Calibration System of the the Muon g-2 Experiment at Fermilab

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International School on Muon Dipole Moments and Hadronic Effects

Outline

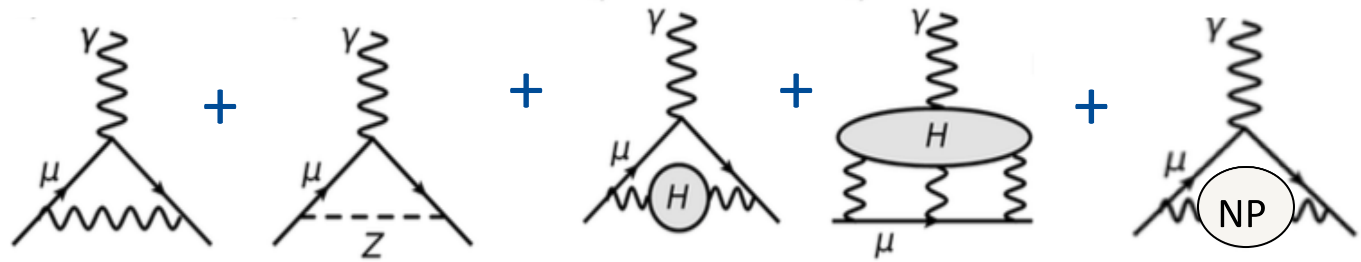
- Theoretical Background and Basic Technique
- Experimental Setup and Systematics
- Laser Calibration System
- Local Monitors of the Laser Calibration System
- Stability of the Local Monitors – time evolution studies
- Stability of the Local Monitors – temperature studies
- Conclusions

Muon g-2: The Basics

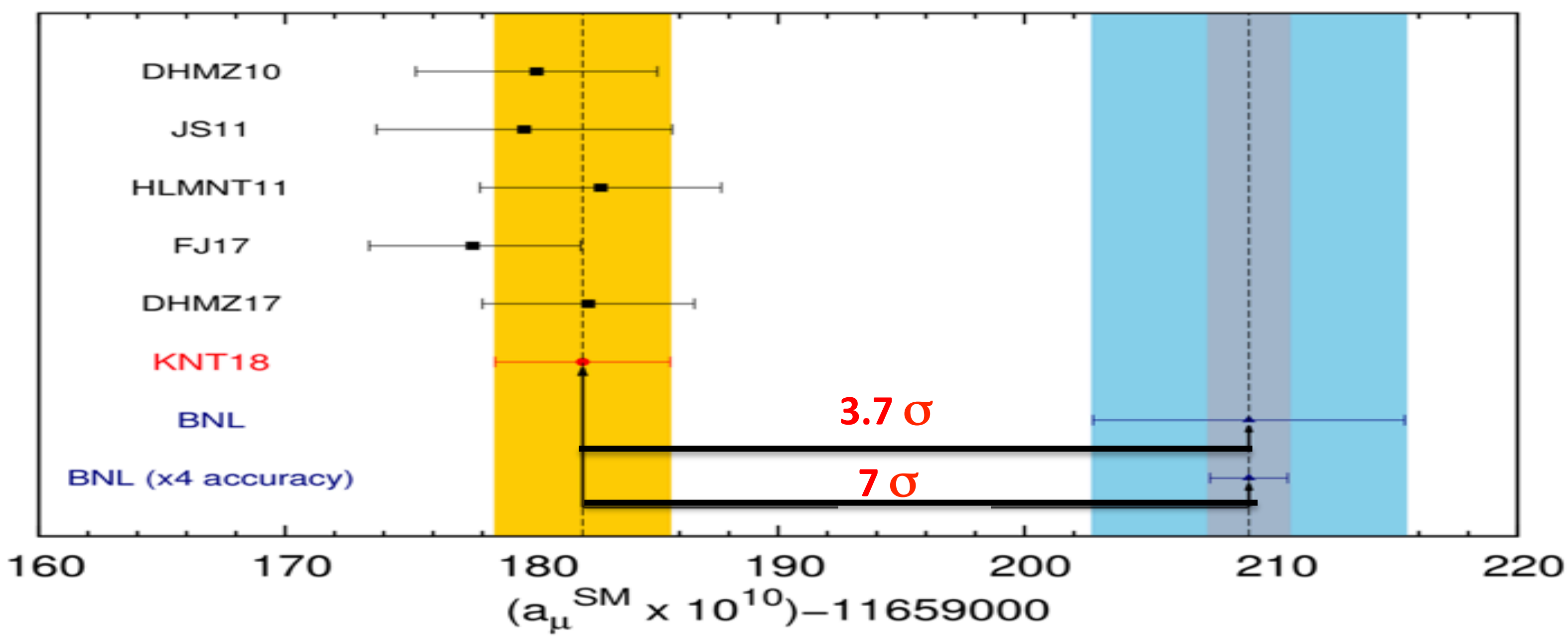
$\vec{\mu} = g\frac{q}{2m}\vec{s}$ with g = 2 for a tree level anomaly (Dirac)

$g = 2(\text{Dirac}) + O(10^{-3})_{QED} + O(10^{-9})_{EW} + O(10^{-7})_{QCD} + \text{NP (?)}$

$g_{SM} + g_{NP?} =$

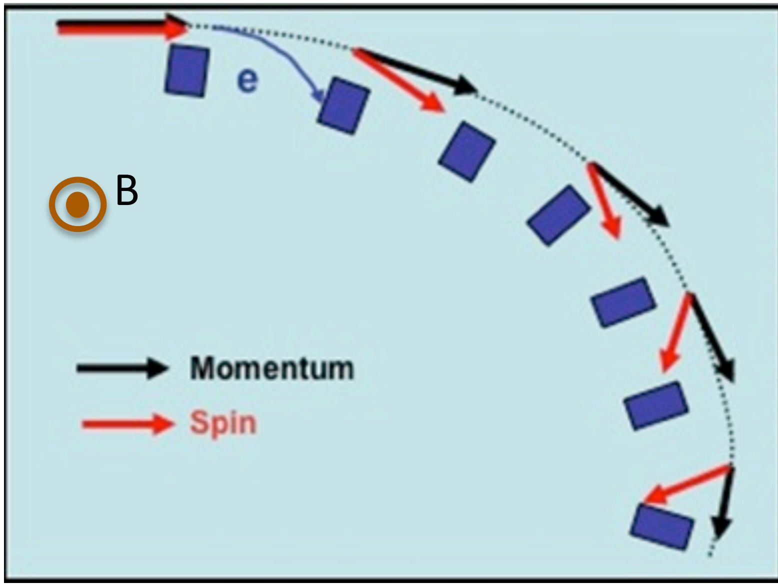


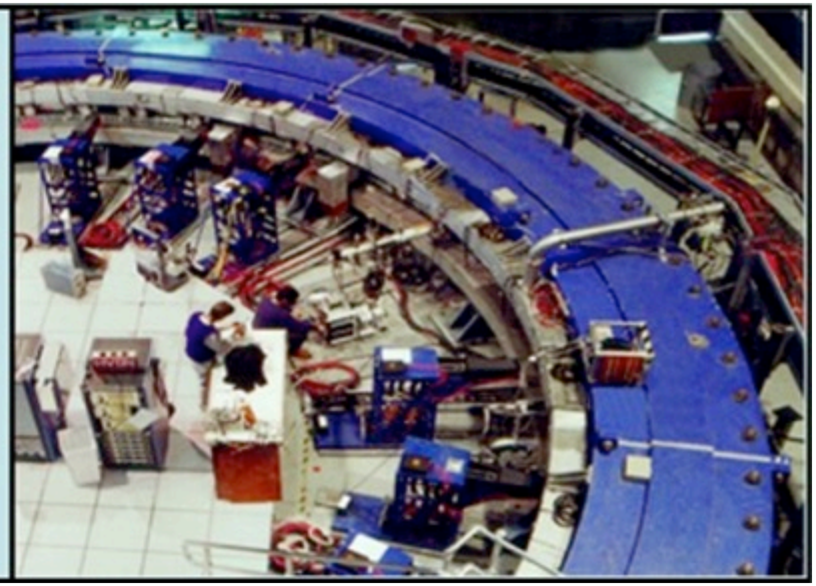
arXiv:1802.02995 [hep-ph]



Muon g-2: The Experiment

$$\vec{\mu} = g\frac{q}{2m}\vec{s}$$ with g = 2 for a tree level anomaly (Dirac)





$$\vec{\omega}_a = \vec{\omega}_S - \vec{\omega}_C$$ Magic p = 3.09 GeV at γ = 29.3

$$= -\frac{q}{m}\left[a_\mu \vec{B} - \cancel{\left(a_\mu - \frac{1}{\gamma^2 - 1}\right)}\frac{\vec{\beta}\times\vec{E}}{c}\right]$$

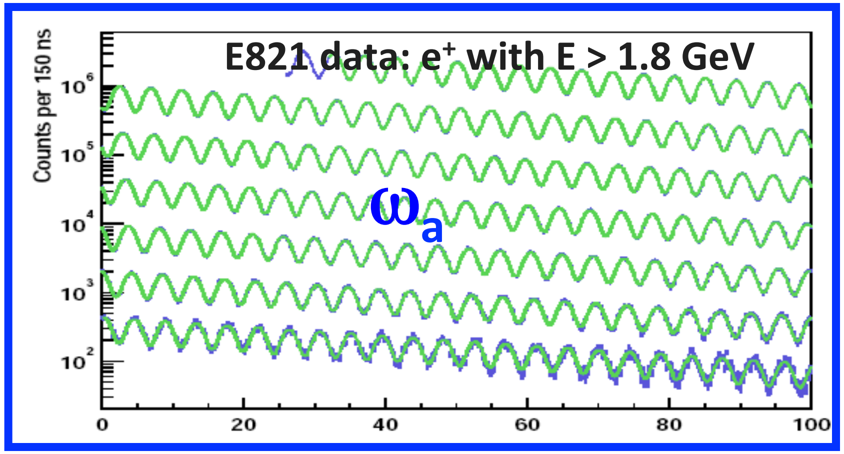
$$\omega_a = \omega_S - \omega_c = \frac{eB}{m}a_\mu$$

Muon anomalous moment measurement

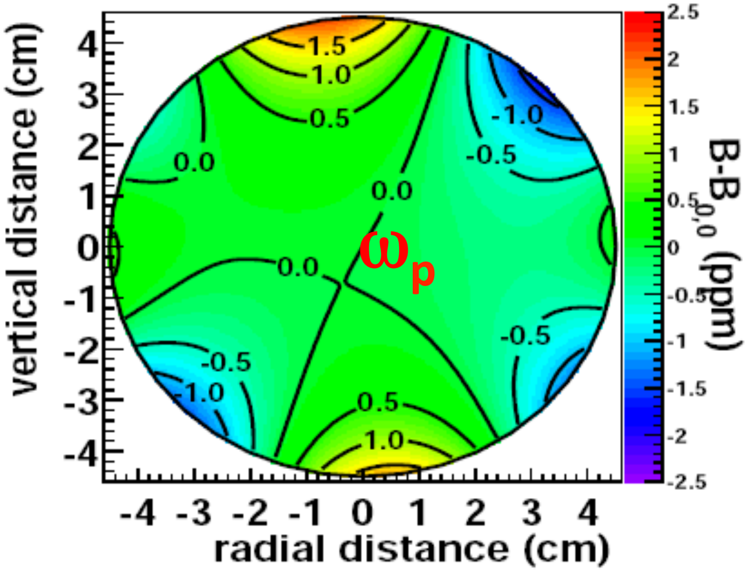
$$a_\mu = \frac{\omega_a/\omega_p}{\mu_\mu/\mu_p - \omega_a/\omega_p}$$

Measure B → via NMR → recast a_μ in terms of proton precession frequency, ω_p (at B in its rest frame).

Muonic hyperfine experiment gives μ_μ/μ_p at ~26 ppb precision (ref. arXiv:1203.5425)



$$N(t) = N_0 e^{-t/\tau}\left(1 + A cos(\omega_a t + \phi)\right)$$



Systematic effects in the positron spectrum due to:

- Pileup, gain stability
- Beam Effects, Muon losses

Systematic Improvements on ω_a

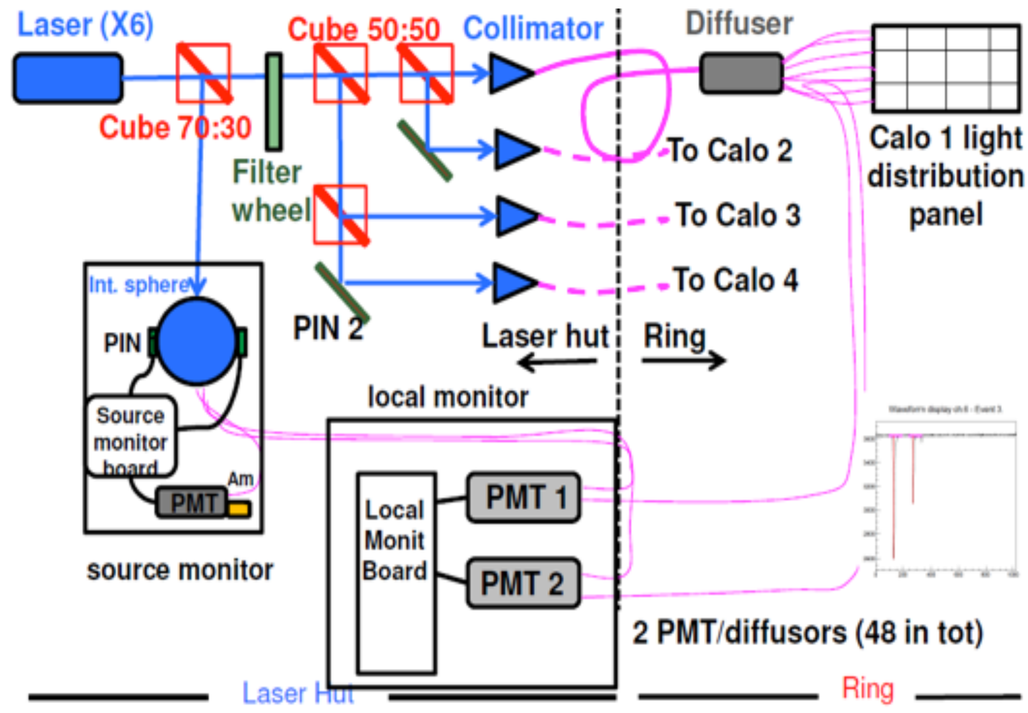
Systematics on ω_a 180 → 70 ppb compared to E821. Achieved by:

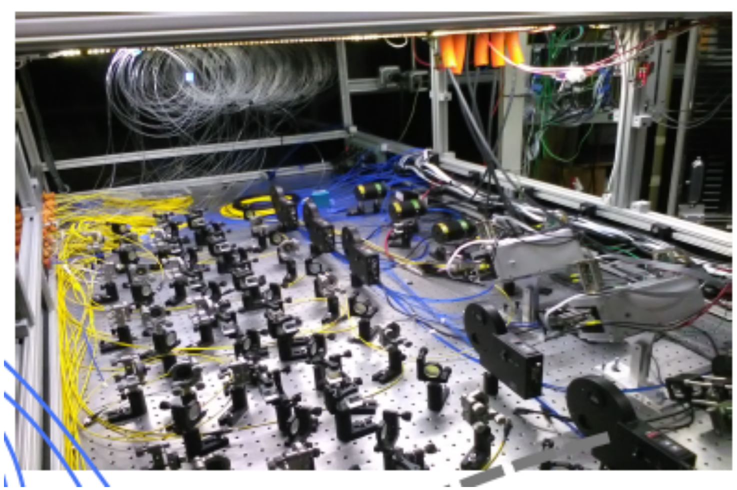
- ✦Improved Calorimeters
- ✦Much improved Laser control system
- ✦New Straw Tracker (two installed in run1)

Category	E821 [ppb]	E989 Improvement Plans	Goal [ppb]	Key element:
Gain changes	120	Better laser calibration low-energy threshold	20	**Laser**
Pileup	80	Low-energy samples recorded calorimeter segmentation	40	Calo + Laser
Lost muons	90	Better collimation in ring	20	Calo + Laser
CBO	70	Higher n value (frequency) Better match of beamline to ring	< 30	Inflector + Kicker
E and pitch	50	Improved tracker Precise storage ring simulations	30	Tracker
Total	180	Quadrature sum	70	

Monitoring / Calibration of Calorimeters - Laser

- Laser calibration system –Optical fibers carry laser shots to each of the 1296 calorimeter crystals. One laser head sends light to 4 calos as shown in the right fig.
- 6 SM (source monitors - 2 pin diodes + 1 PMT) to check and correct for laser light fluctuations.
- 24 LM (local monitors) each with two PMTs that are used to check stability of the light distribution chain.

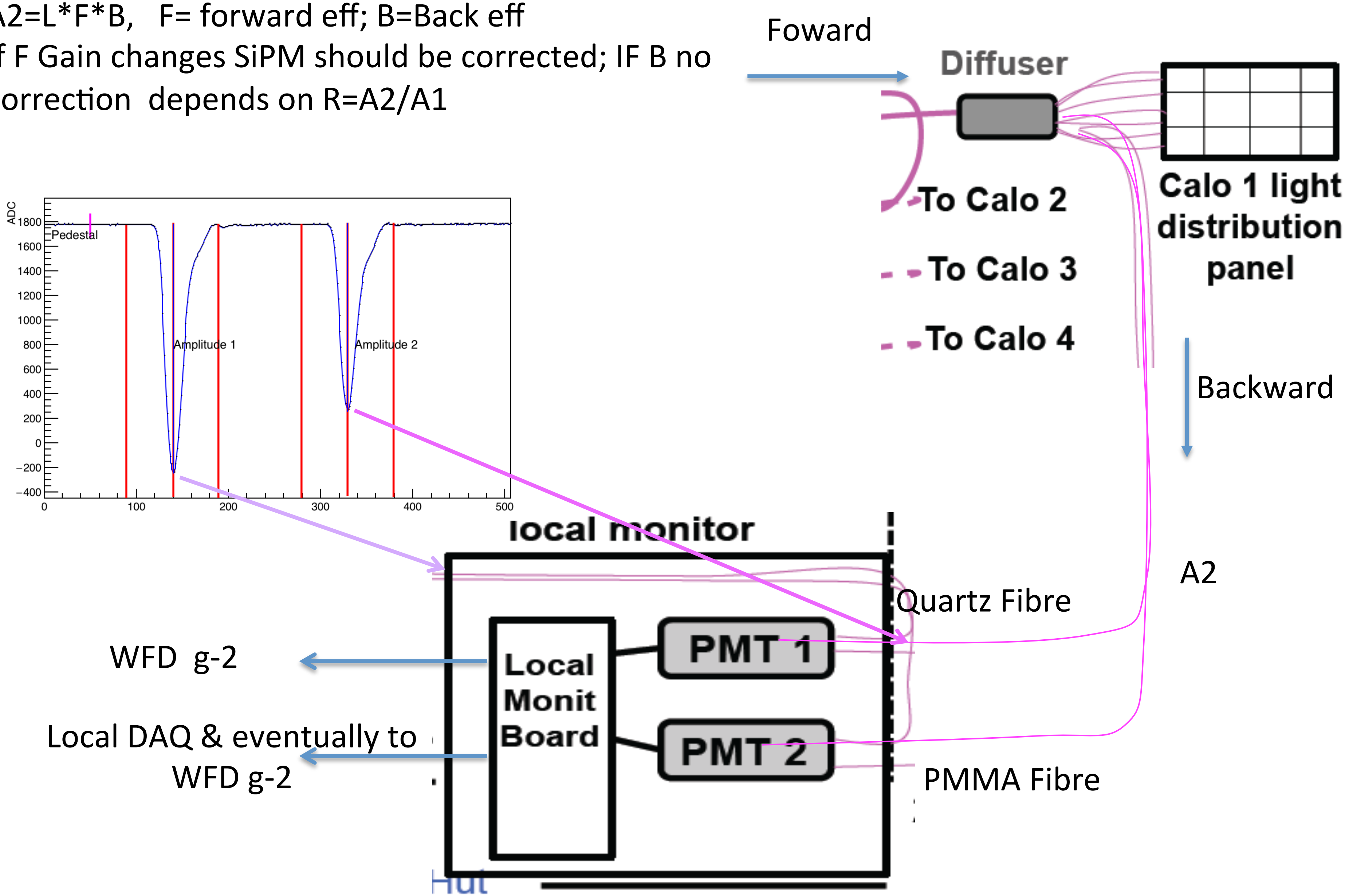




The picture on left shows the entire laser calibration system in the laser hut of the experimental hall.

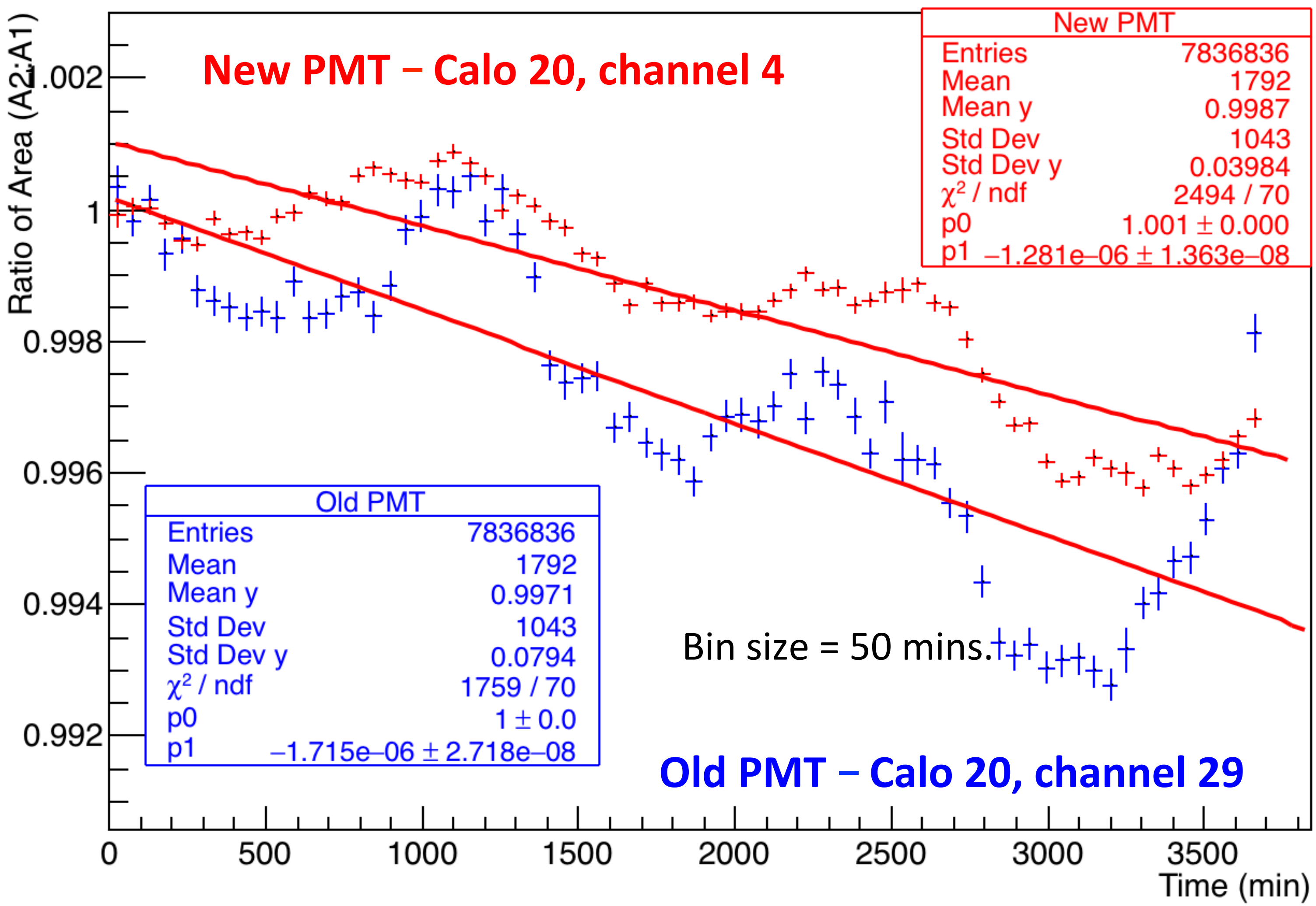
Local Monitors - details

A2=L*F*B,   F= forward eff; B=Back eff
If F Gain changes SiPM should be corrected; IF B no correction depends on R=A2/A1



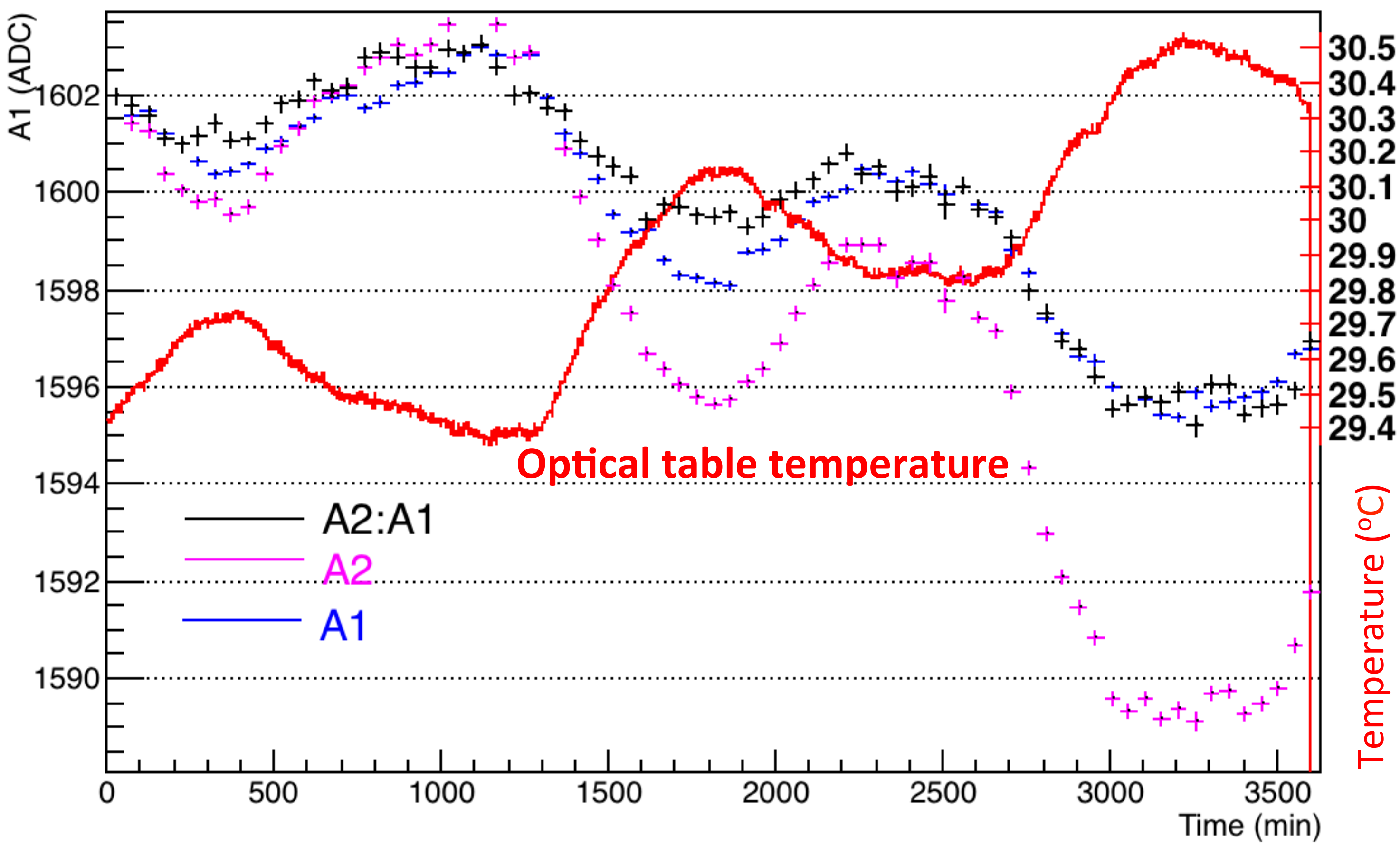
LM Analysis – time evolution studies for 60 hours dataset 22/4 - 1:09 pm to 25/4 – 2:20 am

Comparison of old and new PMTs for Calo 20

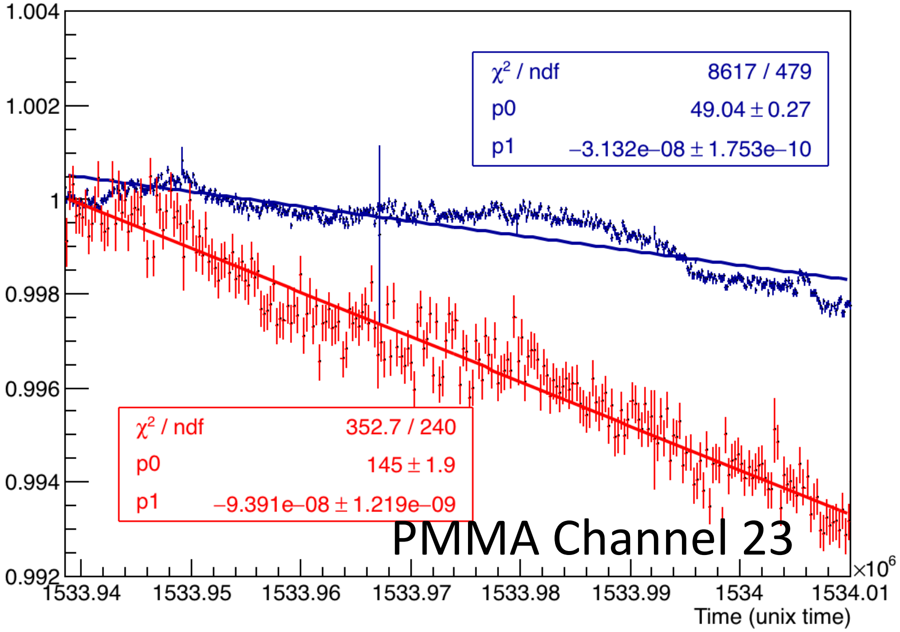


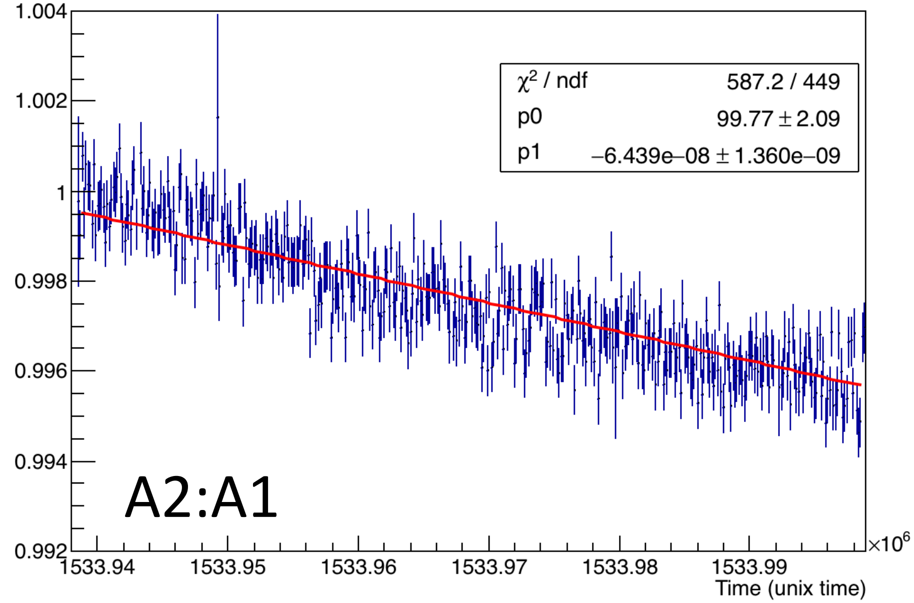
Temperature Variation – Channel 4

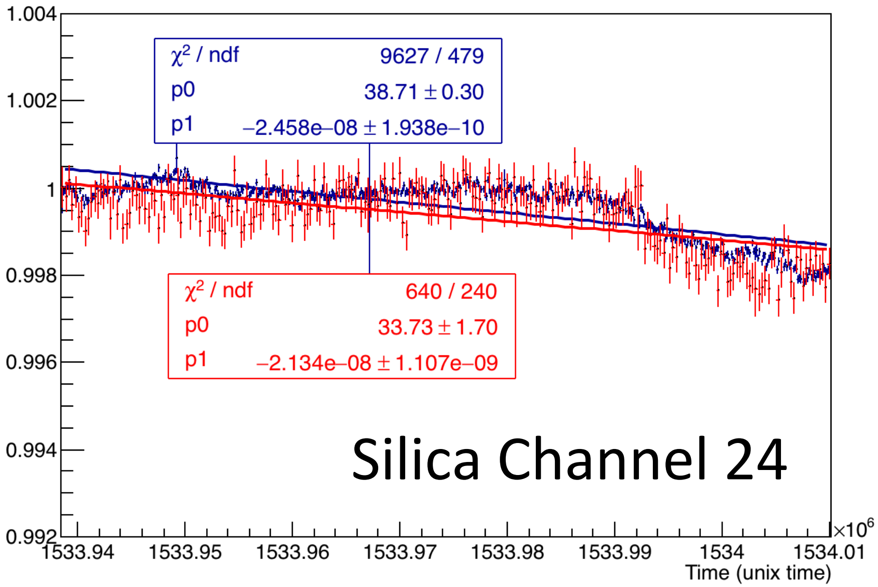
Overlaid temperature and A1, A2 and A2:A1 on the same plot, after normalizing all to A1 for consistency

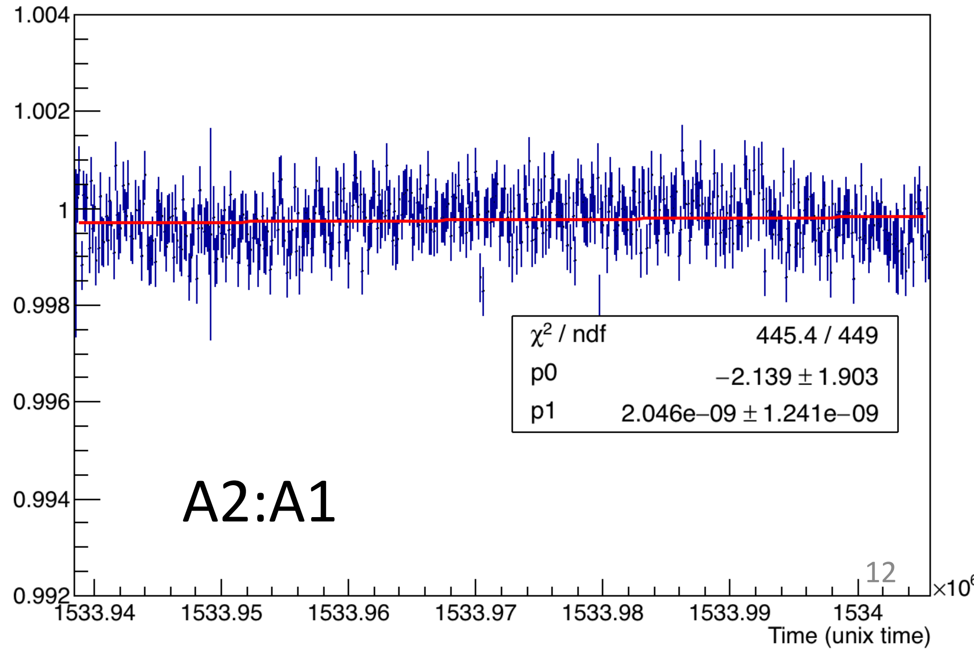


A1 and A2 overlaid and A2:A1 – 20 hr test dataset



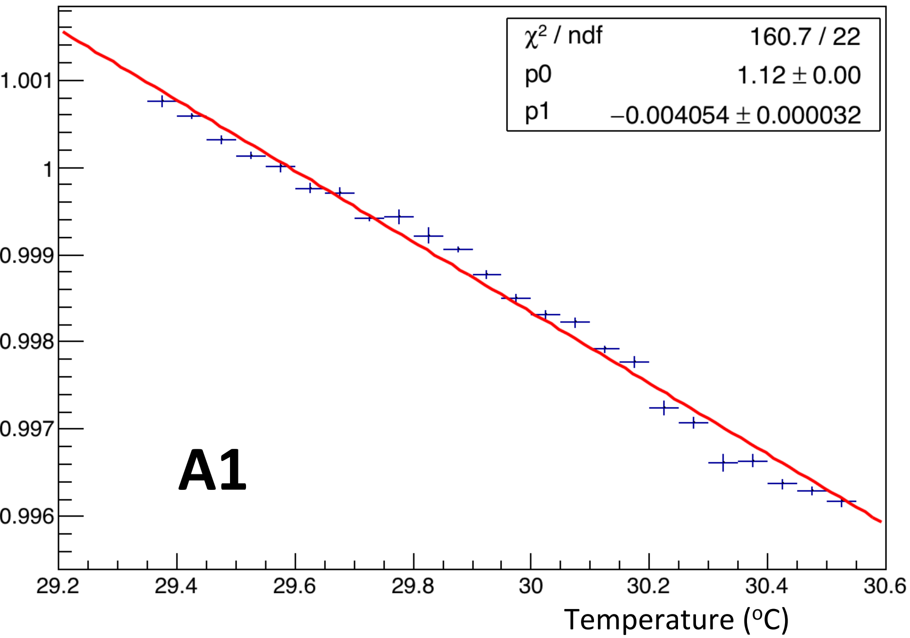


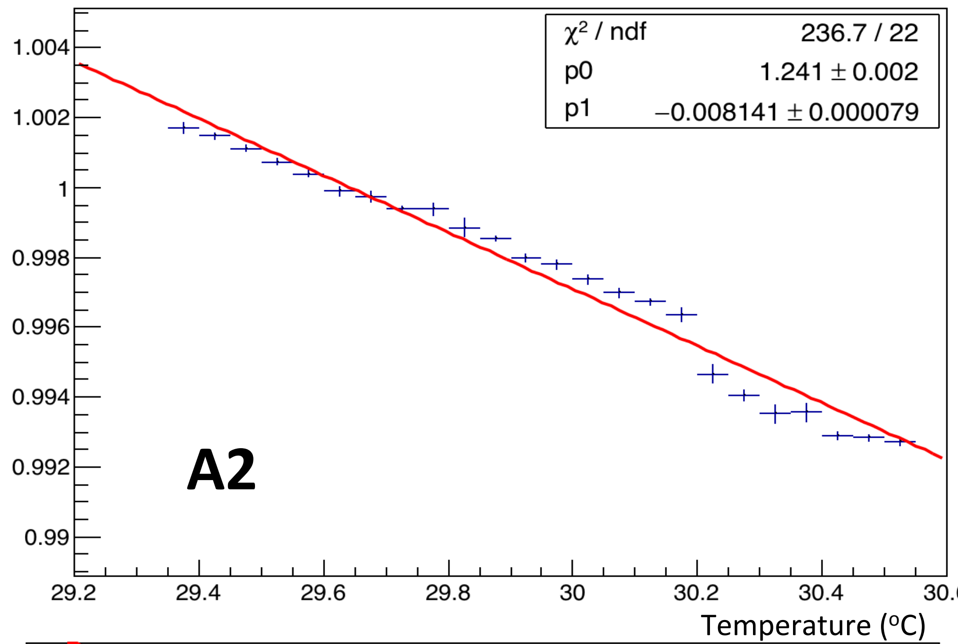




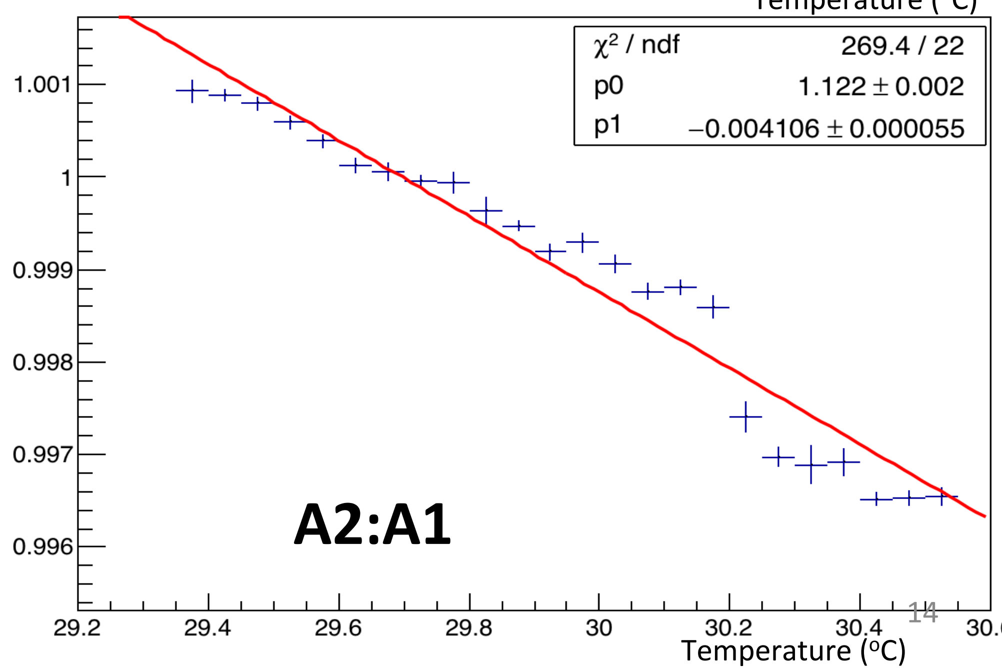
LM Analysis – temperature studies of 60 hr dataset 22/4 - 1:09 pm to 25/4 – 2:20 am

Amplitude Vs. Temp – Channel 4

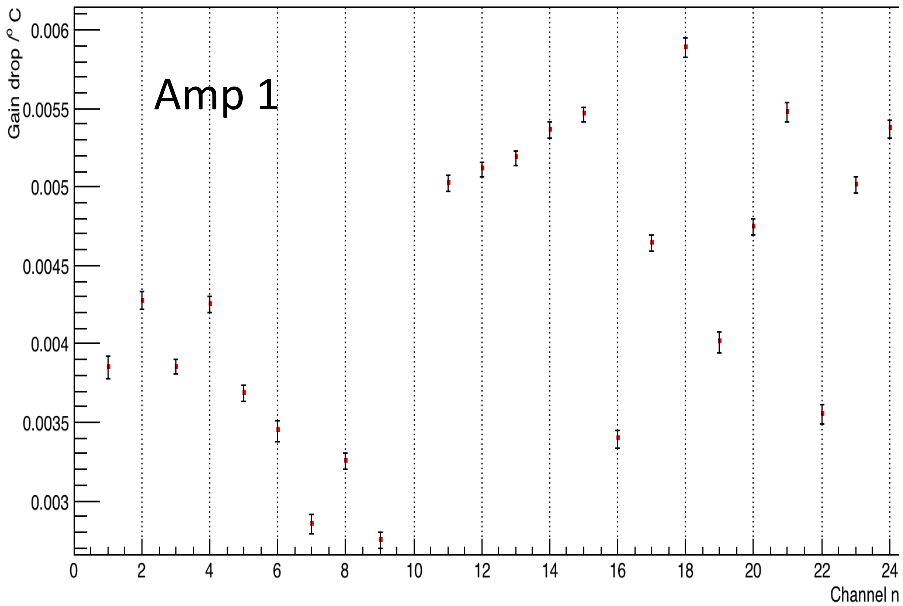


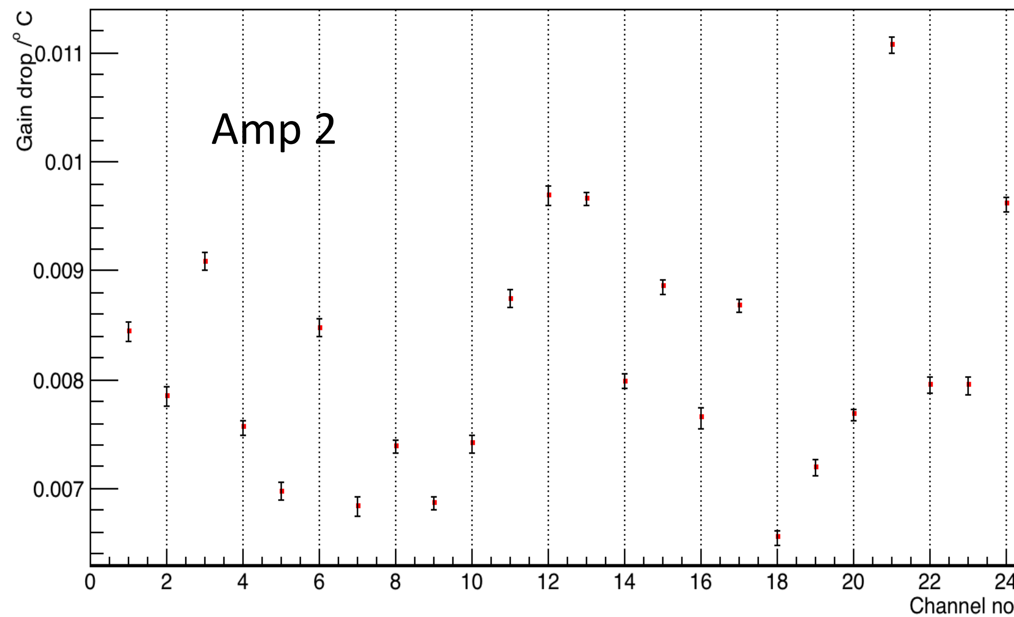


The slope appears to change at 29.8 C.

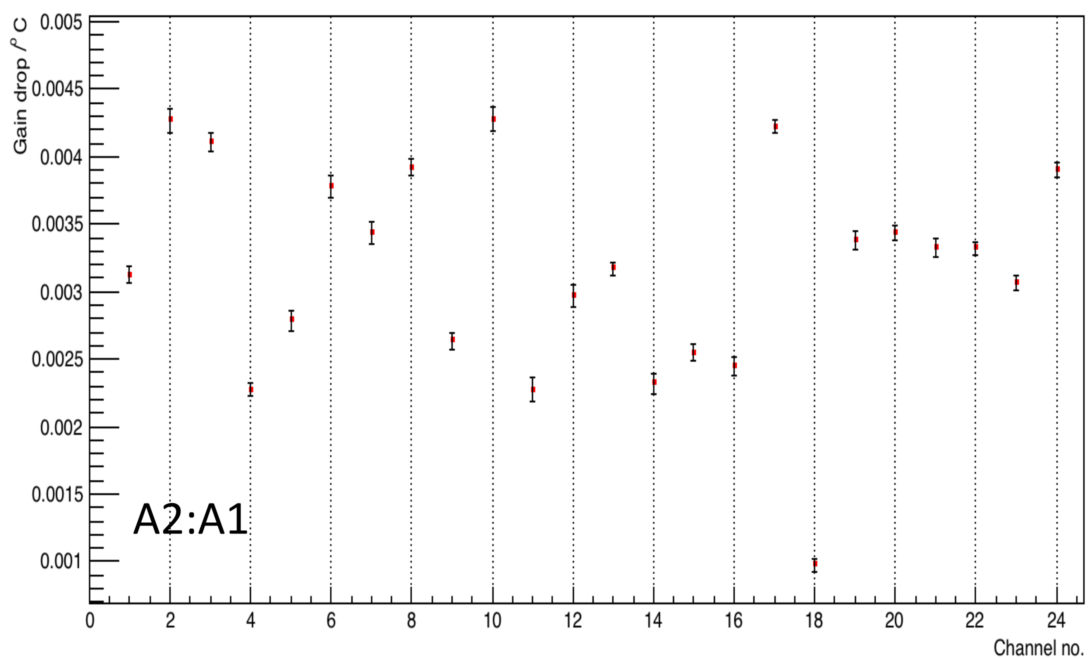


Amplitude Vs. Temp – channels 1 - 24

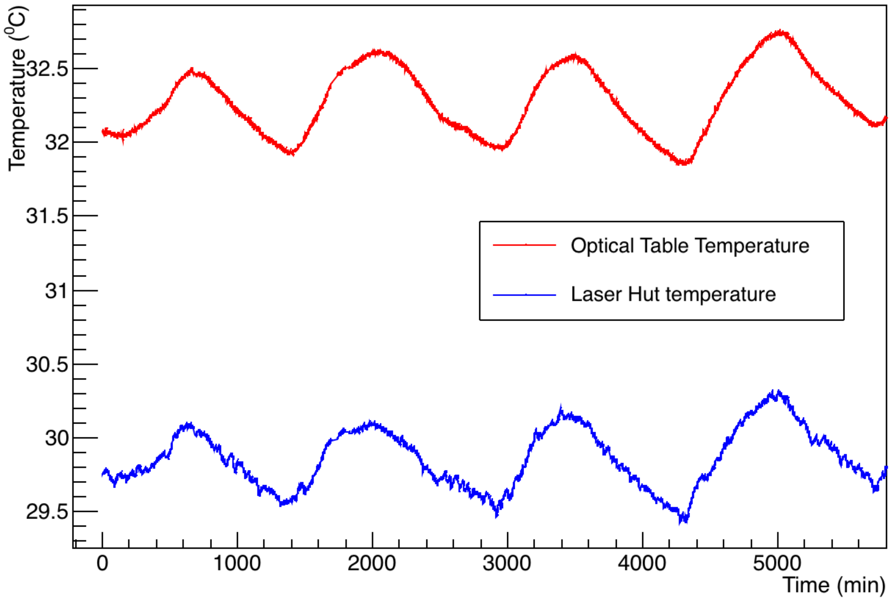




Results obtained by linear fits of each channel.

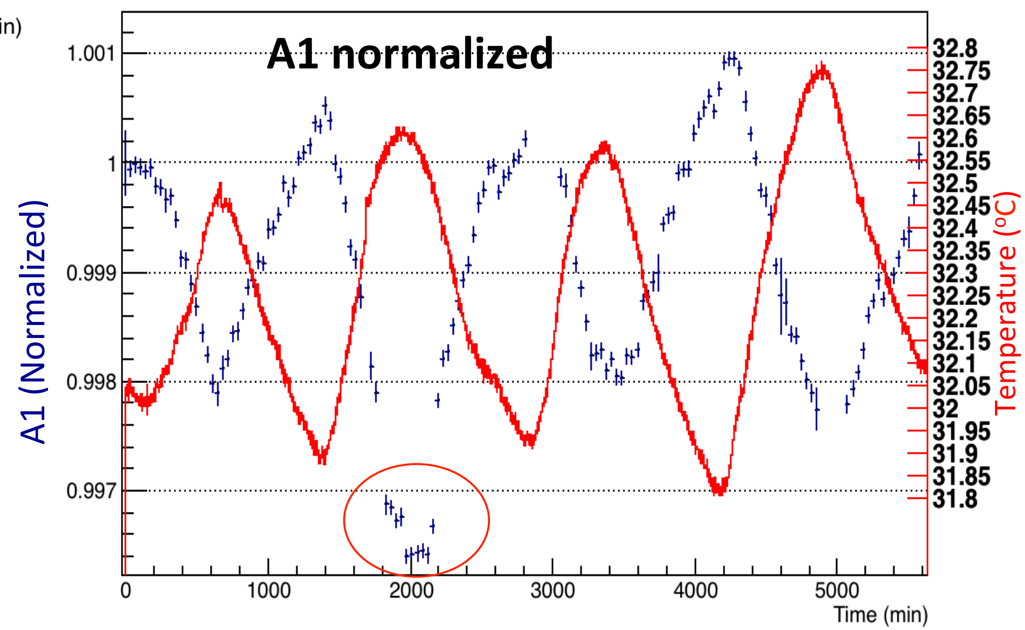


100 hours dataset – Temperature Vs. A1 – Channel 4

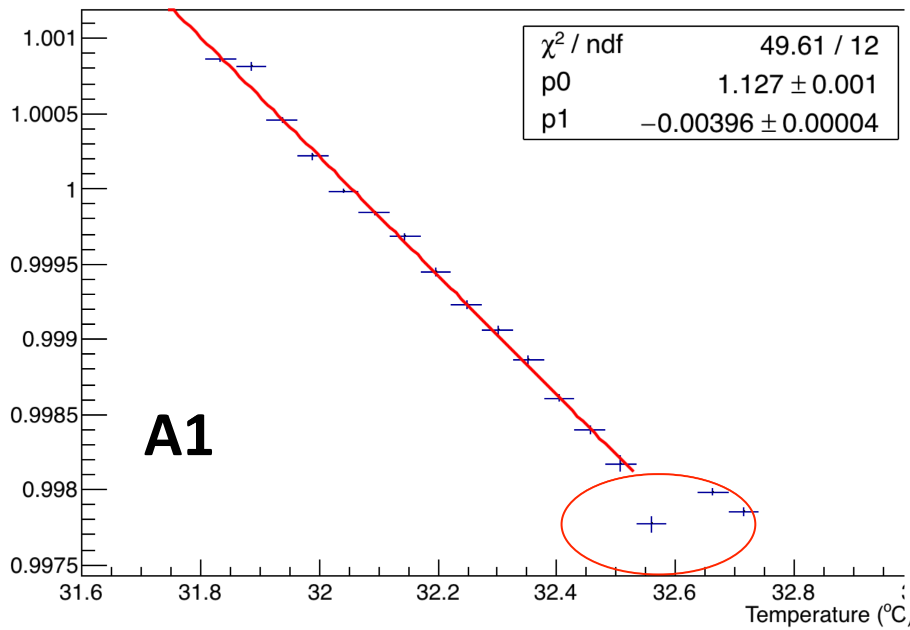


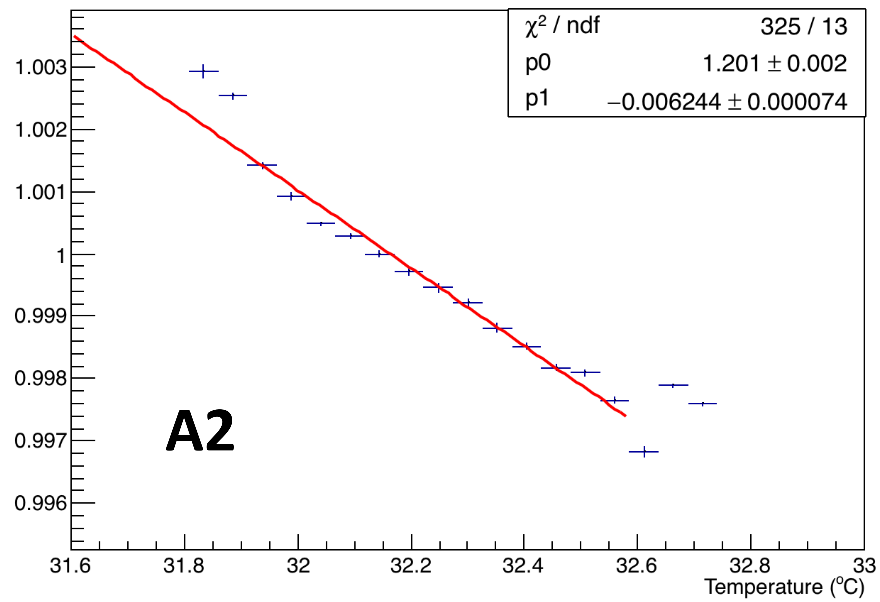
A different dataset confirming the negative temperature coefficient of gain with temperature. Around the temperature of 32.65 °C, we had a couple of bad runs which causes a small distortion (red circle below).

Thus, a cross check with another dataset and another channel confirms similar results

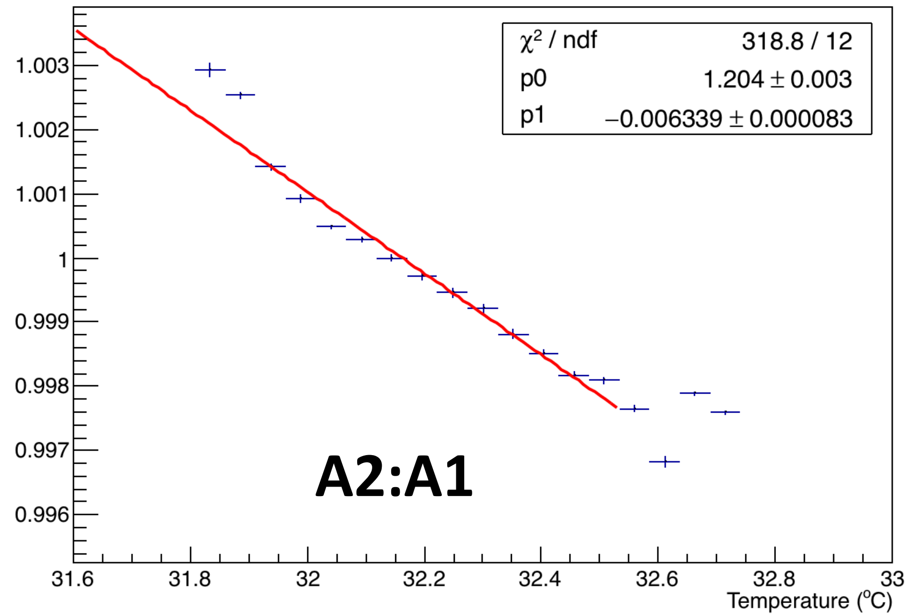


Temperature studies of 100 hour dataset





New PMT – Silica fiber both forward and return directions



Conclusions

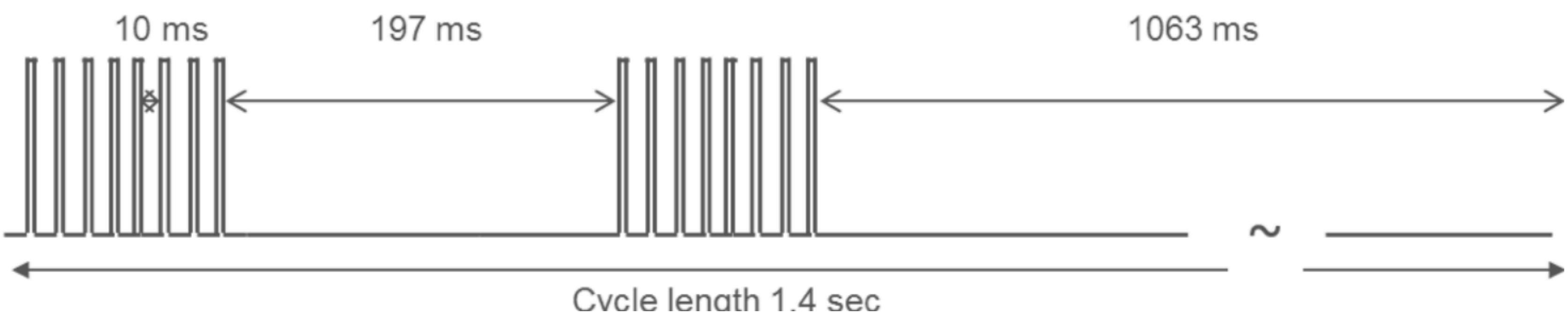
- Variation of A1 with temperature shows a negative correlation of PMT gain with temperature (as expected).
- A2:A1 is almost constant with time for the (for longer time ranges some variation appears especially for the old PMTs)
- Channels 0 to 23 i.e. the new PMTs (refer slide 9) show a comparatively stable A2:A1 drop with temperature (it ranges from ~0.1% to 0.45%) which is much better than the old PMTs and confirms a reasonably stable behaviour (in gain) which meets the required precision of the experiment.

Thank You!!

Back up slides

Back up and other basic info

- About laser used – PicoQuant(LDH-P-C-405M), max pulse energy 1 nJ, pulse width 700 ps @ wavelength 405$\pm$10 nm max. repetition rate 40 MHz.
- Beam fill structure: Fill is 600 us each. Has 3 out of fill windows of 10 ms, ~200 ms and ~1000 ms

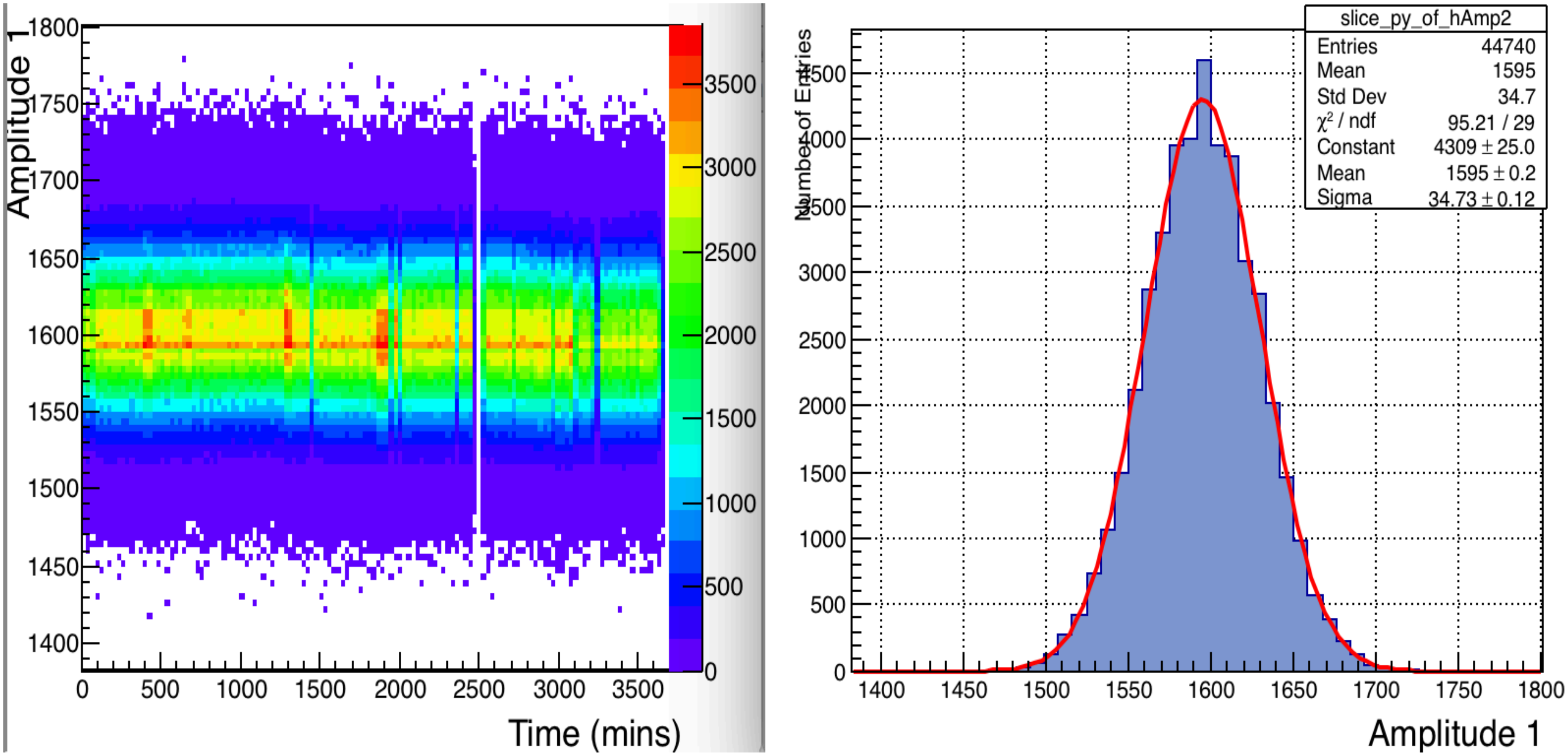


- Pulse quality display in next slides

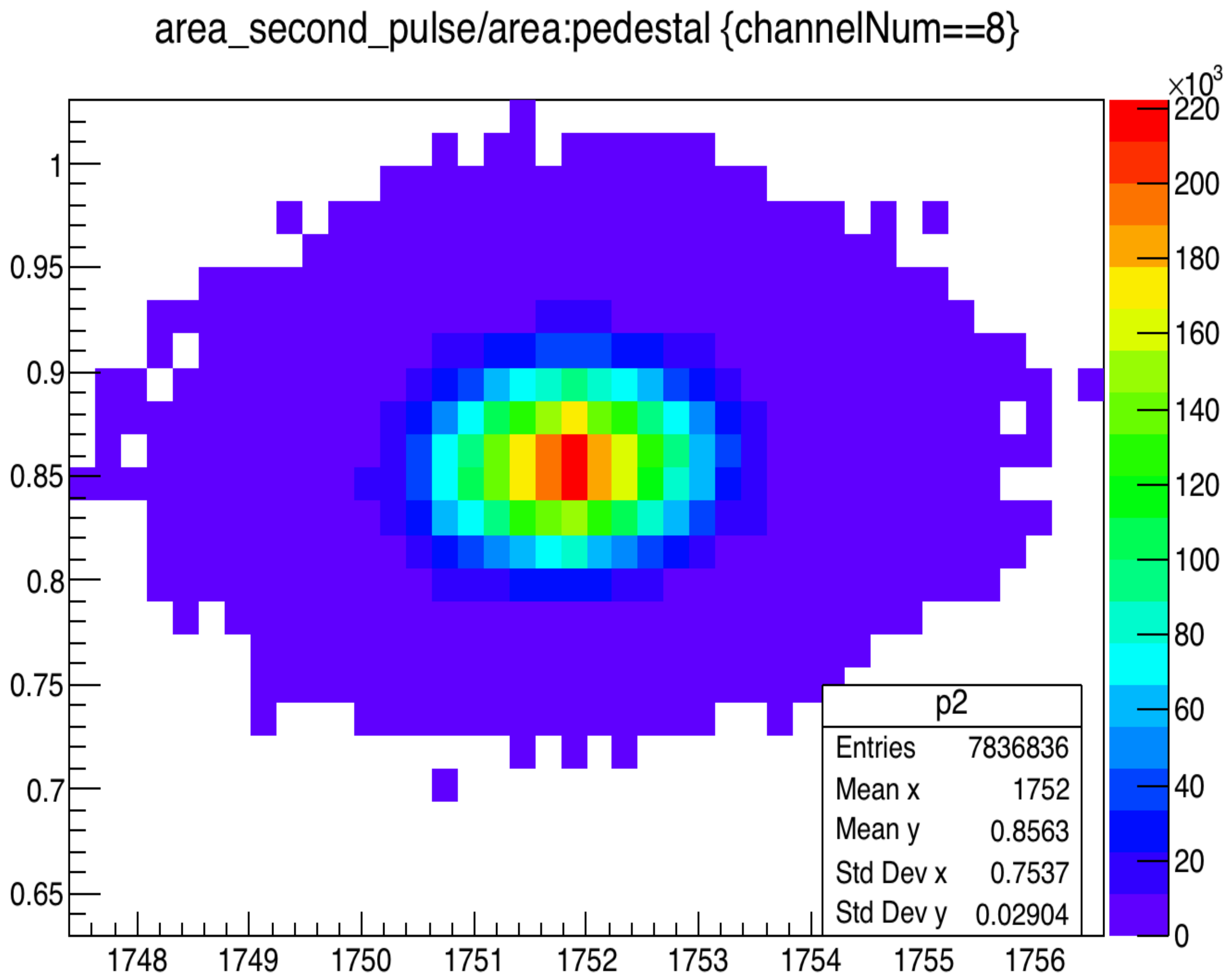
Calorimeters

- 24 calo − each divided in a grid of 9x6 PbFl Cerenkov crystals read out with SiPM − 1 calo 54 SiPM (for better pileup) @ 800 MSPS, uTCA crates read by a MIDAS/U DAQ
- energy res of 50 MeV at 2 GeV.
- Pile up separation 4.5 ns and time res 25 ps at 3 GeV
- Additionally have 3 straw trackers 128 straws Ar:CO2 gas − would help track positrons

Some Studies/Observations –Scatter plot and projection of a bin – good Gaussian



Correlation between Ped / amplitude ratio



Revisit temperature

A1 with temp overlaid. Again shows negative correlation. Analyzed till 1100 mins. Explains plots of slide 12.