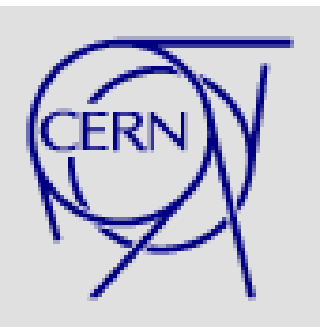


Status of Standard EM Libraries

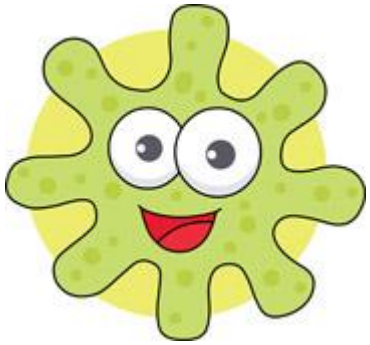
V. Ivanchenko CERN & Tomsk State University, Russia

For Geant4 standard EM working group

23th Geant4 Collaboration Workshop

Lund (Sweden) - August 27-31, 2018

Outline



- EM physics in Geant4 10.4 patch1 and patch2
- EM model developments for Geant4 10.5
- Highlights on EM physics in Geant4 10.5beta
- Recent updates of infrastructure
- Prospects and plans

EM physics in Geant4 10.4 patch1 and patch2

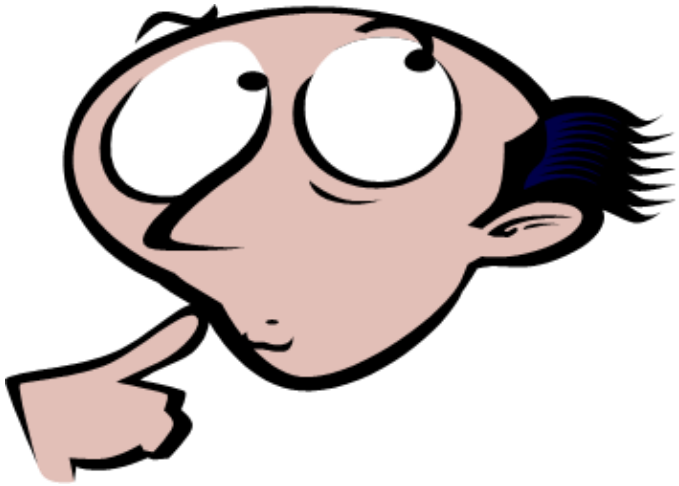
- Re-enable user-defined material properties in G4MaterialPropertiesTable and G4MaterialPropertiesIndex (D.Sawkey)
  - Addressing problem report #2030 from LHCb.
- Fixed G4PairProductionRelModel (problem #2017) (M.Novak)
  - fixed misuse of G4Pow (A13(..) should be used instead of Z13(..))
  - Proper initialisation of an element cache before sampling of final state
- G4EmParametersMessenger, G4EmParameters, G4VEmProcess, G4VEnergyLossProcess (V.Ivanchenko)
  - technical fixes – consistent usage of parameters and UI commands
- G4VXTRenergyLoss: extended XTR angle limit up to 250/gamma (V.Grichine)
  - ATLAS request
- It is recommended to switch to 10.4p01 for users of EM physics
  - especially, for HEP applications

EM model developments for Geant4 10.5 (completed)

- Multiple and single scattering:
  - GS model of e+- multiple scattering – fixed initialization (M.Novak)
  - Urban msc model – new parameterizations for lateral displacement sampling algorithm (L.Urban)
  - Mott corrections are included into WentzelVI cross sections for e`+- (V.Ivanchenko)
- Bremsstrahlung:
  - Reviewed and optimized sampling algorithm (M.Novak)
- Gamma conversion:
  - Reviewed and optimized sampling algorithm (M.Novak)
  - New 5D model (D.Bernard, I.Semeniouk)
  - New interface to angular generators for pair production (V.Ivanchenko)
    - Improved final e+e- final state angles
- Coulomb correction to muon pair production at threshold (H.Burkhardt)

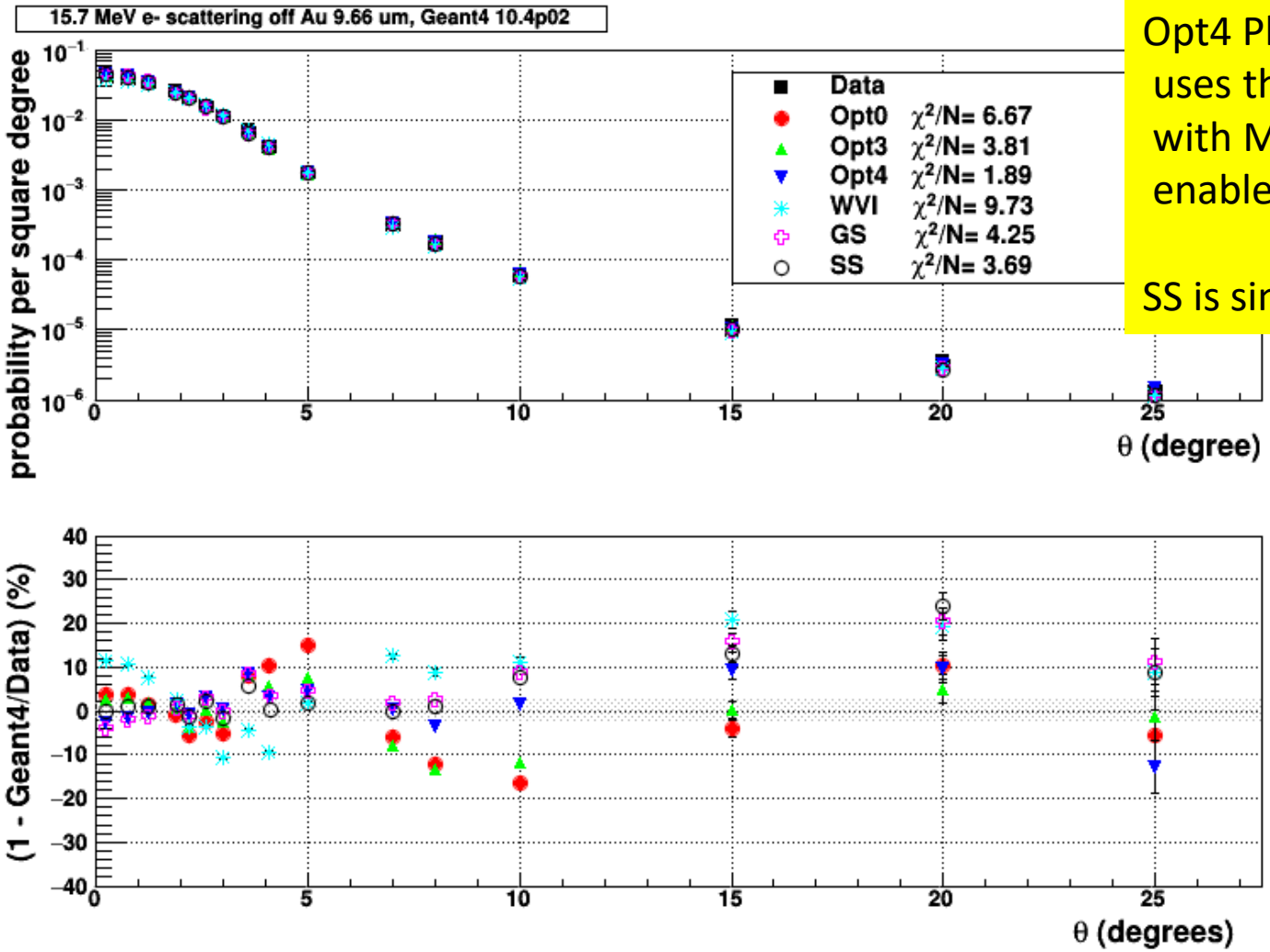
EM model developments for Geant4 10.5 (in progress)

- Gamma processes:
  - Updated parameterization of photoelectric using EPICS2017 (M.Bandieromonte)
  - 3 gamma annihilation (A.Alkin, O.Kadri, V.Ivanchenko)
  - G4GammaSuperProcess (V.Ivanchenko)
- Ion ionization:
  - G4LinhardSorensenIonModel (A.Bagulia)
  - G4AtimaEnergyLossModel and G4AtimaFluctuations (J.L.R.Sanchez)
- Implementation of ICRU90 stopping power data (GATE group)
  - Accurate data for limited number of materials



Highlights on EM physics in Geant4 10.5beta

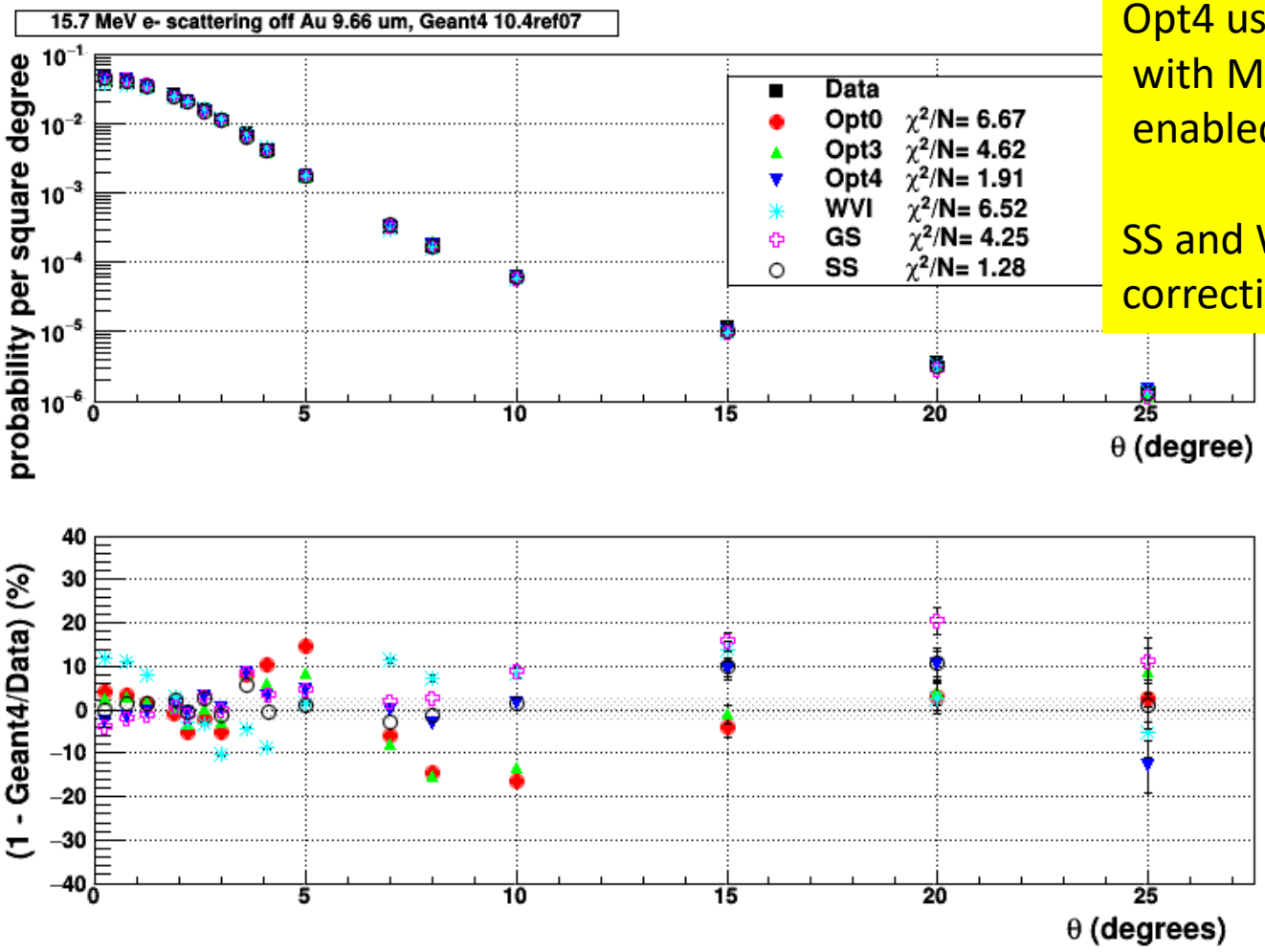
Hanson data for electron scattering off Gold target (*Phys. Rev.* **84**, 634-637, 1951)



Opt4 Physics List uses the GS model with Mott corrections enabled

SS is single scattering

Mott corrections in WentzelVI

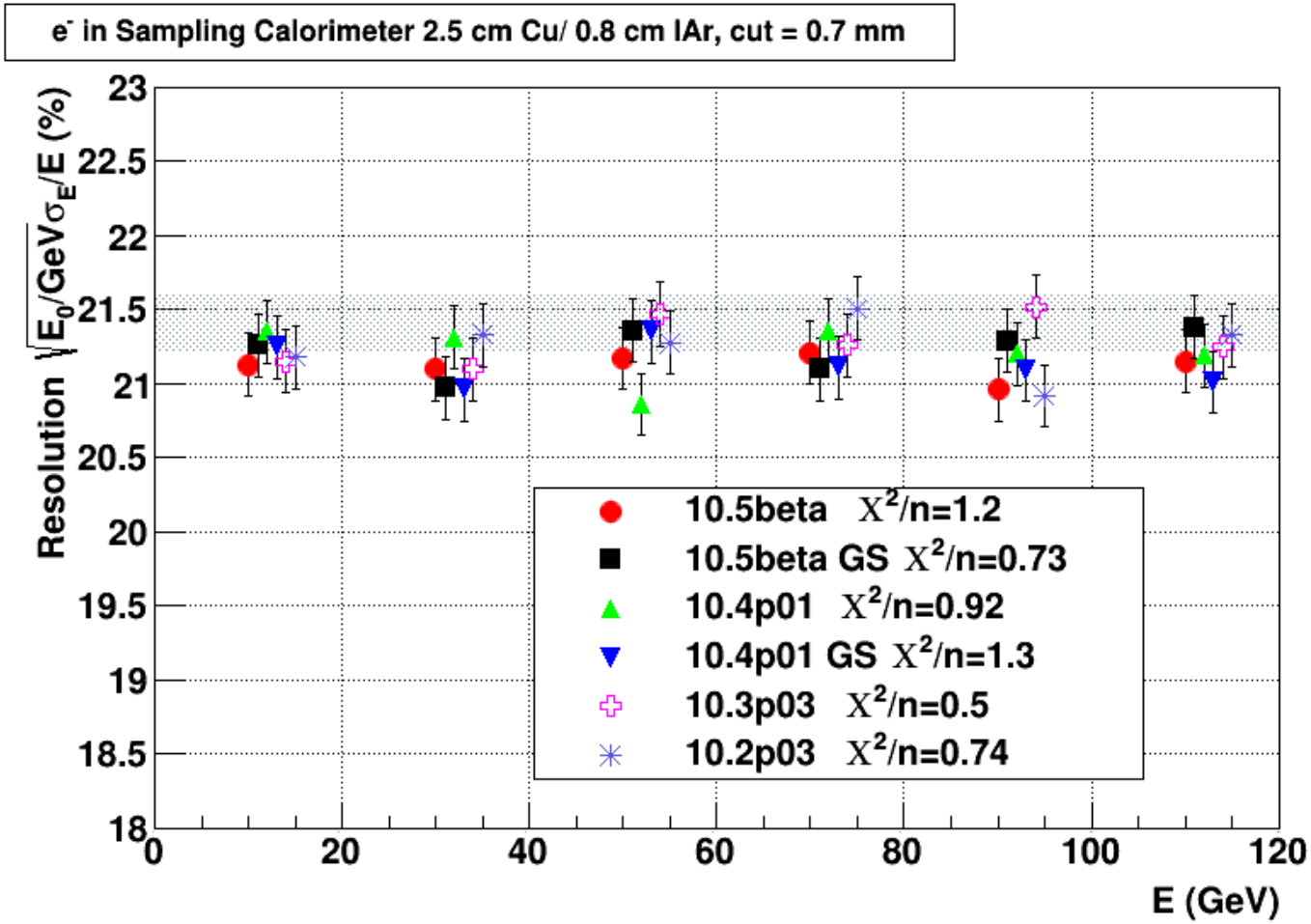


Opt4 uses GS model with Mott corrections enabled

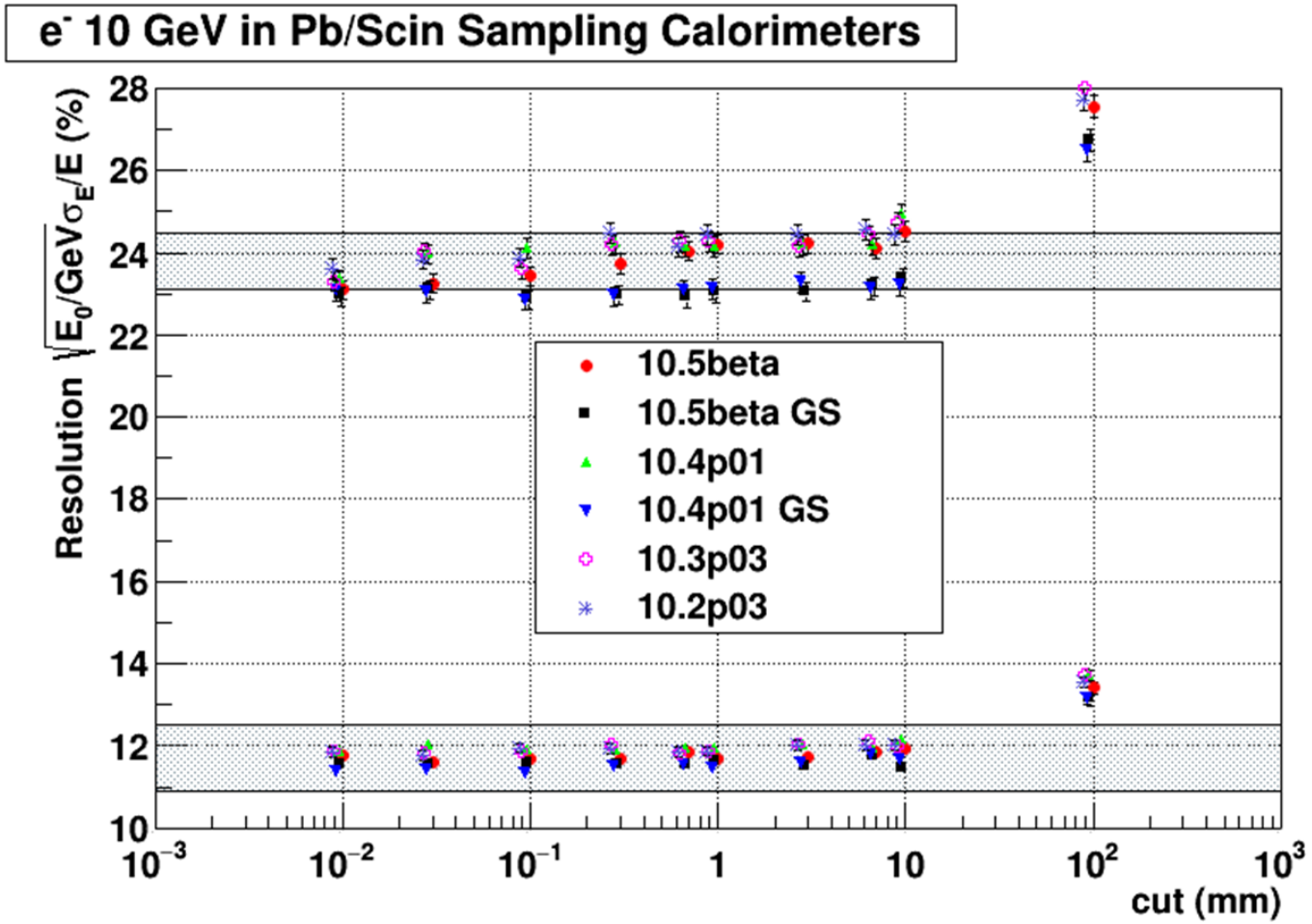
SS and WVI use Mott corrections

This is essential for sampling of high energy e+- scattering

Electron energy resolution in simplified ATLAS HEC as a function of beam energy for different Geant4 versions and EM physics

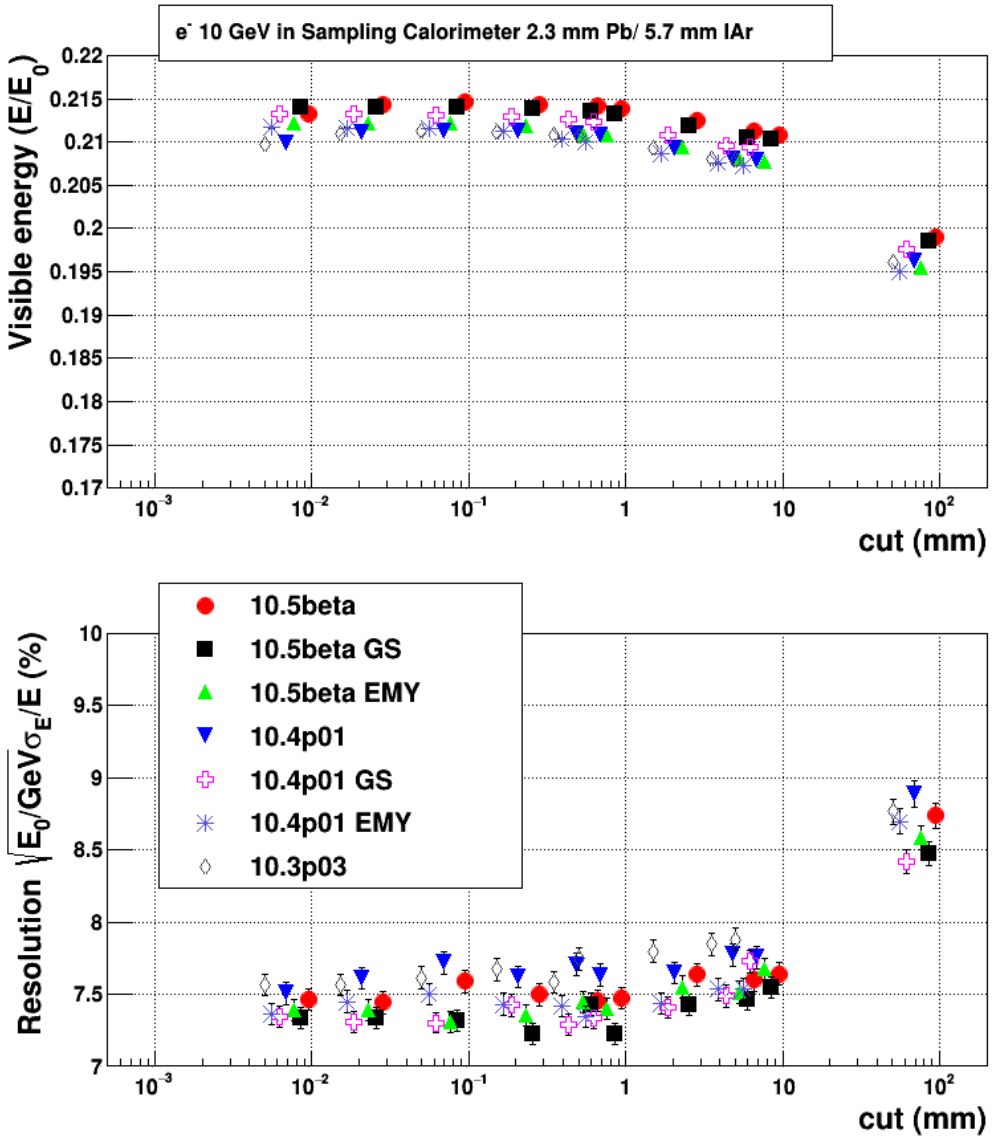


Electron energy resolution in simplified Pb/Sc calorimeters of two configurations as a function of the cut in range for different Geant4 versions and EM physics configurations



Cut dependence of ATLAS type calorimeter response

- Response increased by 1.5%, resolution decreased by 2%
  - Mainly due to improvement of lateral displacement sampling in the Urban msc model
  - Opt0 and GS become closer to each other
- We need to decide soon if we step back to 10.4 with the Urban model



RECENT UPDATES OF INFRASTRUCTURE

Configuration of EM physics

- A set of EM physics constructors are provided together with each recent Geant4 version
  - The default (Opt0) EM physics is optimized for use in HEP
  - There are variants Opt1 (EMV) and Opt2 (EMY) with simplified multiple scattering and other options
  - The alternative Opt4 (EMZ) physics is combination of the most accurate EM models
    - It is substantially slower than the default
    - Is recommended for R&D and detector performance studies
- On top of any EM physics configuration it is possible to customize EM parameters via UI commands and C++ interface
  - G4EmParameters class may be called
  - EM physics configuration and PAI ionization model may be defined for or more G4Region(s)
    - This feature is used by ALICE and CMS

EM Physics List approach

- We are trying keep stable
  - Opt0 – for ATLAS
  - Opt1 – for CMS
  - Livermore
  - Penelope
  - Opt3 – standard models
- Improved models are included in
  - Opt4 – our recommendation for the most accurate physics
  - GS – Opt0 with GS msc for e+-
  - WVI – WentzelVI model
  - Lowenergy - 5D-pair production, LS ion ionization
  - SS . Single scattering

EM testing suite

- About 60 EM use cases
  - examples/electromagnetic, tests, validation/electromagnetic
  - Validated calorimeter response, show shape, forward and backward scattering, tracking devices
  - Applied regression to previous version or comparisons with the data
  - Data/MC plots and Chi2 analysis of results
  - https://test-geant4-tools.web.cern.ch/test-geant4-tools/emtesting/
- Recent developments (A.Bagulya)
  - Build of all relevant tests is performed with cmake and may be done as locally and centrally with other tests
  - Run may be done locally or submitted to lxbatch
    - ~24h at lxbatch for full test
  - Internal analysis used for run all tests (no ROOT for run)
  - ROOT6 is used by separate scripts at the second stage
  - Results are accessed via web from afs and eos

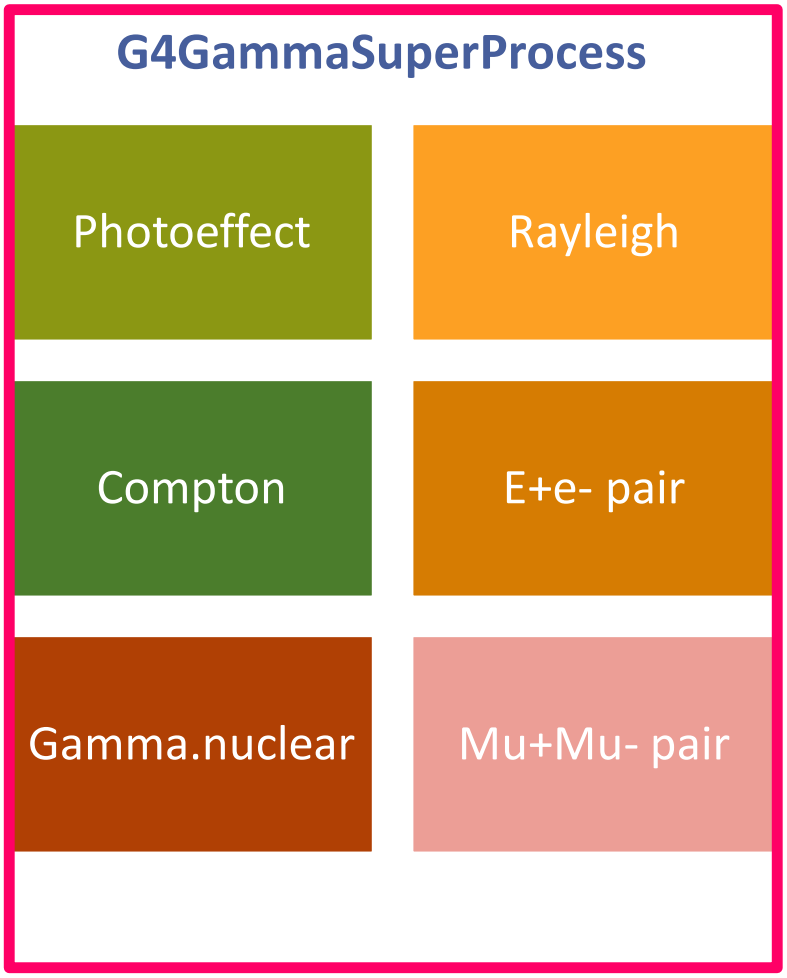
EM testing suite comments

- Testing suite is focused not on publication of a particular test but on run for each reference tag of Geant4
- Current EM testing suite mainly focused on LHC and other HEP applications
  - Other applications use the same models and Physics Lists
- If we want increasing statistics and number of use cases we should run testing suite at grid
  - We have prepared testing suite software for run at grid
  - Geant4 Val is proofed to be able incorporate EM tests
- To control aspects of EM physics, which are not tested by the current EM testing suite new tests should be added
  - There are requirements to a test, which is included in the suite
  - Build, run, analysis should fit to existing scheme
- In order to test important medical applications extra work from medical physics community is needed

Computing performance of EM physics

- We use only shared data between threads
  - Normally data filled at initialization by master thread
  - Possible to make initialization if the master thread does not exist
- M. Novak make substantial efforts to speedup sampling of final states
  - Gamma conversion
  - Bremsstrahlung
  - He propose update G4DynamicParticle adding G4Log(E)
- Another R&D recently added is “Super” process
  - G4GammaSuperProcess is implemented
  - G4ElectronSuperProcess is not yet
  - The main idea is to reduce number of computations at a step
  - Together with M.Novak innovations may expect substantial speed-up

Details of implementation



- SteppingManager see only 1 physics process
  - Only 1 mean free path
  - Plus transportation
- User see all processes as before
  - /tracking/verbose unchaged
- Enabled via UI command
  - Implemented for Opt0, Opt1, Opt4 so far
- Reduced number of instructions
  - Advantage in CPU
  - Extra PhysicsTables shared between threads
  - Final numbers on CPU are not yet known

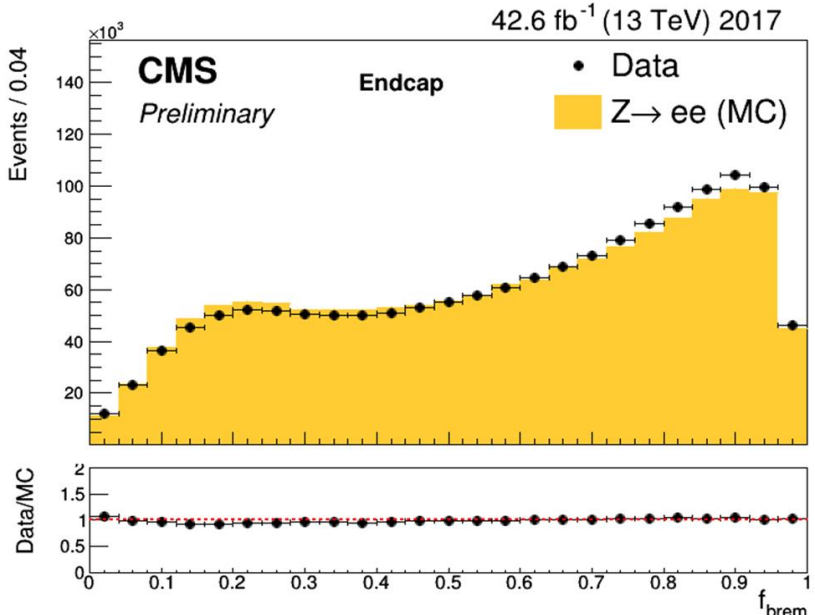
PROSPECTS AND PLANS

Main challenges for EM physics in future experiments

- LHC Run-3 and HL-LHC physics analysis
  - Will require higher statistics of simulation
  - Current EM physics modelling uncertainties may contribute to systematic uncertainty of physics observables
  - Rare EM processes with O(%) cross section and below may potentially create non-standard event patterns
- In dark matter search experiments rare EM processes are background
- For FCC design we need reliable EM simulation up to 100 TeV
  - LPM suppression for gamma conversion and bremsstrahlung
  - Nuclear recoil effects
  - Nuclear and atomic form-factors
  - Specific EM processes for study of interaction region design
- Current priorities in Geant4 EM physics developments:
  - Review and update of all models according to the best state of art
  - Focus on model extensions to implement next to leading order corrections for cross sections
  - Add sampling of second order final states
    - extra recoil atomic electron , extra gamma or e+e- pair, recoil nucleus

Current accuracy of Geant4 EM

- Since Geant4 9.6
  - Accuracy of EM cross sections, shower response and resolution O(%)
  - EM shower shapes are monitored in regression on level O(10^{-3})
- Some discrepancies observed with LHC data do not clearly indicate the level of inaccuracy of the current EM physics but may be attributed to
  - Inaccuracy of geometry descriptions of detectors
  - Inaccuracy of simulation of digitization including pileup effects
- For more details see materials of the LPCC workshop



Recent example of Run-2 simulation:

CMS-DP-2018/017: Electron and Photon performance in CMS with the full 2017 data sample

Less agreement with data for the endcap than for the barrel

The fraction of the momentum lost to bremsstrahlung measured in the tracker, defined as f_{brem} for ECAL endcap .

Current developments

- Geant4 10.4 offers several new developments
  - New options for EM model configuration
  - New GS model for e+-, improved Opt4 EM physics
  - Several form factor parameterisations
- Geant4 10.5 will offers further improvements
  - Mott corrections for e+e- scattering are available and are used for all energies by default
  - Improved lateral displacement sampling in the Urban multiple scattering
  - New 5D model for gamma conversion
    - Triplet production, accurate angular correlations, and polarization
  - 1st version of 3-gamma positron annihilation
  - New relativistic ion ionisation models

Known problems for 10.5

- For Urban model of multiple scattering we need to decide what variant of lateral displacement algorithm can be left
  - This is the key choice for LHC applications
- We need sorting out EPICS2017 data
  - Updated parametrization of photo-effect
- New models validations
  - new ion ionization models
  - 3-gamma annihilation

Prospects for 2019

- We may try to achieve maximum CPU speedup for gamma and electrons
  - All type of technical improvements
- We need to understand if it is possible to include GS model into Opt0
  - Both CPU performance and calorimeter response are of concerns
- We may include 5D and 3-gamma annihilation model to Opt4
- We need to have EM physics with gamma polarization
- Can we have better model of energy loss fluctuations?

THANK YOU