Geant4 Physics : Work Plan for 2020

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Outline

- Highlights of Geant4 physics in 2019
  - What has been included in G4 10.6
    - Extracted from the G4 Technical Forum on January 16th
- Program of Work for 2020
  - Electromagnetic and Hadronic physics
    - The full version will be presented to the users at the next G4 Technical Forum

Notes:

- *A large fraction of the work goes to support, and regular testing & validation, which do not appear in the work program !*
- *Names of the people are omitted here for brevity & simplicity*
- *Colors are used for activities with SFT-related contributions;*
  grey for activities without direct and significant SFT participation

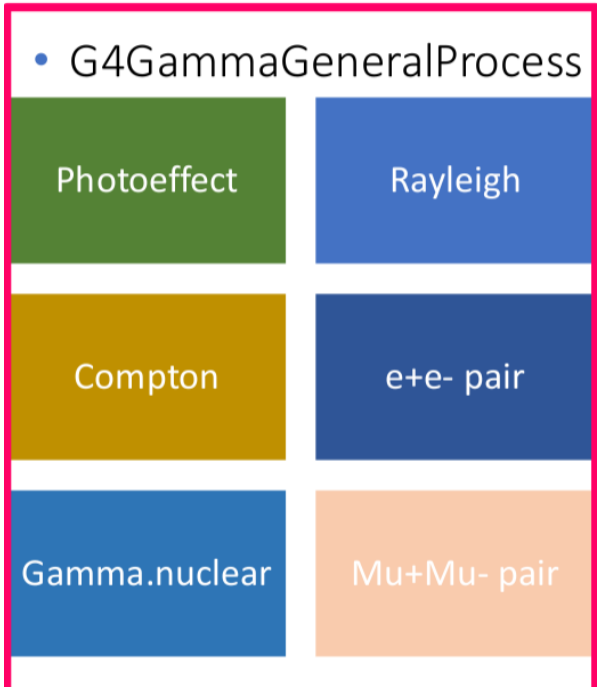
1st Part

Highlights of
Physics Achievements in 2019
included in G4 10.6

Electromagnetic Physics (Standard only)

EM Physics (1/2)

- Developments focus to improve **CPU performance**
  (physics improvements, e.g. multiple scattering, made in previous versions)
  - Removed redundant computations of the logarithm of particle's kinetic energy
    - At each step of particle transport, various physics quantities are computed using internal tables (prepared at initialization) which are binned in particle kinetic energy
    - CPU speed-up in CMS geometry : **~ 5 %**
    - Applied also for **neutron transport**
    - Included in Geant4 **10.6**
  - Introduced "General gamma process"
    - During the transport of a gamma, one single physics process (instead of 6) is asked to provide the mean free path
    - CPU speed-up : **~ 5 %**
    - Not used by default, but can be enabled via UI command
    - Default for Opt1 EM physics (used by CMS)



EM Physics (2/2)

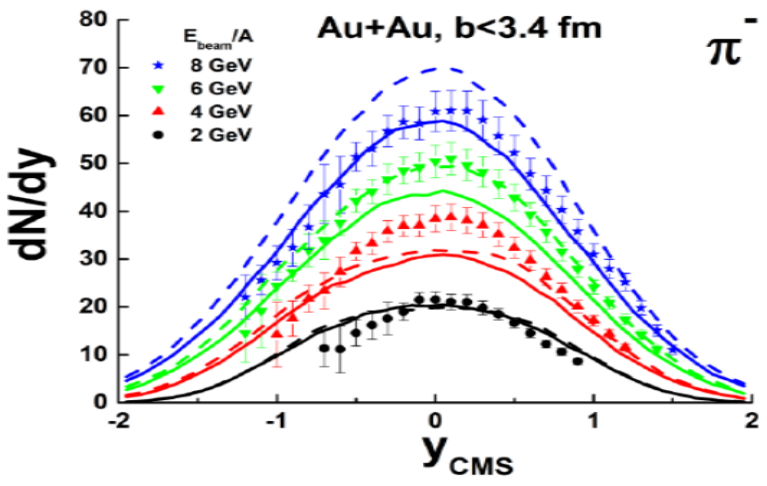
- Other developments
  - Gamma conversion to muon pair was extended down to production threshold
    - Request from the Gamma Factory R&D group
  - New helper class G4NIELCalculator
    - Request from the Fluka group for DPA (Displacement Per Atom) calculations
  - Updates of Materials
    - New class G4DensityEffectCalculator (from a user's suggestion to compute density effect correction on-the-fly without any parameterisation) : improves dE/dx in steel for NOvA .
      It is an option that can be activated via UI command.

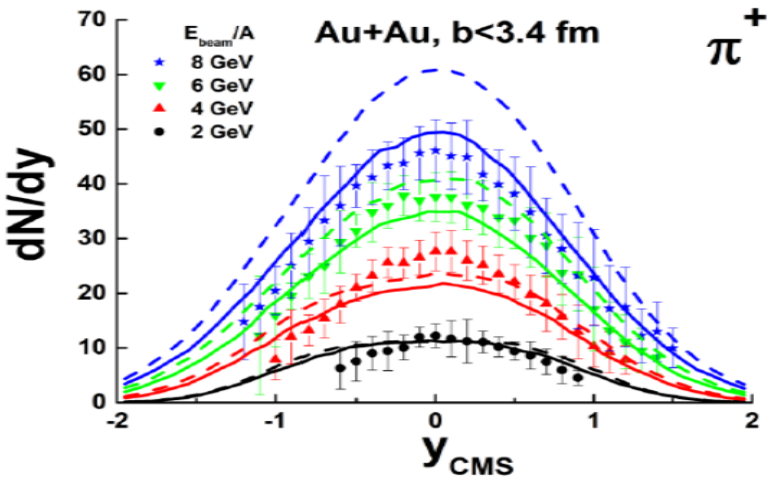
- Note: physics results remain stable
  - Electromagnetic showers stay very close to those in G4 10.5

Hadronic Physics

String Models

- **FTF** (Fritiof) and **QGS** (Quark Gluon String)
  - Extended to heavy hadrons (i.e. charmed and bottom mesons and hadrons)
    - The string fragmentation can handle charmed and bottom quarks and diquarks in the strings
    - Not yet activated in physics lists
  - Validation and refinement of nucleus – nucleus collisions in FTF





Cross Sections

- Reviewed and improved the low-energy behaviour of all hadron – nucleon (elastic and inelastic) cross sections
  - Used by Glauber-Gribov hadron – nucleus cross sections
- Extended Glauber-Gribov cross sections for charmed and bottom hadrons (mesons and baryons)
  - Not yet used in physics lists
- Use Glauber-Gribov cross-sections for hyperons and anti-hyperons nuclear interactions
  - Both elastic and inelastic
- Removed default Gheisha cross sections
  - We have better alternatives for all cases

Others

- Improved pion-elastic scattering at lower energies (< 1 GeV)
- Extended the coverage of neutrino interactions in Geant4
- Shown how to get “hadronic-model per region”
  - Not allowed by the hadronic framework, but possible with “generic biasing”
    - Useful for ALICE : INCL model used only in the Tracker region, without CPU overhead
- Changed transition region between hadronic string models and intra-nuclear cascade models
  - From [3, 12] GeV to **[3, 6] GeV**, and now consistently for all particle types
  - For most physics lists, such as the recommended FTFP_BERT
    - Not for FTFP_BERT_ATL (transition [9, 12] GeV)
  - Changes in hadronic showers mostly due to this change in transition region
    - New Birks’ quenching treatment highly recommended !

Validation Portal

geant-val.cern.ch

- We rely heavily on this tool for testing and validating Geant4
  - For major, minor, patches and internal (reference tags) versions
- The only tool in Geant4
  - The development of DoSSIER (FNAL) has been stopped
- Keep extending it in several areas
  - Wider coverage of electromagnetic physics
    - Including a new set of simplified EM calorimeters
  - Low-energy electromagnetic physics
  - Low-energy hadronic physics
  - Medical physics

2nd Part

WORK PLAN 2020
for Geant4 PHYSICS

ELECTROMAGNETIC PHYSICS (Standard only)

EM Developments for Speed-Up

- Implement an alternative, specialized transport for e± and γ for HEP
  - More ambitious attempt to speed-up simulations specialized for high-energy applications, based on a new framework, minimal and efficient
- Consolidate the “general gamma process” and extend it for electrons and positrons
  - Most promising attempt to get some speed-up in the current framework
- Other directions (less promising)
  - Review of relevant classes related to tracking
  - Reduce CPU for initialisation in MT mode

EM Developments for Physics

- Develop an alternative model for energy-loss fluctuations
  - Currently the parameterised Urban (energy-loss fluctuation) model is used as default in all EM options; PAI (Photon Absorption Ionization) model exists as an alternative, but it is CPU consuming, so the goal is to investigate another theory-based model with better CPU performance
- Implement linear gamma polarization option for any gamma model
  - For HEP applications
- Improve ion ionisation models for relativistic ions
  - Existing new model, G4LindhardSorensenIonModel , needs further refinement before it can be the default model

EM Validation

- Perform regular validation of monthly Geant4 versions
  - Extend geant-val to cover the whole EM testing suite
- Implement an example with a detailed analysis at the level of tracks and steps
  - This can be used for understanding the details of the simulation, which can then be used to optimize the simulation settings
    - production thresholds, multiple scattering parameters, tracking-in-field parameters, *etc.*
- Create a new validation test based on CMS HGCal test-beam set-up
  - Offers the possibility of studying (EM and HAD) showers in great detail and use these data to benchmark simulation

HADRONIC PHYSICS

Hadronic String models

- Include heavy-hadron nuclear interactions in physics lists
  - This requires also to deal with the decays of heavy hadrons in Geant4
- Tuning and validation of charm production for **FTF** and **QGS**
- Extension, improvement, tuning and validation of anti-baryon annihilation and interaction in the **FTF** model
  - From at rest to hundreds GeV
    - ALCE, CERN AD antiproton experiments, GAPS, Panda/GSI, *etc.*
- Improvement of elastic scattering for anti-baryons and light anti-nuclei
- Review of the nuclear residual excitation energy in hadronic models
- Development and validation of a coalescence model
  - Included in G4 10.6 a first version of coalescence for nucleus-nucleus collisions: to be improved, validated and extended for hadron-nucleus interactions

Intra-nuclear Cascade models

- **Bertini** (BERT) model
  - Maintenance and user-support
- **Binary** (BIC) model
  - Code review and maintenance
- **Liege** (INCL++) model
  - Maintenance and user-support
  - Maintenance of ABLA++ model and improvements in the production of hypernuclei

Precompound / De-Excitation models

- Maintenance and code improvements
- Complete, validate and release the new GEM model
- Tuning of evaporation probabilities
- Add test on gamma production

Radioactive Decay model

- Maintenance and development
- Add test in **geant-val**
- Add functionality of user spectrum definition for beta spectrum shape
- Beta-delayed particle emission
- Superheavy elements

ParticleHP model

- Validation & Maintenance of ParticleHP
- Investigate the CPU performance degradation with G4NDL4.6
- Implement an option that forces ParticleHP to respect event-by-event conservations (energy-momentum, baryonic number, etc.)
- Extend ParticleHP model to higher energies
- Implement a more detailed physics for organic neutron detectors
- Insert in G4 the NuDEX code (to generate EM de-excitation cascades)
- Document the ParticleHP database format
- Create a tool to automatically change the charged particle cross sections adding user experimental data

Hadron Elastic models

- Extend hadron elastic for heavy hadrons (i.e. charmed and bottom mesons and baryons) and use it in physics lists
- Improvement and validation of the diffuse elastic model
- Interface for changing easily elastic models on top of any physics list
- Extend elastic scattering validation for antiproton and light anti-ions

Other Hadronic models

- Development and validation of neutrino/lepton – nuclear physics
- Maintenance and investigation of possible extension of QMD model
- Muonic atom physics
- Explore the possibility of using Deep Learning to emulate a low-energy nuclear interaction model (BLOB) and to port it to GPU

Hadronic Cross Sections

- Improvement of elementary (hadron-nucleon) cross sections
  - Make class fully static (to avoid instantiation of it many times in each thread)
  - Extend tests to pbar and gamma
- Verify and extend G4PARTICLEXS dataset
  - Evaluate data for light targets
  - Provide data for n , d , t , He3 , α on p , d , t , He3 , α needed for fusion
  - Add data for elastic scattering for proton and light ions
  - Add gamma cross sections
- Interface for changing easily cross sections on top of any physics list
  - Identify reliable alternatives to default hadronic cross sections
  - Allow user-defined cross section per element or per material

Extra

SFT Contribution to Geant4 Physics for 2020

A. Bagulya
G. Folger
A. Galoyan
V. Grichine
V. Ivanchenko
D. Konstantinov
G. Latyshev
M. Novak
I. Razumov
A. Ribon
V. Uzhinsky
A. Zaborowska

The contribution of this people for Geant4 Physics amounts to ~5-6 FTEs

4th LPCC Detector Simulation Workshop

- We are planning to have a fourth workshop
  - A full 2-day workshop, so far done every ~3 years
  - Dates are not yet finalized, but likely in the period October − December
- Feedback from the experiments on the validation of Geant4 physics
  - We are eager to see whether EM Opt4 solve the disagreements, reported in the past, of the lateral shape tails of EM showers
    - Major improvement in the modeling of multiple scattering (GS + Mott corrections) since G4 10.4
  - Effects of the new, suggested treatment of Birks' quenching
- Expected physics accuracy needs of Geant4 simulations for HL-LHC
  - For at least some important physics analyses
  - Aim to identify areas where fast simulation could help