HRPPD in magnetic field

CERN M113

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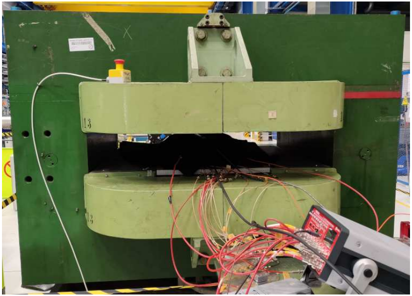
Why measuring HRPPD response in magnetic field

- High Rate Picosecond Photodetectors (HRPPD) were expected to operate in magnetic fields,
- ePIC pfRICH (hpDIRC?) and PET applications require detector tolerance to about 1.5 T magnetic fields with not very large inclination angles (field vs. normal $\theta < 40$ deg.),
- it was already established that LAPPD gain and efficiency dropped in magnetic field, but could be recovered by higher bias voltage: J. Agarwala et al., NIMA (2024) 170122, similar to smaller MCPs from other brands: (E. Morenzoni et al.,NIMA 263 (1988) 397),
- it was unclear whether the HRPPD exhibited different behavior in magnetic field,
- we decided to verify this on M113 magnet at CERN.

M113 magnet at CERN

- large bore warm dipole magnet:
  1. M113: large area 1.5 T dipole magnet (both polarities) with 17 cm gap height,
- room temperature operation,
- available accurate current-to-magnetic field calibrations, 1D Hall-probe available to check settings.

M113

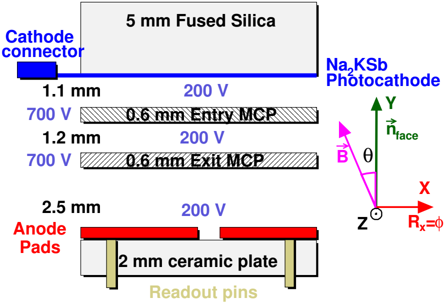


Measurement setup

- pulse generator providing triggers to laser (800 Hz),
- PicoQuant 405 nm pulsed laser source connected through 62.5 μm optical fiber to HRPPD in darkbox and tuned to $\lambda \simeq 0.05$ (<2.5% of >1 p.e. signals),
- HRPPD N.25 in inclinable dark box ($|\theta| \leq 40$ deg.),
- 5 bias voltages from stacked power supply DT1415ET.

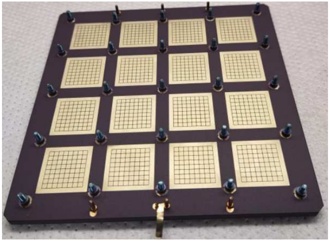
HRPPD N.25

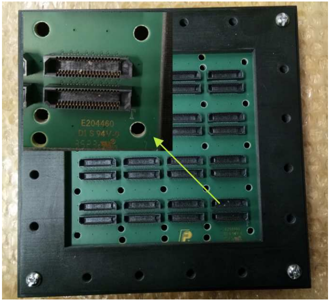
- Gen II, 10 μm capillary, short stack, Multi-Alkali,
- ROP 200/700/200/700/200, gain 1.9×10^7, TTS SPE 77 ps,
- MCP maximum bias 800 V, 7÷8 MΩ/MCP,
- Dark Count Rate (th. 4 mV) 2.58 kHz/cm^2 over 81 cm^2, means 0.23 kHz/3 mm pad,
- QE(405 nm)$\simeq$20% (max. at 365 nm 29%),
- Resistive and Emissive Coatings: Chem 5.



HRPPD readout

- HRPPD anode is segmented in 3×3 mm^2 pads separated by 0.2 mm gaps,
- readout PCB connects them (through interposers) to pins of Samtec ERF8 sockets,
- Samtec ERCD micro-coaxial cables connect them to ERF8-SMA adapter boards and then to V1742 digitizer,
- anode pads are directly connected to the digitizer.





Data summary

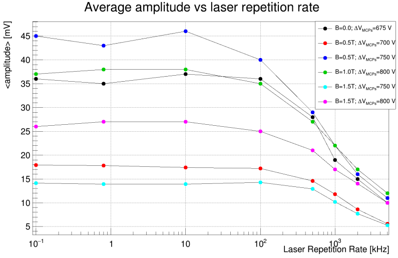
- at $>$700 V measured 21 θ-inclinations: -40, -30, -20, -15, -14, -13, -12, -11, -10, -5, 0, +5, +10, +11, +13, +14, +15, +20, +25, +30, +40 deg.
- at 650 V measured 13 θ-inclinations: -40, -30, -20, -15, -13, -10, 0, +10, +13, +15, +20, +30, +40 deg.

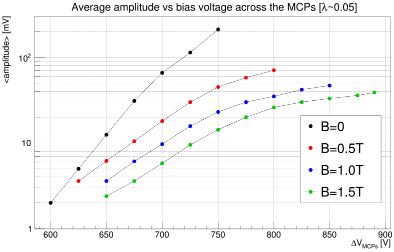
V_{MCP} [V]	B=0	B=0.5 T	B=1 T	B=1.5 T	B=-1.5 T
650	✓	✓	✓	✓	-
750	✓	✓	✓	✓	-
800	-	✓	✓	✓	-40, +25, +30, +40
840	-	-	✓	✓	-
875	-	-	-	✓	-

Gain evolution in magnetic field

- gain saturates at >1 MHz/cm^2 (pad area 0.09 cm^2) independently of the presence of magnetic field;
- $\ln G(V_{MCP})$ is linear in MCP bias voltage until 700-750 V, in magnetic field saturation begin at higher voltage;
- slope of $\ln G(V_{MCP})$ in magnetic field is smaller suggesting significant reduction of the number of collisions n or collision energy (and therefore SEY δ):

$$\ln G = n \times \ln \delta \ ,$$

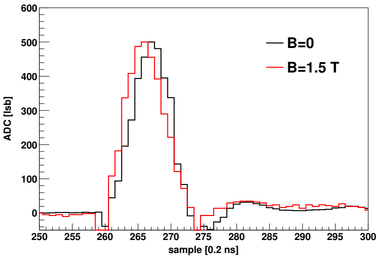




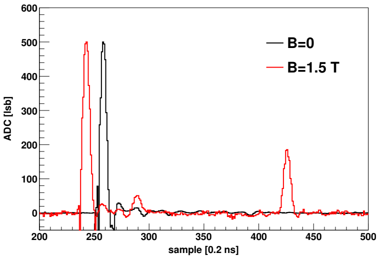
Measured HRPPD signals

- HRPPD risetime (20-80%) was about 0.45 ns, dominated by V1742 digitizer ABW=0.5 GHz,
- signal shape does not change in magnetic field,
- integral of the signal provides the anode charge:

$$Q = \frac{2}{R_{load}} \sum_{i=i_0}^{15} V_i \Delta t_i \; ,$$



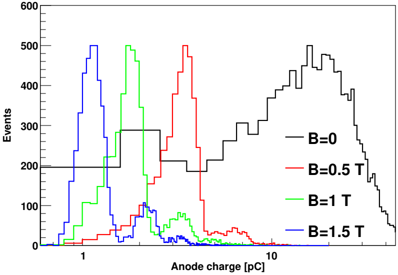
AfterPulses at 875 V



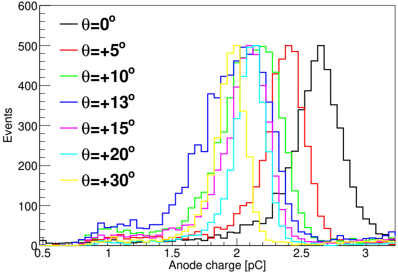
Collected charge spectra

- integrating signals, normalizing to load resistance 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,
- instead the angular dependence is weak.

θ=0, MCP=750 V



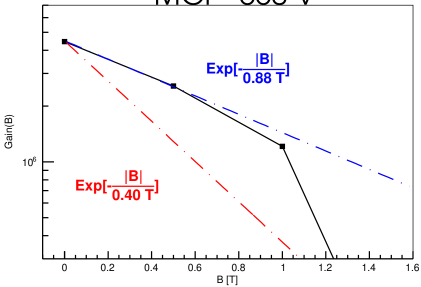
B=1.5 T, MCP=875 V



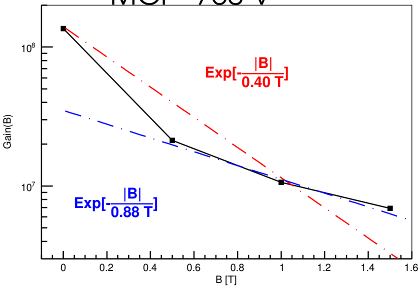
HRPPD gain in magnetic field

- gain fall is almost exponential in **B**-magnitude,
- width of exponential is about 0.88 T (0.40 for LAPPD),
- the reduction of magnetic field sensitivity likely to be attributed to Chem 5 ALD with much higher secondary yield,
- at large gain exhibits discontinuity from **B**=0, also shape of charge spectrum changes.

MCP=650 V

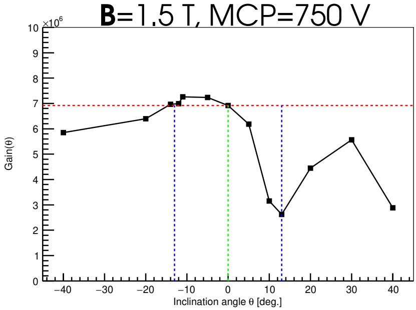


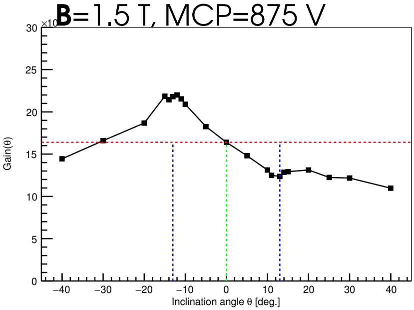
MCP=750 V



HRPPD gain in magnetic field: angular dep.

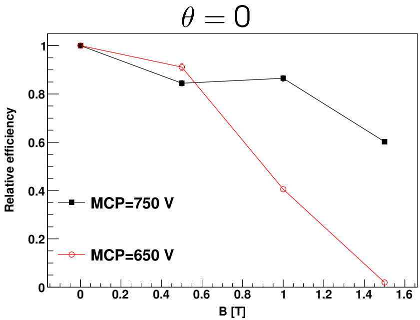
- almost flat angular dependence except for:
  1. the peak around $\theta \sim$-13^o, suppressed at low gain;
  2. dip at $\theta \sim$+13^o for low gain data;
  3. depletion at positive angles;
  4. reduction at largest angles.





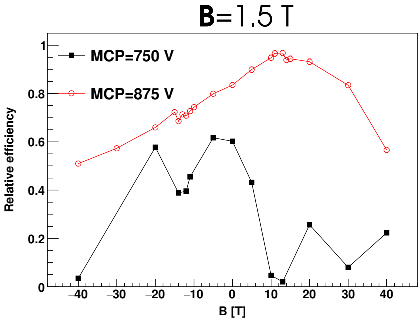
HRPPD efficiency in magnetic field

- 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 efficiency loss at high B-values.



HRPPD efficiency in magnetic field: angular dep.

- broad peak of efficiency at about +10 deg., similar to simulations in Lin Chen et al., NIMA 827, (2016) 124,
- at low gain the threshold is too high and at some angles cuts most of SPE charge distribution.



Summary

- tested in 0.5-1.5 T magnetic field 10 μm pore HRPPD N.25 with 3 mm anode pads, directly coupled to the custom readout board,
- tests performed at CERN M113 magnet,
- HRPPD gain drops exponentially with **B**-magnitude, but 2 times slower than for LAPPD,
- gain reduction was roughly independent of the field angle, except $\theta = \pm 13$ deg. and $|\theta| \geq 20$ deg.,
- at | **B** | >0 MCP bias could be increased on +100 V beyond limits, reaching at 1.5 T x2 of **B**=0 gain,
- efficiency is also reduced in magnetic field, especially at $\theta \geq 10$ deg. and $\theta < -20$ deg.,
- most of inefficiency **B**-dependence can be recovered by increase of MCP biases.