Update of the fluctuation model

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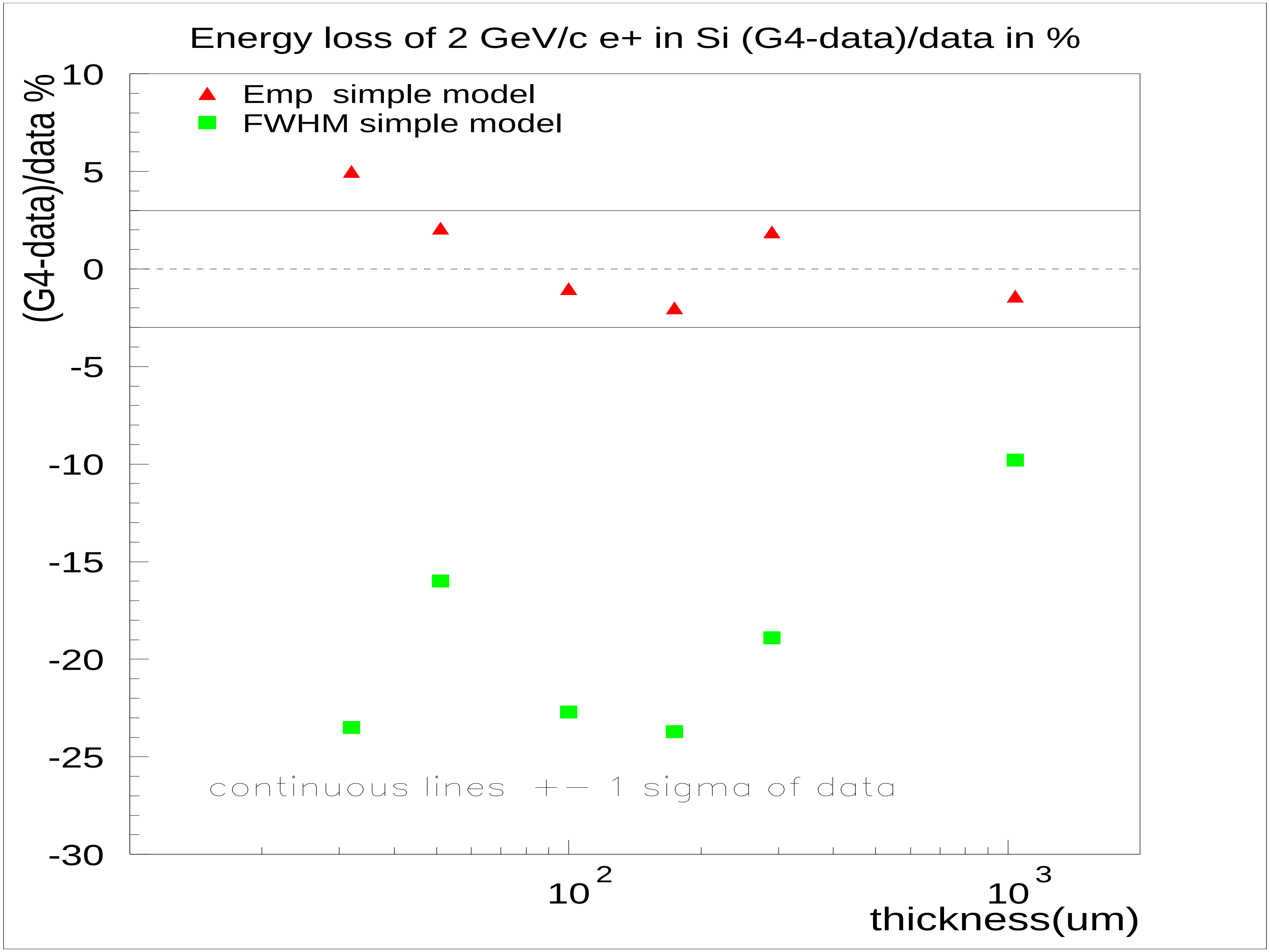
Very simple fluctuation model : 2 energy levels with energy ϵ_1, ϵ_2

energy loss : excitation with energy loss ϵ_1 or ϵ_2

ionization with loss distributed according to a spectrum $1/\epsilon^2$

It gives good peak position, E_{mp}, but the $FWHM$ width of the energy loss distribution is too small.

see next slide


Energy loss of 2 GeV/c e+ in Si (G4-data)/data in %
(G4-data)/data %
Emp simple model
FWHM simple model
10
5
0
-5
-10
-15
-20
-25
-30
continuous lines +− 1 sigma of data
10^2
10^3
thickness(um)

some kind of width correction algorithm needed
basic idea: we have to scale somehow the number of excitations and the excitation energies ϵ_1,ϵ_2 in such a way that the mean (discrete) energy loss should be the same as before

$\longrightarrow$ the width of the distribution will change
we have to use some data in order to tune the width (high energy e+/e- in Si counters).

there are many possibilities for such an algorithm.
empirical width correction in the model (starting from Geant4 version 9.0)

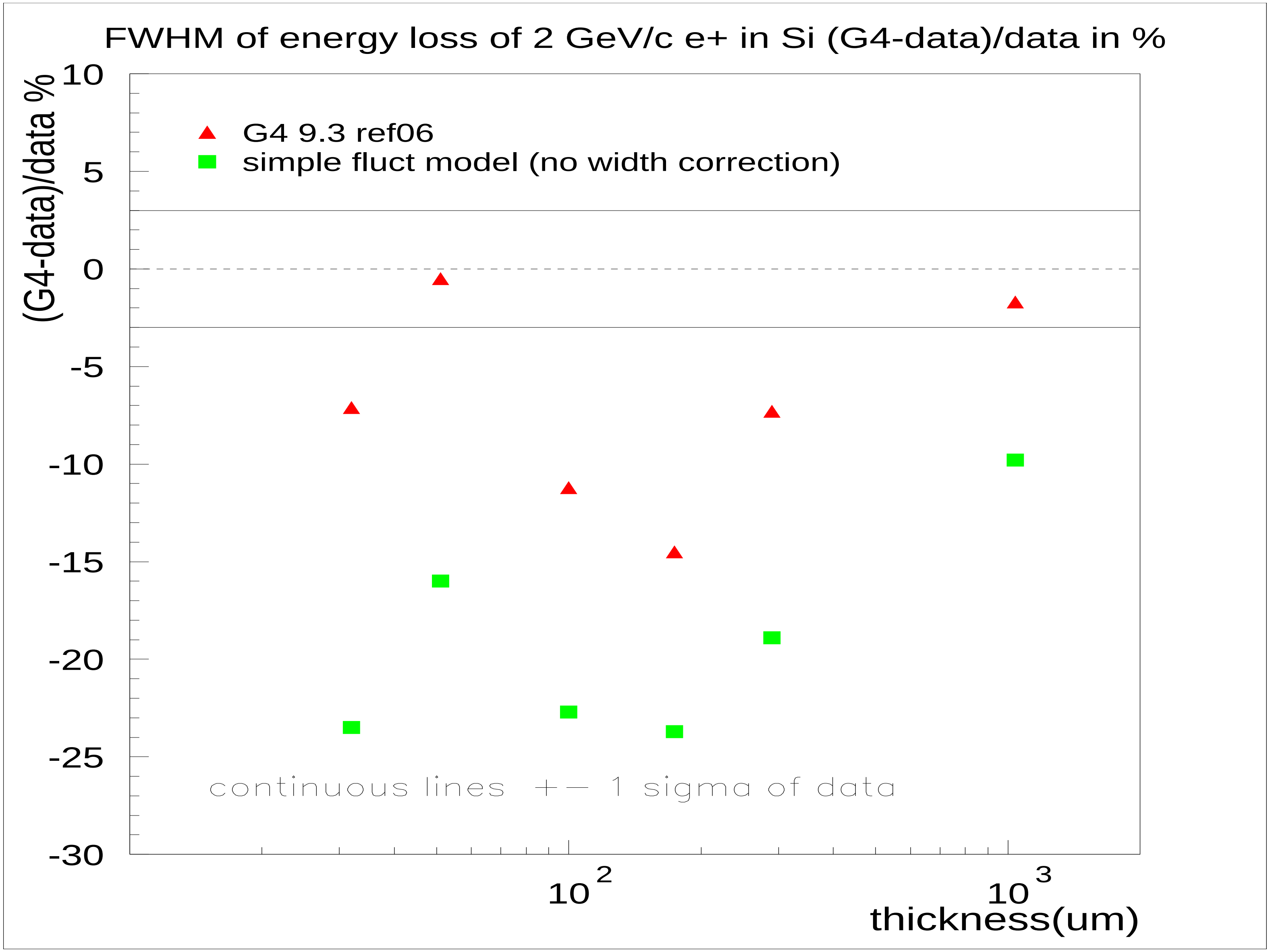
width correction algorithm can depend on the mean loss, the material and the number of exitation with energies ϵ_1, ϵ_2.

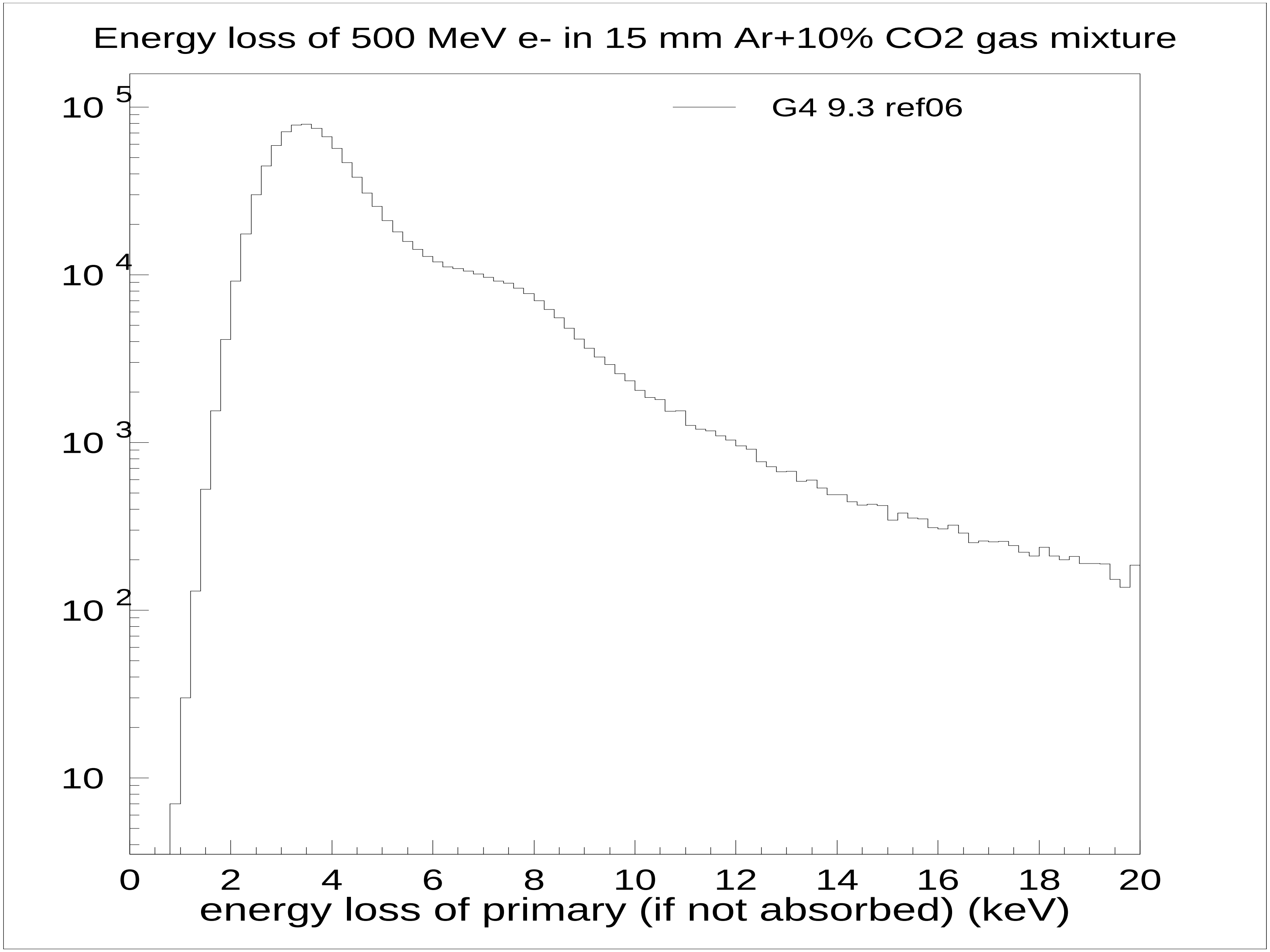
width correction in Geant4 9.3 ref06 gives better FWHM values for high energy particles passing through Si counters than the simple model without width corrections,

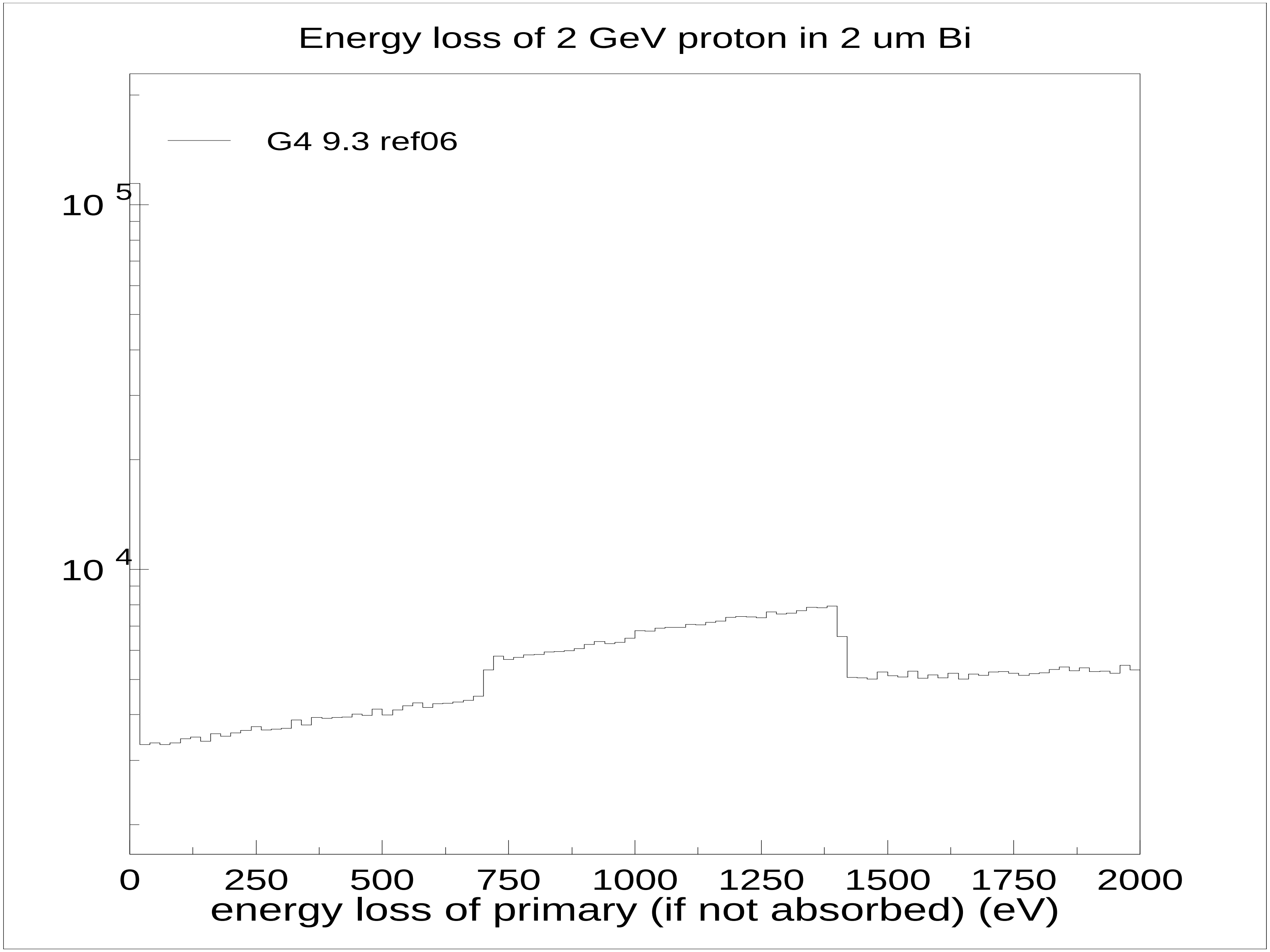
but it has several problems

- FWHM values are better than in simple model, but not good
- shape of the energy loss distribution has an unphysical shoulder for thin target
- shape of the loss distr. is bad for extreme thin targets

next slides


FWHM of energy loss of 2 GeV/c e+ in Si (G4-data)/data in %
(G4-data)/data %
10
5
0
-5
-10
-15
-20
-25
-30
G4 9.3 ref06
simple fluct model (no width correction)
continuous lines +− 1 sigma of data
10 2
10 3
thickness(um)

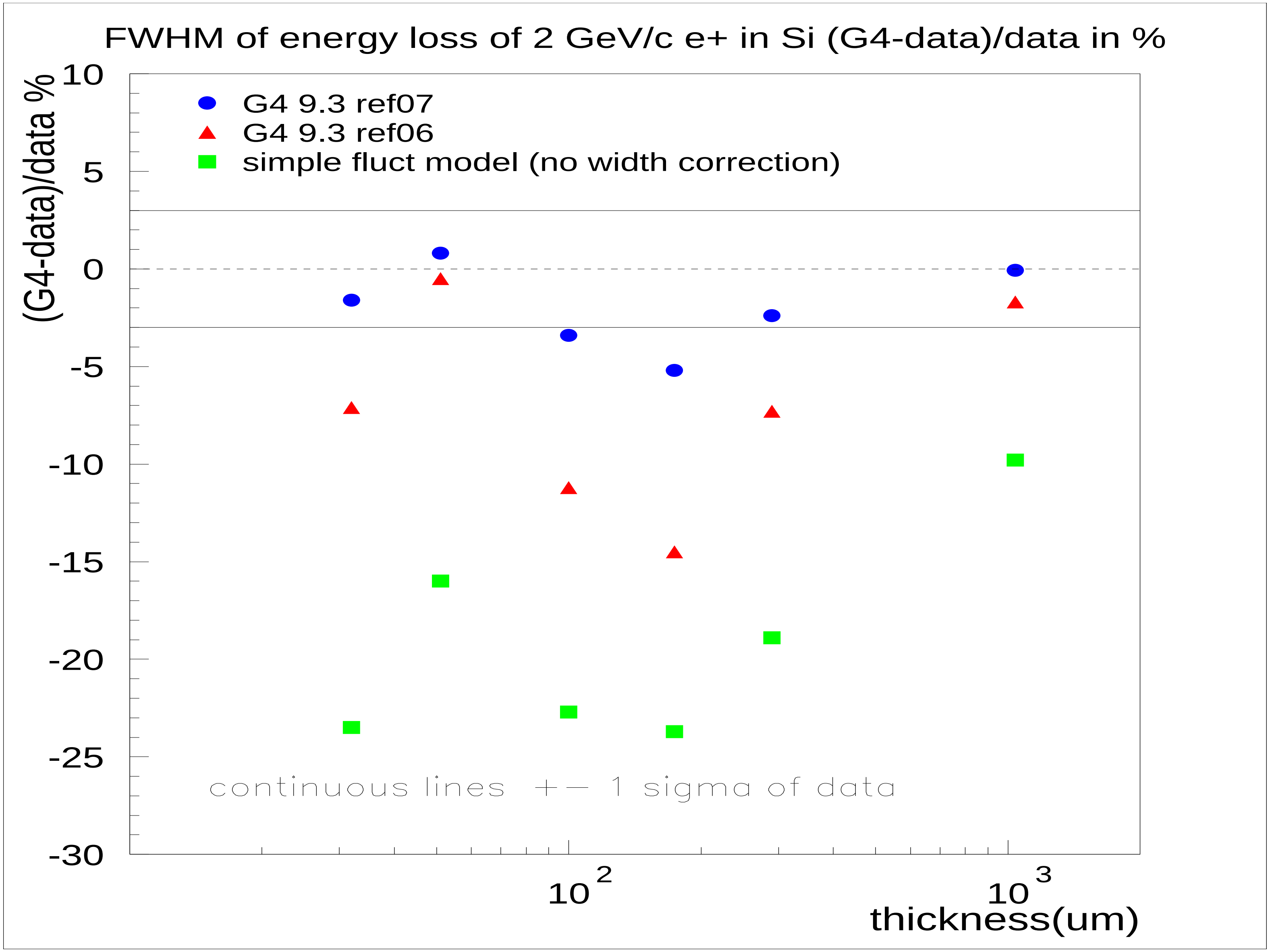

Energy loss of 500 MeV e- in 15 mm Ar+10% CO2 gas mixture
G4 9.3 ref06
10 5
10 4
10 3
10 2
10
0
2
4
6
8
10
12
14
16
18
20
energy loss of primary (if not absorbed) (keV)

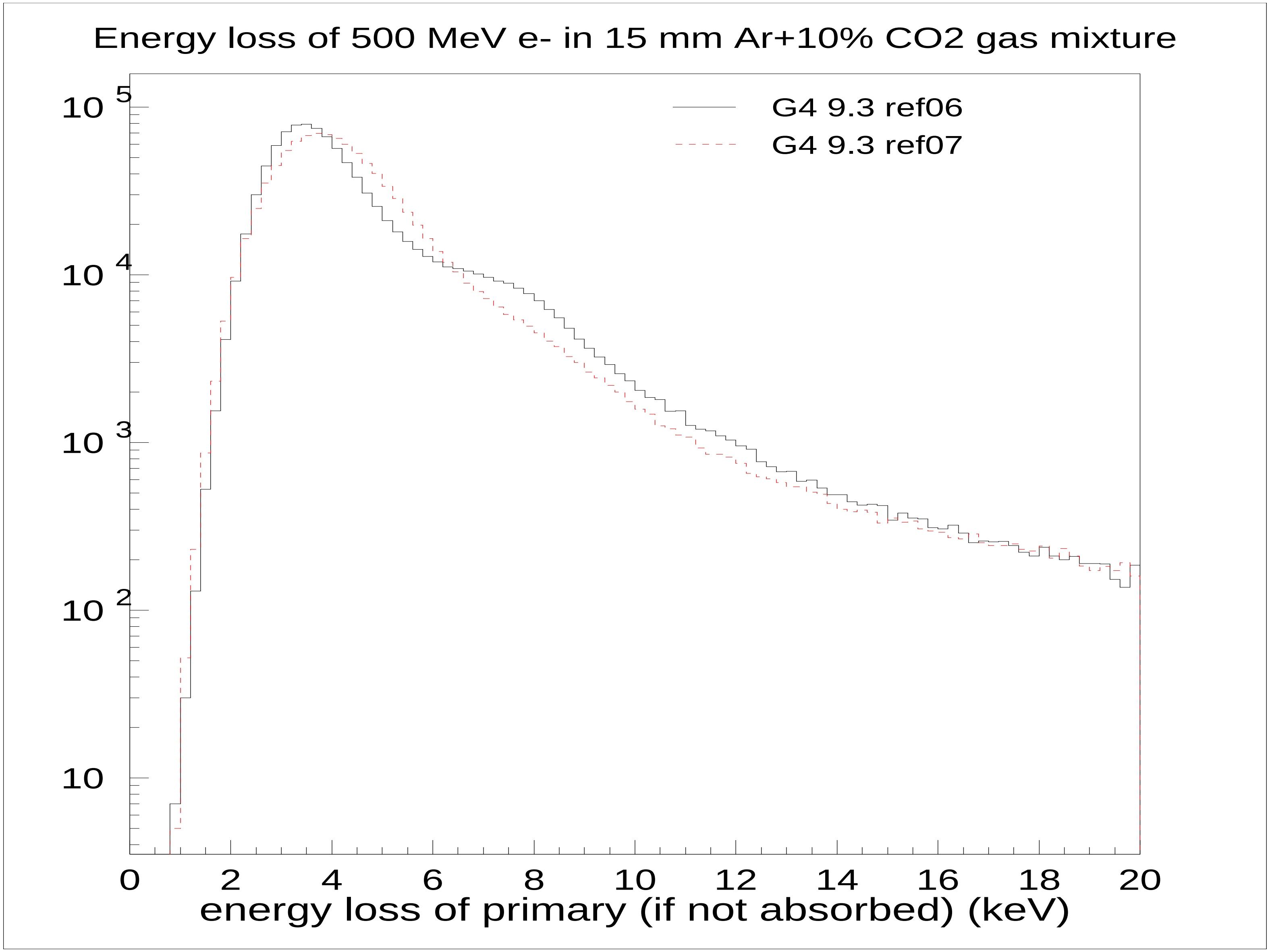

Energy loss of 2 GeV proton in 2 um Bi
G4 9.3 ref06
10 5
10 4
0
250
500
750
1000
1250
1500
1750
2000
energy loss of primary (if not absorbed) (eV)

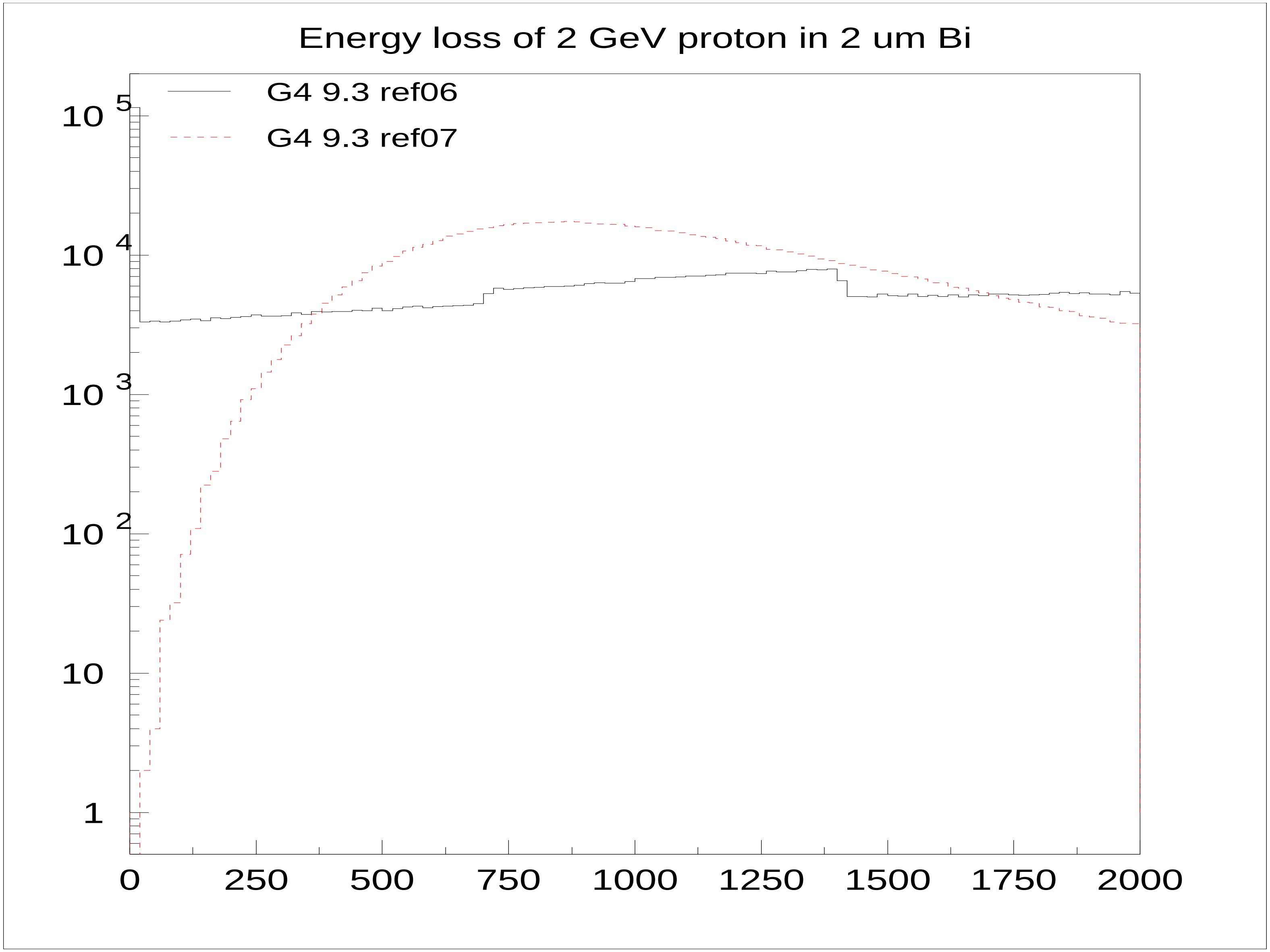
Geant4 9.3 ref07: new width correction algorithm to cure the problems of the fluct. model in ref06

the algorithm does not depend on the mean energy loss in the step, it depends on the material and the number of exitation with energies ϵ_1, ϵ_2
and it is not the same technically than it was in ref 06.

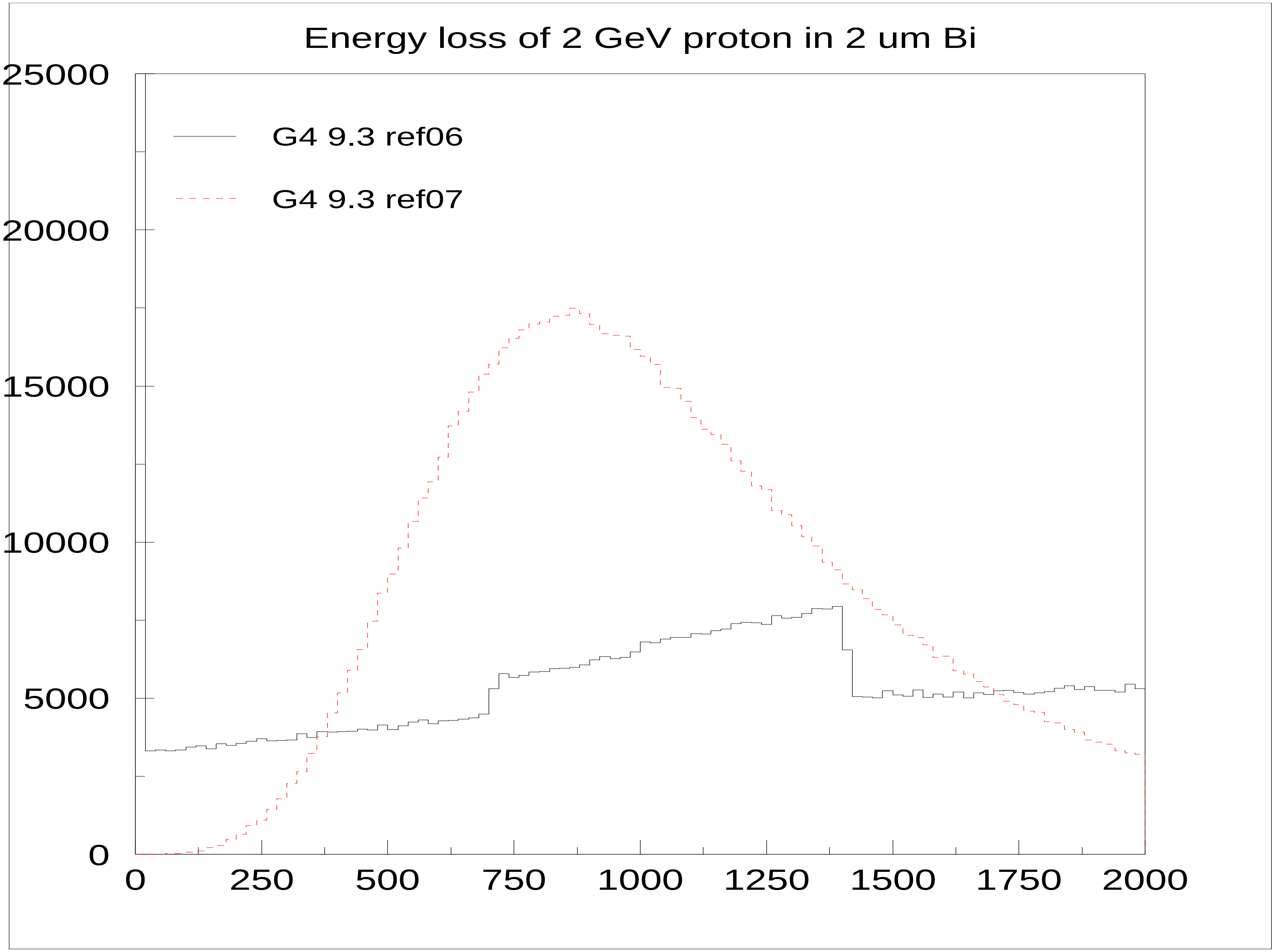
some results are in the following slides..


FWHM of energy loss of 2 GeV/c e+ in Si (G4-data)/data in %
(G4-data)/data %
G4 9.3 ref07
G4 9.3 ref06
simple fluct model (no width correction)
continuous lines +− 1 sigma of data
thickness(um)
10
5
0
-5
-10
-15
-20
-25
-30
10^2
10^3


Energy loss of 500 MeV e- in 15 mm Ar+10% CO2 gas mixture
G4 9.3 ref06
G4 9.3 ref07
10
10 2
10 3
10 4
10 5
0
2
4
6
8
10
12
14
16
18
20
energy loss of primary (if not absorbed) (keV)



Energy loss of 2 GeV proton in 2 um Bi
G4 9.3 ref06
G4 9.3 ref07
10 5
10 4
10 3
10 2
10
1
0
250
500
750
1000
1250
1500
1750
2000


Energy loss of 2 GeV proton in 2 um Bi
G4 9.3 ref06
G4 9.3 ref07
25000
20000
15000
10000
5000
0
0
250
500
750
1000
1250
1500
1750
2000

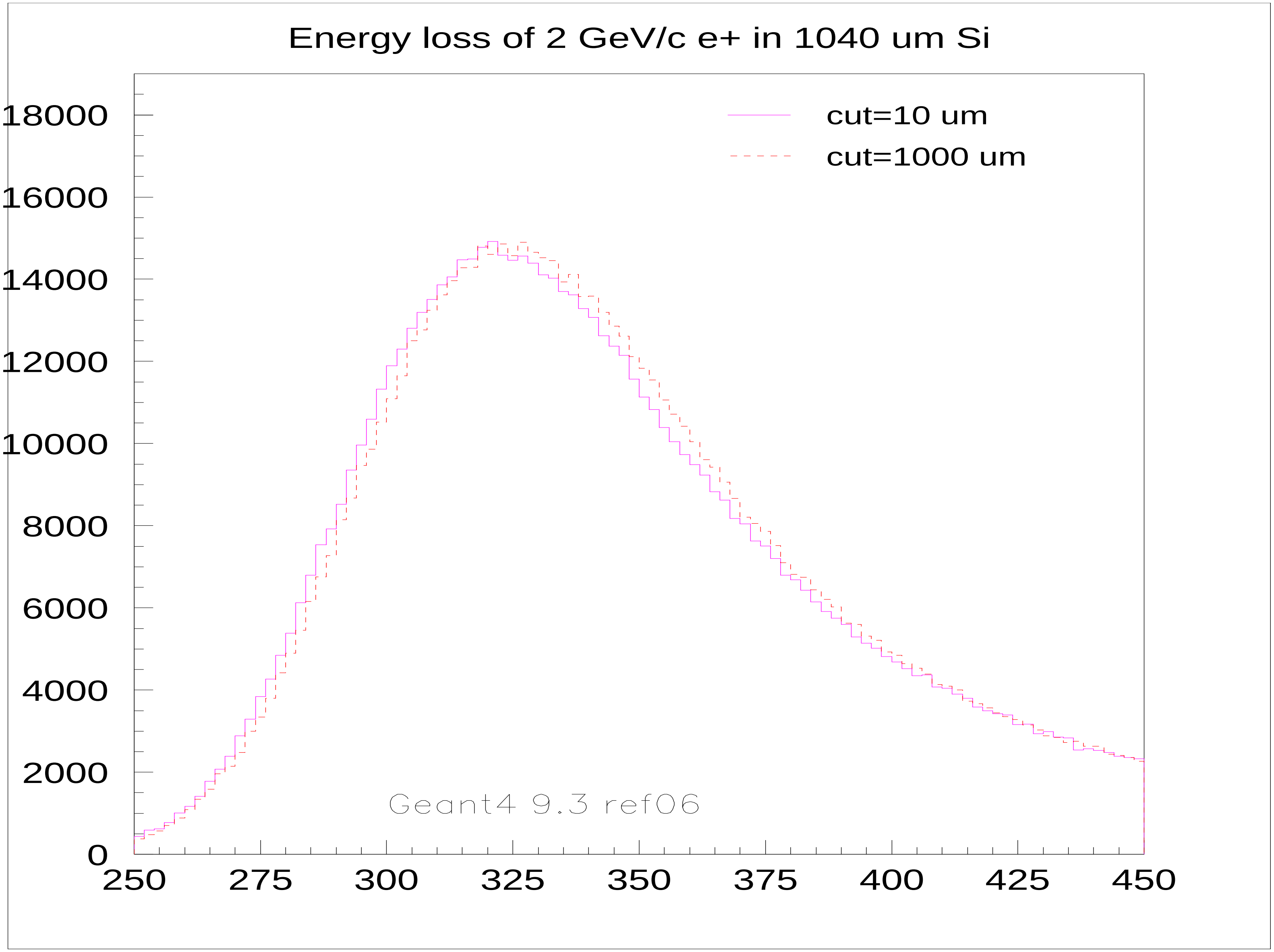
Other results/tests

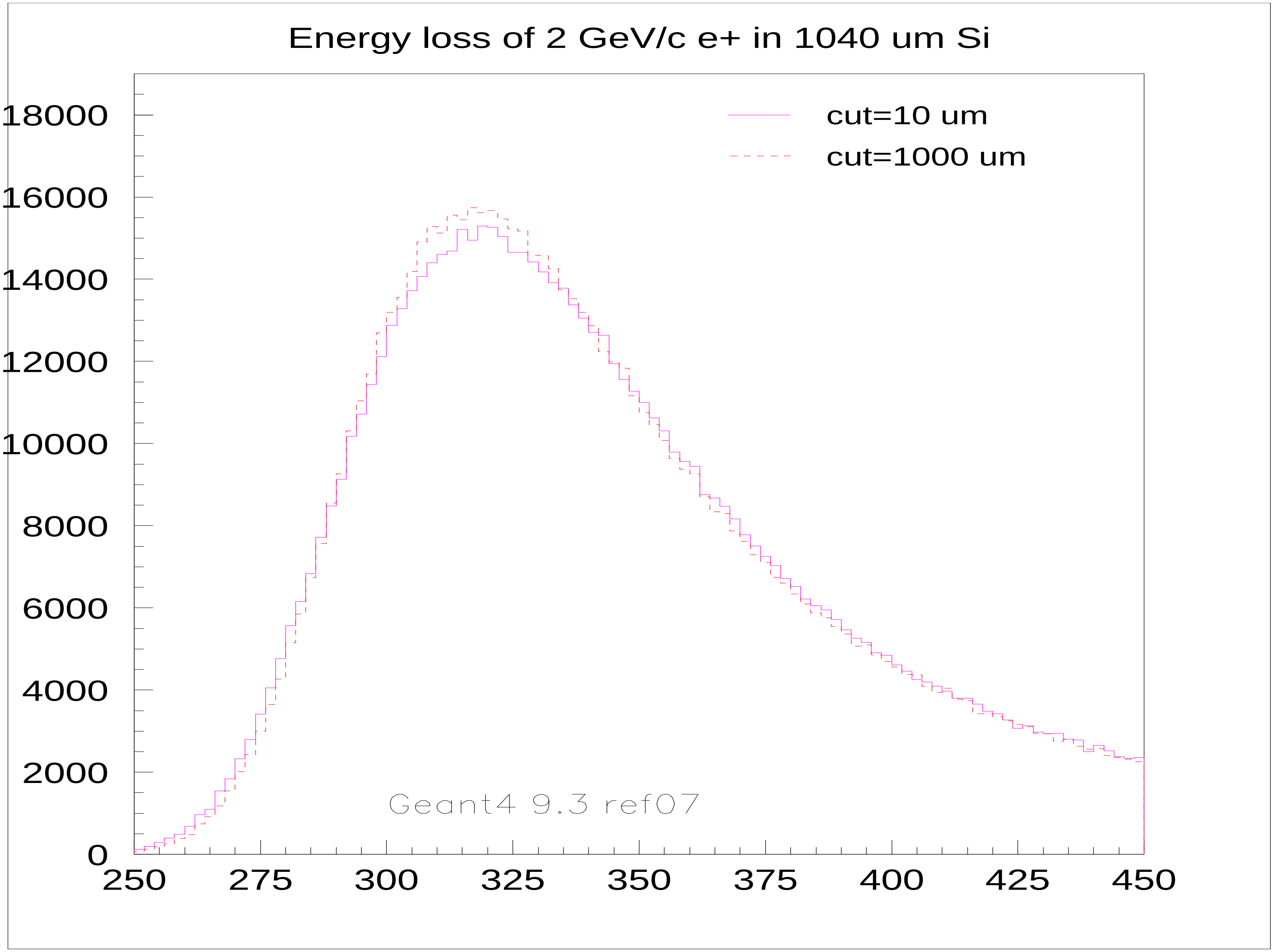
Cut dependence: 2 GeV/c e+ in 1040 um Si, cut=10 um and 1000 um.

weak cut dependence in ref06

the dependence weaker in ref07

see next 2 slides


Energy loss of 2 GeV/c e+ in 1040 um Si
cut=10 um
cut=1000 um
Geant4 9.3 ref06
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
250
275
300
325
350
375
400
425
450


Energy loss of 2 GeV/c e+ in 1040 um Si
cut=10 um
cut=1000 um
Geant4 9.3 ref07
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
250
275
300
325
350
375
400
425
450

Other results/tests

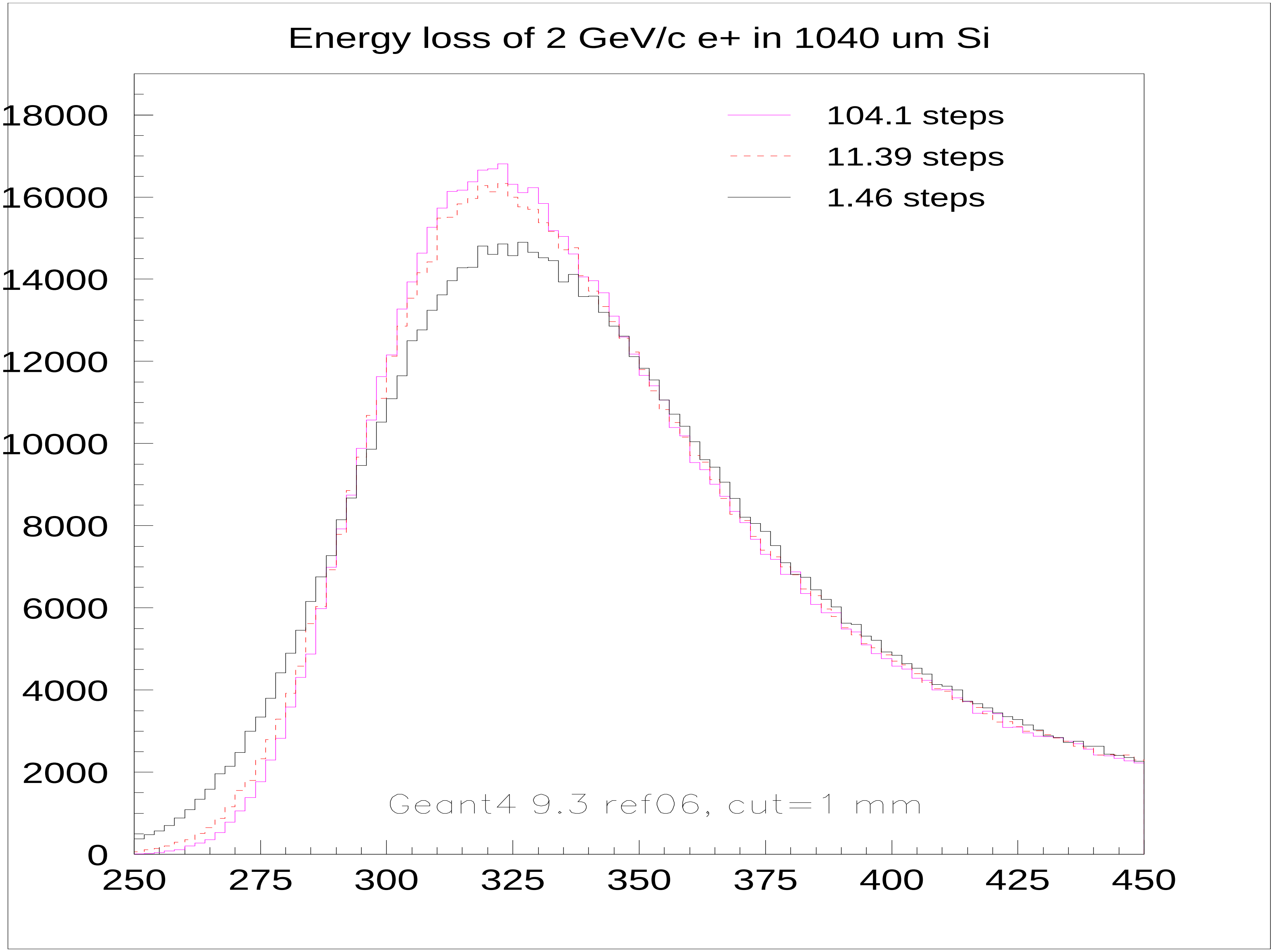
Step dependence: 2 GeV/c e+ in 1040 um Si, no stepmax,

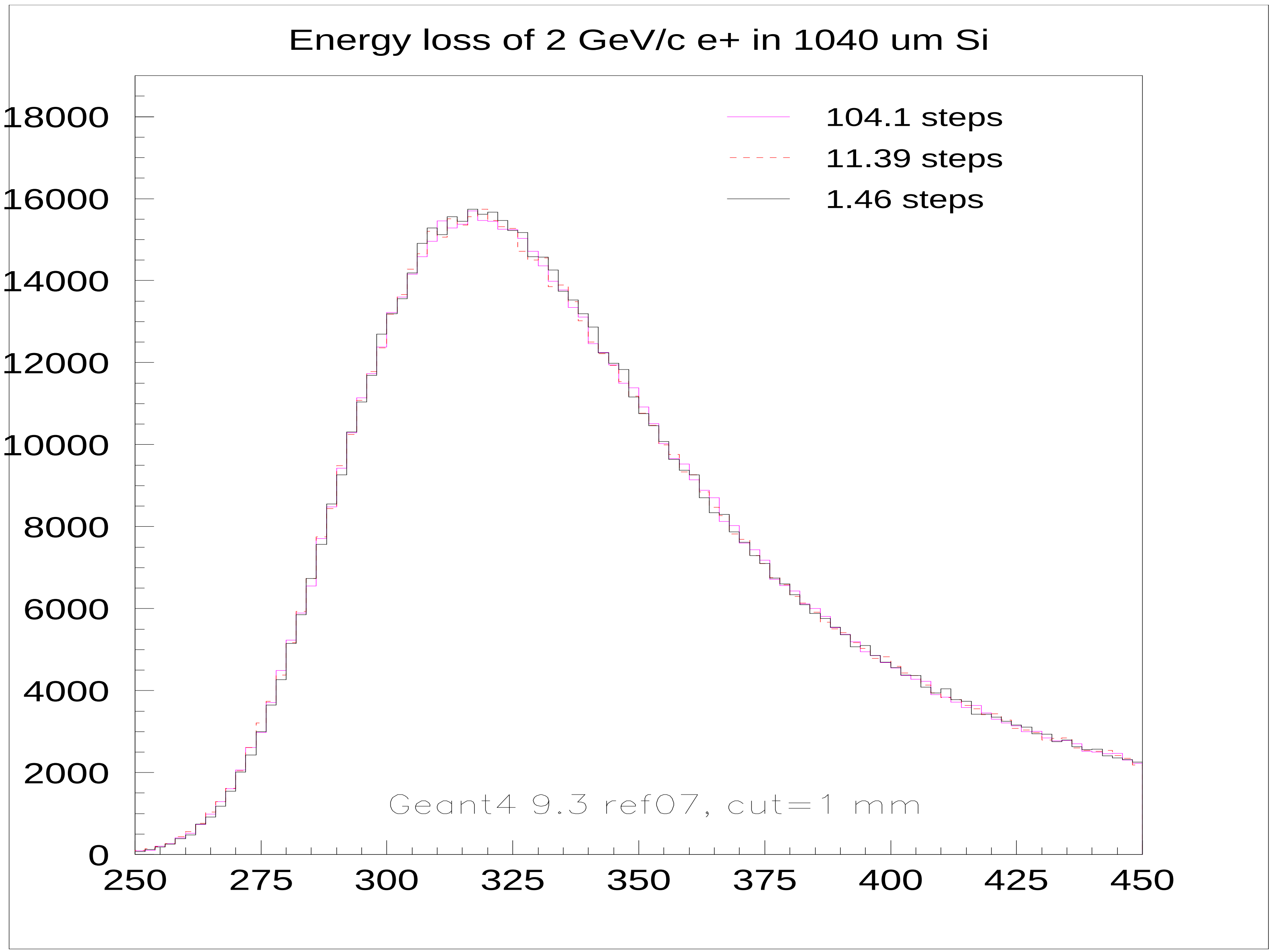
stepmax=104 um, stepmax=10.4 um

step dependence in ref06

practically no step dependence in ref07

see next 2 slides


Energy loss of 2 GeV/c e+ in 1040 um Si
104.1 steps
11.39 steps
1.46 steps
Geant4 9.3 ref06, cut=1 mm
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
250
275
300
325
350
375
400
425
450


Energy loss of 2 GeV/c e+ in 1040 um Si
104.1 steps
11.39 steps
1.46 steps
Geant4 9.3 ref07, cut=1 mm
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
250
275
300
325
350
375
400
425
450

FWHM has been tuned using e+/e- data in silicon.

What about E_{mp} and $FWHM$ in other materials ?

Geant4 9.3 ref07 results only, data - simulation comparisons

Table 1: E_{mp} in MeV for e- energy losses

target	t(g/cm2)	Tkin (MeV)	data	error	theory	Geant4
Li	2.715	150.	3.78	0.12	3.81	3.80
Be	0.748	15.7	0.95	0.02	0.94	0.94
C	1.820	150.	2.78	0.09	2.73	2.70
Al	0.859	15.7	1.11	0.02	1.15	1.15
Cu	0.840	15.7	0.98	0.02	1.00	1.01
Pb	1.135	11.5	1.25	0.10	1.14	1.26

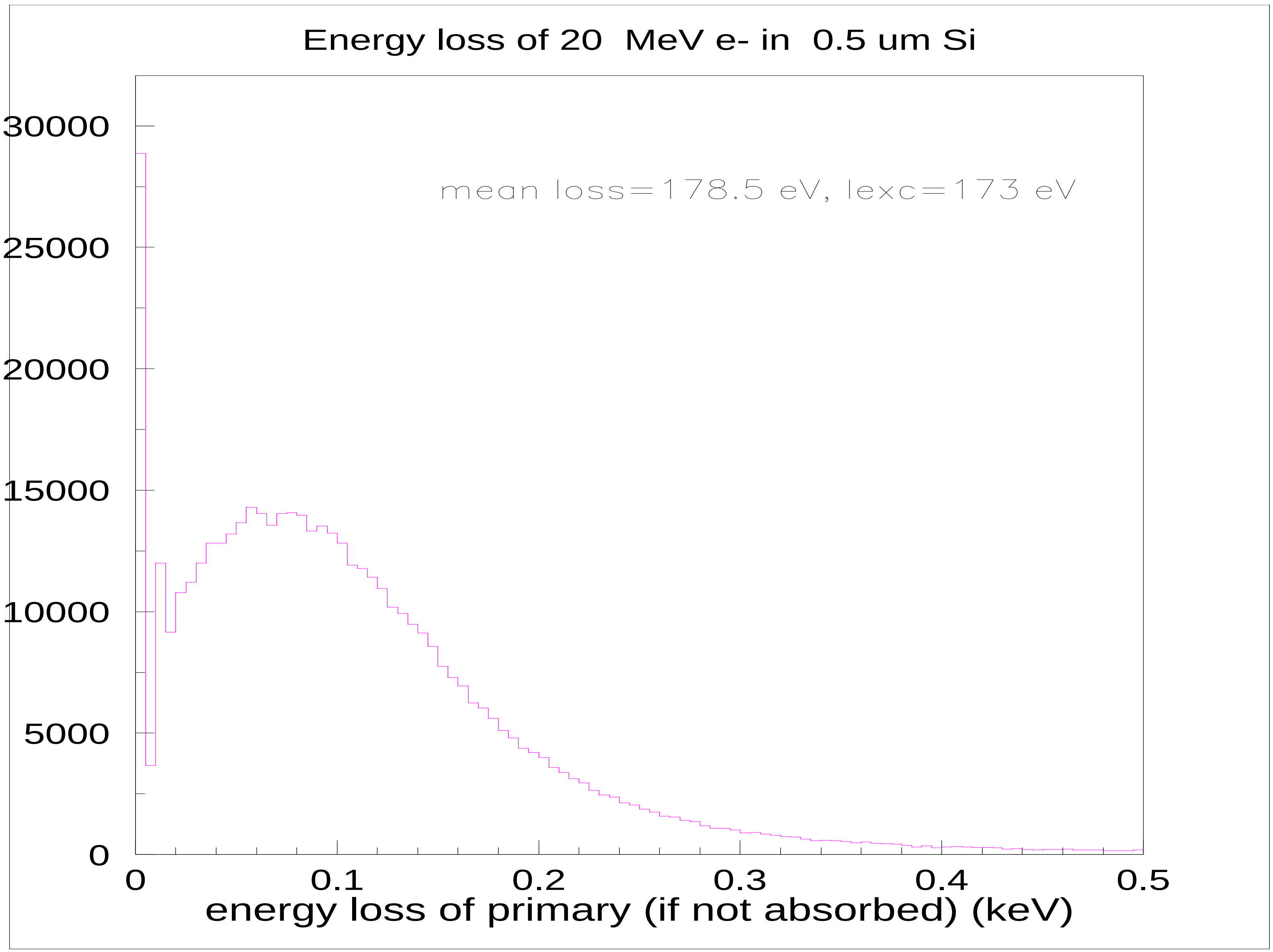
Table 2: *FWHM* MeV for e- energy losses

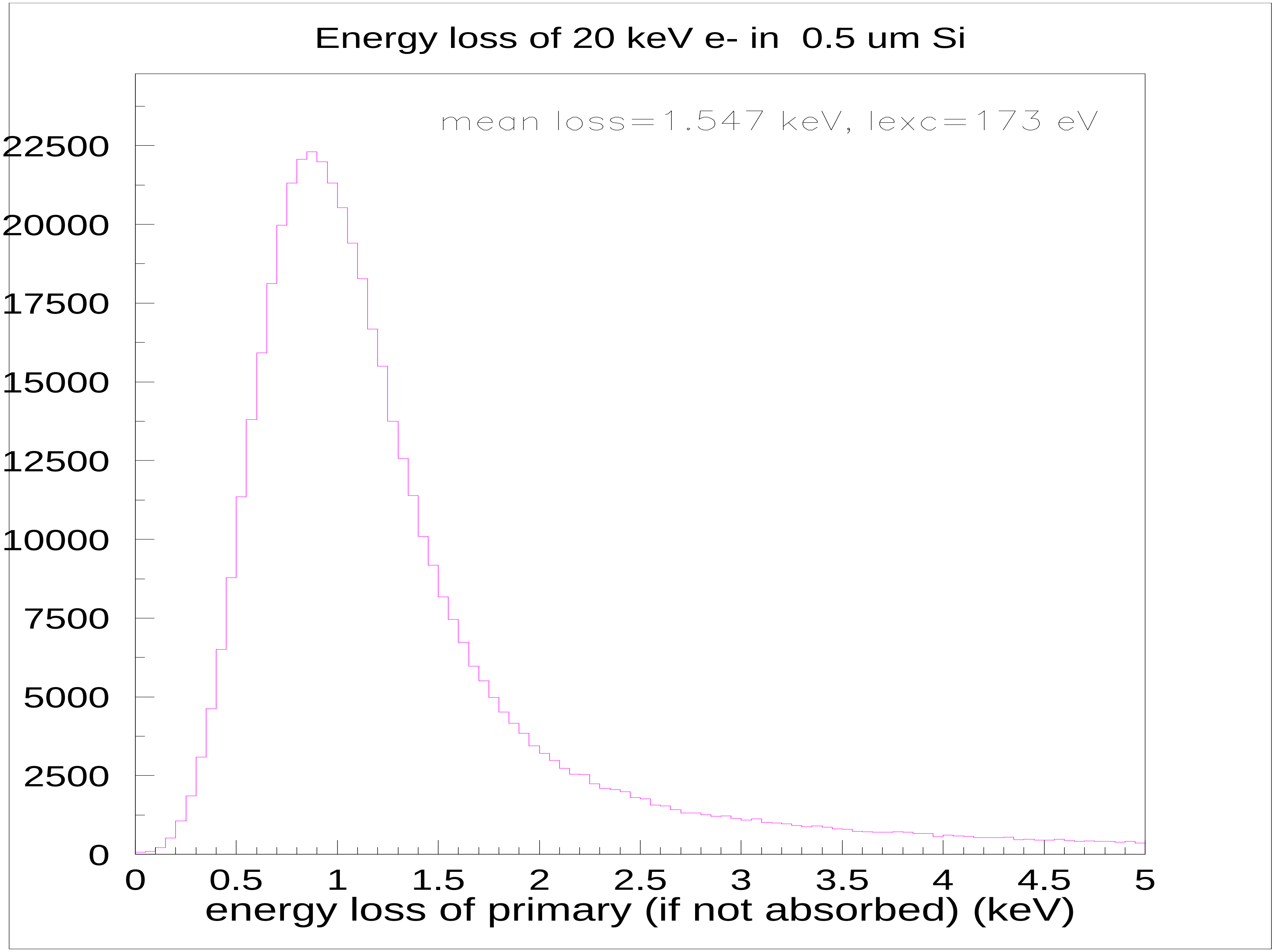
target	t(g/cm2)	Tkin (MeV)	data	error	theory	Geant4
Li	2.715	150.	0.90	0.01	0.78	0.82
Be	0.748	15.7	0.20	0.02	0.20	0.21
C	1.820	150.	0.81	0.01	0.67	0.66
Al	0.859	15.7	0.27	0.02	0.27	0.29
Cu	0.840	15.7	0.28	0.02	0.27	0.29
Pb	1.135	11.5	—-	—-	0.63	0.66

The results of the simulation seem to be OK, when the simulation differs from data it agrees with the theory as written down in ref. 2. and 3.

Limits of validity of the model

Thick targets : model approaches the Gaussian mode smoothly
Thin targets : the limit is not in thickness of the target
the model gives good (reliable) energy loss distribution if the mean energy loss in the target is $\geq$ (few times)*I_{exc}, where I_{exc} is the mean excitation energy of the target.
examples on next 2 slides


Energy loss of 20 MeV e- in 0.5 um Si
mean loss=178.5 eV, Iexc=173 eV
30000
25000
20000
15000
10000
5000
0
0
0.1
0.2
0.3
0.4
0.5
energy loss of primary (if not absorbed) (keV)


Energy loss of 20 keV e- in 0.5 um Si
mean loss=1.547 keV, Iexc=173 eV
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
energy loss of primary (if not absorbed) (keV)

References (energy loss distribution data)

1. H.Bichsel, Rev.Mod.Phys., Vol 60 (1968) p. 663-698. (theory for Si losses+ Si data)
2. J.L. Matthews at al. NIM 180 (1981) p. 573-579. (e- energy loss distributions)
3. Y. Mejaddem at al. NIM B 173 (2001) p. 397-410. (e- energy loss distributions).