# Update of SoLID Beam Test and ECal Status

Michael Nycz (University of Virginia)

## SoLID Collaboration Meeting

December 2023

**Xinzhan Bai, Alexandre Camsonne, Jimmy Caylor, Carter Hedinger, Tim Holmstrom, Simona Malace,Spencer Opatrny, Ye Tian, Darren Upton, Jixie Zhang, Xiaochao Zheng**

U.S. DEPARTMENT OF ENERGY | Office of Science
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# Beam Test Overview

SoLID Director’s Review (2021)

- Calorimeter and SPD detectors not tested under high background / high luminosity environment
- Detector test utilizing a full set of SoLID prototype detectors under “realistic SoLID running condition”

Goals

1. Ensuring scintillators and ECal can trigger at high rates
2. Particle Identification
3. Identifying MIP signals in ECal above background
4. Ensuring GEMs work properly and can find tracks
5. Comparison with and benchmark of the SoLID simulation

# Outline of Beam Test

June 2022

82°

Detector Installation and checkout

December 2022

Cosmic calibration over holiday break

January 2023

7°

High Rate setting 1

Dedicated 5 μA runs

February 2023

18°

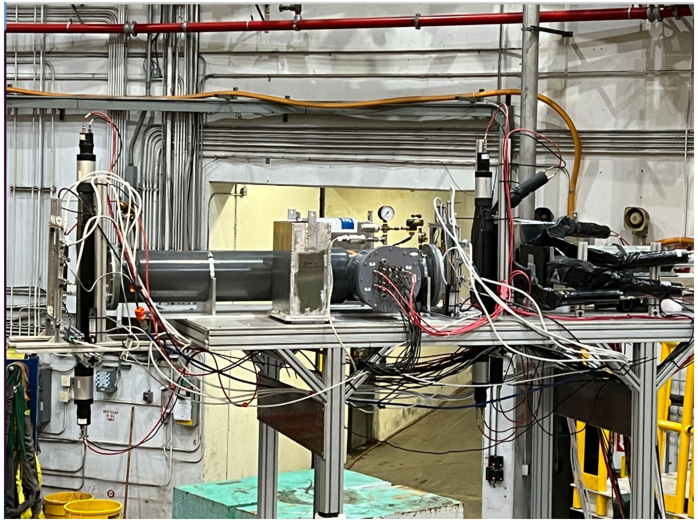
High rate setting 2

Primary data used for analysis

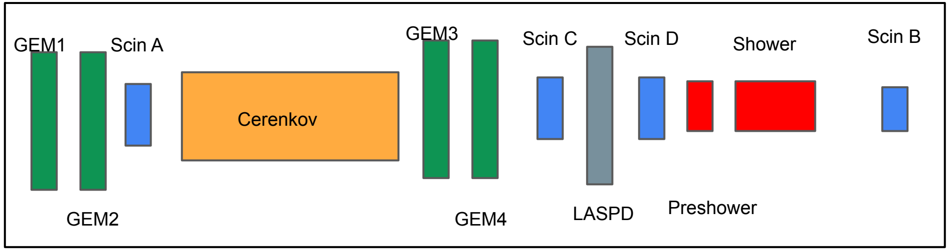
9 months in Hall C
3 Detector (and bunker) installations

# Detector System

- 4 10x10 cm GEMs (UVa)
- Gas Cherenkov (Temple)
- LASPD
- 3 Scintillators upstream of Ecal
- 3 Preshower modules (UVa)
- 3 (shashlyk) shower modules (UVa)
- 1 Scintillator after shower



Detector layout



# 18°: High Rate Setting

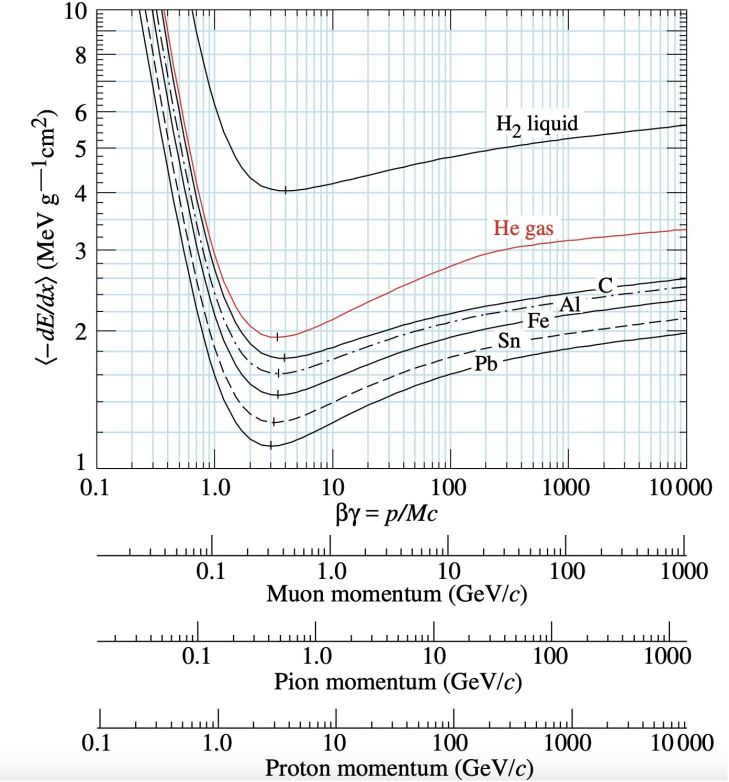
- February - March 2022 (~ 30 days)
- Data collected continuously during experimental running
- Data summary
  - Beam Current
    - High current: 40 - 65 μA
    - Low current: 10 μA (Boiling study)
    - Dedicated: 5 μA (short-Detector checkout)
  - Targets
    - Deuterium, Carbon, and Dummy
- Experimental dosimetry (on front GEM)
  - 70  kRad

# Summary of work since the last collaboration meeting

1. GEM optimization - see Xinzhan Bai’s update
2. Beam test comparison with simulation - see Ye Tian’s update
3. SPD timing study (Carter Hedinger)
4. Pileup at high current
    a. Deconvolution algorithm implemented (Jixie Zhang)
5. Cherenkov SPE (Zhiwen Zhao & Bo Yu)
    a. Bench test with JLab Detector Group
6. **Gain shift in shower PMT**
7. $\pi^{+/-}$ Rejection of ECal
    a. Simulation (Darren Upton and Spencer Opatrny)
    b. Data

# Minimum-Ionizing Particle Peak

- Mean energy loss near minimum of⟨dE/dx⟩
- Used for gain calibration / stability



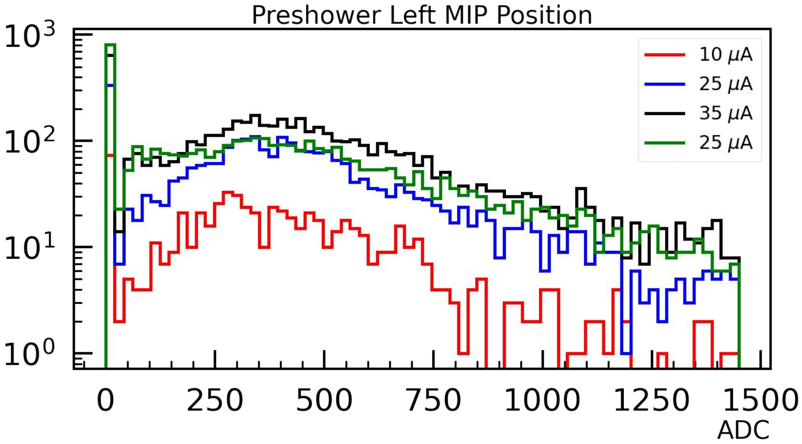
From PDG

# Minimum-Ionizing Particle Peak: Preshower Modules

- Mean energy loss near minimum of⟨dE/dx⟩
- Used for gain calibration / stability

<u>Beam Test</u>

- Minimum ionization peak (from $\pi$) observed in all scintillators and Ecal detectors at 18°setting
- At constant high voltage settings
  - Consistent MIP peak position
- **No current dependence of MIP peak observed in preshower**



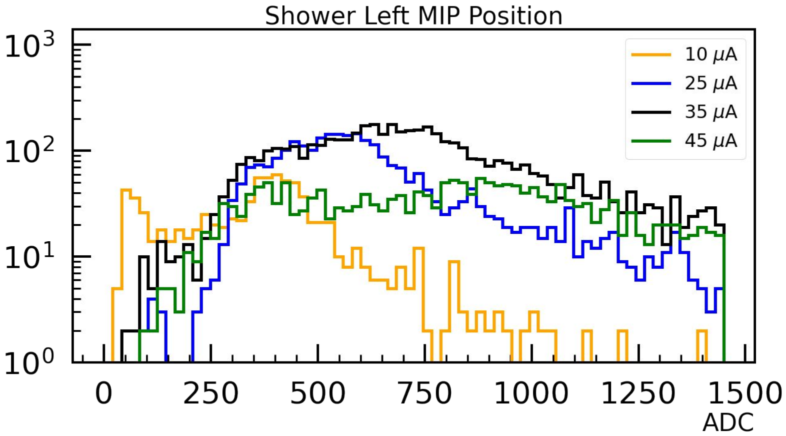
Preshower MIP position as function of beam current

# Minimum-Ionizing Particle Peak: Shower Modules

- Mean energy loss near minimum of ⟨dE/dx⟩
- Used for gain calibration / stability

<u>Beam Test</u>

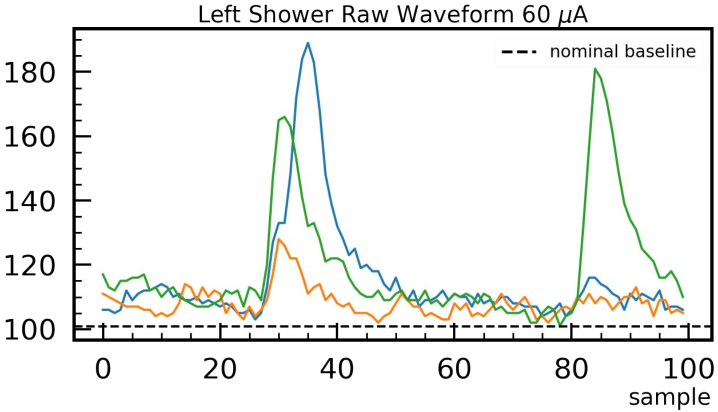
- Minimum ionization peak (from $\pi$) observed in all scintillators and Ecal detectors at 18°setting
- At constant high voltage settings
  - Consistent MIP peak position
- No current dependence of MIP peak observed in preshower
- Shower modules
  - Distinct current dependence of MIP peak position observed

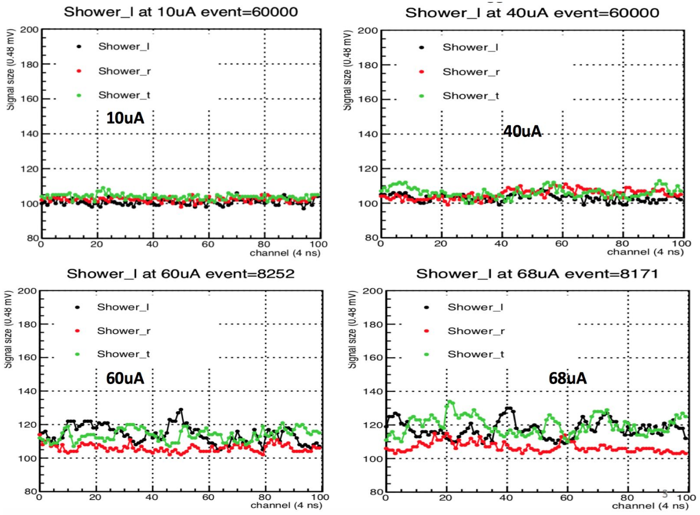


End points are shifted

# Source of Current Dependence

1. Baseline shift
    a. Pileup at higher current
    b. Pedestal measured without beam
    c. Not properly subtracting baseline
    d. Integrating fraction of baseline in each sample

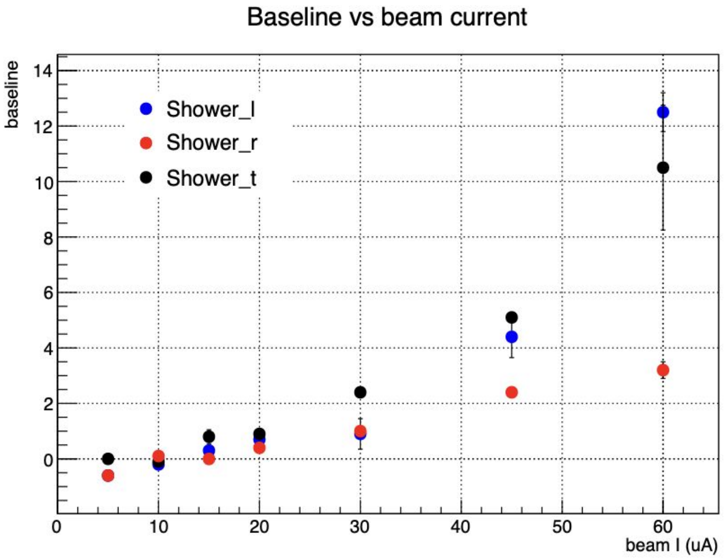




From Ye Tian

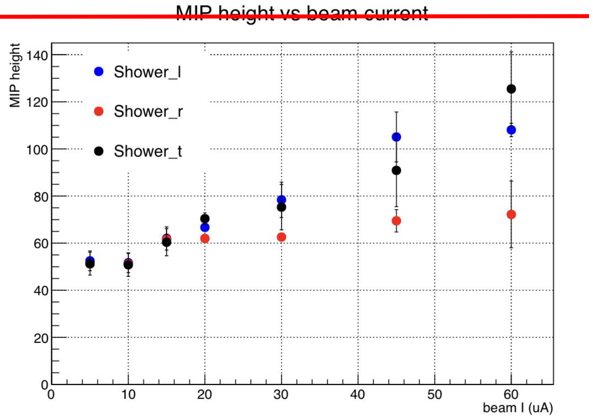
# MIP Peak Rate Dependence

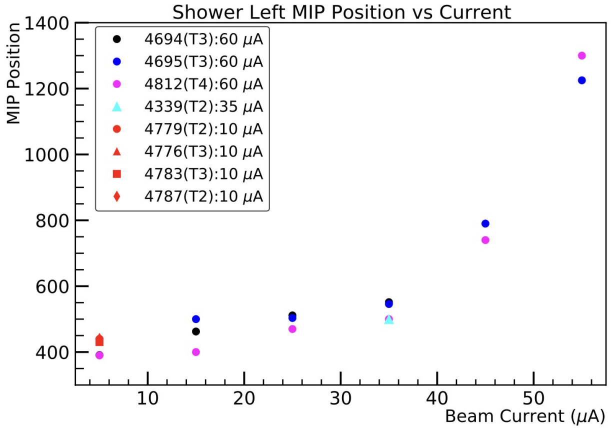
1. Baseline shift
   a. Pileup at higher current
   b. Pedestal measured without beam
   c. Not properly subtracting baseline
   d. Integrating fraction of baseline in each sample
   **e. Too small to account for observed shift**



# MIP Peak Rate Dependence

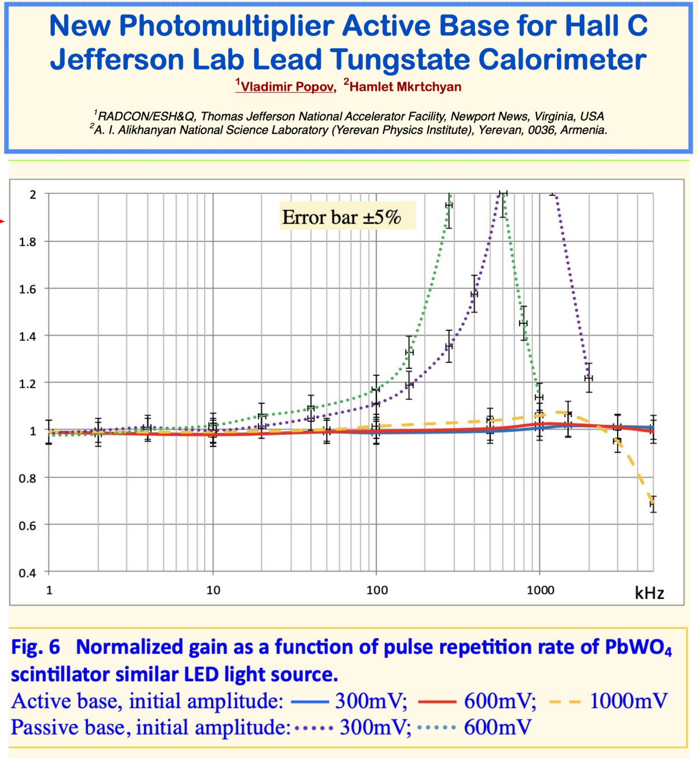
1. Baseline shift
    a. Pileup at higher current
    b. Pedestal measured without beam
    c. Not properly subtracting baseline
    d. Integrating fraction of baseline in each sample
    e. Too small to account for observed shift
2. Changing PMT Base gain
    a. Increase in amplitude of raw signal at higher currents
    b. Indicative of a redistribution of HV among dynodes





# MIP Summary

- Shower modules experienced a (non-linear) increase in HV with increase in beam current
- Behavior was observed in test for NPS passive PMT bases (2012)
  - Passive bases used in beam test shower modules
- Left shower module (closest to beamline)
  - Started to fail around 60 μA
  - Recovered and continued to work properly at low currents
- Possible future bench test to further understand behavior with these bases



**New Photomultiplier Active Base for Hall C Jefferson Lab Lead Tungstate Calorimeter**

[1]Vladimir Popov, [2]Hamlet Mkrtchyan

*[1]RADCON/ESH&Q, Thomas Jefferson National Accelerator Facility, Newport News, Virginia, USA*
*[2]A. I. Alikhanyan National Science Laboratory (Yerevan Physics Institute), Yerevan, 0036, Armenia.*

**Fig. 6 Normalized gain as a function of pulse repetition rate of $PbWO_4$ scintillator similar LED light source.**
Active base, initial amplitude: —— 300mV; —— 600mV; – – 1000mV
Passive base, initial amplitude: ····· 300mV; ····· 600mV

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5. Cherenkov SPE (Zhiwen Zhao & Bo Yu)
   a. Bench test with JLab Detector Group
6. Gain shift in shower pmt
7. **$\pi^{+/-}$ Rejection of ECal**
   a. Simulation - Machine Learning (Darren Upton
   b. Simulation - Classical PID (Spencer Opatrny)
   c. Data

# Particle Identification: Electromagnetic Calorimeter

**$e^-$ Efficiency:**

Not feasible without momentum selection

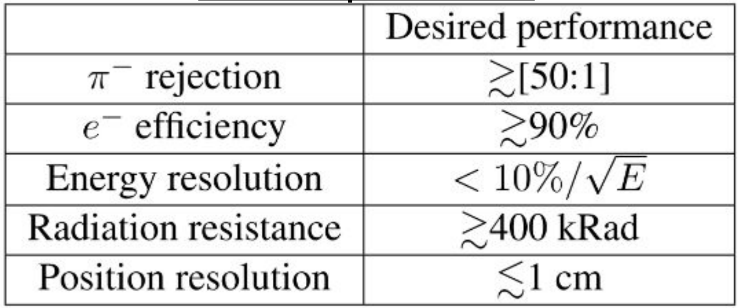
Dominated by low energy background

**$\pi^{+/-}$ Rejection:**

Comparison with SoLID simulation

Comparison with SoLID pre-CDR

SoLID pre-CDR



| | Desired performance |
|---|---|
| $\pi^-$ rejection | $\gtrsim$[50:1] |
| $e^-$ efficiency | $\gtrsim$90% |
| Energy resolution | $< 10\%/\sqrt{E}$ |
| Radiation resistance | $\gtrsim$400 kRad |
| Position resolution | $\lesssim$1 cm |

# $\pi^{+/-}$ Rejection: ECal

<u>Cuts</u>

Cherenkov

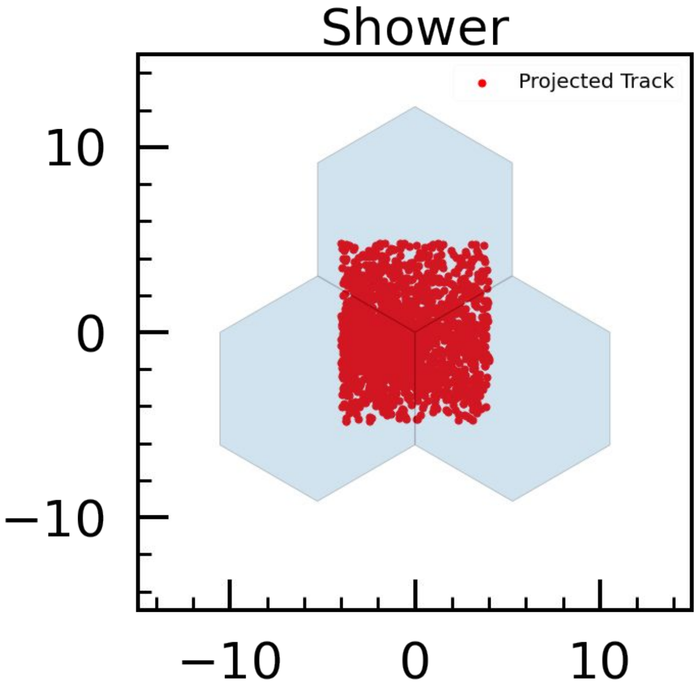
- Cherenkov NPE < 5

GEM track

- Projected tracking hitting center of Ecal

Scintillators

- Scin D and Scin B >200



# $\pi^{+/-}$ Rejection: ECal

Cuts

Cherenkov

- Cherenkov SPE < 5

GEM track

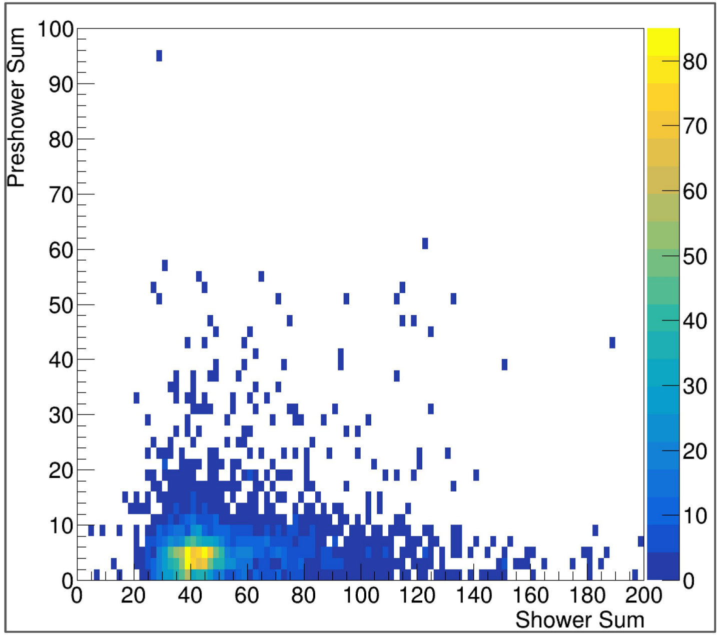
- Projected tracking passing through Ecal

Scintillators

- Scin D and Scin B >200

Preshower vs. Shower: 2-d cut (slope = -0.85)

Data: 10 $\mu$A



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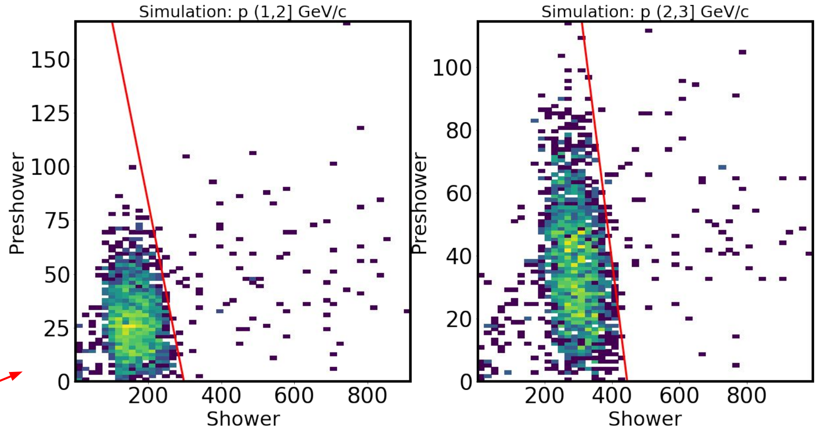
Preshower vs. Shower: 2-d cut (slope = -0.85)

Cut adapted from PID on Simulation

Electron Distribution: Simulation



Spencer Opartny

# $\pi^{+/-}$ Rejection: ECal

Cuts

Cherenkov

- Cherenkov SPE < 5

GEM track

- Projected tracking passing through Ecal

Scintillators

- Scin D and Scin B >200

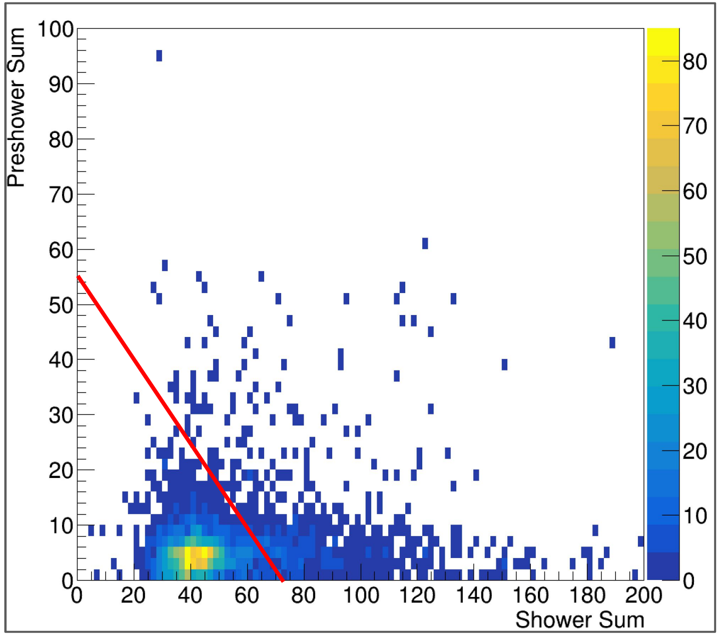
Preshower vs. Shower: 2-d cut (slope = -0.85)

Cut adapted from PID on Simulation

Applied to beam test data

Scan cut to obtain $\pi_{rej}$ vs intercept

Data: 10 $\mu$A

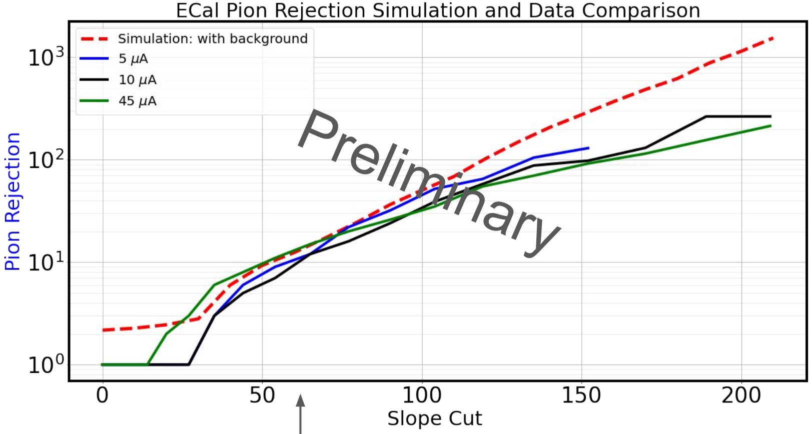


# Summary and Status of PID

- Apply same cuts to simulation
    - Trigger, Scintillator, Cherenkov, etc…
- Provides a baseline for comparison with data

<u>Next Steps</u>

1. Simulation
    - Did not use true PID in simulation
    - Better mixing of background
2. Data
    - Further refinements to Cherenkov SPE from recent bench test
    - Improvement with updates from GEM tracking

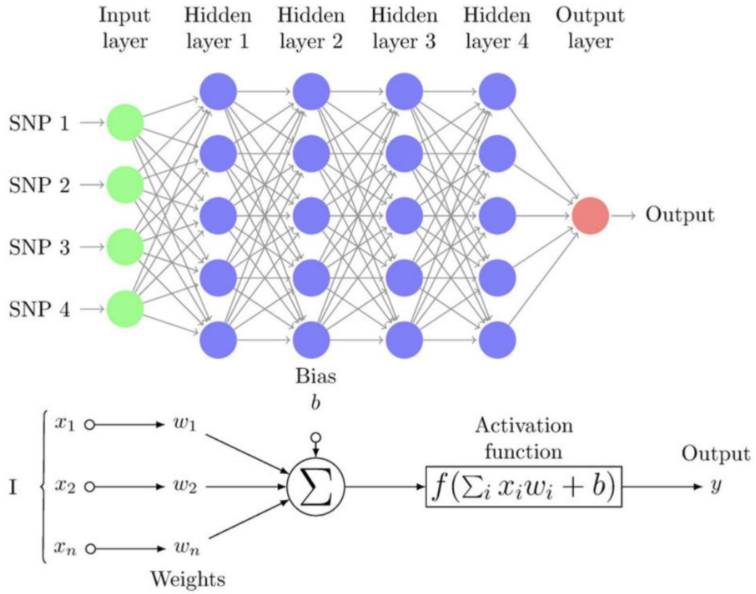


1 GeV electron

# PID: Machine Learning (**Darren Upton** SULI project)

SoLID simulation (Beam Test)

- Applied Machine Learning techniques to perform PID on beam test simulated data
- Additional guidance from JLab Data Science group
- Multi-Layer Perceptron (MLP)
    - Shower, Preshower, Scintillators, GEM hit



From Darren Upton

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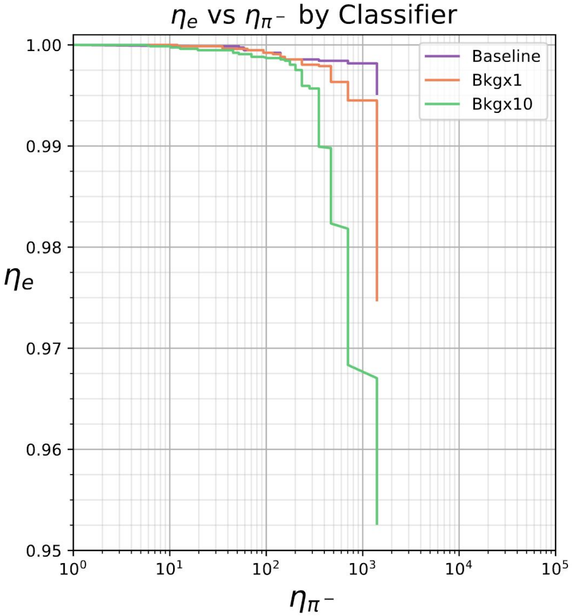
SoLID simulation (Beam Test)

- Applied Machine Learning techniques to perform PID on beam test simulated data
- Additional guidance from JLab Data Science group
- Multi-Layer Perceptron (MLP)
    - Shower, Preshower, Scintillators, GEM hit

In the initial phase. Needs additional work

Possibility to extend to data…



From Darren Upton

# Summary and Conclusion

- Recent beam test has provided opportunity to
  - Study detector performance in high luminosity + background environment
  - Make comparison with SoLID simulation
- Shower base exhibited current dependent behavior
  - Due to passive PMT base
  - May study further in bench test
- Particle ID studies ongoing
  - $\pi^{+/-}$ Rejection of Ecal
- Documentation and summary report
  - Technical notes summarizing work and analysis
- Test data provide foundation for possible future AI/ML PID work

**Thank You**

Hall A/C staff, Hall C Technical Staff, Hall C Engineering Staff, RADCON, and (all) the running experiments

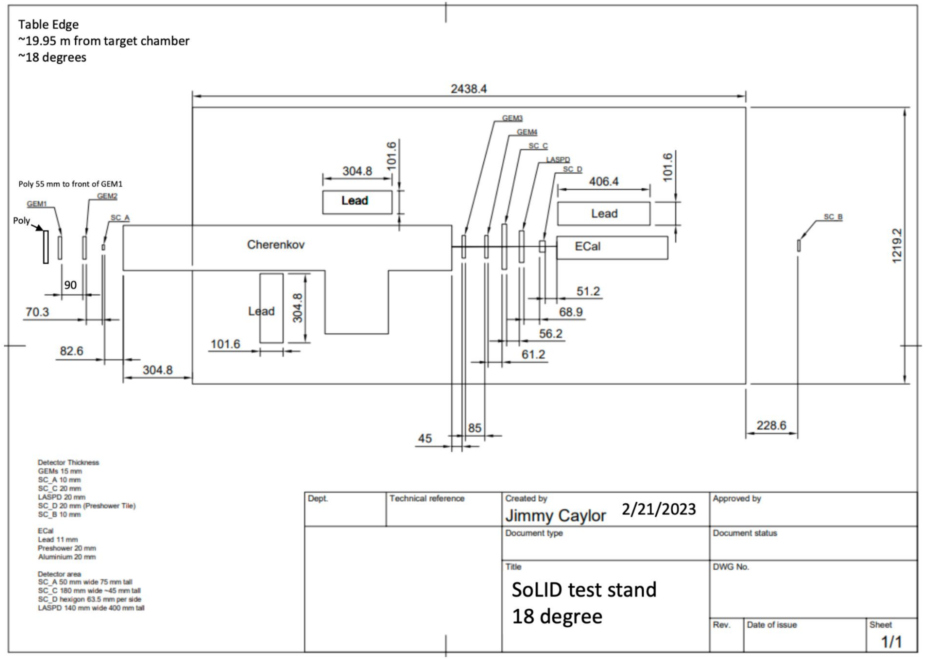


Table Edge
~19.95 m from target chamber
~18 degrees

Poly 55 mm to front of GEM1

Detector Thickness
GEMs 15 mm
SC_A 10 mm
SC_C 20 mm
LASPD 20 mm
SC_D 20 mm (Preshower Tile)
SC_B 10 mm

ECal
Lead 11 mm
Preshower 20 mm
Aluminium 20 mm

Detector area
SC_A 50 mm wide 75 mm tall
SC_C 180 mm wide ~45 mm tall
SC_D hexigon 63.5 mm per side
LASPD 140 mm wide 400 mm tall

|  |  |  |  |
|---|---|---|---|
| Dept. | Technical reference | Created by<br>Jimmy Caylor 2/21/2023 | Approved by |
|  |  | Document type | Document status |
|  |  | Title<br>SoLID test stand<br>18 degree | DWG No. |
|  |  |  | Rev. \| Date of issue \| Sheet 1/1 |

# Trigger Design: 18° (move to backup)

| Trigger Name | Logic | Threshold | Particle |
|---|---|---|---|
| TS 1 | Cherenkov Sum + Shower Sum | Cherenkov: 2 pe<br>Shower Sum: 0.5 mip | e |
| TS 2 | Scin D + Scin B | 0.5 mip | $\pi$ |
| TS 3* | Scin A + Scin D |  | MIP |
| TS 4 | Shower Sum | Variable | High energy e and $\gamma$ |
| TS 5 | 2 out 16 Cherenkov |  |  |

*TS 3 was modified due to the high rate in Scin A

**TS 3 = Scin C + Scin D + Shower Sum**

# GEMs: Tracking