Comprehensive characterization of LAPPD and HRPPD photodetectors

at CERN PS/MNP-17/M113

Jinky Agarwala[1], Chandradoy Chatterjee[1], Silvia Dalla Torre[1], Mikhail Osipenko[2], Fulvio Tessarotto[1]

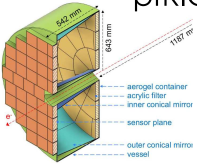
[1]INFN Trieste [2]INFN Genova

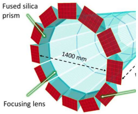
7th international workshop on new Photon-Detectors (PD2025), 3-5 Dec. 2025, Bologna, Italy

Why studying LAPPDs/HRPPDs?

- HRPPDs are baseline photosensors in pfRICH (also hadron ToF) of ePIC,
- HRPPDs are alternative photosensors in hpDIRC of ePIC,
- LAPPDs were considered as backup option for dRICH of ePIC.

pfRICH





hpDIRC

Requirements to validate:

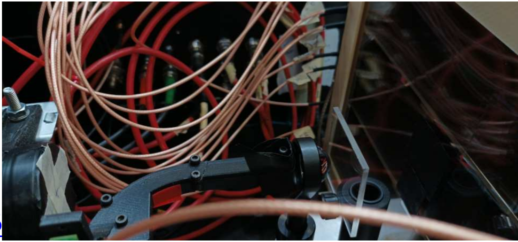
1. good SPE timing ($<$100 ps),
2. operation in B$<$1.5 T field,
3. low ageing ($>$10 C/cm^2).

Pros:

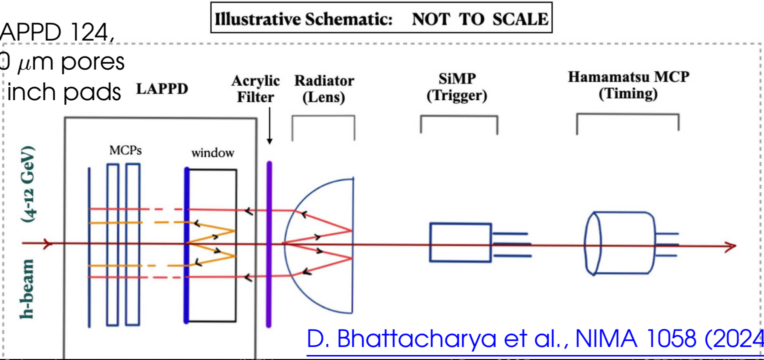
- cost: 26 k\$/400 cm^2=6 \$/(3 mm)^2 (less than SiPMs),
- low DRC: few kHz/cm^2 (much less than cooled SiPM),
- capable to high rates MHz/cm^2 (HRPPD), radiation hard, no cooling.

SPE time resolution measurement setup

- Cherenkov radiation cone from quartz lens,
- Cherenkov spot in LAPPD window (quartz),
- Reference time from: Hamamatsu MCP-PMT R3809U-5



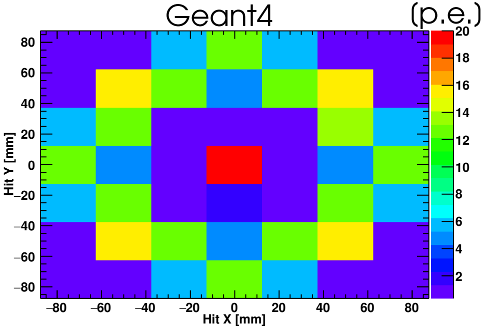
LAPPD 124,
20 μm pores
1 inch pads

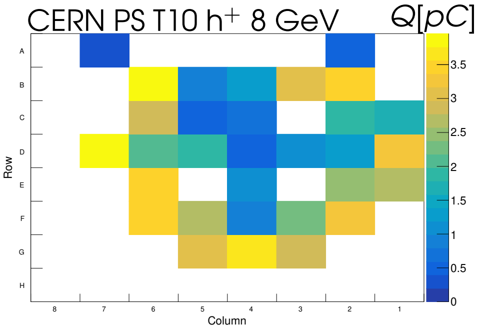


D. Bhattacharya et al., NIMA 1058 (2024) 168937

Lens Cherenkov ring in UV and VIS

- without filter lens Cherenkov ring was observed at expected radius (60 mm), with expected shape,
- 3 p.e./pad were measured, Geant4: 12 p.e./pad,
- beam spot was suppressed by a factor of >100 (grease+black tape on the window),
- with filter Cherenkov ring signal was 0.5 p.e./pad.





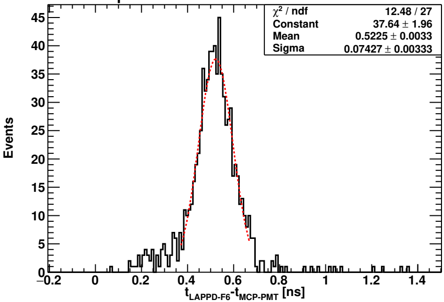
beam spot 180 p.e.

D. Bhattacharya et al., NIMA 1058 (2024) 168937

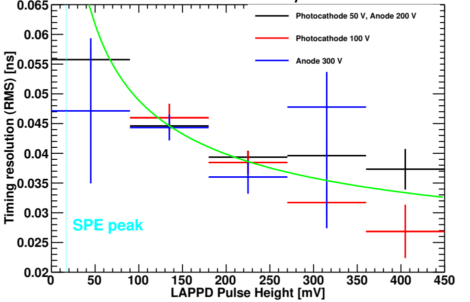
SPE timing results

- time difference (w.r.t. reference MCP) distributions mostly appeared as a Gaussian-like peak,
- Gaussian fit was used to determine time resolution,
- best SPE timing was 75 ps (pad F6, ch2), mean 87 ps,
- time resolution follow $1/\sqrt{N_{p.e.}}$ for multi-PE events,
- increasing Photocatode voltage from 50 V to 100 V leads to improvement at large pulse heights.

pad F6, ch2

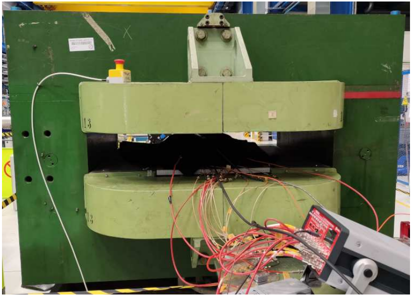


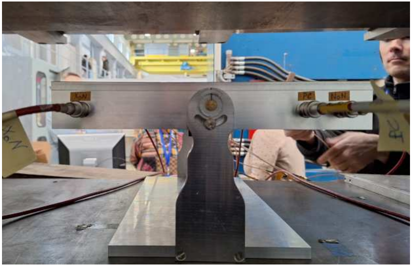
resolution vs. PC/Anode bias



Magnetic field test setup

- pulse generator providing triggers to laser and DAQ,
- PicoQuant 405 nm pulsed laser source connected though optical fiber to LAPPD in darkbox,
- 10 μm pore LAPPD N.153 in inclinable dark box,
- 5 bias voltages from stacked power supply DT1415ET,
- M113 magnet: large area 1.5 T dipole magnet (both polarities) with 17 cm gap height.

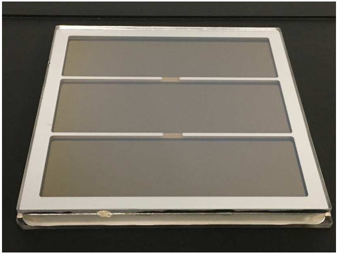


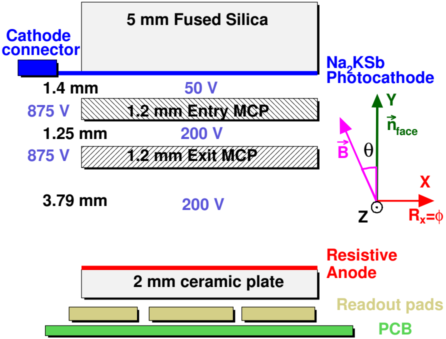


LAPPD N.153

- Gen II, 10 μm capillary, short stack, Multi-Alkali,
- ROP 50/875/200/875/200, gain 7.45×10^6, TTS SPE 68 ps,
- MCP maximum bias 900 V, 5.5 MΩ/MCP,
- Dark Count Rate (th. 4 mV) 2.1 kHz/cm^2 over 373 cm^2, means 0.76 kHz/6 mm pad,
- QE(405 nm)$\simeq$18% (max. at 365 nm 25%).

J. Agarwala et al., NIMA (2025) 170122

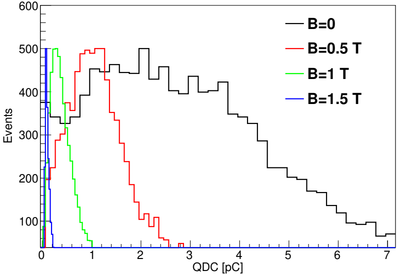




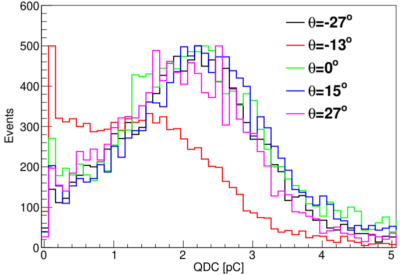
Collected charge spectra

- integrating signals, normalizing to load resistance and scaling for amplifier gain we obtained charge collected on the anode (assume no loss in coupling),
- collected charge spectra exhibit evident SPE peaks,
- collected charge drops with magnetic field, and spectrum shape is changed at **B**$>$0,
- angular dependence is weak, except $\theta \sim$-13^o.

θ=0, MCP=875 V



B=0.5 T, MCP=925 V

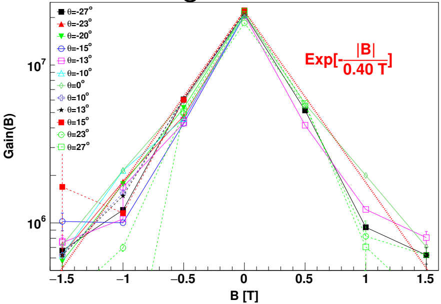


J. Agarwala et al., NIMA (2025) 170122

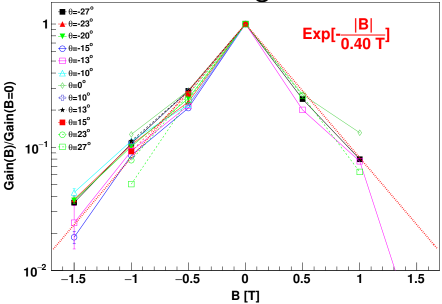
LAPPD gain in magnetic field

- gain fall is almost exponential in **B**-magnitude,
- the width of exponential is about 0.4 T,
- angular dependence is small w.r.t. **B**-dependence,
- **B**-dependencies of absolute gain (at MCP=875 V) and relative gains (ratios of gains at different MCP voltages) agree.

Absolute gain at MCP=875 V



Relative gain

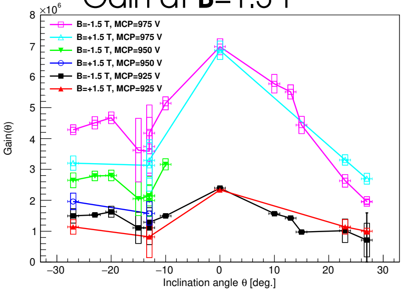


J. Agarwala et al., NIMA (2025) 170122

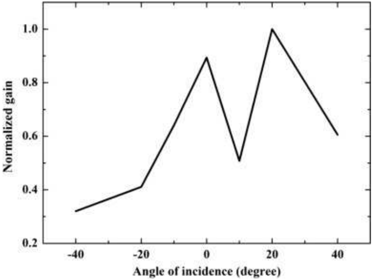
Gain angular dep.: data vs. simulations

- simulations were performed for a single MCP with 10 μm pores inclined at θ =+10°,
- MCP bias voltage was set 800 V,
- no magnetic field was applied, but photo-electron inclination was considered,
- simulations show dip in gain when photo-electrons impact on MCP at the angle of pores,
- data show the same, but for the Exit MCP.

Gain at **B**=1.5 T



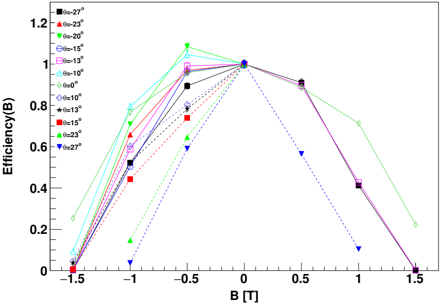
Lin Chen et al., NIMA 827, (2016) 124



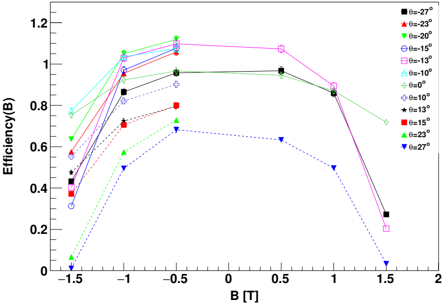
LAPPD efficiency in magnetic field

- charge collection efficiency ($\sim 1 - e^{-\delta}$) is affected by magnetic field ($R_{Larmor}(1\ eV) \sim \frac{2.2\ \mu m}{B/1\ T}$):
  1. path length between collisions $\sim R_{Larmor}$,
  2. energy gain of secondary decreases $\delta \simeq \sqrt{\frac{E_{coll}}{20\ eV}}$.
- increase of MCP bias voltage compensates gain loss,
- $\theta > 13^o$ vertical E-field acceleration is suppressed in the entry MCP (partially substituted with $v \sim \frac{E}{B}$ drift).

MCP=875 V



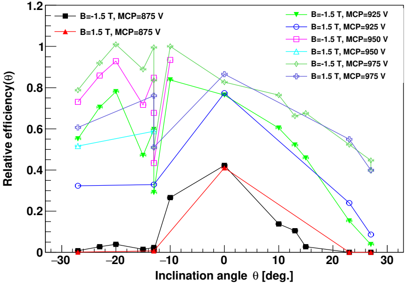
MCP=925 V



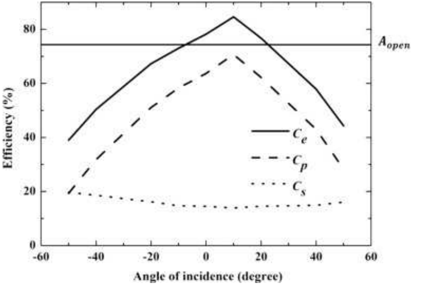
Efficiency angular dep.: data vs. simulations

- simulations were performed for a single MCP with 10 μm pores inclined at $\theta = +10°$,
- MCP bias voltage was set 800 V,
- no magnetic field was applied, but photo-electron inclination was considered,
- simulations show a broad peak at $\theta = +10°$ (pore dir.),
- high gain data show the same, but for the Exit MCP.

Gain at **B**=1.5 T

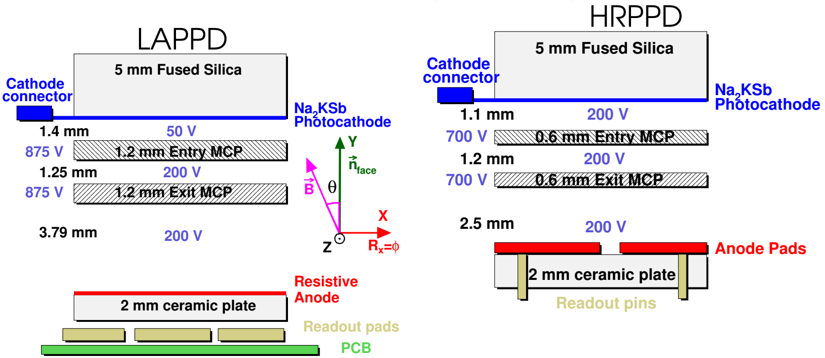


Lin Chen et al., NIMA 827, (2016) 124

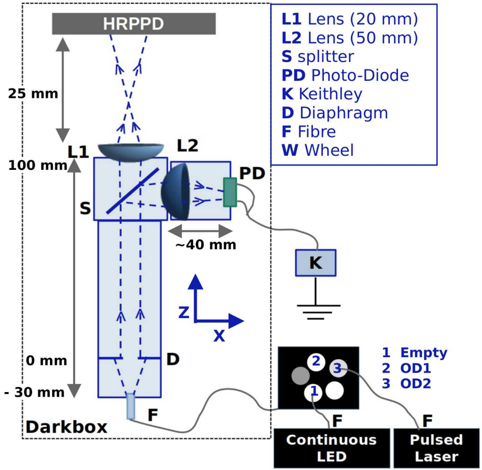


HRPPD vs. LAPPD

- HRPPD total gap height of 4.8 mm is 25% smaller than that in LAPPD (6.44 mm in Gen.II),
- HRPPD MCPs are two times shorter than in LAPPD,
- smaller gaps and increased electric field should reduce magnetic field effects,
- time delays should also be reduced, but angular dependence of delays might be larger.



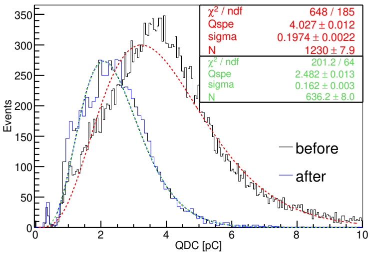
Ageing setup

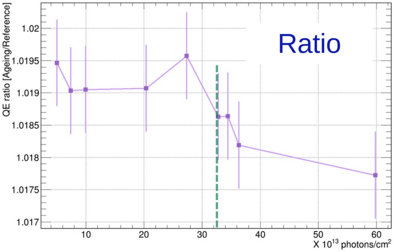


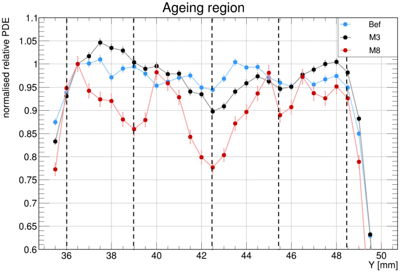
- **Accelerated ageing**: LED with 10^8 ph./cm^2/s on 1 cm spot, Exit MCP off and on;
- **QE scan**: LED induced photocurrent, MCPs off;
- **PDE scan**: fraction of laser pulses with signal;
- **Gain**: SPE collected charge distribution;
- **AfterPulse Rate**: fraction of events with trailing ($<$150 ns) signals.
- **DCR**: no source + scaler.

QE, PDE and Gain

- average QE measurements show no significant variation;
- PDE scan instead shows 20% depletion in the aged spot, especially with Exit MCP ON;
- Gain is also found to be suppressed by -38% at the end of ageing campaign.

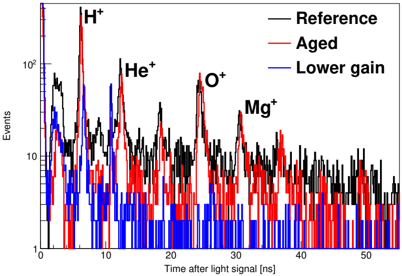


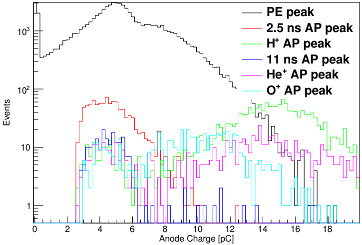




After Pulses

- peaks in delay time from the p.e. signal were observed, few were identified by $\Delta t(V)$;
- He^+ (24.6 eV), O^+ (13.62 eV) and Mg^+ (7.646 eV) peaks show up only for MCP1$\geq$800 V;
- H^+ and O^+ peaks move with electric field as $1/\sqrt{V}$;
- no correlation with ageing was observed.





Summary

☞ measured timing of 20 μm pore LAPPD N.124, capacitively coupled to the Incom readout board with 1 inch pads, published in: Nucl. Instrum. Methods A1058, 168937 (2024).,

- observed SPE timing RMS of about 80 ps ✓,

☞ tested in 0.1-1.5 T magnetic field 10 μm pore LAPPD N.153, capacitively coupled to the custom readout board with 6 mm pads, published in: Nucl. Instrum. Methods A1072, 170122 (2025).,

- most of inefficiency **B**-dependence can be recovered by an increase of MCP and PC biases ✓,

☞ Ageing study was performed on 1 cm spot up to 6×10^{14} photons/cm^2 corresponding to 2000 C at ROP,

- QE was found to be almost unaffected, while PDE and Gain were reduced by 20-40% in 60 years of EIC ✓.