RECENT PROGRESS ON SILICON PHOTOMULTIPLIERS FOR BCAL

WILL BROOKS, ON BEHALF OF THE USM, JLAB, AND REGINA TEAMS

SERGEY KULESHOV, ALAM TORO, HAYK HAKOBYAN, ORLANDO SOTO, RICARDO OYARZÚN, RIMSKY ROJAS, RENE RÍOS, JAVIERA QUIROZ, W.B., USM

MEHRNOOSH TAHANI, GEORGE LOLOS, ZISIS PAPANDREOU, ANDREI SEMENOV, U. REGINA

YI QIANG, CARL ZORN, CHRIS STANISLAV, SCOT SPIEGEL, JIM FOCHTMAN, FERNANDO BARBOSA, JLAB

HALL D COLLABORATION MEETING, 17 FEB 2012

OVERVIEW

- USM: ACCEPTANCE TESTS AND DEVICE CHARACTERIZATION OF 2800 MPPC'S
- JLAB: ACCEPTANCE TESTS AND DEVICE CHARACTERIZATION OF 1200 MPPCS
- U. REGINA: SYSTEMATIC STUDIES OF MPPCS USING A VARIETY OF EXPERIMENTAL TECHNIQUES

PRODUCTION TESTING: STATUS

- USM: 2800 MPPC'S
  - ON-SITE REVIEW PASSED DEC 15, 2011
  - COMMISSIONING COMPLETED AND PRODUCTION TESTING STARTED WITH 2 OF THE 3 TEST STATIONS
  - COMMISSIONING OF TEST STATION 3 EXPECTED TO FINISH WITHIN 2 WEEKS
- JLAB: 1200 MPPCS
  - HARDWARE SETUP IS ALMOST READY
  - BOTH CONTROL AND ANALYSIS SOFTWARE ARE READY
  - PRODUCTION TESTING STARTING SOON

QUANTITIES CHARACTERIZED, USM TESTS, PAGE 1

#	**Property**	**Testing plan**
1	Gain at nominal operating voltage	All cells at 2 temperatures
2	Photo-sensitive area > 144 mm^2	Microscope inspection, all arrays
3	Macroscopic active area coverage > 75%	Microscope inspection, all arrays
4	Number of micro-pixels > 56000	Estimate lower limit from linearity measurement
5	Sensitivity to magnetic field	Unmeasured, Hamamatsu exception
6	PDE at 490 nm	3 MPPCs of 32 measured directly, estimate for the remainder
7	Dark rate	All cells at 2 temperatures
8	Dark current	All arrays at 2 temperatures
9	Sensitivity to temperature	All cells at operating voltage and 5°C
10	Maximum output difference of any cell within one array from the array's average	All arrays, operating voltage and 5°C
11	Variation of the average output of arrays under uniform illumination at their nominal operating voltage	All arrays at 5°C
12	Nominal operating voltage	All arrays at 5°C

QUANTITIES CHARACTERIZED, USM TESTS, PAGE 1

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12	Nominal operating voltage	All arrays at 5°C

QUANTITIES CHARACTERIZED, USM TESTS, PAGE 2

13	Nominal operating voltage is above breakdown voltage by 0.9-3.0V	All arrays at 5°C
14	Fraction of multiple photoelectrons in dark noise < 5%	All cells at 2 temperatures
15	Package dimensions	Microscope inspection, all arrays
16	Package substrate	Reference to HAMAMATSU model #
17	Inputs (sign of bias voltage)	All arrays
18	Outputs (16 individual outputs)	All arrays
19	Output connector	Reference to HAMAMATSU model # and microscope inspection, all arrays
20	Rise time 10%-90%	All cells
21	Pulse width 10%-10%	All cells
22	Sensitivity of signal-to-noise to radiation	Unmeasured, Hamamatsu exception

Table 2. Mapping between specification document and unit testing plan. Each row matches a row in Table 1. ***In the table, "all arrays" means 2800 MPPC arrays, and "all cells" means 2800x16 MPPC array cells.***

QUANTITIES CHARACTERIZED, USM TESTS, PAGE 2

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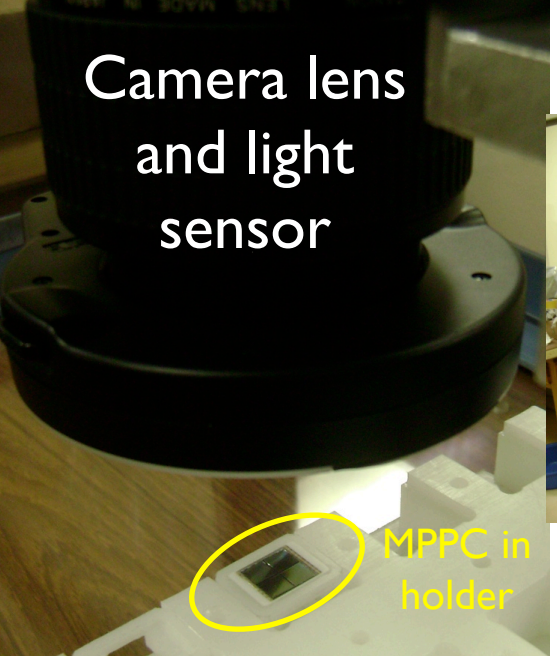
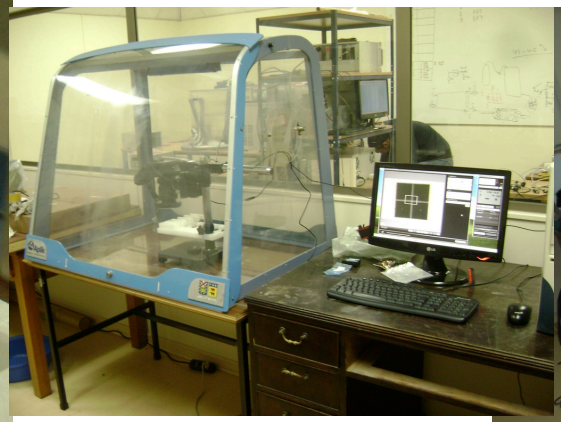
USM MEASUREMENTS - 3 STAGES

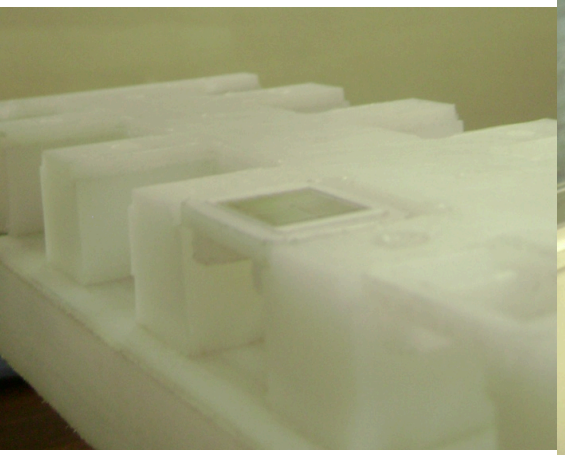
- STATION 1 - INSPECTION STATION
  - HIGH-RESOLUTION PHOTOGRAPH, OBSERVATIONS
- STATION 2 - PDE MEASUREMENTS FOR 10% OF MPPCS, PULSE SHAPE MEASUREMENTS FOR 100% OF MPPCS
  - ROOM TEMPERATURE, ONE MPPC AT A TIME
- STATION 3 - DARK RATE, I-V CURVES, GAIN, CROSS-CALIBRATION TO DETERMINE RELATIVE PDE
  - TEMPERATURE-CONTROLLED FROM 5-20 DEGREES C
  - 32 MPPCS AT A TIME

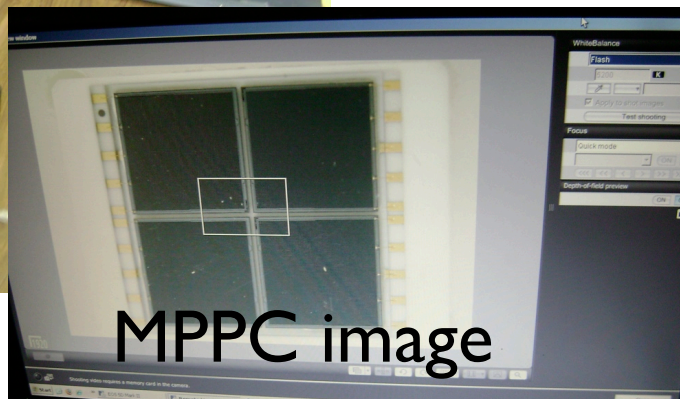
Layout of two rooms for MPPC tests at USM

Inspection Station (Stage I)

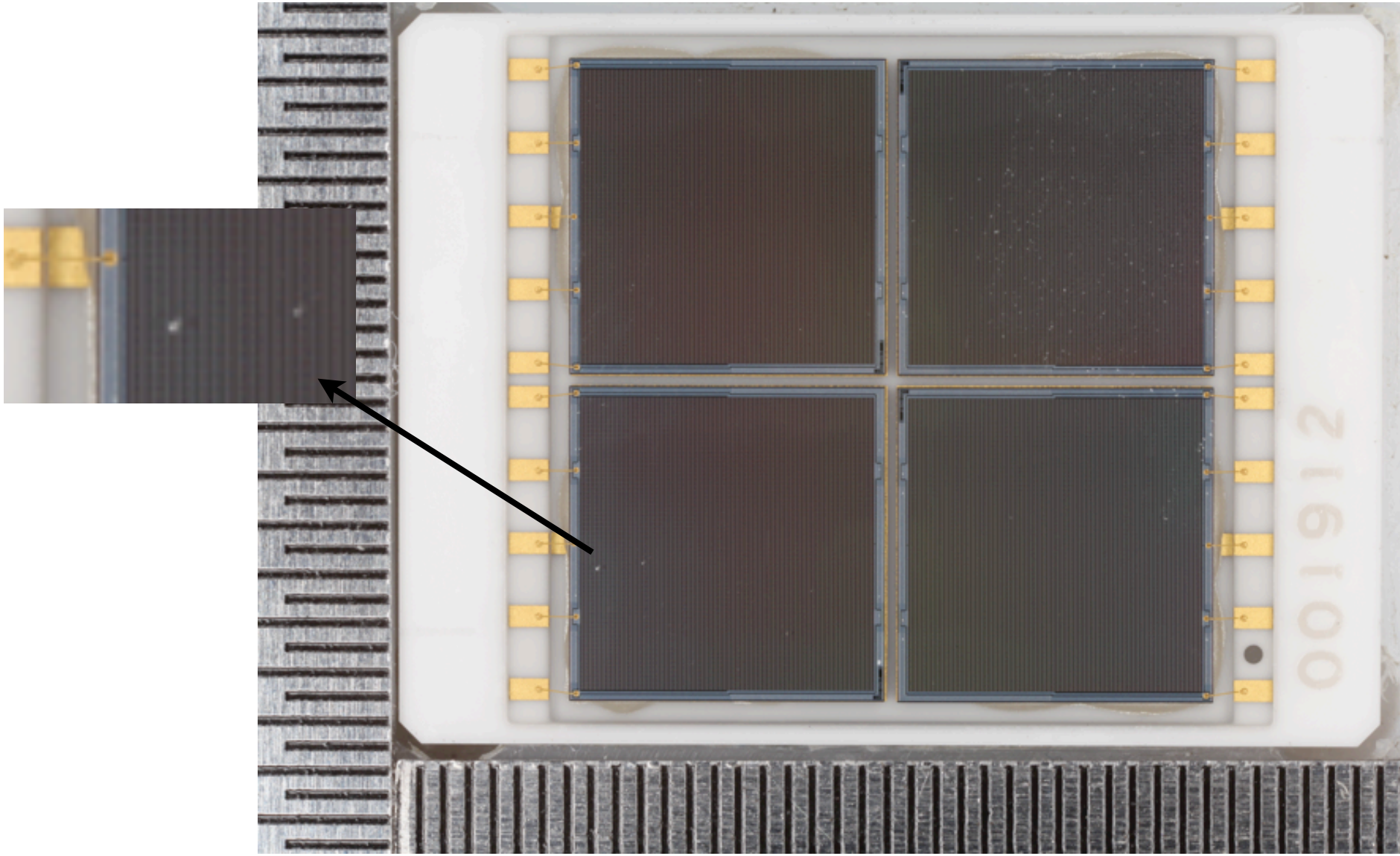




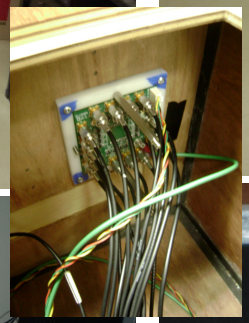


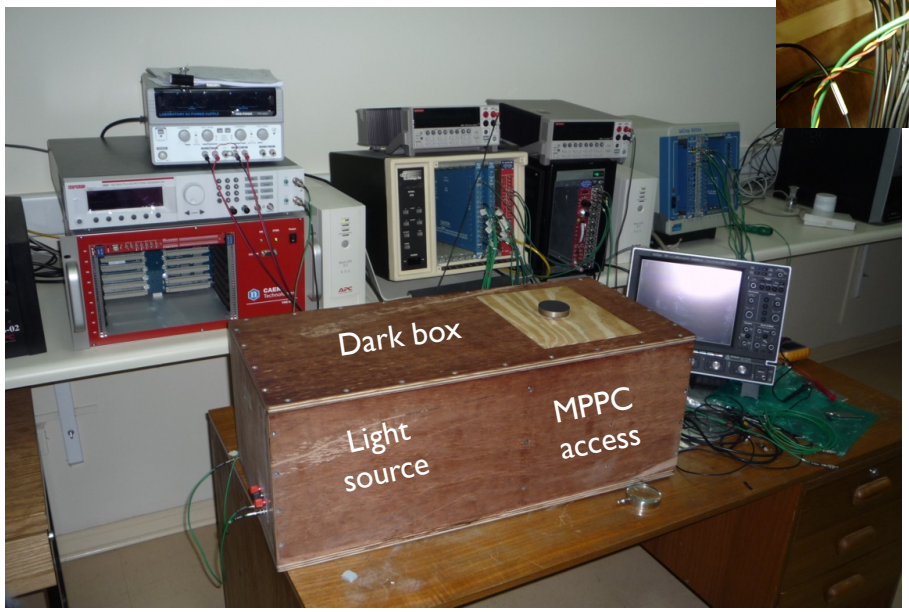


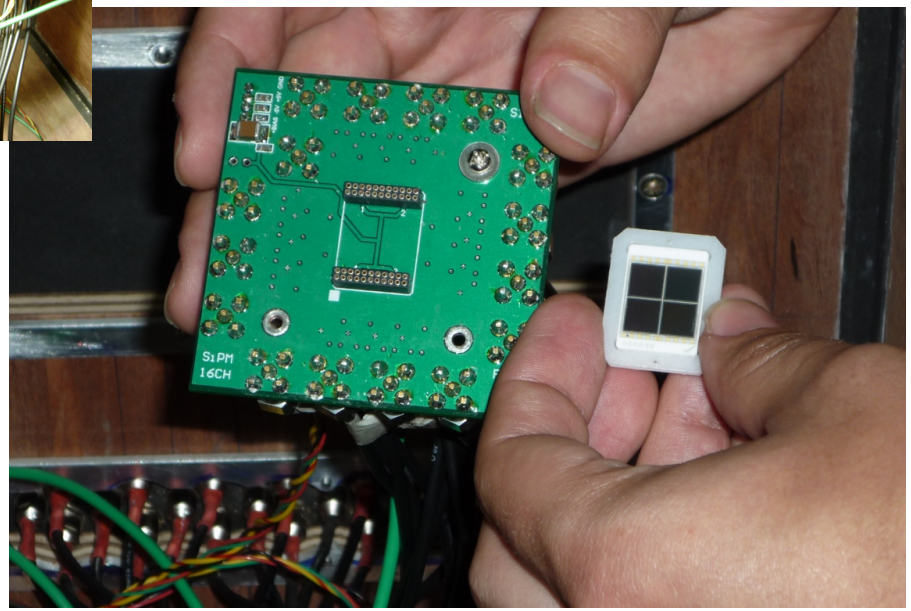
MPPC image



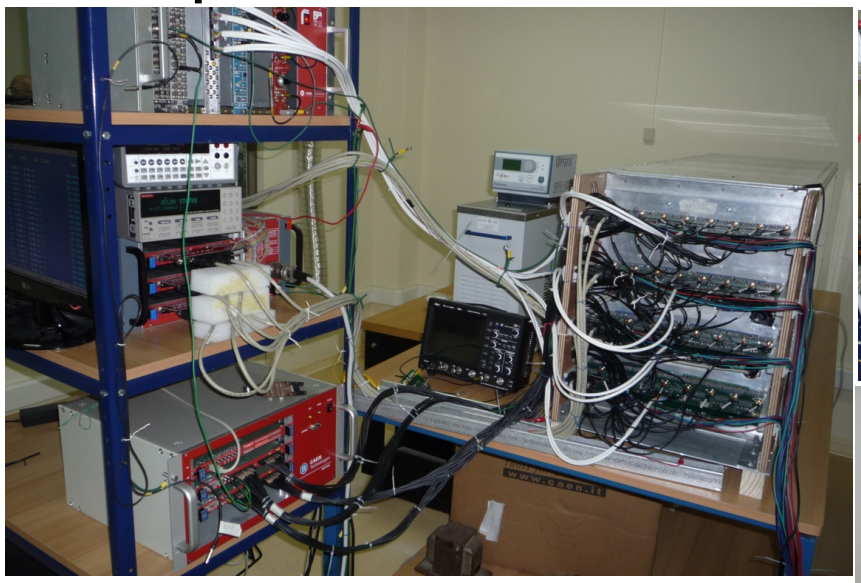
PDE Station (Stage II)

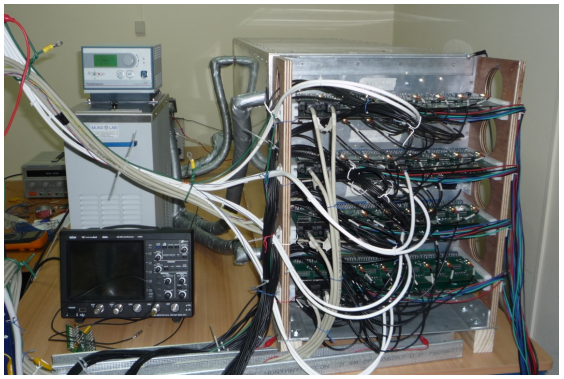


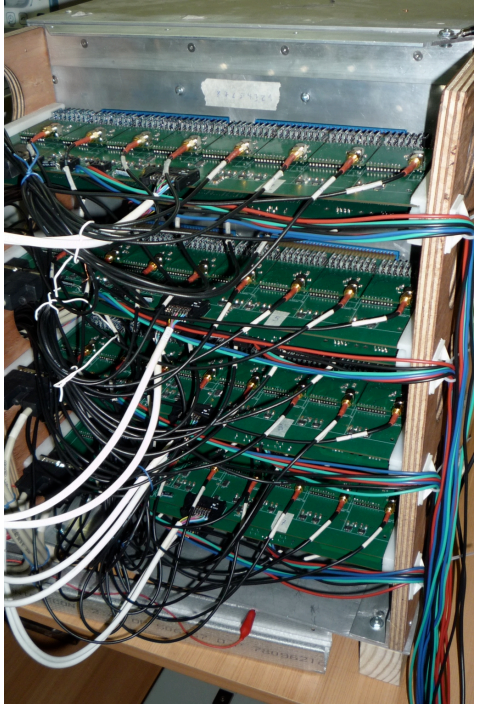


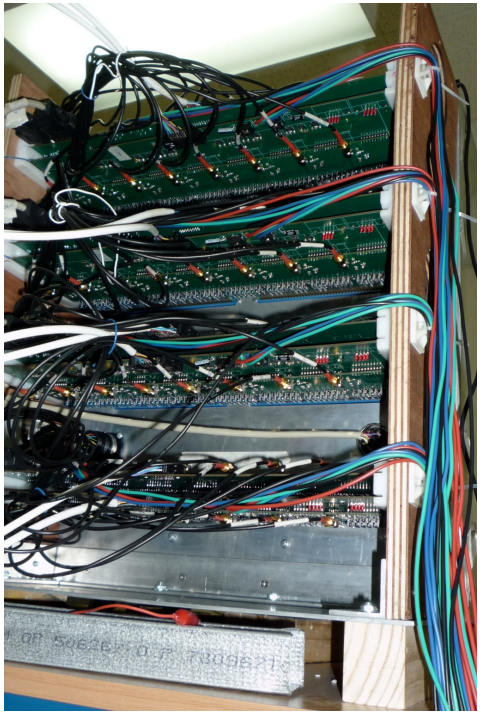


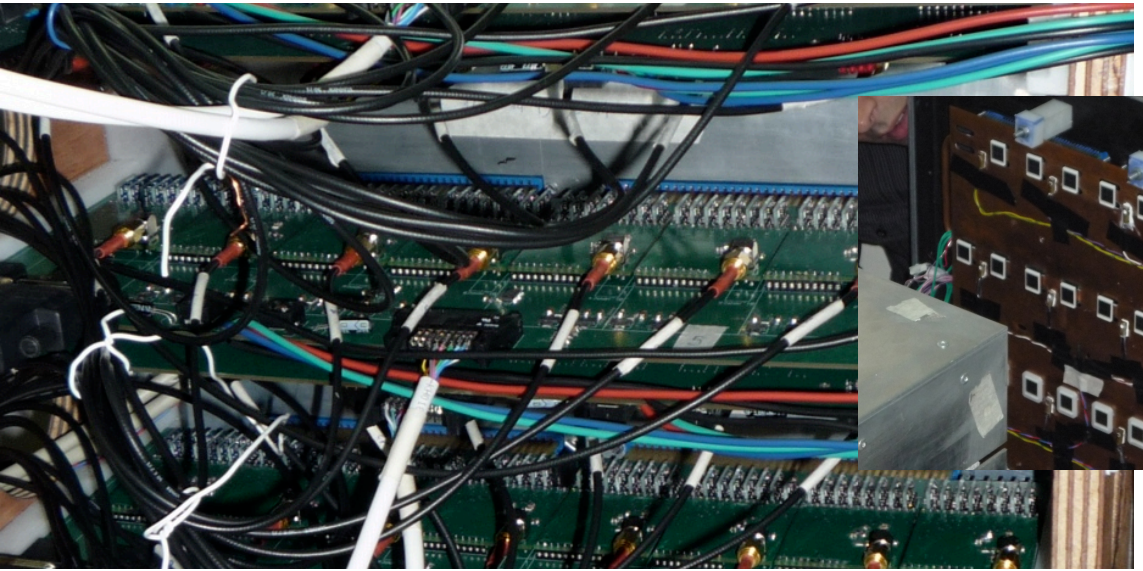
Temperature-Controlled Station (Stage III)









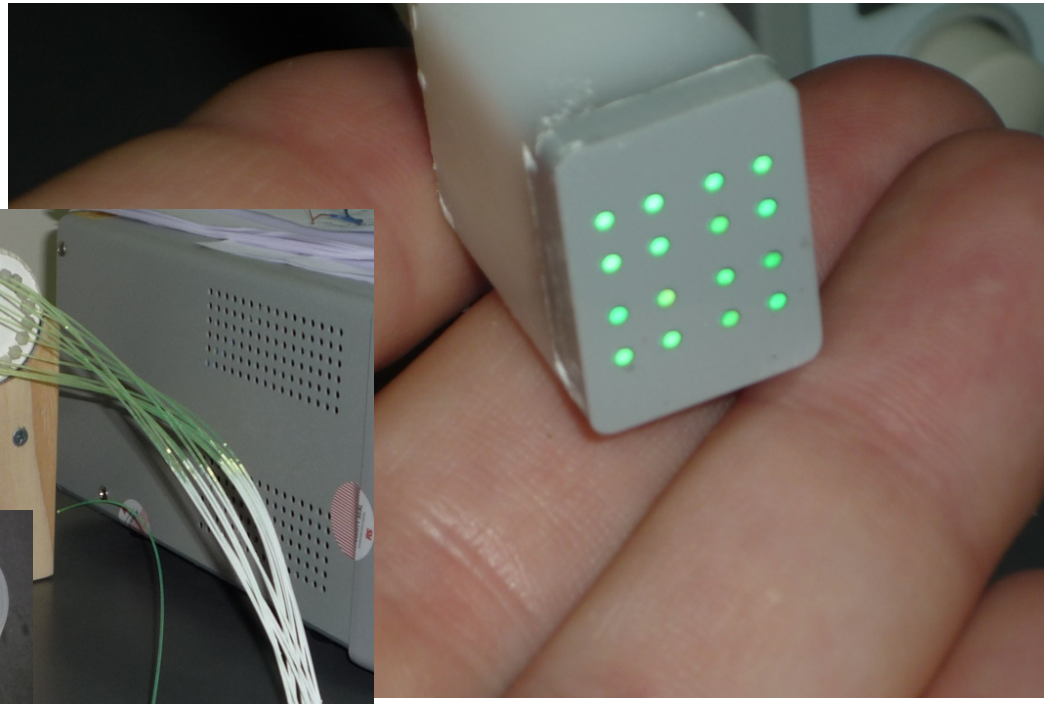


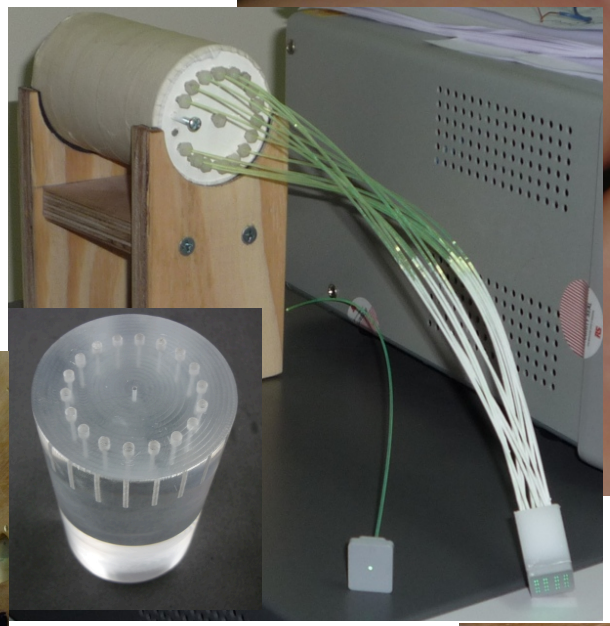
USM Light Sources

- Light source for PDE station: blue LED illuminating green fibers (LED - clear fiber - mixer - 17 fibers out)
- See picture next page for PDE station
- Light source for temperature-controlled station is a green LED with a variable current driver, and a diffuser, at a distance 1.5 meters from MPPCs

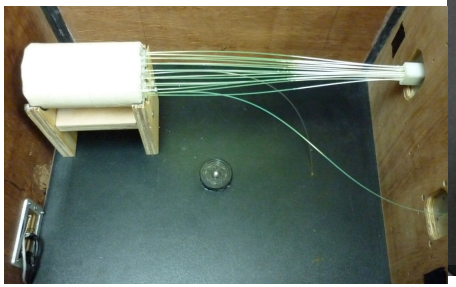
USM PDE Station Light Source

Recessed positioner; fibers on this side, MPPC on other side

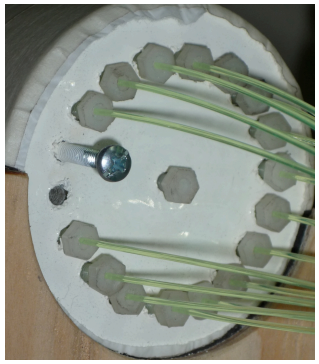




Light mixer (clear fiber goes into center)

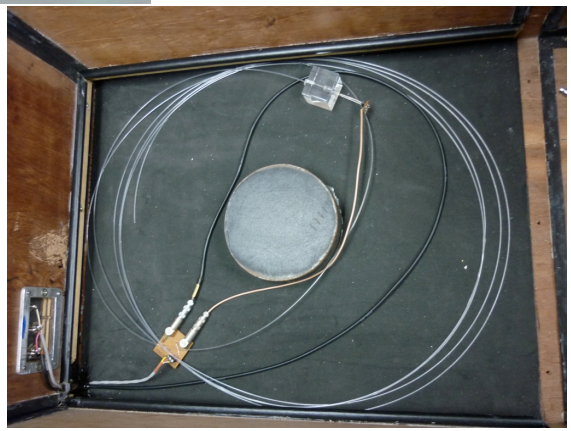


Output of 16 green fibers following mixer



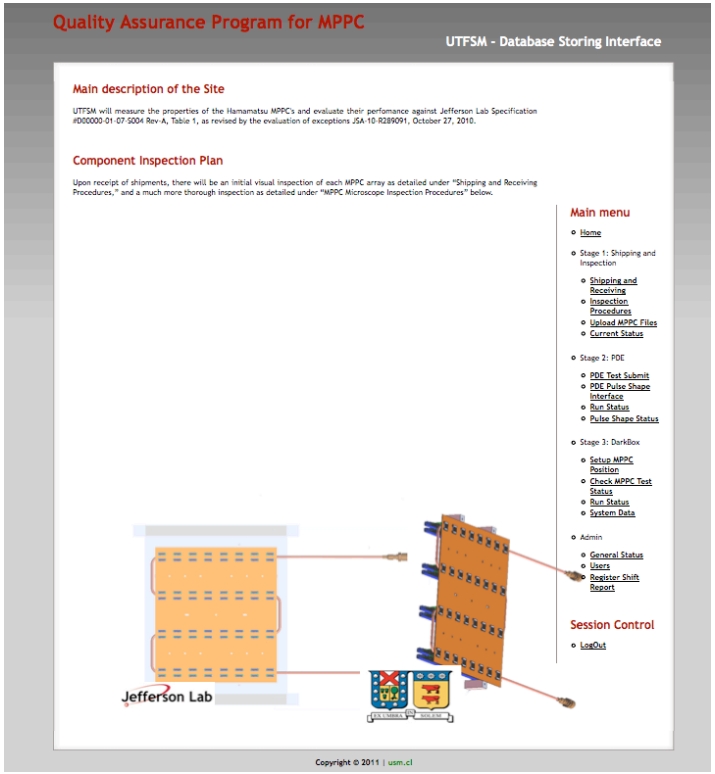
1-fiber input, 17-fiber output (16 to MPPC, 17th to monitor PMT

Blue LED feeding clear fiber



Archiving of SiPM parameters

- MySQL database with RAID backup
- Interfaces for each of the three stations for manual and automated entry of data
- Web interface



Data from database available via the web [here]

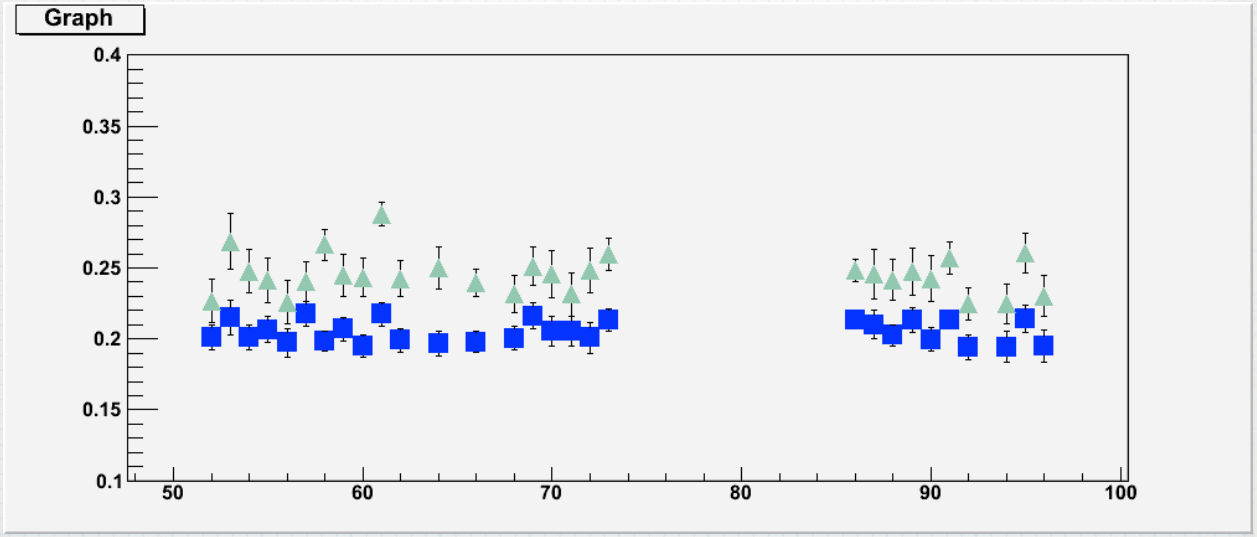
MAIN ELEMENTS OF COMMISSIONING PLAN

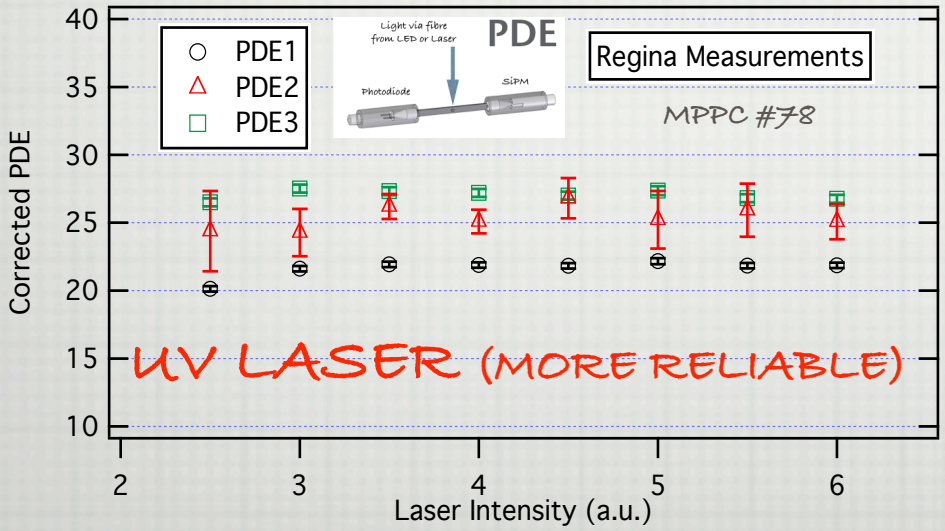
WE HAVE 30 MPPCS THAT JLAB HAS ALREADY MEASURED

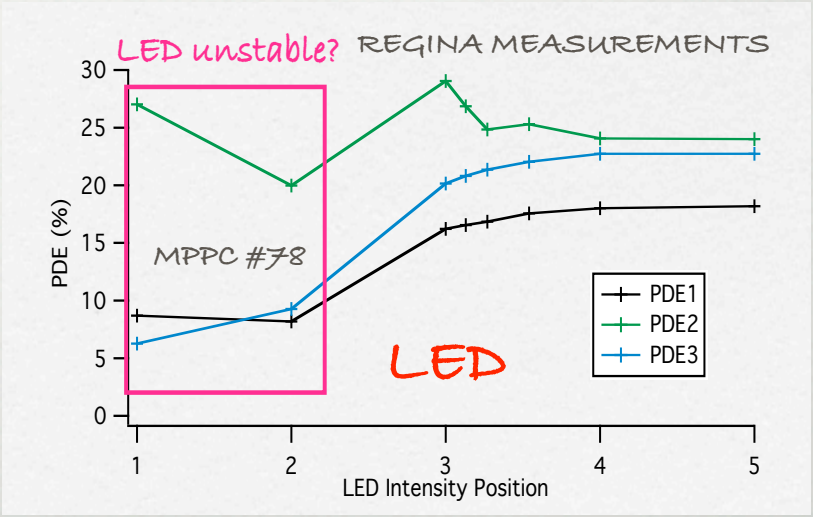
- ☐ MEASURE PDE IN STATION 2 FOR ALL 30 (DONE)
  - ☐ COMPARE WITH JLAB AND REGINA MEASUREMENTS (DONE, BUT STILL UNDER DISCUSSION)
- ☐ INSTALL THE SAME 30 MPPCS IN STATION 3
  - ☐ COMPARE WITH JLAB/HAMAMATSU MEASUREMENTS (DONE, UNDER DISCUSSION)
  - ☐ DETERMINE LIGHT INTENSITY PATTERN (FIRST PASS ATTEMPTED, MORE WORK NEEDED)
  - ☐ PERFORM CROSS-CHECKS (E.G., CHANNEL MAPPING), FIXING PROBLEM CHANNELS, CHECKING AMPLIFIER GAINS, CHECKING QDC CALIBRATION, ETC

JLAB & USM

* PDE for 29 MPPCs △-USM ■-JLAB



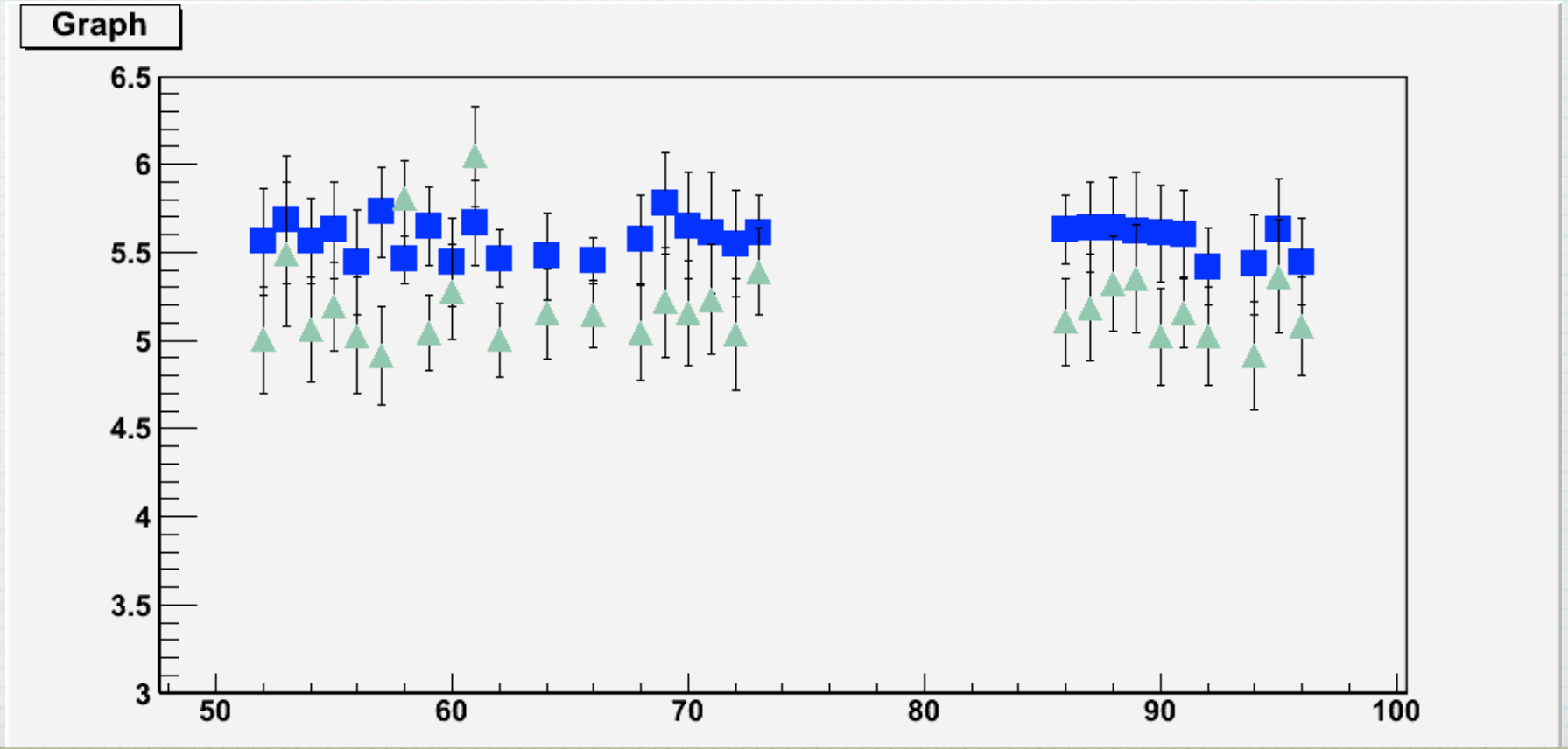


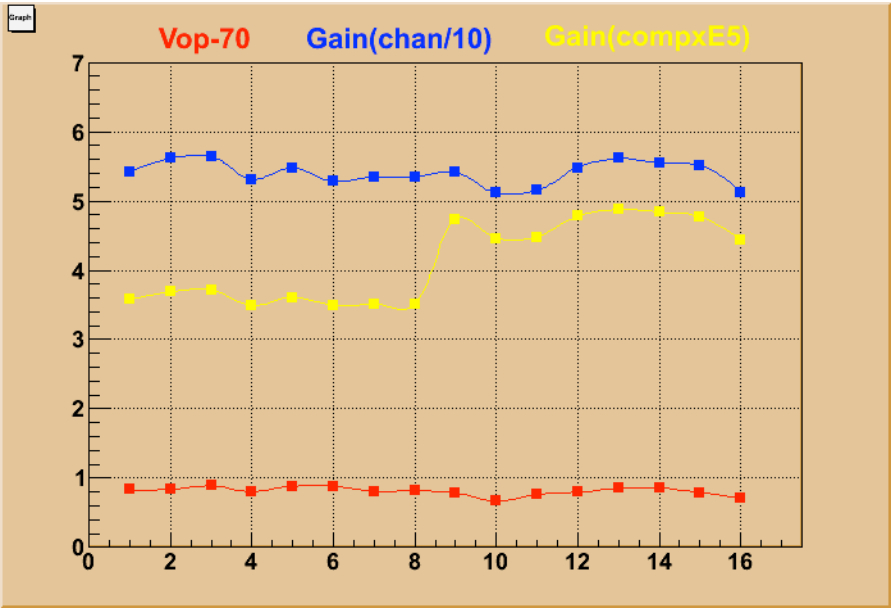


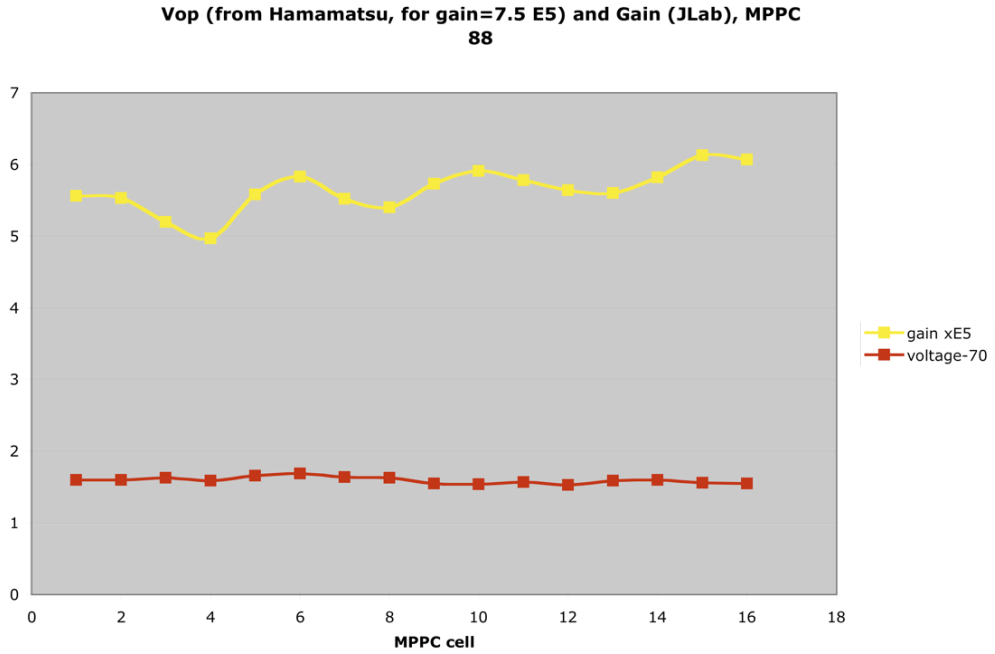
JLAB & USM

RESULTS FROM STATION 2

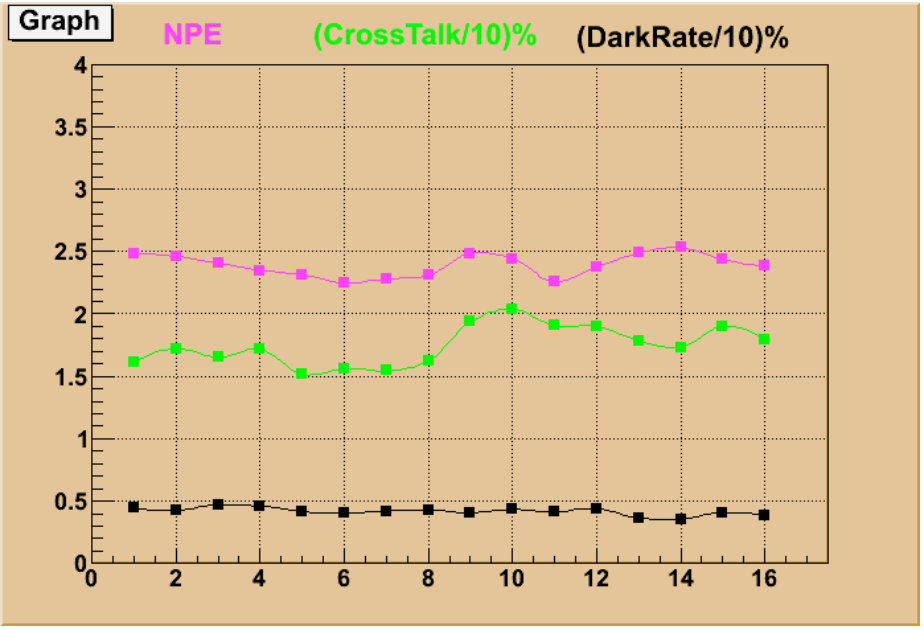
* Gain for 29 MPPCs ▲ -USM ■ - JLAB

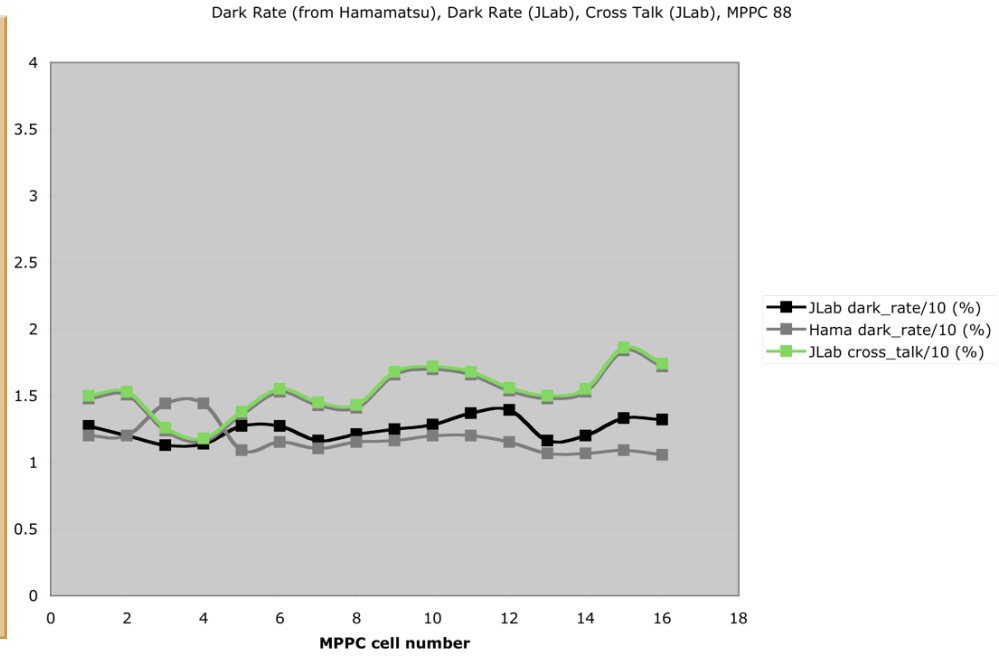


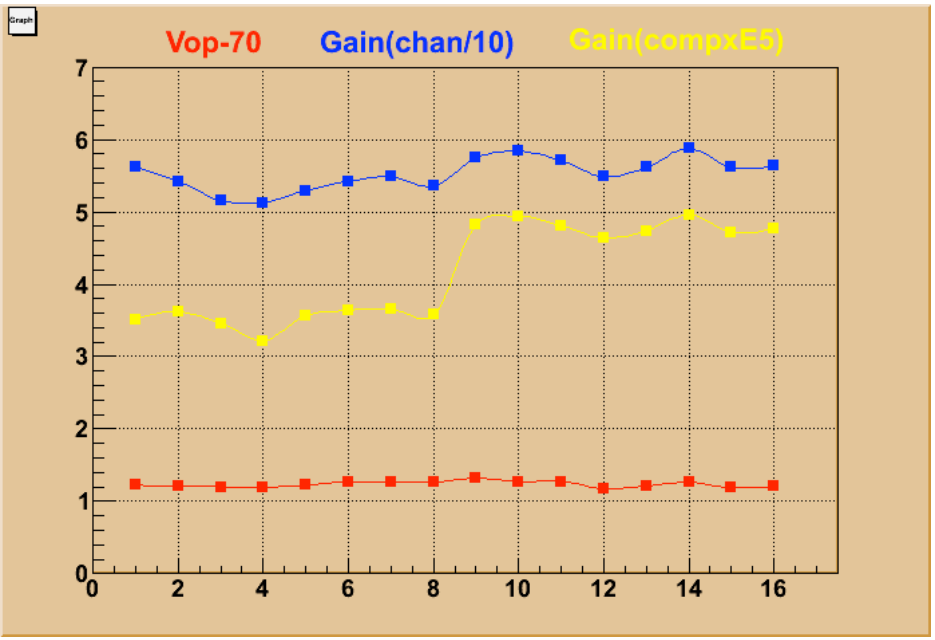

Vop-70
Gain(chan/10)
Gain(compxE5)

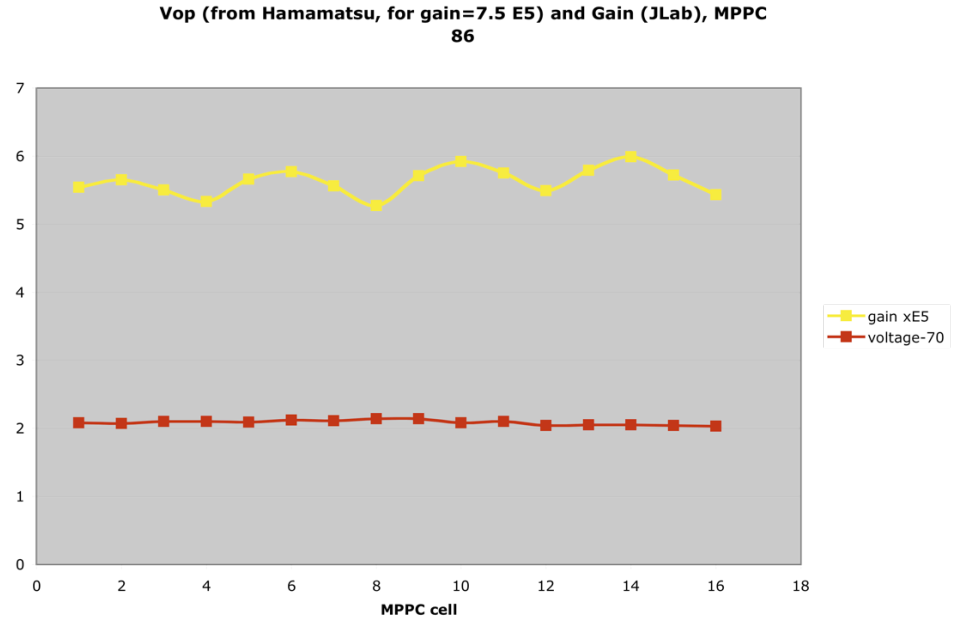

Vop (from Hamamatsu, for gain=7.5 E5) and Gain (JLab), MPPC 88
gain xE5
voltage-70
MPPC cell

20℃

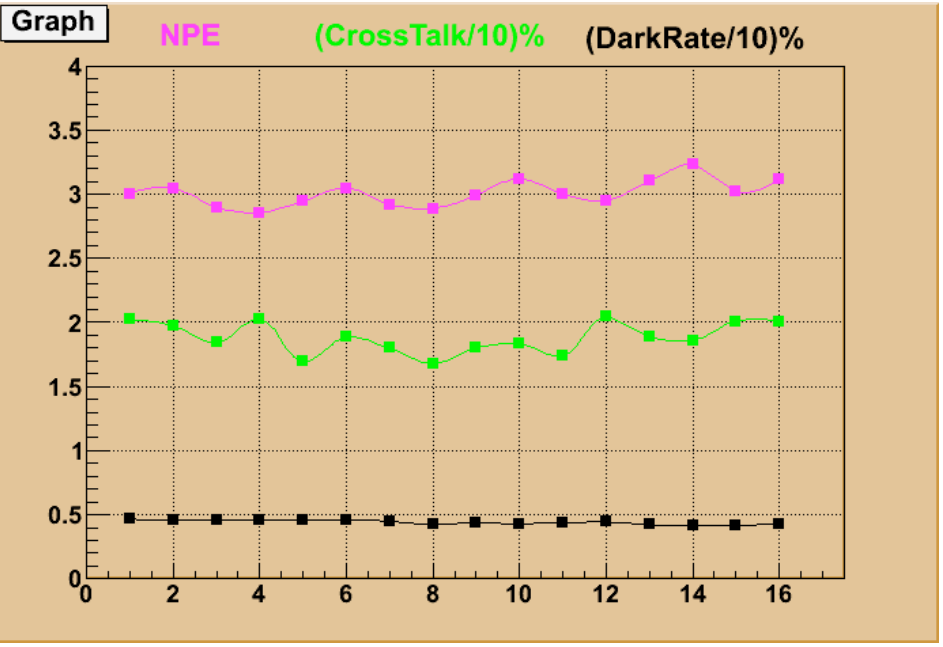

Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

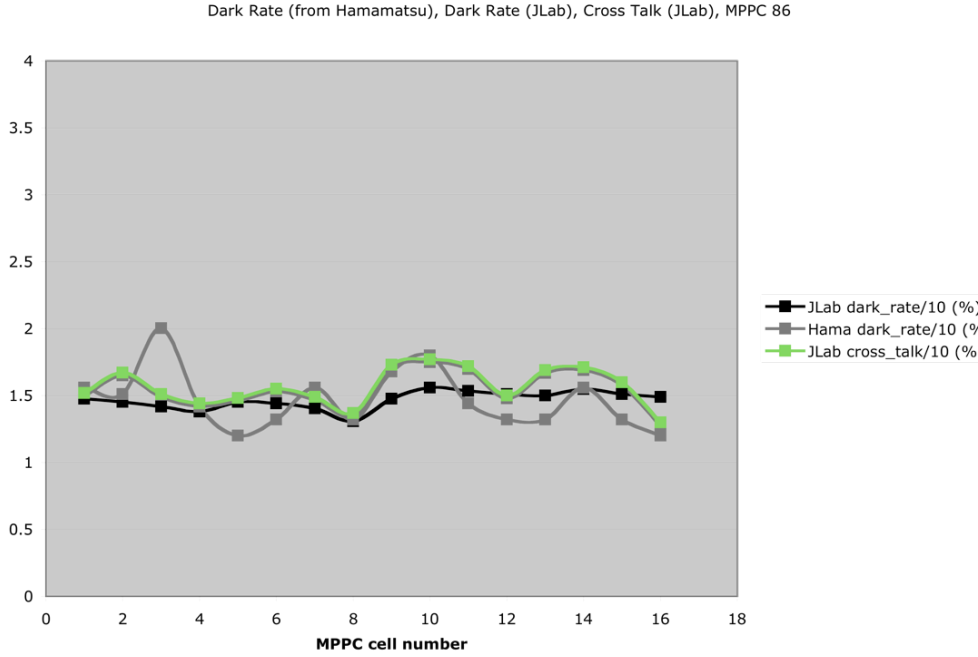

Dark Rate (from Hamamatsu), Dark Rate (JLab), Cross Talk (JLab), MPPC 88
JLab dark_rate/10 (%)
Hama dark_rate/10 (%)
JLab cross_talk/10 (%)
MPPC cell number

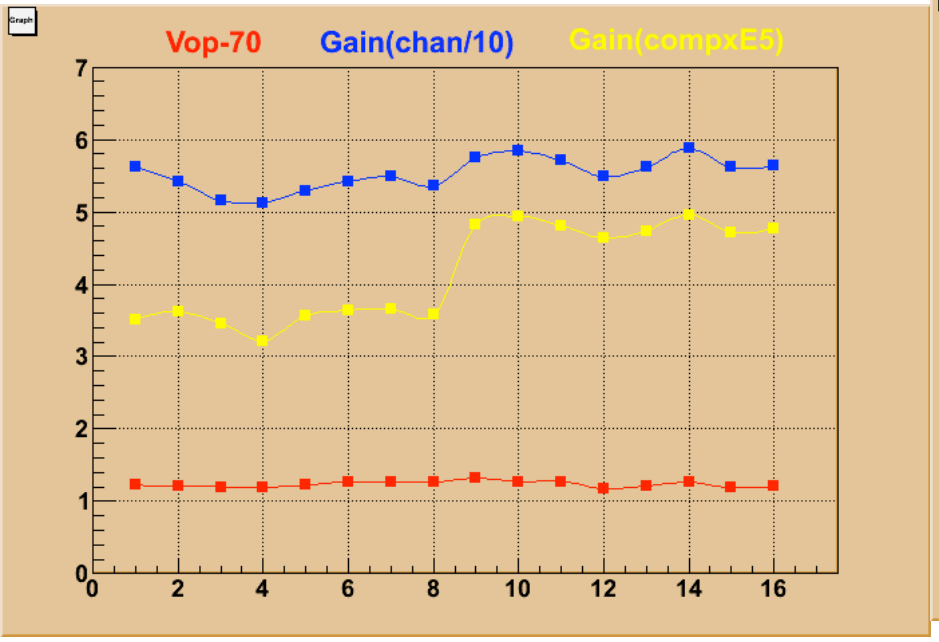

Graph
Vop-70
Gain(chan/10)
Gain(compxE5)


Vop (from Hamamatsu, for gain=7.5 E5) and Gain (JLab), MPPC 86
gain xE5
voltage-70
MPPC cell

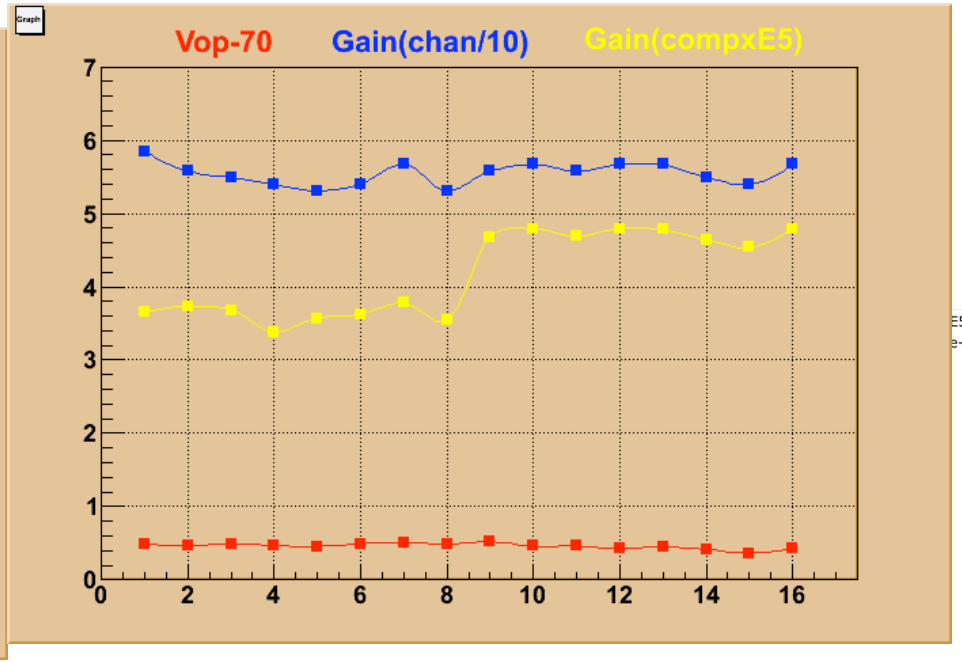
20℃


Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

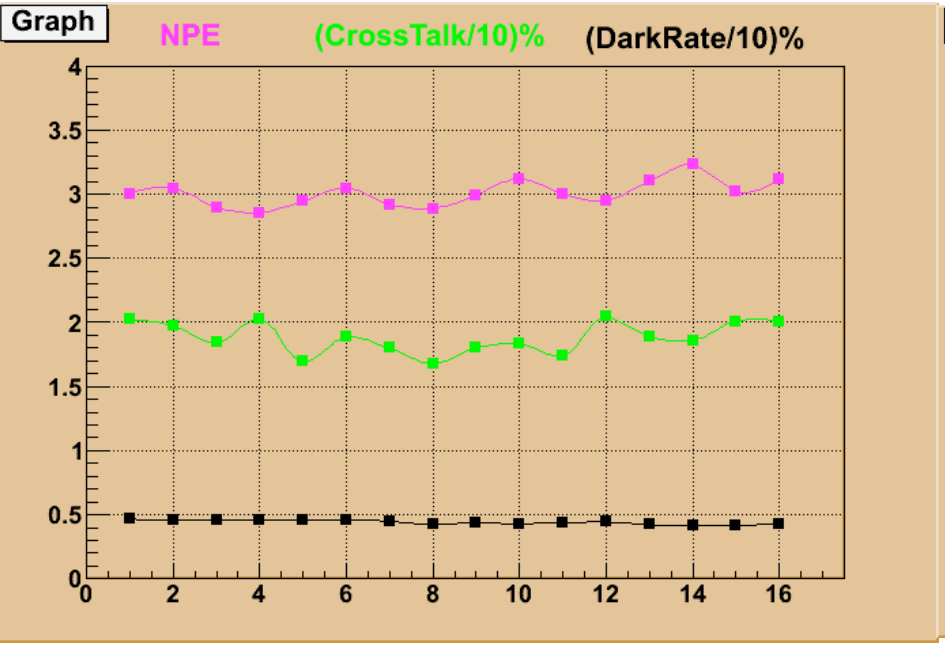

Dark Rate (from Hamamatsu), Dark Rate (JLab), Cross Talk (JLab), MPPC 86
JLab dark_rate/10 (%)
Hama dark_rate/10 (%
JLab cross_talk/10 (%
MPPC cell number

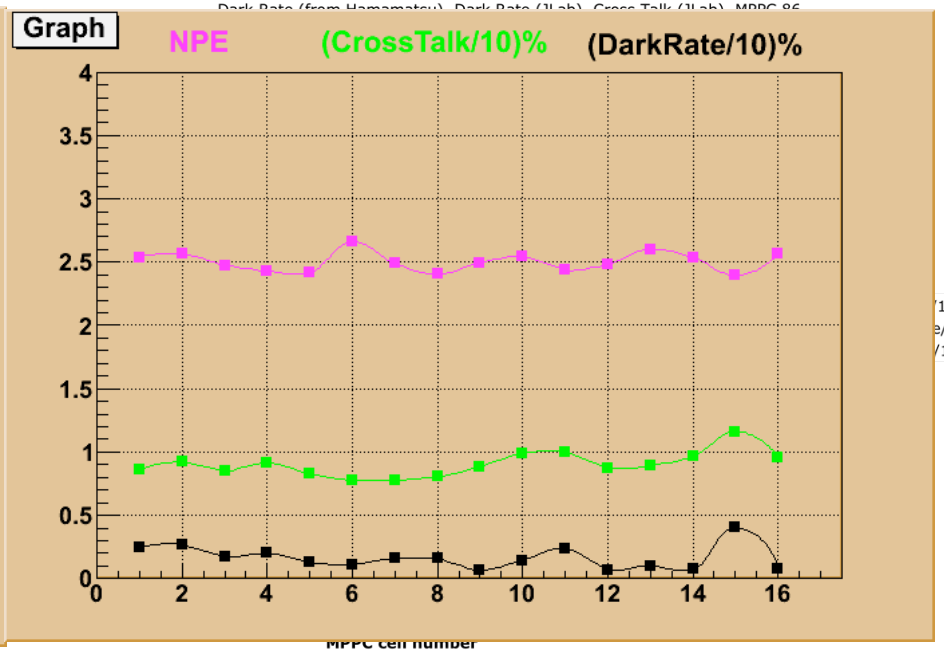

Graph
Vop-70
Gain(chan/10)
Gain(compxE5)

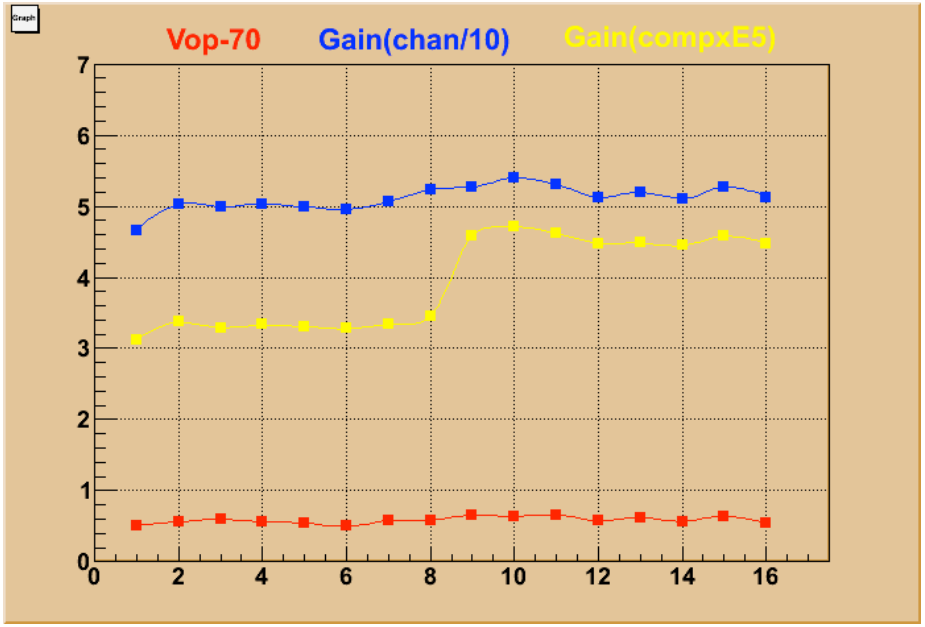
20℃

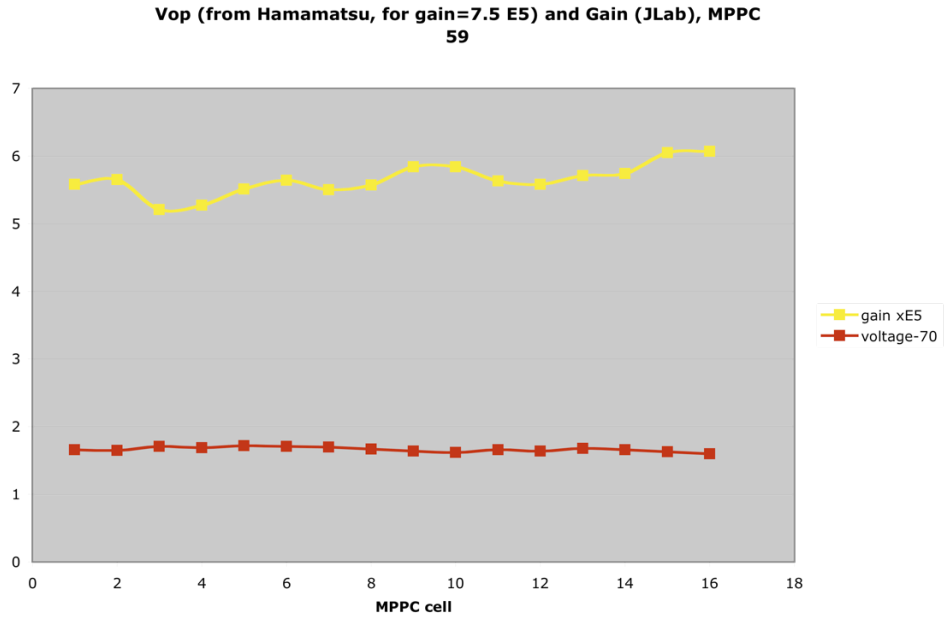

Graph
Vop-70
Gain(chan/10)
Gain(compxE5)

5℃

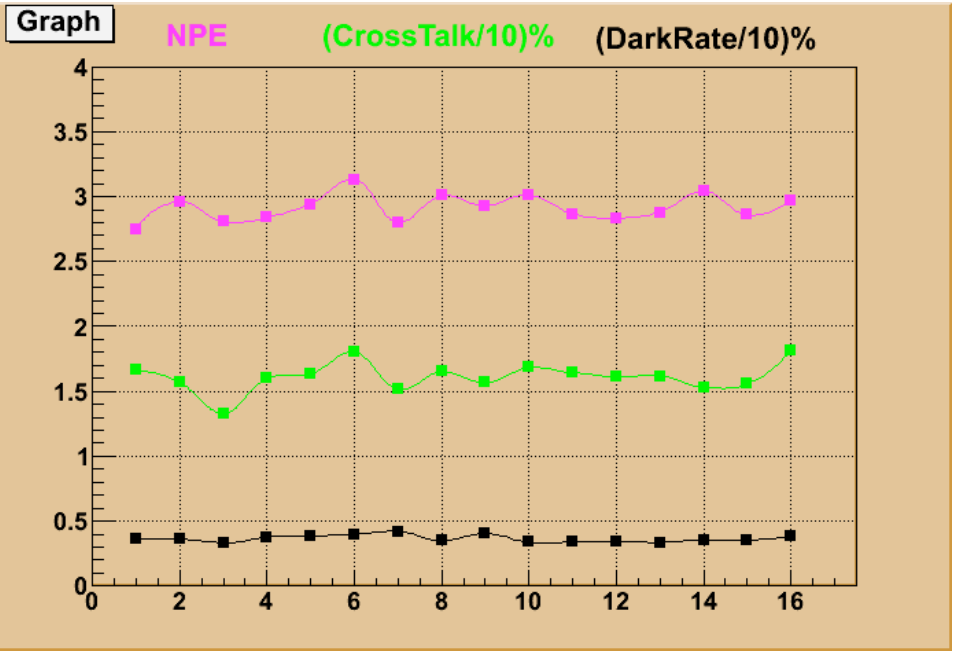

Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

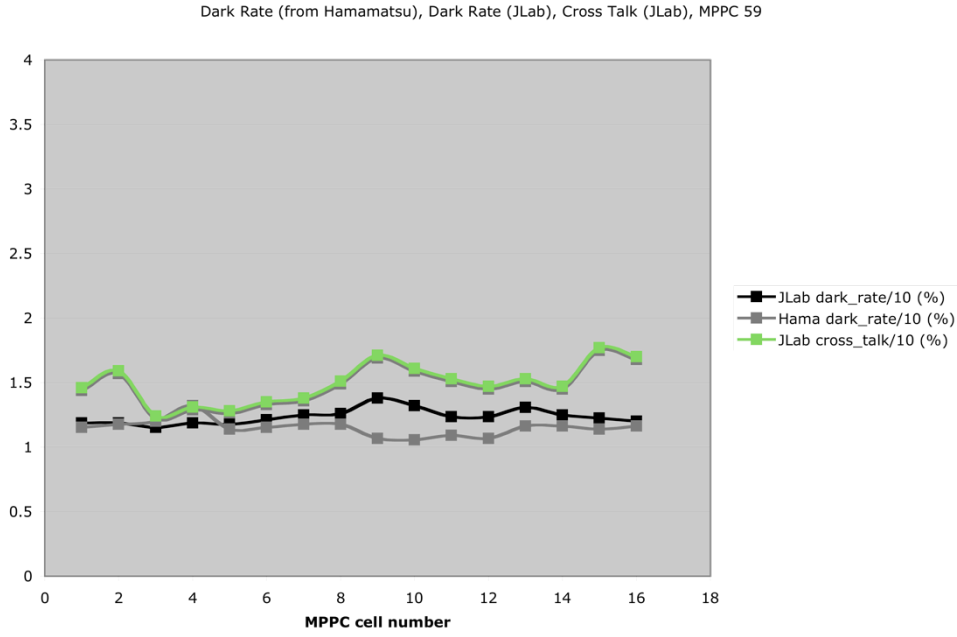

Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

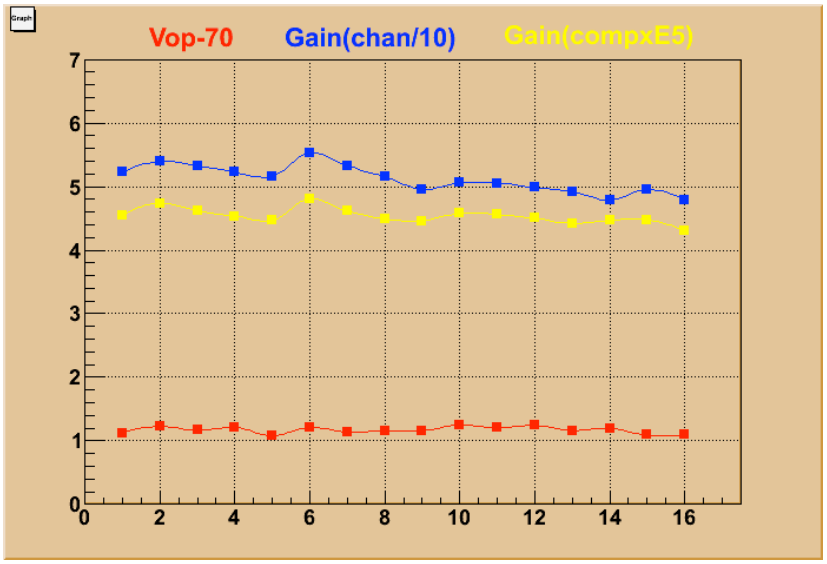

Vop-70
Gain(chan/10)
Gain(compxE5)

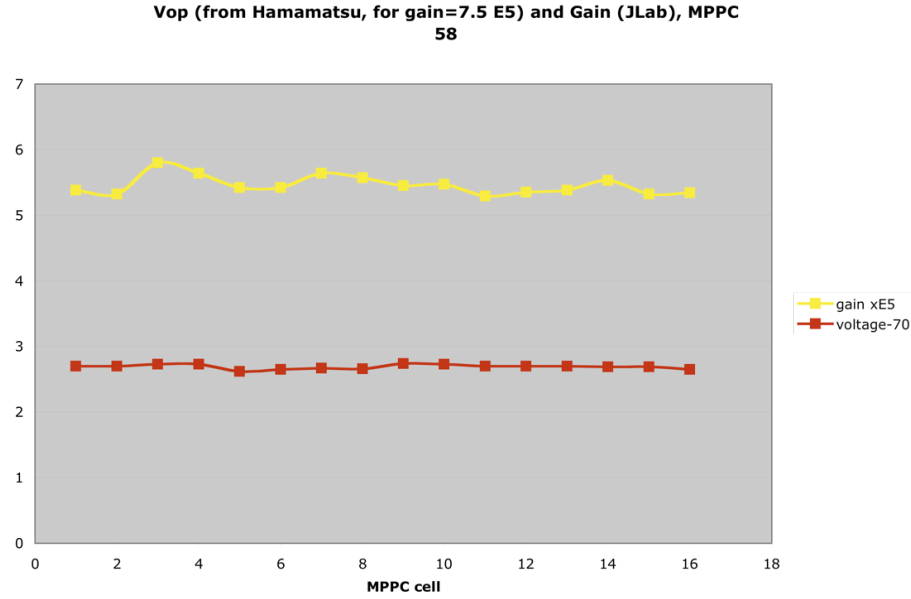

Vop (from Hamamatsu, for gain=7.5 E5) and Gain (JLab), MPPC 59
gain xE5
voltage-70
MPPC cell

20℃

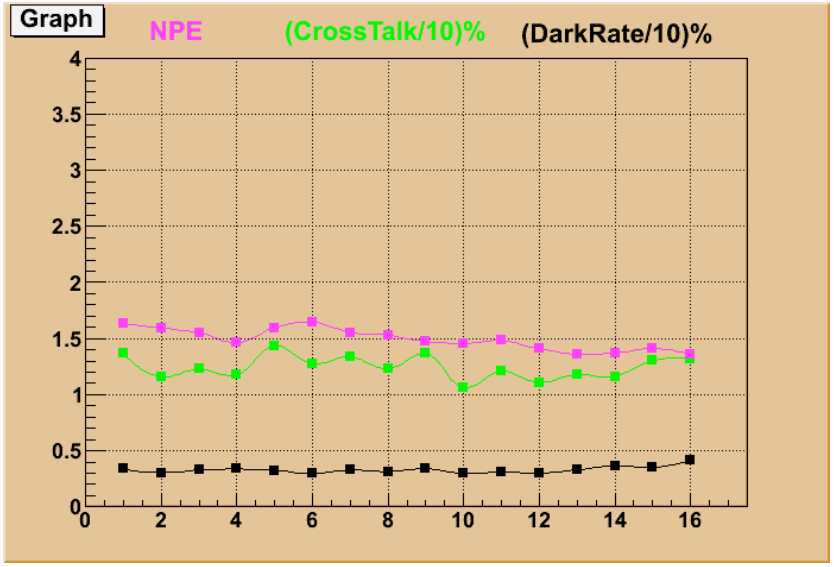

Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

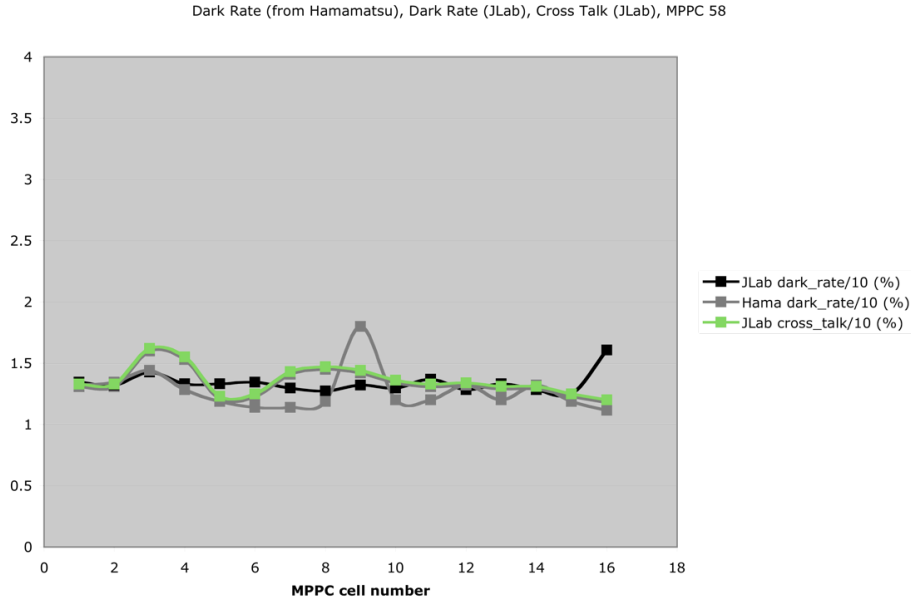

Dark Rate (from Hamamatsu), Dark Rate (JLab), Cross Talk (JLab), MPPC 59
JLab dark_rate/10 (%)
Hama dark_rate/10 (%)
JLab cross_talk/10 (%)
MPPC cell number

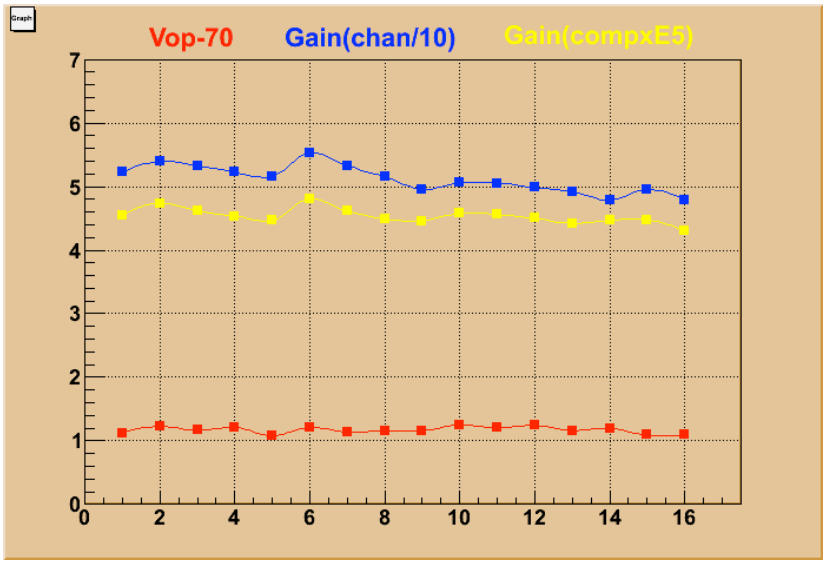

Graph
Vop-70
Gain(chan/10)
Gain(compxE5)

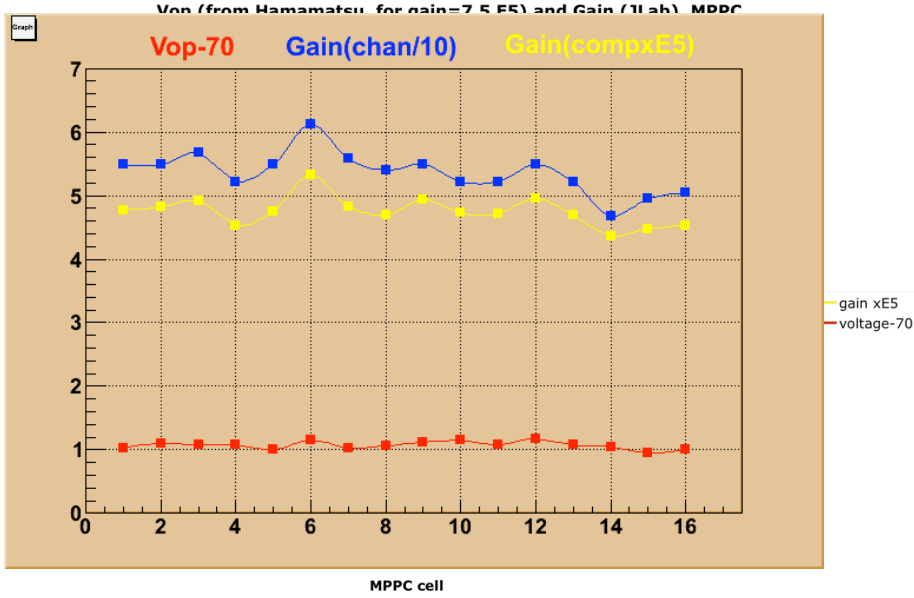

Vop (from Hamamatsu, for gain=7.5 E5) and Gain (JLab), MPPC 58
gain xE5
voltage-70
MPPC cell

20℃


Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

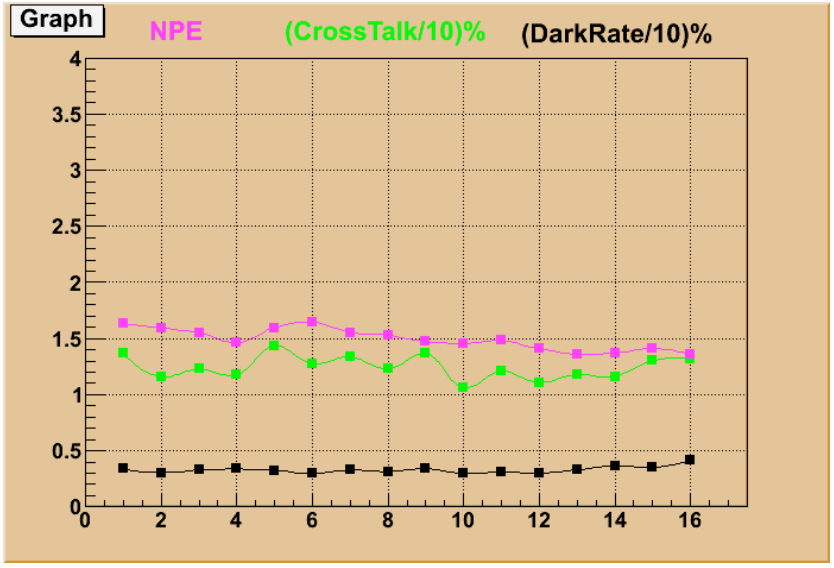

Dark Rate (from Hamamatsu), Dark Rate (JLab), Cross Talk (JLab), MPPC 58
JLab dark_rate/10 (%)
Hama dark_rate/10 (%)
JLab cross_talk/10 (%)
MPPC cell number

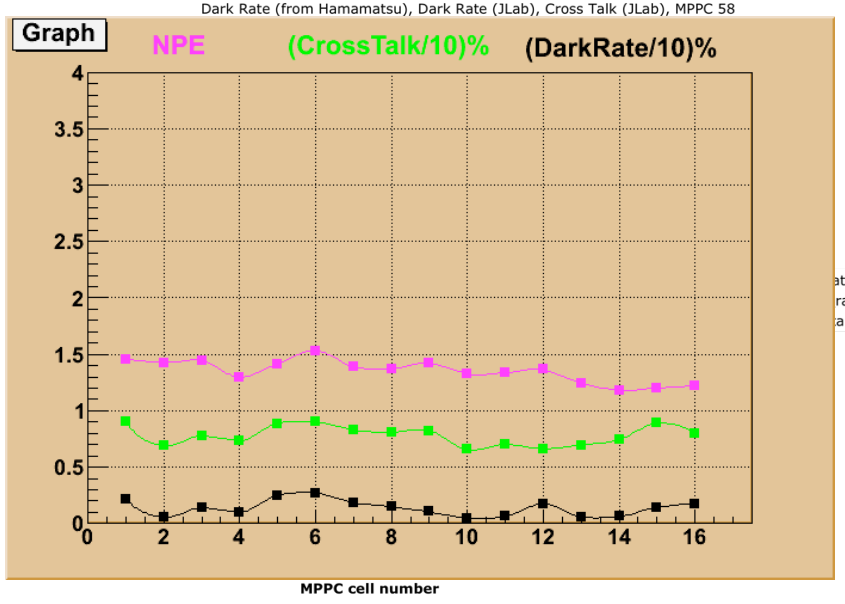

Vop-70
Gain(chan/10)
Gain(compxE5)

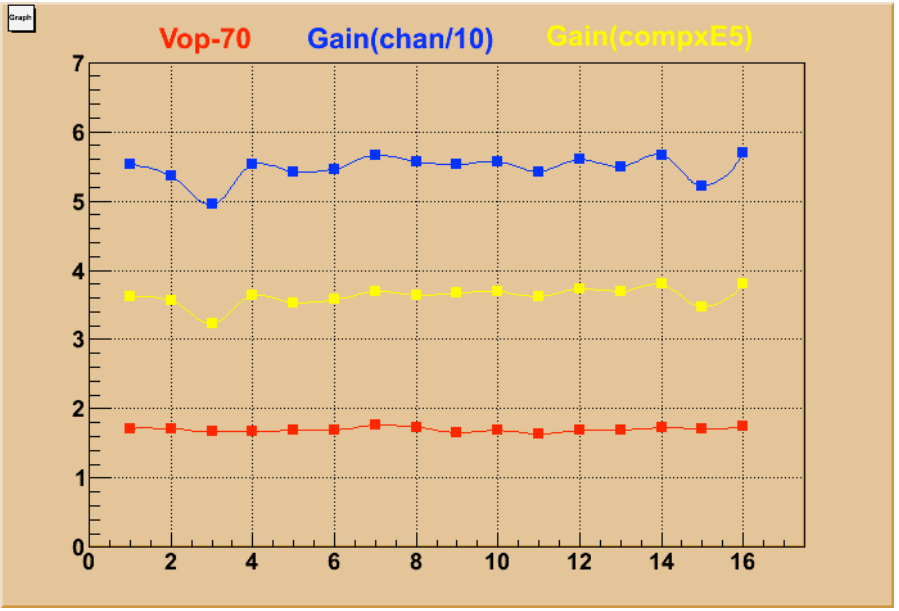

Vop-70
Gain(chan/10)
Gain(compxE5)
gain xE5
voltage-70
MPPC cell

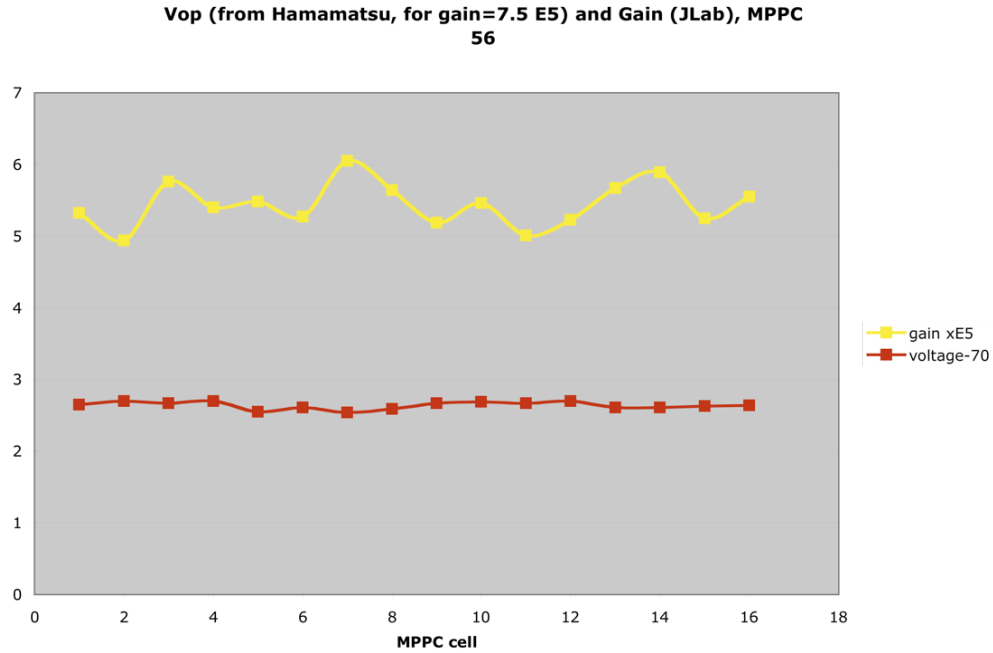
20℃

5℃

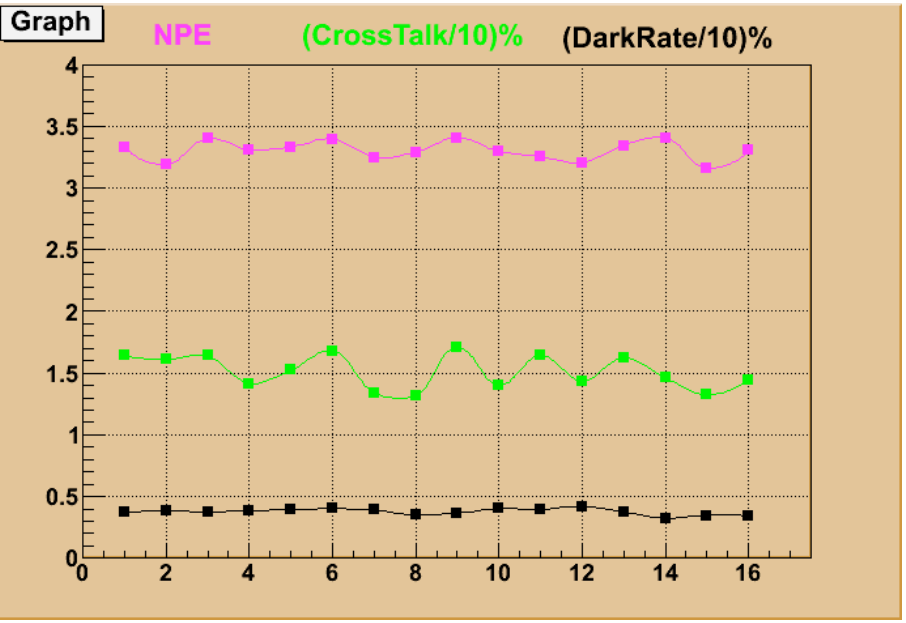

Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

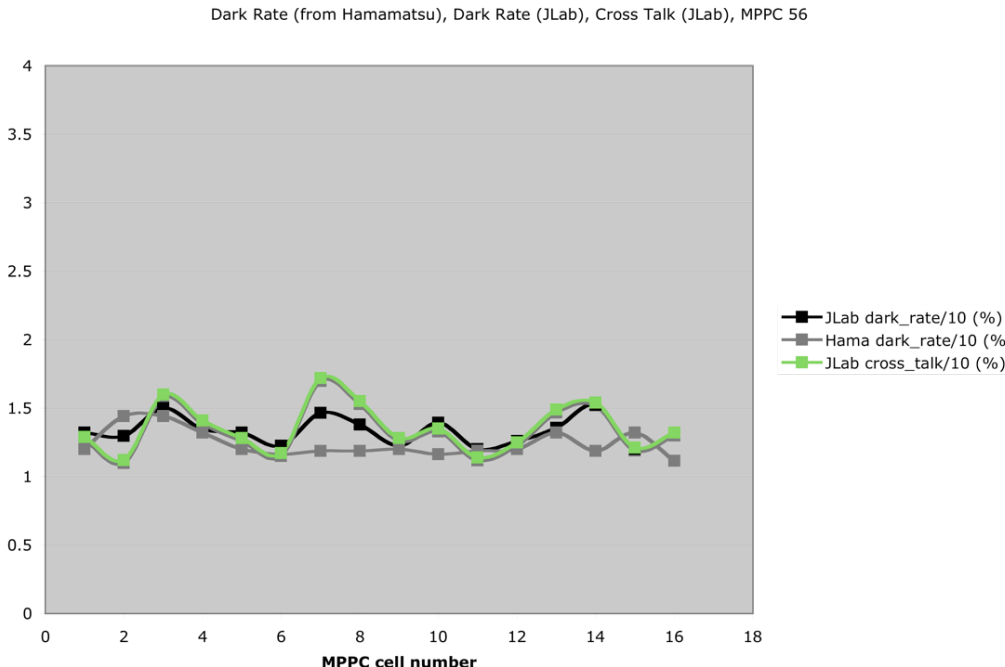

Dark Rate (from Hamamatsu), Dark Rate (JLab), Cross Talk (JLab), MPPC 58
Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%
MPPC cell number

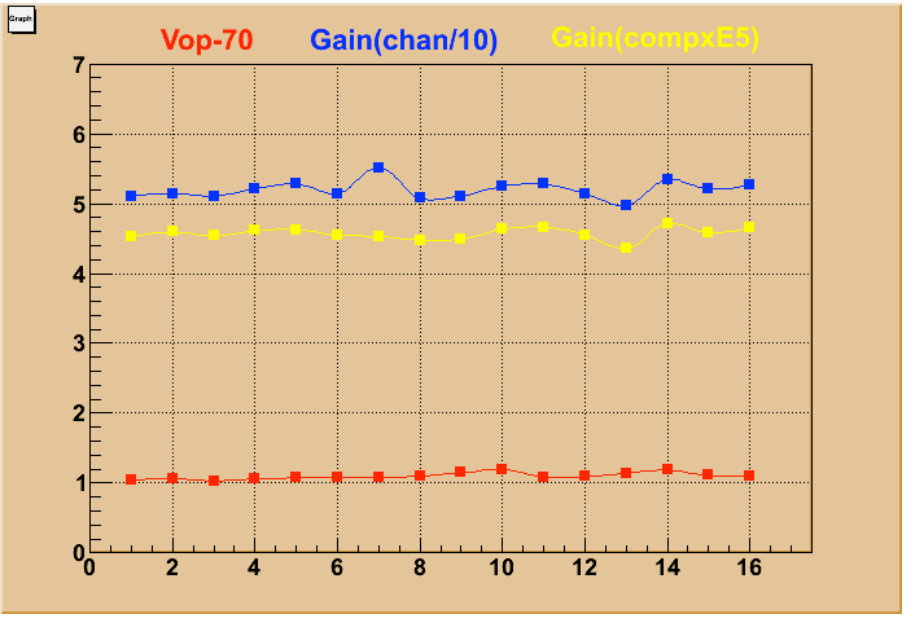

Vop-70
Gain(chan/10)
Gain(compxE5)

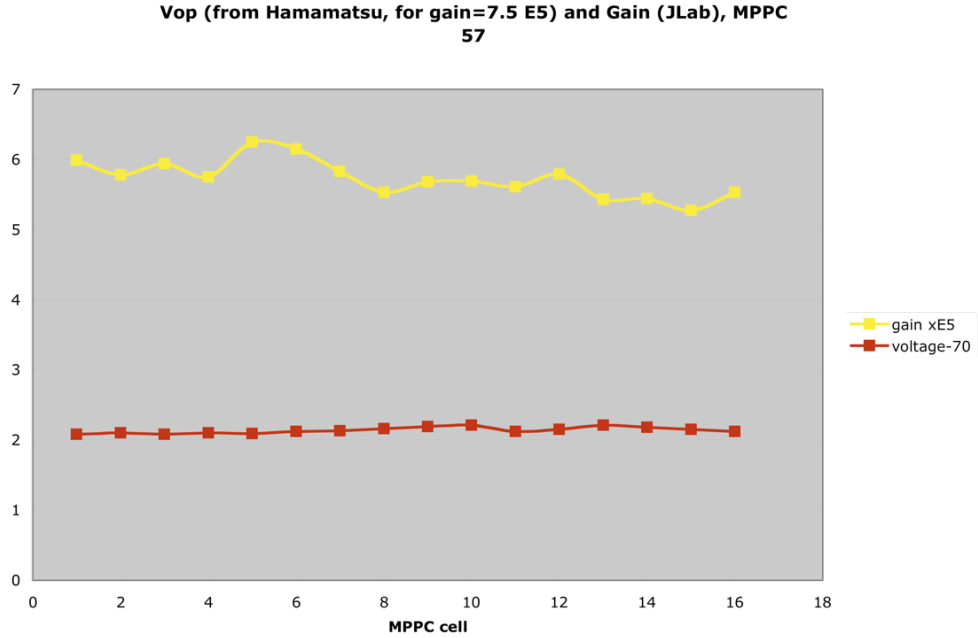

Vop (from Hamamatsu, for gain=7.5 E5) and Gain (JLab), MPPC 56
gain xE5
voltage-70
MPPC cell

20℃

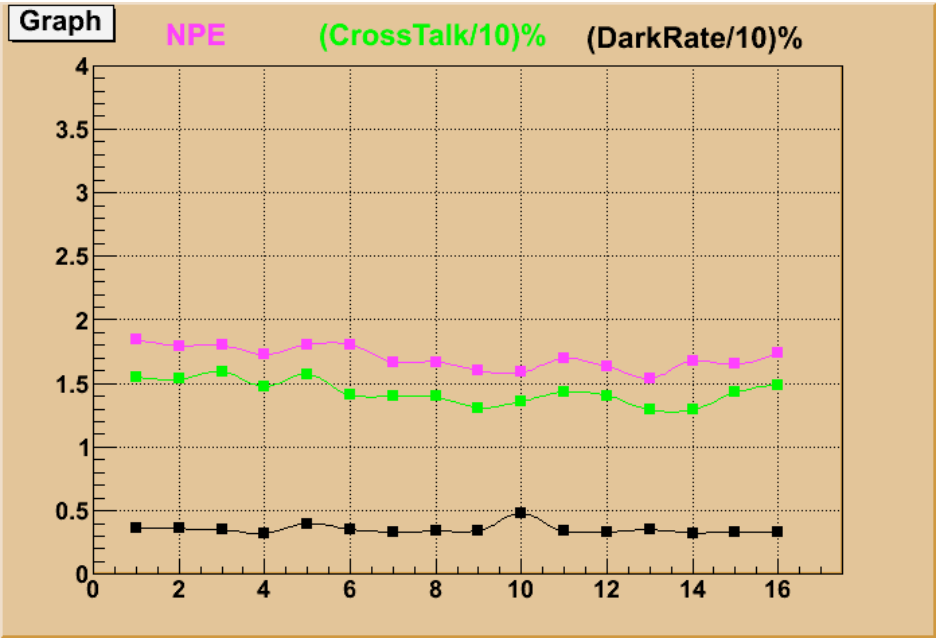

Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

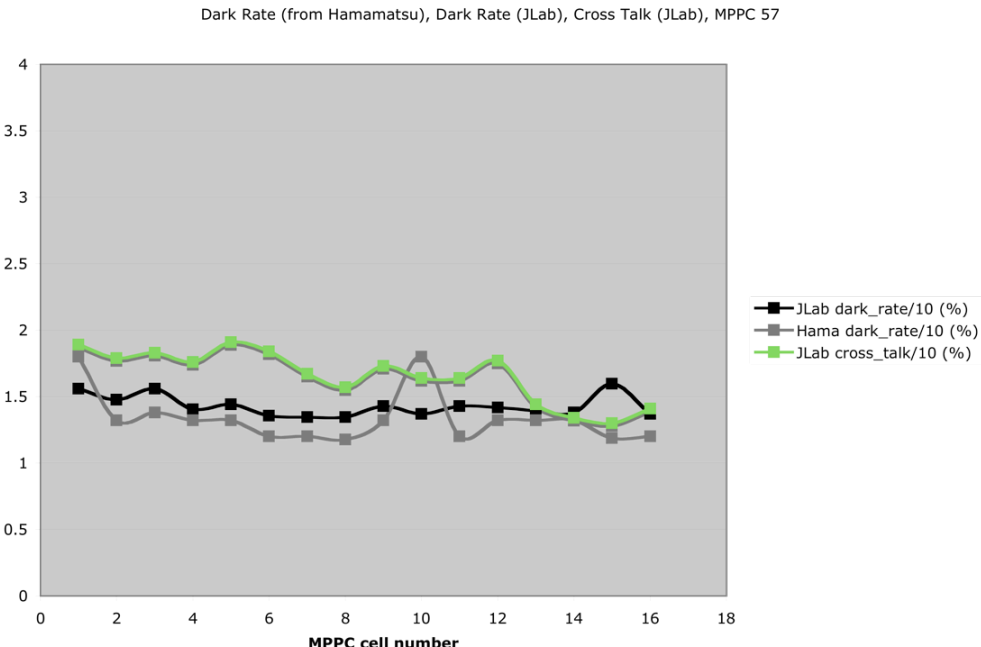

Dark Rate (from Hamamatsu), Dark Rate (JLab), Cross Talk (JLab), MPPC 56
JLab dark_rate/10 (%)
Hama dark_rate/10 (%
JLab cross_talk/10 (%)
MPPC cell number


Vop-70
Gain(chan/10)
Gain(compxE5)

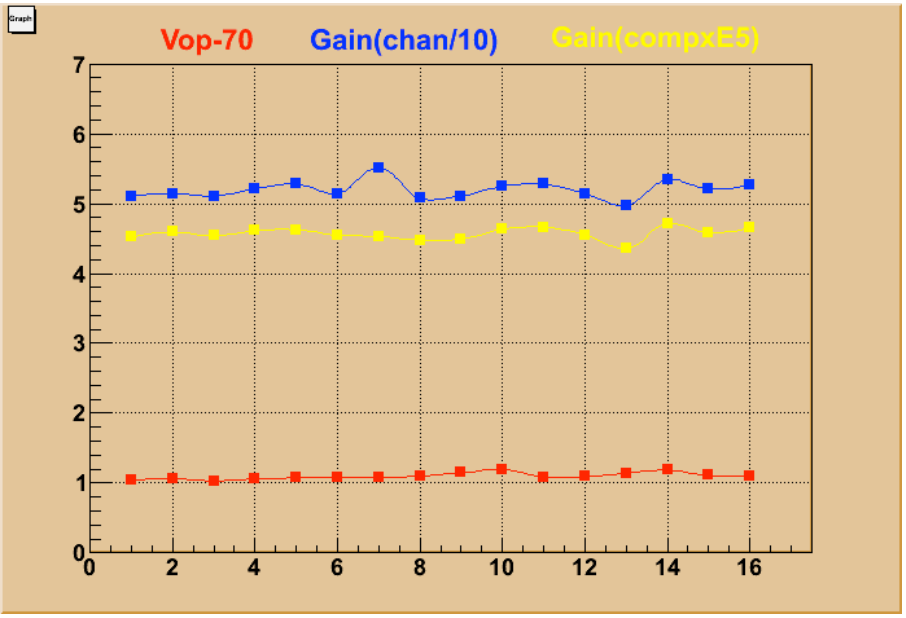

Vop (from Hamamatsu, for gain=7.5 E5) and Gain (JLab), MPPC 57
gain xE5
voltage-70
MPPC cell

20℃

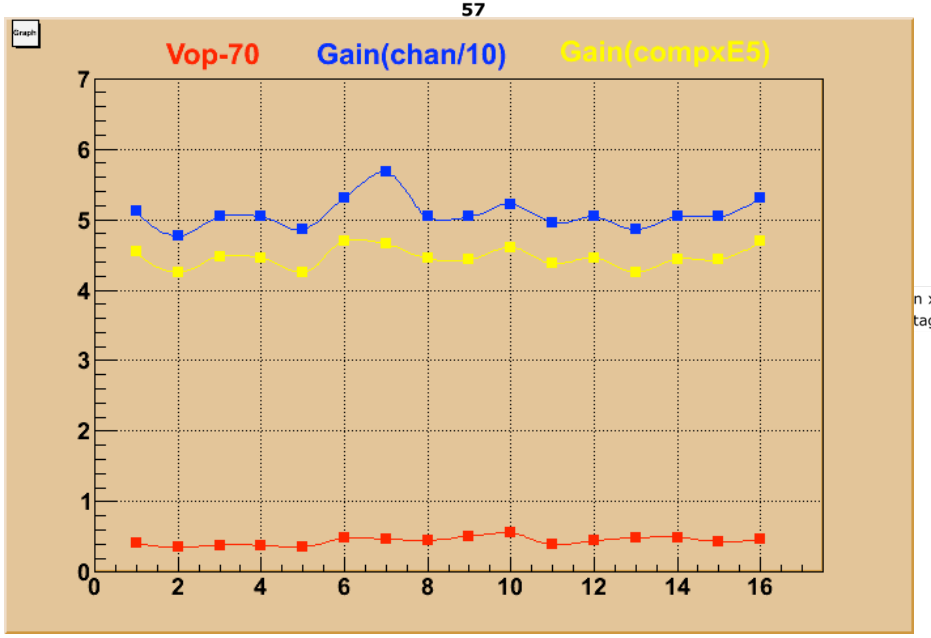

Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%


Dark Rate (from Hamamatsu), Dark Rate (JLab), Cross Talk (JLab), MPPC 57
JLab dark_rate/10 (%)
Hama dark_rate/10 (%)
JLab cross_talk/10 (%)
MPPC cell number

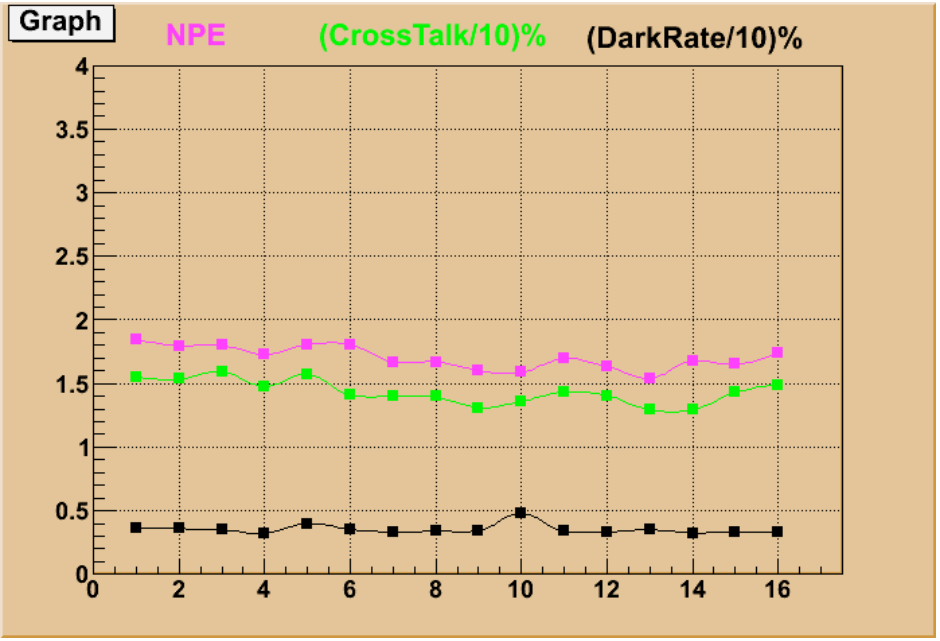
Vop (from Hamamatsu, for gain=7.5 E5) and Gain (JLab), MPPC 57

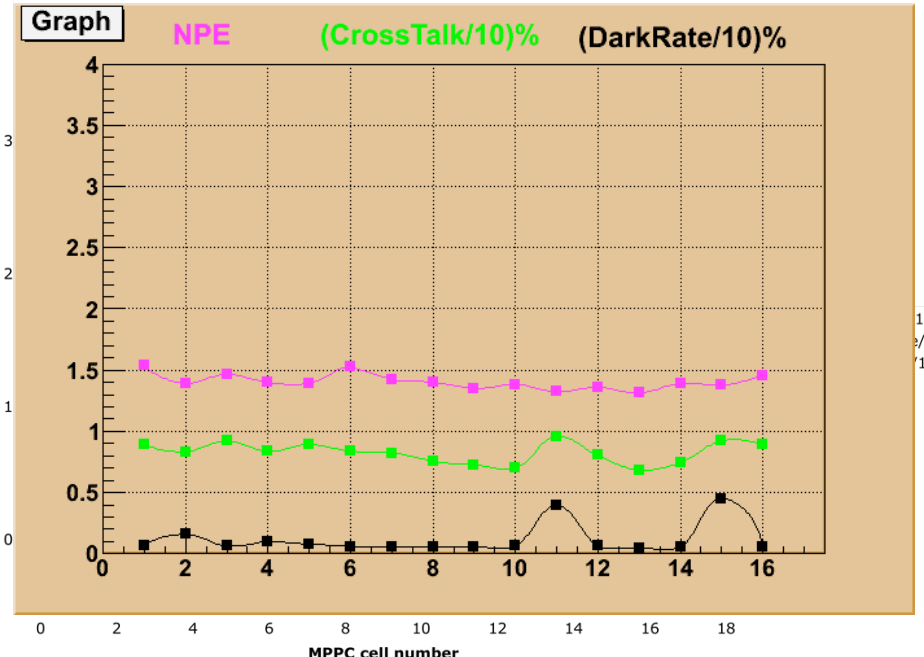


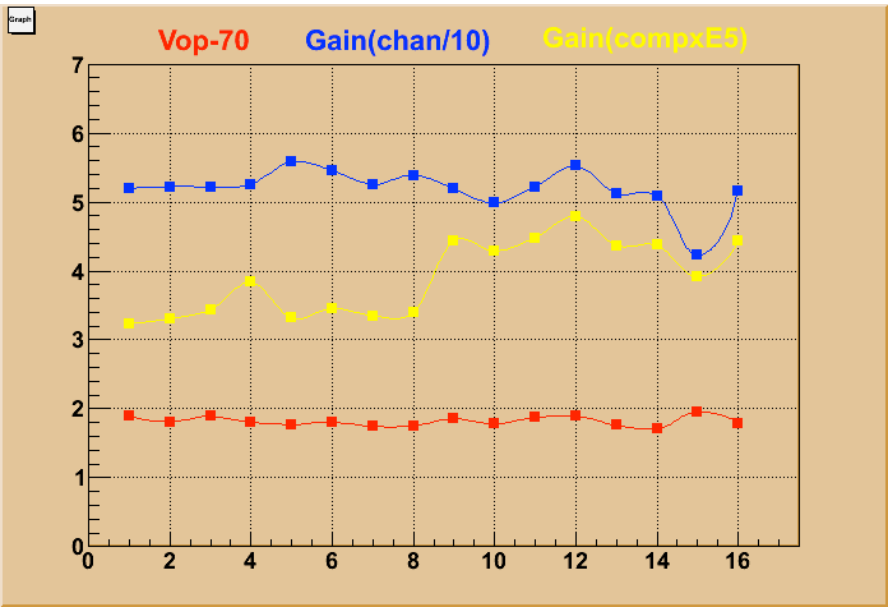
20℃

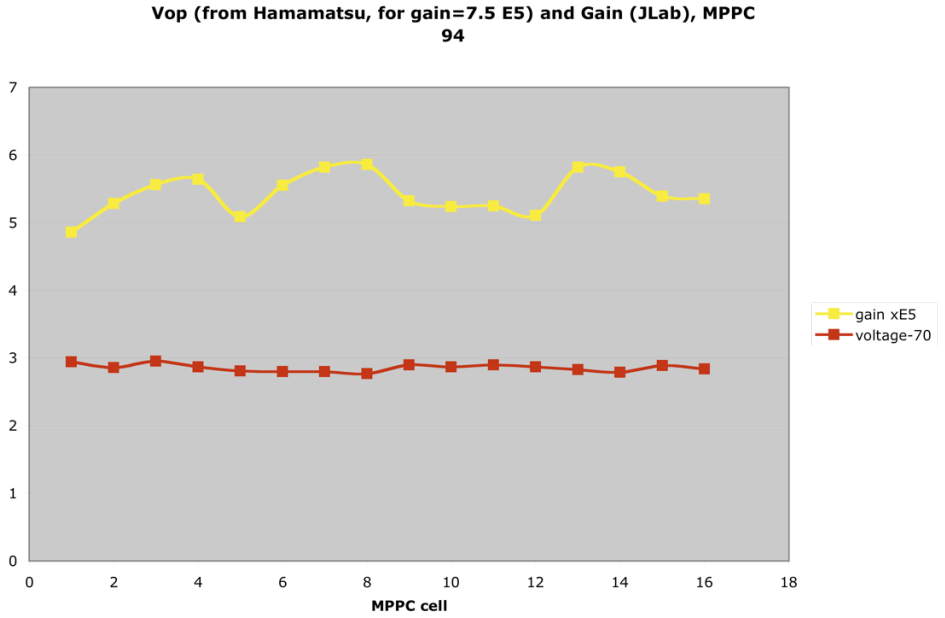


5℃

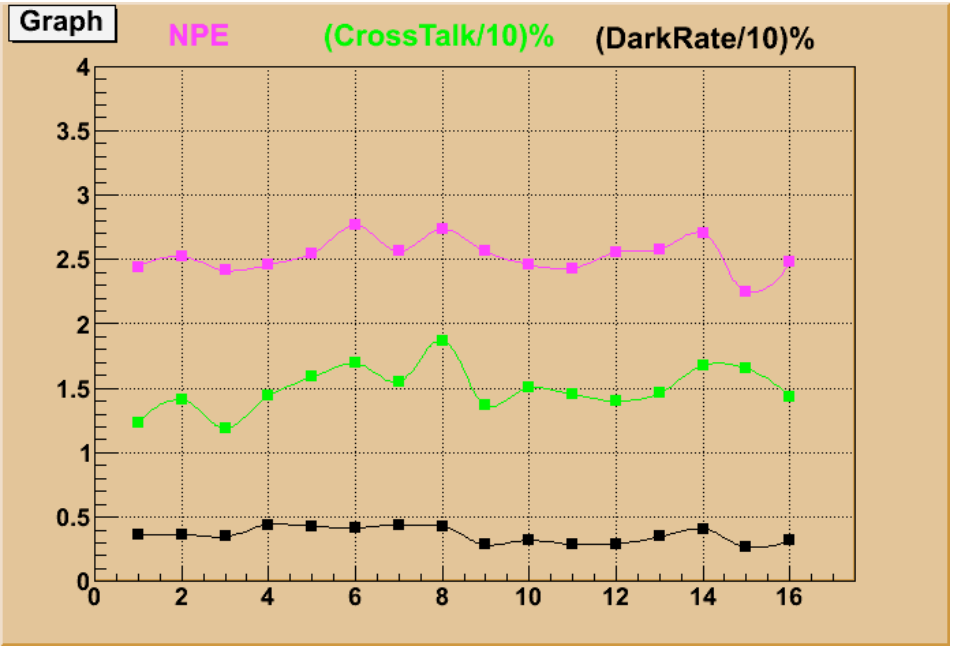


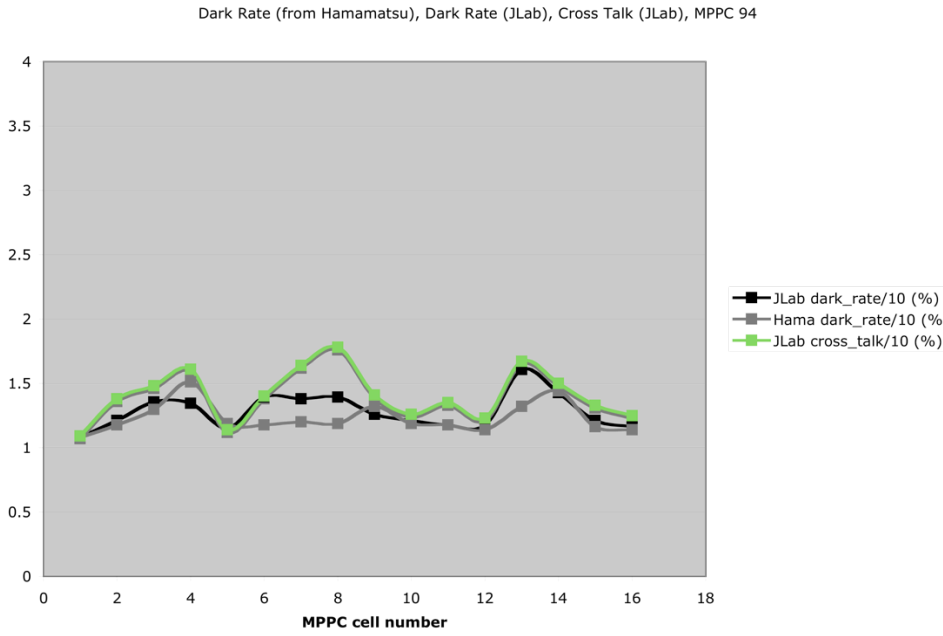


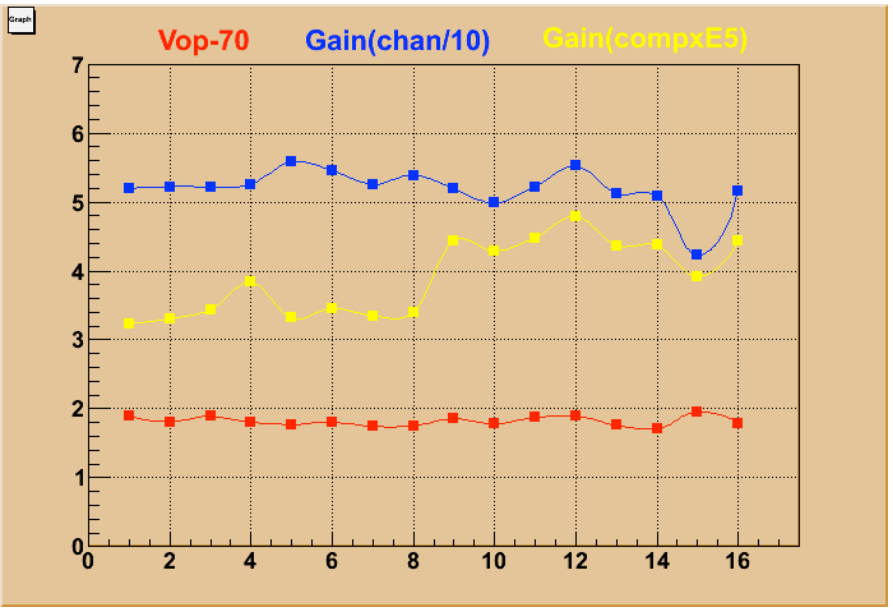

Vop-70
Gain(chan/10)
Gain(compxE5)

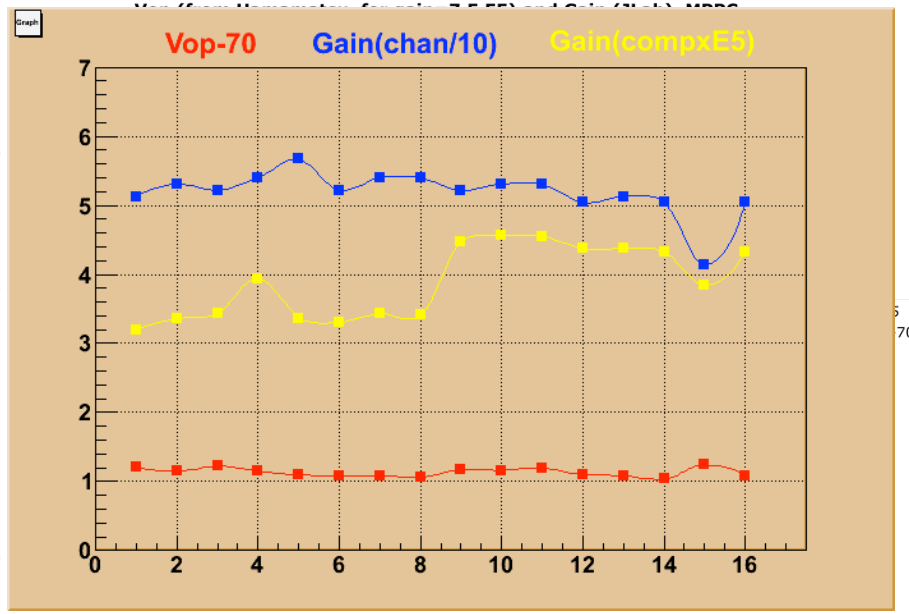

Vop (from Hamamatsu, for gain=7.5 E5) and Gain (JLab), MPPC 94
gain xE5
voltage-70
MPPC cell

20℃


Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

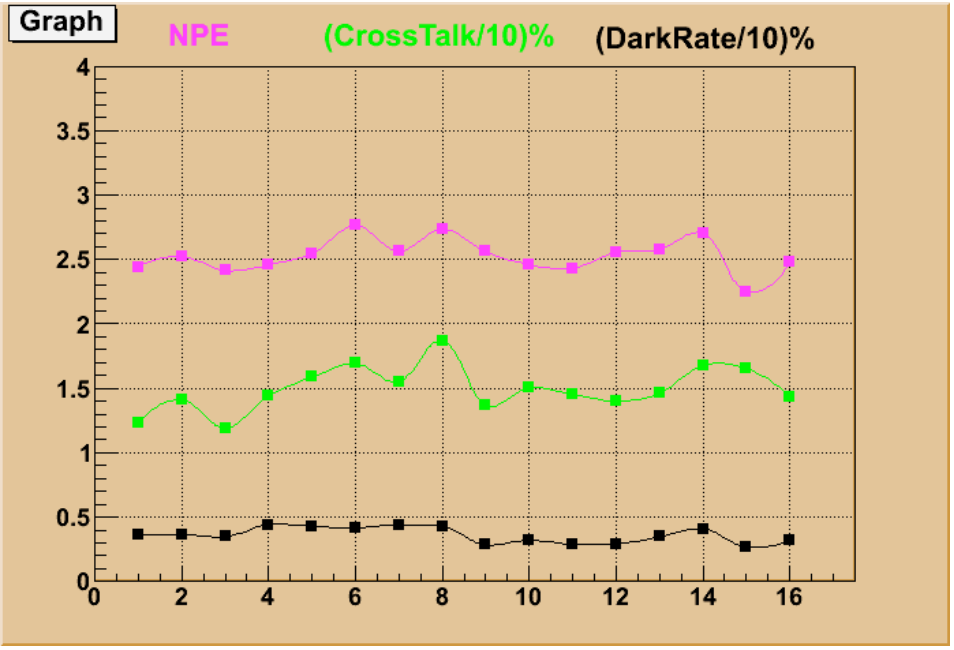

Dark Rate (from Hamamatsu), Dark Rate (JLab), Cross Talk (JLab), MPPC 94
JLab dark_rate/10 (%)
Hama dark_rate/10 (%
JLab cross_talk/10 (%)
MPPC cell number

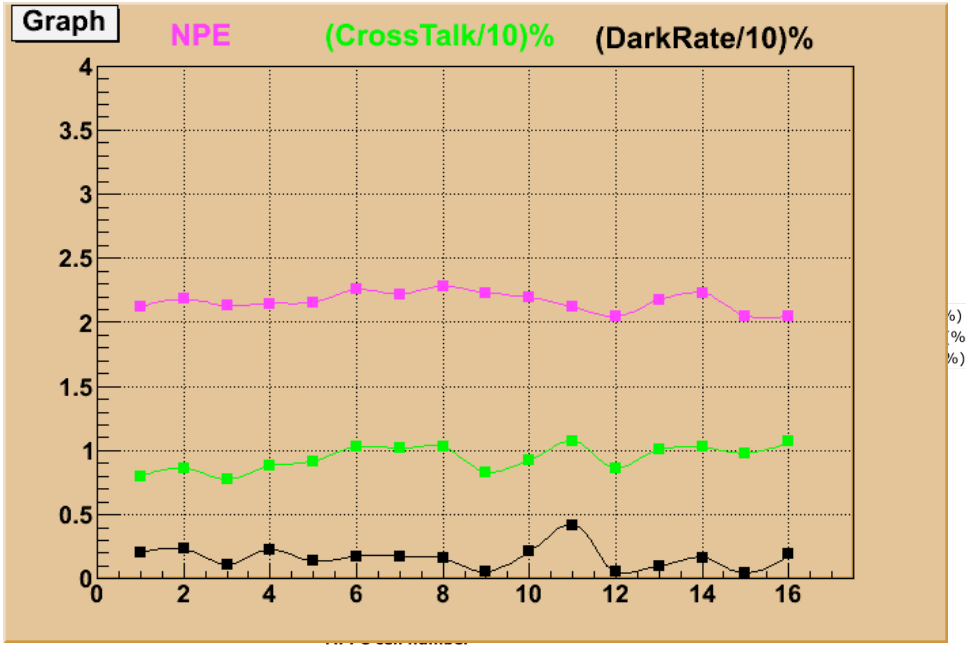

Vop-70
Gain(chan/10)
Gain(compxE5)


Vop-70
Gain(chan/10)
Gain(compxE5)

20℃

5℃


Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

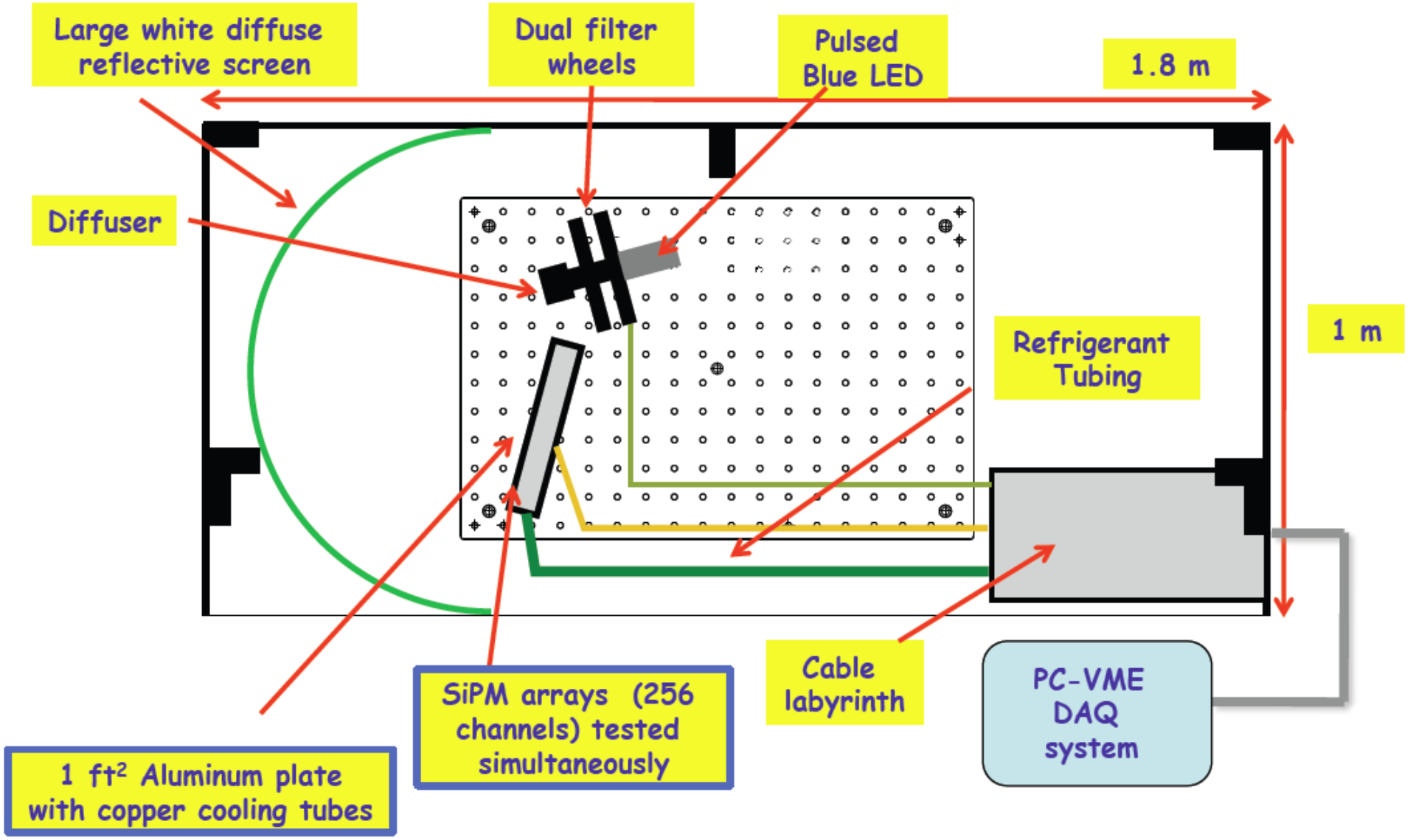

Graph
NPE
(CrossTalk/10)%
(DarkRate/10)%

OBSERVATIONS

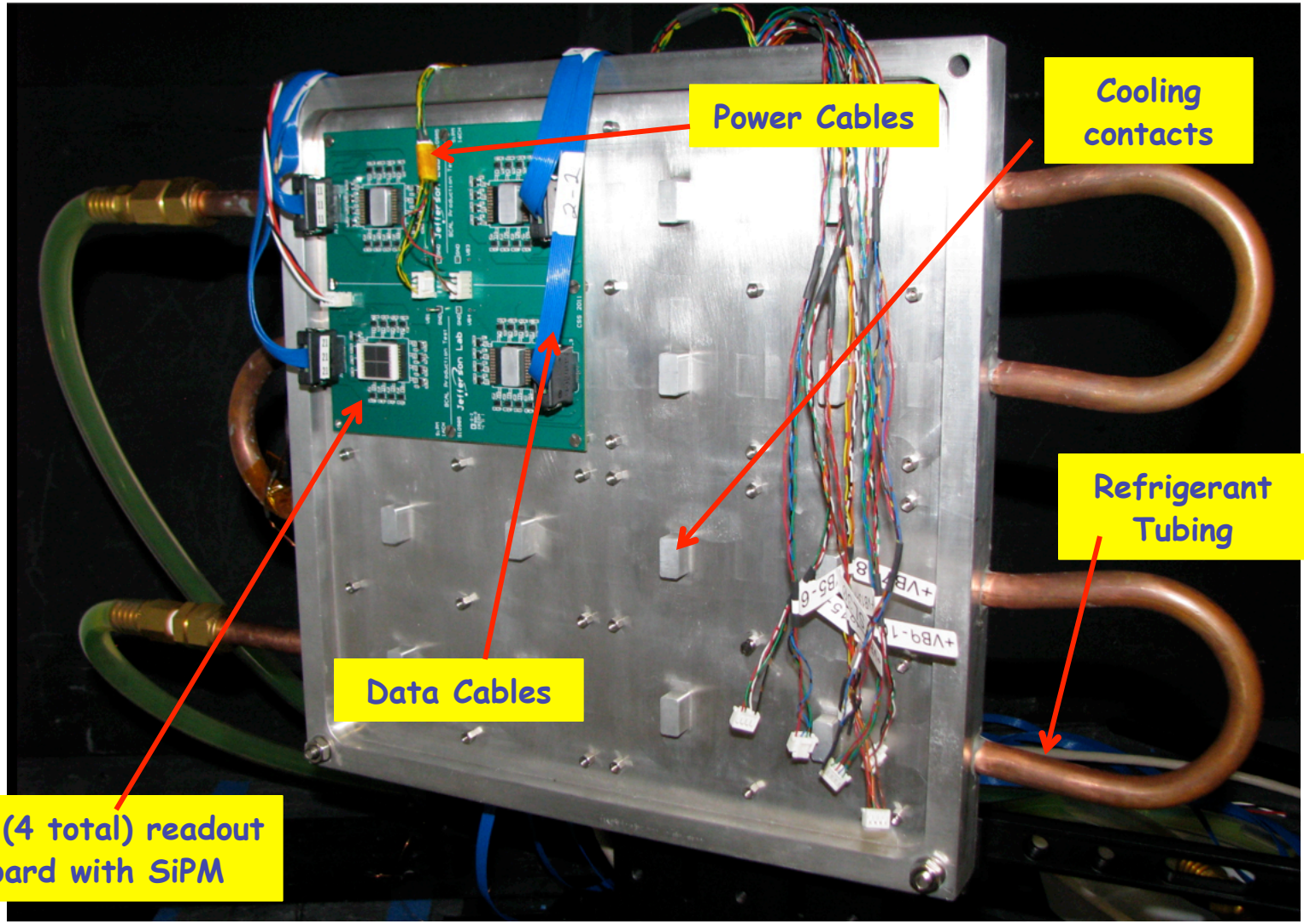
- USM PDE MEASUREMENTS ARE FAIRLY CONSISTENT WITH THE AVERAGE OF REGINA'S LASER MEASUREMENT, AND ARE LARGER THAN JLAB'S PDE BY ABOUT 20% (PDE~21% VS. ~25%). THESE MEASUREMENTS ALL USE DIFFERENT APPROACHES.
- USM CROSS TALK MEASUREMENTS GIVE RESULTS VERY CONSISTENT WITH JLAB'S MEASUREMENTS.
- WE SEEM TO FIND LESS DARK CURRENT THAN JLAB OR HAMAMATSU, EVEN TAKING TEMPERATURE INTO ACCOUNT
- WE MEASURE A SMALLER GAIN IN STATION 3 THAN IN STATION 2 - NEEDS TO BE UNDERSTOOD - 10% EFFECT

Production SiPM Units Test at Jefferson Lab

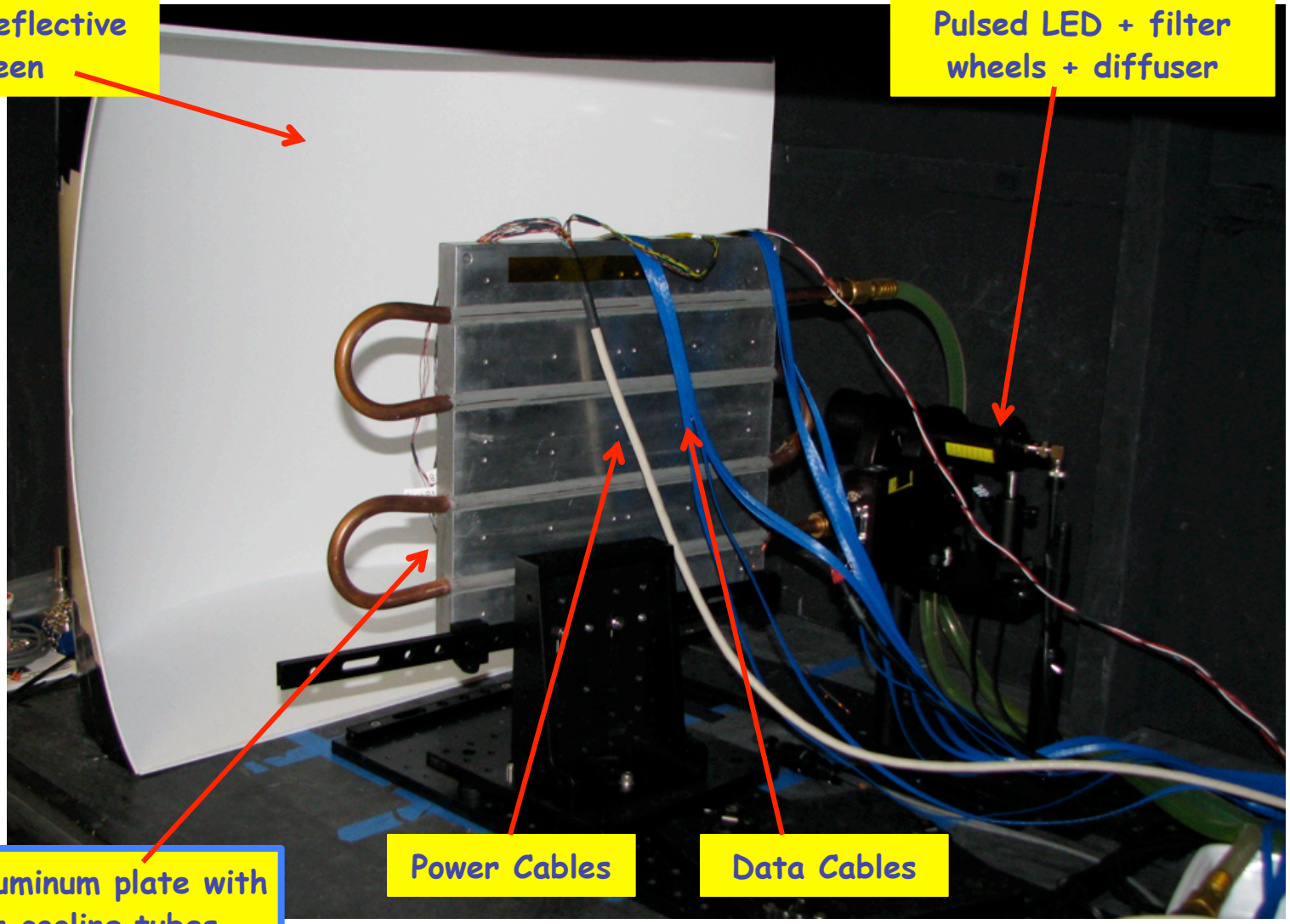
Hardware Setup: Dark Box



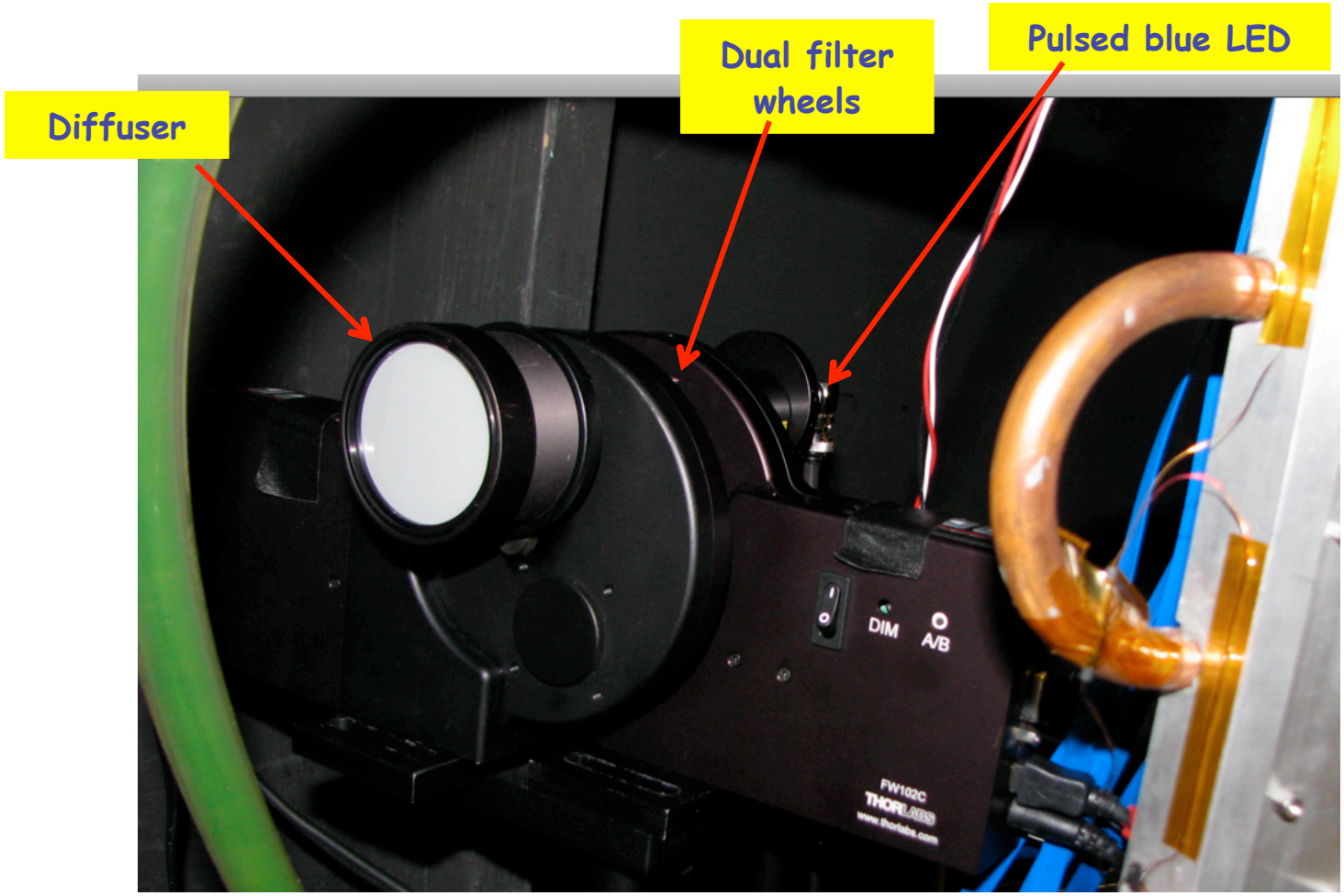
SiPM Test Station – SiPM Test Plate



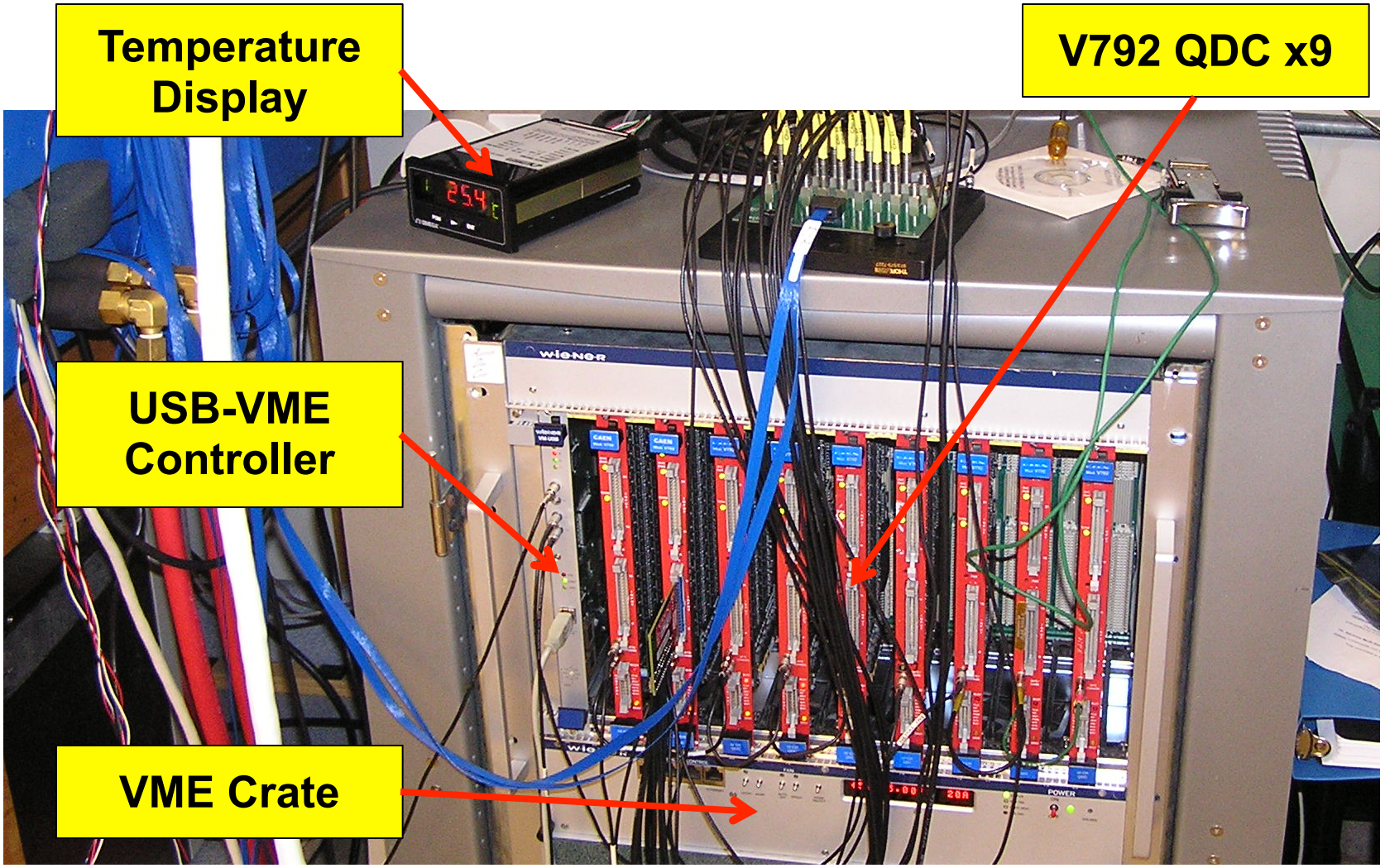
SiPM Test Station – SiPM Illumination



SiPM Test Station – Light Source



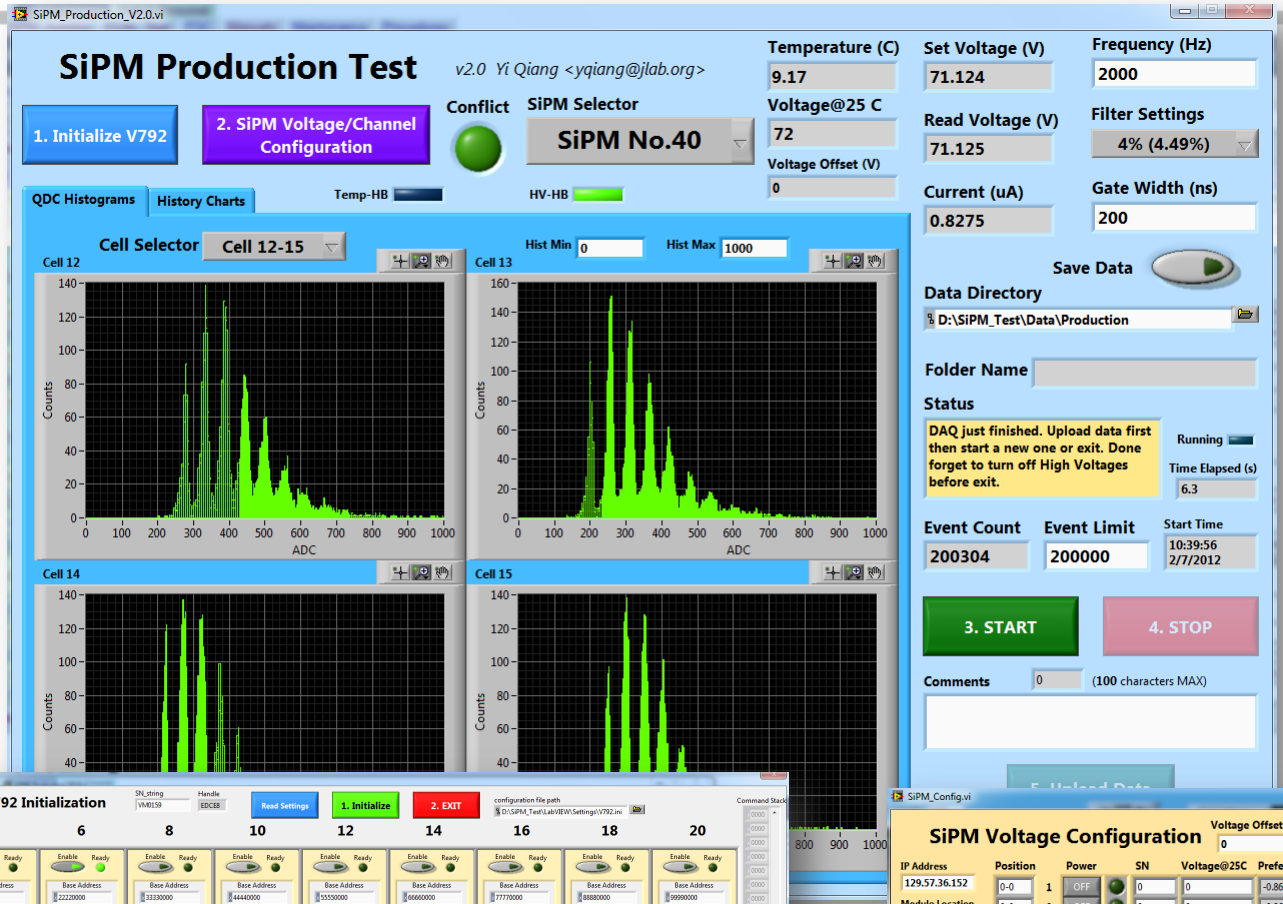
DAQ Hardware

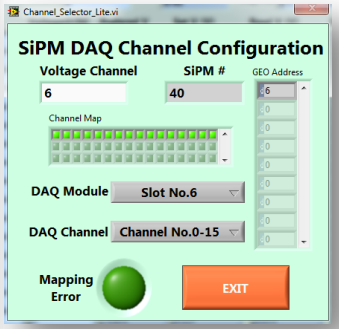


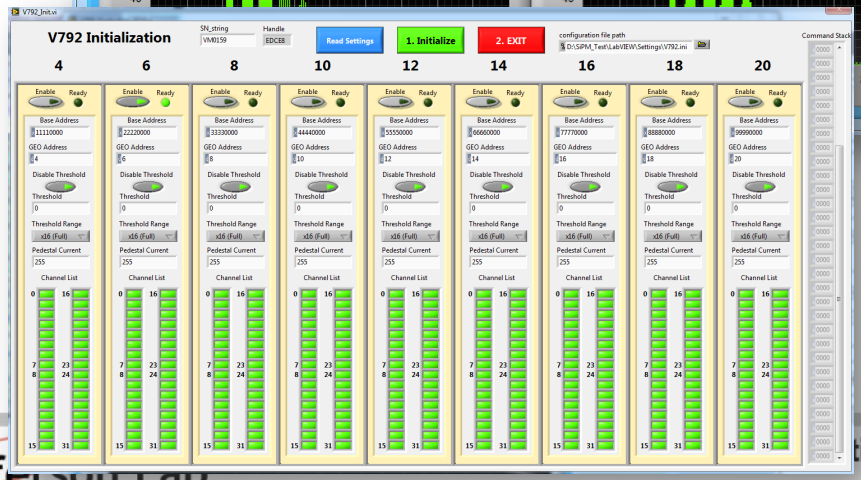
Software

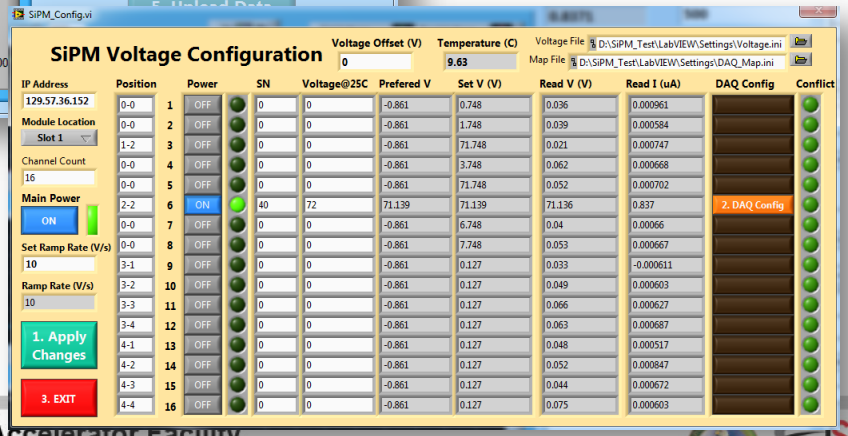
- MySQL database to store spec and test info
  - Server: halldweb1.jlab.org
  - Database: halld_sipm
  - Tables: sipm_spec, sipm_data …
- LabVIEW Control of all hardware components
  - Light source, pulse frequency, filter wheels
  - SiPM HV control and read back including current
  - Temperature read back
  - DAQ control and record data
  - Upload data to JLab farm disk: /work/halld/Subsystems/SiPM/production
  - Automatically fill new info to MySQL database
- Analysis scripts
  - ROOT fitting scripts: extract gain, PDE, cross-talk …
  - Perl scripts to do batch analysis locally or on JLab batch farm
  - Automatically exchange info with MySQL database
- ELOG: https://halldweb1.jlab.org/elog-halld/SiPM/

LabVIEW Screens





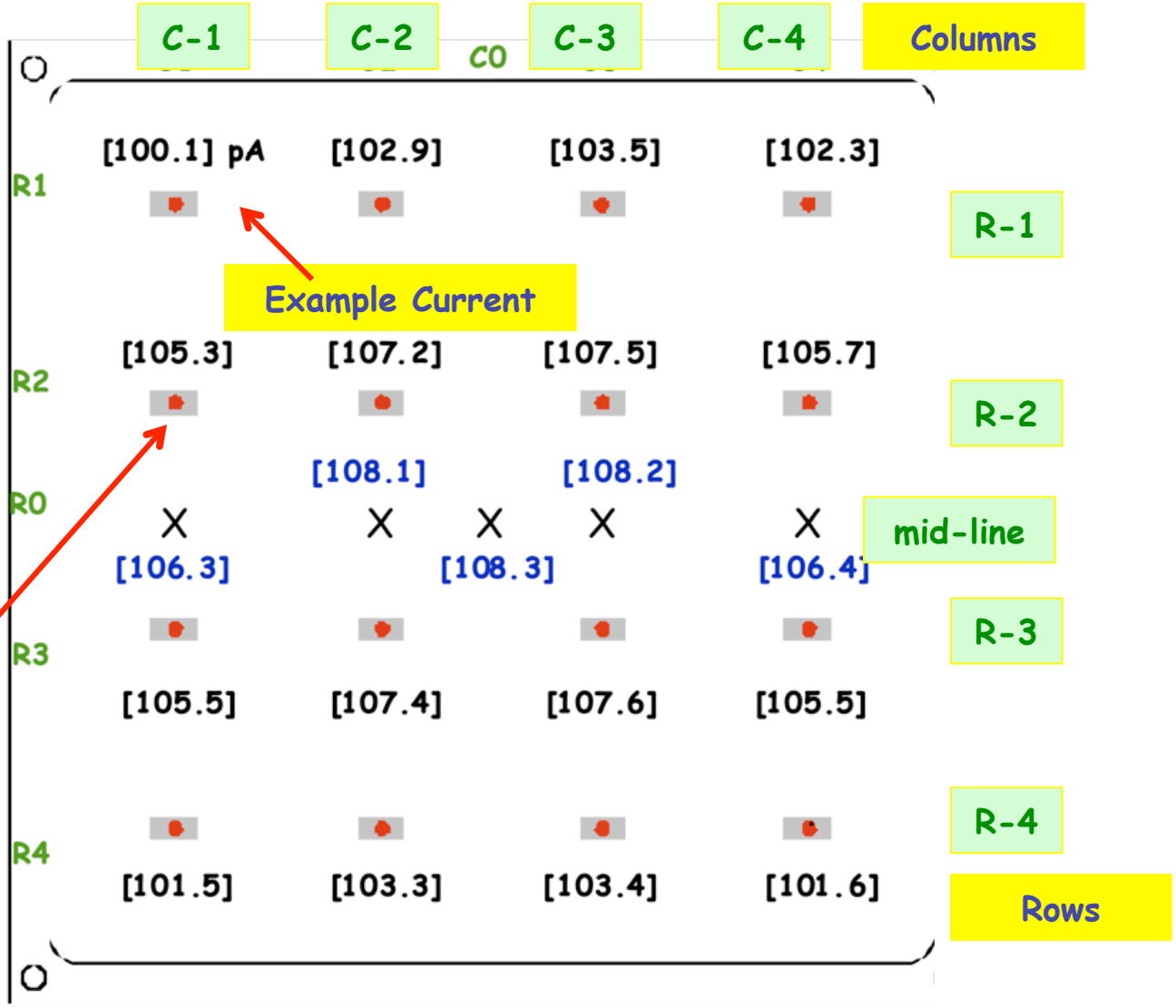




Illumination Uniformity of Test Plate

Scan with S2281 diode ~ 1 cm Ø run LED at high freq (300 kHz) to get good signal

SiPM position

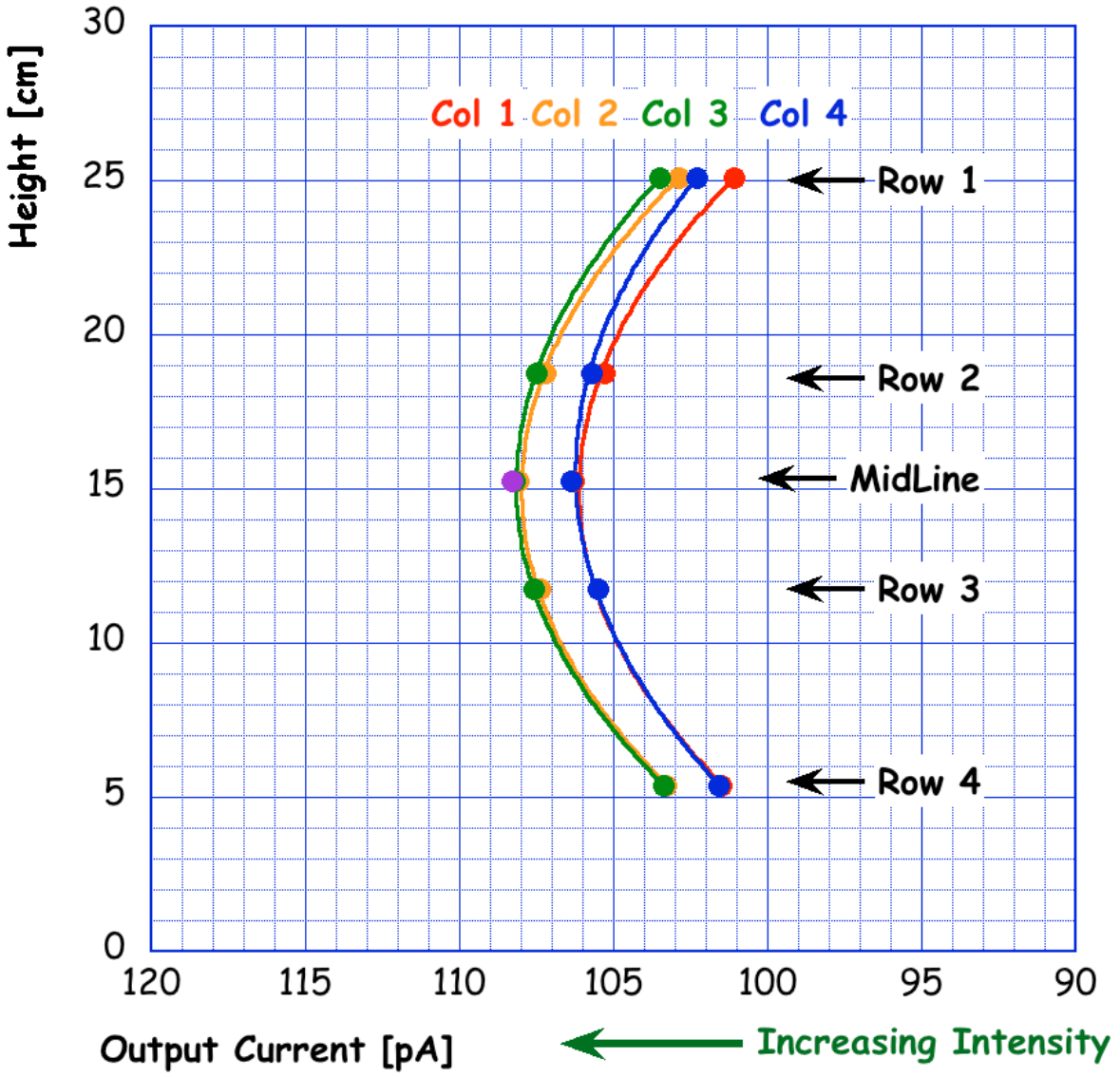


Illumination Uniformity of Test Plate

Variation in Rows (1,4) & (2,3) = 1%

Inner Rows (2,3) are 4% > Outer Rows (1,4)

get good signal



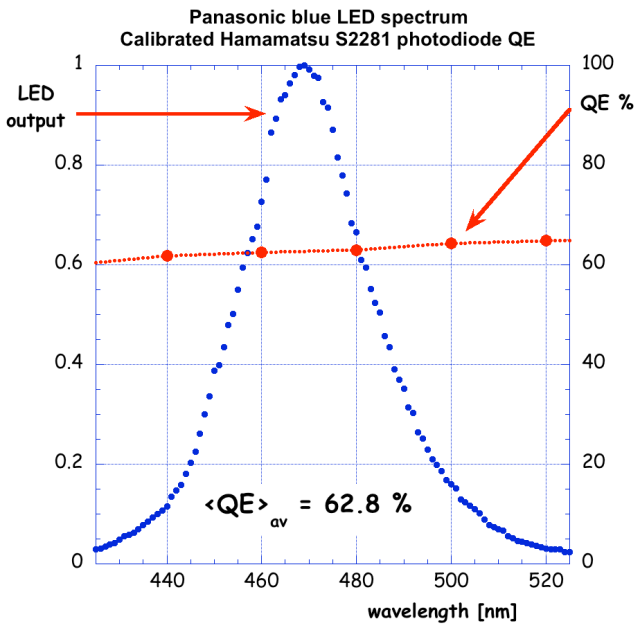
Illumination Uniformity and Photon Flux Calibration

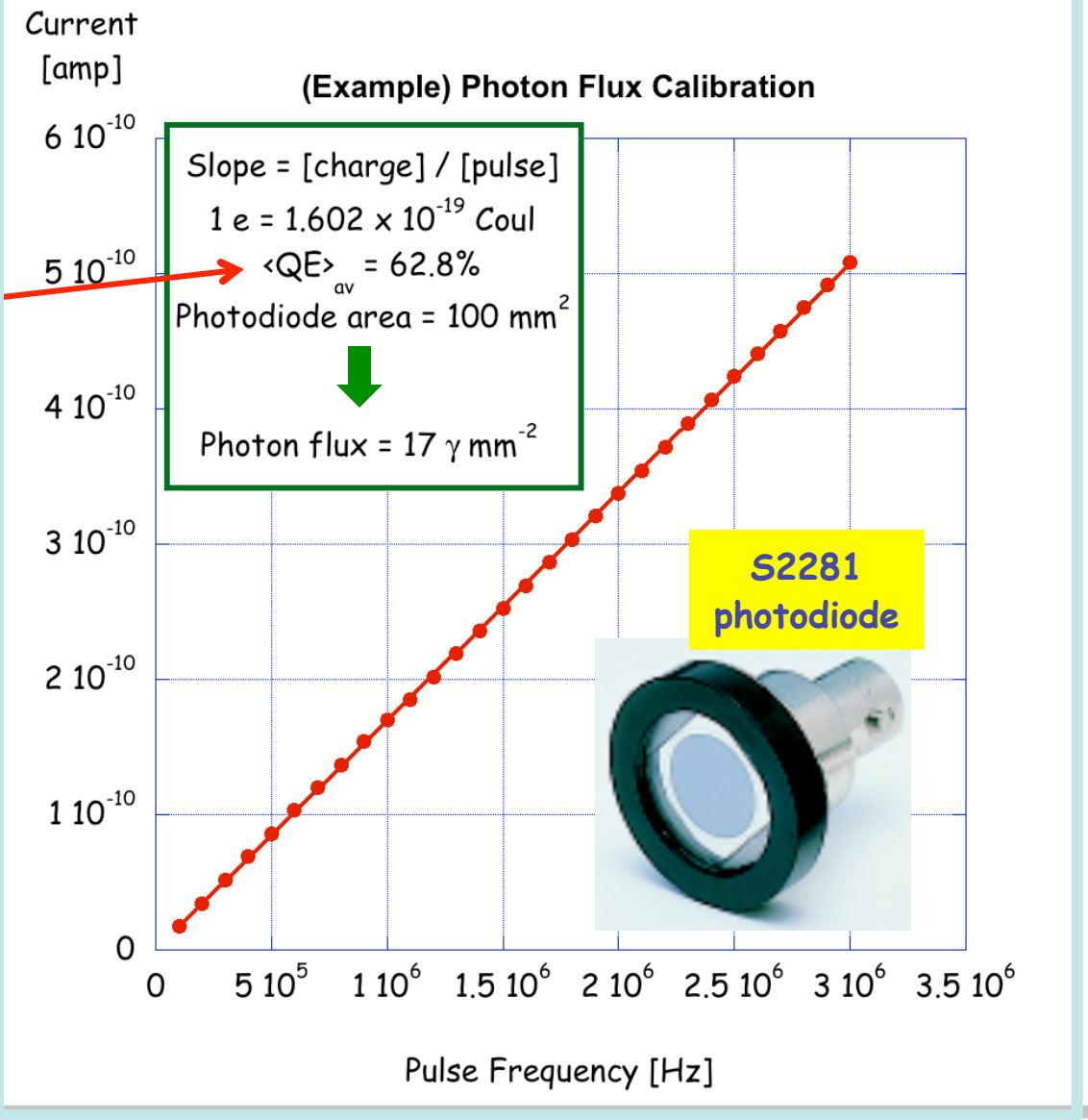
- There is also albedo effect – when bare Al plate in place, 4% increase in intensity compared to covered plate (w. black cloth)
- Need to re-measure this with all boards, connectors and cables in place – expect it to be much smaller effect
- Basic photon flux calibration:

  Measure flux at center of plate – then correct for albedo and row position (inner, outer pairs)
- Will check this with 1st article samples for comparison

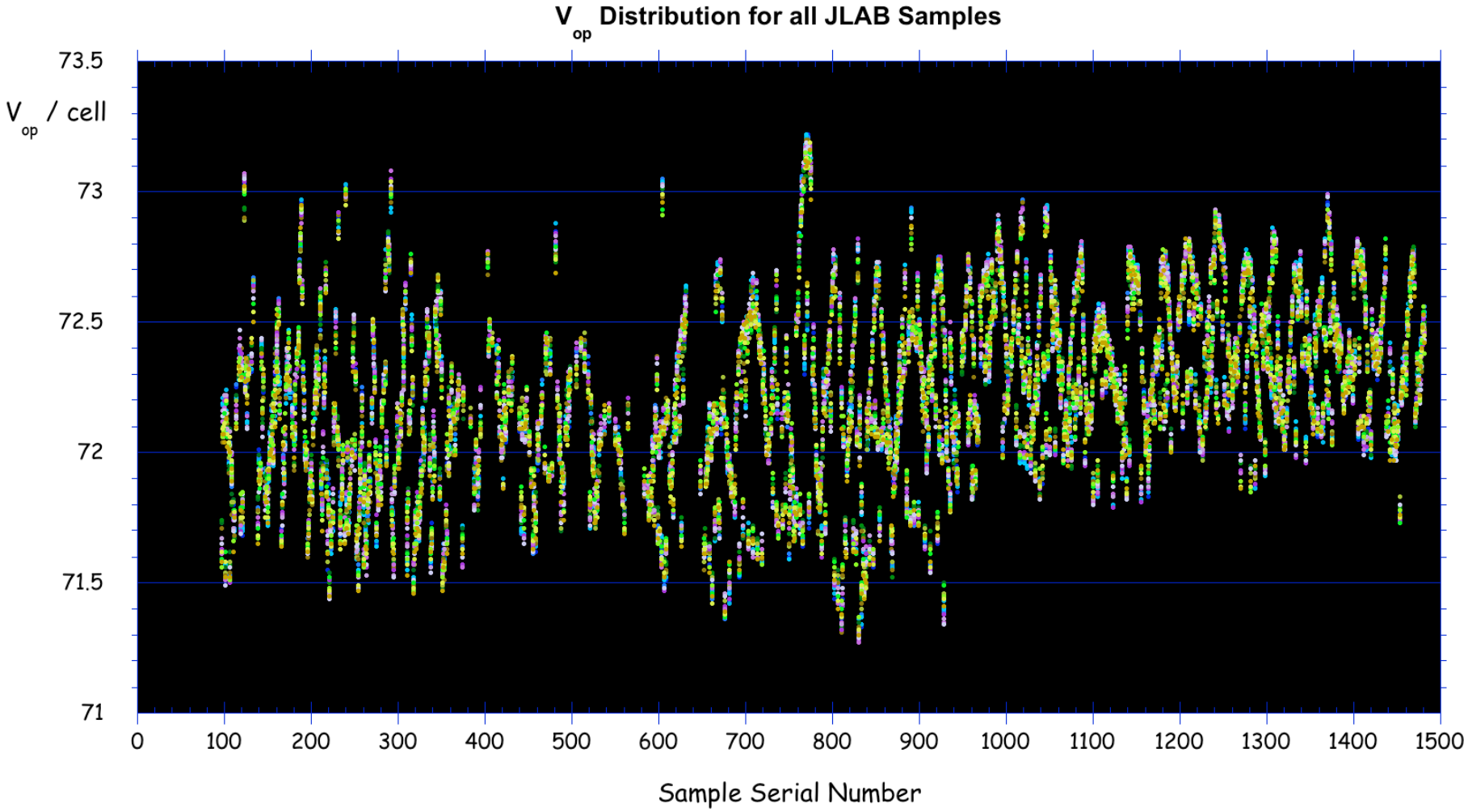
Illumination Uniformity and Photon Flux Calibration

LED emission spectrum And Photodiode QE

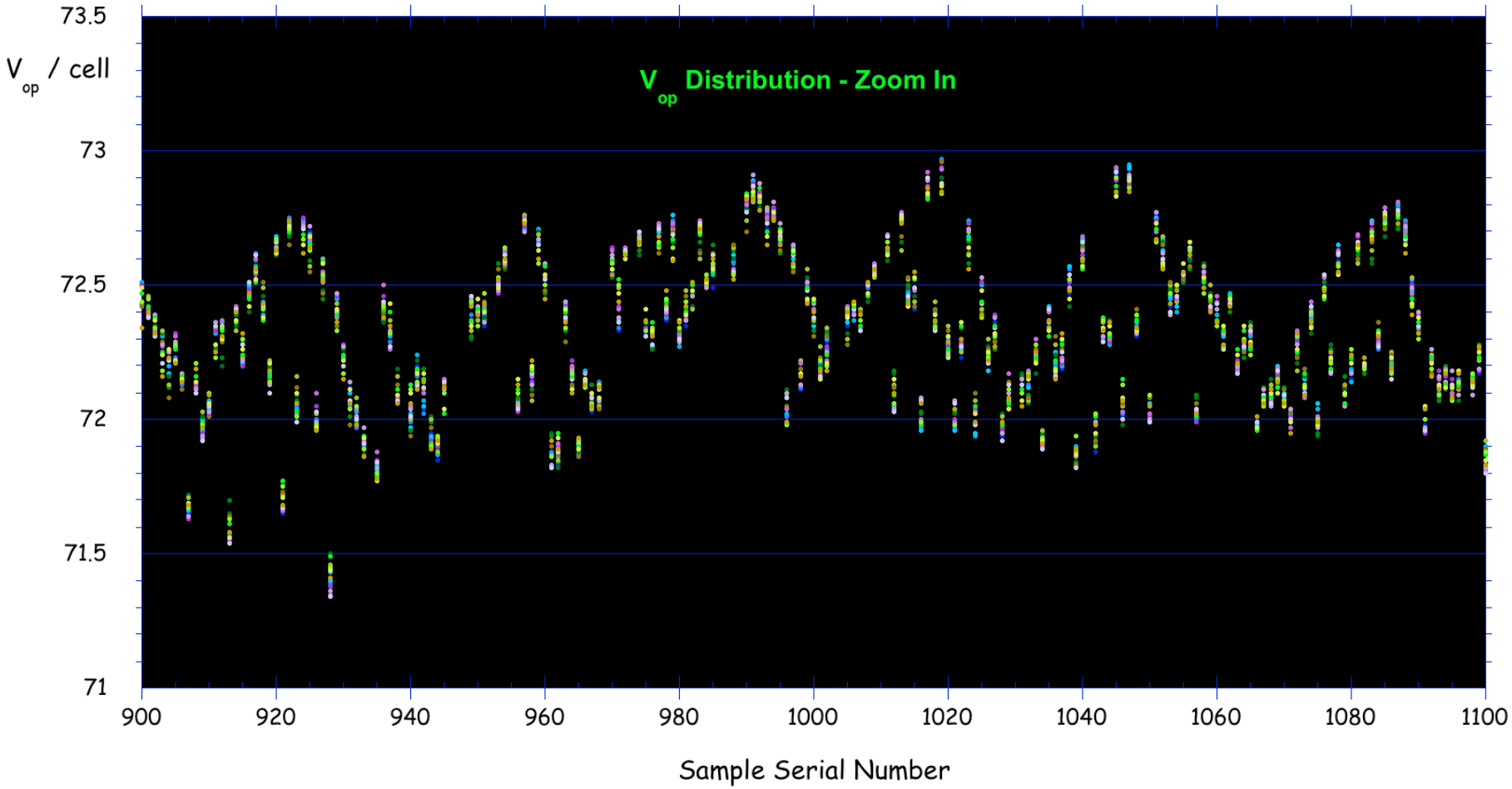




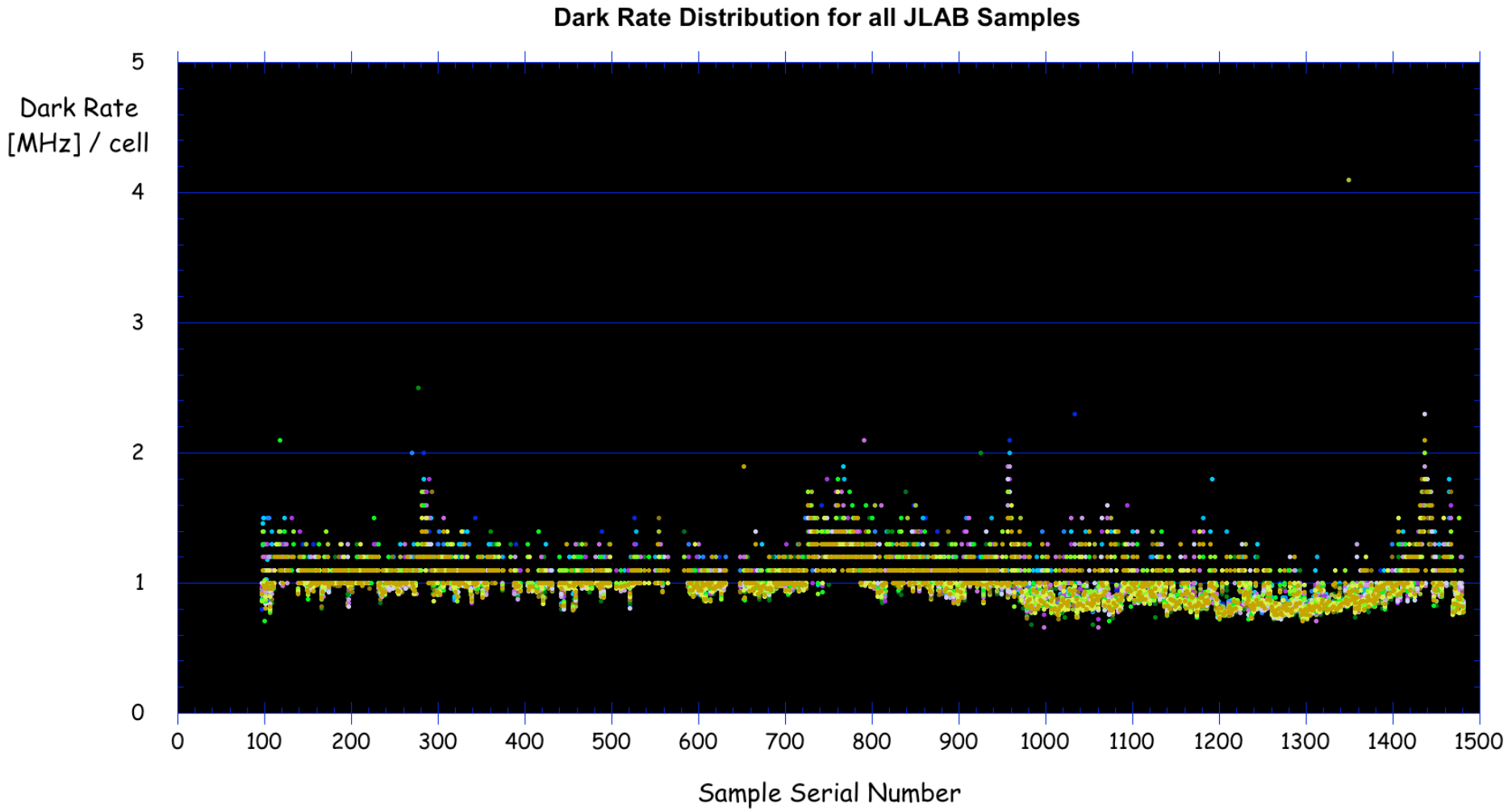
Distribution of all V_{op} values for all JLAB samples



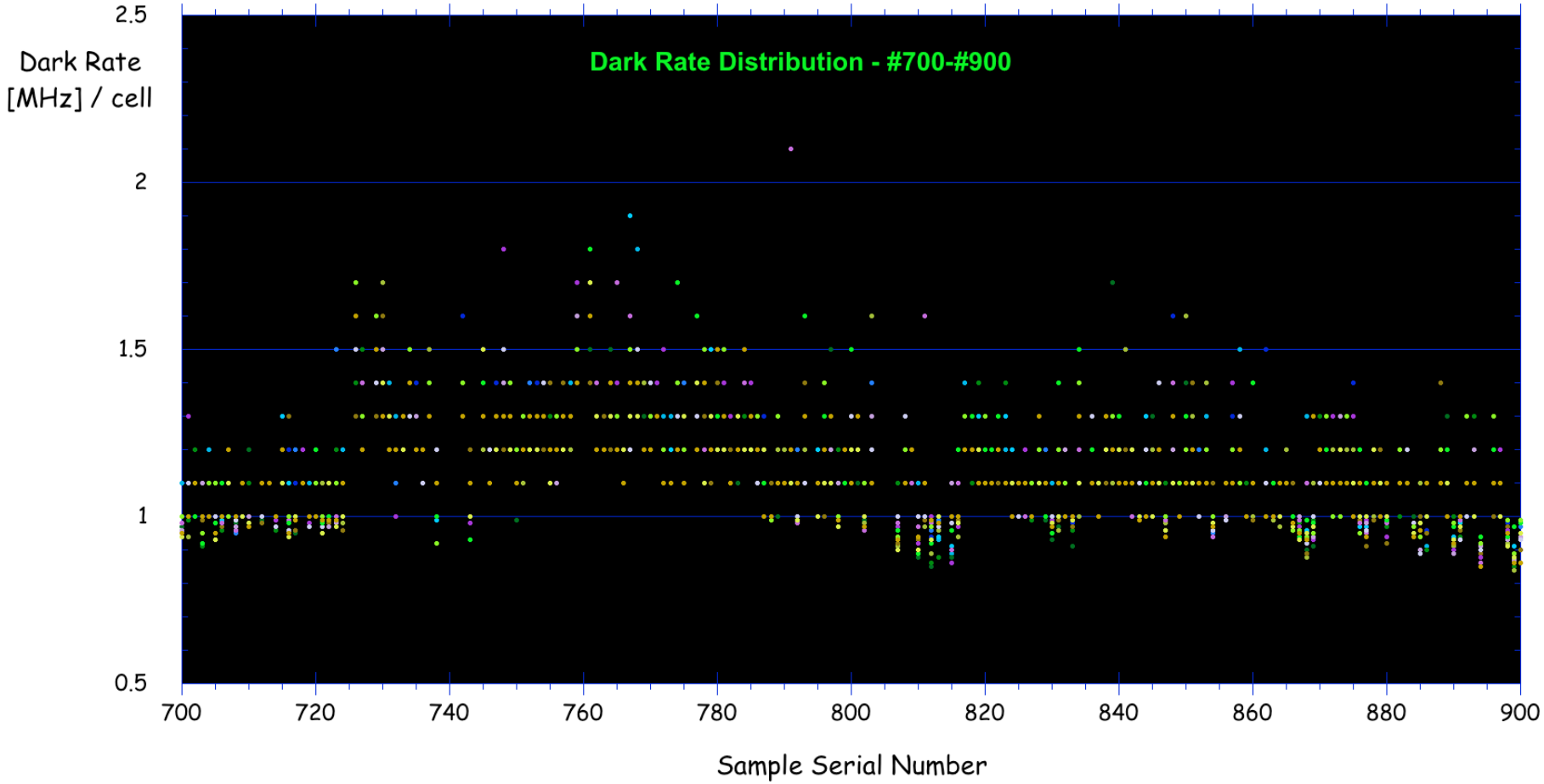
Zoom in on samples 900 - 1100



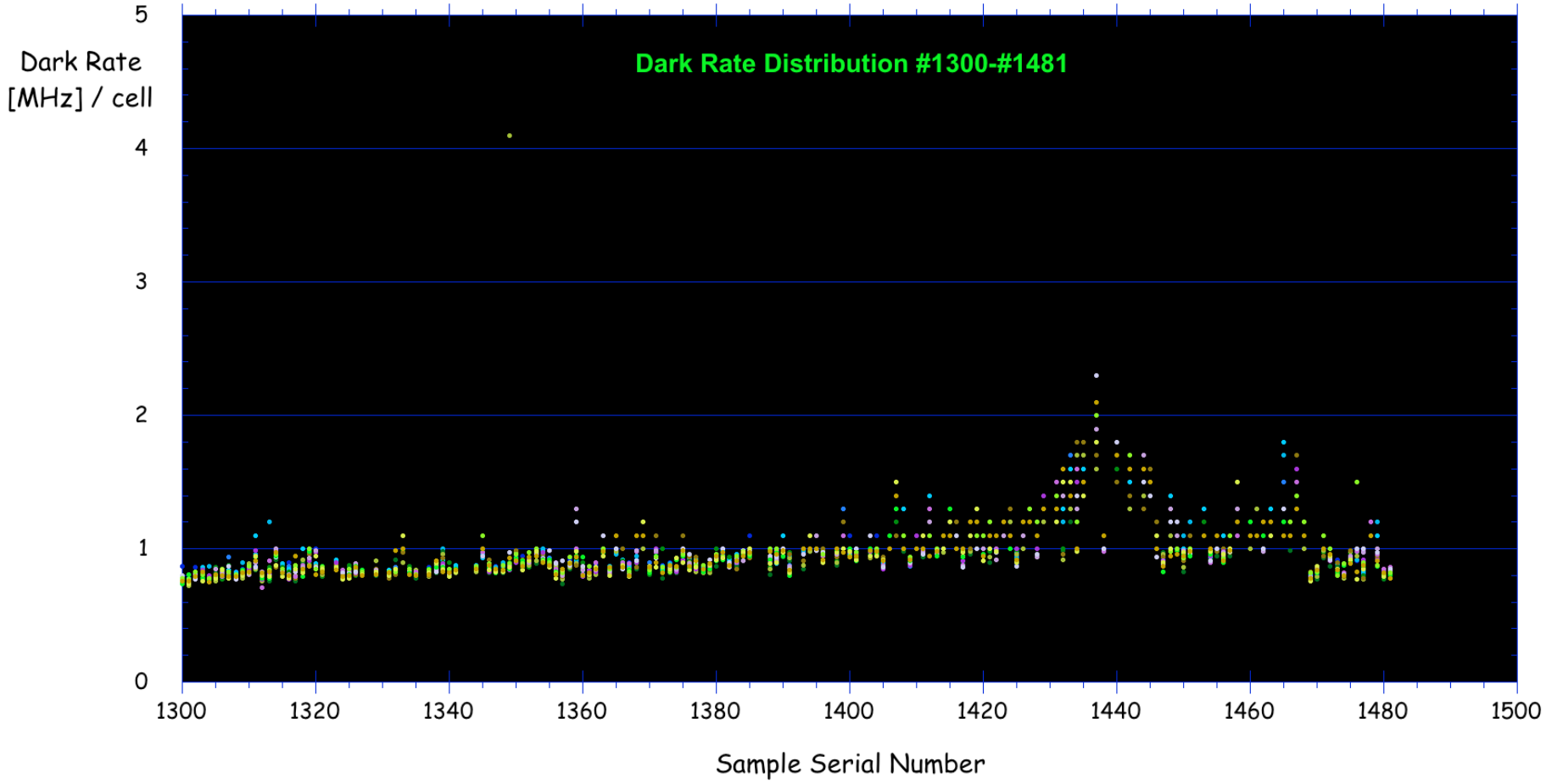
Dark Rate distribution for all JLAB samples



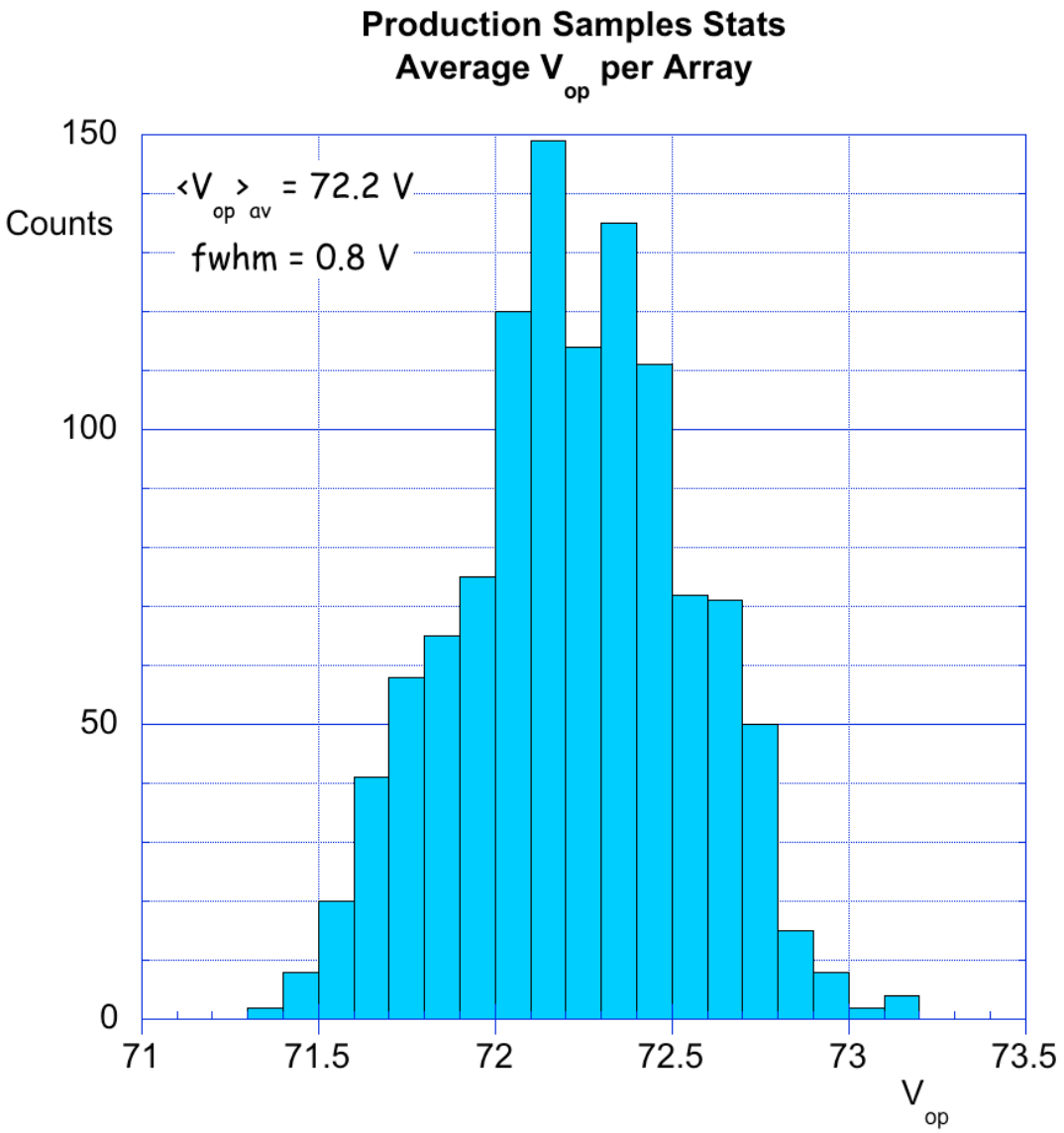
Dark Rate distribution – zoom in on #700 - #900



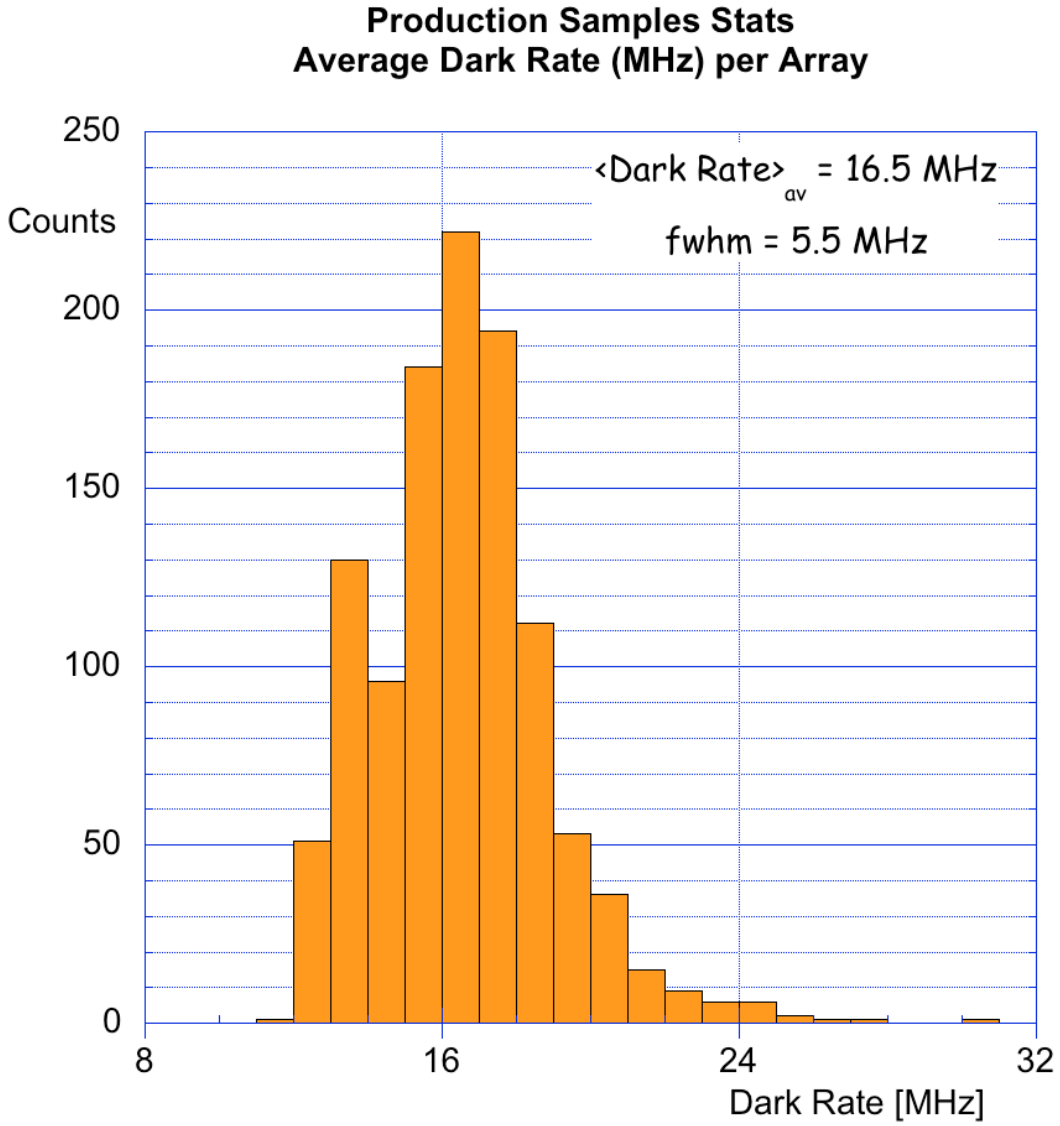
Dark rate distribution - #1300 - #1481



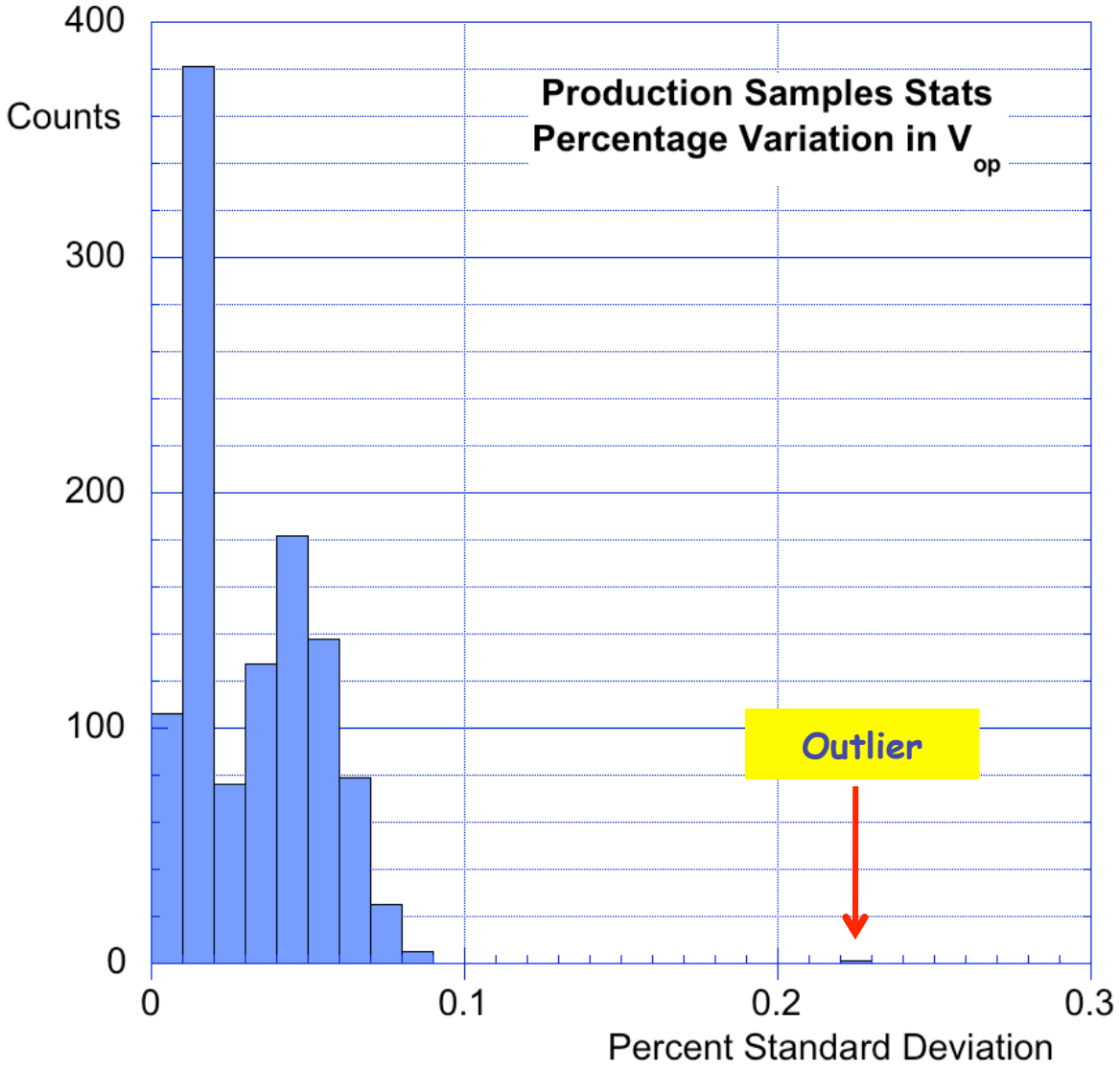
Average V_{op} per sample (JLAB)



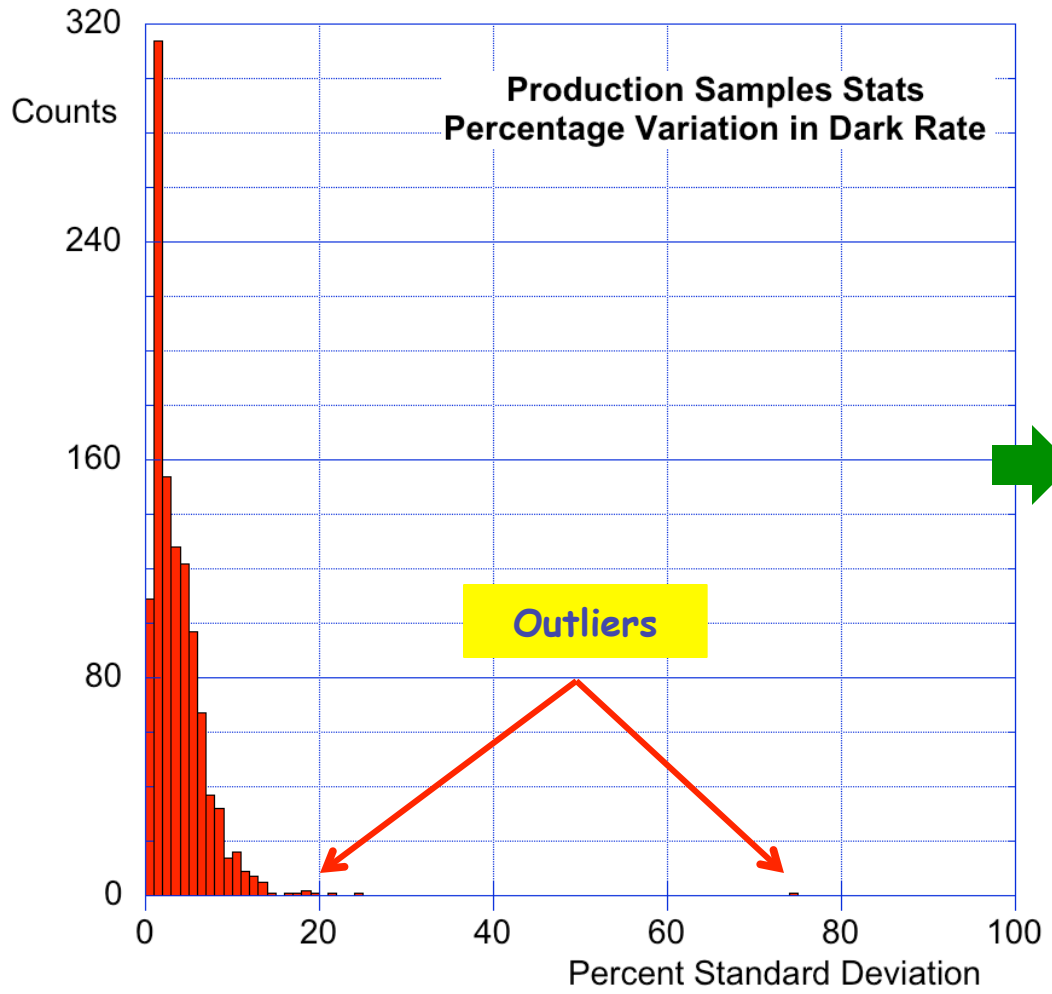
Total Dark Rate per Sample (JLAB)

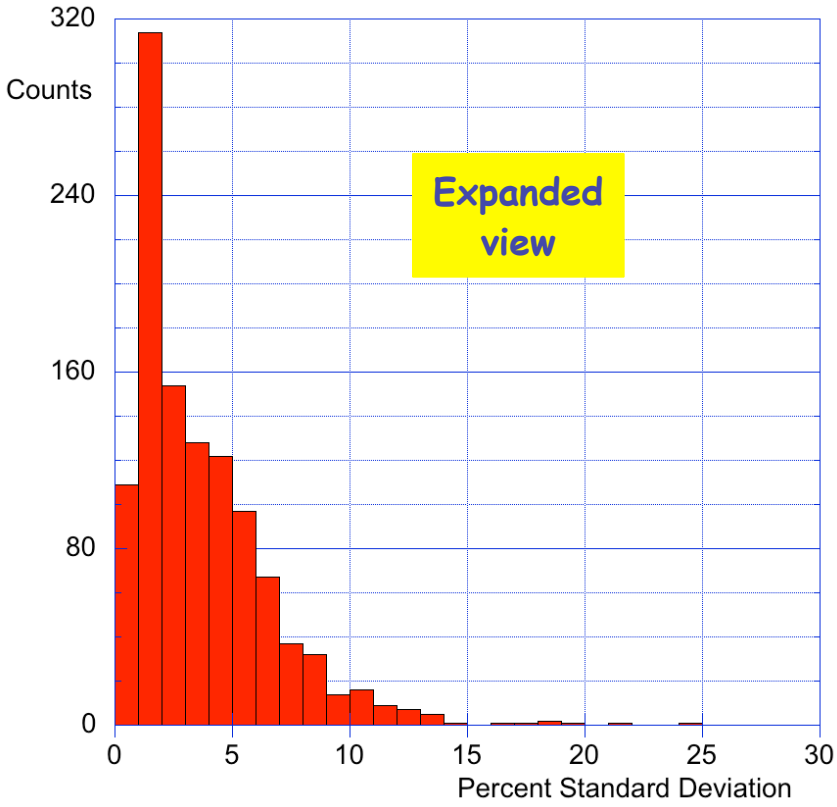


% variation in average V_{op} per sample



% variation in Dark Rate per sample (JLAB)





Summary of Jlab SiPM Test

- Hardware setup is almost ready
  - All preamplifier boards will be modified to be AC coupling to address positive DC offset issue
    - First modified board tested working properly
    - Waiting for the rest of the boards
  - Light uniformity better than 2%, needs to be verified with preamplifier boards installed and cables connected
- Both control and analysis software are ready to go
- Will start production test shortly

BACKUP SLIDES

MPPC Specifications, page 1

Table 1. Technical requirements for silicon photomultiplier arrays for the Hall D BCAL. All requirements must be met at the nominal operating voltage and at a specified temperature in the range between 5 and 30° C.

Property	Specification
Gain at nominal operating voltage	$(0.5–2)x10^6$
Photo-sensitive area	>140 mm^2
Macroscopic active area coverage	> 75%
Number of micro-pixels	> 56000
Sensitivity to magnetic field	< 1% gain change at 2 T independent of orientation
PDE at 490 nm [Note 1]	> 19 % [Note 2]
Dark rate	< 100 MHz [Note 2]
Dark current	< 40 μA
Sensitivity to temperature	< 10% charge amplitude change/deg C
Maximum output difference of any cell within one array from the array's average	<+/- 7.5%
Variation between average output of arrays under uniform illumination at their nominal operating voltage	<+/- 5%

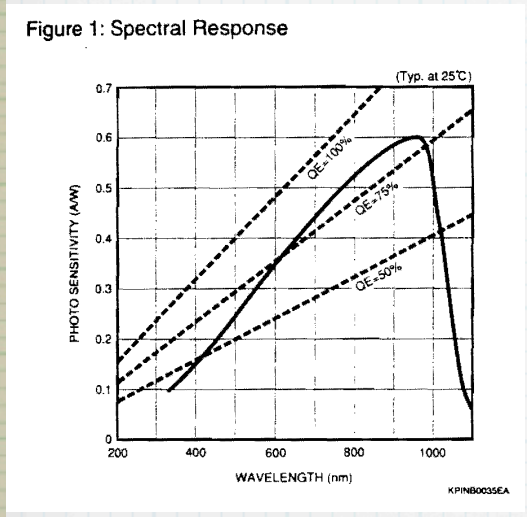
MPPC Specifications, page 2

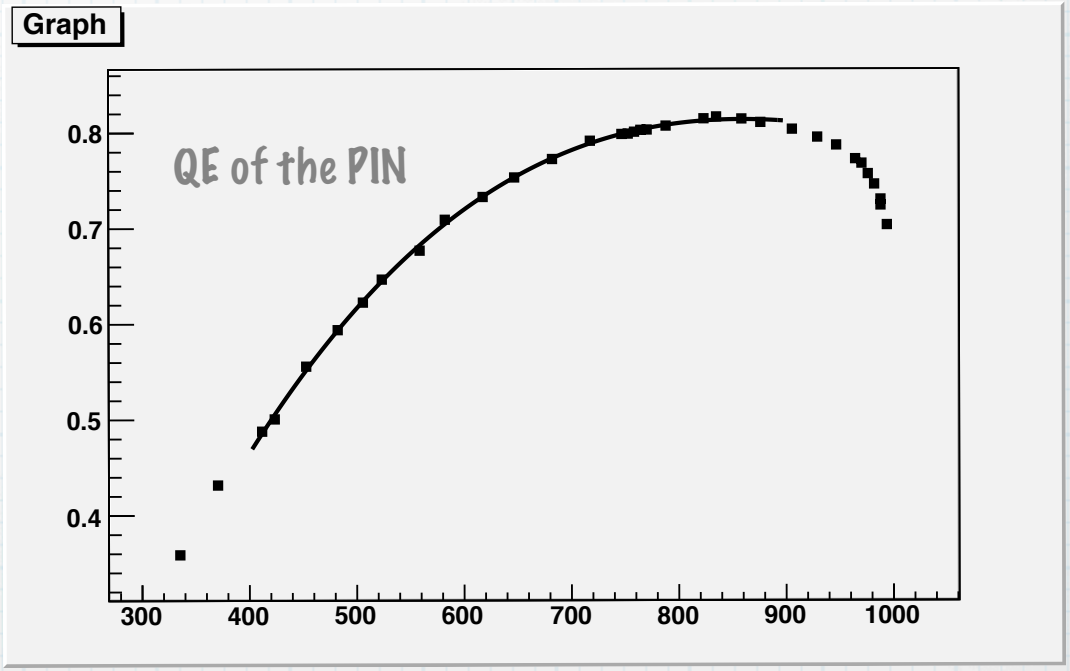
Nominal operating voltage	25-80 V
Nominal operating voltage above breakdown voltage	0.9–3.0 V
Fraction of multiple photoelectrons in dark noise	< 5%
Package dimensions	See Drawing D00000-01-07-3000
Package substrate	Al_2O_3
Inputs	Positive bias voltage
Outputs	16 individual outputs
Output connector	Cu alloy pins on 0.05" centers
Rise time 10%–90%	< 16 ns [Note 3]
Pulse width 10%–10%	< 100 ns
Sensitivity of signal-to-noise to radiation	< 1%/Gy

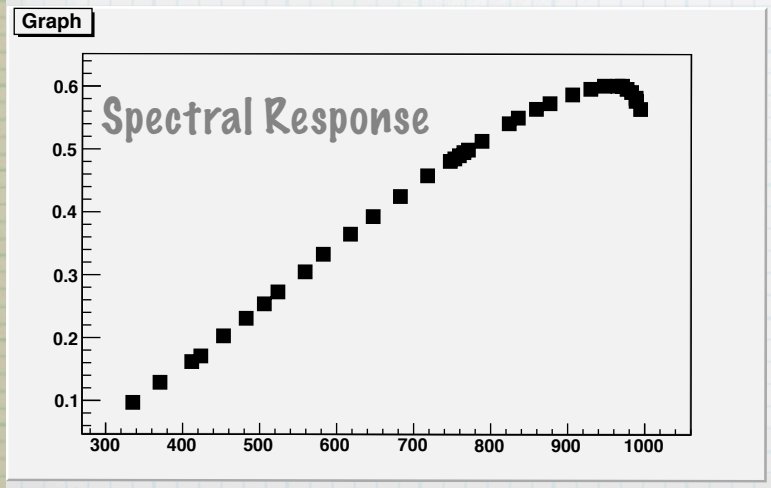
[Note 1] The PDE measurement is made in pulsed mode.
[Note 2] There is a tradeoff between specific values of PDE and dark current to obtain a fixed detector resolution. The tradeoff is made explicit in the following equation: PDE > 0.0518 + √(0.002685 + 0.01629•DR(MHz)/100), where the dark rate DR is given in MHz;
[Note 3] Measured with a light input pulse of less than 7 ns.

Revision and Corrections ...

* we got the spectral response of our reference pin diode (S3590-03)



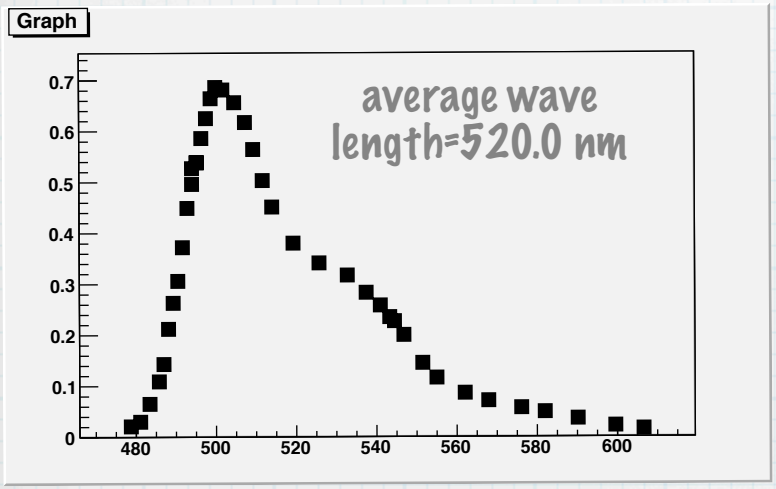


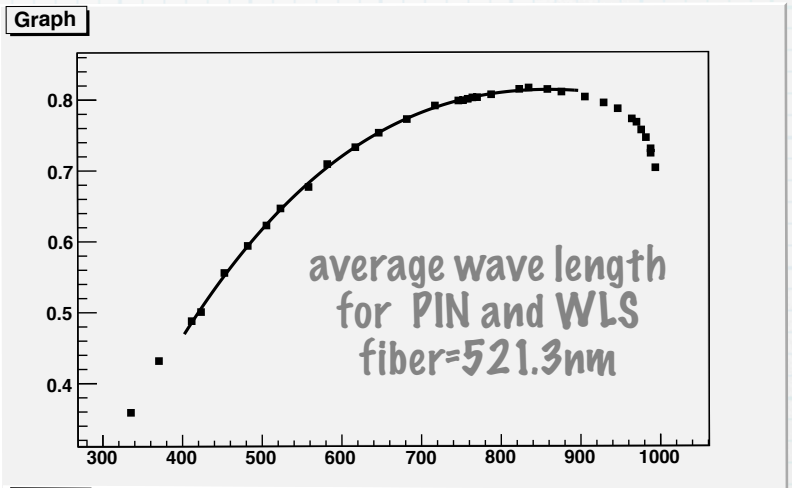


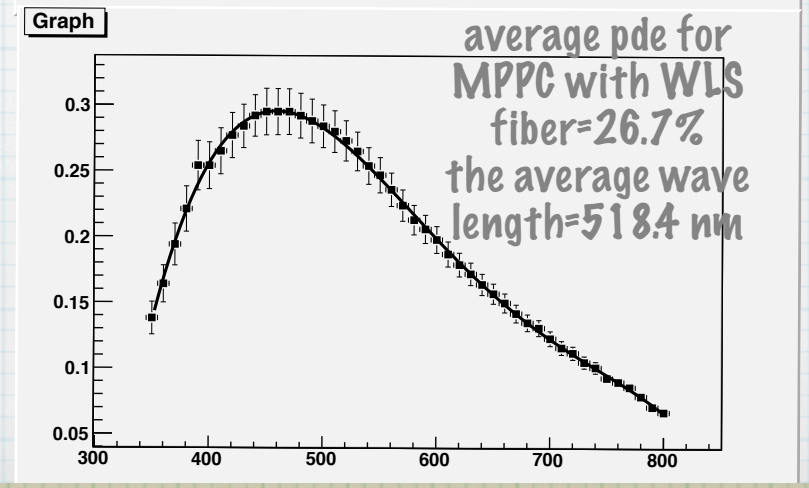
Y11(200)

* average QE for PIN with WLS fiber is 64.0% (instead 75%)

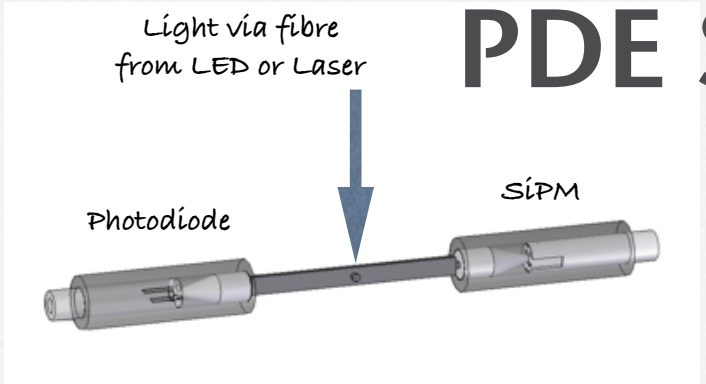
30 cm of Y11(200)

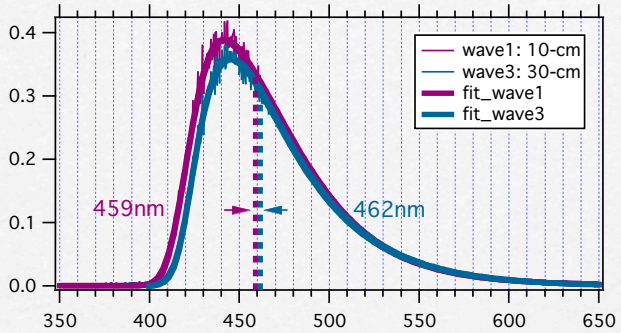


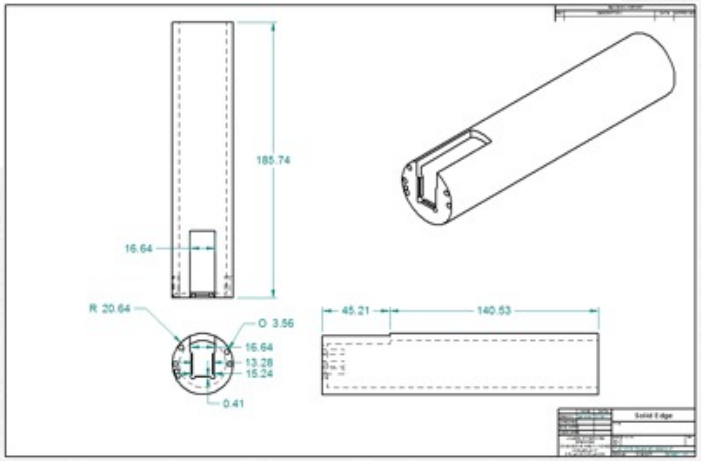


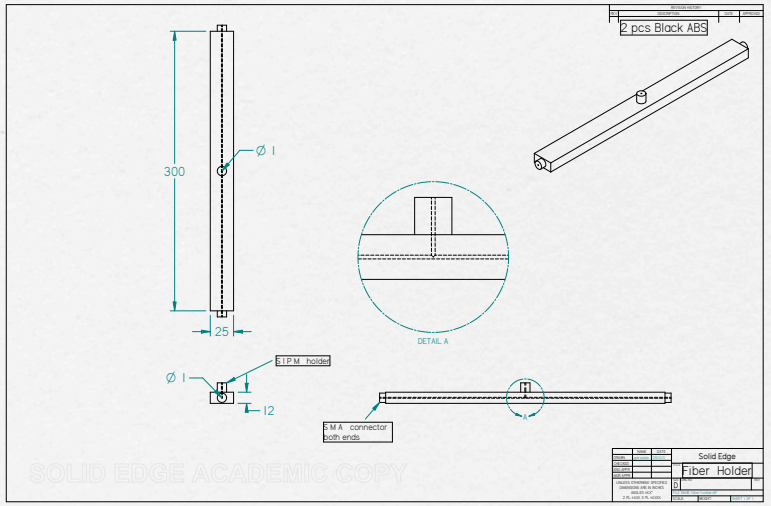


PDE Setup









Set up was tested for symmetry:
PDE from relative measurement

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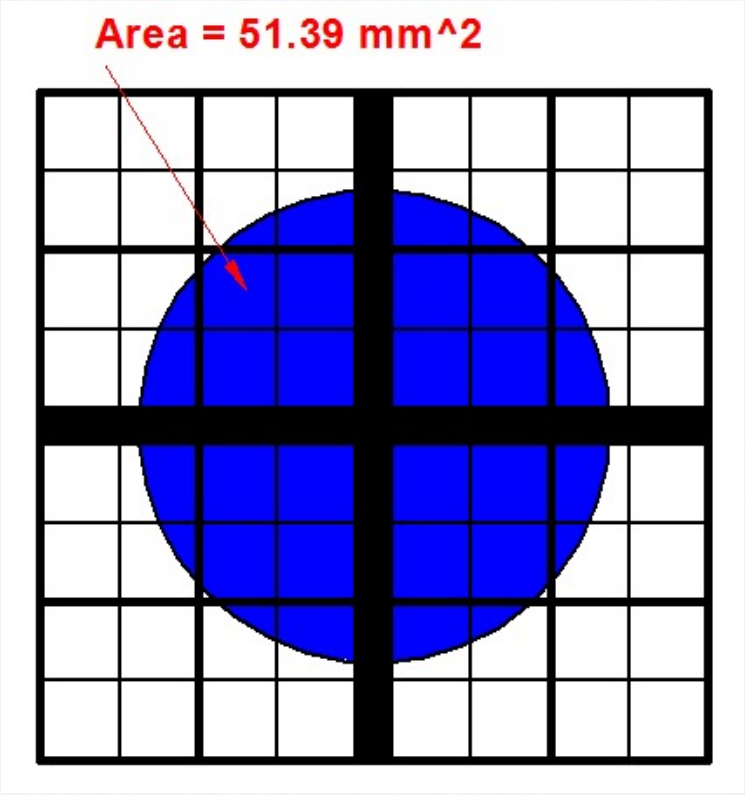
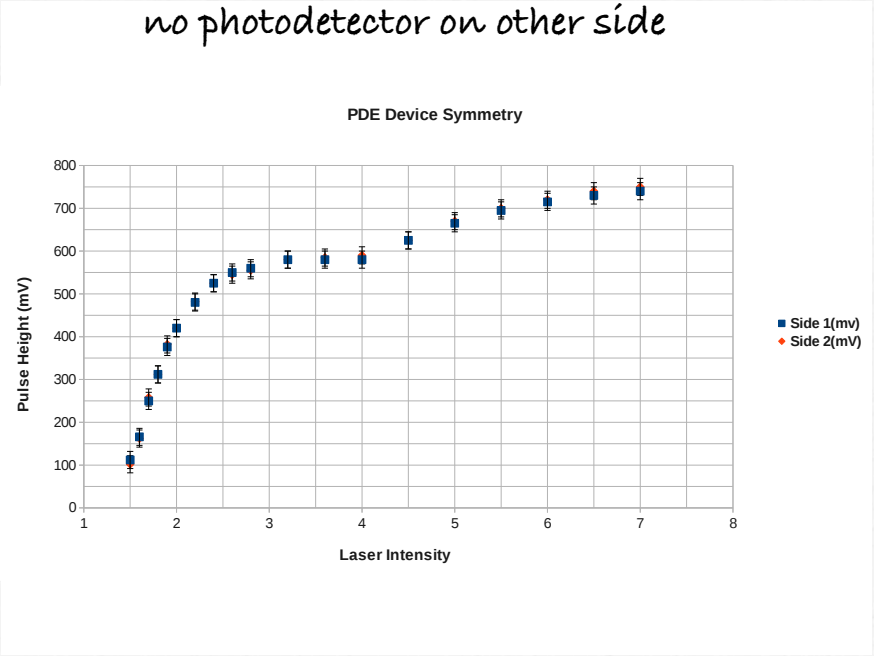
Laser Profile



SiPM tested alone:
no photodetector on other side



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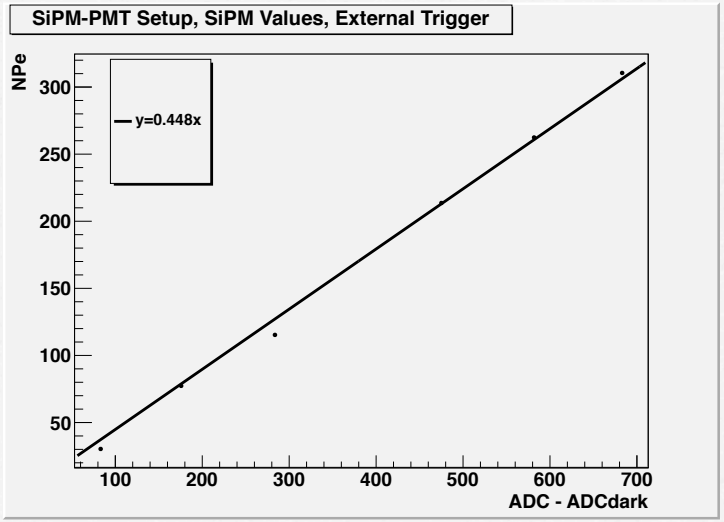
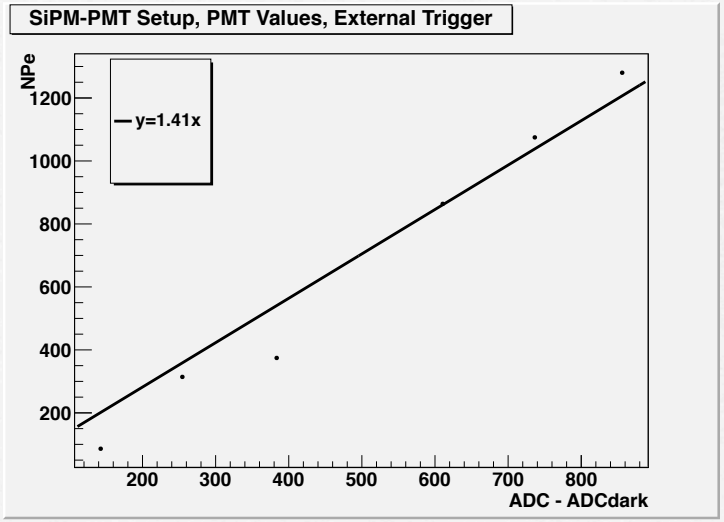
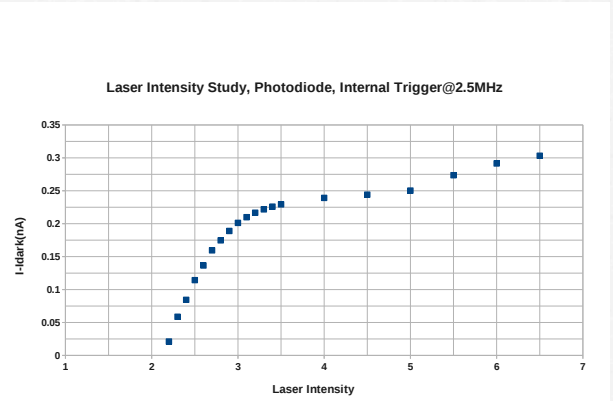
Run specifics

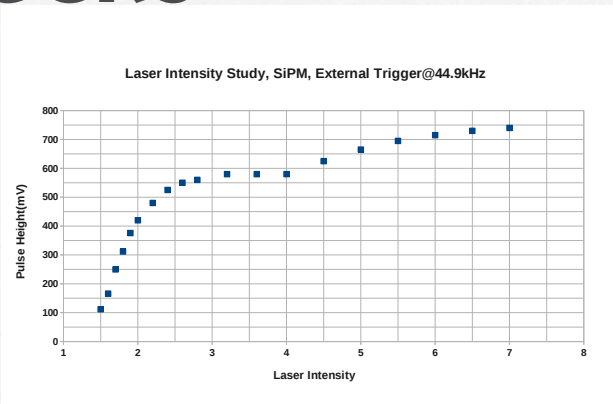
- Laser trigger externally (44kHz and up...)
- Photodiode - Hamamatsu S2281
- SiPM - Hamamatsu S10943-0258(X)

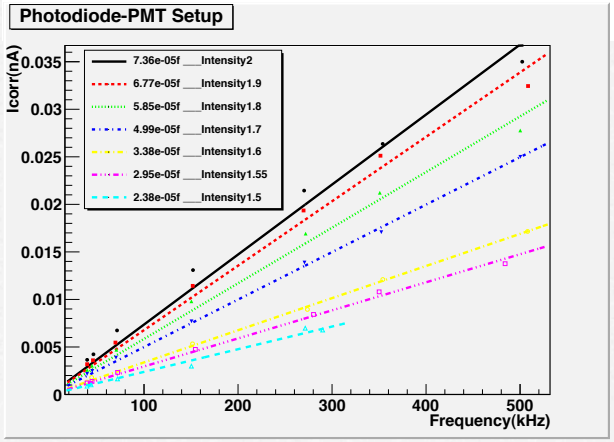


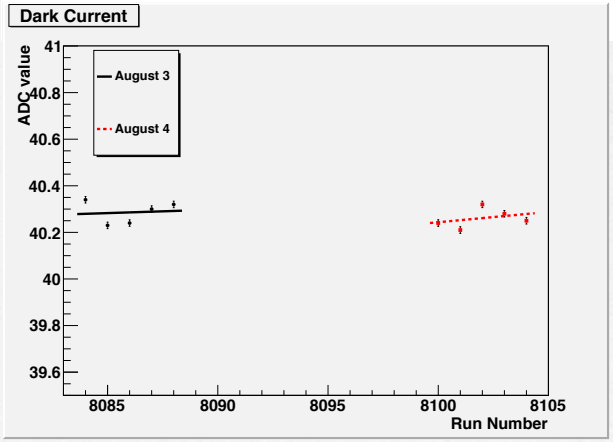


Checks


Laser Intensity Study, Photodiode, Internal Trigger@2.5MHz
I-Idark(nA)
Laser Intensity


Laser Intensity Study, SiPM, External Trigger@44.9kHz
Pulse Height(mV)
Laser Intensity


Photodiode-PMT Setup
Icorr(nA)
7.36e-05f ___Intensity2
6.77e-05f ___Intensity1.9
5.85e-05f ___Intensity1.8
4.99e-05f ___Intensity1.7
3.38e-05f ___Intensity1.6
2.95e-05f ___Intensity1.55
2.38e-05f ___Intensity1.5
Frequency(kHz)


Dark Current
ADC value
August 3
August 4
Run Number

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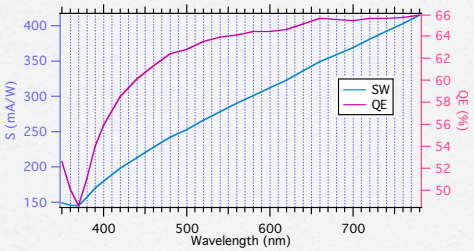
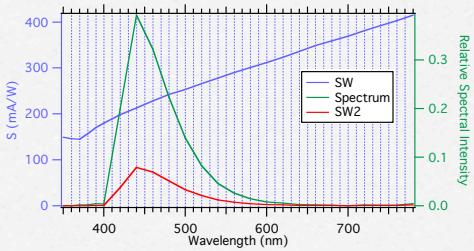
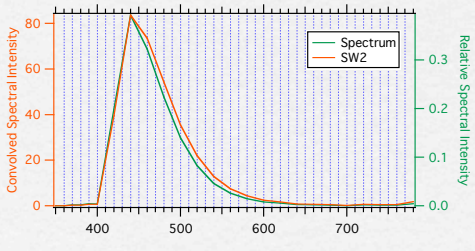
Extraction Methods

- Method 1: **NPE = (ADC-ADCdark)^2/(RMS^2-RMSdark^2)**
- Method 2: **NPE = scope pulse height* pulse width/(2* 50 ohm* electron charge*(gain=1.7*6*e5)**
- Method 3: **NPE (ADC)=(ADC-ADCped)*(0.25pc/chan)/((1.6e-19)*(gain= 1.7*6E5))**

Photodiode







Npho = **Npho of photodiode (N= (I-Idark)/((Eof460nm)*(Sof460nm)*(LED frequency))**

E of 460 = 4.3E-19 ; S of 460 = 228E-3 A/W; LED frequency ~ 1.72E5 Hz

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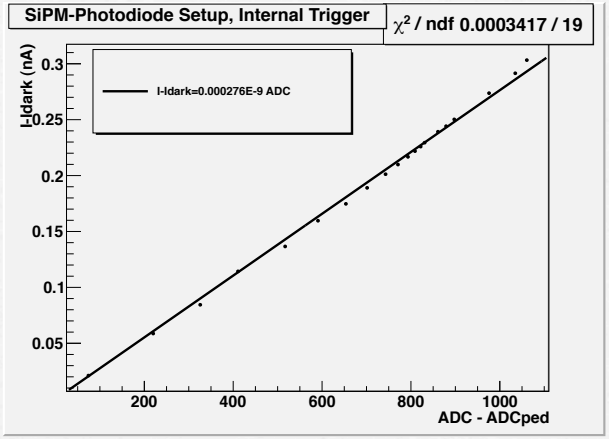
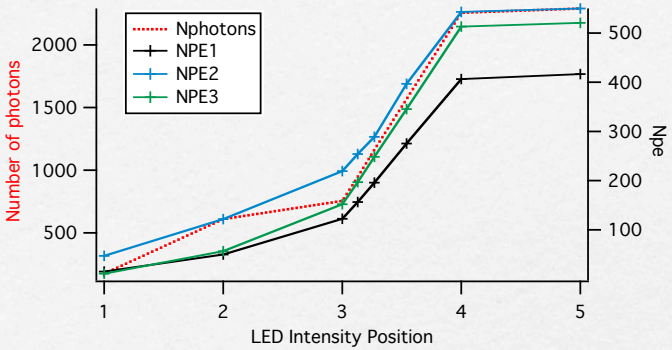
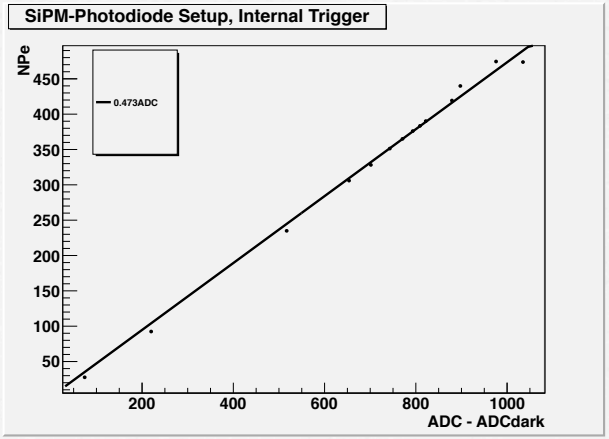
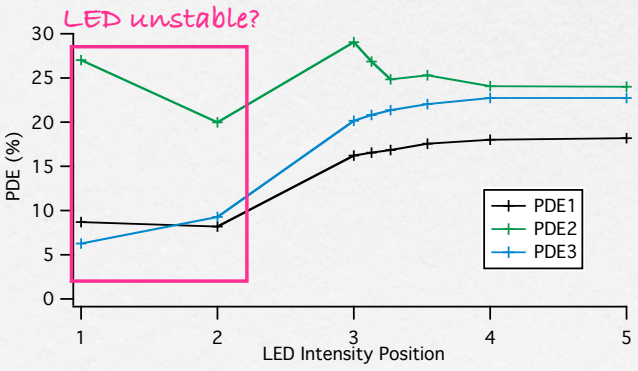
Measurements









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