

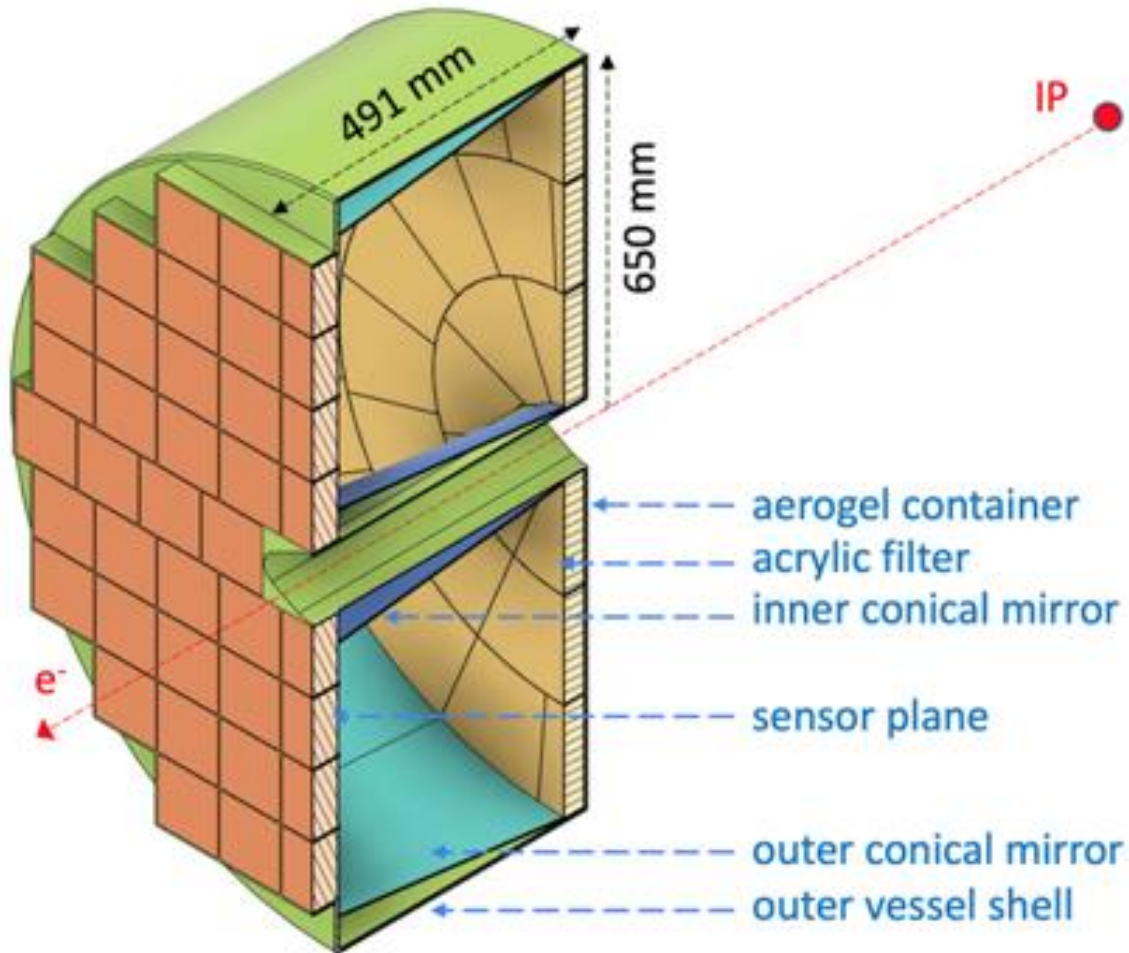
pfRICH Photosensor Requirements and HRPPD Qualification Studies

Brian Page – pfRICH/HRPPD Team

ePIC TIC Meeting

August 10, 2026

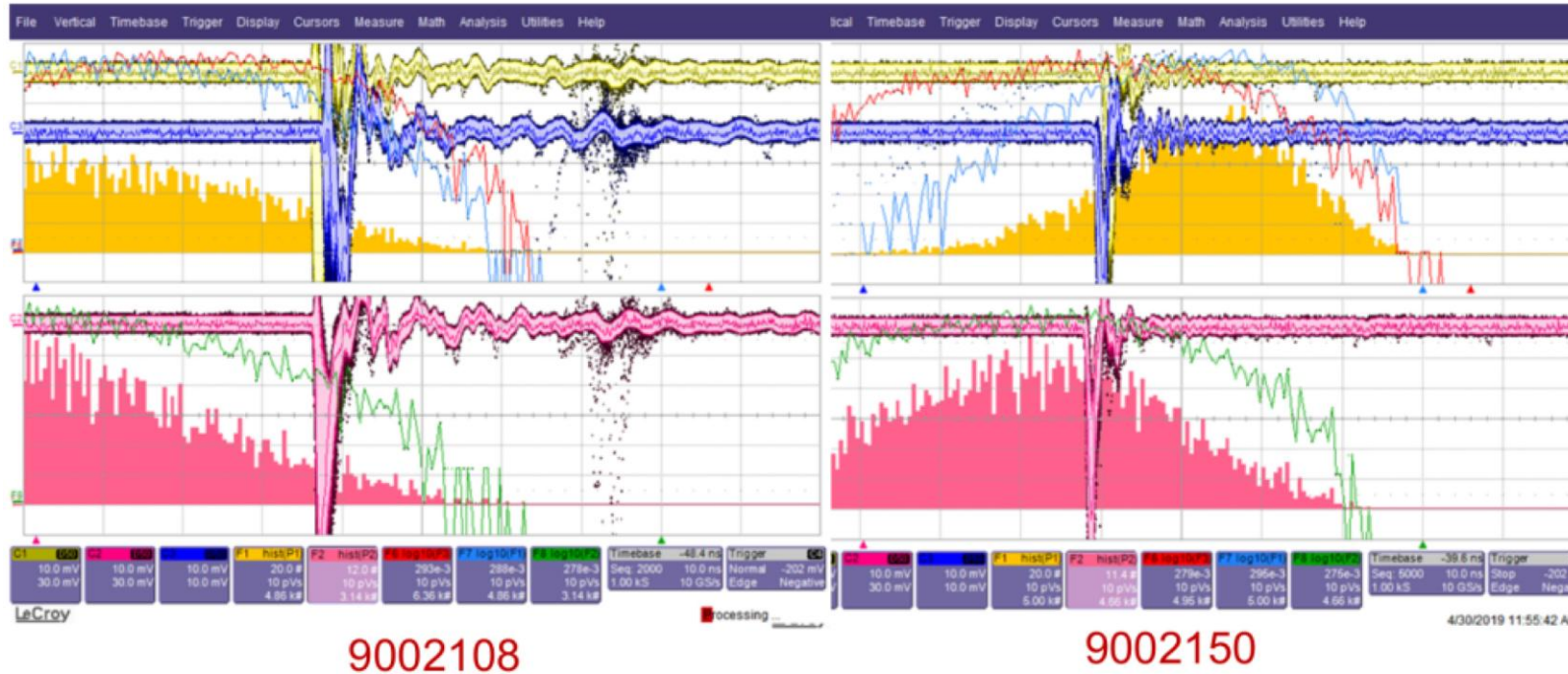
pfRICH Photosensor Requirements



- ❑ Sub millimeter spatial resolution (should not be dominant contribution to Cherenkov photon resolution)
- ❑ SPE timing resolution: sigma of gaussian core < 50 ps
- ❑ Dark count rate: few KHz/cm² is acceptable
- ❑ Low power dissipation
- ❑ Compact form factor to maximize space for proximity gap

Ringling Study

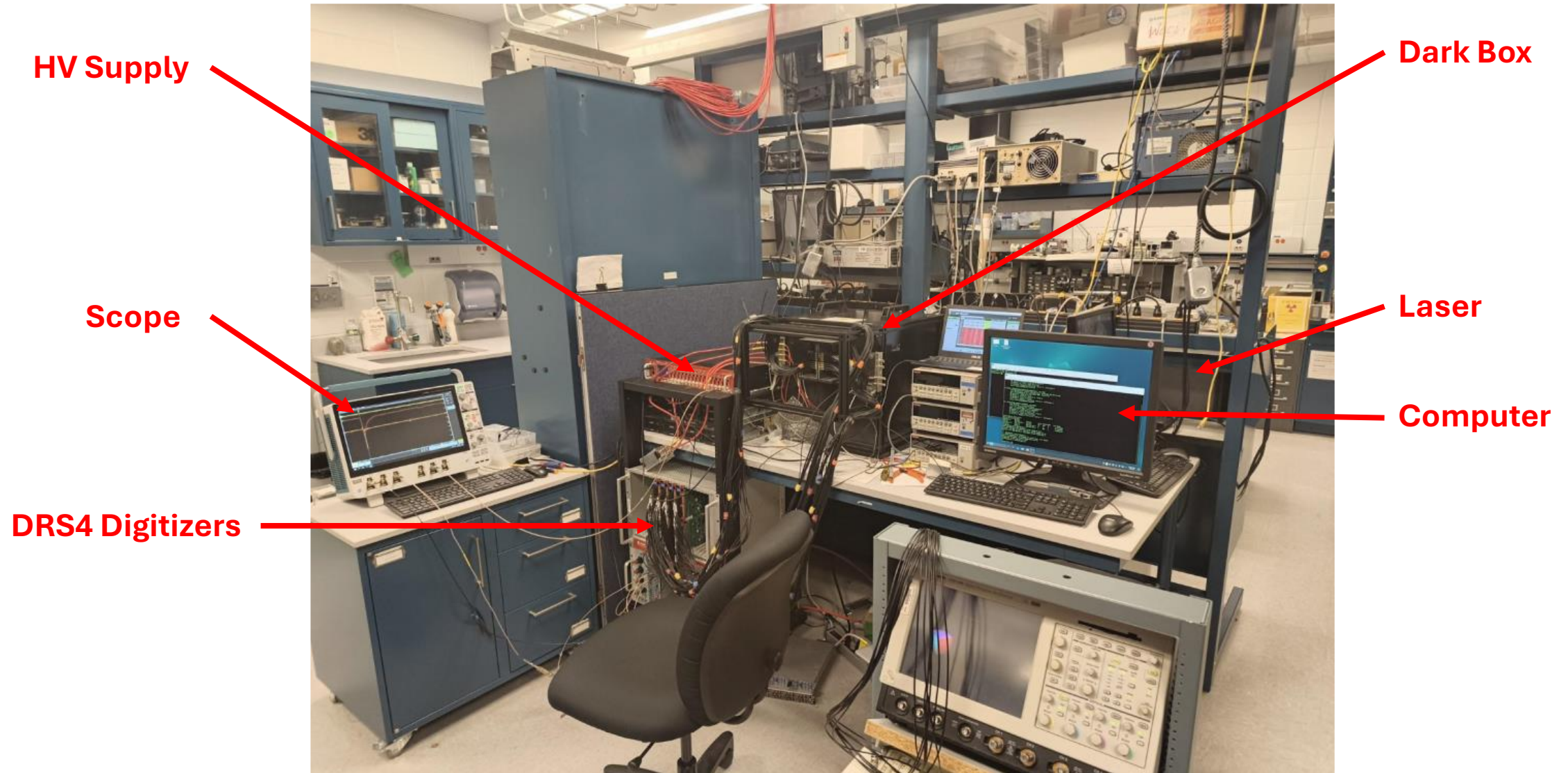
MCP-PMT Ringing



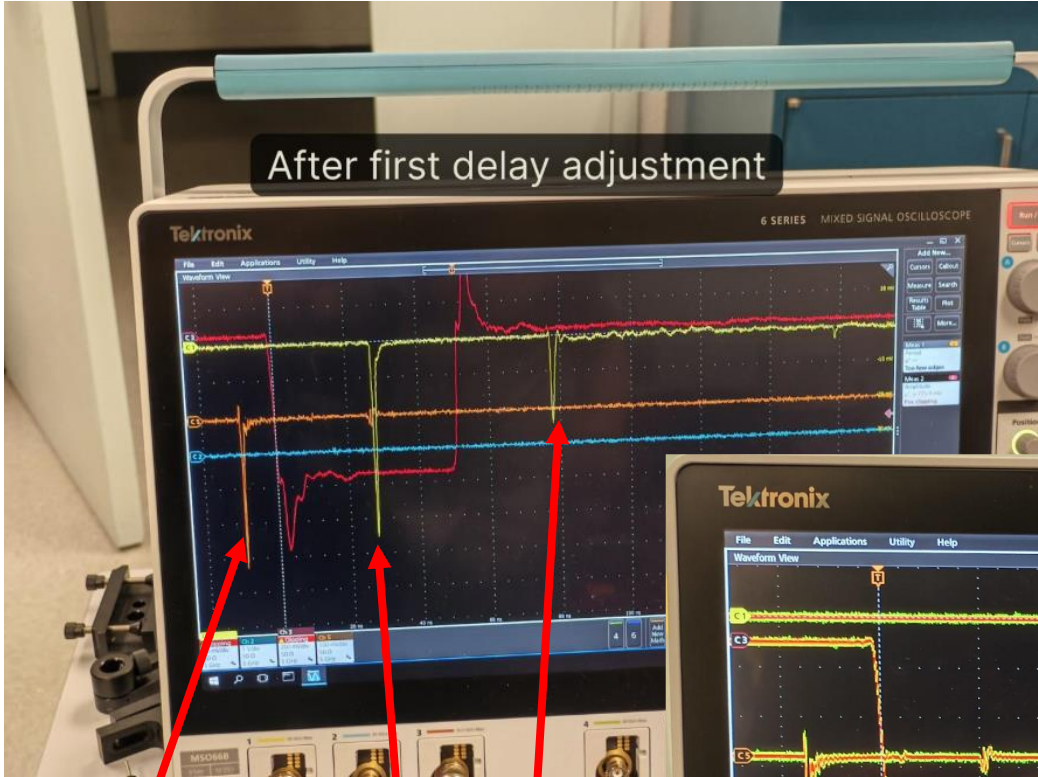
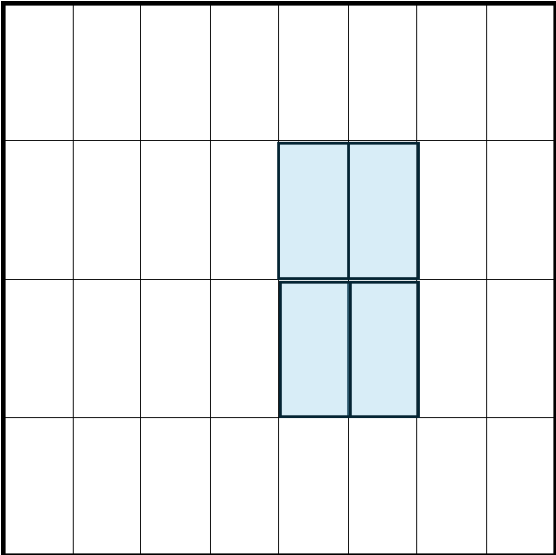
- ❑ Observed that PHOTONIS MCP-PMTs can develop coherent oscillations or “ringing” (9002108) when hit with many photons at once – would extend into unilluminated areas
- ❑ Redesign of readout backplane largely eliminated the problem

- ❑ Ringing is unlikely to be an issue in the pfRICH where photon occupancy will be low – even with background
- ❑ hpDIRC will see much higher occupancies – sometimes up to 200 photons in a 20 – 30 ns window
- ❑ Crucial that we test the HRPPDs under these conditions to see if such coherent oscillations arise
- ❑ Look for the onset of and quantify the ringing effect and probe how multiphoton background affects a signal pulse

BNL HRPPD Test Stand



Pulsed LED Setup



FPD Laser Trigger

Laser Signal

LED Signal + ringing

Delayed laser pulse to after the LED fired

Can see the ringing well in fast acquisition



Pulsed LED Intensity Scan

Run 311032

LED HV = 19.4

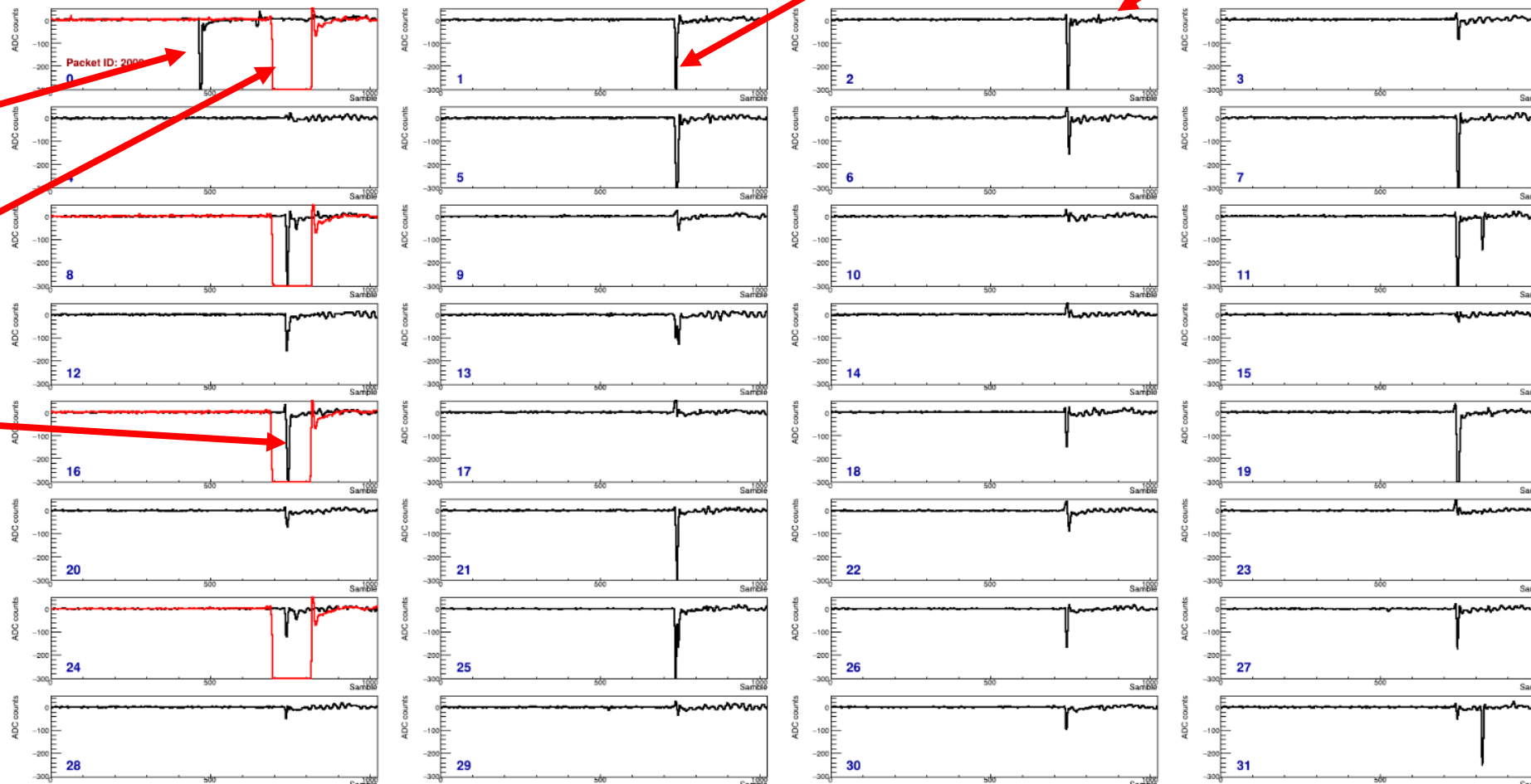
LED

Ringling

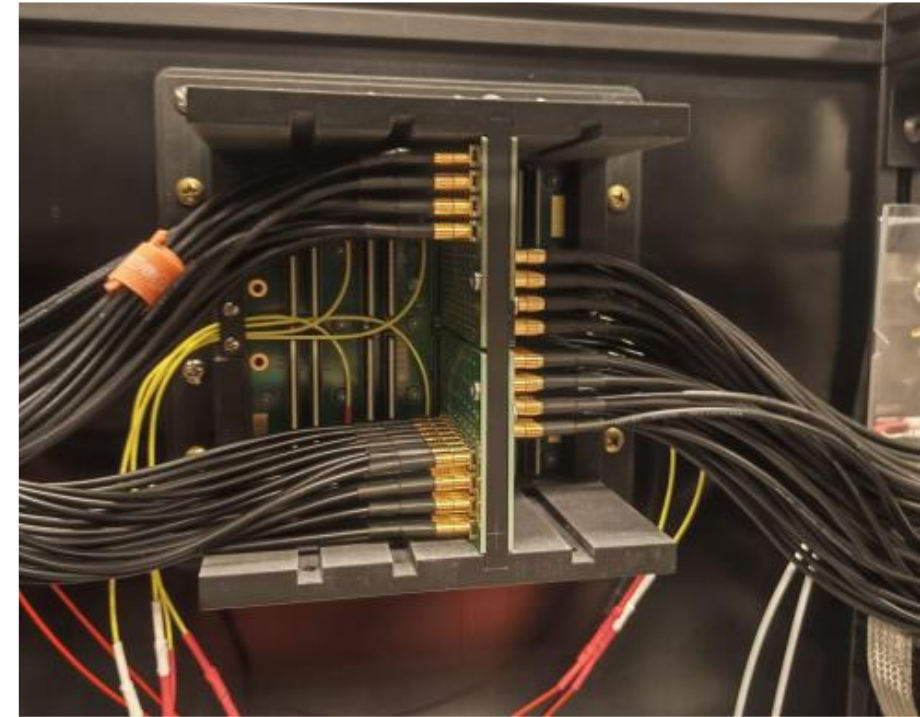
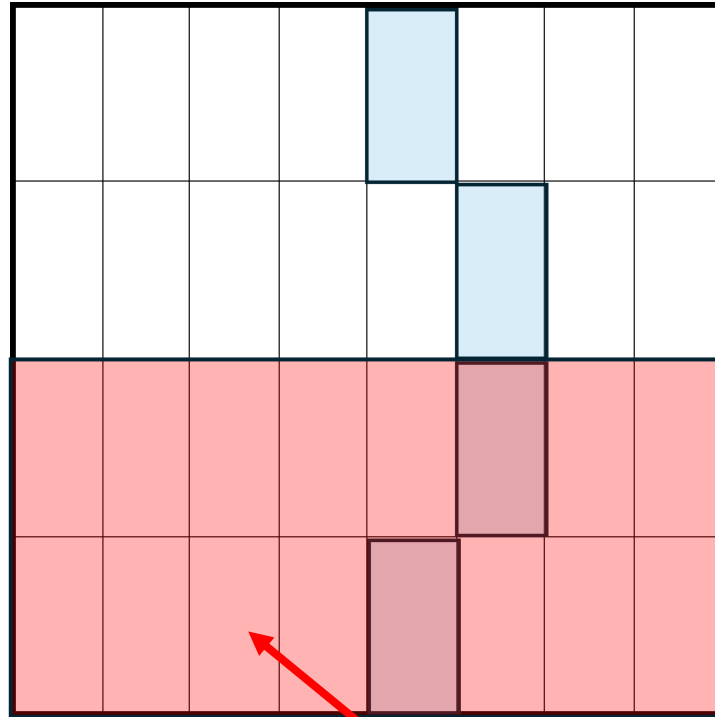
Trigger

Discriminated
Trigger

Laser

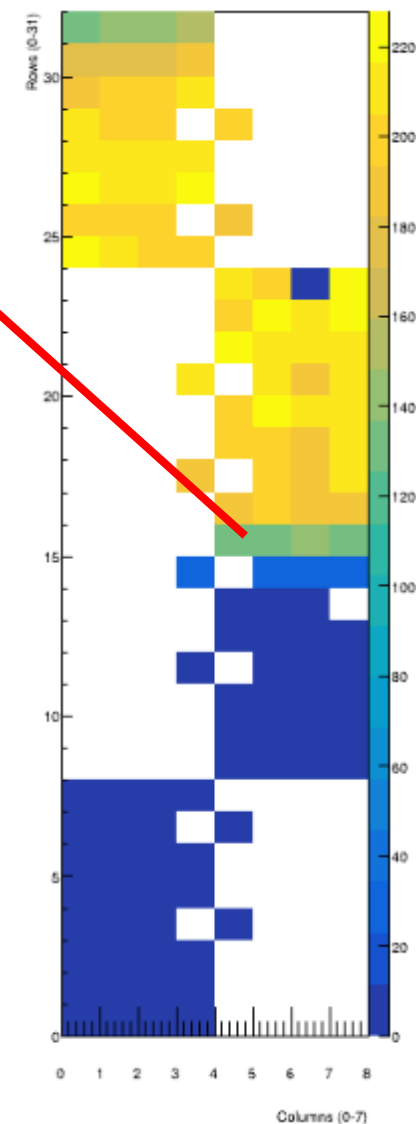
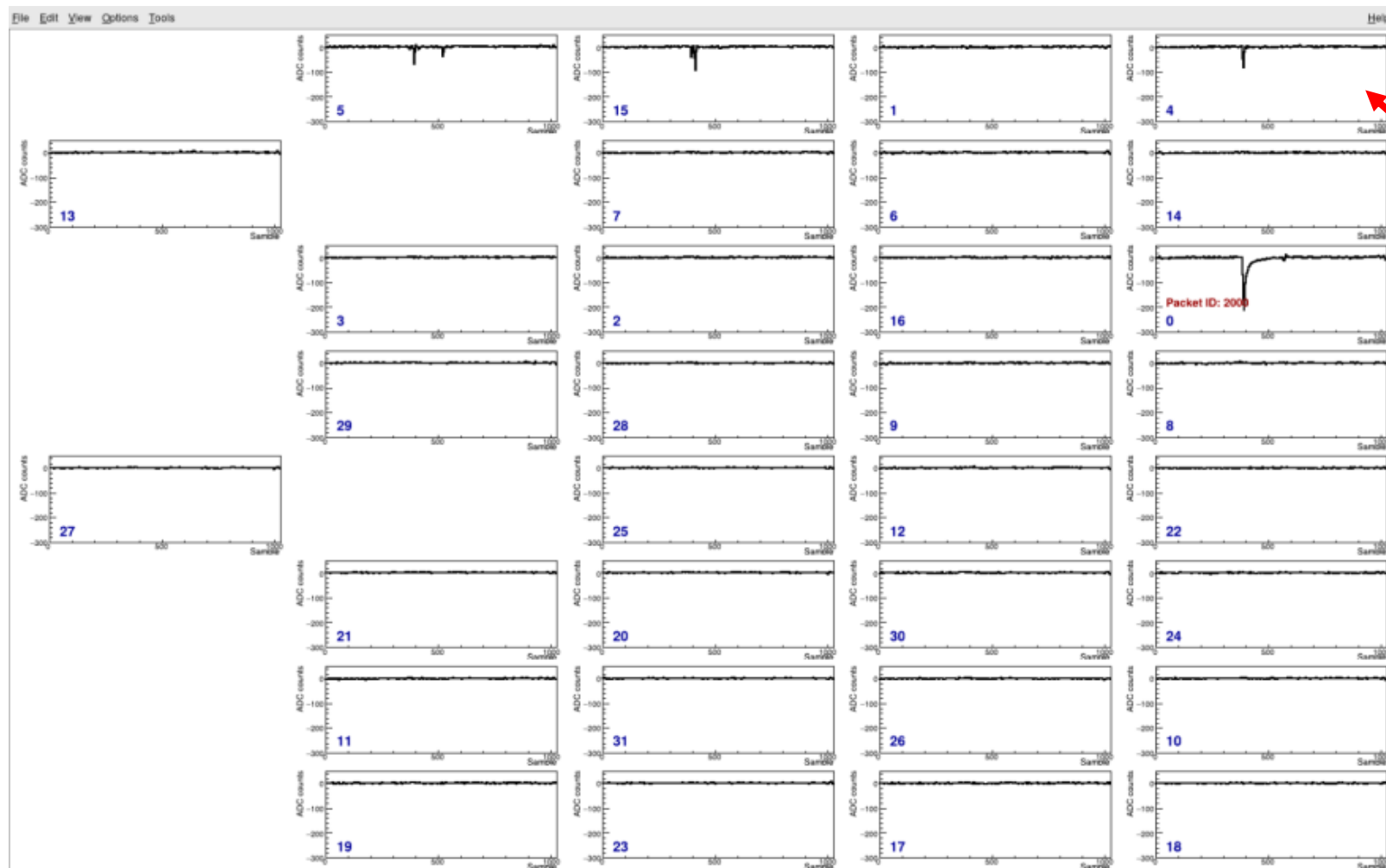


HRPPD Mask and Readout Change

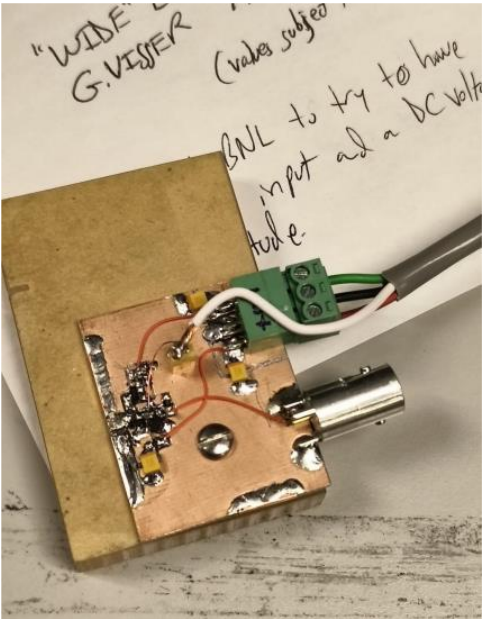


Mask bottom half of HRPPD

HRPPD Mask and Readout Change

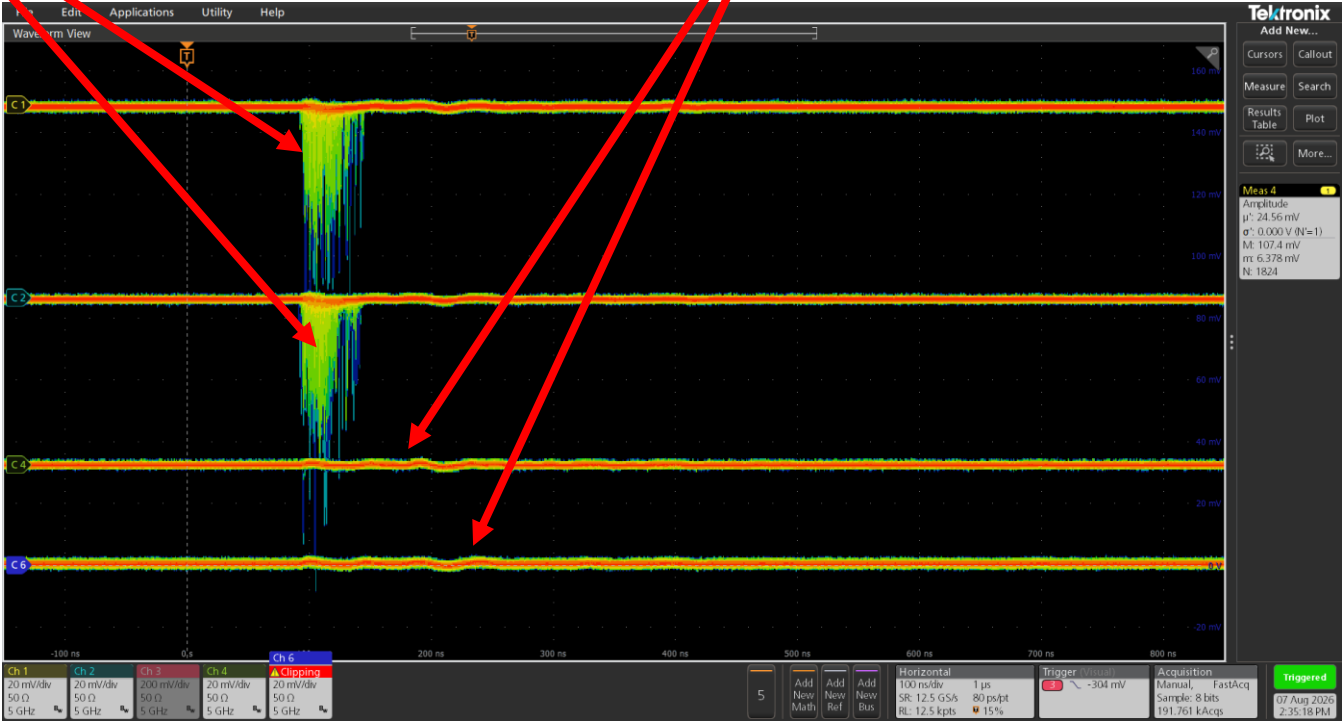
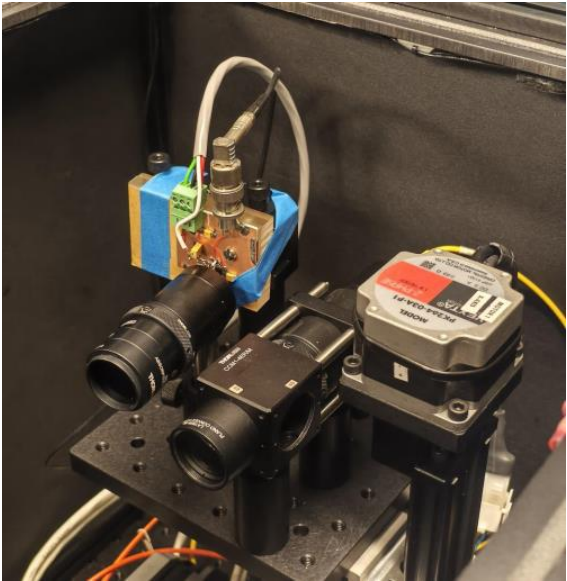


Long-Duration LED Pulser



Long LED Pulser on unmasked channels

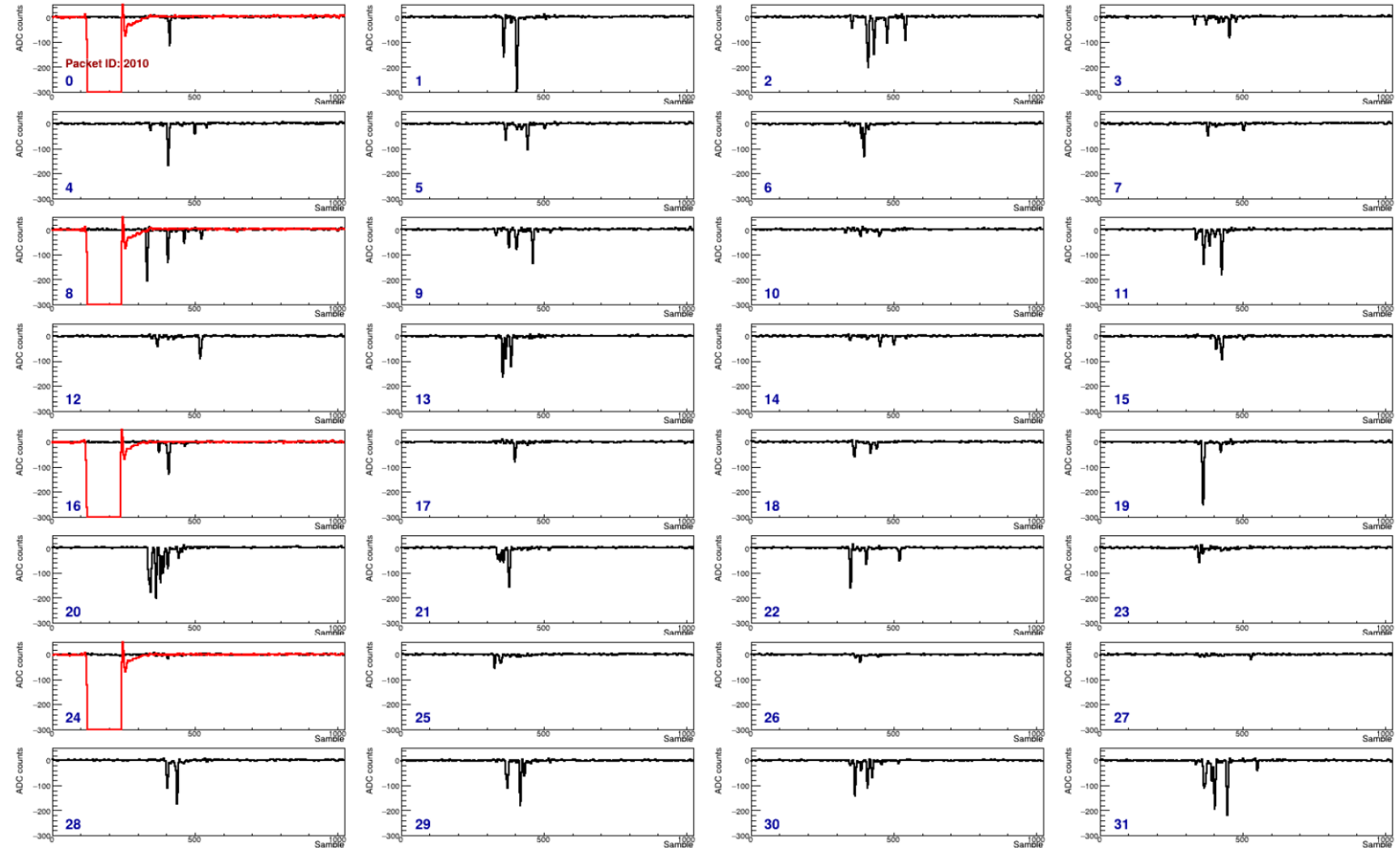
Ringing seen in masked channels



Long Duration LED Digitizer Signals

Run 311067 – long
duration LED

- ☐ Long duration LED pulses
seen in unmasked
channels
- ☐ Ringing after LED pulse
not as prominent as was
seen for the short
duration LED
- ☐ Difference in intensity?
Filter effects?

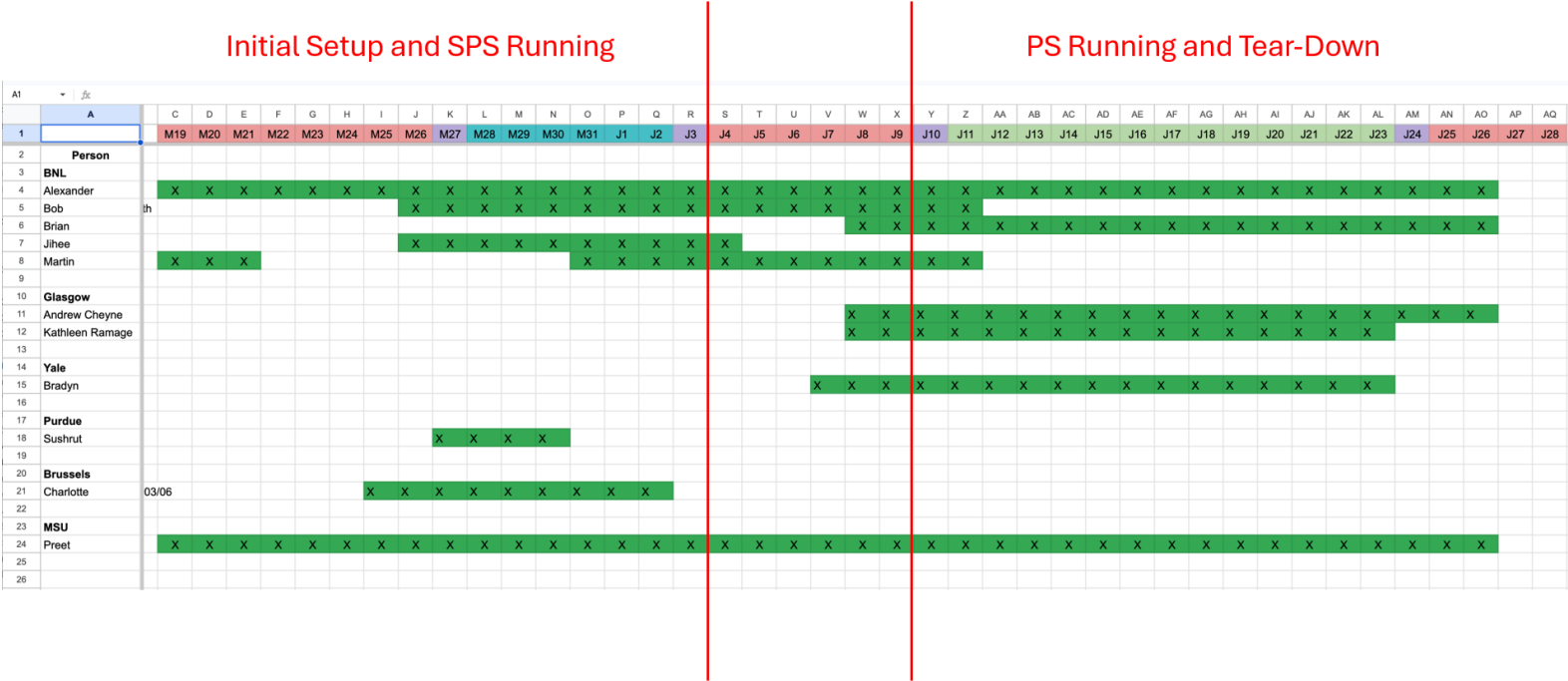


HRPPD Ringing To-Dos

- ☐ Ringing studies are very new – extensive offline analysis still needs to be completed
- ☐ Need to cross calibrate data from the two LEDs and estimate photon flux
- ☐ LED delay can be adjusted – took several data sets with reference laser pulse in or out of LED pulse. Quantify effect that “background” photons have on “signal” pulse
- ☐ Gerard modified an HRPPD to capacitively couple the bottom MCP to ground – take data with this configuration

CERN Test Beam

pfRICH / HRPPD Test Beam @ CERN



SPS to PS Transition

See presentation in pfRICH General Meeting:
<https://indico.bnl.gov/event/33511/>

Week	Description
May 20-27	Partial assembly & pre-commissioning
May 27 - June 3	Final assembly & SPS run (aka commissioning)
June 3 - 10	SPS -> PS transition; re-assessment of the PS run goals
June 10 - 24(27)	Re-assembly, PS run (main part of the beam test), dis-assembly

Test Beam Goals

- ☐ HRPPD performance in particle beam
 - Imaging photons
 - Window flashes
 - Timing

- ☐ Direct N_{pe} measurement (aerogel + filter + HRPPD PDE)

- ☐ Cherenkov angle resolution (comparison to MC)

- ☐ π/K and e/π separation

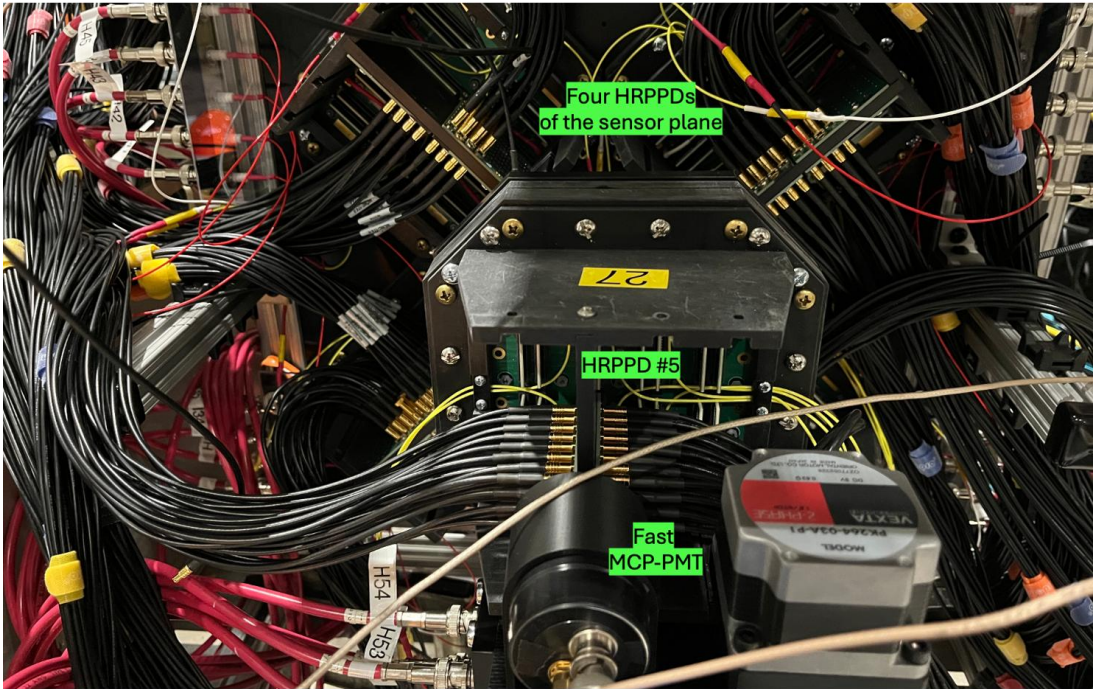
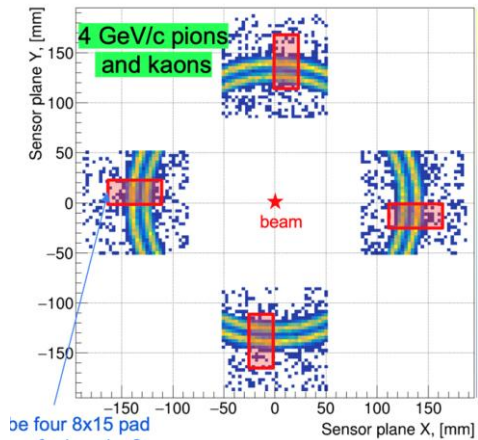
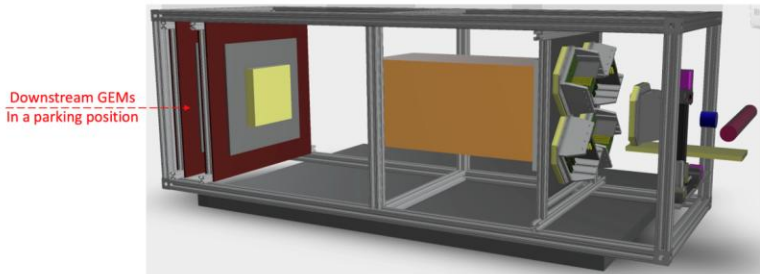
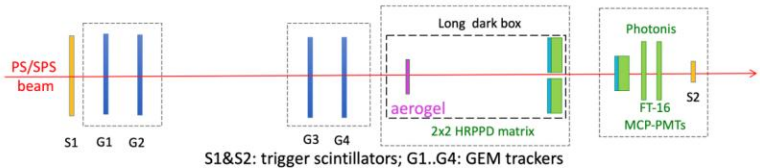
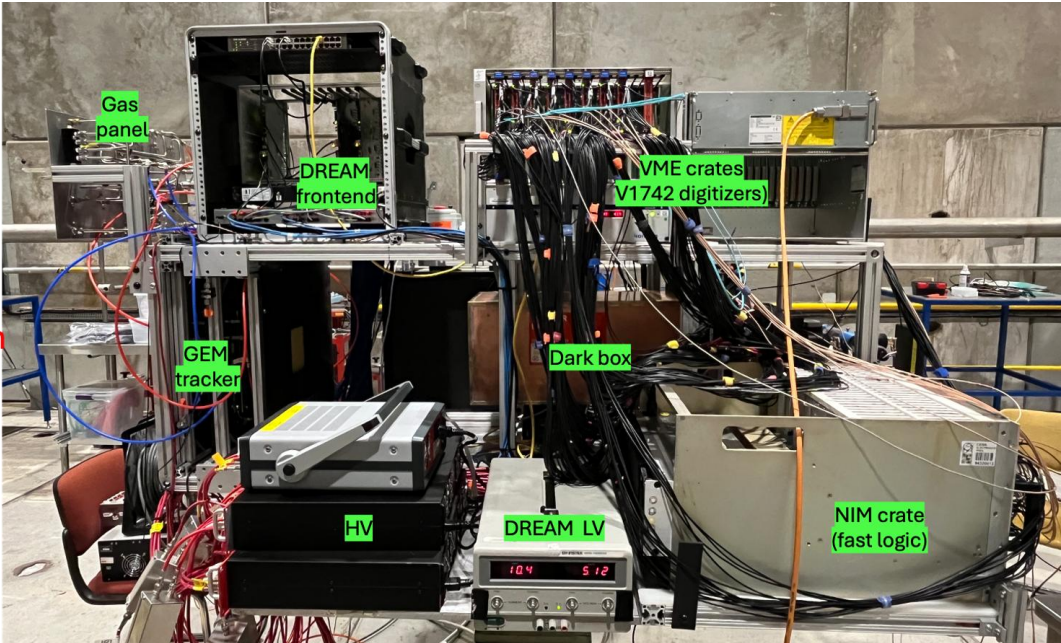
- ☐ FCFD first look

- ☐ Mirror evaluation (conical and pyramid)
 - ID reflected photons

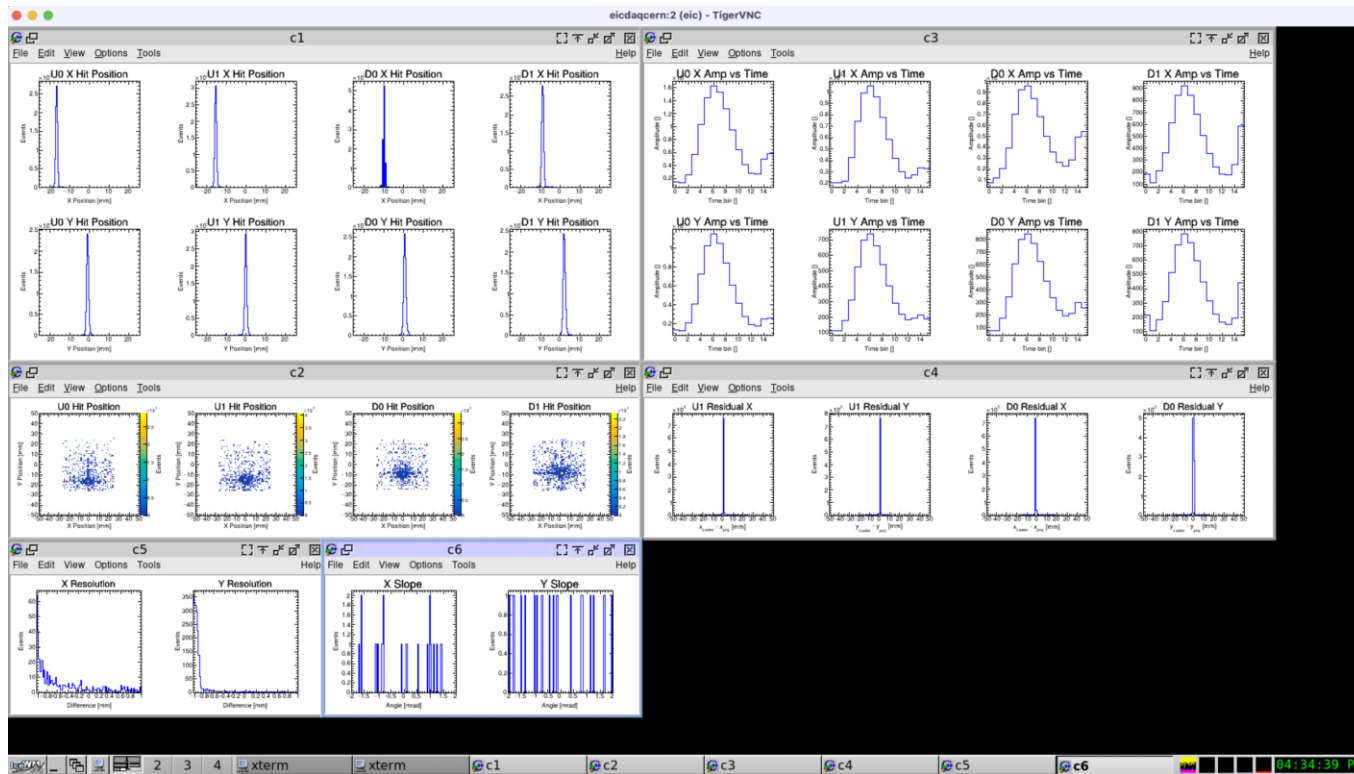
- ☐ Laser monitoring system
 - Delay calibration using PiLas laser

Apparatus

SPS beam

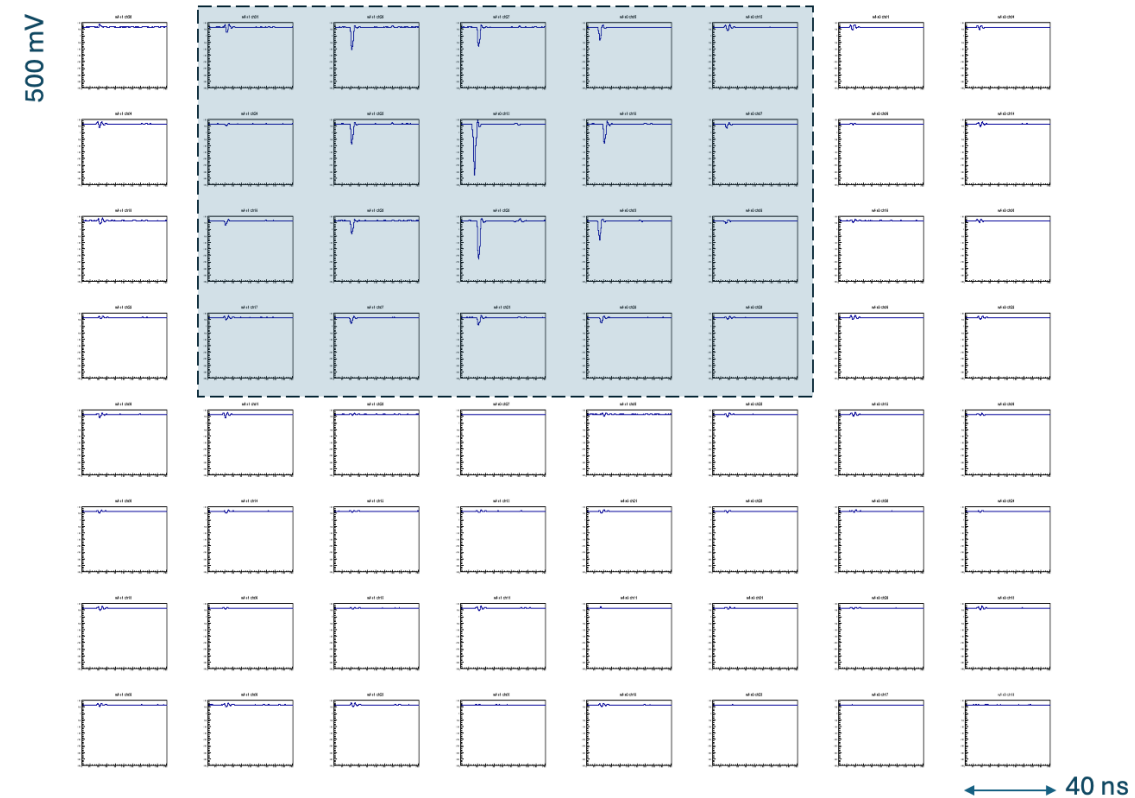


SPS Results



Above: Example of online monitoring plots for GEM trackers showing hit positions, amplitudes, residuals, etc.

Below: A single events with waveforms of a multi-photon flash produced by a beam particle in the HRPPD #5 window (8x8 pad area)



PS Beam Time Summary

- ❑ Jihee (6/4), Bob, and Martin (6/12) leave – Andrew, Bradyn, Brian, & Kathleen arrive

- ❑ June 10 & 11: Assemble test stand
 - Safety inspection passed ~ 3pm on the 11th

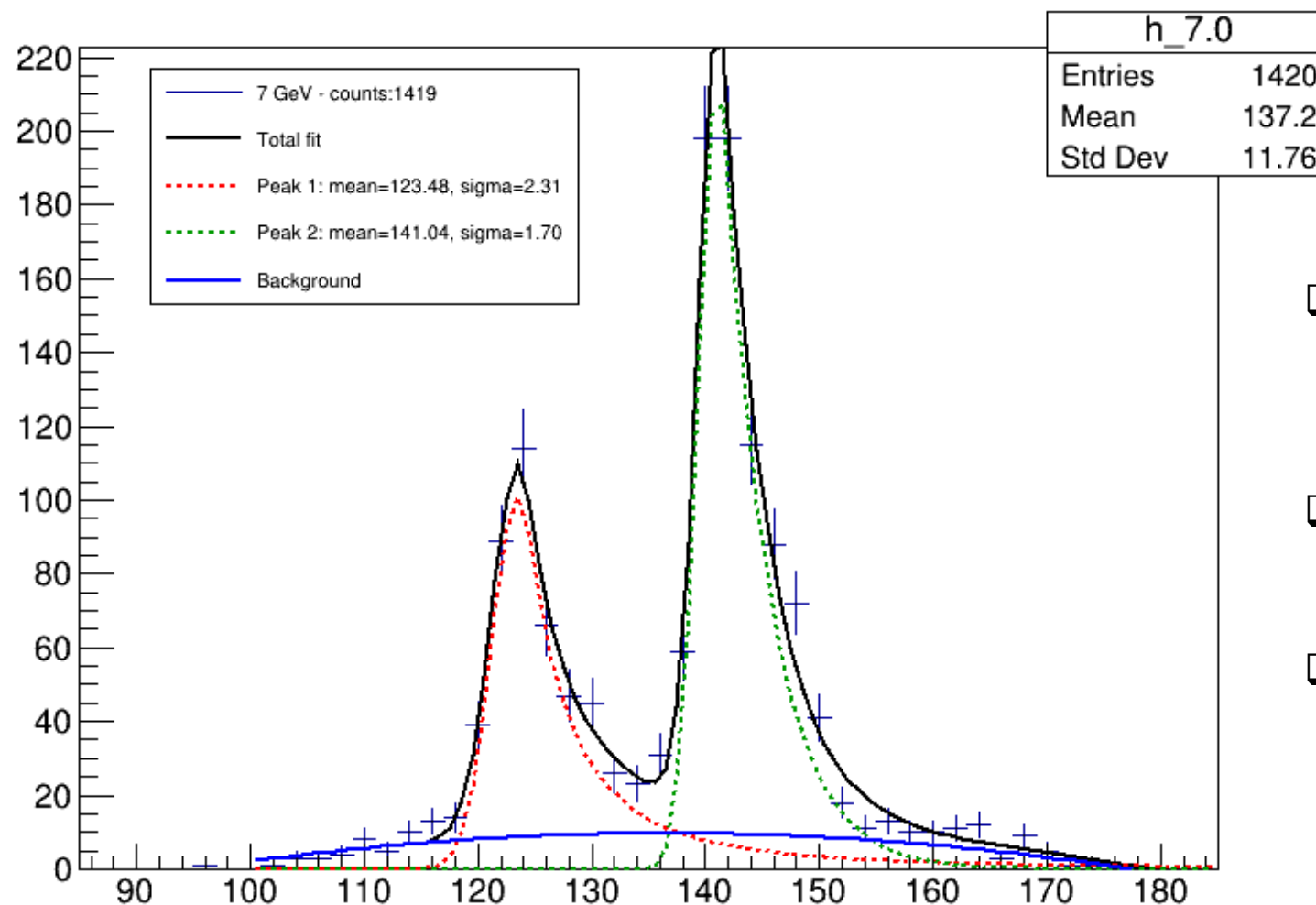
- ❑ June 12 – 19: Troubleshoot various issues
 - DAQ problems (computer crashes, computer swaps, synch issues)
 - Trigger setup / logic
 - Rate optimizations
 - Digitizer configuration
 - Power supply

- ❑ June 19 - 24: ~Stable running
 - Energy scans
 - Expansion volume scans
 - FCFD
 - Mirrors
 - Timing
 - Dedicated electron ID

PS Period Data Set

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
	Run Number	Start Time (HH:MM:SS)	End Time (HH:MM:SS)	Length (s)	Beam Energy (GeV)	Beam Charge (nC)	Number of Targets	Events/Min	GM Function	Laser Info	Aerogel Position	Witness X,Y	Aerogel Values	HRRPD Voltages	Quality Flag	Comments					
1	300170	6/23/2026 9:17:06	6/23/2026 9:17:06	0.00	12.175	32.706	1	0	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	6 position test (per design doc)					
2	300171	juke	6/23/2026 9:17:06	0.00	12.175	32.706	1	0	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
3	300172	juke	6/23/2026 9:17:06	0.00	12.175	32.706	1	0	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
4	300173	juke	6/23/2026 9:17:06	0.00	12.175	32.706	1	0	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
5	300174	6/23/2026 13:42:55	6/23/2026 13:50:44	7.82	12.175	32.706	1914	252.5377316	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	trapped 5 cables - gain very low, trapped 5 is off					
6	300175	6/23/2026 14:02:30	6/23/2026 14:05:02	2.53	12.175	32.706	896	235.2631584	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
7	300176	6/23/2026 14:05:32	6/23/2026 14:14:38	8.93	12.175	32.706	3142	351.7164718	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
8	300177	6/23/2026 14:16:12	6/23/2026 14:26:30	10.20	12.175	32.706	5299	352.1599912	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
9	300178	6/23/2026 14:39:15	6/23/2026 15:11:11	31.95	12.175	32.706	12096	315.4759917	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	zpos 486 (13 script value)					
10	300179	6/23/2026 15:12:51	6/23/2026 15:41:58	29.06	12.175	32.706	6546	218.5642788	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	zpos 481 (28 script)					
11	300180	6/23/2026 16:03:41	6/23/2026 16:11:19	7.63	12.175	32.706	0	0	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
12	300181	6/23/2026 16:03:43	6/23/2026 16:13:48	10.05	12.175	32.706	3194	316.7603306	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	Mirrors are in, aerogel at 10 (450nm)					
13	300182	6/23/2026 16:14:34	6/23/2026 16:33:08	18.57	12.175	32.706	6721	361.9038186	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
14	300183	6/23/2026 16:33:47	6/23/2026 16:53:12	19.42	12.175	32.706	8630	445.4929822	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
15	300184	6/23/2026 16:54:07	6/23/2026 16:59:41	5.33	12.175	32.706	7428	475.5989172	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
16	300185	6/23/2026 16:29:54	6/23/2026 16:36:38	6.53	12.175	32.706	2410	368.8775872	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
17	300186	juke	6/23/2026 20:09:14	0.00	12.175	32.706	0	0	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
18	300187	6/23/2026 20:09:14	6/23/2026 20:13:38	4.40	12.175	32.706	1222	277.727273	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	H1 trapped PC, aerogel at 1					
19	300188	6/23/2026 20:16:35	6/23/2026 20:45:28	28.88	12.175	32.706	10639	375.9607618	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
20	300189	juke	6/23/2026 21:21:20	0.00	12.175	32.706	0	0	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	recording delay table					
21	300190	6/23/2026 21:20:49	6/23/2026 21:21:20	0.00	12.175	32.706	10646	345.5139248	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	aerogel at 26					
22	300191	6/23/2026 21:22:46	6/23/2026 21:24:46	2.00	12.175	32.706	1120	215.6466665	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	aerogel at 51, switched to -11					
23	300192	6/23/2026 21:27:22	6/23/2026 21:45:33	18.10	12.175	32.706	9107	363.665775	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
24	300193	6/23/2026 22:16:39	6/23/2026 22:44:33	27.93	12.175	32.706	11487	440.4871058	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	HRRPD #1 PC Wp, reduced PC layer by 50V					
25	300194	6/23/2026 22:44:58	6/23/2026 22:58:57	13.98	12.175	32.706	7099	567.678844	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	adjusted the mirror - aerogel at 1					
26	300195	6/23/2026 22:59:35	6/23/2026 23:30:30	30.95	12.175	32.706	10602	342.9218259	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	aerogel at 51					
27	300196	6/23/2026 23:31:22	6/23/2026 23:36:31	5.09	12.175	32.706	8008	257.3798044	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
28	300197	6/24/2026 0:06:20	6/24/2026 0:45:28	37.13	12.175	32.706	10603	271.5602886	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
29	300198	6/24/2026 0:45:02	6/24/2026 0:51:27	6.25	12.175	32.706	1051	277.701045	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
30	300199	6/24/2026 0:51:40	6/24/2026 1:04:31	12.77	12.175	32.706	4572	358.1201942	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
31	300200	6/24/2026 1:44:43	6/24/2026 1:51:49	5.15	12.175	32.706	99	151.262736	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	aerogel was left at position 50 from access. Short run as a result					
32	300201	6/24/2026 1:44:40	6/24/2026 1:51:49	5.15	12.175	32.706	779	151.262736	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	Aerogel moved to position 58, 440 mm					
33	300202	6/24/2026 1:52:56	6/24/2026 2:09:25	16.48	12.175	32.706	4151	251.8301313	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	The cherenkov counters are set for 2 geo not figs. Cannot use separation. (currently @ 4 bar on bc sideplane crashed red run.					
34	300203	6/24/2026 2:12:01	6/24/2026 3:01:59	11.79	12.175	32.706	6941	363.301918	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
35	300204	6/24/2026 3:09:12	6/24/2026 3:15:04	5.92	12.175	32.706	4401	374.2415701	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
36	300205	6/24/2026 3:20:12	6/24/2026 3:24:04	3.92	12.175	32.706	3507	402.3202662	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	XCEST pressure moving from 4 to 2 bar (not waiting for it to come down, just taking data) Calibration					
37	300206	6/24/2026 3:25:23	6/24/2026 3:26:08	0.05	12.175	32.706	3507	402.3202662	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
38	300207	6/24/2026 3:24:22	6/24/2026 3:47:39	23.28	12.175	32.706	10962	470.8088761	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	XCESTs changed both to 1.0 Bar, not there yet. Calibration = 12					
39	300208	6/24/2026 3:47:58	6/24/2026 3:59:25	11.45	12.175	32.706	6171	538.9519653	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
40	300209	6/24/2026 4:01:20	6/24/2026 4:21:49	20.48	12.175	32.706	10096	490.9307201	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
41	300210	6/24/2026 4:22:17	6/24/2026 4:48:42	26.42	12.175	32.706	10544	395.1419358	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	Cherenkov Counters reached 1 bar					
42	300211	6/24/2026 4:49:05	6/24/2026 5:01:42	11.79	12.175	32.706	6407	565.7991914	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	Mounting counters back to 2 bar					
43	300212	6/24/2026 5:02:05	6/24/2026 5:11:12	9.12	12.175	32.706	5129	562.5959778	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	XCESTs at 2 bar					
44	300213	6/24/2026 5:12:23	6/24/2026 5:20:36	8.23	12.175	32.706	2446	297.6876267	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	Gas pressure set to 4 bar					
45	300214	6/24/2026 5:20:57	6/24/2026 6:11:26	50.48	12.175	32.706	16895	334.6640505	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK	Gas reached 4 bar					
46	300215	6/24/2026 6:11:44	6/24/2026 6:30:08	18.40	12.175	32.706	7585	412.2282607	OK	Off	Inserted	-	-	H1 (200-760-200-760-100)H2(200-470-200-470-50)H3(200-470-200-470-50)H4(200-430-200-430-50)H5	OK						
47	300216	6/24/2026 6:30:08																			

Example Fast-Offline Result



- ❑ Distance from track to photon at the sensor plane (in mm) from a 7 GeV run – Cherenkov ring radius at the HRPPDs
- ❑ Pion (right) and proton (left) peaks clearly visible – Kaon fraction will be tiny
- ❑ Peak positions roughly consistent with aerogel refractive index, expansion distance, and refraction at aerogel-gas boundary

Beam Test Summary

- ☐ HRPPD performance in particle beam ✓
 - Imaging photons
 - Window flashes
 - Timing
- ☐ Direct N_{pe} measurement (aerogel + filter + HRPPD PDE) ✓
- ☐ Cherenkov angle resolution (comparison to MC) ✓
- ☐ π/K and e/π separation ✓
- ☐ FCFD first look ✓
- ☐ Mirror evaluation (conical and pyramid) ✓
 - ID reflected photons
- ☐ Laser monitoring system ✓
 - Delay calibration using PiLas laser

- ☐ Decision made to apply for CERN beam time in ~January, meaning we had < 6 months to fully implement a program at an entirely new facility – huge effort by all involved
- ☐ Despite loss of beam at SPS and difficult conditions at PS, we took significant data in most planned configurations
- ☐ Data analysis is just beginning, and ultimate conclusions are not known – but indications are that we will be able to meaningfully address many of our goals
- ☐ PS should be back on-line in 2028...



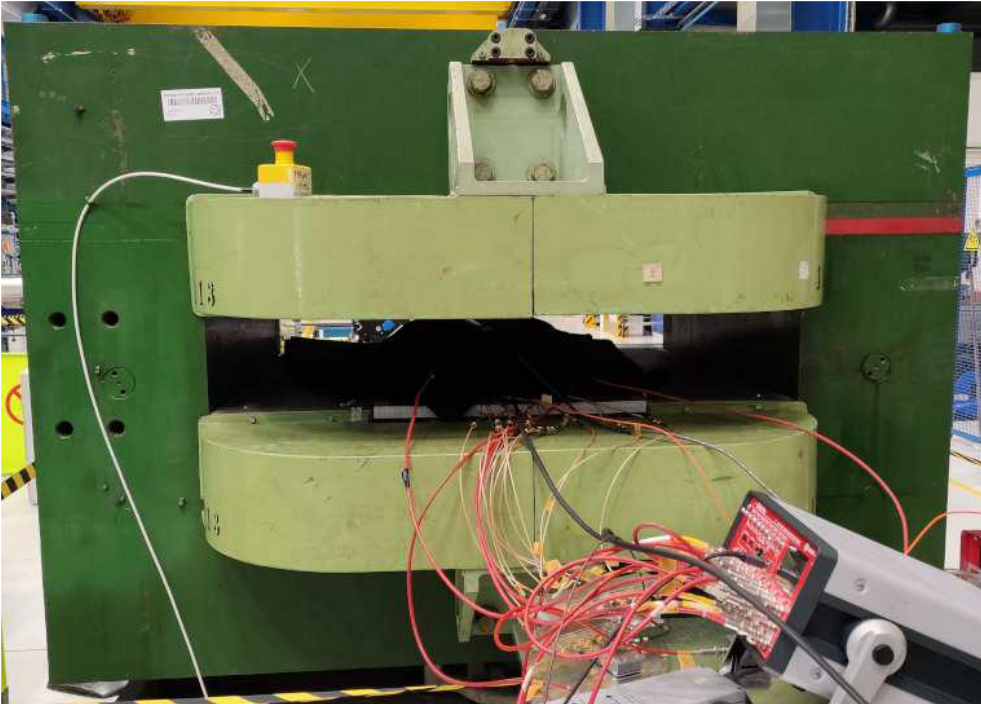
B-Field Resilience Tests

HRPPD B-Field Test Introduction

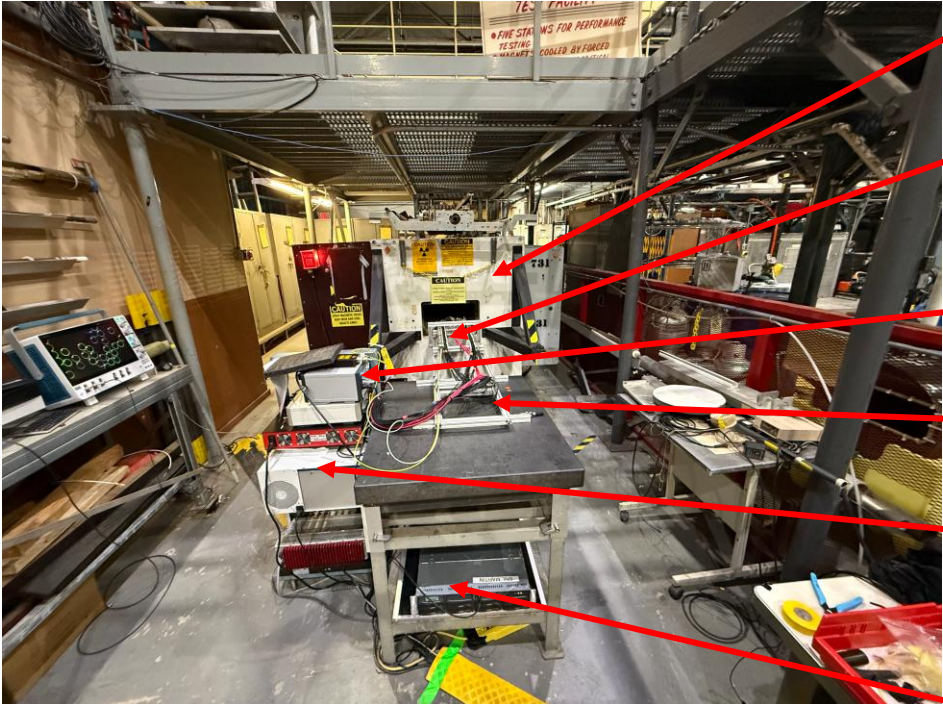
- ❑ HRPPDs at ePIC will operate in magnetic fields on order of 1.5 T and angles of up to 13 degrees between the window normal and B-Field direction
- ❑ Already established that LAPPD gain and efficiency drop in magnetic field but recovery is possible by increasing bias voltages
- ❑ Establish if HRPPDs show similar behavior by investigating HRPPD performance (gain, timing, afterpulsing, etc) over HV, B-Field strength, inclination angle parameter space
- ❑ Independent tests carried out at CERN by INFN Trieste & Genova teams and at BNL by Incom, Yale, USC, and BNL personnel
- ❑ See reports at Jan 12 TIC meeting for more detail:
<https://indico.bnl.gov/event/31009/>

CERN and BNL Setups

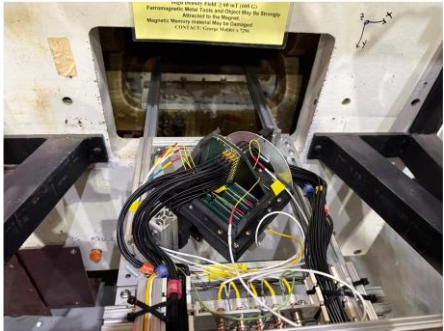
M113 Magnet (CERN)



18D72 Type Dipole @ SMD (BNL)



- Warm Dipole
- Sled-mounted HRPPD enclosure
- PiLas laser control
- 10' rail system
- HV, digitizers, NIM logic
- DAQ PC



B-Field Data Sets

- at >700 V measured 21 θ -inclinations: -40, -30, -20, -15, -14, -13, -12, -11, -10, -5, 0, +5, +10, +11, +13, +14, +15, +20, +25, +30, +40 deg.
- at 650 V measured 13 θ -inclinations: -40, -30, -20, -15, -13, -10, 0, +10, +13, +15, +20, +30, +40 deg.

V_{MCP} [V]	B=0	B=0.5 T	B=1 T	B=1.5 T	B=-1.5 T
650	✓	✓	✓	✓	-
750	✓	✓	✓	✓	-
800	-	✓	✓	✓	-40, +25, +30, +40
840	-	-	✓	✓	-
875	-	-	-	✓	-

HRPPD B-Field Data Summary

File Edit View Insert Format Data Tools Extensions Help

100% 123 Default...

13

Laser was on sinc yesterday, HRPPD warmed up 15 mins, no-field-flip scan

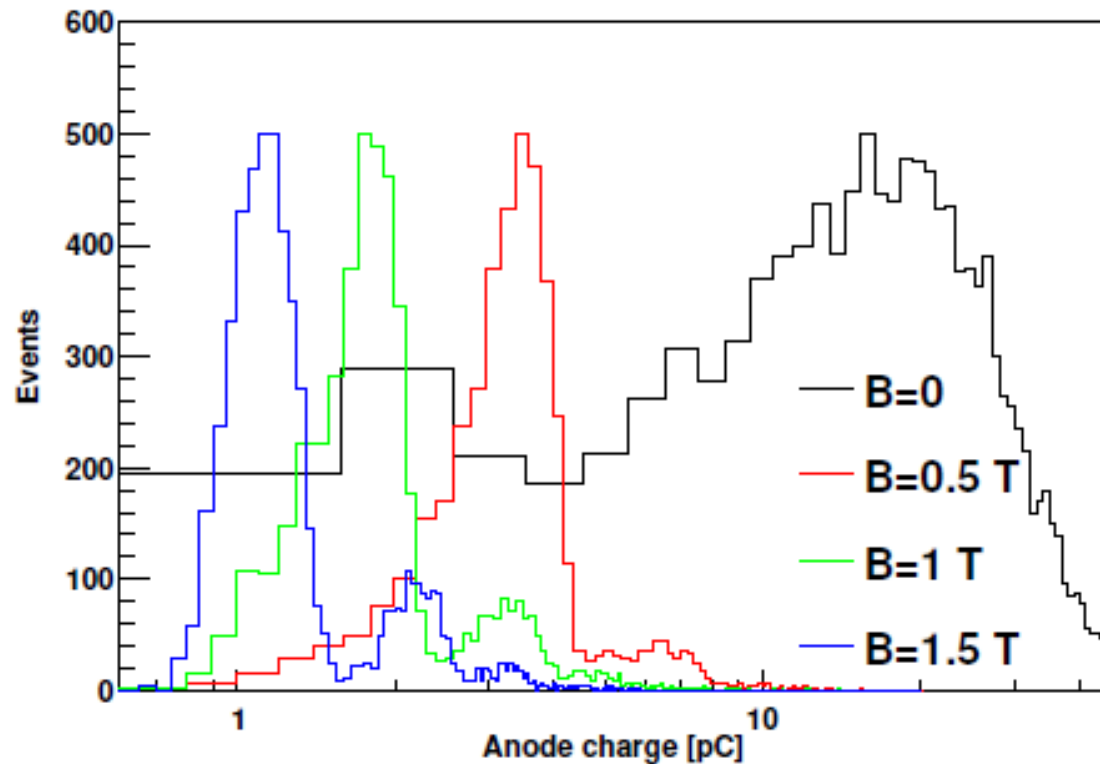
Iteration	Tilt Axis	Nom. Angle (deg)	Time	Run #	Mag. Curr. (Amp)	B-Field_Tot (T)	B-Field Bx (T)	laser	HV Setting	Note	Channel Selector	PDE	q0	q1
3	+X	+10		201365	0			1.6 kHz, 40 %					8.48	1766.83
4	+X	+10	7:59	201366	0			1.6 kHz, 40 %					8.79	3585.67
5	+X	+10		201367	400			1.6 kHz, 40 %					6.87	405.249
6	+X	+10	8:05	201368	400	0.374	0.052	1.6 kHz, 40 %					6.69	548.909
7	+X	+10		201369	400			1.6 kHz, 40 %					7.35	601.248
8	+X	+10	8:09	201370	800	0.752	0.105	1.6 kHz, 40 %		Ch 17, 18	3	6.72	301.162	
9	+X	+10	8:10	201371	800	0.752	0.105	1.6 kHz, 40 %		Ch 17, 18	3	6.82	381.746	
10	+X	+10		201372	800	0.752	0.105	1.6 kHz, 40 %		Ch 17, 18, afterpulse	3	7.5	564.045	
11	+X	+10	8:13	201373	800	0.752	0.105	1.6 kHz, 40 %		Ch 17, 18, afterpulse	3	6.76	654.819	
12	+X	+10	8:16	201374	1200	1.135	0.159	1.6 kHz, 40 %		Ch 17, 18	3	6.81	178.101	
13	+X	+10	8:17	201375	1200	1.137	0.159	1.6 kHz, 40 %		Ch 17, 18	3	6.64	306.736	
14	+X	+10	8:19	201376	1200	1.137	0.159	1.6 kHz, 40 %		Ch 17, 18	3	6.62	378.622	
15	+X	+10	8:21	201377	1200	1.137	0.159	1.6 kHz, 40 %		Ch 17, 18, afterpulse	3	6.85	488.117	
16	+X	+10	8:23	201378	1600	1.507	0.212	1.6 kHz, 40 %		Ch 17	1	6.53	108.82	
17	+X	+10	8:25	201379	1600	1.508	0.212	1.6 kHz, 40 %		Ch 17, 18	3		160.061	
18	+X	+10	8:26	201380	1600	1.508	0.212	1.6 kHz, 40 %		Ch 17, 18	3	6.52	223.806	
19	+X	+10	8:28	201381	1600	1.508	0.212	1.6 kHz, 40 %		Ch 17, 18, afterpulse	3	6.53	340.865	
20	+X	+10	8:30	201382	1900	1.774	0.250	1.6 kHz, 40 %		Ch 17	1	5.24	75.8572	
21	+X	+10	8:32	201383	1900	1.775	0.250	1.6 kHz, 40 %		Ch 17	1	6.36	105.37	
22	+X	+10	8:33	201384	1900	1.775	0.250	1.6 kHz, 40 %		Ch 17, 18	3	6.87	143.701	
23	+X	+10	8:35	201385	1900	1.775	0.250	1.6 kHz, 40 %		Ch 17, 18, afterpulse	3	6.84	162.763	
24	+X	+10	8:39	201386	0	0.004	0.001	1.6 kHz, 40 %		Ch 18, 17, 24, 23, 12, ...		7.85	1797.79	
25	+X	+10	8:40	201387	0	0.003	0.000	1.6 kHz, 40 %		Ch 18, 17, 24, 12, 23, 19, 11		8.91	3685.13	
26	+X	+15	8:44	201388	0	0.001	0.000	1.6 kHz, 40 %		Ch 18, 17, 24, ...		8.33	1839.87	
27	+X	+15	8:45	201389	0	0.001	0.000	1.6 kHz, 40 %		Ch 18, 17, 24, 23, 19, 12, 11		8.66	3617.76	

BNL: ~1500 runs ~7.5 TB of data

Charge Spectra vs B-Field

INFN

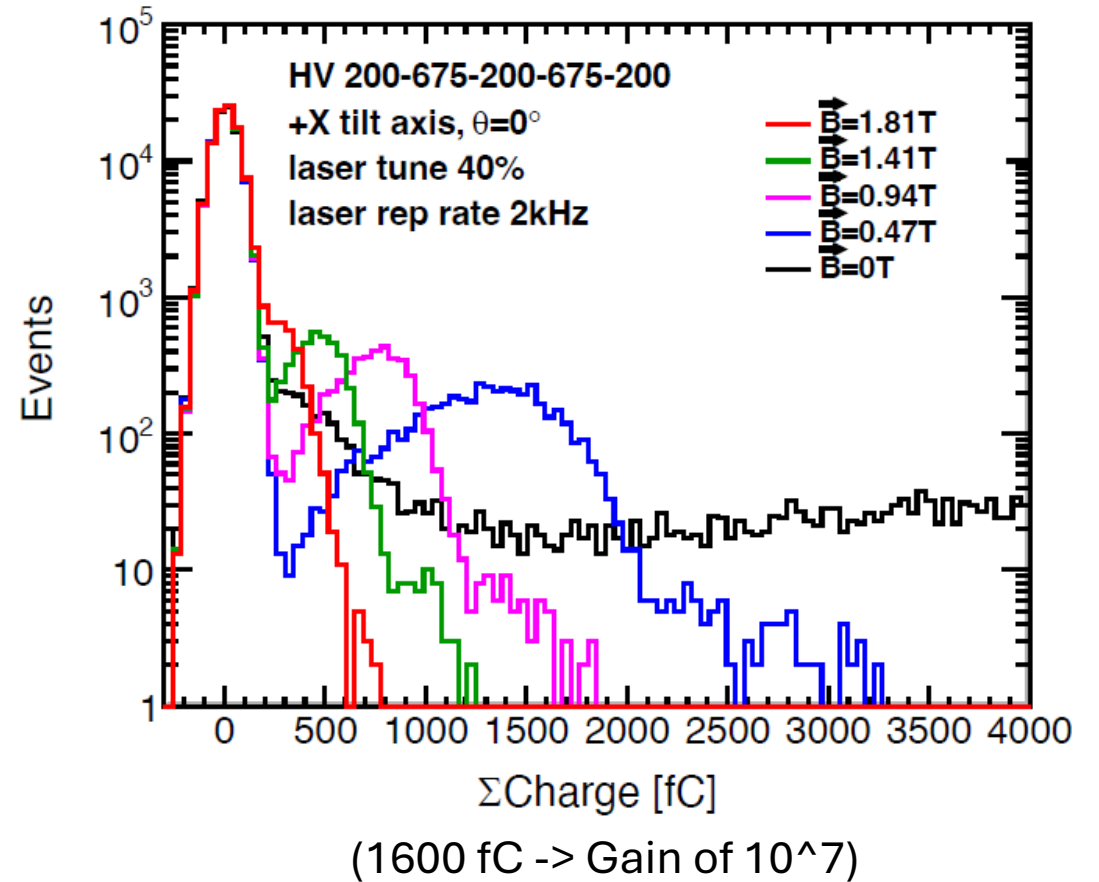
$\theta=0$, MCP=750 V



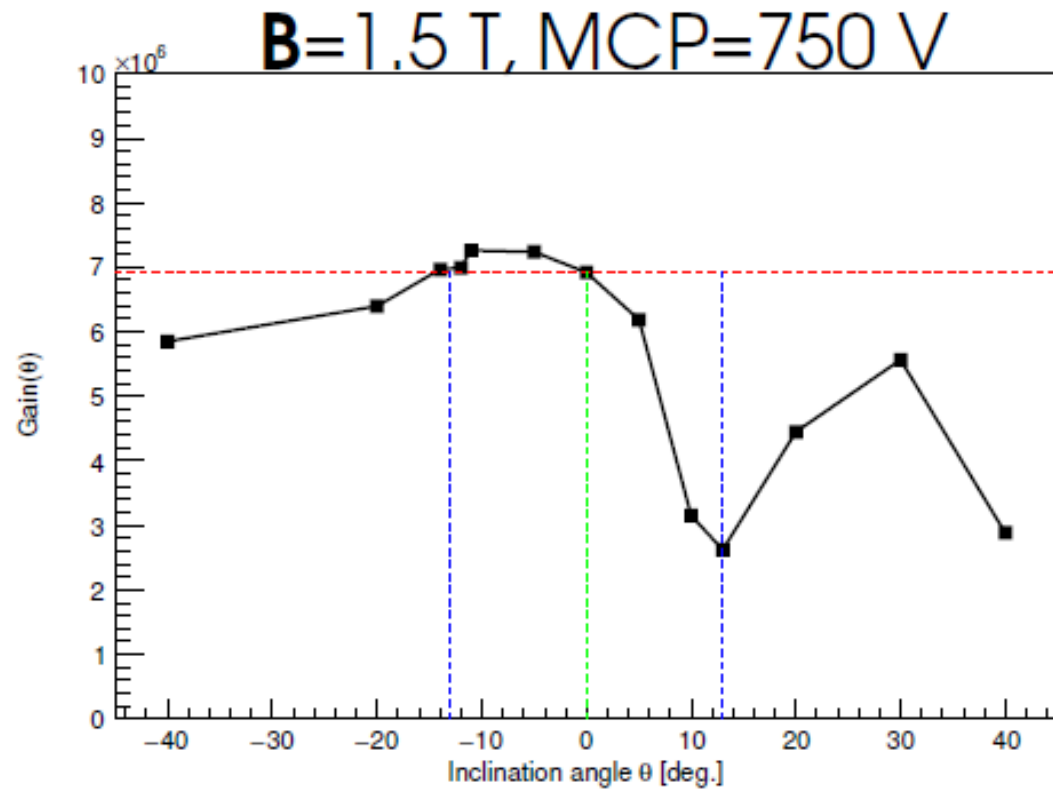
❑ Collected charge (gain) drops exponentially as a function of B-Field

BNL

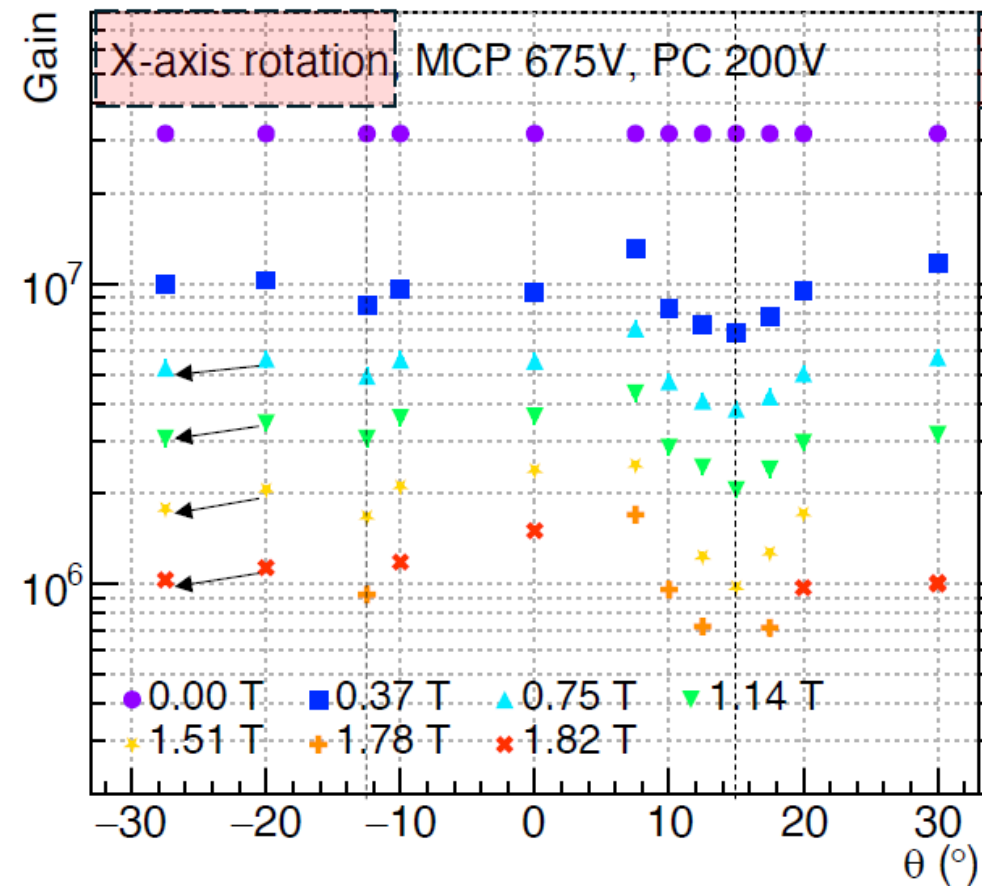
Zoomed in non-zero B-field data



HRPPD Gain Vs Tilt Angle



- ❑ Both tests show dip in gain at a tilt angle corresponding to the capillary orientation of MCP closest to the photocathode
- ❑ Also, slight dip seen when alignment matches other MCP



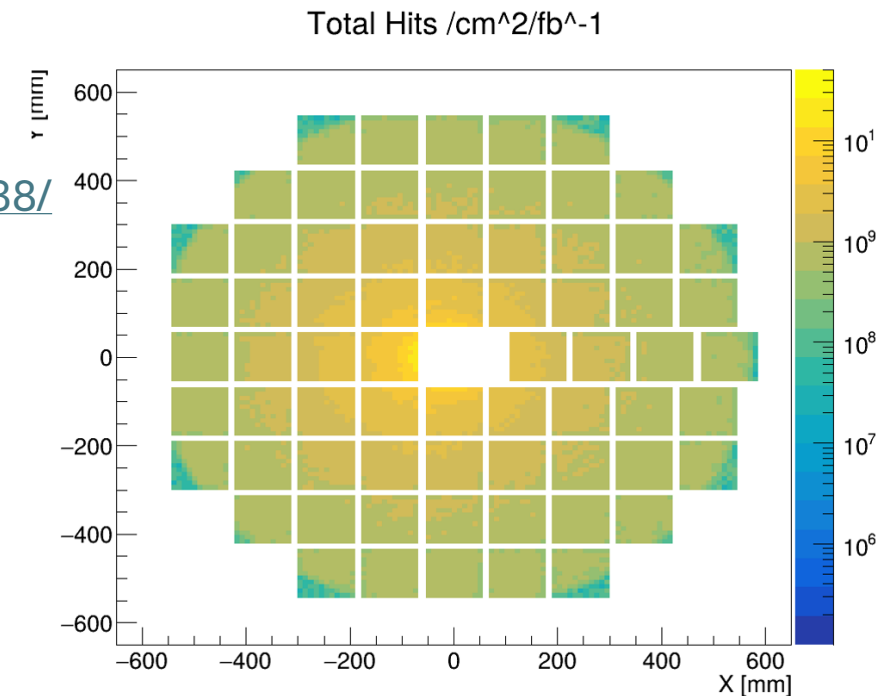
B-Field Summary

HRPPD Aging Studies

HRPPD Aging Introduction

- ❑ Extended operation can damage the photocathode (ion backflow altering PC chemistry) – lowering quantum efficiency over time
- ❑ Damage should be proportional to incident photon flux on HRPPD – detailed estimates for flux at pfRICH compiled by A. Tamis and B. Page
- ❑ Accelerated aging test stands at Jlab, BNL, and Trieste
- ❑ See report at Oct 20, 2025 TIC meeting: <https://indico.bnl.gov/event/30238/>
- ❑ See talk by J. Agarwala at [RICH2025](#)

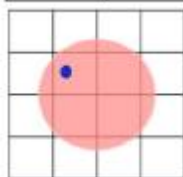
See report at May 18 TIC meeting:
<https://indico.bnl.gov/event/32710/>



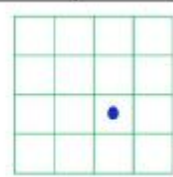
Aging Setup at INFN



D0	C0	B0	A0
D2			A2
D3			



AGEING D1B

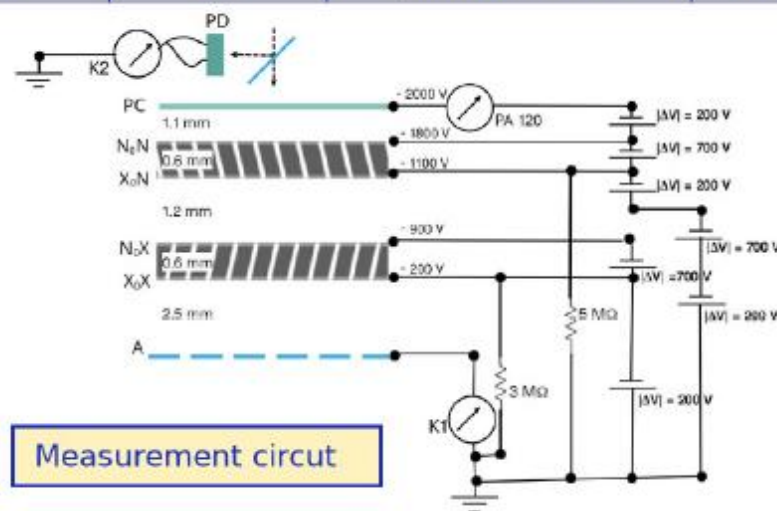


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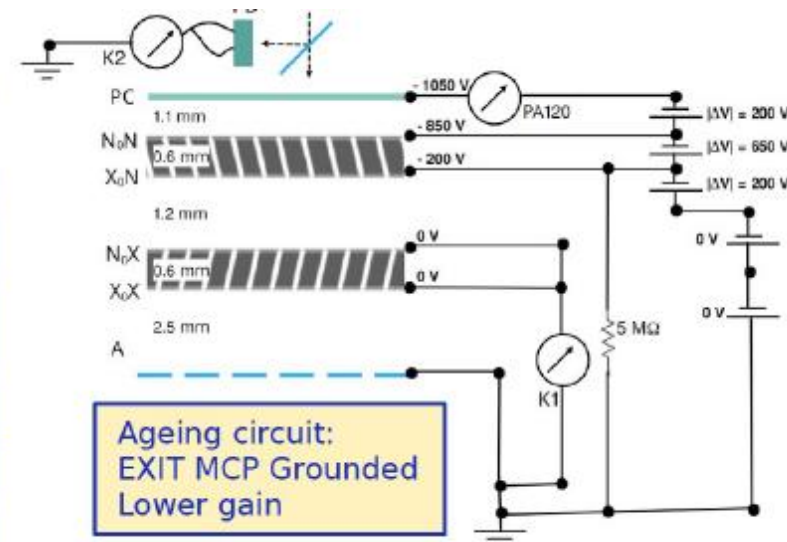
$r_{\text{AGEING}}: 5.32 \text{ mm}$
 $r_{\text{FOCUSED}}: < 0.5 \text{ mm}$

$10^{14} \text{ photons/cm}^2$ in 10 years at ePIC (simulation)
 10 years $\rightarrow$ 10 days in lab (**Accelerated ageing**)

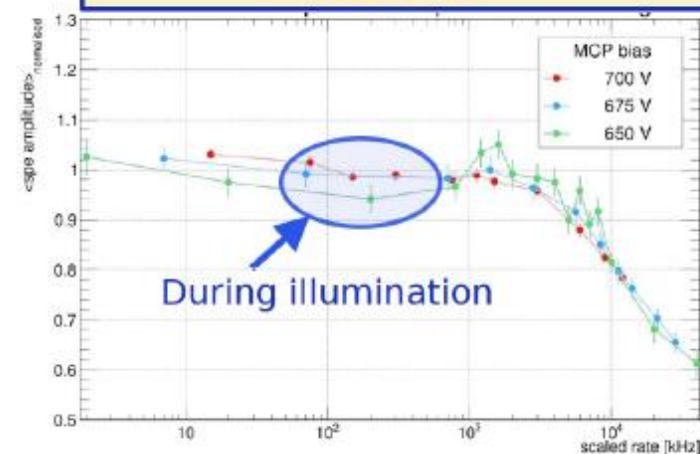
Measurement	HV bias	Light source	Light spot
PDE SCAN	ROP	pulsed Laser, $\lambda=0.20$ (OD1)	focused
QE SCAN	-50 V at PC EntryMCP at G	Cont. LED $I_{\text{LEDSET}}=300 \text{ mA}$	focused
Average QE	-50 V at PC EntryMCP at G	Cont. LED $I_{\text{LEDSET}}=300 \text{ mA}$	defocused
Gain	ROP	pulsed Laser, $\lambda=0.01$ (OD2)	focused
DCR	ROP	X	X
APR	ROP	pulsed Laser, $\lambda=3$	focused



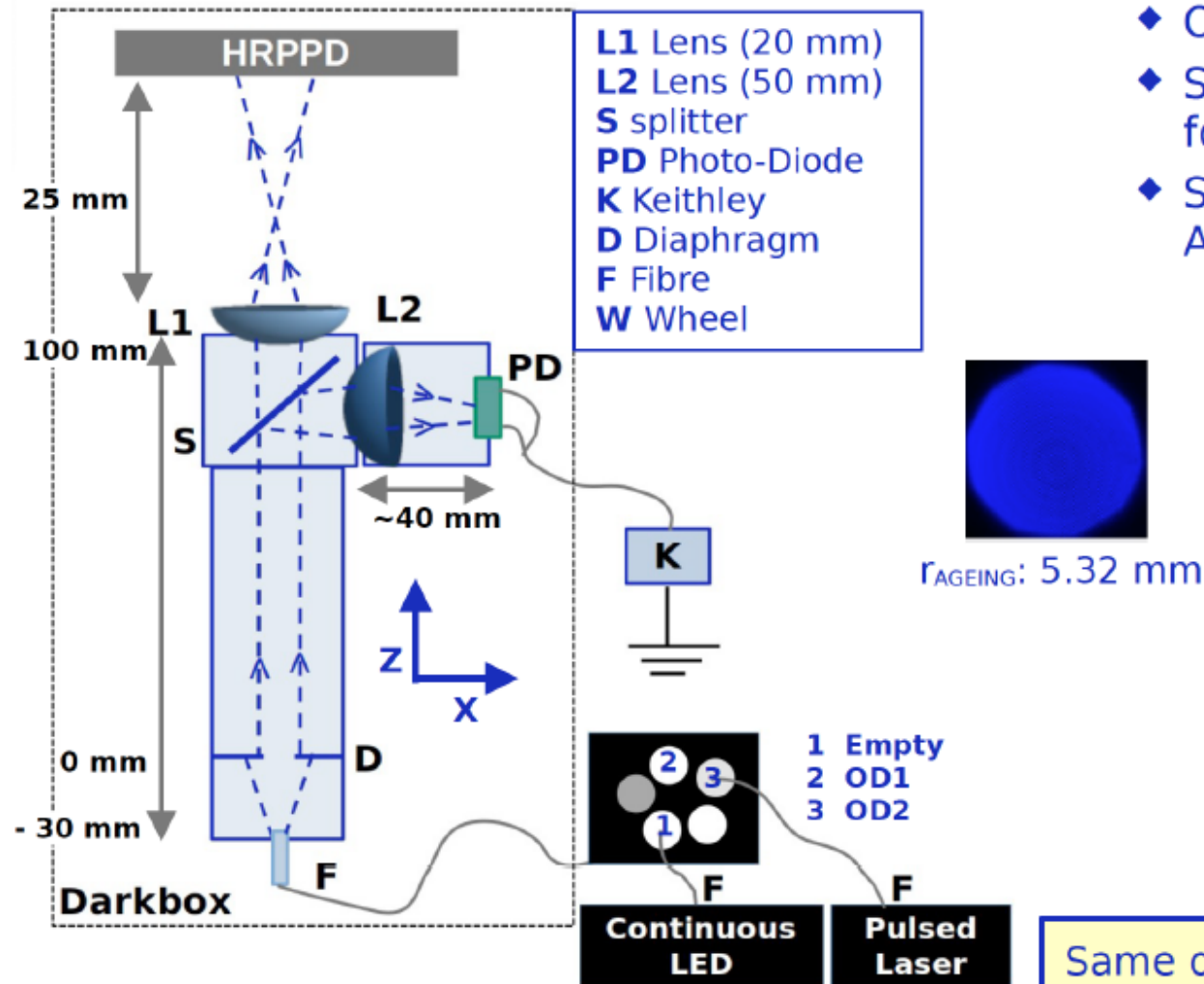
Measurement circuit



Universal amplitude vs. rate curve
 (10^6 gain)



Aging Optics at INFN

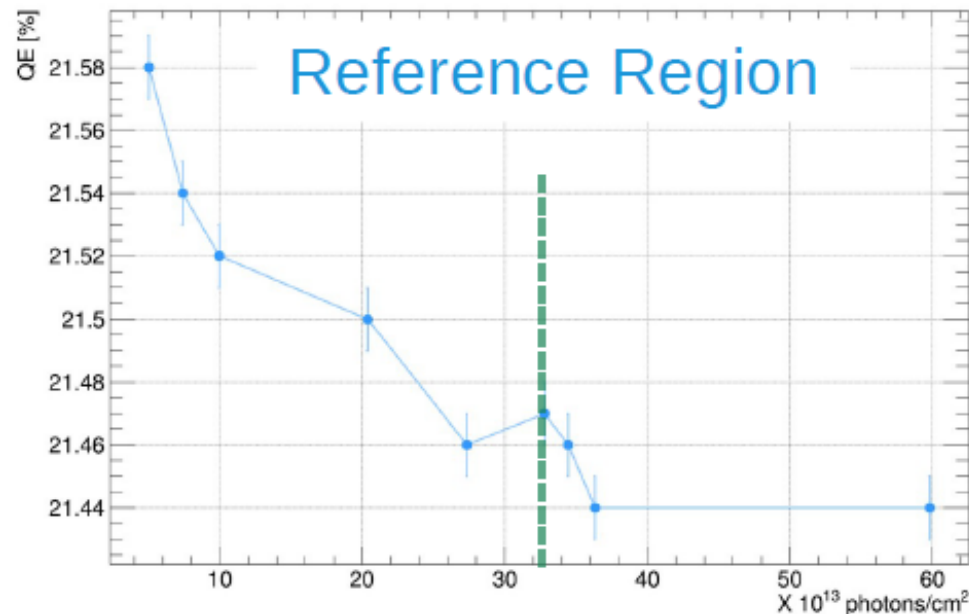
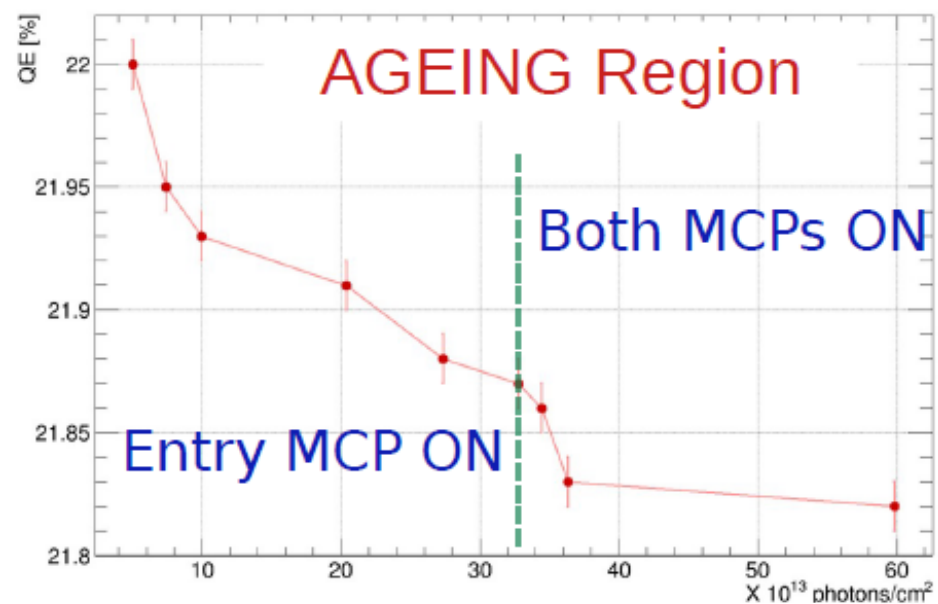


- ◆ Optics installed on movable (XYZ) system
- ◆ Same optics at two different Z positions - focused/ defocused spots
- ◆ Same optics at two different X positions - Ageing/Reference region

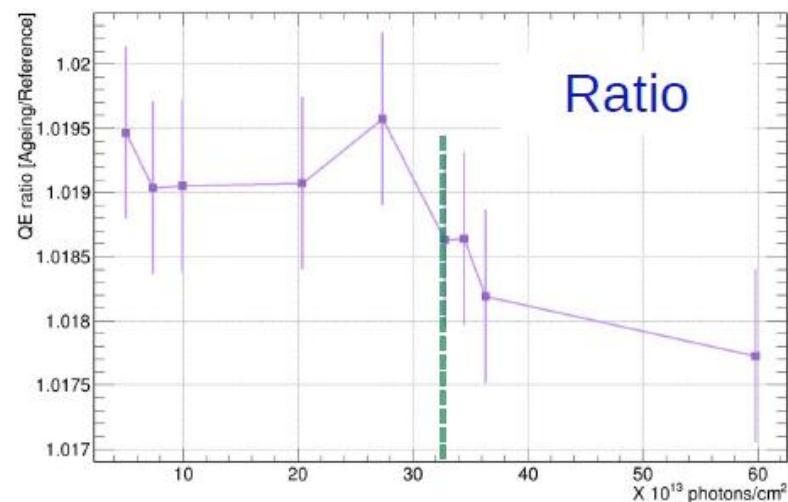
Five optics configurations (405 nm)	
Picoquant Pulsed Laser	Continuous LED (M405F3)
~1% SPE ($\lambda=0.01$), OD2 measurements	Fibre direct QE LED $I_{\text{SET}} = 300 \text{ mA}$
~20% SPE ($\lambda=0.2$), OD1 measurements	Fibre via 1 AGEING LED $I_{\text{SET}} = 85 \text{ mA}$
~3 PE ($\lambda=3$) measurements	

Same optics for ageing and intermediate measurements

Aging Results - INFN



J. Agarwala



So far, NO evidence of ageing after a photocathode illumination corresponding to 60 years of expected equivalent ePIC run

General HRPPD QA

General HRPPD QA Introduction

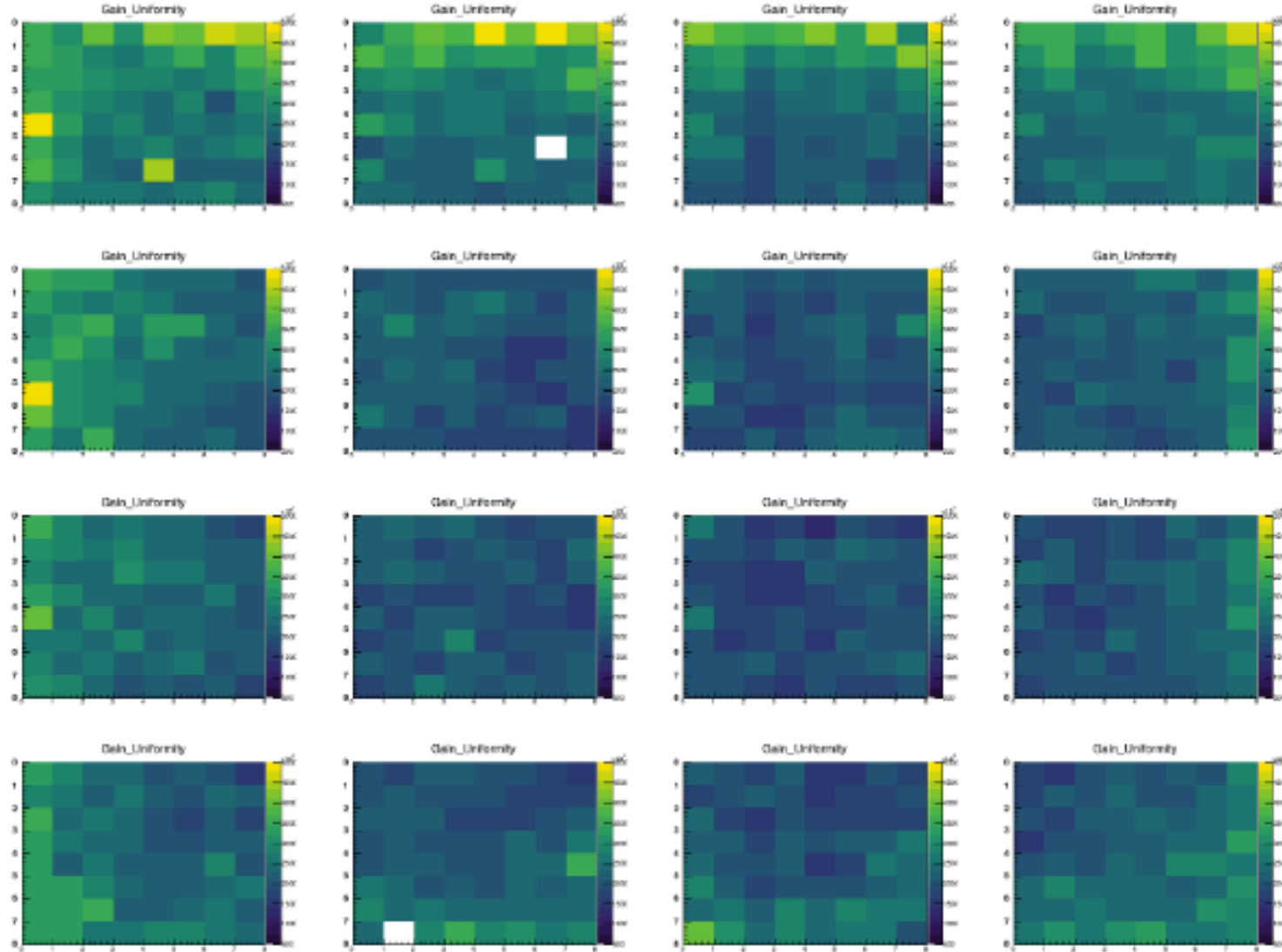
- ❑ There are a number of “operational” quantities which are important for the suitability of the use of HRPPDs in the pfRICH
 - Gain
 - Quantum Efficiency
 - Photon Detection Efficiency / Collection Efficiency
 - Transit Time Spread
 - Dark Count Rate
 - Afterpulsing

- ❑ Test stands available at JLab, BNL, and Trieste

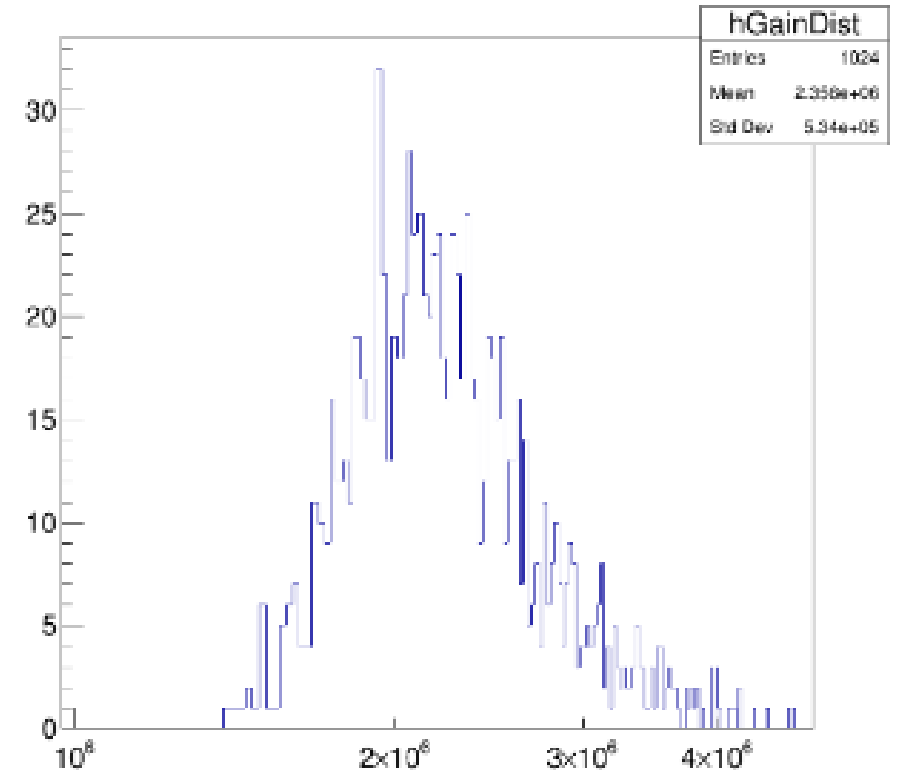
- ❑ See talks by C. Chatterjee at Lehigh Collaboration Meeting and Aging Meetings:
<https://indico.bnl.gov/event/24127/>, <https://indico.bnl.gov/event/29198/>

- ❑ See report at Oct 20, 2025 TIC meeting: <https://indico.bnl.gov/event/30238/>

Gain Scans at BNL

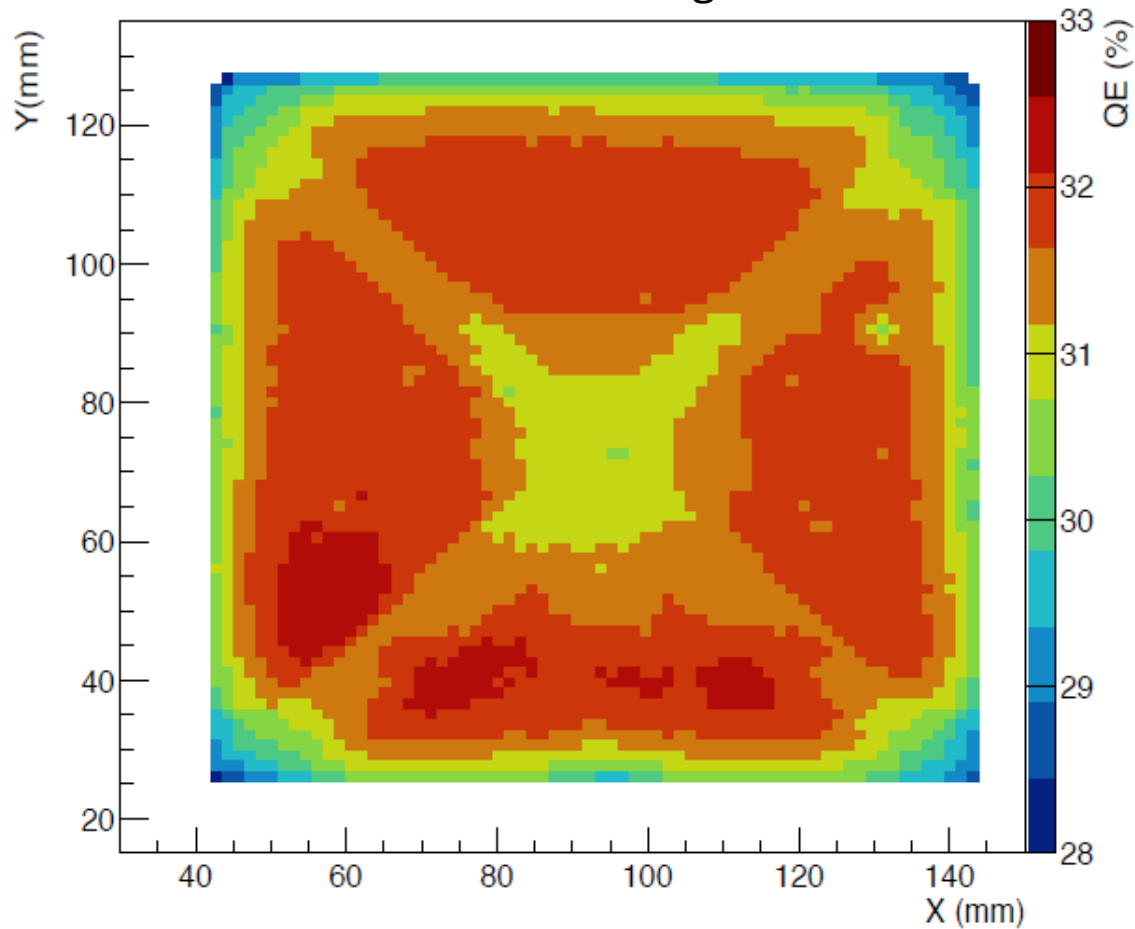


Gain Distribution

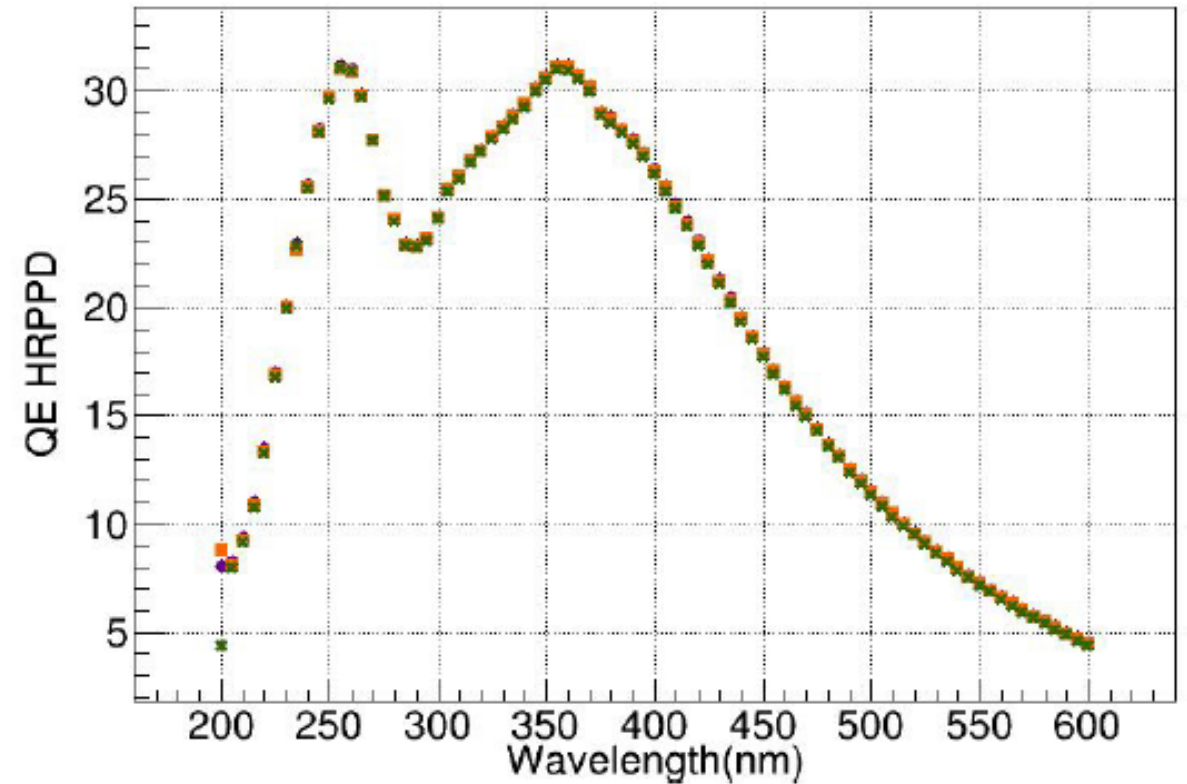


QE Scans at BNL

Measurement Wavelength = 365 nm

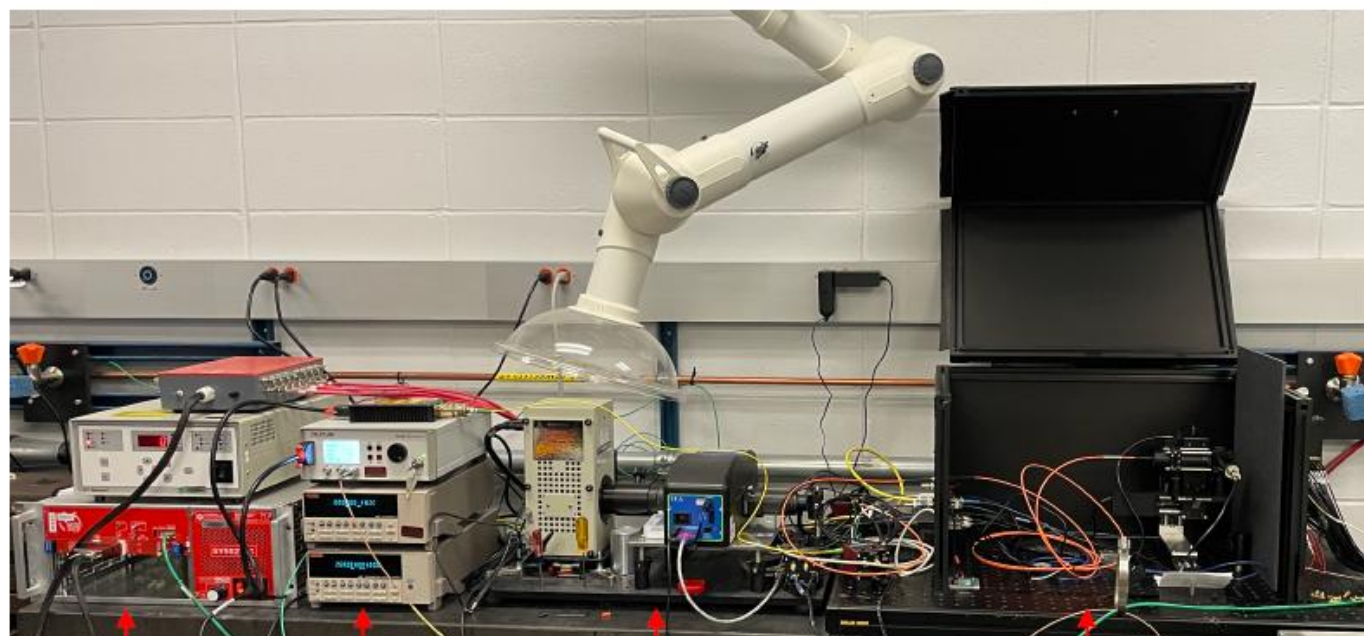


HRPPD 16 (sealing tank #2)



HRPPD 16 (sealing tank #2)

PDE Scans at BNL



HV

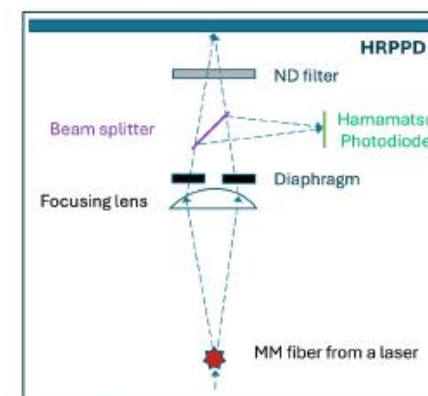
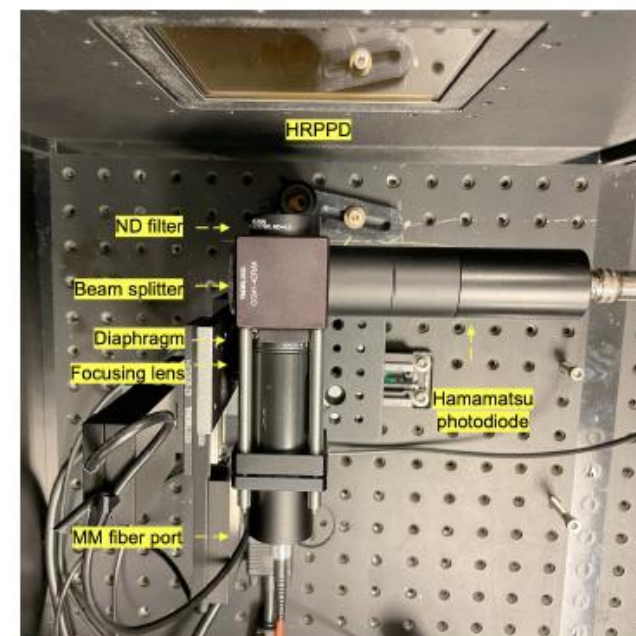
Picoammeters

PiLas laser

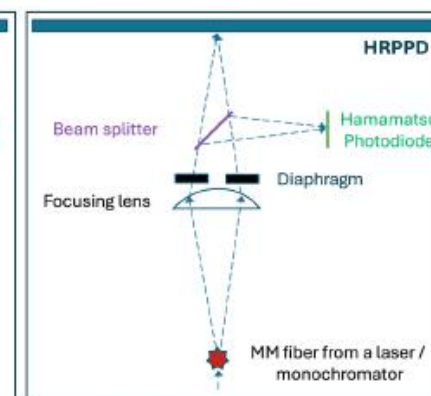
Monochromator

Dark box

- Use a newly built HRPPD aging test station at BNL
- Usable to measure PDE (in a pulse counting mode)
 - Where from $CE = PDE / QE \sim 70.3 \pm 1.6\%$



PDE (counting mode)

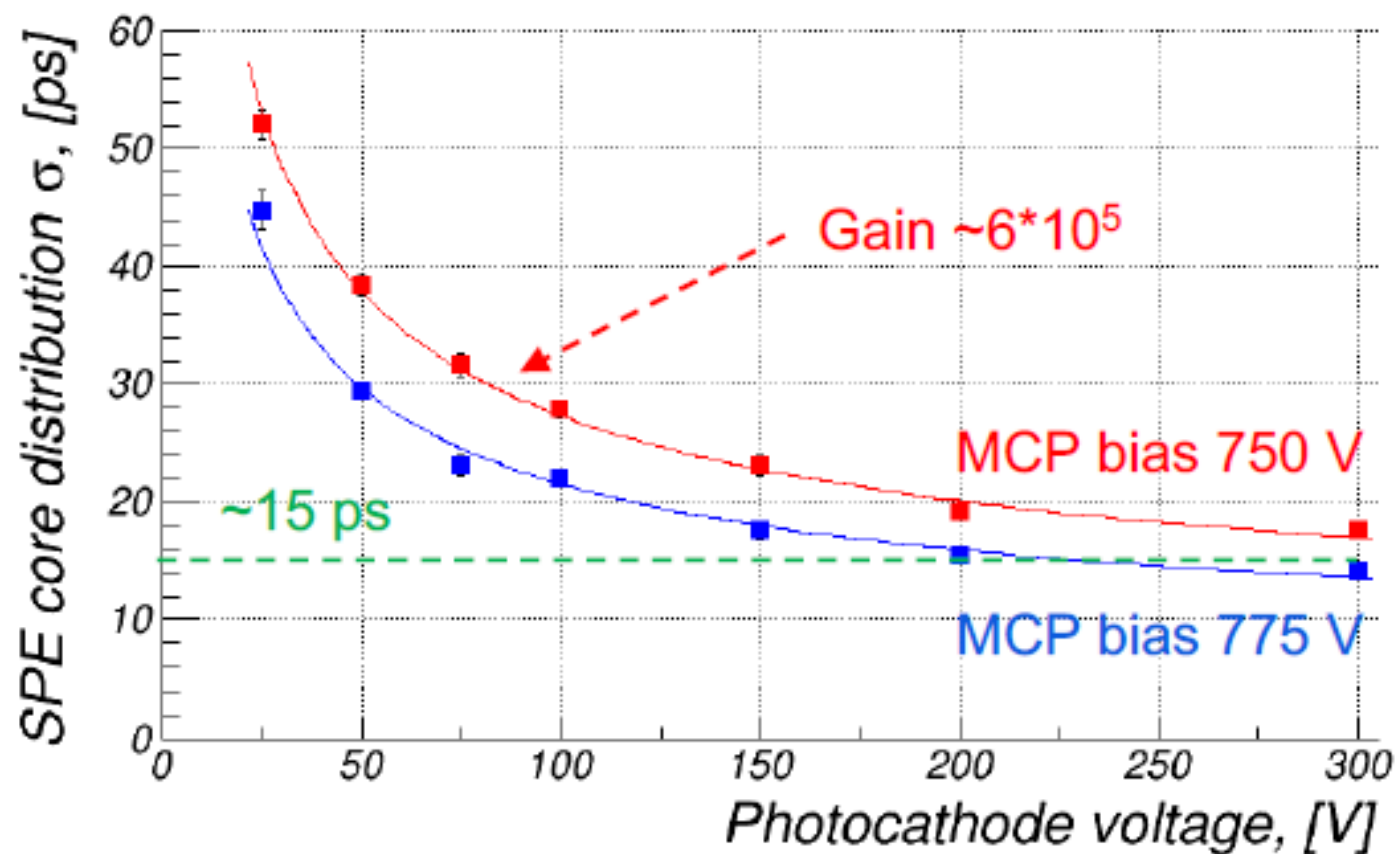


QE (PC current mode)

12

Nucl.Instrum.Meth.A 1082 (2026) 171058

Timing Resolution Studies at BNL



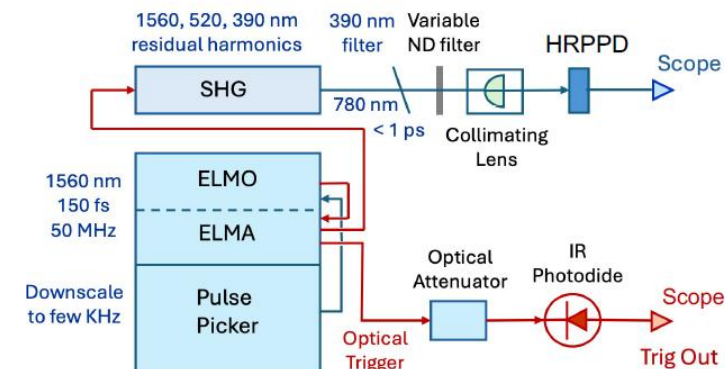
Single photon timing resolution

Menlo Systems Elmo 780 Erbium Fiber Femtosecond Laser

ELMO = Primary Laser Oscillator

ELMA = Optical Amplifier

SHG = 2nd Harmonic Generator



HRPPD QA Summary

- ☐ Test stands and procedures are in place to do tile-by-tile QA
 - HRPPD QA document being written up
- ☐ QA on initial batch of HRPPDs from Incom show performance within our specifications