Geant4 Physics Lists: Status and Proposed Upgrades

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Outline

- Contents of a few preferred Geant4 physics lists
- Updating/augmenting the physics lists
- Comparing Fluka and Geant4

Physics Lists Currently in Use

- QGSP_BERT
  - recommended for most use cases
- QGSP_BERT_HP
  - same as above except for more detailed treatment of neutrons below 20 MeV
- LBE
  - specialises in low energy EM
  - radioactive decay for recoiling nuclei
  - optical photons
- many others which are variations on above 3

Physics Lists Currently in Use

- Problem
  - if each group uses a different physics list it is difficult to compare results
- Goal
  - reduce confusion by adopting a single physics list adapted for use in background studies
- Plan
  - take recommended best physics list from Geant4 and add the necessary pieces specific to dark matter search applications
  - start by examining what we have

QGSP_BERT contents (1)

- protons:
  - Bertini cascade (0 – 9.9 GeV), GHEISHA (9.5 – 25 GeV), QGSP (12 GeV – 100 TeV)
  - HadronElastic (all energies)
  - Standard EM package
- neutrons:
  - Bertini cascade (0 – 9.9 GeV), GHEISHA (9.5 – 25 GeV), QGSP (12 GeV to 100 TeV)
  - HadronElastic (all energies)
  - GHEISHA capture (all energies)
  - GHEISHA fission (all energies)

QGSP_BERT contents (2)

- charged pions and all kaons
  - Bertini cascade (0 – 9.9 GeV), GHEISHA (9.5 – 25 GeV), QGSP (12 GeV – 100 TeV)
  - HadronElastic (all energies)
  - Standard EM package
- Hyperons and anti-baryons
  - GHEISHA (all energies)
  - HadronElastic (all energies)
  - Standard EM package

QGSP_BERT contents (3)

- Light ions (alpha and smaller)
  - GHEISHA-style hadronic interactions
  - Standard EM package
- Heavy ions
  - Standard EM package

QGSP_BERT contents (4)

- Gammas
  - CHIPS gamma-nuclear (0 – 3.5 GeV)
  - QGSP (3 GeV – 100 TeV)
  - Standard EM package
- Electrons, positrons
  - CHIP electro-nuclear (0 – 30 TeV)
  - Standard EM package
- Muons
  - CHIPS capture
  - GHEISHA-style muon-nuclear (optional)
  - Standard EM package

QGSP_BERT_HP contents

- Identical to QGSP_BERT, except
  - high precision neutron (NeutronHP) models used for neutron elastic, inelastic, capture and fission below energies of 20 MeV
- Notes:
  - QGSP_BERT, QGSP_BERT_HP do not use the radioactive decay model: it must be added
  - all models, hadronic and electromagnetic, used in any of the reference physics lists (QGSP_BERT, QGSP_BERT_HP, etc.) are listed in the log file output from each run

LBE contents (1)

- protons, pions, kaons, hyperons
  - GHEISHA-style hadronic models
  - standard EM package
- Neutrons
  - GHEISHA-style hadronic models above 20 MeV
  - NeutronHP models below 20 MeV
- Ions
  - standard EM package
  - radioactive decay

LBE contents (2)

- Gammas
  - low energy EM package
  - optical processes for low energy photons
- Electrons, positrons
  - mix of low energy and standard EM models
- Muons
  - Standard EM package

Shielding

- New physics list in Geant4 9.4
  - designed for use in shielding applications, and also in high energy
  - similar to QGSP_BERT_HP, except
    - uses a different string fragmentation model (FTF instead of QGS)
    - better handling of ions (Binary cascade for light, QMD for heavy)
    - improved neutron cross sections from JENDL database

Updating/augmenting Physics Lists (1)

- Specific weaknesses :
  - QGSP_BERT, QGSP_BERT_HP, Shielding
    - no radioactive decay
    - muon-nuclear process old and buggy (and maybe wrong)
  - LBE
    - outdated hadronic models
    - no gamma-nuclear, muon-nuclear or muon capture
- General weaknesses
  - quality of light-ion-induced reactions
  - quality of muon-nuclear reactions

Updating/augmenting Physics Lists (2)

- Solutions:
  - use Shielding physics list to replace all others
    - will likely replace QGSP_BERT at LHC detectors
    - can add to it to customize for background studies
  - use G4 builder classes to extend Shielding
    - add radioactivity model to all recoil ions with option to de-activate
    - could also add optical photons
  - improved light-ion-induced reactions
    - Shielding already replaces old GHEISHA-style models with G4BinaryLightIon and QMD models
  - improve muon-nuclear reactions
    - make new model

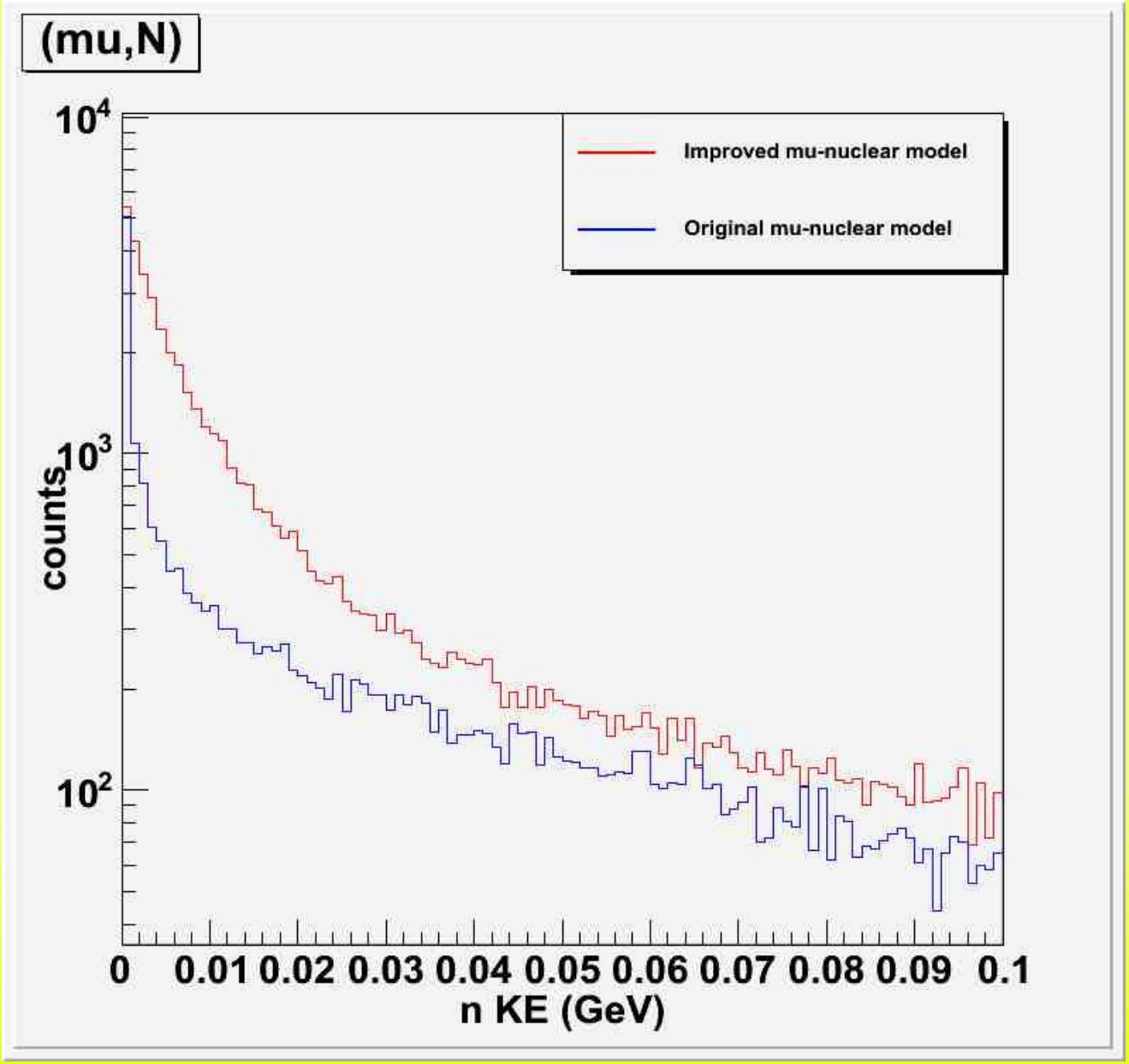
Updating/augmenting Physics Lists (3)

- Steps taken so far:
  - radioactive decay added to local 9.4 version of Shielding physics list (Mike Kelsey)
  - 9.4 version of Shielding (w/o radioactive decay) back-ported to local copy of Geant4 9.3p02
    - temporary measure until users are satisfied with 9.4 and until next official version of Geant4 comes out
  - new muon-nuclear process, model and cross section developed
    - new model added to the above 9.3p02 version
    - will be part of next Geant4 release

Improved Muon-nuclear Model

- Original model (part of almost all HEP physics lists) was old, buggy and did not conserve energy/momentum
  - some reports that it under-produced neutrons compared to Fluka
- New model
  - general scheme the same as the original: muon exchanges virtual photon with nucleus, virtual photon treated as pion to interact with nucleus
  - now pions interact using Bertini cascade (0 – 10 GeV) and FTFP models
  - mu-nuclear cross section same as original, but now properly code as a Geant4 cross section class
  - still room for improvement, but early tests are encouraging

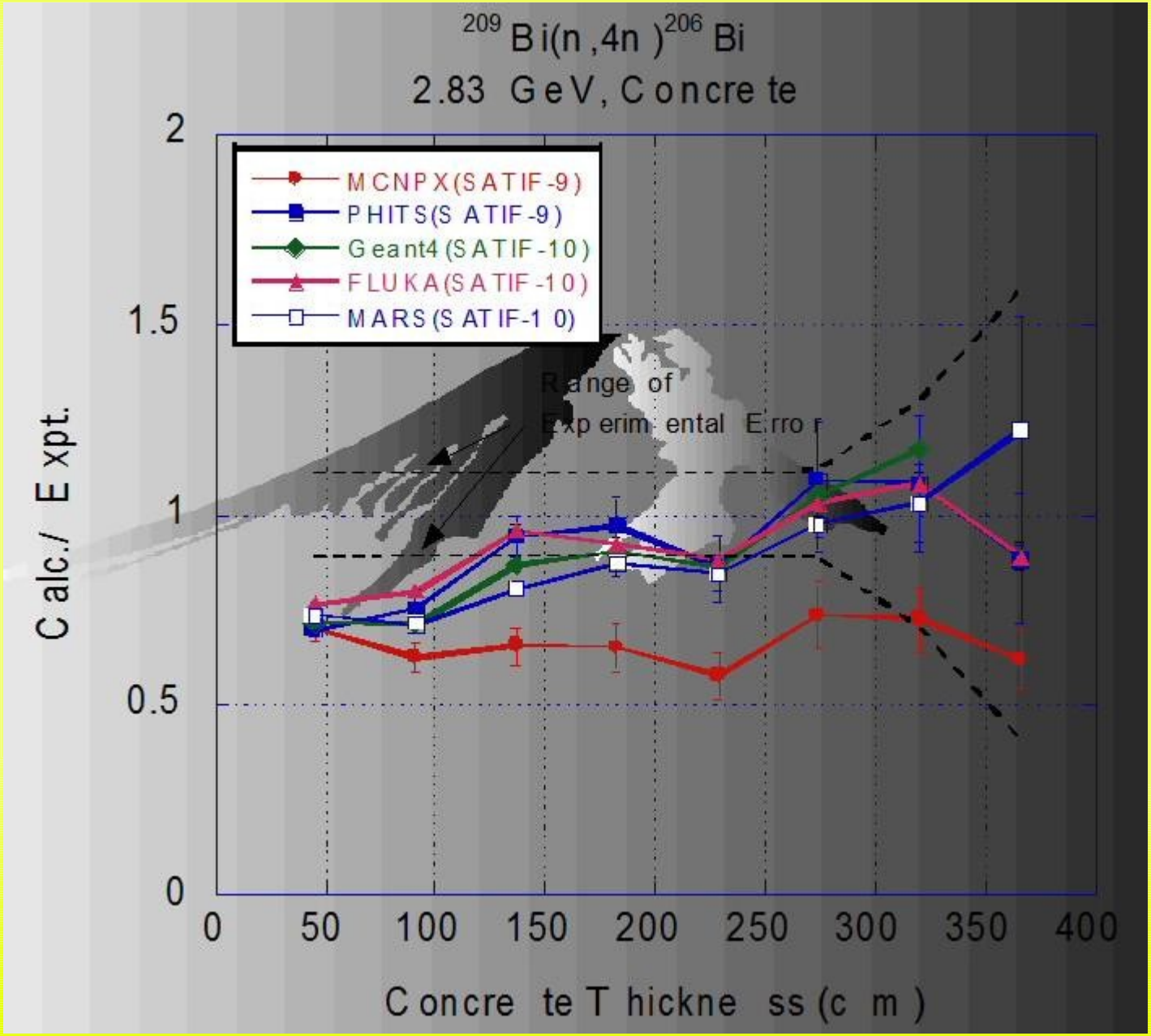
New and Old Geant4 Mu-Nuclear Models for 300 GeV/c mu- on Fe



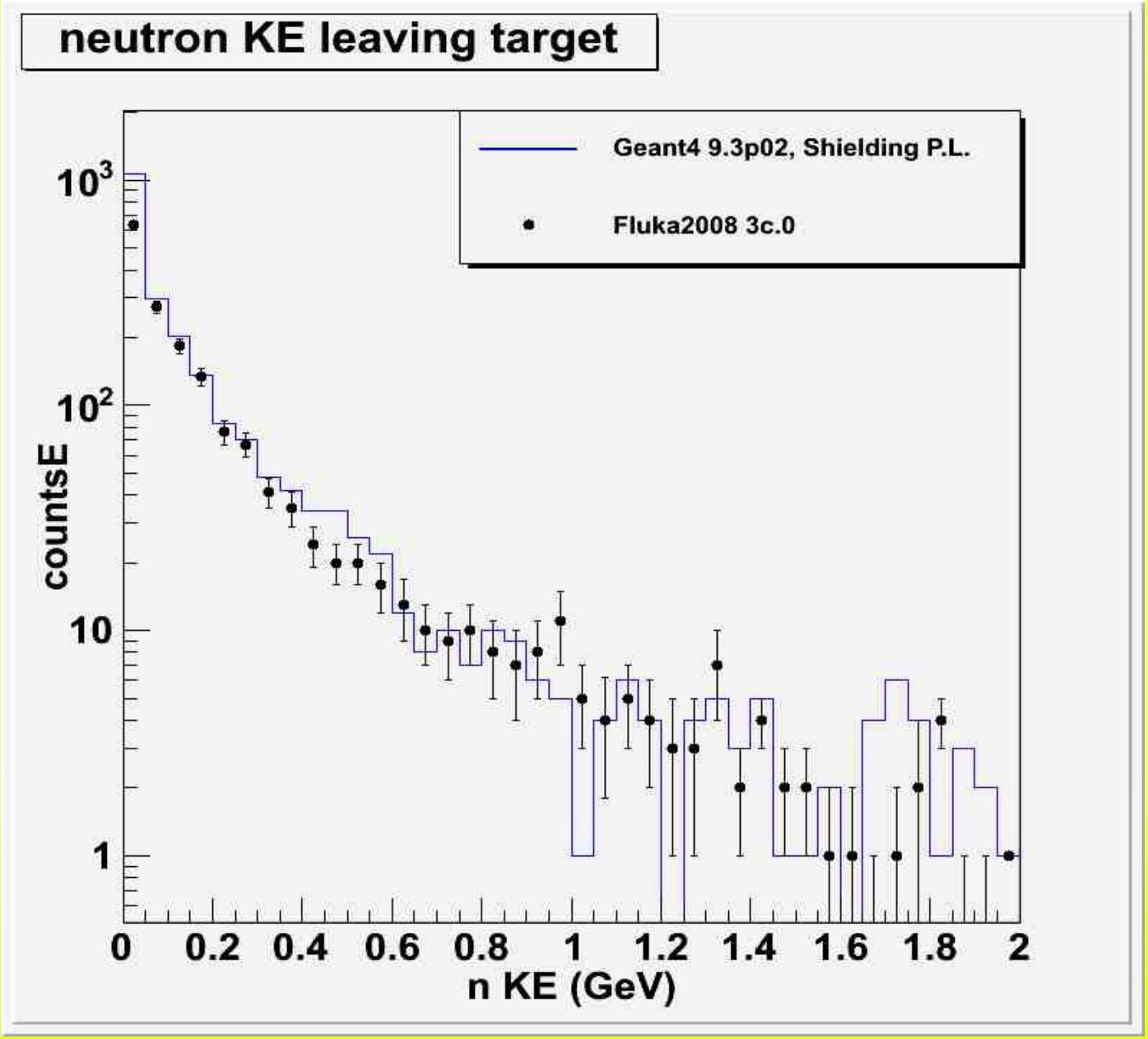
Reducing Uncertainties in the Simulation

- Comparison to data
  - many simulation models especially in the nuclear physics energy range
  - usually large variations from model to model
    - see recent IAEA or SATIF results
  - data is the best way to decide which is best, however:
    - data is usually scarce
- Comparison to other codes
  - consistency check, but without data which is right?
  - possibilities:
    - FLUKA
    - MCNP6

Comparing Geant4 to Fluka
Ratio Predicted/Measured Dose in Concrete



Comparing Geant4 to Fluka
280 GeV/c mu- on 1m of H_2O



Summary

- Several physics lists out there
  - with the exception of LBE, all physics lists used are similar to QGSP_BERT, whose contents were listed
- Upgrading of physics models and physics lists underway
  - several steps taken to develop one universal background physics list based on the Shielding P.L.
  - improved muon-nuclear model finished and now being tested
- Comparison to other codes
  - new comparisons of Geant4 and Fluka have begun
  - so far agreement is good