Antisymmetrized Molecular Dynamics Calculations for Heavy-Ion Collisions

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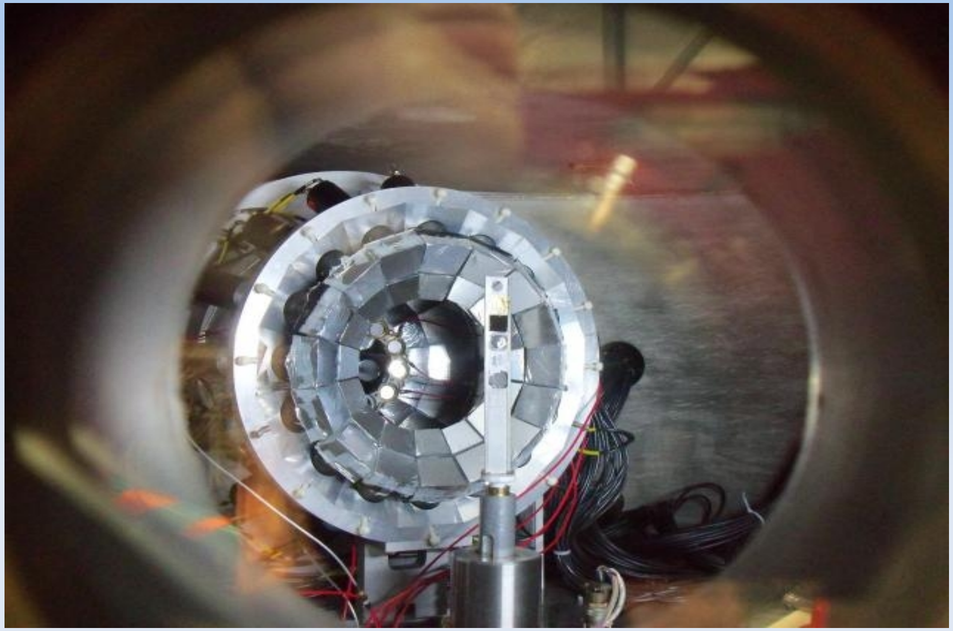
- Introduction and motivation
- Antisymmetrized Molecular Dynamics (AMD)
- Preliminary results
- Conclusion

Introduction and motivation

- Heavy-Ion collisions at intermediate energies using the multidetector HERACLES
- Why intermediate energies?
  - 5-200 AMeV
  - Phase transition liquid-gas
    - Multifragmentation (IMF with Z>2)
  - Transition between low energies and relativistic energies
    - Competing mechanisms

      -Mean field -Stochastic collisions
  - Nucleonic dynamics

- HERACLES description
- See Jérôme Gauthier presentation for more details



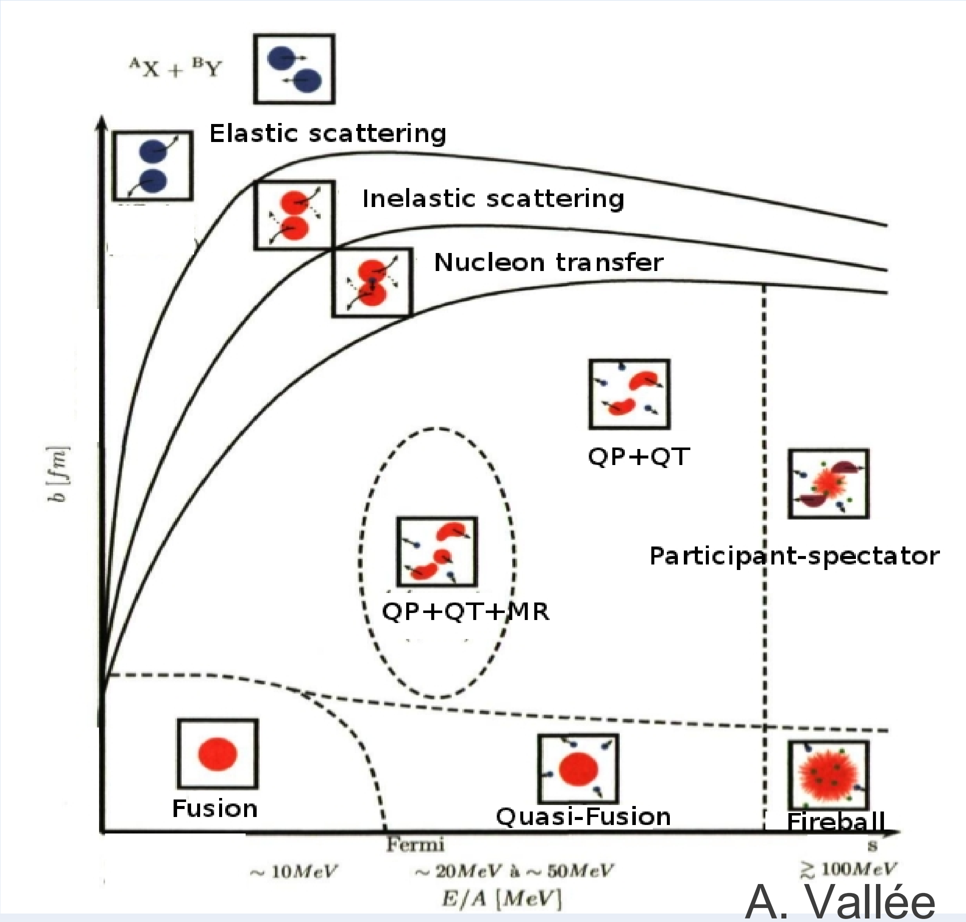
Ring No.	ΔE detector	E detector	θ_{min} (°)	θ_{max} (°)	N	$\Delta\phi$ (°)	ΔE thickness (μm)
0	BC408	BaF_2	4.8	6	6	15	100
1	Si	CsI(Tl)	6	10	8	18	50
2	BC408	BC444	10.5	16	16	22.5	100
3	BC408	BC444	16	24	16	22.5	100
4	-	CsI(Tl)	24	34	16	22.5	-
5	-	CsI(Tl)	34	46	16	22.5	-

- Dynamic of heavy-ion collisions at intermediate energies

QP=Quasi-Projectile

QT=Quasi-Target

MR=Mid-Rapidity



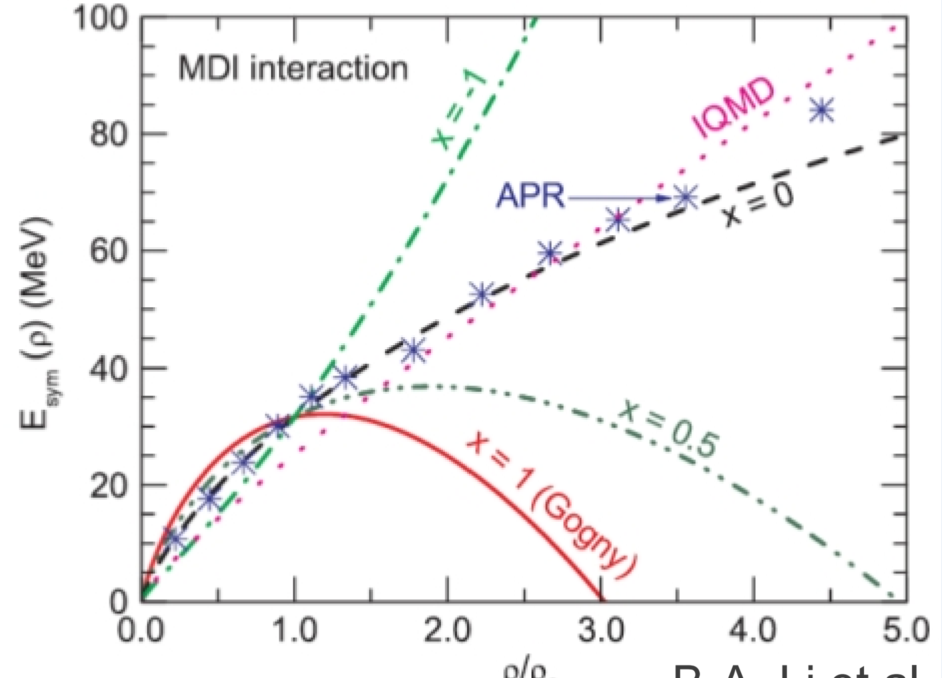
A. Vallée

- Equation of state (EOS)
  - $E(\rho, \delta) = E(\rho, \delta=0) + E_{sym}(\rho) \cdot \delta^2 + \ldots$

    $\delta = (\rho_n - \rho_p)/\rho$

    ρ_n = neutron density

    ρ_p = proton density



B-A. Li et al.

- TRIUMF ISAC-II Rare-Isotope beams
  - Rare-Isotope beams are available up to 15 AMeV

- July 2011 experiment

$^{25}Na+^{12}C$ at 9.23 AMeV   N/Z=1.27

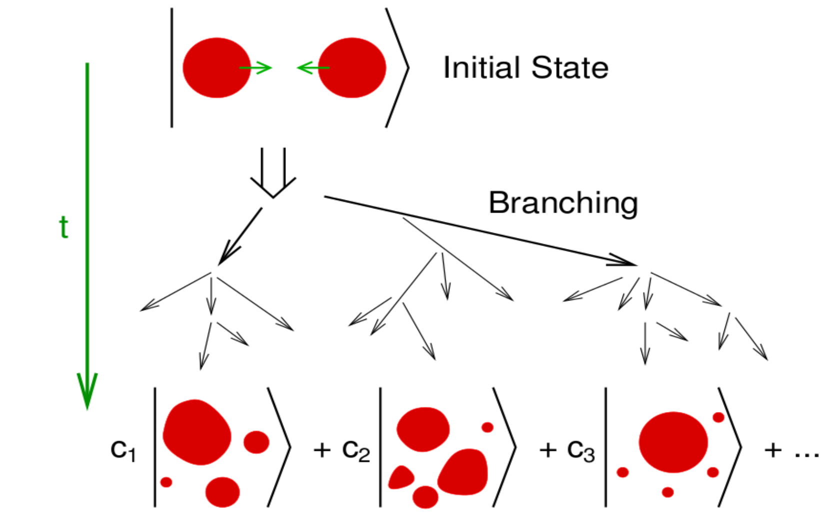
$^{25}Mg+^{12}C$ at 9.23 AMeV   N/Z=1.08

AMD

- Transport models
  - Microscopic one-body
    - Time-Dependent Hartee-Fock (TDHF)
      - Mean field only
      - Difficulty to produce fragments distribution and fusion at intermediate energy
    - Boltzmann-Uehling-Uhlenbeck (BUU)
      - Mean field and NN collision
      - Not applicable below 10-15 AMeV

- Microscopic N-body
  - Classic molecular dynamics
    - Follow motion of N body using the Hamiltonian
    - Don't respect Pauli principle
  - Quantum molecular dynamics (QMD)
    - Respect Pauli principle using BUU-type two-body collisions
  - Antisymmetrized molecular dynamics (AMD)
    - Build to respect Pauli principle

- AMD details
  - Nucleon are represented by wave packet with fixed width
  - Antisymmetrization of wave functions
  - A stochastic BUU-type NN collision algorithm is used
  - Quantum Branching



A. Ono et al.

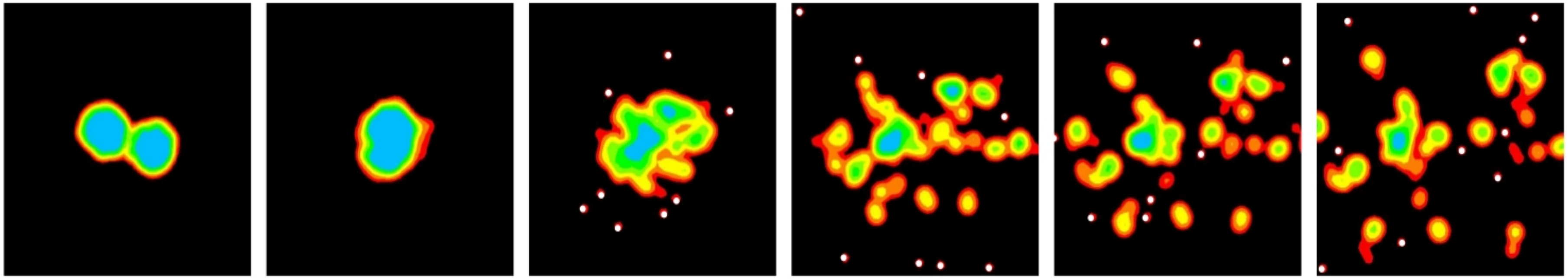
- AMD wave function and stochastic equation of motion

$$|\Phi(Z)\rangle = \det_{ij}\left[\exp\left\{-\nu\left(r_j - \frac{Z_i}{\sqrt{\nu}}\right)^2\right\}\chi_{\alpha_i}(j)\right]|\varphi\rangle$$

$$Z_i = \sqrt{\nu}D_i + \frac{i}{2\hbar\sqrt{\nu}}K_i$$

$$\frac{d}{dt}Z_i = \{Z_i, \mathrm{H}\} + \Delta Z_i(t) + (NN\ collisions)$$

- Schematic time evolution of a Xe + Sn at 50 AMeV reaction simulated by AMD



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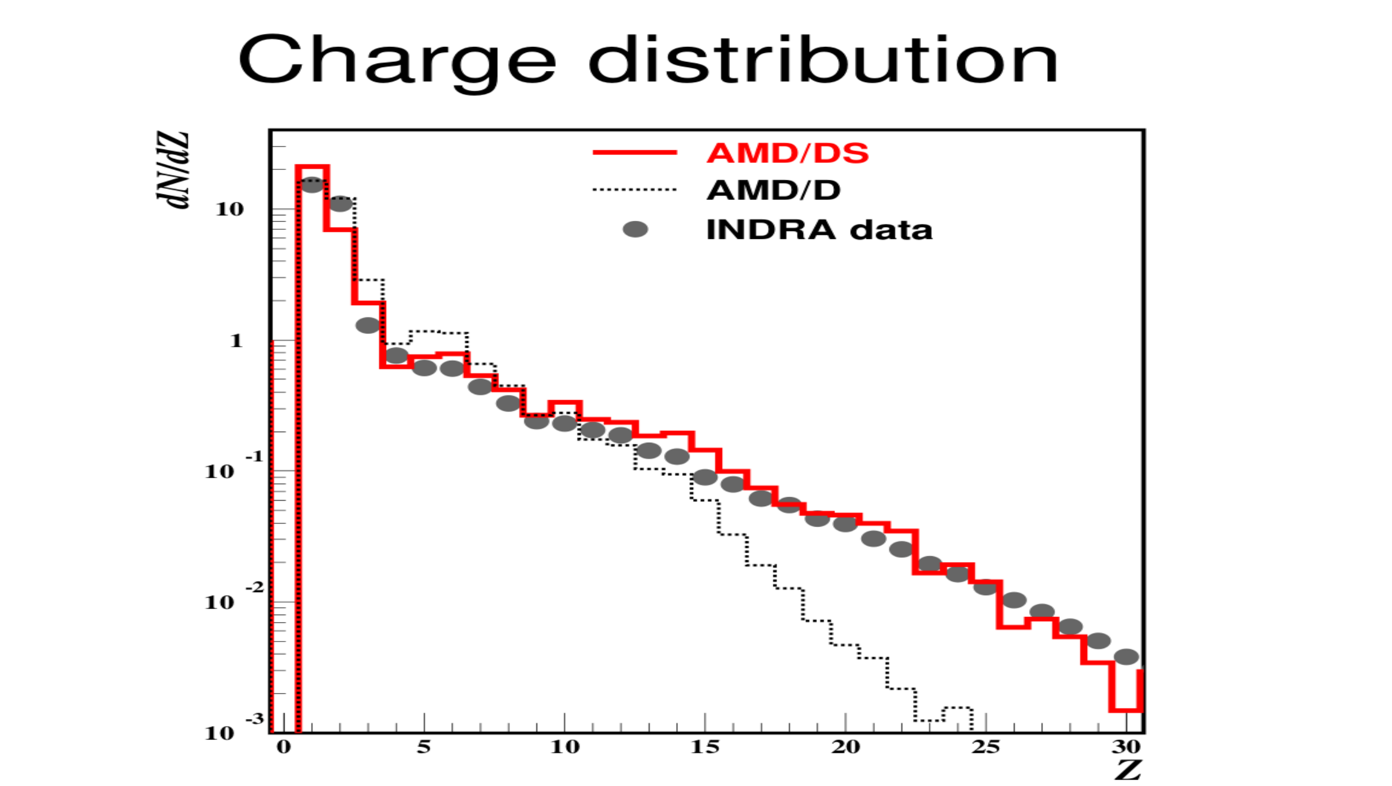
- AMD results compared with INDRA data for Xe + Sn at 50 AMeV

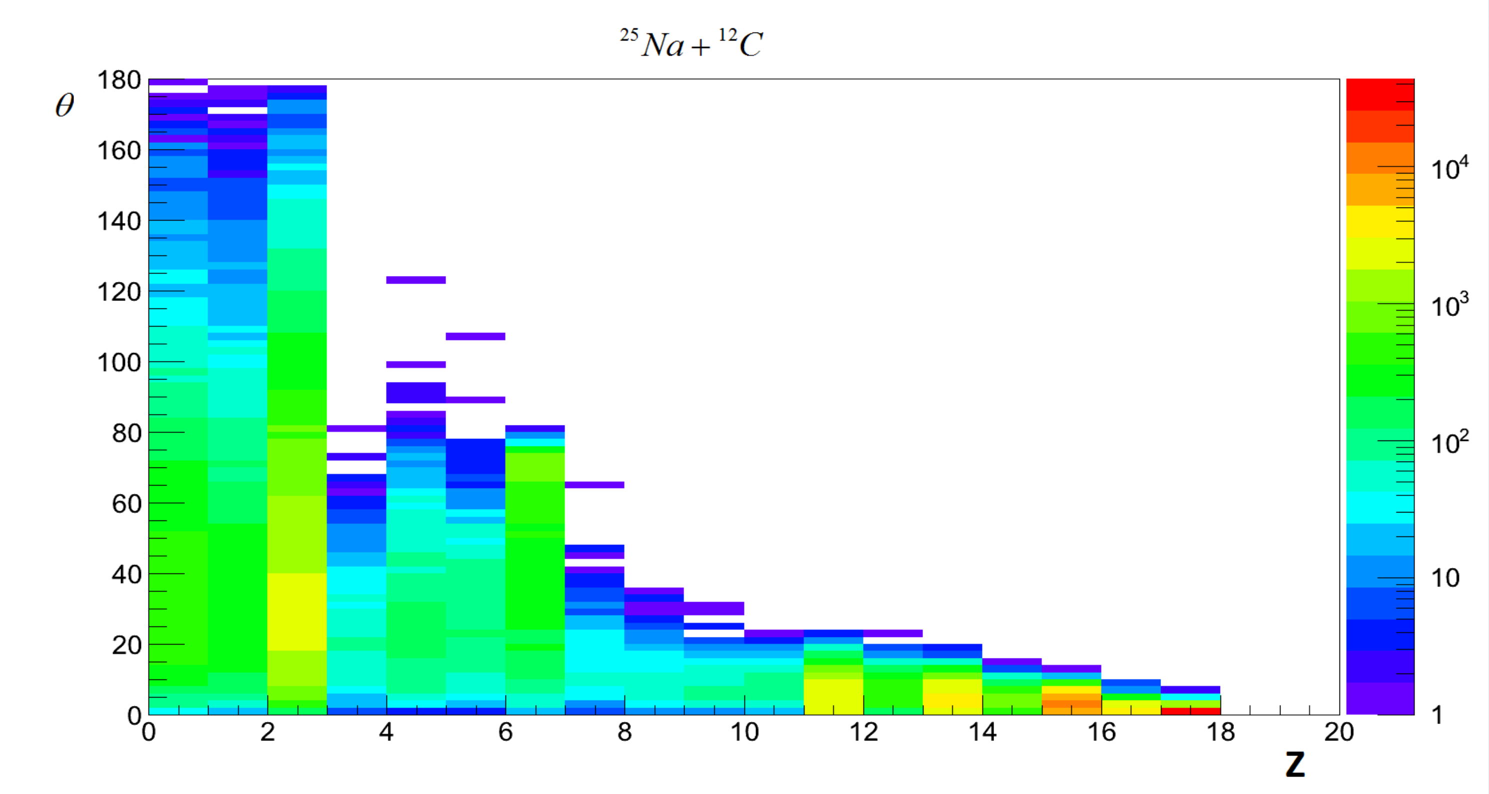


A.Ono et al.

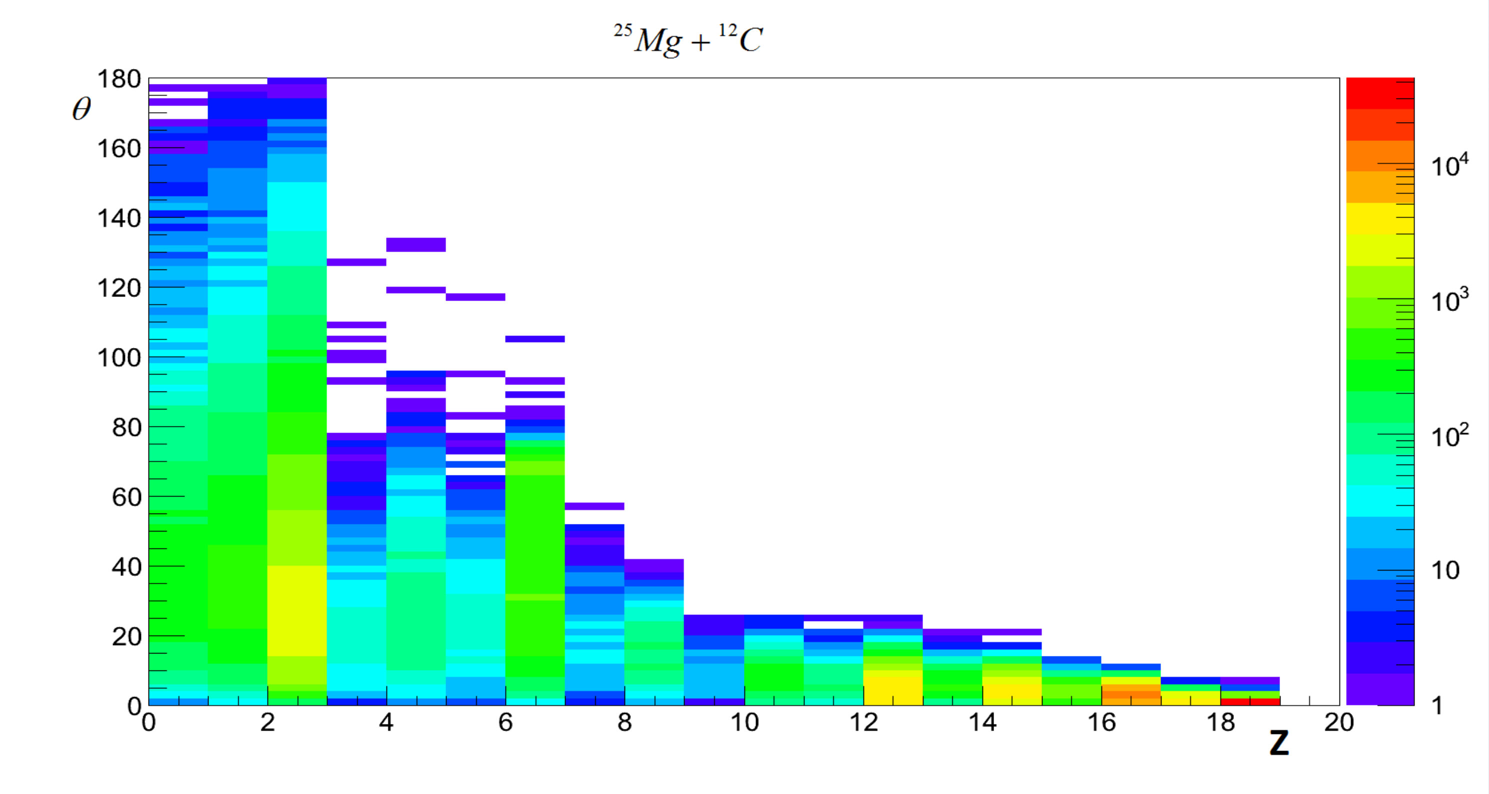
Preliminary Results

- Simulation summary
  - 115 000 events simulated for ^{25}Na + ^{12}C and ^{25}Mg + ^{12}C at 9.23 AMeV
  - Impact parameter 0< b <7 (fm)
  - Freeze-out at t=300 fm/c and dt=0.75 fm/c
  - Standard Gogny interaction
  - 24 hours of compute time on 320 cores (Colosse)

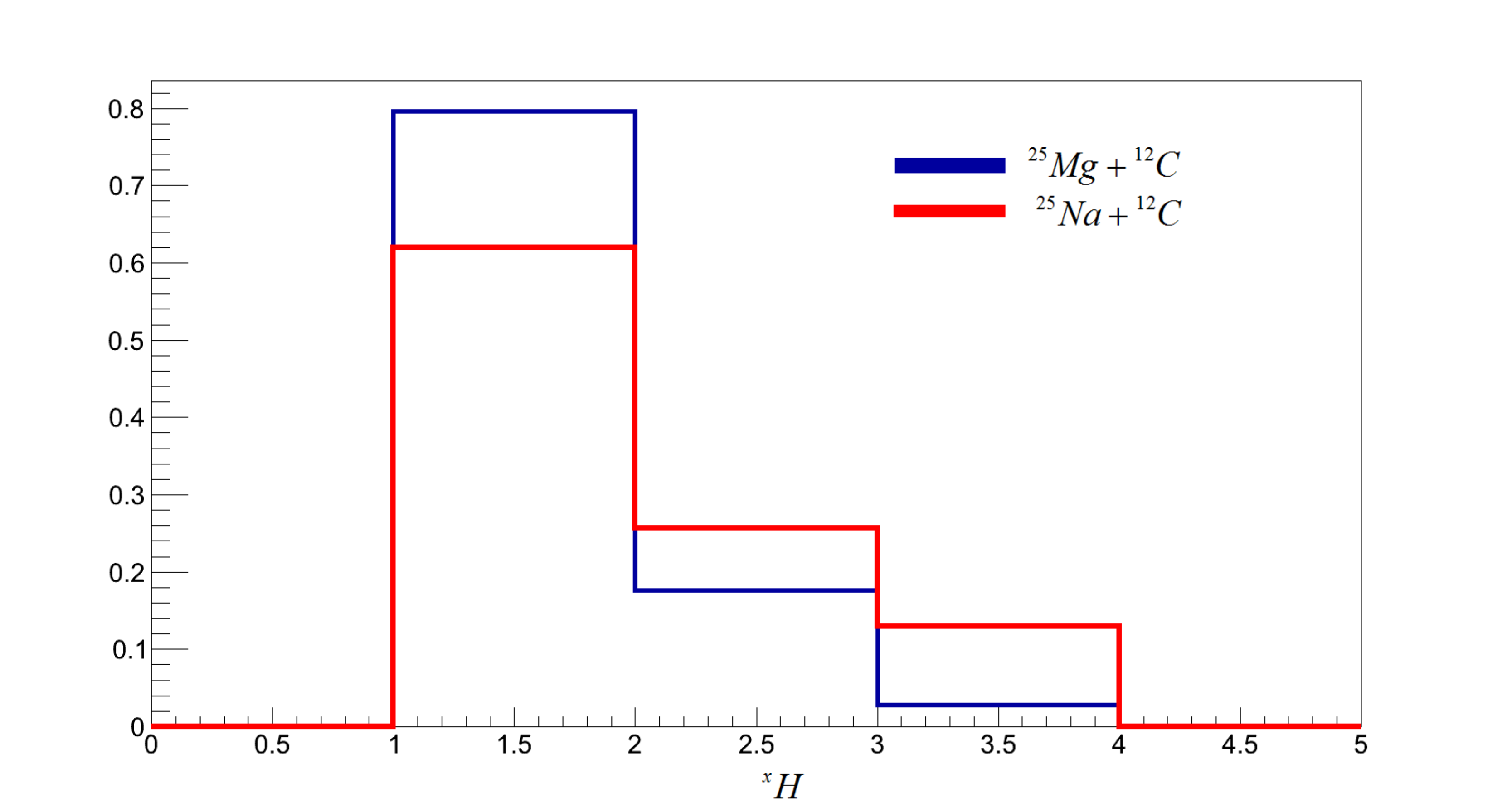
- Fragments distribution at freeze-out t=300 fm/c $^{25}Na + ^{12}C$ at 9.23 AMeV



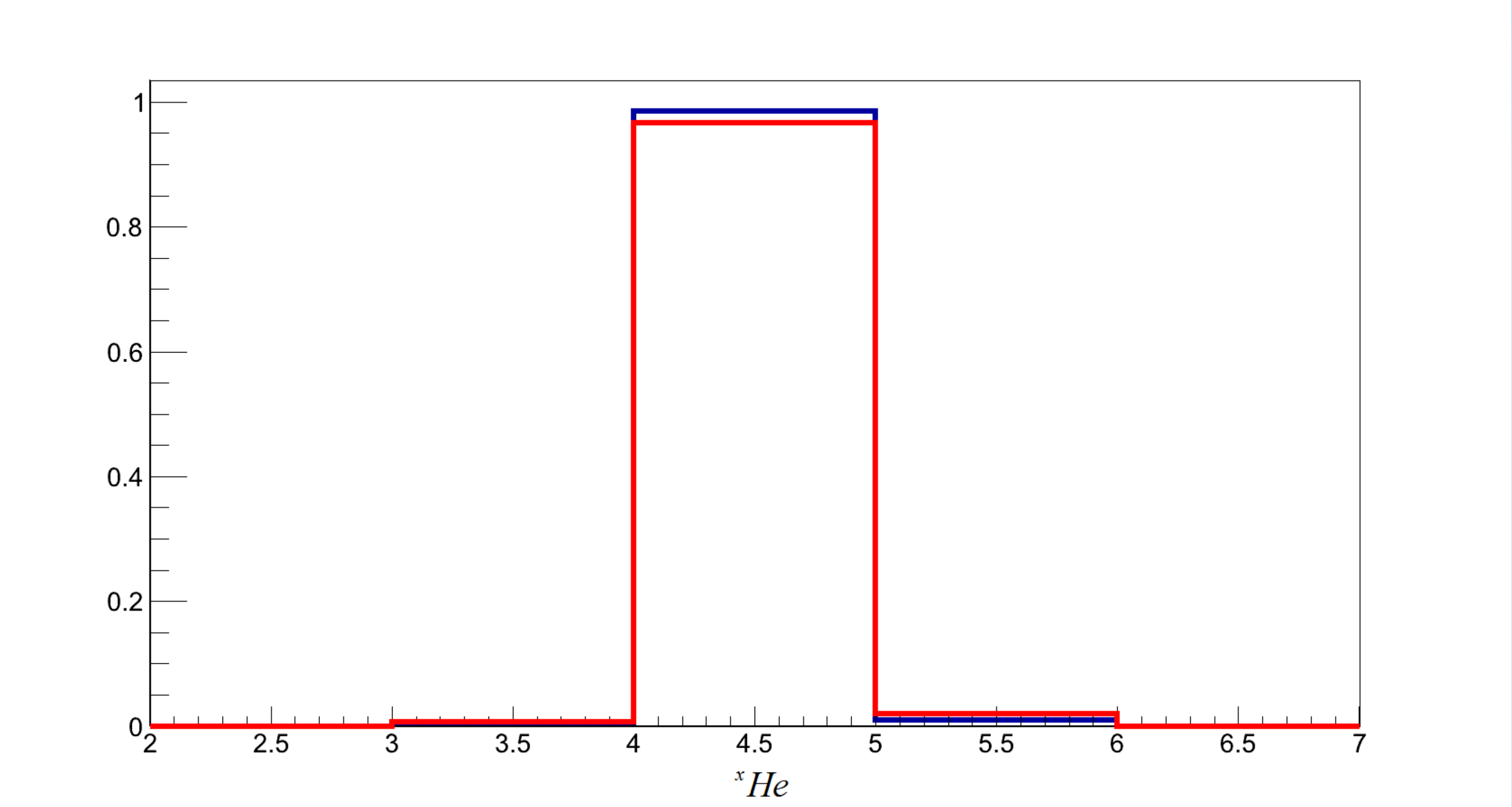
- Fragments distribution at freeze-out t=300 fm/c
$^{25}Mg + {}^{12}C$ at 9.23 AMeV



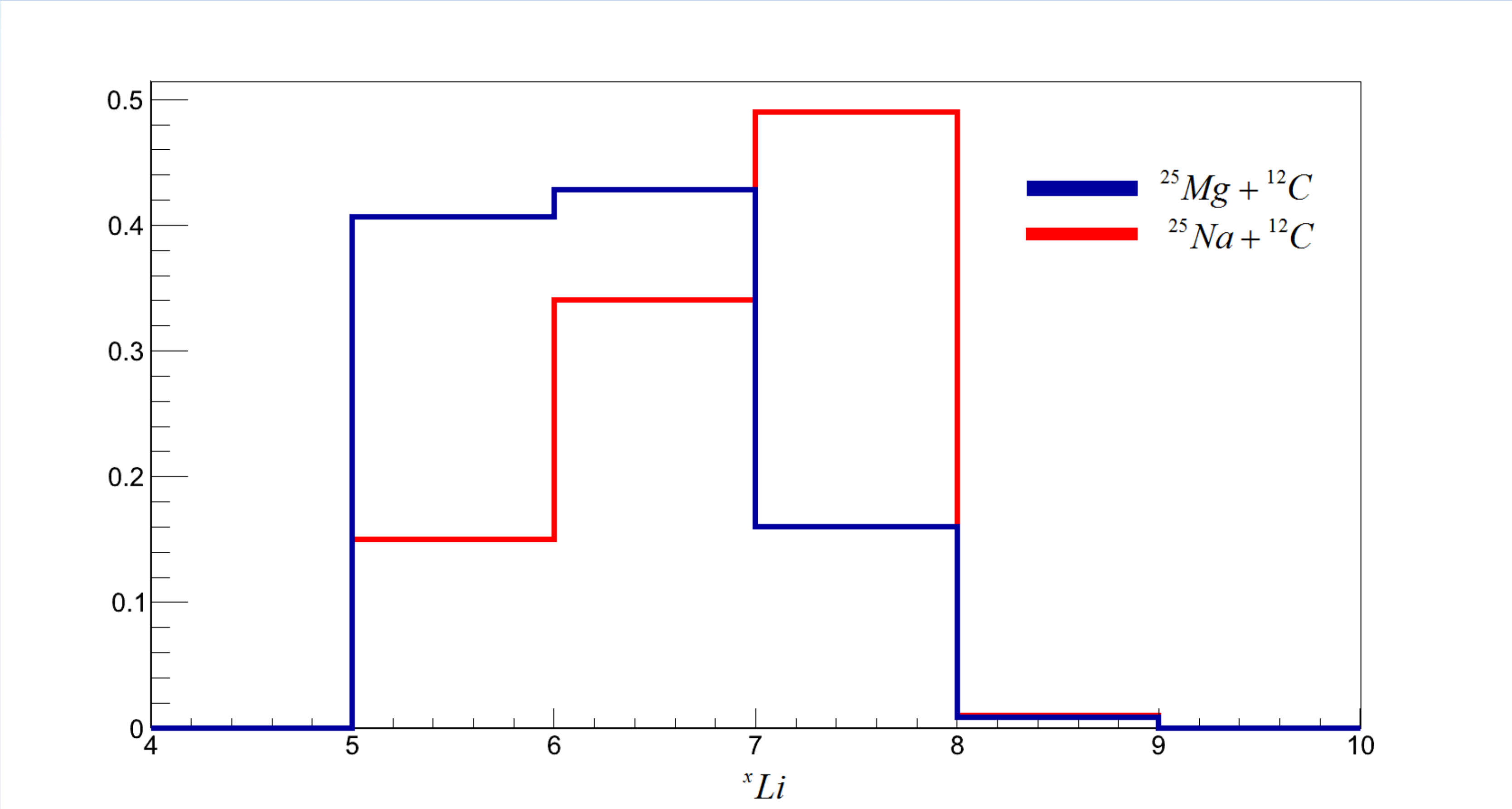
- Isotope distributions at t=300 fm/c - H



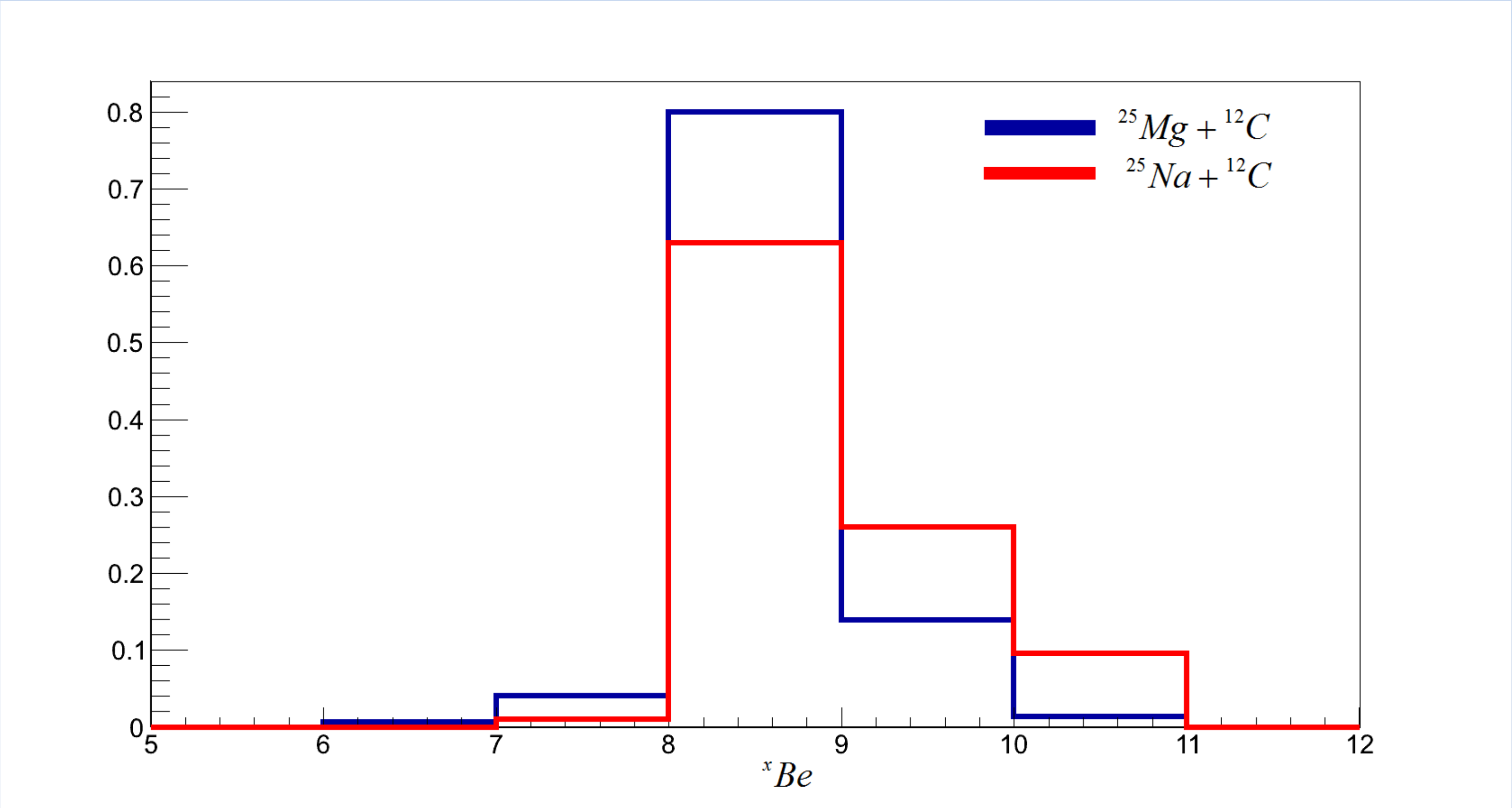
- Isotope distributions at t=300 fm/c - He



- Isotope distributions at t=300 fm/c - Li



- Isotope distributions at t=300 fm/c - Be



Conclusion

- Still a lot of work to do
  - Statistical decay of fragments
  - Test other interactions (Skyrme, Gogny-As)
  - Compare with experimental data
- Identification and calibration is already done on experimental data