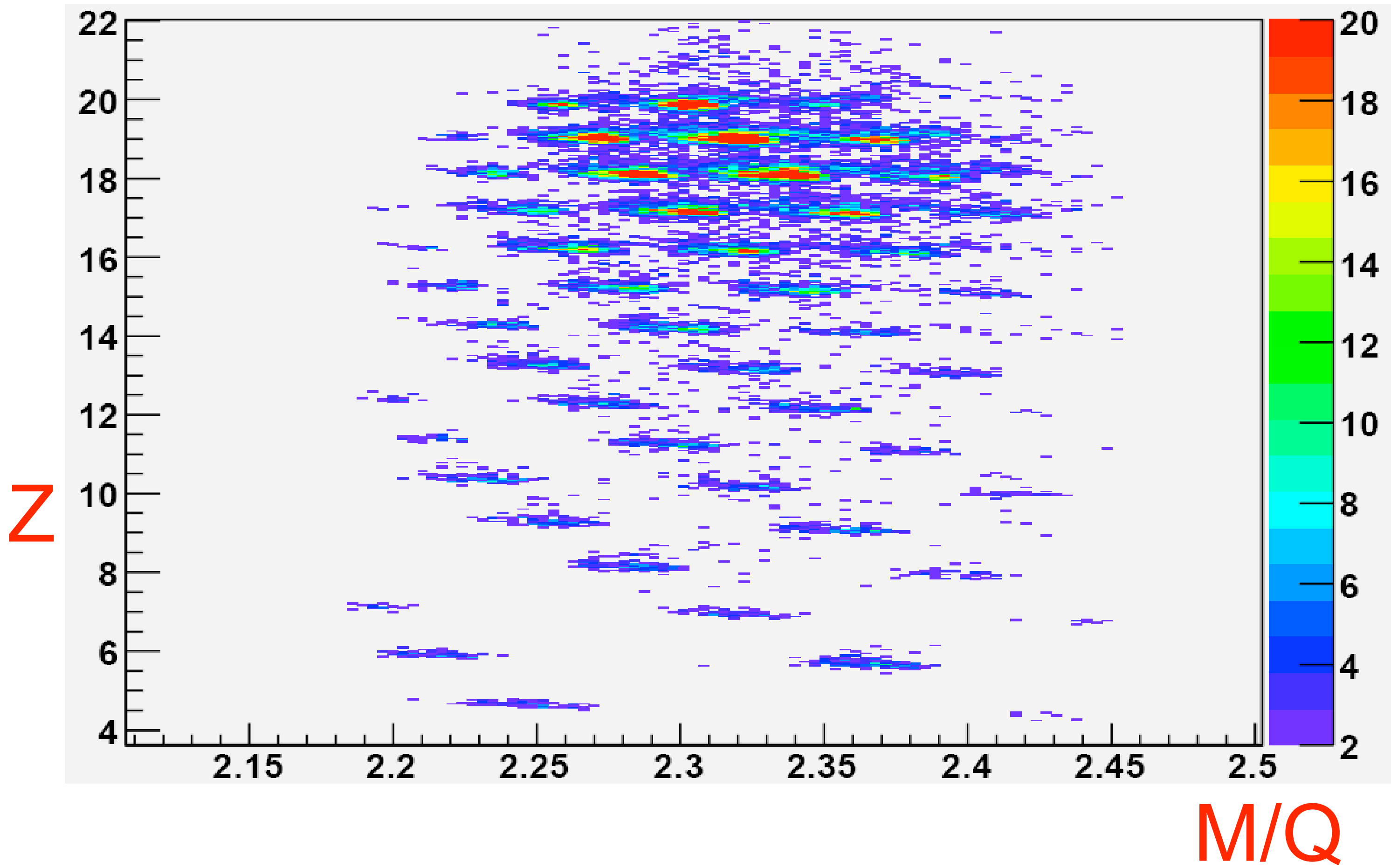
VAMOS Spectrometer



Zagreb 2009

A. Ch

Charge vs M/Q

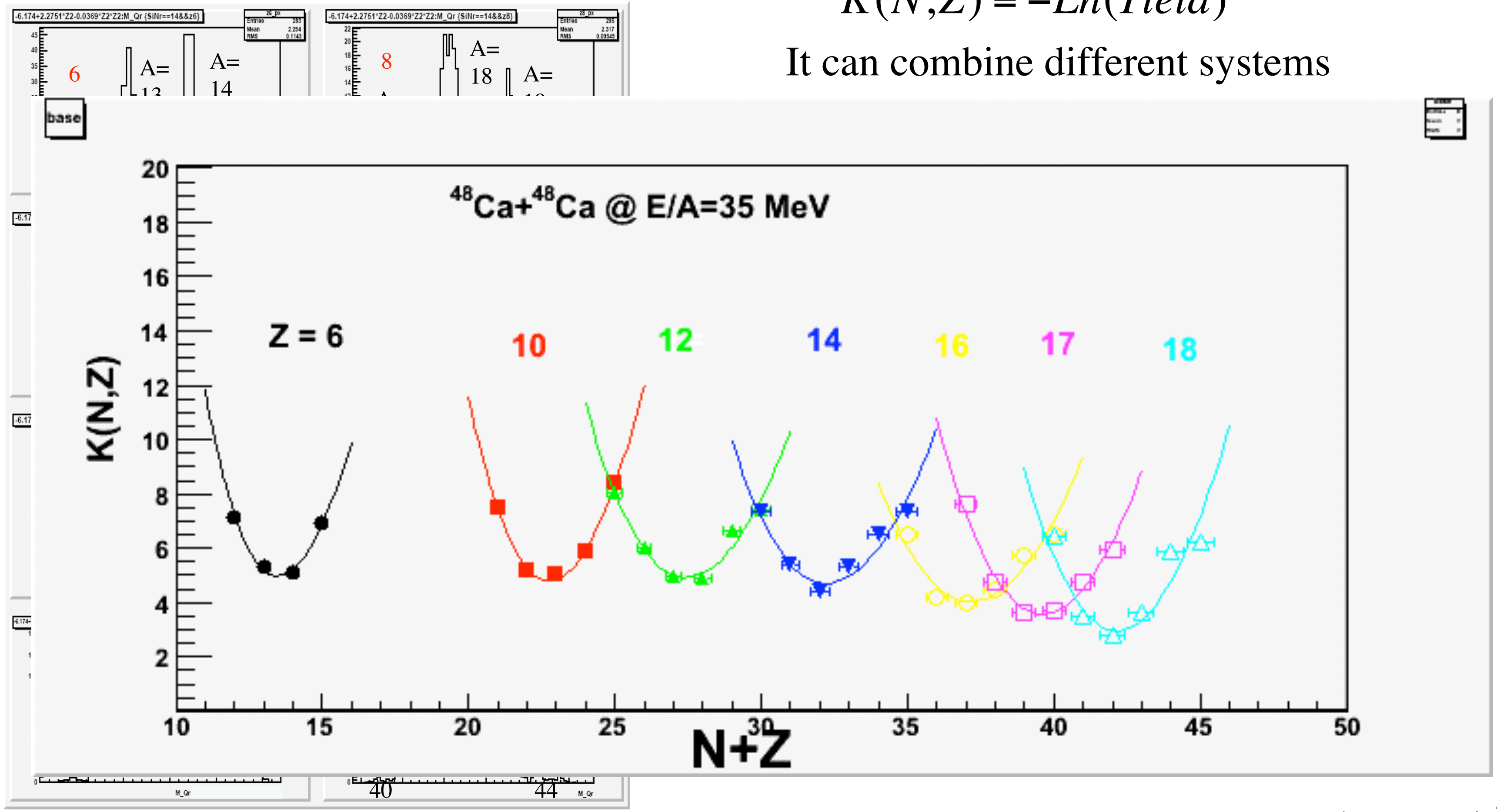


22
20
18
16
14
12
10
8
6
4
2.15
2.2
2.25
2.3
2.35
2.4
2.45
2.5
20
18
16
14
12
10
8
6
4
2
Z
M/Q

Preliminary result @ given Bρ and for a given Si detector

$$K(N,Z) = -Ln(Yield)$$

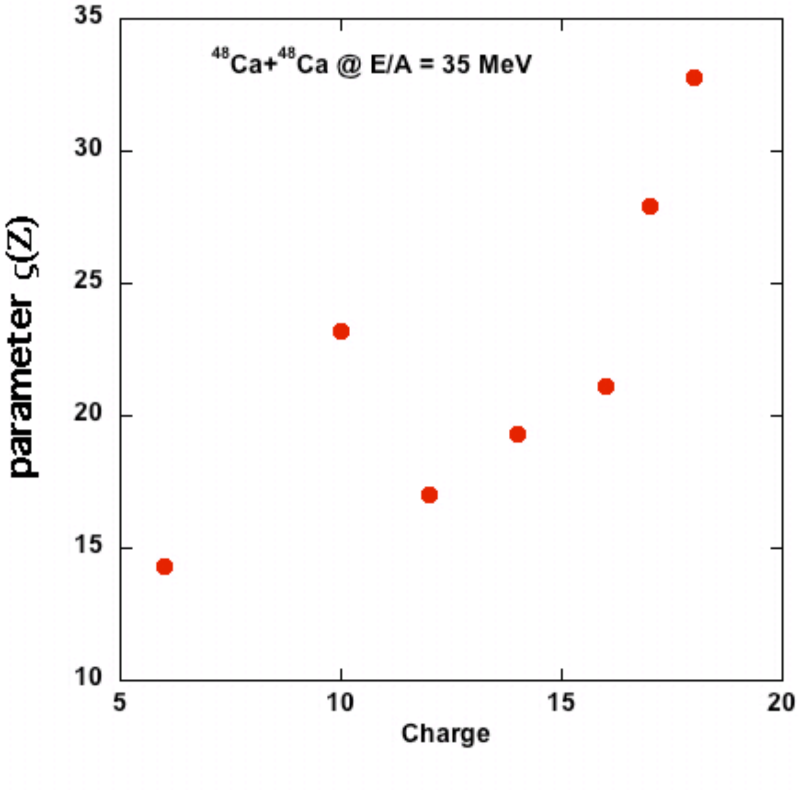
It can combine different systems



^{48}Ca + ^{48}Ca

$$K(N,Z) = \xi(Z)N + \eta(Z) + \zeta(Z)\frac{(N-Z)^2}{N+Z}$$

Symmetry energy vs fragment charge (preliminary)



For comparison to AMD calculations

1- need to perform this analysis over all Brho

2- to take into account the secondary decays

3- INDRA multiplicity to select Central Col.

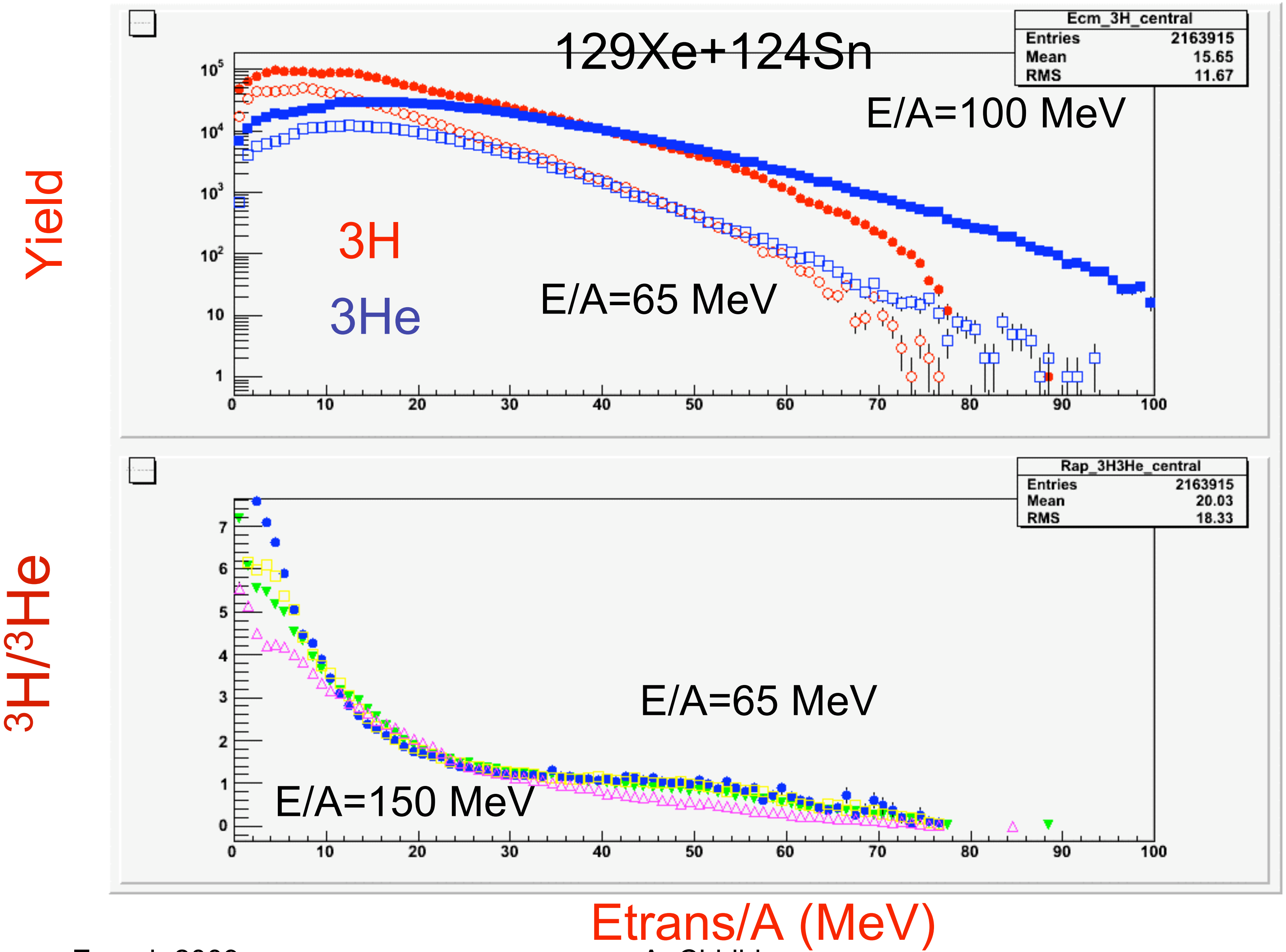
Secondary decay ?

- Statistical decay calculation to the prim. frag. (AMD)
  - Level density parameter (Isospin dependence experiment)
  - Comparison to the data
  - Sensitivity to the EOS or to the SM parameters ?
- Experimental reconstruction of primary fragments and then compare to primary observables of transport calculation

INDRA@GSI experiments

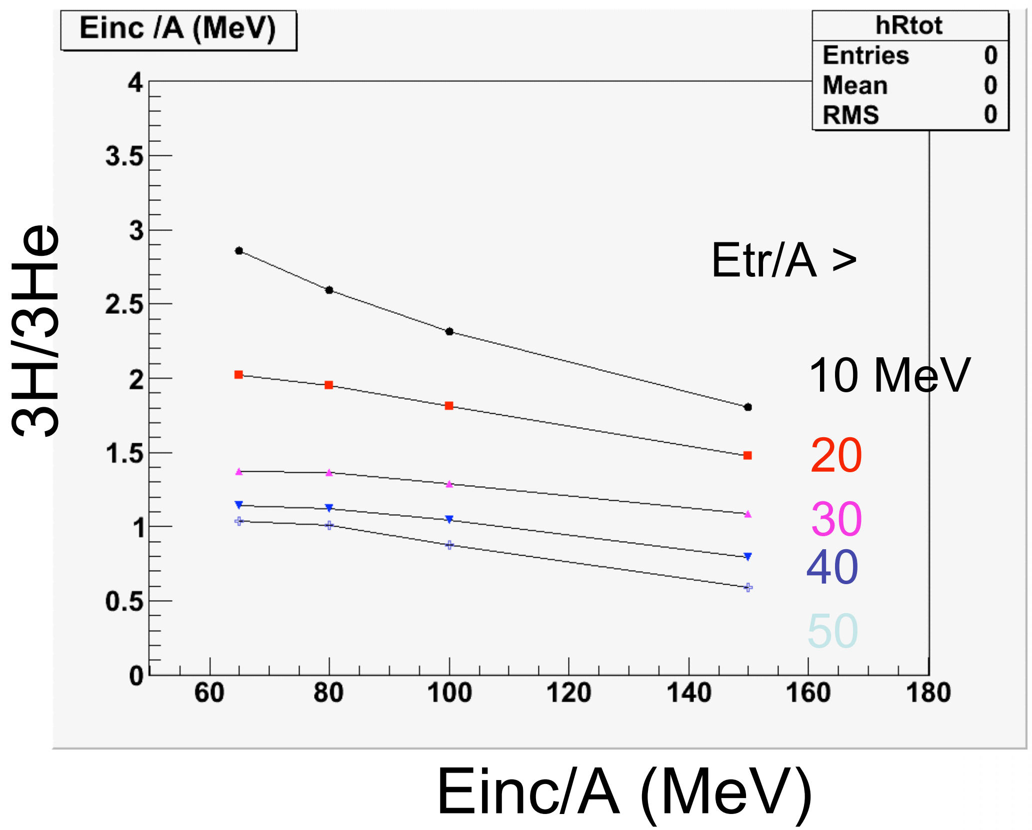
Probe : Spectra of light cluster $^{3}H/^{3}He$

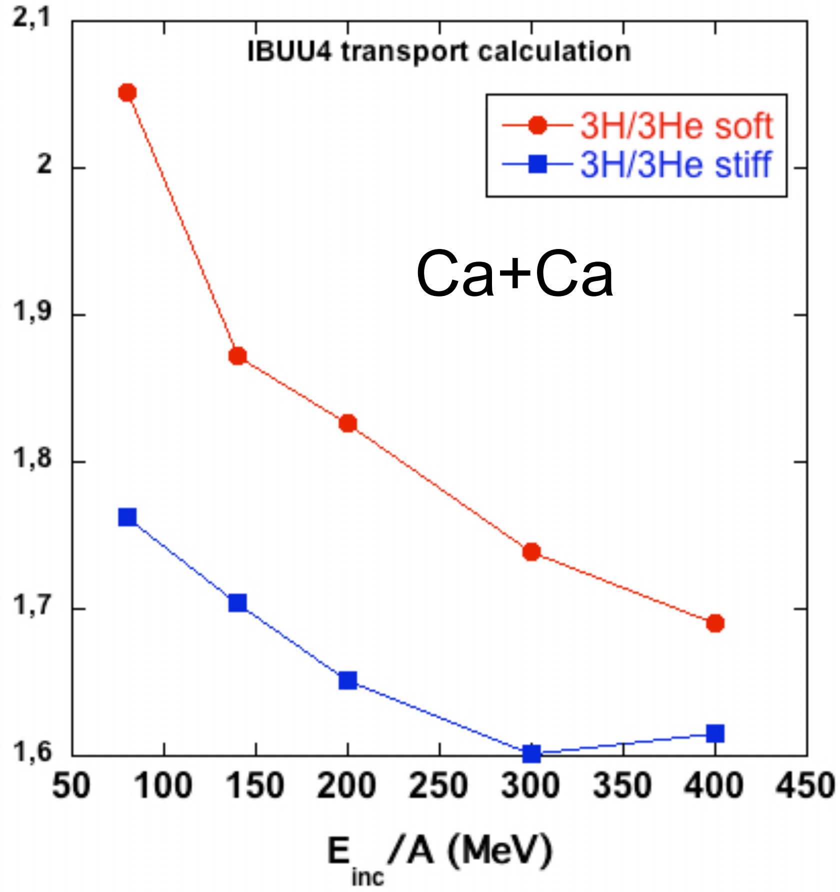
$^3H/^3He$ dependence on beam energy



$^{3}H/^{3}He$ dependence on beam energy qualitative comparison to IBUU4

129Xe+124Sn 60-150 AMeV





Conclusion

- Unique measurements coupling INDRA-VAMOS have been done for Ca+Ca in order to access the symmetry energy through different observables :
  - isotopic distributions
  - 3H/3He and 7Li/7Be energy spectra
  - Isospin diffusion
- Secondary decays require special considerations
  - Experimental Reconstruction of the primary fragments
  - Experimental determination of the level density parameter for different N/Z sources

•3H/3He ratio provide an interesting probe to Esym(ρ)

–Calculation for the system Xe+Sn are in the way

–Excitation function for 3H/3He will be extended to low energies (see R. Bougault)

–Hard constraint on the transport calculations

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