Fano cavity simulation

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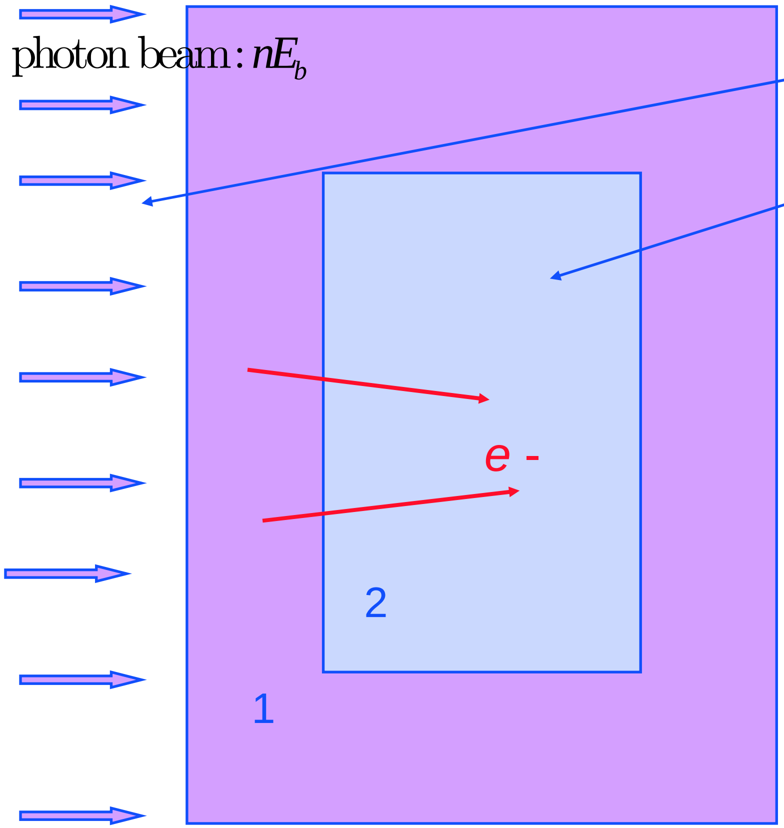
June 2006

Fano cavity principle

Materials 1 and 2 : same A, but different density ρ1 and ρ2



beam energy fluence : $\Phi = \frac{nE_b}{S_1}$

dose in material 2 : D_2

energy transfert coefficient : $\mu_{tr}(E_b) = \mu_{abs}(E_b)\frac{\langle T \rangle}{E_b}$

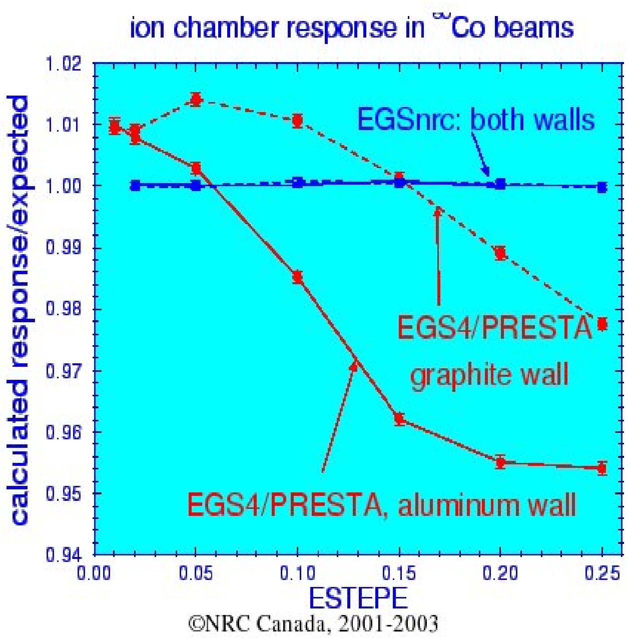
$\langle T \rangle$ is the mean kinetic energy of emited e^-

Under *charged particle equilibium* condition :

$$\frac{D_2}{\Phi(E_b)} = \left(\frac{\mu_{tr}(E_b)}{\rho} \right)_1 = \text{const}$$

i.e. independent of the tracking parameters of the simulation

E. Poon and al.
Phys. Med. Bio. 50(2005) 681



I.Kawrakow *Med.Phys. 27-3 (2000) 499*

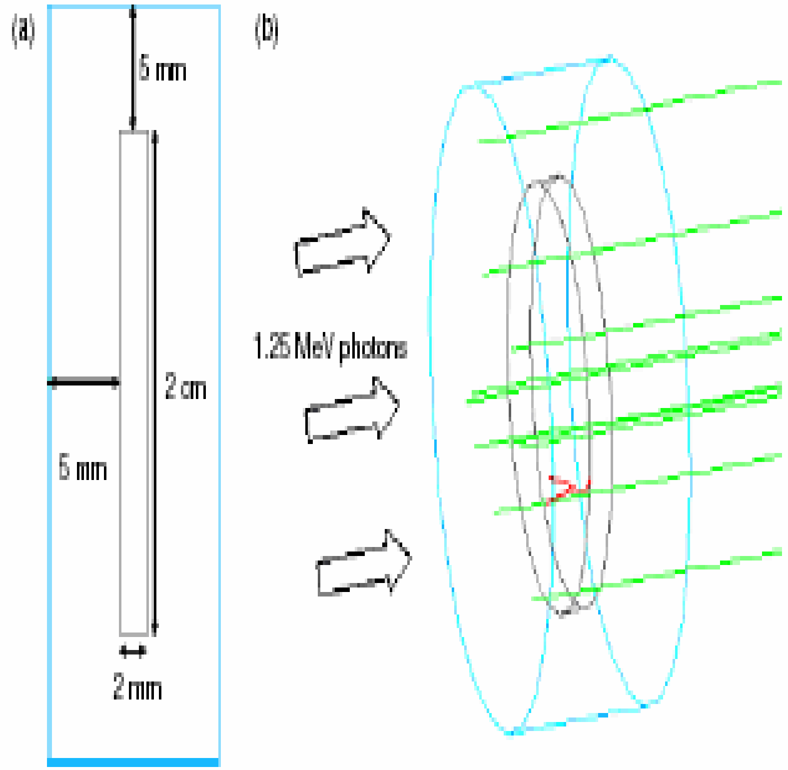


Figure 1. (a) Dimensions of pancake ion chamber for Fano cavity study. The entire chamber is composed of water, and the cavity has a reduced density of 0.001 g cm^{-3}. (b) A 1.25 MeV photon broad beam impinges on the flat end of the chamber. The photon regeneration technique is used to restore the photon energy and direction to its original states at every interaction site.

Geant4: e$^-$ step limitation from physics

- Ionization and brems
  - production threshold *aka* *Cut*

  → indirect effect : the mean free path between discrete interactions depend of Cut

- Continuous energy loss
  - Max fractional energy loss per step. dR/R < *dRoverRange*
  - Down to a certain limit : *finalRange*

- Multiple scattering
  - Limit defined at first step and reevaluated after a boundary, to allow back scattering of low energy e$^-$

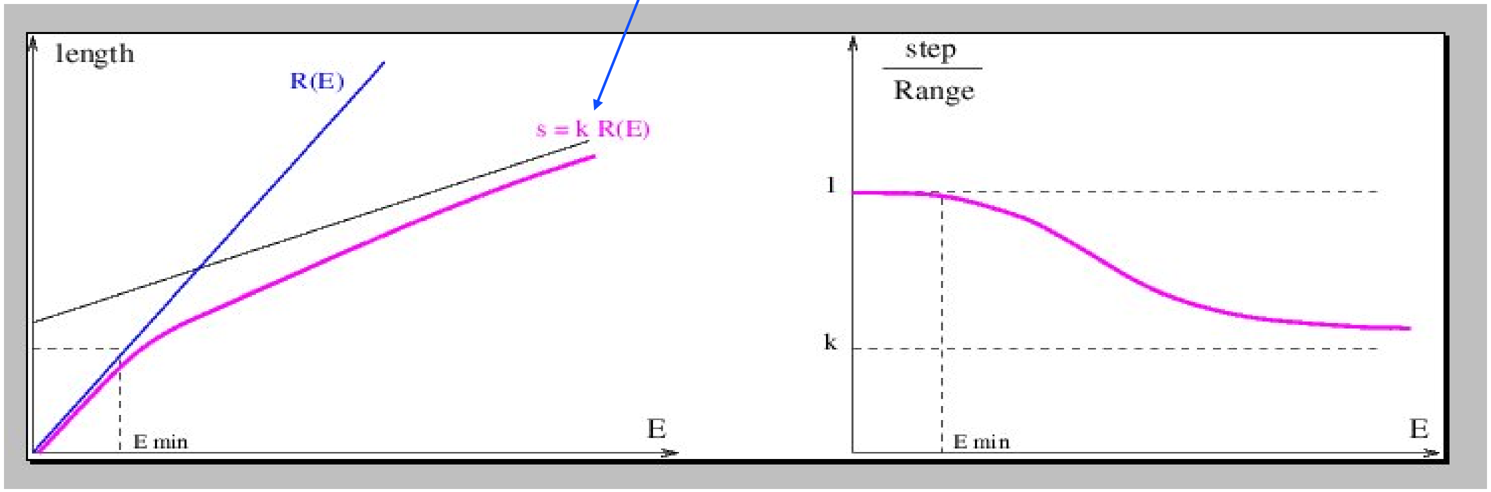
  → step = fr.max(range,λ)   fr = *facRange*
  - Geometry : force more than 1 step in any volume : *facGeom*

Step limitation from continuous energy loss

- The cross sections depend of the energy. The step size must be small enough to ensure a small fraction of energy loss along the step :

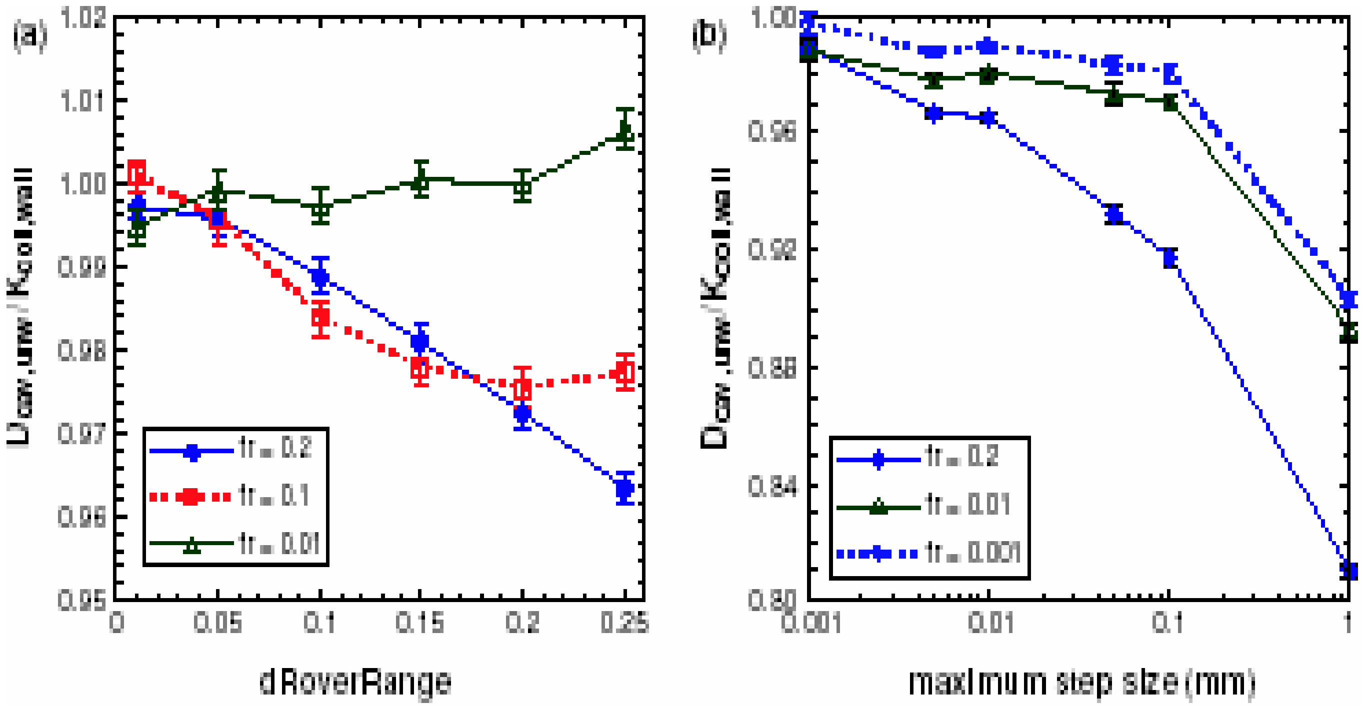
$$\frac{\text{step}}{\text{Range(E)}} \le \text{dRoverRange}$$

- This constraint must be relaxed when E → 0



finalRange

Geant4 6.2



E. Poon and al.

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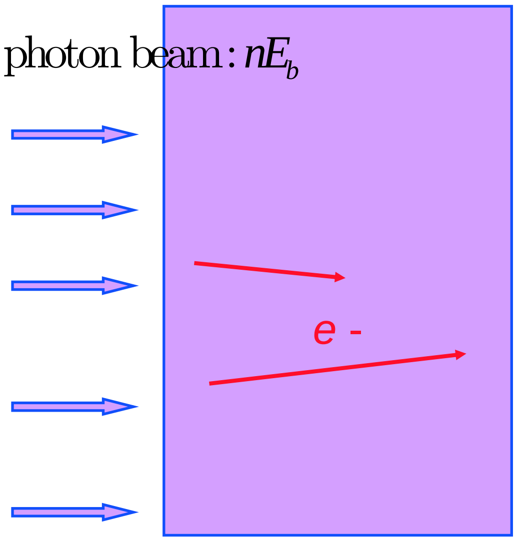
Figure 2. Fano cavity response of 1.25 MeV incident photons as a function of (a) *dRoverRange* (maximum electron step = 1 m), and (b) maximum electron step size (*dRoverRange* = 1). For the default case (*dRoverRange* = 1, unlimited maximum electron step, f_r = 0.2) the cavity response is 0.609 ± 0.002. Simulations were run using the CSDA approximation. Error bars represent the standard errors of the mean.

Geant4 : from 6.2 to 8.1

- dRoverRange : 1 → 0.2 (finalRange = 1 mm)
- facRange : 0.2 → 0.02, applied to the whole track
- facGeom : 1→3
- Better evalution of lateral displacement : reevaluate safety radius before to perform lateral displacement
  → displ < safety (*safefy was often underestimated*)
- Correlate final direction with lateral displacement
  → u.d = f (λ) taken from Lewis theory
- Angular distribution : both central part and tail slightly modified

Transfer energy coefficient

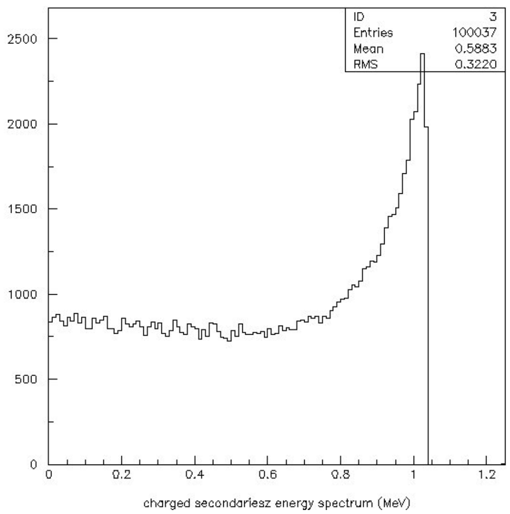


$$\mu_{tr}(E_b) = \frac{1}{E_b}\int_{T_{min}}^{T_{max}} \frac{d\sigma_{tot}}{dT}\, T\, dT = \sigma_{tot}(E_b)\frac{\langle T \rangle}{E_b}$$

σ_{tot} : total cross section per volume

T : kinetic energy of emited e^-

$$\left(\frac{\mu_{tr}(1.25\text{ MeV})}{\rho}\right)_{water} = 0.02998\text{ cm}^2/\text{g}$$



From TestEm14:

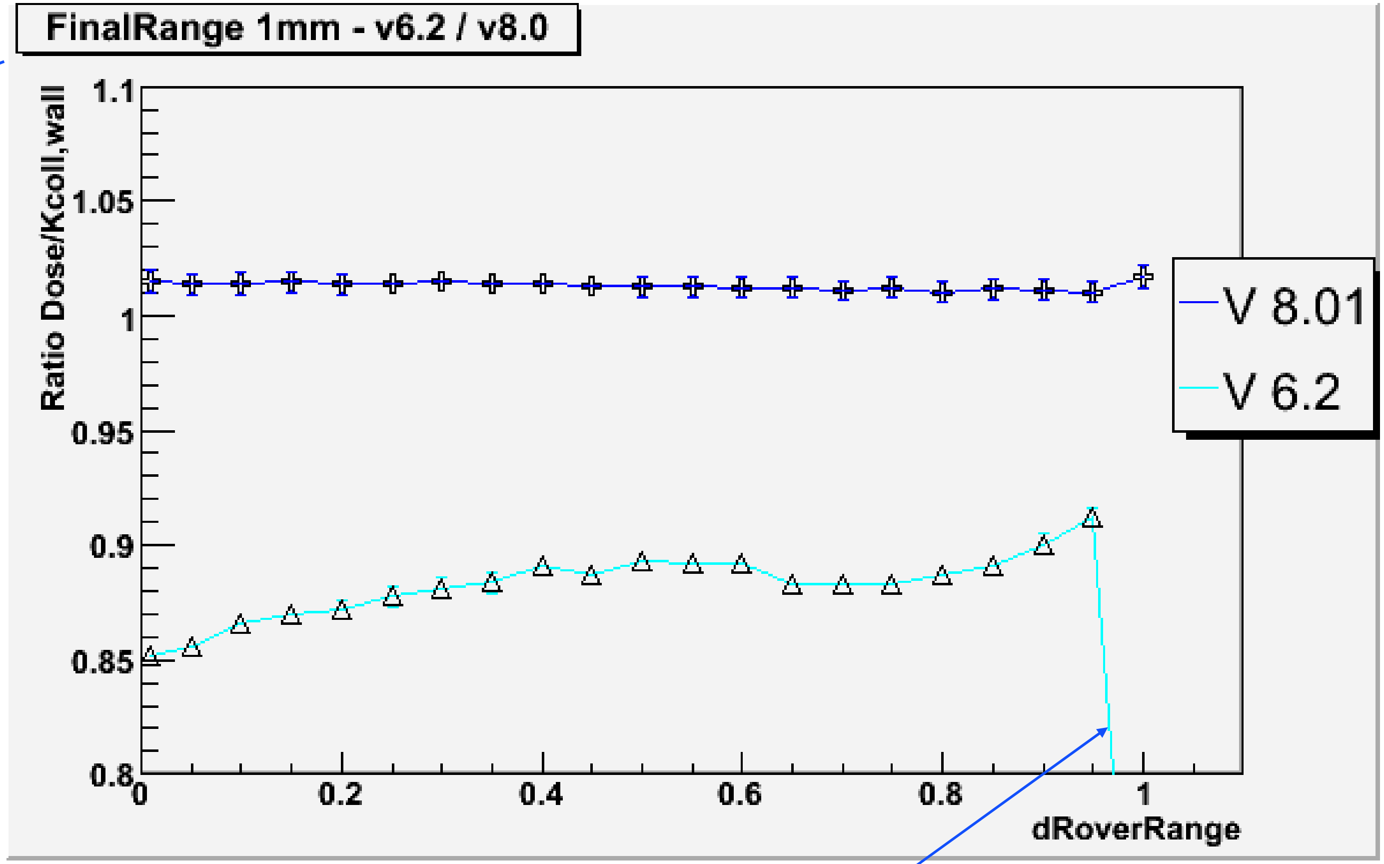
```
The run consists of 100000 gamma of 1.25 MeV through 100 m   of Water (density: 1 g/cm3 )

Process calls frequency --->   compt = 99961   conv = 37      phot = 2

MeanFreePath:  15.704 cm  +- 15.663 cm         massic: 15.704 g/cm2
CrossSection:  0.063678 cm^-1                  massic: 0.063678 cm2/g

mean energy of charged secondaries: 588.52 keV ---> mass_energy_transfer coef: 0.029981 cm2/g

Verification : crossSections from G4EmCalculator
          compt= 0.063447 cm2/g   conv= 2.0941e-05 cm2/g   phot= 2.2833e-06 cm2/g   total= 0.06347 cm2/g

User=8.3s Real=8.7s Sys=0.07s
```

finalRange = 1 mm

1 mm ~ 300 keV
for e- in water

V 6.2 : fr = 0.2

V 8.1 : fr = 0.02

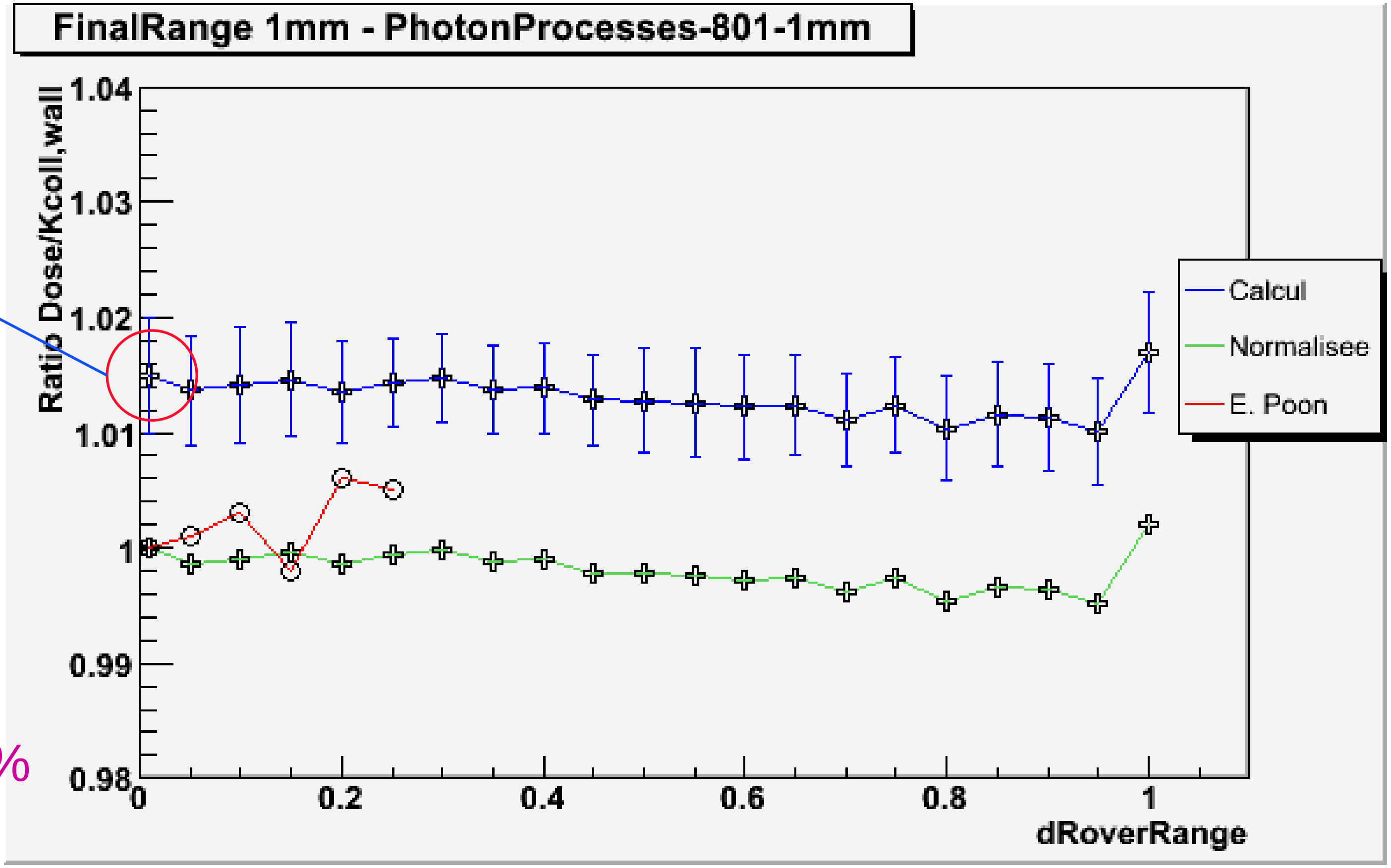


~ 4 10^8 events per point

V 6.2 : aberrant point for dR = 1

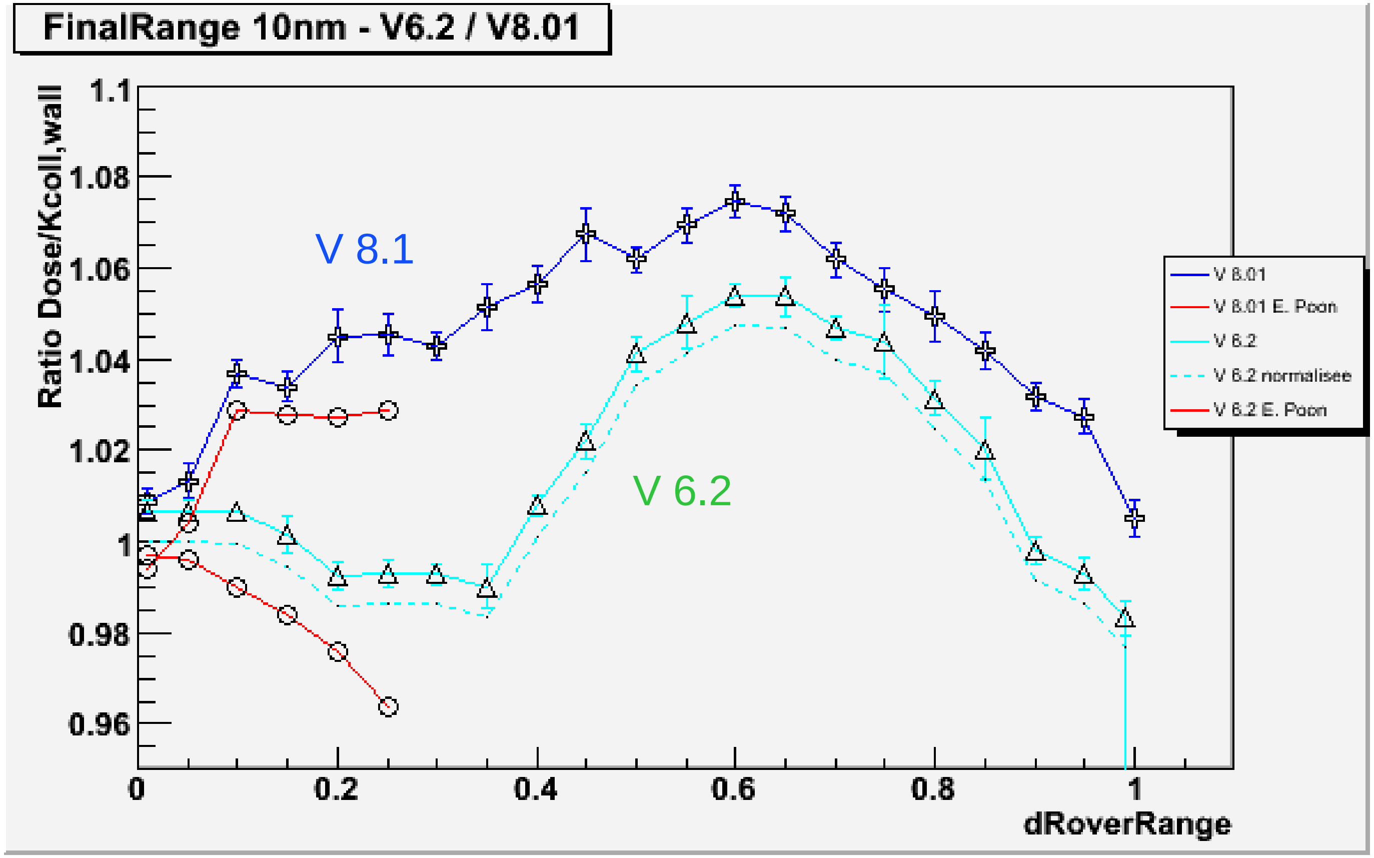
Geant4 V8.1 : zoom

Do not converge to 1 !



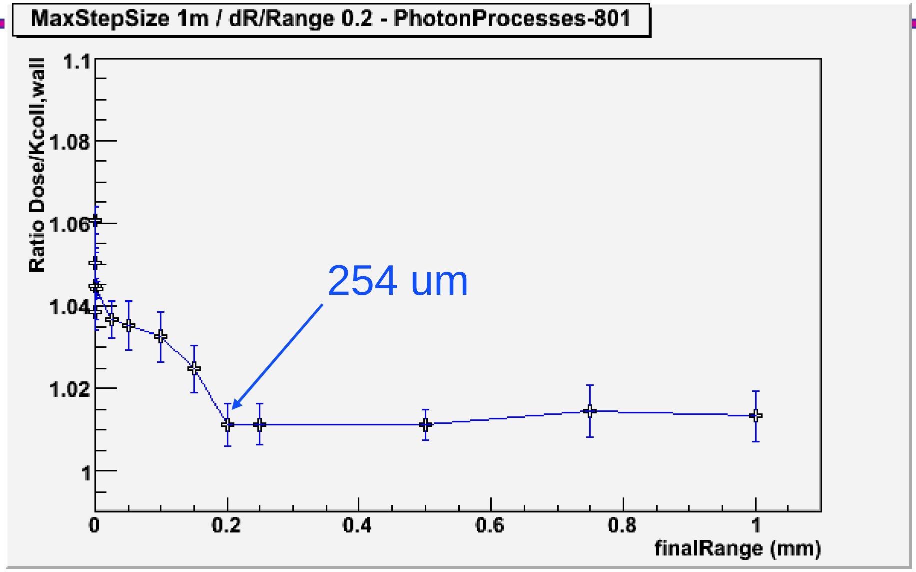
Stability within 1%

finalRange = 10 nm

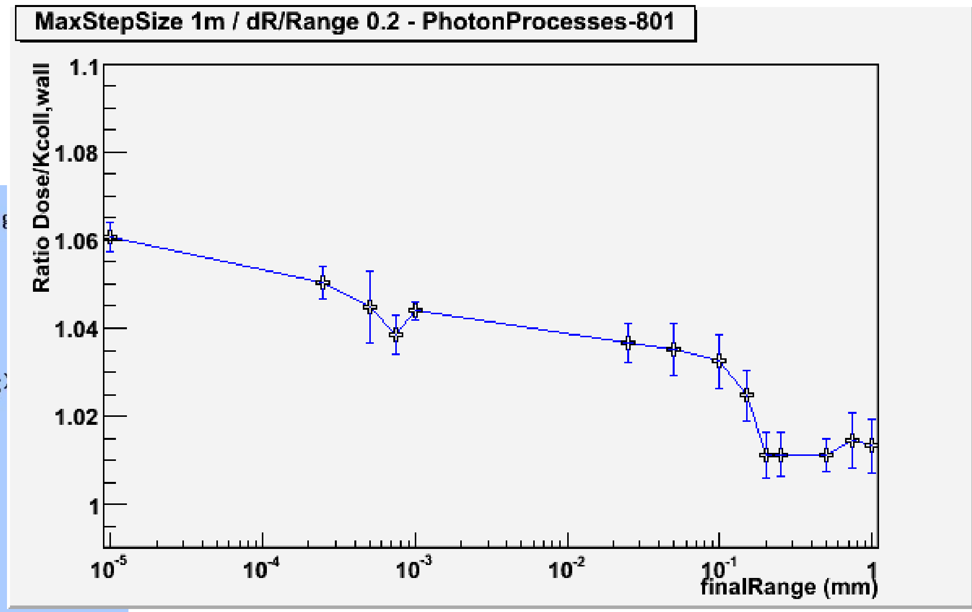


V6.2 : fr = 0.2
V8.1 : fr = 0.02

finalRange dependance




```
The run consists of 100000 e- of 1 MeV through 100 m   of Water (density: 1 g

Process calls frequency --->   msc = 100000

truePathLength :       253.99 um  +- 2.8483 Ang
geomPathLength :       248.83 um  +- 3.5895 um
lateralDisplac :       35.27 um  +- 5.6339 um
Psi            :       140.94 mrad +- 23.193 mrad  (8.0753 deg +- 1.3289 deg)

Theta_plane    :       244.34 mrad  (13.999 deg)
phi correlation:       0.11193 +- 0.14731  (std::cos(phi_pos - phi_dir))

Verification from G4EmCalculator.

transport mean free path :     6.3499 mm
range from restrict dE/dx:     4.3623 mm
---> effective facRange  :     0.04

compute theta0 from Highland : 195.23 mrad  (11.186 deg)
```



from TestEm15

still on the way …

- Evident gain on stability from 6.2 to 8.1
- We do not yet fully agree with E. Poon results
  - → understand normalisation
  - → understand the impact of the geometry
- Understand the effect of small *finalRange*
- Implement single Coulomb scattering mode near a boundary