Recent Developments in Geant4 Hadronic Physics

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Recently Released

- Many new features added in Geant4 9.4 (December 2010)
  - and patch 9.4 p01

Energy/Momentum Checking

- All hadronic processes now have energy/momentum checking available
  - from physics list, can select model or process to check
  - energy and momenta sums checked separately
  - each model has a range within which some non-conservation is acceptable
- Invoke by method:
  - SetEpReportLevel(n), where n = 0 turns checking off, n > 0 sets verbosity level
  - currently must do this for each process to be checked

Integer Z and A

- Hadronic interfaces now require that only integer Z and A be used
  - means you can no longer call hadronic processes for materials with effective values like A = 12.01
- This is to enforce proper use of isotope mixtures to define elements
  - in the past, people would make effective materials in which fractional Z and A would no longer refer to real elements
  - if you want an element with a non-standard isotope abundance, you must define it as a mixture of isotopes

Faster Neutron Models

- Three new cross section sets have been released
  - G4NeutronElasticXS, G4NeutronInelasticXS and G4NeutronCaptureXS
- Because of the thousands of sharp resonances in the high precision neutron models, models using those cross sections were very slow
  - new cross sections average over those resonances to increase speed, but at the cost of less detail
  - new cross sections still better at low energies than the previous default set
- Must download data set from Geant4 web site and set environment variable, G4NEUTRONXSDATA

Bertini Cascade Improvements

- Improved memory management
  - fewer news and deletes reduce memory footprint and speed up code
- Significantly improved energy/momentum conservation
  - typically conserved to a few parts per thousand
  - some light nuclei still present problems
- Improved angular distributions of two-body scattering
- Interface to G4Precompound model
  - Bertini has its own internal precompound model, but the G4Precompound model is better
  - now have an option to use either one

Radioactive Decay Improvements

- Isomer decay table added to extend the number of isomers treated by radioactive decay
  - all new isomers will be decayed by IT (isomeric transition)
- New README file included in both the radioactive decay code directory and the downloadable data file
  - describes the format of the ENDSF data entries and how to read it

Nucleus-nucleus Scattering

- Quantum Molecular Dynamic (QMD) model for nucleus-nucleus collisions had previously been limited to about 5-10 GeV/n
  - due to lack of relativistic treatment of nucleon participants
- Use of RQMD now extends the validity of QMD up to about 20 GeV/n
  - covariant hamiltonian implemented
- Also a new elastic scattering model for nucleus-nucleus scattering is available
  - G4NuclNuclDiffuseElastic
  - before this, no good elastic model available

Anti-nucleon and Anti-nucleus Cross Sections

- New cross section class, G4ComponentAntiNuclNuclearXS, makes possible the scattering of anti-nucleons and anti-nuclei from nuclei
  - actual scattering models not yet ready, but soon to follow
- Anti-baryon elastic scattering added to CHIPS model
  - cross sections included

Improved Nuclear De-excitation Models

- The Fermi breakup model (for de-excitation of light nuclei) has been extended to nuclei with $1 < A < 5$
  - previously only $4 < A < 17$
- README file now included in code directory for photo-evaporation explaining the levels listed in the data file
  - also available from the downloadable data file
- More extensive use of the Generalized Evaporation Model (GEM)
  - Fermi breakup model is now a hybrid of original Fermi breakup and GEM

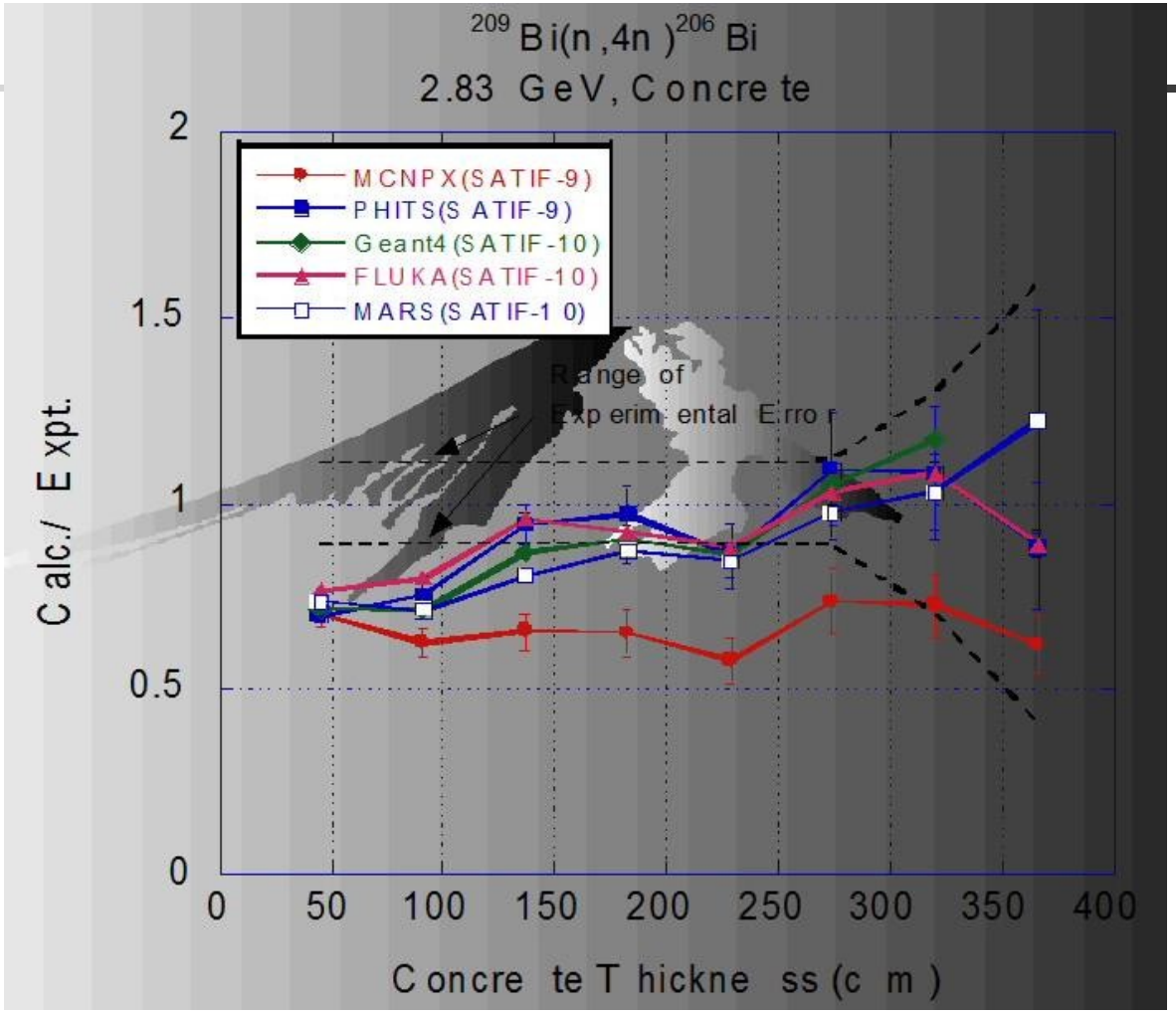
Low Energy Behavior of FTF Model Improved

- The Fritiof fragmentation model is used for the description of high energy hadron-nucleus interactions
  - historically not valid below 10 - 15 GeV
- Improvements to the code extend this range down to 3 GeV
  - treatment of very low mass strings
  - addition of reggeon cascade in the post-collision nucleus
  - tuning of model parameters based on data
- Good low energy behavior allows this model to be smoothly coupled to Bertini cascade in physics lists

Shielding – A New Physics List

- Designed for use in designing accelerator shielding
  - compares favorably to Fluka for neutron penetration in iron and concrete
  - should also be good for high energy physics
- Based on existing FTFP_BERT_HP physics list, but with
  - improved inelastic neutron cross sections using G4NDL cross sections below 20 MeV, JENDL cross sections between 20 MeV and 3 GeV
  - improved modeling of nucleus-nucleus collisions using QMD model and ion-ion cross sections
- Slower than FTFP_BERT because of use of NeutronHP models

Shielding – A New Physics List



Soon to Be Released

- What's coming in the beta release of Geant4 9.5 (June 2011)
  - and full release 9.5 in December 2011

Two New Neutron Databases

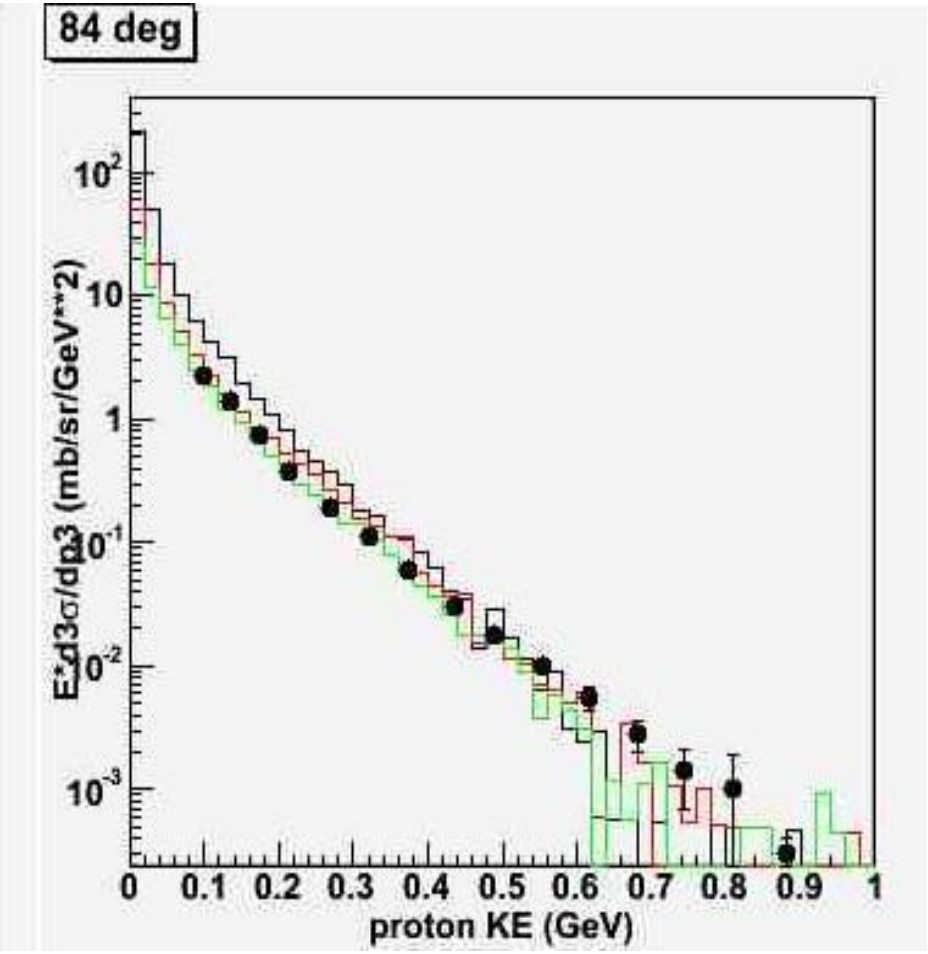
- The existing Geant4 G4NDL database is currently being maintained but no longer developed
  - two replacement databases to be released soon
- LEND/GIDI
  - Livermore Low Energy Neutron Database
  - GIDI: online interface to database
  - LEND: new G4 low energy models that will access GIDI
- New superset of G4NDL
  - more isotopes than G4NDL, from more evaluated databases
  - reprocessing of data by CIEMAT at three temperatures (0 K, 84 K and 300 K)

More Bertini Cascade

- Extending the cascade
  - Bertini is used in Geant4 up to 10 GeV – well above the traditional cascade energy range
  - source of discontinuities in detector response when pairing this model with string models (QGS, FTF)
- The trailing effect can help
  - fast particles produced in cascade interact first in nucleus, leaving lower density for slower particles
  - number of final state low energy nucleons is therefore reduced
  - just what we need at energies above 5 GeV
- Trailing effect recently added to Bertini cascade and tested

Trailing Effect

- 3.1 GeV protons on Pb
  - measure KE of outgoing protons
- Legend:
  - Black: original Bertini
  - Green: Bertini with trailing effect



Antimatter Collisions

- FTF model will be upgraded to handle anti-nucleon and anti-nuclei interactions
  - new cross sections for inelastic anti-nucleon and anti-nucleus scattering already developed
  - perhaps valid down to 0 energy
  - physics lists to use this are not yet developed
- Upgrades made at requests of HEP and cosmic ray communities

Updated and Improved Radioactive Decay

- Planned update of Geant4 radioactive decay database
  - current version based on ENDSF 1998
  - more isotopes, more decays
  - several bug fixes already implemented

Automatic Documentation of Physics Lists

- Currently, there is a printout (to standard output) of all the processes and models used in a given physics list
  - look in your log file
- Now cross sections will be added to this printout
- Soon an option will be added to turn this output into an html file to be posted on the Geant4 website
  - will augment existing physics list documentation
  - will include links to simple explanations of various models and cross sections

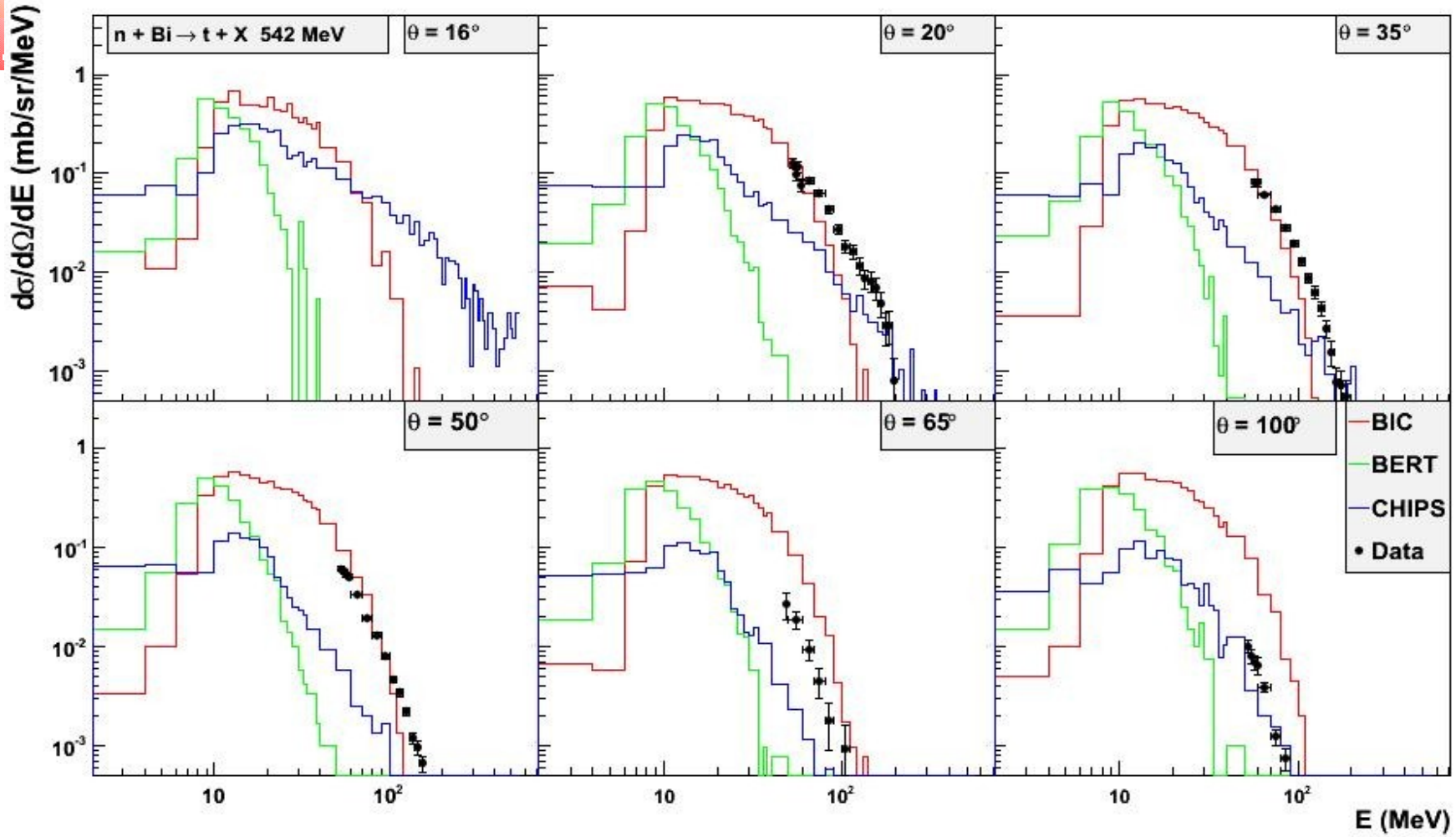
INCL (the third cascade model)

- There has been for some time a third intra-nuclear cascade model available in Geant4
  - INCL/ABLA
  - valid from 0 to 3 GeV incident pions and nucleons
  - tuned on spallation data
    - in this range, more precise than Binary or Bertini cascades
- Upgraded model INCL5 available soon
  - for medical applications, may be a good alternative to Binary cascade
  - physics lists now being developed to use it

Coalescence Models

- Recent comparisons to IAEA spallation data have shown that Geant4 hadronic models did not describe the emission of light nuclei very well
  - a few d, t and 3He produced by Bertini and none by Binary cascade
- Improvements to G4Precompound (used by Binary cascade) improved the agreement significantly
  - however, Bertini still needs work
- Coalescence models will soon be added
  - individual nucleons with similar momenta produced in the cascade and precompound stages are grouped into 2s, 3s and 4s and then emitted as d, t, 3He and alpha

The Need for Coalescence Models



Summary (Highlights)

- Released with Geant4 9.4
  - energy/momentum checking and reporting
  - faster low energy neutron models
  - nucleus-nucleus models and cross sections extended
  - anti-baryon, anti-nucleus cross sections added
  - low energy behavior of FTF model improved
- Coming soon
  - two low energy neutron databases (Livermore, and expanded G4NDL)
  - updated radioactive decay database
  - antimatter collisions
  - new online physics list documentation