Open and new requirements - HEP Intensity and Cosmic Frontier experiments

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Outline

- Selected aspects of experiments' Geant4 usage
- Requirements currently in Geant4 JIRA system
- Other requests
- Summary

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Comments/mistakes/omissions/opinions are the author's

Geant4 usage by Intensity Frontier experiments (I)

- DUNE subgroups and some other experiments which use LArSoft mainly use Geant4 10.6.p01 and QGSP_BERT physics list (with some groups using Geant4 10.5.0 and 10.3.p03) considering 11+)
  - Compile with gcc 9.3.0, (also clang 7.0.0) and use C++17
  - Uses Scientific Linux (SL) SL7, run in sequential mode
- NOvA uses Geant4 10.4.p02 (with a patch for the density effect correction for the ionization loss and a patch for G4ExtrudedSolid back-ported from Geant4 10.6), with QGSP_BERT_HP physics list extended with NRESP71 model for neutron capture, to correctly model photon multiplicity distributions and MENATE_R neutron scattering cross section simulation package as a custom physics process; working on migration to Geant4 11.0+
  - Compiles with gcc 8.2.0, and use C++17
  - Uses SL7, runs in sequential mode

Geant4 usage by Intensity Frontier experiments (II)

- Mu2e uses Geant4 10.7.p03 with ShieldingM(_EMZ) physics list; testing 11.0+
  - Uses gcc 9.3.0 and C++17, considering gcc 12.1.0
  - Uses SL7; runs in sequential or MT mode (up to 16 threads)

- Muon g-2 uses Geant4 10.3.p03 (with a patch correcting a spin tracking aspect), FTFP_BERT physics list, VecGeom and CADMesh for parts of the geometry (https://github.com/christopherpoole/CADMesh)
  - Uses gcc 6.4.0, C++14
  - Uses SL7; runs in sequential mode

- EMPHATIC - Experiment at Fermilab https://arxiv.org/abs/1912.08841 focused on hadron production measurements with beam of p, pi, K of specific momenta between 4-120 GeV/c (also see page 11)
  - Uses Geant4 10.7.p01; willing to consider Geant4 v11.0+
  - Uses gcc 8.2.0, SL7; runs in sequential mode (for now)

Geant4 usage by Intensity Frontier experiments (III)

- Some experiments use containers, mainly Docker, some use Singularity/Apptainer, which is also used by computing grids
- Liquid Argon experiments have an option to use NEST (http://nest.physics.ucdavis.edu) when not using simpler algorithms applied after Geant4 stage
- If optical processes are needed, experiments usually pregenerate and use lookup tables to simulate photon effects due to high CPU cost of those calculations; Interested in using Opticks https://doi.org/10.1051/epjconf/201921402027 (and/or AI techniques)

Geant4 usage by Dark Matter Search experiments

- LZ (LUX-ZEPLIN)
  - Uses Geant4 10.3.p02 with custom physics list which includes G4EmLivermorePhysics, G4EmExtraPhysics, G4RadioactiveDecayPhysics, QGSP_BIC_HP with some internal modifications for the Gd neutron capture, G4Cerenkov, optical processes, plus additional internal physics list to simulate the liquid Xenon response using the NEST model
  - Uses gcc 8.2.0, C++17; Runs on CentOS7 in sequential mode
  - Currently testing with 10.6.p02 and considering 10.7.p02+ and run in MT mode
  - Working on integrating Opticks

- SuperCDMS
  - Uses Geant4 10.6.p03 (& 10.5.p01) with Shielding physics list, optical physics, G4CMP (https://github.com/kelseymh/G4CMP), have adapted G4ScreenedNuclearRecoil from TestEm8, adapted most EM energy loss modules for use with fractionally charged particles (as the Geant4 defaults do not give correct results), deactivate G4NuclearStopping to avoid incorrect Lindhard partitioning, replace G4Decay with G4RadioactiveDecay for tritium, use LEND data for the photonuclear process
  - Plan on moving to Geant4 10.7+ at some point; Regard Geant4 11+ as having too many breaking changes
  - Compiles with LLVM 10.0.0, gcc 6.5.0, 7.3.0, 9.3.0 (4.8.5 for 10.5.p01 builds) and uses C++14 (and some C++17); Runs on CentOS7 (with some legacy RedHat EL6 and MacOS) in MT mode (up to 20 threads)

Open or recently modified requirements in JIRA (I)

- UR-28 Anti-proton production from proton beam
  - Correct the discrepancy in anti-proton production for proton beam at about 10 GeV on various targets
    - Currently no personpower to implement it, but important, e.g., to Mu2e
- UR-49 Neutron self-shielding effect
  - Neutron flux through a material can be significantly modified when the neutron energy is in the resonance region
  - The capture process can reduce the flux at one position in a crystal creating a kind of shadow in which the downstream atoms see a different background flux (a ~10% effect)
  - Accepted as a valid requirement, currently no personpower to implement it
  - This is also a Nuclear Physics experiments requirement

Open or recently modified requirements in JIRA (II)

- UR-50 Improve simulation of gamma induced neutron background
  - Low energy gammas producing neutrons in various materials can be a significant background
    - Photo-nuclear process does not model this well below 30 MeV
      - An improved process using the G4LEND gamma models is required
  - Accepted as a valid requirement
    - In ShieldingLEND physics list since 10.4/10.5
      - Below 20 MeV
    - Careful verification of code aspects in various areas needed
    - Alternative model to treat low-energy gamma-nuclear interactions is available since 10.7. We need to study its effect.
- This is also a Nuclear Physics experiments requirement

- For the list of all requirements in JIRA please see:
  - https://jira-geant4.kek.jp/projects/UR

Requests from last year with comments
(to be included in JIRA) (I)

- DUNE is interested in
  - A(n external) decayer handling taus (including the polarization aspect)
    - An extended example has been provided: eventgenerator/pythia/py8decayer in v11.0 (and the solution has been incorporated in DUNE software stack already, for both taus and charm)
  - Charm production (and decays, in order to model the tau neutrino component of the beam)
    - Production of charm has been available since v10.7 already
  - Propagation of polarized muons and taus in dense media
    - To be worked on
  - In the pion inelastic process (in pi-Ar scattering), would like to
    - turn off intranuclear scattering; turn off short range correlation; be able to obtain the momentum of the initial nucleon (Fermi momentum)
      - No action taken as there is currently no active development of the Bertini model

Requests from last year with comments
(to be included in JIRA) (II)

- Mu2e would like the pbar annihilation process to be improved, including being able to affect the nuclear destruction process at energy below 2 GeV; Is observing an excess ratio of pi-/pi+ in p W reaction, when using Bertini cascade and would like that to be looked at
  - Work is ongoing on INCLXX to extend it to pbars; No action regarding the Bertini model
- Muon g-2 is interested in having a symplectic stepper
  - It is a subject of a Geant4 Google Summer of Code project
- Many experiments would like to be able to perform fast (and accurate) simulations of optical photon processes
  - There is an ongoing effort to fully integrate Opticks with current versions of Geant4. A related advanced example CaTS was added (in Geant4 v11.0); still more work needed, e.g., implementation of WLS process

New requests

- Mu2e
  - Would like to discuss refactoring G4MTRunManager, so that Mu2e MT run manager class only needs to override functions that are empty in the base class (This would enable a wider use of MT among the experiments using the art framework at Fermilab)
- NOvA
  - Making MENATE_R package available as an alternative model in Geant4, removing the need for a custom physics process, would be nice but is not essential
- SuperCDMS
  - Would like the currently "customized" databases, for PhotonEvaporation and RadioactiveDecay to be (fully?) included in the official releases
  - Would like the LCG CVMFS Geant4 installations to include non VecGeom variants (and/or the problems with VecGeom variants to be addressed in a timely manner)
- *Feedback request: EMPHATIC (Experiment to Measure the Production of Hadrons At a Test beam In Chicagoland, i.e., at the Fermilab Test Beam Facility, https://ftbf.fnal.gov) with beam of p, pi, K at 4, 8,12, 20, 31, 60, 80, 120 GeV/c and C, Al, Fe, H_2O, Be, B, BN, B_2O_3, Ca, Hg, Ti targets, is offering to discuss what specific measurements and observables would be most useful to report to compare with Geant4 models*

Summary

- Requirements evolve
  - Some have been addressed
  - Some became part of working groups work plans
  - Unfortunately, some are on hold, some for a long time, due to lack of personpower
- More sophisticated use of Geant4 and more precise experiments lead to new requirements
- User involvement in providing ideas and contributions is an important element of Geant4 code and Geant4 Collaboration evolution
- Fulfilling the requirements and significant improvements in the toolkit provide incentives for long running experiments to migrate to newer versions of Geant4