Gen.II LAPPD magnetic field test results

CERN M113/MNP-17

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4th LAPPD Workshop, remote

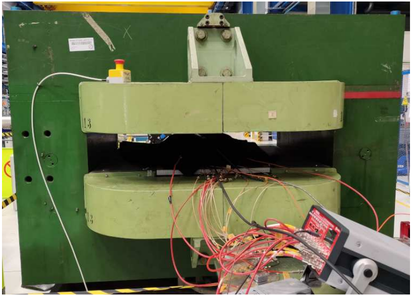
Why measuring LAPPD response in magnetic field

- Large Area Picosecond Photodetectors (LAPPD) were expected to operate in magnetic fields,
- RICH and PET applications require detector tolerance to about 1 T magnetic fields,
- it is already established that LAPPD gain drops in magnetic field, but can be recovered by higher bias voltage,
- similar for smaller MCPs from other brands (E. Morenzoni et al.,NIMA 263 (1988) 397),
- it is yet not clear whether efficiency, timing and spacial resolutions are also affected,
- we decided to verify these on magnets at CERN.

M113 and MNP-17 magnets at CERN

- large bore warm dipole magnets:
  1. M113: large area 1.5 T dipole magnet (both polarities) with 17 cm gap height,
  2. MNP-17: large area 0.5 T dipole magnet (field-up only) with 30 cm gap height,
- room temperature operation,
- available current-to-magnetic field calibrations, 1D Hall-probe available to check settings.

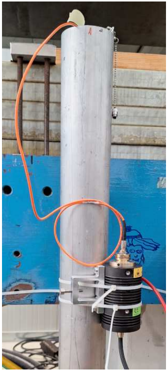
M113

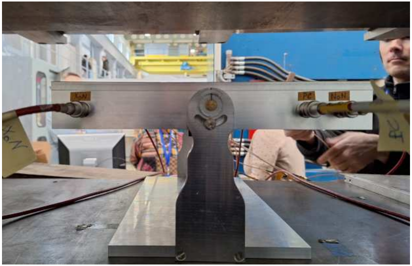


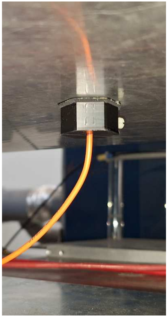
MNP-17

Measurement 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,
- 3D Hall-probe to monitor field vector.

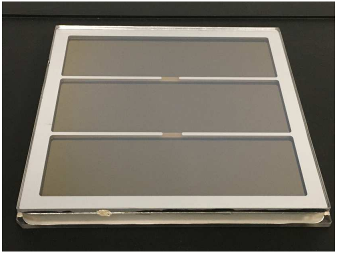


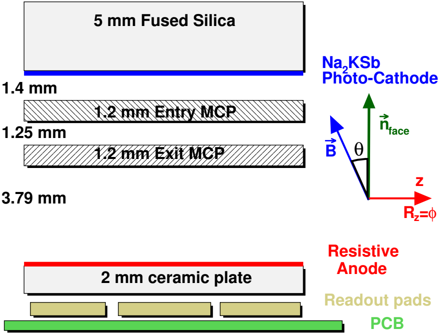




LAPPD N.153

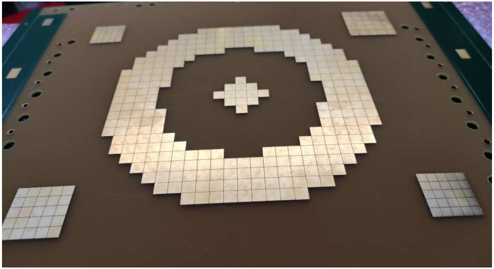
- Gen II, 10 μm capillary, short stack, Multi-Alkali,
- ROP 50/875/200/875/200, gain 7.45×10^6, TTS SPE 68 ps,
- MCP maximum bias 900 V, 5.5 MΩ/MCP,
- Dark Count Rate (th. 4 mV) 2.1 kHz/cm^2 over 373 cm^2, means 0.76 kHz/6 mm pad,
- QE(405 nm)$\simeq$18% (max. at 365 nm 25%).

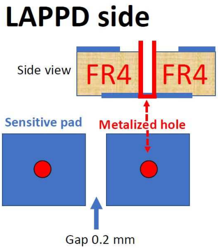


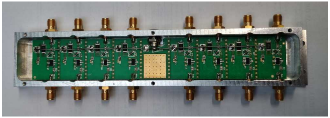


LAPPD readout

- LAPPD is capacitively coupled to PCB pads: squares of 6×6 mm^2 separated by 0.2 mm gaps,
- PCB pads are directly connected to amplifiers,
- 1 GHz amplifiers have 20 dB gain, 0.22 mV noise and $<$0.2% cross-talk.

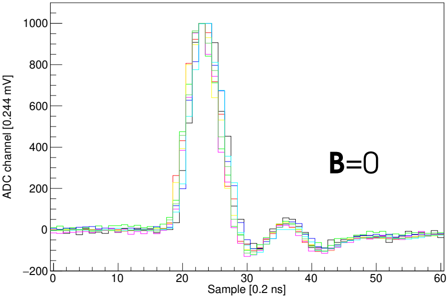


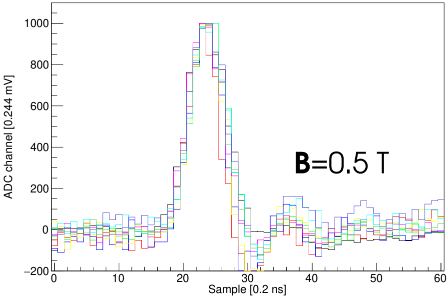




Measured LAPPD signals

- LAPPD risetime (20-80%) was about 0.45 ns,
- V1742 digitizer has BW=0.5 GHz $\rightarrow$0.45 ns is its intrinsic limit on risetime (20-80%),
- LAPPD 6 mm pad has capacitance 1.6 pF, assuming 50Ω load we expected 80 ps,
- **B**=0.5, 1 and 1.5 T fields increased signal risetime on 25%.

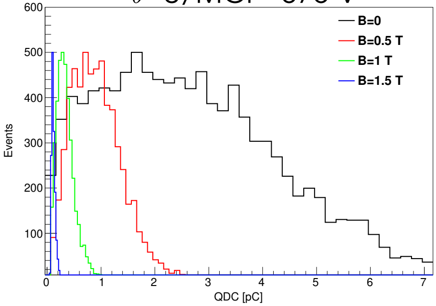




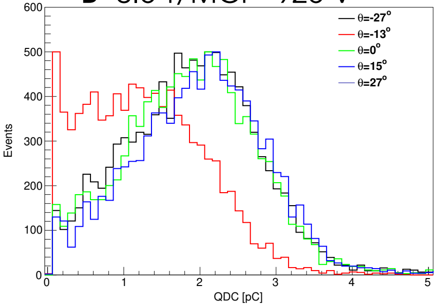
Collected charge spectra

- 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

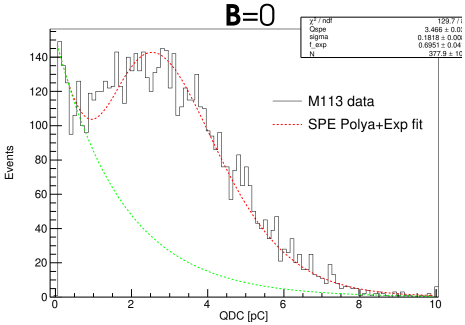


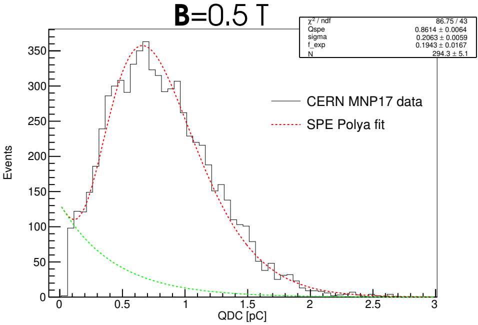
B=0.5 T, MCP=925 V



LAPPD gain estimate

- spectra were fitted with Polya + Exp functions,
- mean of Polya was taken as the SPE charge value,
- Exp width fixed to 0.5 PE (adjusted to high gain data),
- at **B**>0 the exponential part is suppressed (except $\theta \sim$-13^o).

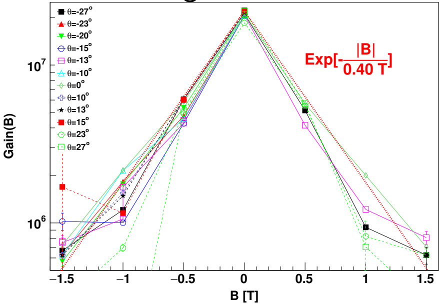




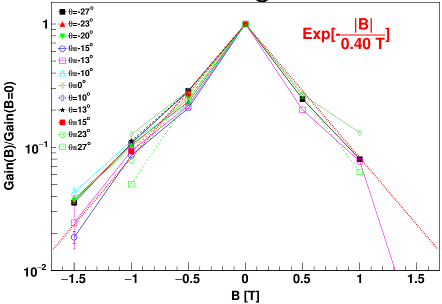
LAPPD gain in magnetic field

- 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**-dependences of absolute gain (at MCP=875 V) and relative gains (ratios of gains at different MCP voltages) agree.

Absolute gain at MCP=875 V



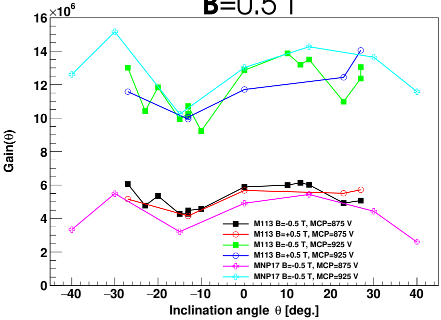
Relative gain



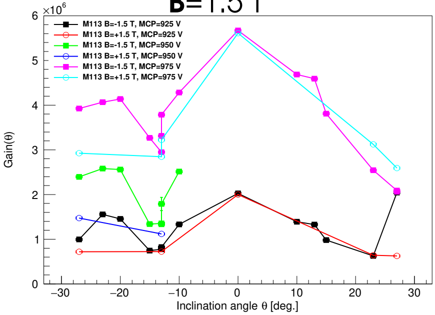
LAPPD gain in magnetic field: angular dep.

- almost flat angular dependence except dip at $\theta \sim$-13^o and reduction at largest angles,
- independent from sign of **B**-direction w.r.t. LAPPD normal, except for $|\theta|>20^o$ at **B**$>$0,
- data taken at M113 and MNP-17 agree,
- at **B**$>$0 MCP bias can be increased +100 V beyond nominal limits (would be unstable at **B**=0).

B=0.5 T



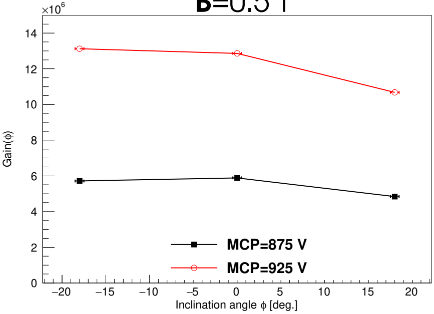
B=1.5 T



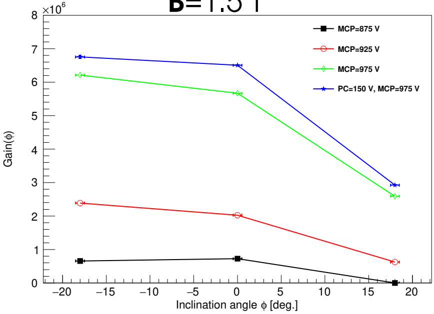
LAPPD gain in magnetic field: angular dep.$\perp$

- flat orthogonal angular dependence except $\phi \sim$+18^o, where gain reduction increases with **B**,
- at **B**=1.5 T exit MCP currents are lower at $\phi \sim$+18^o (-12 μA/545 μA), but could be due to DCR gain reduction,
- capillaries are not bent only in PC-to-face normal plane?
- $\phi > 0$ means PhotoCathode contact in bottom.

B=0.5 T



B=1.5 T



LAPPD efficiency estimates

- fraction of laser pulses N_{trig} resulting in an observed LAPPD signal (in coincidence with laser) N_{coin}:

$$p(B,\theta) = \frac{N_{coin}(B,\theta)}{N_{trig}(B,\theta)} , \quad p(B=0) \simeq 0.057 \pm 0.0015 ,$$

estimates the mean number of PE per laser pulse,

$$\lambda(B,\theta) = -\ln(1 - p(B,\theta)) \simeq p(B,\theta) ,$$

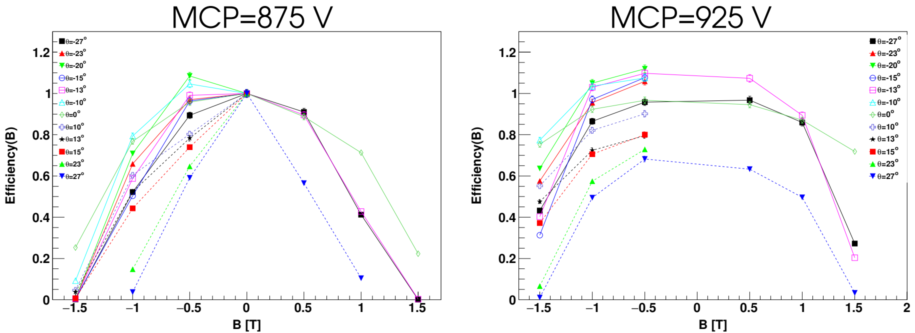
- relative efficiency of LAPPD in magnetic field can be estimated by:

$$\varepsilon(B,\theta) = \frac{\lambda(B,\theta)}{\lambda(B=0,\theta)} ,$$

- however this definition depends on LAPPD signal threshold (if applied to the data).

LAPPD efficiency in magnetic field

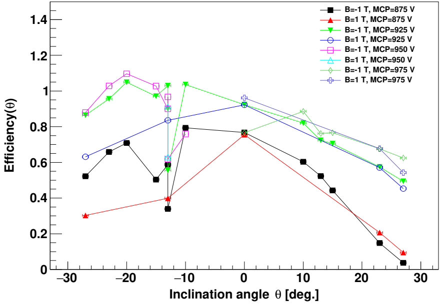
- charge collection efficiency ($\sim 1 - e^{-\delta}$) is affected by magnetic field ($R_{Larmor}(1\ eV) \sim \frac{2.2\ \mu m}{B/1\ T}$):
  1. path length between collisions $\sim R_{Larmor}$,
  2. energy gain of secondary decreases $\delta \simeq \sqrt{\frac{E_{coll}}{20\ eV}}$.
- increase of MCP 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).



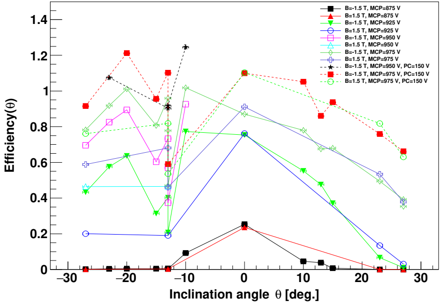
LAPPD efficiency in magnetic field: angular dep.

- broad peak of efficiency at about -10 deg., similar to simulations in [Lin Chen et al., NIMA 827, (2016) 124](), but for the exit MCP,
- dip at -13 deg. is absent in simulations, but it is likely related electrons confined in the center of capillaries,
- PhotoCathode potential increases the efficiency (+15%/100 V at 1.5 T).

B=1 T



B=1.5 T



Summary

- tested in 0.5-1.5 T magnetic field 10 μm pore LAPPD N.153, capacitively coupled to the custom readout board with 6 mm pads,
- tests performed at CERN MNP-17 and M113 magnets,
- LAPPD gain drops exponentially with **B**-magnitude,
- gain reduction was almost independent of the field angle, except $\theta = -13$ deg. and $|\theta| \geq 20$ deg.,
- at **B**$>$0 MCP bias could be increased on +100 V beyond limits, reaching at 1.5 T 1/3 of **B**=0 gain,
- efficiency is also reduced in magnetic field, especially at $\theta = -13$ deg. and $\theta \geq 13$ deg.,
- most of inefficiency **B**-dependence can be recovered by increase of MCP and PC biases.