Recent Developments in Geant4

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1st Cosmic Ray Antideuteron Workshop

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Outline

- Geant4 v10/Multi-threading
- Geometry
- Electromagnetic physics
  - multiple scattering, phonons
- Radioactive decay
- Hadronic physics updates
- Nucleus-nucleus and antinucleus-nucleus physics
  - the Fritiof QCD string model
  - nucleus-nucleus collisions
  - antinucleus physics

Multi-threading in Geant4

- Version 10 supports (optional) event-level parallelism
  - can now take advantage of the full CPU power of your machine which likely has more than 1 core
  - you can select a build with up to N threads where N is the number of cores your machine has available (8 for a MacBook Pro)
  - you may still opt for a sequential (non-multi-threaded) build

- Installation
  - as usual, see the Geant4 Installation Guide accessible from the Geant4 web page (User Support -> Documentation -> Installation Guide)
  - see also latest developments and performance at twiki.cern.ch/twiki/bin/view/Geant4/MultiThreadingTaskForce

Linearity (MT vs. Sequential Cores)

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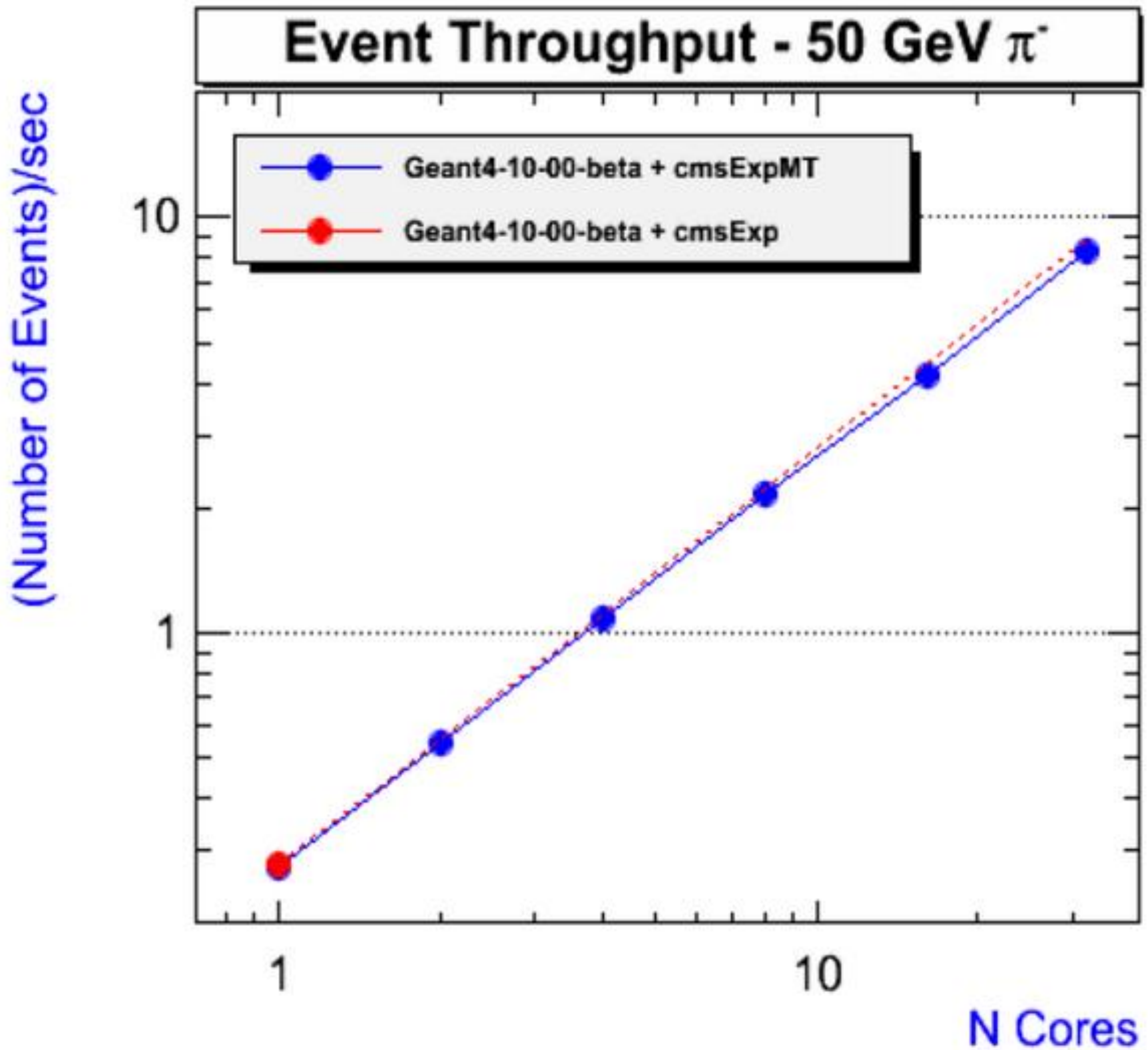

Multi-threaded Physics Performance

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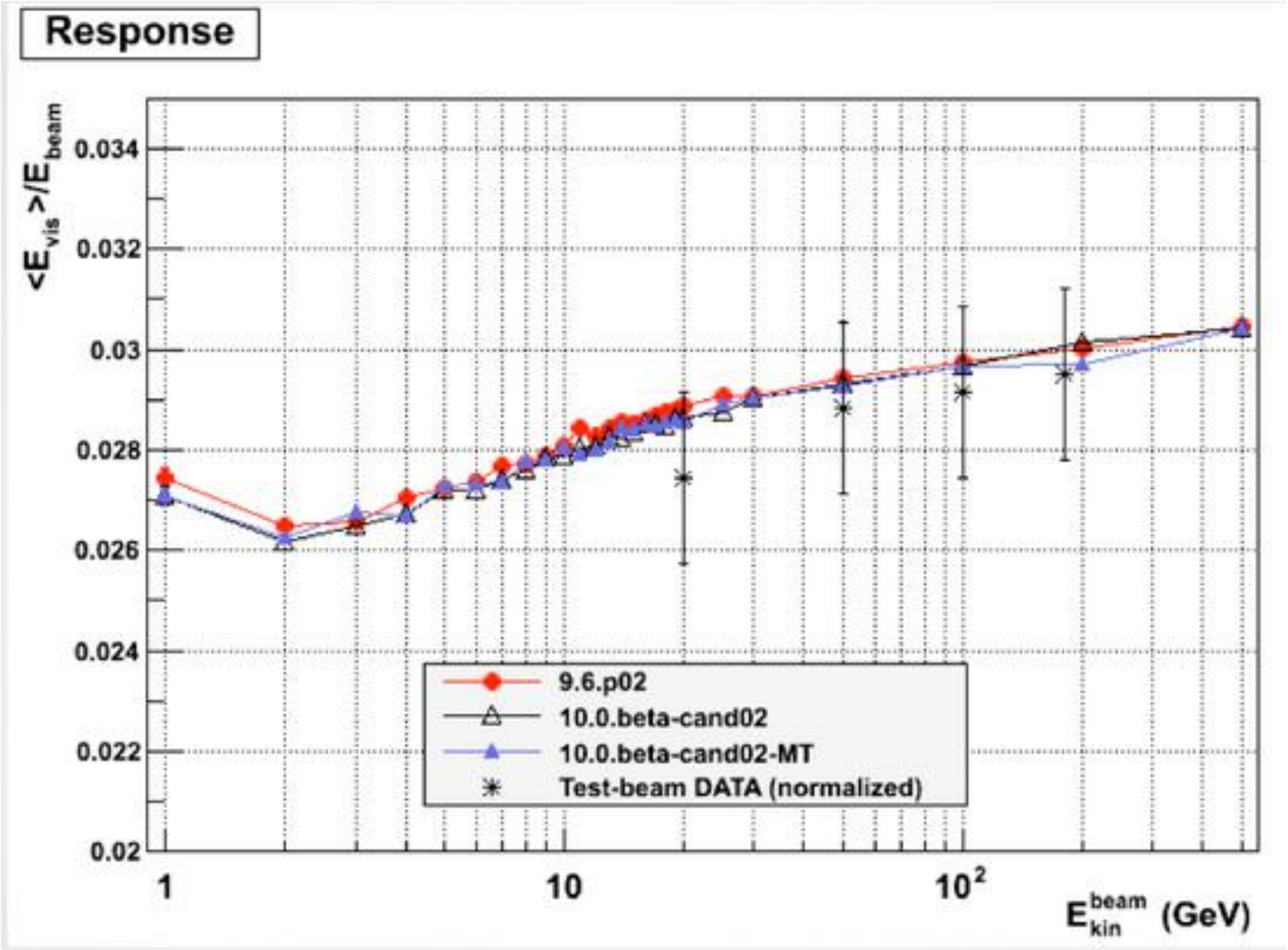


Some Multi-threading Details (1)

- At the end of the first kernel initialization, N worker threads are created and initialized
  - each of these threads is responsible for simulating events
- Each thread is tasked with an event on first come, first serve basis
  - event numbers per thread are not sequential
- Objects that consume the largest fraction of memory are shared among threads
  - geometry
  - physics tables
- Built-in command-based scorers or g4tools histogramming perform collection and reduction of all events automatically at end of each run
  - user is responsible for collecting user-developed quantities

Some Multi-threading Details (2)

- Based on POSIX standards (pthreads) and on an extension of thread local storage (TLS)
  - smaller chunks of memory need not be shared
- Caveats:
  - although heavily tested, note that this a major architecture modification
    - can expect some bugs
  - integral numbered build
    - developers allowed to break user code if absolutely necessary => not necessarily related to multi-threading
- Version 10.0 patch2 already released
  - subsequent patches expected

Geometry Improvements

- Unified solid library
  - code review and algorithm optimization for most-used primitives
    - box, trapezoid, sphere, orb, tube, cone, tetrahedron
  - updated solids considerably faster in most cases

- Improved G4TessellatedSolid
  - o(1000) times faster for volumes with > 100k facets
  - due to use of spatial partitioning for decomposition into grid of voxels

- MultiUnion
  - fast replacement for G4UnionSolid in the case of large numbers of constituent volumes
  - ready for next minor release

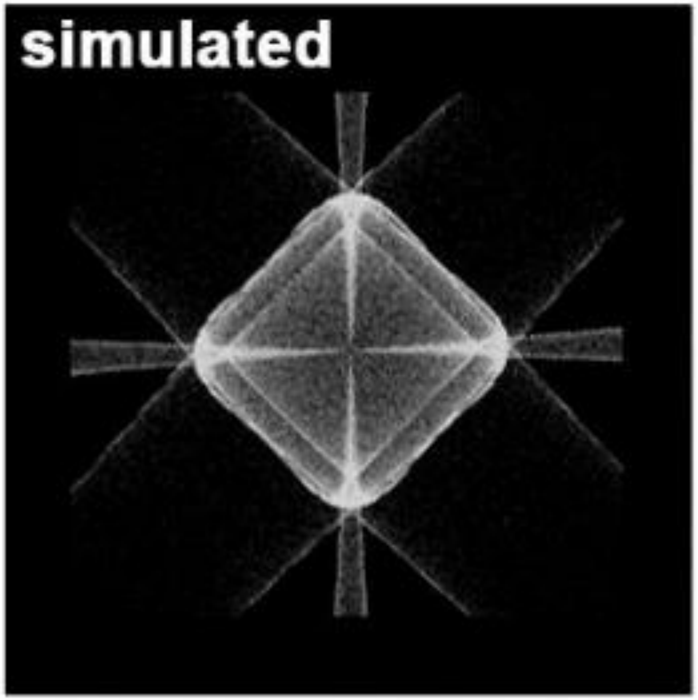
Electromagnetic Physics Improvements

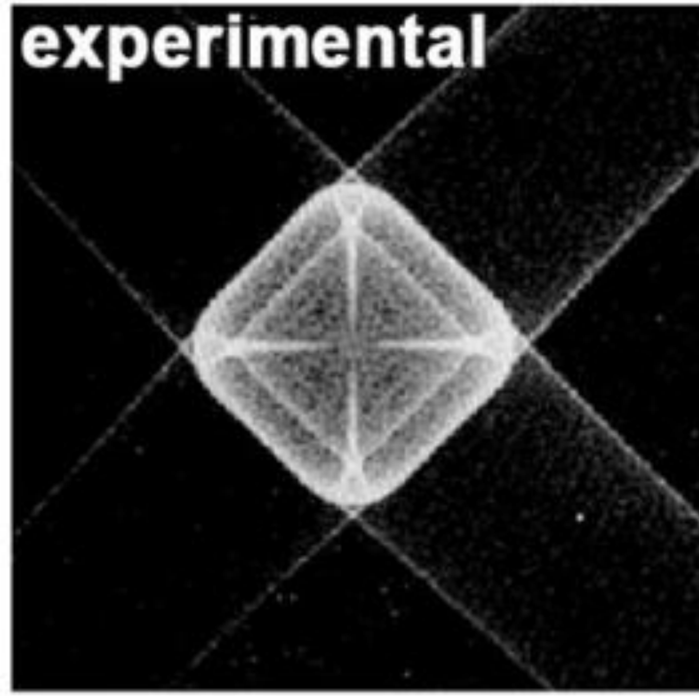
- Consolidated model for all multiple scattering processes
  - G4UrbanMscModel
    - improved tuning of the Urban multiple scattering model
    - improved Urban model of fluctuations
    - replaces all previous versions: Urban 90, 93,95, 96

- Improved e^+/e^- pair production by HE muons and hadrons
  - more detailed tabulation grid of differential cross sections

- New, minimal framework for low temperature phonon propagation introduced
  - G4 materials can now support crystal structure
  - new particle types: G4Phonon
  - new phonon processes: scattering, down-conversion
  - see examples/extended/exoticphysics/phonons

Propagated Phonon Pattern at Face of Ge Crystal (caustic)





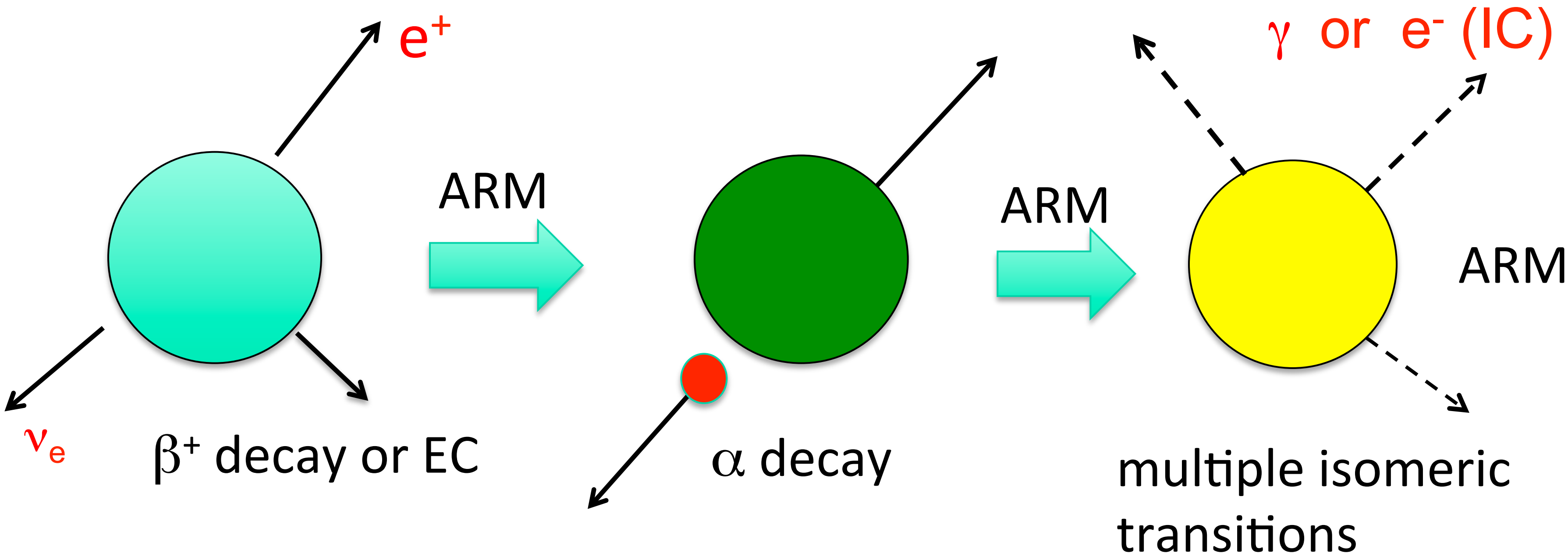
Caustics in Ge collected by phonons example

Caustics in Ge observed by Northrop and Wolfe PRL 19, 1424 (1979)

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 RadioactiveDecay4.1
    - includes all meta-stable states with lifetimes longer than 1 ns
  - all known gamma transitions (regardless of lifetime) for 2071 nuclides
    - download-able as PhotonEvaporation3.1
  - 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 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

Hadronic Physics Improvements

- Bertini cascade (0 – 10 GeV) improvements
  - better two-body final state angular distributions (from SAID)
  - improved multi-body phase space calculations
  - can now do muon capture by using quasi-deuteron absorption model
- INCL++
  - an alternative to Bertini cascade
  - valid from 0 to 5 GeV
  - works with most hadrons and nuclear projectiles up to ^{12}C
- NeutronHP
  - multi-threading warning: large memory consumption
    - OK in single-threaded mode
  - G4NDL now uses zlib for easier handling, faster loading
    - database size before zlib: 1.54 Gb, now 429 Mb

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

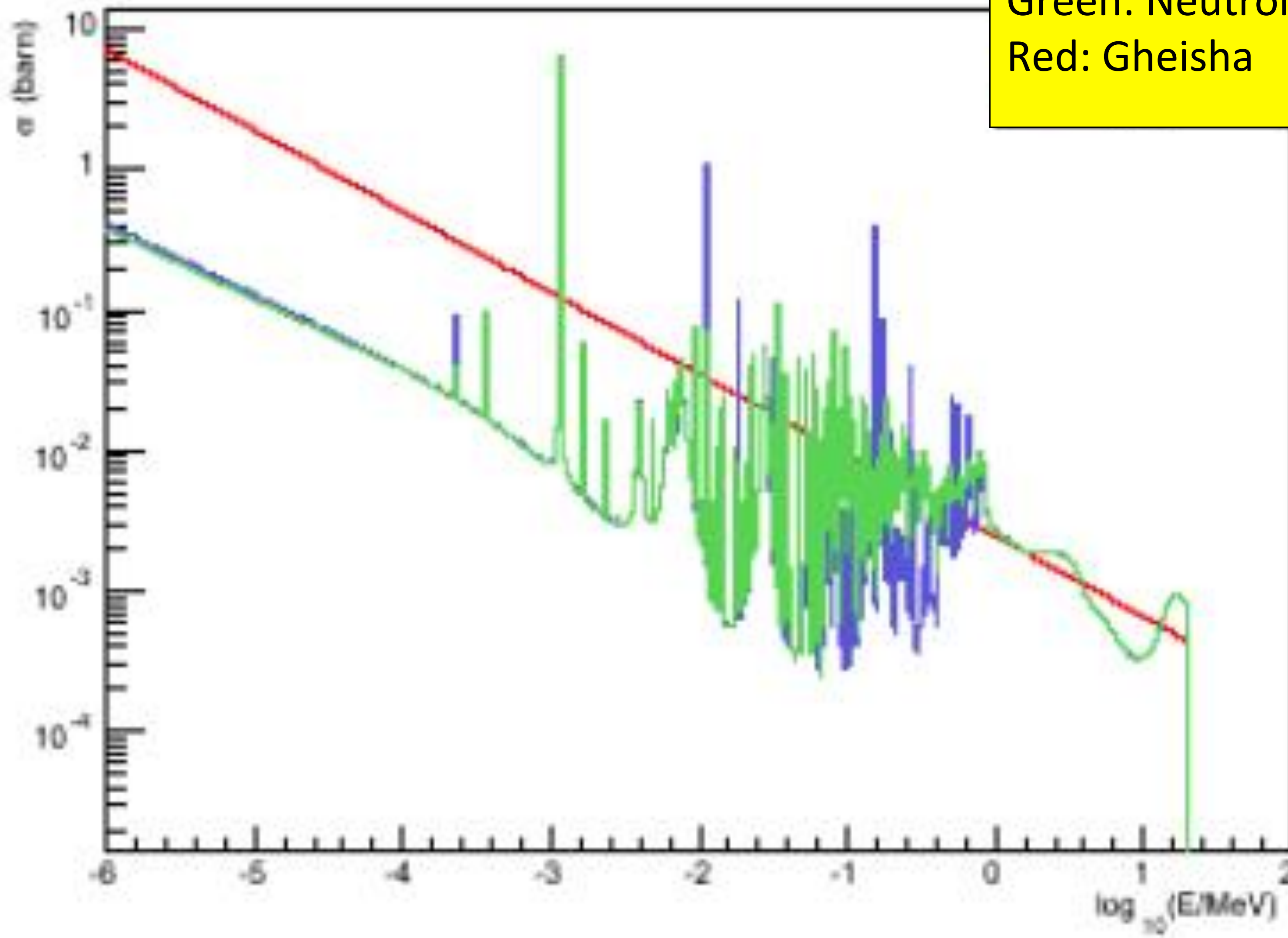
NeutronXS

- Alternative to NeutronHP cross sections
  - faster (3-5 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

Blue: HP
Green: NeutronXS
Red: Gheisha



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

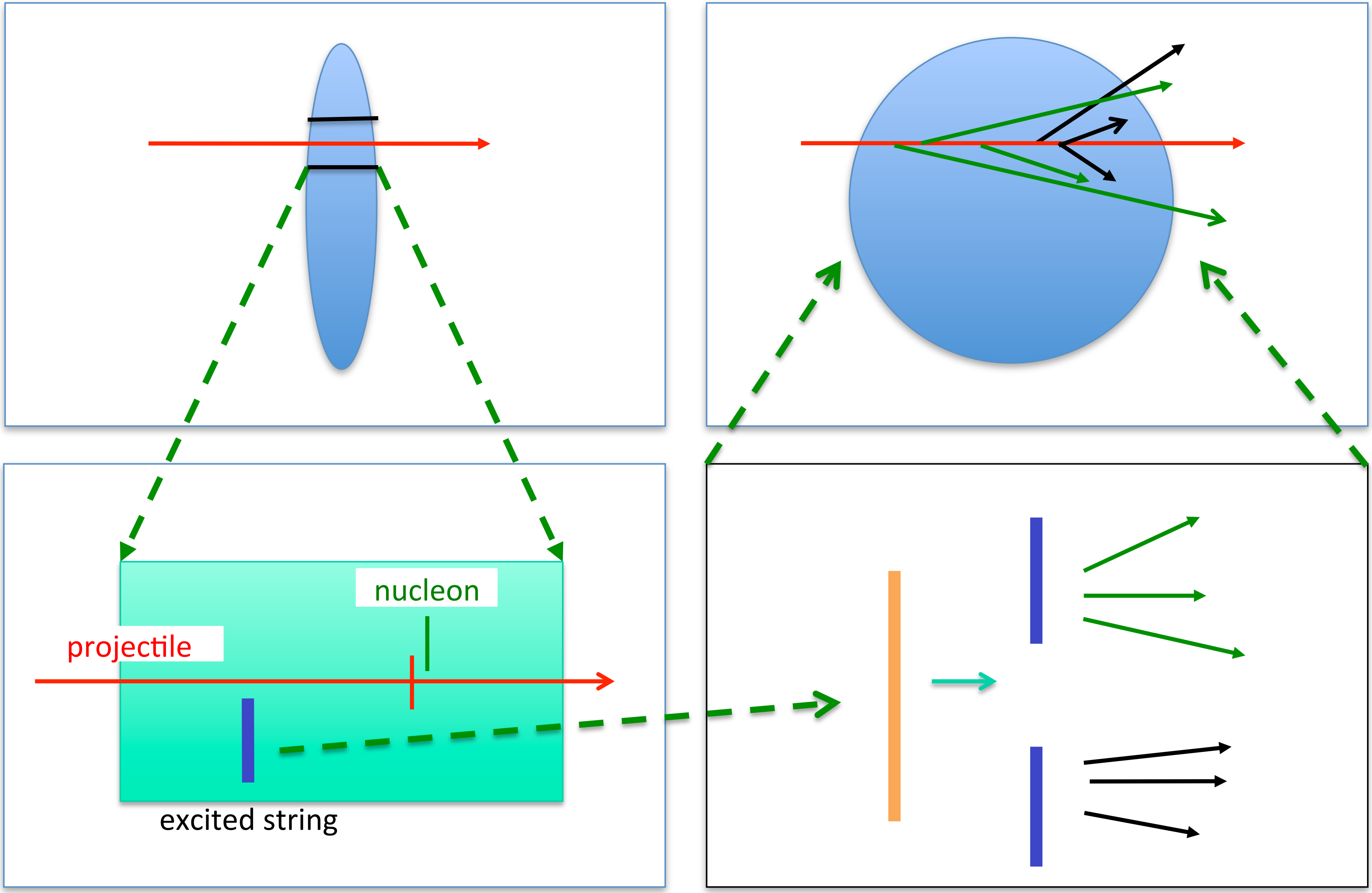
Fritiof (FTF) Model

- QCD string model
  - nominally for use at 10 GeV and above
  - extended for use down to 2 GeV by adjusting string masses

- Recent improvements
  - enlarged set of thin-target data to tune on
  - extended to handle nucleus-nucleus collisions
  - extended for use with anti-p and anti-n
    - at least 2 GeV now available for string formation
    - now can extend down to 0

- Anti-matter applications:
  - now the best model to use for anti-proton, anti-neutron inelastic interactions with nuclei at all energies
  - even for absorption of stopped anti-protons, slow anti-neutrons

FTF Hadron-Nucleus Interaction

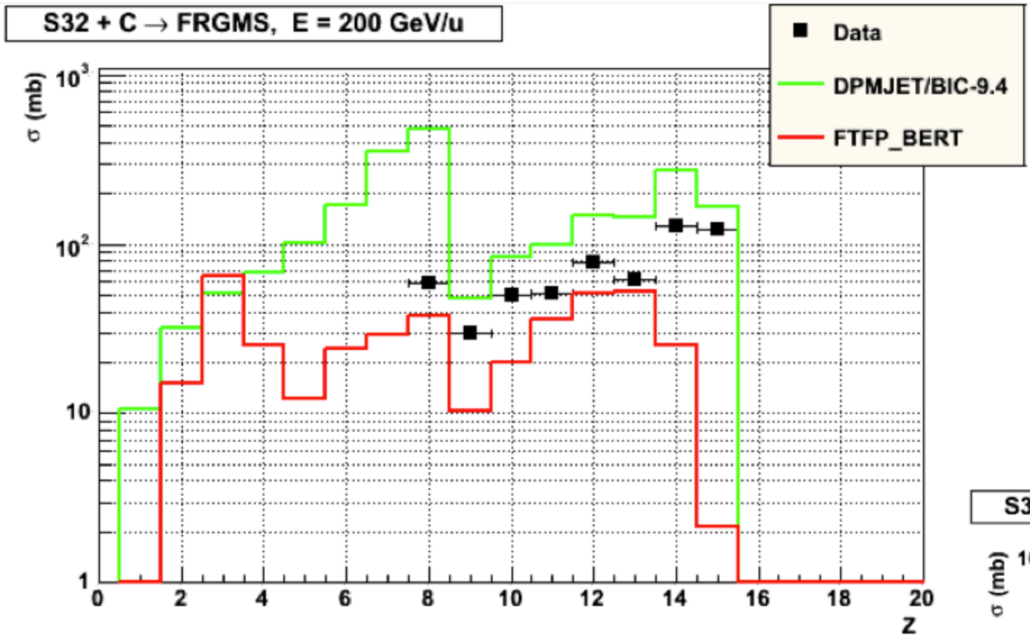


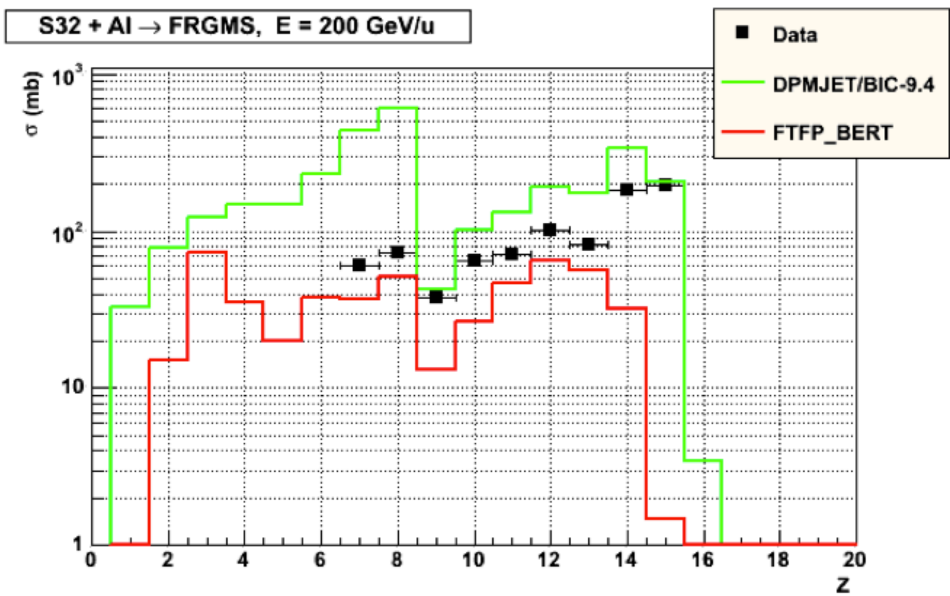
Fritiof Nucleus-nucleus

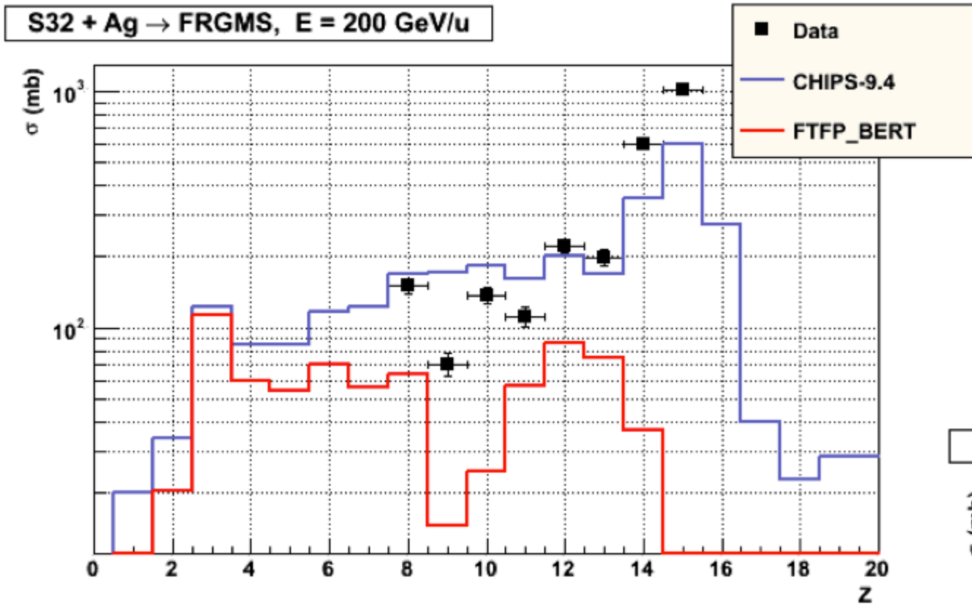
- Interface to DPMJET II.5 no longer works
  - serious energy non-conservation problems and maybe more
  - also limited to Z < 26
  - compiles and runs, but difficult to maintain Fortran code and interface

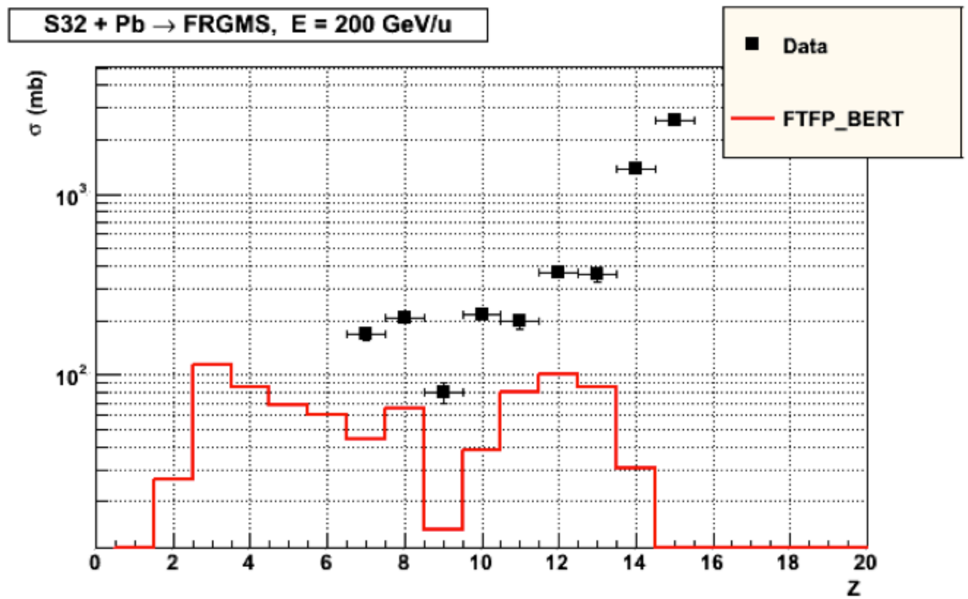
- Would like to have native G4 code for high energy nucleus-nucleus collisions
  - FTF can now do nucleus-nucleus; try it
  - validate against 1987 data from CERN SPS:
    - 200 GeV/u ^{32}S on C, Al, S, Cu, Ag, Pb
  - CPU for DPMJET and FTF similar

- FTF looks promising
  - same as DPMJET for light targets

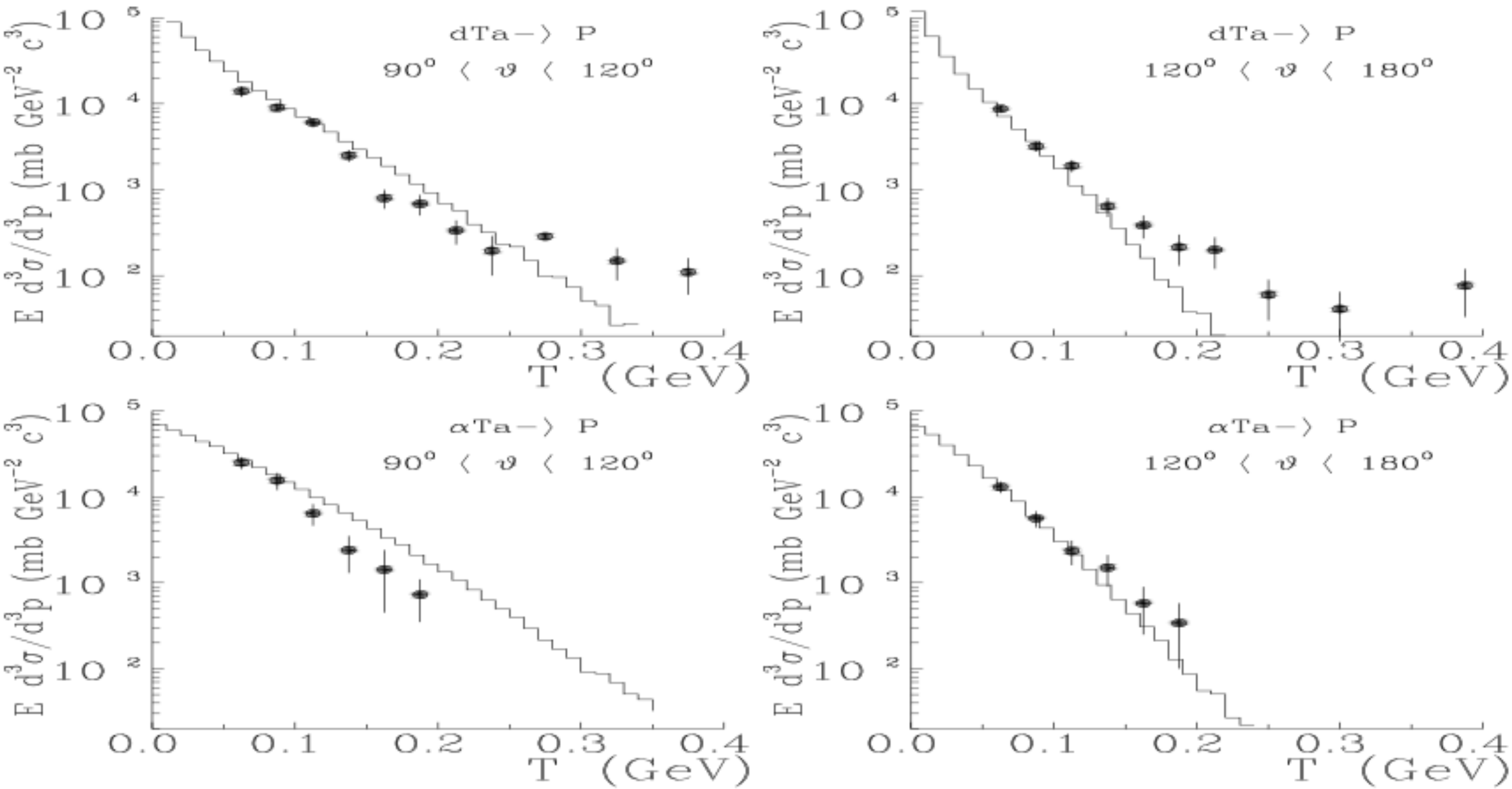

S32 + C → FRGMS, E = 200 GeV/u
Data
DPMJET/BIC-9.4
FTFP_BERT
σ (mb)
Z


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


S32 + 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

4.5 GeV/c/nucleon d and α on Ta



Anti-nucleus Physics

- anti- (p, d, t, ^{3}He, α) all have the following processes
  - multiple scattering
  - ionization
  - hadron inelastic (G4AntiDeuteronInelasticProcess, etc.)
  - hadron elastic (G4HadronElasticProcess)

- All are included in the Geant4 supported physics lists
  - FTFP_BERT, QGSP_BIC, ...
  - see:
    - source/physics_lists/builders/src/G4AntiBarionBuilder.cc
    - source/physics_lists/builders/src/G4FTFPAntiBarionBuilder.cc

- Enabling technology for hadronic model:
  - antinucleus-nucleus model by V. Uzhinsky and A. Galoyan: arXiv: 1208.3614v1 [nucl-th] 17 Aug 2012.

Fritiof Anti-nucleus Nucleus

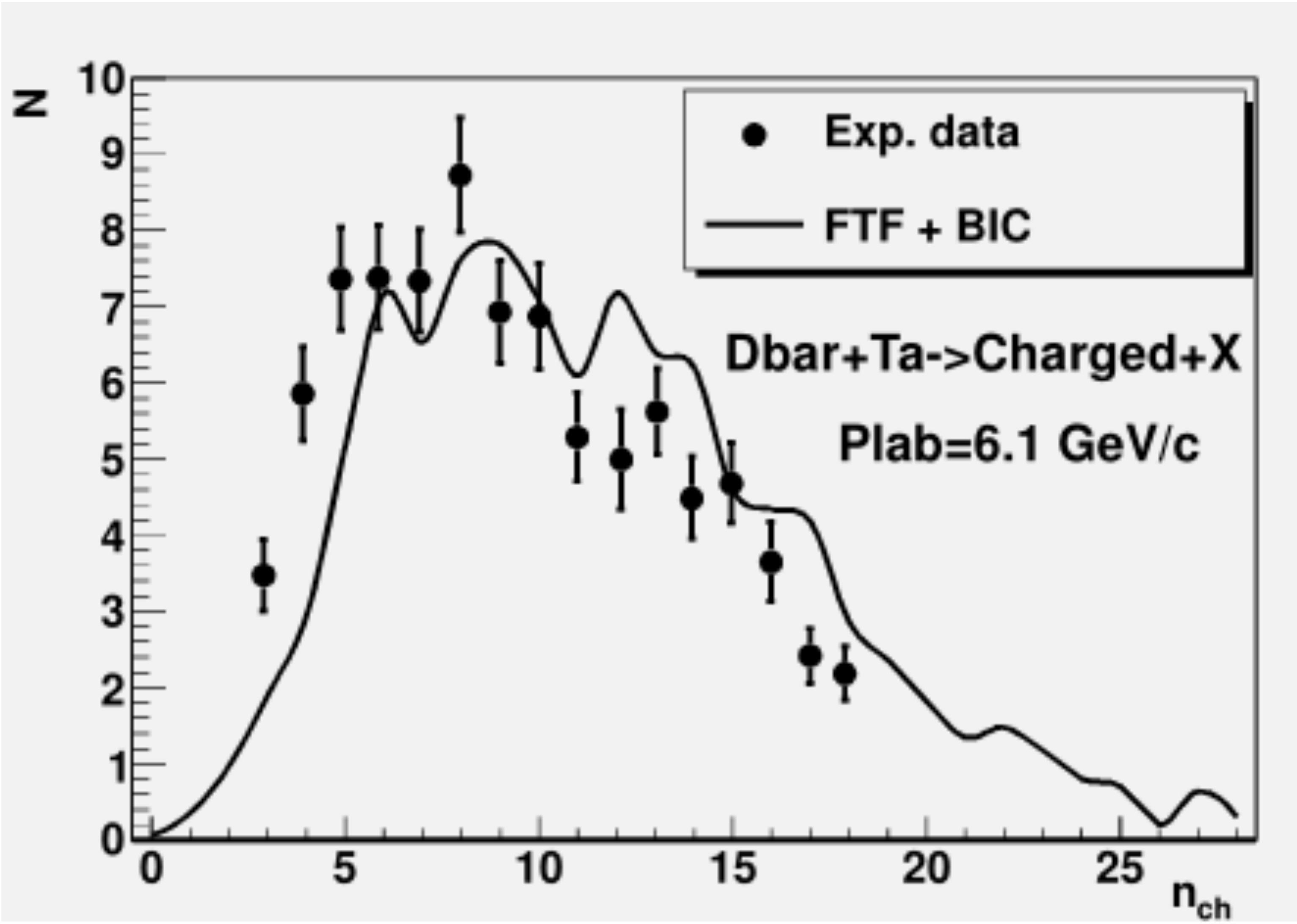
- Fritiof (FTF) high energy QCD string model extended
  - to zero energy because at least 2 GeV is available to form strings
  - to antinuclear projectiles because of Glauber theory – same machinery used to calculate nucleus-nucleus collisions in FTF

- Model features:
  - energy dependence of antinucleon-nucleon collisions used to parameterize antinucleus-nucleus collisions
  - assume no cascade of secondary particles in projectile (it's just a source of antinucleons)

  - chain of successive interactions of projectile in nucleus terminated with annihilation
  - once interaction partners are chosen, FTF model does QCD string interactions

6.1 GeV/c antideuterons on Ta

data: V.F. Andreyev et al., Nuov. Cim., 103A, 1163 (1989).



Summary

- Multi-threading will allow use of all cores in your computer
- Faster geometry for complex set-ups
- Consolidated multiple scattering model
- Further radioactive decay improvements
- Improved physics for cascade models, neutrons
- High energy nucleus-nucleus collisions supported for all A
- Light antinucleus propagation and collisions with nuclei now supported