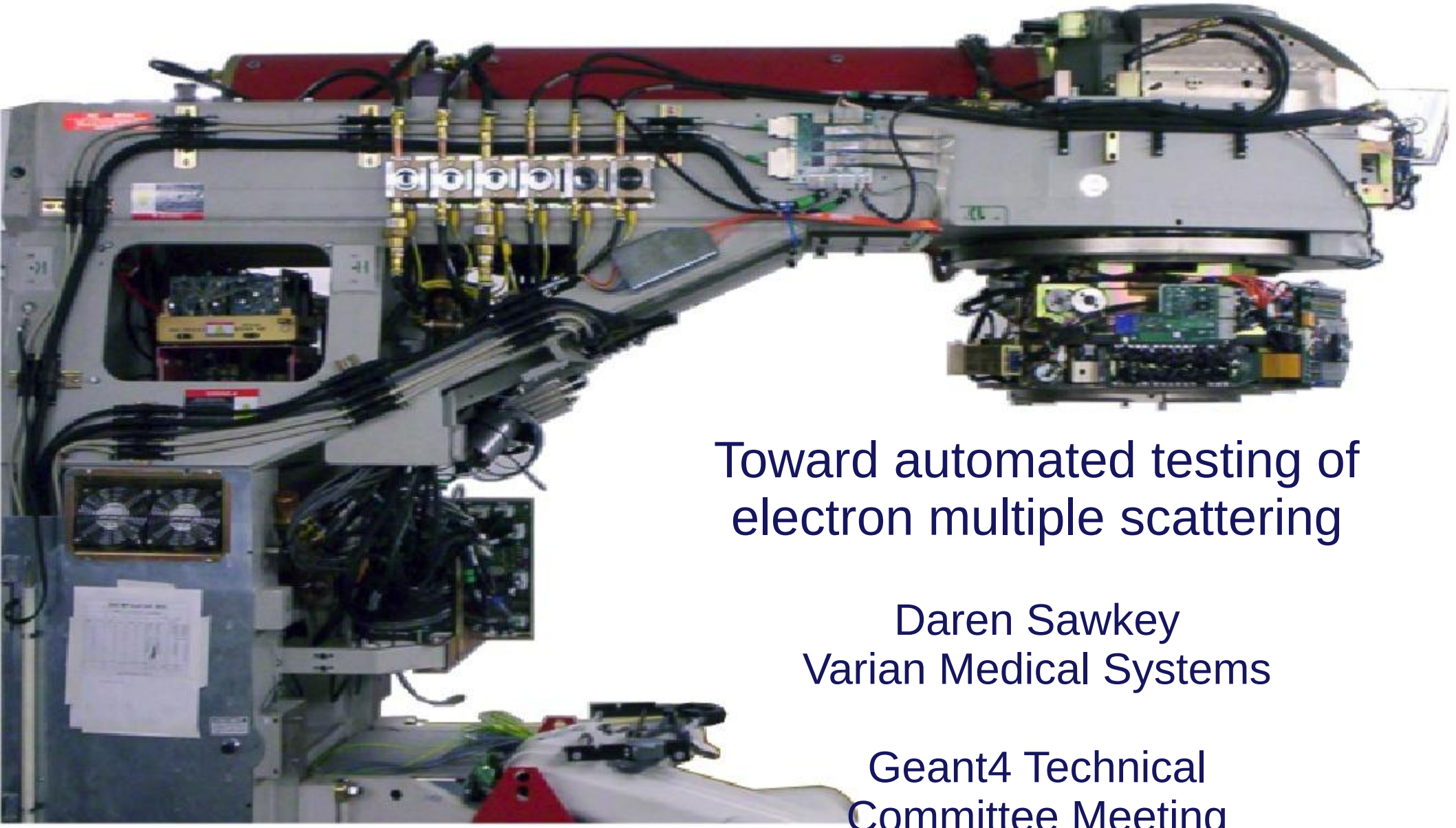


Toward automated testing of electron multiple scattering

Daren Sawkey
Varian Medical Systems

Geant4 Technical Committee Meeting

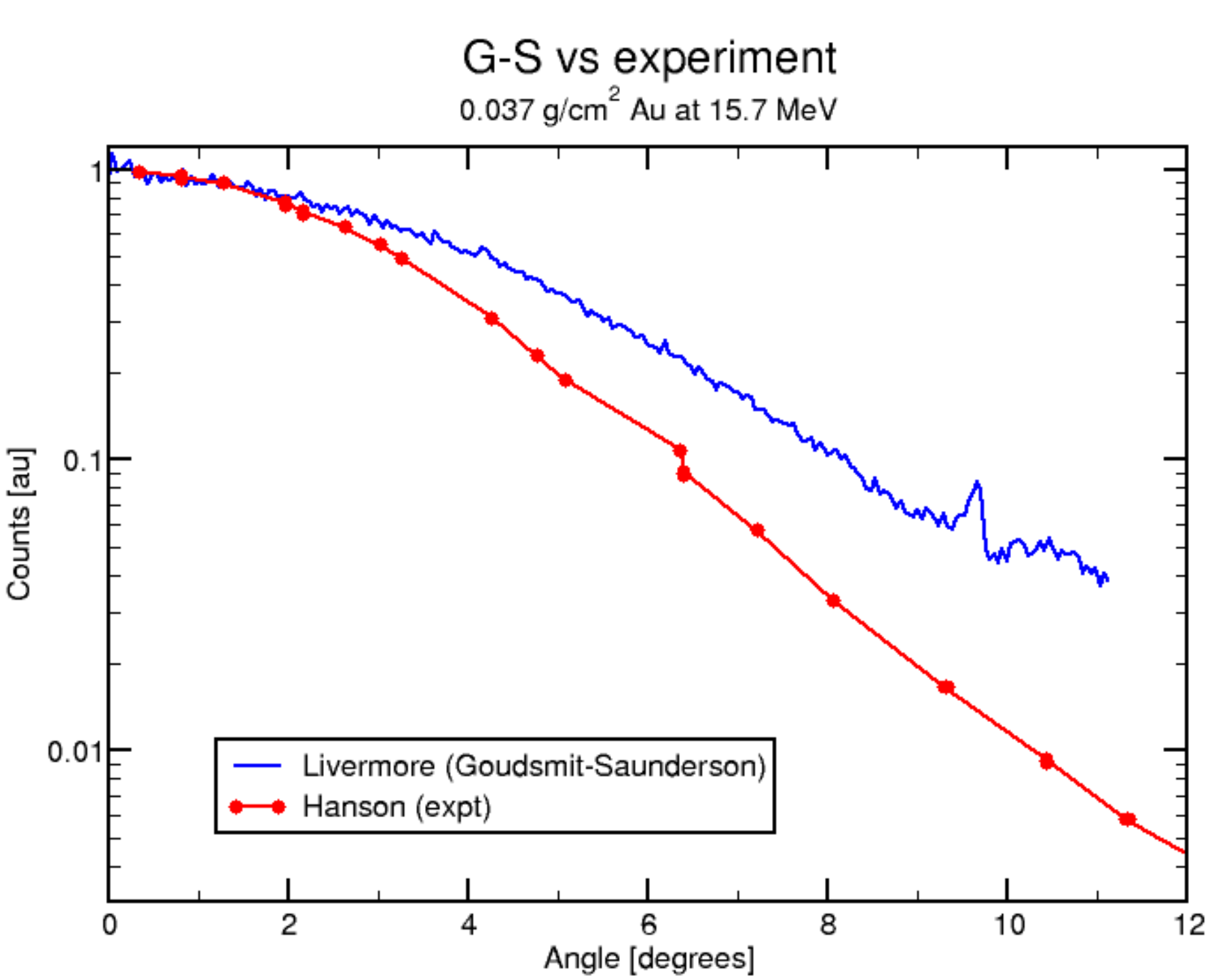
September 19, 2011

Acknowledgements:

Joseph Perl
Vladimir Ivantchenko

Varian Medical Systems

Geant4 developers

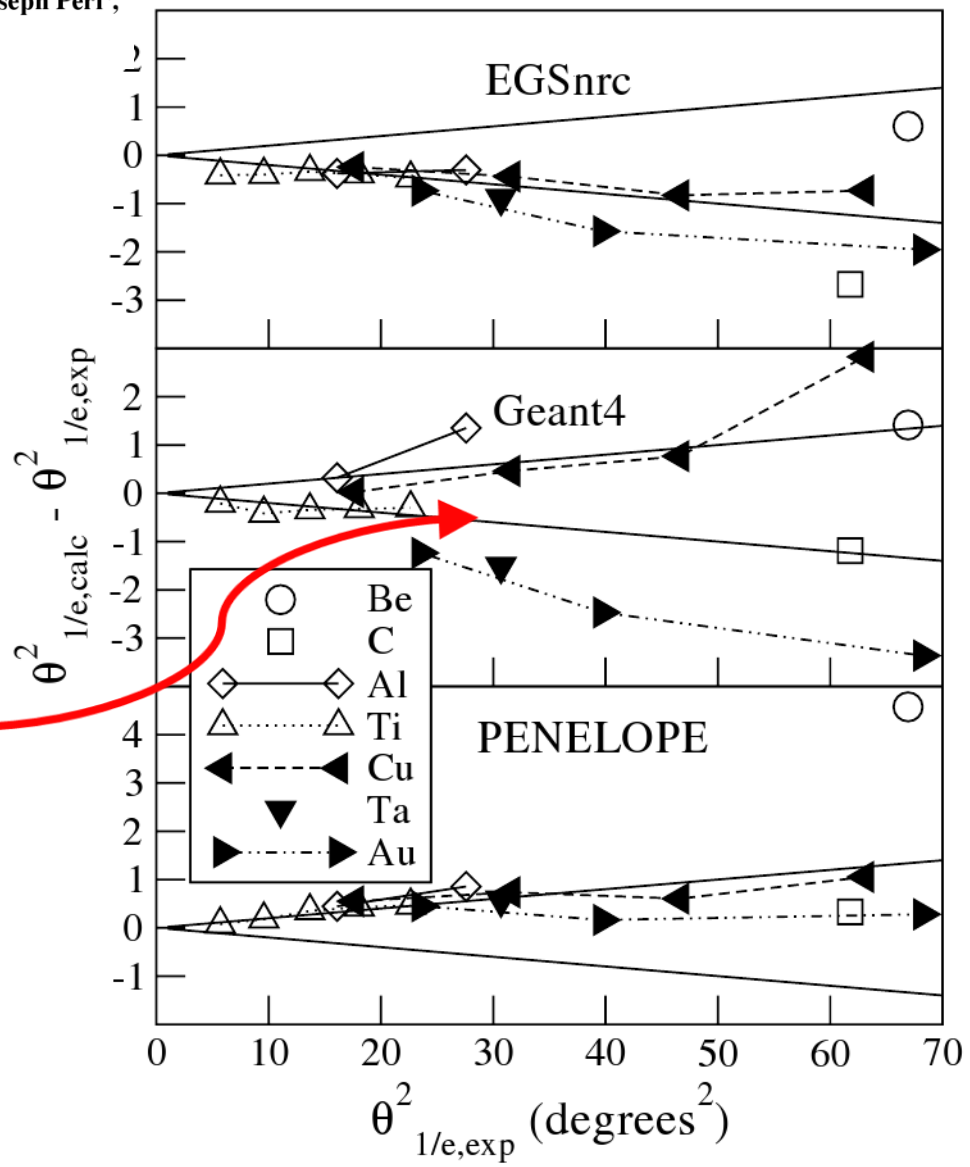

G-S vs experiment
0.037 g/cm2 Au at 15.7 MeV
Counts [au]
1
0.1
0.01
0
2
4
6
8
10
12
Angle [degrees]
Livermore (Goudsmit-Saunderson)
Hanson (expt)

The accuracy of EGSnrc, Geant4 and PENELOPE Monte Carlo systems for the simulation of electron scatter in external beam radiotherapy

Bruce A Faddegon[1], Iwan Kawrakow[2], Yuri Kubyshin[3,6], Joseph Perl[4], Josep Sempau[3] and Laszlo Urban[5]

2009
Geant4.9.2 + Δ
Option 0

Lines are 1% difference



Motivation:

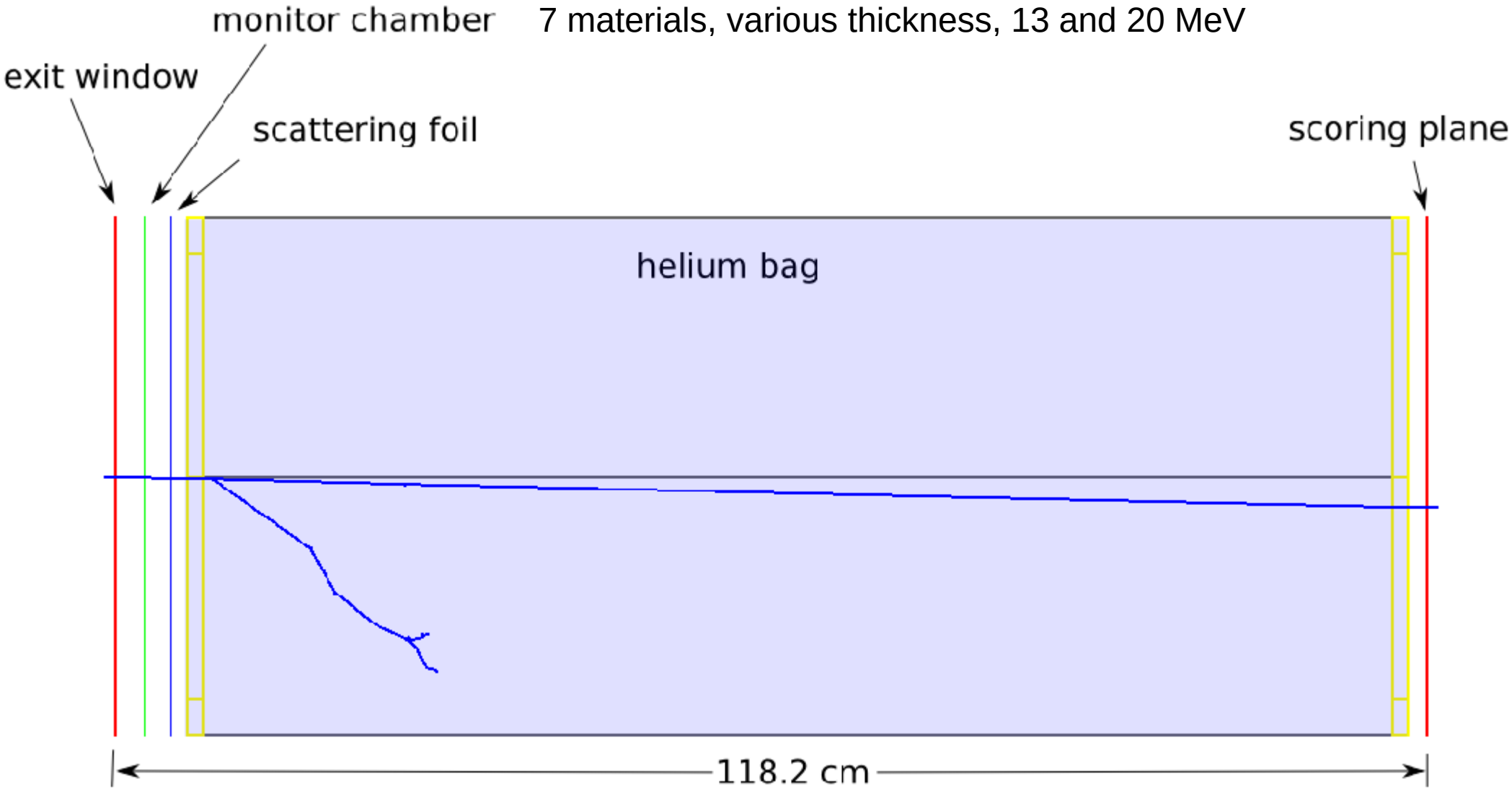
1. Avoid gross errors
2. Fine-tune msc models

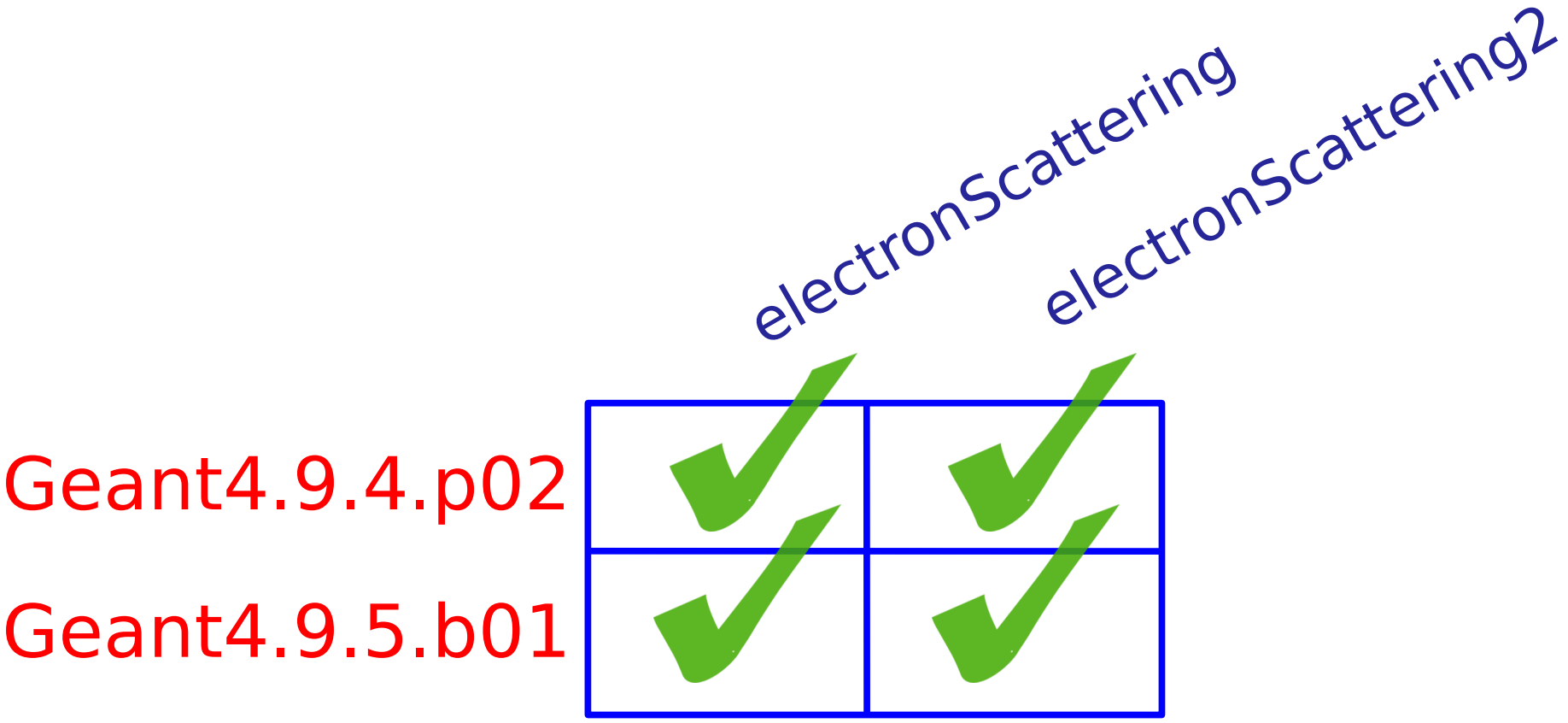
Disclaimer:

Not much physics yet

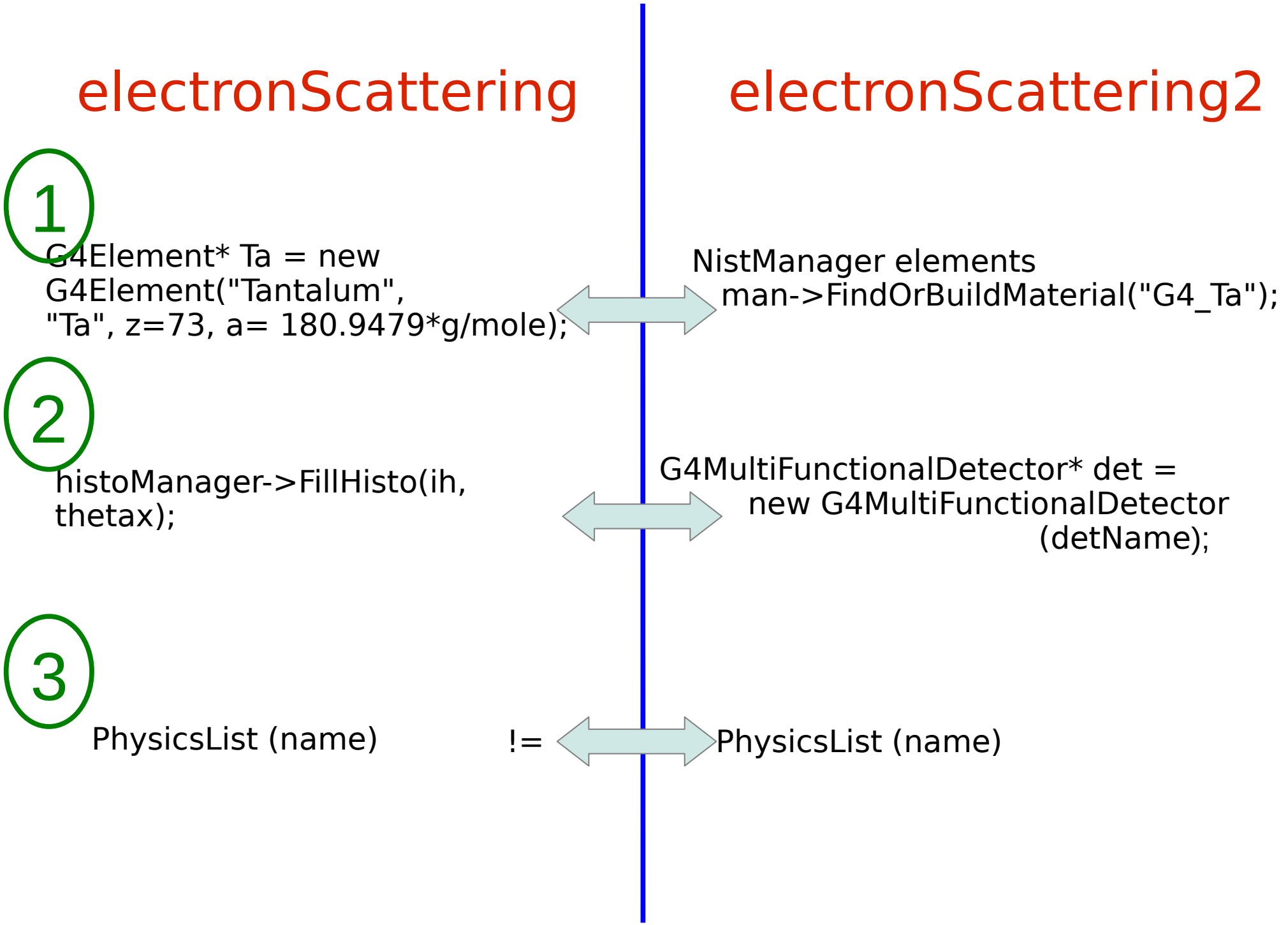
Experiment: Ross et al., Med. Phys. **35,** 4121 (2008)

7 materials, various thickness, 13 and 20 MeV





“out of the box”


electronScattering
electronScattering2
1
G4Element* Ta = new
G4Element("Tantalum",
"Ta", z=73, a= 180.9479*g/mole);
NistManager elements
man->FindOrBuildMaterial("G4_Ta");
2
histoManager->FillHisto(ih,
thetax);
G4MultiFunctionalDetector* det =
new G4MultiFunctionalDetector
(detName);
3
PhysicsList (name)
!=
PhysicsList (name)

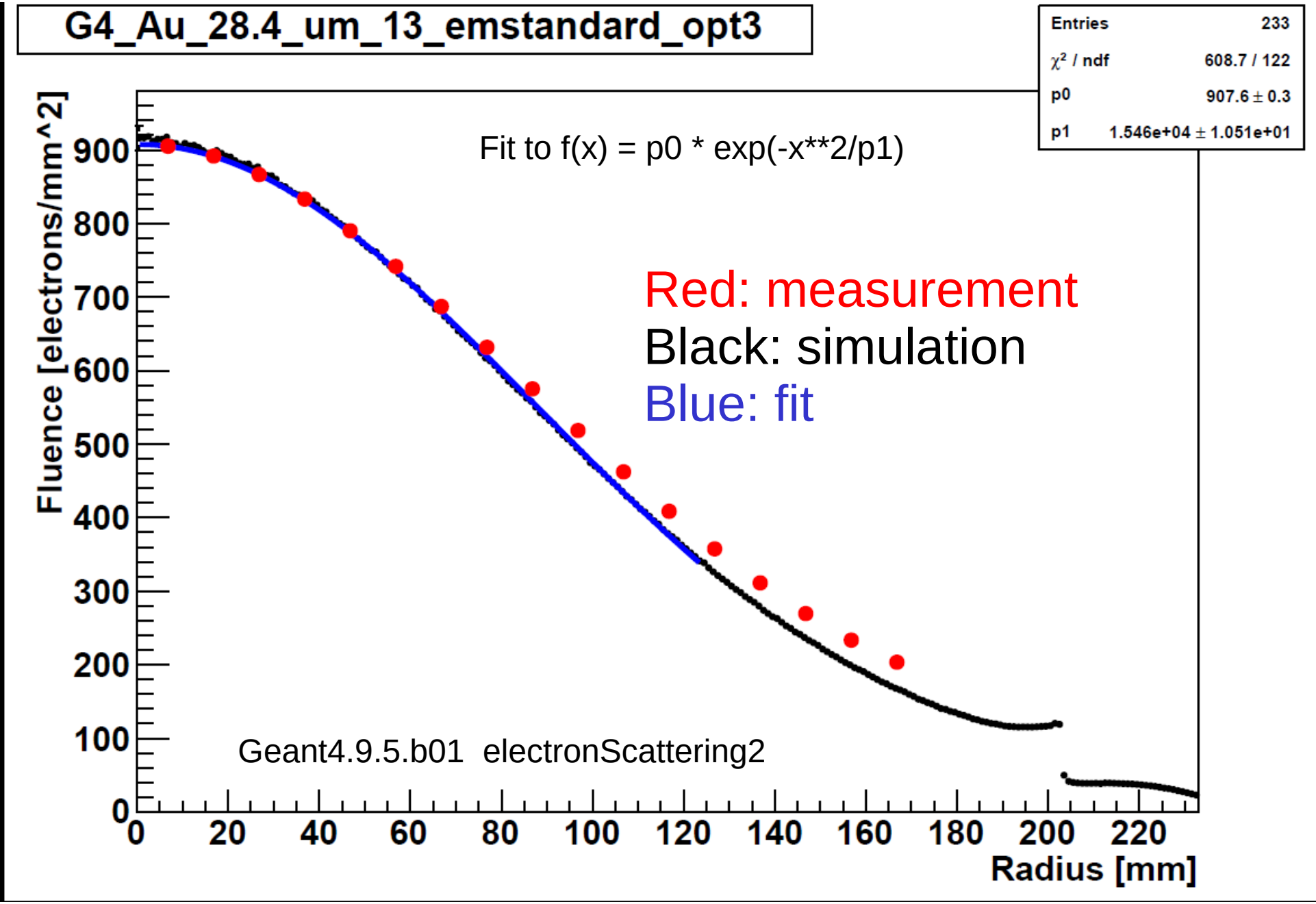
Geant4.9.5.b01 electronScattering physics lists

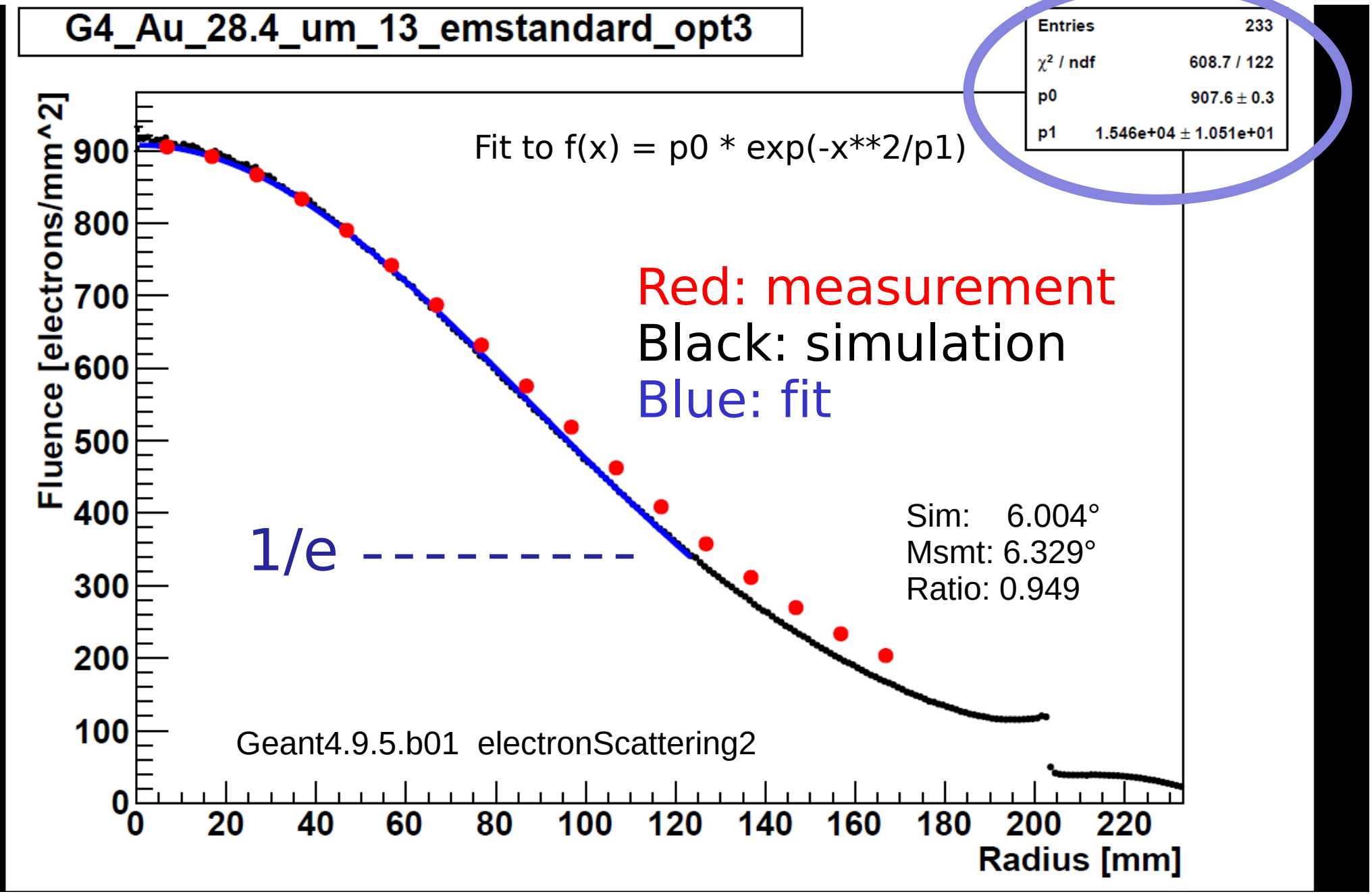
```
opt0:
      ph->RegisterProcess(new G4eMultipleScattering(), particle);
      ph->RegisterProcess(new G4eIonisation(), particle);
      ph->RegisterProcess(new G4eBremsstrahlung(), particle);

opt1:
      G4eIonisation* eioni = new G4eIonisation();
      eioni->SetStepFunction(0.8, 1.0*mm);
      G4eMultipleScattering* msc = new G4eMultipleScattering;
      msc->SetStepLimitType(fMinimal);
      ph->RegisterProcess(msc, particle);
      ph->RegisterProcess(eioni, particle);
      ph->RegisterProcess(new G4eBremsstrahlung(), particle);

opt2:
      G4eMultipleScattering* msc = new G4eMultipleScattering();
          //msc->AddEmModel(0, new G4WentzelVIModel());
          //msc->SetRangeFactor(0.04);
      msc->AddEmModel(0, new G4UrbanMscModel95());
          //     msc->AddEmModel(0, new G4GoudsmitSaundersonMscModel());
      G4eBremsstrahlung* brem = new G4eBremsstrahlung();
      G4eBremsstrahlungRelModel* br1 = new G4eBremsstrahlungRelModel();
      G4eBremsstrahlungRelModel* br2 = new G4eBremsstrahlungRelModel();
      br1->SetAngularDistribution(new G4Generator2BS());
      br2->SetAngularDistribution(new G4Generator2BS());
      brem->SetEmModel(br1,1);
      brem->SetEmModel(br2,2);
      br2->SetLowEnergyLimit(100*MeV);
      ph->RegisterProcess(msc, particle);
      ph->RegisterProcess(new G4eIonisation(), particle);
      ph->RegisterProcess(brem, particle);

opt3:
      G4eMultipleScattering* msc = new G4eMultipleScattering();
      msc->AddEmModel(0, new G4UrbanMscModel95());
      msc->SetStepLimitType(fUseDistanceToBoundary);
      G4eIonisation* eIoni = new G4eIonisation();
      eIoni->SetStepFunction(0.2, 100*um);
      ph->RegisterProcess(msc, particle);
      ph->RegisterProcess(eIoni, particle);
      ph->RegisterProcess(new G4eBremsstrahlung(), particle);
```

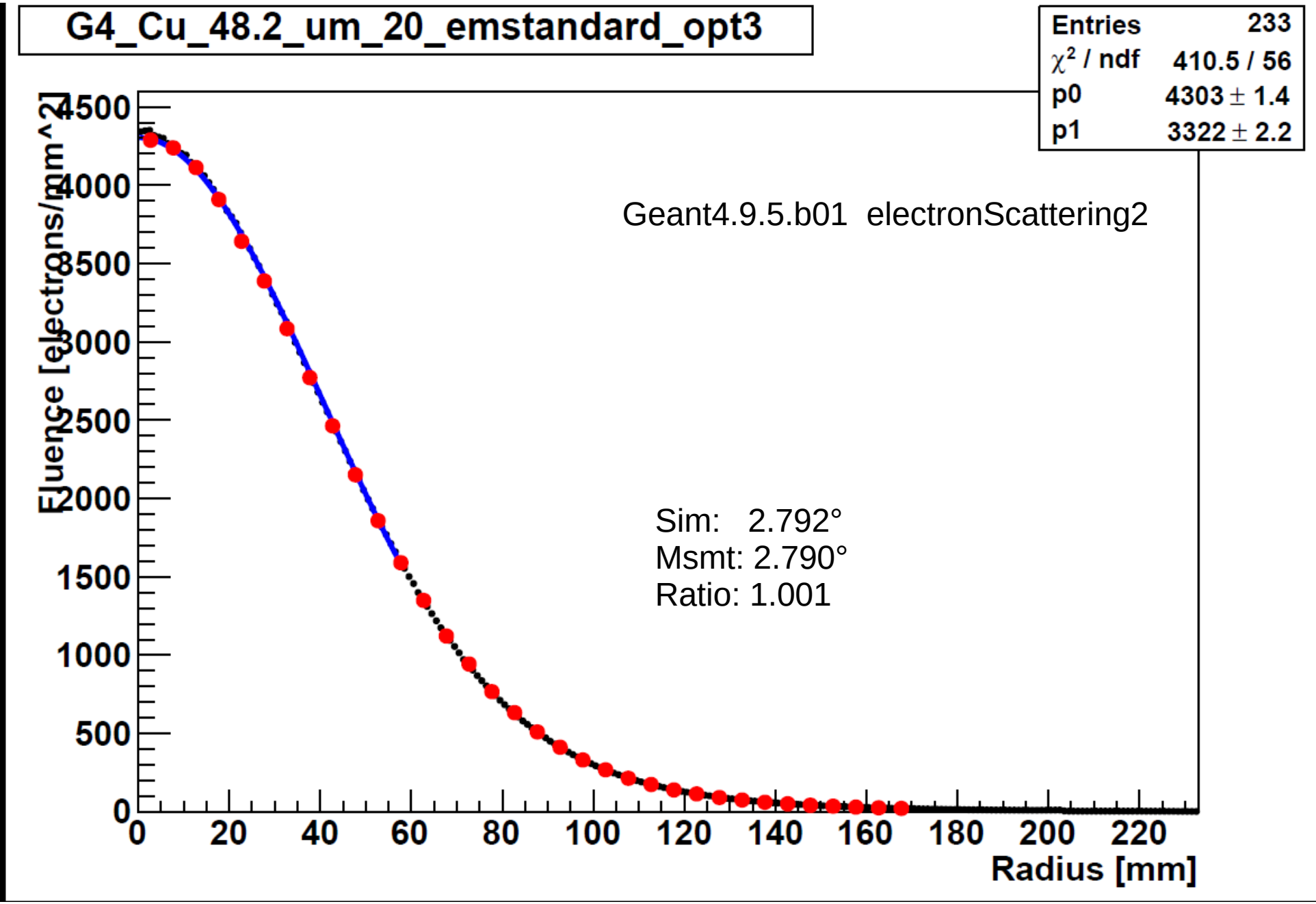
```
local:
      G4eMultipleScattering* msc = new G4eMultipleScattering();
      msc->AddEmModel(0, new G4UrbanMscModel95());  **93**
      ph->RegisterProcess(msc, particle);
      G4eIonisation* eIoni = new G4eIonisation();
      eIoni->SetStepFunction(0.1, 100*um);
      ph->RegisterProcess(eIoni, particle);
      ph->RegisterProcess(new G4eBremsstrahlung(), particle);

standardSS:
      pmanager->AddDiscreteProcess(new G4CoulombScattering);
      pmanager->AddProcess(new G4eIonisation,        -1, 1, 1);
      pmanager->AddProcess(new G4eBremsstrahlung,    -1, 2, 2);

standardGS:
      G4eMultipleScattering* msc = new G4eMultipleScattering();
      msc->AddEmModel(0, new G4GoudsmitSaundersonMscModel());
      pmanager->AddProcess(msc,                       -1, 1, 1);
      pmanager->AddProcess(new G4eIonisation,         -1, 2, 2);
      pmanager->AddProcess(new G4eBremsstrahlung,     -1, 3, 3);

standardWVI:
      G4eMultipleScattering* msc = new G4eMultipleScattering();
      msc->AddEmModel(0, new G4WentzelVIModel());
      pmanager->AddProcess(msc,                       -1, 1, 1);
      pmanager->AddProcess(new G4eIonisation,         -1, 2, 2);
      pmanager->AddProcess(new G4eBremsstrahlung,     -1, 3, 3);
      pmanager->AddProcess(new G4CoulombScattering,   -1,-1, 4);
```

Workflow:

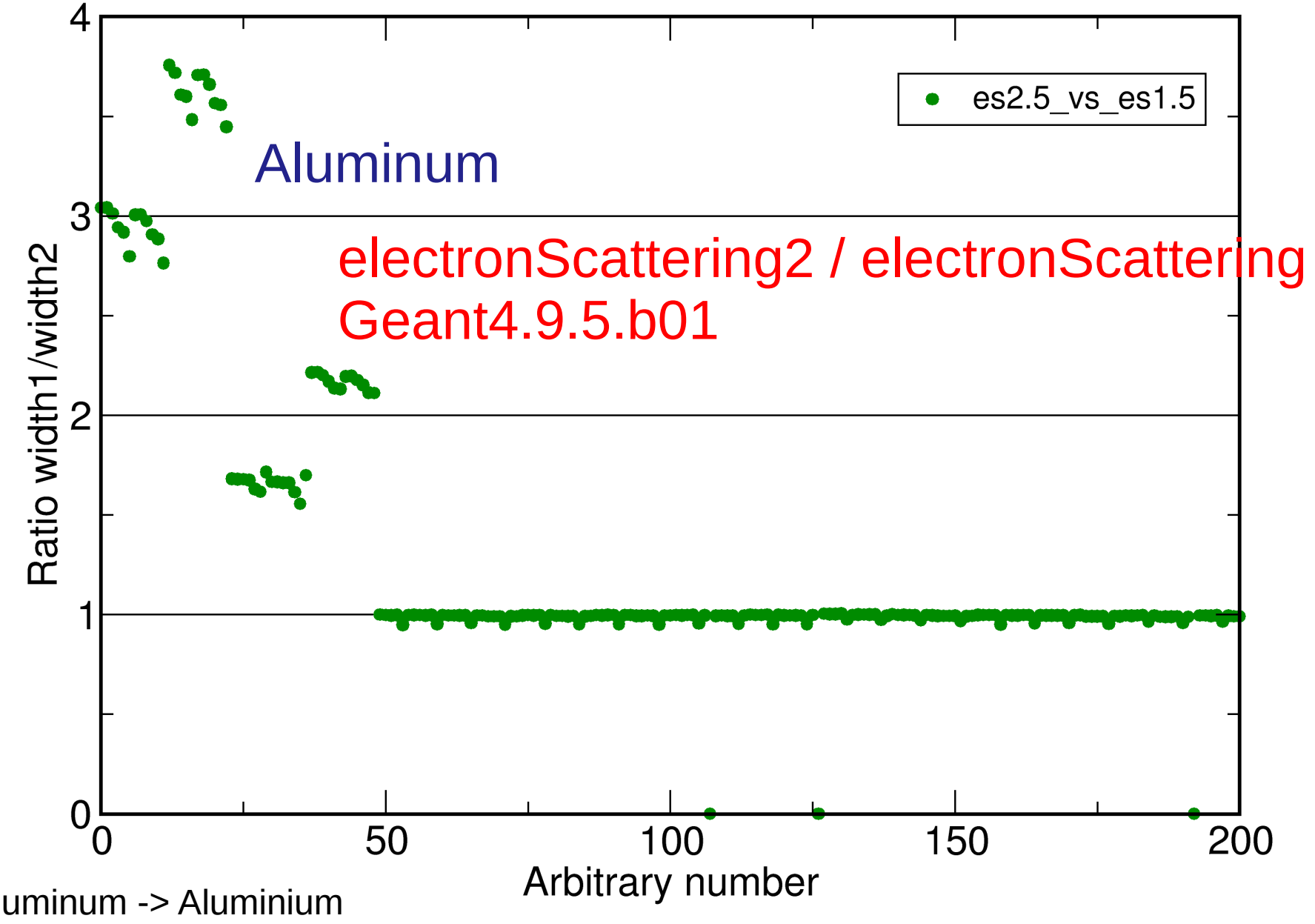
1. Submit many jobs: Python script + Geant4 macro template
2. Post-process: Python script
3. Analyze: Root macro + Python script
4. Collate: Python scripts


G4_Au_28.4_um_13_emstandard_opt3
Entries 233
χ² / ndf 608.7 / 122
p0 907.6 ± 0.3
p1 1.546e+04 ± 1.051e+01
Fit to f(x) = p0 * exp(-x**2/p1)
Red: measurement
Black: simulation
Blue: fit
Geant4.9.5.b01 electronScattering2
Fluence [electrons/mm^2]
Radius [mm]
0
100
200
300
400
500
600
700
800
900
0
20
40
60
80
100
120
140
160
180
200
220

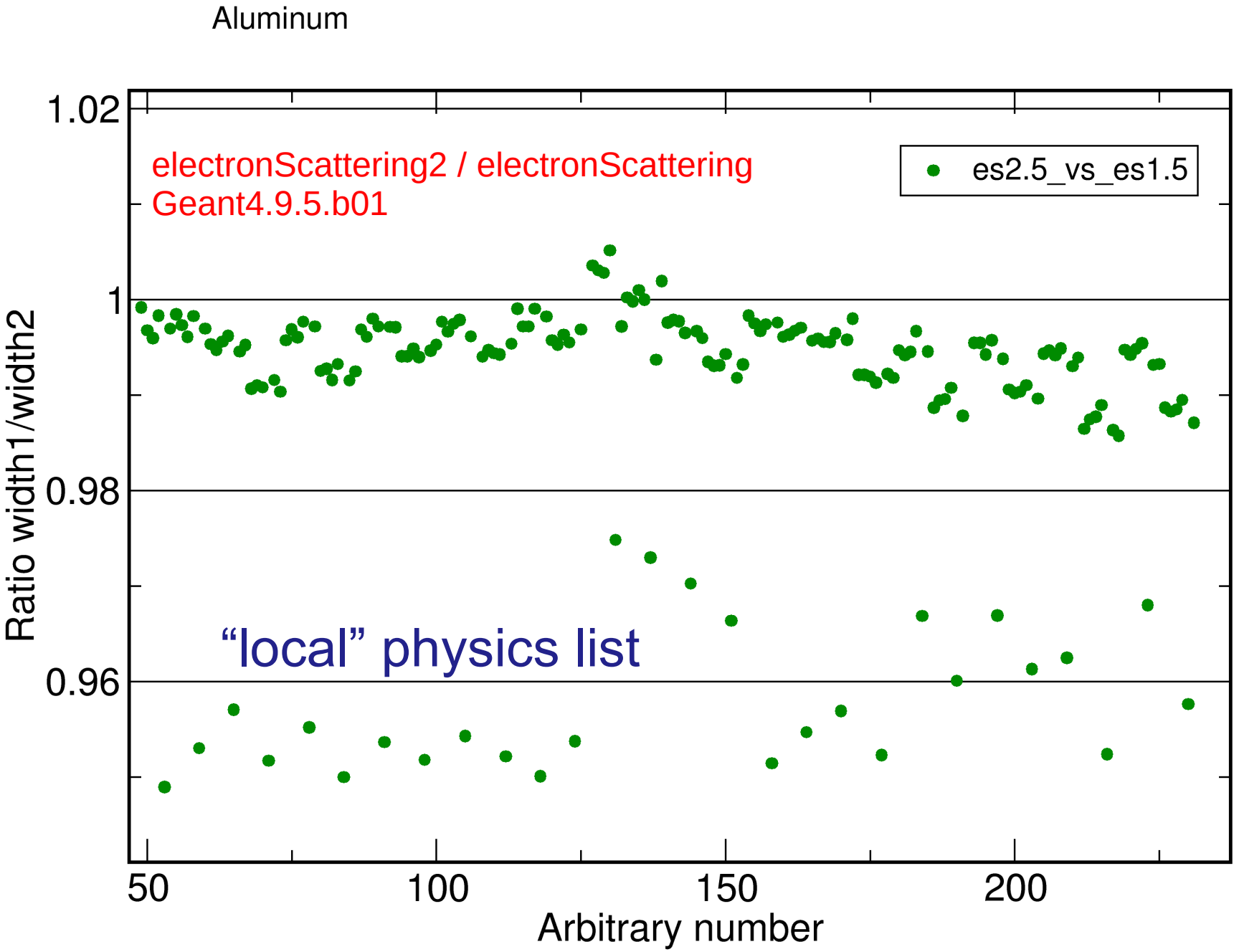

G4_Au_28.4_um_13_emstandard_opt3
Entries 233
χ² / ndf 608.7 / 122
p0 907.6 ± 0.3
p1 1.546e+04 ± 1.051e+01
Fit to f(x) = p0 * exp(-x**2/p1)
Red: measurement
Black: simulation
Blue: fit
1/e
Sim: 6.004°
Msmt: 6.329°
Ratio: 0.949
Geant4.9.5.b01 electronScattering2
Fluence [electrons/mm^2]
Radius [mm]
0
100
200
300
400
500
600
700
800
900
0
20
40
60
80
100
120
140
160
180
200
220

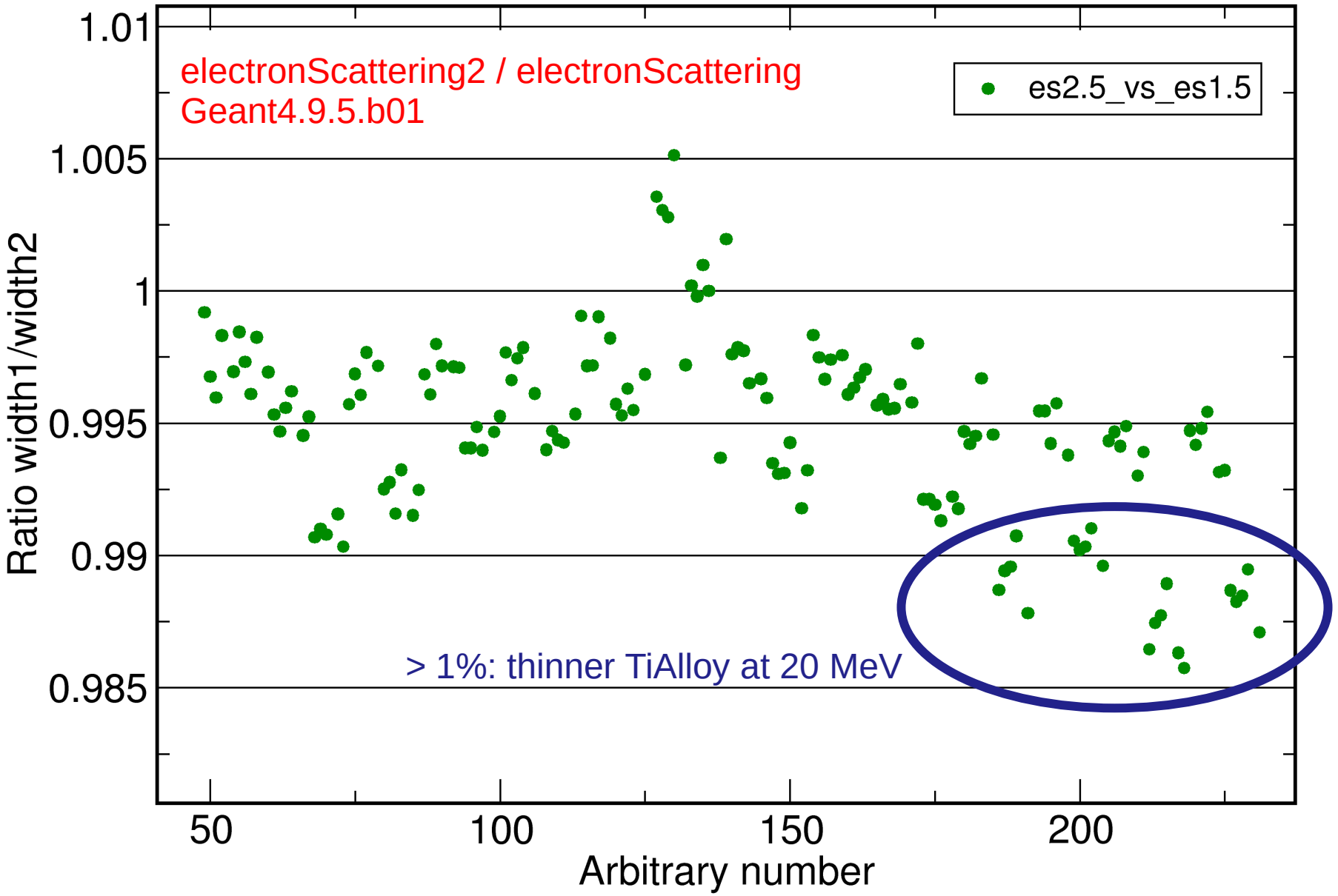

G4_Cu_48.2_um_20_emstandard_opt3
Entries 233
χ² / ndf 410.5 / 56
p0 4303 ± 1.4
p1 3322 ± 2.2
Geant4.9.5.b01 electronScattering2
Sim: 2.792°
Msmt: 2.790°
Ratio: 1.001
Fluence [electrons/mm^2]
Radius [mm]
0
500
1000
1500
2000
2500
3000
3500
4000
4500
0
20
40
60
80
100
120
140
160
180
200
220

Comparison of two simulations

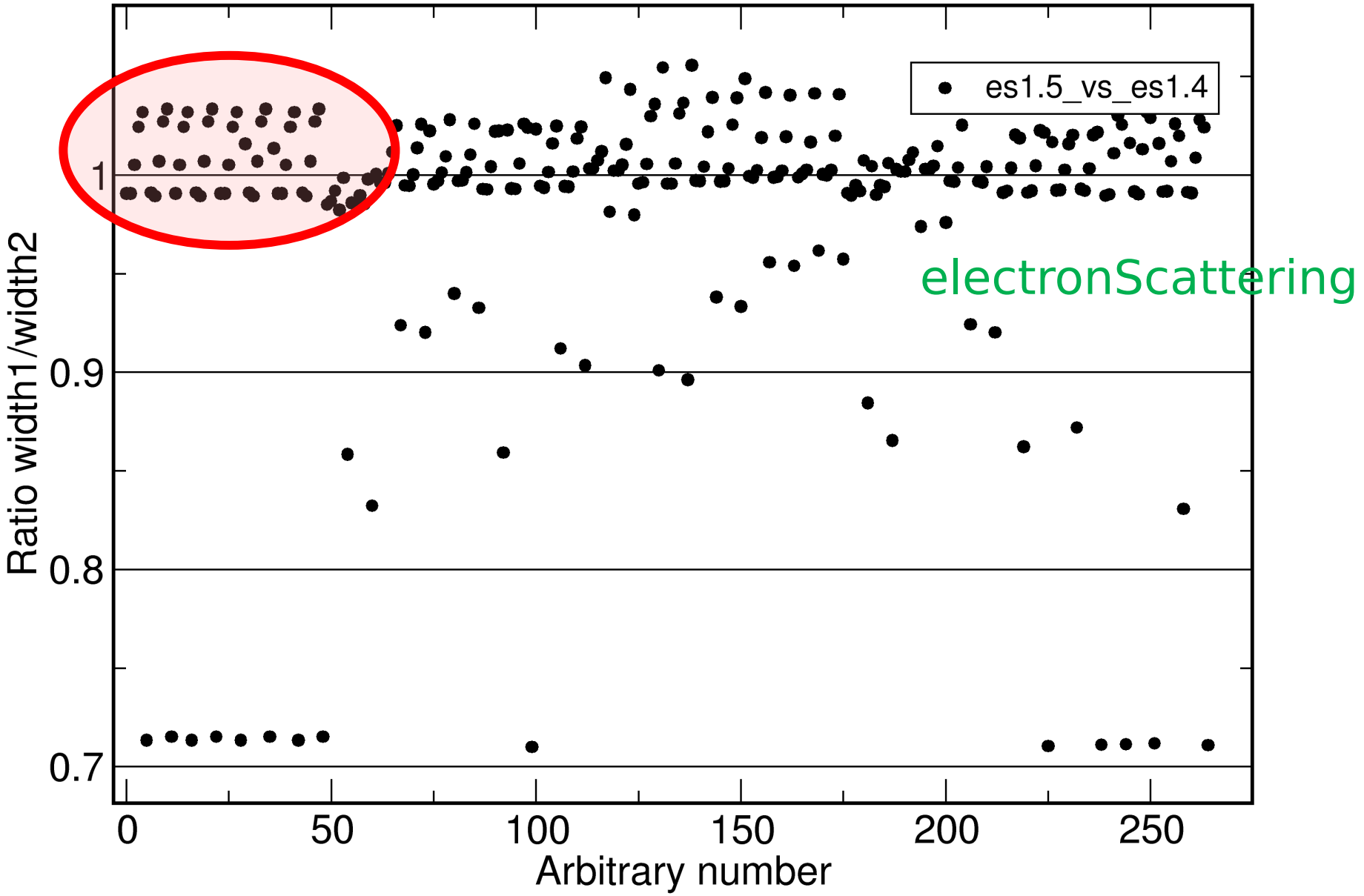


Aluminum -> Aluminium


Aluminum
electronScattering2 / electronScattering
Geant4.9.5.b01
es2.5_vs_es1.5
“local” physics list
Ratio width1/width2
Arbitrary number
1.02
1
0.98
0.96
50
100
150
200

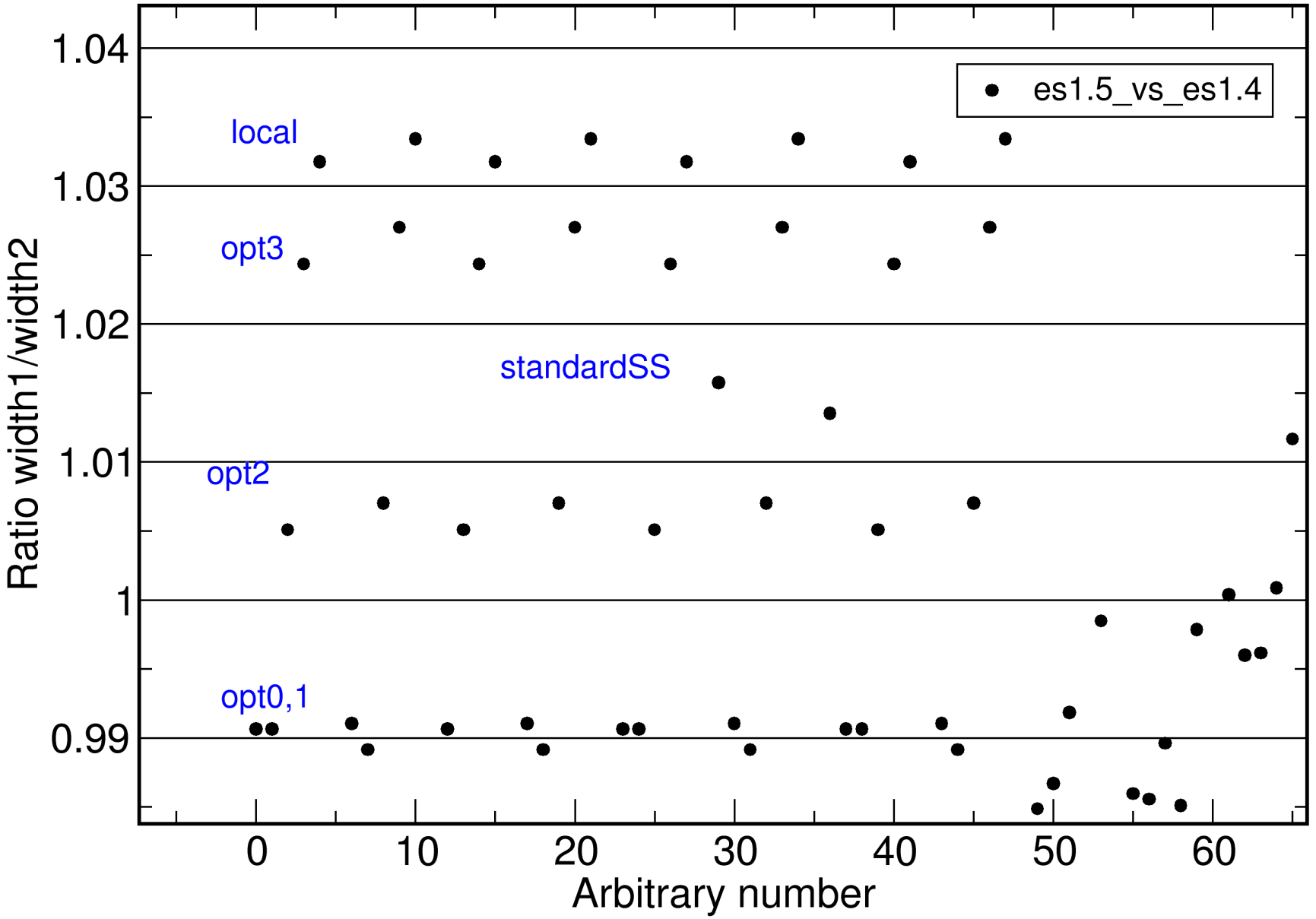

electronScattering2 / electronScattering
Geant4.9.5.b01
es2.5_vs_es1.5
> 1%: thinner TiAlloy at 20 MeV
Ratio width1/width2
Arbitrary number
1.01
1.005
1
0.995
0.99
0.985
50
100
150
200

Geant4.9.5.b01 vs Geant4.9.4.p02



low points: GS

Geant4.9.5.b01 vs Geant4.9.4.p02

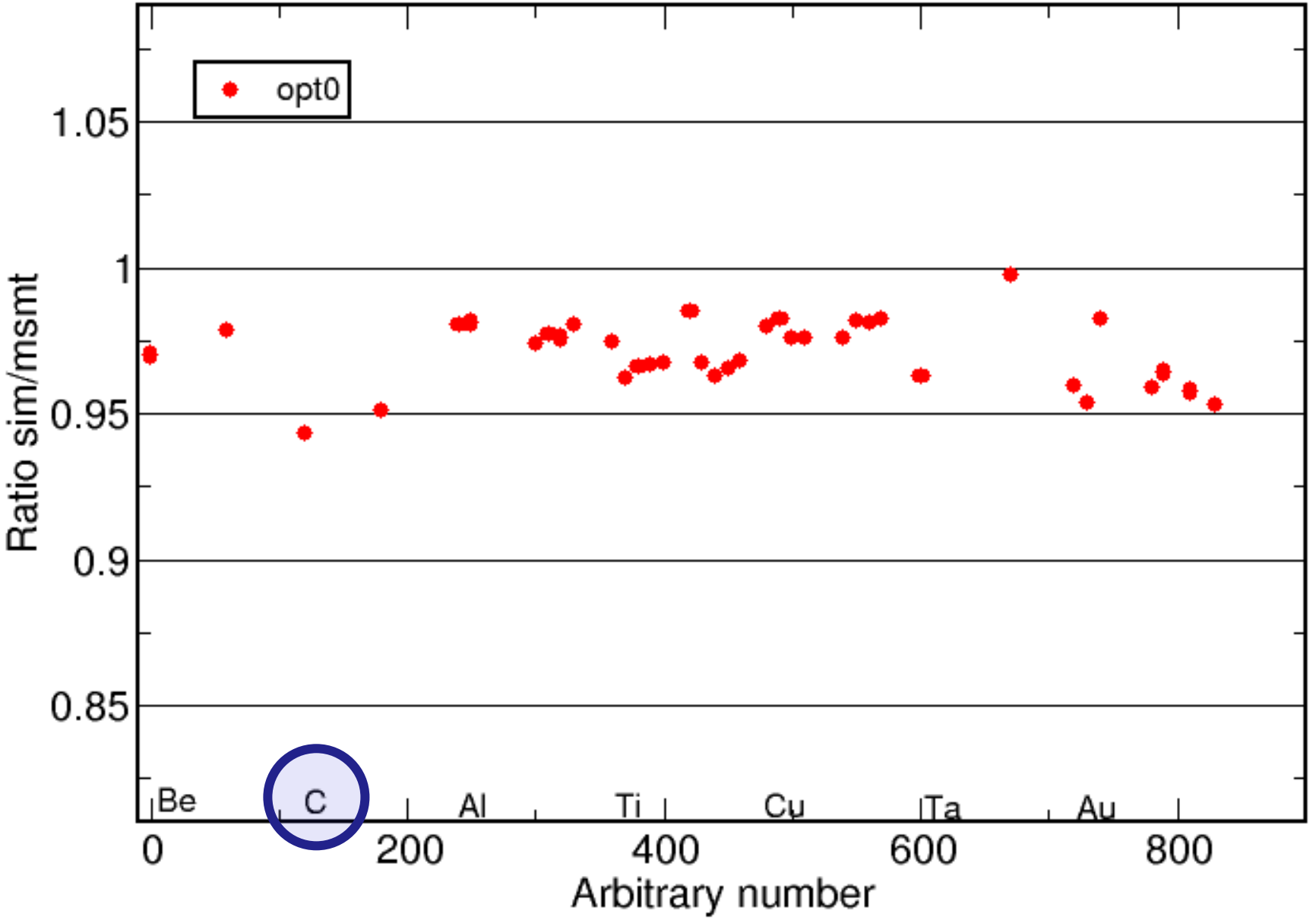


Comparison to measurement

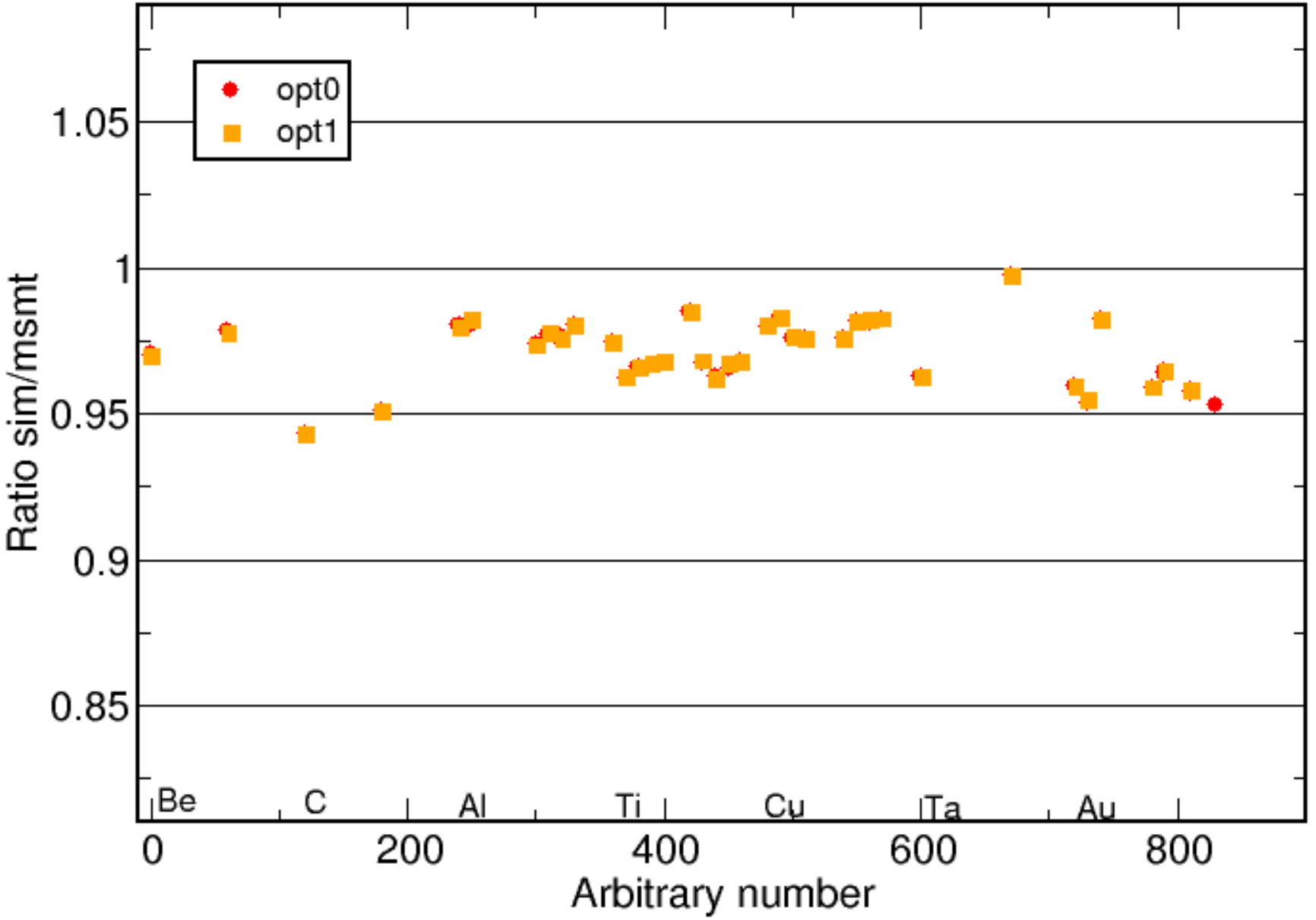
electronScattering2

Geant4.9.5.b01

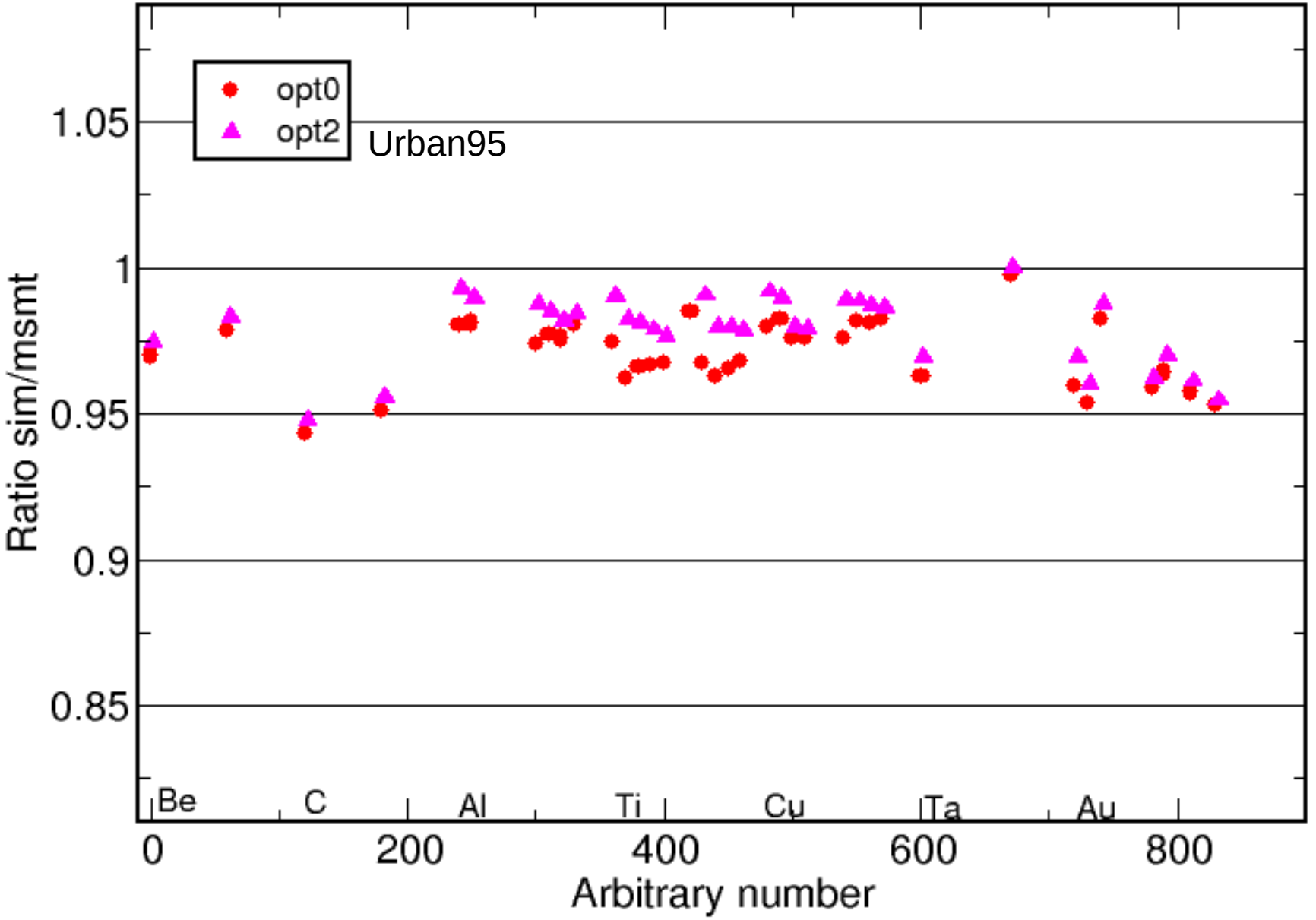
Geant4.9.5.b01 electronScattering2



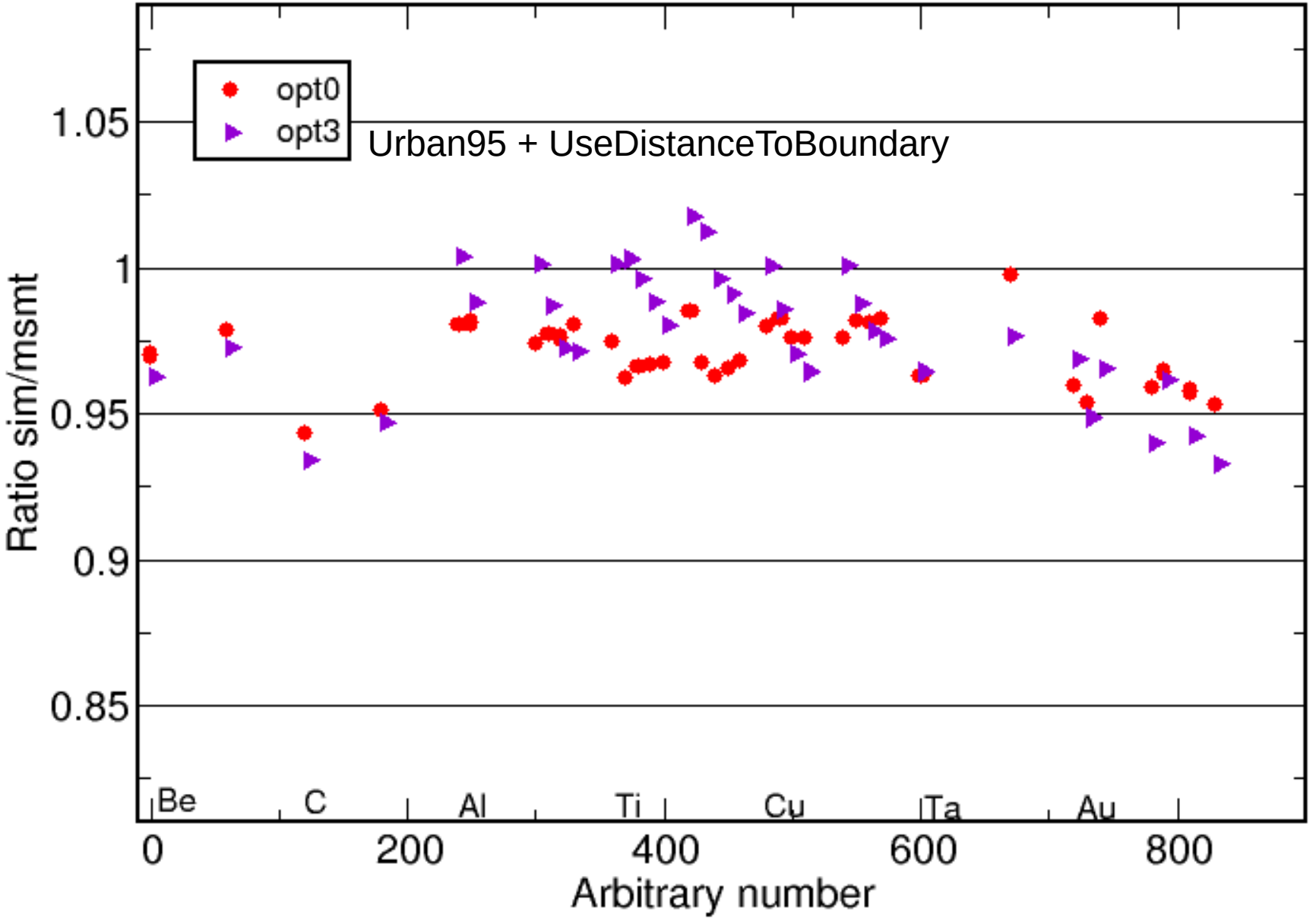
Geant4.9.5.b01 electronScattering2



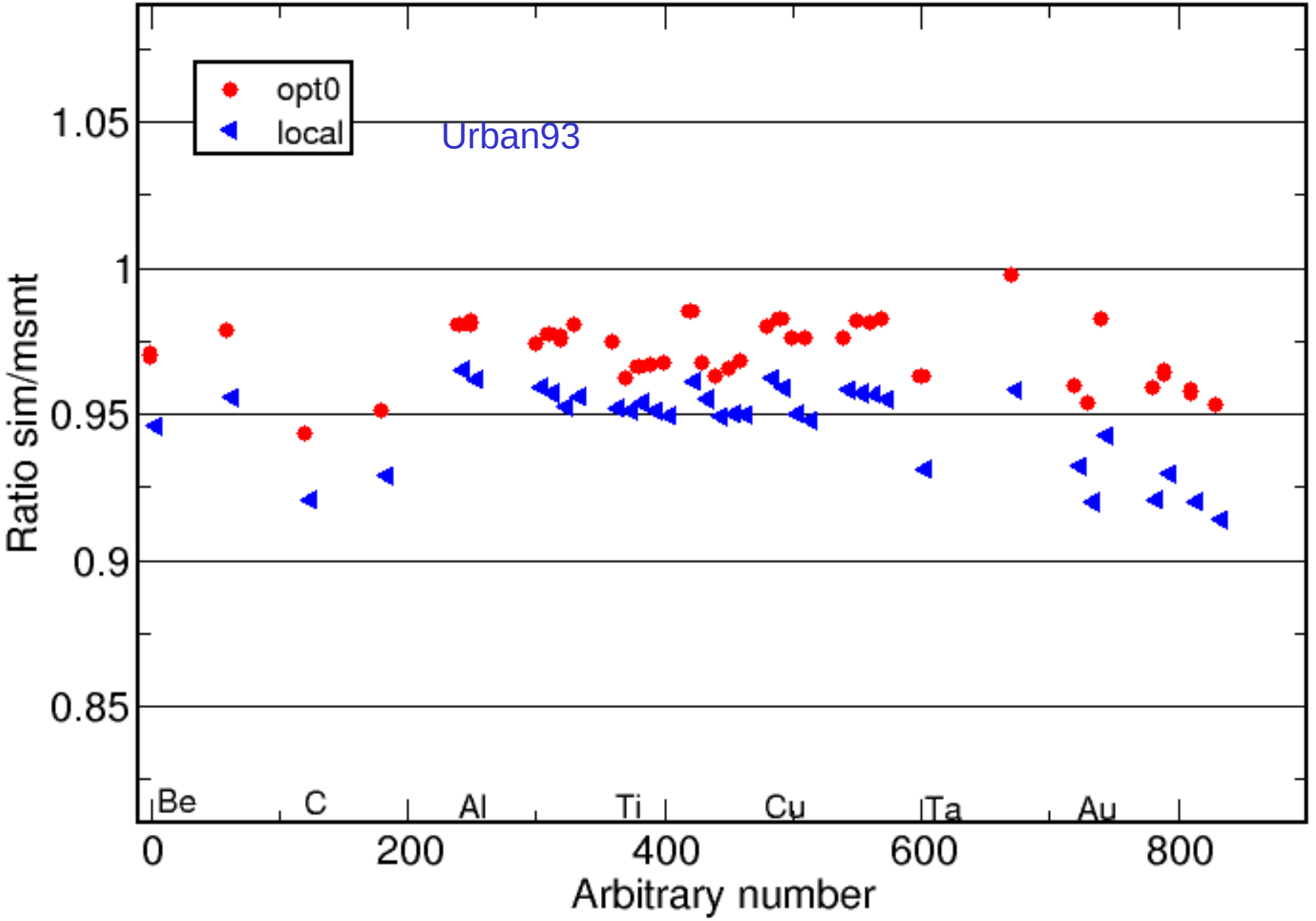
Geant4.9.5.b01 electronScattering2



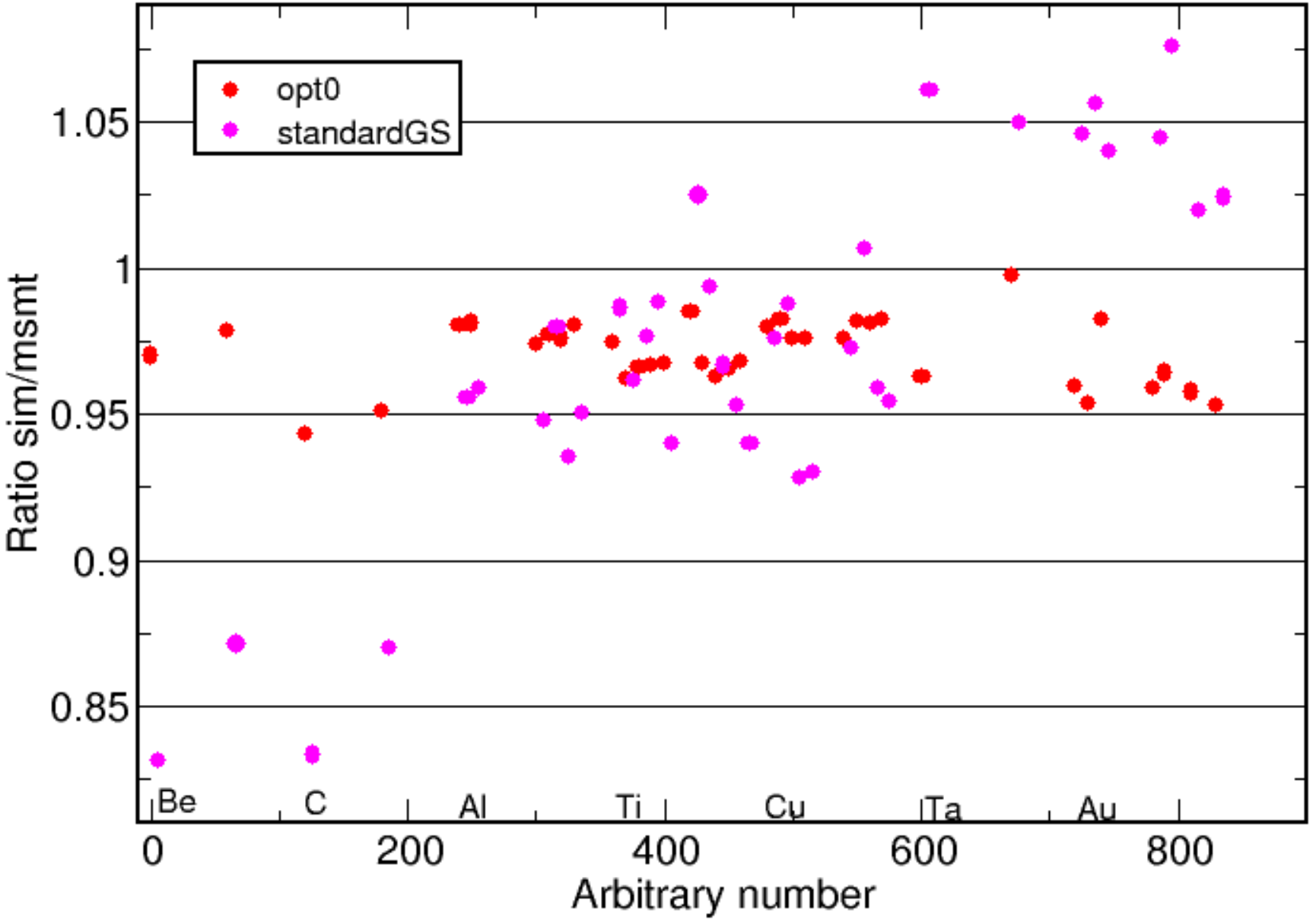
Geant4.9.5.b01 electronScattering2



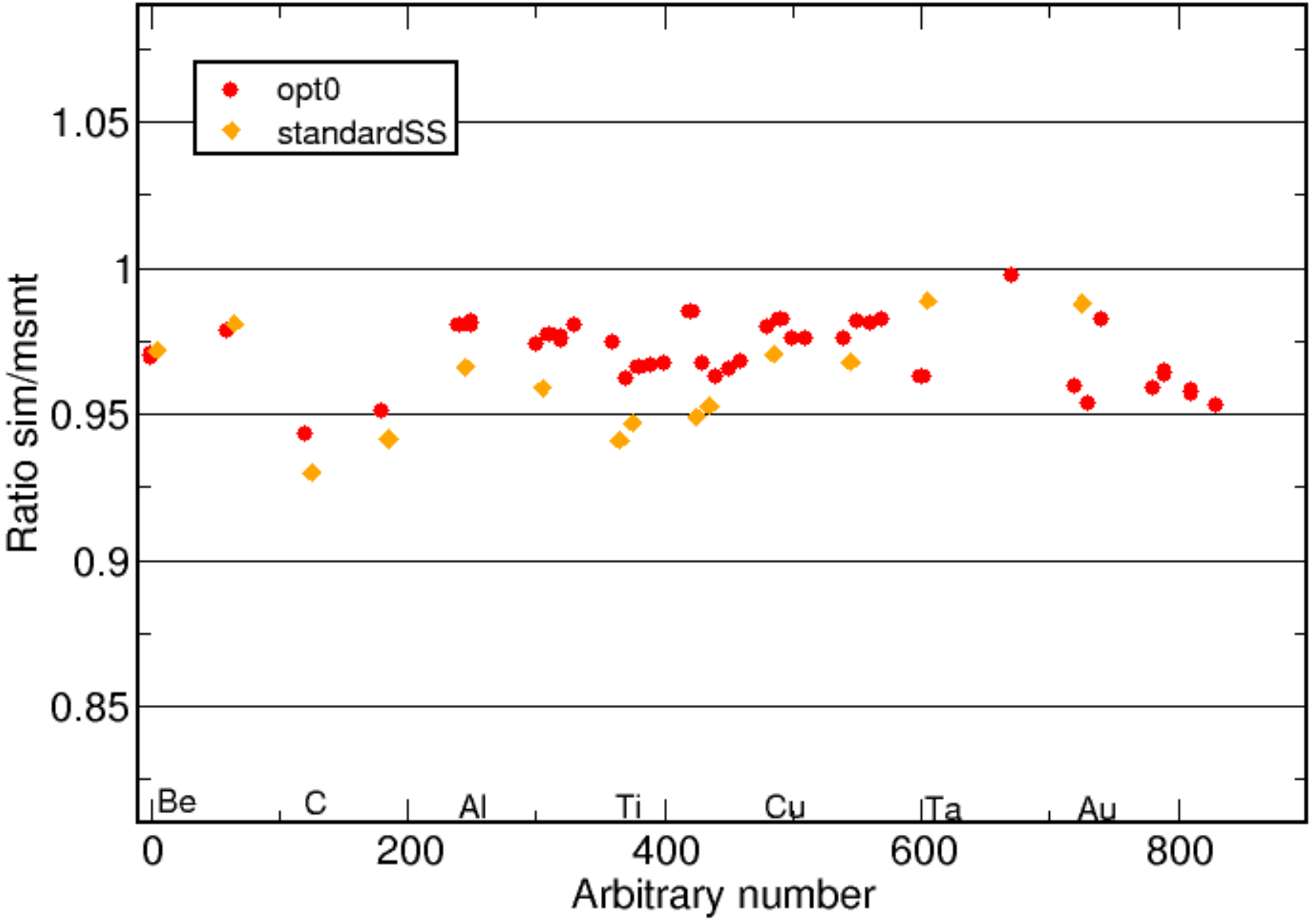
Geant4.9.5.b01 electronScattering2

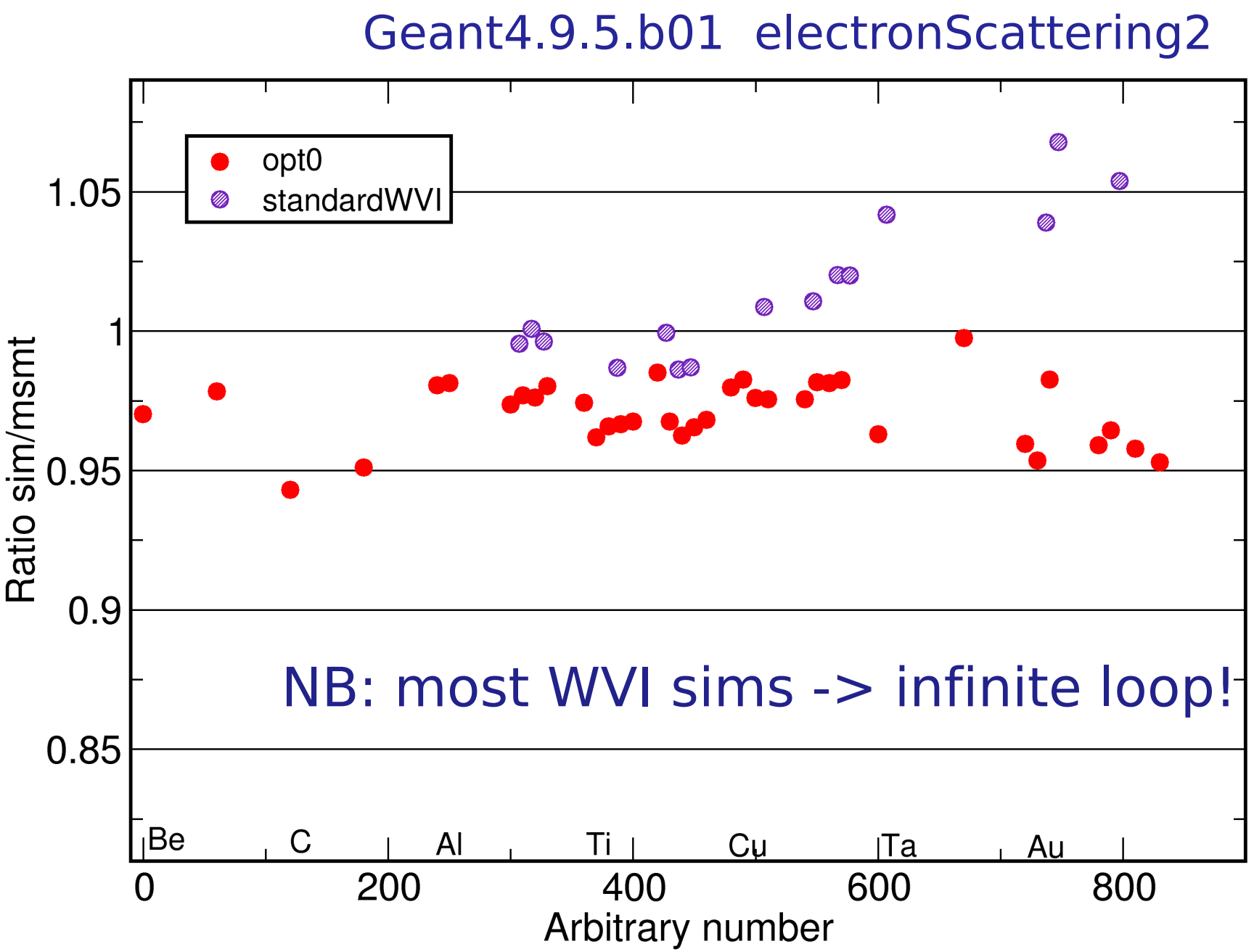


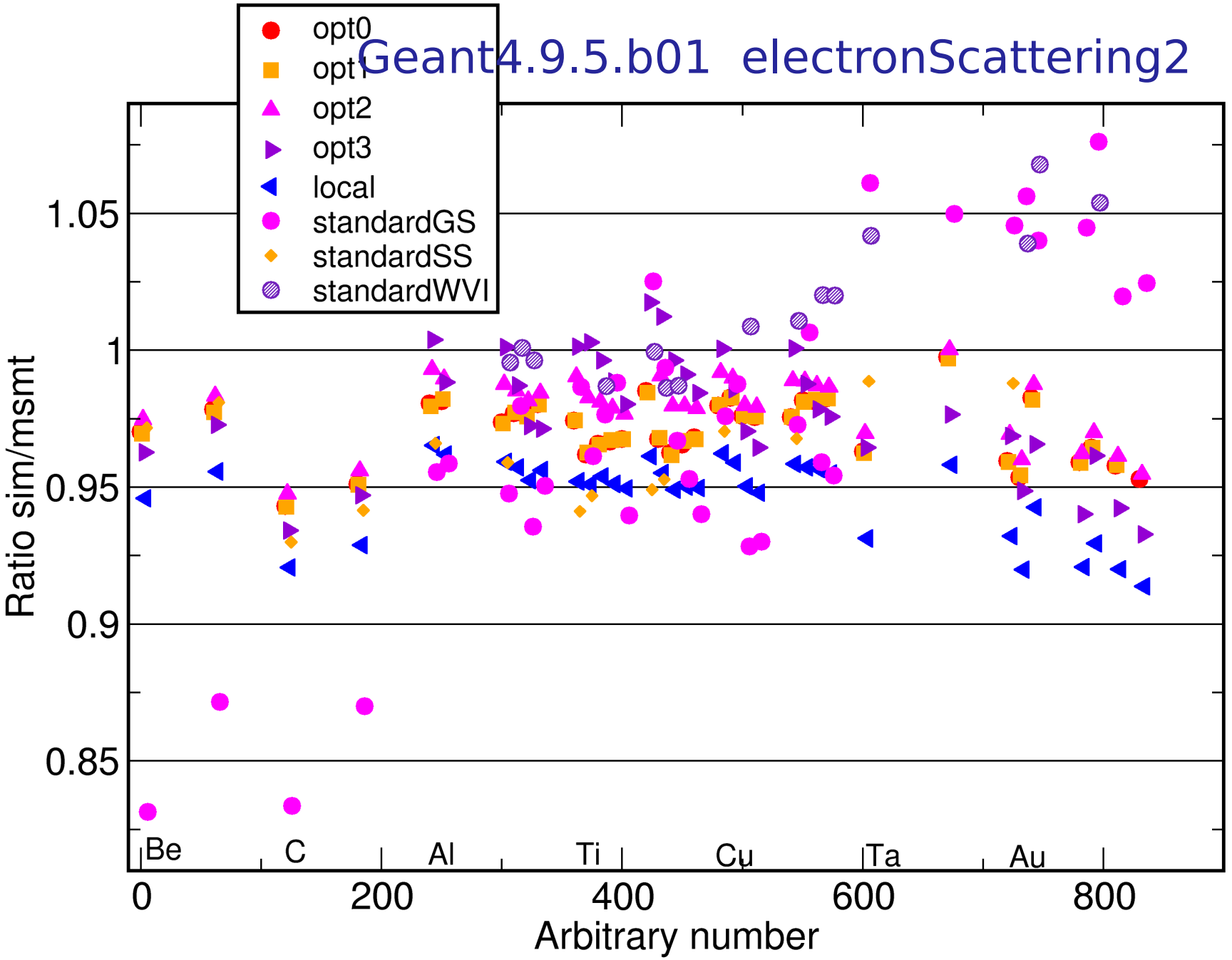
Geant4.9.5.b01 electronScattering2



Geant4.9.5.b01 electronScattering2




Geant4.9.5.b01 electronScattering2
opt0
standardWVI
Ratio sim/msmt
1.05
1
0.95
0.9
0.85
NB: most WVI sims -> infinite loop!
Be
C
Al
Ti
Cu
Ta
Au
0
200
400
600
800
Arbitrary number


Geant4.9.5.b01 electronScattering2
opt0
opt1
opt2
opt3
local
standardGS
standardSS
standardWVI
Ratio sim/msmt
1.05
1
0.95
0.9
0.85
Be
C
Al
Ti
Cu
Ta
Au
0
200
400
600
800
Arbitrary number

Conclusions:

Semi-automated validation of electron multiple scattering

Can find large, small discrepancies

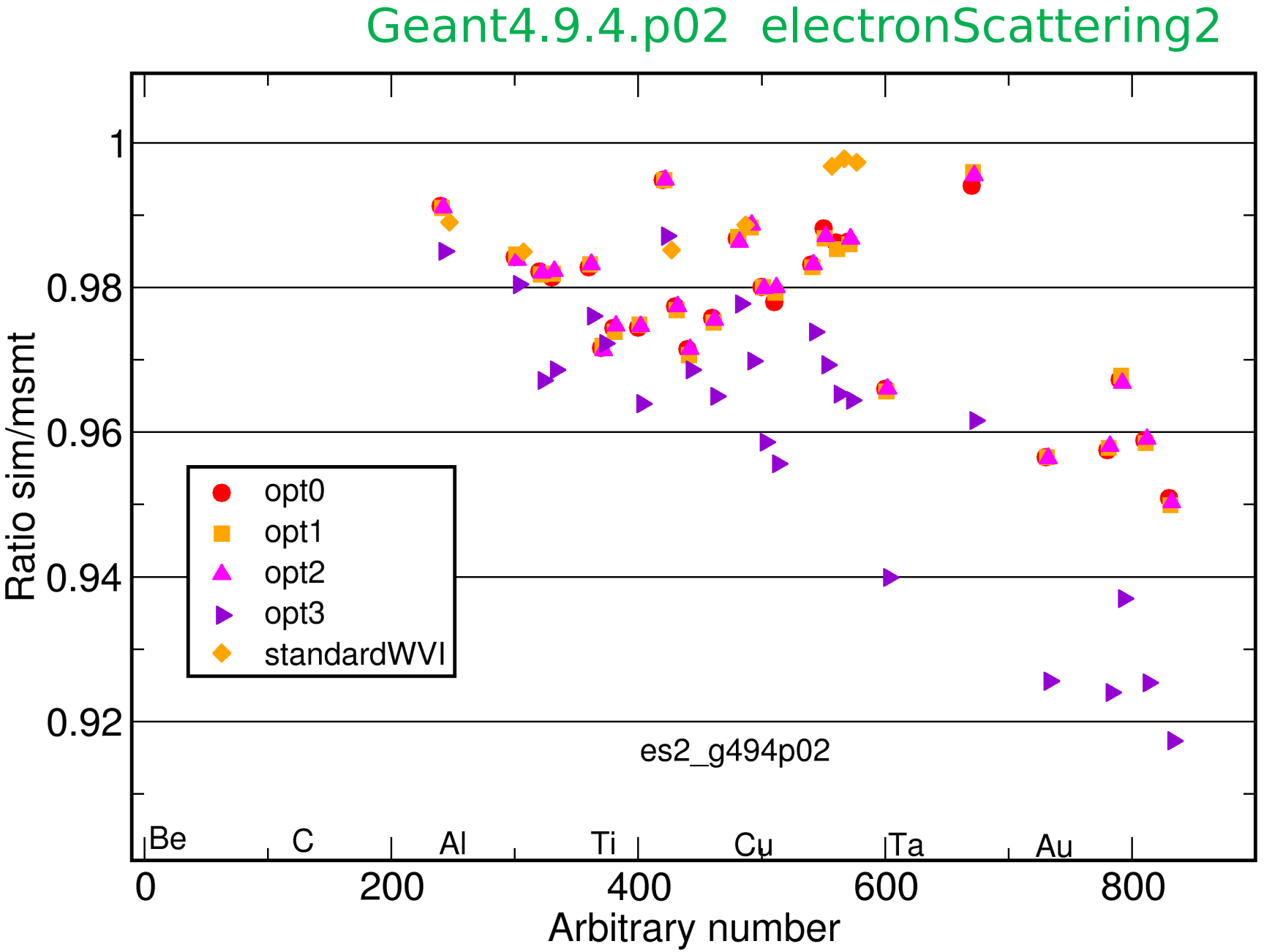
Fewer histories need to be run

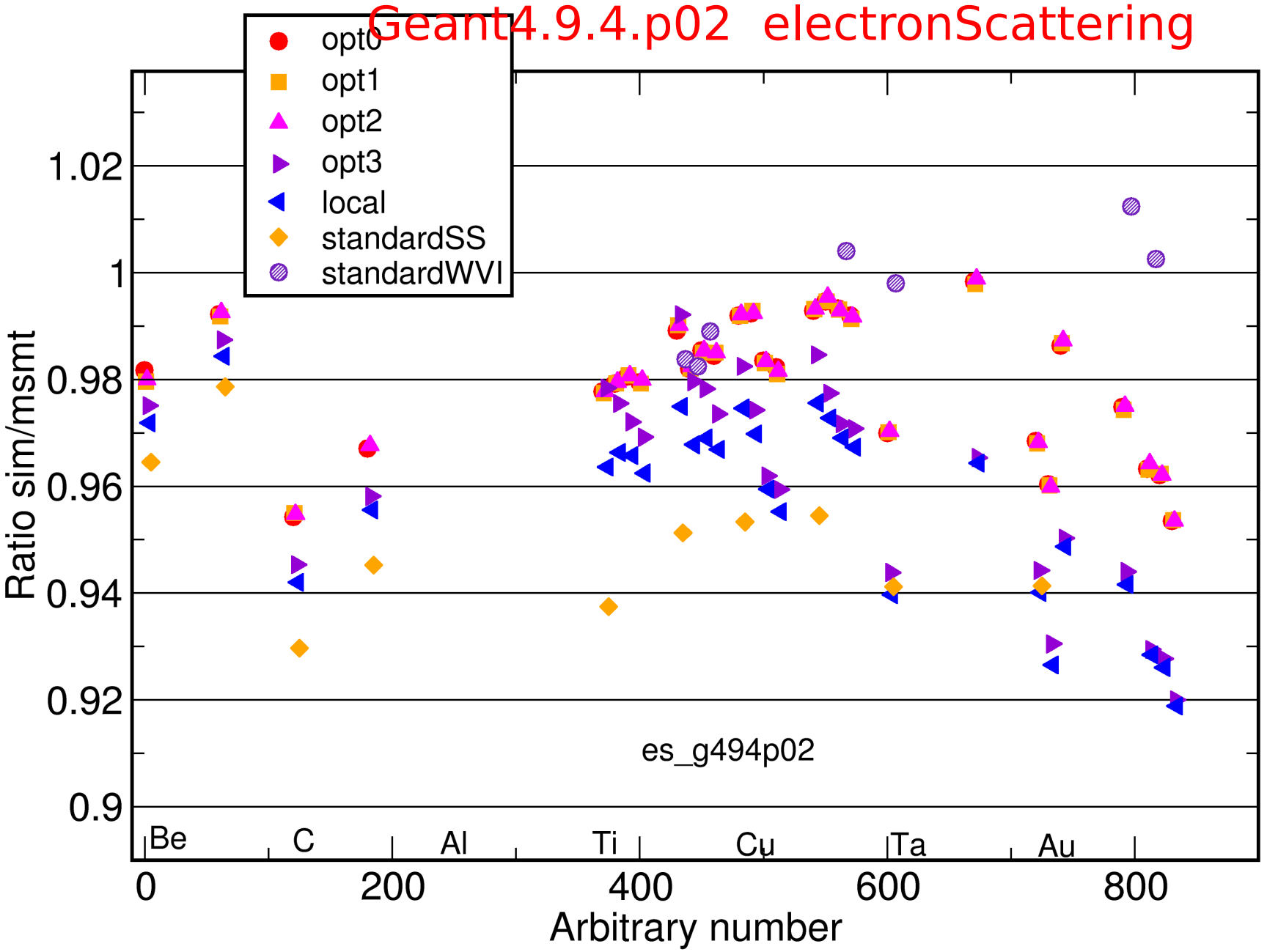
Only considered central Gaussian part

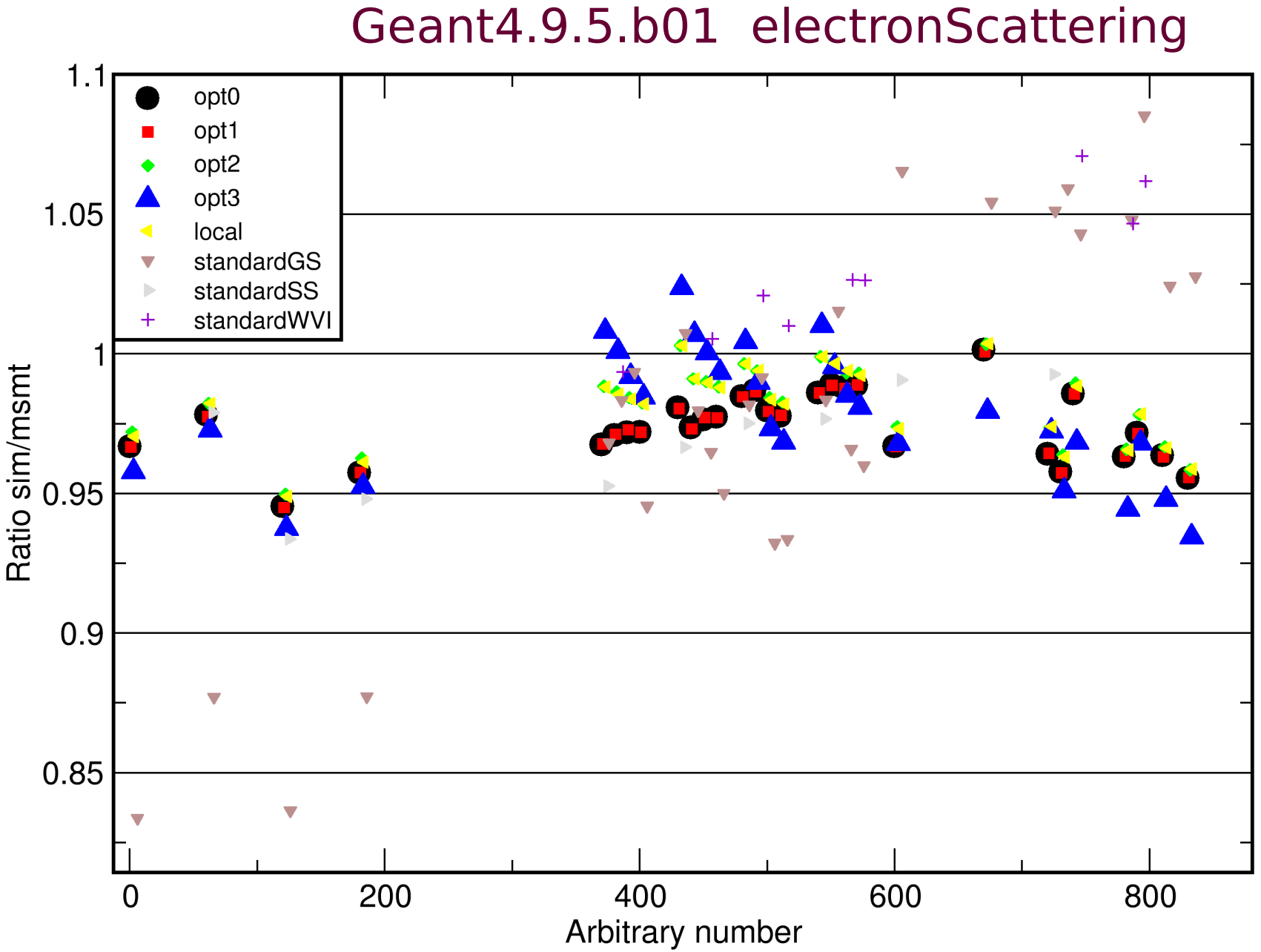
Option0, 1 consistently 2% narrower (1/e) than measurement

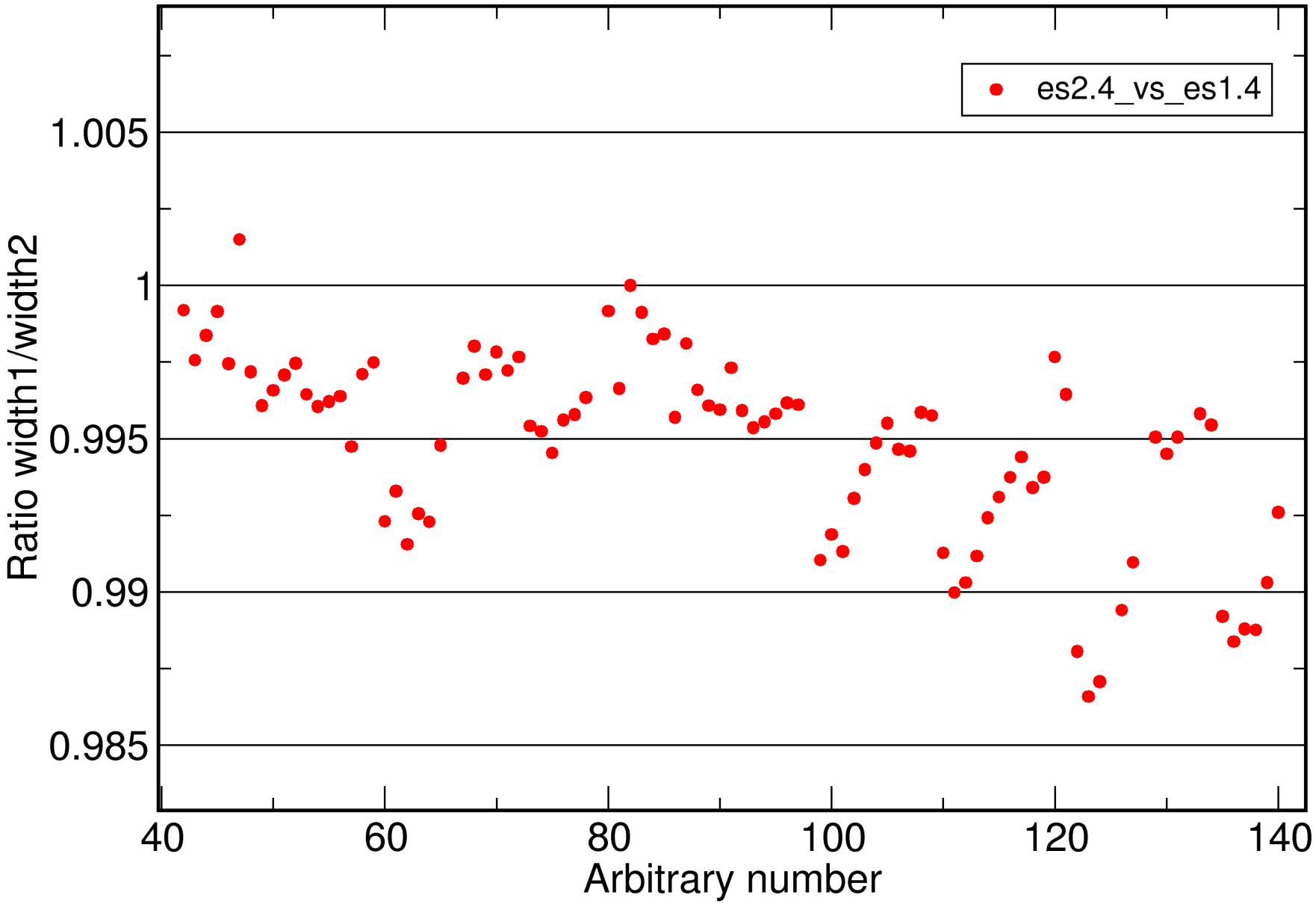
Urban95 better than Urban93 by 2%

Others vary

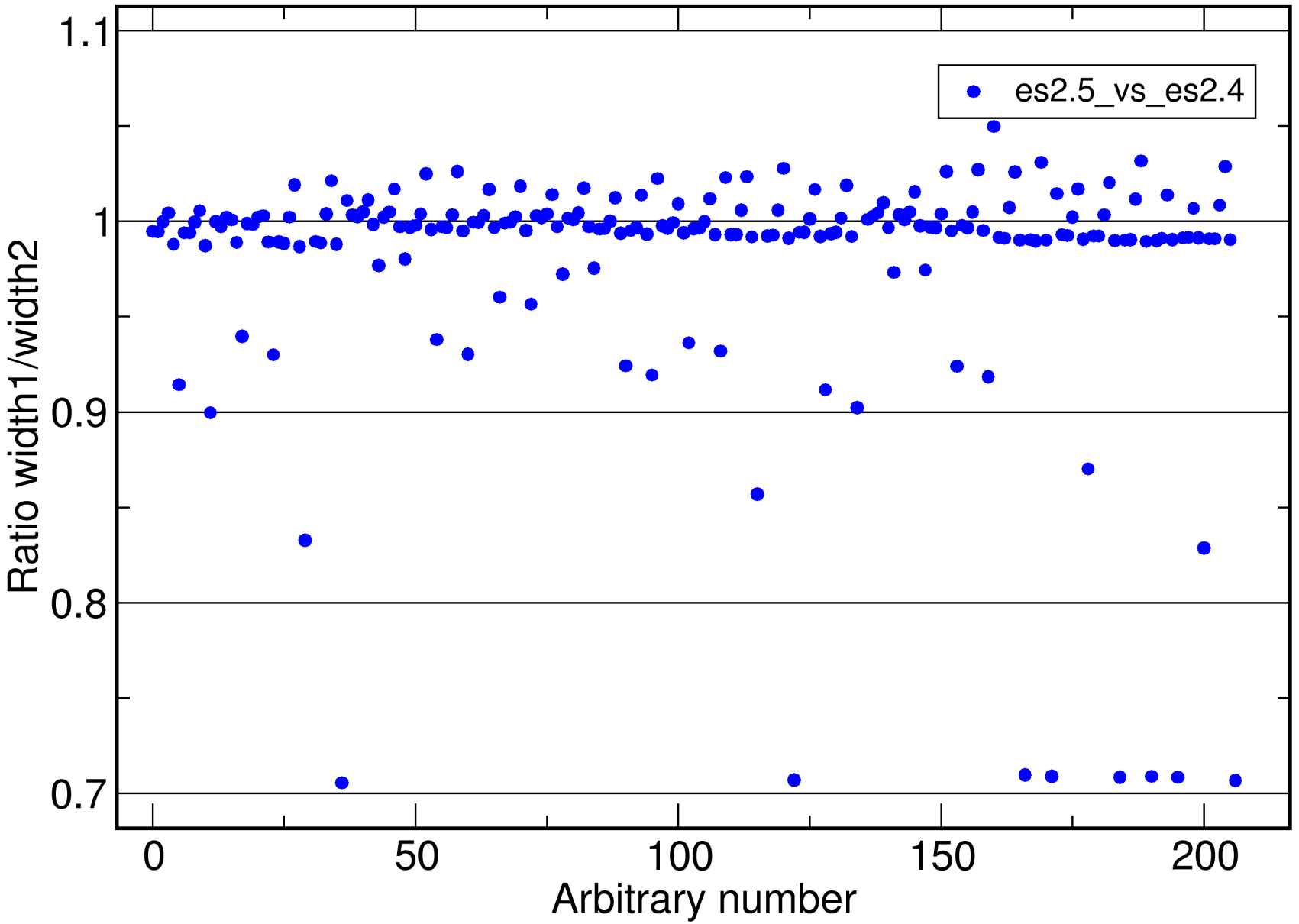

Geant4.9.4.p02 electronScattering2
Ratio sim/msmt
1
0.98
0.96
0.94
0.92
opt0
opt1
opt2
opt3
standardWVI
es2_g494p02
Be
C
Al
Ti
Cu
Ta
Au
0
200
400
600
800
Arbitrary number


Geant4.9.4.p02 electronScattering
opt0
opt1
opt2
opt3
local
standardSS
standardWVI
Ratio sim/msmt
1.02
1
0.98
0.96
0.94
0.92
0.9
es_g494p02
Be
C
Al
Ti
Cu
Ta
Au
0
200
400
600
800
Arbitrary number

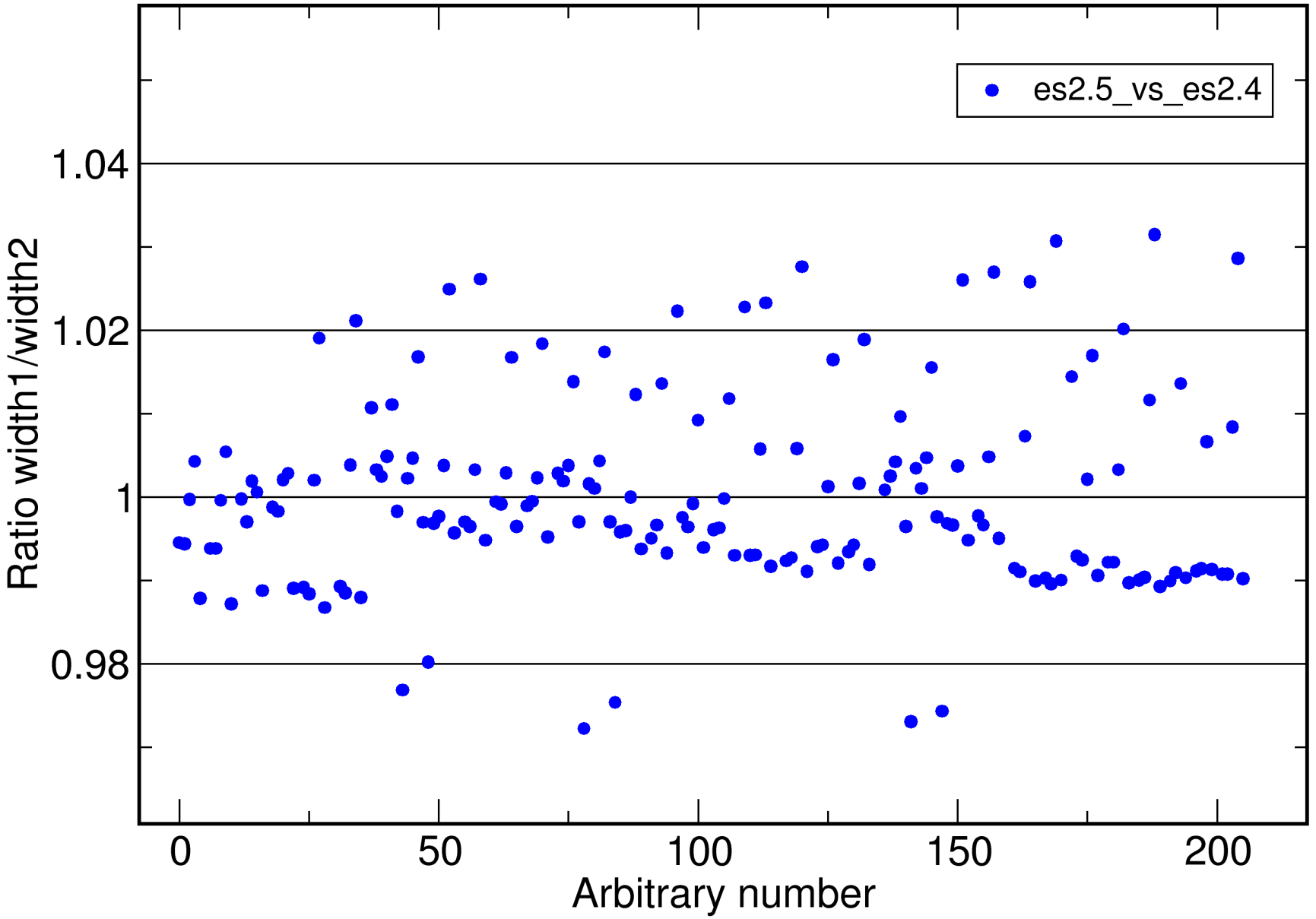

Geant4.9.5.b01 electronScattering
opt0
opt1
opt2
opt3
local
standardGS
standardSS
standardWVI
Ratio sim/msmt
Arbitrary number
1.1
1.05
1
0.95
0.9
0.85
0
200
400
600
800



Ti at 20 MeV again



low points: GS high points: opt3



high points opt3, otherwise tends to 1% decrease