PMT Rate Dependence Investigation

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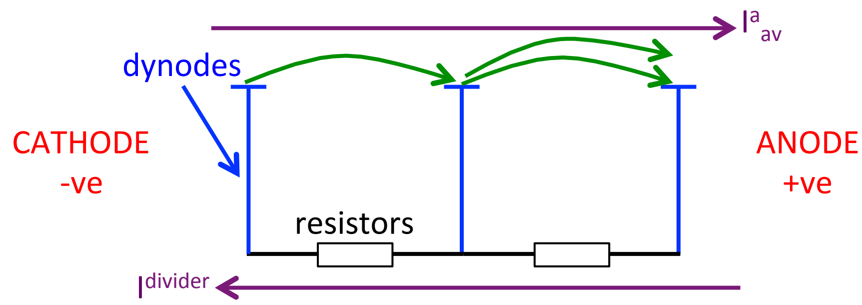
Introduction

- Various test beams have shown that there is some sort of dependence of the PMT response on the rate of the proton beam. In particular of note is data from:
  - Clatterbridge August 2016
  (http://www.hep.ucl.ac.uk/pbt/wikiData/presentations/2016/clatterbridge_aug2016_analysis.pptx)
  - Clatterbridge November 2016
  (http://www.hep.ucl.ac.uk/pbt/wikiData/presentations/2016/clatterbridge_nov2016_analysis.pptx)
  - medAustron March 2017
  (http://www.hep.ucl.ac.uk/pbt/wikiData/presentations/2017/medAustron_mar2017_analysis.pptx)

- Investigate this at UCL by:
  - pulsing an LED via an optical fibre into the scintillator optically coupled to the PMT at a voltage that matches a specific peak current
  - study response at several PMT operational high voltages and several peak currents

PMT Currents

- When considering a PMT, there are two main currents to consider:
  - The DC current running through the resistor chain, $\mathbf{I^{divider}}$ (also know as the "bleeder" current)
  - The average anode current, $\mathbf{I^{a}_{av}}$, which is the current caused by the avalanche of electrons and travels in the opposite direction to I^{div}



  - In order for the PMT to function correctly $\mathbf{I^{a}_{av} \ll I^{div}}$!
  - For the R13089-100-11 PMT with the negative Hamamatsu active divider base to function correctly: $I^{a}_{av} < 100\ \mu A$, according to Hamamatsu specifications
  - Pulse LED at several different peak currents and rates and observe behaviour when $I^{a}_{av} \approx 100\ \mu A$ is reached, using the following to estimate what rate this happens at:

$$I^{a(node)}_{av(erage)} = I^{a(node)}_{peak} . \Delta t(fwhm) . f$$

where

I^{a}_{av} = average anode current, A,

I^{a}_{peak} = peak current at the anode, A = pulse height (V)/impedence (Ω),

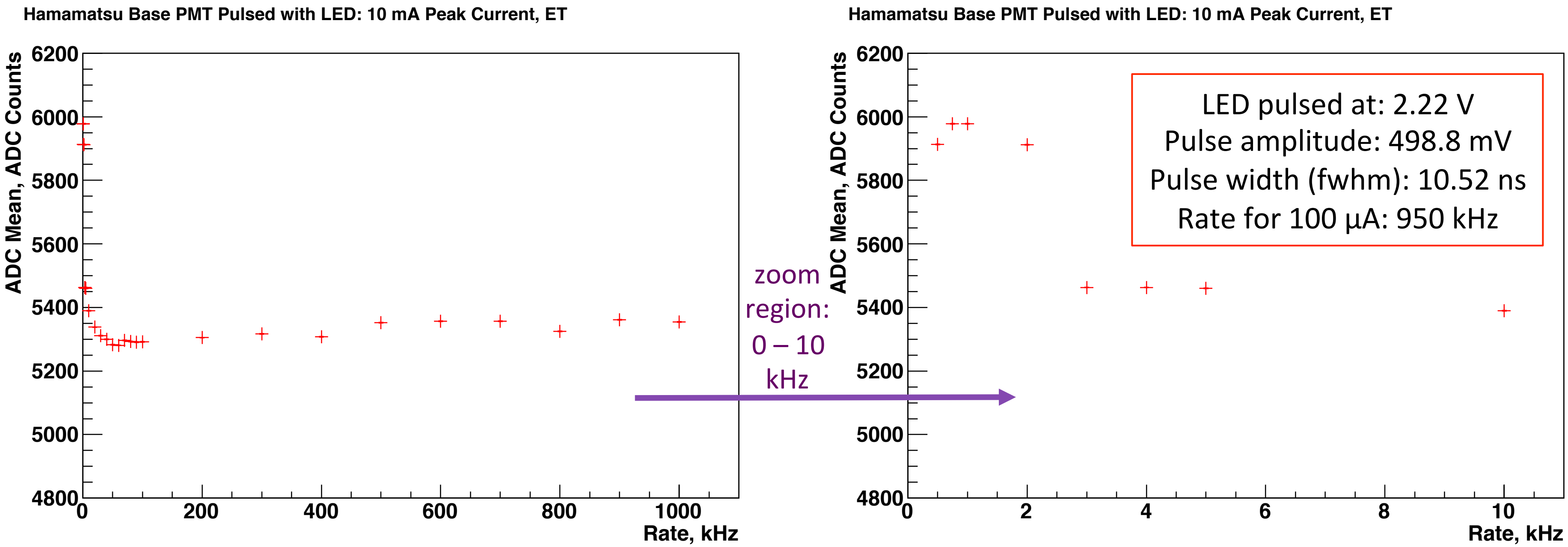
Δt = pulse width at the full width at half maximum, s,

f = frequency, Hz.

Measurement Setup 1:

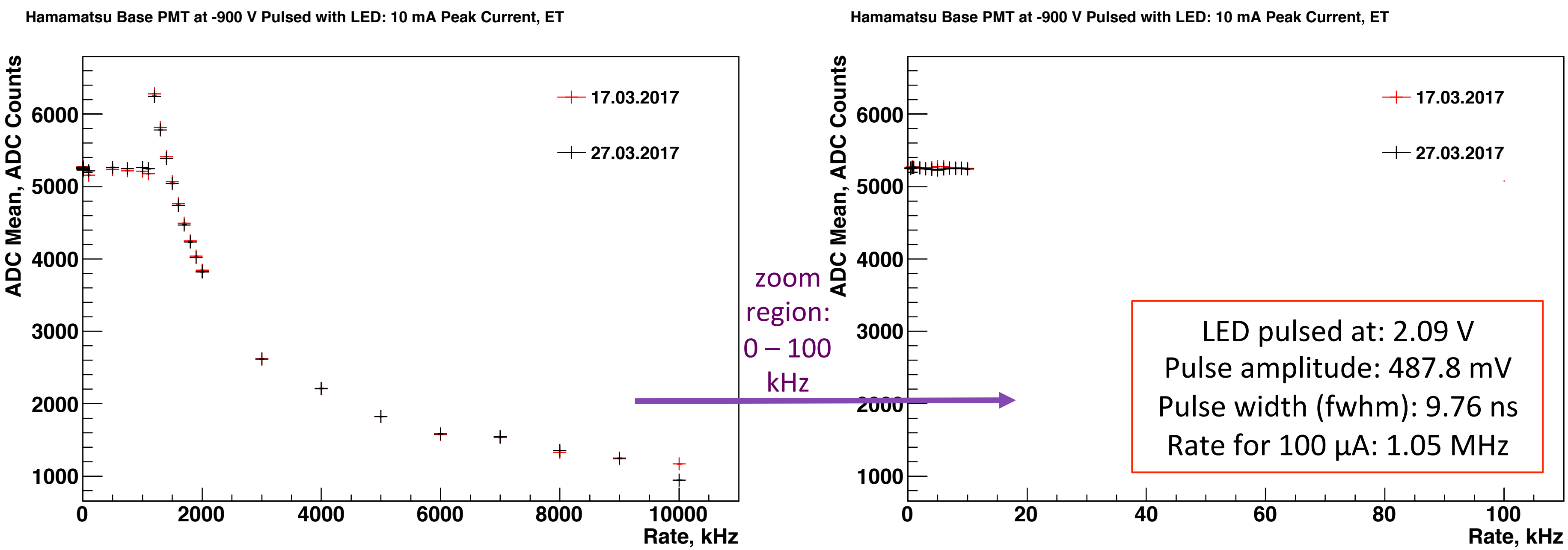
- 2" Hamamatsu R13089-100-11 PMT with negative HV active divider base (made by Hamamatsu)
- 3 cm x 3 cm x 5 cm cuboid ENVINET standard scintillator
- Coupled with BC-630 Saint Gobain silicone optical gel (refractive index = 1.465)
  http://www.crystals.saint-gobain.com/uploadedFiles/SG-Crystals/Documents/Organic%20Product%20Accessories%20Data%20Sheet.pdf

HV: -900 V, I_{peak} = 10 mA (1)



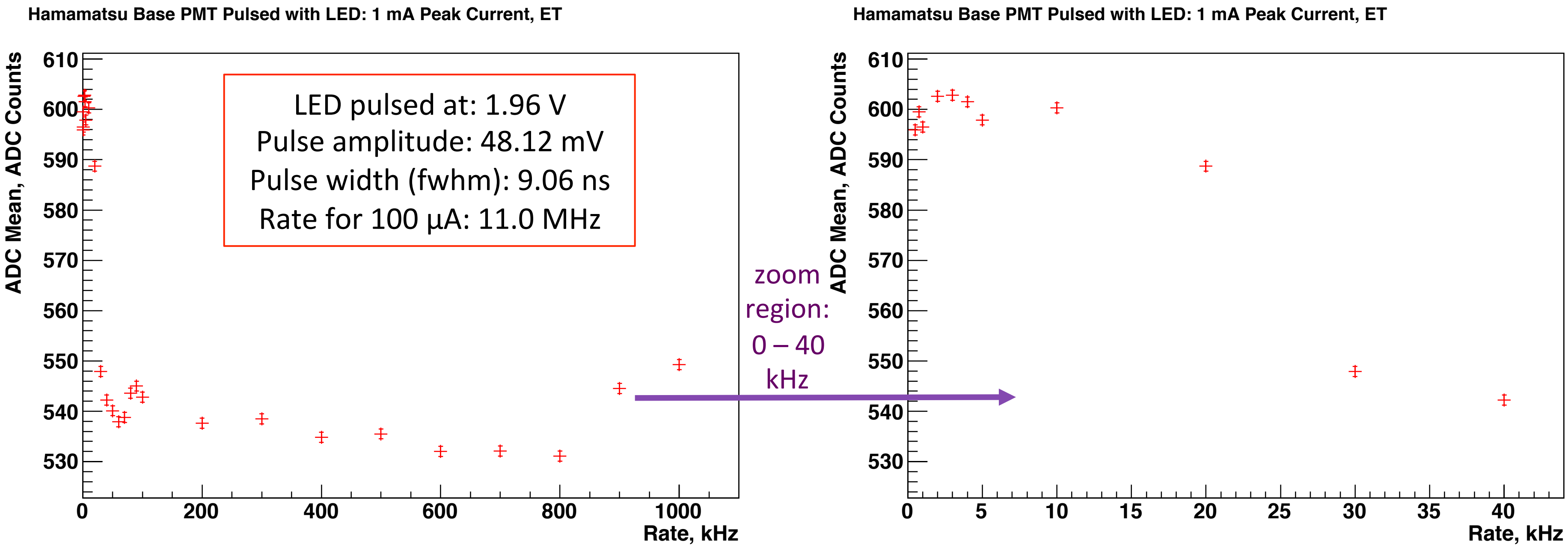
- Deviation from linearity occurs at:
  - unknown for this measurement, carried out before the I^a_{av} deductions were made
- But we also see another effect:
  - A ~ 10% drop in ADC mean at lower rates of 500 Hz – 3 kHz
  - This effect goes with the current, as seen on slide 7.
  - What could be causing this?

HV: -900 V, I_{peak} = 10 mA (2)



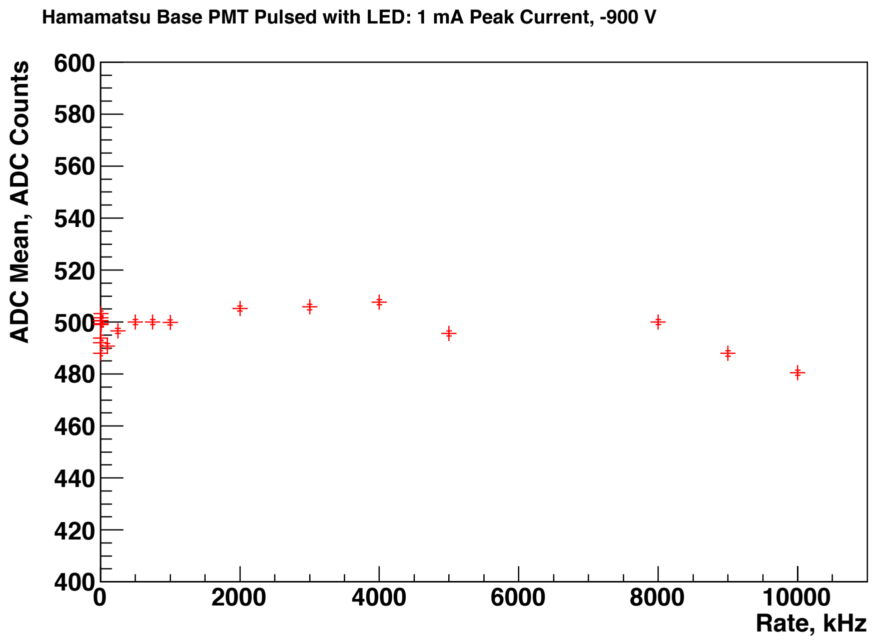
- Repeat tests at a slightly later date in order to reach rates required for $I^{a}_{av} \approx 100\ \mu A$
- Deviation from linearity occurs at at ~ 1.2 MHz, corresponding to an anode average current, $I_A \approx 113\ \mu A$
- But for this set of measurements we no longer see the decrease in amplitude effect between 0 and 5 kHz!
  - Why?!

HV: -900 V, I_{peak} = 1 mA (1)



- Deviation from linearity occurs at:
  - unknown for this measurement, carried out before the I^{a}_{av} deductions were made
- But we see the ADC drop effect again:
  - A ~ 10% drop in ADC mean at rates of 10 kHz – 30 kHz
  - This effect goes with the current (compare to 500 Hz – 3 kHz for a peak current of 10 mA, slide 5).
  - What could be causing this?

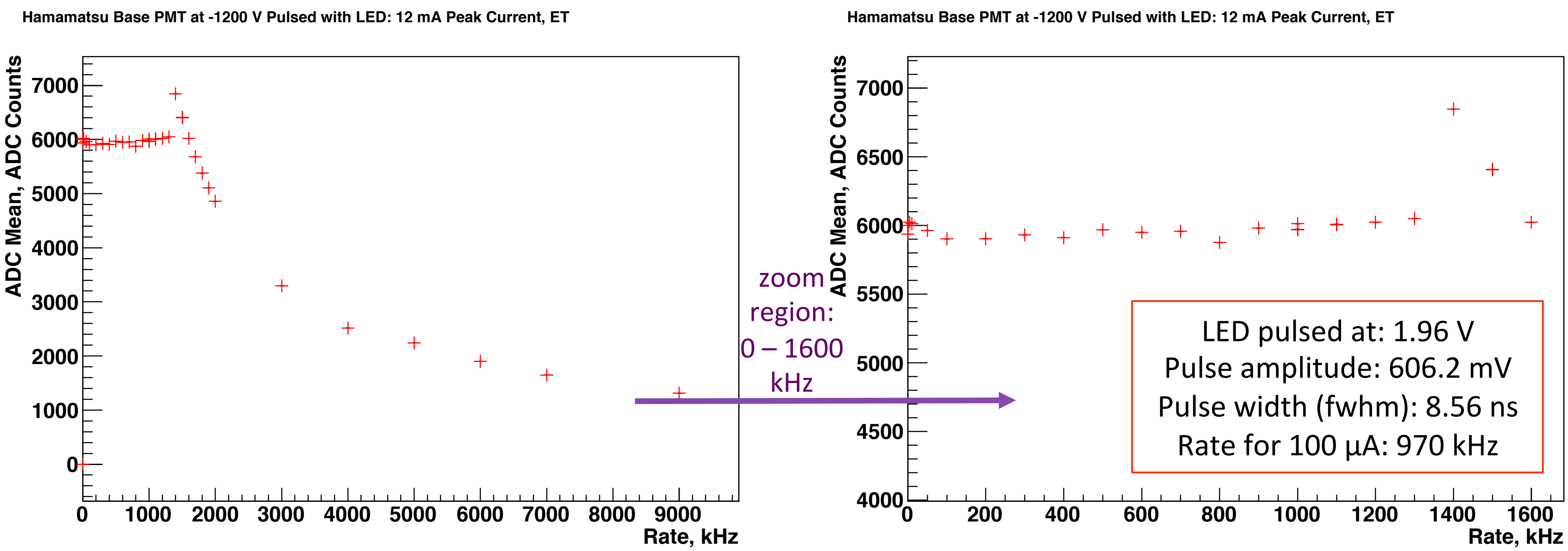
HV: -900 V, I_{peak} = 1 mA (2)



LED pulsed at: 1.90 V
Pulse amplitude: 51.77 mV
Pulse width (fwhm): 8.48 ns
Rate for 100 μA: 11.3 MHz

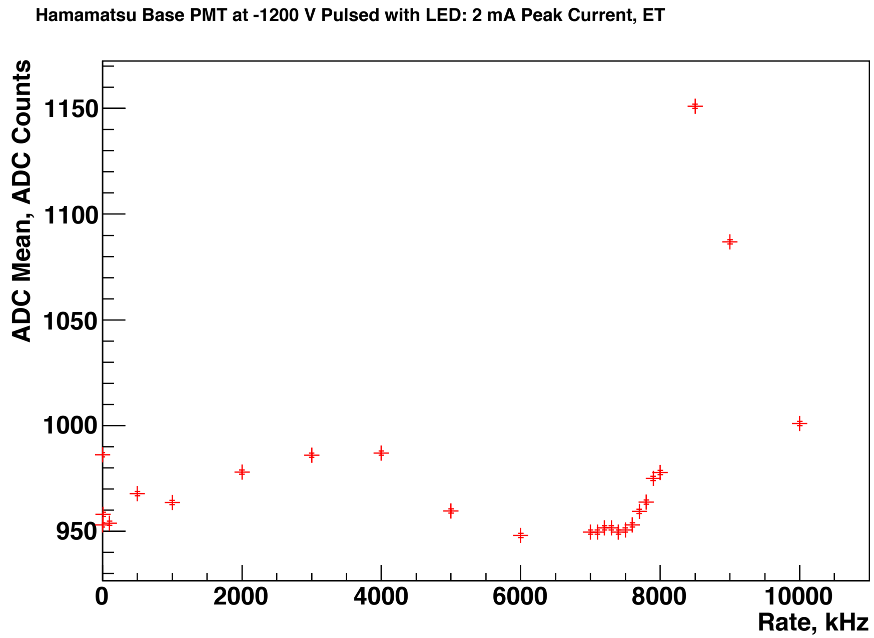
- Deviation from linearity occurs at:
  - Unable to pulse LED at a rate high enough
- But for this set of measurements we no longer see the decrease in amplitude effect between 10 and 30 kHz!
  - Why?!

HV: -1200 V, I_{peak} = 12 mA



- Deviation from linearity occurs at at ~ 1.4 MHz, corresponding to an anode average current, I^a_{av} ≈ 145 μA
- Again, for this set of measurements we do not see the decrease in amplitude effect!
  - Why?!

HV: -1200 V, I_{peak} = 2 mA



LED pulsed at: 1.86 V
Pulse amplitude: 106.6 mV
Pulse width (fwhm): 8.00 ns
Rate for 100 µA: 6.25 MHz

- Deviation from linearity occurs at ~ 9 MHz, corresponding to an anode average current, $I^a_{av} \approx 145\ \mu A$
- Again, for this set of measurements we do not see the decrease in amplitude effect!
  - Why?!

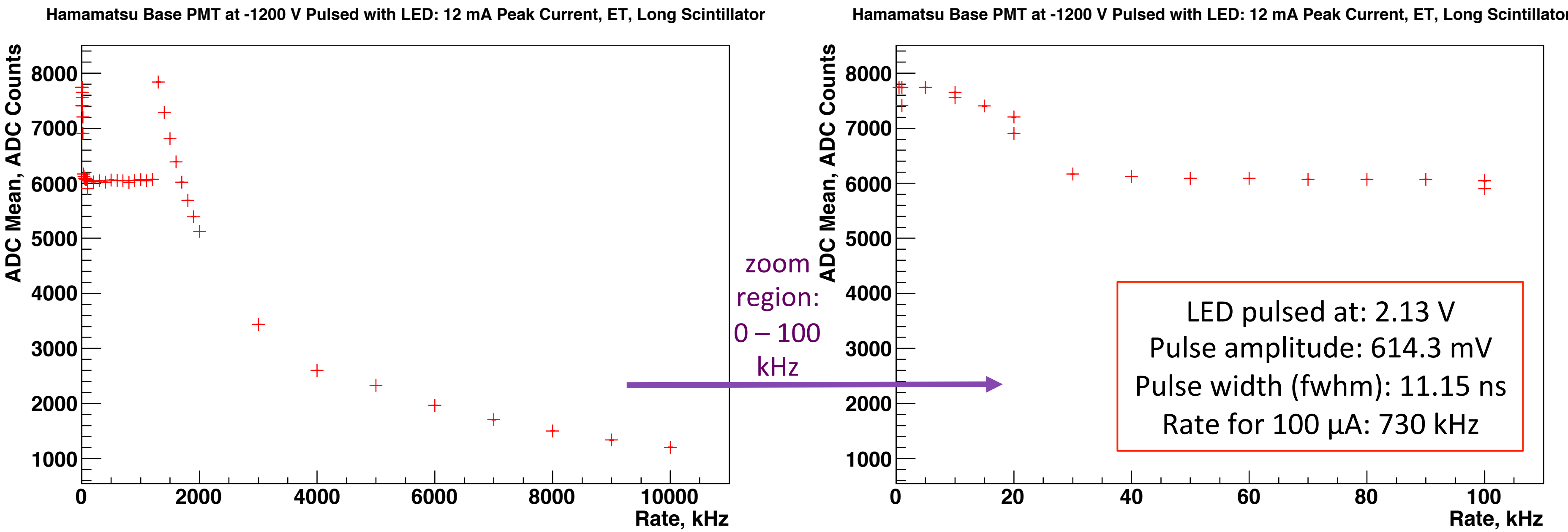
- **Conclusions** for "short" scintillator measurements:
  - For $I^a_{av} > 100\ \mu A$ we see behaviour in line with expectation
  - For some measurements (2/7) we see an effect where the ADC mean decreases by ~ 10% at low rates. Currently the cause of this is not understood.

Measurement Setup 2:

- 2” Hamamatsu R13089-100-11 PMT with negative HV active divider base (made by Hamamatsu)
- 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

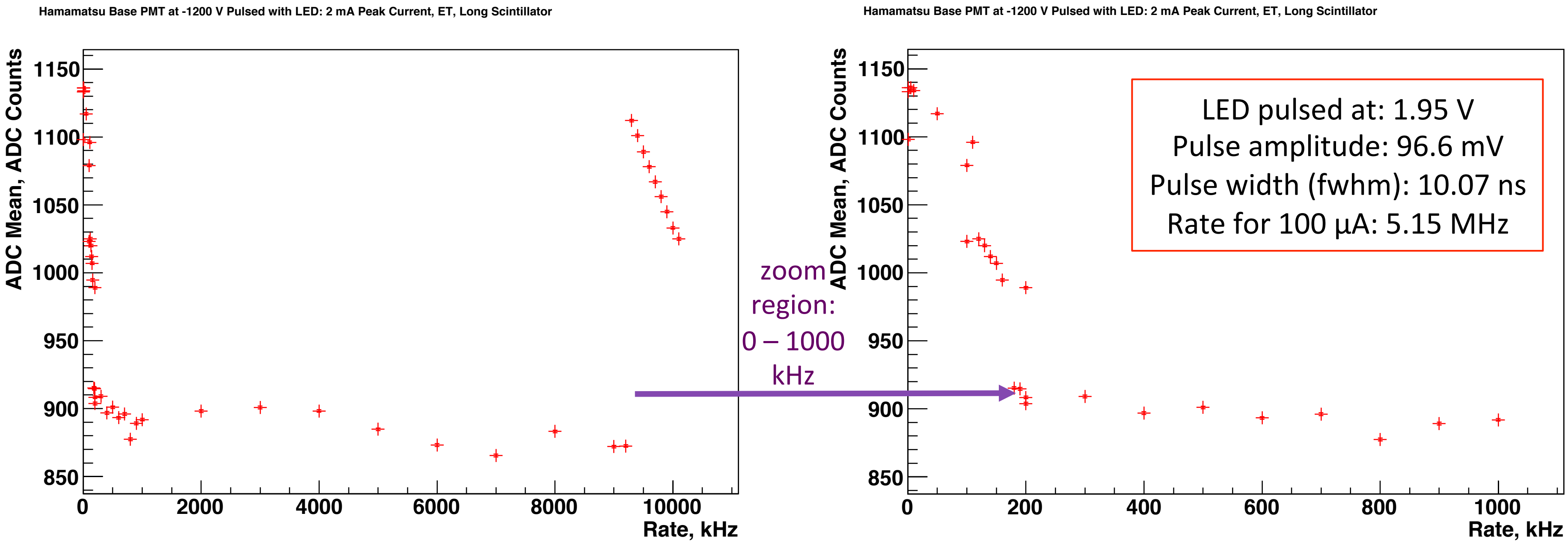
Aim: Do we see the same behaviour for $I^a_{av} > 100\ \mu A$ with our long scintillator as we do with the short?

HV: -1200 V, I_{peak} = 12 mA



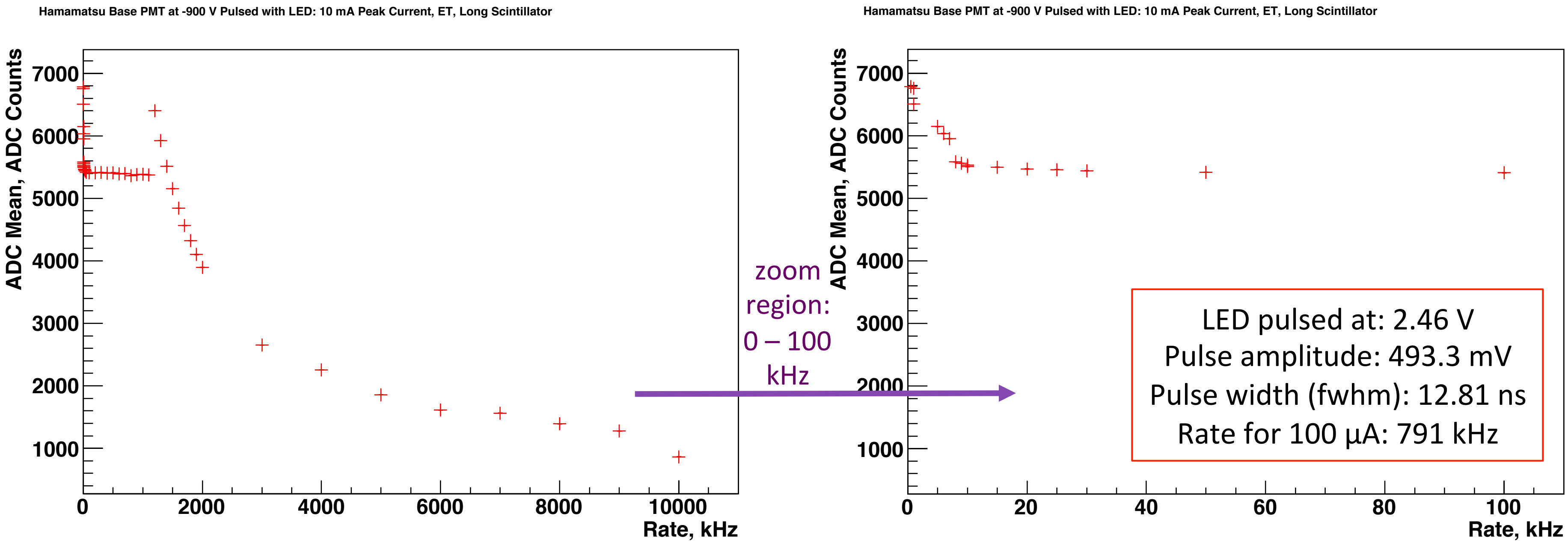
- Deviation from linearity occurs at ~ 1.3 MHz, corresponding to an anode average current, I^{a}_{av} ≈ 180 µA
- But we also see another effect:
  - A ~ 20% drop in ADC mean at lower rates of 10 – 30 kHz
  - This effect goes with the current, as seen on slide 13.
  - What could be causing this?

HV: -1200 V, I_{peak} = 2 mA



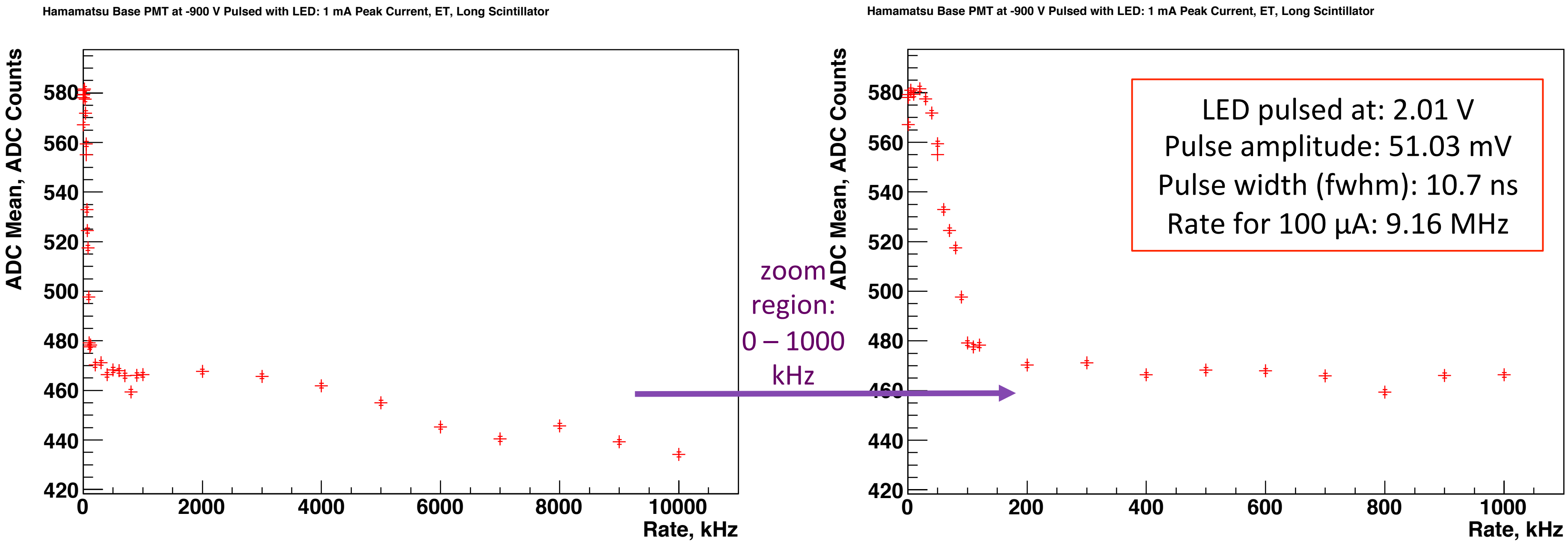
- Deviation from linearity occurs at ~ 9.3 MHz, corresponding to an anode average current, I^a_{av} ≈ 180 μA
- But we also see another effect:
  - A ~ 20% drop in ADC mean at lower rates of 50 – 180 kHz
  - This effect goes with the current, compare to 10 – 30 kHz for a peak current of 12 mA, slide 12).
  - What could be causing this?

HV: -900 V, I_{peak} = 10 mA



- Deviation from linearity occurs at ~ 1.2 MHz, corresponding to an anode average current, I^a_{av} ≈ 150 µA
- But we also see another effect:
  - A ~ 20% drop in ADC mean at lower rates of 5 – 10 kHz
  - This effect goes with the current, as seen on slide 15.
  - What could be causing this?

HV: -900 V, I_{peak} = 1 mA



- Deviation from linearity occurs at ~ 14 MHz, corresponding to an anode average current, I^a_{av} ≈ 150 µA
  - Deduced from increase in the current drawn by the PMT, monitored on the HV unit
- But we also see another effect:
  - A ~ 20% drop in ADC mean at lower rates of 50 – 100 kHz
  - This effect goes with the current, compare to 5 – 10 kHz for a peak current of 10 mA, slide 14).
  - What could be causing this? Effect seen for 4/4 measurements with the long scintillator!

Conclusions for Rate Tests

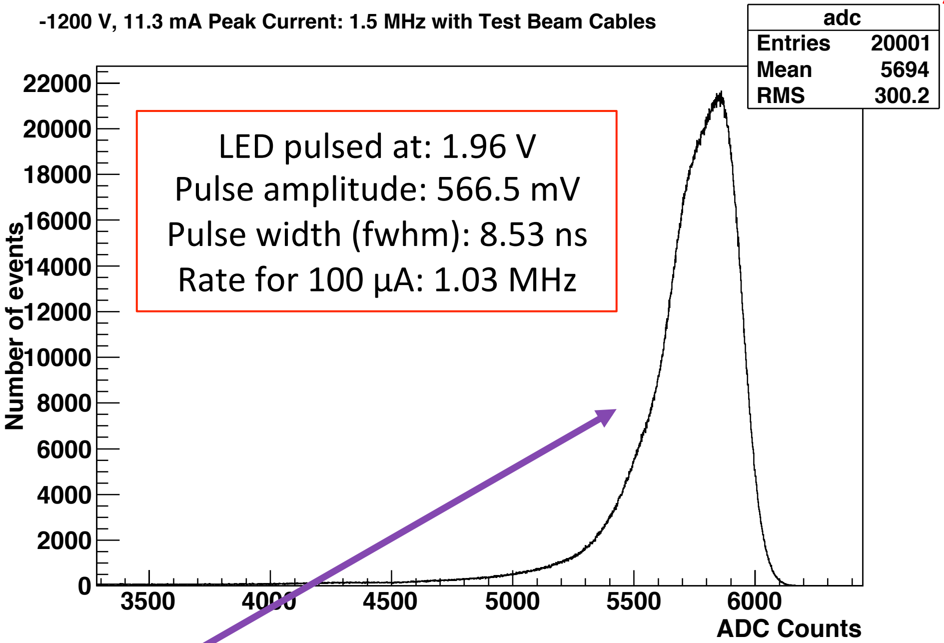
- For I^a_{av} > 100 μA we see behaviour in line with expectation both when using a short (3 cm x 3 cm x 5 cm) and long (3 cm x 3 cm x 45 cm) scintillators
- For some measurements (6/11) we see an effect where the ADC mean decreases by ~ 10% at low rates. Currently the cause of this is not understood.
  - We are shortly contacting Hamamatsu with these results to see if they can shed any light on this…
- Meanwhile, we have ordered new PMT bases from Hamamatsu to help us keep the PMT in its working regime for I^a_{av} > 100 μA:
  - Base with signal collected from the 4th dynode
  - Base with signal collected from the 5th dynode
  - "Gated" base
  - Base with "tapered" divider

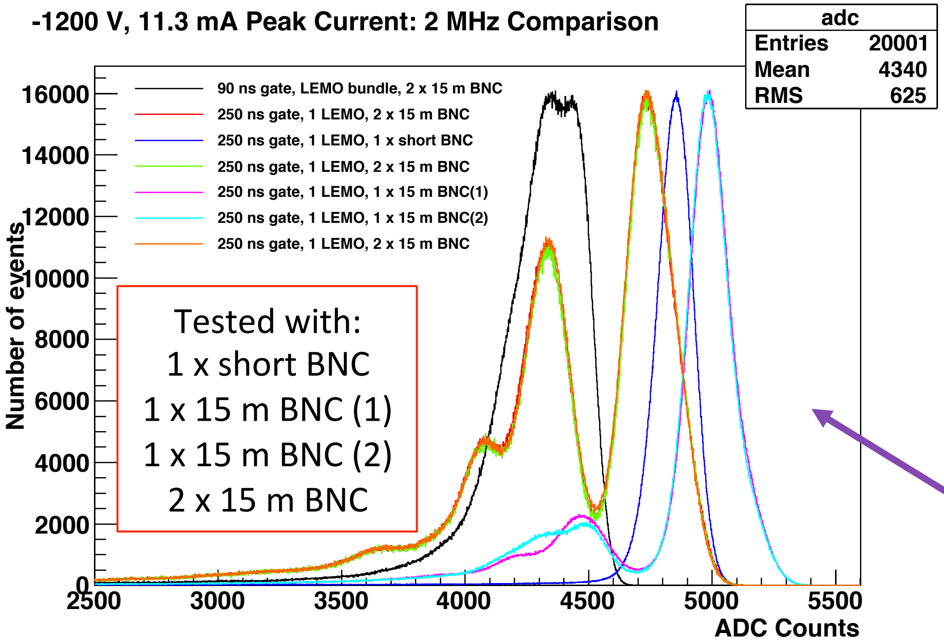
Measurement Setup 3:

- 2” Hamamatsu R13089-100-11 PMT with negative HV active divider base (made by Hamamatsu)
- 3 cm x 3 cm x 3 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
- Usual “short” cables used for testing at UCL replaced with the cable setup used during test beams

Aim: Do the “long” BNC and HV cables we use during test beam affect our measurements in any way?

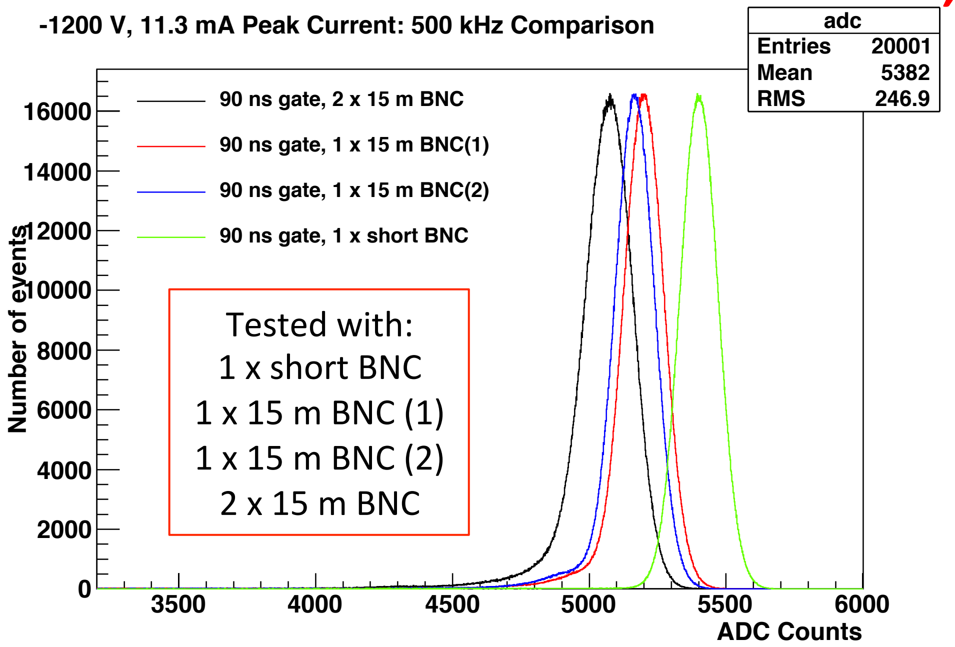
HV: -1200 V, $I_{peak} \approx 12$ mA:
2 x 15 m BNC cables, 2 x 25 m SHV cables

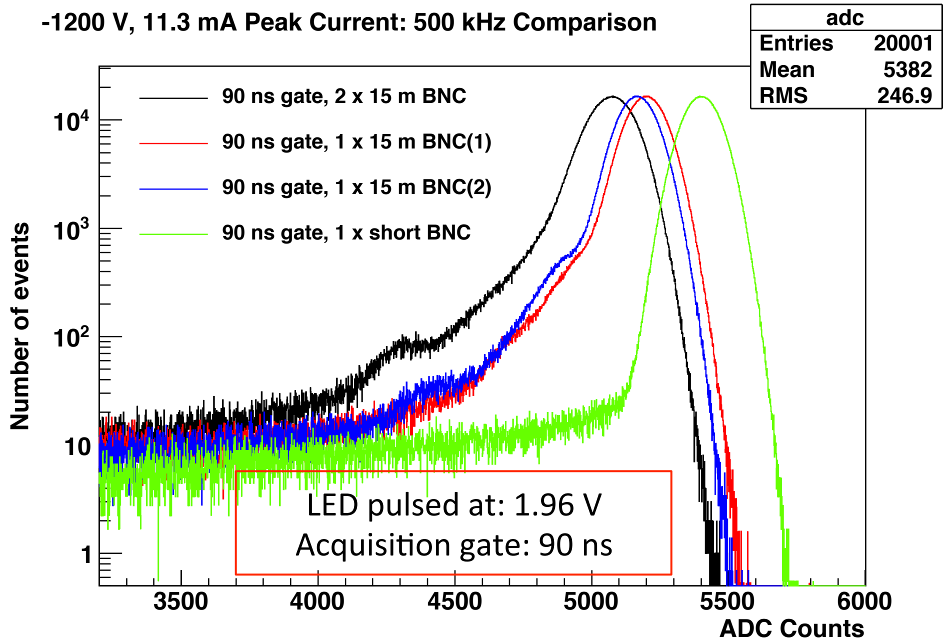




- During data taking it was noticed that data started looking non-Gaussian around the peak, rather than just the usual non-Gaussian tail seen on the left of the spectrum that appears at ~ 2 MHz
- For a gate of 250 ns at a rate of 2 MHz using the long BNC cables starts introducing multiple peaks – this data is not useable to extract the ΔE/E.
  - Has this affected us during test beam?
  - Look at a gate of 90 ns (usual acquisition gate for these tests and closer to test beam)

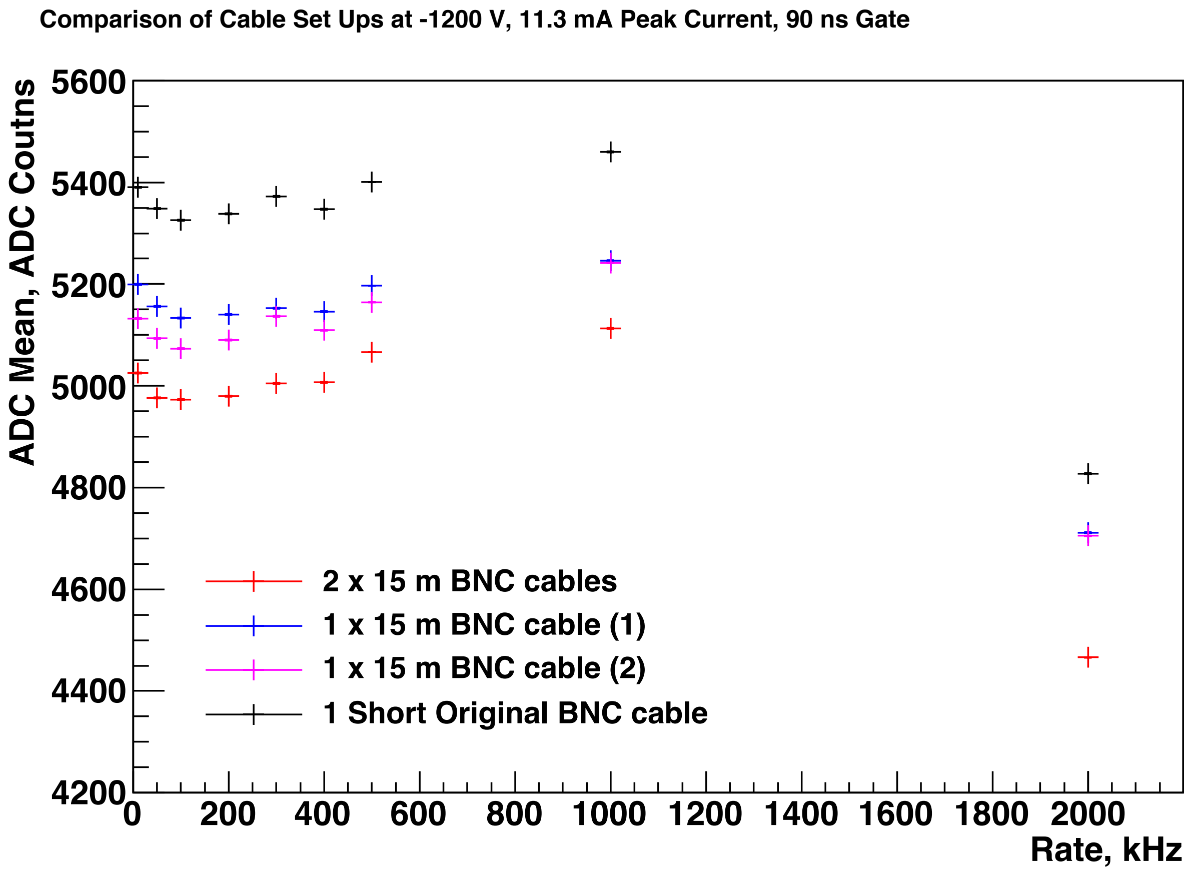
HV: -1200 V, I_{peak} ≈ 12 mA: 2 x 15 m BNC cables, 2 x 25 m SHV cables





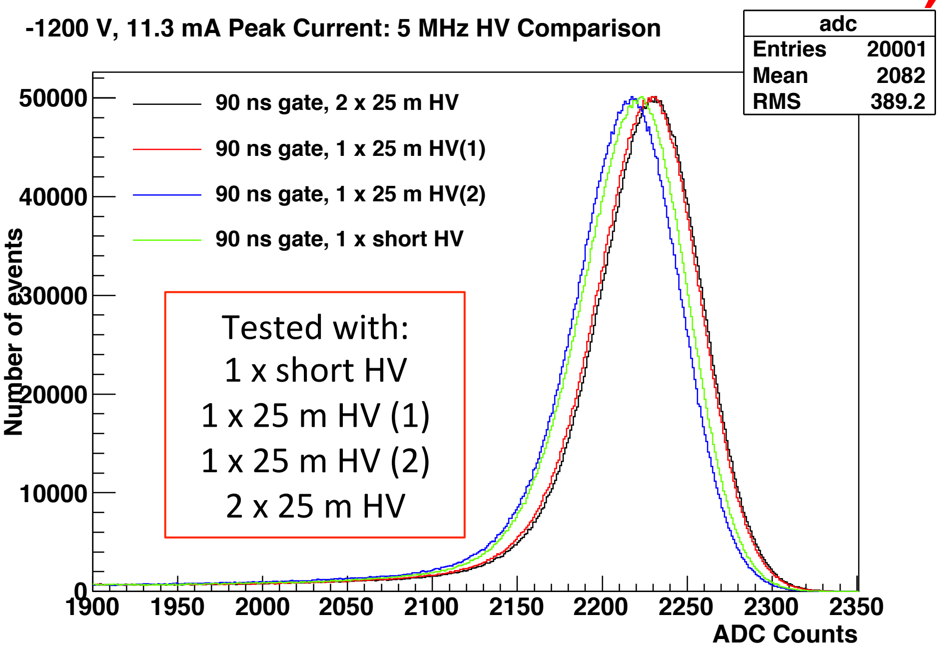
- The peak first starts to look non-Gaussian for setups involving one or two long BNC cables at ~ 500 kHz
  - Rates we work with at test beam!
- Other observations:
  - Able to extract a rough ADC mean up to a rate of ~ 2 MHz
  - σ cannot be extracted accurately for rates > 1 MHz
  - And when we can obtain a measurement of σ it is larger for tests done with long cables compared to tests with the short cable

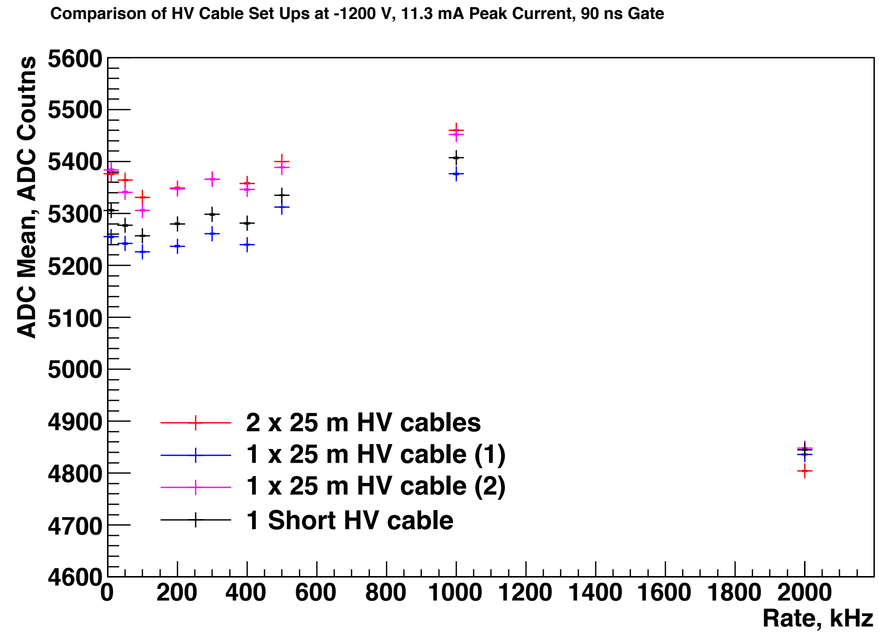
HV: -1200 V, $I_{peak} \approx 12$ mA: 2 x 15 m BNC cables, 2 x 25 m SHV cables



- ADC mean as a function of rates for all BNC cable setups:
  - We still see the same trend, but a change in mean.

HV: -1200 V, $I_{peak} \approx 12$ mA: 1 x short BNC cable, 2 x 25 m SHV cables





- Using long HV cables does not affect the data, as can be seen above for an example at 5 MHz. Tests were carried out up to 10 MHz with no effect due to using long HV cables observed.
- Other observations:
  - Some change in the mean is seen in the ADC mean as a function of rate plot above, but this change is too small to impact the ΔE/E.

Conclusions for Long Cable Tests

- Using long HV cables does not effect the ADC distribution

- Using long BNC cables DOES effect the distribution:
  - From a rate as low as 500 kHz
  - Could have impacted our previous test beam data!

- Solutions:
  - The CAEN digitiser cannot be put on any network, either wirelessly or wired.
  - CAEN currently have no products that are able to do this, but are working on it.
  - Instead, we have to set up a network with two (or more) computers:
    - One Windows machine that will remain in the treatment room, that the digitiser will be connected to.
    - A second laptop that will be in the control room and can access the Windows machine in the treatment room to control the digitiser.
    - This has now been set up and tested using Microsoft Remote Desktop and a router.
    - Next, work on adding the oscilloscope to the Windows machine so it can also be controlled remotely. Also – can we get a good quality enough splitter to not affect our signal?!