SIDIS Cerenkov Update: Hardware Tests maPMT H8500C-03

S.P. Malace (JLab), H. Gao (Duke)

(reference *S.P. Malace, B.D. Sawatzky, H. Gao, to be submitted to NIM A*)

Acknowledgements: Brad Sawatzky, Drew Weisenberger, Jack Mckisson and the detector group, Chris Cuevas

SoLID Collaboration Meeting, Dec. 14 – 15 2012, JLab

Outline

(reference *S.P. Malace, B.D. Sawatzky, H. Gao, to be submitted to NIM A – an arXiv number will be available soon*)

→ **Since September 2012 (last collaboration meeting) we performed single-photoelectron (SPE) measurements and mapping of H8500C-03 response to magnetic field (more than 2000 runs taken, many hours of data)**

→ **We tested 3 individual pixels and 2 groups of 16 pixels (2 quads)**

Single-photoelectron measurements

→ **We clearly identified SPE signals on both individual pixels and sum of pixels (quads)**
→ **We used an established PMT response function to extract the SPE resolution of the H8500C-03**
→ **We gain-matched pixels and shown that the resolution could be improved for sum of pixels**

Outline

(reference *S.P. Malace, B.D. Sawatzky, H. Gao, to be submitted to NIM A – an arXiv number will be available soon*)

Magnetic field measurements

→ **We measured the effect of magnetic field on SPE distributions on both individual pixels and sum of pixels (quads) –** ***due to time constraints will not be shown in this presentation***

→ **We measured the effect of magnetic field on large signals (40 photoelectrons or larger) on both individual pixels and sum of pixels (quads)**

→ **We use magnetic fields as larger as 300 gauss (highest to date on this PMT to our knowledge)**

Experimental Setup

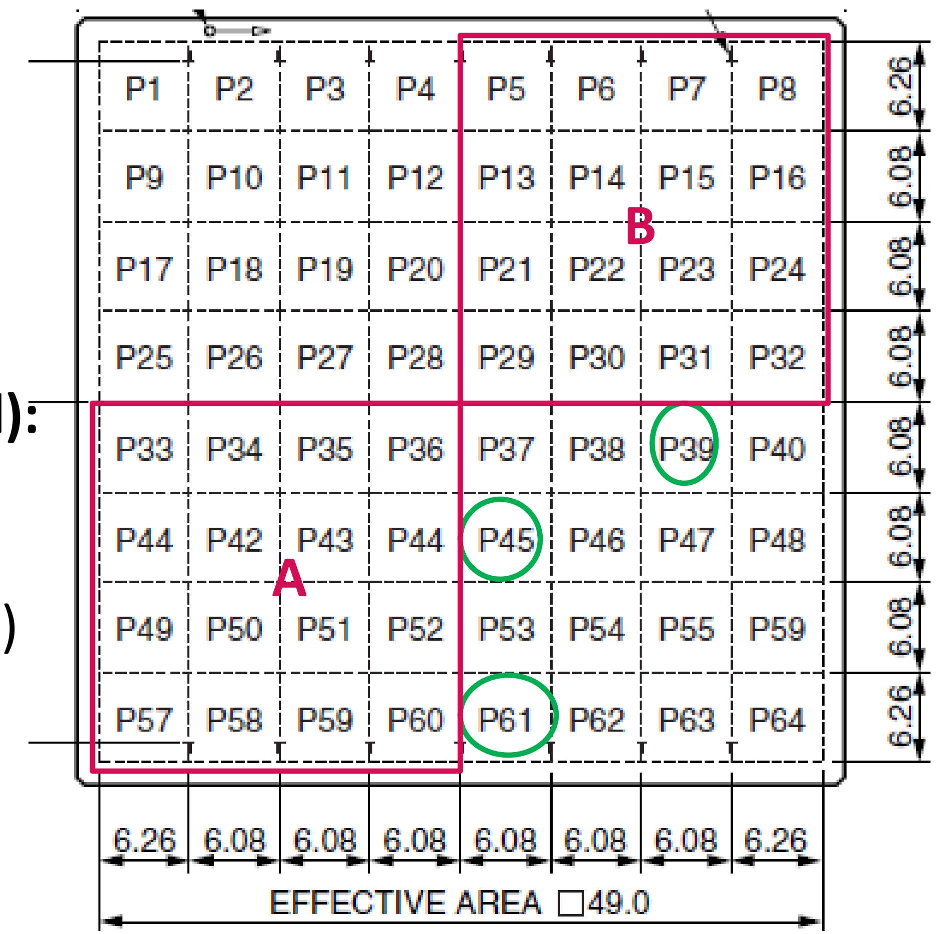
What is it that we measure?

→ We measure the output of 3 individual pixels:

Highest gain - pixel 61 (edge pixel): output = 100
Moderate gain - pixel 45 (central pixel): output = 79
Low gain - pixel 39: output = 51
(output as read from Hamamatsu map)

Edge pixels behave very differently in magnetic field than central pixels

→ We measure the output of 2 groups of 16 pixels (2 quads: A and B) – likely a configuration to be used for SoLID



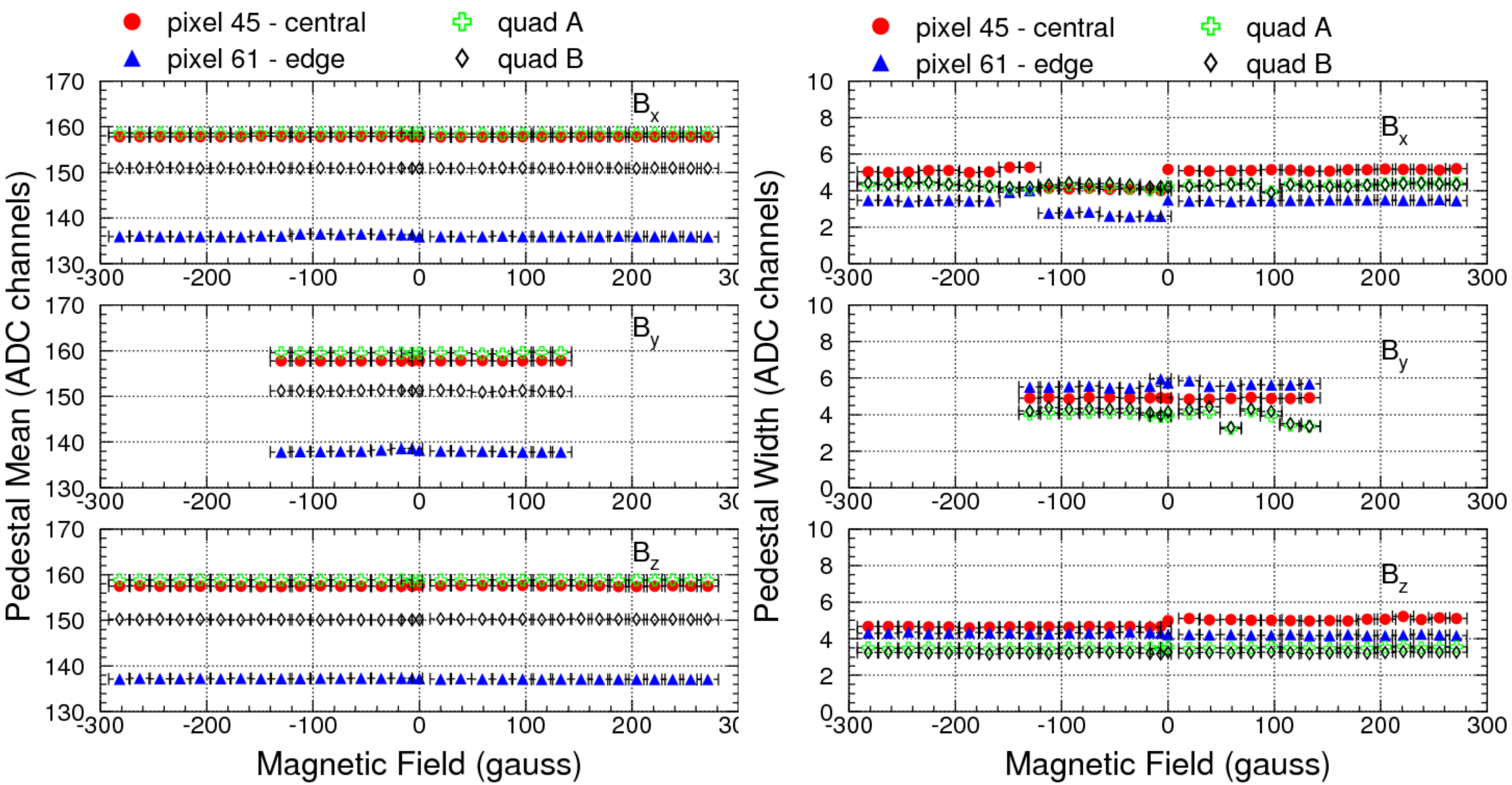
Experimental Setup

→ **Tests were performed at JLab, EEL 126, since September 2012**

- We triggered on the pulse that fed the green LED used to illuminate the PMT
  - Characteristics of the LED pulse:
    - → 20 ns wide
    - → amplitude varied from 0.8 V to 4.5 V depending on the goal of the tests
    - → rate: 2 kHz
- The PMT signal was passed through 10 X amplification
- For PMT signal detection we used a charge integrating ADC: 32-cannels V792 (we stayed away from the regions of nonlinearities this time:); ADC gate = 200 ns
- For data acquisition we used CODA 2.5

Experimental Setup

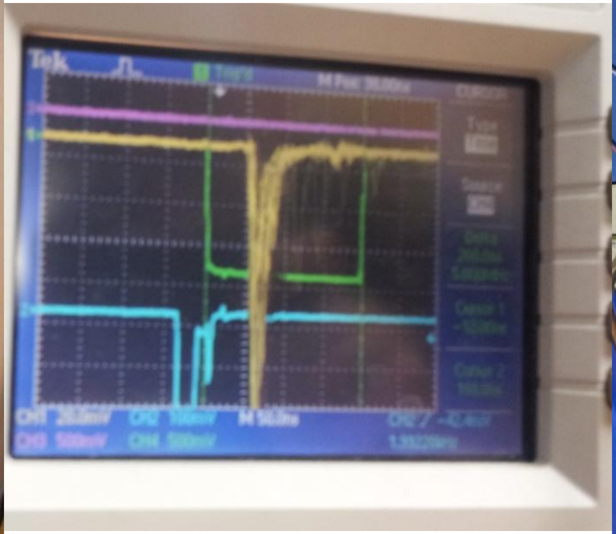
→ **The experimental setup has been very stable over the course of 3 months**

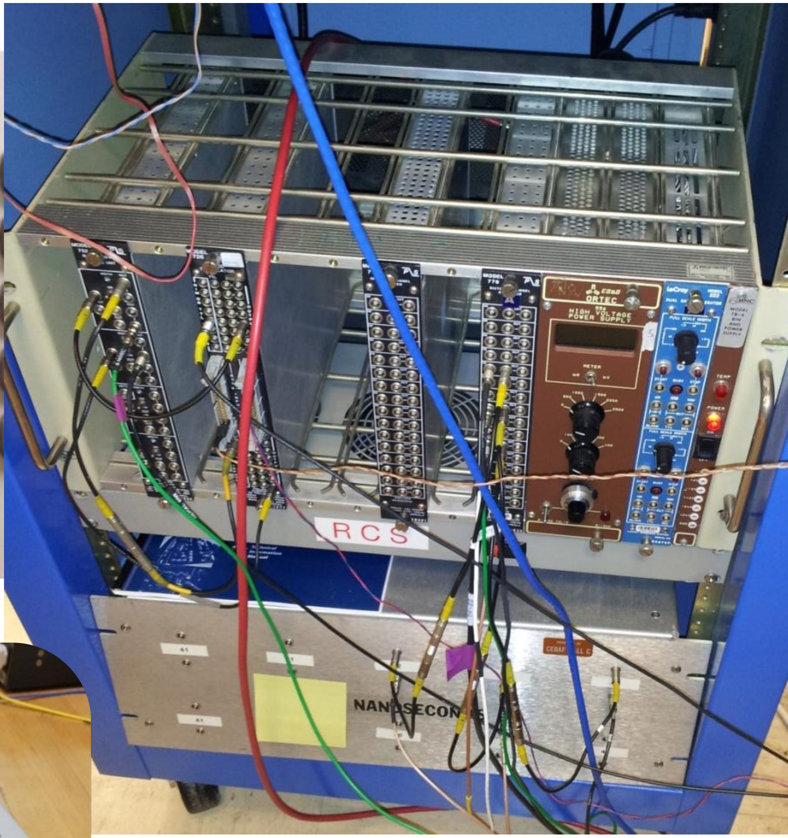


Example: mean and standard deviation of the pedestal runs taken during the magnetic field measurements over the course of ~2 months

Experimental Setup

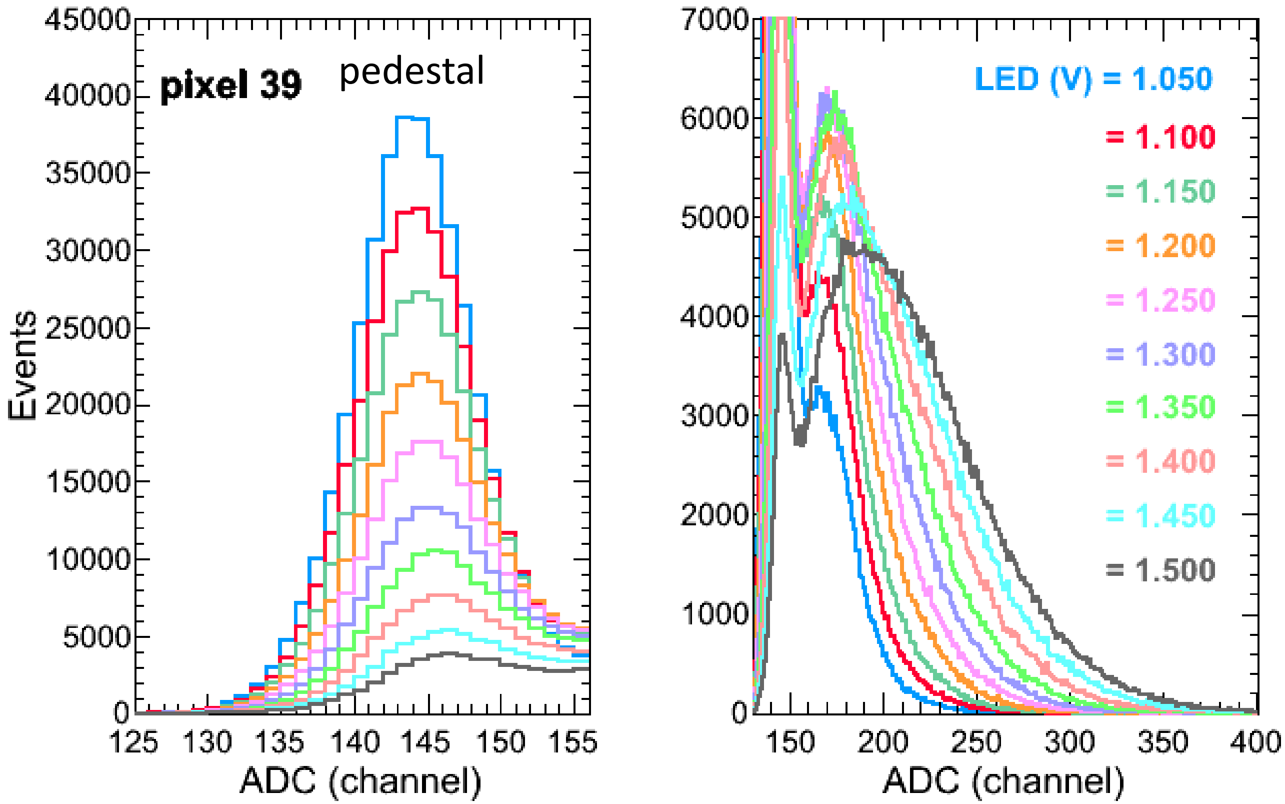
→ **The experimental setup in EEL 126 at JLab**





SPE Measurements: Pixel 39

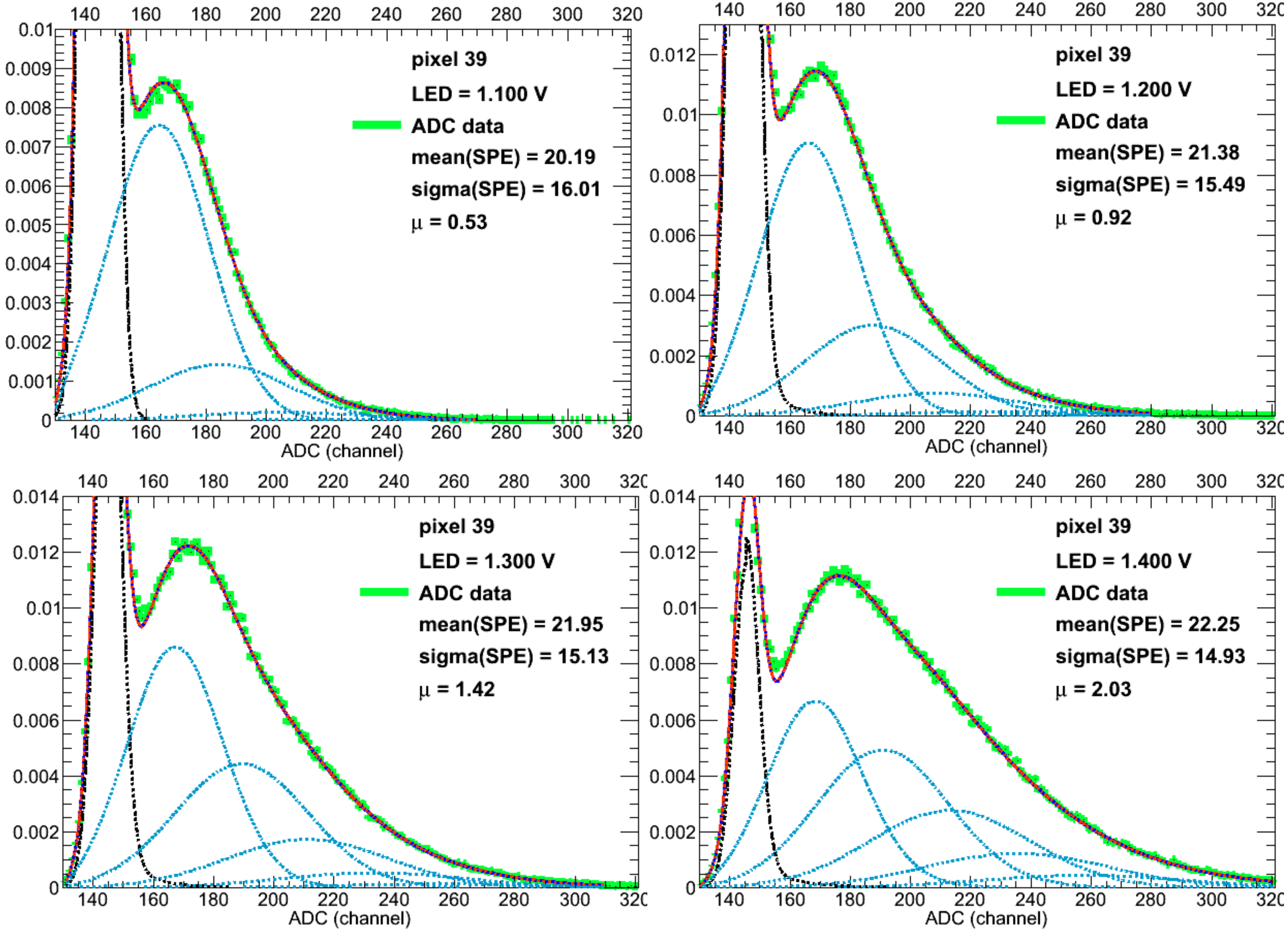
→ The yield of photons produced by the LED has been "chosen" such that the production of single photoelectrons from the PMT photocathode is favored; *by varying the LED voltage in small steps we reveal the quantum nature of the process*



→ We use a well established PMT response function to extract the **mean** (above pedestal) and the **standard deviation** of the SPE distribution

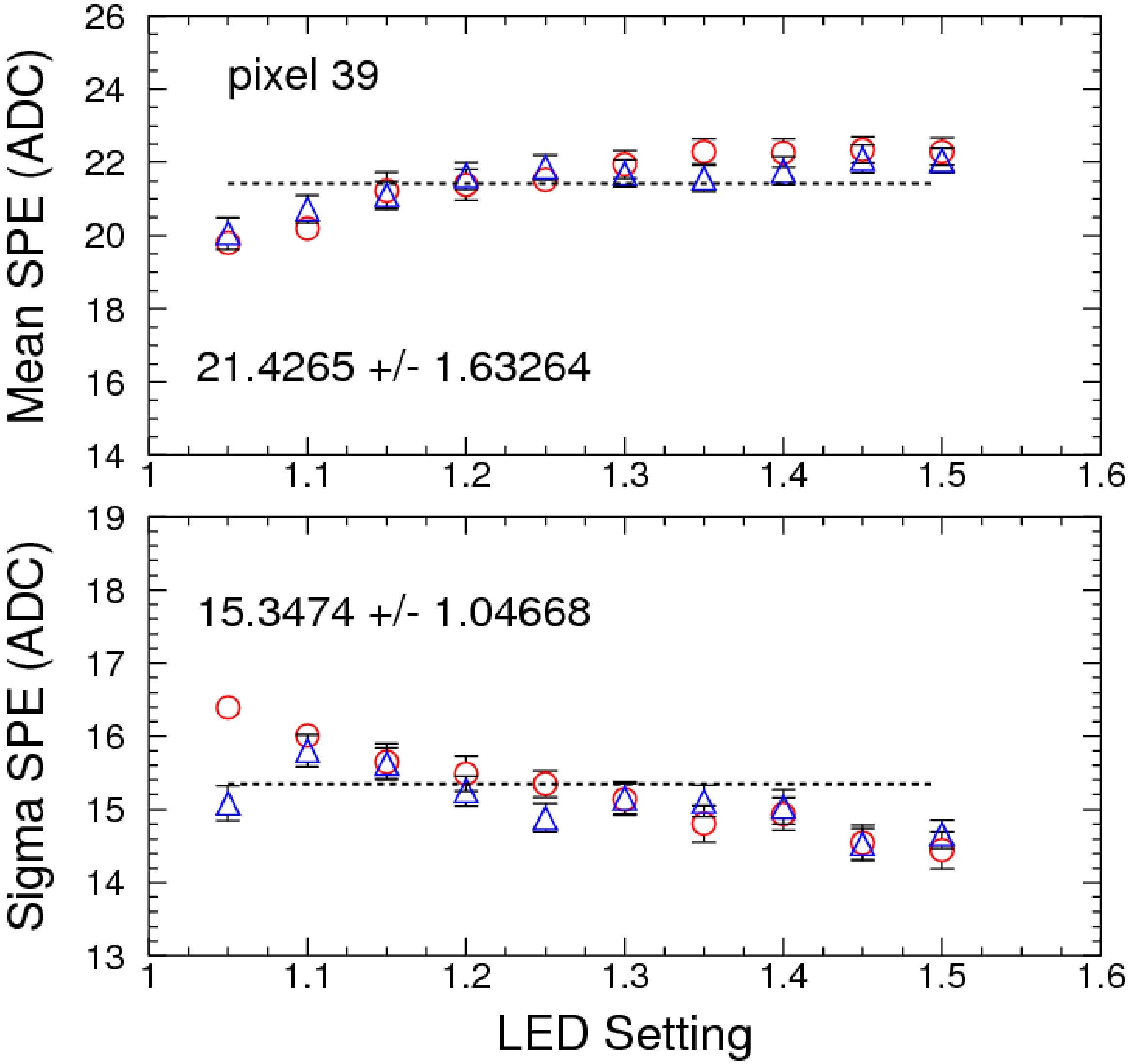
$$S_{\text{real}}(x) = \int S_{\text{ideal}}(x')B(x-x')\,\mathrm{d}x' = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \times \left[(1-w)G_n(x-Q_0) + wI_{G_n \otimes E}(x-Q_0)\right]$$

SPE Measurements: Pixel 39



SPE Measurements: Pixel 39

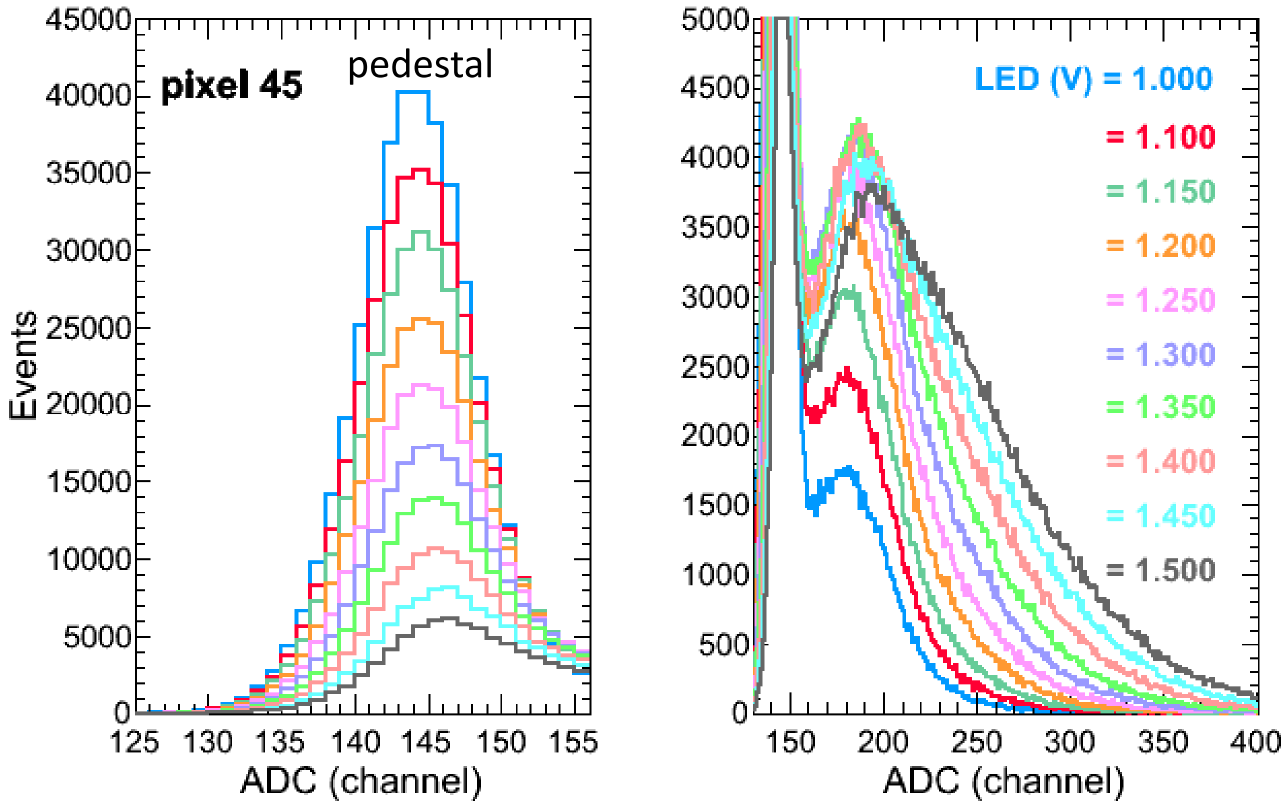
→ **Fit** extraction of the **mean** (measured from pedestal) and the **standard deviation** of the SPE distribution from ADC data corresponding to different LED settings is consistent



- *Different symbols correspond to different starting values for the fit parameters*
- *Mean: all data points within 1.6 channels from the average*
- *Standard deviation: all data points within 1 channel from the average*
- *Resolution of pixel 39: better than 1 photoelectron*

SPE Measurements: Pixel 45

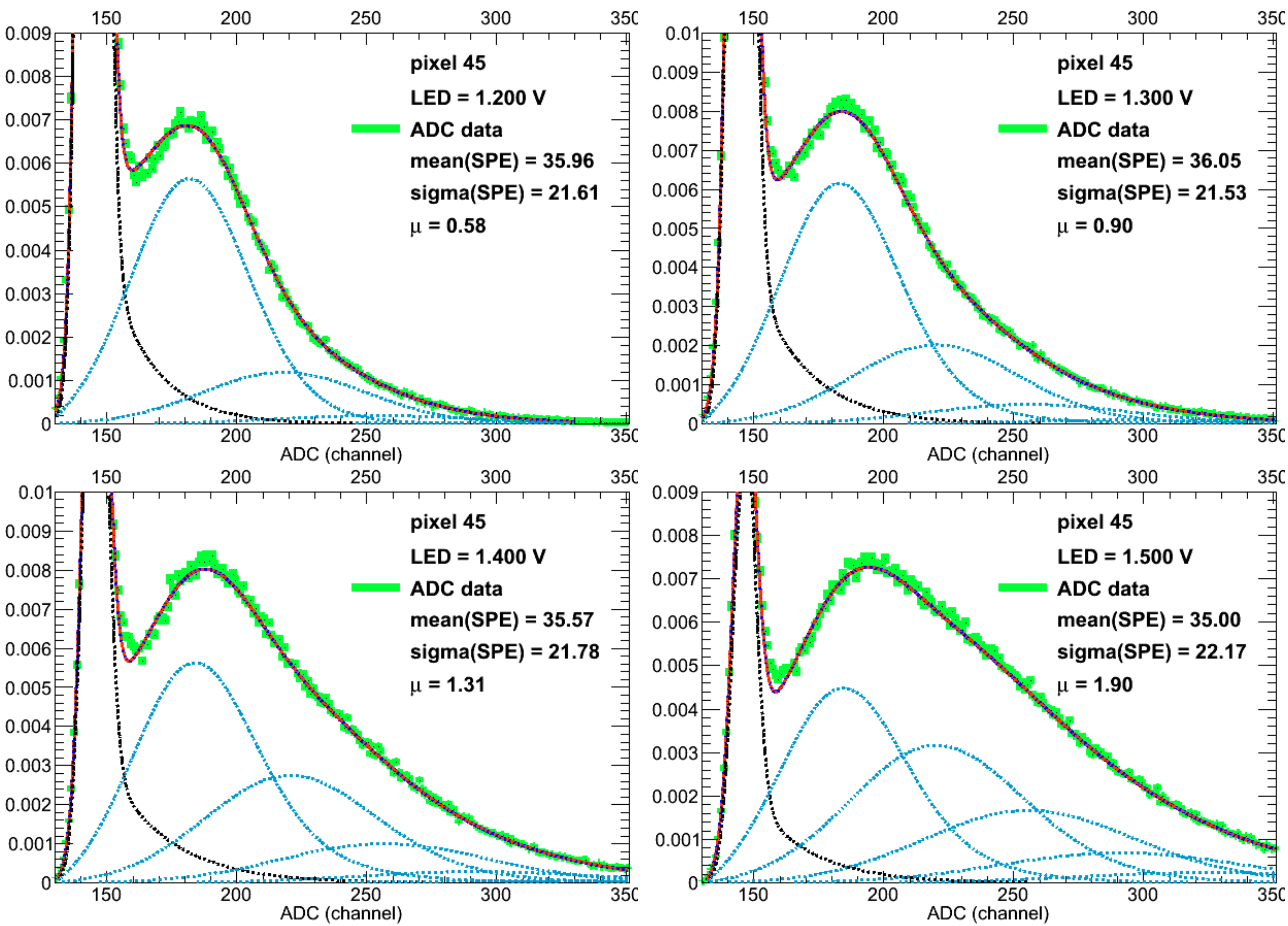
→ The yield of photons produced by the LED has been "chosen" such that the production of single photoelectrons from the PMT photocathode is favored; *by varying the LED voltage in small steps we reveal the quantum nature of the process*



→ We use a well established PMT response function to extract the **mean** (above pedestal) and the **standard deviation** of the SPE distribution

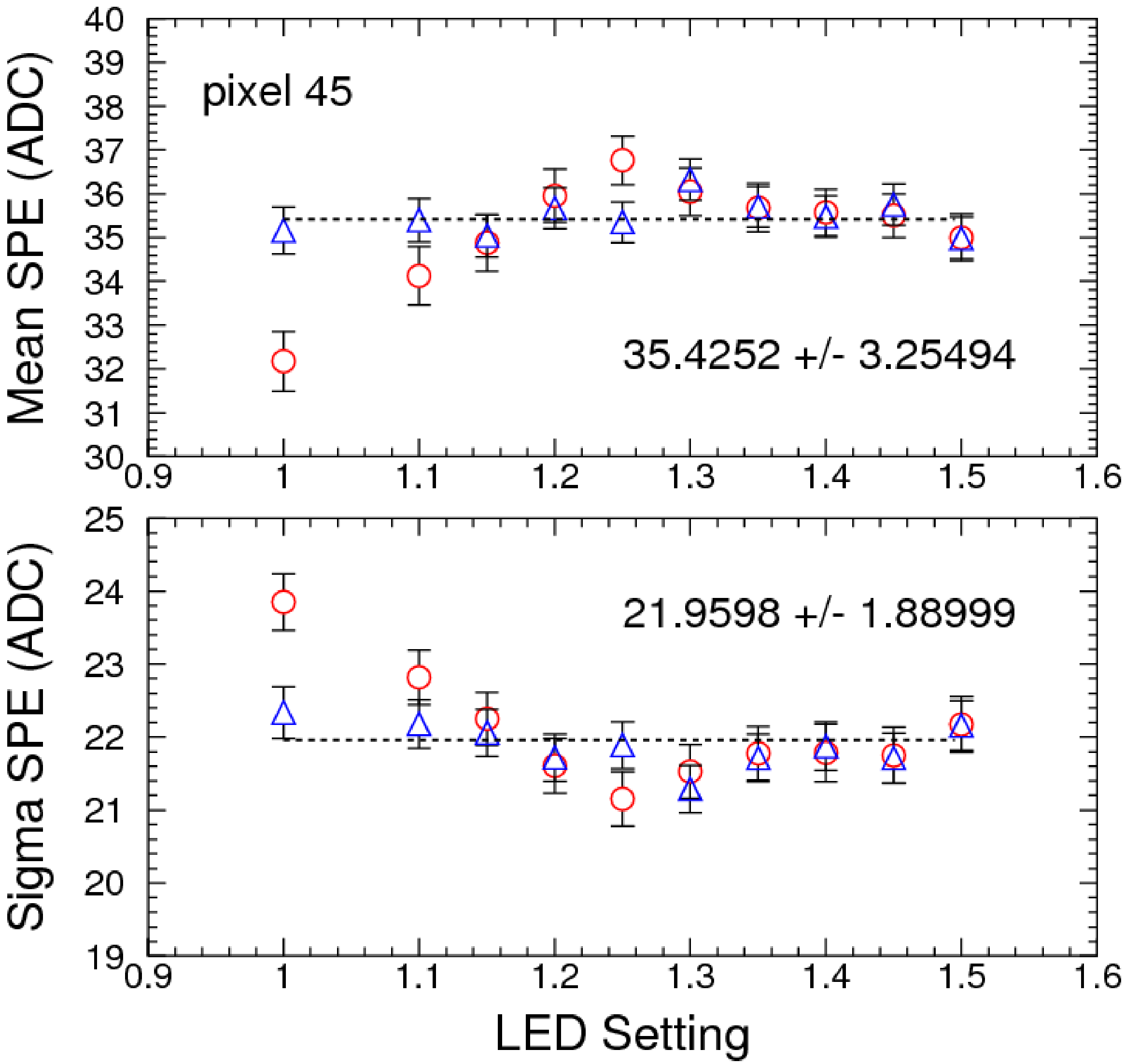
$$S_{real}(x) = \int S_{ideal}(x')B(x-x')\,dx' = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \times \left[(1-w)G_n(x-Q_0) + wI_{G_n \otimes E}(x-Q_0)\right]$$

SPE Measurements: Pixel 45



SPE Measurements: Pixel 45

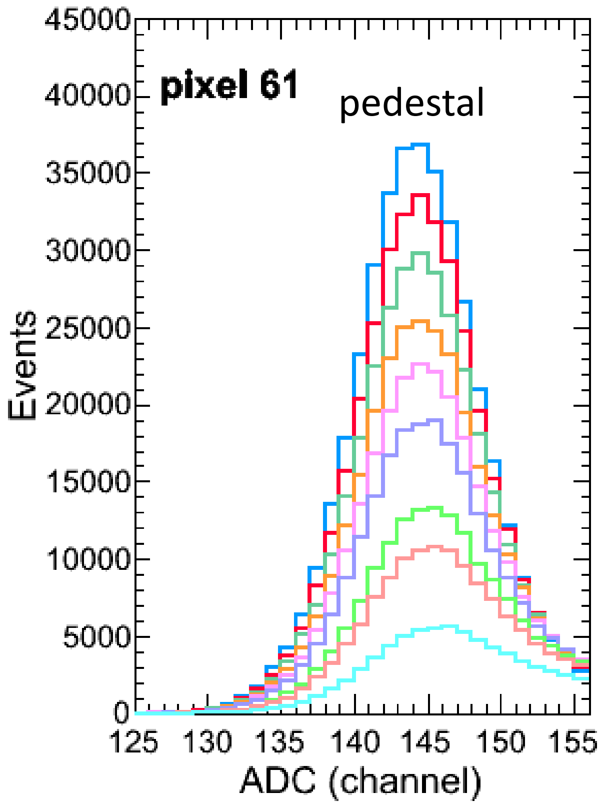
→ **Fit** extraction of the **mean** (measured from pedestal) and the **standard deviation** of the SPE distribution from ADC data corresponding to different LED settings is consistent

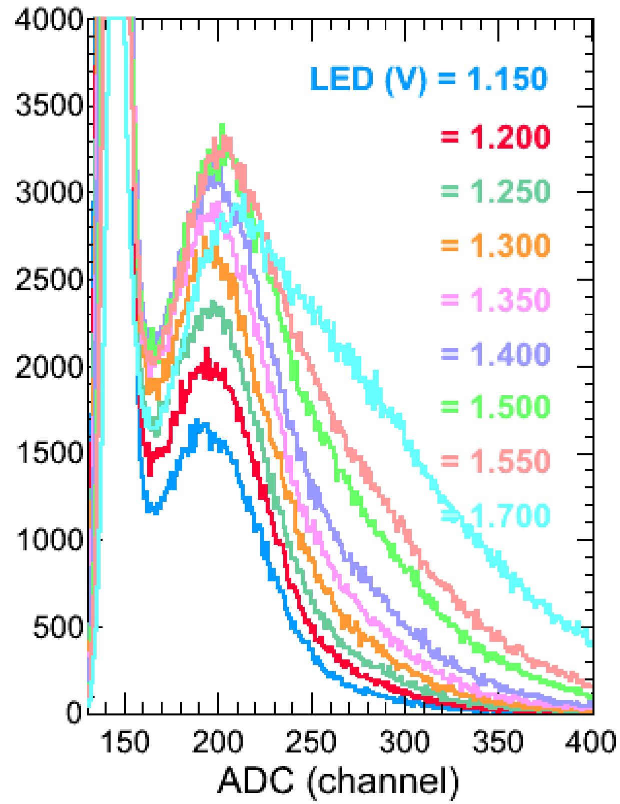


- *Different symbols correspond to different starting values for the fit parameters*
- *Mean: all data points within 3.3 channels from the average*
- *Standard deviation: all data points within 1.9 channels from the average*
- *Resolution of pixel 45: better than 1 photoelectron*

SPE Measurements: Pixel 61

→ The yield of photons produced by the LED has been "chosen" such that the production of single photoelectrons from the PMT photocathode is favored; *by varying the LED voltage in small steps we reveal the quantum nature of the process*

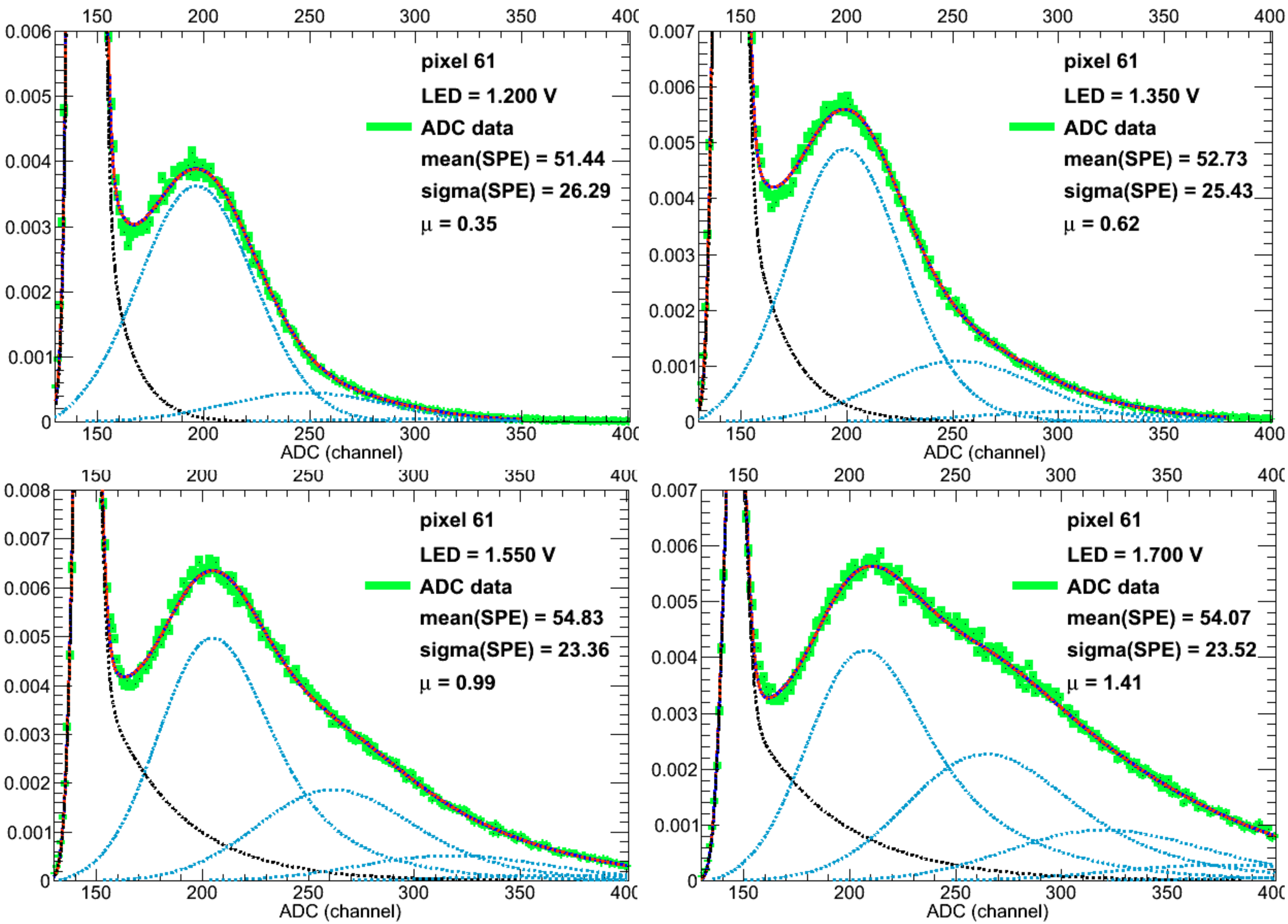




→ We use a well established PMT response function to extract the **mean** (above pedestal) and the **standard deviation** of the SPE distribution

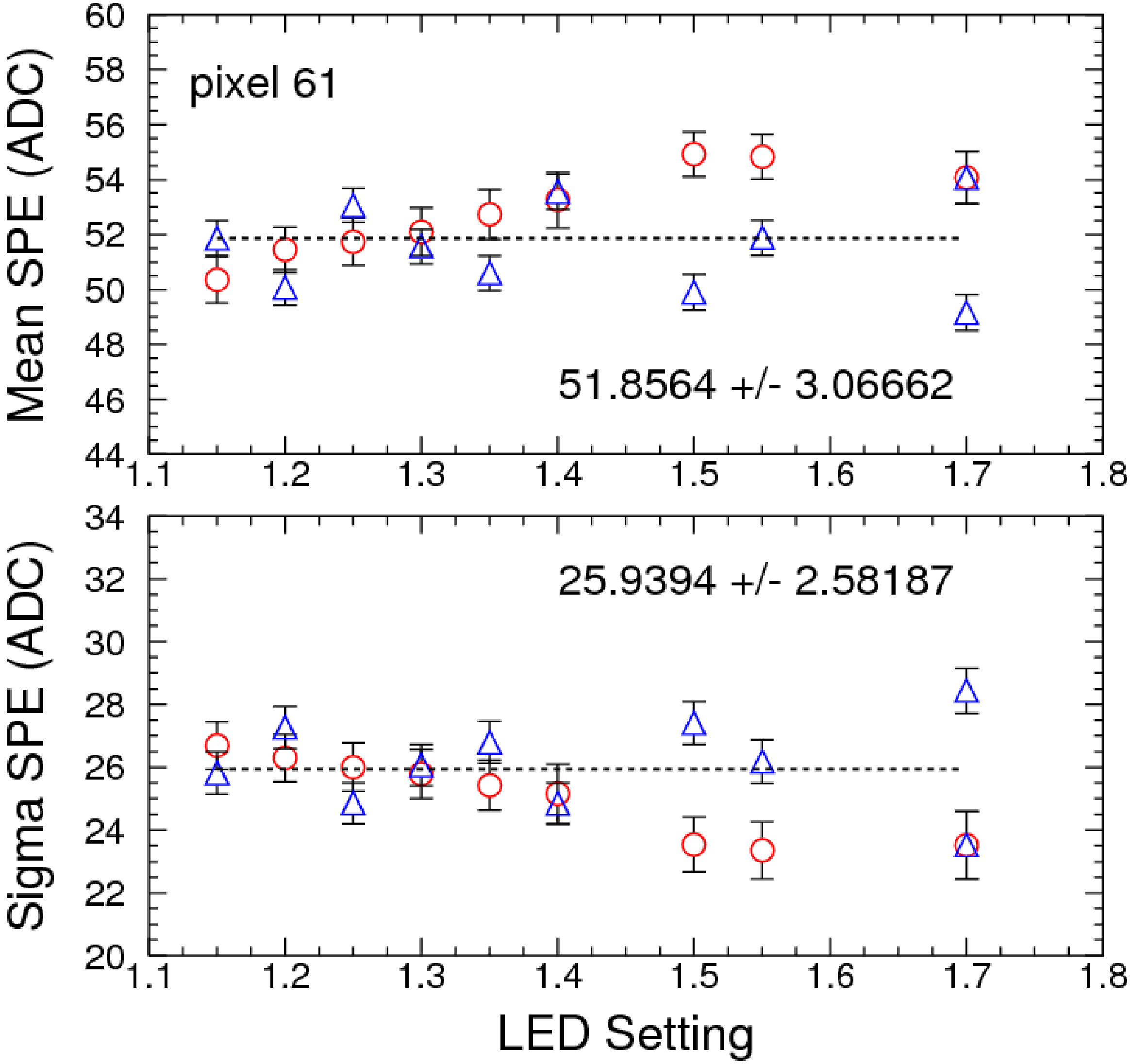
$$S_{\mathrm{real}}(x) = \int S_{\mathrm{ideal}}(x')B(x-x')\,\mathrm{d}x' = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \times \left[(1-w)G_n(x-Q_0) + wI_{G_n \otimes E}(x-Q_0)\right]$$

SPE Measurements: Pixel 61



SPE Measurements: Pixel 61

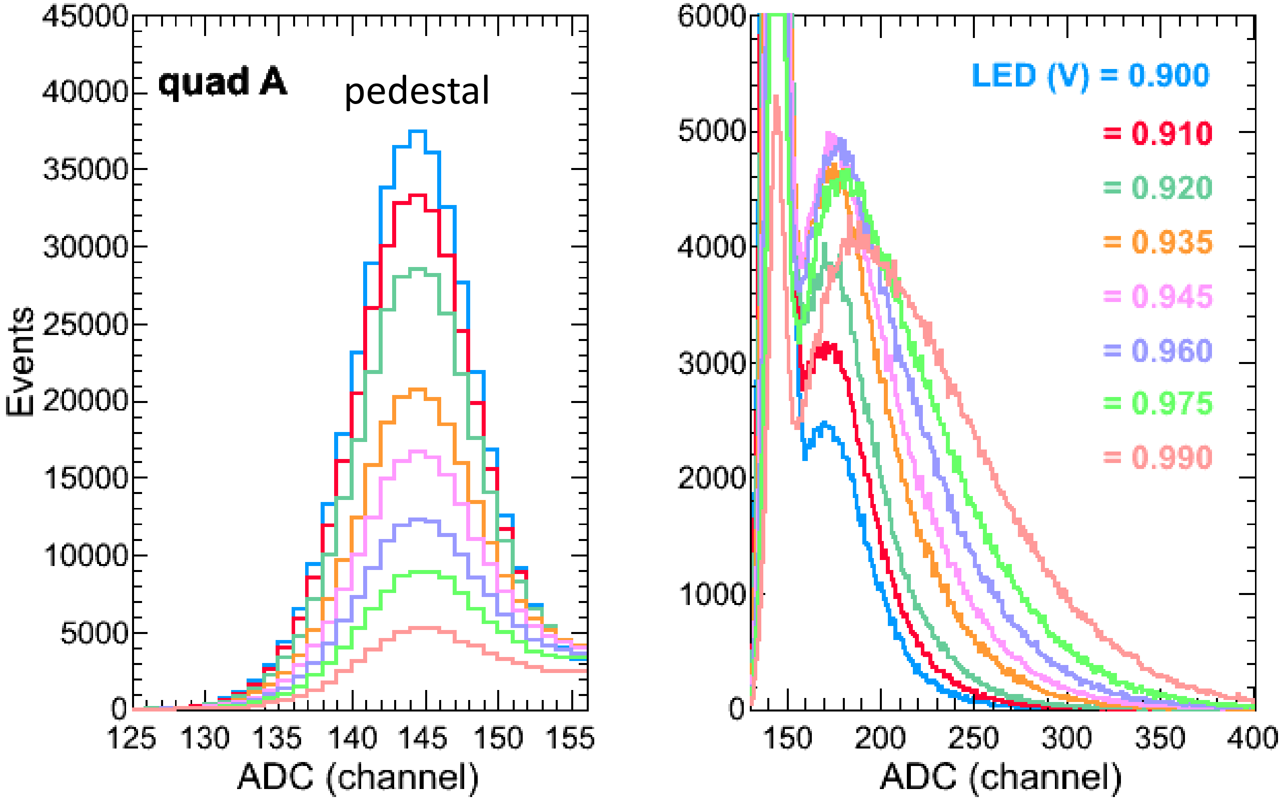
→ **Fit** extraction of the **mean** (measured from pedestal) and the **standard deviation** of the SPE distribution from ADC data corresponding to different LED settings is consistent



- *Different symbols correspond to different starting values for the fit parameters*
- *Mean: all data points within 3 channels from the average*
- *Standard deviation: all data points within 2.6 channels from the average*
- *Resolution of pixel 61: better than 1 photoelectron*

SPE Measurements: Quad A

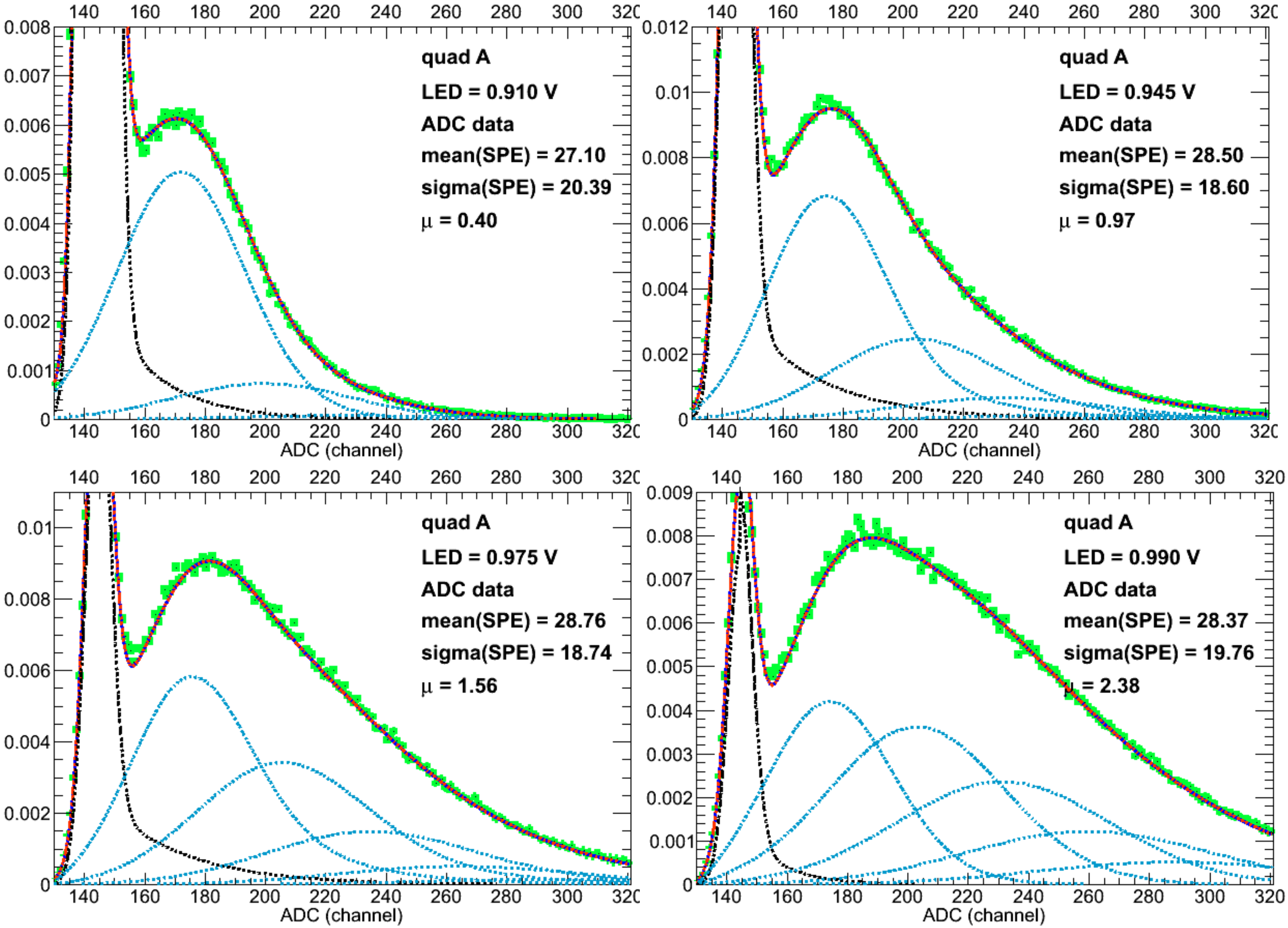
→ The yield of photons produced by the LED has been “chosen” such that the production of single photoelectrons from the PMT photocathode is favored; *by varying the LED voltage in small steps we reveal the quantum nature of the process*



→ We use a well established PMT response function to extract the **mean** (above pedestal) and the **standard deviation** of the SPE distribution

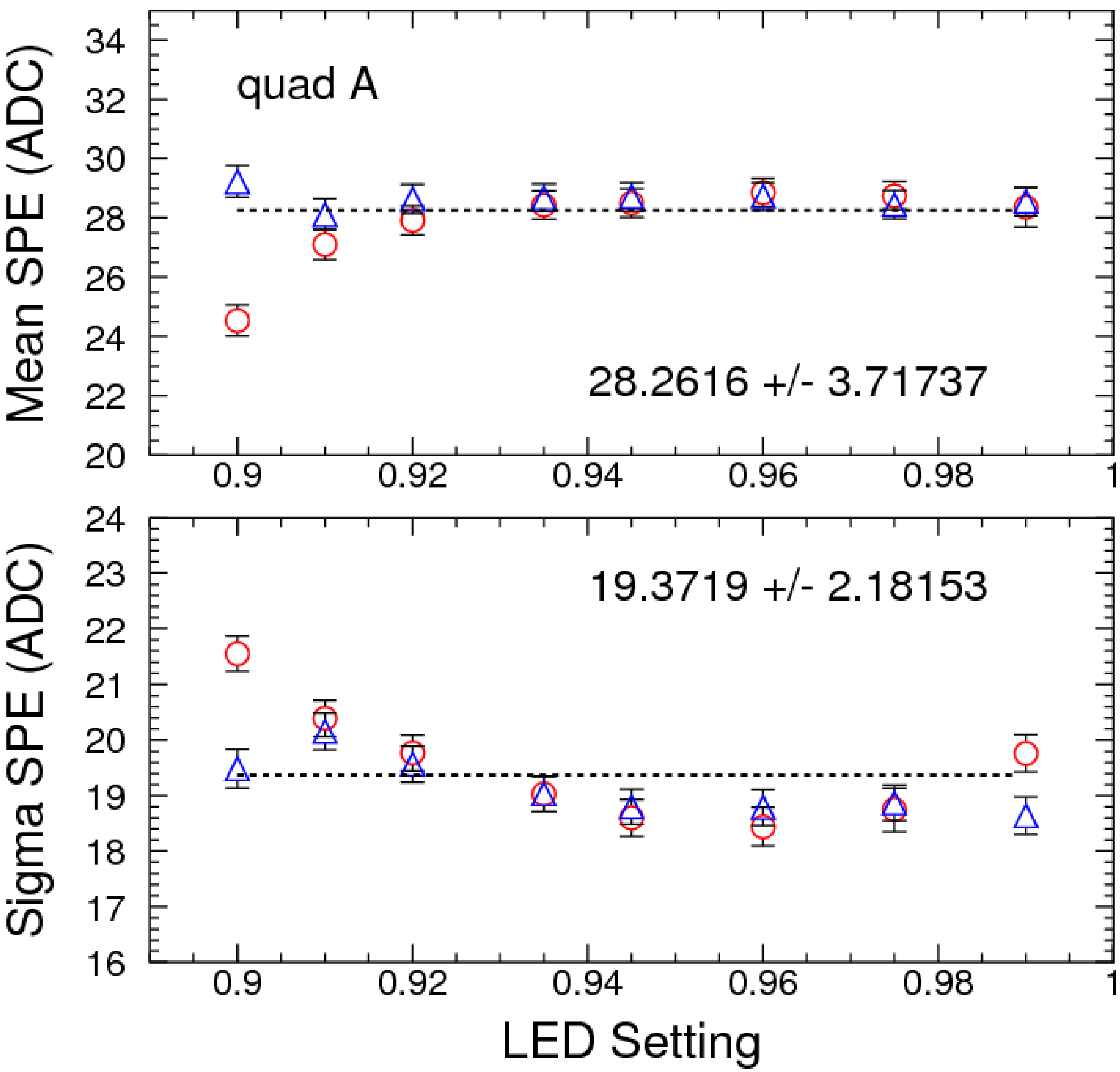
$$S_{\mathrm{real}}(x) = \int S_{\mathrm{ideal}}(x')B(x-x')\,\mathrm{d}x' = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \times \left[(1-w)G_n(x-Q_0) + wI_{G_n \otimes E}(x-Q_0)\right]$$

SPE Measurements: Quad A



SPE Measurements: Quad A

→ **Fit** extraction of the **mean** (measured from pedestal) and the **standard deviation** of the SPE distribution from ADC data corresponding to different LED settings is consistent

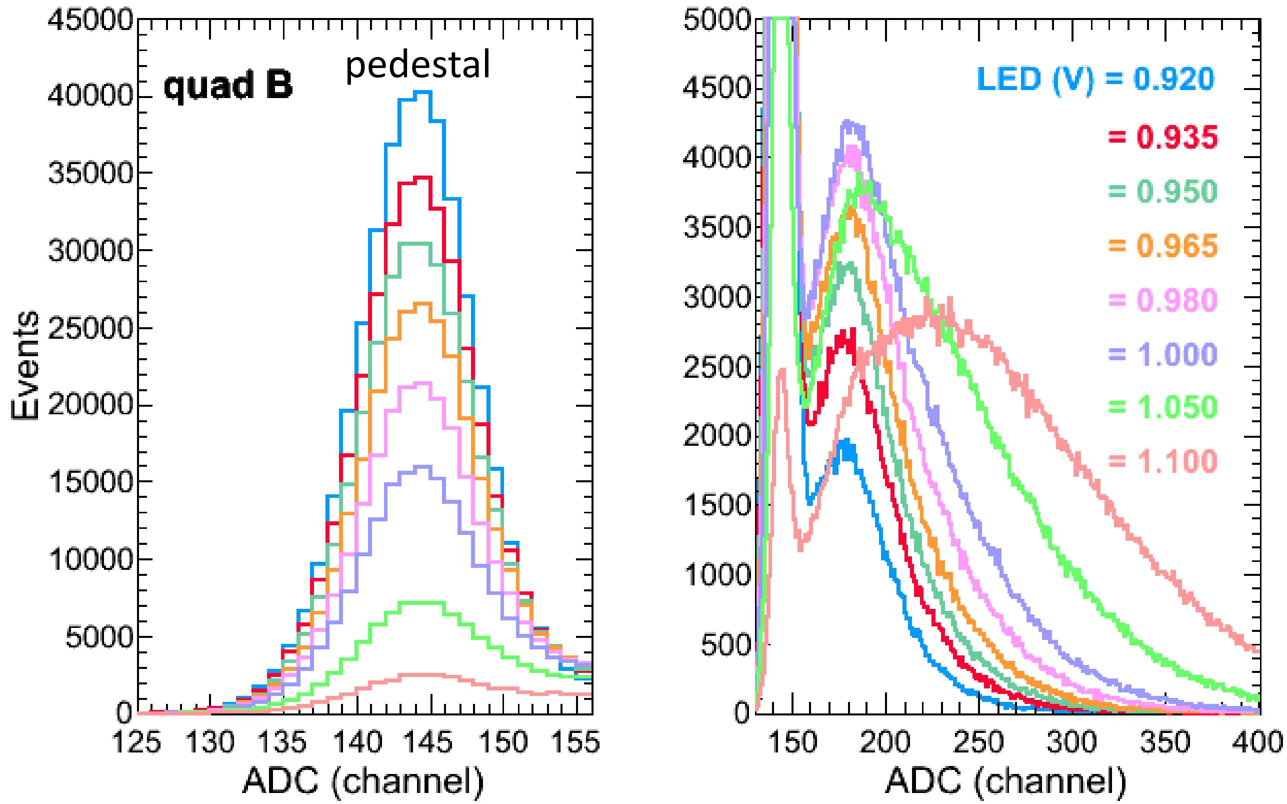


- *Different symbols correspond to different starting values for the fit parameters*
- *Mean: all data points within 3.7 channels from the average*
- *Standard deviation: all data points within 2.2 channels from the average*
- *Resolution of quad A: better than 1 photoelectron*

Quads (sum of pixels) behave just like individual pixels

SPE Measurements: Quad B

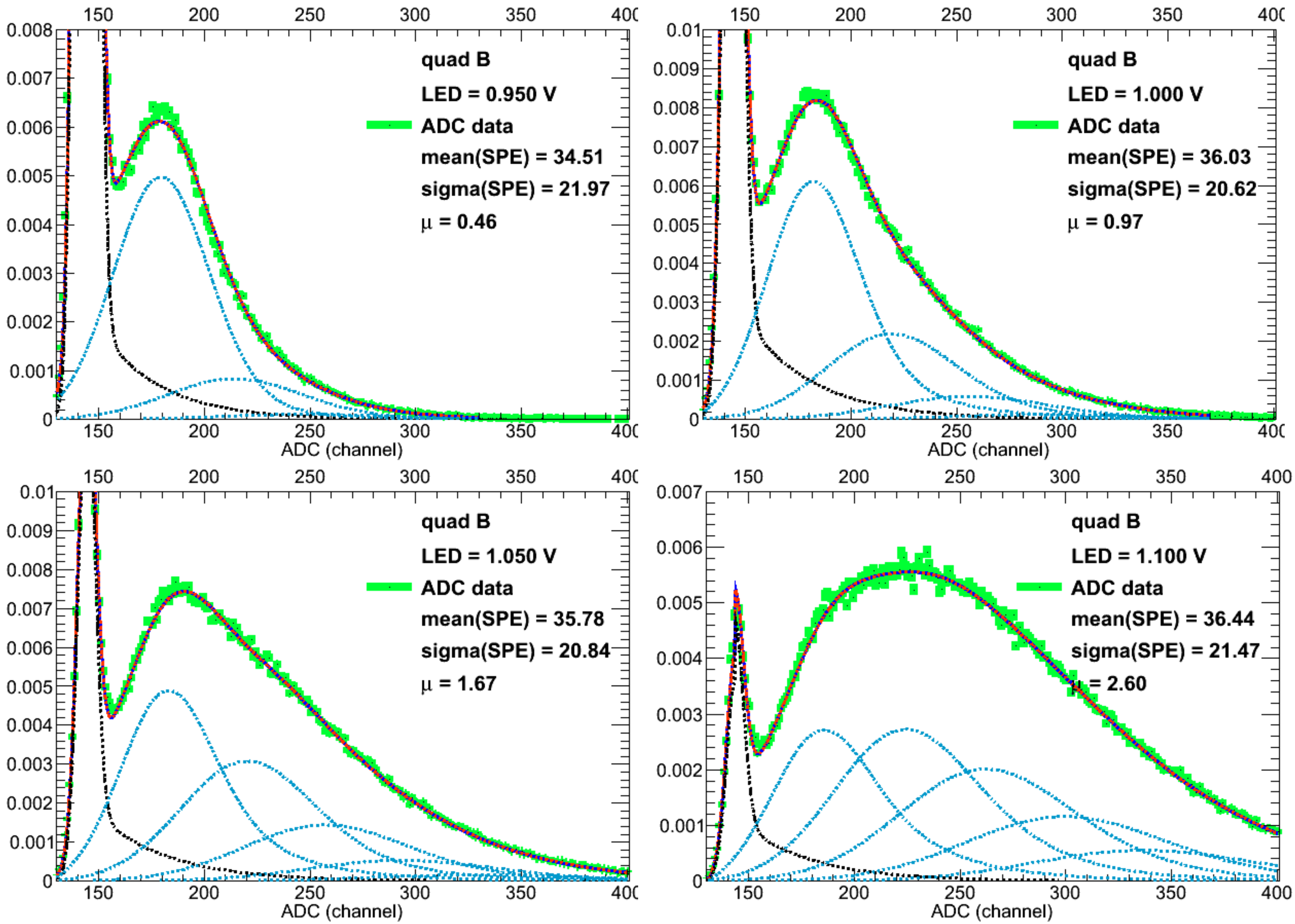
→ The yield of photons produced by the LED has been "chosen" such that the production of single photoelectrons from the PMT photocathode is favored; *by varying the LED voltage in small steps we reveal the quantum nature of the process*



→ We use a well established PMT response function to extract the **mean** (above pedestal) and the **standard deviation** of the SPE distribution

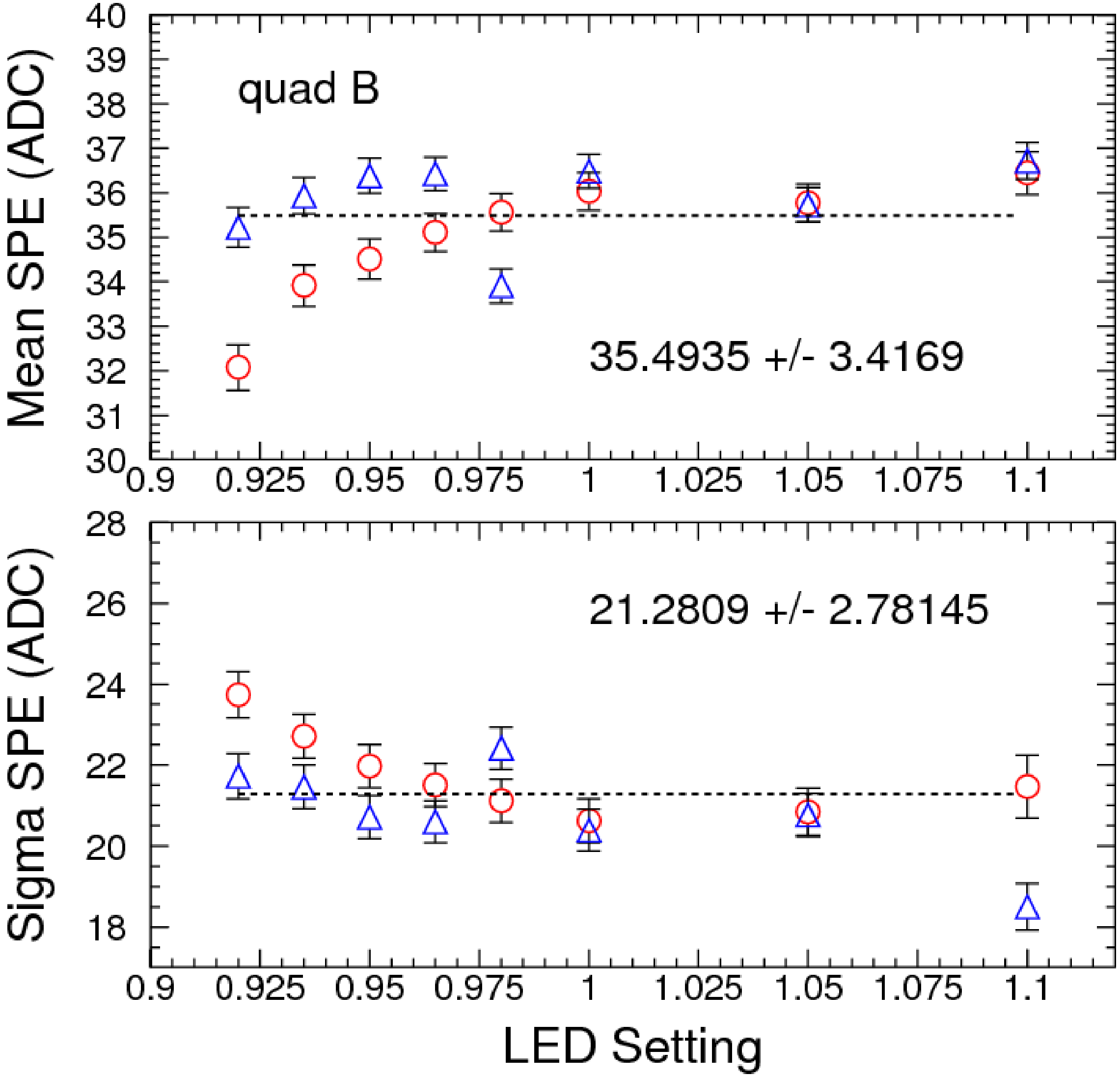
$$S_{real}(x) = \int S_{ideal}(x')B(x-x')\,dx' = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \times \left[(1-w)G_n(x-Q_0) + wI_{G_n \otimes E}(x-Q_0)\right]$$

SPE Measurements: Quad B



SPE Measurements: Quad B

→ **Fit** extraction of the **mean** (measured from pedestal) and the **standard deviation** of the SPE distribution from ADC data corresponding to different LED settings is consistent



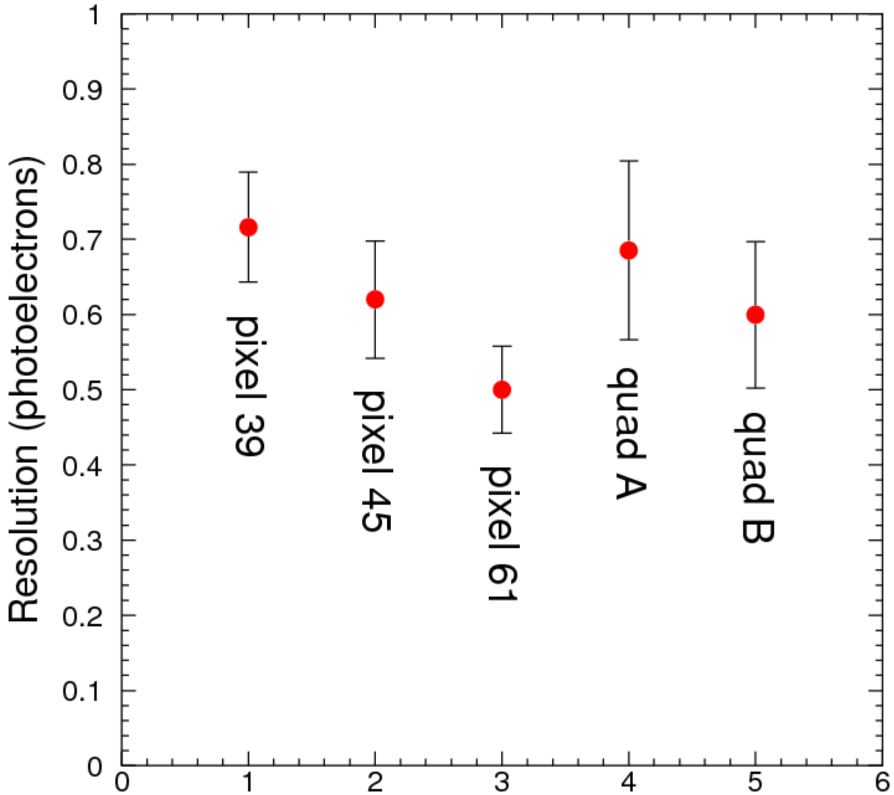
- *Different symbols correspond to different starting values for the fit parameters*
- *Mean: all data points within 3.4 channels from the average*
- *Standard deviation: all data points within 2.8 channels from the average*
- *Resolution of quad B: better than 1 photoelectron*

Quads (sum of pixels) behave just like individual pixels

SPE Measurements: Summary

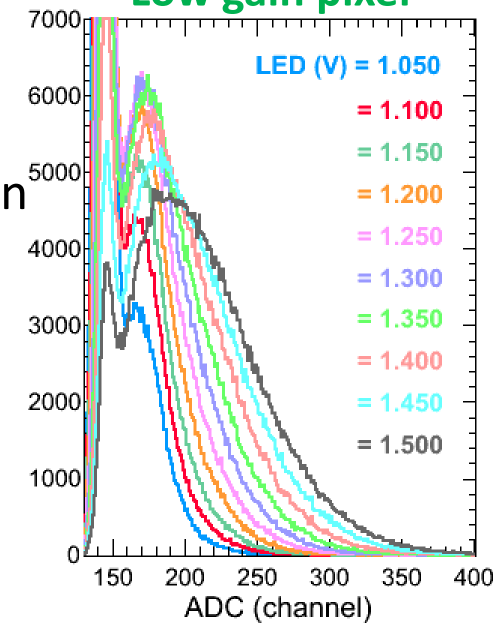
→ H8500C-03: good SPE resolution, better than 1 photoelectron

→ Our measurements follow the trend shown in the Hamamatsu map of pixels gain

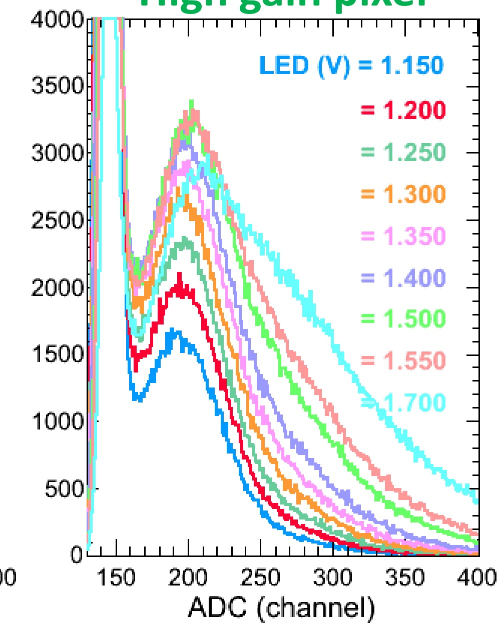


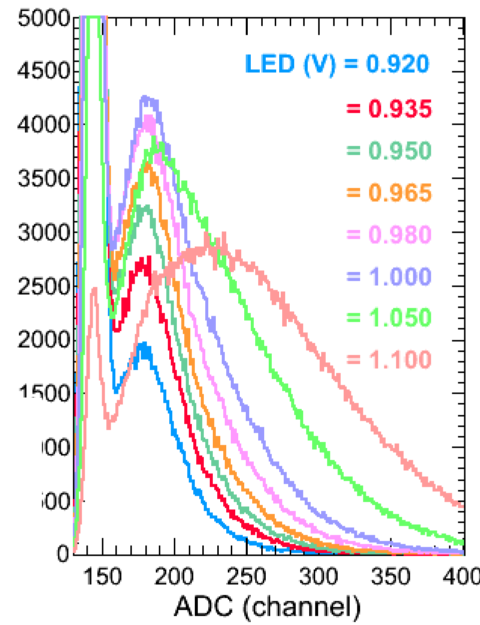
→ Though the quads are superpositions of 16 pixels with possibly different gains, the SPE is still clearly identifiable

Low gain pixel



High gain pixel



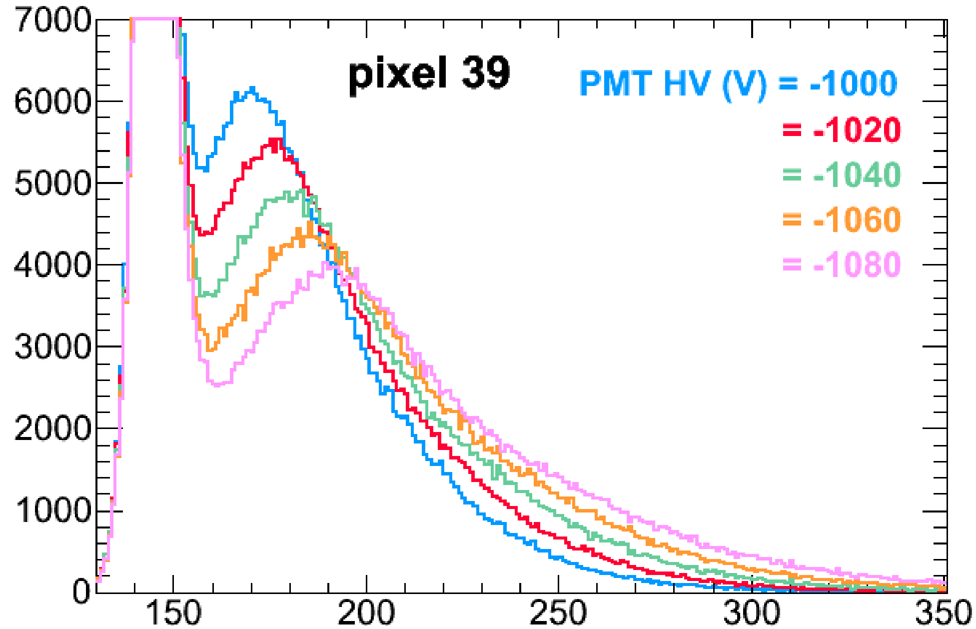


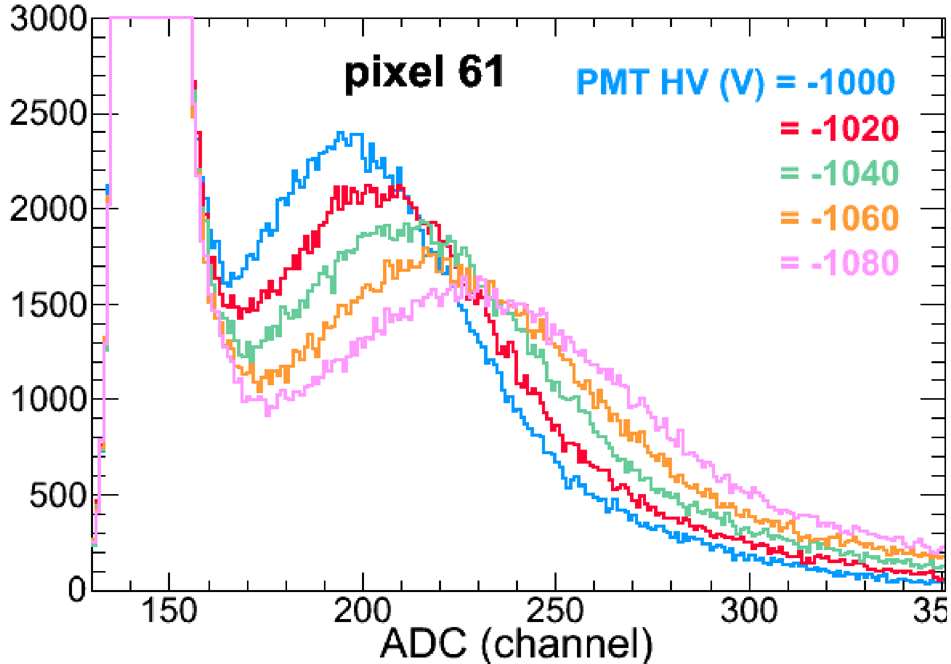
Quad: sum of 16 pixels
SPE clearly identified

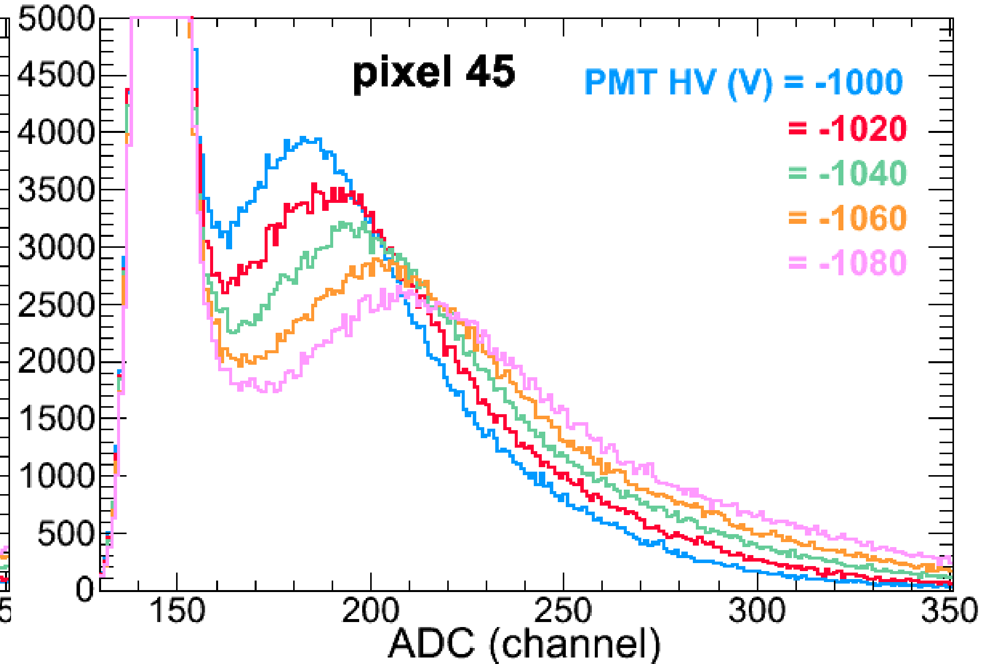
SPE Measurements: PMT High Voltage Scan

→ Keeping constant the yield of photons on pixel (i.e. the LED setting is fixed) we increase the PMT HV – this will boost up the pixels gain

→ The boost in gain with increasing PMT HV is clearly seen in our data for all 3 pixels tested

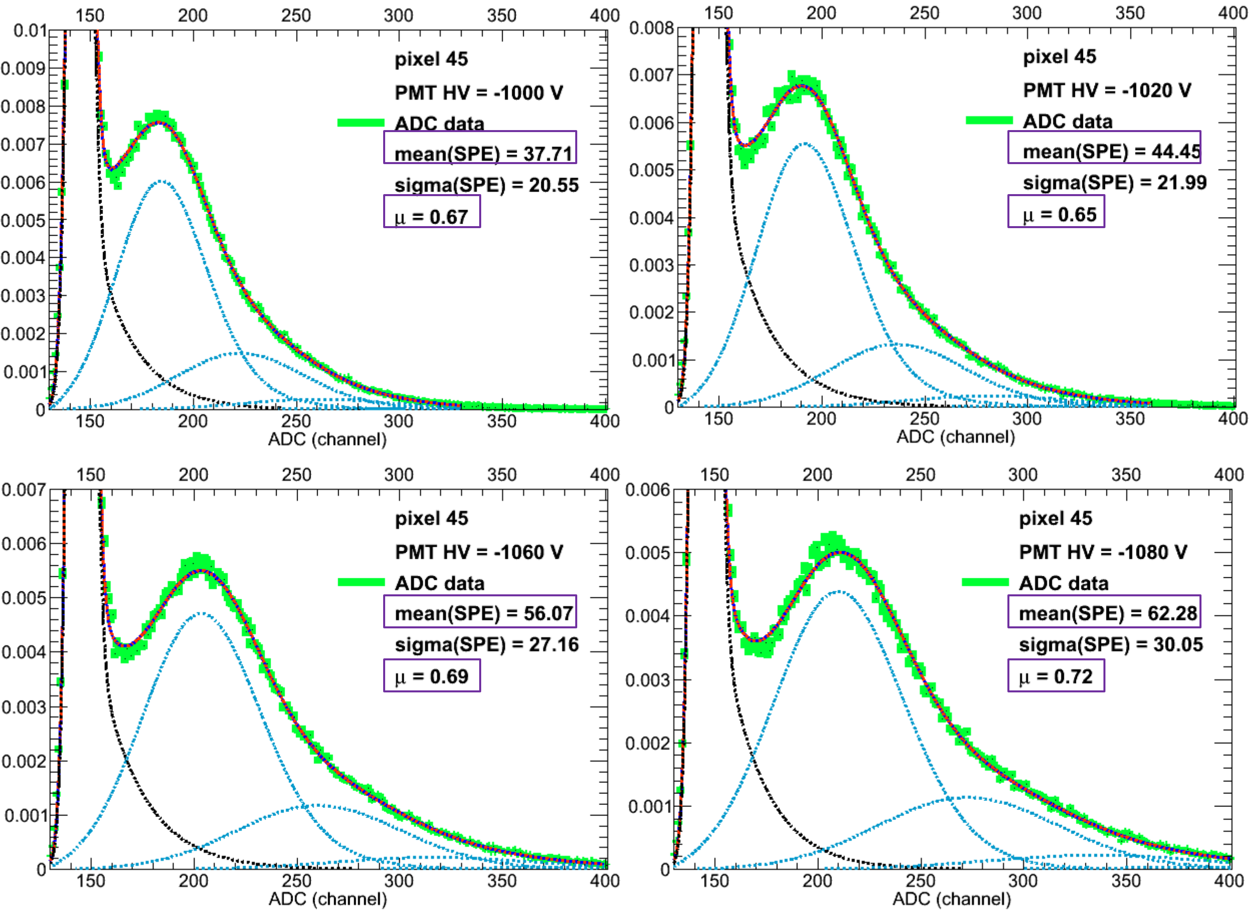






SPE Measurements: PMT High Voltage Scan

Example: Pixel 45



SPE resolution at -1000 V = 0.52

SPE resolution at -1080 V = 0.48

Fit is stable

→ The mean of the Poisson distribution, **μ**, stays the same with increasing PMT HV (as expected given that the yield of photons illuminating the pixel stays the same)

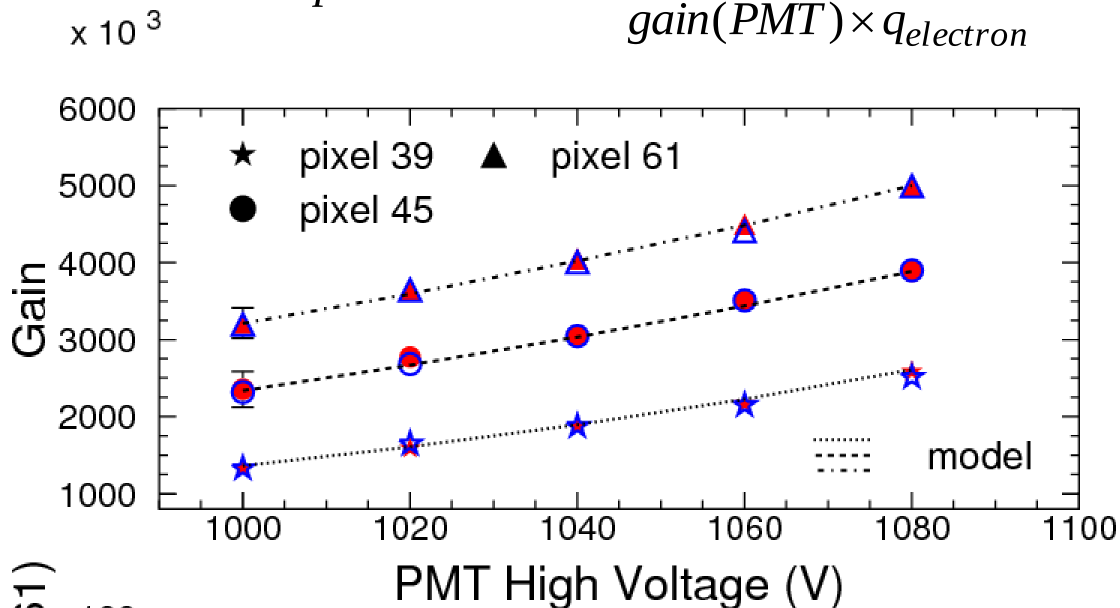
→ The number of channels above the PED corresponding to the SPE signal, **mean(SPE)**, increases with increasing PMT HV, i.e. the pixel gain increases and the SPE resolution gets better

H8500C-03 Gain Extraction from SPE Data

→ We extract the H8500C-03 gain from our SPE measurements

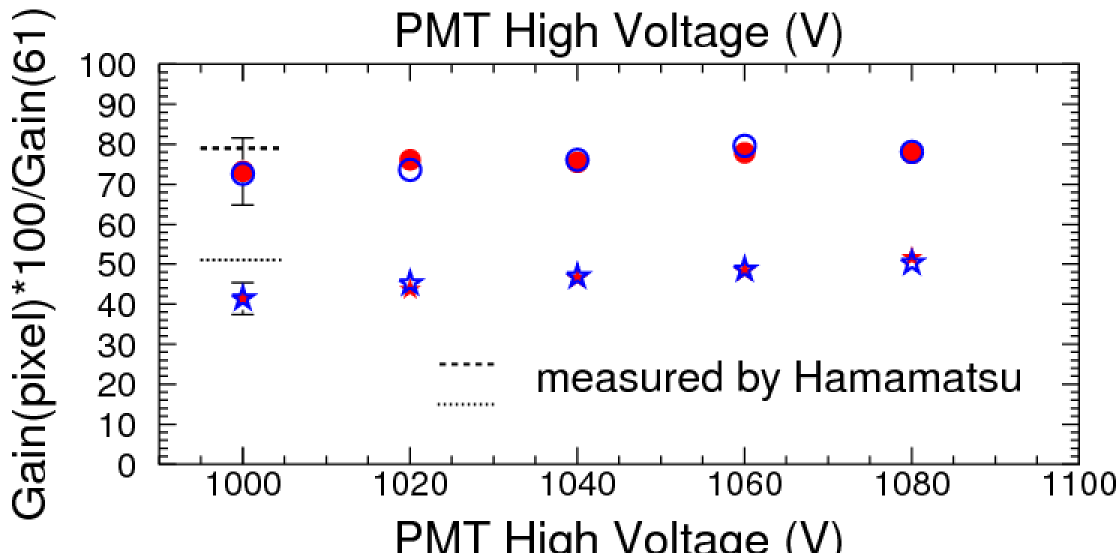
$$1\ photoelectron = \frac{Q_{ADC}}{gain(PMT) \times q_{electron}}$$

$$Q_{ADC} = \frac{Q_{ADC}^{per\_channel} \times mean(SPE)}{amplification}$$



$$\text{gain (model)} = \frac{a^{12}}{13^{k*12}} \times V^{k*12}$$

*We extract coefficients **a** and **k** from data at -1000 and -1080 V*

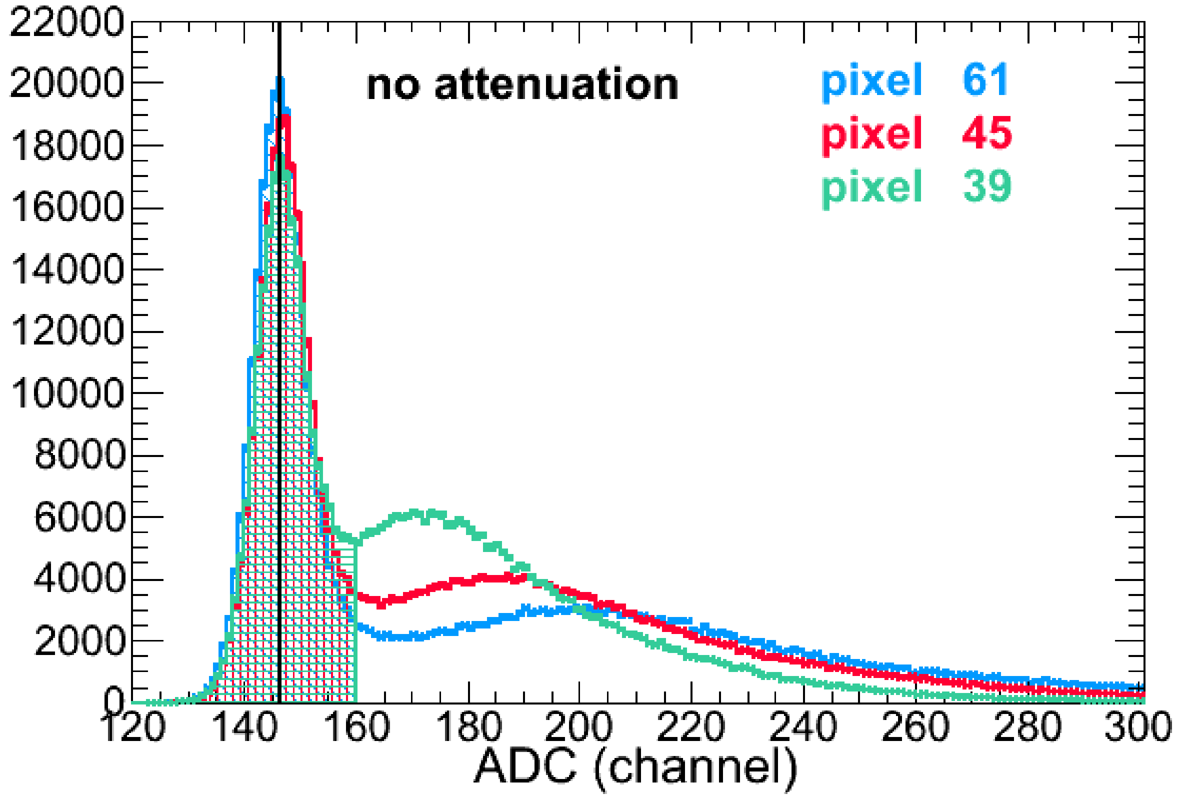


Our measurements of pixel gain variation agree reasonably well with data provided by Hamamatsu (their measurements were done using large yields of photoelectrons)

Pixel Gain Matching

→ It is well established that the gain of pixels within the same PMT can vary by factor of 2 or more

→ Hamamatsu provides a map with pixel to pixel gain variation

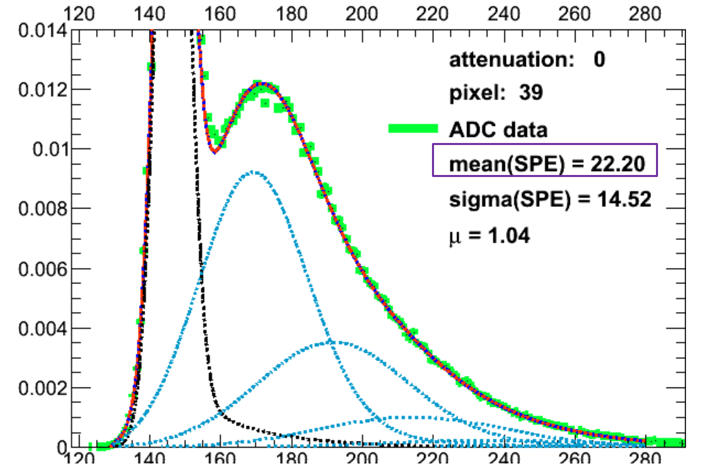


→ We have shown that even for sum of pixels (quads) reasonable SPE resolution can be achieved

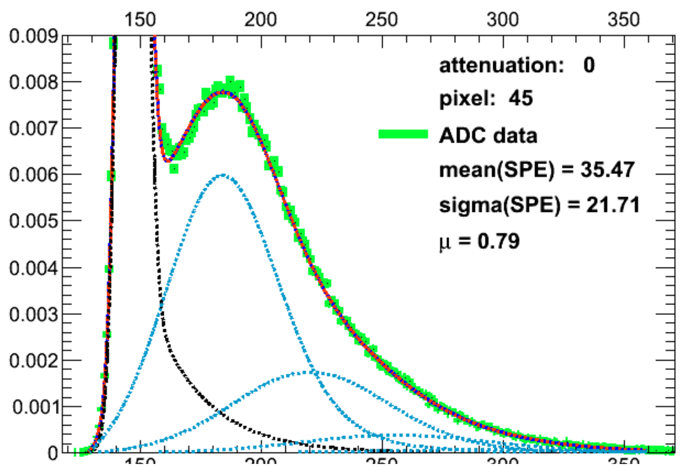
→ However, if better resolution would be needed matching the gain of all pixels to the lowest output pixel could be the solution

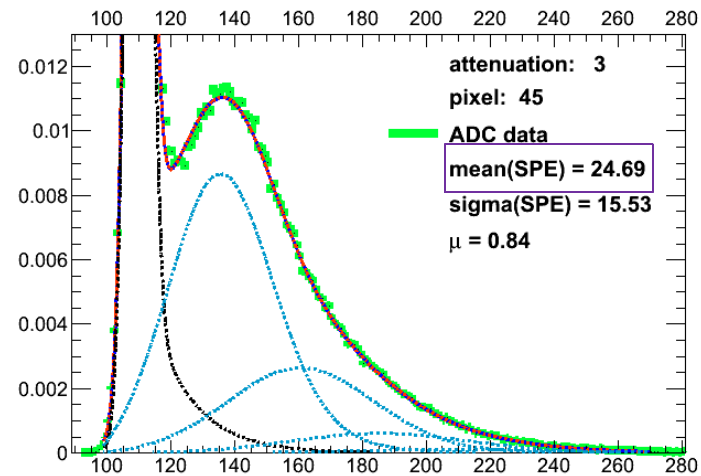
Pixel Gain Matching

→ We used a rotary attenuator to normalize the output of the pixels with higher gains, 45 and 61, to the pixel with lowest gain, pixel 39

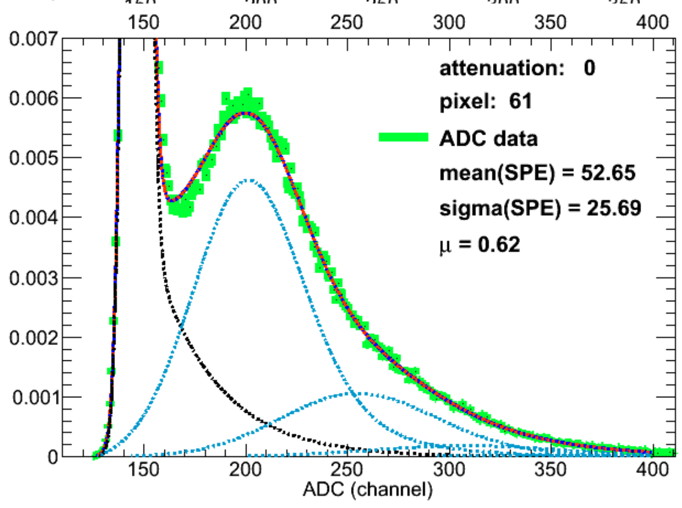


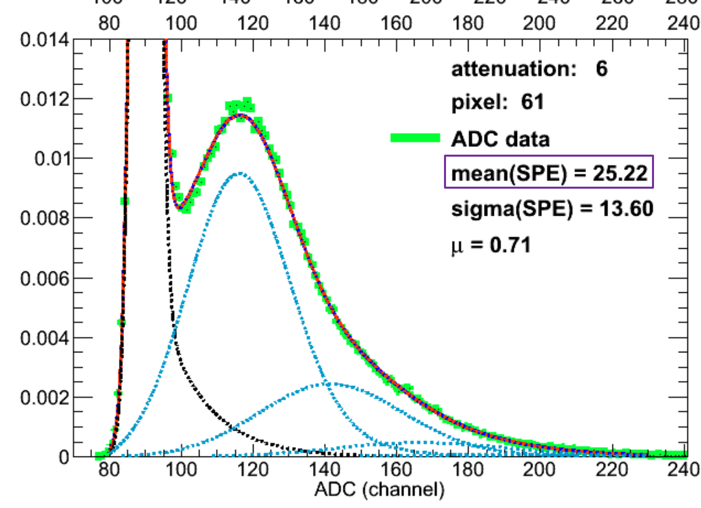
Output from pixel 45 is attenuated by 3 dB



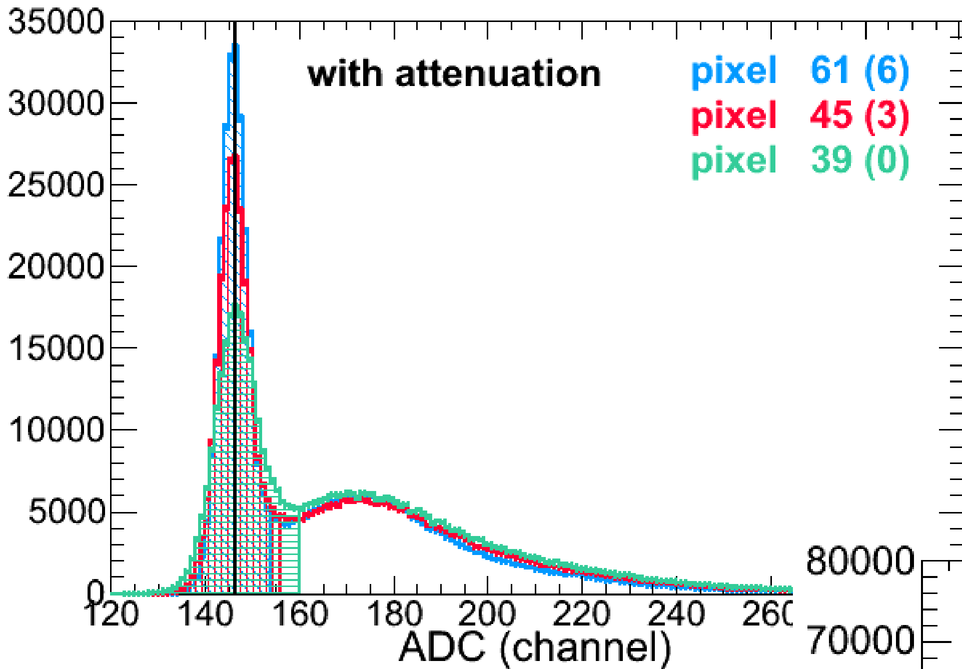


Output from pixel 61 is attenuated by 6 dB



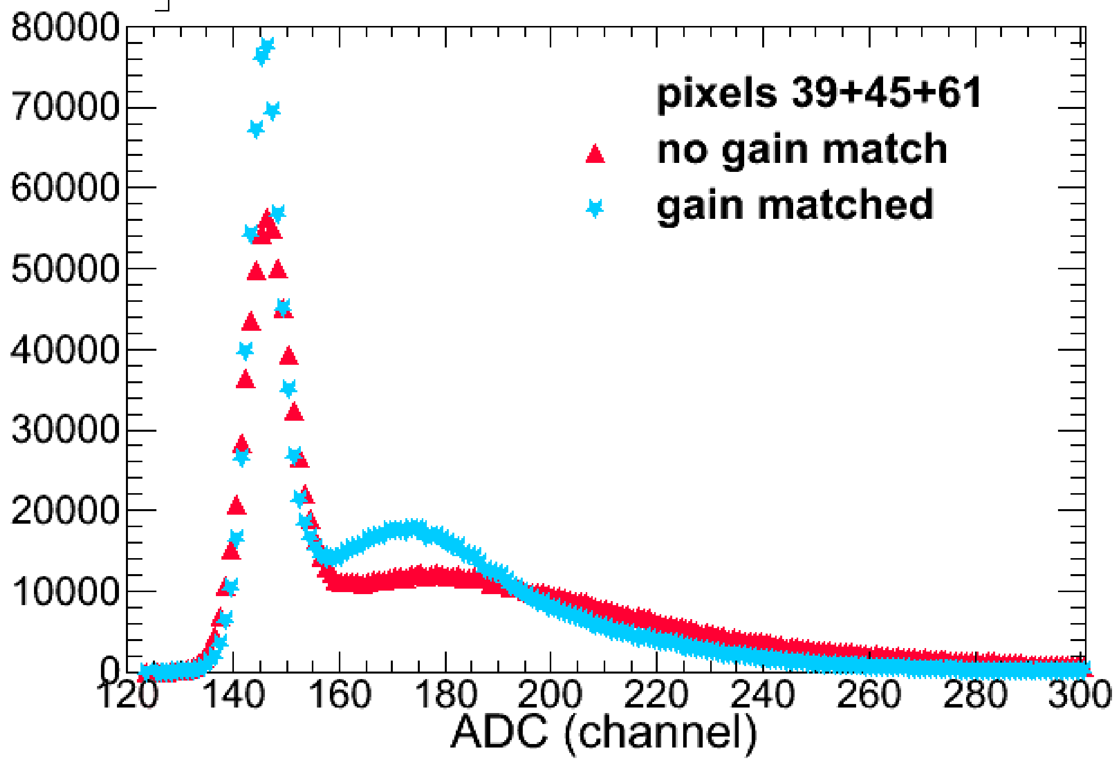


Pixel Gain Matching



→ After signal attenuation of higher gain pixels, the charge corresponding to the SPE as recorded by the ADC is ~ the same for all 3 pixels (clearly seen in the ADC distributions)

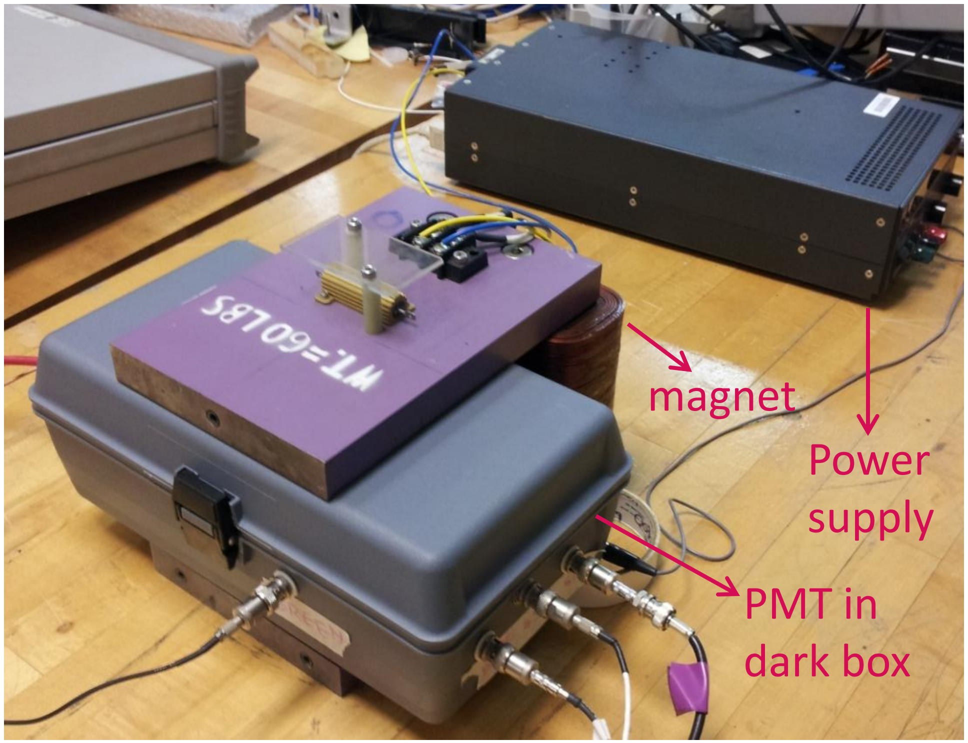
→ The effect of gain matching is a more pronounced SPE peak in the ADC distribution

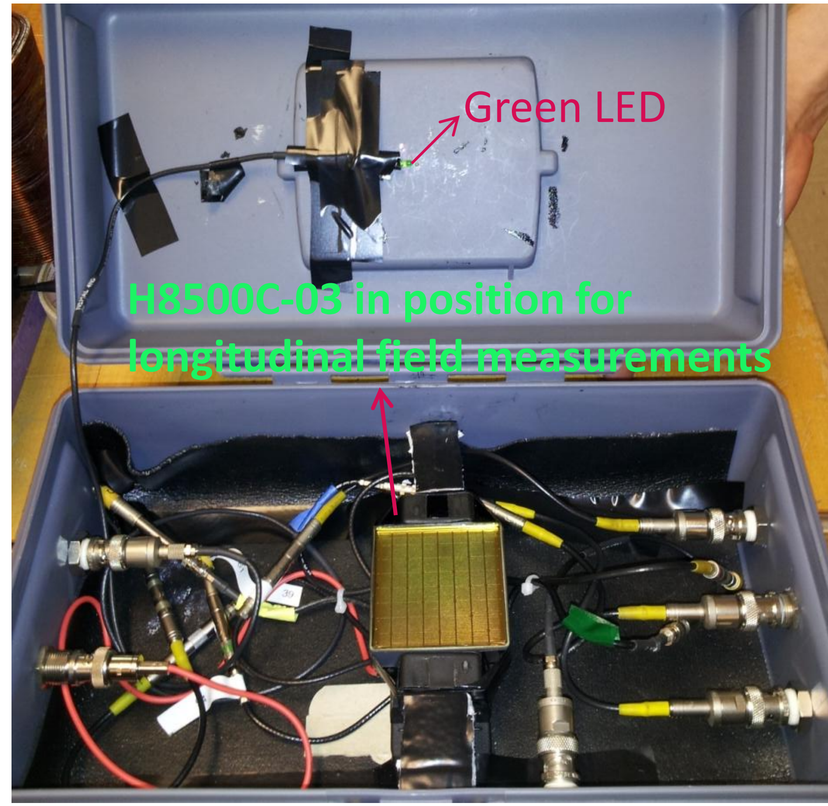


Magnetic Field Measurements
(a sub-set of data)

Experimental Setup

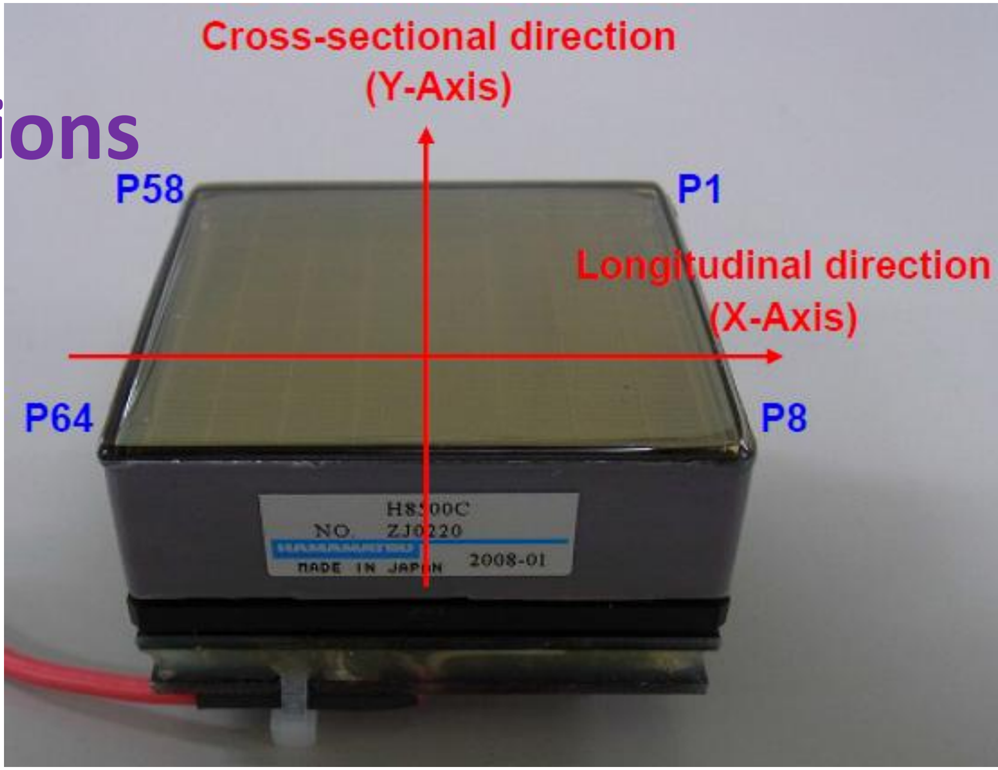
→ **We quantified the response to magnetic field of 1 central pixel (45), 1 edge pixel (61) and 2 groups of 16 pixels (2 quads)**





→ **We paid special attention to the PMT orientation w.r.t. the direction of the magnetic field: we surveyed the PMT tilt angle w.r.t. the longitudinal and transverse field orientations and ensured that we measure the PMT response to purely transverse/longitudinal fields**

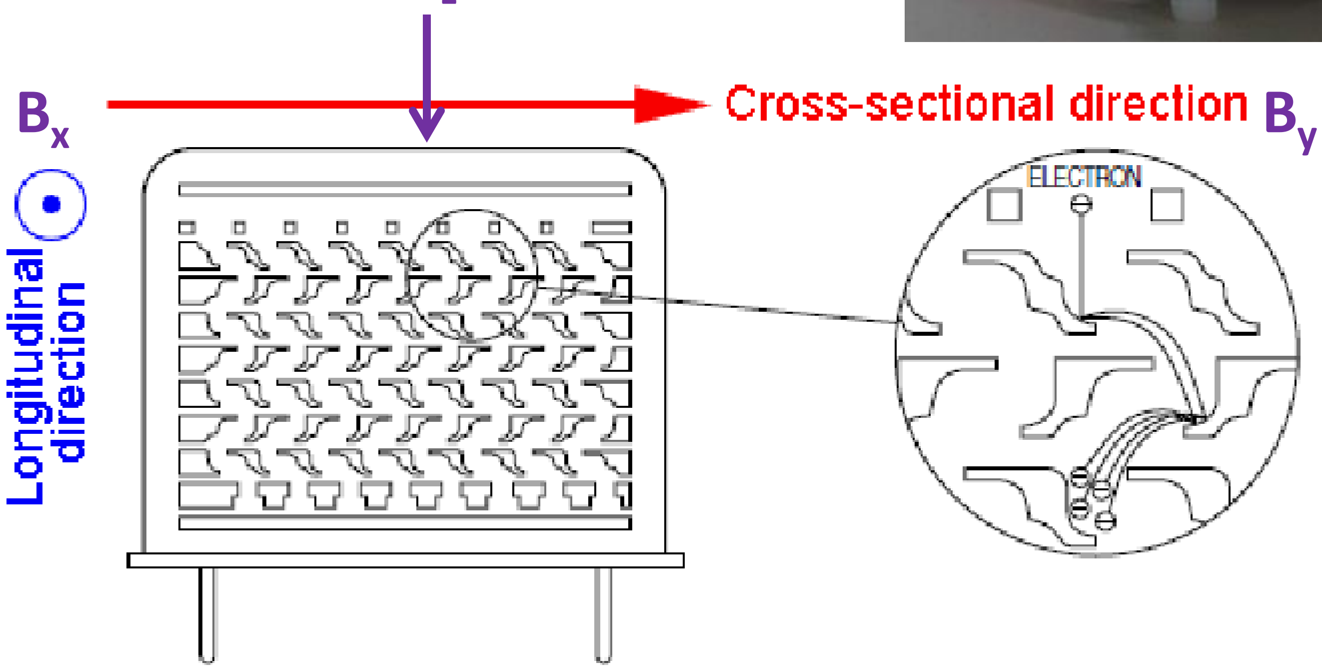
Experimental Setup: Magnetic Field Orientations



→We use the same convention as Hamamatsu to label different field orientations:

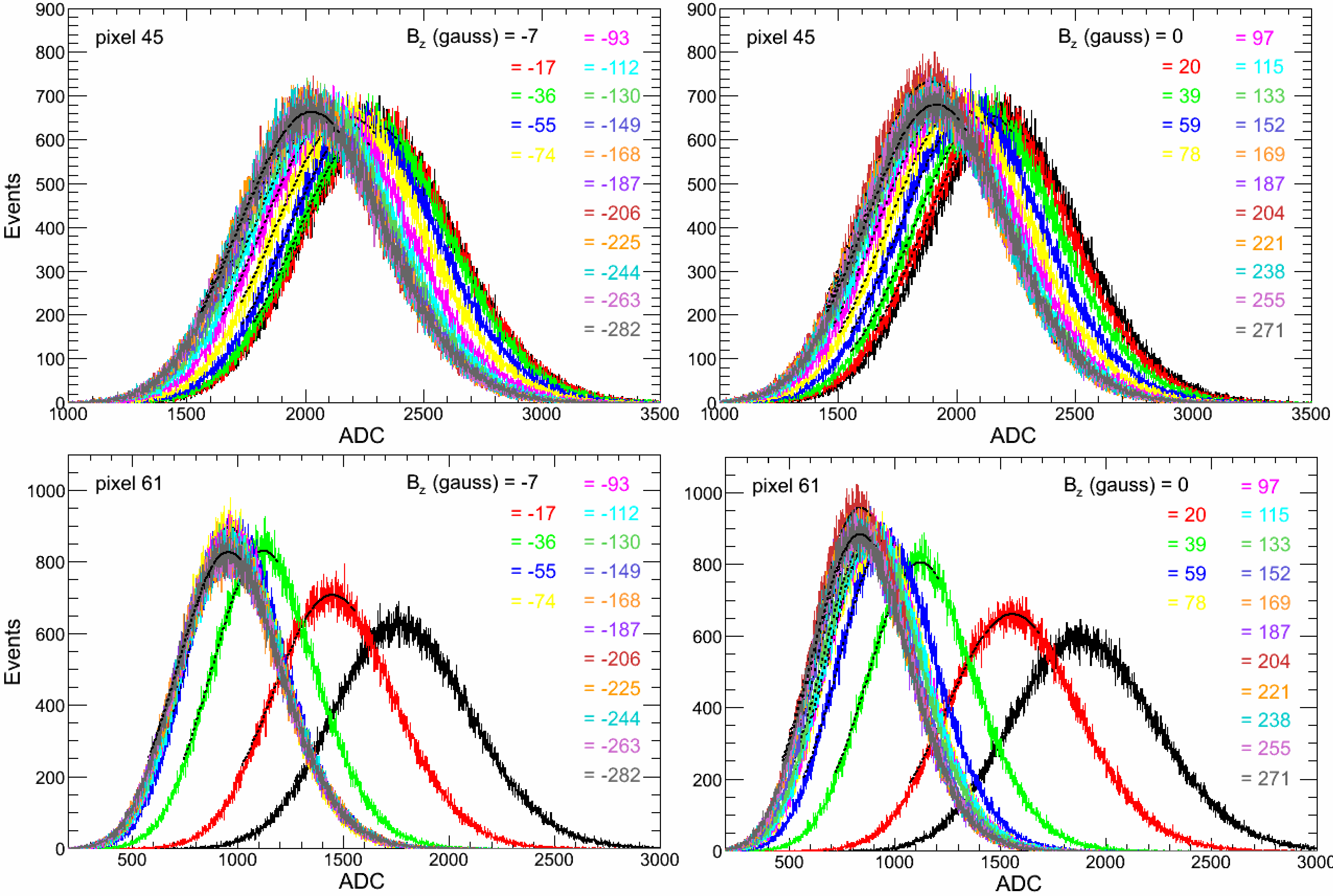
B_z – perpendicular to the face of the PMT – longitudinal field

B_x and By – perpendicular to the sides – transverse field

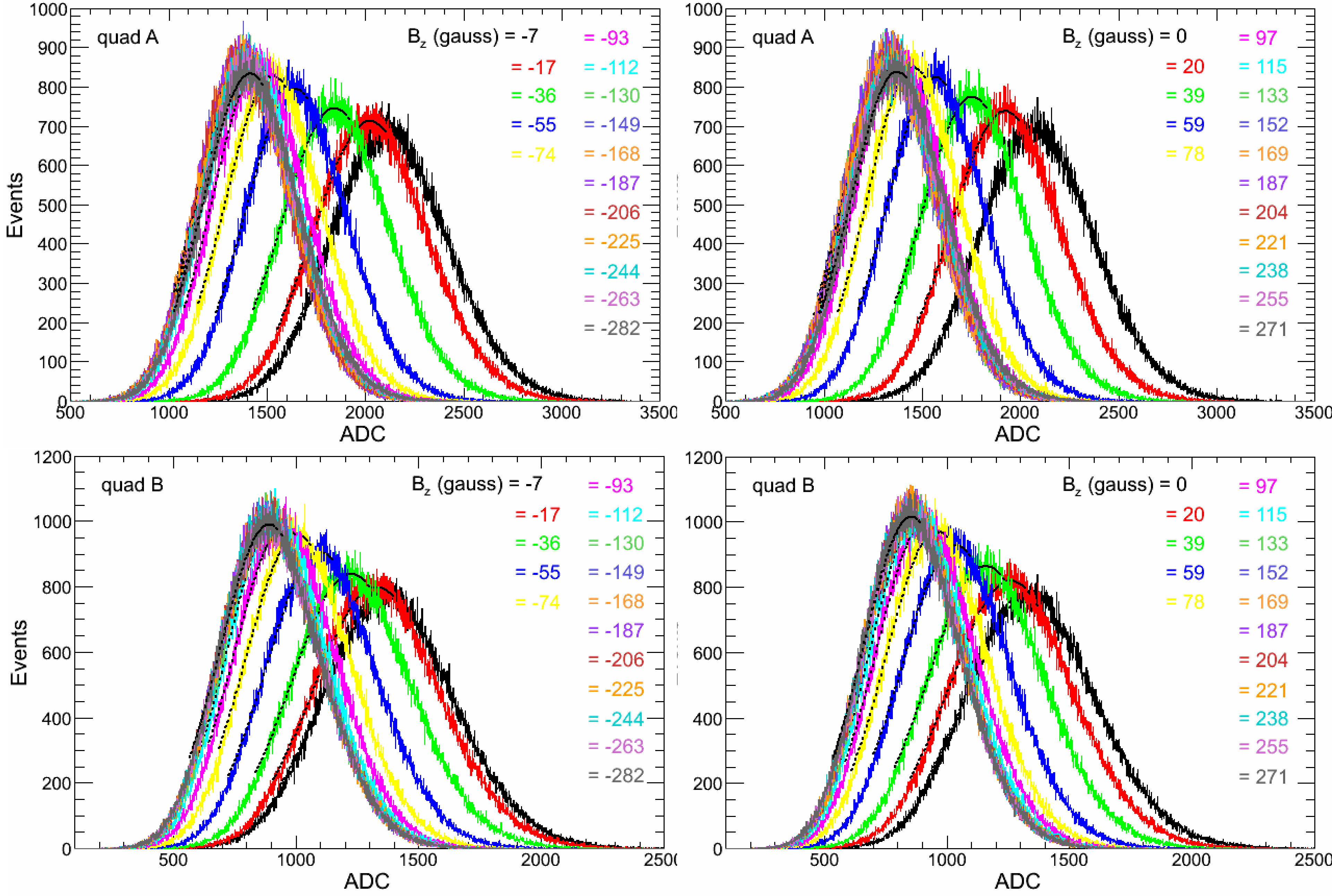


Pictures from Hamamatsu: thanks to Ardavan Ghassemi

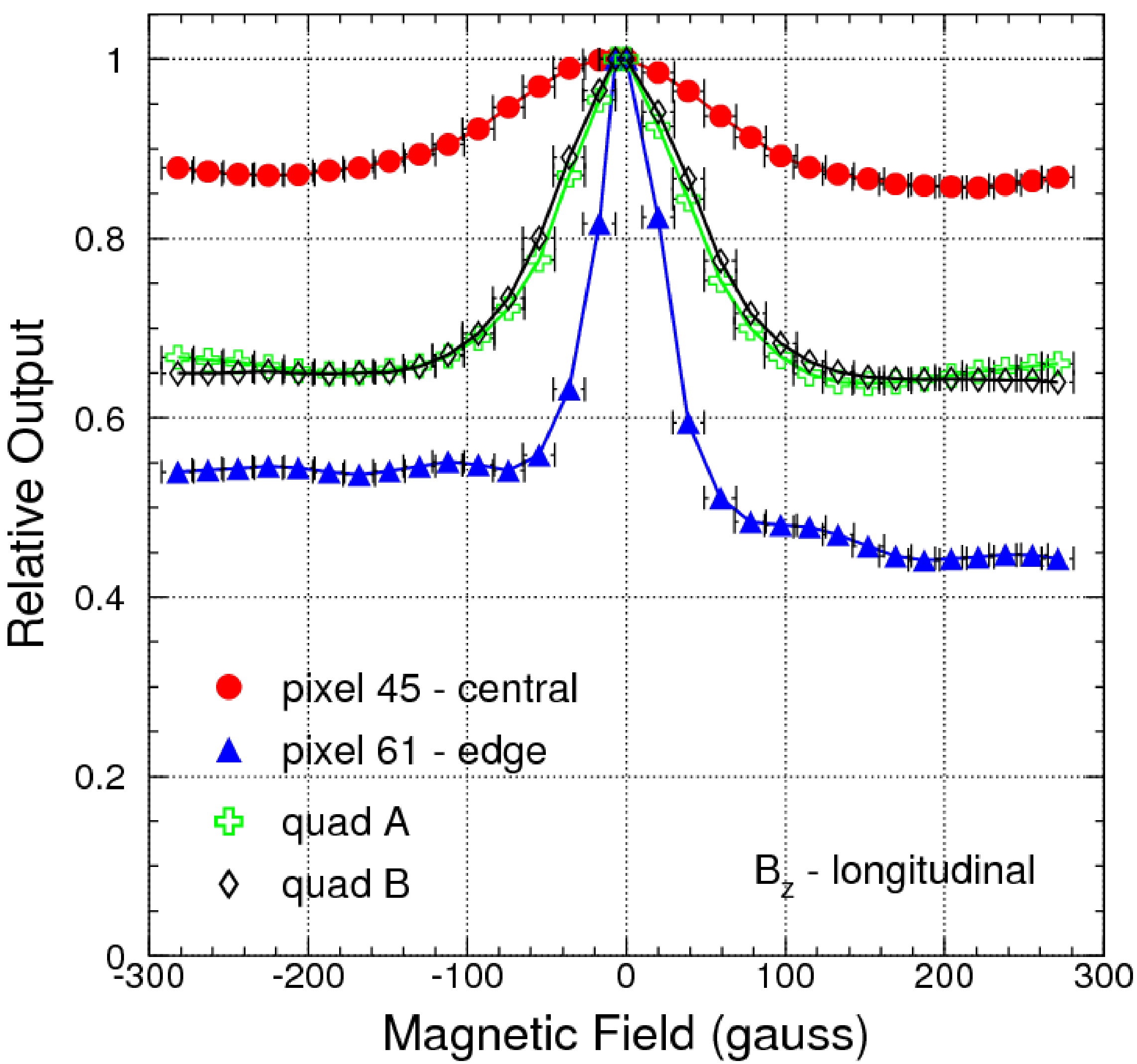
H8500C-03 response to longitudinal B_z field: Pixels



H8500C-03 response to longitudinal B_z field: Quads



H8500C-03 response to longitudinal B_z field: Summary



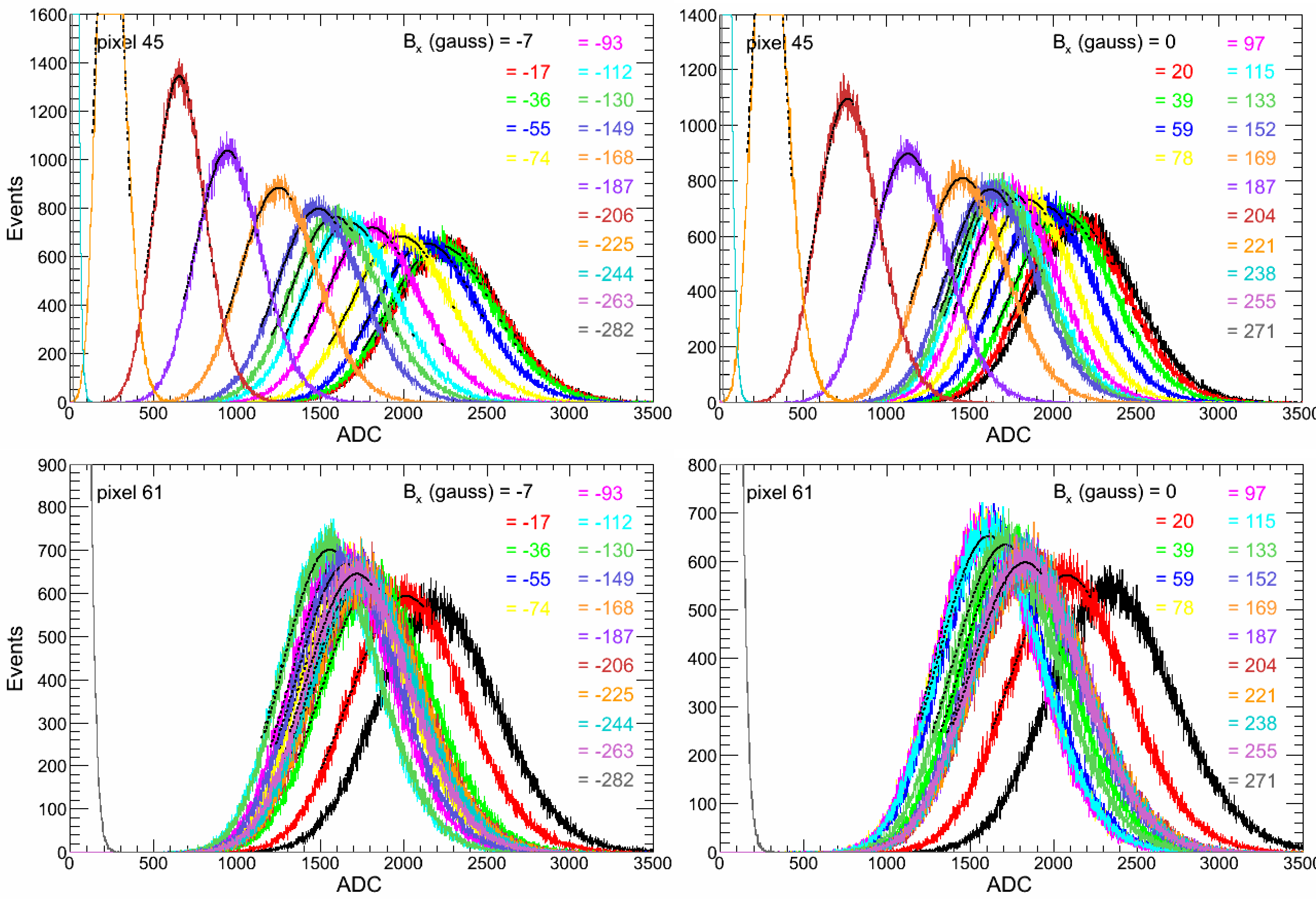
→ "Relative output" represents the mean of the ADC distribution at a given field value normalized to the mean of the ADC distribution at "zero" field value

→ The yield of photoelectrons at "zero" field value is ~ 40-50

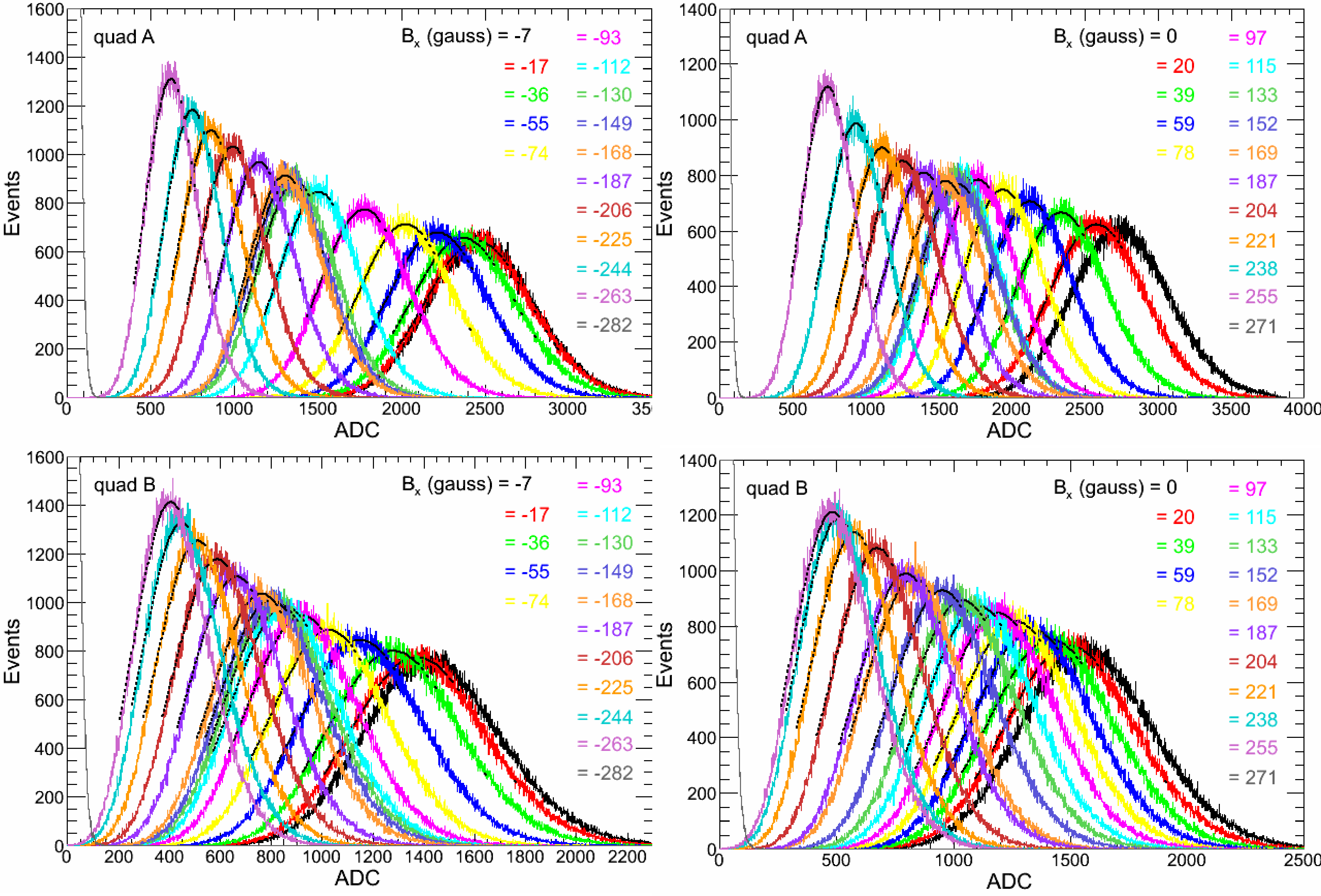
→ Edge pixel experience a greater loss in field than central pixel while quads (sum of pixels) are somewhere in between

→ There is a pronounced drop with field of the relative output up to ~80 gauss; beyond that loss of signal remains constant up to 300 gauss

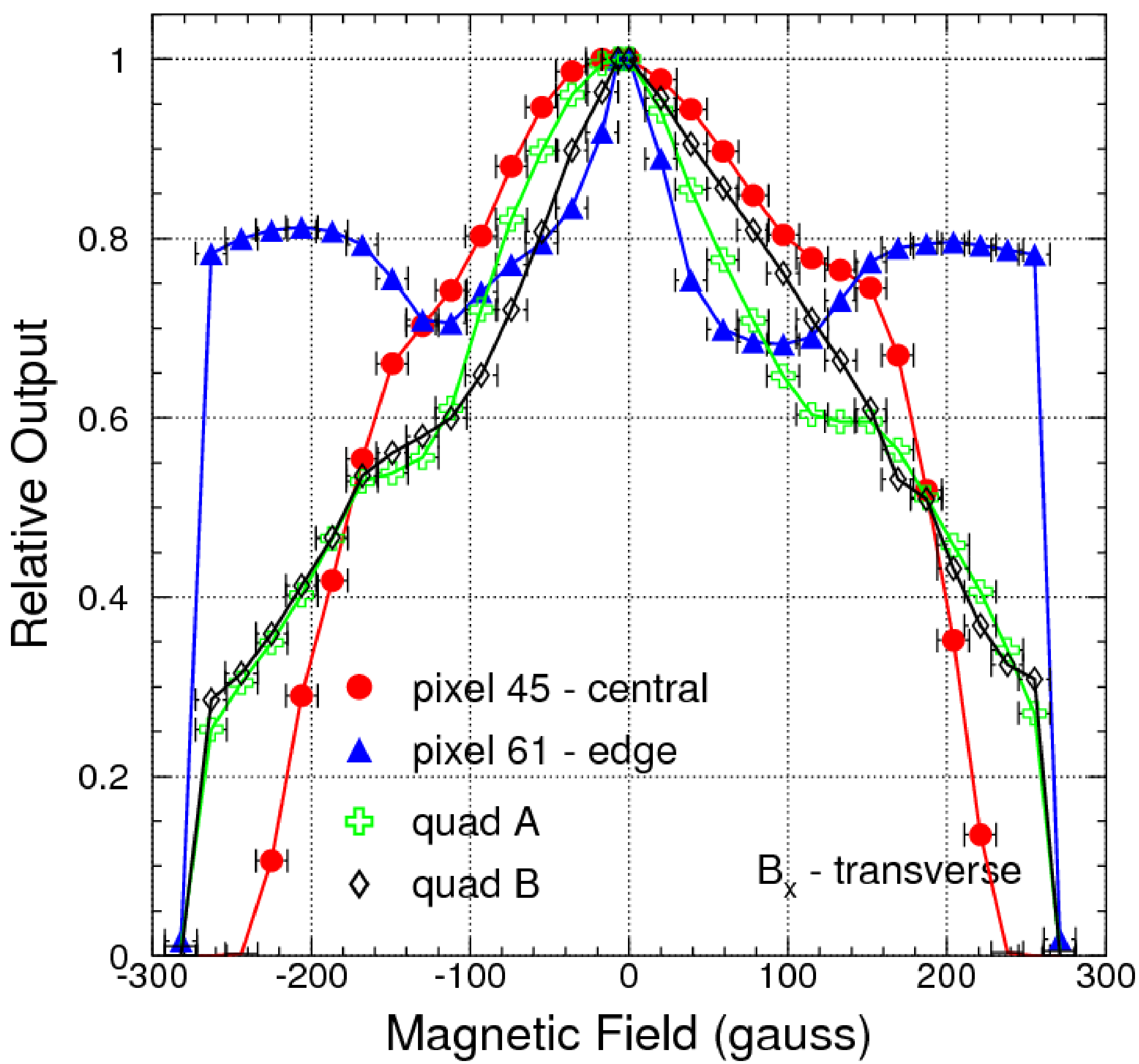
H8500C-03 response to transverse B_x field: Pixels



H8500C-03 response to transverse B_x field: Quads

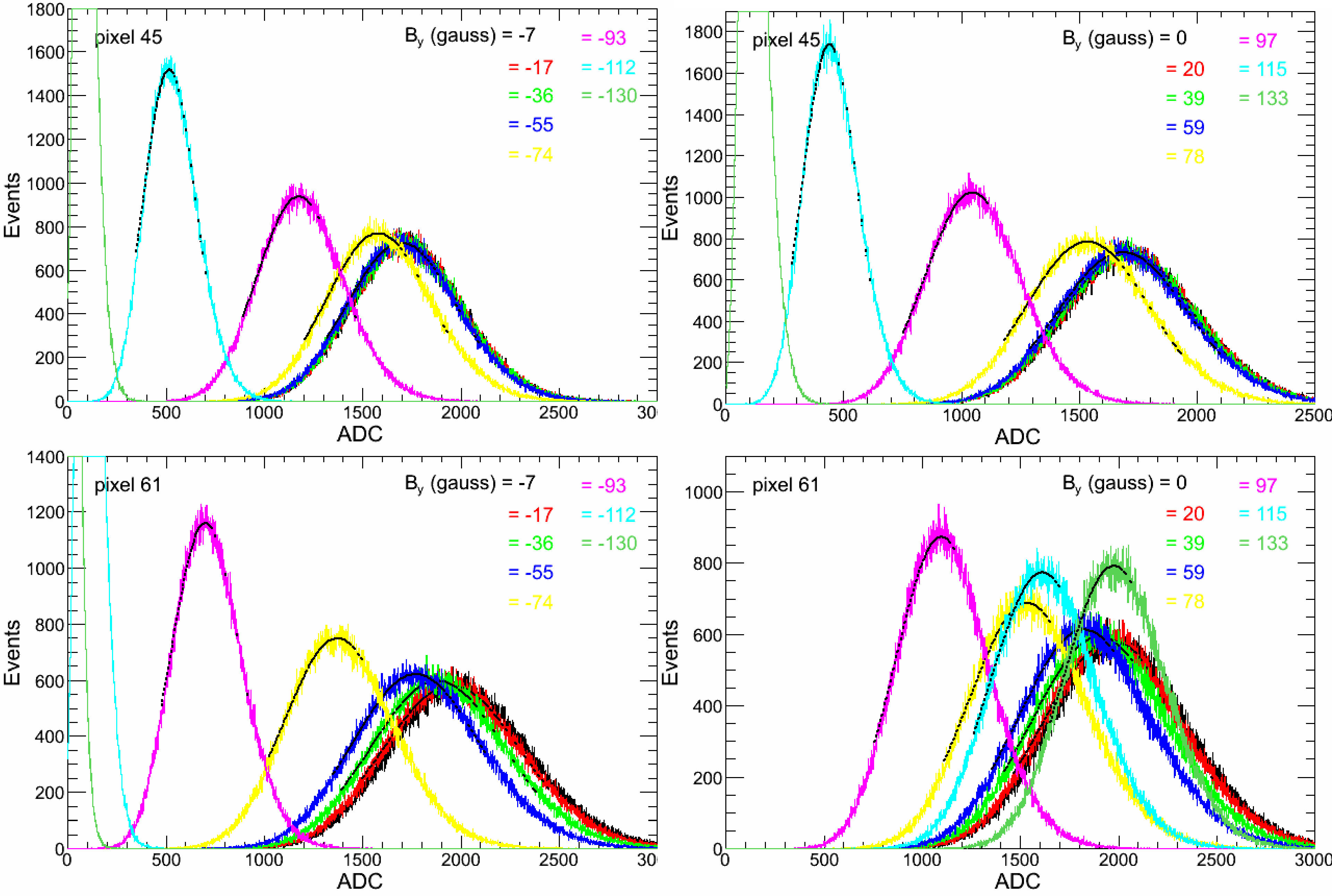


H8500C-03 response to transverse B_x field: Summary

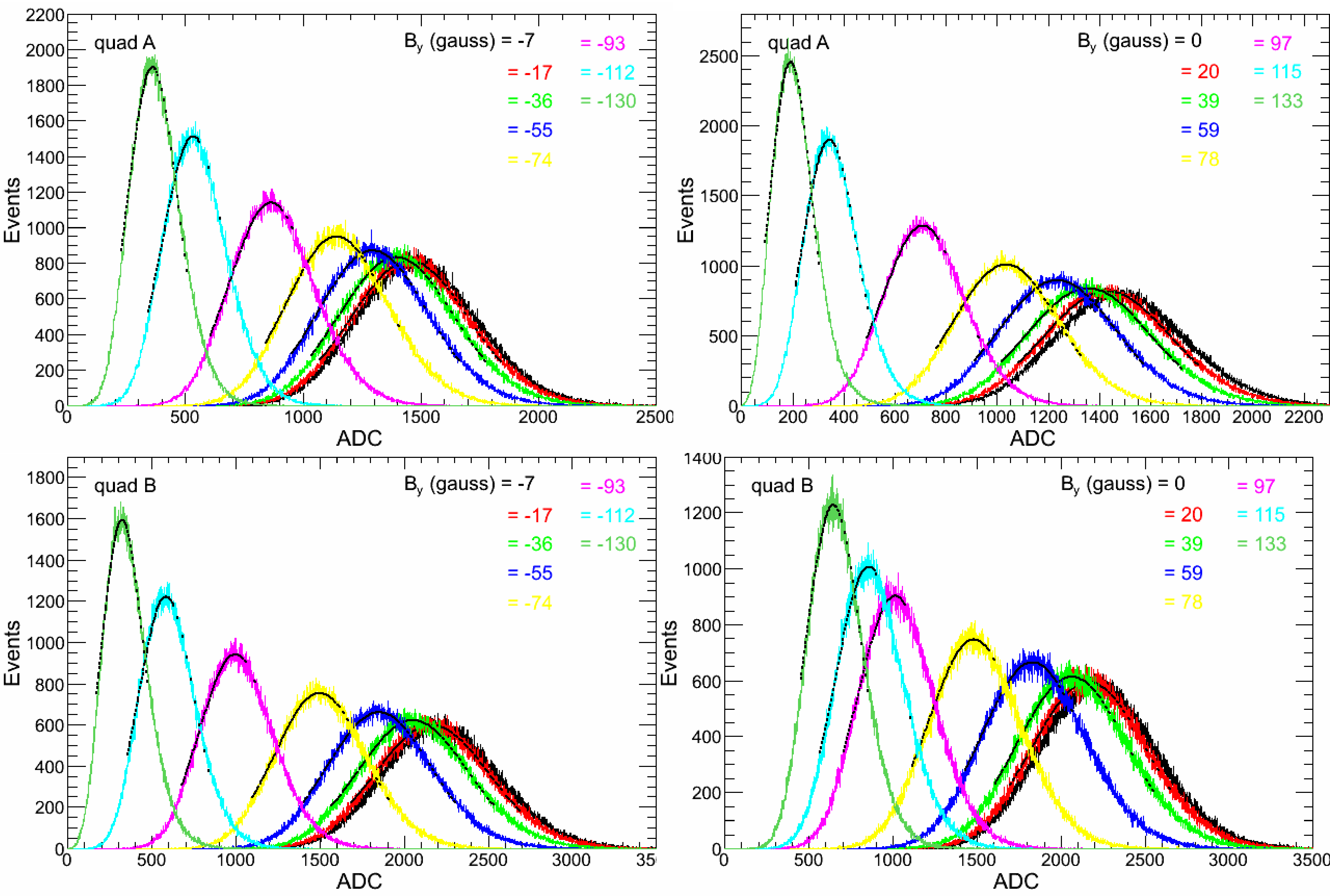


- → "Relative output" represents the mean of the ADC distribution at a given field value normalized to the mean of the ADC distribution at "zero" field value
- → The yield of photoelectrons at "zero" field value is ~ 40-50
- → Edge pixel behave … strange
- → There is a pronounced drop with field of the relative output all the way up to 300 gauss

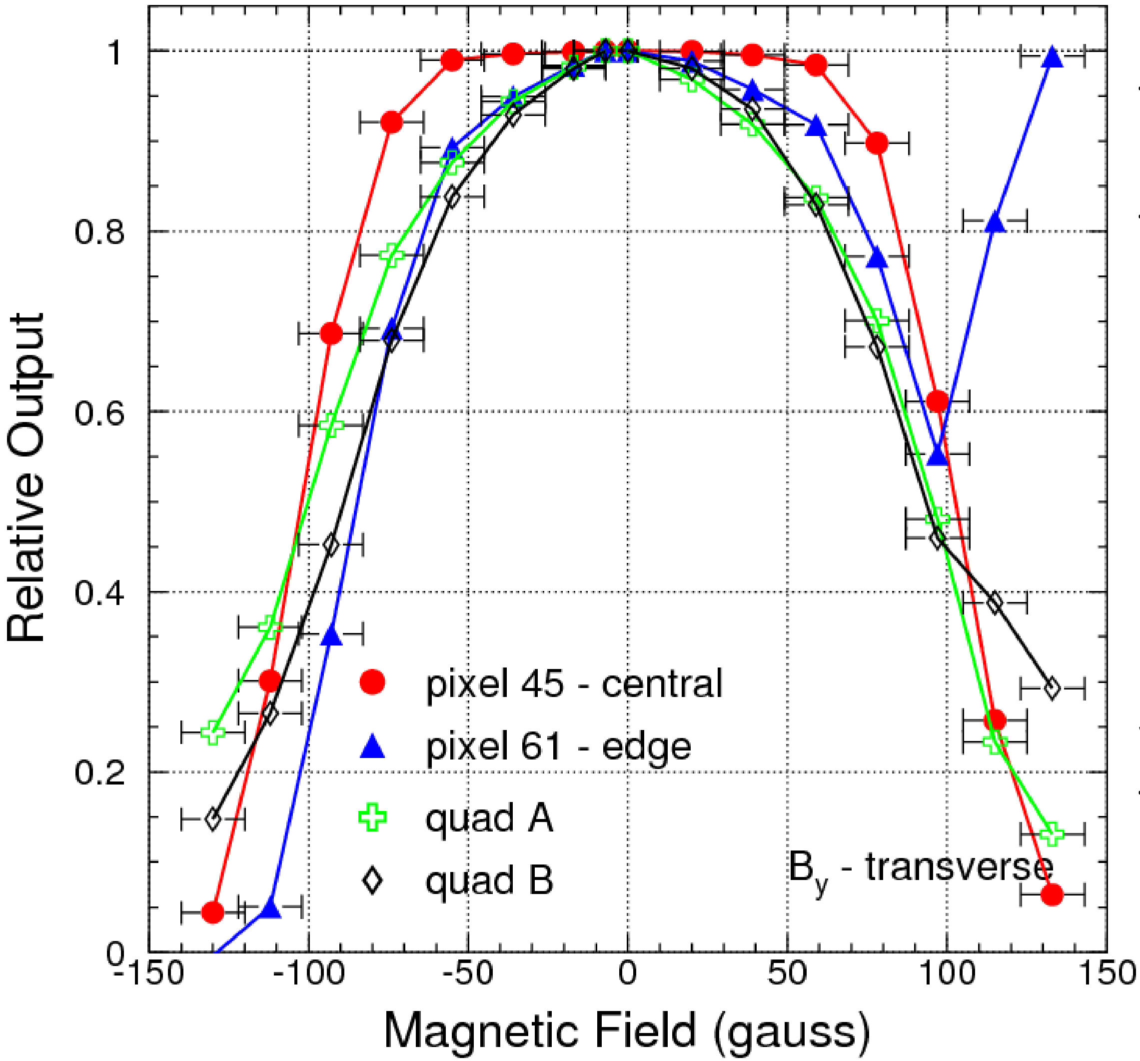
H8500C-03 response to transverse B_y field: Pixels



H8500C-03 response to transverse B_y field: Pixels



H8500C-03 response to transverse B_y field: Summary



→ "Relative output" represents the mean of the ADC distribution at a given field value normalized to the mean of the ADC distribution at "zero" field value

→ The yield of photoelectrons at "zero" field value is ~ 40-50

→ Edge pixel behave … strange

→ There is a pronounced drop with field of the relative output all the way up to 300 gauss