

# **RICH Detector for SIDIS**

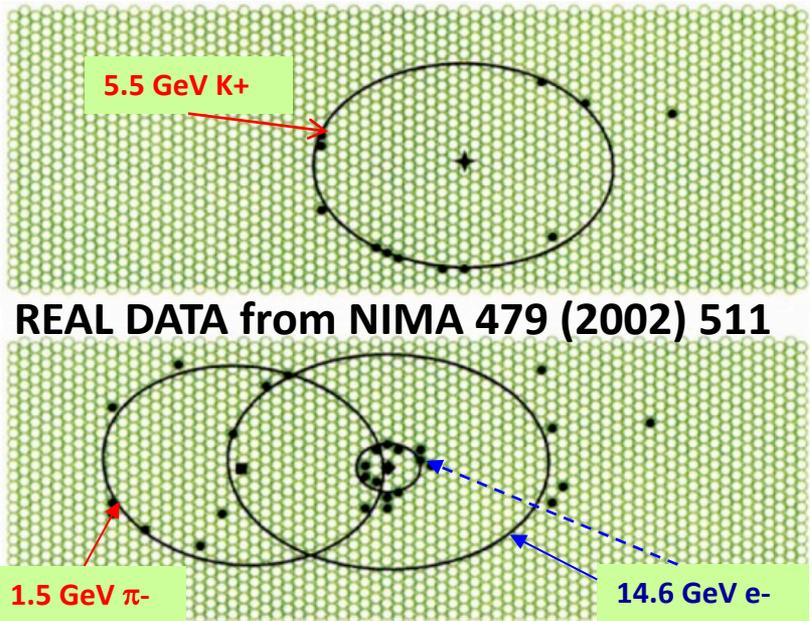
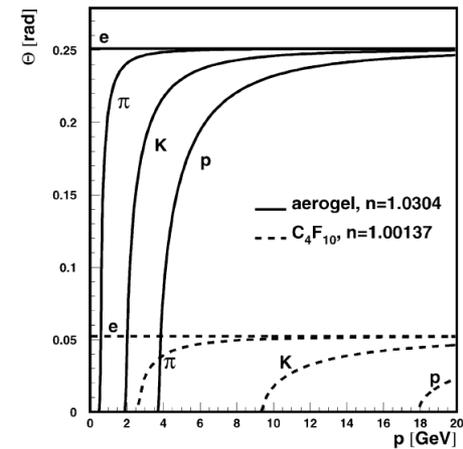
Andrew Puckett

University of Connecticut

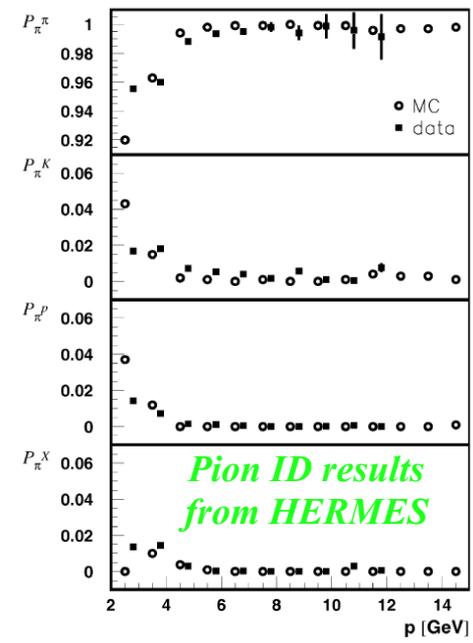
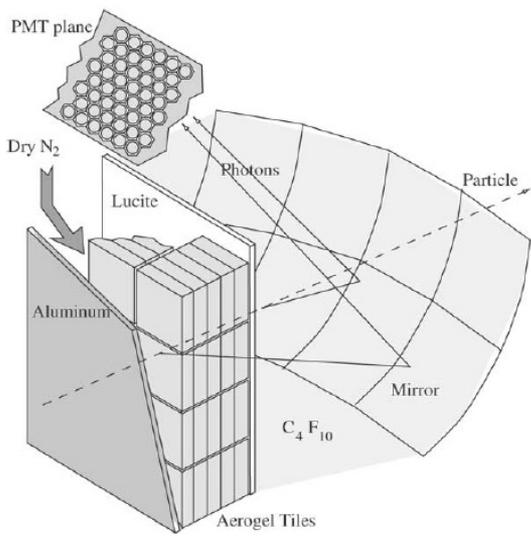
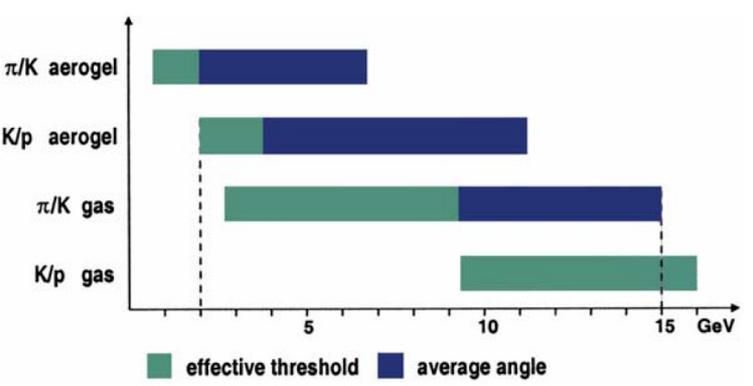
SBS Collaboration Meeting 2026

# The HERMES RICH detector

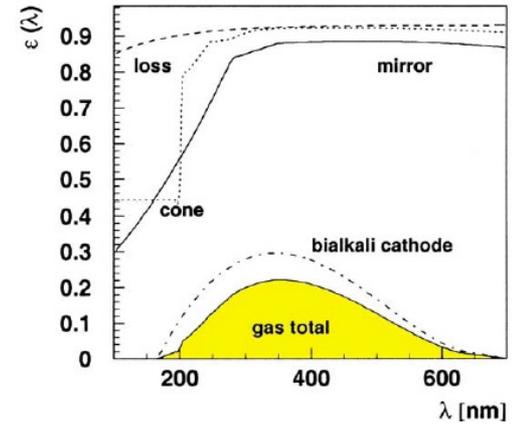
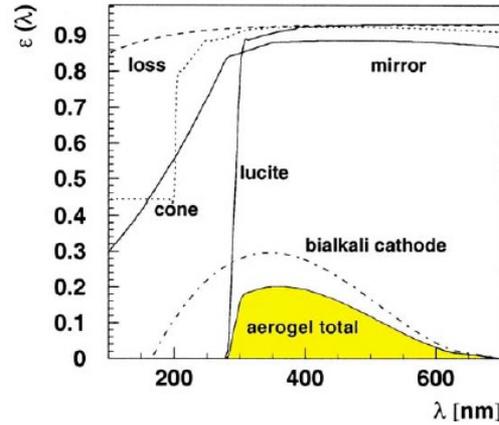
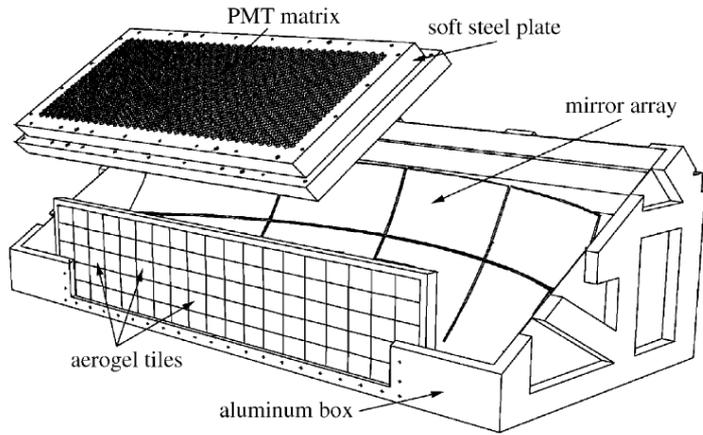
- *HERMES RICH geometry, performance characteristics well matched to SBS needs.*
- $\pi/K/p$  separation for  $p$  from 2-15 GeV based on dual-radiator design.
- Re-use one half of detector, both aerogels



REAL DATA from NIMA 479 (2002) 511



# HERMES RICH Design Aspects



Optical properties contributing to overall detection efficiency

- Aerogel wall: tiles  $11.4 \times 11.4 \times 1.13 \text{ cm}^3$ , 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 heavy gas and absorbs UV photons  $\lambda < 300 \text{ nm}$  (Rayleigh scattering dominates at UV wavelengths)
- Windows:
  - Entry: 1 mm-thick Al, dimensions  $187.7 \times 46.4 \text{ cm}^2$
  - Exit: 1 mm-thick Al, dimensions  $257 \times 59 \text{ cm}^2$
- Mirrors: Carbon-fiber composite,  $0.01 X_0$  thickness, spherical geometry,  $R = 2.2 \text{ m}$
- Photon detector: Phillips XP1911/UV PMTs, 0.75"-diameter (15 mm active diameter). Hexagonal close-packed arrangement, packing fraction  $\sim 0.38$ . Light-collecting funnels increase collection efficiency/effective packing fraction to  $\sim 0.60$

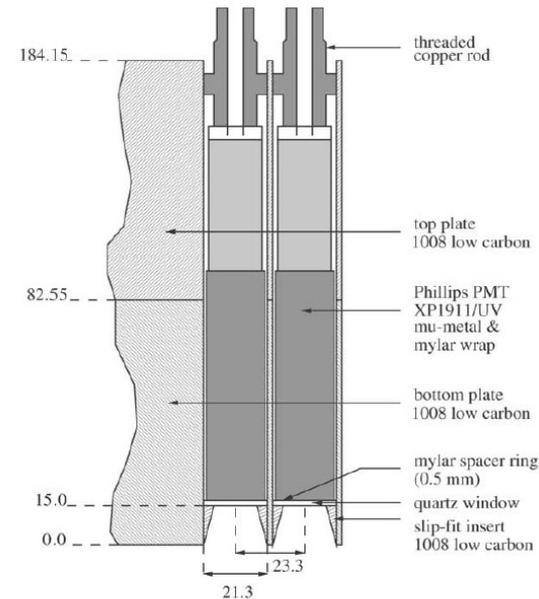
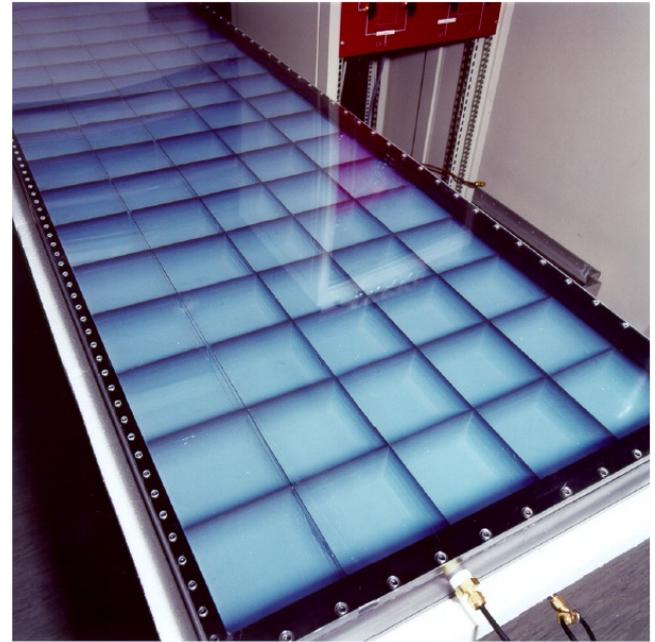


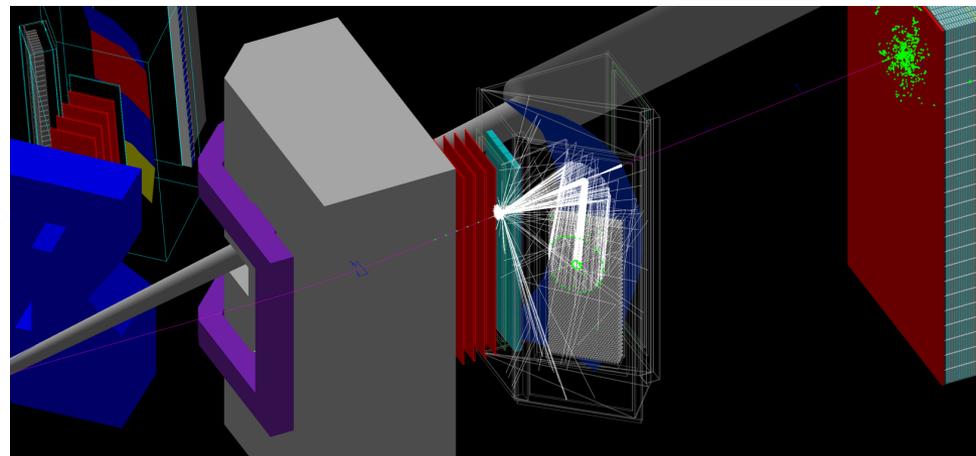
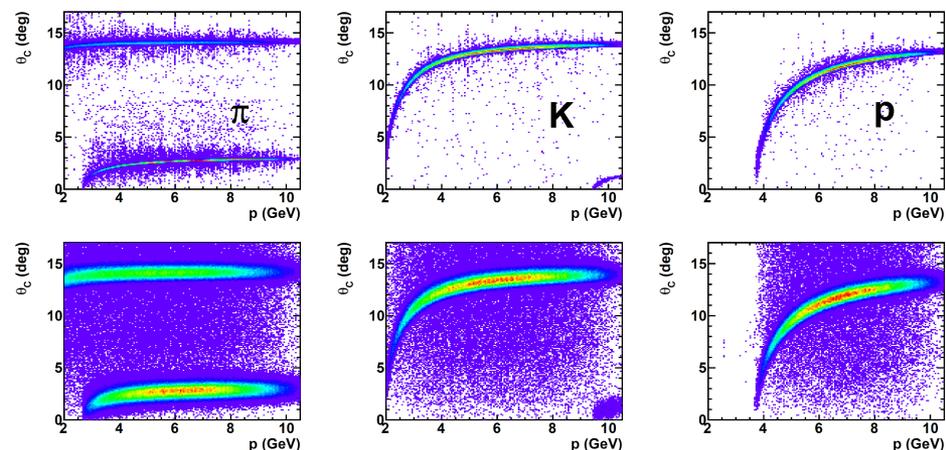
Fig. 7. Schematic photon detector design. All units are in mm.

# SBS RICH Detector Photos

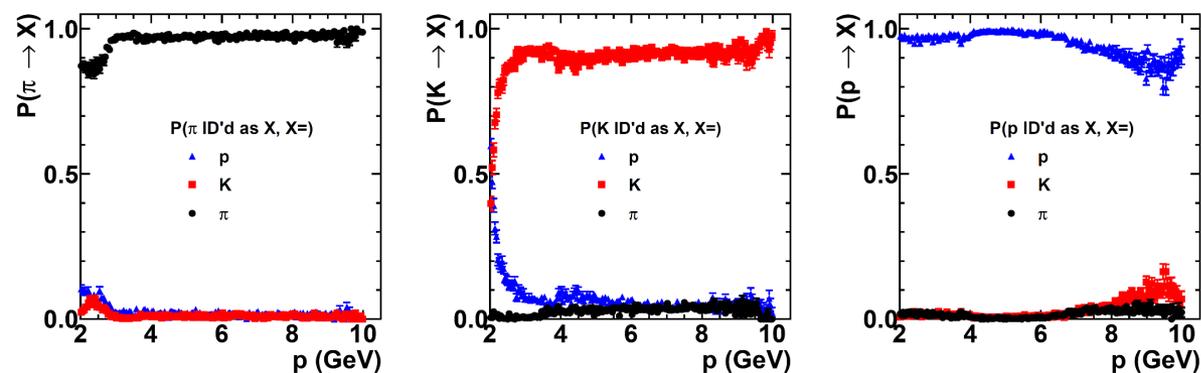


- Above, left: Old picture of one half of RICH with aerogel wall removed
- Above, right: Old picture of one aerogel wall w/containment vessel
- Bottom right: RICH delivery to storage facility @UVA, 2009

# HERMES RICH in SBS—Monte Carlo



## GEANT4-simulated RICH performance in SBS

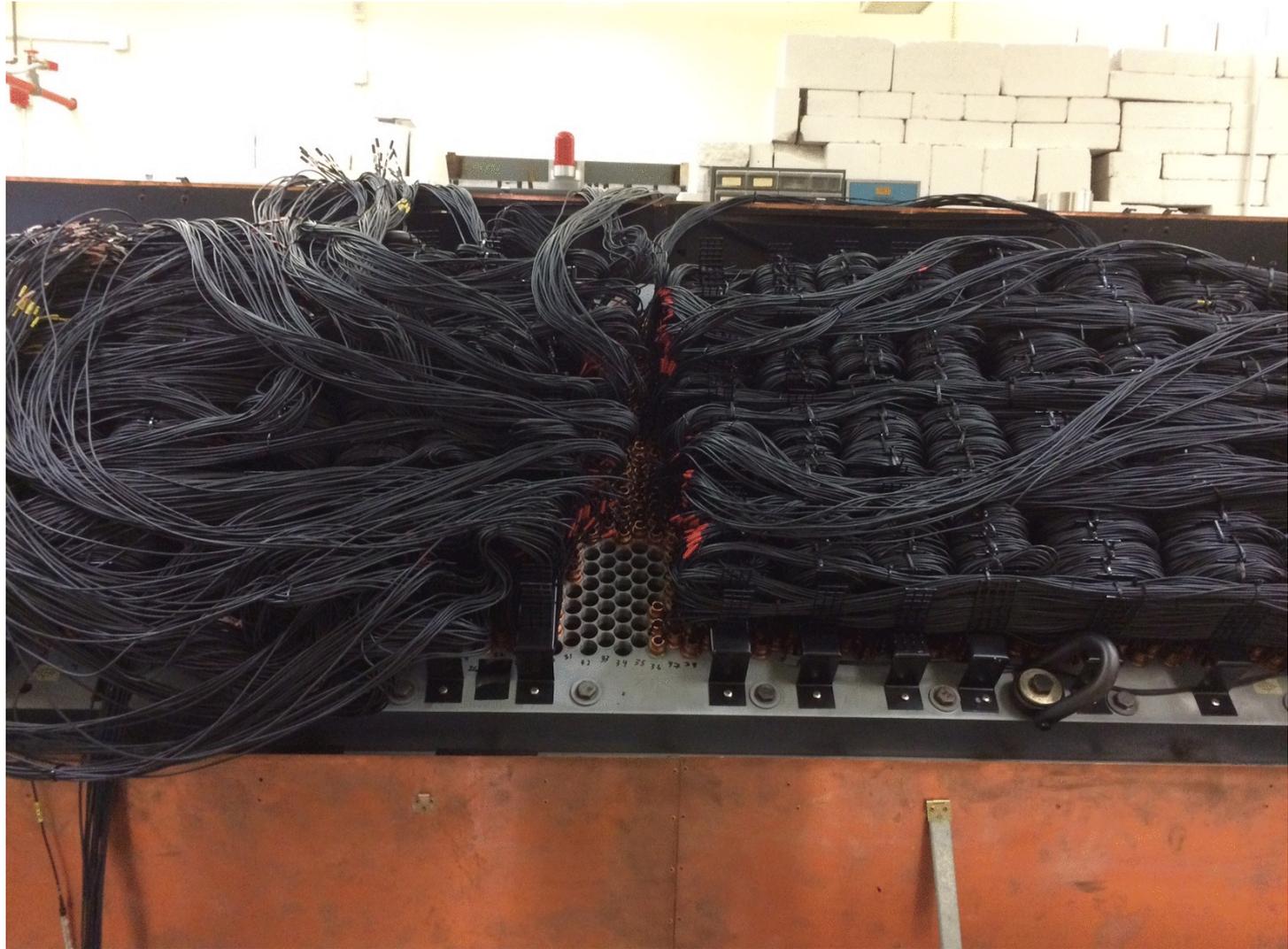


## Simulated RICH PID performance in SBS for $\pi/K/p$



HERMES/SBS RICH @Uconn, ca. 2014

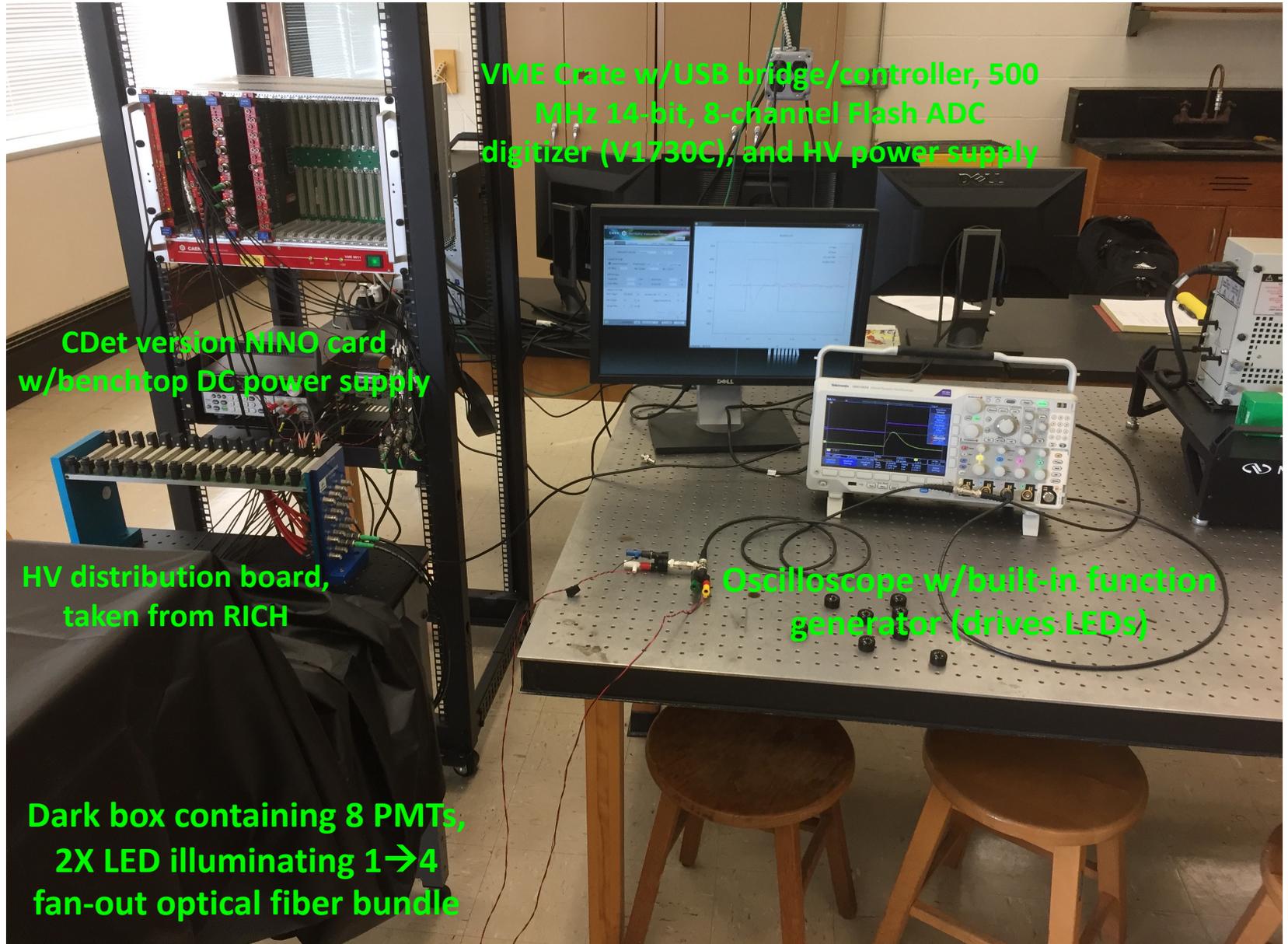
# Decabling the RICH/PMT Removal (June 2016)



# RICH PMTs



# RICH PMT test stand @UConn (pulsed LED setup, ca. 2016)



VME Crate w/USB bridge/controller, 500 MHz 14-bit, 8-channel Flash ADC digitizer (V1730C), and HV power supply

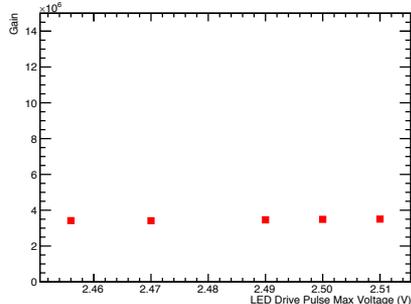
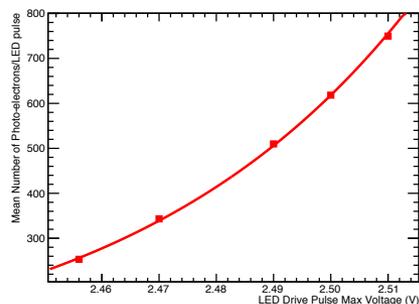
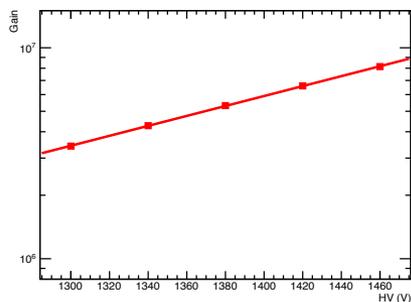
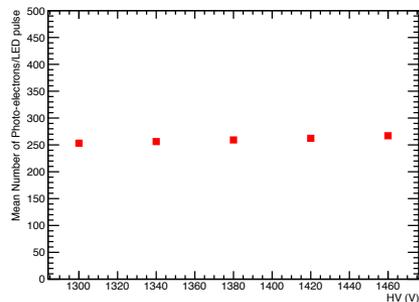
CDet version NINO card w/benchtop DC power supply

HV distribution board, taken from RICH

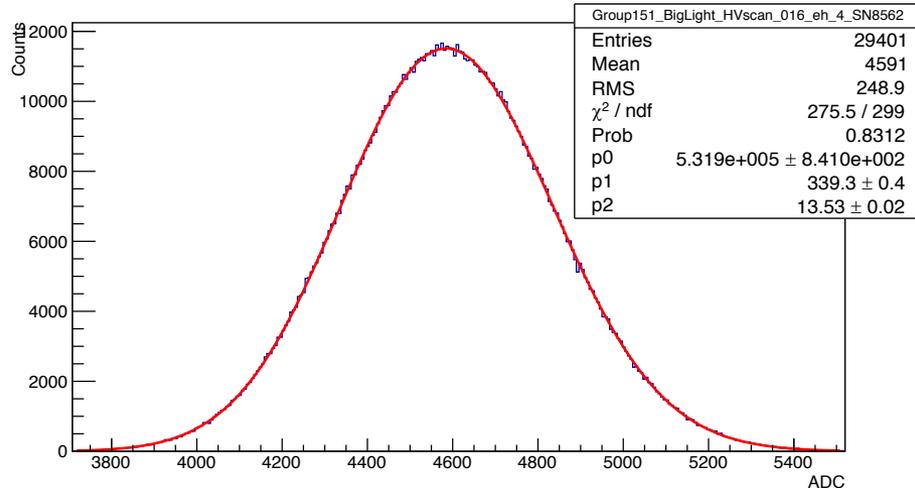
Oscilloscope w/built-in function generator (drives LEDs)

Dark box containing 8 PMTs, 2X LED illuminating 1→4 fan-out optical fiber bundle

# Gain and photoelectron yield estimates in 2016 pulsed LED setup



Group 151, S/N 8562: ADC - Ped (80fC), HV Group 0, 1300V , AFG 2.48V



- Example Poisson fit to ADC spectrum:

$$P(\text{ADC}) = N \frac{(\mu)^{\frac{\text{ADC}}{G}} e^{-\mu}}{\left(\frac{\text{ADC}}{G}\right)!}$$

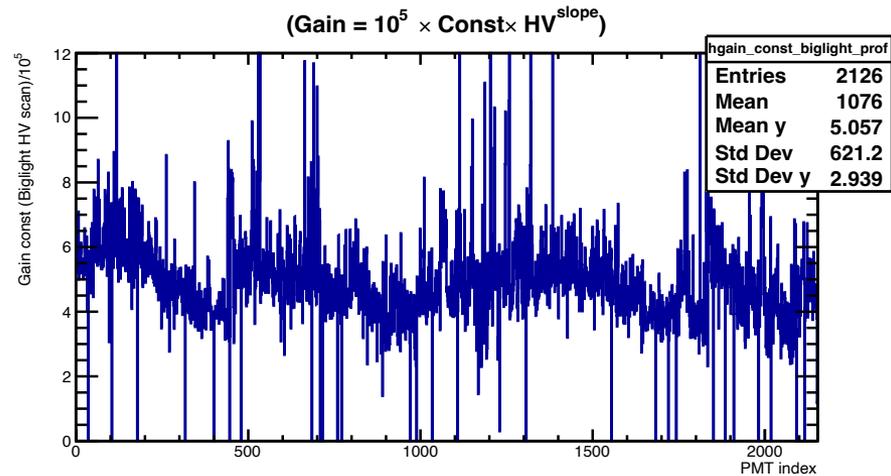
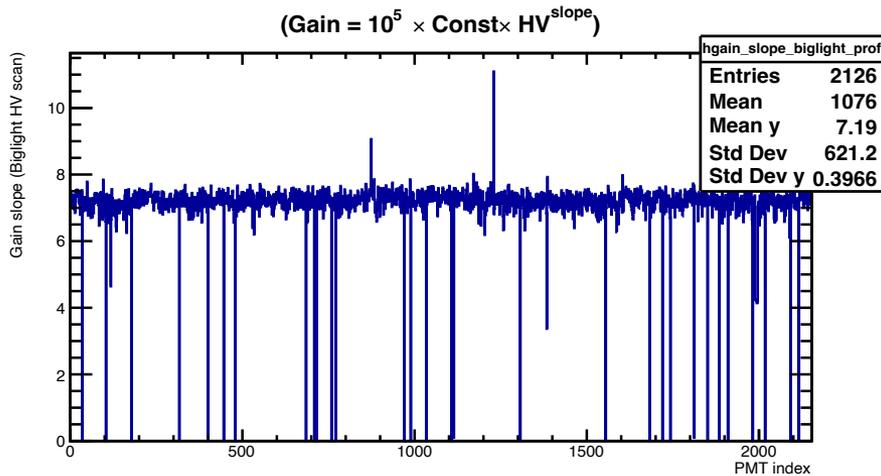
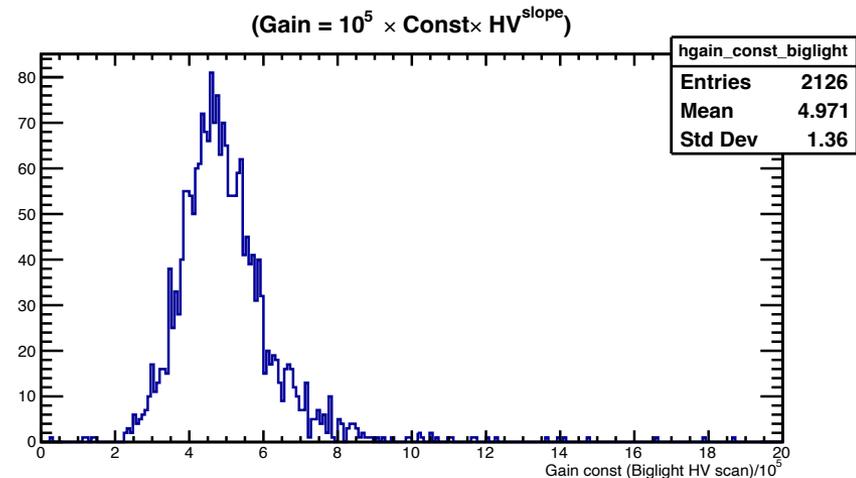
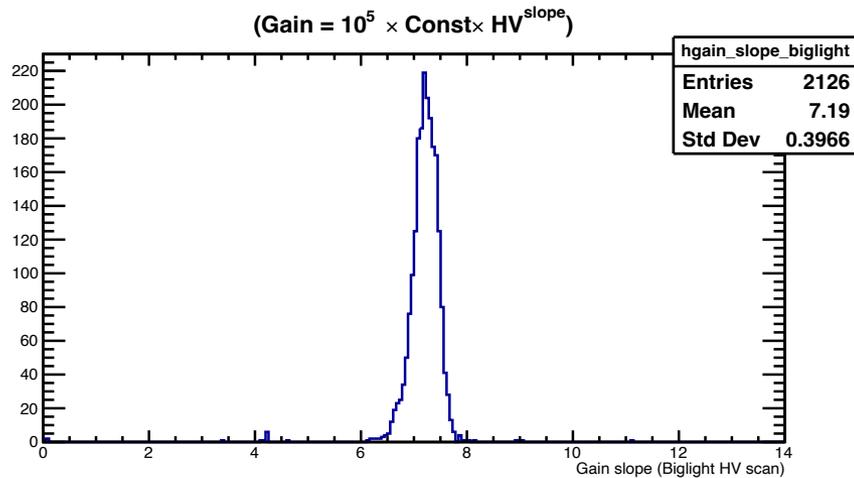
$$N = p_0 = \text{Normalization}$$

$$\mu = p_1 = \text{Mean number of photoelectrons}$$

$$G = p_2 = \text{"Gain"} \text{ (proportional to actual gain)}$$

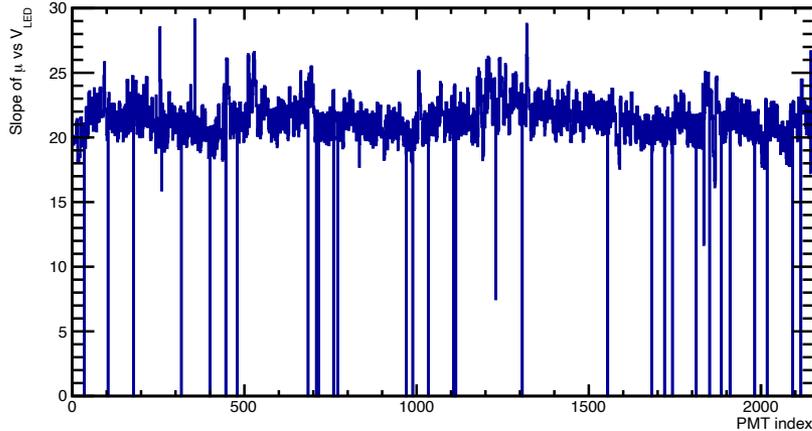
- Light-level scan at constant HV
- HV scan at constant light level

# Gain results (2016 pulsed LED data)

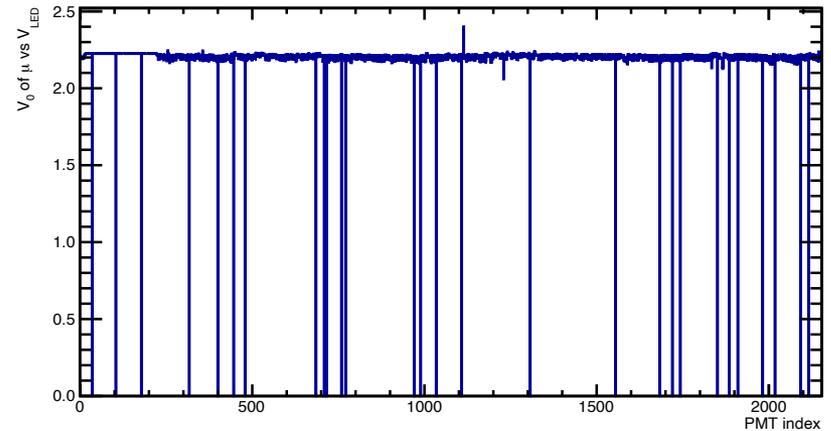


# LED voltage scan results (2016 pulsed LED data)

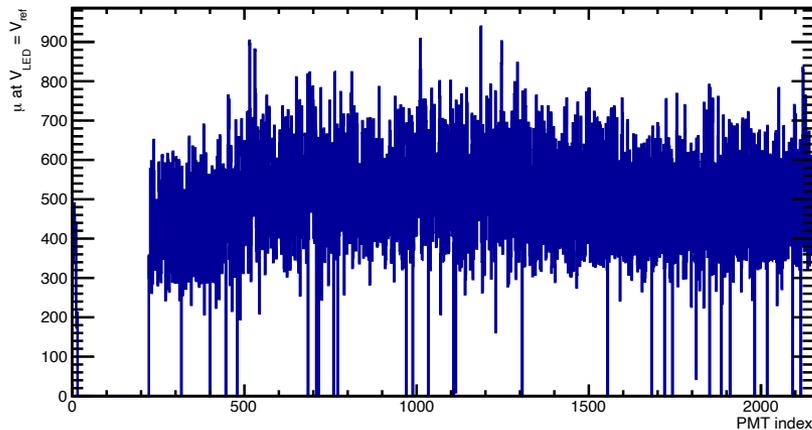
Slope of LED exponential fit



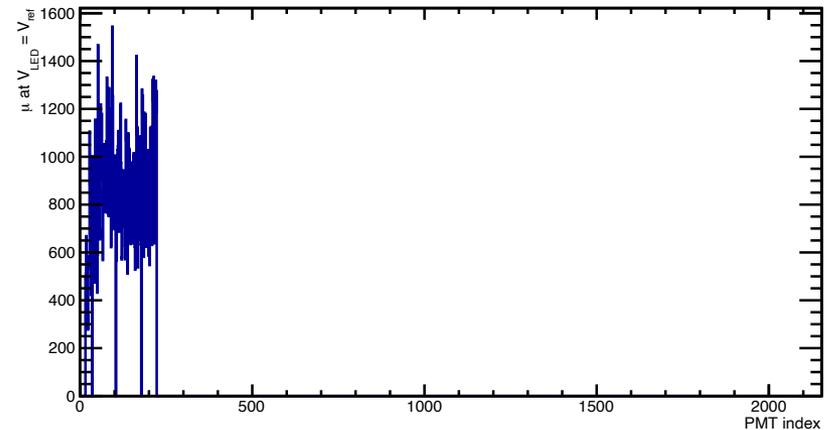
Turn-on voltage of LED exponential fit



Mean number of Photoelectrons at reference  $V_{LED} = 2.5$  V



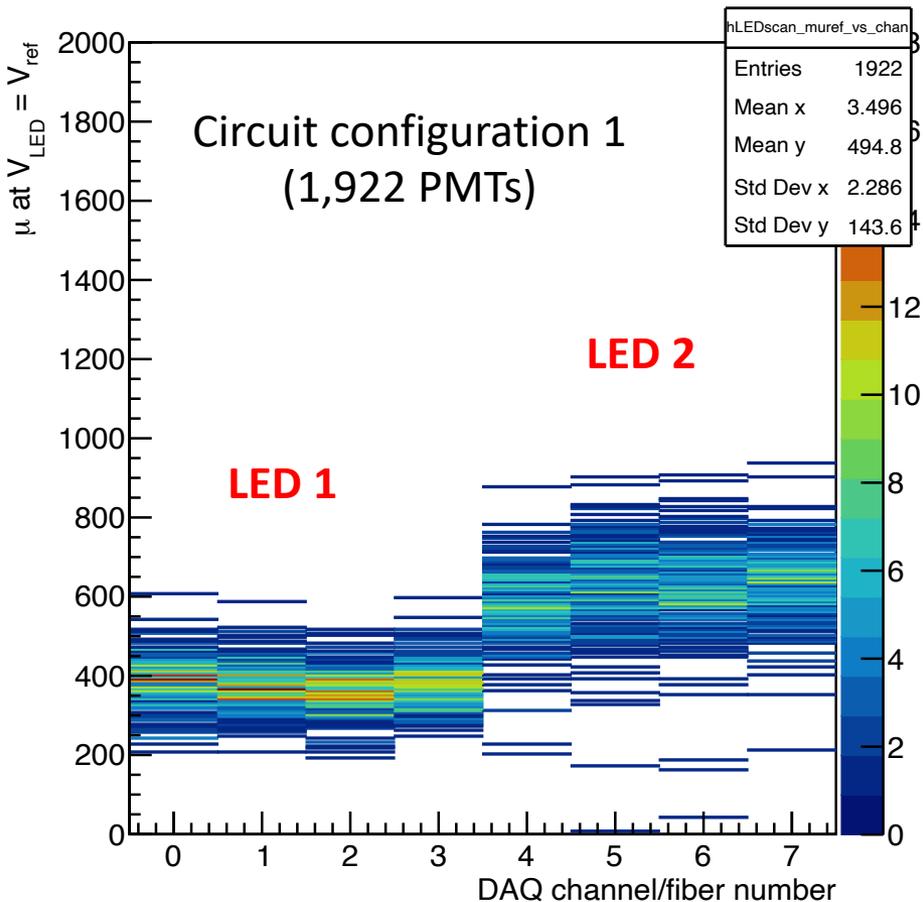
Mean number of Photoelectrons at reference  $V_{LED} = 2.75$  V



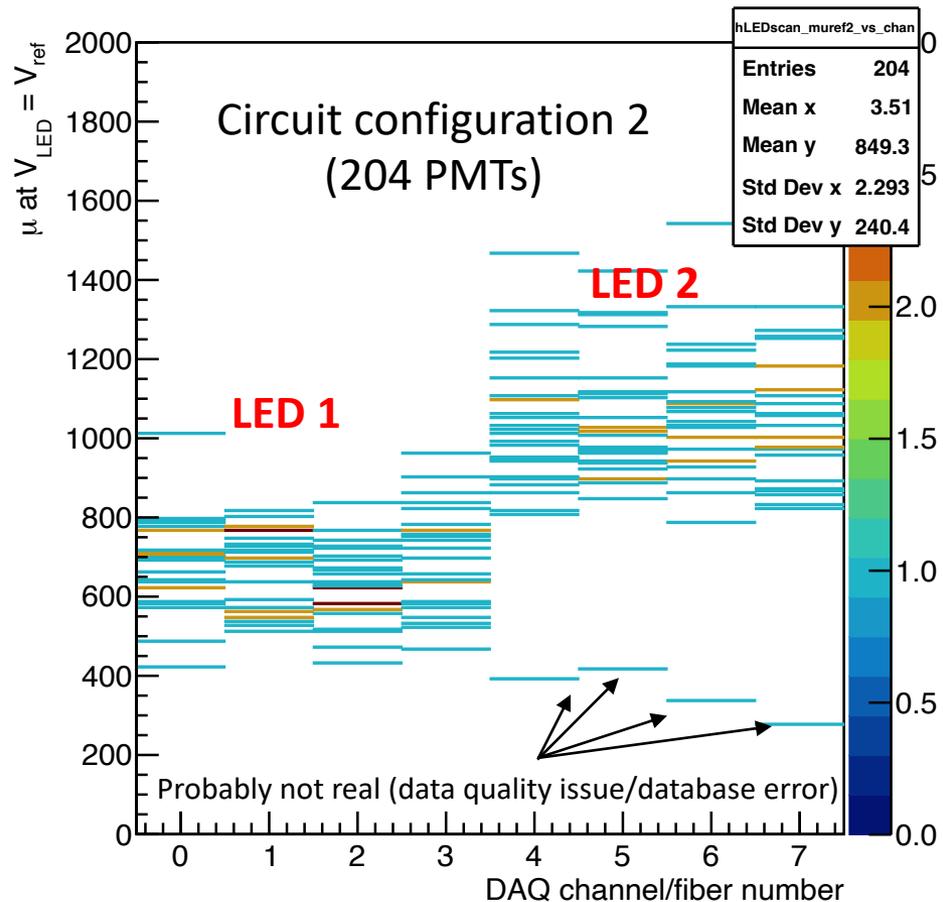
- Two slightly different LED circuit configurations lead to different relation between LED bias voltage and photoelectron yield; therefore yields between the two configurations cannot be directly compared.

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

Mean number of Ph.e. at reference VLED = 2.5 V vs. chan



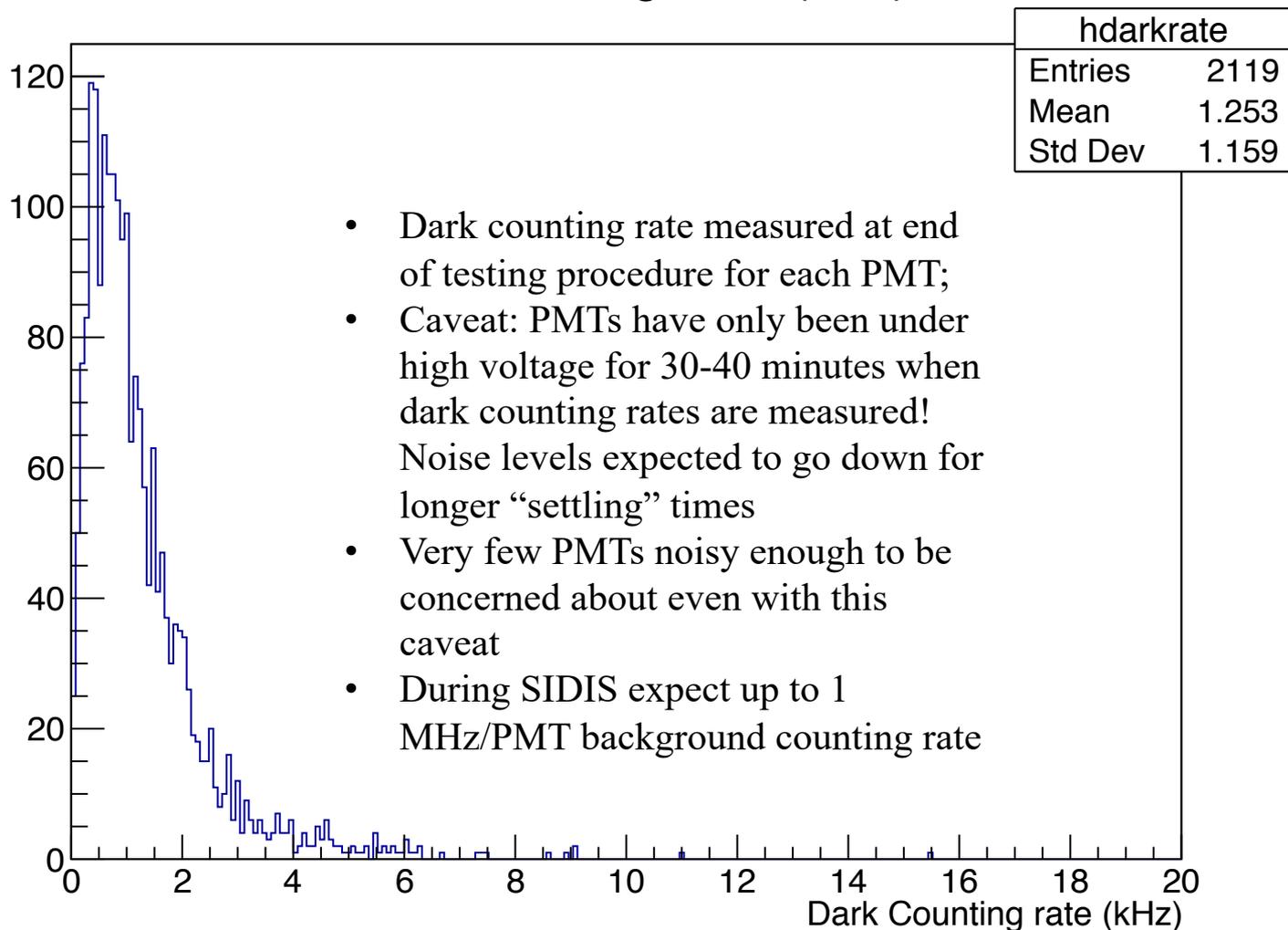
Mean number of Ph.e. at reference VLED = 2.75 V vs. chan



- 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

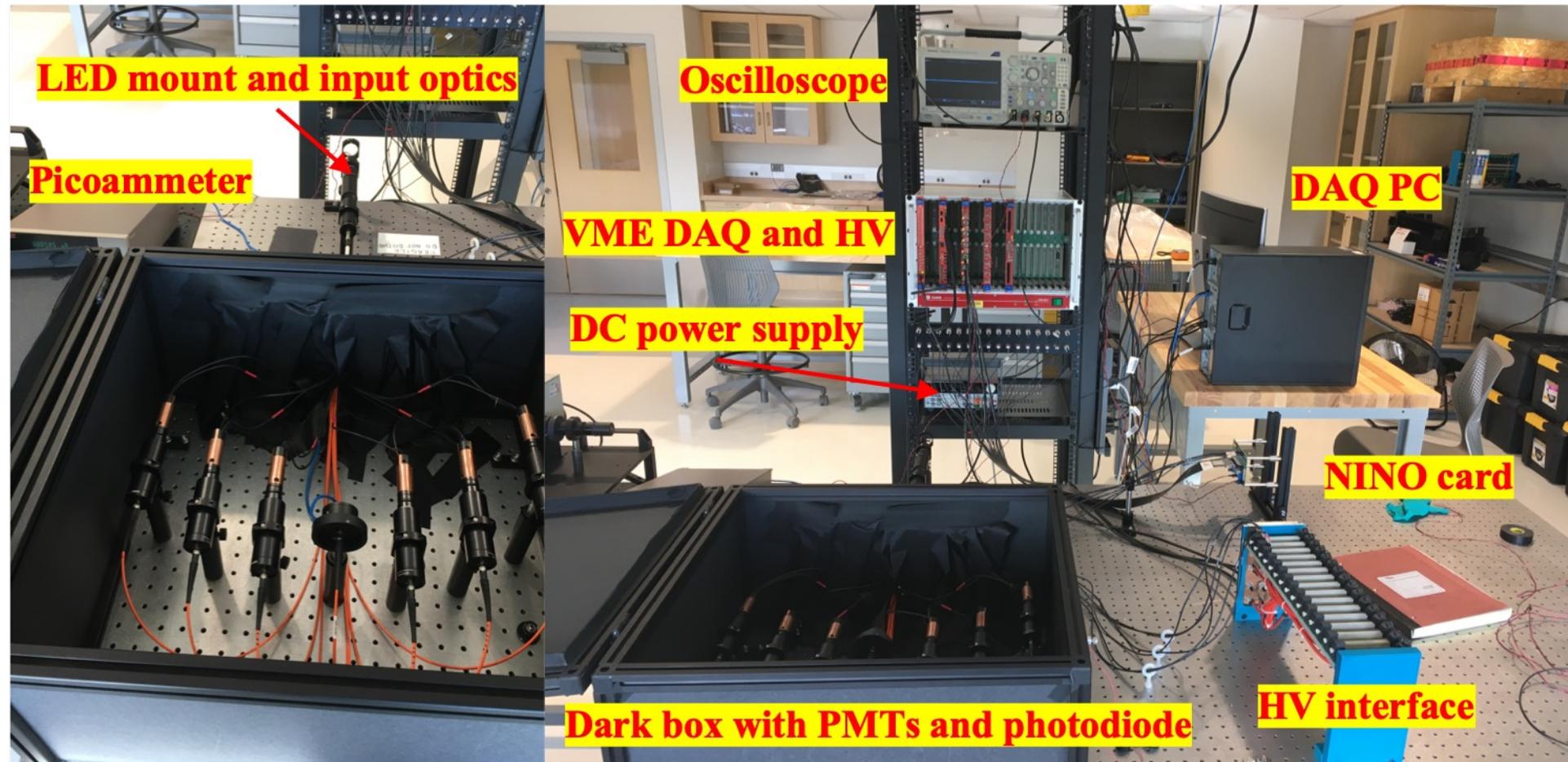
## Dark Counting Rate (kHz)



# RICH move to JLab—Delivery to ESB, April 2018

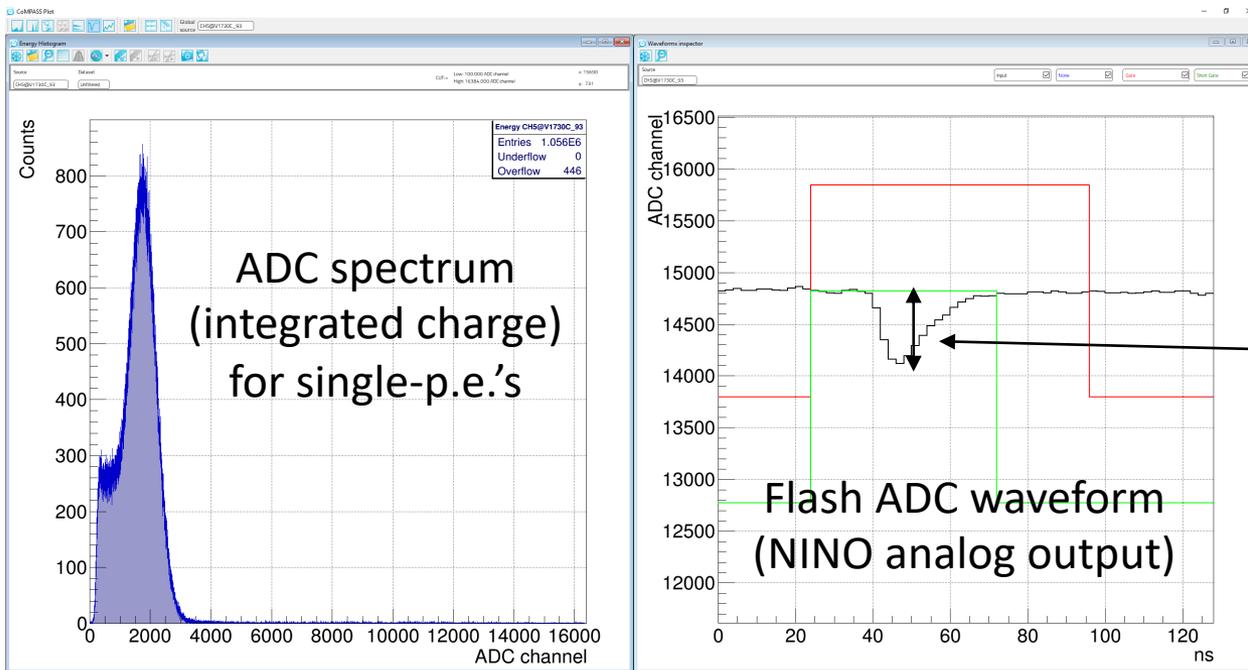


# PMT “Absolute” Quantum Efficiency Setup—2018-2020



- 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  $\sim 21$  mV ( $\sim 5$  mV raw PMT signal with NINO amplifier gain of 4X)

## Online DAQ rate monitoring

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

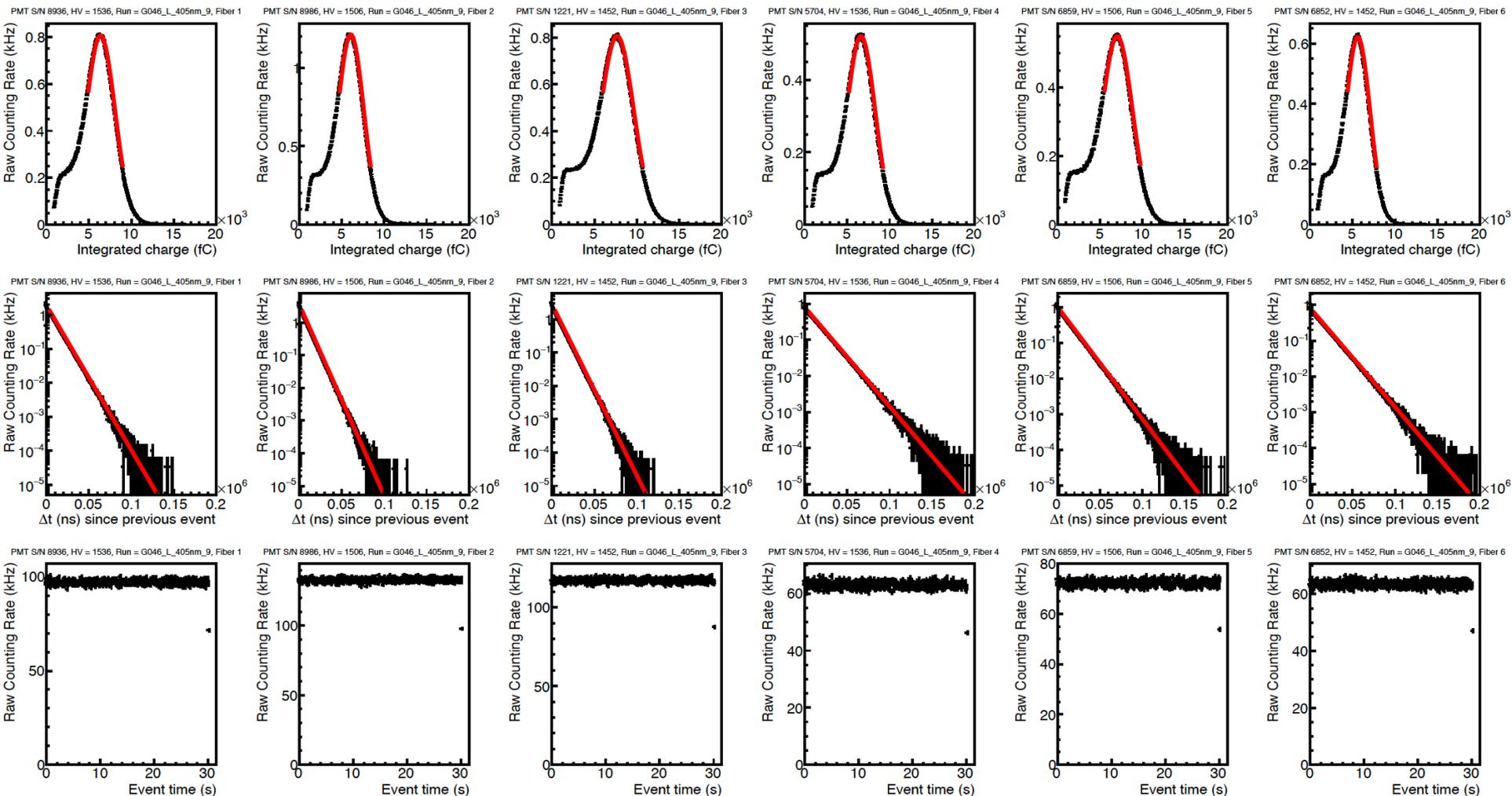
BOARD: V1730C\_93 READOUT: 4.193 MB/s

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

Data acquisition is running

E:\DATA\RAWDATA\_2020

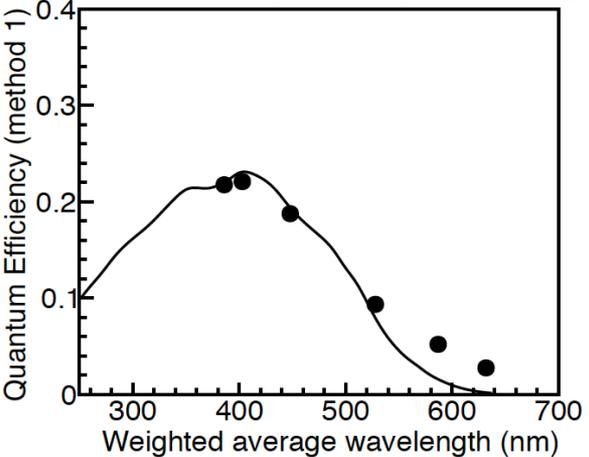
# Typical QE Measurement Run with 6 PMTs (30 seconds)



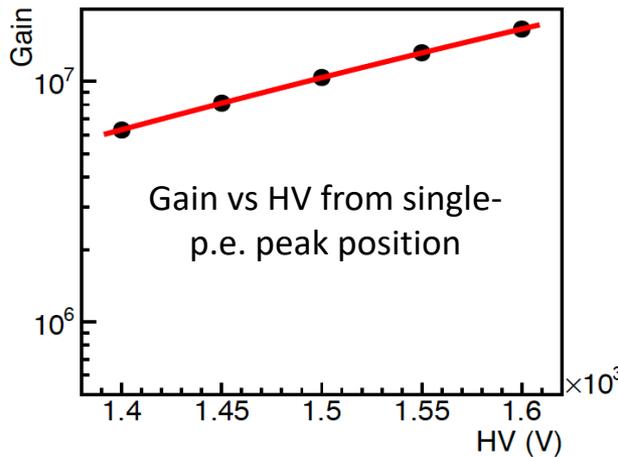
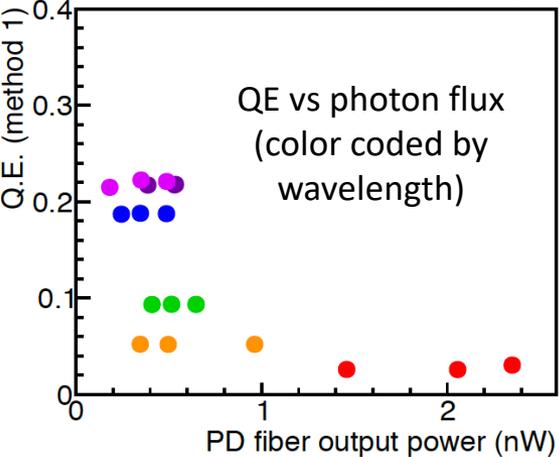
- Top: Single-photoelectron charge spectra (after rough gain matching)
- Middle: Distribution of time differences between consecutive single-photon detections
- Bottom: Raw single-photoelectron counting rate vs. time during a 30-s run

# Typical QE Measurement Results for a Single PMT

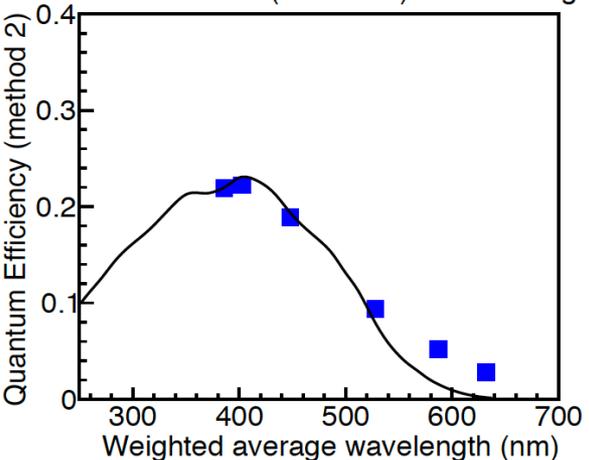
PMT S/N 6859 Q.E. (method 1) vs wavelength



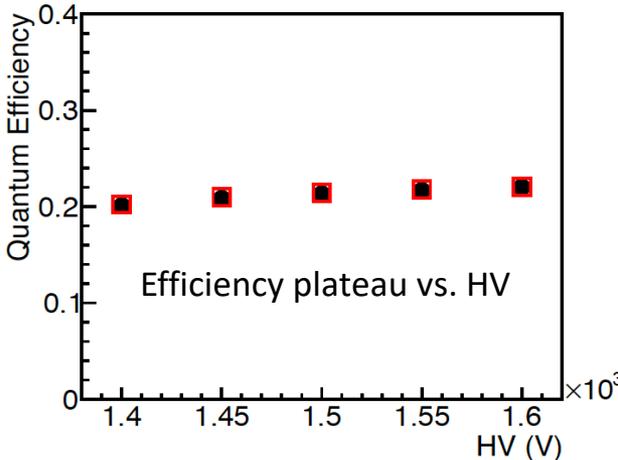
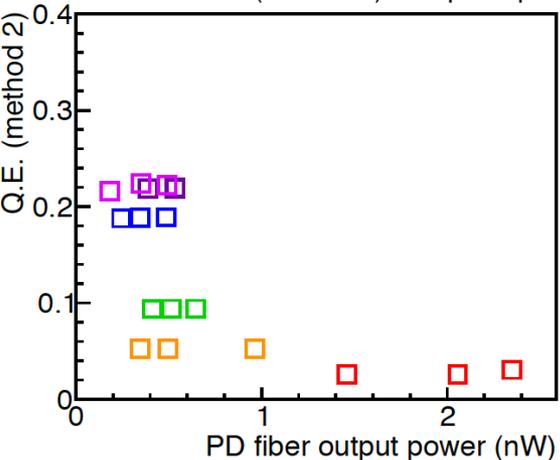
PMT S/N 6859 Q.E. (method 1) vs. optical power



PMT S/N 6859 Q.E. (method 2) vs wavelength

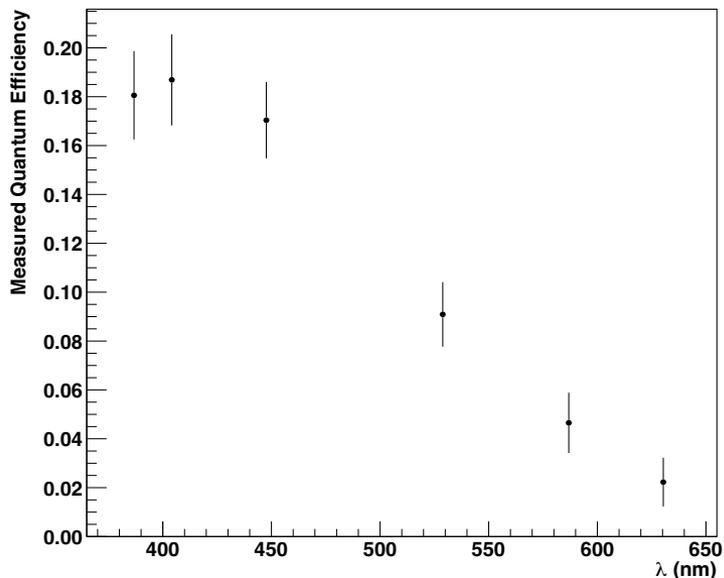


PMT S/N 6859 Q.E. (method 2) vs. optical power

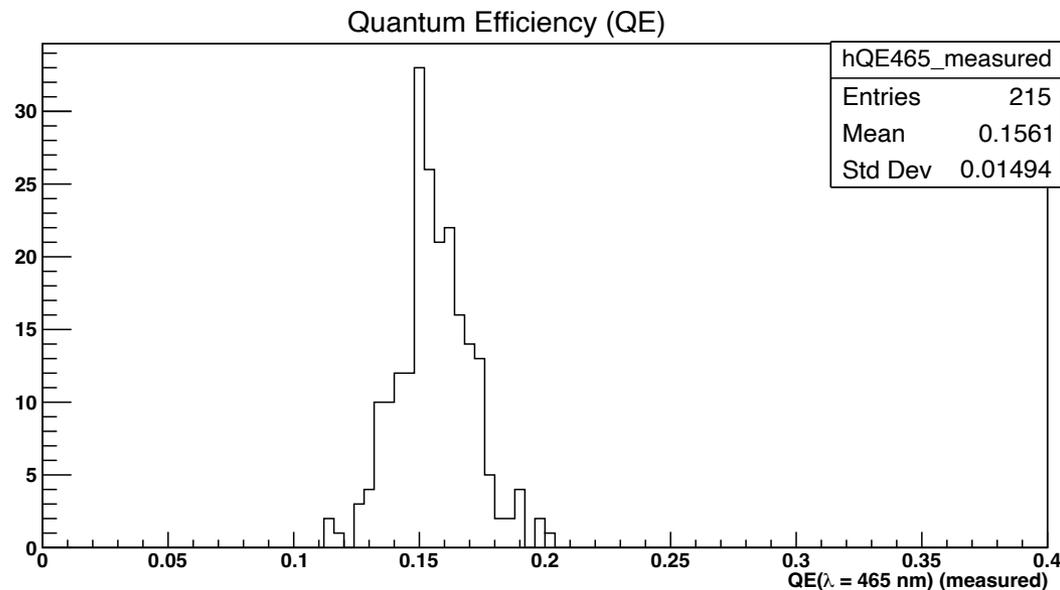


- “Method 1” = Slope of exponential distribution of time differences between random photon detections—Free of deadtime corrections
- “Method 2” = Average PMT counting rate, with (small) deadtime correction

# Aggregate analysis of QE results



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

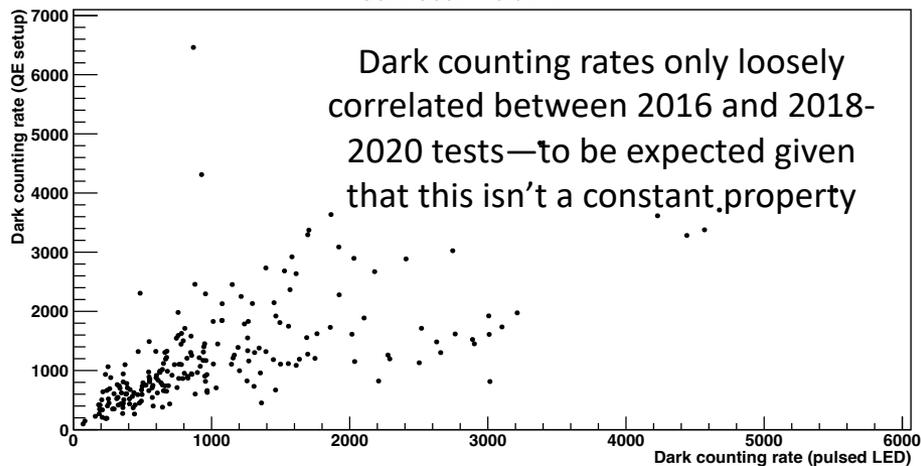


Quantum efficiency interpolated to 465 nm (wavelength of pulsed LED data from 2016)

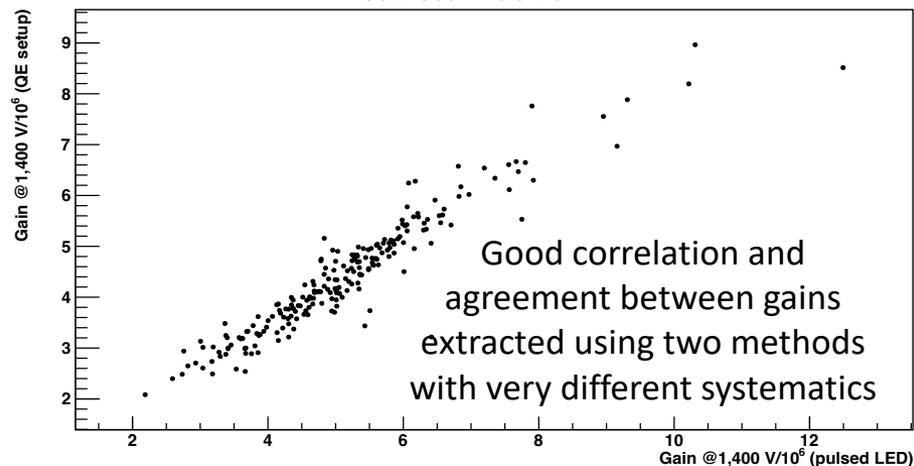
- 215 PMTs tested in absolute QE setup so far; mostly by UConn undergraduates.
- Of those tested, mean QE interpolated to a common wavelength of 465 nm is 15.6%, standard deviation 1.5% (~10% relative to the mean)
- By comparing photoelectron yields from PMTs measured in the QE setup to others viewing 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

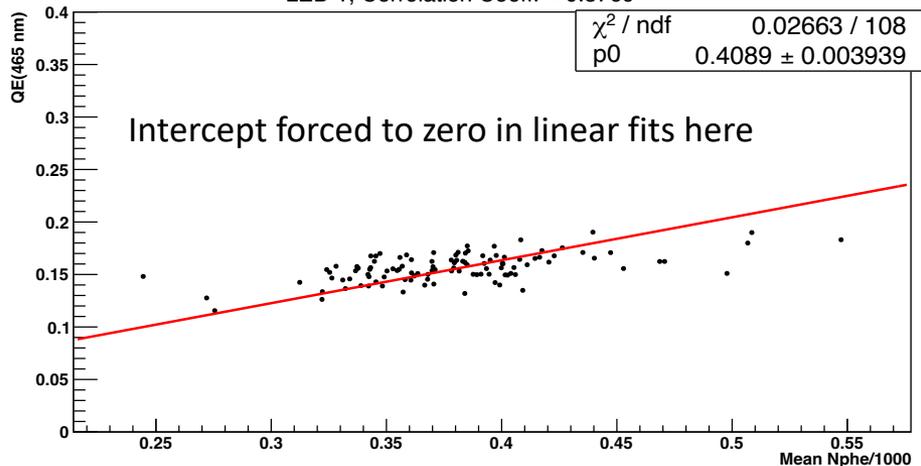
Corr. Coeff = 0.6417



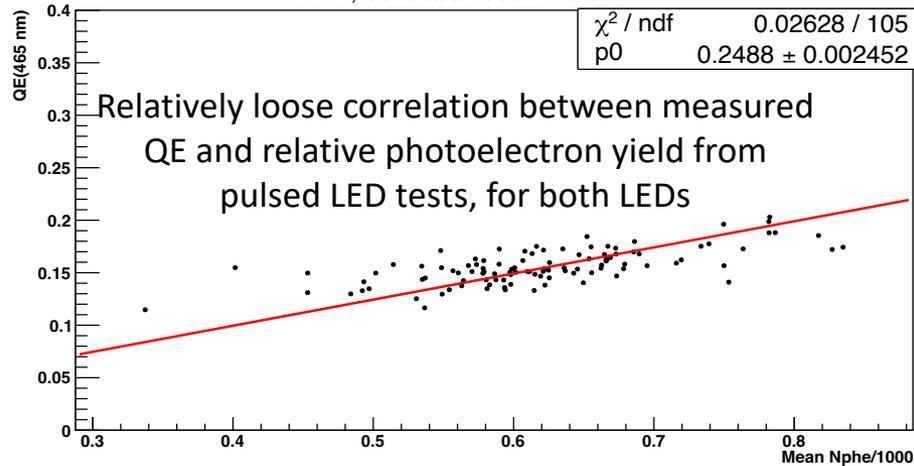
Corr. Coeff = 0.9476



LED 1, Correlation Coeff. = 0.5769

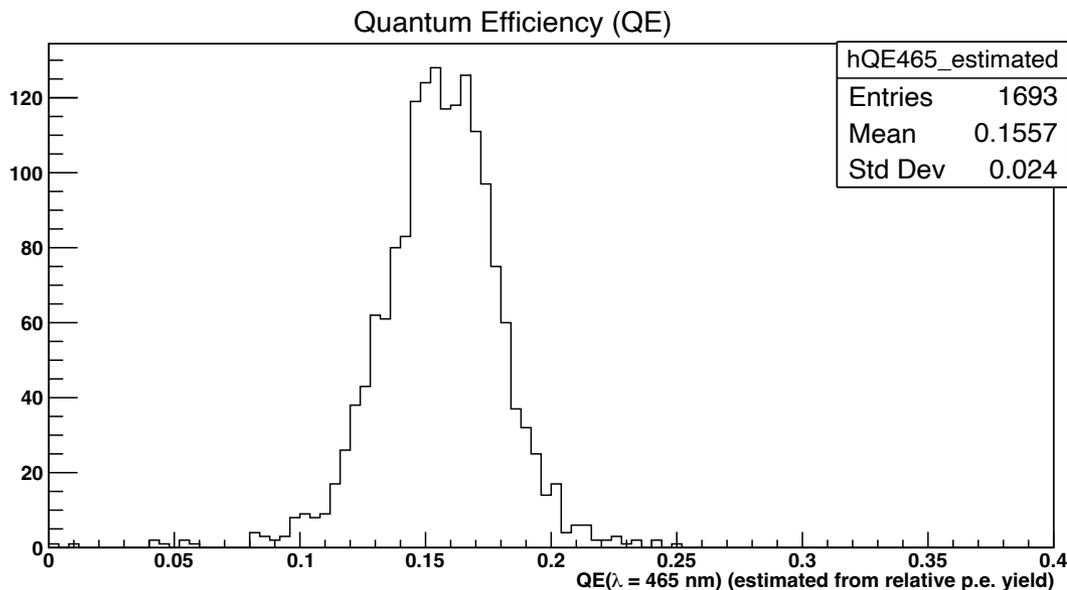


LED 2, Correlation Coeff. = 0.6867



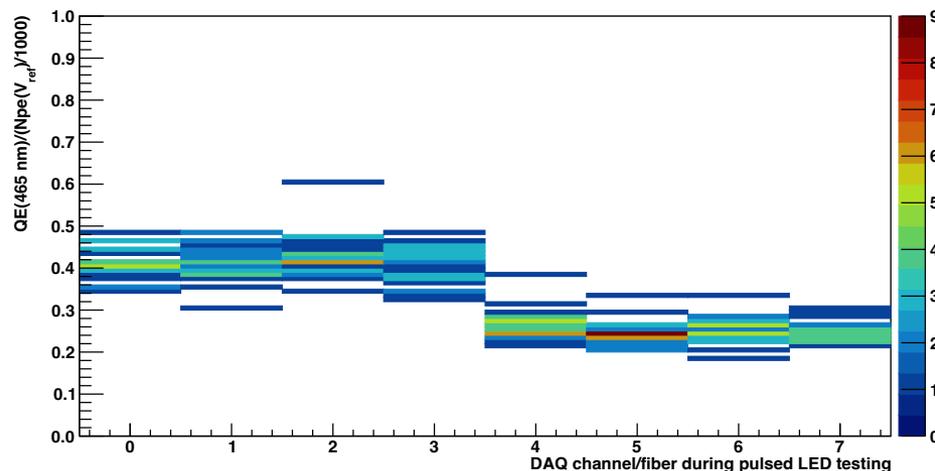
- For the subset of PMTs tested in both absolute QE setup and pulsed LED setup, worth looking at repeatability of common measurements and correlation between relative photoelectron yield at reference LED voltage and measured quantum efficiency interpolated to 465 nm

# Estimated Quantum efficiency for other PMTs

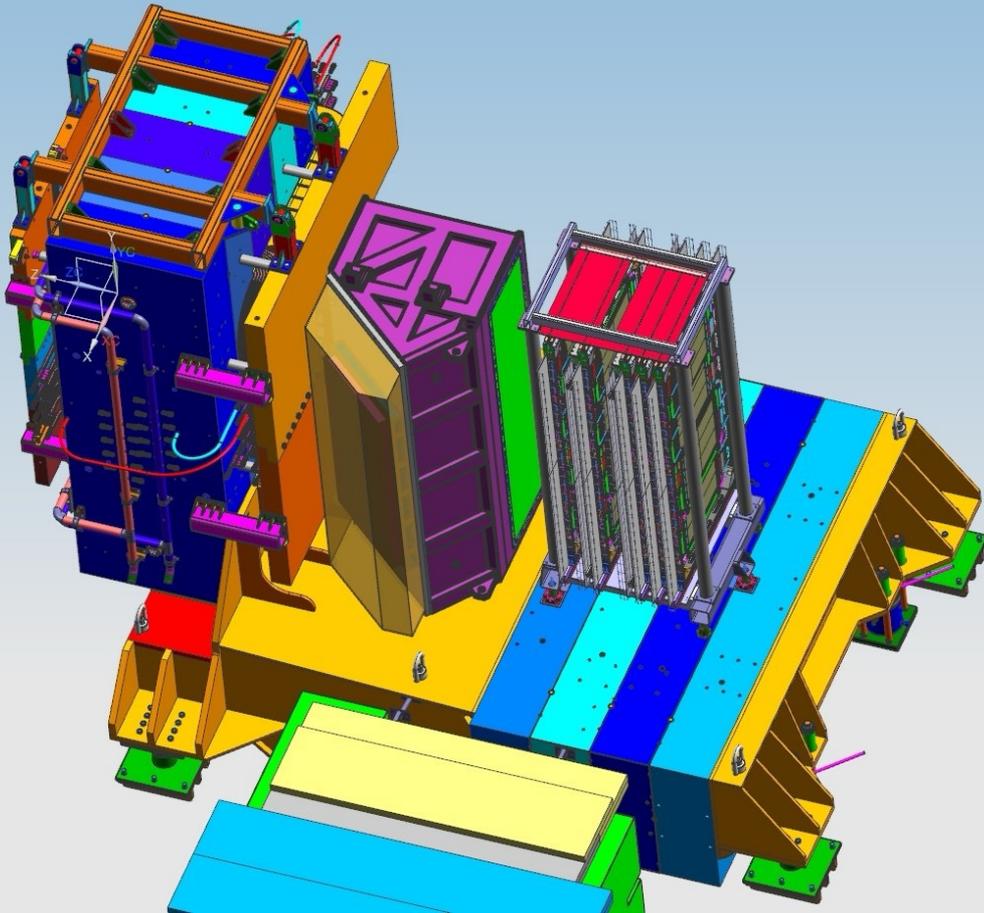


- Absolute QE measurements for 215 PMTs so far allow us to estimate QE @465 nm for approximately 1,700 other PMTs
- Approximately 200 other PMTs tested with slightly different LED driving circuit cannot be directly compared to any of the PMTs measured in absolute QE setup so far.

- 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**



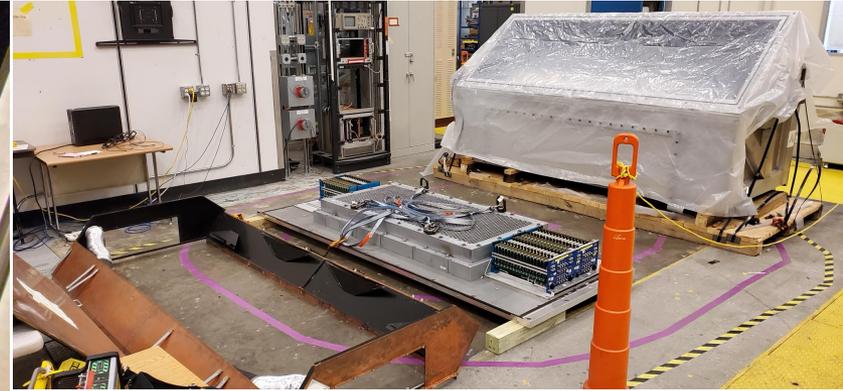
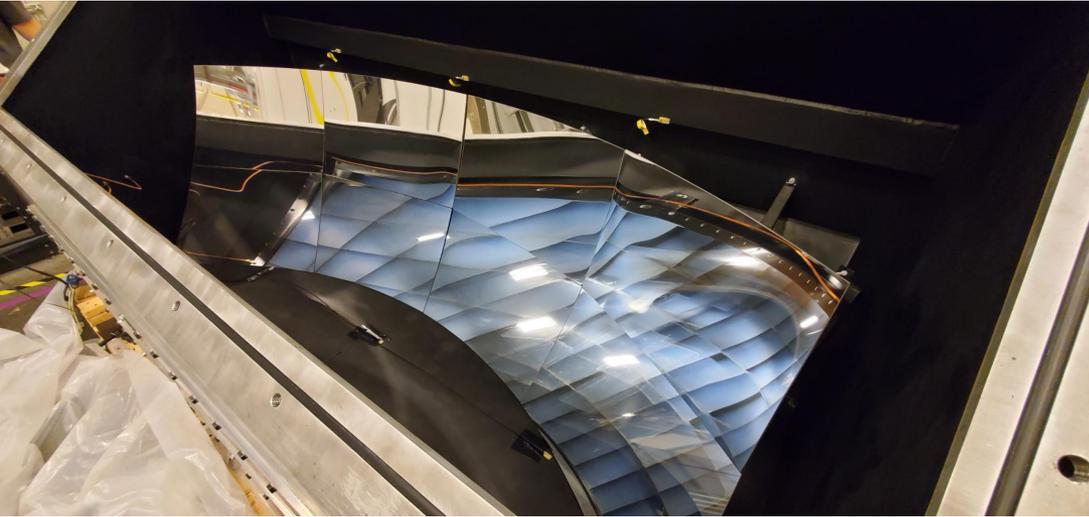
# HERMES RICH in SBS



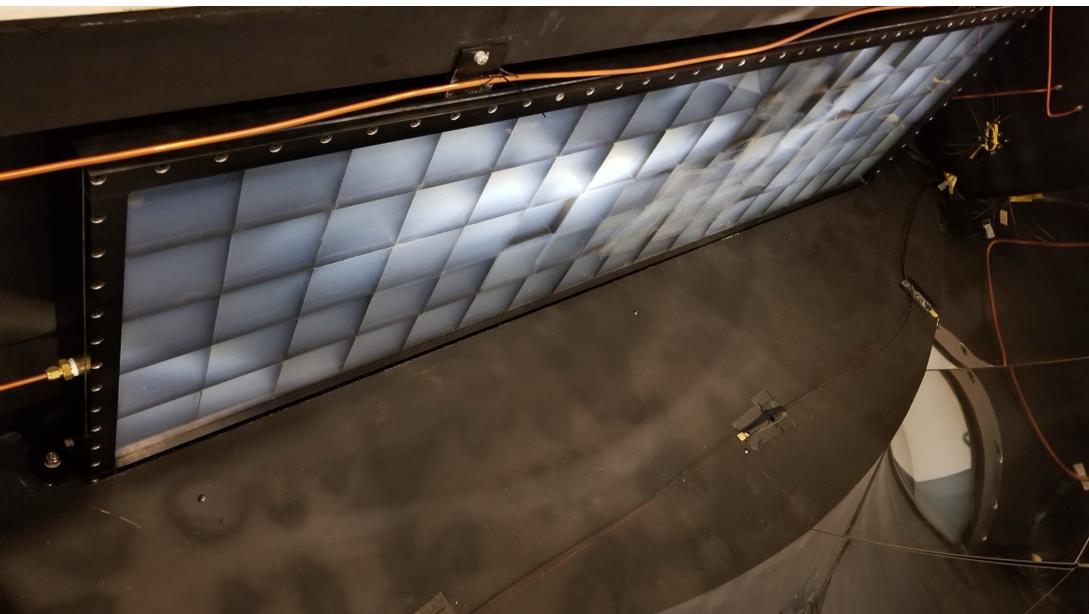
CAD drawing of SBS RICH in SIDIS

- HERMES RICH entry window is acceptance-limiting aperture at  $\sim 46 \times 190$  cm—makes sense to locate RICH *in front of* tracker  $\rightarrow$  However, space will be tight for cable-routing, NINO card mounting, etc.
- Need to evaluate fringe field and magnetic shielding at proposed RICH location
- Assemble tracker from UVA X/Y SBS GEM layers (6 should be sufficient for SIDIS luminosity but we can use more)
- Re-use NINO cards and VETROC electronics from CDET

# Opening the RICH in testlab—2022



- Above, left: spherical mirror array *appears* in good shape
- Above, right: PMT mount plate removed
- Below, left: some aerogel tiles found to have moved/cracked (fortunately we have the other intact aerogel wall at Uconn)



# RICH power supply/electronics needs

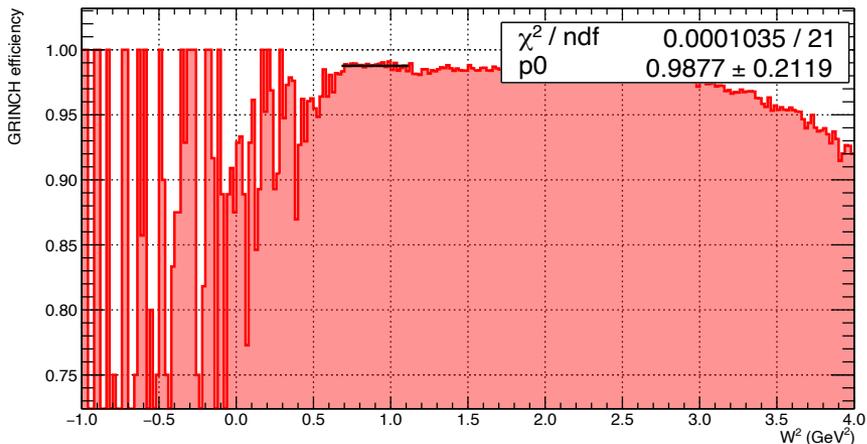
- 1,934 PMTs (plus ~220 spares) exist
- HV supply considerations: RICH PMTs require *positive* HV, typical operating HV 1,300-1,700 V to be in “plateau” region for maximum single-photoelectron efficiency (maximum 1.9 kV according to manufacturer datasheet)
  - HV divider ~38 M $\Omega$ , typical divider current draw ~40  $\mu$ A @1,500 V
  - Typical dark counting rate ~1-2 kHz in UConn test setup
  - Power 32 PMTs on a single HV channel; group PMTs with similar gains together on the same power supply  $\rightarrow$  HV supply must support up to 2 kV at up to ~3-4 mA  $\rightarrow$  required number of positive HV channels is 61 (would need some spares as well)
  - Expected counting rate under SIDIS conditions: ~few hundred kHz/PMT, mostly single p.e.
  - For safety margin, let’s assume 1 MHz/PMT.
  - Typical PMT gain at typical HV of 1.5 kV to be in single-p.e. efficiency plateau is  $\sim 8.5 \times 10^6$
  - Implied anode current under SIDIS luminosity condition, assuming 1 MHz of single p.e. per PMT, is of order 1-few  $\mu$ A per PMT.
- RICH only *requires* timing readout as most signals are single-p.e.
- Default plan is to re-use NINO front-end amplifier/discriminator cards and VETROC modules from CDET (more than sufficient channels exist)
- However, we could also use FADC readout if we happened to have enough channels “just lying around”.
- Expected timing resolution ~1-2 ns under either readout scenario. Effective timing cut for offline analysis  $\sim 5$ -10 ns ( $\sim 10$ -20X smaller timing window than HERMES RICH operation at  $\sim 10^{32}$  cm $^{-2}$ s $^{-1}$ )

# HERMES RICH Status, TO-DO

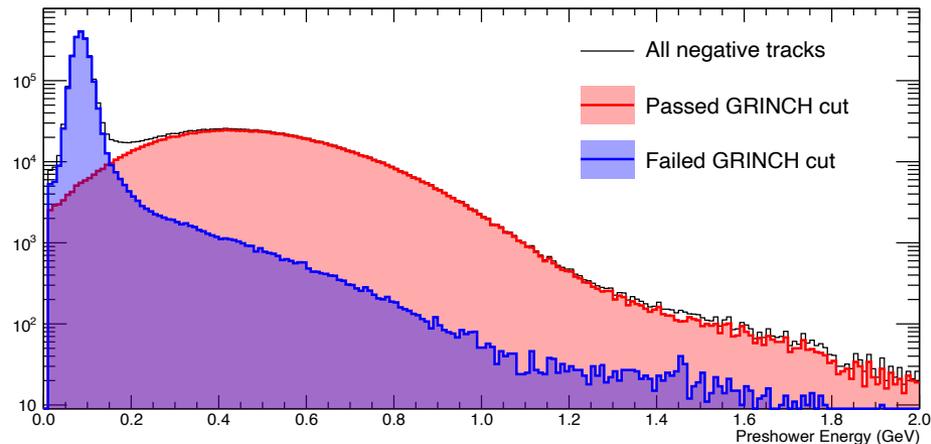
- RICH effort essentially on pause for the last few years due to demands of running the form factor program
- AFAIK, RICH was moved back to storage in ESB at some point during 2025
- Need to arrange appropriate space and infrastructure at JLab (benches, relay racks, power, HV and LV, front-end and readout electronics, etc) to prepare/test RICH with built-in LED system and/or cosmics.
  - When can this start?
  - UConn group can provide workforce for testing/commissioning/etc, but we are just one faculty plus a handful of students and a postdoc at any given time → we will need infrastructure/technical/design support from JLab and/or SBS Collaboration to accomplish RICH preparation/integration work.
- Need to check mirror reflectivity and alignment before re-sealing detector (need to re-open if it was already sealed before moving back to ESB)
- Need to re-crate and (very slowly, carefully) move intact aerogel wall from UConn and install in RICH tank—other aerogel wall is compromised with broken tiles/etc.
- Need to re-start regular SIDIS meetings, work in parallel with  $^3\text{He}$  target development toward ERR/scheduling.
- **Thanks for your attention → Questions?**

# GRINCH Success Demonstrates RICH Feasibility

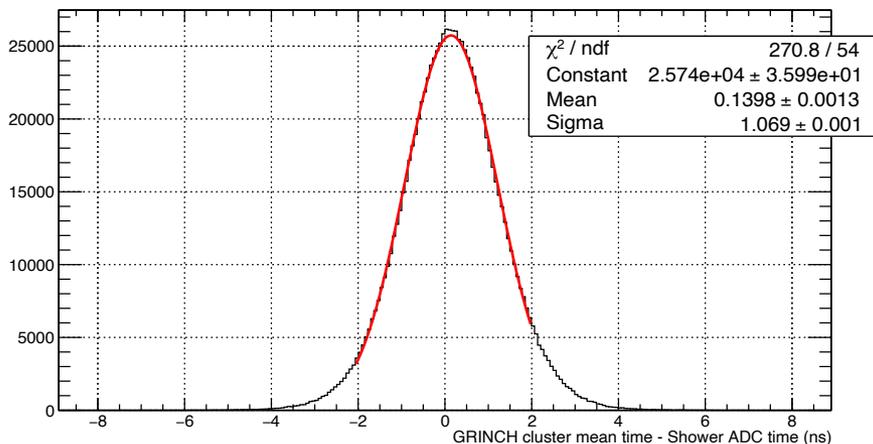
Elastic  $E'_e = 1.6$  GeV



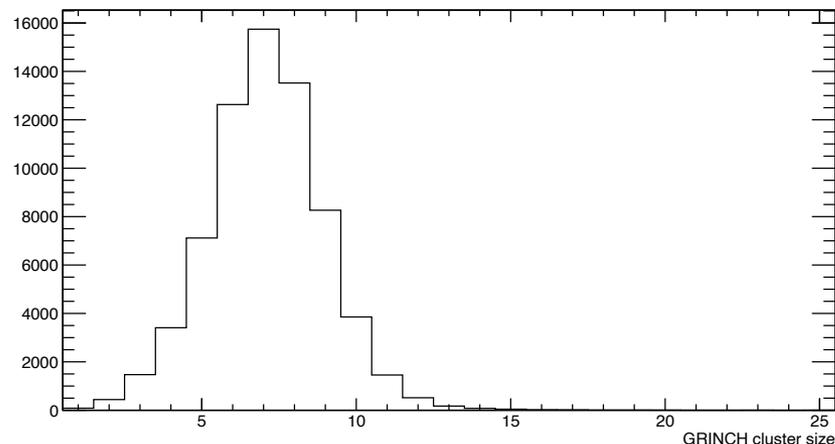
$Q^2 = 4.5$  GeV<sup>2</sup>,  $E = 4$  GeV



Good Electrons



Elastic electrons



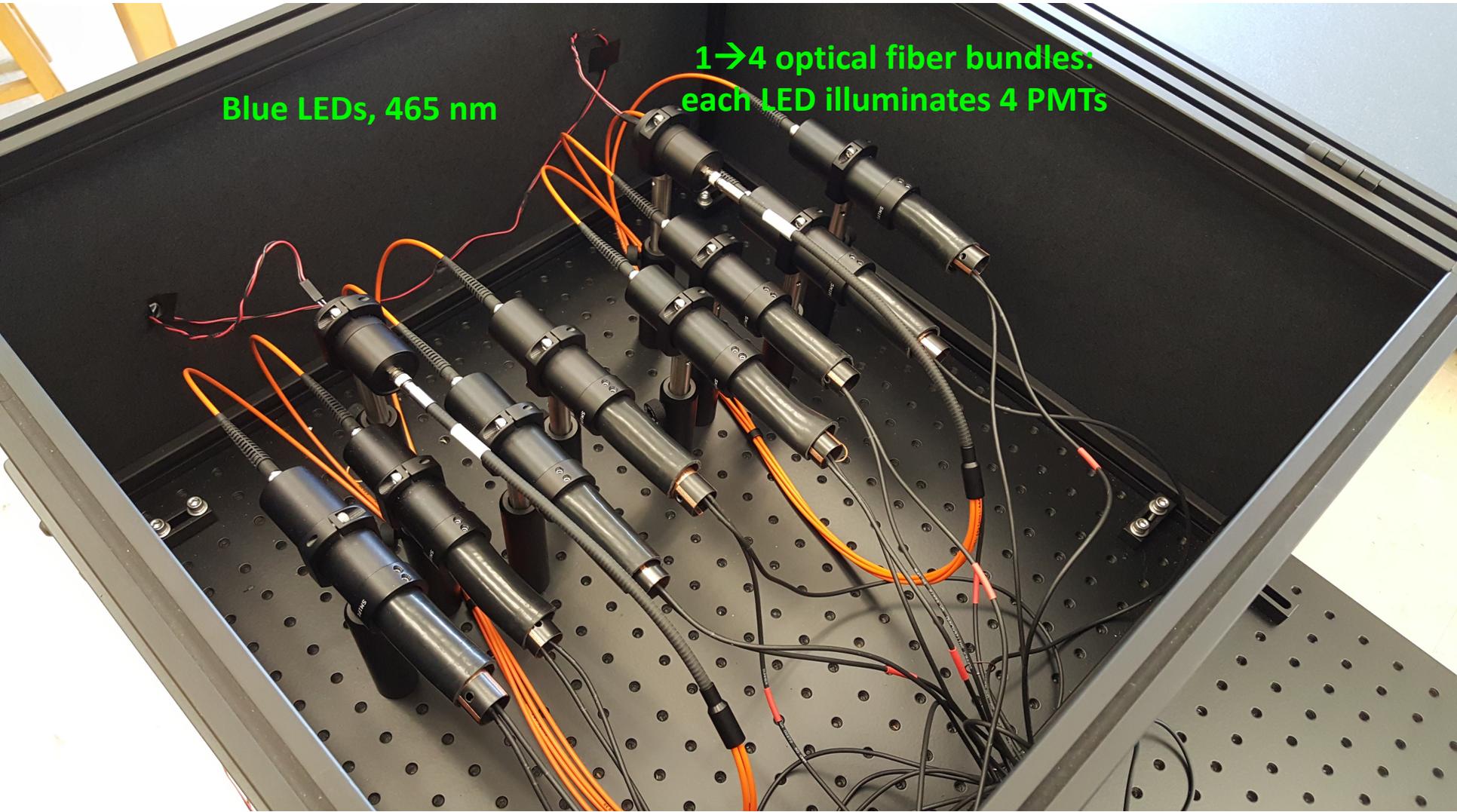
- GRINCH efficiency for 1.6 GeV electrons, track-matched cluster with >2 PMTs ~99%
- Cluster mean time resolution ~1 ns
- Single PMT hit time resolution ~1.8 ns

# Summary and Conclusions

- E12-09-018 is a fully-approved experiment with more beam time than any other experiment in the SBS program.
  - Doesn't need much development, at least on the detector front
  - Just needs a target, and room in the schedule in Hall A or C
- Potentially huge, transformative impact on transverse spin physics, complementary with SOLID/EIC
- All SIDIS detectors (except RICH) already successfully operated under more demanding luminosity conditions.
- GRINCH success proves feasibility of operating highly-segmented Cherenkov counter with single-p.e. signals in SBS luminosity.
- **Personal Opinion: it would be a huge mistake for JLab and the SBS collaboration to neglect this experiment/leave this physics on the table**
- **No progress on transverse target SSA in SIDIS since start of JLab 12 GeV**
- **Foolish not to pick the low-hanging fruit of E12-09-018—bread-and-butter hadron structure physics, can run soon with effort/commitment**
- With FFs completed, the time is now to start a renewed push to prepare this experiment: ERR within 3 years?

# Backup Slides

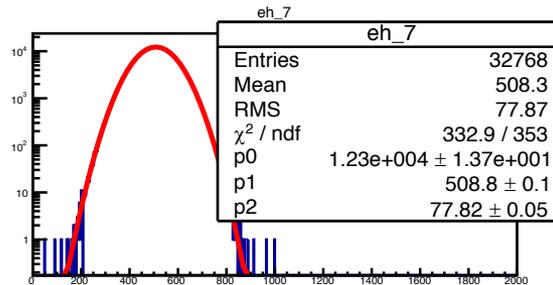
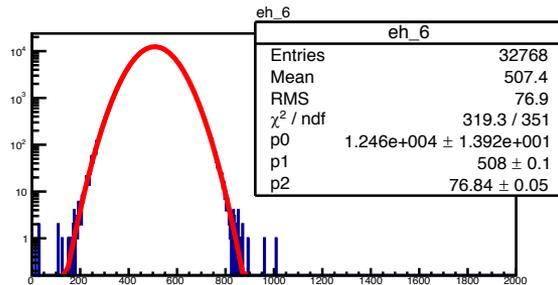
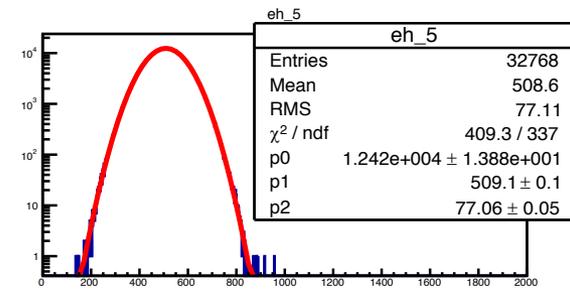
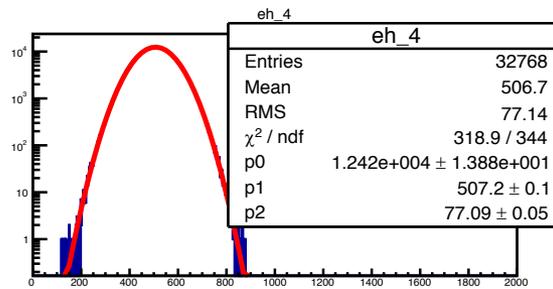
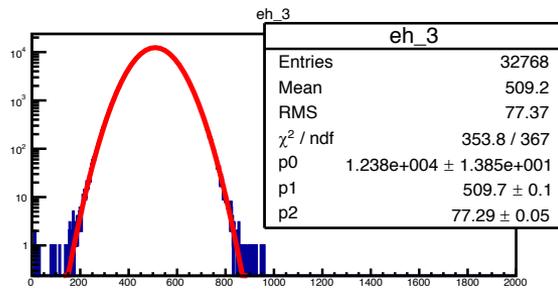
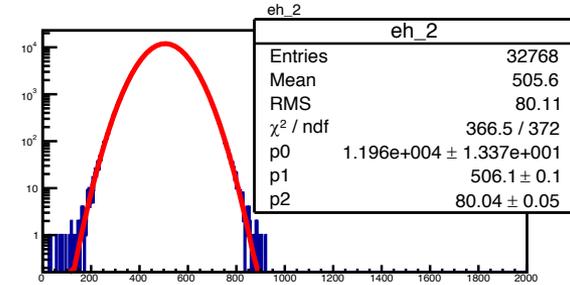
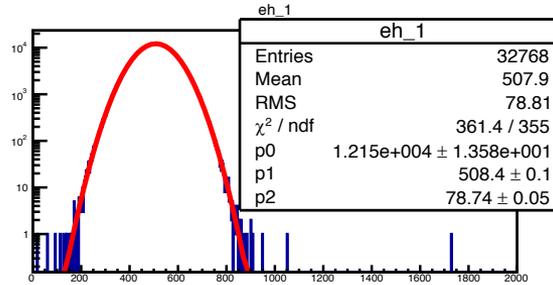
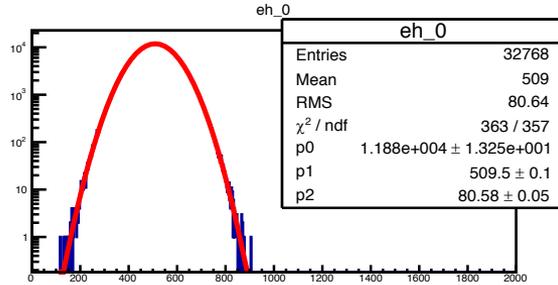
# Dark box



Blue LEDs, 465 nm

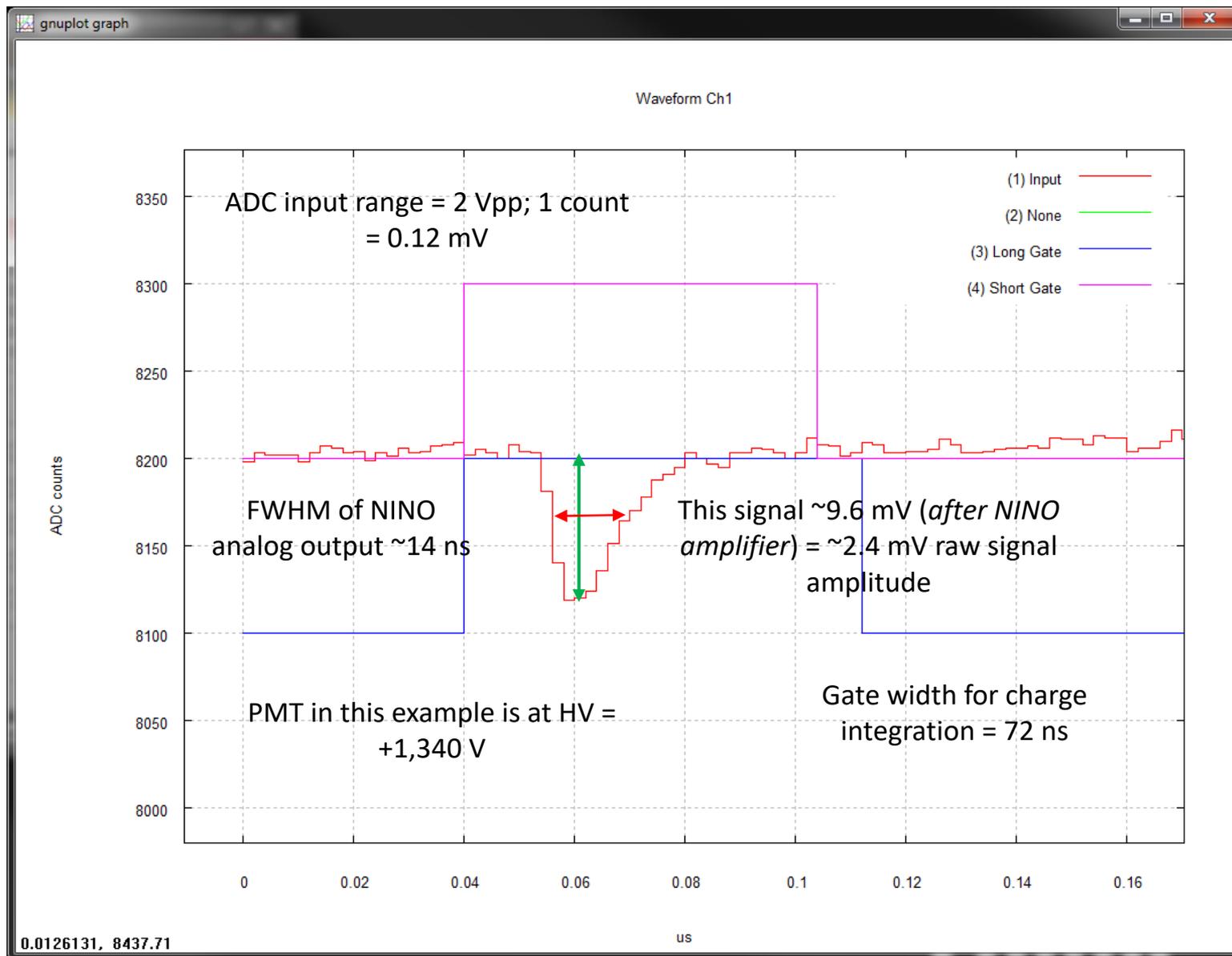
1 → 4 optical fiber bundles:  
each LED illuminates 4 PMTs

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



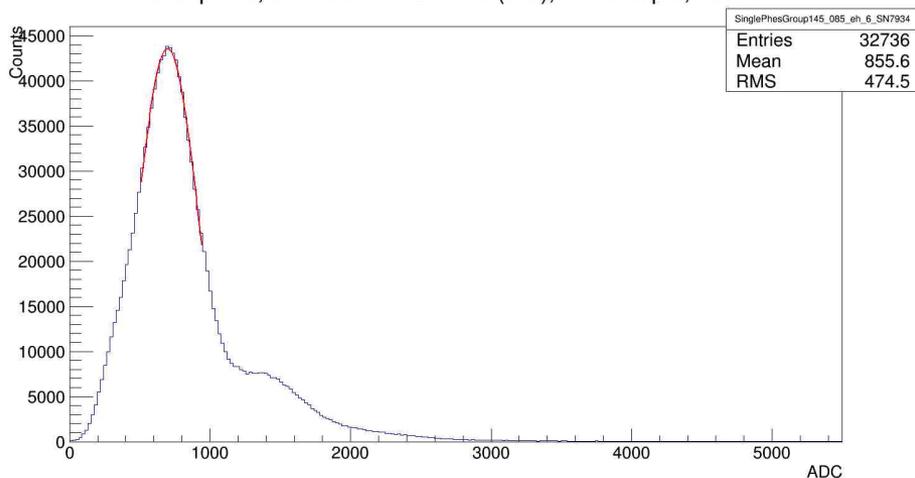
- The DAQ performs automatic baseline determination and subtraction; however, we configured it to insert a charge “pedestal” so that we can easily determine the noise level in each channel and optimally separate the small single-ph.e. signals from noise.
- The individual sample noise width is related 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

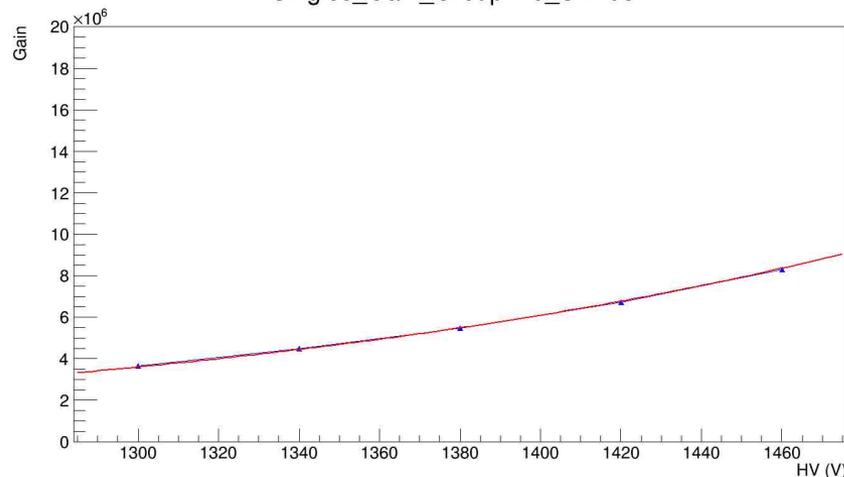


# Absolute Gain Determination from Single-Ph.e.'s

Group 145, S/N 7934: ADC - Ped (5fC), HV Group 0, 1380V

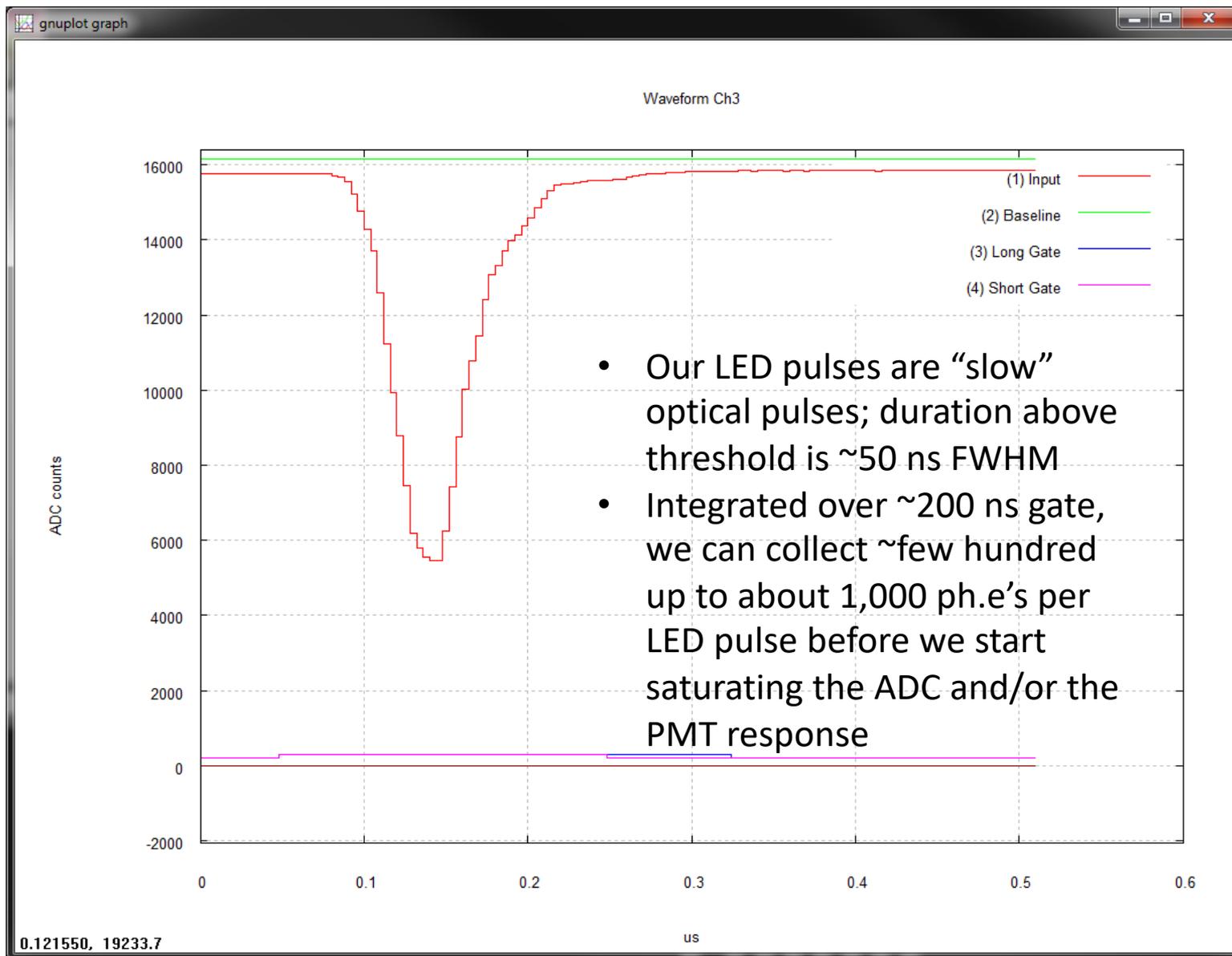


Singles\_Gain\_Group145\_SN7934

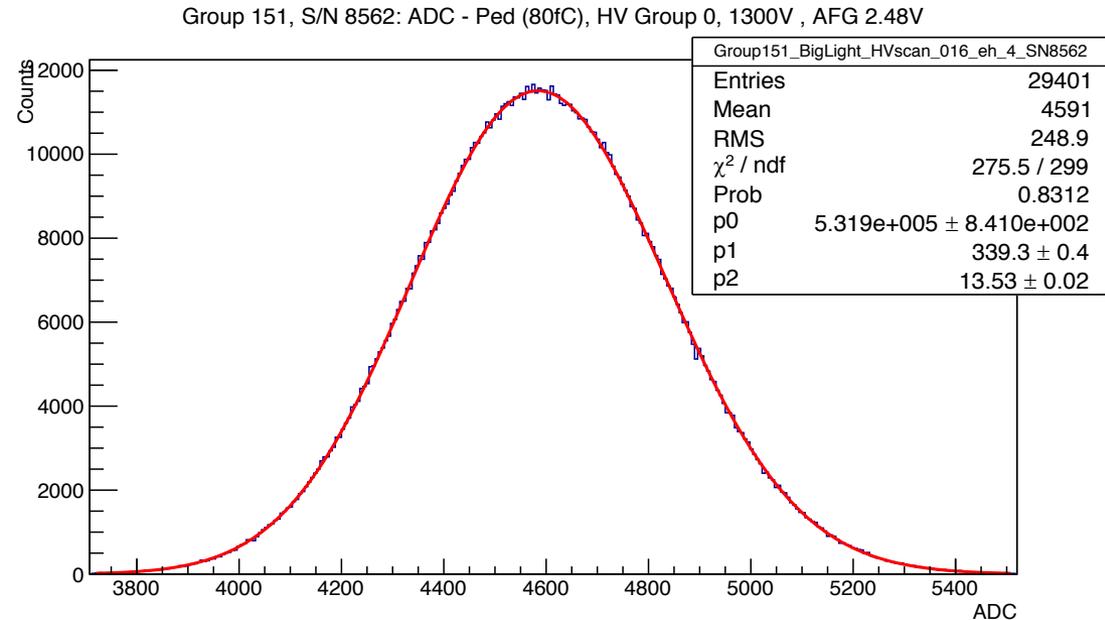
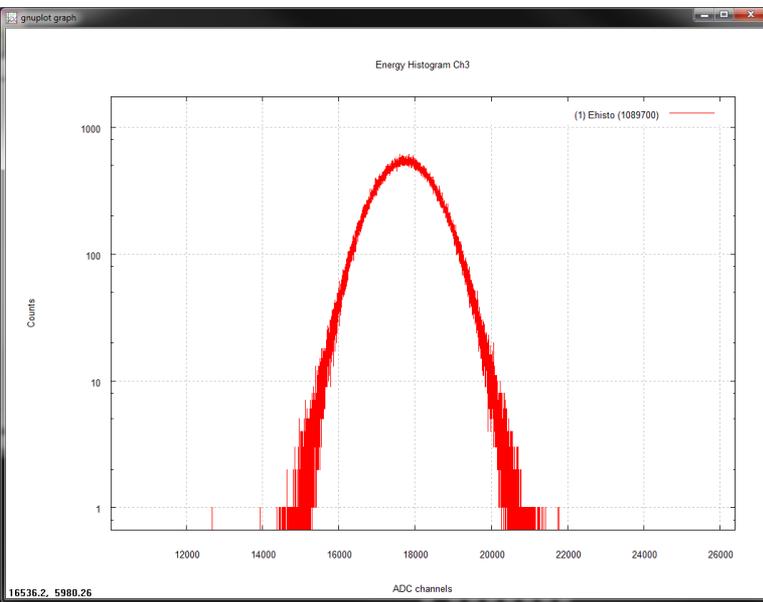


- Collect single-photoelectron charge spectra for different HV's from 1,300-1,460 V in 40-V increments.
- Fit Gaussian to single-photoelectron peaks.
- Correct for NINO amplifier gain of 4
- Fit HV-dependence of gain with power-law curve to determine gain slope
- At HVs below  $\sim 1,300$  V, this method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

# “Big” LED pulses



# 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:

$$P(\text{ADC}) = N \frac{(\mu)^{\frac{\text{ADC}}{G}} e^{-\mu}}{\left(\frac{\text{ADC}}{G}\right)!}$$

$$N = p_0 = \text{Normalization}$$

$$\mu = p_1 = \text{Mean number of photoelectrons}$$

$$G = p_2 = \text{“Gain” (proportional to actual gain)}$$

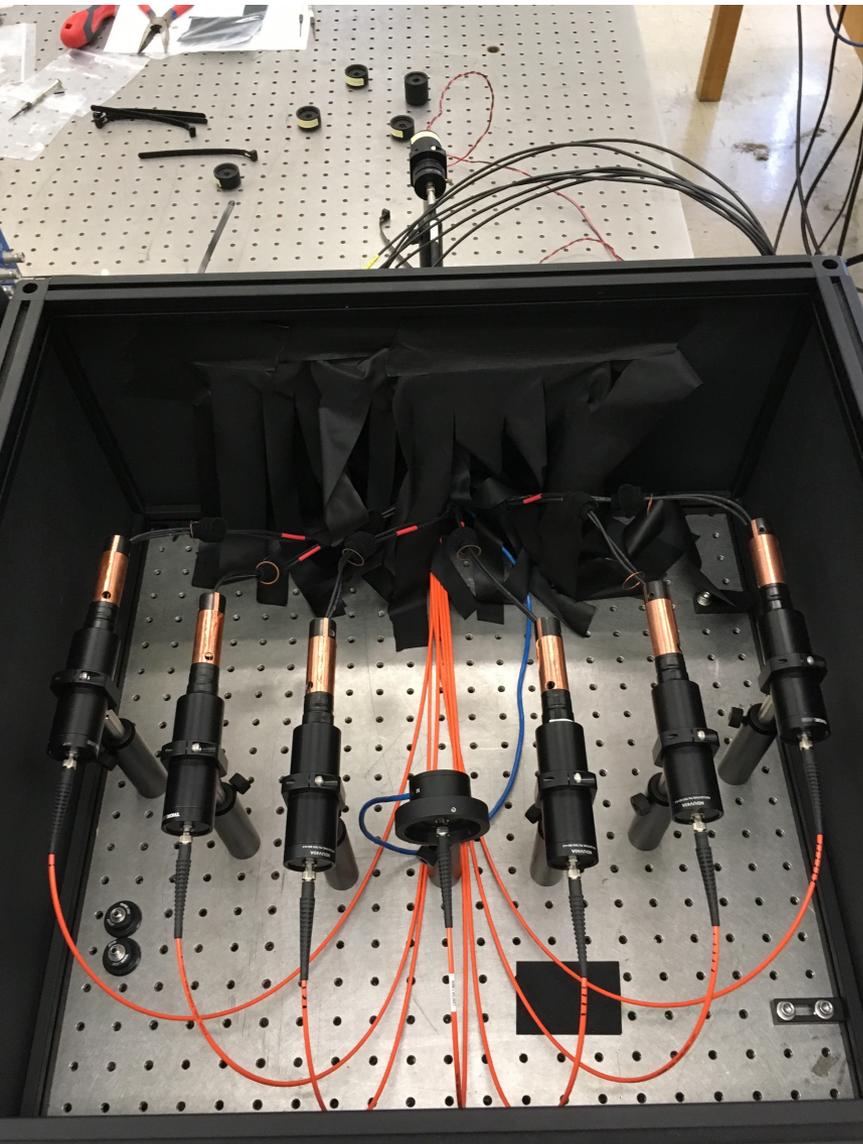
# RICH move to JLab—Rigging Out (I)



# 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)