Geant4 11.1.p01 and 11.0.p04 & Hadronic Physics Group Work Plan for 2023

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On behalf of the Geant4 Hadronic Physics Working Group

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1st part: G4 11.1.p01

Main Changes in Hadronics *vs.* G4 11.1

- *particles /*
  - *G4AntiNeutron* : set the “PDG stable” flag to “false”, as for *G4Neutron*
  - *G4OmegacZero, G4AntiOmegacZero :* updated mean life time
    - From 0.069e-3*ns to 2.68e-4*ns - but it was wrongly written as 0.0268e-3*ns (*i.e.* 10 times smaller!). It will be corrected in the next patch, 11.1.p02
- *physics_lists / constructors / decay /*
  - *G4RadioactiveDecayPhysics* : assigned *RadioactiveDecay* to *G4Triton*
    - This is the only light ion that can decay. Before, triton did not have beta decay (*i.e.* it was wrongly treated as stable even when radioactive decay physics was enabled; anti-triton did not, and still does not, have beta decay (because *RadioactiveDecay* does not handle anti-ions)) ...
- *hadronic / processes /*
  - *G4HadronElasticProcess* : added forgotten integral approach for charged particles
  - *G4NeutronGeneralProcess* : code optimizations

2nd part: G4 11.**0**.p0**4**

Main Changes in Hadronics *vs.* G4 11.0.p03 (1/2)

- *particles /*
  - *G4Triton, G4AntiTriton* : correct mean lifetime (instead of incorrectly using the half lifetime)
  - *G4XicZero* (and *G4AntiXicZero*), *G4OmegacZero* (and *G4AntiOmegacZero*) : updated mean lifetime values according to the latest PDG (*i.e.* PDG-2022)
    - From 0.112e-3*ns to 1.519e-4*ns (Ξ°c) ; from 0.069e-3*ns to 2.68e-4*ns (Ω°c)
- *physics_lists / constructors / decay /*
  - *G4RadioactiveDecayPhysics* : assigned *RadioactiveDecay* to *G4Triton*
    - This is the only light ion that can decay. Before, triton did not have beta decay (*i.e.* it was wrongly treated as stable even when radioactive decay physics was enabled; anti-triton did not, and still does not, have beta decay (because *RadioactiveDecay* does not handle anti-ions)) ...
- *hadronic / cross_sections /*
  - *G4NeutronInelasticXS , G4ParticleInelasticXS* : fixed computation of isotope cross sections
  - *G4ComponentAntiNuclNuclearXS* : fix in methods *GetTotalElementCrossSection* and *GetInelasticElementCrossSection* for antiproton projectile on light target nuclei (d, t, He3, He4)
- *hadronic / util /*
  - *G4Nucleus* : corrected method *GetN_asInt()* for the case of a hypernucleus

Main Changes in Hadronics *vs.* G4 11.0.p03 (2/2)

- *cascade /* (BERT)
  - *G4NumIntTwoBodyAngDst* : correct incomplete initialization of a vector
  - *G4TwoBodyAngularDist* : correct the charge exchange reaction $\pi^+ n \rightarrow \pi^\circ p$
- *parton_string /*
  - *G4DiffractiveSplitableHadron* : fixed rare, large energy violations in FTF with charm and bottom hadron nuclear interactions
  - *G4LundStringFragmentation, G4QGSMFragmentation* : corrected probability for c-cbar creation
    - A factor of 10 higher was set to enhance the production for testing purposes, and then forgotten
  - *G4QGSMFragmentation* : bug-fix in the method *GetLightConeZ()*
    - Which might cause rare access to arrays with a wrong index
- *particle_hp /*
  - *G4ParticleHPContAngularPar* : added protection against zero probability for both discrete and continuous emissions
- *lepto_nuclear /*
  - *G4ElectroVDNuclearModel* : added protections against null pointers to gamma cross section and material, responsible for rare crashes

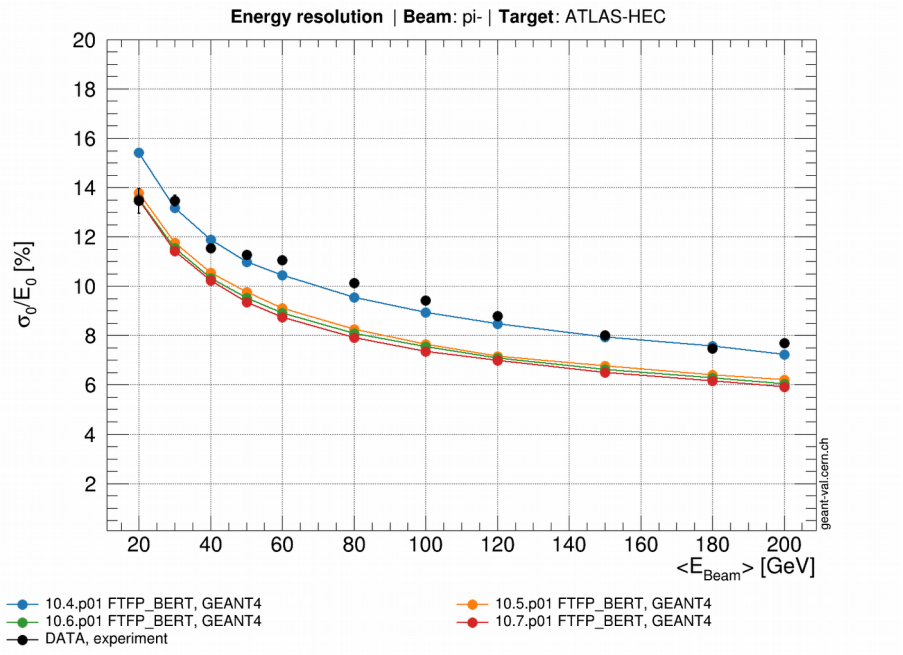
3rd part: Hadronic **Work Plan**

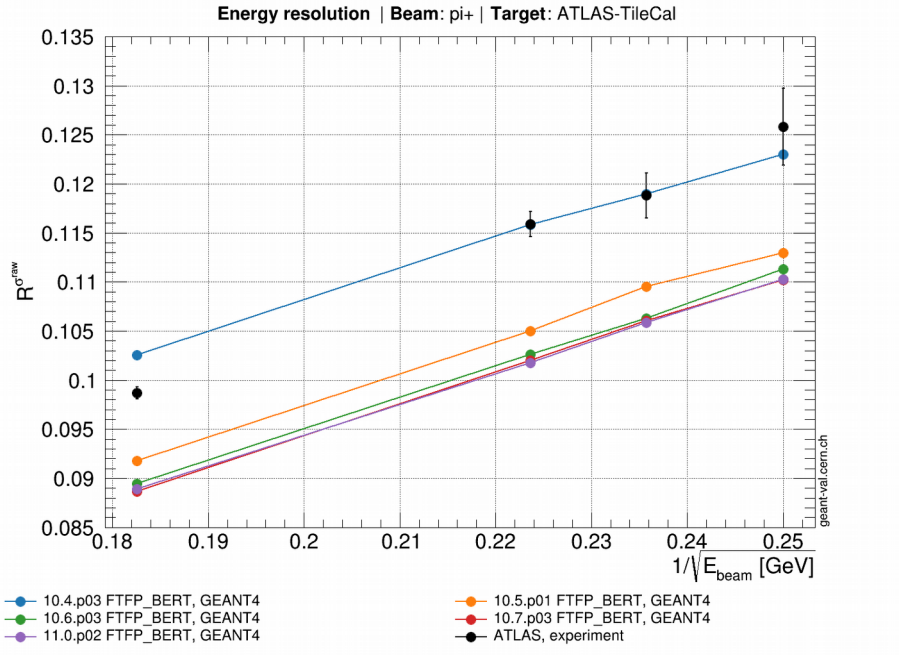
Hadronic String models (1/2)

- Review of experimental and theoretical studies of hypernuclei and anti-hypernuclei, and improvements of their nuclear interactions in Geant4
  - First version, very simplified, released in G4 11.1
- Validation of charm production for **FTF** and **QGS**
  - In proton-proton, proton-nucleus, nucleus-nucleus interactions
- Improvement and validation of antiproton, antineutron and light anti-nuclei annihilations in **FTF**
- Validation of **FTF** nucleus-nucleus interactions
  - d-d, d-A, t-A, He4-He4, He4-A, C12-A, *etc.*
- Continue the model parameter studies of **FTF**
  - And other models (Preco, Bertini, *etc.*) as well
- Maintenance and improvement of the hadronic framework; code improvements of **FTF** and **QGS** models

Hadronic String models (2/2)

- Investigate the **FTF** problem of too optimistic energy resolution for pion showers in ATLAS calorimeters
  - ~20% disagreement since G4 10.5, seen in both ATLAS HEC and TileCal





Intra-nuclear Cascade models

- Bertini-like (**BERT**) model
  - Maintenance and user-support
- Binary (**BIC**) model
  - Code review and maintenance
- Liege (**INCLXX**) model
  - Maintenance and user-support
  - **Extension for antiproton**
  - Short range correlations in INCL and improvements for ABLA

Precompound / De-excitation models

- Maintenance and user support
  - Continue the effort of resolving bug reports related to de-excitation
- Evaluate FermiBreakUp model, alternative GEM model, and Multi-Fragmentation model
- Improve the simplified treatment of de-excitation for hypernuclei

Radioactive Decay model

- Maintenance, user support and improvement
- Maintenance of the database

ParticleHP model

- Validation, maintenance and user support
- Support for thermal scattering data,
  implementation of Doppler Broadening Rejection Correction (DBRC),
  implementation of probability table for Unresolved Resonance Region (URR),
  development of new variance reduction techniques (*e.g.* AMS - Adaptive Multilevel Splitting)
- Improvement and speed-up of the code
- Creating a physics list with explicit thermal scattering, *e.g. QGSP_BIC_HP**T***

- Extend ParticleHP model to higher energies
- Insert in Geant4 the NuDEX code (to generate EM de-excitation cascades)

LEND model

LEND = Low Energy Neutron Data
GIDI = General Interaction Data Interface

- LEND and GIDI update

NCrystal model

Model for ~meV neutron scattering in crystals

- Geant4-NCrystal integration

Other Hadronic models (1/2)

- Development and validation of neutrino / lepton – nuclear physics
  - In particular, neutrino oscillation
- Review of the neutrino classes, and biasing of neutrino physics
- C++ interface to (Fortran) Fluka-Cern and applications
  - New hadronic extended examples
- Use of Pythia8 as an external generator in Geant4
  - Application for LDMX experiment
- Continue developing muonic atoms code
  - In particular, muon catalyzed fusion

Other Hadronic models (2/2)

- Add charge exchange option to hadronics
  - Potentially important for hadronic showers : can convert charged pions into neutral ones
  - Existing class *G4ChargeExchange*, *G4ChargeExchangeProcess,* and *G4ChargeExchangePhysics* are currently not used in any reference physics lists
- Emulating hadronic models with generative graph neural networks
  - *E.g.* precise but very slow models like BLOB
- Low-energy hadronic interactions of protons with 11B

Hadronic Validation and Testing

- Continue integrating calorimeter test-beams for hadronic validation in *geant-val*
  - *E.g.* Dual Readout calorimeter, CMS HGCal, CALICE HCAL, and others
- Use thin-target and calorimeter data for hadronic validation
- Studying the sensitivity of the MC predictions to the variations of various parameters and development of needed infrastructure
- Tests and user support via public Geant4 examples
- Validation of electro-production using electron beam at JLab's energies
- Validation of neutron physics with the TARC test
- New test case for thermal neutron transport
- Validation of rare isotopes interaction with matter