INCL intra-nuclear cascade and ABLA de-excitation models in Geant4

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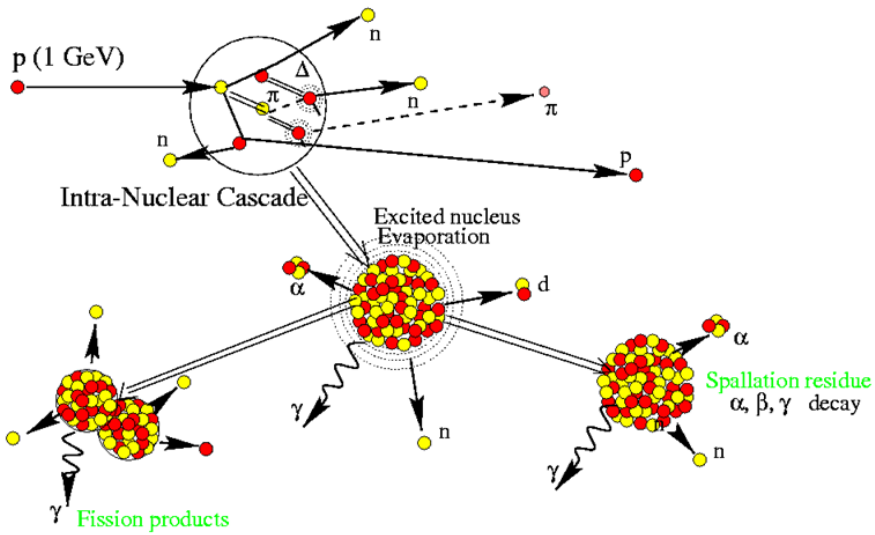
INCL intra-nuclear cascade and ABLA de-excitation

Projectile	p, n, π, deuteron, triton, He3, alpha
Energy range	150 MeV - 3 GeV
Target nuclei	Carbon - Uranium

Table: Model validity range



Interactions (isospin dependence):

$NN \longrightarrow NN$

$NN \longrightarrow N\Delta$

$N\Delta \longrightarrow NN$
$N\Delta \longrightarrow N\Delta$
$\Delta\Delta \longrightarrow \Delta\Delta$

No $N\Delta \longrightarrow \Delta\Delta$

Δ = $\Delta 33$ (1232 MeV)
(No other baryonic resonances)

No $\pi N \longrightarrow \pi N$

No $\pi N \longrightarrow 2\pi N$,
but $\Delta \rightleftharpoons \pi N$

INCL physics ingredients

INCL4.2 (in Geant4):

- Realistic nuclear density (target nucleus): Woods-Saxon, Modified harmonic oscillator, Gaussian
- Track particles along straight line trajectories
- Self-consistent cascade stopping time ($t_{stop} = f_{stop} t_c (\frac{A}{208})^{0.16}$, where $f_{stop} = 1$, $t_c = 70$ fm/c)
- Pauli blocking
- Few parameters, predictive power

Newer, not yet in Geant4:

- Light cluster emission
- Energy dependent, separate potentials for protons and neutrons
- Pion potential

Applications

Traditional applications:

- Spallation
- Accelerator driven systems (ADS)
- Nucleon/pion beams, heavy targets

Interesting future applications:

- Medical applications, treatment of cancer using C^{12} beams
- Space applications, radiation damage
- Ion projectiles, often light targets

Extension of the model is needed. First crude approximation: extend the light ion support up to C^{12}.

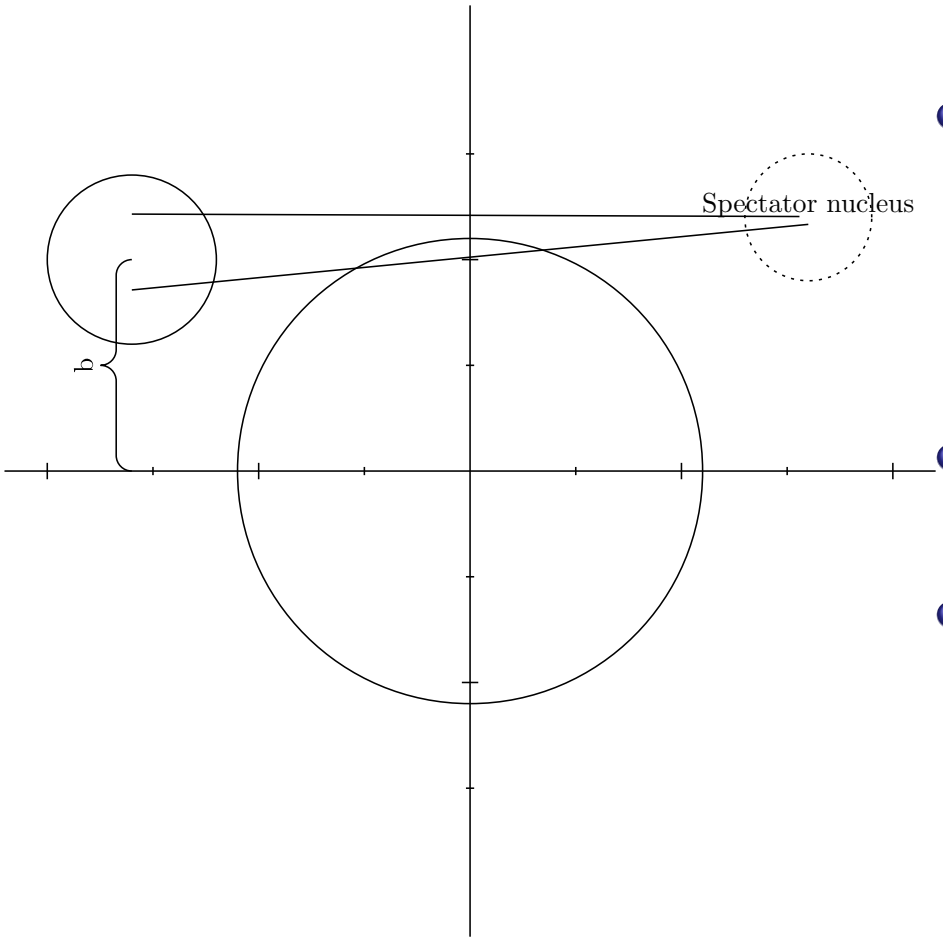
Light ion projectile

INCL light ion projectile treatment has been extended up to C^{12}.

- Projectile is a collection of independent nucleons
- Position distribution of projectile nucleons is gaussian with realistic standard deviation
- Momentum distribution is gaussian with standard deviation of 100 MeV/c

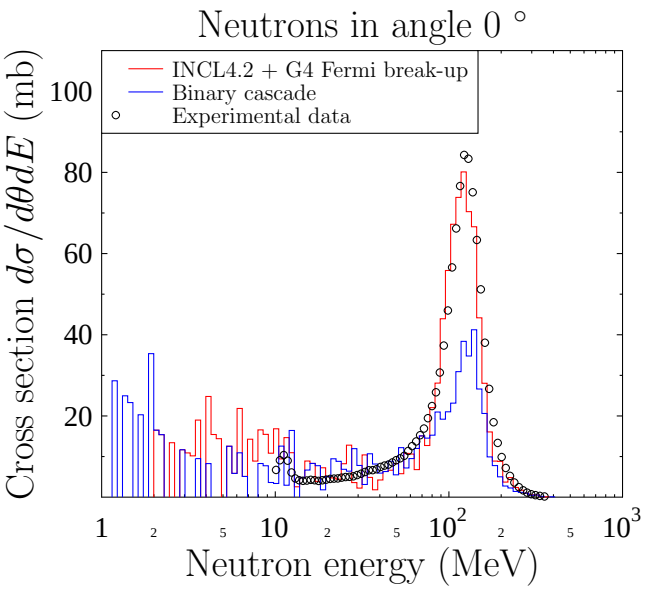
All stable ions up to C^{12} supported

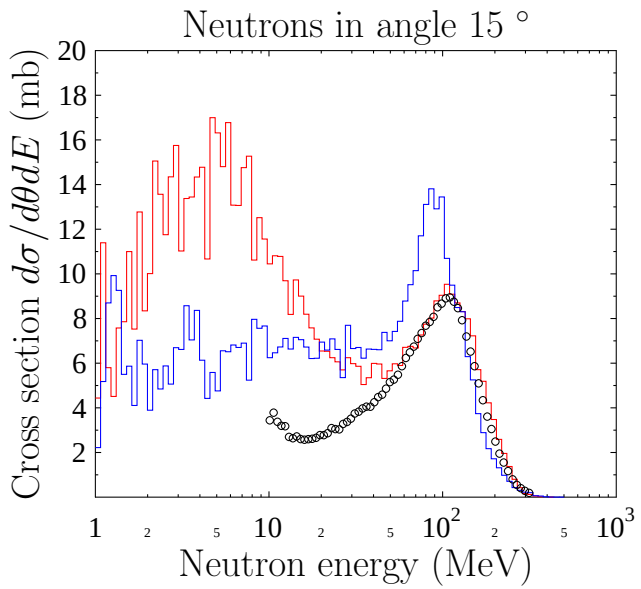
Treatment of composite projectile

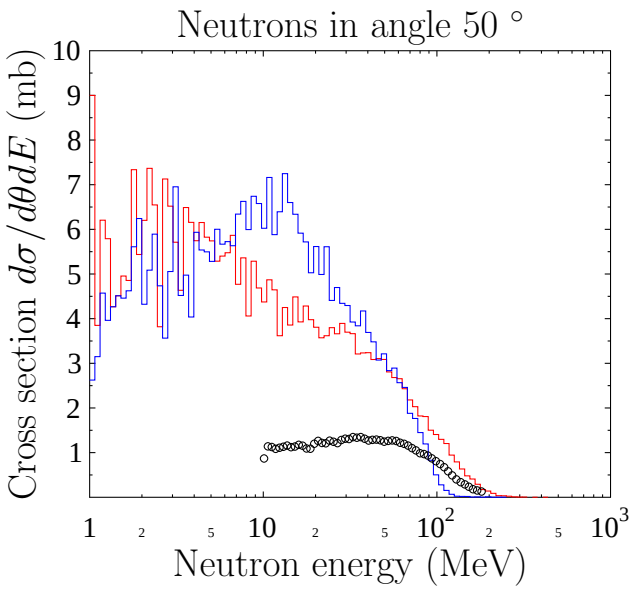


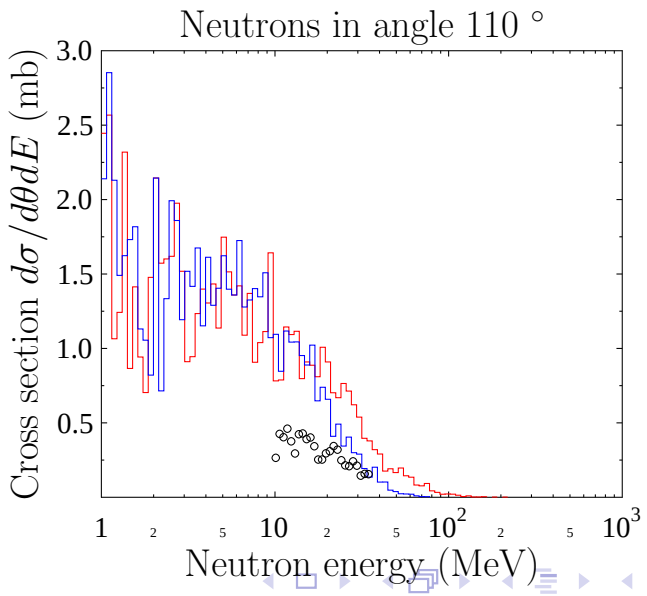
- Spectator nucleons combined into *spectator nucleus*
  - De-excitation using Geant4 Fermi break-up
- Participant nucleons start intra-nuclear cascade
- Target remnant de-excitation:
  - Light: Geant4 Fermi break-up
  - Heavy: ABLA fission/evaporation

Neutron production: C + C @ 135 MeV/nucleon



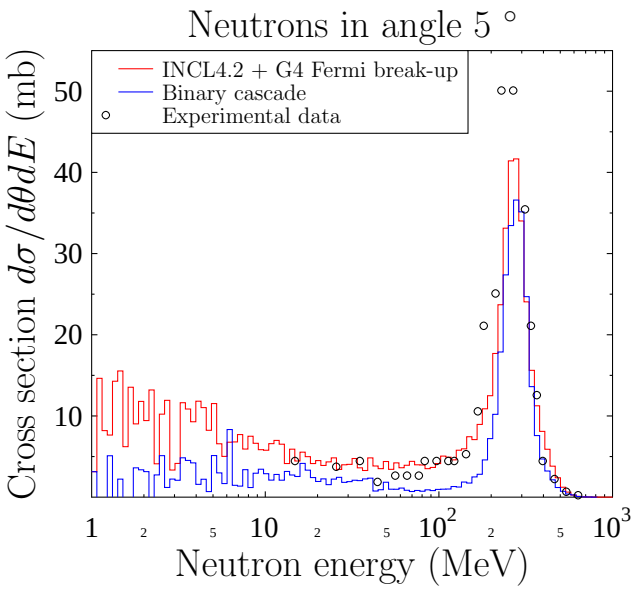


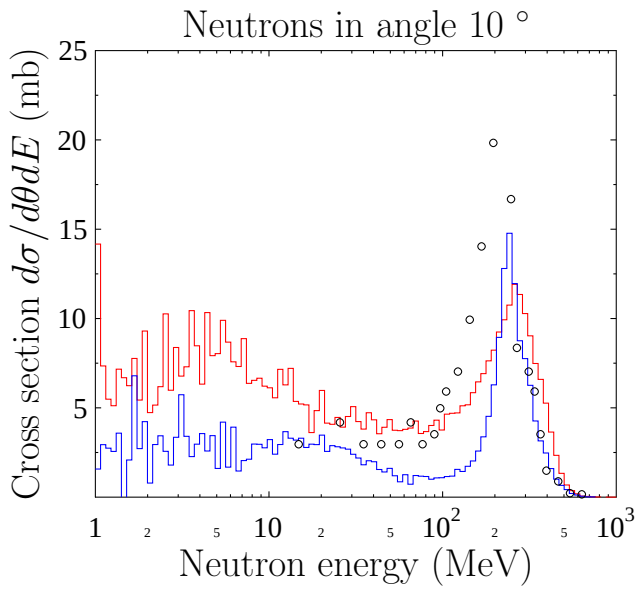


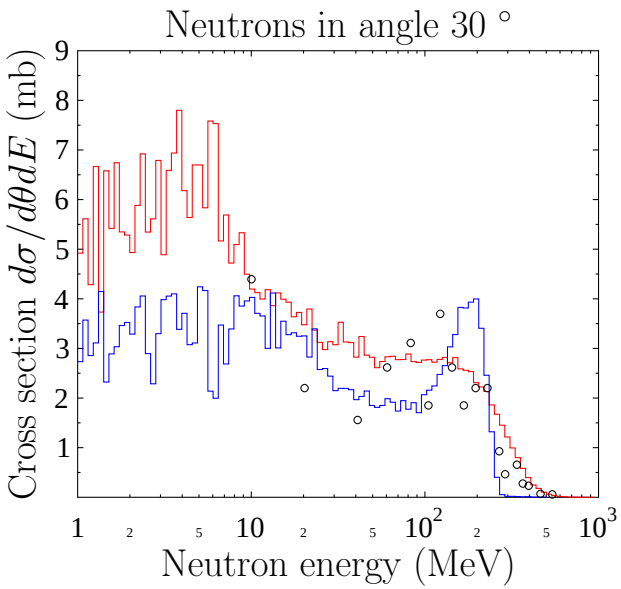


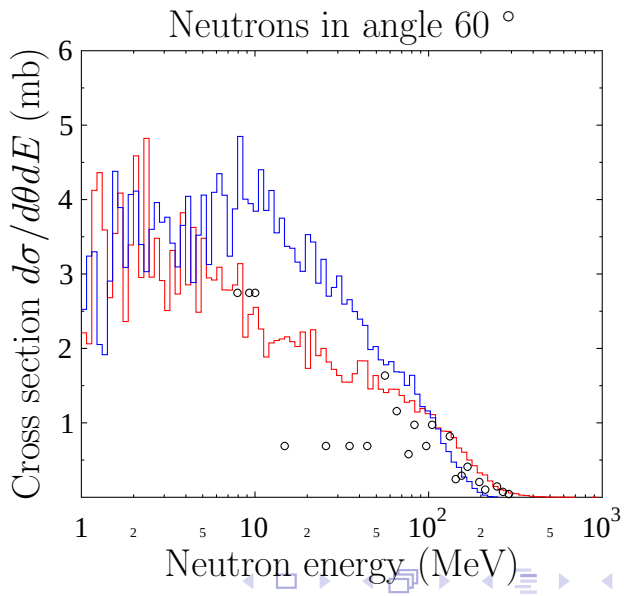
Expermental data: H. Sato et al., Physical Review C 64 (2001) 034607

Neutron production: C + C @ 290 MeV/nucleon



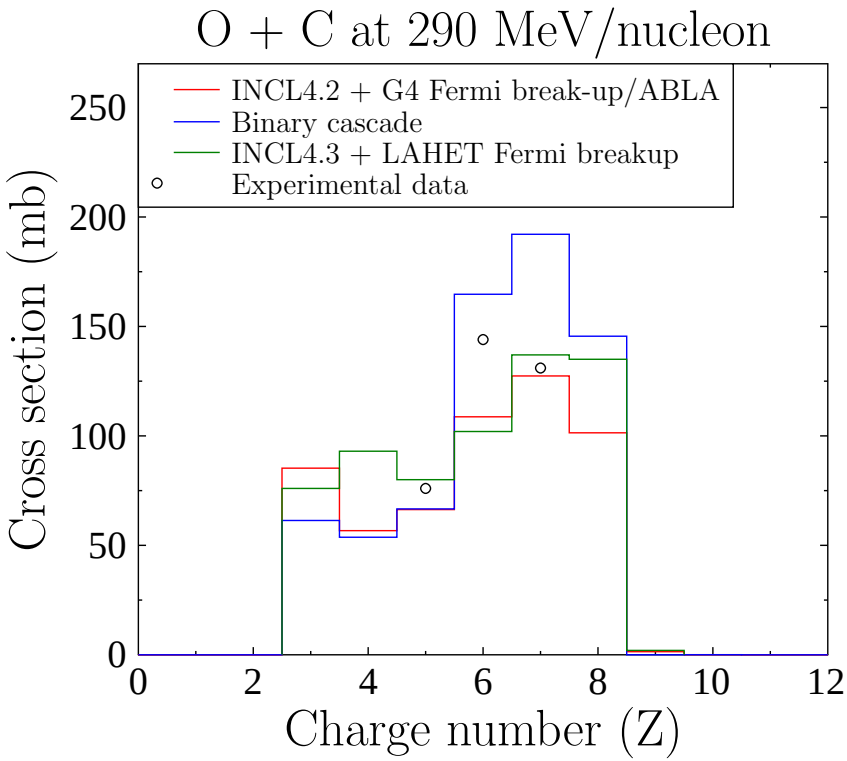


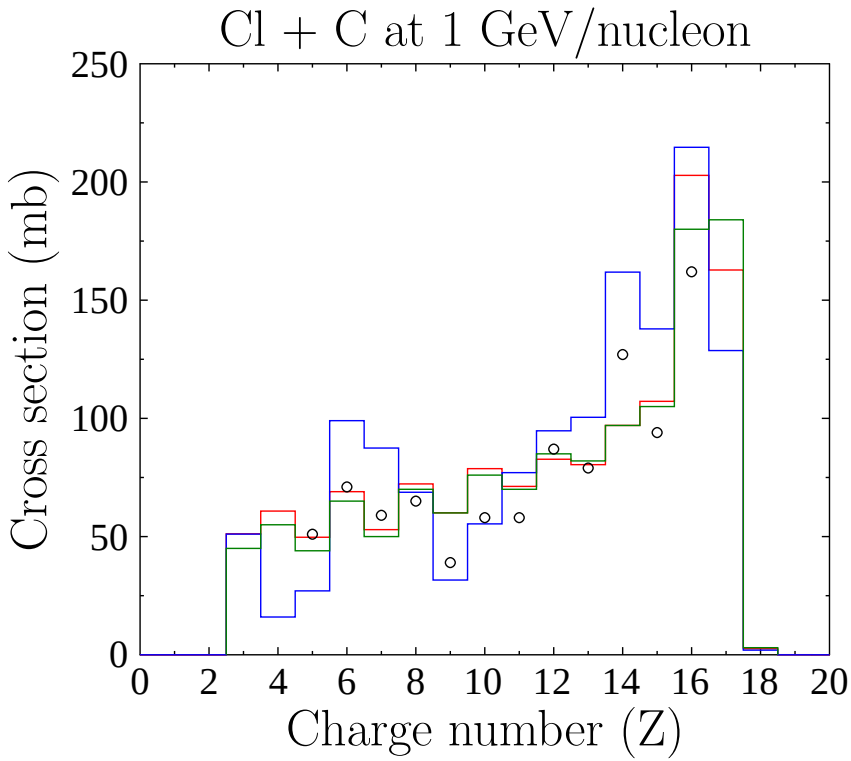




Experimental data: Y. Iwata Physical Review C 64 (2001) 034607

Oxygen and chlorine fragmentation



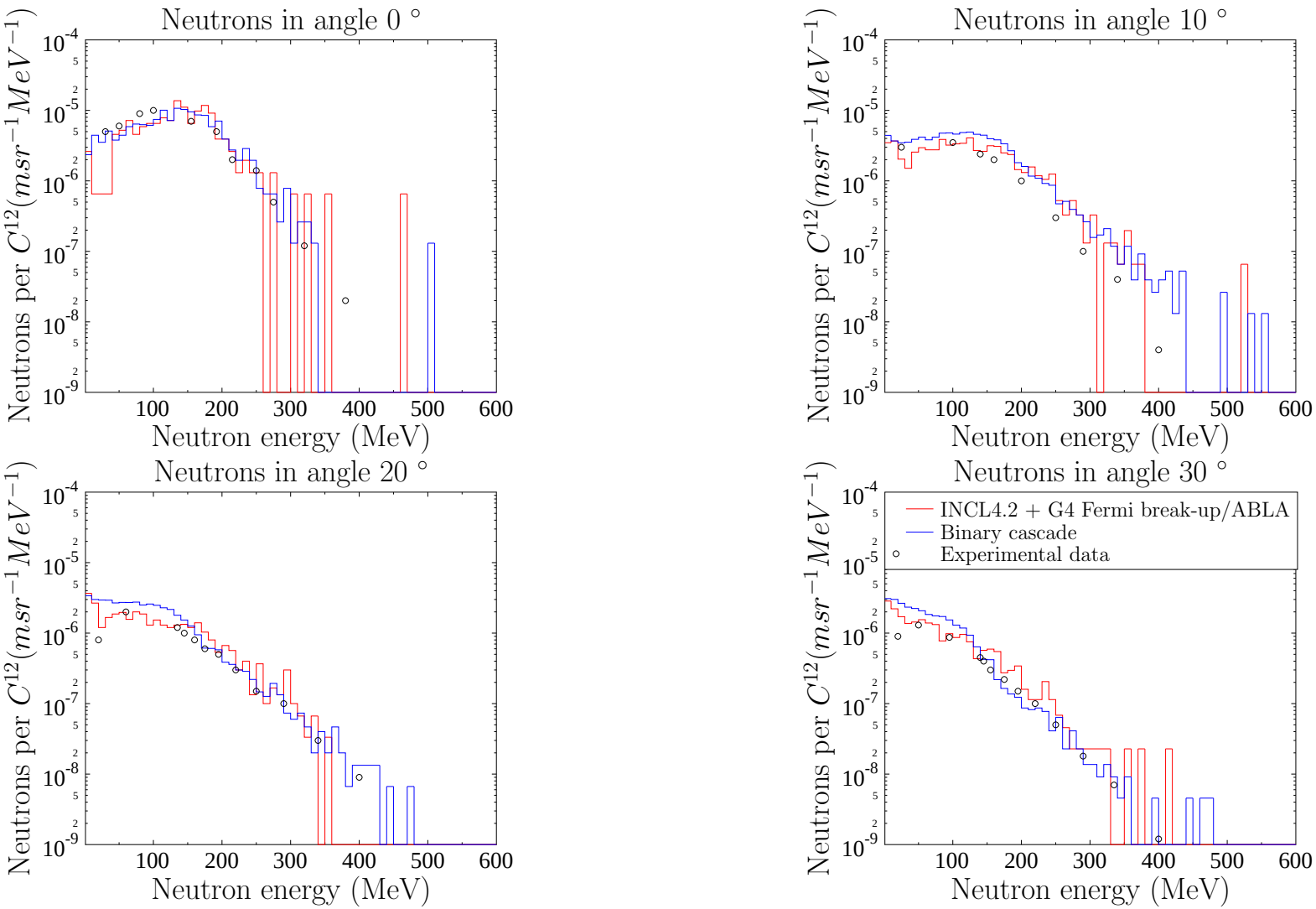


Simulation using inverse kinematics:

- Experiment: projectile fragmentation
- Simulation: target fragmentation

Experimental data: C. Zeitlin et al., Physical Review C 77 (2008) 034605

C + water (12.78 cm) @ 200 MeV/nucleon



Experimental data: K. Gunzert-Marx, H. Iwase, D. Schardt, and R.S. Simon, Secondary beam fragments produced by 200 MeV/u ^{12}C ions in water and their dose contribution in radiotherapy, New Journal of Physics 10 (2008)

Light ion projectiles - conclusions

Status of INCL light ion projectile support:

- Encouraging first results
- Need to find suitable complementary models below 50 MeV/nucleon

Current INCL light ion extension is fairly crude:

- Projectile and target are not treated symmetrically
- Collision of potentials not taken into account
- Current implementation is difficult to extend to heavier projectiles than carbon

More radical transformation of the code is needed.

INCL++: real C++ version of INCL

Physics features of new INCL versions have been significantly improved.

Current technical limitations:

- FORTRAN77
- Monolithic code
- Tight coupling between different parts of the code
- Fragmentation to different versions or "variants"

Need to improve the "working environment" of physicists working on INCL.

Current status of INCL versions

INCL versions:

- INCL4.2 standalone code
  - MCNPX version
  - C++ translation for Geant4
- INCL4.3 standalone code
  - INCL4.3_HI, special standalone code for light-ion reactions
- INCL4.5 standalone code (IAEA spallation benchmark)
  - MCNPX version (interface under development)
- INCL4.6 standalone code (current mainline of development)

Multi-platform approach

INCL developers currently support three "distributions" of INCL:

- Standalone thin-target calculation
- MCNPX
- Geant4

INCL++ must be able to suppport all three as well.

Goals:

- Single source tree that allows us to build all versions
- Solid base for future physics developments

Summary and outlook

INCL4.2 C++ version has been extended to support light ions up to C^{12}.

- Promising first results (both thick and thin target)
- Will be included in the upcoming Geant4 9.4 release
- Search for complementary models (below 50 MeV) underway

INCL++:

- One code, multiple "platforms"
- Long-term, investment in the future
- Improved working environment for INCL developers