A new approach to detect hypernuclei and isotopes in the QMD phase space distribution at relativistic energies

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- ➡ Because, apart from emitted elementary particles, they carry the only information that the experimental instruments can measure.

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- ➡ Because, apart from emitted elementary particles, they carry the only information that the experimental instruments can measure.
- Making clusters is not an easy task, because it involves, in a complex environment:
  - the fundamental nuclear properties,
  - quantum effects,
  - and variable timescales.

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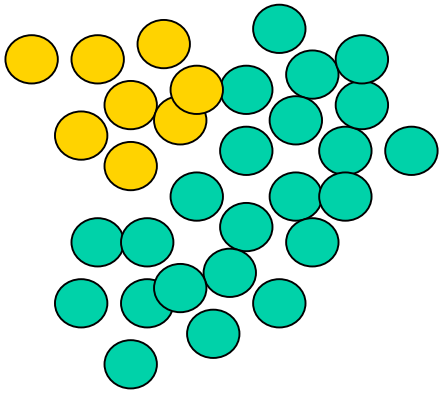
d) Choose that configuration which has the highest binding energy.
Simulations show: Clusters chosen that way at early times are the pre-fragments of the final state clusters, because fragments are not a random collection of nucleons at the end but initial-final state correlations.

SACA: How does this work?

Simulated Annealing Procedure: PLB301:328,1993; later called SACA.

2 steps:

1) Pre-select good «candidates» for fragments according to proximity criteria: real space coalescence = Minimum Spanning Tree (MST) procedure.



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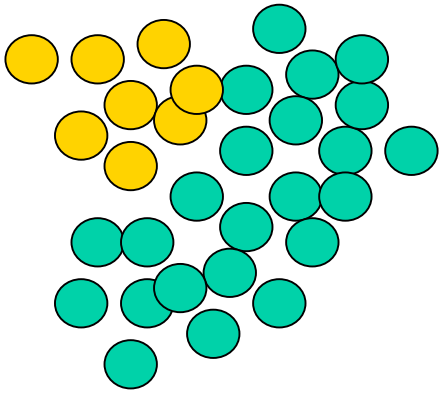

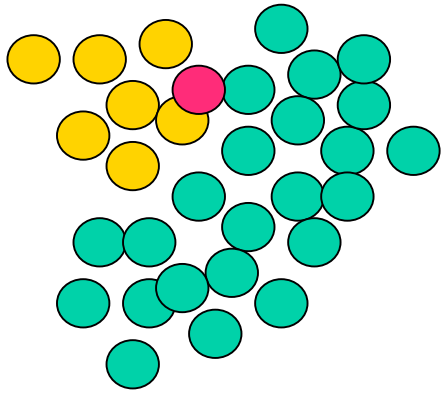

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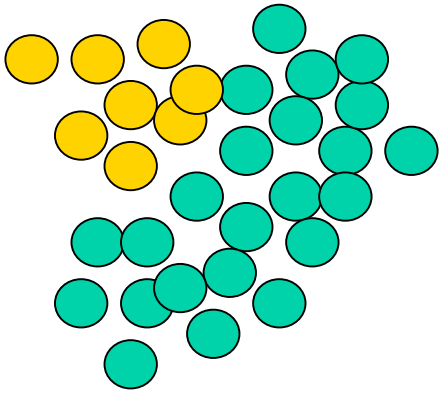

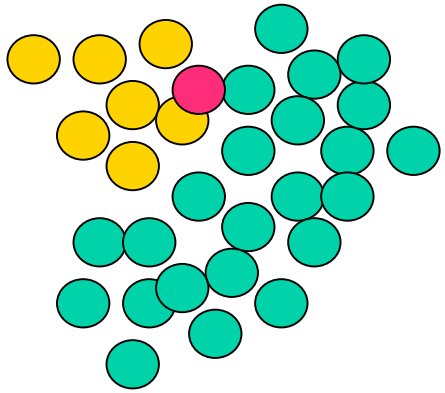

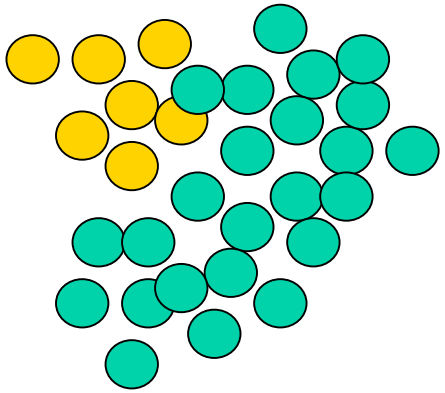

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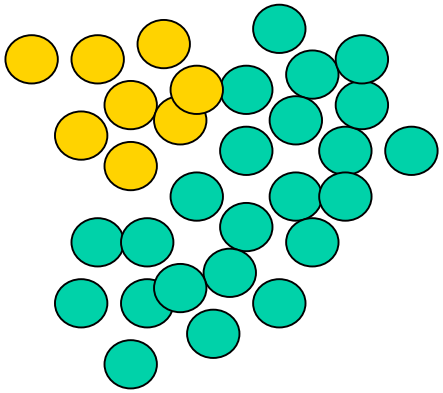

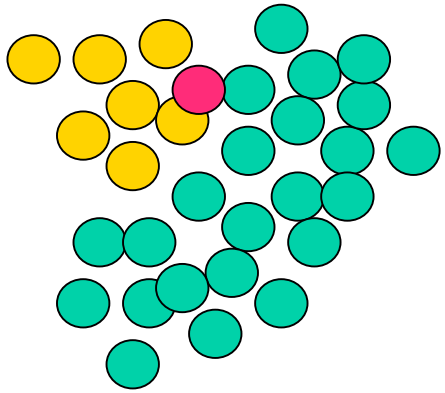

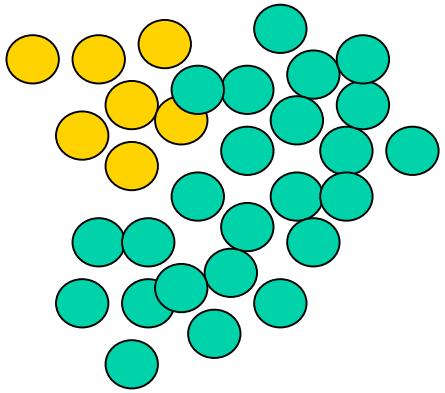

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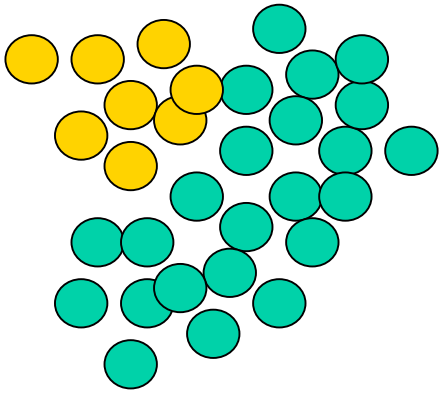

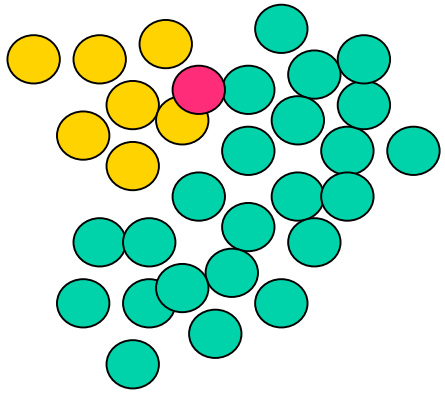

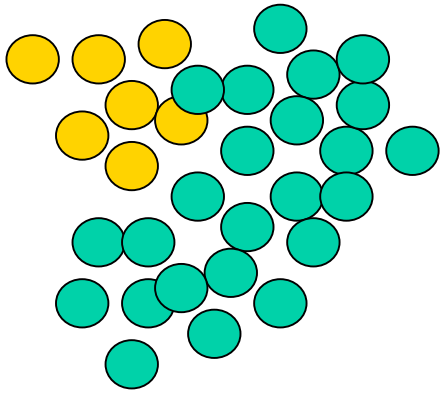

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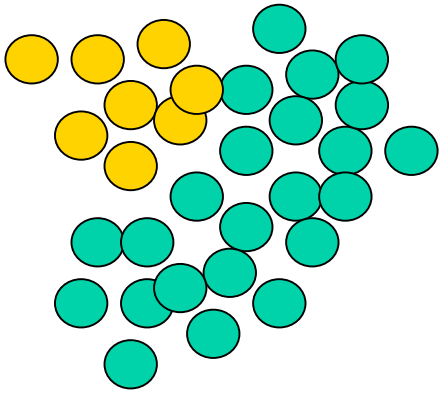

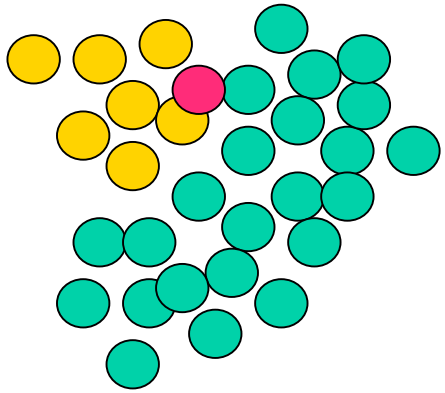

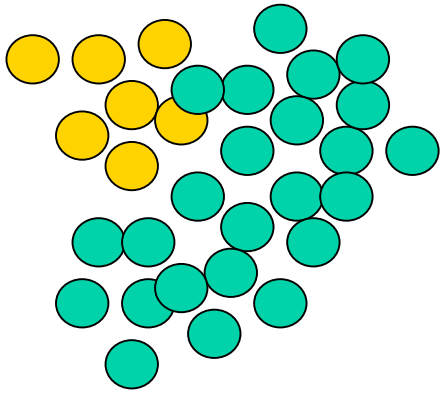

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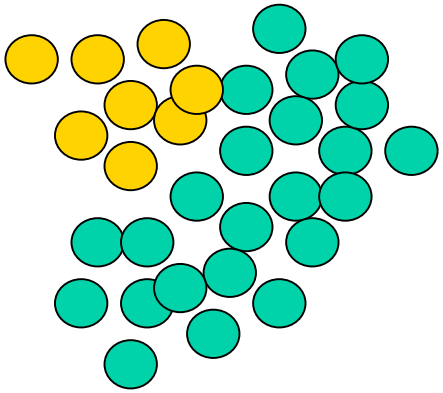

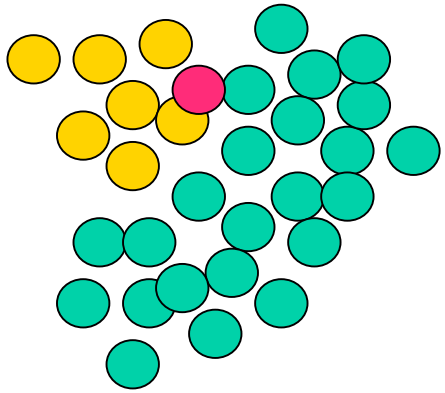

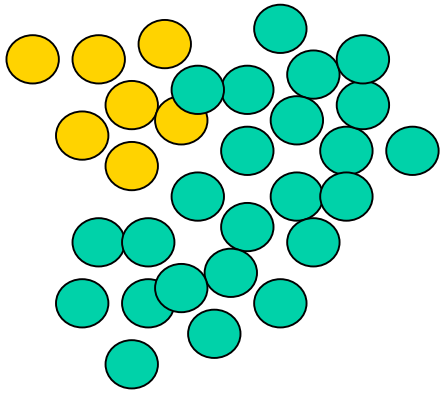

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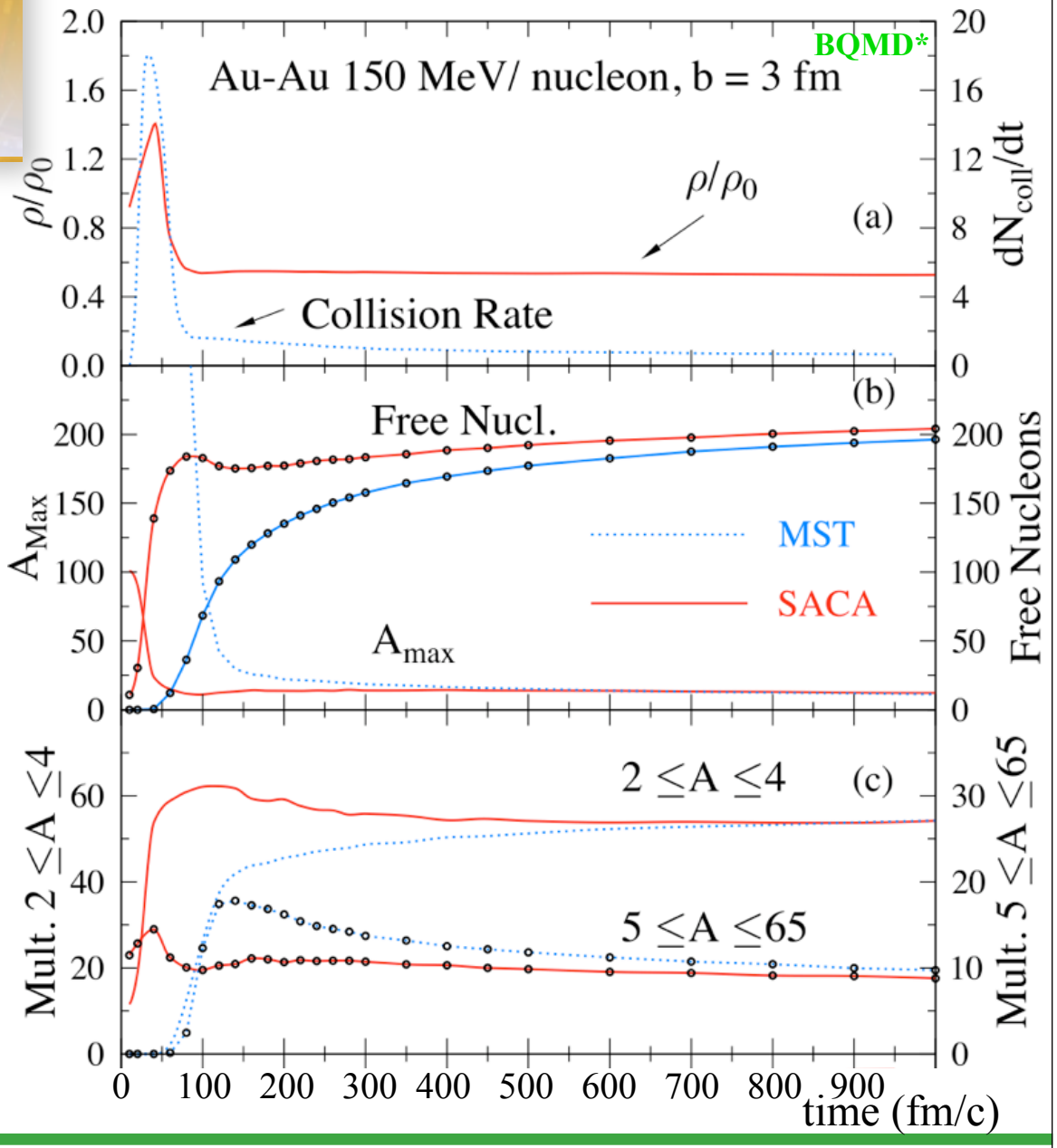
It leads automatically to the most bound configuration.

SACA versus coalescence (Minimum Spanning Tree)



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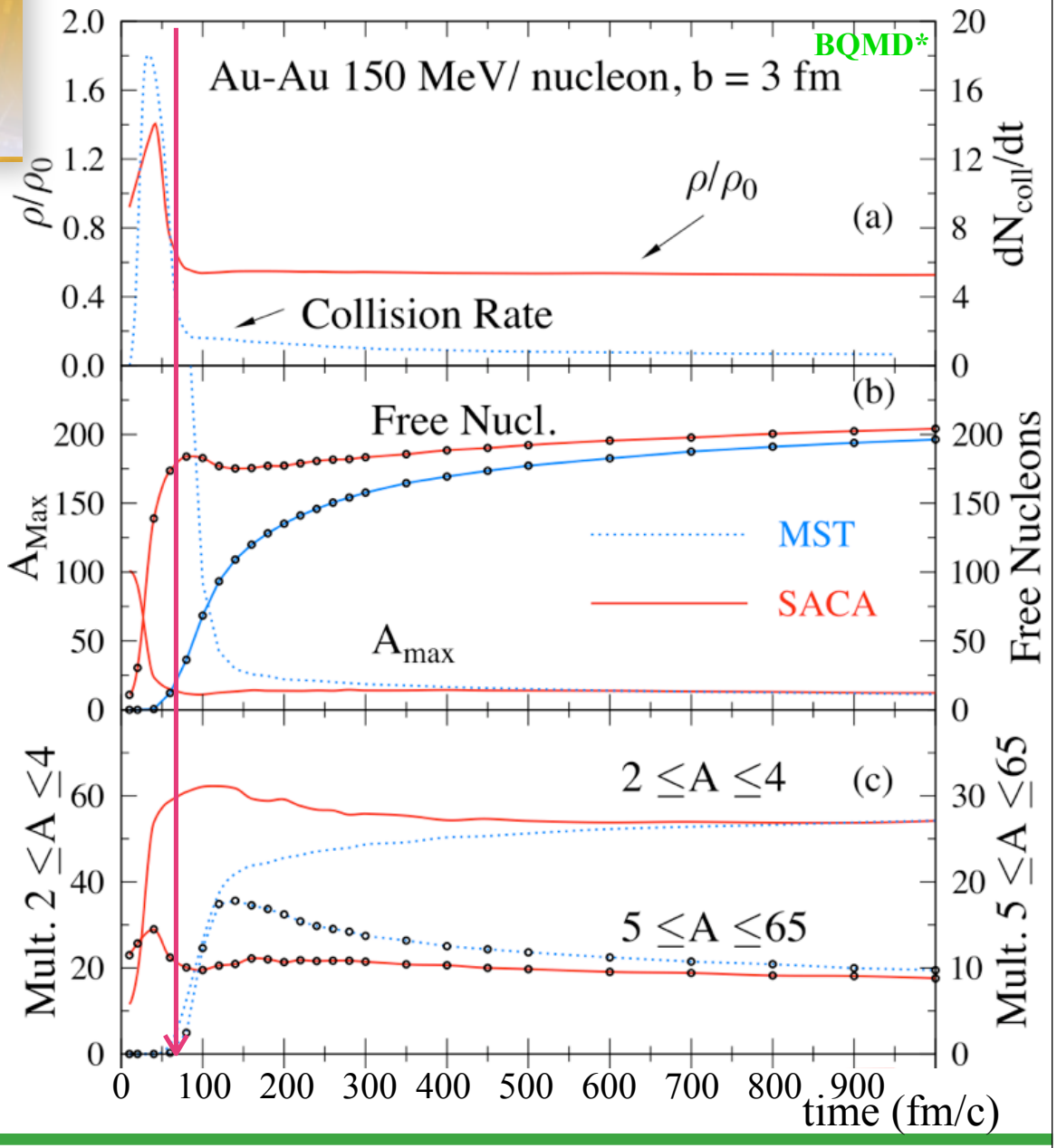

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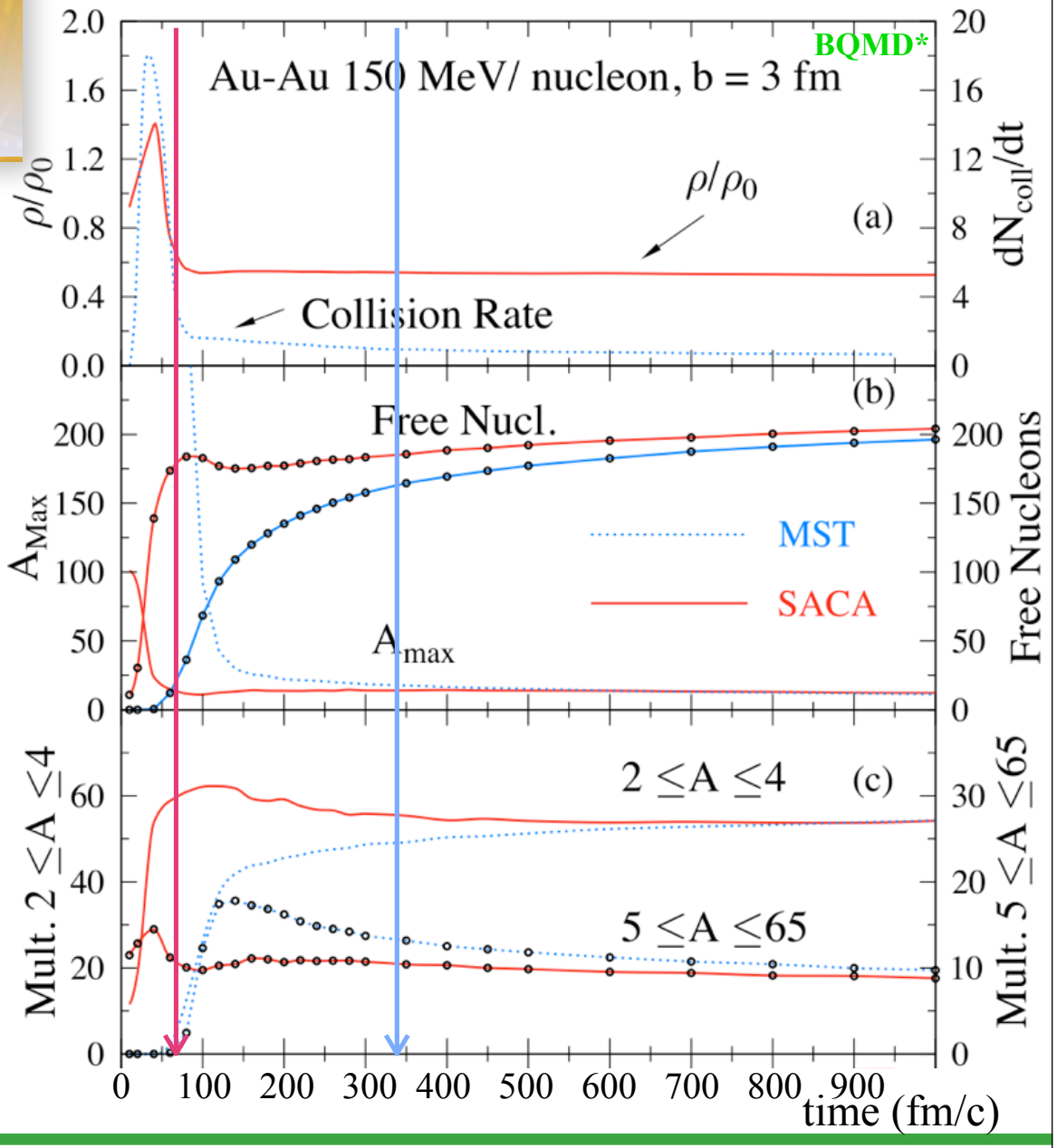

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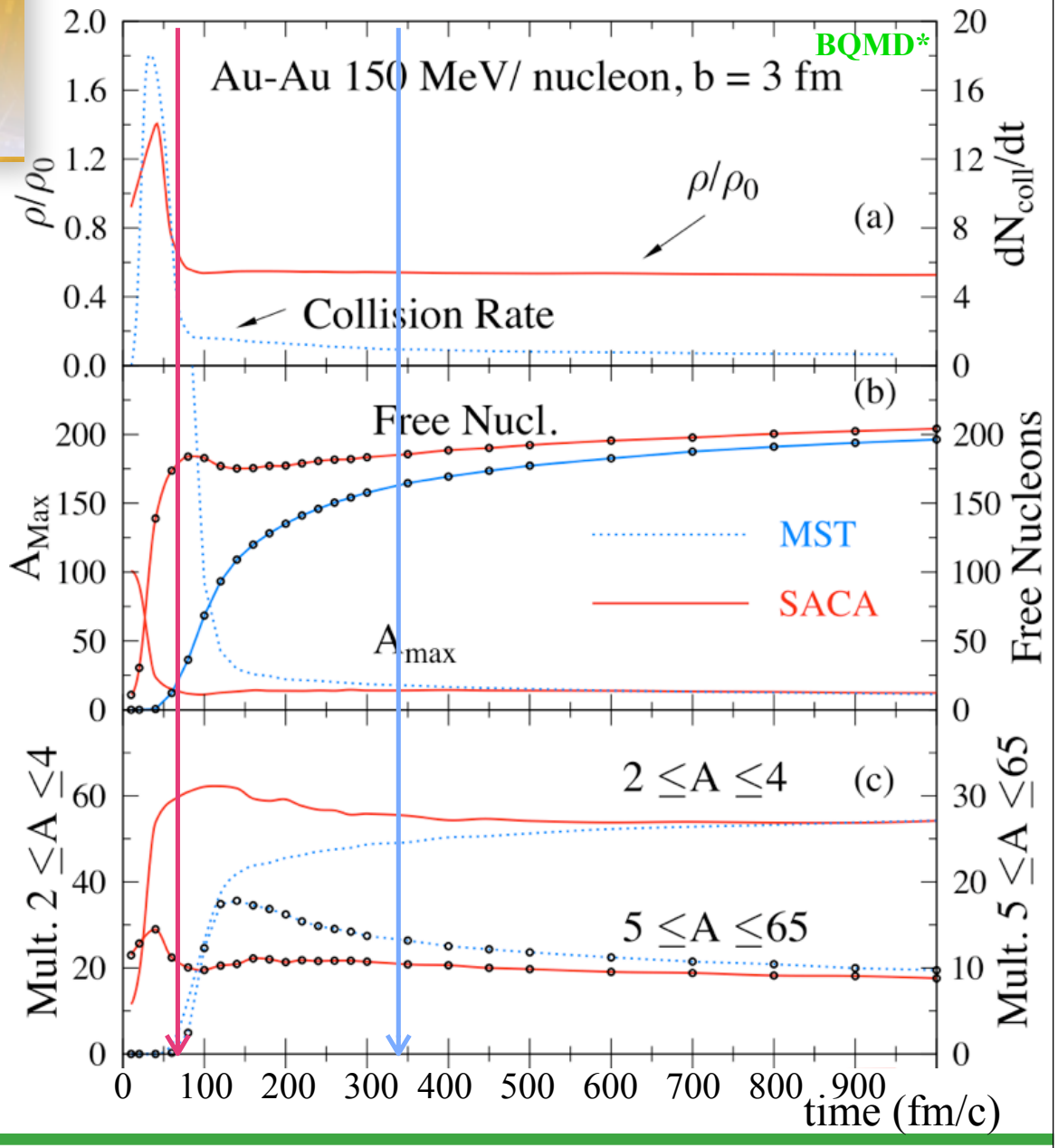

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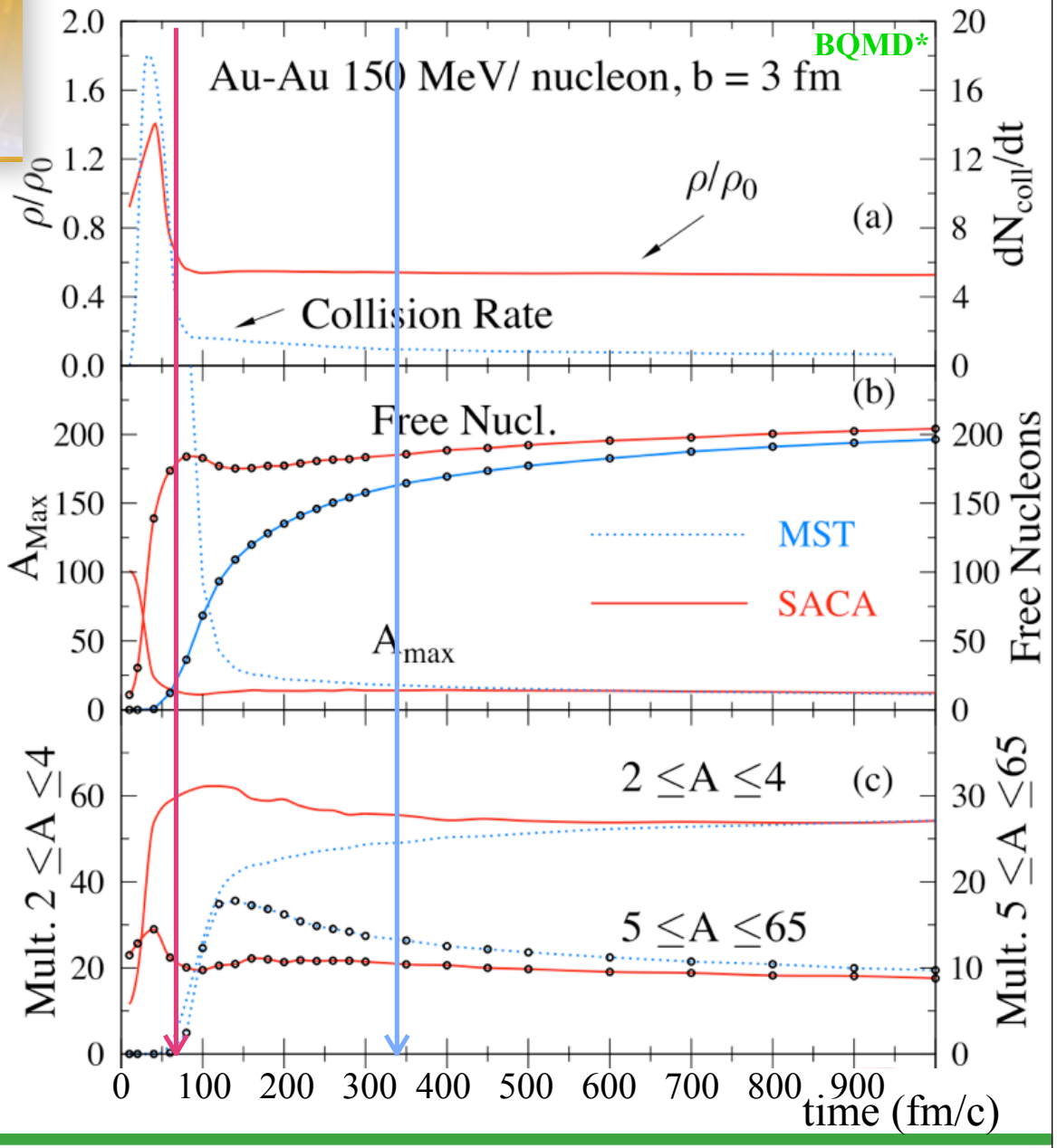

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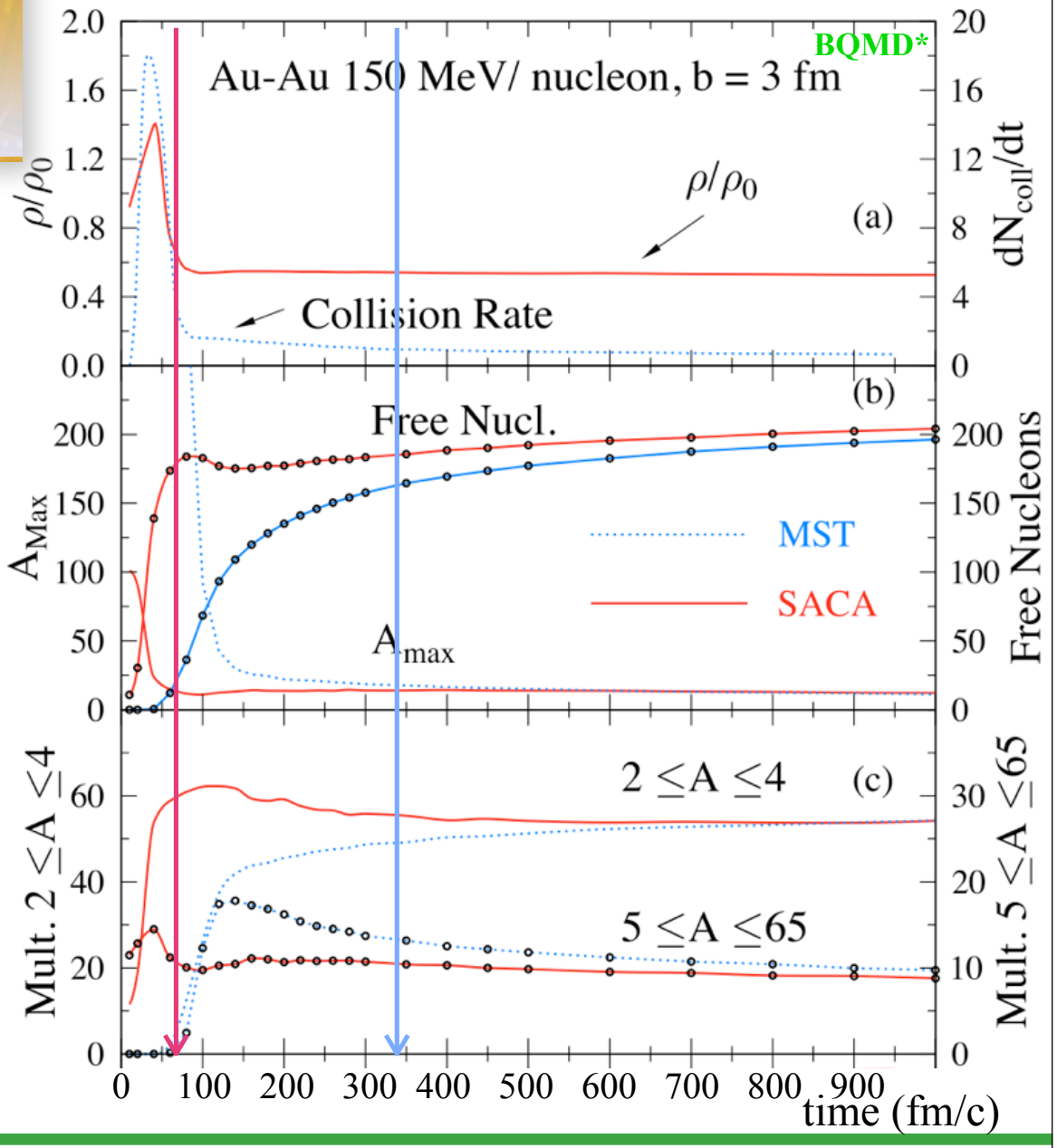
▸ Advantage of SACA : the fragment partitions can reflect the early dynamical conditions (Coulomb, density, flow details, strangeness...).



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Toward the isotope yields... IQMD + new SACA

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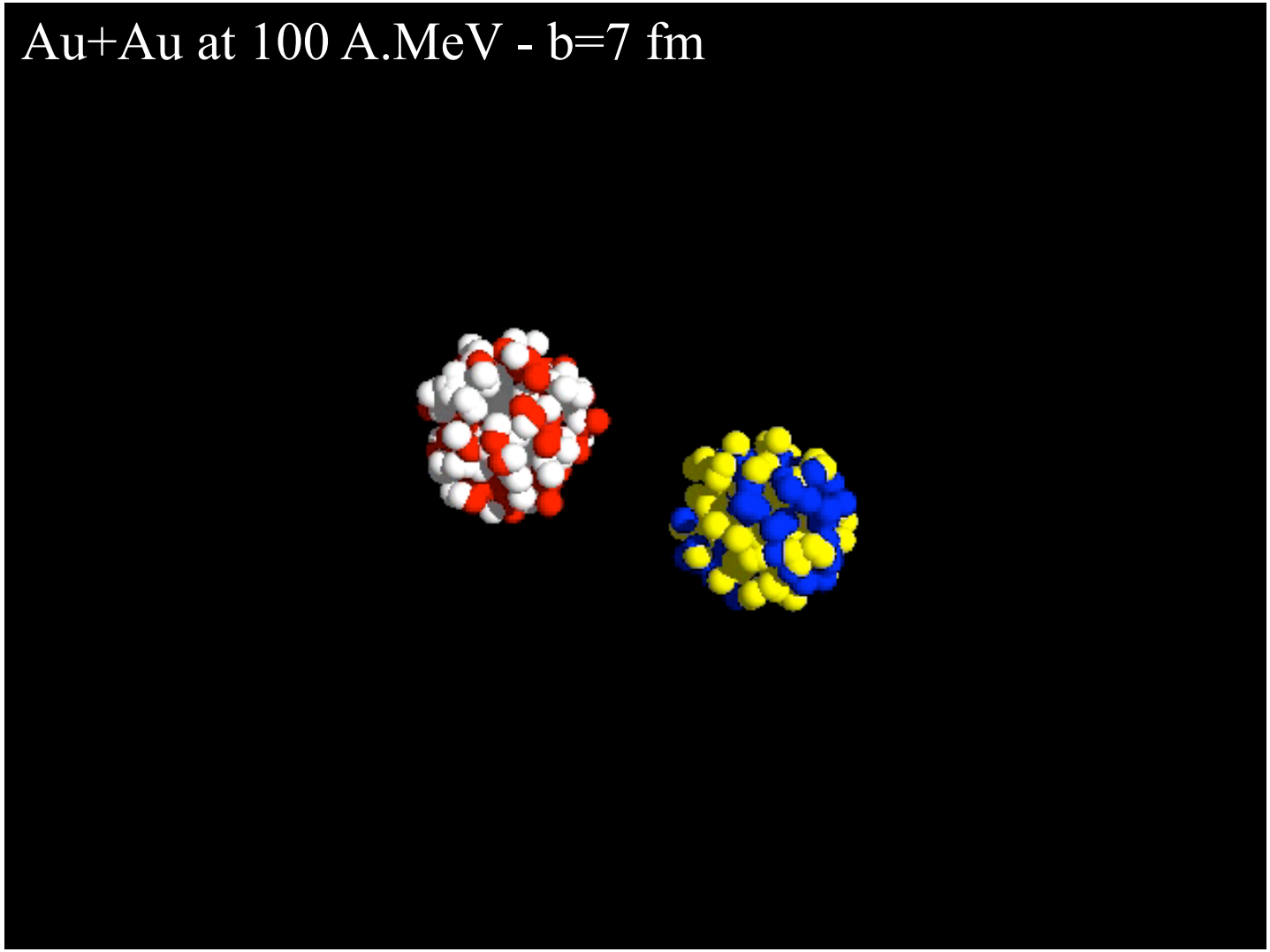

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Large Z range of measured isotopes,
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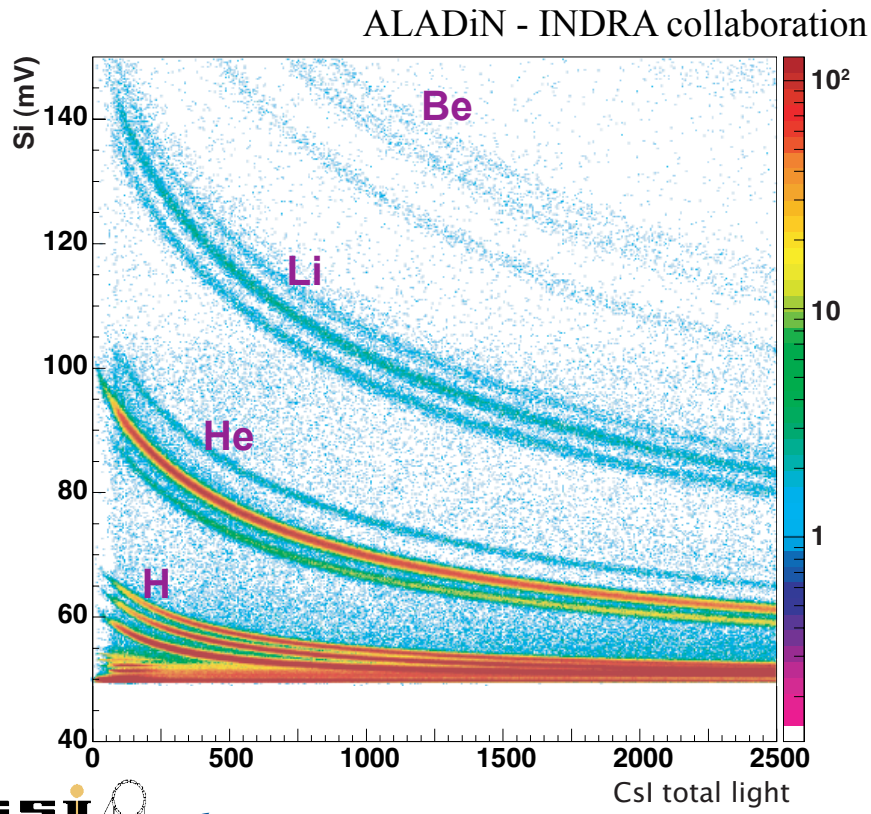

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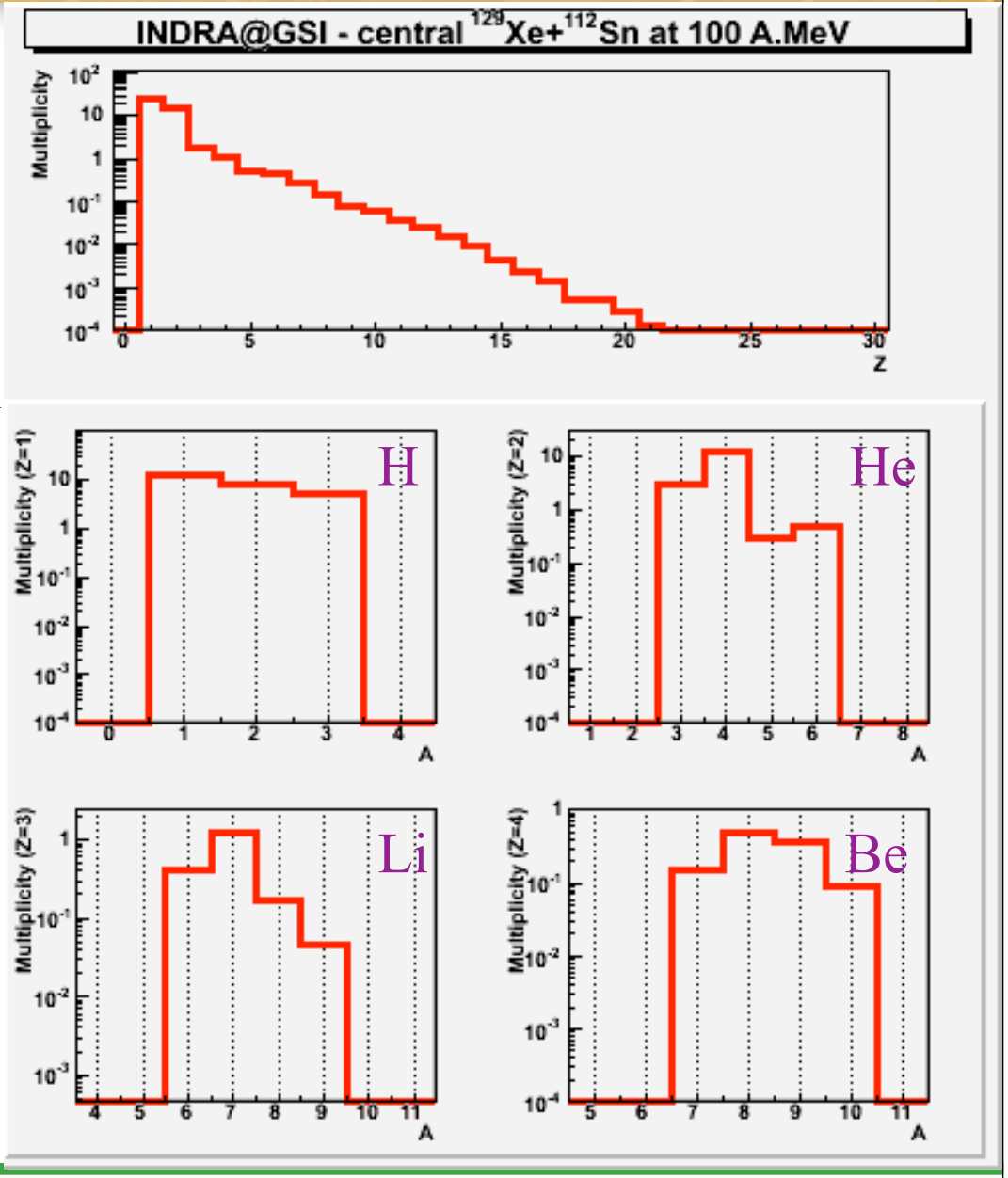

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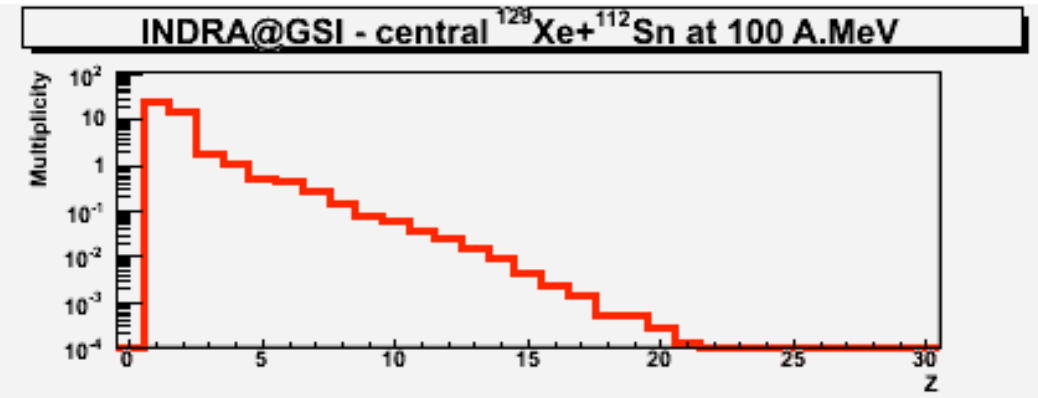
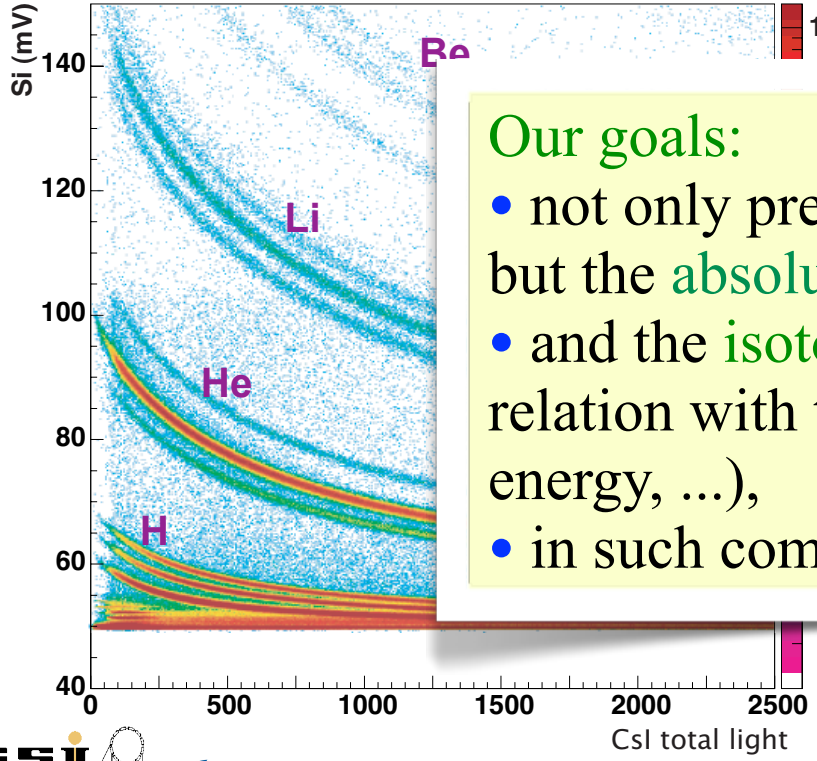
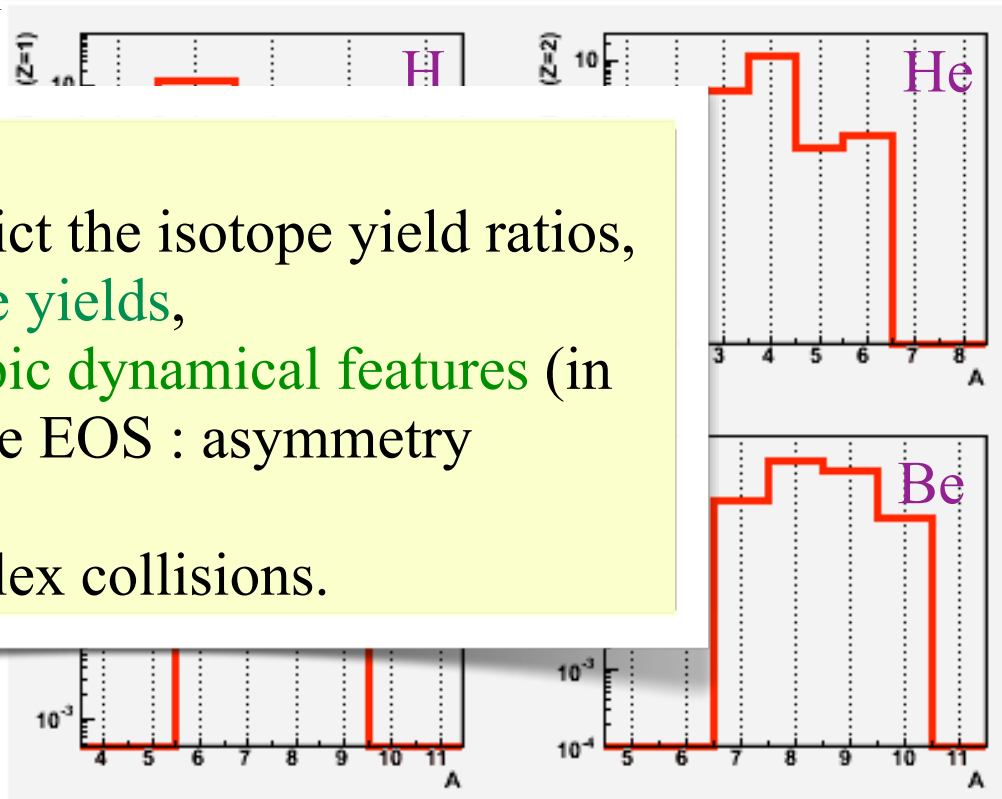


ALADiN - INDRA collaboration





Our goals:

- not only predict the isotope yield ratios, but the absolute yields,
- and the isotopic dynamical features (in relation with the EOS : asymmetry energy, ...),
- in such complex collisions.

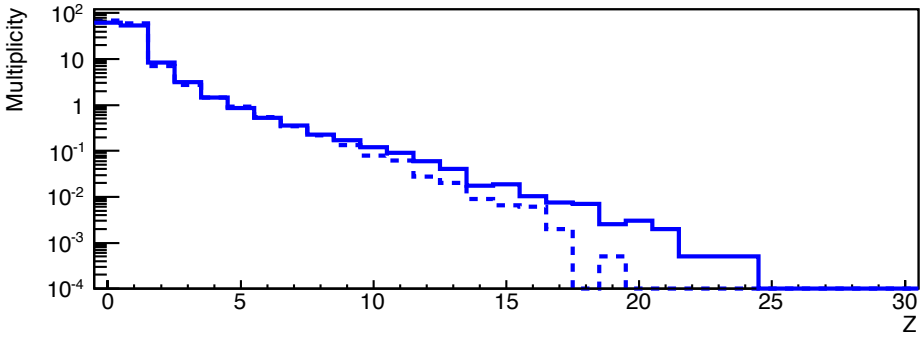
SACA versus coalescence (Minimum Spanning Tree)

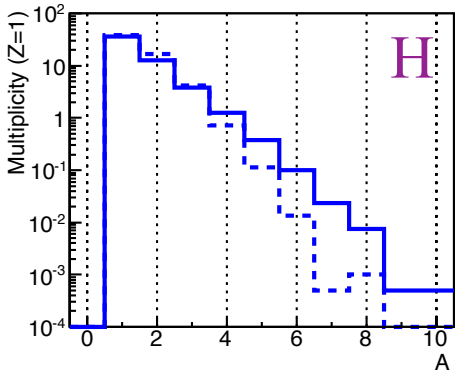
IQMD ^{136}Xe+^{112}Sn at 100 A.MeV, b=1 fm, t_{SACA}=60 fm/c

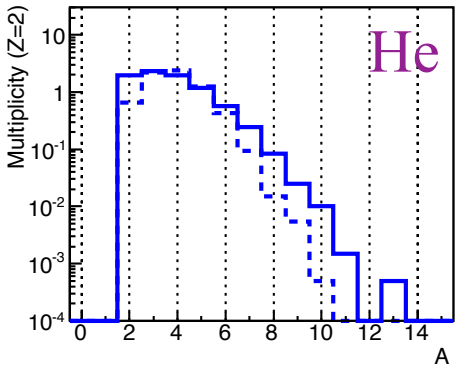
SACA version:

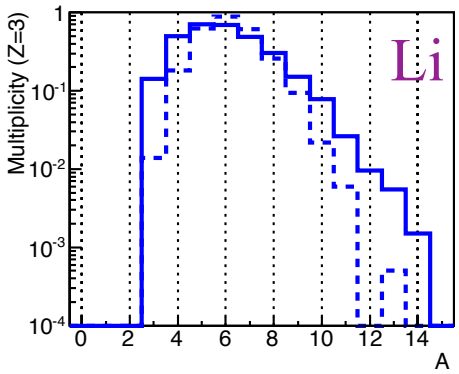
MST only (200 fm/c)

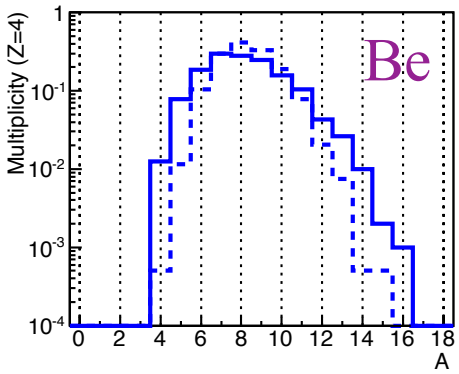
E_{asy}=0, no pairing











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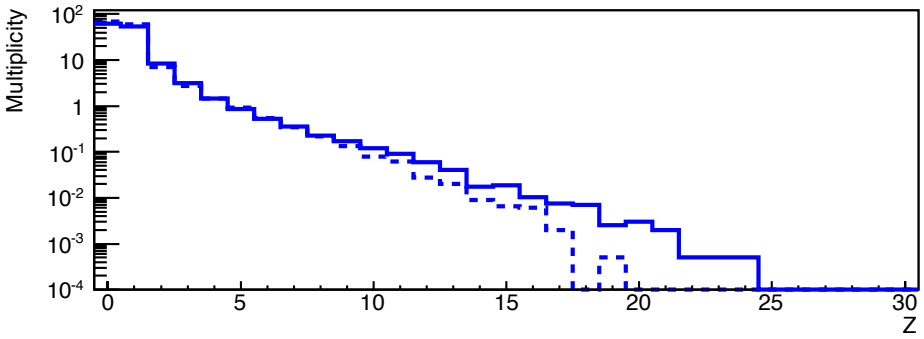
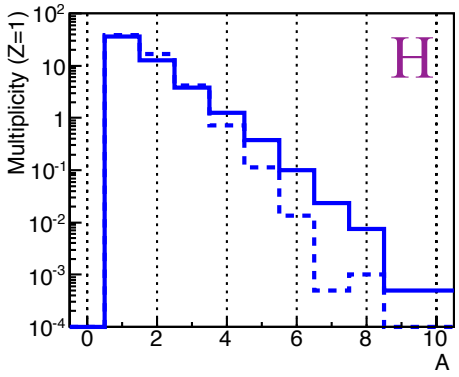
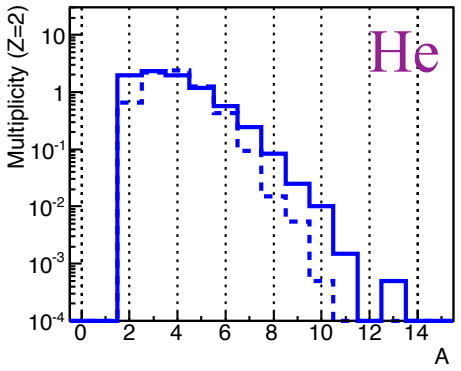


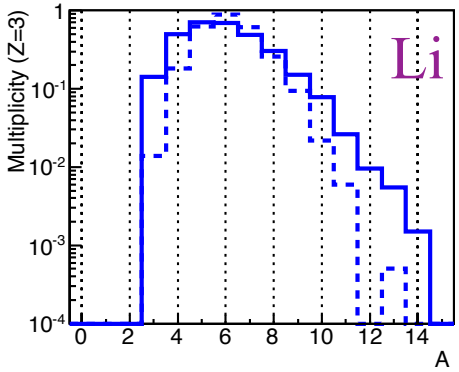
At this stage, SACA contains as ingredients of the potential making the binding energy of the clusters :

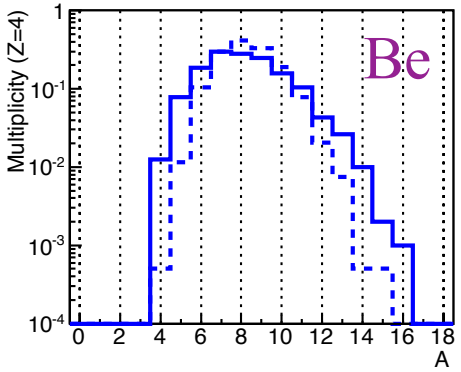
① volume component:
mean field (Skyrme, dominant)

② correction of surface effects:
Yukawa









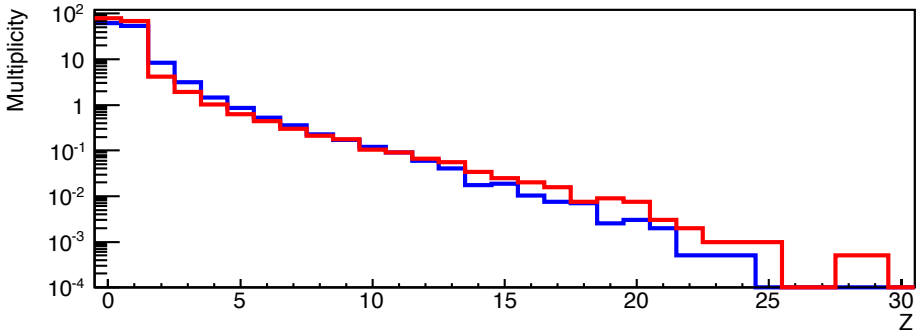
SACA with asymmetry energy

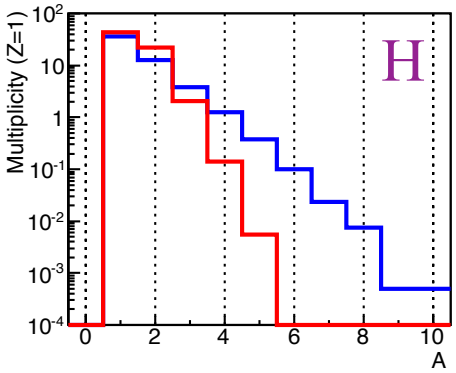
IQMD ^{136}Xe+^{112}Sn at 100 A.MeV, b=1 fm, t_{SACA}=60 fm/c

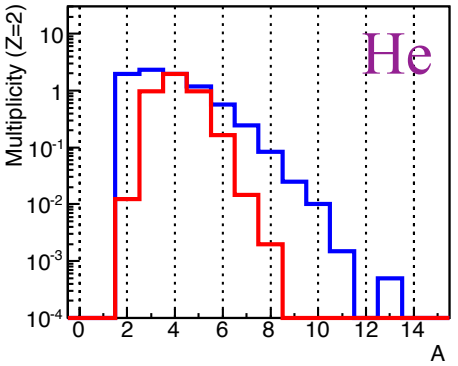
SACA version:

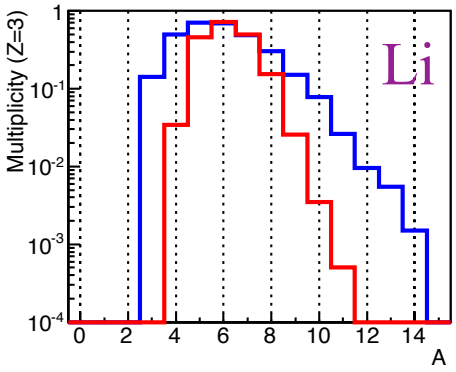
E_{asy}=0, no pairing

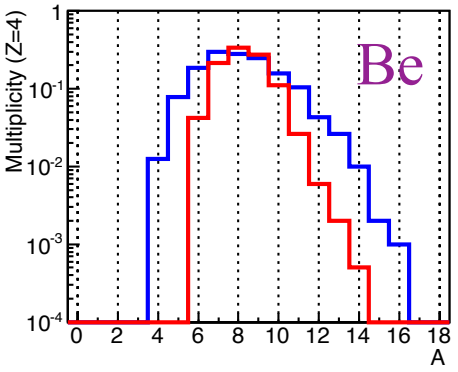
E_{asy}=32 MeV (γ=1), no pairing











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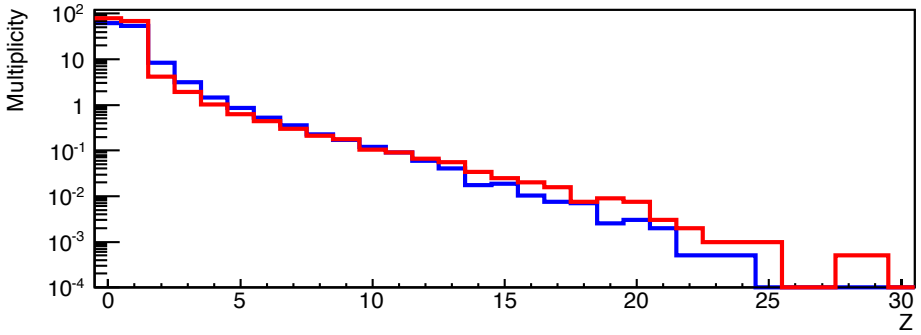


Here,
in IQMD and SACA, we adopt the following asymmetry energy parametrisation:

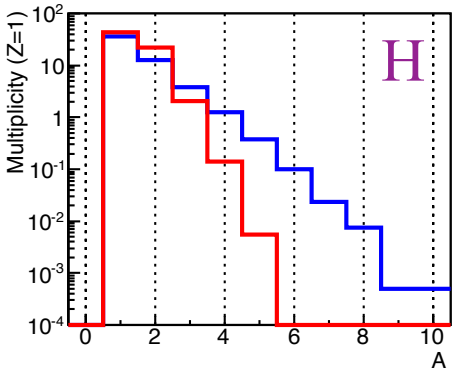
$E_{asy}=E_0.(<\rho_B>/\rho_0)^{(\gamma-1)}.(<\rho_n>-<\rho_p>)/<\rho_B>$

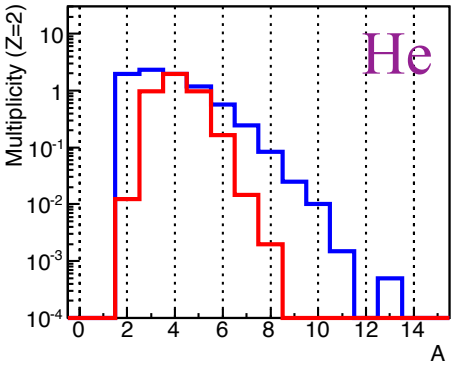
with E_0=32 MeV, γ=1 («stiff»)

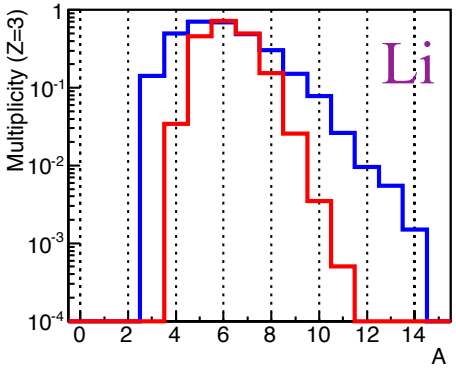
➡ Z and A yields not strongly modified

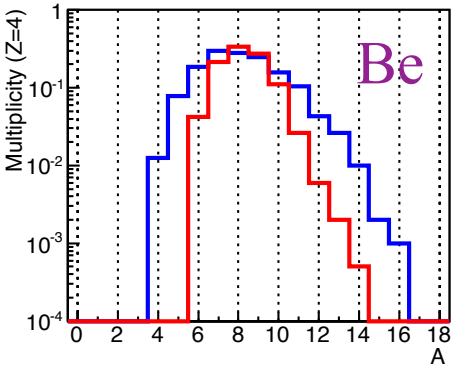
➡ Isotope yields shrink onto the N=Z line

➡ Still not fully realistic: shell, odd-even effects (pairing) still absent.







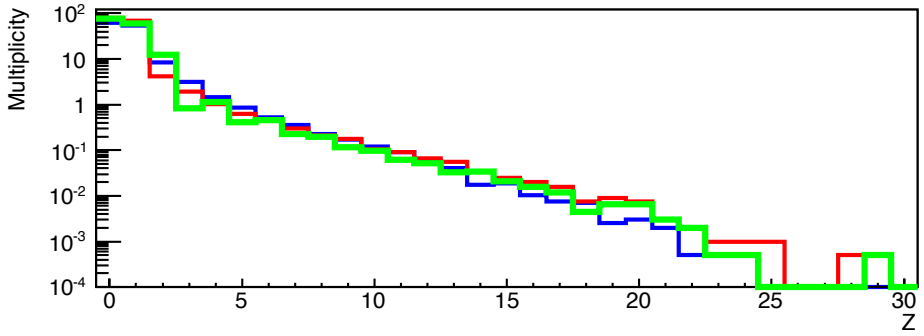


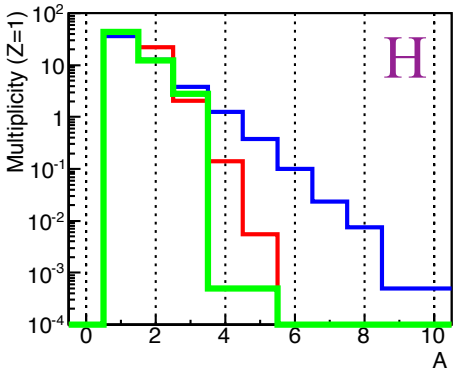
SACA with asymmetry energy and pairing

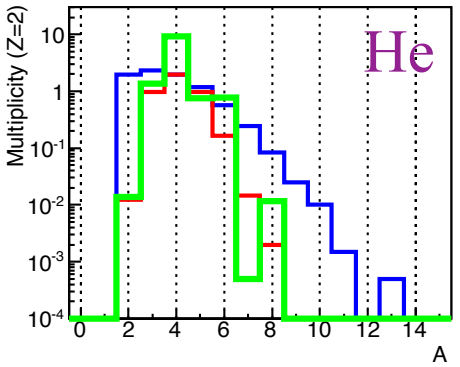
INDRA@GSI - central ^{129}Xe+^{112}Sn at 100 A.MeV

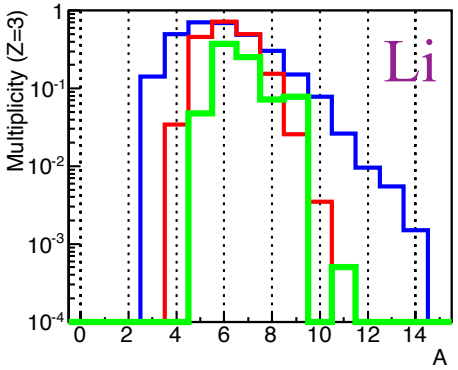
SACA version:

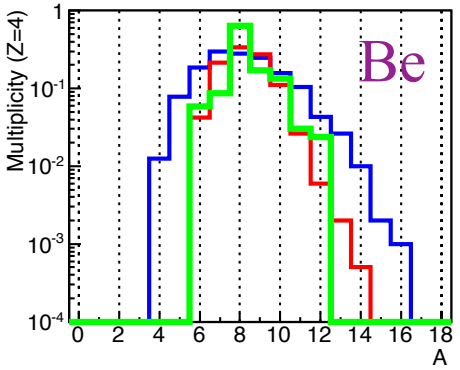
- E_{asy}=0, no pairing
- E_{asy}=32 MeV (γ=1), no pairing
- E_{asy}=32 MeV (γ=1) + $\eta_{pairing}$=0.25



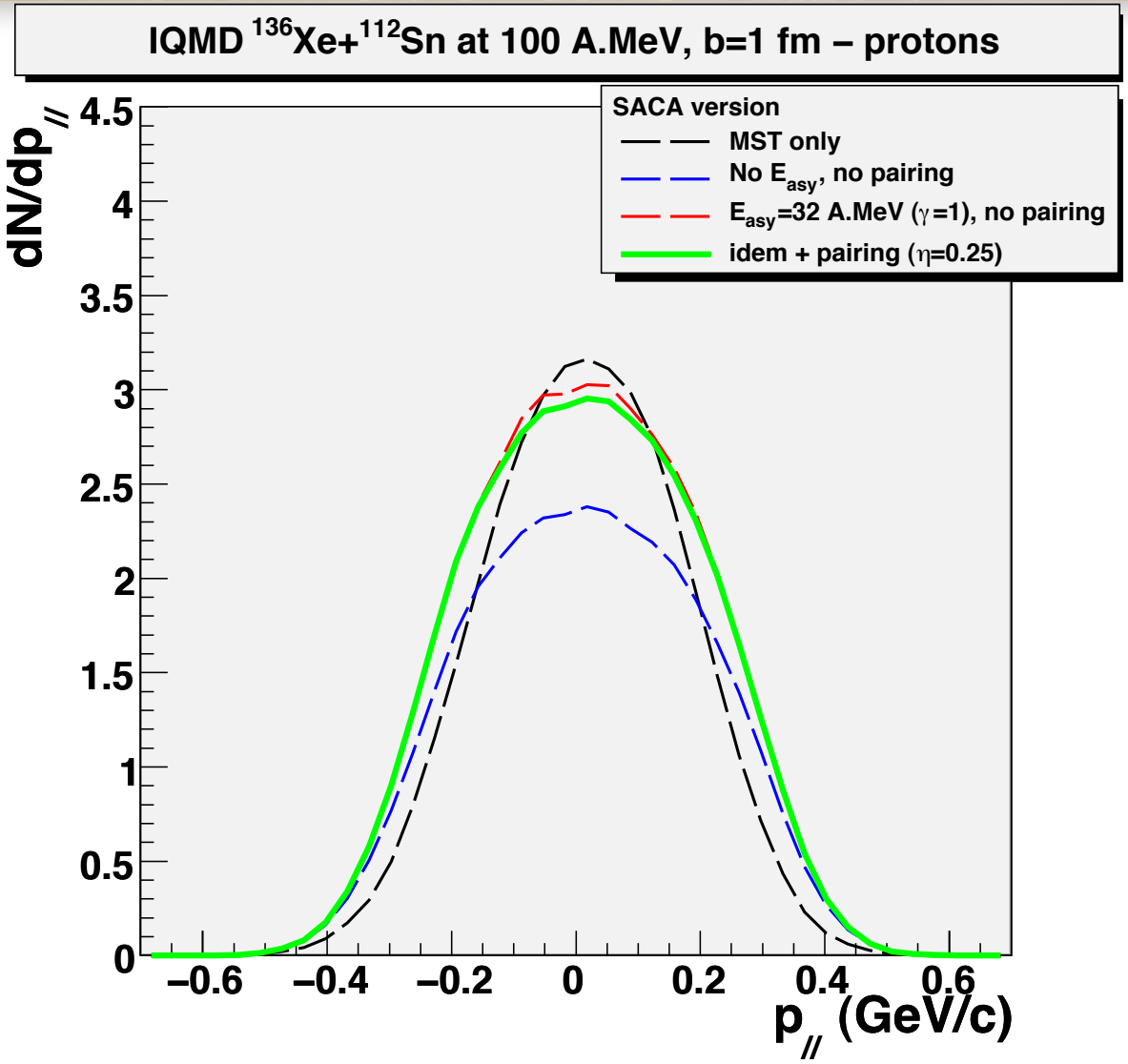








How the dynamical patterns of isotopes are affected



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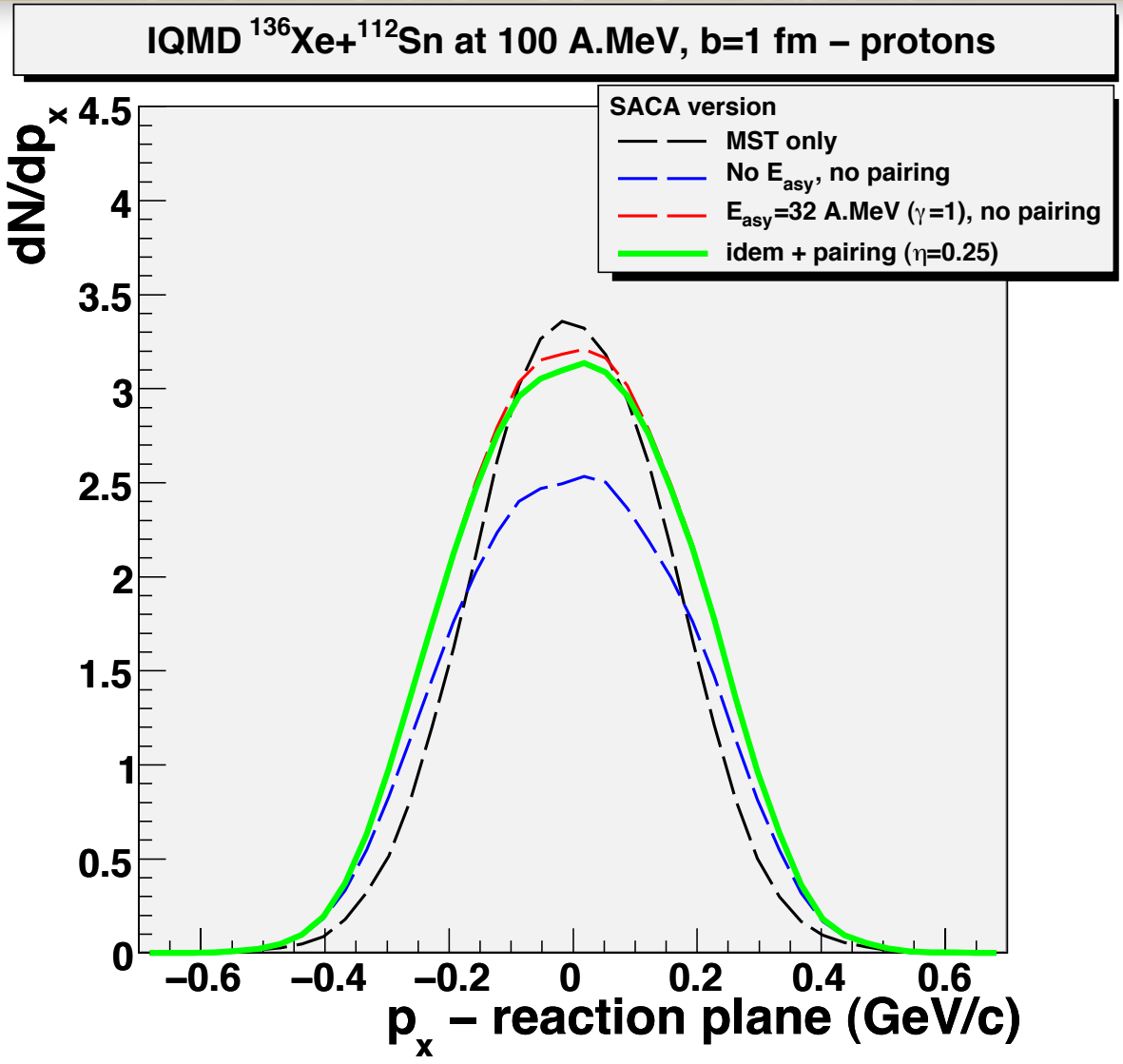

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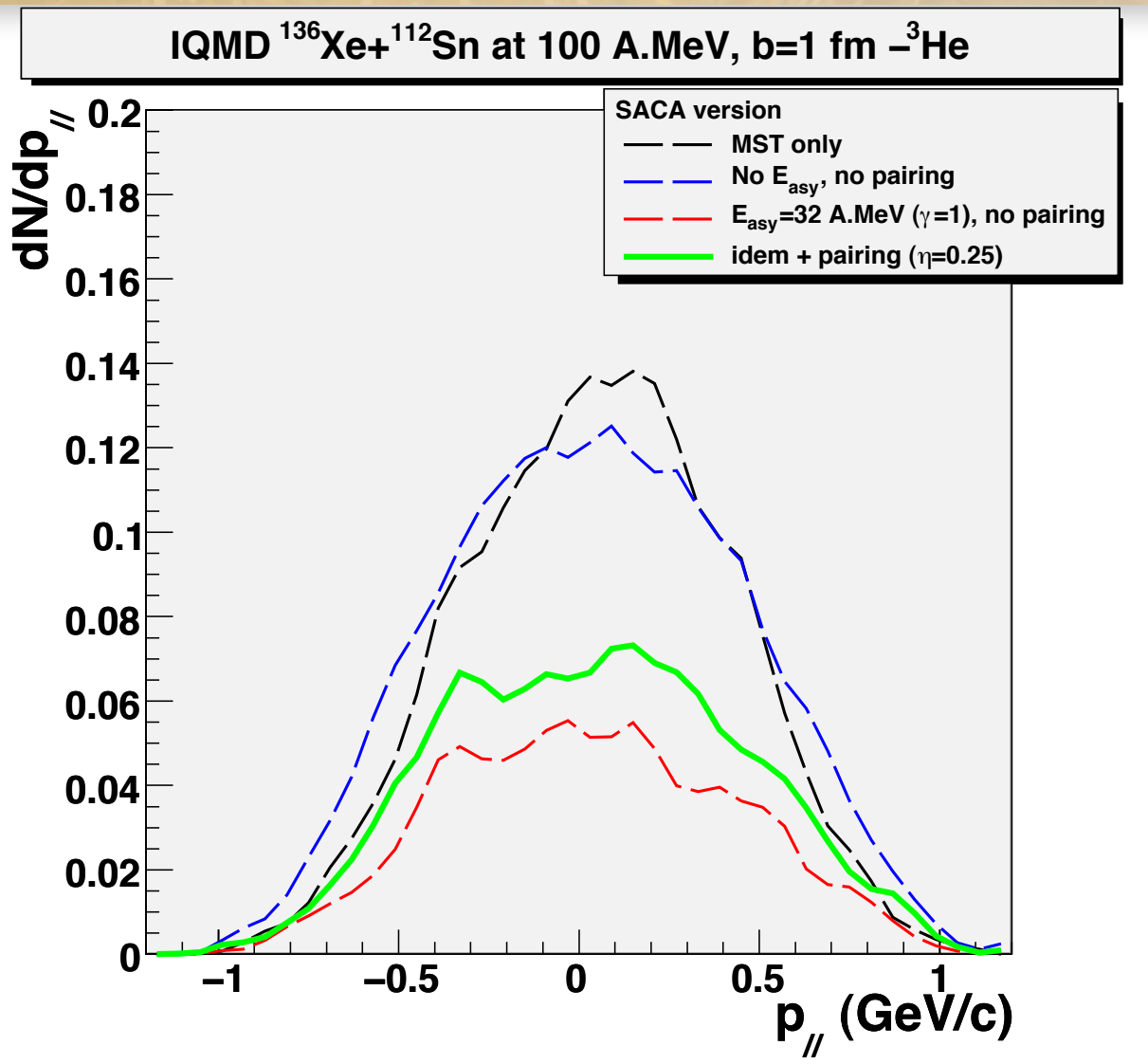

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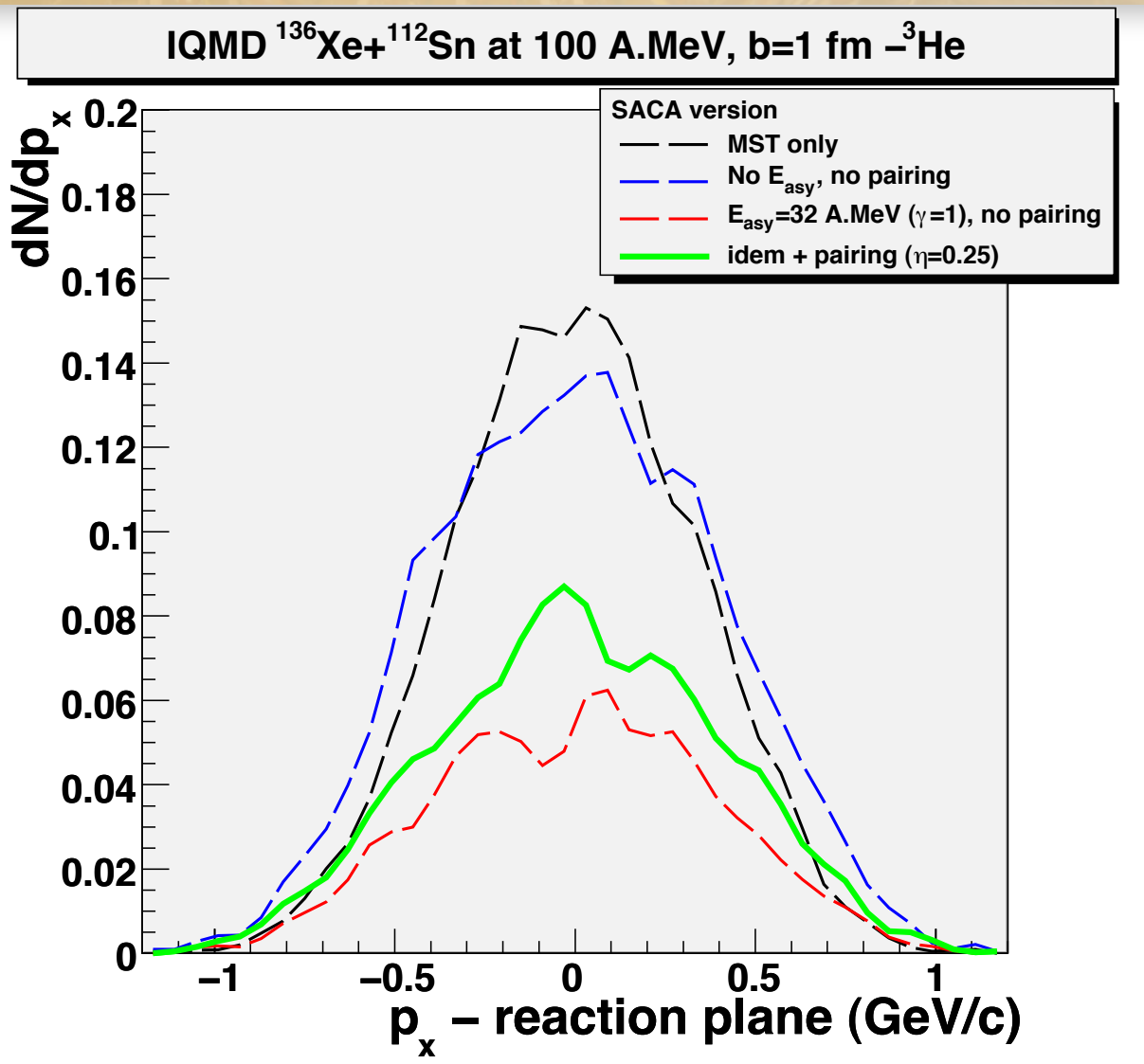

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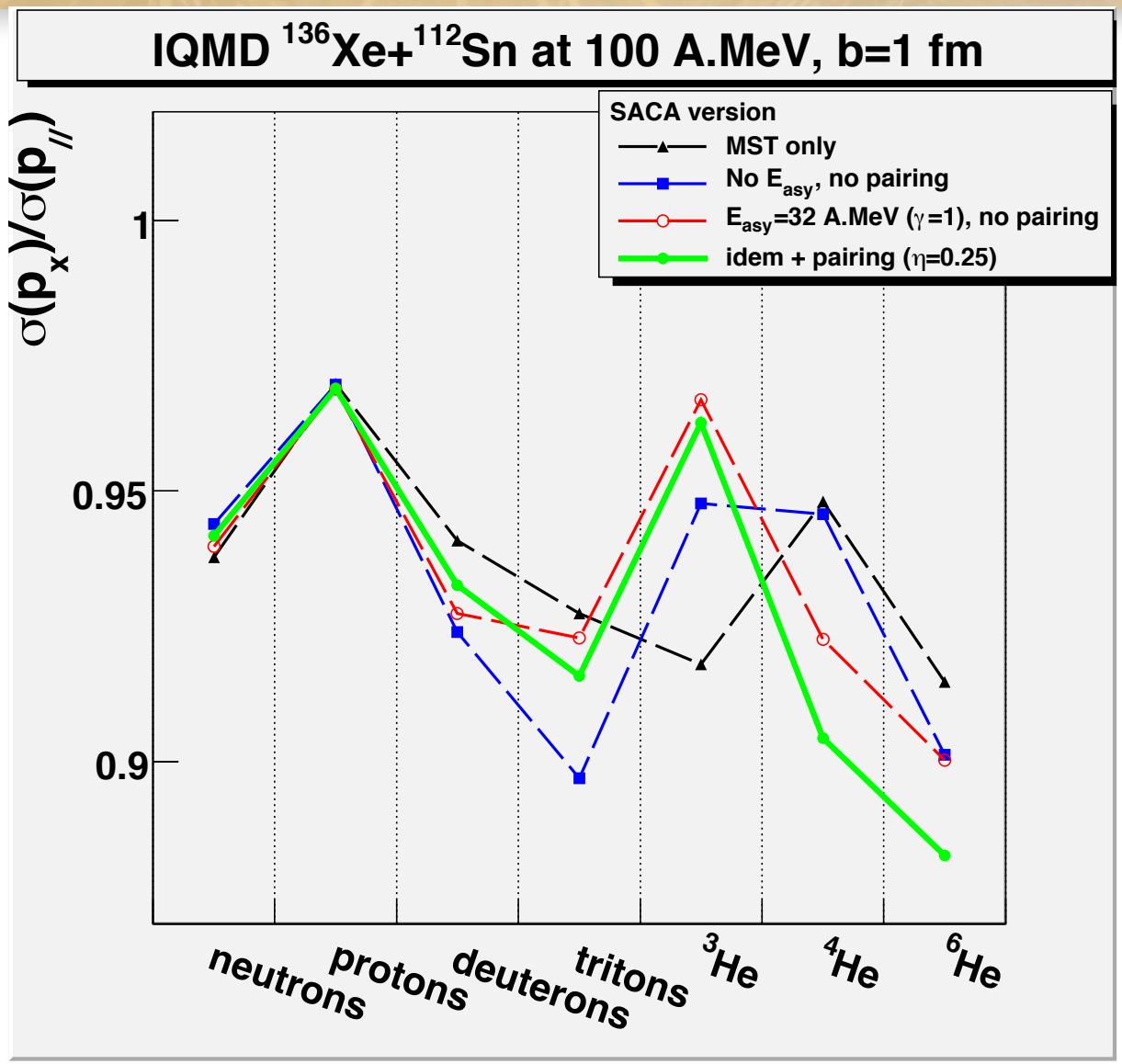

Excitation energy of the primary fragments

$$E^* = E_{g.s.} - E_{bind}$$

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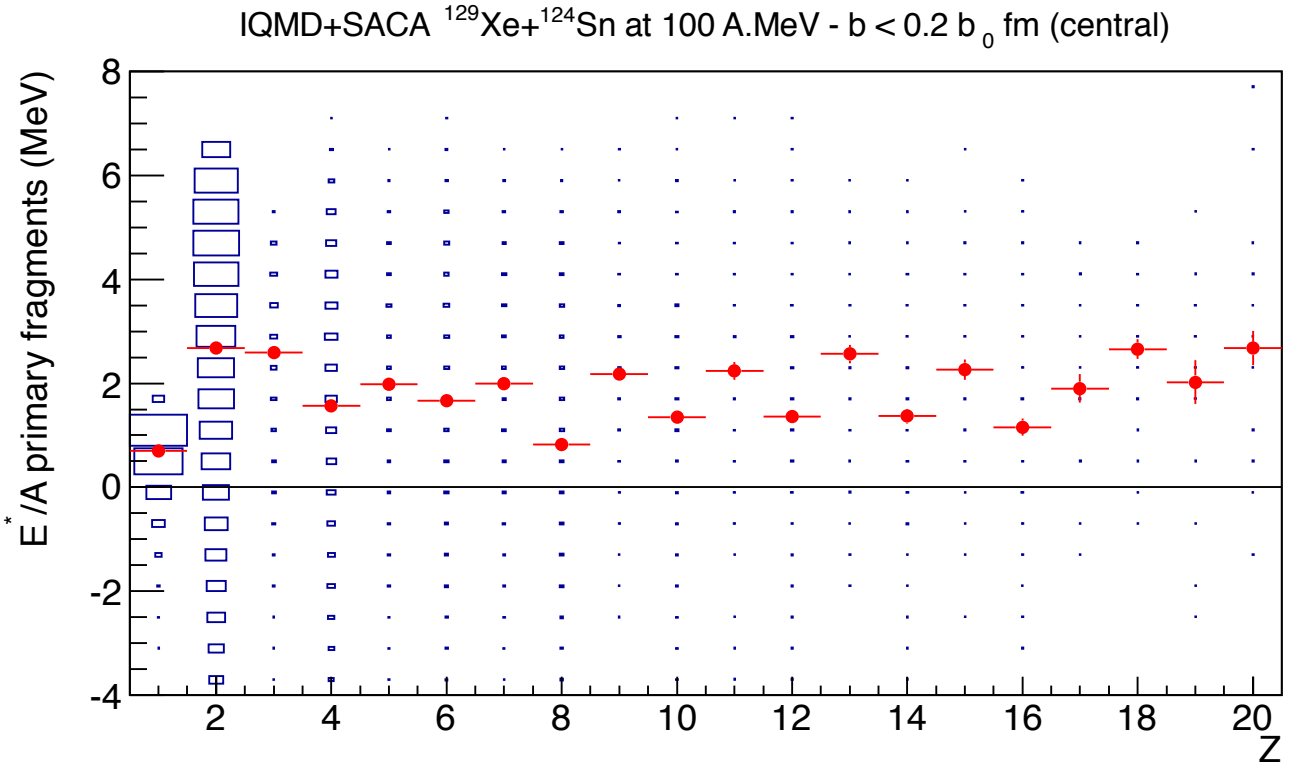

On Average, 2 A.MeV of excitation energy. Corresponds to findings of S. Hudan et al. (INDRA collaboration), PRC 67, 064613 (2003).
=> secondary decay (GEMINI) justified here.

Excitation energy of the primary fragments

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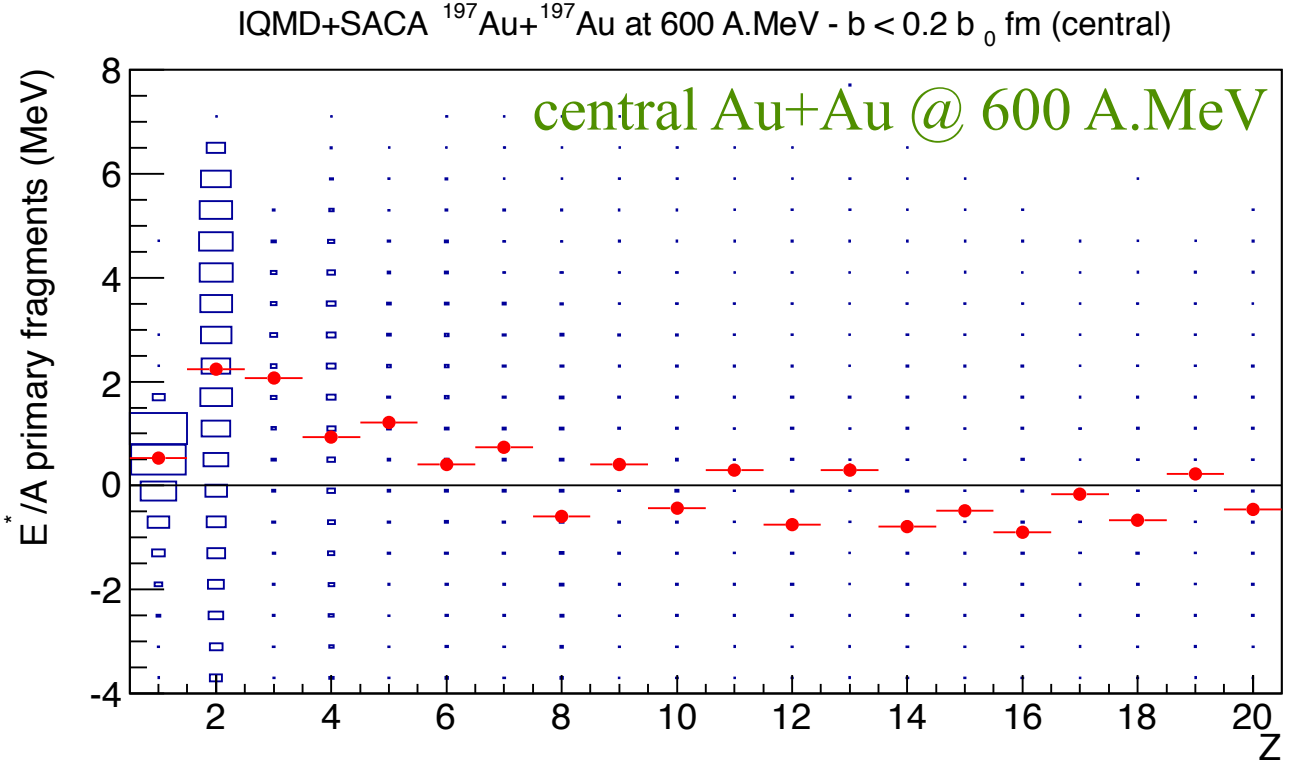

At relativistic energies, in the participant-spectator regime, heavy primary clusters are produced colder on average.

What can we learn from the isotope yields regarding the asymmetry energy?

Mean radius of primary clusters

IQMD+SACA

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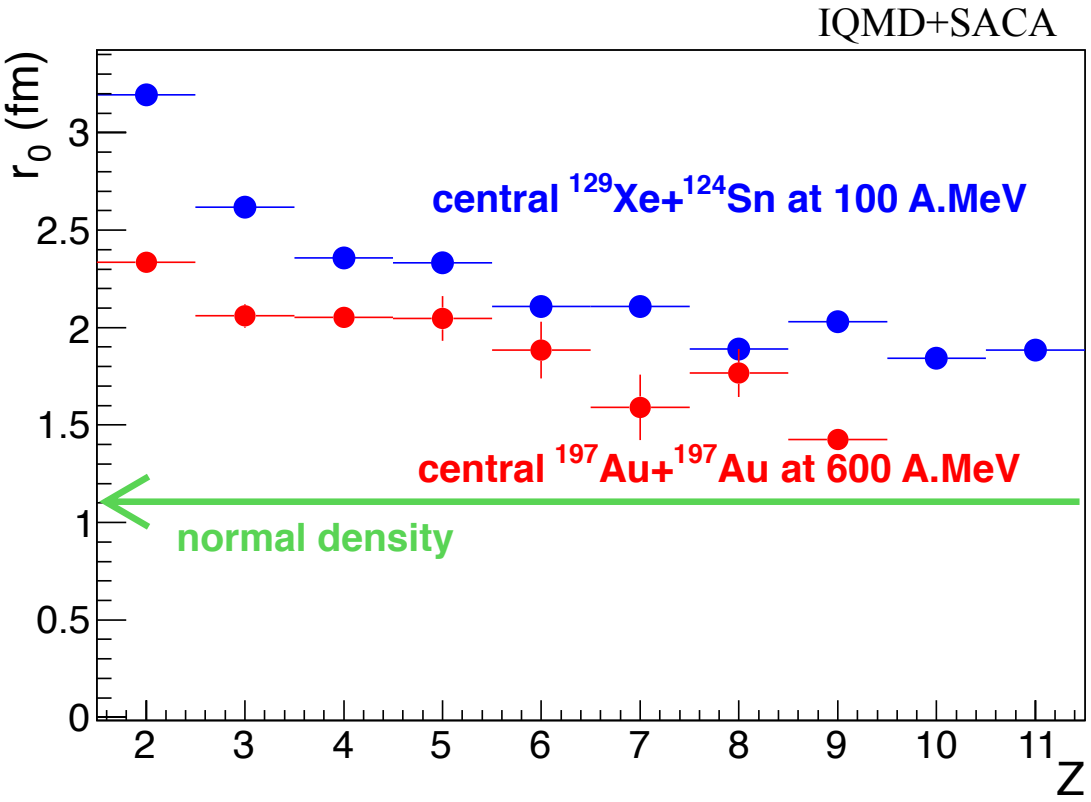
Mean radius of primary clusters



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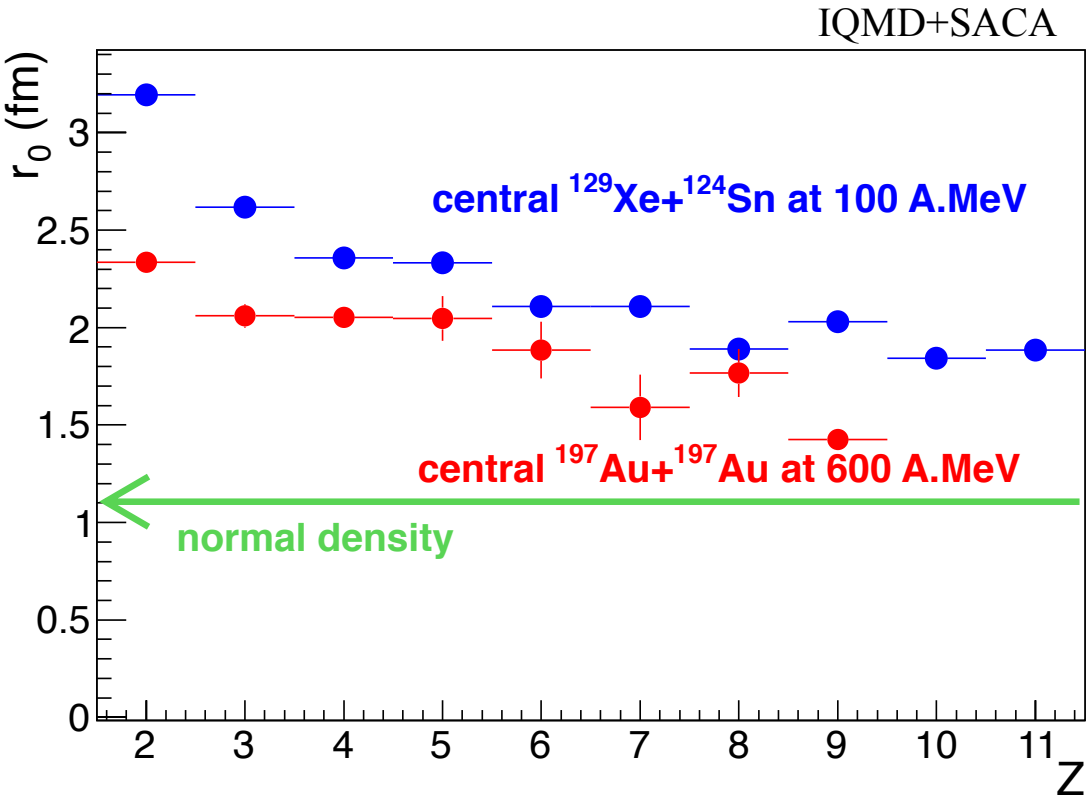

Though the medium is dense at this early stage, the dense clusters are disfavoured, because they would correspond to nucleons flowing against each other, hence with too high relative momenta to make a cluster.

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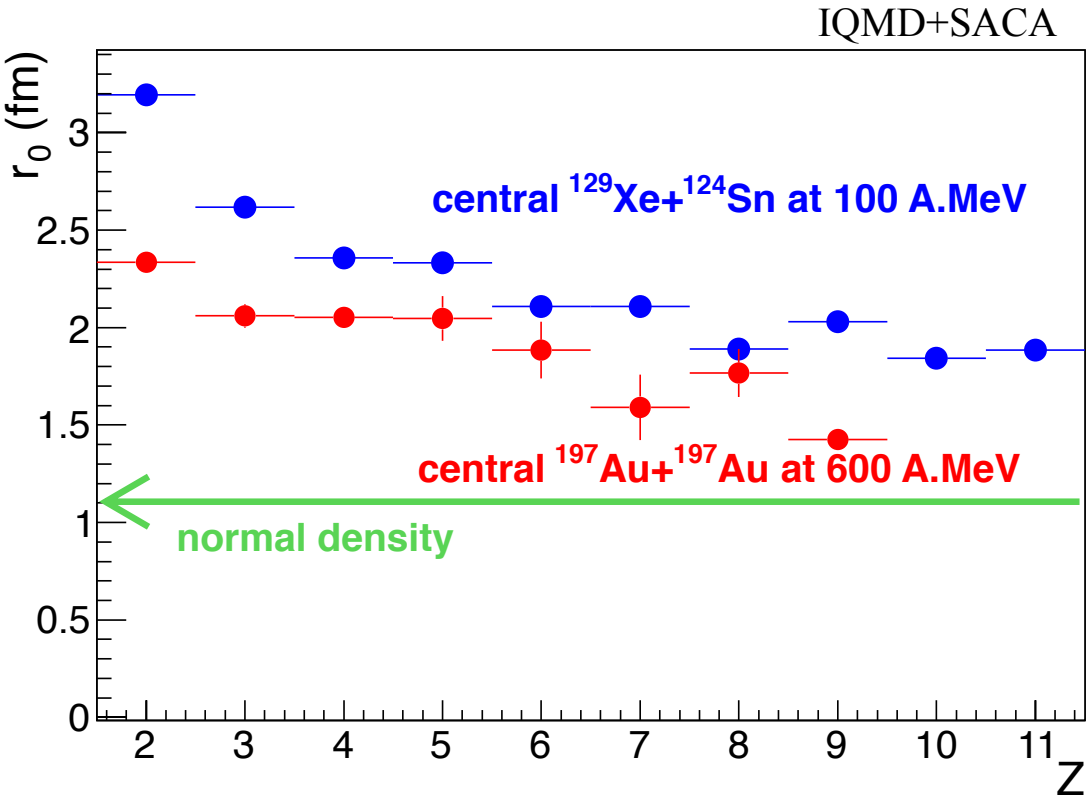

Though the medium is dense at this early stage, the dense clusters are disfavoured, because they would correspond to nucleons flowing against each other, hence with too high relative momenta to make a cluster.

=> The isotope yields can only inform on the low density dependence on the asymmetry energy.

Asymmetry energy influence versus system energy

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W. Reisdorf and the FOPI Collaboration

Nuclear Physics A 848 (2010) 366–427

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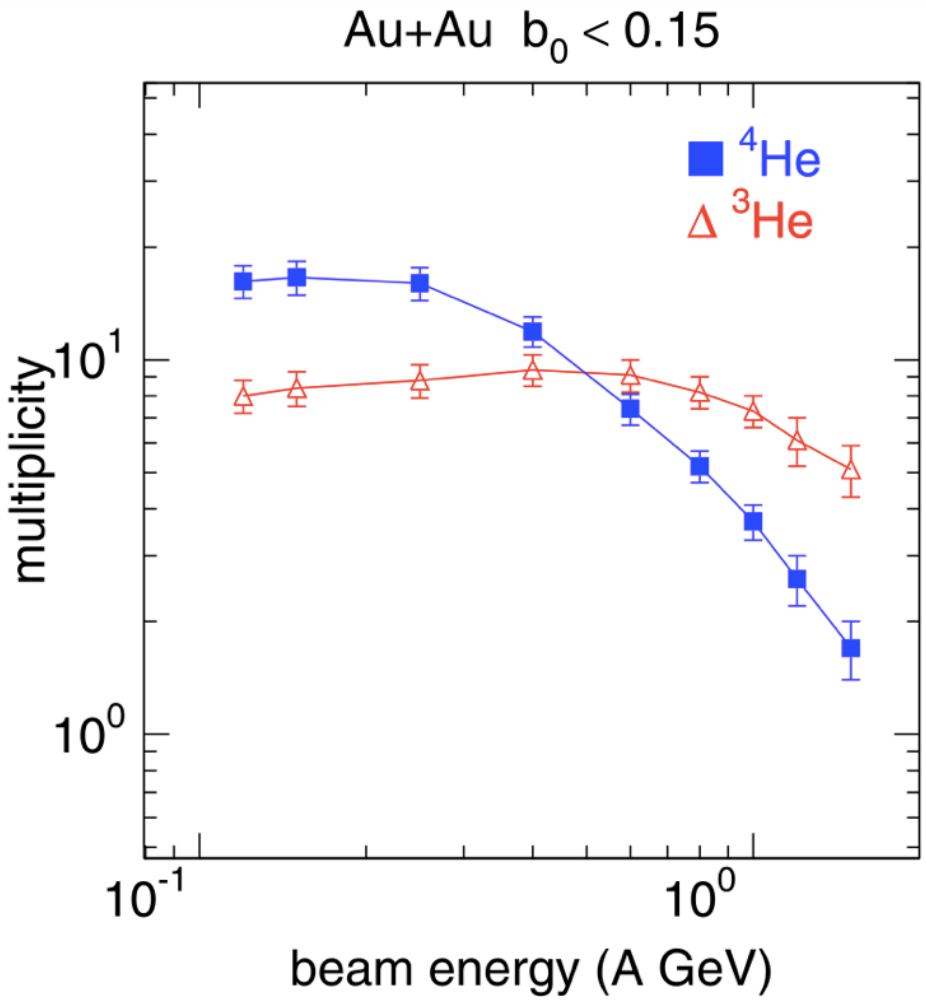

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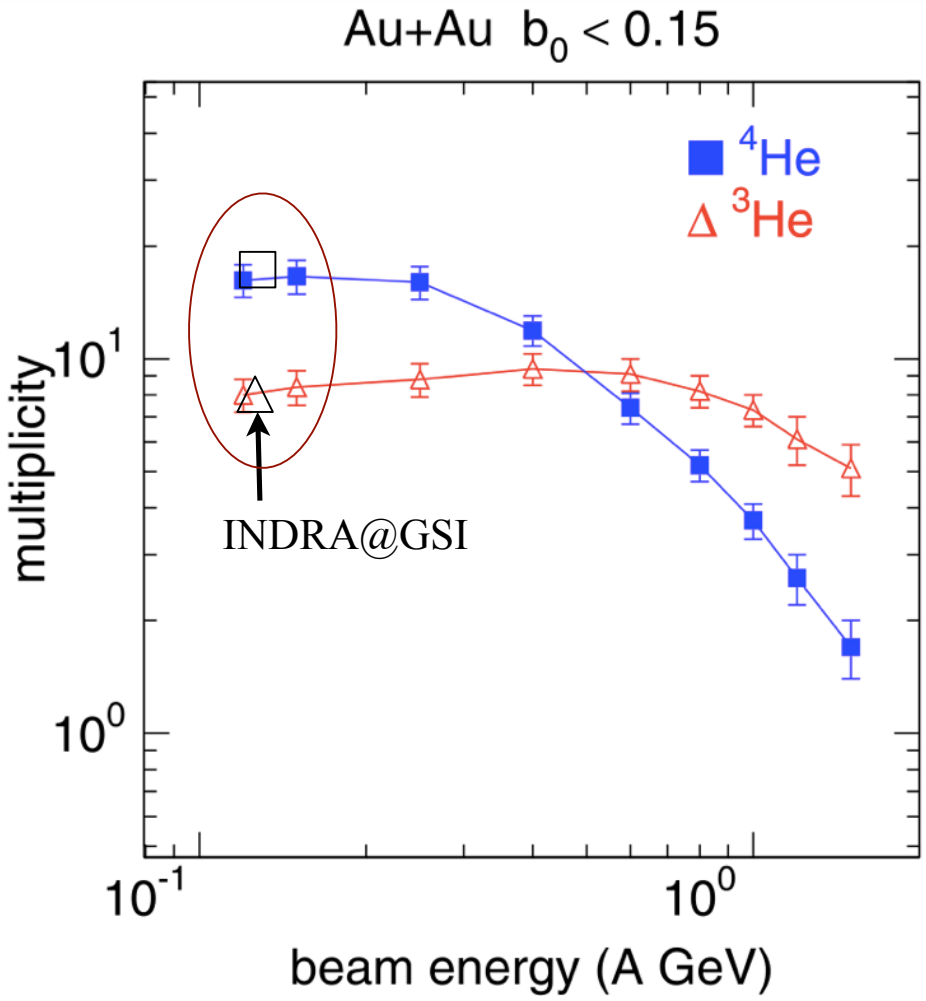

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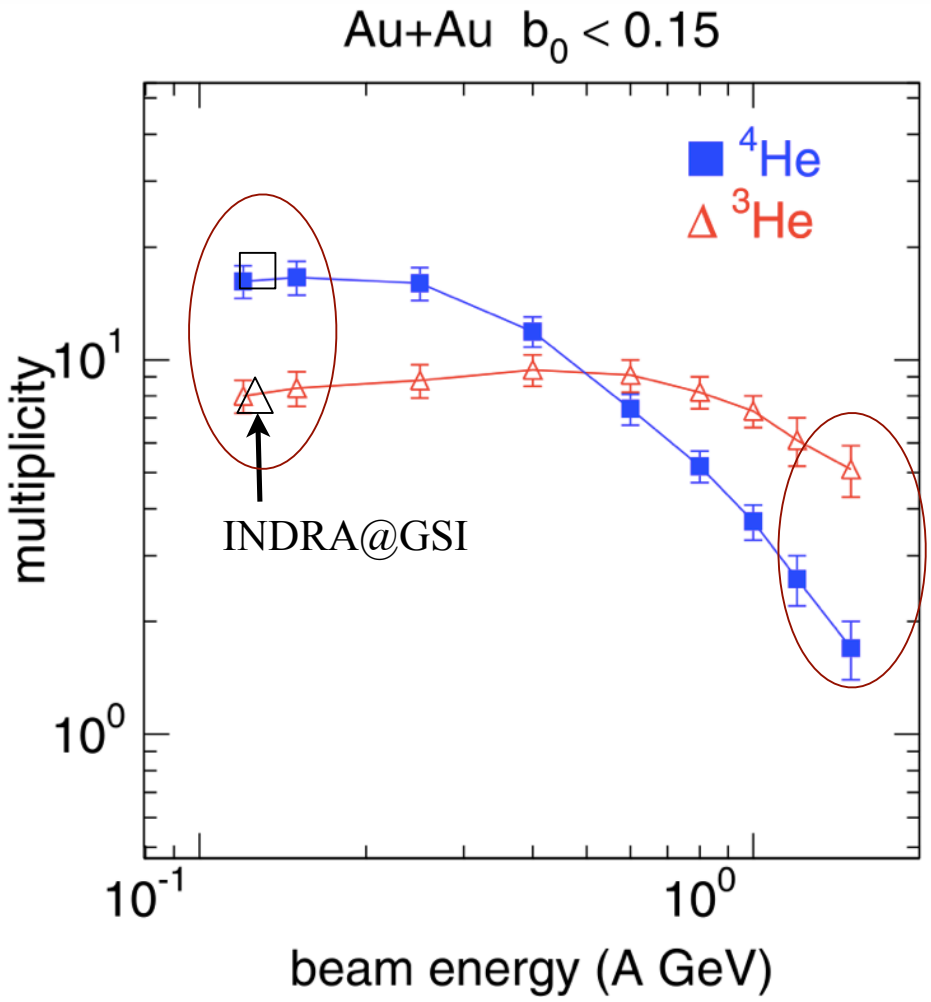

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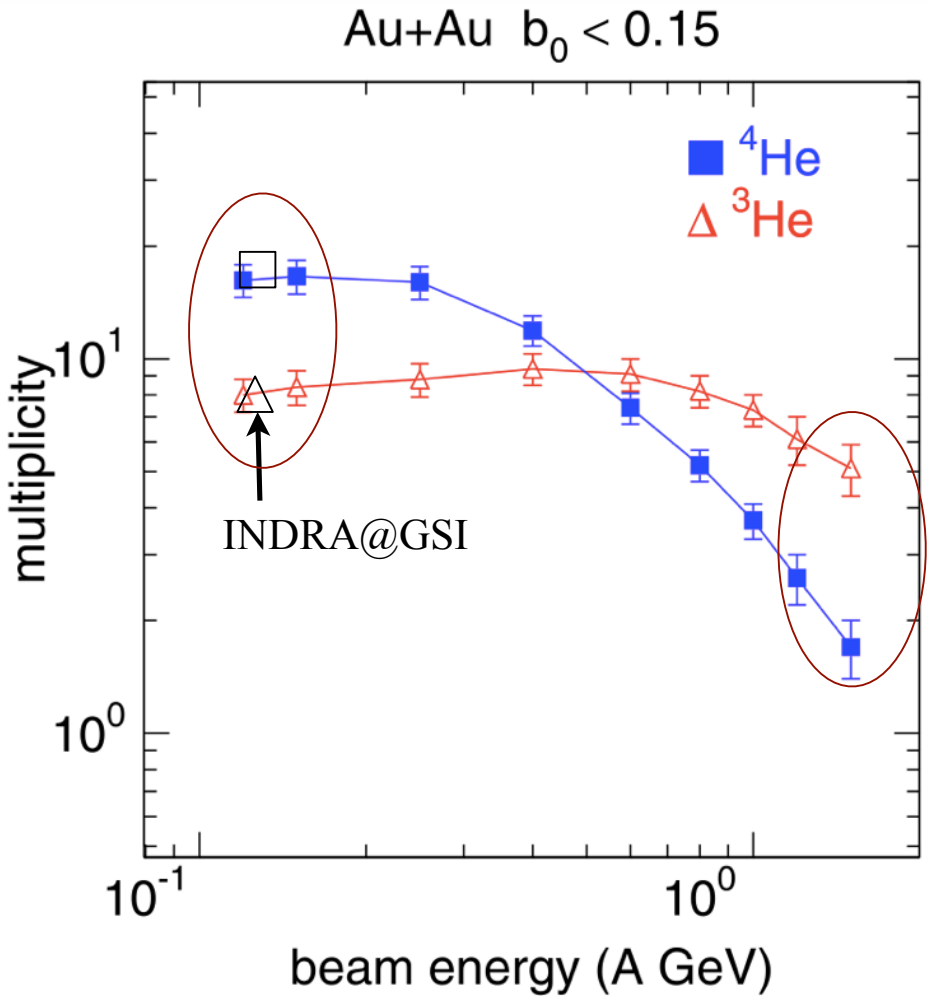
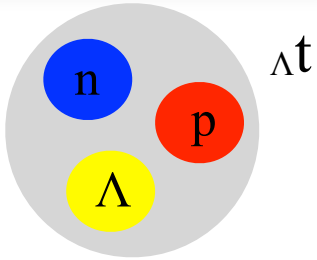


=> At high energy, the asymmetry energy effect on clusters seems to vanish. Timescale effect? Non-linear dependence on the density?

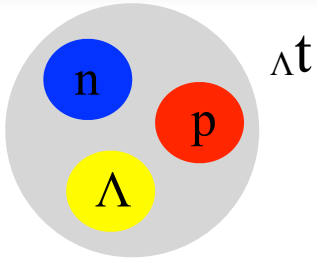
Another application of SACA : hypernuclei production



$_{\Lambda}t$

Another application of SACA : hypernuclei production

A hypernucleus is a nucleus which contains at least one hyperon (Λ(uds), ...) in addition to nucleons.



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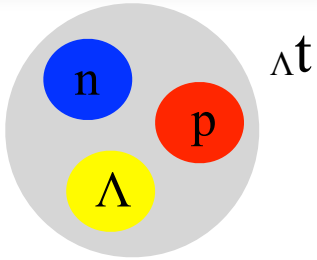

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Extending SACA for clusterising hadrons with hyperons (lambdas,...) for making hypernuclei is straightforward:

- one replaces $V_{n\text{-}p}$ by $V_{\Lambda\text{-}p}$ and $V_{n\text{-}n}$ by $V_{\Lambda\text{-}n}$
- and applies with these modifications the SACA algorithm.

If in a final fragment there is a lambda, a hypernucleus should be created.
As a first approach, we have adopted $V_{\Lambda\text{-}N} = 2/3\ V_{n\text{-}N}$; further refinements are possible.

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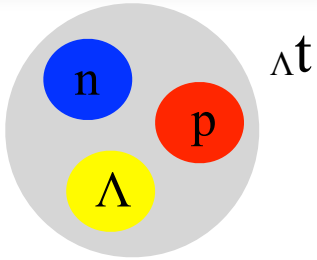

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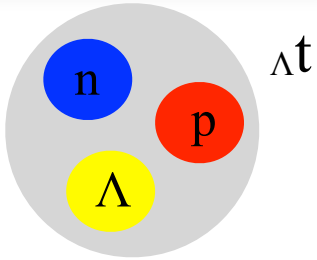
Many ways of producing lambdas: $K\ N \rightarrow \Lambda\ \pi$, $\pi^+\ n \rightarrow \Lambda\ K^+$, $\pi^-\ p \rightarrow \Lambda\ K_0$, $p\ p \rightarrow \Lambda\ X$
$\Rightarrow$ influence of the EOS, in medium-properties, etc.

Another application of SACA : hypernuclei production

IQMD+SACA
$^{58}Ni+^{58}Ni$
at
1.91 A.GeV
(b < 6 fm) -
$t_{cluster.}$=20 fm/c



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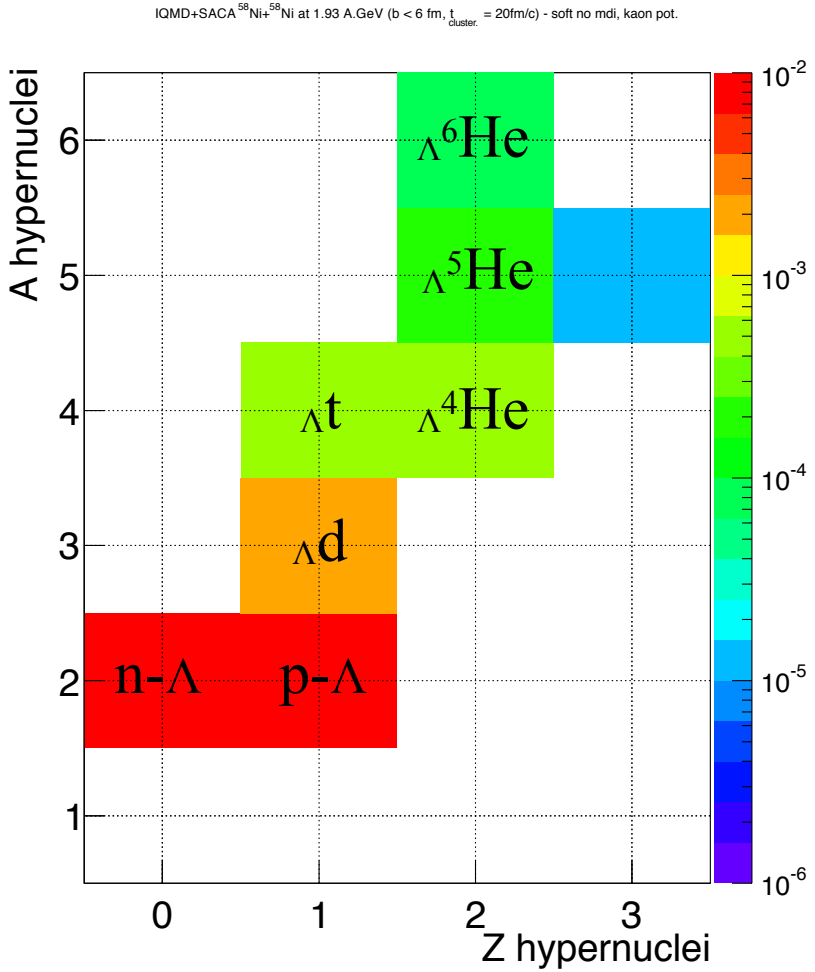

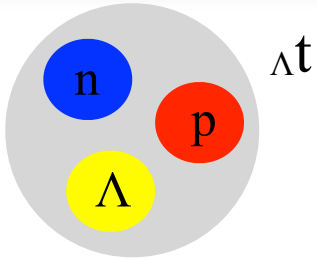

Soft EOS
no m.d.i.
with Kaon pot.

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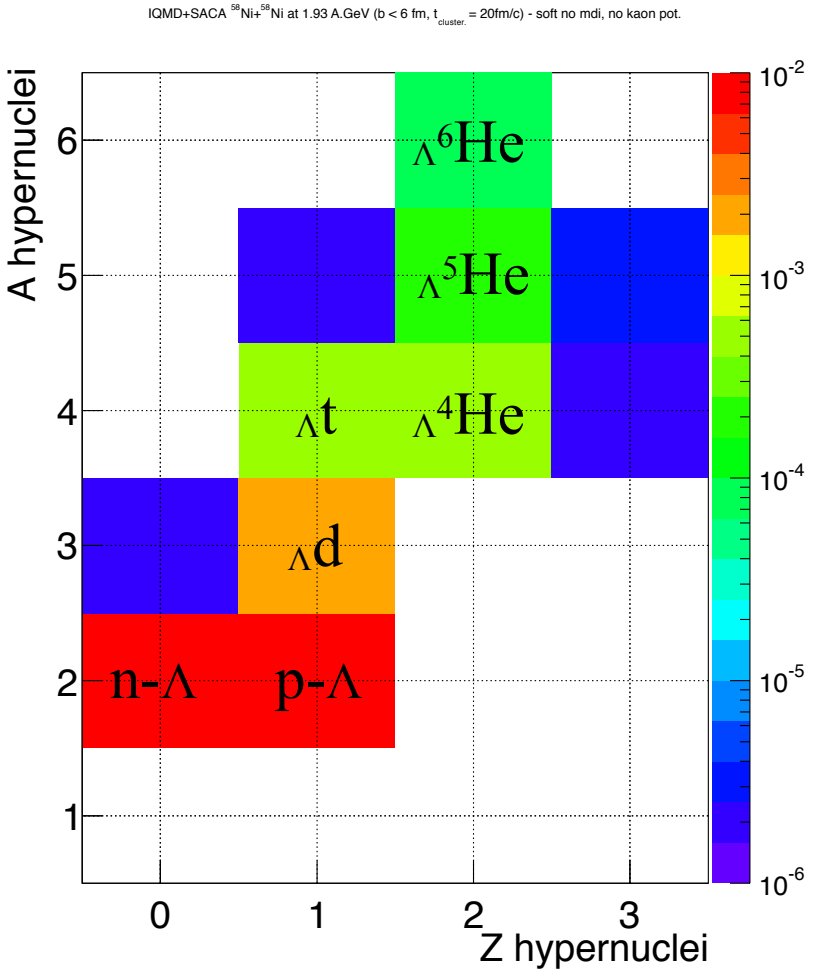

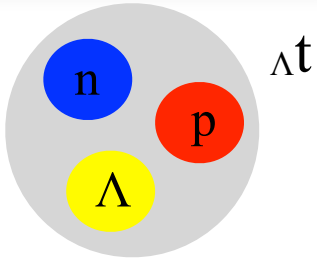

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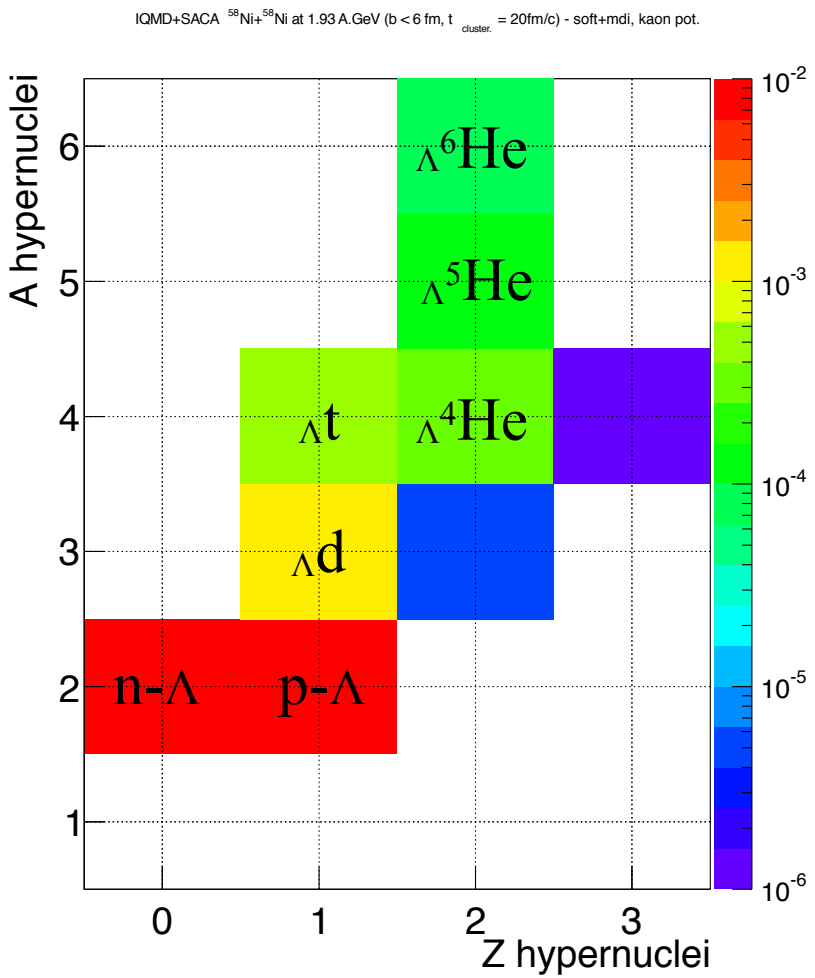

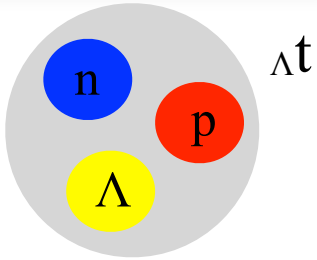

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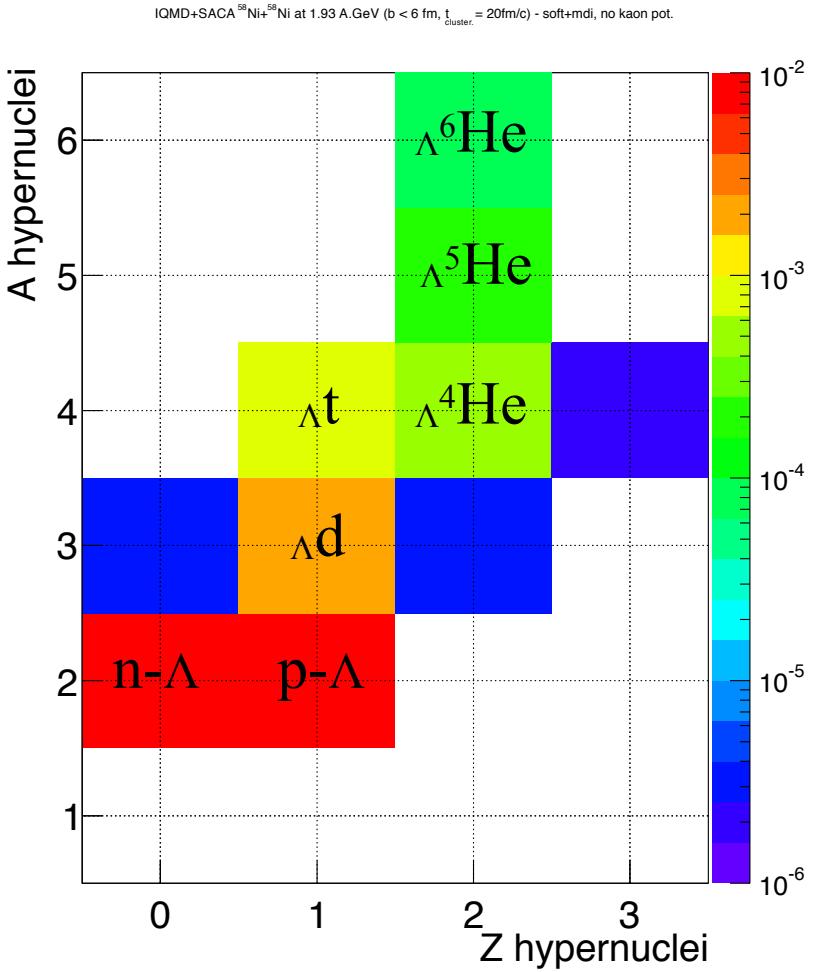

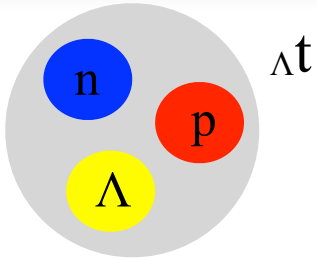

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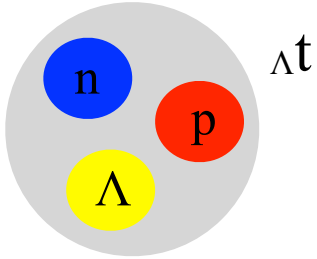
Strong phase space constraints



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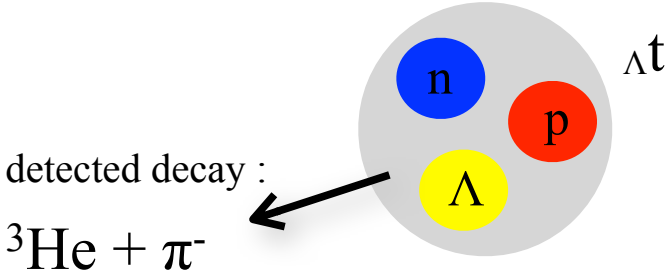

detected decay :

$^{3}He + \pi^{-}$

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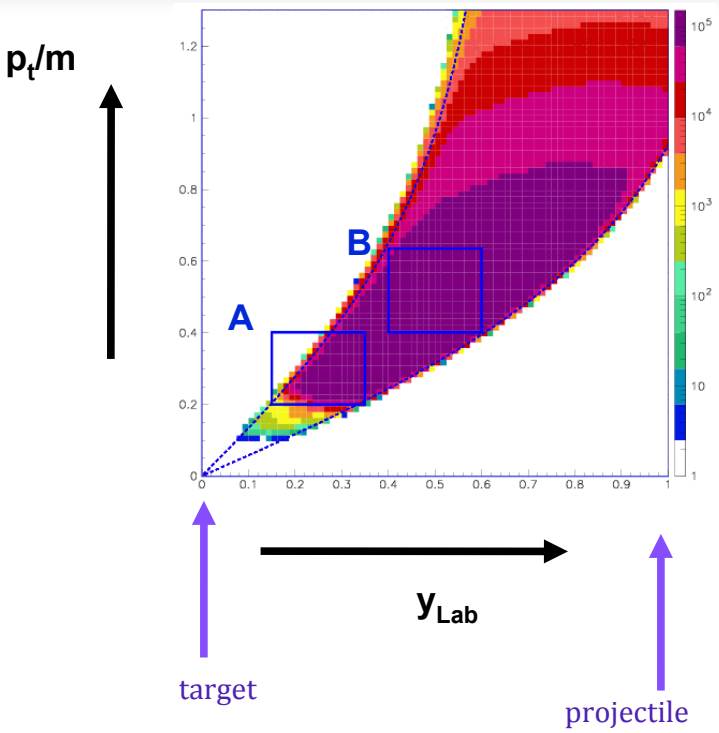
FOPI Coll.
Y. Zhang, Heidelberg



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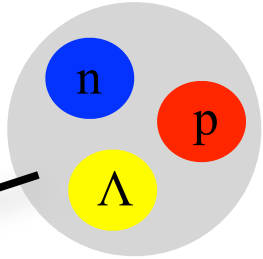

$_{\Lambda}t$

Ni+Ni @ 1.91 A.GeV

Preliminary

Strong phase space constraints

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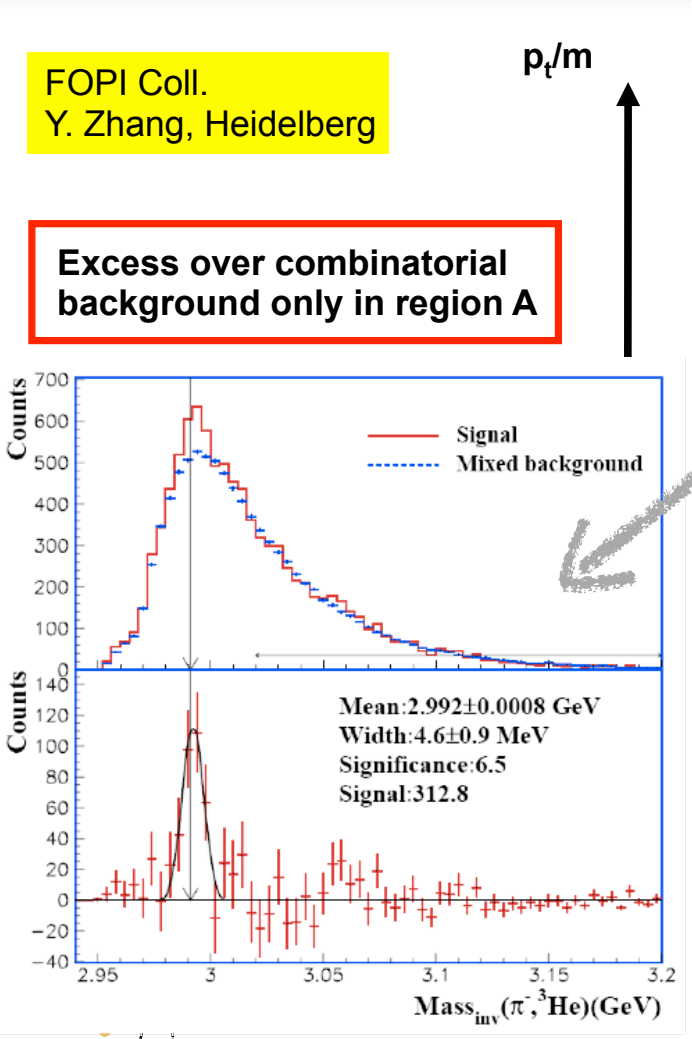
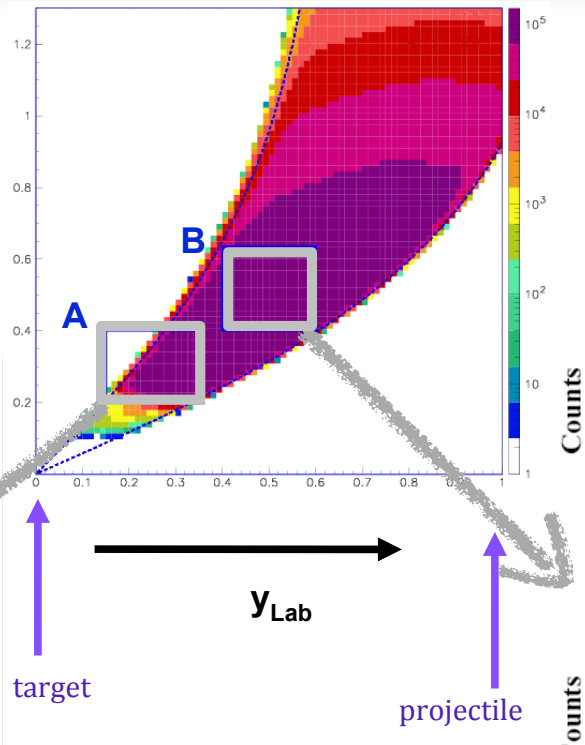
Y. Zhang, Heidelberg

Excess over combinatorial background only in region A





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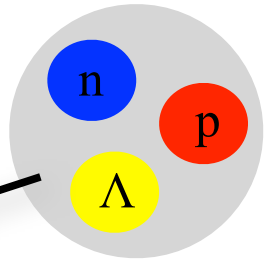

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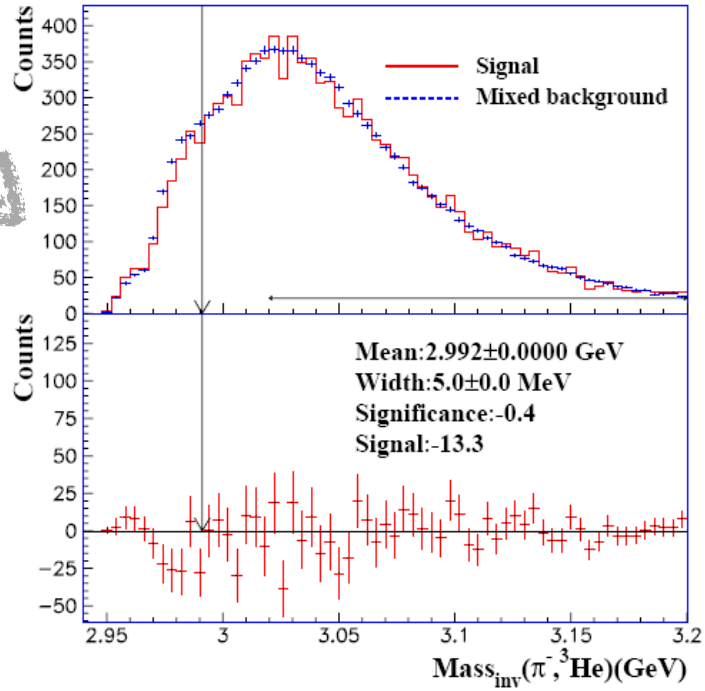

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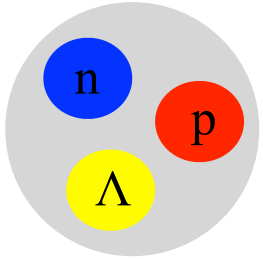

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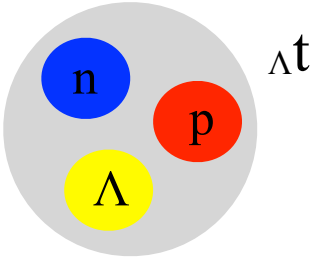

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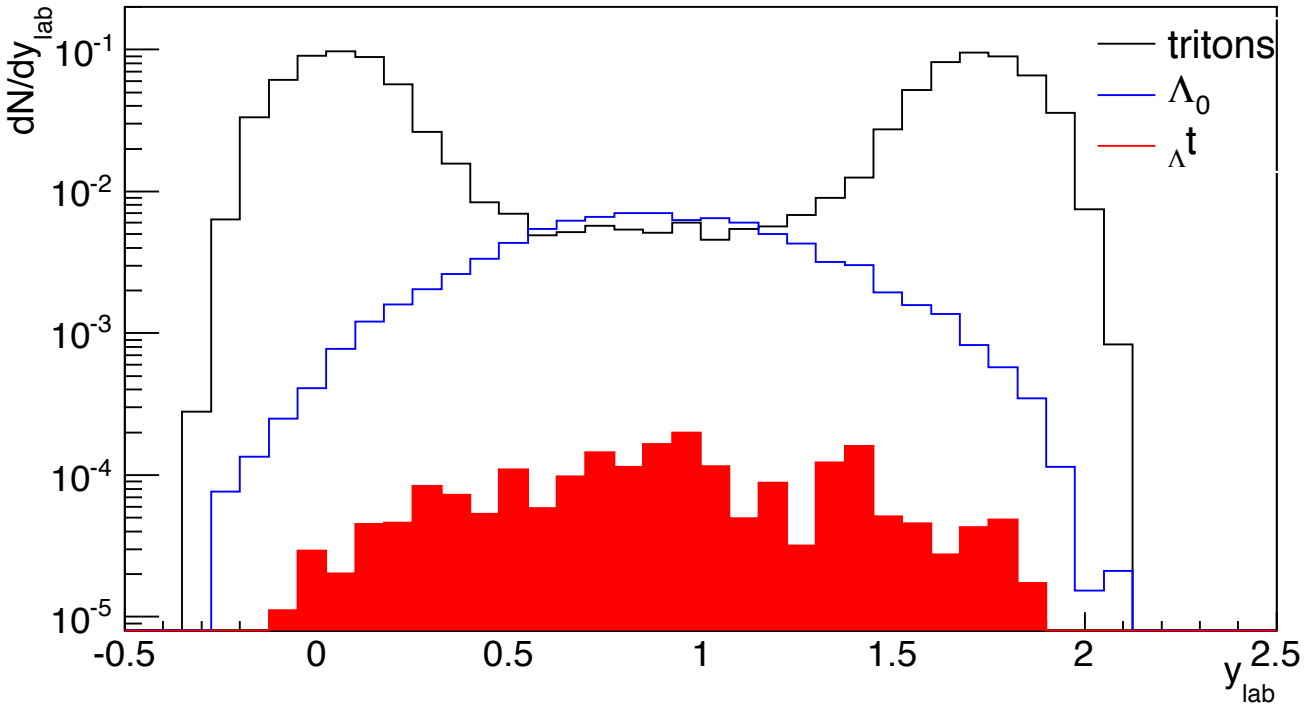

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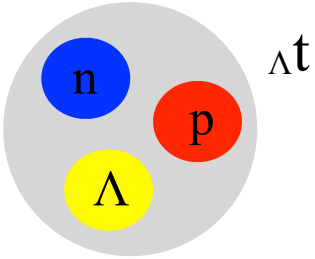

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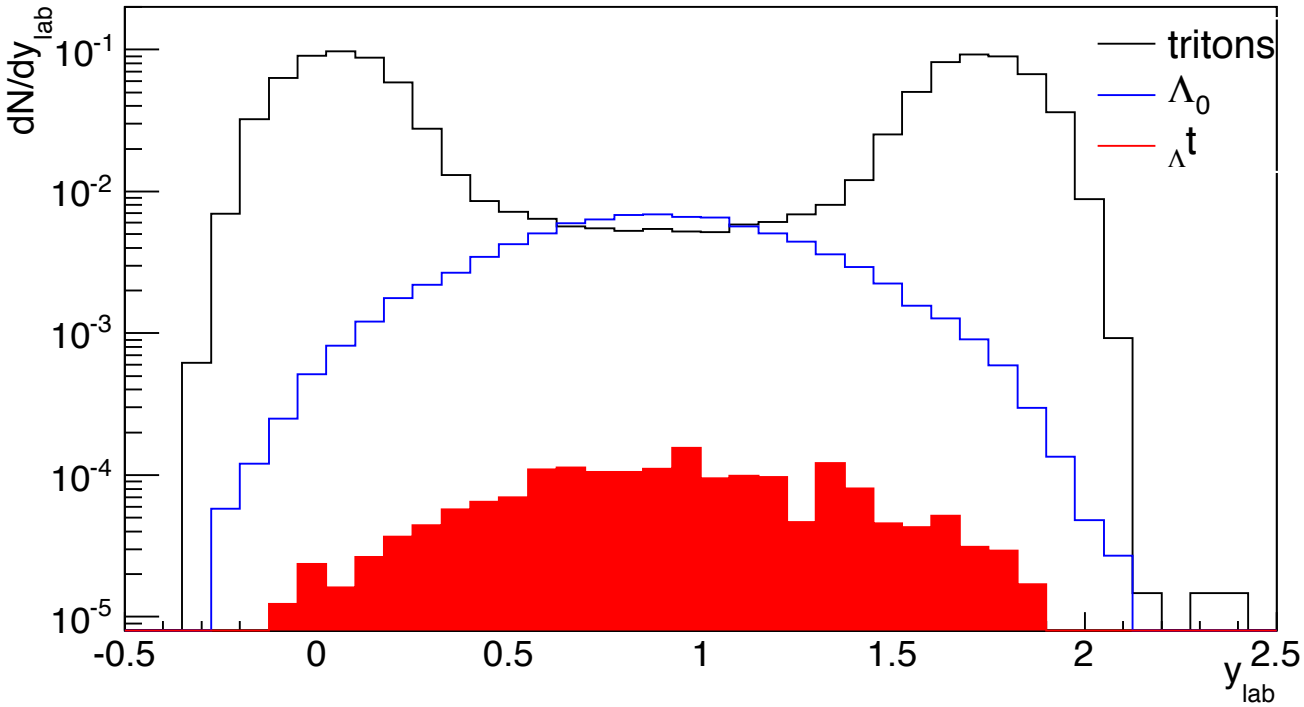

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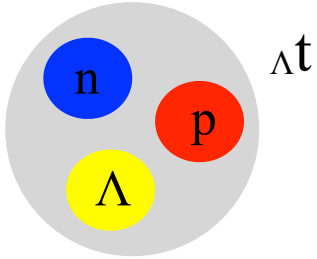

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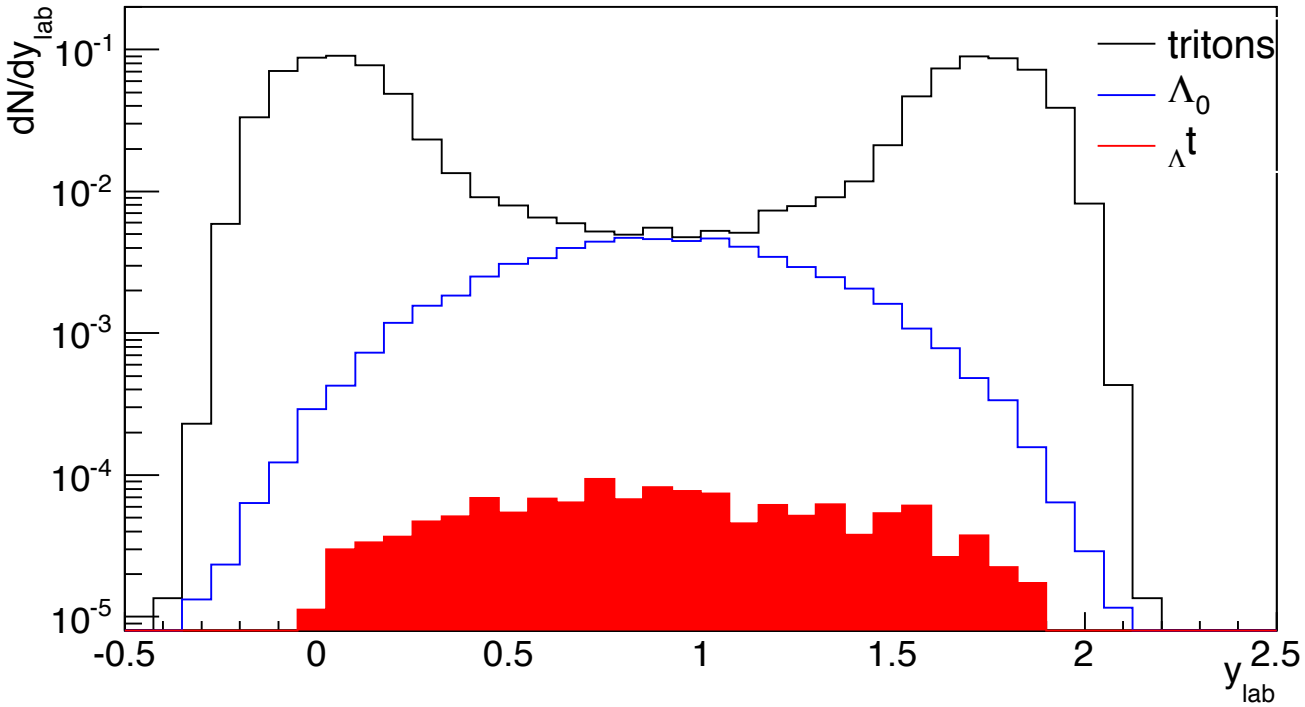

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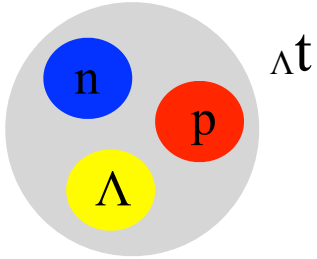

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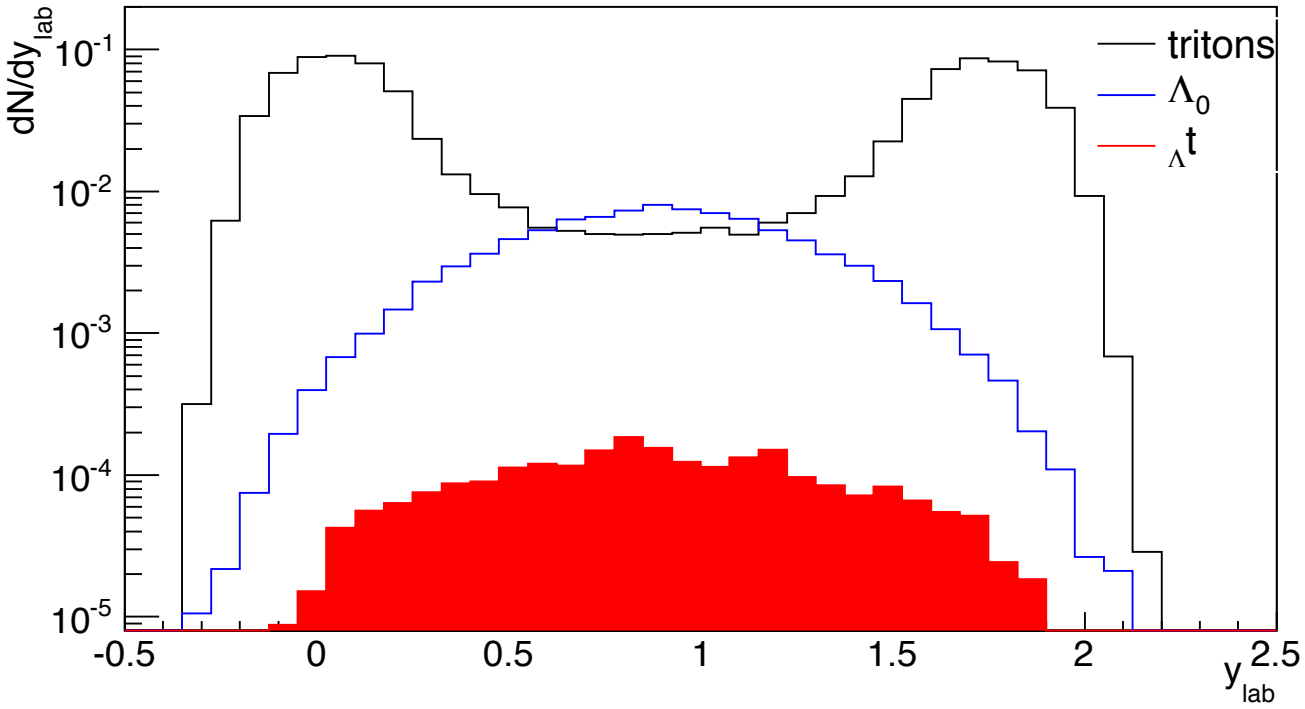

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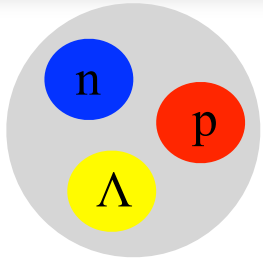

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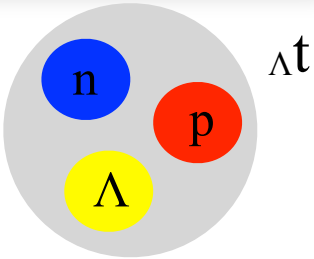

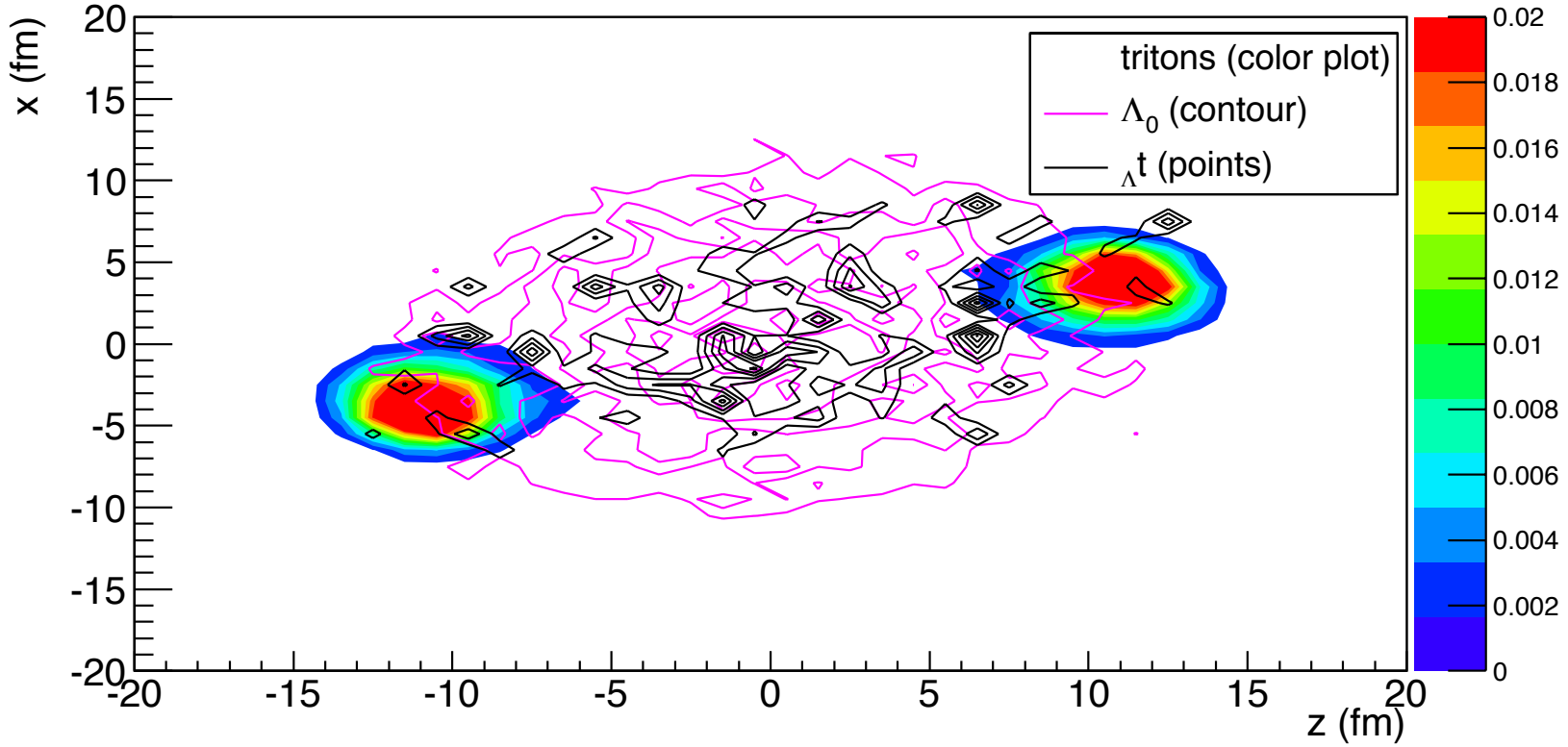

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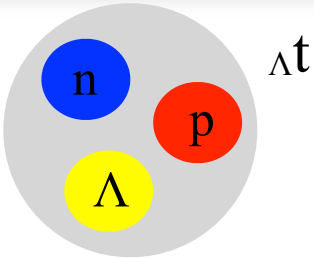

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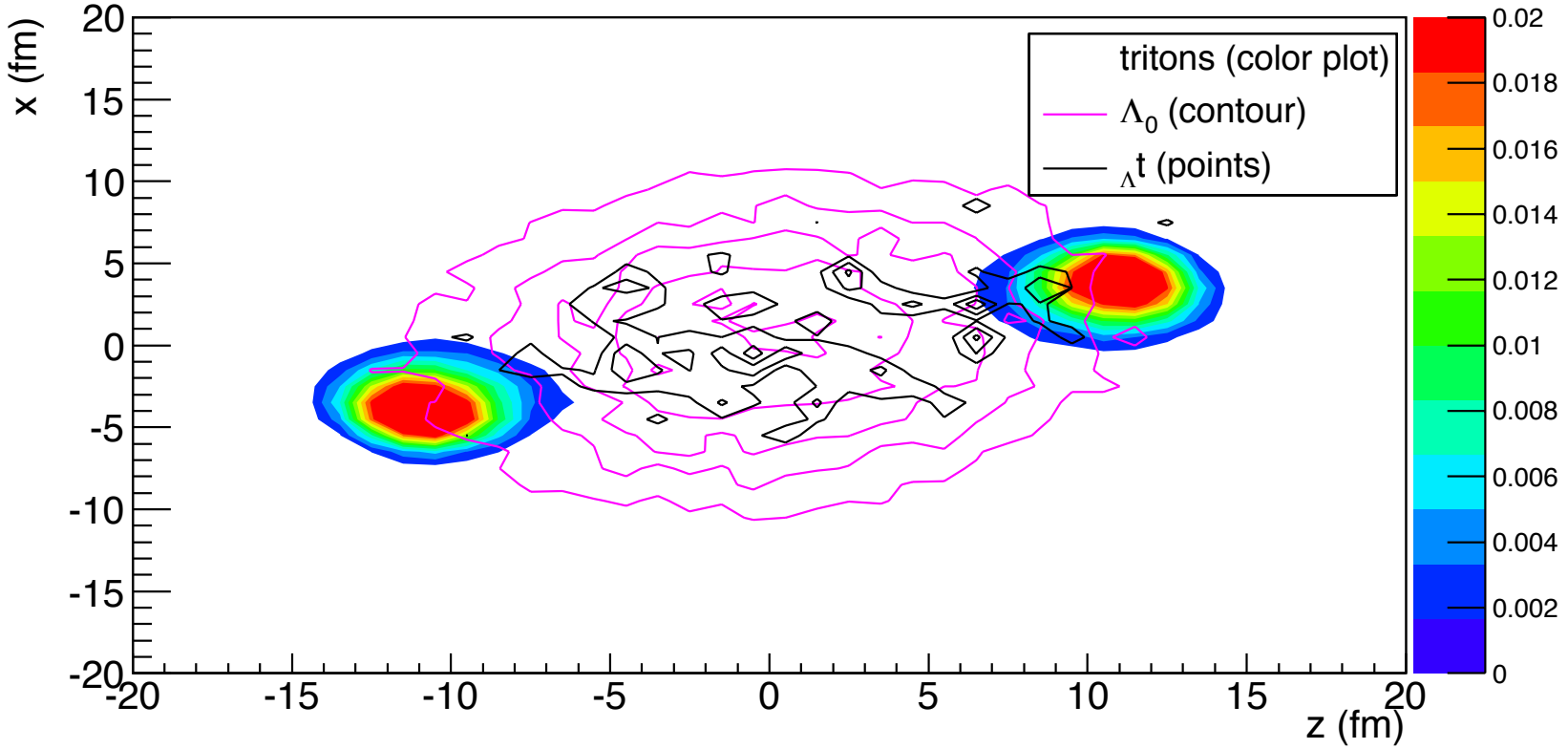

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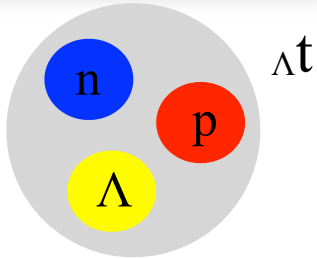

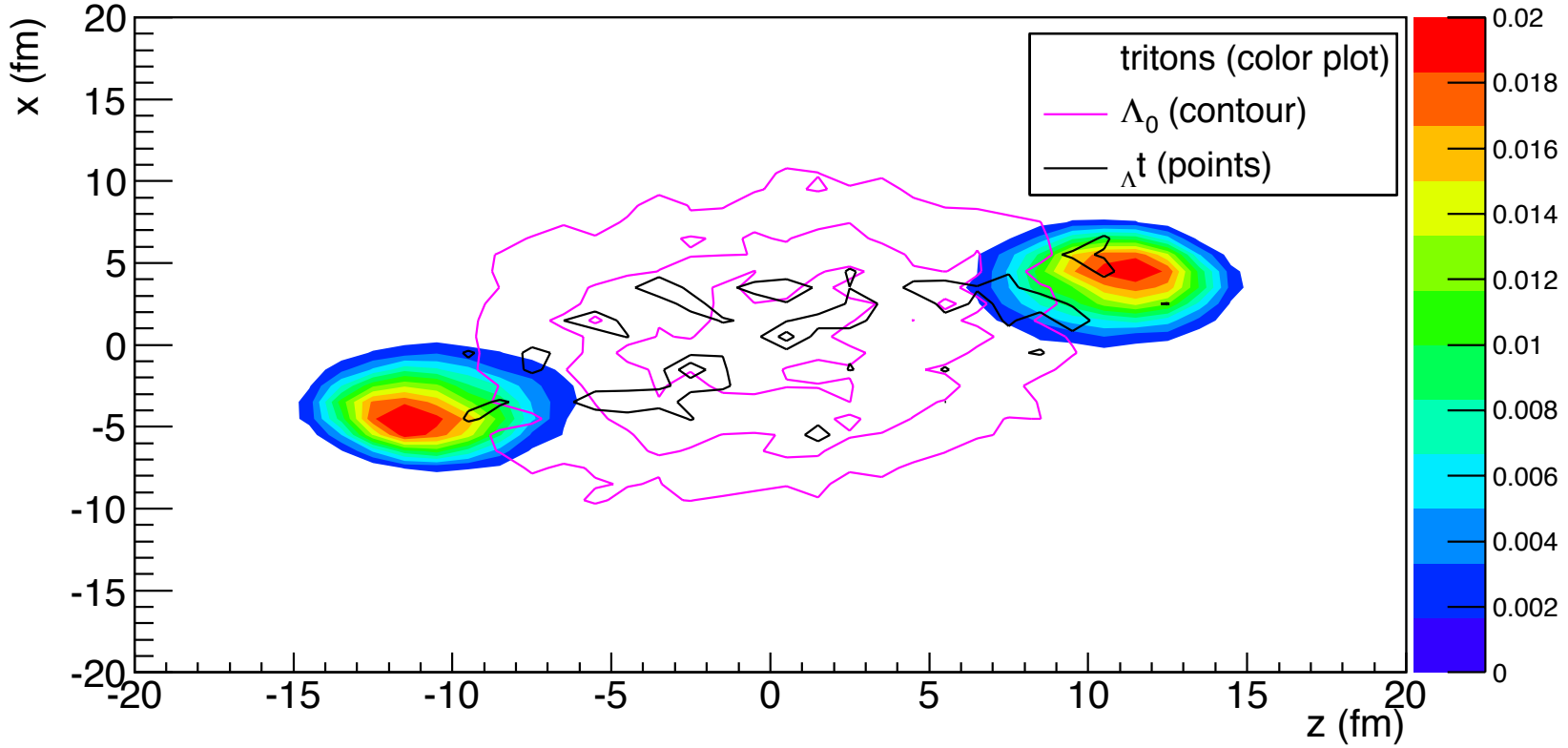

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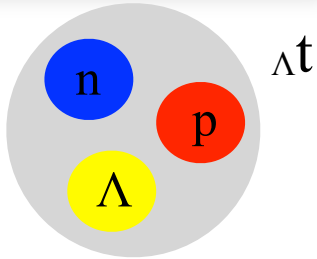

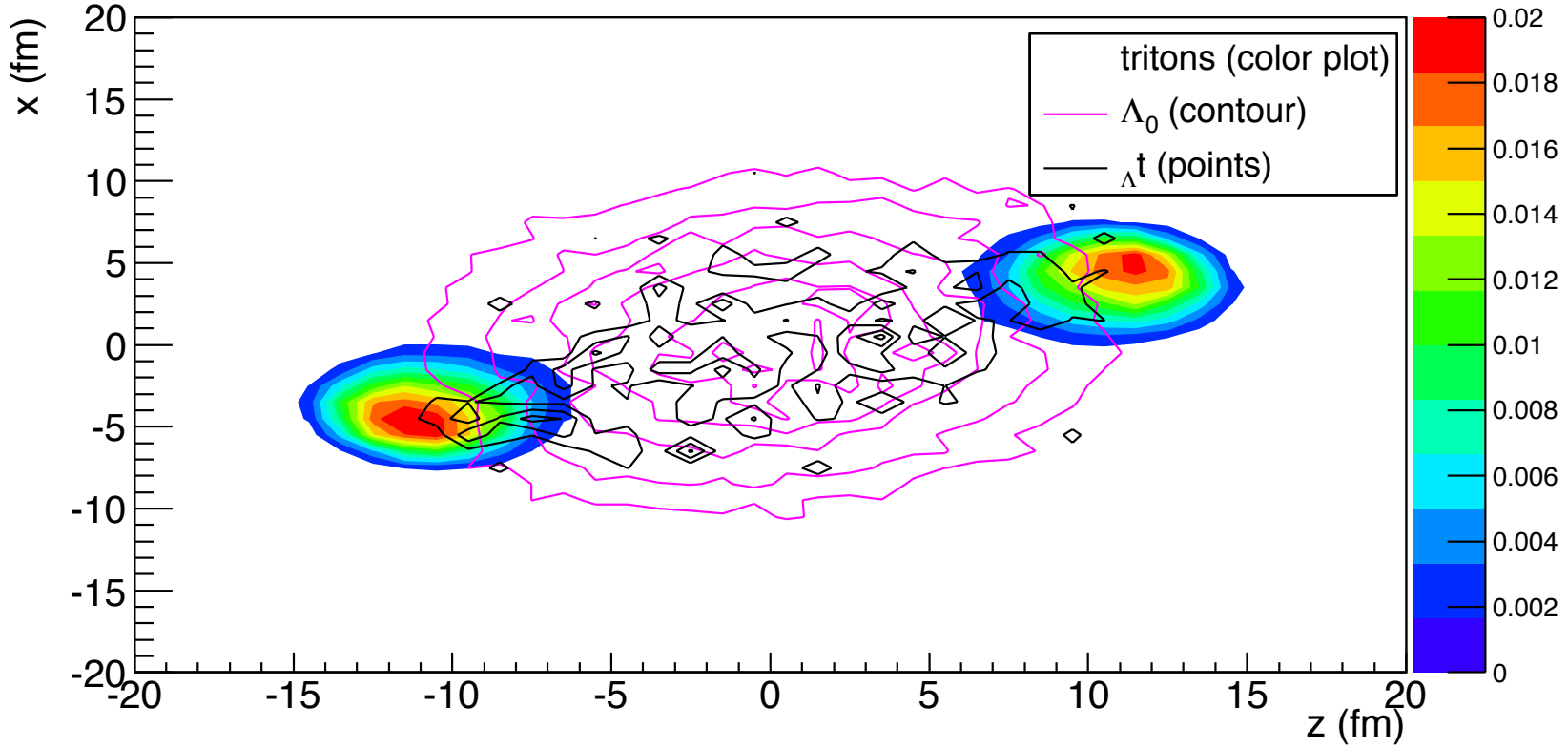

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- Supplying SACA with a more precise description of nuclei binding energy at abnormal density allows promising, realistic predictions of absolute isotope yields, and hypernuclei.
- The asymmetry energy has a strong influence on the anisotropy (apparent stopping power) for some isotopes (^{3}He, ^{4}He, ...).
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Further developments:

After processing SACA, proceed:

❖ further decay of primary unstable isotopes like ^{8}Be, ^{5}He, etc., which lifetime do not allow to detect them still bound in the detectors,

❖ allow early ^{3}He + n → ^{4}He according to its particularly high cross-section.

❖ secondary decay (evaporation code like GEMINI) of still excited clusters. Particularly relevant at intermediate energies (E_{beam} 100 A.MeV down to the Fermi regime)

❖ for hypernuclei formation, refine lambda-N potential in SACA or EOS/Kaon potential in IQMD in order to predict reasonnably the measured cross-sections, and momentum distributions, which are very constraining.