SHMS Hodoscopes

G. Niculescu, I. Niculescu – JMU
A. Amidouch, S. Danagoulian – NC A&T

S. Malace
Norfolk State University (not for long)

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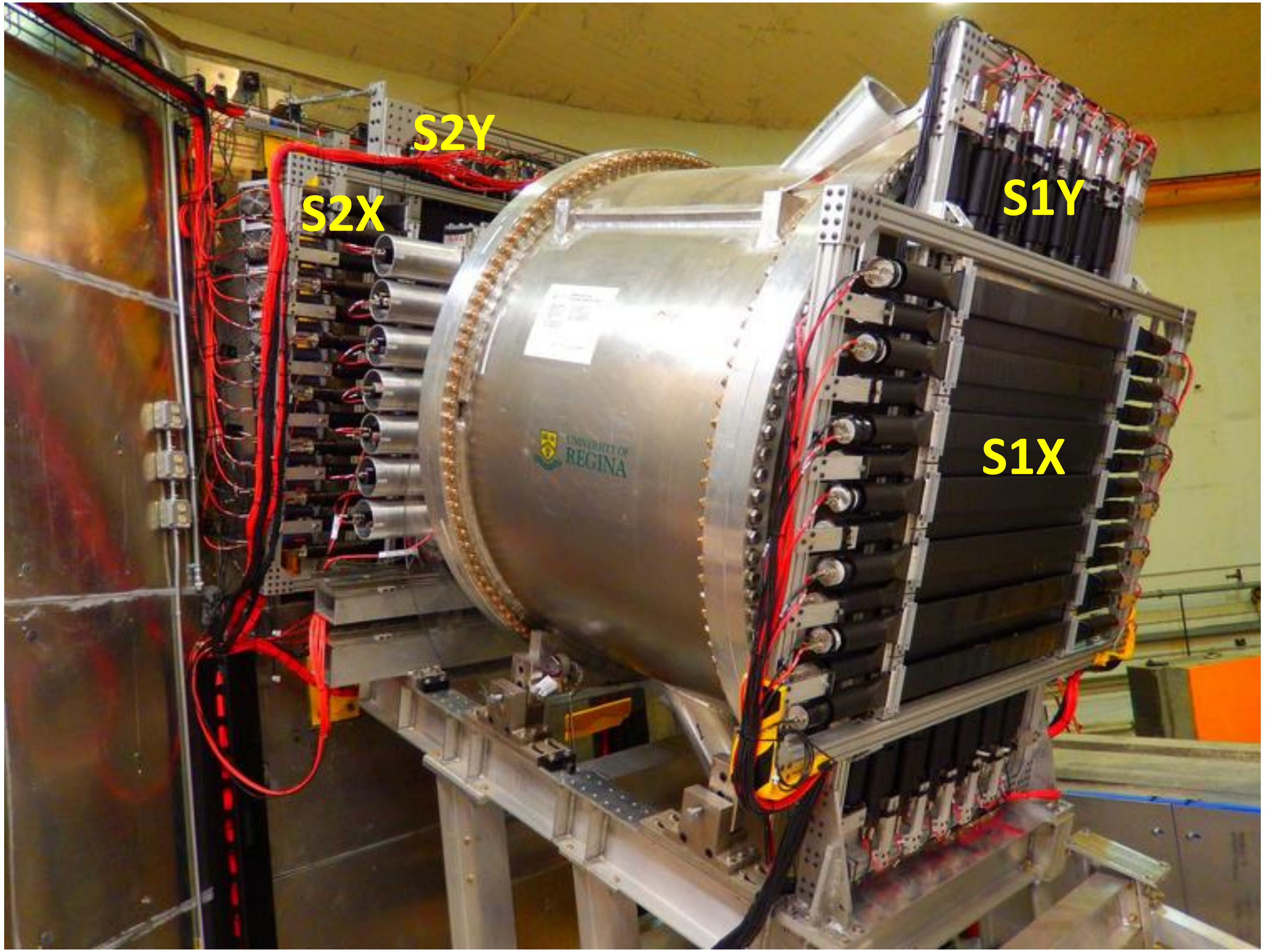
Jefferson Lab

Hall C Meeting, Jan 20-21 2017

SHMS Hodoscopes: Overview

S1X, S1Y, S2X – plastic scintillator detectors built by G. Niculescu and I. Niculescu at JMU



S2Y – quartz bars hodoscope plane built by A. Amidouch and S. Danagoulian at NC A&T

SHMS Plastic Scintillators: Overview

- Built by Gabi Niculescu and Ioana Niculescu at JMU; they are also responsible for commissioning without and with beam

3 planes: S1X and S1Y with 13 paddles each and S2X with 14 paddles (0.5 cm thickness)

→ Scintillator: RP-408 from Rexon

Wavelength of Max. Emission, nm:	425
Rise Time, ns:	0.9
Decay Time, ns:	2.1
PulseWidth, FWHM, ns:	2.5

→ 2 types of PMTs used: XP2262 (like in HMS hodoscopes) and ET9214B

- XP2262 and ET9214B operate in different HV ranges (negative HV)

- There is enough gain variation among ET9214B s to result in pretty different HV operating ranges from PMT to PMT (will show data)

ET9214B

	unit	min	typ	max
photocathode: bialkali				
active diameter	mm		46	
quantum efficiency at peak	%		30	
luminous sensitivity	μA/lm		70	
with CB filter		8	11.5	
with CR filter			2	
dynodes: 12LFSbCs				
anode sensitivity in divider A:				
nominal anode sensitivity	A/lm		500	
max. rated anode sensitivity	A/lm		2000	
overall V for nominal A/lm	V		1250	1800
overall V for max. rated A/lm	V		1450	
gain at nominal A/lm	$\times 10^6$		7	
dark current at 20 °C:				
dc at nominal A/lm	nA		1	10
dc at max. rated A/lm	nA		4	
dark count	s^{-1}		300	
maximum ratings:				
anode current	μA			100
cathode current	nA			100
gain	$\times 10^6$			30
sensitivity	A/lm			2000
temperature	°C	-30		60
V (k-a)[1]	V			2300
V (k-d1)	V			500
V (d-d)[2]	V			450
ambient pressure (absolute)	kPa			202

[1] subject to not exceeding max. rated sensitivity [2] subject to not exceeding max rated V(k-a)

XP2262

Description	
Window material	Lime glass
Photocathode	Bi-alkali
Refr. Index at 420nm	1.54
Multiplier structure	Linear focused

Photocathode characteristics	Min	Typ	Max	Unit
Spectral range:		290-650		nm
Maximum sensitivity at		420		nm
Sensitivity:				
Luminous		70		μA/lm
Blue *	9	11.2		μA/lmf
Radiant, at 420nm		90		mA/W
Characteristics with voltage divider A	**Min**	**Typ**	**Max**	**Unit**
Gain slope (vs supp. Volt., log/log)		9		
For a gain of		3×10^7		V
Supply voltage *	1500	1800	2400	V
Anode dark current *		10		nA
Background noise *		1000	6000	cps
Single electron spectrum resolution		70		%
Peak to valley ratio		3		

SHMS Plastic Scintillators: Arrangement

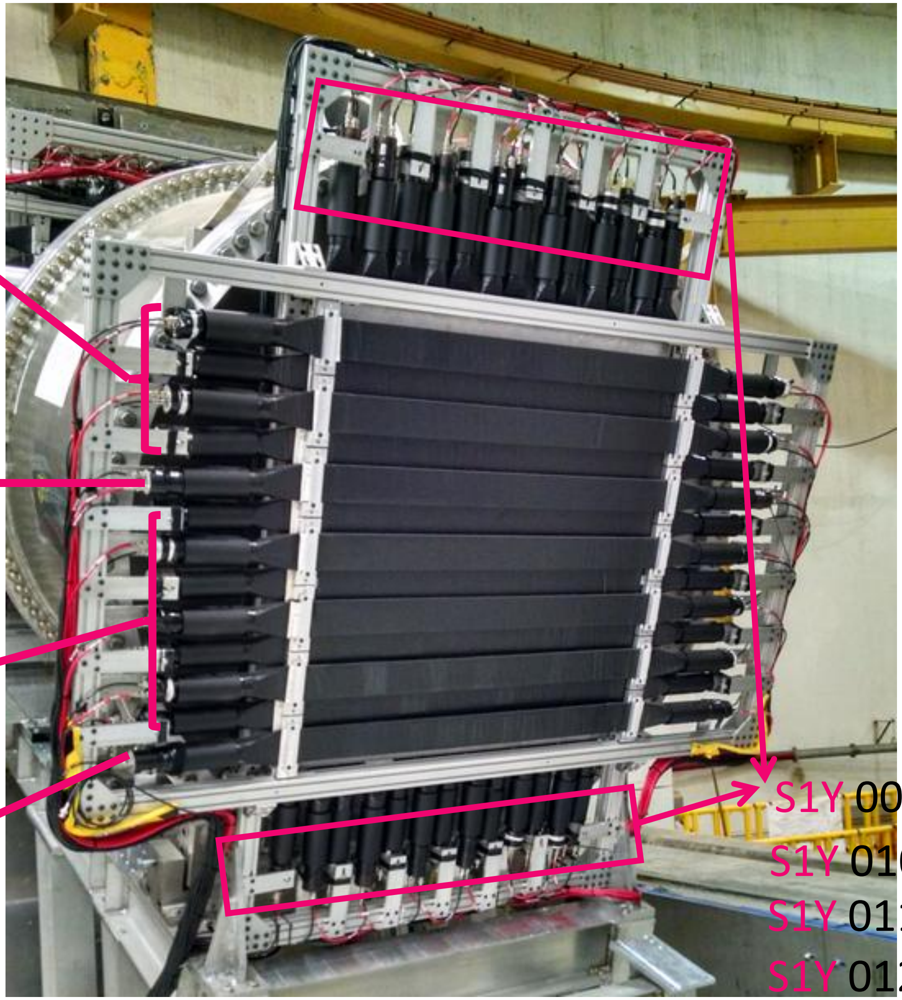
- Built by Gabi Niculescu and Ioana Niculescu at JMU; they are also responsible for commissioning without and with beam

S1X 001-004 (L and R): ET9214B

S1X 005 (L and R): XP2262

S1X 006-012 (L and R): ET9214B

S1X 013 (L and R): XP2262



S1Y 001-009 (T and B): XP2262

S1Y 010 (T and B): ET9214

S1Y 011 (T and B): XP2262

S1Y 012 (T and B): ET9214

S2X 001-002 (T and B): XP2262

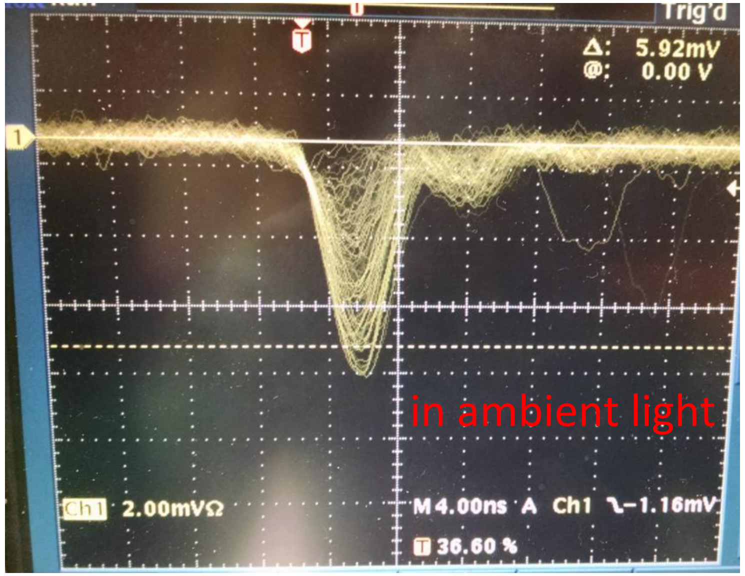
S2X 003,005 (T and B): ET9214B

S2X 006-014 (T and B): XP2262

S2X

SHMS Plastic Scintillators: Checked for Light Leaks

- Did a thorough check for light leaks using a narrow-beam flash light, a scope and a picoammeter



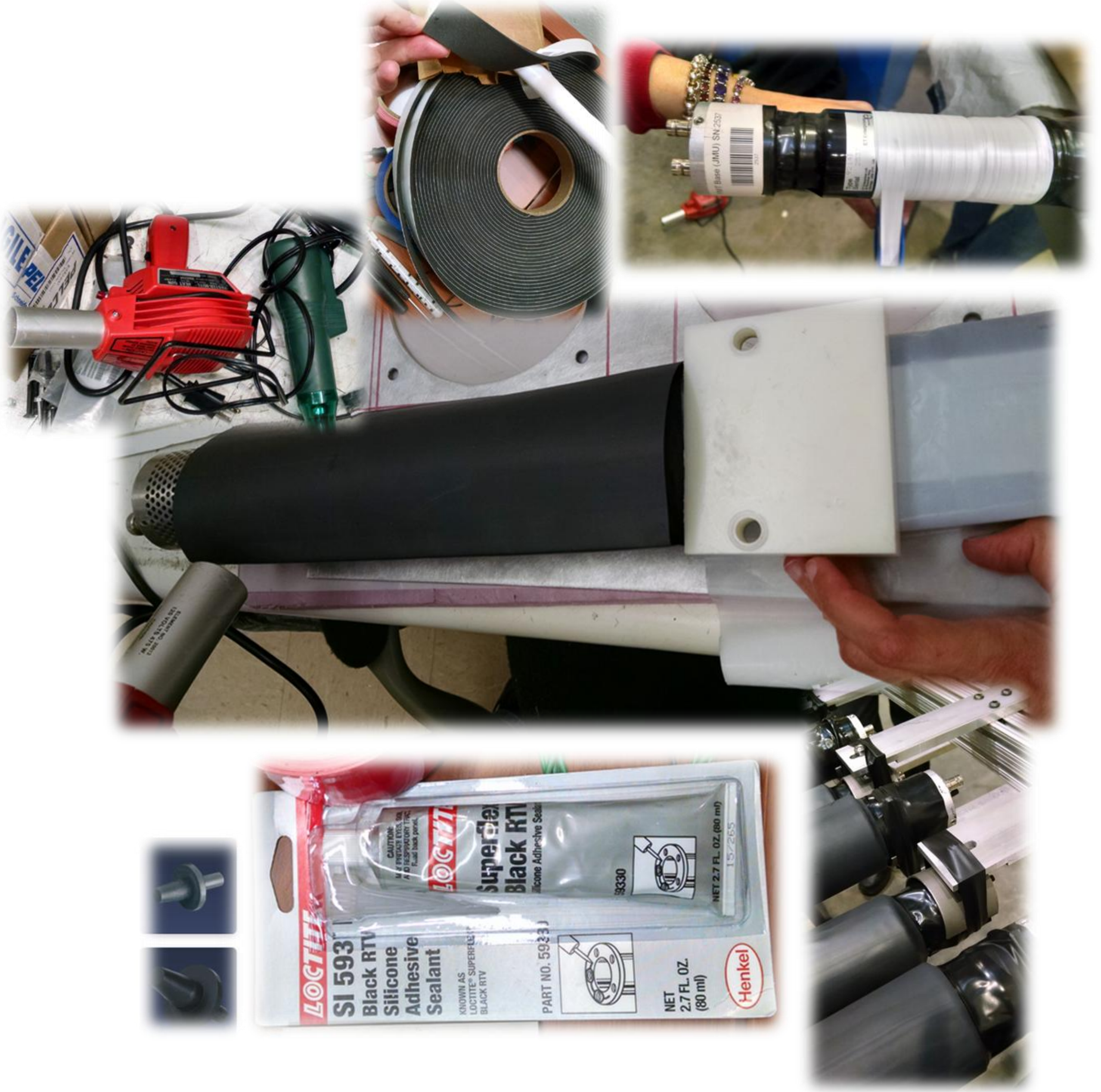
PMT	Label	V (-)	Drawn current	Patch panel	Ambient light
9214B	S1X001L	1200	242	G391	6.5 μA
9214B	S1X002L	1200	242	G392	0.22 μA
9214B	S1X003L	1200	242	G393	0.97 μA
9214B	S1X004L	1200	243	G394	10 μA
9214B	S1X006L	1200	241.5	G396	0.9 μA
9214B	S1X009L	1200	242	G399	1.35 μA
9214B	S1X010L	1200	242.5	G400	0.4 μA
9214B	S1X011L	1200	241.4	G401	0.38 μA
9214B	S1X012L	1200	243	G402	3.36 μA

→ It was decided to eliminate sources of light leaks

SHMS Plastic Scintillators: Fixed Light Leaks

Procedure: same as used for HMS years back

1) Apply teflon at the cathode (and beyond)
2) Tape over teflon
3) Wrap foam at the ends of the PMT to support the mu-metal shield
4) Position mu-metal (Gabi's instructions: must extend 1 cm over the PMT-fishtail joint)
5) Put on the heat shrink, extends over mu-metal and part of the base case
6) Use thick sheet of teflon (and some more) to protect the paddle and then start heating; use smaller aperture heat gun close to the paddle
7) When heat shrink assumed the shape of mu-metal & base case tape the boundaries
8) For ET9214B plug the hole in the back plate with plugs
9) Apply silicone around boundary at the back plate

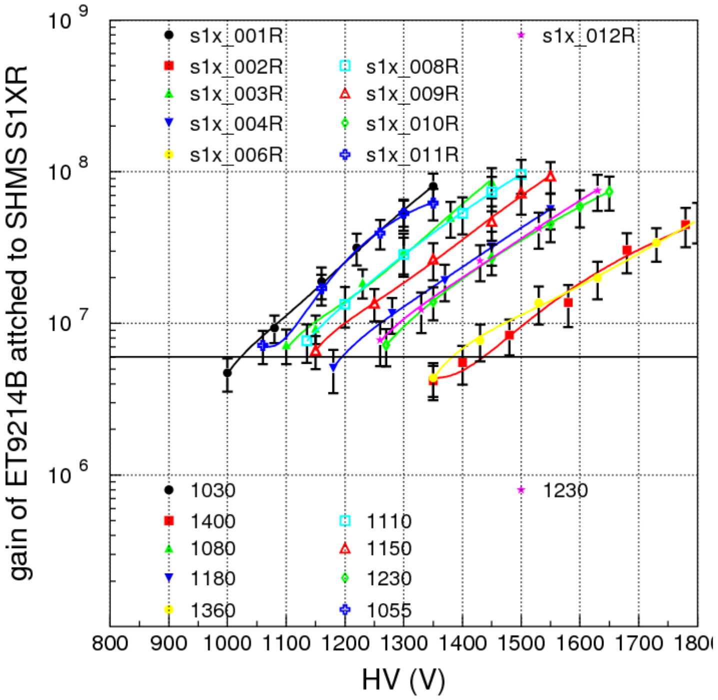


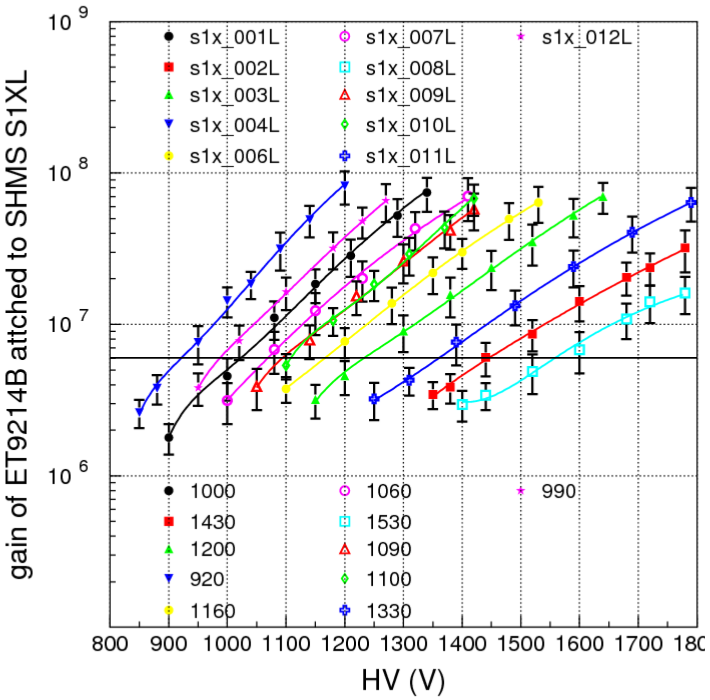
SHMS Plastic Scintillators: Fixed Light Leaks

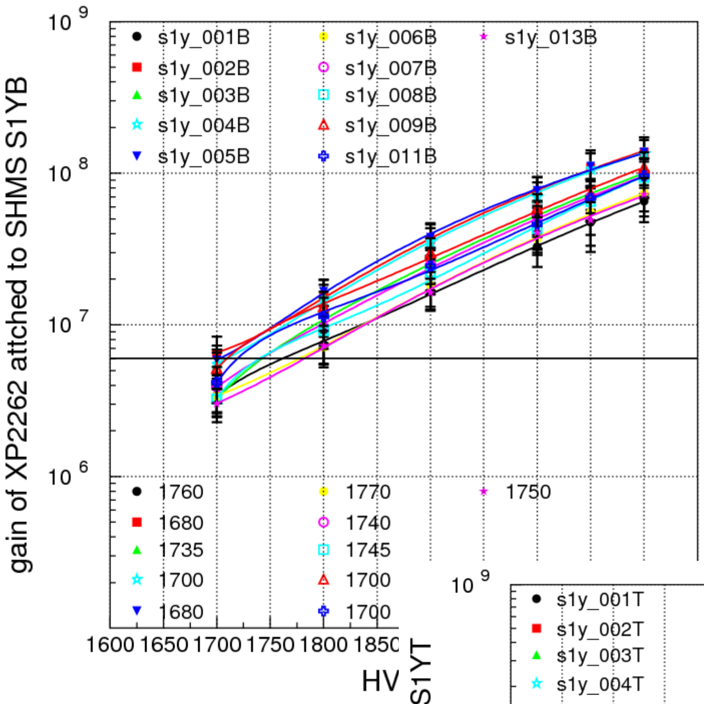
Location	Type	Output Current (nA)
S1X-013R	ET	6 nA at 1000 V
S1X-012R	ET	5 nA at 1200 V 9 nA at 1300 V
S1X-011R	ET	5 nA at 1000 V
S1X-010R	ET	5 nA at 1100 V 8 nA at 1200 V
S1X-008R	ET	4 nA at 1200 V 6 nA at 1300 V
S1X-007R	ET	4 nA at 900 V 9 nA at 1000 V
S1X-006R	ET	5 nA at 1000 V 9 nA at 1100 V
S1X-005R	ET	6 nA at 1100 V 12 nA at 1200 V
S1X-004R	ET	6 nA at 1200 V
S1X-003R	ET	4 nA at 1000 V 7 nA at 1100 V
S1X-002R	ET	5 nA at 1100 V 8 nA at 1200 V

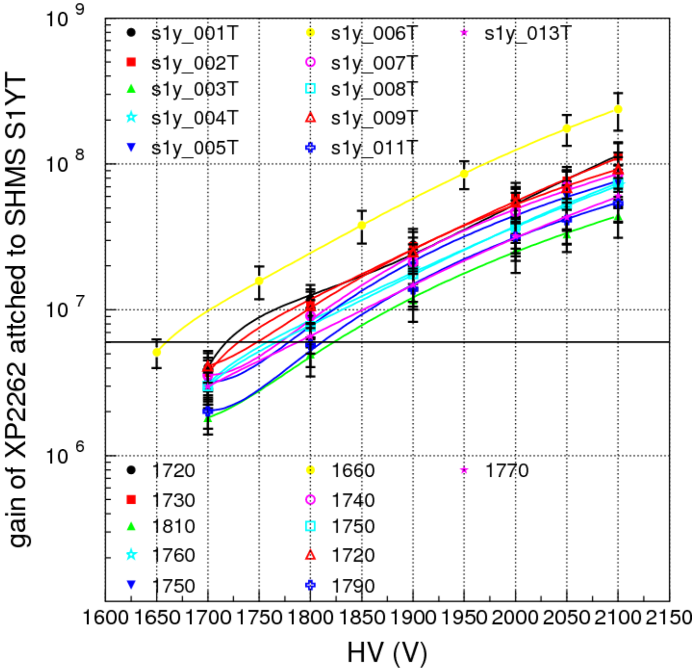
Location	Type	Output Current (nA)
S1X-013L	ET	4 nA at 900 V 10 nA at 1000 V
S1X-012L	ET	3 nA at 1200 V
S1X-011L	ET	7 nA at 1200 V
S1X-010L	ET	6 nA at 900 V
S1X-008L	ET	5 nA at 1100 V 11 nA at 1200 V
S1X-007L	ET	6 nA at 1000 V
S1X-006L	ET	1.5 nA at 1200 V 6 nA at 1400 V
S1X-005L	ET	4 nA at 1000 V
S1X-004L	ET	5.5 nA at 1000 V
S1X-003L	ET	5 nA at 1200 V
S1X-002L	ET	5 nA at 900 V 9 nA at 1000 V

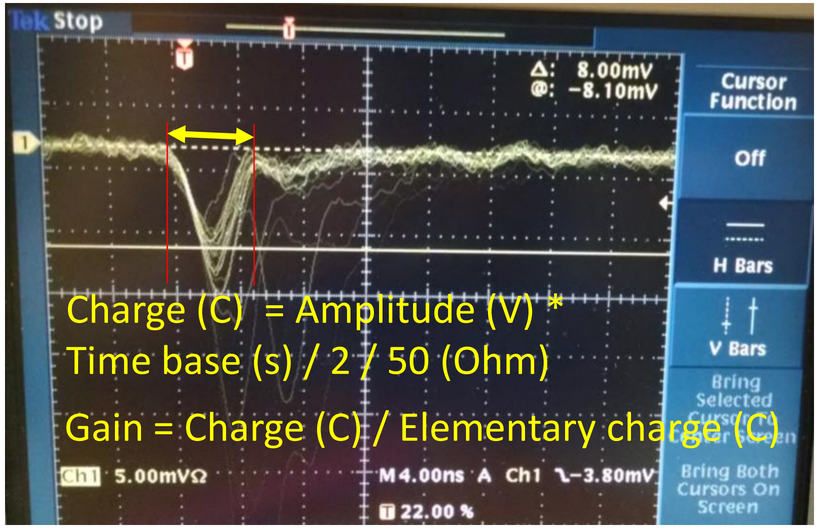
SHMS Plastic Scintillators: Operating Voltages











Take care when restoring HV from scratch; desired voltages and permissible ranges will be well publicized during operations

SHMS Plastic Scintillators: Servicing

- ➢ Servicing having to do with the HV power supply: make sure we have enough spare cards around

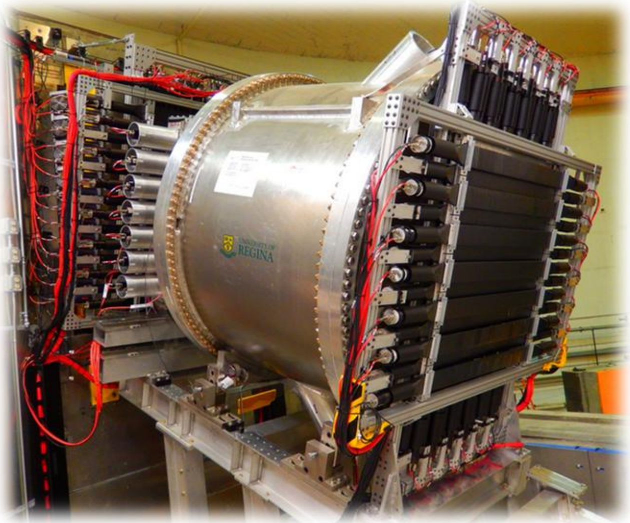
- ➢ Base replacement (though unlikely): more than 13 bases available for XP2262 (shared with HMS hodoscopes) and parts for 3 bases available for ET9214B

→ Take care when replacing bases: pins of PMTs not fixed by a reinforcing plastic socket

Detector accessibility:

→ In the stack: by ladder for most S1X and S2X PMTs; for S1Y top we need platform mounted on the HGC (design drawings done, waiting for money to build it)

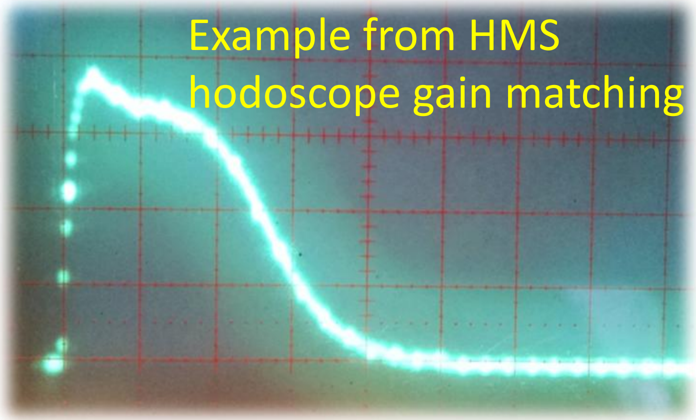
→ If servicing requires plane removal from stack, then major effort involved: S1X and S1Y on common support and same for S2X and S2Y; extremely work intensive to remove/put back S2X-S2Y especially



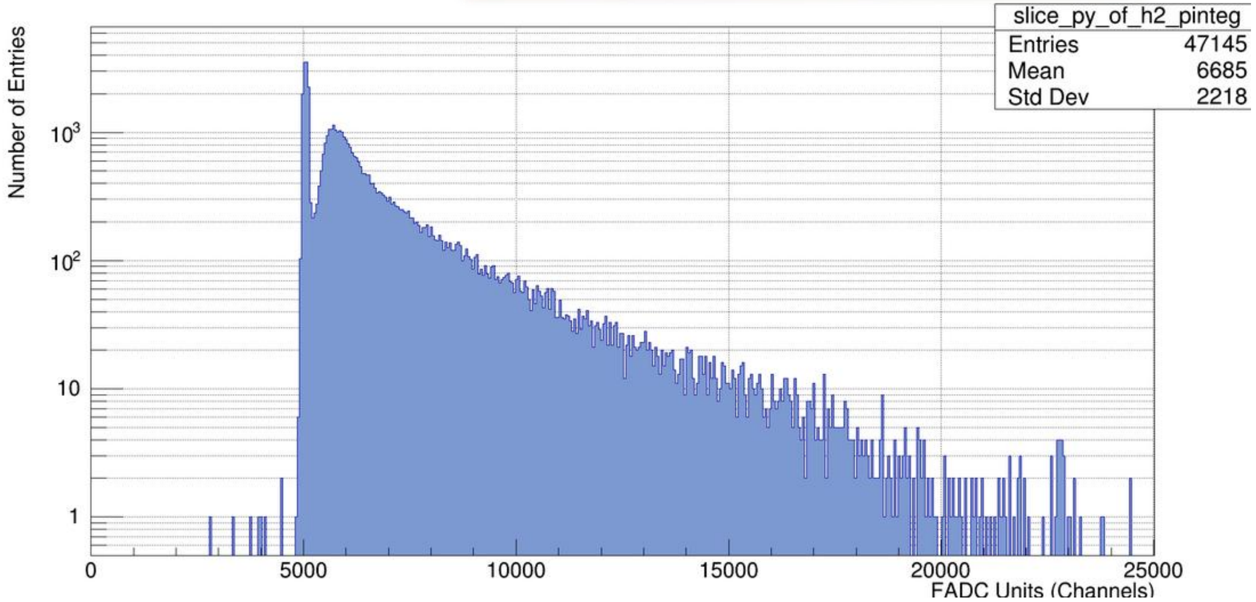
SHMS Plastic Scintillators: Going Forward (before beam)

➢ Gain matching using a Co 60 source (same as it was done for HMS in 2015): will start coming Monday with S2X

→ We will be using the Compton edge of Co 60 to set the gain for PMTs such that the plastic scintillators will be ~ 100 % efficient even for electrons with the lowest energy deposition when taking into account the attenuation through the entire paddle; then the discriminators thresholds will be set accordingly



➢ After gain matching we will continue taking cosmic runs



Plot made by Eric Pooser

SHMS Quartz Plane: Overview

- Built by Abdellah Amidouch and Sam Danagoulian at NC A&T; they are also responsible for commissioning without and with beam

→ 21 quartz bars with 125 cm length, 5.5 cm width and 2.5 cm thickness

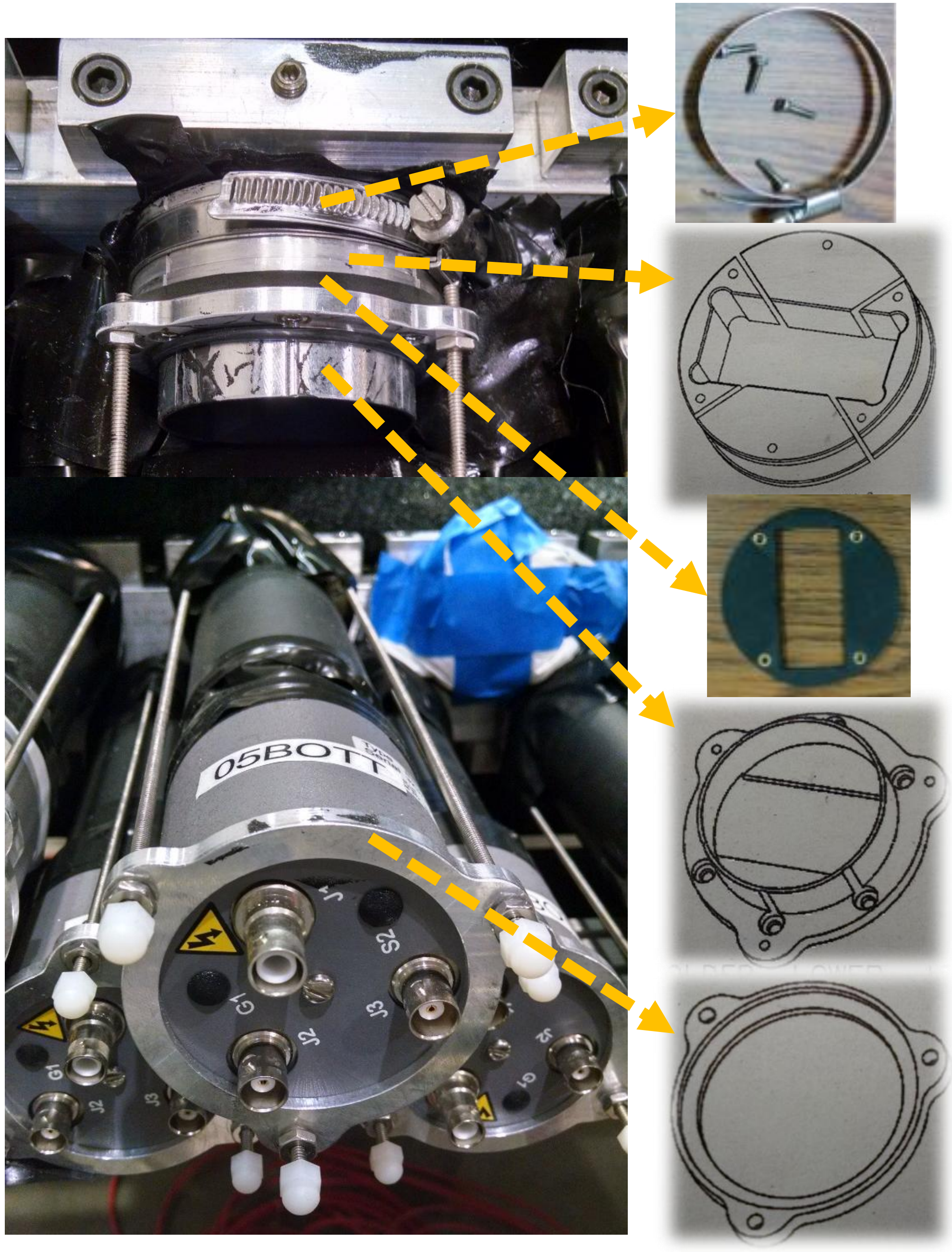
→ No light guides, PMTs mechanically and optically coupled to the quartz bars

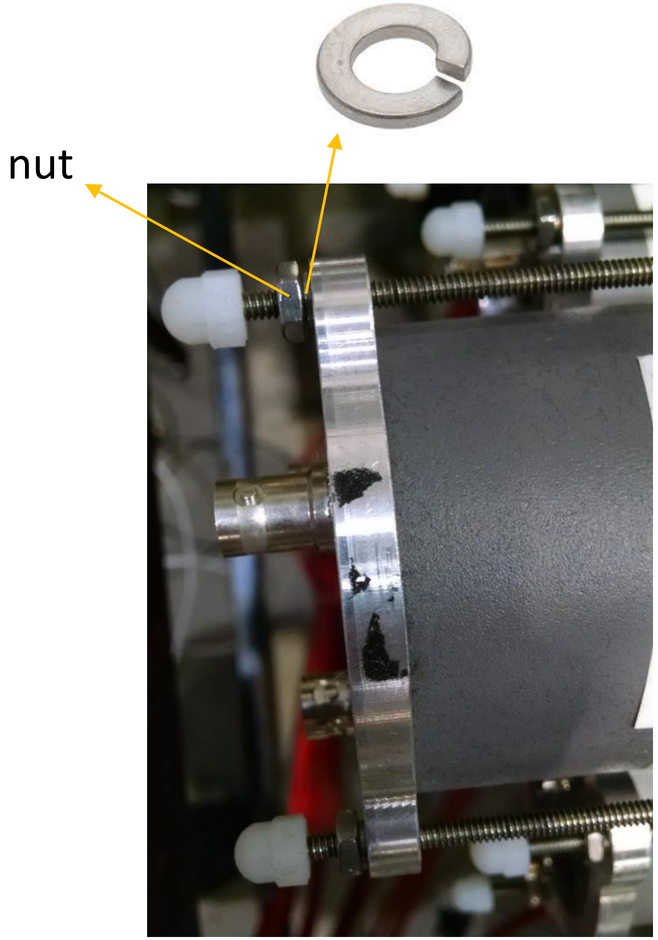
→ 2 types of PMTs used: XP2020Q (24) and ET9814QB (18)

→ Positive HV; **max** for XP2020Q is 2600 V and for ET9814QB is 2300 V

→ Tests at NC A&T showed an average yield of 25 p.e. per PMT or higher

SHMS Quartz Plane: PMT-Bar Mechanical Coupling

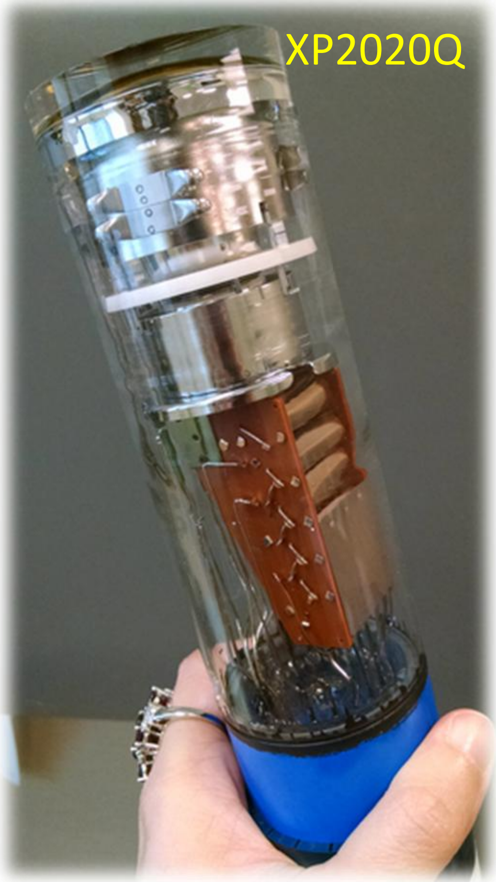




Instructions from designer on how much torque to apply to only tighten nuts until lock washer is compressed

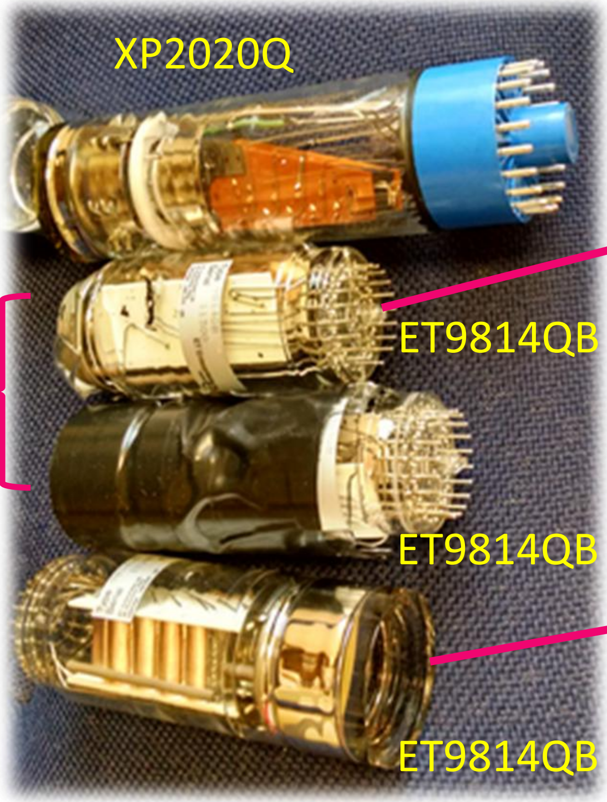
SHMS Quartz Plane: PMT-Bar Mechanical Coupling

- Fun fact: quartz window tubes have a region of transition between the quartz window and the borosilicate glass bulb stem that's called a graded seal and tends to be "very fragile" per Hamamatsu manual



For ET9814QB "the graded seal section starts 40+/-3mm from the front of the window and can be up to 50mm long."

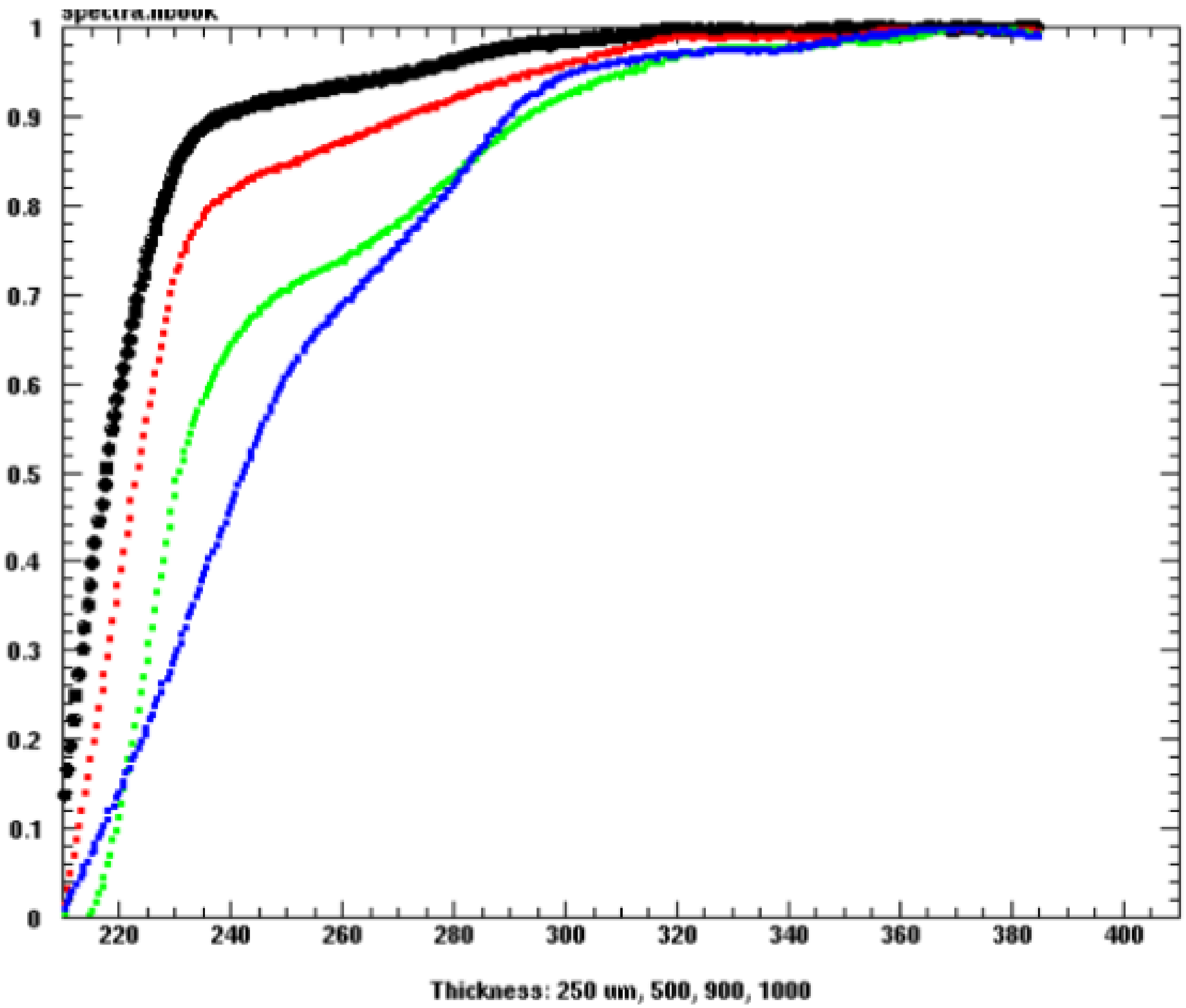
These 2 ETs broke after installation on the quartz bars for no apparent reason while they were in storage at NC A&T



No photocathode? (never used in the detector)

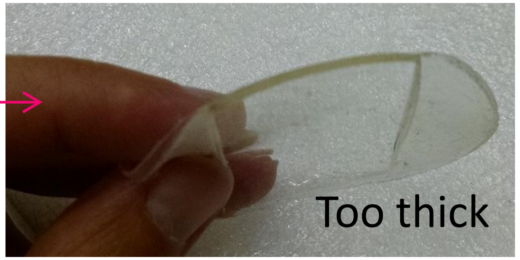
SHMS Quartz Plane: PMT-Bar Optical Coupling

- Optical coupling via Silicone rubber compound RTV615A



→ Transparency studies from NC A&T for four different thicknesses: 250 um or less needed to avoid loss of too many UV photons

→ We removed several PMTs from bars (will learn in next slide why) and in **most cases the thickness was appropriate**



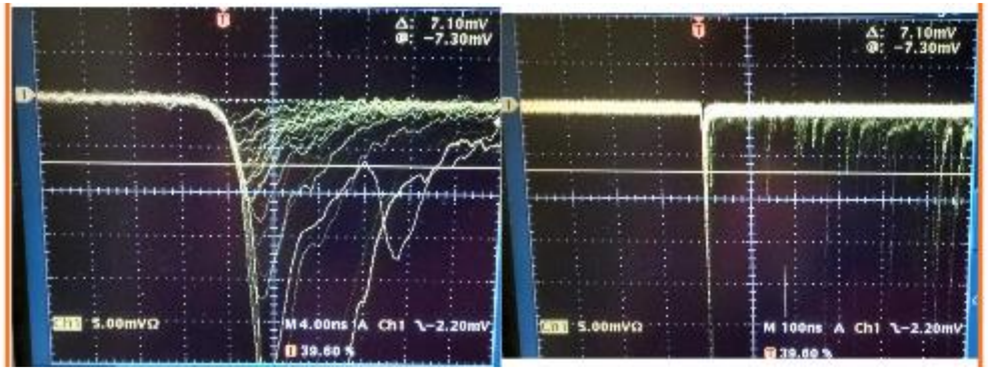
SHMS Quartz Plane: Malfunctioning XP2020Q

- Most XP2020Q PMTs cannot be used

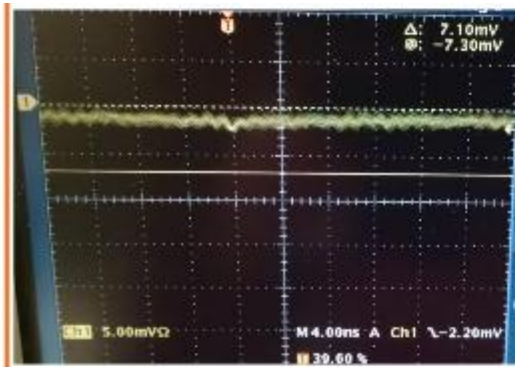
  - They produce an excessively noisy signal when operated at reasonable gain and voltage

  - They will lose output signal above some threshold voltage that's way below the manufacturer's recommended max value (2600 V); the signal can be restored if lowering the voltage to 1000 V or lower only to be lost again when going to higher HV

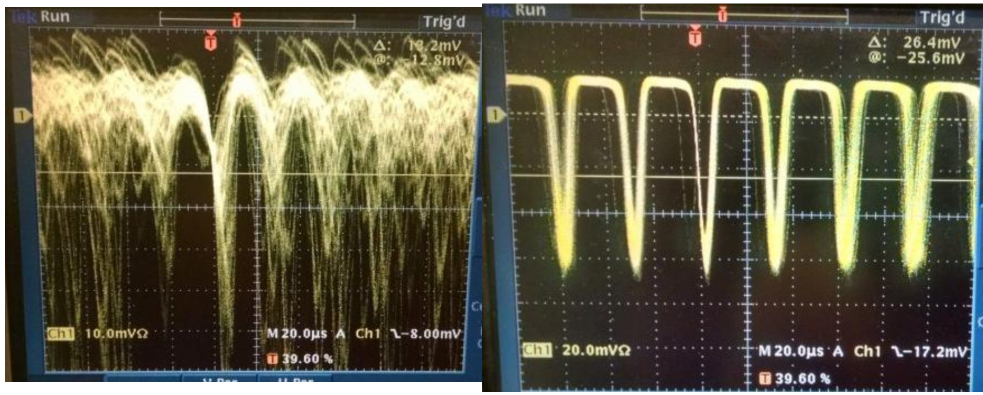
  - The threshold voltage for signal loss gets lower with time



XP2020Q at 1700 V



Same PMT at 1800 V



SHMS Quartz Plane: Malfunctioning XP2020Q

➢ We involved the Detector Group at JLab (Carl Zorn and Drew Weisenberger) to help us speculate on what the cause was

Troubleshooting Photonis XP2020Q PMTs in the Hall C Quartz Hodoscope Detector

C. Zorn

JLAB Radiation Detector and Imaging Group

Steve Wood asked the JLAB Detector Group to help diagnose some extreme noise problems generated in some (or all) XP2020Q PMTs installed in the Quartz Hodoscope detector (Hall C) that was built by the group from the North Carolina A&T State University [1,2]. Our immediate contact is with Simona Malace of Norfolk State University who has carried out an extensive diagnosis of the problem PMTs [3].

Could be caused by:

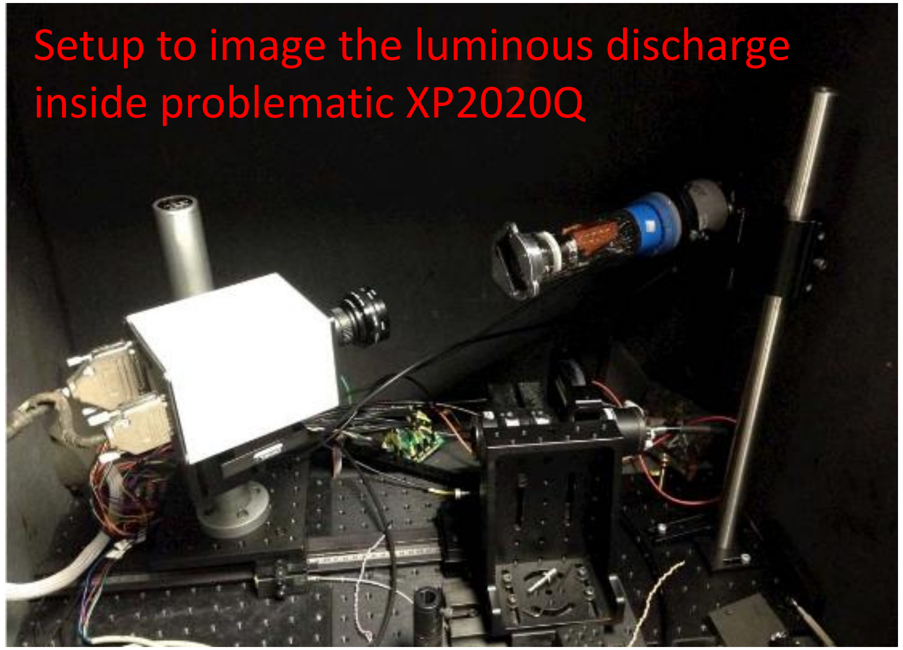
- Small atmospheric leak: the support is rigid enough to cause that
- He leak: some afterpulsing noticed at ~300-400 ns
- Inherent problem from manufacturing stage (water vapor sealed inside?): XPs do behave differently than ETs

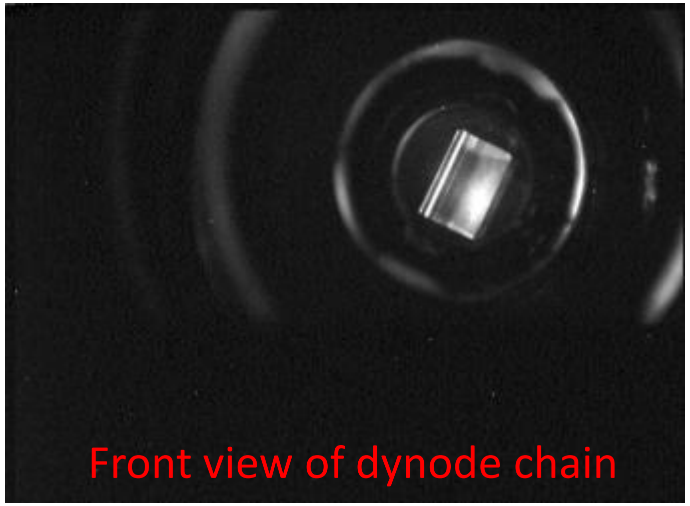
Recommendations:

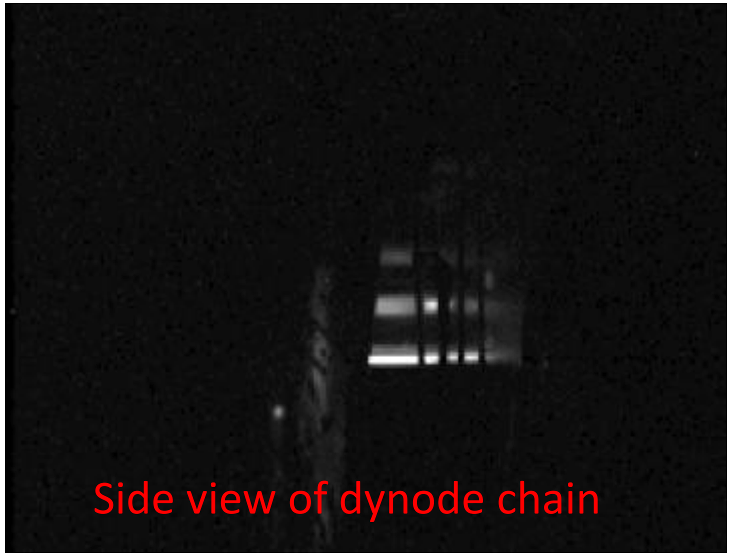
- Look into perhaps modifying the mounting mechanism to avoid too much stress on the PMTs (replace lock washer with a spring)
- Switch to UV glass PMTs - the RTV used for optical coupling cuts the deep UV photons anyway – they are more robust

SHMS Quartz Plane: Tests by Carl Zorn

- The goal of Carl's tests was to look for internal light generation in XP2020Q which would be an indication that the tube is gassy
  - A functional PMT was placed facing the problematic XP2020Q : there was a very marked increase in the dark pulse rate on the functional PMT when the threshold for loss of signal was attained in the problematic XP2020Q; there was no output at the anode in XP2020Q just light inside the PMT
  - A CCD camera was used to find out where the "luminous discharge" takes place: somewhere in the dynode chain
  - The HV threshold for internal discharge increases with time when multiple runs are taken to study the PMT: from 1600 V to 2400 V


Setup to image the luminous discharge inside problematic XP2020Q


Front view of dynode chain

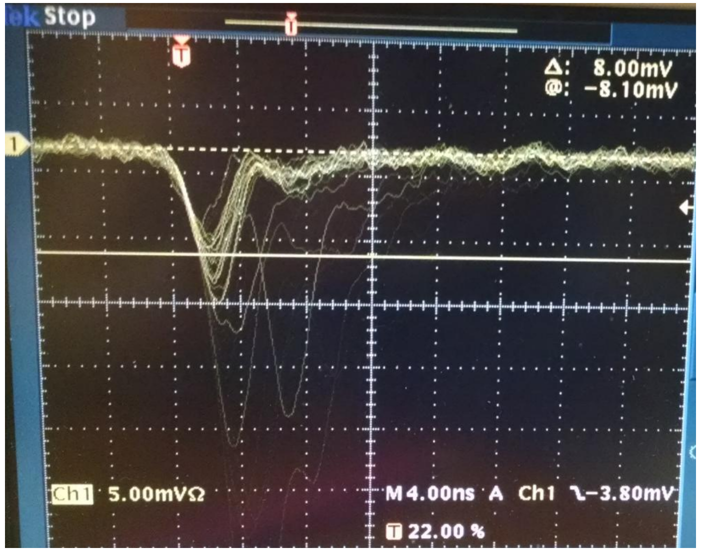

Side view of dynode chain

SHMS Quartz Plane: ET9814QB ~O.K. if Operated at Low to Moderate Gain

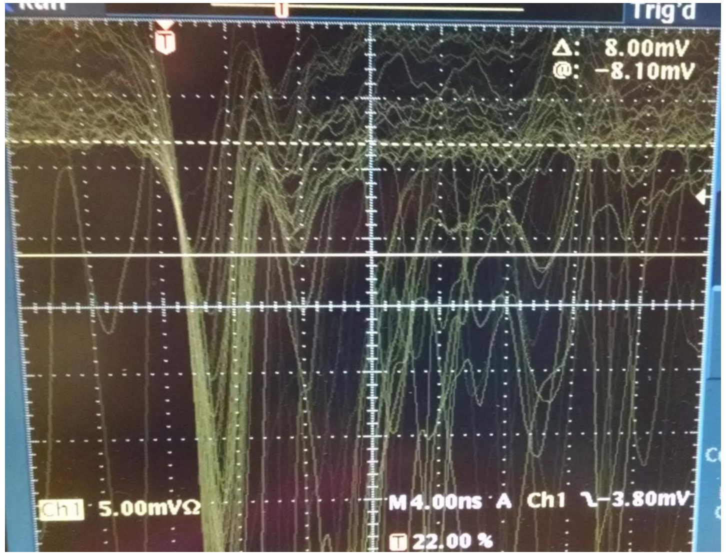
- The ET tubes are stable if operated below a certain gain
- They do become noisy if operated at gains that approach 1E7 (maximum operating gain for ET9814QB is 3E7)

<u>One example:</u>

1580 V



1800 V



PMT label	Noisy at:
003B	1800 V
004B	1700 V
006B	1850 V
008B	1850 V
010B	1800 V
011B	Not up to 1950 V
012B	1900 V
018B	1900 V

PMT label	Noisy at:
003T	1800 V
004T	1800 V
005T	1800 V
006T	1800 V
008T	1800 V
010T	1800 V
011T	1800 V
012T	1700 V
018T	1800 V
019T	1700 V

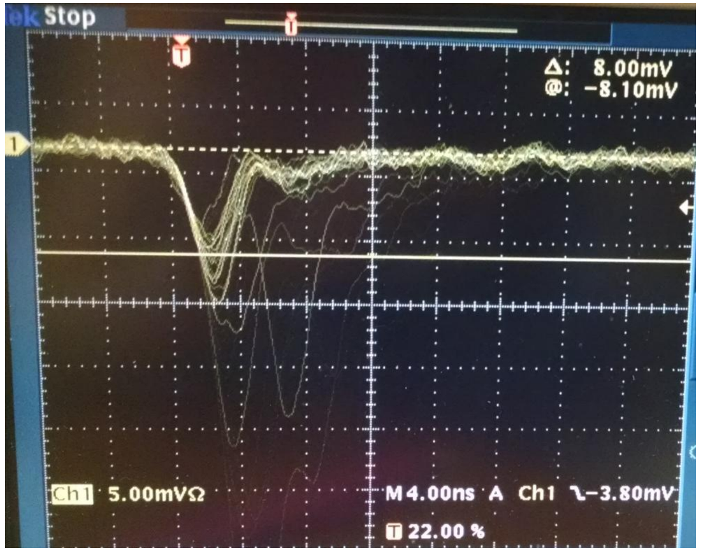
- In months of testing the HV threshold for noisy behavior never changed!!

SHMS Quartz Plane: ET9814QB ~O.K. if Operated at Low to Moderate Gain

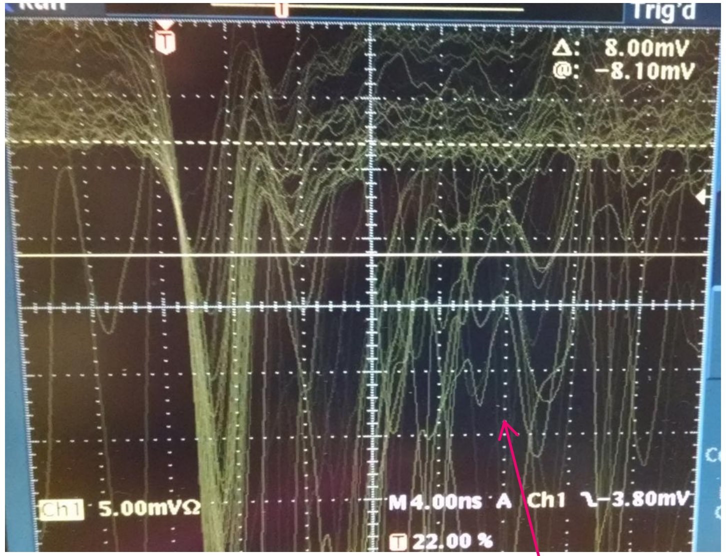
- The ET tubes are stable if operated below a certain gain
- They do become noisy if operated at gains that approach 1E7 (maximum operating gain for ET9814QB is 3E7)

<u>One example:</u>

1580 V



1800 V



PMT label	Noisy at:
003B	1800 V
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PMT label	Noisy at:
003T	1800 V
004T	1800 V
005T	1800 V
006T	1800 V
008T	1800 V
010T	1800 V
011T	1800 V
012T	1700 V
018T	1800 V
019T	1700 V

- In months of testing the HV threshold for noisy behavior never changed!!

ET9814QB can be used, just don't go there!

SHMS Quartz Plane: Preparing for Spring 2017 Run

- We rearranged the quartz bars so that most of the acceptance is covered by bars with functional and stable ET9814QB PMTs
  - → 9 bars have 17 ET and 1 XP
  - → 1 bars has2 XPs

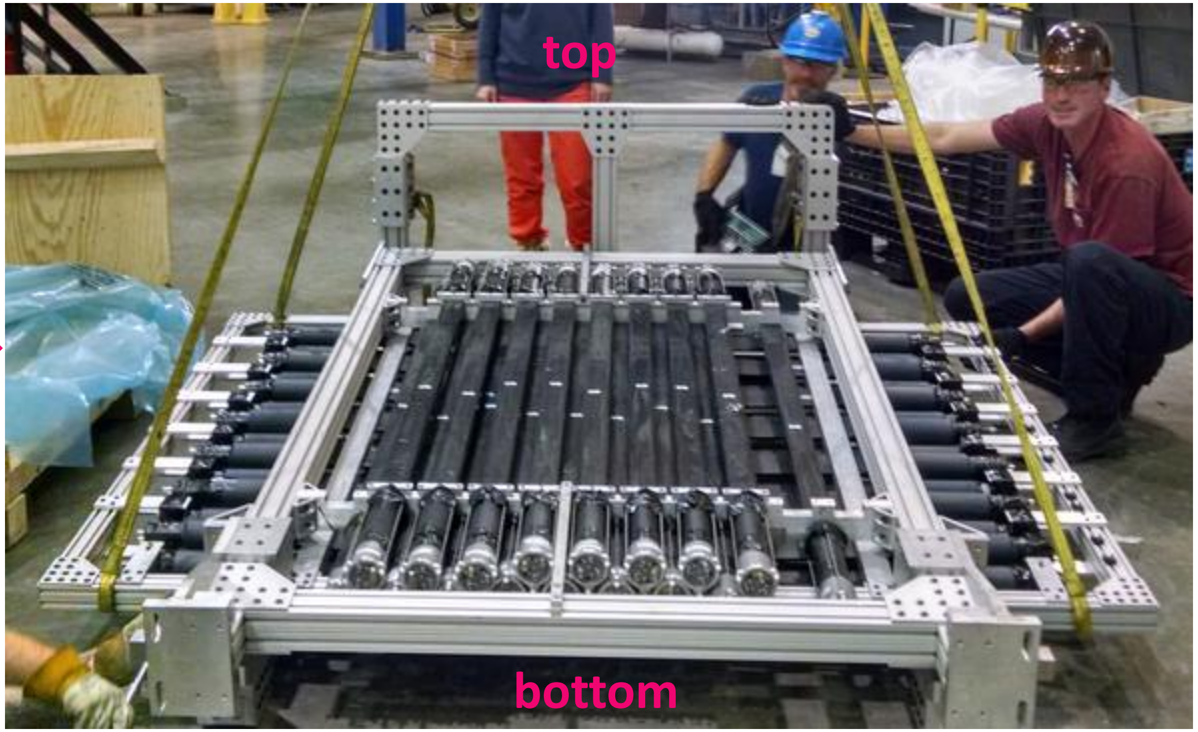
before

Cable	PMT
1B (T)	21B (T)
2B (T)	20B (T)
….	….
21B (T)	1B (T)

after

Cable	PMT
7B	6B (ET)
8B	4B (ET)
9B	18B (ET)
10B	12B (ET)
11B	11B (ET)
12B	10B (ET)
13B	3B (ET)
14B	8B (ET)
15B	5B (**XP**)
16B	13B (**XP**)

Cable	PMT
7T	6T (ET)
8T	4T (ET)
9T	18T (ET)
10T	12T (ET)
11T	11T (ET)
12T	10T (ET)
13T	3T (ET)
14T	8T (ET)
15T	5T (ET)
16T	13T (**XP**)

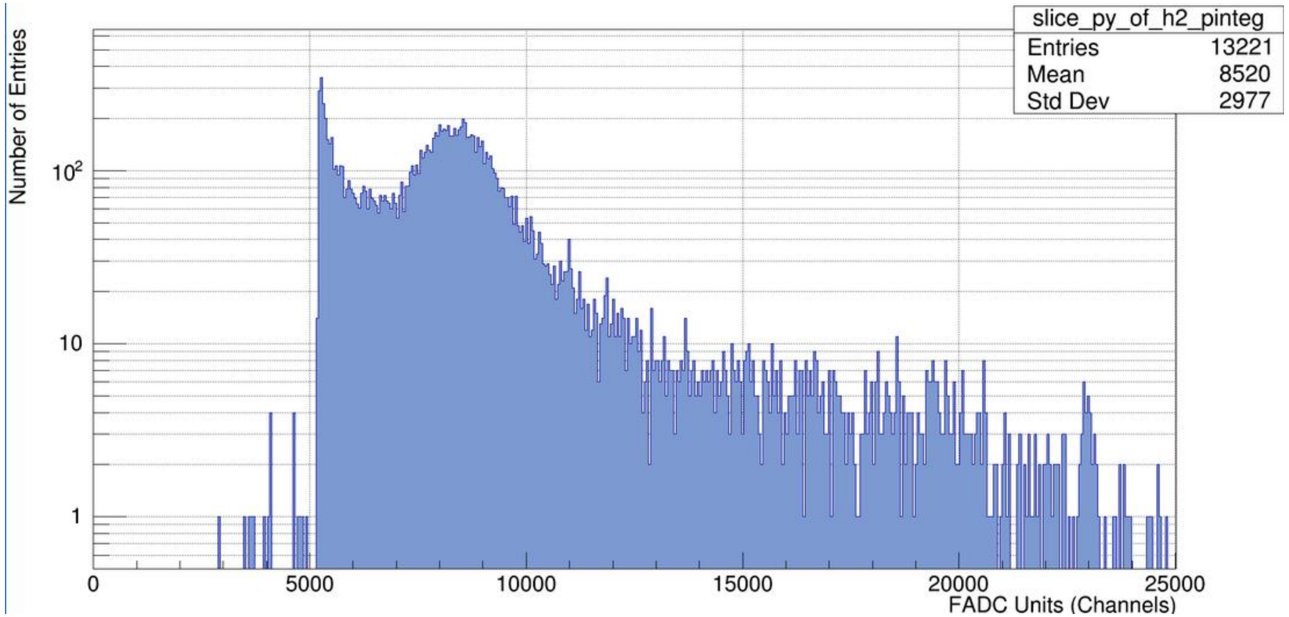


SHMS Quartz Plane: Preparing for Spring 2017 Run

- Since the quartz plane signals go straight into an amplifier we are running the PMTs in a low gain mode: SPE amplitude between 1 and 2 mV

Cable	PMT	HV (V)
7B	6B (ET)	1430
8B	4B (ET)	1420
9B	18B (ET)	1415
10B	12B (ET)	1460
11B	11B (ET)	1580
12B	10B (ET)	1430
13B	3B (ET)	1445
14B	8B (ET)	1470
15B	5B (XP)	1570
16B	13B (XP)	1380

Cable	PMT	HV (V)
7T	6T (ET)	1400
8T	4T (ET)	1420
9T	18T (ET)	1445
10T	12T (ET)	1385
11T	11T (ET)	1390
12T	10T (ET)	1410
13T	3T (ET)	1390
14T	8T (ET)	1425
15T	5T (ET)	1410
16T	13T (XP)	1520

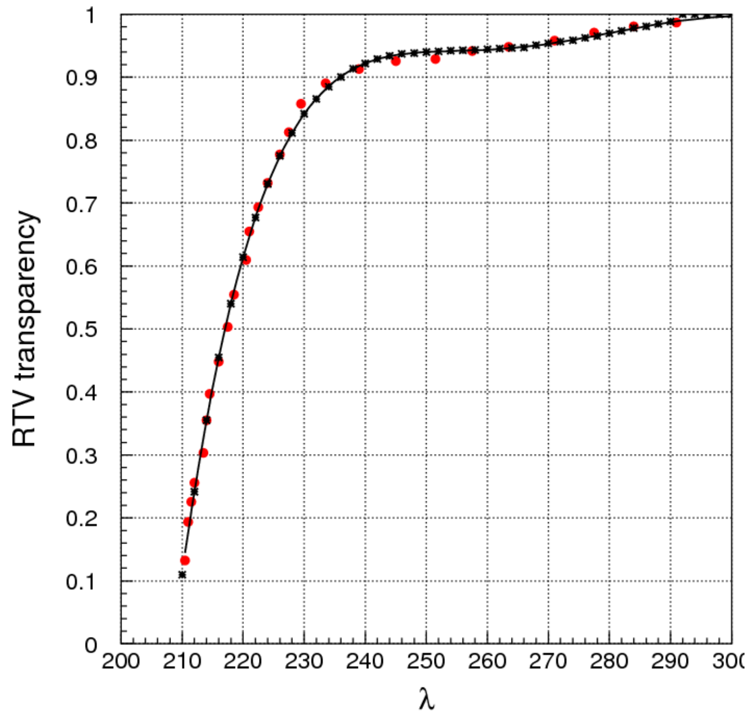


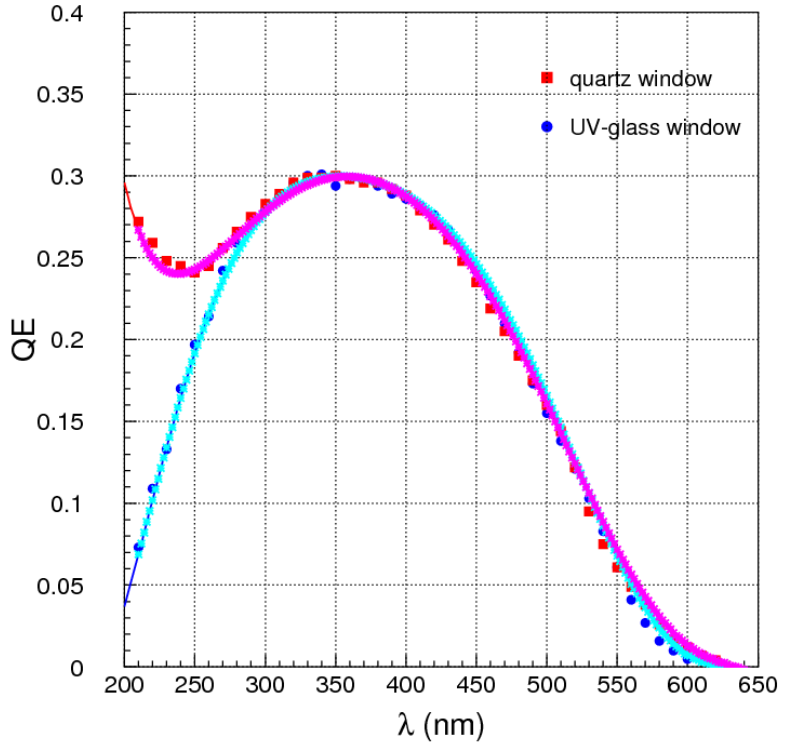
Plot made by Eric Pooser

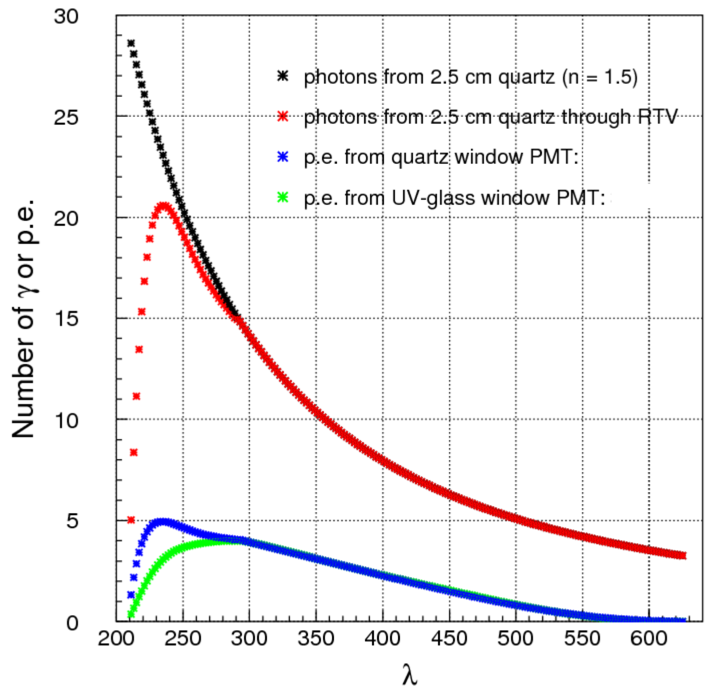
SHMS Quartz Plane: Looking Beyond the Spring Run

- ➢ Eventually all the tubes would have to be replaced: we are looking into buying UV-glass ET9814WB

  → Calculation shows that we would loose 10% of the p.e. yield when going from quartz to UV glass





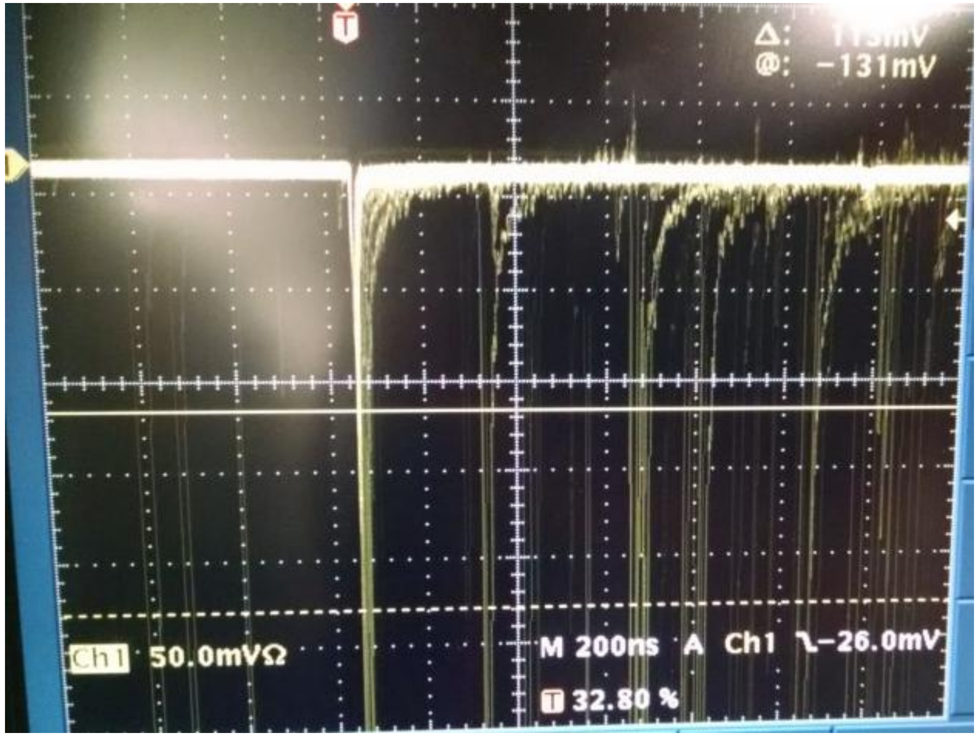


1) the UV-glass PMTs are more robust since there is no need for a graded seal
2) UV-glass is less permeable than quartz to He
3) UV-glass window PMTs are cheaper though not by much ($100 only if we buy from ET)

HMS Hodoscopes and Aerogel

- HMS hodoscopes have been gain matched in 2015; we are taking cosmic data to iterate through the appropriate discriminators thresholds

- HMS aerogel PMTs exhibit similar symptoms as the SHMS quartz plane XP2020Q PMTs; we would need at least a few months heads-up if this detector is needed for data taking after the first year of running



Summary

- SHMS plastic scintillators are in good shape; we will do gain matching with Co 60 and take cosmic runs to ensure that all looks OK

- SHMS quartz plane: we have 9 functional bars that cover most of our acceptance (with H and D targets); we will take cosmics to iterate through the appropriate thresholds to maximize efficiency while minimizing noise

- HMS plastic scintillators have been gain matched in 2015; now taking comic data

- HMS aerogel tubes are gassy and cannot be used; if you need the detector for physics, let us know well in advance so we can replace the tubes

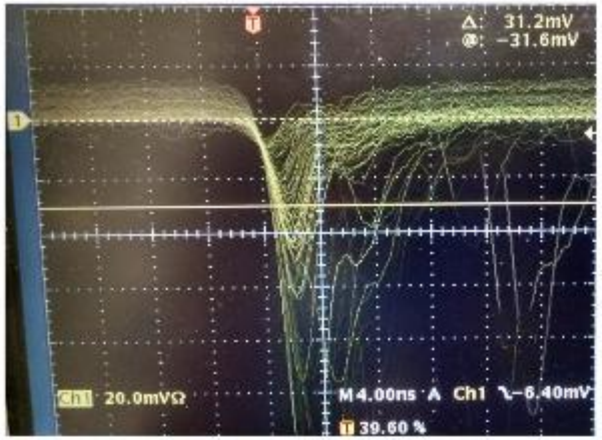
Backup

Typical Behavior for ET9814QB: S2Y-004T at 1900 V

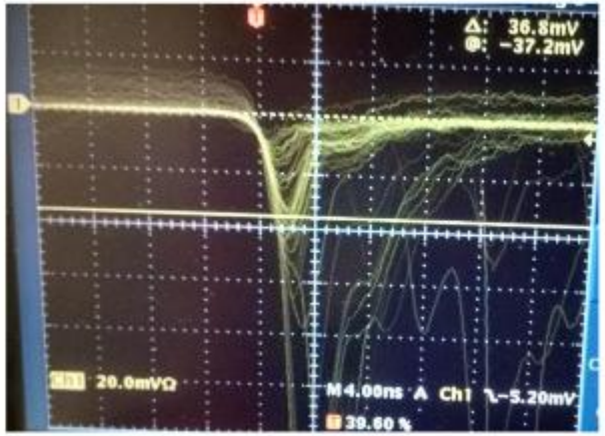
Independent of power supply

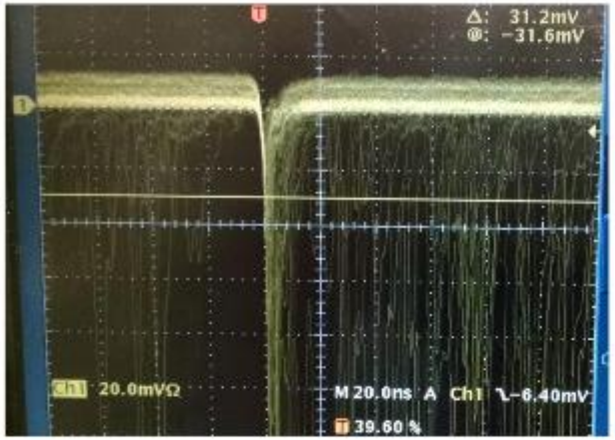
CAEN HV supply

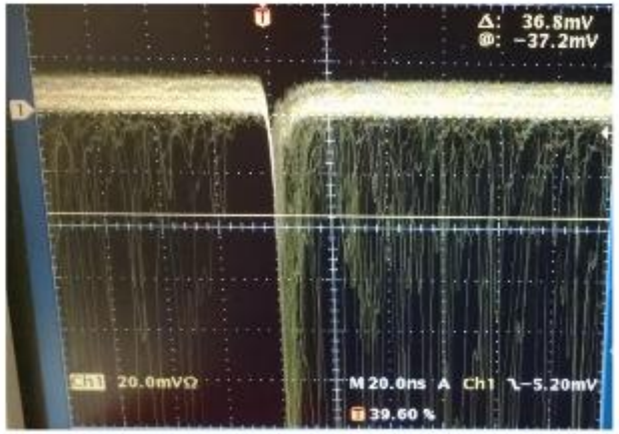
ORTEC HV supply



let's call this "noisy"







The purpose of this calculation is to estimate how many photoelectrons we would lose if we switch from quartz window 9814 PMTs to UV-glass window 9814 PMTs

The following assumptions were made:

→ No photons are lost due to absorption through the quartz bar

→ All photons created in the quartz bar make it to the RTV and photons are lost only due to absorption in the RTV

→ The index of refraction of the quartz bar material is wavelength independent. This, of course, is not true: for the wavelength range we are interested in it varies from 1.56 to 1.46. However, the relative calculation will not be affected by this assumption: the absolute number of photons produced through the bar will depend on the index of refraction but the difference in the number of photoelectrons when going from quartz window PMTs to UV-glass PMTs will not. It is the latter we are interested in

→ The RTV transparency used in this calculation is that obtained from measurements in NC for a thickness of the RTV of 250 microns

→ My calculation included the wavelength range between 210 nm and 626 nm. The high wavelength cut is given by the PMT quantum efficiency. The low wavelength cut is ARTIFICIALLY given by the lack of RTV transparency data below 210 nm. This should not bias the result in any meaningful way: if we extrapolate the RTV transparency data obtained by Sam and Abdellah (next slide) we see that the transparency becomes zero at ~207 nm for a RTV thickness of 250 nm

This is how the calculation was done:

Differential number of photons produced by an electron with relative velocity β as it traverses a material with index of refraction n:

$$\frac{d^2N}{dxd\lambda} = \frac{2\pi\alpha}{\lambda^2}\left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right)$$

If we ignore the wavelength dependence of n, then the integrated number of photons becomes:

$$N = 2\pi\alpha\left(1 - \frac{1}{\beta^2 n^2}\right)\int_{x1}^{x2} dx \int_{\lambda\_small}^{\lambda\_large} \frac{1}{\lambda^2} d\lambda = 2\pi\alpha l\left(1 - \frac{1}{\beta^2 n^2}\right)\left(\frac{1}{\lambda\_small} - \frac{1}{\lambda\_large}\right)$$

l = 2.5 cm = 25000000 nm for the NC quartz bars
n = 1.5
β = 1 for the GeV electrons we are interested in
2πα = 2 * 3.14159 * 0.007297 = 0.045848

N will be reduced due to absorption through the RTV and the inefficiency in converting photons in photoelectrons in the PMT