Photomultiplier Linearity Studies

Presented by:
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Motivation

- Want to understand usability range of Photomultiplier Tubes to be used as Luminosity Monitors.
- Want to find conditions for good linearity, better than 2%, for January run.
- For PREX, would like to have linearity better than 0.5-1%.

Formalism

- A PMT's non-linear response can be expressed as follows:

$$N^{\pm}_{PMT} = N^{\pm} \times \left(1 + \beta N^{\pm}\right)$$

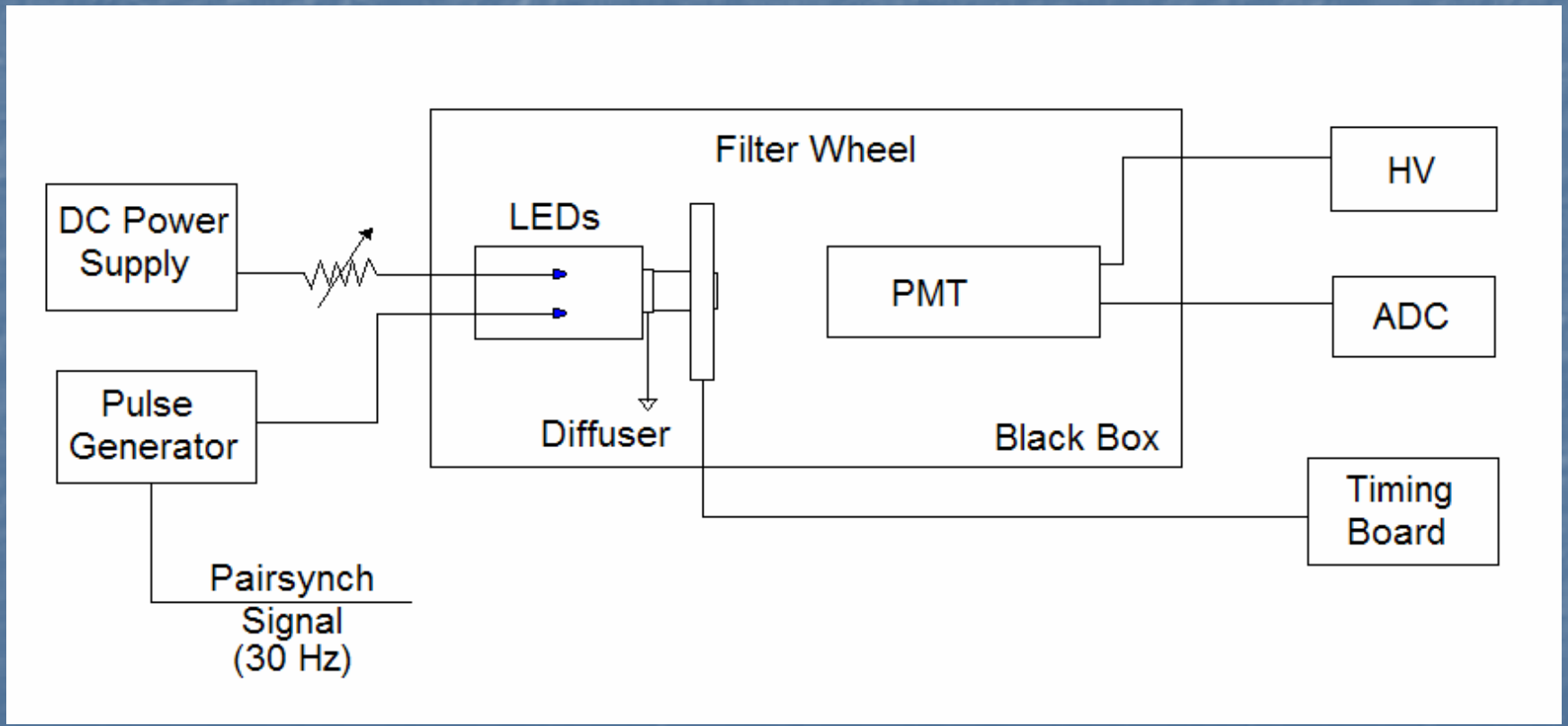
- Experimental asymmetry can be approximated:

$$A_{\exp} = \frac{N^{+}_{PMT} - N^{-}_{PMT}}{N^{+}_{PMT} + N^{-}_{PMT}} = A_{true} \times \left(1 + \beta N_0\right)$$

Experimental Test Setup

- 2 LEDs (1 kept constant, 1 pulsed at 30Hz) used to generate small asymmetry.
- Filter Wheel attenuates both light signals after passing through a diffuser. There are six filter settings (0,20,40,60,80 & 100%).
- Small aperture is used for stability.
- PMT output is integrated by a 16 bit HAPPEx ADC.

Experimental Test Setup

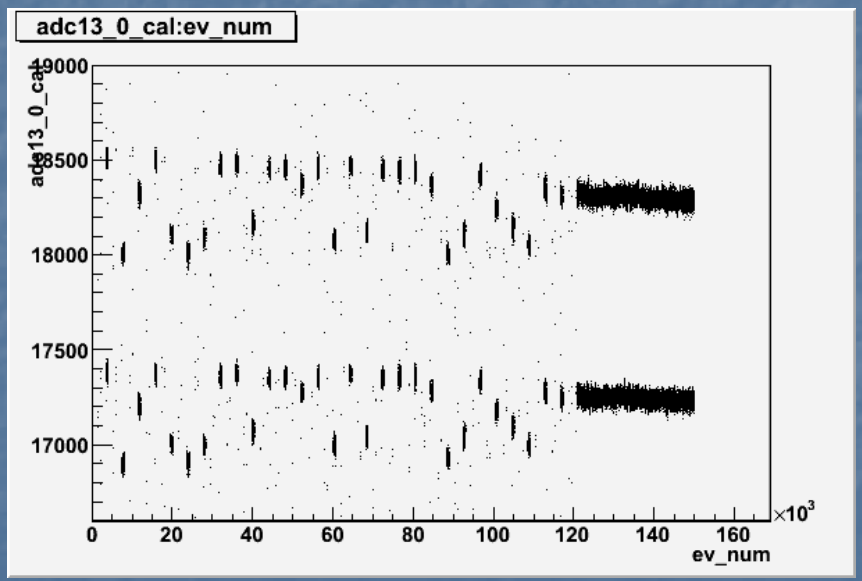


Evolution of Setup

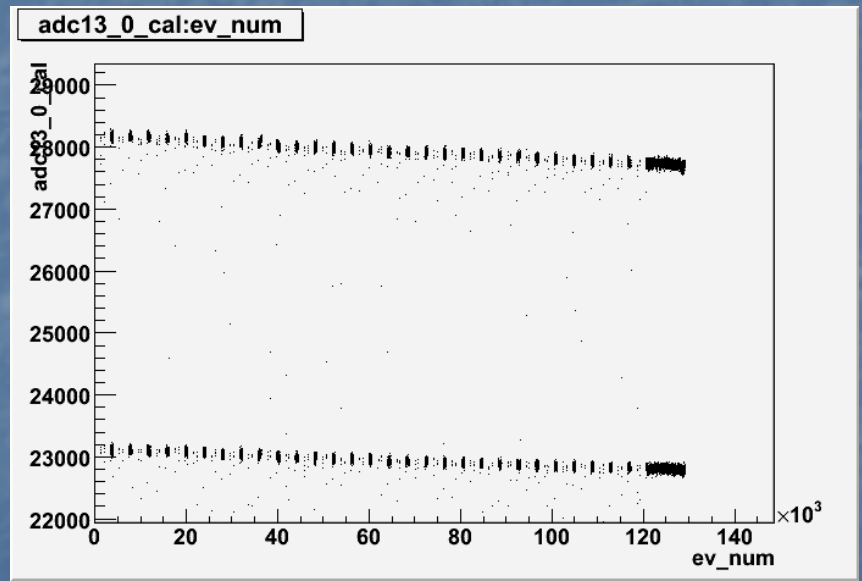
- Diffuser added to minimize effects from filter non-homogeneity.
- Randomization/automation of Filter Wheel setting.
- Aperture added to minimize signal scatter.
- Discovered gross non-linearity in lower end of modified ADC board 13.
- Started work with ADC board 17, where this effect is much smaller.

Aperture Effects

- Each bit of data represents the LED signals when the filter wheel returns to the 100% setting.



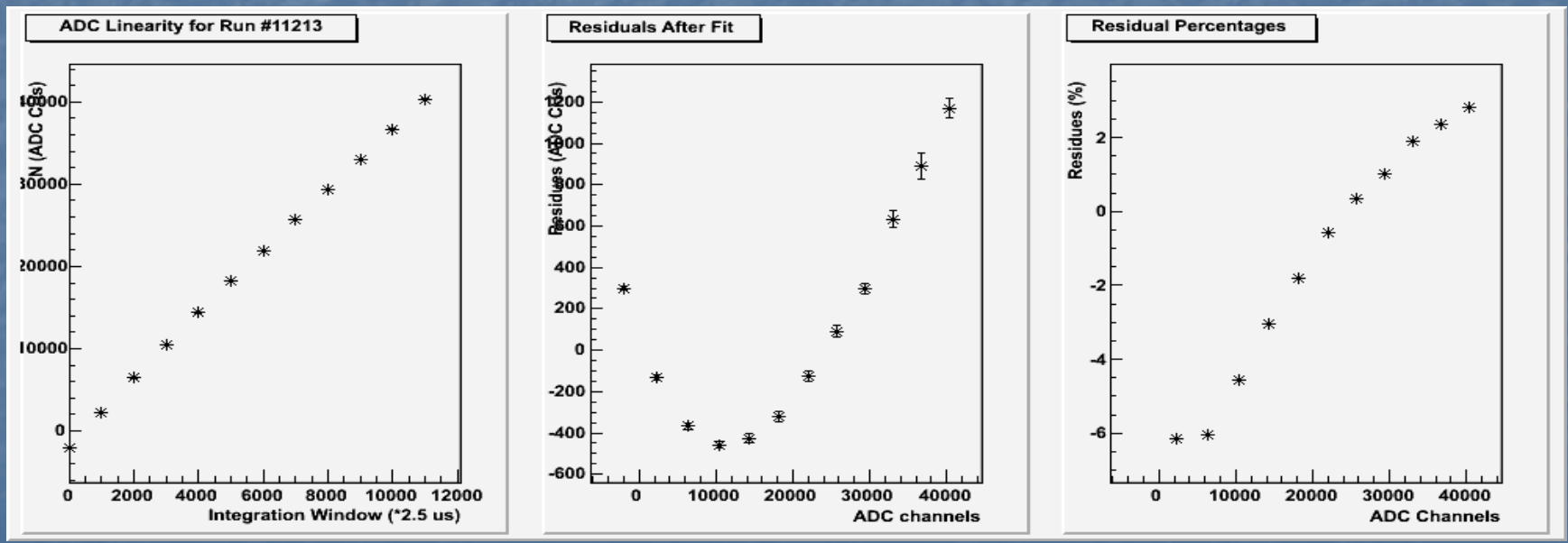
Before



After

Non-linearity of Board 13

- (Left) ADC response to CW LED w.r.t. Integration Time. (Center) Residuals after fitting data above 25K CHs. (Right) Residual Percentages.



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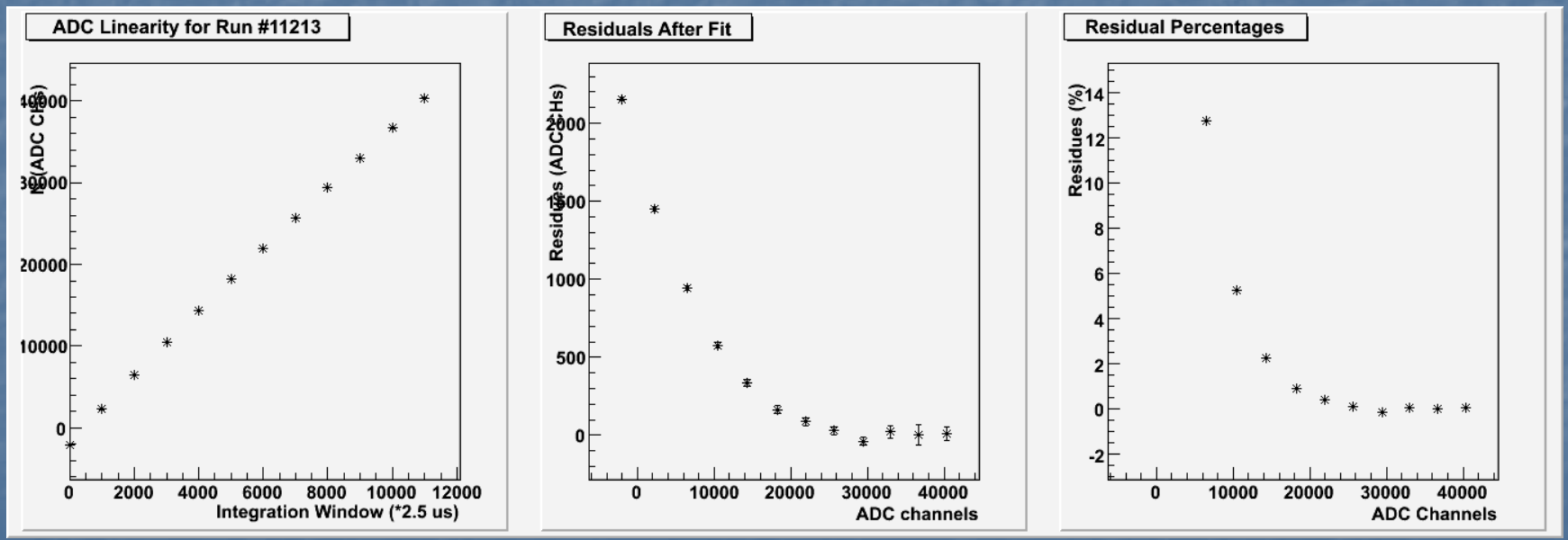
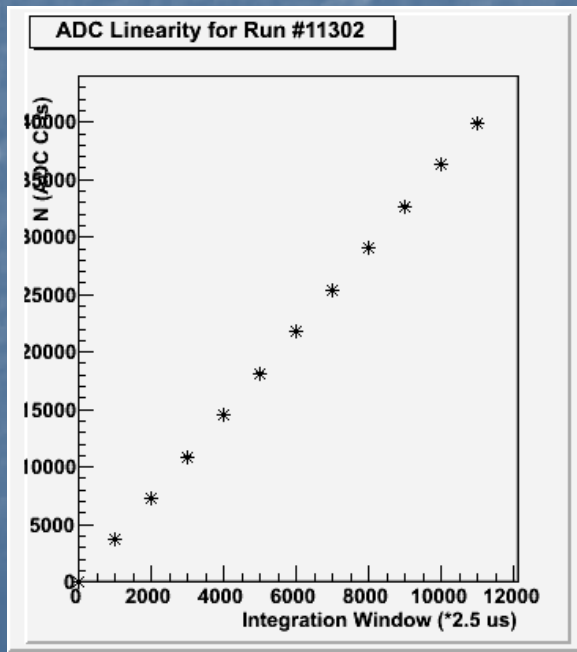
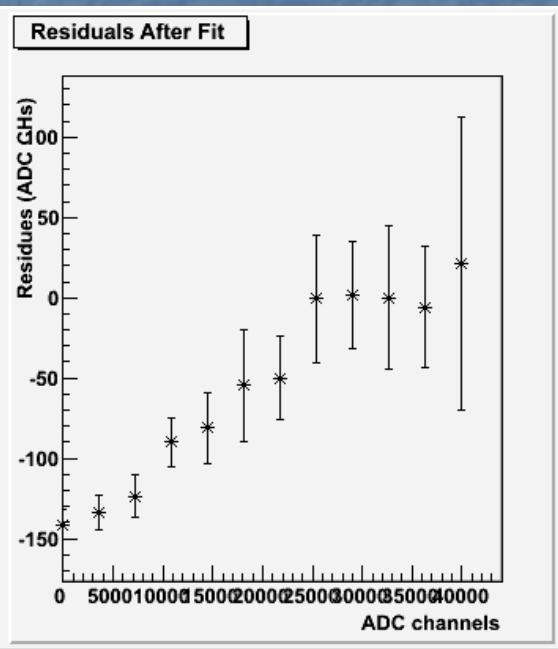
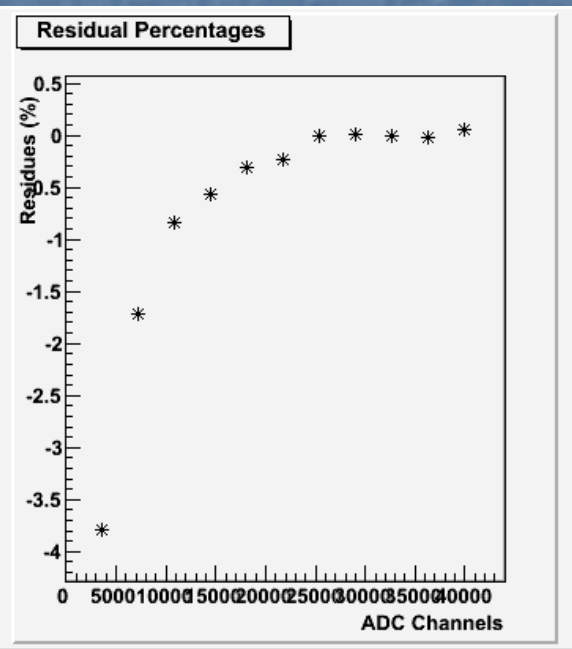


Non-linearity of Board 17

- Same plots for board 17.
- These runs are used to re-calibrate pedestals.





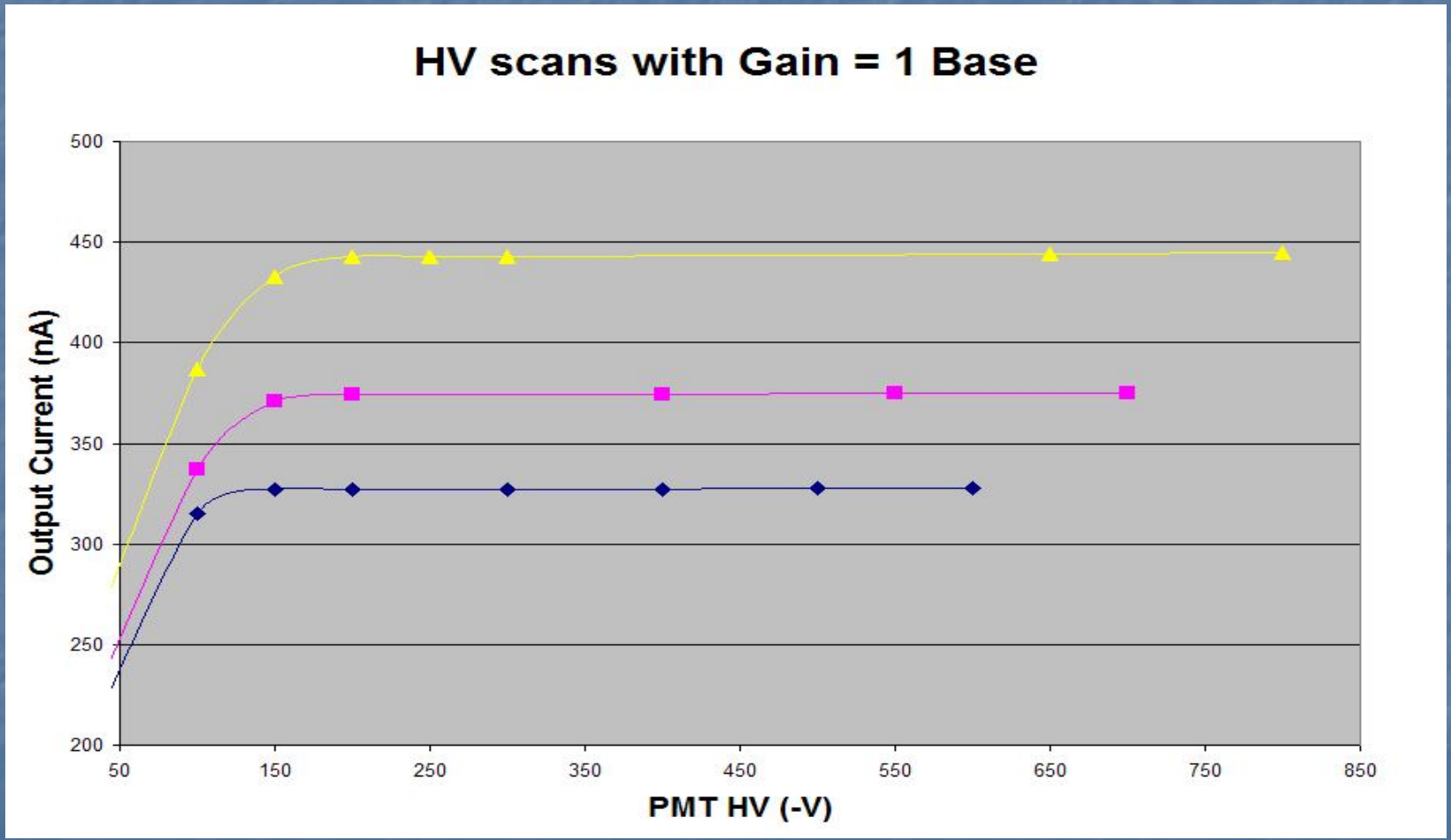


DATA AQUISITION

Calibrating PMT input

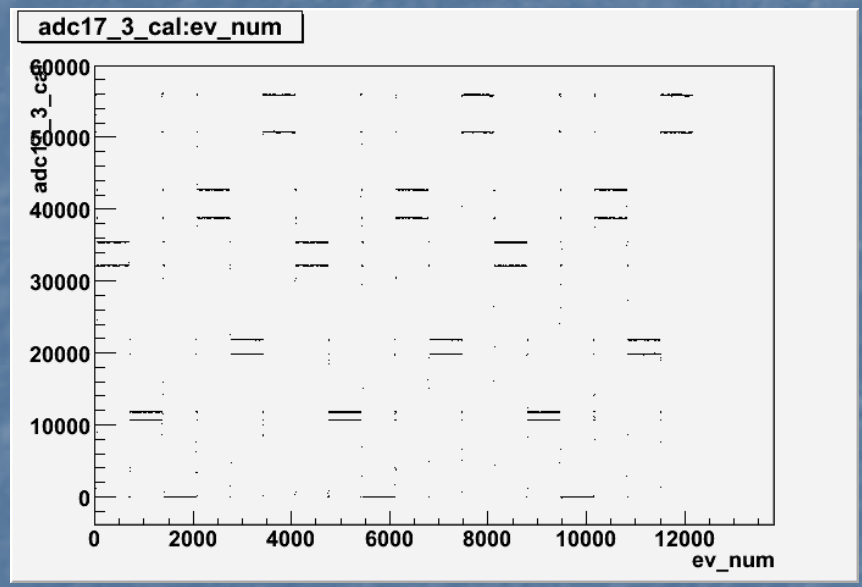
- Different LED light levels were calibrated before testing.
- Calibration done with a Gain=1 PMT base, provided by Riad Suleiman.

Calibrating PMT input



Analyzing the Data

- Typical run is 12000 events.
- Each filter setting is sampled 3 times.
- Max continuous signal is set at ~50000 CHs.
- Asymmetry of 100% signal is set at ~5%.



Analysis Method

- Plot asymmetry versus continuous signal ADC counts.
- Fit a line and interpret results.

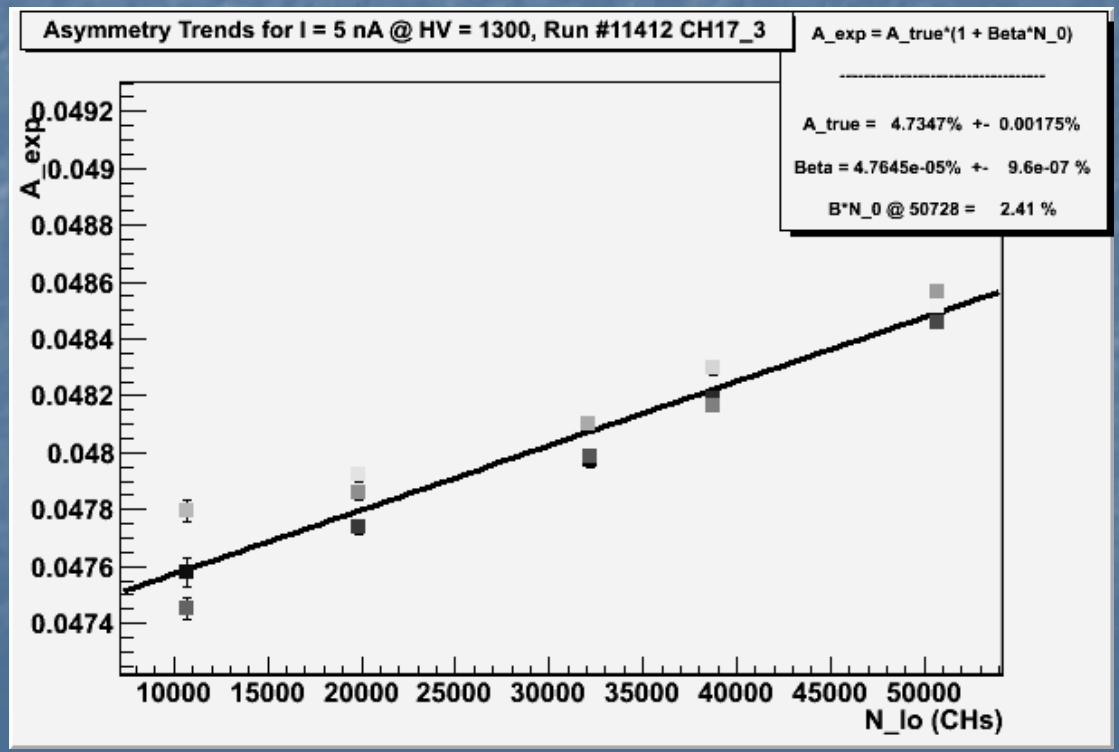
$$A_{\exp} = A_{true} \times \left(1 + \beta N_0\right)$$

Input = 5nA

HV = 1300

Output = 68uA

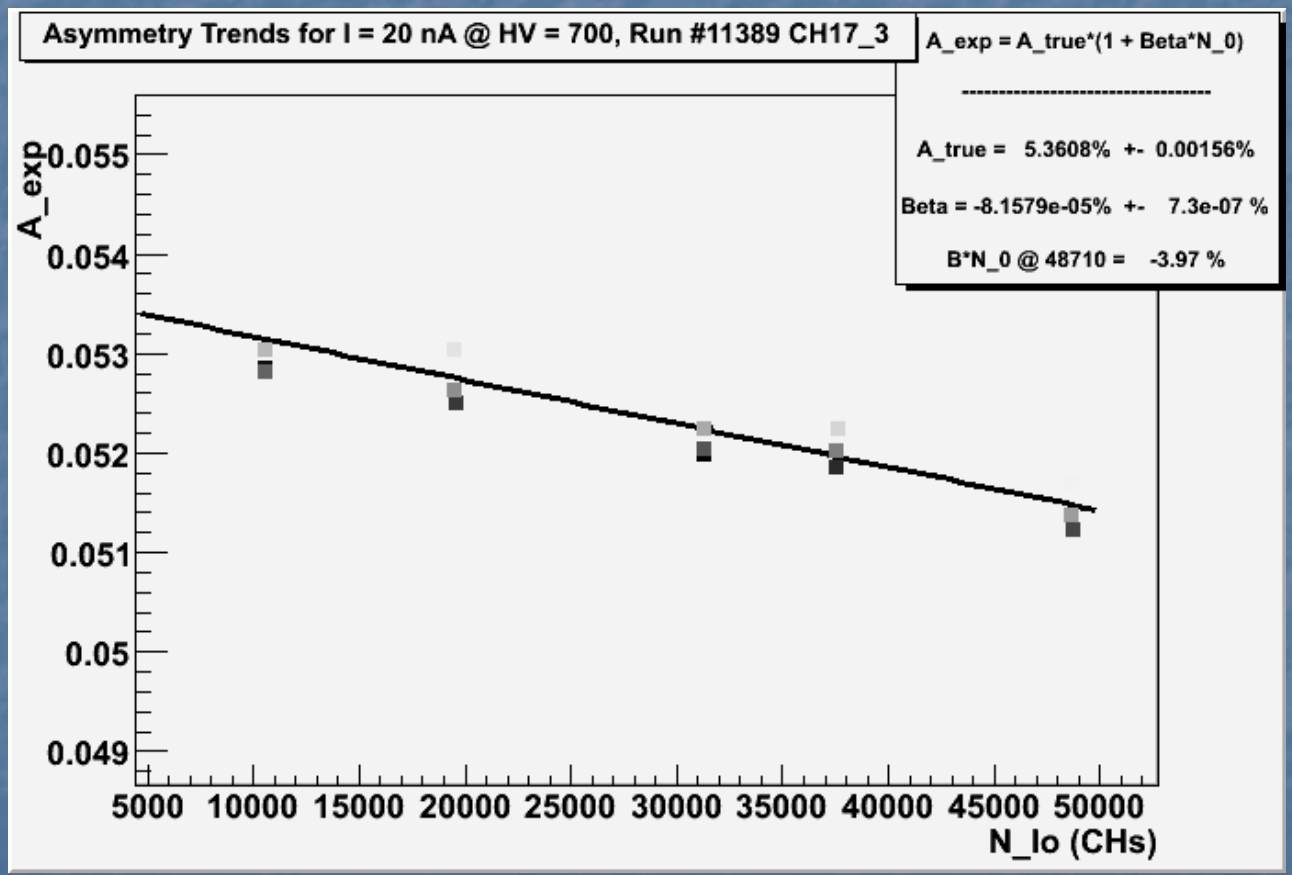
B*N_0 = 2.4%



Studies of Good Usability Range

- How does linearity depend on PMT input/output current?
- Observed hard ceiling of photocathode current.
- PMT is saturated at photocathode currents higher than ~30nA.

PMT input saturation



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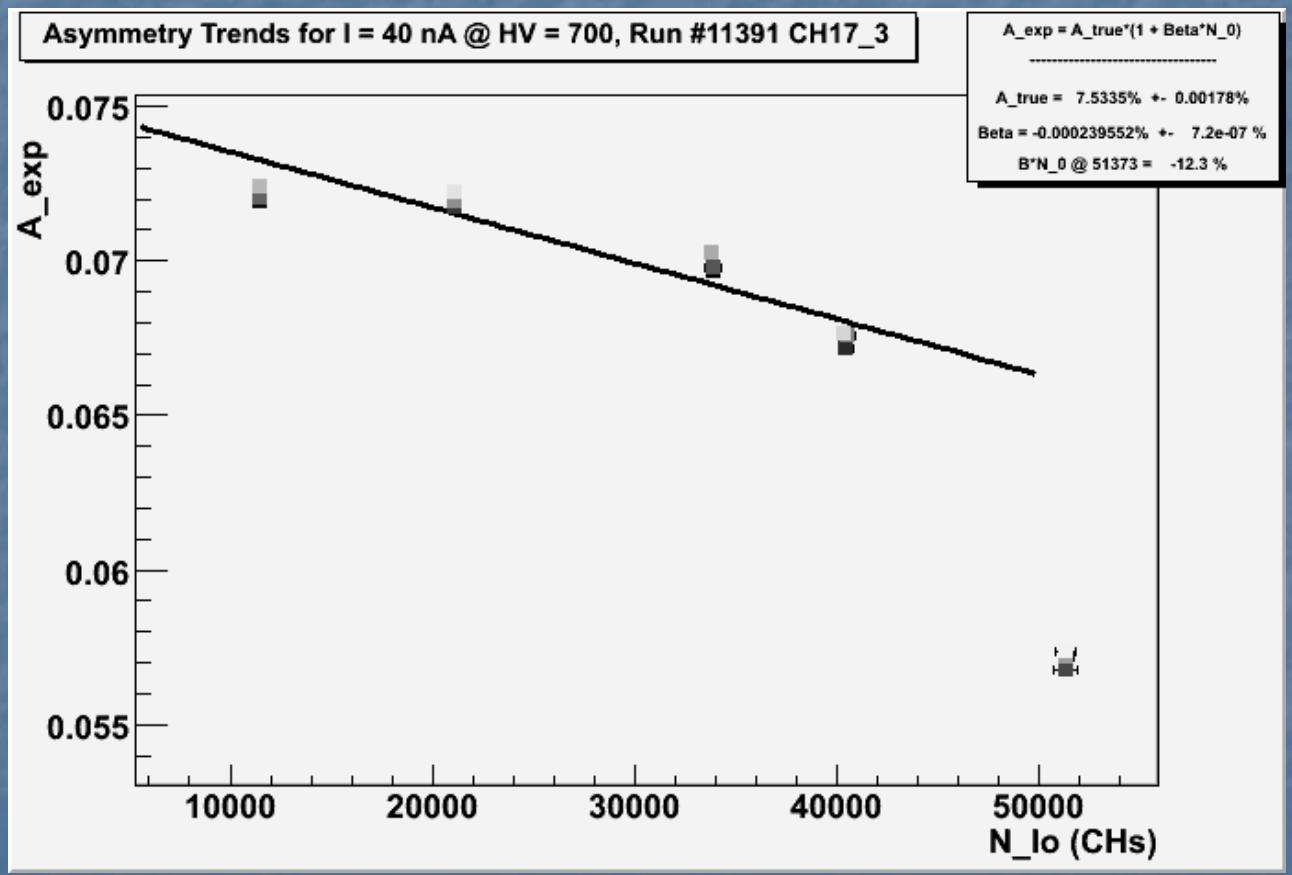

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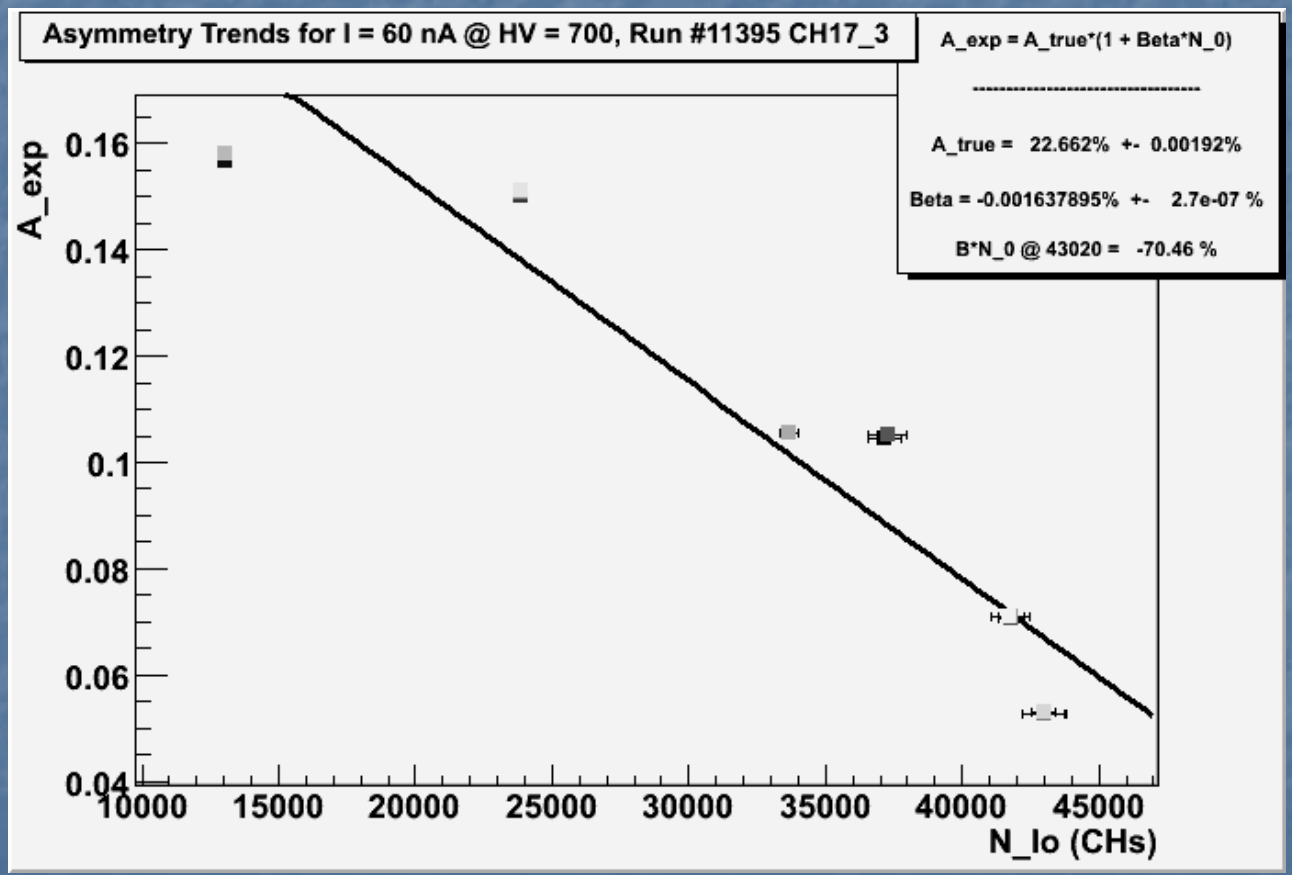

Studies of Good Usability Range

- For lower photocathode currents, observed HV range that produces good linearity. Typical I_{max}~50uA.
- Results good to sub-1%, but residual instabilities preclude making conclusions at better than the 0.5% level.

HV scan for 10nA

HV (-V)	I (uA)	IT (*2.5us)	Beta*N_0 (%)
1300	155	116	5.2
1200	104	172	3.48
1100	68	262	2.52
1000	43	415	1.32
900	26	689	0.78
800	15	1213	0.28
700	7.8	2300	-0.54
600	3.7	4820	-0.48
500	1.56	11300	-0.9
400	0.54	11300	-5.5

HV scan for 5nA

HV (-V)	I (uA)	IT (*2.5us)	Beta*N_0 (%)
1300	70	256	2.41
1200	48.5	369	1.29
1100	32.4	553	0.82
1000	20.7	867	0.11
900	12.6	1425	-0.26
800	7.2	2480	-0.21
700	3.8	4700	-0.34
600	1.8	9922	-0.39
500	0.76	11300	-1.96
400	0.26	11300	-13.85

HV scan for 2nA

HV (-V)	I (uA)	IT (*2.5us)	Beta*N_0 (%)
1700	44	404	2.79
1600	34	522	1.98
1500	26.3	680	1.27
1400	18.8	955	0.88
1300	13.5	1330	1.03
1200	9.4	1900	0.51
1100	6.3	2830	0.79
1000	4.1	4300	0.93
900	2.5	7300	0.23
800	1.4	11300	-0.075
700	0.75	11300	-3.15

New Developments

- Learned how to produce consistent results with 2 LED experimental test setup.
- Discovered ADC nonlinearity on modified board. This led to new pedestal calibration methods.
- Have way to calibrate photocathode current with Gain=1 PMT.
- Found good operational range for LUMI PMT at inputs up to 10 nA.

Next Up

- Would like to focus on minimizing pedestal noise, which is now ~100ppm.
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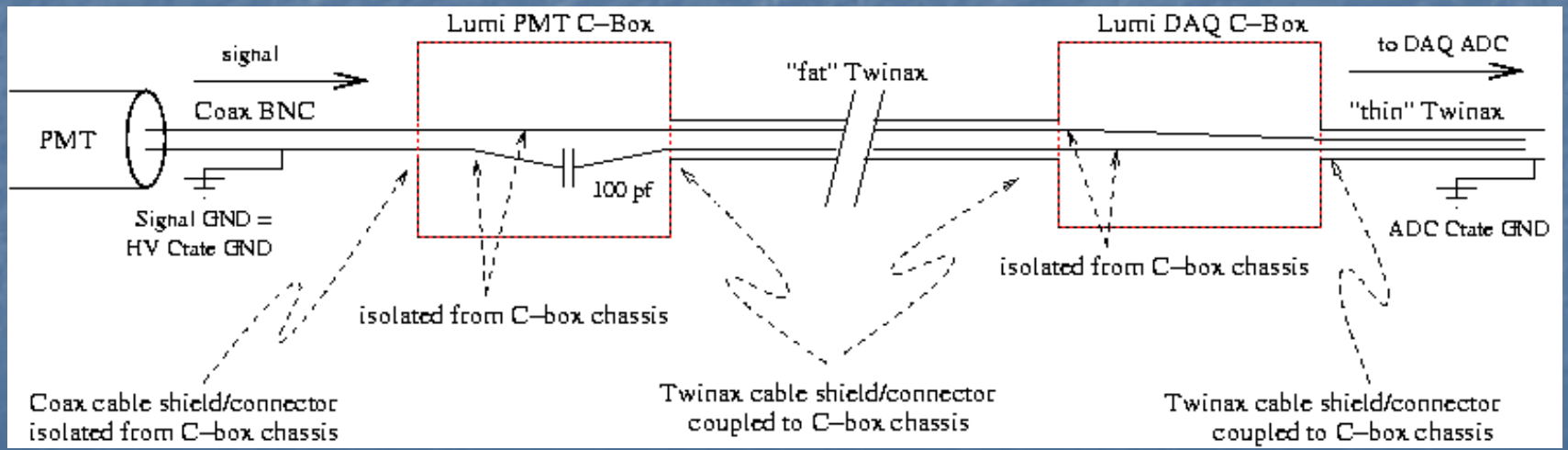


Next Up

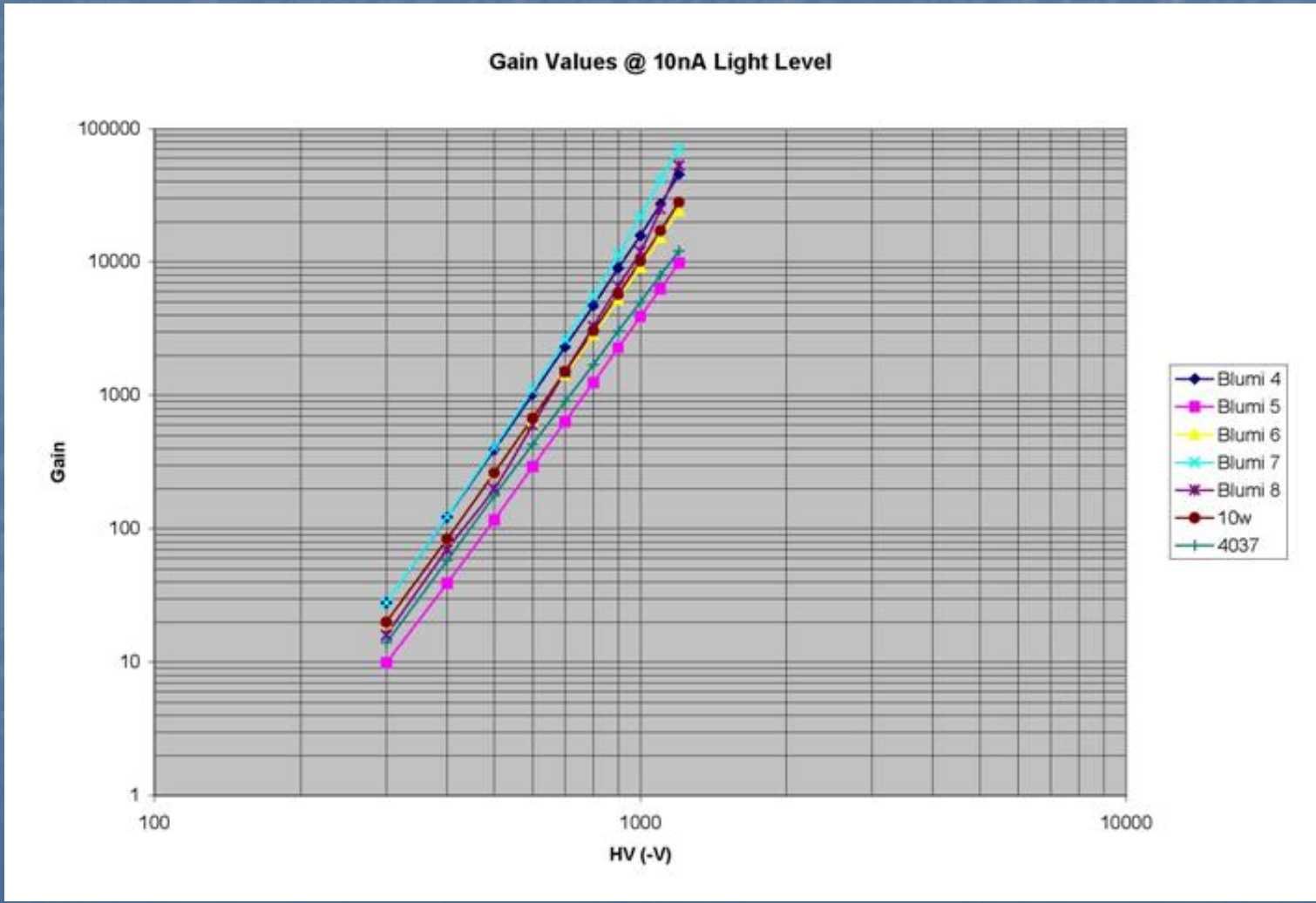
- Would like to focus on minimizing pedestal noise, which is now ~100ppm.
  - This will be done by reproducing LUMI setup inside Hall A.
- Want final gain curves for all LUMI PMTs.
- Document good linearity regions for all available LUMI PMTs in preparation for January run.

Acknowledgements

- Thanks to:
  - Krishna Kumar
  - Kent Pashke
  - Dustin McNulty
  - Robert Michaels
  - Riad Suleiman

Extra Stuff

LUMI PMT Gain Curves



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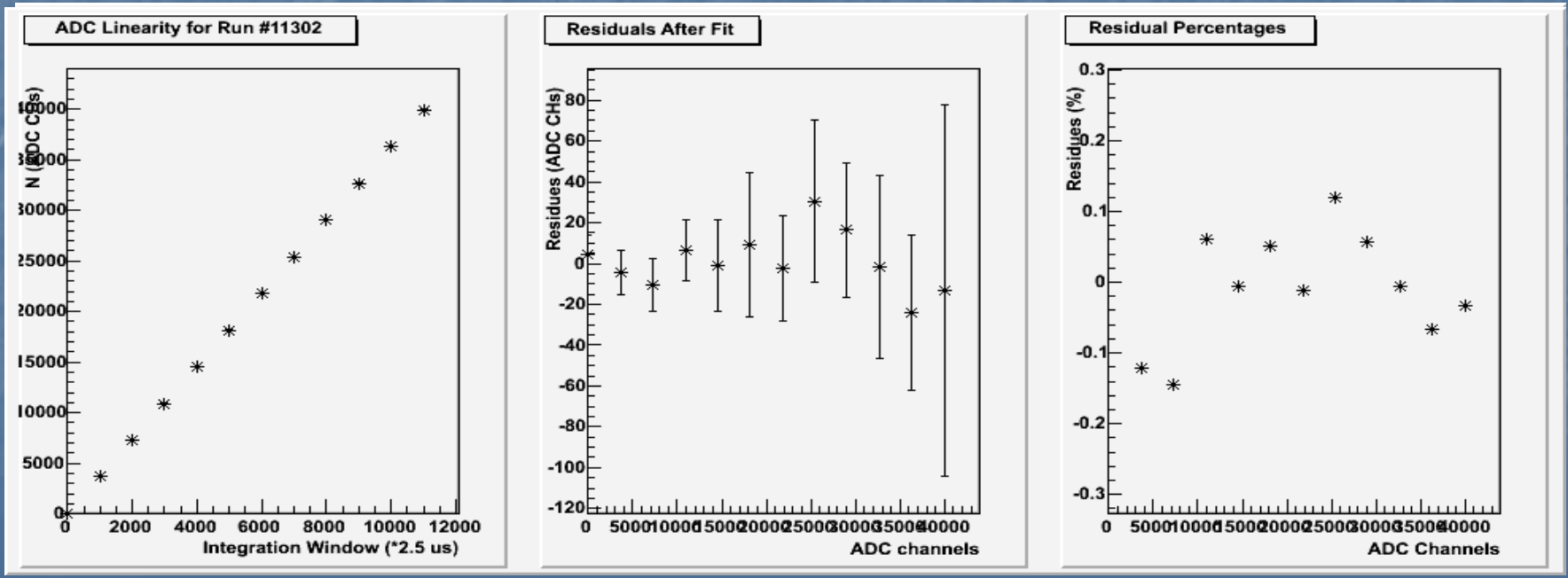

Pedestal Noise