Recent Hadronic Developments

Dennis Wright
Geant4 Space Users Workshop
28 May 2014

Outline

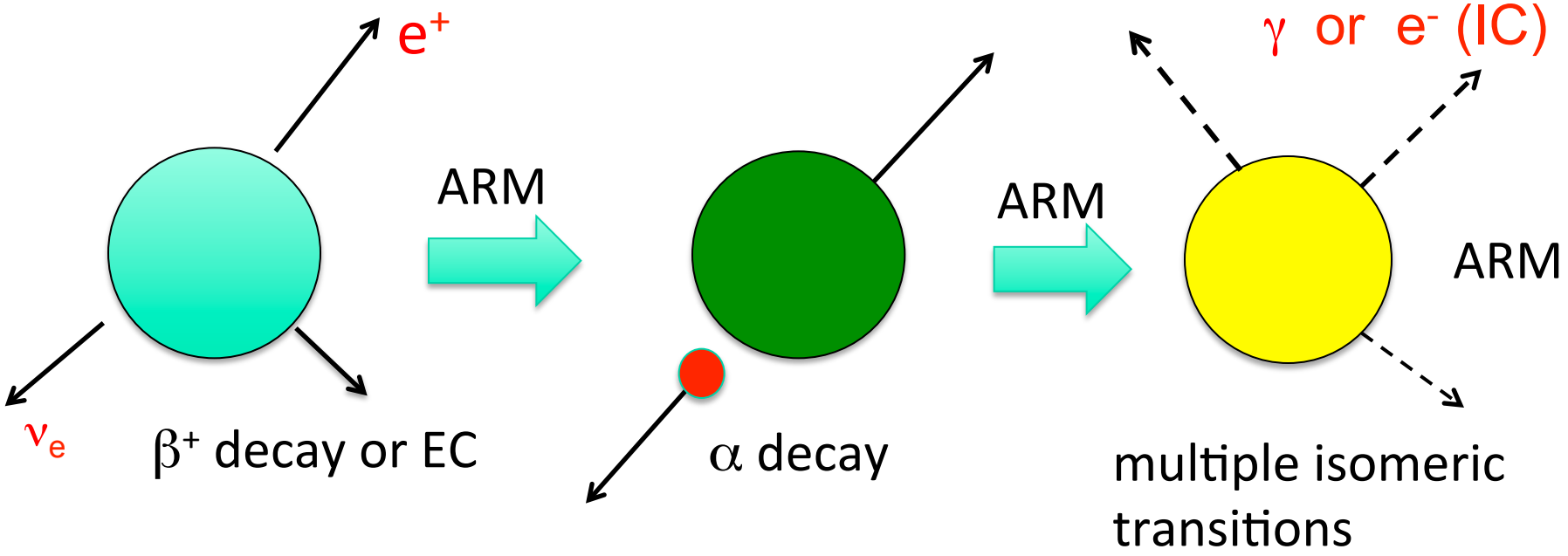
- Radioactive Decay
- Stopping Models
- Low Energy Neutrons
  - zipped libraries
  - Wendt model
- Cascade models
  - Bertini
  - INCL++
- High Energy models
- Retired models

- Coming soon (2014/2015)

Radioactive Decay

- Process to simulate radioactive decay of nuclei
  - α, β^+, β^-, γ decay, electron capture (EC), internal conversion (IC), Auger and fluorescence processes implemented
- Many improvements for version 10.0:
  - now 2792 data files taken from Evaluated Nuclear Structure Data Files (ENSDF)
    - download-able as RadioactiveDecay4.0
    - includes all meta-stable states with lifetimes longer than 1 ns
  - all known gamma transitions (regardless of lifetime) for 2071 nuclides
    - download-able as PhotonEvaporation3.0
  - more consistent treatment of decay chains

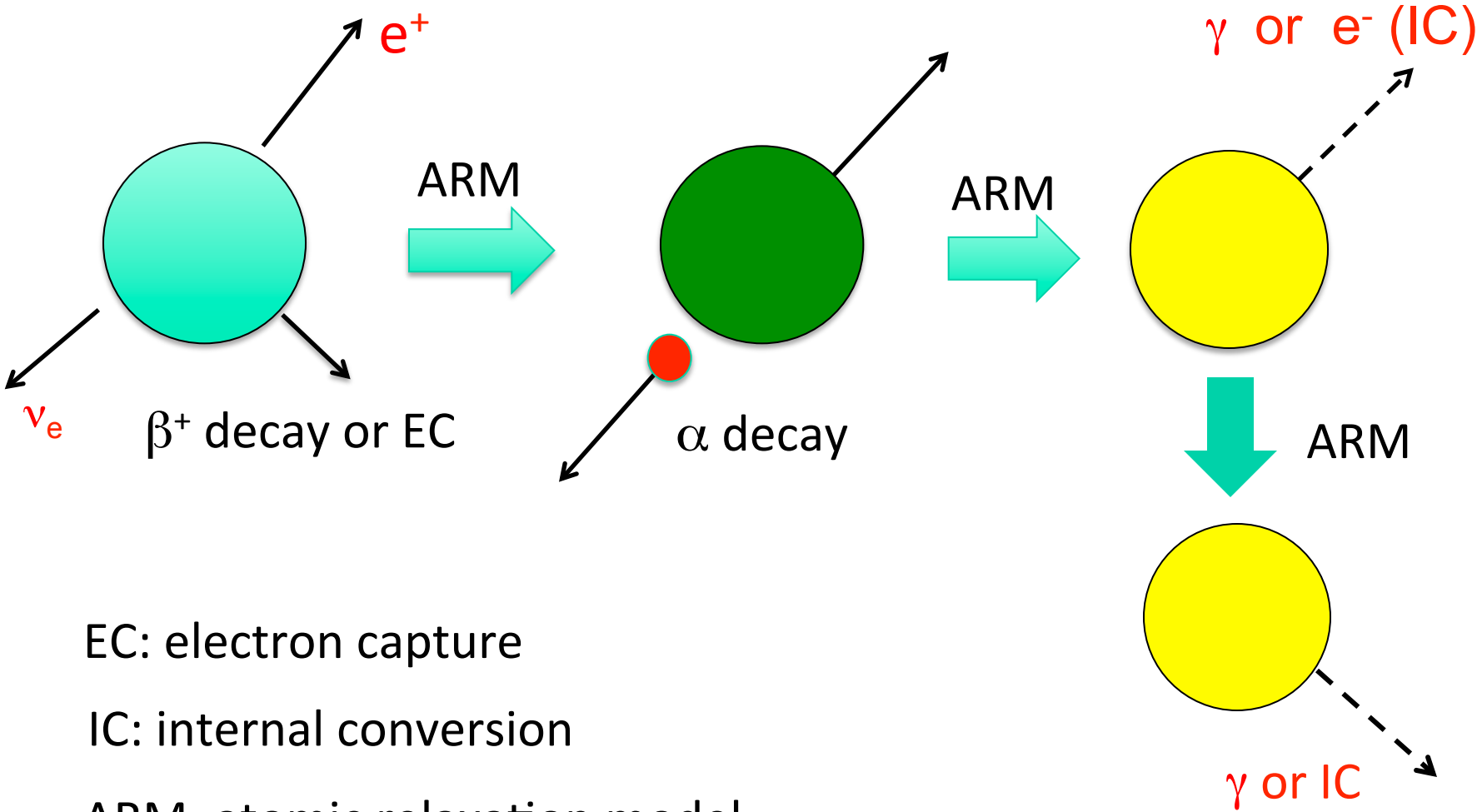
Radioactive Decay Chain before 10.0



States with γ decay lifetimes < 1 ns would decay immediately in the same step all the way to the ground state

Gammas from ^{60}Co decay, e.g., would not have correct timing

Radioactive Decay Chain in Version 10.0



EC: electron capture

IC: internal conversion

ARM: atomic relaxation model

Radioactive Decay Errata

- Events using radioactive decay are not reproducible in multi-threaded mode
  - random seed at end of series of events not always the same given identical seeds at beginning
  - completely reproducible in sequential mode
  - working on this
- Small energy non-conservations (~ keV) still exist for some reactions (α , γ)
  - working on this, too
- Minor inconsistencies between ground state gamma transitions in RadioactiveDecay4.0 and PhotonEvaporation3.0
  - fixed in RadioacticeDecay4.1 and PhotonEvaporation3.1

Stopping Models

- G4PiMinusAbsorptionBertini
  - pion starts out in Bertini cascade, forms particle-hole state which is decayed using G4Precompound and Geant4 native de-excitation code
- G4Kaon(Sigma)MinusAbsorptionBertini
  - similar to pi minus code above, but kaon (sigma) is forced to decay before forming hypernucleus
- G4AntiProton(AntiSigmaPlus)AbsorptionFritiof
  - Fritiof low energy limit is 2 GeV – just enough to handle this
- G4MuonMinusCapture
  - see Bertini slides

NeutronHP

- High Precision neutron models can now read compressed data files (zlib)
  - improved ease of handling, loading of G4NDL database (was 1.54 Gb, now 429 Mb) since version 4.3 (June 2013)
  - thermal cross sections used to be in separate library due to size
    - now combined with the main libraries

- Problem with multi-threaded running
  - large memory consumption – problem being worked on

- User-defined thermal scattering files now supported
  - user must prepare in G4NDL format
- Single temperature data files now supported
  - but still under development

NeutronHP

- Removed HPorLE models
  - used Gheisha models when there was no data for chosen isotope
  - now choose isotope nearest in A and use its data (default case)
  - option to set cross section to zero instead: set env. var. G4NEUTRONHP_SKIP_MISSING_ISOTOPES

- Meta-stable isotopes produced in hadronic interactions
  - default minimum lifetime is 1 μs
  - can be changed by G4NuclideTable::SetThresholdOfHalfLife(G4double)
  - if < 1 ns user must set set G4ENSDFSTATEDATA to point to new (optional) data set
  - uses new G4ENSDFSTATE-1.0 database (download-able)

NeutronHP: Wendt Fission Model

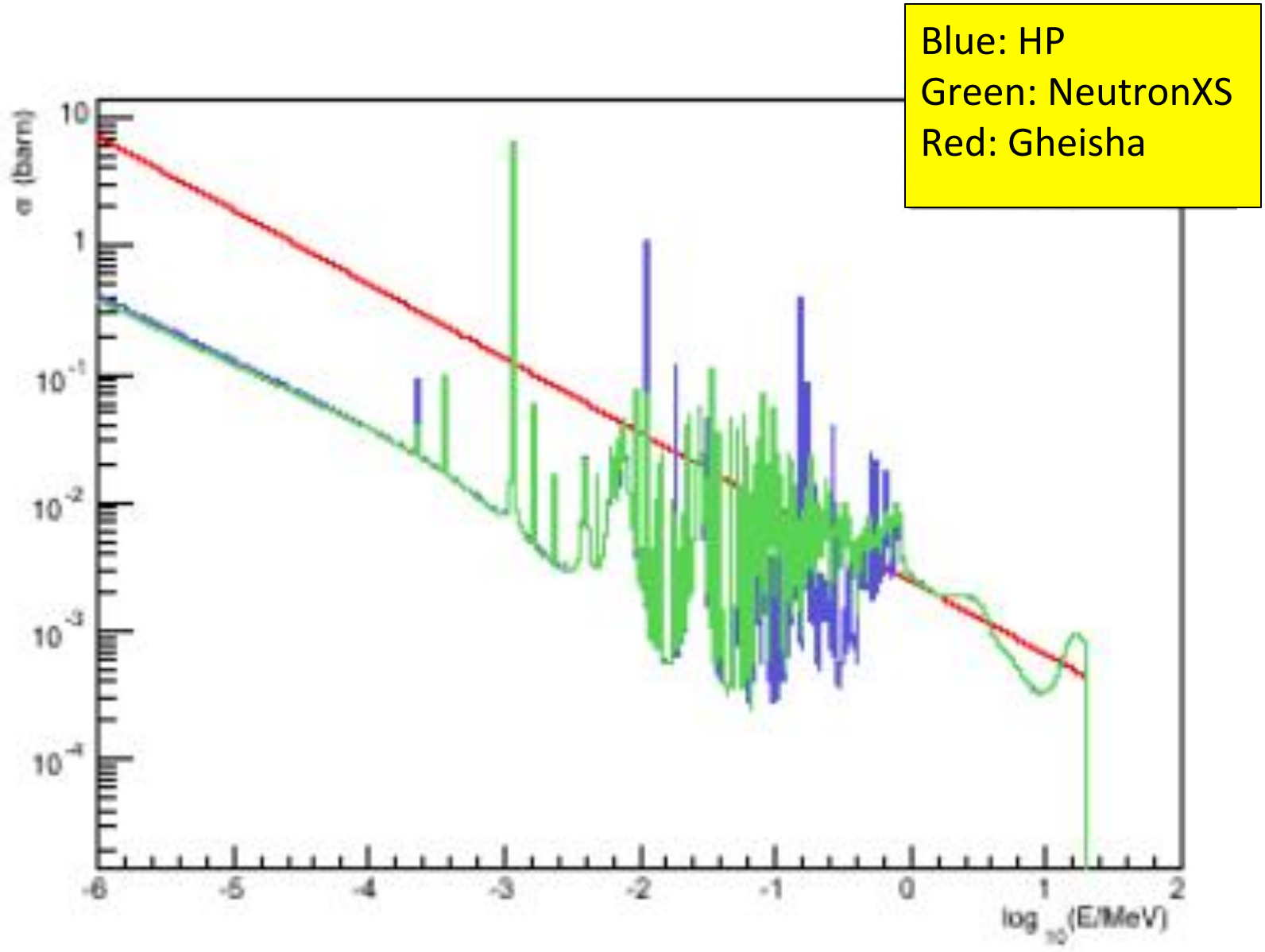
- NeutronHP fission model produces neutrons from fission
  - fragments produced only if G4NEUTRONHP_PRODUCE_FISSION_FRAGMENTS is set
- New model contributed by Bryson Wendt
  - based on data from NIFFTE TPC
  - still under development
- Wendt model produces neutrons, fragments, gammas
  - samples angular distributions for these
  - using existing fission yield data from NeutronHP
  - also NIFFTE experimental data hard-coded as new G4 classes
- Invoke by setting environment variable
  - G4NEUTRON_HP_USE_WENDT_FISSION_MODEL

NeutronXS

- Alternative to NeutronHP cross sections
  - faster (3-5 x times depending on application)
  - covers all energies
  - less precise below 20 MeV
    - but far more precise than GHEISHA model

- Produced by binning NeutronHP cross sections into log vector
  - elastic, inelastic, capture for all natural composition elements
  - inelastic, capture for most commonly used isotopes
  - binning causes some differences with original HP data

NeutronXS Capture Cross Section in Fe



NeutronXS Usage

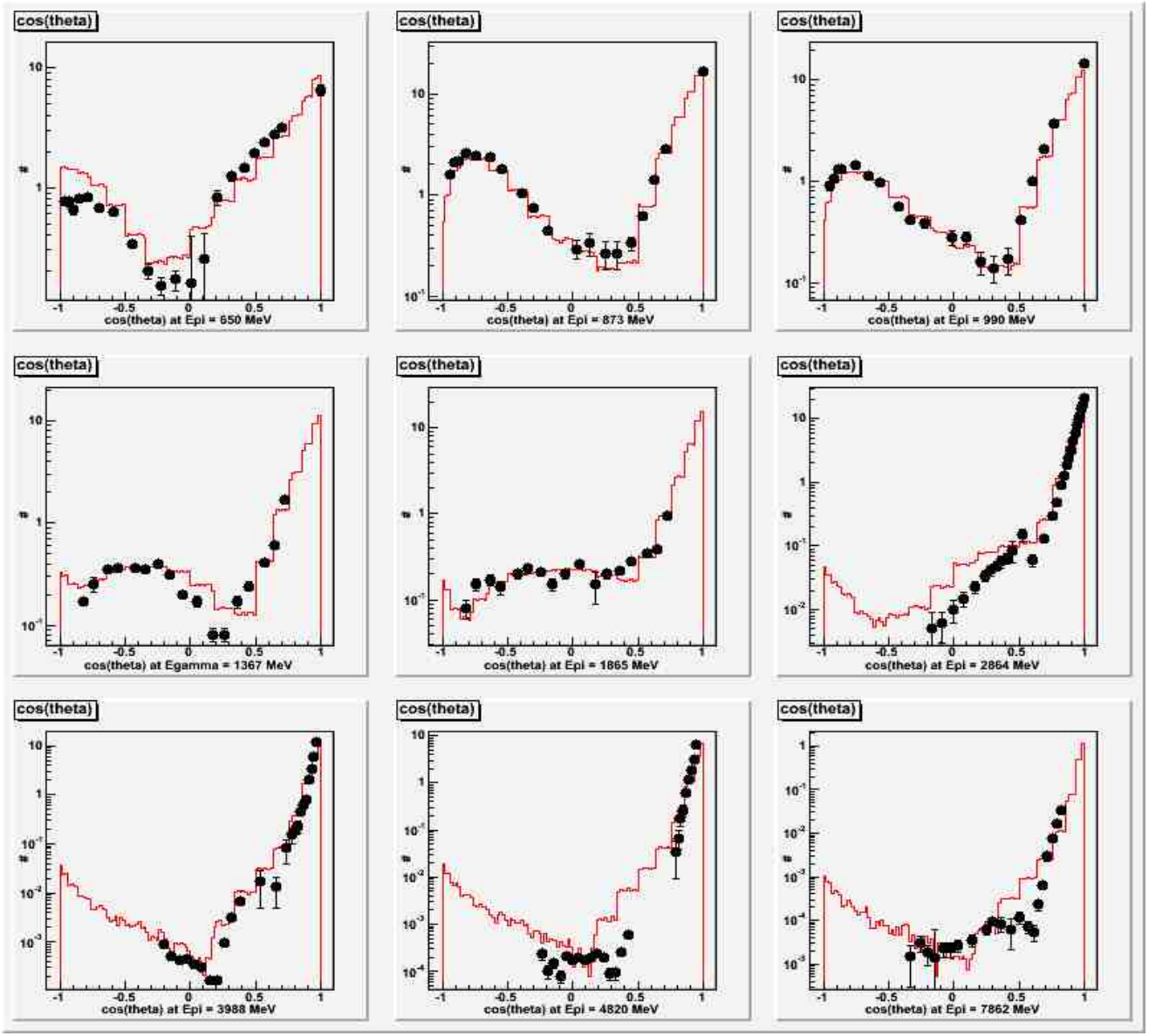
- Used in almost all supported physics lists
  - for _HP lists, HP cross sections and models used below 20 MeV
  - Env. var: G4NEUTRONXSDATA, download G4NEUTRONXS 1.4

- Inelastic: G4NeutronInelasticProcess
  - model: Bertini + FTFP, Binary + QGSP, etc.
  - cross section: G4NeutronInelasticXS
- Capture: G4HadronCaptureProcess
  - model: G4NeutronRadCapture
  - cross section: G4NeutronCaptureXS
- Elastic: G4HadronElasticProcess
  - model: G4ChipsNeutronElasticModel
  - cross section: G4ChipsNeutronElasticXS

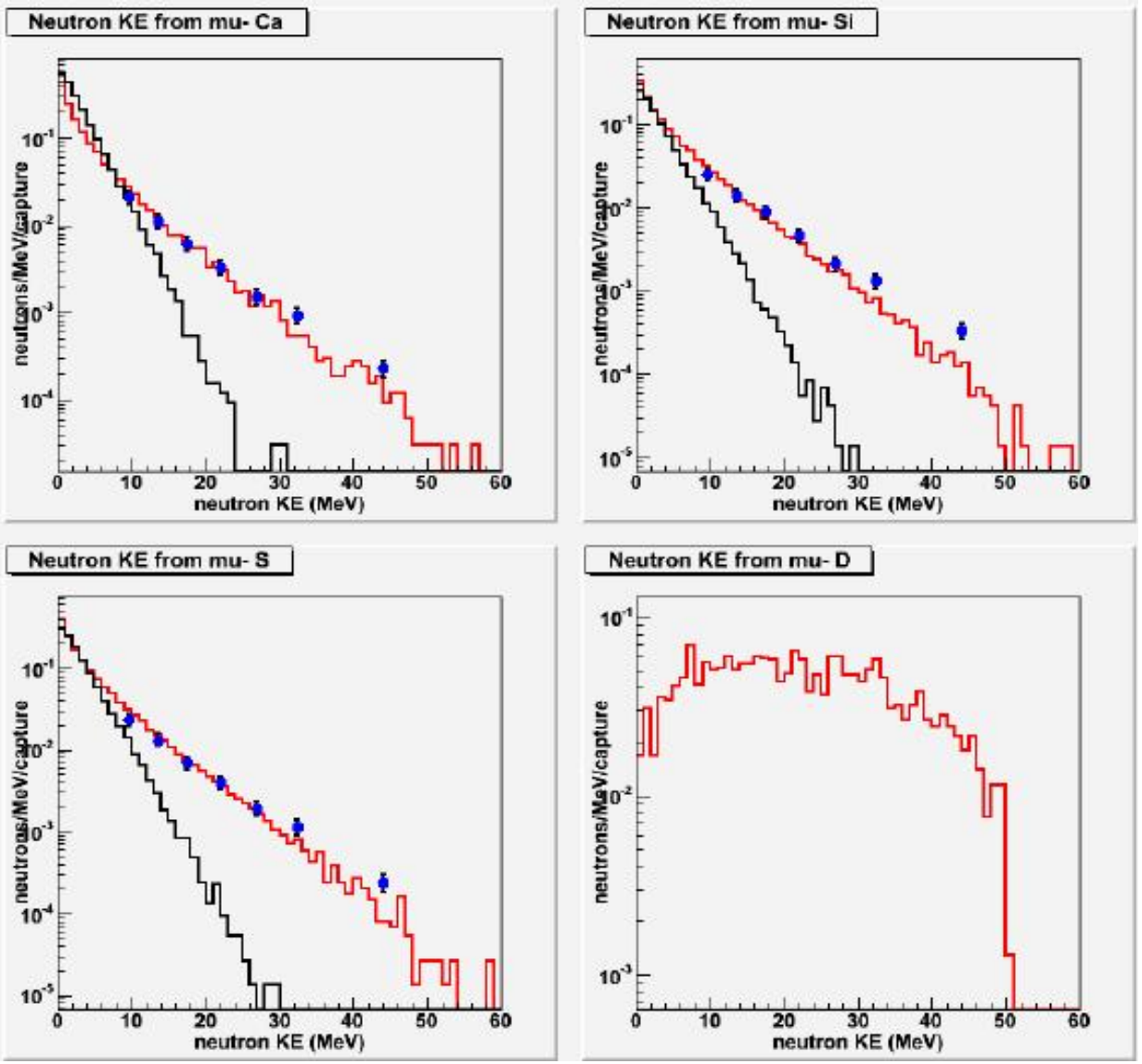
Bertini Cascade

- Better two-body nucleon-nucleon final state angular distributions
  - replace Barashenkov polynomial parameterizations with SAID phase shift fits up to about 3 GeV
  - from 3 – 10 GeV use measured angular distributions in 10 degree bins
- Better two-body pion-nucleon final state angular distributions
  - replace Barashenkov with SAID up to 3 GeV
  - 3 – 10 GeV: use measured distributions
- Improved multi-body phase space calculations
  - for three-body and higher multiplicity final states
- Implemented a simple quasi-deuteron absorption model
  - two-nucleon absorption
  - can now do muon capture

π^- p Elastic Angular Distributions



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

- 

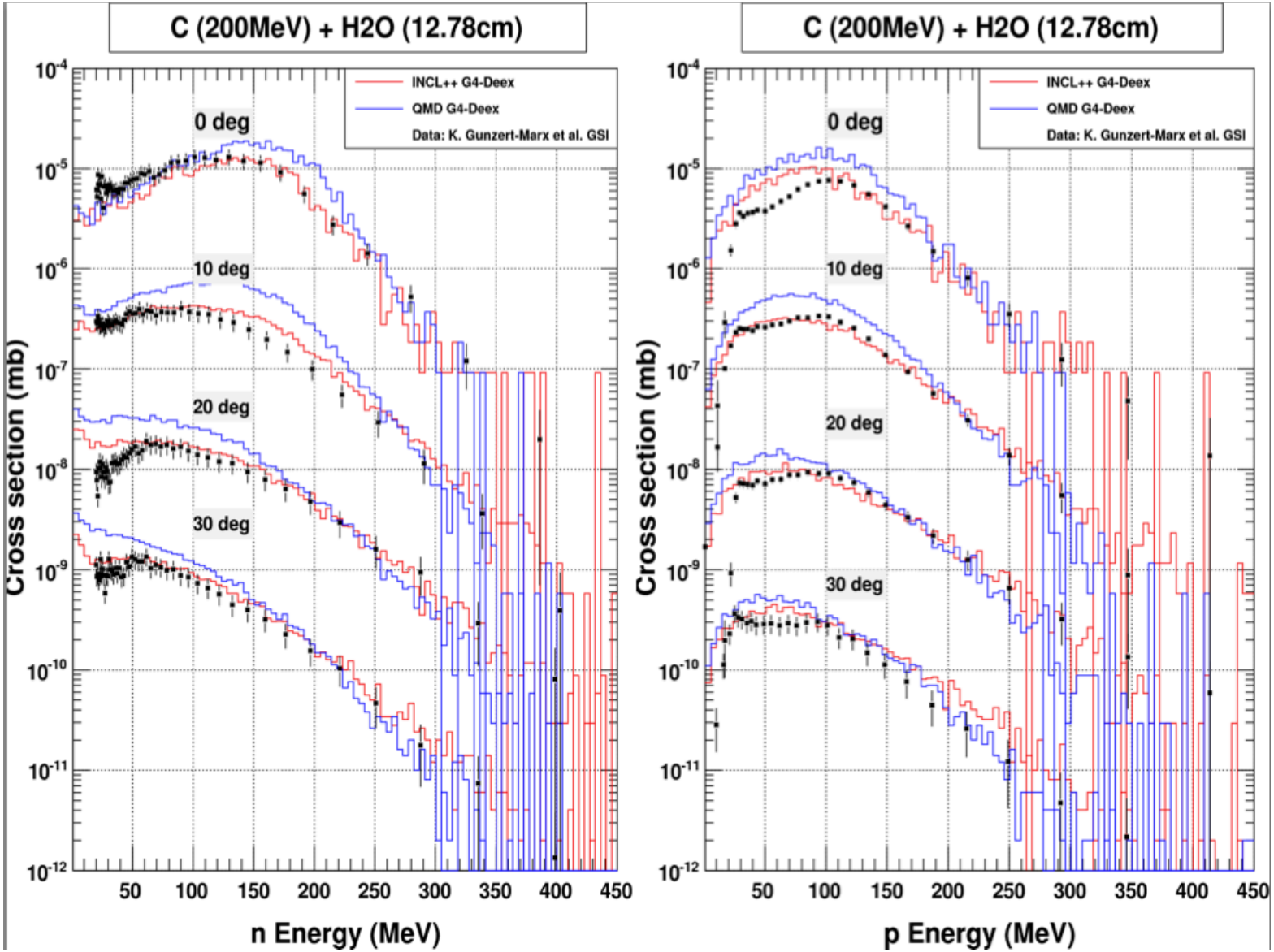
INCL++ Cascade

- Lineage: Liege intra-nuclear cascade -> INCL -> INCL++

- Latest Geant4 version contains many improvements
  - originally for pion- and nucleon-induced cascades between 100 MeV and 3 GeV
  - can now do light ion projectiles (up to and including ^{12}C)
  - uses Geant4 de-excitation package to bring residual nucleus to ground state, improve light cluster formation

- Good alternative to G4BinaryCascade or G4QMD
  - especially good for spallation energies
  - slower than G4BinaryCascade
  - new physics lists: QGSP_INCLXX, QGSP_INCLXX_HP

INCL++ Cascade



Fritiof High Energy Model

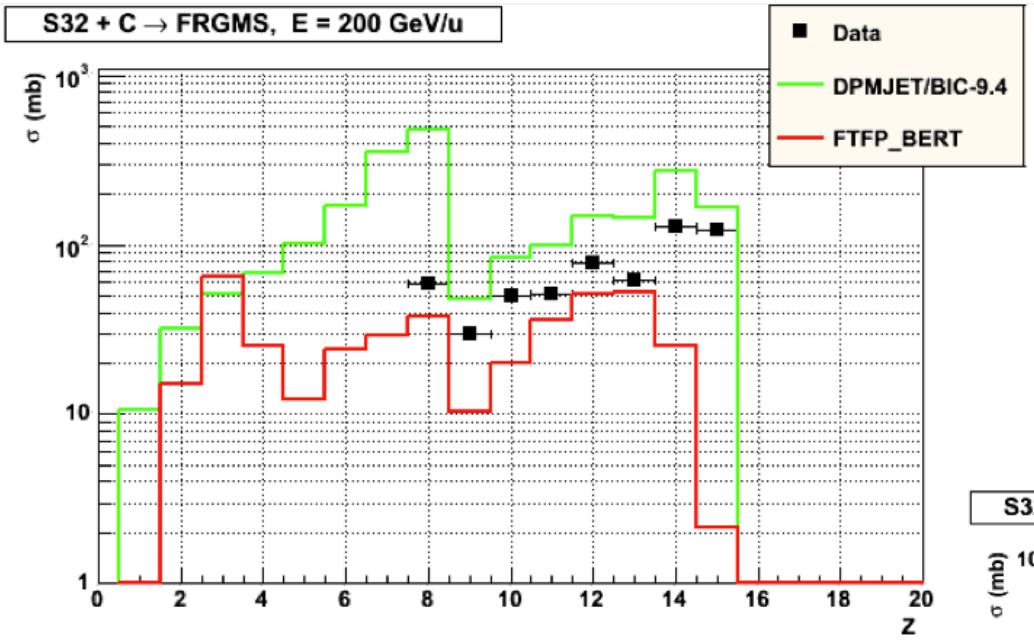
- FTF model improvements
  - improved nucleon-nucleon diffraction
  - Reggeon cascade tuned: delta isobar probability increased (returned 25% of that which was removed earlier)
    - above two items should make showers a bit wider
  - string parameters re-tuned, based on enlarged body of thin-target data
    - hadronic showers a bit narrower than before tuning

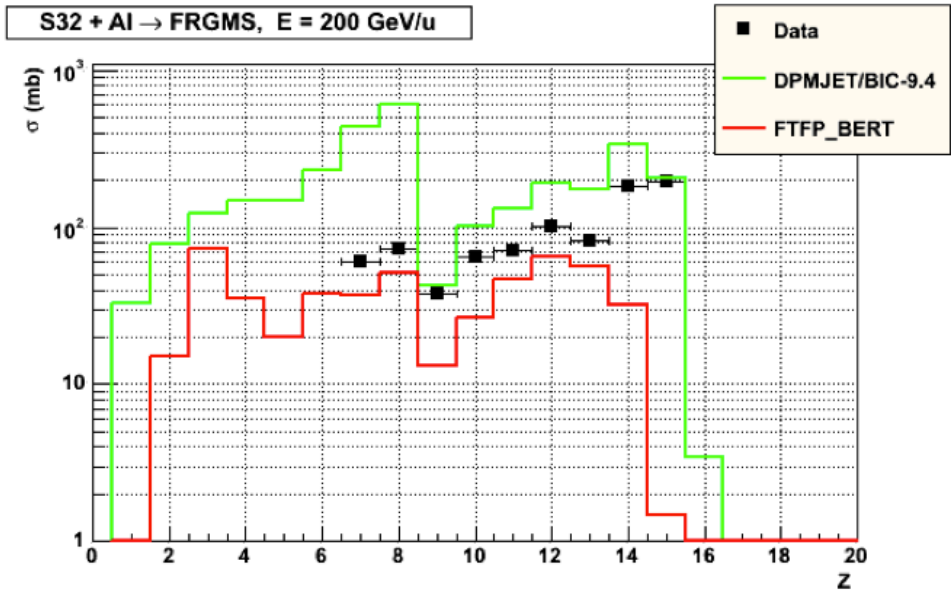
Fritiof Nucleus-nucleus

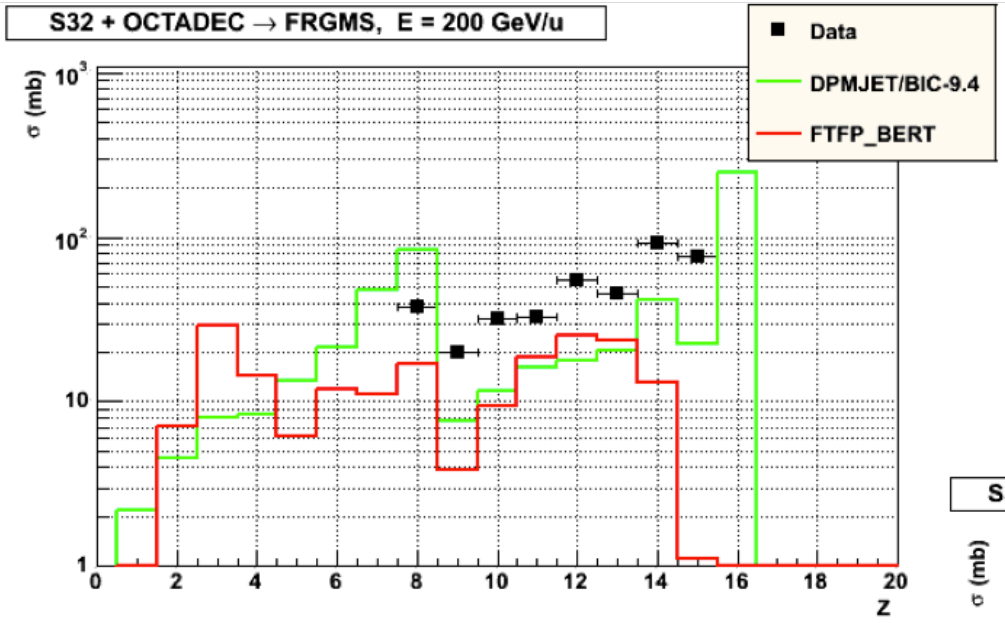
- Interface to DPMJET II.5 no longer works
  - serious energy non-conservation problems and maybe more
  - also limited to Z < 26
  - compiles and runs, but difficult to maintain Fortran code and interface

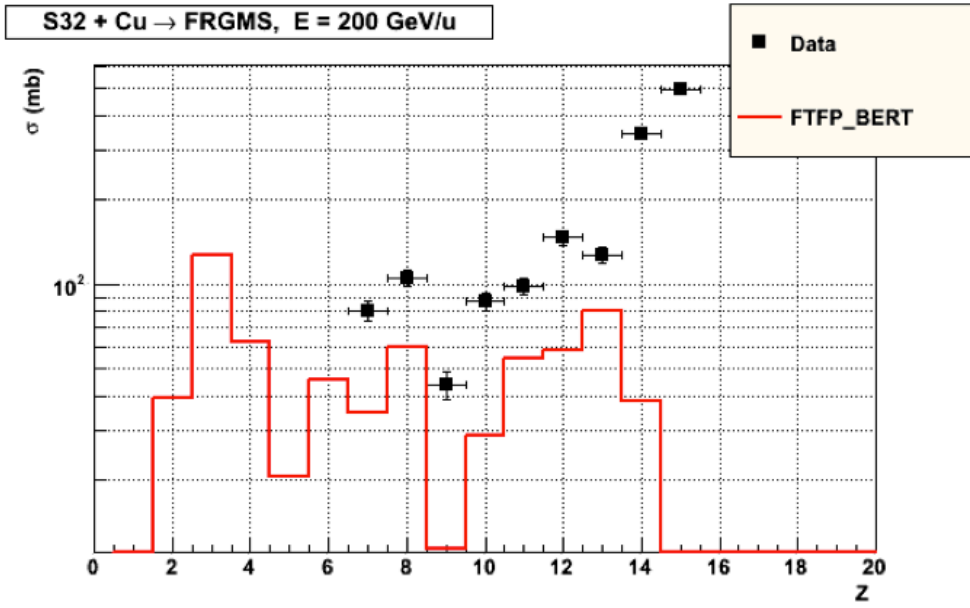
- Would like to have native G4 code for high energy nucleus-nucleus collisions
  - FTF can now do nucleus-nucleus; try it
  - validate against 1987 data from CERN SPS:
    - 200 GeV/u ^{32}S on C, Al, S, Cu, Ag, Pb
  - CPU for DPMJET and FTF similar

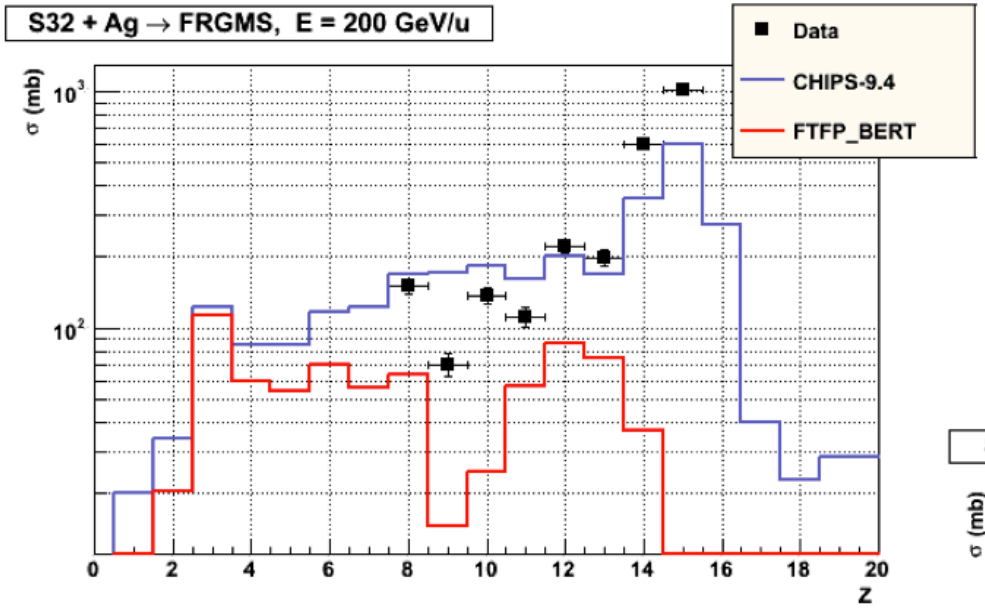
- FTF looks promising
  - better than DPMJET for light targets

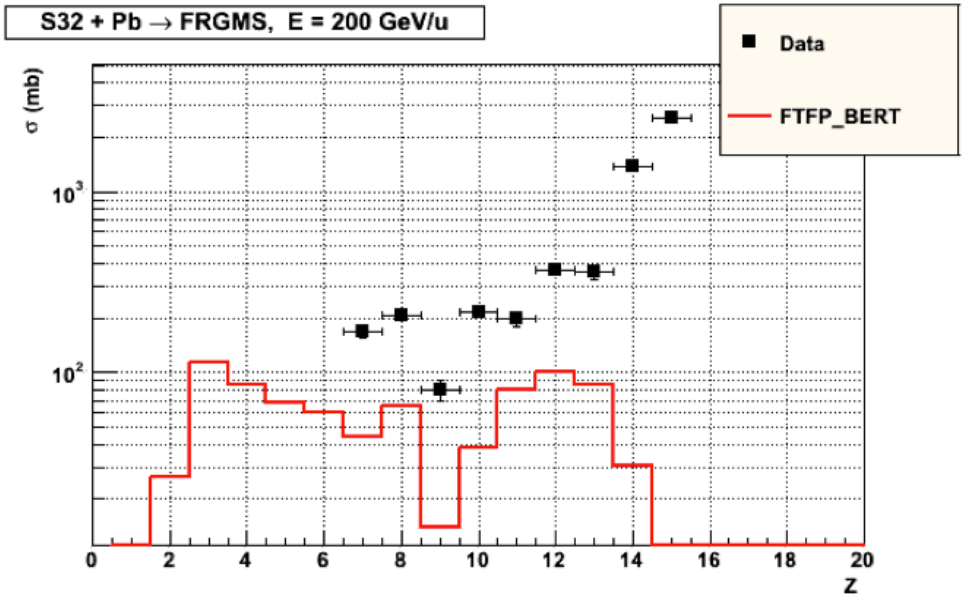

S32 + C → FRGMS, E = 200 GeV/u
Data
DPMJET/BIC-9.4
FTFP_BERT
σ (mb)
Z


S32 + Al → FRGMS, E = 200 GeV/u
Data
DPMJET/BIC-9.4
FTFP_BERT
σ (mb)
Z


S32 + OCTADEC → FRGMS, E = 200 GeV/u
Data
DPMJET/BIC-9.4
FTFP_BERT
σ (mb)
Z


S32 + Cu → FRGMS, E = 200 GeV/u
Data
FTFP_BERT
σ (mb)
Z


S32 + Ag → FRGMS, E = 200 GeV/u
Data
CHIPS-9.4
FTFP_BERT
σ (mb)
10^3
10^2
0
2
4
6
8
10
12
14
16
18
20
Z


S32 + Pb → FRGMS, E = 200 GeV/u
Data
FTFP_BERT
σ (mb)
10^3
10^2
0
2
4
6
8
10
12
14
16
18
20
Z

Retired Hadronic Models

- LEP, HEP (Low and High Energy Parameterized) models
  - based on the old GHEISHA Fortran models of Geant3
  - replaced by extended versions of the Bertini cascade and FTF qcd string models

- CHIPS (Chiral Invariant Phase Space) models
  - thermodynamic clustering model of hadron nucleus interactions
  - formerly used for stopping, electro-, gamma-nuclear reactions
  - now replaced by Bertini, FTF
  - some CHIPS elastic and inelastic cross sections retained and made into separate classes

- Isotope production model
  - based on LEP models
  - now redundant, since all recoil nuclei are kept for tracking

Coming in 2014/2015

- High precision charged particle induced reactions
  - like NeutronHP but for incident p, α
  - we've been promising this for the last two years
    - sorry about that
    - special working session planned for this year to get it done

- Further radioactive decay improvements
  - more validation
  - better examples
  - rare reactions (double beta decay)

- Improved Quark-Gluon string model to compete with FTF model at high energies