Recent and ongoing developments in hadronics

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Outline

This talk presents some of the work made in Hadronics which is of general interest and has not been covered in other talks:

- CHIPS package decoupling
- Reproducibility
- Energy-momentum conservation checks

- Summary and outlook

CHIPS package decoupling (1/3)

CHIPS package is very difficult to maintain, therefore we decided to extract (*i.e.* clone) only the minimum which is needed, and then adapt the interfaces to G4 standards

- Quasi-elastic scattering
  - Both cross sections and final states (used in QGS-based P.L.)
  - Already separated in G4 9.5
- Elastic scattering
  - Final states of elastic scattering p-A , n-A (for all A)
  - Cross sections of elastic scattering p-H , n-H , p-He , n-He
  - Cross sections of elastic scattering h-p , h-n (used in FTF)

=> all h – A elastic cross sections have been isolated

CHIPS package decoupling (2/3)

- Inelastic scattering
  - kaon/hyperon – nucleus inelastic cross sections
  - hadron – nucleon inelastic cross sections (used in FTF)

    => All h – A inelastic cross sections have been isolated
  - Removed caching
  - Extended the cross section registry to avoid multiple instances of the same cross sections
- Gamma- and electro-nuclear
  - Cross sections of γ – A interactions : already separated
  - Virtual photon generation and conversion to real photon (for electro-nuclear) : extracted now in Bertini electro-nuclear
  - Final states of γ – A interactions: cannot be isolated from CHIPS
    - Now an alternative exists: Bertini *(see M. Kelsey talk on Session 4)*

CHIPS package decoupling (3/3)

- Nuclear capture at rest
  - For all negatively charged hadrons: π- , K-, p̲ , Σ-, Σ̲+, Ξ- , Ω-
  - Only final states (no cross sections needed)
  - As for the final states of γ – A interactions,
    the final states cannot be isolated from CHIPS
    (because of the heavy coupling with all the CHIPS world, *e.g.* quasmons etc.)
    - Now an alternative exists: Bertini (π-, K-, Σ-, Ξ-, Ω-) + FTF/Preco (p̲, Σ̲+)
      (see M. Kelsey talk on Session 4)

Major achievement in hadronics

The recommended physics list for HEP, **FTFP_BERT** in **G4 9.6.beta** does not depend anymore on the CHIPS package:

- Nuclear capture at rest
  - **Bertini** is used for **π^-** , **K^-** , **Σ^-** (and soon also for **Ξ^-** and **Ω^-**)
  - **Fritiof** (+ Precompound) is used for **$\bar{p}$** and **$\bar{\Sigma}^+$**
- Lepton-nuclear
  - **Bertini** is used for **γ** , **e-** , **e+** , **μ-** , **μ+**
- Decoupled cross sections from CHIPS
  - for inelastic interactions of kaons and hyperons
  - for nucleon elastic scattering
  - for hadron-nucleon elastic & inelastic used in FTF

Reproducibility

- Reproducibility of the (pseudo-)random sequence
  - Useful in practice, for debugging
  - One of the quality metrics of a simulation code
- Two types of reproducibility:
  1. **Weak reproducibility**
     - at run-level, i.e. starting with ***currentRun.rndm***
  2. **Strong reproducibility**
     - at event-level, i.e. starting with any ***currentEvent.rndm***
- Before G4 9.6.beta
  1. Weak reproducibility always valid
  2. Strong reproducibility sometimes violated
     - More frequently in FTFP_BERT (and other PLs) than LHEP
     - More frequently in more recent versions of Geant4

Reproducibility tests

- Improved the existing reproducibility tests of physics lists based on simplified calorimeters
- Created new tests at model-level
- Included in CDash one quick test (test68) of FTFP_BERT
- Typical pattern of reproducibility violation
  - To save time, instead of re-compute something each time it is needed, cache and re-use it whenever possible
  - Cashing can violate reproducibility if some of the cached values are history-dependent
    - Example: **cache_vector[Z] = function(Z, A)**

      where the first isotope encountered for a given Z is used to compute the function, and then re-used for all other isotopes of the same element...
    - Example: **cache_vector[i] = cross_section(p)**

      where the momentum of the first particle is used to compute the function, instead of the center of the momentum bin...

Reproducibility fixes up to G4 9.5.ref08

- Fixed problems
  - CHIPS quasi-elastic
  - Starkov elastic final state model for π± > 1 GeV
  - Ion ionization corrections
  - Fission in Bertini
  - Bertini cascade, when hyperons are involved
    (it turned out a problem in *G4PhaseSpaceDecayChannel*)
  - CHIPS hadron-nucleon inelastic cross sections, used by FTFP
  - Multiple scattering (combination of 2 models for e±)

  => **LHEP** and **FTFP_BERT** are now fully reproducible!
- Reproducibility problems still to fix
  - CHIPS stopping at rest : used in QGS-based physics lists; not worth now
  - Neutron HP : painful to debug because extremely slow
  - Binary cascade : hope to fix it for G4 9.6

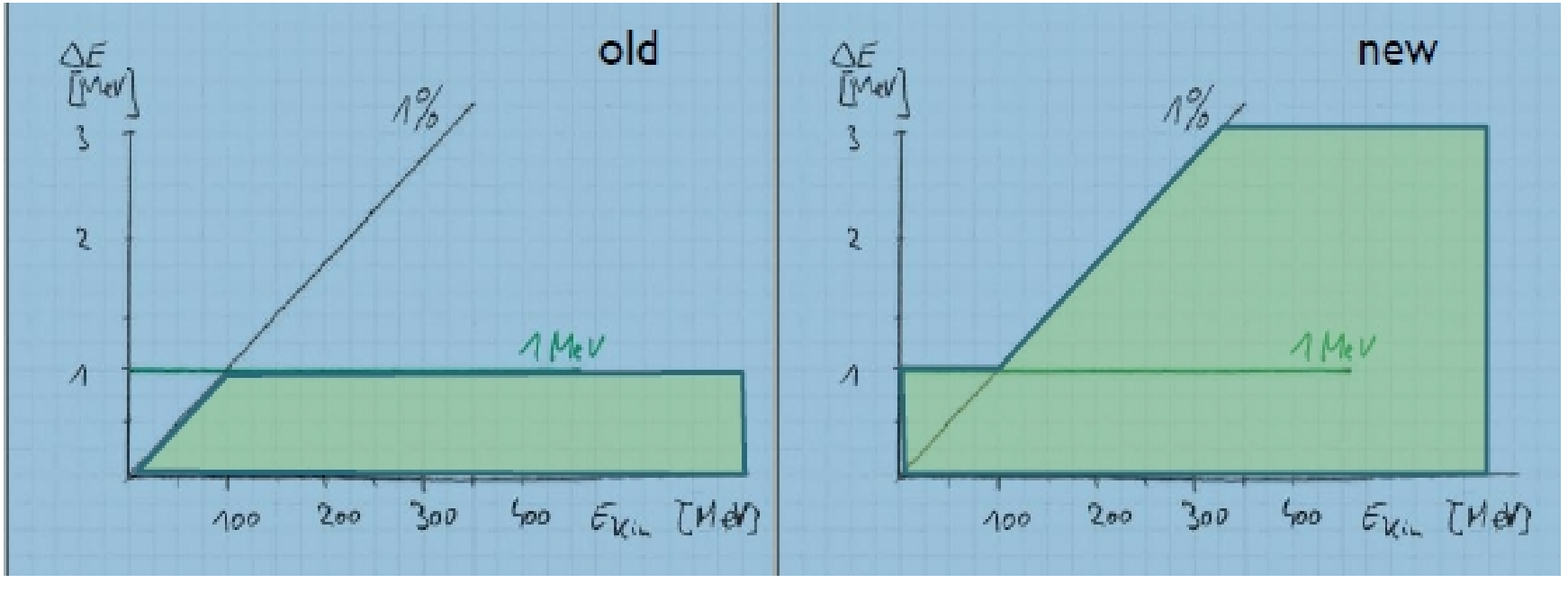
Checking energy-momentum

- Two kinds of checks
  1. Optional : check and inform (old, but extended in 9.6.β)
  2. Mandatory : protect against “catastrophic” violations (new in 9.6.β)
- Implemented in *G4HadronicProcess*
- Optional checks and reports:
  - Values refer to: (initial – final)
  - Variables that are considered:
    - energy (old) ; momentum, charge, baryon number (new)
  - Each model or process needs to set limits
  - Needs an environment variable to activate:
    G4Hadronic_epReportLevel Default: 0 (no checks)
  - Limits can be set via environmental variables:
    G4Hadronic_epCheckRelativeLevel
    G4Hadronic_epCheckAbsoluteLevel These override internal limits

Optional checks

- **G4Hadronic_epReportLevel**
  - **0** : default, no checks and no reports
  - **1** : report when E/p is not conserved
  - **2** : always report
  - **3** : extended report when E/p is not conserved
  - **4** : always extended report
  - **-N** : same as above, but report to stderr (instead of stdout)

- Process/Model: **SetEnergyMomentumCheckLevels(** 1*perCent**,** 1*MeV **);**
  or user: export **G4Hadronic_epCheckRelativeLevel=**0.01
  export **G4Hadronic_epCheckAbsoluteLevel=**1.0



Mandatory checks

- Check only for "catastrophic" energy non-conservations
- Default limits: relative = **10%** , absolute = **5 GeV**
- Model may provide different limits, via the method:
  GetFatalEnergyCheckLevels()
  - for example: (5% , 250 GeV) for **LEP** and **HEP**
    (10% , DBL_MAX) for **HP**

- If check fails:
  - Raise G4Exception "JustWarning"
  - Re-sample the interaction
  - If more than 100 consecutive re-samplings, "FatalException"

or, when *G4Hadronic_epReportLevel < 0* (check mode)

- Raise G4Exception "EventMustBeAborted"

Summary and outlook

- **FTFP_BERT** in G4 **9.6**
  - Does not depend on the CHIPS package
  - Is fully reproducible
- The same applies to other physics lists (e.g. QGSP_BERT) if:
  - Replace CHIPS stopping with BERT + FTFP stopping
  - Replace CHIPS gamma- and electro-nuclear with BERT
  - Replace CHIPS cross sections with the cloned (isolated) ones

  Should we do that for G4 9.6 ?

- We will keep working on:
  - Removing old hadronic classes which are not used
  - Cleaning and improving interfaces of hadronics
  - Improving the code quality of hadronics

Acknowledgment

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- CHIPS decoupling: Witold
- Reproducibility: A., Gabriele, Gunter, Vladimir I., Witold
- Energy-momentum checks : Gunter, John A., Vladimir I.