Readiness Review: Testing of Light Sensors for BCAL

Will Brooks, on behalf of the USM/SiLab team

Agenda

All meetings in T-building conference room

08:30 (06:30 JLab) - Arrival
09:00 (07:00 JLab) - Project Overview
- Scope of Contract and Current Review
- Status of Equipment
- Training of Personnel
- Testing Procedures
- Storage and Shipping to Jefferson Lab. (Storage at JLab?)

10:00 (08:00 JLab) - Description of Test Setup / Analysis
- Description of light source
- Test conditions
- How to determine parameters from data
- Comparison of SiPM specifications between USM and JLab measurements
- Archiving of SiPM parameters

10:30 (08:30 JLab) - Break
11:00 (09:00 JLab) - Review of Technical Contractual Documents
- Final Construction Plan
- Quality Assurance and Acceptance Test Plan
- Feedback and Questions from QA team
- Schedule
- Review of Milestones

12:00 (10:00 JLab) - Financial, Billing and Reporting (video conference with JLab)(closed session, JLab and USM management)
- Meet with (Contract Officers) from the Sponsored Research Office
- Procurement Requirements, Billing and Invoicing
- Official Schedule and Tracking

12:30 (10:30 JLab) - Lunch
16:00 (14:00 JLab) - JLab Executive Session (closed session, JLab)

Staff and Roles

Director, SiLab Detector Laboratory: Sergey Kuleshov

Head engineer: Alam Toro

Production manager: Pablo Viveros

Project engineering: Orlando Soto, René Rios, Rimsky Rojas

Software coordination: Hayk Hakobyan

Software engineering: Ricardo Oyarzún, Juan Pavez

Director, CCTVal: Ivan Schmidt

Business and Projects Management, CCTVal: Francisco Soto

Administrative: Alison Sherman, Cynthia Sánchez

Project Coordination: Will Brooks

Project Overview

Project Overview

- Scope of Contract and Current Review:
  - Contract:
    - purchase 2800 MPPCs from Hamamatsu
    - measure characteristics of MPPCs according to the testing plan given in Table 2 (in following slides)
    - determine whether each MPPC meets specifications in Table 1 (subsequent slides) or not
    - ship tested MPPCs to JLab and provide all technical documentation
    - adhere to the schedule, particularly the delivery milestones

Quantities Characterized in 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 in 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.***

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.

Project Overview

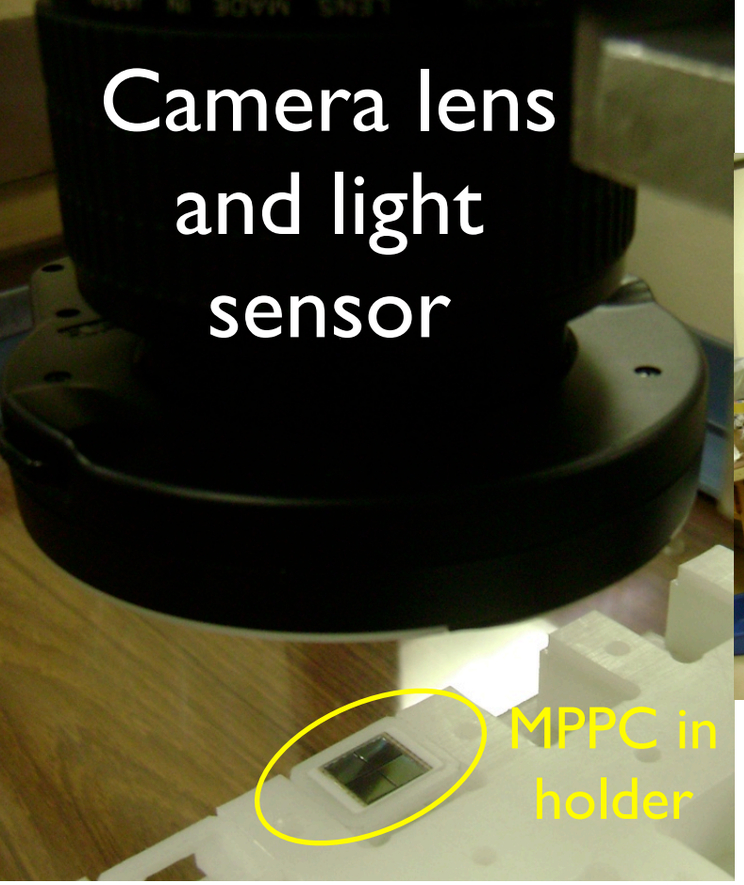
- Scope of Contract and Current Review, continued:
  - Review:
    - Determine whether or not USM is sufficiently prepared to begin production testing
    - Primary basis for permission to proceed

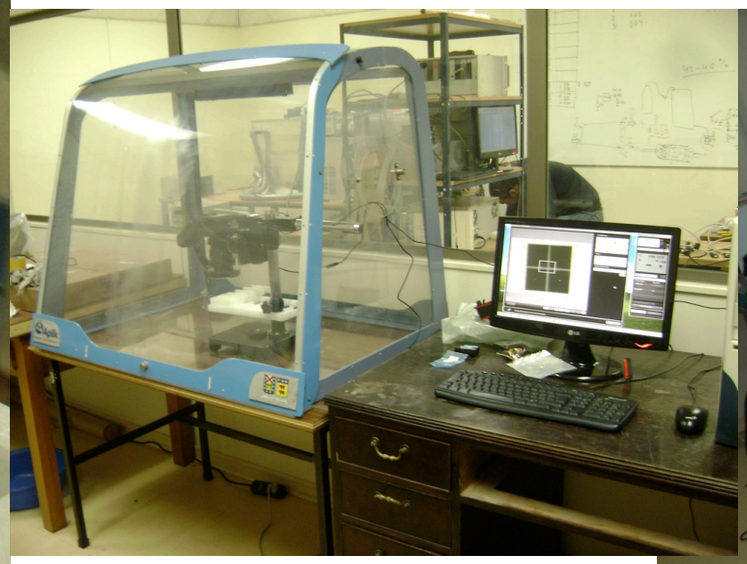
Project Overview

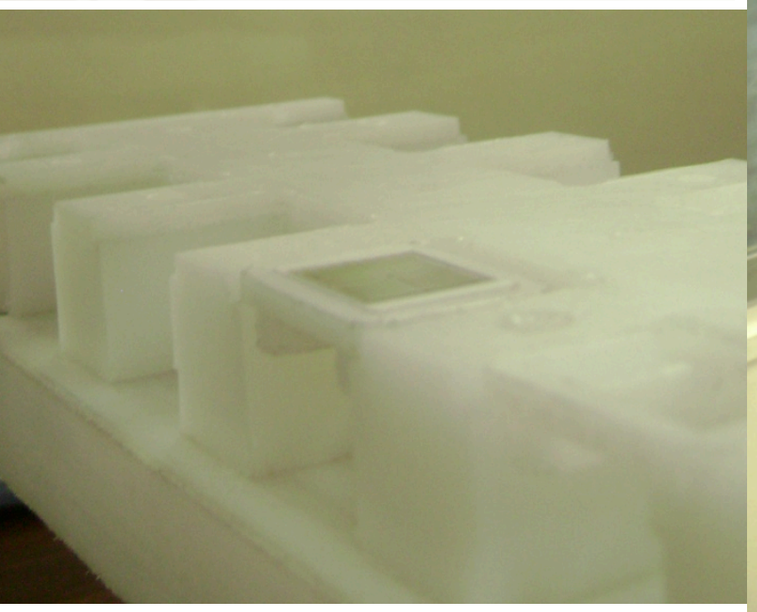
- Status of Equipment: *all equipment is ready*
  - Station I: visual inspection station is in use, photographs are put in database, operator-database interface is in use, comments are stored in database.
  - Station II: PDE station is in use, taking data with LED/ green-fiber light source, storing spectra in database; pulse characteristics can be determined.
  - Station III: 32-MPPC station is in use, can take data with 30 MPPCs, can change temperatures over wide range, can measure and store I-V curves, can store spectra from variable-intensity LED pulses in database.

Layout of two rooms for MPPC tests

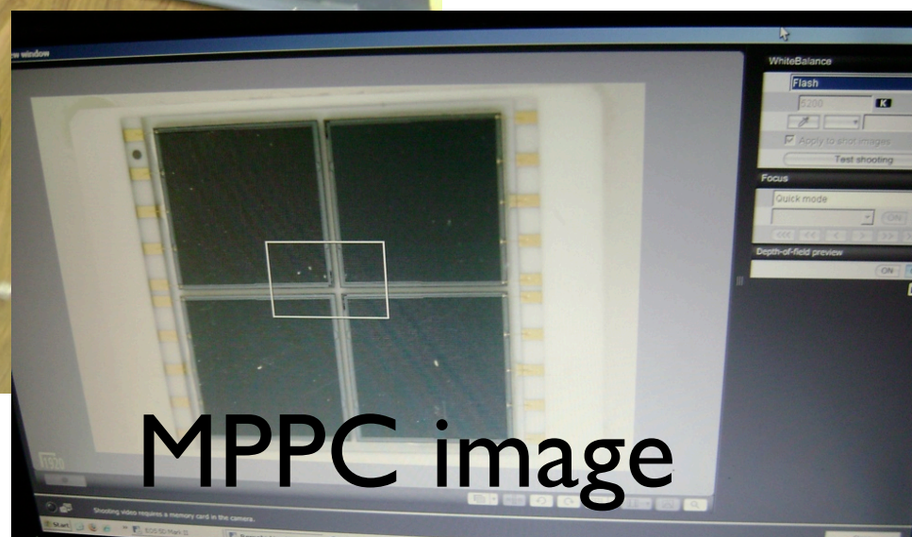
Inspection Station (Stage 1)





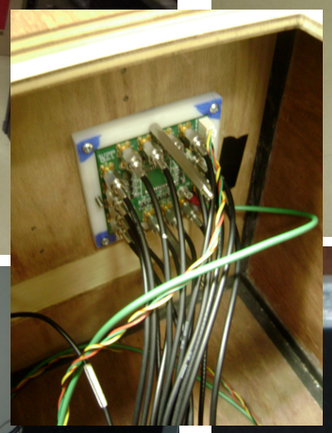


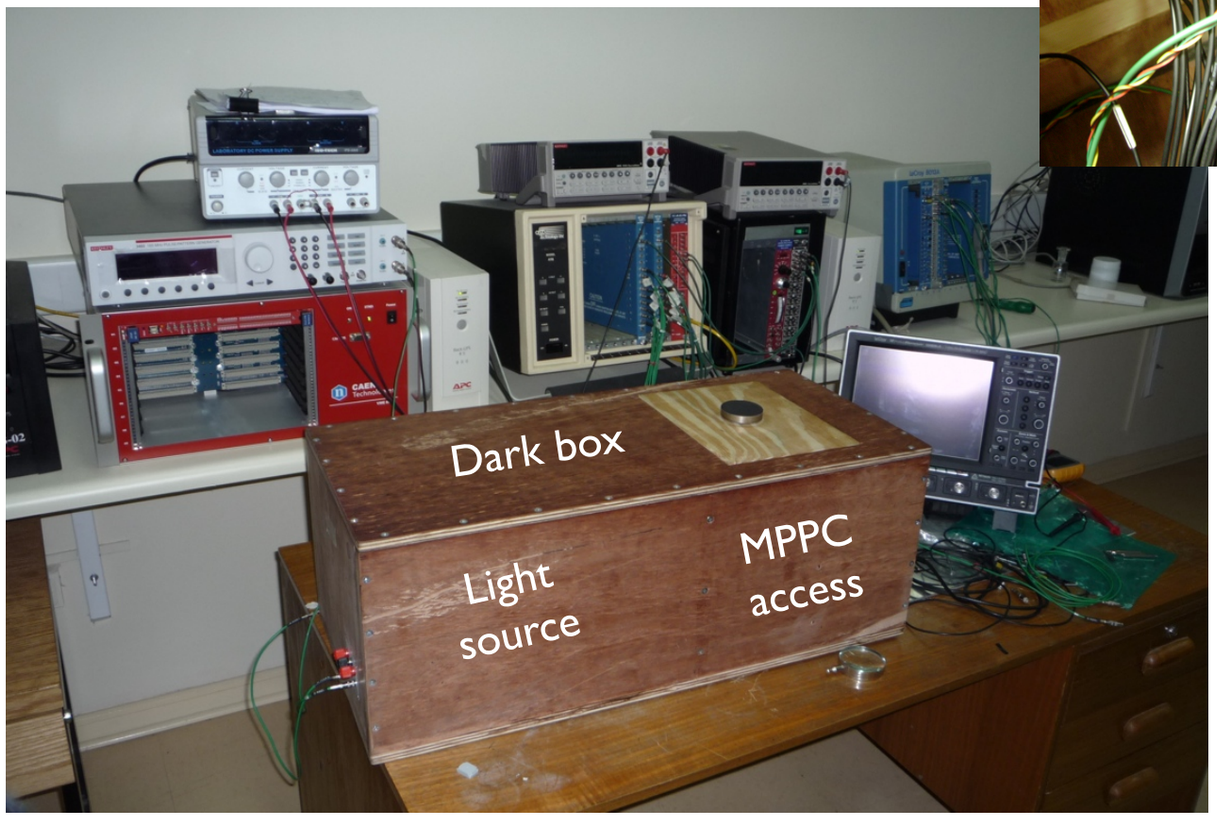
Camera setup

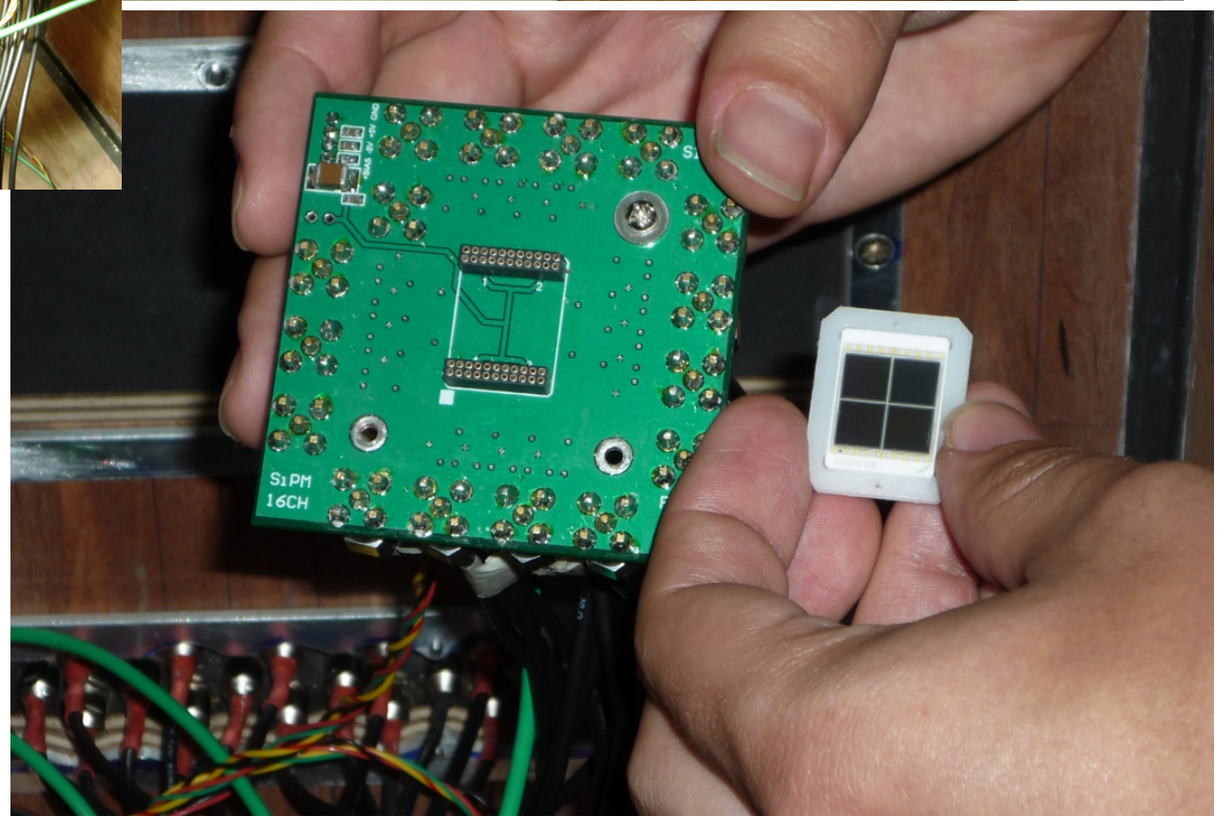


MPPC image

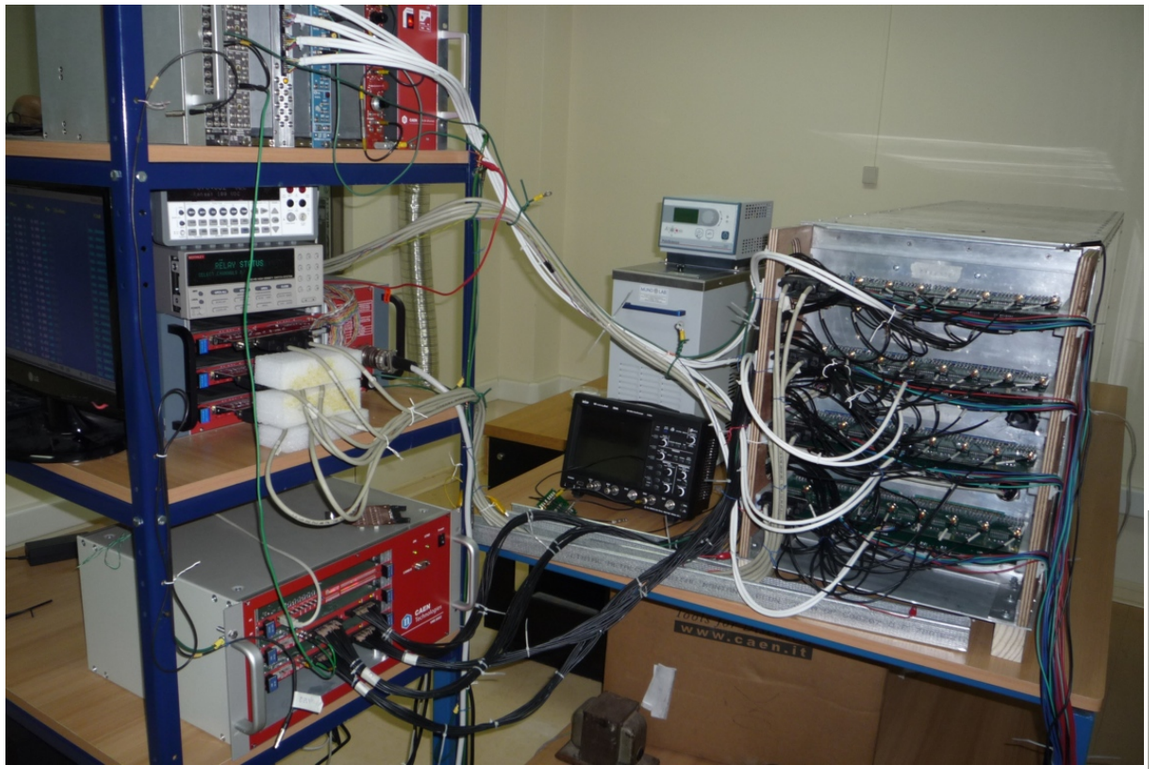
PDE Station (Stage II)

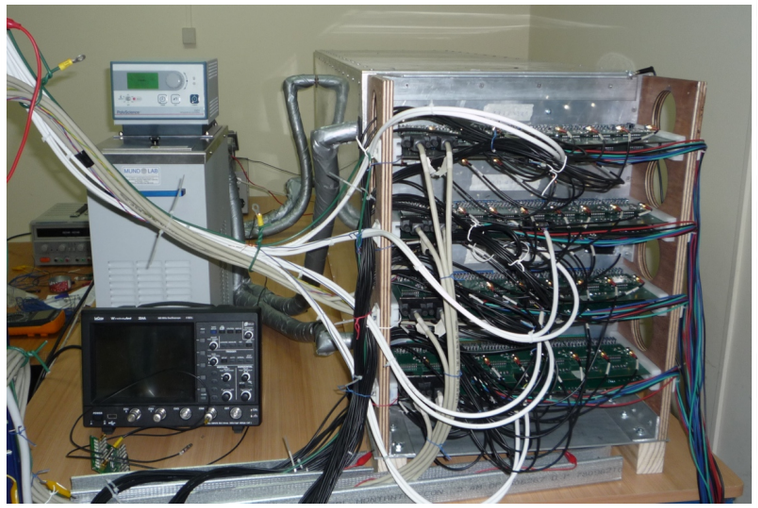


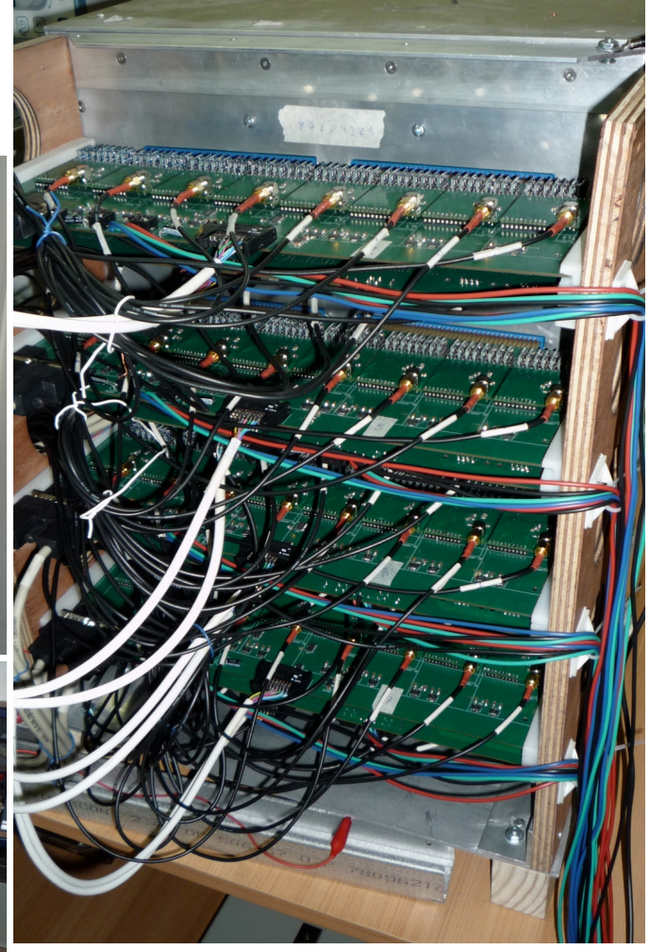


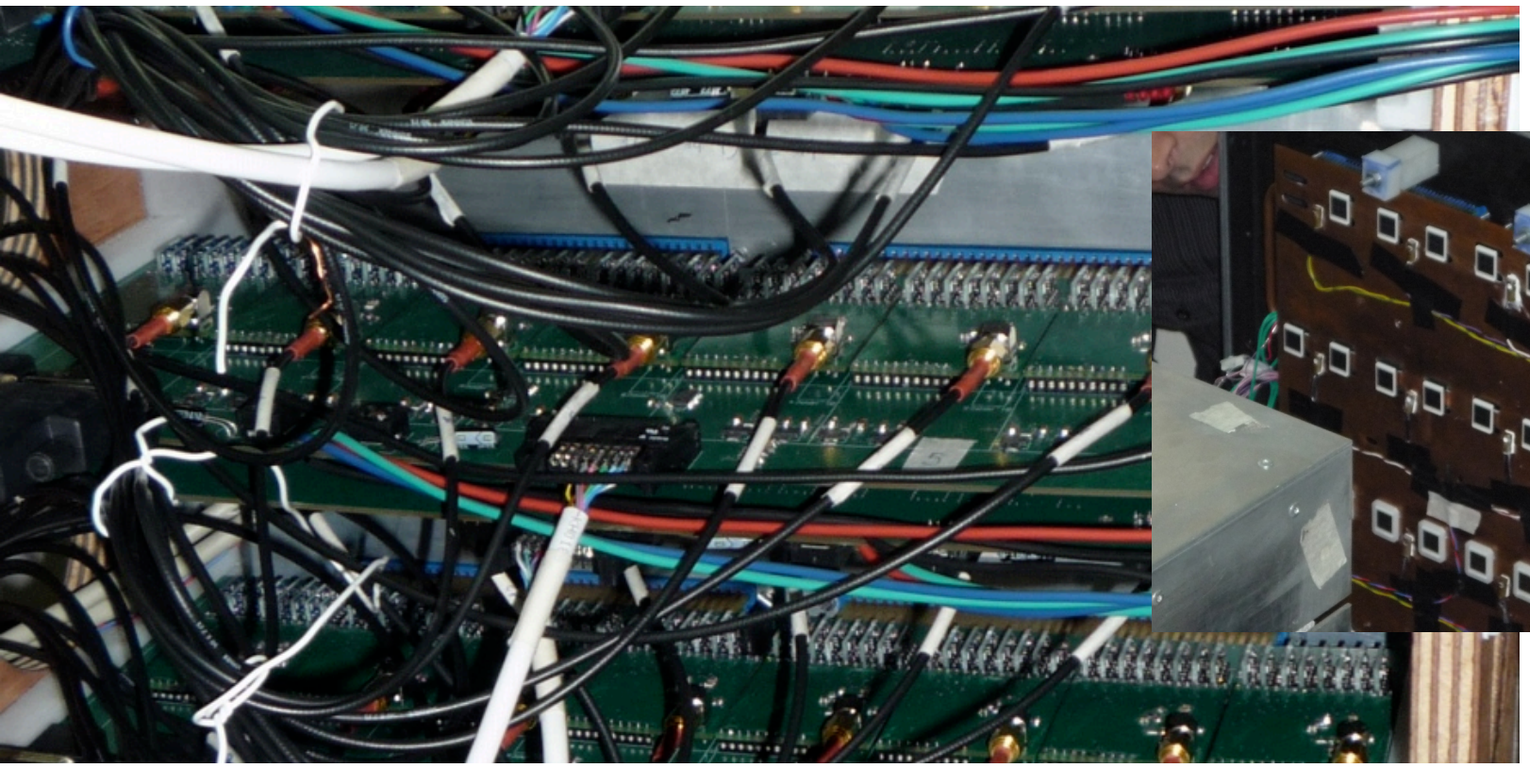


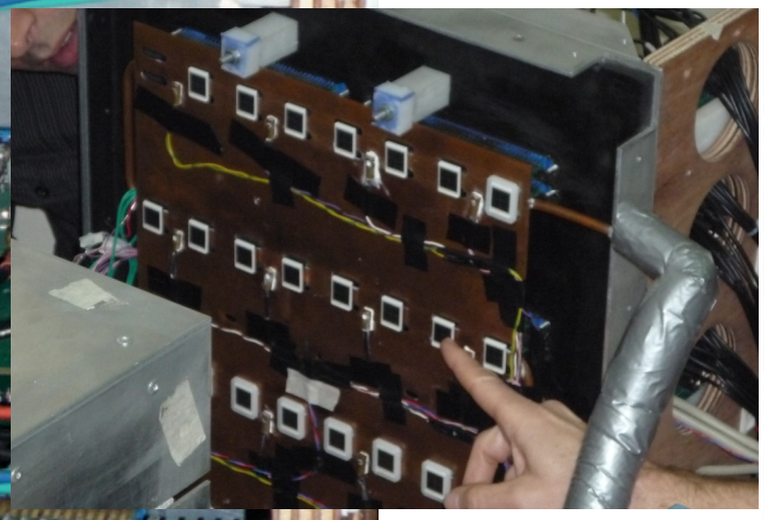
Temperature-Controlled Station (Stage III)

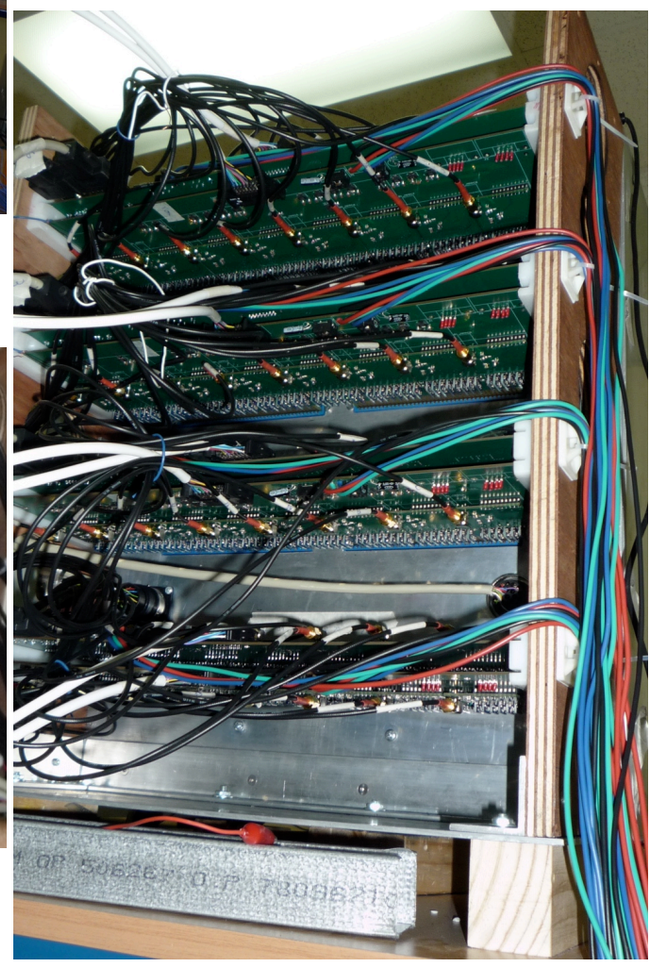












Project Overview

- Status of Equipment: *known items needing to be addressed*
  - Thermal connection MPPC to copper plate: need silicone pads
  - Temperature measurement of copper plate: can take data as is (measured at 16 points on plate), but final calibration method still under discussion
- Inspection station needs faster computer - 20 Mbyte digital images handled too slowly to be practical
- New holders for MPPCs to be completed (1-2 days)
- Would like to get fully calibrated photodiode

- Training of Personnel
  - All personnel currently involved have been the people who developed the hardware and software. Currently we have:
  - Two operators for Stage 3 (Alam and Orlando)
  - One operator for Stage 2 (Rimsky)
  - One operator for Stage 1 (René)
- As production begins, will hire more people as needed
  - Training consists of explanation of procedures and two or more "shadow shifts"
  - Completion of training of new operators is certified in writing by existing operator and counter-signed by Sergey Kuleshov, Alam Toro, and Pablo Viveros

Project Overview

- Storage and Shipping to Jefferson Lab. (Storage at JLab?)
  - MPPCs are kept in fire-resistant safe in a locked room next to visual inspection station
  - Shipping to JLab is via FedEx, with whom CCTVal has a contract:
    - This contract has been exercised via shipping of MPPCs from Hamamatsu
    - Customs issues have been addressed
    - ~1.5 weeks door-to-door including customs

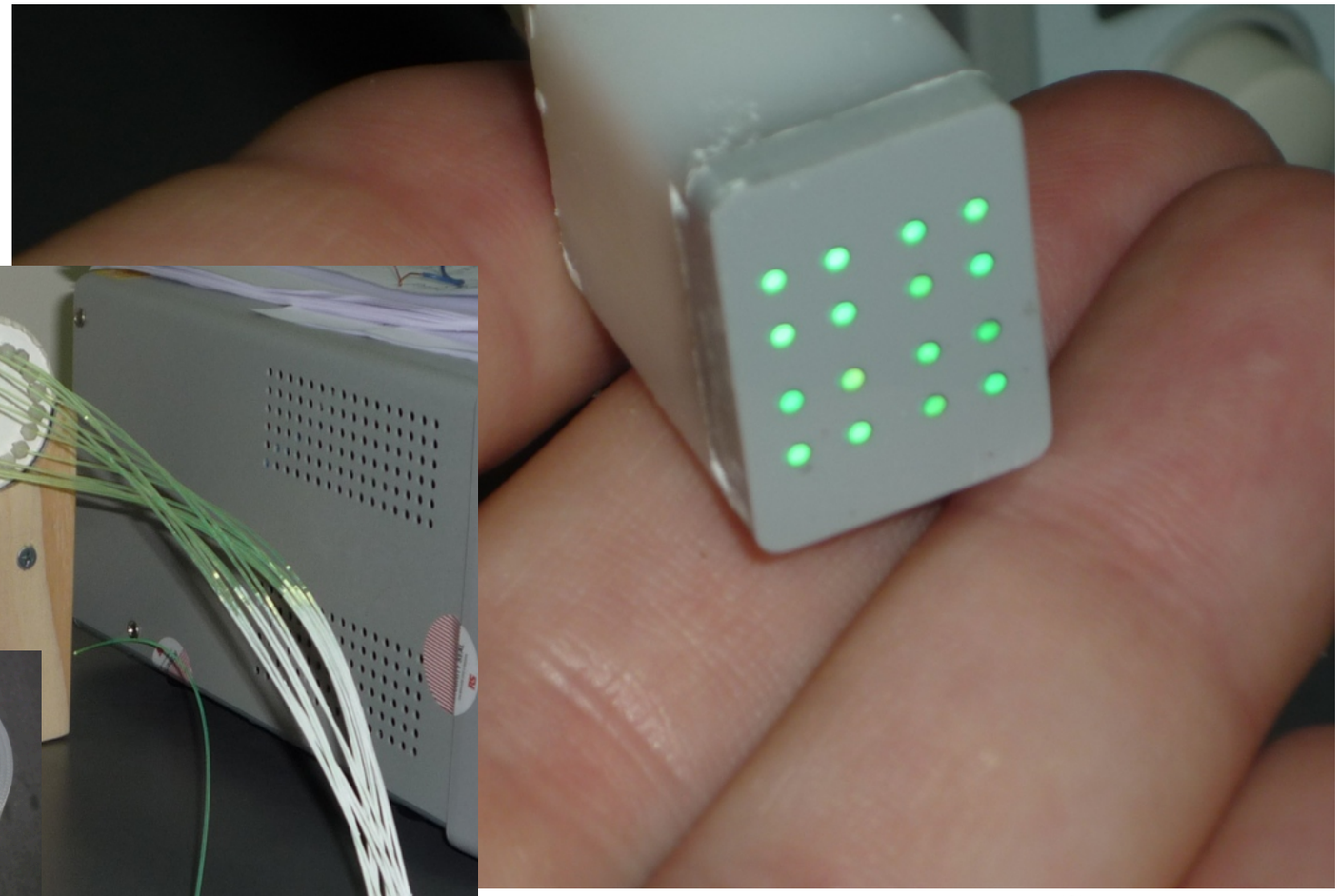
Description of Test Setup/Analysis

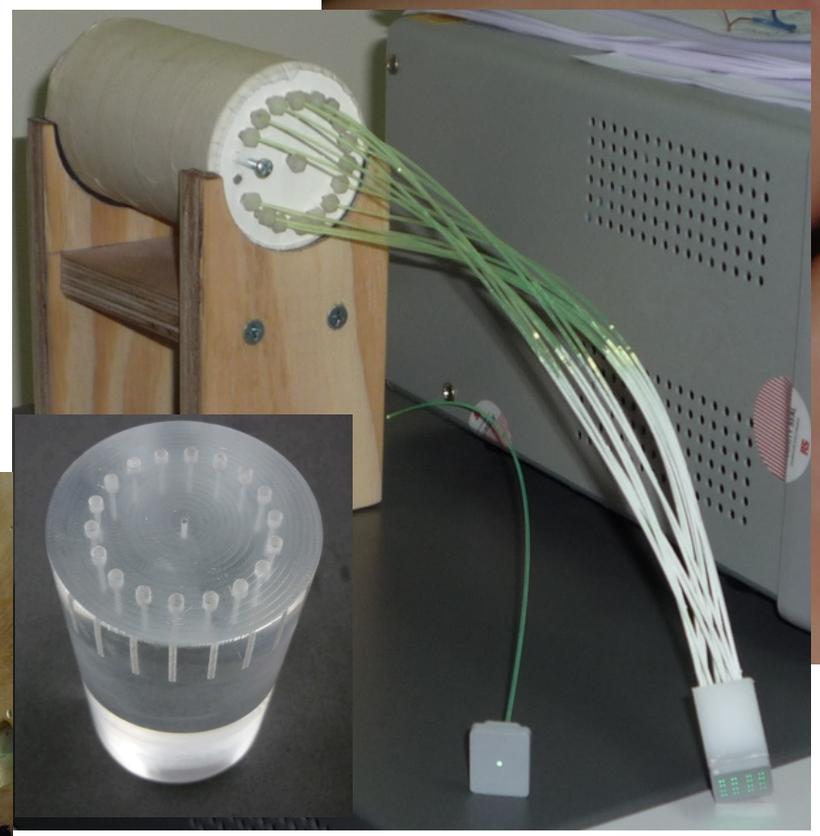
Description of Test Setup/Analysis

- Description of light source
  - 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

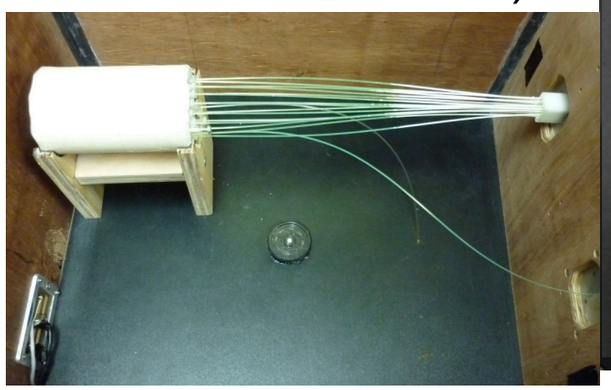
PDE Station Light Source

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

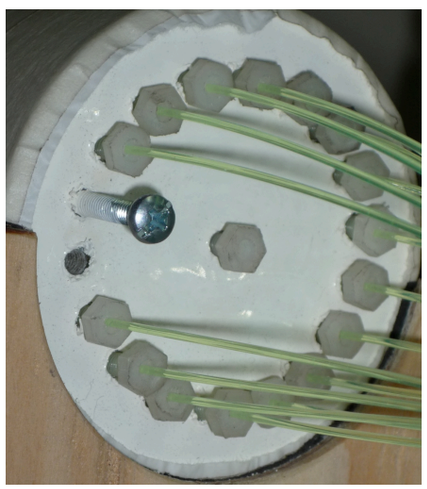




Light mixer (clear fiber goes into center)

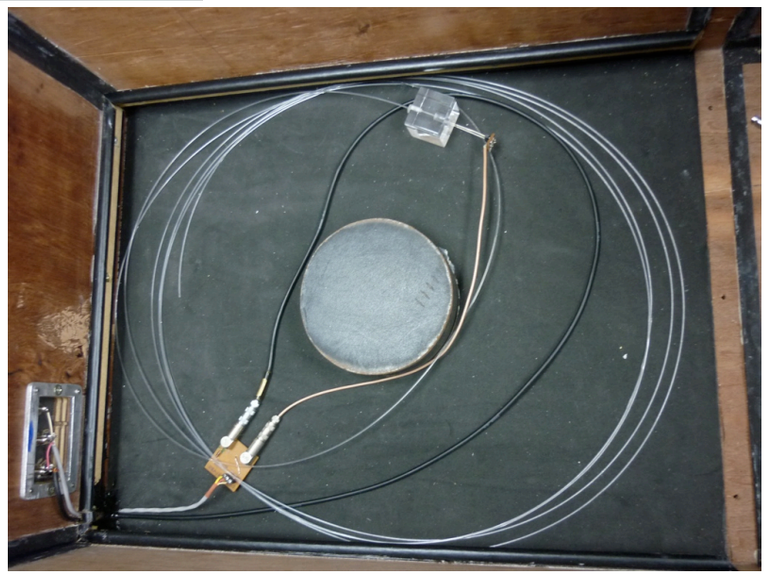


Output of 16 green fibers following mixer



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

Blue LED feeding clear fiber

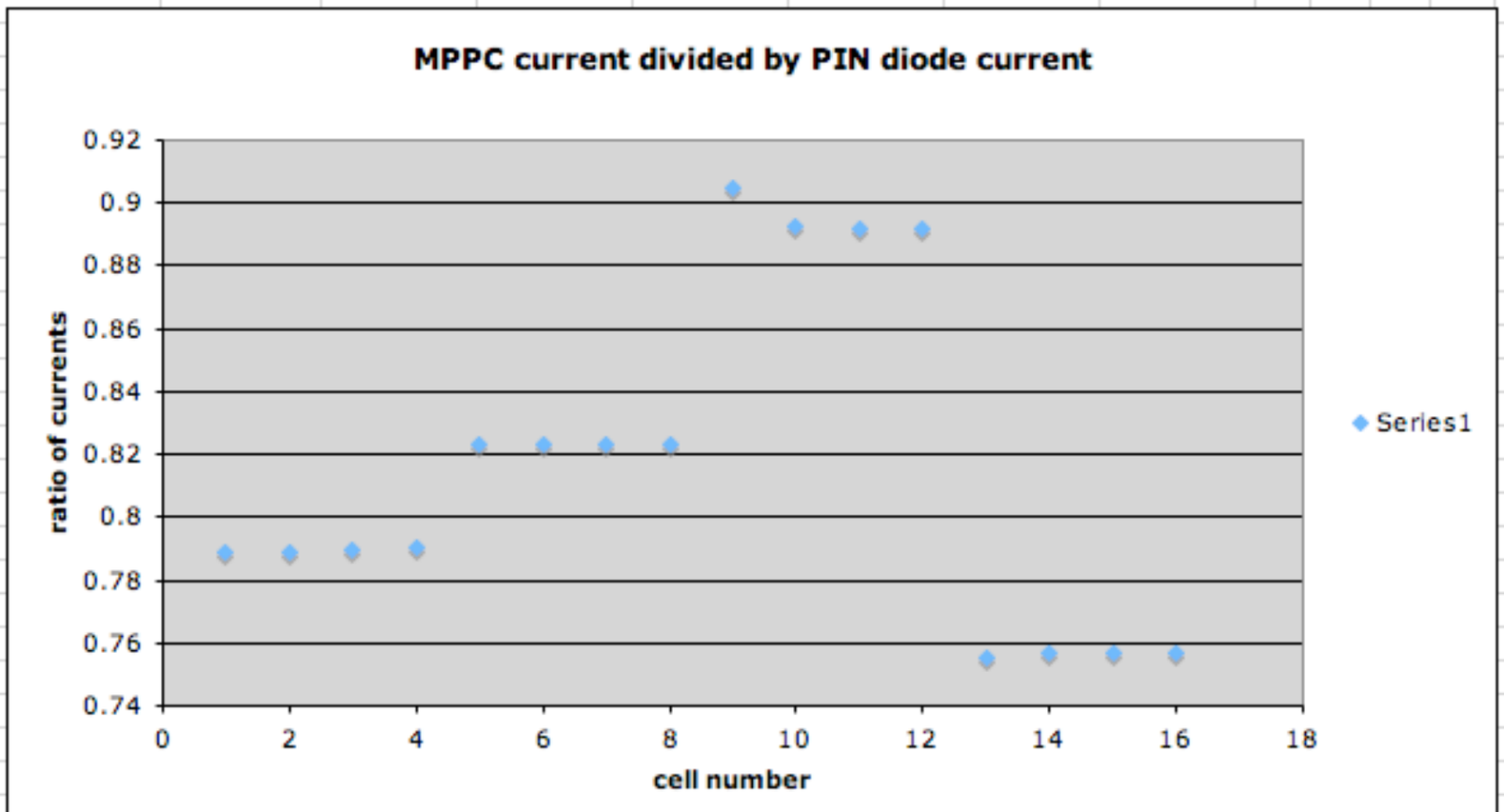


PDE station - Fiber Light Uniformity

- Use each cell in MPPC as individual PIN diode
- Illuminate cell with output fiber of USM light mixer
- Interpret cell-to-cell current, normalized to independent PIN diode, as the uniformity of out put of USM light mixer

PDE station - Fiber Light Uniformity

ch	Ipin diode Pedestal [uA]	I MPPC Pedestal [nA]	Ipin diode [uA]	I MPPC [nA]	ratio of MPPC cell current to PIN diode current						
1-1	2	1.09	97.5	76.88	0.78851282						
1-2	2	1.12	97.6	77.01	0.78903689		MPPC matrix				
1-3	2	1.15	97.7	77.15	0.78966223						
1-4	2	1.14	97.55	77.1	0.79036392			2-4	2-1	1-4	1-1
2-1	2	1.14	97.55	80.28	0.82296258			2-3	2-2	1-3	1-2
2-2	2	1.12	97.5	80.25	0.82307692			4-4	4-1	3-4	3-1
2-3	2	1.1	97.49	80.22	0.82285363			4-3	4-2	3-3	3-2
2-4	2	1.1	97.39	80.2	0.82349317						
3-1	2	1.23	97.38	88.1	0.90470322						
3-2	1	1.17	97.4	86.9	0.89219713						
3-3	1	1.13	97.45	86.9	0.89173935						
3-4	1	1.11	97.35	86.8	0.89162815						
4-1	1	0.93	97.74	73.8	0.75506446						
4-2	1	0.92	97.6	73.84	0.75655738						
4-3	1	0.91	97.55	73.82	0.75674013						
4-4	1	0.9	97.5	73.82	0.75712821						
3-2	1	0.97	97.5	87	measure after all of the rest						



Description of Test Setup/Analysis

- Test conditions: *PDE station*
  - Fixed amount of light, room temperature, 1 MPPC
  - Light from fibers measured by monitoring PMT and 16 MPPC cells
  - Measure fast light pulse amplitudes and pulse shape characteristics
- Test conditions: *Temperature-controlled station*
  - Variable amount of light, fixed temperature, 32 MPPCs
  - Several MPPCs with precisely measured PDE to cross-calibrate the rest
  - Measure fast light pulse amplitudes and I-V curves

Description of Test Setup/Analysis

- How to determine parameters from data
  - Gain
    - Determine breakdown voltage by extrapolating one-electron peak signal vs. voltage to zero. Operate at fixed voltage above breakdown voltage.
    - At operating voltage, determine spacing between n-electron peaks, convert to charge equivalent, normalize to electron charge
  - Dark current/rate
    - Measure DC current directly
    - Measure rate in a gate of known length

Description of Test Setup/Analysis

- How to determine parameters from data, continued
  - PDE
    - Using light splitter of measured uniformity, put equal amounts of light into each of 16 MPPC cells and into one PMT
    - Determine PMT calibration from 1-photoelectron peak, use as constant monitor
    - Determine absolute light calibration from silicon device of known efficiency
- Other quantities: see posted writeup for complete explanation

Description of Test Setup/Analysis

- Comparison of SiPM specifications between USM and JLab measurements
  - PDE measurements consistent with ~20%
    - Calibrated photodiode will provide optimal normalization
    - Gain vs. voltage measured to determine breakdown voltage, see subsequent slides
- First gain, dark rate, crosstalk measurements on following slide

First look at comparing JLab measurements with USM's

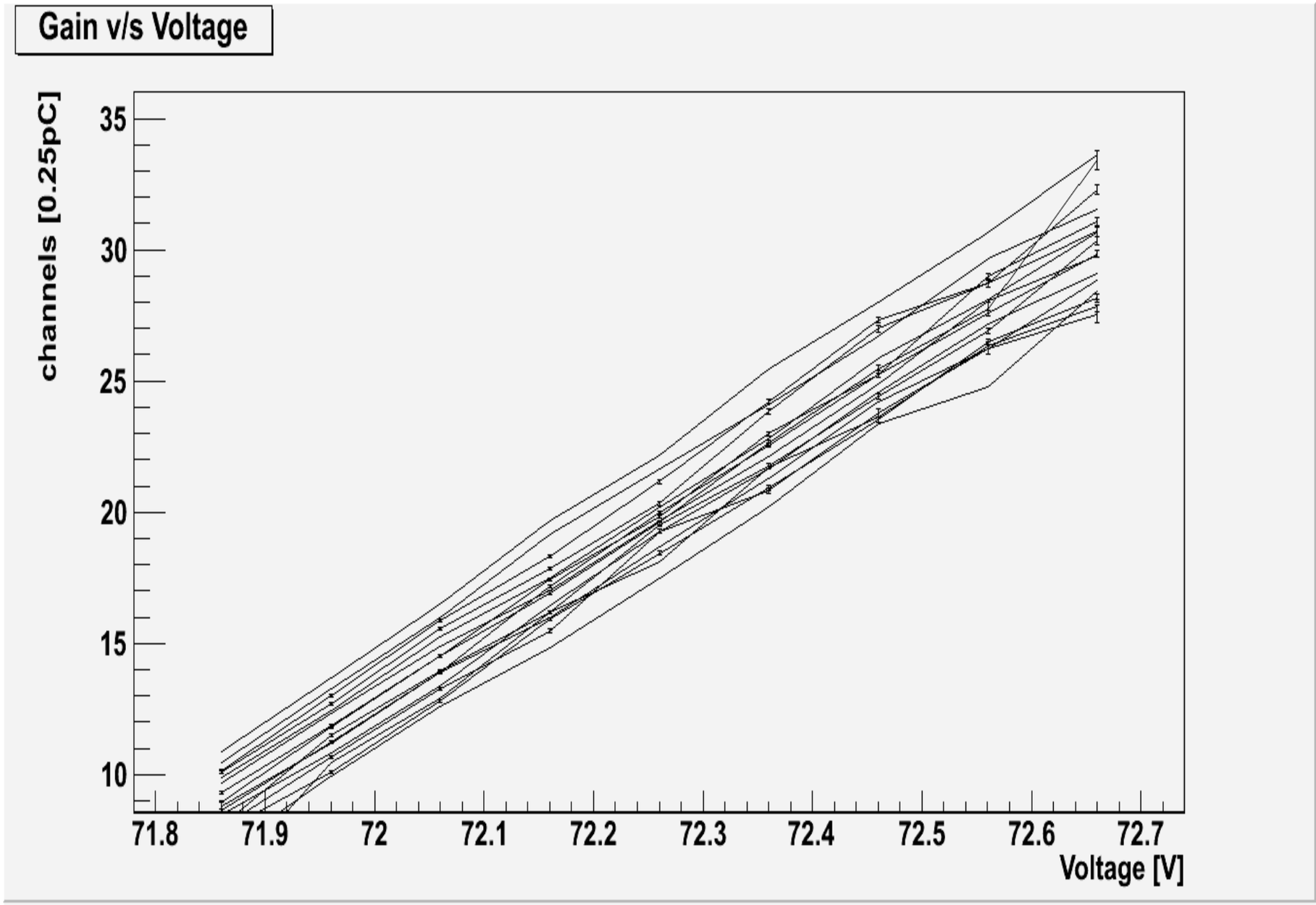
(note, 100 ns gate at USM vs 1000 ns gate at JLab)

Position	*MPPC S/N*	*UTFSM Gain*	*Jlab Gain*	*UTFSM dark rate*	*Jlab dark rate*	*UTFSM Crosstalk + Afterpulses*	*Jlab Crosstalk + Afterpulses*
4	95	5.1	5.63	0.78	1.2	0.34	0.16
5	96	5.1	5.45	0.83	1.1	0.37	0.14
6	86	4.8	5.63	0.81	1.2	0.34	0.16
7	87	5.5	5.64	0.75	1.2	0.39	0.15
8	88	5.0	5.64	0.73	1.0	0.34	0.15
9	89	5.1	6.62	0.71	1.2	0.35	0.16
10	90	5.7	5.61	0.88	1.0	0.36	0.15
12	64	4.7	5.48	0.69	1.1	0.32	0.14
13	65	5.0	5.65	0.78	1.1	0.31	0.16
14	66	5.0	5.45	0.78	1.1	0.30	0.14
25	70	6.5	5.65	0.56	1.1	0.36	0.16
26	72	5.6	5.55	0.63	1.1	0.36	0.14
31	57	4.9	5.73	0.61	1.2	0.32	0.17

First look at gain vs. voltage from PDE station for MPPC #39

Break Down Voltage ch1: 71.4802
Break Down Voltage ch2: 71.5453
Break Down Voltage ch3: 71.5225
Break Down Voltage ch4: 71.5724
Break Down Voltage ch5: 71.4843
Break Down Voltage ch6: 71.5491
Break Down Voltage ch7: 71.4902
Break Down Voltage ch8: 71.5523
Break Down Voltage ch9: 71.5299
Break Down Voltage ch10: 71.5837
Break Down Voltage ch11: 71.5117
Break Down Voltage ch12: 71.581
Break Down Voltage ch13: 71.4807
Break Down Voltage ch14: 71.551
Break Down Voltage ch15: 71.4737
Break Down Voltage ch16: 71.4734

all this for mppc N° 39



Description of Test Setup/Analysis

- 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

Description of Test Setup/Analysis

- Commissioning plan
  - Cross-check of JLab and Hamamatsu numbers for the 30 MPPCs sent from JLab
  - Calibrate PDE for 32 MPPCs, install all 32 into temperature-controlled darkbox
    - Determine light intensity pattern
    - Determine temperature uniformity?
    - Measure all properties, 3-4 different temperatures
- Rearrange the same set of 32 MPPCs
  - Re-measure all properties, check for consistency
  - Re-arrange and repeat until consistency verified