

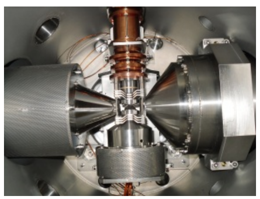
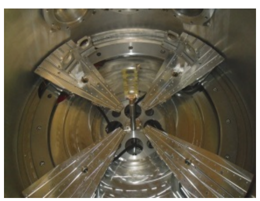

International Workshop on Multi facets of EoS and Clustering
Catania 2018

Isospin transport properties in nuclear matter : light clusters as isospin trackers

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INDRA collaboration

May 24, 2018

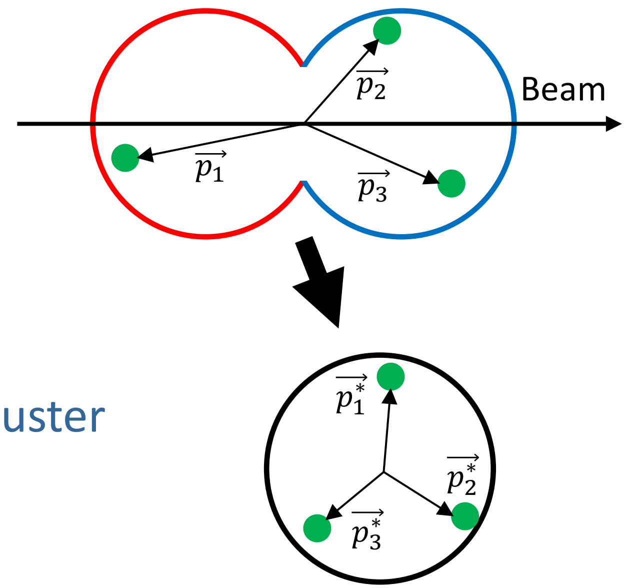
Introduction

Goals : in central heavy ion collisions
- study the production of clusters in nuclear matter
- study the isospin transport with clusters as probes

Tools : - combinatorial coalescence of A=3 clusters (^{3}H, ^{3}He)
- experimental data used (*INDRA*) :
  - ➢ from Ni+Ni to Au+Au for cluster production study
  - ➢ with $^{136,124}Xe$ + $^{124,112}Sn$ at 32 MeV/A for isospin transport study
- selection of central events[1] (~2 % of detected cross-section)

[1] G. Lehaut et al., *Phys. Rev. Let.* **104**, 232701 (2010)

Nucleons coalescence



1 – Cluster formation :

- assuming two Fermi spheres in the P-space
- randomly choose 3 nucleons
- bring them in the CM frame of the cluster (Z_C,A_C)
- computing their mean internal energy $\langle E \rangle$ in the cluster

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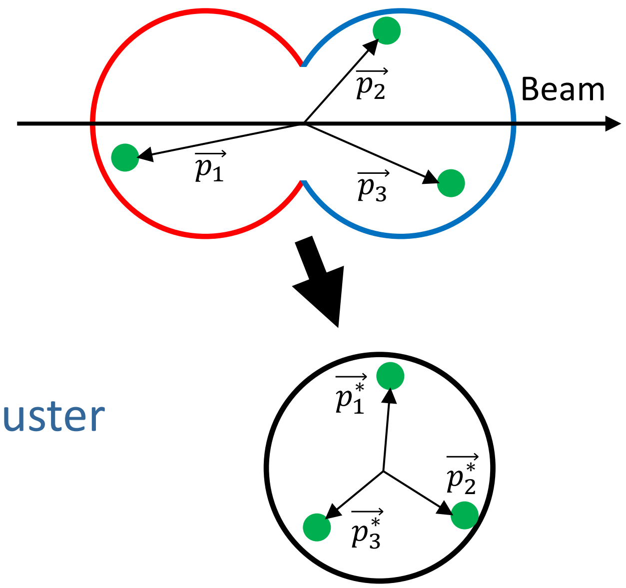

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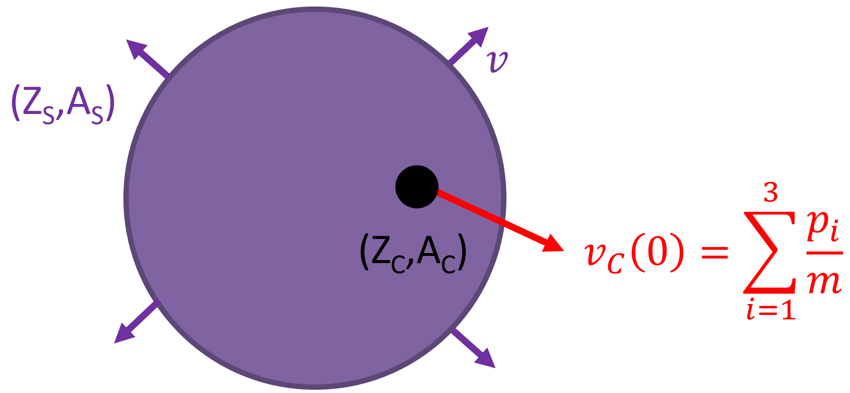
2 – Final state interactions :

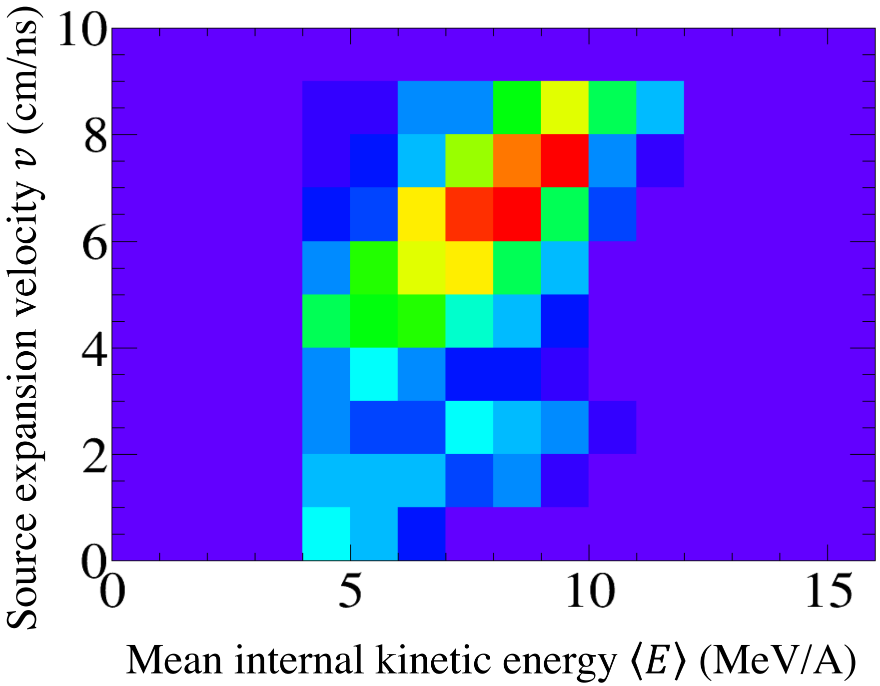
- uniform charged sphere (Z_S,A_S) in R-space to represent the fragments
- Coulomb interaction between the sphere and the cluster
- sphere in expansion with a velocity v to simulate repulsion between fragments



Nucleons coalescence

To constrain the final distributions we (here $^{129}Xe + ^{119}Sn$ @ 50 MeV/A for ^{3}He) :

- discretize the $\{\langle E\rangle, v\}$ space into slices of 1 MeV and 1 cm/ns
- for a given couple $(\langle E\rangle, v)$ we :
  - compare experimental and simulated (filtered) $v_{\perp}^{cm}$ and $v_{\parallel}^{cm}$ distributions and get the χ^2
  - compute the likelihood $\mathcal{L} = \exp\left(-\frac{\chi^2}{2}\right)$



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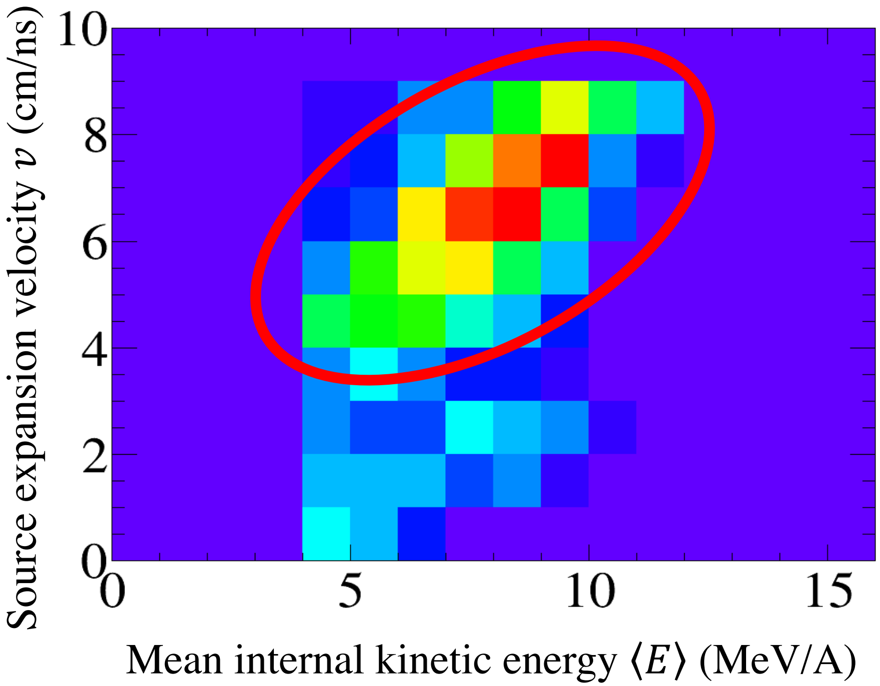

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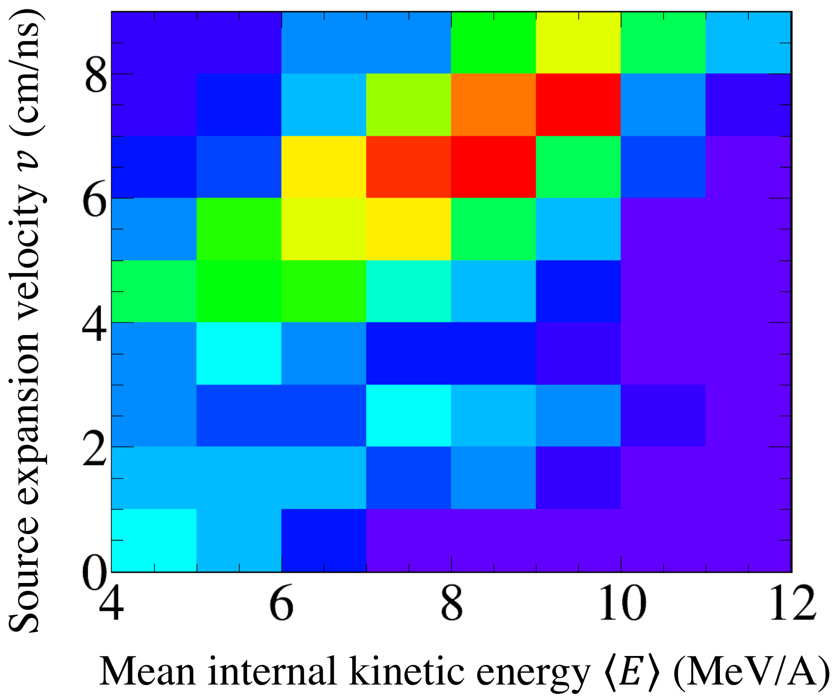

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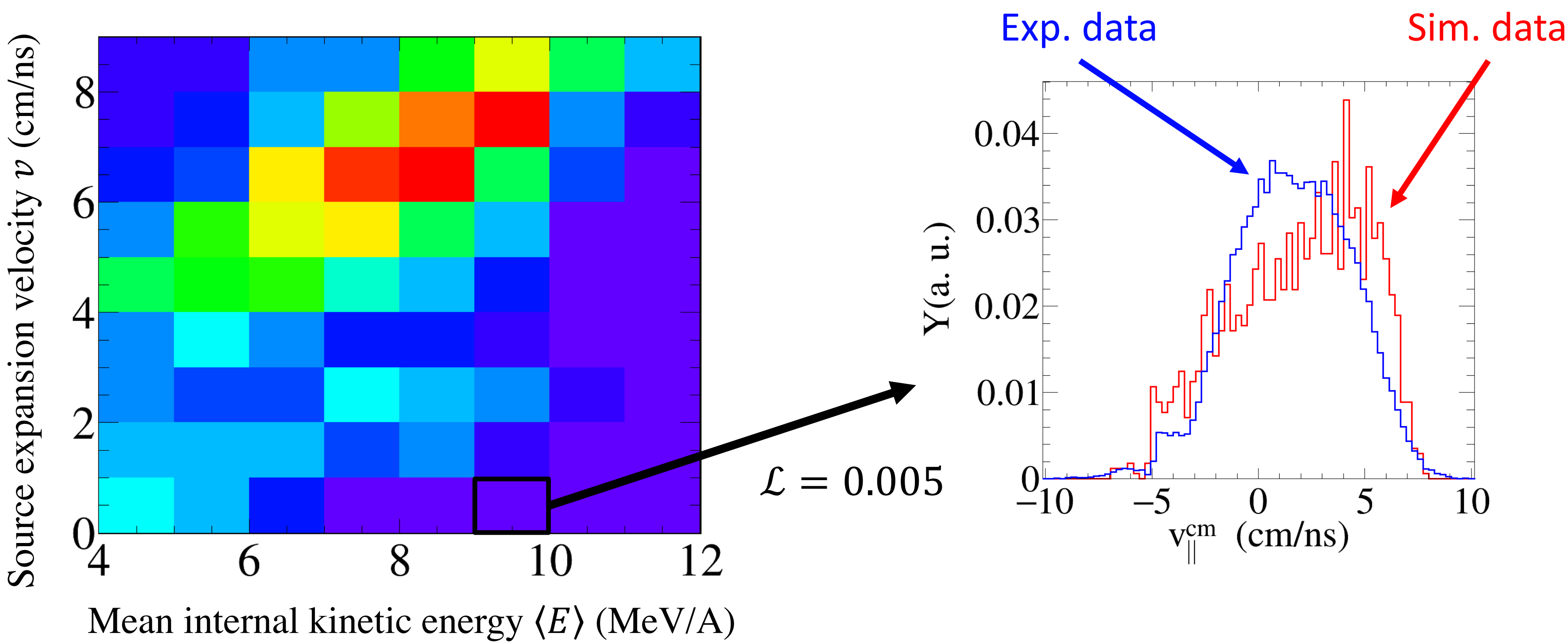

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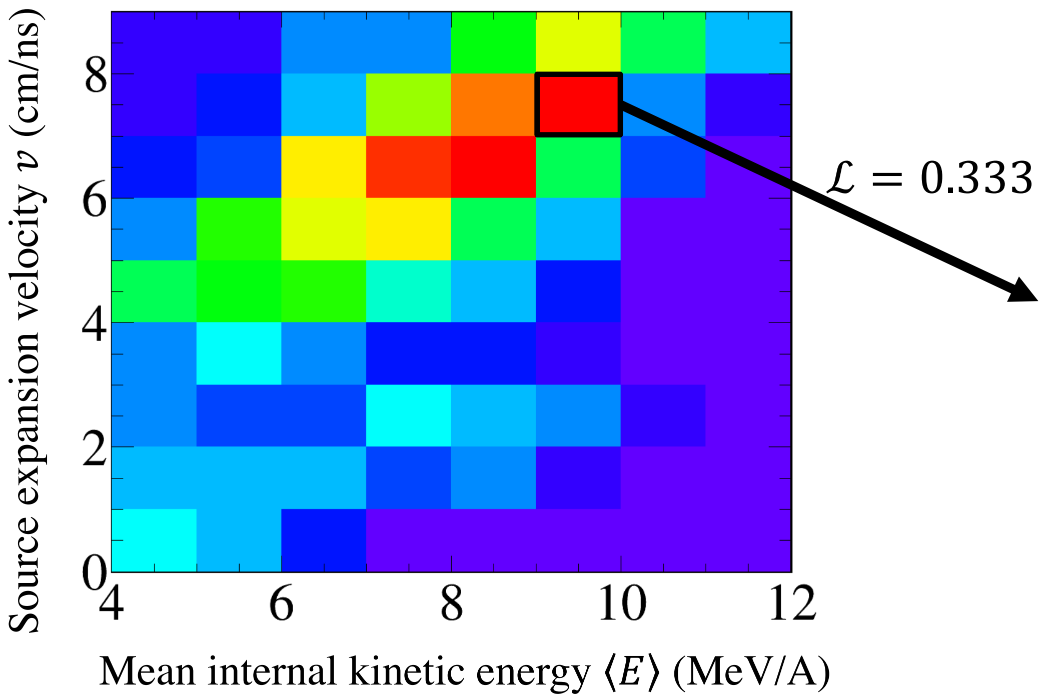

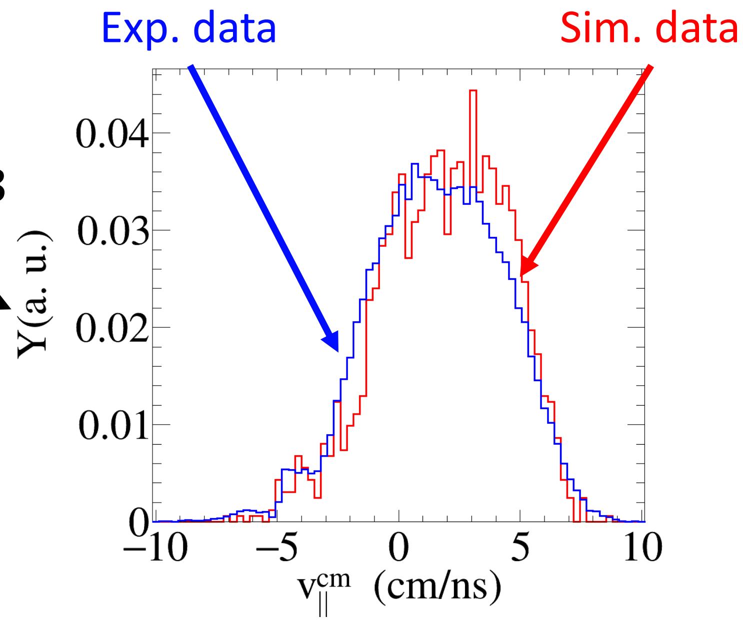

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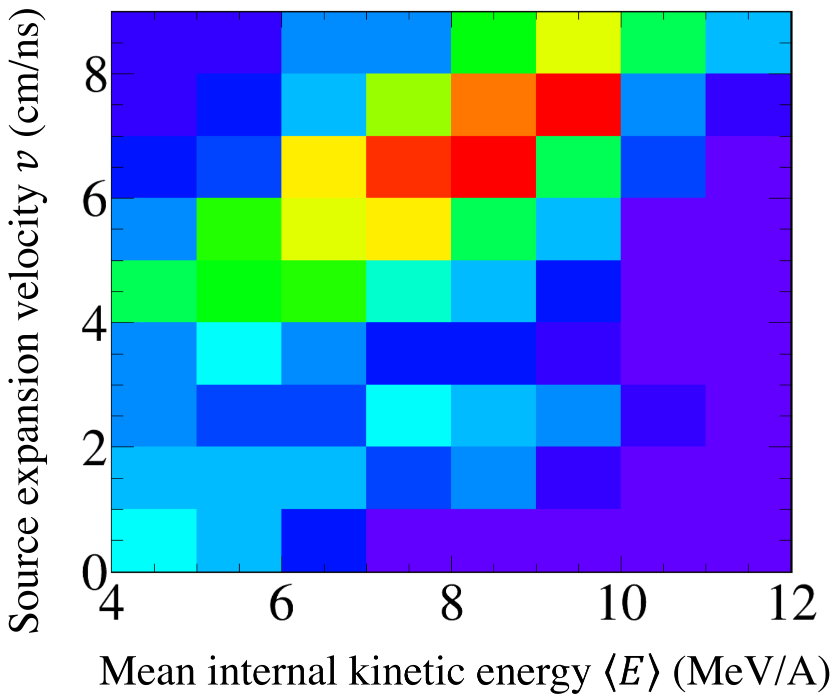
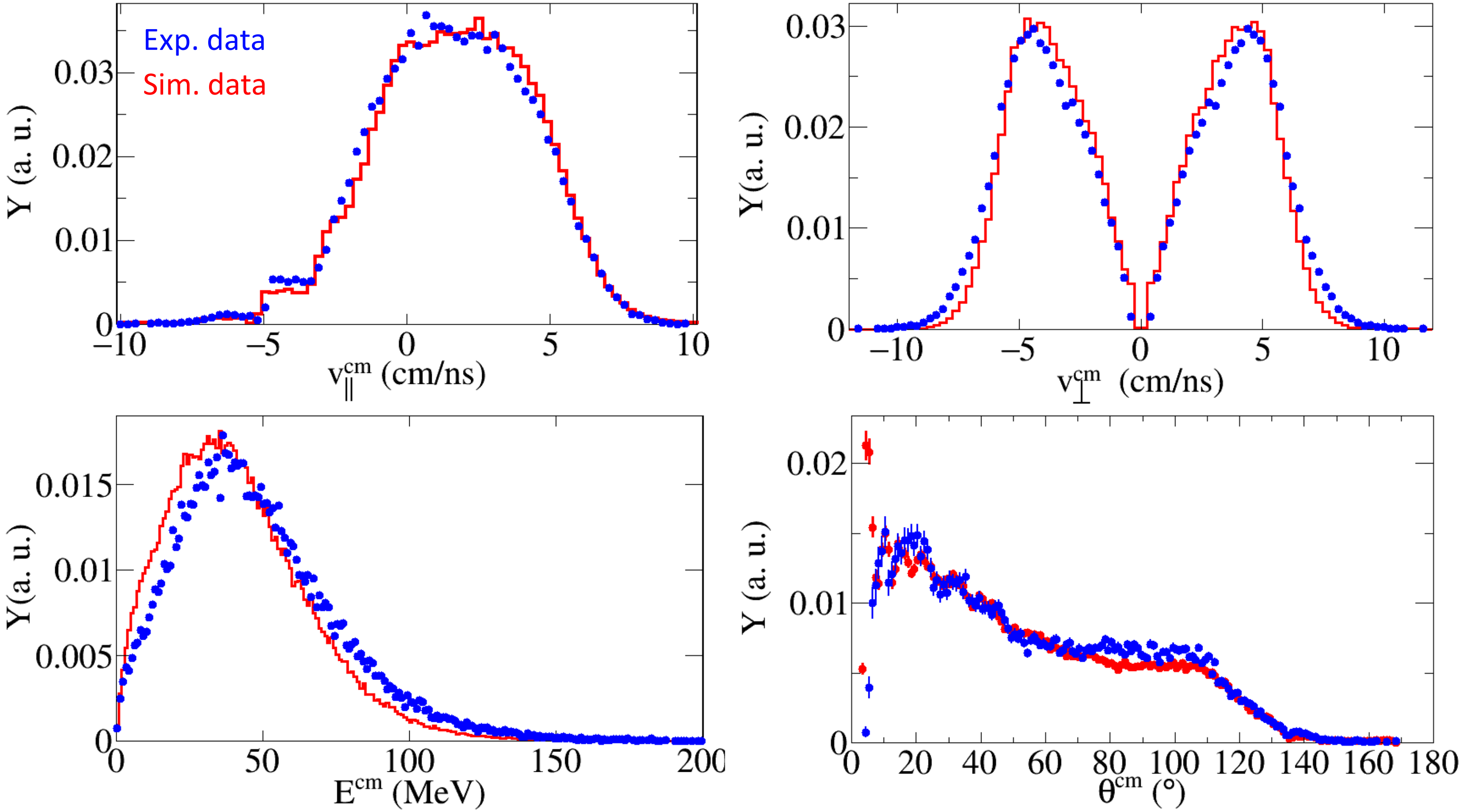


$\Longrightarrow$ We sum all the distributions of the $\{\langle E\rangle, v\}$ space, weighted by $\mathcal{L}$

Nucleons coalescence

At the end we can construct $v_{\perp}^{cm}, v_{\parallel}^{cm}, \theta^{cm}$ and E^{cm} distributions from the simulation

$\Longrightarrow$ Here for the ^{3}He for the system ^{129}Xe + ^{119}Sn at 50 MeV/A we get :

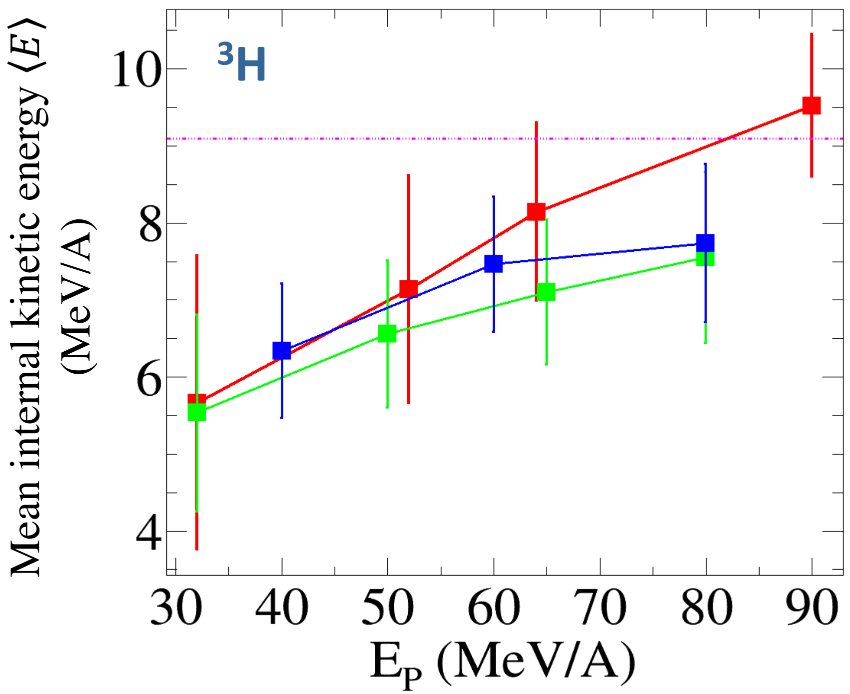


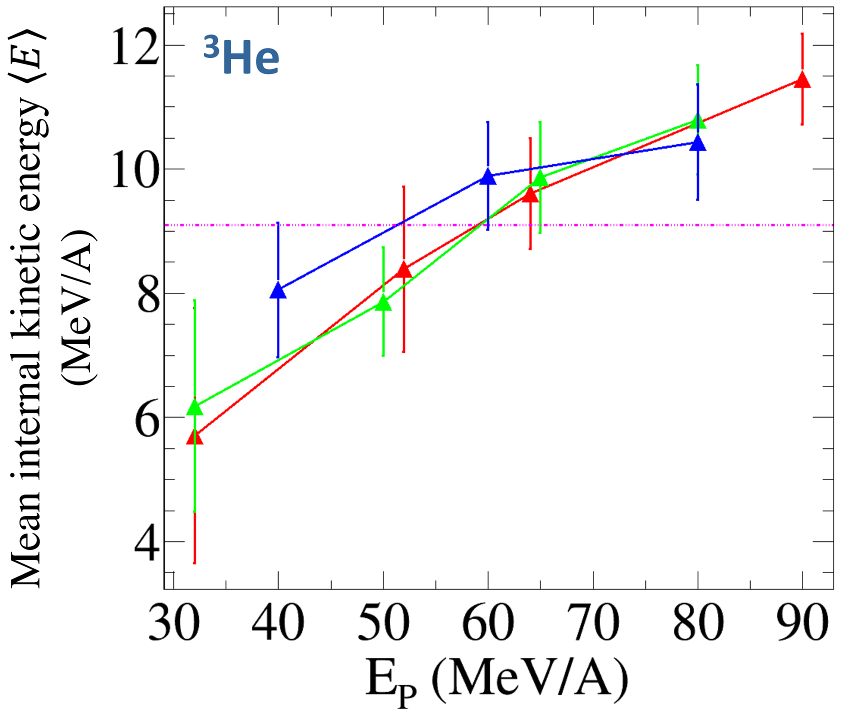
Production of clusters in nuclear matter

For each system :

- generate N clusters ^3H
- generate N clusters ^3He
- extract the mean value of $\langle E \rangle$

System	Energies (MeV/A)
Ni + Ni	32,52,64,90
Xe + Sn	32,50,65,80
Au + Au	40,60,80





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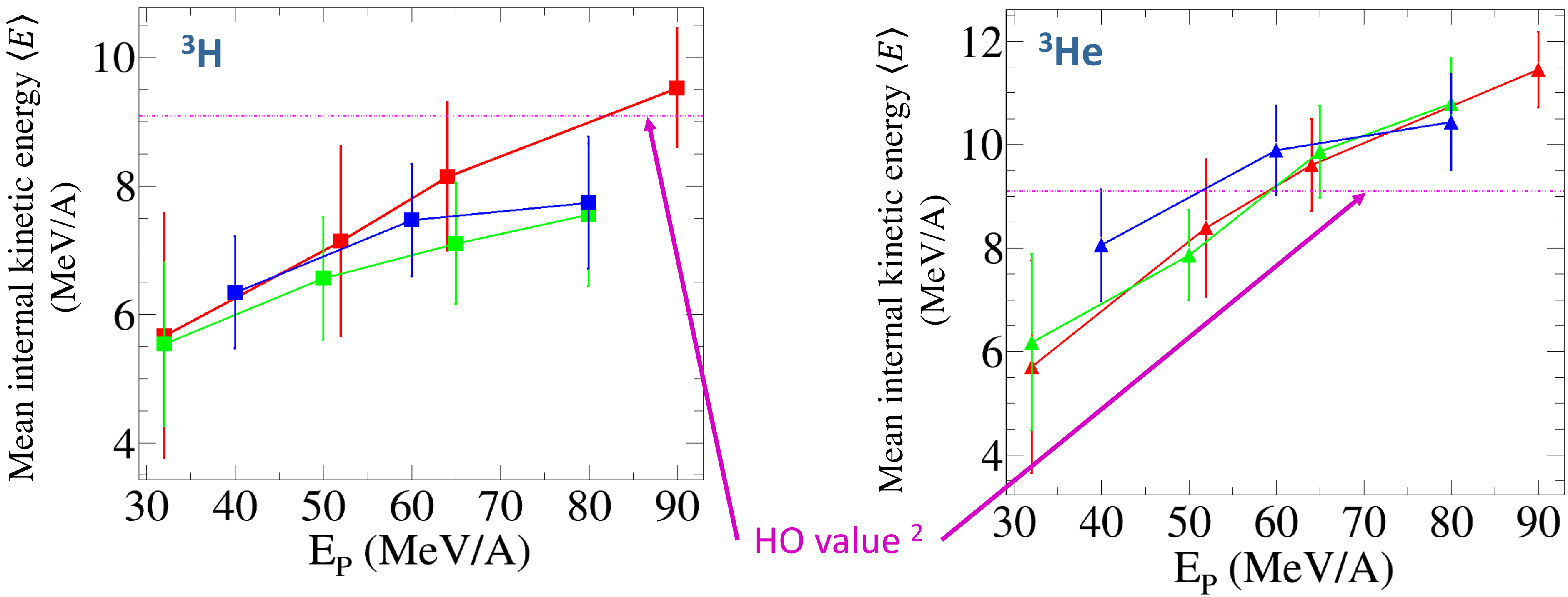


$\Longrightarrow$ Clear dependence between $\langle E \rangle$ and E_P

↳ Possible explanations ?

[2] G. M. Daskalov et al., *Z. Phys. A-Hadron Nucl.* **345**, 223-226 (1993)

Production of clusters in nuclear matter

Possible explanations for the evolution of the mean internal energy of the nucleons in the cluster $\langle E \rangle$ with the projectile energy E_P :

- entrance channel effect : relative momentum increases with E_P

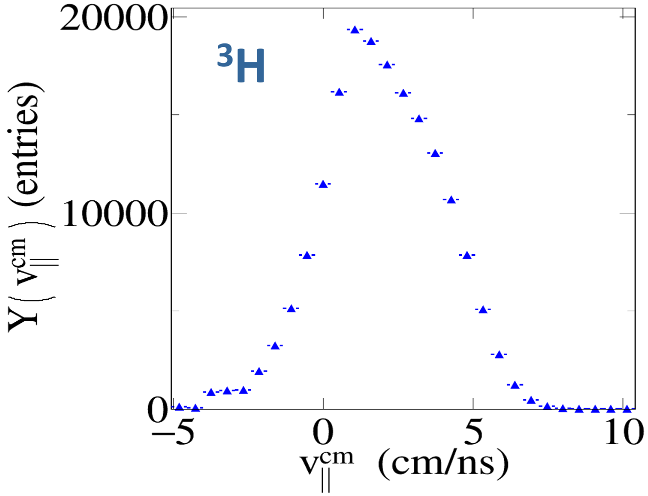
- in-medium effect during compression phase : link with the density

- link with the p_0 momentum of the coalescence approach

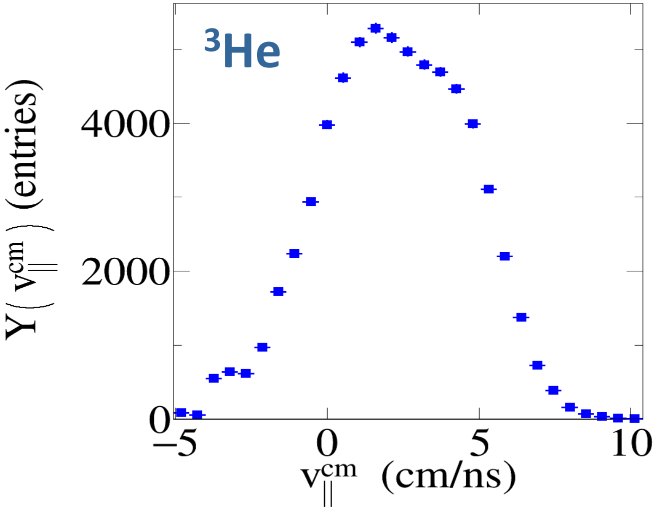
- other explanations ?

Isospin transport with A=3 clusters as trackers

We are looking for this study at the parallel velocity distributions of the ^{3}H and ^{3}He, and computing for each systems the ratio between those distributions :



(here ^{129}Xe + ^{119}Sn @ 50 MeV/A for ^{3}He)



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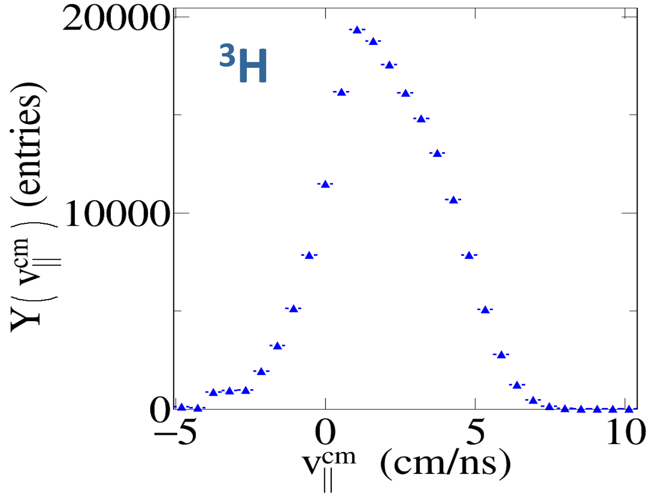

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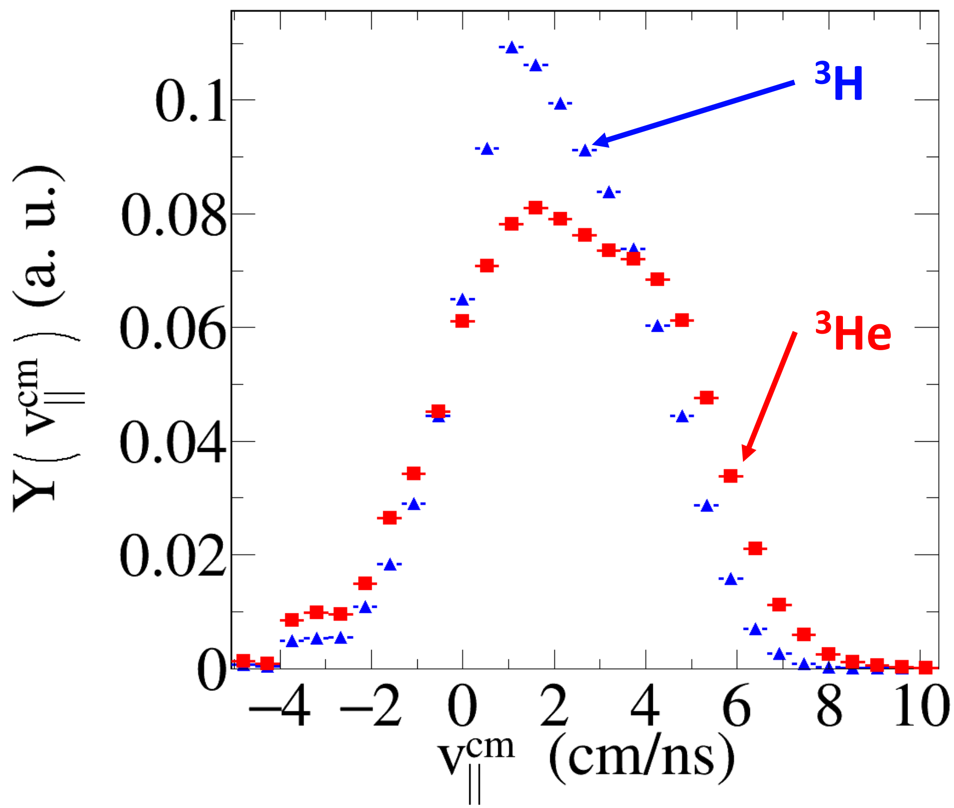

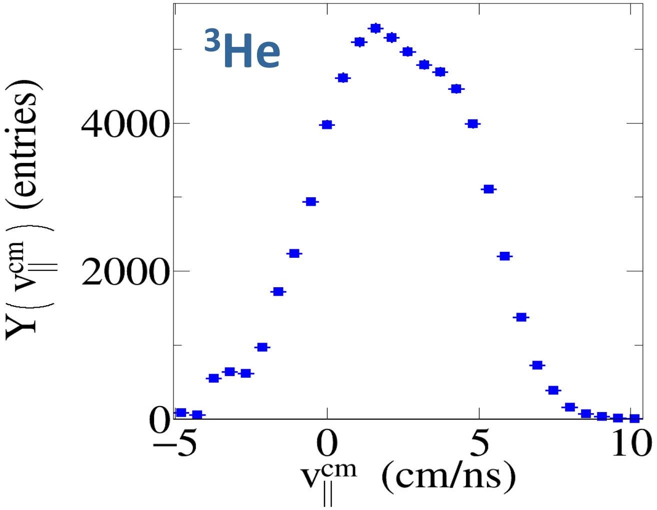

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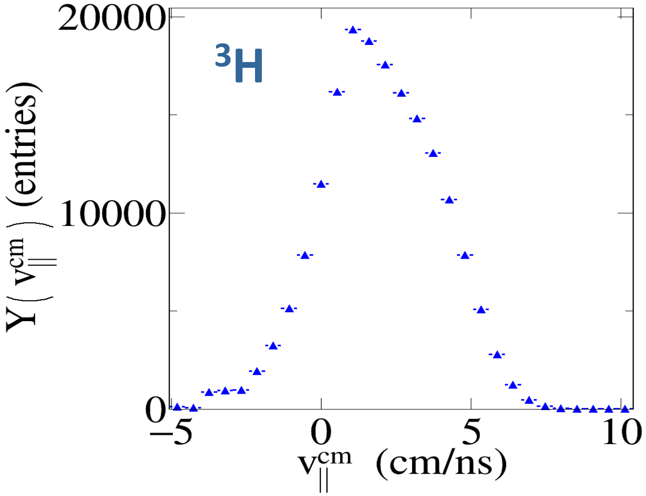

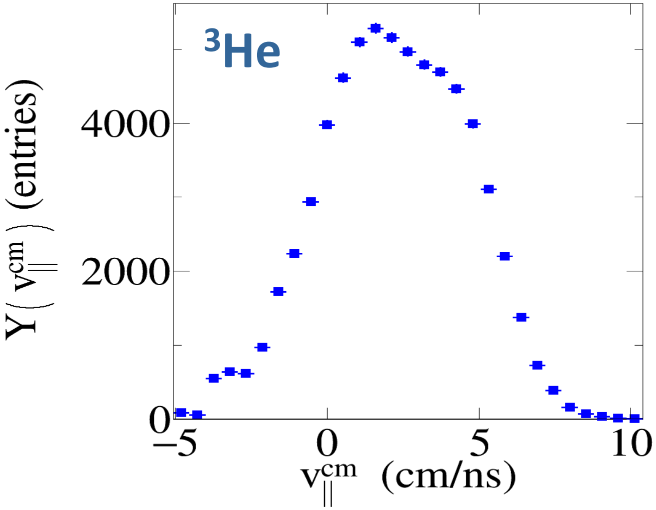

(here $^{129}Xe + ^{119}Sn$ @ 50 MeV/A for ^3He)

$$R_3 = \frac{Y(v_{\parallel}^{cm},\ ^3H)}{Y(v_{\parallel}^{cm},\ ^3He)}$$

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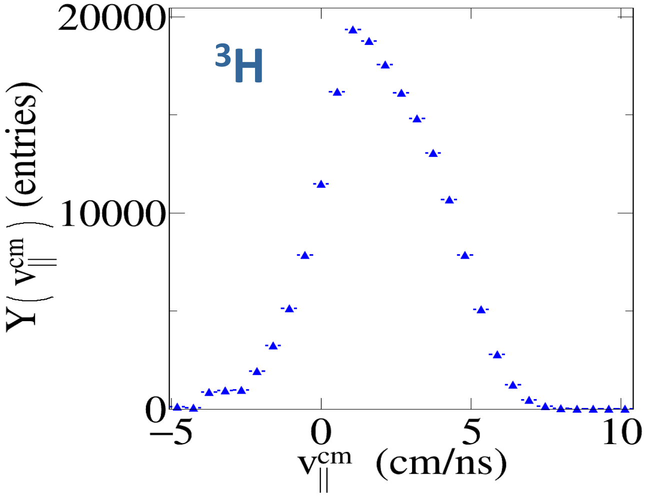

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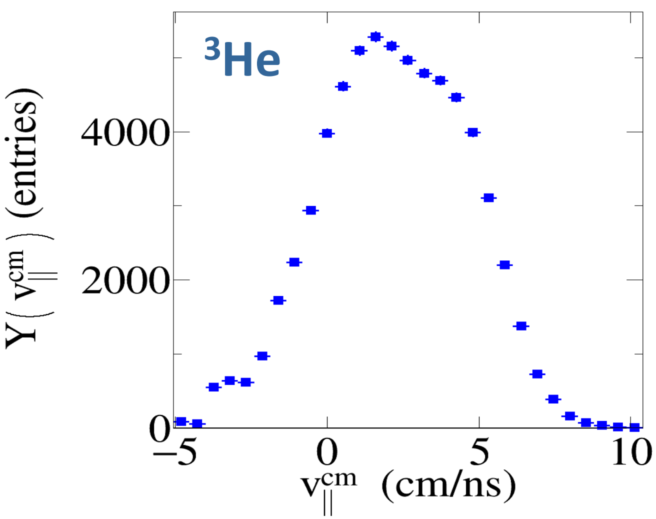
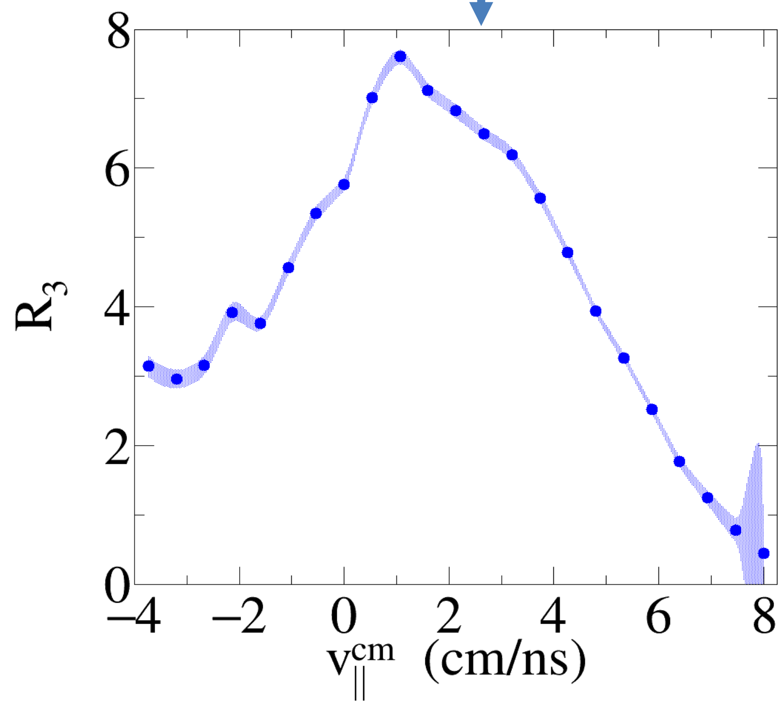


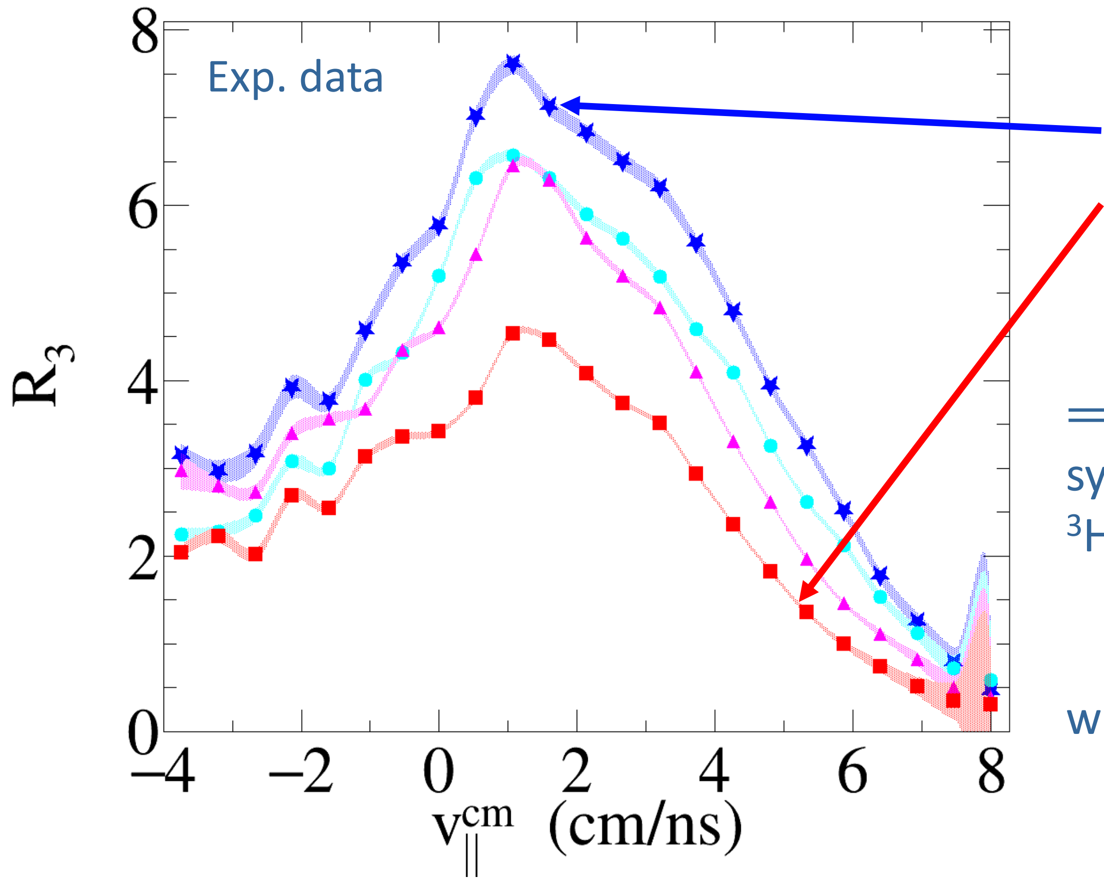


Isospin transport with A=3 clusters as trackers

For the analysis with use 4 systems with an isospin asymmetry from 0.12 to 0.20

R_3 ratios on experimental data give :

System (at 32 MeV/A)	δ
$^{136}Xe + ^{124}Sn$ (★)	0.20
$^{136}Xe + ^{112}Sn$ (●)	0.16
$^{124}Xe + ^{124}Sn$ (▲)	0.16
$^{124}Xe + ^{112}Sn$ (■)	0.12



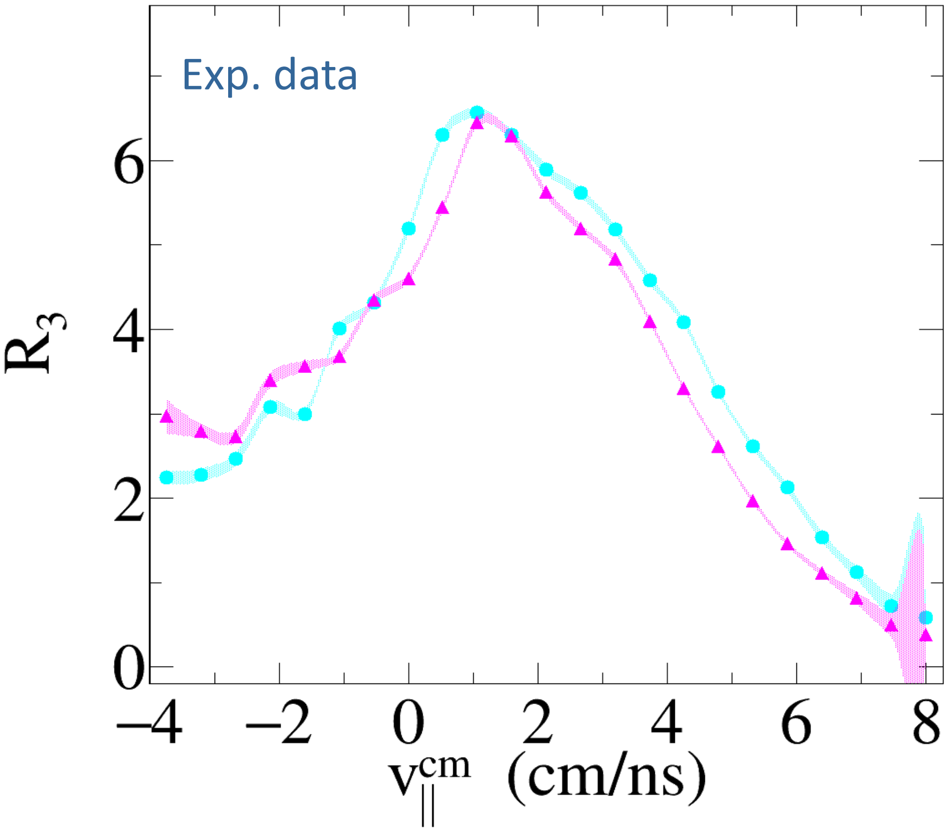
⟹ In the data, the more neutron rich system lead to a higher production of ^3H than the more neutron poor one

↳ What about the two systems with the same number of neutrons?

Isospin transport with A=3 clusters as trackers

System (at 32 MeV/A)	δ
$^{136}Xe + ^{112}Sn$ (●)	0.16
$^{124}Xe + ^{124}Sn$ (▲)	0.16

Focus here on the two systems with the same total number of neutrons.



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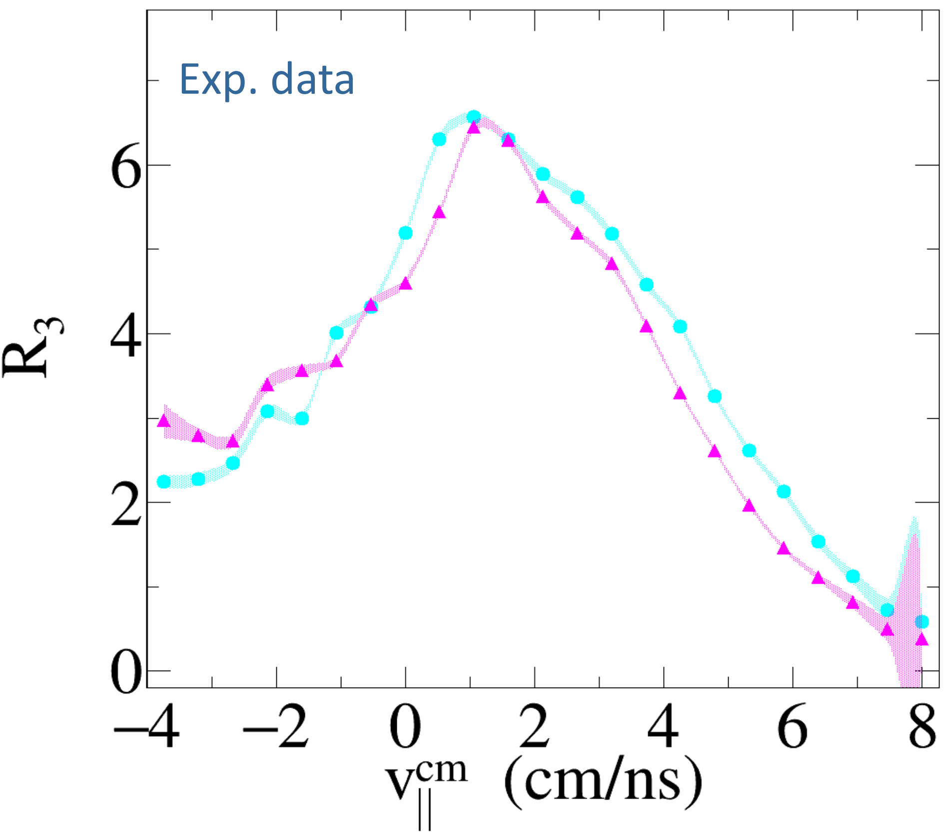

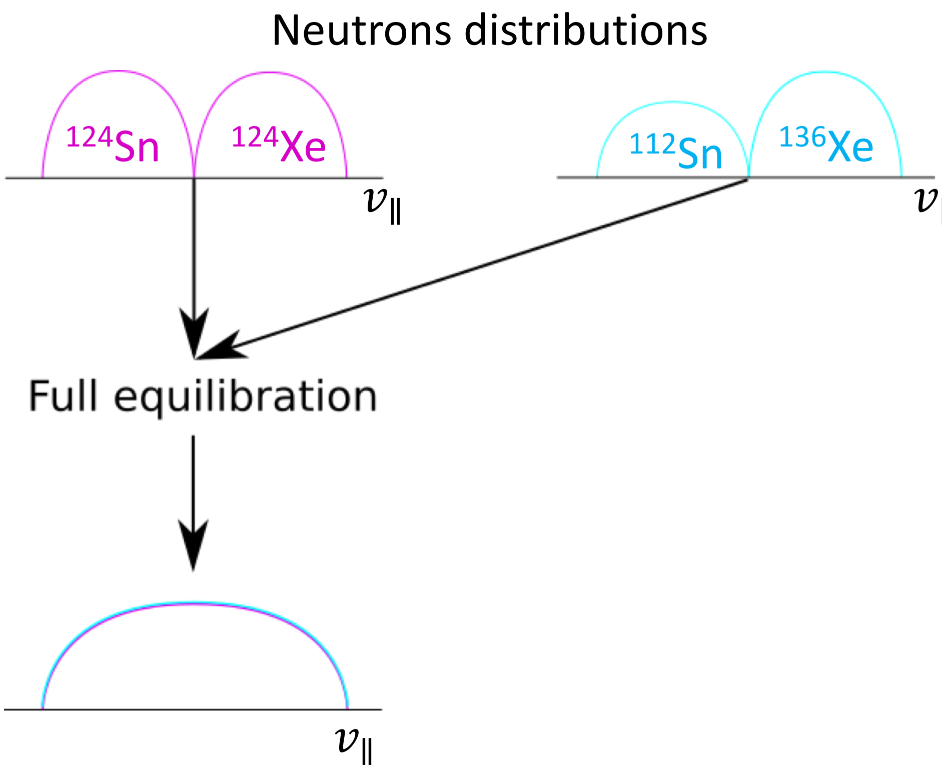

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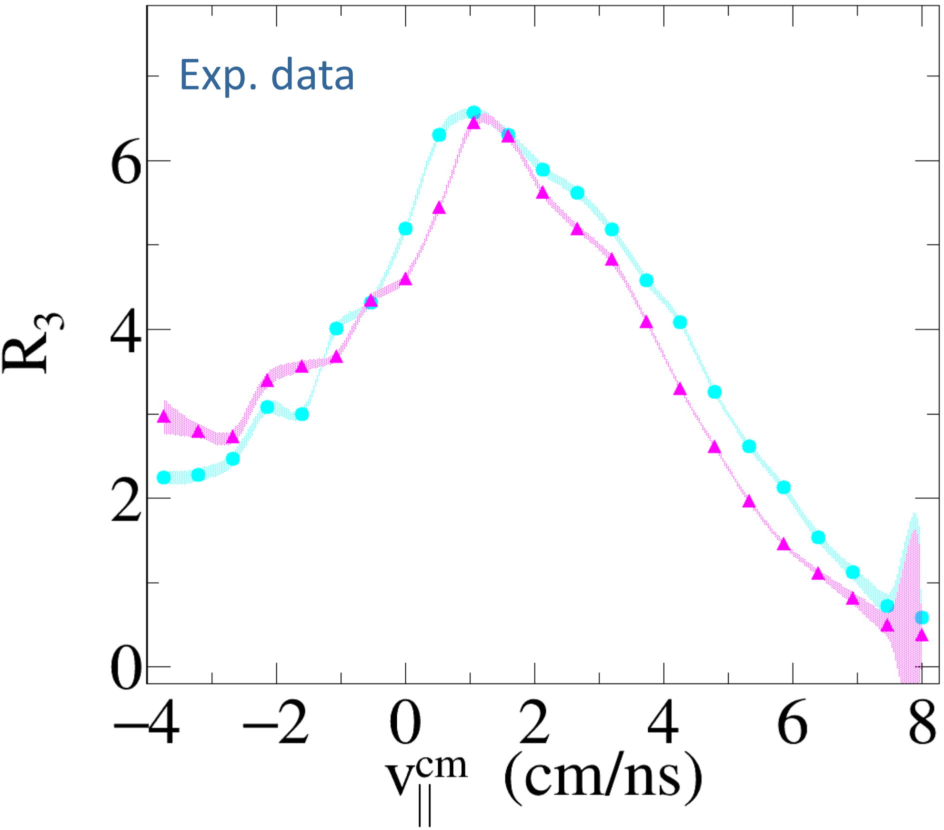

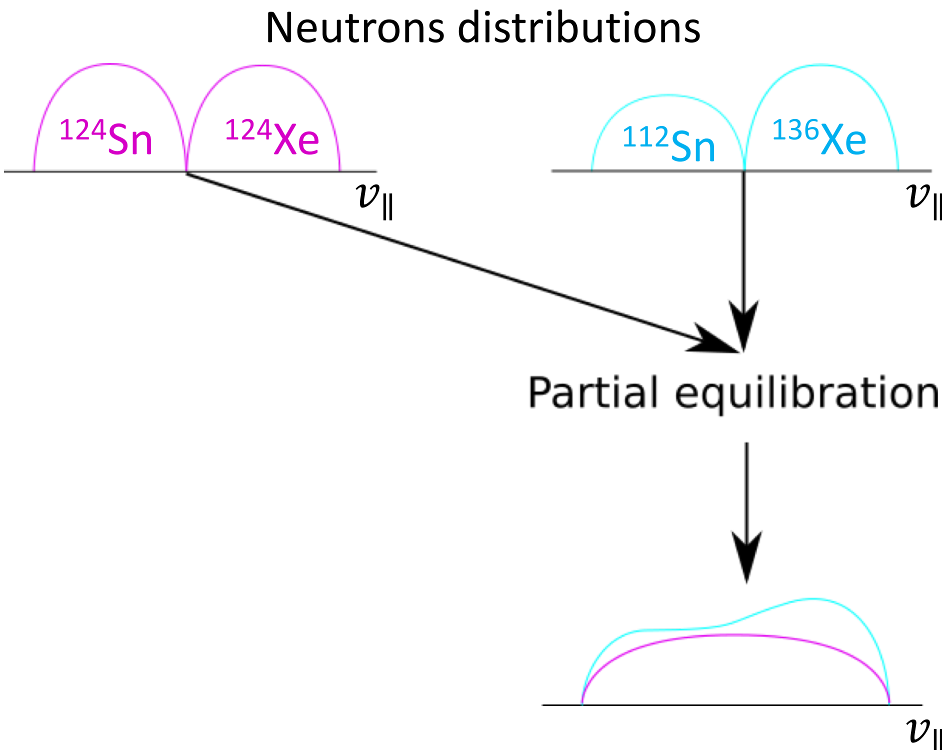

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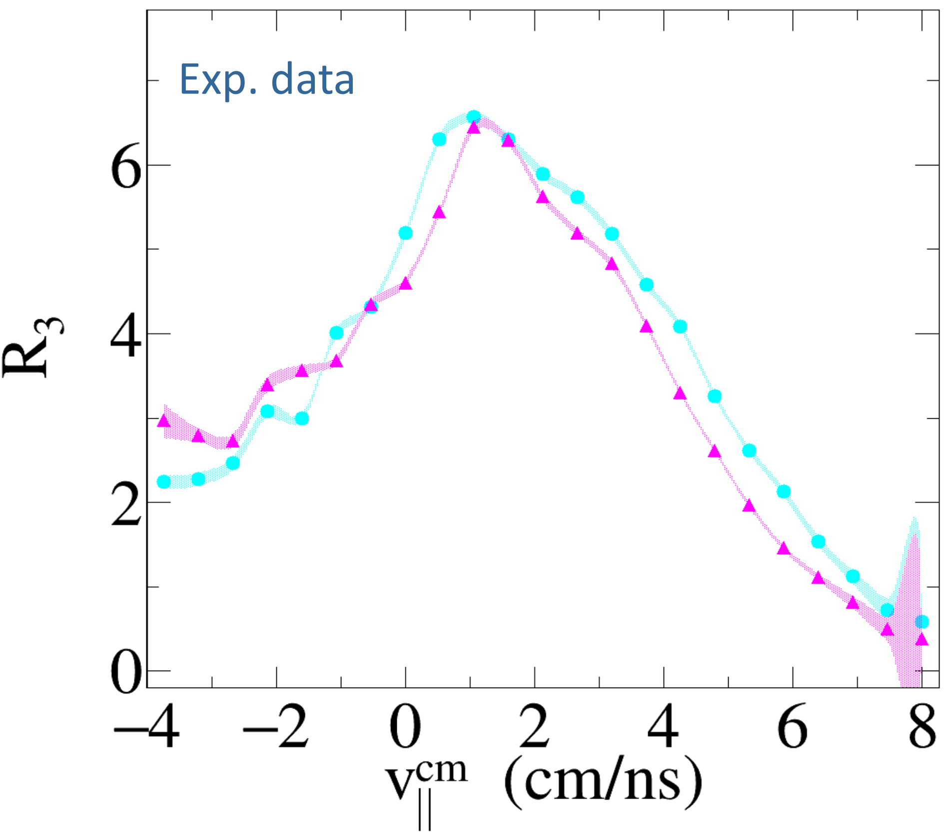
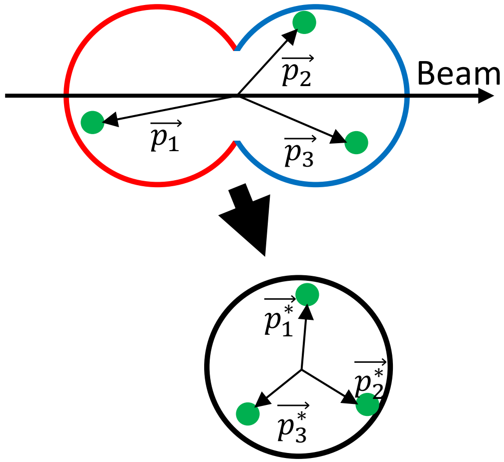


⟹ Suggests that isospin is not fully equilibrated in central collisions for isobaric A=3 clusters as probes

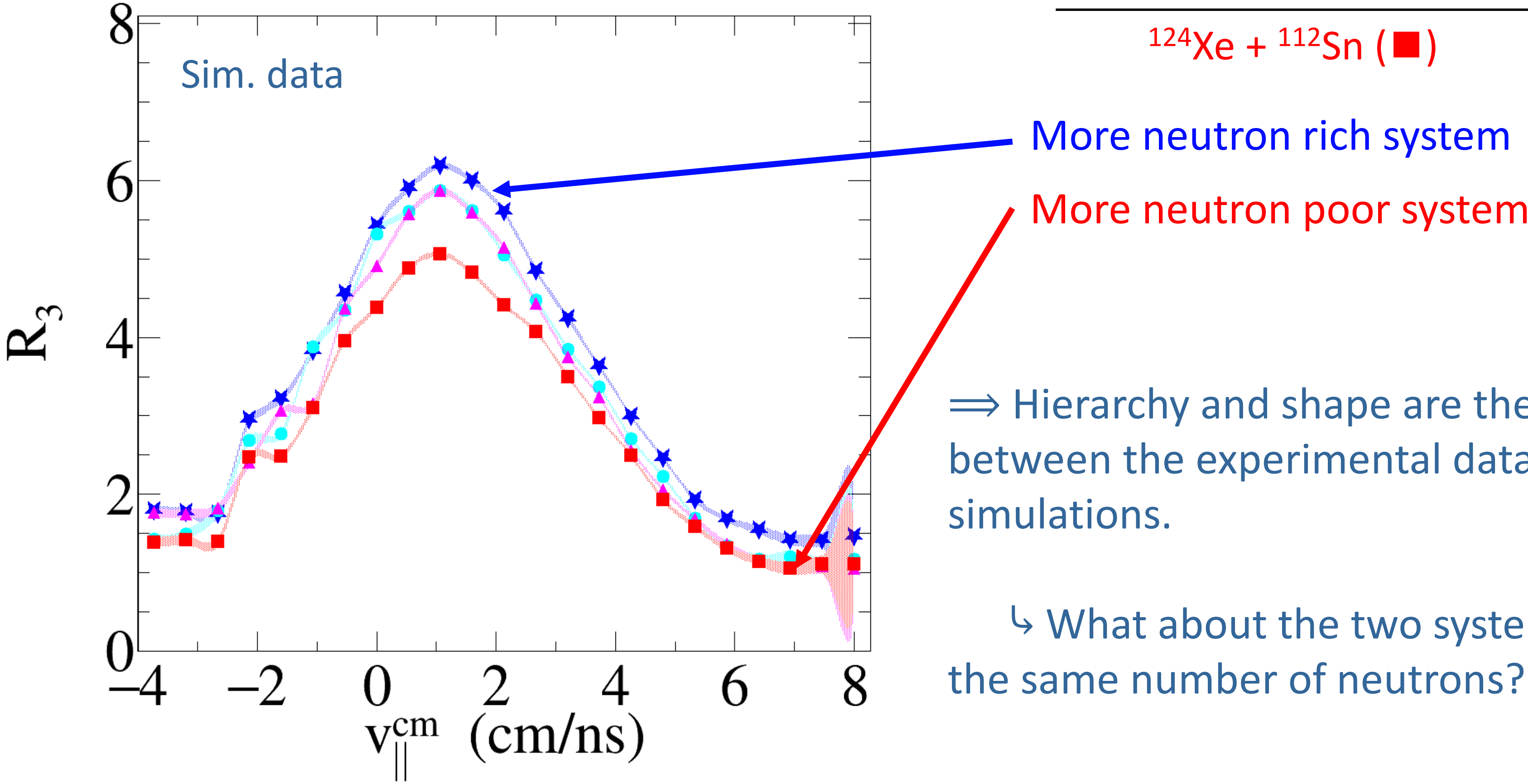
↳ Is the model able to reproduce the same trends ?



Isospin transport with A=3 clusters as trackers

For each system :
- generate N clusters A=3 (^3H,^3He)
- compute R_3 ratios

System (at 32 MeV/A)	δ
$^{136}Xe + ^{124}Sn$ (★)	0.20
$^{136}Xe + ^{112}Sn$ (●)	0.16
$^{124}Xe + ^{124}Sn$ (▲)	0.16
$^{124}Xe + ^{112}Sn$ (■)	0.12

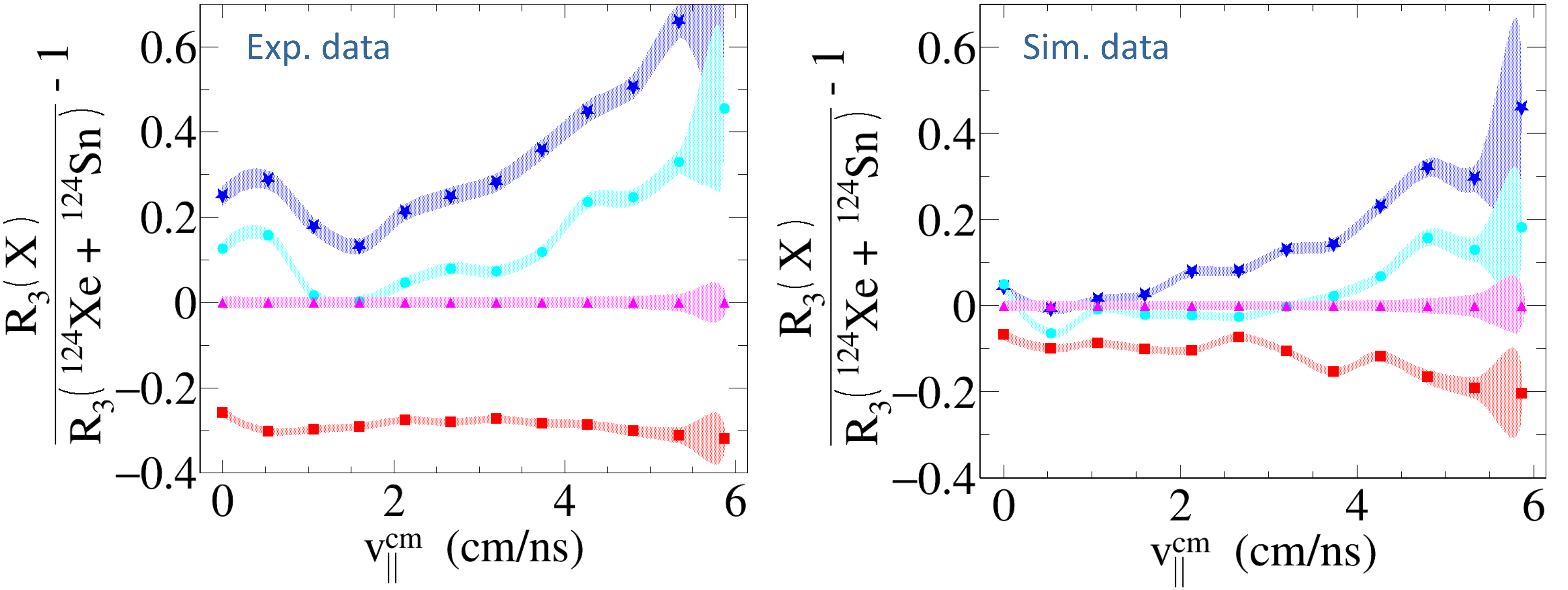


⟹ Hierarchy and shape are the same between the experimental data and the simulations.

↳ What about the two systems with the same number of neutrons?

Isospin transport with A=3 clusters as trackers

We compare experimental data and simulations by "normalizing" the R_3 ratios by the one of the $^{124}Xe + ^{124}Sn$

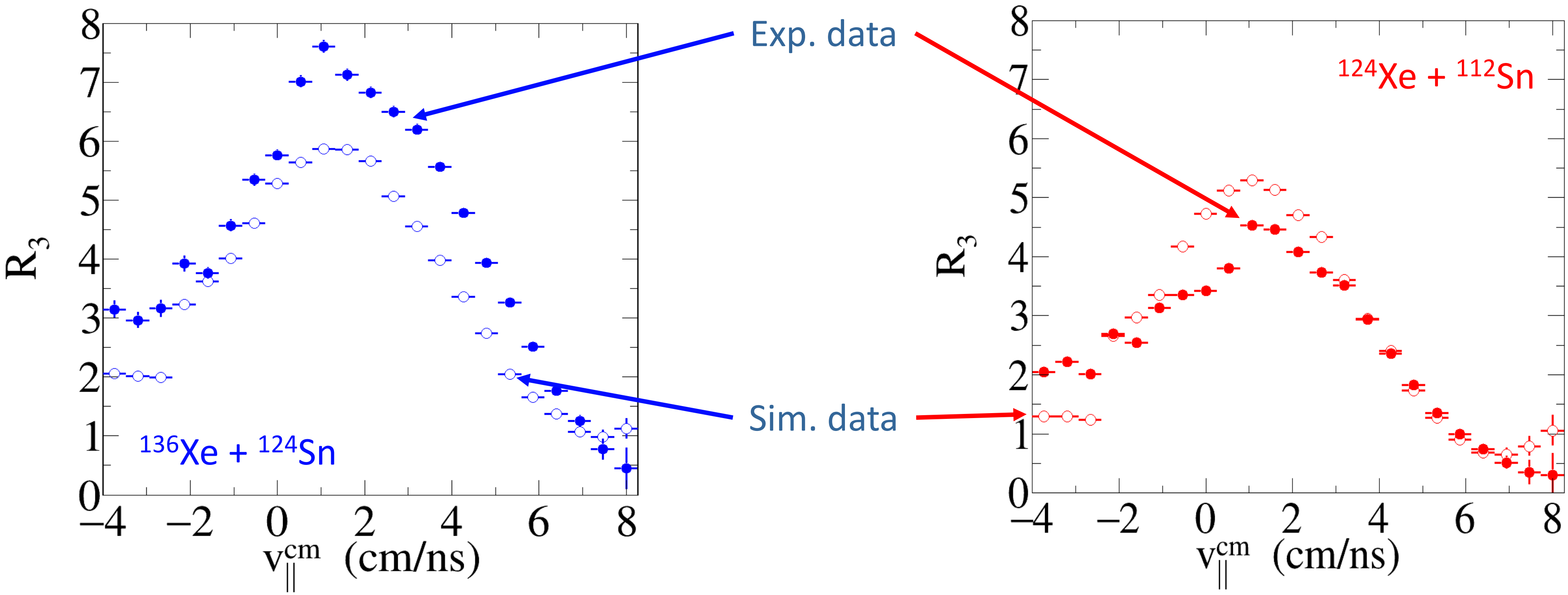


⟹ In the experimental data or the simulated ones : isospin not fully equilibrated, but the effect is very small in the simulation

↳ Do we know why ?

Isospin transport with A=3 clusters as trackers

By looking at the R_3 ratios we see that the simulation does not reproduced the production rates of the ^3H and/or ^3He



⟹ Deviation from pure combinatorial model

↳ Use more realistic models (from inclusive to exclusive approach) !

⟹ Secondary decay may populates ^3H distributions

Conclusions and outlooks

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- with combinatorial and coalescence model we were able to reproduce the experimental distributions of $v_{\perp}^{cm}, v_{\parallel}^{cm}, \theta^{cm}$ and E^{cm}.
- nucleons mean internal energy $\langle E \rangle$ evolves with E_P
- results suggests that isospin is not fully equilibrated in central collisions with A=3 clusters as probes, but that the effect is very small in the simulated data
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Outlooks :

- use more realistic events generators
- relaxing centrality condition to observe how isospin transport observables are modified
- include fragments in the isospin study (FAZIA/INDRA program at GANIL)

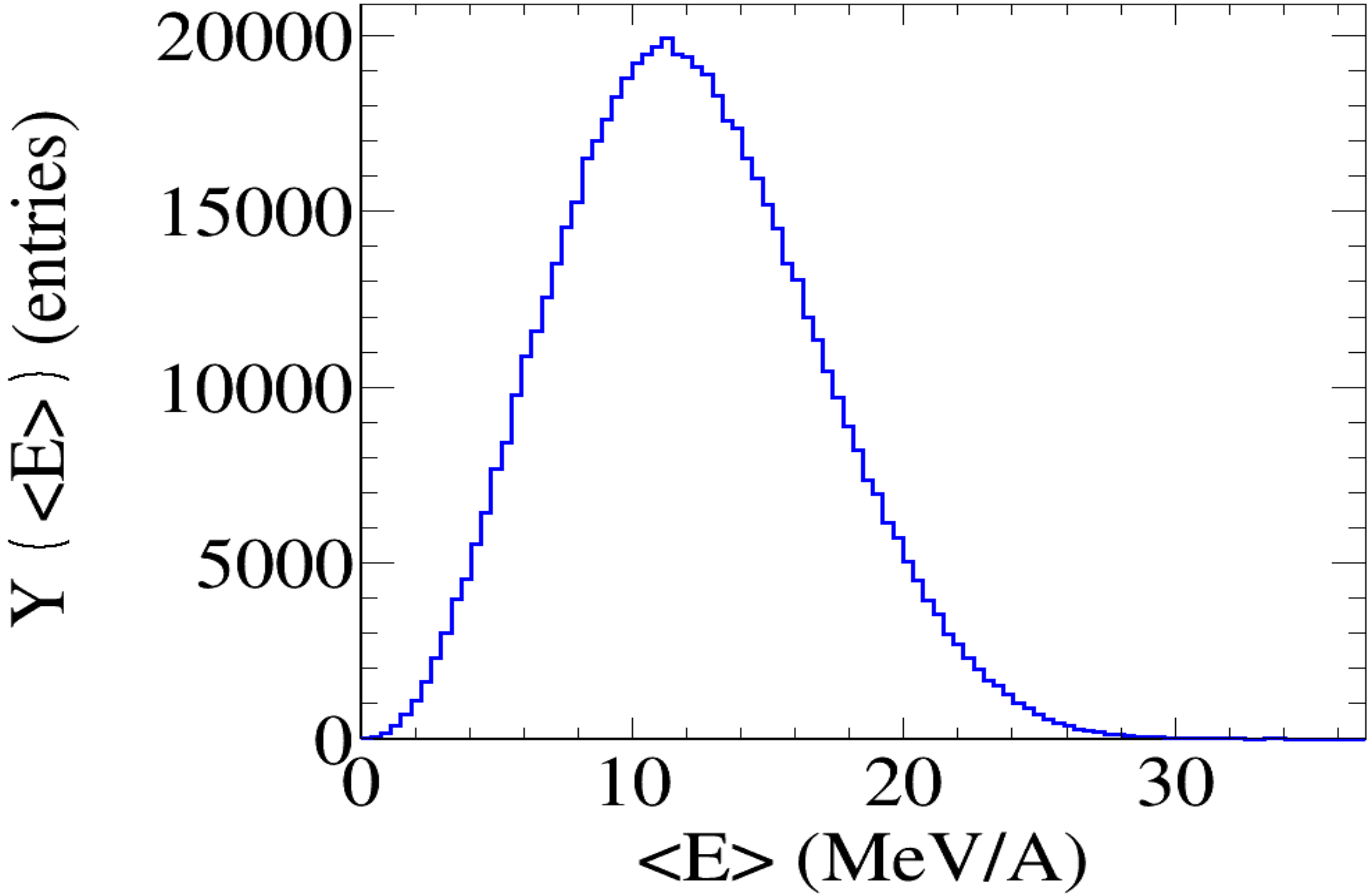
Backup

Integrated produced clusters

System	Exp. data		Sim. data	
	^{3}H	^{3}He	^{3}H	^{3}He
$^{136}Xe + ^{124}Sn$	73 %	27 %	68 %	32 %
$^{136}Xe + ^{112}Sn$	70 %	30 %	67 %	33 %
$^{124}Xe + ^{124}Sn$	68 %	32 %	67 %	33 %
$^{124}Xe + ^{112}Sn$	61 %	39 %	65 %	35 %

Integrated production rate of the ^{3}H and the ^{3}He in the experimental data and in the simulated data.
We clearly see the difference between the experiment and the simulation.

Mean energy of nucleons in cluster



Distribution of the mean internal kinetic energy of the nucleons in the cluster, from the filtered simulation for the system $^{129}Xe + ^{119}Sn$ at 50 MeV/A for the ^{3}He cluster.