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# Status of EM Physics

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27th Geant4 Collaboration Meeting, 26–30 Sept 2022

# Outline

- Update of infrastructure for EM physics
- Selected model developments
- New approaches for EM physics
- EM Physics Lists
- Summary

For the release 11.0 all EM libraries were revised and updated. Such massive modification required detailed validation but important component of such validation – CMS experiment simulation was not available until March 2022 due to migration of CMSSW to DD4hep geometry package.

Due to this delay, important problems in EM physics were identified and fixed only in patch02 (May 2022) and recently in patch03 (September 2022)

# Updates for materials

- Problems #2346, #2474, #2486 are fixed
  - handling of complex materials and parameterization of density effect correction
- Mean ionization potential for carbon is changed from 81 to 78 eV
  - Choice what NIST data to take
- G4MaterialPropertyVector, G4OpticalMaterialProperties:
  - Insist material property vectors are in increasing order of energy (PR #42);
  - default verbosity=1 as everywhere in Geant4 physics
- G4DensityEffectData:
  - Matthew Strait fix typos in the density effect data table (#2423) for 8 materials, the most significant fix for G4\_Tm, small for G4\_Be, G4\_Mg, G4\_Fe, and G4\_Y.

# Updates in kernel libraries for physics

- Added virtual `GetCrossSection(...)` method for `G4VDiscreteProcess` to be used for initialisation
  - Needed for the integral method
- Added virtual `GetCreatorProcess(...)` method for `G4VProcess`
  - Needed for combined processes
- For particle change
  - `G4VParticleChange`, `G4ParticleChangeForLoss`, `G4ParticleChangeForGamma`, `G4ParticleChangeForMSC`:
    - `SetNumberOfSecondaries(..)` is not mandatory anymore, because `std::vector` is used instead `std::array`
    - Reduce number of “if” and calls to virtual functions
    - Improved diagnostic for wrong energy/momentum/time (useful for studies on #2353, #2368)
    - Substitute severity “`EventShouldBeAborted`” by “`JustWarning`”
- For `G4SteppingManager`:
  - Removed unused “`ApplyCuts`” facility
  - Updated code to identify `CreatorProcess` pointer having in mind combined processes
    - Important for gamma general, neutron general, transportation with msc

# Updates in base EM classes inside electromagnetic/utils

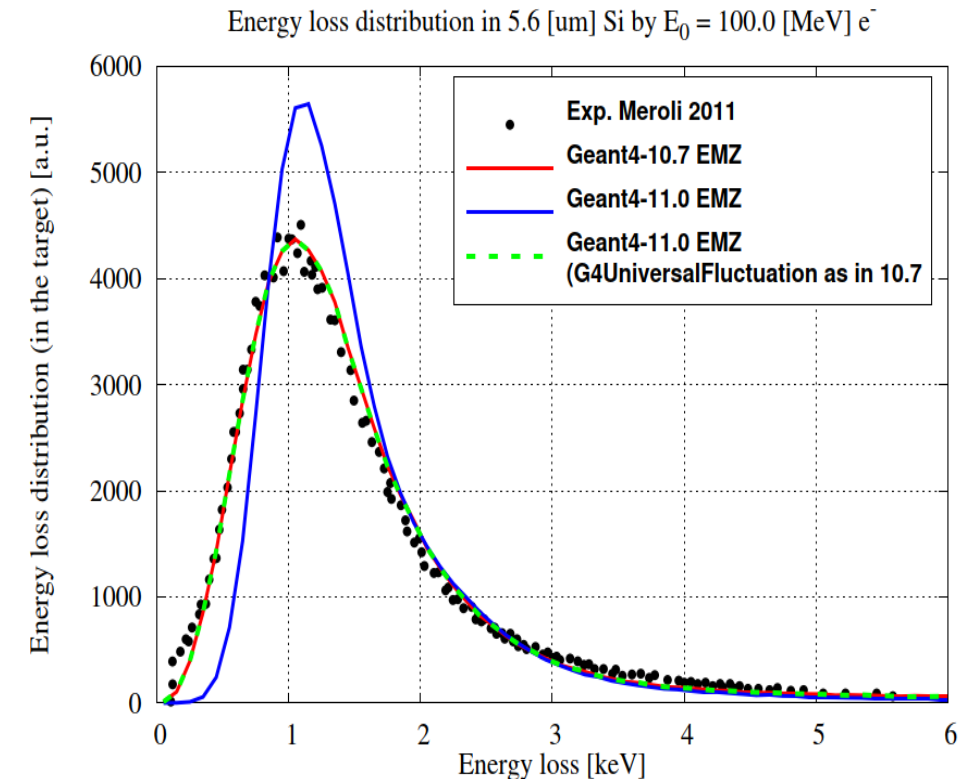
- **G4VEmProcess, G4VEnergyLossProcess, G4VMultipleScattering:**
  - Moved general part of initialisation to G4EmTableUtil and G4EmUtility
    - 27-30% class length reduction – easier to navigate inside classes
  - Implemented integral method for cross sections without precomputed tables
- **Physics improvements**
  - Using new utilities implemented general selection of G4Element and G4Isotope for all EM models
  - Added new UI command and C++ interface to define type of fluctuation model in all physics lists
    - G4UniversalFluctuation is the default
    - G4UrbanFluctuation and G4LossFluctuationDummy are alternatives
  - Change the default Livermore DB from EPDL97 to EPICS2017
  - Removed dependence on G4magneticfield
- **Fixed problems:**
  - #2495 – definition of StepFunction for ions, which is important for low-energy applications
  - #2492 – fixed typo in the messenger
  - #2480 – energy shift in CMS HCAL due to multiple scattering
  - Fixed pointer to fluctuation model if a model is added for G4Region
  - Fixed typo in bremsstrahlung model name in the model catalogue
- **Applied cling-tidy (D. Sawkey)**

# Selected model developments

# Updates in standard EM processes/models electromagnetic/standard

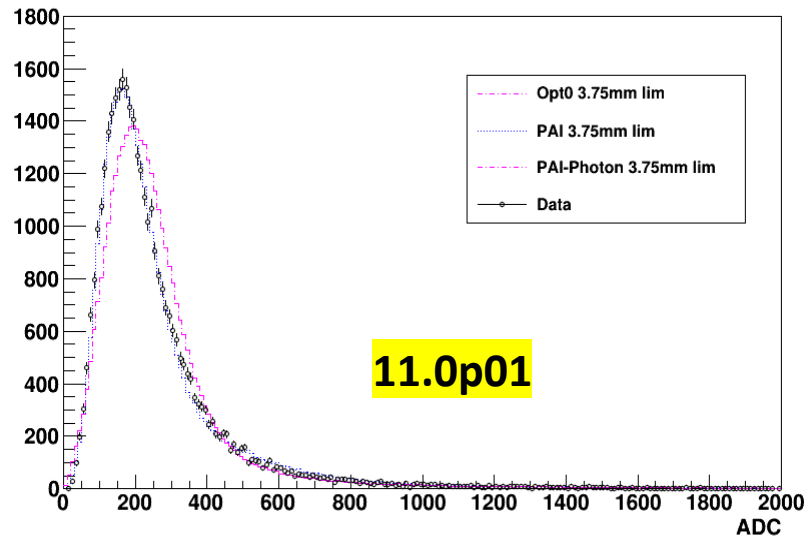
- Review was done of all processes and helper classes
  - Linear interpolation of tables are used for smooth cross sections
- Introduced choice of model of fluctuations (fix #2466)
  - **G4UniversalFluctuation** – default fast
  - **G4UrbanFluctuation** – most accurate model
  - **G4IonFluctuations**
  - **G4LossFluctuationDummy**
  - Now an external model of fluctuation may be used
- **G4UrbanMscModel** – technical improvements
  - Extended precomputed data structure
  - Reduced number of instructions
  - Laszlo Urban has prepared updates with modification of few parameters
    - Not yet integrated and may be left for the next year
- Applied cling-tidy (D. Sawkey)

M. Novak

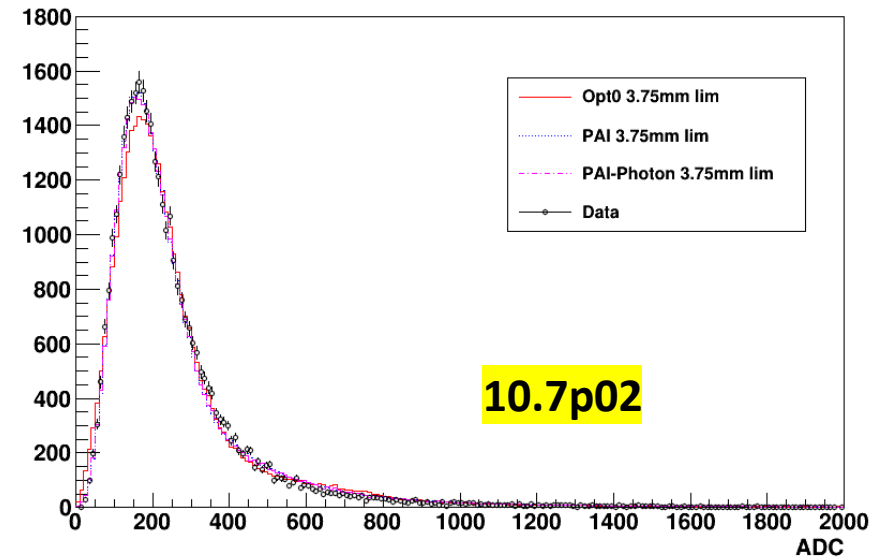


# ALICE TPC test – light gas mixture

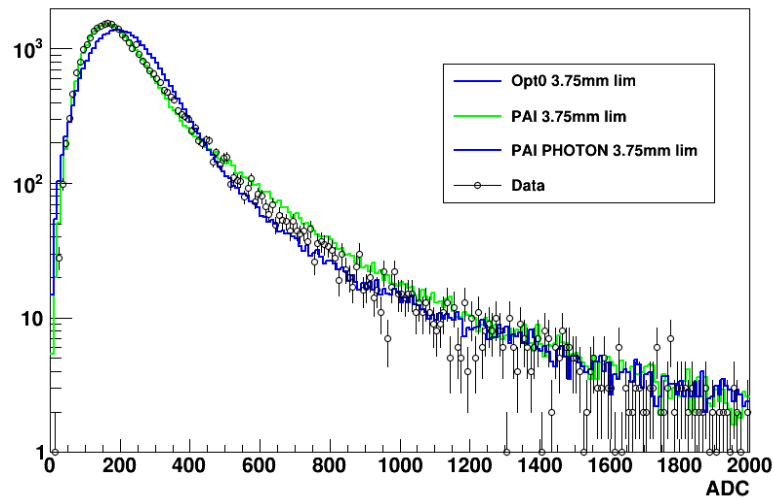
Energy deposition in ADC for 3 GeV/c p in 7.5 mm gap, G4 11.0p01



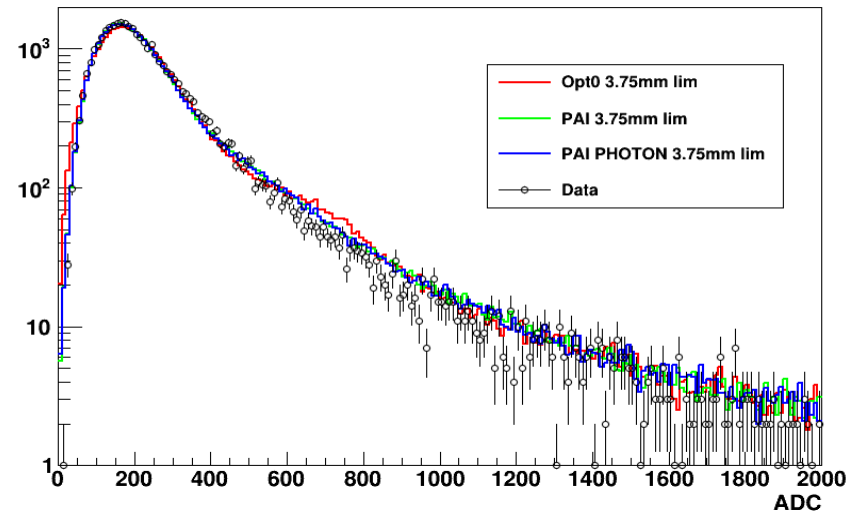
Energy deposition in ADC for 3 GeV/c p in 7.5 mm gap, G4 10.7p02



Energy deposition in ADC for 3 GeV/c p in 7.5 mm gap, G4 11.0p01



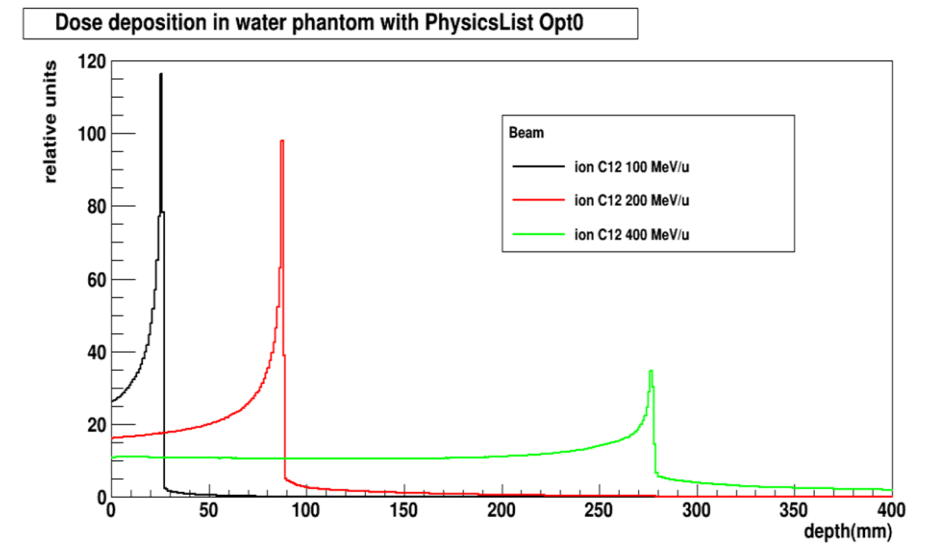
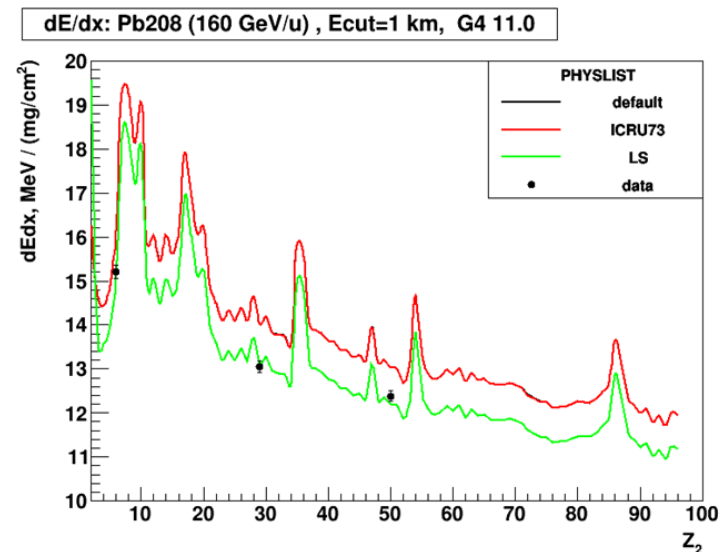
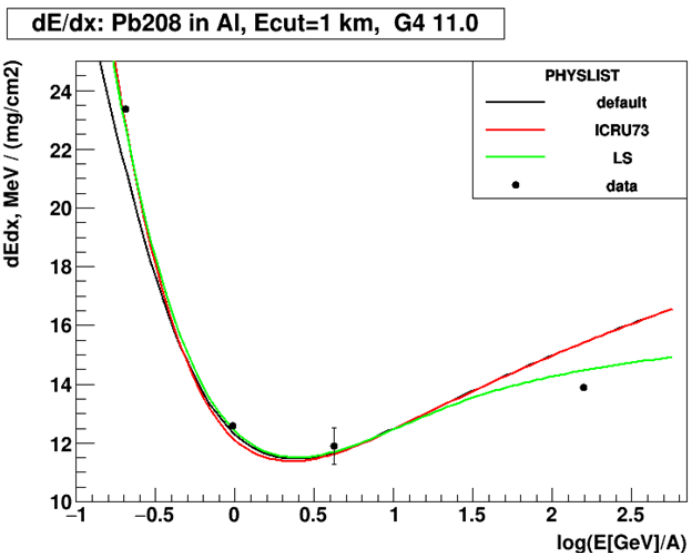
Energy deposition in ADC for 3 GeV/c p in 7.5 mm gap, G4 10.7p02

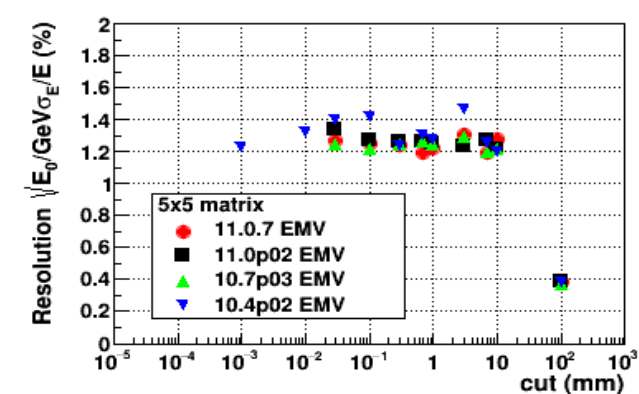
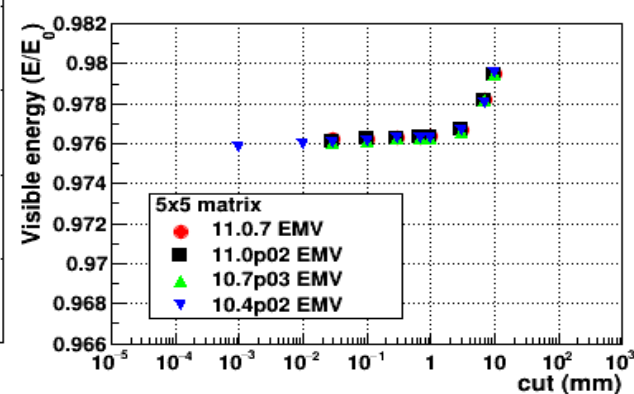
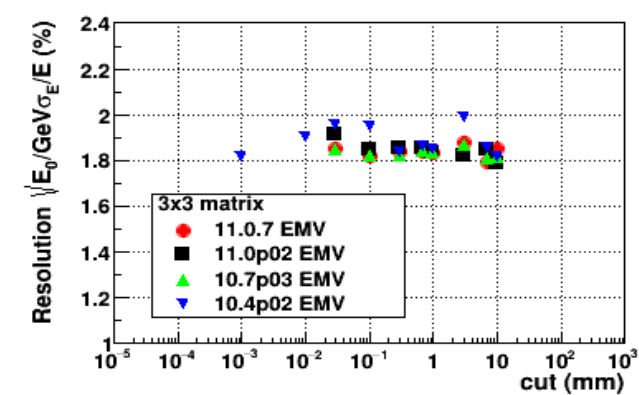
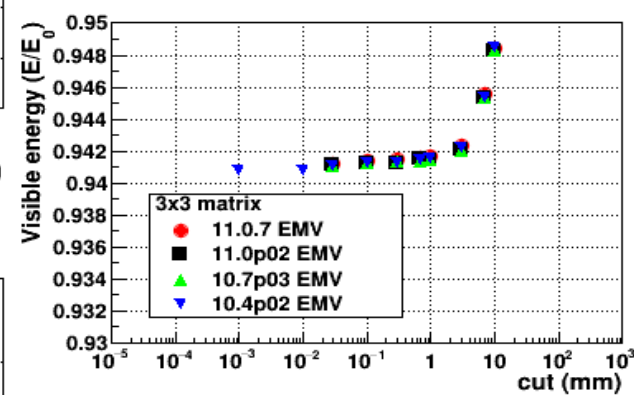
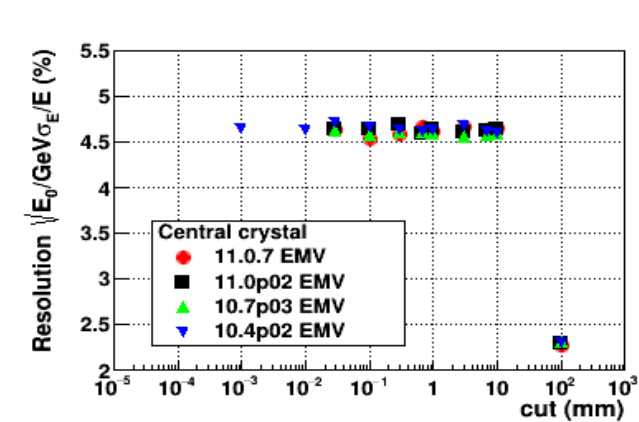
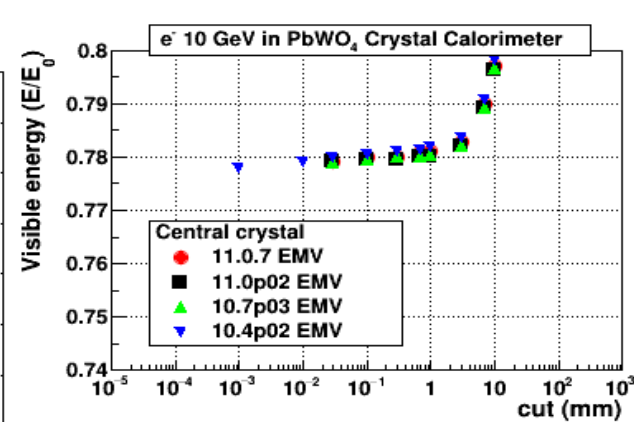
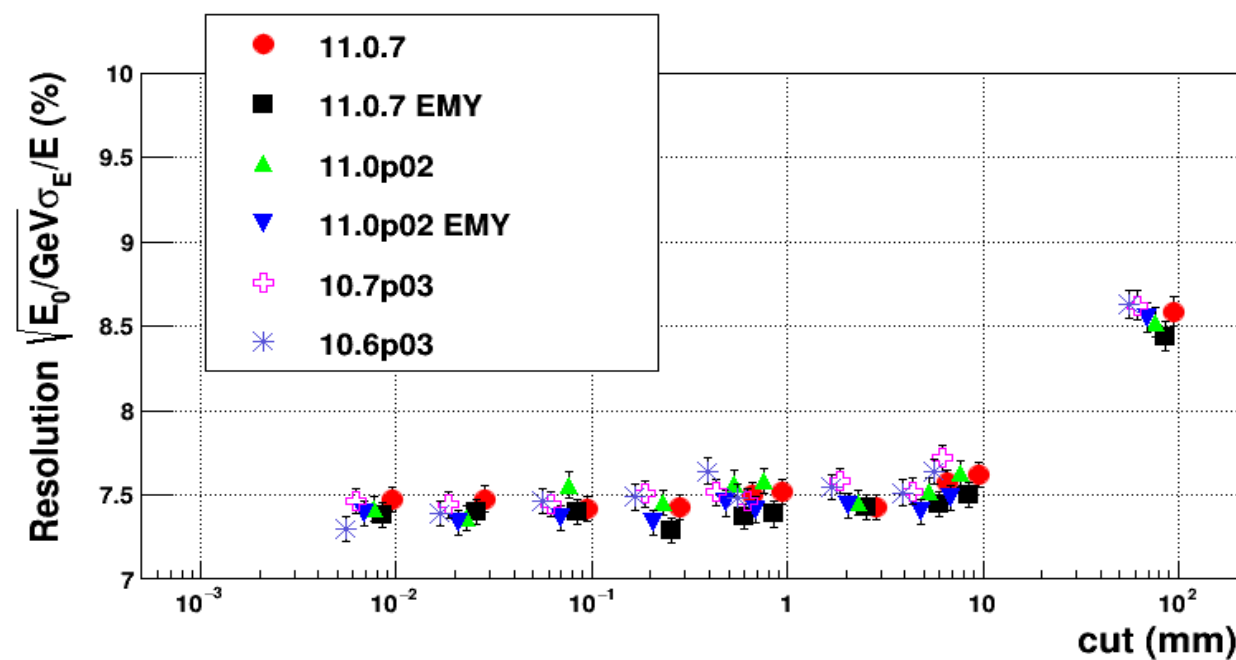
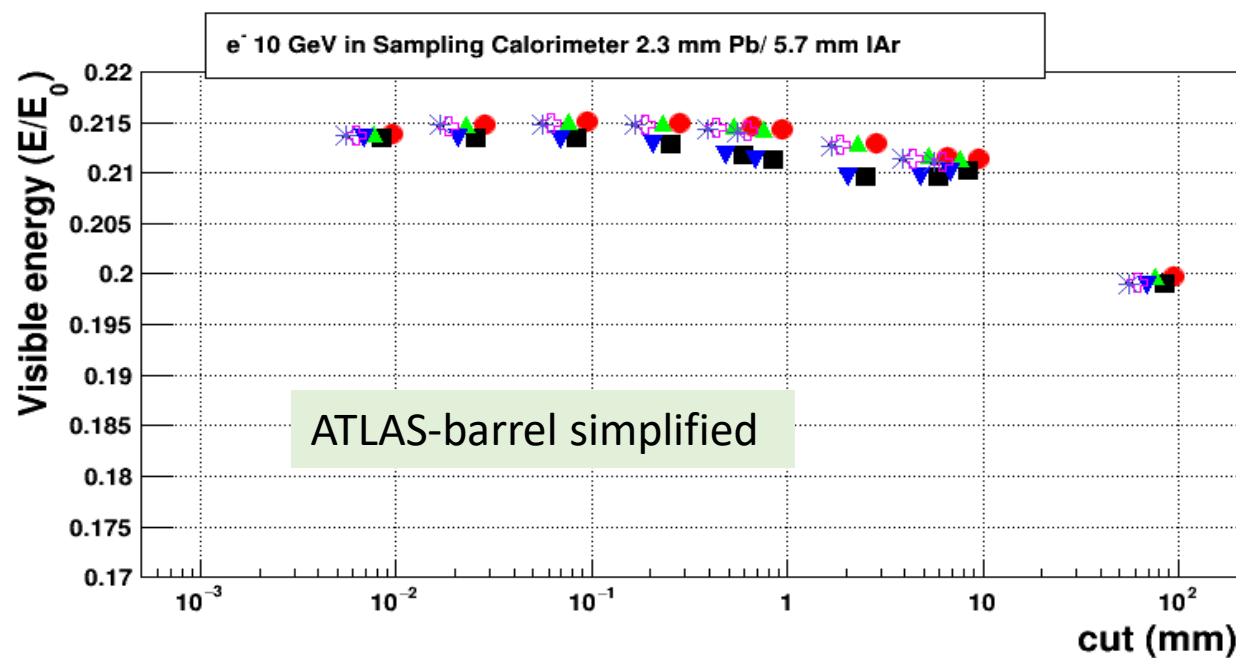




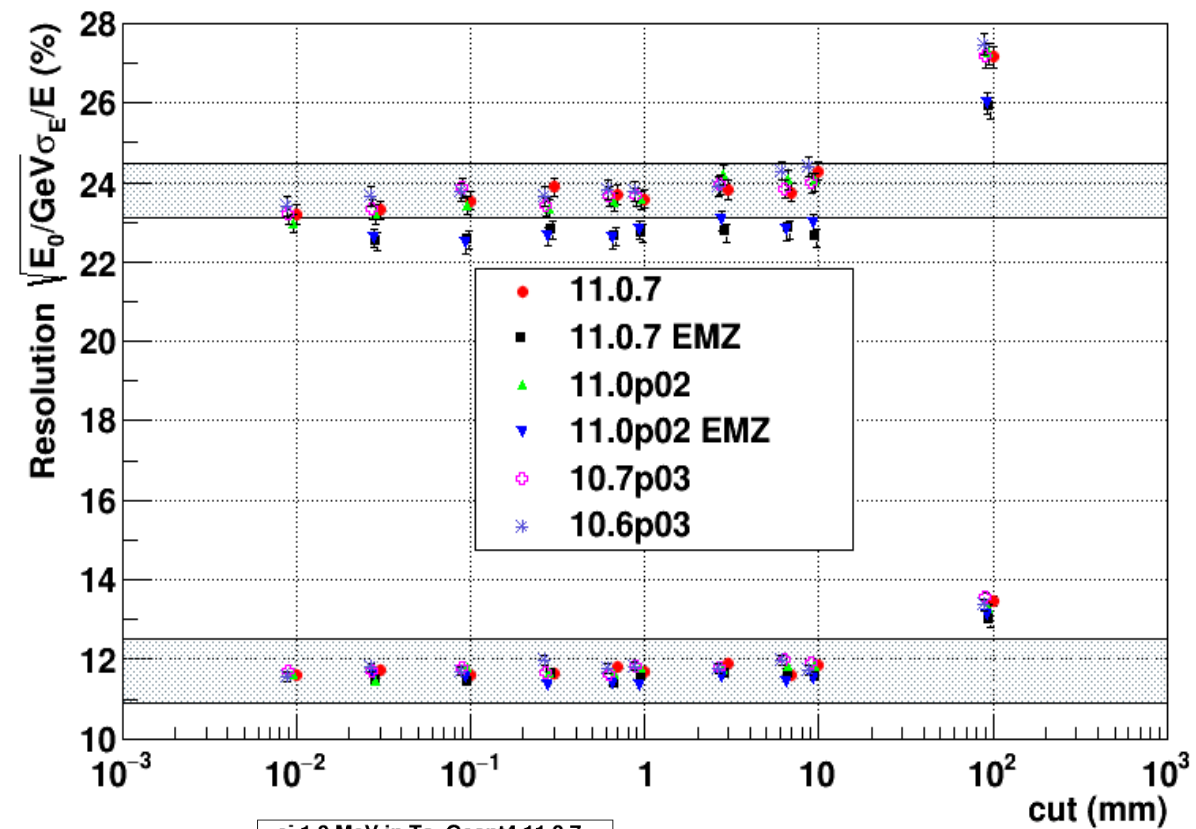
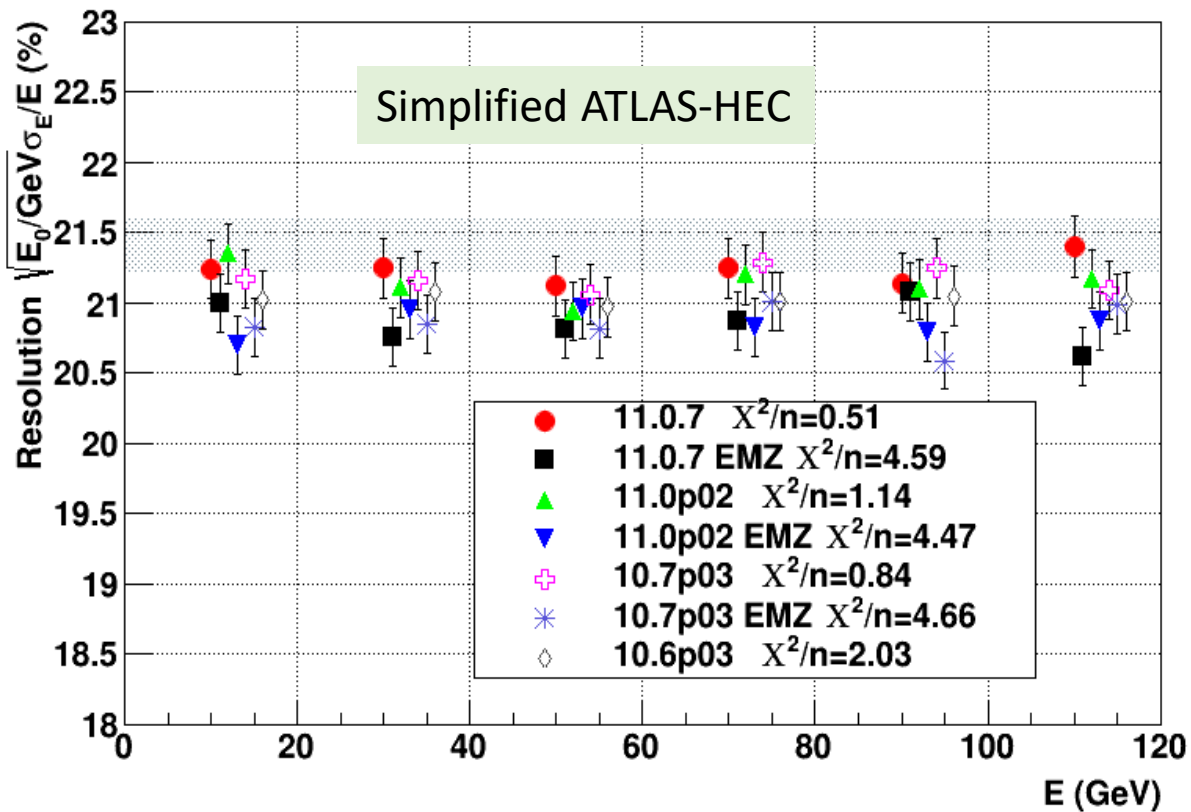
# Lindhard-Sorensen ion ionization model

- G4LindhardSorensenIonModel is a combined models for the full energy range
  - Lindhard-Sorensen model above (*J. Lindhard & A.H. Sorensen, Phys. Rev. A 53 (1996) 2443-2455*)
  - Data are shared between threads, optimization of data access
    - Initialisation before the run and lazy initialization during the run
  - Is significantly faster than the old G4ParametrizedIonModel and includes extended data
    - ICRU73 and ICRU90 data at low energy below 2 MeV/amu
    - Model is working and reproducing ion Bragg peak

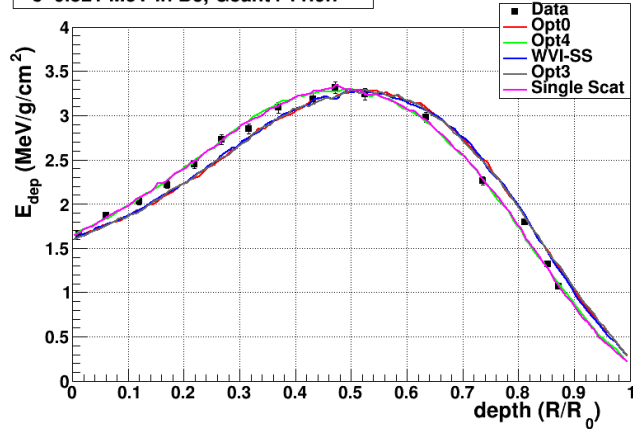




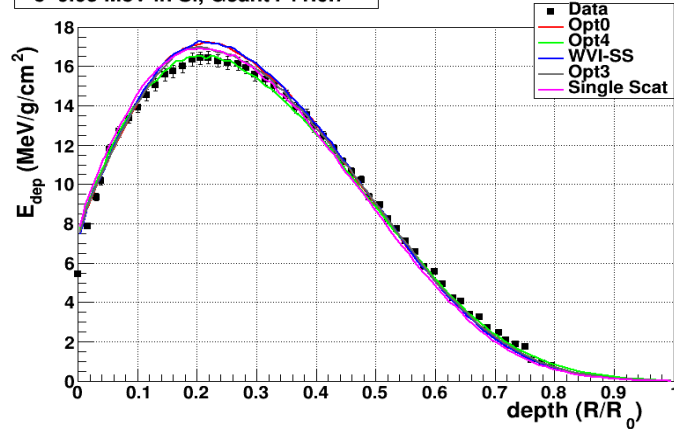
CMS ECAL simplified



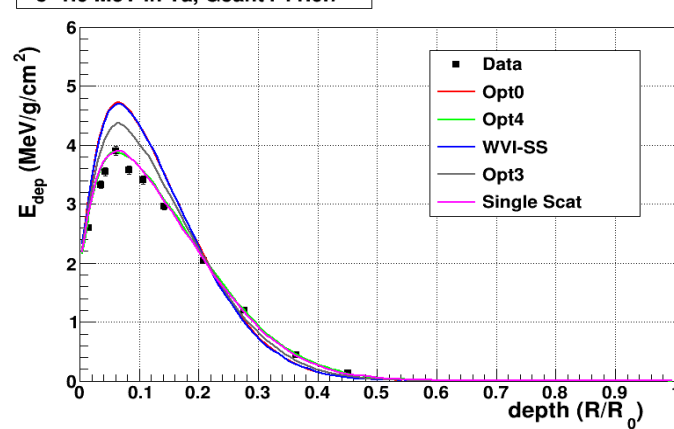
$e^-$  0.521 MeV in Be, Geant4 11.0.7



$e^-$  0.05 MeV in Si, Geant4 11.0.7

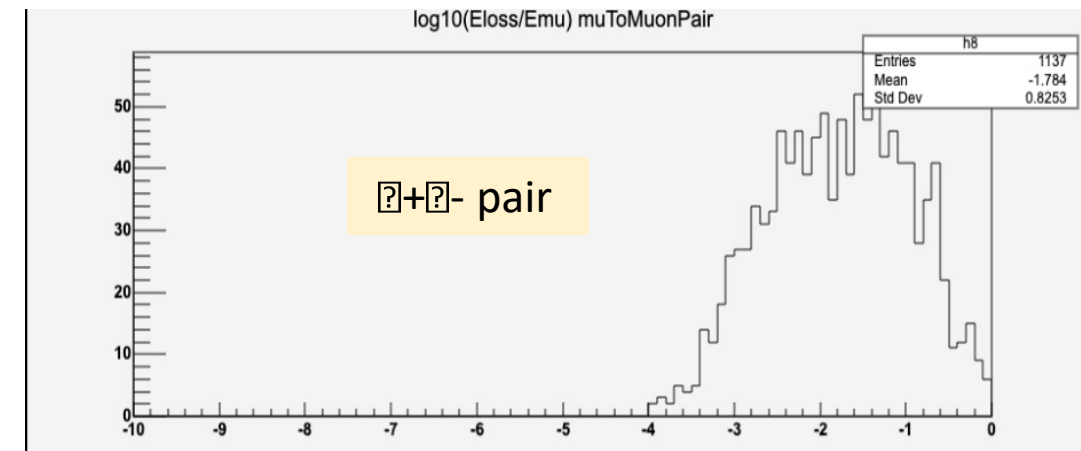
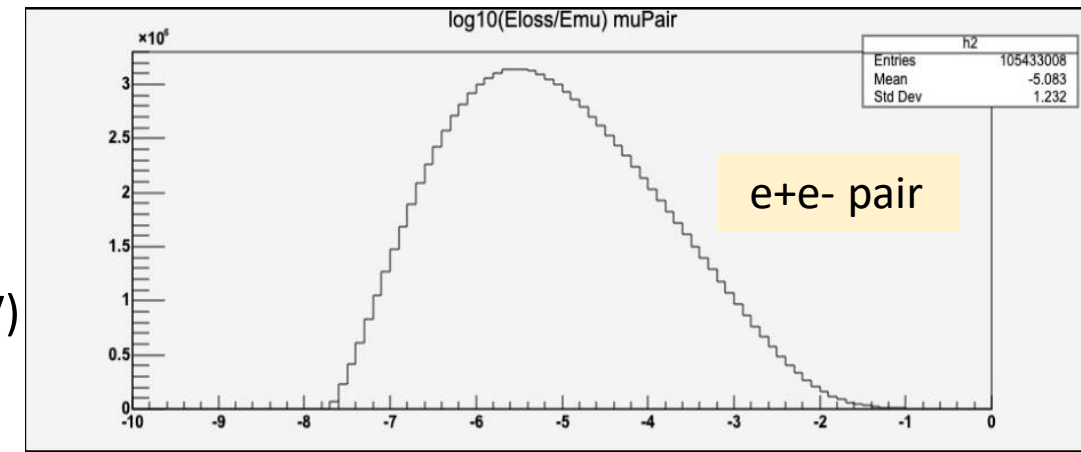


$e^-$  1.0 MeV in Ta, Geant4 11.0.7



# Updates in muons processes/models electromagnetic/muons

- Review was done of all processes
  - Linear interpolation of tables are used for smooth cross sections
- Reduced low-energy limits
  - **G4MuBetheBlochModel** – down to 0.2 MeV (was 100 MeV)
  - **G4MuBremsstrahlungModel** – down to 100 MeV (was 1 GeV)
  - **G4MuPairProductionModel** – down to 850 MeV (was 1 GeV)
- New process/model (CERN summer student S. Yajaman)
  - **G4MuonToMuonPairProduction**
  - **G4MuonToMuonPairProductionModel**
  - Cross section is  $\sim 10^{-5}$  of  $e^+e^-$  pair production
  - Spectrum of muons is much harder
    - High energy muon pair may be produced by energetic muon is a calorimeter
- Applied cling-tidy (D. Sawkey)



# Updates in DNA processes/models

## electromagnetic/dna

- DNA sub-library dependences are resolved (H. Tran)
- G4Pow, G4Log, G4Exp are used in DNA models (P. Dondero)
- Many updates for chemistry models (H. Tran)
- Molecular dna: an extended example in Geant4 11.1 (H. Tran)
  - Full chain DNA example
  - Simulation of physics, physics-chemistry and chemistry processes in DNA geometries
- Extension proton transport to 300 MeV (M. A. Cortes-Girardo)
  - G4DNARPWBAExcitationModel, G4DNARPWBAIonisationModel

# New approaches for EM physics

- **G4GammaGeneralProcess**
  - Adopted both by ATLAS and CMS
  - Is current Geant4 default
  - fixed problem of sampling of the Compton scattering below 150 keV
  - Use spline interpolation of x-section tables below 150 keV and above 100 MeV
- **G4TransportationWithMSC (J. Hahnfeld)**
  - New combined process
  - User may enable this process via UI command and/or C++ interface
  - Cannot work with G4CoupleTransportation
- **G4HepEM (J. Hahnfeld, B. Morgan, M. Novak)**
  - Alternative EM physics library
- **Details in Jonas Hahnfeld talk**

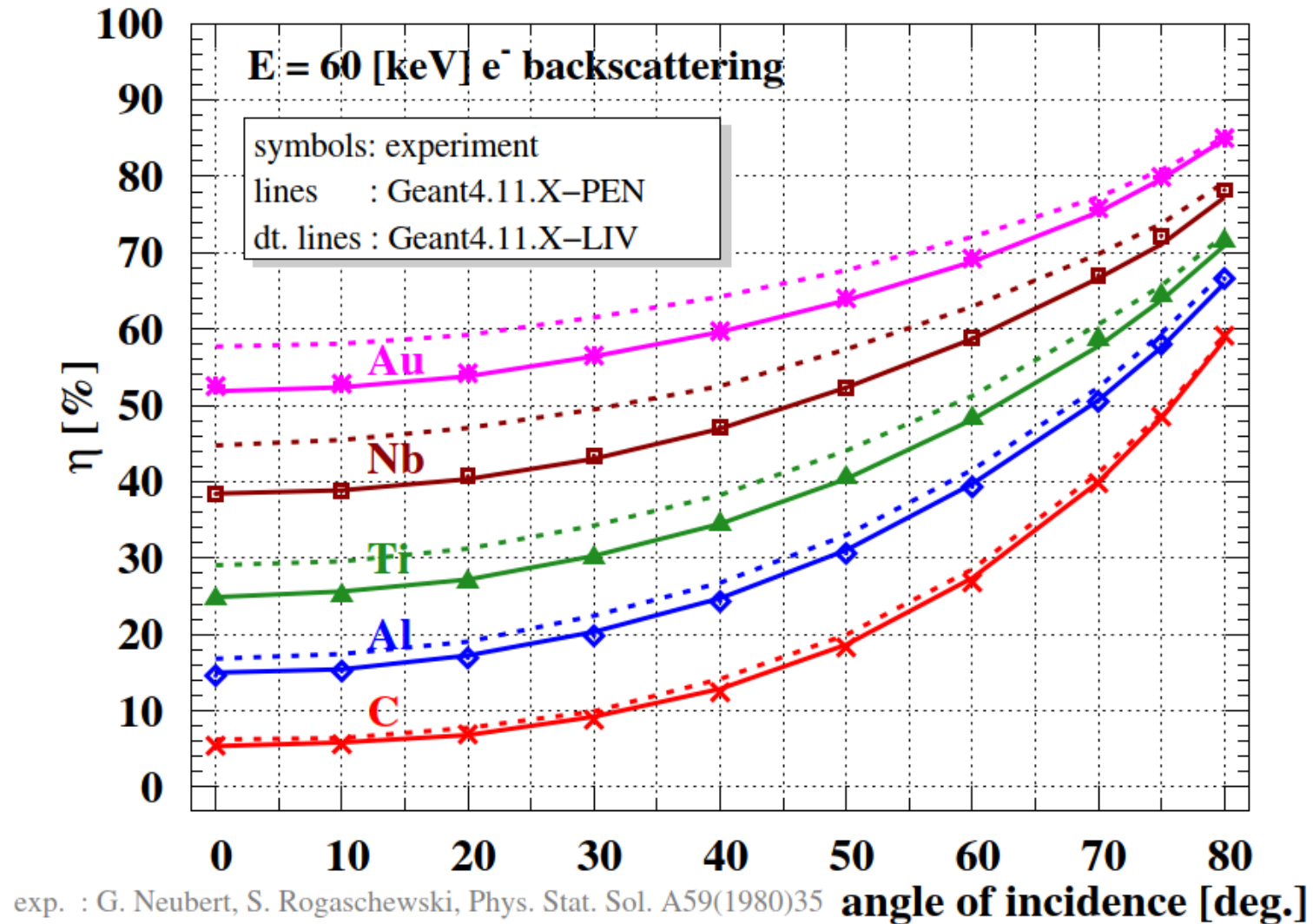
# EM Physics Lists

# Modifications in EM physics for 11.1

- **G4EmStandardPhysics**
  - Gamma general process
  - G4UrbanFluctuation
- **G4EmStandardPhysics\_option1**
  - G4TransportationWithMsc
- **G4EmStandardPhysics\_option3**
  - Gamma general process
  - G4UrbanFluctuation
  - G4LinhardSorensen ion ionisation model
  - MSC RangeFactor=0.03
- **G4EmStandardPhysics\_option4**
  - Gamma general process
  - Penelope (instead of Livermore) ionisation for e- below 100 keV
  - G4UrbanFluctuation
  - G4LinhardSorensen ion ionisation model
- **G4EmLivermorePhysics**
  - G4UrbanFluctuation
  - G4LinhardSorensen ion ionisation model
  - EPICS2017 gamma cross sections
- **G4EmPenelopePhysics**
  - G4UrbanFluctuation
  - G4LinhardSorensen ion ionisation model



# Backscattering MC/data by M. Novak



# Extended utility classes to build EM physics

- **G4EmBuilder**
  - Added instantiation of G4TransportationWithMsc
- **G4EmModelActivator**
  - Fixed instantiation of PAI model per region
  - Fixed light ion instantiation per region
- **All G4EmDNAPhysics\_X are inheriting of G4EmDNAPhysics**
  - Common method **ConstructParticle()**
  - **ConstructProcess()** is now implemented via **G4EmDNABuilder** utility
    - Set of parameters for G4EmDNABuilder is different for each X
    - Classes become much more compact; maintenance become significantly easier
  - Standard upper energy limit 100 MeV
- **G4EmDNAPhysicsActivator**
  - Provides combined standard/DNA physics configuration
  - **G4EmDNABuilder** utility are used in the same way as inside **G4EmDNAPhysics\_X**

# Summary

- Active developments were carried out in different EM physics domains
  - Improved code quality
  - Improvement of CPU efficiency for HEP applications
  - New model of muon pair production by muons
  - Addition of new models for DNA physics
  - Improved Physics List configurations
- Recommendation for users
  - Due to COVID and other circumstances Geant4 11.0p03 or 11.1beta should be used for EM physics instead of earlier versions of 11.X release series
- Geant4 11.1 is in a good shape
  - EM developments for HEP are practically completed
  - Before the release we should address existing bug-reports and user complains