RICH Detector for SIDIS

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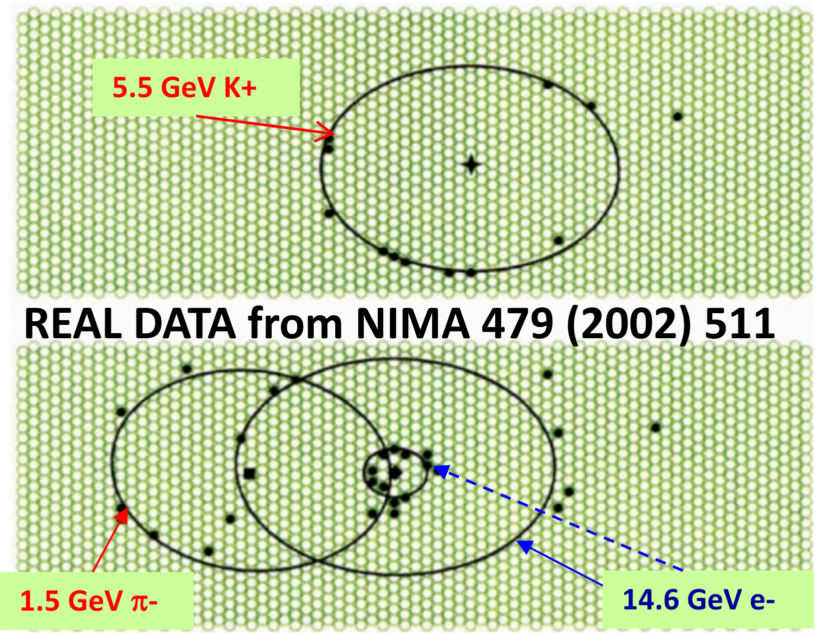
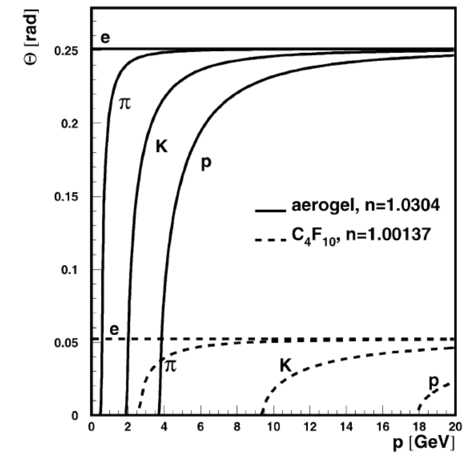
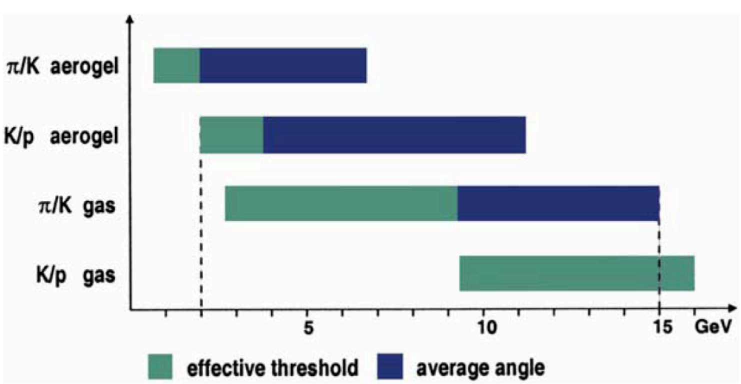
SBS Summer Collaboration Meeting 2020

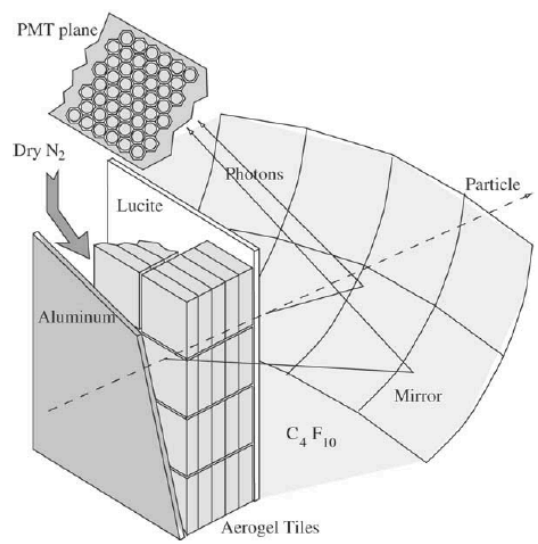
The HERMES RICH detector

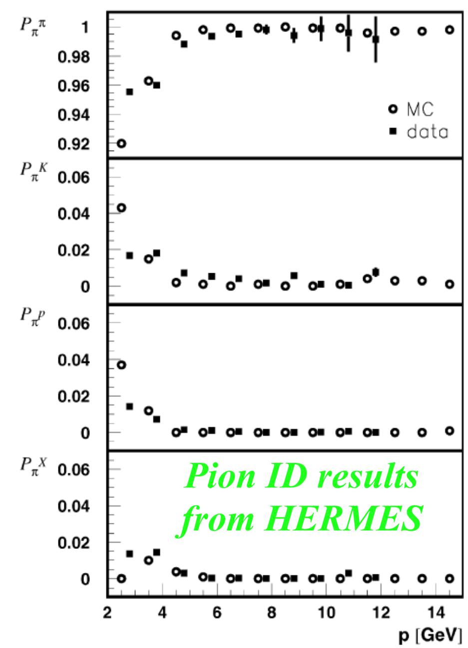


- ***HERMES RICH geometry, performance characteristics well matched to SBS needs.***
- π/K/p separation for p from 2-15 GeV based on dual-radiator design.
- Re-use one half of detector, both aerogels

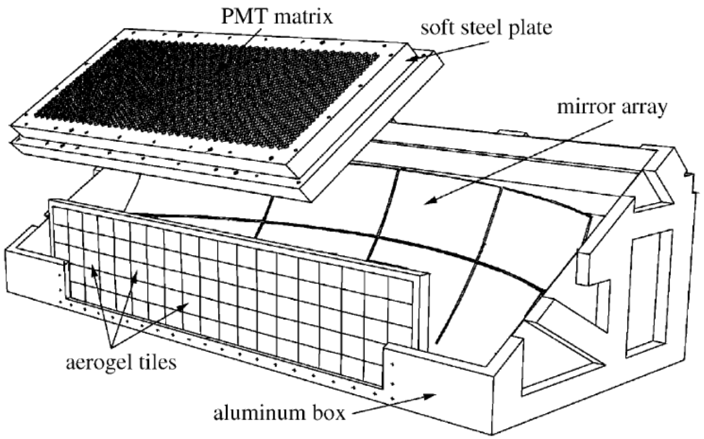


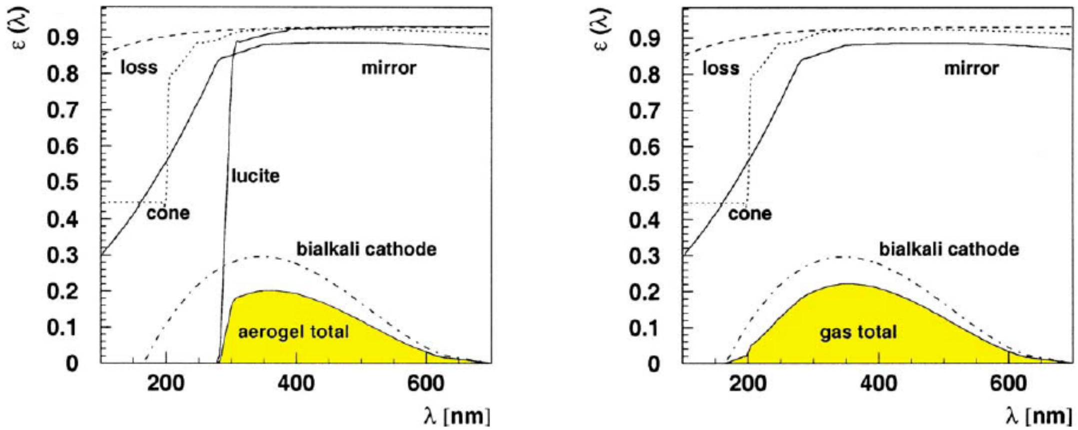






HERMES RICH Design Aspects





Optical properties contributing to overall detection efficiency

- Aerogel wall: tiles 11.4 x 11.4 x 1.13 cm^3, stacked in 5 rows, 17 columns, 5 tiles deep.
- Sheets of Tedlar between tiles reduce distortion from photons crossing stack boundaries
- UVT-lucite window protects aerogel from C_4F_{10} and absorbs UV photons $\lambda < 300$ nm (Rayleigh scattering dominates at UV wavelengths)
- Windows:
    - Entry: 1 mm-thick Al, dimensions 187.7 x 46.4 cm^2
    - Exit: 1 mm-thick Al, dimensions 257 x 59 cm^2
- Mirrors: Carbon-fiber composite, 0.01 X_0 thickness, spherical geometry, R = 2.2 m
- Photon detector: Phillips XP1911/UV PMTs, 0.75"-diameter (15 mm active diameter). Hexagonal close-packed arrangement, packing fraction ~0.38. Light-collecting funnels increase collection efficiency/effective packing fraction to ~0.60

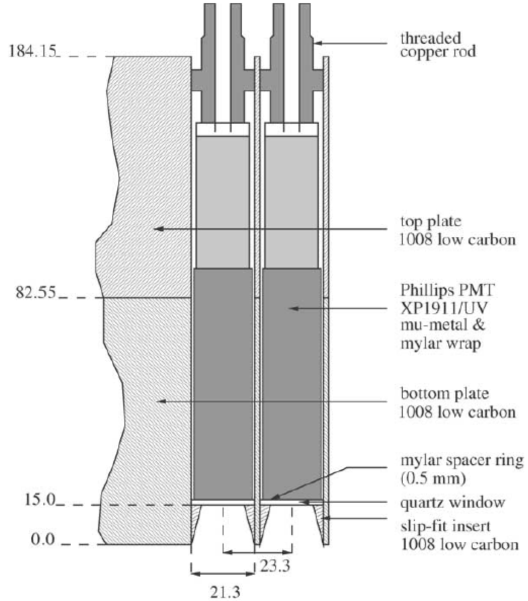
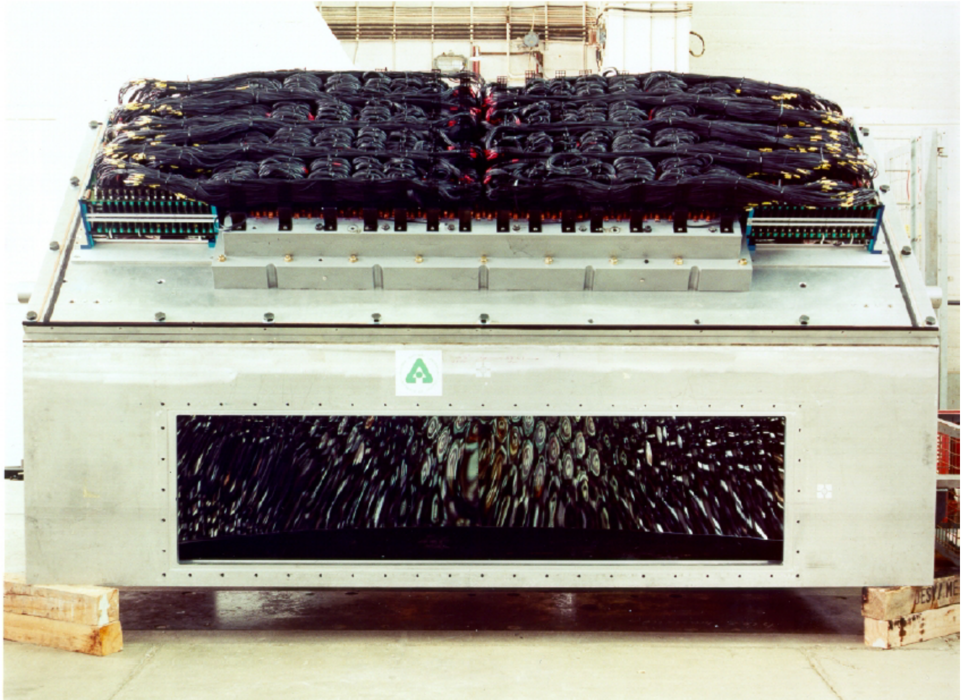
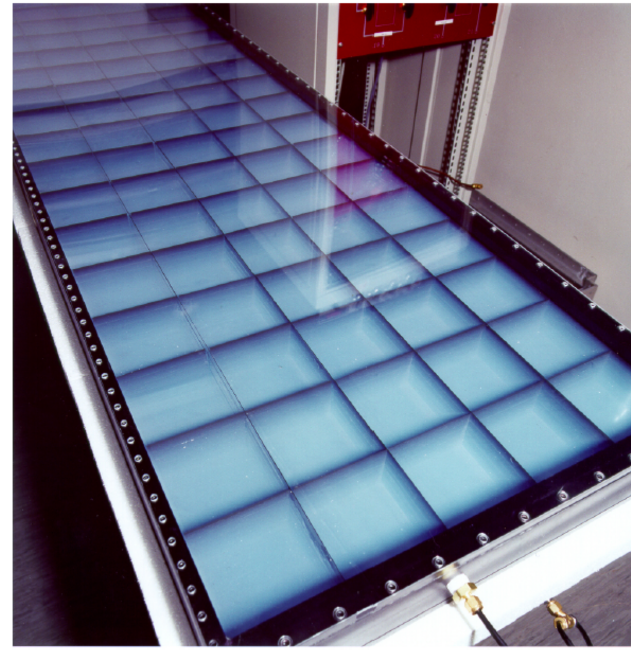


Fig. 7. Schematic photon detector design. All units are in mm.

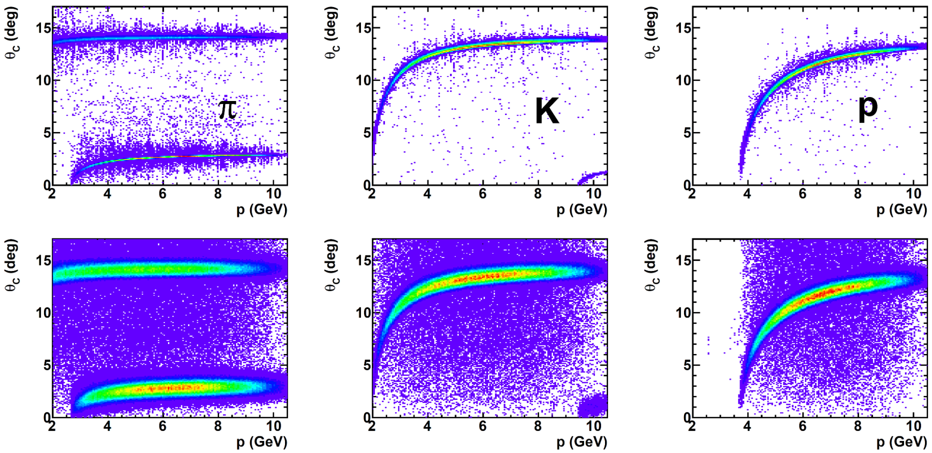
SBS RICH Detector Photos

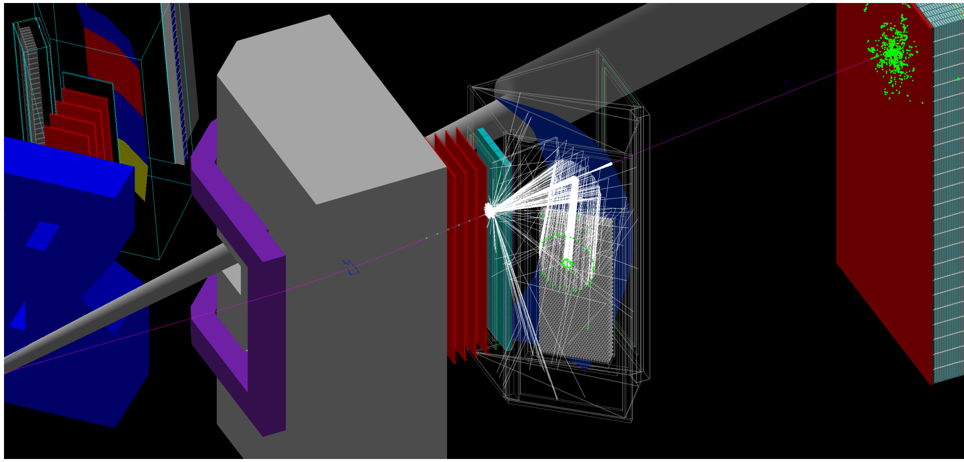




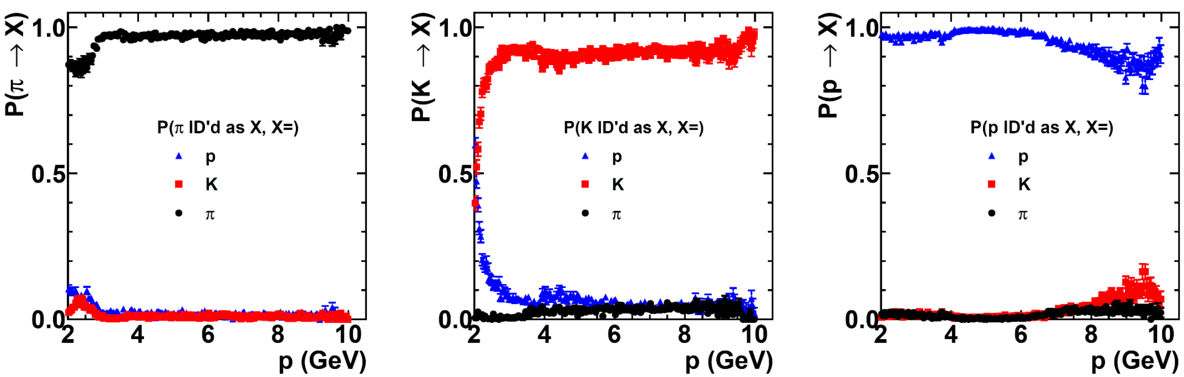
- Above, left: Old picture of one half of RICH with aerogel wall removed
- Above, right: Old picture of one aerogel wall w/containment vessel
- Bottom right: RICH delivery to storage facility @UVA, 2009

HERMES RICH in SBS—Monte Carlo

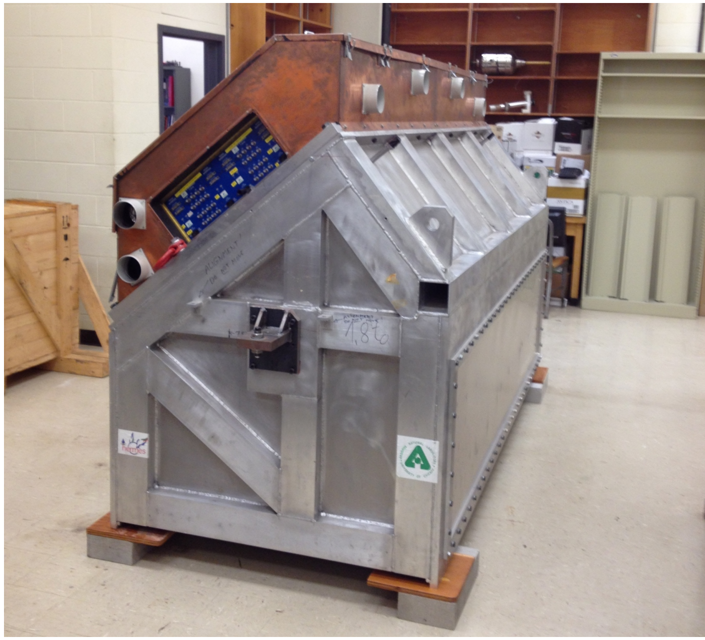




GEANT4-simulated RICH performance in SBS

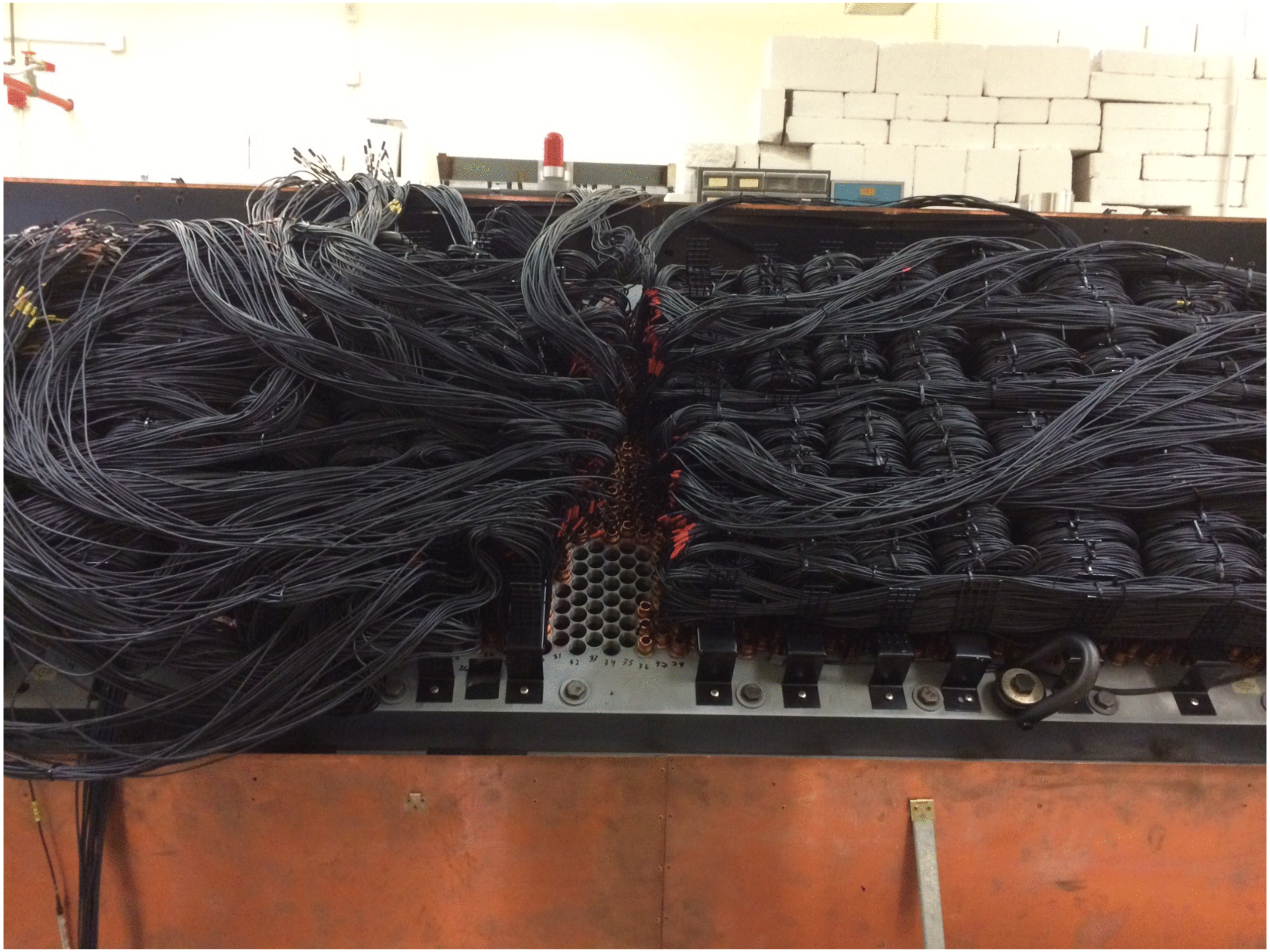


Simulated RICH PID performance in SBS for π/K/p



HERMES/SBS RICH testing underway @UConn

Decabling the RICH/PMT Removal (June 2016)



RICH PMTs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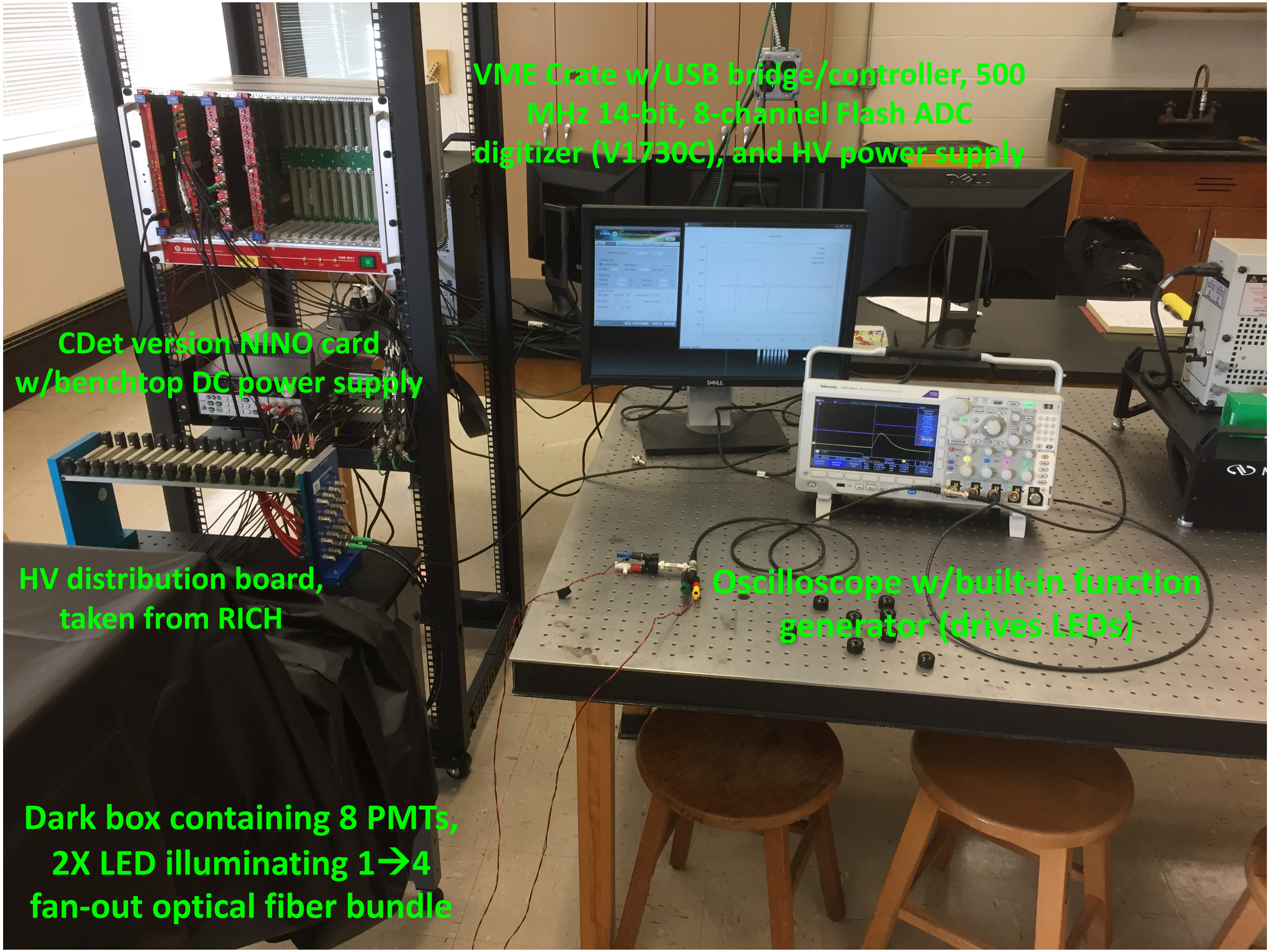
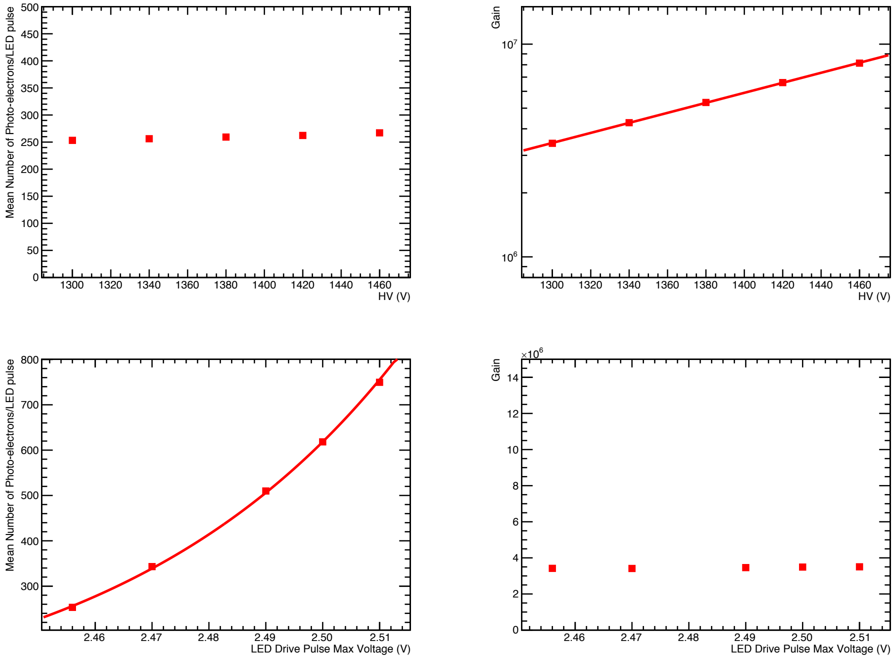
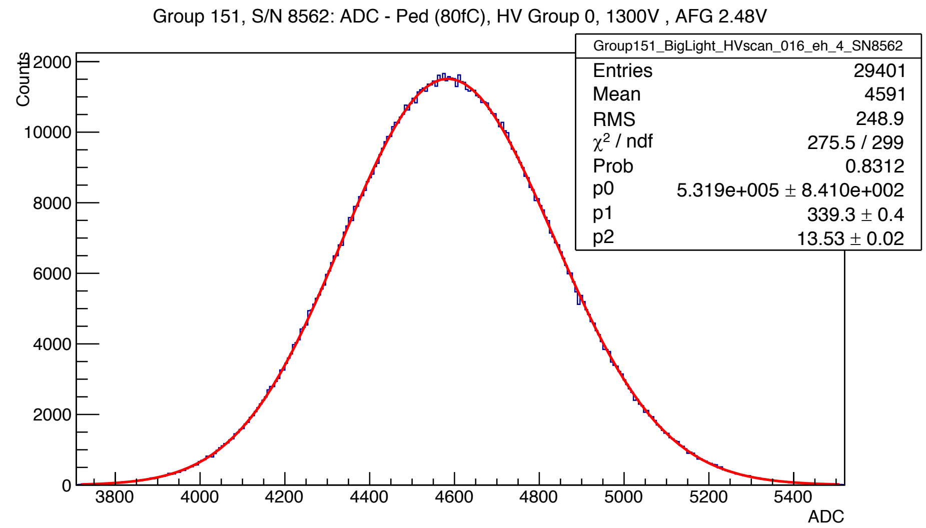
RICH PMT test stand @UConn (ca. 2016)



Gain and photoelectron yield estimates in 2016 pulsed LED setup



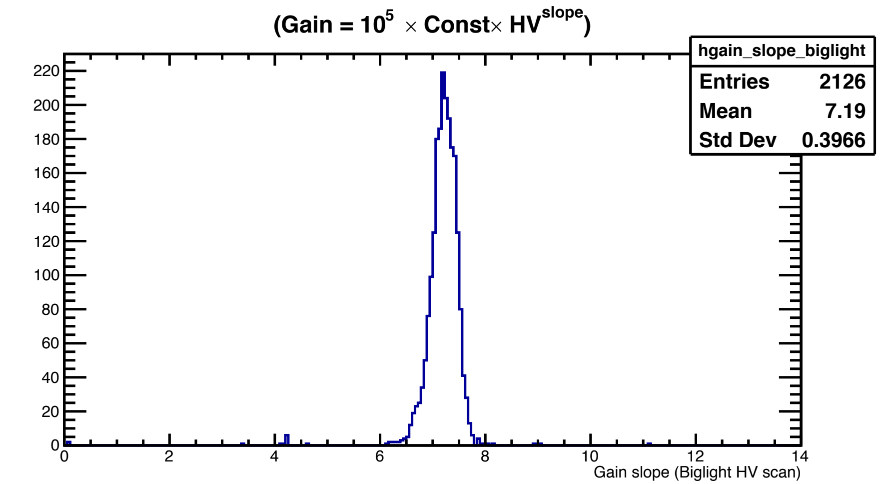


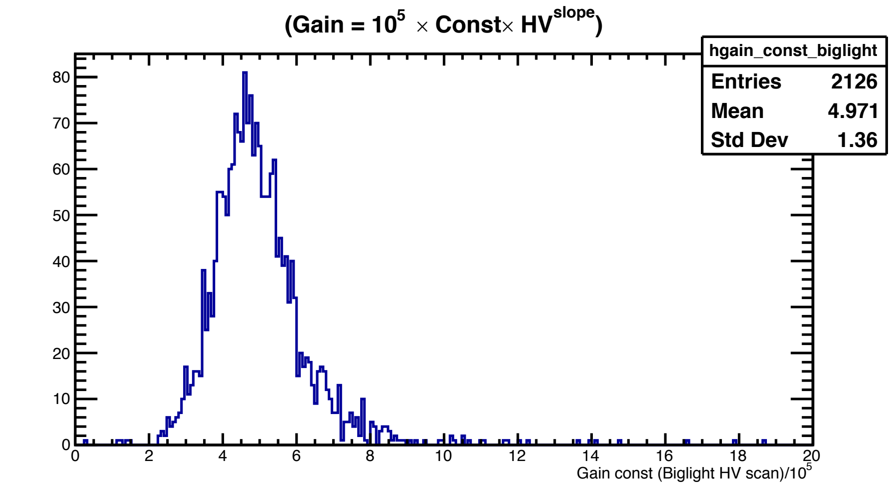
- Example Poisson fit to ADC spectrum:

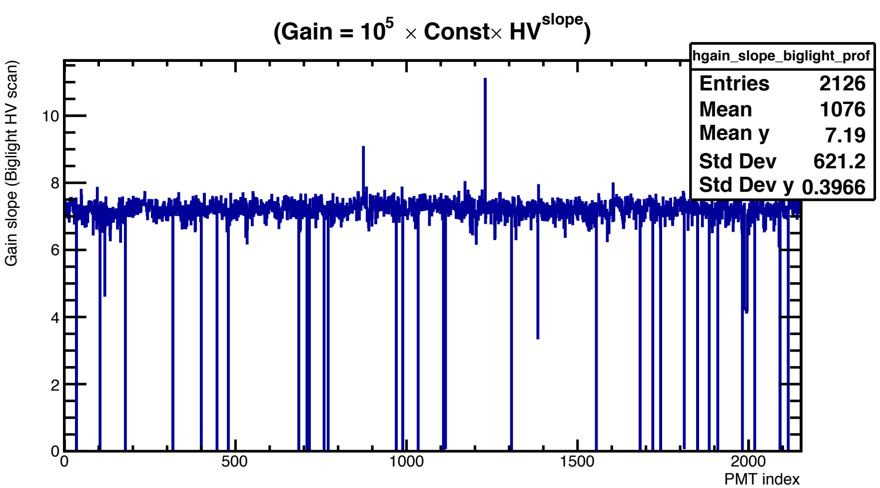
$$
\begin{aligned}
P(ADC) &= N\frac{(\mu)^{\frac{ADC}{G}}e^{-\mu}}{\left(\frac{ADC}{G}\right)!} \\
N &= p_0 = \text{Normalization} \\
\mu &= p_1 = \text{Mean number of photoelectrons} \\
G &= p_2 = \text{"Gain" (proportional to actual gain)}
\end{aligned}
$$

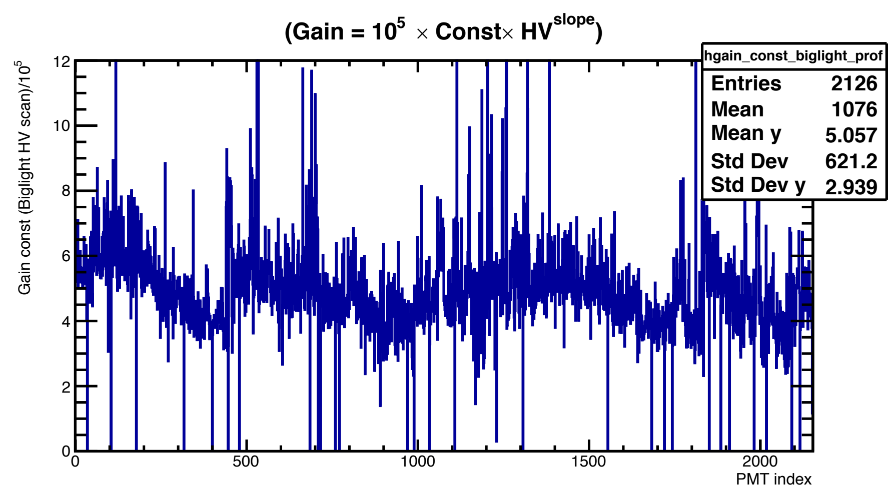
- Light-level scan at constant HV
- HV scan at constant light level

Gain results (2016 pulsed LED data)

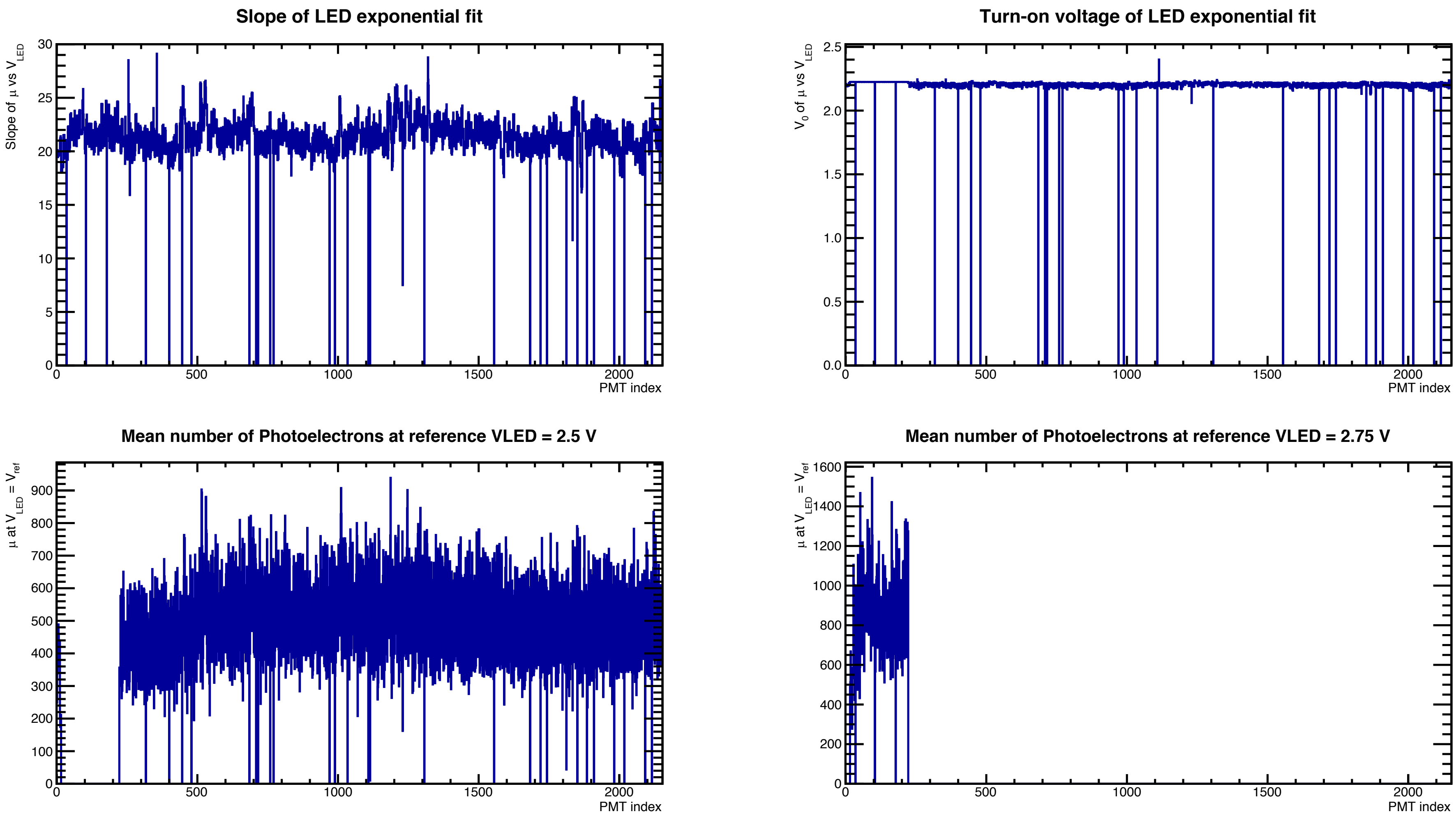






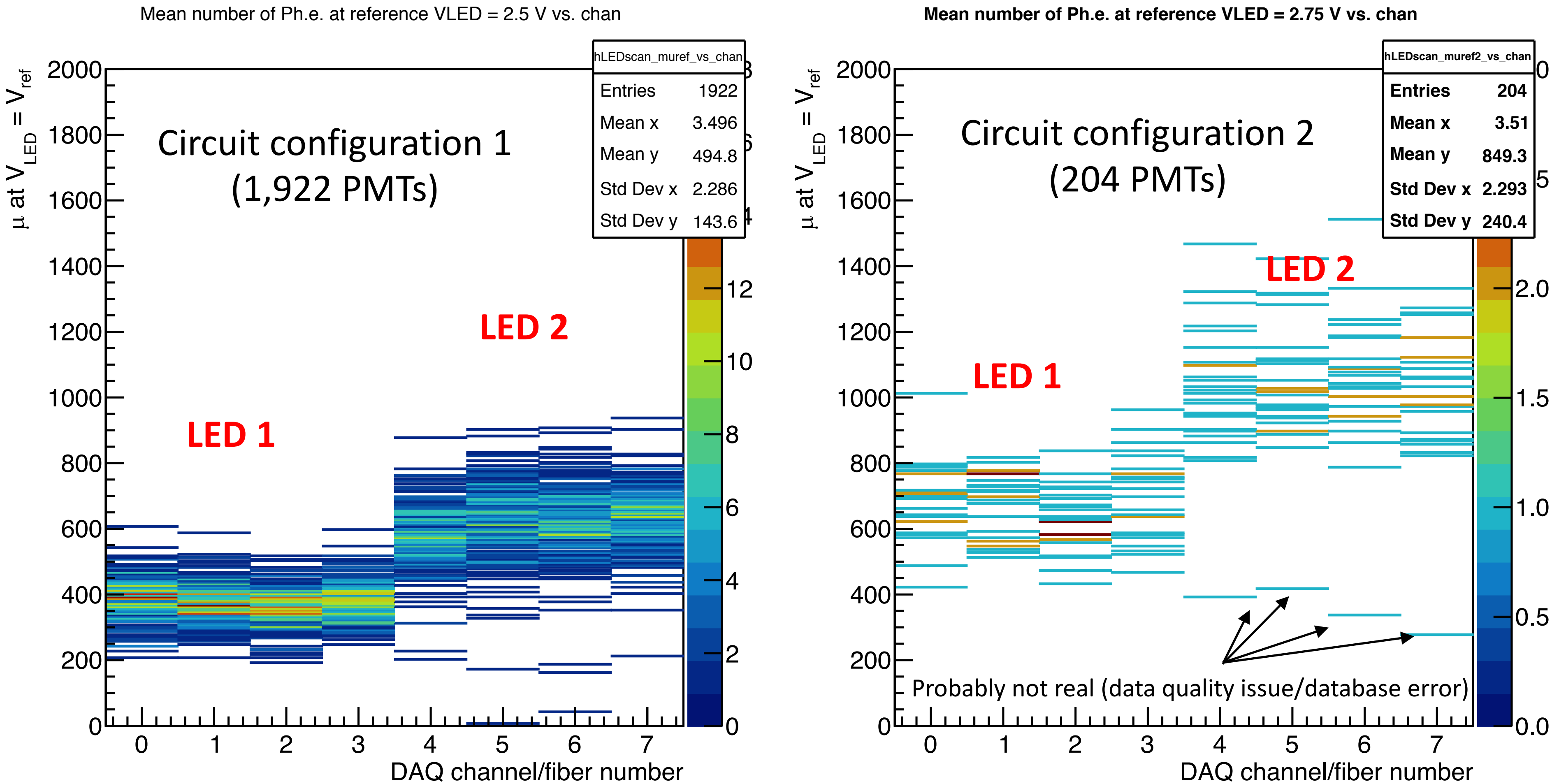


LED voltage scan results (2016 pulsed LED data)



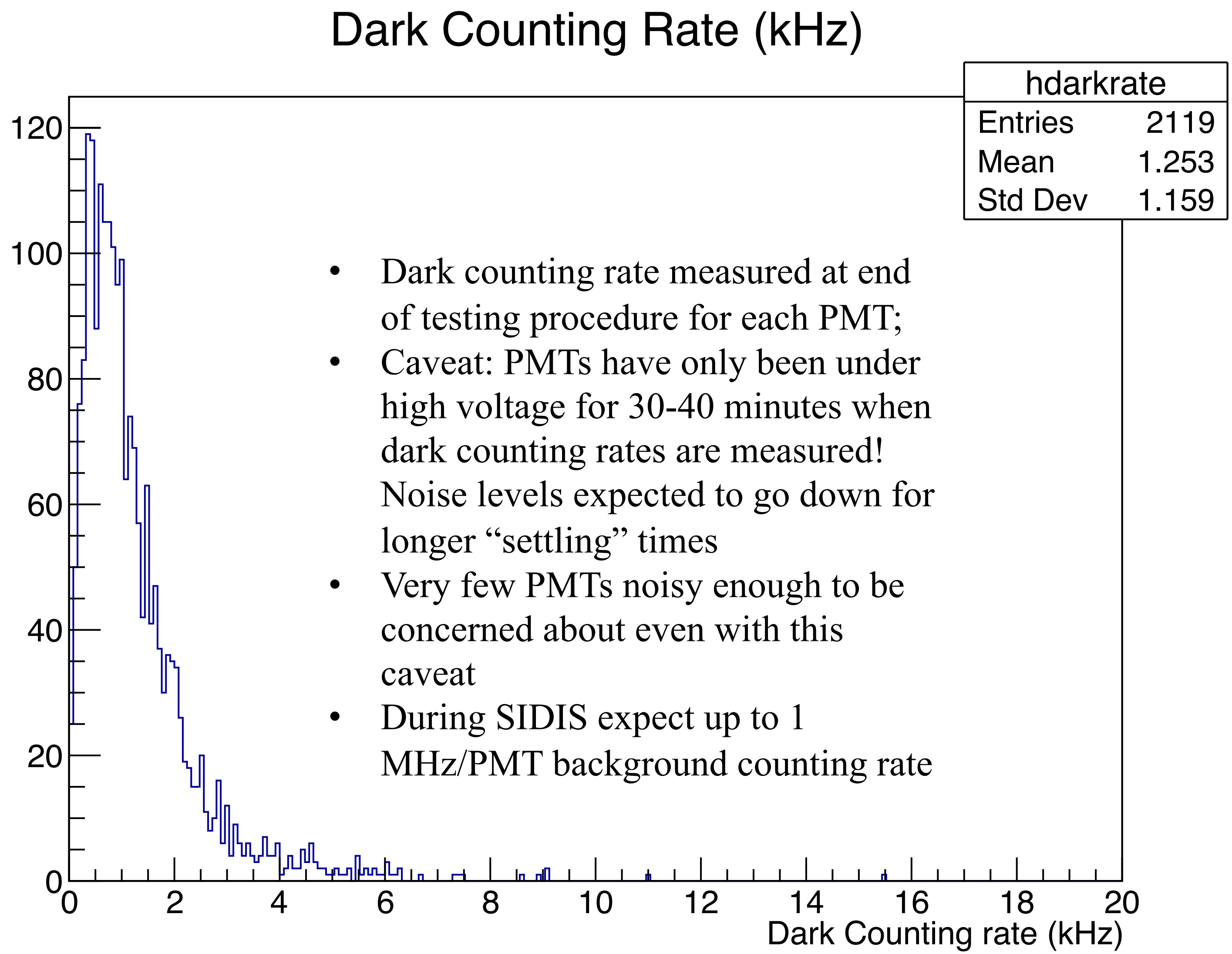
- Two slightly different LED circuit configurations lead to different relation between LED bias voltage and photoelectron yield; therefore yields between the two configurations cannot be directly compared.

”Reference” Photoelectron yields vs. fiber number (2016 data)



- In theory, photoelectron yield for PMTs viewing the same fiber during the pulsed LED testing is proportional to relative quantum efficiency.
- In practice, this is only approximate and depends on a lot of assumptions that are violated to a varying extent (repeatability of LED output, PMT positioning wrt fiber output, etc)

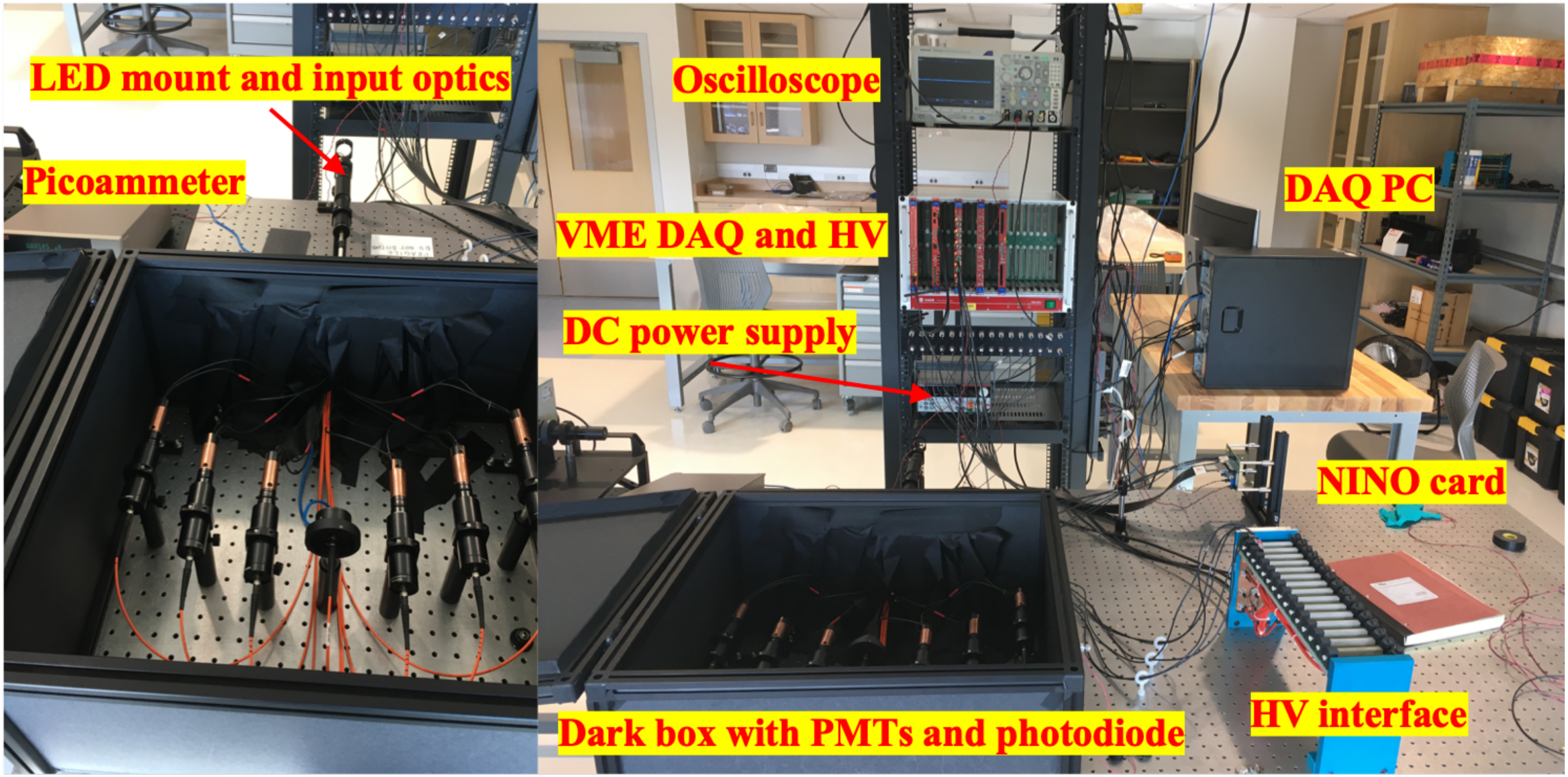
2016 test data summary—Dark Counting Rates



- Dark counting rate measured at end of testing procedure for each PMT;
- Caveat: PMTs have only been under high voltage for 30-40 minutes when dark counting rates are measured! Noise levels expected to go down for longer “settling” times
- Very few PMTs noisy enough to be concerned about even with this caveat
- During SIDIS expect up to 1 MHz/PMT background counting rate

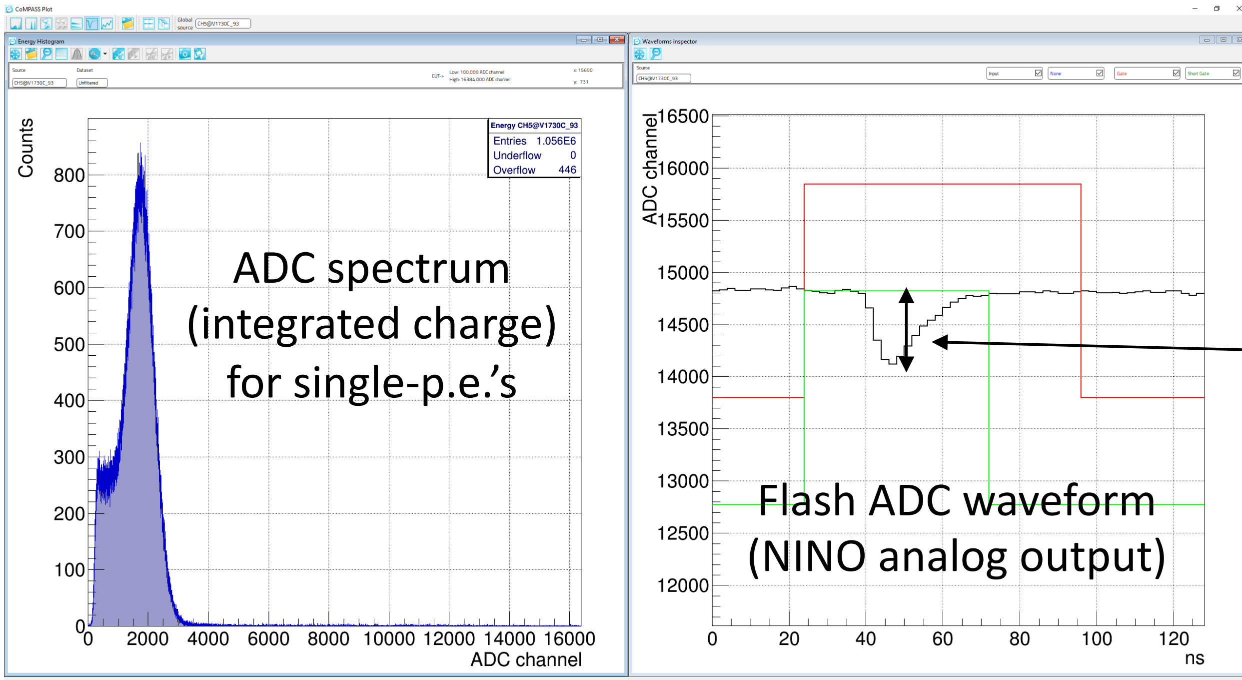
RICH move to JLab—Delivery to ESB, April 2018

PMT Quantum Efficiency Setup—2018-2020

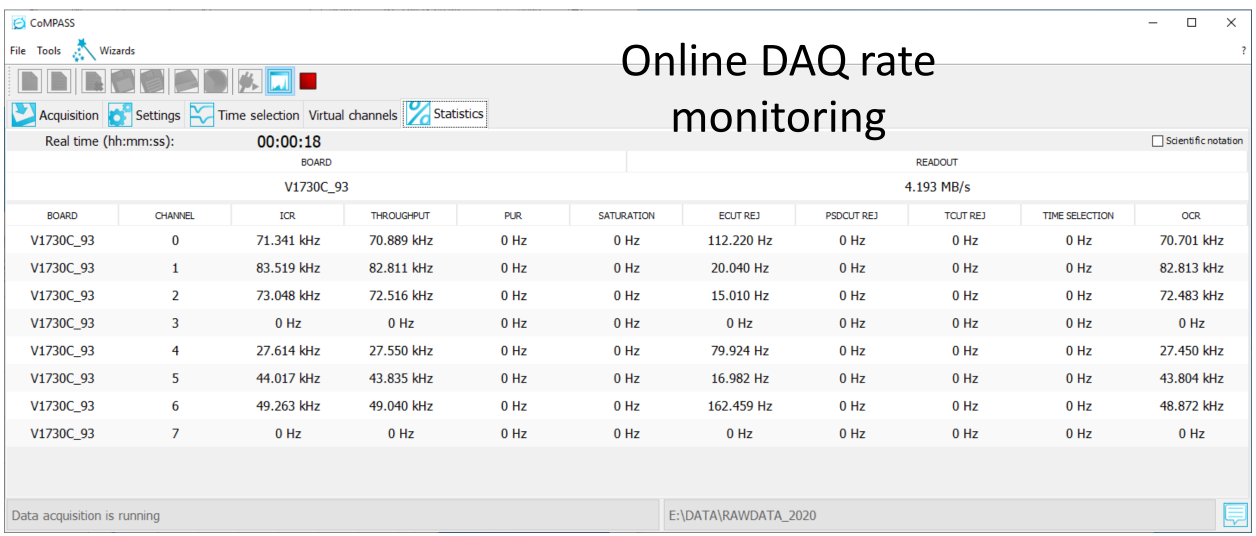


- Uses DC-biased single-color LEDs with calibrated photodiode, optical fiber bundle, and metallic reflective ND filters to match PMT and photodiode dynamic range;
- Ratio of single-photon counting rate to incident photon flux gives quantum efficiency (after corrections for filter transmission, fiber output ratios, photodiode response, etc).

“Online” DAQ @UConn



This single-p.e. pulse amplitude ~21 mV (~5 mV raw PMT signal with NINO amplifier gain of 4X)



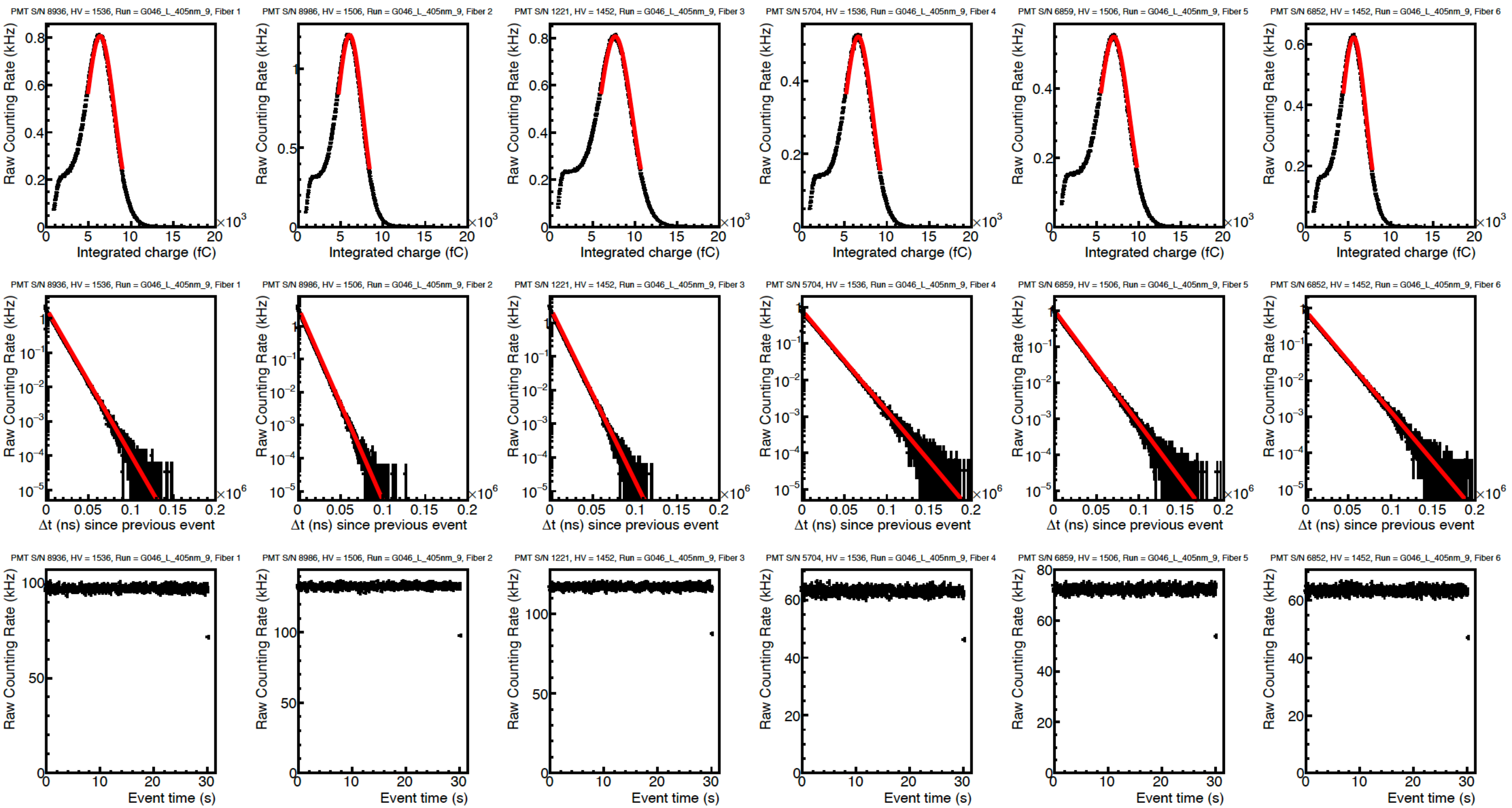
Online DAQ rate monitoring

Real time (hh:mm:ss): 00:00:18

BOARD	READOUT
V1730C_93	4.193 MB/s

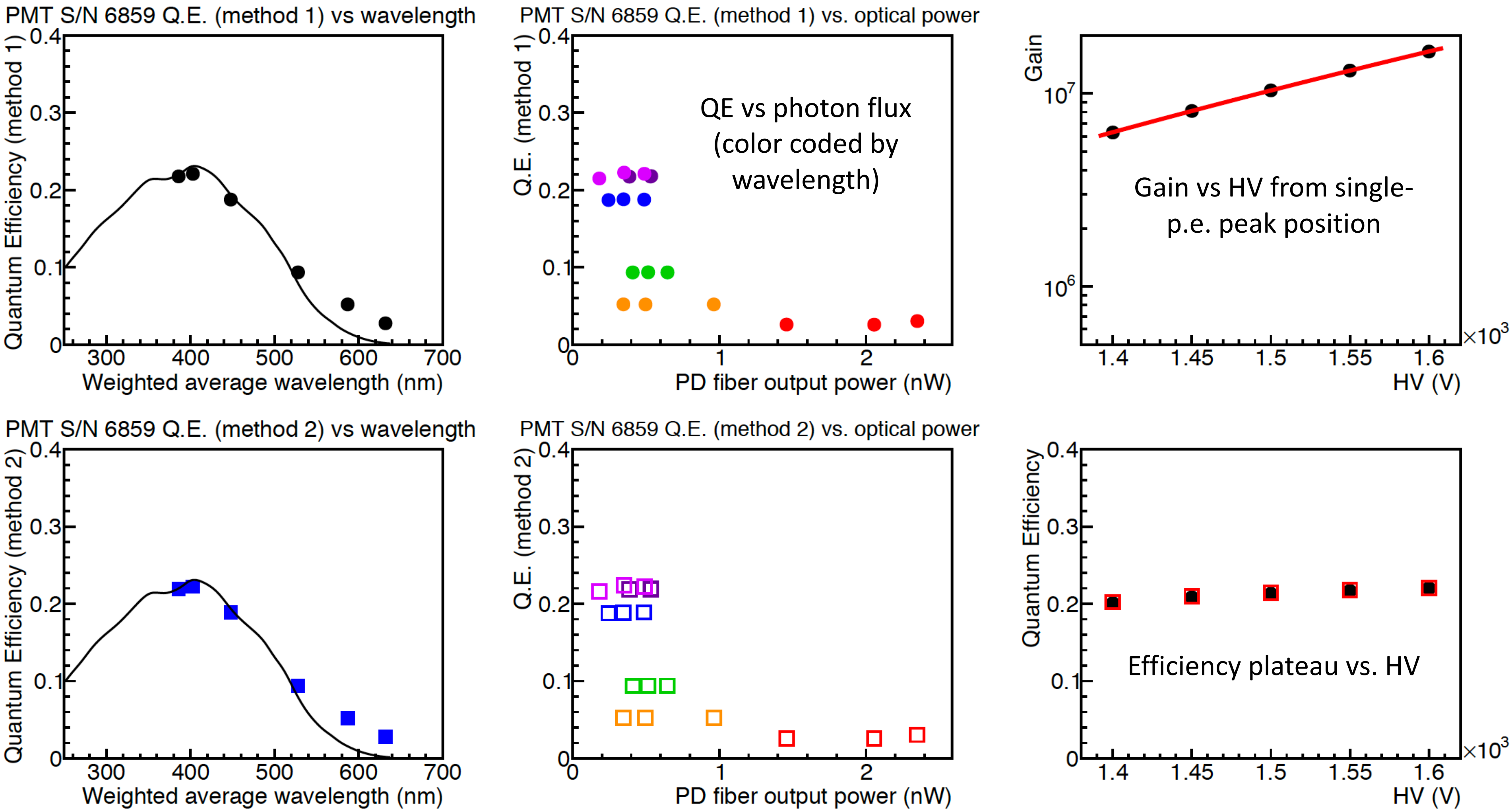
BOARD	CHANNEL	ICR	THROUGHPUT	PUR	SATURATION	ECUT REJ	PSDCUT REJ	TCUT REJ	TIME SELECTION	OCR
V1730C_93	0	71.341 kHz	70.889 kHz	0 Hz	0 Hz	112.220 Hz	0 Hz	0 Hz	0 Hz	70.701 kHz
V1730C_93	1	83.519 kHz	82.811 kHz	0 Hz	0 Hz	20.040 Hz	0 Hz	0 Hz	0 Hz	82.813 kHz
V1730C_93	2	73.048 kHz	72.516 kHz	0 Hz	0 Hz	15.010 Hz	0 Hz	0 Hz	0 Hz	72.483 kHz
V1730C_93	3	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz
V1730C_93	4	27.614 kHz	27.550 kHz	0 Hz	0 Hz	79.924 Hz	0 Hz	0 Hz	0 Hz	27.450 kHz
V1730C_93	5	44.017 kHz	43.835 kHz	0 Hz	0 Hz	16.982 Hz	0 Hz	0 Hz	0 Hz	43.804 kHz
V1730C_93	6	49.263 kHz	49.040 kHz	0 Hz	0 Hz	162.459 Hz	0 Hz	0 Hz	0 Hz	48.872 kHz
V1730C_93	7	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz	0 Hz

Typical QE Measurement Run with 6 PMTs (30 seconds)



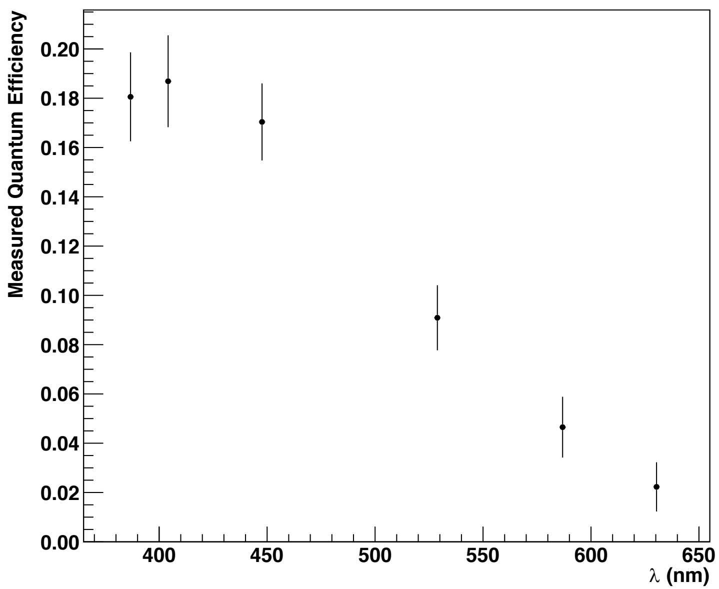
- Top: Single-photoelectron charge spectra (after rough gain matching)
- Middle: Distribution of time differences between consecutive single-photon detections
- Bottom: Raw single-photoelectron counting rate vs. time during a 30-s run

Typical QE Measurement Results for a Single PMT

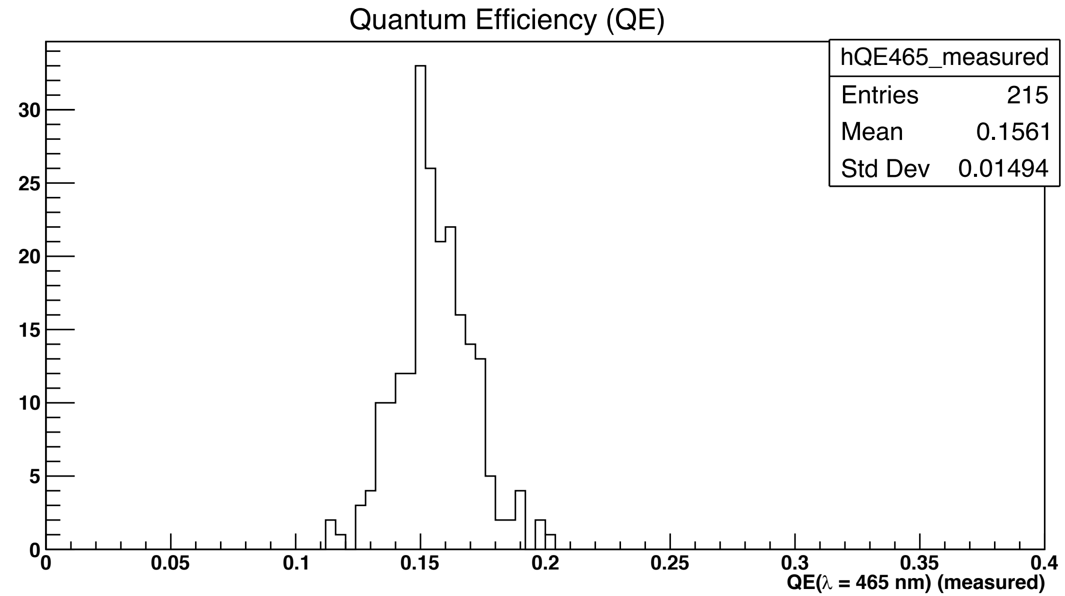


- “Method 1” = Slope of exponential distribution of time differences between random photon detections—Free of deadtime corrections
- “Method 2” = Average PMT counting rate, with (small) deadtime correction

Aggregate analysis of QE results (NEW)



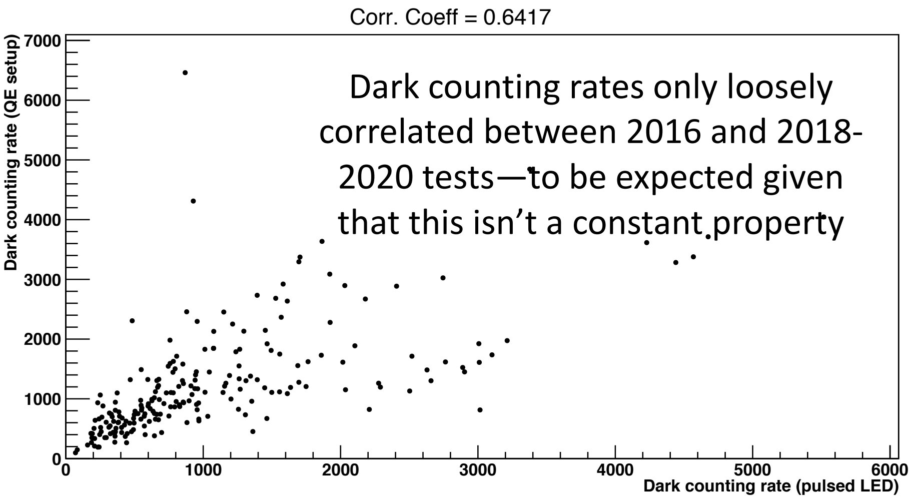
QE Wavelength dependence: data points = mean of 215 PMTs, error bars = standard deviation

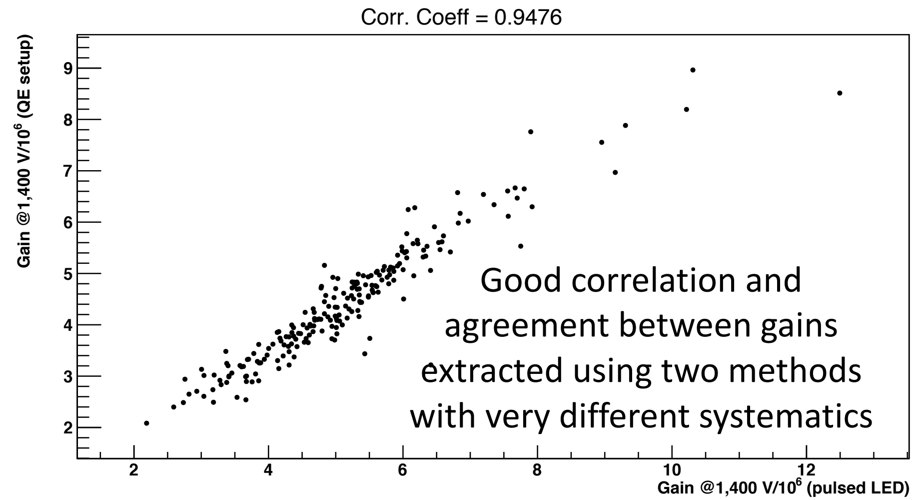


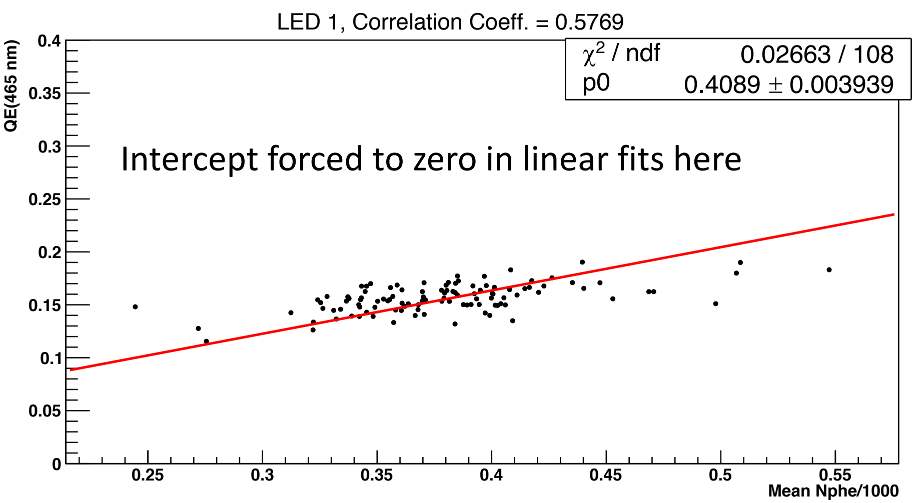
Quantum efficiency interpolated to 465 nm (wavelength of pulsed LED data from 2016)

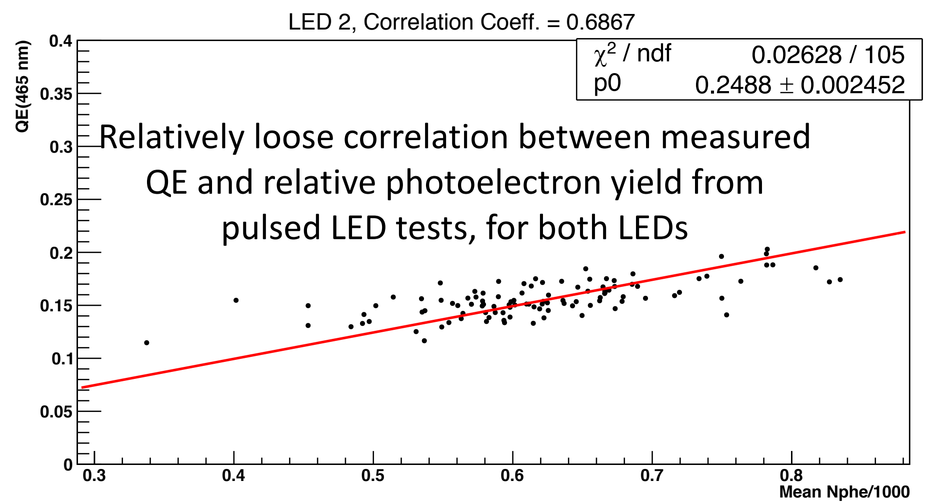
- 215 PMTs tested in absolute QE setup so far; mostly by UConn undergraduates.
- Of those tested, mean QE interpolated to a common wavelength of 465 nm is 15.6%, standard deviation 1.5% (~10% relative to the mean)
- By comparing photoelectron yields from PMTs measured in the QE setup to others viewing the same fiber under same conditions in pulsed LED testing, we can estimate QE @465 nm for a large fraction of all PMTs

Pulsed LED (2016) vs. QE (2018-2020) setup



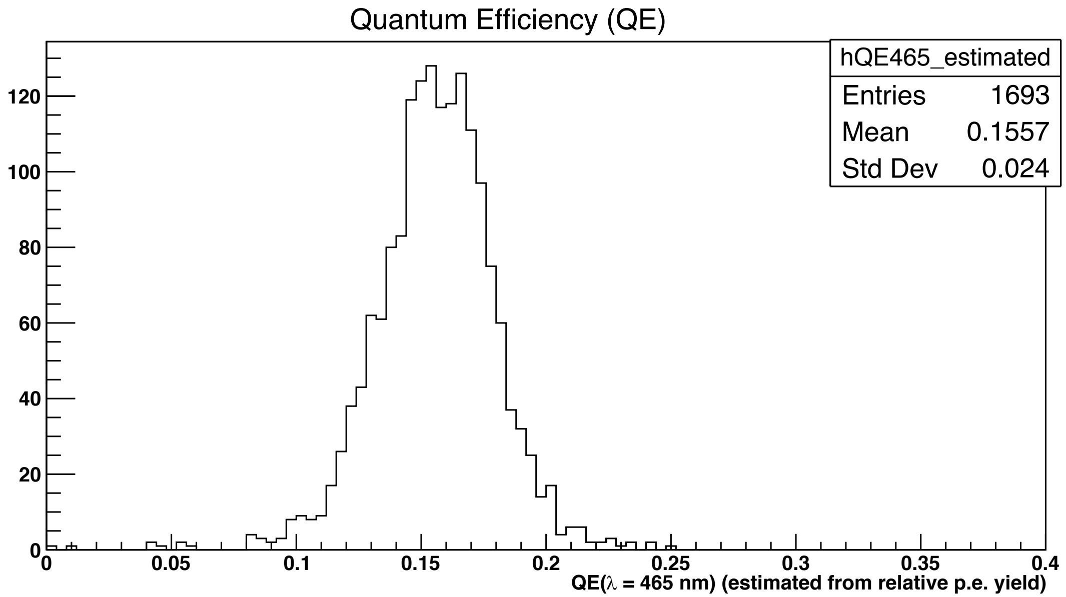






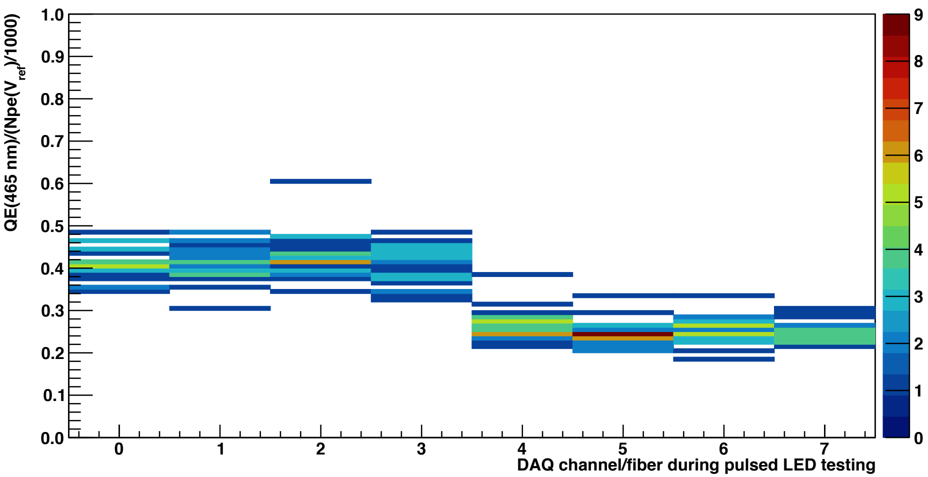
- **For the subset of PMTs tested in both absolute QE setup and pulsed LED setup, worth looking at repeatability of common measurements and correlation between relative photoelectron yield at reference LED voltage and measured quantum efficiency interpolated to 465 nm**

Estimated Quantum efficiency for other PMTs



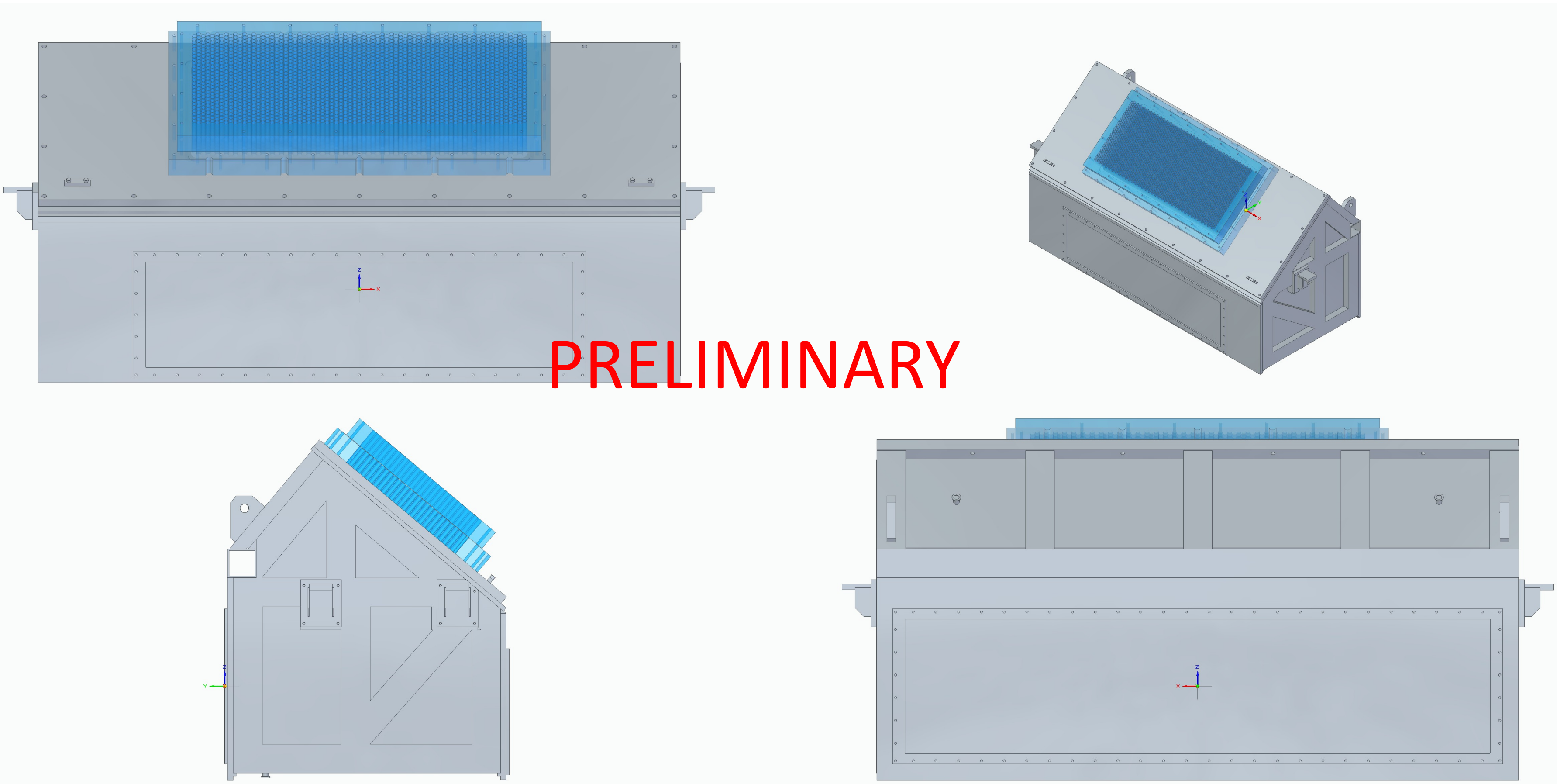
- Absolute QE measurements for 215 PMTs so far allow us to estimate QE @465 nm for approximately 1,700 other PMTs
- Approximately 200 other PMTs tested with slightly different LED driving circuit cannot be directly compared to any of the PMTS measured in absolute QE setup so far.

- It is reasonable to ask "How reliable a proxy for relative QE is the relative photoelectron yield"?
- **For PMTs measured in absolute QE setup, the standard deviation of the ratio QE/Npe is about 10% (relative)**
- **The standard deviation of the *estimated* relative QE for all other PMTs is about 15%**
- If we take 10% as the random systematic uncertainty of the proportionality between p.e. yield and QE, then **subtracting 10% from 15% in quadrature yields ~11% as the estimated standard deviation of "true" QE(465 nm) in this batch of over 1,900 PMTs**



RICH 3D Model

- Created from existing 2D .dwg drawings using SIEMENS SolidEdge, *by UConn undergraduate physics and mechanical engineering major Eva Gurra*
- According to Robin, SolidEdge is compatible with JLab's CAD system, so I hope this isn't useless as a starting point for support frame and other design…



High-level remaining tasks on RICH

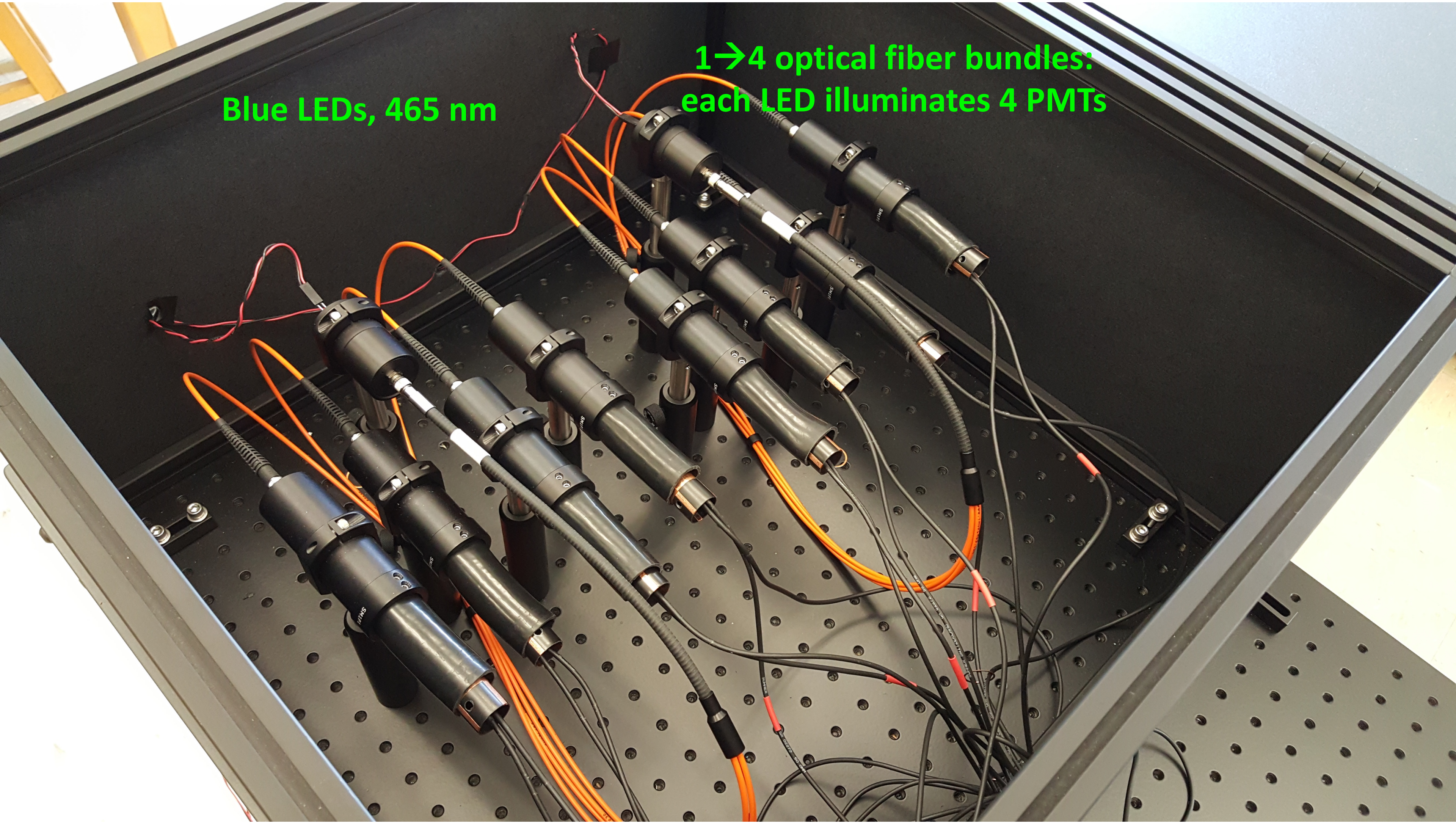
- Support frame design and install for RICH + 5-layer GEM tracker assembled from UVA modules: ~1? month designer time (JLab), ~$10k-20k? fabrication cost (3D model of RICH itself exists)
- Gas system design, procure, and install:
  - Plan to copy/re-use GRINCH design as much as possible, ~few weeks designer time, ~$5k-10k cost plus gas cost during SIDIS run = ?? (Heavy gas cost/availability very volatile)
- Design mounting/patch panels/cabling from PMTs→Front-end electronics (NINO card): anticipate requiring some support from JLab electronics group
- Reinstall PMTs, cable up front-end and readout electronics, and HV
- Open RICH box, check aerogel and mirror condition, align mirrors
- Close RICH box, check for gas and light leaks
- Commission full DAQ system and optical components with cosmic rays and/or beam
- Install RICH + GEMs in SBS prior to SIDIS run ~late 2022?
- Develop and execute beam commissioning procedures
- **UConn group is responsible, but all of the above need help from new and existing collaborators if we are going to pull off SIDIS after GEN in late 2022, before GEP (which makes the most sense from a scheduling POV)**
- **SIDIS experiment has more approved PAC days than any other SBS experiment, promises a large number of high-impact publications and Ph.D. theses, and RICH is an essential component. UConn group will not be able to pull it off by ourselves with existing manpower/resources…**

UConn Manpower and RICH planning

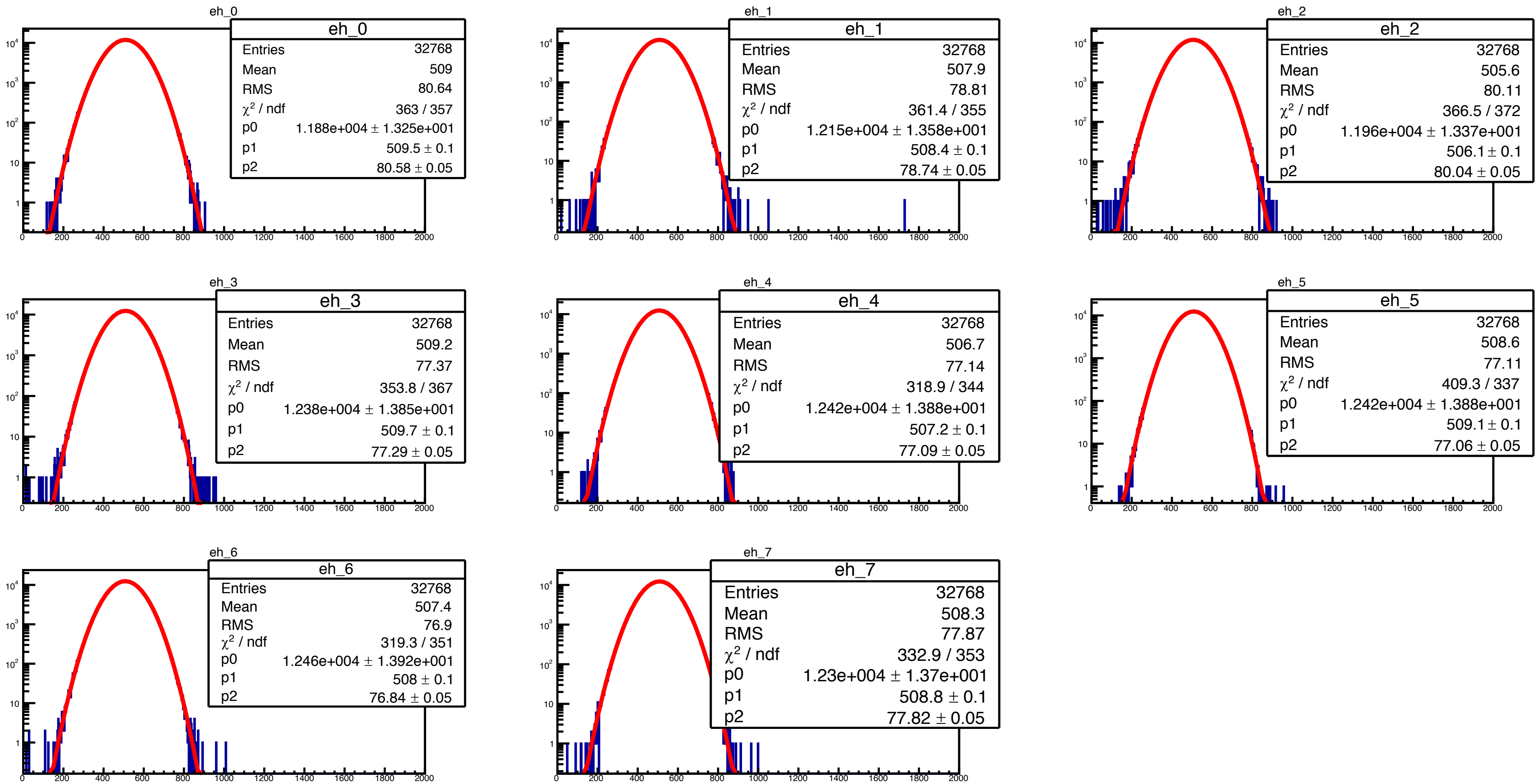
- UConn group:
  - Andrew Puckett (PI)
  - Eric Fuchey (PD)
  - Provakar Datta (Ph.D. student, full-time on site ~Dec. 2020)
  - Sebastian Seeds (Ph.D. student, full-time on site ~Aug. 2020)
- Puckett sabbatical Spring 2021 + (potentially) Fall 2021
  - May seek postponement of sabbatical if SBS installation schedule looks too long/running schedule delayed
  - RICH prep should begin by early 2021 either way
- VETROC upgrade for CDET and RICH DAQ should dramatically simplify readout of both detectors/eliminate a major performance bottleneck…
- Best-case SIDIS run: late 2022
- Critical to bring RICH out of storage, begin preparations during my sabbatical for RICH to be ready on time.
- **Many good opportunities for new collaborator/grad student involvement–and E12-09-018 will easily yield ~10 Ph.D. theses/high-profile publications**

Backup Slides

Dark box

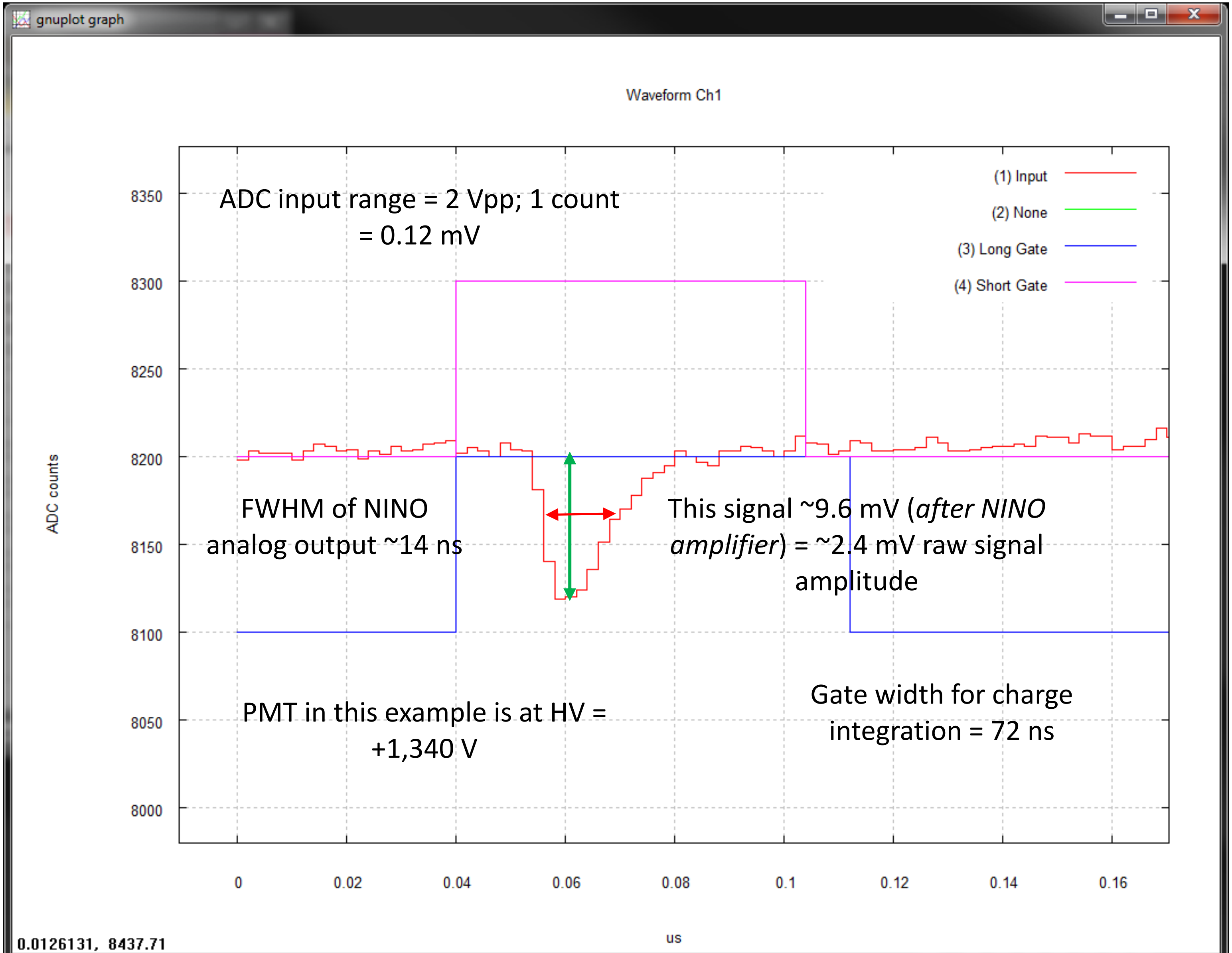

Blue LEDs, 465 nm
1→4 optical fiber bundles:
each LED illuminates 4 PMTs

Pedestal mean and width (5 fC/LSB charge sensitivity)

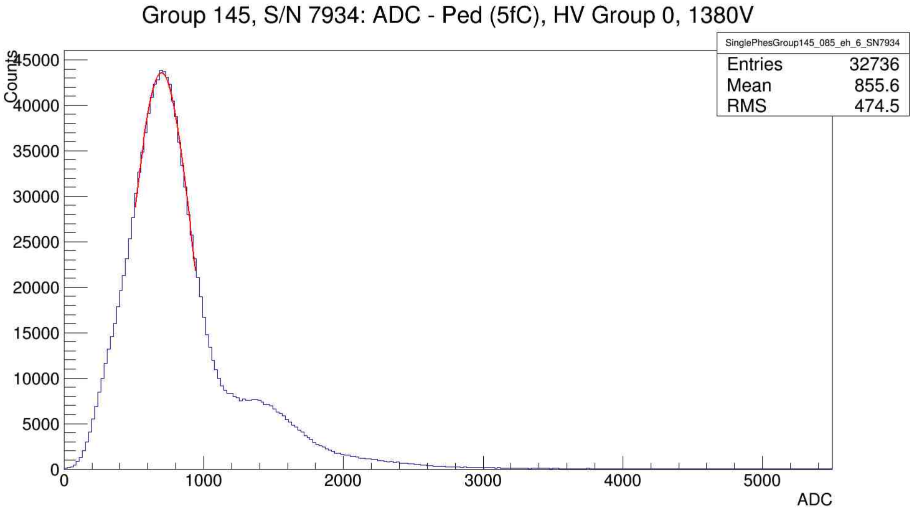


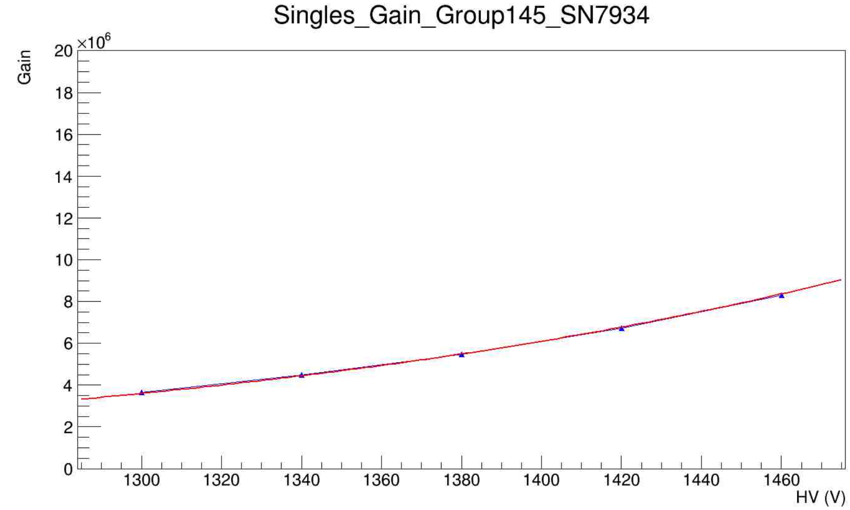
- The DAQ performs automatic baseline determination and subtraction; however, we configured it to insert a charge "pedestal" so that we can easily determine the noise level in each channel and optimally separate the small single-ph.e. signals from noise.
- The individual sample noise width is related to the pedestal width by statistical factors depending on the number of samples used for the baseline determination and the number of samples in the gate for charge integration

Single Photo-electron Signals



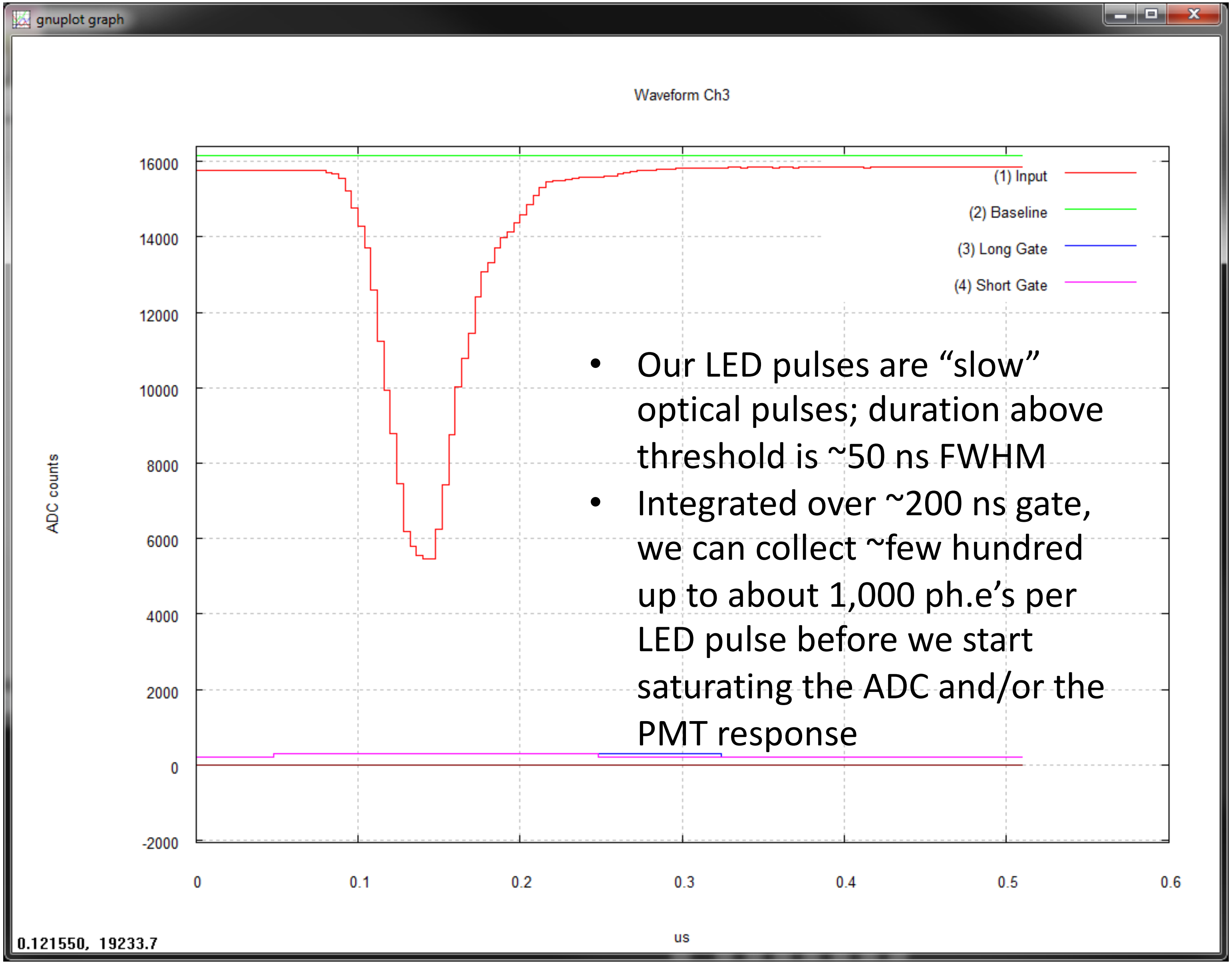
Absolute Gain Determination from Single-Ph.e.'s





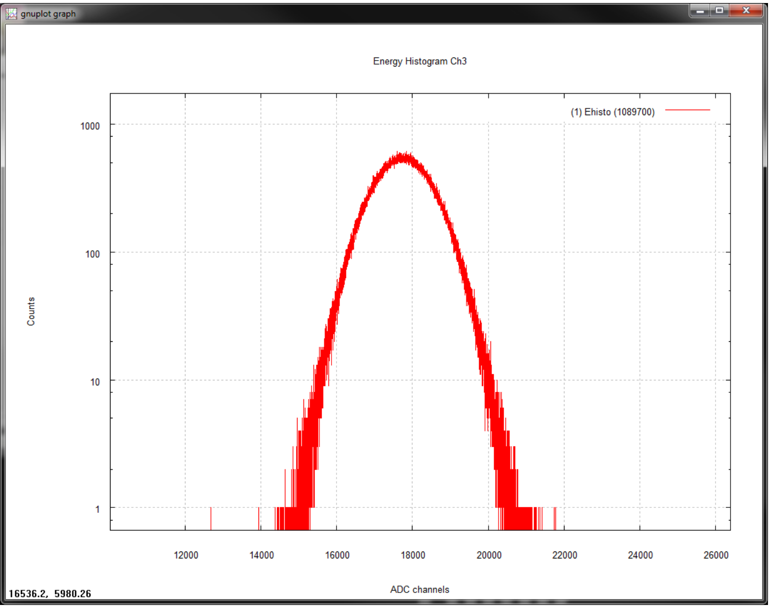
- Collect single-photoelectron charge spectra for different HV's from 1,300-1,460 V in 40-V increments.
- Fit Gaussian to single-photoelectron peaks.
- Correct for NINO amplifier gain of 4
- Fit HV-dependence of gain with power-law curve to determine gain slope
- At HVs below ~1,300 V, this method starts to suffer from trigger/threshold bias of single-ph.e. peak position

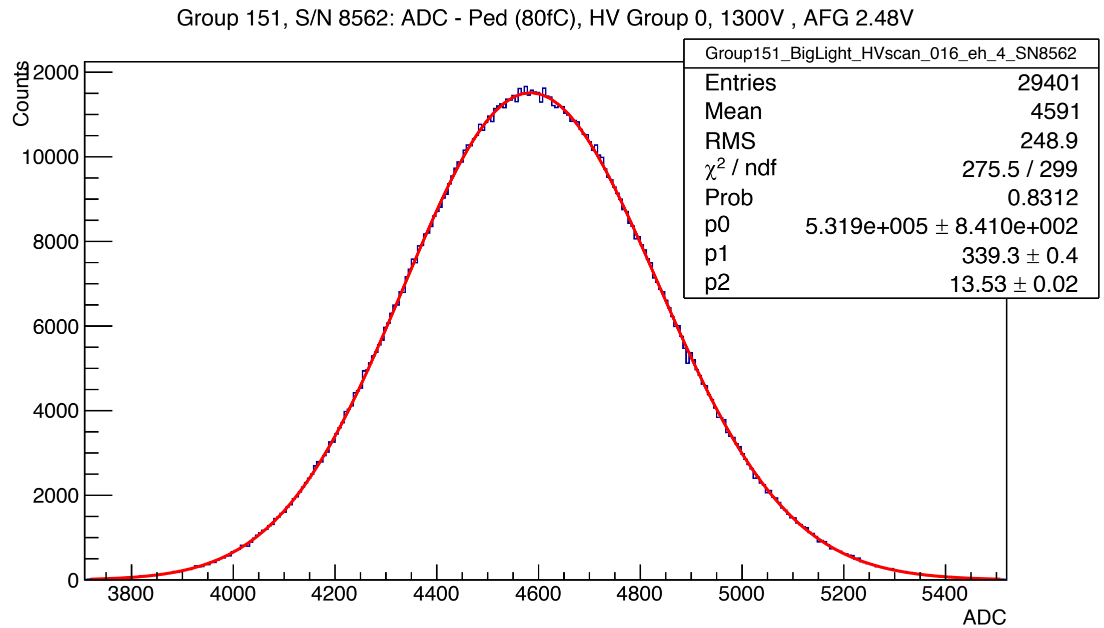
“Big” LED pulses



- Our LED pulses are “slow” optical pulses; duration above threshold is ~50 ns FWHM
- Integrated over ~200 ns gate, we can collect ~few hundred up to about 1,000 ph.e’s per LED pulse before we start saturating the ADC and/or the PMT response

Charge spectrum for "Big" light pulses and determination of photoelectron yield





- Example of "online" big-light charge spectrum at 80 fC/LSB charge sensitivity

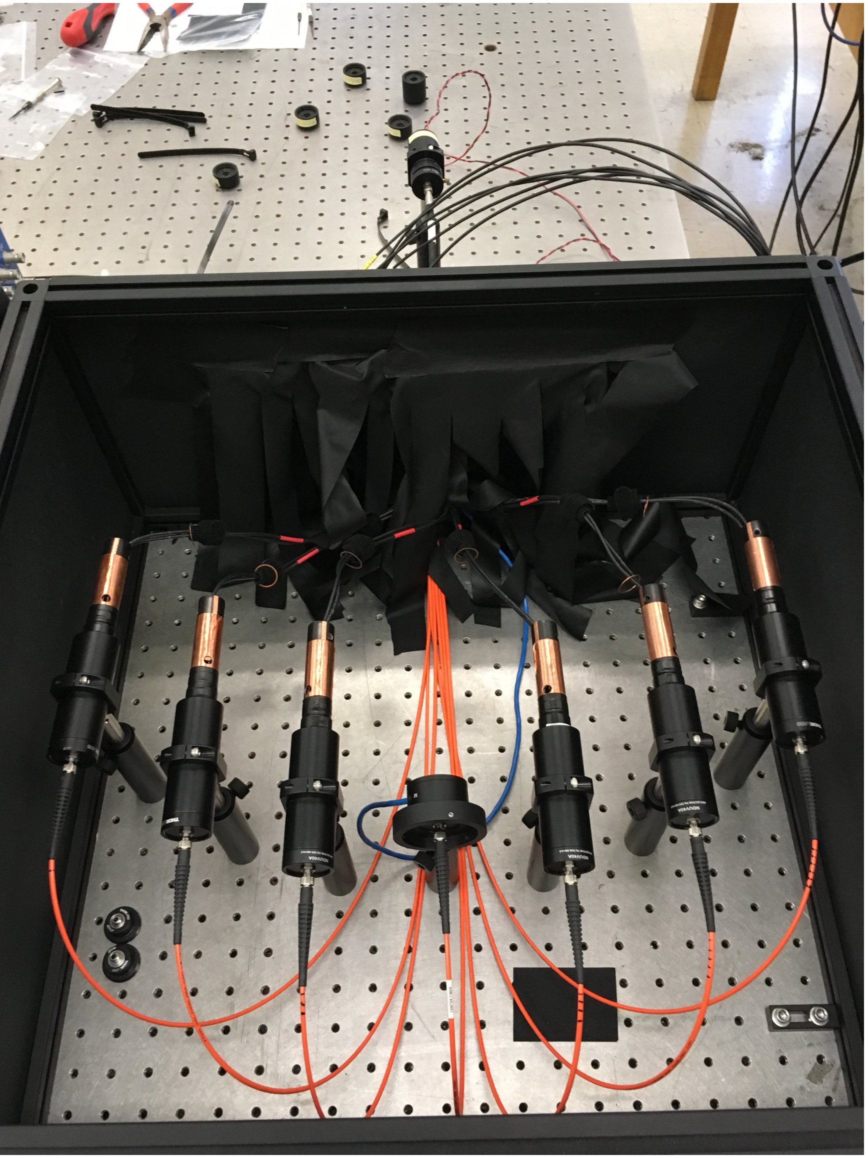
- Example Poisson fit to ADC spectrum:

$$
\begin{aligned}
P(ADC) &= N\frac{(\mu)^{\frac{ADC}{G}}e^{-\mu}}{\left(\frac{ADC}{G}\right)!} \\
N &= p_0 = \text{Normalization} \\
\mu &= p_1 = \text{Mean number of photoelectrons} \\
G &= p_2 = \text{"Gain" (proportional to actual gain)}
\end{aligned}
$$

RICH move to JLab—Rigging Out (I)

RICH move to JLab—Shipment Prep @G&F Warehouse

2018-2019: Absolute Quantum Efficiency Setup



Methodology:

- Single-color, DC-biased LEDs illuminate input of 1→7 fan-out fiber bundle.
  - Diffusers between LEDs/fiber input homogenize input illumination/output ratios
  - LEDs on threaded, removable mounts with repeatable positioning
  - Manual shutter allows to switch LEDs without turning off HV
- Calibrated photodiode monitors output of center fiber.
- Fiber relative output ratios measured for each LED, uniform to within ~5%
- Reflective, metallic ND filters (chosen for uniform transmission in UV-visible spectrum) reduce optical power incident on PMTs by a factor of a few $\times 10^{-4}$ relative to fiber output.
- Transmission of each filter is measured for each LED.
- Threaded rings inside lens tube hold PMT on axis (relatively snug slip-fit).
- PMT windows pushed against black rubber spacers inside lens tube for repeatable positioning with active photocathode area covering 100% of fiber numerical aperture.

Summary of PMT 2016 test results

- All PMTs have been tested (1,934 RICH + 224 spare minus two PMTs that ended in special LEMO connectors (presumably for monitoring) that need to be adapted to our test stand
- 32 PMTs rejected either because they were "dead" (no signals), were extremely noisy, had extremely low gain/poor signal quality, or had obvious visible defects on inspection.
  - This is 1.5% of the total number of PMTs available
  - These PMTs were manufactured in 1997-1998
- With all the "good" PMTs on hand, we have enough to instrument the RICH with 192 to spare (~10% spare capacity