Study of 1D and 2D scaling methods for proton and carbon beams

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GEANT4 Simulations

→ Electromagnetic and nuclear processes

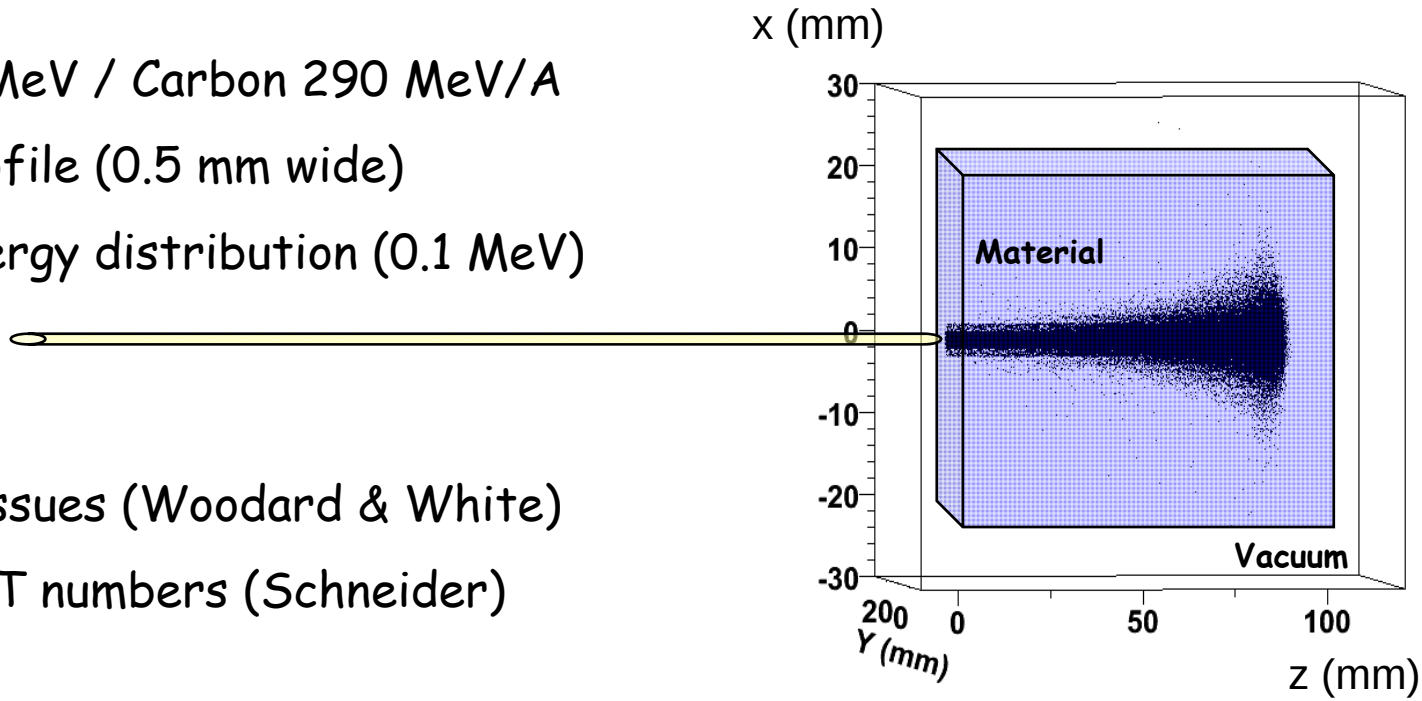
→ 20 000 events

Beam

→ Proton 135 MeV / Carbon 290 MeV/A

→ Gaussian profile (0.5 mm wide)

→ Gaussian energy distribution (0.1 MeV)

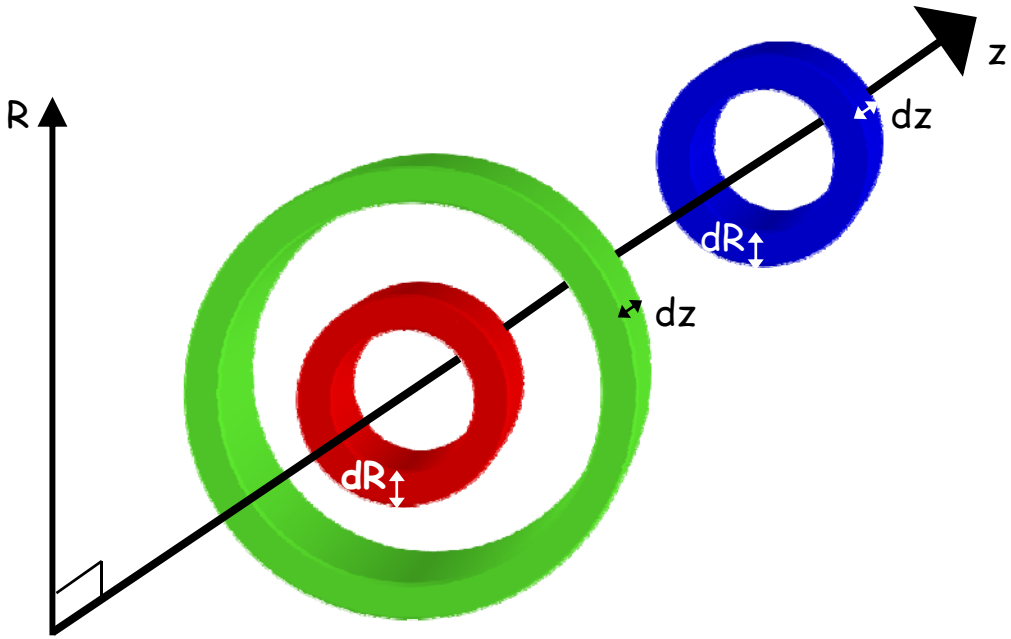


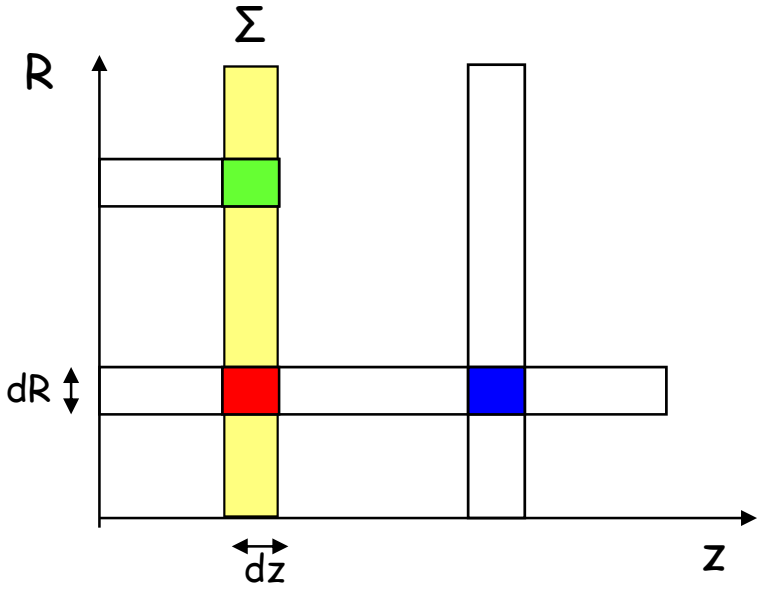
Materials

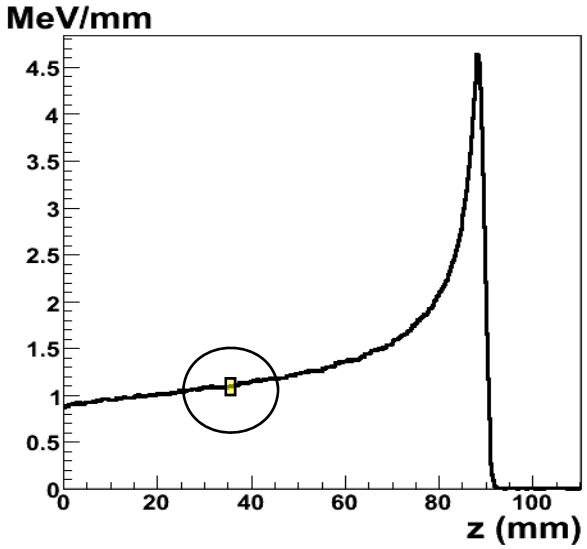
→ 76 human tissues (Woodard & White)

→ calculated CT numbers (Schneider)

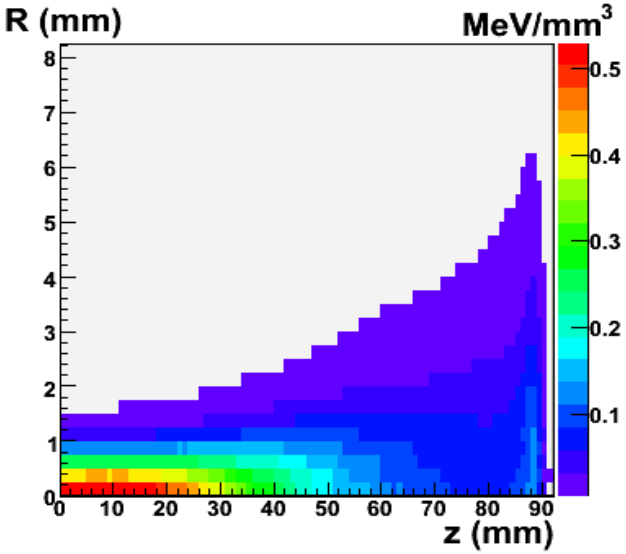
Pshenichnov I et al. Phys. Med. Biol (50), 5493-5507 (2005)
Woodard & White Br. J. Radiol (59), 1209-1219 (1986)
Woodard & White Br. J. Radiol (60), 907-913 (1987)
Schneider et al. Phys. Med. Biol (45), 459-478 (2000)





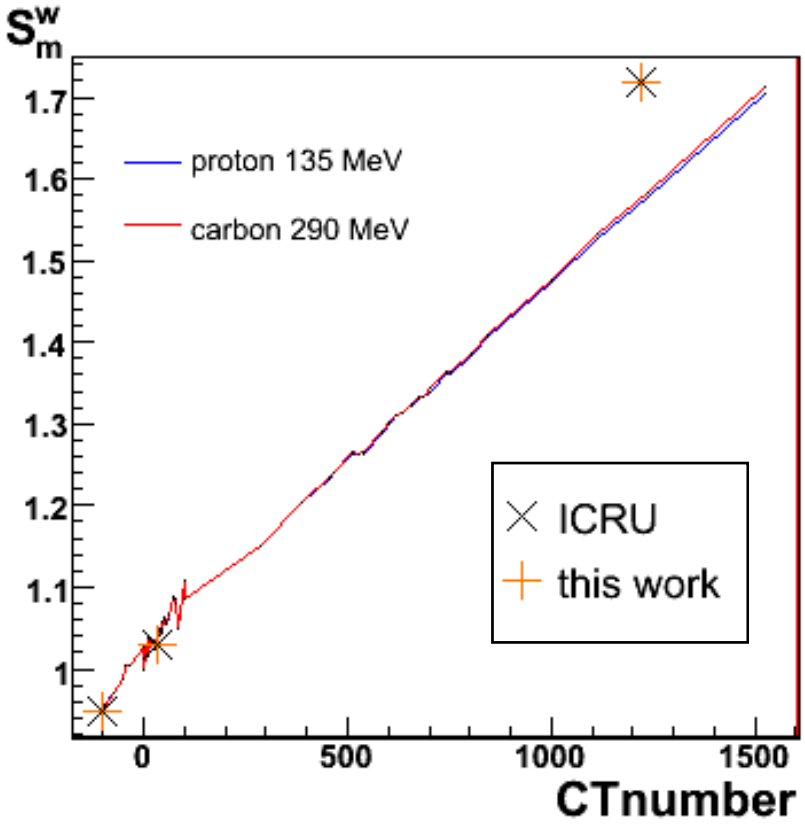


LET curve



Lateral Broadening

$$z_m = z_w S_m^w$$

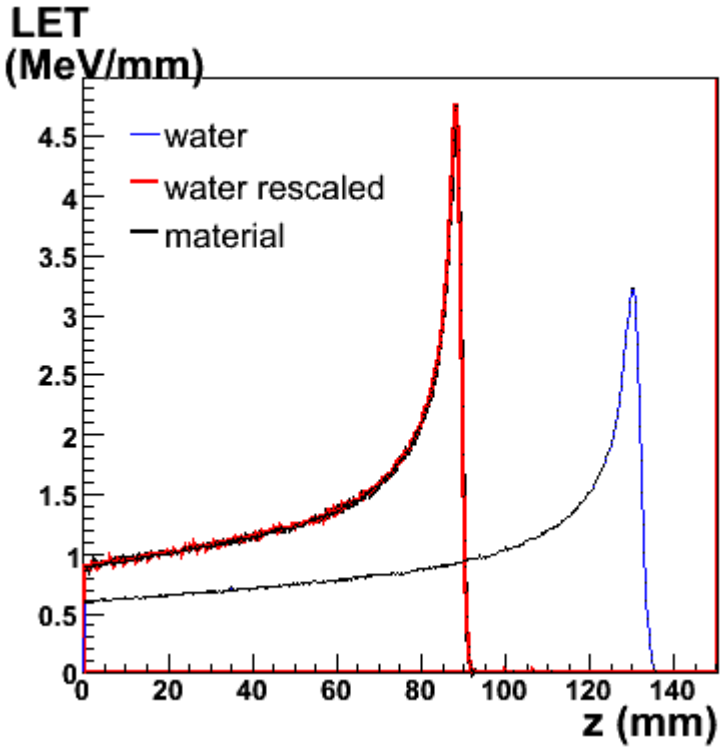


S_m^w = ratio of Bragg Peak locations

S_m^w independent of

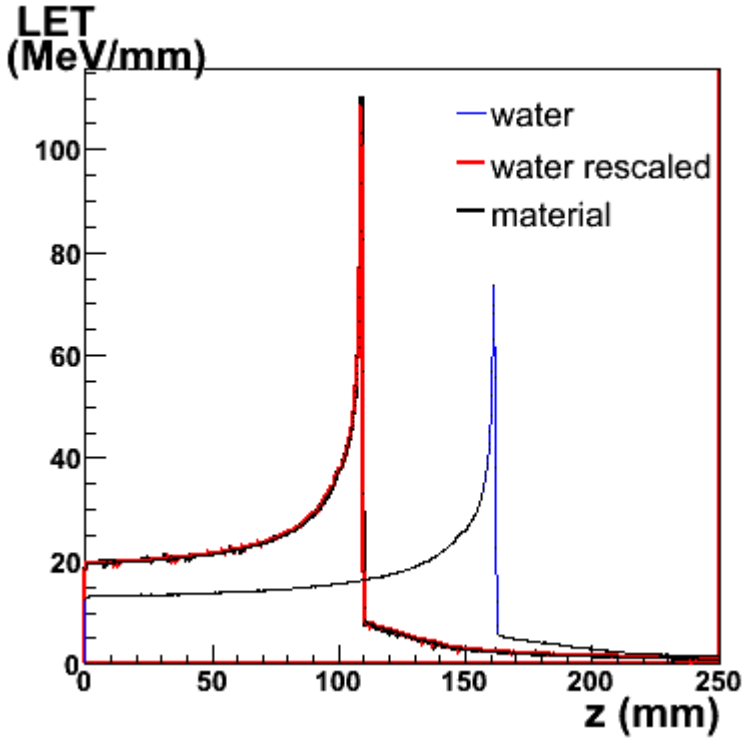
- beam energy
- beam width
- particle nature

proton 135 MeV

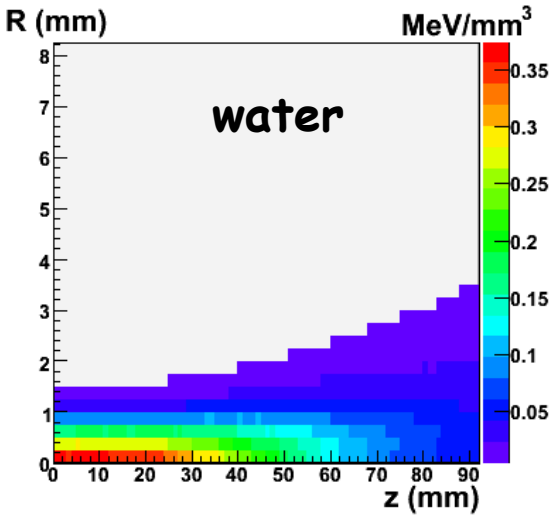


cranium

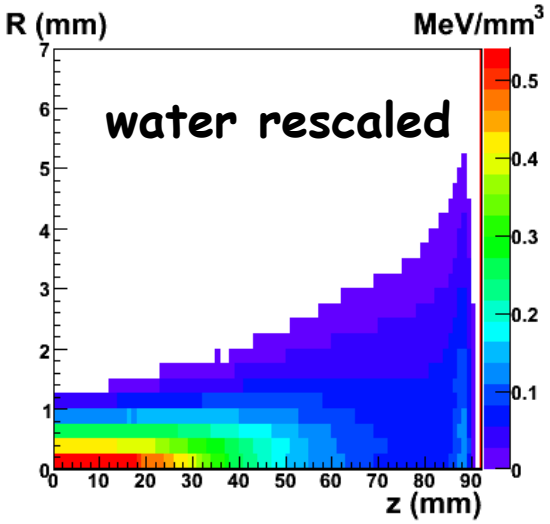
carbon 290 MeV



γ < 2% / 2mm



S_m^w →



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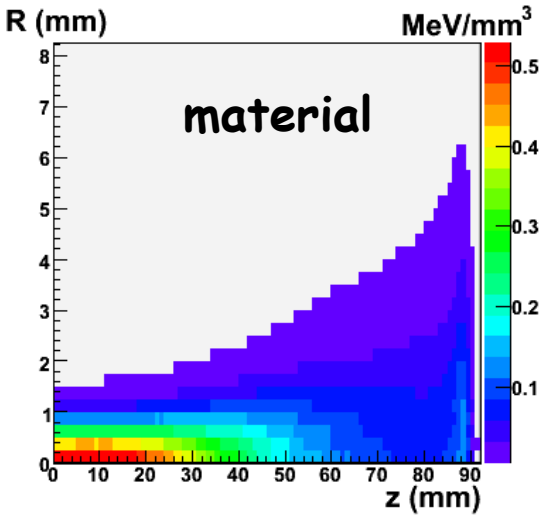

1D scaling not sufficient for an accurate 2D energy deposit determination

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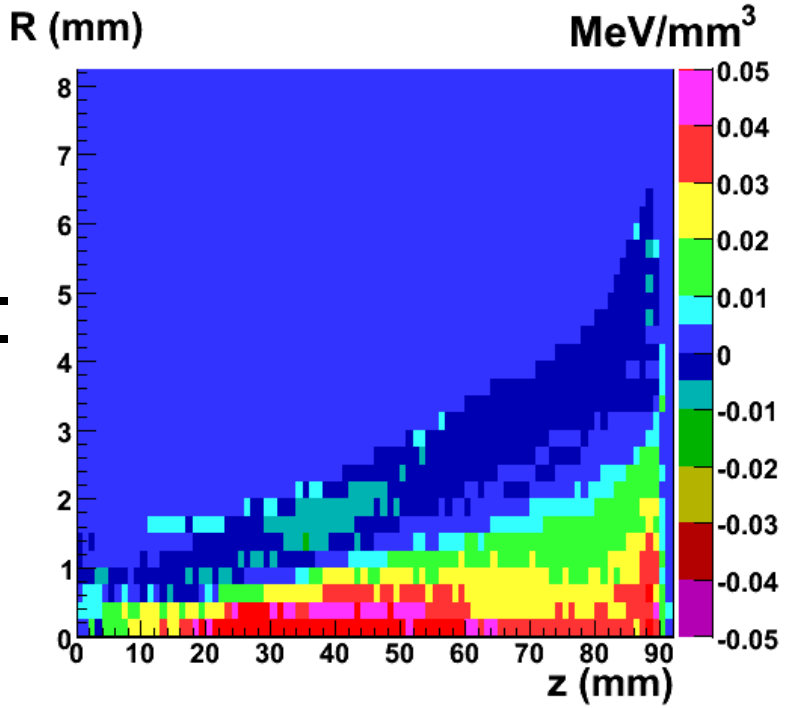


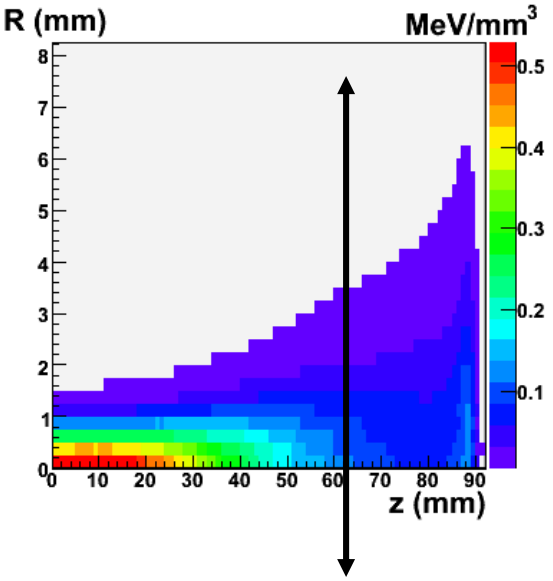
(Szymanowski)

$$\left(F_w^m\right)^2 \approx \frac{\sigma_m^2\left(z, E_0\right)}{\sigma_w^2\left(\frac{z}{S_w^m}, E_0\right)}$$

$$\sigma_m^2(z) = \sigma_s^2(z) - \sigma_0^2$$

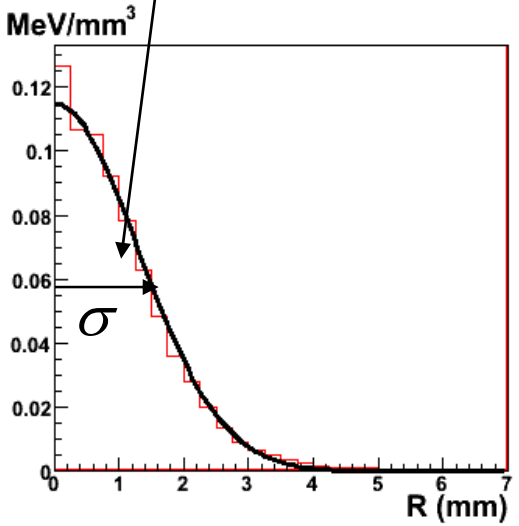
$\sigma_s^2(z)$: from simulations

σ_0^2: initial beam width

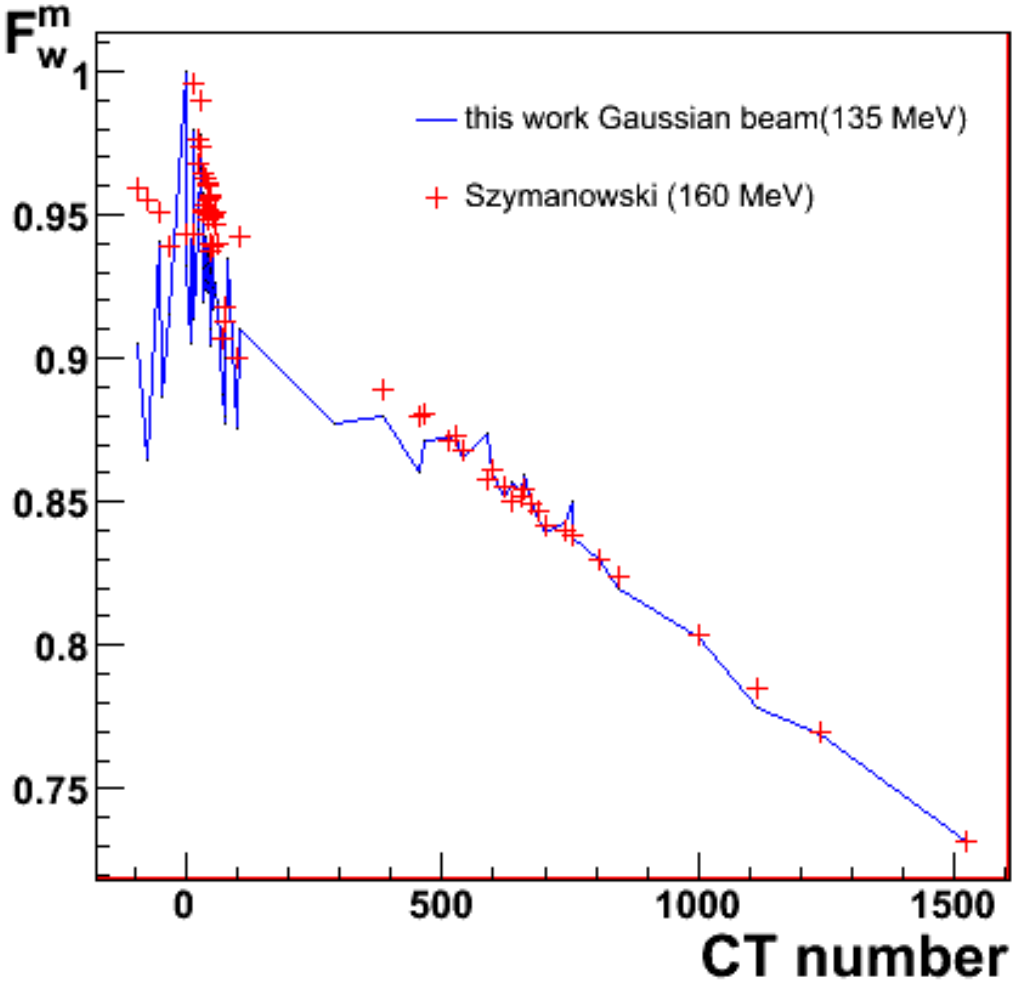


projection

Gaussian fit

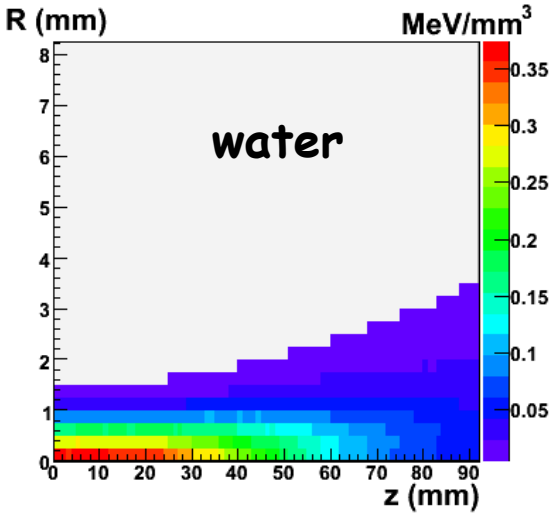


Szymanowski et al. Phys. Med. Biol (47), 3313-3330 (2002).

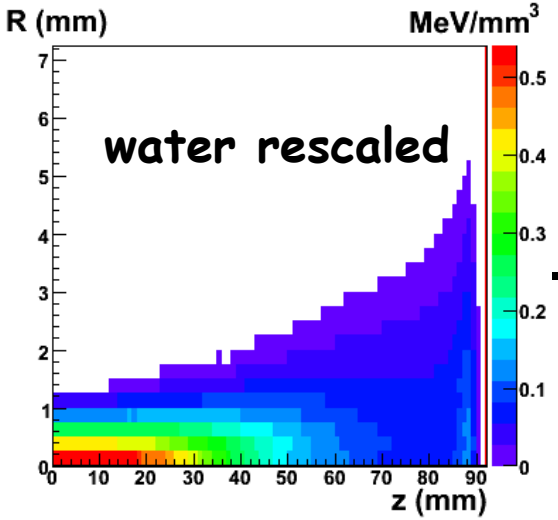


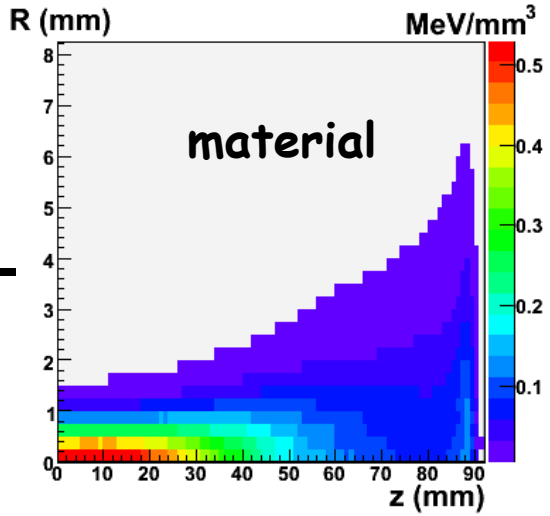
F^w_m independent of

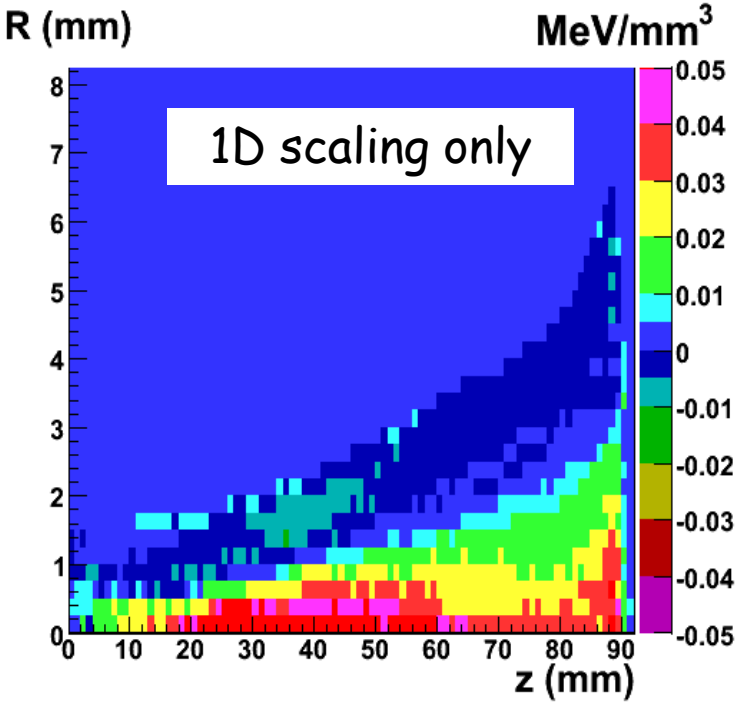
- beam energy
- beam width

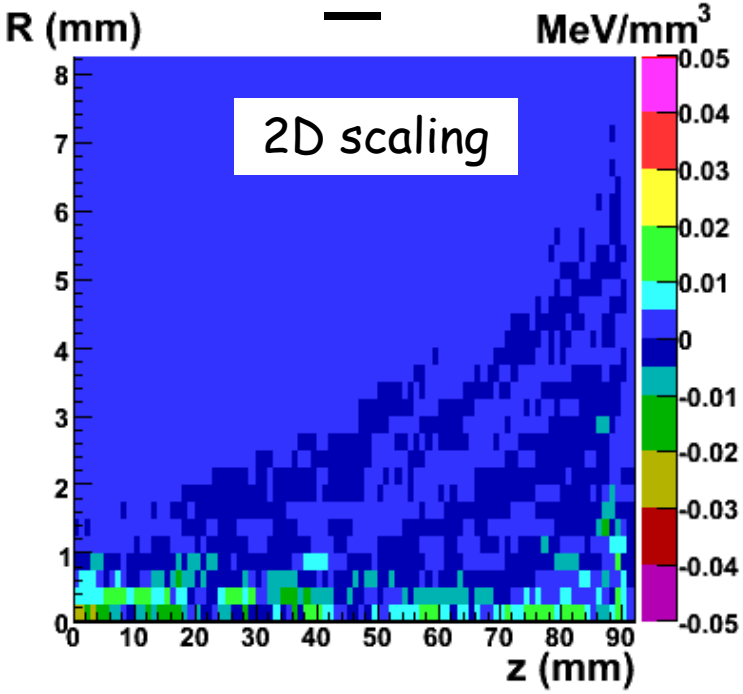


$$S_m^w \rightarrow F_w^m$$









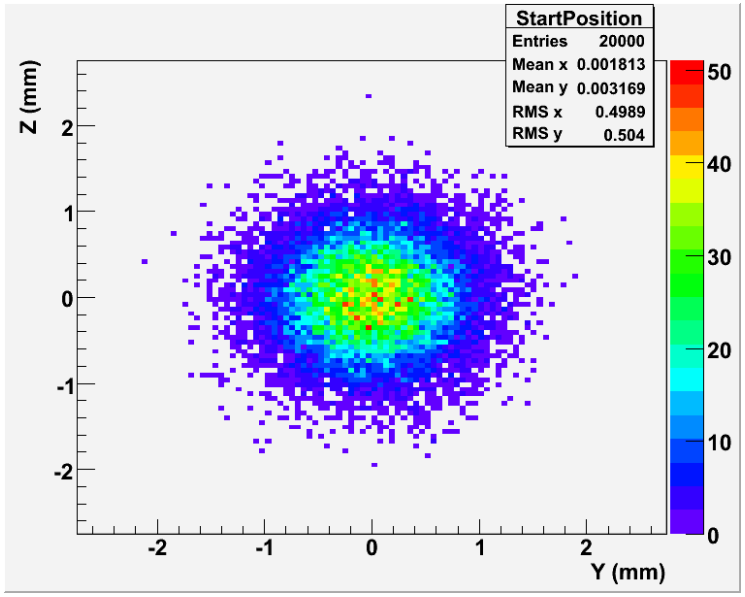
1D scaling S_m^w

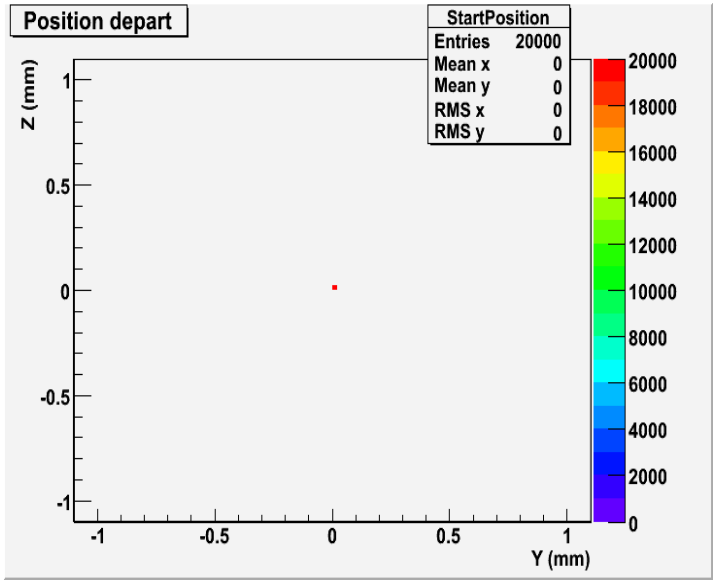
- Same factor for proton and carbon beams
- Independent of beam width and beam energy
- Good results on LET curve, insufficient if one wants to take into account lateral broadening

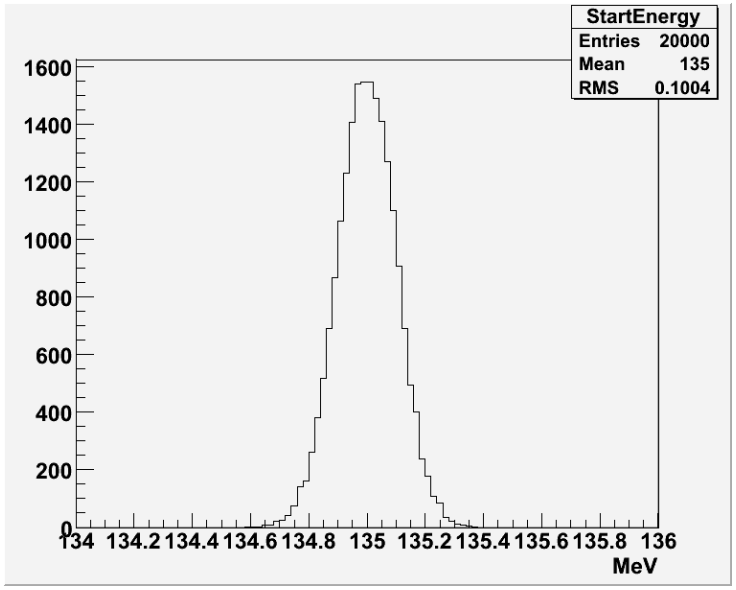
2D scaling F_w^m

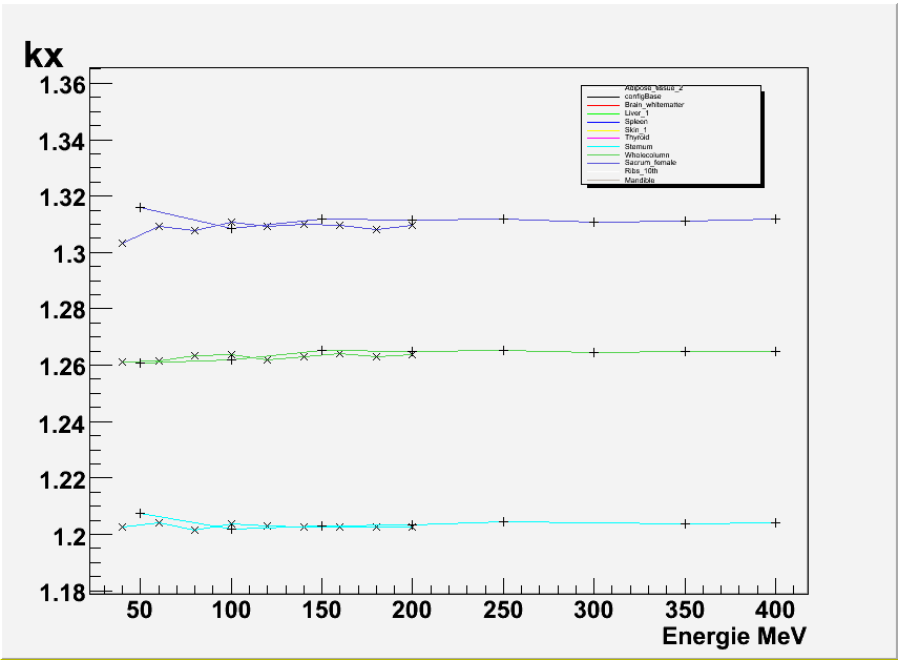
- Improved results in 2D for proton beams
- Determination and variation of the factor still under study (for the carbon beam)

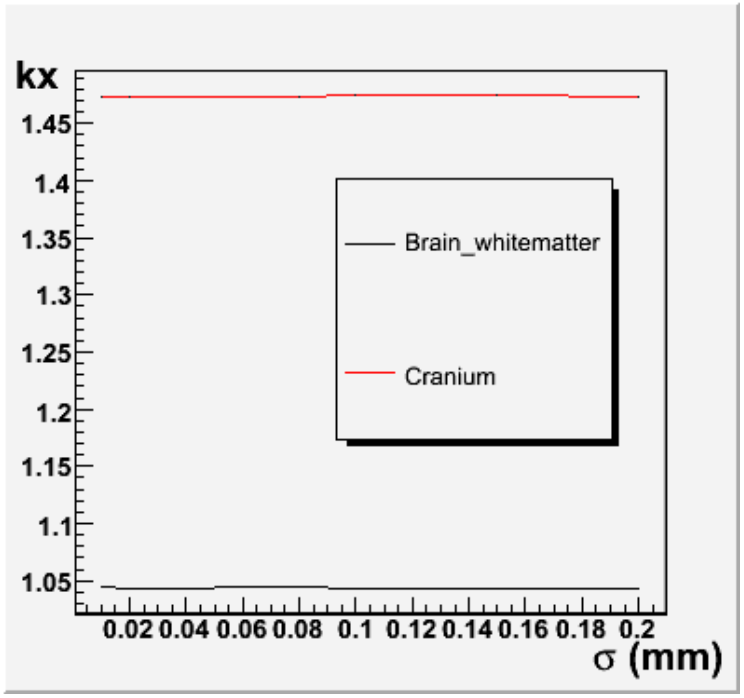
→ Consequences of the variation of this two factors with the CT number

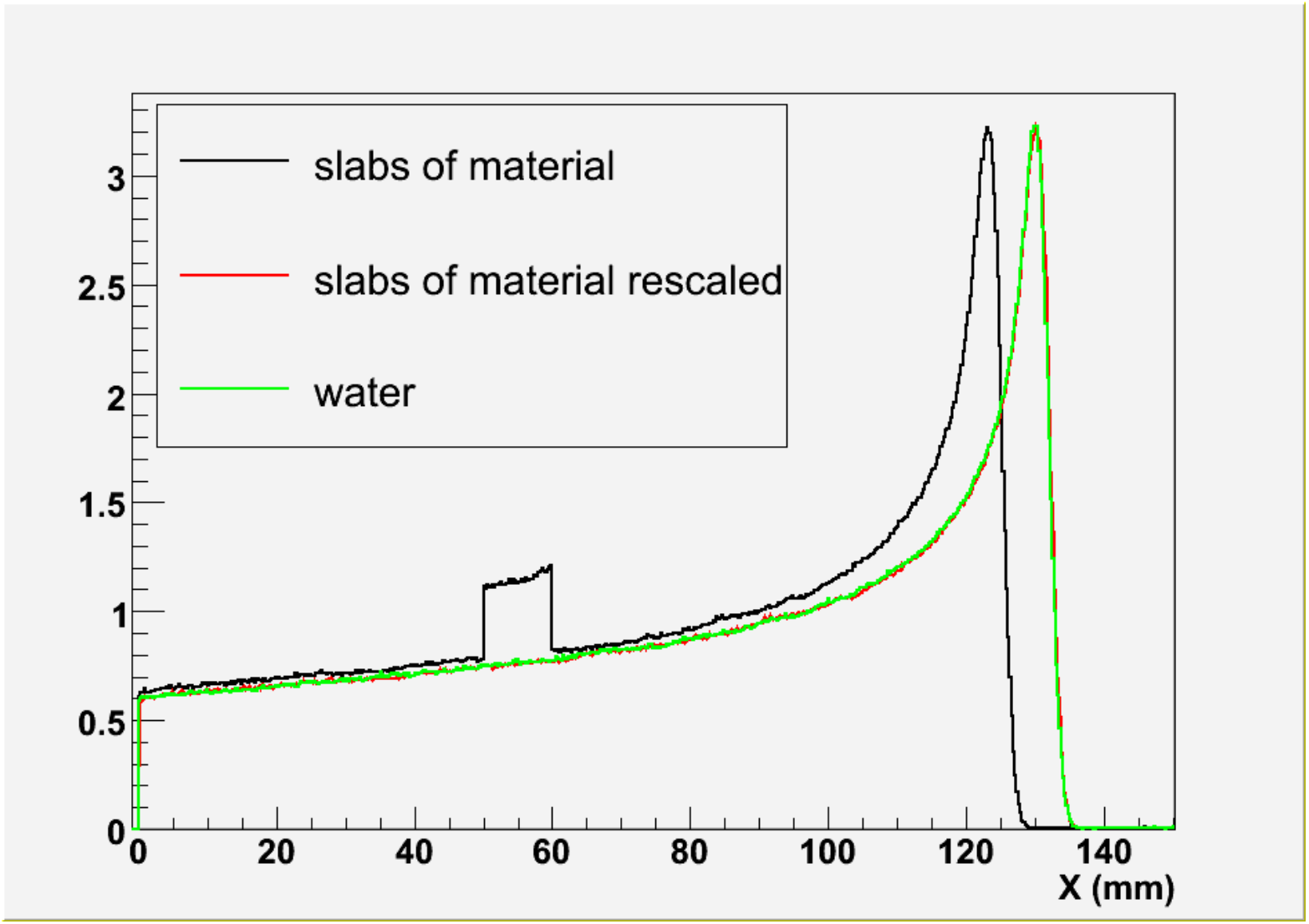

StartPosition
Entries 20000
Mean x 0.001813
Mean y 0.003169
RMS x 0.4989
RMS y 0.504
Z (mm)
Y (mm)

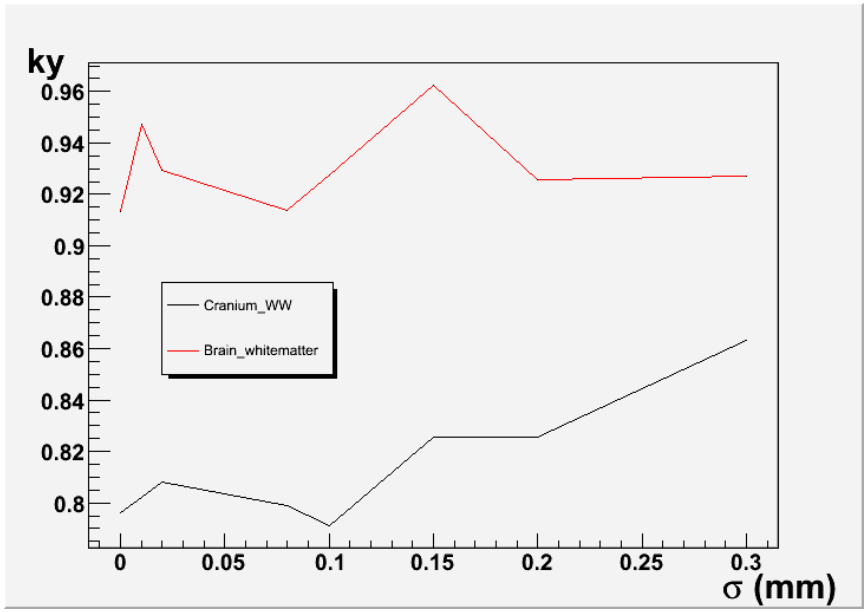

Position depart
StartPosition
Entries 20000
Mean x 0
Mean y 0
RMS x 0
RMS y 0
Z (mm)
Y (mm)

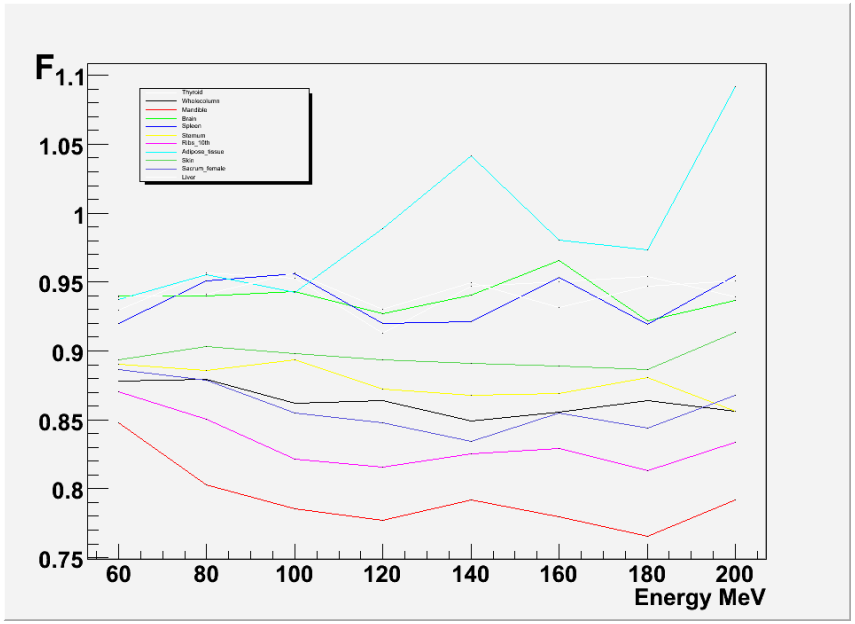

StartEnergy
Entries 20000
Mean 135
RMS 0.1004
MeV

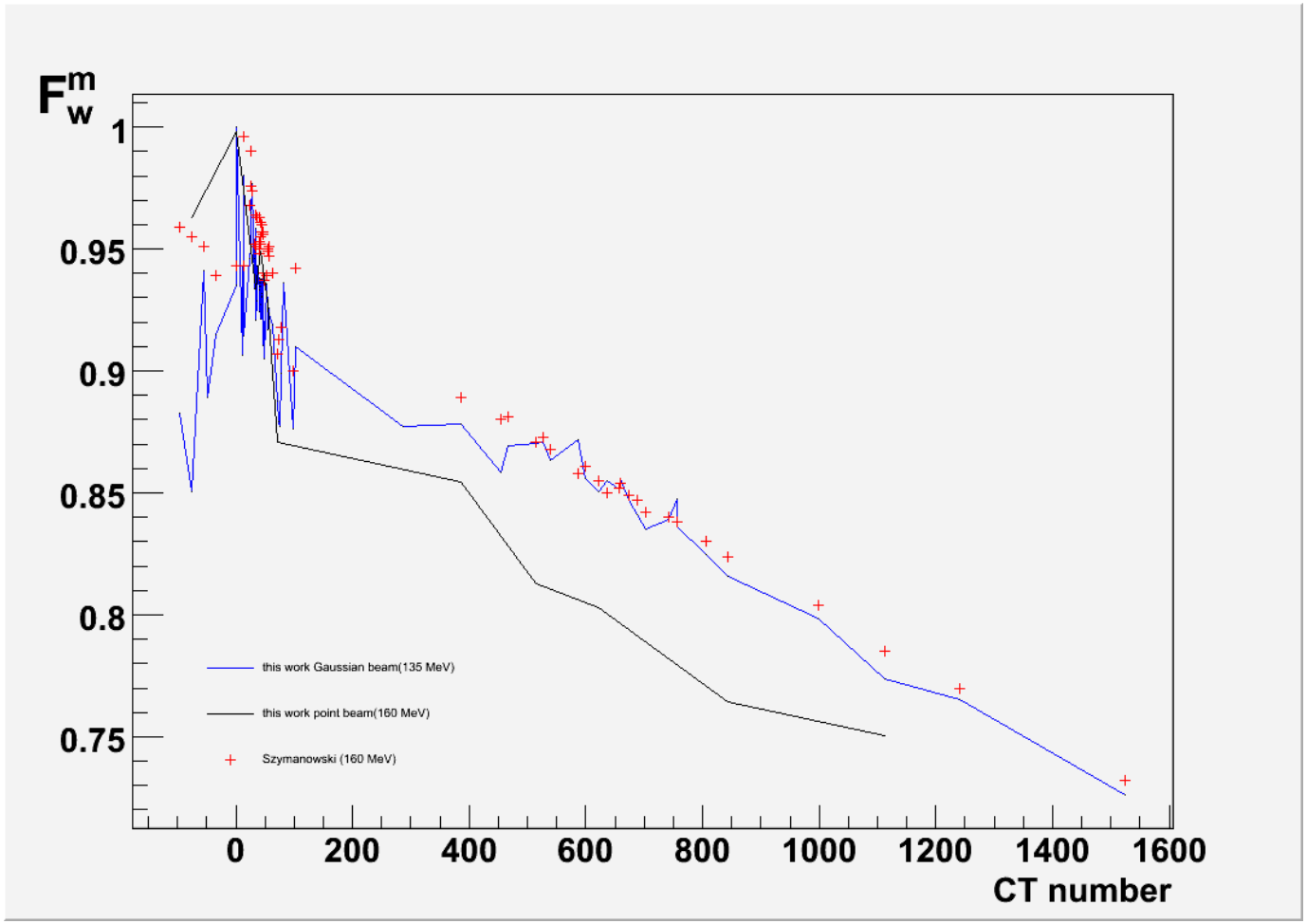

kx
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
1.18
50
100
150
200
250
300
350
400
Energie MeV


kx
1.45
1.4
1.35
1.3
1.25
1.2
1.15
1.1
1.05
Brain_whitematter
Cranium
0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2
σ (mm)


slabs of material
slabs of material rescaled
water
0
0.5
1
1.5
2
2.5
3
0
20
40
60
80
100
120
140
X (mm)


ky
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0
0.05
0.1
0.15
0.2
0.25
0.3
σ (mm)
Cranium_WW
Brain_whitematter


F
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
60
80
100
120
140
160
180
200
Energy MeV


F_w^m
1
0.95
0.9
0.85
0.8
0.75
this work Gaussian beam(135 MeV)
this work point beam(160 MeV)
Szymanowski (160 MeV)
0
200
400
600
800
1000
1200
1400
1600
CT number

Adipose tissue