RICH Status Update

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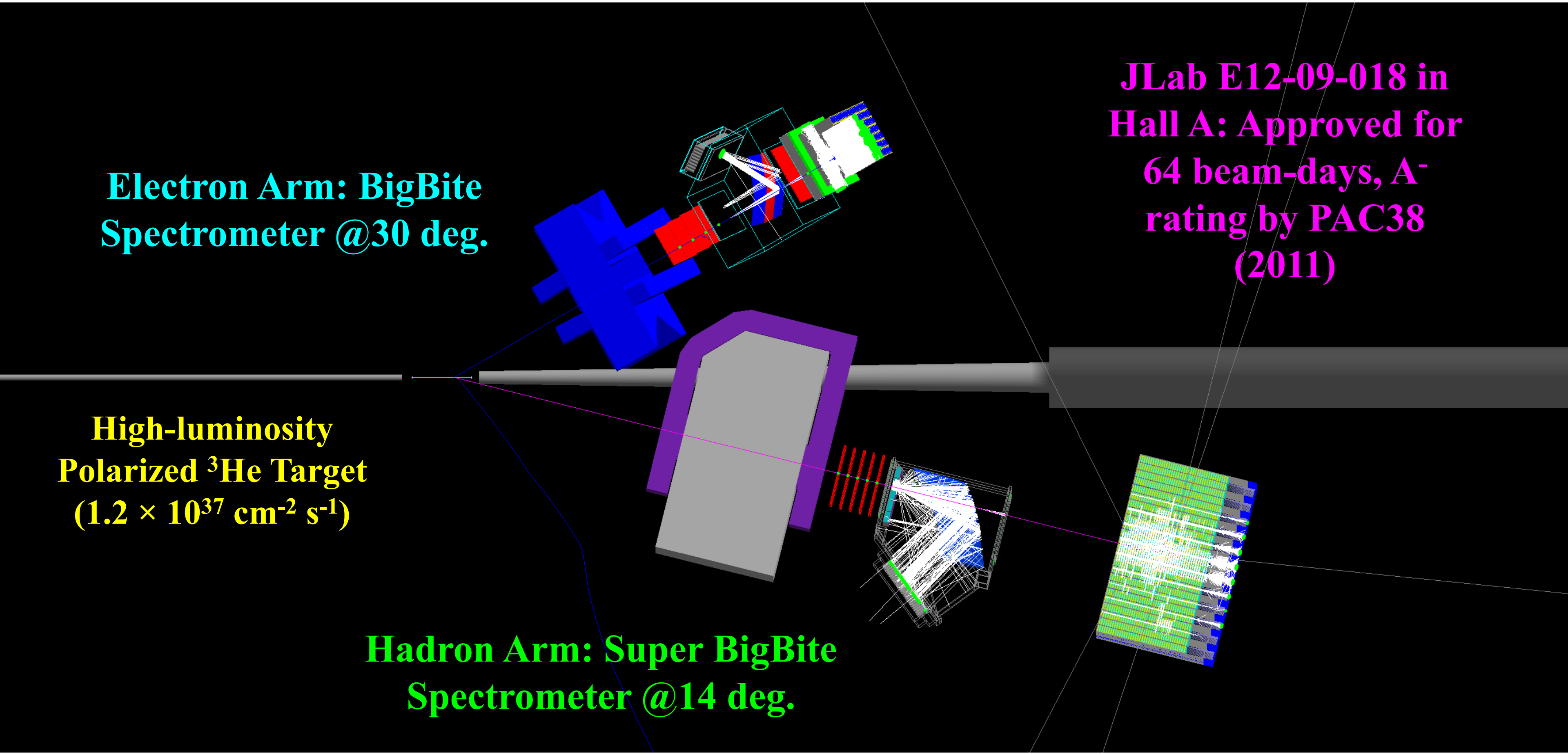
University of Connecticut
TDIS Collaboration Meeting
Feb. 22, 2018

UCONN Jefferson Lab

Outline

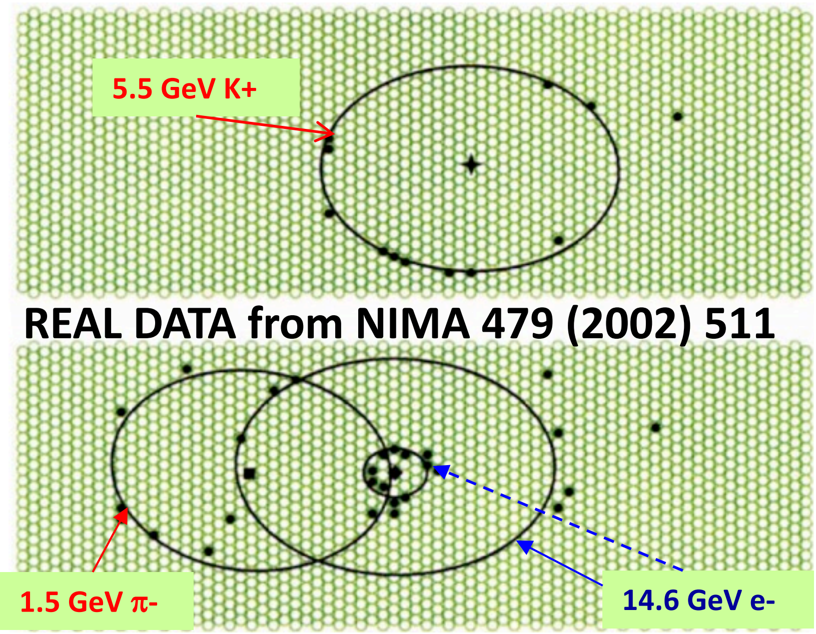
- Brief overview of RICH—design and purpose
  - Experiment E12-09-018 (SIDIS)—Ring-imaging Cherenkov for charged hadron PID
  - Experiment C12-15-006 (TDIS)—”threshold” Cherenkov for electron ID
- Ongoing activities at UConn
  - Absolute PMT quantum efficiency measurement
  - Inspection of spare aerogel tiles
  - New simulation studies
- Planning for shipment of the RICH to JLab
  - Cost estimate
- Thoughts on use of SBS RICH as threshold Cherenkov for online/offline electron ID.

E12-09-018: Transverse Target SSA in ^{3}He(e,e'h)X



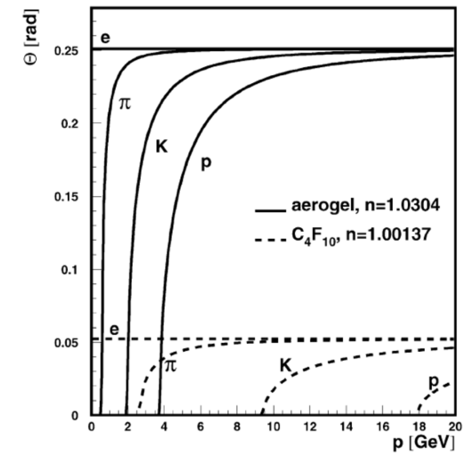
- **E12-09-018** in Hall A: transverse spin physics with high-luminosity polarized ^{3}He.
- 40 (20) days production at E = 11 (8.8) GeV—significant Q^2 range at fixed x
- Collins, Sivers, Pretzelosity, A_{LT} for n(e,e'h)X, h = $\pi^+/\pi^-/\pi^0/K^+/K^-$
- Re-use HERMES RICH detector for charged hadron PID
- Reach high x (up to ~0.7) and high statistical FOM (~1,000X Hall A E06-010 @6 GeV)

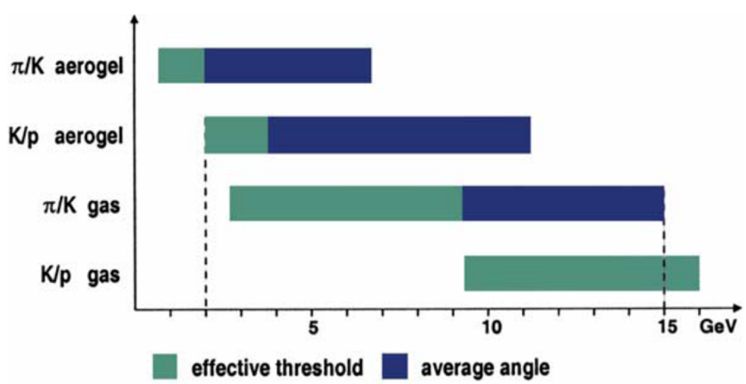
The HERMES RICH detector

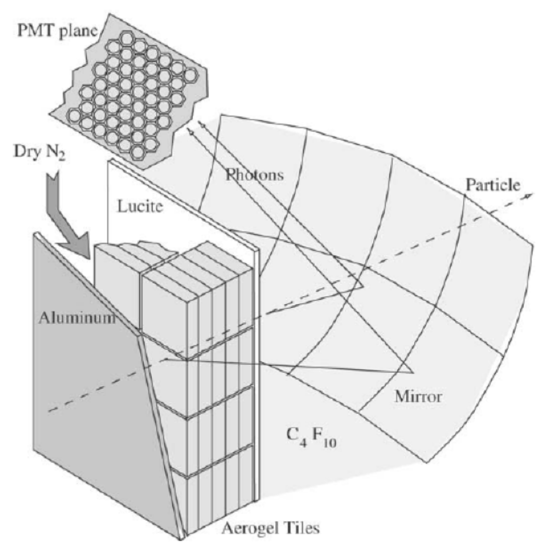


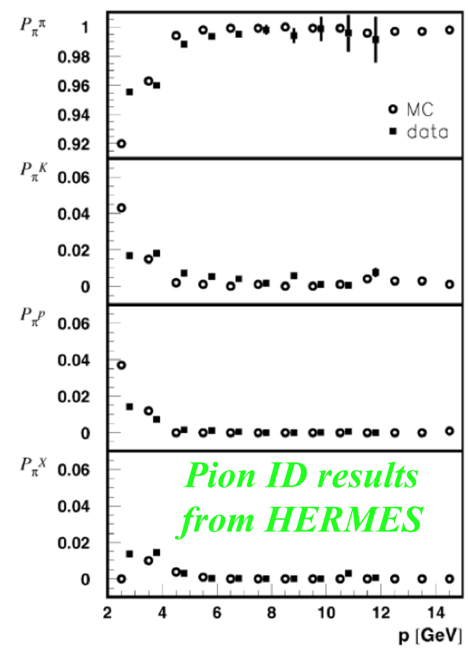
REAL DATA from NIMA 479 (2002) 511

- ***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



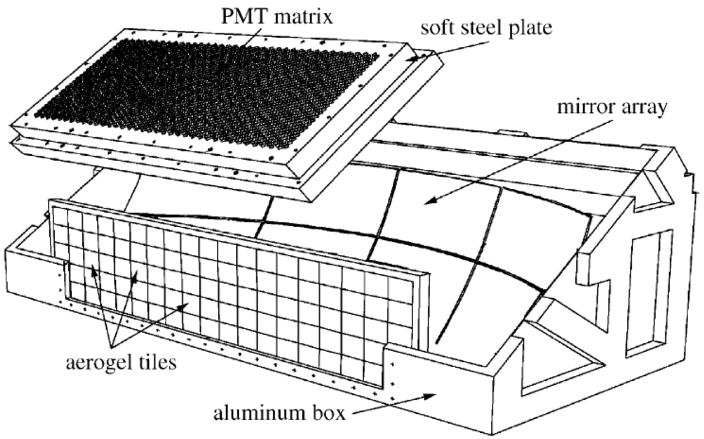


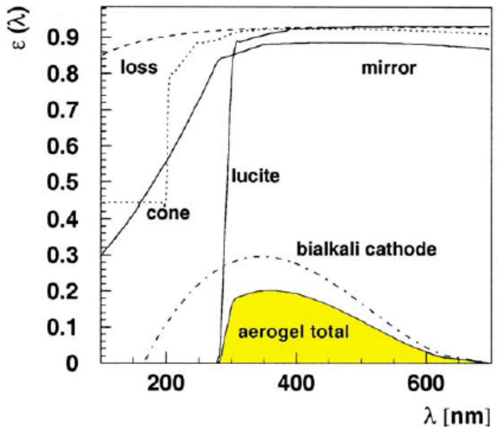


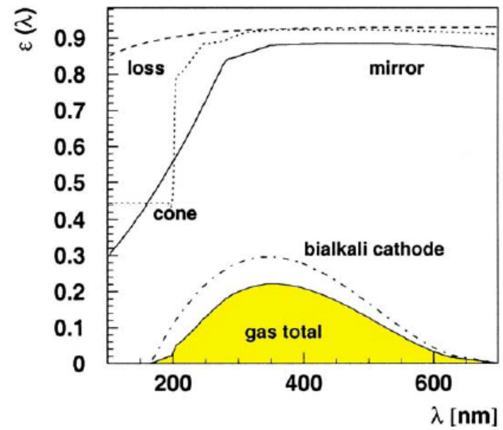


Pion ID results from HERMES

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 track 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.

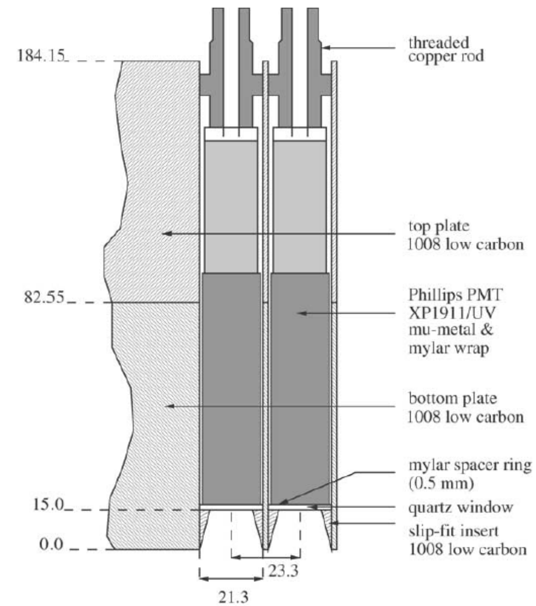
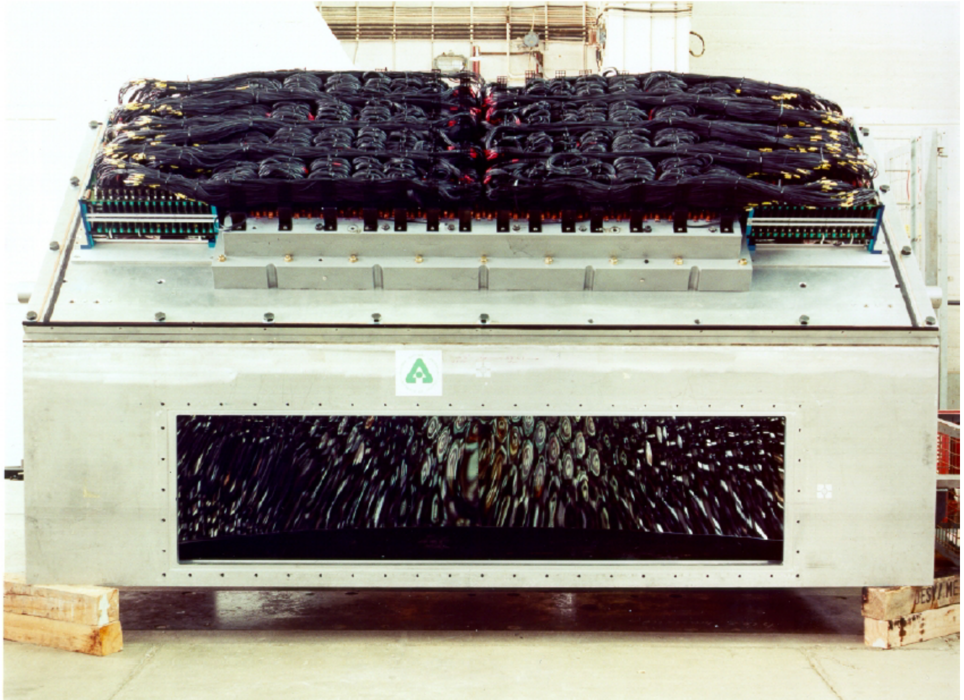
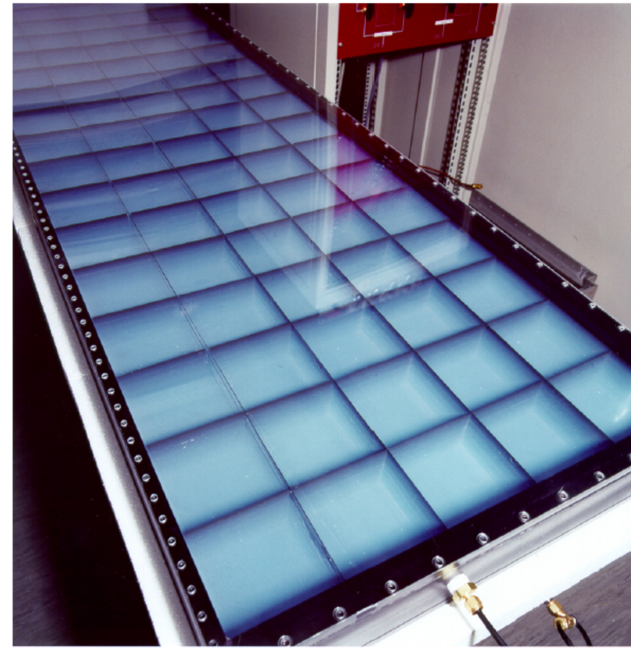


Fig. 7. Schematic photon detector design. All units are in mm.

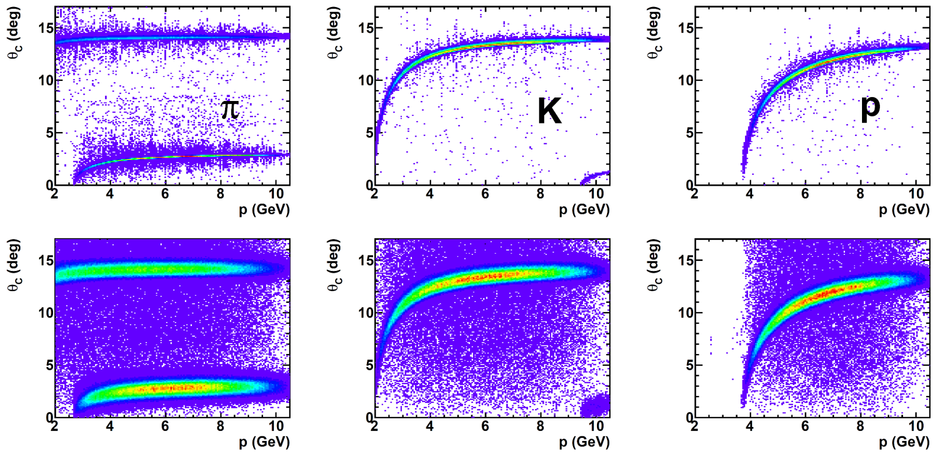
SBS RICH Detector Photos

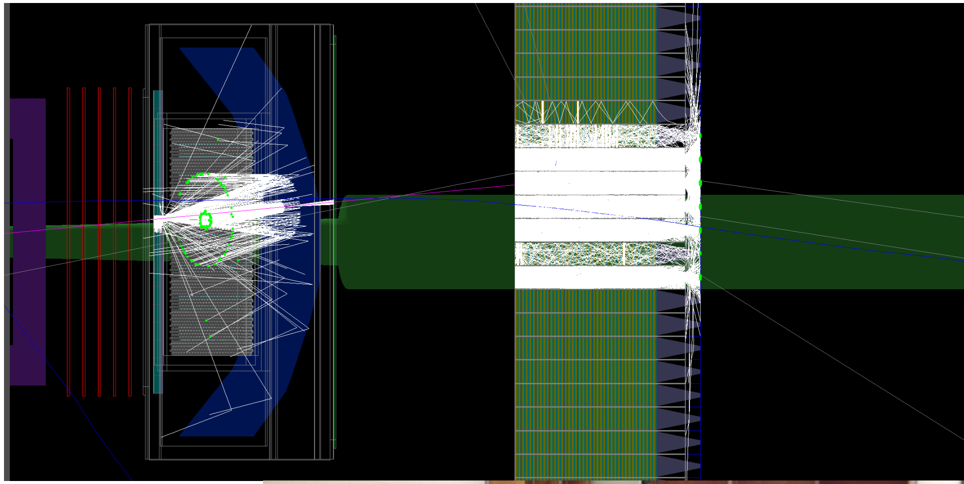




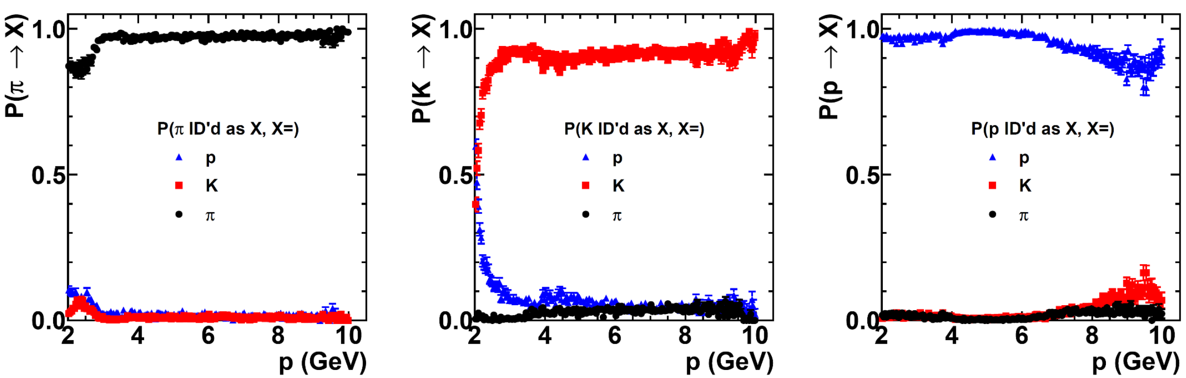
- Above, left: Old picture of one half of RICH with aerogel wall and entry window removed
- Above, right: Old picture of one aerogel wall w/containment vessel
- Bottom right: RICH delivery to storage facility @UVA, 2009

HERMES RICH in SBS





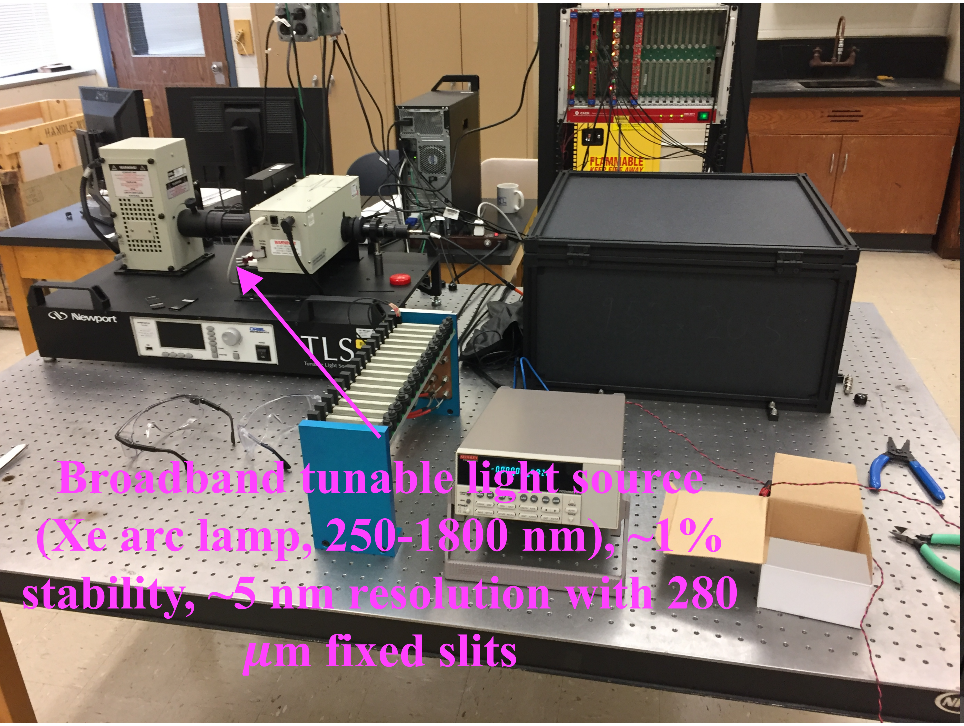
GEANT4-simulated RICH performance in SBS

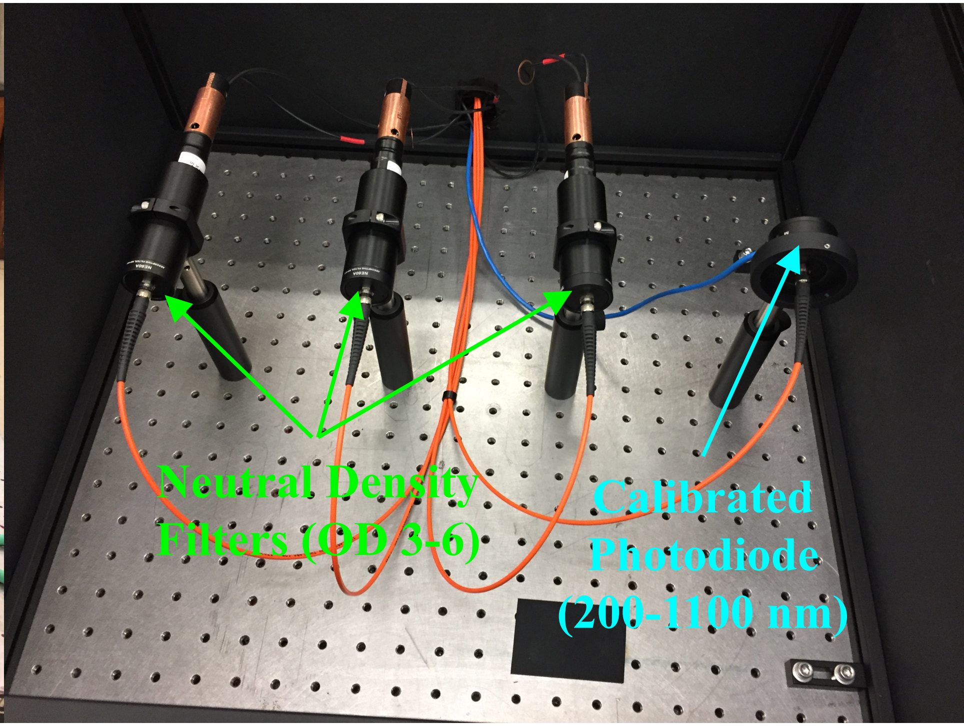


GEANT4 simulated RICH PID performance in SBS for π/K/p

HERMES/SBS RICH @UConn, Sept. 2014

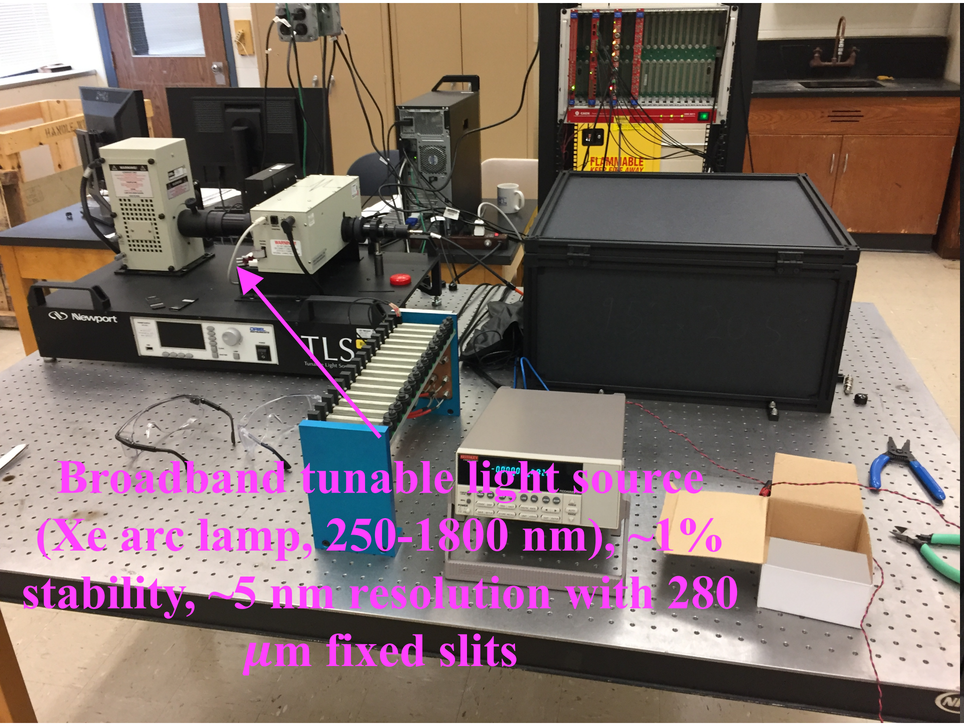
New-–PMT absolute quantum efficiency measurement

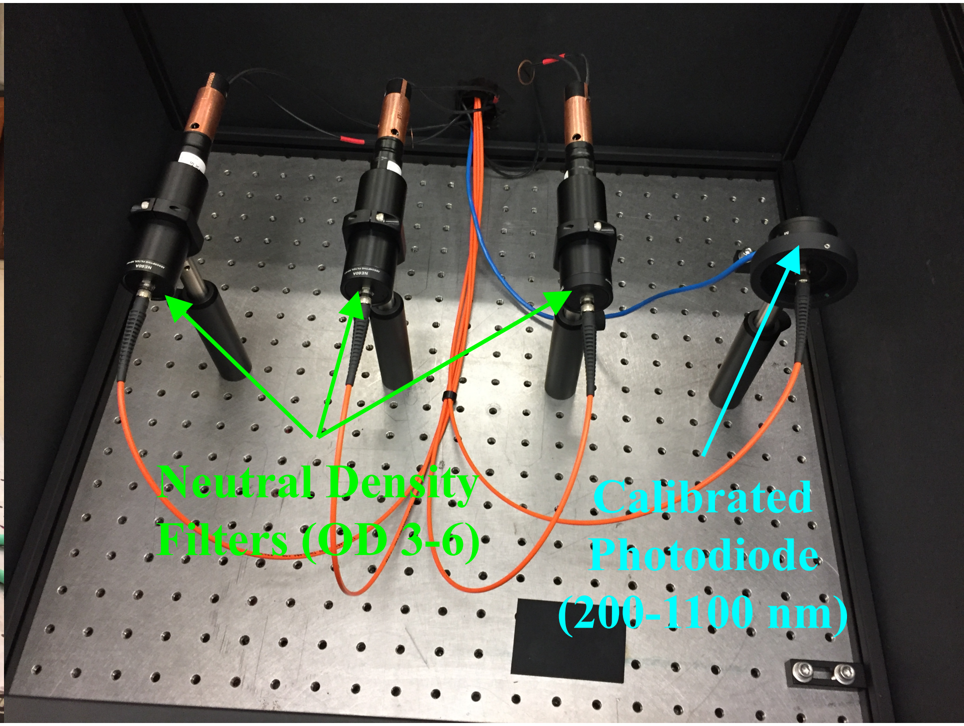




- Reconfiguration of UConn PMT test stand to measure absolute PMT quantum efficiency vs. wavelength (with ~5-10% absolute accuracy)
- Use broadband (250-1800 nm) tunable light source based on a 300 W Xe arc lamp with ~1% stability illuminating a monochromator with ~5 nm spectral resolution (up to 0.7 nm possible using smaller slit width)
- Measure the optical power output vs wavelength for each fiber using a calibrated photodiode.
- Monitor relative fluctuations in lamp output during the measurement by viewing the fourth fiber output with the calibrated photodiode
- Passively filter/attenuate the (DC) output of each fiber illuminating a PMT using ND filters to reduce the counting rate to something manageable ($\frac{dN}{dt} \leq 1\ MHz$) at any given wavelength.

PMT absolute quantum efficiency measurement (cont.)





- To obtain the quantum efficiency, we measure the counting rate as a function of wavelength for each PMT, divide by the transmittance of the ND filter, and convert the photon counting rate to an optical power via $E_{photon} = \frac{hc}{\lambda}$, $\epsilon(\lambda) = \frac{E_{photon}(\lambda)}{P_{fiber}(\lambda)T_{filter}(\lambda)} \frac{dN_{photon}(\lambda)}{dt}$
- We calibrate the spectral distribution of the transmittance of each ND filter in a separate, dedicated measurement. This increases the uncertainty of the final result.
- The distance from the output of each fiber to the PMT photocathode (or photodiode surface, as applicable) is fixed to be small enough to ensure 100% "effective" collection efficiency while illuminating a reasonable fraction of the photocathode surface area.

PMT Quantum Efficiency Measurement—Status and Plans

- UConn undergraduate physics major Chris Oldham is leading this effort as part of an independent study project
- We are currently debugging and troubleshooting LabView-based control of the "slow" instrumentation:
  - The monochromator (Setting wavelength scan parameters, including the table of gratings and order-sorting filters to use in appropriate wavelength ranges)
  - The picoammeter (photodiode readout synchronized with wavelength scan)
- Picoammeter also has scaled analog voltage output which could be sent directly to the oscilloscope and/or the DAQ—we are evaluating several options for using the analog voltage output.
- After establishing measurement procedure and uncertainties, our plan is to do detailed measurement on a subset of (50-100) PMTs to determine the level of variations of absolute QE among existing PMTs, then cross-reference this subset against existing pulsed LED data for all PMTs by comparing relative photoelectron yields for other PMTs viewing the same LED/fiber—this could allow us to estimate absolute QE for all PMTs, albeit with lower accuracy, since LED data were obtained under varying conditions with many uncontrolled parameters (LED-PMT window distance, LED max. driving voltage, etc).

"Spare" aerogel uncrating

- This is the "spare" aerogel wall from the "other" half of the RICH detector not in our possession, that was crated and shipped separately from the main detector.
- We uncrated this over the summer, it appears visually to be in good condition, relatively uniform appearance in terms of color, texture, consistency, cloudiness, etc.
- We will soon attempt to open the containment vessel and begin optical measurements on a subset of the tiles.
- We have no plans to open the main RICH tank at UConn. The aerogel in the main tank is presumably in similar condition to the "spare" one.

Planned measurements for "spare" aerogel tiles

- Refractive index (two or more different methods for cross-check of systematics):
  - Minimum-deflection method with violet laser (405 nm) and possibly also red laser to check dispersion
  - Interferometric method—use a Michelson-type interferometer, count fringes while rotating a tile through a known angle
  - Indirect method—measure tile density and use the approximate relation between aerogel density and refractive index.
- Transparency
- Tile dimensions
  - using caliper
  - using interferometry

Preparations for shipment to JLab

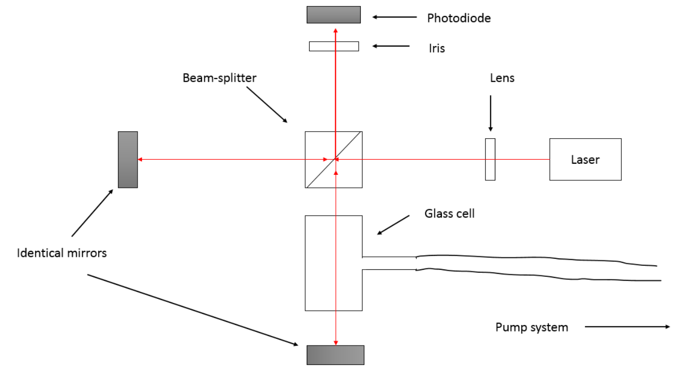
- We met with UConn's contract rigger in October, 2017
- This is the same rigger who uncrated and moved the RICH into its current location in a basement lab space at UConn.
- Cost estimate:
  - Total end-to-end cost, including rigging, full crating, shipping = $6.25k
  - Cost without crating: ~$5k
- Currently coordinating with JLab on the location/preparation of the space for RICH testing/preparation activities (and/or storage) at JLab.
- UConn physics department is eager to recover the space where the RICH is currently stored as lab space for recent experimental faculty hires in AMO.
- Physics department will move into a newly renovated space in the 2018-2019 time frame.
- RICH delivery to JLab is planned for late March, after the end of the spring 2018 running period.

Other near-term activities for RICH

- Prepare "white paper" detailing system requirements for SIDIS/TDIS
- New simulations: optimize SBS detector layout for SIDIS:
  - SBS magnetic field strength → lower is better for acceptance and fringe field near polarized target. Clarify minimum momentum resolution requirements for PID and kinematic reconstruction
  - HCAL distance → with lower SBS field, increase distance to HCAL to lower background rates without cutting acceptance (and improve pi0 resolution).
    - Also improve HCAL angular + TOF resolution, improved constraints for tracking
  - Revisit background rates/PID performance
  - Develop analysis framework for SBS in SIDIS: trigger, tracking and PID
  - Trigger/DAQ rates and occupancies
- Start to think about beamline and SIDIS target design.
  - What is truly needed vs. what is "nice to have"?

Gas Possibilities—From Todd Averett, Hall A Collaboration Meeting, Jan. 2018

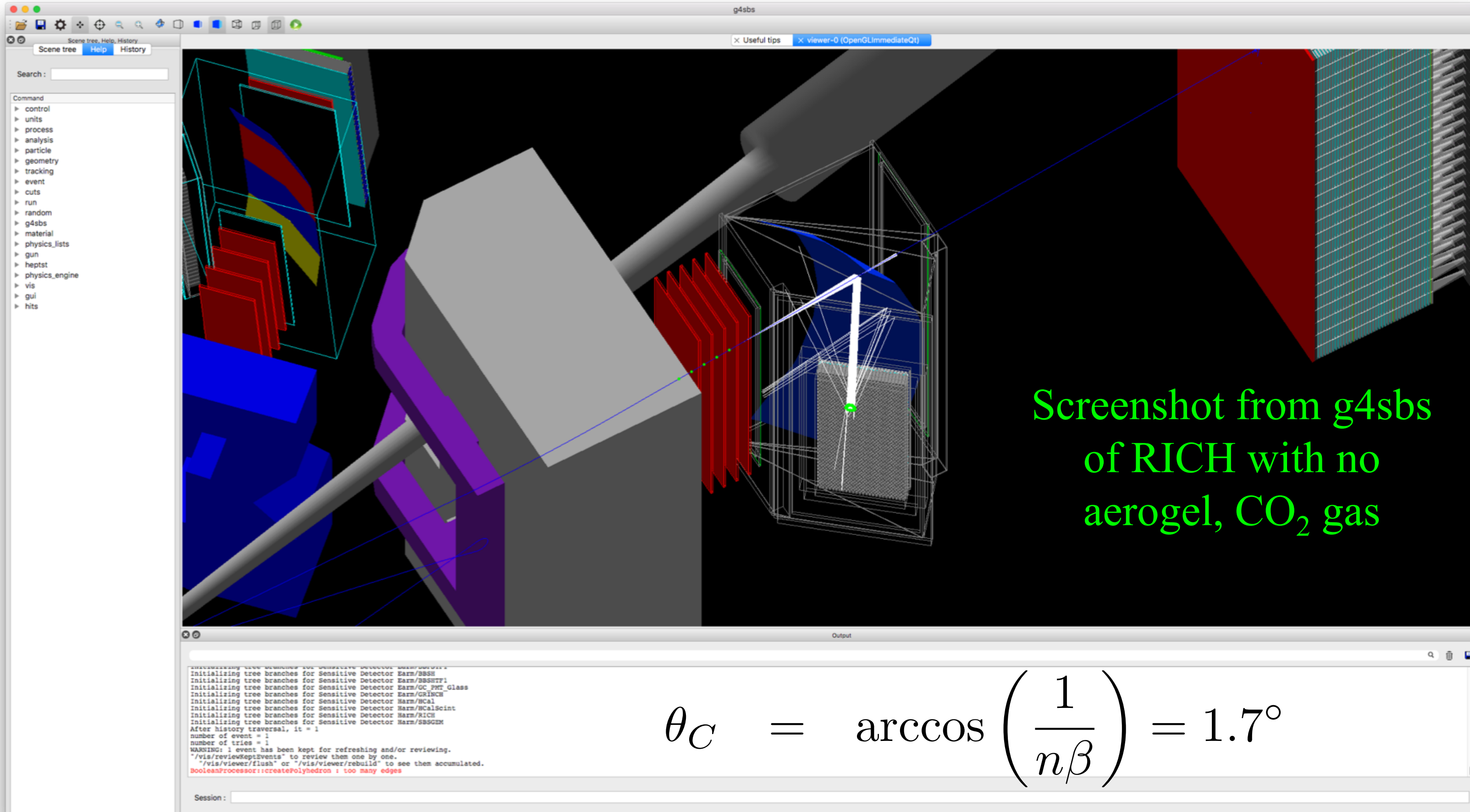
- C_4F_{10} looks prohibitively expensive. Largest loss is through leakage based on Hall A and B experience.
- Measuring index of refraction and UV absorbance of 3 less-expensive gases: SF_6 , C_4F_8 , C_3F_8.
- Possibility of using CO_2 for $G_M{}^n$ experiment which only needs 10:1 pion rejection. But CO_2 gives a factor of three fewer photons.
- Non-toxic, non-flammable; all are greenhouse gases



W&M interferometer for measuring refractive index

Chemical Name	Molecular Formula	Molecular mass (g/mol)	Index of Ref.	Rel Photon Yield	Pion Threshold (GeV)	250 kg price	
Decafluorobutane (Perfluorobutane)	C_4F_{10}	238	1.00135	1	2.7	$195/kg	Currently used
Octafluorocyclobutane (Perfluorocyclobutane)	C_4F_8	200	?	?	?	$75-$95/kg	
Octafluoropropane	C_3F_8	188	?	?	?	$150/kg	
Sulfur Hexafluoride	SF_6	146	1.00078	0.58	3.5	$45/kg	
Carbon Dioxide	CO_2	44	1.00045	0.33	4.7	cheap	

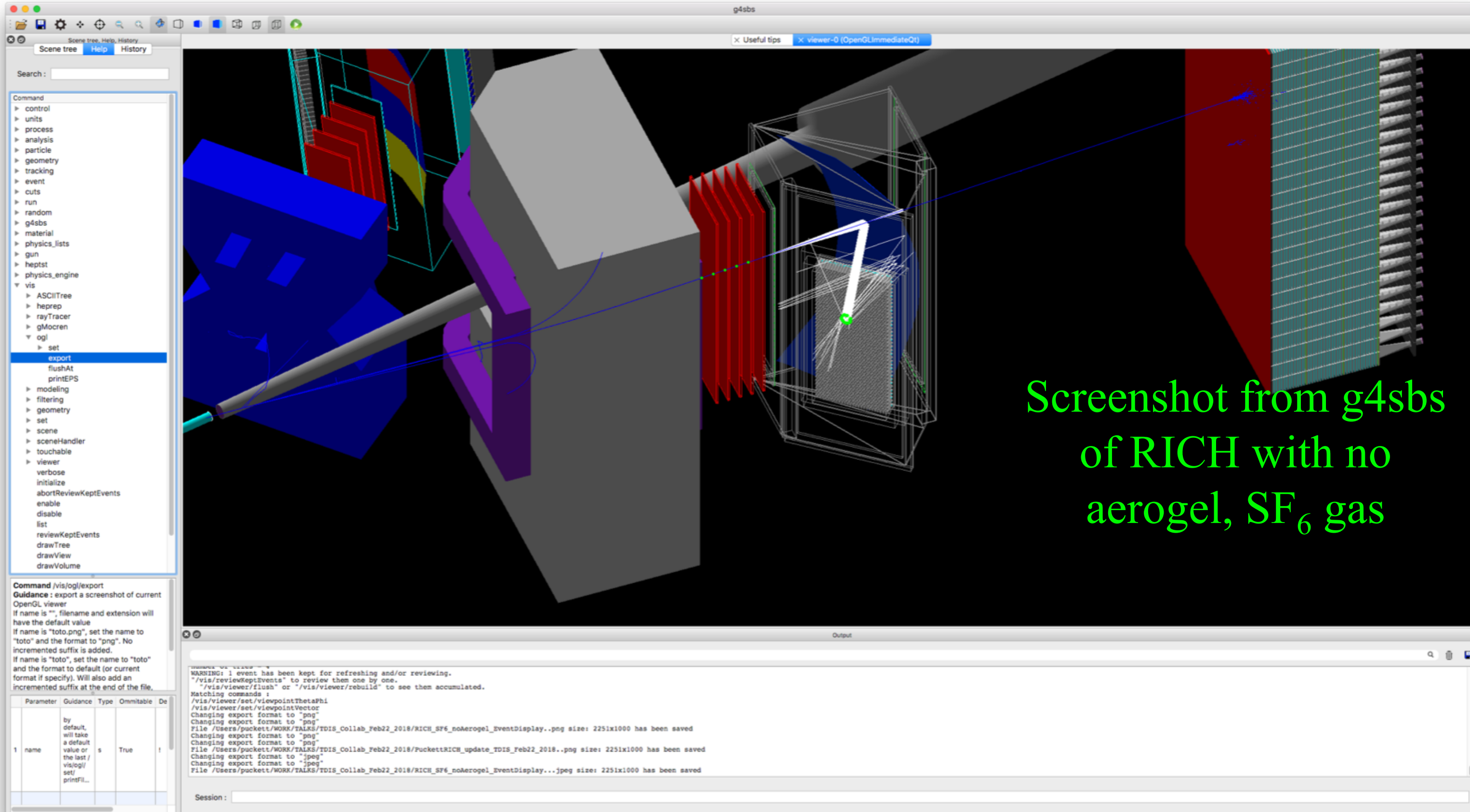
Exploratory simulation studies—RICH with various gases



$$\theta_C = \arccos\left(\frac{1}{n\beta}\right) = 1.7^\circ$$

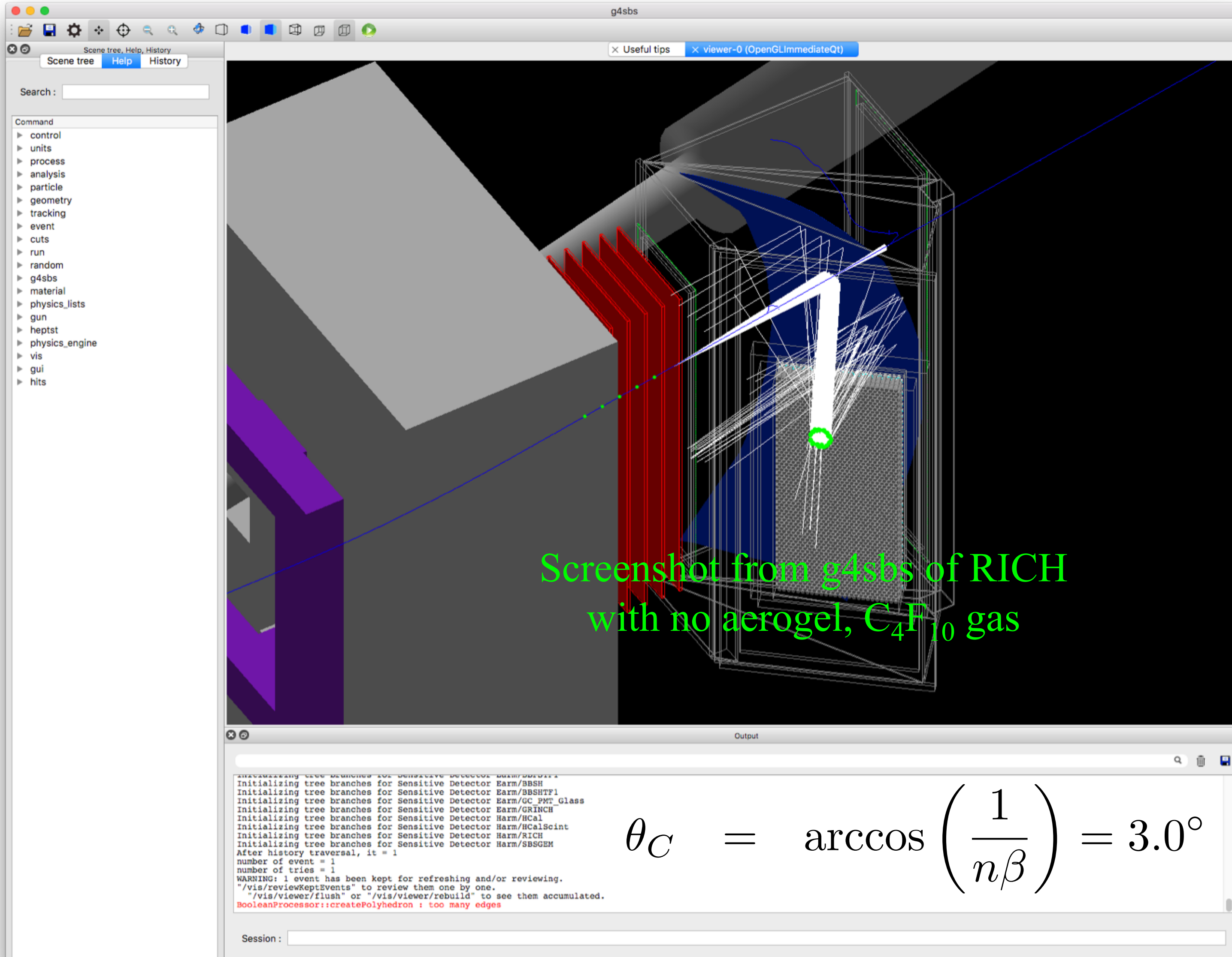
- In order to use RICH for *online* pion rejection, the baseline scenario would be to remove the aerogel tiles, and use it as a Gas Cherenkov *a la* GRINCH being built at W&M for BigBite.
- CO_2 has high pion threshold (~4.7 GeV), but particle path length in CO_2 and photon yield is a concern
- High segmentation keeps individual PMT occupancies low, but this also mandates as low as possible threshold to maintain high efficiency

Exploratory simulation studies—RICH with various gases



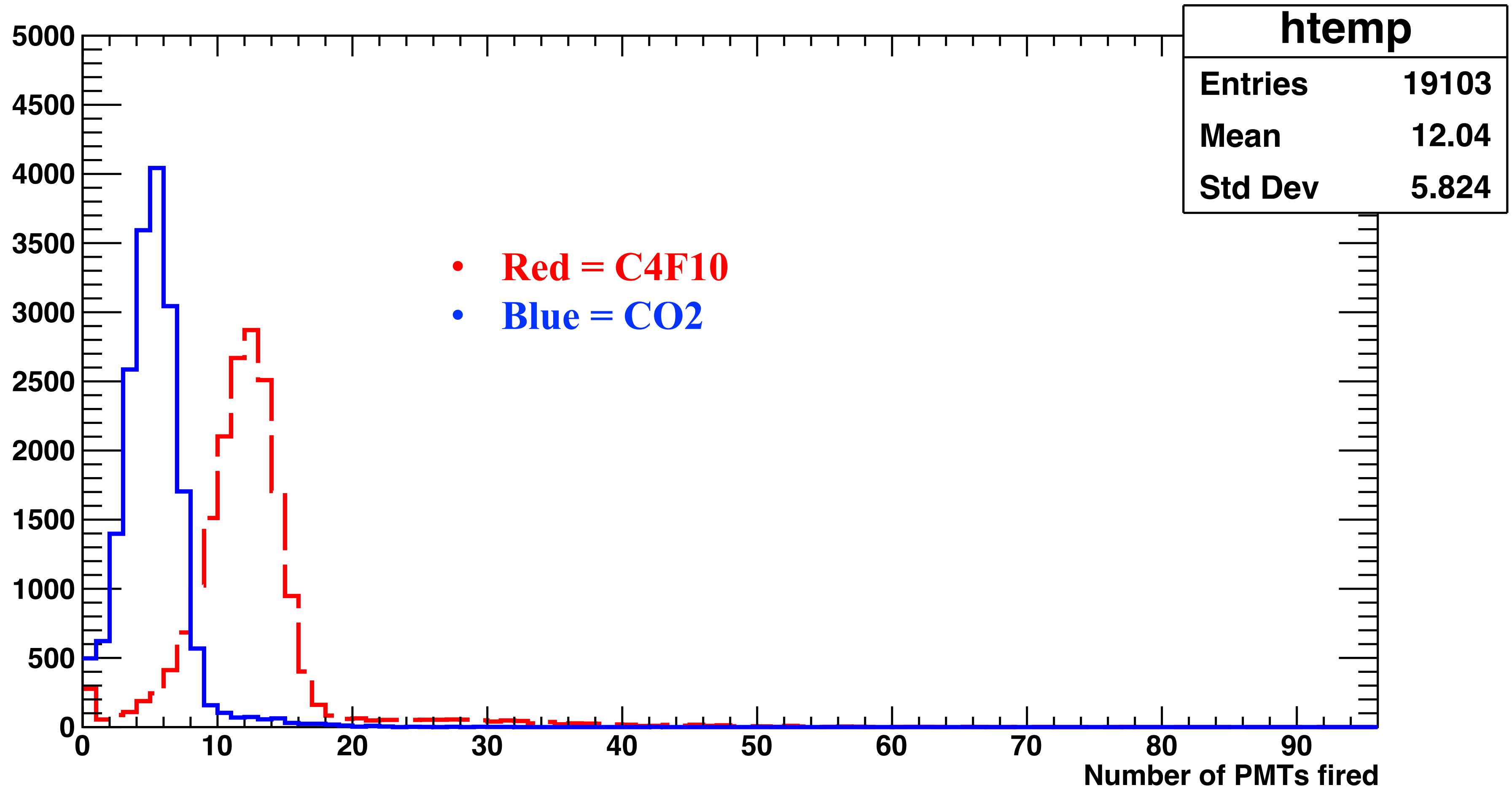
$$\theta_C \quad = \quad \arccos\left(\frac{1}{n\beta}\right) = 2.3^\circ$$

Exploratory simulation studies—RICH with various gases



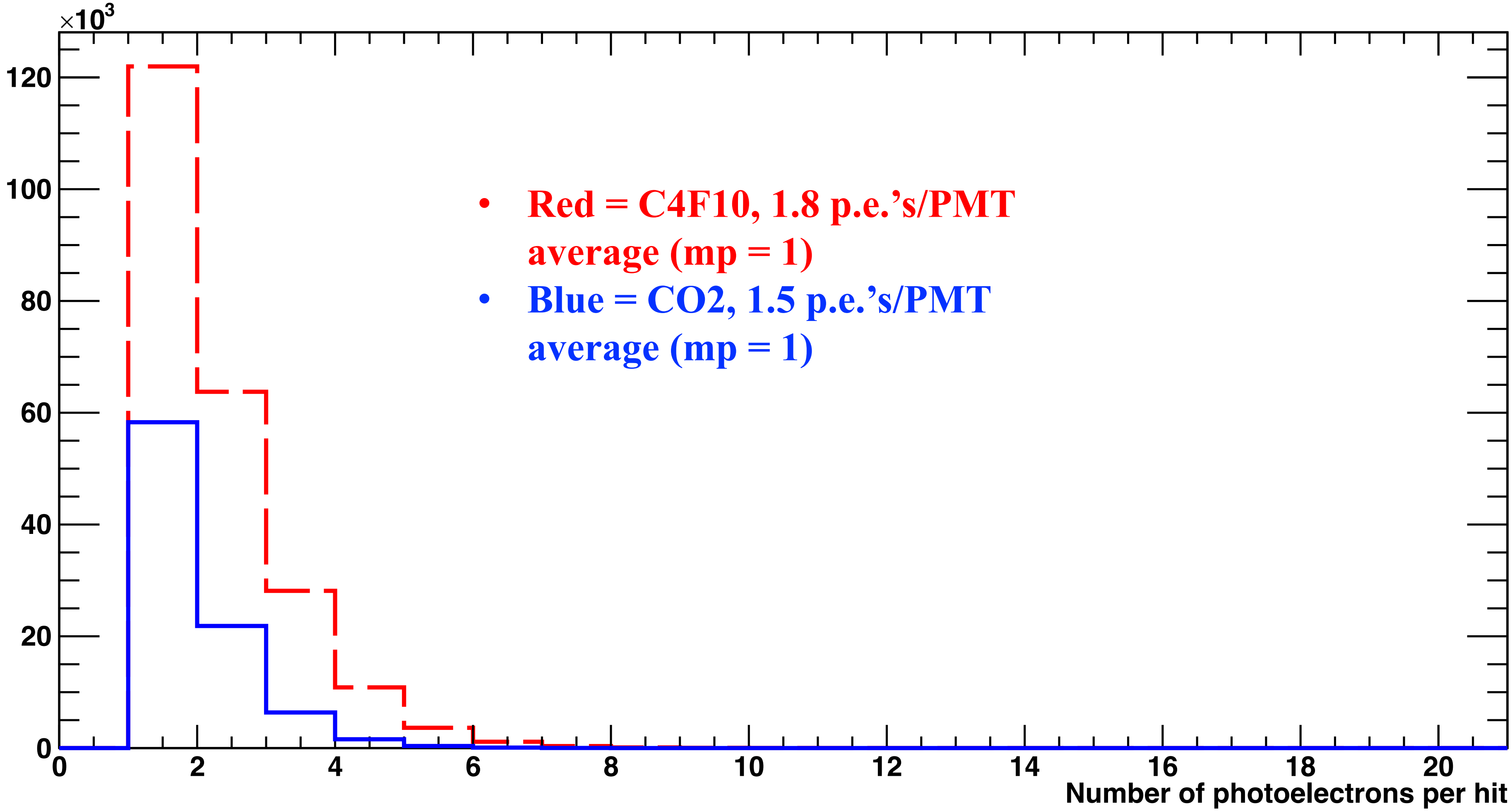
$$\theta_C = \arccos\left(\frac{1}{n\beta}\right) = 3.0^\circ$$

Hit multiplicities for good DIS electrons



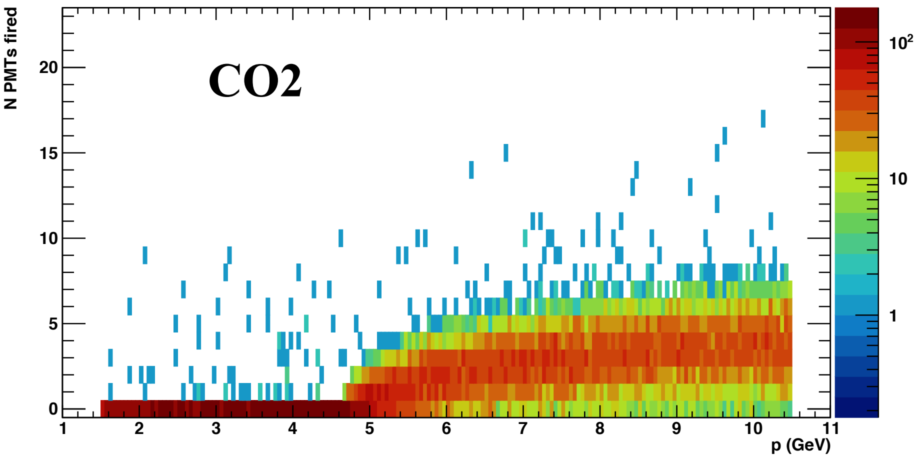
- Expected background rates could be of order ~1 MHz/PMT (from SIDIS case, similar angle, luminosity ~10^{37})

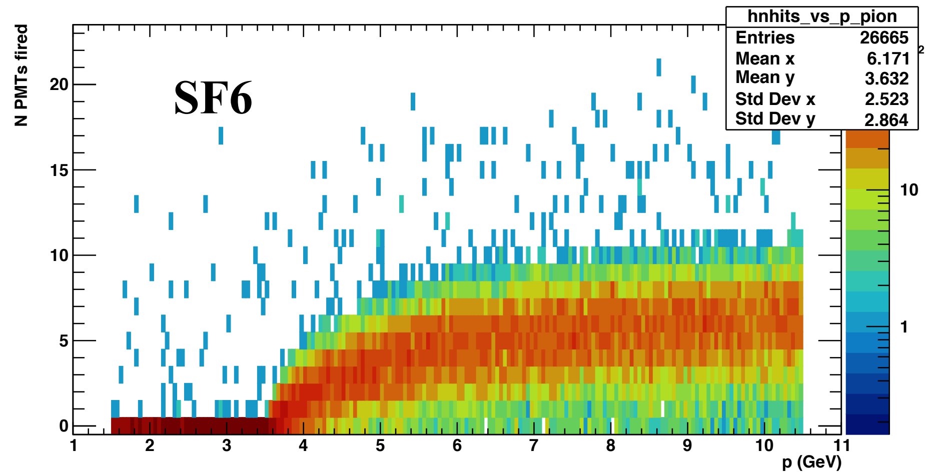
Photoelectrons per hit for good DIS electrons

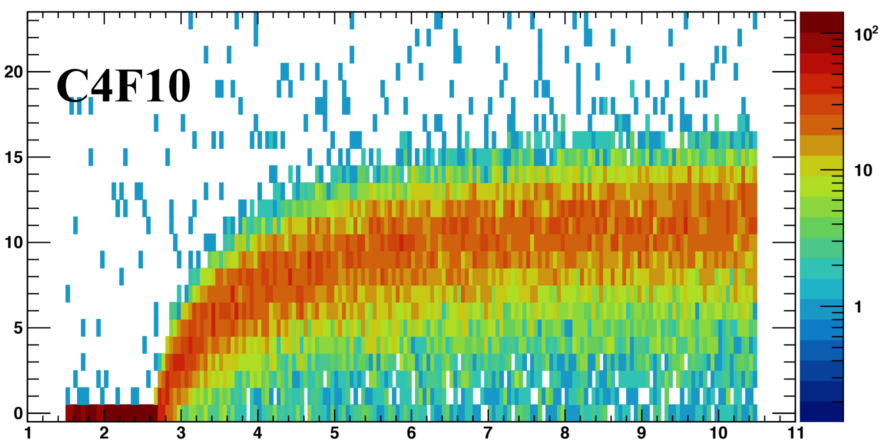


- To-do: look at possible "online" clustering algorithms, positional correlation with LAC, etc.

Pion sensitivity for various gases







- Higher photon yield, high efficiency for electrons comes, of course, at the expense of lower pion threshold and larger signals for pions as well.
- On the other hand, $\frac{\pi}{e}$ ratios should decrease, and LAC e/π separation should improve, at higher momentum
- SF_6 may represent a good compromise in terms of “good enough” electron efficiency and momentum range for good pion rejection
- Waiting for W&M test results for C3F8/C4F8

Summary/conclusions

- Re-use of HERMES RICH in SBS is a low-cost PID solution enabling high-impact SIDIS physics with SBS, can be adapted to future novel applications such as TDIS.
- Mass testing of 2,158 RICH PMTs was completed Oct. 2016:
  - Single-ph.e. spectra
  - Absolute gain curves vs. HV
- PMTs are in good condition; less than 2% of tested PMTs rejected → we have ~10% spare capacity to run SIDIS
- Longer-term issues:
  - gas system is a major question mark—mainly a cost issue, but technical questions also exist—issues similar to GRINCH, but on a larger scale.
  - Design of support structure/installation
  - Interface to front-end electronics (NINO cards)—will require some reconfiguration of the cabling layout; new patch panels/ribbon cables/etc.
  - Aim to re-use existing cables, readout electronics, and HV power supplies as much as possible.
  - Requires 61 channels of positive HV power supplies; 32 PMTs/channel, 40 μA/PMT @1,350 V = 1.3 mA/1.7 W
- Repurposing as a ”threshold” electron Cherenkov detector should be feasible without major redesign or cost, with similar performance parameters as BigBite GRINCH—but would probably require readout upgrade to use online as part of trigger.

Backups

RICH PMTs

Philips XP1911/UV Specs

photomultiplier tubes **XP1911/UV**
preliminary product specification

A UV-sensitive, 10-stage, 19 mm (3/4") round tube

Applications :	For high energy physics and scintillation counting under limited dimensional conditions.		
Description :	Window :	Material :	UV glass
		Photocathode :	bi-alkali
		Refractive index at 400 nm :	1.48
	Multiplier :	Structure :	linear focused
		Number of stages :	10
	Mass :	21 g	

Photocathode characteristics

Spectral range :				200-650	nm
	Maximum sensitivity at :			420	nm
Sensitivity ① :	Luminous :		typ.:	90	µA/lm
☒	Blue :	min.: 9.0	typ.:	10.5	µA/lmF
	Radiant, at 420 nm :		typ.:	80	mA/W

Characteristics with voltage divider A

Gain slope (vs supp. volt., log/log) :				7.5	
For an anode blue sensitivity of :				10	A/lmF
☒ Supply voltage :		max.:1350 min.: 1000	typ.:	1200	V
Gain :				$9x10^5$	
☒ Background noise ② :		max.:5000	typ.:	2000	c/s
Pulse amplitude resolution for ^{137}Cs ③:				7.5	%
Mean anode sensitivity deviation ④ :					
	long term (16 h):			1.5	%
	after change of count rate:			1.5	%
Gain halved for a magnetic field	perpendicular to axis "n" of :			0.3	mT

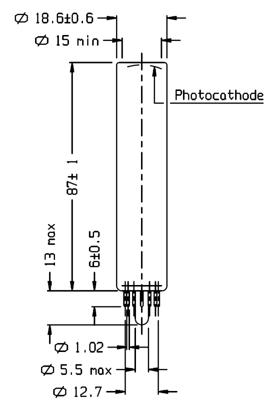
Characteristics with voltage divider :

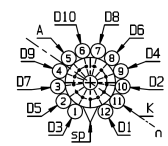
		B	A	
For a supply voltage of :		1700	1500	V
Gain :		$4.5x10^6$	$5.1x10^6$	
Linearity (2%) of anode current up to ⑤ :		80	20	mA
Anode pulse ⑥ :	Rise time :	2.4	2.3	ns
	Duration at half height :	3.8	3.5	ns
	Transit Time :	23	22	ns
	Transit Time Difference centre of photocathode up to 7 mm from it:	1.5	1.5	ns
Capacitance	anode to all :	4	4	pF

PAGE 1 / 3 28/01/99

PHOTONIS imaging sensors

photomultiplier tubes **XP1911/UV**
preliminary product specification

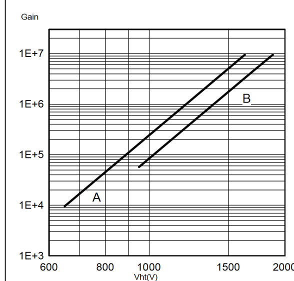




ref.: 99901157
sp: short pin
n: plane of symmetry of the multiplier

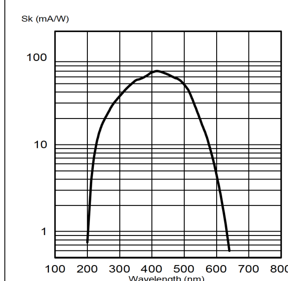
K: cathode
Dn: dynode
A: anode

Typical gain curve



XP1911/UV

Typical spectral characteristics



XP1911/UV

Accessories

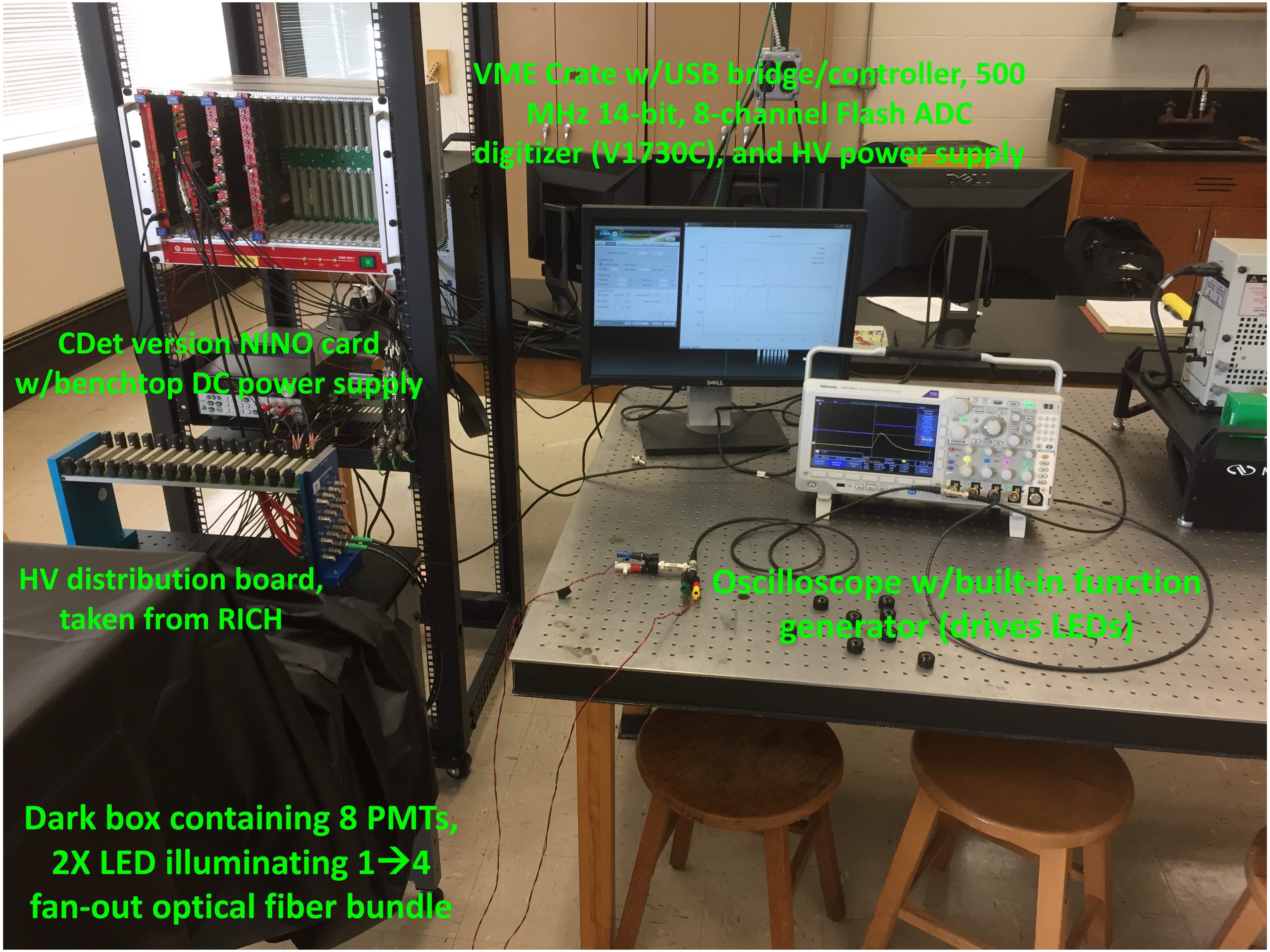
Socket:	FE1004
Socket for PCB:	FE3112
Mu-metal shield:	MS178
Voltage divider assemblies:	
+HV:	VD308
- HV:	VD108

PAGE 3 / 3 28/01/99

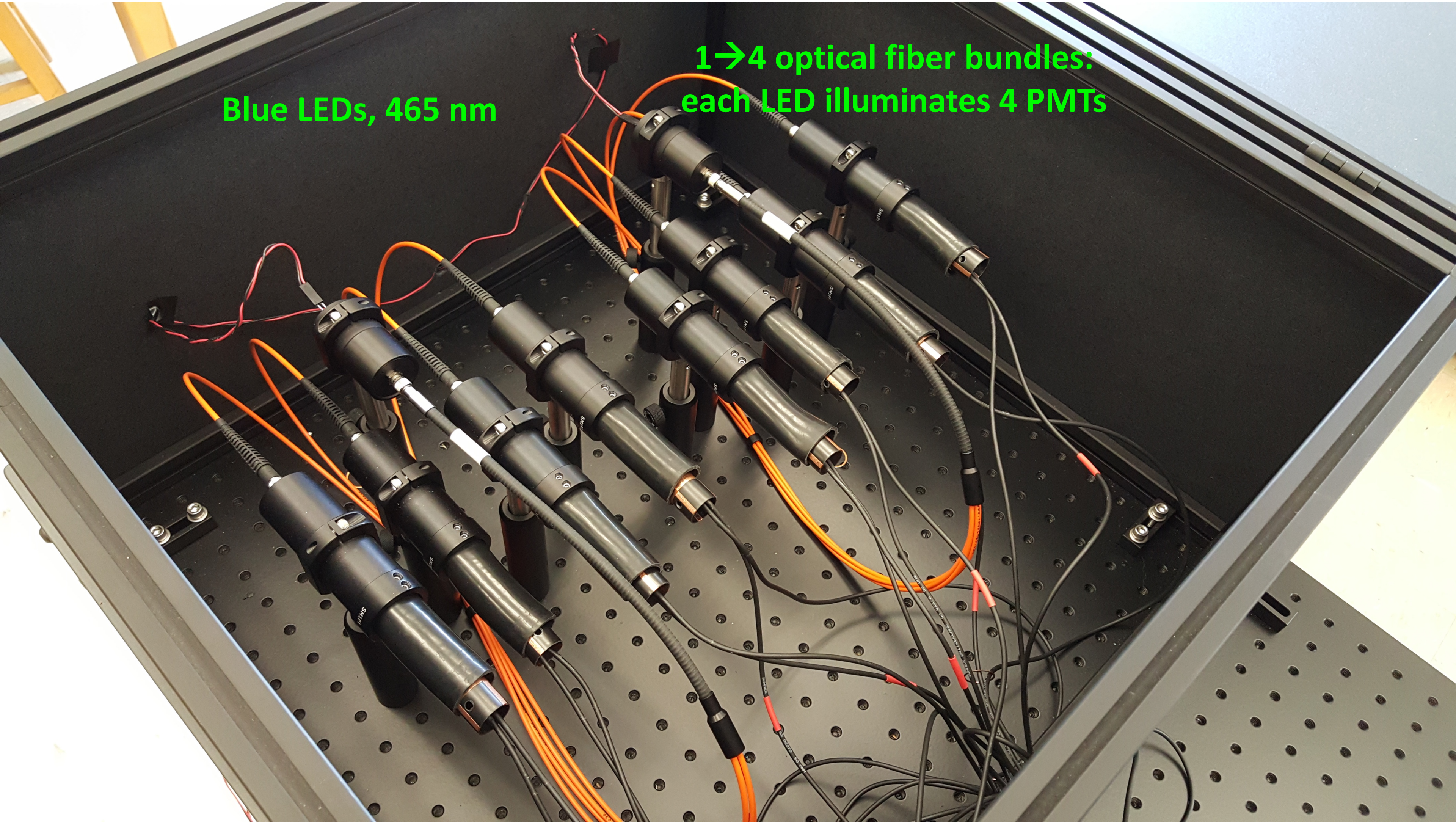
PHOTONIS imaging sensors

- Pulse characteristics in HERMES w/custom voltage divider @typical HV ~ +1,350 V: ~5 mV single p.e., 10 ns FWHM, gain of 3 × 10^6
- Current draw per PMT ~0.05 mA → Group 32 PMTs on a single HV channel

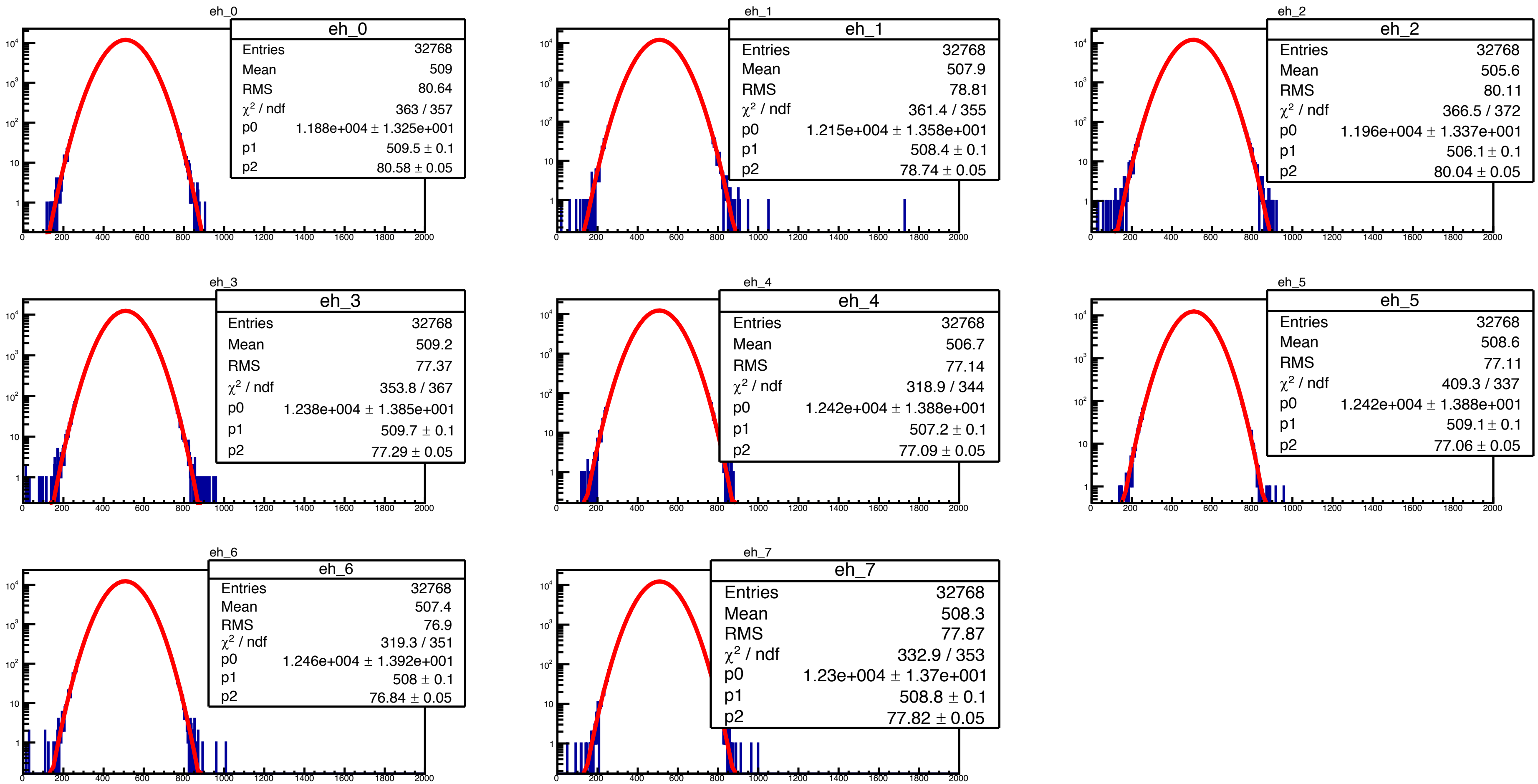
RICH PMT test stand @UConn



Dark box

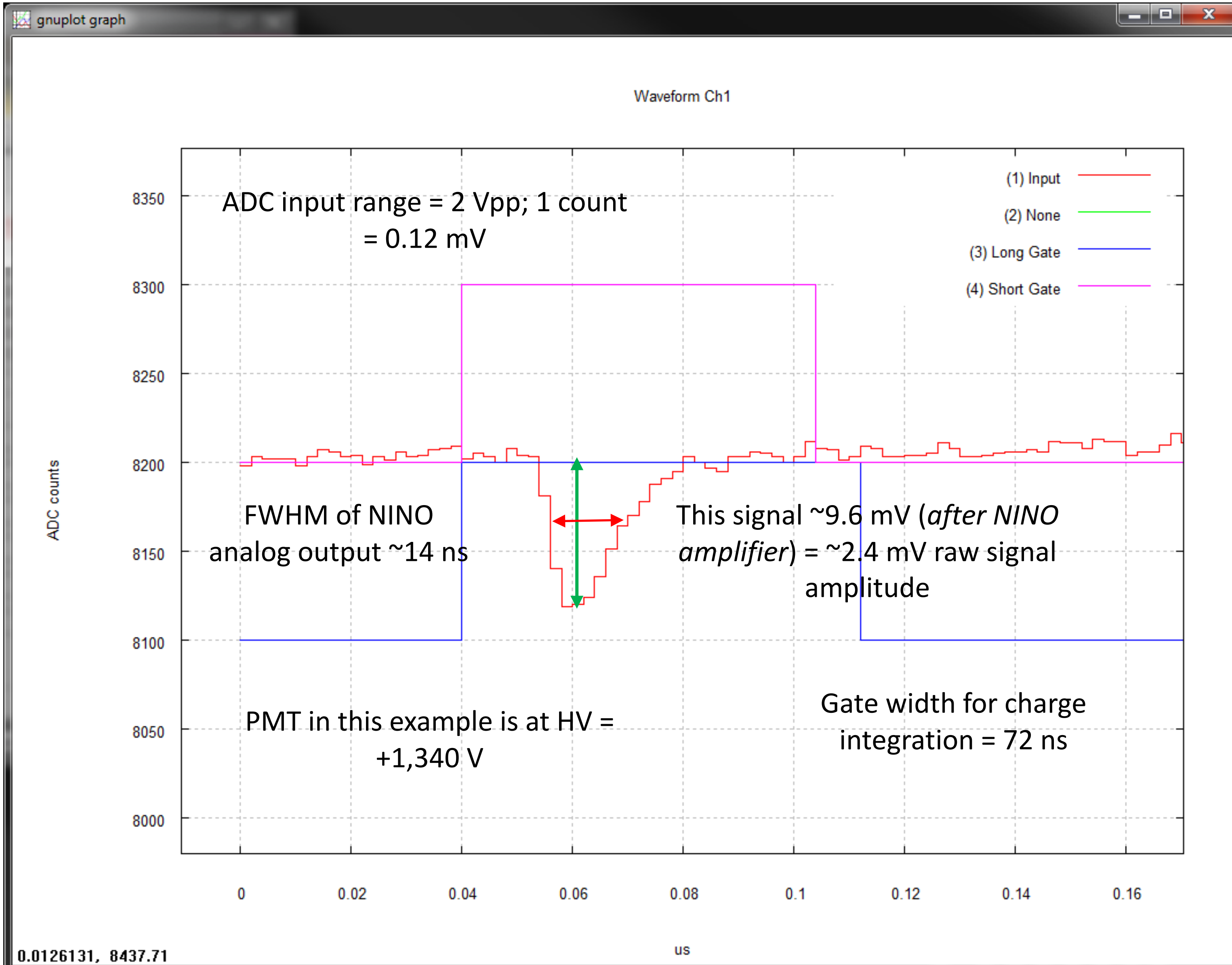

Blue LEDs, 465 nm
1→4 optical fiber bundles:
each LED illuminates 4 PMTs

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

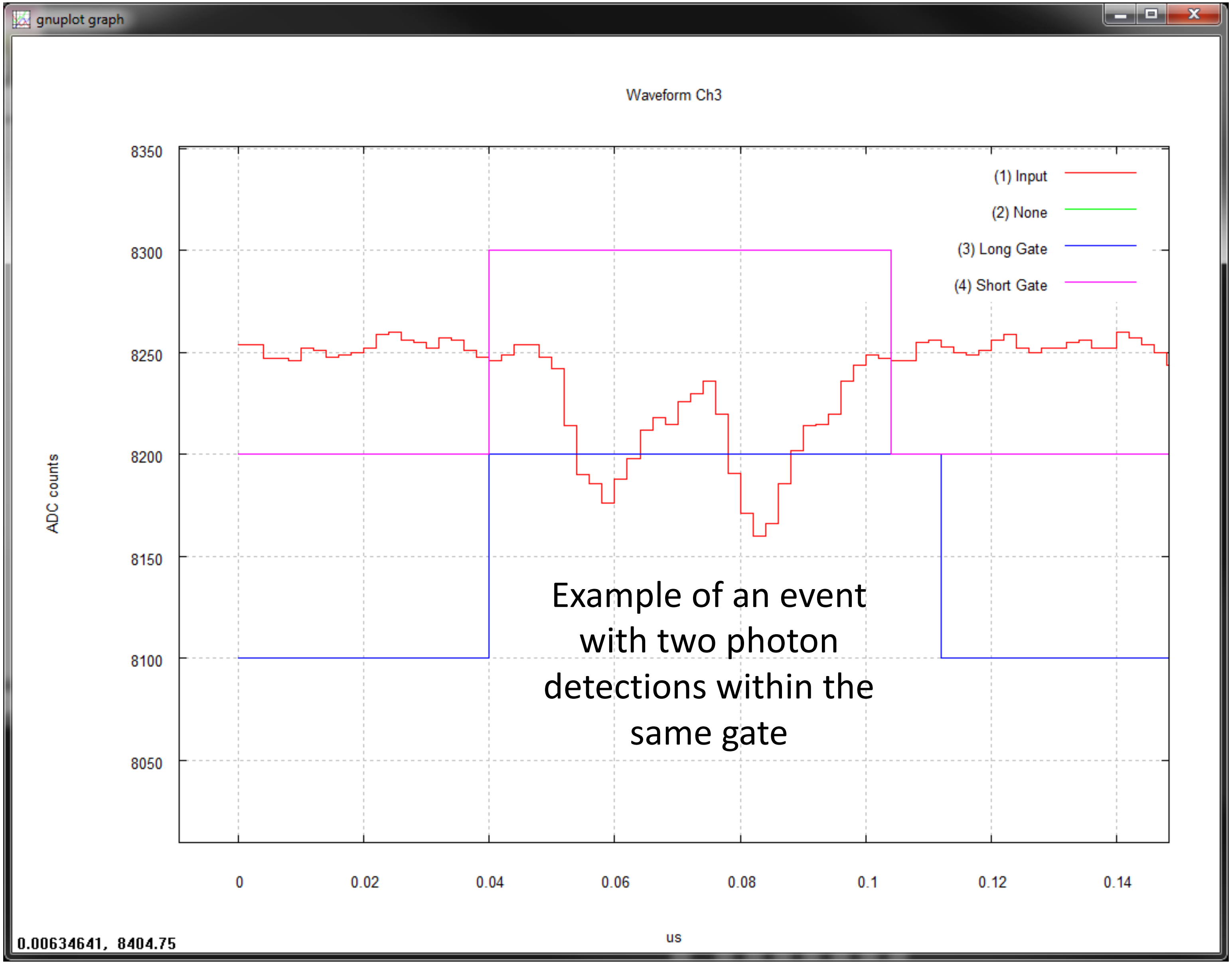


- The DAQ performs automatic baseline determination and subtraction; however, we configured it to insert a charge "pedestal" so that we can easily determine the noise level in each channel and optimally separate the small single-ph.e. signals from noise.
- The individual sample noise width is related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

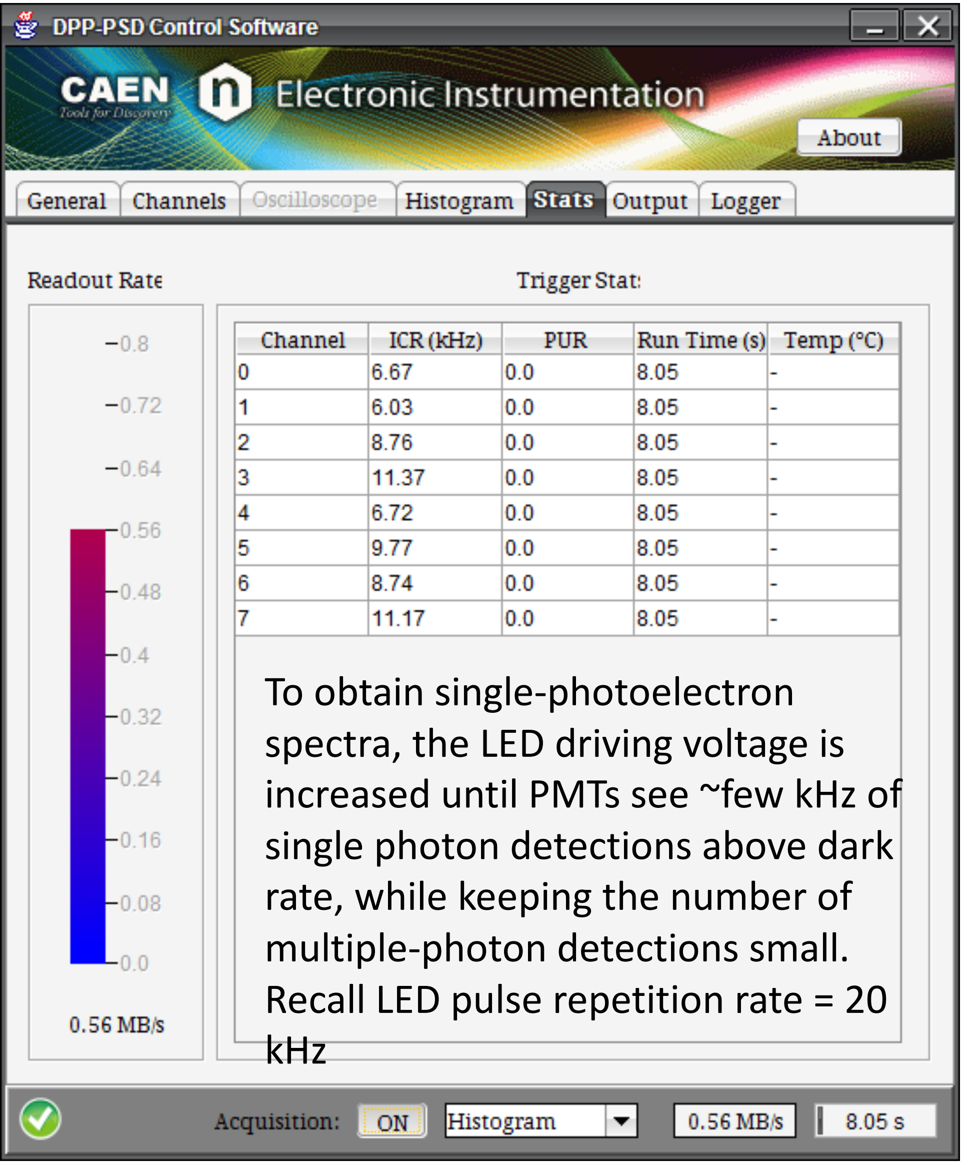
Single Photo-electron Signals



A Pileup Event

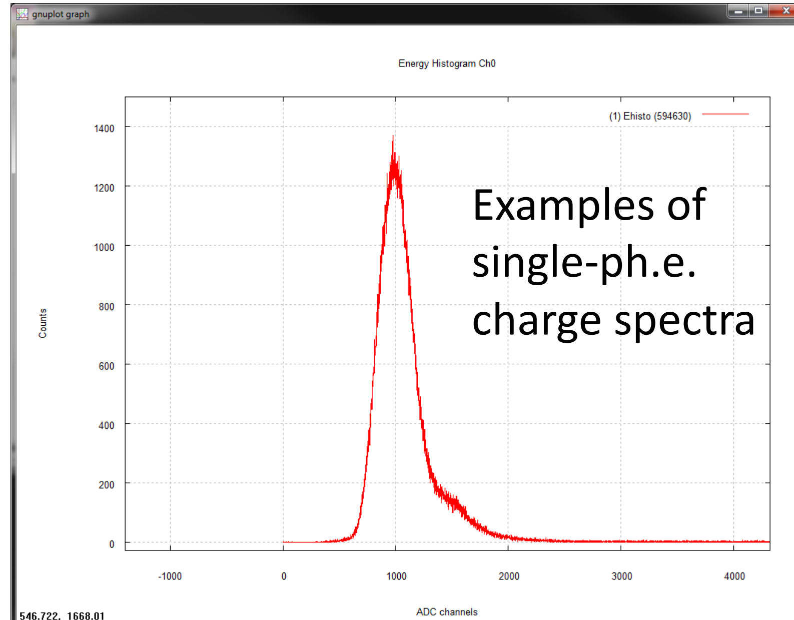


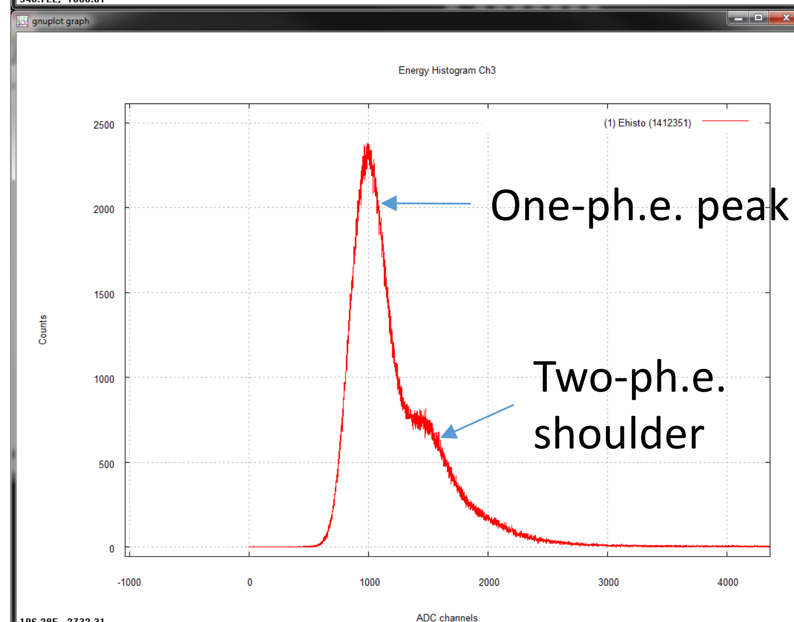
"Histogramming mode" DAQ



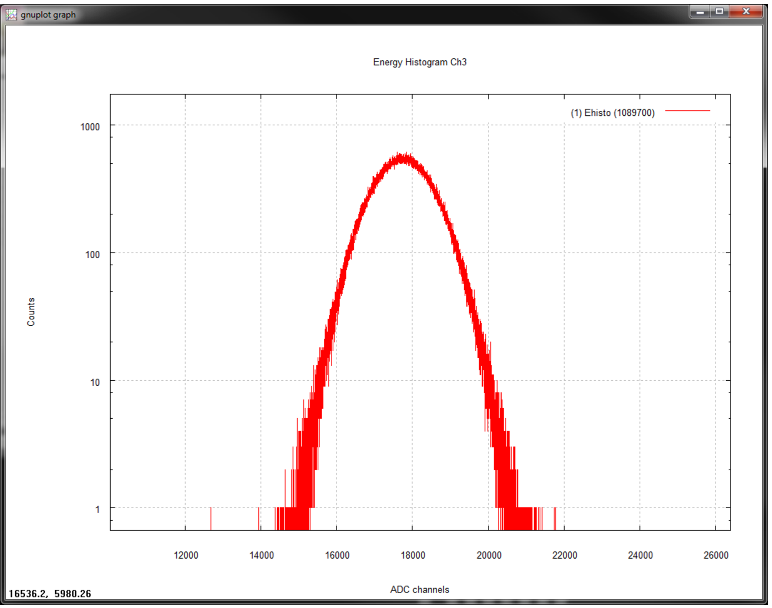
Channel	ICR (kHz)	PUR	Run Time (s)	Temp (°C)
0	6.67	0.0	8.05	-
1	6.03	0.0	8.05	-
2	8.76	0.0	8.05	-
3	11.37	0.0	8.05	-
4	6.72	0.0	8.05	-
5	9.77	0.0	8.05	-
6	8.74	0.0	8.05	-
7	11.17	0.0	8.05	-

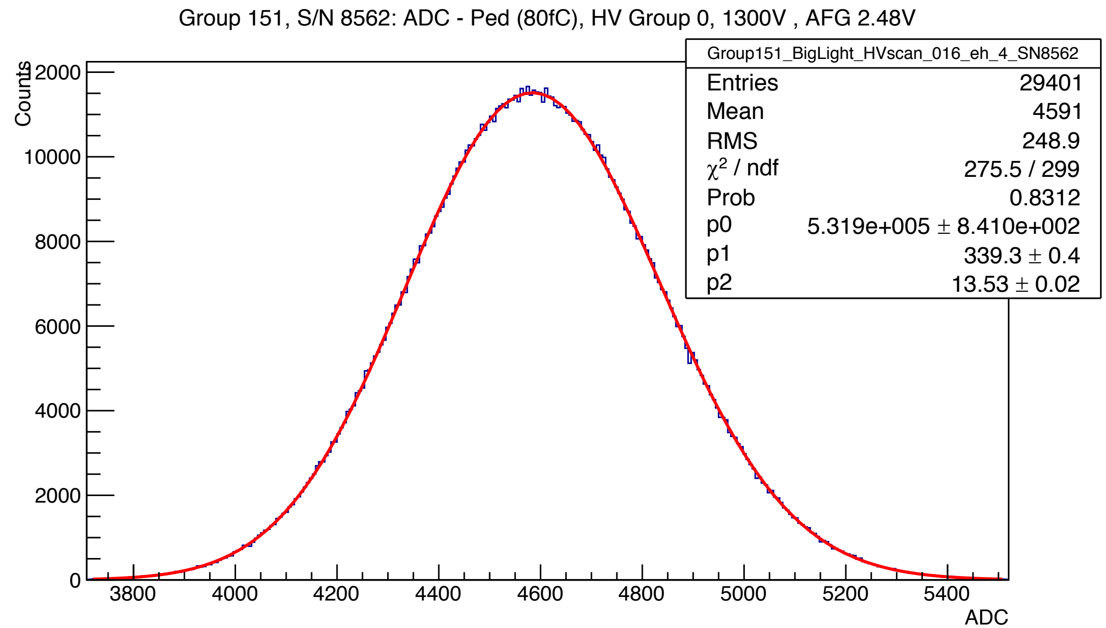
To obtain single-photoelectron spectra, the LED driving voltage is increased until PMTs see ~few kHz of single photon detections above dark rate, while keeping the number of multiple-photon detections small. Recall LED pulse repetition rate = 20 kHz





Charge spectrum for "Big" light pulses and determination of number of photoelectrons



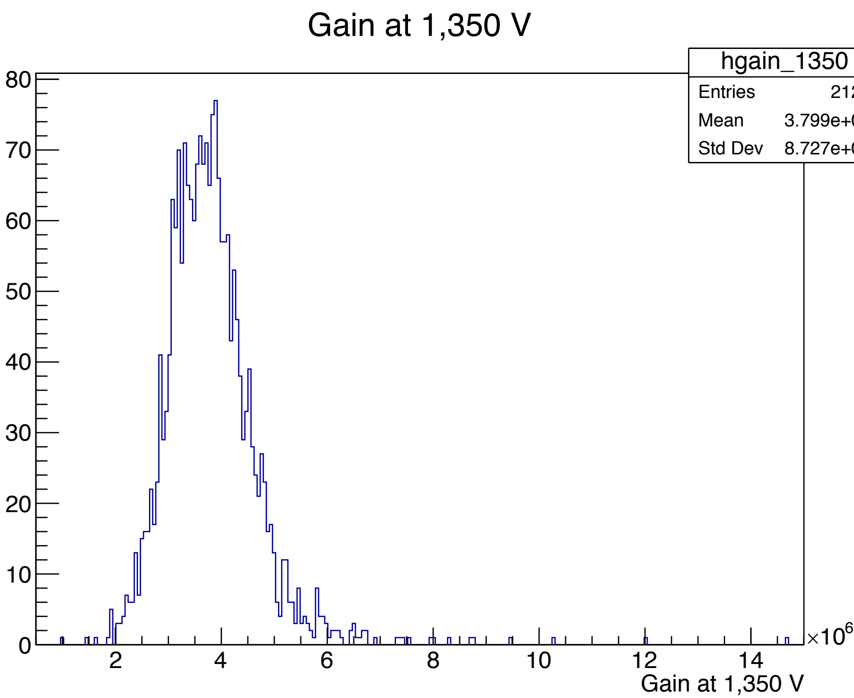


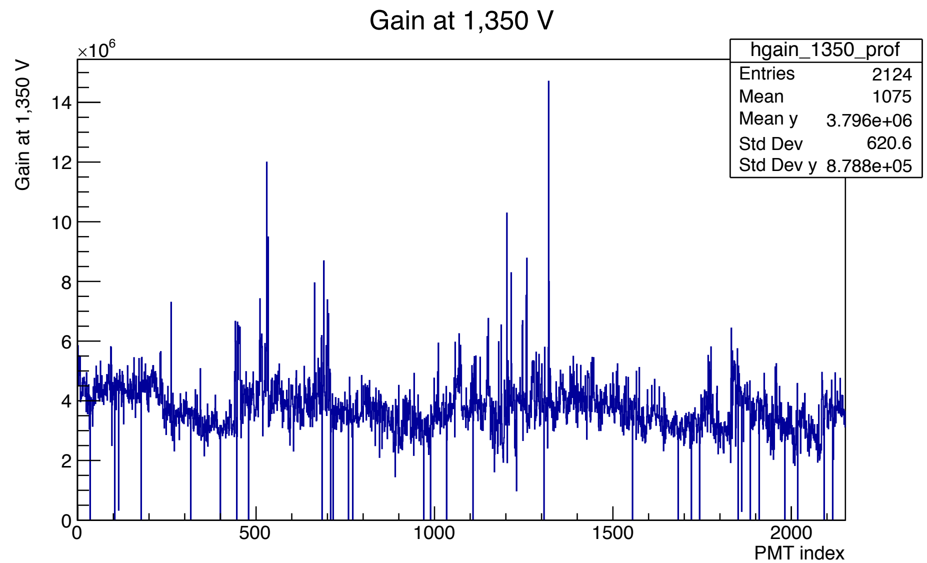
- Example of "online" big-light charge spectrum at 80 fC/LSB charge sensitivity

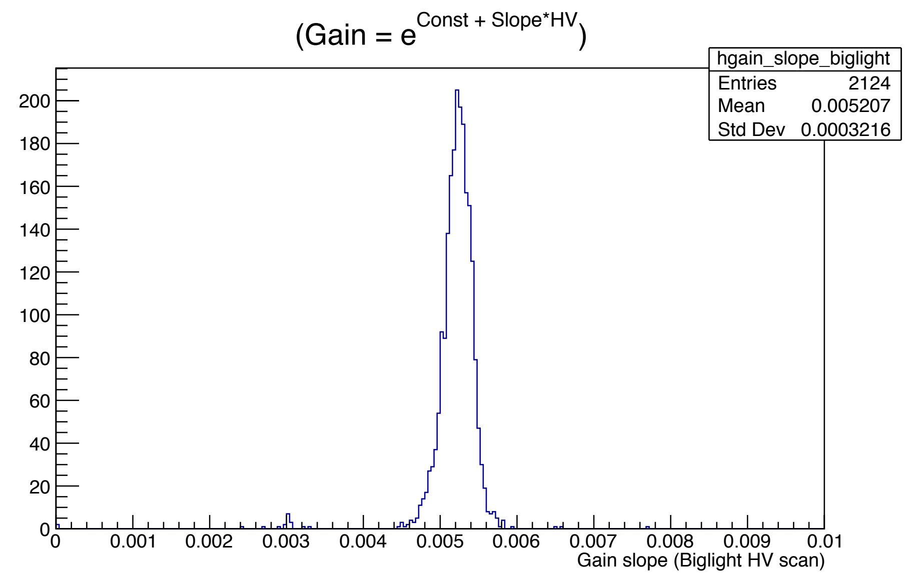
- Example Poisson fit to ADC spectrum:

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

Gain results

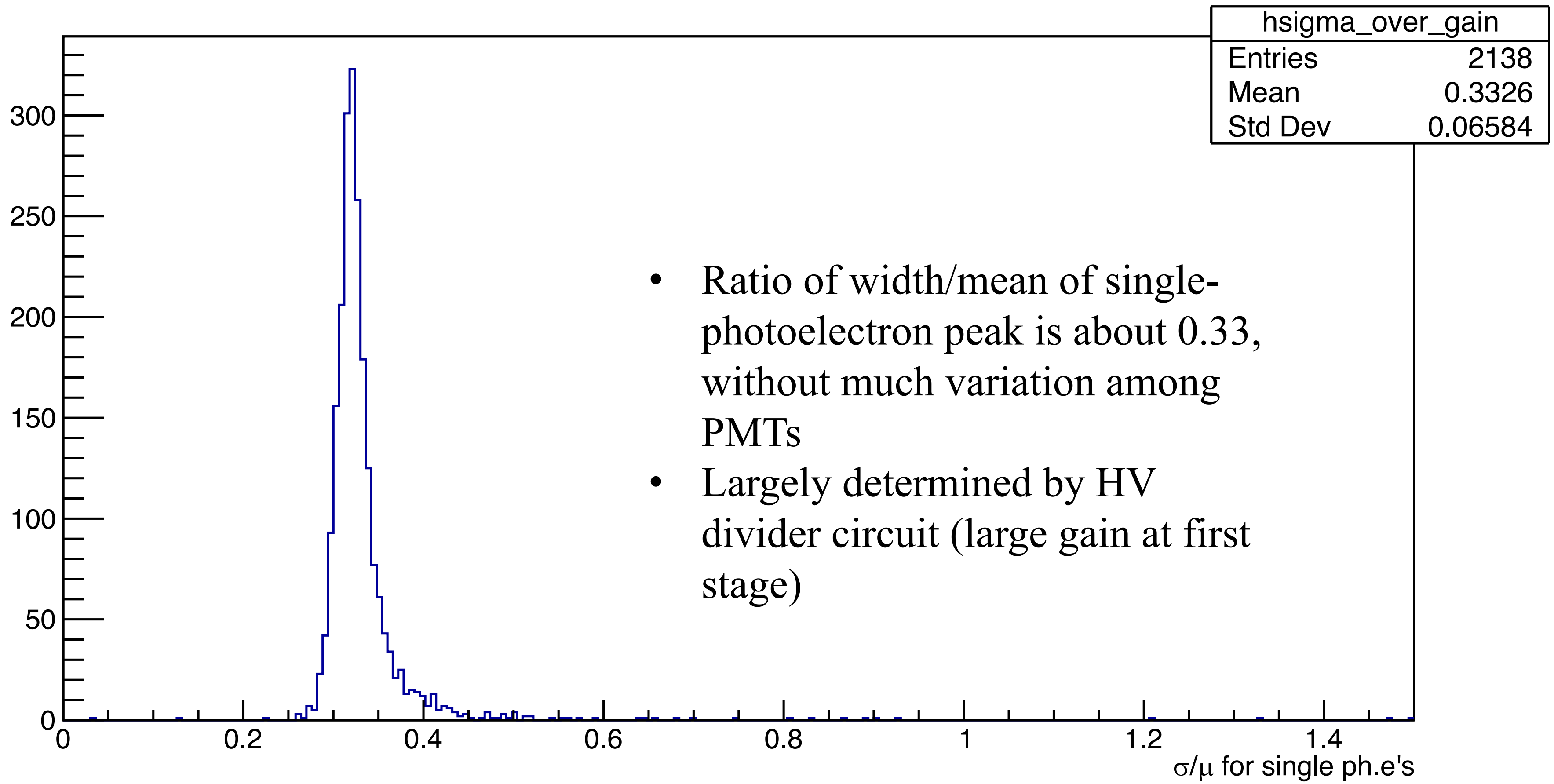






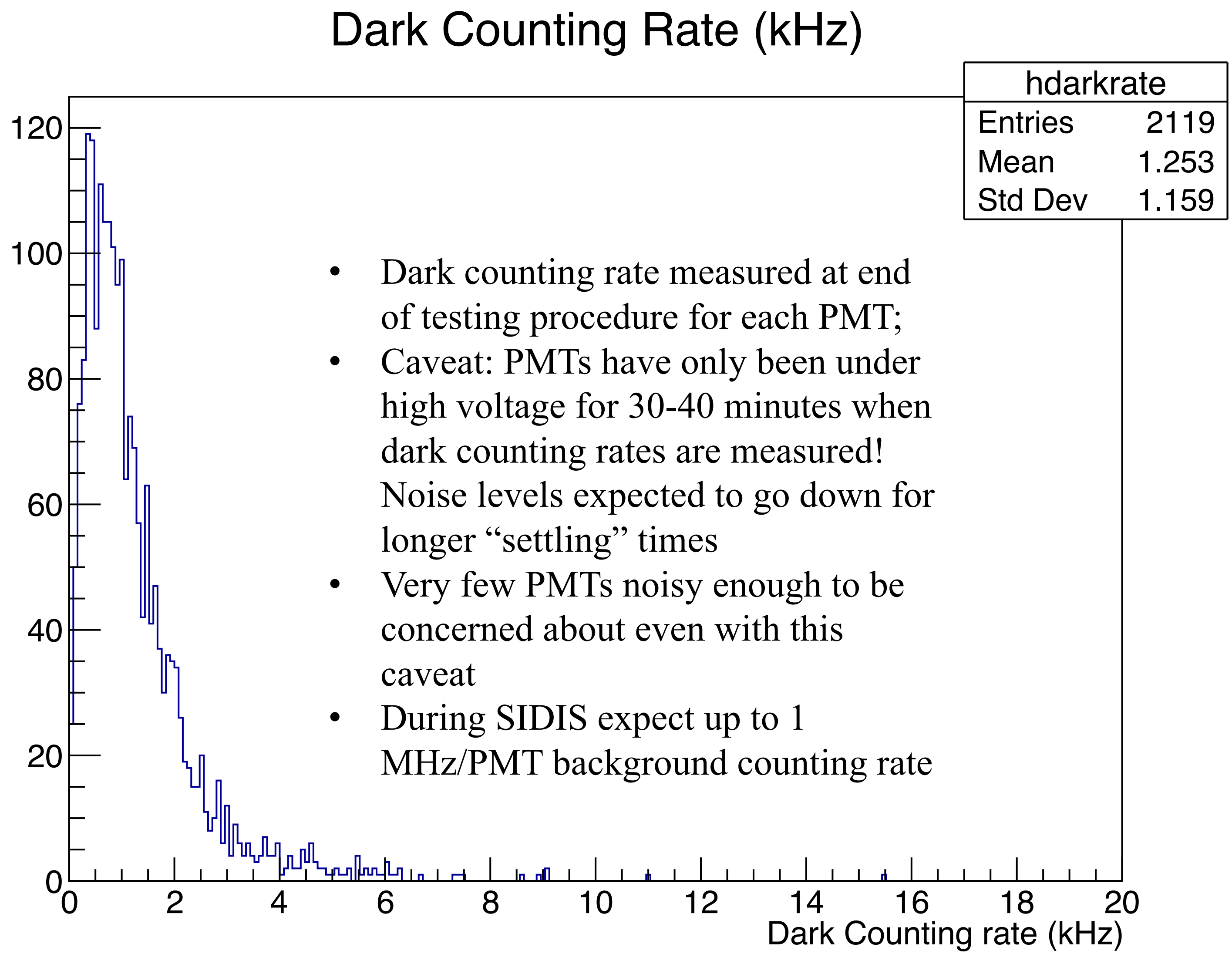
- Above, left: Absolute gain at 1,350 V
- Above, right: Gain at 1,350 V by PMT number
- Below, right: Gain “slope” parameter (from exponential fit to HV scan data)
- Compromise: Gain slope fixed by “Big Light” data, normalization determined by single-ph.e. spectra

Single-Photoelectron peak width



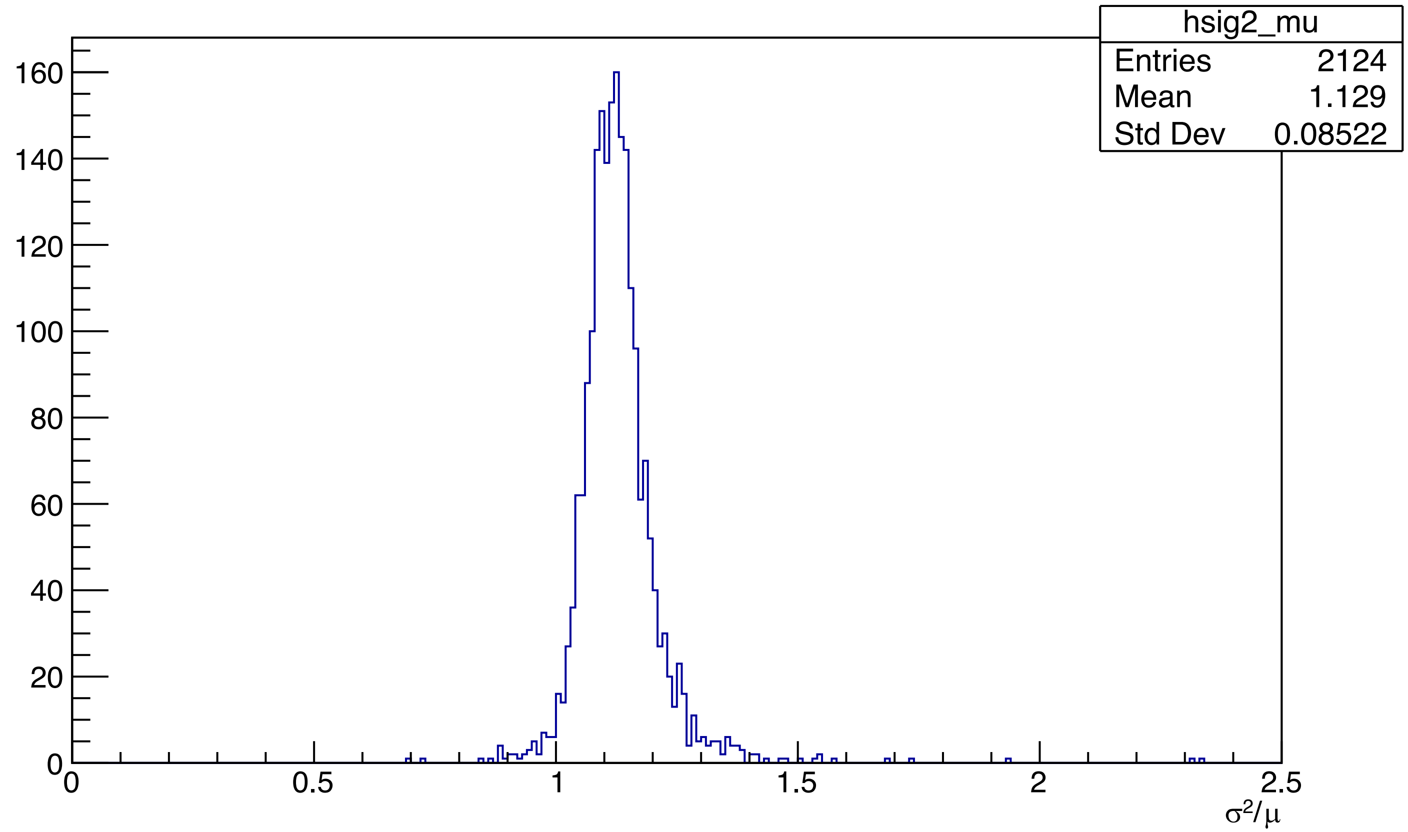
- Ratio of width/mean of single-photoelectron peak is about 0.33, without much variation among PMTs
- Largely determined by HV divider circuit (large gain at first stage)

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

"Relative Quantum Efficiency"



- This is the average ratio of the variance to the mean of the "BigLight" runs by PMT, where μ is the mean number of photoelectrons, and σ^2 is the variance in the number of photoelectrons/pulse, with the gain fixed at the value determined from the single-photoelectron runs. Very crudely speaking, a larger value of this ratio indicates a lower relative quantum efficiency at 465 nm (lots of caveats to this)