ECal and Beam Test Update

Michael Nycz

On Behalf of the SoLID Working Group

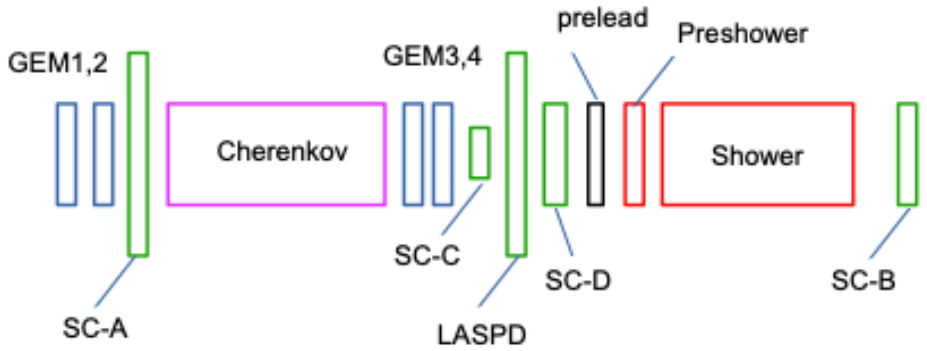
Outline

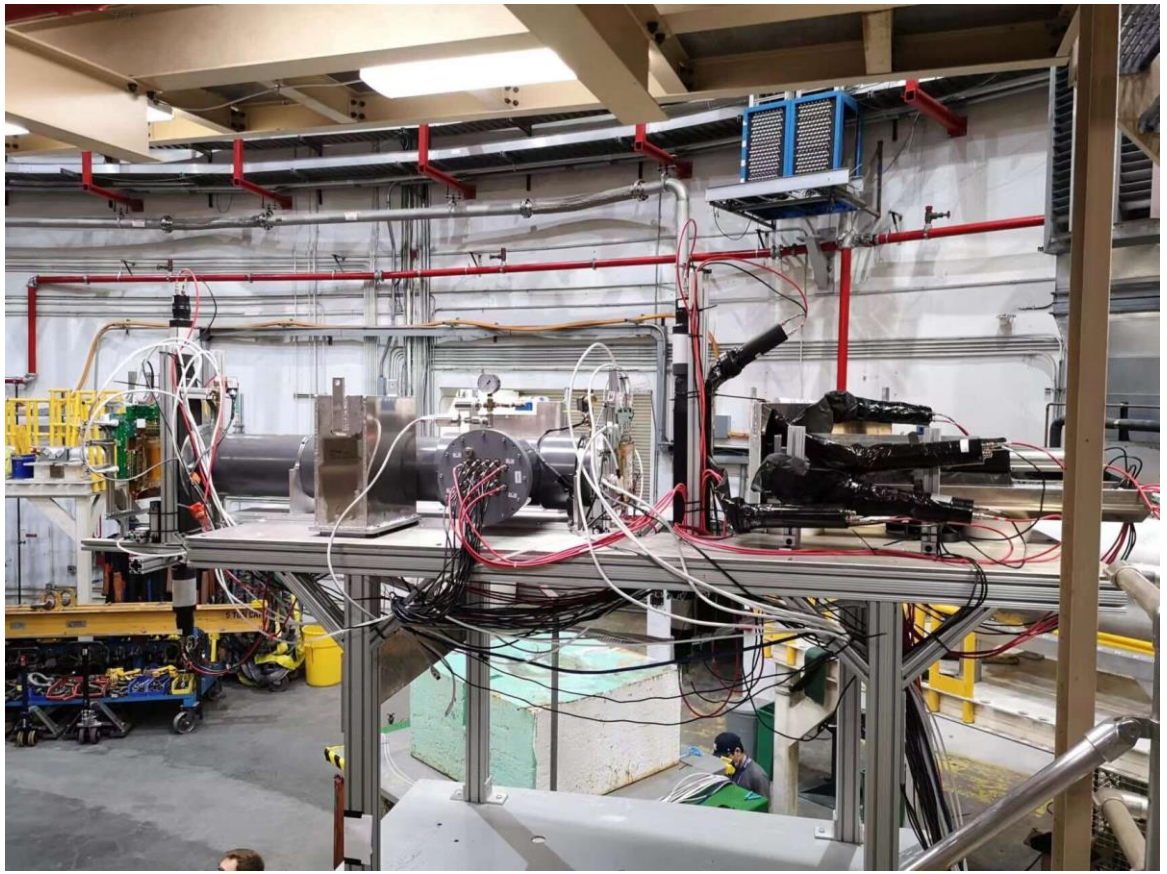
- ECal Beam test (2022-2023)
  - Overview
  - Highlights
  - Recent updated - shower gain shift bench testing
    - Michael Lowry (UVa) and Carl Zorn (Jlab)
    - Yanan Liu and Shulong Ji (Shandong University)
- ECal preparation for upcoming Tracking beam test
- Ongoing and Future work

2022– 2023 Ecal Beam Test

- Goals - Performance of Ecal in high-rate environment

- Three phases
  - Phase 1 – detector commissioning (82°)
  - Phase 2 – High rate 1 (7°)
  - Phase 3 – High rate 2 (18°)





Comparison of high-rate (18°) conditions to SoLID

(18°) setting

Run	Target	Thickness (g/cm^2)	I_{beam} (μA)	Luminosity ($cm^{-2}s^{-1}$)
prod.	LH_2	0.71	10	2.7×10^{37}
prod.	LD_2	1.69	10	3.2×10^{37}
Luminosity scan	LD_2	1.69	15- 70	$(4.8 - 22) \times 10^{37}$
	carbon	0.574	15- 70	$(0.3 - 1.3) \times 10^{37}$
	aluminum	0.476	15- 70	$(1.0 - 4.6) \times 10^{36}$

SoLID

Experiment	Target	I_{beam} (μA)	Luminosity ($cm^{-2}s^{-1}$)	Rates (kHz)
SIDIS (n)	40-cm $^3\vec{He}$	15	1.0×10^{36}	100
SIDIS (p)	3-cm $N\vec{H}_3$	0.1	1.0×10^{35}	10
J/ψ	15-cm LH_2	3	1.2×10^{37}	30
PVDIS (d)	40-cm LD_2	050	8.0×10^{38}	15×30
PVDIS (p)	40-cm LH_2	50	6.7×10^{38}	15×30

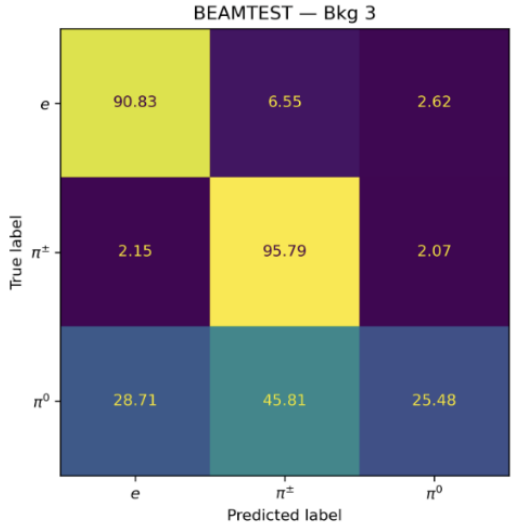
2022– 2023 ECal Beam Test

- Detector performance
  - LASPD photon PID
  - ECal PID – charged pion rejection
  - Shower non-linearity (Michael Lowry)
- Simulation benchmarking (Ye Tian, Zhiwen Zhao)
- Machine-Learning based PID (Darren Upton, Mohhamed Rafi)

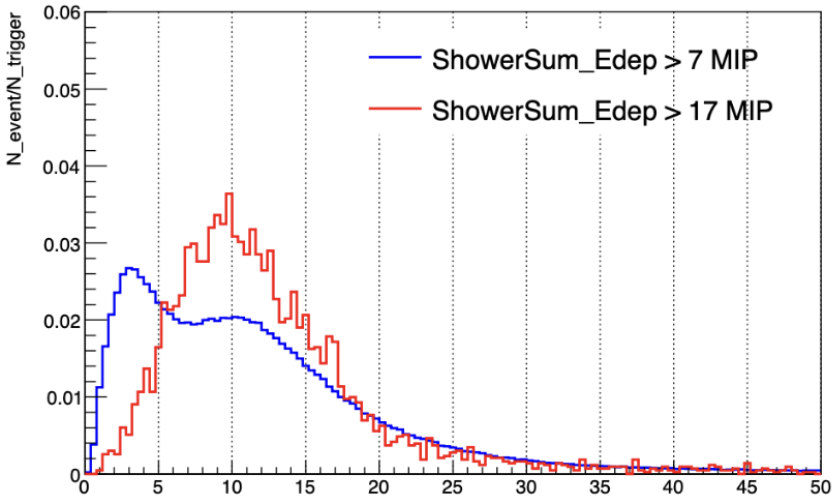
Data and Simulation Comparison

Detector	e^-	π^-	π^+	π^0	EM	total	data
SC-A	8.66e-5	0.35	0.22	0.068	869	870	720
SC-D	1.35e-4	0.41	0.26	0.16	258	259	197
PreSh	8.2e-5	0.26	0.16	0.23	20.3	21.0	17.9
Shower	7.1e-5	0.21	0.13	0.2	0	0.54	0.45
SC-B	1.11e-5	0.079	0.038	0.029	702	702	175

Classifier Confusion Matrix



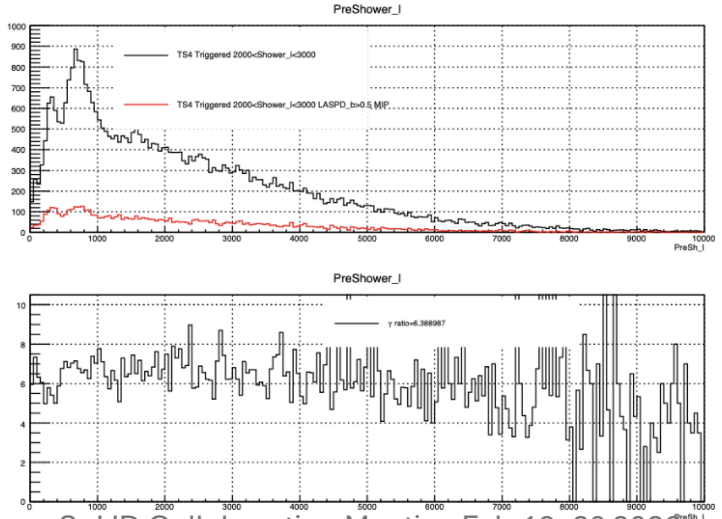
Detector Performance



Cherenkov NPE ~ ½ expected from simulation
(Mirror reflectivity test)

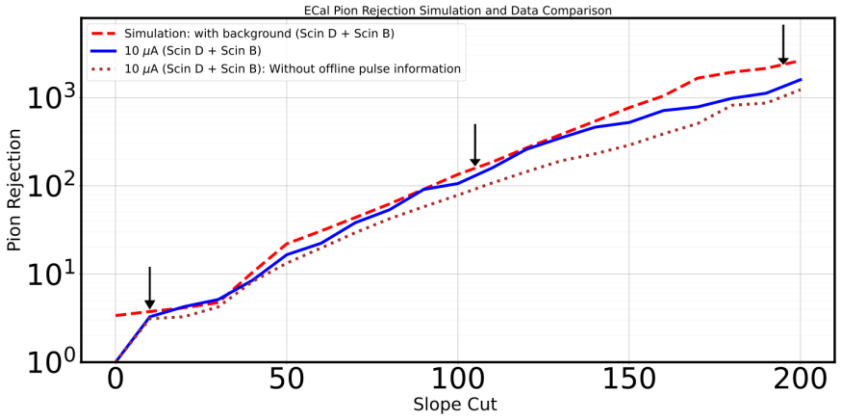
Detector Performance

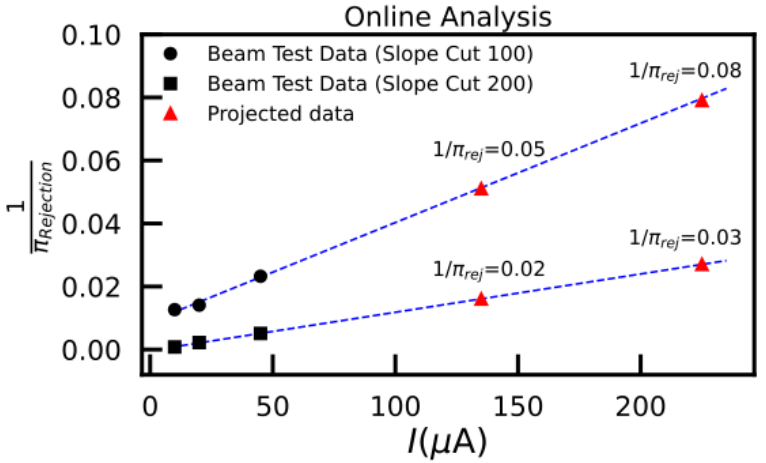
LASPD meet SoLID's requirements for photon rejection



Detector Performance

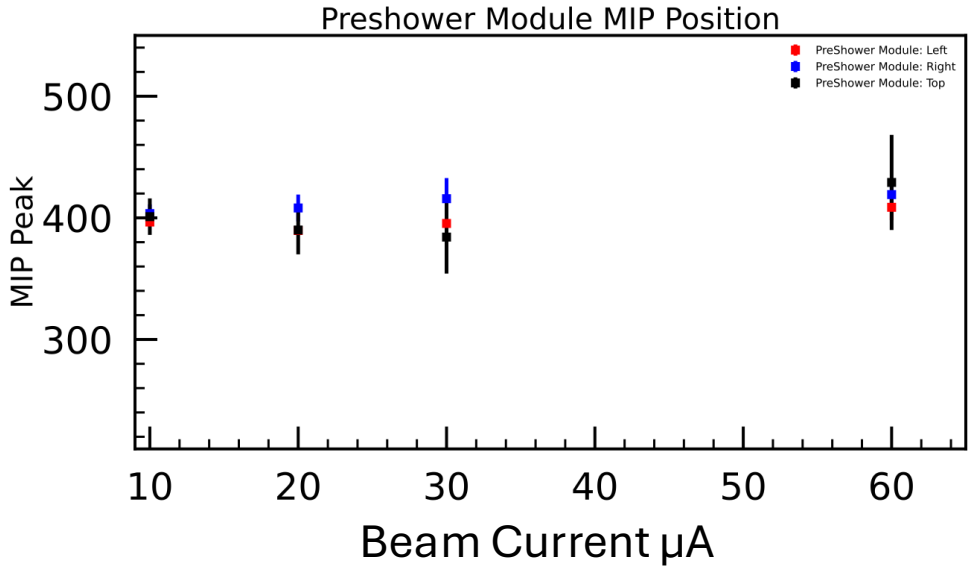
Confidence that the ECal can provide the PID performance required by all of the SoLID program





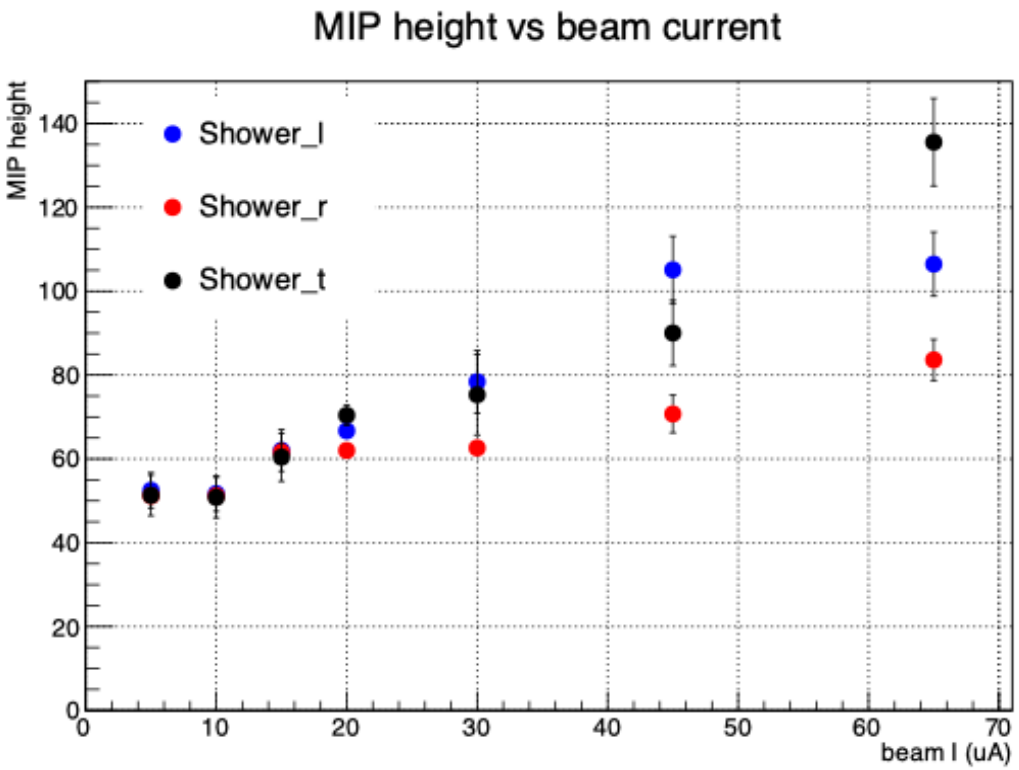
Shower PMT Gain Shift

- MIP signals monitored throughout test for detectors
  - Scin A (B,C,D), LASPD, Preshower, and Shower



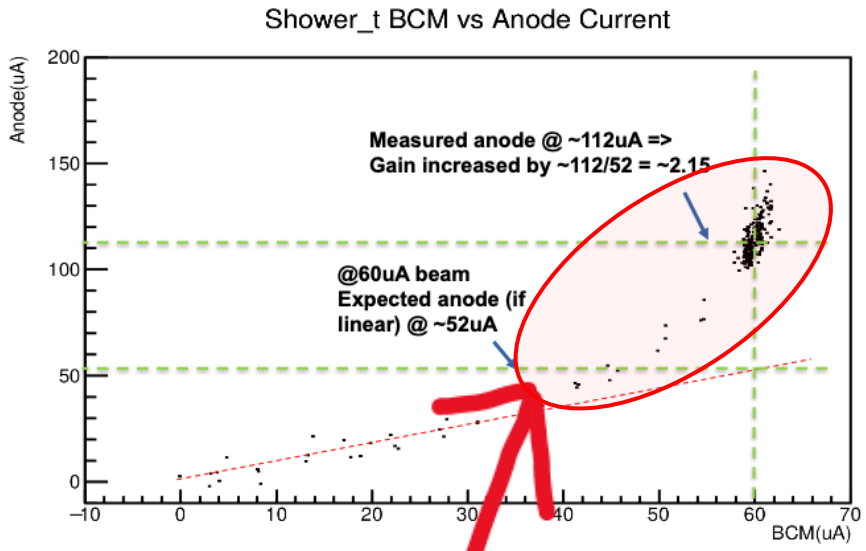
Shower PMT Gain Shift

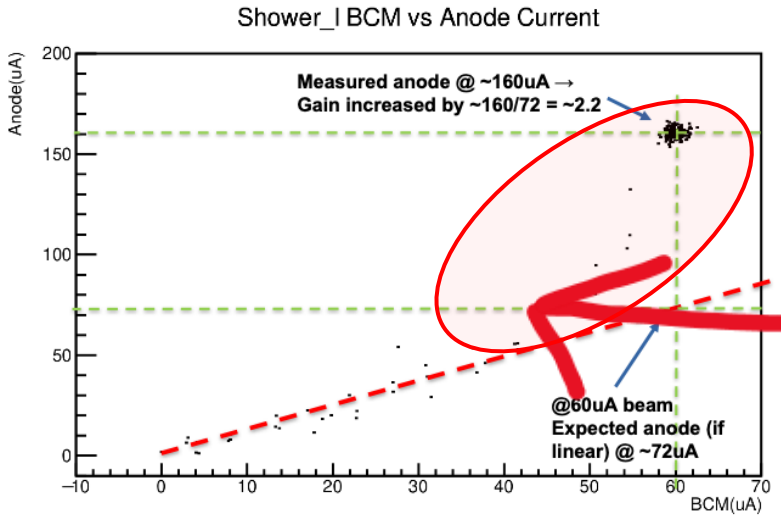
- MIP signals monitored throughout test for detectors
  - Scin A (B,C,D), LASPD, Preshower, and Shower
- Observed an increase in MIP position of shower models
  - Most dramatic in Shower Top & Left
- Shower Top and Left
  - factor 2 gain increase
- Shower Right
  - ~25% gain increase



Plot courtesy of Ye Tian

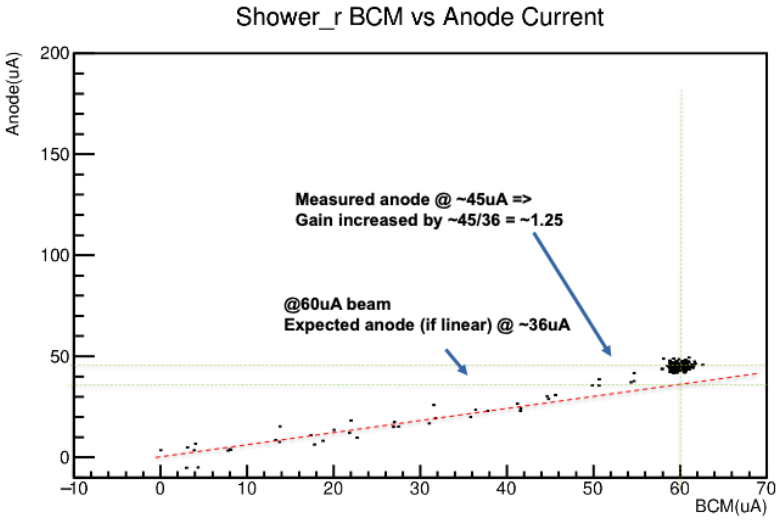
Shower PMT Anode current





- Anode currents extracted using FADC signals before event

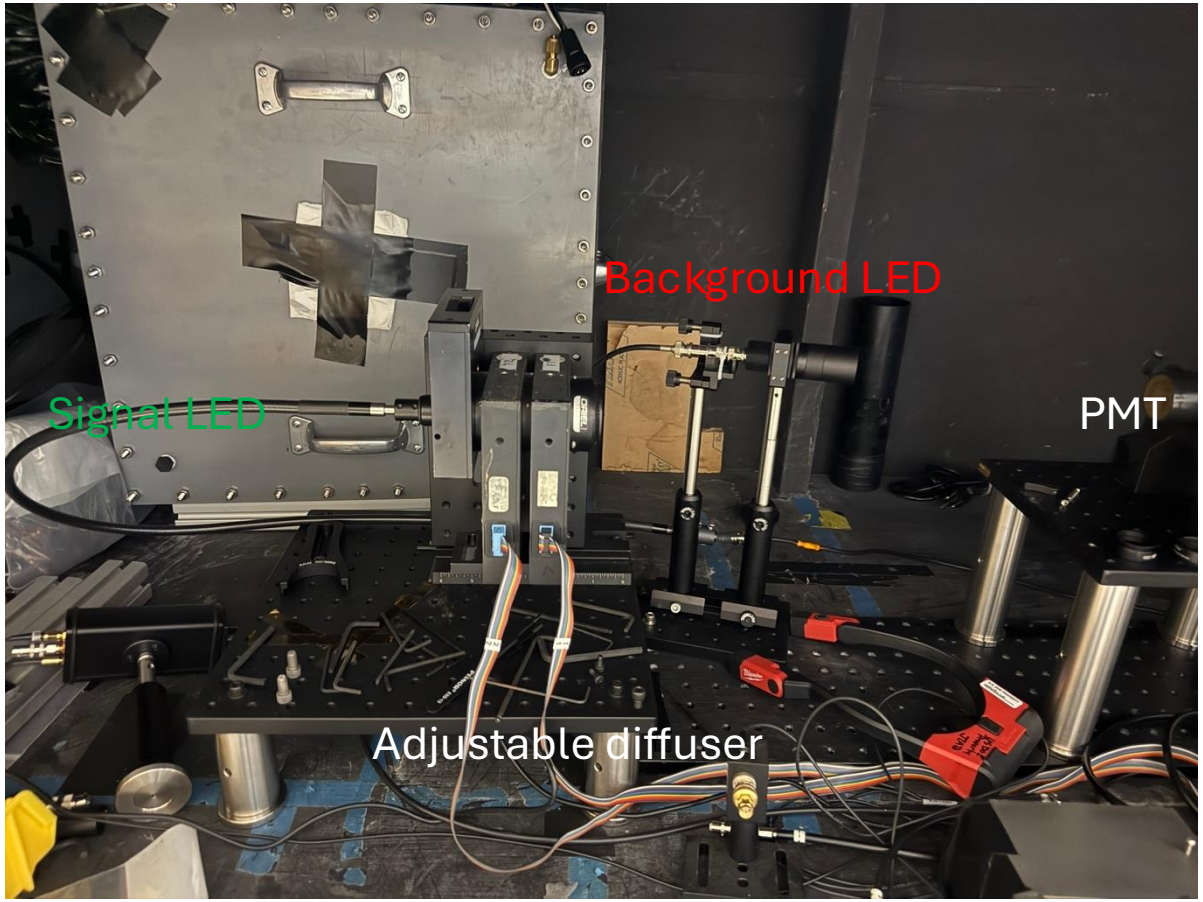
Anode current non-linear in the region of 45-50 μA



Plots Courtesy of Ben Raydo

2025 Bench Test - JLab

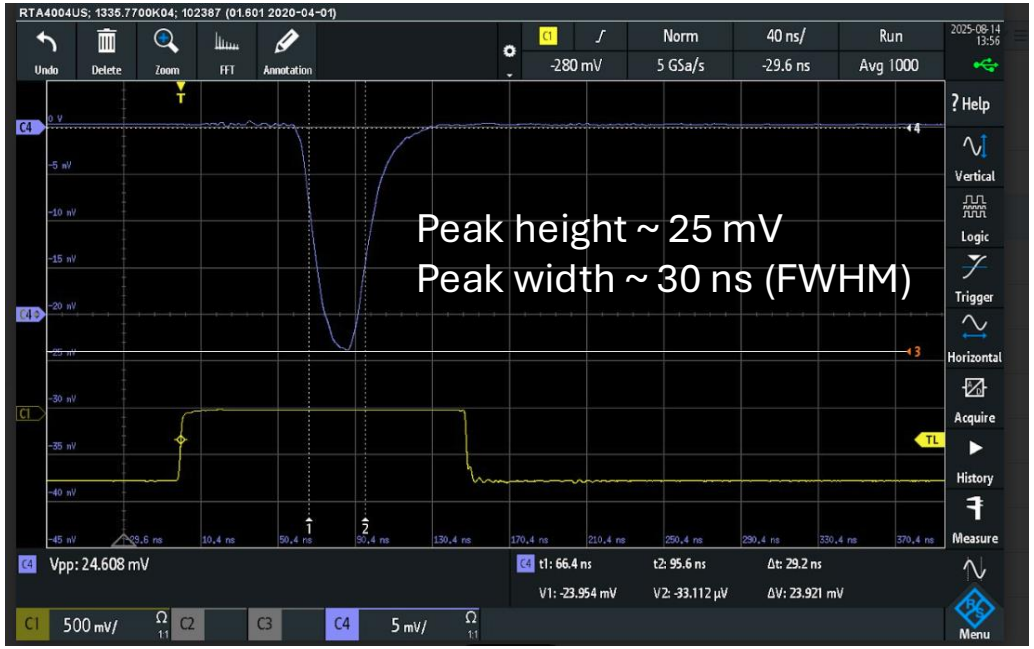
- Reproduce shower behavior during high-rate detector test
- Carl Zorn's PMT setup to mimic beam test
  - Signal - LED constant 1 kHz
  - Background - LED varied (MHz)
- Same HV as during beam test
- No DAQ setup
  - Exported series of samples from oscilloscope for offline analysis
- Similar bench test preformed by Shandong group with different bases
- Left PMT likely damaged during initial set-up & testing



Tests performed by Michael Lowry (Uva)

2025 Bench Test - JLab

- Signal characteristics kept consistent among different PMTs
  - Peak height: 25 mV
  - Peak width: 30 ns (FWHM)



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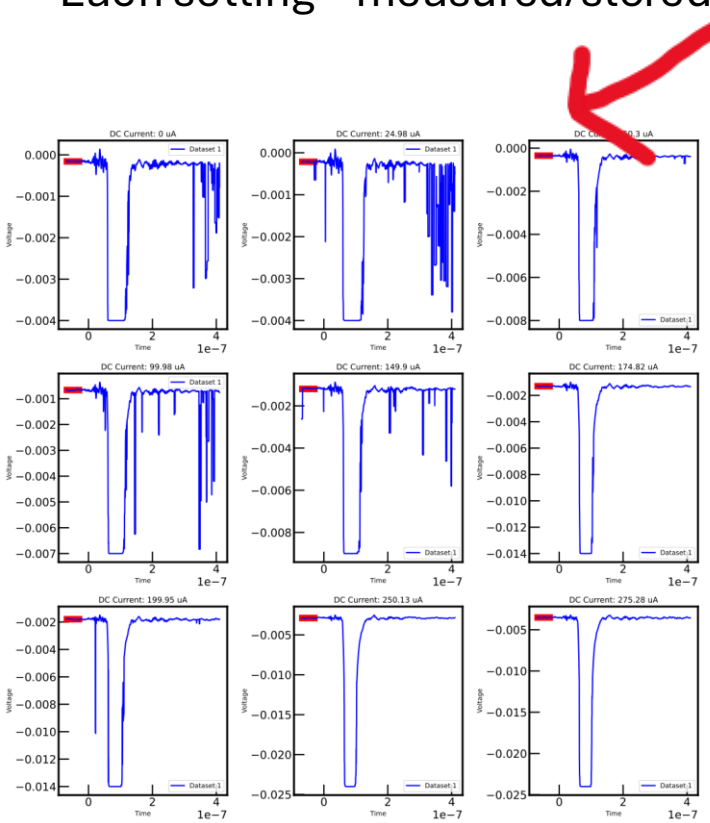
- Signal characteristics kept consistent among different PMTs
  - Peak height: 25 mV
  - Peak width: 30 ns (FWHM)
- Signal LED kept constant, background increased

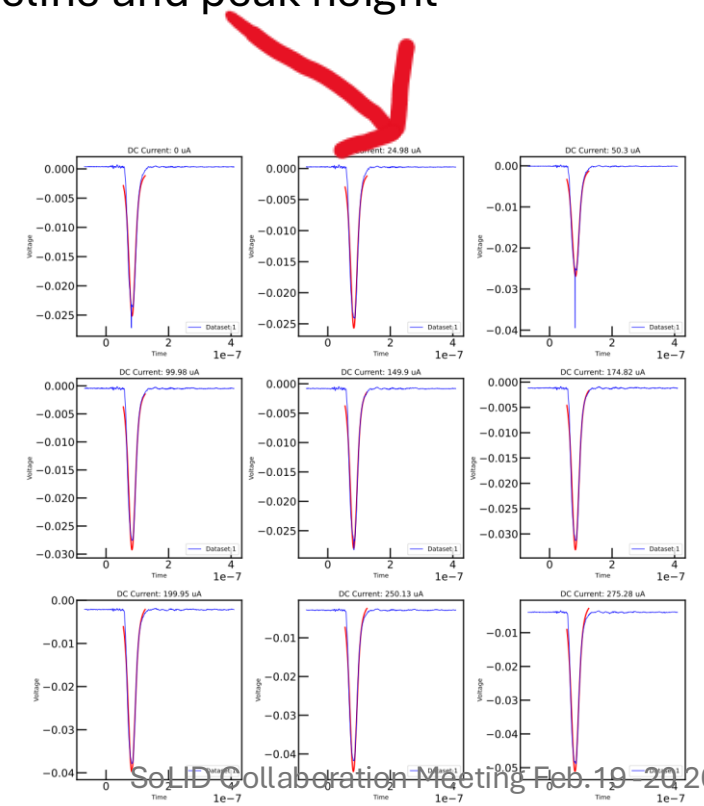
Top PMT

Signal Rate [kHz]	Background LED Current [μA]
1.0	0.00
1.0	24.98
1.0	50.03
1.0	99.98
1.0	149.90
1.0	174.82
1.0	199.95
1.0	250.13
1.0	275.13

2025 Bench Test - JLab

- Signal characteristics kept consistent among different PMTs
  - Peak height: 25 mV
  - Peak width: 30 ns (FWHM)
- Signal LED kept constant, background increased
- Each setting – measured/stored baseline and peak height





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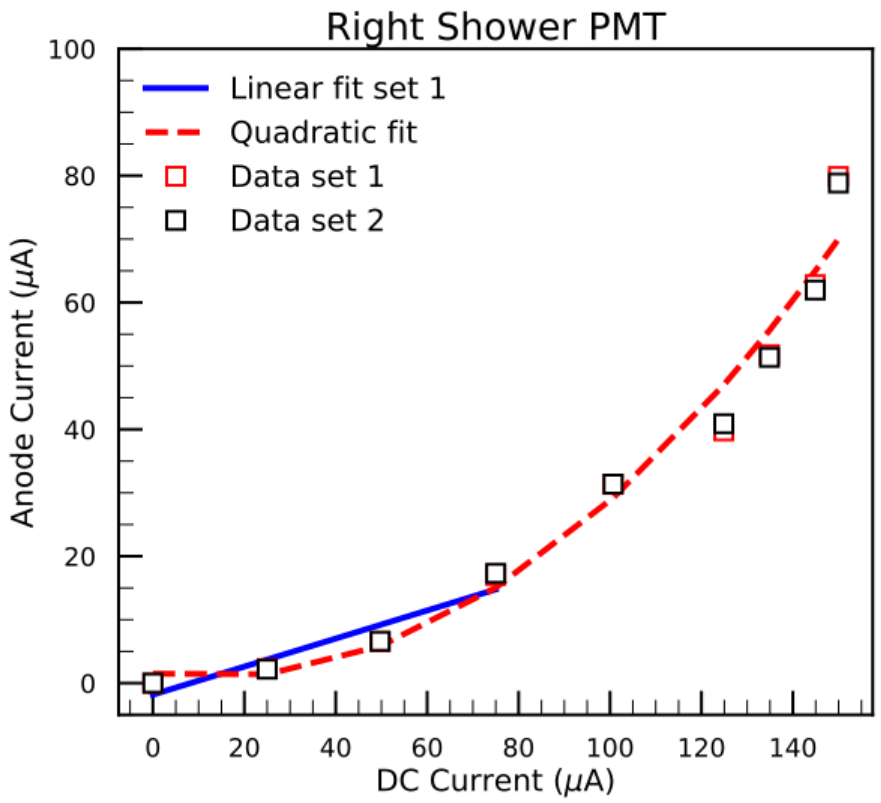
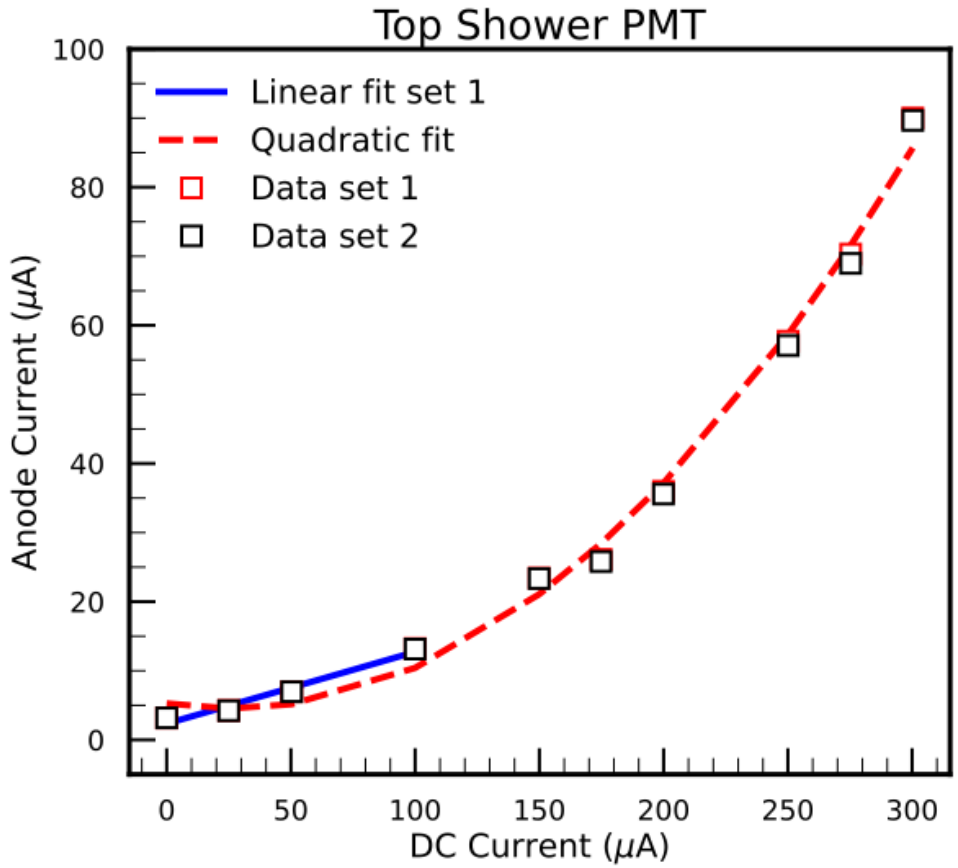
2025 Bench Test – Jlab: Results

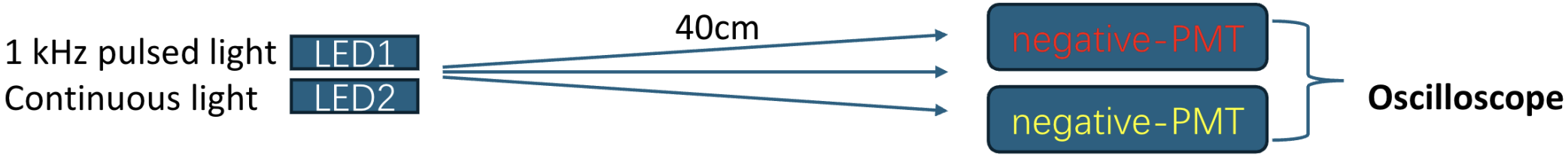




Right PMT appeared to become non-linear earlier than in beam test

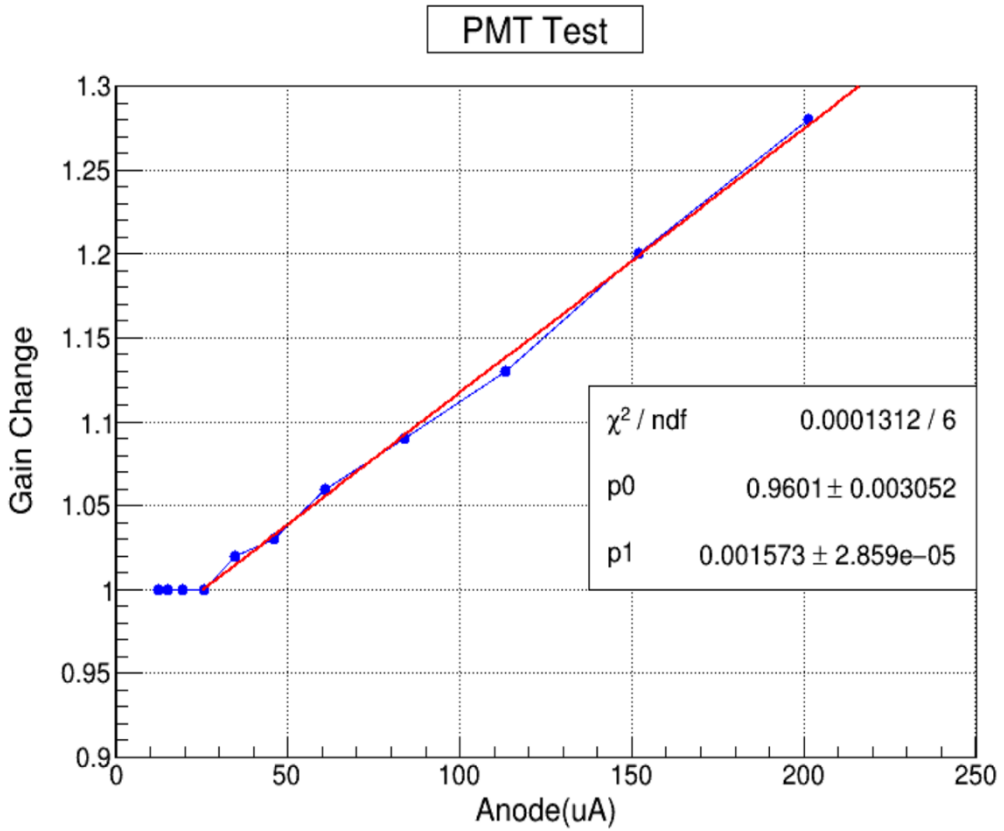
Shandong University PMT Bench Test

- PMT and HV divider ： cr-284 from Zhihong Ye(ThU)
  - active base： negative-HV
  - two PMT: ID5785\ID5804
  - Test range:for continuous light from about -1mV - -10mV



Slide Courtesy Yanan Liu and Shulong Ji

Shandong University PMT Bench Test



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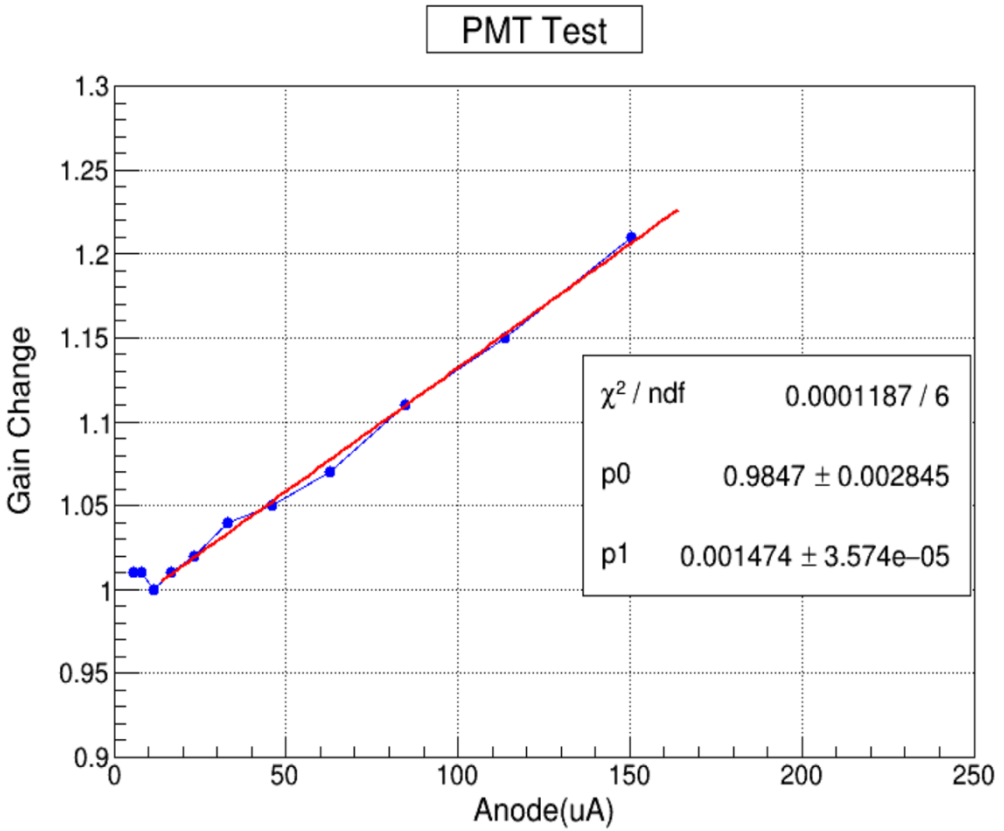


5804

Conclusion

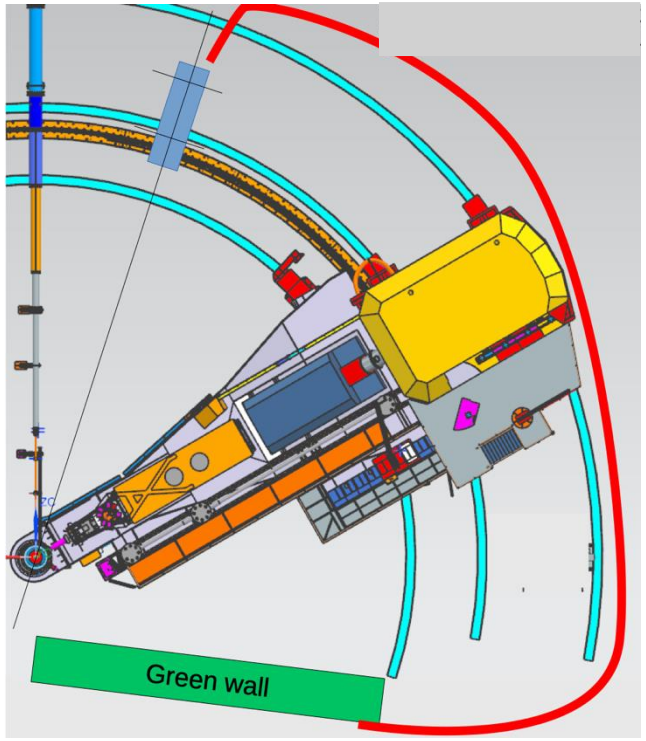
1. The gain of the anode current remains basically unchanged within 20 μA
2. 20 - 200 μA gain increase is linear

Figures Courtesy Yanan Liu and Shulong Ji

ECal preparation for upcoming beam test

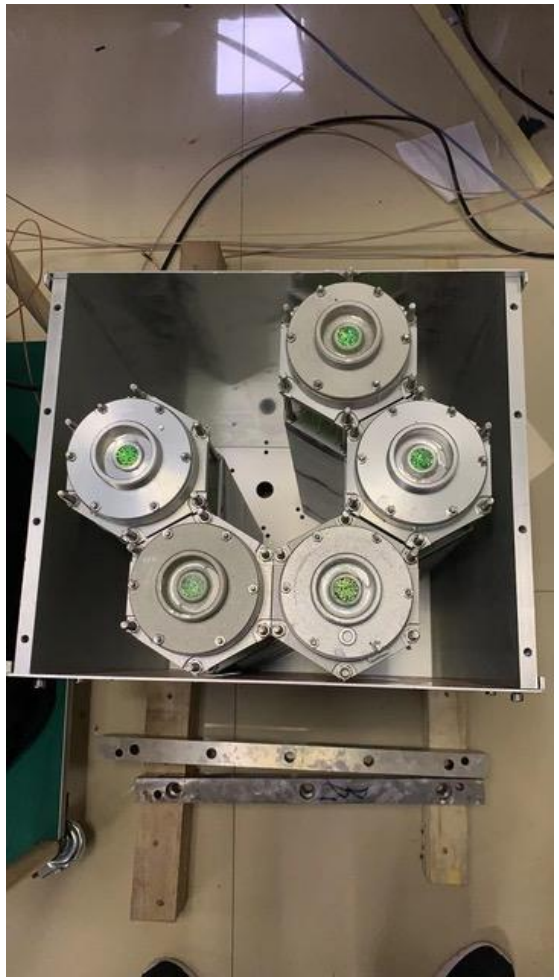
2026 Tracker Beam Test Preparation

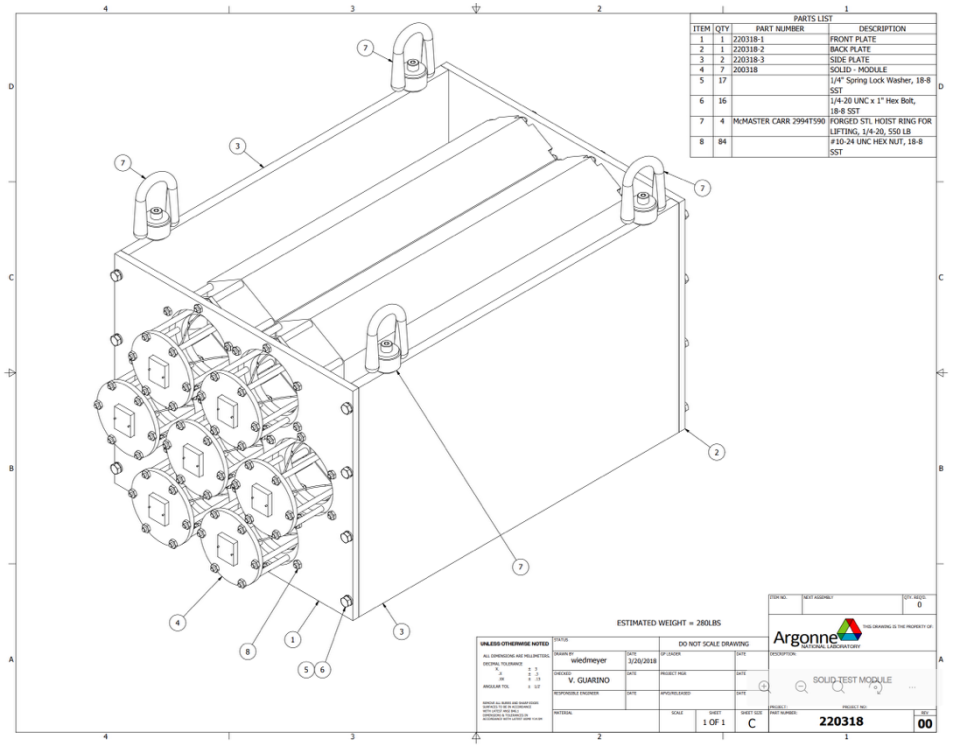
- ECal super-module (7 modules) in place of 3 module shower
  - Different PMT bases than 3 module
- ECal super-module requires new support on existing table
  - Designed by Hall C engineering
  - Flexible to use for 3 module (back-up)
  - Can be used for fiducialization



See Eric Fuchey's talk for more details

ECal Super Module

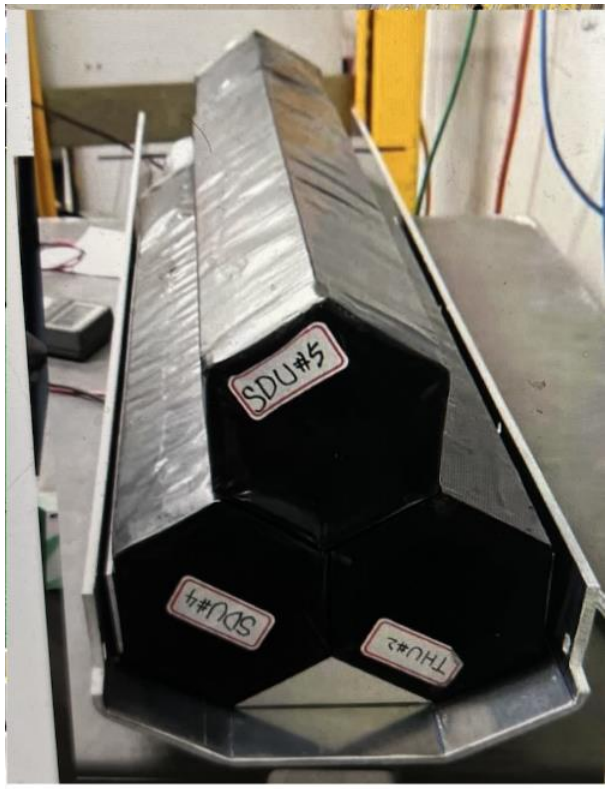




Images courtesy of Zhihong Ye

3 Module Backup

- 3 module shower needed to be considered due to delay in ECal shipment
  - **Before recent decision to delay installation**
  - Preparation to reuse the 3-module set-up
- Super-module support
  - Flexible to use for 3 module ✓



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- Super-module support
  - Flexible to use for 3 module ✓
- New trackers before ECal
  - Cover previous screws which attached plate to table
  - 3 modules moved back – 2 new holes added on table ✓

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  - **Before recent decision to delay installation**
  - Preparation to reuse the 3-module set-up
- Super-module support
  - Flexible to use for 3 module ✓
- New trackers before ECal
  - Cover previous screws which attached plate to table
  - 3 modules moved back – 2 new holes added on table ✓
- Replace Left shower PMT damaged during bench test
  - Have 1 spare that needs tested ✓
  - Spare PMTs purchased - 5x R11102 ✓
  - 3x bases (for R11102) ✓

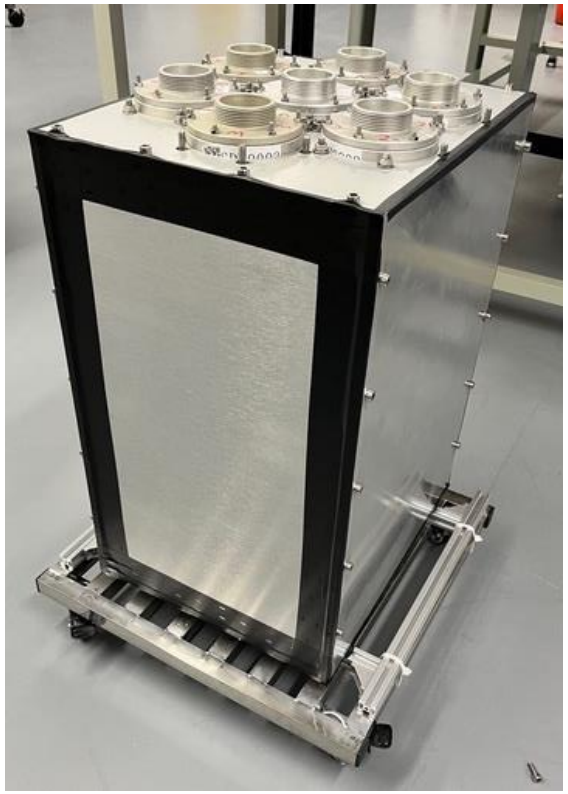
3 Module Backup

- 3 module shower needed to be considered due to delay in ECal shipment
  - **Before recent decision to delay installation**
  - Preparation to reuse the 3 module set-up
- Super-module support
  - Flexible to use for 3 module ✓
- New trackers before ECal
  - Cover previous screws which attached plate to table
  - 3 modules moved back – 2 new holes added on table ✓
- Replace Left shower PMT damaged during bench test
  - Have 1 spare that needs tested ✓
  - Spare PMTs purchased ✓

- **Plan remains to use super-module**
- **Modification are minimal and will only serve as a back-up**

Things to do

- Prepare/Test super-module after shipment
  - Test PMTs
  - Can preform similar LED bench test as was preformed by Tsinghua group
  - Carl Zorn's dark box set-up
- 5 preshower tiles & WLS fibers also in shipment
  - Test MAPMTs with preshower
- Test spare PMT to replace Left PMT (3 module)
- Modify/update ECal replay
- Design plan for commissioning of ECal



Remaining (pre)R&D Activities

ECal Update (Xiaochao Zheng): SoLID Collaboration Meeting (July 7-8 2025)

- For SoLID ECal, we still need (pre)R&D on:
  - MAPMT readout of Preshower (unless we decide on using regular PMTs – much safer but higher cost)
  - MCP-PMT readout of LASPD
  - PMT active base design and testing → R&D

- 5 Preshower tiles also included in shipment with super module
  - Good opportunity to test MAPMTs with Preshower
- 5 Shower PMTs and 3 bases purchased – spares
  - Will work with Electronics group on base

Summary

- The 2022-2023 beam test analysis is (nearly) complete
  - ML PID nearing completion with the recent help of the simulation group
- Completed shower PMT bench test to confirm gain shift observed during the beam test
  - Companion bench test preformed by Shandong University group provides input for future base design
  - Shandong University will repeat study using a high-rate pulsed LED
- Preparation is ongoing for the upcoming beam test

2026 Tracker Beam Test Preparation

- Will use a 7 module ECal (super module)
  - Being shipped from China
- Delay in shipping-Modify to begin with 3 module during commissioning
  - Update position on table
  - new screws to secure to table and support
  - Replace Left PMT
- With installation delay
  - 7 module ECal will arrive early to mid march
  - Needs to be tested
- 5 preshower tiles also included in
  - May be a good idea to test MAPMTs with preshower

See Eric Fuchey's talk for more details

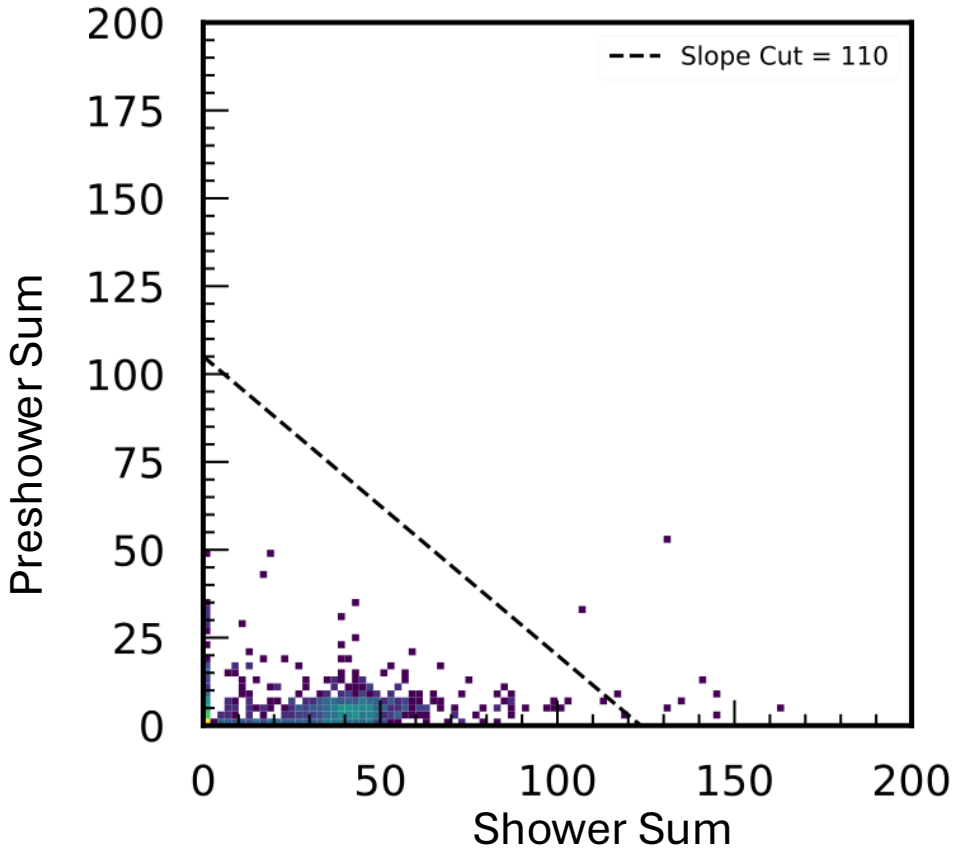
2022-2023 Summary

- Completed a high-rate Ecal test
- Completed
  - detector performance
  - PID analysese
  - Nearly completed ML PID analysis
  - Bench test
- Machine Learning PID near competition
  - Requires additional statistics from simulation
- Beam test summary available

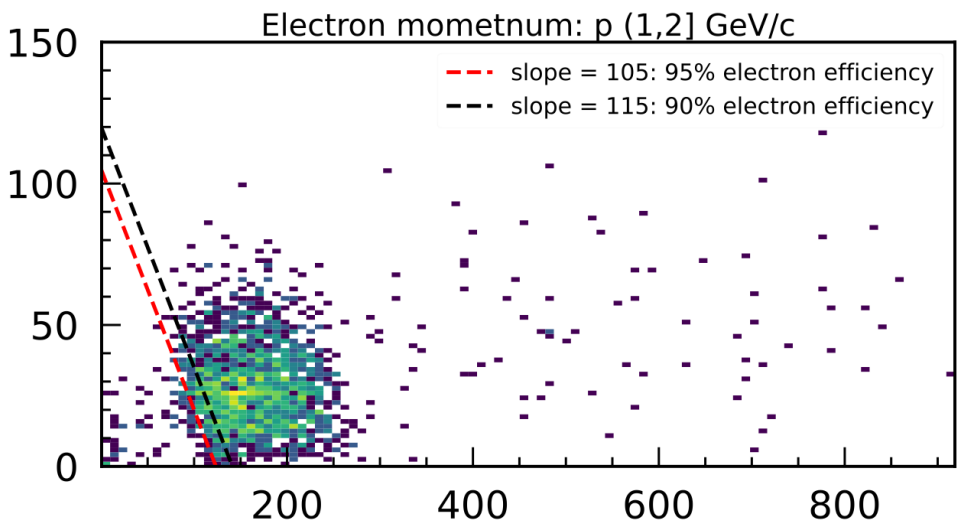
Electromagnetic Calorimeter Performance In a High Rate Environment for the SoLID Physics Program

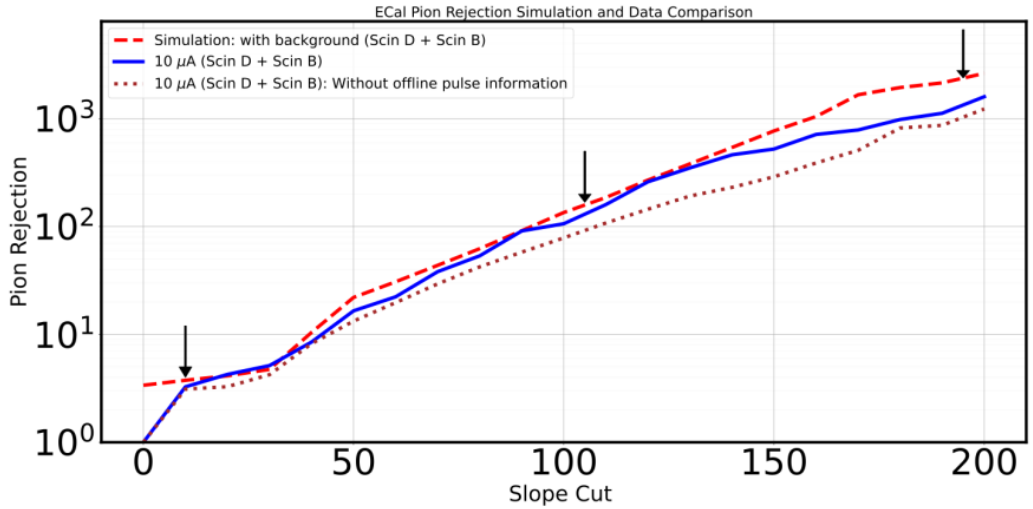
Charged pion rejection

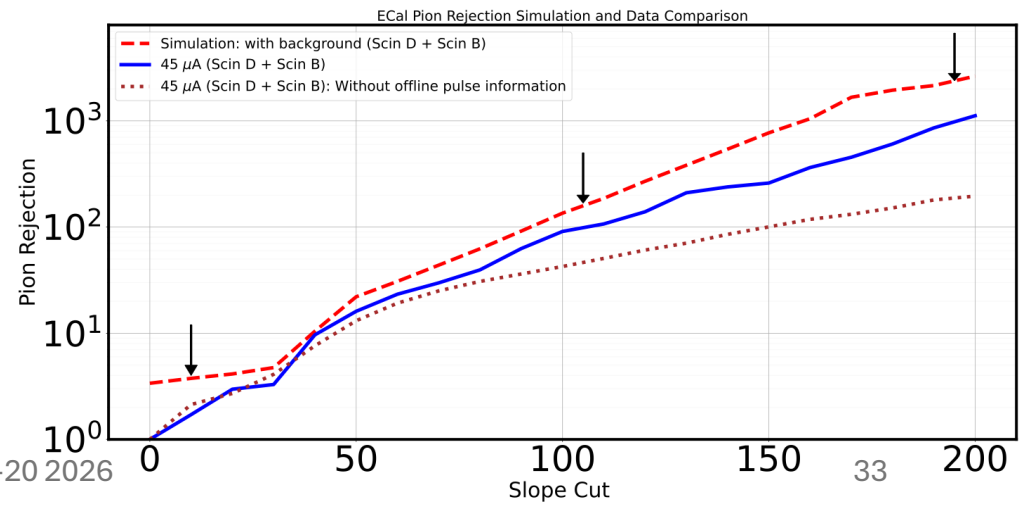
- With open geometry (no magnet)
  - Can only preform charged pion rejection
- Used traditional PID
  - Cherenkov Sum ~ 0
- Apply a ”slope” cut in PSh vs. Sh
  - Calculate pion rejection
- Compare with simulation
  - Perform same analysis using Simulation
  - (i.e. trigger, NPE, Scintillator cut)
- Additional studies performed
  - “Offline” to reduce background
  - Machine learning – near completion



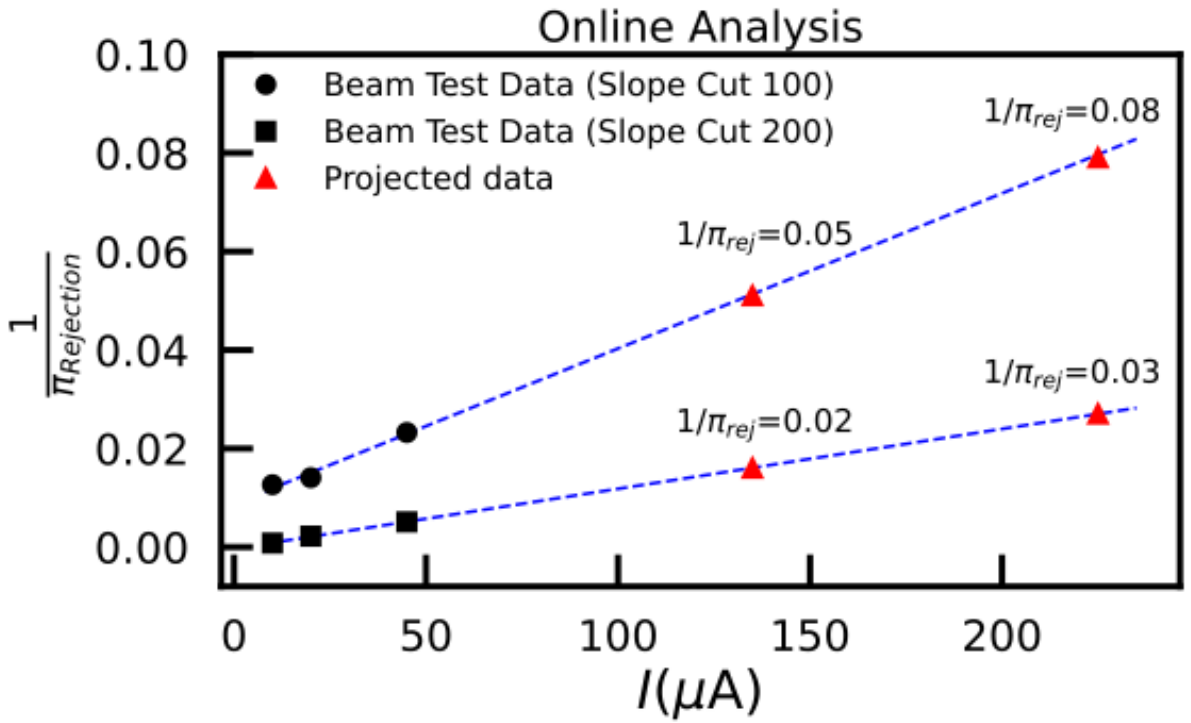
- Pion rejection at low current consist
- An offline analysis helped to reduce background

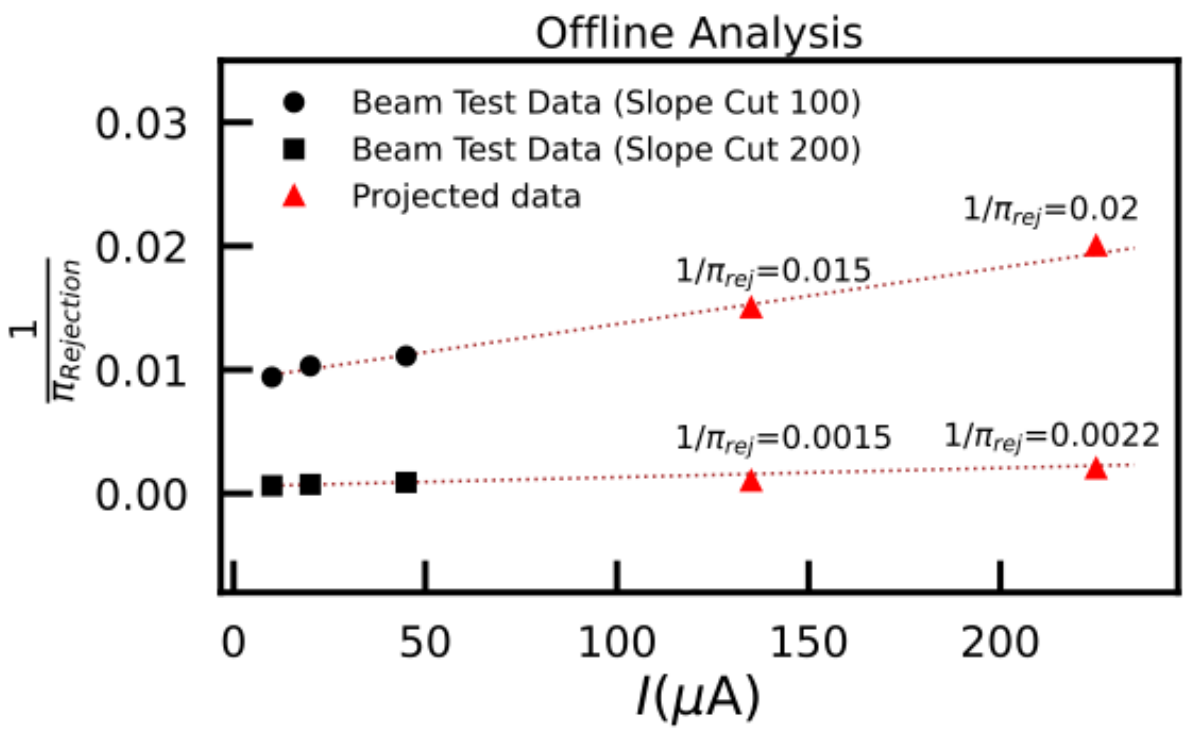






Charged pion rejection





2022– 2023 Ecal Beam Test

- Goal - Performance of Ecal in high-rate environment