Exploring Source Based Energy Calibration Strategies and Modelling of Electro-Magnetic Interactions

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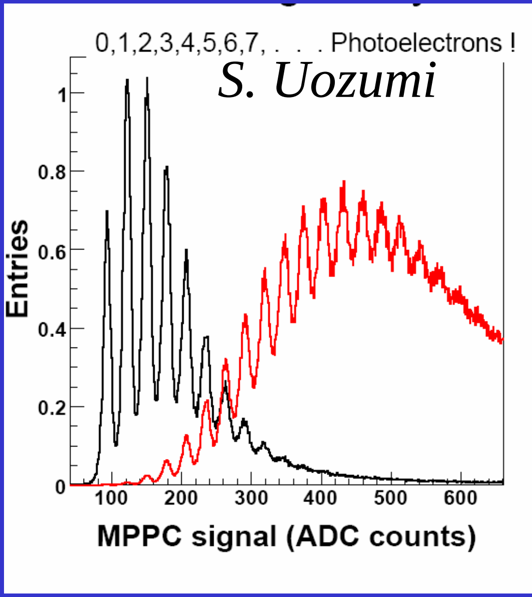
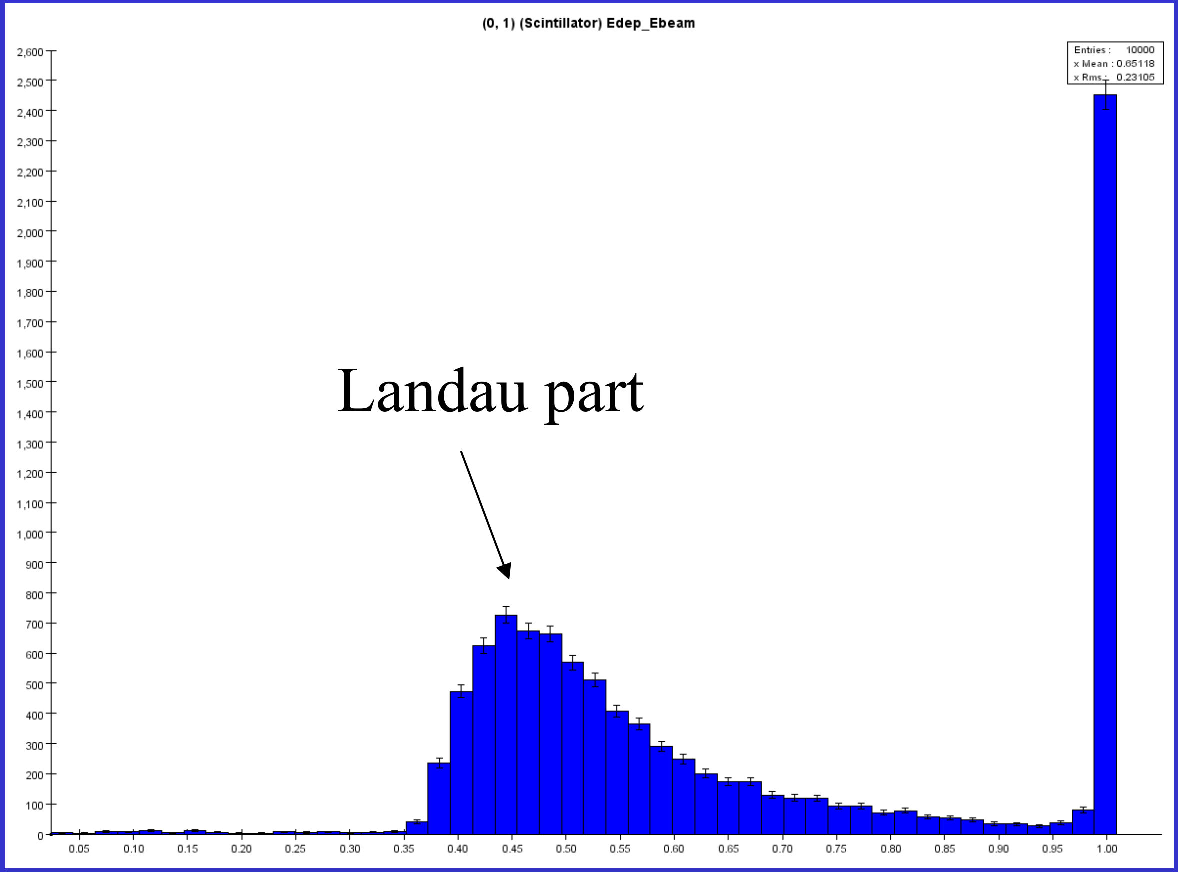
CALICE Meeting, Manchester, September 2008

Calibration strategy ?

- Typical detector designs have MANY cells.
- Essential physics calibration is ADC → deposited energy for scintillator and/or Silicon.
- In the Si-PM era, pe → ADC calibration is straightforward (modulo saturation).
- In thin active media, like ECAL Scintillator, calibration with sources may be an attractive, high statistics way to deal with non-uniformities, saturation, material thickness etc.
  - Current thinking is centered on procedures which could certainly be carried out during production, and maybe also in situ. (especially if push/pull is realized !)
  - Following plots are data with a conventional PMT setup (self-triggered) aimed at commissioning ability in a well defined setup before going on to applying to technologies suitable for ILC such as thin tiles.
  - Can check low energy EM interaction detector response simulation.



Bi-207. 1047 keV e-. 2.5mm Scint.



5mm air

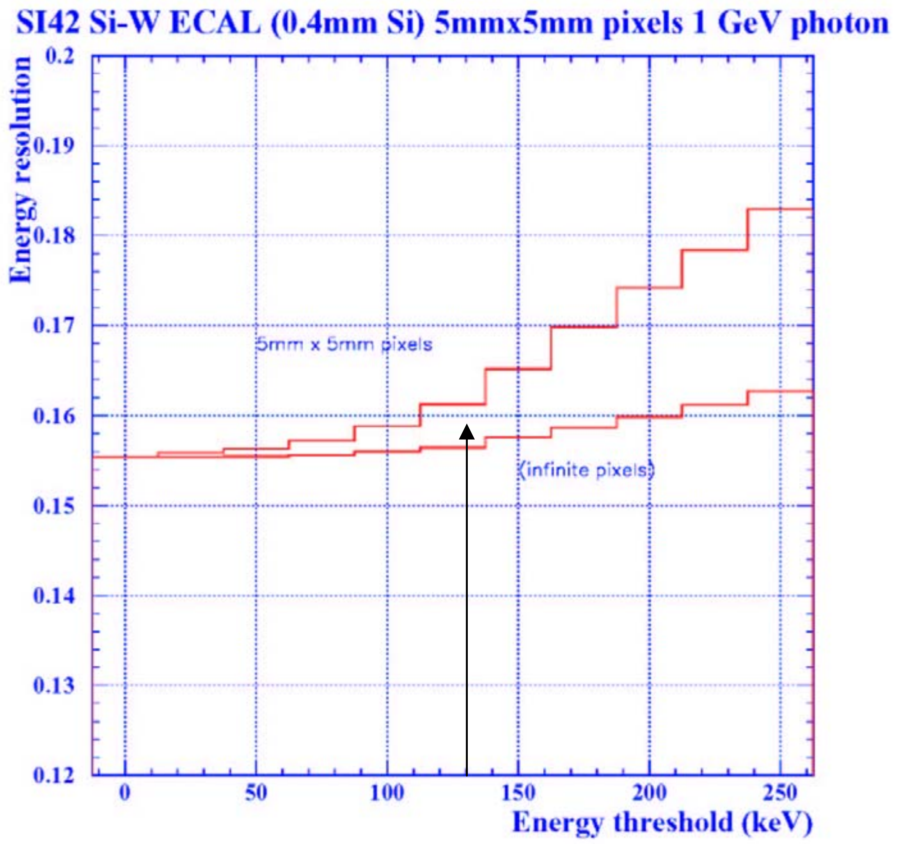
Total absorption

Deposited energy fraction

ECAL Energy resolution

Need threshold well below 1 MIP level in order to approach asymptotic resolution.

Value depends on transverse segmentation.



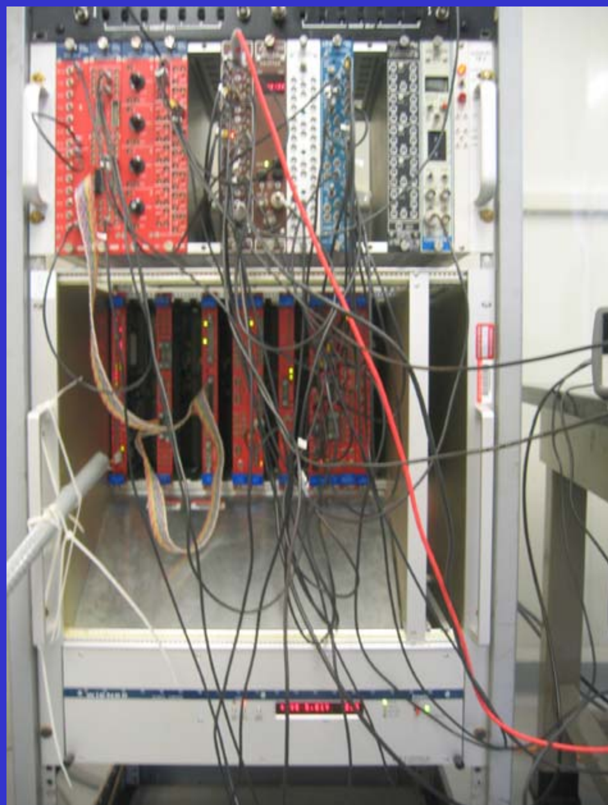
Shower Age Corrections

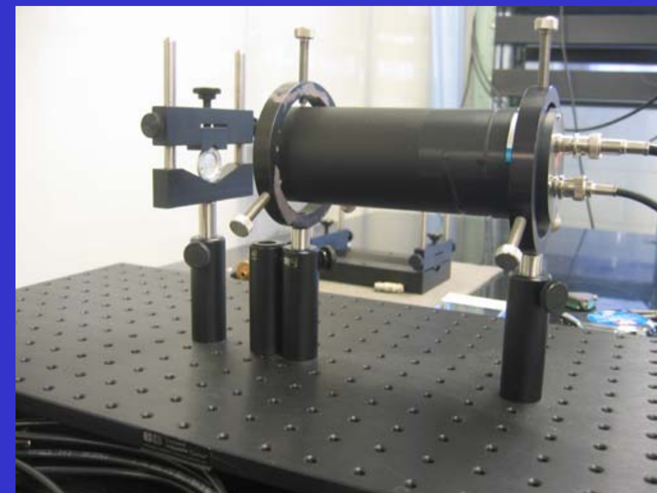
- EM calorimeters with good longitudinal segmentation can be used to correct for the e/MIP response variations with shower age.
  - (more and more of an electron's energy is deposited in the passive (high Z) material as the shower ages and the average shower particle energy decreases)
  - e/MIP can easily be 0.6 or so for Pb/Scint deep in a shower.
  - Since these effects are relatively big, it may also be important to check directly the electron and MIP response of the scintillator.
    - The scintillator response presumably becomes more Compton dominated with shower age.

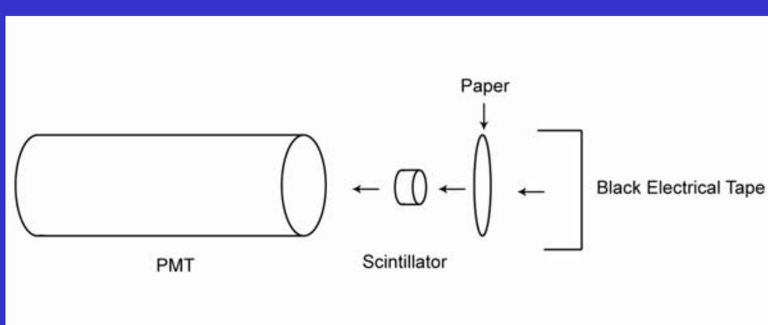
Developing Lab

- Aims:
  - Develop in-situ ability to appreciate technical feasibility of different approaches.
  - Test single planes of detectors well before going to test-beam.
  - Test simulation of particle interactions with matter with available tools.
  - Train and motivate students in research, particularly detectors, DAQ and electronics.

Lab Measurements with Sources and Cosmics



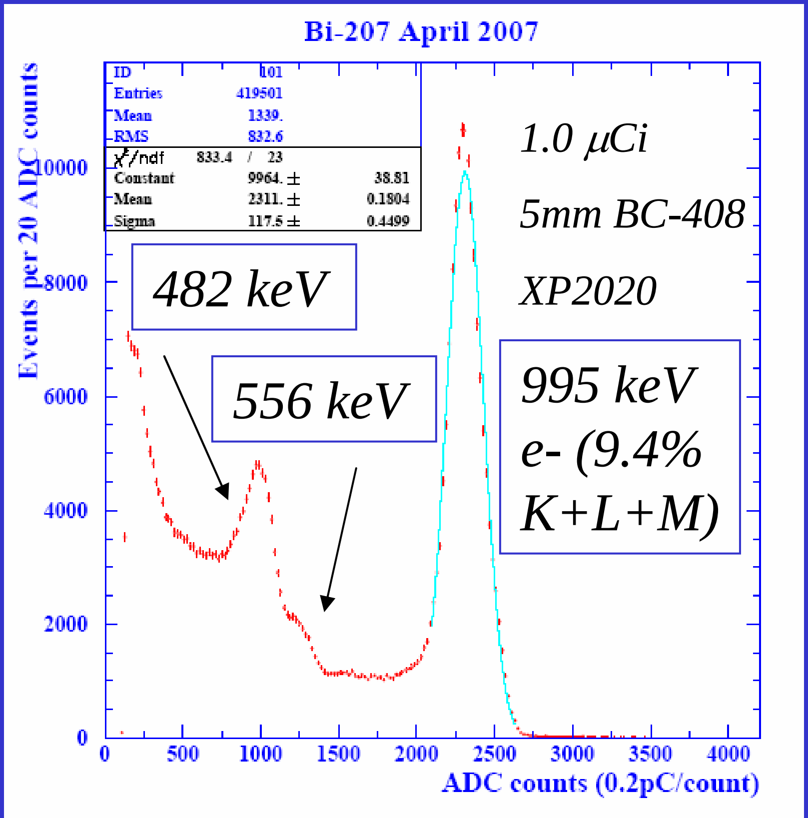




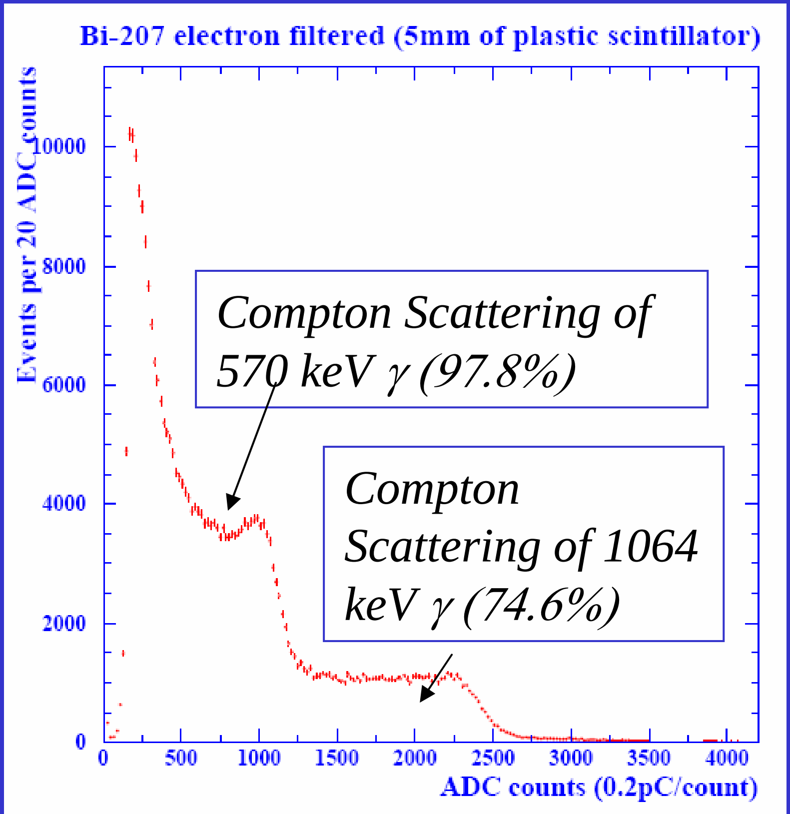
Exploring Calibration Strategies

Bi-207 with Al mylar window: internal conversion electrons.

All plots are data with 5mm BC-408 scintillator.

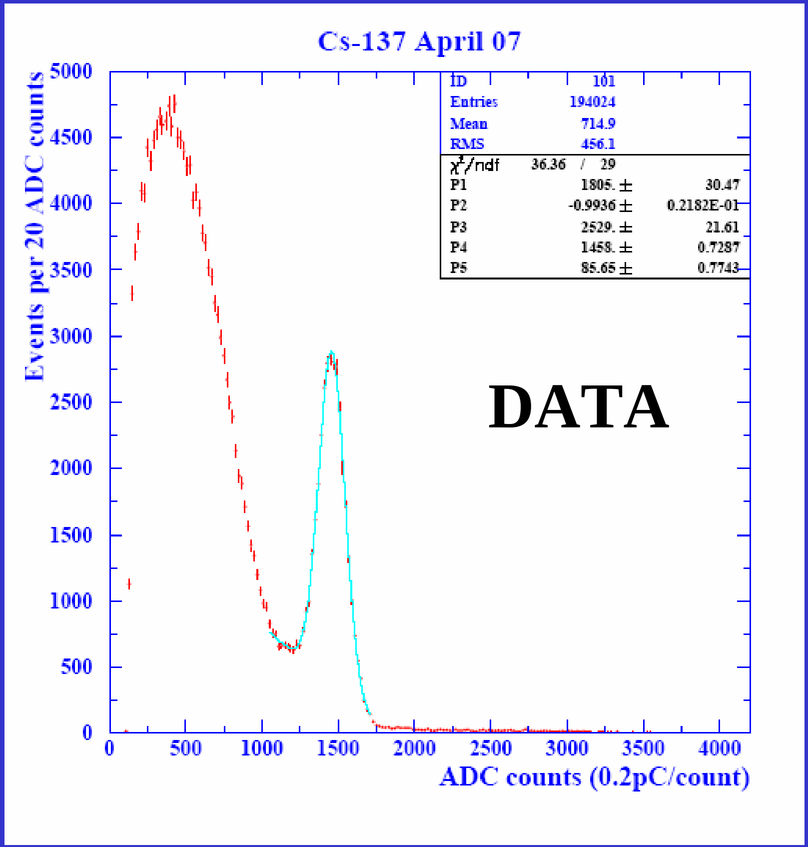


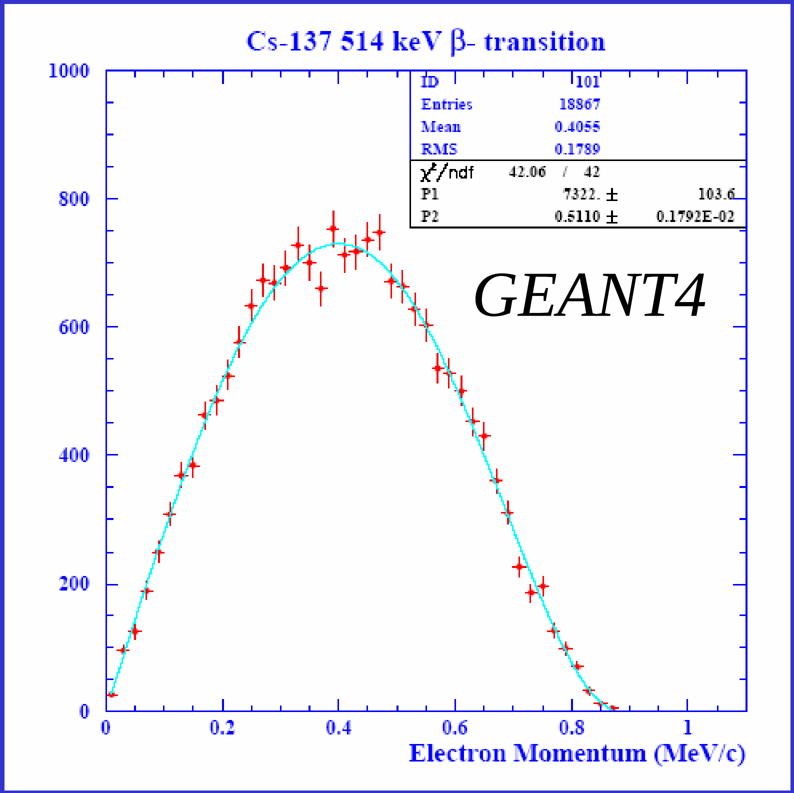
Absorption peak $\sigma_E/E = 5.5\%$. (intrinsic splitting: 3.3%). Energy scale stat. error of < 0.01% !



Energy loss in upstream material, leads to the 482 keV e^- peak overlapping with 570 keV Compton edge (393 keV)

Cs-137





γ : 662 keV (85.1%)

e^- : 624 (7.7%), 656 (1.4%)

β_1^- 514 keV endpoint (94.4%)

β_2^- 1176 keV endpoint (5.6%)

Procedure

- Collect real data (usually 100k events in about 15 minutes)

D. File

- GEANT4 Detector Model
  - Geant4.9.1.p02
  - 5cm source – detector distance.
  - Full 3-d geometry model.
- Generate electrons and gammas according to nuclear data-sheets
- Find predicted energy deposition in scintillator.
- Fit binned real data using χ^2 approach allowing for:
  - Pedestal (measured with pulser events)
  - Normalization factor
  - Energy scale (ADC counts per MeV deposited energy)
  - Energy Resolution
  - Optional Gamma to Electron Multiplicative Factor

B. Van Doren

- Ideogram method is used to smooth MC.

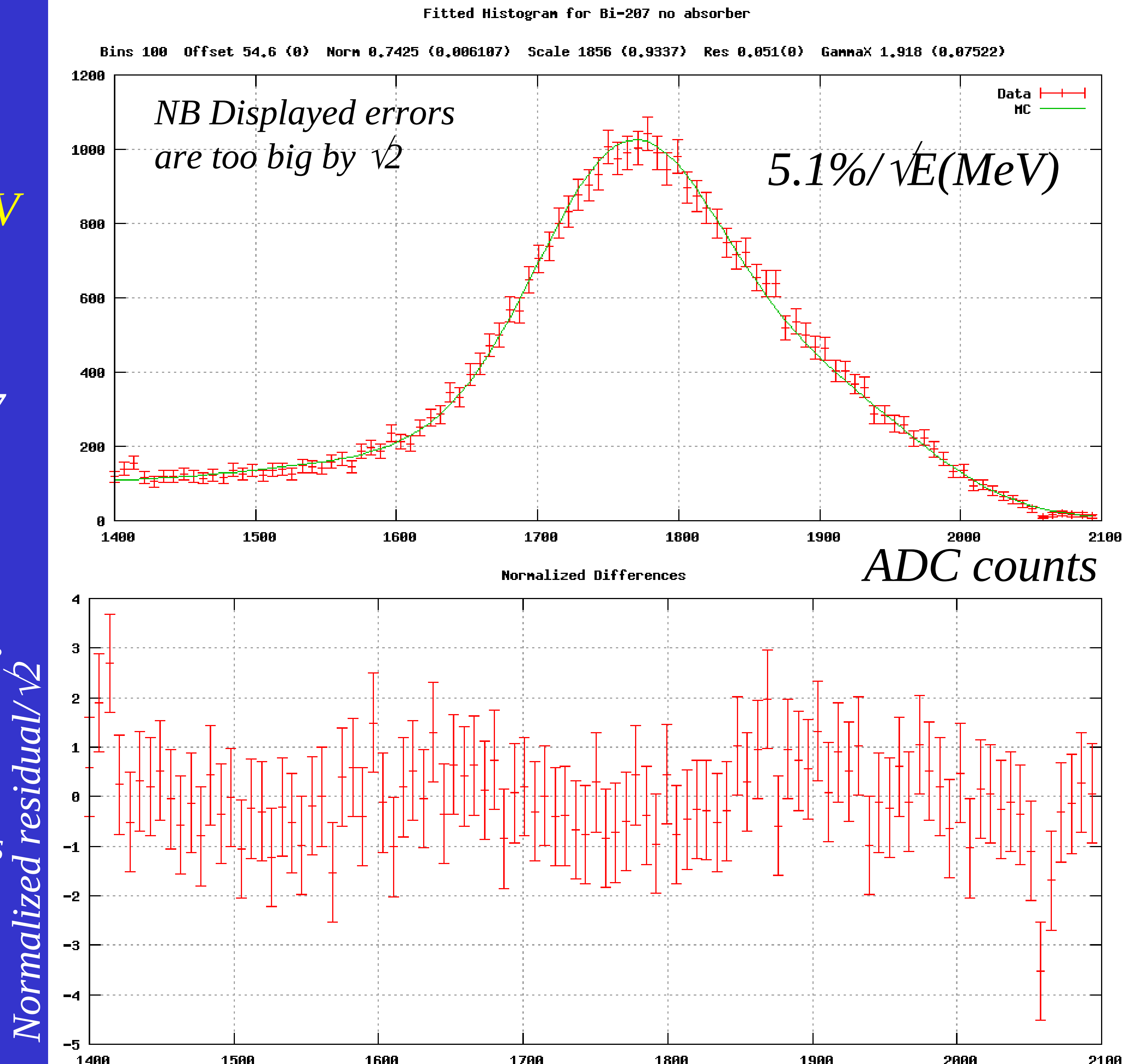
Bi-207

No absorber

(mostly 976 keV conversion electrons)

$\chi^2/dof = 134/97$

Not a perfect fit, but not too bad. Needed to include the gamma/e fudge factor dof to fit the data below the electron peak. Deficit of electrons or excess of gammas ?



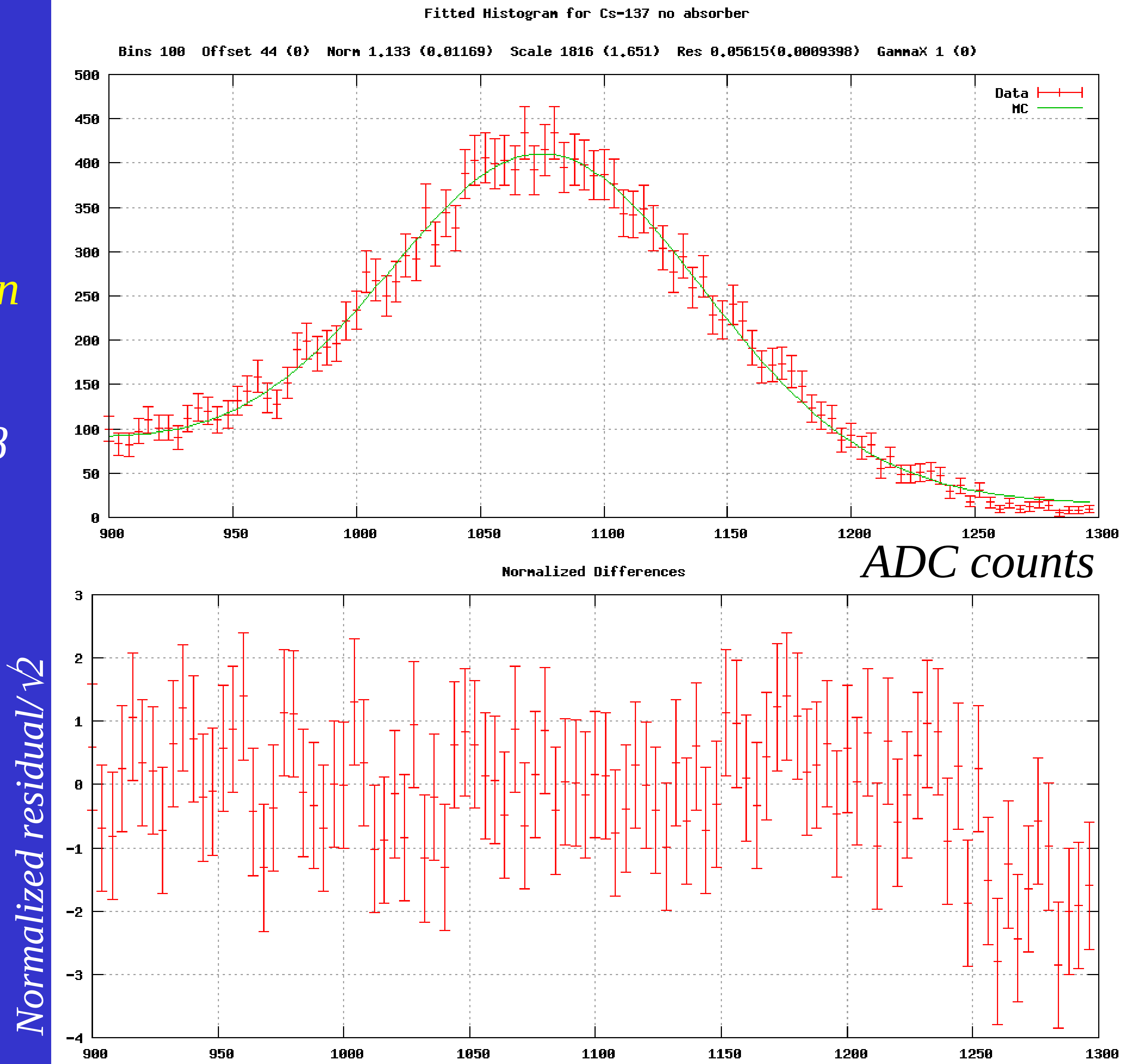
Cs-137

No absorber

(mostly 624 keV conversion electrons)

χ^2/dof= 174/98

Fit not very good above the electron peak. Perhaps in this case the gamma to electron factor needs to be used too to allow for a smaller resolution value.



Bi-207

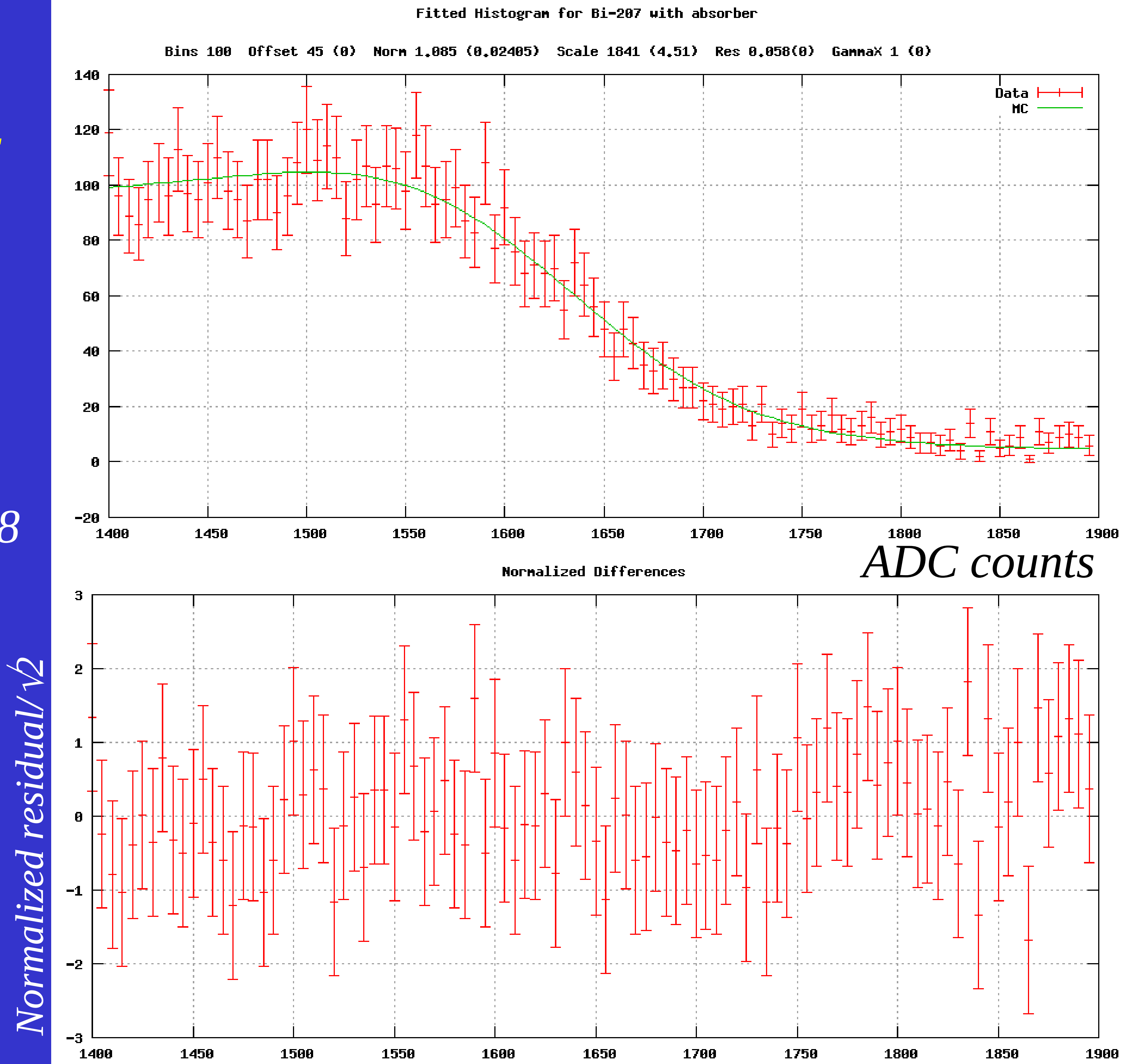
With absorber

(6mm LDPE)

(Compton edge of 1074 keV gamma)

χ^2/dof= 107/98

Fit is pretty good !



Cs-137

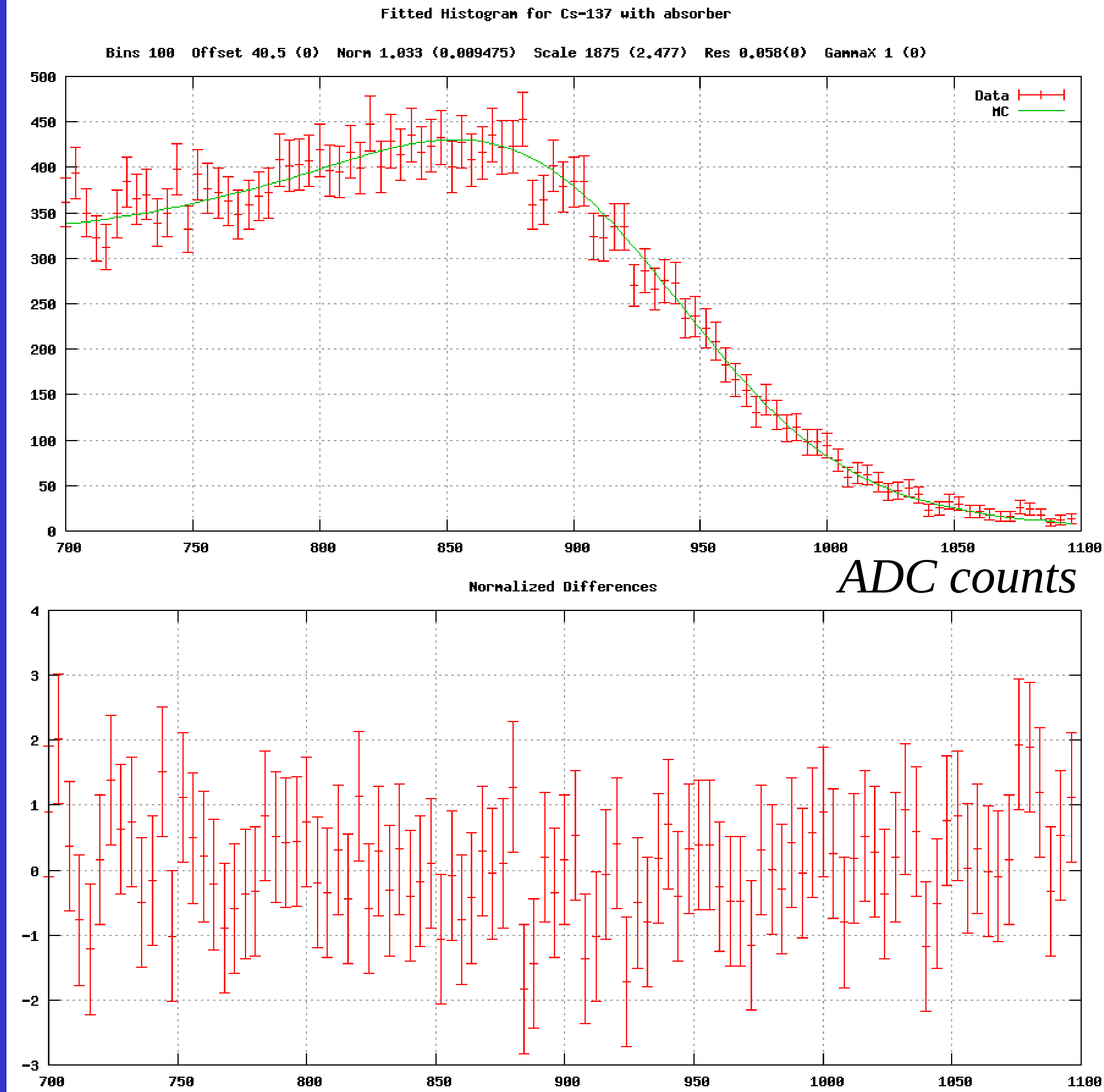
With absorber

(6mm LDPE)

(Compton edge of 662 keV gamma)

χ^2/dof= 116/98

Fit is pretty good !



Bi-207

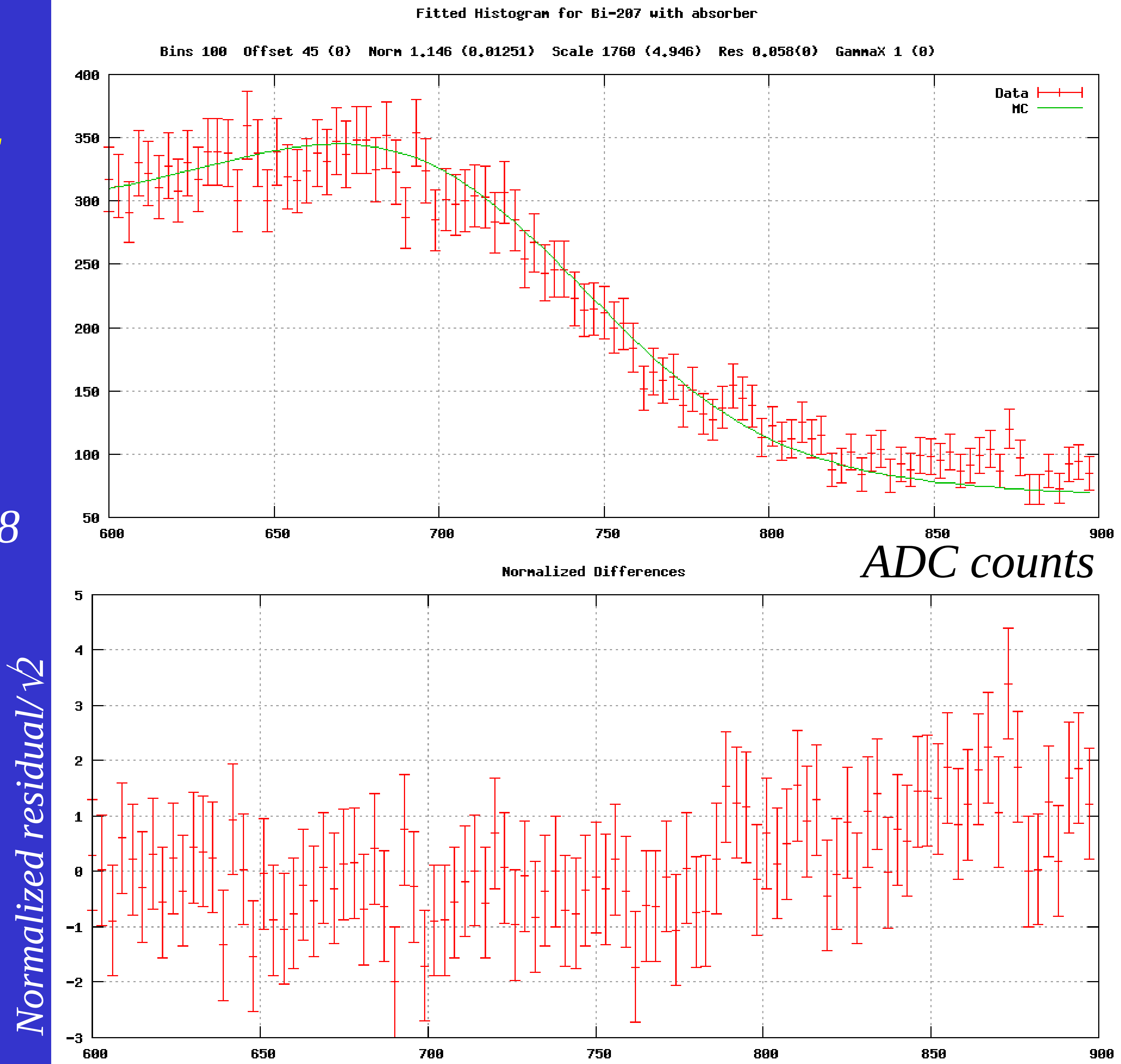
With absorber

(6mm LDPE)

(Compton edge of 570 keV gamma)

χ^2/dof= 187/98

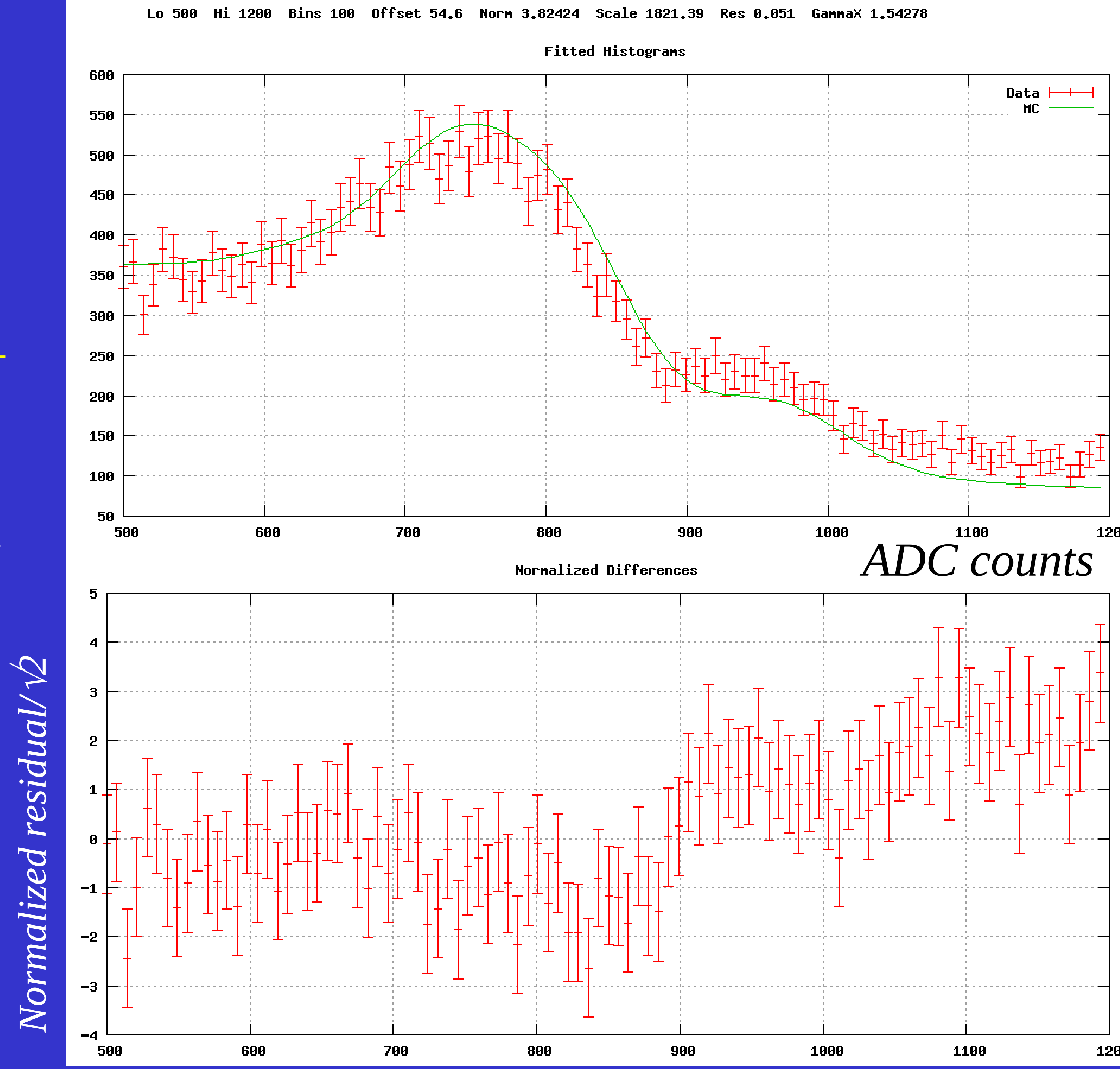
Not so good, and quite different purported energy scale.



Bi-207

No absorber

(Compton edge of 570 keV gamma + its CEs)



χ^2/dof= 418/97

Not so hot !

Energy Scale Estimates

(reasonable fits only)

- 1856 ± 1 ADC counts / MeV (Bi-207 976 keV e^-)
- 1841 ± 5 " (Bi-207 1064 keV γ Compton edge)
- 1875 ± 3 " (Cs-137 662 keV γ Compton edge)

Energy scale estimates consistent to within about 1-2% level with different techniques over a relatively small energy range.

Compton edges tend to give broader resolution.

Potential Systematic Errors

Lots of things to get right at the <1% level …

- Material description
  - Upstream material
    - Need at least two reliable electron measurements for data-based control of this.
  - Surrounding material
  - Source geometry
- Geant4 interaction model
  - Need low energy EM ?
    - Broadening of Compton edge?
  - Scintillator saturation (Birks) necessary for electrons ?
  - Is multiple Coulomb scattering OK ?
- Nuclear modelling
  - True coincidence summing effects
  - Auger electrons, X-rays
- Noise
- Random coincidence
- ADC linearity (< 0.5%)
- Scintillator / Light collection efficiency vs scintillator depth
- Resolution model (constant term, noise)

Planned Improvements

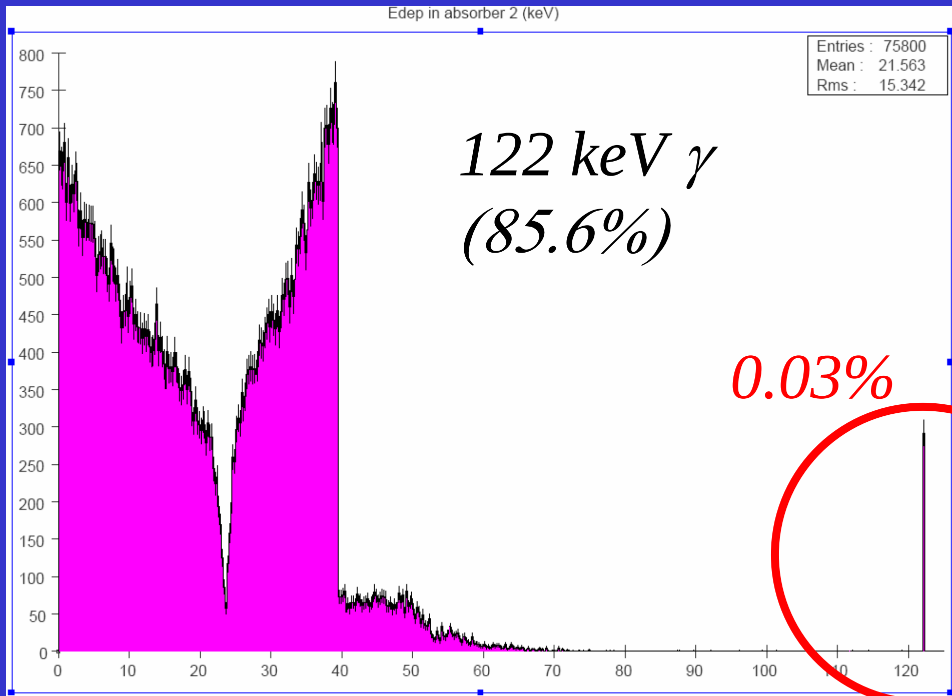
- Less upstream material (should make it easier to resolve electrons and gammas in no absorber data)
  - Also minimize environmental material
- Some collimation
- Test homogeneity with position scans
- Integrate LED pulser for in-situ ADC/pe calibration
- Investigate Compton coincidence technique with NaI trigger on back-scattered Compton gamma
- Apply to new photo-detectors
- Apply to scintillating fibers
- Extend to other sources.

Conclusions

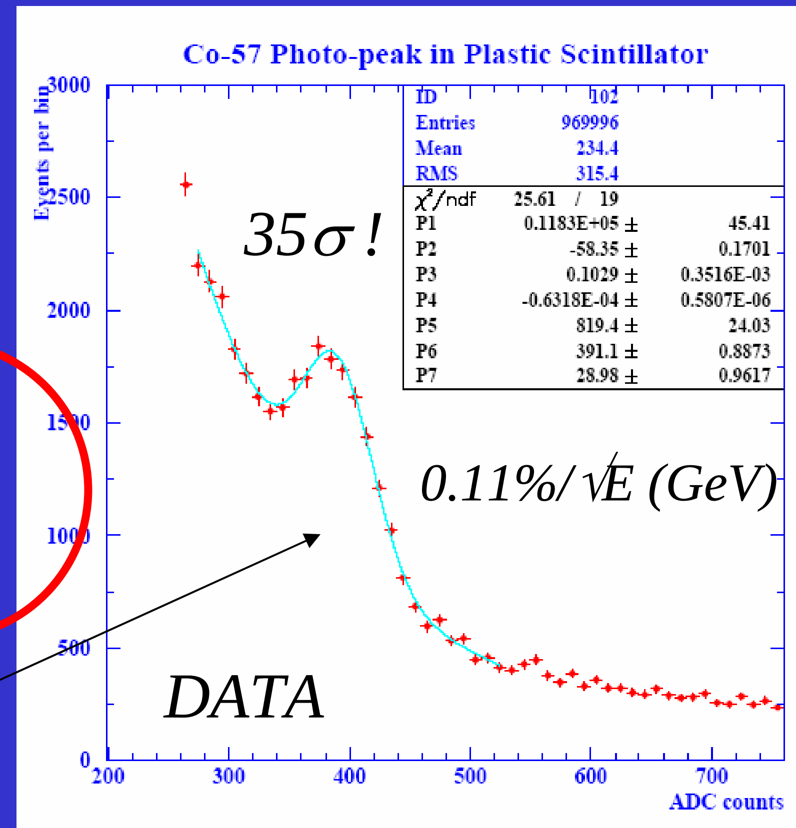
- Initial results are promising.
- Obtaining precision results needs care.
- 1 MeV electron test-beam is potentially very powerful $\rightarrow$ need excellent control of material as expected
- Compton-edge calibration technique looks very encouraging.
- Need to sort out some systematic effects / improve experimental setup before combined fitting of different data-sets makes sense.

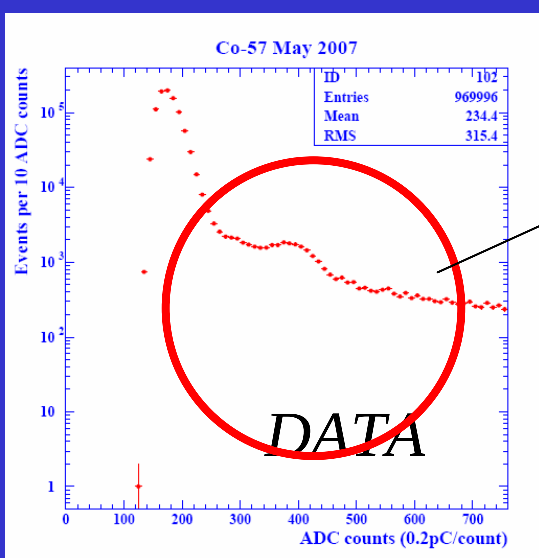
Backup Slides

Co-57 ($t_{1/2}$=272 d)



Energy (keV)

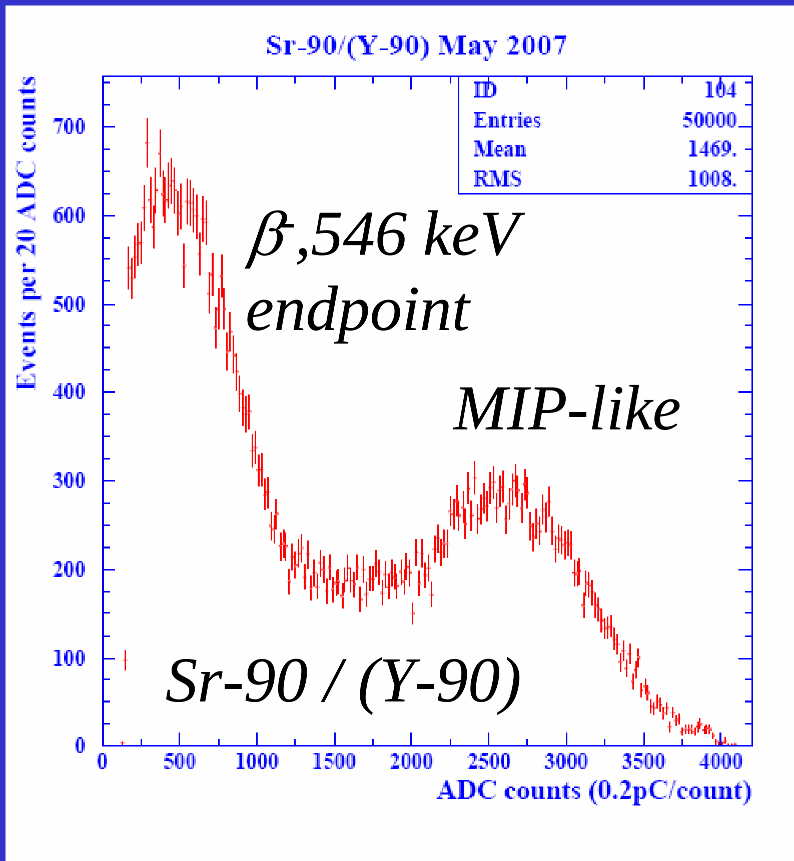




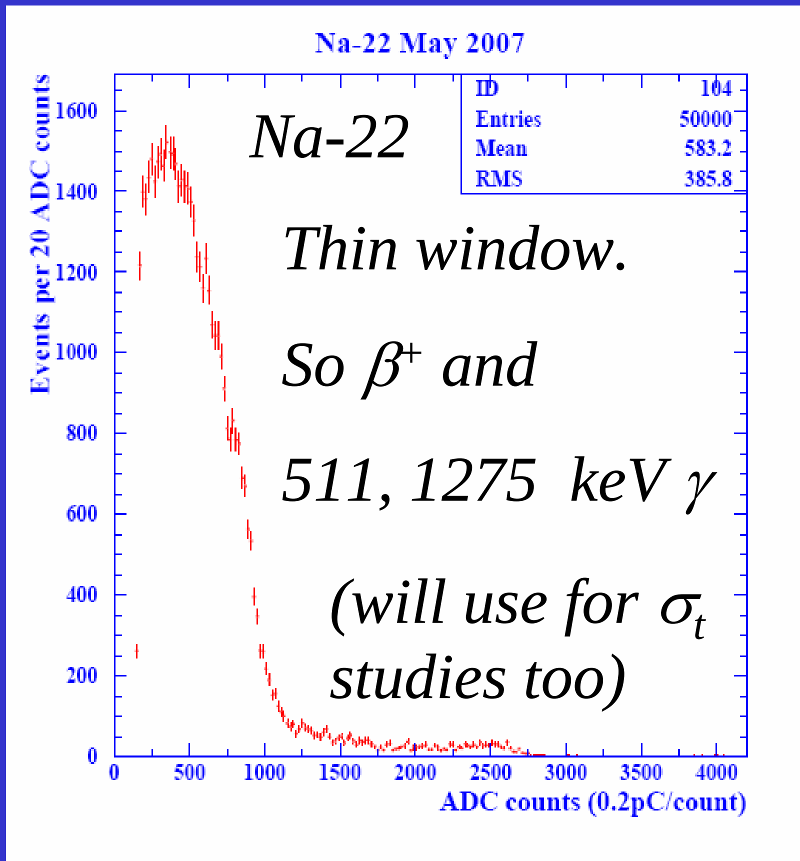
Full-energy peak corresponding to 0.1 MIP.

Lower energies (eg. Am-241, 60 keV) with higher full-energy efficiency could be interesting.

Check response to various EM particles



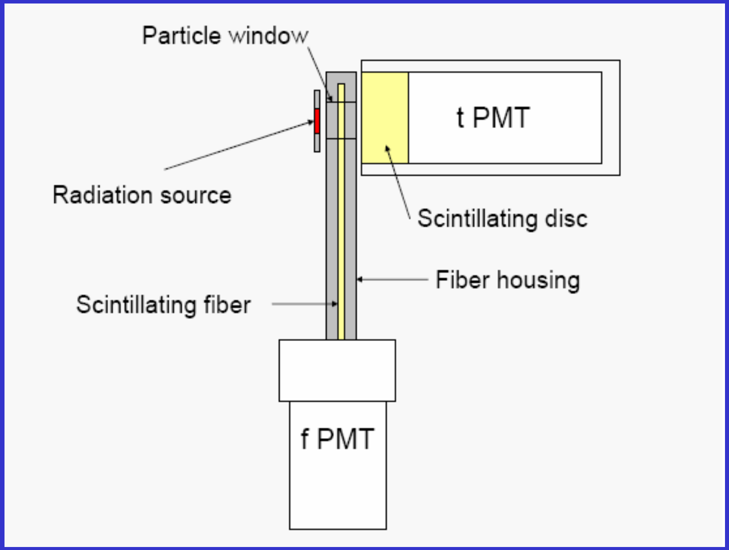
Relativistic electrons

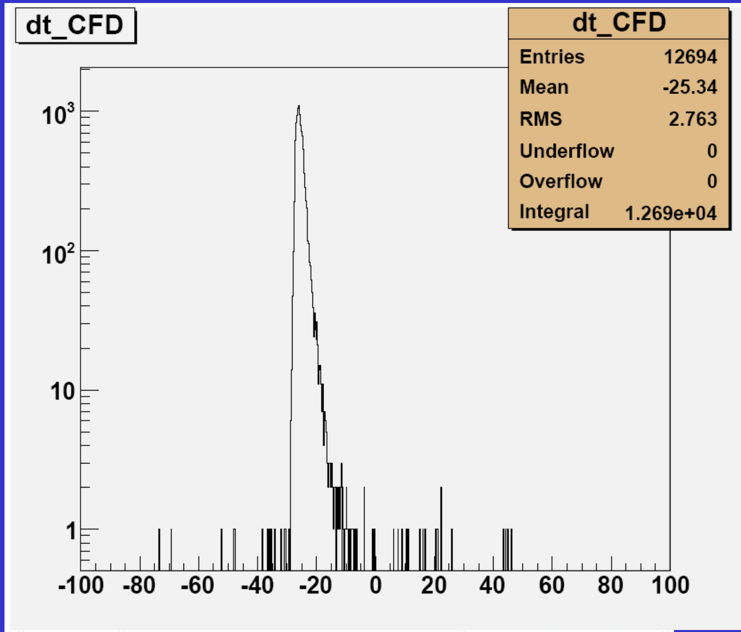


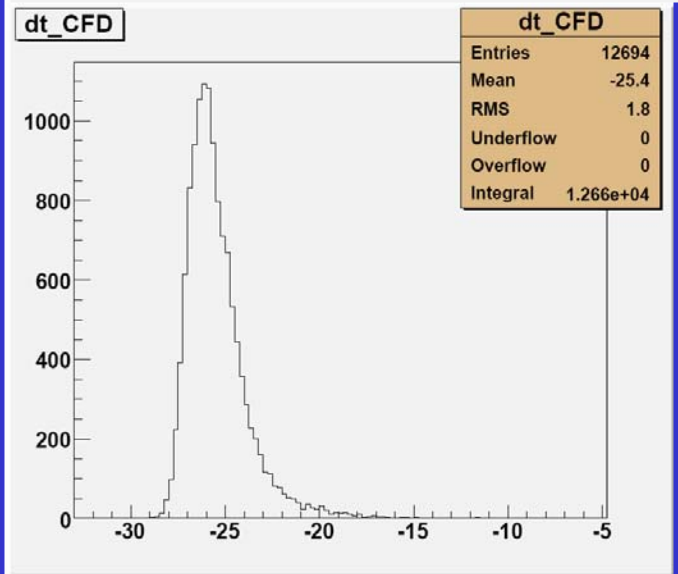
Positrons and gammas

Scintillating Fiber Decay Time Measurement

Designed with Don Claus (UG student)



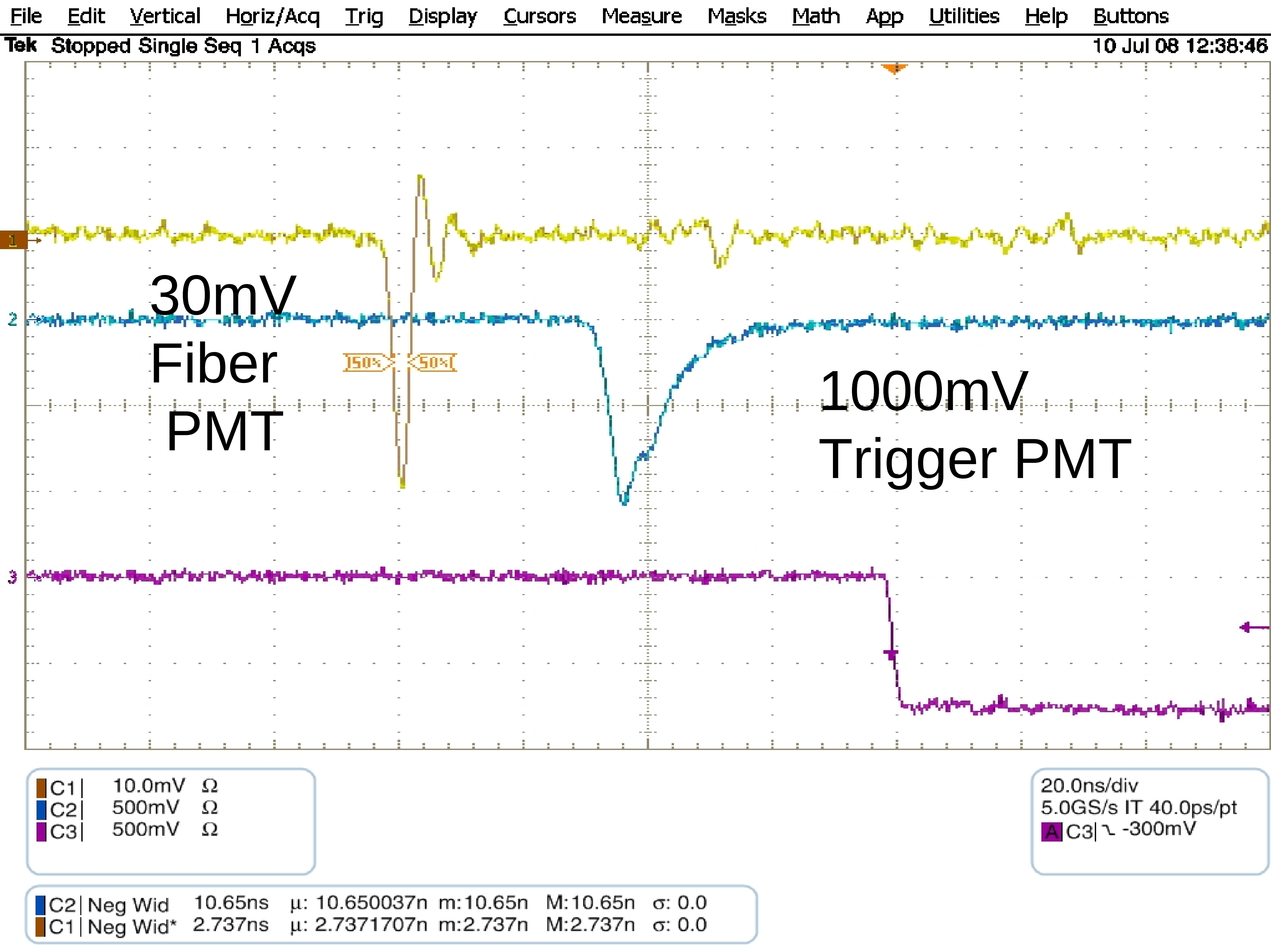




DT (ns)

Trigger electrons with t PMT measure $\Delta T = t_{f\,PMT} - t_{t\,PMT}$

BCF-12 fiber (τ = 3.5ns)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C2 | 500mV Ω
C3 | 500mV Ω
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5.0GS/s IT 40.0ps/pt
A C3 | ↴ -300mV
C2 | Neg Wid 10.65ns µ: 10.650037n m:10.65n M:10.65n σ: 0.0
C1 | Neg Wid* 2.737ns µ: 2.7371707n m:2.737n M:2.737n σ: 0.0