Improving the Medium and Low Energy Physics Models in Geant4

Calorimetry at the High Energy Frontier
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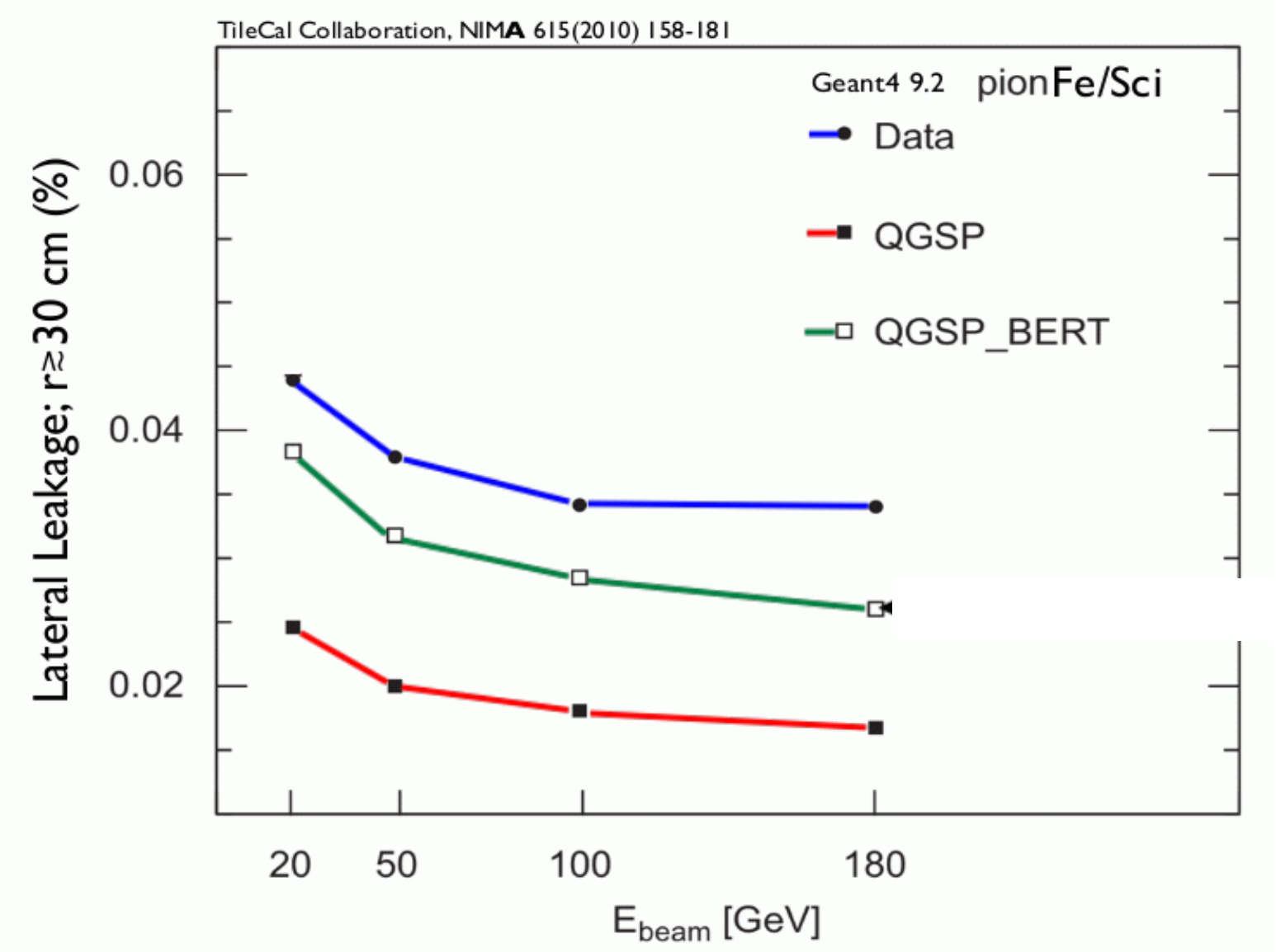
Medium and Low Energy Hadronic Processes in Calorimetry

- Shower parameters strongly affected by details in medium and low energy hadronic models (< 10 GeV)
  - shower width (cascade)
  - energy resolution (cascade, precompound and de-excitation)
  - energy deposit (de-excitation and low energy neutrons)
  - time structure (low energy neutrons)

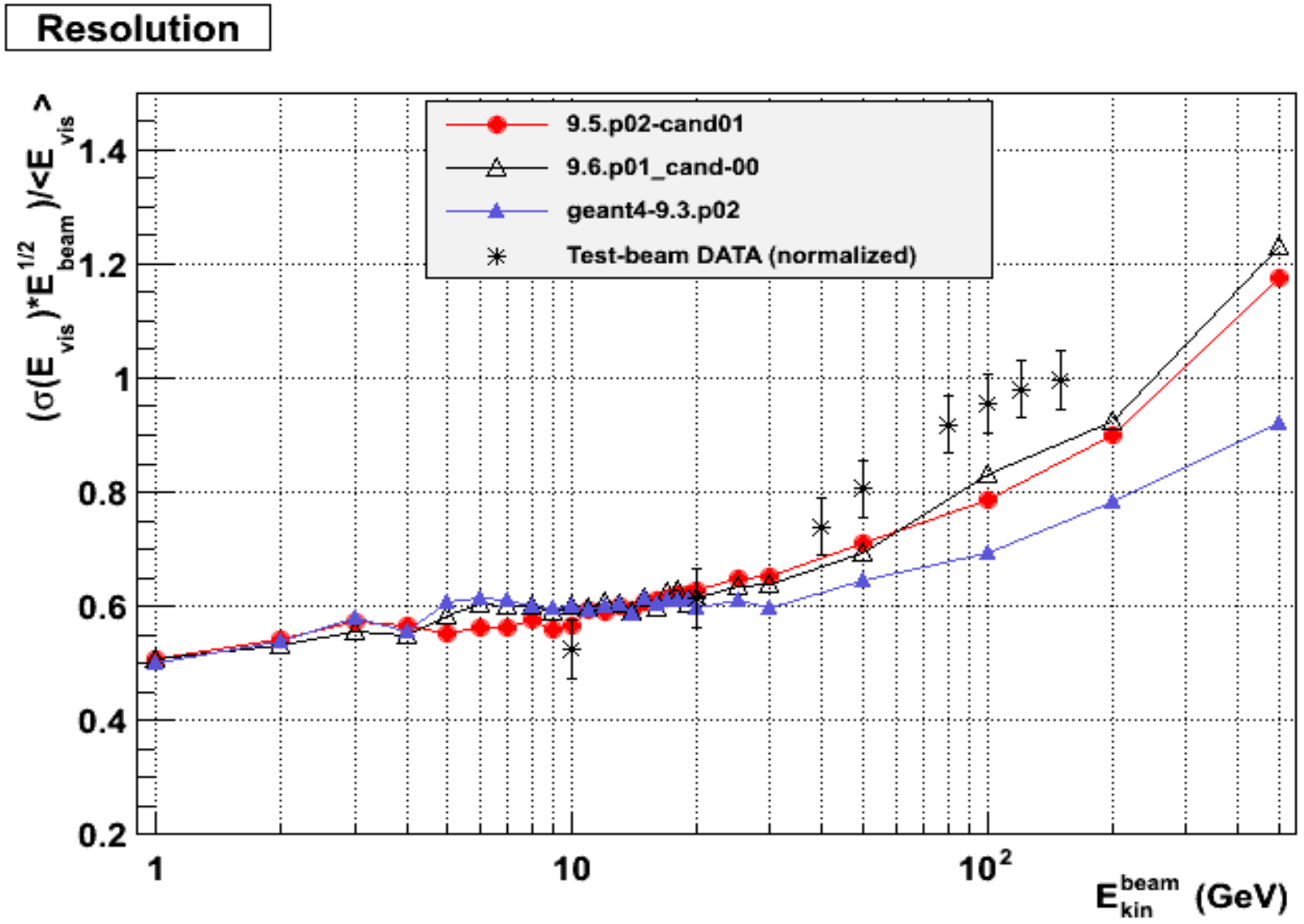
- Given this sensitivity, it's important to get the details right
  - over past few years agreement with LHC test beam data and Calice fine-grained calorimeter has improved
  - comes from improved or added physics, not tuning

- We give here the highlights of these physics improvements

Effect of Intra-nuclear Cascade



Energy Resolution Improvement (LArCu)

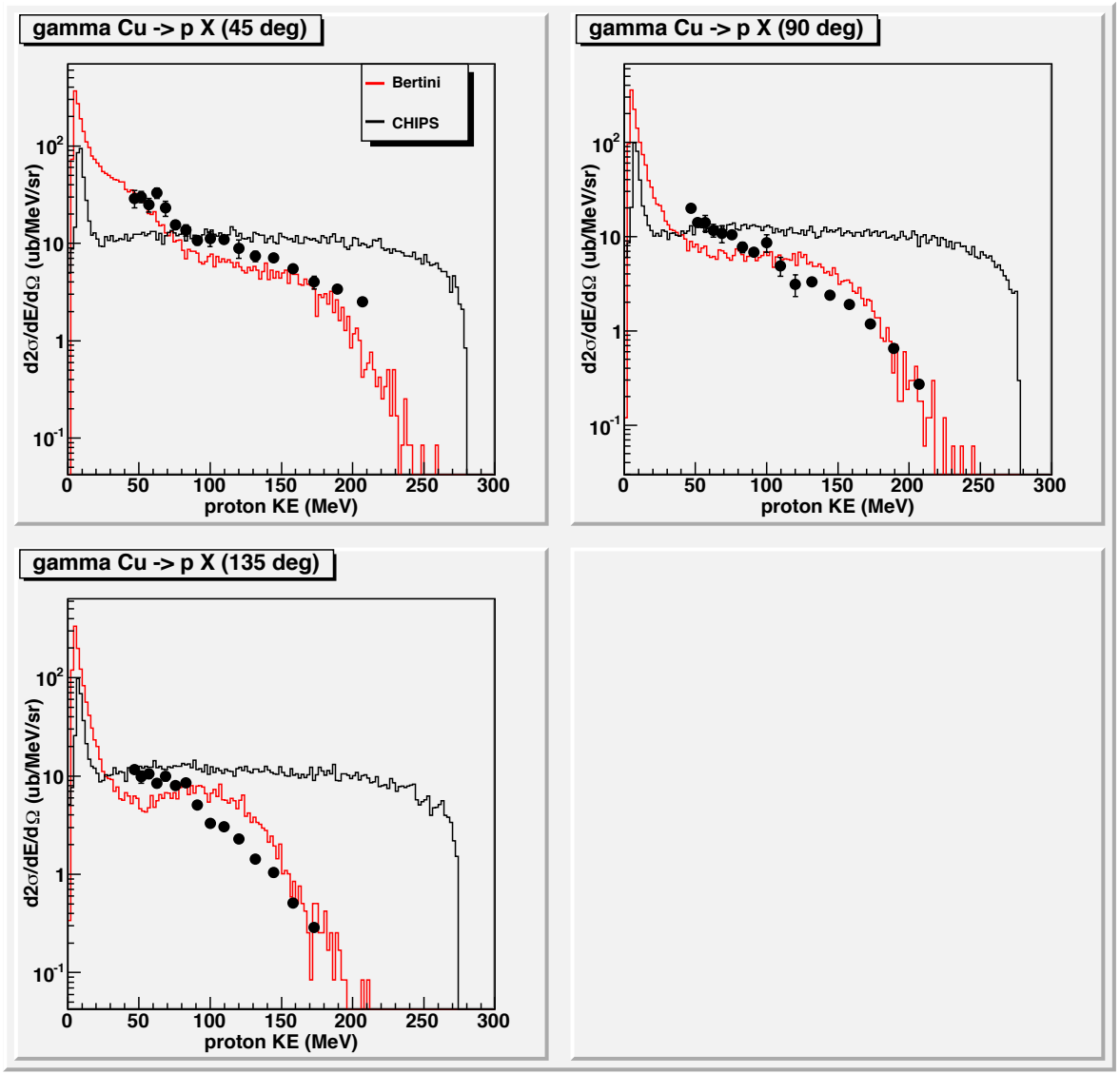


Bertini-style Intra-nuclear Cascade (1)

- Now an "all-hadron" code
  - all long-lived hadrons from π^0 to Ω^- up to ~10 GeV
- γ : improved photo-nuclear process
  - gammas from ~10 MeV to 10 GeV now interact directly with nuclei using the cascade
  - above 10 GeV, the FTF string model is used, but first the gamma is converted to a pion

- And some others, too
  - electro-nuclear for e^-/e^+ (G4ElectroVDNuclearModel)
    - as in old model, uses CHIPS cross sections and virtual gamma generation
    - uses Bertini-style cascade to interact gamma below 10 GeV, FTF above 10 GeV
  - muon-nuclear for μ^+/μ^- (G4MuonVDNuclearModel)

γ Cu -> p X (300 MeV) with Bertini



Bertini-style Intra-nuclear Cascade (2)

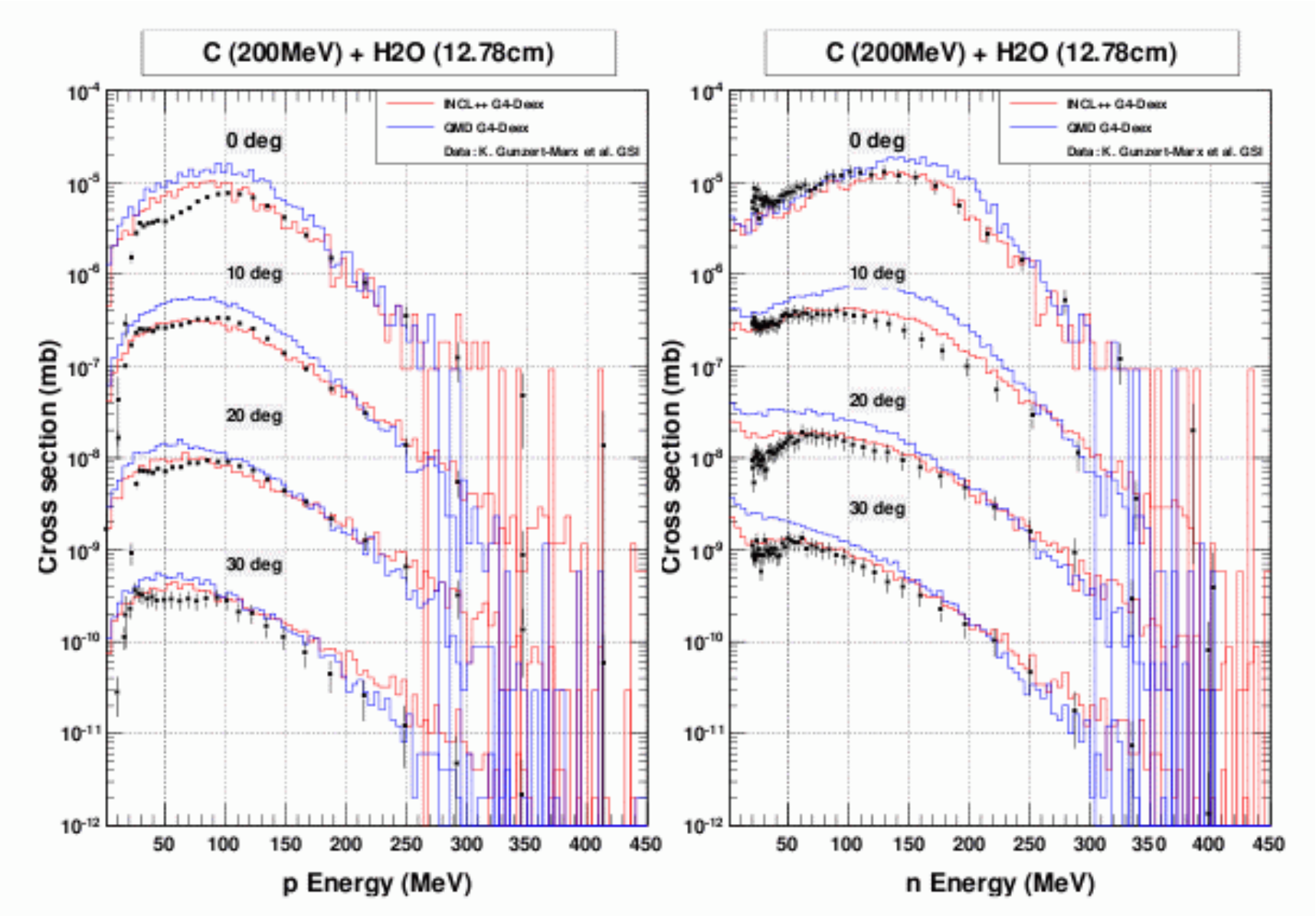
- Interfaces
  - Bertini works fairly well outside its original range of applicability (100 MeV – 5 GeV)
  - but other codes do better at low energies (G4Precompound), and at high energies (Fritiof)
  - interfaces to both these codes are now available
- G4Precompound interface
  - see later slide
- Rescattering interface
  - secondaries from first high energy interaction by string model (Fritiof) are often too high in energy to be passed to nuclear precompound model
  - should use cascade instead
  - interface for this now exists and is being validated

INCL++

- Lineage: Liege intra-nuclear cascade -> INCL -> INCL++
- Latest Geant4 version contains many improvements
  - originally for pion- and nucleon-induced cascades between 100 MeV – 3 GeV
  - now completely re-designed, written in C++
  - 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 emission

- An excellent alternative to G4BinaryCascade or G4QMD
  - especially good for spallation energies
  - new physics lists soon to be available using this model
- Plans to extend to higher energies, more projectile types

Ion-ion Collisions in INCL++

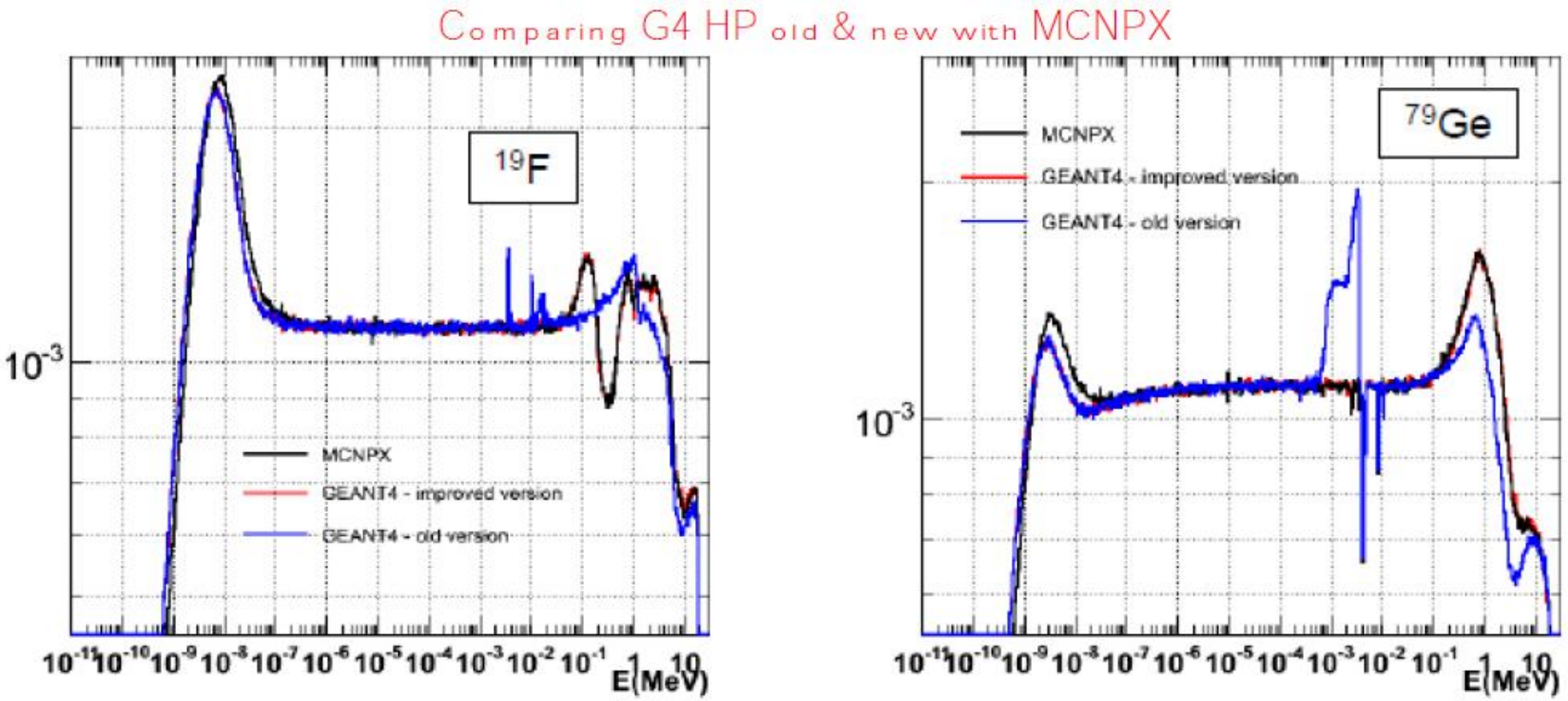


G4NeutronHP Models

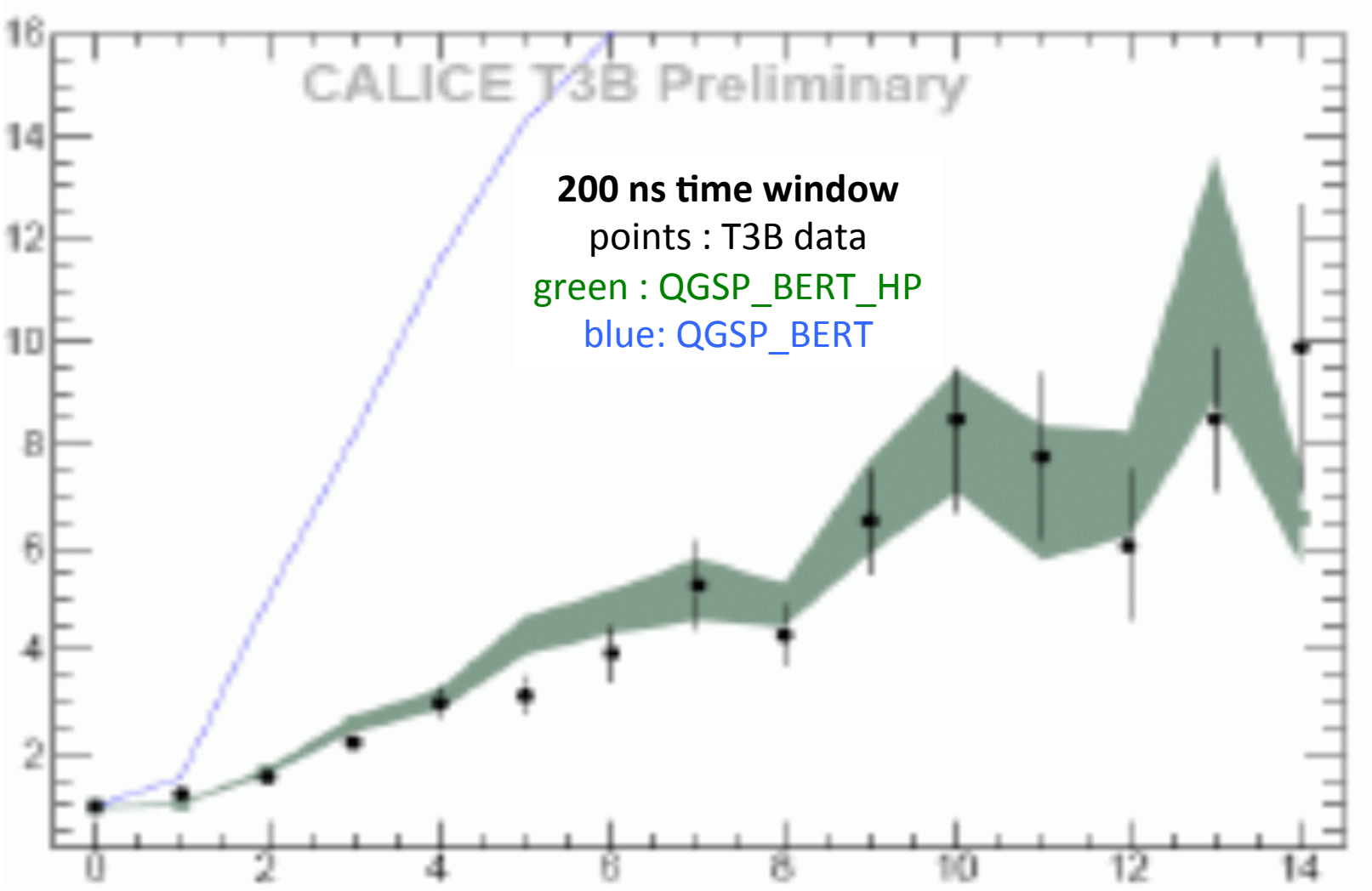
- The old standard for elastic, inelastic and capture below 20 MeV, but now more data library options
  - the neutron database G4NDL used to be a mix of 8 different evaluated databases
  - now based entirely on ENDF/B VII
  - each of the other 7 databases (JENDL, MENDL, CENDL, etc.) available for substitution

- Extended to do low energy reactions on nuclei bound in molecules
- Extension to low energy charged particles (p, d, α) planned
  - prototype for protons available, still being tested
  - α model expected sometime this year
  - will have same data sources as neutronHP

High Precision Neutrons
Comparing Geant4 and MCNPX



Effect of Low Energy Neutrons on Showers



LEND Models

- New alternative to Neutron HP
  - based on GIDI (General Interaction Data Interface) – a new format for nuclear data using the Livermore database
  - ENDF, JEFF, JENDL, ENDL will be converted to this format

- G4LEND models are interfaces to GIDI
  - all NeutronHP models have counterparts in LEND (elastic, inelastic, capture, fission)
  - available for use, but not all DBs are converted to GIDI format yet

- Performance
  - 5 X faster than NeutronHP due to pre-calculated Doppler broadening

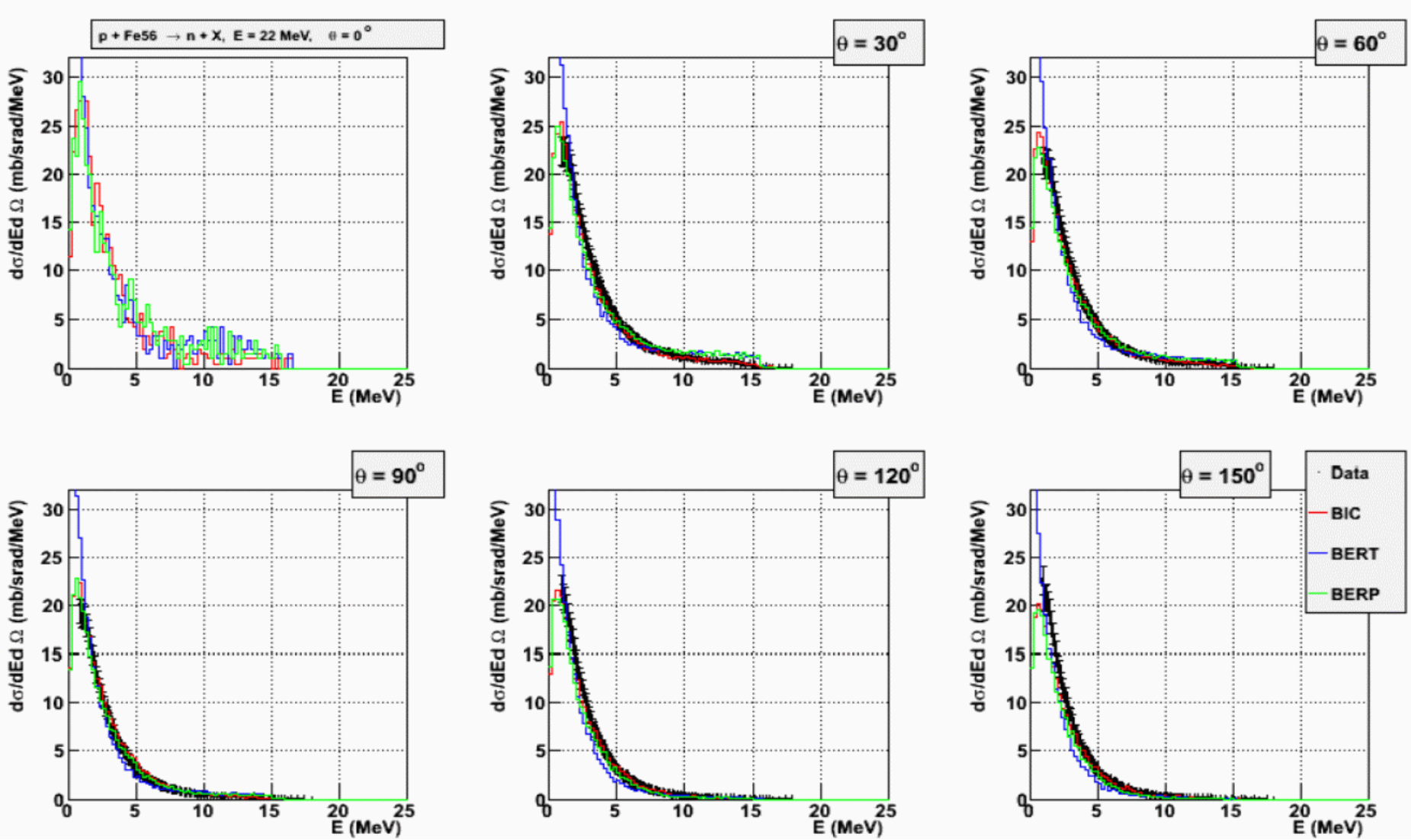
G4Precompound Model

- Many improvements over past few years
  - our best model for p, n induced reactions below 170 MeV
  - used to de-excite nucleus after FTF, QGS high energy models, binary cascade
  - after precompound stage, calls evaporation, multi-fragmentation, Fermi break-up

- Interfaced to other cascades
  - Bertini cascade -> BERP
  - better than Bertini's internal precompound model for E < 50 MeV
  - my eventually help to bring shower resolution closer to data, as it produces fewer low energy nucleons

- G4 deexcitation package interfaced to INCL++ in order to extend its range down to 0 and improve light fragment emission

G4Precompound Validation: 22 MeV p+Fe -> n+X



Particle Stopping and Capture

- New stopping models (to replace old CHIPS models)
  - G4PiMinusAbsorptionBertini
  - G4KaonMinusAbsorptionBertini
  - G4SigmaMinusAbsorptionBertini
  - G4AntiProtonAbsorptionFritiof

- Improved mu-stopping
  - current model is quite simple, with too-soft neutron spectrum
  - replace with Bertini using both one and two nucleon muon absorption
  - expected by 1st half of this year

Radioactive Decay

- New data set required
  - RadioactiveDecay3.6 (available in download area)
  - 534 nuclear states now have precise beta decay spectrum shapes (classified as 1^{st}, 2^{nd}, or 3^{rd} unique forbidden)

- Activation now added
  - good agreement with proton activation data

- Directional biasing of decay daughters
- Production and propagation of isomers/metastable nuclear states
  - coming 1^{st} half of this year

Deprecated Models

- LEP, HEP (Gheisha-style) models are deprecated
  - better models now available to cover all particles, all energies formerly handled by L/HEP
  - after Geant4 10.0, physics lists using LEP, HEP models will not work

- CHIPS (Chiral Invariant Phase Space) code deprecated
  - cross sections and other important pieces of code extracted into other models
  - physics lists using original CHIPS code will disappear
    - this includes some stopping and nuclear de-excitation code

Summary

- Shower shapes, time structure and energy resolution depend strongly on medium and low energy hadronic models

- During the past few years agreement of Geant4 predictions with data from various calorimeters has improved
  - ATLAS, Calice, CMS
  - main reason: improved physics, not tuning

- Existing models have improved
  - Bertini-style cascade, G4Precompound model, NeutronHP model, G4RadioactiveDecay

- Alternate models added
  - INCL++ cascade, G4LEND neutron low energy neutron models