Overview of Geant4 Hadronics

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Outline

- Hadronic processes
  - Review of G4 processes
  - Model and cross section management
  - Class diagrams
- Models
  - Types
  - Organization
  - Class diagrams
- Cross Sections
  - Short description of available sets
Decides when and where an interaction will occur using GetPhysicalInteractionLength (GPIL) method

- Needs cross sections

Generates the final state using Dolt method

- Needs interaction model

Three types of GPIL, Dolt methods

- PostStep, AlongStep, AtRest
Each particle class has a process manager

- Particle
  - Process 1
    - Model 1
      - Model 2
        - .
        - .
        - Model n
  - Process 2
    - .
    - .
  - Process 3
    - C.S. Set 1
      - C.S. Set 2
        - .
        - .
        - C.S. Set n
  - Process n

Energy range manager

Cross section data store
Cross Section Management

GetCrossSection() sees last set loaded for energy range

Set 1
Set 2
Set 3
Set 4

Energy
Model Management

Model returned by GetHadronicInteraction()

Model 1
Model 3
Model 5
Model 4
Model 2

Energy
Hadronic Models – Data Driven

- Characterized by lots of data
  - Cross section
  - Angular distribution
  - Multiplicity

- To get interaction length and final state, models simply interpolate data
  - Usually linear interp of cross section, coef of Legendre polynomials

- Examples
  - Neutrons (E < 20 MeV)
  - Coherent elastic scattering (pp, np, nn)
  - Radioactive decay
Hadronic Models – Theory Driven

- Dominated by theory (QCD, Strings, ChPT, …)
  - Not as much data (used for normalization, validation)
- Final states determined by sampling theoretical distributions
- Examples:
  - Parton String (projectiles with $E > 5$ GeV)
  - Intra-nuclear cascade (intermediate energies)
  - Nuclear de-excitation and breakup
  - Chiral invariant phase space (all energies)
Hadronic Models - Parameterized

- Depends on both data and theory
  - Enough data to parameterize cross sections, multiplicities, angular distributions
- Final states determined by theory, sampling
  - Use conservation laws to get charge, energy, etc.
- Examples
  - Low energy, high energy models (GHEISHA)
  - Fission
  - Capture
In G4 hadronics, “model” has two meanings:

1. A class, which can be registered to a process, which provides final state information and sometimes initial state interaction. Derived classes are derived from G4HadronicInteraction.

2. A class which implements the methods of (1) using an underlying physics model such as G4ChiralInvariantPhaseSpaceModel or G4PreCompoundModel.
Hadronic Process/Model Framework

Process
- At rest
- In flight

Cross sections

Models
- Data driven
- Parameterized
- Theory driven

Intranuclear cascade

String/parton

Level 1

Level 2

Level 3

Level 4
G4HadronicProcess
-G4CrossSection
-GetCrossSection
-ChooseHadInteraction

G4Hadron-FissionProcess
G4Hadron-InelasticProcess
G4Hadron-ElasticProcess
G4Hadron-CaptureProcess

G4CrossSection-DataStore
-AddDataSet
-GetCrossSection

Data Set 1

G4VCrossSection-DataSet
-IsApplicable
-GetCrossSection

Data Set 2
G4HadronicProcess
  GeneralPostStepDoIt
  RegisterIsotopeProductionModel
  EnableIsotopeProduction
  DisableIsotopeProduction

G4IsoParticleChange

G4VIsotopeProduction

G4NeutronIsotopeProduction
G4HadronicInteraction
- ApplyYourself
- SetMinEnergy
- SetMaxEnergy
- DeActivateFor

G4TheoFSGenerator
- ApplyYourself

G4VHighEnergy-Generator

G4VIntraNuclear-TransportModel
- ApplyYourself
- Propagate

G4HadronKinetic-Model

G4VPseudoCompound-Model
- ApplyYourself
- DeExcite
- SetExcitationHandler

G4VExcitation-Handler
- BreakItUp
G4VPartonStringModel
   Scatter
   GetWoundedNucleus
   GetStrings

G4VStringFragmentation
   FragmentString

G4FTFModel
   GetStrings
   GetWoundedNucleus

G4QuarkGluonStringModel
   GetStrings
   GetWoundedNucleus

G4PythiaFragmentation Interface

G4LongitudinalStringDecay
Default cross section sets for each type of hadronic process
- Fission, capture, elastic, inelastic (GHEISHA)
- Can be overridden or completely replaced

Different types of cross section sets
- Some contain only a few numbers to parameterize c.s.
- Some represent large databases (data driven models)
Available Cross Sections (1)

Low energy neutrons
- G4NDL available as Geant4 distribution data files
  - Available with or without thermal cross sections
- All data sets conform to ENDF/B-VI format
- Data taken from several Evaluated Nuclear Data Libraries: ENDF/B, Jef, EFF, JENDL, FENDL, CENDL, ENSDF, Brond, MENDL
Available Cross Sections (2)

Photo-nuclear
- For gammas from neutron threshold upward
- GDR, quasideuteron, Delta included
- Parameterized from data from 14 nuclei (H to U)

Electro-nuclear
- Use method of equivalent photons, then photo-nuclear cross section to calculate electro-nuclear
- Tabulated up to 2 GeV, function above 2 GeV
Available Cross Sections (3)

Ion reactions on hydrogen
- Taken from inelastic proton cross section
- Good for E/A < 20 GeV, for incident ions A > 4

Ion-nucleus reactions
- Calculated using Tripathi cross section formula
- Good for E/A < 1 GeV, for incident ions A > 2
Available Cross Sections (4)

- “High energy” neutron and proton cross sections
  - Use reaction cross section
  - Valid between 20 MeV and 20 GeV

- Data for isotope production models
  - Both neutron and proton induced production
  - Based on MENDL (medium energy nuclear data library), inclusive cross section parameterizations and G4NDL
  - Good for $E < 100$ MeV
Conclusions (1)

Many processes, models, cross sections to choose from (compare to EM)

Very flexible framework of models – easy to add new ones at any level

Problems:
- Difficult to choose correct model
- Much validation to be done
Conclusions (2)

Geant4 Policy:
- Don’t provide default processes, models
- Allow user to choose

To make things easier, example physics lists will soon be available