Preliminary results coupling SMF and BLOB with Geant4

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Geant4 (GEometry ANd Traking)

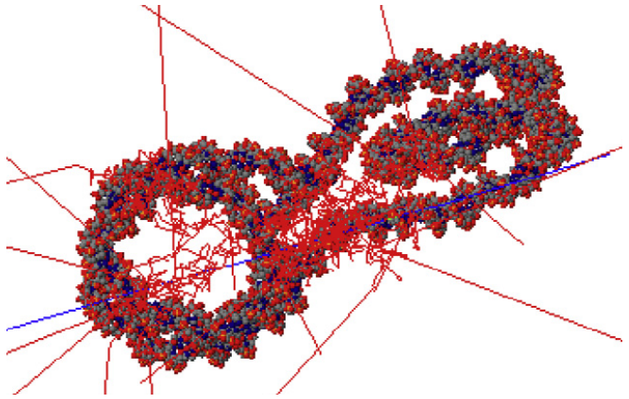
- Developed by an International Collaboration
  - Established in 1998
  - Approximately 100 members, from Europe, US and Japan
  - http://geant4.org
- Open source
- Written in C++ language
  - Takes advantage from the Object Oriented software technology

[Geant4, a simulation toolkit Nucl. Inst. and Methods Phys. Res. A, 506 250-303

Geant4 developments and applications Transaction on Nuclear Science 53, 270-278]

Geant4 applications

- Nuclear Physics experiments
- Hadrontherapy
- Radiobiology
- Radio-protection in space mission
- Radiation damages to electronics
- Nuclear spallation sources
- Radioactive waste



atomistic view of a dinucleosome irradiated by a single 100 keV proton

Image from M. A. Bernal et al Physica Medica, vol. 31, no. 8, pp. 861–874, Dec. 2015.

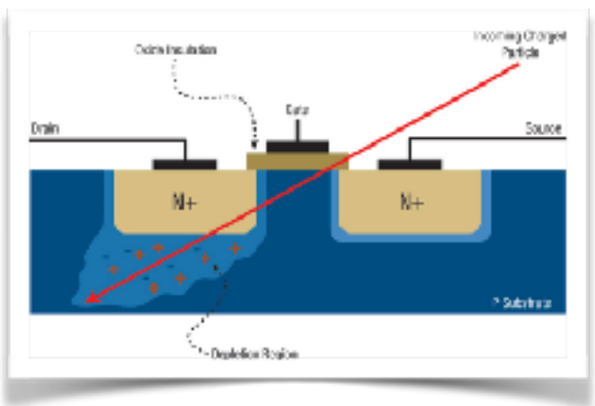


Figure from M. Sawant, COTS Journal Jan. 2012

First slide of the talk “ESA Geant4 R&D Activities from the Geant4 Space User Workshop Hiroshima, 26 August 2015

Problems below 100MeV/A

- Despite the numerous and relevant application would use it, there is no dedicated model to nuclear interaction below 100 MeV/A in Geant4

- Many papers showed the difficulties of Geant4 in this energy domain:

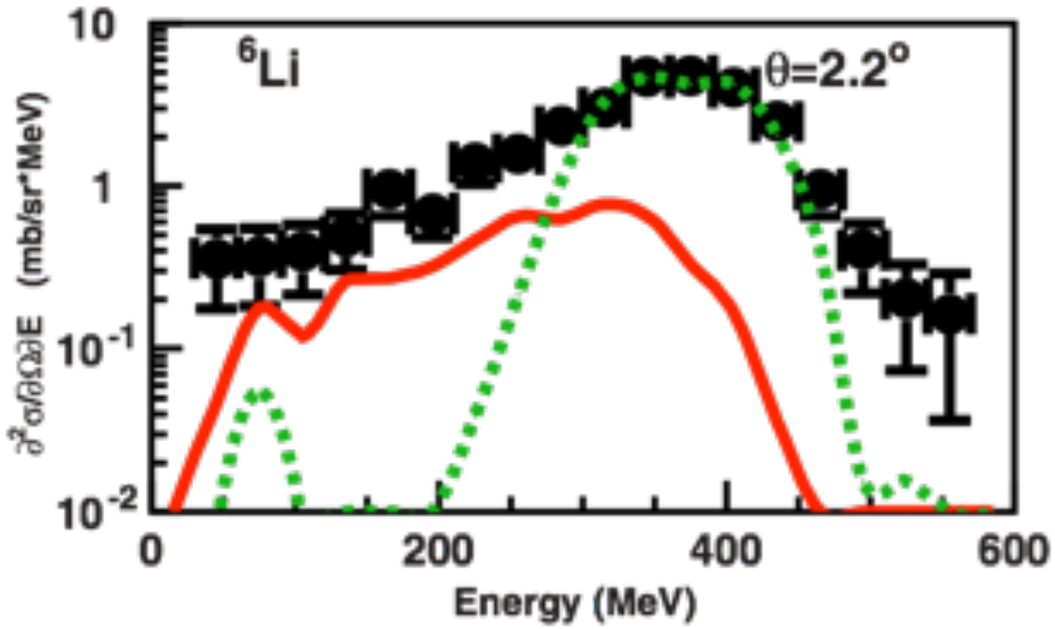
  - Braunn et al. have shown discrepancies up to one order of magnitude in ^{12}C fragmentation at 95 MeV/A on thick PMMA target

  - De Napoli et al. showed discrepancy specially on angular distribution of the secondaries emitted in the interaction of 62 MeV/A ^{12}C on thin carbon target

  - Dudouet et al. found similar results with a 95 MeV/A ^{12}C beam on H, C, O, Al and Ti targets

- **Exp. data**
- **G4-BIC**
- **G4-QMD**

[Plot from De Napoli et al. Phys. Med. Biol., vol. 57, no. 22, pp. 7651–7671, Nov. 2012]



Cross section of the ^{6}Li production at 2.2 degree in a ^{12}C on ^{nat}C reaction at 62 MeV/A.

GeNIALE

Geant Nuclear Interaction At Low Energy

- Aims at improving the capacity of Geant4 to simulate low energy nuclear reactions

- The core of GeNIALE is the implementation in Geant4 of a new model for the first stage of the interaction between a hadron -or a nucleus- and a target nucleus

- Such a model will be coupled with the models already implemented in Geant4 for the second stage, and with the Geant4 framework in general

- Granted by the INFN
  National Scientific Committee 5 (CSN5)

- CSN5 is devoted to technological and inter-disciplinary research

- 6 grants every year for young researcher

Suitable models

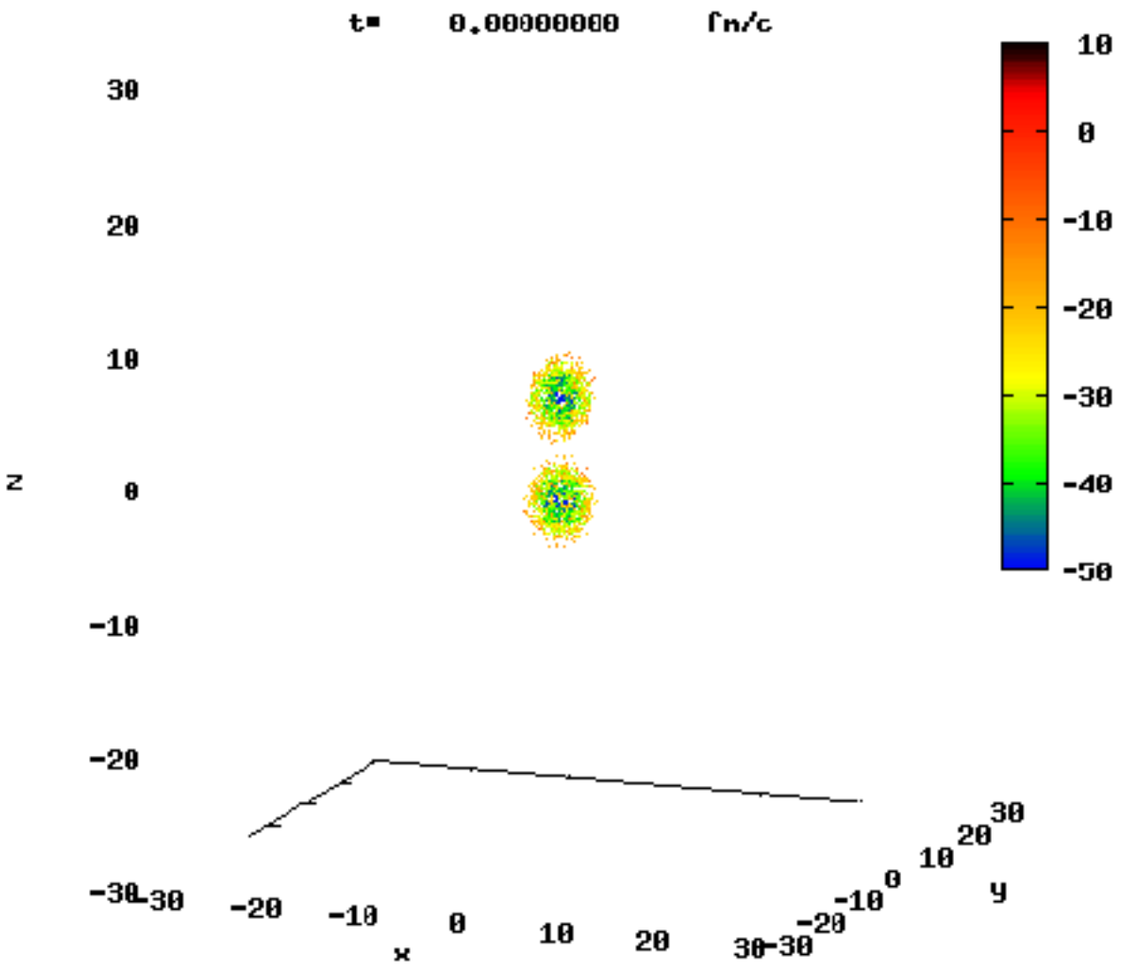
SMF (Stochastic Mean Field)

- Developed by Maria Colonna (INFN LNS, Catania)
- describes the time evolution of the density distribution
- involves the implementation of an effective attractive mean-field nuclear interaction
- mean-field is self-consistent, depends on the density
- includes two-bodies correlations through nucleon-nucleon collisions

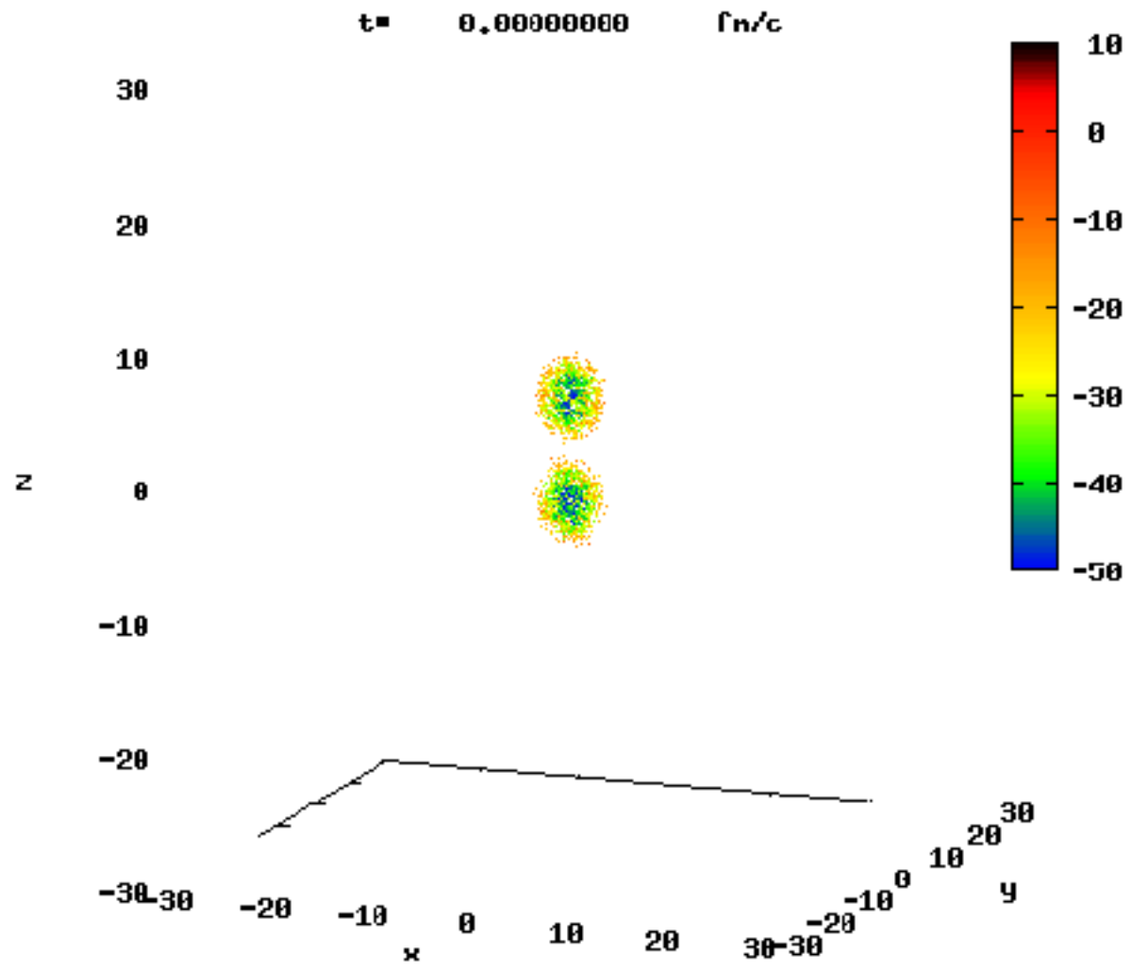
BLOB (Boltzmann-Lagevein One Body)

- Implemented by Paolo Napolitani (IPN, Orsay)
- Derived from SMF
- Adds fluctuations in the dynamics treating the nucleon-nucleon collisions as a stochastic process

SMF and BLOB



SMF



BLOB

100 test particles per nucleon
^{12}C on ^{12}C at 62 MeV/n

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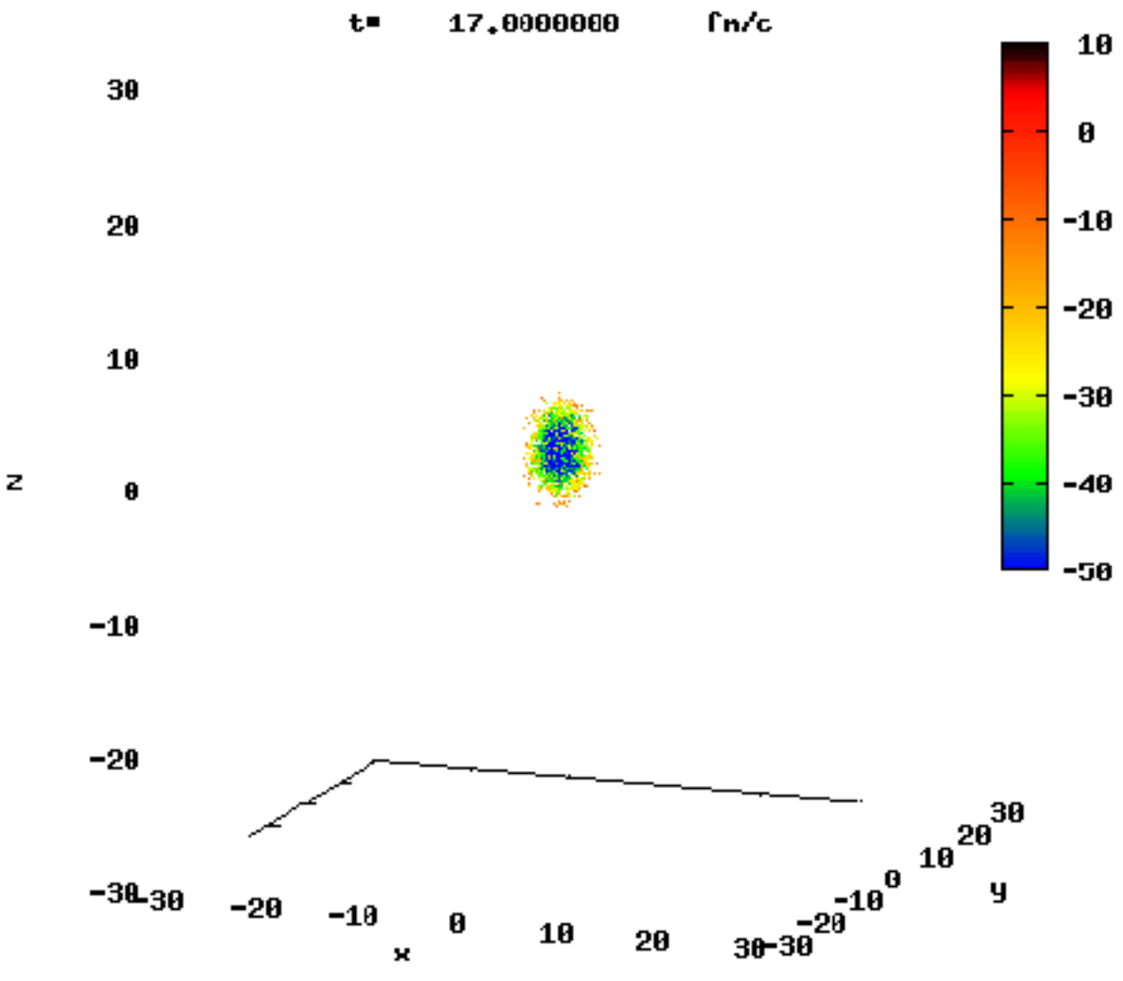

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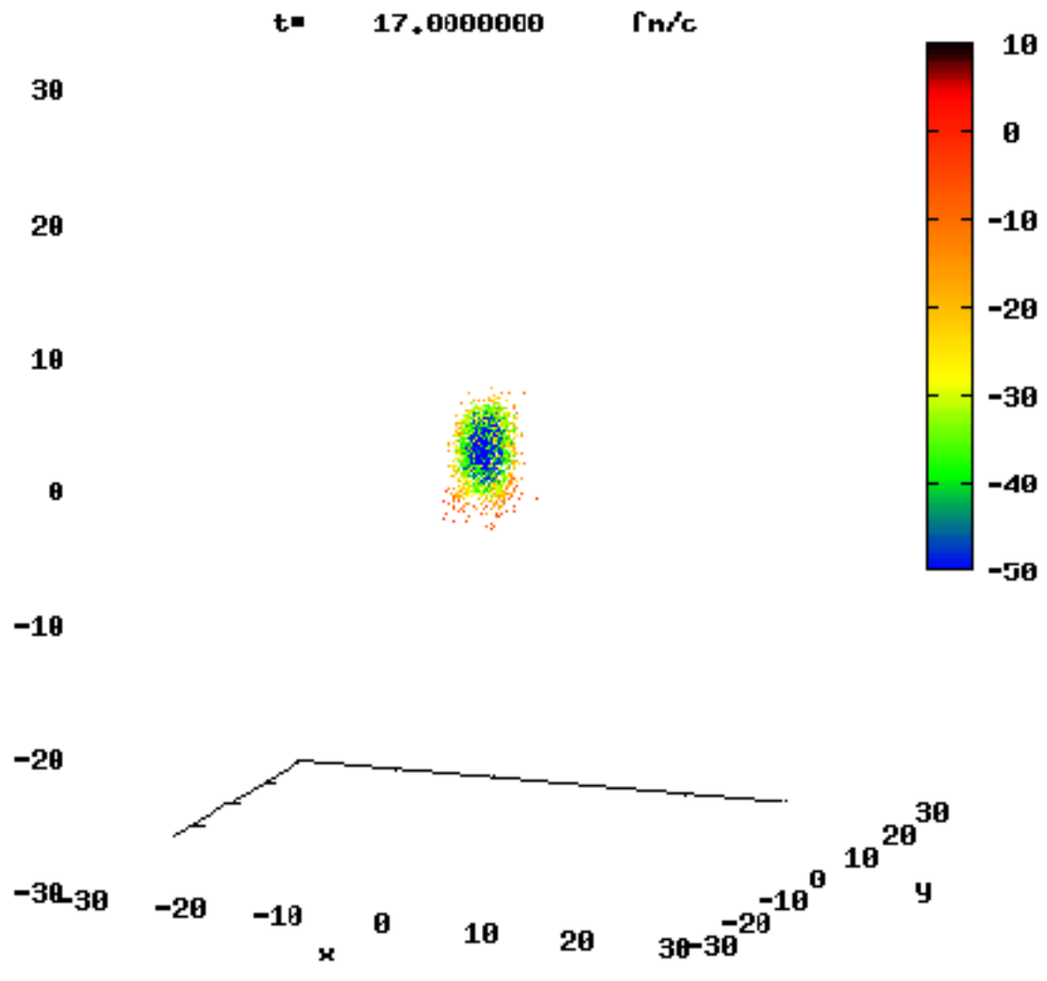

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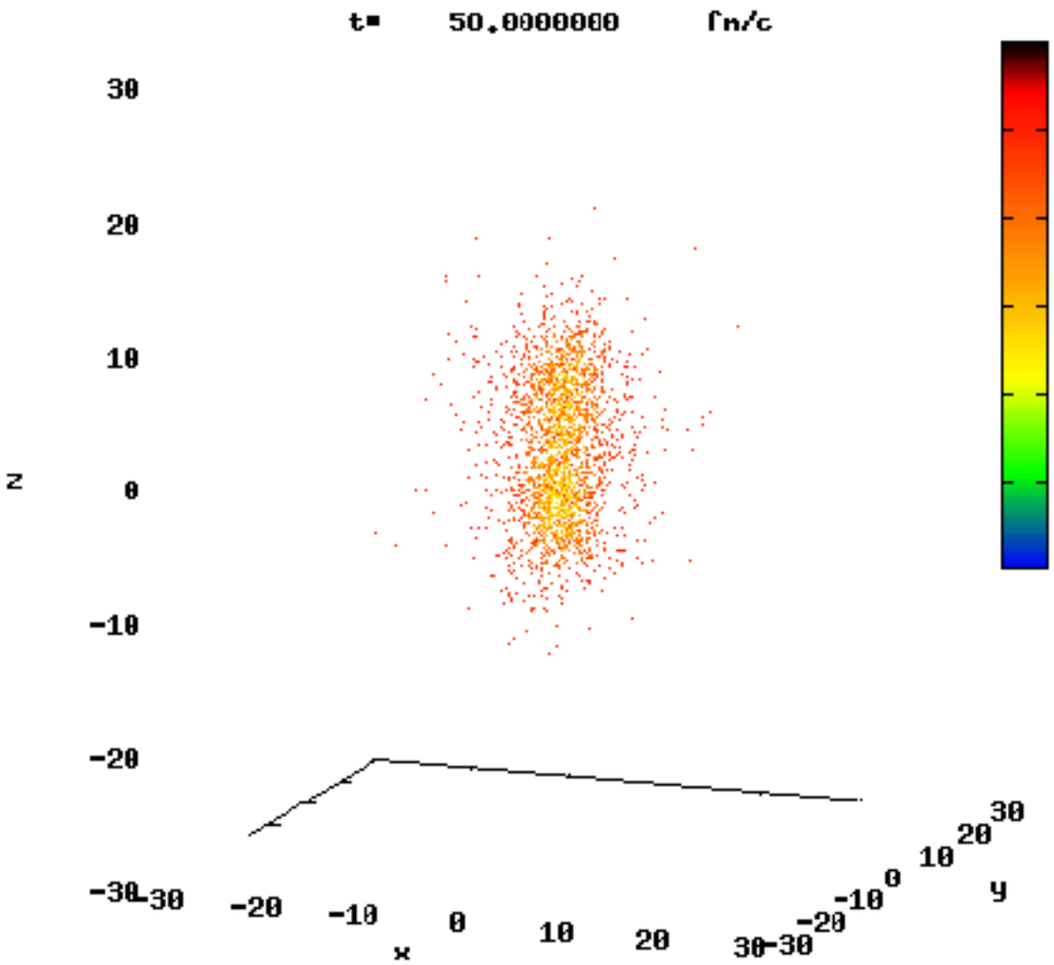

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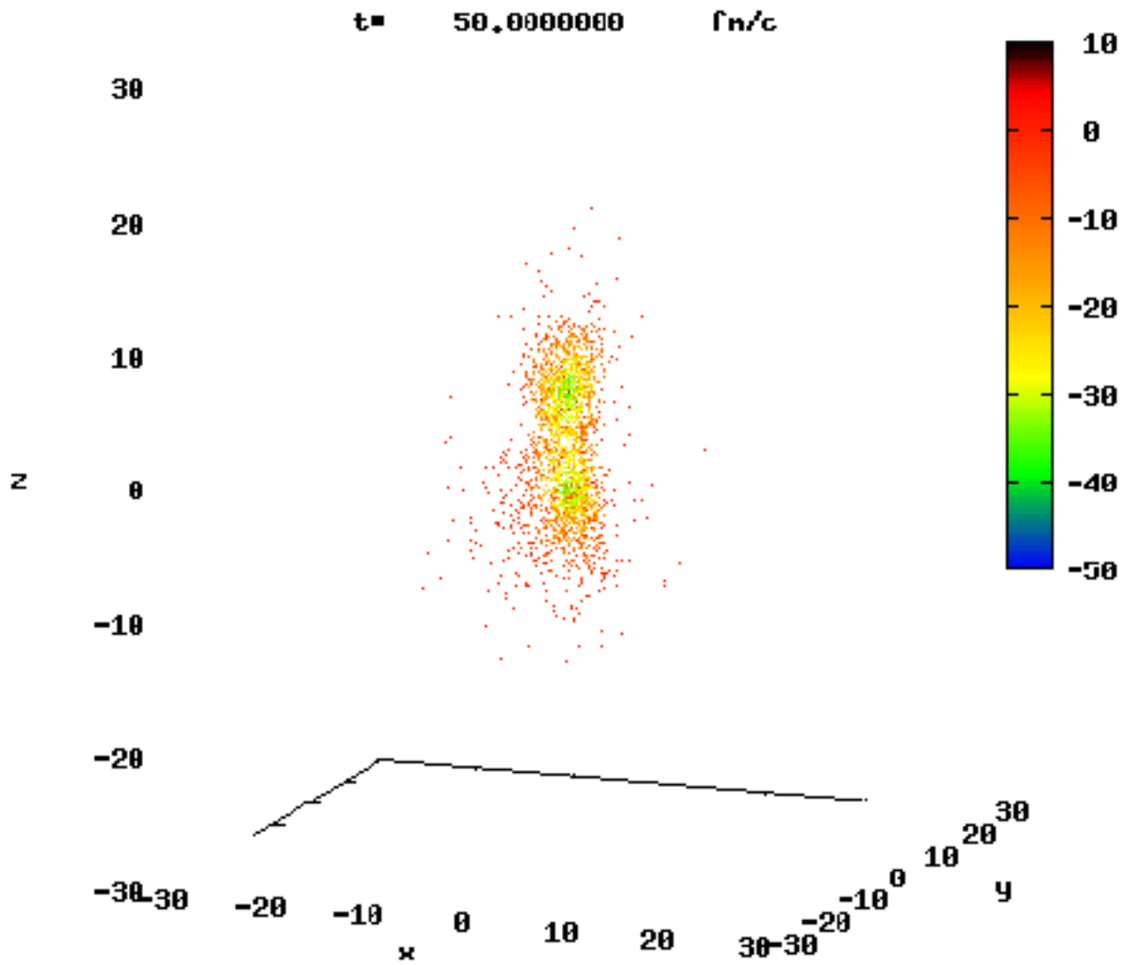

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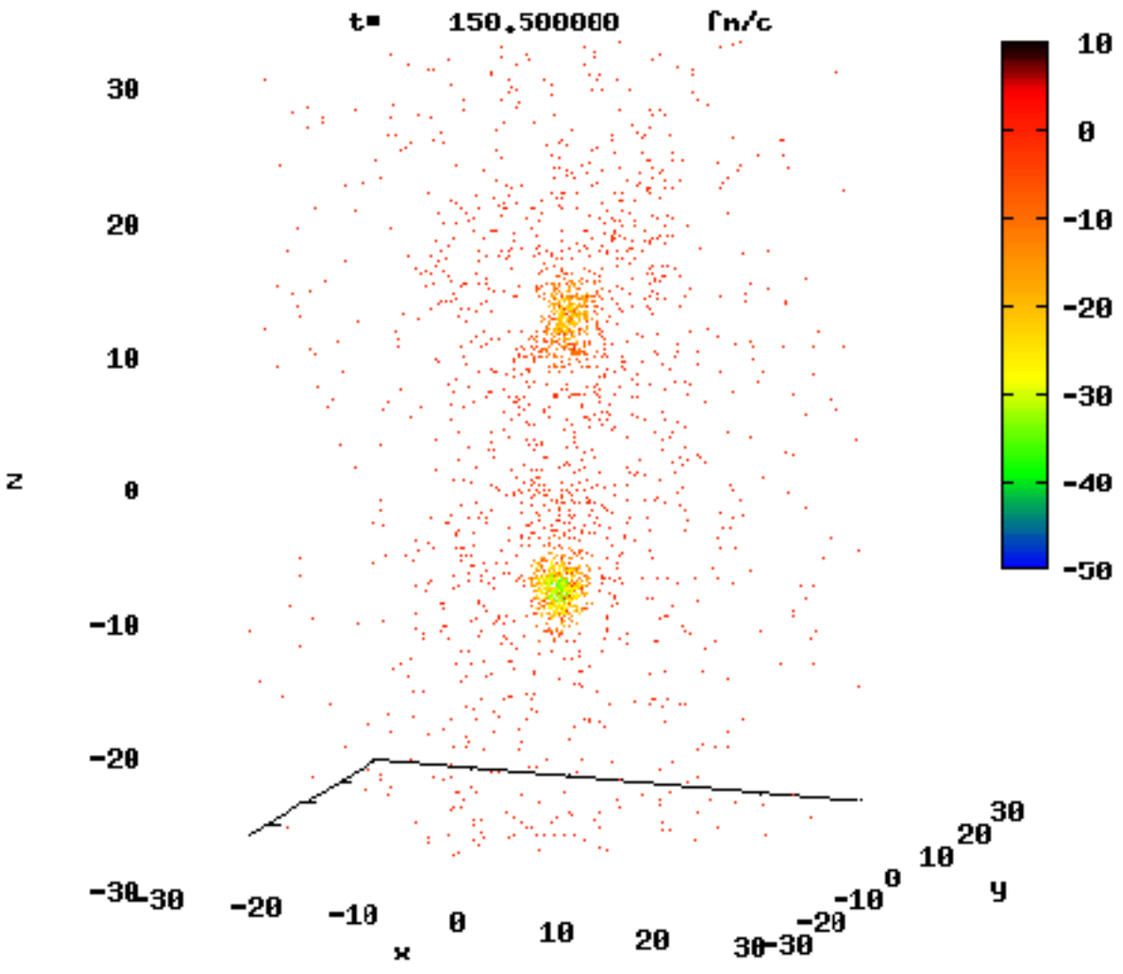

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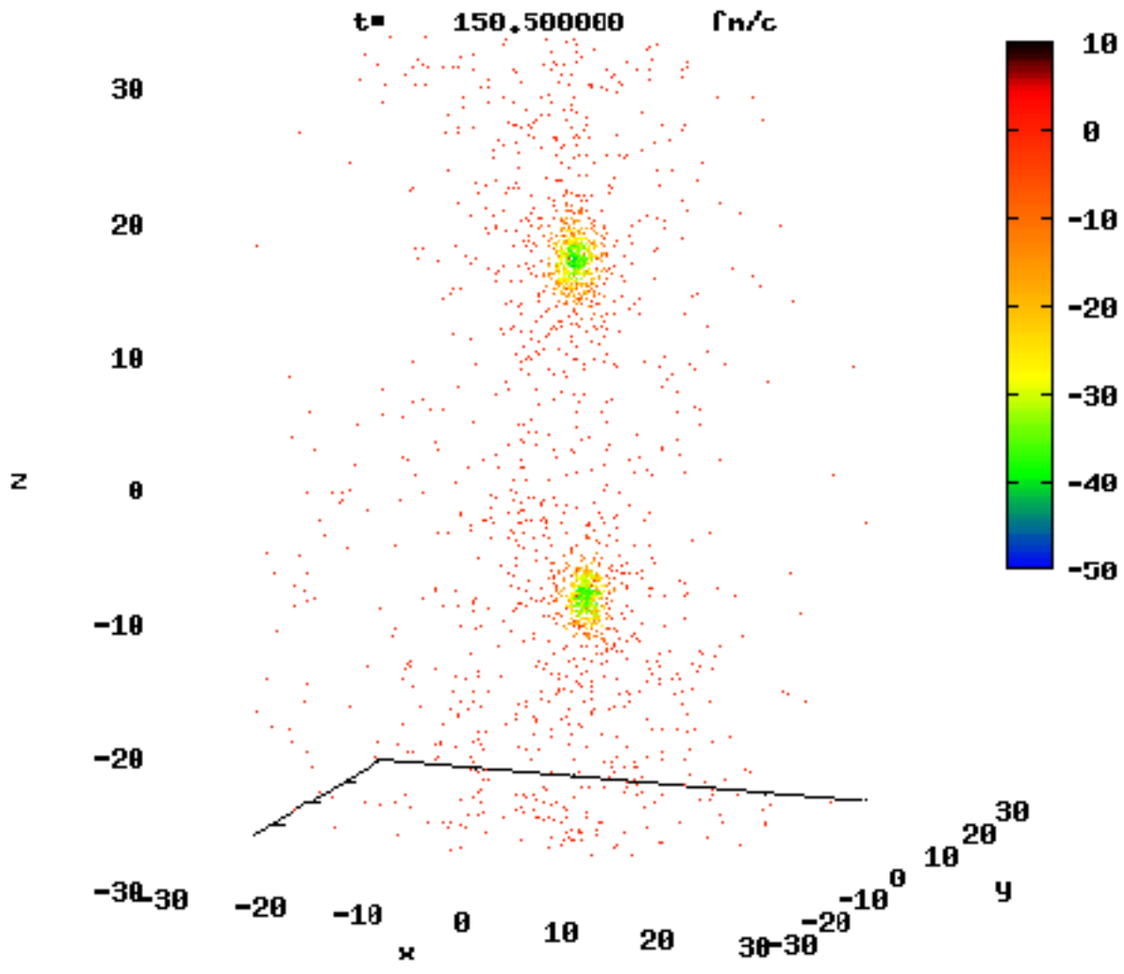

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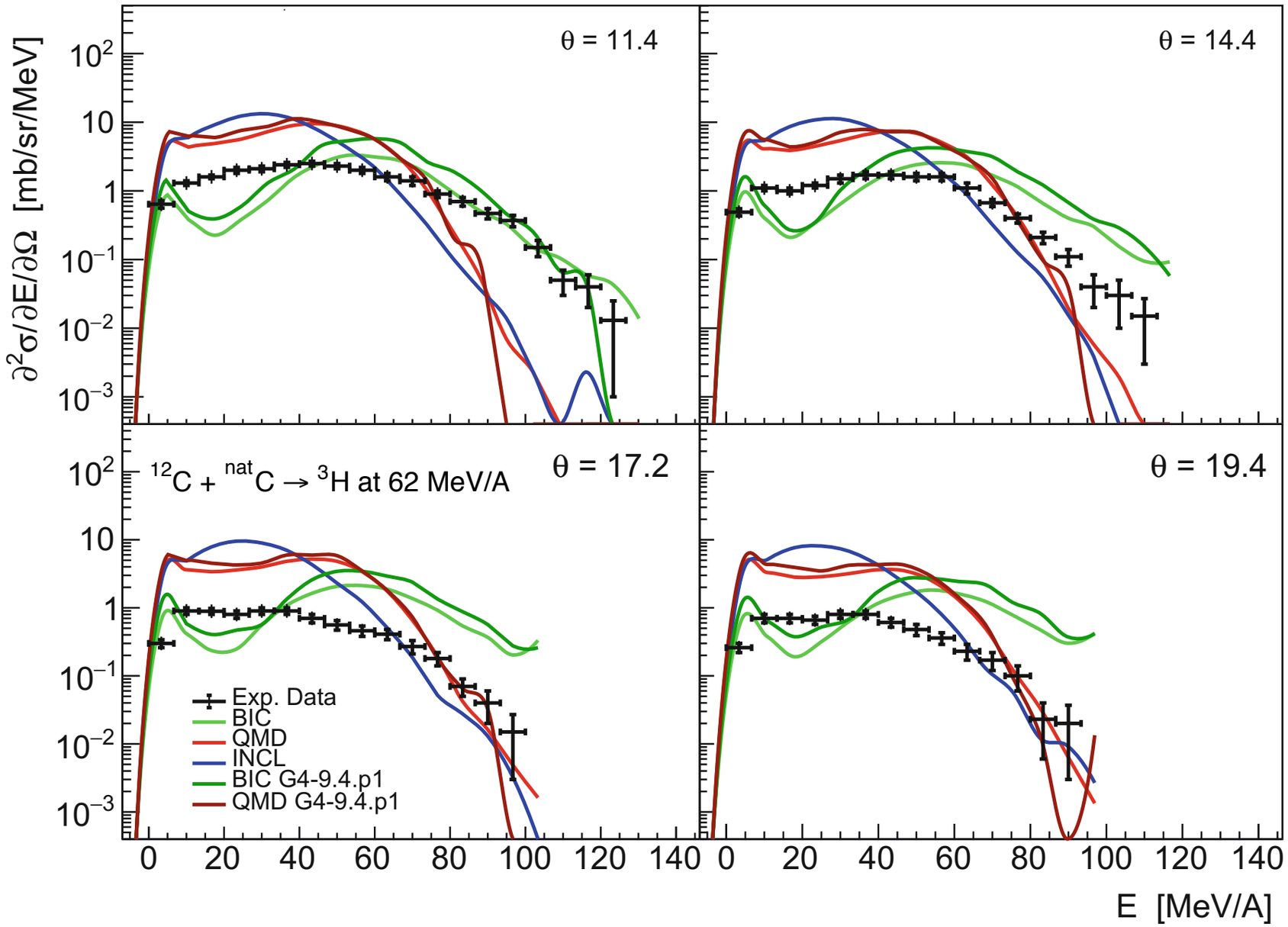
Update of a ^{12}C fragmentation benchmark

[Update of the benchmark originally published on De Napoli et al. Phys. Med. Biol., vol. 57, no. 22, pp. 7651–7671, Nov. 2012]

- 62 MeV/A ^{12}C on thin carbon target
- doubly differential cross sections
- INCL was not available at the time of the original publication



[C. Mancini-Terracciano et al. IFMBE Proceedings Series 68/1 (2018), pp. 675–685. doi: 10.1007/978-981-10-9035- 6_126]

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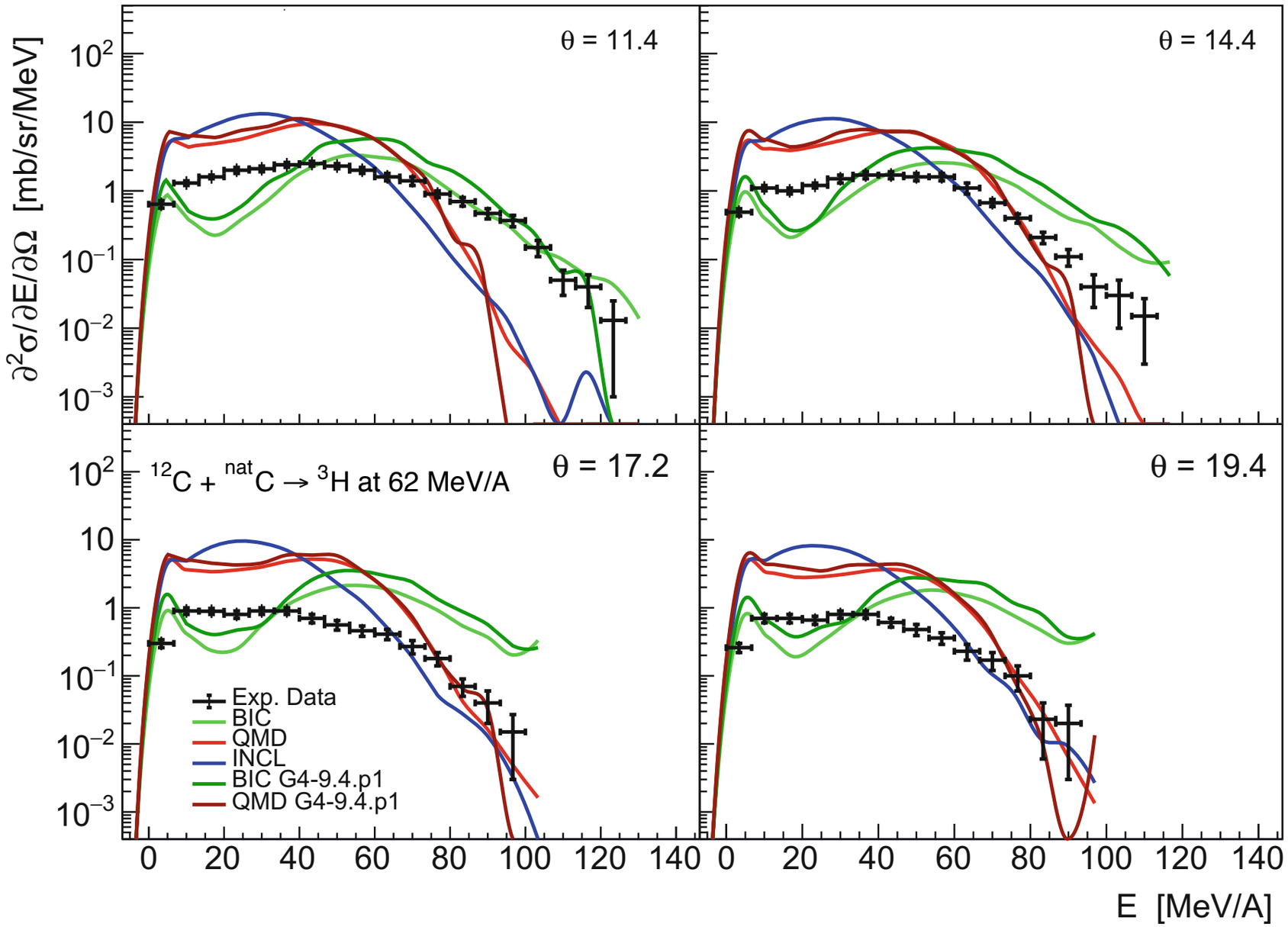

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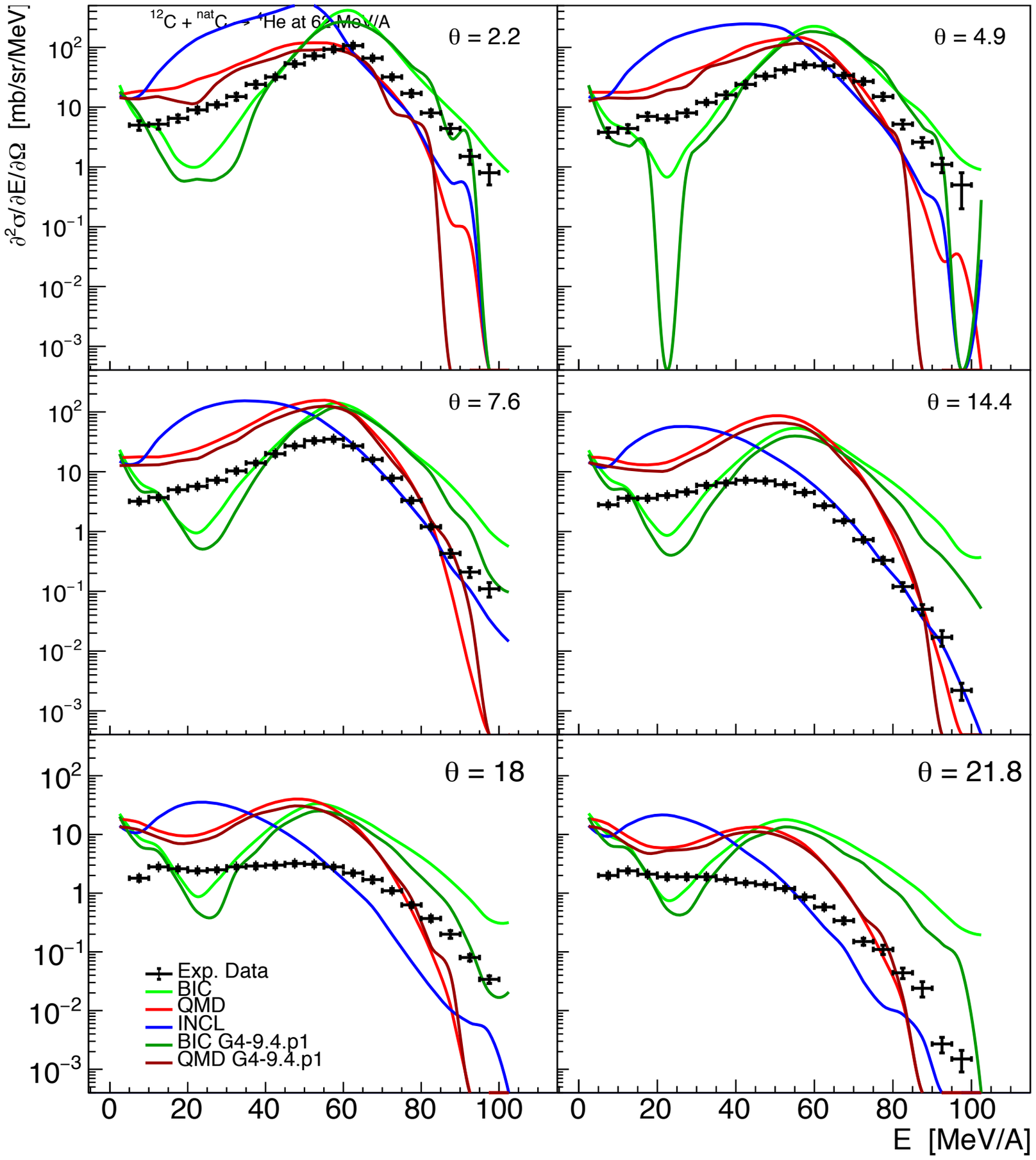
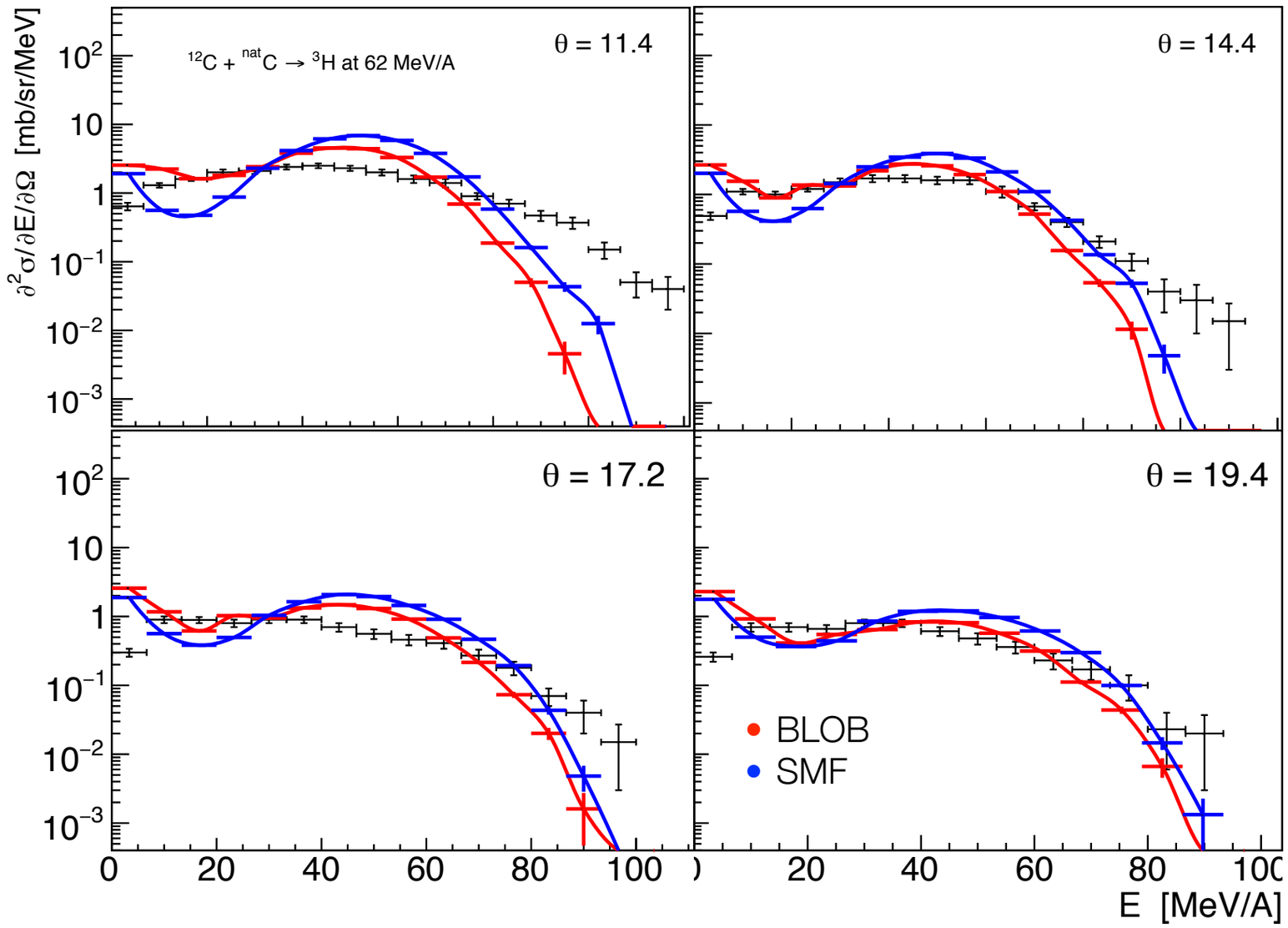


Interfacing SMF and BLOB to Geant4

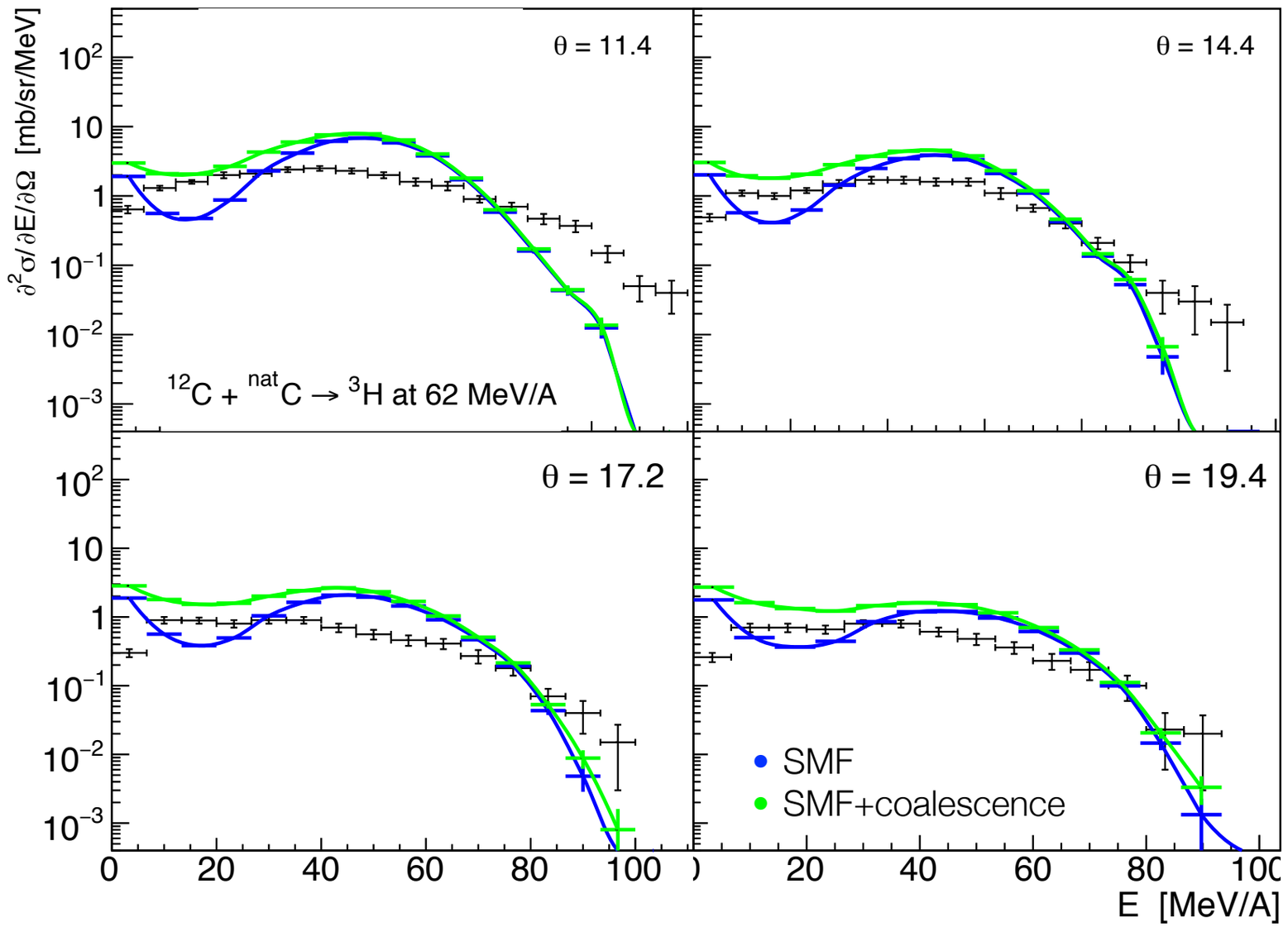
- SMF and BLOB had been interfaced with Geant4 and its de-excitation phase
- Dummy G4-model, loads the model results
- Similar results between SMF and BLOB



preliminary

Coalescence

- To insert more than two bodies correlation in an effective way, a dedicated coalescence phase has been implemented between SMF and the de-excitation phase



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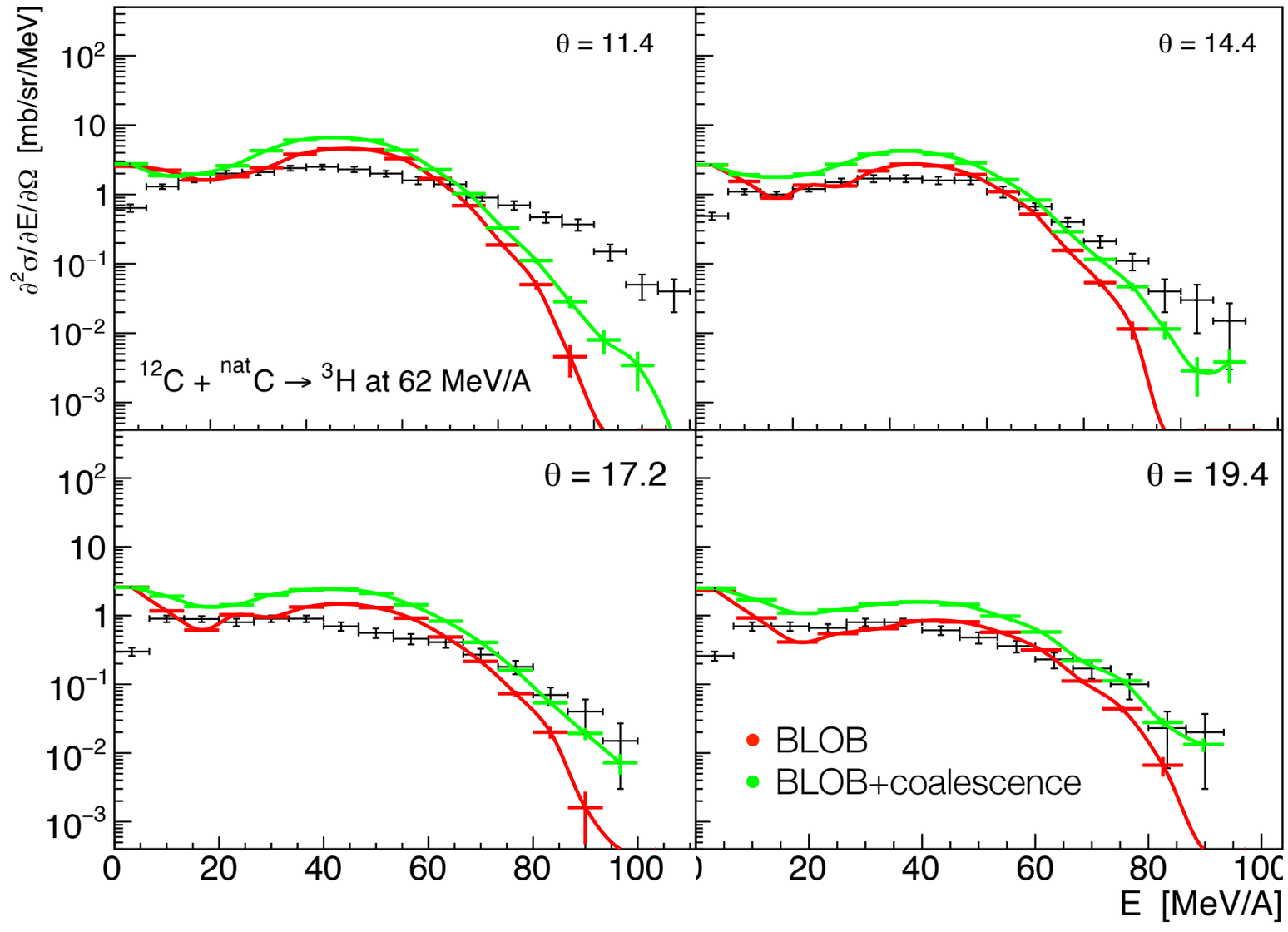
Coalescence

- Similar results with BLOB
- Coalescence produces high energy tritium



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Coalescence

- Mitigates the gap between projectile and target fragments

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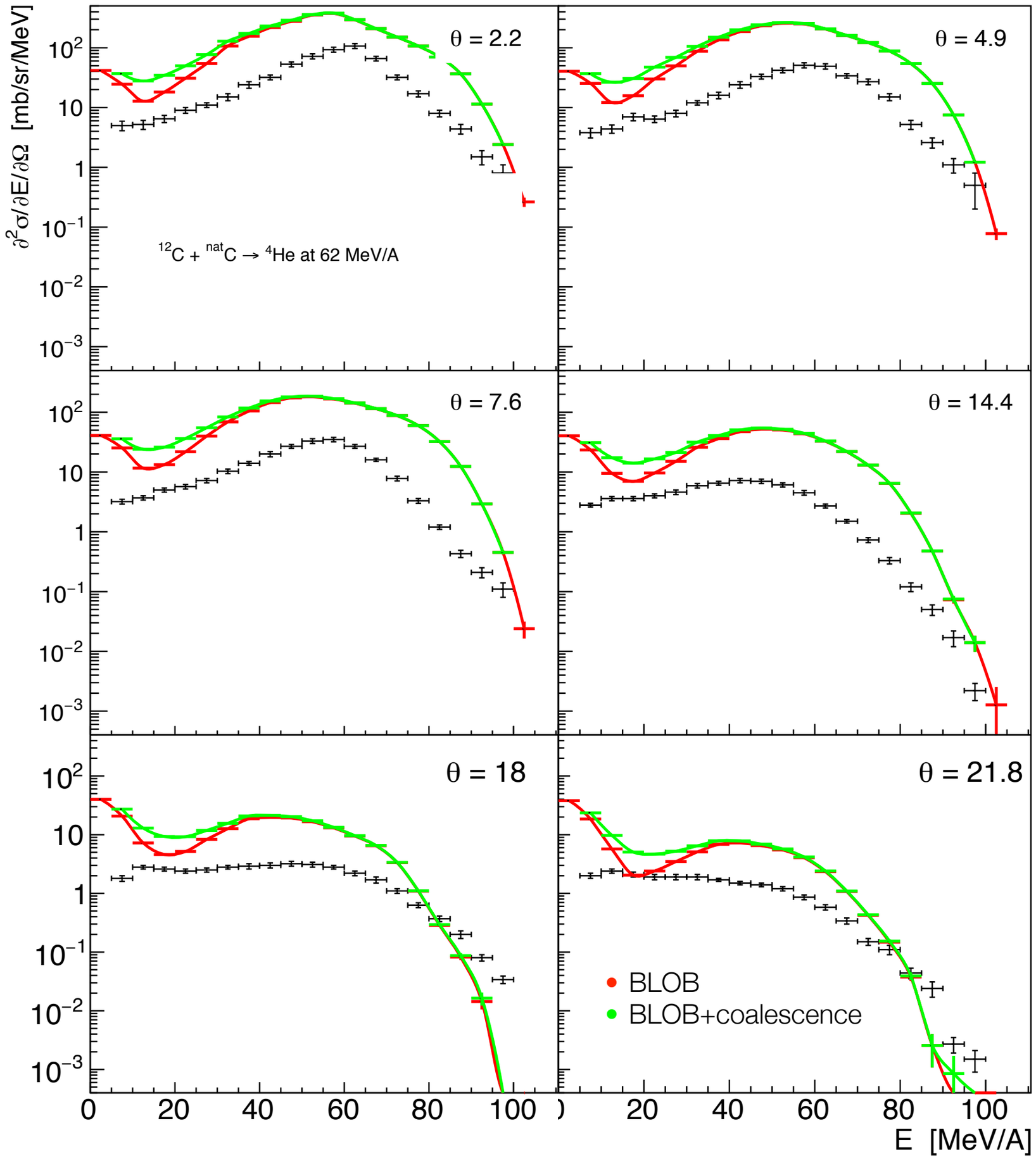
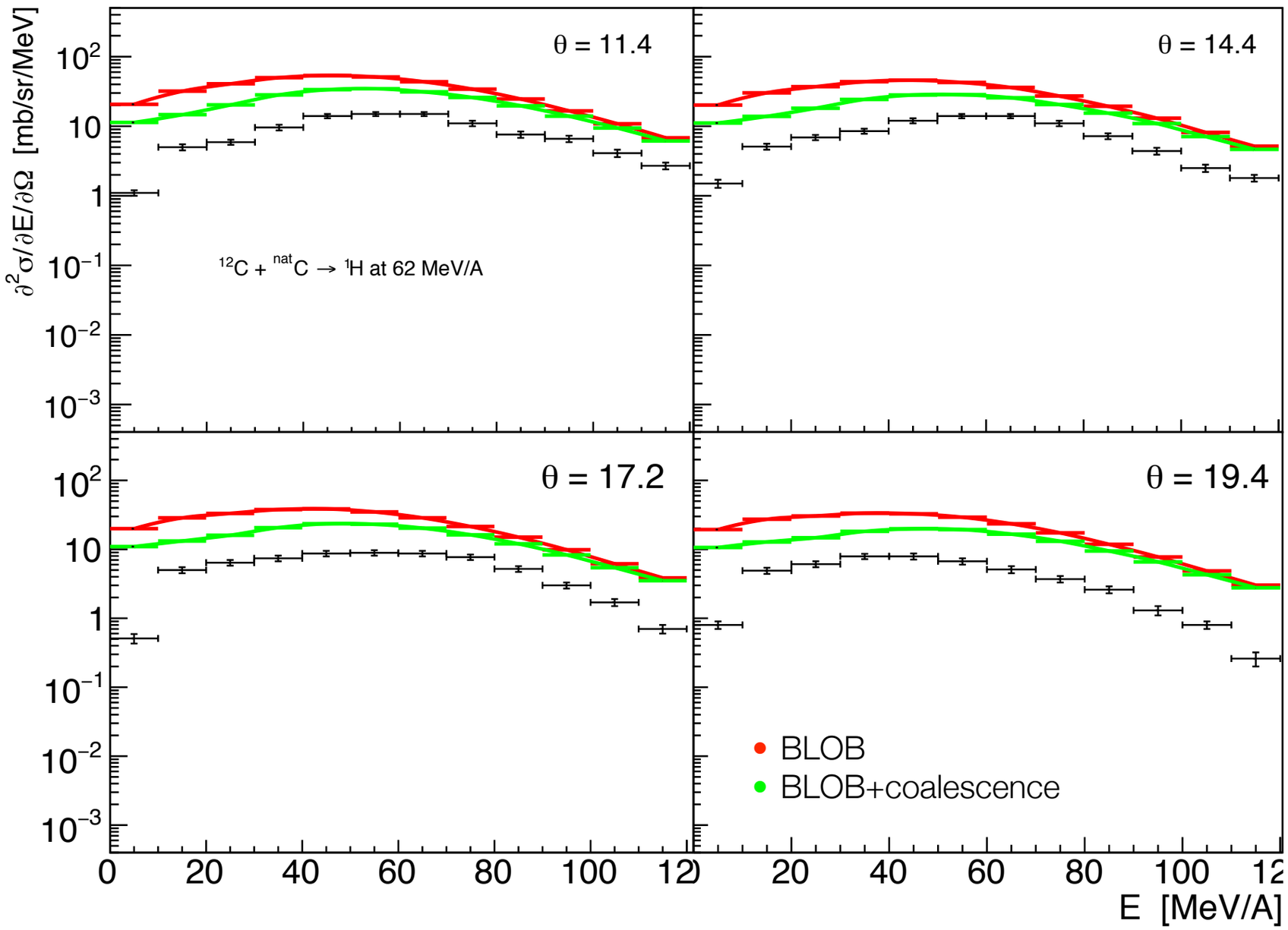


Coalescence

- Reduces the excess of proton



preliminary

Summary

- Geant4 is a multipurpose MC toolkit widely used for several kind of applications
- The models implemented in Geant4 are not so good in simulating nuclear fragmentation below 100 MeV/A
- GeNIALE aims at improving the Geant4 performances in nuclear fragmentation below 100 MeV/A
- We interfaced a dedicated model in collaboration with the theoreticians of LNS (Catania) and IPN (Orsay)
- A coalescence has been introduced
- The free parameters of the model and the coalescence have to be optimised

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Models already implemented in Geant4 for the entrance channel

- **Binary Intra-nuclear Cascade (BIC)** “participating” particles, are tracked in the nucleus. The interactions are between them and an individual nucleon of the nucleus.

- **Quantum Molecular Dynamics (QMD)** all the nucleons are considered as “participants”, scattering between them is included

- **Liège Intranuclear Cascade (INCL++)** The nucleons are modelled as a free Fermi gas in a static potential well. The particles are assumed to propagate along straight-line trajectories until an interaction

Models already implemented in Geant4 for the exit channel

- **Evaporation Model** associates the probability that a nucleus with A nucleons emits one of them, remaining with A-1 nucleons, to the probability that the produced nucleus, with A-1 nucleon, captures the nucleon in object

- **Generalized Evaporation Model (GEM)** same approach of the previous one, but it takes into account the emission of fragments heavier than α particles and uses a more accurate level density function, based on the Fermi gas model

- **Fermi Break-up** considers the decay of an excited light (Z<9 and A<17) nucleus into several stable fragments. The break-up probabilities for each decay channel are calculated by considering the n-body phase space distribution