Multiple Scattering Upgrade: Better Sampling of Lateral Displacement and Lateral Correlation

László Urbán

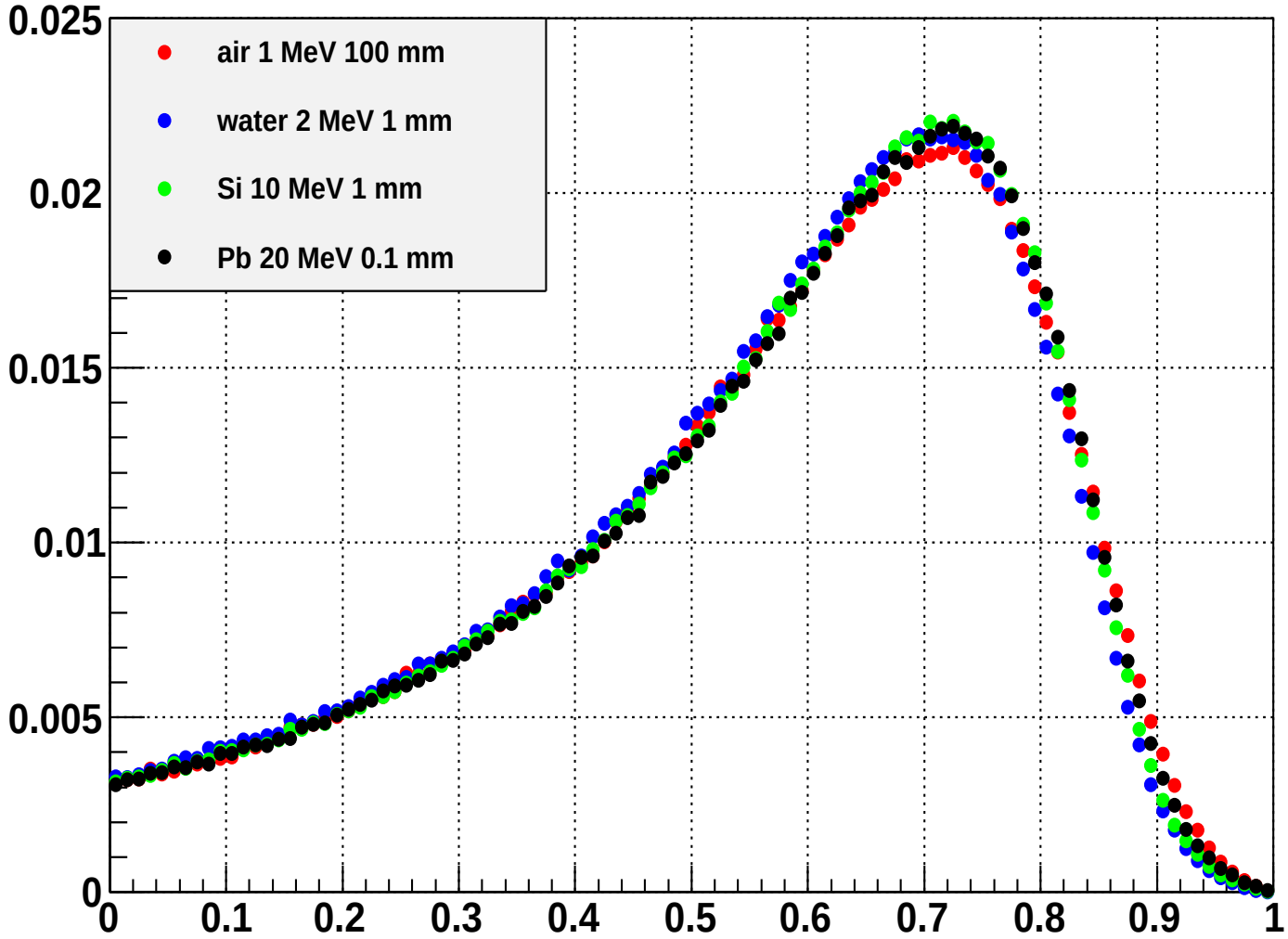
Geant4 Associates International

21 Sept 2015

problem: The Lewis theory gives the mean values of the lateral displacement and lateral correlation, but not their distributions.
until now: lateral displacement sampled according the simple distribution $f(r) = \frac{3r^2}{r_{max}^3}$ and the direction of the lat. displacement computed from r and the mean value of the lat. correlation.

update: take the shape of the distributions from the single scattering , see the next 2 slides. The first plot shows the $\frac{r^2}{r_{max}^2}$ distibution, where r is the lateral displacement, r_{max} is the maximum value of the lateral displacement determined by the true step length and geometrical step length as

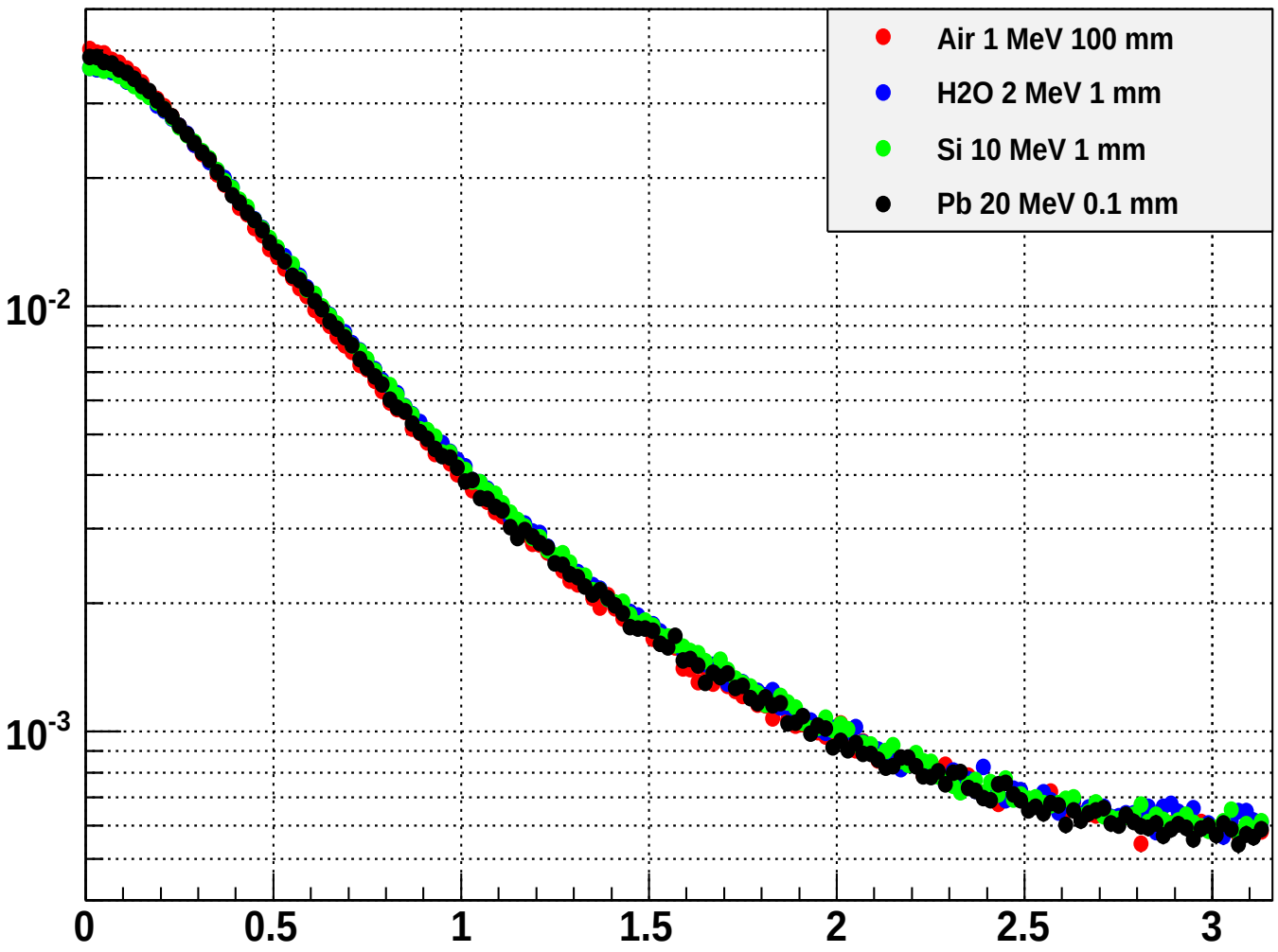
$$r_{max} = \sqrt{t^2 - z^2} \tag{1}$$


(r/rmax)**2 distribution (ss)
air 1 MeV 100 mm
water 2 MeV 1 mm
Si 10 MeV 1 mm
Pb 20 MeV 0.1 mm
0.025
0.02
0.015
0.01
0.005
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

the second plot shows the distribution of the quantity $\Phi - \phi = \arccos \frac{lat.corr}{rsin\theta}$ for different energies and materials , where $lat.corr$ is the lateral correlation, θ and ϕ determine the particle direction, Φ gives the direction of the lateral displacement.
The lateral correlation can be written as

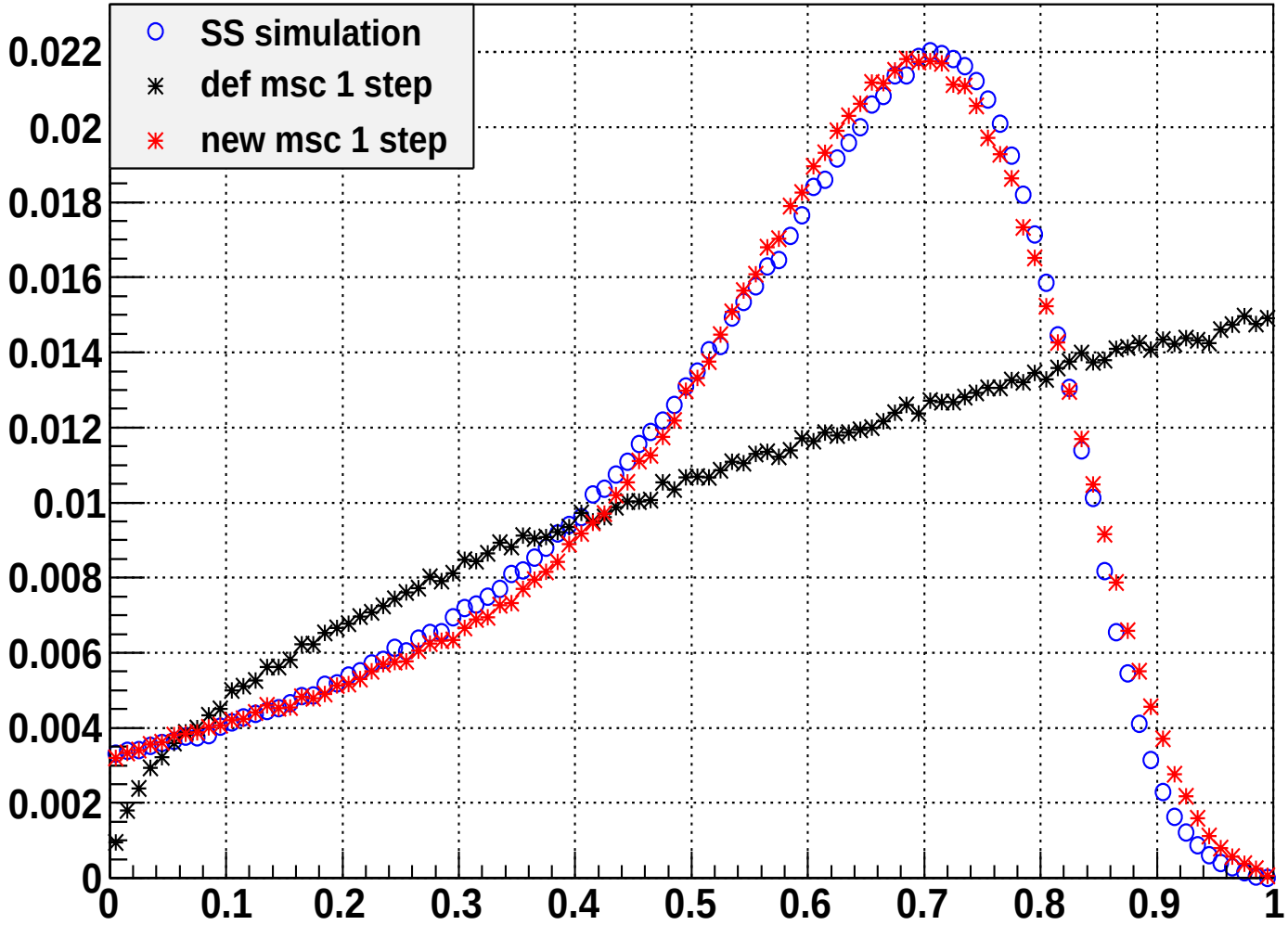
$$lat.corr = rsin\theta \cos(\Phi - \phi) \tag{2}$$

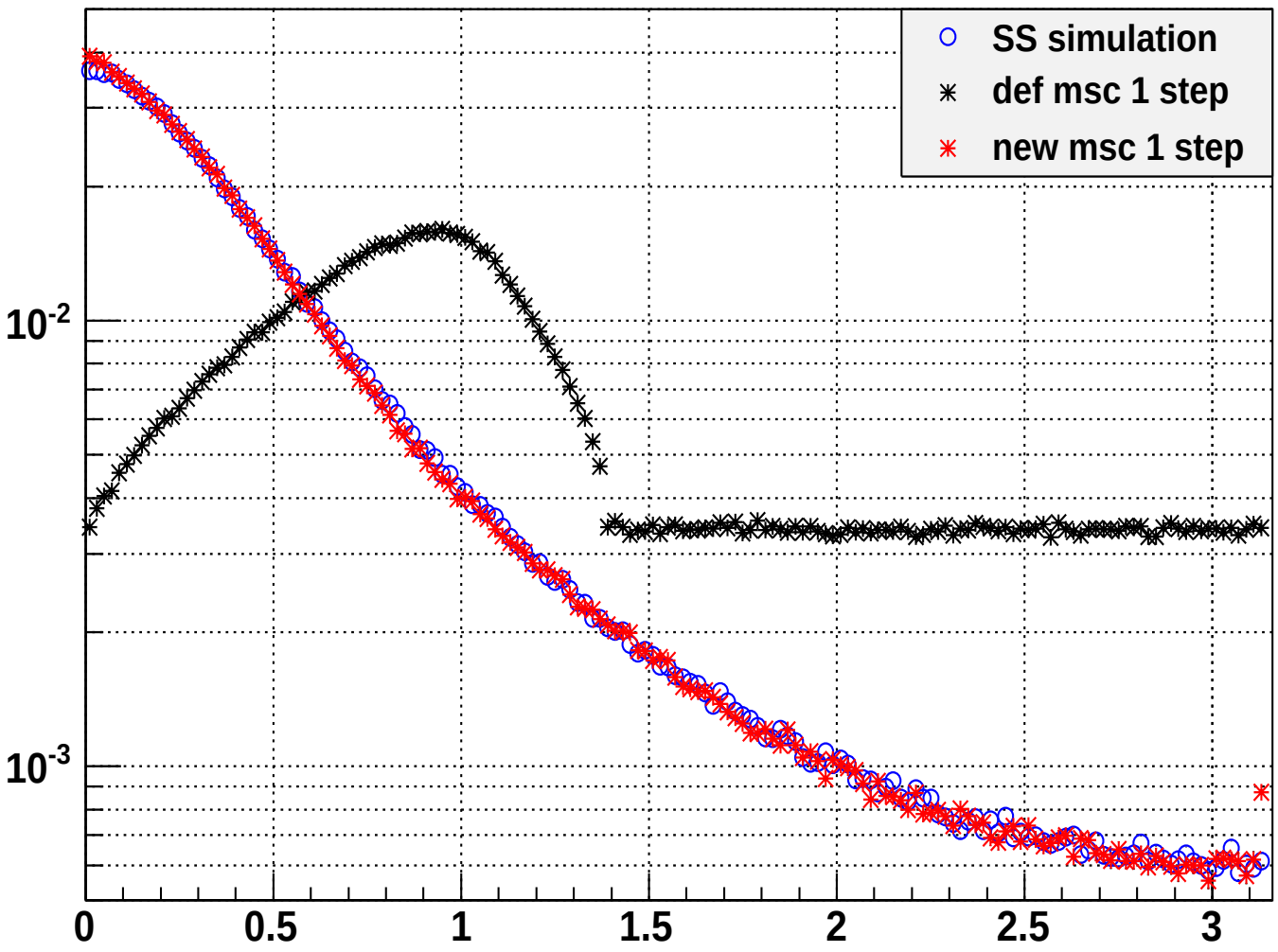
As it can be seen in the plots both distributions are *universal* i.e. do not depend on the energy and material.(The point was to find such variables which have universal distributions.)


Phi-phi=acos(lc/(r*sth)) SS simulation
Air 1 MeV 100 mm
H2O 2 MeV 1 mm
Si 10 MeV 1 mm
Pb 20 MeV 0.1 mm
10-2
10-3
0
0.5
1
1.5
2
2.5
3

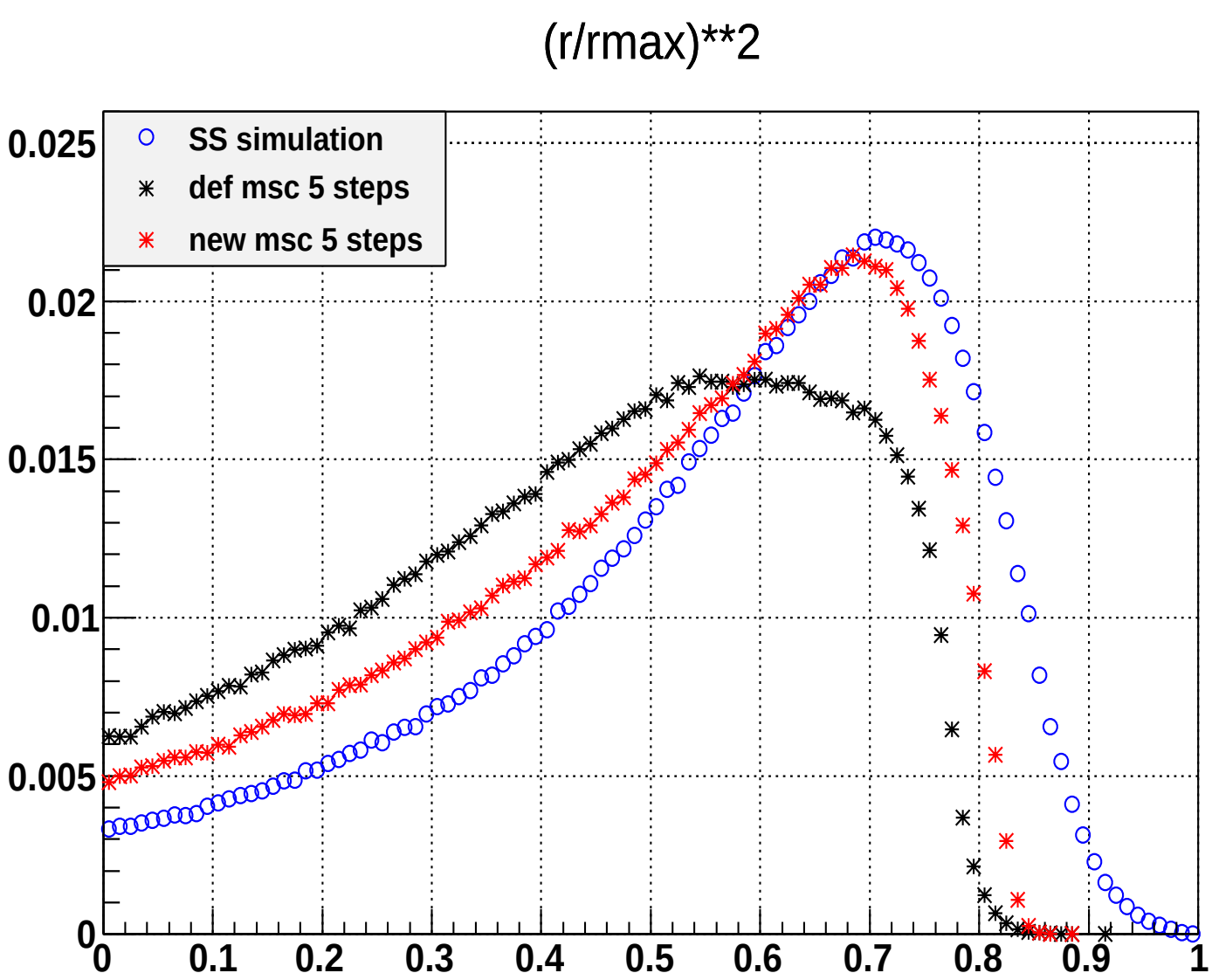
In the updated msc version the lateral displacement and lateral correlation are sampled according to the distributions shown above.

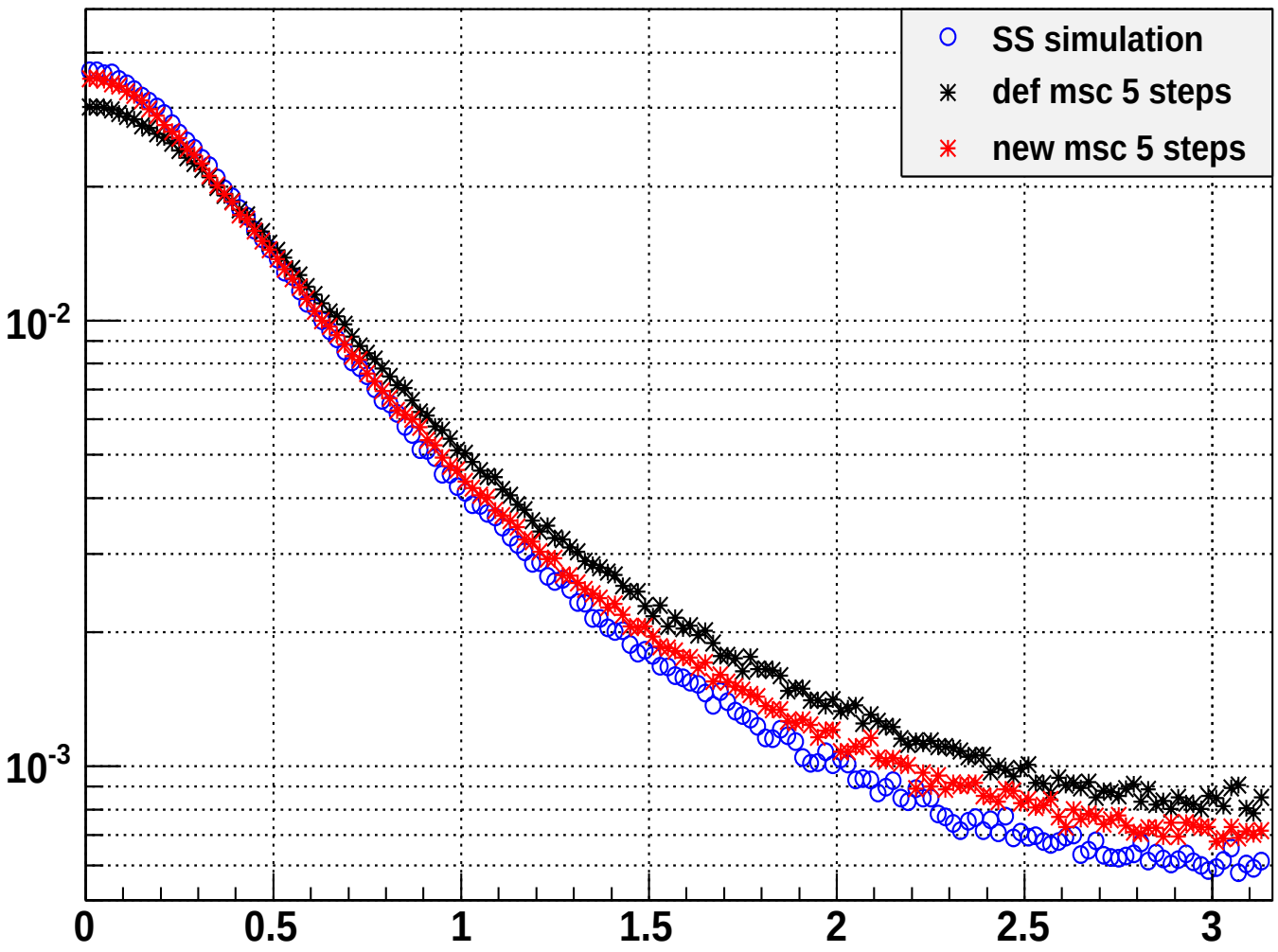
In the next 2 slides show the comparison of the default and new msc results. As it can be seen the difference is really big for both distributions.


(r/rmax)**2
SS simulation
def msc 1 step
new msc 1 step
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Phi-phi = acos(lc/(r*sth))
SS simulation
def msc 1 step
new msc 1 step
10-2
10-3
0
0.5
1
1.5
2
2.5
3

In "real" simulations the difference is not so dramatic. If the particle travels the given pathlength in 5 steps (and not in 1 step), the difference is much smaller, but the new msc version is closer to the SS simulation. This case can be seen in the following 2 plots.


(r/rmax)**2
SS simulation
def msc 5 steps
new msc 5 steps
0.025
0.02
0.015
0.01
0.005
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

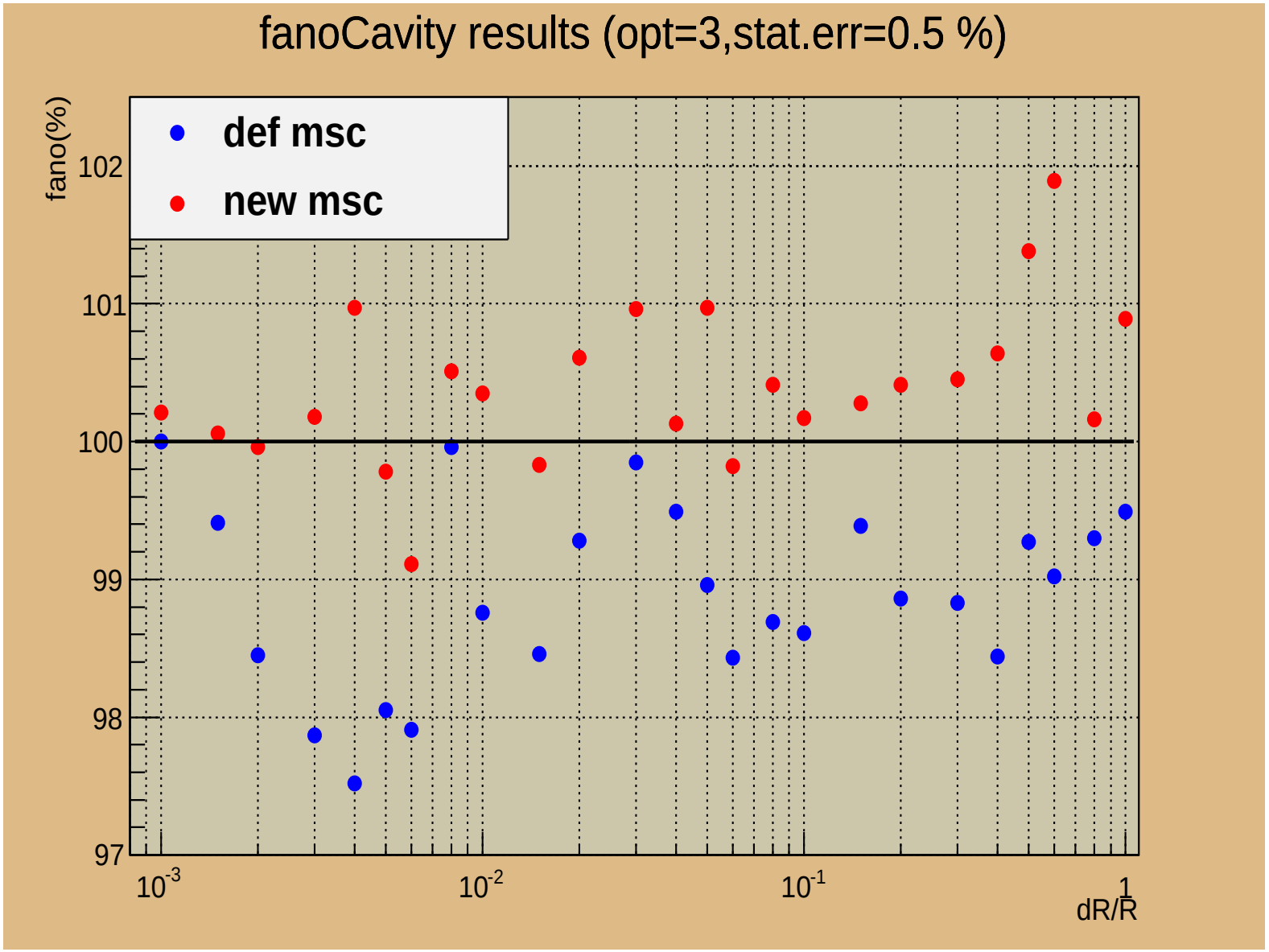

Phi-phi = acos(lc/(r*sth))
SS simulation
def msc 5 steps
new msc 5 steps
10-2
10-3
0
0.5
1
1.5
2
2.5
3

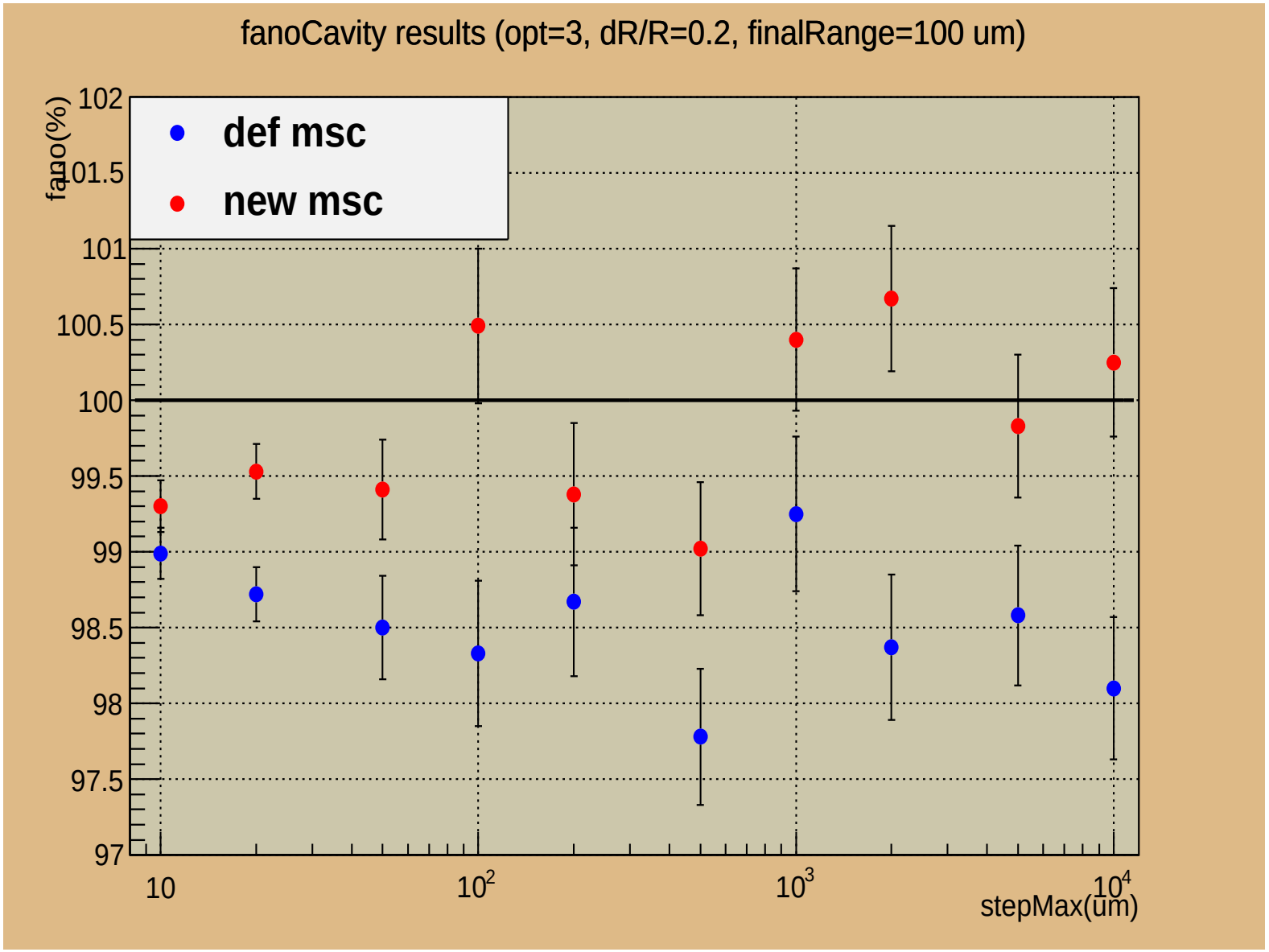
Tests for the new msc code : 1. Fano Cavity test (theory $\leftrightarrow$ MC code)

The first plot is the usual FanoCavity plot, it shows the Fano Cavity results for different step functions, i.e. with step functions with different dR/R values.

The 2nd plot shows the simulation results using the standard step function ($dR/R = 0.2, finalR = 0.1mm$) with different stepmax values.

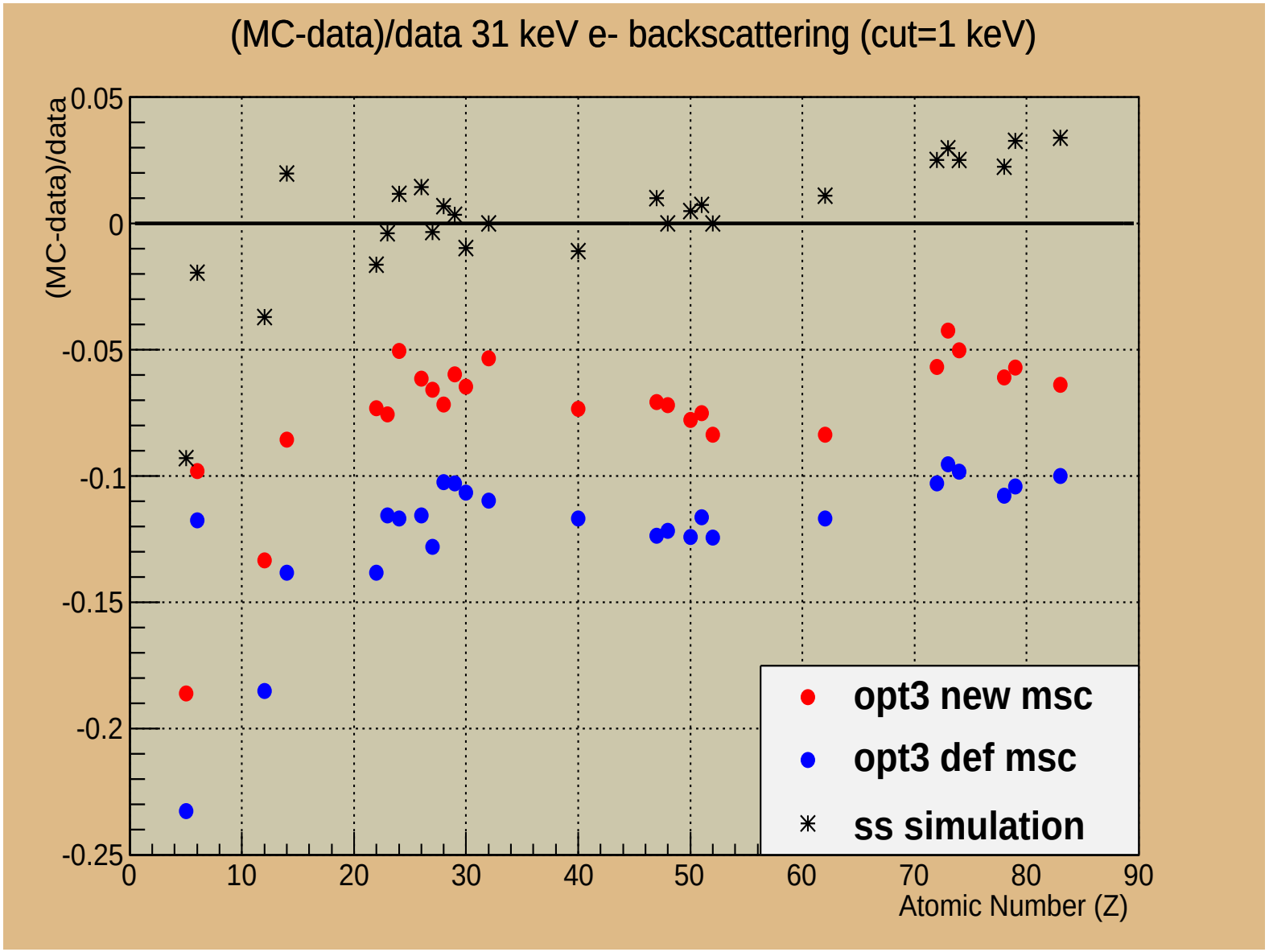
As it can be seen in the plots, the new msc version performs better in both cases.


fanoCavity results (opt=3,stat.err=0.5 %)
def msc
new msc
fano(%)
102
101
100
99
98
97
10^{-3}
10^{-2}
10^{-1}
1
dR/R


fanoCavity results (opt=3, dR/R=0.2, finalRange=100 um)
def msc
new msc
fano(%)
102
101.5
101
100.5
100
99.5
99
98.5
98
97.5
97
10
10^2
10^3
10^4
stepMax(um)

Tests for the new msc code : 2. electron backscattering (data $\leftrightarrow$ MC results)

The next plot shows the backscattering of 31 keV electrons from different (thick) targets. The results of the default msc, the new msc and the single scattering are plotted. The new msc gives better results than the default one, while the ss simulation outperform both of them. It can be seen too, that the backscattering from light materials ($Z \leq 15$) gives the poorest result.


(MC-data)/data 31 keV e- backscattering (cut=1 keV)
(MC-data)/data
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
10
20
30
40
50
60
70
80
90
Atomic Number (Z)
opt3 new msc
opt3 def msc
ss simulation

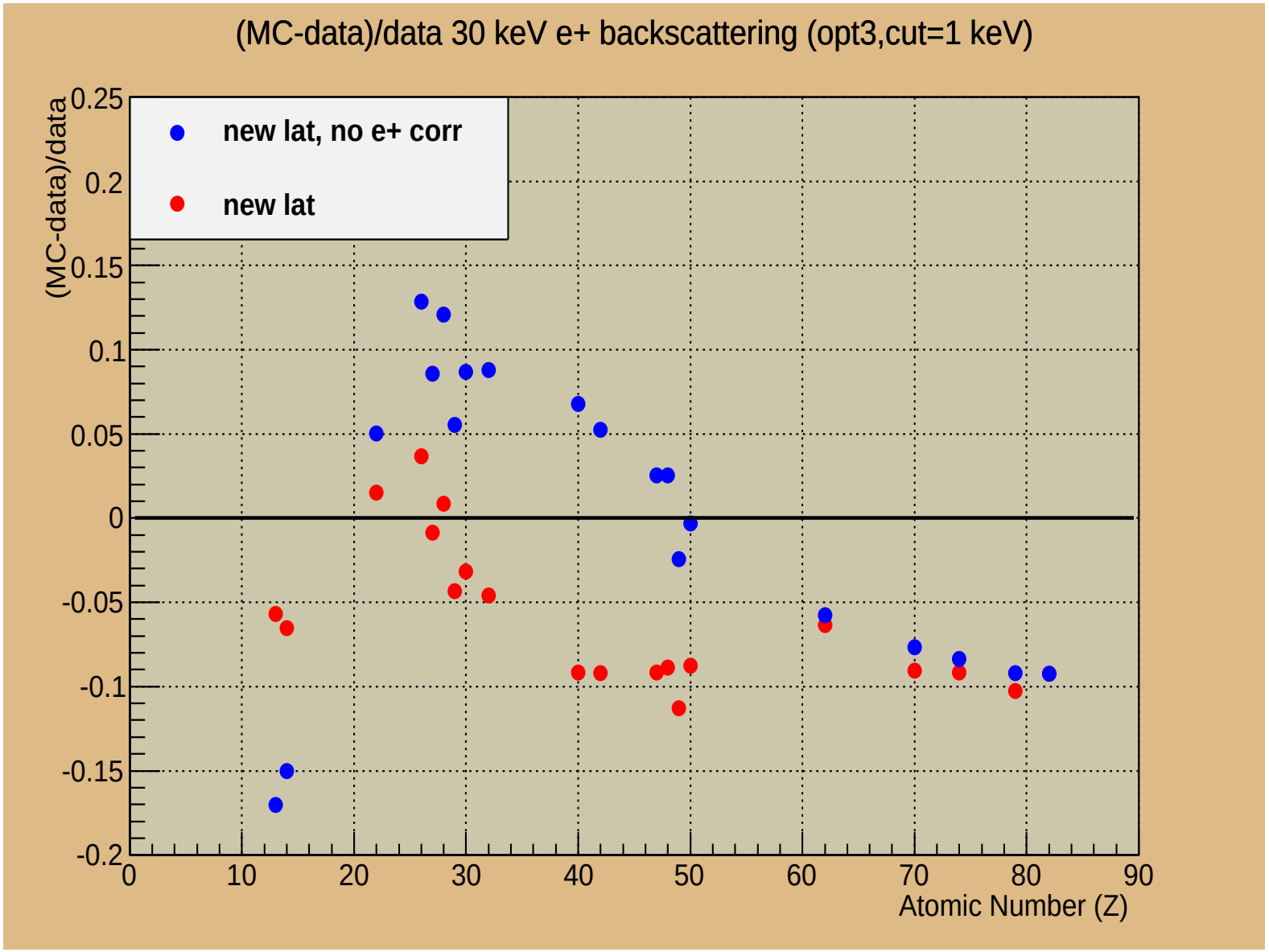
Other tests

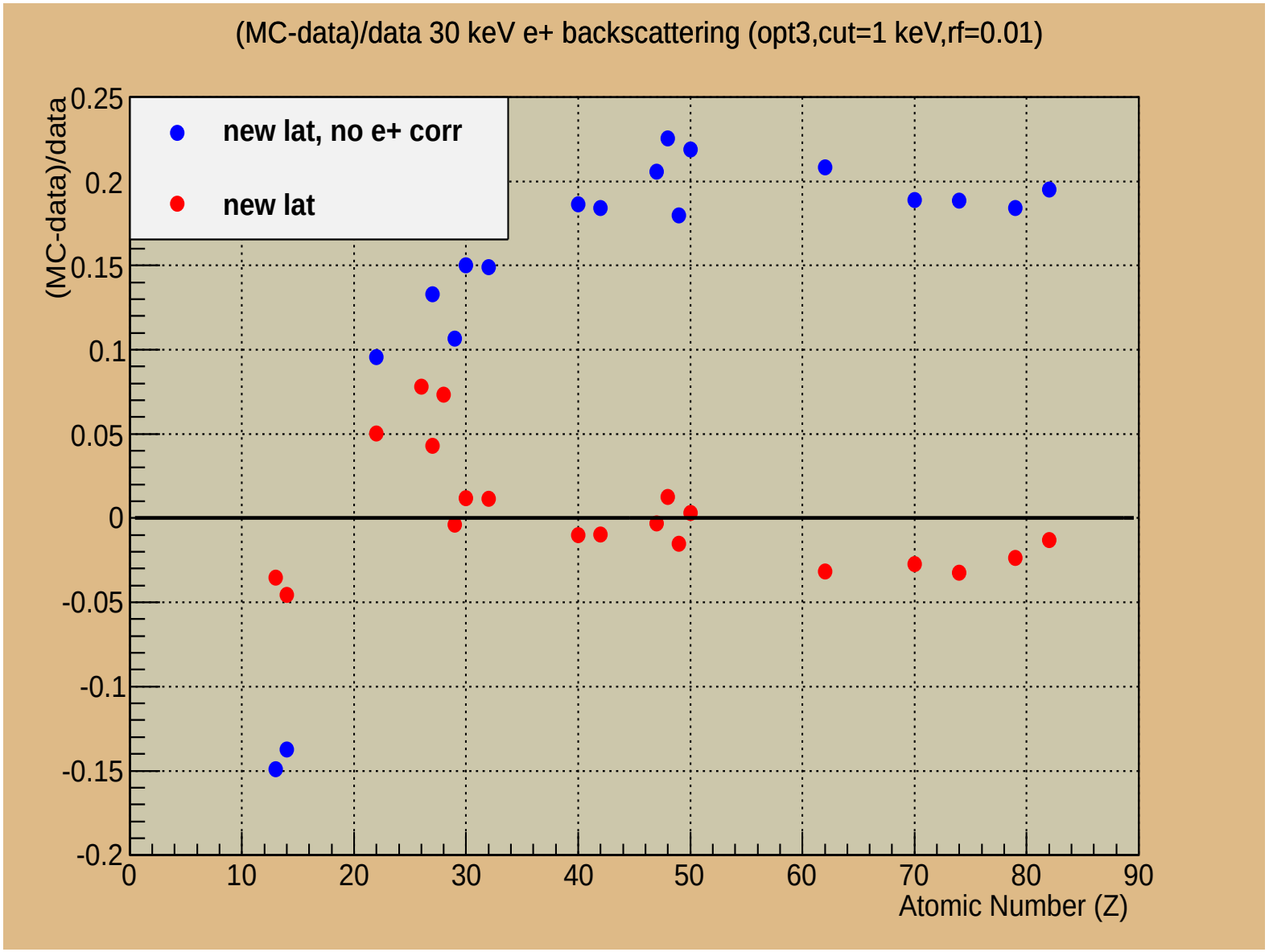
- e- scattering on thin layers: def and new msc give the same results (extreme small differences)
- depth dose distribution for e- in different materials (compared with Sandia data): small differences, new is slightly better for high Z materials.
- depth dose profile in spherical geometry (TestEm12): def and new msc give the same results
- sampling calorimeters : new msc gives bigger E_{vis} by $\approx 1 - 2\%$

Another update : correction to e+ multiple scattering

Simulating the positron backscattering Geant4 gives too big backscattering values, the values are nearly the same as those for e- with the same energy. Examining the code it turned out that there is a part of the model where the code exactly the same for e- and e+, this is the computation of the θ_0 model parameter. I've put a correction for e+ into this part in order to get the positron backscattering correctly.

The simulation results can be seen in the next 2 plots. The 1st gives the results of the 30 keV e+ backscattering without and with the e+ correction, using opt3 and the default $RangeFactor$ 0.04, while the 2nd shows the same simulation using $RangeFactor = 0.01$ (this value is used generally for backscattering simulations).


(MC-data)/data 30 keV e+ backscattering (opt3,cut=1 keV)
new lat, no e+ corr
new lat
(MC-data)/data
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
10
20
30
40
50
60
70
80
90
Atomic Number (Z)


(MC-data)/data 30 keV e+ backscattering (opt3,cut=1 keV,rf=0.01)
new lat, no e+ corr
new lat
(MC-data)/data
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
10
20
30
40
50
60
70
80
90
Atomic Number (Z)

Test of the e+ correction

The correction was made using the 30 keV e+ backscattering data so some other test needed. I have compared the e+ backscattering simulation with data for lower (7 keV) and higher (few MeV) energy, the corrected version is much closer to the data.

The difficulty is that practically there are no other e+ data than backscattering. Therefore I used Berger's ETRAN MC results on the transmission of e- and e+ for thin Al and Au layers. The corrected msc gives results close to Berger's numbers, while the uncorrected version gives good results for electrons and too small transmission for positrons.