Fission Models in Geant4: Status and Plans

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Outline

- Survey of fission in Geant4
- Strengths and weaknesses of models
- Improvements required or desired
- Plans/Tasks and Discussion
- Summary

Fission Process and Models in Geant4

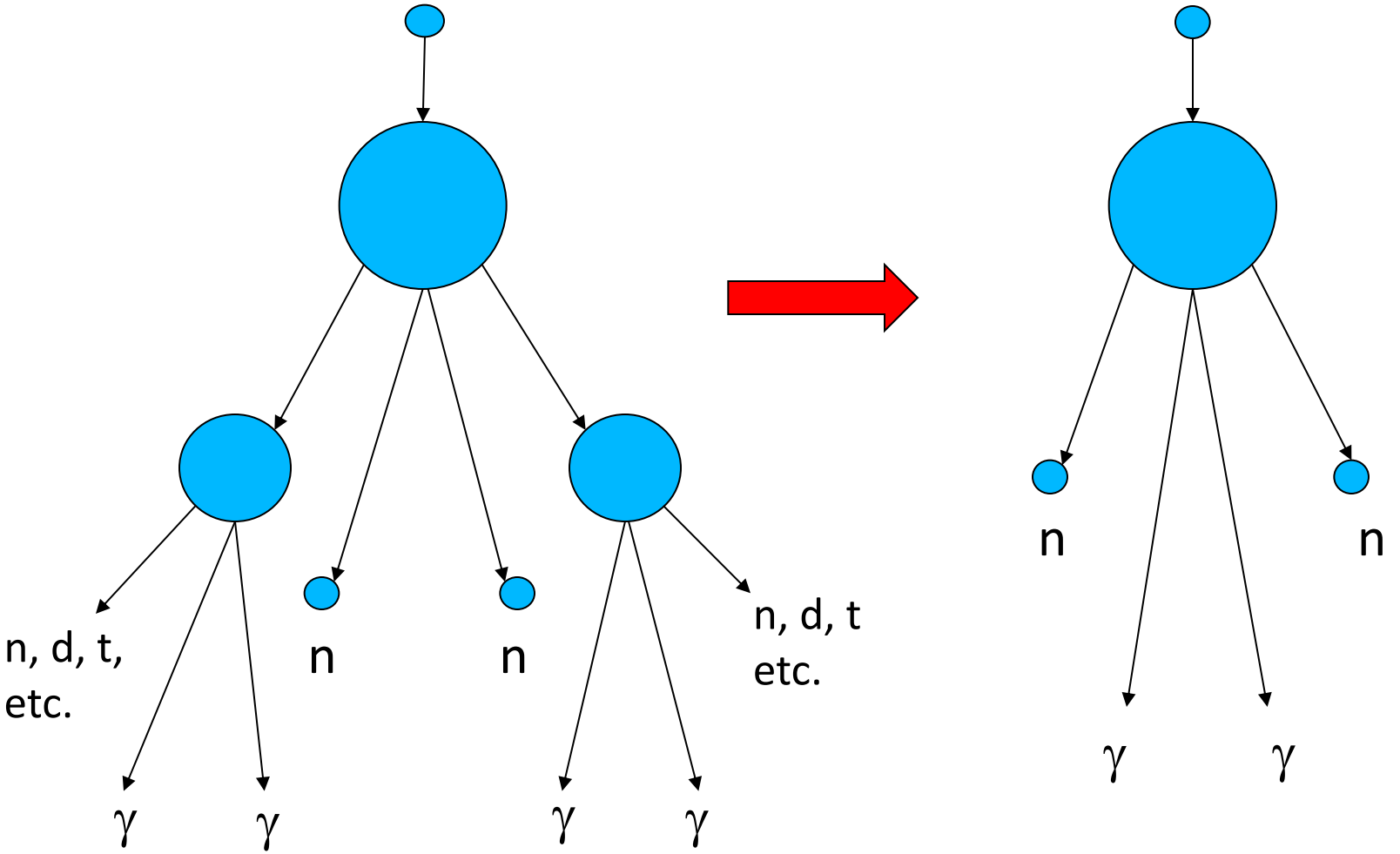
Survey of Fission in Geant4

- G4HadronFissionProcess
  - a separate process in the hadronic framework
  - models: G4LFission, ParticleHP, LEND
- INCL++/ABLA
  - option to use G4Precompound
- Bertini
  - G4Fissioner
  - G4EquilibriumEvaporator
  - option to use G4Precompound
- Deexcitation/fission called by G4Precompound
- Spontaneous fission
  - see radioactive decay

G4HadronFissionProcess

- One of the four main hadronic processes
  - along with G4HadronElastic, G4HadronInelasticProcess, G4HadronCaptureProcess
  - according to hadronic framework design, all hadronic physics code should derive from or be registered to one of the above base classes
    - fission is the exception – often fission is part of a model assigned to an inelastic process
- Only G4LFission, G4ParticleHPFission and G4LENDFission models “obey the framework”
  - registered to G4HadronFissionProcess in physics lists
- All other fission codes are part of other models

Fission and its Approximations in Geant4



Models That Can Be Registered to G4HadronFissionProcess

- G4LFission
  - neutron-induced fission based on old GHEISHA model FISSIO
  - emits parameterized spectra of neutron and gammas
  - isotropic angular distribution
  - no heavy nuclear fragments in final state
  - for neutrons of all energies, does not use ENDF or other database

Models That Can Be Registered to G4HadronFissionProcess

- G4ParticleHPFission
  - neutron-induced fission using the G4NDL database (only uranium available)
  - flux and angular distributions come from energy-interpolated ENDF tables
  - for neutrons (only) below 20 MeV
  - no gammas or heavy fragments produced unless Wendt model is used
  - G4WendtFissionFragmentGenerator available for this model
    - part of ParticleHP code
    - turn on by setting environment variable G4NEUTRON_HP_USE_WENDT_FISSION_MODEL

Models That Can Be Registered to G4HadronFissionProcess

- G4LENDFission
  - neutron-induced fission using the Generalized Nuclear Data format
  - uses LEND, Geant4 interface to General Interaction Data Interface
  - for neutrons below 20 MeV
  - neutron, gamma, fragment emission provided
  - flux and angular distributions come from energy-interpolated tables
  - only a little validation has been done for this model

Fission Codes Which Are Part of Inelastic Models (Binary cascade, FTFP, QGSP)

- G4CompetitiveFission
  - used by G4EvaporationDefaultGEMFactory, G4EvaporationGEMFactory, G4EvaporationGEMFactoryVI
  - competes with photon evaporation
  - for A > 64
  - produces fission fragments, which may later emit gammas
- G4ParaFissionModel
  - not used in physics lists
  - neutron-induced fission for incident energies below 60 MeV
  - produces fission fragments using G4CompetitiveFission, then de-excites the fragments using G4ExcitationHandler

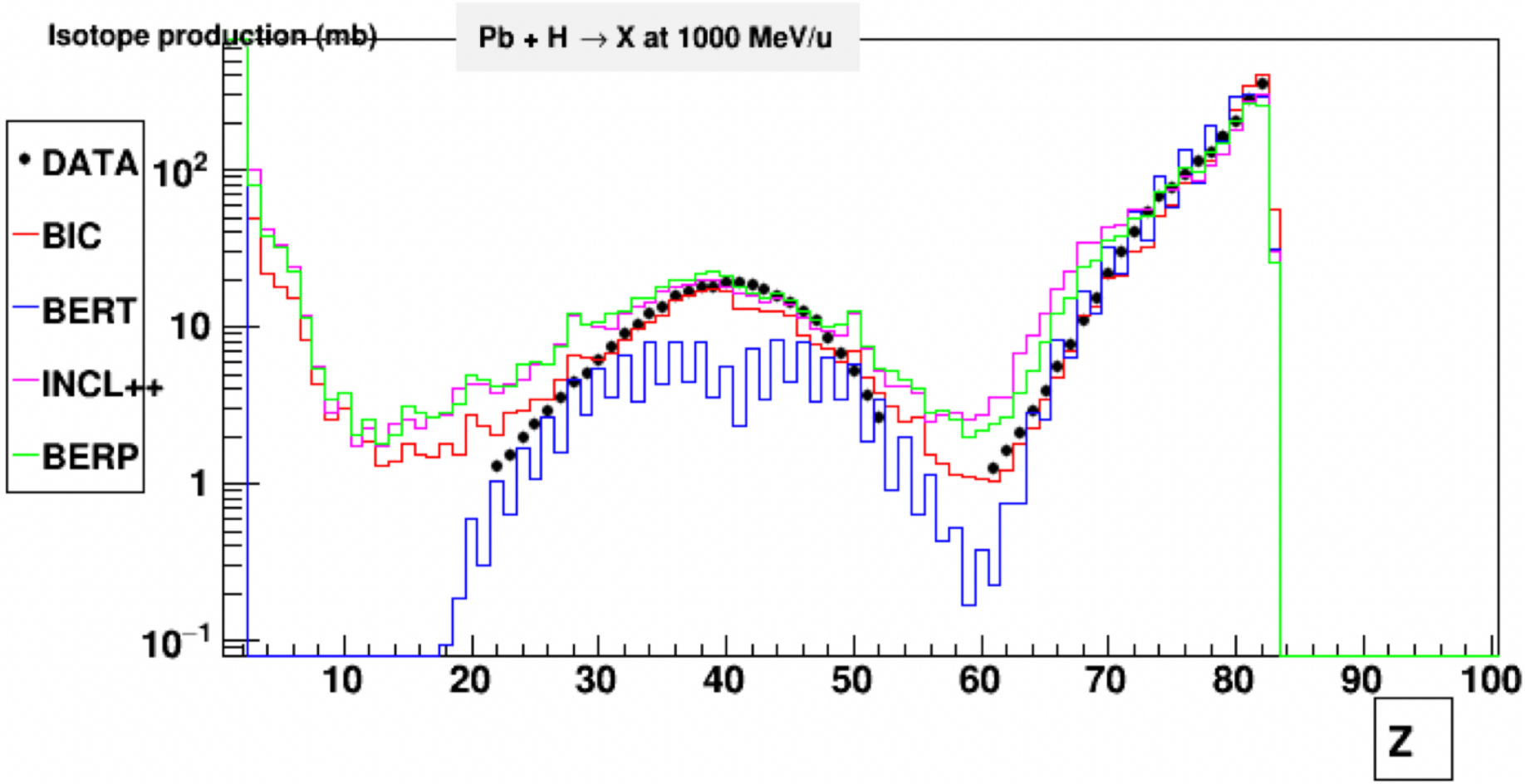
Fission Codes Which Are Part of Inelastic Models

- Bertini cascade
  - parameterized statistical fission model for A > 99 produces only fission fragments, no neutrons
  - fragment de-excited by Bertini class G4EquilibriumEvaporator
    - can emit n, p, d, t, ^{3}He and α
  - fission and photon emission compete in Bertini class G4EquilibriumEvaporator

Fission Codes Which Are Part of Inelastic Models

- G4INCLXX/Abla statistical de-excitation model
  - statistical fission model
  - isotropic distribution of fission fragments
  - fission competes with particle emission, gamma emission
  - more sophisticated than Bertini model
  - comparable to fission in G4ExcitationHandler ?

Fission from Various Cascades



Strengths and Weaknesses of G4 Fission

- Models based on evaluated data sets are good as long as the data is good
  - ParticleHP (but only U isotopes)
  - LEND needs validation
  - cannot expect full energy conservation due to binning, incomplete data, etc.

- Parameterized models vary in quality
  - Bertini not so good
  - INCL++, G4ExcitationHandler better
  - some detail of fission process lost: fragments, correlations, timing, etc.

Strengths and Weaknesses of G4 Fission

- Fission fragments for the most part are not well treated
  - either absent entirely or have simplified mass parameterizations
  - Wendt model (ParticleHP) looks OK
  - fragments from deexcitation codes look OK

- Some validation of these models has been done
  - need a lot more

Required Features and Design

Desired Features

- Requests from users for other forms of fission
  - photo-fission, muon fission, spontaneous fission

- Photon-induced fission
  - indirectly included in Bertini
    - photon absorbed, excited nucleus may decay by fission
    - not very good, according to users
    - never validated
  - not included in INCL++, ParticleHP
  - in principle, included in LEND models
    - never validated
  - LLNL stand-alone generator available in Geant4

Desired Features

- Muon-induced fission
  - indirectly included in Bertini
    - muon absorbed, excited nucleus may decay by fission
    - never validated
  - not included in INCL++
  - not included in LEND models
  - not included in ParticleHP

- Fission induced by other particles?
  - protons, alphas, etc.
  - possible in principle in ParticleHP

Desired Features

- Spontaneous fission
  - not currently part of Geant4, except as stand-alone LLNL process
  - now being put into G4RadioactiveDecay
    - place holder for fission channel added years ago
    - branching ratios and competing channels already in RadioactiveDecay database (ENSDF)
  - final state to be generated by LLNL spontaneous fission model
  - only neutrons and gammas in final state
  - see talk on radioactive decay

Plans, Tasks and Discussion

Re-design??

- No comprehensive treatment
  - neutron-induced already included in physics lists
  - users can add fission processes, but there is risk of double counting
  - code in various directories around Geant4
  - can we treat fission consistently throughout the hadronic code?

- Keep hadronic framework?
  - should fission be it's own process?

- Do we need new, more detailed models?

Validation

- Some exists – need more
  - especially for de-excitation codes which use fission
- Lack of validation is biggest problem for Geant4 fission
  - address this before doing anything else
  - will help to decide which code needs the most work
- Specific fission test in isolation – data?

Tasks

- Verify and validate all available Geant4 fission codes
  - collect sufficient data
  - set up fission test suite
- Evaluate users' (and collaborators') requests
  - should new models be developed, or simply improve existing ones?
  - shiny new fission model that does everything?
- Re-evaluate the way fission is used in Geant4

Summary

- Problems identified
  - fission code spread throughout the hadronic processes and models, no standard interface
    - easy to use incorrectly in physics lists
  - ParticleHP models only active for U isotopes
  - most models do not produce heavy fragments, usually only neutrons and gammas
  - very little validation

- Improvements made
  - Wendt fission model was a step forward
  - LEND fission may be better - needs validation
- Message to Geant4 developers
  - think about redesign of hadronic framework for fission

Statistical Fission

- Potential energy at saddle point is all converted to excitation energy and that statistical equilibrium among all possible states is established at scission point

- Probability of formation of pair of fragments based on density of states

- Maybe not true, but relatively simple model