Evolution of cluster production with fragmentation degree*

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* Many nuclei were mistreated to perform this analysis

Outline

- Motivations
- Presentation of 58Ni+58Ni@INDRA reactions
- Evolution of cluster production with fragmentation degree (Z1).
- Conclusion & Outlook

Motivations

- Understanding the production of clusters (namely nucleons ended together) produced in heavy ion collisions (HIC) is a hot and hard topic.
- Bringing experimentally constraints on that topic should help to constrain both EOS of

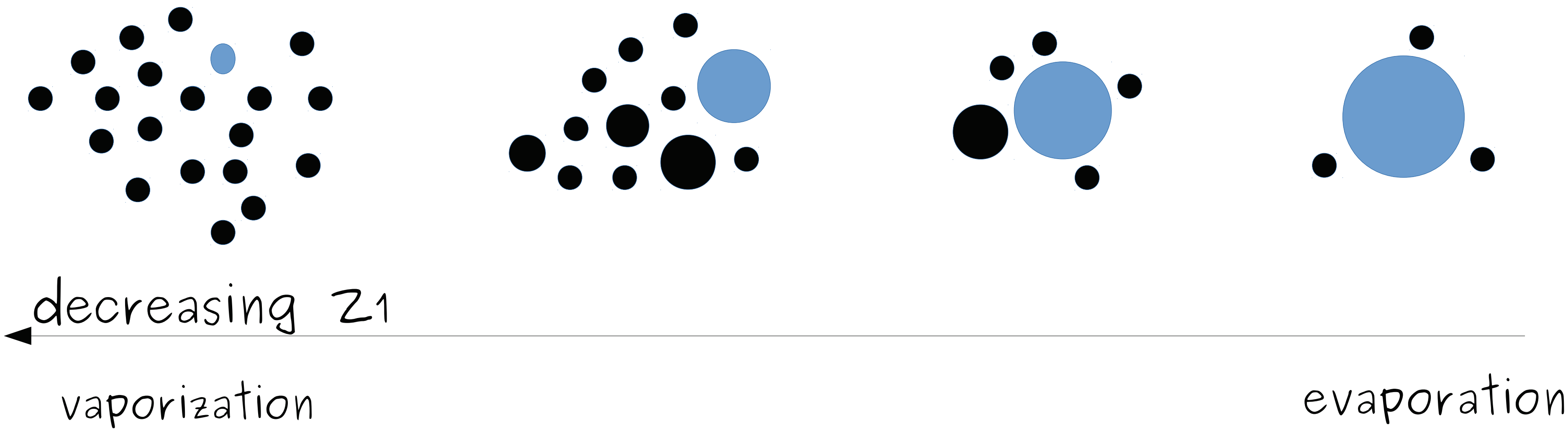
  non-homogeneous nuclear matter (NM) and transport models.

Motivations

- One point concerning HIC respect to NM is the finite number of nucleons involved.
- This means that depending on the fragmentation degree associated to different excitation/dissipation/violence the available nucleons to build “clusters” is not the same.
- This can be easily understood looking at the various mechanisms identified looking at final detected partitions

Motivations

- Inside final partitions, Z1, the charge of the biggest fragment is a straight forward and robust estimation of the fragmentation degree
- Using it, we can draw easily a continuous evolution between evaporation and vaporization passing through multifragmentation.



Motivations

- In the following, we aim to look at evolution of the contributions of the different species to the final detected partitions according to the value of the charge of the biggest fragment (Z_1).
- As we want to minimize experimental bias over the whole range of accessible Z_1 values we choose a light system and look at the $^{58}Ni+^{58}Ni$ reactions collected with INDRA

58Ni+58Ni@INDRA reactions

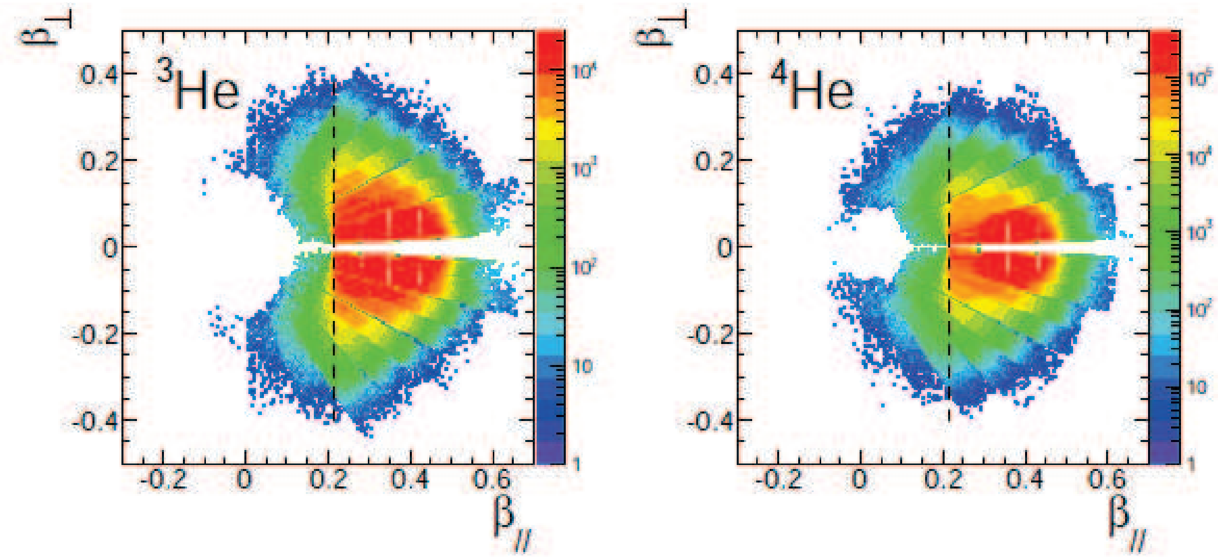
- These data already used to :
  - probe isospin diffusion in semi peripheral collisions
  - measure fusion cross sections in light systems with a significant contribution at 32&40 MeV/A
- Detailed description of this experiment can be found in the related publications :
  - E. Galichet et al, Phys. Rev. C 79 , 064614 (2009)
  - P. Lautesse et al, Eur. Phys. J. A 27, 349-357 (2006)

58Ni+58Ni@INDRA reactions

- Incident beam energies : 32,40,52,64,74,82,90 MeV/A
  - Test the effect of increasing the energy deposition in the system
- The data selection is the following :
  - In the ellipsoid frame deduced from the kinetic energy tensor diagonalization, we kept only forward part of each event.

58Ni+58Ni@INDRA reactions

- We focus on the forward part of each event because :
  - A complete isotopic identification up to 10Be is achieved



Only well isotopically resolved clusters are kept

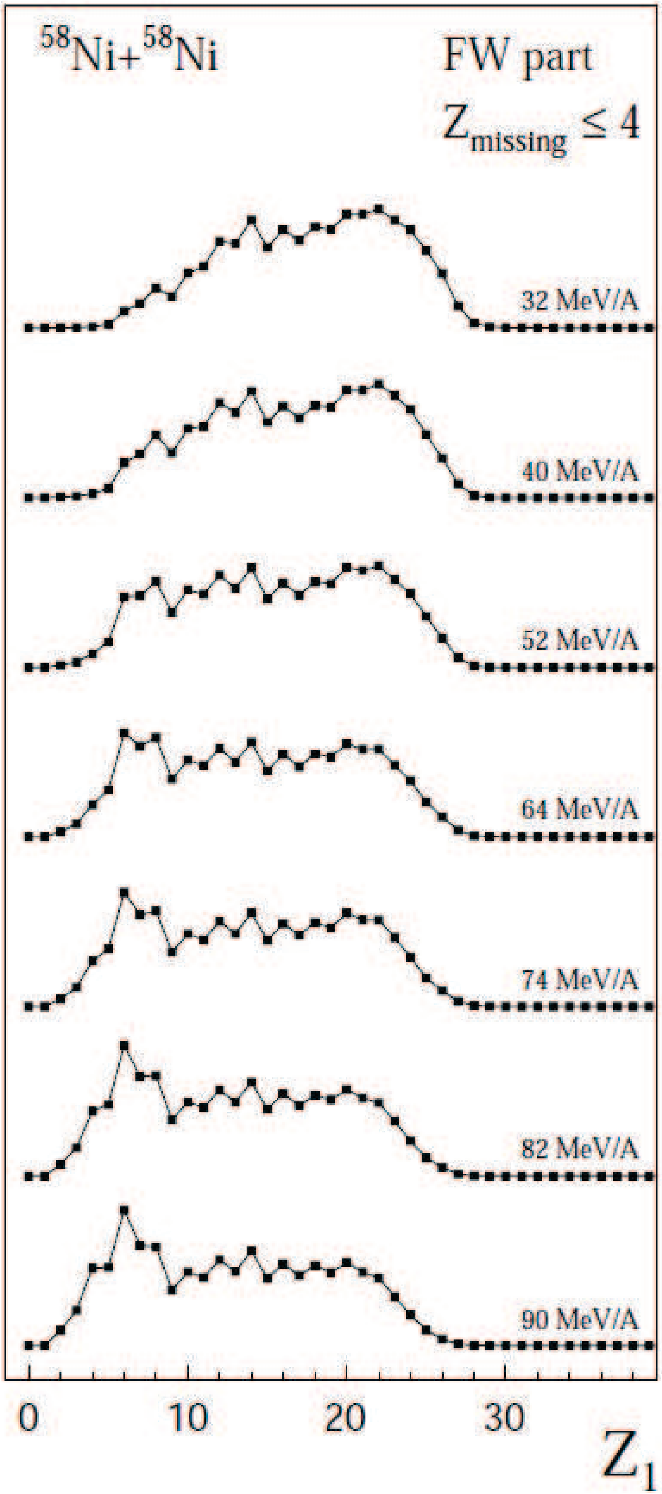
58Ni+58Ni@INDRA reactions

- We focus on the forward part of each event because :
  - A complete isotopic identification up to 10Be is achieved
  - The detection efficiency is almost independent of the reaction mechanism minimizing possible experimental bias
  - As it is a symmetric system, it gives, in average, a good description of what happens for the whole system

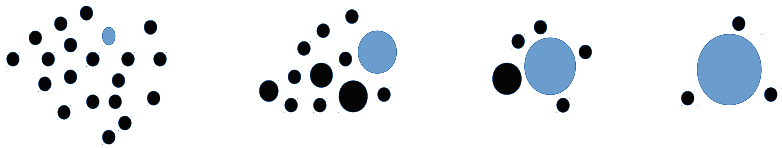
58Ni+58Ni@INDRA reactions

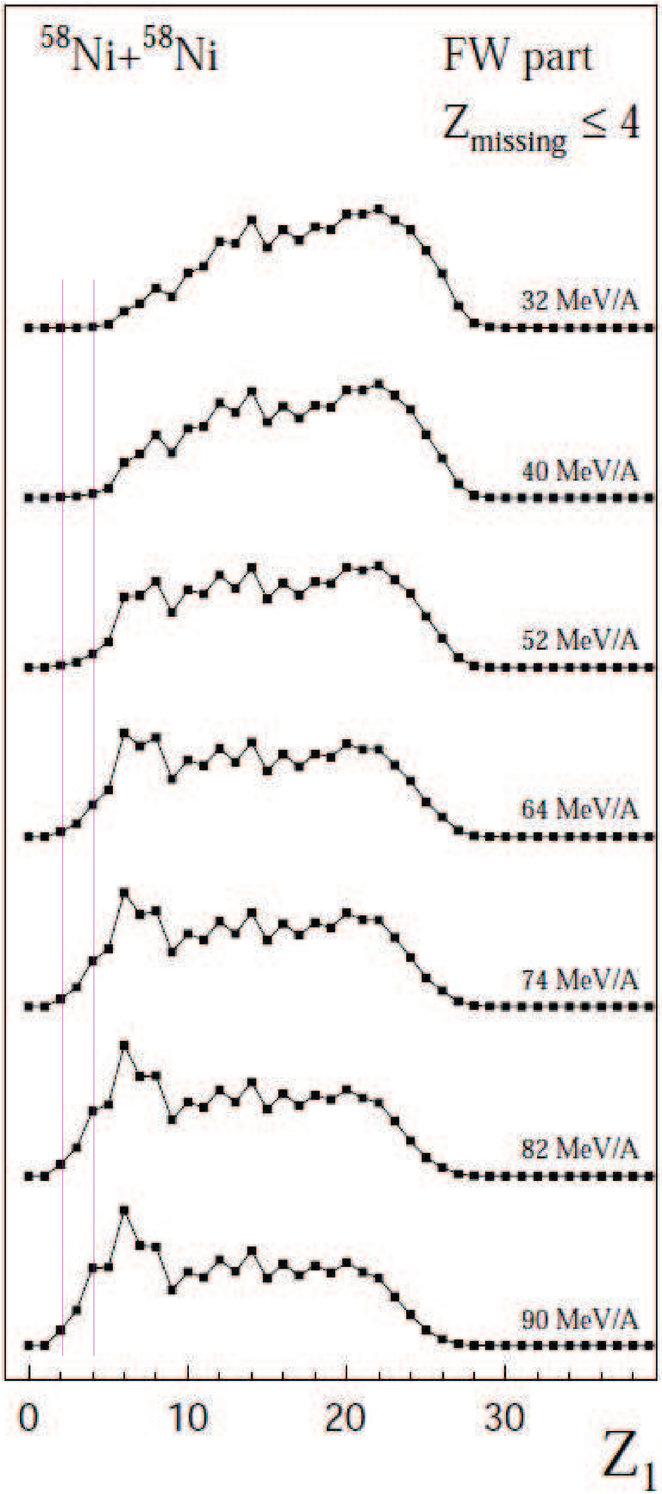
- Incident beam energies : 32,40,52,64,74,82,90 MeV/A
  - Test the effect of increasing the energy deposition in the system
- The data selection is the following :
  - In the ellipsoid frame deduced from the kinetic energy tensor diagonalization, we kept only forward part of each event.
  - We keep events with missing charge less than 5 compare to the 58Ni charge (Z=28) to ensure that the Z1 fragment is part of the event.

Results



Evolution with incident energy (Einc) of the distribution of the charge of
the biggest fragment (Z1) used in the present work as sorting parameter.





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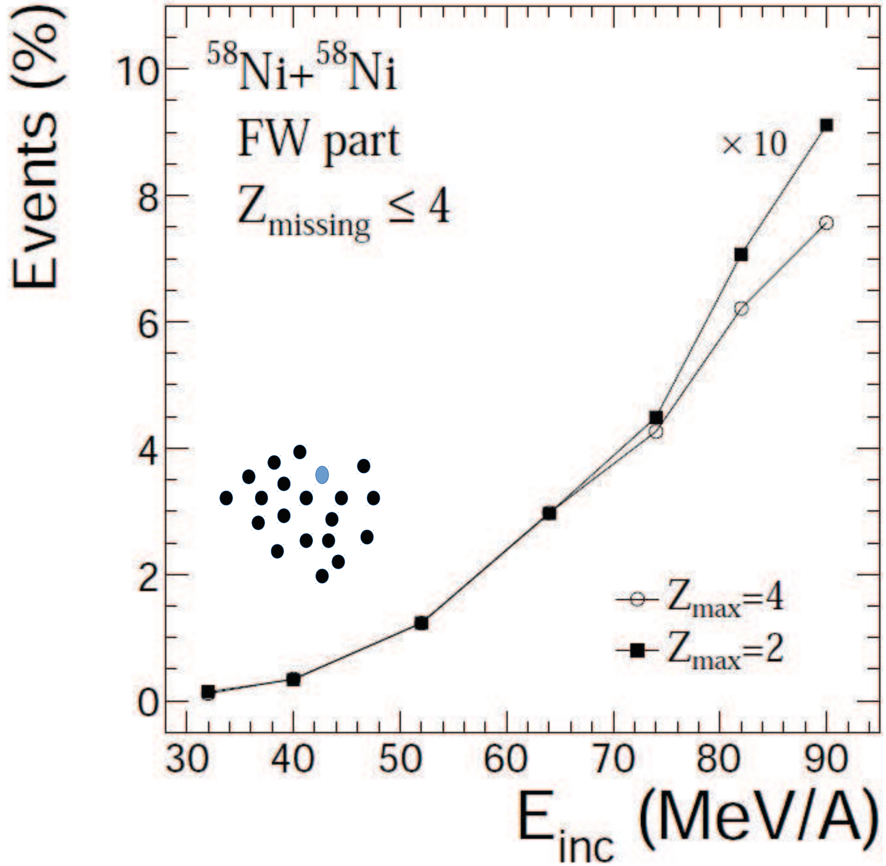
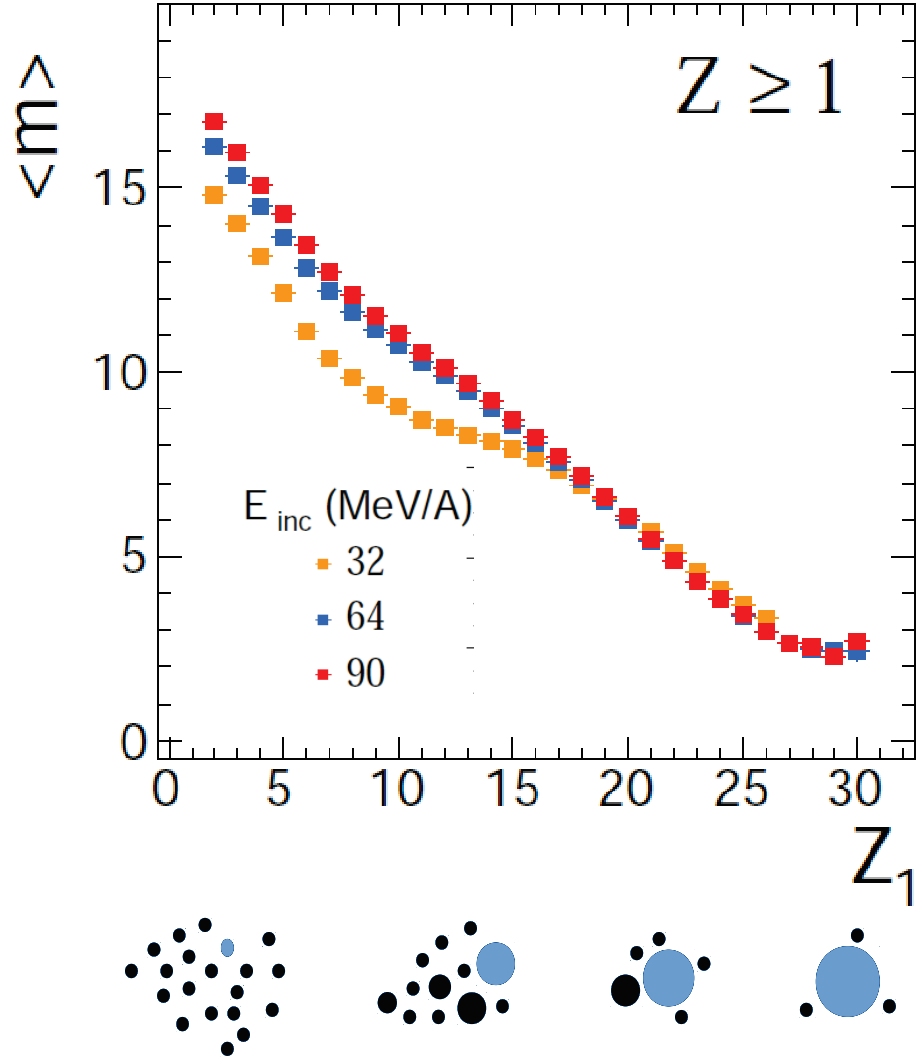
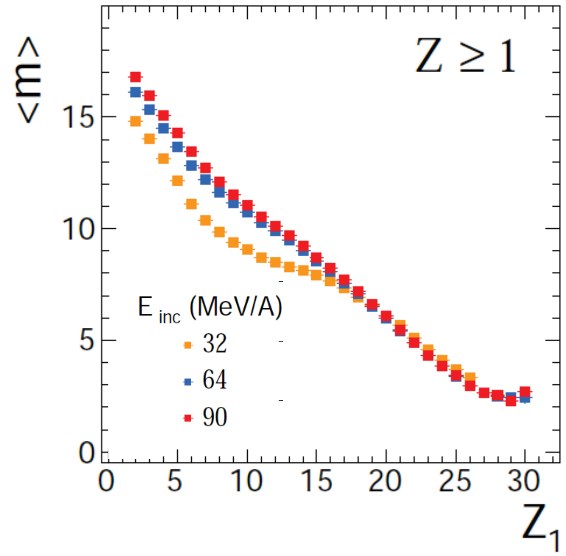


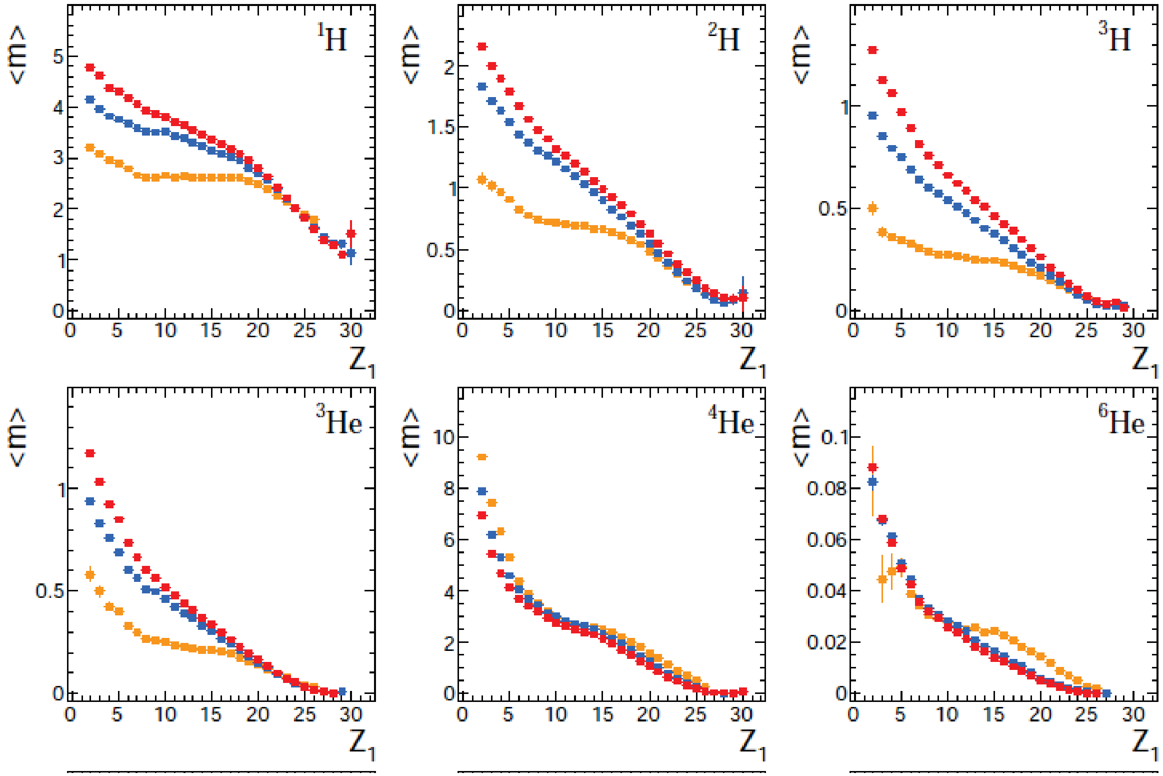
Percentage of vaporization events

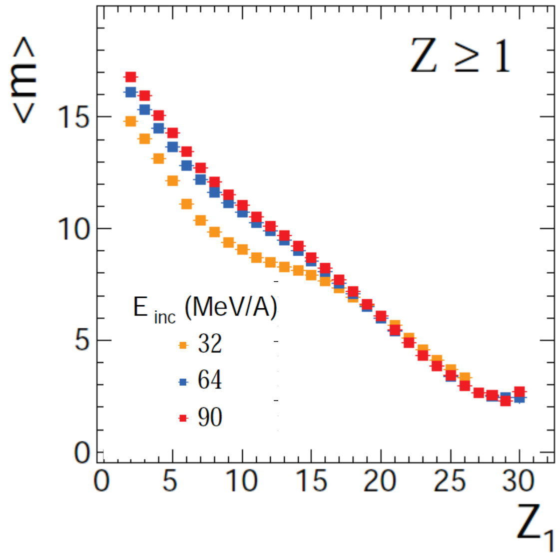
Evolution of mean multiplicities with Z1



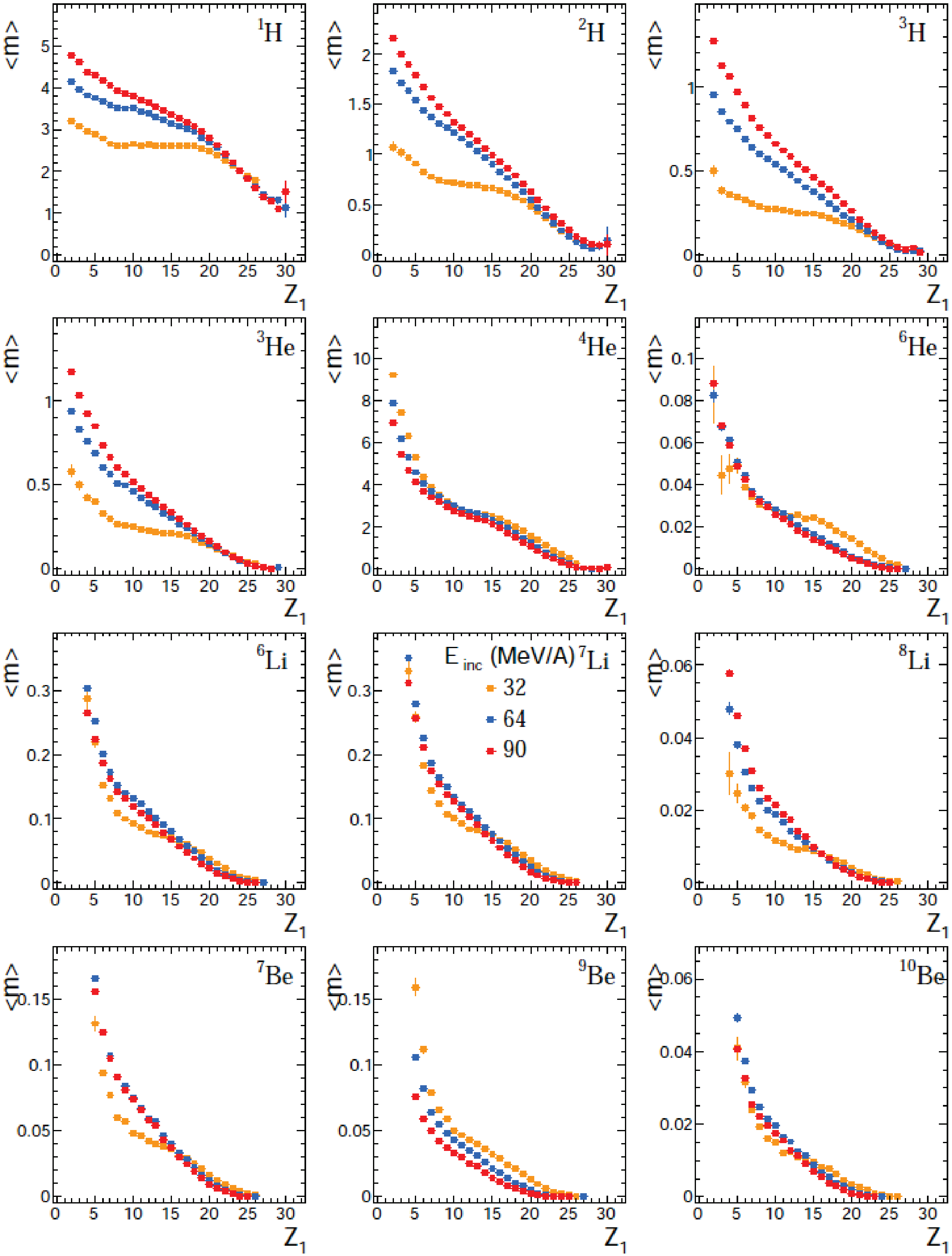


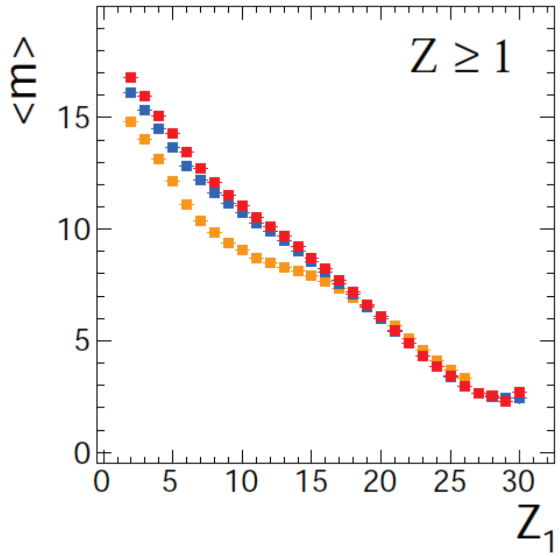
Evolution of mean multiplicities with Z1



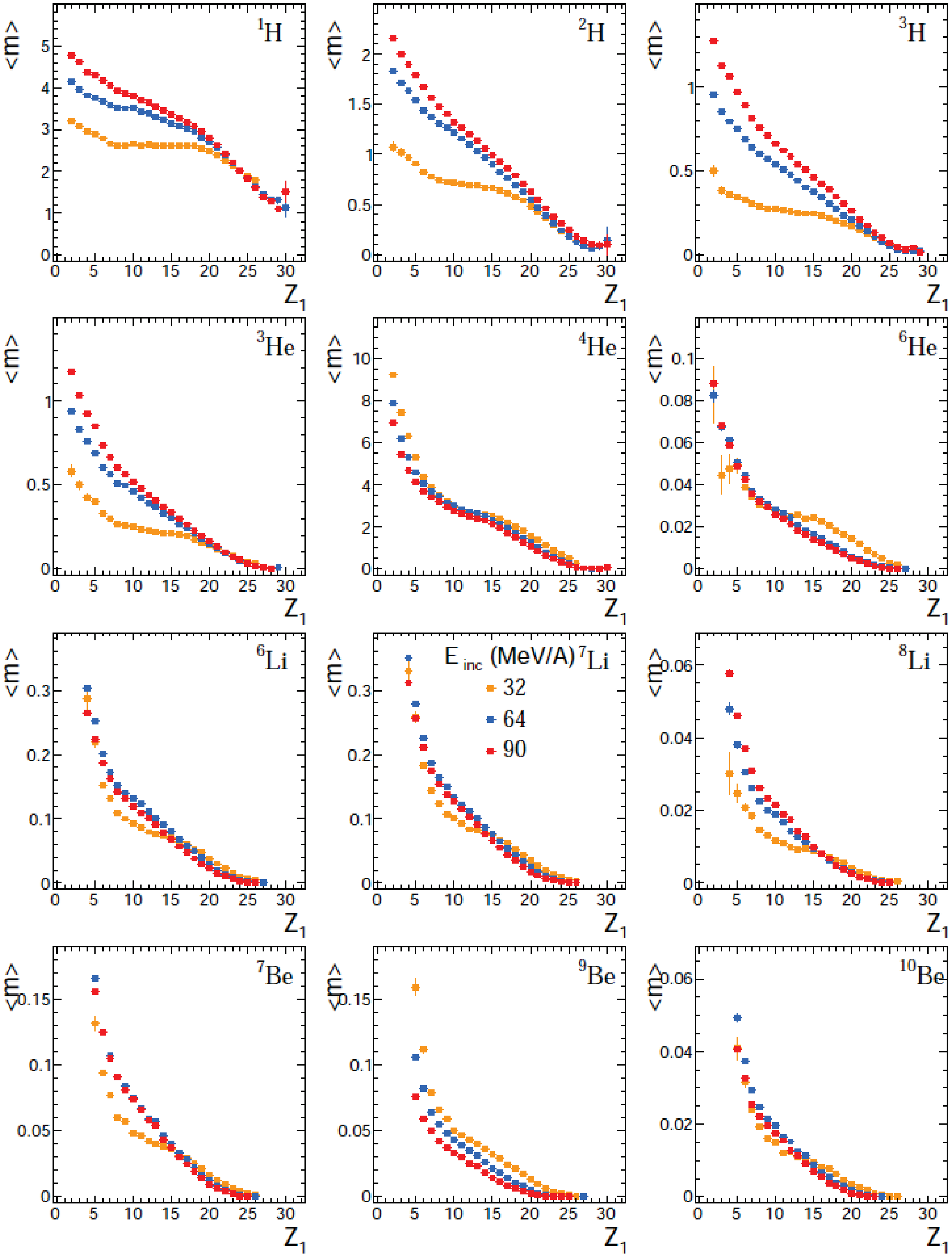


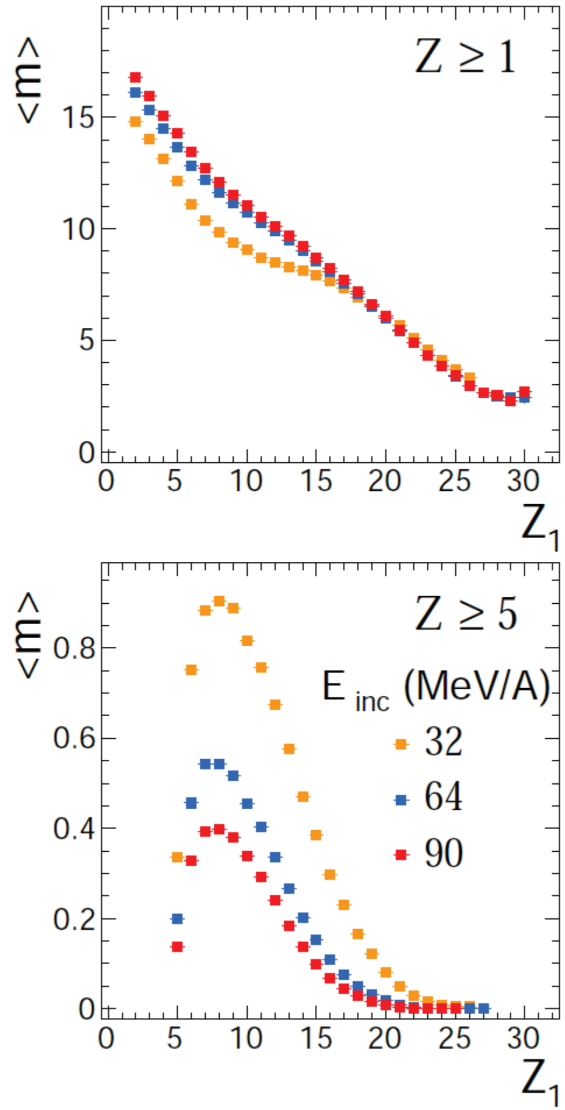
Evolution of mean multiplicities with Z_1





Evolution of mean multiplicities with Z1



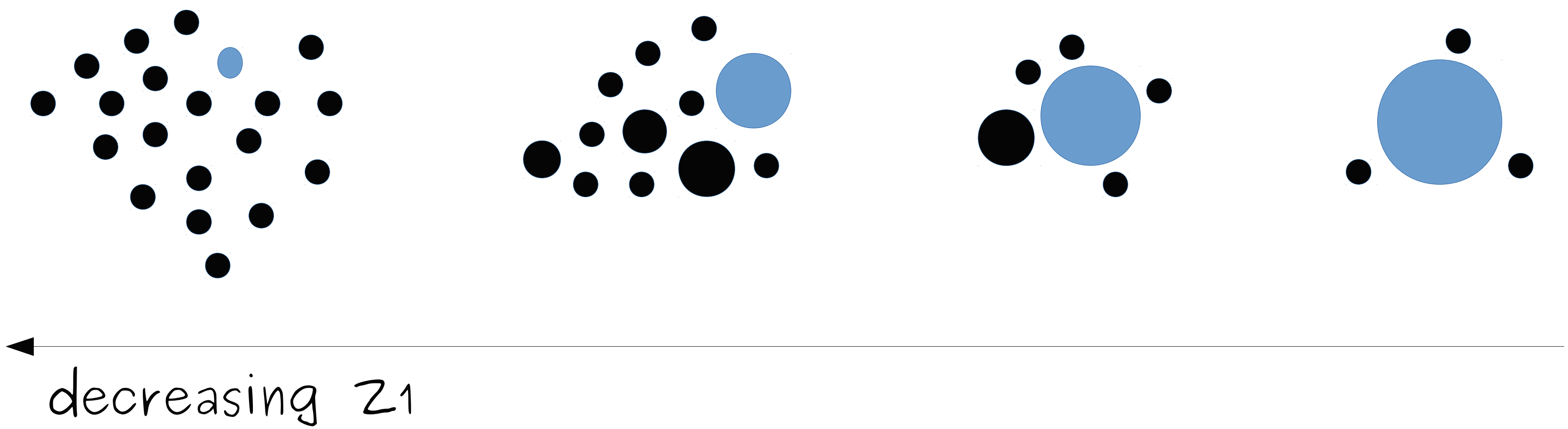


Evolution of mean multiplicities with Z_1

Evolution of mean mass fraction with Z1

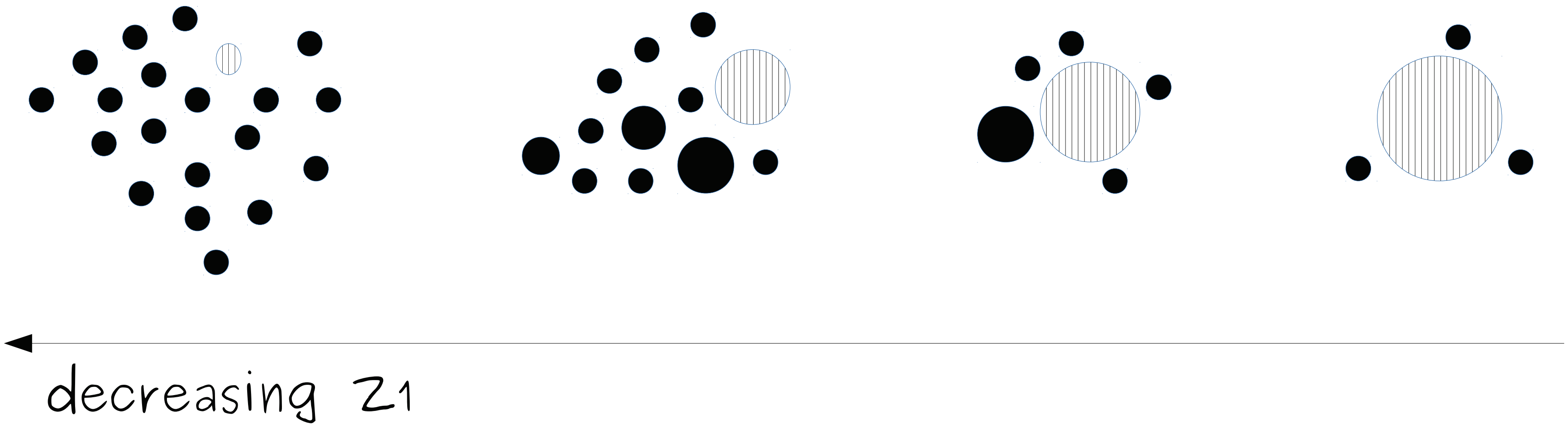
Relative contribution of species

- We introduce the mass fraction (X_A) which is the probability for a nucleon to belong to one or an other species.



Relative contribution of species

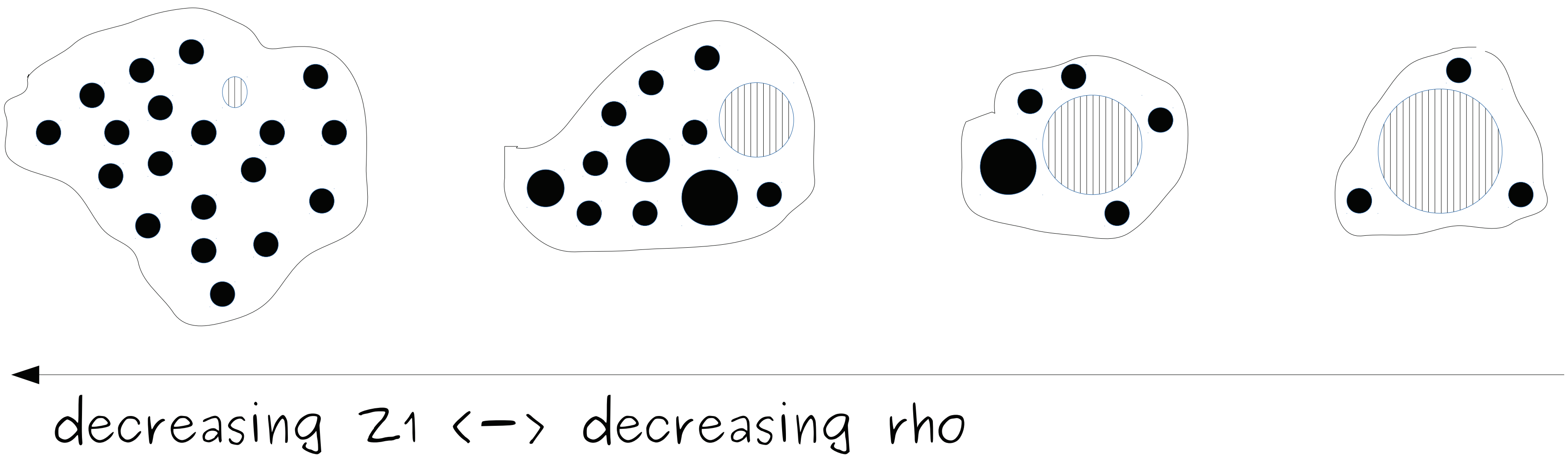
- We are interested looking at nucleons which are not bound in Z1
- We compute mass fraction on the remaining part



$$X_A^{(i)} = m_i A_i \,/ (\sum_{j=1}^{m_{tot}} A_j - A_1)$$

Relative contribution of species

- Composition of the remaining part is then studied using Z1 sorting as a mimic of density sorting of the initial system (Freeze Out picture).

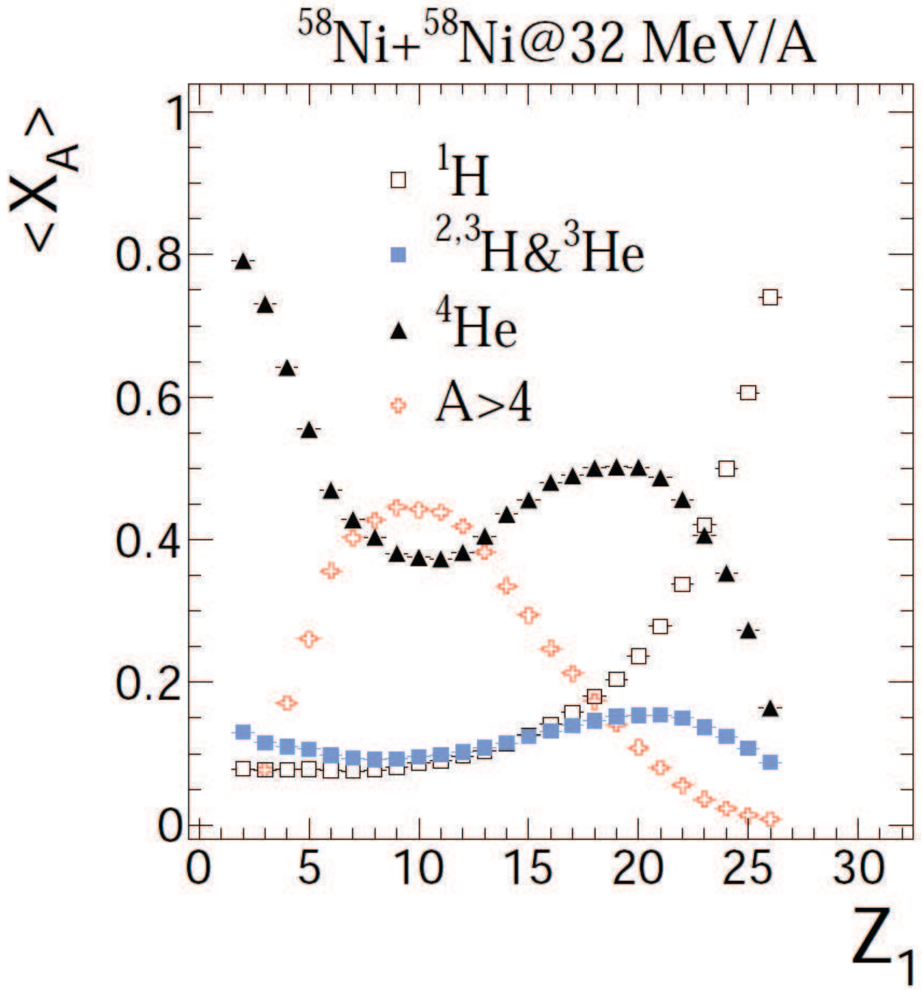


$$X_A^{(i)} = m_i A_i \,/ (\sum_{j=1}^{m_{tot}} A_j - A_1)$$

Mass fraction

- From multiplicity evolutions we can gather :
  - 2H, 3H et 3He : $^{2,3}H \& ^{3}He$
  - A>4 products (heavier 4He products)
  - 1H and 4He are kept alone

Mass fraction evolution with Z1



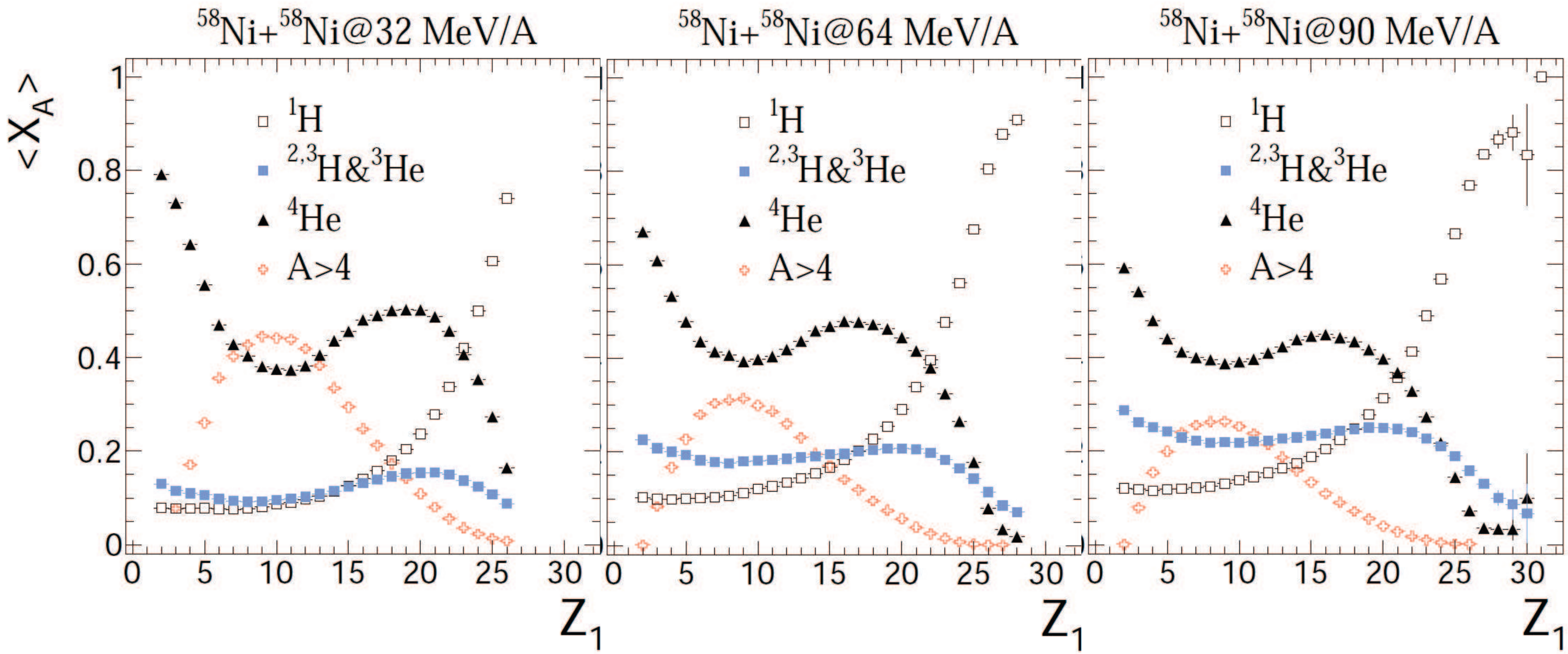
General trends :

Continuous decrease of the 1H with a saturation around 0.1

Back-bending shape of 4He and ^{2,3}H&^{3}He contributions directly linked to the A>4 one

Predominant role of the 4He contribution whatever the Z1 values are.

When incident energy increases ...



Conclusion

- We have looked at the contribution of species which composed final partitions produced in the $^{58}Ni+^{58}Ni$ reactions.
- Using Z_1 as sorting observable, we can sample classes of events from evaporation to vaporization.
- We can distinguish different behaviour depending on the species.
- Looking at multiplicities :
  - $^{1,2,3}H$ & ^{3}He are affected by incident energies for $Z_1<15$ while heavier isotopes are not.
  - At 32 MeV/A, plateaux are observed for proton and light clusters when $Z>5$ fragments start to be produced significantly.
  - These plateaux are softened increasing incident energies, except for ^{4}He
- Looking at mass fraction :
  - The $A>4$ contribution are framed by the light clusters contribution
  - ^{1}H contribution is constant for $Z_1<15$
- ^{4}He contribution is predominant whatever the underlying mechanism leading to final observed partitions

Outlook

- Present results are averaged from deposit energy distribution
- Going further in the analysis using an excitation energy (E*) sorting
- Extend the analysis for higher mass systems