CALICE
Calorimeter for ILC

Eperience with the AHCAL Calibration System in the Test Beam

G. Eigen, Bergen
representing CALICE collaboration

Chicago, November 18, 2008

Outline

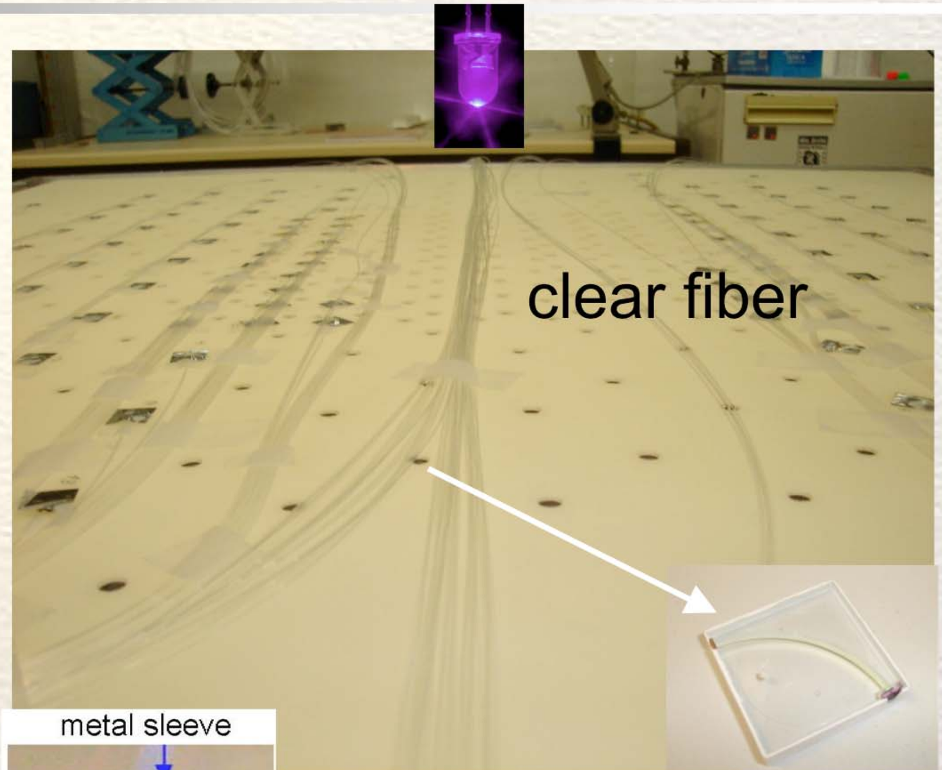
- Introduction
- AHCAL calibration/monitoring system and calibration procedure
- Corrections methods for gain and light yield changes
- Studies of the SIPM response function
- Hardware options for calibration/monitoring system in LC detector
- Conclusion and outlook

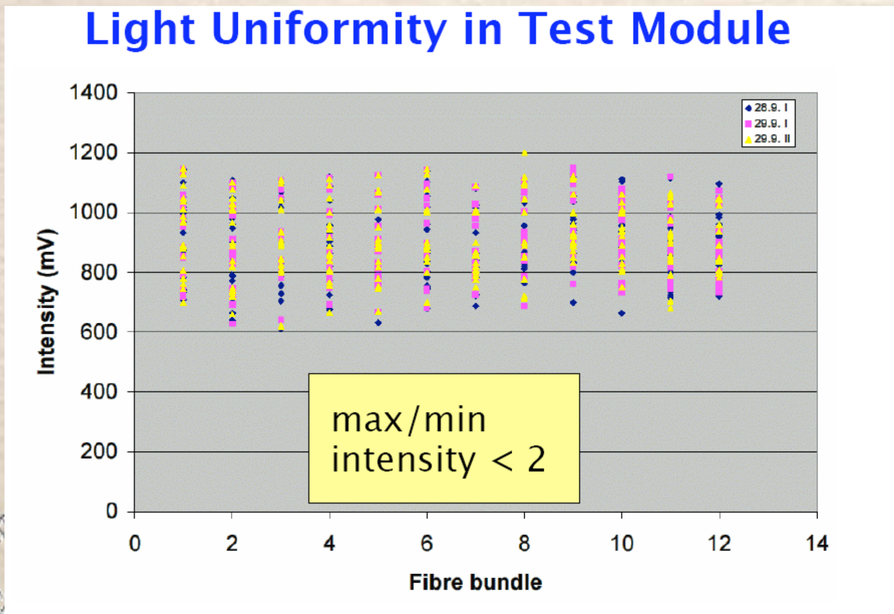
Introduction

- Due to the limited # of pixels SiPMs have a non-linear response
  ➔ we have to monitor the SiPM response to correct for non-linearity
- In AHCAL prototype we installed LED/PIN-based monitoring system
  ➔ measure the SiPM gain
  ➔ monitor the SiPM response for a fixed light intensity
  ➔ record the full SiPM response function when necessary
- A primary task is to find out if the measured SiPM response can be represented by an analytic function that is measured once for each SiPM and is cross-checked by a few key measurements
  ➔ this would allow tremendous simplification of the monitoring system
- The SiPM response depends further on bias voltage and temperature that affect gain, light yield and noise
  ➔ we monitor the temperature in each layer with 5 sensors
  ➔ corrections for changes in gain and light yield may be sufficient
- So far we studied 4 calibration runs in 2006/2007 test beam data, we examined temperature & voltageeffects on gain/light yield

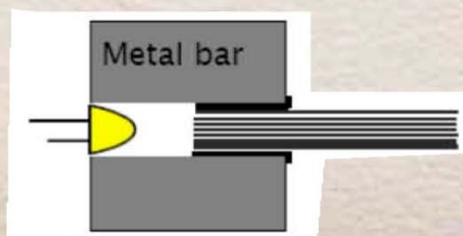
Calibration-Monitoring System

- Provide UV light to each tile via clear fiber
- Monitor each LED with PIN diode
- Record temperature & voltage with slow control system (5 temperature sensor/module)





bundle of 19 fibers
18 → tiles, 1 → PIN diode



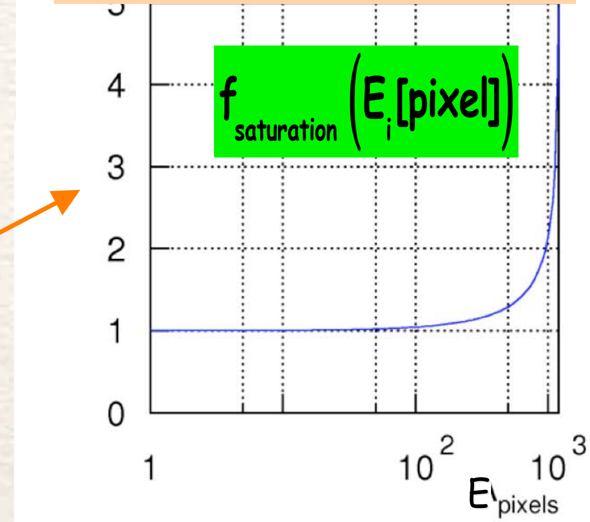
LED fiber coupling

Calibration of an AHCAL Cell

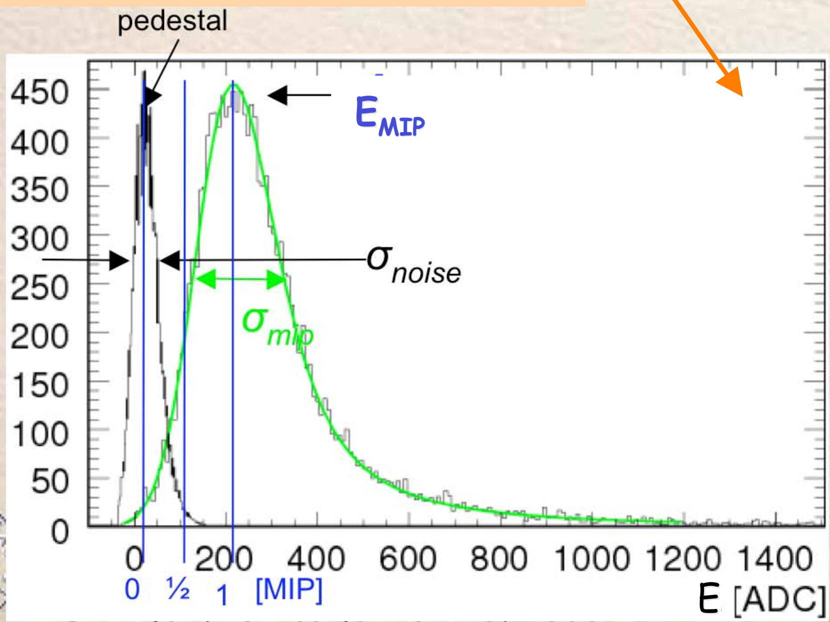
- Measure gain using low-intensity LED light
- Measure MIP peak with muons
- Measure SiPM non-linearity with LED light

$$E_{cell}^{meas}\left[MIP\right] = \frac{Q_{cell}^{meas}\left[ADC\right]}{C_{cell}^{MIP}\left[ADC\right]} \cdot f_{saturation}\left(Q_{cell}^{meas}[pixel]\right)$$

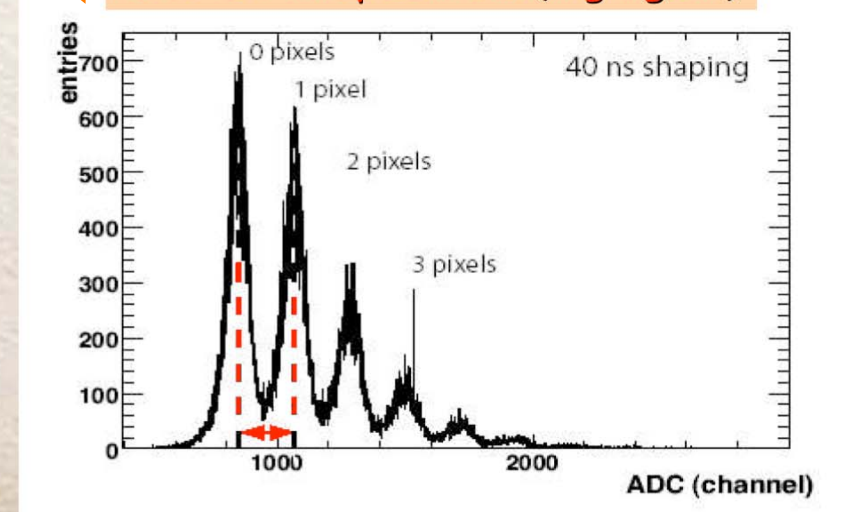
Non-linearity correction



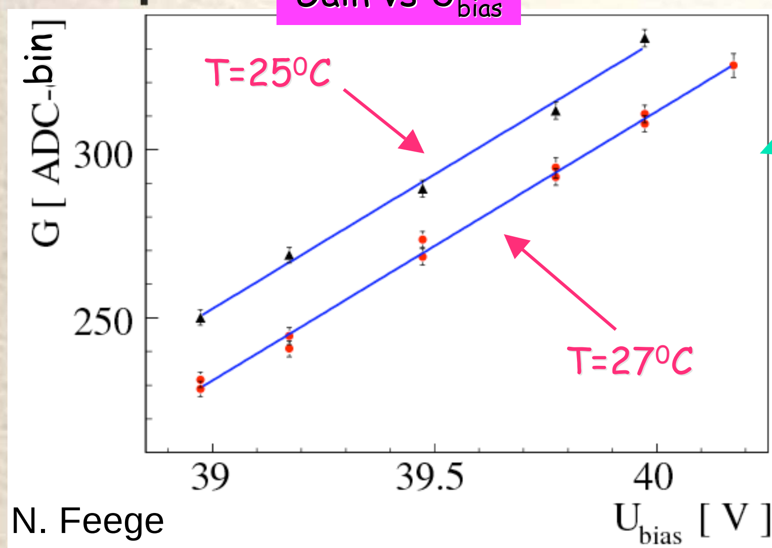
SiPM spectrum of μ's (low gain)



LED SiPM spectrum (high gain)

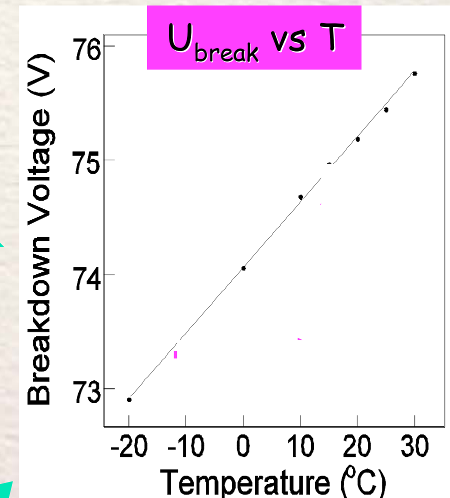


SiPM Gain and Light Yield Dependences

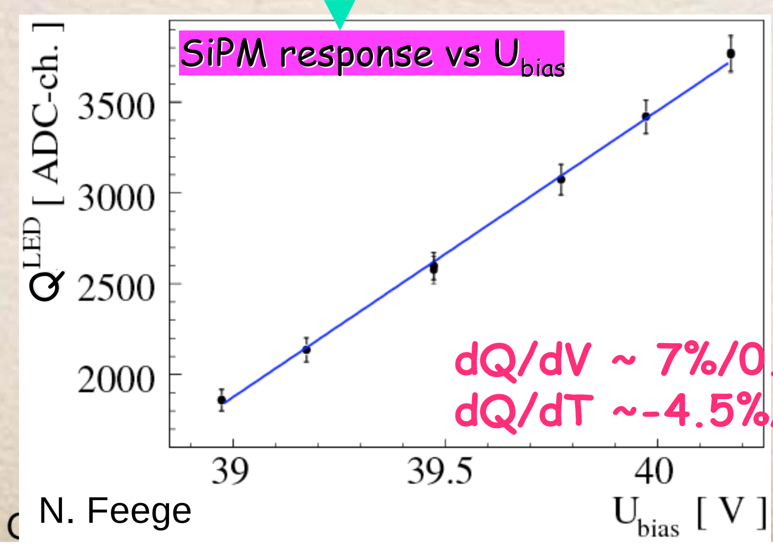


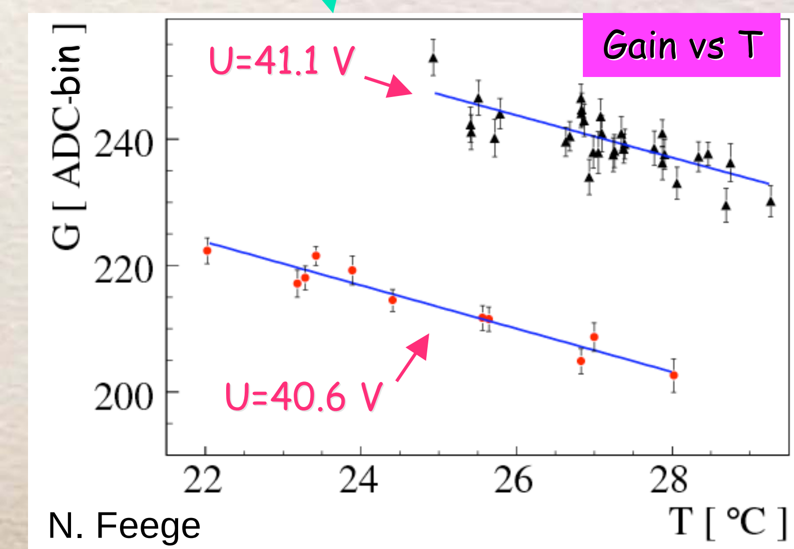
- The SiPM gain increases with voltage above bias voltage $\Delta U = U_{bias} - U_{break}$
  ➔ increases with U_{bias}
  dG/dV ~2.5%/0.1V

- U_{break} increases with temperature (T)
  ➔ SiPM gain decreases with T
  dG/dT ~-1.7%/K



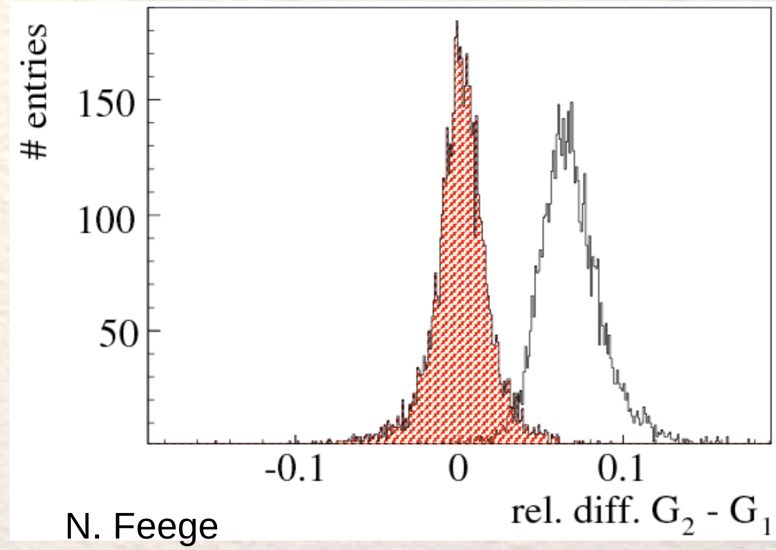
- Light yield shows stronger dependence on U_{bias} &T

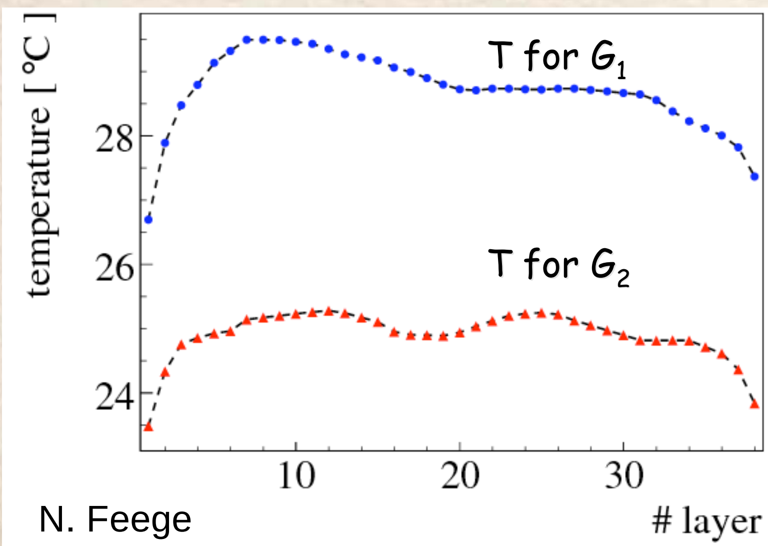


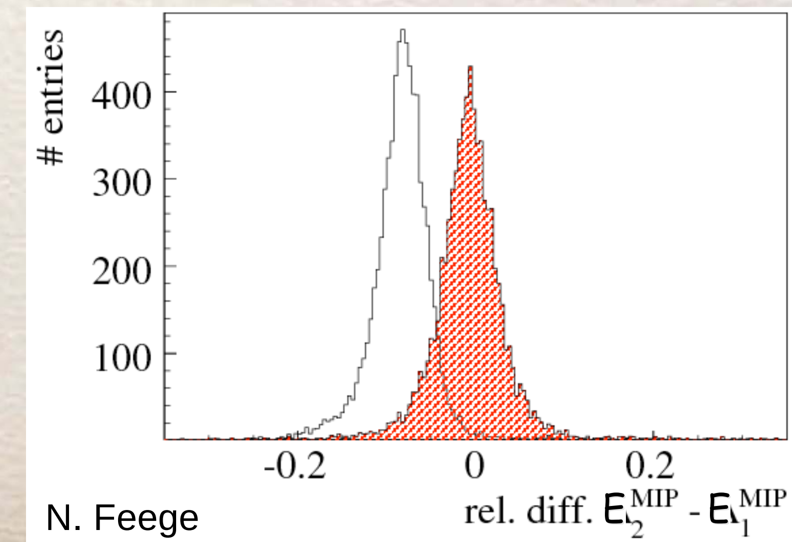


Compensation for Temperature Changes

- Temperature variations over data taking period are substantial
- Raw energy measurements need to be corrected for T variation
- After T corrections both gain and energy measurements from different runs agree



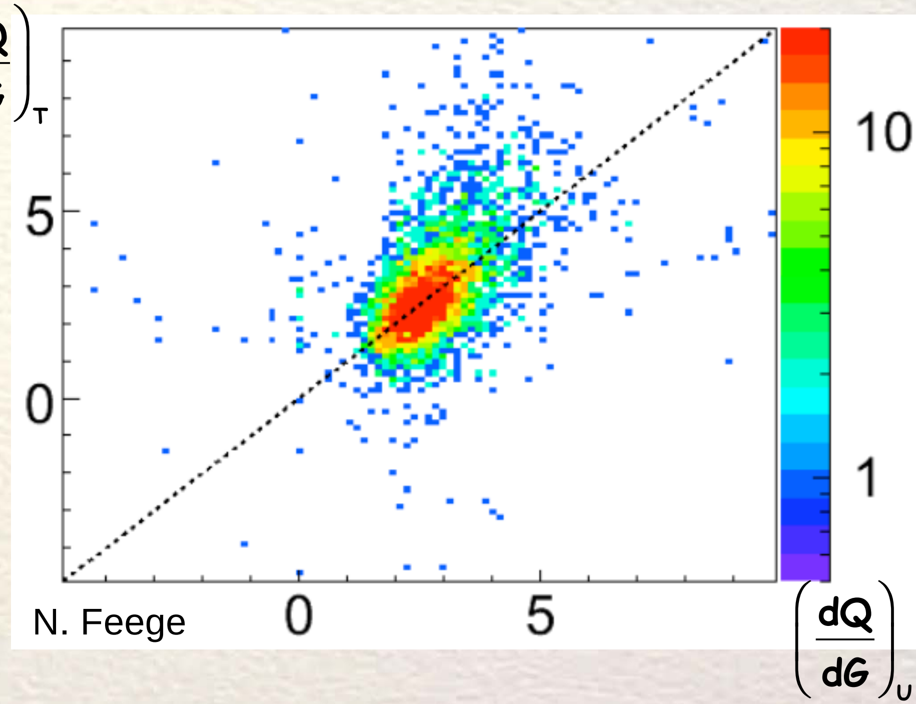




Methods to Correct for Run Variations

- Temperature $$\left(\frac{dQ}{dG}\right)_T = \frac{dQ/dT}{dG/dT}$$
- Voltage $$\left(\frac{dQ}{dG}\right)_U = \frac{dQ/dU}{dG/dU}$$
- Standard correction method: correct light yield Q and gain G for temperature T

$$Q = Q_0 + \frac{dQ}{dT}\Delta T \qquad G = G_0 + \frac{dG}{dT}\Delta T$$



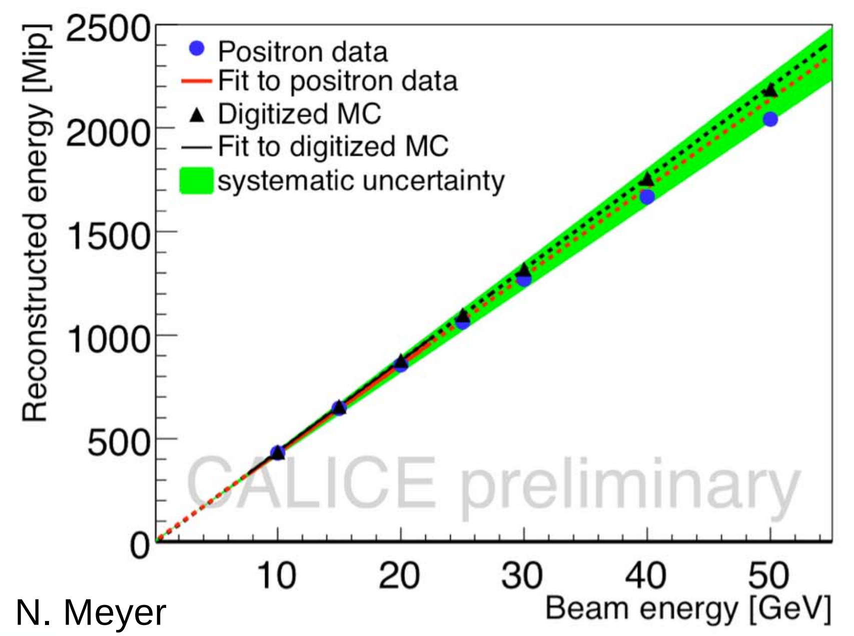
➔ pro: instantaneous, since T is measured frequently during runs
➔ con: not-local, since we only have 5 T-sensors per module

- New procedure: correct light yield Q for gain change $$Q = Q_0 + \frac{dQ}{dG}\Delta G$$

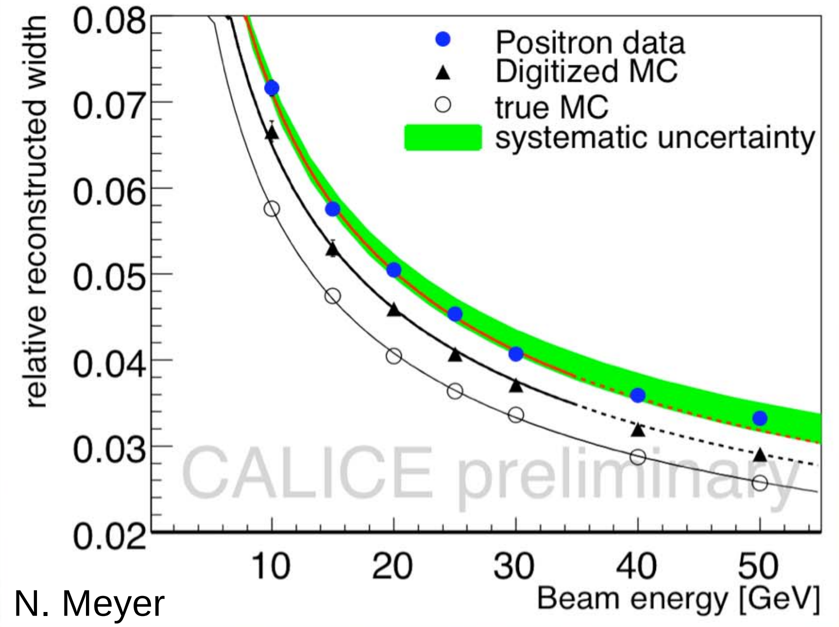
➔ pro: local, since gain is measured for each cell
➔ con: not instantaneous, since gain is measured only a few times/day

Response to EM showers

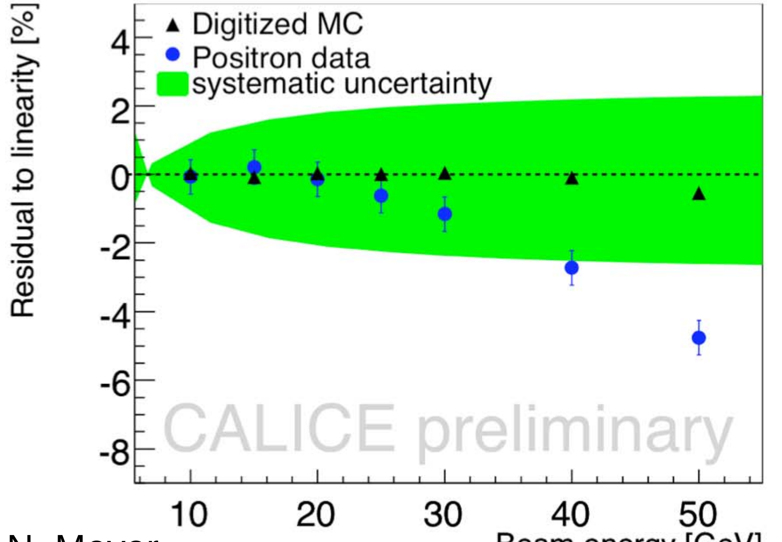
- Perform average correction for temperature and saturation effects ➔ restore linearity
- Uncertainties do not include uncertainties from digitization



N. Meyer



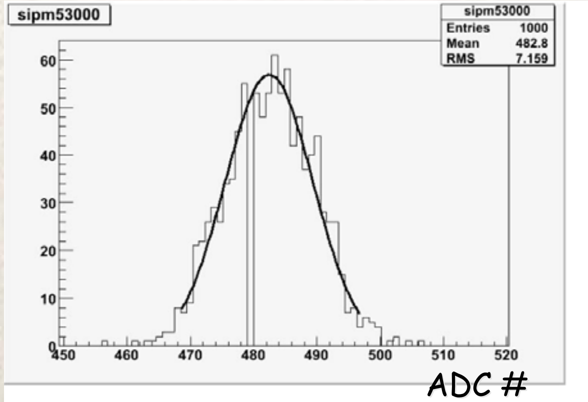
N. Meyer



N. Meyer

Analysis Procedure for SiPM Response

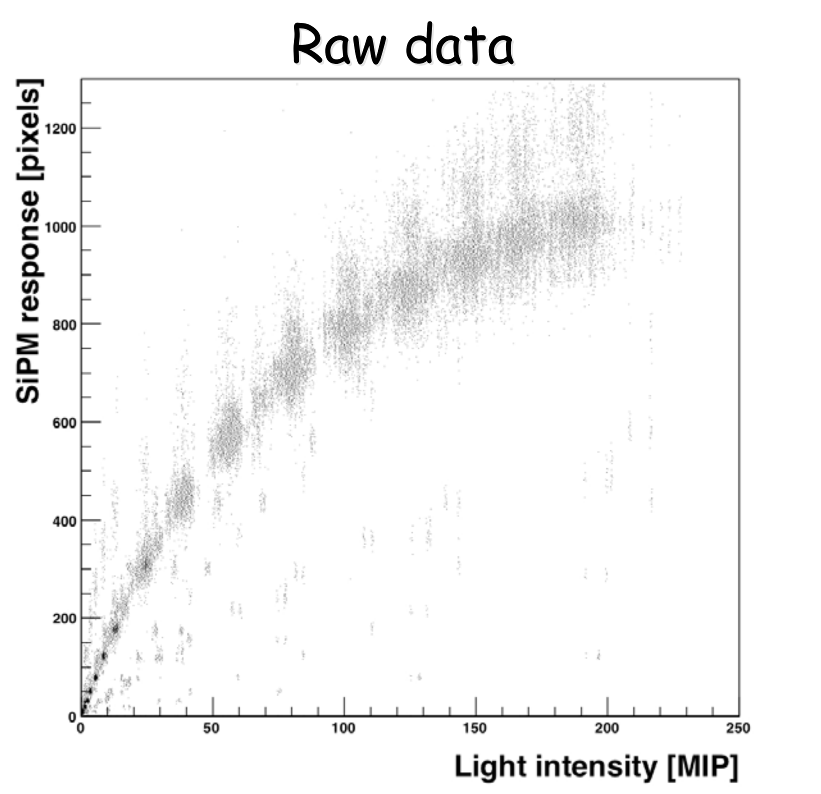
- Extract SiPM & PIN diode values from LCIO files
- Perform pedestal subtraction using beam events taken shortly before or after VCalib run
- Apply gain corrections and use intercalibration constants
- Perform Gaussian fit for each Vcalib to SiPM & PIN response
  ➔ determine mean and error on the mean
- Plot PIN response vs SiPM response
- Rescale PIN values to force the initial slope to be one and to start at a common origin

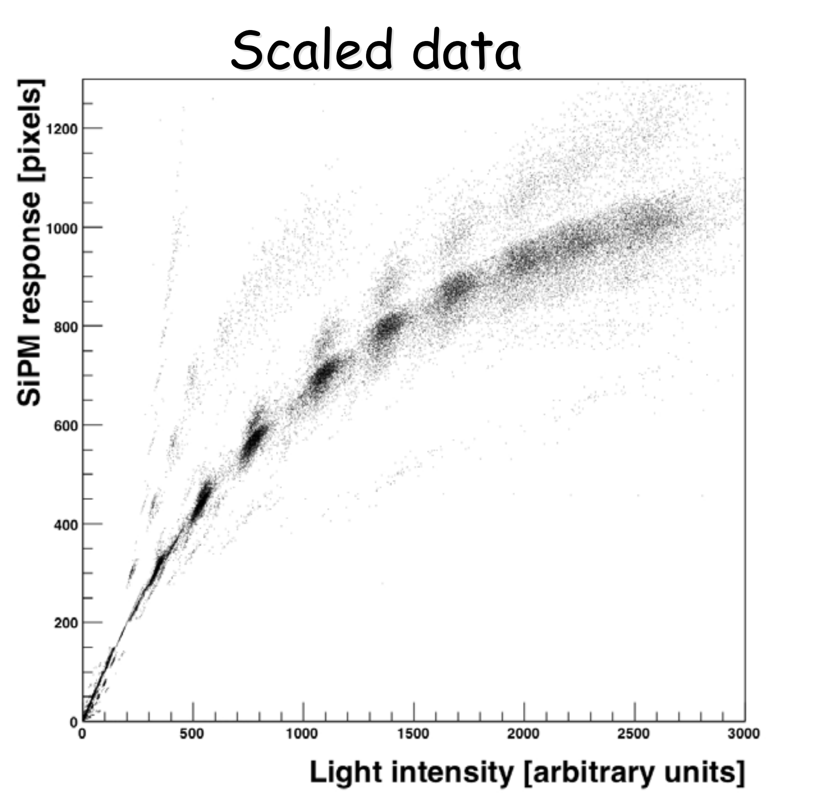


- Focus on July 2007 runs for all modules, though October/August 2006 runs have been studied as well (modules 3-15)

SiPM Response Curves at ITEP

- ITEP measured the response curves of all SiPM prior to installation into the AHCAL prototype with calibrated LED light (tile-fiber-SiPM readout)
- The raw data are scaled to come from a common origin with slope one

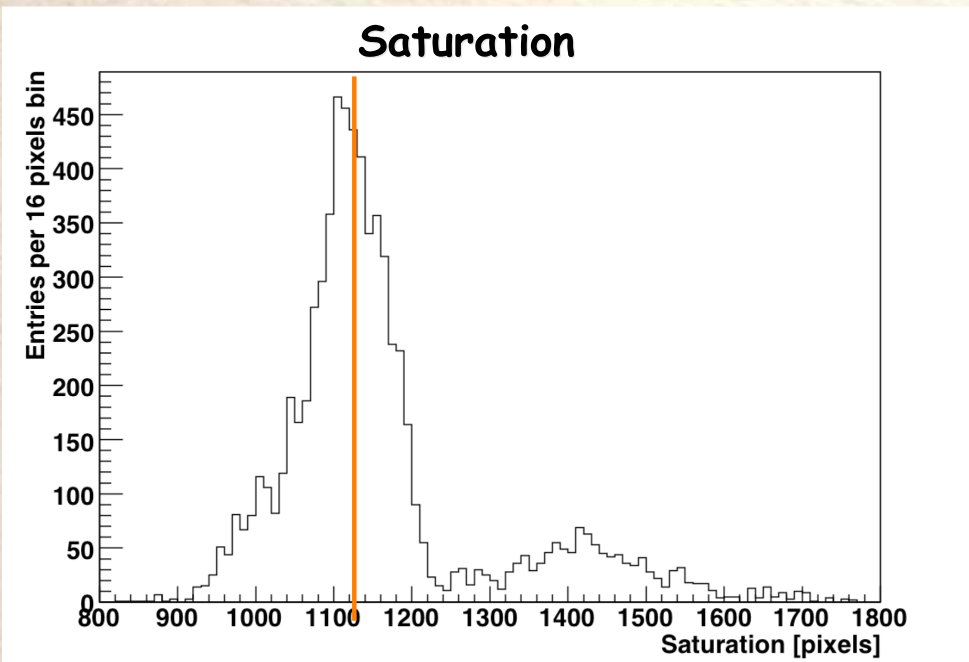




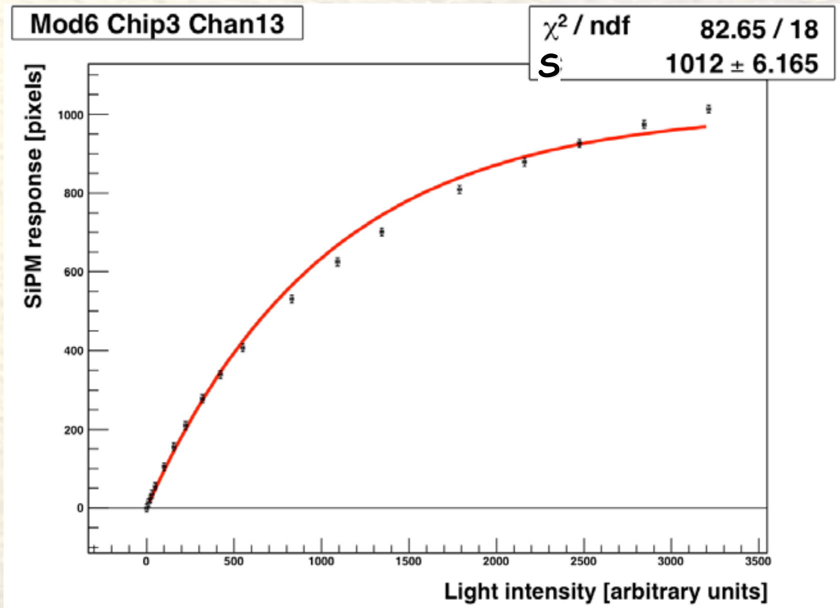
SiPM Response Functions at ITEP

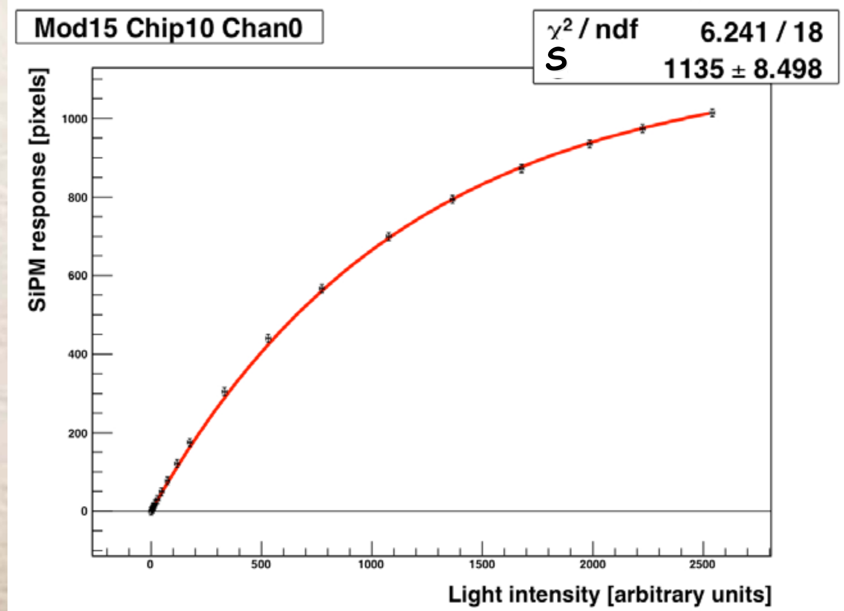
- The SiPM response curves measured at ITEP are successfully fit with

$$f(x) = S\left(1 - \exp(-ax)\right)$$



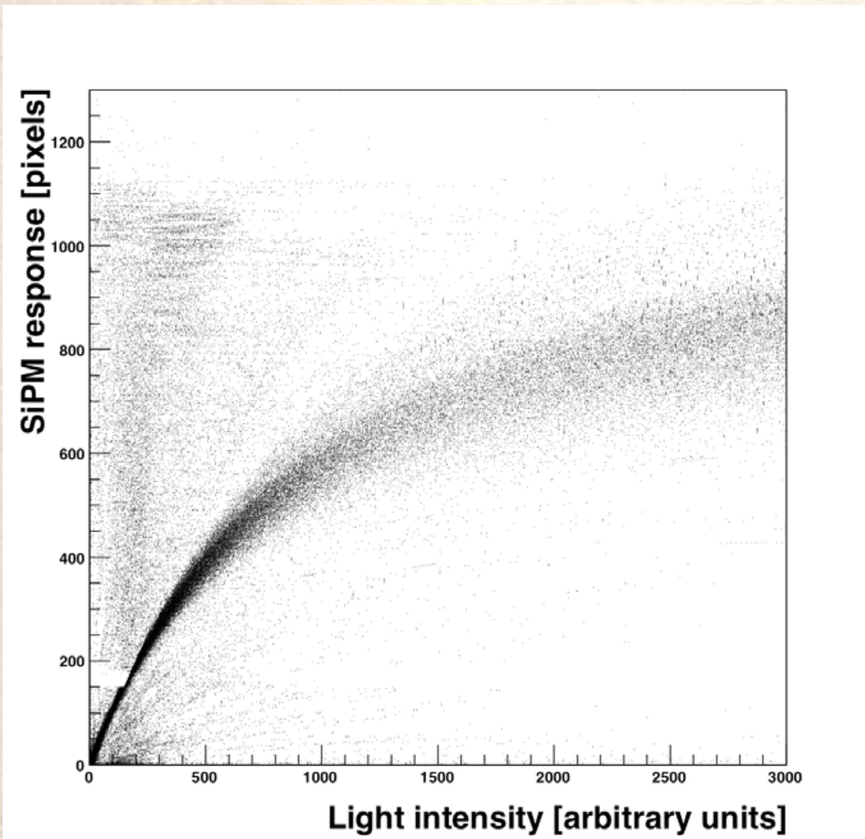
- Saturation peaks at ~1150 pixels
- Second peak ~ 1400 pixels

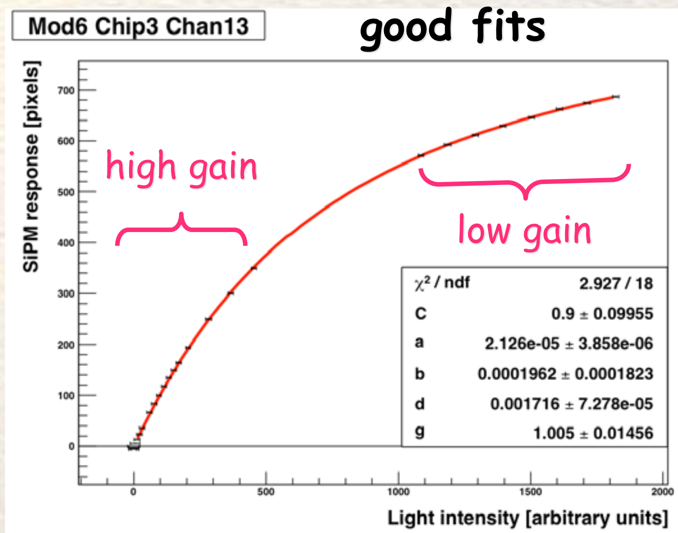


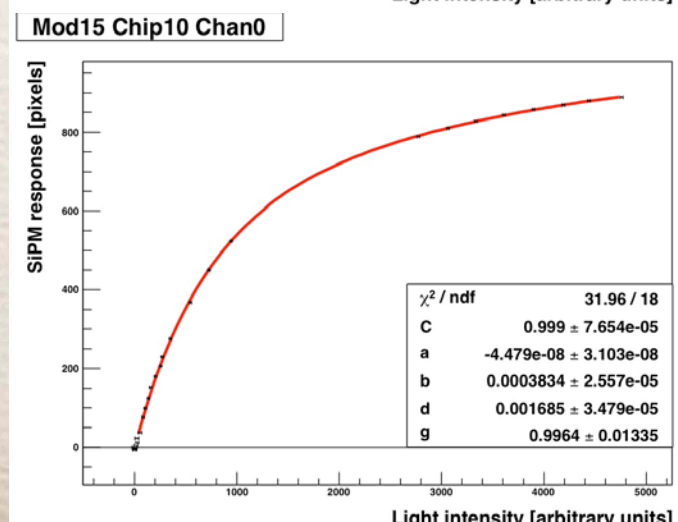


SiPM Response Curves in Test Beam Runs

- Measurement of SiPM response during test beam running for high gain & low gain preamplifier setting







Parameterize SiPM Response Functions

- Goal is to parameterize the SiPM response with analytical function
- Since high-gain and low-gain regions are separated by large gap we need a function that represents both regions

$$f(x) = \frac{1}{g(x)} \left[\underbrace{\frac{(C-1)^2}{a-(b+d)(C-1)}}_{\text{normalization}} \cdot \frac{e^{-bx}+e^{-dx}}{C-e^{ax}} - \underbrace{\frac{2(C-1)}{a-(b+d)(C-1)}}_{\text{saturation}} \right]$$

where C, a, b & d are free parameters determined from the fit

- For C=1 shape is Fermi function like, for C=0 get a 2 exponential fit
- The parameters b & d introduce two damping factors
- We have also tried a function without the Exp[-d*x] term, but the χ^2 term becomes much larger in many fits
- The function g(x) accounts for changes between low & high gain runs
- We have tried to fit all 7608 SiPMs in the AHCAL prototype

Fit Results for 4 Calibration Runs

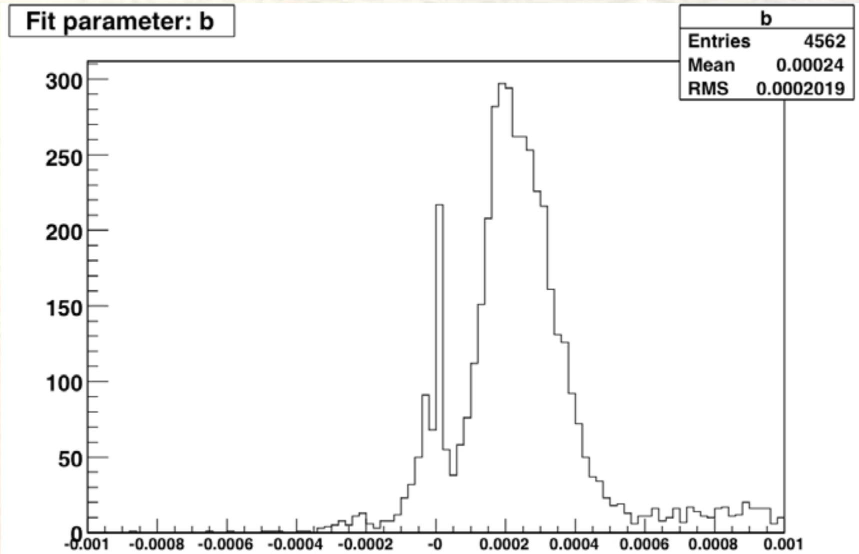
- Most SiPMs in the four run periods can be fit with function f(x)

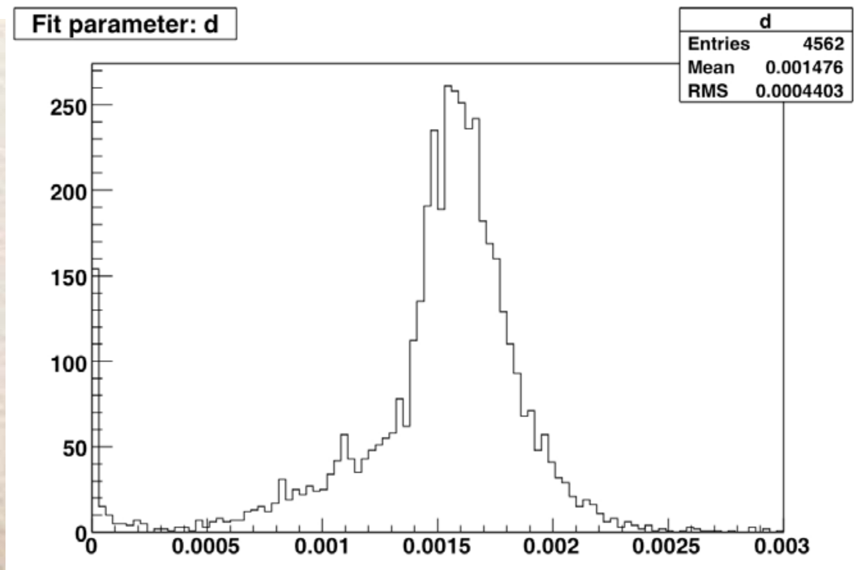
	Run 300325 28. Aug 2006	Run 300723 22. Oct 2006	Run 330362 12. Jul 2007	Run 331212 31. Jul 2007
Number of modules	15	15	38	38
Number of channels	3240	3240	7608	7608
Points per channel	41	31	35	32
Successful fits	1893 (58.4%)	2059 (63.5%)	3758 (49.4%)	4562 (60.0%)
Error cat. 1	655 (20.2%)	36 (1.1%)	510 (6.7%)	202 (2.7%)
Error cat. 2	20 (0.6%)	46 (1.4%)	48 (0.6%)	275 (3.6%)
Error cat. 3	0 (0%)	0 (0%)	622 (8.2%)	199 (2.6%)
Error cat. 4	18 (0.6%)	0 (0.0%)	279 (3.7%)	19 (0.2%)
Error cat. 5	654 (20.2%)	1099 (33.9%)	2391 (31.4%)	2351 (30.9%)

1. SiPM is not working (maximum < 10 pixels), PIN ok
2. SiPM has problems (10< maximum < 100 pixels), PIN ok
3. PIN is not working properly (< 10 ADC bins), SiPM ok
4. Both SiPM and PIN are not working
5. Shape cannot be fit with this function ($P(\chi^2) < 10^{-8}$)

Results for Fit Parameters b & d

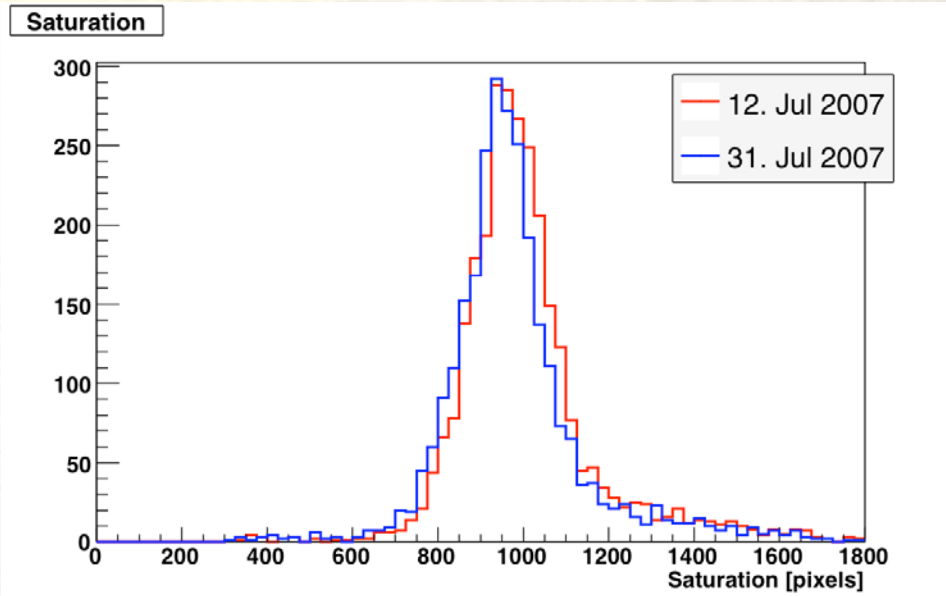
- Fits from calibration run July 31, 2007
- We require b<d in the fit
- Results for b:
  - b peaks at ~0.00025, FWHM~0.0002
  - Apart from outliers at high b there is a spike near zero
- Results for d:
  - d peaks at~0.0016, FWHM~0.00035
  - Long tail at small values peak at zero
- Results for a, g, C
  - a ~0.3
  - C=1, g~1

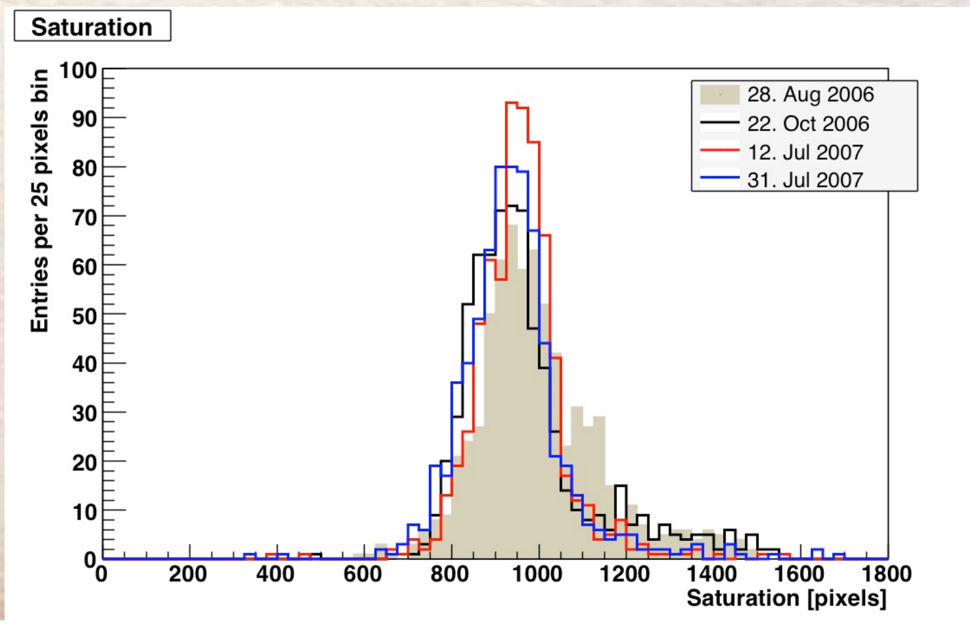




Measurement of SiPM Saturation

- For July 31 calibration run
  - saturation peaks at 930 FWHM~180
- Saturation curves from 2 test beam periods in 2007 are similar (no T correction of light yield)
- Comparison with 2006 data yields similar results
  ➔ we see no time dependence of the saturation



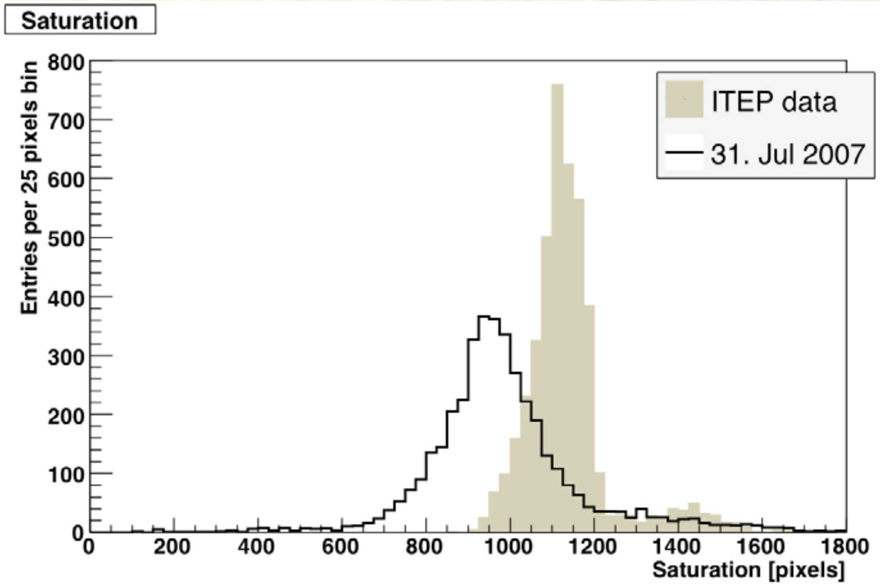


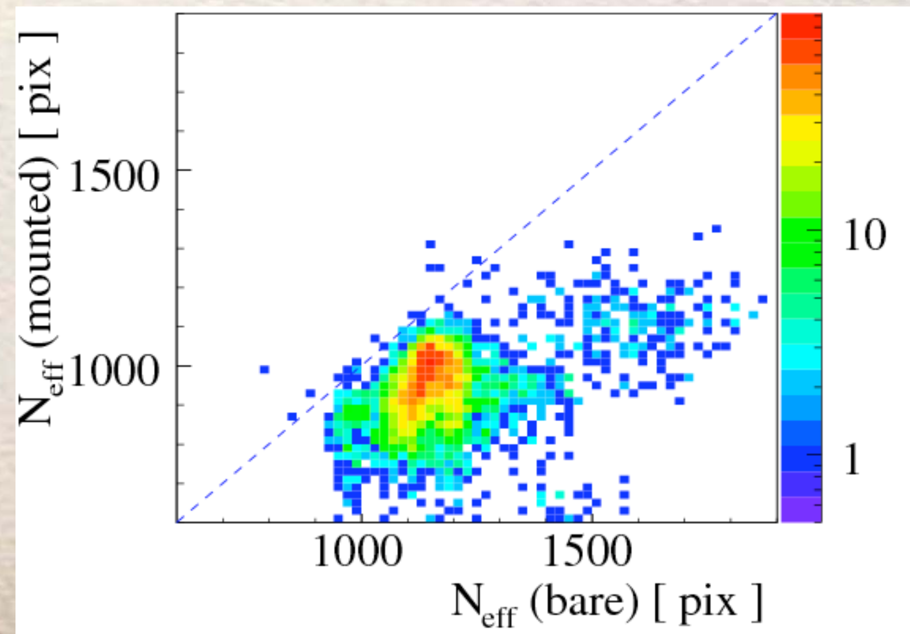
SiPM Saturation at ITEP and in Beam Test

- Saturation measured at ITEP peaks ~200 pixels higher (near the maximal number of pixels) than in situ calibration runs
- At ITEP all pixels get uniform illumination from WLS fiber
- In situ SiPM may not be fully illuminated (more complicated readout: LED → 19 fibers → scintillator tiles → WLS fibers → airgap → SiPM)

➔ we cannot normalize SiPM response to LED intensity over the full dynamic range

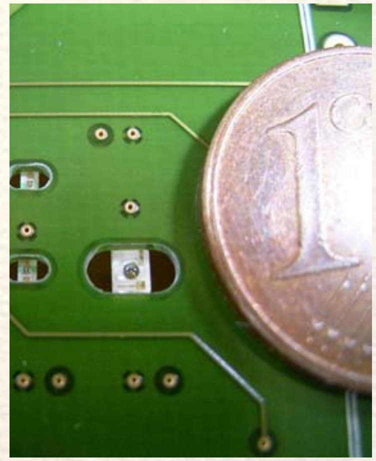
➔ so we use ITEP saturation curve and scale by ratio of saturation values

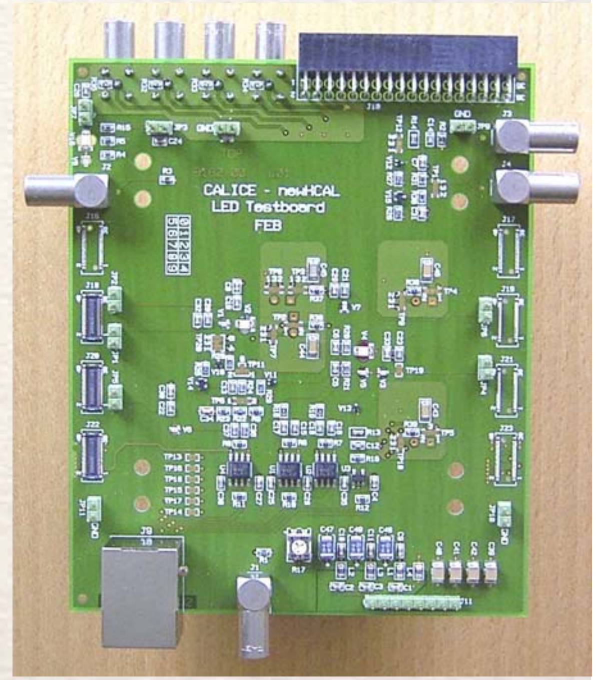


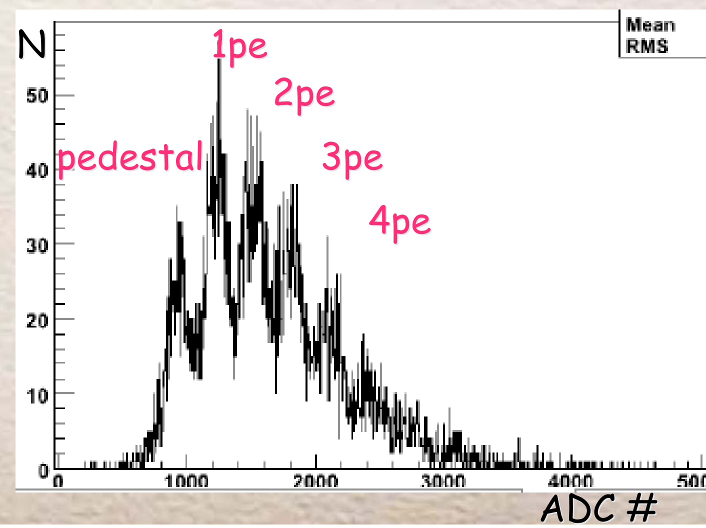


Hardware Options for LC Detector

- LED plus clear fiber for one row of tiles (see Jaroslav Zalesak's talk)
- Embedded LEDs: pro no fibers, con: large # of LEDs, one/tile
- We started LED system test
  - Optimize LED position
  - Test homogeneity of response
  - Test different LED types
  - Compare light calibration with particle response from radioactive source
  - System will be temperature controlled
- Tests show no cross-talk
- Need optimization for dynamic range & LED uniformity







Conclusion and Outlook

- SiPM gain and light yield depend on bias voltage and temperature
  ➔ for excellent performance these effects need to be corrected for in each cell on an event-by-event basis, (e.g. determine correction factors from dedicated calibration runs several times a day)

- Though we found a reasonably-well working analytic function, I think that at the present level of understanding we need to keep a calibration/monitoring system in the AHCAL
  ➔ We have to determine correction factors from dedicated calibration runs with fixed light intensities several times a day
  ➔ We need ability to record the full dynamic range for cross checks

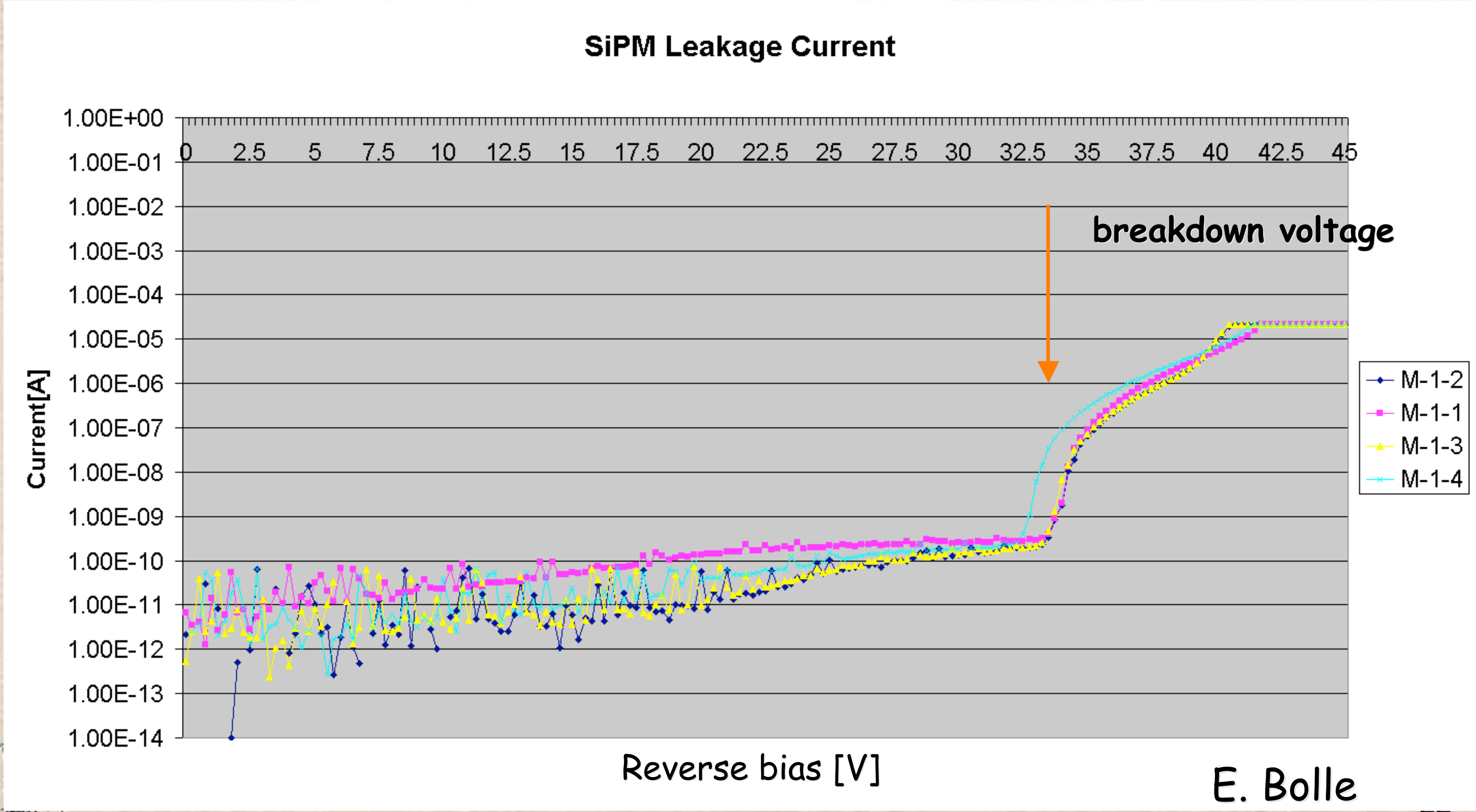
- The calibration/monitoring system, however, should be simplified
  ➔ 2 options are under study (embedded LEDs, one fiber/row of tiles)

- The studies of the SIPM response need to be continued
  ➔ e.g. include calibration runs from 2008 Fermilab test beam data

Backup Slides

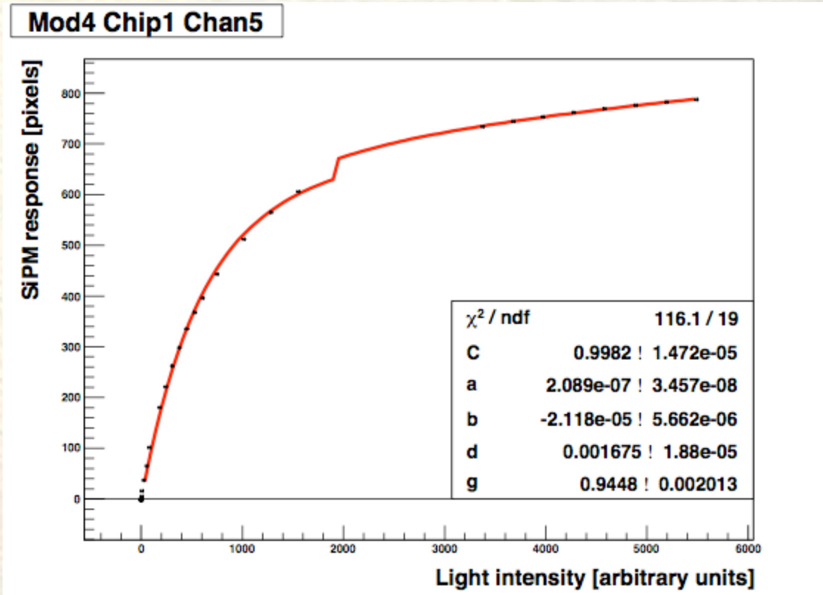
I-V Curves of 4 SiPMs

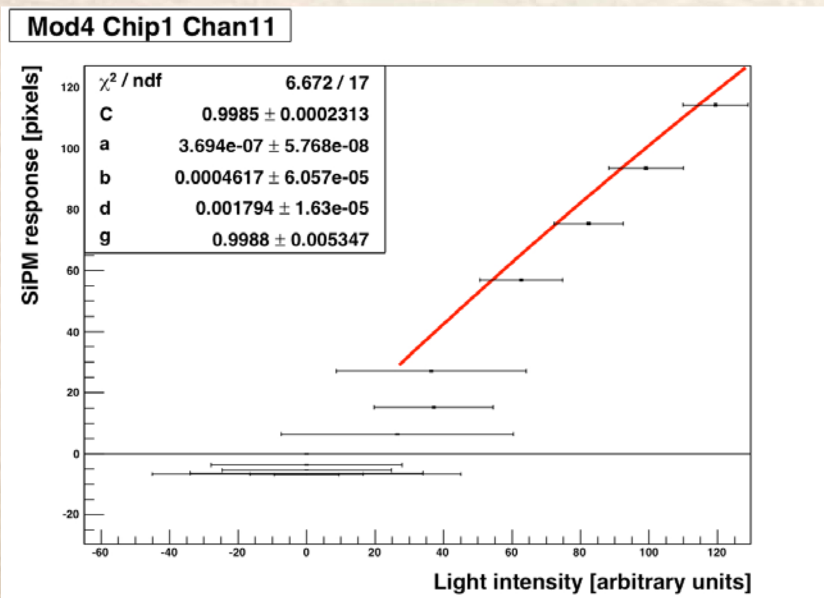
- In Oslo E. Bolle measured the I-V curves of 4 SiPMs

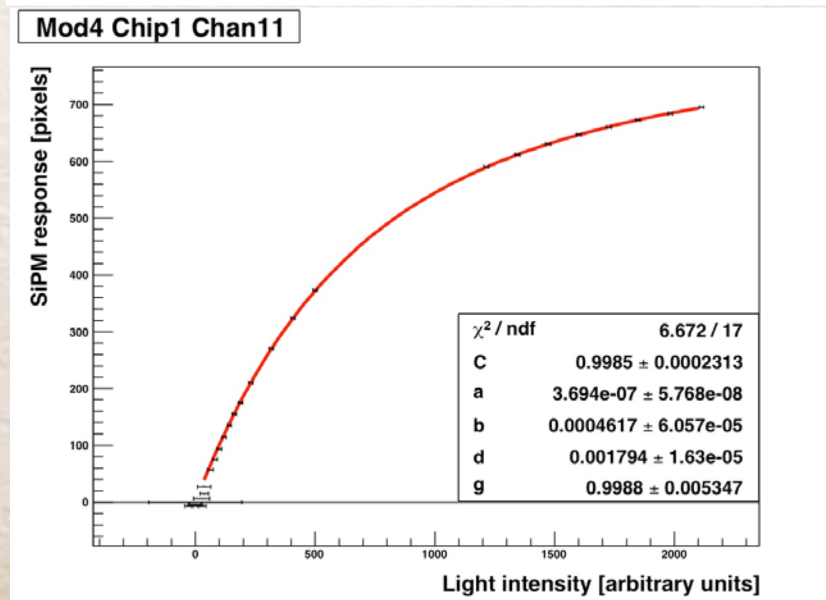


Examples of Failed Fits

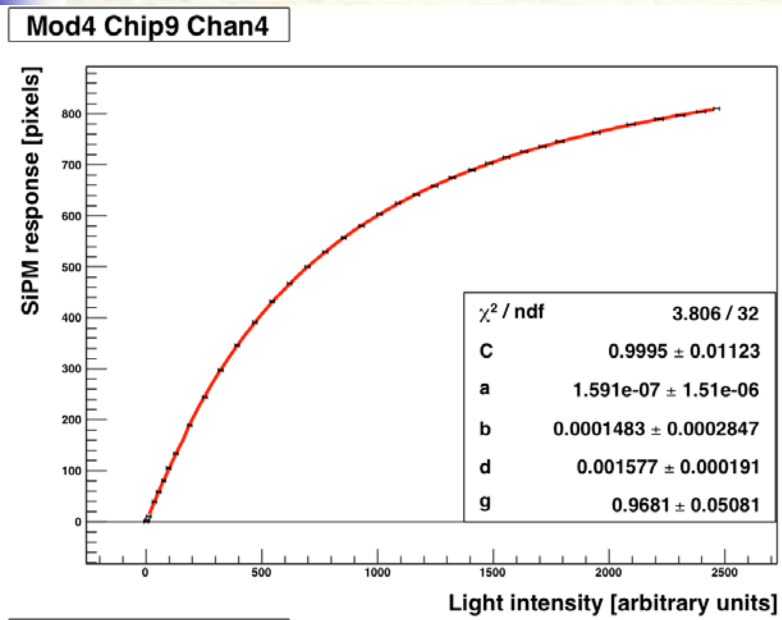
- The two gain settings do not match
- Problems with PIN and/or SiPM

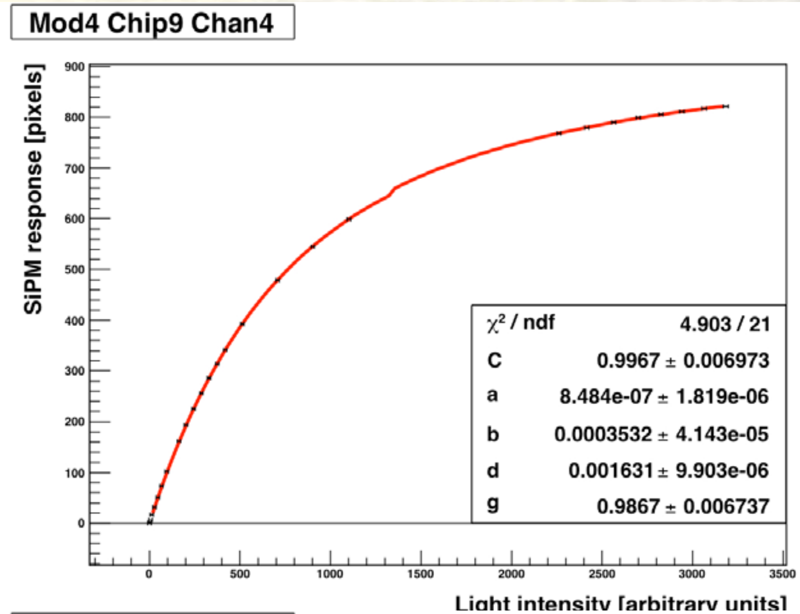


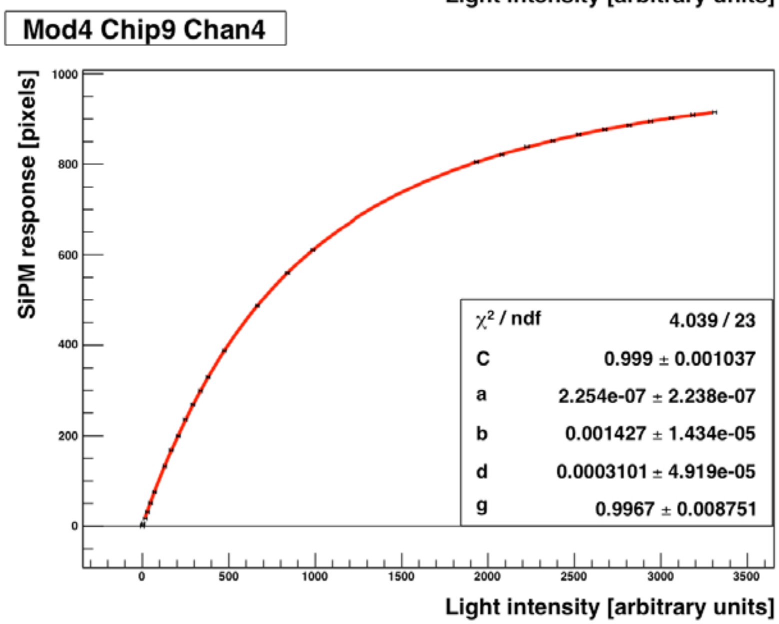


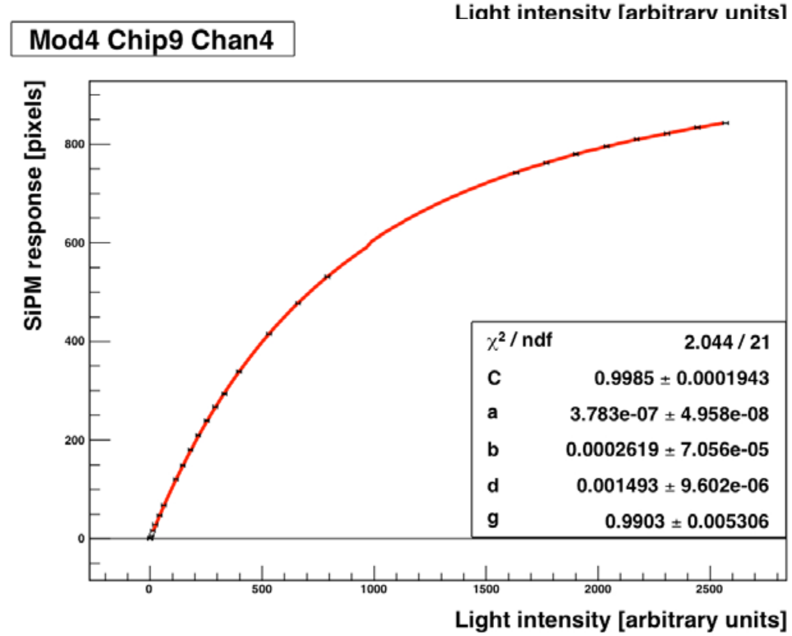


Comparison of a Cell in 4 Runs



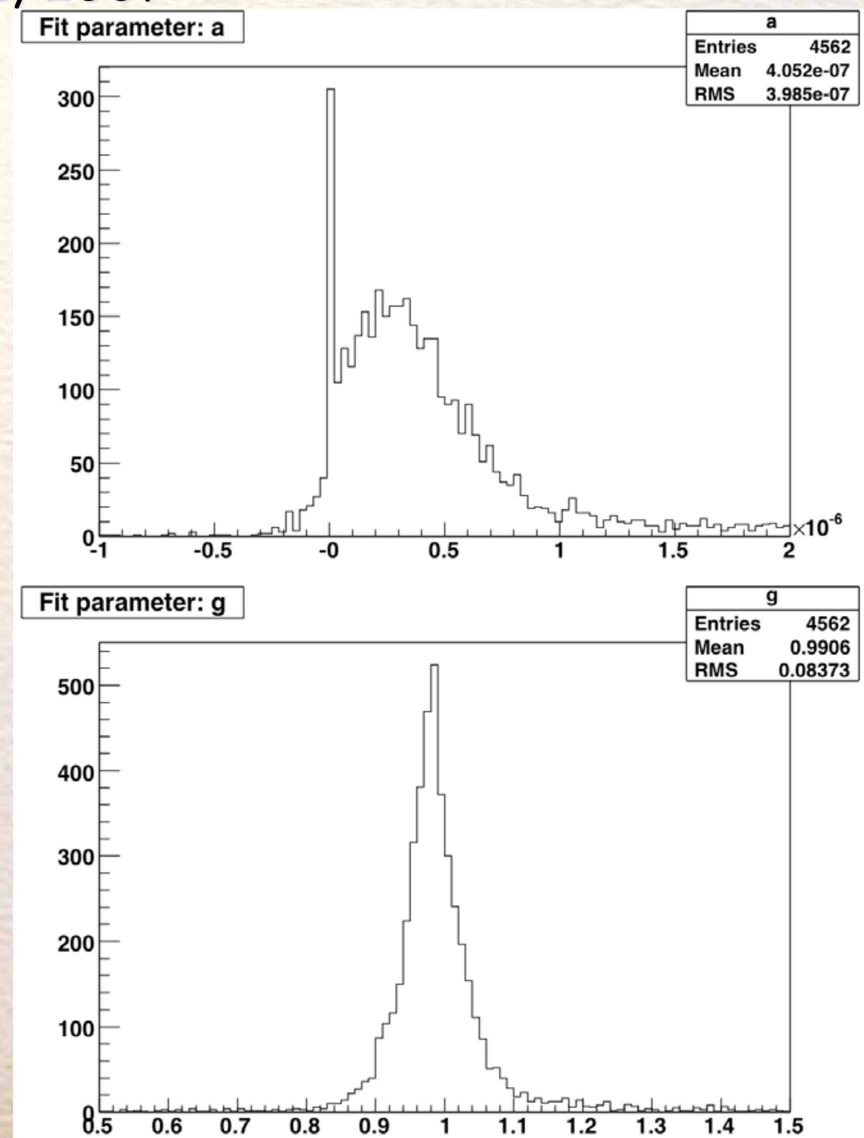






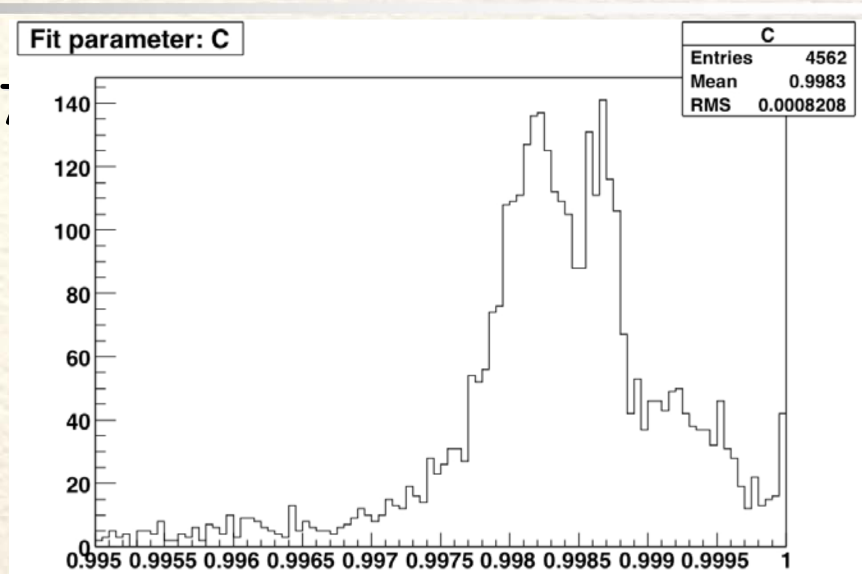
Results for Fit Parameters a & g

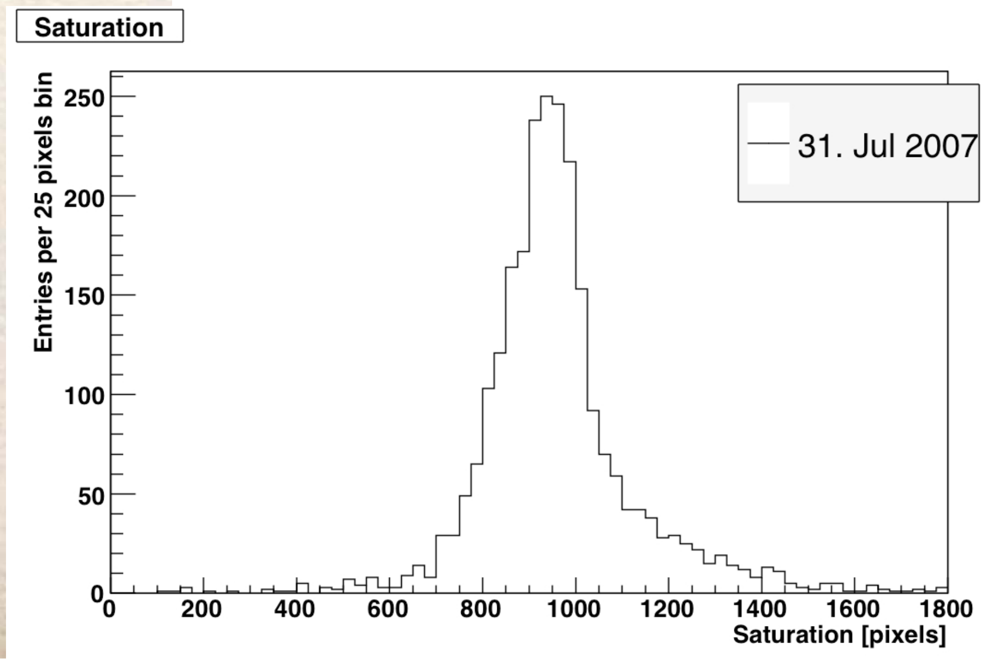
- Fits from calibration run July 31, 2007
- Results for a:
  - a peaks near~0.3, FWHM~0.6
  - There is a spike at zero and an asymmetric tail on the high side
- Results for g:
  - g peaks at 0.99, FWHM~0.09



Results for Fit Parameter C & Saturation

- Fits from calibration run July 31, 2007
- Results for C:
  - C is essentially one
    FWHM~0.001
- Saturation:
  - peak at 930,
    FWHM~180





Correlations between Fit Parameters