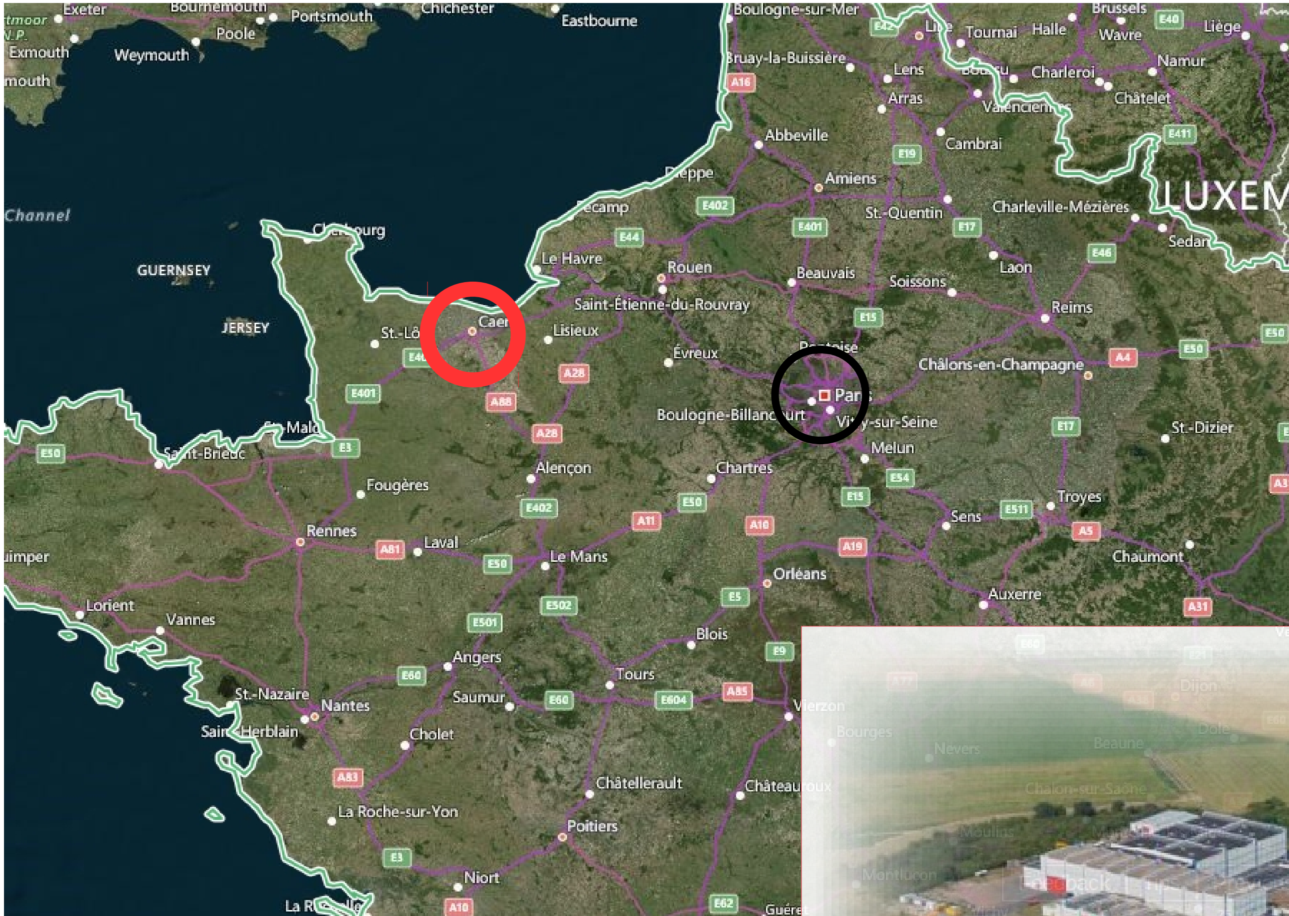
General announcement addressed to the audience and the organizers of the NUSYM symposium series

from Abdu Chbihi

GANIL runs for the organization of the next NUSYM conference

Already announced by Abdu during the last edition in Krakow



Caen in Normandy, Noth West of France

Close to Paris (2 hours by train)

GANIL

- French national laboratory for Nuclear physics
- Different facilities for nuclear science from fundamental research to applications
- Attract a worldwide community of users

Next year at GANIL

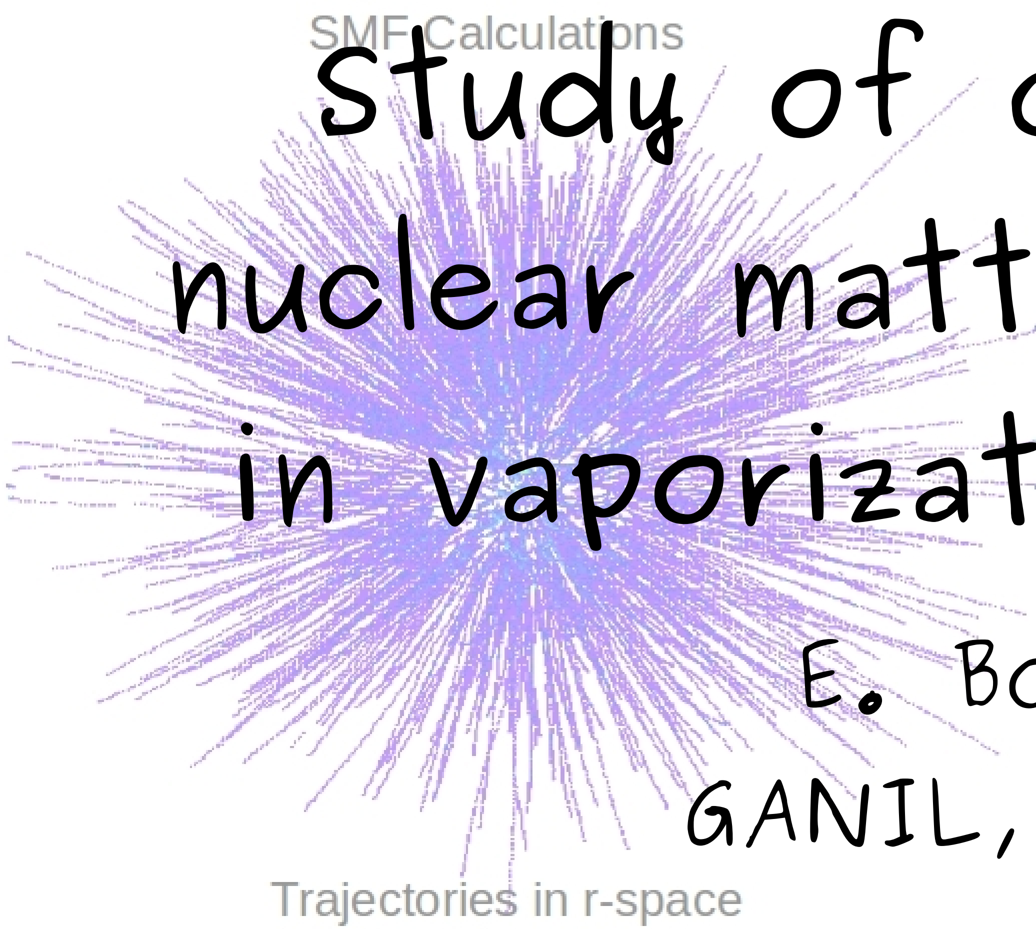
- SPIRAL2 commissioning and first experiment(s)
- Continuation of the AGATA-VAMOS campaign
- Beginning of the INDRA-FAZIA coupling

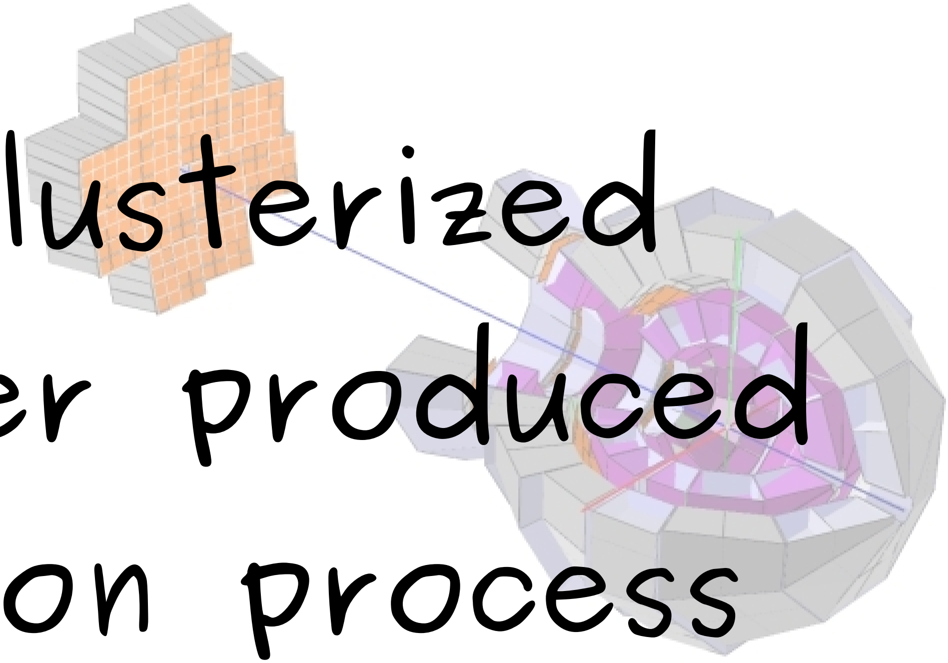
Organization of Workshops and Conferences

- IWM-EC (International WS on multifragmentation), every 2 years, last edition in May
- FISSION WS (2013), FUSION conf. (2011)
- FUSTIPEN topical meetings
- Nuclear talent schools (summer school for students)

- Next IPAC conference in 2020

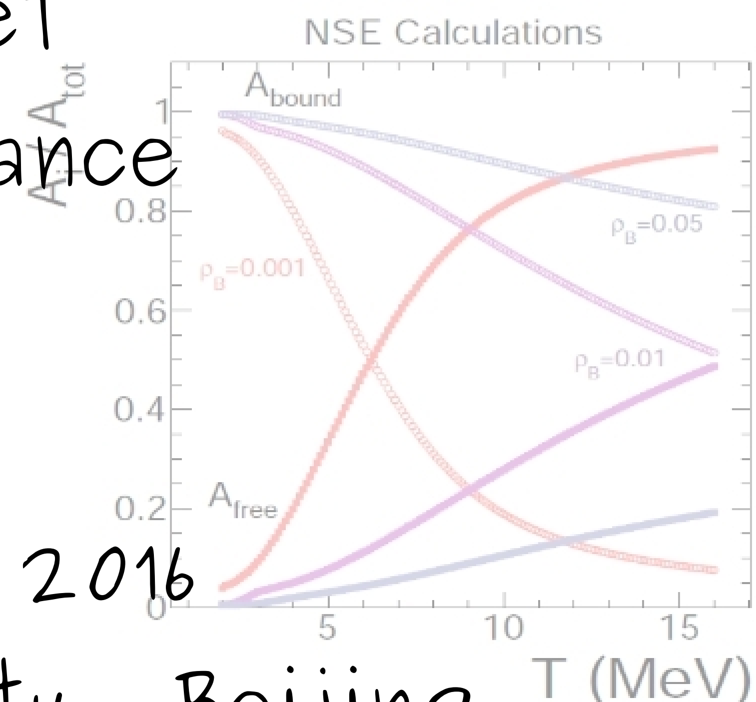
Study of clusterized nuclear matter produced in vaporization process





E. Bonnet

GANIL, France



NUSYM

13–17 June 2016

Tsinghua University, Beijing

Rise-and-Fall : from multifragmentation to vaporization

C.A. Ogilvie et al,
Phys. Rev. Lett. 62, 1724 (1991)

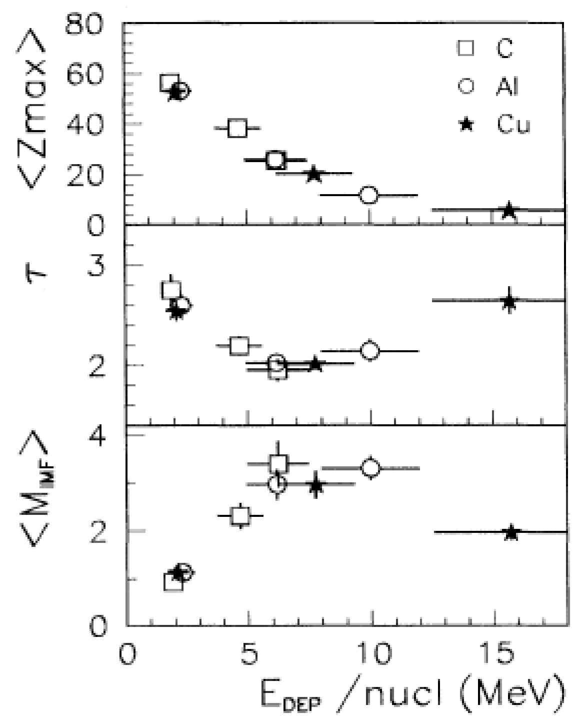


FIG. 3. The average maximum charge in each event, the fitted τ parameter from the charge distribution, and the mean IMF multiplicity plotted vs the calculated deposited energy per nucleon. The squares, circles, and stars represent collisions on the C, Al, and Cu targets, respectively. Each point within a target group corresponds to peripheral, mid-central, and central collisions with the deposited energy increasing with centrality.

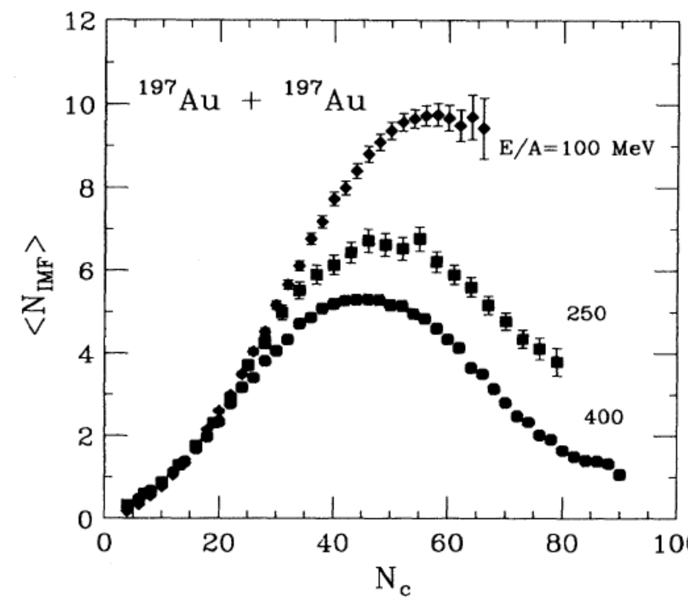


FIG. 1. Correlation between $\langle N_{\mathrm{IMF}} \rangle$, the mean fragment multiplicity, and N_C, the multiplicity of charged particles detected in the Miniball/Miniwall. These are the measured quantities and are not corrected for the energy and angle dependent detection efficiency of the experimental apparatus.

B. Tsang et al,
Phys. Rev. Lett. 71, 1502 (1993)

Vaporization in HIC : Gas phase of the phase transition in nuclear matter

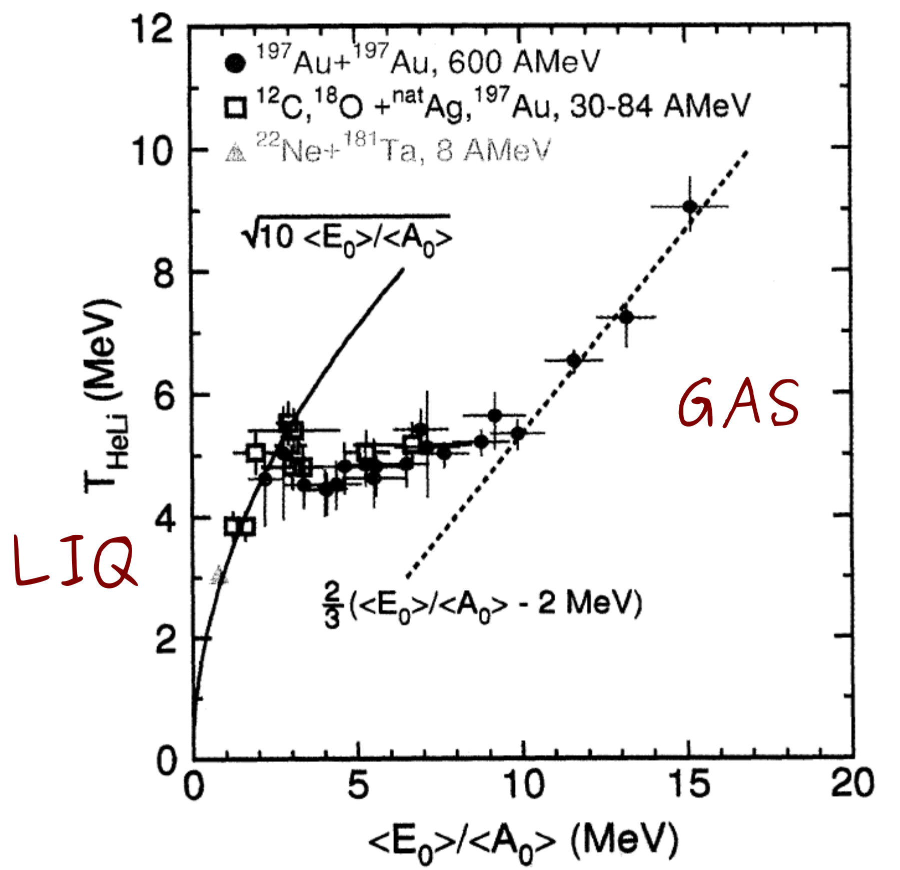


FIG. 2. Caloric curve of nuclei determined by the dependence of the isotope temperature T_{HeLi} on the excitation energy per nucleon. The lines are explained in the text.

J. Pochodzalla et al,

Phys. Rev. Lett. 75, 1040 (1995)

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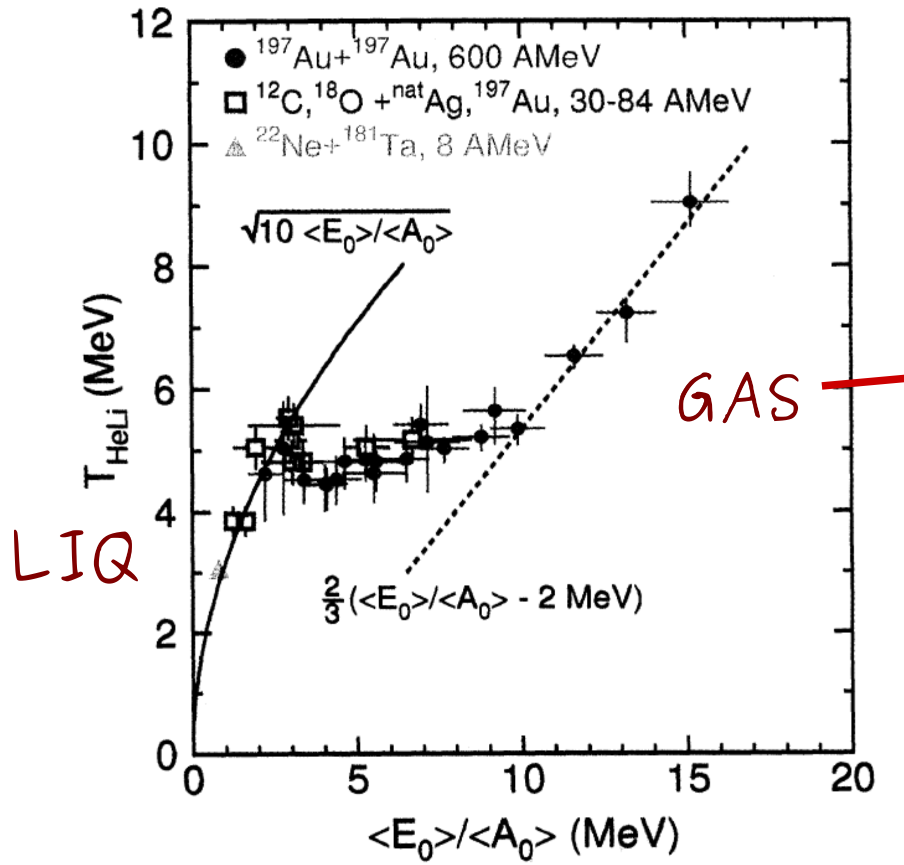

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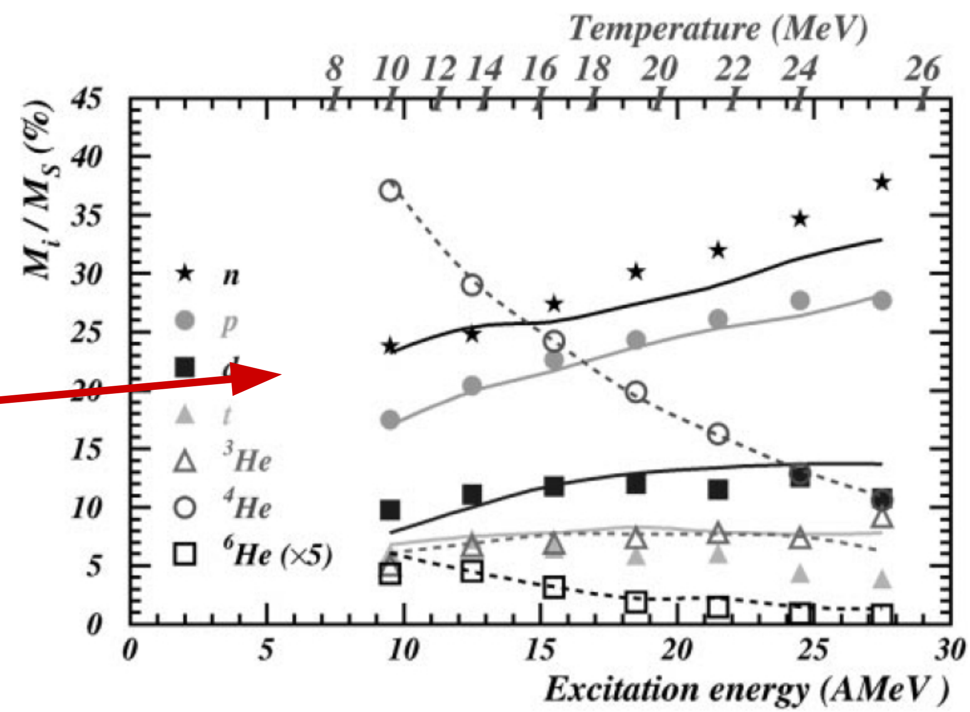
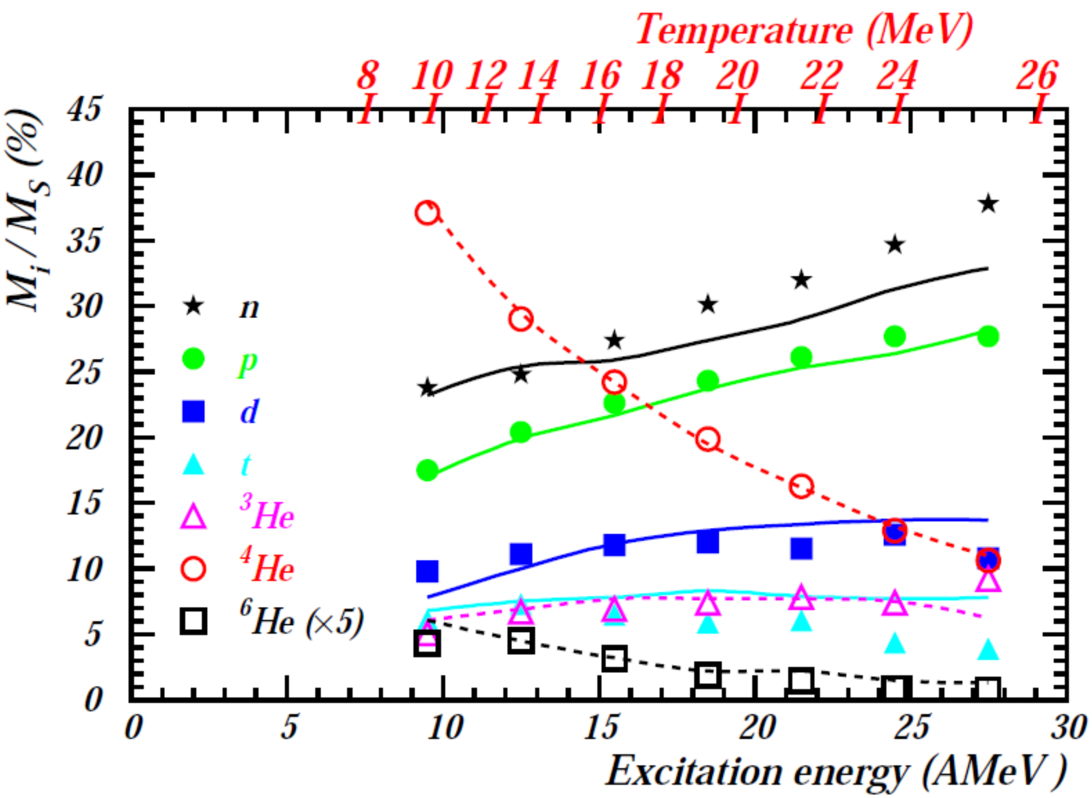


Fig. 3. Composition of the QP as a function of its excitation energy. Symbols are for data while the lines (dashed for He isotopes) are the results of the model. The temperature values used in the model are also given (see text)

INDRA collaboration
B. Borderie et al,
Eur. Phys. J. A 6, 197–202 (1999)

Thermal and chemical equilibrium for vaporizing sources

36Ar+58Ni reactions



- clusters up to 6He
- Grand canonical ensemble
- Excluded volume method
- Excited states up to Ne

At E*=18.5 MeV/A, density fixed at rho0/3 to reproduce alpha-proton ratio

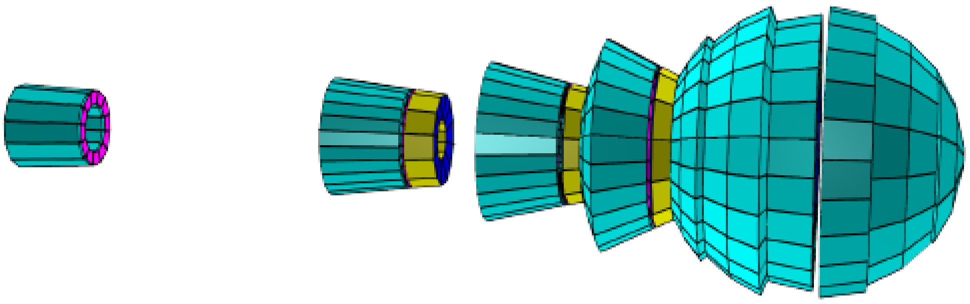
Reproduction using a model describing the properties of a quantum weakly-interacting gas of nuclear species in thermal and chemical equilibrium

From theoretical side

- Low density warm nuclear matter has a renewed interest coming from the need in the description of neutrino sphere region during the core-collapse supernovae (Topical Volume EPJA 50 (2014))
- Data in the subsaturation (rho<rhoo) densities region and finite temperature (T<20 MeV) are needed to constrain new developments and approaches in this topic :
  - "In-medium" nuclear data shift, Non homogeneous matter, Gas-Clusters interaction, Surface effects …
  - Isovector part of the energy functional (symmetry energy)

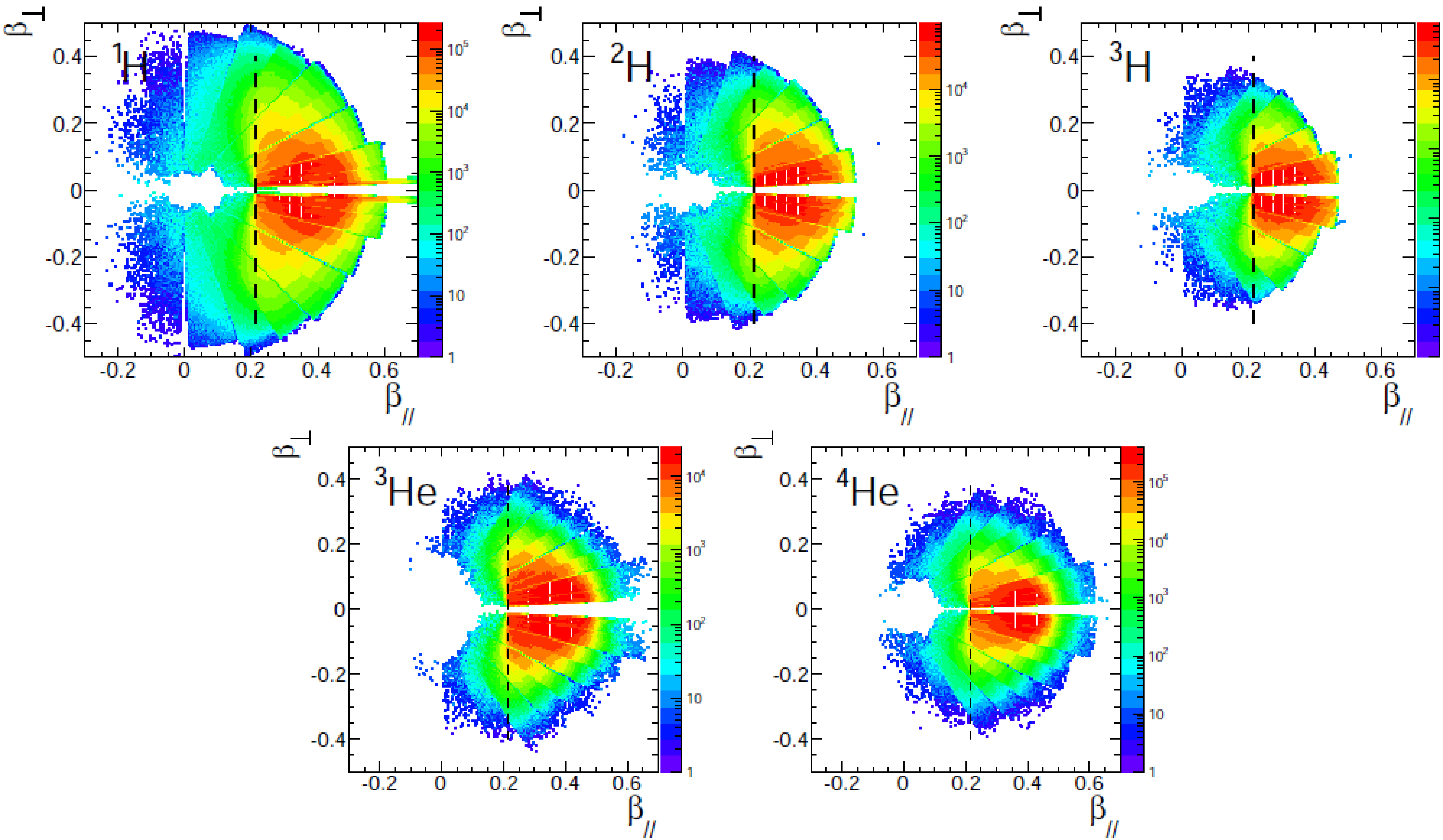
$^{58}Ni+^{58}Ni$ reactions studied with INDRA@GANIL

- Beam energy : 90 MeV/A
- Focus on the forward hemisphere and keep only events with clusters up to ^{4}He
- Ask for a minimum total detected charge of 25 (less than 10% of the Ni charge missing)



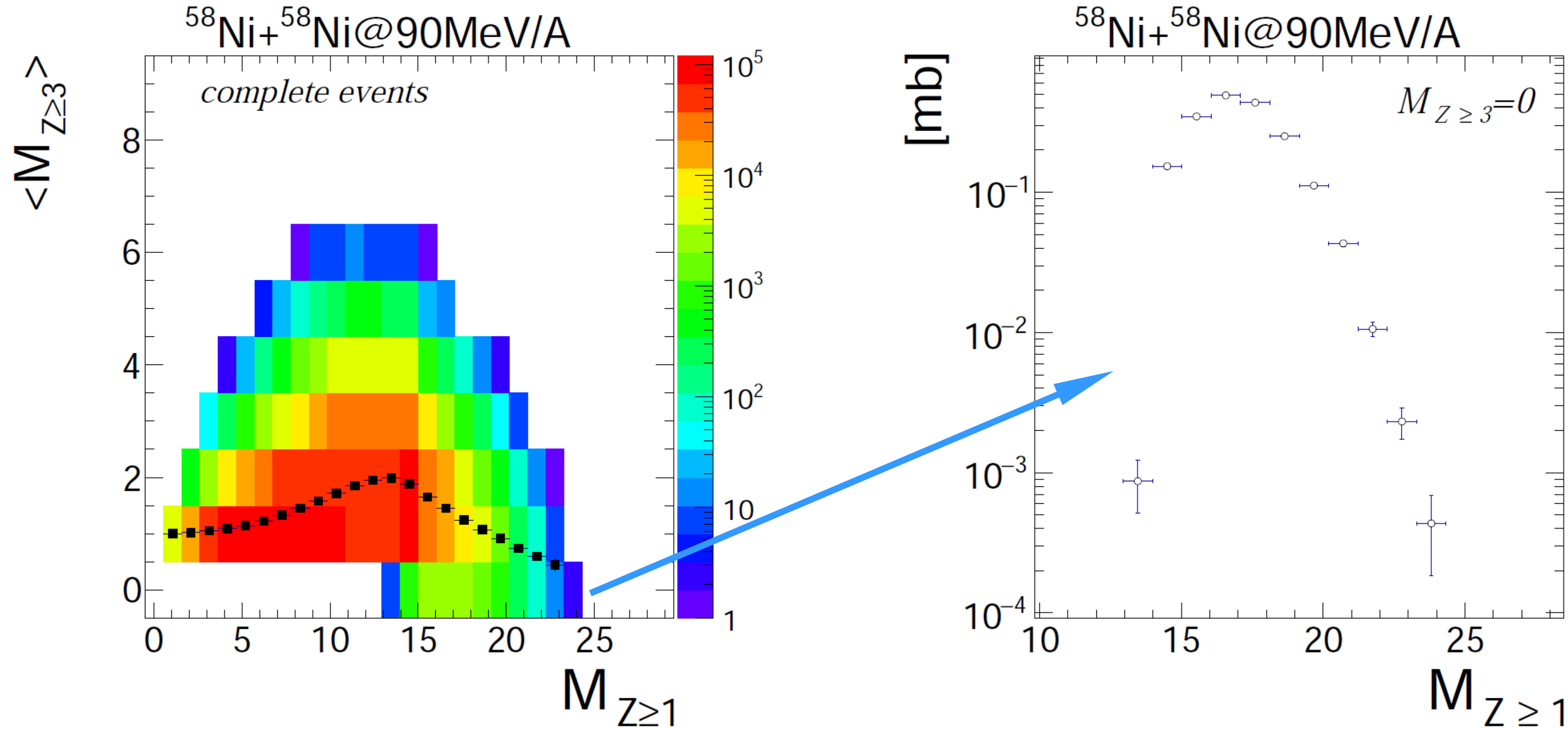
2D velocity space

^{1,2,3}H & ^{3,4}He isotopes



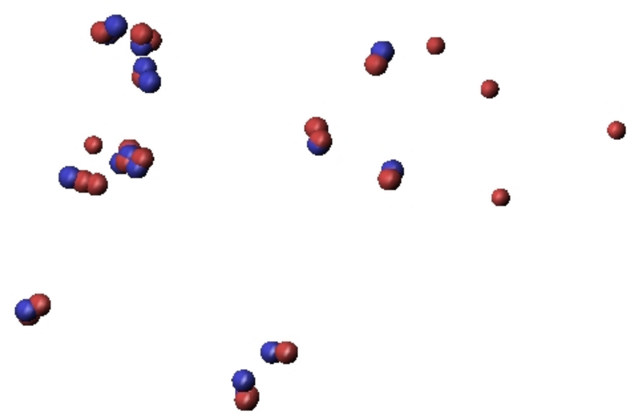
At the forward part, full isotopic resolution is achieved

Rise&Fall of fragment multiplicity



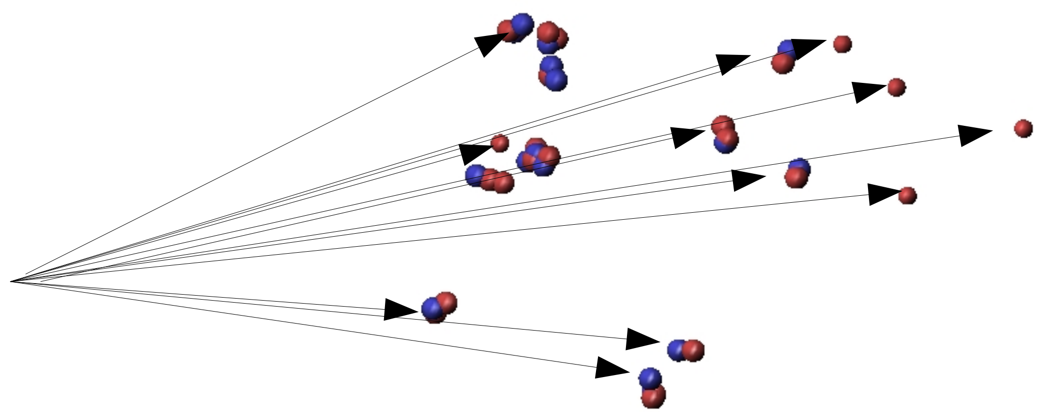
In the following, we performed an event-by-event analysis to extract properties of the vaporization process

Events sorting using Excitation energy



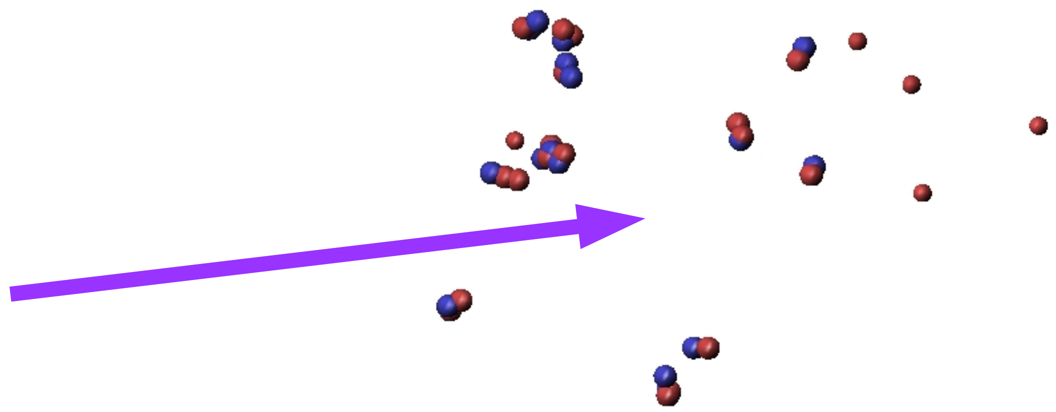
Typical detected event in velocity space

Events sorting using Excitation energy



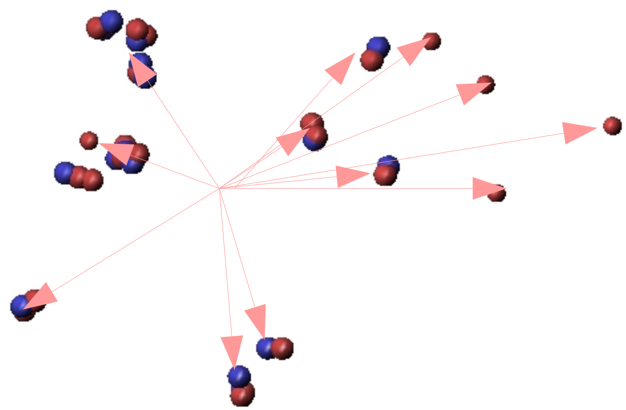
The residual boost of the entrance channel contribute to particle velocities

Events sorting using Excitation energy



To cancel this residual contribution, we compute centre-of-mass of particles.

Events sorting using Excitation energy



We calculate excitation energy (E*)using calorimetry procedure based on mass & energy balance.

$$E^* = \sum_{i=1}^{M_{tot}} (\epsilon_k^{(i)} + \delta^{(i)}) - \delta_{ini}$$

As neutrons are not detected, 2 assumptions are made to include them:

$$E^* = \sum_{i=1}^{M_{Z\geq 1}} (\epsilon_k^{(i)} + \delta^{(i)}) + \sum_{j=1}^{M_n} (\varepsilon_k^{(j)} + \delta^{(j)}) - \delta_{ini}$$

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For their multiplicity:

Conservation of the A/Z ratio

$$M_n = \left(\frac{A}{Z}\right)_{^{58}Ni} \times \sum_{i=1}^{M_{Z\geq 1}} Z^{(i)} - \sum_{i=1}^{M_{Z\geq 1}} A^{(i)}$$

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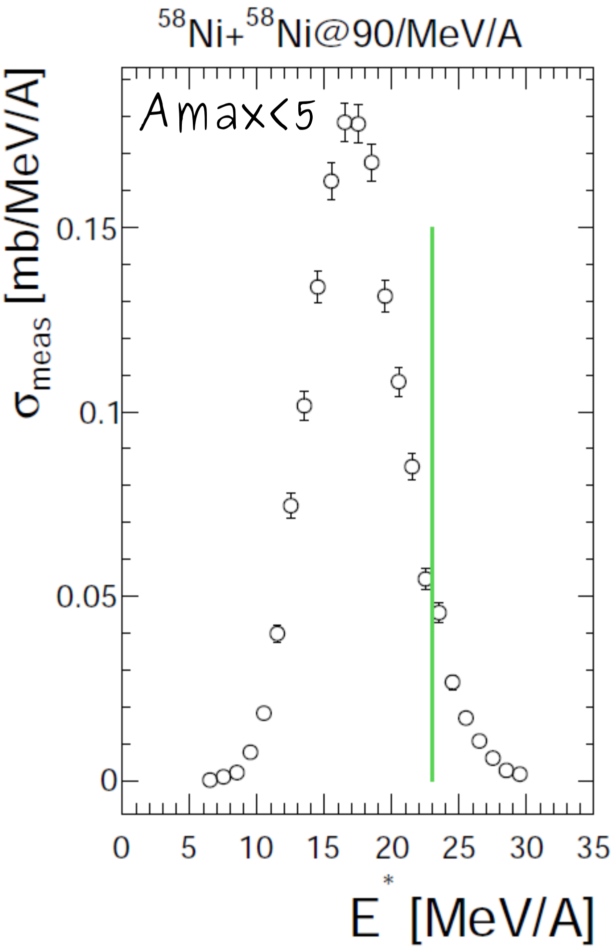
For their mean kinetic energy:

Same as the charged particles

$$< \varepsilon_k^n > = < \varepsilon_k^{Z\geq 1} > = \frac{1}{M_{Z\geq 1}} \sum_{i=1}^{M_{Z\geq 1}} \varepsilon_k^{(i)}$$

Vaporization events (Amax<5)

Xsection 1.9 mb (w/o detection efficiency correction)



$$E^* = \sum_{i=1}^{M_{Z\geq 1}} (\varepsilon_k^{(i)} + \delta^{(i)}) + M_n < \varepsilon_k^n > -\delta_{ini}$$

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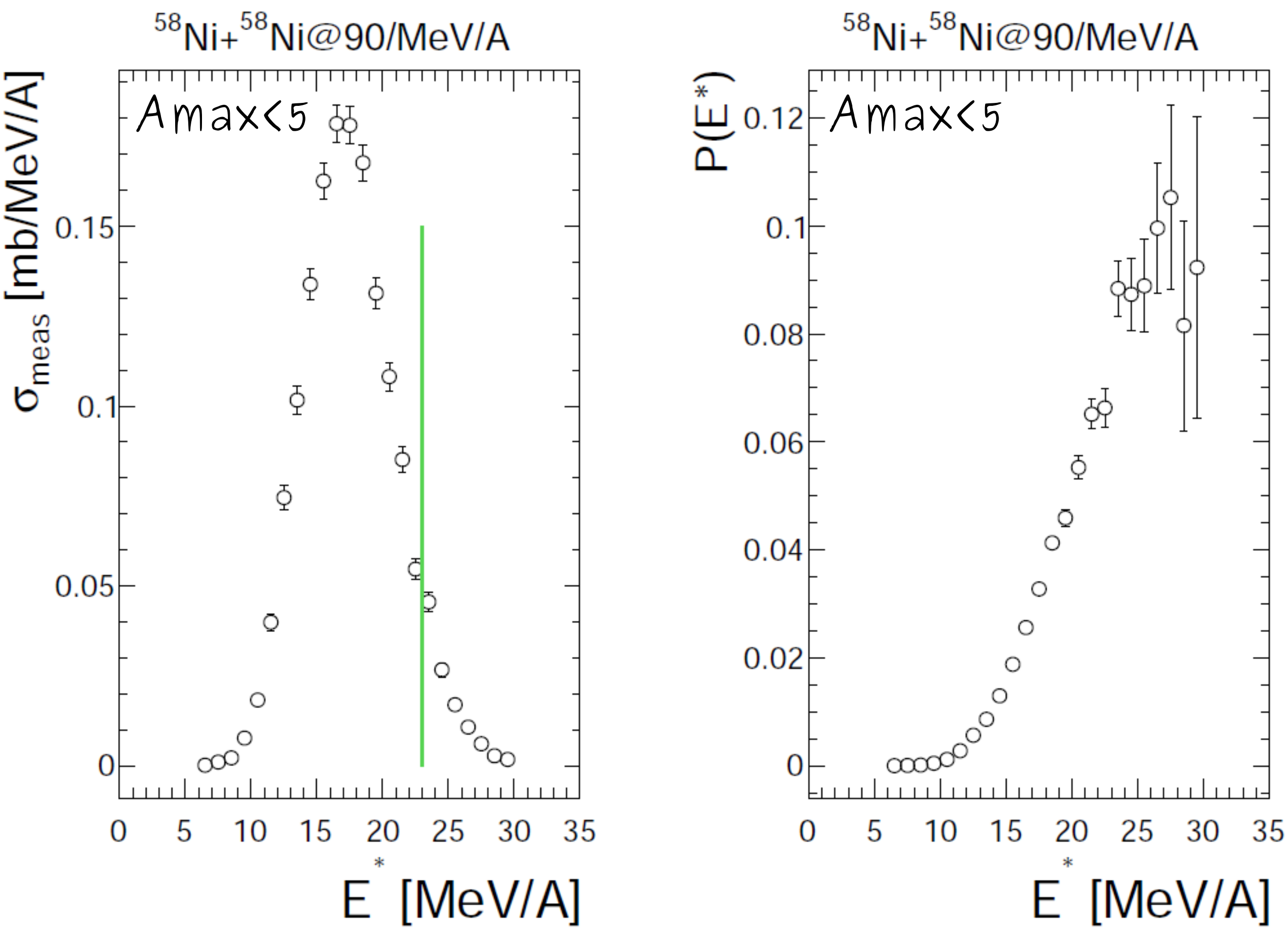

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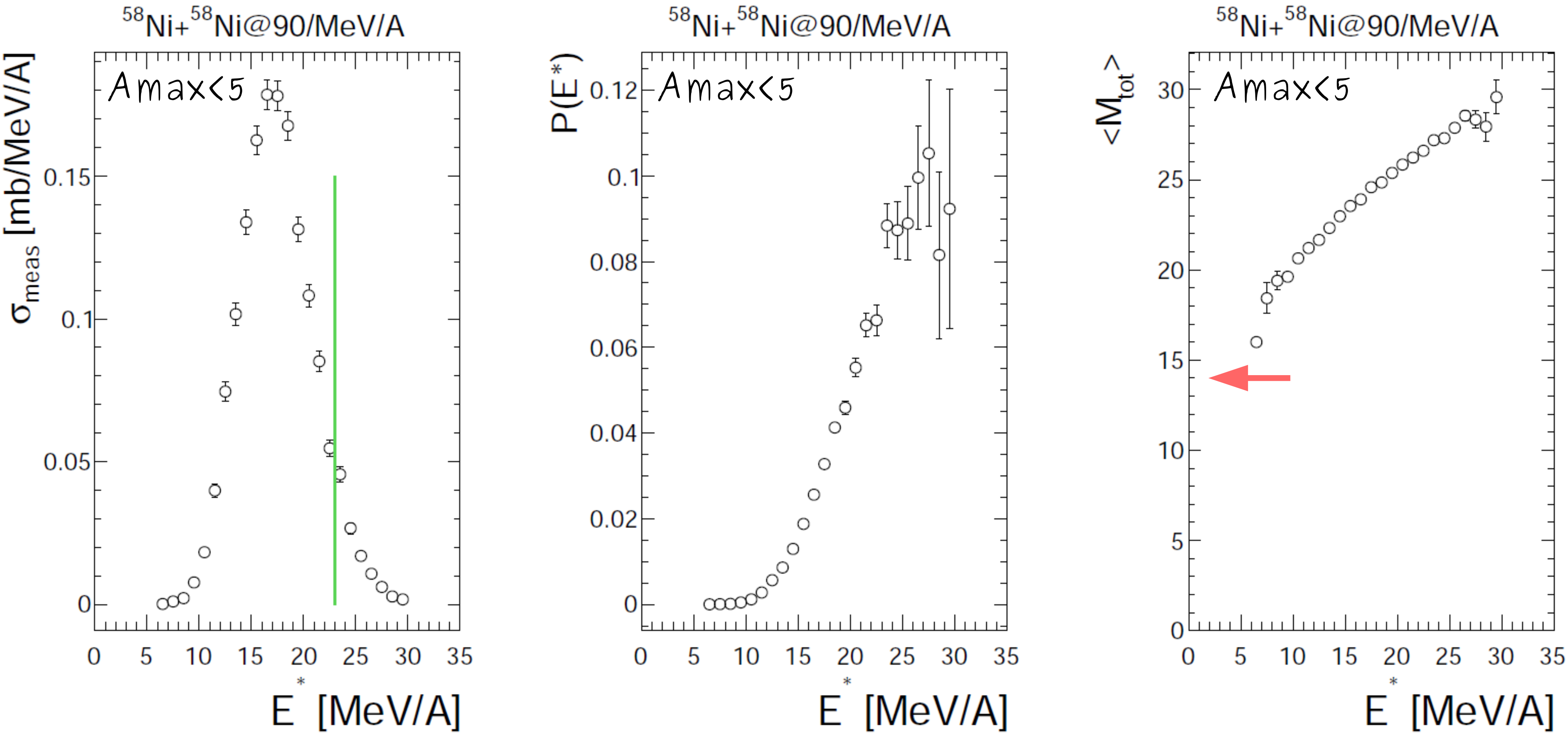
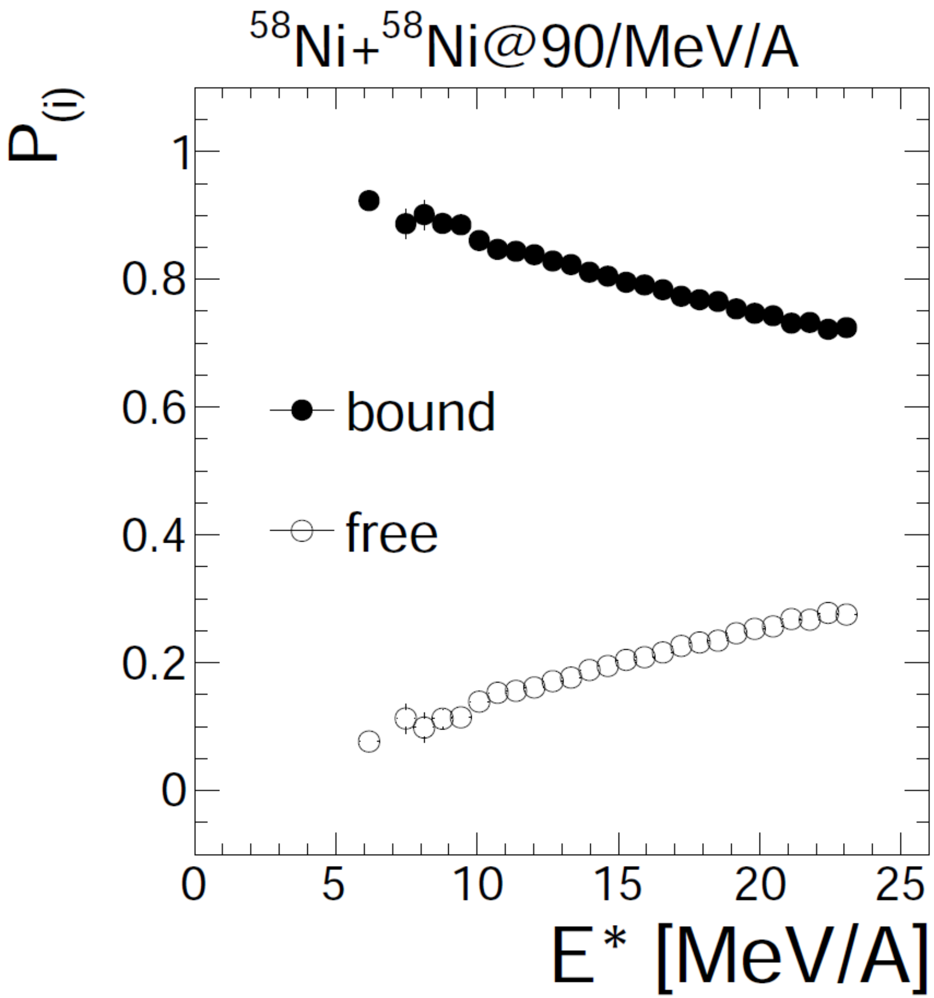


$$E^* = \sum_{i=1}^{M_{Z\geq 1}} (\varepsilon_k^{(i)} + \delta^{(i)}) + M_n < \varepsilon_k^n > -\delta_{ini}$$

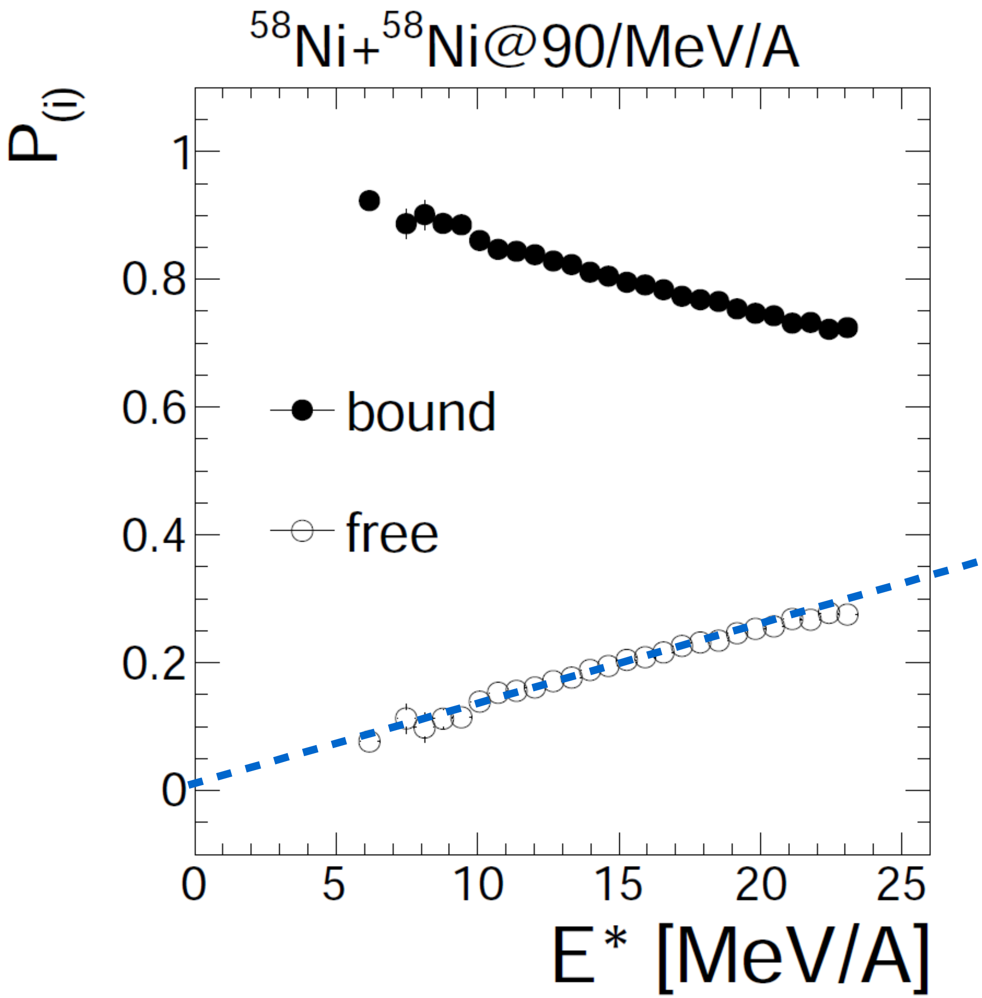
Vaporization properties

Nucleon repartition between clusters and the gas

Nucleon repartition between clusters and the gas



Nucleon repartition between clusters and the gas

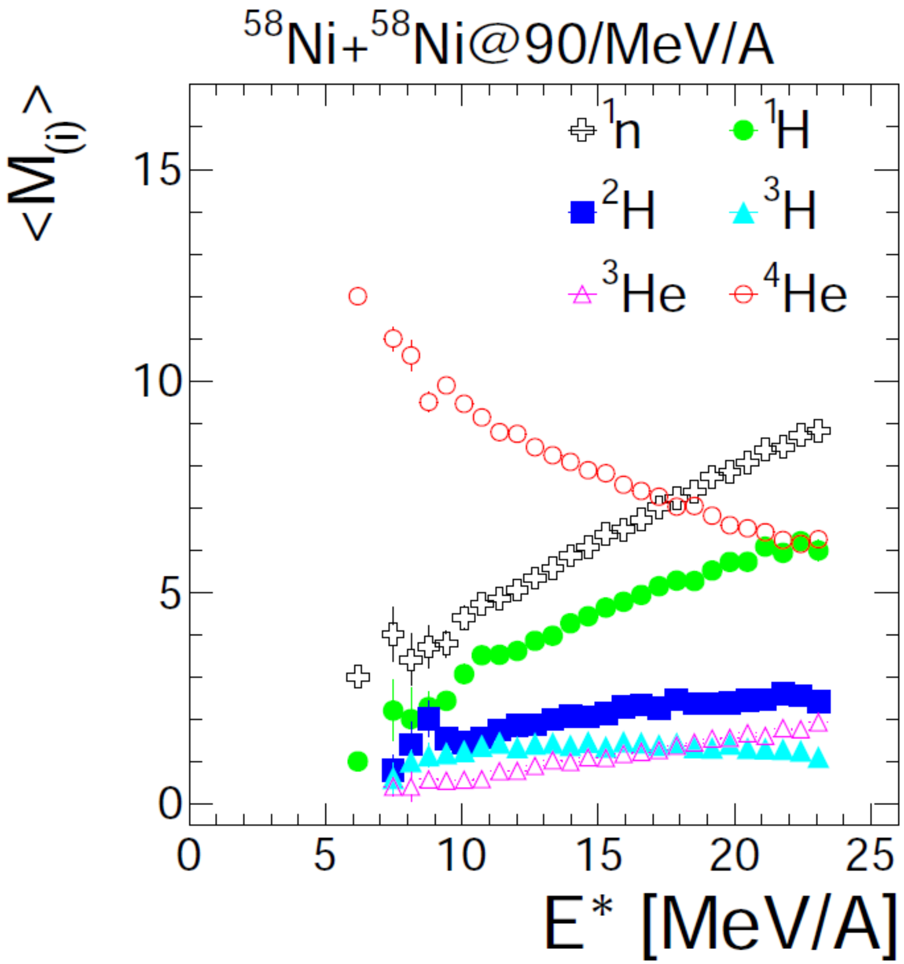


From linear Extrapolation,

E*=38MeV/A: Same repartition

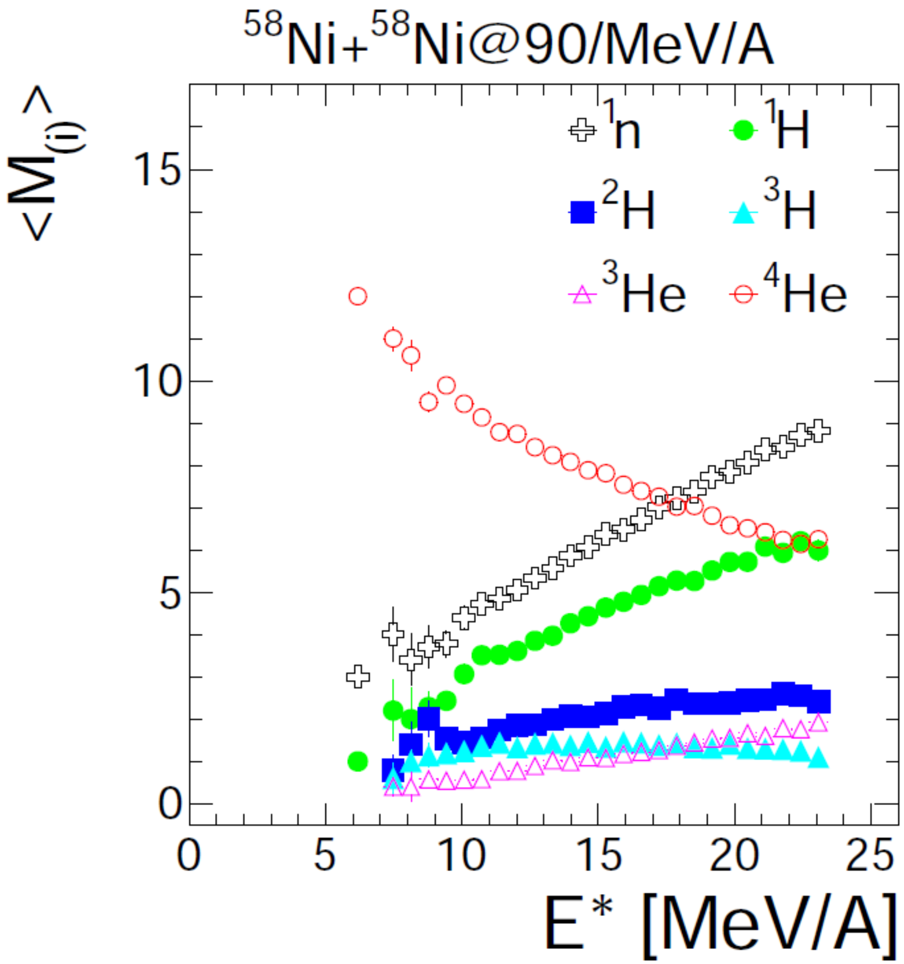
E*=77MeV/A: Pure nucleon gas

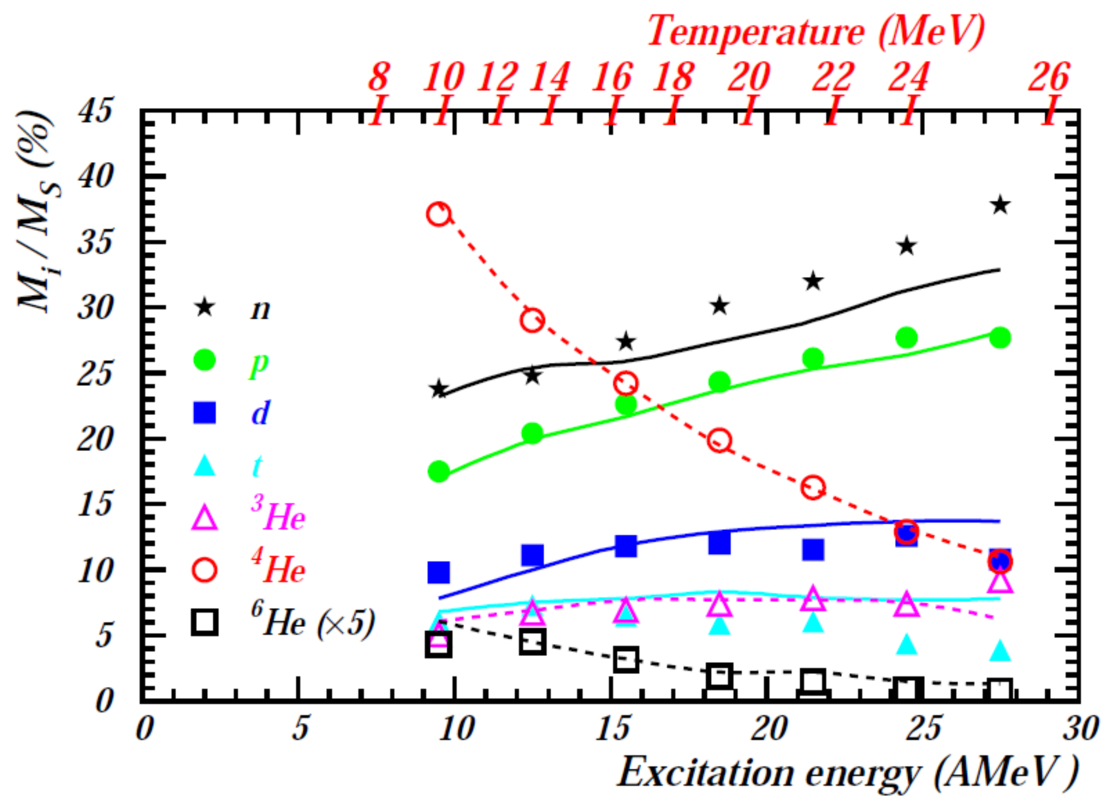
Cluster properties: multiplicities



Same trends as in the previous work: continuous decreasing of the 4He production, counterbalanced by free nucleons production

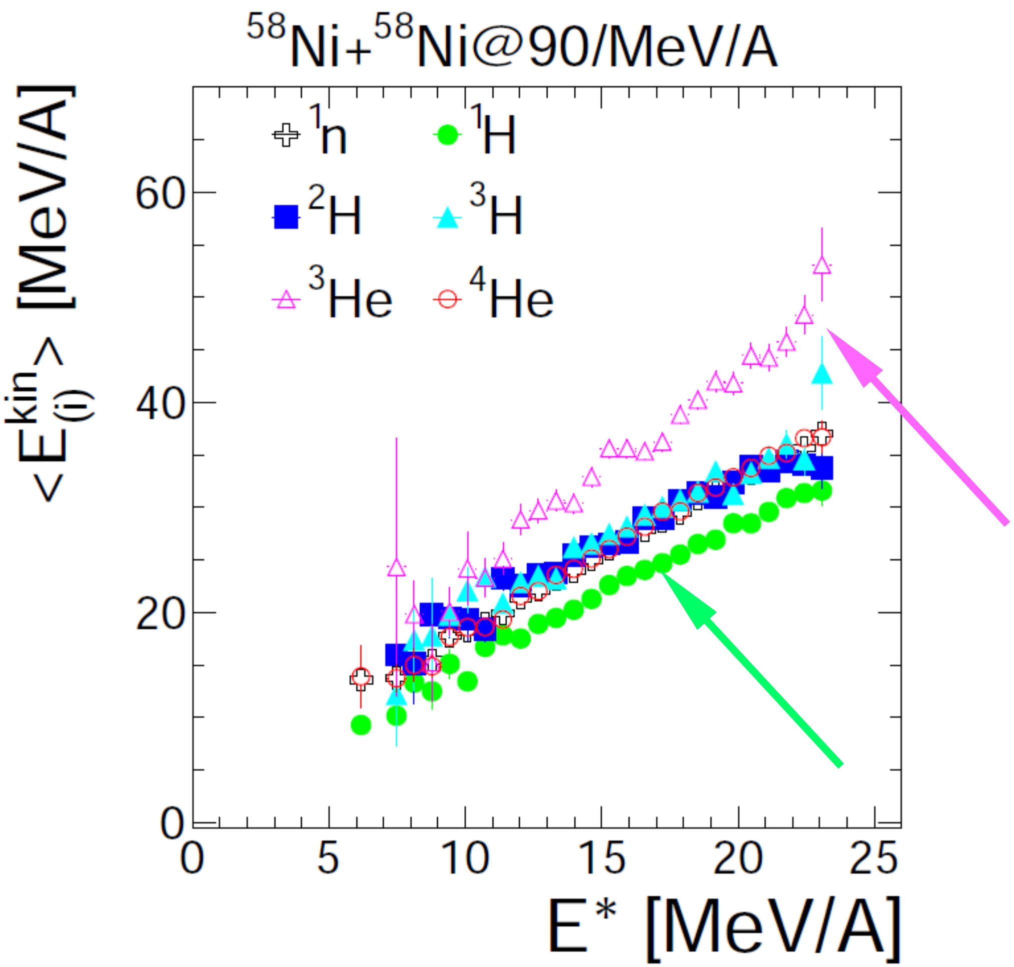
Cluster properties: multiplicities





Same trends as in the previous work: continuous decreasing of the 4He production, counterbalanced by free nucleons production

Cluster properties: kinetic energies



Mean values of the kinetic energy spectra of 3He are above, with an increasing with E*. For 1H, there is a systematic shift below (5 MeV).

Cluster properties: sigma

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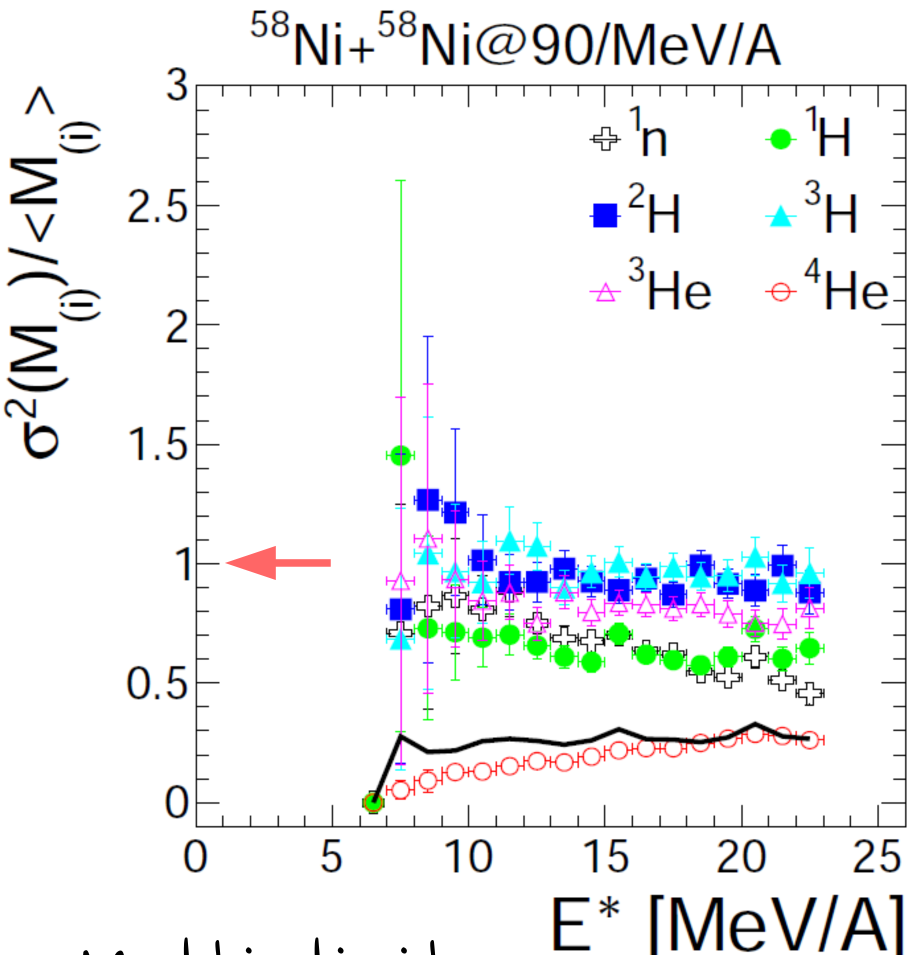
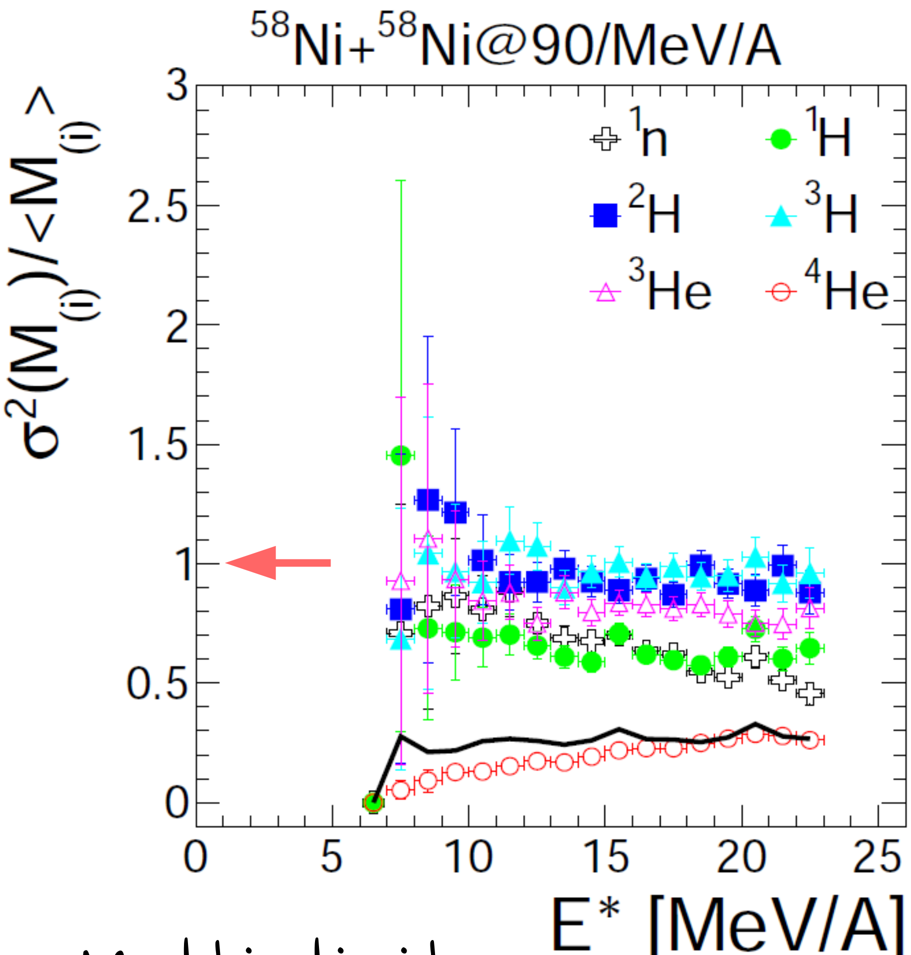


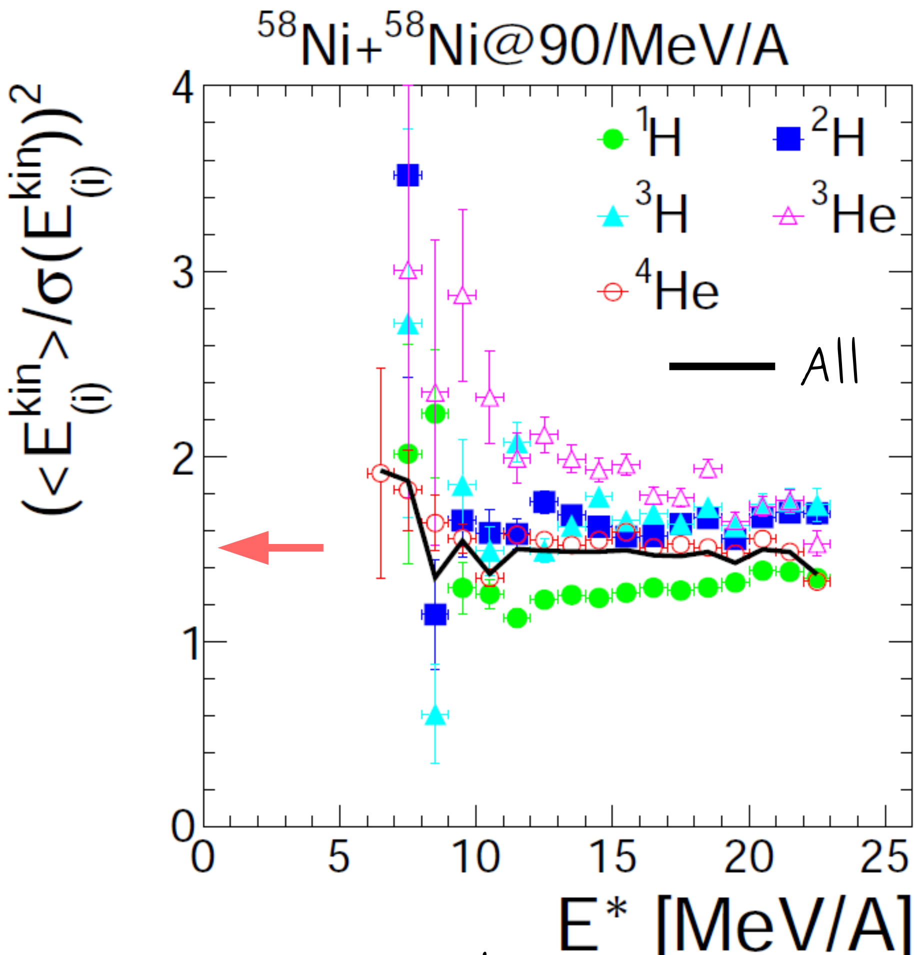
Multiplicity

Classical infinite gas,

Expected value: 1

Cluster properties: fluctutations





Multiplicity

Kinetic energy

Classical infinite gas,

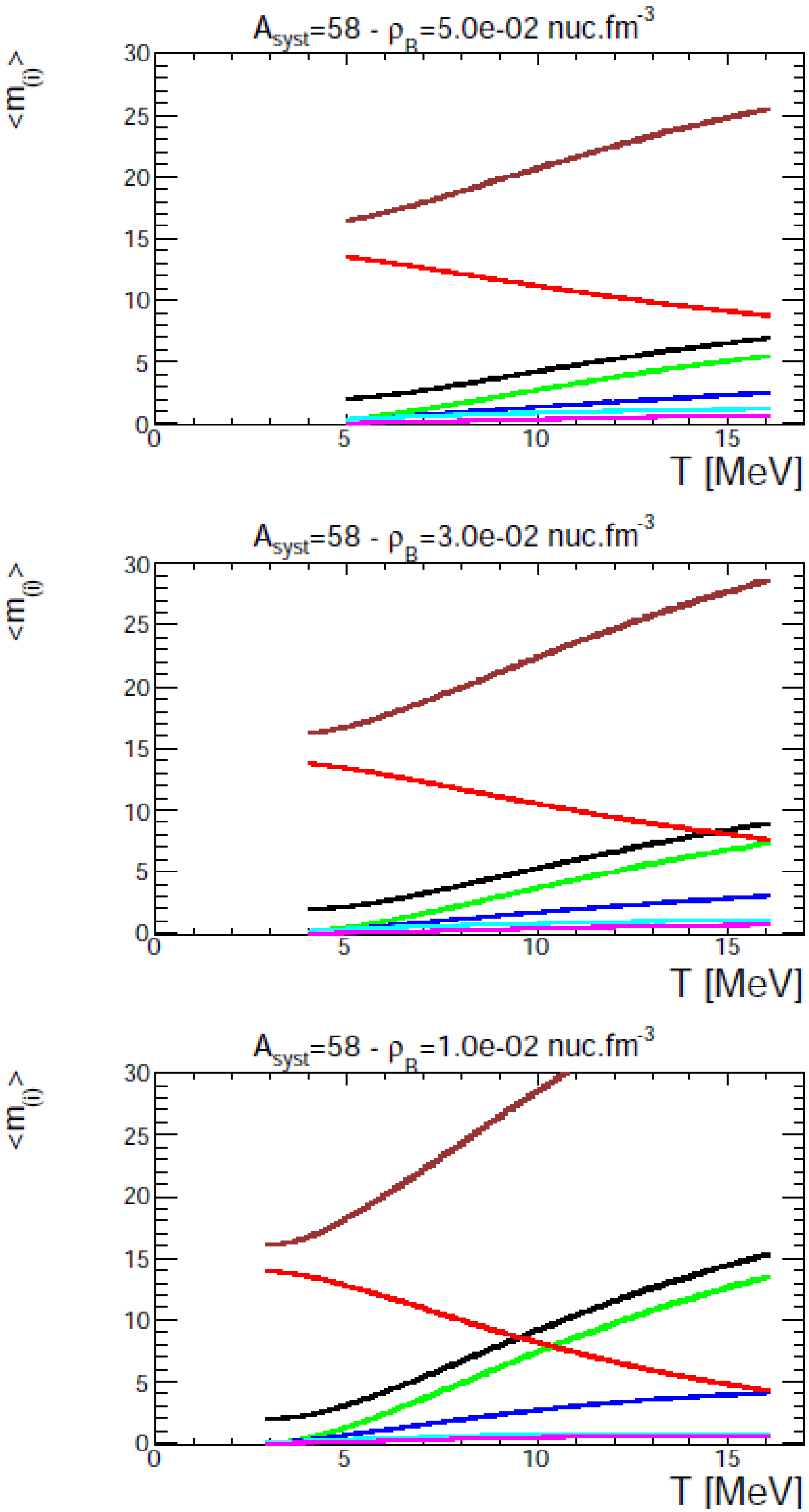
Expected value: 1

(Grand-)canonical ensemble,

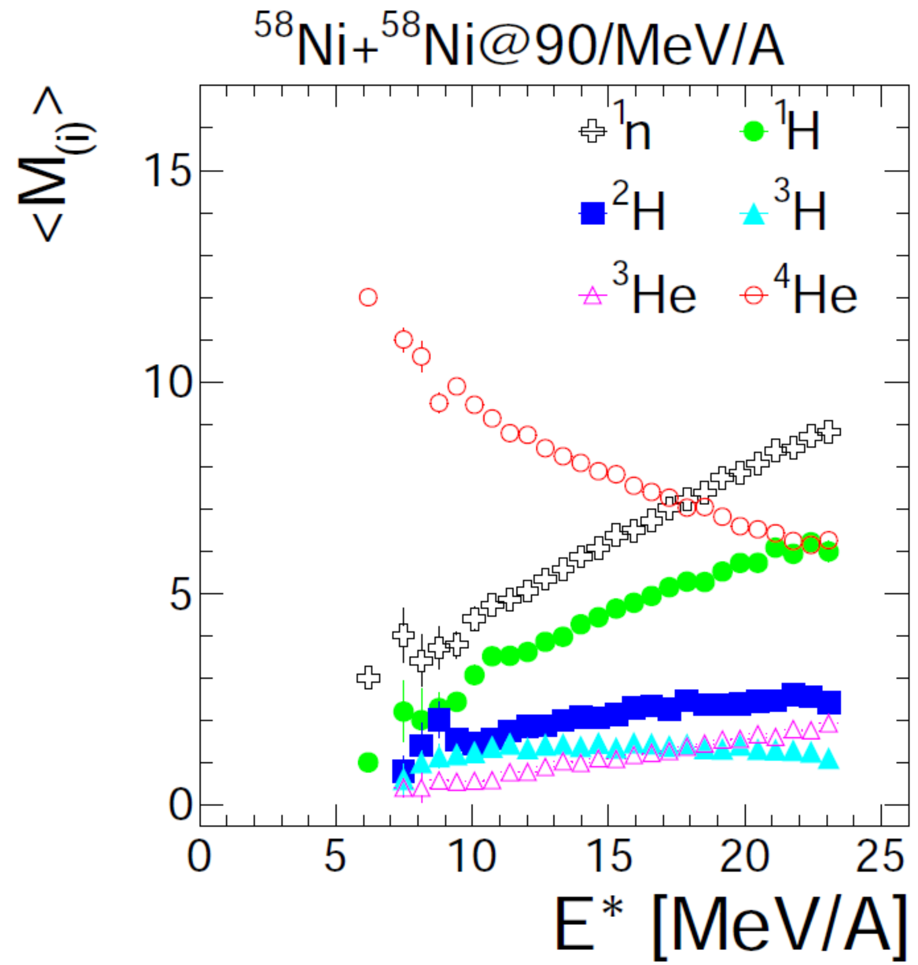
expected value: 1.5

Comparison with NSE model

- F. Gulminelli and Ad. R. Raduta,
  - Phys. Rev. C 92, 055803 (2015) & re. therein
- Developed for stellar matter studies (sub-saturation density, T=0 & T>0)
- Grand canonical ensemble
- Inputs : baryonic density, temperature and proton fraction
- Contains : gas-clusters interaction, surface effects, in-medium mass shift, etc ...



Evolutions of multiplicities with temperature are consistent with data.



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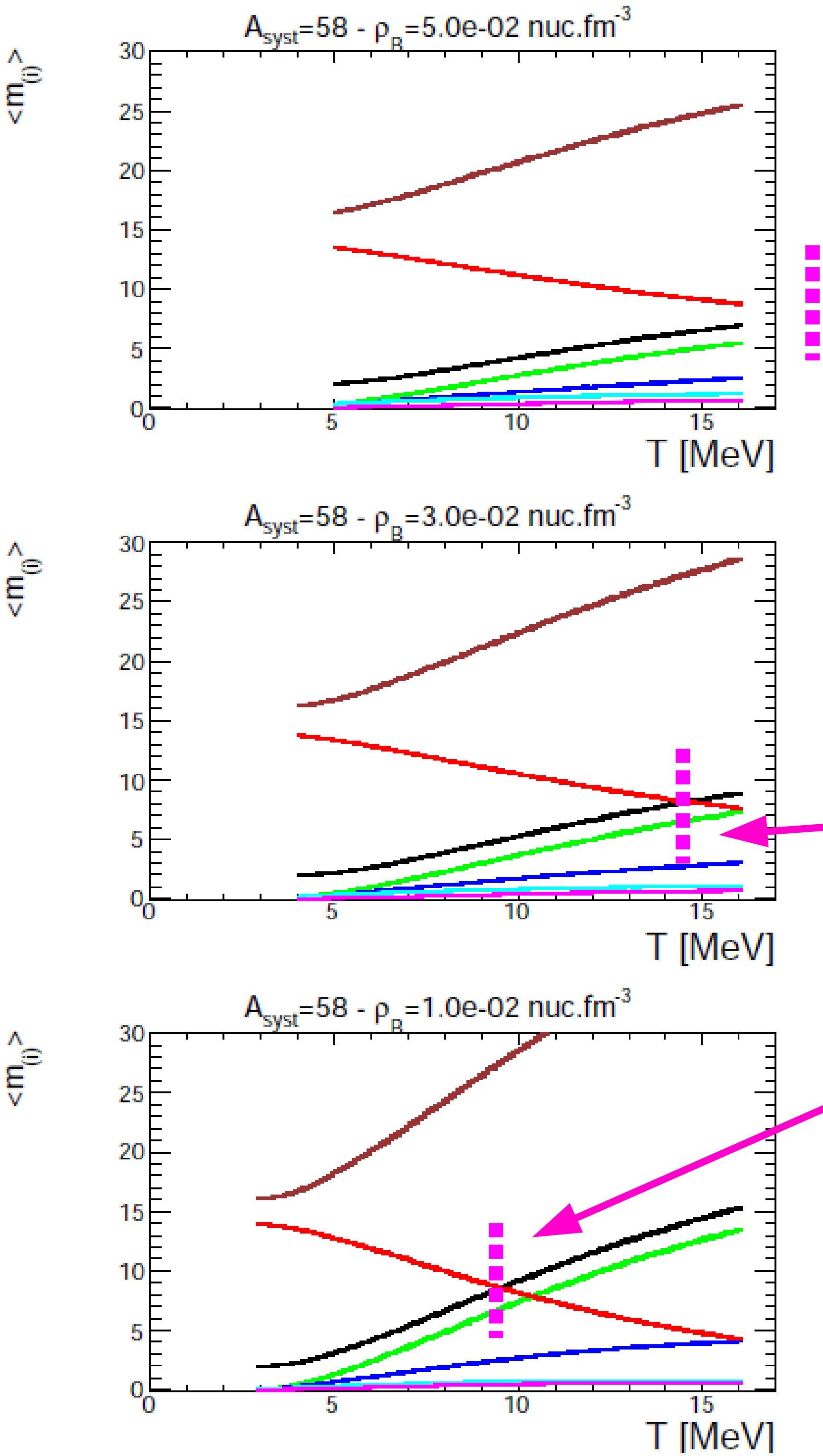
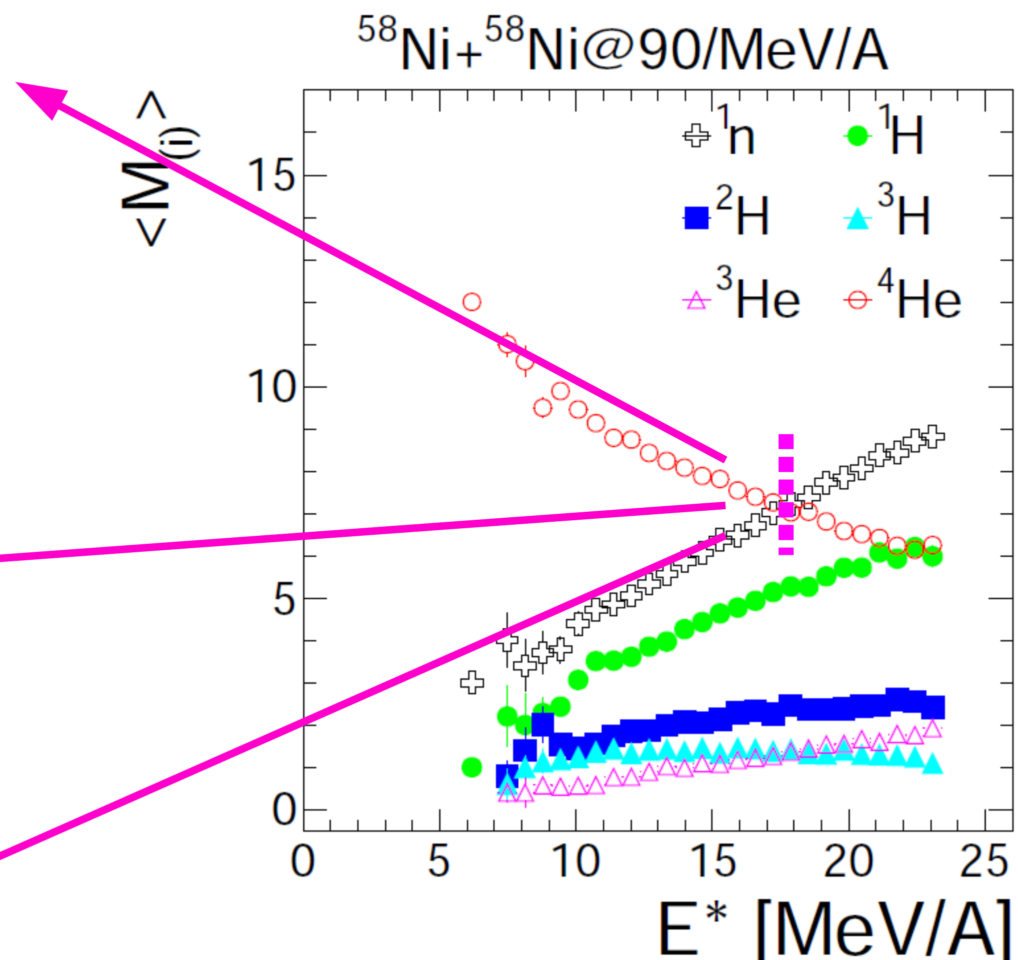
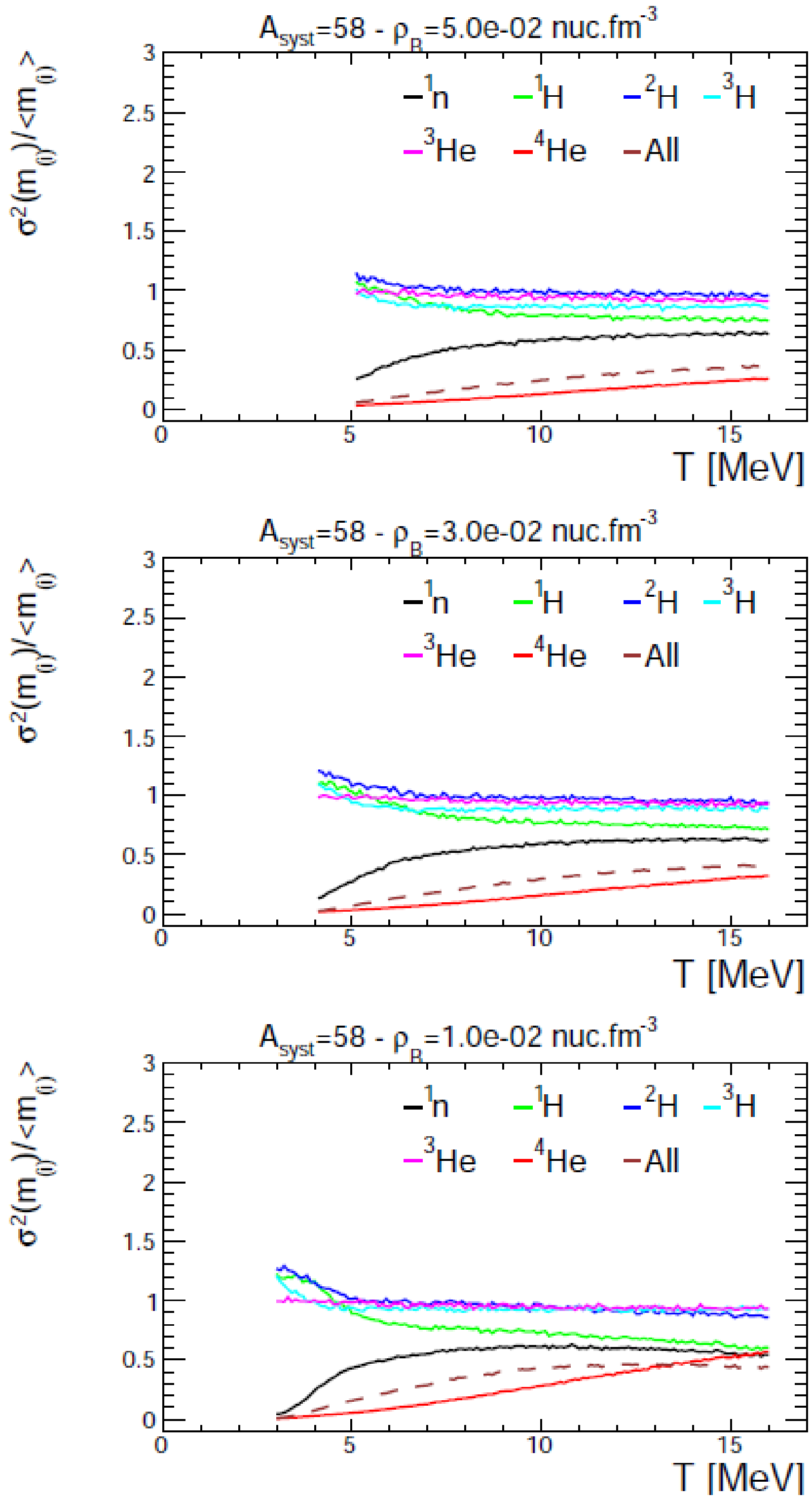
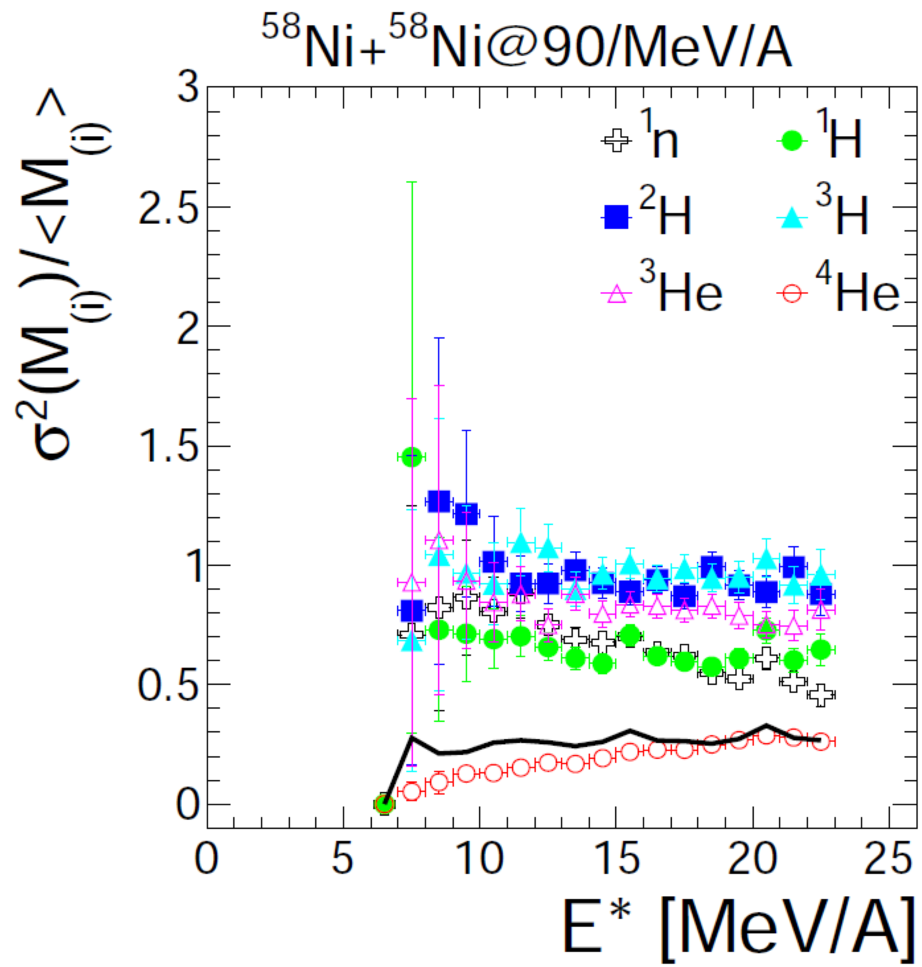




But the scaling between E* and T is different for one density to another ...

Multiplicity fluctuations are, at 1st order, determined by the mass conservation





Reproduction of experimental multiplicities by NSE model is effective along a line in the T-density plane

Additional constraint is needed from data :
experimental determination of temperature

1. Temperature computed using yields ratio

$$T_{\mathrm{HHe}} = 14.3\ \mathrm{MeV}\left(\ln\left[1.59\frac{Y_\alpha Y_d}{Y_t Y_h}\right]\right)^{-1/2}$$

Introduced by Albergo, Nuovo Cimento A 89 (1985)
and extensively used by the TexaxA&M group

1. Temperature computed using yields ratio

$$T_{\mathrm{HHe}} = 14.3\ \mathrm{MeV}\left(\ln\left[1.59\frac{Y_\alpha Y_d}{Y_t Y_h}\right]\right)^{-1/2}$$

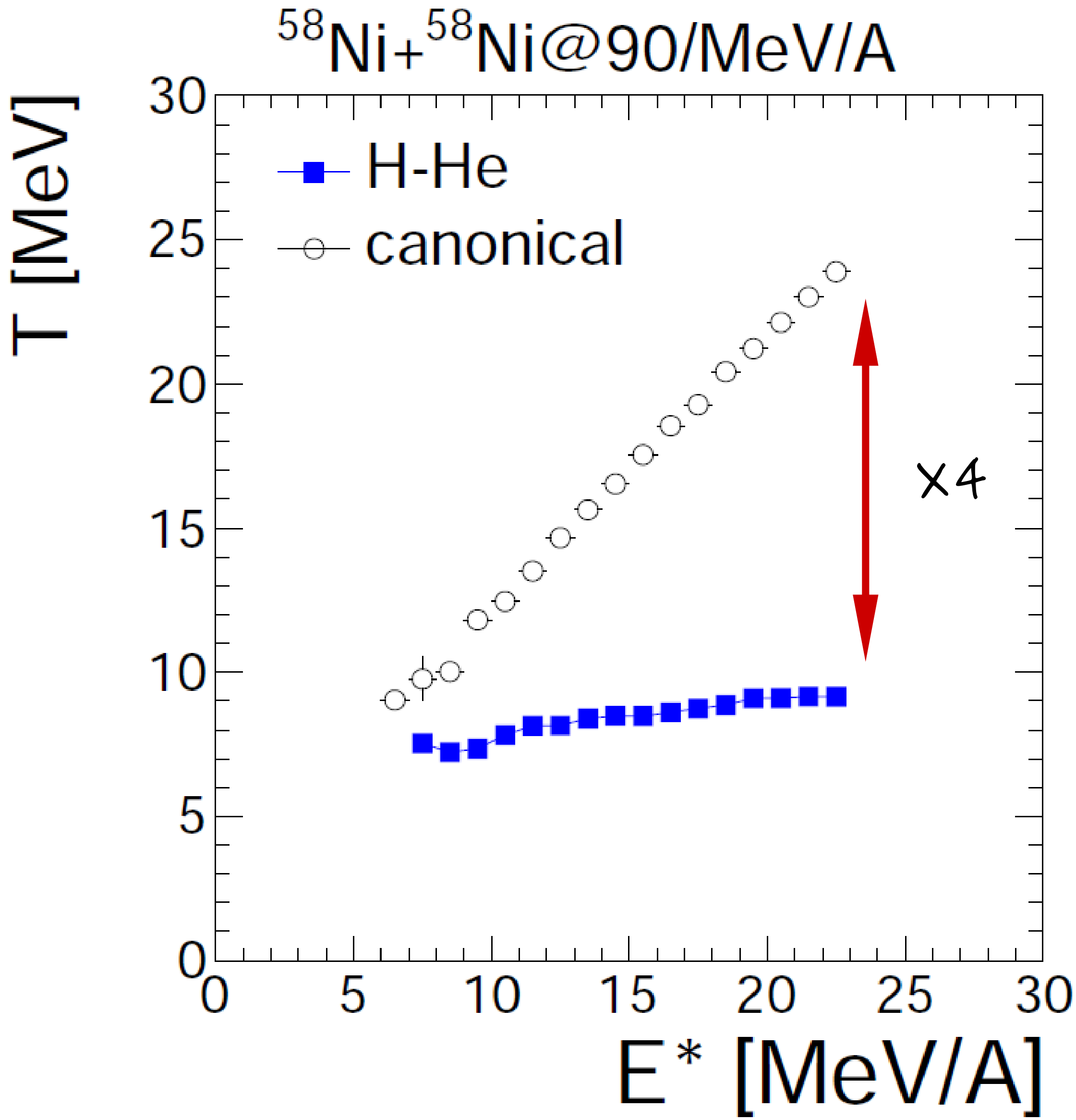
Introduced by Albergo, Nuovo Cimento A 89 (1985) and extensively used by the TexaxA&M group

2. Temperature derived from mean kinetic energy assuming canonical ensemble

$T = 2/3 \langle E_k \rangle$

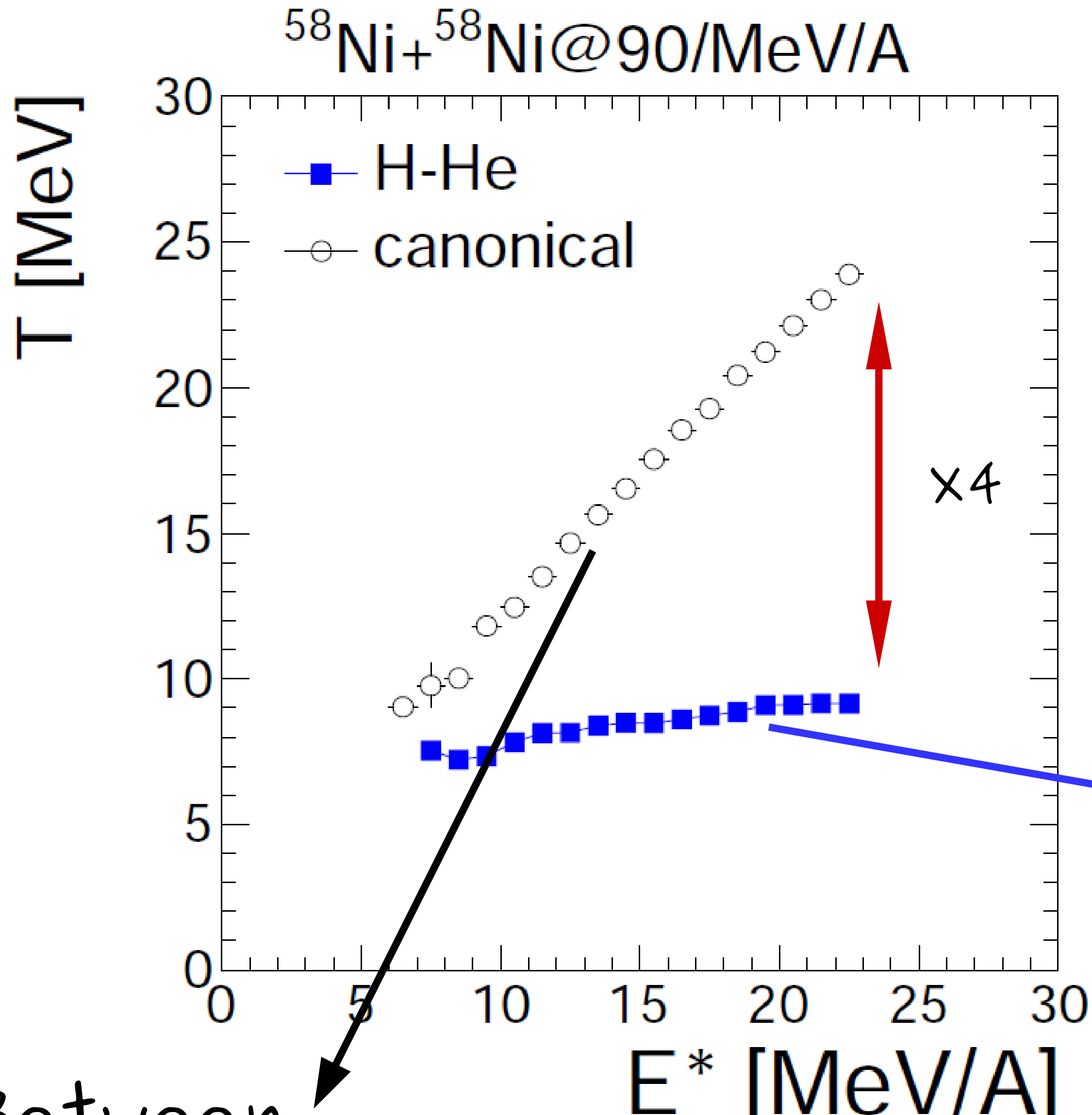
Motivated by the experimental values of the fluctuation of kinetic energy and the reproduction of experimental multiplicity trends by NSE.

Experimental determination of temperatures



Differences are hugged and will produce big differences in density

Experimental determination of temperatures



Differences are hugged and will produce big differences in density

Between
1.e^{-4} and 1.e^{-3} fm^{-3}

Between
0.03 and 1.e^{-2} fm^{-3}

The not unique solution, in T and density, using NSE like approaches lead the needs of temperature and/or density extracted from data.

Discrepancies between "experimental" temperatures have to be understood:

One explanation is that the production of the different species of clusters happens at different times of the reaction, in different density and temperature conditions.

The step forward is to study light clusters production in transport models.

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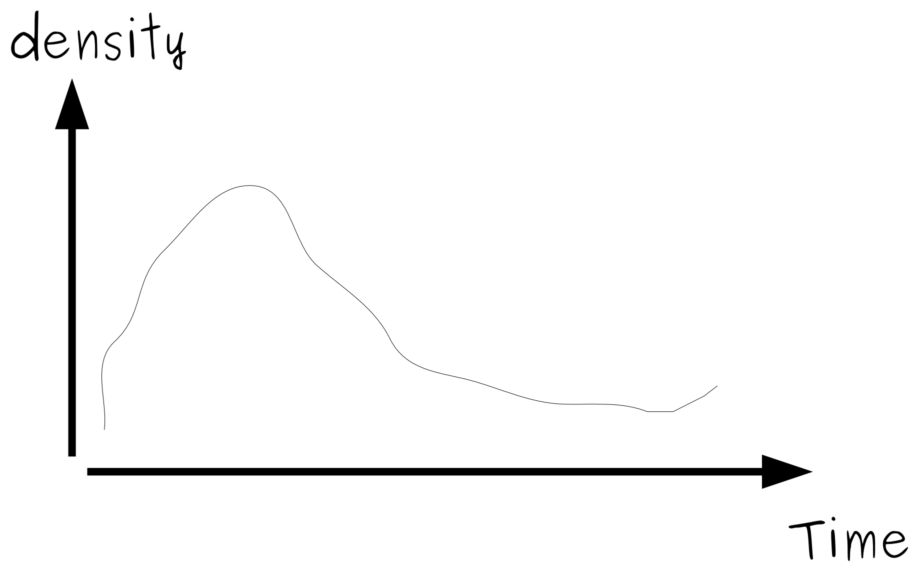

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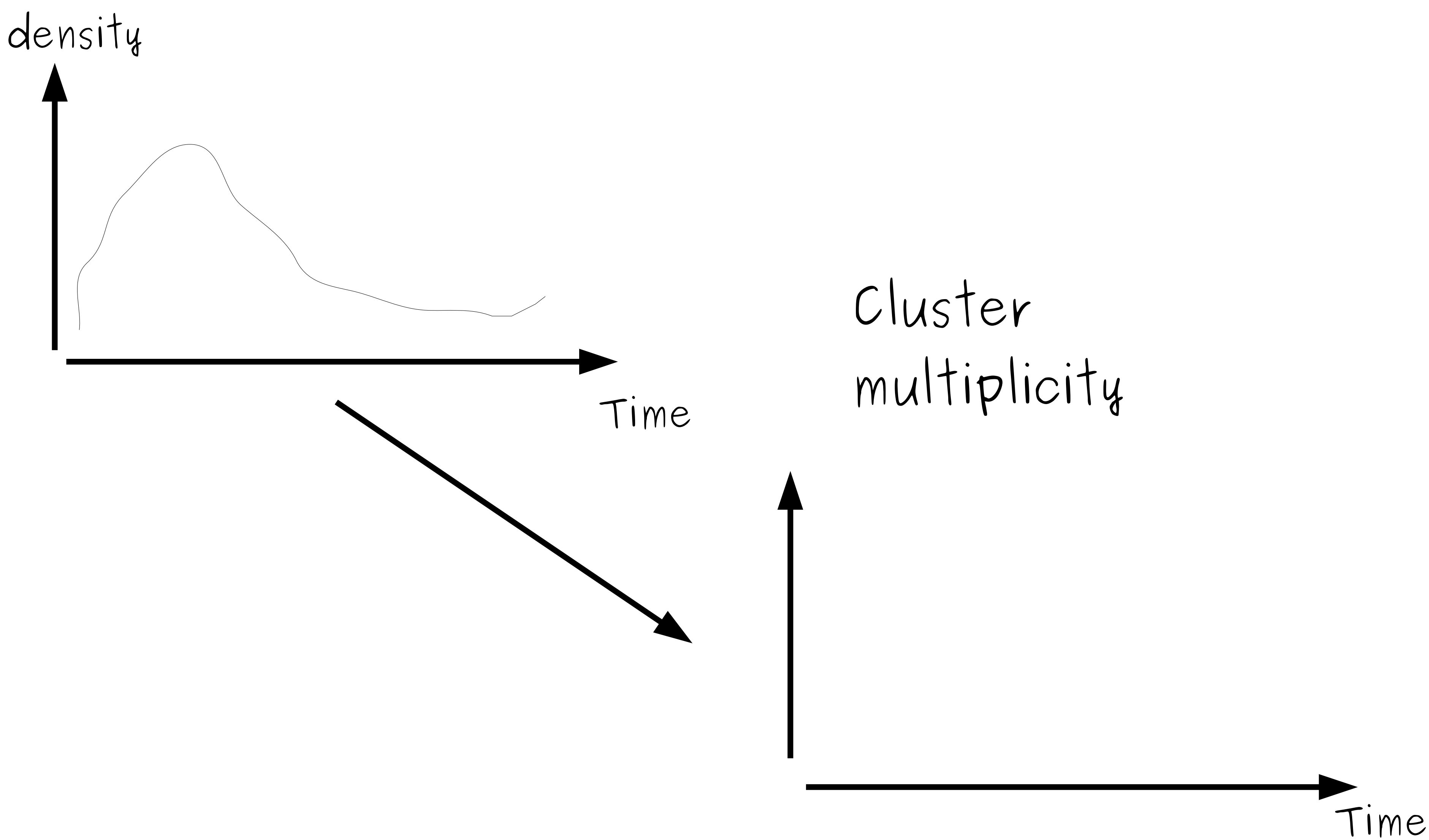

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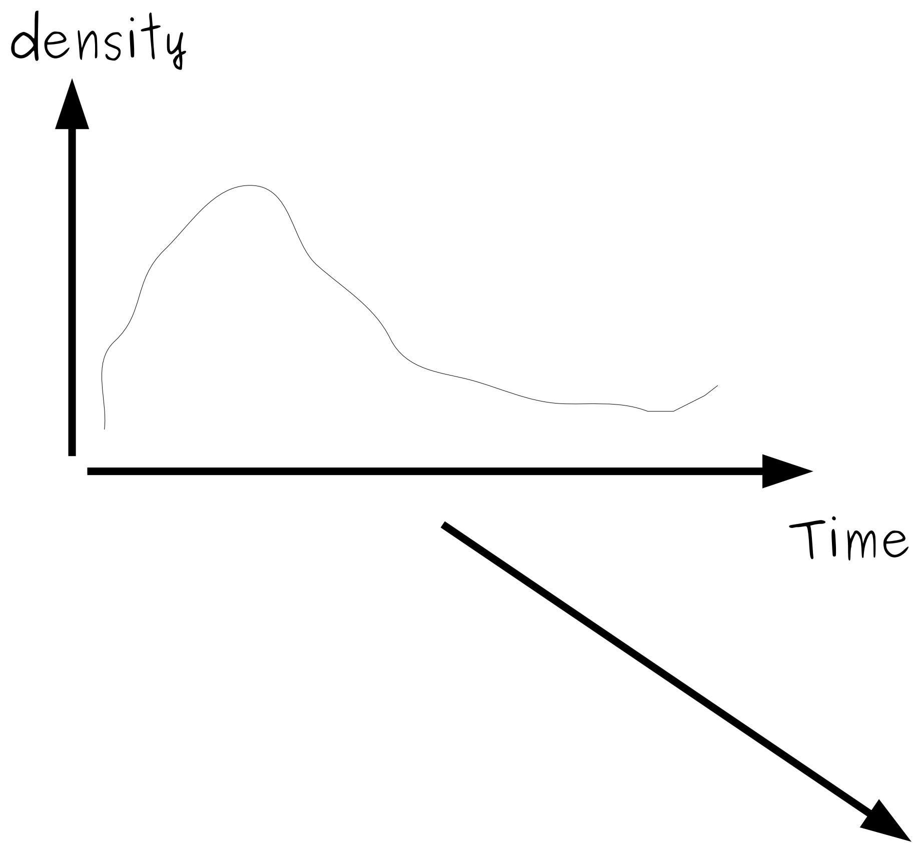
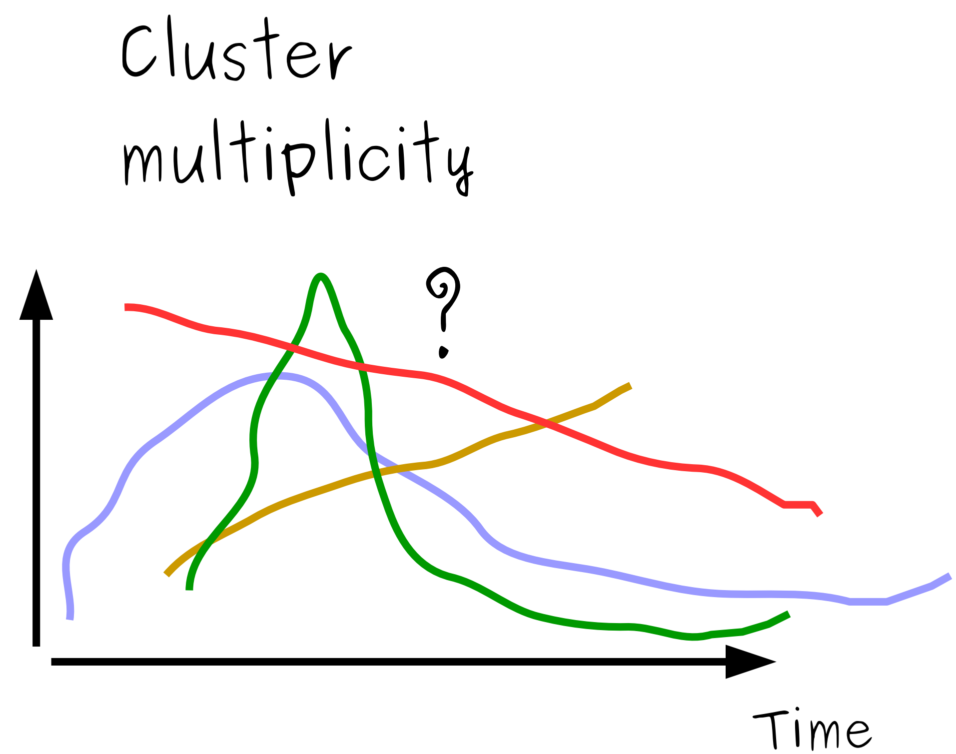


At least up to 4He clusters



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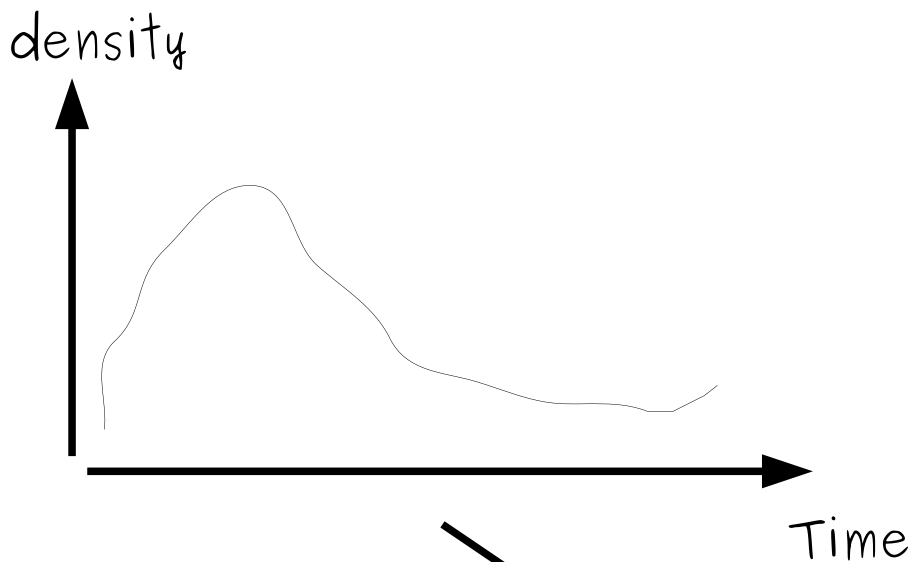

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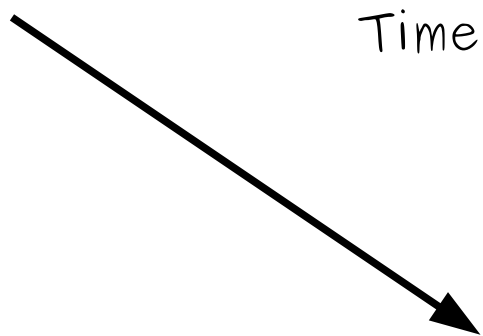
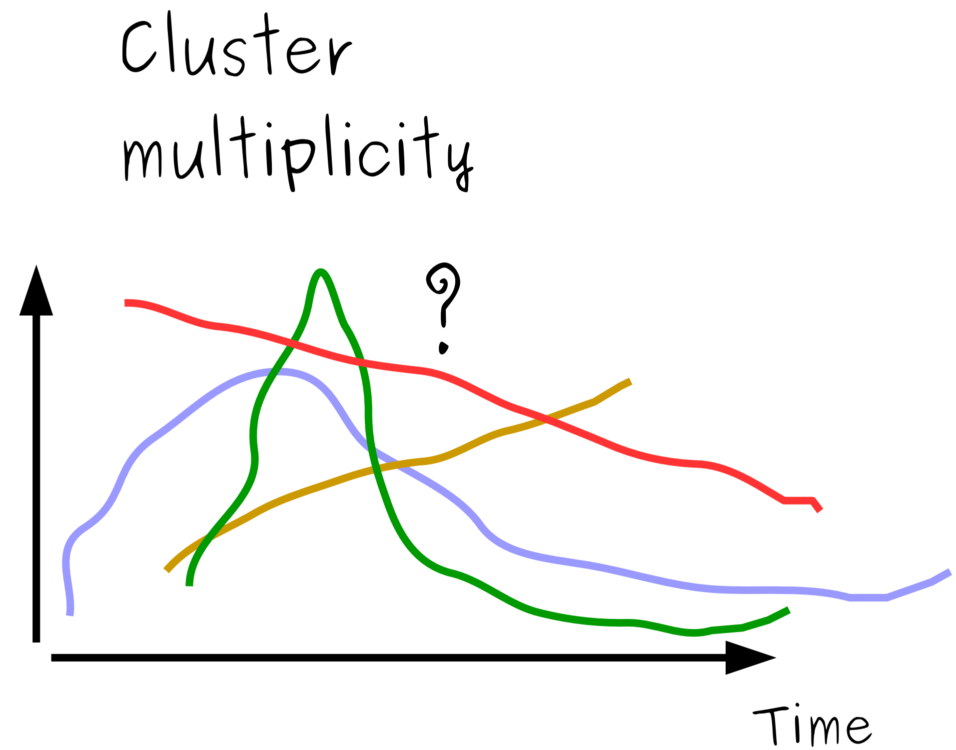
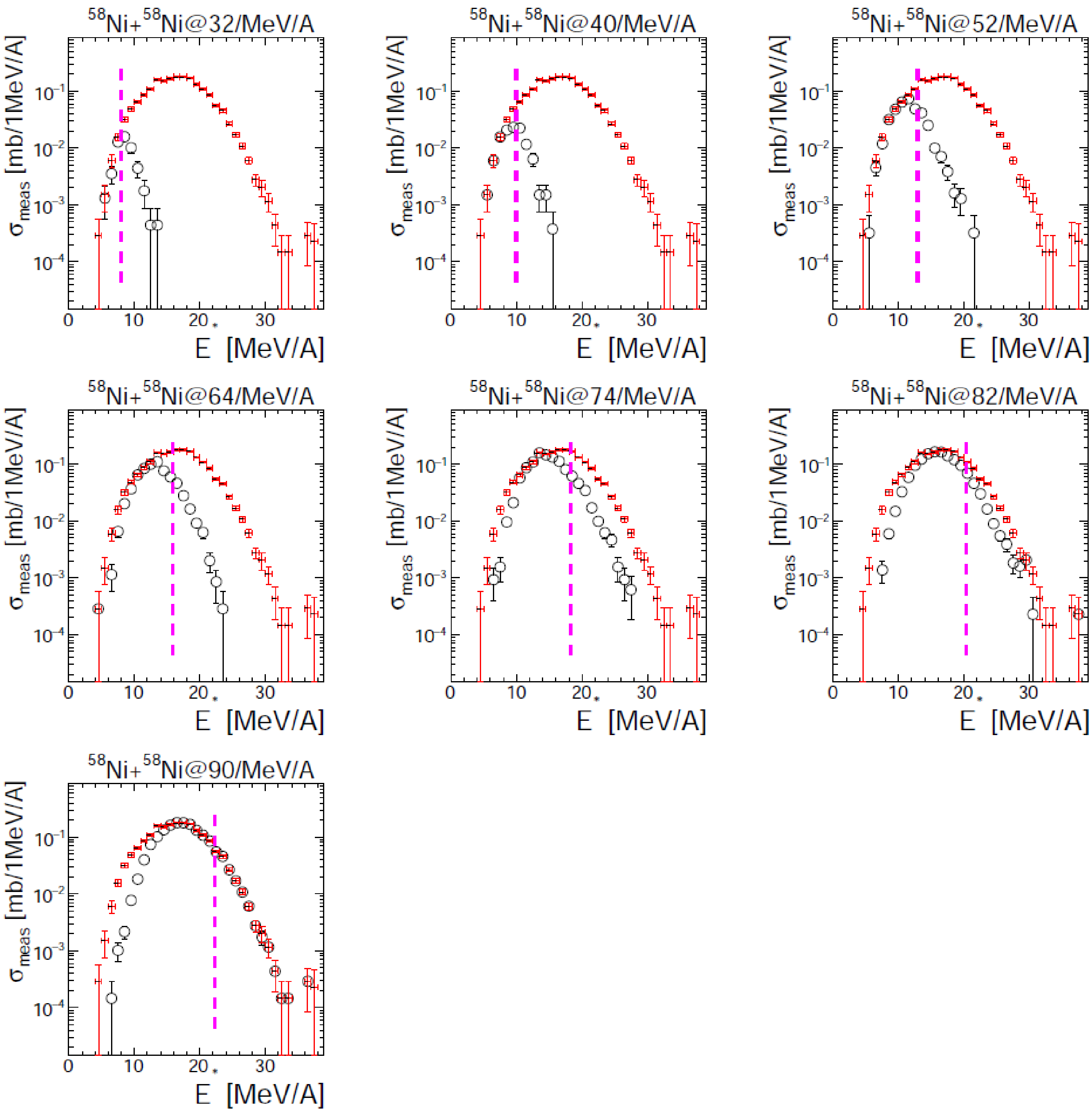


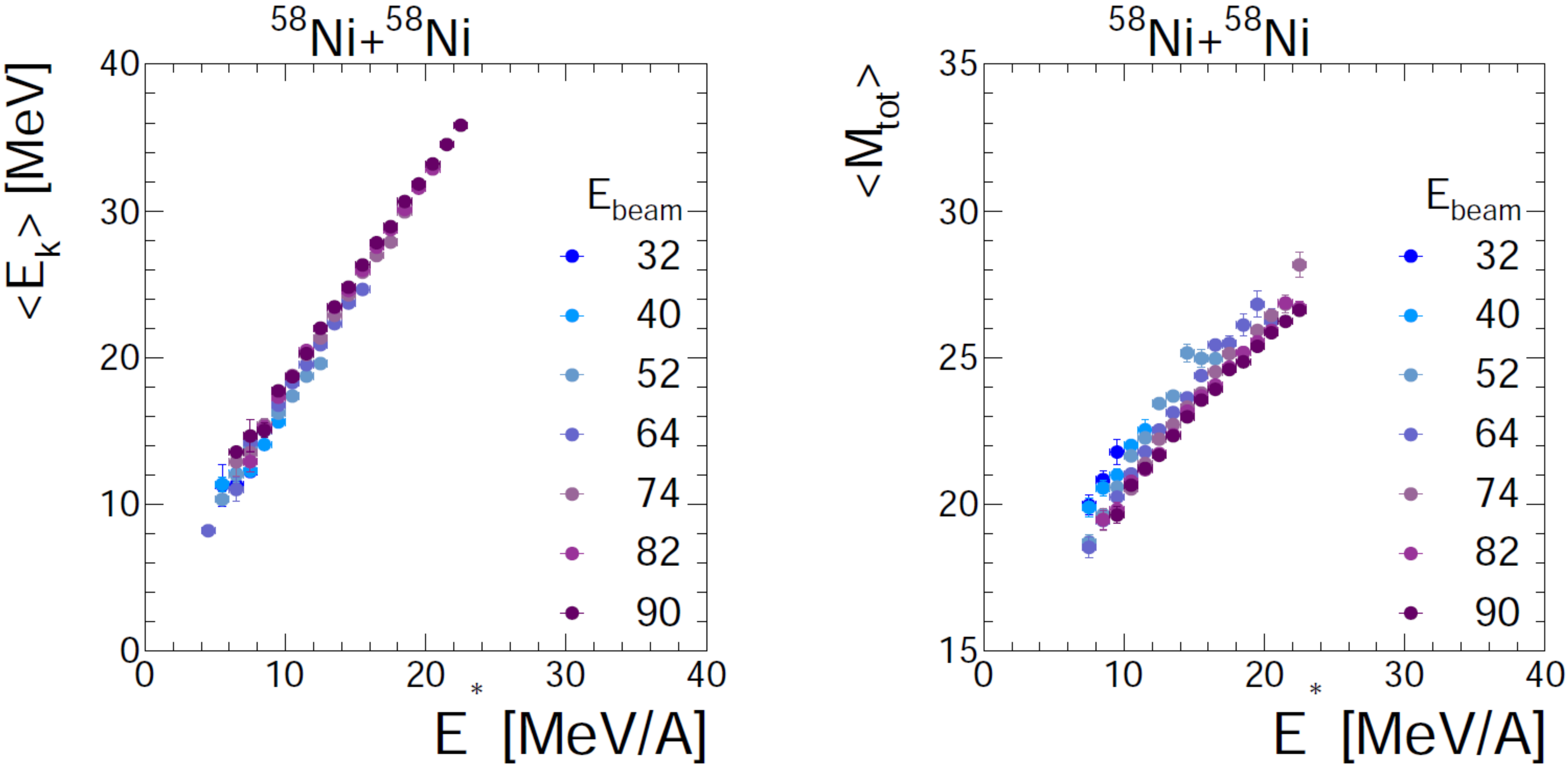


(Only ?) one candidate : AMD

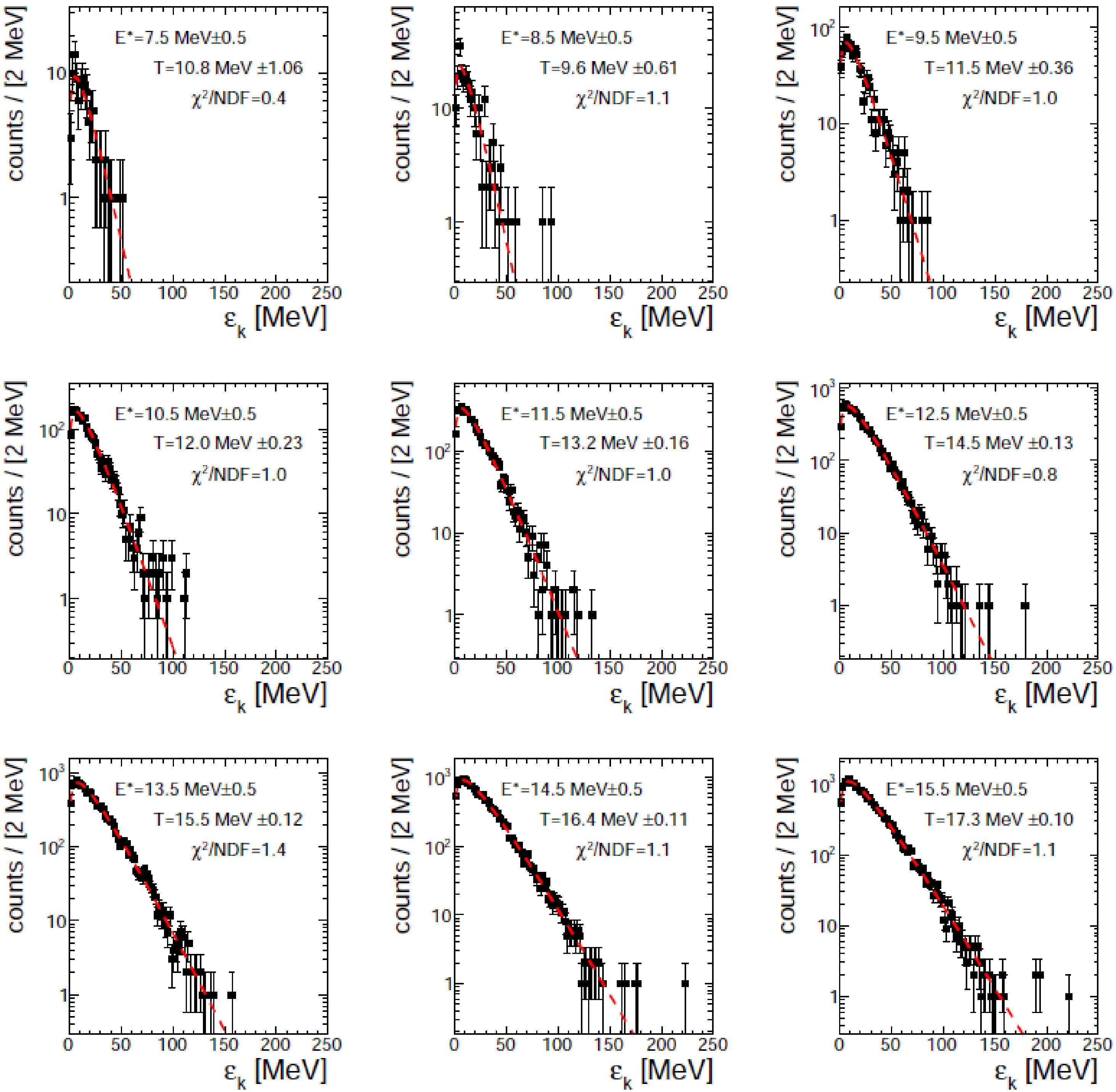
Thank you for your attention

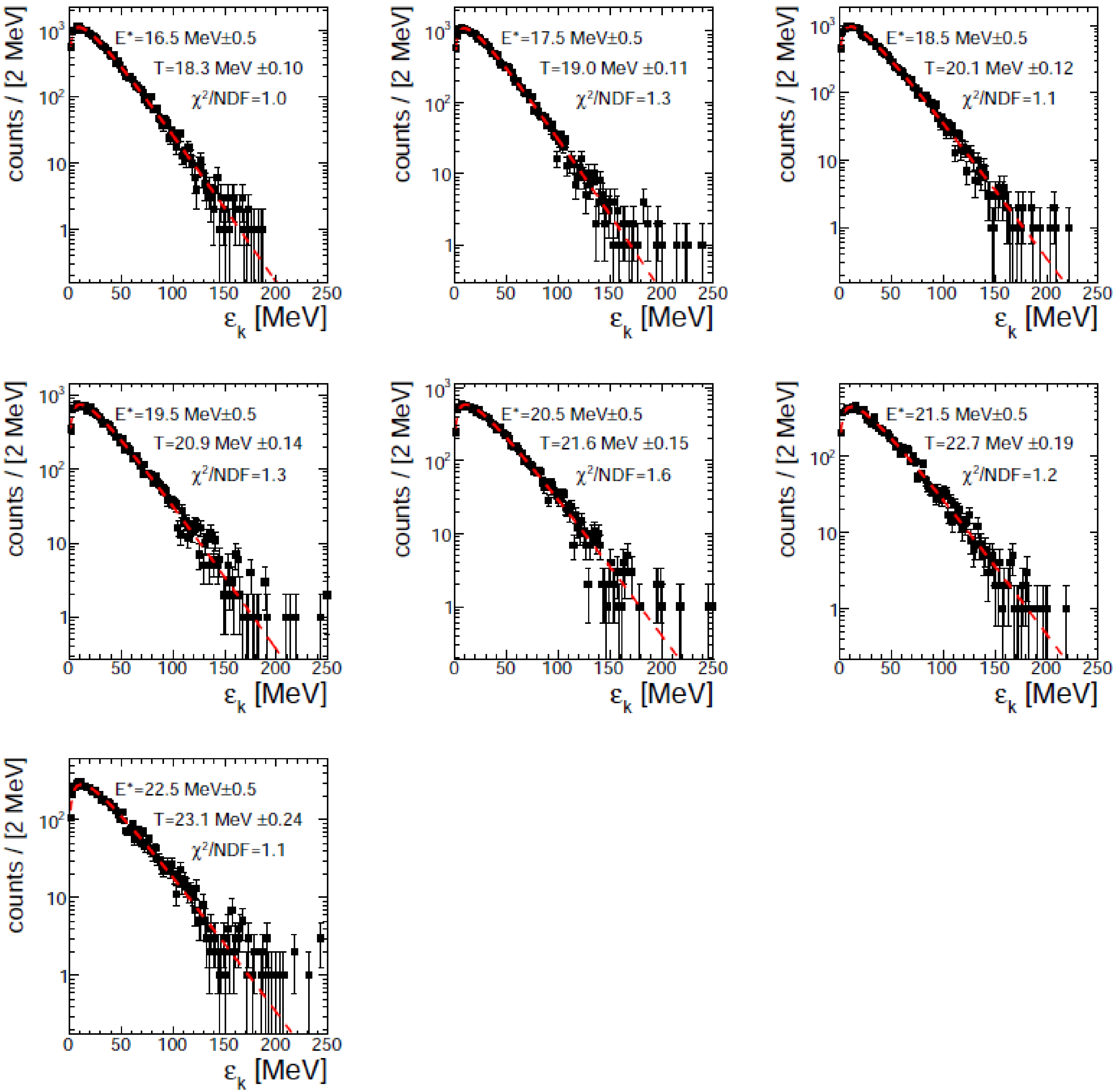
X section


58Ni+58Ni@32/MeV/A
58Ni+58Ni@40/MeV/A
58Ni+58Ni@52/MeV/A
58Ni+58Ni@64/MeV/A
58Ni+58Ni@74/MeV/A
58Ni+58Ni@82/MeV/A
58Ni+58Ni@90/MeV/A
σmeas [mb/1MeV/A]
E* [MeV/A]



$^{58}Ni+^{58}Ni$
$<E_k>$ [MeV]
E^* [MeV/A]
E_{beam}
32
40
52
64
74
82
90
$^{58}Ni+^{58}Ni$
$<M_{tot}>$
E^* [MeV/A]
E_{beam}
32
40
52
64
74
82
90


E*=7.5 MeV±0.5
T=10.8 MeV ±1.06
χ²/NDF=0.4
E*=8.5 MeV±0.5
T=9.6 MeV ±0.61
χ²/NDF=1.1
E*=9.5 MeV±0.5
T=11.5 MeV ±0.36
χ²/NDF=1.0
E*=10.5 MeV±0.5
T=12.0 MeV ±0.23
χ²/NDF=1.0
E*=11.5 MeV±0.5
T=13.2 MeV ±0.16
χ²/NDF=1.0
E*=12.5 MeV±0.5
T=14.5 MeV ±0.13
χ²/NDF=0.8
E*=13.5 MeV±0.5
T=15.5 MeV ±0.12
χ²/NDF=1.4
E*=14.5 MeV±0.5
T=16.4 MeV ±0.11
χ²/NDF=1.1
E*=15.5 MeV±0.5
T=17.3 MeV ±0.10
χ²/NDF=1.1
counts / [2 MeV]
εk [MeV]



counts / [2 MeV]
ε_k [MeV]
E*=16.5 MeV±0.5
T=18.3 MeV ±0.10
χ^2/NDF=1.0
E*=17.5 MeV±0.5
T=19.0 MeV ±0.11
χ^2/NDF=1.3
E*=18.5 MeV±0.5
T=20.1 MeV ±0.12
χ^2/NDF=1.1
E*=19.5 MeV±0.5
T=20.9 MeV ±0.14
χ^2/NDF=1.3
E*=20.5 MeV±0.5
T=21.6 MeV ±0.15
χ^2/NDF=1.6
E*=21.5 MeV±0.5
T=22.7 MeV ±0.19
χ^2/NDF=1.2
E*=22.5 MeV±0.5
T=23.1 MeV ±0.24
χ^2/NDF=1.1
0 50 100 150 200 250
1 10 10^2 10^3