Open and new Geant4 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/comments
- Summary/comments

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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 with QGSP_BERT (and QGSP_BERT_HP_EMZ) physics list (with some groups using Geant4 10.5.0 and 10.3.p03); considering Geant4 11+ (11.1+)

  Compile with gcc 9.3.0, (also clang 7.0.0) and use C++17

  Use Scientific Linux (SL) SL7, some usage of Alma Linux (AL) AL9, run in sequential mode

- NOvA currently 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; moving to 11.0.p03 with QGSP_BERT_HP_EMZ.

  Compiles with gcc 7.3.9, migrating to 9.3.0 and use C++17

  Uses SL7, runs in sequential mode

- NOvA Beam Simulation currently uses Geant4 9.2.p03, transitioning to 10.4.p02 (also considering latest version) with FTFP_BERT, QGSP_BERT physics lists

  Compiles with gcc 4.8.5; Uses SL7, runs in sequential mode (and MT with version 10+)

Geant4 usage by Intensity Frontier experiments (II)

- MicroBooNE uses Geant4 10.3.p03 with a custom physics list based on QGSP_BERT with extensions like e.g., optical physics; integrating Geant4 10.6.p01

  Uses gcc 7.3.0/9.3.0, C++17; plans to move to gcc 12.1.0

  Uses SL7; runs in sequential mode

- ICARUS/SBND (almost) uses Geant4 10.6.p01 with QGSP_BERT physics lists with the neutron tracking cut removed

  Use gcc 9.3.0, C++17

  Use SL7; run in sequential mode

Geant4 usage by Intensity Frontier experiments (III)

- Mu2e uses Geant4 11.1.p02 with ShieldingM(_EMZ) physics list

  Uses gcc 9.3.0 and C++17, migrating to gcc 13.1.0 and C++20

  Uses SL7; expects to use AL9 this fall; runs in sequential or MT mode (mostly 2 to 4 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

Geant4 usage by Intensity Frontier experiments (IV)

- T2K/nd280 uses Geant4 10.01.p03 with QGSP_BERT or QGSP_BERT_HP physics lists, plus private interface to NEUT secondary interactions processes

  Uses gcc of the operating system, C++11

  Uses CentOS 7, AL8.7, Debian 10.13; runs in sequential mode

- T2K/Beam Simulations uses Geant4 11.0.p03 with QGSP_BERT, FTFP_BERT physics lists; planning to move to Geant4 11.1 p02

  Uses gcc 8.3.0, C++11

  Uses CentOS7; runs in sequential mode, working on running in the MT mode

Geant4 usage by Intensity Frontier experiments (V)

- 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 (I)

- 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, G4OpAbsorption, G4OpRayleigh, G4OpBoundaryProcess, G4OpWLS, 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 10.6.p02 and considering 10.7.p02+ and running in MT mode

  Working on integrating Opticks (simulating optical photons is a bottleneck)

Geant4 usage by Dark Matter Search experiments (II)

- SuperCDMS

  Uses Geant4 10.6.p03 and 10.7.p04 with the following physics lists: Shielding (for neutron backgrounds), FTFP_BERT_EMZ (for gamma backgrounds) with additions for optical physics, G4CMPPhysics (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 (to

  Do not plan to move to Geant4 11+ for a while due to non backward compatibility

  Compiles with LLVM 10.0.0, gcc 5.4 to 12.0 depending on the site and mainly uses C++14 (and some C++17); Runs on CentOS7 (with some legacy RedHat EL6 and MacOS 10.14) 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-32 Neutron production in muon showers at the %-level

  Requested by LZ; Requires a large amount of work; No personpower to implement it

- 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

  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.

  Some progress made, but more validation is needed. JLab is willing to contribute to the validation of gamma-nuclear.

  This is also a Nuclear Physics experiments requirement

- UR-68 Propagation of polarized muons and taus in dense media

  DUNE request; Open, no activity/personpower?

- UR-69 Ability to turn off intranuclear scattering (in the Bertini Model)

  DUNE request; No personpower available as of now

Open or recently modified requirements in JIRA (III)

- UR-70 Improve pbar annihilation process

  Request by Mu2e; Important to several experiments; Work is on-going on INCLXX to extend it to antiprotons

- UR-71 Excess ratio of pi-/pi+ in p W reaction with Bertini

  Report by Mu2e; No personpower available as of now

- UR-85 Making MENATE_R package available as an alternative model

  Requested by NOvA on a low priority; No personpower available as of now

- UR-86 Consider refactoring of G4MTRunManager to allow override some of the functions in the base class

  Requested by Mu2e; Important to experiments using e.g., the ART framework; No personpower assigned at this time

- UR-87 Include (currently customized for SuperCDMS) databases for PhotonEvaporation and RadioactiveDecay in the official releases

  Requested by SuperCDMS; No personpower available as of now

- For the list of all requirements in JIRA and more details please see:

  https://jira-geant4.kek.jp/projects/UR

Some requests from last year with comments

- Muon g-2 is interested in having a symplectic stepper

  Was a subject of a Geant4 Google Summer of Code project; 2nd order symplectic integration method, G4BorisDriver was included in Geant4 v11.1

- 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, also due to the evolving Opticks code

New requests or related comments

- MicroBooNE

  New developments related to Geant4Reweight (https://github.com/NuSoftHEP/Geant4Reweight) may be of interest for adjustments to systematics. Don't anticipate any changes to central-value Geant4 model at this point.

- T2K/Beam Simulations

  Would like to save arrays to Ntuples (temporary solution is saving arrays as strings and use an external code to transform the strings back to arrays)

- LZ

  Would like to have NuDEX (A new nuclear γ-ray cascades generator) incorporated into Geant4 to improve the deexcitation gamma simulations following n-capture.

- SuperCDMS

  An extremely early version of some G4CMP classes were included in Geant4 around 2013 or so. Since then, the code in G4CMP has been extended significantly and diverged from the Geant4 versions.

Summary/Comments

- Requirements evolve

  Some have been addressed

  Some became part of working groups work plans

- Unfortunately, a growing number of requirements is on hold, some for a long time, due to the lack of people to work on them
- 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