Status of Geant4 Hadronic Physics

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on behalf of the Geant4 Hadronic Physics Working Group

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String Models

- Fritiof (**FTF**) model

  - No physics development after G4 11.2

  - On-going physics validation

  - Reminder: **FTFP_BERT** is the recommended physics list for HEP !

- Quark-Gluon String (**QGS**) model

  - No physics development after G4 11.2

  - On-going physics validation

- Vladimir Uzhinsky is the main author of both models

Intra-nuclear Cascade Models

- **BERT** (Bertini-like cascade)

    - Improved angular emissions for 4-body and higher-body generation

        – Work by Dennis Wright

        – It has an impact on hadronic showers

            • Increased energy response, narrower lateral shapes: BERT gets a bit closer to FTFP

        – Reminder: BERT is the most used, workhorse cascade model in HEP

- **BIC** (Binary Cascade)

    - Stable

        – Reminder: used in medical physics, and sometimes in HEP for evaluating systematic errors

- **INCLXX** (Liege cascade)   *See talk by Jean-Christophe David in this session !*

    - Consolidation of the antiproton physics introduced in 11.2

        – Great interest in this recent development from the antiproton physics experiments at CERN

        – Reminder: INCLXX is used in production by ALICE;
            moreover, there is a growing interest by the neutrino community...

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PreCompound

- Changed treatment of inverse cross sections

  - From Kalbach's parameterisation (Option 3)
    to *G4NeutronInelasticXS* & *G4ParticleInelasticXS* (Option 1)

- Learned lesson: unexpected strong effect on hadronic showers by the applicability range of PreCompound

  - PreCompound is applied when the excitation energy per nucleon is [100 keV , **30** MeV]

    – Outside this interval, de-excitation is used

  - For G4 11.2.ref0**7** only, for curiosity, a different range was tried out, [100 keV , **3** MeV] :
    for pion showers, observed a significant impact on energy fluctuation
    (and, consequently, on energy resolution) in heavy materials (W, Pb)

    – Rolled back to [100 keV , **30** MeV] in Ref0**8**, but this transition is worth further investigations

- Work by Vladimir Ivanchenko, in collaboration with J.M. Quesada

Nuclear De-excitation

- Several technical changes, a few physics fixes and improvements

  - Fixed usage of pairing corrections, with better agreement with experimental data

  - Fixed computation of the minimal kinetic energy of fragments and use of Coulomb barrier

  - Simplified computation of corrections and probabilities

  - Introduced a new class, *G4InterfaceToXS*, to compute the inverse cross sections

    – Based on G4PARTICLEXS for neutron and light ions

  - ...

- Implementation by Vladimir Ivanchenko, in collaboration with J.M. Quesada

Updated Hadronic Datasets

- ## G4ENSDFSTATE**3.0** , PhotonEvaporation**6.0** , RadioactiveDecay**6.0.1**

  - ### Available in G4 11.2.ref08
    - A few corrections are likely to happen before the December release

  - ### Compliant with ENSDF version of March 5th 2024

  - ### One of the main goals is to make these three datasets more consistent with each other (in particular for nuclear levels with incomplete information), and with fewer (possible none) unphysical information, with respect to the previous datasets
    - Several open bugs in hadronics are due to these shortcomings

  - ### Major work by Laurent Desorgher
    - Scripts and tools used by Laurent have been shared: we are discussing where to put and make them publicly available
    - Some collaborators (Alvaro, Pico, Emilio, Loic, Vladimir I., *etc.*) are interested to learn and share the effort for future versions; also the Fluka-Cern colleagues are interested

Hadronic Showers *(see plots in backup slides)*

- **Current hadronic showers up to now (*i.e.* G4 11.2.ref08):**
  - A bit higher energy response and narrower showers for both FTF- and QGS-based physics lists
    – With respect to those of G4 11.2.p02
    – Mainly due to the improvement in BERT
  - Showers of QGSP_BERT *vs.* those of FTFP_BERT
    – A bit higher energy response, larger energy fluctuations, longer and narrower shower shapes

Including NuDEX in Geant4

- New alternative and more sophisticated nuclear de-excitation model, for the emission of gammas and internal conversion electrons

  - Major work by Emilio Mendoza and Daniel Cano

  - Useful for more precise simulations of gamma and electron emissions in nuclear reactions

- Available since G4 11.2.ref05

  - Relies on a new hadronic dataset, G4NUDEXLIB1.0 (~80 MB, ascii files)
    - Various parameters from ENSDF, BrICC, RIPL-3, and IAEA
    - Pointed by the environmental variable G4NUDEXLIBDATA

  - When it cannot be applied, it relies on *G4PhotonEvaporation*

  - For the time being, it is used only for neutron capture when ParticleHP is utilised in the QGSP_BERT_HP physics list
    - In the future, it will be possible to use it more generally, as an alternative evaporation model, as well as in other physics lists

Unresolved Resonance Region (URR) treatment via Probability Tables (PT)

See talk by Loic Thulliez in this session !

- Major physics improvement in the treatment of low-energy neutrons

  - Work by Marek Zmeskal and Loic Thulliez

  - Relevant for more precise simulations of nuclear reactor criticality and shielding applications

    – Making Geant4 another step closer to MCNP and TRIPOLI

- Available since G4 11.3.beta

  - Relies on a new dataset, G4URRPT1.1 (~290 MB, .z files)

    – Probability tables at temperature 293.15 K processed with both NJOY and CALENDF, from the JEFF-3.3 library and consistent with G4NDL4.7.1

    – Pointed by the environmental variable G4URRPTDATA

  - By default, it is not included

    – A new physics list constructor needs to be introduced to include this physics extension

    – The choice of the type of PT between NJOY or CALENDF is done via C++ interface, *e.g.* *G4HadronicParameters::Instance()->SetTypeTablePT("calendf");*

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geant-val.cern.ch

CHE pion response | **Beam:** pi- | **Target:** CMS-HGCAL

- 10.4.p03 FTFP_BERT, GEANT4
- 11.2 FTFP_BERT, GEANT4
- 10.6.p03 FTFP_BERT, GEANT4
- DATA, experiment

We are extending the coverage of *geant-val, e.g.* in 2024 the CMS HGCal beam test has been integrated in geant-val
(work made by Lorenzo Pezzotti, in collaboration with the CMS team)

AHCAL

CE-H

Beam direction

Backup

Pion− showers

G4 11.2.p02   FTFP_BERT
G4 11.2.ref08   FTFP_BERT

G4 11.2.p02   QGSP_BERT
G4 11.2.ref08   QGSP_BERT

Note : conventional Birks treatment
        (easier and no experimental h/e to fit !)

Energy Response

Energy Width

Energy Resolution

Longitudinal Shape

Lateral Shape