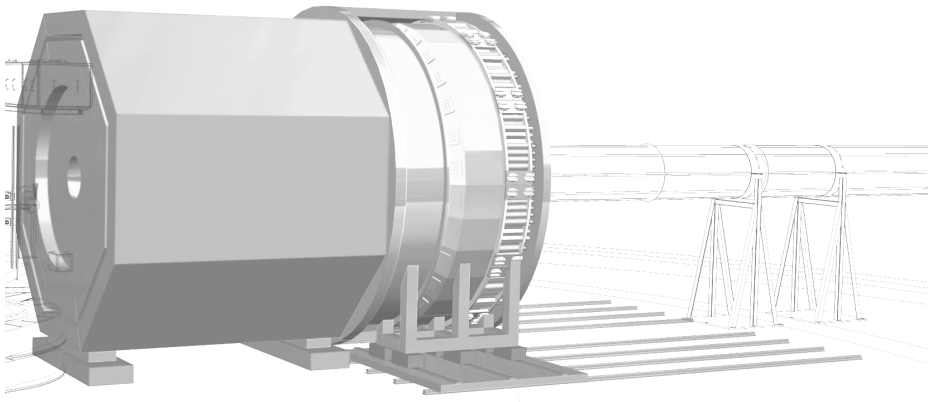
Pre-R&D bench test progress and plan for HGC



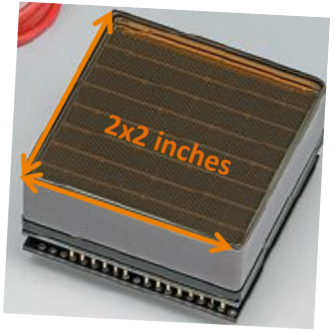
Bishnu Karki
Duke University

SoLID Collaboration meeting
Dec 15 -16, 2021

Outline

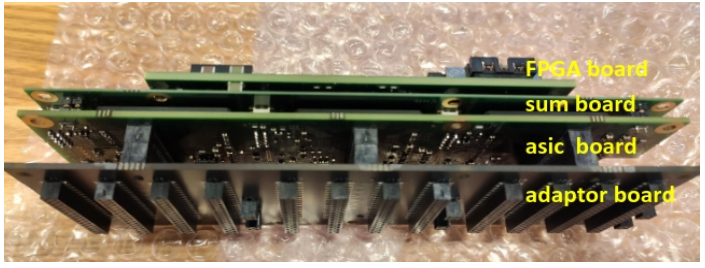
- Bench test results
  - Ring analysis to study the separation of background
  - Saturation study of MAROC sum board
- HGC
  - HGC magnetic shielding test
  - Update and plan
- Summary

MaPMT MAROC sum readout



MaPMT:

- Single photoelectron resolution
- Resistant to magnetic fields
- Readout by MAROC sum board
  - TDC : pixel hit information from 64 pixels
  - FADC : sum signals: 4 quads (16) & 1 total sum (64)

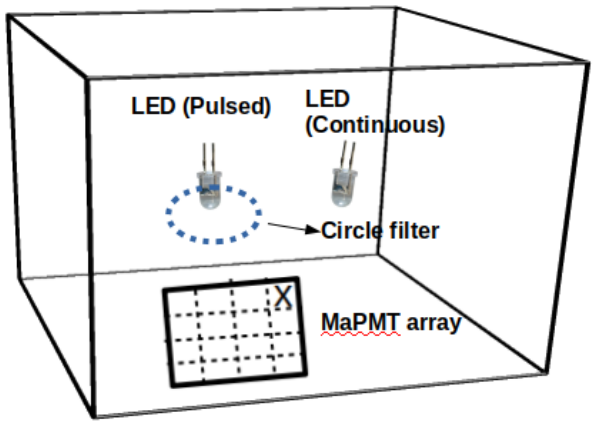


MAROC sum board

- Cherenkov detector rate as high as 200 kHz/pixel (pixel) or 4 MHz/PMT (sum)
- MaPMT with MAROC sum readout can be a potential option to handle such a high rate
- CLAS12 RICH detector validated performance only up to 2 kHz/pixel
- To check and confirm the expected performance of MaPMT MAROC sum readout at bench

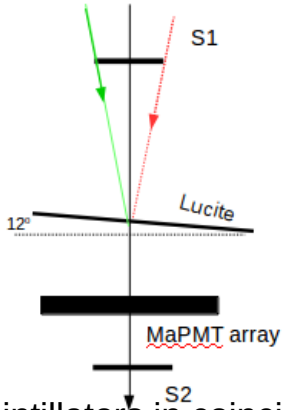
Bench test setup for ring in MaPMT

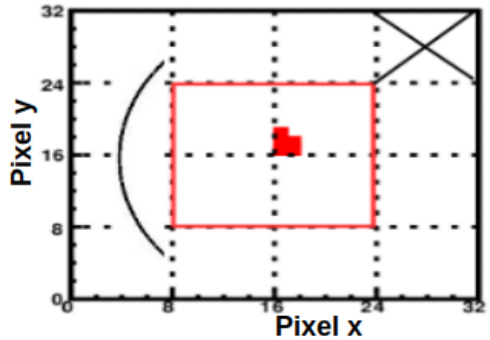
LED ring



- Pulsed LED synchronized with clock for signal
- Second LED operated with DC voltage for continuous random background
- Mean radius of ring = 4.7 cm (7.75 pixels)
- Ring analysis is simpler relative to cosmic data but it to check our algorithm

Cosmic ring





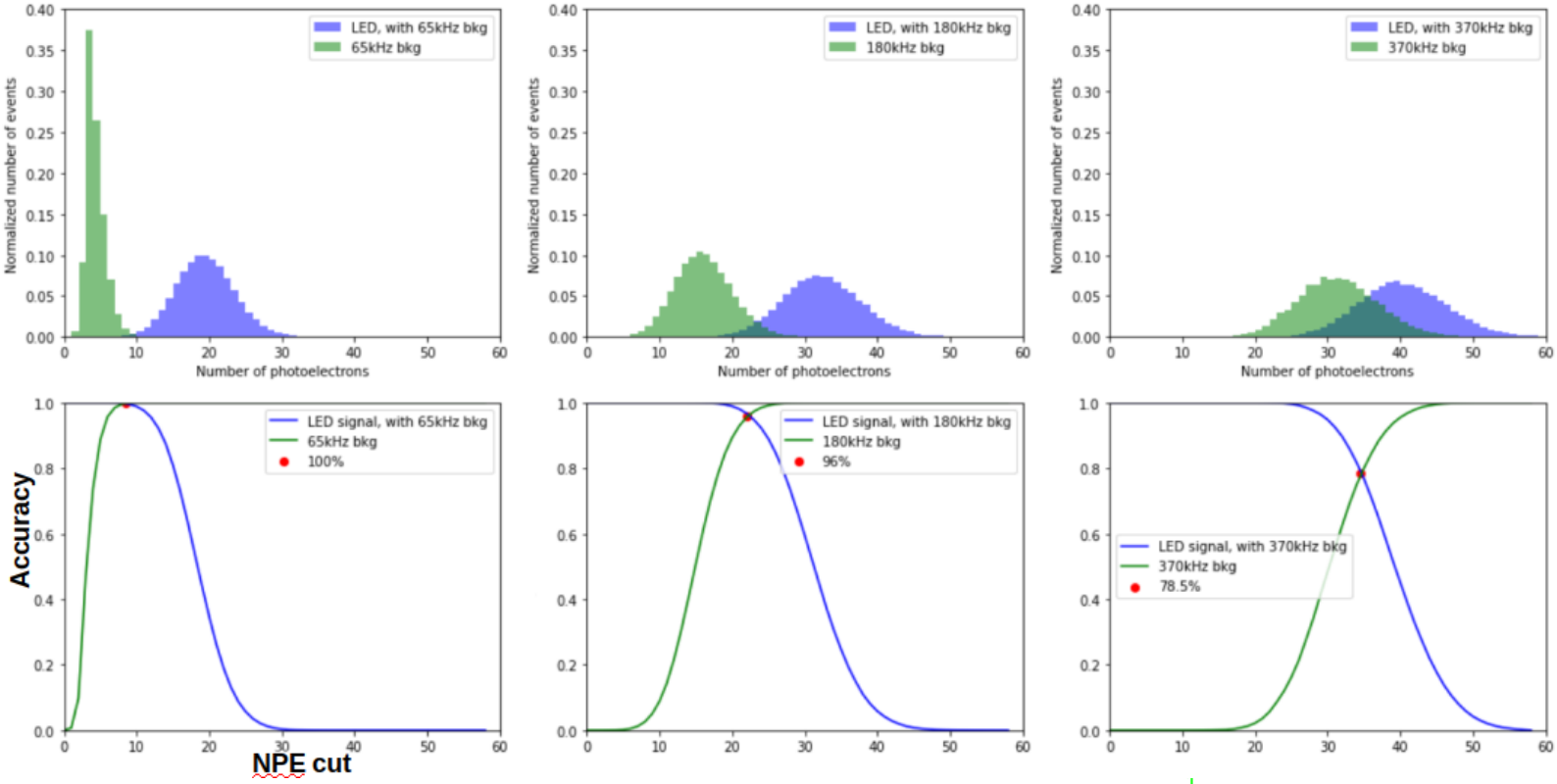
- Two scintillators in coincidence forms trigger (5 x 5 cm overlap area)
- 4 cm thick lucite is used as radiator (refractive index 1.5)
- $\theta_{opening}$ (48°) > $\theta_{critical}$ (42°), only quarter of the Cherenkov ring is observed
- Lucite is inclined to take advantage of vertical cosmic flux
- Angular acceptance 6°
- Data taken analysis underway

Algorithms for ring analysis

- Number of photoelectron cut, most straightforward
- Hough circular transform, ring finder algorithm from computer vision

LED ring (pixel readout)

Analysis by Bo Yu



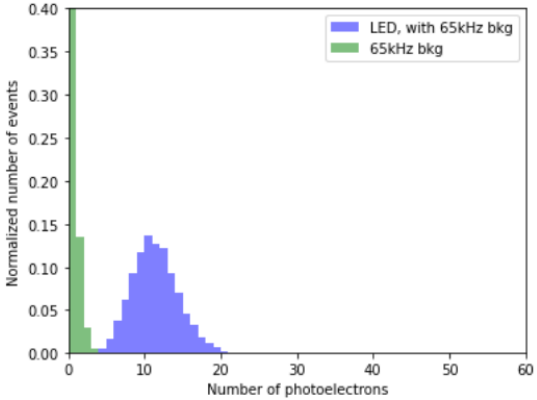
$$Accuracy = \frac{\text{Number of accepted signal events}}{\text{total signal events}}$$

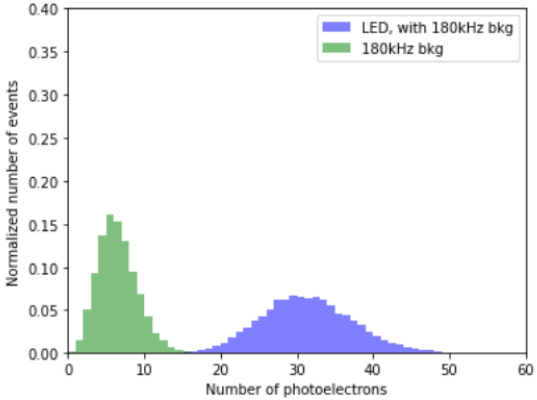
$$Accuracy = 1 - \frac{1}{rejection\,factor}$$

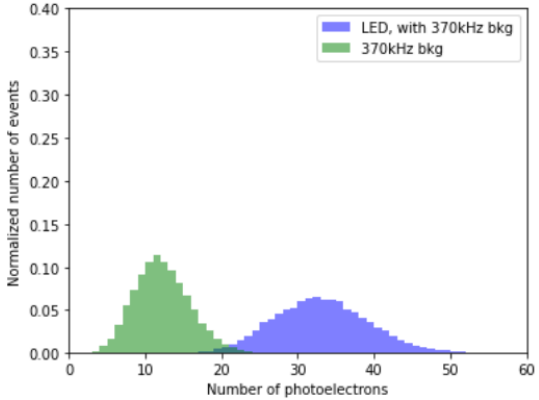
- LED background agrees well with the estimation
- Separation between signal and background peaks are very clear at lower rate, NPE cut is sufficient
- Above 200 kHz/pixel using Hough transformation we achieved accuracy >90%

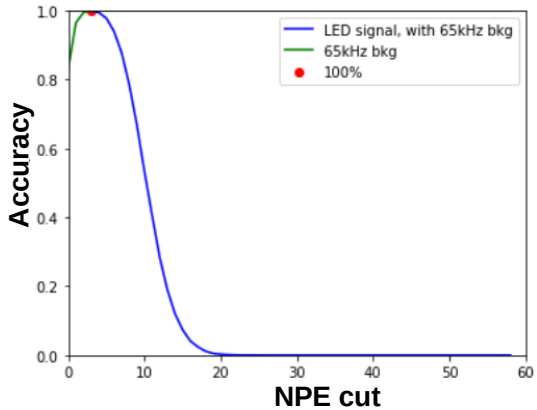
LED ring (quad readout)

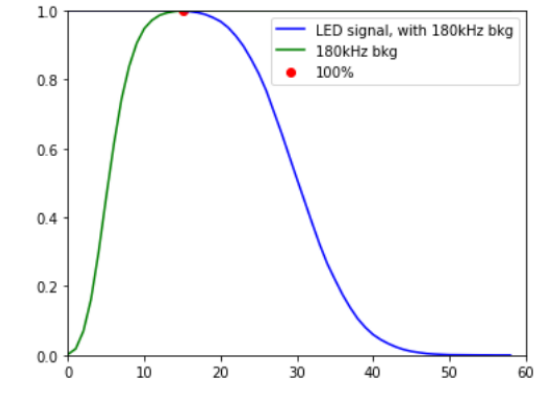
Analysis by Bo Yu

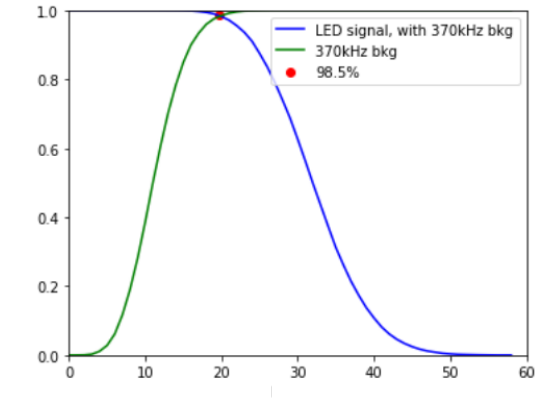












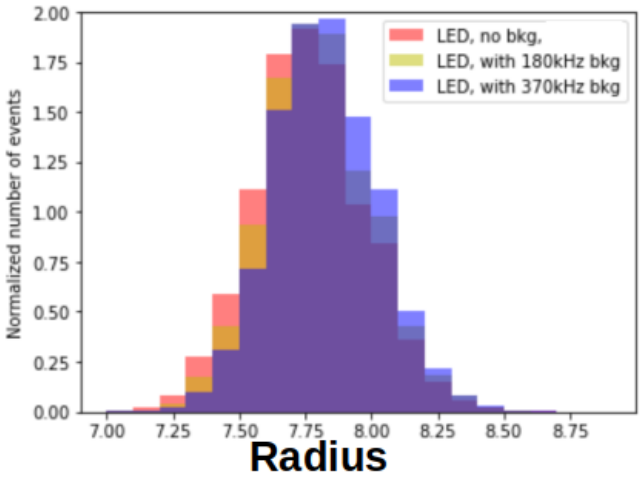
$$Accuracy = \frac{\text{Number of accepted signal events}}{\text{total signal events}}$$

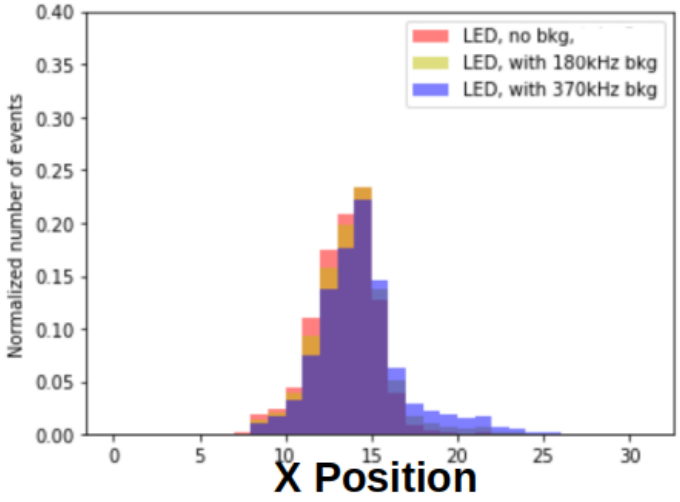
$$Accuracy = 1 - \frac{1}{rejection factor}$$

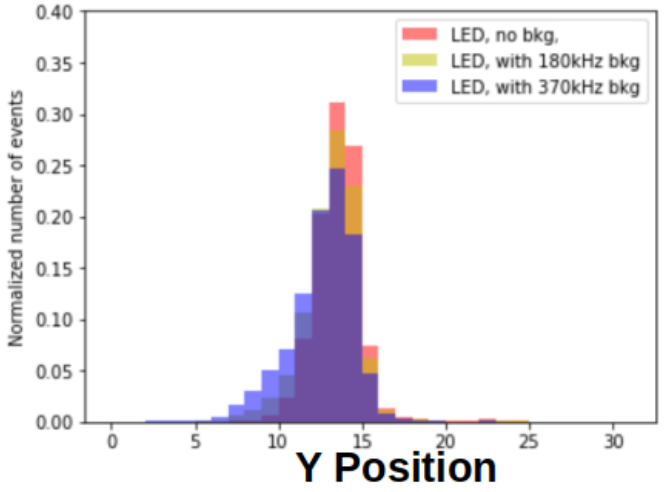
- LED background agrees well with the estimation
- For sum readout signal time window is half relative to pixel readout (36 ns vs 80 ns)
- Signal and background peak are well separated for all 3 backgrounds, NPE cut is sufficient to reject background

LED ring (pixel readout)
Parameters of ring

Analysis by Bo Yu







Pattern recognization using Hough transformation

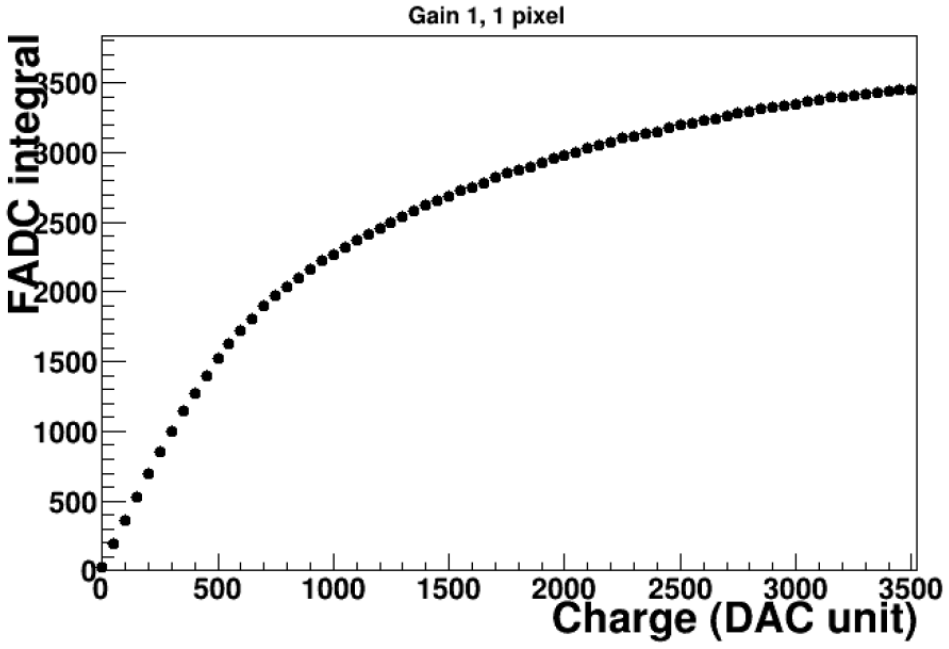
- Pixel readout
  - Parameters of recognized rings agree well with the experimental setup up to 370kHz/pixel
  - Hough transformation for pattern recognition works well for LED ring

- Quad readout
  - Analysis underway

Saturation study of MAROC sum board

Saturation study of MAROC sum readout

- MAROC sum readout
  - TDC information from 64 pixels
  - **FADC information from 4 Quads (16 pixels) + 1 total sum (64)**
- Dynamic range linear region for pixel/quad/sum signal

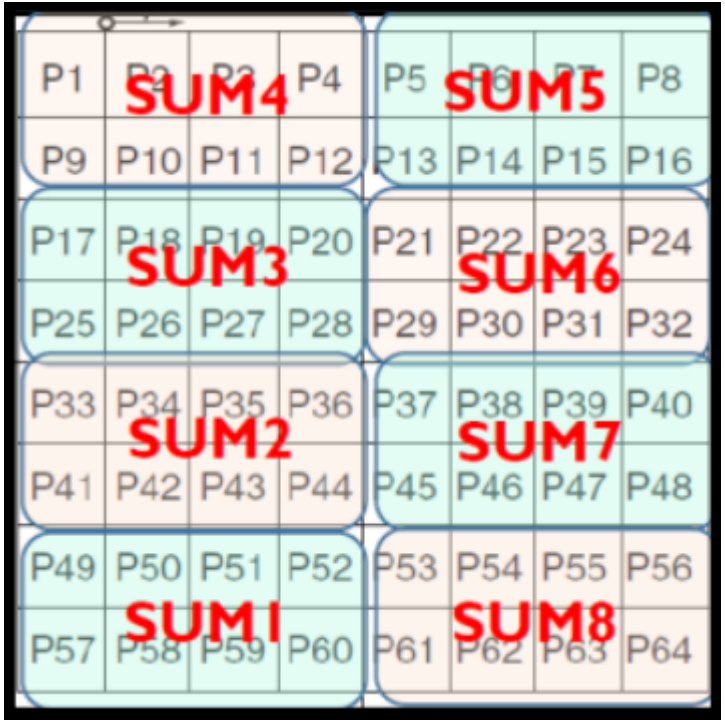


Dynamic range of linear region depends on HV applied to PMT

MAROC sum readout

MAROC Sum signal sums output from 8 pixels

- Quad 1= sum 1 + sum 2
- Quad 2= sum 3 + sum 4
- Quad 3= sum 5 + sum 6
- Quad 4= sum 7 + sum 8

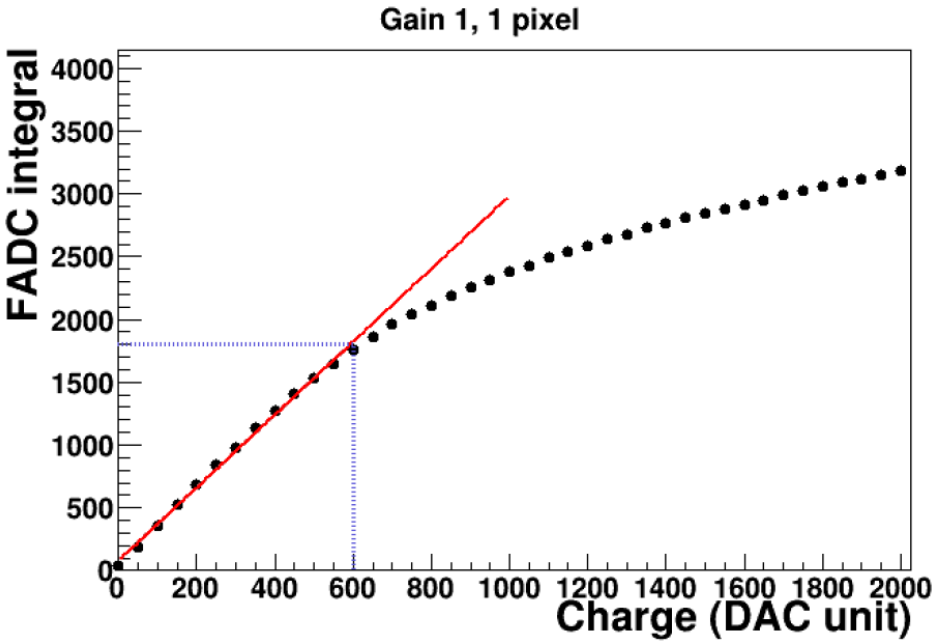


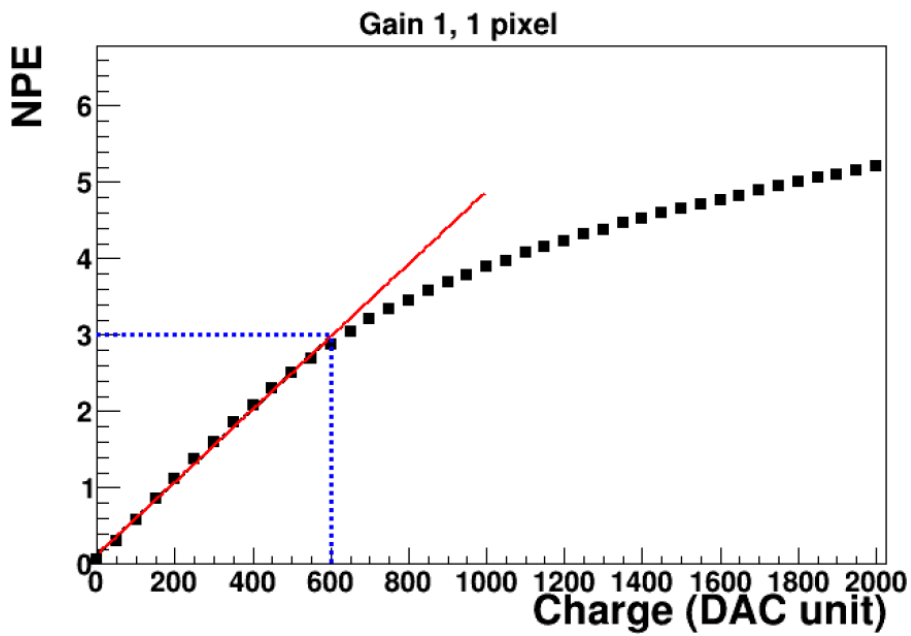
Data: range of charge was injected in various combination of pixels (within in sum 1)

- Charge injected in 1 pixel of sum 1
- Charge injected in n pixels of sum 1
- Charge injected in n pixels of total sum

- Saturation from MAROC sum board
  - Pixel saturation
  - Sum saturation (group of 8 pixels)

Linearity of sum signal





- With enabling 1 pixels in sum1, it saturates at 1800 ADC (600 DAC unit charge)
- Using measured value of SPE (for instance at 850 V), 1800 ADC is equivalent to 3 photoelectrons
- At 850 V, we will have linearity up to 3 npe for each pixels

Linearity of sum signal

Saturation threshold in terms of NPE at different HV

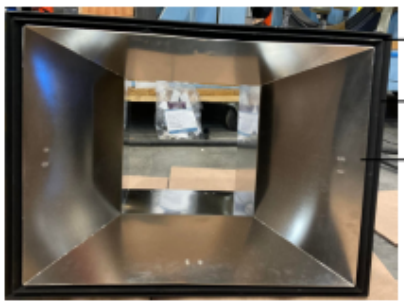
Pixel (1 pixel)	Quad (16 pixels)	Sum (64 pixels)
850 V		
3	10	44
900 V		
2	7	29
1000 V		
1	4	17

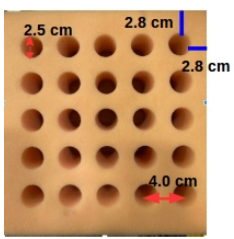
Dynamic range of linear region depends on HV applied to MaPMT

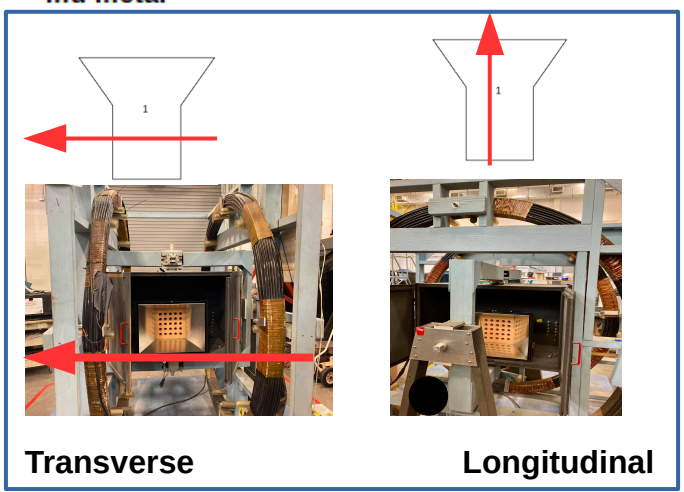
HGC Magnetic shielding test

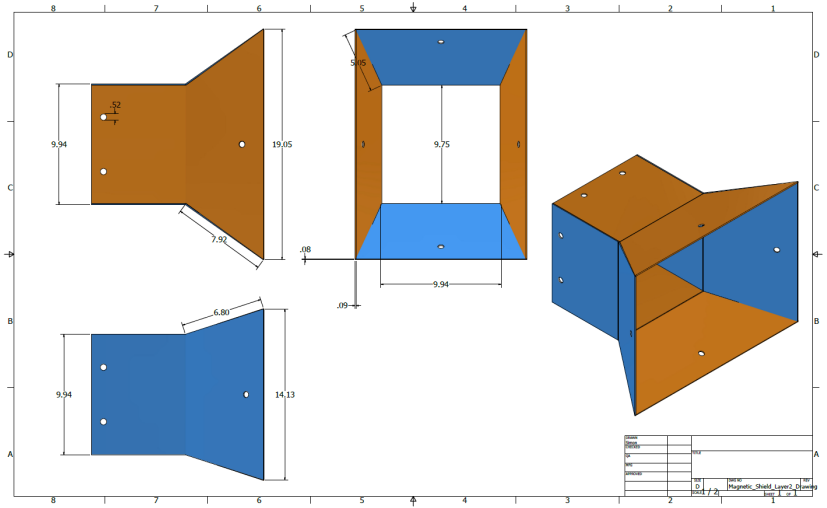
HGC magnetic shielding test

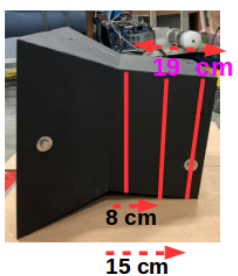
- Latest field at HGC PMT location < 80 G
- 20 G transverse or longitudinal field can reduce MaPMT gain by 2% or 5% (arxiv:1306.6277 For MaPMT H8500-03)
- MaPMT HA12700-03 rough test show similar result, no pixel test yet
- “Magnetic Shielding Corp” made netic (iron) and co-netic (mumetal) layer assembly with proper annealing
- External field of 90 G is applied using Helmholtz coil
- Measured both transverse and longitudinal field











HGC magnetic shielding test

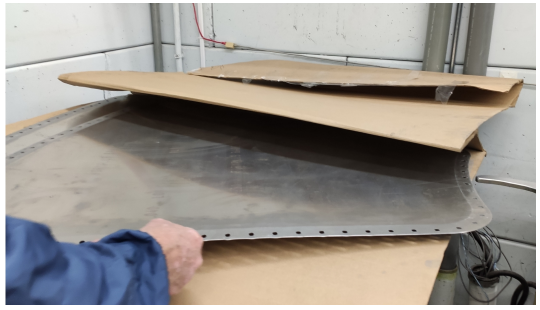
0.095” netic + 0.095” netic

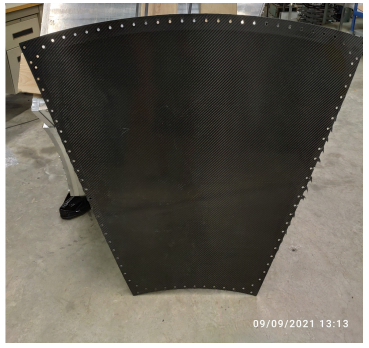
At PMT location	Longitudinal (+/- 0.3 G)	Transverse (+/- 0.3 G)
Test	**22 G**	**5 G**
Simulation	**28 G**	**8 G**

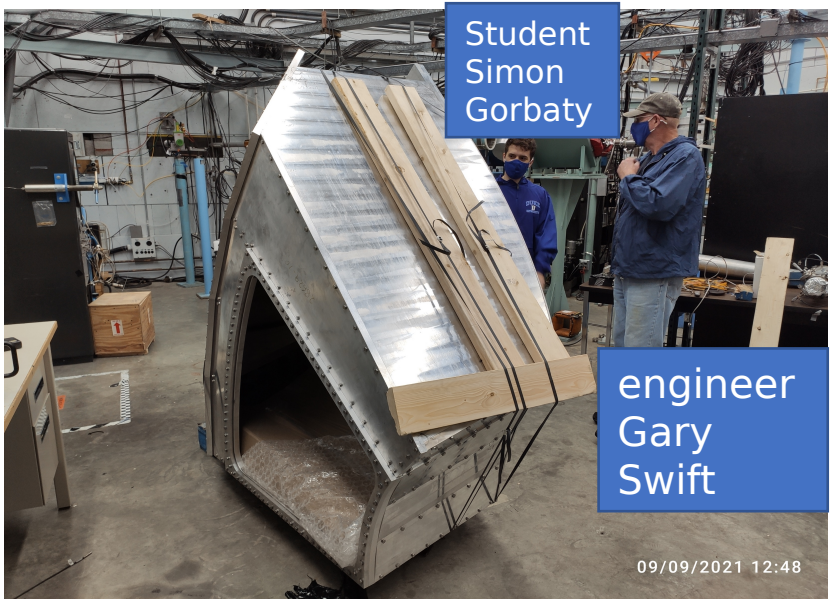
- 0.095 netic + 0.095” netic can reduce field from 90 G to 22 G
- Residual field at a few Gauss
- Both simulation and test shows additional 0.08” mumetal layer can reduce field by another 20%, but it adds weight and cost
- Simulation at external 100 G by Wei Ji
- Test at external field 90 G
- Simulation has limited space due to computing demand and it can have some bias
- There is no endcap which leaves more freedom for readout design

HGC Prototype at Duke

- Shipped from UofR and arrived Duke late Aug 2021, Stored at TUNL.
- Including the tank and two aluminum windows and one carbon fiber window
- It can be used for mirror and readout mounting test in future. but we need to do standalone design and test first



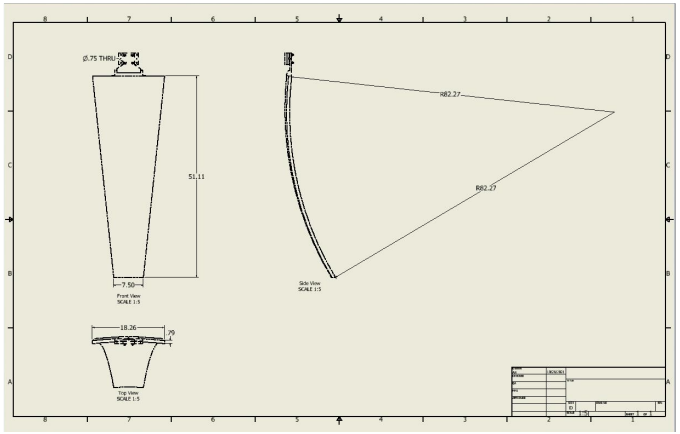


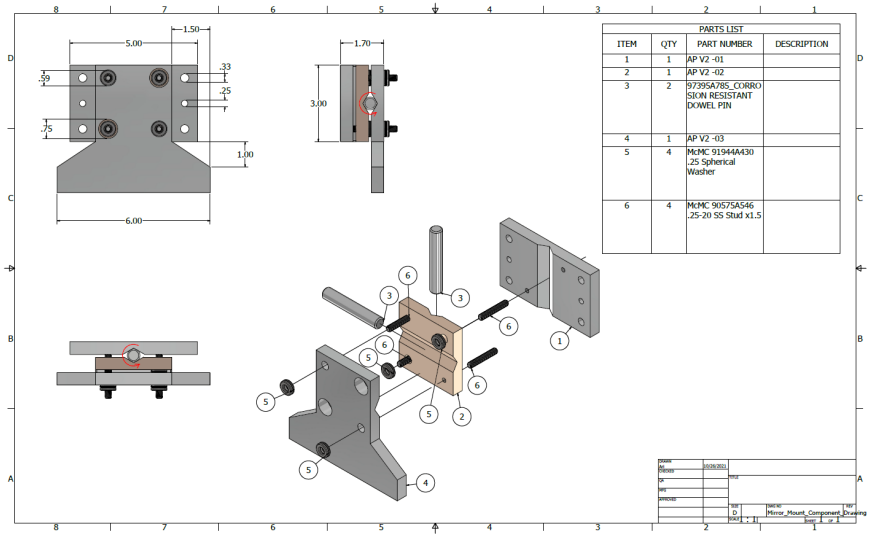


Slide courtesy Zhiwen Zhao

Mirror mounting

- Concept design holding mirror on top edge only
- It can have ~4deg mirror tilting which allows PMT assembly ~5cm shift. Maybe it alone is enough for optical aliment.
- We plan to make a mounting prototype and a mockup flat mirror to test it outside the tank first



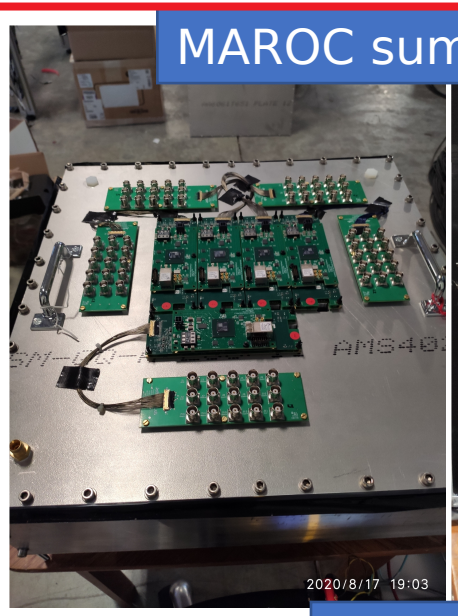


Slide courtesy Zhiwen Zhao

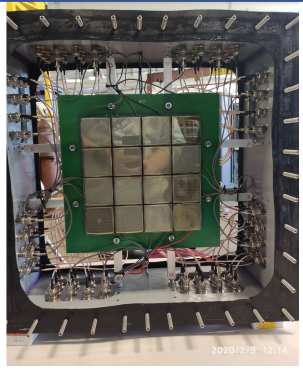
Readout box

- Readout needs to be pressure tight at 1.7atm also, which is not included as part of UofR test
- Simple sum box uses commercial hermetic BNC and SHV connectors
- MAROC sum box rely on MAROC rubber gasket to seal, will test it first

MAROC sum box



MAROC sum box



Slide courtesy Zhiwen Zhao

Potential Canadian Funds for SoLID HGC

INNOVATION.CA
CANADA FOUNDATION FOR INNOVATION | FONDATION CANADIENNE POUR L'INNOVATION

innovation SASKATCHEWAN

- **CFI Innovation Fund (IF)** funds research infrastructure in Canada. There is a ~C$400 million competition every two years, covering all disciplines. Formally, the application comes from the university, not the researcher.
- SoLID HGC vessel cost is ~C$1 million, based on pCDR budget. U.Regina VP-Research has agreed to support an application to CFI-IF for SoLID HGC Vessel for C$509.5k.
- If approved, U.Regina would ask the Province of Saskatchewan to match this amount, to fully cover HGC vessel cost estimate in pCDR.
- This could reduce pressure on funds provided by US-DOE, and may allow some other de-scoped SoLID component to go forward.
- **2023 CFI-IF Competition Deadlines:**
  - Submit notice of intent: February 2022
  - Submit proposal: June 2022
  - Decisions announced: March 2023
  - Decision for SK match: Sept 2023
- **Funds will be contingent on US-DOE, same as MOLLER CFI-IF award**

Slide courtesy Garth Huber

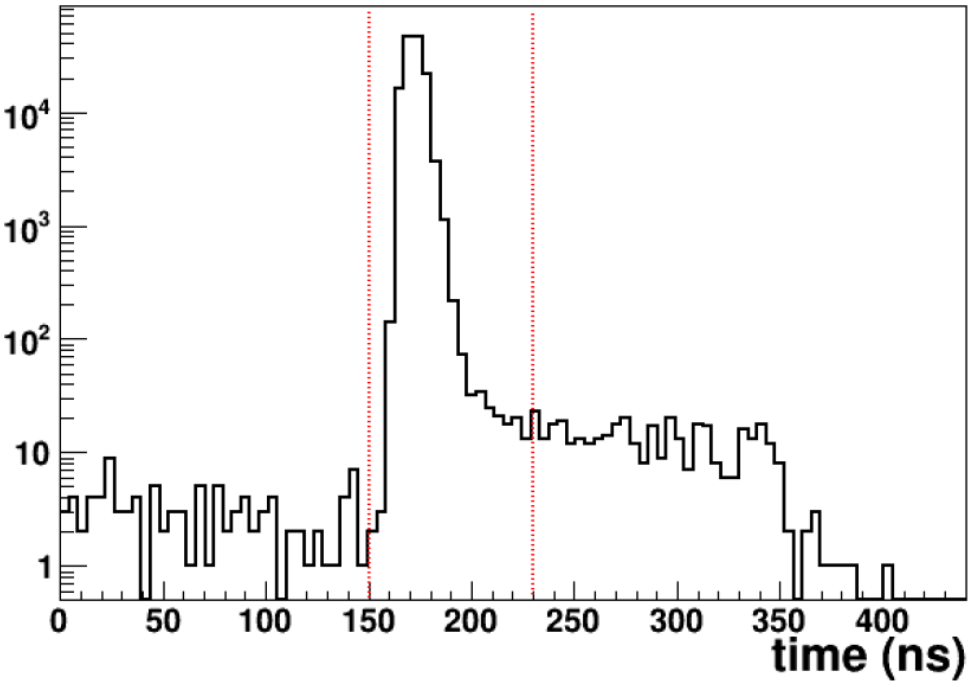
Summary

- LED simulated ring
  - For pixel readout with background below 200 kHz/pixel NPE cut is sufficient to reject background efficiently
  - Up to 370 kHz/pixel Hough transformation reproduce the expected parameter of ring (radius, position)
  - For the quad readout the width of signal window is half compared to TDC readout. NPE cut is sufficient to reject the background
- Cosmic data taken, analysis underway
- Saturation of pixel/quad/sum signal studied
- With 2 netic can reduce magnetic field from 90 G to 22 G
- HGC prototype at Duke, it can be used for mirror and readout mounting test

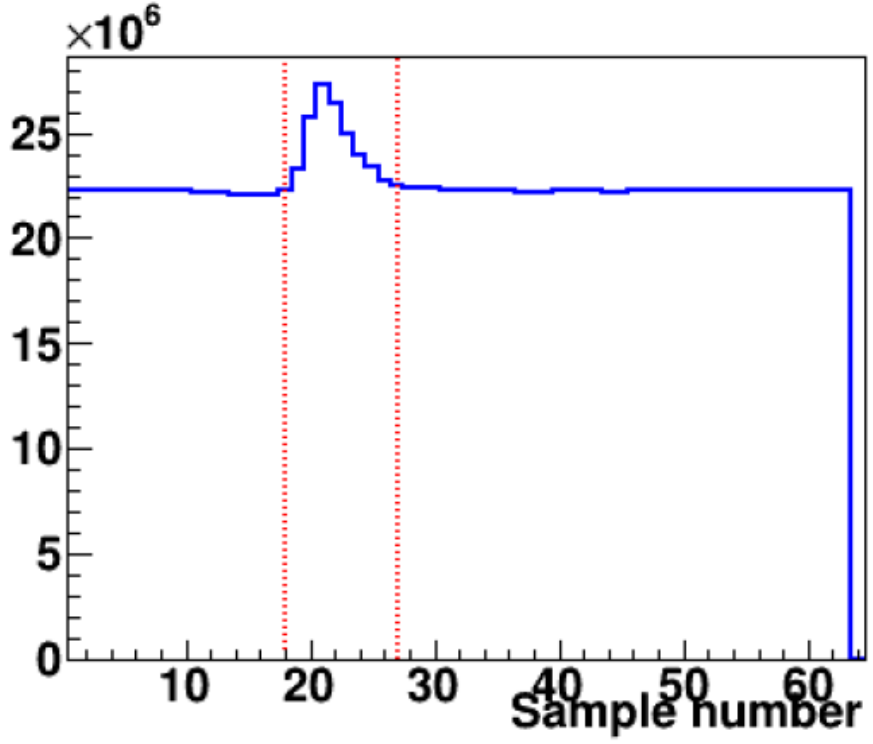
Back up

Signal window for TDC and FADC signal

TDC signal window (~80 ns)



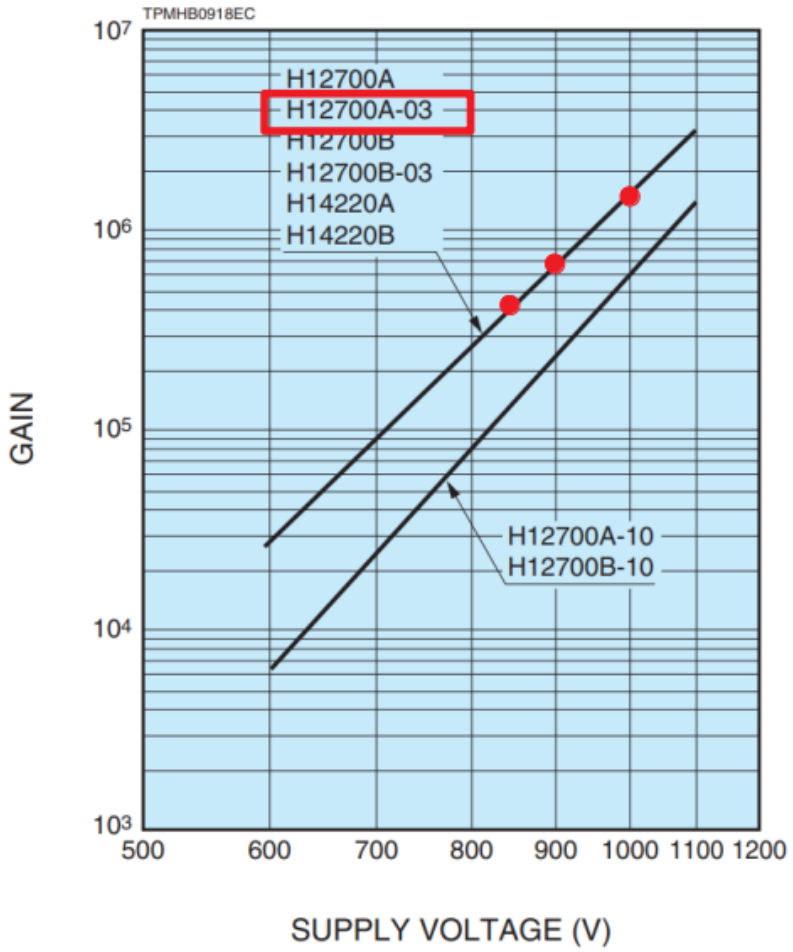
FADC signal window (~36 ns)



TDC signal window is twice as large as FADC signal window

PMT gain at different HV

Data sheet from Hamamatsu



HV	Gain (10^6)	Rel. to 850 V	SPE peak (Mean)	Rel. to 850 V
850	0.45	1.0	611	1.0
900	0.65	1.4	938	1.5
1000	1.5	3.3	1614	2.6
1050	2.2	4.8	1846	3.0

- 3rd column: gain relative to 850 V
- 5th column: Mean SPE peak relative to peak at 850 V
- Relative difference in measured mean SPE peak relative to 850 V is in agreement with relative difference in gain within 50%

Magnetic shielding test

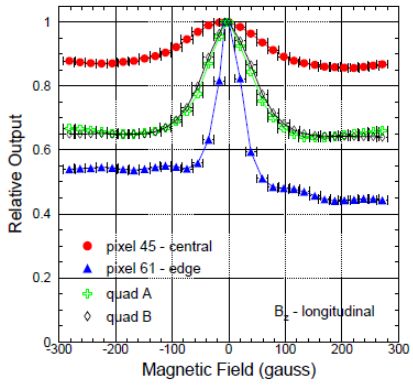
Latest field at HGC PMT location < 80G

hgc_moved PMT array center at (216,344)cm and corners

MAPMT H8500-03 test show

- ~20G transverse has 1% or 10% reduction in gain for central or edge pixel, on average 2%
- ~20G longitudinal has 1% or 20% reduction in gain for central or edge pixel, on average 5%
- MAPMT HA12700-03 rough test show similar result, no pixel test yet

arxiv:1306.6277
For MAPMT H8500-03



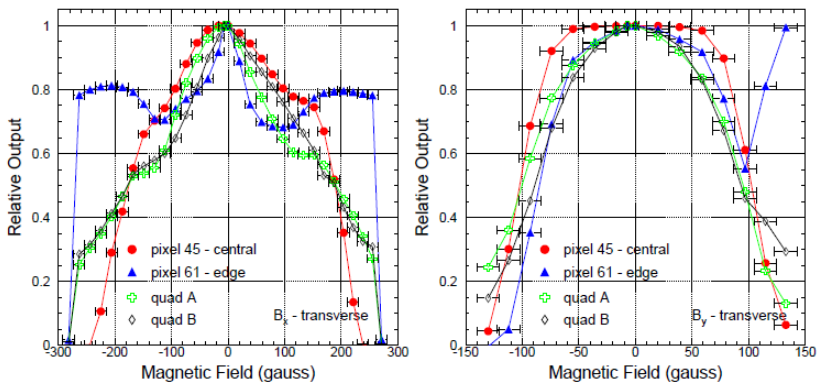
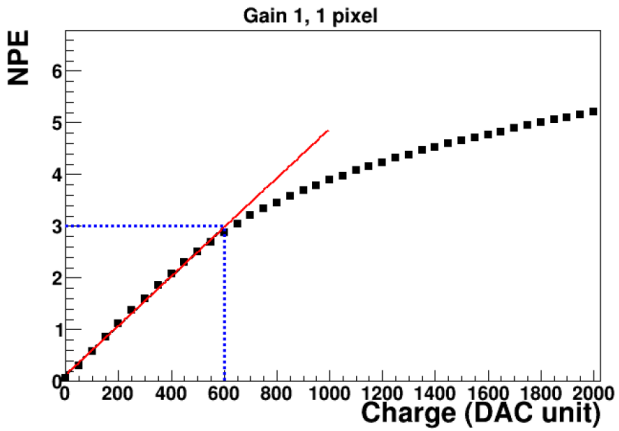
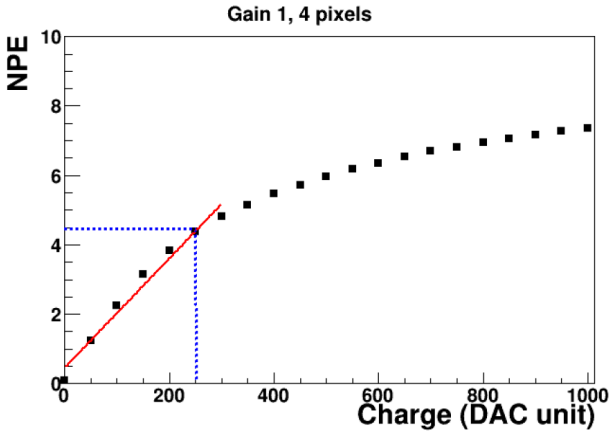
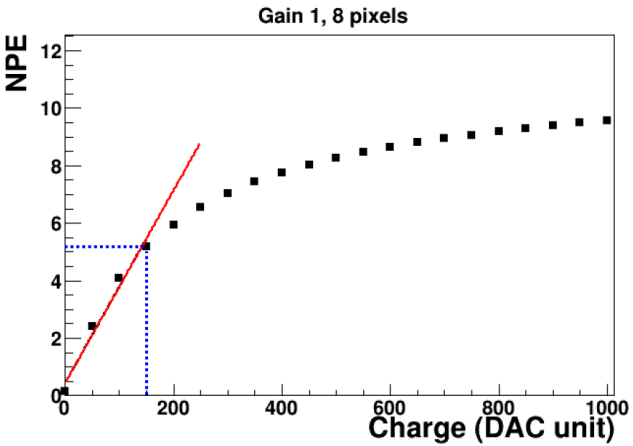


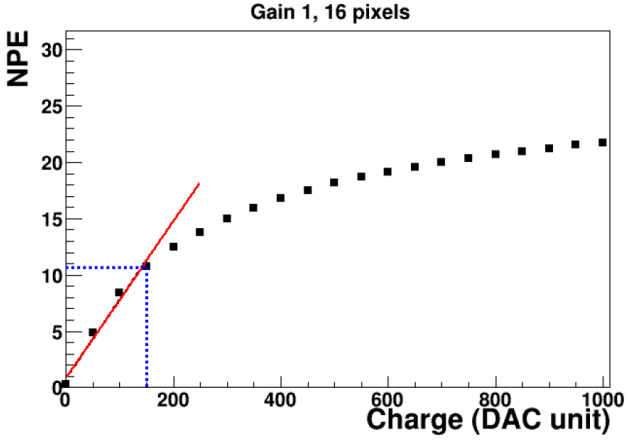
Figure 21: Relative change in output (*v.s.* no-field configuration) in a longitudinal (top) and transverse (bottom) magnetic field for pixels 45 and 61 and for quads A and B. The curves are shown to guide the eye.

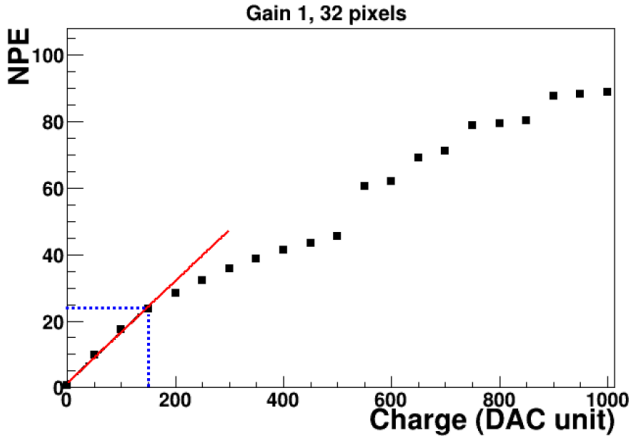
Linearity of sum signal

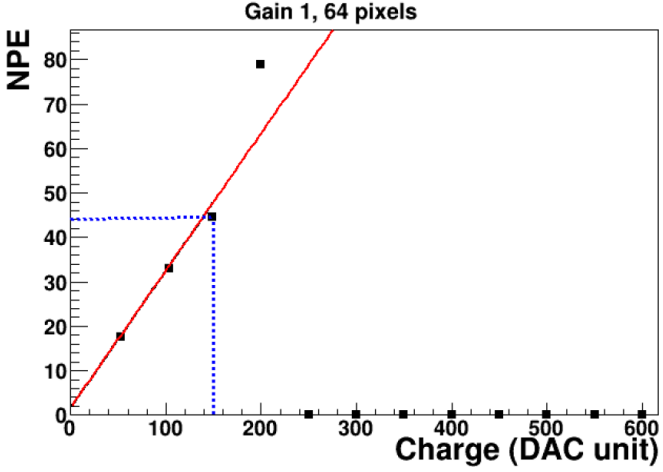






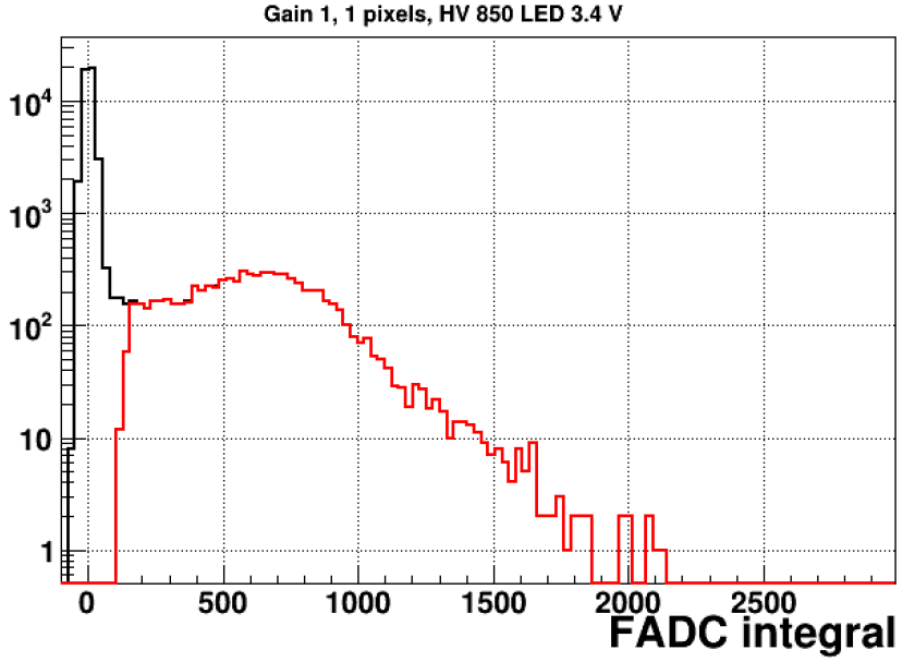


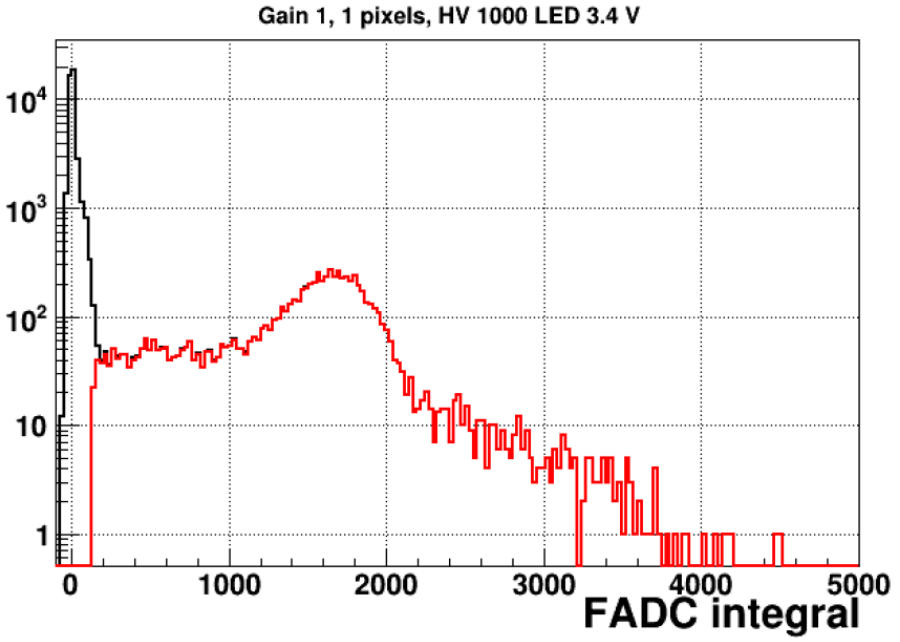




- Sum of 8 pixels saturates above ~5.5
- Quad saturates at 11 photo-electrons
- Sum saturates at 44 photo-electrons

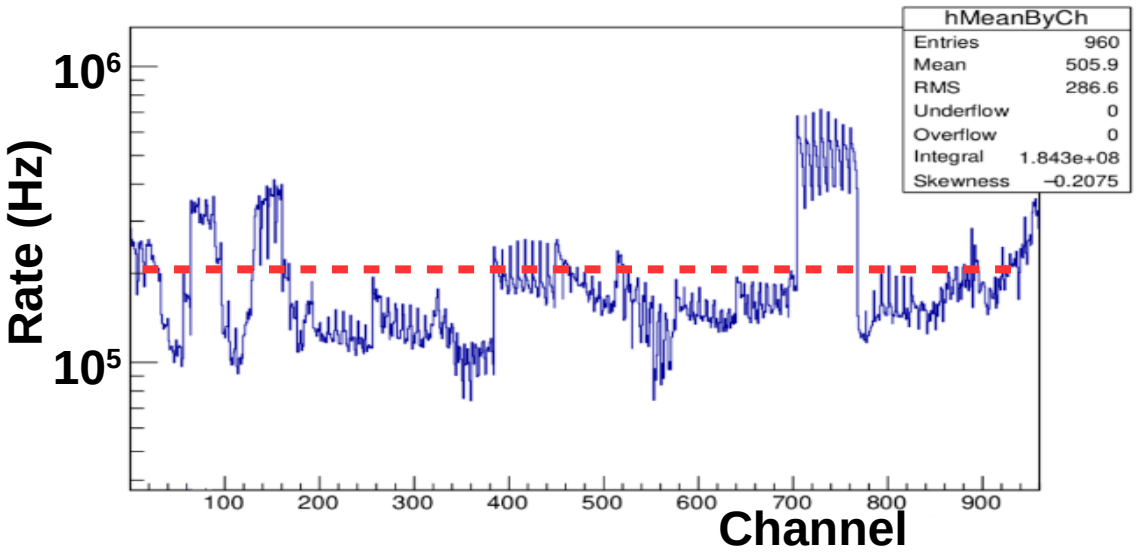
TDC threshold study





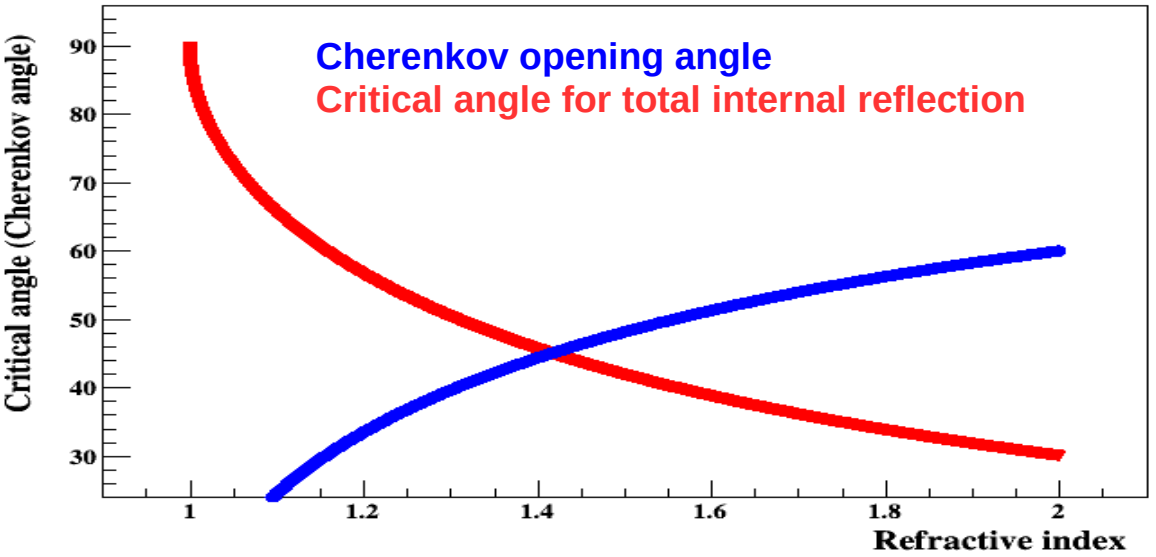
- LED data with single pixel enabled for SPE measurement
- Fadc integral of all events
- Fadc integral of events with TDC hits (TDC Threshold = Pedestal + 30)
- TDC threshold cut Mean pedestal +30 = 0.1xSPE (850 V)

Background from continuous LED



In average 200 kHz/pixel background from continuous LED

Total internal reflection



- To observe the full ring material with refractive index less than 1.4 is needed
- Solid material with refractive less than 1.4 is not available

$$\theta_c = Sin^{-1}\left(\frac{1}{\mu}\right) = 41.8^\circ$$

where θ_c is critical angle above which light gets internally reflected.

$$\theta_{cone} = Cos^{-1}\left(\frac{1}{\mu}\right) = 48.2^\circ$$

where θ_{cone} is opening angle of the Cherenkov light.