Open and new Geant4 requirements -

HEP Intensity and Cosmic Frontier experiments

Krzysztof Genser/Fermilab

29th Geant4 Collaboration Meeting, Catania, Italy

October 7th, 2024

FERMILAB-SLIDES-24-0266-CSAID

Outline

- Selected aspects of experiments' Geant4 usage
- Requirements in Geant4 JIRA system
- New requests/comments/offers
- Summary/comments

Thank you to all who provided input (directly or indirectly):

D. Brailsford, C. Bronner, G. Cerati, S. Dolan, R. Fatemi, L. Fields, S. Gardiner, W. Gu, R. Hatcher, T. Junk, M. Kelsey, R. Kutschke, A. Lister, K. Mahn, A. Mastbaum, M. E. Monzani, M. Muether, Y. Nakajima, L. Paulucci, Z. Pavlovic, A. Sutton, T. Vladisavljevic, A. Waldron, H-J. Wenzel, Q. Xia, T. Yang, L. Zambelli, and others

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 FTFP_BERT_HP, QGSP_BIC_HP) physics list (with some groups using Geant4 10.3.p03); considering Geant4 11.2+

  Compile with gcc 12.1.0 and use C++17 (Some groups use older gcc and C++14, some use clang for auxiliary checks)

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

- NOvA detector group uses Geant4 11.0.p03 with patches for infinite loops reported in Bugzilla report 2546 and outdated carbon excitation energy reported in Bugzilla report 2568 with QGSP_BERT_HP_EMZ physics list with a custom MENATE_R implementation to replace neutron-on-carbon inelastic scatters between 20-100 MeV

  Compiles with gcc 9.3.0 and use C++17

  Uses SL7 (in a container), runs in the sequential mode

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; integrating/testing gcc 12.1.0

  Uses SL7 (in a container); runs in the sequential mode

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

  Use gcc 12.1.0, C++17

  Use SL7 (in a container); run in the sequential mode

- ANNIE (Accelerator Neutrino Neutron Interaction Experiment) uses Geant4 10.1.p03, with FTFP_BERT_HP, OpticalPhysics, with ANNRI custom model for Gd neutron capture and Geant4 10.7.p02 with FTFP_BERT_HP; testing 11+

  Uses gcc 4.9.2 and 8.5.0, C++14

  Uses CentOS7, runs in the sequential mode

Geant4 usage by Intensity Frontier experiments (III)

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

  Uses gcc 13.1.0 and C++20

  Uses AL9 and currently runs in the sequential mode

- 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 (in a container); runs in the sequential mode

Geant4 usage by Intensity Frontier experiments (IV)

- T2K/nd280 uses Geant4 10.1.p03 with QGSP_BERT or QGSP_BERT_HP physics lists, plus private interface to NEUT neutrino generator secondary interactions processes (pion inelastic interactions)

  Uses gcc C++17

  Uses AL9, runs in the sequential mode

- T2K/Beam Simulations uses Geant4 11.2.p01 with QGSP_BERT, FTFP_BERT physics lists; also testing the FLUKA.CERN interface

  Uses gcc 8.3.0, C++11

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

Geant4 usage by Intensity Frontier experiments (V)

- Many experiments use containers, (Docker/Singularity/Apptainer) which are also used by computing grids
- Liquid Argon experiments have an option to use NEST(Noble Element Simulation Technique, 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, G4HadronElasticPhysicsHP with some modification for thermal neutron scattering, G4Scintillation with modified GdLS properties, 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 the sequential mode

  Currently testing 10.6.p02 and considering 11.1+ and running in the MT mode

Geant4 usage by Dark Matter Search experiments (II)

- SuperCDMS

  Uses Geant4 10.7.p04 with the following physics lists: Shielding_EMZ (for neutron backgrounds), FTFP_BERT_HP (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

  Do not currently plan to move to Geant4 11+ due to non backward compatibility challenges

  Compiles with gcc 12.0, C++17 Runs on CentOS7 in the MT mode (up to 40 threads)

Requirements resolved/closed within last year

Issue	Labels	Summary	Geant4 release	Reqest. Exp
UR-70	5503	Improve pbar annihilation process	11.2	Mu2e, CERN AD, astro

Requirements added within last year

Issue	Labels	Summary	Status	Reqest. Exp
UR-85	5714	Making MENATE_R package available as an alternative model	Lack of Resources	NOvA
UR-87	5716	Include (currently customised for SuperCDMS) databases for PhotonEvaporation and RadioactiveDecay in the official releases	Lack of Resources	SuperCDMS
UR-96		Incorporate NuDEX generator into Geant4	Targeting 11.3	LZ
UR-97		Remove early/obsolete G4CMP code	In Progress	SuperCDMS

Open requirements including the ones added last year

Issue	Labels	Summary	Status	Reqest. Exp
UR-50	5006	Improve simulation of gamma induced neutron background	In Progress	LZ/ SuperCDMS
UR-68	5501	Propagation of polarized muons and taus in dense media	Open	DUNE
UR-96		Incorporate NuDEX generator into Geant4	Targeting 11.3	LZ
UR-97		Remove early/obsolete G4CMP code	In Progress	SuperCDMS

Valid requirements lacking people who could work on them

Issue	Labels	Summary	Reqest. Exp
UR-28	4001	Anti-proton production from proton beam	Mu2e
UR-32	4005	Neutron production in muon showers at the %-level	LZ
UR-49	5005	Neutron self-shielding effect	SuperCDMS
UR-69	5502	Ability to turn off intranuclear scattering	DUNE
UR-71	5504	Excess ratio of pi-/pi+ in p W reaction with Bertini	Mu2e
UR-85	5714	Making MENATE_R package available as an alternative model	NOvA
UR-87	5716	Include (currently customised for SuperCDMS) databases for PhotonEvaporation and RadioactiveDecay in the official releases	SuperCDMS

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

Geant4 question/offer from SuperCDMS

- SuperCDMS had done some development of features "within" Geant4
  - Added some missing energy levels/decays for Germanium isotopes.
  - Implemented JAEA elastic scattering model which includes energy transfer to target material
  - Importance biasing for MT with tracking of separate indices for each split track; supports management of individual weighted topologies within each event.
  - Throwing of properly uniform surface points with arbitrary complex solids, and throwing of uniform bulk points with arbitrary solids, for use with PrimaryGeneratorAction.

If any of these are of interest for adoption into Geant4, please let SuperCDMS (MK) know

A long-standing request/comments

- Many experiments would like/need 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 evolution of Opticks code.

  A parallel activity within Celeritas project began with the aim to provide a more portable solution not tied to a specific GPU hardware.

New requests or related comments

- T2K would like more description of classes, methods and parameters added to the Doxygen documentation as well as a simpler way to use FLUKA.CERN physics lists and more guidance on/an interface to save arrays as ROOT branches.
- Fermilab beam simulations for neutrino experiments strongly rely on the hadron production by the 120GeV proton beam (on, mainly, Carbon targets).
- DUNE would like a way to tag the Quasi Elastic (QE), charge exchange and other type of events
- NOVA would like a native implementation of additional alternative (neutron-specific) inelastic scattering/deexcitation models. This includes MENATE_R and NucDeEx

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