

Hadronic Physics II

Geant4 Tutorial at Chalk River

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Outline

- Elastic processes and models
- Low energy neutron and proton physics
- Ion-ion physics
- Capture, stopping and fission reactions

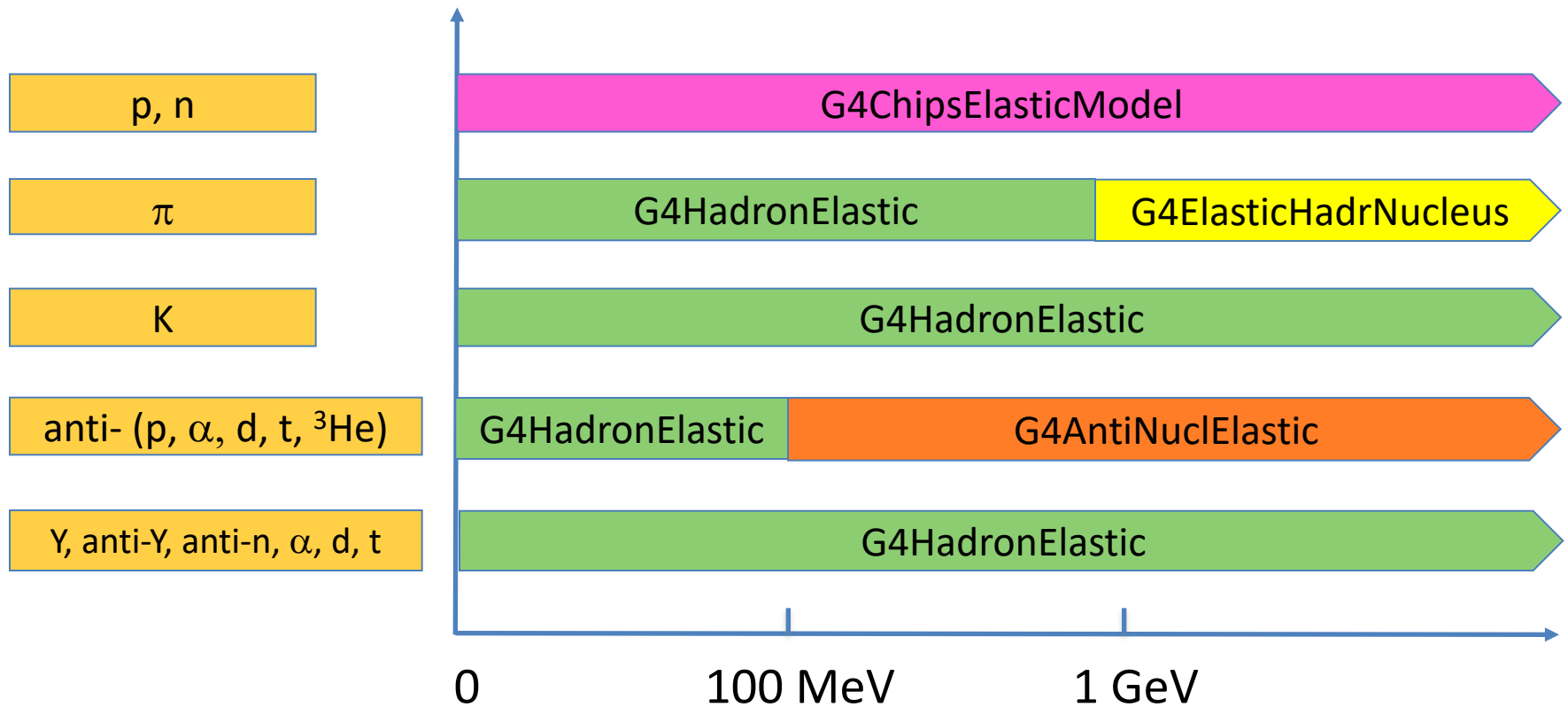
Hadron Elastic Scattering

- G4HadronElasticProcess: general elastic scattering
 - valid for all energies, all projectiles
 - includes p, n, π , K, hyperons, anti-nucleons, anti-hyperons, ...
 - uses proton cut values (scaled by Z) for recoil nucleus generation
- Implemented by
 - elastic cross section data sets
 - elastic models

Hadron Elastic Cross Sections

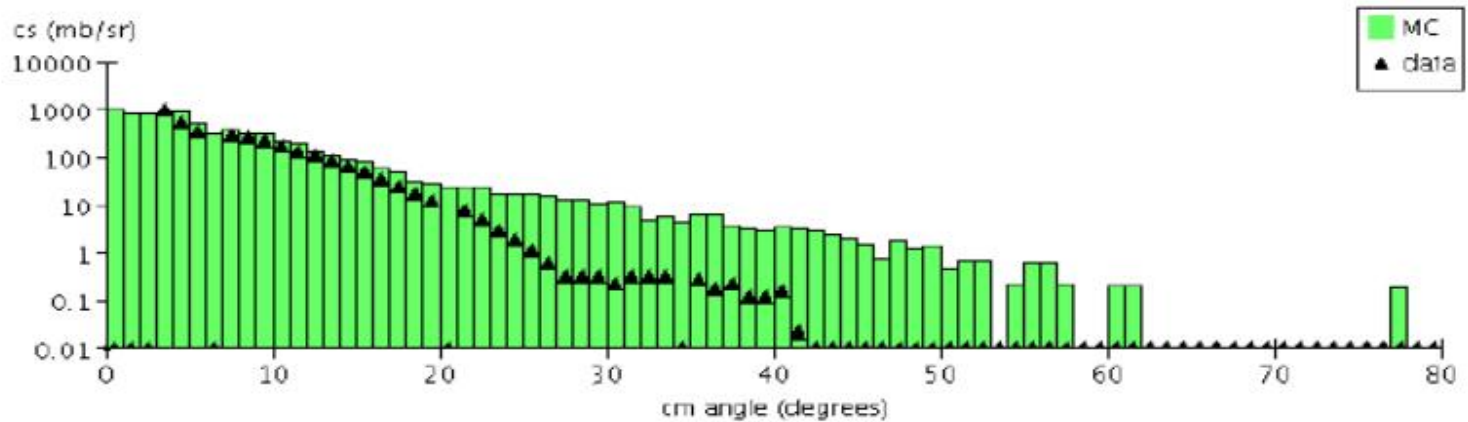
- G4HadronElasticDataSet (from Geant4/Gheisha)
- G4ComponentAntiNuclNuclearXS
 - anti-nucleon and anti-light nucleus elastic scattering from nuclei using Glauber approach
- G4BGGPionElasticXS
 - Barashenkov-Glauber-Gribov elastic scattering of pions and from nuclei using Barashenkov parameterization below 91 GeV and Glauber-Gribov parameterization above
- G4ChipsNeutron(Proton)ElasticXS
 - elastic cross sections extracted from CHIPS framework

Hadronic Models Implementing G4HadronElasticProcess

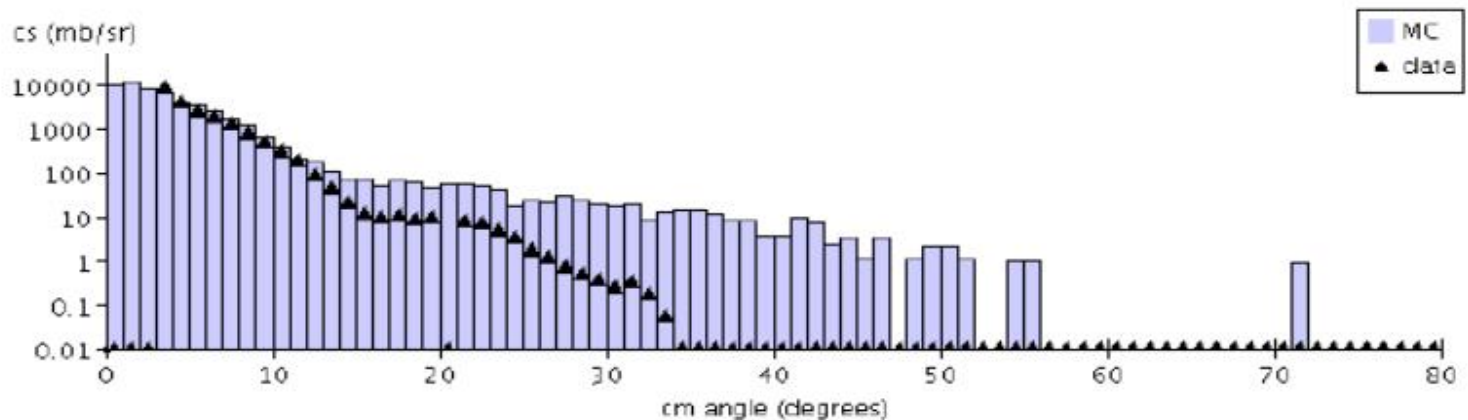


Elastic Scattering Validation (G4HadronElastic)

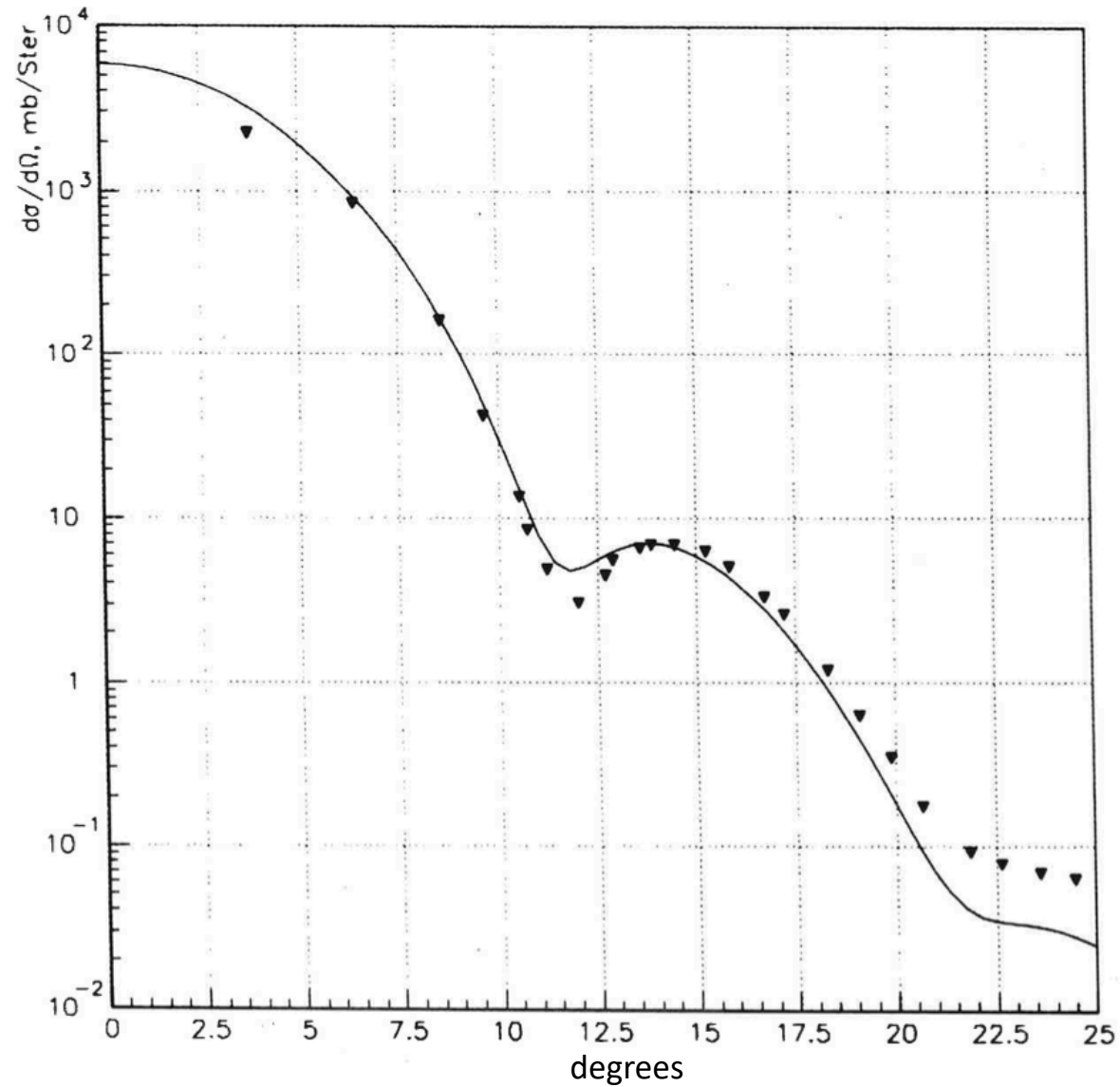
Elastic K^+ scattering from C at 800 MeV/c



Elastic K^+ scattering from Ca at 800 MeV/c



G4ElasticHadrNucleusHE (1 GeV p on C)



Low Energy Hadron Physics

- Below 20 MeV incident energy, Geant4 provides several models for treating n, p, d, t, ^3He and α interactions in detail
- The high precision models (ParticleHP) are data-driven and depend on a large database of cross sections, etc.
 - the G4NDL database is available for download from the Geant4 web site
 - TENDL optional database is also available
 - elastic, inelastic, capture and fission models all use this isotope-dependent data
- There are also models to handle thermal scattering from chemically bound atoms

High Precision Particles

- ParticleHP models provide elastic, inelastic, capture and fission for incident n, p, d, t, ^3He , α
 - mostly below 20 MeV for n
 - $0 < E < 200$ MeV for charged
 - also depends on large database (ENDF)
 - alternative dbs ready: TENDL, IAEA medical, IBANDL
 - recently merged with NeutronHP
- Code currently available
 - good comparisons so far with MCNP

Geant4 Neutron Data Library (G4NDL)

- Contains the data files for the high precision neutron models
 - includes both cross sections and final states
- From Geant4 9.5 onward, G4NDL is based solely on the ENDF/B-VII database
 - G4NDL data is now taken only from ENDF/B-VII, but still has G4NDL format
 - use G4NDL 4.0 or later
- Prior to G4 9.5 G4NDL selected data from 9 different databases, each with its own format
 - Brond-2.1, CENDL2.2, EFF-3, ENDF/B-VI, FENDL/E2.0, JEF2.2, JENDL-FF, JENDL-3 and MENDL-2
 - G4NDL also had its own (undocumented) format

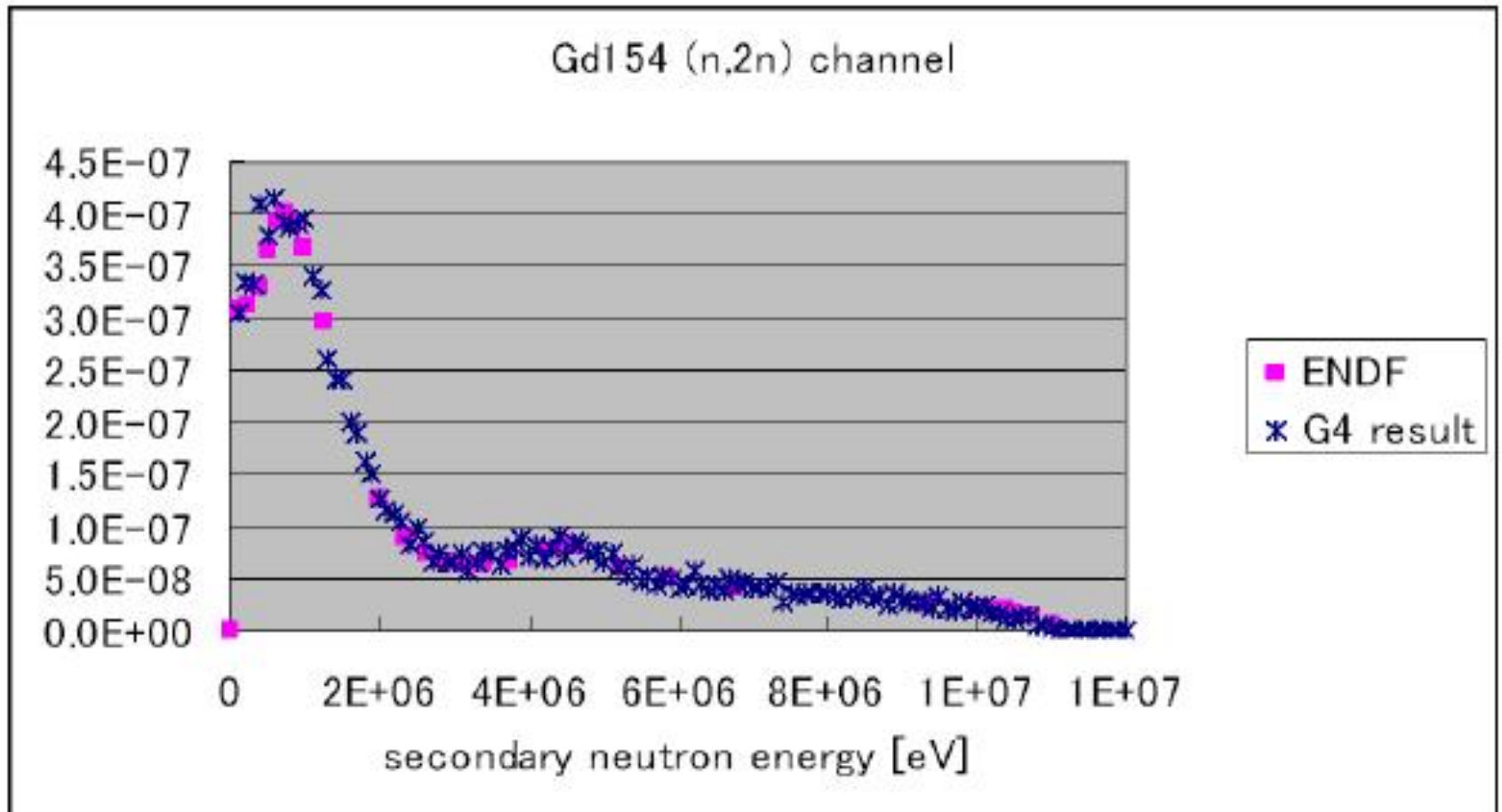
G4ParticleHPElastic

- Handles elastic scattering of n, p, d, t, ^3He , α by sampling differential cross section data
 - interpolates between points in the cross section tables as a function of energy
 - also interpolates between Legendre polynomial coefficients to get the angular distribution as a function of energy
 - scattered particle and recoil nucleus generated as final state
- Note that because look-up tables are based on binned data, there will always be a small energy non-conservation
 - true for inelastic, capture and fission processes as well

G4ParticleHPInelastic

- Currently supports many inelastic final states + n gamma (discrete and continuum)
 - $n(A,Z) \rightarrow (A-1, Z-1) n p$
 - $n(A,Z) \rightarrow (A-3, Z) n n n n$
 - $n(A,Z) \rightarrow (A-4, Z-2) d t$
 -
- Secondary distribution probabilities
 - isotropic emission
 - discrete two-body kinematics
 - N-body phase space
 - continuum energy-angle distributions (in lab and CM)

Neutron Inelastic: ^{154}Gd (n,2n) Comparison to Data



LEND – the new Livermore Neutron Models

- An alternative to the HP models
 - better code design
 - faster
 - Livermore database not yet as extensive G4NDL
- Corresponding model for each model in HP
 - elastic, inelastic, capture, fission
- Invocation in physics list:
 - use model names G4LENDElastic, G4LENDInelastic, G4LENDCapture, G4LENDFission, and cross sections G4LENDElasticCrossSection, G4LENDInelasticCrossSection, G4LENDCaptureCrossSection, G4LENDFissionCrossSection
- Database to use: go to <ftp://gdo-nuclear.ucllnl.org/pub/> and select G4LEND, then ENDF-B-VII.0.tar.gz

Ion-Ion Inelastic Scattering

- Up to now we've considered only hadron-nucleus interactions, but Geant4 has six different nucleus-nucleus collision models
 - G4BinaryLightIon
 - G4WilsonAbrasion/G4WilsonAblation
 - G4EMDissociationModel
 - G4QMD
 - G4Incl
 - FTF
- Also provided are several ion-ion cross section data sets
- Currently no ion-ion elastic scattering models provided

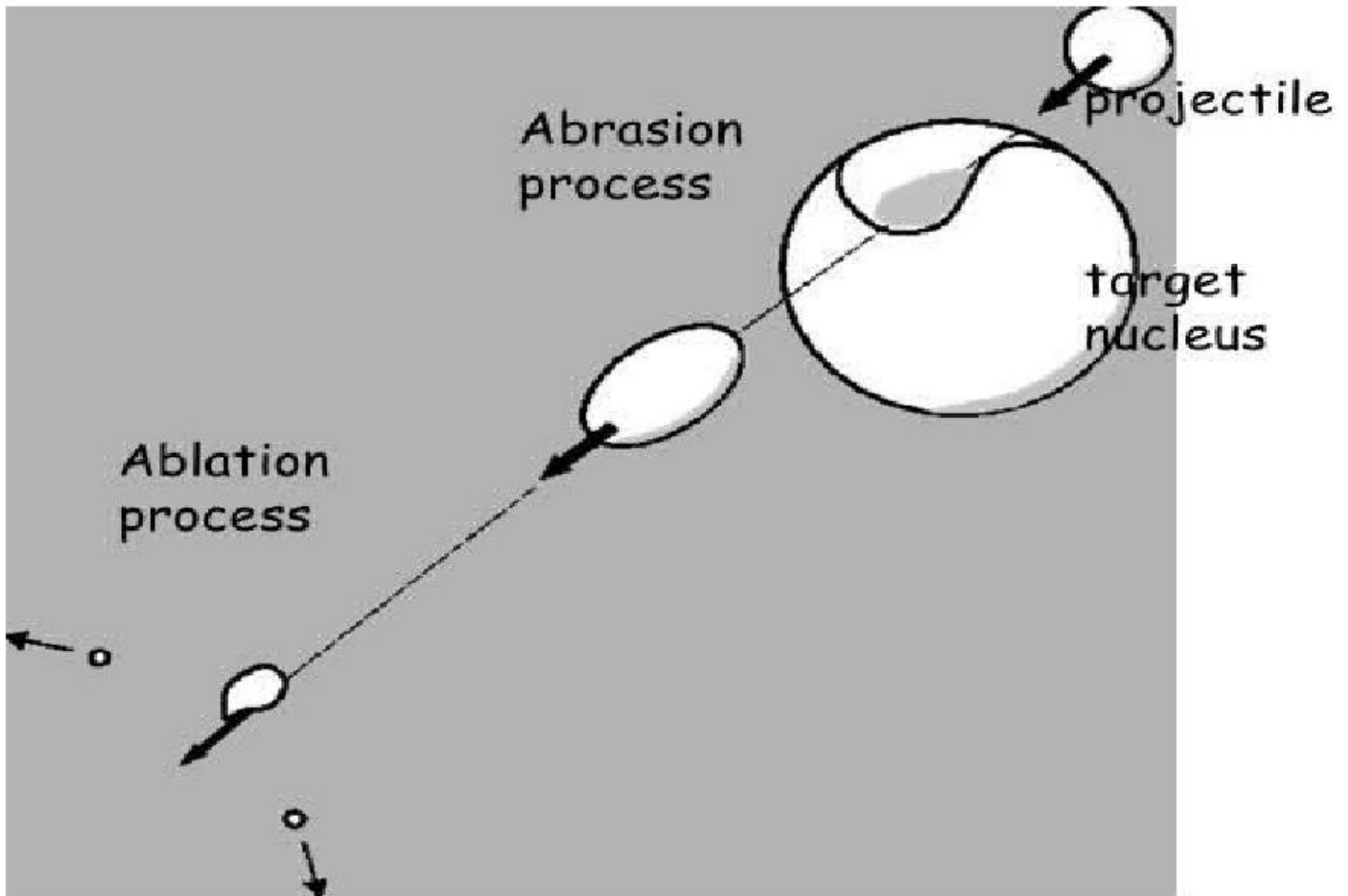
G4BinaryLightIonReaction

- This model is an extension of the G4BinaryCascade model (to be discussed later)
- The hadron-nuclear interaction part is identical, but the nucleus-nucleus part involves:
 - preparation of two 3D nuclei with Woods-Saxon or harmonic oscillator potentials
 - lighter nucleus is always assumed to be the projectile
 - nucleons in the projectile are entered with their positions and momenta into the initial collision state
 - nucleons are interacted one-by-one with the target nucleus, using the original Binary cascade model

G4WilsonAbrasion and G4WilsonAblation

- A simplified macroscopic model of nucleus-nucleus collisions
 - based largely on geometric arguments
 - faster than Binary cascade or QMD models, but less detailed
- The two models are used together
 - G4WilsonAbrasion handles the initial collision in which a chunk of the target nucleus is gouged out by the projectile nucleus
 - G4WilsonAblation handles the de-excitation of the resulting fragments
- Based on the NUCFRG2 model (NASA TP 3533)
- Can be used up to 10 GeV/n

Wilson Abrasion/Ablation



G4EMDissociation Model

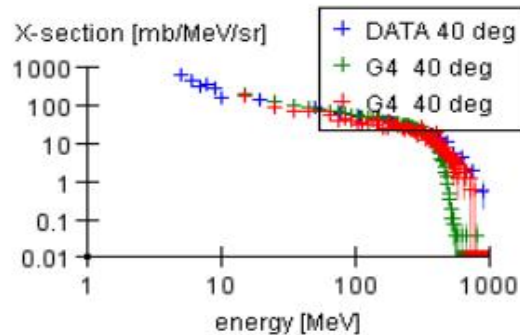
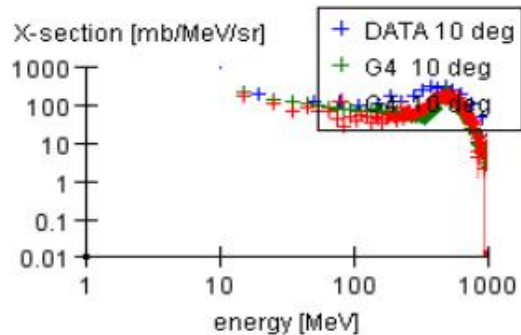
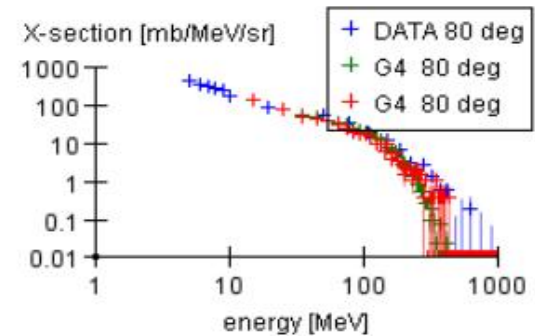
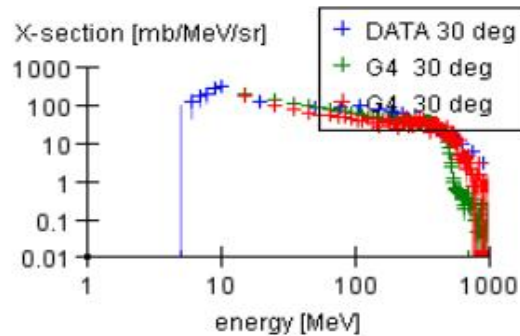
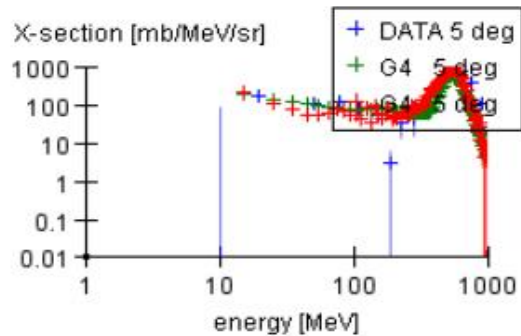
- Electromagnetic dissociation is the liberation of nucleons or nuclear fragments as a result of strong EM fields
 - as when two high-Z nuclei approach
 - exchange of virtual photons instead of nuclear force
- Useful for relativistic nucleus-nucleus collisions where the Z of the nucleus is large
- Model and cross sections are an implementation of the NUCFRG2 model (NASA TP 3533)
- Can be used up to 100 TeV

G4QMD Model

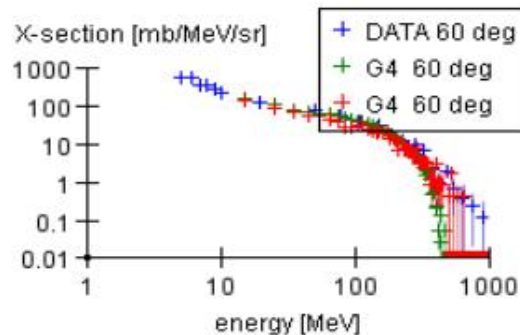
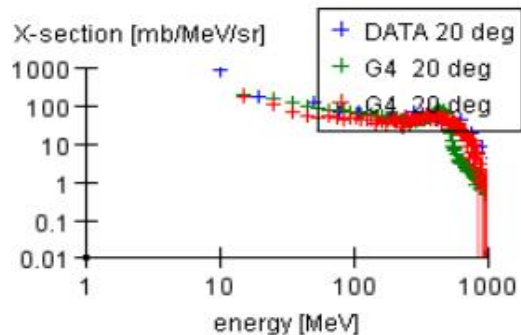
- BinaryLightIonReaction has some limitations
 - neglects participant-participant scattering
 - uses simple time-independent nuclear potential
 - imposes small A limitation for target or projectile
 - Binary cascade base model can only go to 5-10 GeV
- Solution is QMD (quantum molecular dynamics) model
 - an extension of the classical molecular dynamics model
 - treats each nucleon as a gaussian wave packet
 - propagation with scattering which takes Pauli principal into account
 - can be used for high energy, high Z collisions

QMD Validation

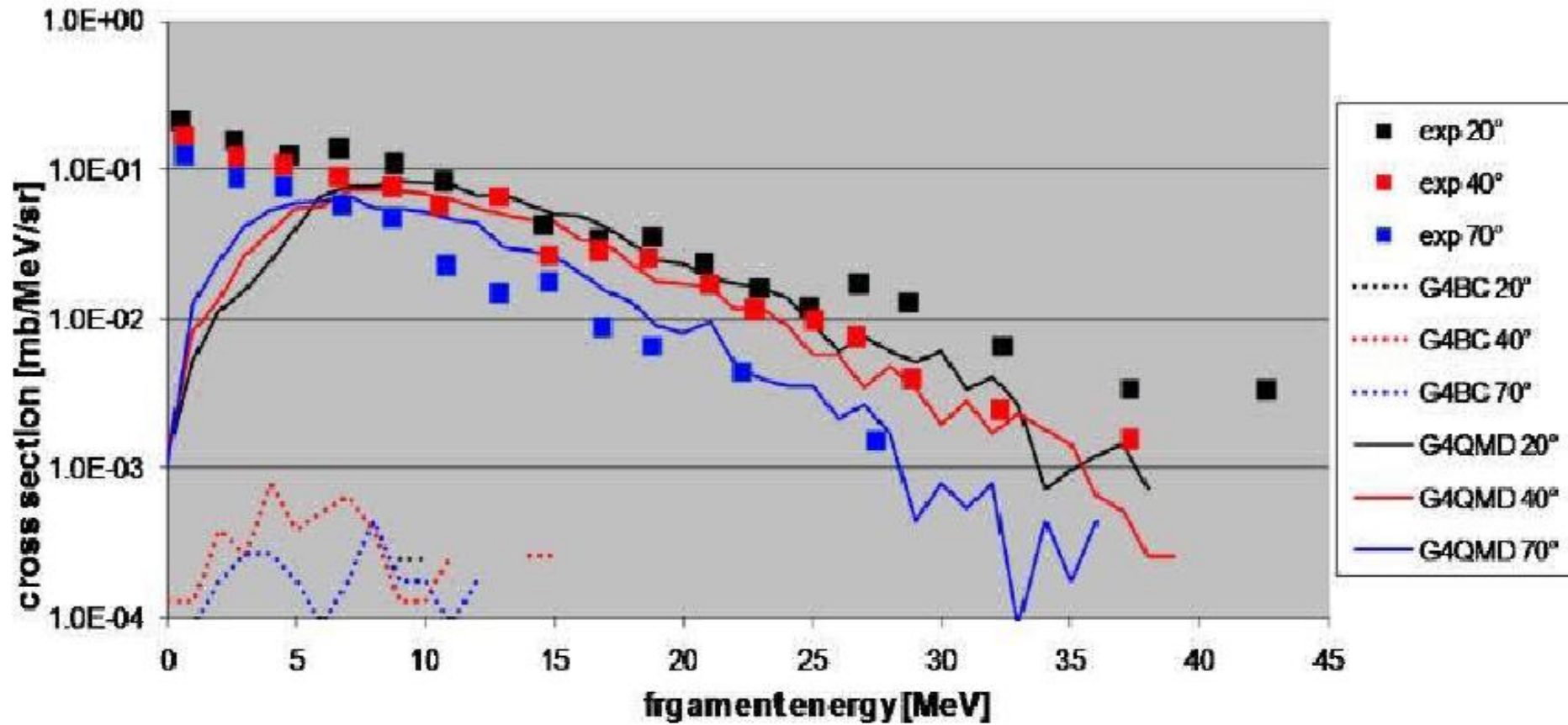
Ar40 560MeV/n on Lead



+ Data
+ G4BinaryCascade
+ G4QMD



180MeV Proton on Al Fragment A=7



Nucleus-nucleus Cross Sections

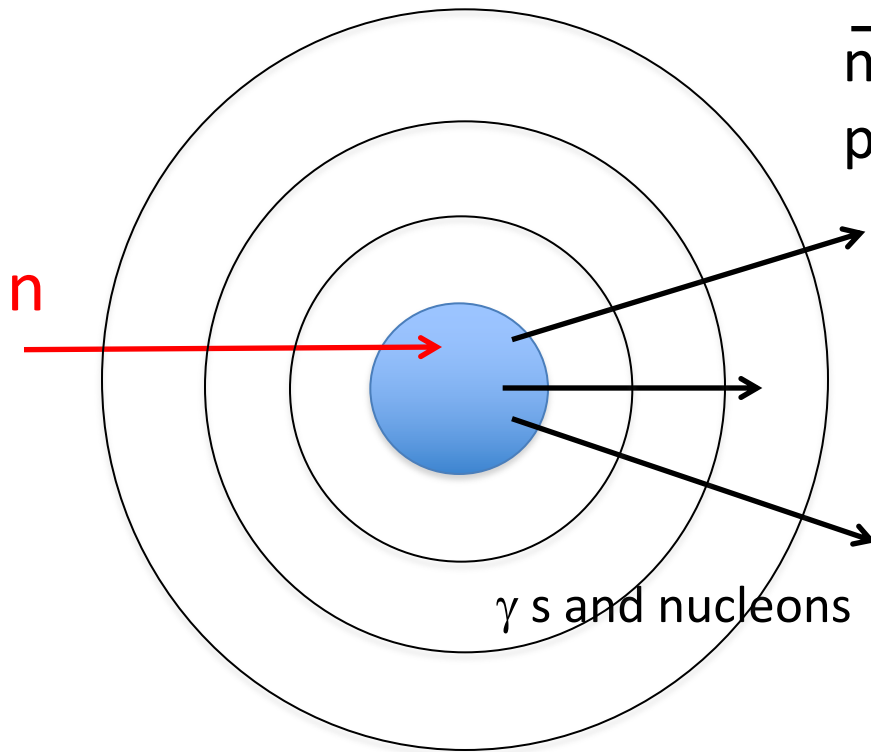
- Cross section data sets available from 10 MeV/N to 10 GeV/N
 - Tripathi, TripathiLight (for light nuclei)
 - Kox
 - Shen
 - Sihver
- These are empirical and parameterized cross section formulae with some theoretical insight
- G4GeneralSpaceNNCrossSection was prepared to assist users in selecting the appropriate cross section formula

Nucleus-nucleus Cross Sections

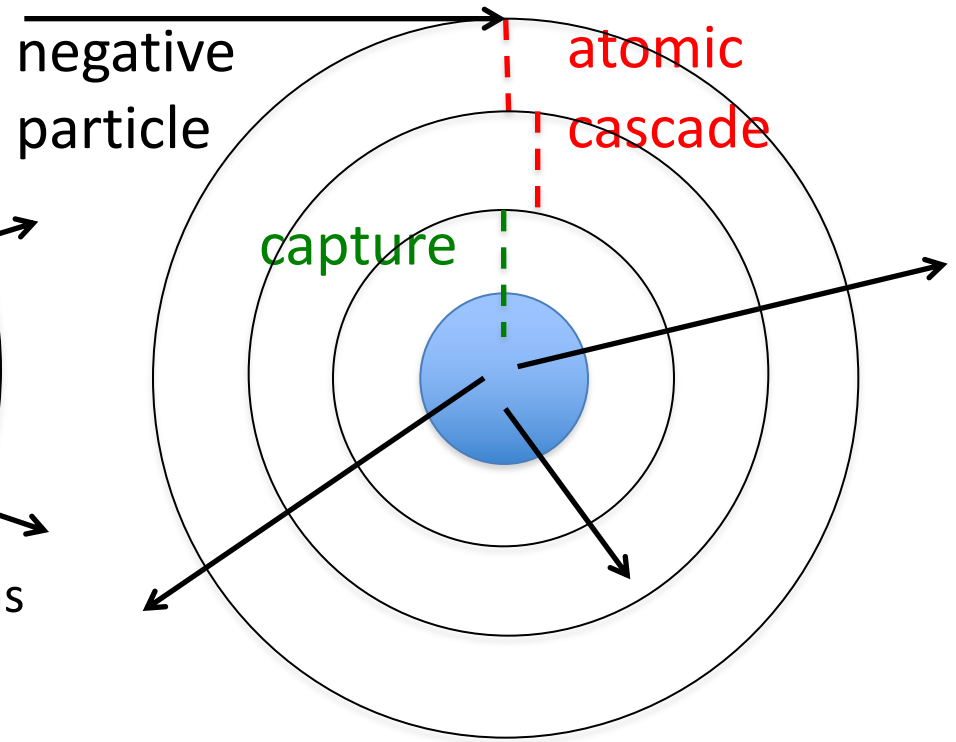
- G4ComponentGGNuclNuclXsc
 - total, inelastic and elastic nucleus-nucleus cross sections using Glauber model with Gribov corrections
- G4ComponentAntiNuclNucleusXS
 - total, inelastic and elastic cross sections for anti-nucleon and anti-nucleus nucleus scattering

Capture and Stopping Models

Capture



Stopping



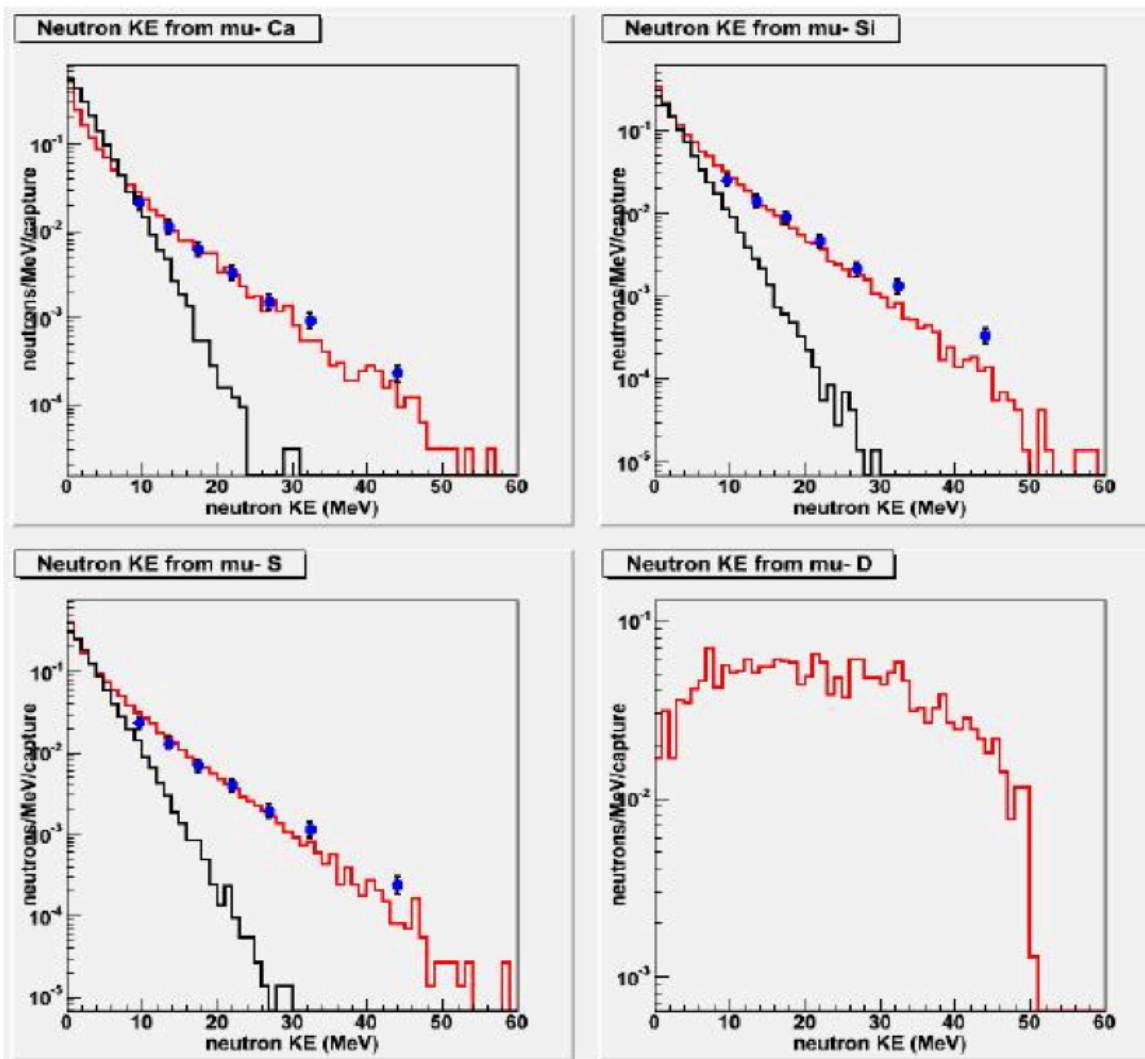
Stopped Hadron Models

- G4PiMinusAbsorptionBertini, G4KaonMinusAbsorptionBertini, G4SigmaMinusAbsorptionBertini
 - at rest process implemented with Bertini cascade model
 - G4Precompound model used for de-excitation of nucleus
 - includes atomic cascade but not decay in orbit
- G4AntiProtonAbsorptionFritiof, G4AntiSigmaPlusAbsorptionFritiof
 - FTF model used because > 2 GeV available in reaction
 - G4Precompound model used for de-excitation of nucleus
 - includes atomic cascade but not decay in orbit

Stopped Muon Models

- G4MuonMinusCapture
 - atomic cascade, with decay in orbit enabled
 - K-shell capture and nuclear de-excitation implemented with Bertini cascade model
 - used in most physics lists
- G4MuonMinusCaptureAtRest
 - atomic cascade, with decay in orbit enabled
 - K-shell capture uses simple particle-hole model
 - nuclear de-excitation handled by G4ExcitationHandler

Muon Capture using Bertini Model (red), old model (black)



Capture Models

- Neutrons, anti-neutrons never really stop, they just slow down from elastic scattering or are absorbed
 - kinetic energy must be taken into account
- G4HadronCaptureProcess
 - in-flight capture for neutrons
 - model implementations:
 - G4ParticleHPCapture (below 20 MeV)
 - G4NeutronRadCapture (all energies)
- G4AntiNeutronAnnihilationAtRest
 - implemented by GHEISHA parameterized model

Fission Processes and Models

- Many hadronic models already include fission implicitly
 - included in nuclear de-excitation code
 - in that case don't add fission process to physics list -> double counting
 - usually only needed in special cases
- G4HadronFissionProcess can use two models
 - G4ParticleHPFission
 - specifically for neutrons below 20 MeV
 - fission fragments produced if desired
 - G4FissLib: Livermore Spontaneous Fission
 - handles spontaneous fission as an inelastic process
 - no fission fragments produced, just neutron spectra

Fission Processes and Models

- Fission fragments can be produced with Wendt fission model
 - automatically available when ParticleHPFission is used
 - invoke by setting two environment variables:
 - G4NEUTRONHP_PRODUCES_FISSION_FRAGMENTS
 - G4NEUTRON_HP_USE_WENDT_FISSION_MODEL
 - see extended example
geant4/examples/extended/hadronic/FissionFragment
- Model developed by Geant4 user who needed fission fragments in addition to emitted neutrons for reactor studies
 - worked with Geant4 developer and contributed code

Summary (1)

- All hadron elastic scattering is handled by one process
 - but implemented by several models depending on energy and particle type
- Specialized high precision models (n, p, d, t, ^3He , α)
 - HP models which use G4NDL, now based entirely on ENDF/B-VII
 - alternative LEND (Livermore) models are faster but currently less extensive – use the ENDF.B-VII library
- Several models for nucleus-nucleus collisions
 - Wilson models fast, but not so detailed
 - Cascade models more detailed but slower
 - QMD model very detailed but not so fast

Summary (2)

- Capture, stopping processes for selected particle types
- Several fission models available
 - some implicitly included in other models
 - some must be explicitly added by users
 - make sure not to double-count !