Low Energy Hadronic Physics

Dennis Wright (SLAC)
Geant4 Collaboration Meeting
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Outline

• General Hadronic
• Cross sections

• Hadron elastic
• ParticleHP

• De-excitation models
• Cascade models

• Radioactive decay
General Hadronic

• Removed final state rotation for both elastic and inelastic processes
  – this was done in past to remove possible phi asymmetries from models
  – models now have the responsibility of generating correct final state angular distributions
    • most models already did this so process rotation was redundant

• GHEISHA cross sections no longer used as defaults
  – either in elastic or inelastic
  – but still available

• Looking at hadronic models per region
  – user-defined processes
  – generic biasing
Hadron Elastic Cross Sections

• GHEISHA cross sections no longer used by default

• Current best list:
  – neutron: NeutronElasticXS
  – proton: Barashenkov-Glauber-Gribov
  – $\pi^+ / \pi^-$: Barashenkov-Glauber-Gribov
  – d, t, $^3$He, $\alpha$: Glauber-Gribov nucleus-nucleus
  – anti-(p, d, t, $^3$He, $\alpha$): Glauber-Gribov anti-nucleus-nucleus
  – everything else (anti-n, kaons, hyperons, anti-hyperons): Glauber-Gribov

• Above cross sections applied at all energies
Hadron Cross Sections

• New cross section sets for hyperons, b- and c-mesons (V. Grichine)

• Low energy behavior of elementary cross section sets examined by (V. Ivantchenko)
  – several internal limits lowered or removed
  – compared several sets: \( pp, pn, \pi^+p, \pi^-p \)
  – improved parameterizations recommended
NS is the current recommendation for elementary x-section. BGG uses NS as an input. XS has internal limit to be fixed.
New Low Energy $\pi$ Validation
(Alikhan Yeltokov)

Most recent results, Low energy
Hadronic Models Implementing G4HadronElasticProcess (10.5)

- $p, n$
- $\pi$
- $K$
- anti-$p$, $\alpha$, $d$, $t$, $^3$He
- $Y$, anti-$Y$, anti-$n$, $\alpha$, $d$, $t$

Graph showing energy levels from 0 MeV to 1 GeV with different models:
- G4ChipsElasticModel
- G4HadronElastic
- G4AntiNuclElastic
- G4ElasticHadrNucleus
Hadronic Models Implementing G4HadronElasticProcess (10.6)

- p, n
- π
- K
- anti- (p, α, d, t, \(^3\)He)
- Y, anti-Y, anti-n, α, d, t

The diagram shows the processes implemented in G4 Hadronic Elastic models:

- G4ChipsElasticModel
- G4ElasticHadrNucleus
- G4HadronElastic
- G4HadronElastic
- G4AntiNuclElastic

The energy range is indicated from 0 to 1 GeV.
Particle HP

• By default tries to conserve energy/momentum event-by-event
  – works sometimes
  – in general no

• Current ParticleHP code often makes common sense modifications to get energy conservation, but this often destroys agreement with ENDF energy distributions
  – ENDF database rules deal only with distributions
  – violating these rules can cause unexpected results (like extra gammas) which make validation difficult
  – many environment variables exist to “fix up” ENDF

• Quick and dirty fix:
  – export G4NEUTRONHP_DO_NOT_ADJUST_FINAL_STATE=1
  – export G4PHP_DO_NOT_ADJUST_FINAL_STATE=1
Particle HP

• Better idea:
  – remove environment variables
  – refactor code for two modes of operation
    • ENDF mode: no event-by-event energy/momentum conservation is forced
    • energy/momentum conservation forced – do not use ENDF data for final state – use a final state model instead

• This choice follows ENDF rules
  – better validation results and cross-code (MCNP) comparisons

• Methods for ENDF mode fairly easy to do
• Significant work to add new methods for modeling the final state in energy conservation mode
Particle HP Verification (E. Mendoza, D. Cano-Ott)

\[ C_1 = \int \Phi(E) \, dE \quad \quad R_1 = C_1(\text{MCNP})/C_1(\text{Geant4}) \]
\[ C_2 = \int \Phi(E) / \sqrt{E} \, dE \quad \quad R_2 = C_2(\text{MCNP})/C_2(\text{Geant4}) \]
\[ C_3 = \int \Phi(E) \cdot \sqrt{E} \, dE \quad \quad R_3 = C_3(\text{MCNP})/C_3(\text{Geant4}) \]
De-excitation Models: Fermi Breakup

• For disintegration of light nuclei (Z < 9, A < 17)
• Breakup into 2-, 3-, 4-body final states

• Geant4 10.4 and earlier: hard-coded data to precompute decay probabilities
  – 260 final states from data files and 399 reactions

• 10.5 and later (G4FermiBreakupVI)
  – 380 final states and 991 reactions including 80 fragment types not known in data (e.g. $^8$H, $^2$He)
  – fully based on data in G4GAMMALEVELDATA
  – only binary decay chains considered, with standard Coulomb barrier calculation
  – slightly slower than old model
De-excitation Models: Evaporation

- **G4Evaporation:**
  - simplified integration of inverse cross section and final state sampling \( \rightarrow \) some speed-up
  - optimized initialization reduced memory churn

- **G4PhotonEvaporation:**
  - if no transition data in database for level, go to nearest level (was ground state in past)
  - corrected internal conversion probability for some isotopes
De-excitation Models: Level Density

• At high excitation values, nuclear levels are too many and too close together to deal with separately -> parameterize the level density

• Before Geant4 10.5 $\rho_L = 0.1*A$

• New parameterization:
  – based on fits to data (A. Mengoni, Yu. Nakajima JNST 31 (1994) 151.)
  – $\rho_L = \alpha A * (1 + \beta / A^{1/3})$
  – same parameterization must be used for fission, evaporation and photon evaporation to get reasonable results

• New option in G4DeexPrecoParameters to get/set LevelDensityFlag
  – new default $\rho_L = 0.075 * A$
Cascade Models: INCLXX

• Updated to INCL++ 6.28
  – independently maintained code on which INCLXX (Geant4 version) is based
  – new data set required: G4INCL-1.0 (pointed to by G4INCLDATA environment variable)

• ABLA
  – extended to include hypernuclei
Cascade Models: Bertini

- Phase space generation
  - for final states with more than two bodies
  - old Bertini generator incorrect

- Tried Kopylov phase space generator
  - validation results inconclusive (better in some regimes, worse in others)
  - keep original generator for now

- New possibility
  - INCL++ uses a biased phase space generator (based on Raubold-Lynch method)
  - entire final state can be rotated by arbitrary angle
  - sample angle from exponential describing elastic p-p and pi-p scattering
  - adapt this to Bertini
Original Bertini Phase Space Generator: samples $\sin(\theta)$ and reflects

$\pi^- p \rightarrow \pi^- X \ @ \ 8 \ GeV/c$

$\pi^+ p \rightarrow \pi^+ X \ @ \ 8 \ GeV/c$
Biased Phase Space $p + C \rightarrow p + X$ @ 8 GeV/c

HARP data: black dots
Original Bertini generator: green crosses
Biased phase space: black crosses
Biased Phase Space $\pi^- + C \rightarrow \pi^- + X$ @ 8 GeV/c

HARP data:
black dots

Original Bertini generator:
green crosses

Biased phase space:
black crosses
Radioactive Decay Refactoring Completed

• Remove all radioactive decay biasing methods from G4RadioactiveDecay
  – better CPU performance for those not using biasing
  – cleaner code
  – new class name: G4RadioactiveDecayBase
  – rename as G4RadioactiveDecay for major release

• Put all biasing functionality in derived class
  – use for activation studies
  – new class name: G4Radioactivation

G4RadioactiveDecayBase (no biasing)

G4Radioactivation (implements all biasing methods)
Radioactive Decay: Fission

- Spontaneous fission channel added
  - competes with all other channels: $\alpha$, $\beta$, IC, IT
  - gets branching ratio from ENSDF database (RadioactiveDecay5.3)

- Uses the Livermore spontaneous fission model already in Geant4 (G4fissionEvent)
  - currently valid only for Cf isotopes since only they have sufficient data
  - neutrons and gammas generated in final state
  - no fragments, but could be added at later date once a fragment generation model is developed
Radioactive Decay: Electron Capture

• N-shell capture added to G4ECDecay
  – machinery is there for all nuclides but currently data for only a few are included in RadioactiveDecay5.3

• Subshell capture ratios added
  – tables of PL2/PL1, PM2/PM1 and PN2/PN1 added to RadioactiveDecay5.3
  – based on bound electron radial wave amplitudes from Bambynek (1977)
  – partial probabilities of subshell capture calculated from above tables
Testing and Validation of Radioactive Decay

• Laurent developed G4Raddecay testing suite
  – checks if Geant4 code reproduces data
  – checks of G4 database agrees with external databases
  – see talk in nuclear physics parallel session

• Suite to be included in Geant4 soon
Summary

• General Hadronic
  – GHEISHA cross sections no longer default
  – no final state rotation at process level

• Cross section review
  – especially for low energy → better behavior

• Hadron elastic
  – validation ongoing
  – better implementation for pions

• ParticleHP
  – develop energy conservation mode and ENDF mode
  – verification ongoing
Summary

• De-excitation models
  – new level density default = 0.075 A
  – improve Fermi breakup model for 10.5 and later

• Cascade models
  – ABLA deexcitation model can now handle hypernuclei
  – Bertini cascade still has phase space problems

• Radioactive decay
  – refactored into biased and un-biased
  – spontaneous fission and N-shell electron capture added
  – testing suite nearly ready