Geant4 v8.0.p01

Hadron Physics II

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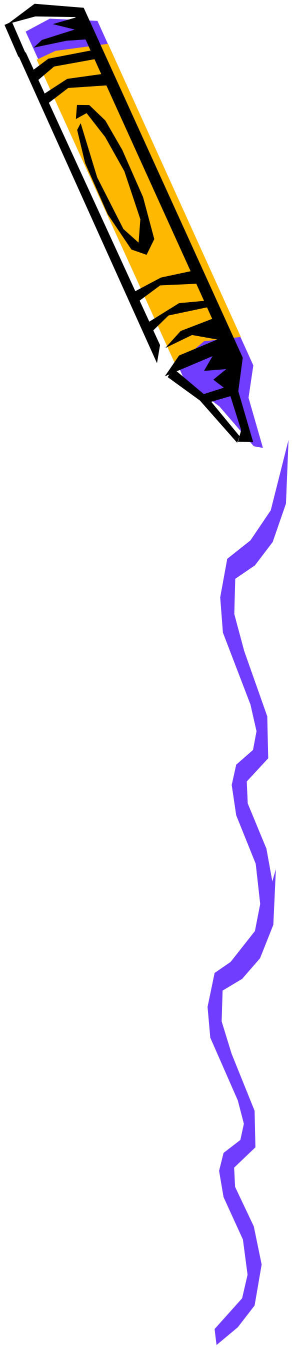
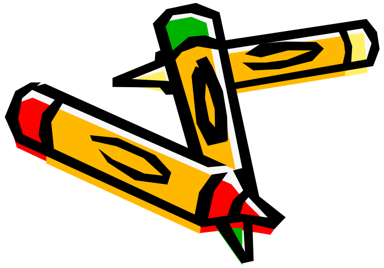
SLAC/SCCS

Geant4 Tutorial Course 2006



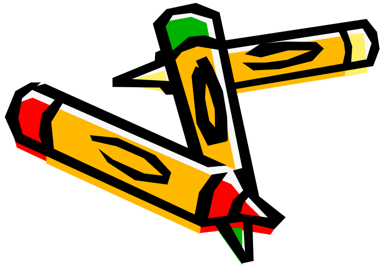
Overview

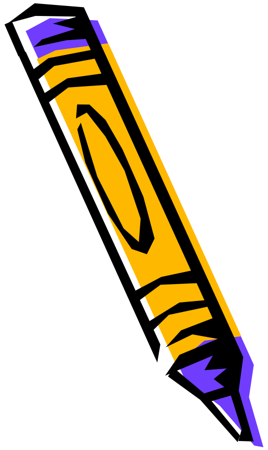
- Low Energy Neutron Physics
  - High Precision Neutron Models
- Ion Physics
  - Inelastic
  - Electromagnetic Dissociation
  - Radio Active Decay



Low energy (< 20MeV) neutrons physics

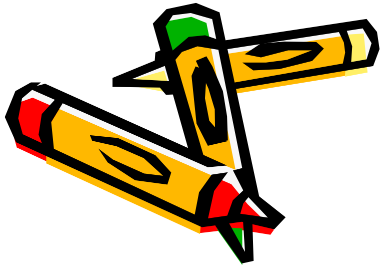
- High Precision Neutron Models (and Cross Section Data Sets)
  - G4NDL
    - ENDF
  - Elastic
  - Inelastic
  - Capture
  - Fission
- NeutronHPorLEModel(s)



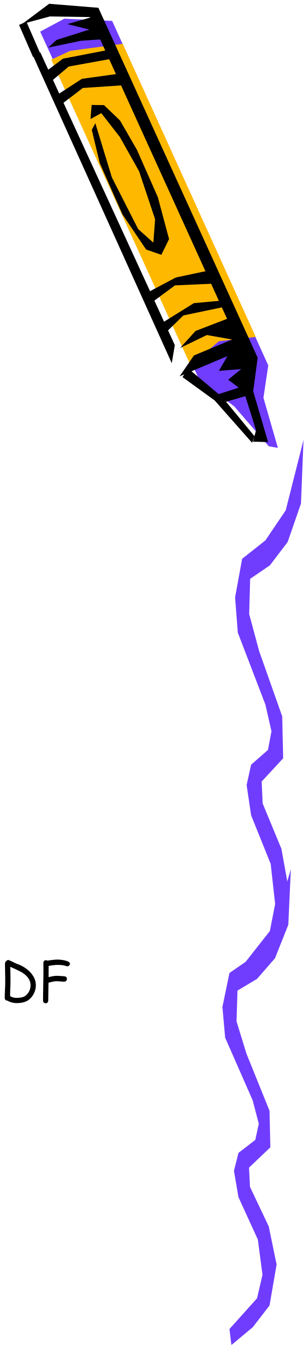


G4NDL
(Geant4 Neutron Data Library)

- The neutron data files for High Precision Neutron models
- The data are including both cross sections and final states.
- The data are derived evaluations based on the following evaluated data libraries (in alphabetic order)
  - Brond-2.1
  - CENDL2.2
  - EFF-3
  - ENDF/B-VI.0, 1, 4
  - FENDL/E2.0
  - JEF2.2
  - JENDL-FF
  - JENDL-3.1,2
  - MENDL-2
- The data format is similar ENDF, however it is not equal to.

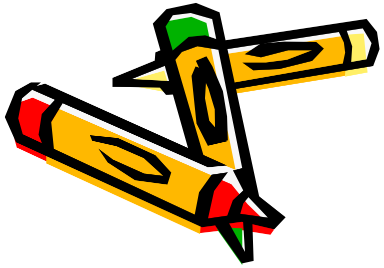


Evaluated Nuclear Data File-6

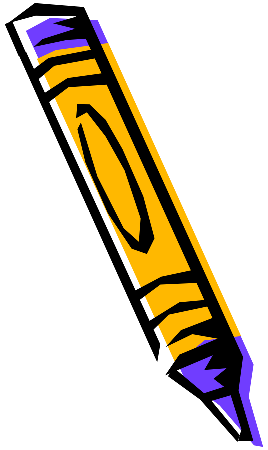


- “ENDF” is used in two meanings
- One is Data Formats and Procedures
  - How to write Nuclear Data files
  - How to use the Nuclear Data files
- The other is Name of recommended libraries of USA nuclear data projects.
  - ENDF/B-VI.8 (latest)
    - 313 isotopes including 5 isomers
    - 15 elements

- After G4NDL3.8 we concentrated translation from ENDF library.
  - No more evaluation by ourselves.



G4NeutronHPElastic

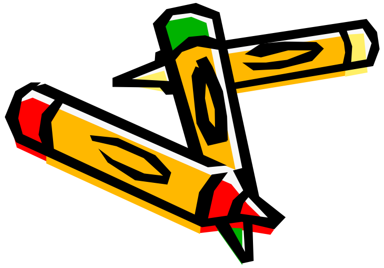


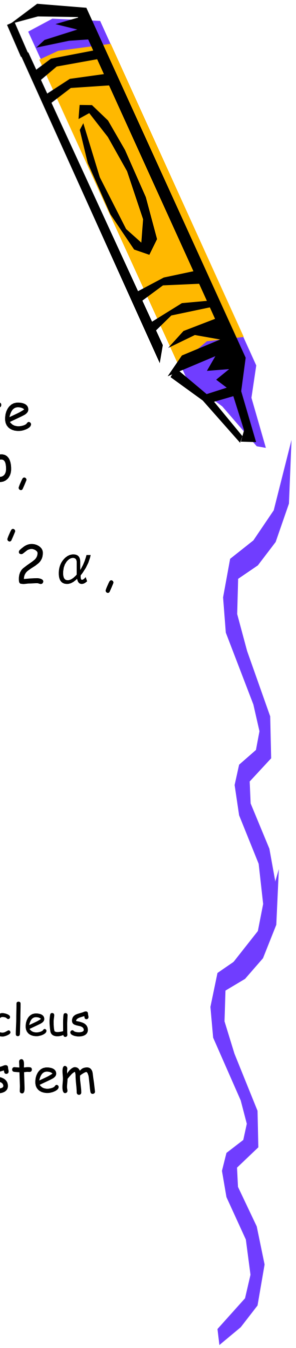
- The final state of elastic scattering is described by sampling the differential scattering cross-sections
  - tabulation of the differential cross-section

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}(\cos\theta, E)$$

  - a series of legendre polynomials and the legendre coefficients

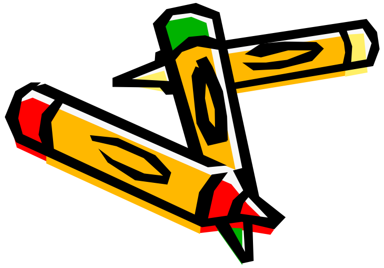
$$\frac{2\pi}{\sigma(E)}\frac{d\sigma}{d\Omega}(\cos\theta, E) = \sum_{l=0}^{n_l}\frac{2l+1}{2}a_l(E)P_l(\cos\theta)$$

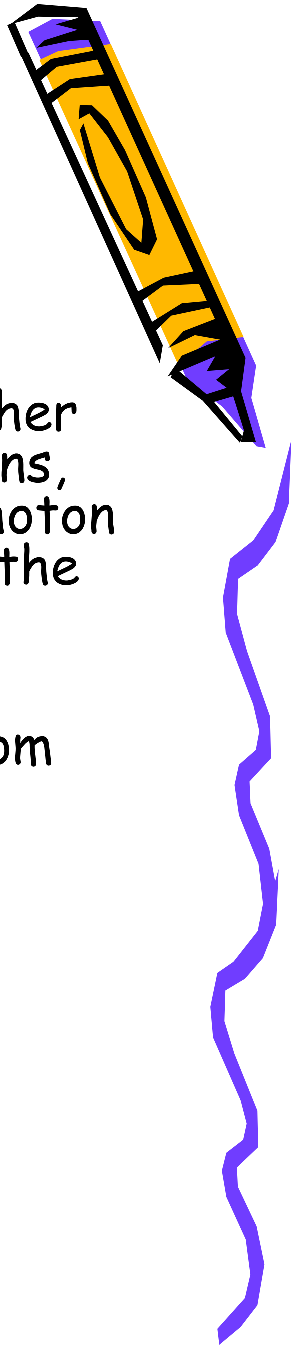




G4NeutronHPInelastic

- Currently supported final states are (nA) nγs (discrete and continuum), np, nd, nt, n ^{3}He, nα, nd2α, nt2α , n2p, n2α, np , n3α, 2nα, 2np, 2nd, 2nα, 2n2α, nX, 3n, 3np, 3nα, 4n, p, pd, pα, 2p d, dα, d2α, dt, t, t2α, ^{3}He, α, 2α, and 3α.
- Secondary distribution probabilities are supported
  - isotropic emission
  - discrete two-body kinematics
  - N-body phase-space distribution
  - continuum energy-angle distributions
    - legendre polynomials and tabulation distribution
    - Kalbach-Mann systematic $A + a \rightarrow C \rightarrow B + b$, C:compound nucleus
  - continuum angle-energy distributions in the laboratory system



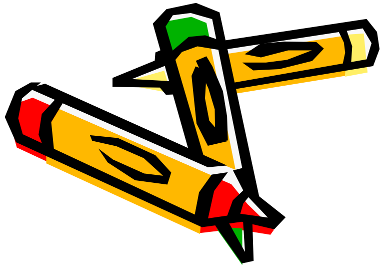


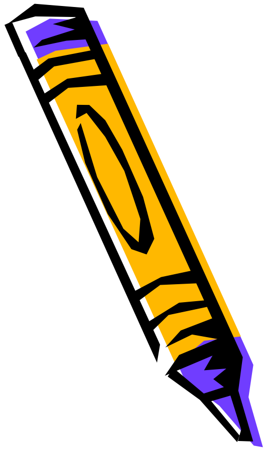
G4NeutronHPCapture

- The final state of radiative capture is described by either photon multiplicities, or photon production cross-sections, and the discrete and continuous contributions to the photon energy spectra, along with the angular distributions of the emitted photons.
- For discrete photon emissions
  - the multiplicities or the cross-sections are given from data libraries
- For continuum contribution
  - E neutron kinetic energy, E_γ photon energies

$$f\left(E \to E_\gamma\right) = \sum_i p_i(E)\, g_i\left(E \to E_\gamma\right)$$

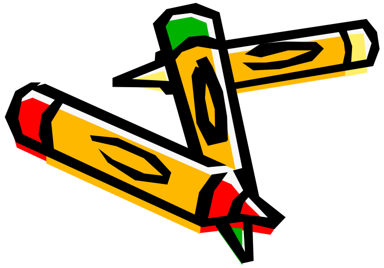
  - p_i and g_i are given from data libraries

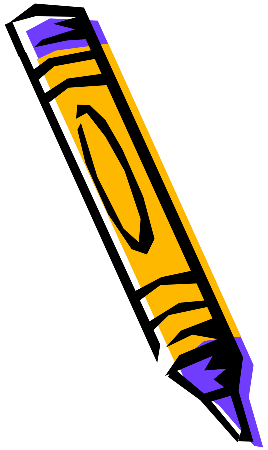




G4NeutronHPFission

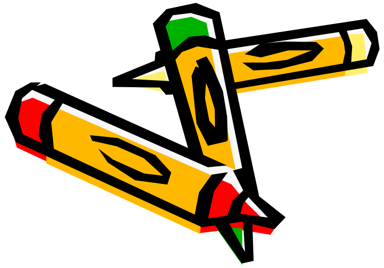
- Currently only Uranium data are available in G4NDL
- first chance, second chance, third chance and forth chance fission are into accounted.
- The neutron energy distributions are implemented in six different possibilities.
  - tabulated as a normalized function of the incoming and outgoing neutron energy - $f(E \to E')$
  - Maxwell spectrum - $f(E \to E') \propto \sqrt{E'} e^{E'/\Theta(E)}$
  - a general evaporation spectrum - $f(E \to E') \propto E' e^{E'/\Theta(E)}$
  - evaporation spectrum - $f(E \to E') = f\left(E' \middle/ \Theta(E) \right)$
  - the energy dependent Watt spectrum - $f(E \to E') \propto e^{E'/a(E)} \sinh \sqrt{b(E)E'}$
  - the Madland Nix spectrum - $f(E \to E') = \frac{1}{2}\left[g\left(E', \langle K_l \rangle\right) + g\left(E', \langle K_h \rangle\right) \right]$



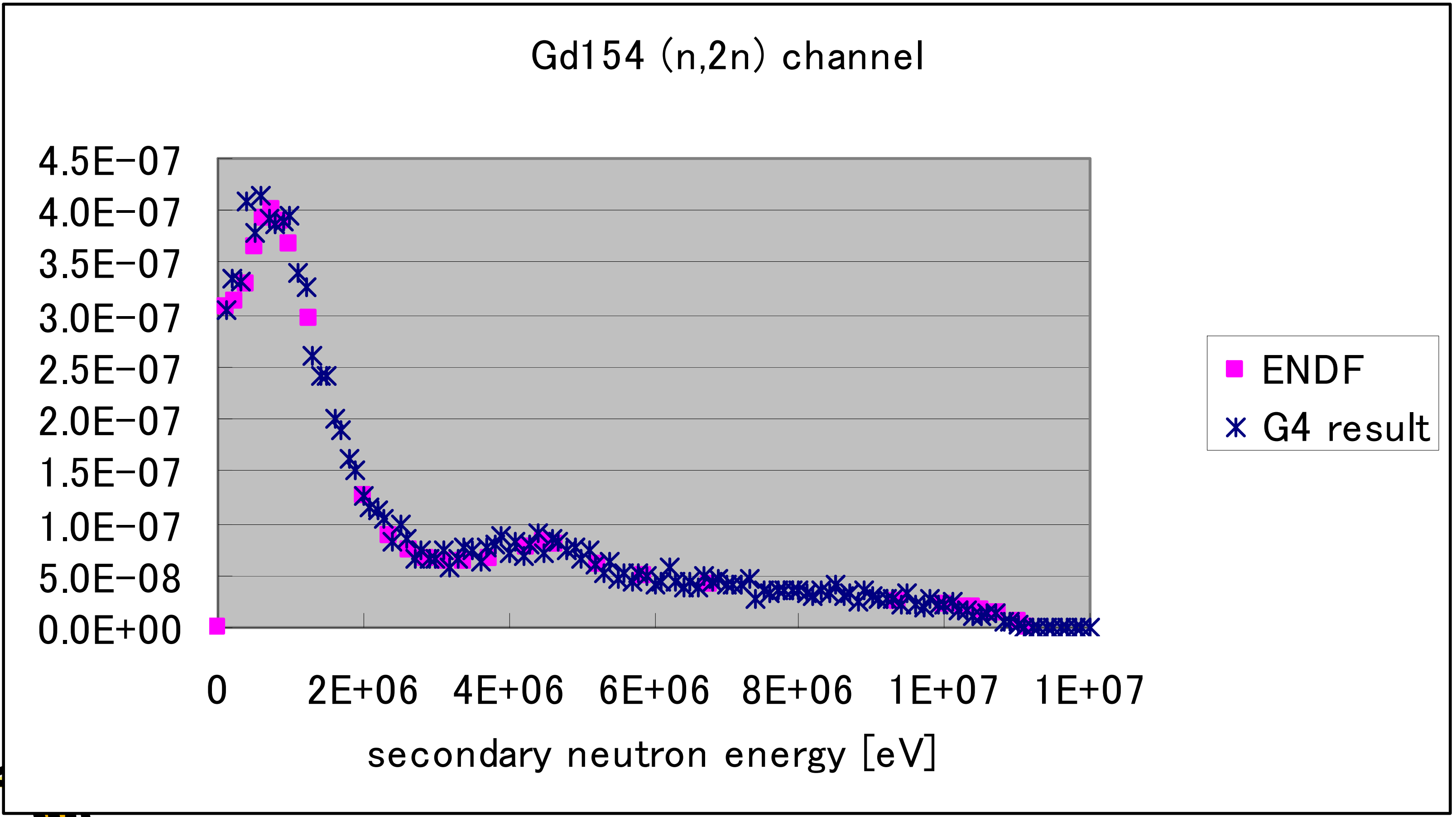


Verification of High Precision Neutron models
Channel Cross Sections
20MeV neutron on Gd157

Geant4 results	ENDF data
Ela XS 3.7104216 [barn]	3.708710+0 [barn]
Inela XS 1.2508858	
Inela XS F01 0.99179298	9.940940E-1
Inela XS F04 0.18413539	1.836200E-1
Inela XS F06 0.020973994	2.126800E-2
Inela XS F10 0.041302787	4.064300E-2
Inela XS F23 0.009658162	9.717300E-3
Inela XS F27 0.0030225183	3.306100E-3
Cap XS 0.0017767842	1.646330E-3

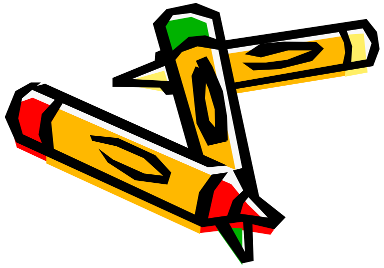


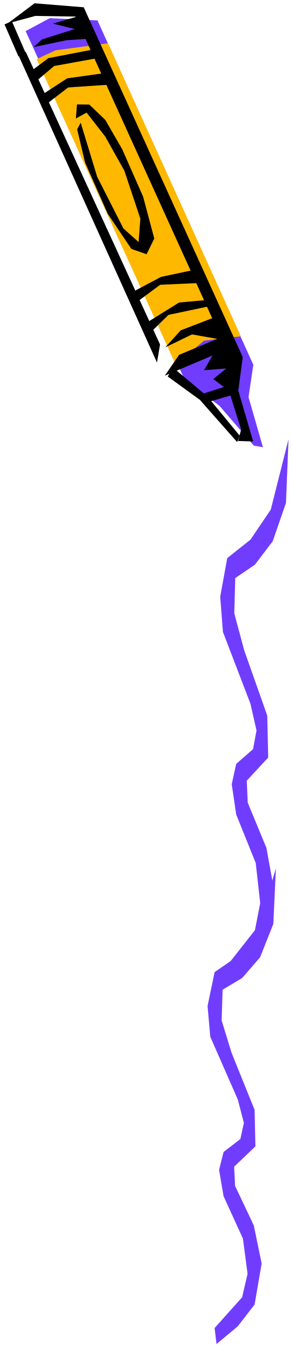
Verification of High Precision Neutron models Energy Spectrum of Secondary Particles



G4NeutornHPorLEModels

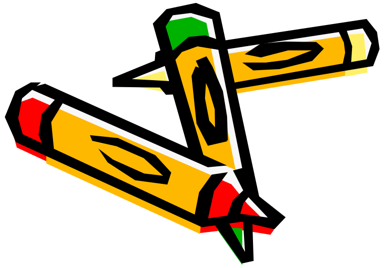
- Many elements remained without data for High Precision models.
- Those models make up for such data deficit.
- If the High Precision data are not available for a reaction, then Low Energy Parameterization Models will handle the reaction.
- Those can be used for not only for models (final state generator) but also for cross sections.
- Elastic, Inelastic, Capture and Fission models are prepared.



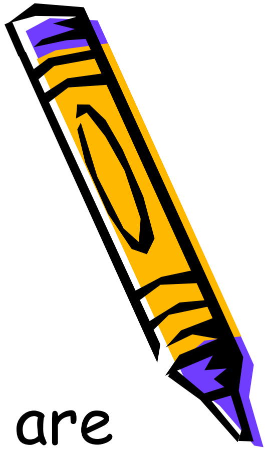


Ion Physics
Inelastic Reactions

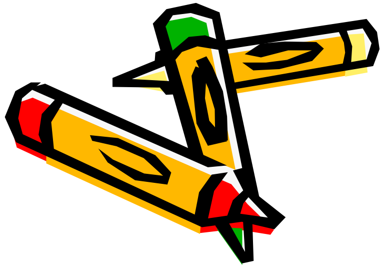
- Cross Sections
- Model
  - G4BinaryLightIon
  - G4WilsonAbrasion



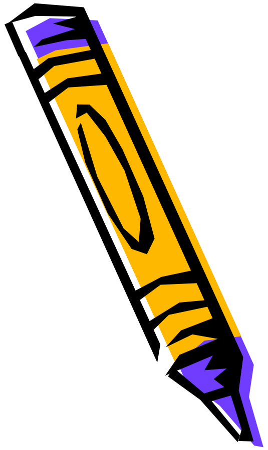
Cross Sections



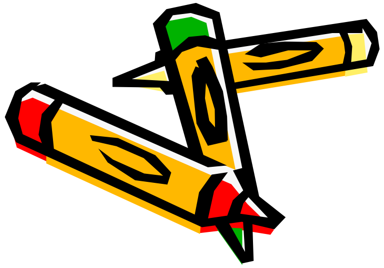
- Many cross section formulae for NN collisions are included in Geant4
  - Tripathi, Shen, Kox and Sihver
- These are empirical and parameterized formulae with theoretical insights.
- G4GeneralSpaceNNCrossSection was prepared to assist users in selecting the appropriate cross section formula.



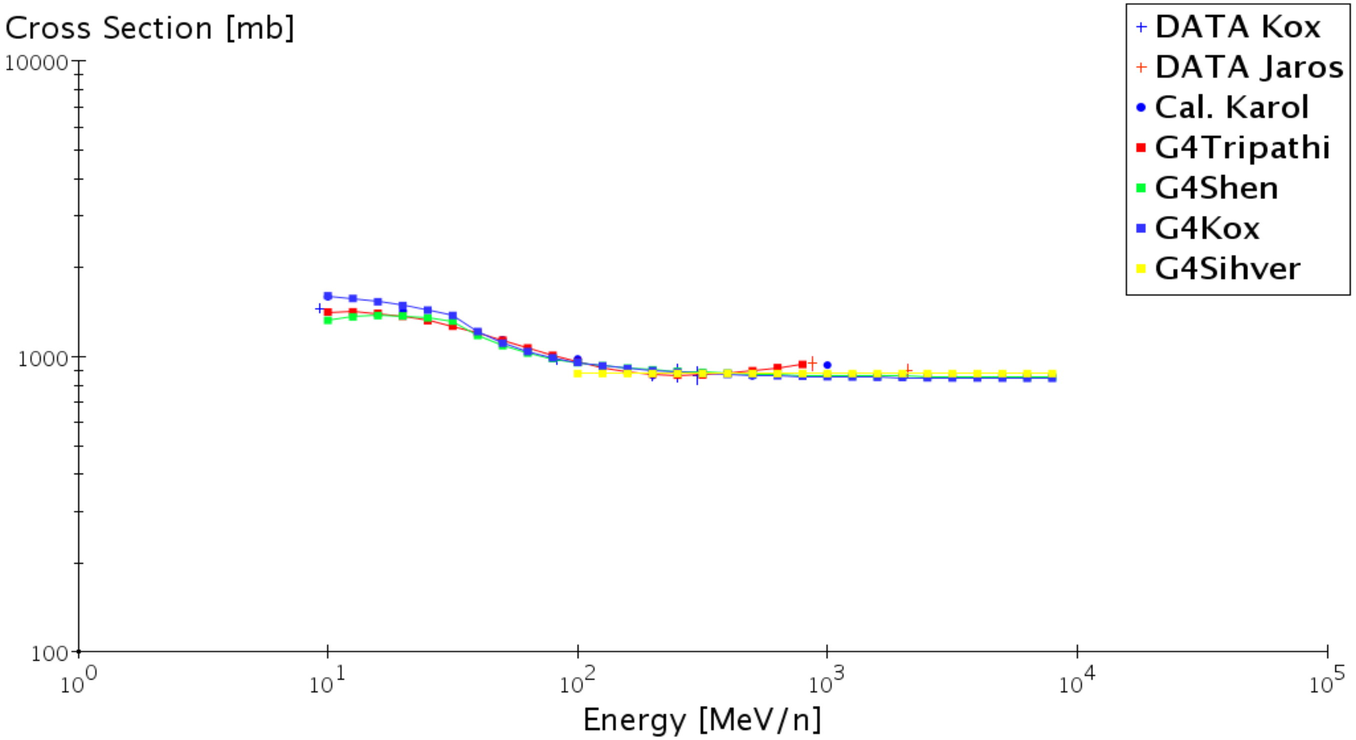
References to NN Cross Section Formulae implemented in Geant4



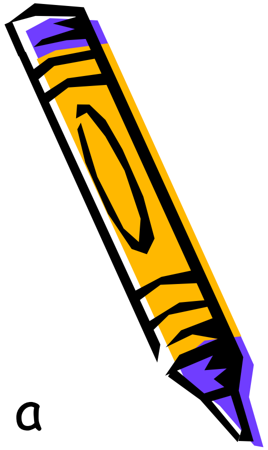
- Tripathi Formula
  - NASA Technical Paper TP-3621 (1997)
- Tripathi Light System
  - NASA Technical Paper TP-209726 (1999)
- Kox Formula
  - Phys. Rev. C 35 1678 (1987)
- Shen Formula
  - Nuclear Physics. A 49 1130 (1989)
- Sihver Formula
  - Phys. Rev. C 47 1225 (1993)



Inelastic Cross Section C12 on C12



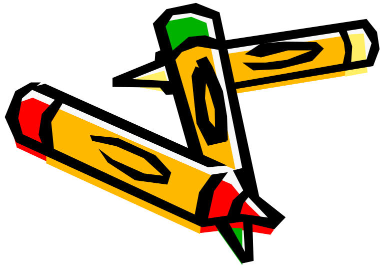
Binary Cascade ~Model Principals~



- In Binary Cascade, each participating nucleon is seen as a Gaussian wave packet, (like QMD)

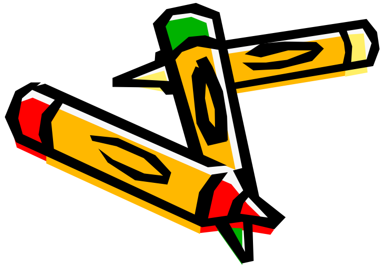
$$\phi(x,q_i,p_i,t)=\left(2/(L\pi)\right)^{3/4}\exp\left(-2/L(x-q_i(t))^2+ip_i(t)x\right)$$

- Total wave function of the nucleus is assumed to be direct product of these. (no anti-symmetrization)
- This wave form have same structure as the classical Hamilton equations and can be solved numerically.
- The Hamiltonian is calculated using simple time independent optical potential. (unlike QMD)

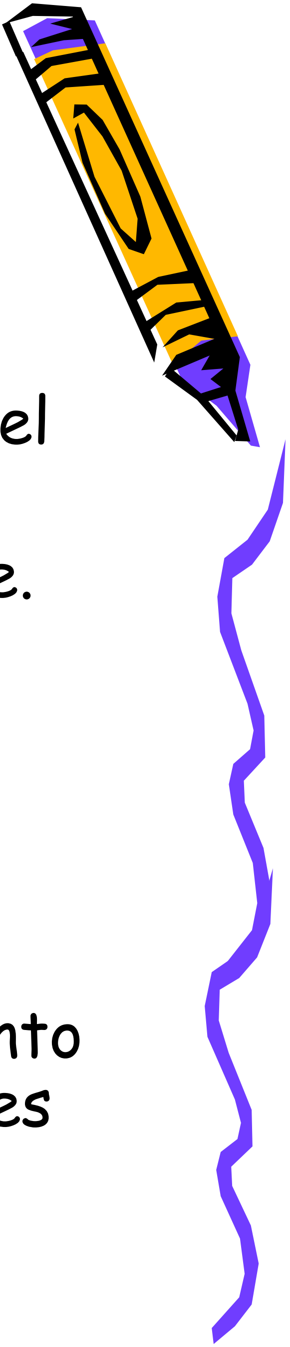


Binary Cascade ~nuclear model ~

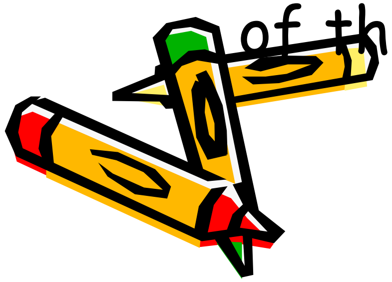
- 3 dimensional model of the nucleus is constructed from A and Z.
- Nucleon distribution follows
  - A>16 Woods-Saxon model
  - Light nuclei harmonic-oscillator shell model
- Nucleon momenta are sampled from 0 to Fermi momentum and sum of these momenta is set to 0.
- time-invariant scalar optical potential is used.



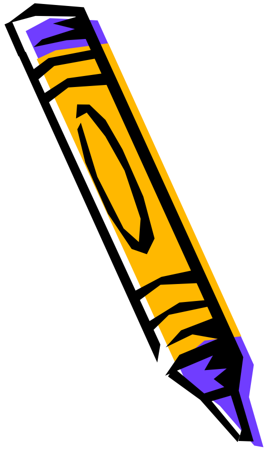
Binary Cascade
~ G4BinaryLightIonReaction ~

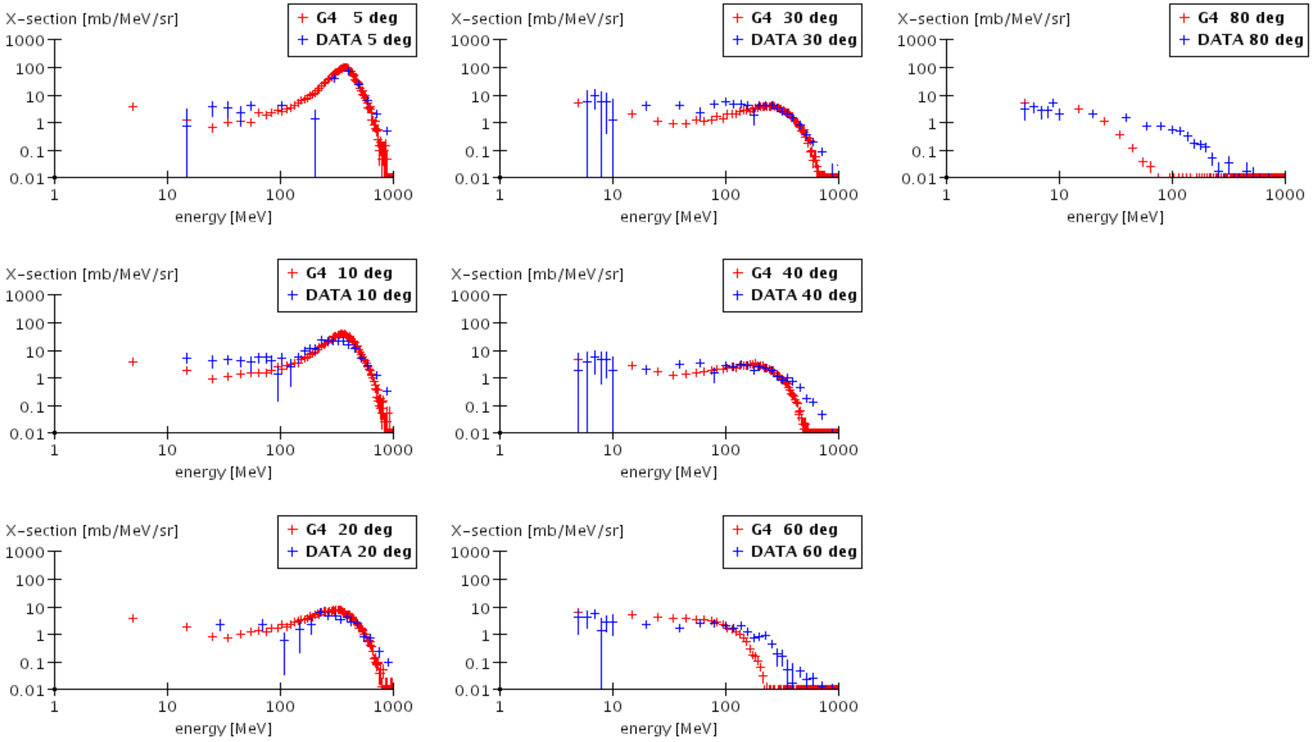


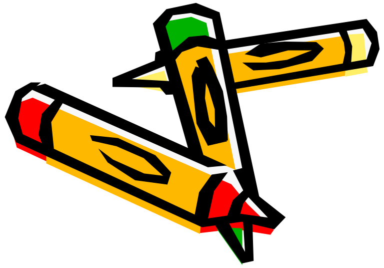
- Two nuclei are prepared according to this model (previous page).
- The lighter nucleus is selected to be projectile.
- Nucleons in the projectile are entered with position and momenta into the initial collision state.
- Until first collision of each nucleon, its Fermi motion is neglected in tracking.
- Fermi motion and the nuclear field are taken into account in collision probabilities and final states of the collisions.



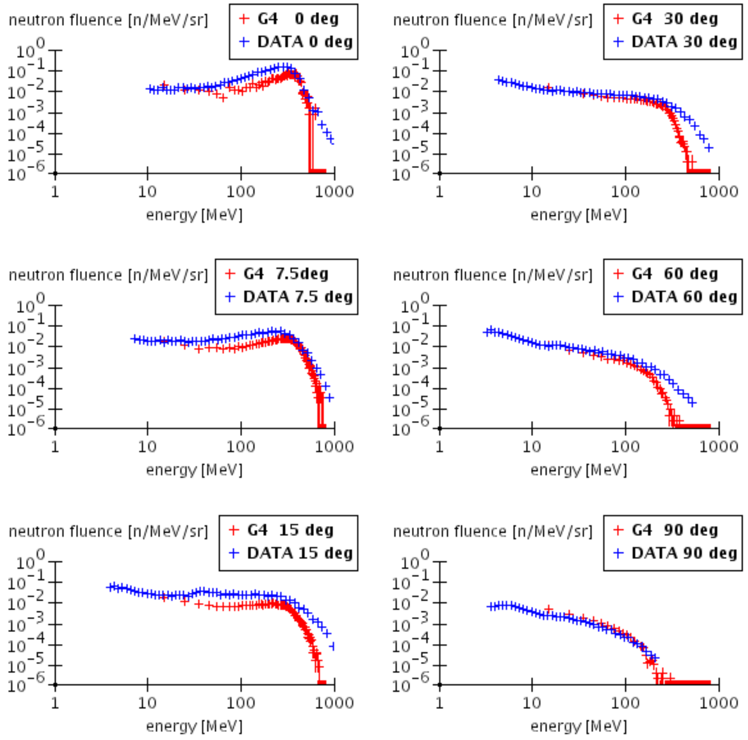
Validation results
Neutrons from 400MeV/n Ne20 on Carbon



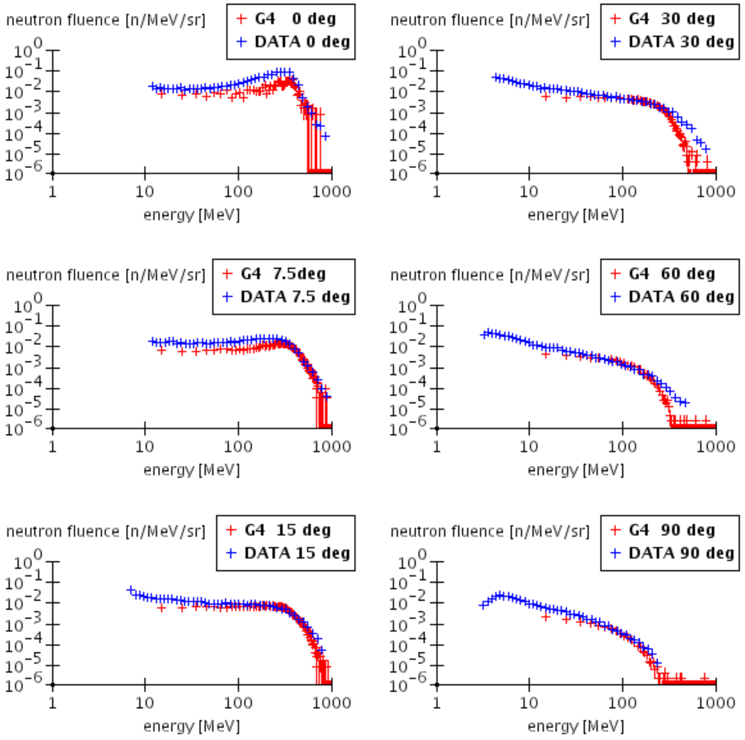




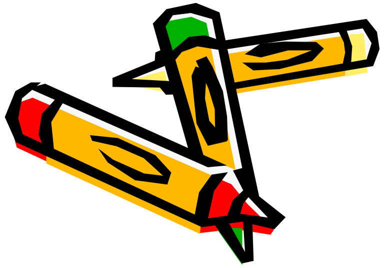
Neutron Yield
Fe 400 MeV/n beams



Copper Thick Target

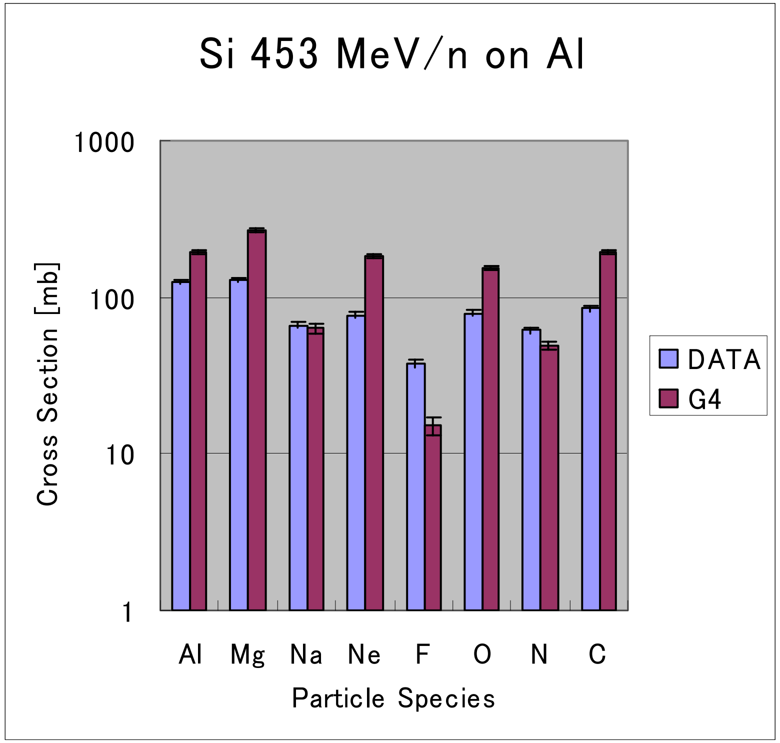


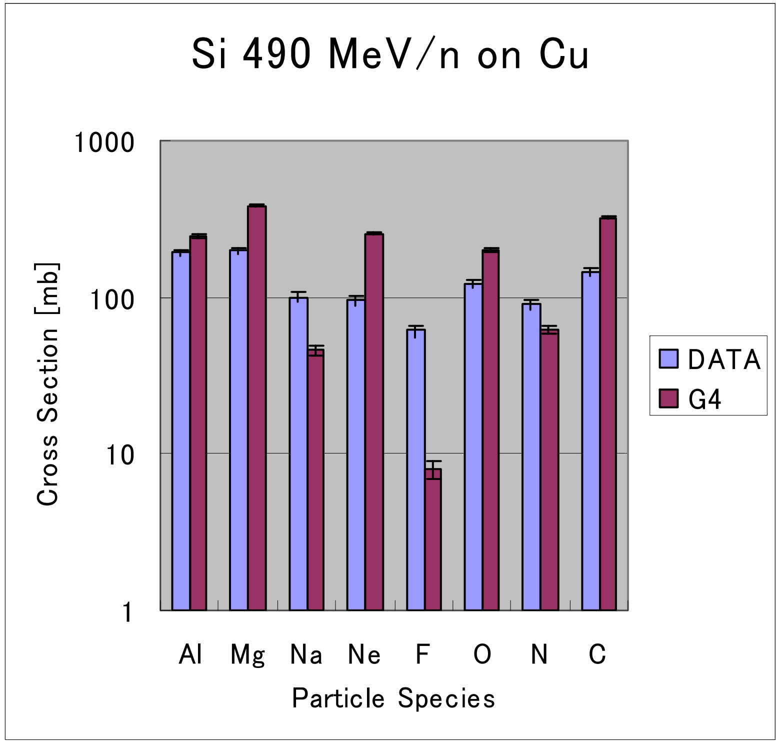
Lead Thick Target

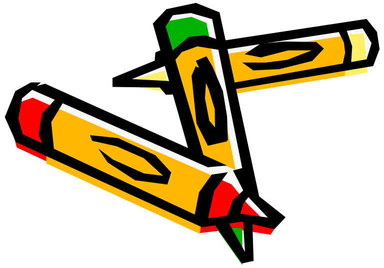


T. Kurosawa et al.,
Phys. Rev. **C62**
pp. 04461501 (2000)

Fragment Production



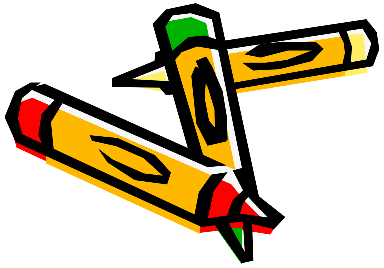


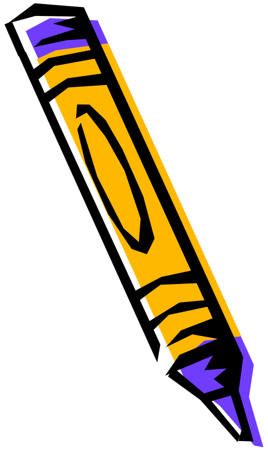


F. Flesch et al.,
J, RM, 34 237 2001

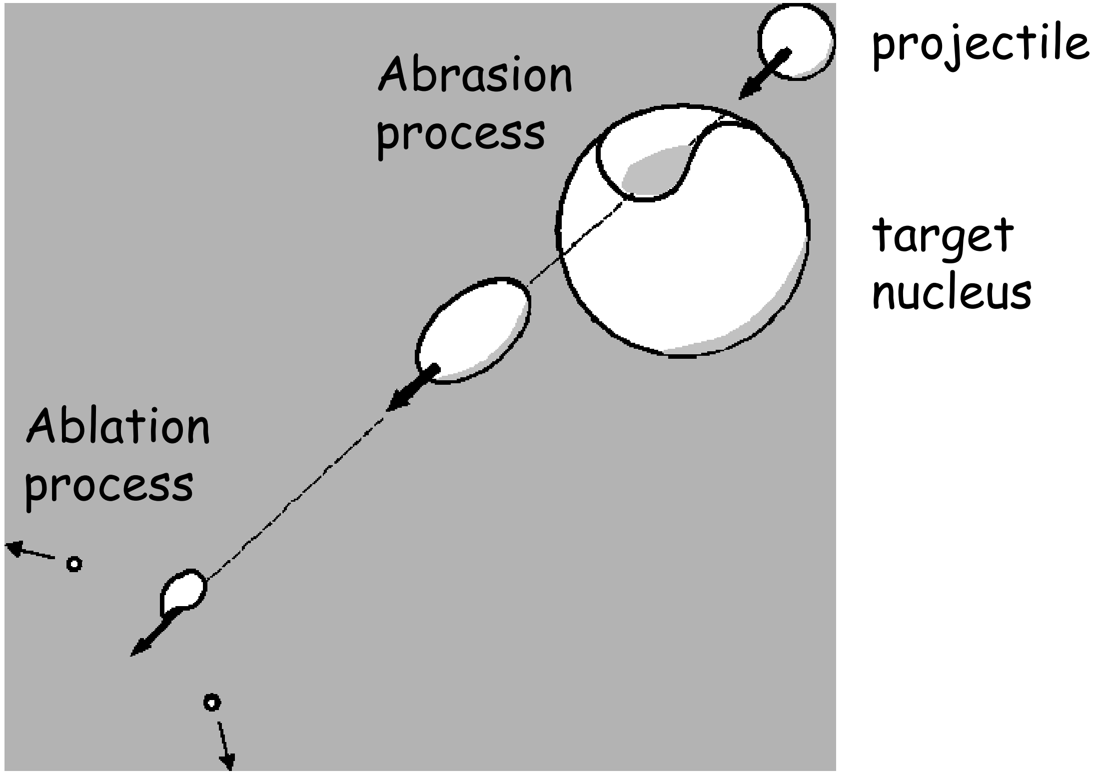
G4WilsonAbrasionModel & G4WilsonAblationModel

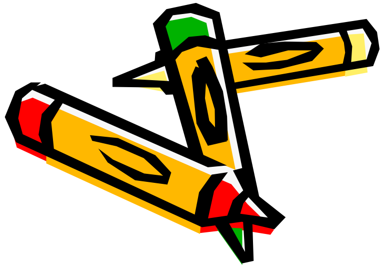
- G4WilsonAbrasionModel is a simplified macroscopic model for nuclear-nuclear interactions based largely on geometric arguments
- The speed of the simulation is found to be faster than models such as G4BinaryCascade, but at the cost of accuracy.
- A nuclear ablation has been developed to provide a better approximation for the final nuclear fragment from an abrasion interaction.
- Performing an ablation process to simulate the de-excitation of the nuclear pre-fragments, nuclear de-excitation models within Geant4 (default).
- G4WilsonAblationModel also prepared and uses the same approach for selecting the final-state nucleus as NUCFRG2 (NASA TP 3533)



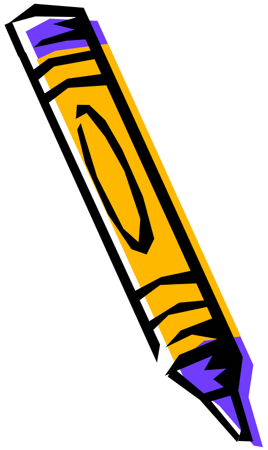


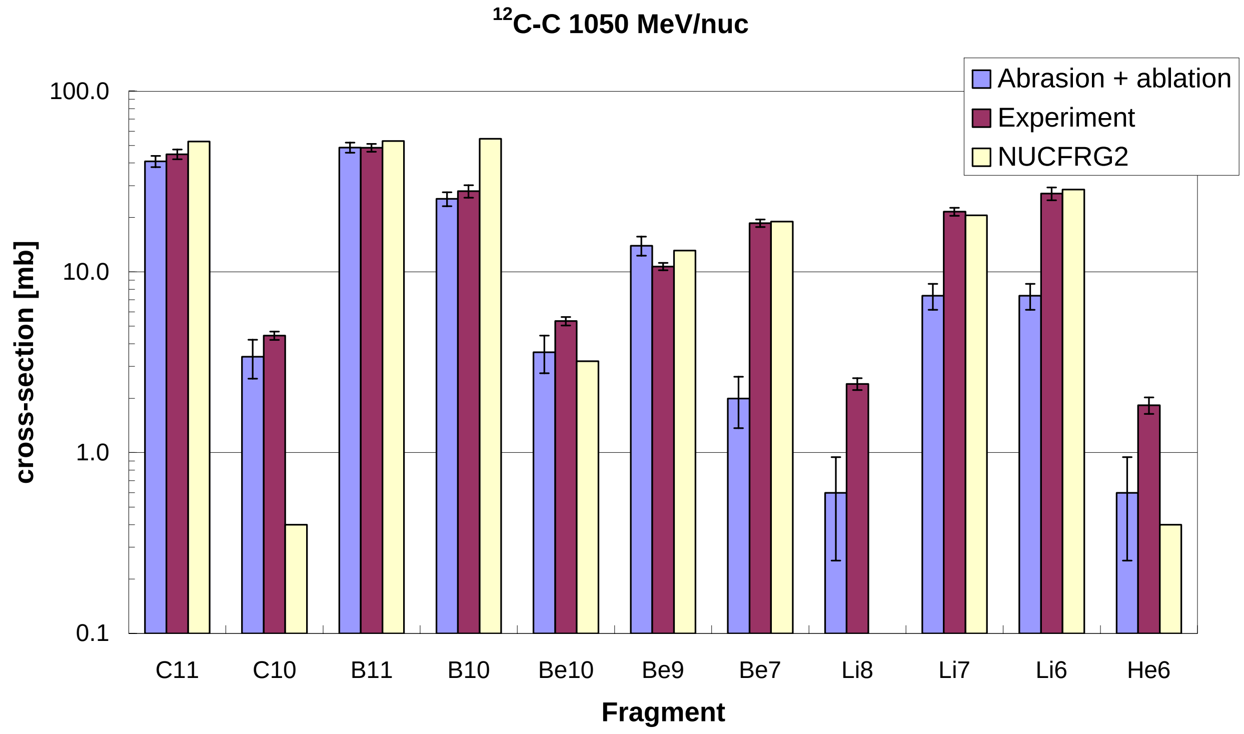
Abrasion & Ablation

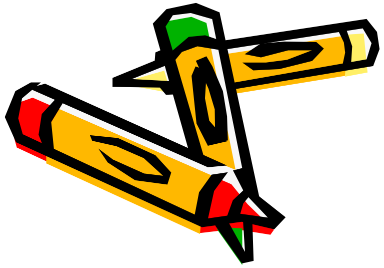


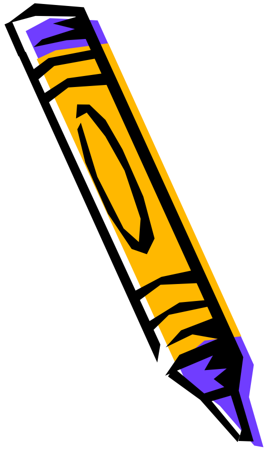


Validation of G4WilsonAbrasion model



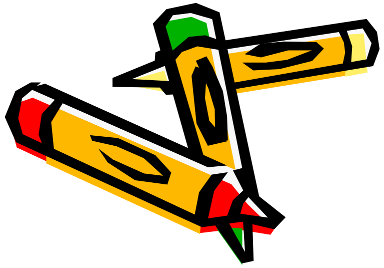






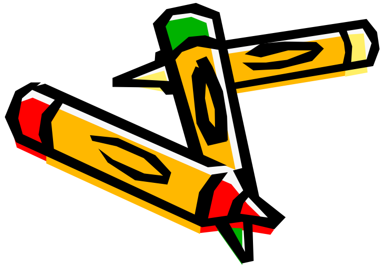
Ion Physics EelectorMagnetic Dissociation

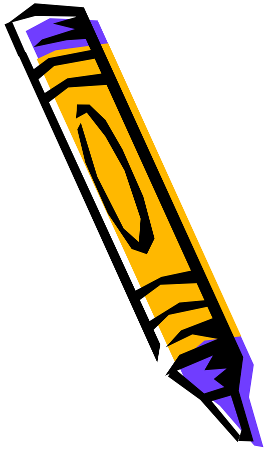
- Electromagnetic dissociation is liberation of nucleons or nuclear fragments as a result of electromagnetic field by exchange of virtual photons, rather than the strong nuclear force
- It is important for relativistic nuclear-nuclear interaction, especially where the proton number of the nucleus is large
- G4EMDissociation model and cross section are an implementation of the NUCFRG2 (NASA TP 3533) physics and treats this electromagnetic dissociation (ED).



Validation of G4EMDissociaton Model and Cross Section

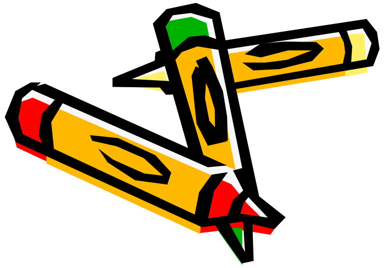
Projectile	Energy [GeV/nuc]	Product from ED	G4EM Dissociation [mbarn]	Experiment [mbarn]
Mg-24	3.7	Na-23 + p	124 ± 2	154 ± 31
Si-28	3.7	Al-27 + p	107 ± 1	186 ± 56
	14.5	Al-27 + p	216 ± 2	165 ± 24† 128 ± 33‡
O-16	200	N-15 + p	331 ± 2	293 ± 39† 342 ± 22*

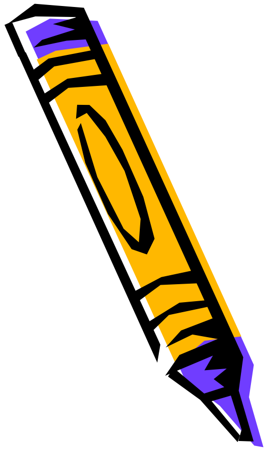




Ion Physics
Radio Active Decay

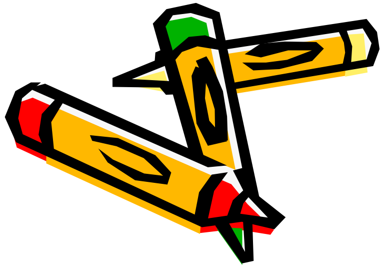
- To simulate the decay of radioactive nuclei
- Empirical and data-driven model
- α , β^{+}, β^{-} decay electron capture (EC) are implemented
- Data (RadioactiveDecay) derived from Evaluated Nuclear Structure Data File (ENSDF)
  - nuclear half-lives
  - nuclear level structure for the parent or daughter nuclide
  - decay branching ratios
  - the energy of the decay process.
- If the daughter of a nuclear decay is an excited isomer, its prompt nuclear de-excitation is treated using the G4PhotonEvapolation





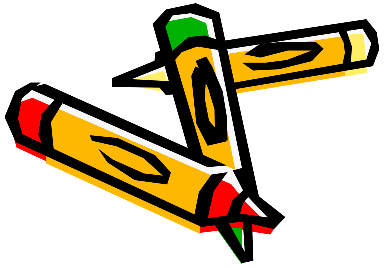
Radio Active Decay

- Analog sampling is default
- Biasing sampling also implemented
  - The decays occur more frequently at certain times
  - For a given decay mode the branching ratios can be sampled with equal probability
  - split parent nuclide into a user-defined number of nuclides



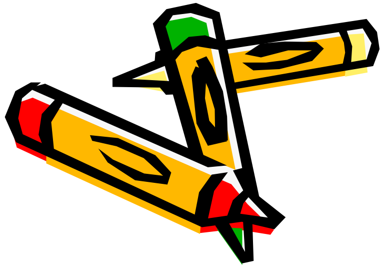
Radio Active Decay

- Many users who are interested in Radio Active Decay also have interests "General Particle Source".
- This will be introduced by Makoto briefly.
- **Geant4 General Particle Source Users Manual** (http://reat.space.qinetiq.com/gps/new_gps_sum_files/gps_sum.htm) is good place where users gets more detailed information.



Radio Active Decay
Important notice for v8.0 users

- Problem report #843
- Previously, G4GenericIon was derived from G4VIon, which overloaded GetAtomicMass() to return the baryon number. G4GenericIon now inherits from G4ParticleDefinition, whose GetAtomicMass() returns a (default) atomic mass number of 0. This makes G4RadioactiveDecay::IsApplicable(G4GenericIon*) fail (atomic mass is out-of-range), and hence renders G4RadioactiveDecay essentially unusable: any physics lists attempting to add G4RadioactiveDecay to ions will exit with an error. A fix users can apply until this bug is fixed is to get the G4GenericIon and call SetAtomicMass(1) before adding G4RadioactiveDecay.
- ------- Additional Comments From kurasige@phys.sci.kobe-u.ac.jp 02/24/06 22:05 ------- Fixed tag of particles-V08-00-01 will be included next release.
  - **Before the next release, users need to call SetAtomicMass(1) for GenericIon before adding G4RadioactiveDecay.**



Summary

- High Precision Neutron models are data driven models and its used evaluated data libraries.
- However the library is not complete because there are no data for several key elements.
- Geant4 has abundant processes for Ion interactions with matter and also without matter.
- Without any extra modules, users may simulate ion transportation in the complex and realistic geometries of Geant4.
- Validation has begun and the first results show reasonable agreement with data. This work continues.