What's new in 11.0: Electromagnetic physics

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Outline

- Main developments for EM
- Revisions of sub-libraries
- Selected physics model revisions
- Validation plots
- Summary

Main developments for EM in 2021

- Coming new major release 11.0 allows performing review and update of EM sub-libraries
  - interface change is allowed
  - obsolete classes may be removed
  - physics results should be preserved
- Parallel R&D development of G4EmHep library and prototype of the G4EmHep/Geant4 plugin
- Performance improvements
  - Optimisation of frequently used run time methods
- Model developments
  - Standard models of ionization
  - Low-energy models
  - Optical

Revision of EM sub-libraries

- General review of EM libraries and examples
  - removed unused variables and headers
  - check interfaces – improve where needed and possible
  - use “const” variables where possible
- Removal of obsolete classes and interfaces
  - the most important is removal of G4EmProcessOptions
- Updated G4PhysicsVector
  - Minor improvement of performance, improved interfaces
- Use C++11 keyword uniformly over EM sub-libraries
  - “virtual” keyword in base classes methods
  - “override” or “final” in derived class methods
  - where possible use advance loop pattern
- Trying common formatting of all classes
  - Uniform clang format not yet agreed but implemented in part of the code
  - moved initialisation of pointers, Boolean, and simple numbers to headers

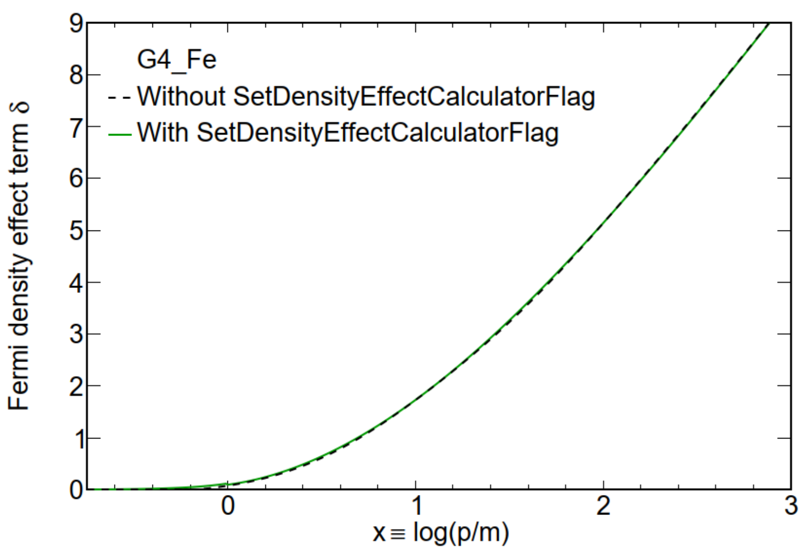
G4PhysicsVector – the main Geant4 EM data structure component

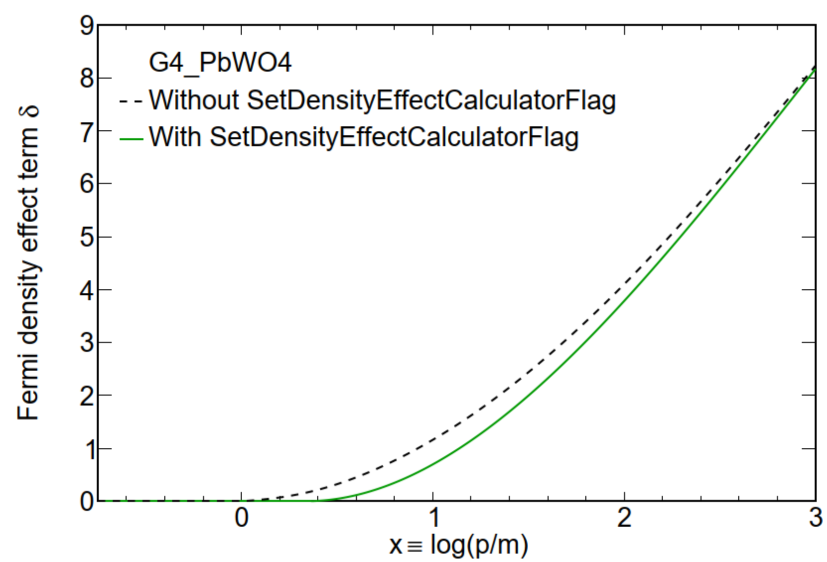
- Only 3 type of vectors remain
  - G4PhysicsLogVector
  - G4PhysicsLinearVector
  - G4PhysicsFreeVector
  - In any constructor a Boolean flag of spline may be added
  - Revised checks on physics vector input
  - Spline flag is not anymore part of G4EmParameters
    - Should be defined by the consumer code, which creates a vector
    - Cannot be set on-fly
- Tree types of spline
  - G4SplineType::Simple
  - G4SplineType::Base // default
  - G4SplineType::FixedEdges
  - G4PhysicsVector::FillSecondDerivatives(const SplineType) // vector should be filled
  - Added check if energy vector can be used for spline
- Optimized run time methods
  - G4PhysicsVector::Value(const G4double e, size_t& idx) // user cache index
  - G4PhysicsVector::Value(const G4double e) // compute index from scratch
  - G4PhysicsVector::LogVectorValue(const G4double e, const G4double loge)

Selected physics models revision

G4DensityEffectCalculator

- Matthew Strait proposed improvement of the algorithm
  - He is an original author of the on-fly computation of the density effect in 10.7, which was committed at last minute and required fixes
  - Improved variant of the method in 11.0 and backported to 10.7
- To enable this method a flag should be set for the material
  - This method brings some CPU penalty but may be useful in gaseous detectors for simulation of dEdx for precise particle identification





G4VEnergyLossProcess base class

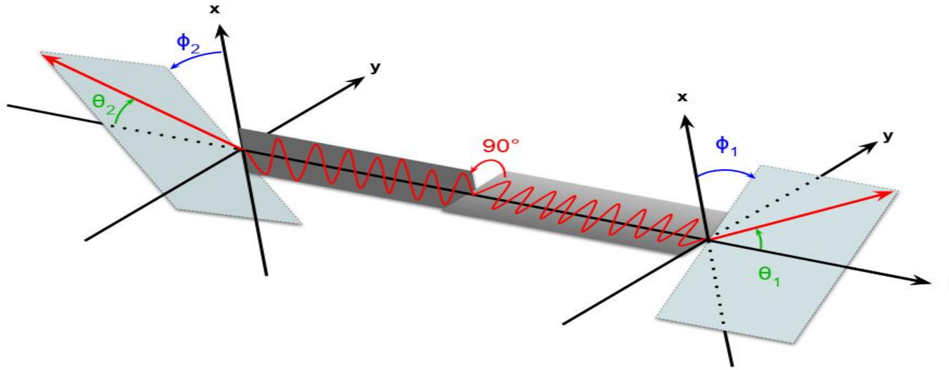
- Ionisation processes and models was reviewed and updated
  - Spline and integral options belong now to each process and not centrally defined via G4EmParameters
    - Depends on a concrete cross section shape
  - G4CrossSectionType is introduced instead of Boolean flag
    - fEmNoIntegral
    - fEmIncreasing
    - fEmDecreasing
    - fEmOnePeak
    - fEmTwoPeacks
  - Subcut delta-electron production option is removed
    - Not widely used and not improving performance in a significant way
    - G4VSubcutProcessor (user hook) interface is available as an alternative
  - CorrectionAlongStep(..) method is optimized in all ion ionization models
- Number of bins in physics vectors are not anymore part of G4EmParameters but are computed via number of bins per decade

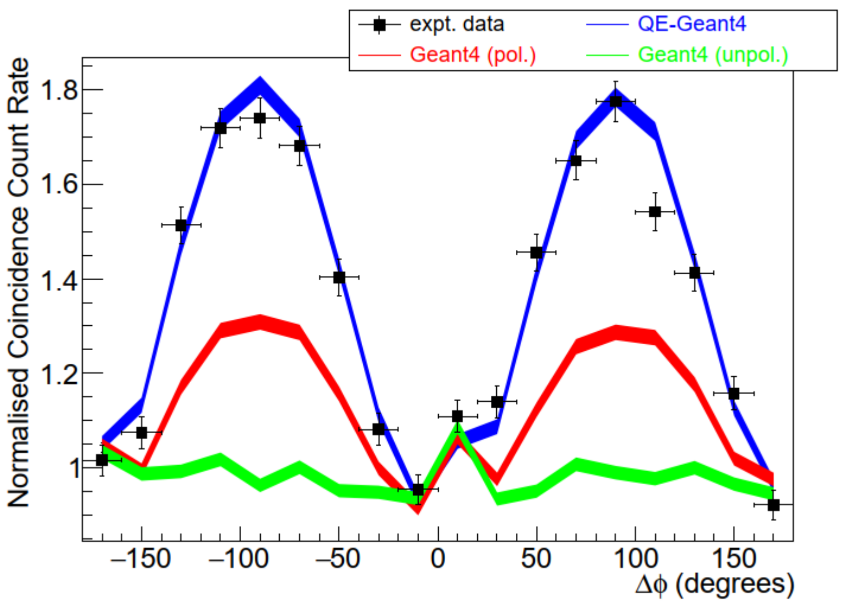
Gamma linear polarization

- Gamma linear polarization may be enabled on top of EM physics constructors
  - Opt0, Opt3, Opt4, Livermore, Penelope, LE
  - Enable via interface G4EmParameters::SetEnablePolarisation(G4bool val)
  - Validation for G4LowEPPhysics (LE) is published in NIM B 502
- In the user primary generator action initial polarization of gamma should be defined
  - For example, for Higgs->$\gamma\gamma$ decay polarization of both gammas should be inserted in interface between generator and Geant4
- Quantum entanglement in positron annihilation may be also enabled
  - G4EmParameters::SetQuantumEntanglement(G4bool v)
  - UI command: "/process/em/QuantumEntanglement true"

Quantum entanglement in positron annihilation

(Nature Commun. 12 (2021) 1, 2646; arXiv: 2012.04939v1)





There is angular correlation for Compton scattering of two photons in PET device

Geant4 method how simulate quantum effects has been developed by J.Allison

The developed method may be potentially used in HEP

Geant4 simulation of X-ray transition radiation at small angles

Contribution by V. Grichine

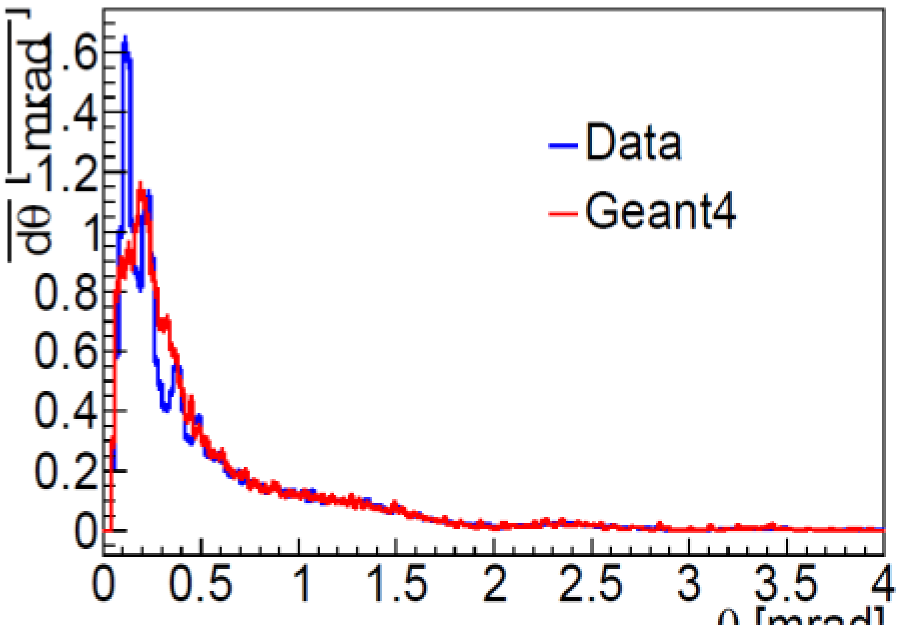
- X-ray transition radiation at small angles (< 1mrad)
- Simulation fails to reproduce experimental data available from ATLAS Test Beam
  - Electrons 20 GeV, regular radiator 30 50-μm-thick mylar foils separated by 2.96 mm air gaps
  - In particular, peaks at low-angles are not properly reproduced
- Problem not due to the model itself but to the limited precision of the numerical integration
  - Simulation reproduces the data if a finer binning is used
  - Developed a method/strategy to adapt the binning dynamically in order to obtain a good precision
  - Benchmark using `TestEm10`

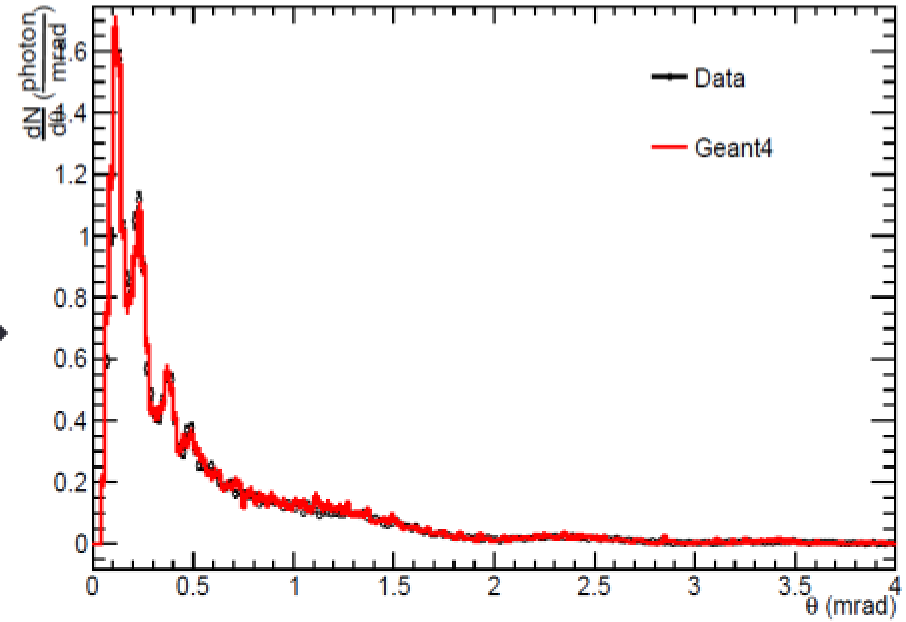
Before and after…

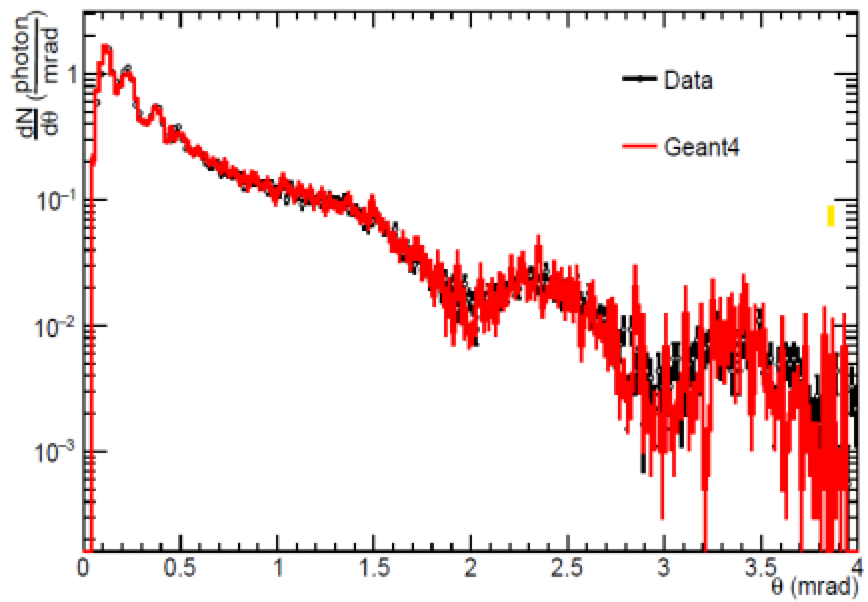
Contribution by V. Grichine

Before

After







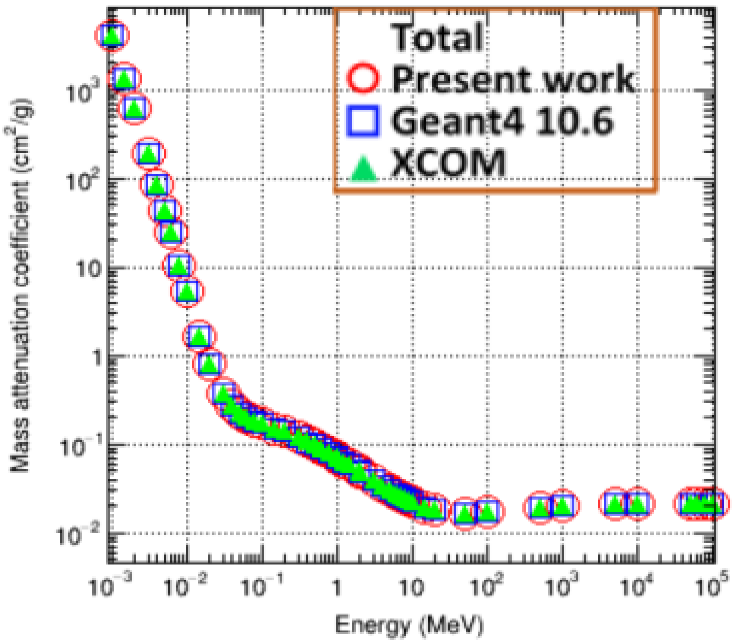
Implementation of the EPICS2017 database for photons in Geant4

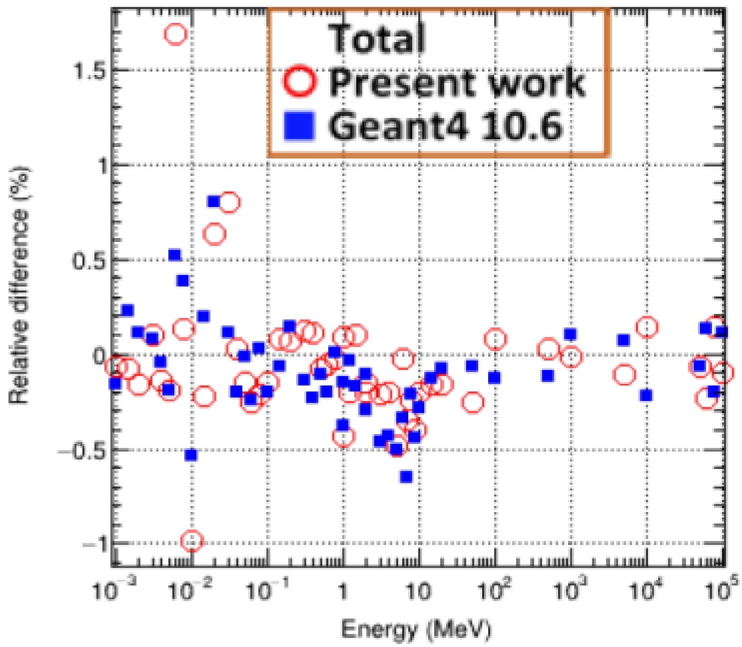
- Livermore low-energy electromagnetic models uses EPDL97 database
- Database EPICS2017 (Electron Photon Interaction Cross Section library) contains physical data (cross section…) for electron and photon transport calculation
  - Evaluated and included into G4EMLOW8.0
- Livermore models for gamma are updated
  - Gamma conversion - available already in Geant4 10.7
  - Compton effect
  - Photoelectric effect
  - Rayleigh scattering

Improved accuracy of parameterisation of gamma cross sections

Comparative study: mass attenuation coefficient

- Example: material = water, for total (all processes)
- A good agreement with XCOM data was observed



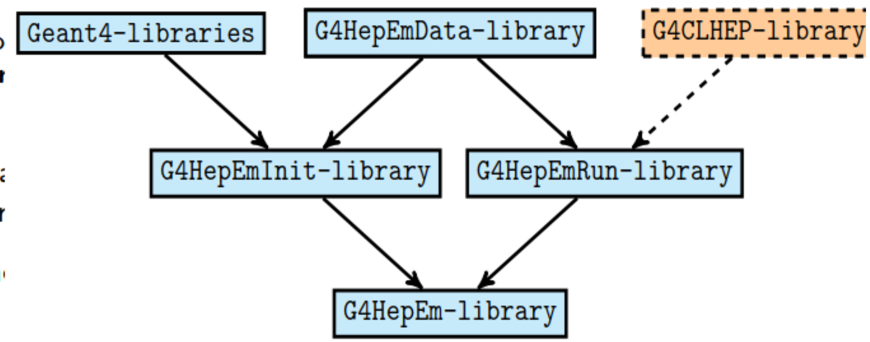


G4HepEm R&D project (M. Novak)

- Specialization of EM physics for HEP shower simulations
  - External library
  - Minimal interface change to use G4HepEm implemented in Geant4 11.0
- In 2022 it would be possible to continue R&D for simulation of LHC experiments

G4HepEm: library **structure** is determined by the main goals and design

- **clear separation of run-time and initialisation-time functionalities**:
  - many information are needed at initialisatio
  - in order to obtain **as compact run-time libr**
- results in **separation of** the **data definitions** C++): isolated, *"single function"* implement according to their input arguments (mostly pr
- all these above have lots of benefits (see som
- G4HepEm is structured along this separation:



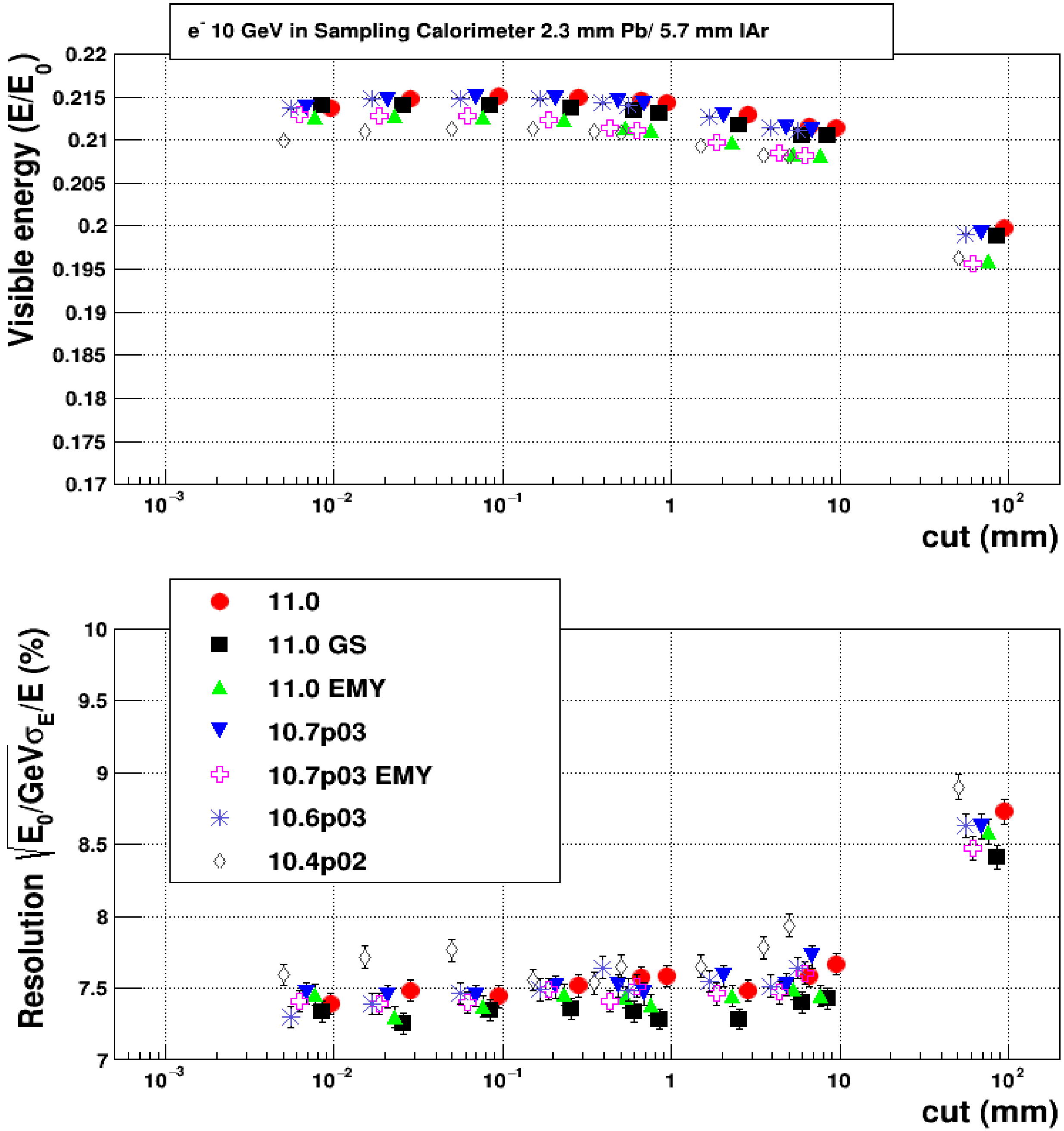
  - G4HepEmData: definition of all data structures **filled at initialisation** and **used at run-time**
  - G4HepEmInit: all **initialisation time functionalities**, e.g. for **constructing** and **populating** the above **data structures** (based on the given application setup) **relying heavily on core** Geant4 **functionalities**
  - G4HepEmRun: all **run-time functionalities**, e.g. for **reading**/(interpolating) **the data structures** constructed and populated at the initialisation time, **compute the step lengths** and **perform the physics interactions**
  - G4HepEm: a tiny library for connecting all the above (a G4VProcess interface implementation as well)

Low-energy and DNA developments

- MicroElec models extension to a greater number of materials
- ANSTO model and data for atomic de-excitation and PIXE
- Rayleigh scattering models considering material formfactors
- Extension of DNA ionization and excitation
  - Goal – increase max energy to 100 MeV
  - Demonstrating in the new DNA example
- Mesoscopic model of water radiolysis for DNA chemistry
  - New DNA examples

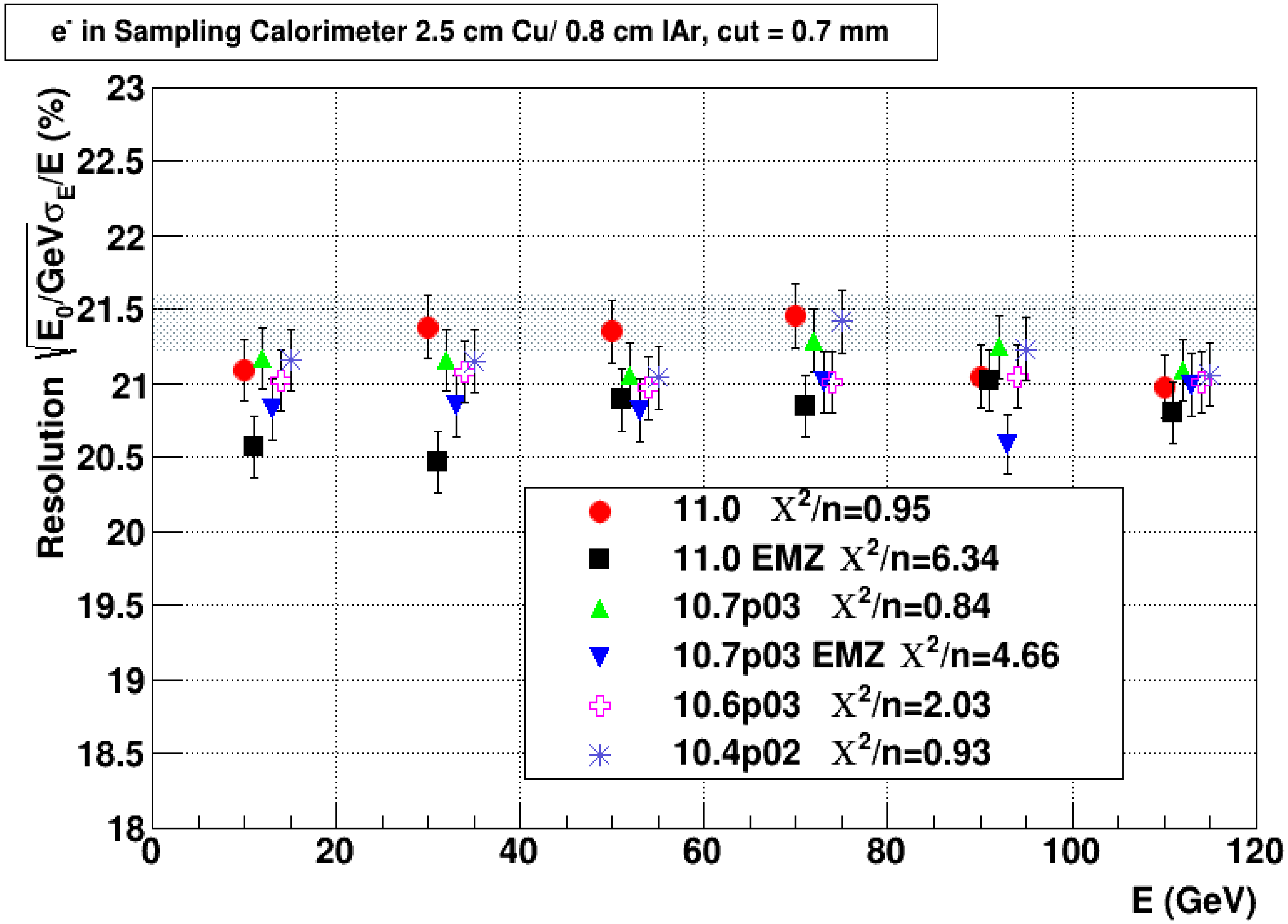
Validation plots for 11.0

Simplified ATLAS Barrel



For this test, results With the default EM Physics were changed With Geant4 10.5 and since 10.6 are stable

Simpified ATLAS HEC



Summary

- General clean-up of EM physics for 11.0 is done
  - Unified class view
  - Minor revision of method signatures
  - Unified handling of G4PhysicsVector
- Performance improvement is achieved
  - 2-3% speed-up depending on geometry
- Physics results are compatible with 10.7
- For the first time we have introduced
  - Gamma linear polarization on top of EM physics constructors
  - Quantum entanglement, which may be enabled for positron tomography simulation
- The R&D G4EmHep project looks promising
- New and/or revised low-energy and DNA models are added