RICH Update (Brief)

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SBS Weekly Meeting

July 11, 2018

Outline

- Completion of RICH move to JLab
- Recent activity at UConn—Absolute Quantum Efficiency measurements of RICH PMTs
  - Principles and Procedures of Measurement
  - Initial results
  - Cross-checks
- Near-term plans
  - “Spare” Aerogel testing
- Summary and outlook

RICH move to JLab—Rigging Out (I)

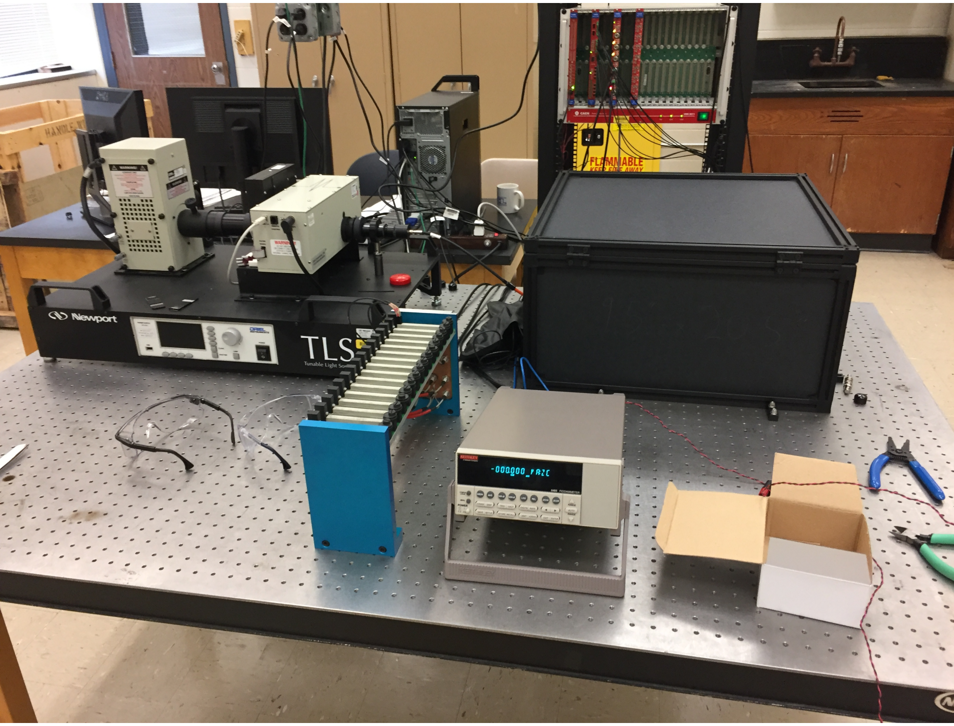
RICH move to JLab—Rigging Out (II)

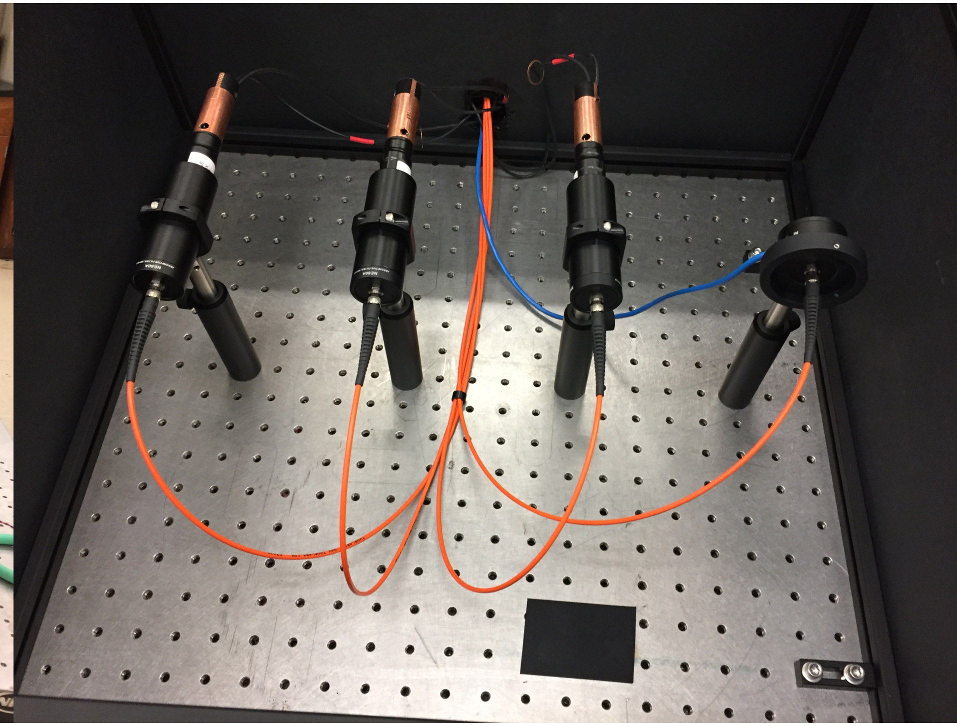
RICH move to JLab—Rigging Out (III)

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

RICH move to JLab—Delivery to ESB

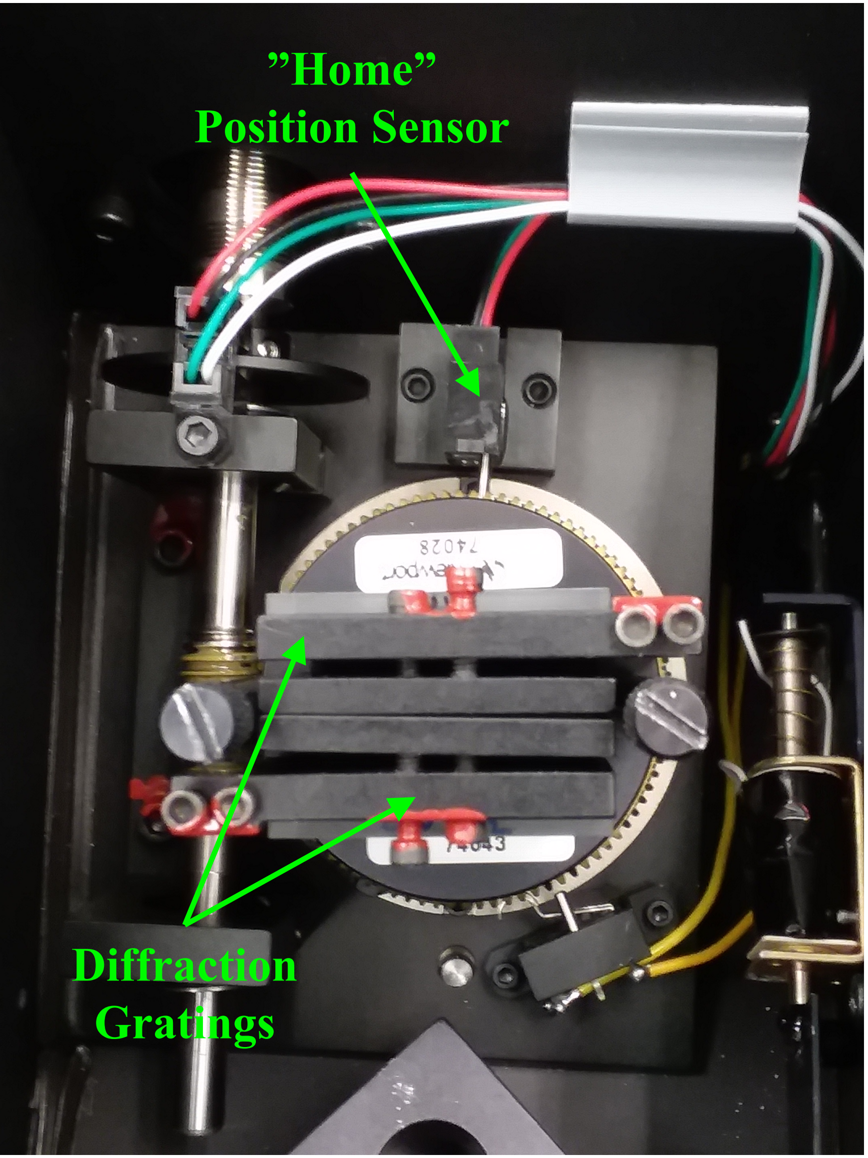
Absolute PMT Quantum Efficiency Measurement





- ***Original plan***: Use broadband tunable light source based on 300 W Xe arc lamp and Newport/CS-130 monochromator to measure PMT quantum efficiency vs. wavelength in 10-nm increments from 250-700 nm.
- Monitor incident light intensity with calibrated photodiode
- Use neutral density filters to attenuate light incident on PMT such that counting rate (10-300 kHz) is dominated by single photoelectrons
- Measure PMT counting rate and photodiode current simultaneously.
- Filter transmission and fiber output ratios measured/corrected for.
- Photodiode responsivity is provided by manufacturer

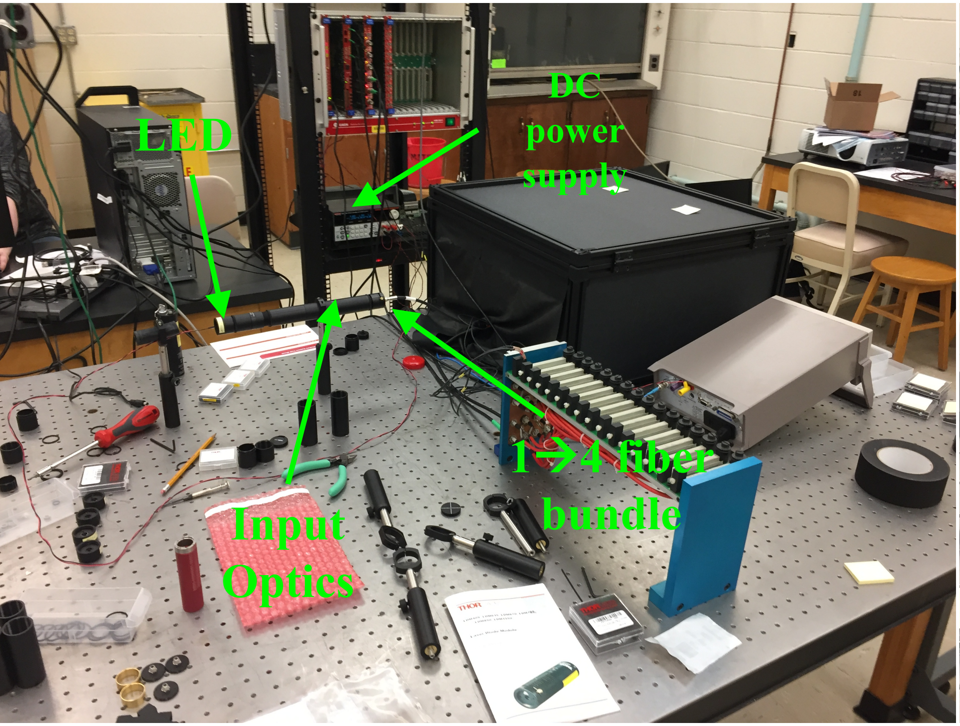
Absolute PMT Quantum Efficiency Measurement (II)

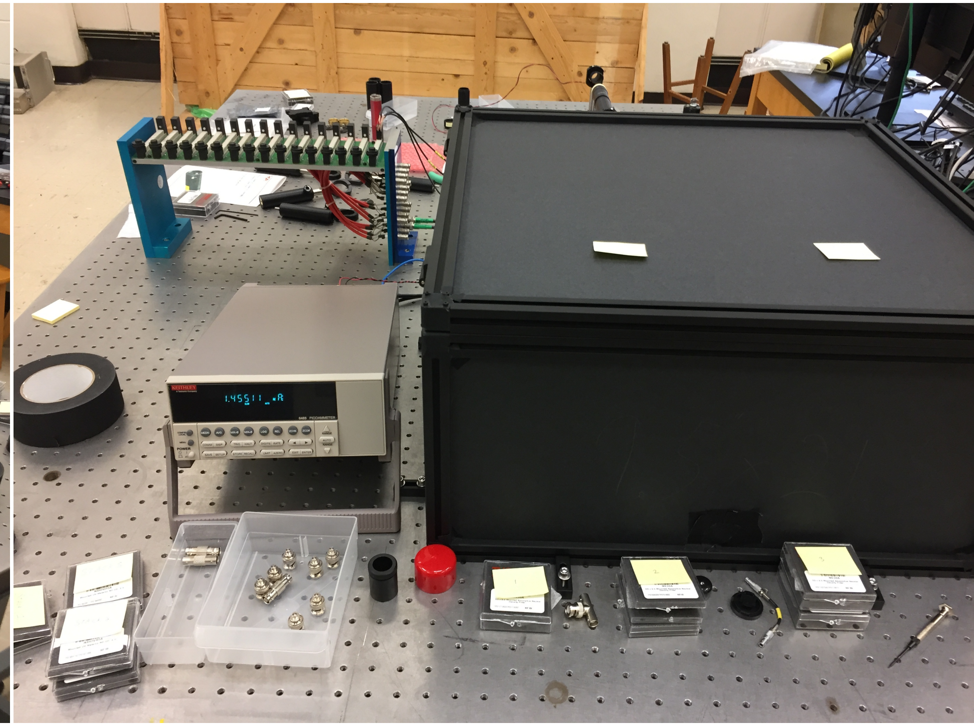


New Plan:

- Wavelength selection from broadband Xe arc lamp is based on diffraction grating/Czerny-Turner optical configuration with computer-controlled/motorized positioning of grating/mirrors.
- Wavelength setting started becoming unreliable late May/early June; reasons unknown, but the prime suspect is hardware damage caused by faulty custom LabView software “accidentally” telling the monochromator to go places it shouldn’t go.
- Precision drive components malfunctioning:
  - Set wavelength != actual wavelength
  - Diffraction grating does not set “home” position accurately, correctly or repeatably, even after “hard” power-cycle
- We are in contact with manufacturer for repair cost estimate, but repairs unlikely to be complete before end of summer (or ever, if repair quote is too expensive)
- Instead, we implemented an alternative method based on DC-biased single-color LEDs at ”discrete” wavelengths

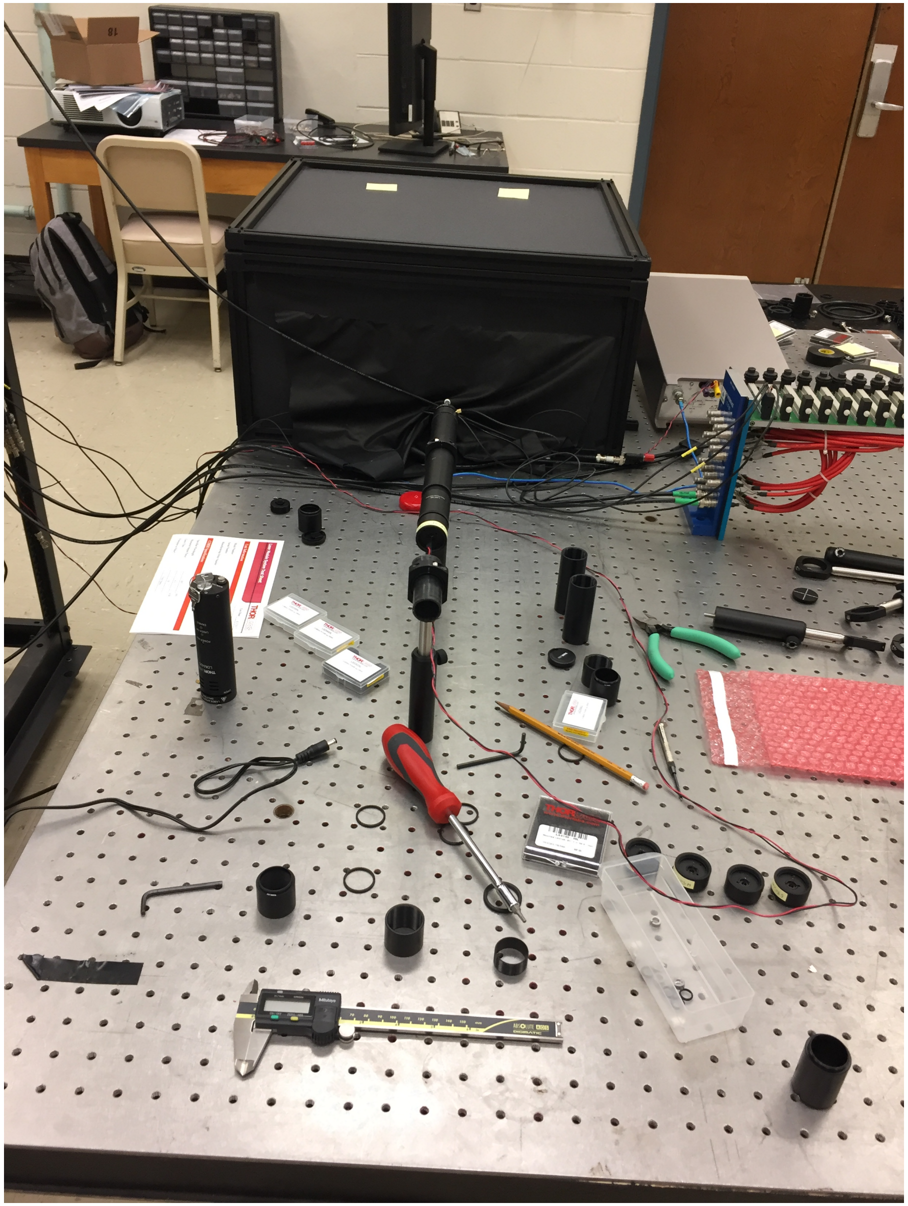
Absolute PMT Quantum Efficiency Measurement (III)

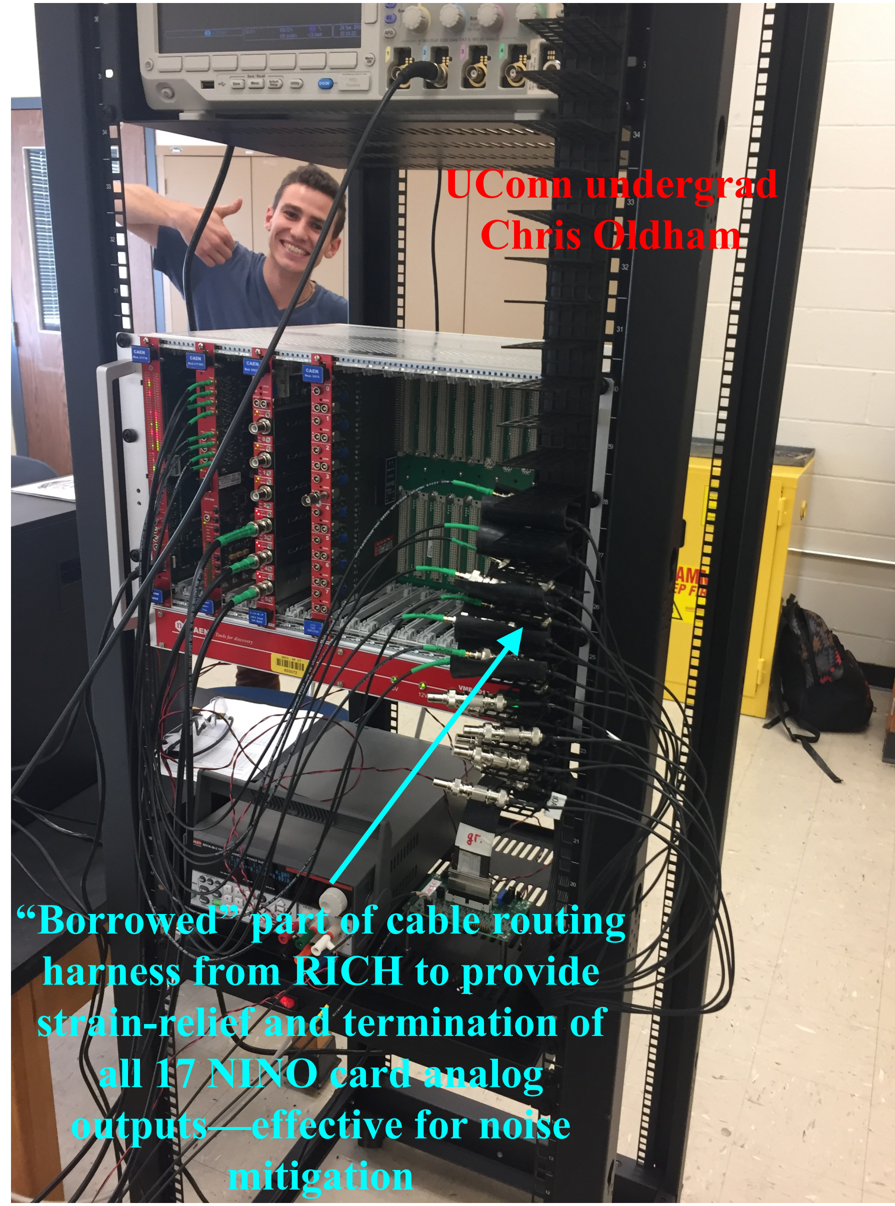




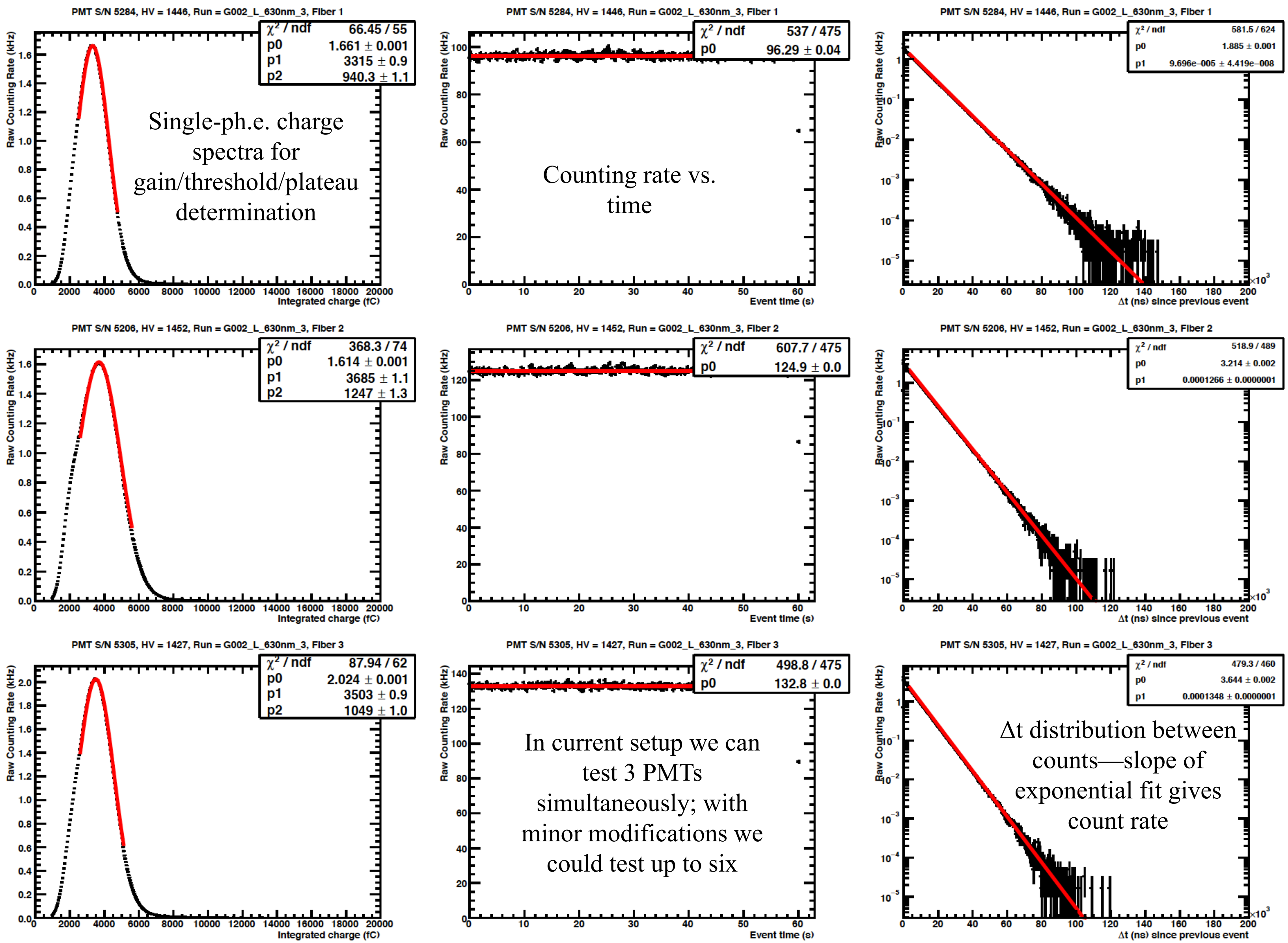
- DC-biased LEDs coupled to input optics designed for uniform-ish illumination of input of 1→4 fan-out optical fiber bundle
- LED in detachable fixed mount for "repeatable" positioning/illumination of input optics
- Picoammeter monitors photodiode current/incident light intensity, during DAQ runs, via scaled analog voltage output, monitored via scope, for absolute measurement and stability check of LED output
- Manual shutter on fiber input allows swapping out of light sources (LED/laser) of different wavelengths without shutting off PMT HV

Absolute PMT Quantum Efficiency Measurement (IV)

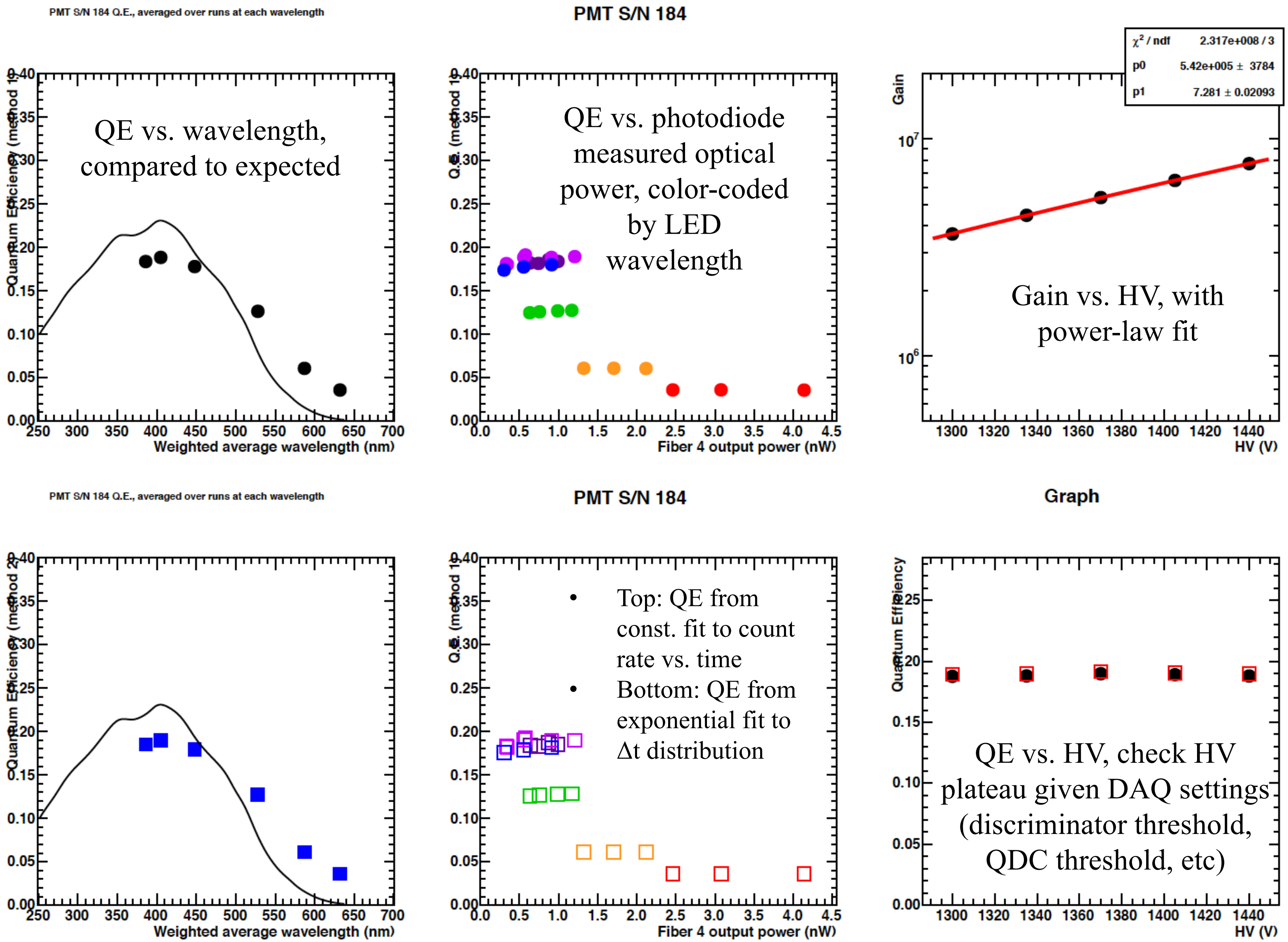




Example QE DAQ run analysis



Example QE results for a single PMT



Summary of QE measurement procedure

- PMTs are positioned close enough to fiber outputs to ensure 100% light collection efficiency by covering full numerical aperture of fiber.
- DC LED bias voltage is adjusted to vary PMT single-ph.e. count rate in the range of 10-200 kHz above dark counting rate (dark rates typically < 1-2 kHz)
- Reflective neutral density filters with approximately flat transmission of ~5e-4 in the UV/VIS spectrum attenuate the light incident on PMTs to keep PMT photon flux/count rate manageable while still having enough light output from the fourth fiber to give a measurable photocurrent within the dynamic range of the photodiode
- Measurements include:
  - HV scan at fixed LED level for gain matching/threshold setting.
    - Choose HV such that gains of three PMTs are matched and each is in the plateau region given DAQ thresholds
  - LED scan at fixed HV for five different LEDs + 405 nm 5 mW laser
    - Varying light level to confirm that ratio of PMT count rate/photodiode current is independent of optical power
- Incident optical power for each PMT is extracted from measured photodiode current/responsivity, measured relative fiber output ratios (long-term repeatability/stability of these ratios is a large source of systematic error), and measured filter transmission (as applicable).
- Convert optical power to photon flux, given LED average wavelength
- Take ratio of dark-count-rate subtracted, deadtime-corrected PMT counting rate to incident photon flux to extract QE.

Main systematics for QE measurement

- **Relative fiber output ratios**: it has proven difficult in our setup to achieve uniform fiber input illumination/output ratios in the absence of more expensive solutions; e.g. integrating sphere, etc. Lots of optical arrangements have been tried; mix of collimating/focusing lenses, ground glass diffusers, apertures, etc. (all "off-the-shelf" components)
  - Best relative fiber output uniformity achieved is ~1-2% relative (for LEDs, which also appear to have long-term repeatability of fiber output ratios at this level)
  - 405 nm laser repeatability is not good, varies at the 5-10% level (sometimes up to 20% or more), and typically requires re-calibration between PMT batches for confidence in QE results.
- Photodiode calibration uncertainty: 1-2% relative (from manufacturer spec)
- HV plateau: ~1-2% relative
- Measurements do NOT appear to be sensitive to where the PMT is mounted, meaning the (calibrated) filter transmission is not a major source of systematic error.

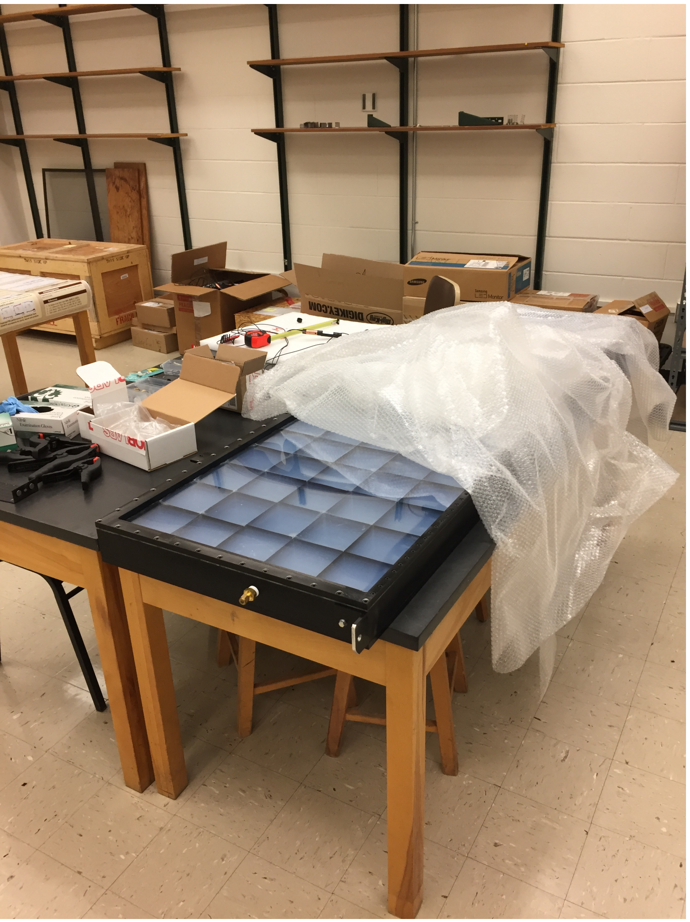
PMT QE—Additional Cross-checks

- With calibrated photodetectors, we can also measure quantum efficiency in our old "pulsed LED" setup, given an appropriate selection of filter(s), LED drive pulse waveform and repetition rate.
- The Keithley 6485 picoammeter can measure the average photocurrent from a pulsed source; provided the average optical power is sufficiently high; response time is relatively slow, but it appears to measure the average photocurrent correctly
- With a fixed repetition rate of "large" light pulses resulting in several hundred photoelectrons per pulse, we can do a cross-check QE extraction that is much less sensitive to threshold/HV plateau issues compared to the method based on DC-biased LEDs and single-photoelectron count rates.
- Plan is to perform absolute QE measurements on ~100-200 PMTs and then attempt to cross-reference with existing data for all PMTs from old pulsed LED setup to evaluate relative QE of PMTs for which absolute QE measurement not performed

Summary of initial QE results

- We have QE measurements in which we are relatively confident for six spectrally distinct light sources (LED/laser) for about 15 PMTs so far.
- Results in the blue-violet-near UV region somewhat below expectation, range from 12-18% for PMTs tested so far.
- Results in the visible region (525, 590, 630 nm) are somewhat higher than expected
- We are still improving the setup with respect to homogenizing the fiber input illumination and achieving uniform/stable/repeatable fiber relative output ratios
- We will do "pulsed LED" cross check on a subset of the PMTs; however, the effectively realized QE for single photoelectrons is more relevant to the planned experimental usage in the SBS RICH.

Testing the "Spare" Aerogel at UConn



- Refractive index measurement exploiting square tile geometry based on minimum-deviation method for 405 nm (and possibly other wavelengths) laser directed through the corner of a 90-degree prism. Snell's law predicts:

$$
\begin{aligned}
\frac{n}{n_{air}} &= \frac{\sin\frac{\alpha+\theta_{min}}{2}}{\sin\frac{\alpha}{2}}, \\
\alpha &= 90^\circ = \frac{\pi}{2} \\
\theta_{min} &= \text{Minimum deviation angle} \\
\frac{n}{n_{air}}(\alpha = 90^\circ) &= \cos\frac{\theta_{min}}{2} + \sin\frac{\theta_{min}}{2} \\
n_{aerogel} = 1.03 &\implies \theta_{min} \approx 3.5^\circ \\
\frac{dn}{d\theta_{min}} &= \frac{n_{air}}{2}\left[\cos\frac{\theta_{min}}{2} - \sin\frac{\theta_{min}}{2}\right] \\
&= \frac{n_{air}}{2}\left[1 - \frac{\theta_{min}}{2} + \mathcal{O}(\theta_{min}^2)\right] \\
&\approx 0.485 \text{ rad}^{-1}
\end{aligned}
$$

- Minimum deviation angle corresponds to ~120 mm deflection of the beam at a distance of 2 m from the tile
- To measure *n-1* with a relative precision of 0.5% or less requires angle measurement with ~1 arcmin resolution. This is not terribly challenging but requires careful planning of alignment of tile/laser/beam deflection measurement apparatus--possible use of mirrors to increase optical path/sensitivity, precise angular positioning hardware, etc.

Near-term RICH plans and Outlook

- I will provide performance parameters/calibration and commissioning requirements document before collaboration meeting (sorry for the delay)
- Reviewing old HERMES RICH documents/drawings, compiling detailed cabling/electronics/DAQ/HV requirements and layout
- Need to start serious efforts at planning/designing RICH support frame in SBS, gas system (intend to more or less copy GRINCH solution given similarity of detector designs/gas requirements/volumes).
- Need to decide where/when to start RICH work at JLab
  - Open main RICH box to check "production" aerogel, check mirror condition and alignment
  - Gas purging/filling, leak-testing, light-proofing, etc.
- Magnetic shielding requirements beyond passive shielding already provided by soft steel PMT matrix plate?
- Ideal goal: Be ready for parasitic in-beam testing during GEn (most similar to SIDIS in terms of experimental conditions).
- Lots of work to do, SIDIS timeline = 2022/23?

Acknowledgements

- UConn undergrads Chris Oldham and Brenna Robertson, leading the RICH component testing activities in the lab this summer
- Peter Monaghan, Bogdan Wojtsekhowski and Glasgow group for loaning NINO card and ribbon→BNC adapter cable.