Validation and verification of Geant4 standard electromagnetic physics

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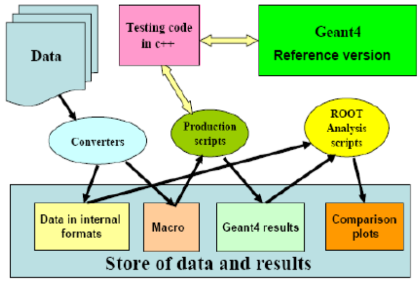
The standard electromagnetic physics packages of Geant4 are used for simulation of particle transport and HEP detector response. The requirements to the precision and stability of computations for LHC experiments are well within 1%. To keep and control long-stand quality of the package the software suites for validation and verification have been developed. In this work we describe main approaches for the validation, the structure of validation software and show examples of comparison between Geant4 simulation and the data.

Validation sequence:
- Developer private tests
- Low and medium statistic tests with control of basic numbers
- High statistic regression tests with comparison to the data
- User validation

Reference Physics Lists are used for regular validation

Validation of electromagnetic models
- Versus specific data and evaluated data sets
- Regression tests versus previous version of Geant4

General scheme of validation software



Basic medium statistic tests of Geant4 electromagnetic physics

TEST	Particle	Primary energy	Cut	Target material	Purpose
TestEm0	e^-	300 keV 10 MeV	1 mm	Ge Water	Cross sections
TestEm1	e^-	100 MeV	1 mm 0.01 mm	Al	Cross sections
TestEm2	e^-	5 GeV	1 mm	$PbWO_4$	Shower shape
TestEm3	e^-	1 GeV	1 mm	Pb/liquidAr	Sampling calorimeter
TestEm4	gamma	9 MeV	1 mm	C_6H_6	Gamma processes
TestEm5	π^+ e^- μ^+ μ^+ p	5 GeV 15.7 MeV 96.2 MeV 100 GeV 174 GeV	0.007 mm 0.01 mm 0.01 mm 1 mm 1 mm	Si Au Polyethylene Fe Al	Multiple scattering
TestEm6	gamma e^+ pbar	100 TeV 1 TeV 1 GeV	1 mm	Fe	Rare high-energy EM processes
TestEm7	p ^{12}C K^+ ^4He ^4He	160 MeV 3.5 GeV 100 MeV 0.265 keV 100 MeV	1 mm	Water Water Cu Vacuum Water	Ranges and Bragg peak for hadrons and ions
TestEm8	p	200 GeV	1 mm	Xe CH_4 C_3H_8 gas	PAI model
TestEm9	e^-	1 GeV	0.3 mm	CsI	Crystal calorimeter, cuts per G4Region
TestEm10	e^-	2 GeV	1 mm	Xe CO_2 gas	Transition radiation
TestEm11	e^-	500 keV	1 mm	Si	Depth dose profile
TestEm12	e^-	4 MeV	0.001 mm	Water	Depth dose profile
TestEm13	gamma e^-	100 keV 100 MeV	1 mm	Water	Cross sections, final states
TestEm14	gamma e^-	100 keV 100 MeV	1 mm	Water	Cross sections, final states
TestEm15	e^-	5 MeV 100 keV	1 mm	Water	Multiple scattering
TestEm16	e^-	10 GeV	1 mm	Vacuum	Synchrotron radiation
TestEm17	μ^+ π^+ p	10 TeV	1 mm	Fe	Bremsstrahlung and e^+e^- pair production by muons and hadrons
TestEm18	e^-	10 MeV	1 mm	Water	Energy loss fluctuations
GammaTherapy	e^-	50 MeV	0.1 mm	Water, Be, W	Dose profile by secondary gamma beam in the water phantom
fanoCavity	gamma	1.25 MeV	10 km	Water, Water-vapor	Test of Fano theorem
fanoCavity2	e^-	1 MeV	10 km	Water, Water-vapor	Test of Fano theorem
Pol01	gamma	10 MeV	0.1 mm	Fe	QED processes with circular polarized photon beam
monopole	monopole	100 GeV	0.7 mm	Si	Classical magnetic monopole ranges

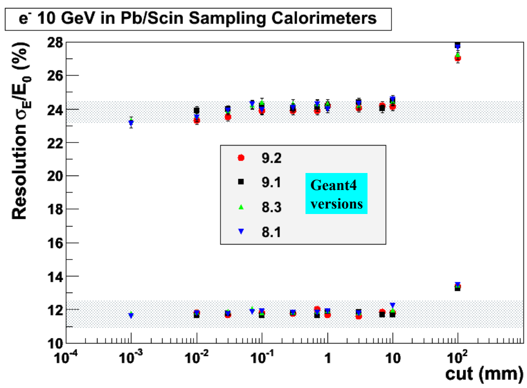
Exercised for each iteration in EM physics
About 10 minutes at SLC4
χ^2 control of the basic results versus evaluated data
Regression tests versus previous version
Included in nightly test of Geant4
Ongoing automation

High statistic tests with detailed comparison against data

TEST	Particle	Primary energy	Type of setup	Target material	Purpose
Sampling calorimeters	e^-	10 GeV 10-120 GeV 10 GeV 3 – 50 GeV	ATLAS barrel ATLAS HEC LHCb ZEUS	Pb/liquidAr Cu/liquidAr Pb/Scintillator Pb/Scintillator	Cut and energy dependences of calorimeter response and resolution
Crystal calorimeter	e^-	10 GeV	CMS ECAL	$PbWO_4$	Cut dependences of calorimeter response, resolution, and transverse shower profile
Combined calorimeter	e^-, gamma, hadrons	1-300 GeV	CMS ECAL + HCAL	$PbWO_4$, Fe, Cu, Scintillator	Shower shape
Energy deposition profile	e^-	0.3 – 1.0 MeV	Semi-infinite media	Al, Mo, Ta, TaAl, AlAuAl	Low-energy gamma and electron transport
Fano theorem	gamma e^-	1 MeV	Cavity in water filled by water vapor	Water	Low-energy gamma and electron transport
Electron scattering	e^-	1 – 16 MeV	Thin targets	Al, Au	Multiple scattering, backward scattering
Muon scattering (MuScat data)	μ^+	96.2 MeV	Thin targets	Fe, Al, CH_2, C, Be, Li, liquidH	Multiple scattering
Bragg peak	p, ^4He, ^{12}C	100-400 MeV/A	Uniform media	Water	Ranges, straggling, scattering
High energy muon penetration	μ^+	100 GeV	Uniform media	Fe	Energy loss, straggling, scattering

Exercised for each public release or major modification in EM physics
About 1 week of running in parallel at CERN lxbatch, LAPP, KEK
Regression tests versus previous version
Results are stored at CERN afs and are accessible via web

Example of validation against classical sampling calorimeter data



Energy resolution of sampling calorimeter as a function of the production thresholds (cut in range).
- hashed arias – the data for two type of calorimeters:
  - 5 mm Pb/ 5 mm scintillator
  - 12.5 mm Pb/ 2.5 mm scintillator
- points – Geant4 simulation with QGSP_BERT Physics List