Recent development of nucleus-nucleus and low energy neutron interactions in Geant4

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QMD

Forward Angle Spallation

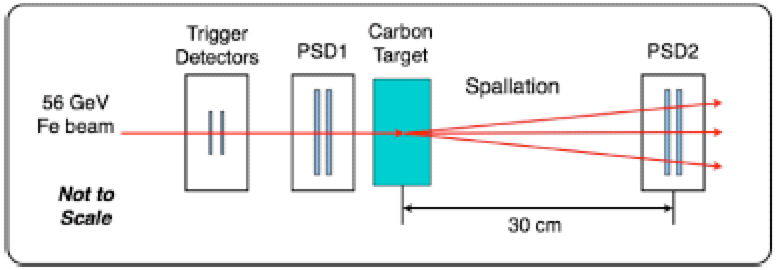


Fig. 1. Experimental setup for Zeitlin et al. [7] experiment. The trigger and PSD1 detectors are for measuring the energy and timing of the Fe ions, and the PSD2 detectors measure the energy deposition from the nuclear fragments.

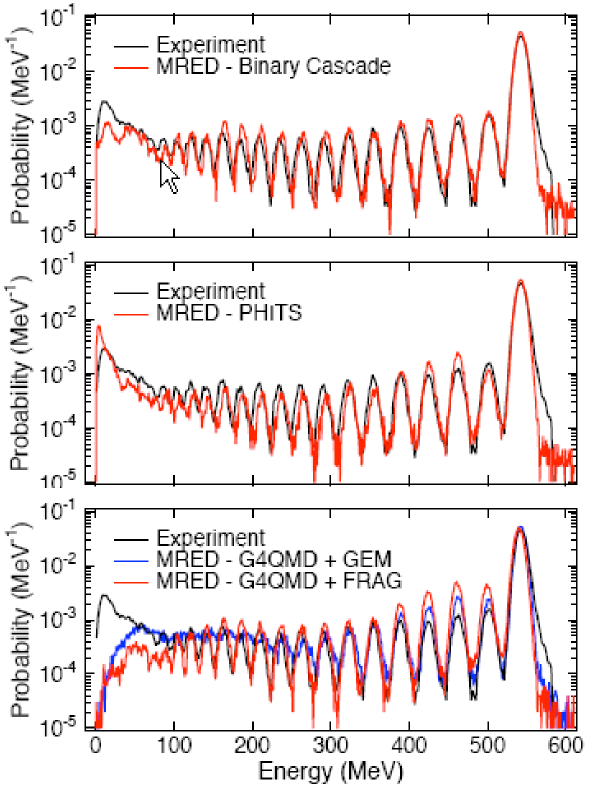
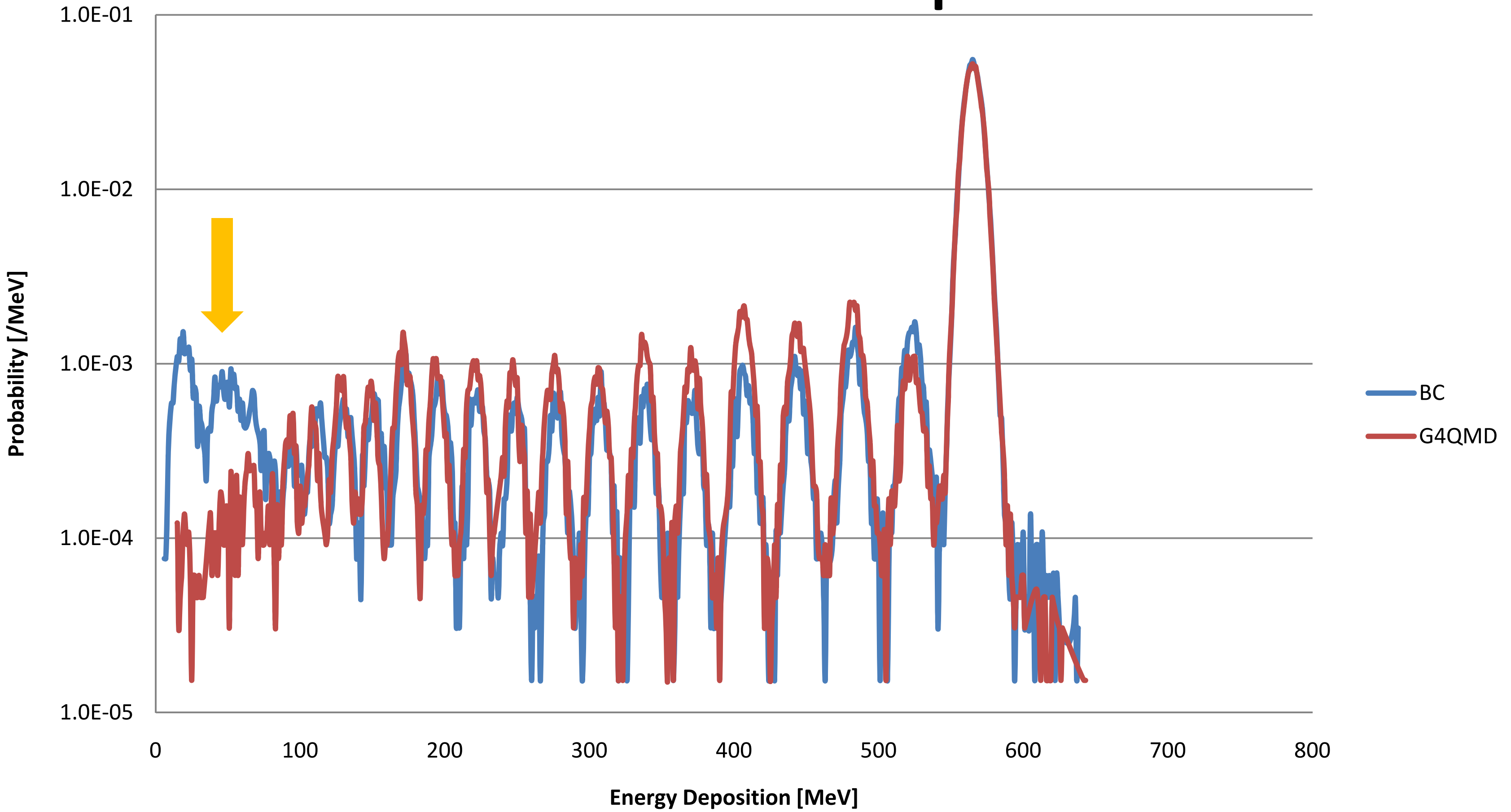


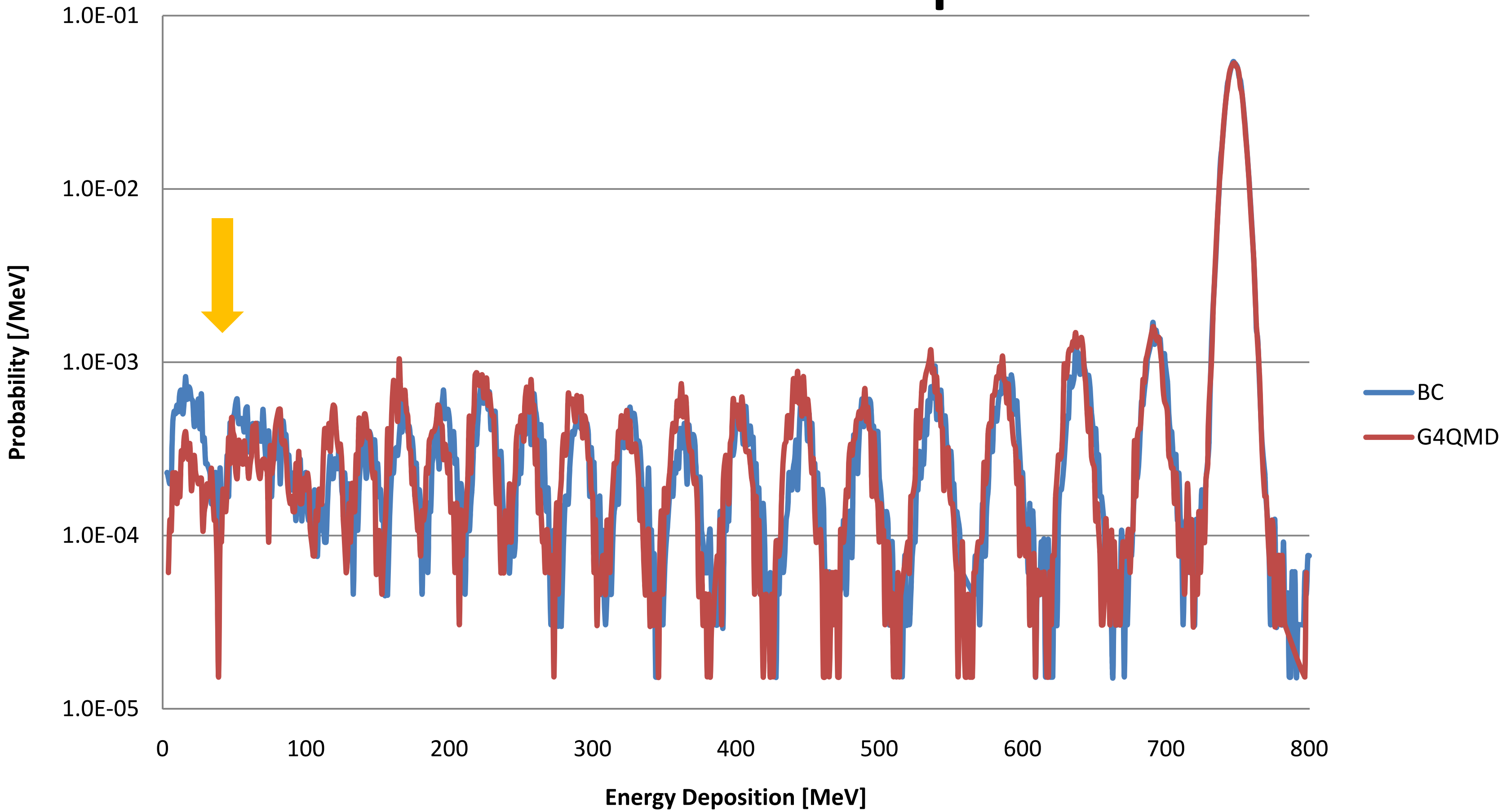
Fig. 2. Histogram of Zeitlin et al. experiment [12] and MRED simulations using the binary light-ion cascade model (top), The PHITS model (middle), and the G4QMD (bottom) with the GEM and Frag models. The rightmost peak corresponds to Fe ions, and each lower energy peak corresponds to lower Z fragments.

M.A. Clemens et al.,
IEEE TRANS, VOL. 56, 3158 (2009)

Forward Angle Spallation 1GeV/n 56Fe on Carbon Geant4 v.9.3.p01



Forward Angle Spallation 500MeV/n 56Fe on Carbon Geant4 v.9.3.p01



Indicate non covariant kinematics caused this trouble

Lorentz covariant dynamics approach (1)

- 8N-dimensional phase space

  6N configuration- and momentum-space + 2N Eigen time and energy
- Physical events are described as world lines in the 6n-dimensional phase space
- 8N-dimensional phase space should be constrained 2n-1 degree of freedom and have 6N+1(grobal timeτ) degree of freedom

- N mass-shell constraints

$$H_i = p_i^2 - m_i^2 - V_i = 0$$

- And N-1 constraints which connect the relative times of the particles

$$\chi_i = \sum_{j \neq i} g_{ij} p_{ij} q_{ij} = 0$$

$$q_{ij} = q_i - q_j, \quad p_{ij} = p_i + p_j, \quad g_{ij} = \exp\left(q_{ij}^2 / L \right) q_{ij}^{-2}$$

Lorentz covariant dynamics approach (2)

- Hamiltonian

$$H = \sum_{i=1}^{N} \lambda_i H_i + \sum_{i=1}^{N-1} \delta\mu_i \chi_i$$

- Equations of motion

$$\frac{dq_j}{d\tau} = \frac{\partial H}{\partial p_j} = 2\lambda_j p_j - \sum_{i=1}^{N} \lambda_i \frac{\partial V_i}{\partial p_j}$$

$$\frac{dp_j}{d\tau} = -\frac{\partial H}{\partial q_j} = \sum_{i=1}^{N} \lambda_i \frac{\partial V_i}{\partial q_j}$$

with the coefficients λ_i

Lorentz covariant dynamics approach (3)

- And λ_i is

$$\lambda_j \approx -\frac{\partial \chi_N}{\partial \tau} S_{Ni}$$

$$\left(S^{-1}\right)_{ij} \equiv \left\{H_i, \chi_j\right\}_{\text{Poisson bracket}}$$

- In order to solve the equations of motion one needs to calculate the coefficients λ_i. For their calculation the matrix S^{-1} must be inverted.

Reference

Poincaré invariant Hamiltonian dynamics: Modelling multi-hadronic interactions in a phase space approach, H. Sorge, H. Stocker and W. Greiner *Ann. Phys*. **192**, 266 1989

Microscopic Models for Ultrarelativistic Heavy Ion Collisions S. A. Bass et al., *Prog. Part. Nucl. Phys*. **41**, 225 1998

However, recently developer of JQMD group issued a new paper

- "In high-energy reactions, two-body collisions are dominant; the purpose of the Lorentz-covariant formalism is only to describe relatively low-energy phenomena between particles in a fast-moving medium. Therefore, we assume a simpler form for the time fixations, namely we set the time coordinates of all the particles to be the same. "

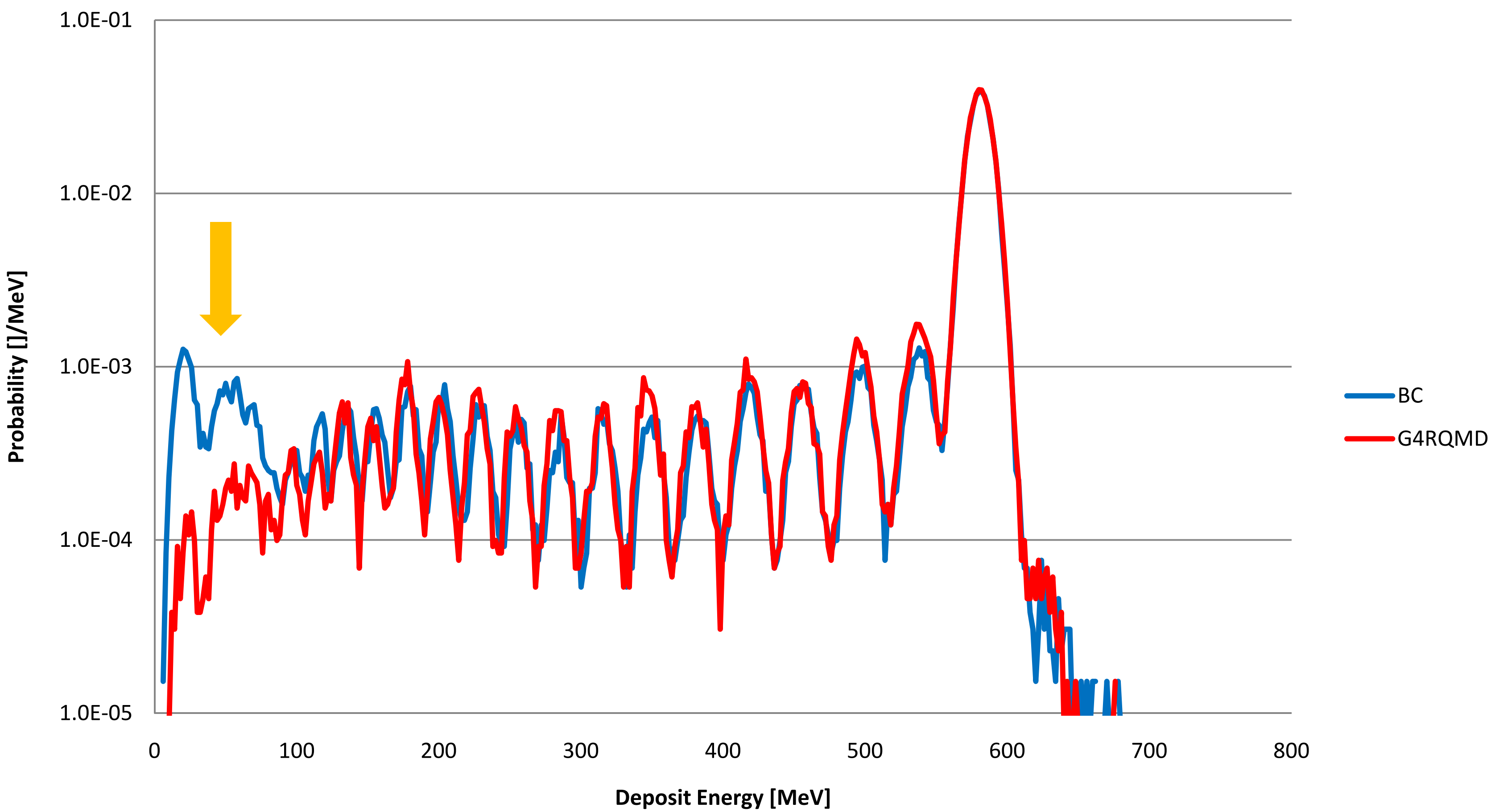
$$\phi_{i+N} \equiv a \cdot (q_i - q_N) \quad (i = 1, 2 \ldots, N-1),$$

$$\phi_{2N} \equiv a \cdot q_N - t$$

- the invert matrix S is not required

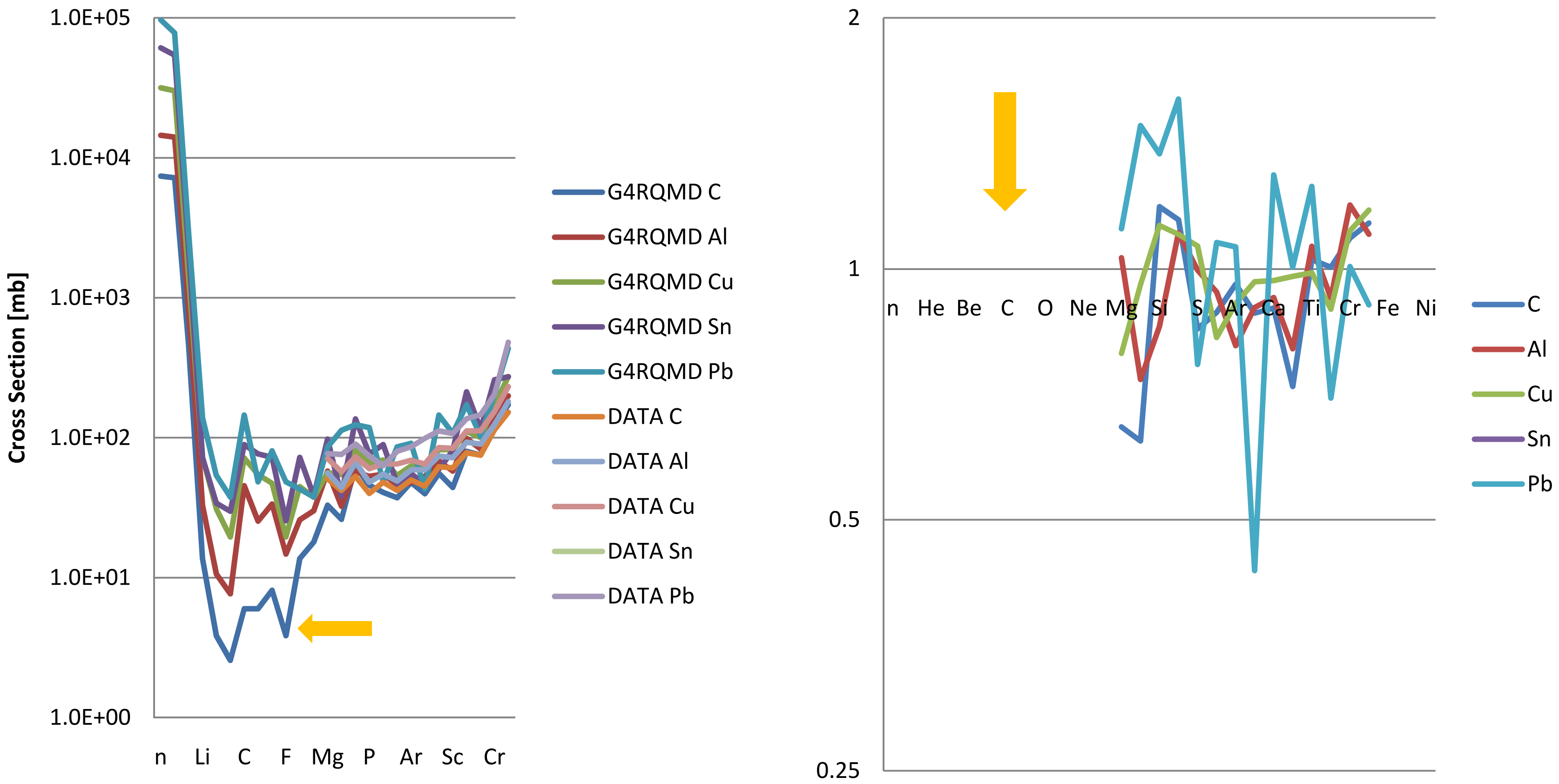
D. M ancusi et al.,
"Stability of nuclei in peripheral collisions in the JAERI quantum molecular dynamics model"
PHYSICAL REVIEW C **79,** 014614 (2009)

Forward Angle Spallation
1GeV/n 56Fe on Carbon

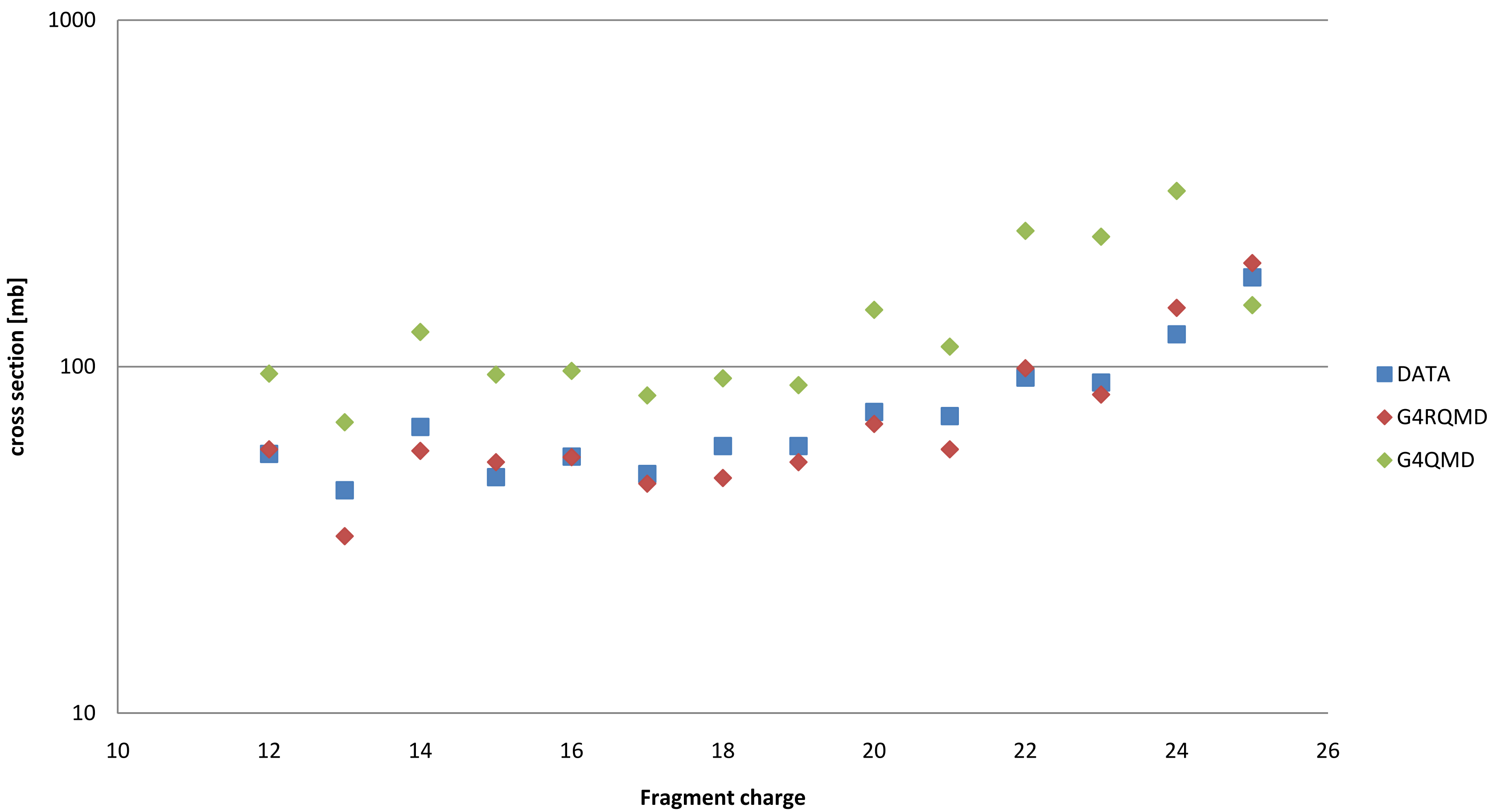


Projetile 1GeV/n 56Fe

G4RQMD/Ratio



Fe 1GeV/n on Al



Fe 1GeV/n on Al

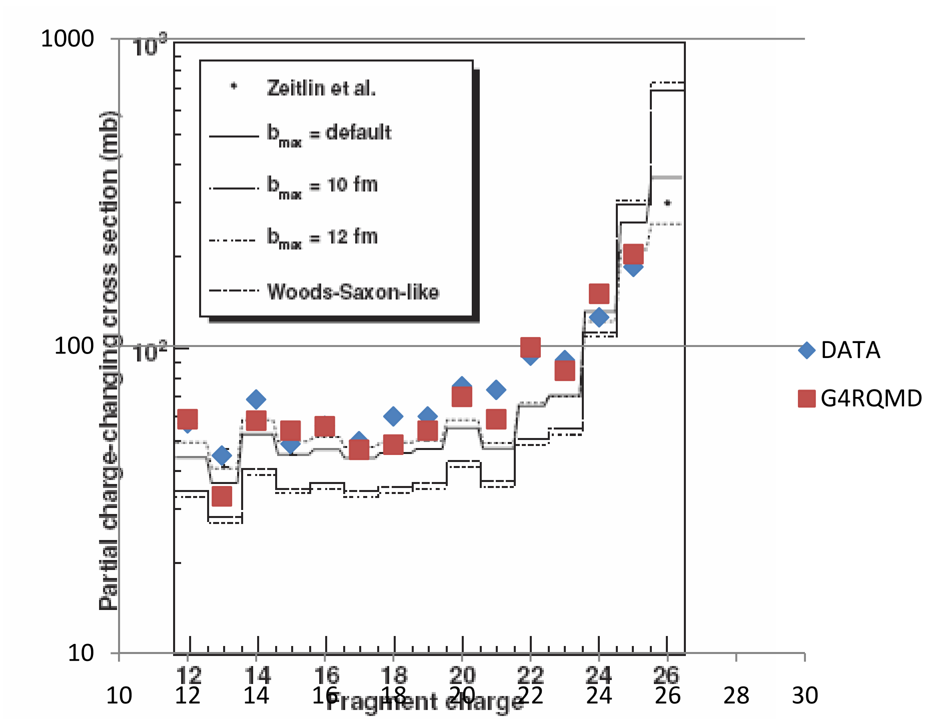


FIG. 6. Fragmentation cross sections for 1 *A* GeV ^{56}Fe on Al, calculated with different impact-parameter distributions. Experimental data are taken from Ref. [30].

D. M ancusi et al.,

"Stability of nuclei in peripheral collisions in the JAERI quantum molecular dynamics model"

PHYSICAL REVIEW C **79,** 014614 (2009)

Neutron HP

- Uncorrelated binary scattering in several channeles was corrected
- Release of v9.3 has a trouble
  - Please use v9.3.p01 or v9.4 beta
- nC->n+3alpha
  - See following slides

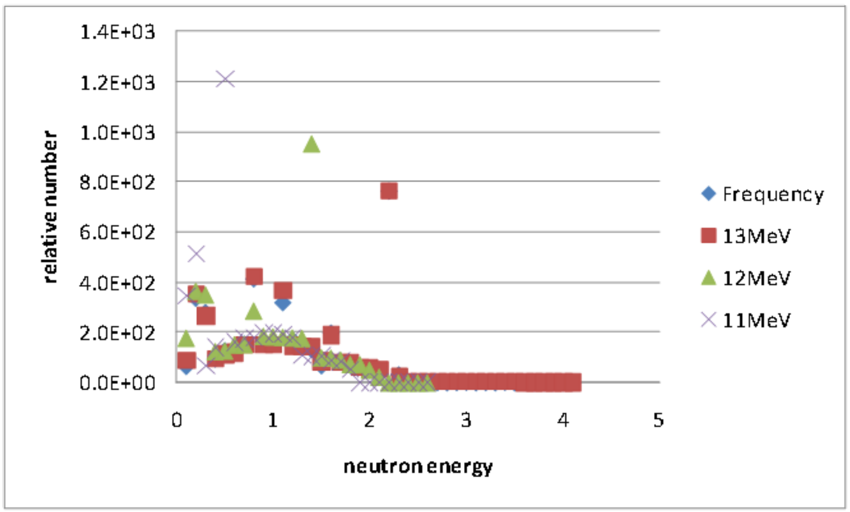
- C->n+3alpha
  A) n+a+a+a
  B) n+C*->n+a+a+a
     ->n+a+Be8-> n+a+a+a
  C) a+Be9*->a+n+a+a
  D) n+a+Be8->n+a+a+a
- Many ENDF files treated this channel internally in nC->nC*
- The Latest CENDL (v3.1) explicitly have this channel.

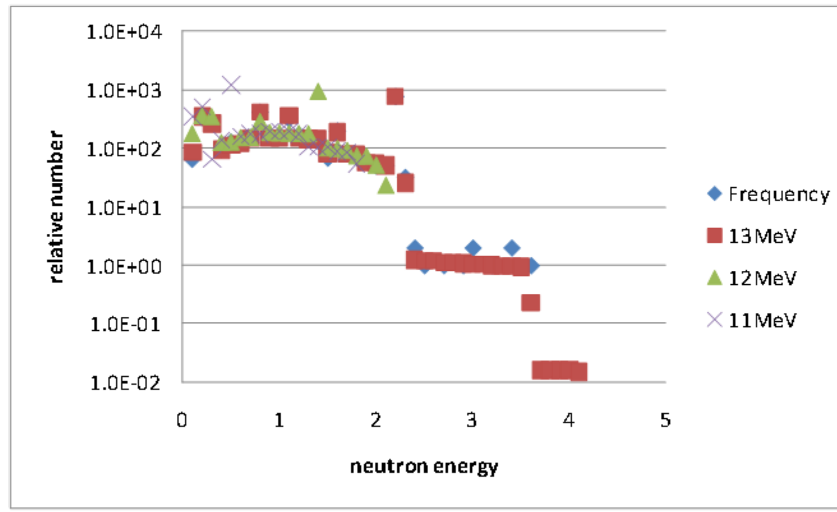
Neutron energy from n(12MeV) on C->n, 3alpha

Linear

Dist. in CM

Log





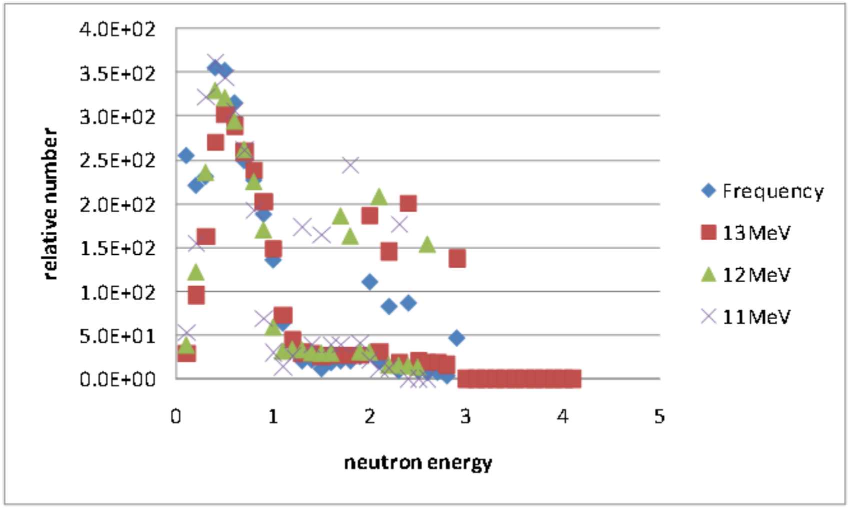
Frequency = simulation result

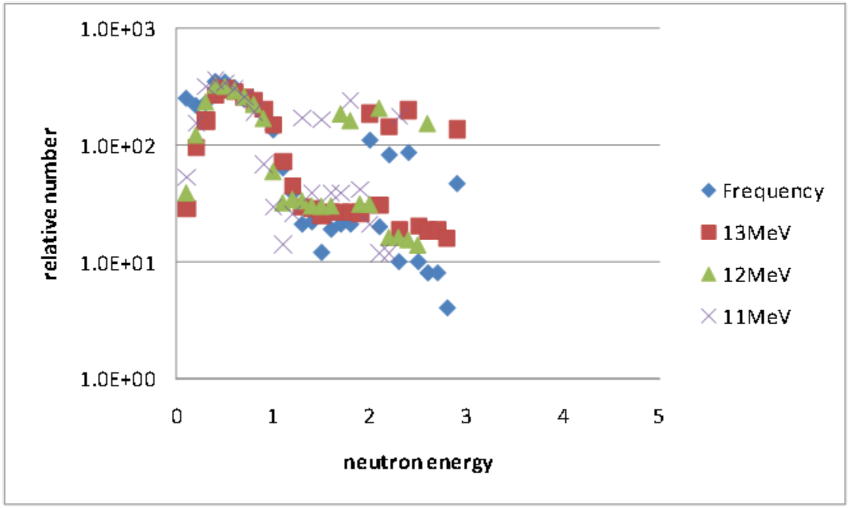
CENDL3.1 MF6MT23

LEP=1 for histogram

alpha energy from n(12MeV) on C->n, 3alpha

Linear Dist. in CM Log

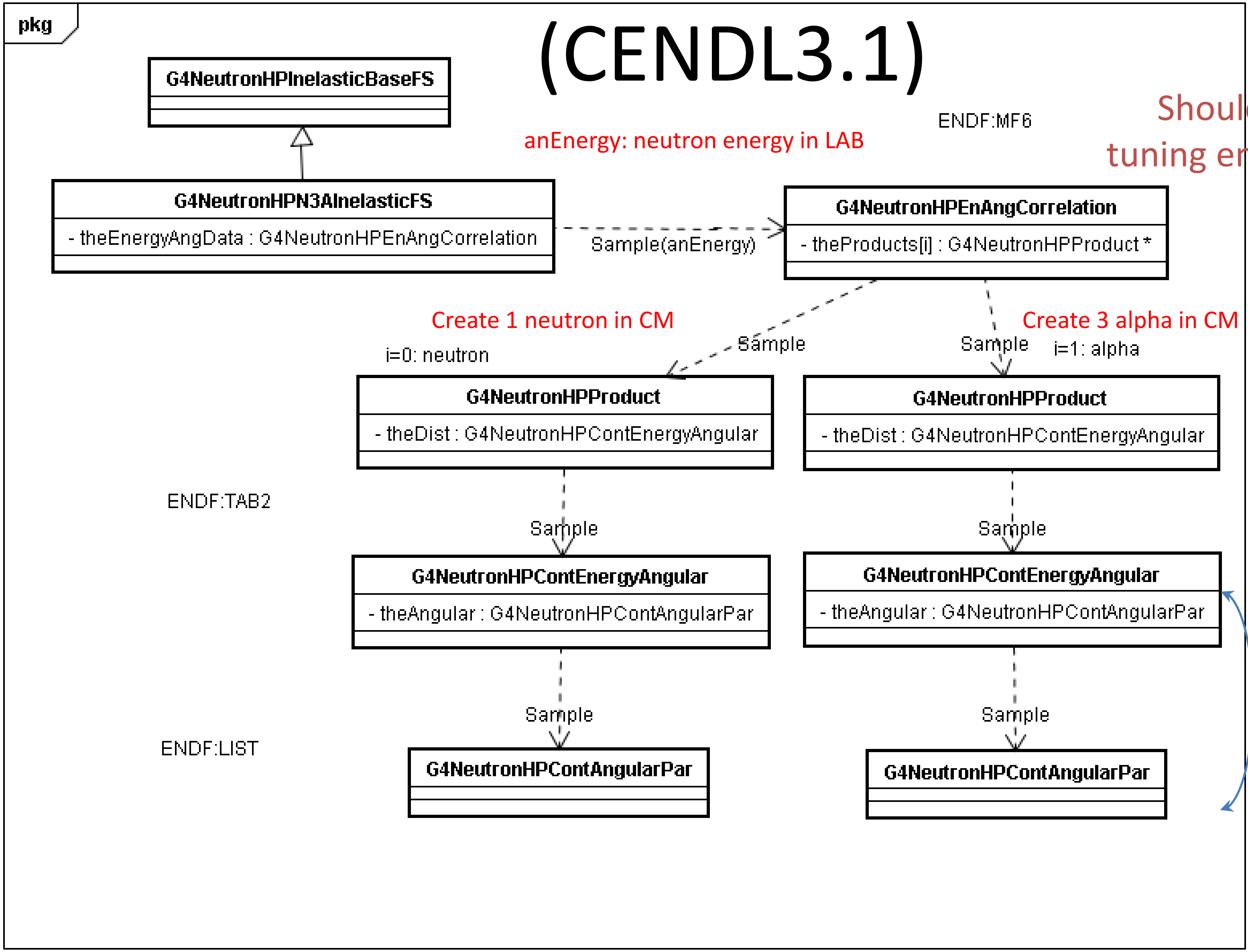




Frequency = simulation result

CENDL3.1 MF6MT23 LEP=1 for histogram

Class diagram for n C -> n3alpha (CENDL3.1)



Should be made tuning energy this level also

tuning energy

- However, it looks like that information in ENDF files is too small to do sophisticated reaction calculation.
- Now we are considering development of a new data driven model based on Dalitz (Plot) kinematics.
  - Final state generator will be developed our side
  - Data should be prepared by users
  - This is a "Horizon 2" project.

At the end of this talk, I can give you some good new

- Vladimir UZHINSKIY will deliver FTF based High Energy N-N model in December!