The Binary Cascade

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Interactions of nucleons, pions, and light ions with nuclei

The Model

•Cascade type model

- •In the model the nucleus consists of individual nucleons
- •Nucleons carry momentum, that is used in the evaluation of cross-sections and collision probabilities, but are invariant in configuration space.

•Nucleons or hadrons interact with nucleons from the 3-dimensional nuclear model in binary collisions.

- •Re-scattering of secondaries in taken into account, leading to an intra-nuclear cascade
- •Particles propagate in a continuous, static nuclear field, and their equations of motion are integrated explicitly.

•The formulation of the imaginary part of the R-matrix uses free 2-body cross-sections from experimental data and parameterizations. For resonance re-scattering, the solution of an in-medium BUU equation is used.

- •The Binary Cascade at present takes the following strong resonances into account:
  - •The delta resonances with masses 1232, 1600, 1620, 1700, 1900, 1905, 1910, 1920, 1930, and 1950 MeV
  - •Excited nucleons with masses 1440, 1520, 1535, 1650, 1675, 1680, 1700, 1710, 1720, 1900, 1990, 2090, 2190, 2220, and 2250 MeV
- •Nucleon-nucleon scattering (t-channel) resonance excitation cross-sections are derived from proton-proton scattering using isospin invariance, and the corresponding Clebsch-Gordon coefficients.
- •Meson-nucleon non-elastic (except true absorption) scattering is modeled as S-channel resonance excitation. The cross-section can be written in form of a the Breit-Wigner function:

$$\sigma\left(\sqrt{s}\right) = \sum_{FS} \frac{2J+1}{(2S_1+1)(2S_2+1)} \frac{\pi}{k^2} \frac{\Gamma_{IS}\,\Gamma_{FS}}{\left(\sqrt{s}-M_R\right)^2 + (\Gamma/2)^2}$$

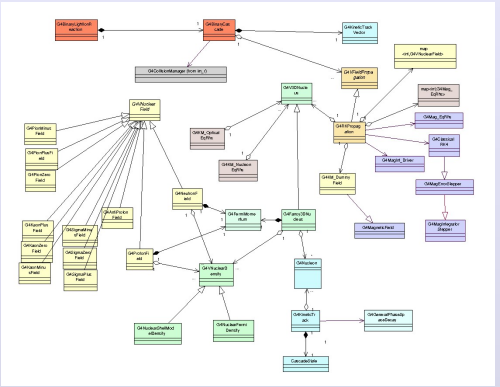
- •True absorption is modeled as S-wave absorption on quasi-deuterons.
- •Nucleon-nucleon elastic scattering angular distributions taken from phase shift analysis (R. Arndt) of experimental data.

•Pauli Blocking is implemented in its classical form, i.e. allowed final states have all nucleons at momenta larger than the Fermi momentum.

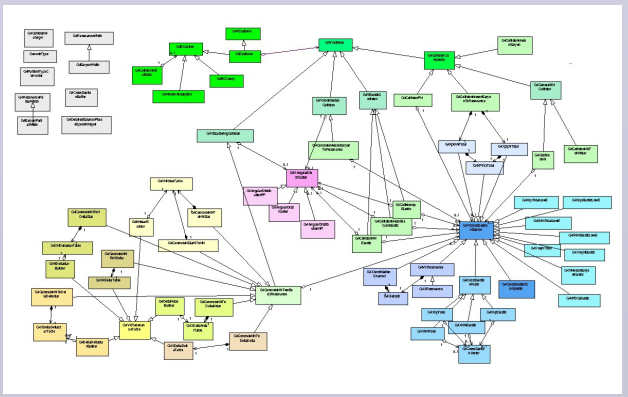
•The Cascade stops when the mean energy of the particles traced in the system is below cut-off.

•When the cascade stops, the properties of the residual exciton system and nucleus are evaluated, and passed to a pre-equilibrium decay code for further treatment.

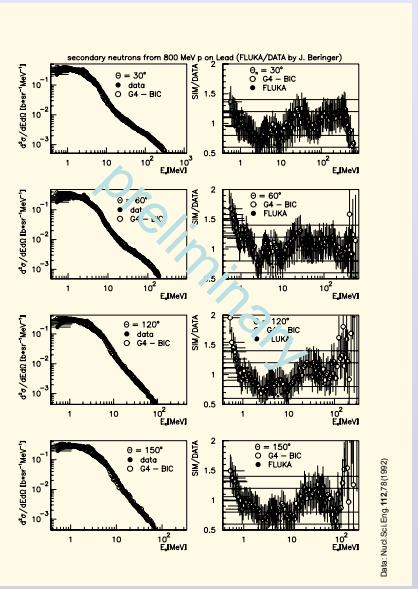
OOA&D

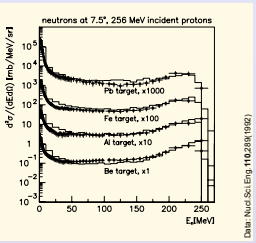


•Object Oriented Design techniques lead to a clear domain decomposition and component structure
•Template Meta Programming is used for compile-time code generation and system configuration
•Abstract interfaces and the design patterns Composite, Bridge and Hidden Adapter are used to achieve decoupling of logic and algorithm.



Some Results





Comparison with measured neutron production cross section for protons scattering off various materials at fixed angle of 5°

Double differential cross section at various angles for secondary neutrons from

p + Pb—> X + n

from a study analyzing the transition from cascade to pre-equilibrium decay.

Differential cross section for neutrons produced in light ion scattering Carbon on Carbon at 290 MeV/c.