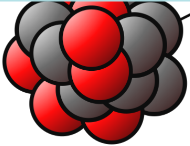
Energy dissipation and cluster correlations in excited light systems at Fermi energies investigated with HIPSE and AMD



Catalin Frosin

for the FAZIA collaboration

XXIInd GANIL Colloque

September 30, 2021

UNIVERSITÀ DEGLI STUDI FIRENZE

INFN Istituto Nazionale di Fisica Nucleare
SEZIONE DI FIRENZE

Fermi energy ≡ Competition between NN collisions and mean-field

Various studies in the medium-heavy mass region:

- Nuclear Equation of State
- Isospin Equilibration
  see for ex. Caterina Ciampi's presentation and many others today

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→ **Data on these systems at Fermi energies are not so abundant[1] and it is interesting to study the limit of such small sources, also considering the possible role of the underlying cluster (α-clustering) and structure effects[2] which is known to affect these systems at lower energies[3]**

1 *Eudes et. al., PRC, 90:034609 (2014)*

2 *Tian et. al., PRC 95, 044613 (2017) & PRC 97, 034610 (2018)*

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⇒ **Constraining Monte-Carlo models for light systems can also be of interest for hadrontherapy purposes**[4]

4 *J. Dudouet, et. al., PRC 88, 024606 (2013)*
J. Dudouet, et. al., PRC 94, 014616 (2016)

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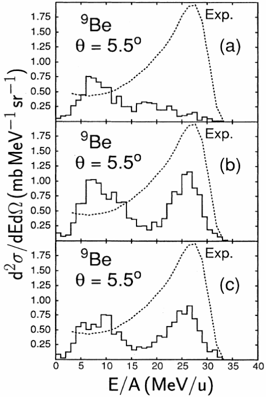
A. Ono et al.,Phys. Rev. C 47, 2652 (1993)

^{12}C+^{12}C at 28.7 MeV/u →Dependence on the stochastic collision process



C=0

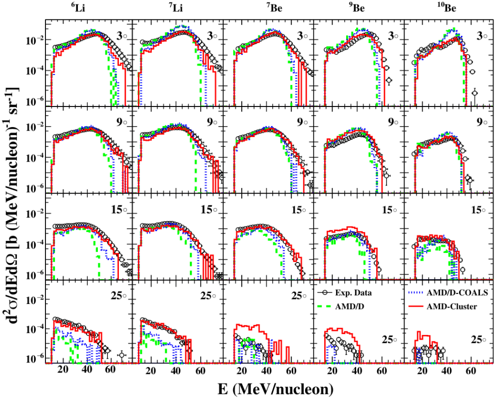
C=1 + N-α

C=2 + N-α

$$\sigma_{NN} = \frac{100\,mb}{1 + E/(200MeV) + C * min[(\rho/\rho_0)^2, 1]}$$

R. Han et al., Phys. Rev. C 102, 064617 (2020)

^{12}C+^{12}C at 50 MeV/u →Dependence on cluster formation



- Green≡ no cluster formation
- Blue≡ coalescence of nucleons up to A≤4
- Red≡ extended cluster correlation in two-nucleon collisions and clusters up to A≤9

A. Ono et al.,Phys. Rev. C 47, 2652 (1993)

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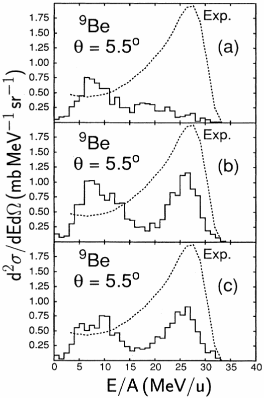

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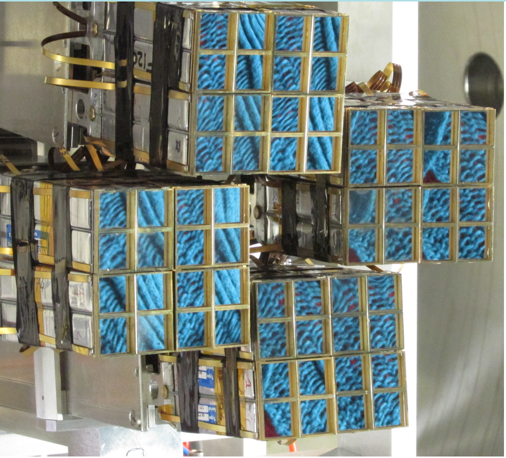
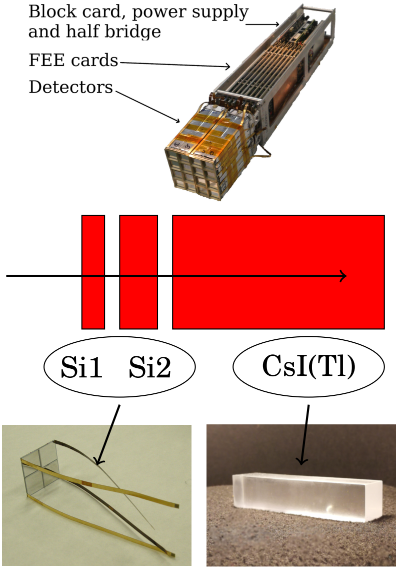
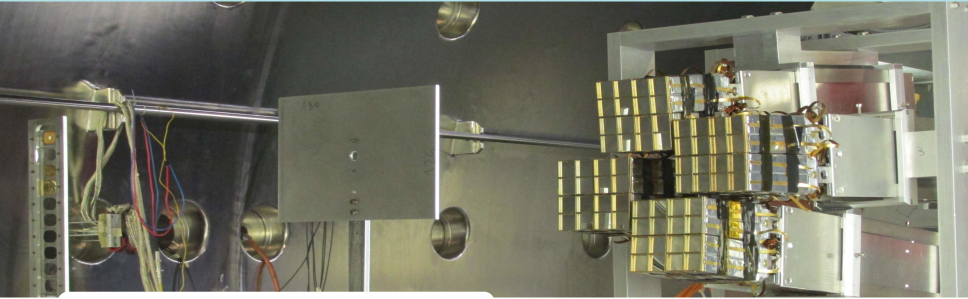




300-500 μm

10 cm

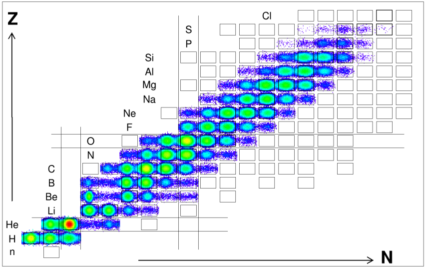
1. S. Barlini et al. NIM A, 600(3), (2009)
2. L. Bardelli et al. NIM A, 605(3), (2009)
3. L. Bardelli et al. NIM A, 654(1), (2011)
4. R. Bougault et al. EPJ A, 50(2), (2014)
5. S. Valdré et al. NIM A, 930, (2019)
6. C. Frosin et al. NIM A, 951, (2020)



- ☑ $^{20}Ne + ^{12}C$ @ 25 & 50 AMeV
- ☑ $^{32}S + ^{12}C$ @ 25 & 50 AMeV

- 4 blocks in a wall configuration
- coverage in $\theta \sim$ 2-8°($\Delta\theta \sim$ 1°)
- Multiplicity trigger $M_{fired} > 1$: removal of elastic scattering events
- A&Z identification for all nuclei produced

^{32}S+^{12}C @ 25 AMeV



1. **Microscopic transport model**: AMD - Antisymmetrized molecular dynamics

A. Ono et al., Prog. of Theoretical Physics, 87(5):1185–1206, 05 1992

A. Ono et al., Prog. Part. Nucl. Phys. 105 (2019) 139

- ✓ two-nucleon collisions as stochastic transitions from an AMD state to one of the possible other AMD states:

$$\sigma_{NN} = \sigma_0 \tanh(\sigma_{free}/\sigma_0)$$
$$\sigma_0 = y\varrho^{-2/3} \quad y = 0.85$$

D. D. S. Coupland et al., Phys. Rev. C, 84:054603, (2011)

- ✓ mean field: effective Skyrme interaction SLy4
- ✓ cluster formation: light clusters (A≤4) and inter-cluster binding (A≤9)

2. **Phenomenological/Semi-classical model**: HIPSE - Heavy Ion Phase Space Exploration→ three adjustable parameters which depend on the incident energy.

D. Lacroix et al., Phys. Rev. C, 69:054604, May 2004

M. Mocko, PhD thesis, MSU, 2006

E_{beam}(AMeV)	α_a	x_{tr}	x_{coll}
25	0.10	0.45	0.02
50	0.20	0.30	0.05

HFℓ: Hauser-Feshbach Light

- sequential evaporation of LCP (n, p, d, t, ^{3}He, α) and ^{6}Li,^{7}Li, ^{8}Be
- transmission coefficients and Level Densities (LD) optimized for A$<$40
- information on measured discrete excited levels from the NUDAT2

L. Morelli et al., JoP G: 41 (7):075107, (2014)
G. Baiocco et al., PRC 87 054614 (2013)
A. Camaiani et al., PRC 97 044607 (2018)

SIMON

- simulates all the possible decay channels from neutron evaporation up to symmetric fission
- Coulomb interaction between the trajectories
- Used only for HIPSE's primary fragments

D. Durand et al., Nucl. Phys. A, 541(2):266–294 (1992)

→ Model data is filtered through a software replica of the apparatus which includes:

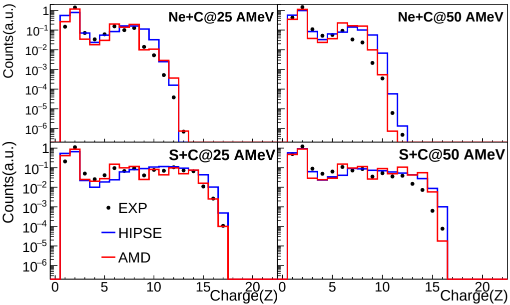
- identification & energy thresholds
- energy resolution
- geometrical efficiency

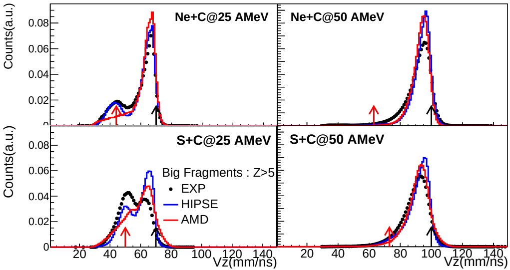
→ AMD: 60000 primary events (500 fm/c) ×1000 secondary decay: 60 mil events

→ HIPSE: 15mil events primary+secondary decay

Results:

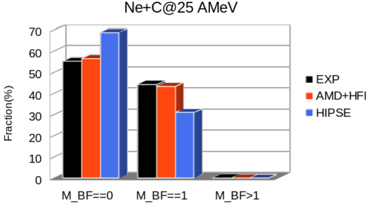
- Good Z reproduction of AMD @ 25 AMeV: staggering effect is present only in AMD+HFl
- All models underestimate the alpha production (common feature for light N=Z nuclei)
- At 50 AMeV both models tend to be less dissipative

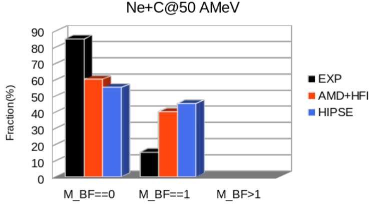


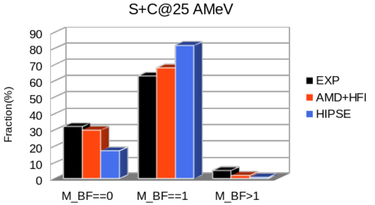


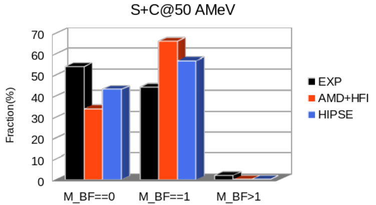
Multiplicity and class of events: Big Fragments

Big Fragments (BF): Z>5 - Intermediate Mass Fragments (IMF): 2<Z≤5 - Light Charged Particles (LCP): Z≤2









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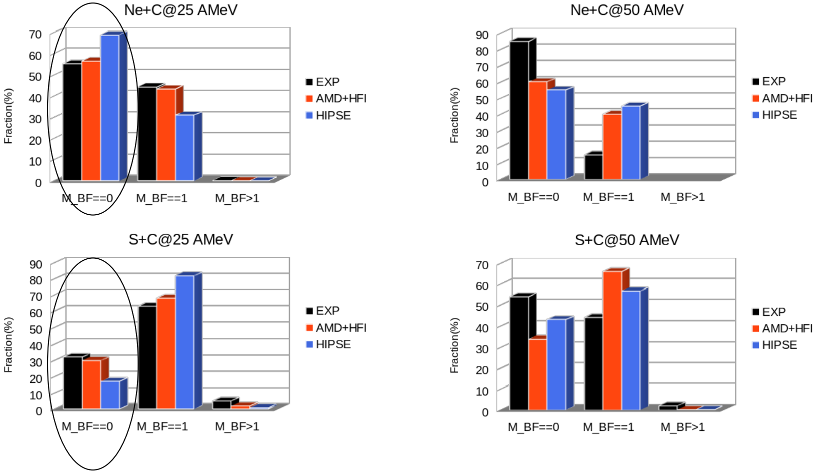

The big fragment event partition is better reproduced by AMD especially at 25 AMeV of beam energy. At 50 AMeV ∼ 20-30% experimentally more M_{BF} =0 events than models

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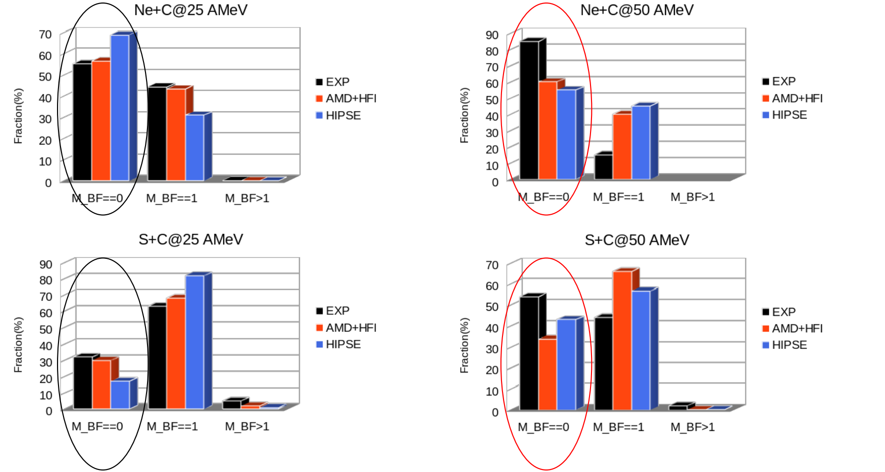

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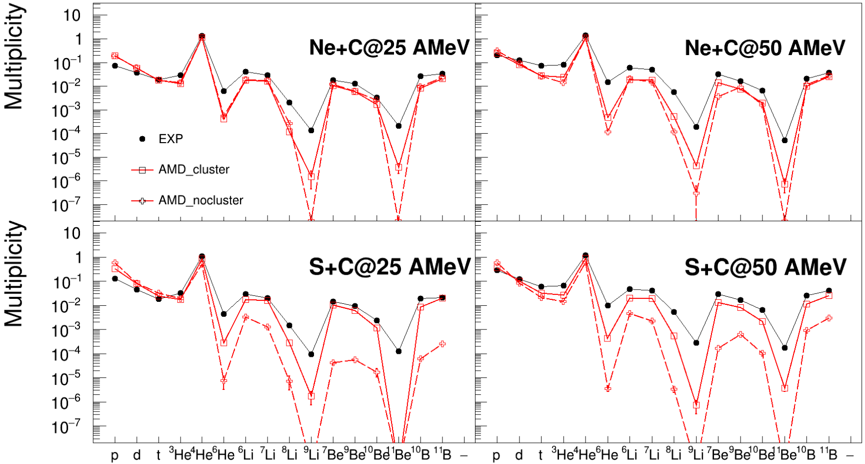
Multiplicity and class of events: LCP and IMF

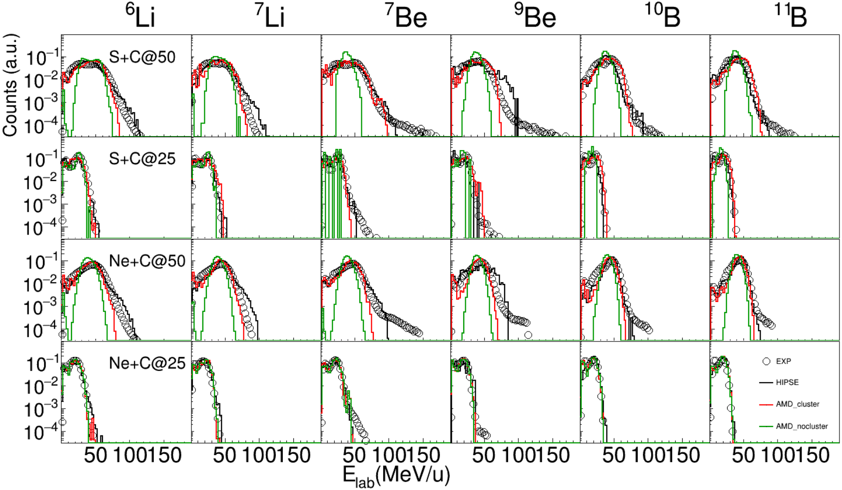
How is the cluster formation affecting the overall multiplicity?



Cluster option fundamental for the heavier IMF production, particularly effective when the mass of the system increases.

Energy distributions: IMF

How is the cluster formation affecting the energy distribution of IMFs?



The improvement of the IMF cluster production is made in two ways, one is the increased production rate of the primary IMFs and the other the enhanced population at the lower excitation energies. The latter enhances the survival probability of the excited IMFs after the secondary decays.


Conclusions

Comparison with state of the art MonteCarlo simulations:

- ☑ extended for the first time the use of the dynamical transport model (AMD) to light systems different from C+C in the Fermi energy range
- ☑ both AMD and HIPSE show less dissipative collisions @ 50 AMeV → might depend on the NN collisions parametrization or the non-inclusion of N-α collisions as beyond mean field effects
- ☑ showed the crucial role of clustering in AMD in describing the experimental data both in terms of multiplicities and energy distributions

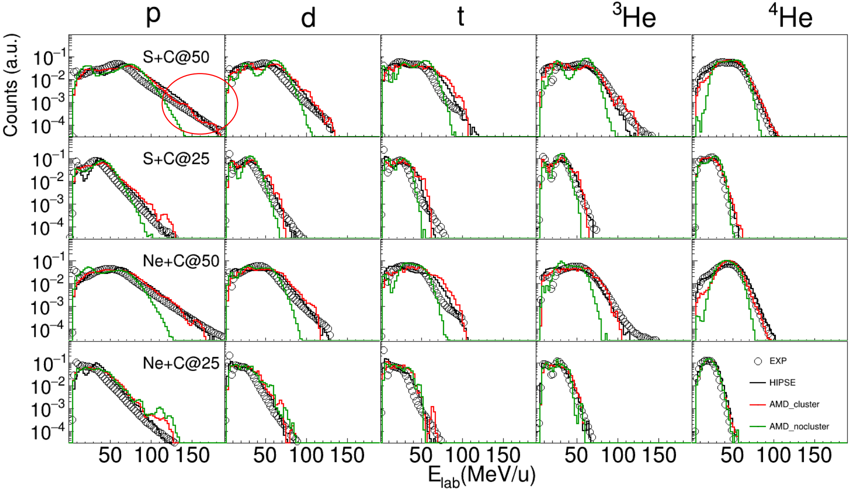
To do list:

1. explore more in depth the afterburner influence
2. play with the AMD parametrizations of σ_{NN} or mean field


THE END
THANK YOU FOR YOUR ATTENTION

Energy distributions: LCP

How is the cluster formation affecting the energy distribution of LCPs?



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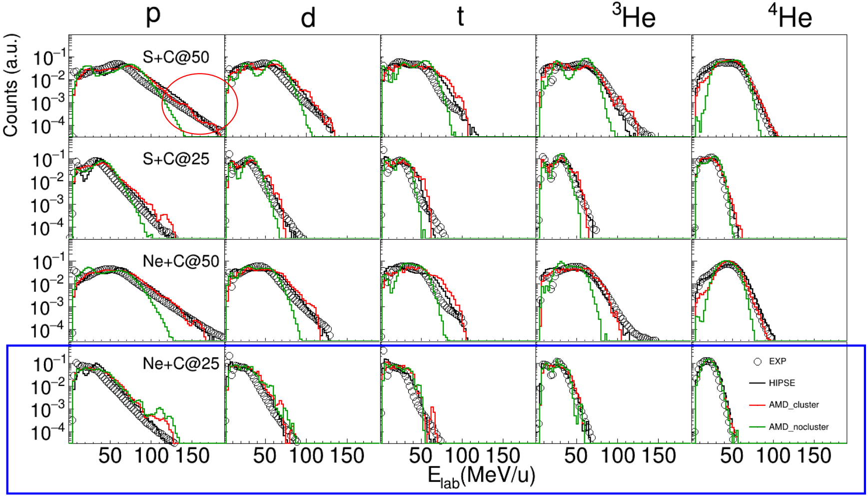

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Energy distributions: Big Fragments

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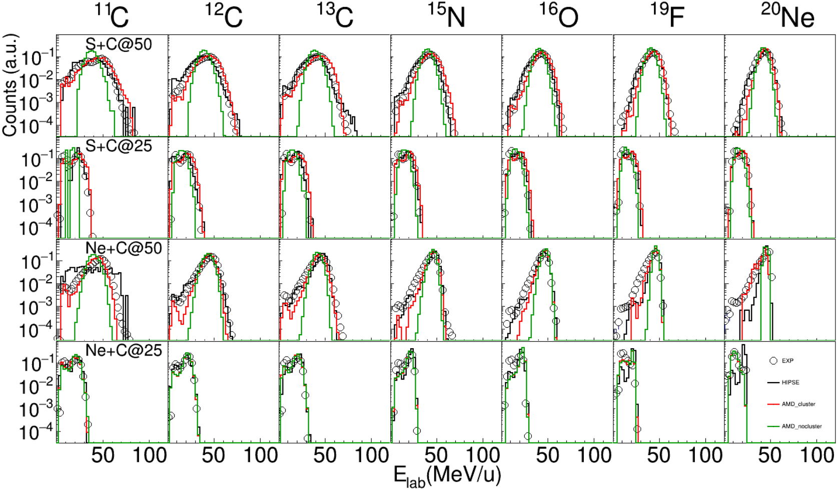
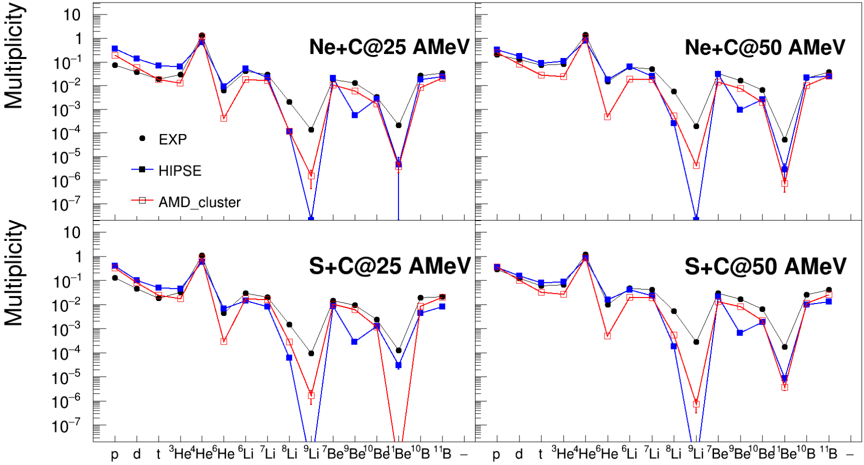


The same shape/width considerations are true also for Big Fragments as for IMF. In certain cases (see for ex. ^{12}C in Ne+C @ 50 AMeV), HIPSE is better at reproducing the low energy end wrt to AMD. The ^{11}C spectra are however better reproduced by AMD.

Multiplicity and class of events: LCP and IMF

A more exclusive selection based on the Z & A of the LCP and IMF



Excitation energy: Primary IMFs