ECal and SPD Updates

The SoLID ECal Working Group + ECal Beam Test Analysis Team

SoLID Collaboration Meeting

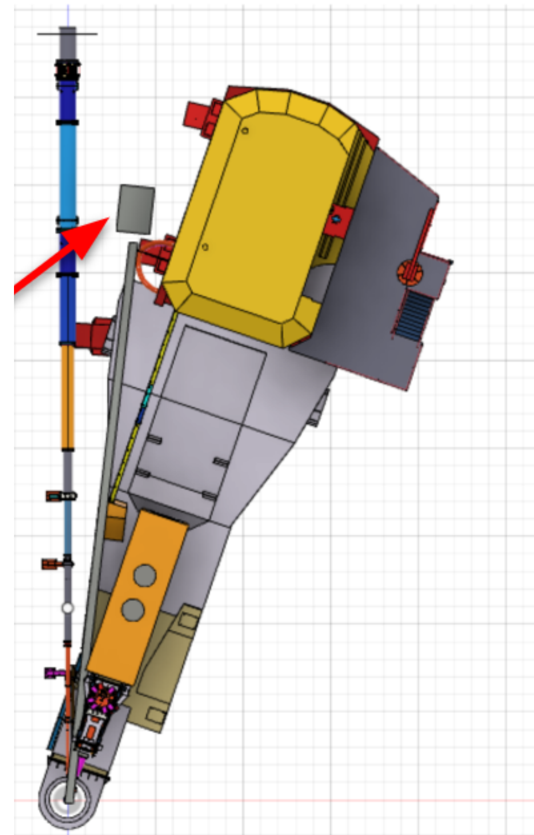
January 9-10, 2025

Outline

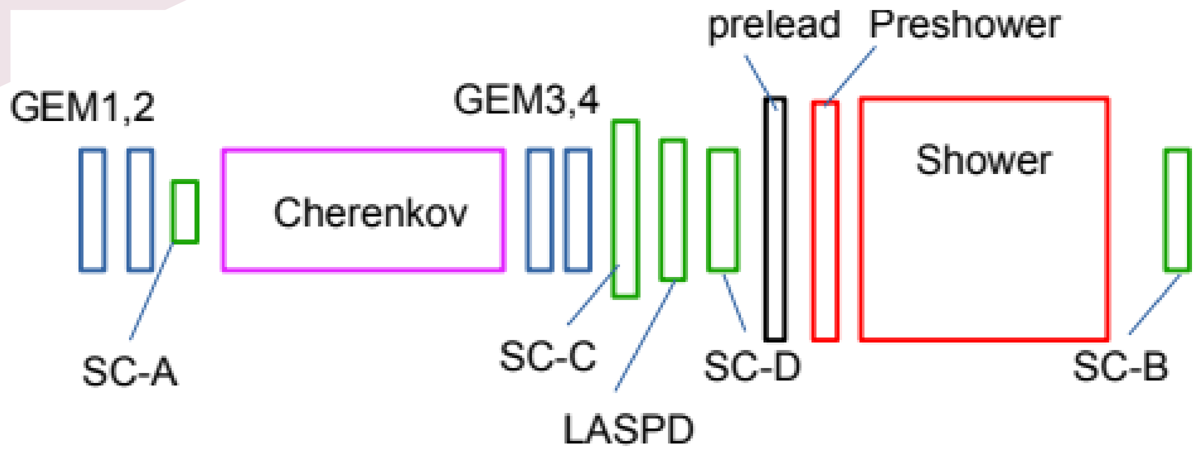
1. Hall C ECal Beam Test Overview
2. Beam Test Analysis Progress and Review
3. Summary and Outlook

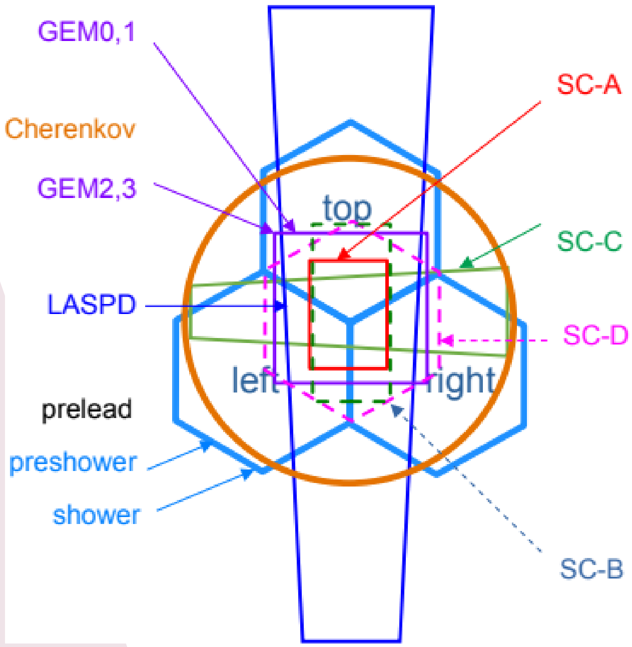
FY22 Hall C Beam Test Overview

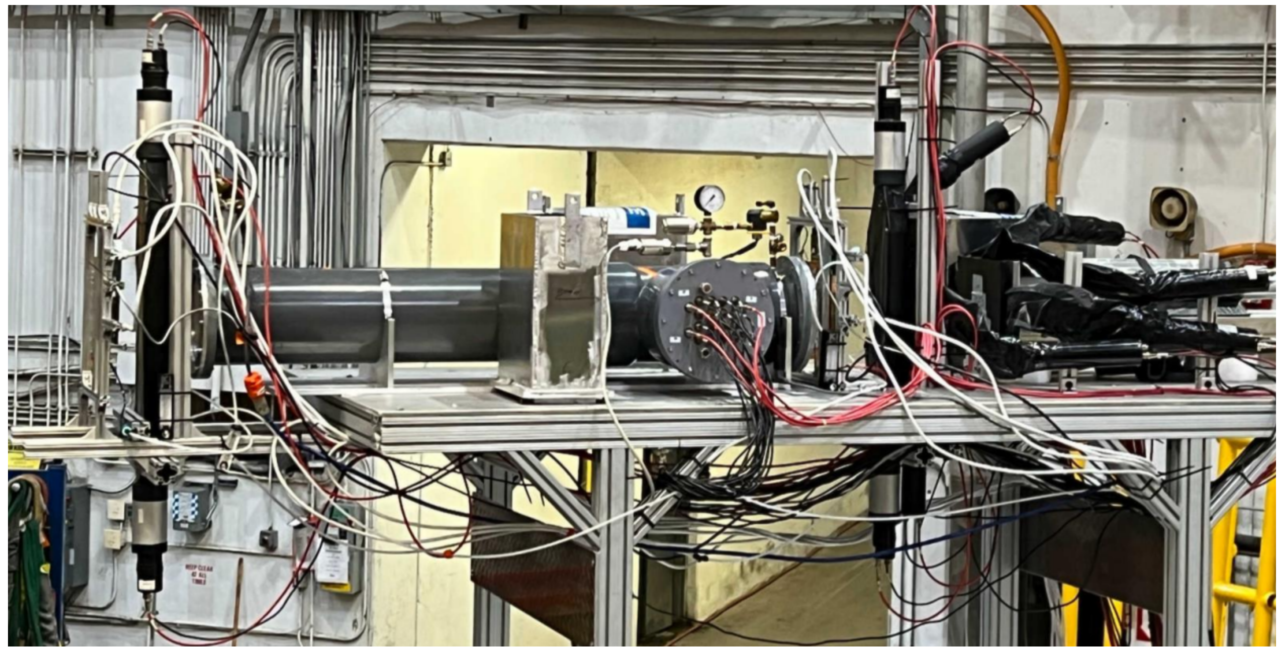
1. Goal was to study ECal and SPD performance under high rate, high radiation
2. Installed in Hall C in summer – fall 2022
3. Three stages:
   - 80 deg beam-left in Fall 2022, low rate “commissioning”
   - 7 deg beam-right in Jan 2023, high rate part 1
   - 18 deg beam-right in Feb-March 2023, high rate part 2
   - de-install in March 2023
4. Analysis was focused on:
   - Comparison of data with simulation (see Ye’s talk)
   - detector performance and stability from low to high rate
   - ECal and SPD PID performance
5. Report now ready for review by collaboration, is part of it publishable?

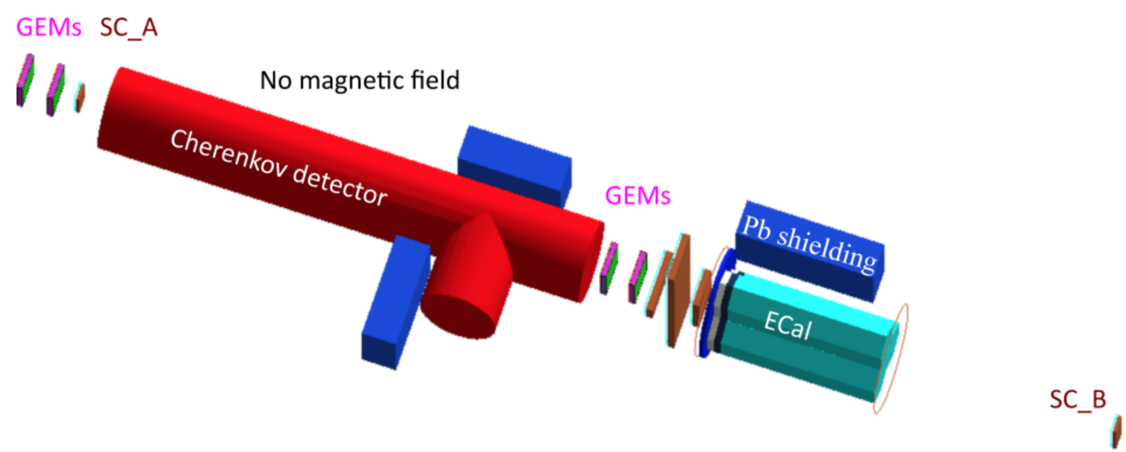


Setup Overview









Test Overview

Most/all 18-deg data were taken during E12-10-003 (deuteron electro-disintegration)

Run	Target	(g/cm^2)	I_{beam} (μA)	$\mathcal{L}$ (cm^{-2}s^{-1})
prod.	LH_2	0.71	10	2.7×10^{37}
prod.	LD_2	1.69	10	3.2×10^{37}
$\mathcal{L}$ 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	$15 - 70$	$(1.0 - 4.6) \times 10^{36}$

TABLE IV. Target and beam currents used for 18° data taking, including production and luminosity scans. The

Experiment	Target	I_{beam} (μA)	$\mathcal{L}$ (max) (cm^{-2}s^{-1})	Rates (kHz)
SIDIS (n)	40-cm $^3\vec{\text{He}}$	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	50	8.0×10^{38}	15×30
PVDIS (p)	40-cm LH_2	50	6.7×10^{38}	(15×13)

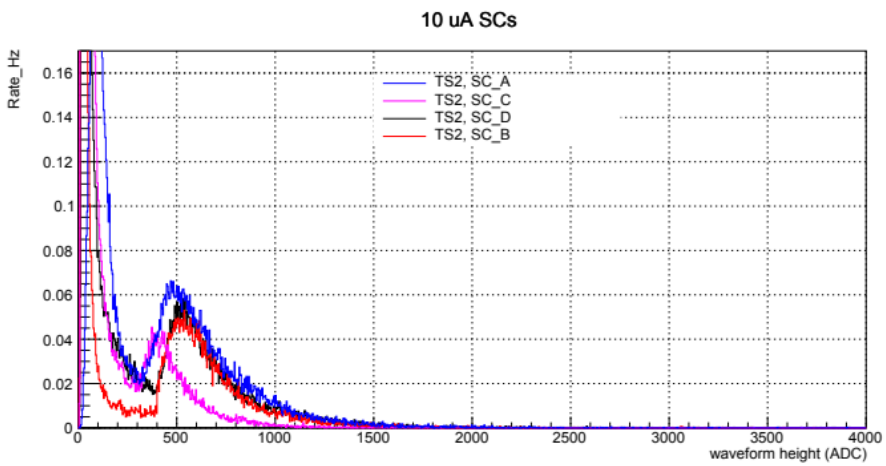
TABLE V. Run conditions for SoLID that include the three main experimental programs. For each program, the maximum luminosity and rates are shown. The

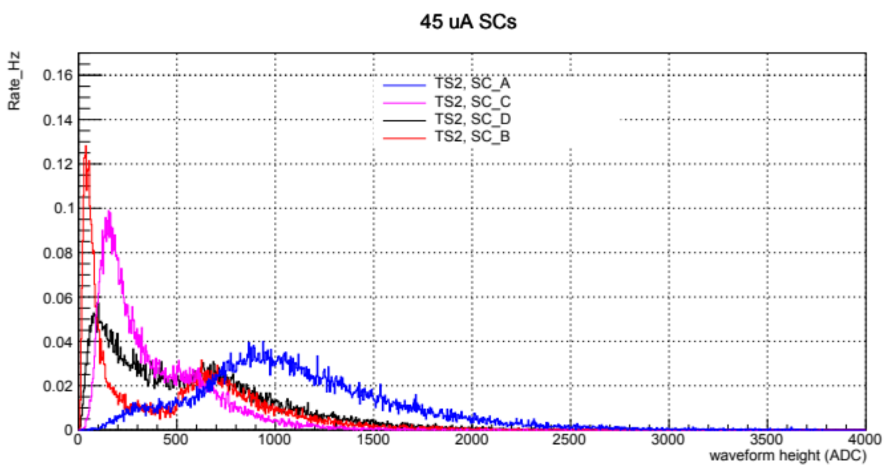
Test Overview

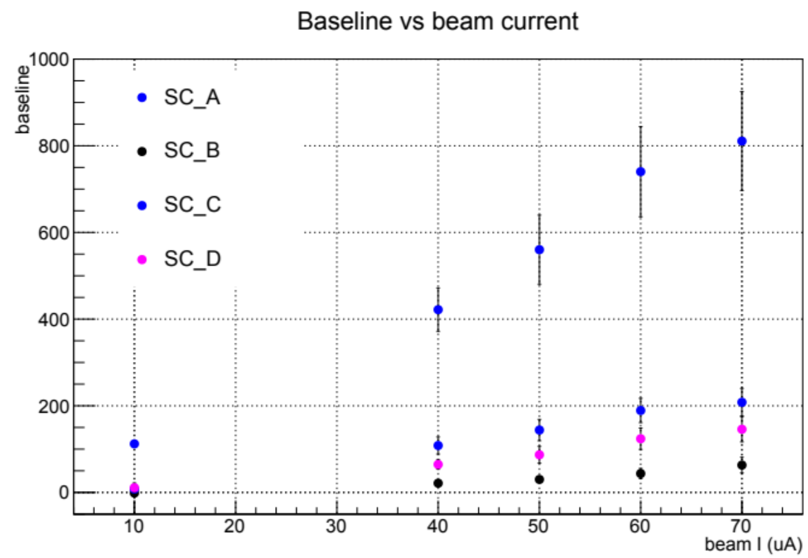
Trigger Signal	Bit	Trig -Type	Trigger Logic (threshold)	Goal
TS1	0001	1	CerSum (35mV) (≈ 2 p.e.)	e
TS2	0010	2	SC-B (35mV) .and. SC-D (35mV) (≈ 0.5 MIP each)	$\pi^{\pm}$
TS3	0100	4	SC-C(31mV).and.SC-D(35mV) .and.ShSum (varies)	$e, \pi^{\pm}$
TS4	1000	8	ShSum (varies)	e or γ

TABLE III. Trigger setup for the majority of the 18° data taking. The threshold for CerSum corresponds to approximately 2 photoelectrons (p.e.), while those of SC-B, SC-C and SC-D correspond approximately to half of the minimal ionization particle (MIP) peak. SC-A was originally used in TS3 in place of SC-C, but was found to saturate and removed from the trigger during the test.

Scintillator Performance and Stability





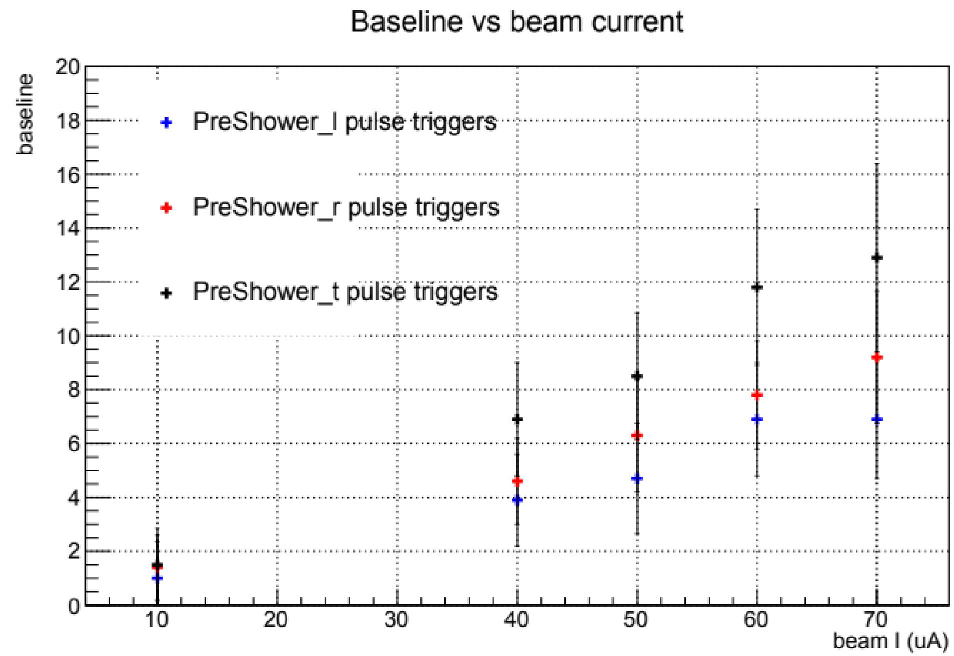


- SC-A failed to trigger at 40 uA
  - Baseline rises above 50 mV (trigger threshold)
  - Anode current reaches max 100 uA

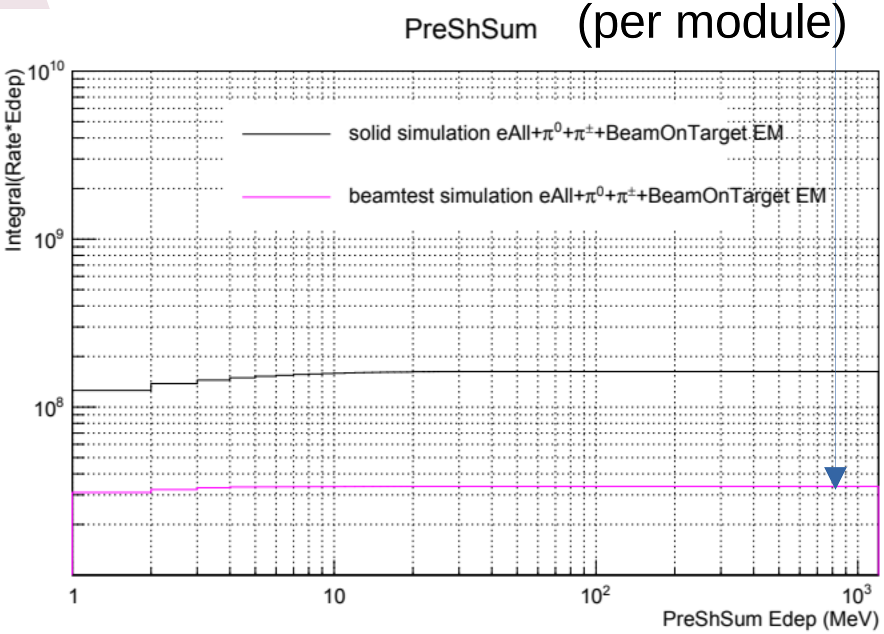
- SC-B,C,D MIP shift consistent with baseline shift

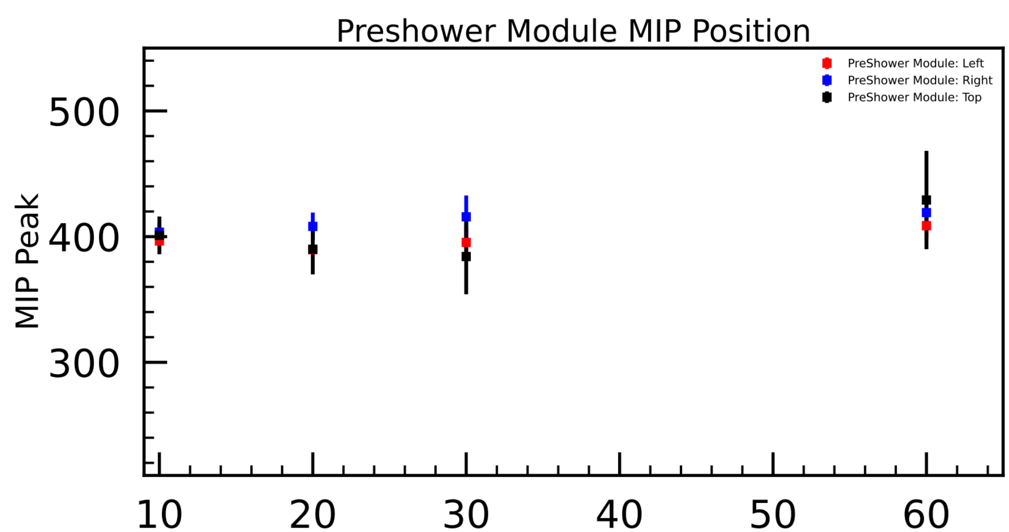
PreShower Performance and Stability

- All three preshower baseline show slight increase from 10 to 70uA
- MIP position remains quite stable
- At 40uA beamtest, baseline shift of 10 ↔ 2.4 uA in PMT anode current
    - Consistent with radiation dose simulation:



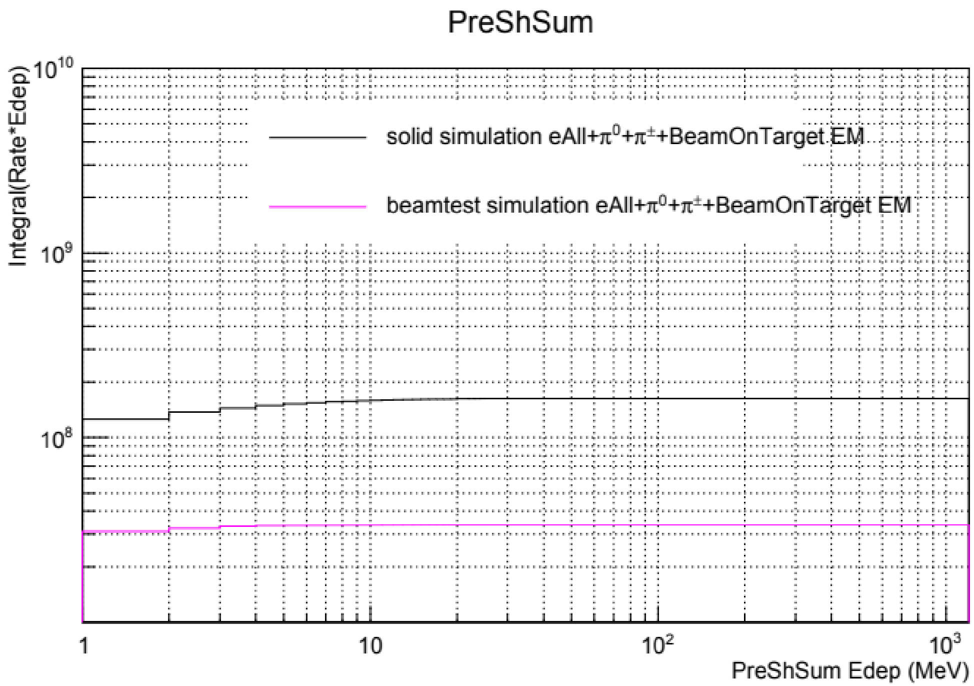
(per module)





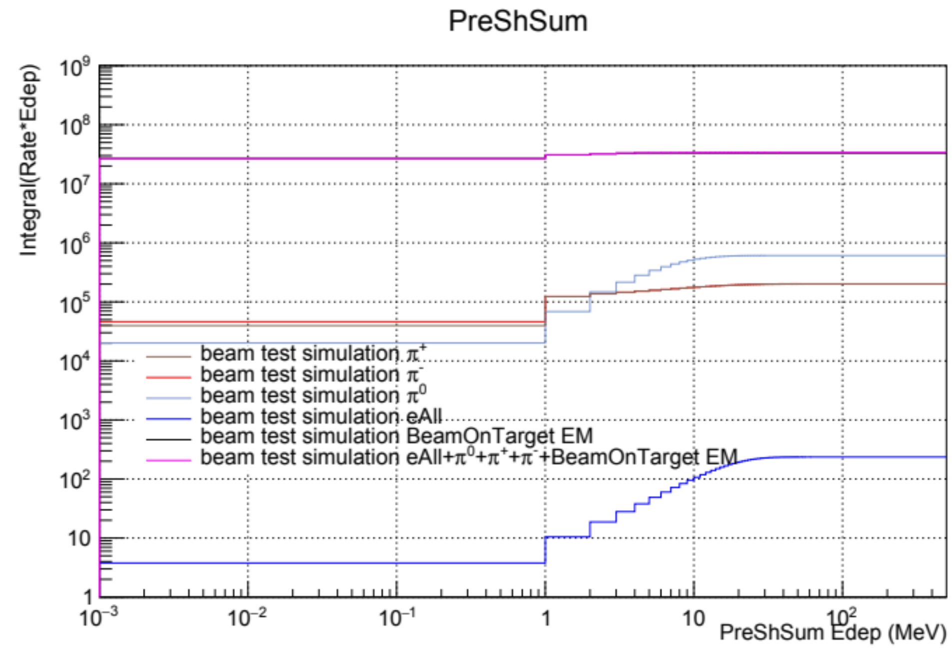
$$3 \times 10^7 \ \mathrm{MeV/s} \times 10 \ \mathrm{e^-/MeV}$$
$$\times 1.6 \times 10^{-19} \ \mathrm{C/e} \times 6 \times 10^4 \ \mathrm{gain} = 3 \ \mu\mathrm{A} \ , \ (13)$$

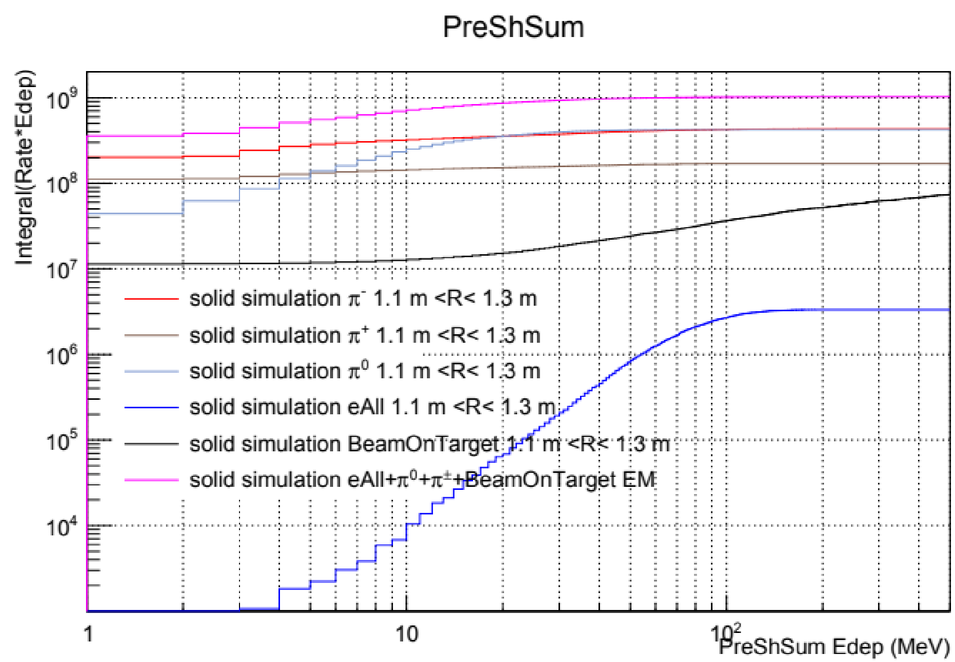
PreShower Radiation Dose



- Radiation dose in Preshower is about factor five lower than SoLID PVDIS running
- radiation dose in the Preshower of SoLID PVDIS is 3 times that of Pre-CDR, due to Pre-CDR only accounted for beam-on-target background:

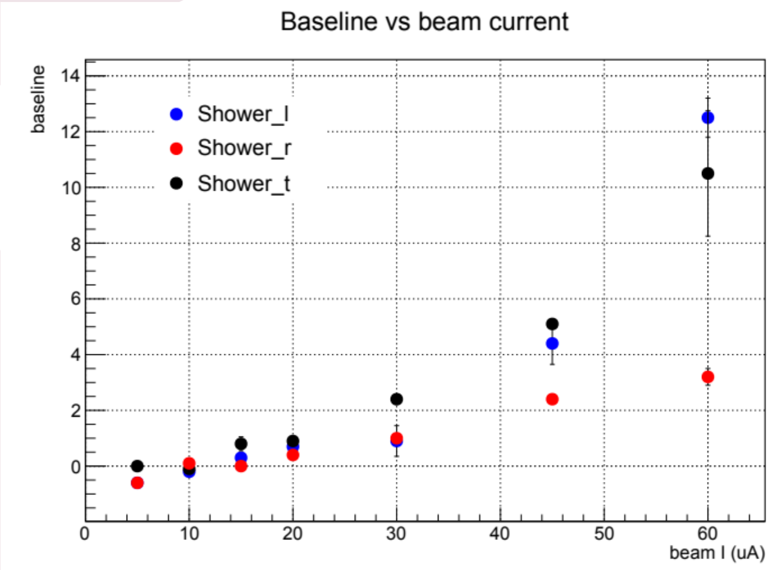
$$\frac{1.5\times 10^{8}\mathrm{MeV/s}\times 2.59\times 10^{6}\mathrm{sec/month}}{200\ \mathrm{g}}$$
$$= 311\ \mathrm{J/kg/month} = 31.1\ \mathrm{krad/month}\ . \quad (12)$$

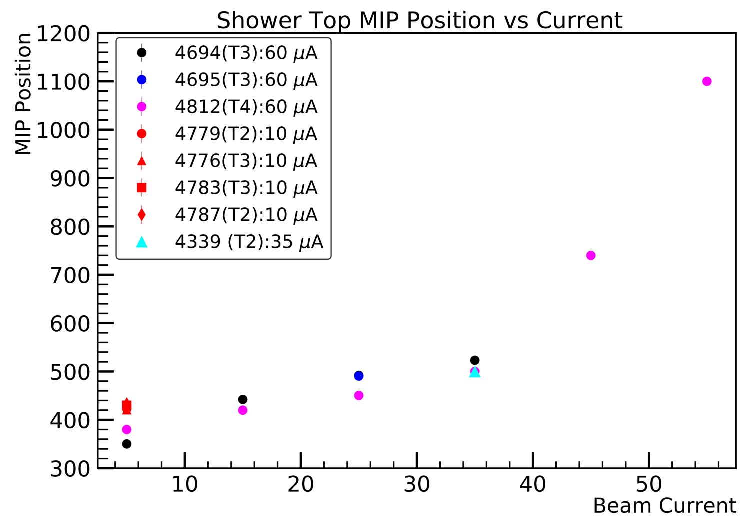


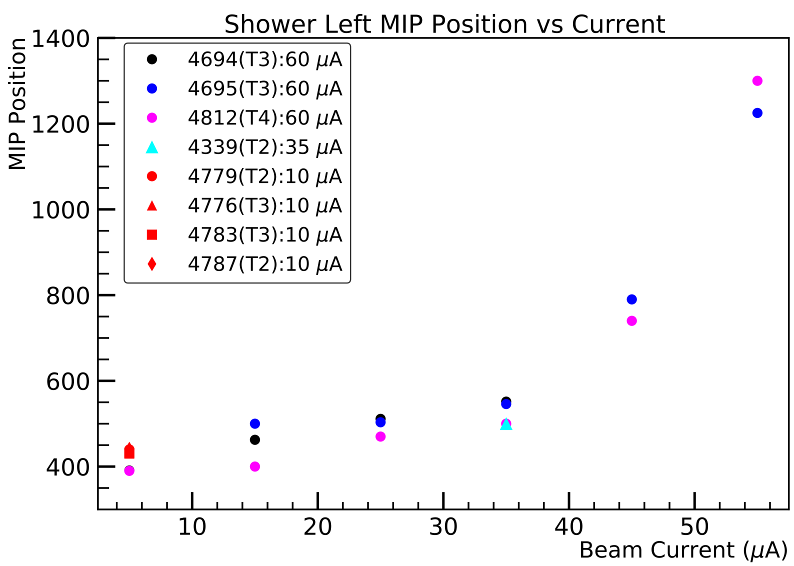


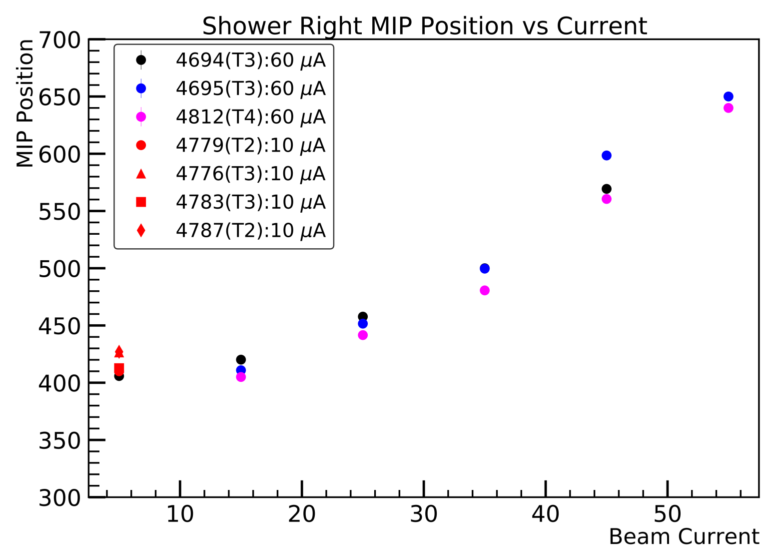
Shower Performance and Stability

- All three shower modules showed baseline shift (larger anode current than Preshower due to lack of pre-amps)
- MIP position shifts nonlinearly with beam current above the baseline shift, indicating PMT gain shifts

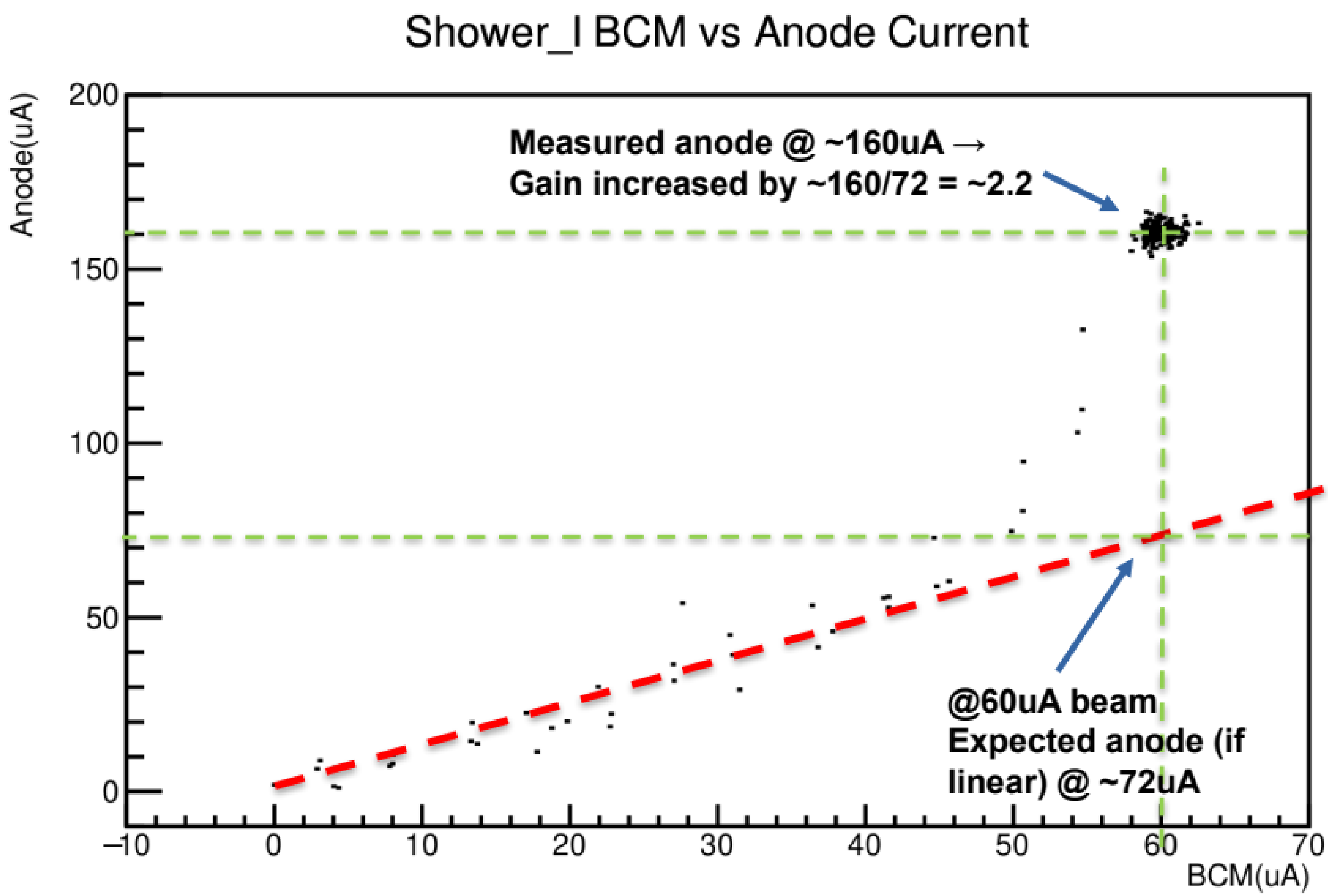






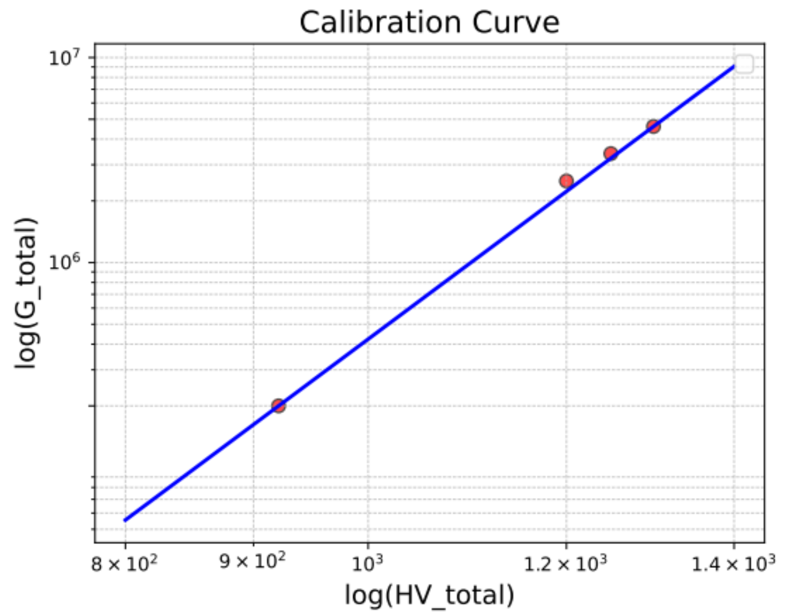


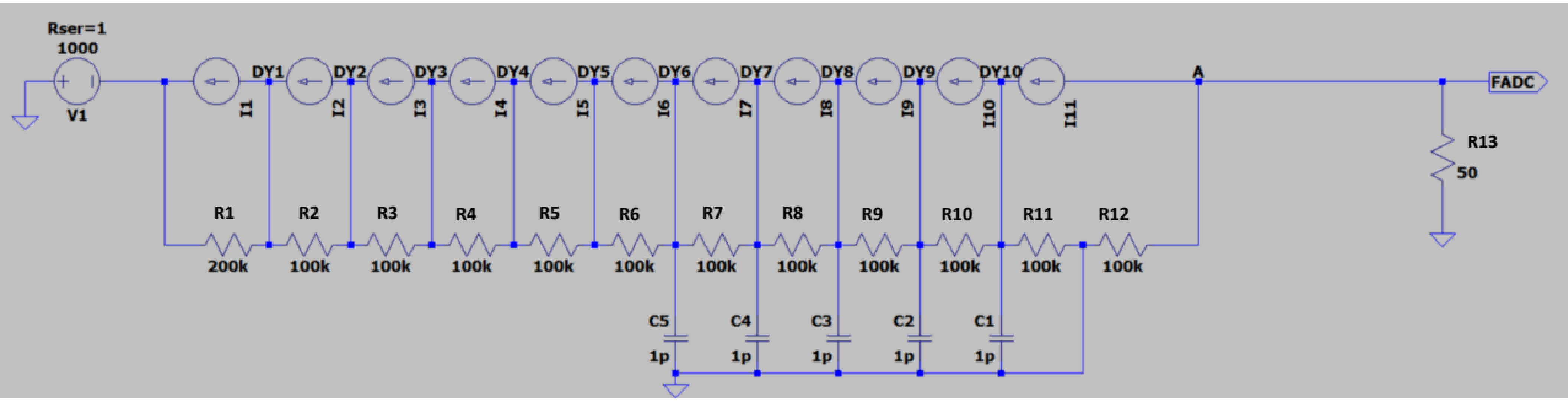
Shower PMT Gain Shift



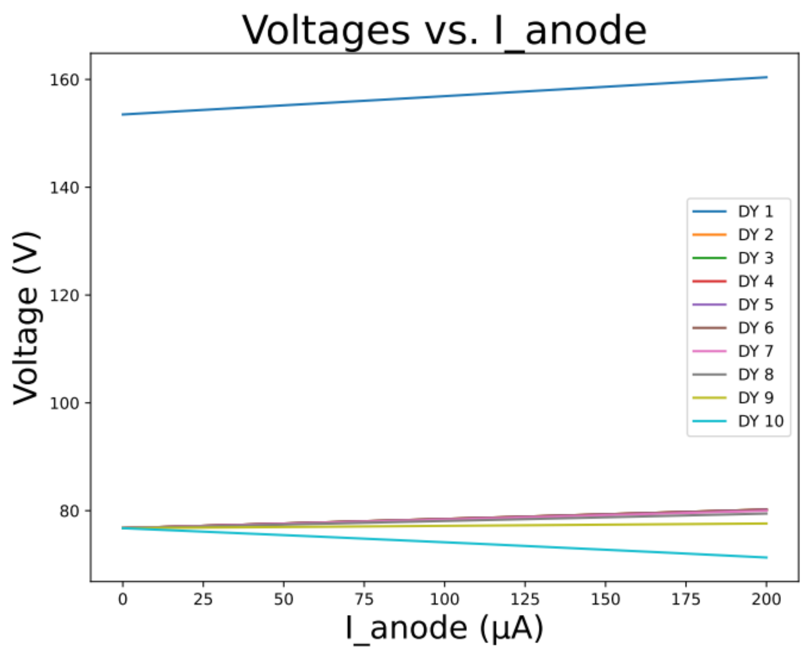
- Figures made by Ben Raydo (JLab)
- Non-linearity starts at an anode current of 50 uA (Shower Left) or 20-30 uA (Shower Right, Top) – vs. PMT max recommended anode current of 100 uA!

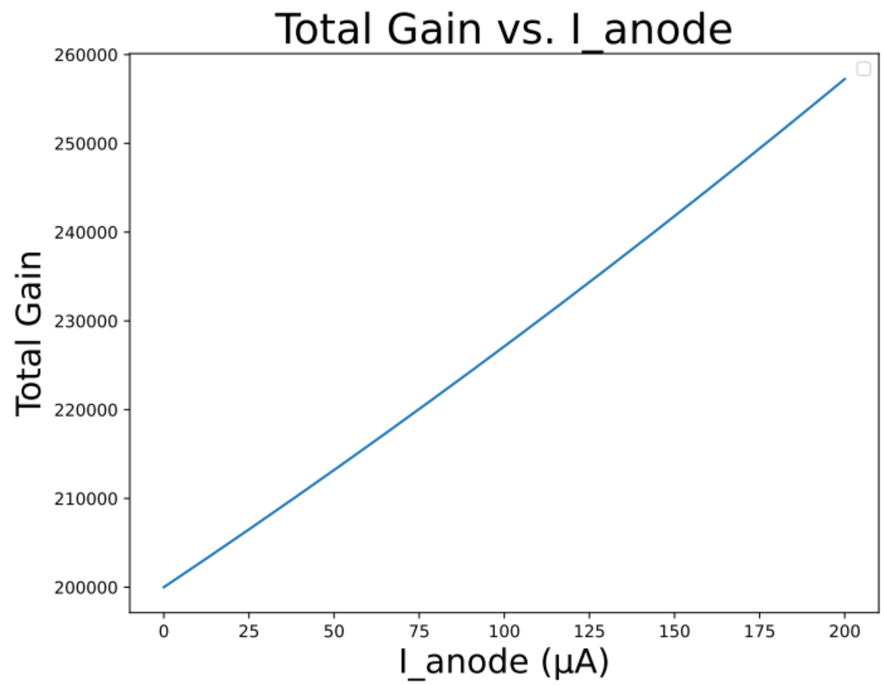
Shower PMT Gain Shift Study

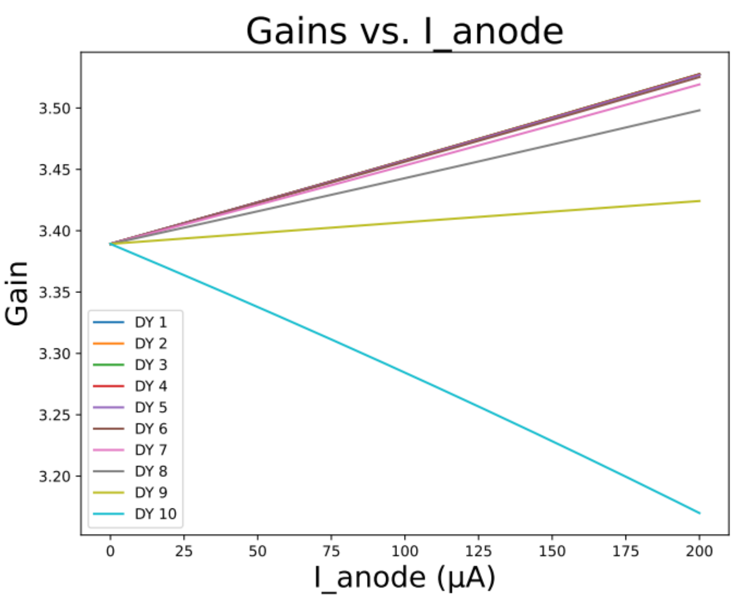




Shower PMT Gain Shift Study







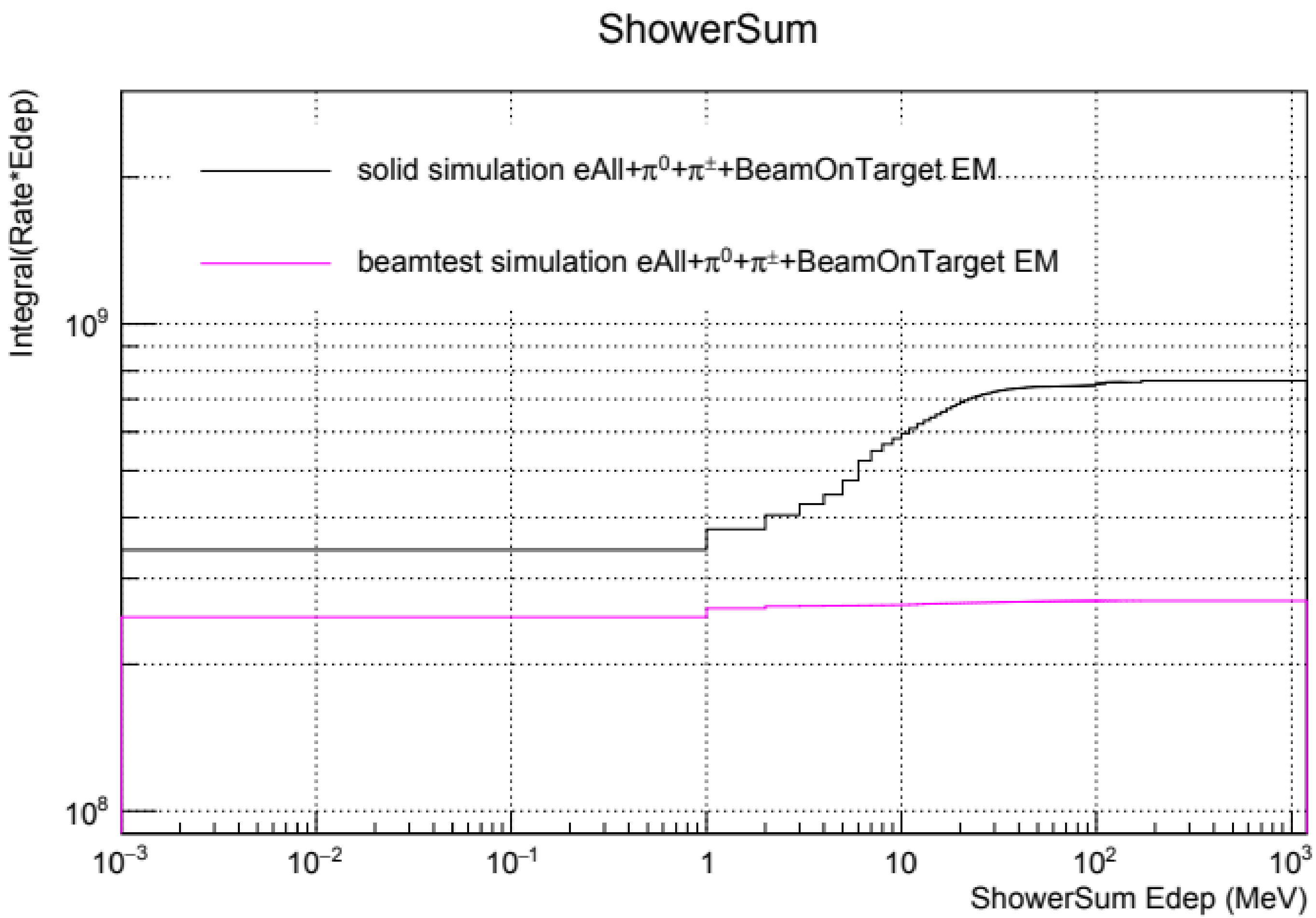
- Work done by Sean Pawlowski (UVA)
- Total gain shifts is of order 20-30%, factor 10 smaller than data
- Remaining non-linearity due to change in dynode emission, or something else

Shower PMT Gain Shift To Do

- Several issues contributed to the PMT gain shift during the beam test:
  - PMT anode current too high (non-negligible to divider current)
  - PMT HV divider redistribution and gain shift – our study shows a Total gain shift of order 20-30%, factor 10 smaller than data
  - Possible change in PMT dynode emission behavior
- Concern: non-linearity appears at only ½ to ¼ of the max anode current

Shower Radiation Dose

- the radiation dose per Shower module of SoLID PVDIS running is approximately 3 times higher than that of the beam test.
- Radiation dose in Shower for beam test consistent with the observed (high) anode current
- Radiation dose in Shower for SoLID PVDIS consistent with the preCDR



SoLID Readout Considerations

	LASPD	FASPD
PMT	MCP-PMT	R11265-100-M16
transverse size (cm^2)	636	466
thickness (cm)	2.0	0.6
Radiation dose (/mon)	2krad	2krad
Total E_{dep} (MeV/s)	6.1×10^7	1.3×10^7
Total $N_{p.e.}/s$	4.6×10^9	1.4×10^8
PMT gain	3E3	1E5
$I_{\rm anode}$ (μA)	2.0 (average)	1.6 (1/4 max)
Pre-amp gain	20	20
Total gain	6E4	2E6
MIP E_{dep} (MeV)	4.0	1.2
MIP N_{pe}	300	10
MIP height(mV)	10	10
$Q_{\rm anode}$ (C)	38	36

TABLE XII. Calculation of PMT requirements for LASPD and FASPD at SoLID SIDIS running conditions. The radiation dose (in krad/month) is from the pre-CDR. The energy deposit rate (in MeV/s) is calculated from the radiation dose. The signal height is estimated using a 30 ns half-width triangular pulse. Note that the MCP-PMT specification indicates "2.0 μA average anode current" rather than a maximum value. The total PMT anode charge is calculated assuming 200 days of SIDIS running at 100% efficiency. *Xiaochao: someone should check these numbers, see my calc here*

	Preshower	Preshower	Shower
PMT	R11265-100-M16	R11102	R11102
size (cm^2)	100	100	100
thickness (cm)	2.0	2.0	30.0
Radiation dose (/mon)	30 krad	30krad	10krad
Total E_{dep} (MeV/s)	1.5×10^8	1.5×10^8	7.2×10^8
Total $N_{p.e.}/s$	1.5×10^9	1.5×10^9	7.2×10^9
PMT gain	8E3	4E4	1E4
$I_{\rm anode}$ (μA)	2.1 ($\frac{1}{3}$ max)	10 ($\frac{1}{10}$ max)	10 ($\frac{1}{10}$ max)
Pre-amp gain	30	6	10
Total gain	2.4E5	2.4E5	1E5
MIP E_{dep} (MeV)	3.0	3.0	40
MIP N_{pe}	30	30	400
MIP height(mV)	10	10	27
e max E_{dep} (GeV)	–	–	2
e max N_{pe}	–	–	20000
e max height (mV)	–	–	2180
$Q_{\rm anode}$	96	480	291

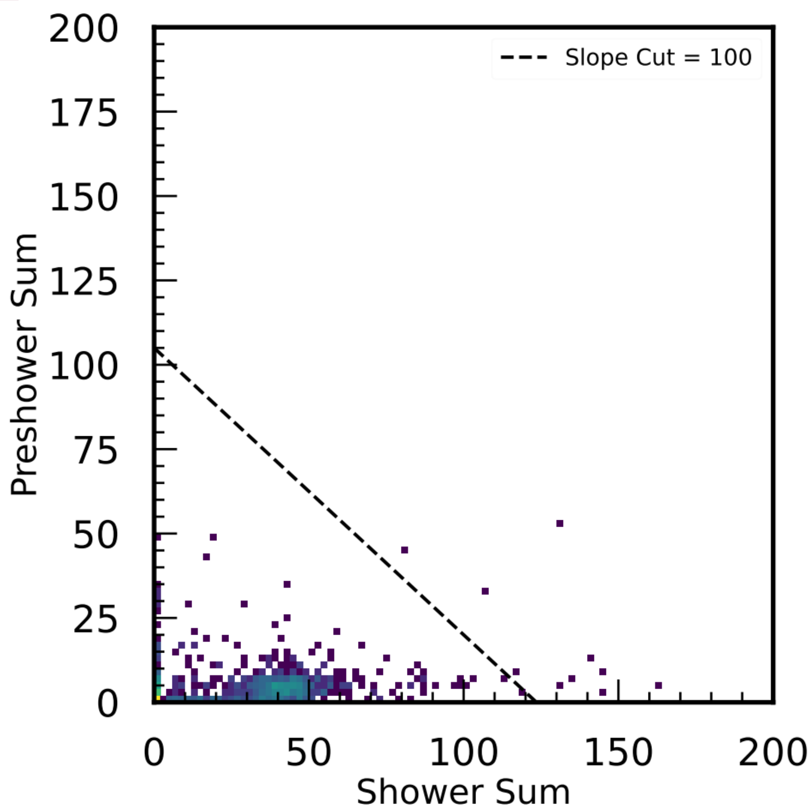
TABLE XIII. Calculation of PMT requirements for Preshower and Shower for SoLID PVDIS conditions. The Shower thickness accounts the scintillators only. The signal height is estimated using a 30 ns half-width triangular pulse. For the Shower, the energy deposit and expected peak height are shown for electrons of maximum momentum of 8 GeV. Note that the Shower preamp gain can be higher, or that it can be used to detect electrons above 10 GeV. The total PMT anode charge is calculated assuming 300 days of PVDIS running at 100% efficiency. (The preshower readout can be problematic because the 96 C is per channel!) *Xiaochao: someone should check these numbers, see my calc here*

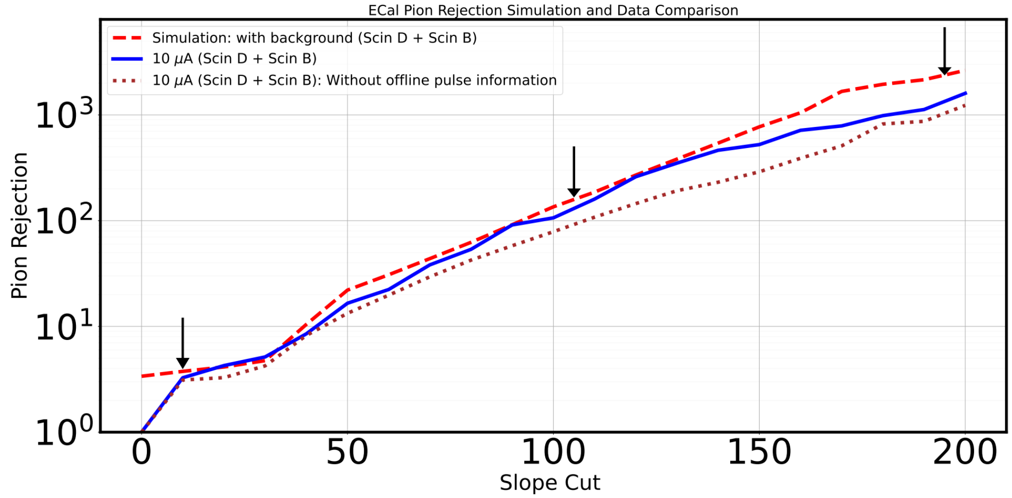
PID Performance

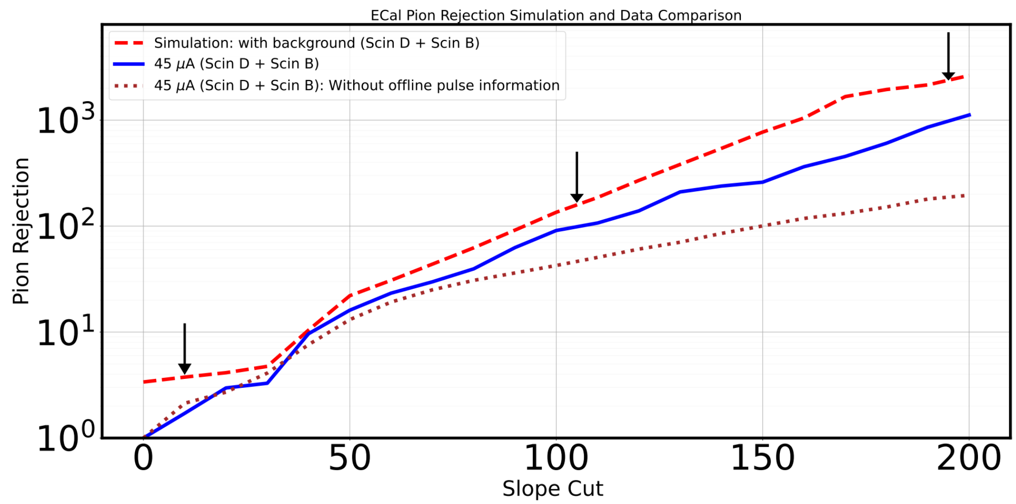
Charged Pion Samples: TS2 events with:

- CerSum<100
- SC-C>500
- LASPD-T(B)>10

A “slope cut” is then applied to study pion rejection of ECal







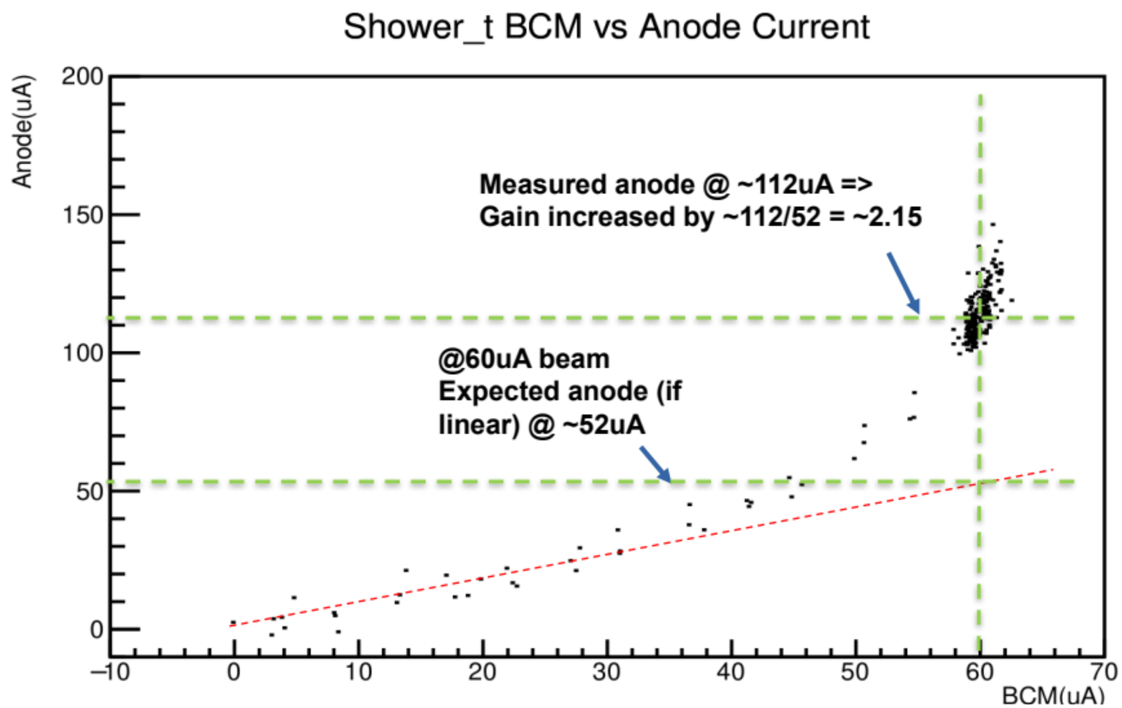
- Arrows in the figure correspond to a 95% electron efficiency for electrons in ranges of (0-1], (1-2], and (2-3] GeV, as determined by simulation
- The three curves are: simulation, data with waveform “cleaning”, and data without waveform “cleaning”
- These appear to satisfy SoLID requirements (offline and triggering), up to the rates tested

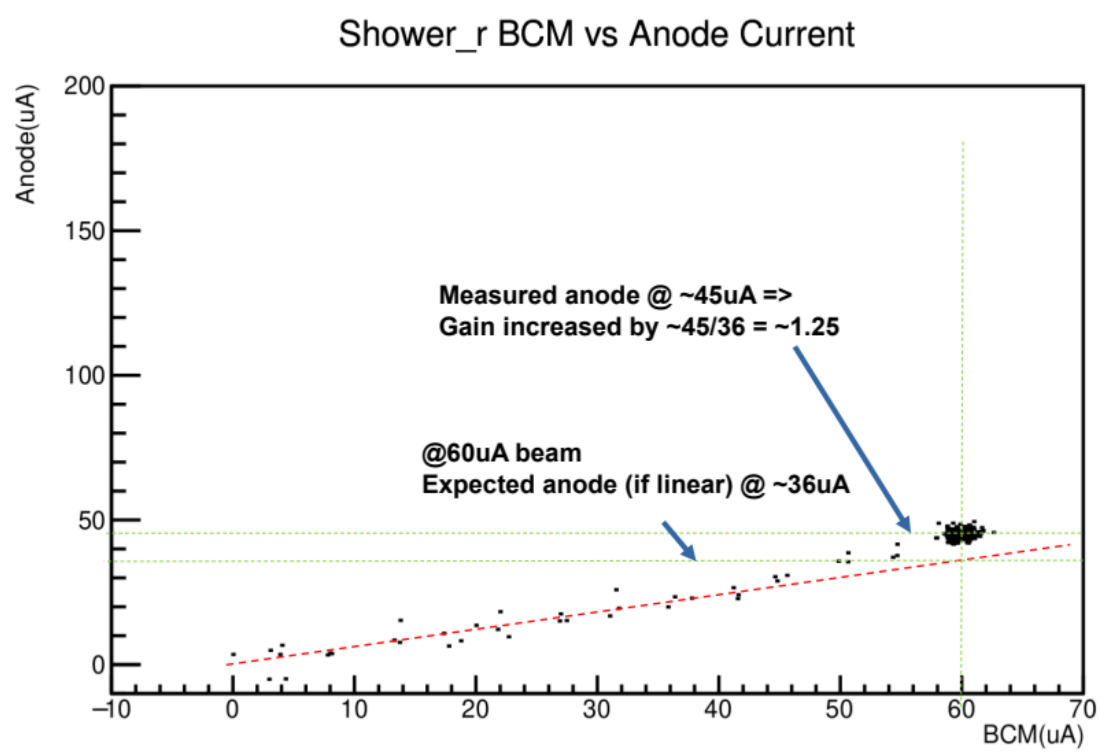
Beam test summary

- Analysis of the beam test is complete and report 99% ready for review and comments by the collaboration
- Would be nice if some of these are publishable
  - (AI/ML PID analysis will need to wait for later)
- Some followup study or measurement is ideally needed:
  - PMT passive base bench testing
  - Cherenkov mirror reflectivity
  - Effect of material non-uniformity in ECal energy resolution (as shown in FTBF report)

- 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

Backup Slides


Shower_t BCM vs Anode Current
Anode(uA)
BCM(uA)
Measured anode @ ~112uA =>
Gain increased by ~112/52 = ~2.15
@60uA beam
Expected anode (if
linear) @ ~52uA
200
150
100
50
0
–10
0
10
20
30
40
50
60
70


Shower_r BCM vs Anode Current
Anode(uA)
BCM(uA)
Measured anode @ ~45uA =>
Gain increased by ~45/36 = ~1.25
@60uA beam
Expected anode (if linear) @ ~36uA
200
150
100
50
0
–10
0
10
20
30
40
50
60
70