RICH Detector for SIDIS

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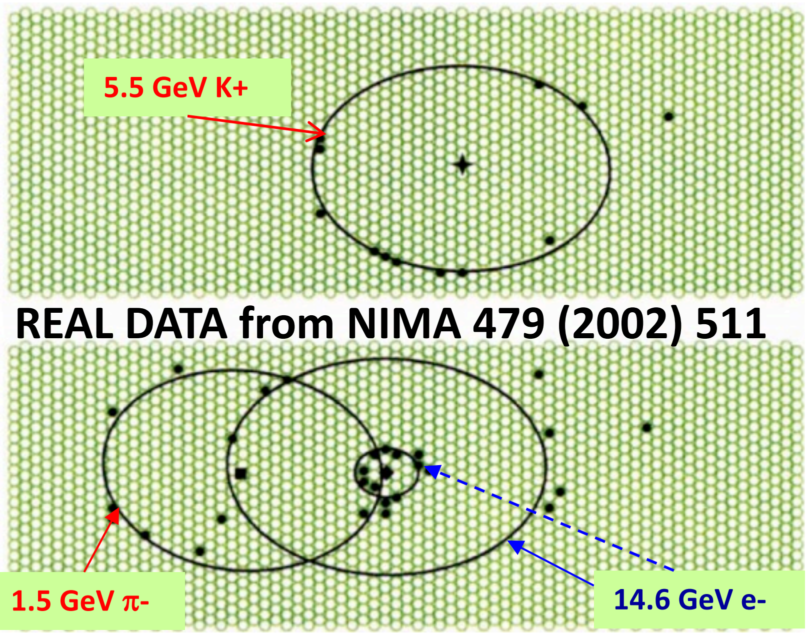
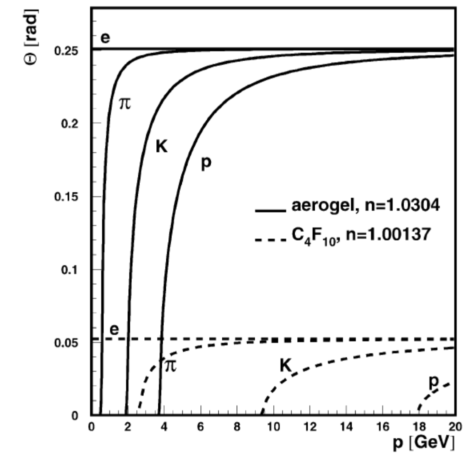
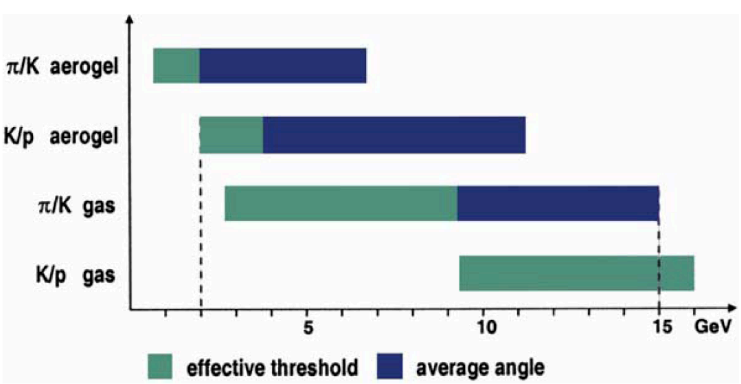
SBS Summer Collaboration Meeting 2019

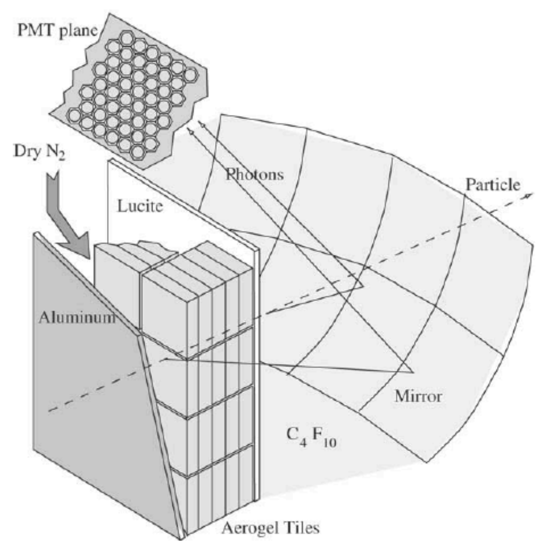
The HERMES RICH detector

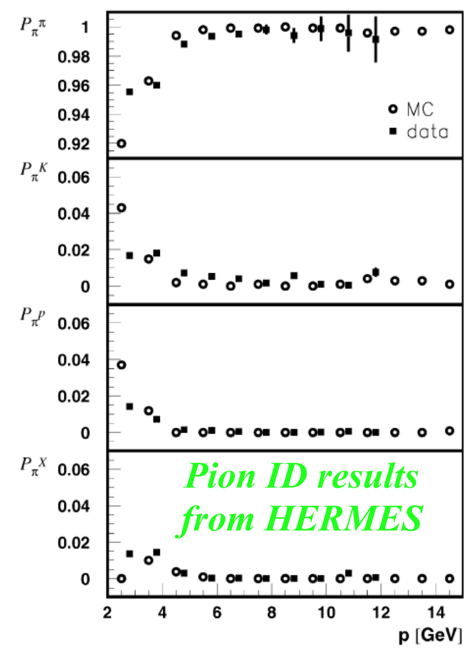


- ***HERMES RICH geometry, performance characteristics well matched to SBS needs.***
- π/K/p separation for p from 2-15 GeV based on dual-radiator design.
- Re-use one half of detector, both aerogels

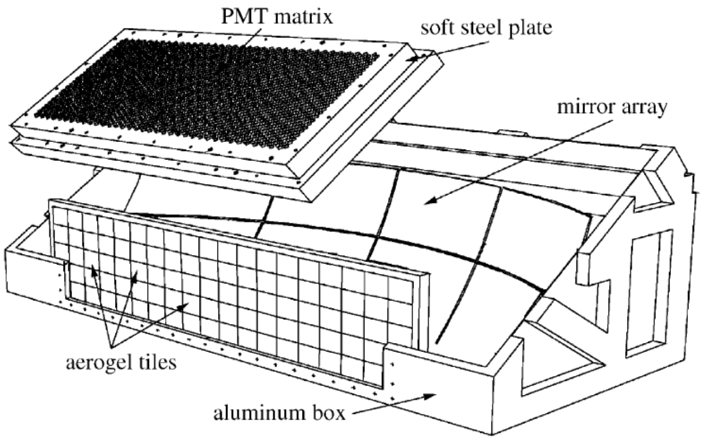


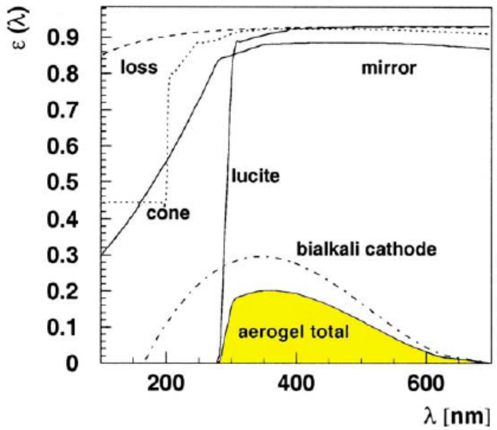


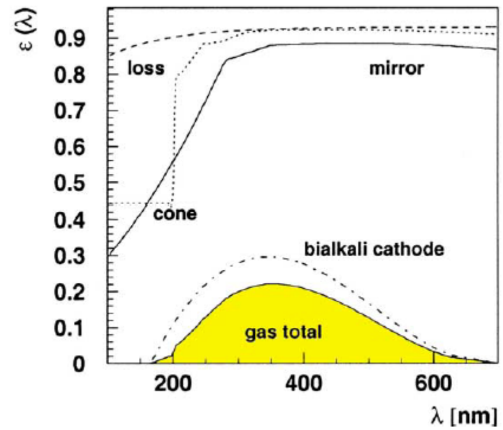




HERMES RICH Design Aspects







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

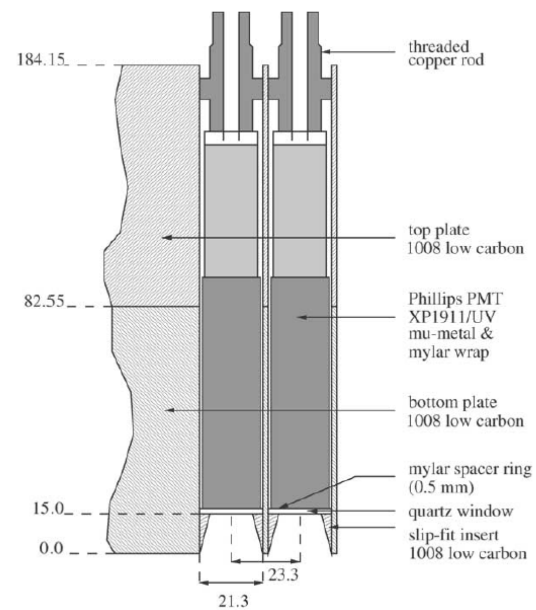
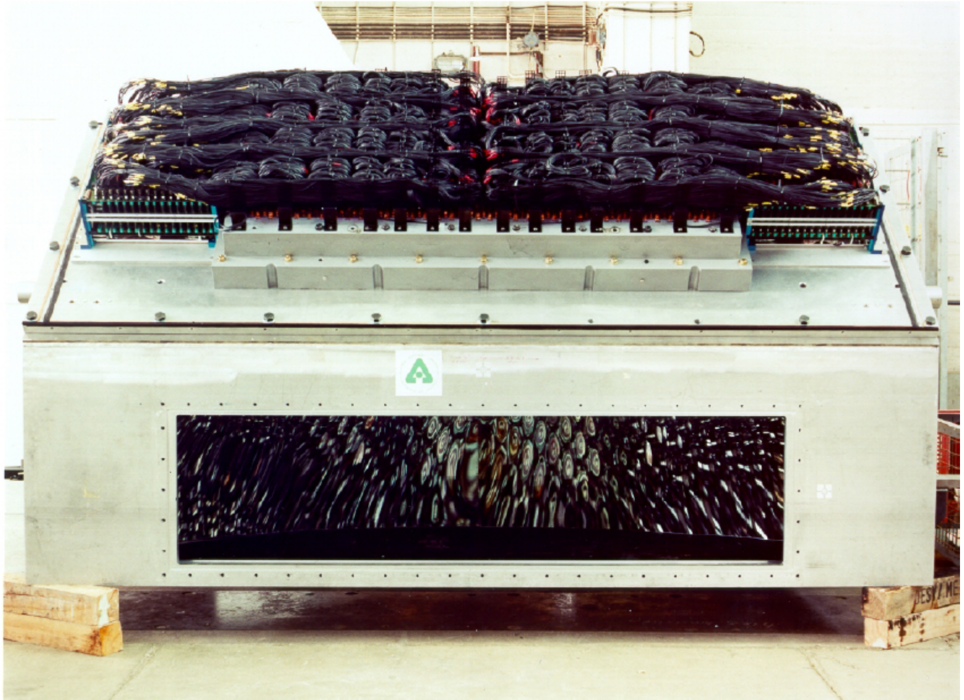
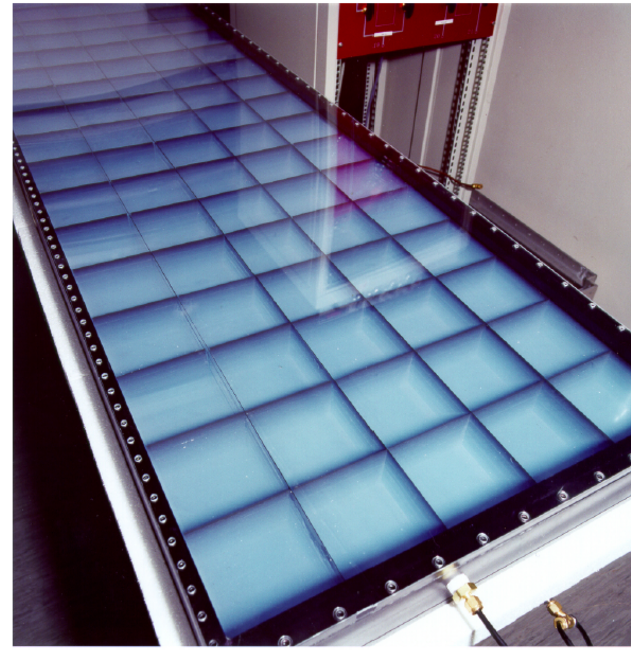


Fig. 7. Schematic photon detector design. All units are in mm.

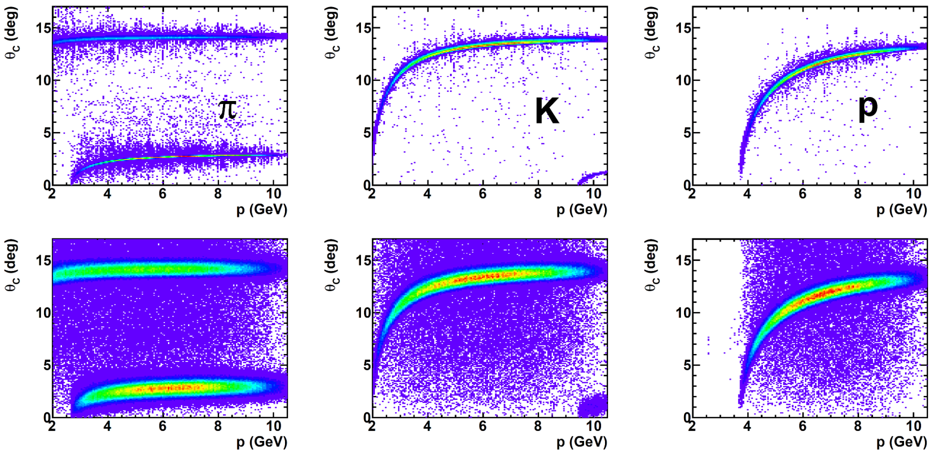
SBS RICH Detector Photos

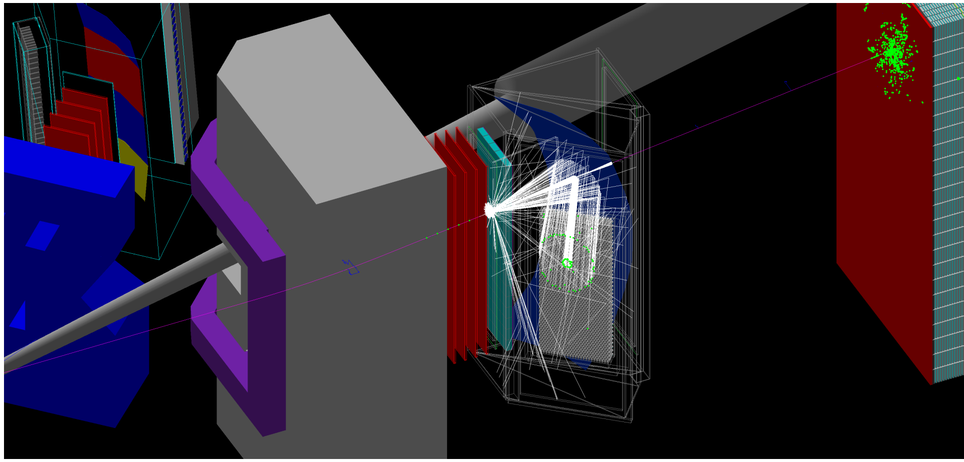




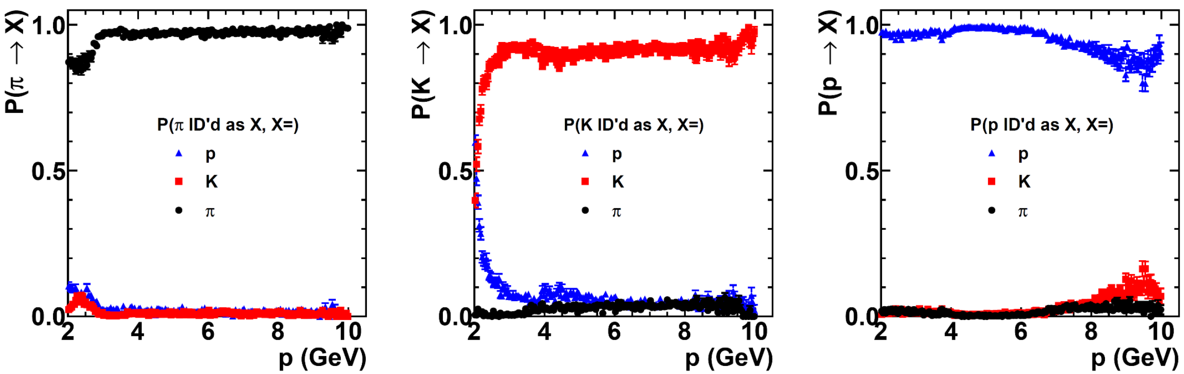
- Above, left: Old picture of one half of RICH with aerogel wall removed
- Above, right: Old picture of one aerogel wall w/containment vessel
- Bottom right: RICH delivery to storage facility @UVA, 2009

HERMES RICH in SBS—Monte Carlo

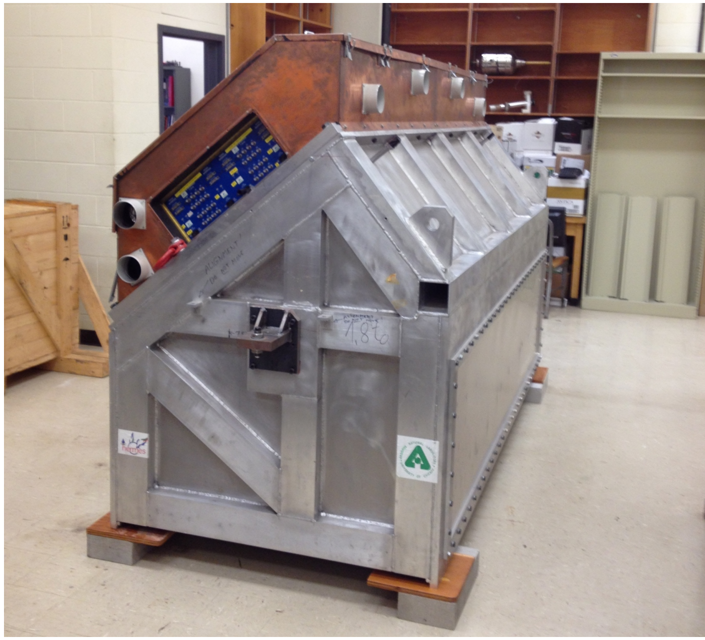




GEANT4-simulated RICH performance in SBS

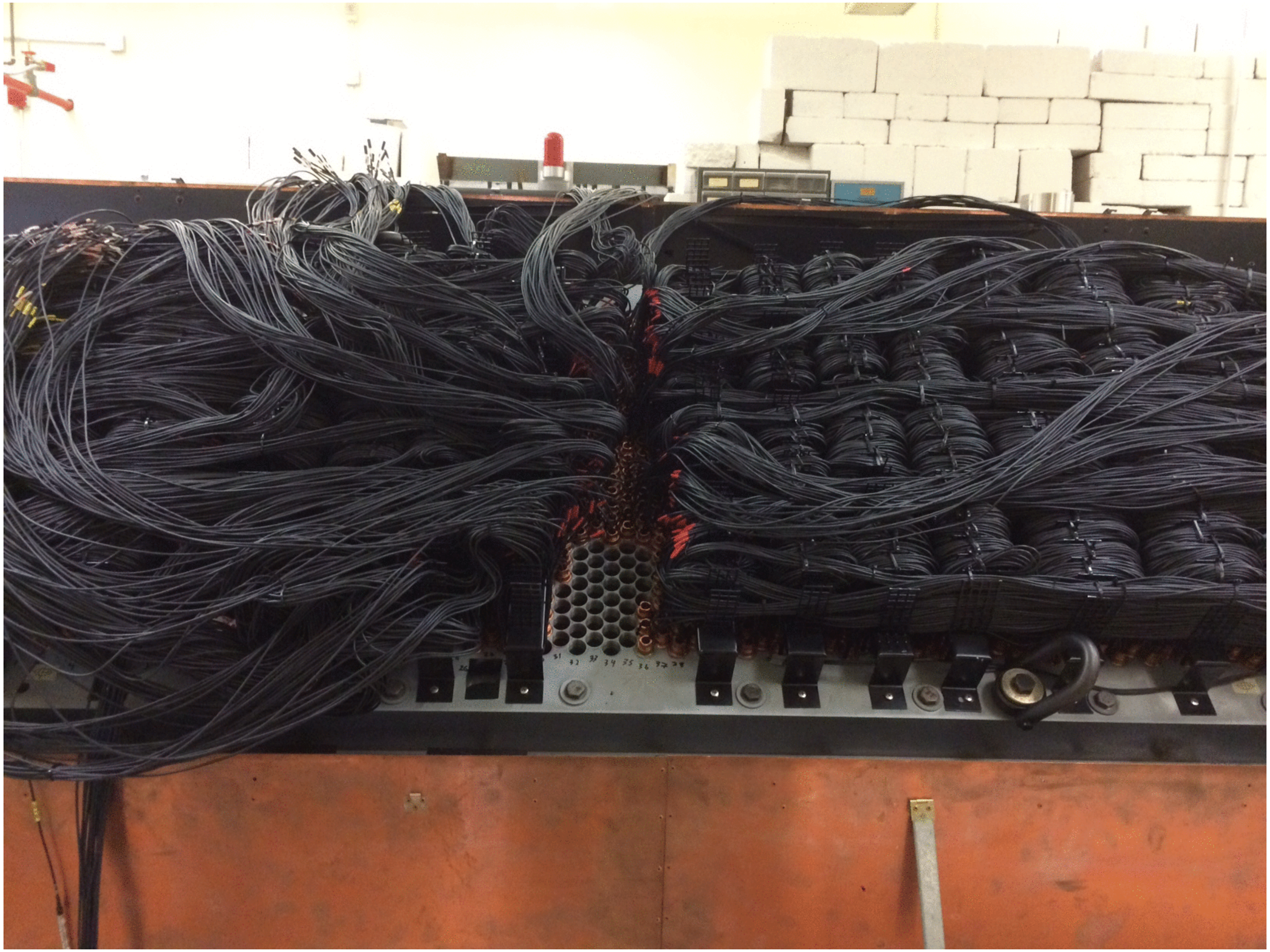


Expected RICH PID performance in SBS for π/K/p



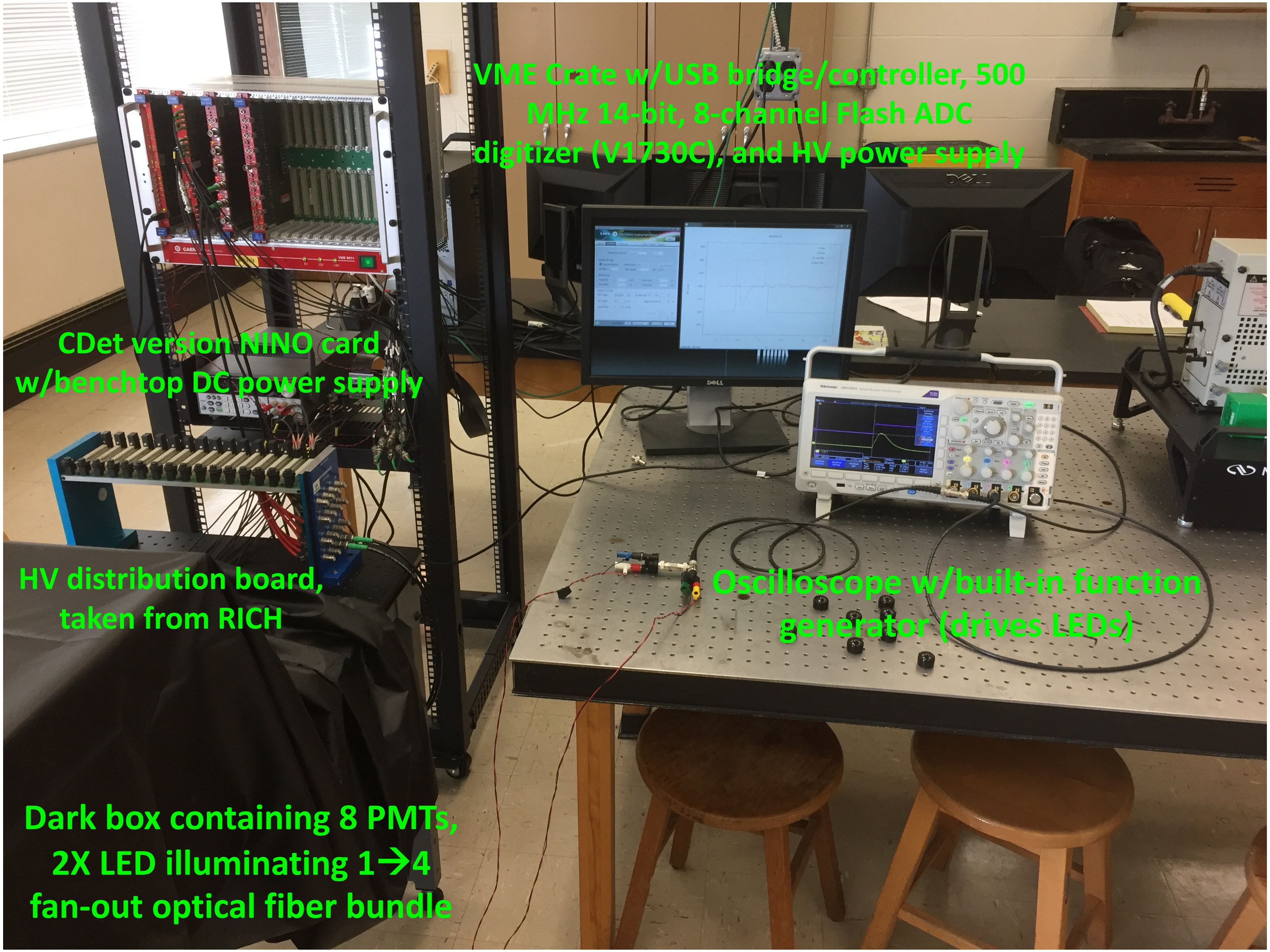
HERMES/SBS RICH testing underway @UConn

Decabling the RICH/PMT Removal (June 2016)

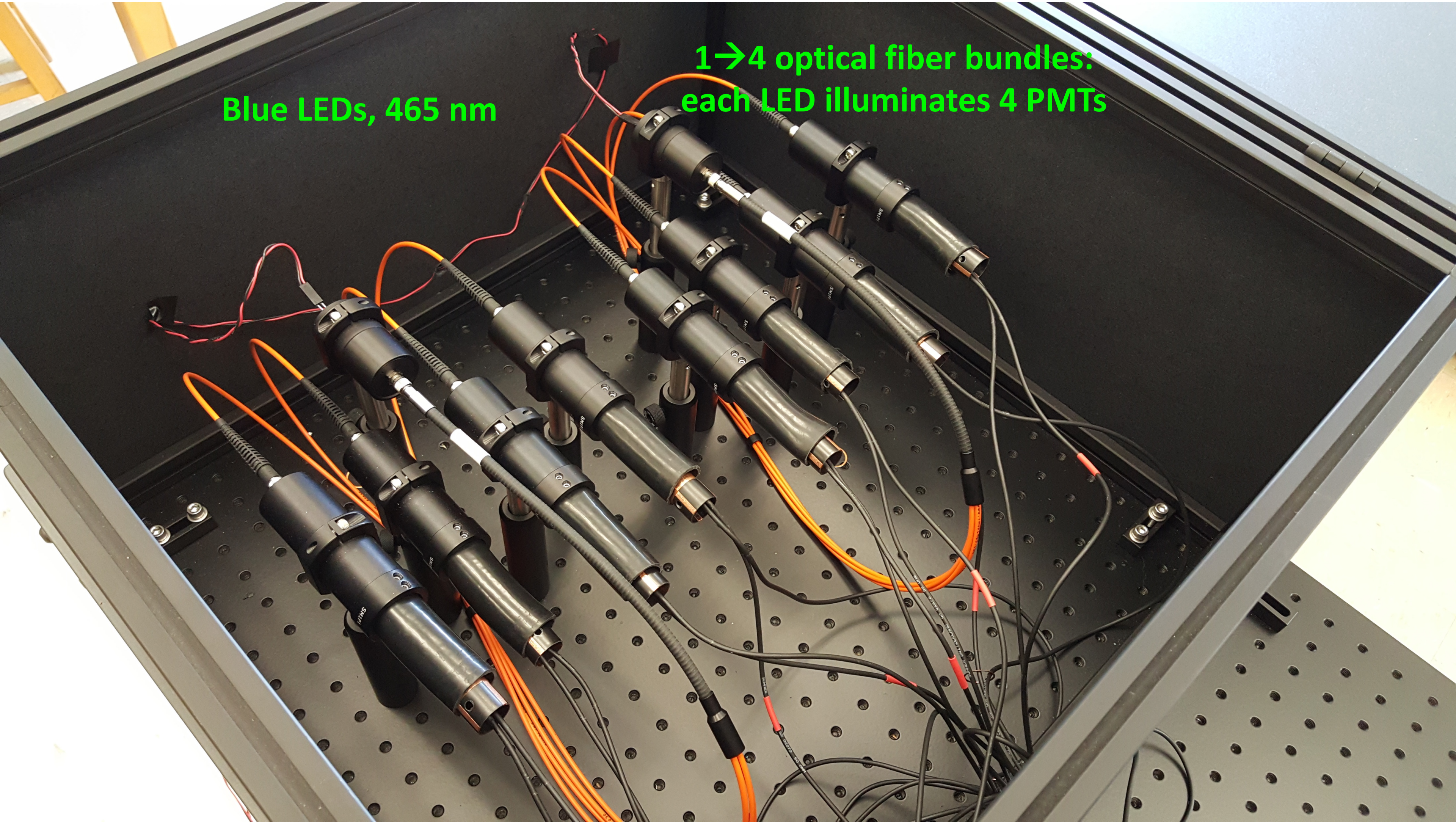


RICH PMTs

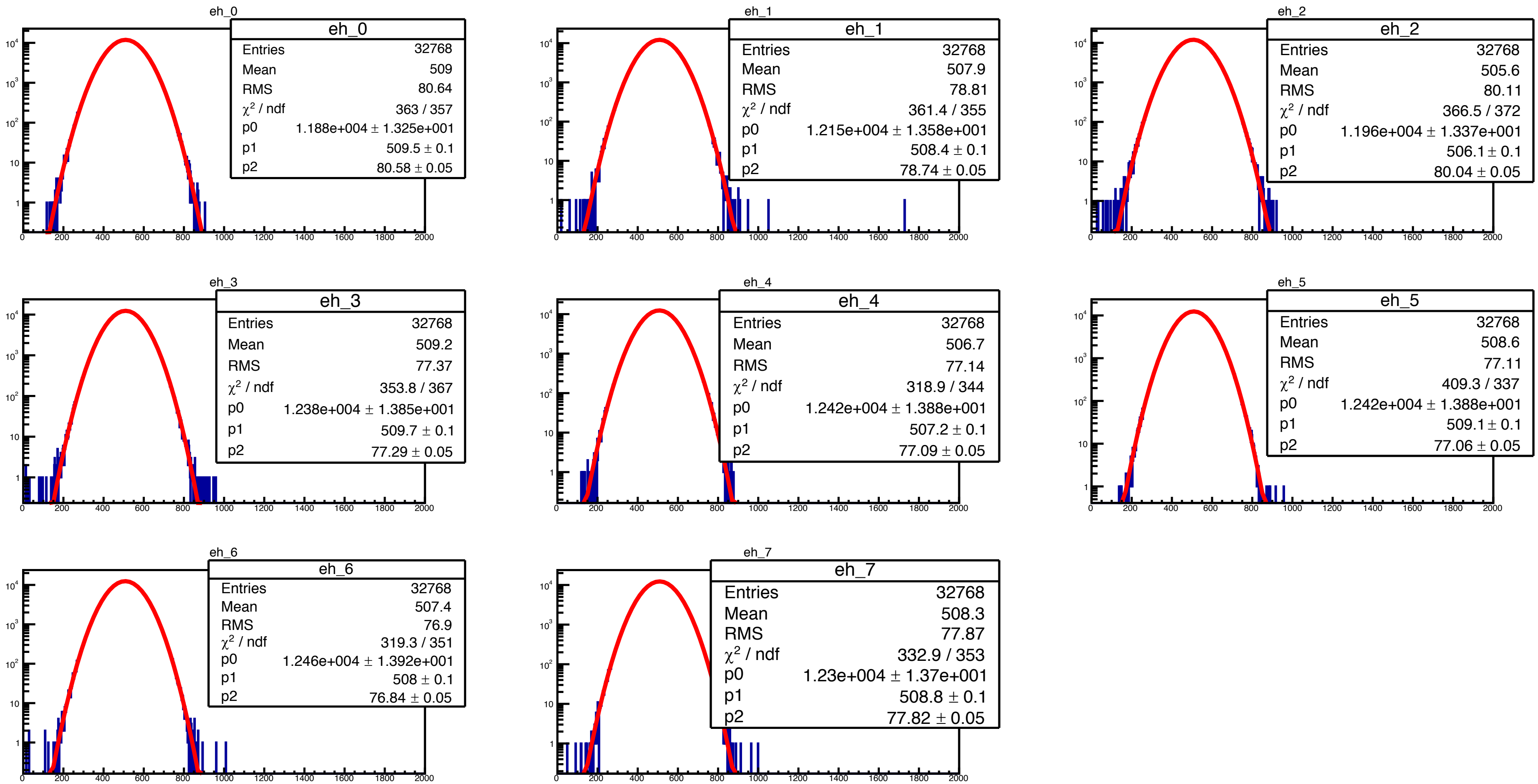
RICH PMT test stand @UConn (ca. 2016)



Dark box

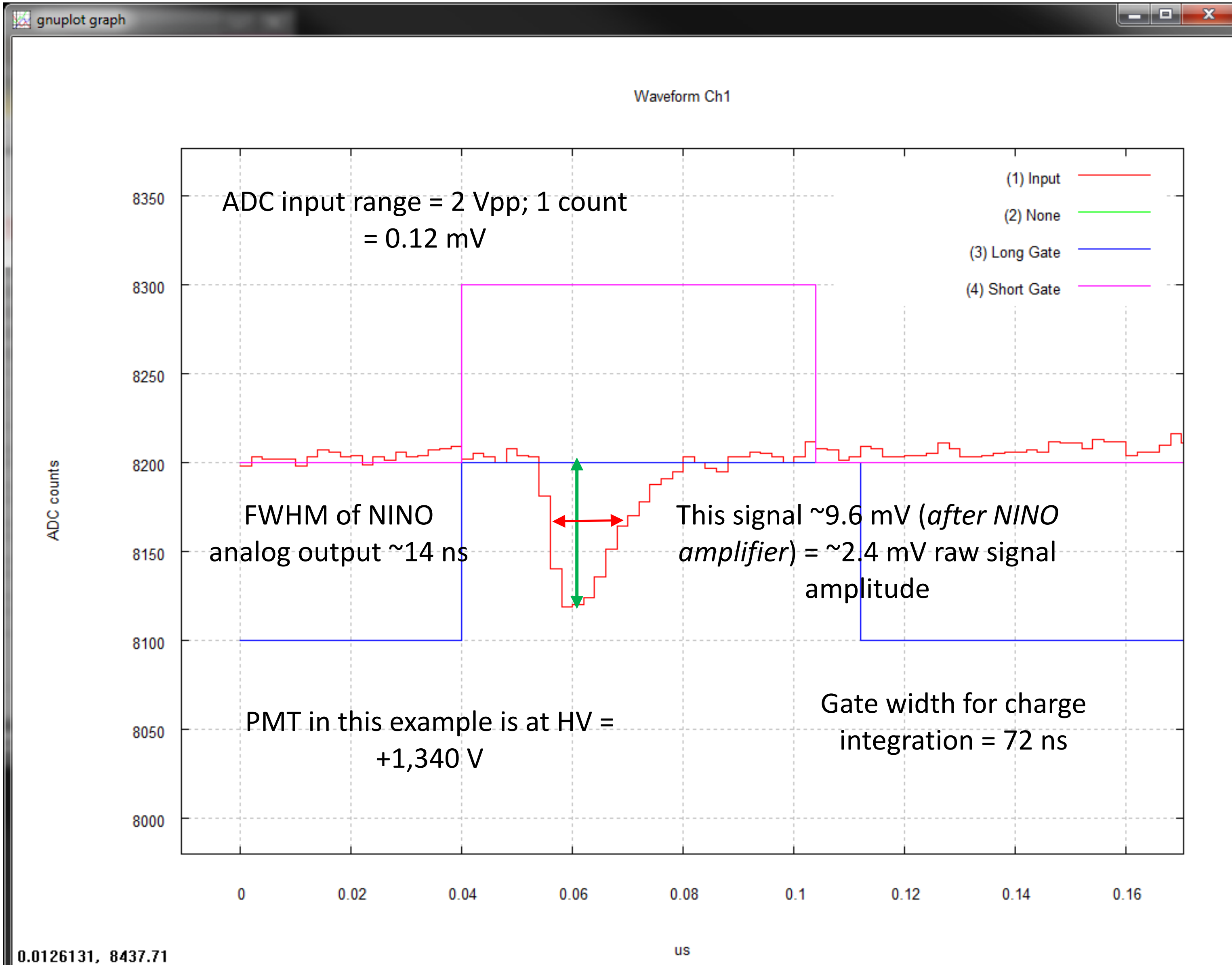

Blue LEDs, 465 nm
1→4 optical fiber bundles:
each LED illuminates 4 PMTs

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

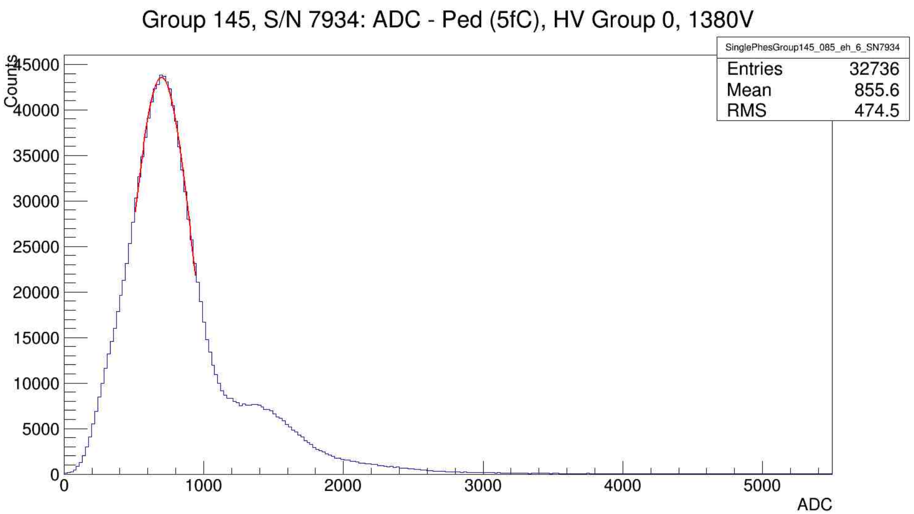


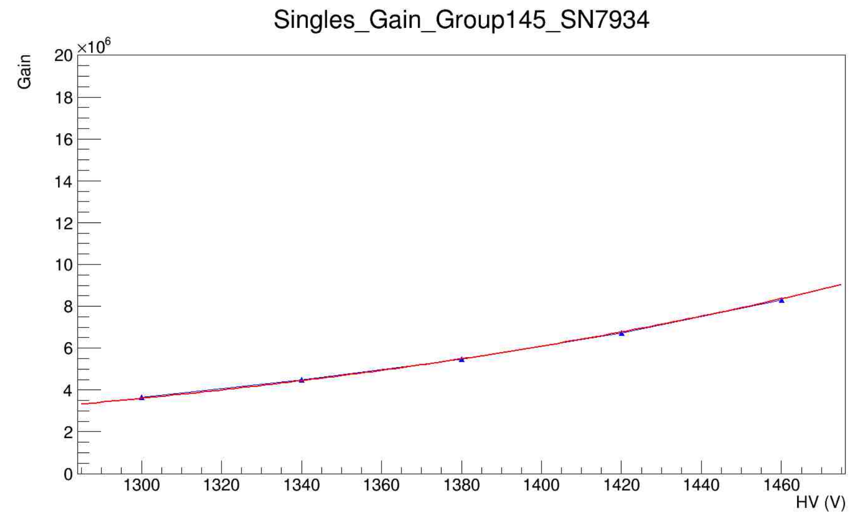
- The DAQ performs automatic baseline determination and subtraction; however, we configured it to insert a charge “pedestal” so that we can easily determine the noise level in each channel and optimally separate the small single-ph.e. signals from noise.
- The individual sample noise width is related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



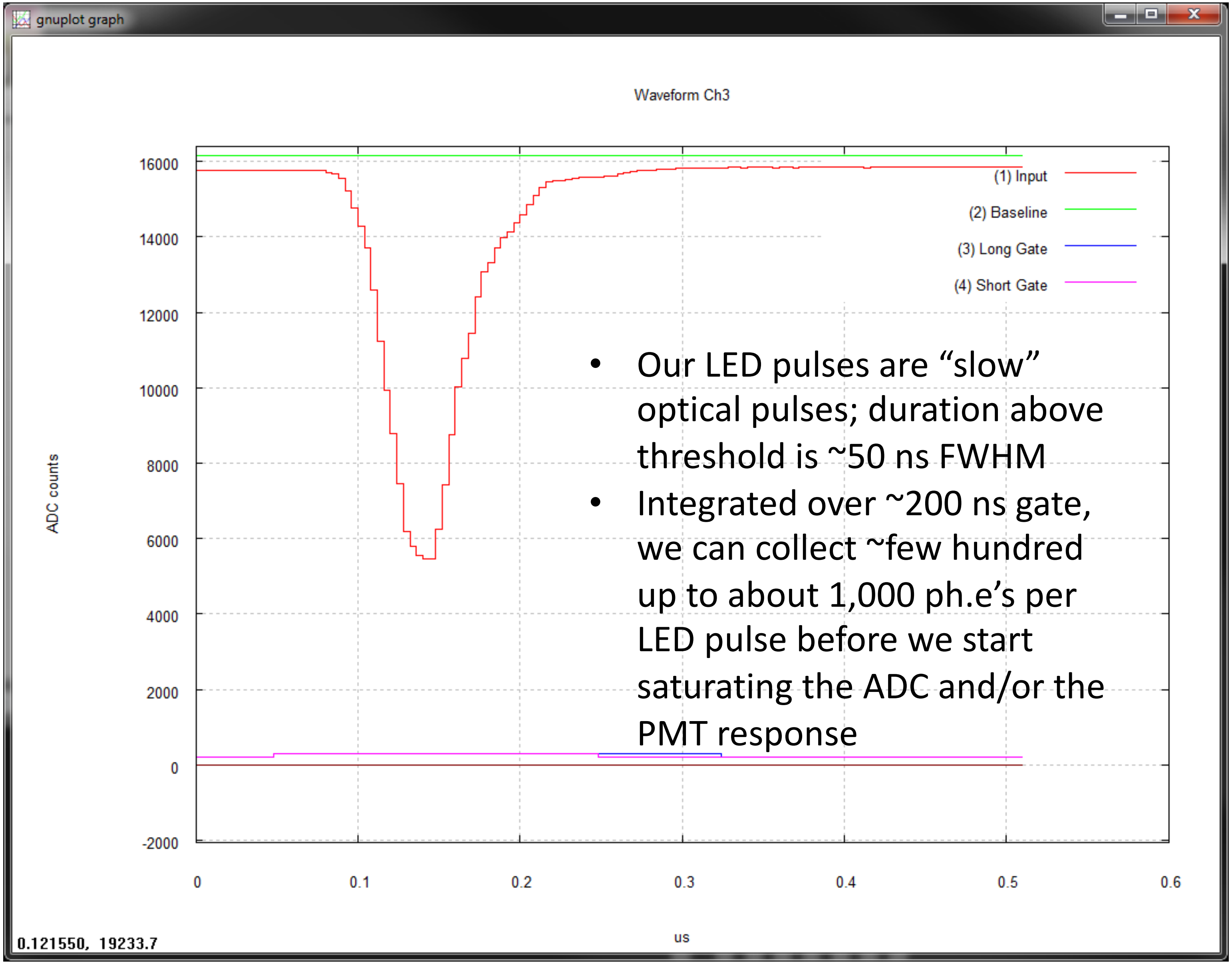
Absolute Gain Determination from Single-Ph.e.'s





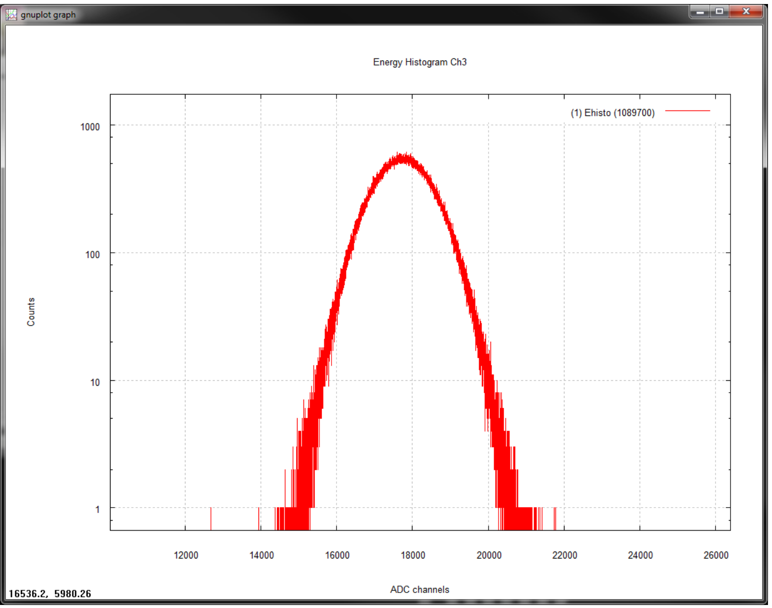
- Collect single-photoelectron charge spectra for different HV's from 1,300-1,460 V in 40-V increments.
- Fit Gaussian to single-photoelectron peaks.
- Correct for NINO amplifier gain of 4
- Fit HV-dependence of gain with power-law curve to determine gain slope
- At HVs below ~1,300 V, this method starts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

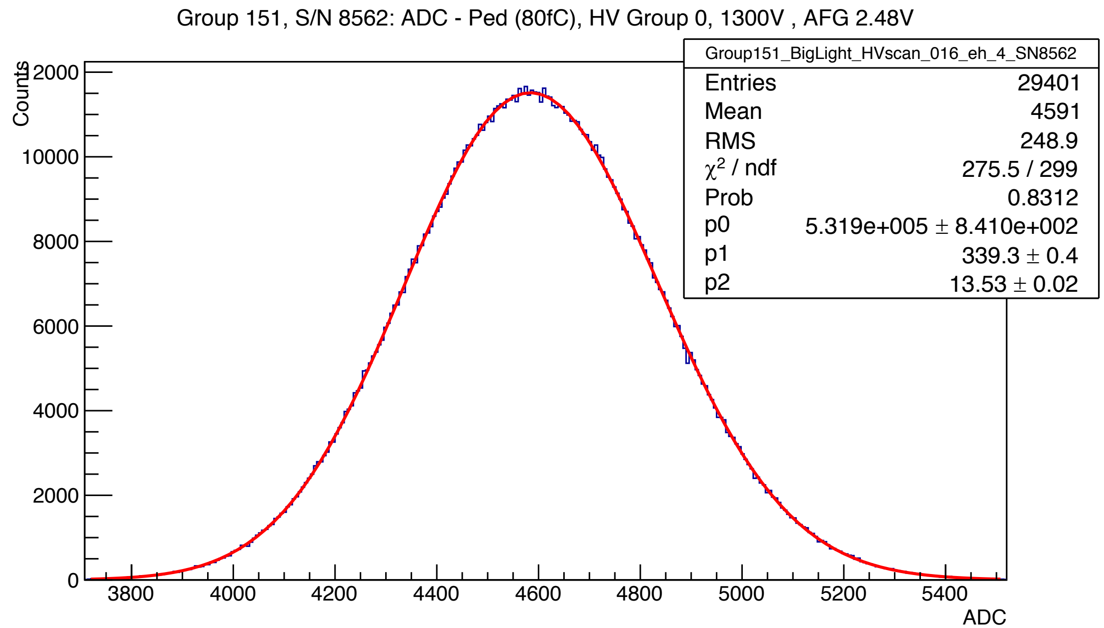
"Big" LED pulses



- 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

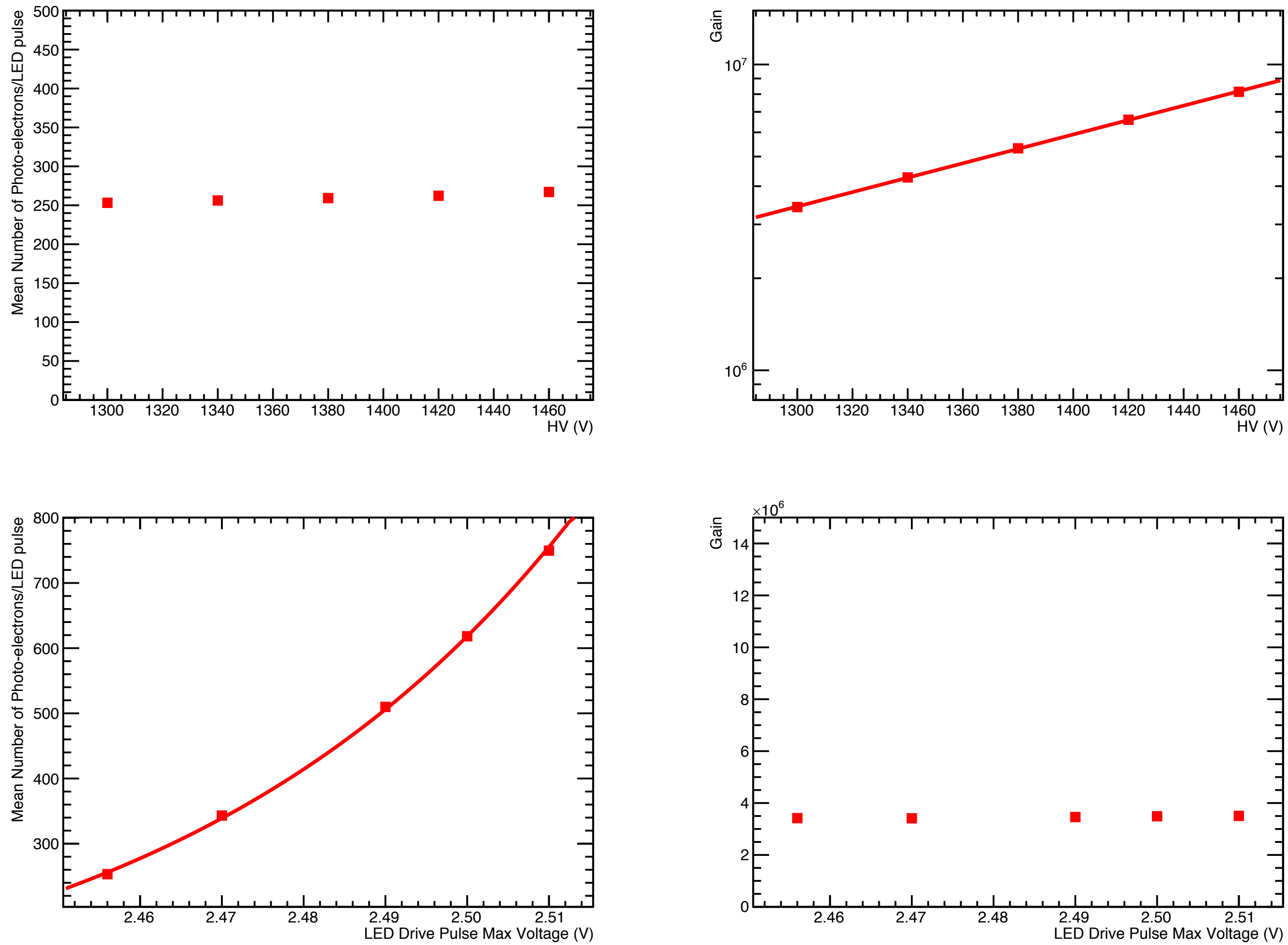




- Example of "online" big-light charge spectrum at 80 fC/LSB charge sensitivity
- Example Poisson fit to ADC spectrum:

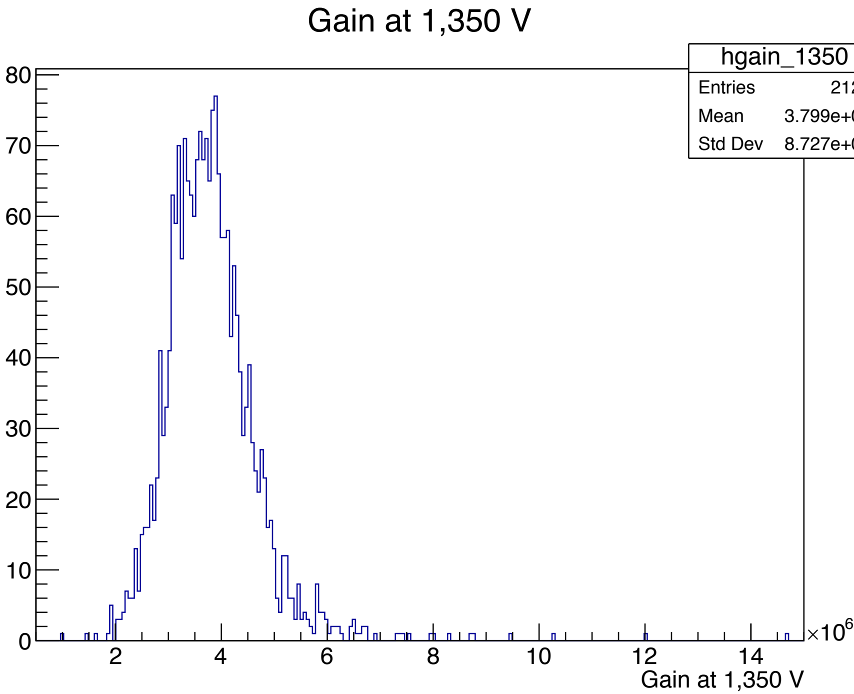
$$
\begin{aligned}
P(ADC) &= N\frac{(\mu)^{\frac{ADC}{G}}e^{-\mu}}{\left(\frac{ADC}{G}\right)!} \\
N &= p_0 = \text{Normalization} \\
\mu &= p_1 = \text{Mean number of photoelectrons} \\
G &= p_2 = \text{"Gain" (proportional to actual gain)}
\end{aligned}
$$

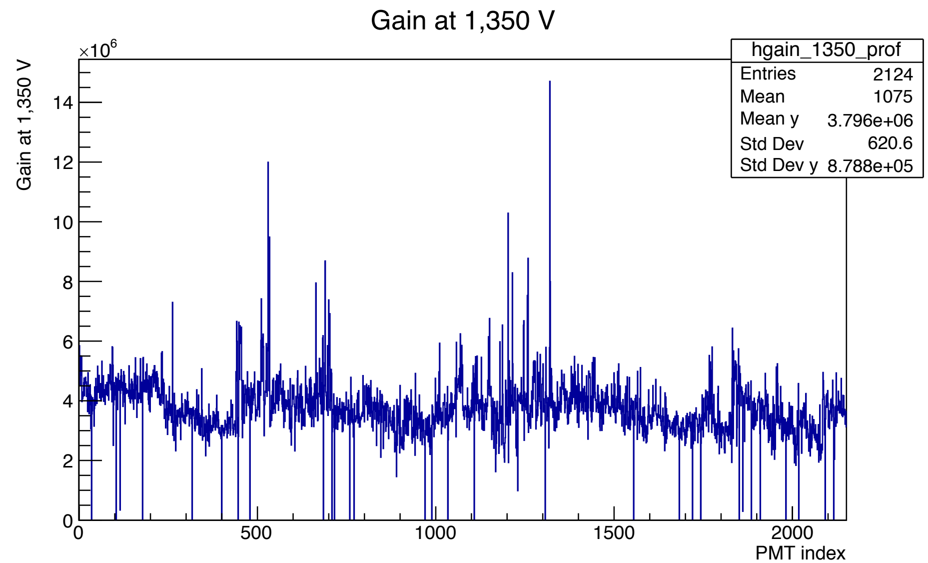
Cross Checking Photoelectron Yield Estimate in Pulsed LED setup



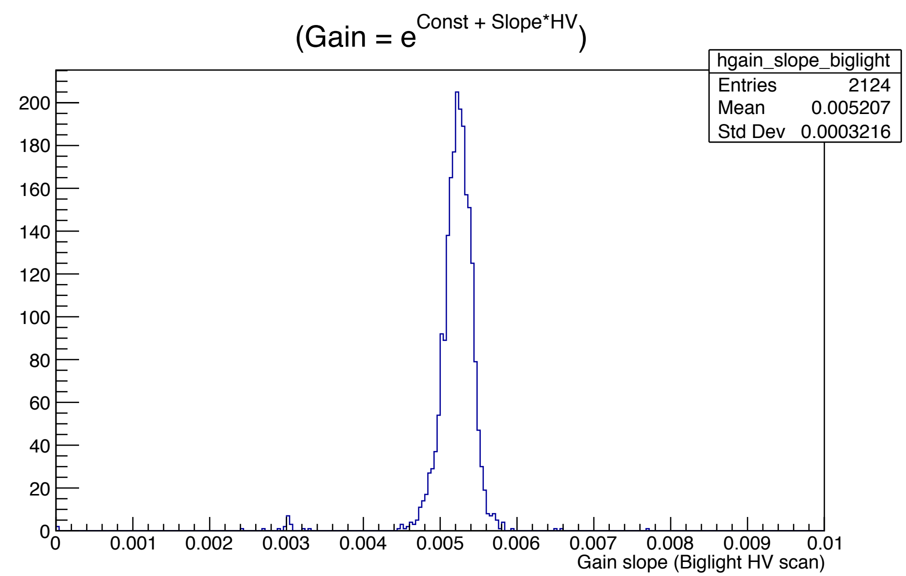
- Light-level scan at constant HV
- HV scan at constant light level

2016 test data summary—Gain results

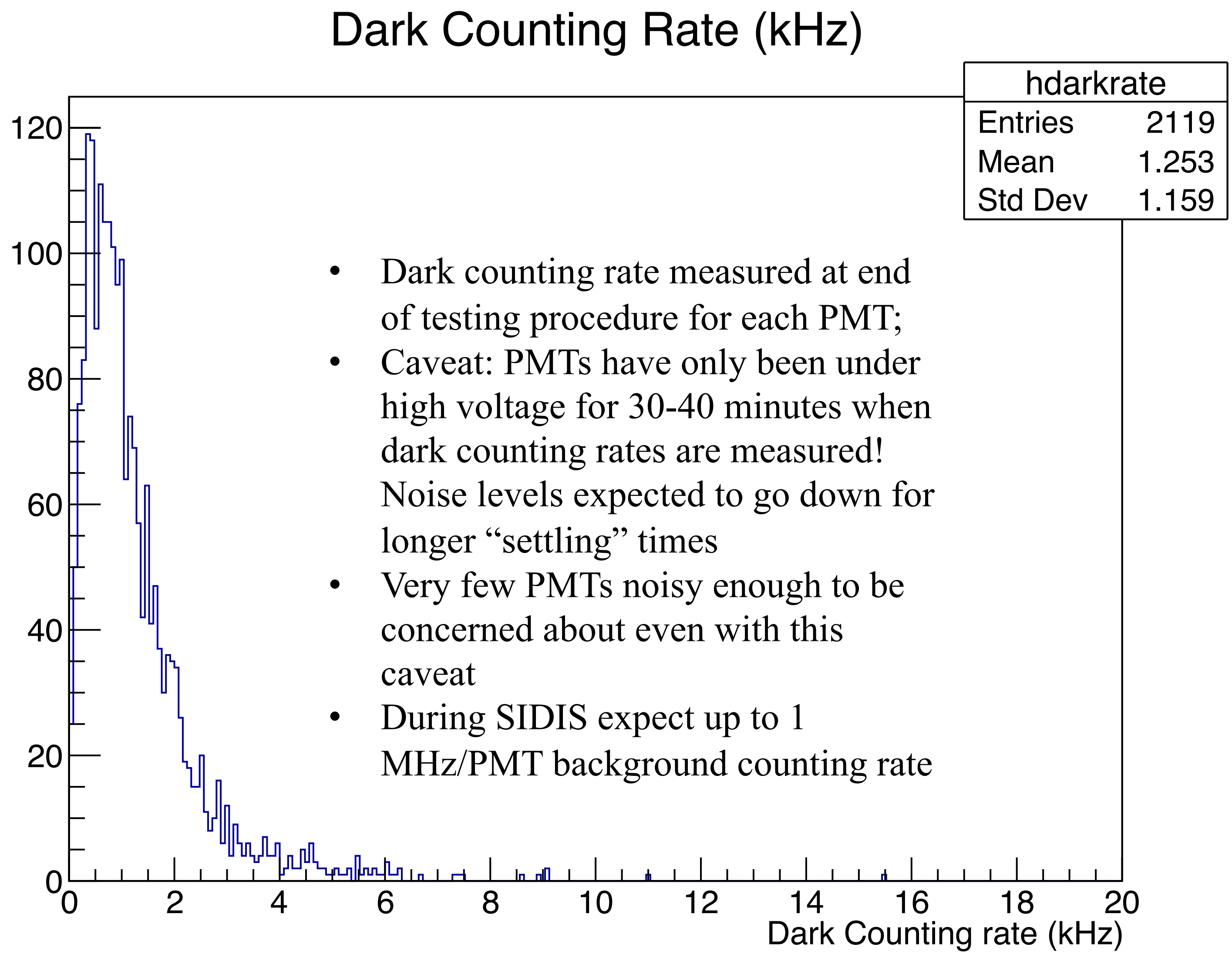




- Above, left: Absolute gain at 1,350 V
- Above, right: Gain at 1,350 V by PMT number
- Below, right: Gain “slope” parameter (from exponential fit to HV scan data)
- Compromise: Gain slope fixed by “Big Light” data, normalization determined by single-ph.e. spectra



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

Summary of PMT 2016 test results

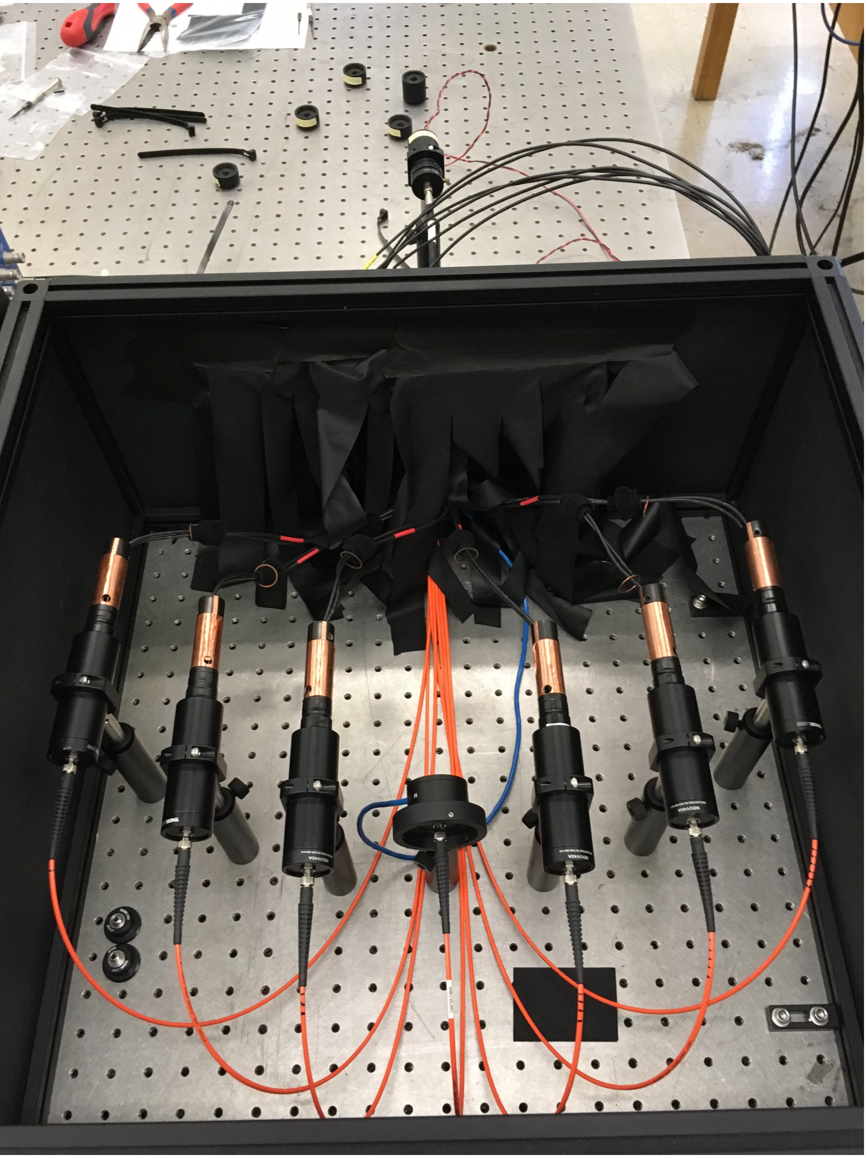
- All PMTs have been tested (1,934 RICH + 224 spare minus two PMTs that ended in special LEMO connectors (presumably for monitoring) that need to be adapted to our test stand
- 32 PMTs rejected either because they were "dead" (no signals), were extremely noisy, had extremely low gain/poor signal quality, 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
- A more detailed characterization of a subset of PMTs (timing resolution, etc.) and more detailed analysis of existing data is ongoing.

RICH move to JLab—Rigging Out (I)

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

RICH move to JLab—Delivery to ESB

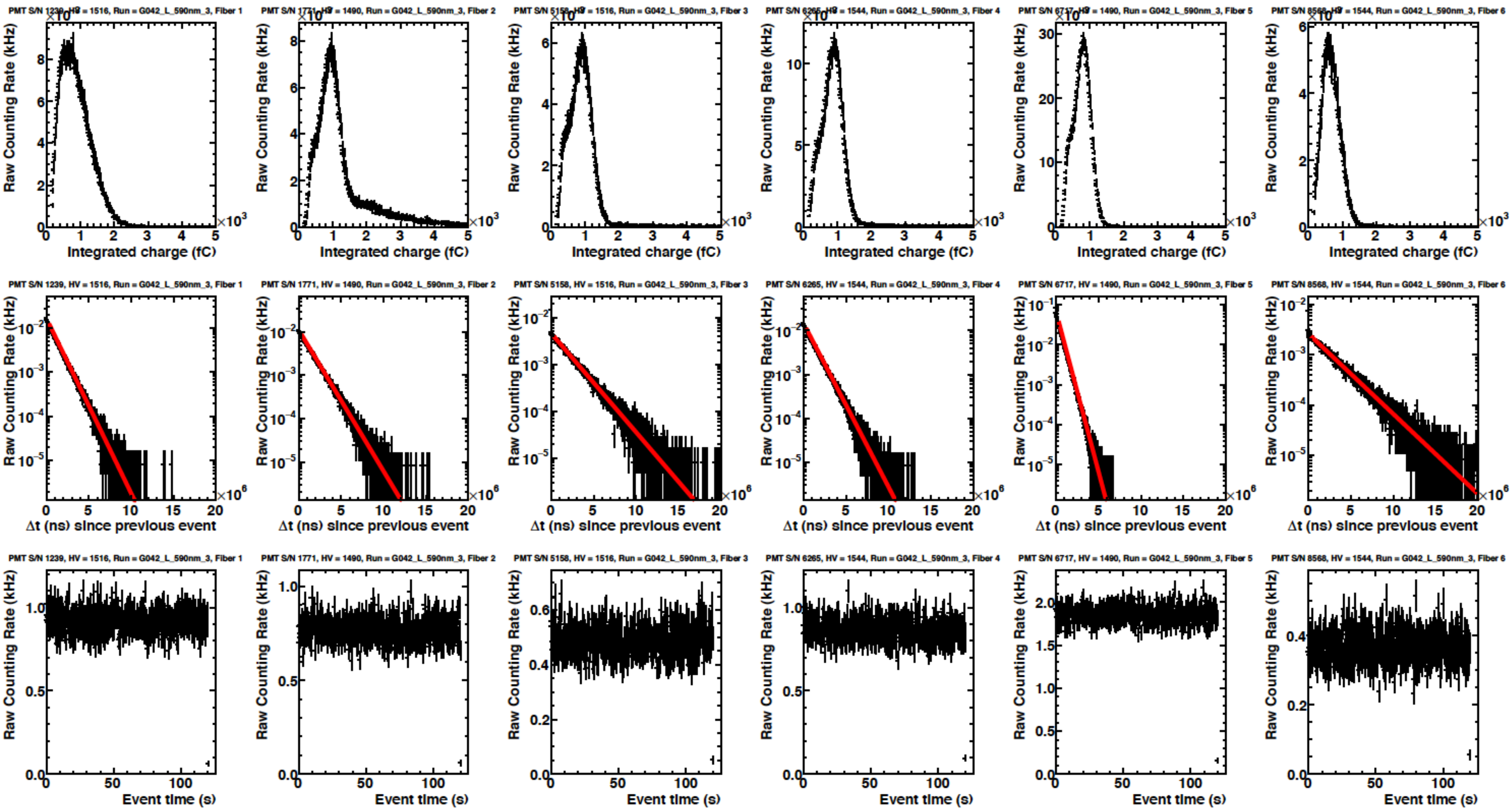
2018-2019: Absolute Quantum Efficiency Setup



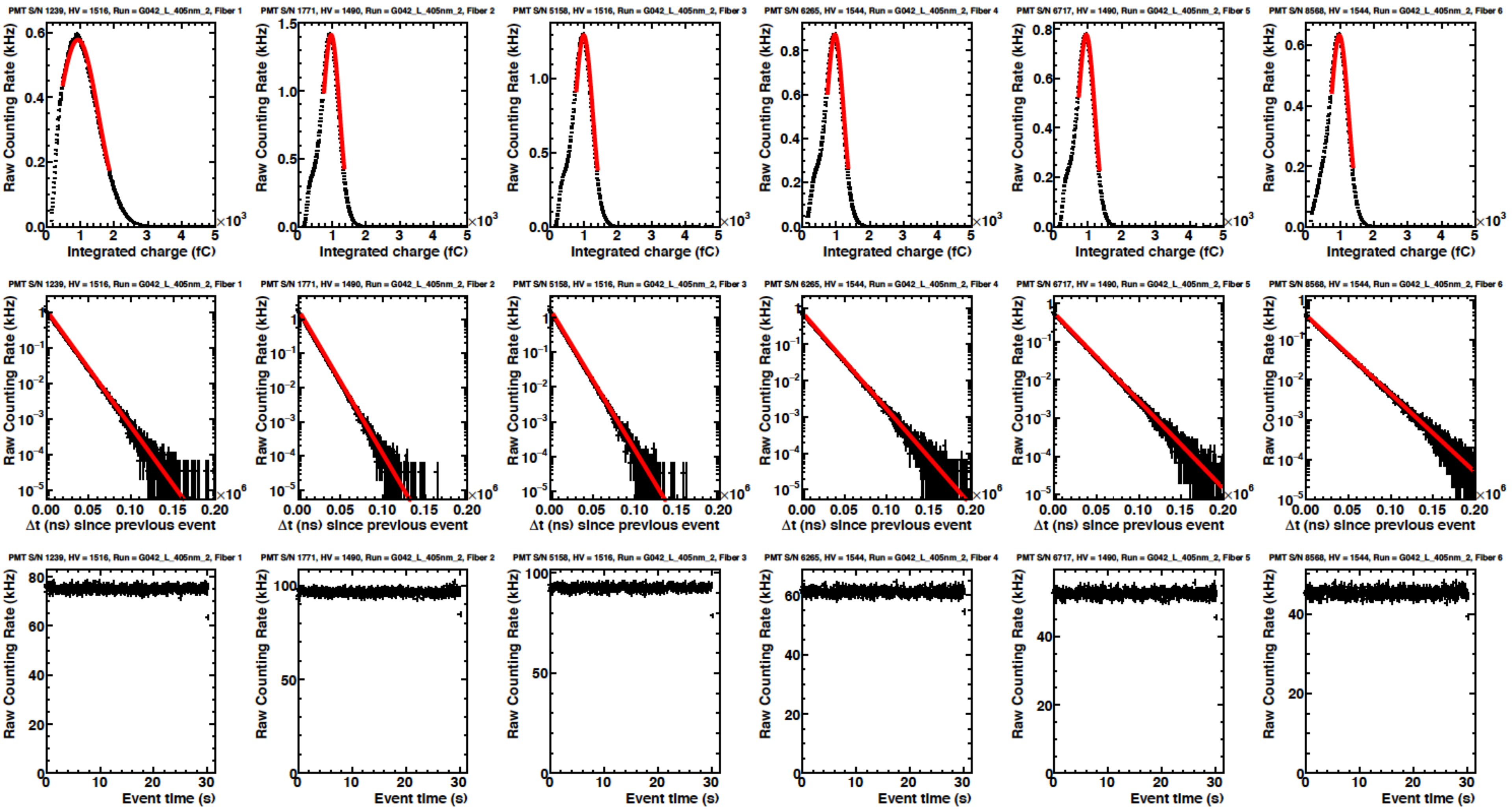
Methodology:

- 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.

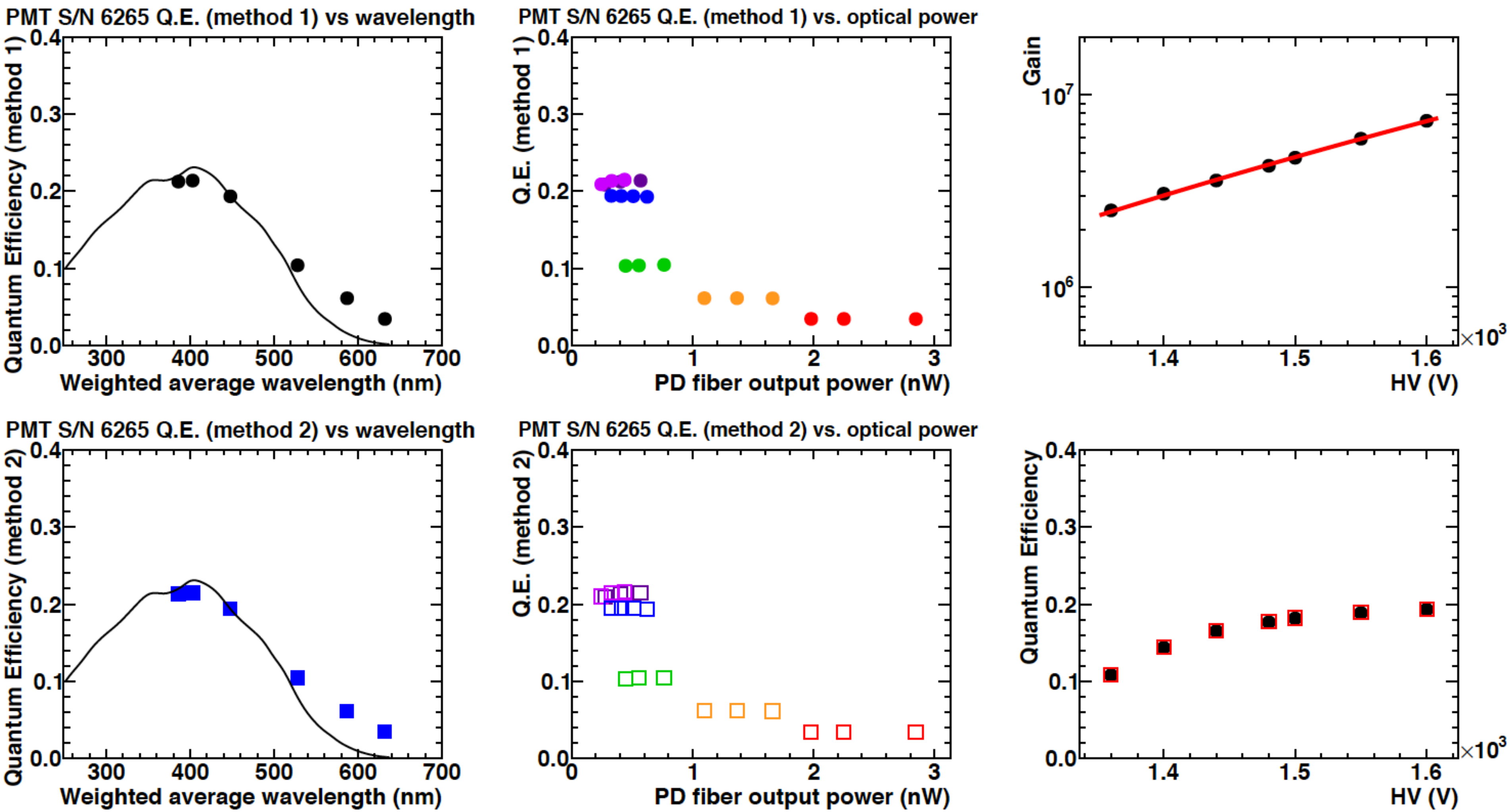
PMT Dark Counting Rate Run in 2018 QE setup



PMT “LED on” QE data from a single run (30 s) @405 nm



Absolute QE results for a single PMT



Preliminary, rough budget estimate for remaining RICH items (*not counting support for personnel, design/engineering time, etc*)

Using 2018 NSF MRI preproposal as a starting point:

Without VETROC readout
(assuming these items aren't otherwise available at JLab):

- **Total ≤ $100k**, of which:
  - HV power supplies ~$30k (64 channels of +HV)
  - SHV cables and connectors ~$7k
  - Gas system ~$5k
  - All other items (including support frame) roughly guesstimated at ~$40-60k.
- Small enough to include in standard grant proposal or "crowdfund" from SBS collaborators/JLab capital equipment?

With VETROC readout system
(probably mandatory for TDIS):

- **Total ≤ $300k**, of which:
  - $182k: 3,000-channel VETROC readout system, including all crates, controllers and other supporting infrastructure
  - $80-100k: everything else
  - By the time TDIS gets going, this could be even cheaper?

Underlying assumptions for RICH budget estimate

- No surprises with condition of RICH aerogel: this still needs to be verified.
- No surprises with condition of RICH mirrors: still needs to be verified.
- No significant modifications to main mechanical structure
- Assumes re-use of existing front-end and readout electronics, signal cables, and connectors from CDET (in the no-VETROC scenario), including NINO cards and LV power supplies, slow controls, Fastbus 1877S TDCs, etc.
  - New patch panel and/or cabling from RICH PMTs to NINO cards will need to be designed and built due to (short) signal cable length and NINO card form factor
- Some mechanical modification of PMT matrix/light-tight enclosure is likely necessary for mounting of NINO cards, new patch panels, etc. (copper enclosure surrounding PMT matrix is also in relatively poor condition→ refurbish or replace.)
- Also does not include cost of radiator gas (C_4F_{10} or similar) during operations

SBS RICH in the context of the SBS experiment timeline

- GMN: Spring 2021?
- GEN: Fall-spring, 2021-2022?
- GEP: Fall-spring, 2022-2023?
- **SIDIS: Fall-spring, 2023-24? OR: After GEN**
- Goal: with dedication of adequate efforts and resources, RICH *could* be ready for parasitic in-beam testing during GEN, which would be desirable as the experiment most similar to SIDIS in terms of kinematics, target, luminosity, etc. **However:**
- In-beam testing of RICH will also require GEM trackers in front of RICH (test results not very meaningful otherwise).
- To proceed with in-beam RICH test during GEN, RICH would need to come out of storage for testing and preparation by Q1 of 2020 at the latest
- Logistics of testing full DAQ system with RICH will be difficult since RICH uses CDET electronics, and CDET will be used in GMN and presumably also during GEN…

Summary and Plans

- Reuse of HERMES RICH is a low-cost solution for PID to enable the ”high impact” physics of E12-09-018
- SBS RICH mechanical structure including aerogel in storage in ESB since April 2018
- PMTs and spare aerogel at UConn for further testing until we are ready to work on RICH at JLab
- Support frame design not yet started—CAD files sent to Hall A Engineering Team
- Gas system design not yet started
- Rough cost estimate to complete preparations $\leq \$100k$ IF CDET electronics reused, $\leq \$300k$ assuming VETROC or VME TDC upgrade.
  - Logistics of checkout prior to beam commissioning difficult if CDET electronics reused.
- We are trying to seek dedicated NSF or DOE funding for RICH preparations, but if we aren’t successful, we assume JLab will absorb (modest) costs—this detector is **required** for E12-09-018 and also TDIS program