MedAustron 1st – 3rd March 2017 ADC Data Analysis

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Summary of Measurements Made

- Optical module setup used:
  - 2” Hamamatsu R13089-100-11 PMT with negative Hamamatsu base
  - 3 cm x 3 cm x 45 cm cuboid ENVINET standard scintillator
  - Coupled with BC-630 Saint Gobain silicone optical gel (refractive index = 1.465) http://www.crystals.saint-gobain.com/uploadedFiles/SG-Crystals/Documents/Organic%20Product%20Accessories%20Data%20Sheet.pdf

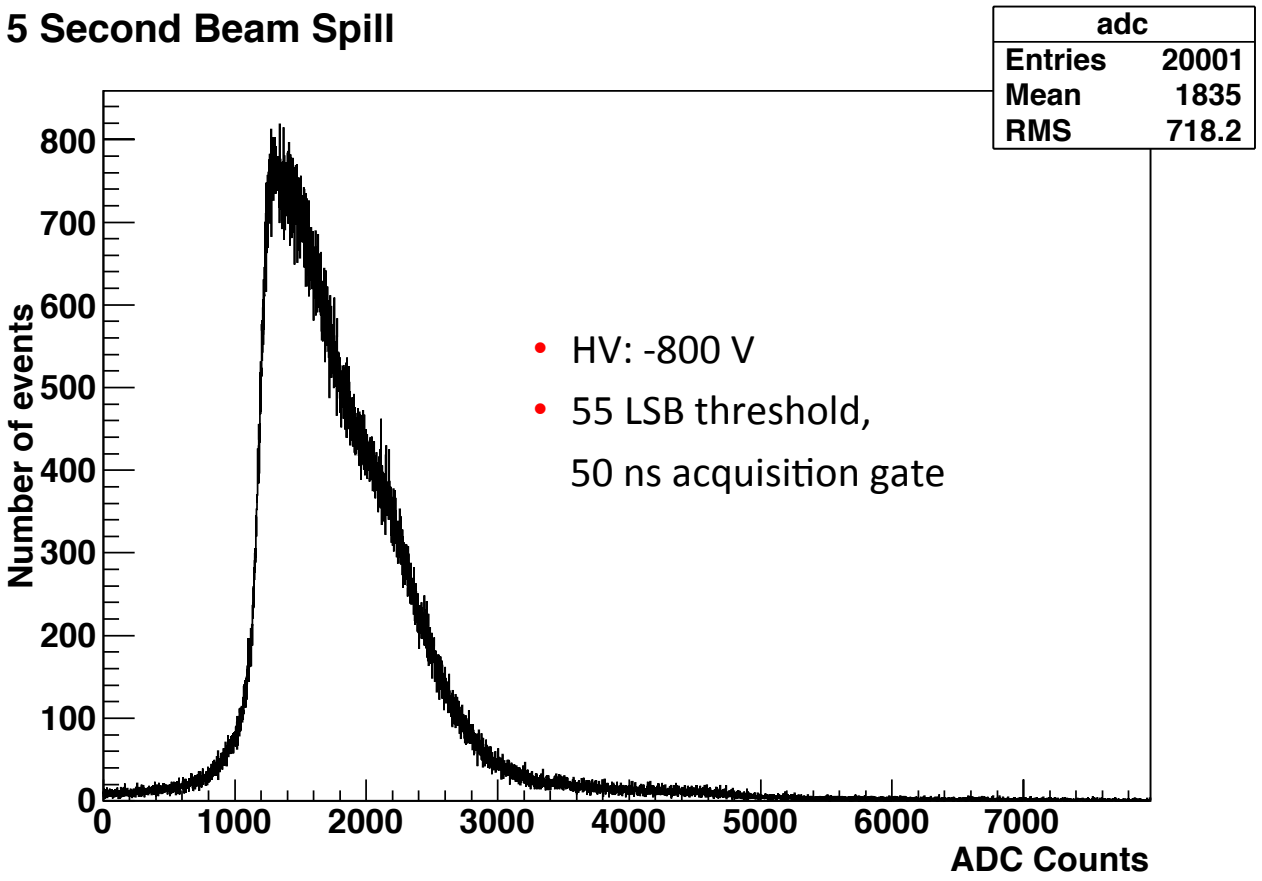
- Wednesday the 1st of March - Thursday the 2nd March of 2017:
  - All measurements carried out using a 6 mm diameter collimator
  - Measurements carried out at -800 V, -900 V, - 1000 V and -1200 V
  - Different digitiser settings tested (threshold and acquisition gate length)
  - Measurements carried out with 5 and 30 second beam spills
  - Measurements carried out for beam energies of 252.4 MeV, 62.4 MeV and 102.4 MeV
  - Note: no measurements of rates or peak current

Summary of Measurements Made

- Thursday the 2nd of March – Wednesday the 3rd of August:
  - All measurements carried out at -1000 V
  - Two calorimeter configurations tested:
    - 4 mm diameter collimator (followed by 6 mm diameter collimator)
    - 6 mm diameter collimator at the isocentre
  - Measurements carried out with 5 and (mostly) 30 second beam spills
  - Beam performance and rates investigated by changing quad and chopper magnet settings
  - Energy scan carried out from 62.4 MeV – 252.4 MeV in steps of 20 MeV
  - ADC and waveform data collected for “nominal” beam settings at rates of > 400 kHz

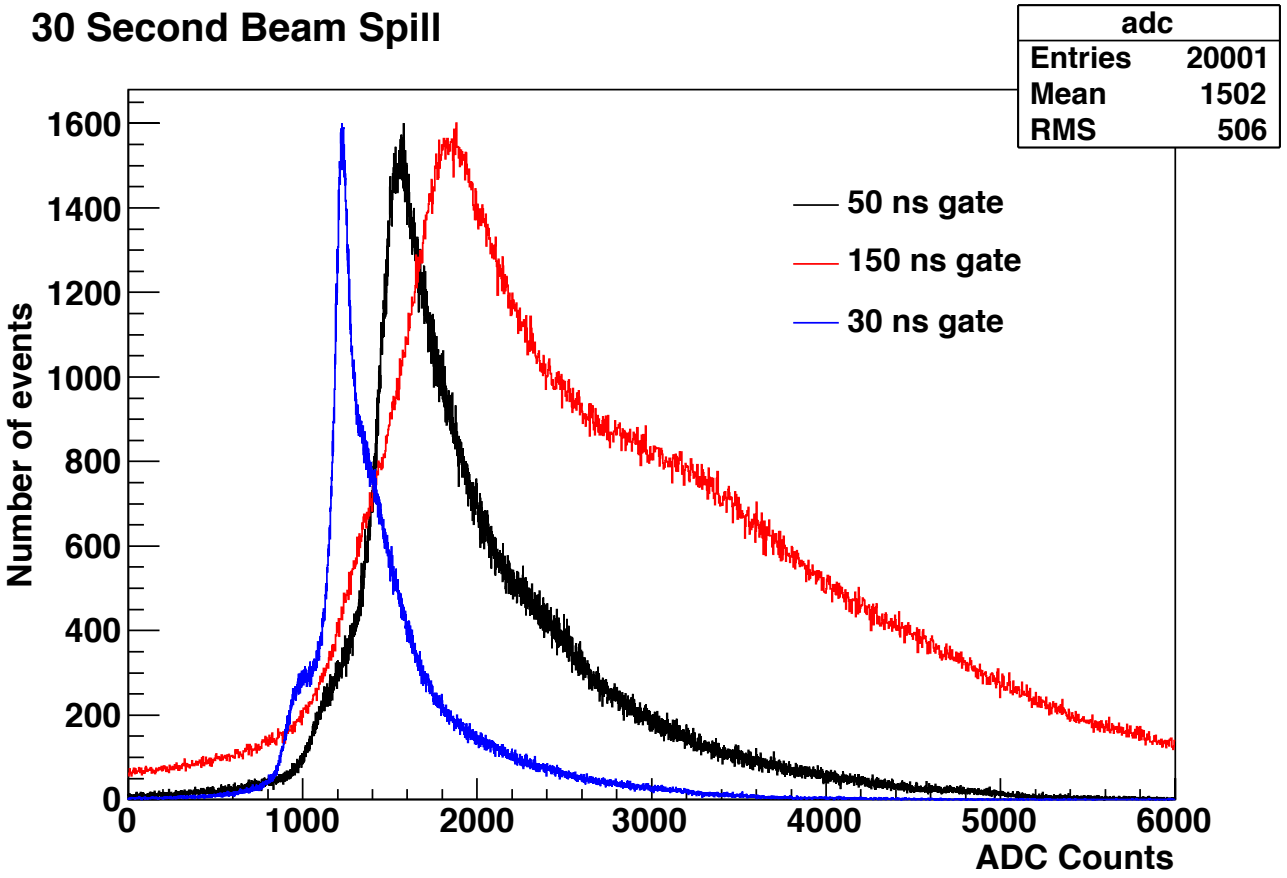
01.03 - 02.03.17 Summary

- Most data from the first night shift is not useful for fitting
- For example:
  - We are unable to work with any 5 second beam spill data (true of both shifts)



01.03 - 02.03.17 Summary

– 30 second beam spill:

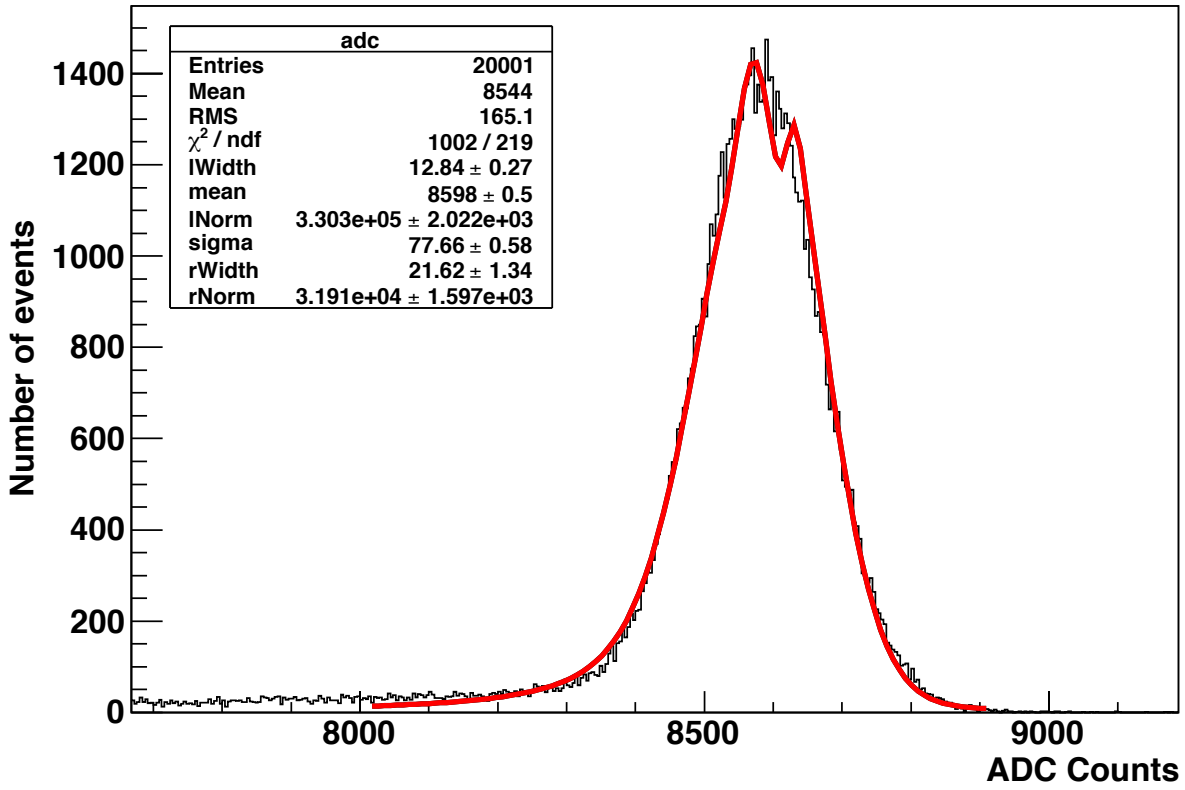


- HV: -800 V
- 55 LSB threshold
- Various length acquisition gates to show the effect of pile up increasing with increasing gate size
- We see the peak width decrease for a smaller size acquisition gate, but we still see a “pile up” shoulder on the right
- Not useful data for extracting energy resolution

01.03 - 02.03.17 Summary

- A few “fittable” runs from the end of the shift at higher HV and for a 30 second beam spill
- For example:
  - -1200 V, 62.4 MeV beam, 100 ns acquisition gate

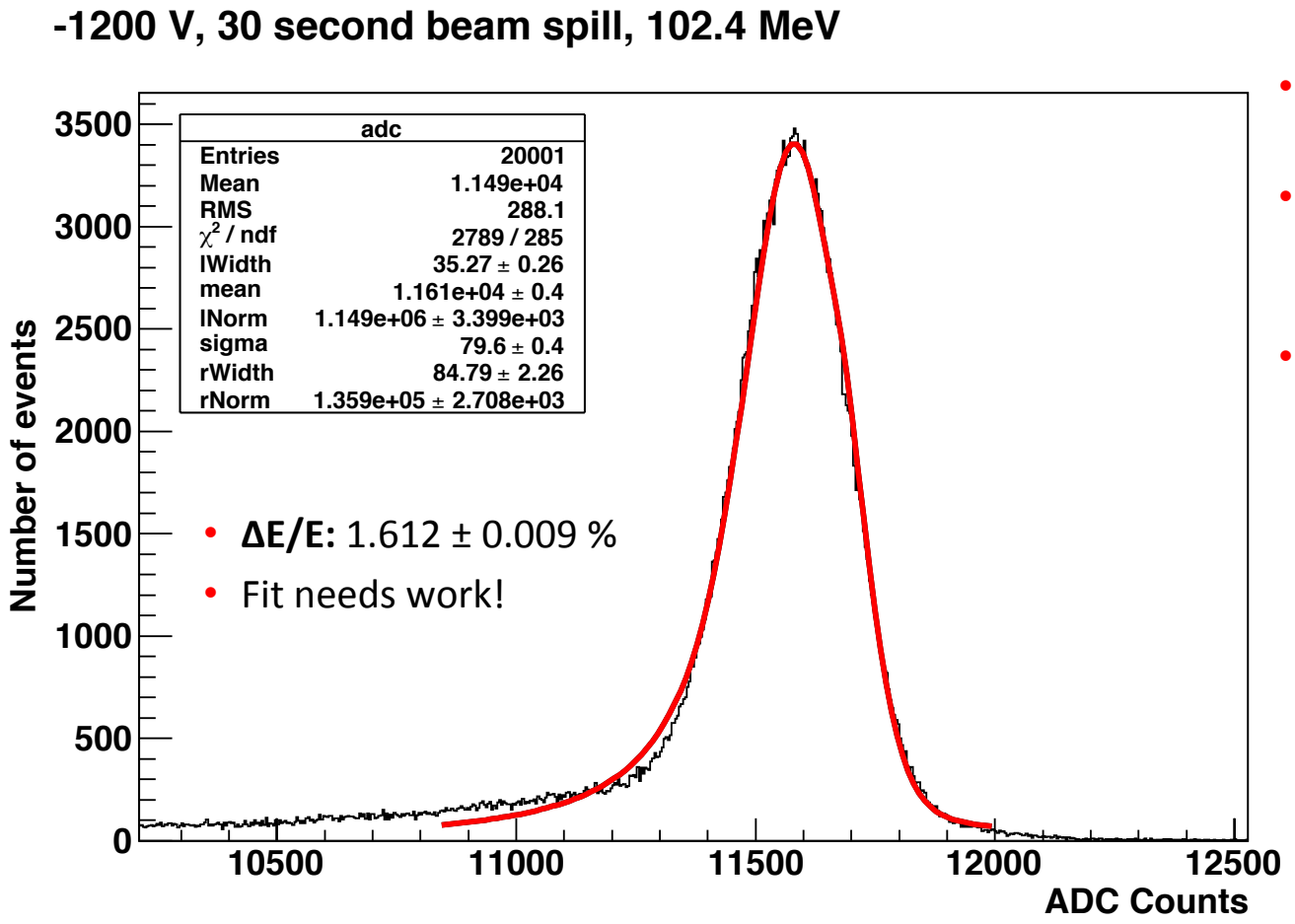
-1200 V, 30 second beam spill, 62.4 MeV



- **ΔE/E:** 2.123 ± 0.016 %
- Fit needs work:
  - To fit larger range more accurately
  - To get rid of the “peak bump”, quite often seen when fitting test beam data from Clatterbridge also

01.03 - 02.03.17 Summary

- -1200 V, 102.4 MeV beam, 100 ns acquisition gate



Conclusions from the first shift:

- 30 second beam spill can work
- No chance with a 5 second beam spill with equipment used at the time
- Indication of following sqrt(E)?
  - ΔE/E: 2.12 % at 60 MeV
  - Therefore ΔE/E at 1 MeV:

  2.12 x sqrt(62.4) = 16.75
  - So we expect:

  16.75 / sqrt(102.4) = 1.66 % at 102.4 MeV

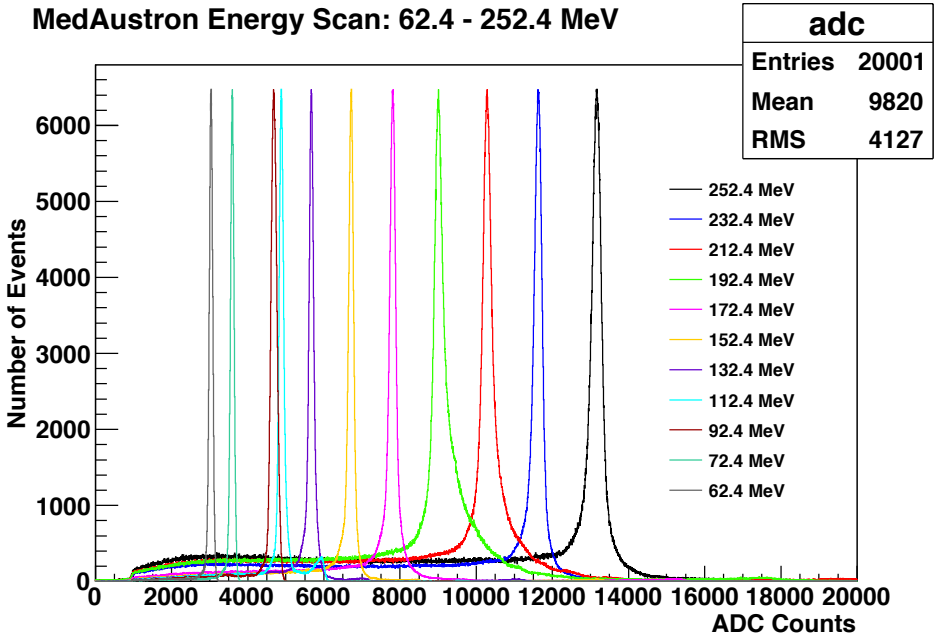
  cf. 1.61 % from measurement!

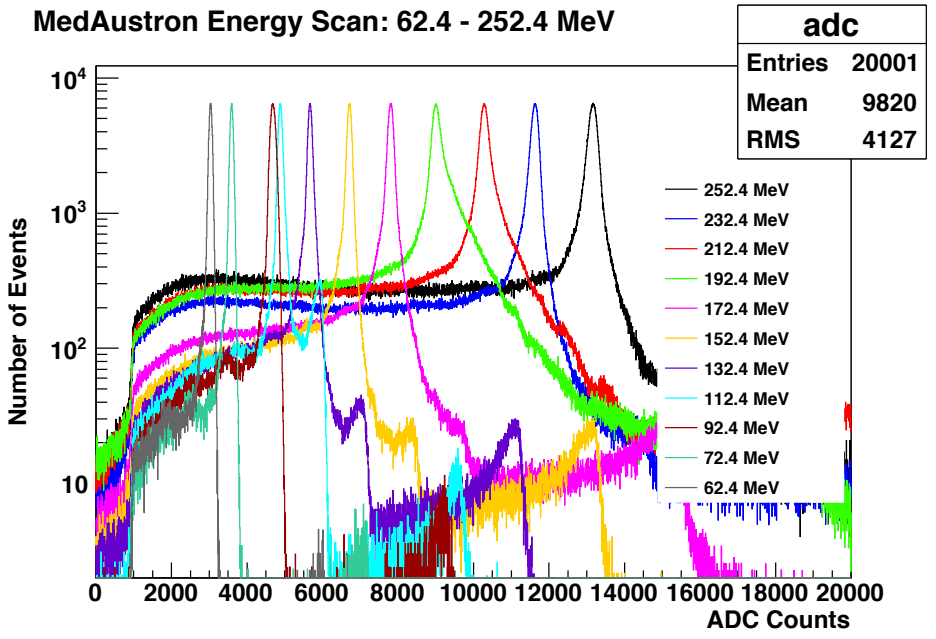
02.03 – 03.03.17 Shift

- Most plots presented for the "best" set of data, taken with the following beam settings:
  - Chopper magnet at 470 A (with the default being 433 A), scraping on outer chopper dump
  - First quad off, second quad at 40 A? Unsure whether this was continued from tests just before the "best" data set or the quads were reset to "standard" settings.
- Rate tests carried out at a 62.4 MeV beam energy
- Waveform files analysed (unfortunately not from the "best" data set)

Scan Across Energies

- Data taken from the “best” beam data set
- 30 second beam spill, 100 – 150 kHz, 6mm diameter collimator placed at the beam isocentre, 100 ns acquisition gate:

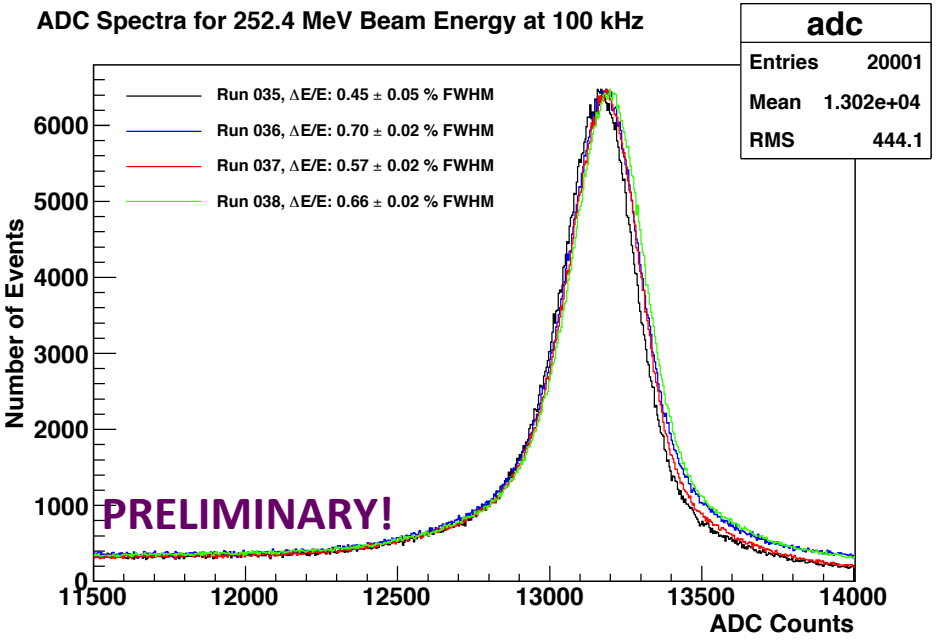


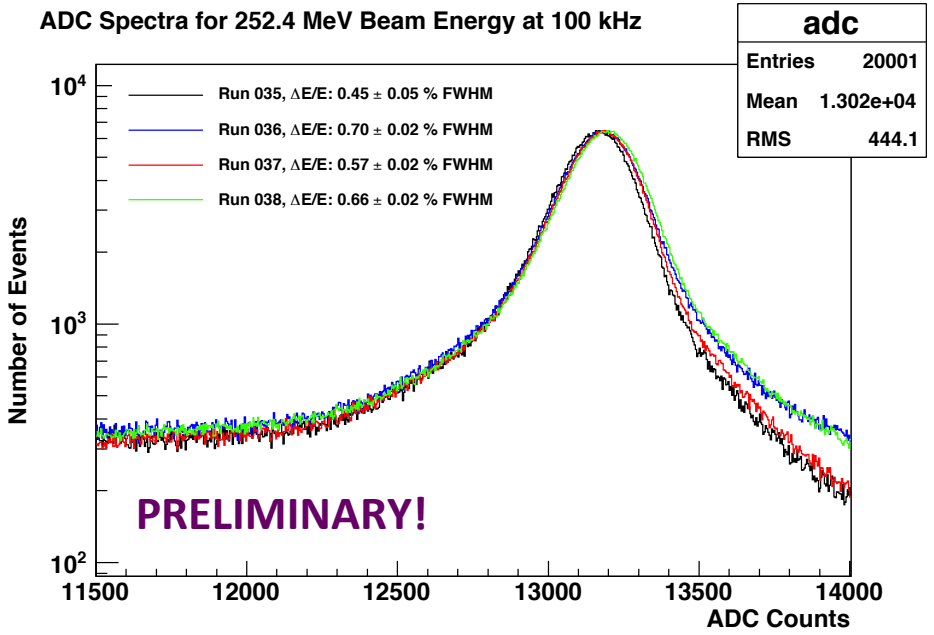


- Note the shoulder on the right of the spectra for 212.4 and 192.4 MeV
  - Makes it difficult to fit distributions at those energies

Measurements at 252.4 MeV (Highest Energy)

- Data taken from the “best” beam data set
- 30 second beam spill, 100 – 150 kHz, 6mm diameter collimator placed at the beam isocentre, 100 ns acquisition gate:

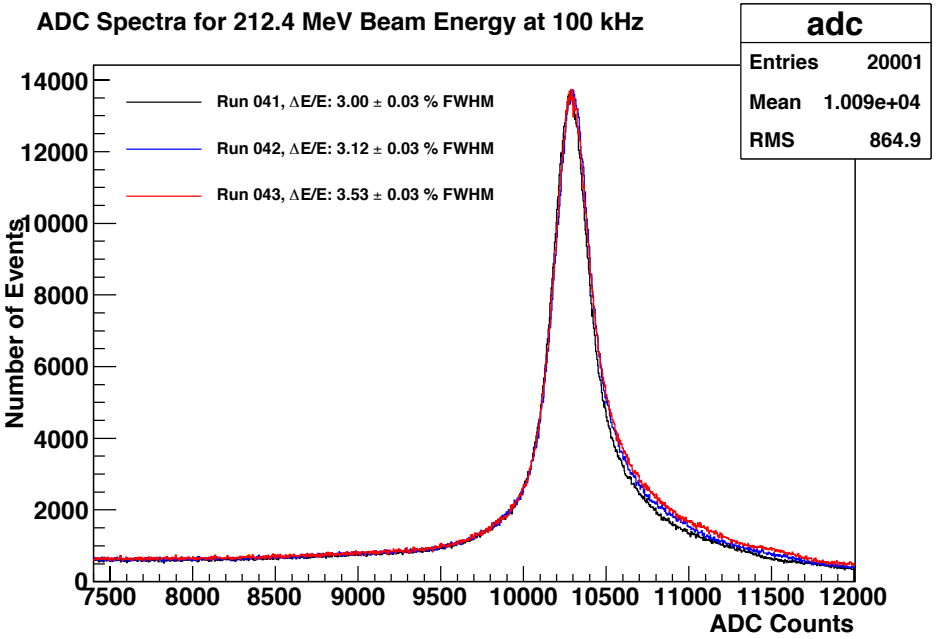


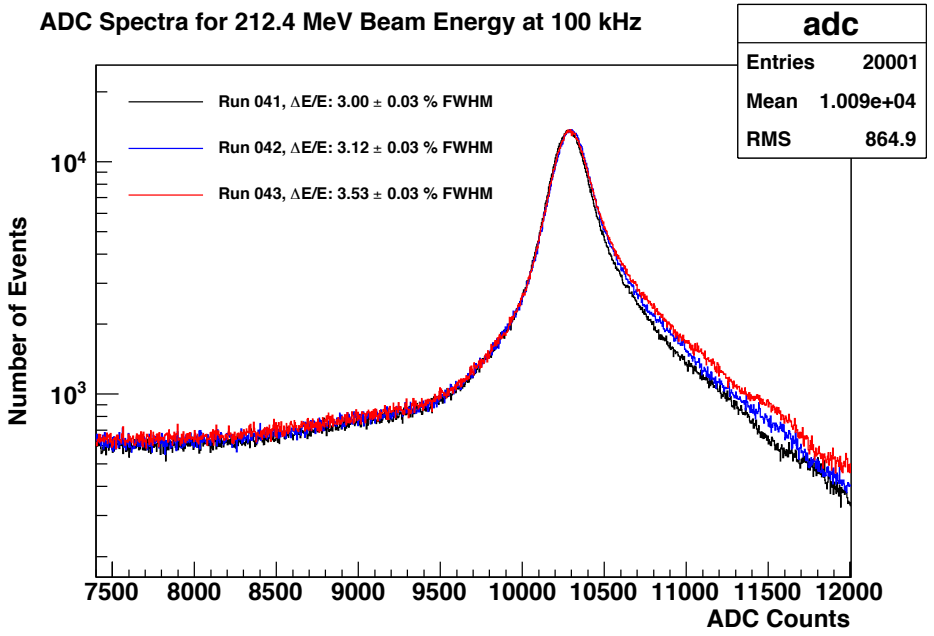


- Good reproducibility of the ADC mean
- Energy resolution: 0.45 – 0.70 % FWHM
- Unsure whether we can trust these results given problems with PMT at certain rates

Repoducibility: Measurements at 212.4 MeV

- Data taken from the “best” beam data set
- 30 second beam spill, 100 – 150 kHz, 6mm diameter collimator placed at the beam isocentre, 100 ns acquisition gate
- Taken one after the other

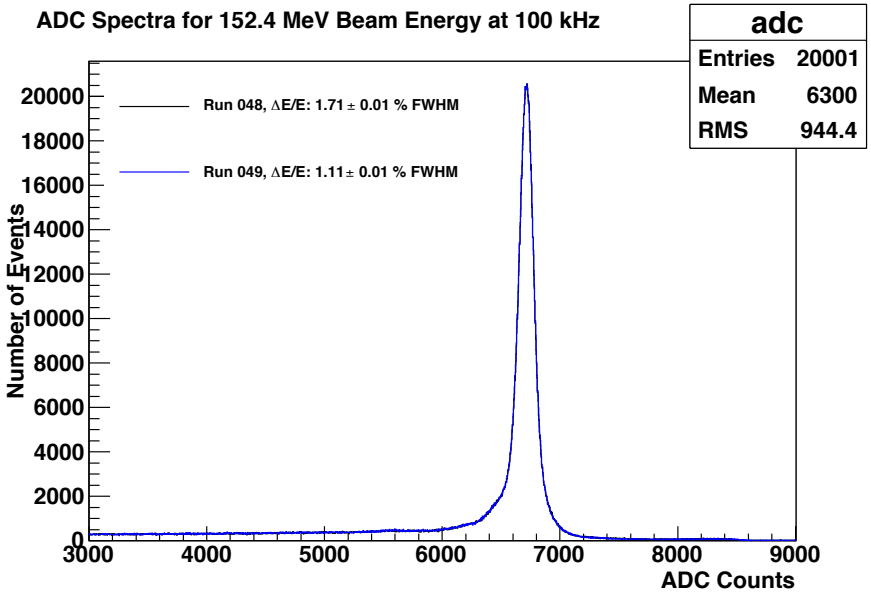


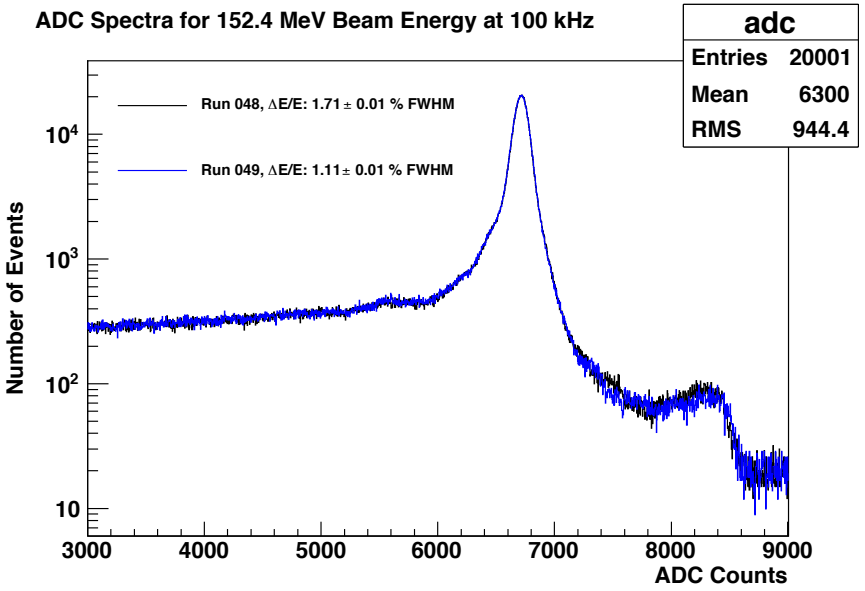


- Difficult to fit these spectra due to the shoulder (pile up?) on the right.

Repoducibility: Measurements at 152.4 MeV

- Data taken from the “best” beam data set
- 30 second beam spill, 100 – 150 kHz, 6mm diameter collimator placed at the beam isocentre, 100 ns acquisition gate
- Taken one after the other

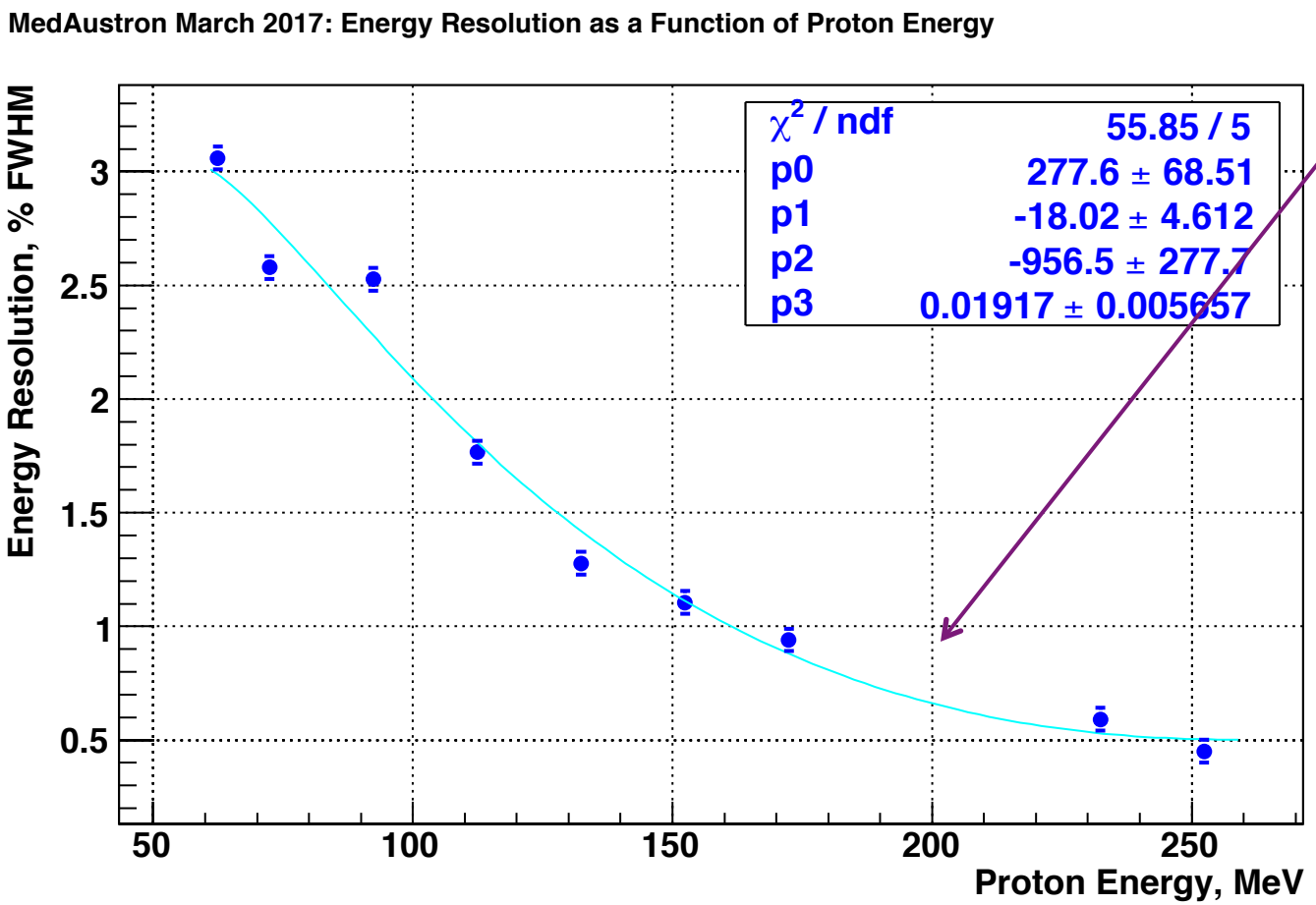




- The spectra look very similar. Why the difference in the energy resolution/sigma? Fit needs work!
- General conclusions about reproducibility for this data set (> 1 measurement per point):
  - Mean always reproduced accurately from measurement to measurement (both “visually” and by the fit)
  - Spectra at same energy generally look very similar to each other from measurement to measurement
  - Some issues with extracting the sigma using the current version of the fit

Energy Resolution as a Function of Energy (FWHM)

$$y = p0 + \frac{p1}{\sqrt{x}} + \frac{p2}{x} + p3 \cdot x$$

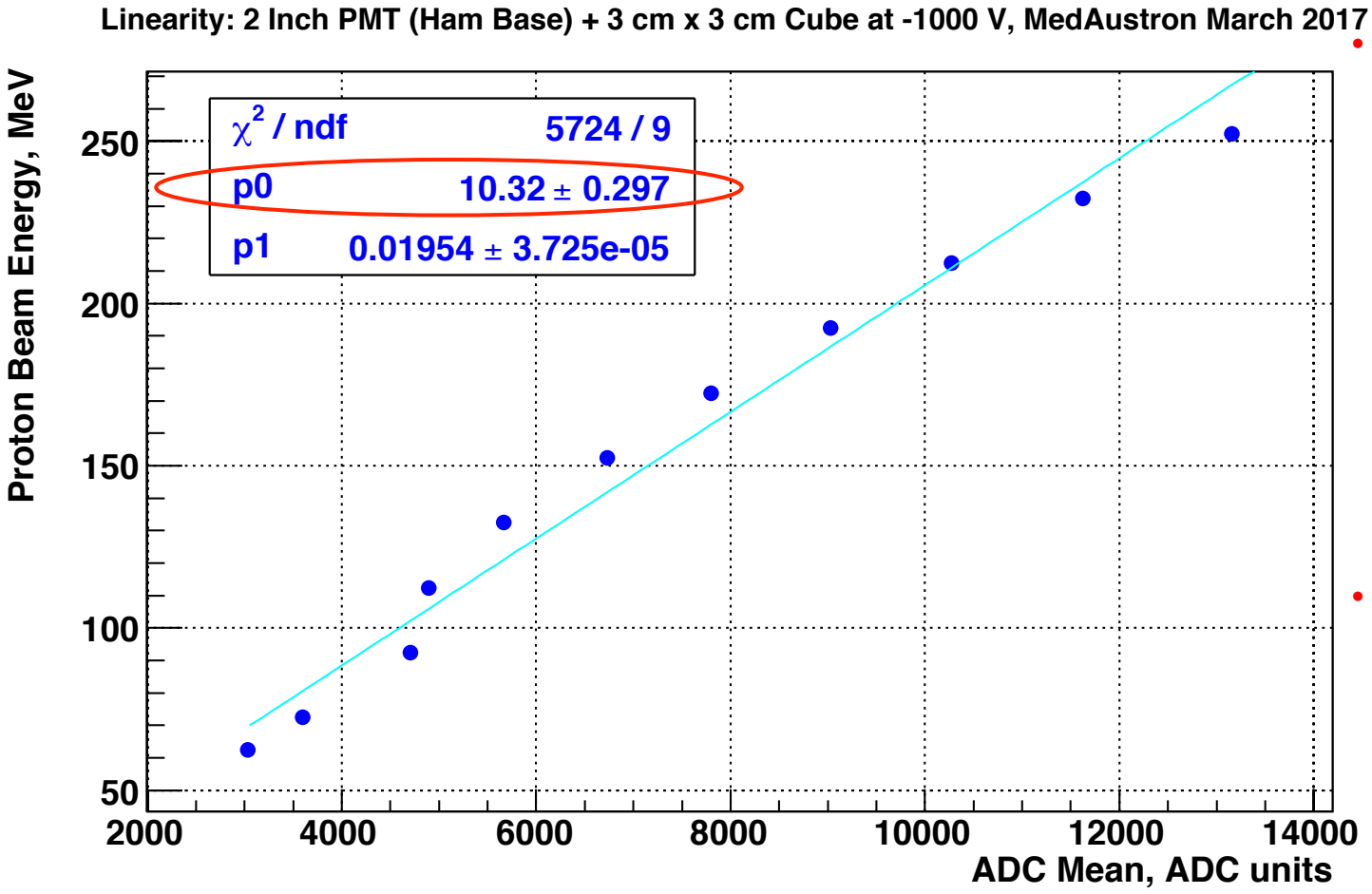


NOTE:

- Systematic errors still need to be estimated for this data set
- "Guesstimate" for now just for the fit, with ± 1% for the lowest energy points
- 212.4 and 192.4 MeV points excluded from plot (off the scale due to "shoulder" on the right making fit difficult)
- Out of multiple runs, the one chosen is the one that "best fits" this curve
- Not very reliable!

Linearity/Energy Scan: -1000 V

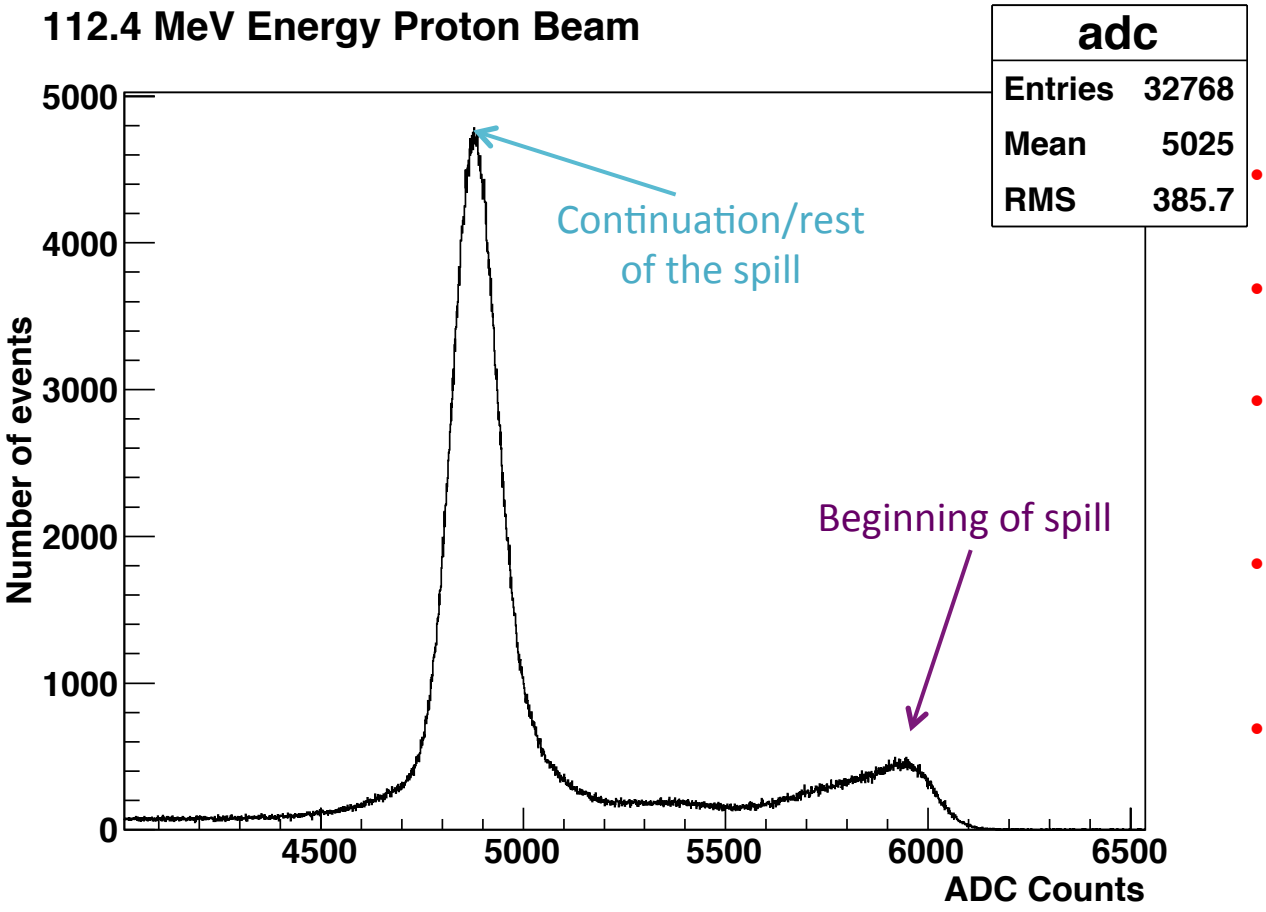
- 1st degree polynomial fit over range shown on plot



- The mean of the distributions returned by the fit is more "stable/ reliable", but we don't see good linearity
  - Most likely due to the PMT average anode current effects we have been investigating since the test beam?
- p0 should give us a rough estimate of quenching in the scintillator (cf 20.49 MeV from simulations for EJ PVT scintillator and ~ 18 from Clatterbridge test beam for NUVIA PS):
  - 10.32

Measurements at 112.4 MeV (Oscillations)

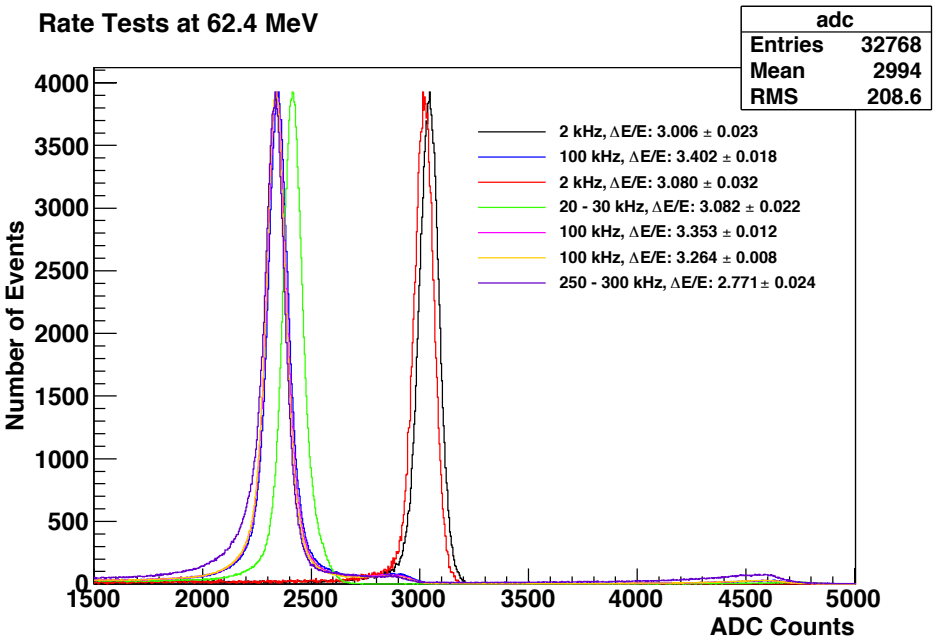
- Data taken from the "best" beam data set
- 30 second beam spill, 100 – 150 kHz, 6mm diameter collimator placed at the beam isocentre, 100 ns acquisition gate

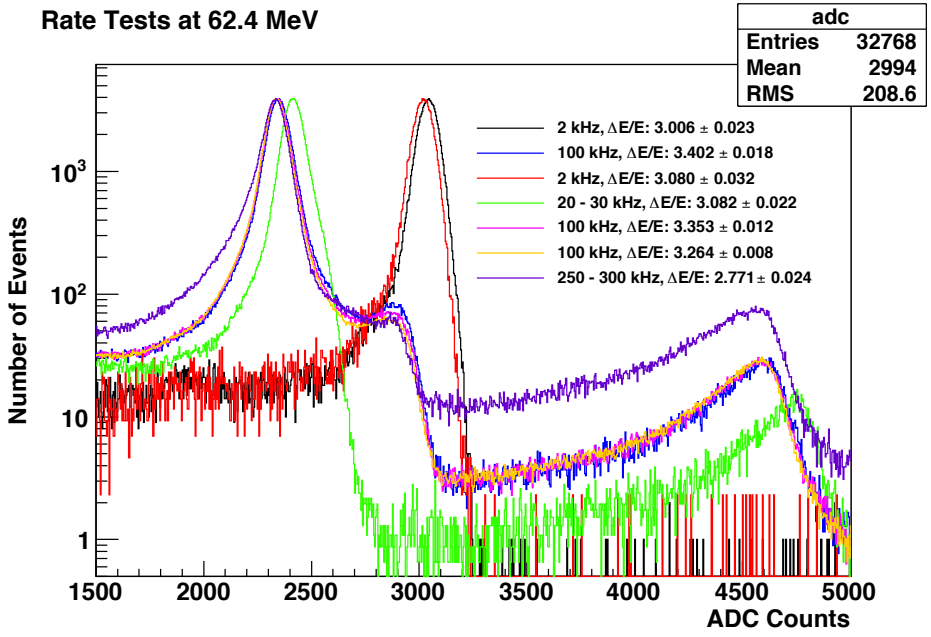


- During the test beam, we noticed for certain energies, for example 112.4 MeV, the ADC spectrum "oscillated" between two points.
- At the beginning of the spill the ADC counts were higher.
- During the rest of the spill the ADC counts were lower.
- This cyclic behaviour was seen at this energy whenever coming back to it.
- The rate at the beginning of the spill is different to the rate during the rest of the spill.
- Indication of our PMT having rate dependence, prompting full on investigation at UCL (see "PMT Rate Dependence Investigation" presentation).

Rate Tests at 62.4 MeV

- Rates changed by moving the chopper magnet

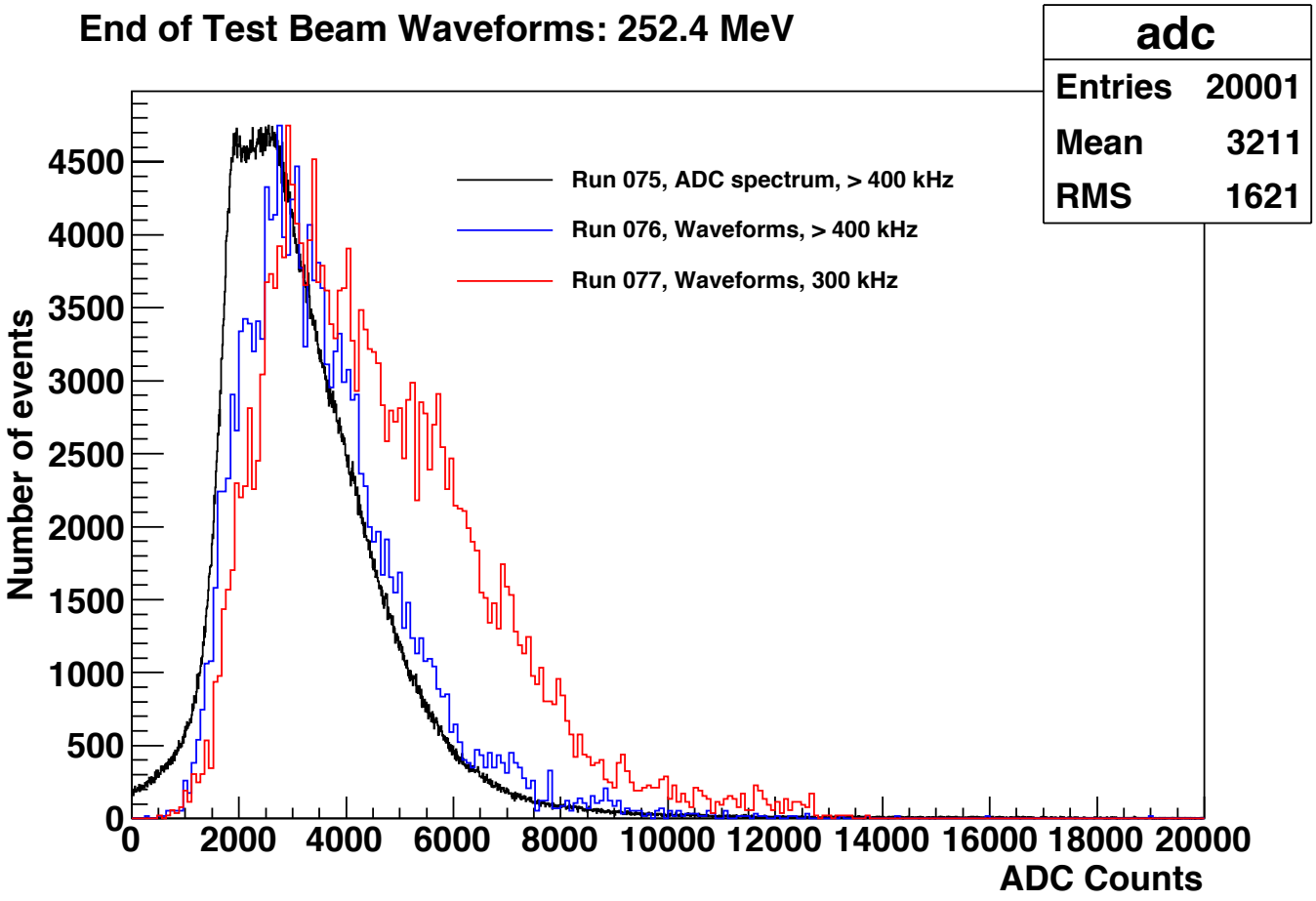




- As rate increases, ADC mean decreases (same observation as during the August 2016 Clatterbridge test beam with the Hamamatsu active divider base)
- Difficult to know which effect we're seeing here as we don't know the peak current, but either:
  - ADC mean dropping at fairly low rates (reason for this behaviour currently unknown), or
  - ADC mean increasing and then progressively dropping when average anode current > 100 μA
  - See "PMT Rate Dependence Investigation" presentation for further details

Waveforms

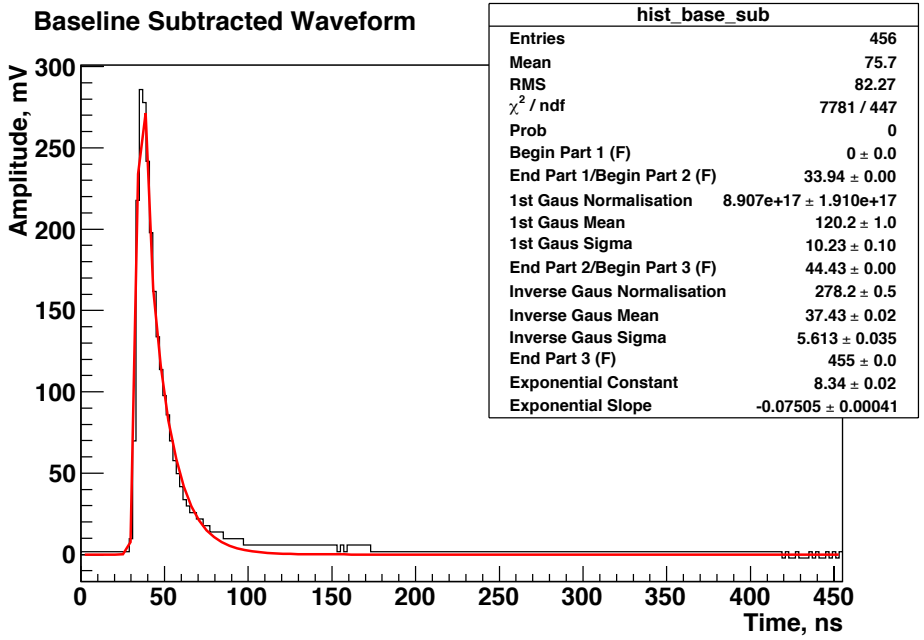
- Taken at the very end of the test beam, not with the beam settings that gave us our "best" data set
  - 252.2 MeV, 30 second beam spill, "nominal medical" beam settings, taken with digitiser

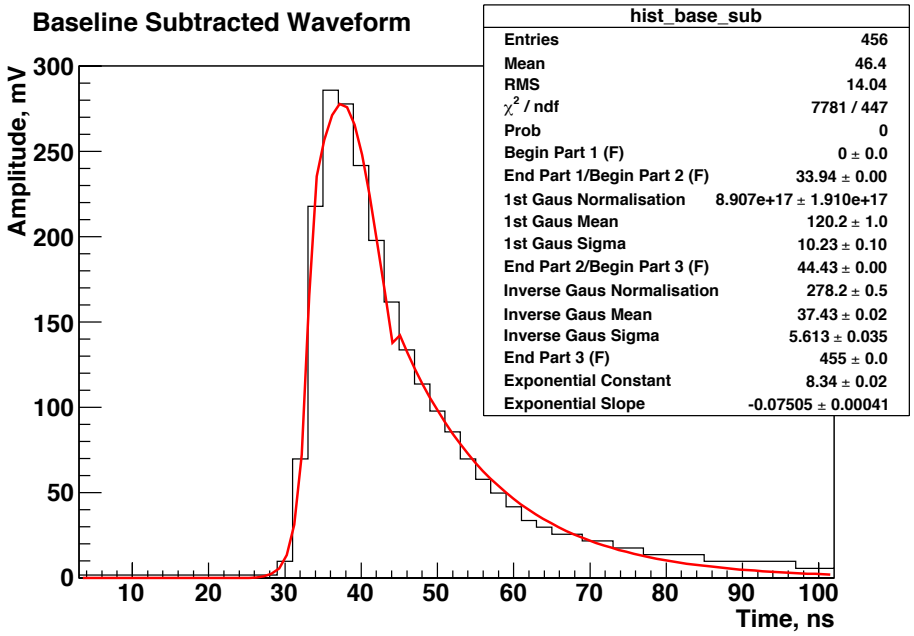


- "ADC mode" spectrum taken just before the waveforms
- Rates for the second waveform run (077) reduced by changing current settings
- Waveform analysis not optimised
- As we can see – no sensible spectrum for beam operation settings at time of this data taking
- ADC mean for 252.2 MeV for the "best" data ~ 13200 ADC counts

Waveforms: Peak Current Estimate

- Although this data does not correspond to the “best” data set we can still use it to estimate a peak current – maybe it could give us an idea of the peak current we saw previously
- Waveform example from run 077, with a corresponding integral of ~ 5000 ADC counts





- Amplitude of waveform: 285 mV
- Therefore peak current: 285 mV/50 Ω = 5.7 mA
- Can this number be useful to us somehow?

Conclusions

- A VERY useful test beam that has finally helped us understand the rate dependence problems we're seeing
  - See "PMT Rate Dependence Investigation"

- Things to remember for next time:

  - Make a peak current measurement!!!
    - Measure the waveform amplitude and width at FWHM
    - Important in order to see whether we are in a regime below or above a 100 µA average anode current
  - Measure the pedestal!!!
    - Whilst the digitiser subtracts the pedestal mean on the fly, it does not subtract the pedestal width. Tests at UCL have shown that the pedestal could be making a significant contribution to the width of the spectrum, hence effecting the energy resolution measurement.