Compton Backscattering for Beam Energy Measurement at ILC

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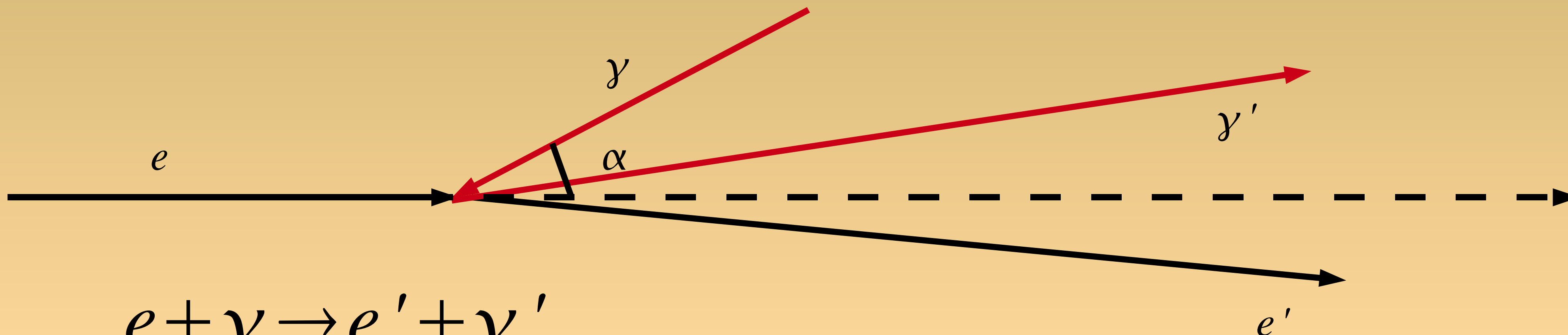
Outline

- Compton Backscattering (CBS) as a means to measure the beam energy at ILC
- Multiple Compton Scattering
- Non Linear Effects in the CBS
- Photons Detection
- Conclusions

Energy Measurement at ILC

- In ILC is crucial to have a precise measurement of the beam energy, that is $\frac{\Delta E}{E} \sim 10^{-4}$
- We are studying the feasibility to use the Compton Backscattering for such a purpose.

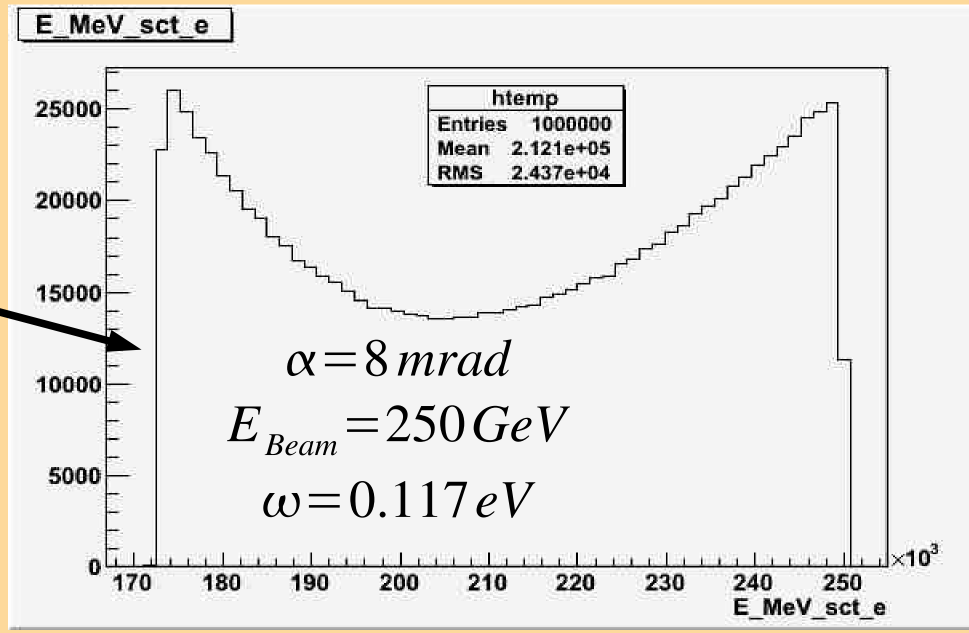
CBS: Basic Idea



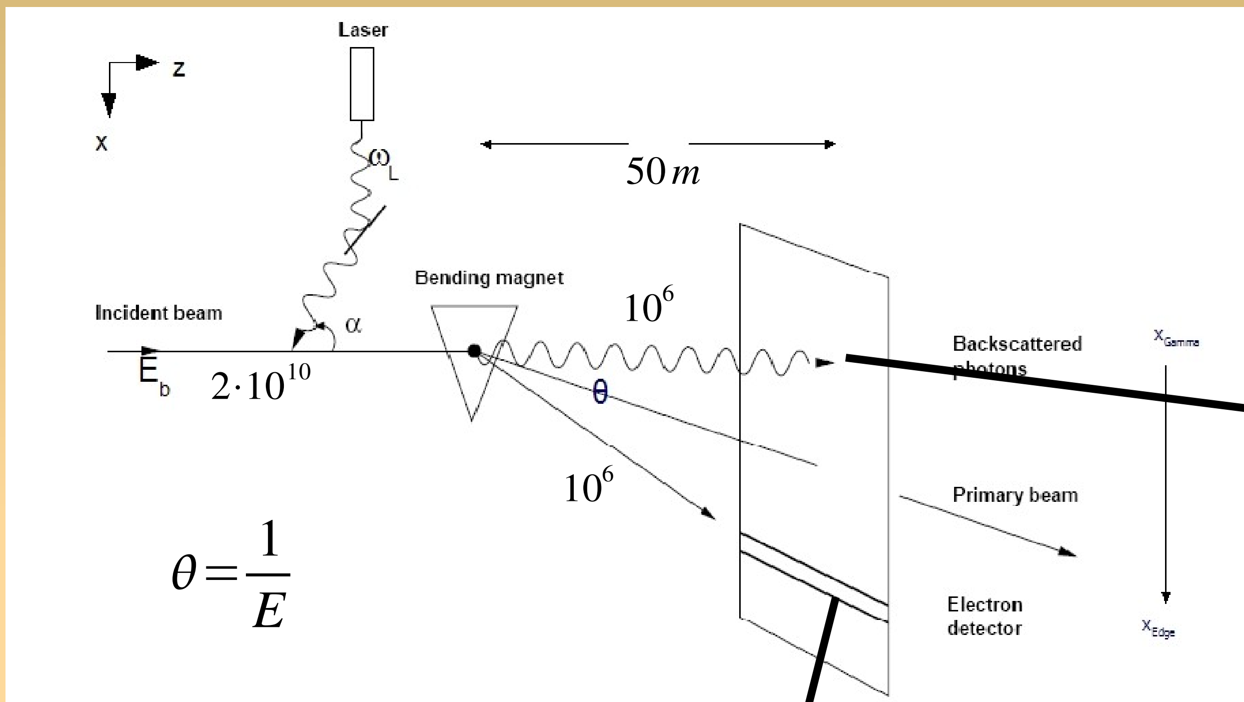
$$e+\gamma\rightarrow e'+\gamma'$$

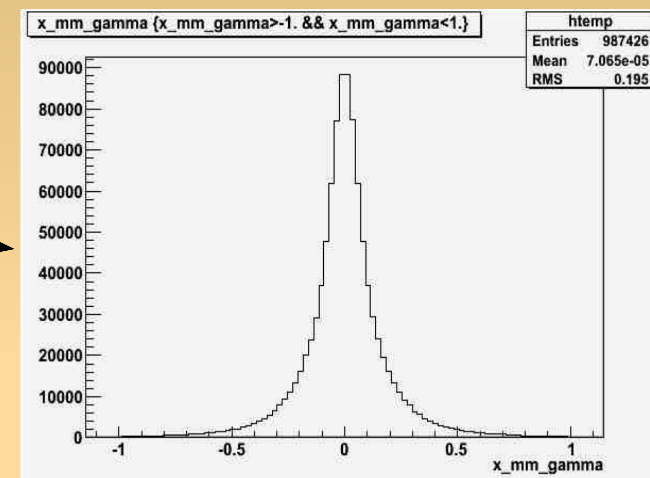
$$\omega_{max}=\frac{x}{1+x}E_{Beam},\quad with\ x=\frac{2E_{Beam}\omega}{m^2}(1+\cos\alpha)$$

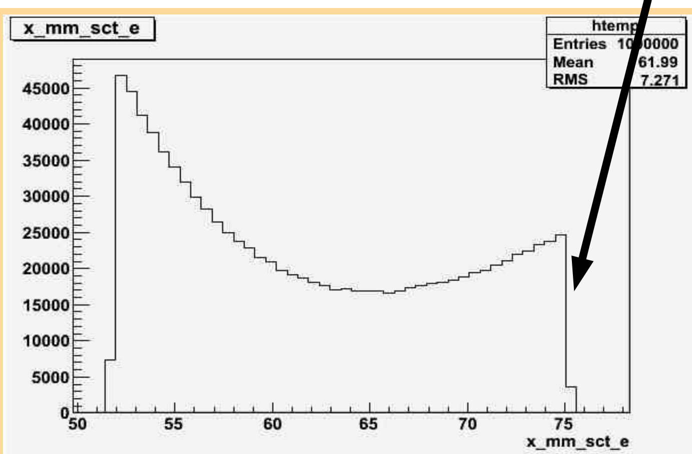
$$E_{Edge}=E_{Beam}-\omega_{max}=\frac{1}{\frac{1}{E_{Beam}}+2\omega\frac{(1+\cos\alpha)}{m^2}}$$



CBS: Basic Layout







$$at\ ILC \quad \frac{\Delta E}{E} \sim 10^{-4}$$

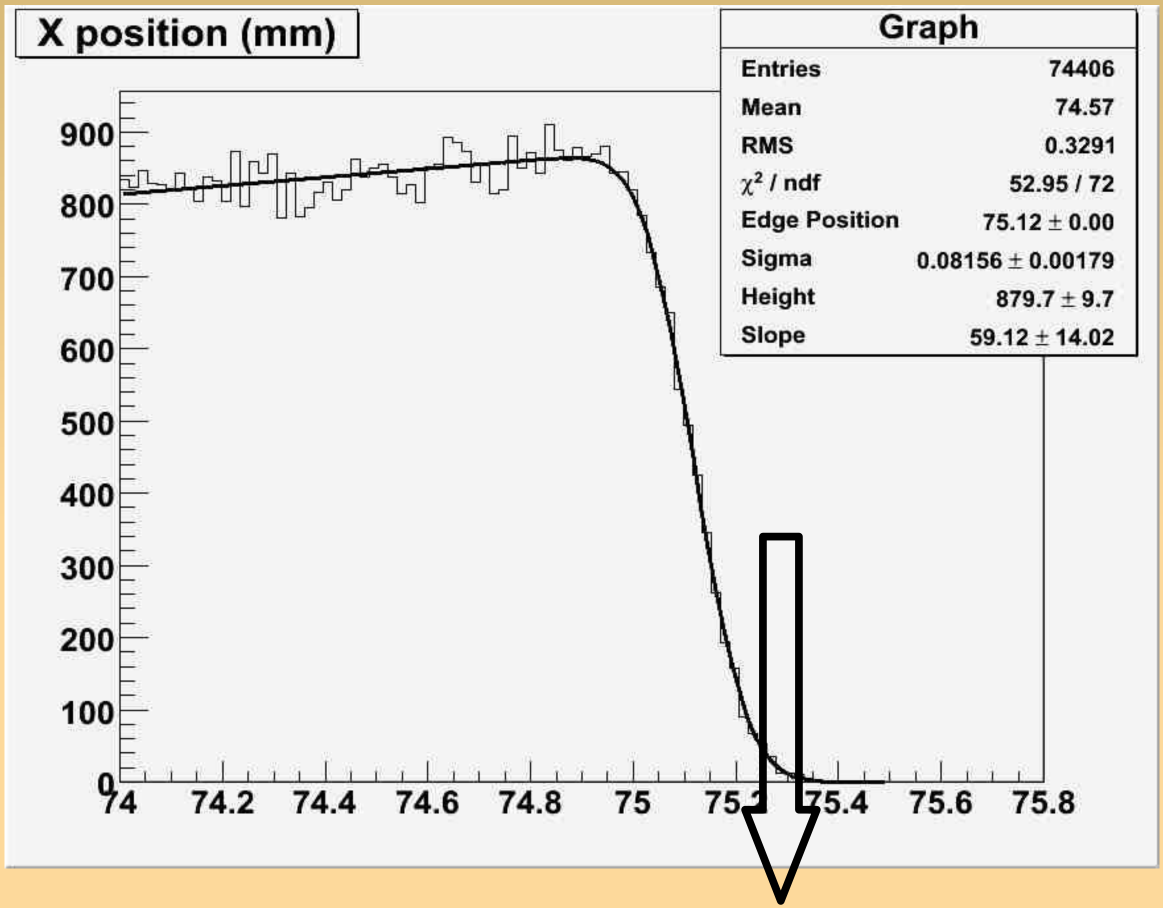
$$considering \quad \frac{\Delta B}{B} \sim 10^{-5} \quad et \quad \frac{\Delta L}{L} \sim 10^{-7}$$

$$we\ must\ have \quad \Delta x_{gamma} \sim \Delta x_{edge} \sim 2-3 \quad \mu m$$

CBS: Some Numbers

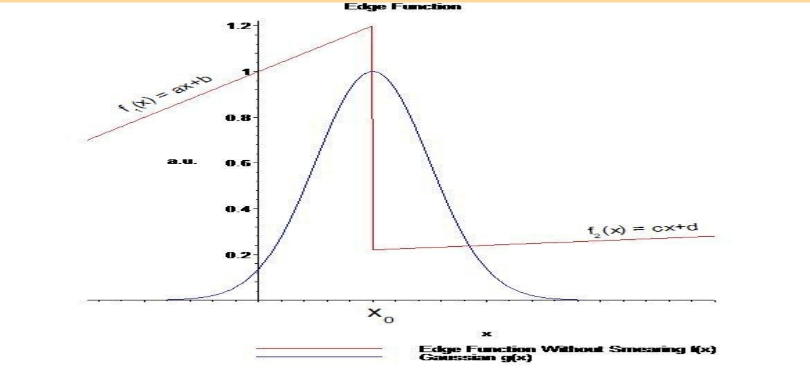
- Gaussian electron and laser bunch
- Gaussian energy distribution for electrons with relative spread of 0.15%
- For electron beam $\sigma_x = 20\,\mu m,\ \sigma_y = 2\,\mu m,\ \sigma_z = 300\,\mu m$
- For the laser $\sigma_x = \sigma_y = 50\,\mu m,\ \sigma_z = 3\,mm,\ Laser\ Power = 1\,\mu J$
- In this presentation in the first part I will consider only the CO2 laser $\omega = 0.117\,eV$ in second YAG Laser $\omega = 1.16\,eV$

CBS: Simulation



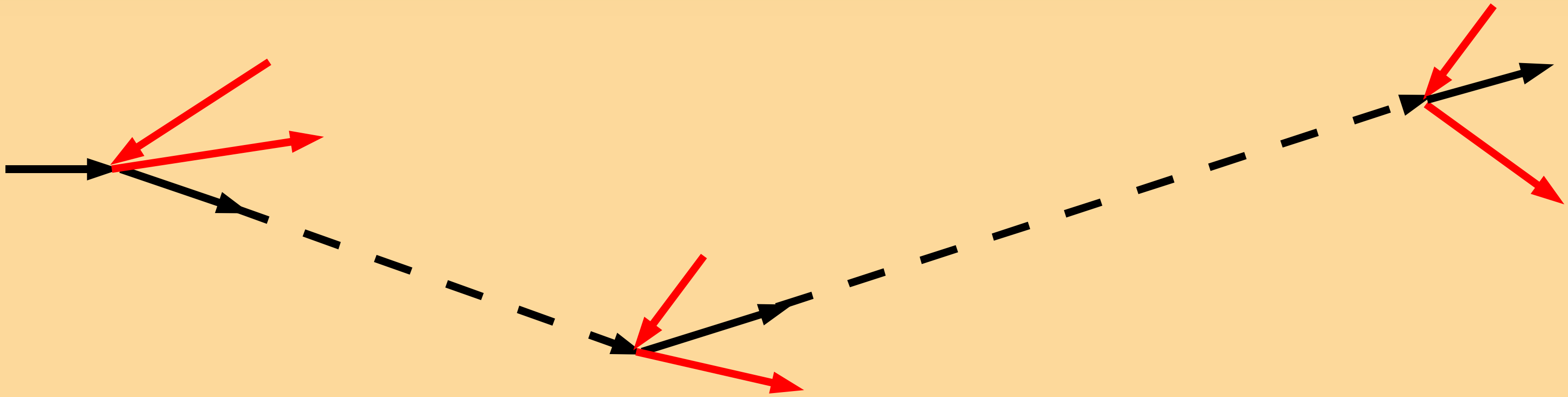
$$X_{Edge} = 75.1191 \pm 0.0022\ mm$$

- Geant4 simulation
- Including in the energy spectrum the smearing to the bunch size and the energy spread
- to fit we use a 'kind' of step function convoluted with a gaussian



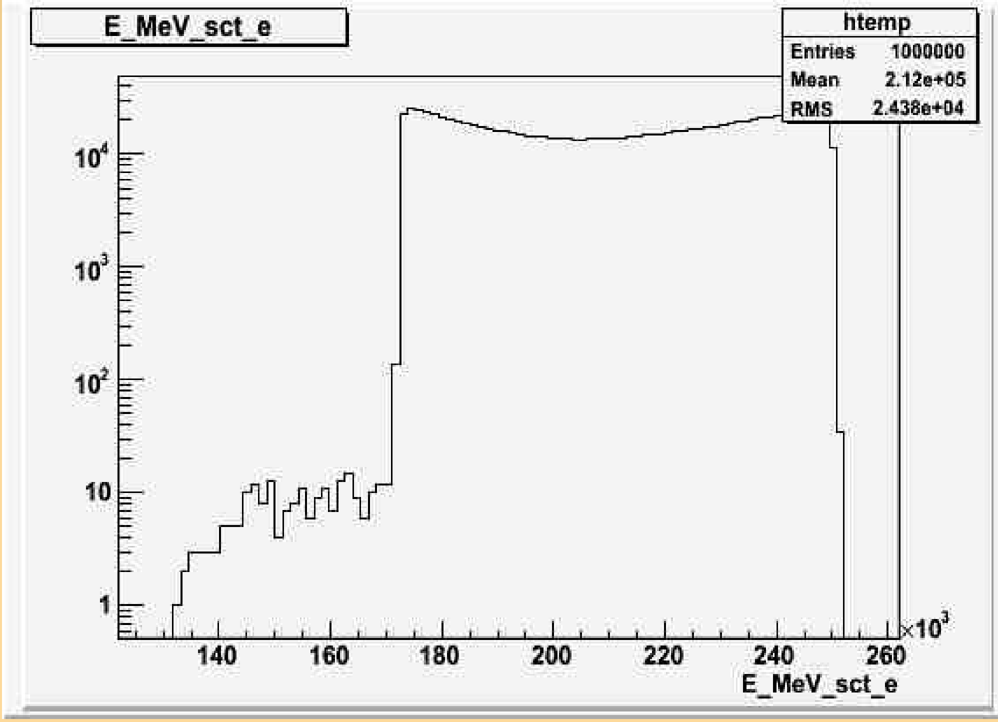
Multiple Compton Scattering

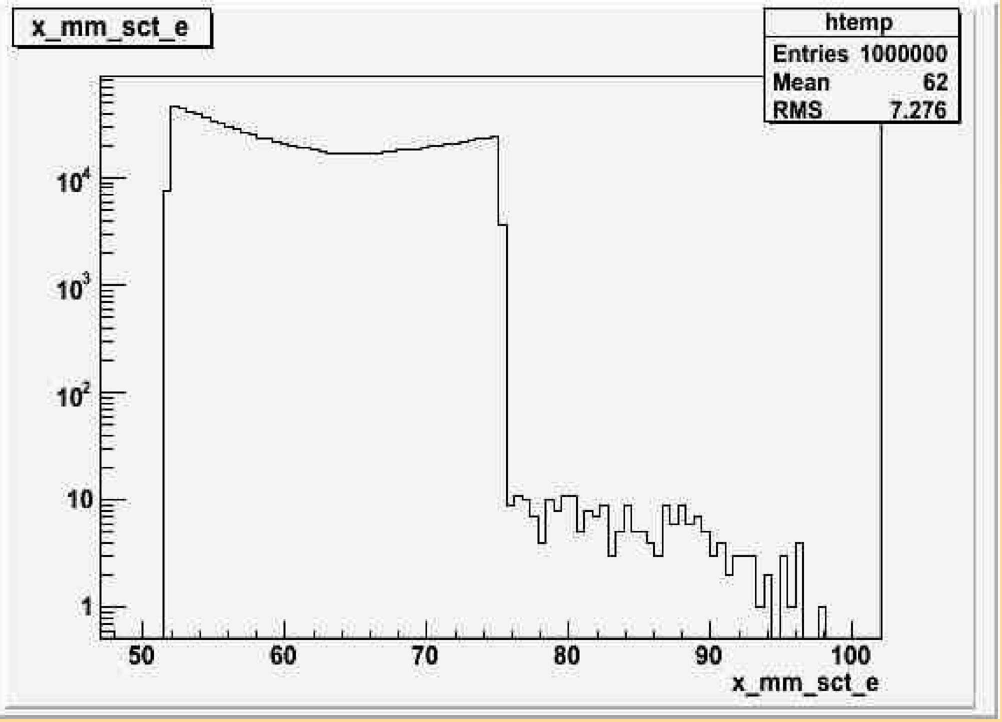
We studied the possibility that an electron scatters with more than one laser photon



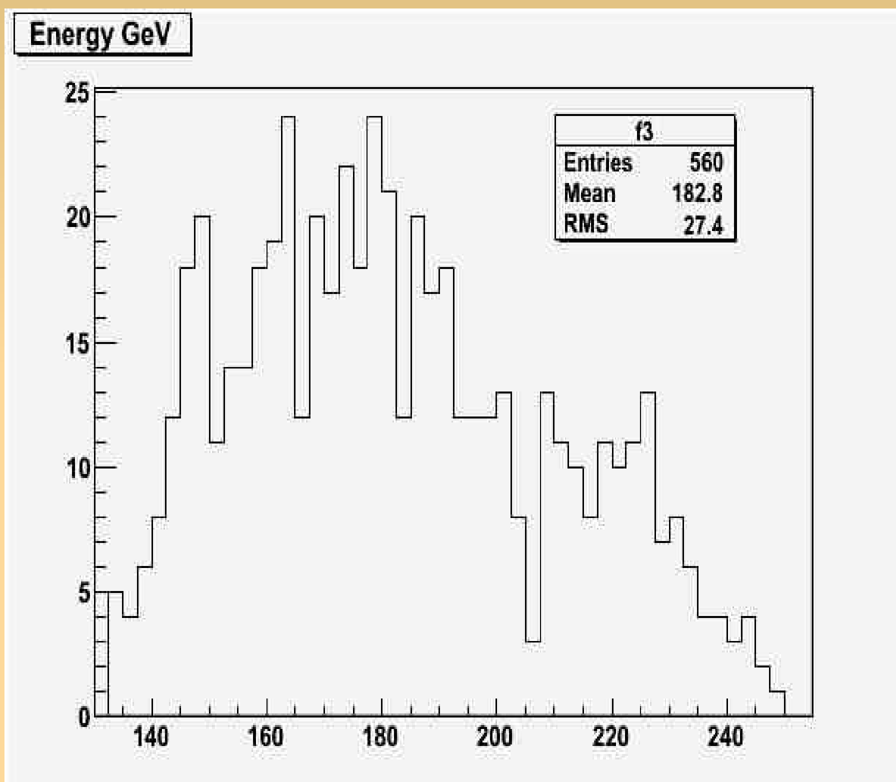
Multiple Compton Scattering

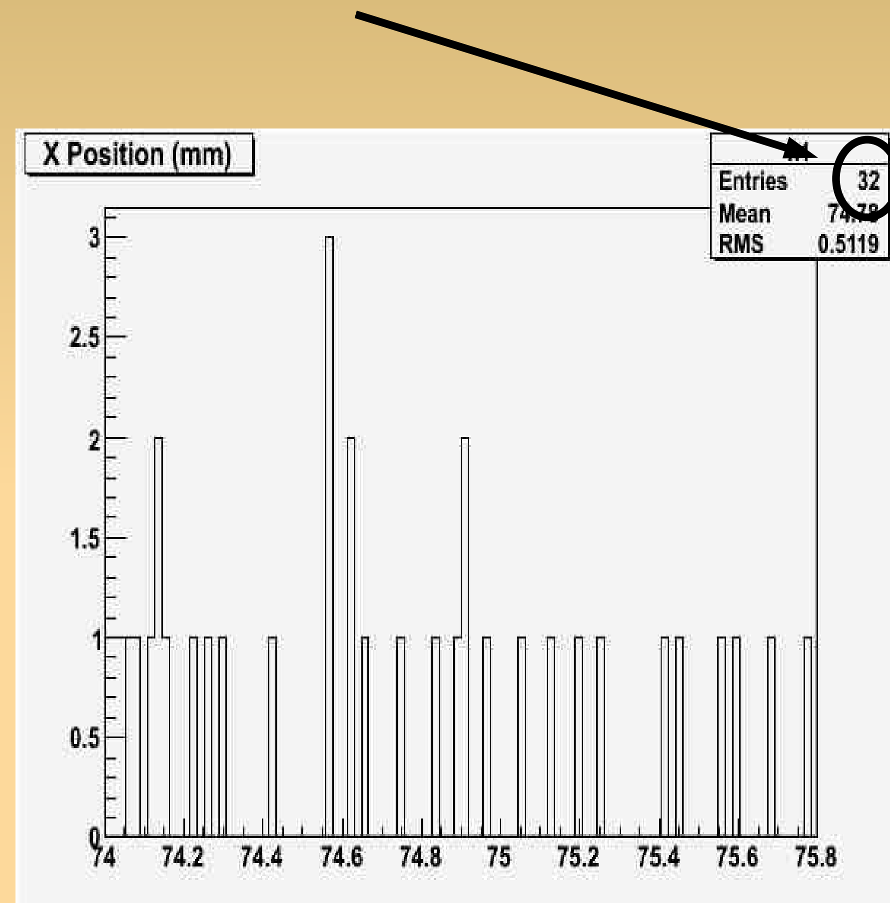
Estimated fraction of electrons which scatter more than once $f \sim 5 \cdot 10^{-4}$



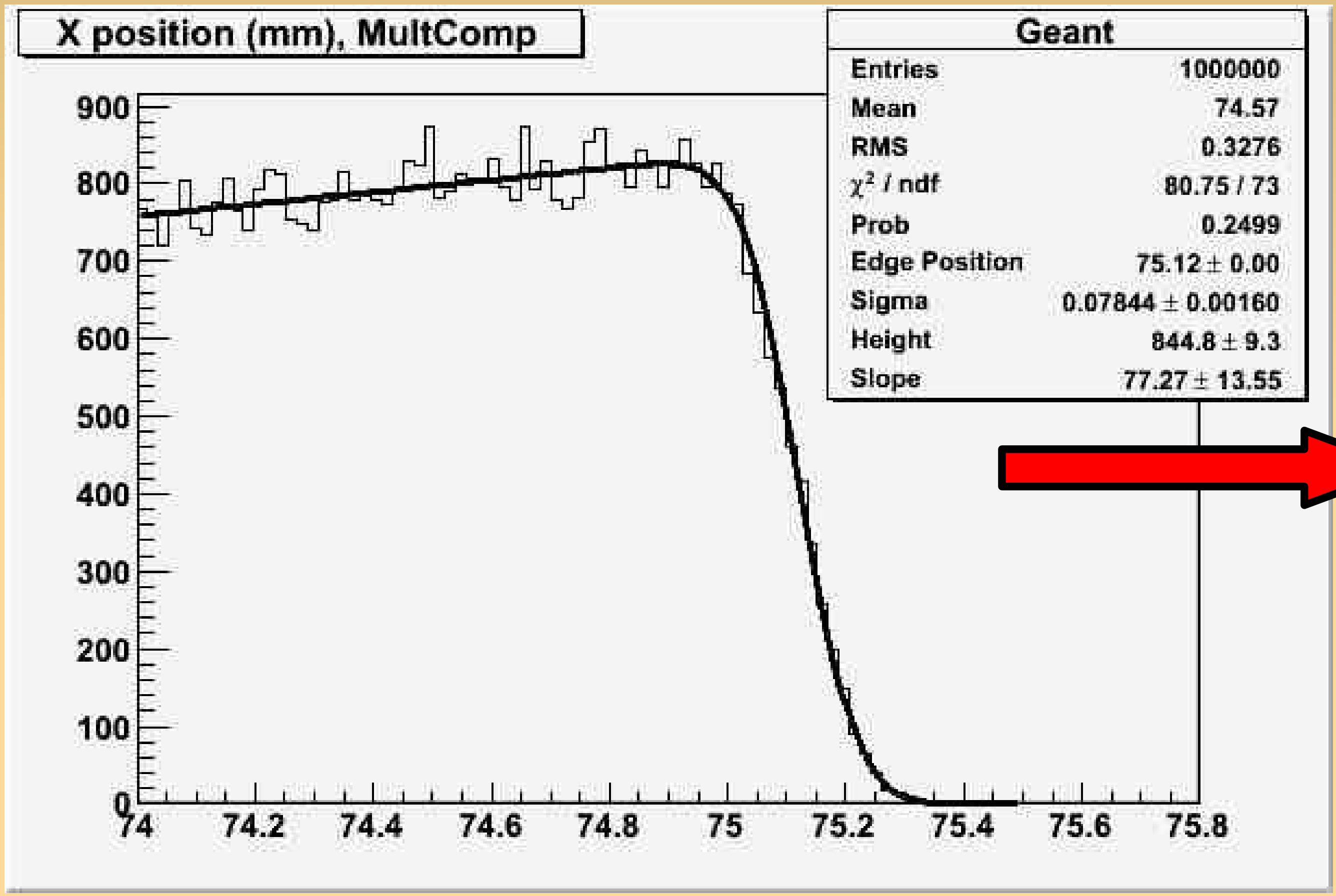


Multiple Compton Scattering





Multiple Compton Scattering



$$X_{Edge}^{Mul}=(75.1191\pm0.0022)\ mm$$

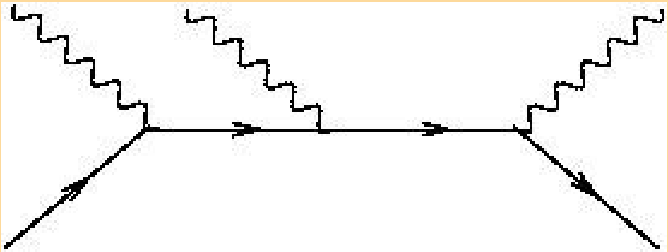
$$X_{Edge}=75.1191\pm0.0022\ mm$$

Non Linear Effects

When the density of the laser is high the electron can interact simultaneously with more than one laser photon:

$$e(p)+n\gamma(k)\rightarrow e(p')+\gamma(k'), n\geqslant 1$$

An intuitive picture can be given with the Feyman diagrams:



Non Linear Effects

Moreover the electron inside the electromagnetic waves of the laser behaves like it has a momentum (called quasi-momentum):

$$q = p + \frac{\xi^2 m^2}{2\, p \cdot k_L} k_L ,\; q^2 = m^2 (1+\xi^2),\; k_L \, laser\ photon\ 4-momentum ,$$

$$p\ \ 4-momentum\ of\ the\ electron$$

$$et\ \ \xi^2 = \frac{2 n_\gamma r_e^2 \lambda}{\alpha} ,\; n_\gamma\ laser\ photon\ density ,\; \lambda\ laser\ wavelength$$

$$r_e^2\ classical\ electron\ radius ,\; \alpha\ fine\ structure\ constant$$

The energy-momentum conservation can be written therefore:

$$q + n k_L = q' + k'$$

Non Linear Effects

The cross section for the process has the form:

$$\sigma_c = \sigma_1 + \sigma_2 + \sigma_3 + \ldots$$

$$\sigma_n = f_{n1}(E_{Beam}, \omega, \xi^2, n) + h_\gamma h_e f_{n2}(E_{Beam}, \omega, \xi^2, n),\ h_\gamma \textit{ polarization for laser},$$

$$h_e \textit{ initial polarization for electron}$$

Where σ_n is the cross section for the process where the electron absorbs n photons (n=1 is the linear Compton).

For each of these processes we can define a maximum energy for the photon:

$$\omega_n^{max} = \frac{nx}{1+nx+\xi^2} E_{Beam},\ \textit{for}\ n=1\ \omega^{max} = \frac{x}{1+x+\xi^2} E_{Beam}$$

Non Linear Effects

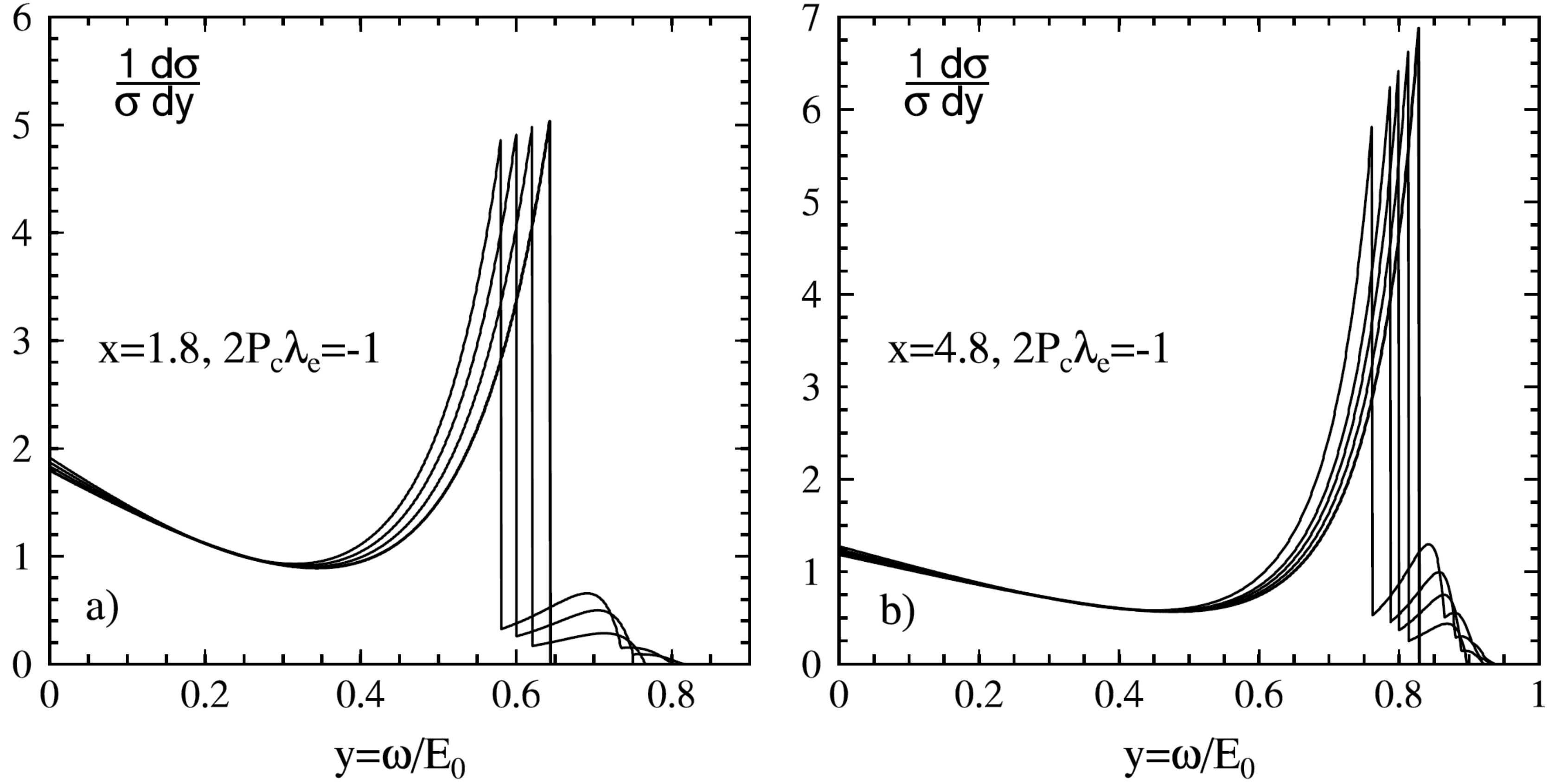
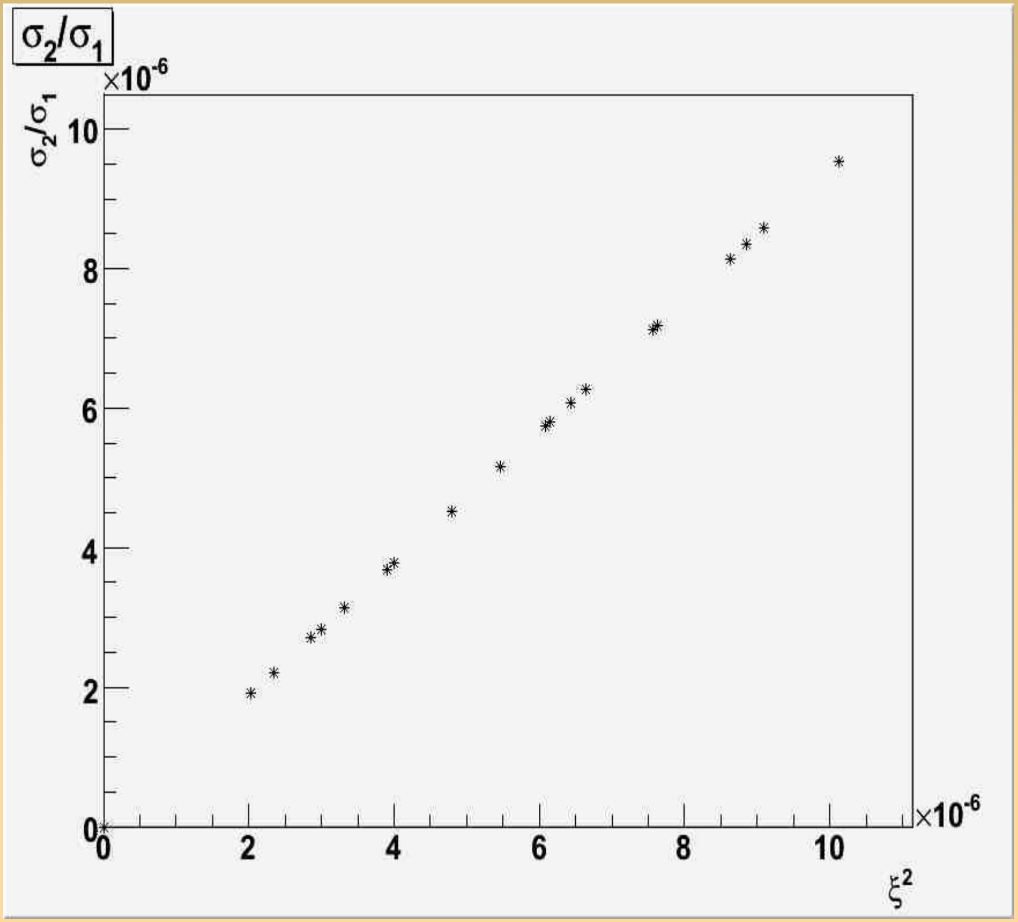


Figure 1.3.5: *Compton spectra for various values of the parameter* ξ^2. *Left figure is for* $x = 1.8$, *right for* $x = 4.8$. *Curves from right to left correspond to* $\xi^2 = 0, 0.1, 0.2, 0.3, 0.5$ *(the last for* $x = 4.8$*, only).*

Non Linear Effects



For our laser parameter:

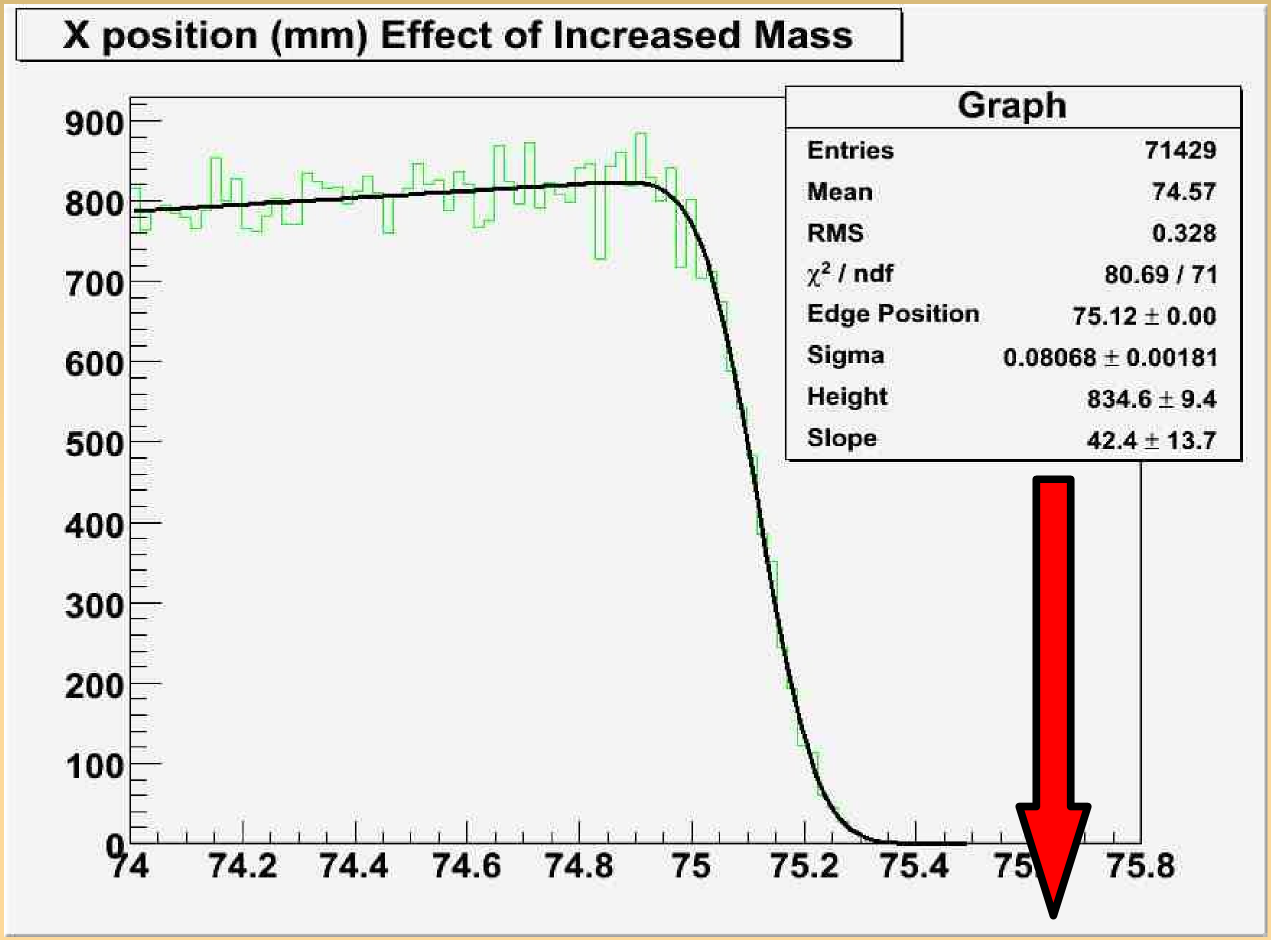
$$0 \leqslant \xi^2 \leqslant 1.04 \cdot 10^{-5}$$

This gives us:

$$\frac{\sigma_2}{\sigma_1} < 10^{-5}$$

For 1 Million of events less than 10 electrons scatter absorbing 2 photons!!!

Non Linear Effect



For the maximum value for ξ^2:

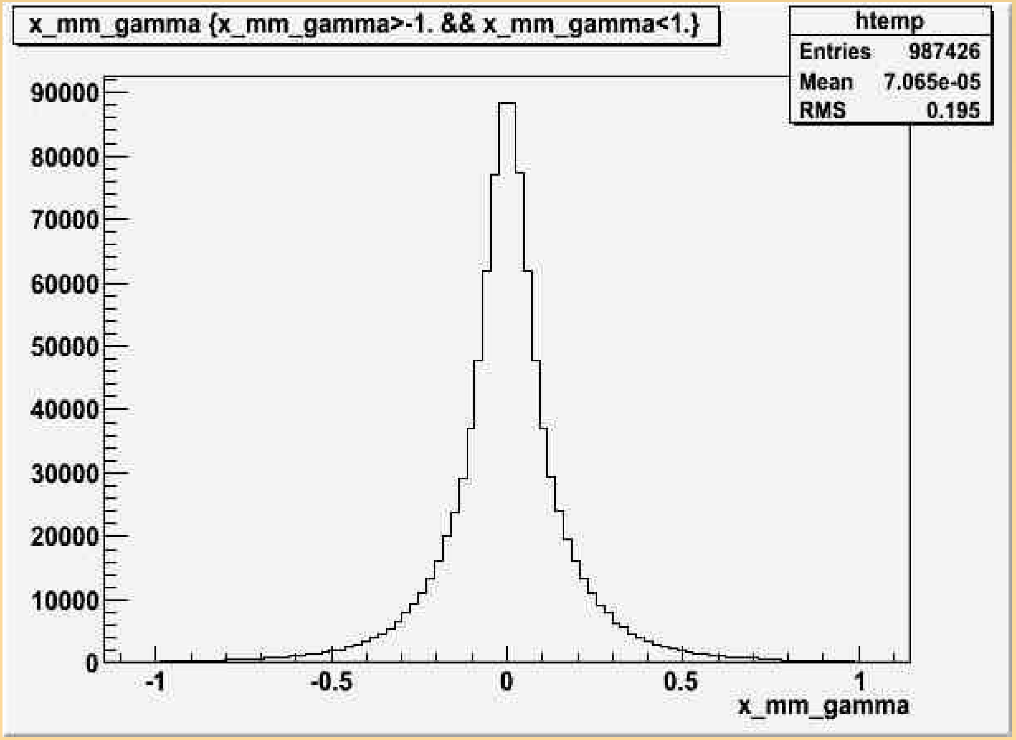
$$\frac{\Delta E}{E} \sim 2.2 \cdot 10^{-6}$$

$$X_{Edge}^{IncMass} = 75.1194 \pm 0.0022\, mm$$

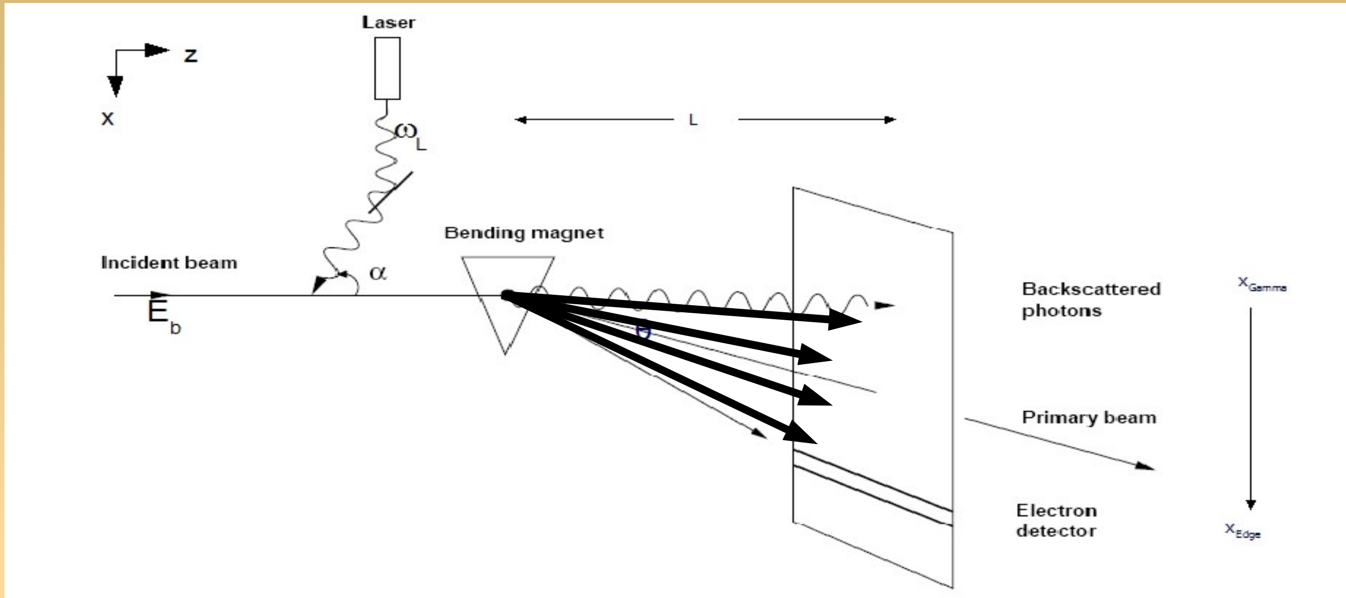
$$X_{Edge} = 75.1191 \pm 0.0022\ mm$$

Photons Detection

To measure the 'zero' we want to use the backscattered photons....



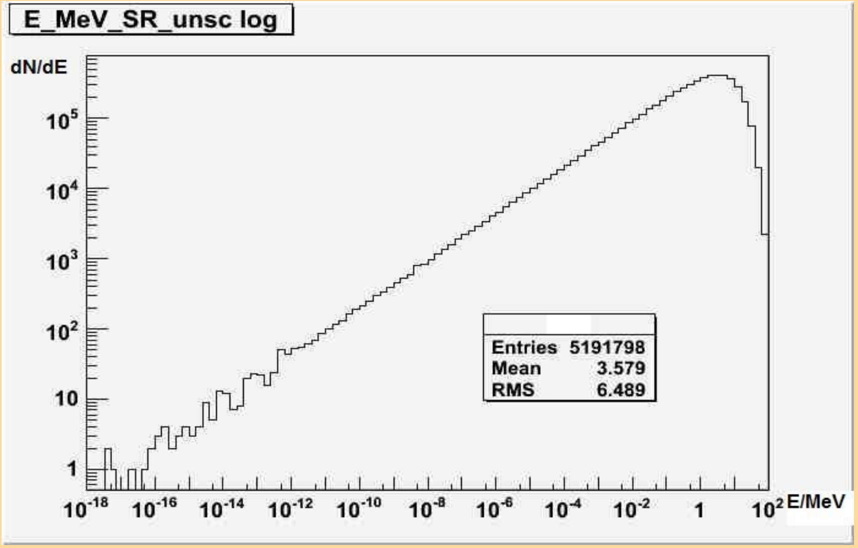
Synchrotron Radiation Background

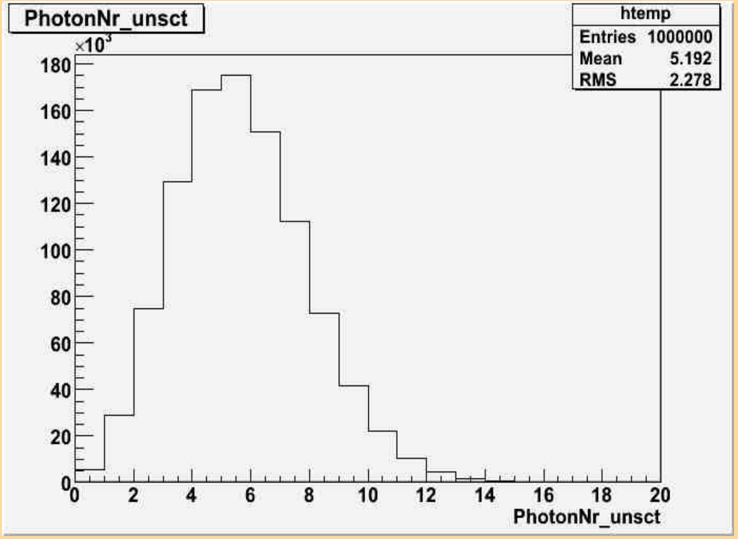


Magnet: B=0.28T

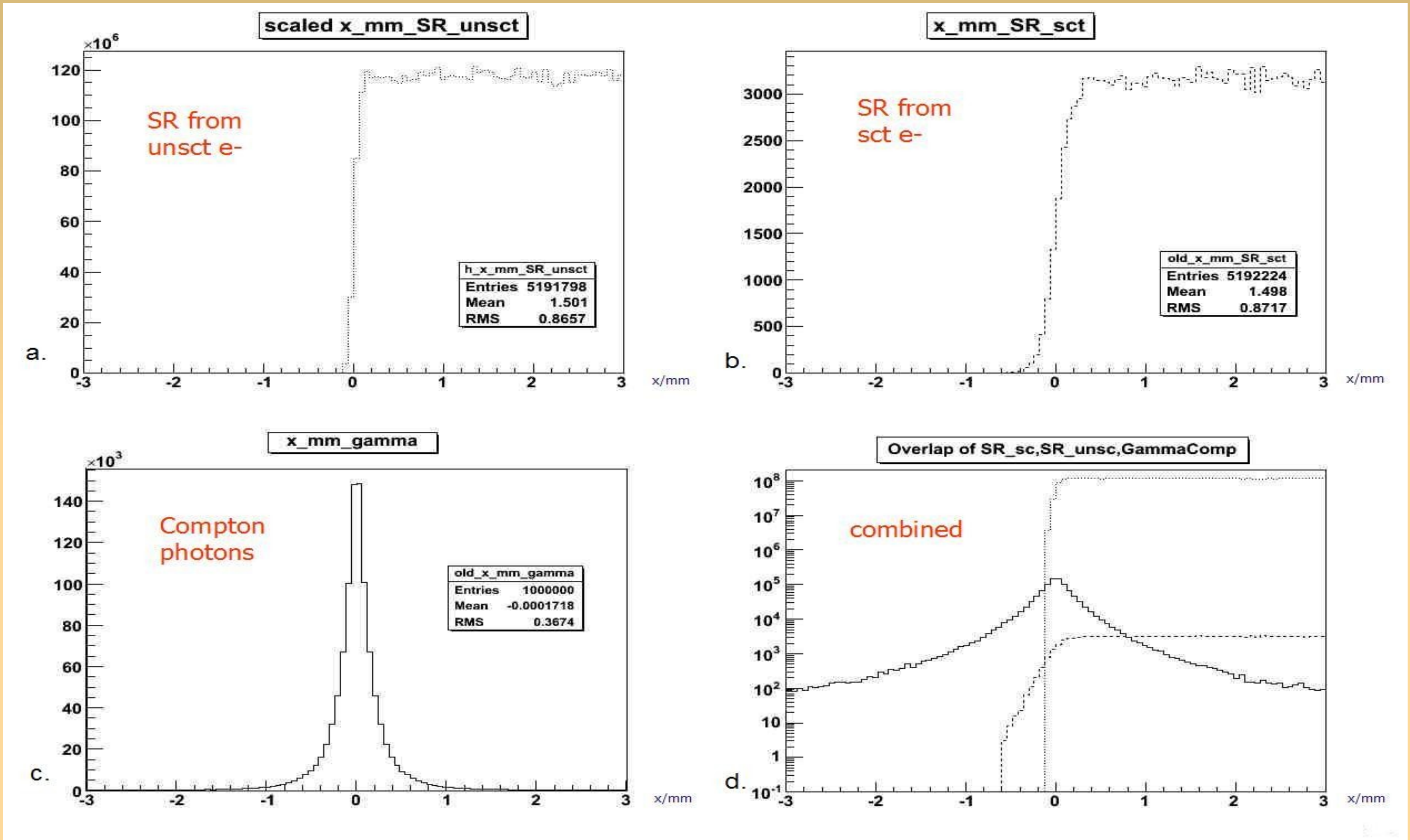
L=3 m

SR: Emean=3.6 Mev



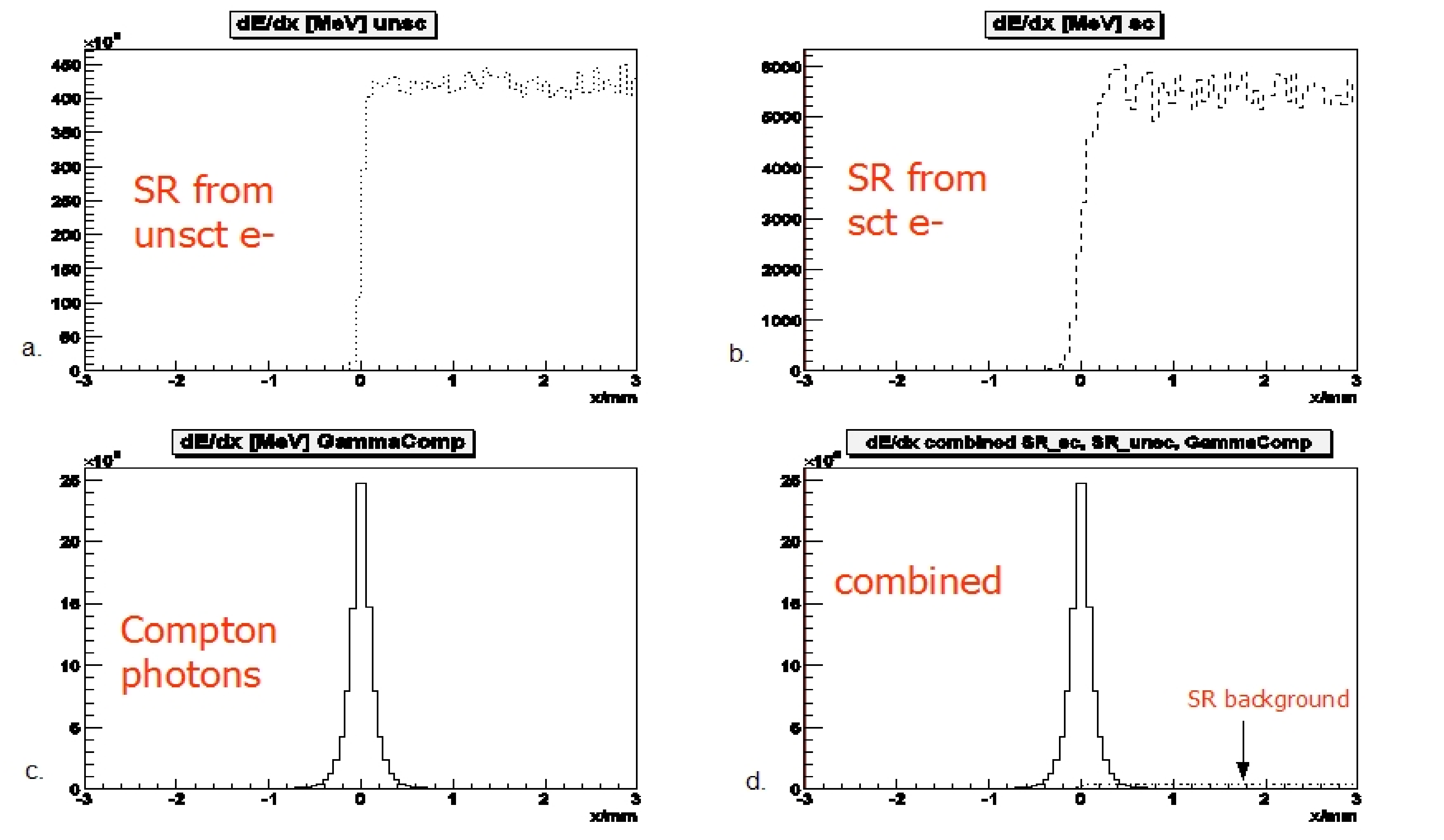


Compton vs. SR (dN/dX)



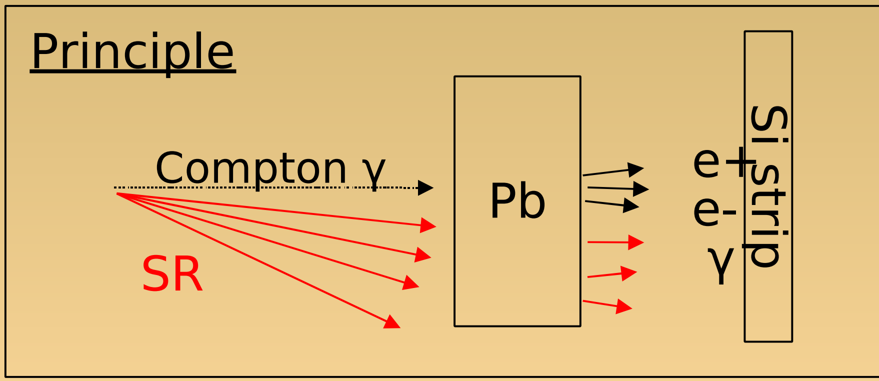
The Background is dominant!!!!!!!!!

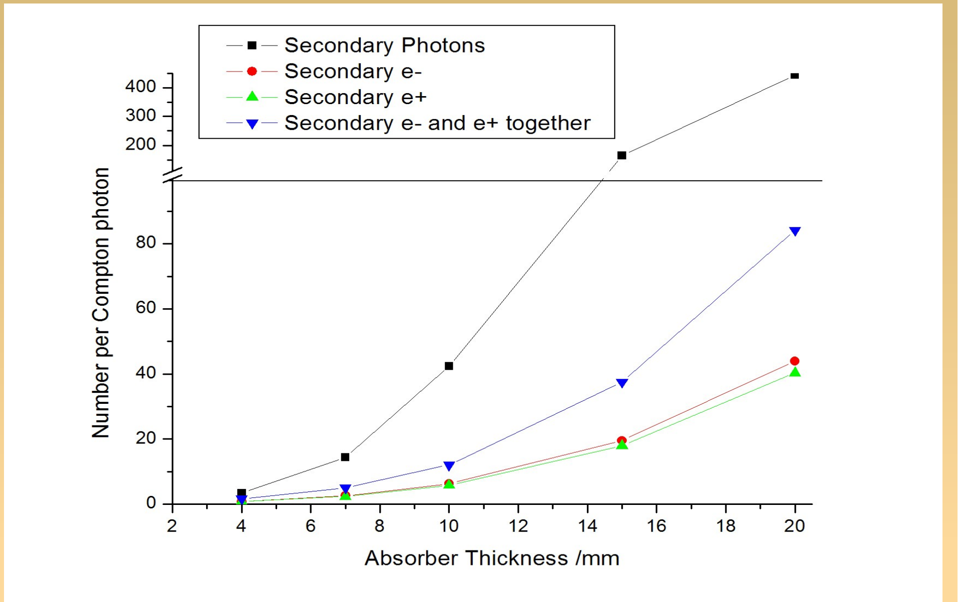
Compton vs SR (dE/dx)

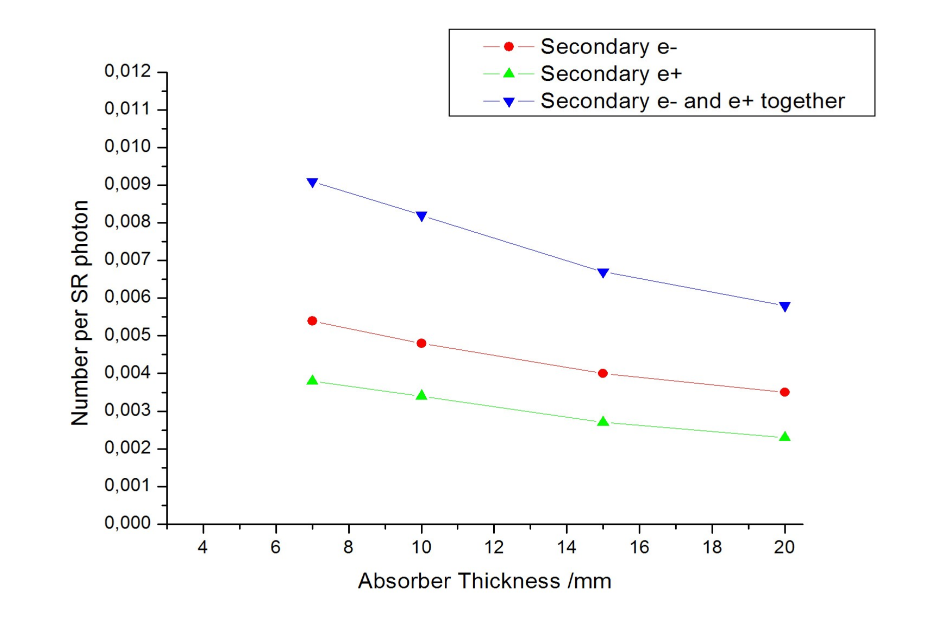


Signal from Compton is dominant!!! Calorimetry needed...

Absorber

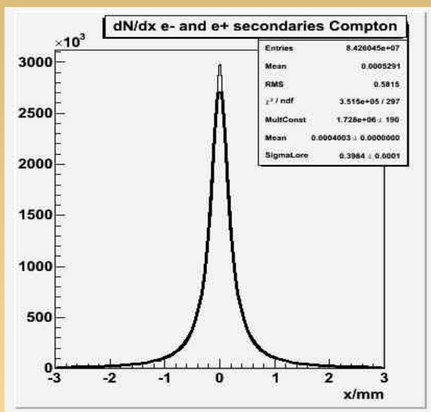


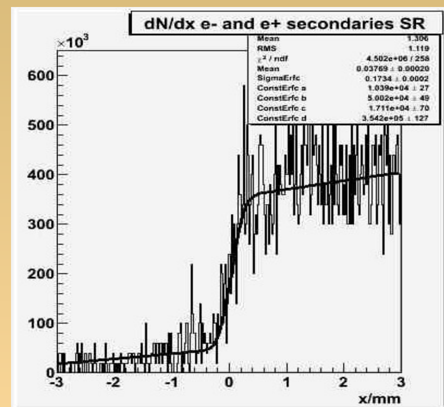




- Absorber converts Compton γ into e+/e– → their dN/dx can be measured with Si strip (up to 5 μm resolution)

Compton Peak Fit

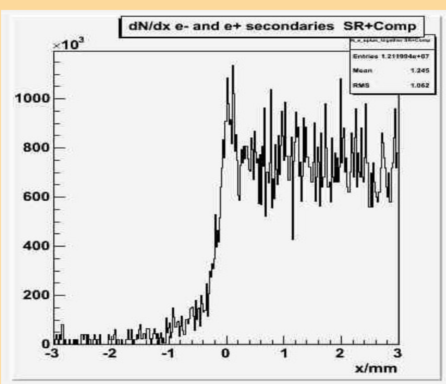


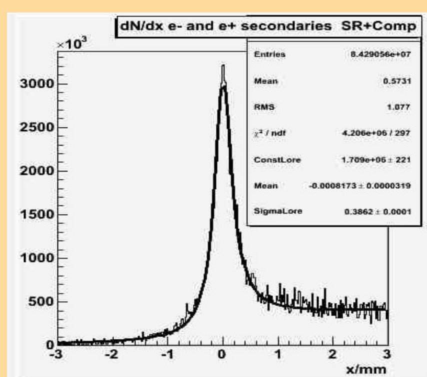


Peak + Background

combined

10mm absorber 20 mm absorber





- Depends on the absorber thickness
- For a good reconstruction of the peak, the background should be **<u>not</u>** measured and fitted independently
  - the background can be subctracted or at the least taken into account for the over fit

$$\longrightarrow X_{Peak} < 0.5\,\mu m$$

Conclusions I

- The Compton Backscattering looks a promising way to measure the beam energy at ILC together with other methods.
- For the Multiple Compton scattering we have, in the region of interest, less 1–2 events per bin
- For our laser parameters we aspect electrons absorb 2 photons in the int. region less than 10
- The relative edge shift for the electrons is in the order of 10^{-6}

⇒ These effects are negligible!!!!!

Conclusions II

For the photon detection, SR is a serious background with many photons but low energy.

- Good solution seems to be a thick absorber (20 mm or even more!) Si strip and calorimetry.

SOME WORK STILL NEEDED!!!!!