Updates on Hadronic Physics

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Geant4 Space Users' Workshop
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Outline

- Hadron elastic scattering
- Cascade models
- QCD string model improvements

- Ions, isomers, nuclides
- Radioactive Decay
- Low energy hadrons

- Coming attractions

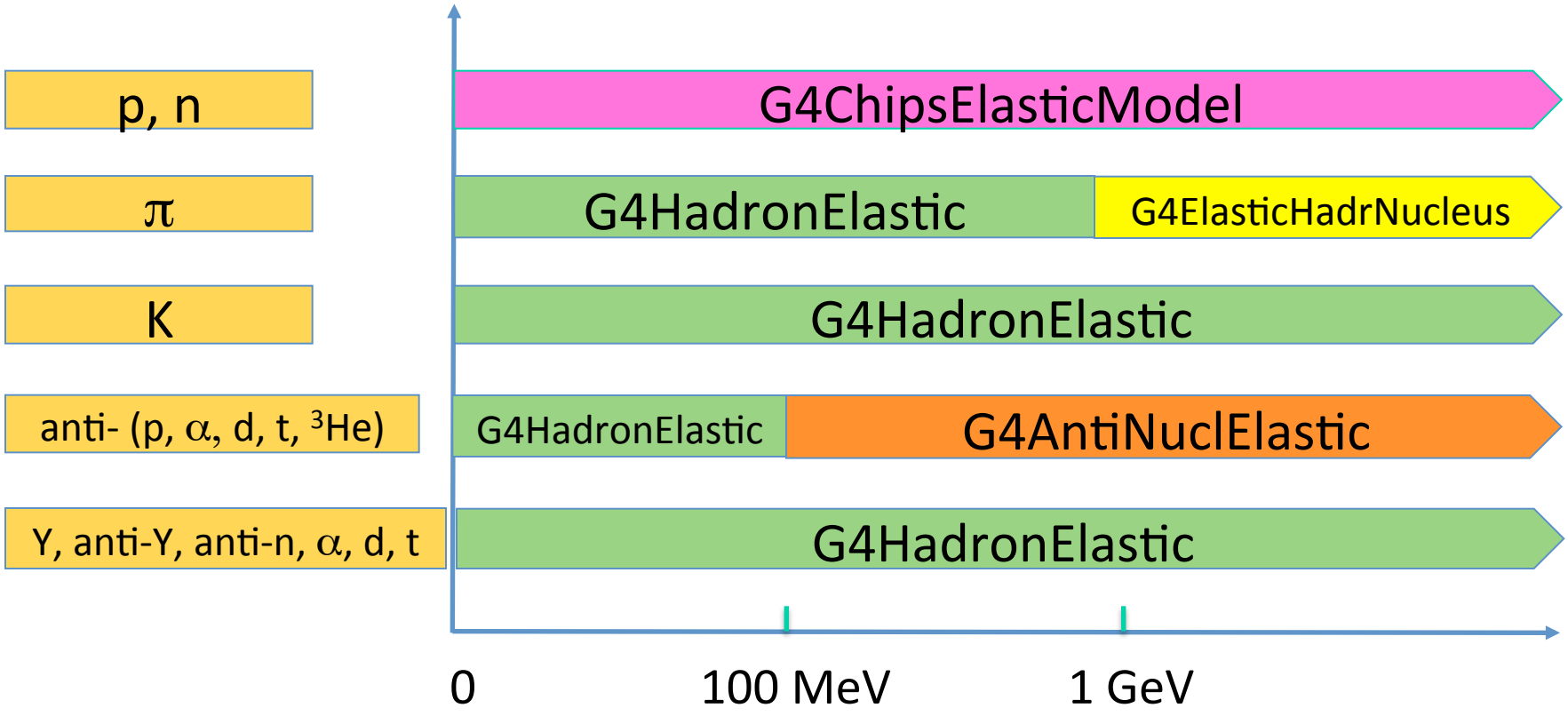
New Elastic Models and Physics Lists

- G4HadronElasticProcess is used in most physics lists
  - now depends less on old Gheisha parameterization, but Gheisha still used for kaons, light nuclei

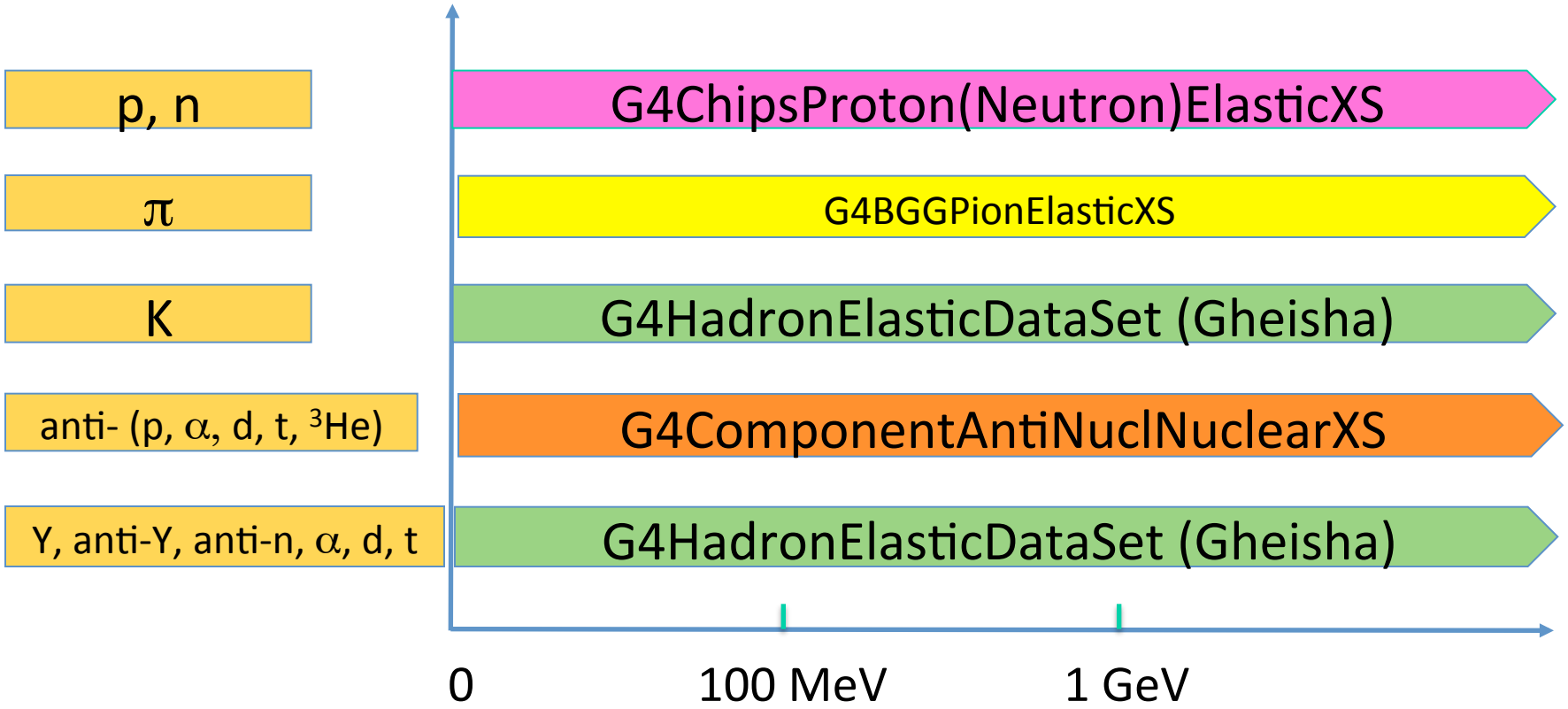
- Anti-nucleon, anti-light-nucleus projectiles
  - improved models (> 100 MeV) and cross sections (all energies) for anti- (p, n, d, t, ^{3}He, α)

- Chips elastic models and cross section classes extracted from old CHIPS framework
  - for protons and neutrons (all energies)
  - also for hyperons in special physics lists (all energies)

Hadronic Models Implementing G4HadronElasticProcess



Hadronic Cross Sections Implementing G4HadronElasticProcess



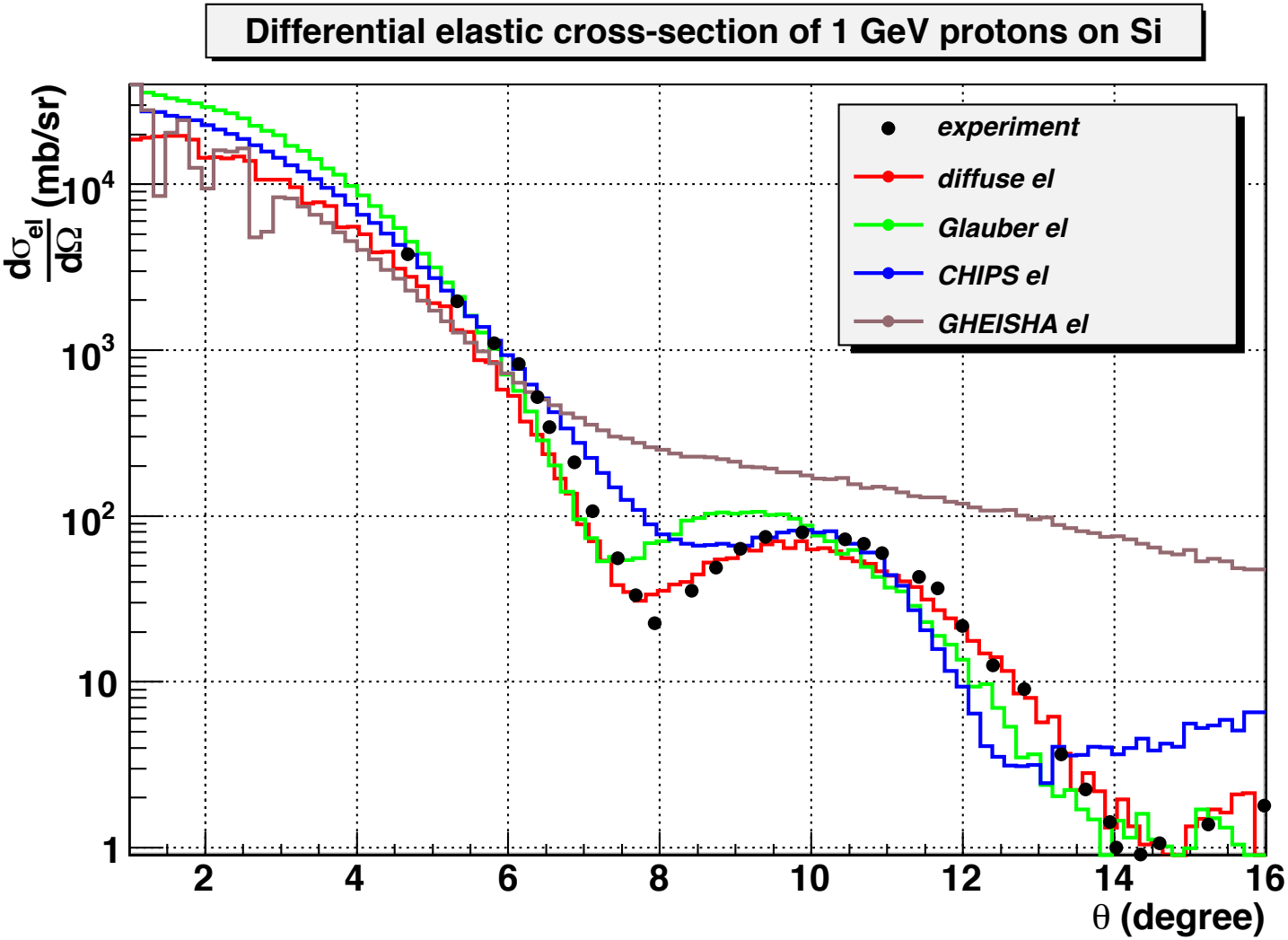
New Elastic Models and Physics Lists

- Want to try the latest?
  - FTFP_BERT_TRV is an experimental physics list where new models, cross sections are tested
  - physics constructor: G4HadronHElasticPhysics

  - uses G4DiffuseElastic for p, n, pions
  - CHIPS models for kaons

- G4DiffuseElastic:
  - optical model of nucleus + diffuse nuclear halo
  - Coulomb effects included
  - nucleus-nucleus version available: G4NuclNuclDiffuseElastic

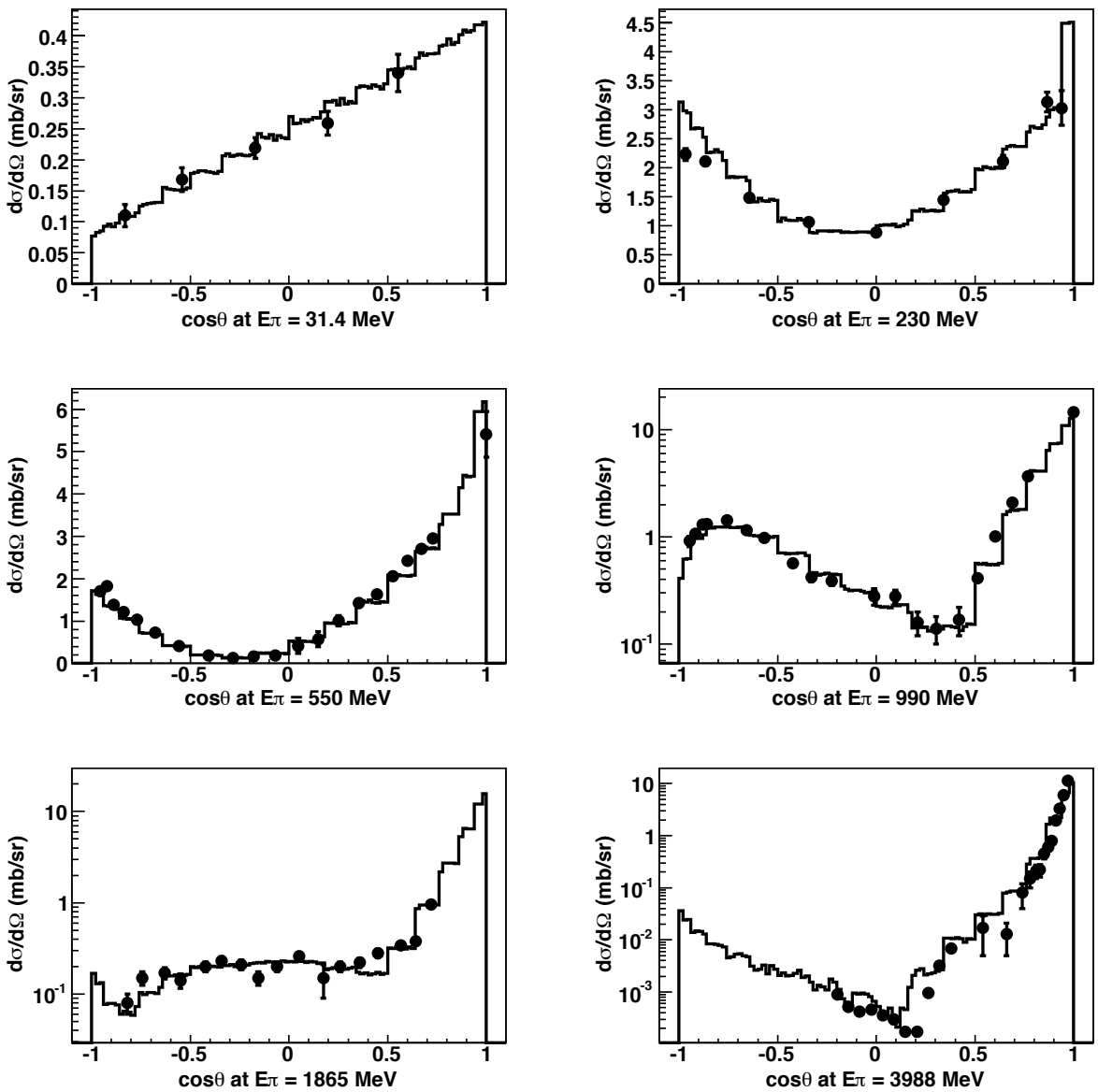
New Elastic Models and Physics Lists



Cascade Models

- INCL++
  - extended to 15-20 GeV
  - large reduction in memory churn → ~ 3% speed increase
- Binary
  - improved behavior using SAID pp, pn and nn cross sections
  - a number of thread safety and multi-threading improvements
- Bertini
  - Upgrade of π – nucleon two-body final state angular distributions
    - was Barashenkov parameterization
    - now use SAID phase shift shapes

Bertini π^- p Final State Angular Distributions



QGS Model Improvements

- Development of QGS model has resumed
  - more theoretically grounded than FTF
  - potential to be extended to much higher (multi-TeV) energies

- Fragmentation functions now much closer to those of Kaidalov (one of original QGS authors)
  - first tuning performed with latest functions

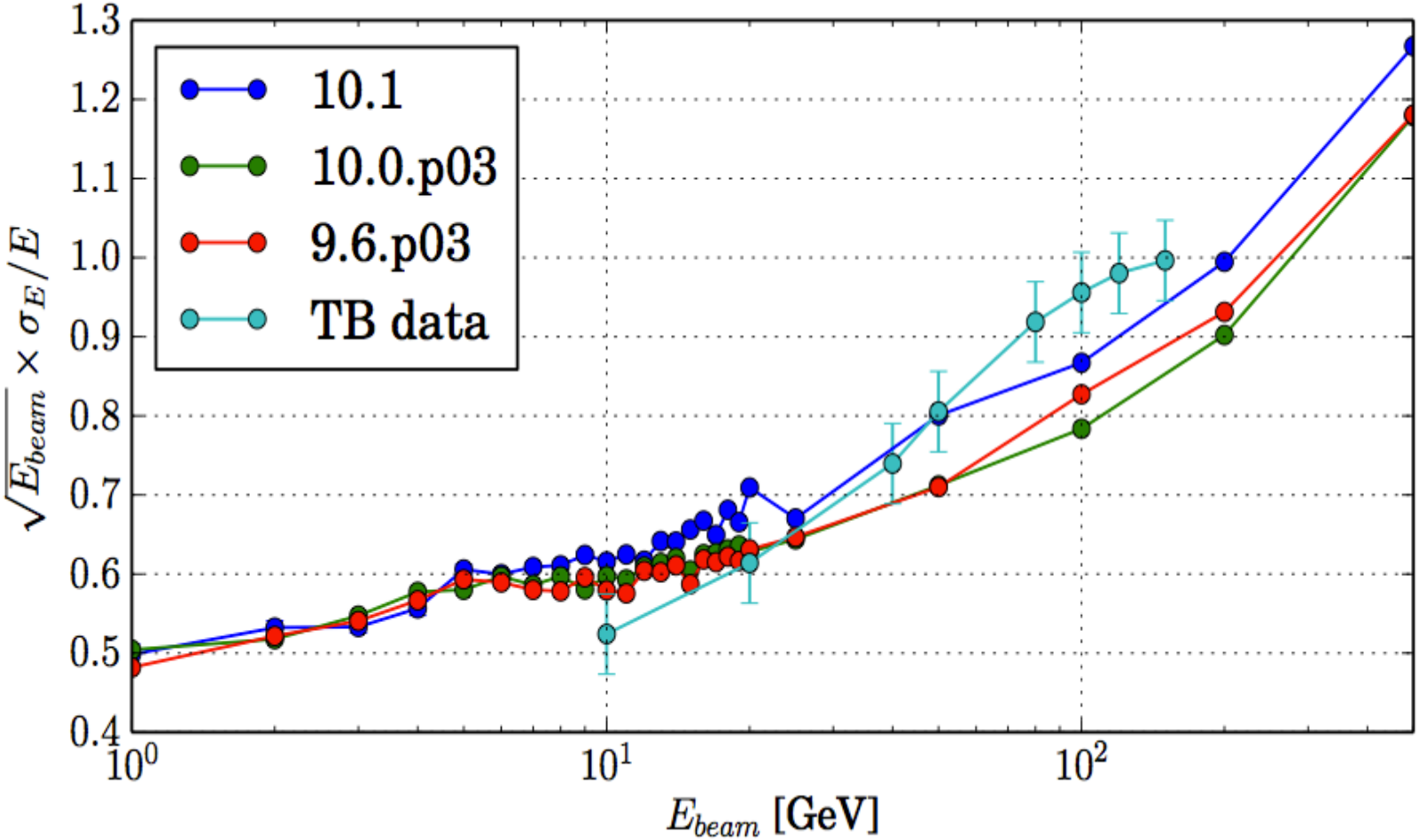
- Recent improvements have resulted in
  - wider and longer showers
  - lower energy response
  - → closer to FTF model and closer to data

FTF Model Improvements

- Large number of bug fixes and tunings
  - fixed bug in G4LundStringFragmentation → increased production of neutral pions, decreased charged pions
  - fixed bug in method which splits baryons into quarks, di-quarks
    - too many diquarks with identical quarks
  - above fixes required re-tuning of G4LundStringFragmentation on thin target data
  - …
- Above changes largely counteract one another as measured by shower length and width
  - but energy resolution decreased (in the direction of data)
  - unexpected benefit due to a decrease in total number of particles produced

Shower Energy Resolution in Cu-LAr Calorimeter

- Comparison to LHC test beam data indicates partition of energy among hadrons has improved with recent tuning of FTF mode



Ions, Isomers and Nuclides

- Nuclides now instantiated as needed during event loop
  - in 10.0 they were all instantiated beforehand
  - pre-instantiation still available by UI command

- Removed FindIon and GetIon methods from G4Particletable
  - now found in G4IonTable
  - reminder:
    - FindIon() returns pointer to ion if it exists
    - GetIon() returns pointer if it exists, if not ion is created

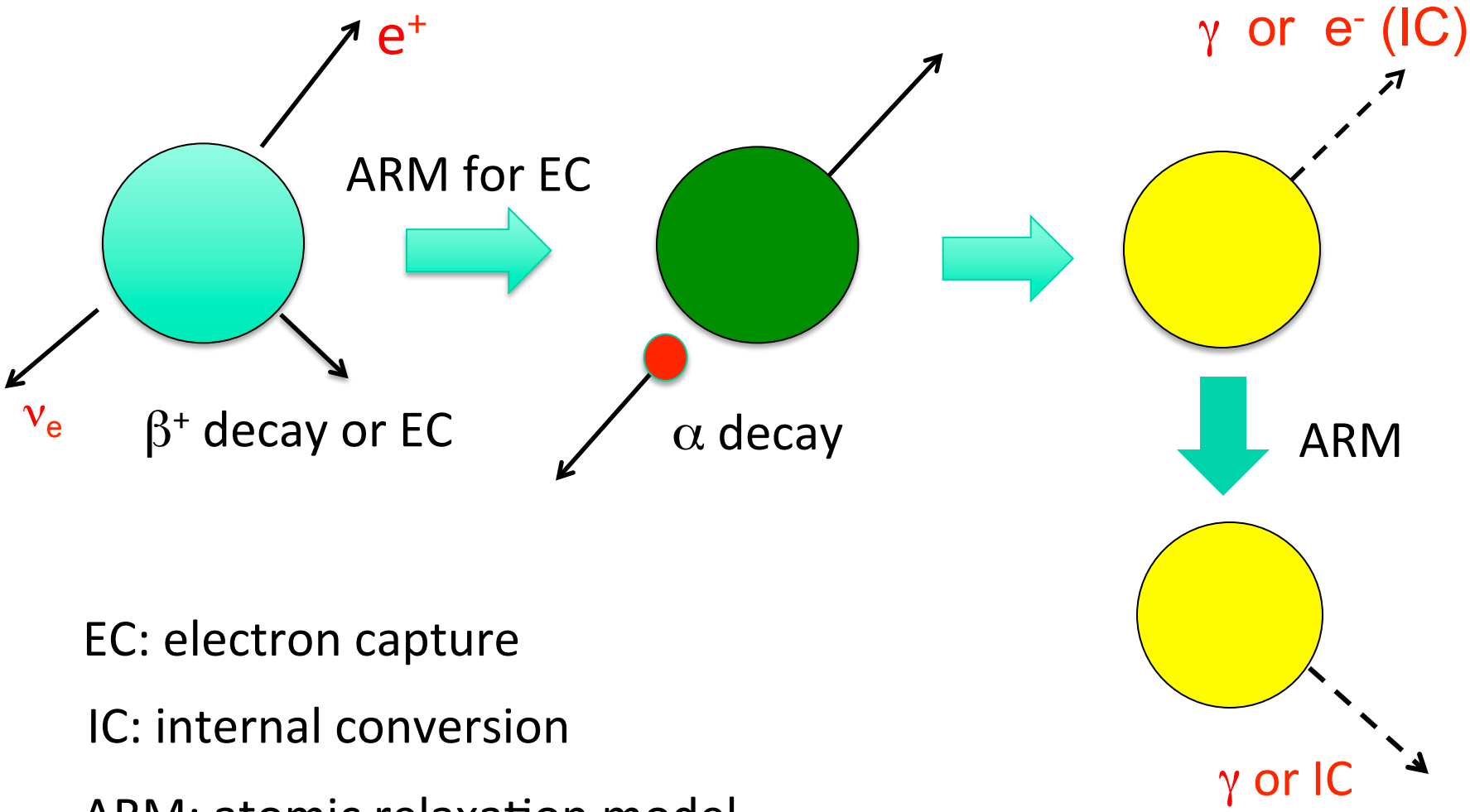
- Working on rationalizing the radioactive decay and photon evaporation data sets
  - levels in same nuclide differ by a few eV or less, difference not always real
  - in current design, causes irreproducibility and missed levels

Radioactive Decay Improvements

- Completed re-design of RDM package
  - more OO, more easily debugged, old code removed
  - → developers now able to concentrate on single decay channels
  - → significant improvement in energy conservation
    - achieved by using atomic masses, not nuclear masses
    - from ~ keV in some cases to ~ eV for α decay, β decay)

- Atomic relaxation now applied only for electron capture (EC) and internal conversion (IC)
  - cases where a hole is left in atomic shells
  - in past atomic relaxation applied to all RDM processes, but not clear if it was needed in β, α decay

Sample Radioactive Decay Chain



EC: electron capture

IC: internal conversion

ARM: atomic relaxation model

Radioactive Decay Improvements

- Reproducibility
  - goal: given the same initial random seed at the beginning of any two identical runs, retrieve same random seed at end of run
  - not achieved when multithreading first implemented
  - suspect problem due to complex system of database file reading
  - physics results OK though

- Reproducibility OK in 10.1, but:
  - fix does not take full advantage of MT
  - working on a fully-MT version → requires major re-write of RDM database file access

Radioactive Decay Improvements

- Updates to RDM, photon evaporation databases
  - use G4RadioactiveDecay4.2 and G4PhotonEvaporation3.1

- "Observationally stable" isotopes (^{209}Bi: 1.9 x 10^{19} y) now decay
  - to accommodate double beta decay and rare alpha decays
  - users should always put a time cut on their hit collection

- Code for decay by proton emission now included
  - database entries still required yet

NeutronHP

- Reproducibility (of random seeds) now restored in sequential running
  - fixed bug first seen in release 10.0

- Still problems with multi-threaded running
  - large memory consumption – problem being worked on
  - still some seed reproducibility

- New data set G4NDL-4.5 required
  - available on Geant4 download page

- Physics lists using this model for elastic scattering now set proton recoil cut to zero
  - improved energy conservation

ParticleHP

- The charged particle analogue of the high precision neutron model
  - for p, d, t, α : (α, n) reactions included
  - mostly for E < 20 MeV, but some higher energy data

- Finally in toolkit
  - was promised for more than two years
  - currently database (~Gbytes) is maintained at CIEMAT (Spain), but eventually to be linked to Geant4 web page

- ParticleHP and NeutronHP now being merged into one package => ParticleHP
  - planned for 10.2 release
  - validation and testing must still be done

Coming in 2015/2016

GND/GIDI/LEND

- Generalized Nuclear Data (GND)
  - new low energy particle database with more modern, rationalized format
  - includes all ENDF/B-VII data
  - upgrade of Generalized Interaction Data Interface (GIDI) used to access new GND format
    - to be delivered late 2015/ early 2016

- Can already try the new data
  - use G4LEND neutron models
  - or G4HadronElasticPhysicsLEND physics constructor
  - need to download data from ftp: //gdo-nuclear.ucllnl.org/pub

User Variation of Model Parameters

- Requested by several user communities
  - most notably for studies of neutrino production targets

- A means of establishing systematic errors for some models
  - Bertini cascade now under study
    - looking at varying nuclear radius, repulsive core radius, etc.

- To be offered on a restricted basis
  - only users working with model developers

Fast Cross Sections

- One of the largest time sinks in Geant4 hadronic models is cross section calculation and look-up
- Hadronic cross section optimization (work of Renci/UNC Chapel Hill)
  - caching cross sections
    - list of particle/material/process "triplets" built for a given application
    - caching ~10 of these is enough to speed things up considerably
    - being tested in Geant4 now
  - surrogate model
    - automatic construction of empirical model (polynomial) of cross section in a given energy range
    - store polynomials for fast access
    - prototype is working, but validation and testing required

Radioactive Decay and Photon Evaporation

- Correlated Gamma Emission
  - Currently photon evaporation code may emit multiple gammas during de-excitation, but they are isotropic and not correlated in angle
  - New code (Jason Detwiler) will make use of J^{π} data in photon evaporation database
    - gamma angular distributions will now be correct

- Spontaneous fission is still in the job queue

- Proton emission for super-heavy nuclei

Neutrino Interactions

- First step: interface of Geant4 to GENIE
  - goal: allow GENIE neutrino generator to use Geant4 hadronic models for fragmentation and final state interactions within nucleus following initial interaction
    - will allow greater variety of models than now available in GENIE
    - planned for end of 2015

- Second step: interface of GENIE to Geant4
  - goal: allow Geant4 to use GENIE's neutrino-nucleus interactions in a Geant4 neutrino process
    - planned for early 2016

- Third step: once neutrino scattering processes are in place, use new Geant4 biasing techniques to do neutrino propagation

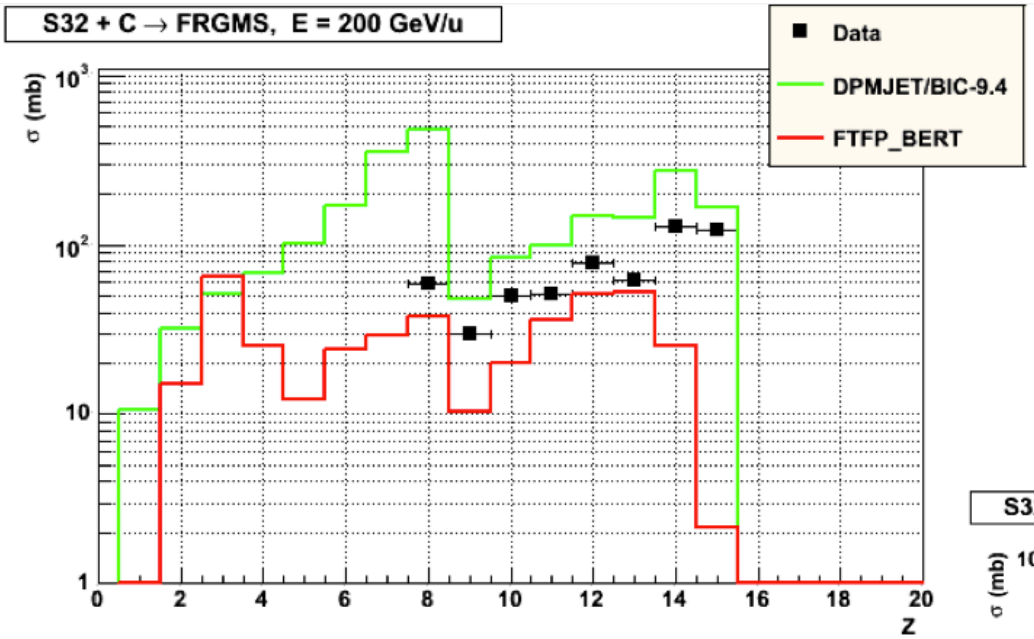
Backup

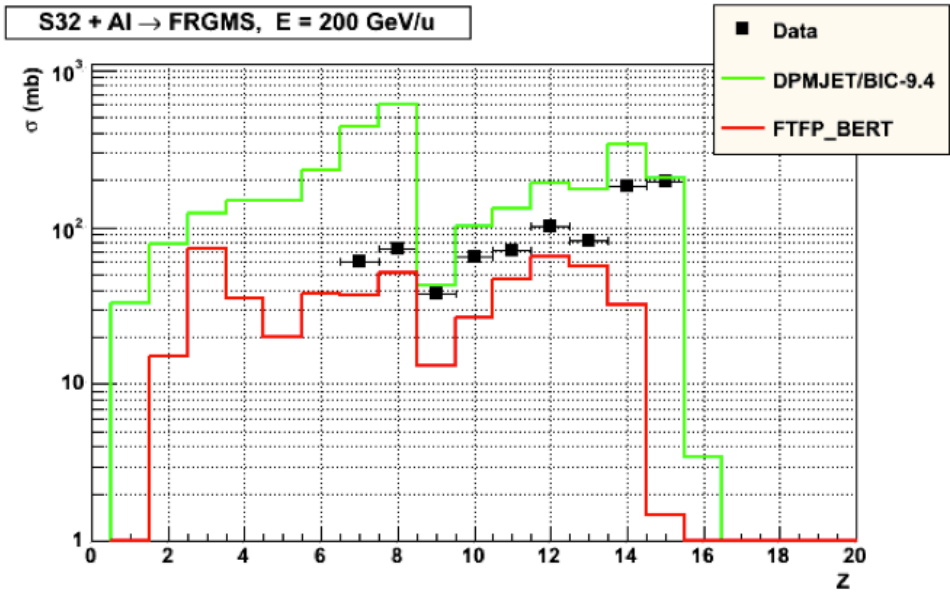
Fritiof Nucleus-nucleus

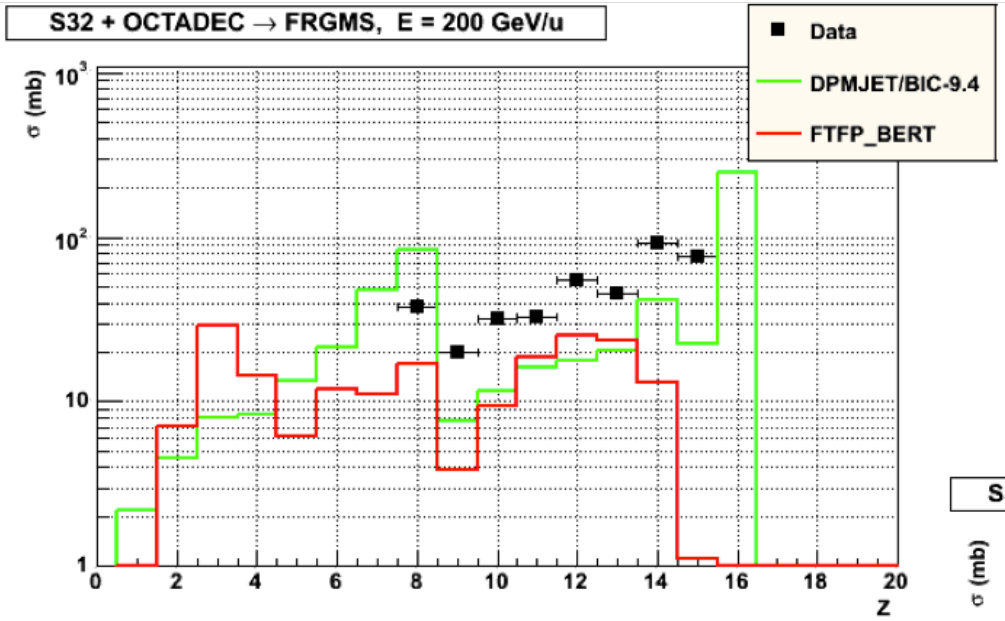
- Interface to DPMJET II.5 no longer works
  - serious energy non-conservation problems and maybe more
  - also limited to Z < 26
  - compiles and runs, but difficult to maintain Fortran code and interface

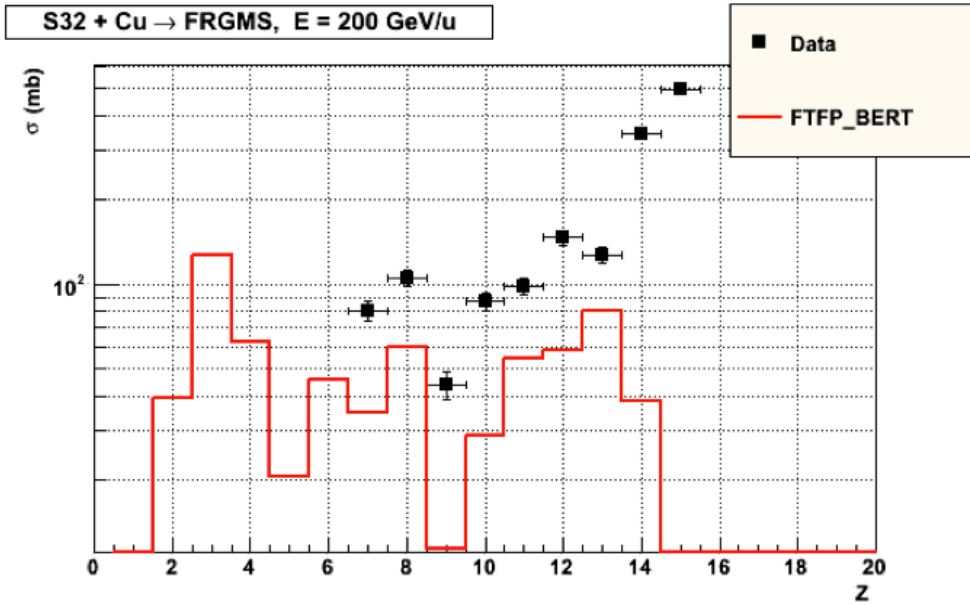
- Would like to have native G4 code for high energy nucleus-nucleus collisions
  - FTF can now do nucleus-nucleus; try it
  - validate against 1987 data from CERN SPS:
    - 200 GeV/u ^{32}S on C, Al, S, Cu, Ag, Pb
  - CPU for DPMJET and FTF similar

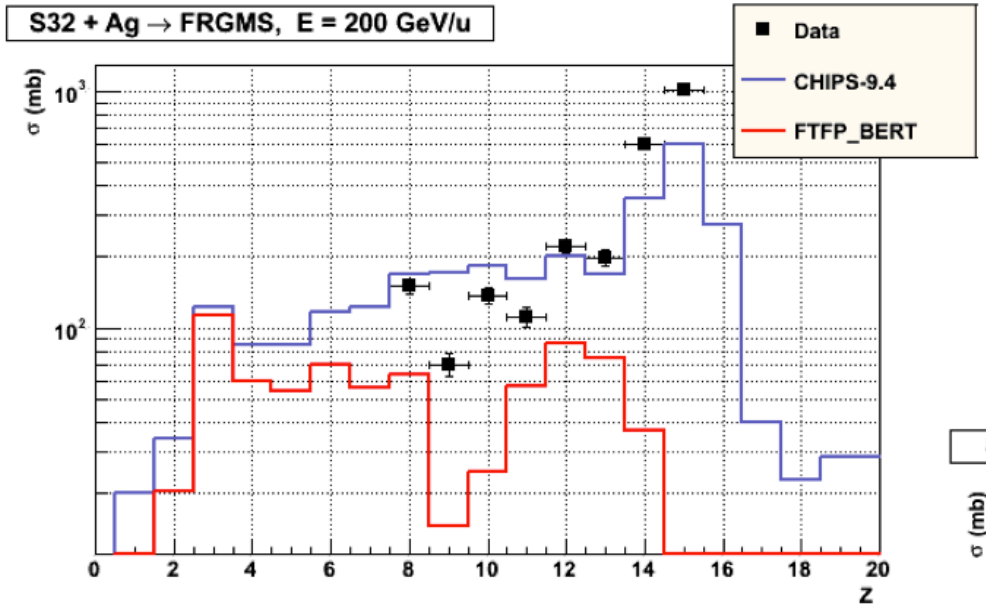
- FTF looks promising
  - better than DPMJET for light targets

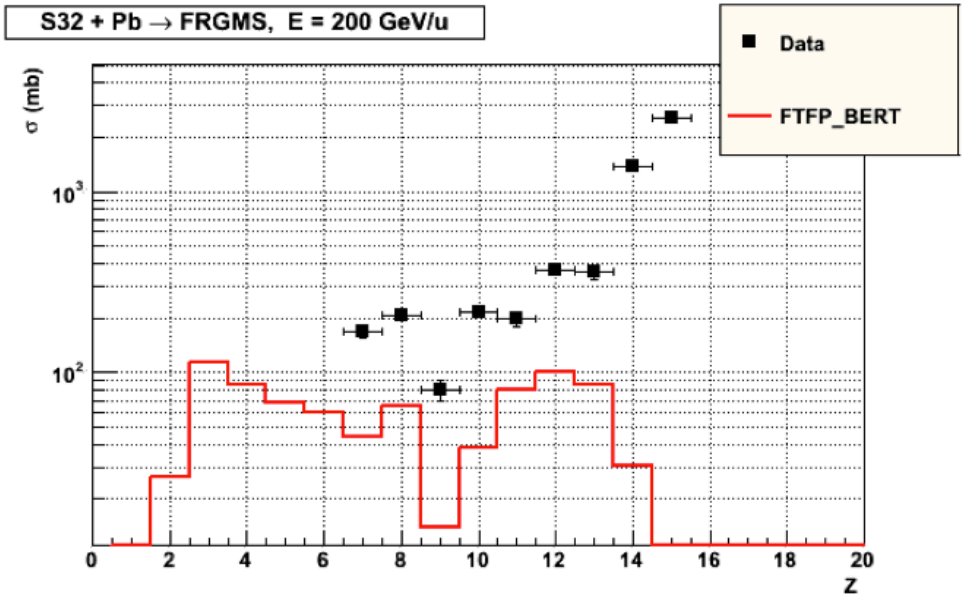

S32 + C → FRGMS, E = 200 GeV/u
Data
DPMJET/BIC-9.4
FTFP_BERT
σ (mb)
Z


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)
Z


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