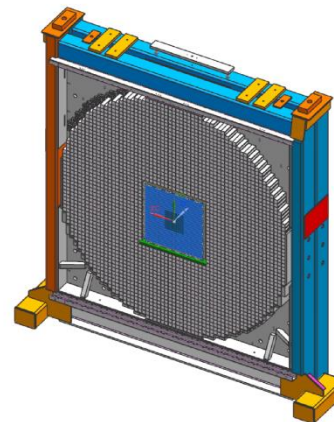


Jefferson Lab



Preparation for PrimEx run in 2021

A. Somov

GlueX collaboration meeting, May 12, 2020

PrimEx Phase I

Commissioning

Time	Beam energy	Calendar Days	PAC days
Fall 2018	10.3 GeV	12	
	8.93 GeV	7	

Phase I

Production, Phase I (Spring 2019)

02/21 – 03/05	11.61 GeV	15	8
03/08 – 04/15	11.17 GeV	38	16
Total		53	24

Efficiency 0.45

Approved by PAC

LH ₂ target	40 days
LHe ₄	30 days
Empty target	6 days
Setup, Calibration	3 days
Total	79 days

Phase II

Production: $76 - 24 = 52$ PAC days

Expected run length: 120 days , 4 months

PrimEx Phase I: Data Sample

- Took data using Be and liquid He targets and with empty target
 - Be data used for normalization
- Production runs we organized in several periods
 - alternate empty target run with production runs

	He empty	He target		Be target	Be empty
	885	470		2789	231
	1085	1257			412
	434	13189			
	476	5210			
	408	7146			
		9056			
		3663			
		979			
Total (M)	3288	40970		2789	643

PrimEx Phase I: Run Conditions

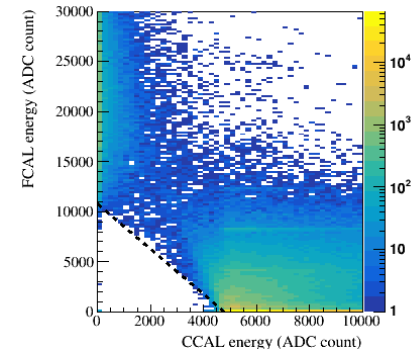
- Beam energies: 11.6 GeV and 11.2 GeV
- Radiator: 10^{-4} R.L. Aluminum
- Beam current: 200 nA for production runs
50 nA and 100 nA for calibration runs with the CDC/FDC
< 2 nA TAC run, CCAL calibration
- PS converter: 750 μm

PrimEx Phase I: Run Conditions

- Main production triggers

Bit 1: CCAL & FCAL $E_{\text{CCAL}} + E_{\text{FCAL}} > 3 \text{ GeV}$
Bit 2: FCAL
Bit 4: PS
Bit 10: CCAL

TS Front Panel: CCAL LED, CCAL ALPHA, FCAL & BCAL LED, Random



- Calibration

CCAL: CCAL calibration, snake scan
PS & CCAL, PS & TAC PS calibration

- Efficiency Studies

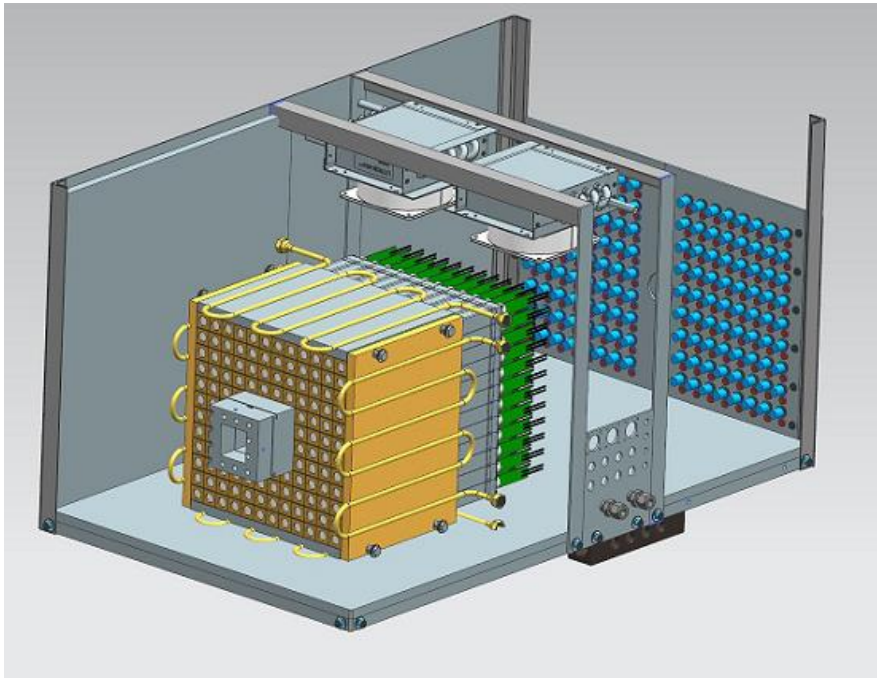
TAGH & ST

Typical trigger rates for PrimEx production:

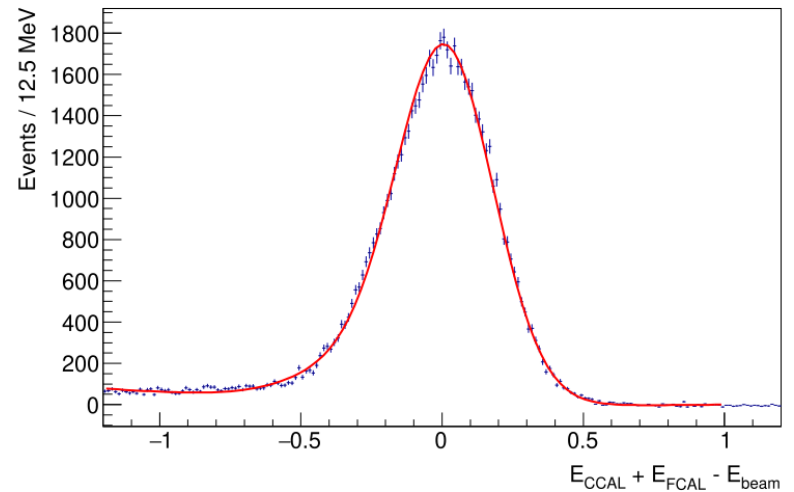
Total: 23 kHz
CCAL & FCAL: 17.7 kHz (FCAL only 1.2 kHz)
PS: 5.5 kHz

Compton Calorimeter

- The new calorimeter installed downstream the FCAL
 - use for cross section normalization and control systematics during data taking
- Relatively good performance during PrimEx run
 - provided clean reconstruction of Compton candidates
- Found some non-linearity in the performance of the PMT active base
 - modify electronics for PrimEx Phase II



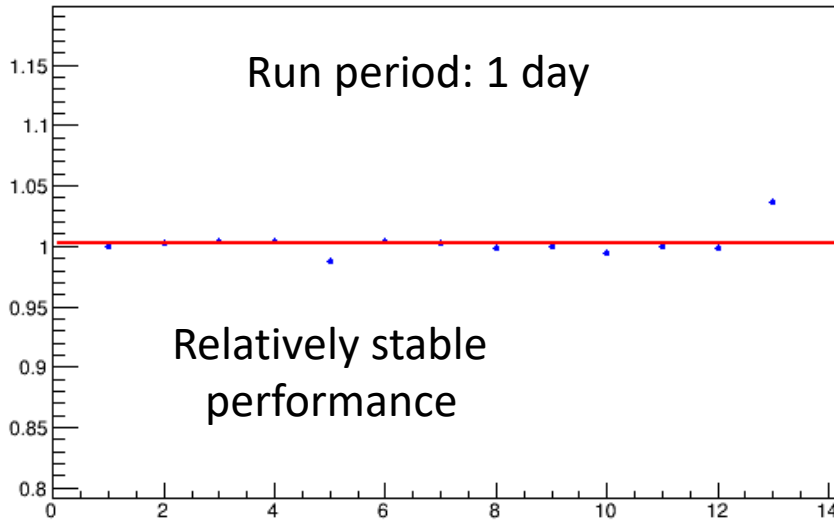
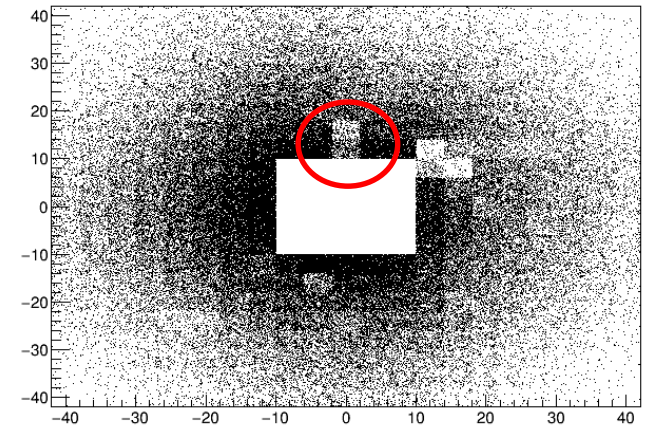
Two-cluster events



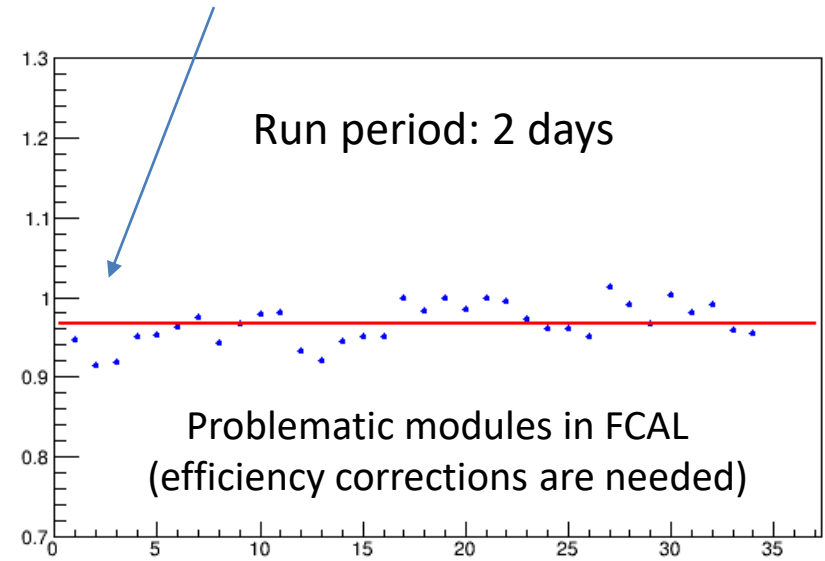
Yield of Two-cluster Events

- Compute tagged flux for all PrimEx production runs (CCDB)
- Flux normalized yield of two-cluster events

FCAL XY of clusters



Runs



Runs

Active Base Tests and Optimization: Timeline

Use Hall C PWO crystals and electronics for CCAL

Test of the 3x3 PWO prototype installed behind the Pair Spectrometer, *GlueX-doc-3590, May 2018*

- first indication of potential problems: too large amplifier gain (x25), energy resolution worse than expected
- light yield is large, amplifier is not needed, PrimEx rate (anode current) was not measured, some amplification may be needed. Discussions how to proceed (PrimEx group, Fernando, V. Popov, Hall C guys) – test performance with beam

CCAL fabricated in September 2018. Beam tests in December 2018

- some non-linearity observed during calibration run (snake scan). Linearity improves when increasing HV

PrimEx production, February 2019 (switch FADCs to 2 V range, increase HV)

- linearity tests, modified versions of divider (gains x3, x6, and x1), *GlueX-doc-3998*
- install bases with bypassed amplifiers (3x3 array), measure energy resolution - agrees with the HyCal resolution. Later confirmed with the PS prototype

After PrimEx run

- modifications of the active base by V.Popov (increase divider current, change resistors in amplifier)
- more performance tests in the lab *GlueX-doc-4076 (GlueX-doc-3272)*

Active Base Tests and Optimization: Timeline

Bench Tests after PrimEx run

- high rate performance: no degradation of the base with bypassed amplifier up to the anode current of 40 – 50 μA (1 V amplitude)

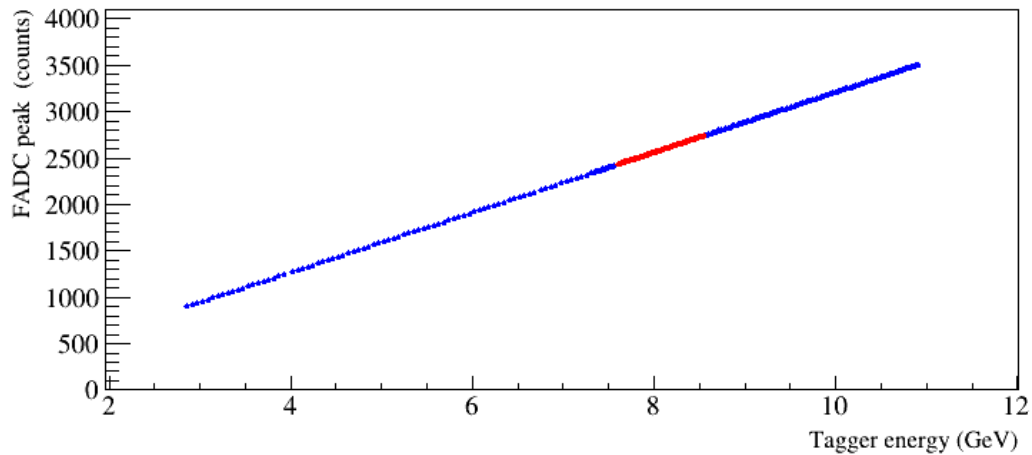
GlueX high-intensity run in 2020

- Measure divider anode current (compare GlueX and PrimEx run conditions), *GlueX-doc-4361*
- 24 modified dividers (gains x3 and x6) were installed inner rings of the CCAL. Used CCAL in GlueX runs (data analysis is in process)
- *Amplifier (seems to be) is not needed for PrimEX run conditions*
- *Small gain (x3) is recommended if we decide to used CCAL in GlueX production runs*

PMT Active Base Performance

- Study linearity using calibration runs (CCAL in the beam)

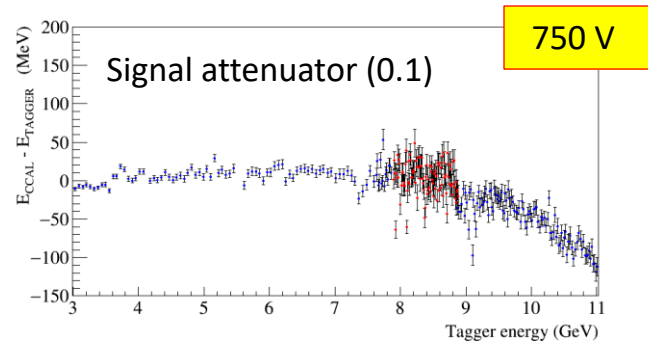
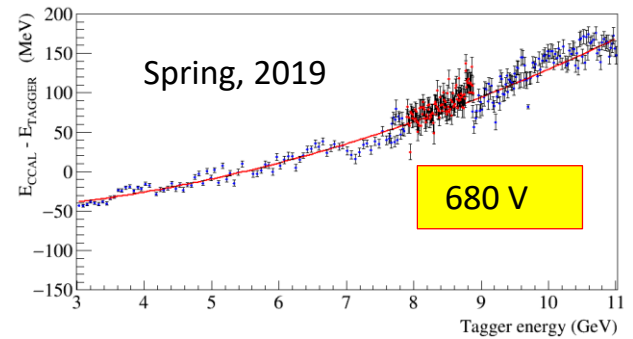
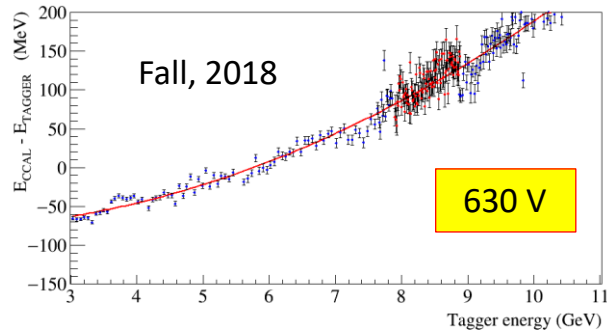
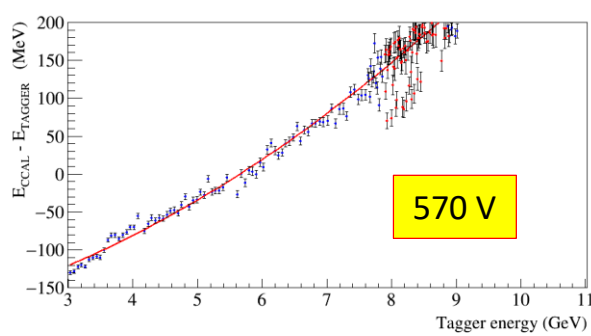
FADC amplitude as a function of the beam energy



10 GeV : 3200 FADC channels

Linearity as a Function of Operational HV

Calorimeter CELL = -4, -4

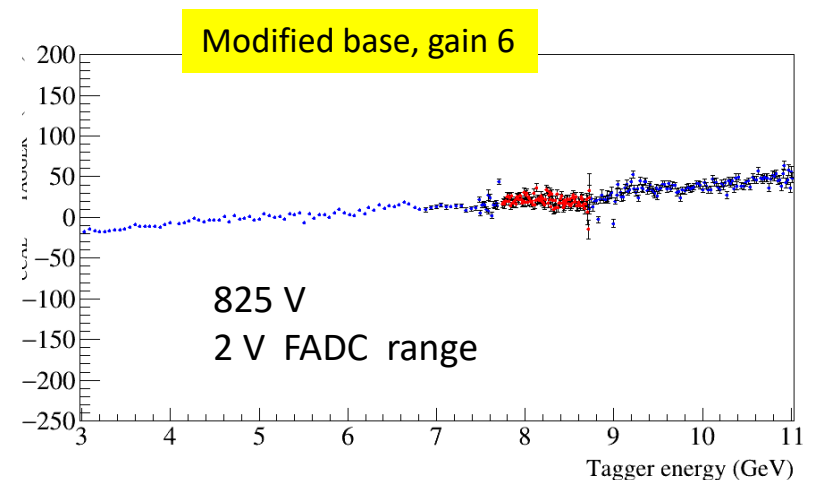
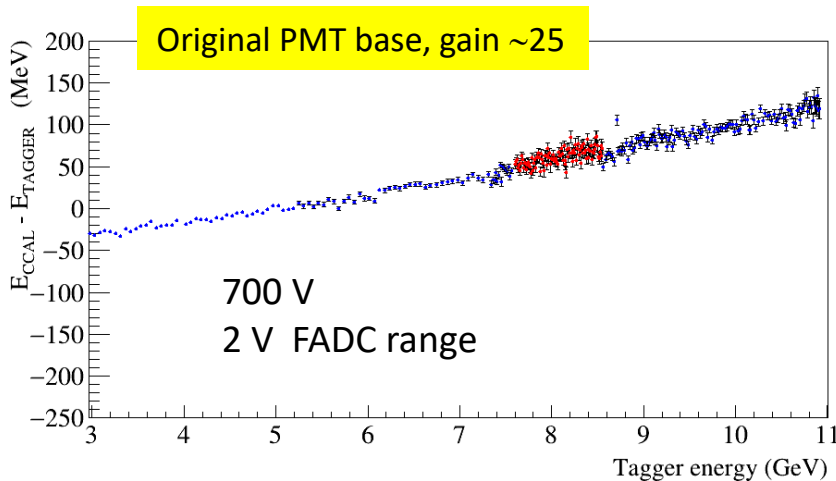


- Linearity is improved with the HV increase

PMT Active Base Linearity

- The linearity can be improved by reducing the amplifier gain and increasing HV
Some tuning of the PMT base are required
- V. Popov modified the active divider (increase the anode current, changed resistors in the amplifier chain)
 - three modified bases were installed on CCAL and tested in January 2020

Linearity of the FADC peak amplitude



Test Modified Active Base with the Bypassed Amplifier

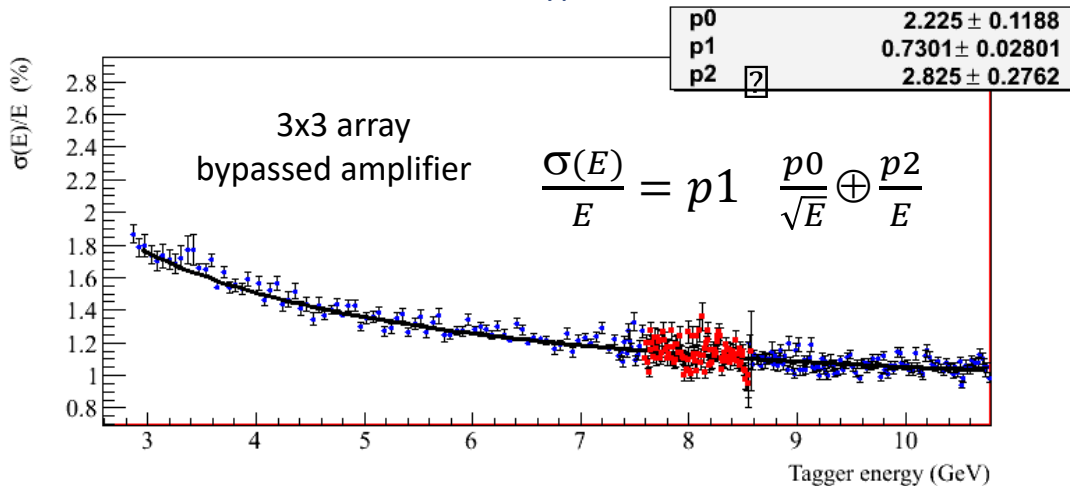
Row 6	6:6 ON	5:6 ON	4:6 ON	3:6 ON	2:6 ON	1:6 ON	-1:6 ON	-2:6 ON	-3:6 ON	-4:6 ON	-5:6 ON	-6:6 ON			
Voltage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Row 5	6:5 ON	[Blue Box]					1:5 ON	-1:5 ON	-2:5 ON	-3:5 ON	-4:5 ON	-5:5 ON	-6:5 ON		
Voltage	0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Current	0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Row 4	6:4 ON	[Blue Box]					1:4 ON	-1:4 ON	-2:4 ON	-3:4 ON	-4:4 ON	-5:4 ON	-6:4 ON		
Voltage	0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Current	0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Row 3	6:3 ON	[Blue Box]					1:3 ON	-1:3 ON	-2:3 ON	-3:3 ON	-4:3 ON	-5:3 ON	-6:3 ON		
Voltage	0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Current	0.0						0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Row 2	6:2 ON	5:2 ON	4:2 ON	3:2 ON	2:2 ON	1:2 ON	-1:2 ON	-2:2 ON	-3:2 ON	-4:2 ON	-5:2 ON	-6:2 ON			
Voltage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Row 1	6:1 ON	5:1 ON	4:1 ON	3:1 ON	2:1 ON	[Red Box All HV]		-2:1 ON	-3:1 ON	-4:1 ON	-5:1 ON	-6:1 ON			
Voltage	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0			
Row -1	6:-1 ON	5:-1 ON	4:-1 ON	3:-1 ON	2:-1 ON	[Red Box All HV]		-2:-1 ON	-3:-1 ON	-4:-1 ON	-5:-1 ON	-6:-1 ON			
Voltage	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0			
Row -2	6:-2 ON	5:-2 ON	4:-2 ON	3:-2 ON	2:-2 ON	1:-2 ON	-1:-2 ON	-2:-2 ON	-3:-2 ON	-4:-2 ON	-5:-2 ON	-6:-2 ON			
Voltage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Row -3	6:-3 ON	5:-3 ON	4:-3 ON	3:-3 ON	2:-3 ON	1:-3 ON	-1:-3 ON	-2:-3 ON	-3:-3 ON	-4:-3 ON	-5:-3 ON	-6:-3 ON			
Voltage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Row -4	6:-4 ON	5:-4 ON	4:-4 ON	3:-4 ON	2:-4 ON	1:-4 ON	-1:-4 ON	-2:-4 ON	-3:-4 ON	-4:-4 ON	-5:-4 ON	-6:-4 ON			
Voltage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Row -5	6:-5 ON	5:-5 ON	4:-5 ON	3:-5 ON	2:-5 ON	1:-5 ON	-1:-5 ON	-2:-5 ON	-3:-5 ON	-4:-5 ON	-5:-5 ON	-6:-5 ON			
Voltage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Row -6	6:-6 ON	5:-6 ON	4:-6 ON	3:-6 ON	2:-6 ON	1:-6 ON	-1:-6 ON	-2:-6 ON	-3:-6 ON	-4:-6 ON	-5:-6 ON	-6:-6 ON			
Voltage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Current	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			

- Install 9 PMT bases with the bypassed amplifier
- Measure energy resolution

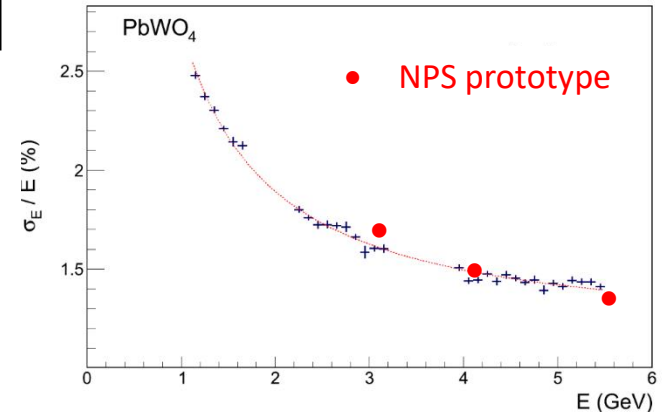
Energy Resolution Measured with CCAL

Preliminary plot, will be updated

NPS Prototype



HyCal (Hall B)



Relatively good energy resolution, which is consistent with the resolution of the Hall B HyCal calorimeter

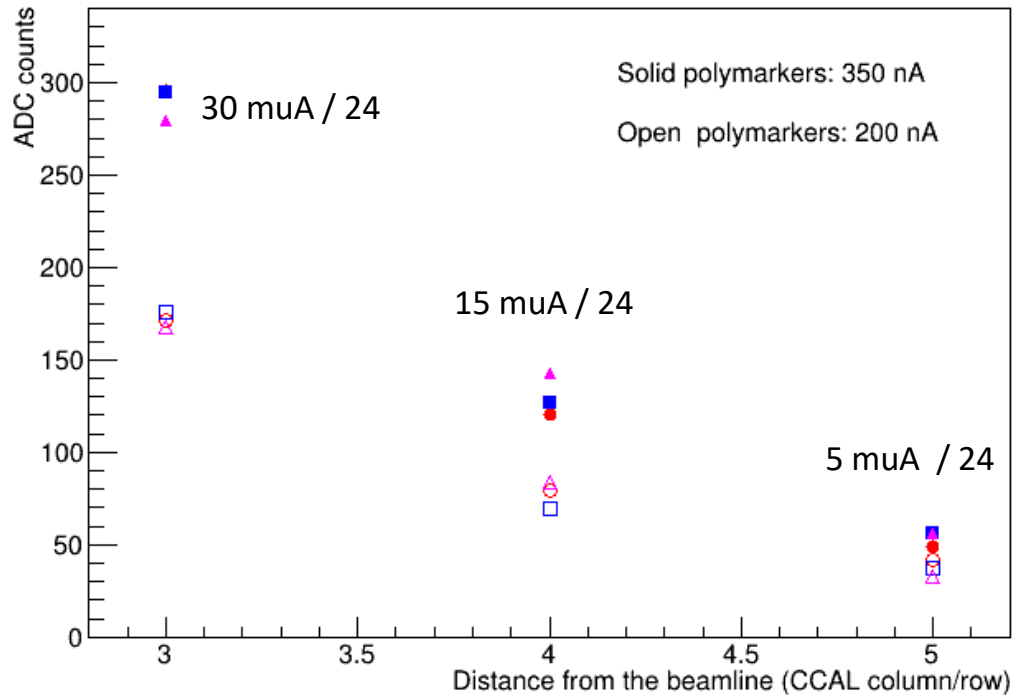
Rate and PMT anode current have to be considered (some measurements were performed)

More details can be found in
GlueX-doc-3590, GlueX-doc-3998, V. Berdnikov, A.Somov, J. Crafts

Sum of FADC amplitudes in 400 ns time window

GlueX-doc-4361

Sum of ADC channels (400 ns window)



Example:

Current seen by FADC in the 3rd row: 30 muA

Current through the divider: $30 \text{ muA} / 24 = 1.25 \text{ muA}$

Current estimates for FCAL:

Beam hole: 2x2

1 layer covered by an absorber

The 3rd layer in FCAL – 5th layer

In CCAL (factor of two difference in Z)

Solid angle correction is $2 \times 2 = 4$

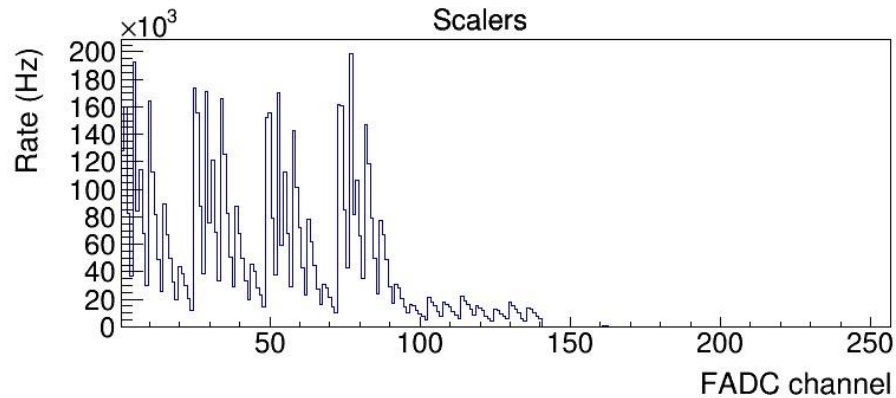
If no amplifier used: $5 \times 4 = 20 \text{ muA}$

Discussion:

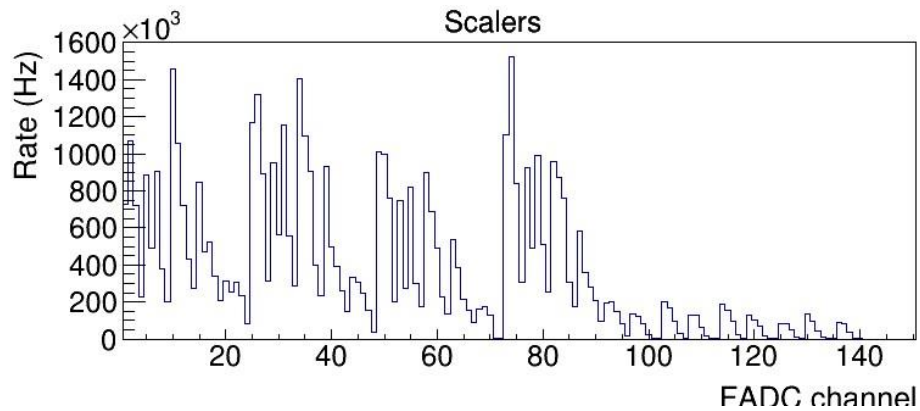
- Use active bases with the gain 3 (or 6) in the inner layers of the FCAL 2
- Don't need amplifiers on other layers

Install 24 active bases with modified dividers (gain 3 and 6) on the CCAL inner layers

CCAL Rates in GlueX and PrimEx



PrimEx production
(200 nA, 10^{-4} R.L., He)

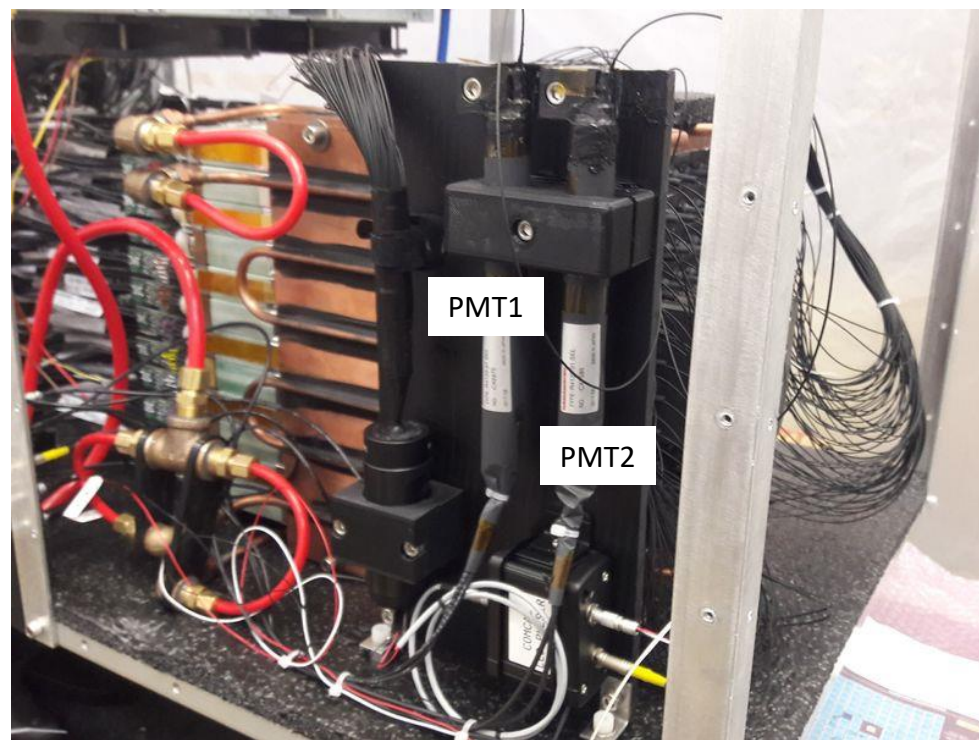


GlueX production
high intensity
(5 mV threshold, 35 MeV)

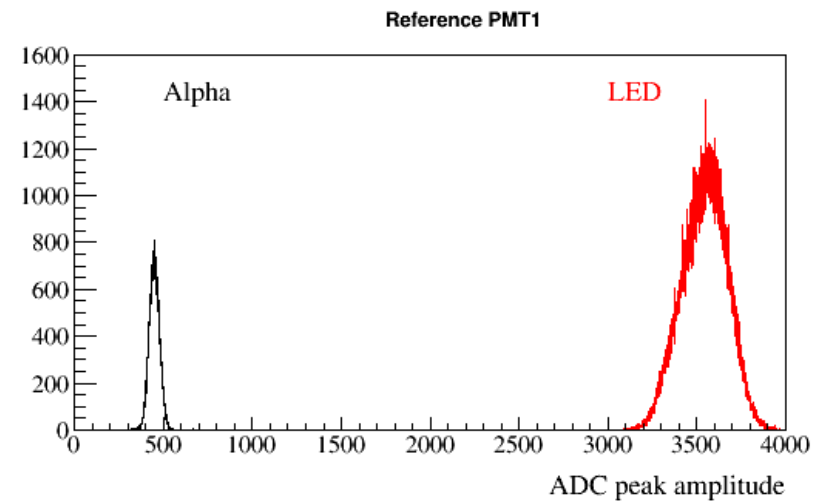
- CCAL rate in GlueX is about 7 times larger than in PrimEx

Light Monitoring System

- Two reference PMTs are installed to monitor LED stability
- Each PMT receives light from the LED fiber and YAP:CE Am light source
- LED and Alpha-source triggers are used during data taking (special trigger types)

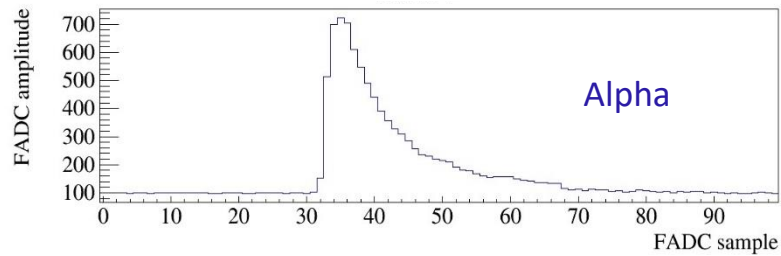


Reference PMT FADC amplitudes

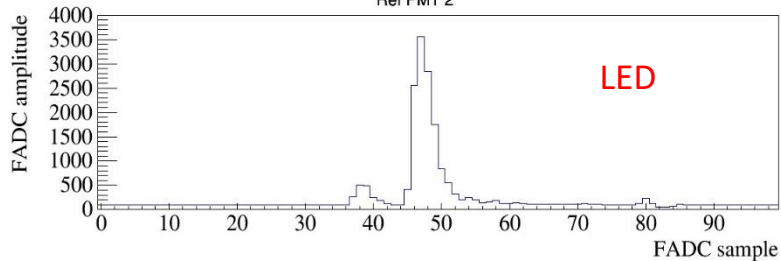


LMS: Signals on Reference PMTs

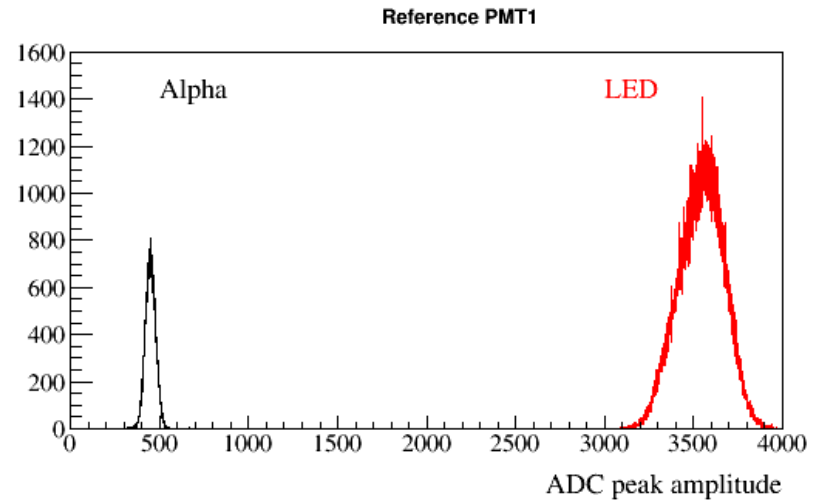
Signal Waveforms



Ref PMT 2

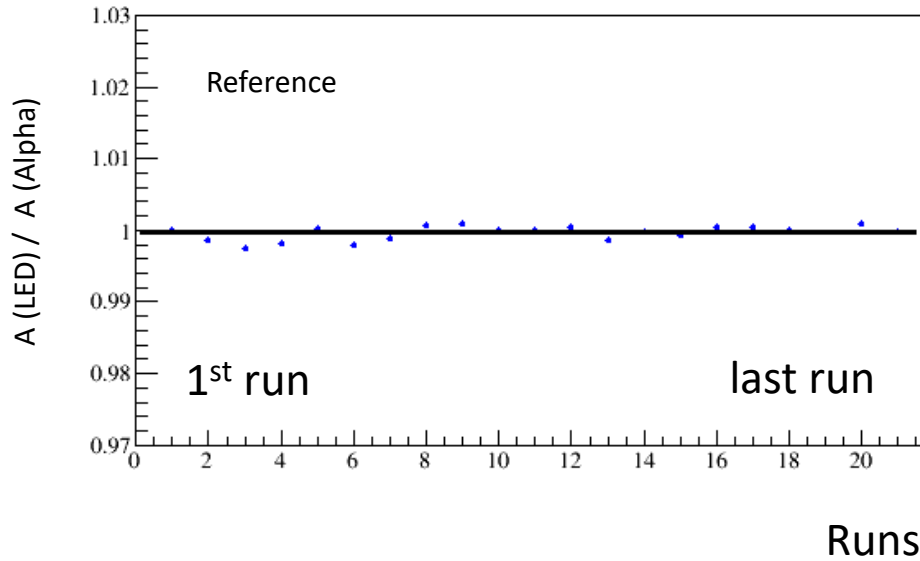


FADC amplitudes in Reference PMT



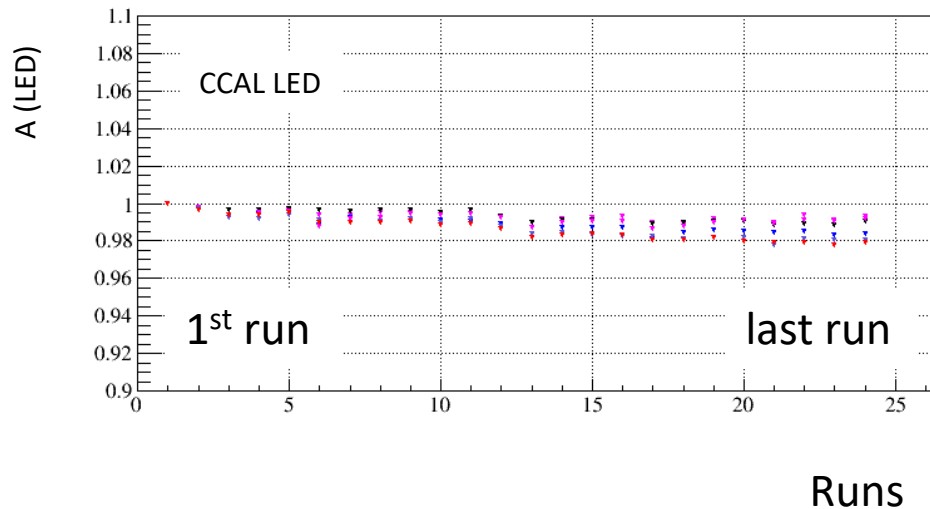
- Adjusted HVs to have pulses from both the LED and Alpha source inside the FADC range
- Special trigger bits for LED and Alpha pulses

CCAL Light Monitoring System



Reference PMT receives light from LED and Alpha source

- good LED stability measured with respect to Alpha, $\pm 0.2\%$



LED response in various CCAL modules

2 %

need to increase light pulse (by a factor of 3 – 4)

Run Plan for PrimEx Phase II

- Tentative calibration plan, has to be coordinated

Condition	Scheduled Work	Total Time	Beam & Radiator (X_0)
Pre-experiment		7 shifts	
	CCAL calibration (ramp magnet down)	4 shifts	< 2 nA, $2 \cdot 10^{-5}$
	Install Be target: Disassemble beam pipe. Retract target. Remove Start Counter (ST). Remove vacuum snout. Remove GlueX cell. Mount Be target (survey). Attach vacuum snout. Attach ST. Target in place. Assemble beam pipe. Pump vacuum.*	3 shifts	

Detector checkout		3 shifts	10 – 300 nA, 10^{-4}
	Establish photon beam, FCAL mask/gain checks, trigger and DAQ test, lumi scans, check scalers		
Production on Be		1 day	200 nA, 10^{-4}
Target change	Remove target cell	2 shifts	no beam
Empty target run no target cell		0.5 days	200 nA, 10^{-4}
Target change	Install He cell	3 shifts	no beam
Empty target run		0.5 days	200 nA, 10^{-4}

Total

3.2 PAC days

Run Plan for PrimEx Phase II

Tentative production plan

- Collect data on liquid He target
- Run conditions similar to Phase I:
 - 10-4 R.L. radiator, 200 nA beam current
(the beam current could be slightly optimized)
- Organize data taking in periods
 - Production on He4 target (5 days), empty target run (1 day)
- Take calibration data:
 - TAC run (2 shifts)
 - Rate scan at 50 nA and 100 nA with the CDC/FDC included (2 days)

Summary & Discussion

- We need to make the final decision regarding the modification of the PMT active base to improve base performance
 - do not use an amplifier for PrimEx run; gain of 3 may be needed if CCAL will be used during GlueX production runs at high intensity
 - Fernando and Chris are working on the PCB layout (feedback from V. Popov). One option is to use a dip switch to change gain on the PCB
- Planning to refurbish all CCAL electronics during this summer
- We need to optimize the LMS system in order to increase signal amplitudes (by about a factor of 4). Use multiple LEDs and an integrating sphere to mix light
- Run conditions for the PrimEx Phase II will be optimized based on the ongoing data analyses

Backup Slide

- We need to make the final decision regarding the modification of the PMT active base to improve base performance
 - do not use an amplifier for PrimEx run; gain of 3 may be needed if CCAL will be used during GlueX production runs at high intensity
 - Fernando and Chris are working on the PCB layout (feedback from V. Popov). One option is to use a dip switch to change gain on the PCB
- Planning to refurbish all CCAL electronics during this summer
- We need to optimize the LMS system in order to increase signal amplitudes (by about a factor of 4). Use multiple LEDs and an integrating sphere to mix light
- Run conditions for the PrimEx Phase II will be optimized based on the ongoing data analyses

Measurement of the PMT Anode Current

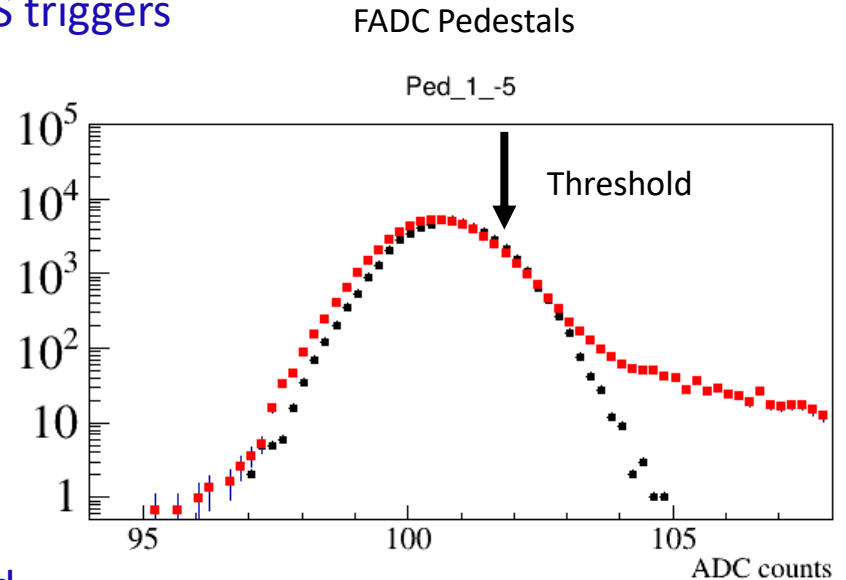
What amplifier gain do we need ?

- Use CCAL to estimate the PMT anode current
- Collect FADC waveforms using random and PS triggers
- Two beam currents: 350 nA and 200 nA
 - no data sparsification (no threshold applied)
 - estimate current using waveforms acquired with the random trigger
 - Use PS trigger to monitor beam trips

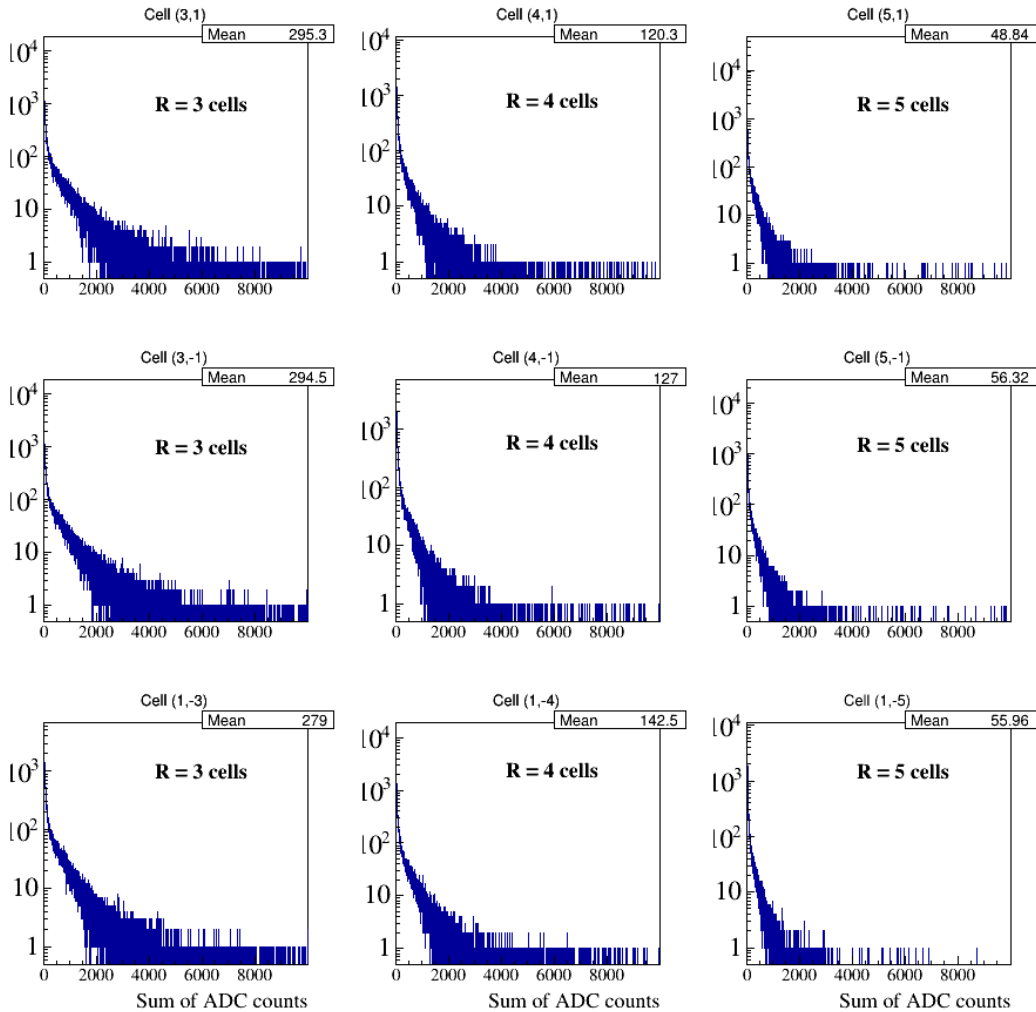
- Sum up FADC amplitudes above the threshold (1 count above the baseline) in a 400 ns window (100 fadc samples)

- Estimate anode current as follows:

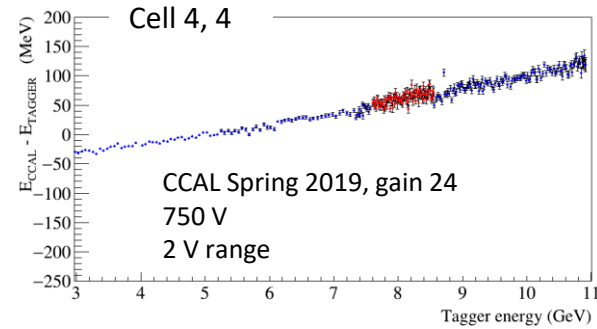
$$A = 5 \times 10^{-4} \text{ V} / 50 \text{ Ohm} \quad \langle A (\text{FADC}) \rangle / 100 \text{ samples} / \text{Gain (Amp)}$$



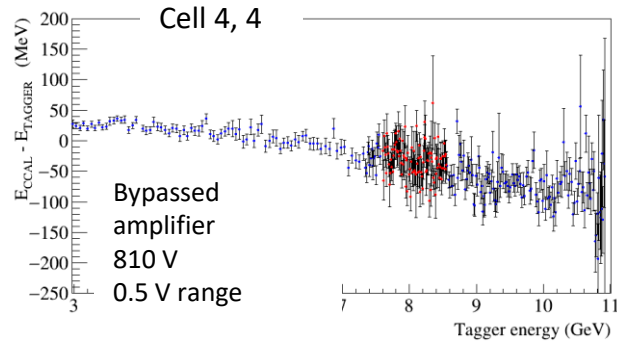
Sum of FADC amplitudes in 400 ns time window



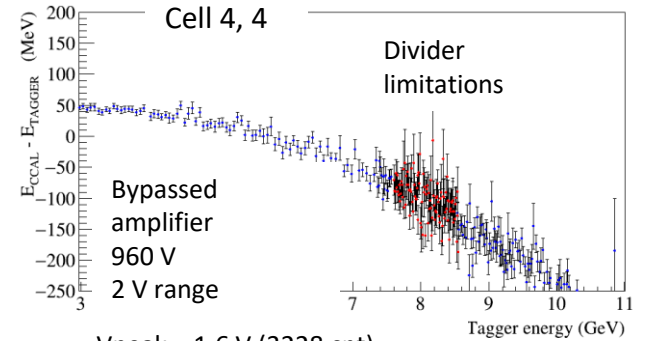
Linearity: ADC Peak Amplitude



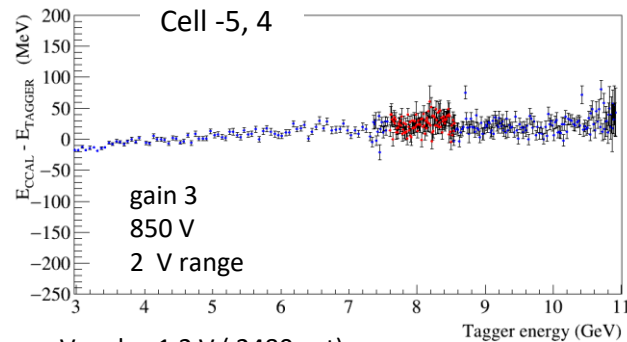
Vpeak = 1.7 V (3501 cnt)



Vpeak = 0.4 V (3474 cnt)



Vpeak = 1.6 V (3228 cnt)



Vpeak = 1.2 V (2480 cnt)