Studies of LAPPD and HRPPD photodetectors for Cherenkov imaging application

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XII International Workshop on Ring Imaging Cherenkov Detectors - RICH2025, Mainz, Germany

Outline

- pfRICH in the ePIC experiment of the EIC
- LAPPD/HRPPD – baseline photosensors for pfRICH application
- Recent and ongoing LAPPD/HRPPD studies

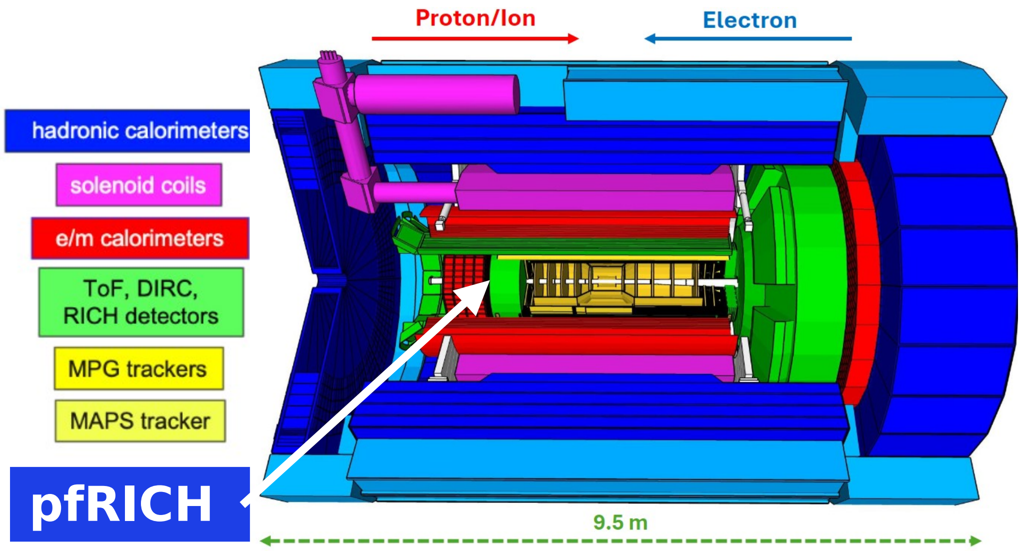
  - LAPPD *timing studies* – CERN PS beam test, October 2022
    D. S. Bhattacharya, et al., NIMA 1058 (2024) 168937

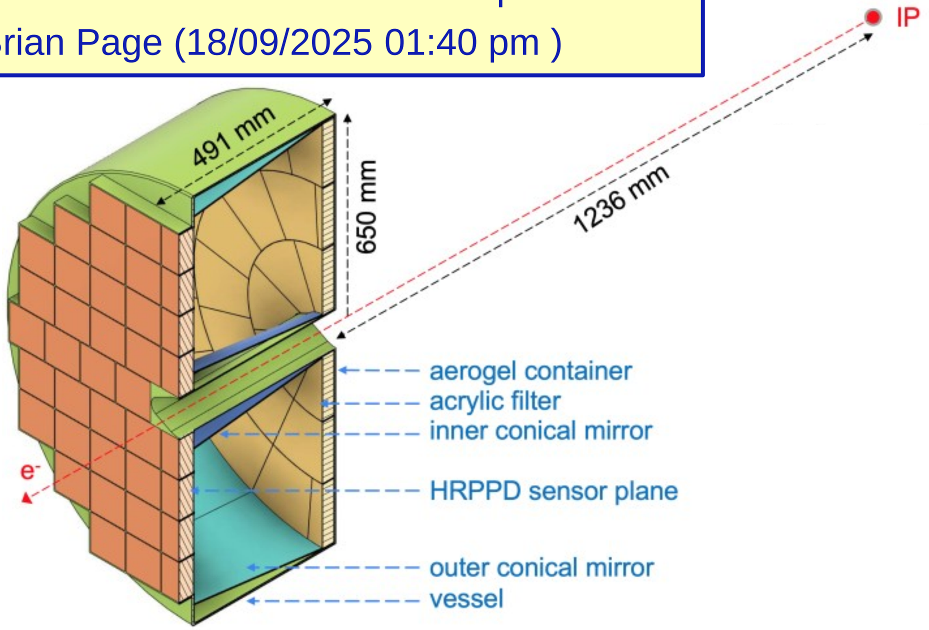
  - LAPPD *responses in magnetic fields* – CERN, October 2023 and March 2024
    J. Agarwala, et al., NIMA (2024) 170122

  - HRPPD *ageing studies* – Trieste laboratory 2025 **(started on August 11, 2025)**

pfRICH in ePIC

A Proximity-Focusing RICH Detector for the ePIC Experiment at the EIC -Talk by Brian Page (18/09/2025 01:40 pm)





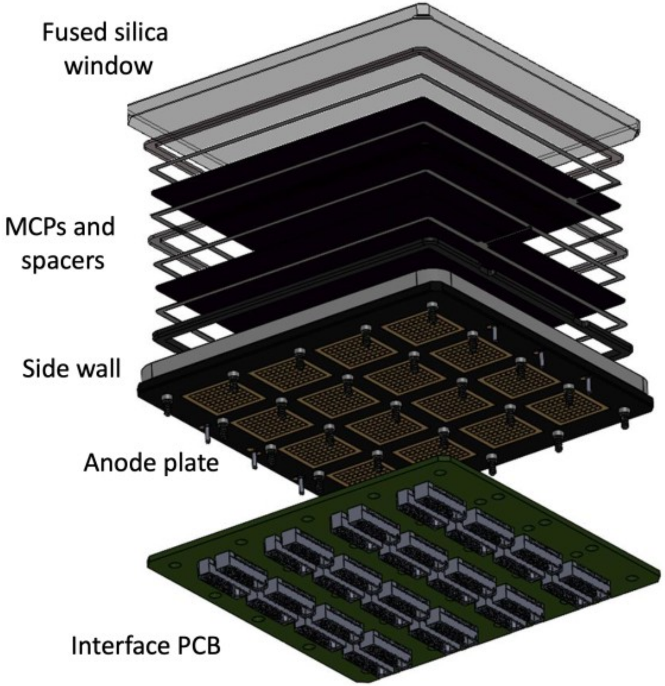
Detector requirements:

- Time resolution better than 100 ps (3σ separation between particle hypothesis pairs)
- Magnetic field tolerance of 1.4 T
- Radiation hardness - excess photons produced (in Aerogel radiator) by beam induced charged particles

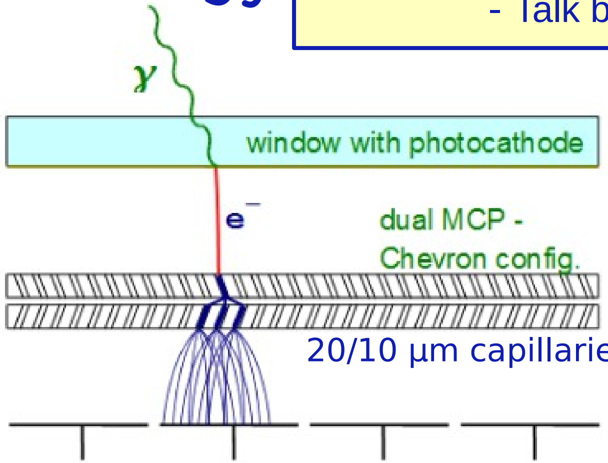
HRPPDs – baseline photosensors

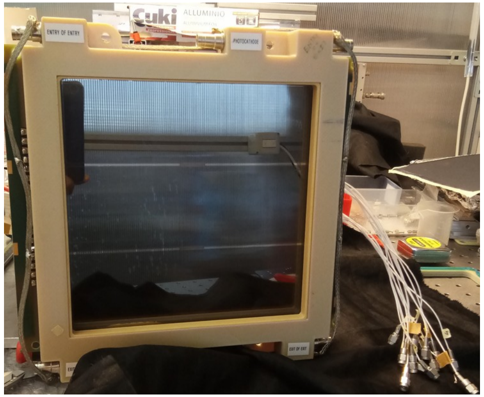
LAPPDs/HRPPDs- MCP technology

Status and perspectives of MCP-based photodetectors - Talk by Alexander Kiselev (17/09/2025)

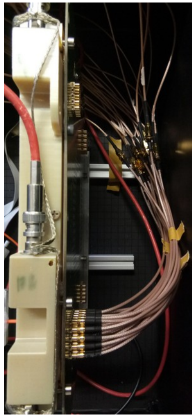


HRPPD (INCOM)
10 x 10 cm²





LAPPD #153
20 x 20 cm²



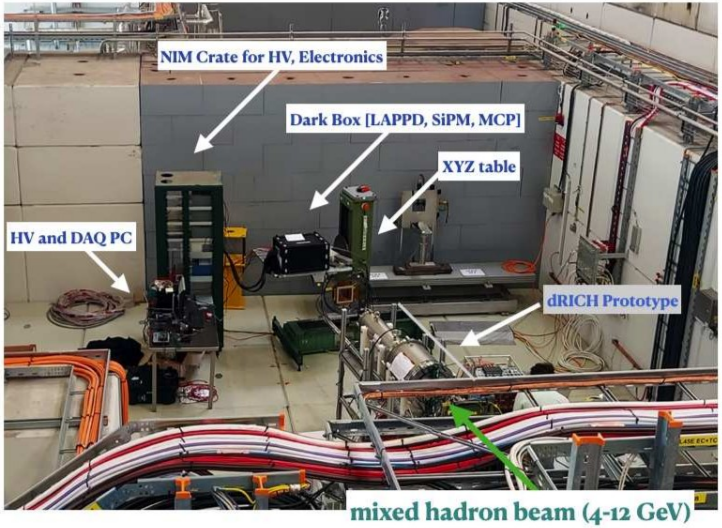
short stack

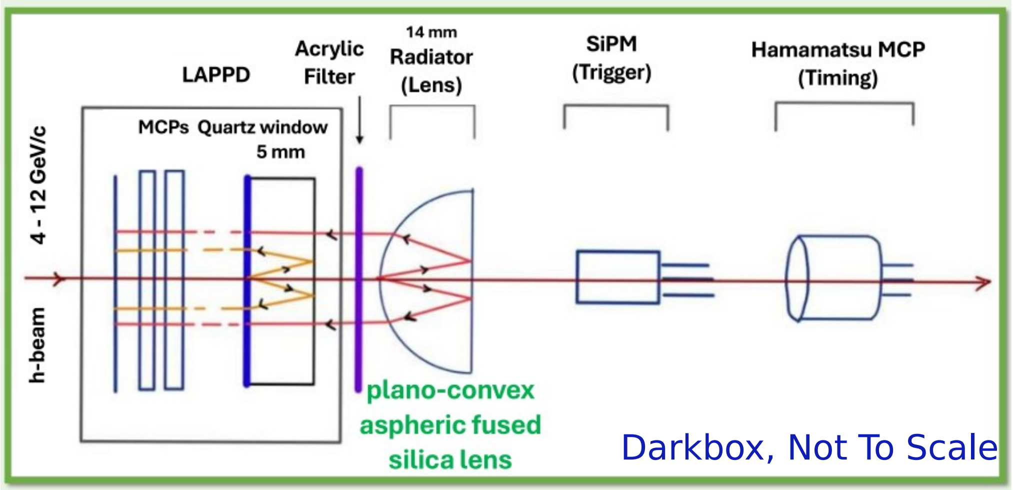
- High Gain > 10^6 (~10 kV/cm across each MCP)
- Excellent time resolution (< 100 ps) for SPE
- High Rate
- Low Dark Count Rates (few kHz/cm²)
- Radiation hard (ALD)

- LAPPDs – potential first step towards HRPPDs
- HRPPD – further compact

HRPPDs - optimal timing performances and good tolerance in **B**-fields

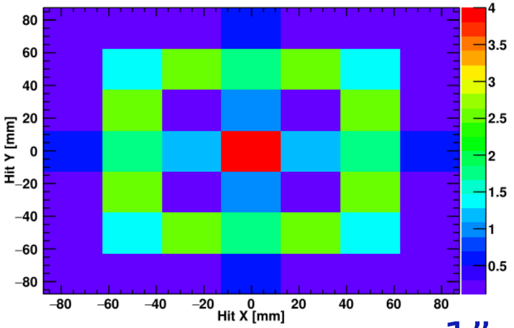
LAPPD timing studies (CERN PS T10 beams, 2022)



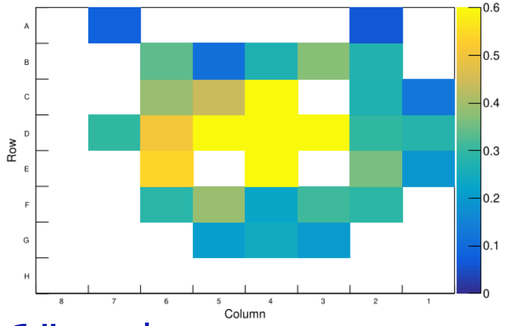


- Mixed *hadron beams* (4-12 GeV)
- Cherenkov photons produced in aspheric lens (ratiator) & LAPPD windows
- SciFi+SiPM as Trigger
- MCP (Hamamatsu) for timing reference
- CAEN V1742 digitizer module (DAQ)

Simulation

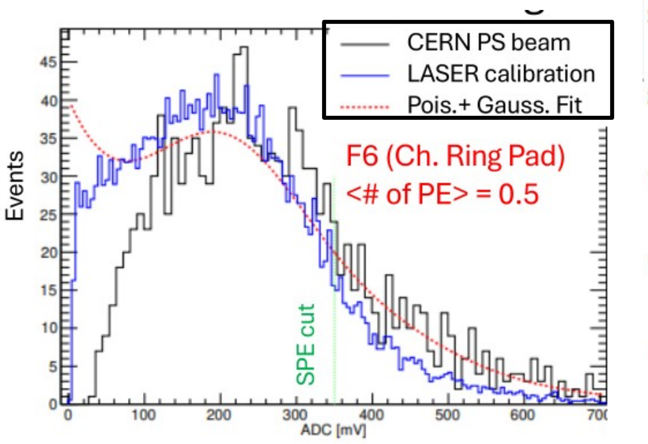


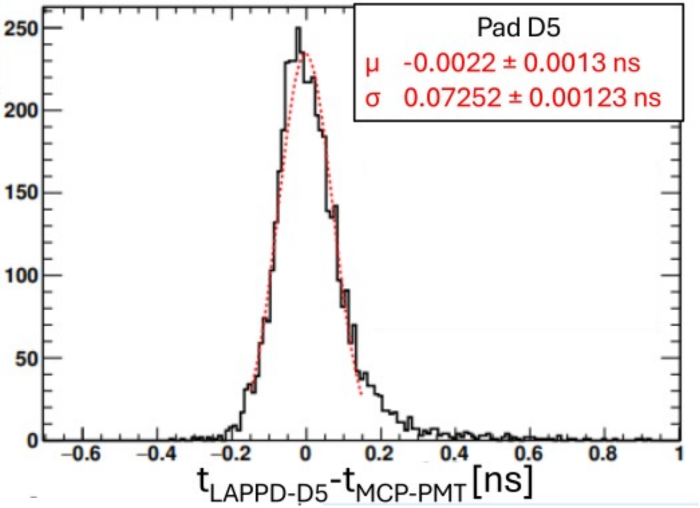
Data

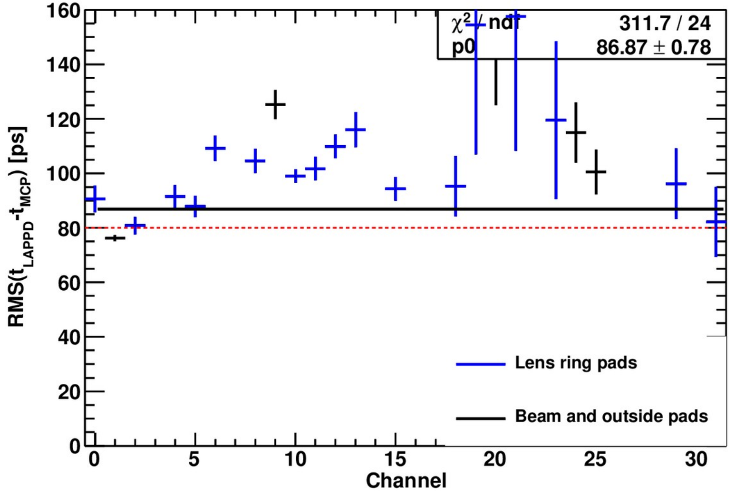


1” x 1” pads

LAPPD timing studies - results



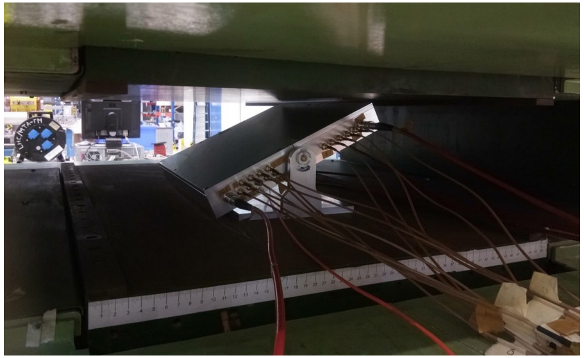




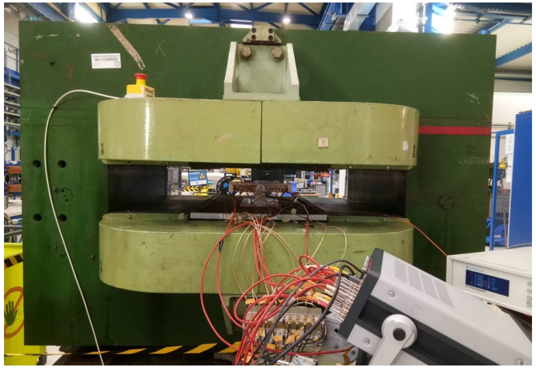
- 50% peak height as signal arrival time
- Transit Time Spread (TTS): Sigma of LAPPD signal arrival with respect to MCP signal arrival
- Dependency on pulse height and bias

Average TTS 87 ps

Tests at CERN magnets (2023, 2024)



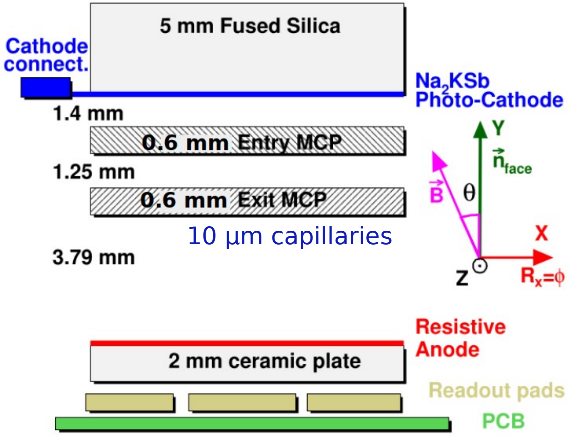
- Vertical dipole magnets, Current to **B**-field converter
- Water cooling system, room temperature operation



- Inclined Darkbox
- Picoquant pulsed laser (λ=405 nm),
- Laser Sync. out fast trigger for DAQ
- CAEN V1742 digitizer module

MNP-17
- 0.5 T
- field direction UP
- 30 cm aperture ~ ±40^0

M113
- 1.5 T
- field direction Up & Down
- 17 cm aperture ~ ±27^0



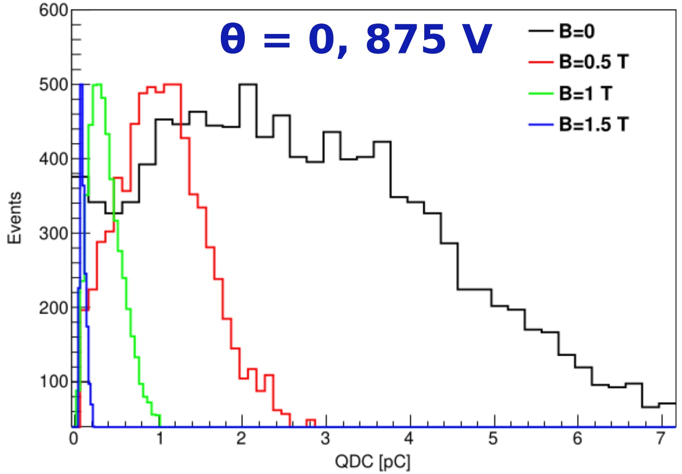
NOT TO SCALE

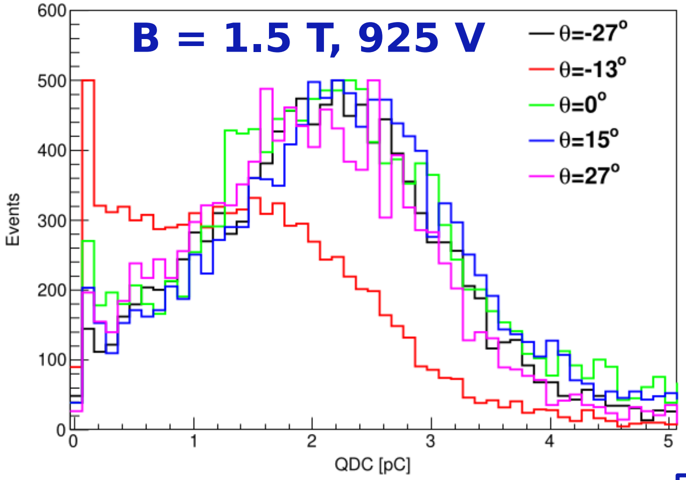
<u>θ in Chevron plain</u>

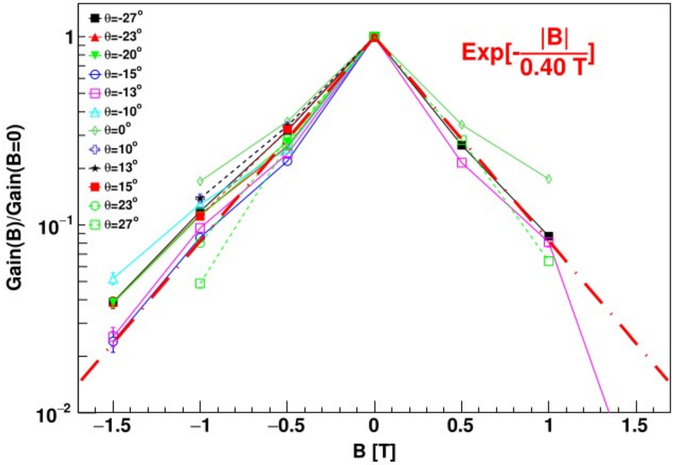
θ +ve when **B**-field along capillaries of Entry MCP

Integrated charge distribution and Gain vs. B-fields

Evident SPE peaks







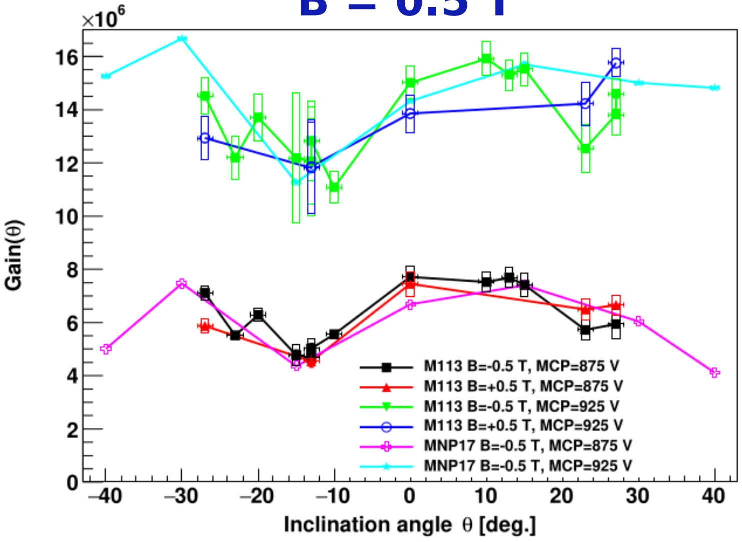
$$Gain(B) = Gain(0) \times e^{-\frac{|B|}{0.40\ T}}$$

- Integrated charge on all pads
- SPE peaks (Gain) shift towards zero in **B**-fields, recover with higher bias
- Weak angular dependence except at θ = -13⁰
- One order of magnitude gain drop from 0.5 T to 1.5 T

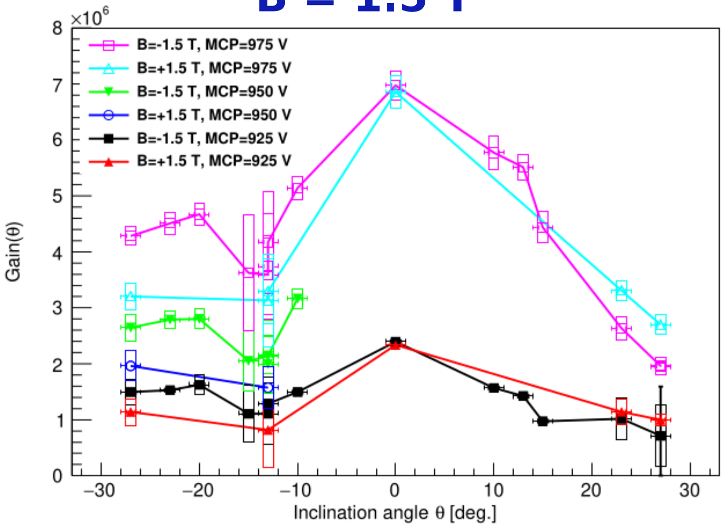
Gain drops exponentially with **B**-field strength

Gain vs. B-field rotation (θ)

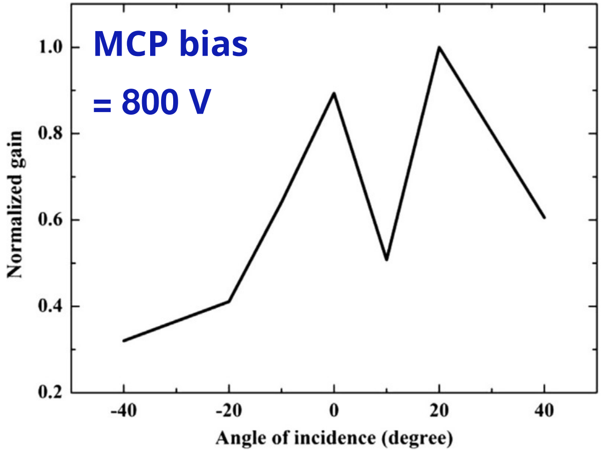
B = 0.5 T



B = 1.5 T



Simulation



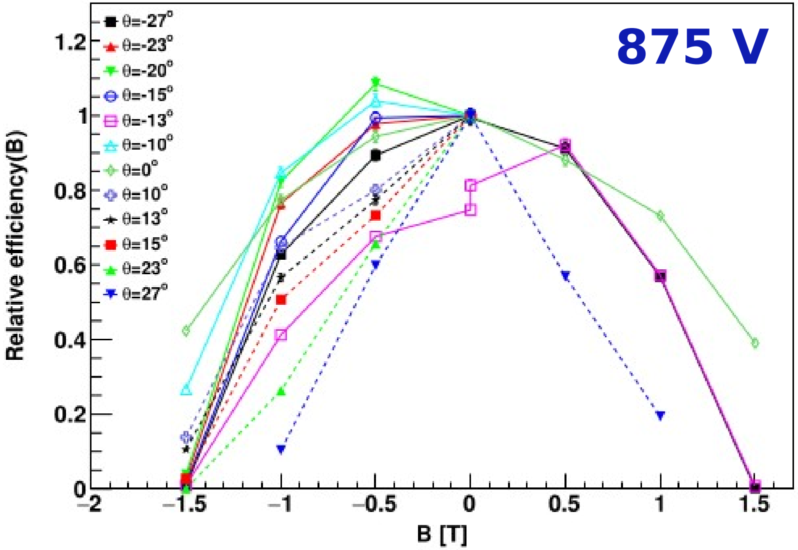
NIMA 827 (2016) 124–130

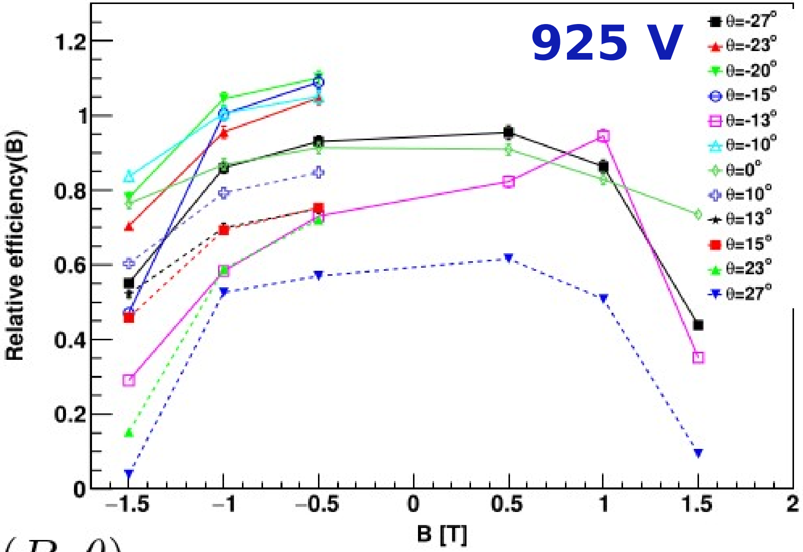
- Very small angular dependence at **B** = 0.5 T
- Some dependence at θ > 20⁰ and **B** ≥ 1.0 T
- Dips at -13⁰ are observed

- Simulation with one MCP (of +10⁰) of 10 μm capillaries for Juno experiment
- Dip at at +10⁰ is present

Qualitative agreement between simulation and data (Exit MCP)

Efficiency vs. B-field strength





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

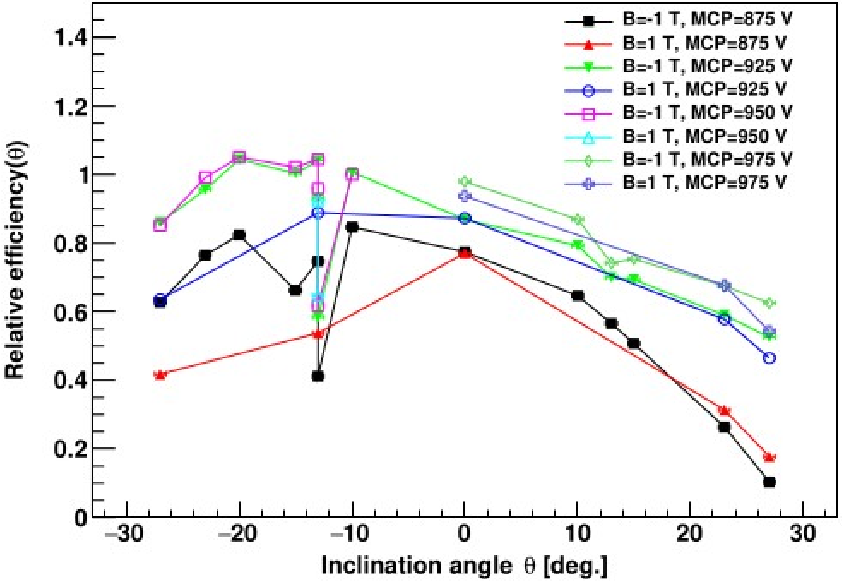
λ = <# of PE/pulse>

- ~ 30% suppression of relative efficiency from 0.5 T to 1.0 T@ 875 V
- Strong dependence on MCP bias, gain compensation by 50 V increase across MCPs

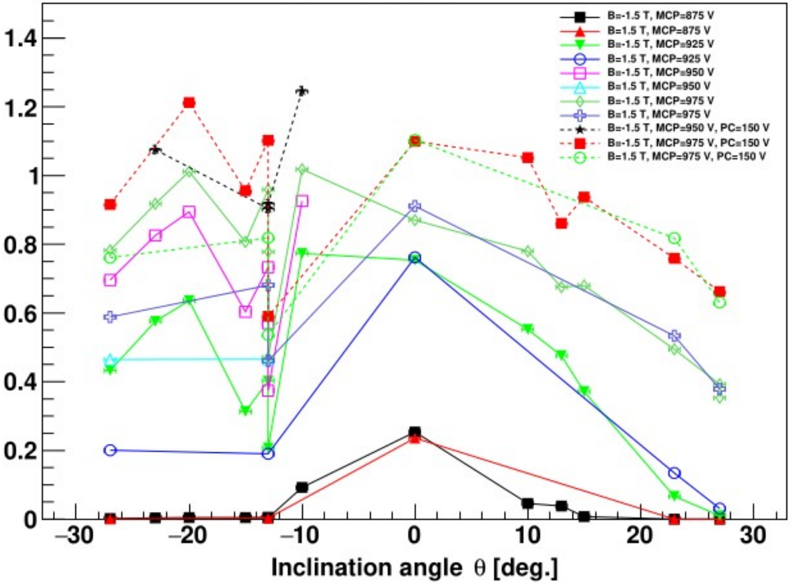
Relative efficiency strongly degrades with **B**-field strengths, recovers largely with higher MCP bias

Efficiency vs. B-field rotation (θ)

B = 1.0 T



B = 1.5 T

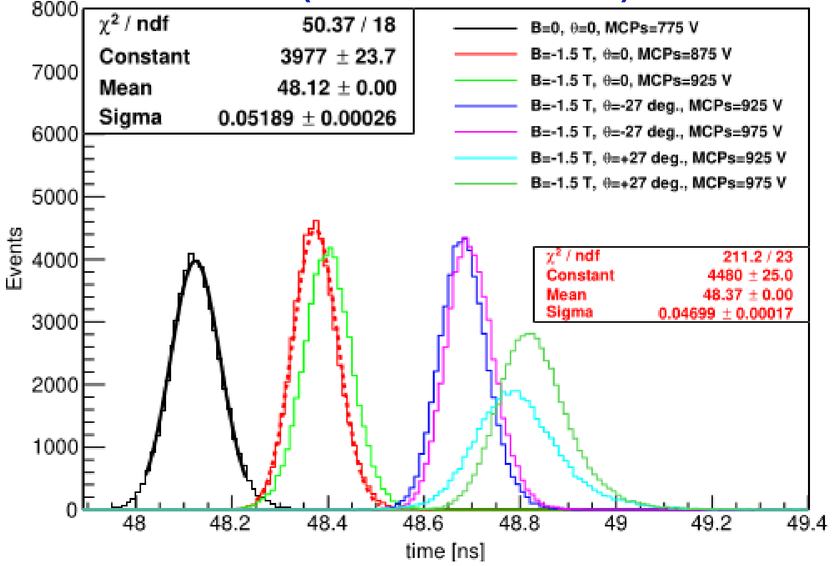


- Clear dip at -13^0 for all points in angular distribution
- Higher PC bias (increment by 100 V) recover the efficiency by ~15%

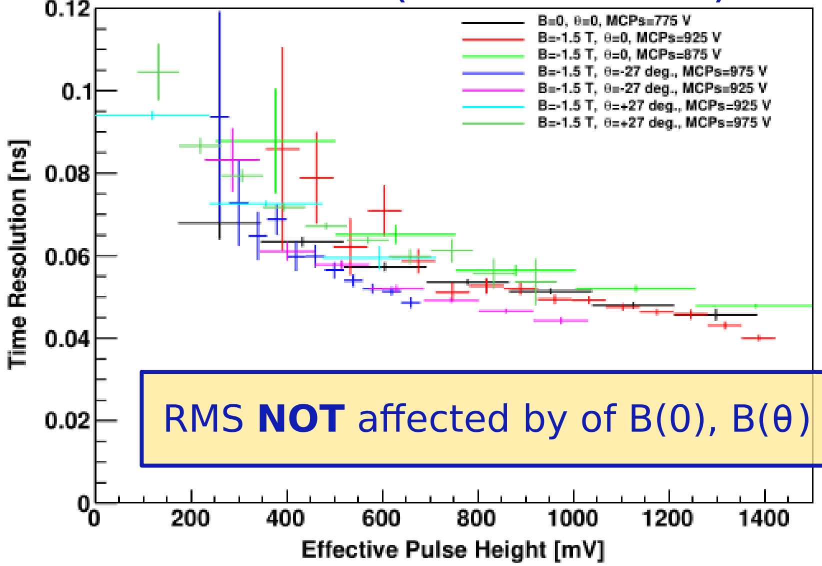
At -13^0 lower production of secondaries - electrons follow the **B**-field lines and don't hit the capillary walls

Timing response in B-field

Δt(LAPPD-Laser)



RMS OF Δt(LAPPD-Laser)



RMS **NOT** affected by of B(0), B(θ)

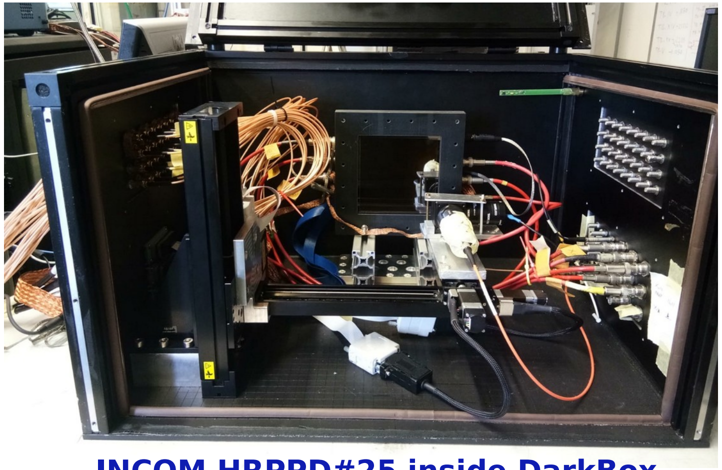
B	θ	Signal delay
1.5 T	0^0	250 ps
1.5 T	-27^0	557 ps
1.5 T	$+27^0$	665 ps

- Measured for few photo-electrons (Not SPE)

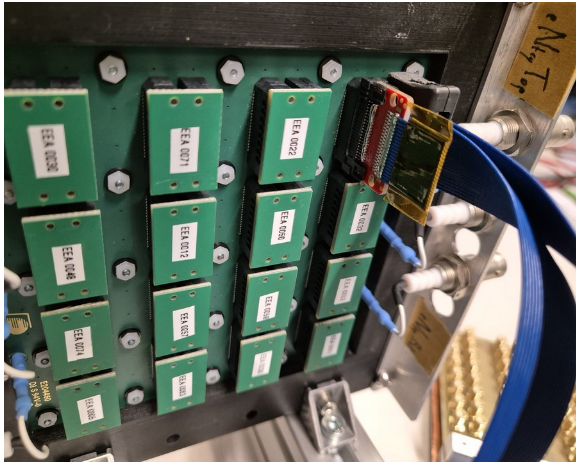
B-field introduces delay in LAPPD signals
Further delay for inclined **B**-fields (longer paths for e^-)

Characteristics of HRPPD#25

Ageing studies with HRPPD#25

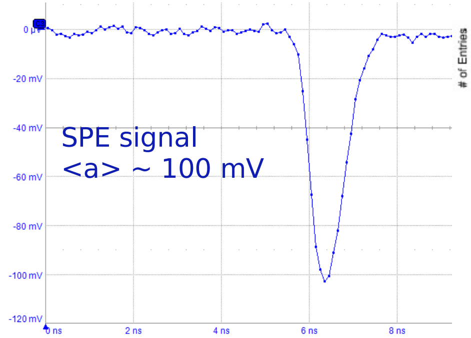


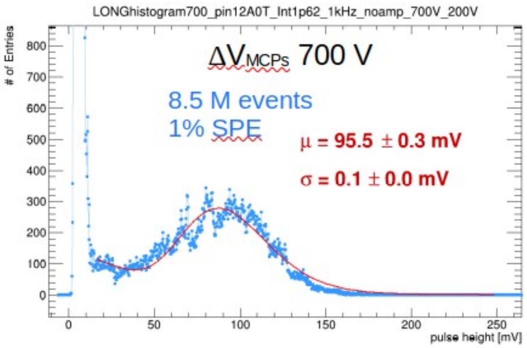
INCOM HRPPD#25 inside DarkBox

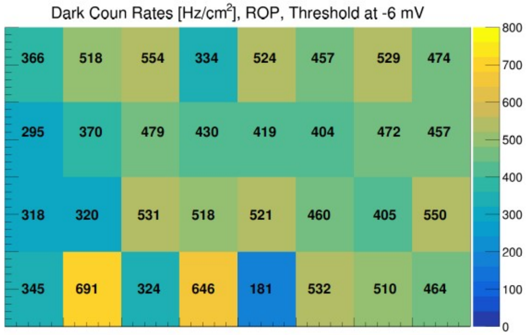


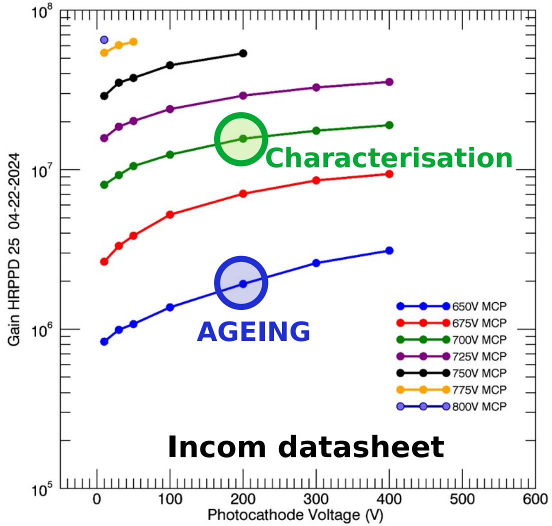
HRPPD#25 Backplane

- 10 x 10 cm², Two MCPs in a Chevron pair, 10 µm pores
- Direct coupled 1024 Anode pads 3 x 3 mm²
- Gain: 1.5 x 10^7 (@ ROP: 200_700_200_700_200V)
- DCR few kHz @ ROP (TH 4mV)

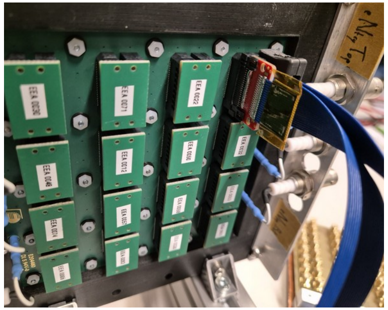


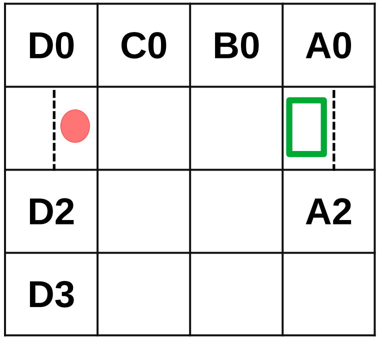


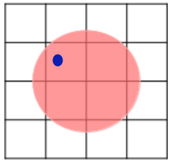


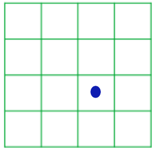


Measurement strategy and protocol









AGEING D1B **REFERENCE A1T**

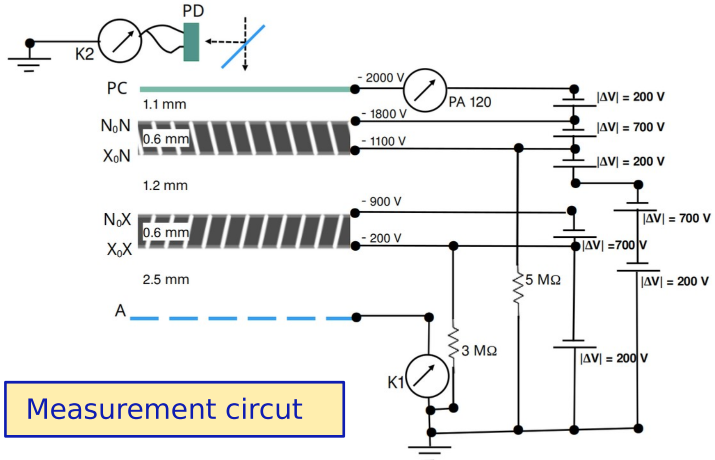
r_{AGEING}: 5.32 mm

$r_{FOCUSED}$: <0.5 mm

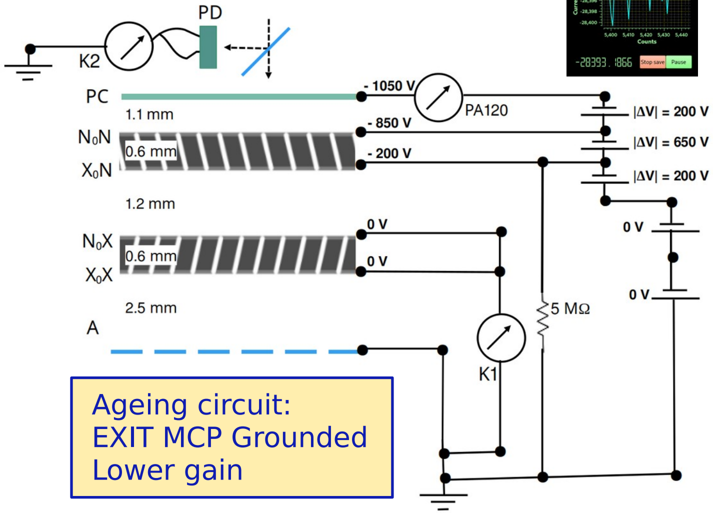
10^{14} photons/cm^2 in 10 years at ePIC (simulation)

10 years → 10 days in lab **(*Accelerated ageing*)**

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

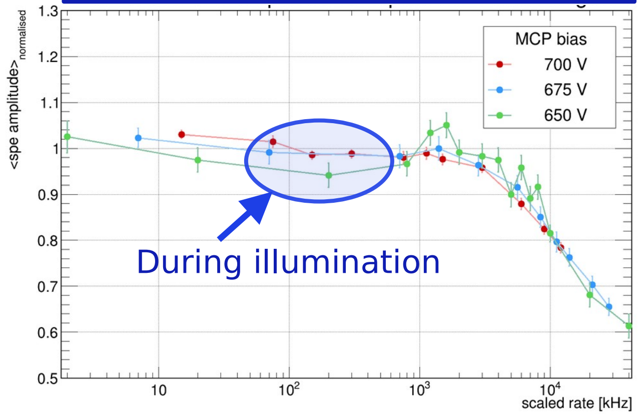


Measurement circut

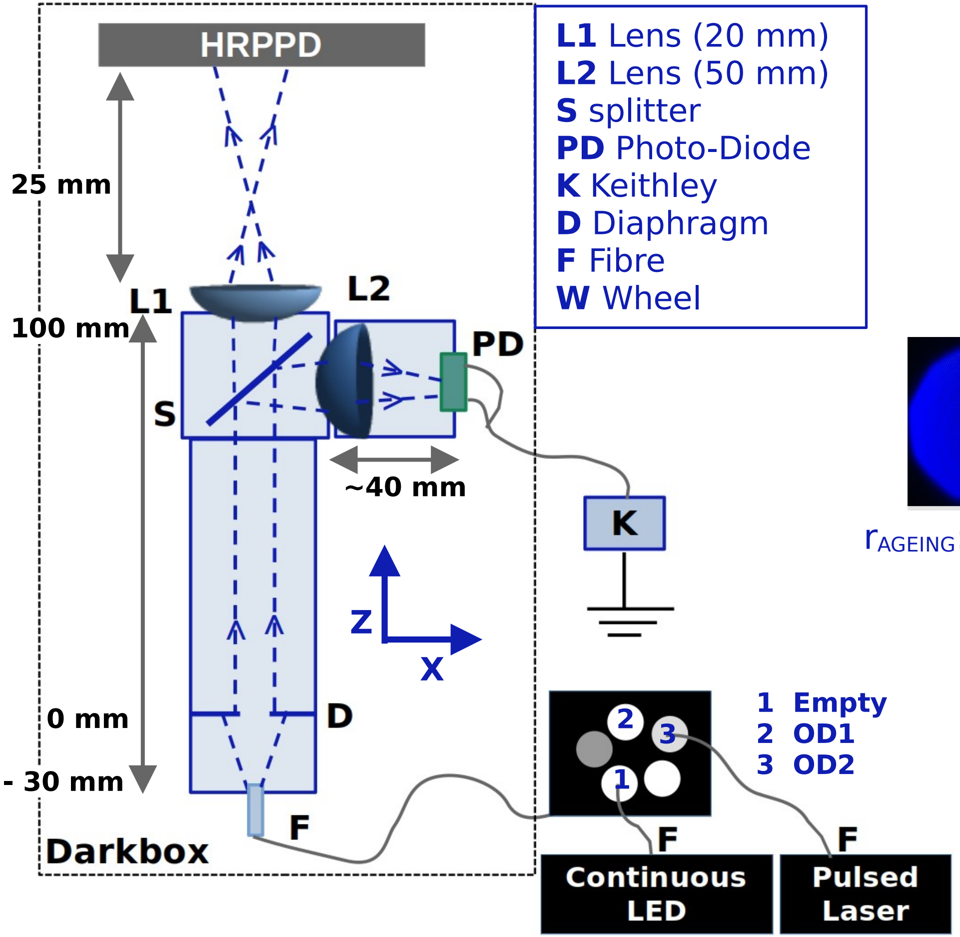


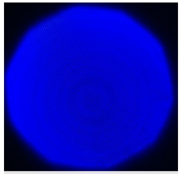
Ageing circuit:
EXIT MCP Grounded
Lower gain

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



Optics setup





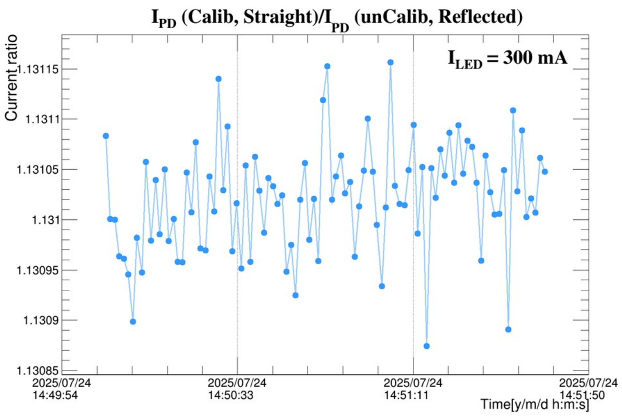
r_{AGEING}: 5.32 mm

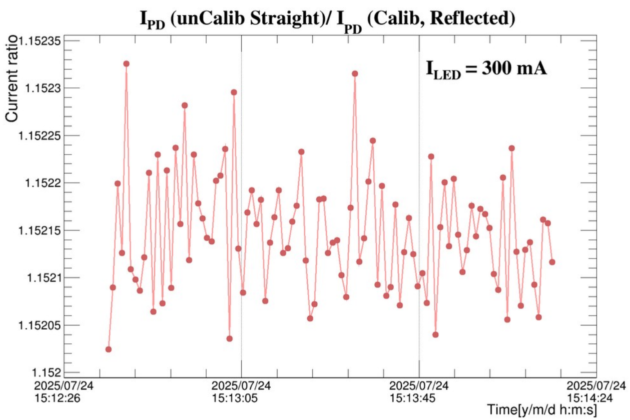
- Optics installed on movable (XYZ) system
- Same optics at two different Z positions – focused/ defocused spots
- Same optics at two different X positions – Ageing/Reference region

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

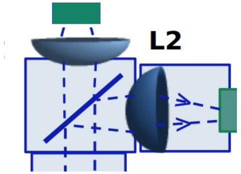
Same optics for ageing and intermediate measurements

Photon flux

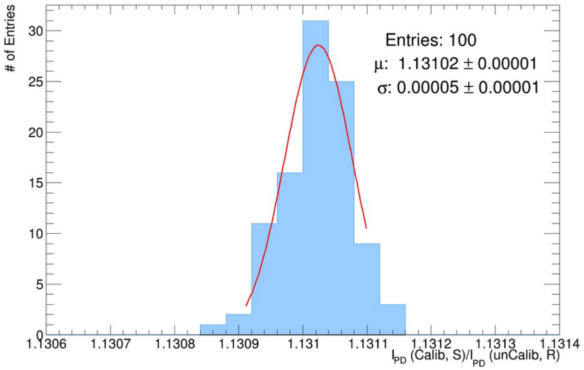


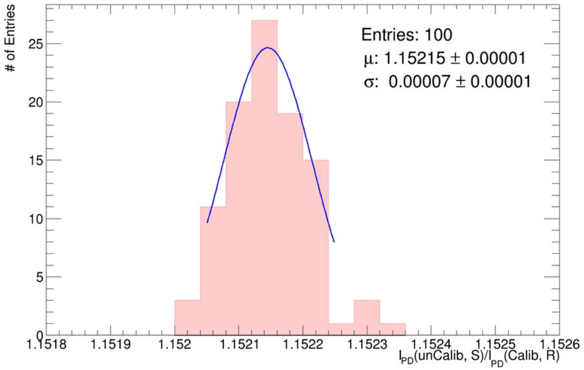


PD (S) In place of HRPPD



PD (R) Monitoring photon flux

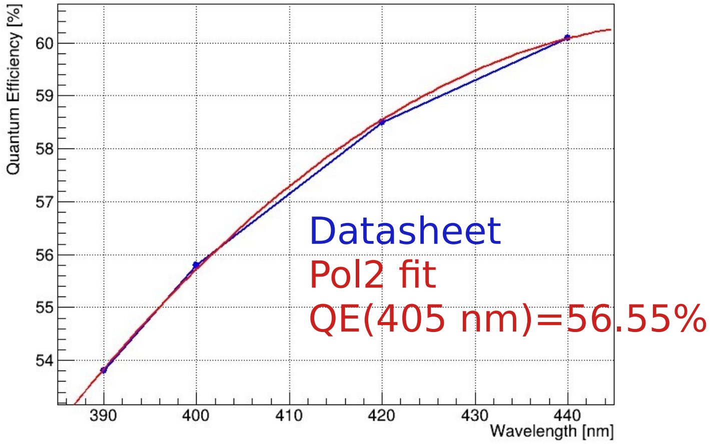




SR = sqrt(I1/I2 x I3/I4)
= 1.14154 ± 0.00001

CC = sqrt((I1/I2) / (I3/I4))
= 0.99079 ± 0.00001

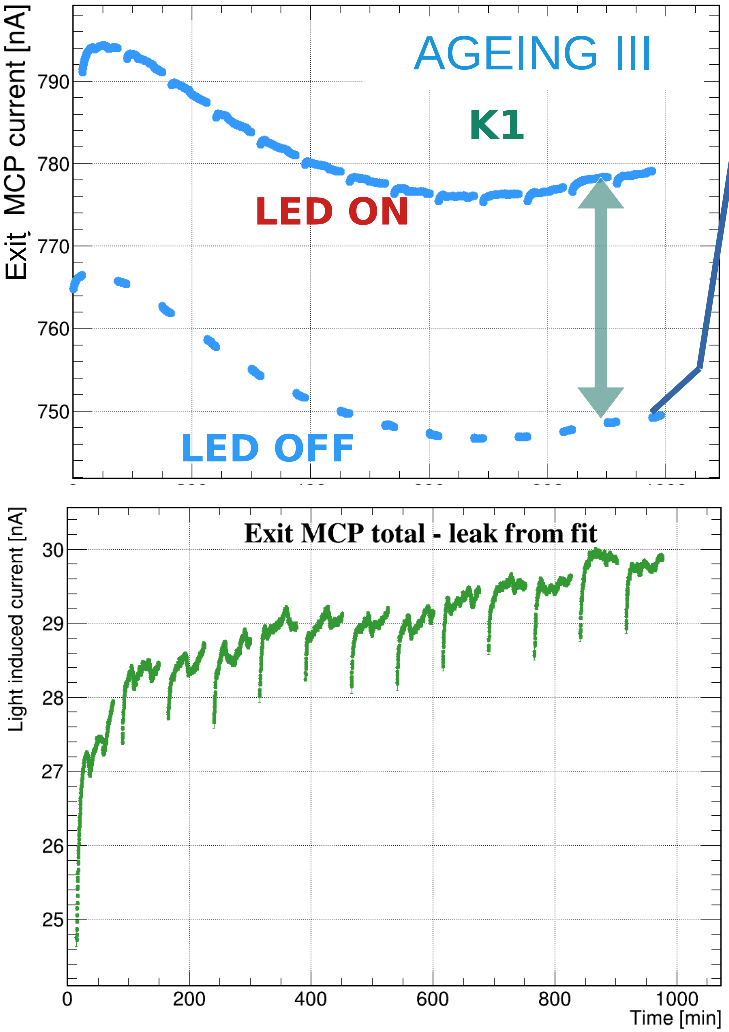
Calibrated PD (HAMAMATSU)

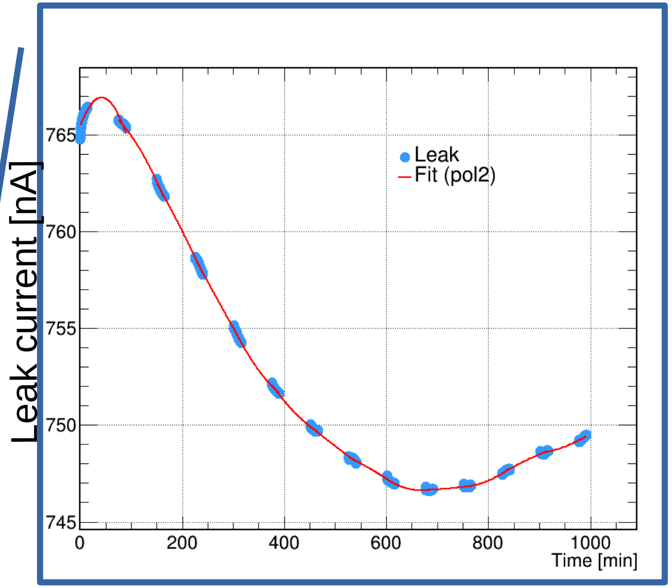


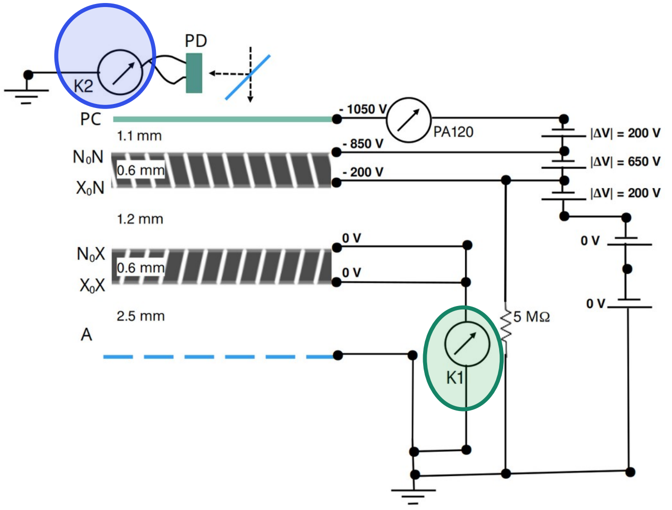
QE (405 nm) of unCalib PD
= 0.99079 x 56.55%
= 56.03%

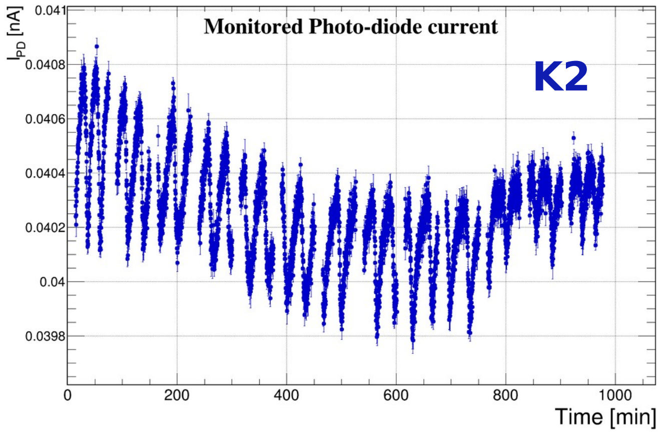
Good control of input illumination

Ageing







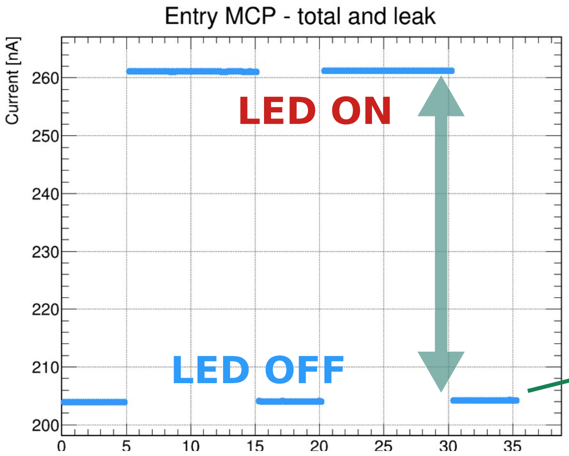


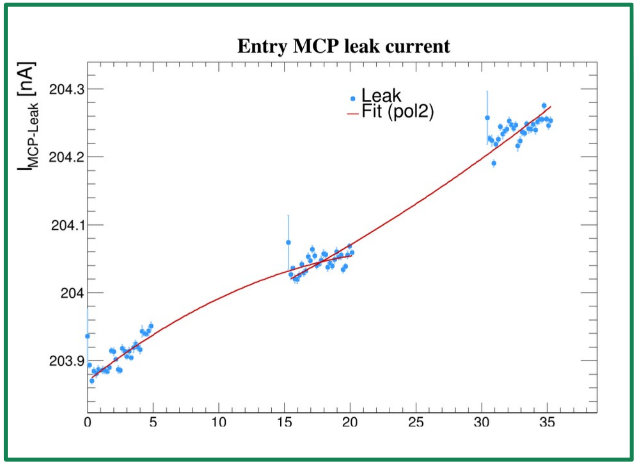
- Ageing tests: (11/08/2025 to 11/09/2025)
- Eight illuminations
- Nine measurements: 1 Before+7 Intermediate + 1 After

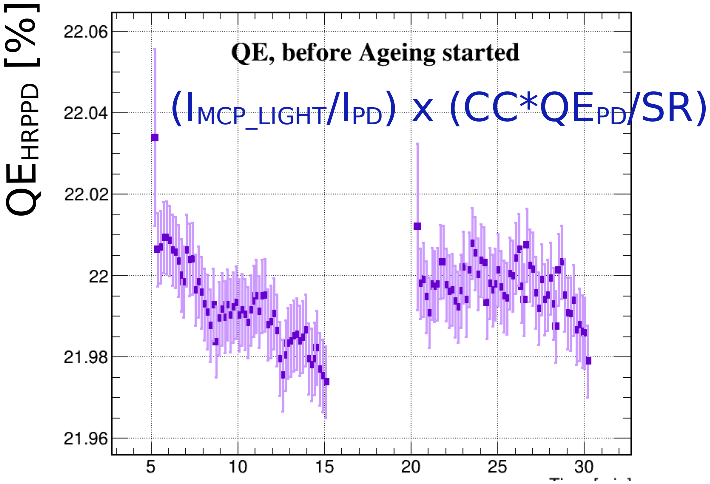
QE average

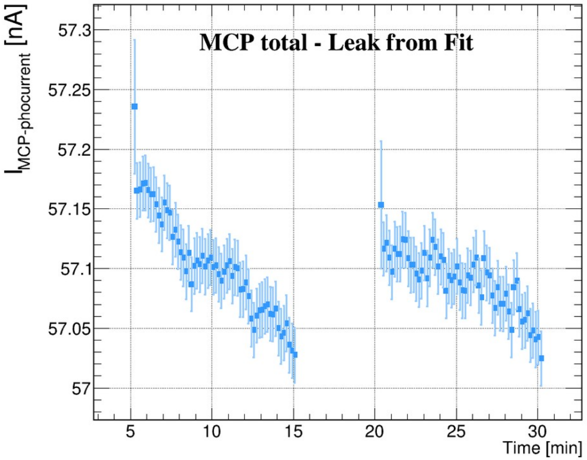
Average QE (defocused) – Ageing region – Before Ageing started

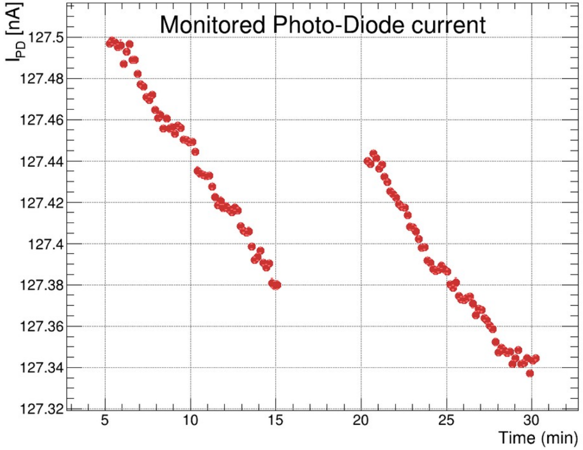
50 V @ the PC, rest electrodes are NOT on HV

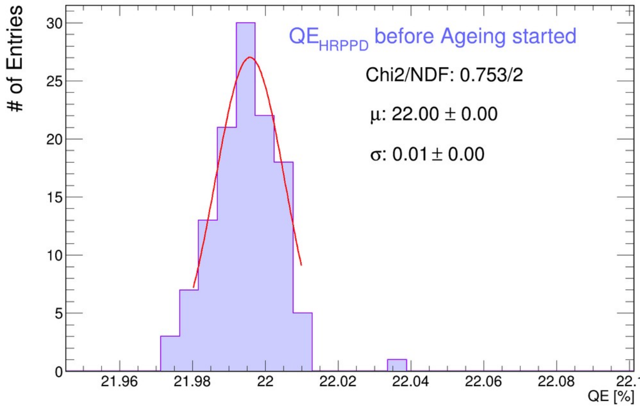






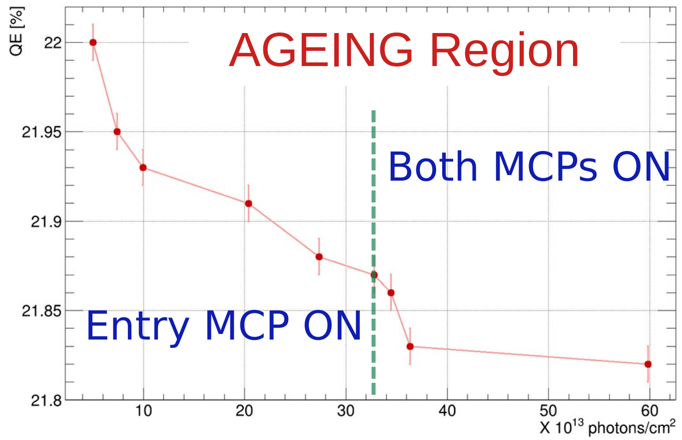


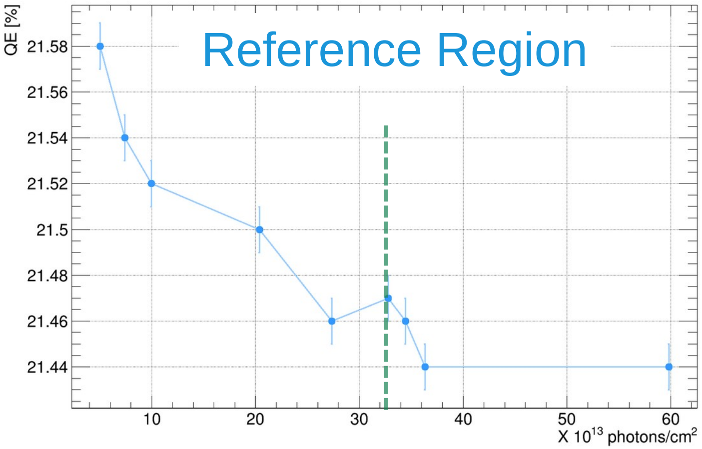


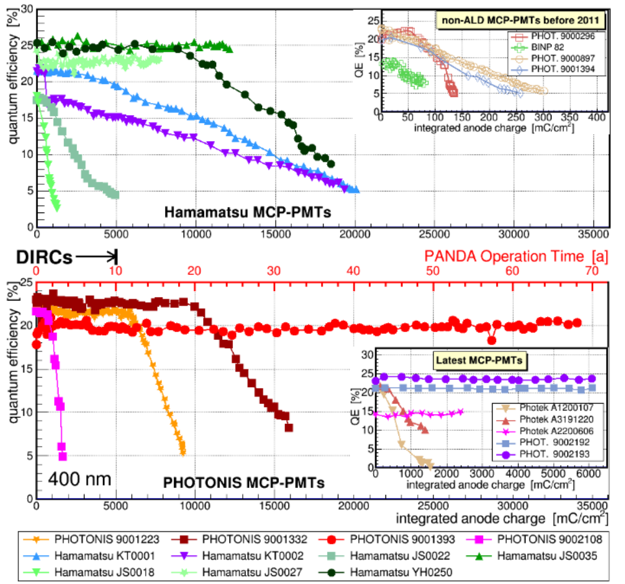


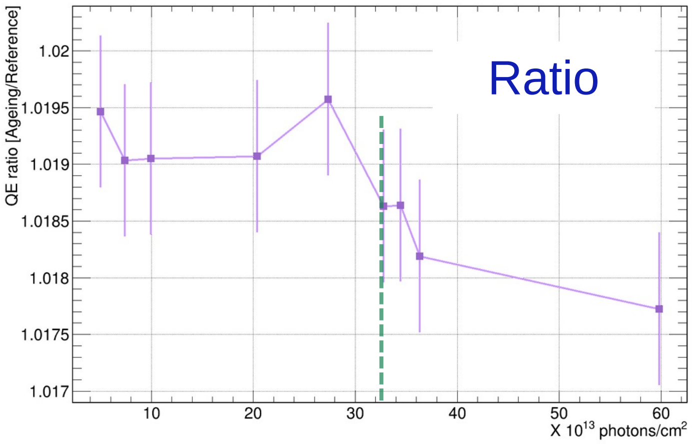
QE average vs. integrated photon fluence

Preliminary Results









8.5 pA in Photo-diode (Reflected position) for 24 hours
→ 1 year equivalent (10^{13} photons/cm^2)

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

Conclusion

- SPE timing resolution for a Gen.II LAPPD (20 µm) was measured (CERN PS) to be ~80 ps.

- Response of an LAPPD (10 µm) in magnetic fields (CERN) was measured:
  - LAPPD gain drops exponentially with **B**-field strength.
  - Reduction in effective PDE.
  - Both the gain and PDE partially recovered with 50/100 V increase across the two MCPs.
  - Time delay for normal (~200 ps) and inclined **B**-fields (~500 ps).

- Ageing studies with an HRPPD unit ongoing in Trieste laboratory:
  - 6 x 10^{14} photons/cm^2 have been illuminated.
  - First measurements show few ‰ degradation of average QE in 60 years of expected equivalent ePIC run.
  - Similar effect in reference region - NO clear evidence of ageing.

Thank you!

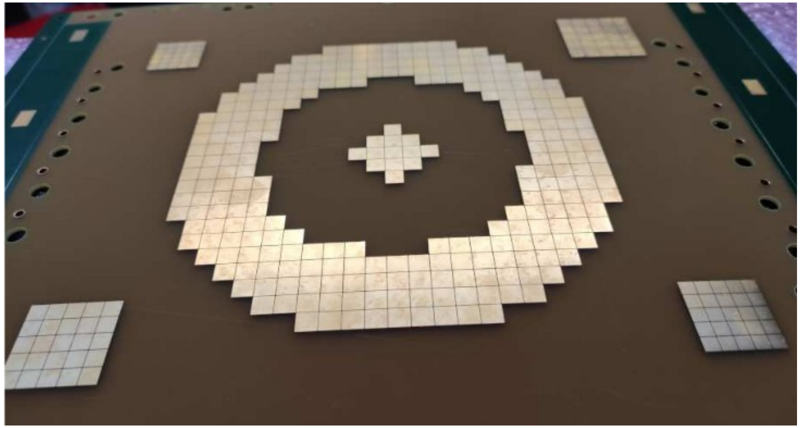
Back up Slides

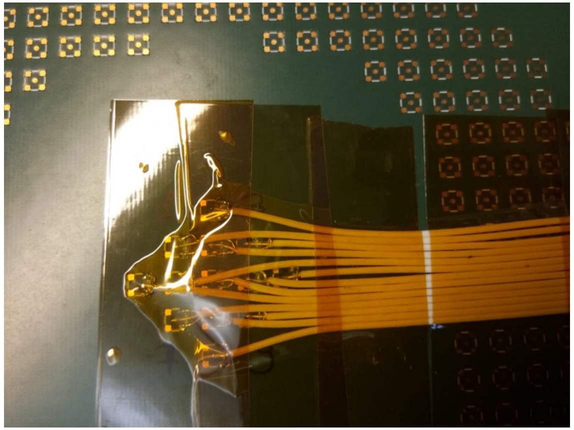
LAPPD #153 MCP features & performance

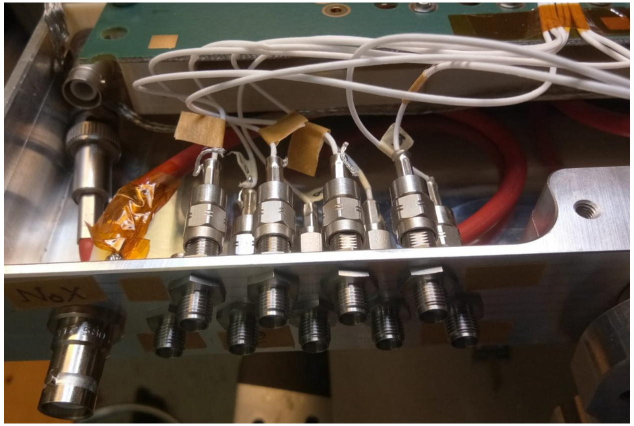
LAPPD 153 Microchannel Plate (MCP) Features & Performance

MCPs	Two Arranged in a Chevron Pair
Dimensions	203 mm x 203 mm X 1.2 mm
MCP Substrate	Incom C5 Glass
Capillary Pore Diameter (µm) Center to Center Pitch (µm)	10 13
Channel Length / diameter Substrate Thickness (mm)	60:1 0.6
Bias Angle	13
Capillary Open Area Ratio	≥65%
Resistive and Emissive Coatings	Chem 1, Applied via Atomic Layer Deposition (ALD)
Secondary Emission (SEE) Layer Material	MgO
Electrode Penetration – Input & Output (Pore Diameter)	0.5-1.0
MCP ID (Entry / Exit)	CJ19574001-007 / CJ19574001-027
MCP resistance, Entry/Exit (at LAPPD M&T)	5.5/5.6 MΩ at 900 V
MCP Dark Rate in the tile (Obtained by setting the photocathode more positive than the entry MCP)	5.7 Hz/cm^2 at a threshold of $8x10^5$ gain (134 fC), 900 V/MCP, 10 V positive on photocathode [A]
Max Voltage	900/900 V/MCP (entry/exit), with -2,210 volts on the photocathode; dark rate limited.

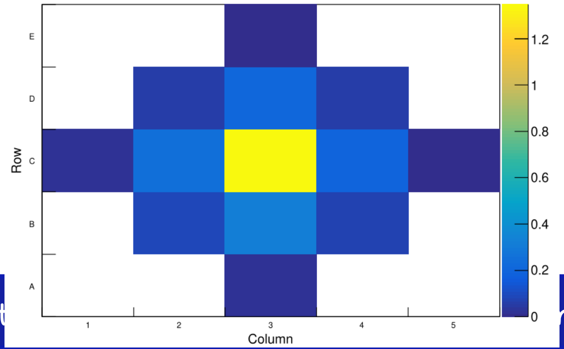
Readout - magnetic field tests

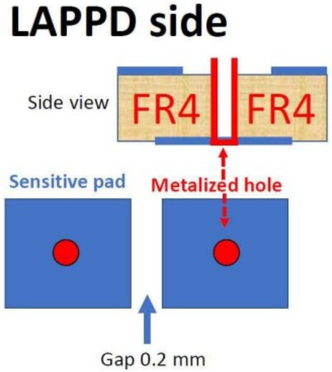




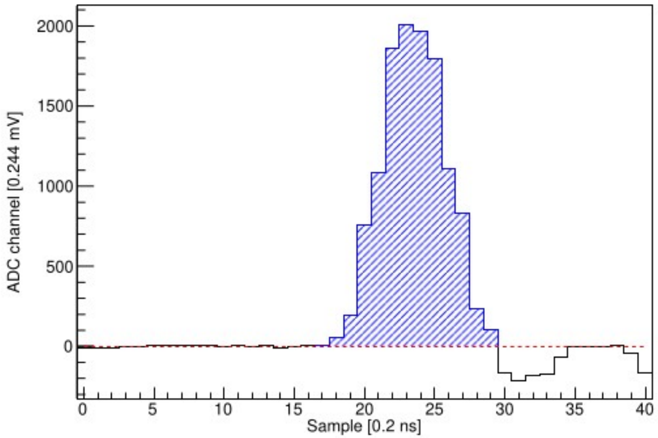


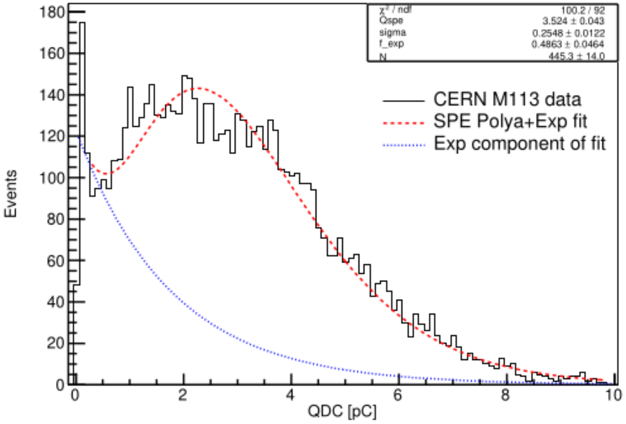
- LAPPD capacitively coupled with custom-designed (INFN-GE) RO PCB
- Central 13 pads (6 mm x 6 mm)
- Coaxial cables (SMA connector on one side) soldered on the pads
- Custom-designed (INFN-GE) amplifiers 1 GHz, 20 dB gain, 0.22 mV noise, <0.2% cross-talk

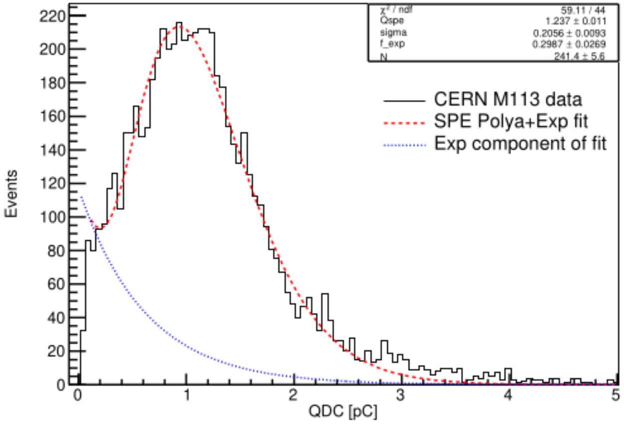




Collected charge and gain







Threshold 10 mV, 0.05 pC

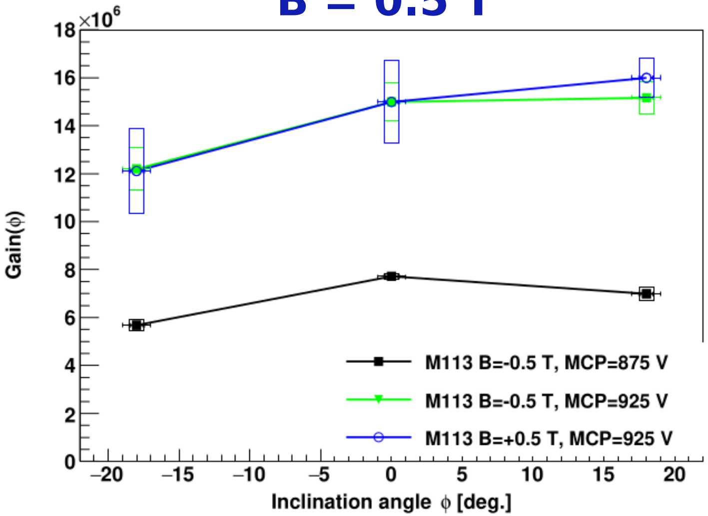
Red line shows average base line

$$QDC(q,\mu,\sigma) = \frac{1}{\sigma\Gamma(\frac{\mu}{\sigma})}\left(\frac{q}{\sigma}\right)^{\frac{\mu}{\sigma}-1} e^{-\frac{q}{\sigma}}$$

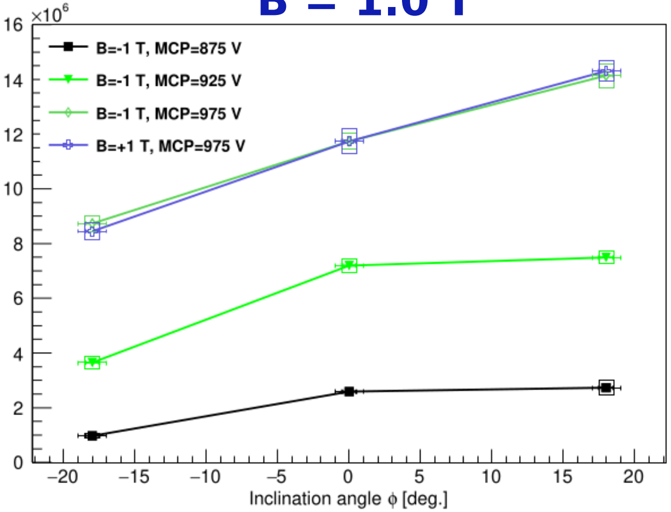
Gain vs. B-field rotation (ϕ)

Inclination in transverse plane
Out of Chevron plane

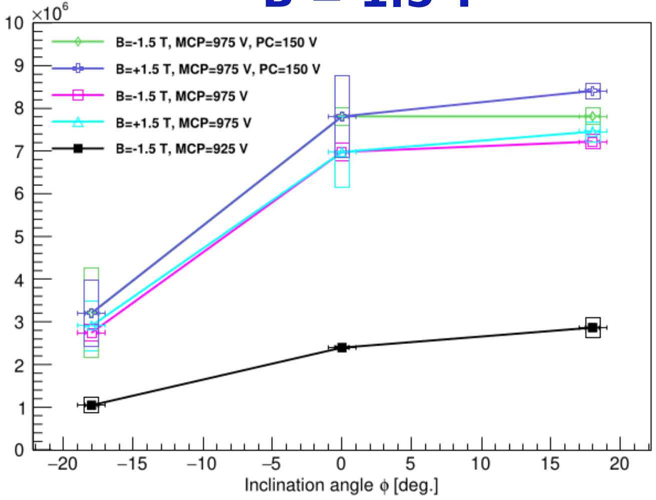
B = 0.5 T



B = 1.0 T



B = 1.5 T



- Non-symmetric behaviour though the LAPPD geometry is symmetric!
- Absolute gain suppression by ~factor 2, at – 18^0 for B = 1.5 T
- Geometrical mismatch between Entry and Exit MCPs??

Studies with HRPPD #25 in M113 magnet at CERN in Oct. 2025

Efficiency definition

$$p(B,\theta) = \frac{N_{coin}(B,\theta)}{N_{trig}(B,\theta)} \ , \quad p(B=0) \simeq 0.057 \pm 0.0015 \ . \tag{3}$$

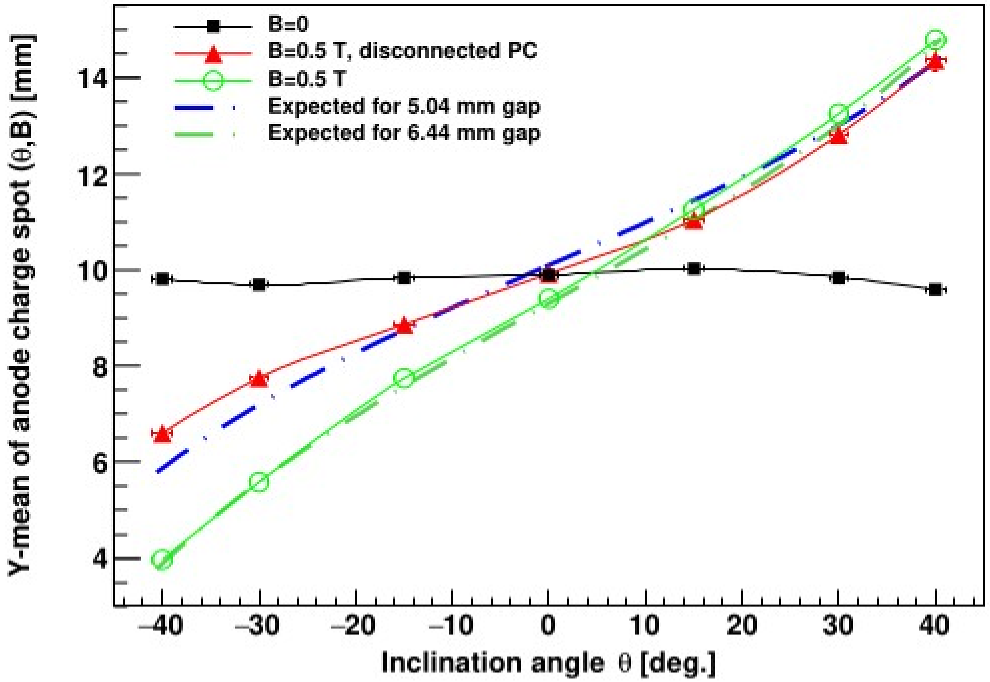
From the probability above we can estimate the mean number of PE per laser pulse:

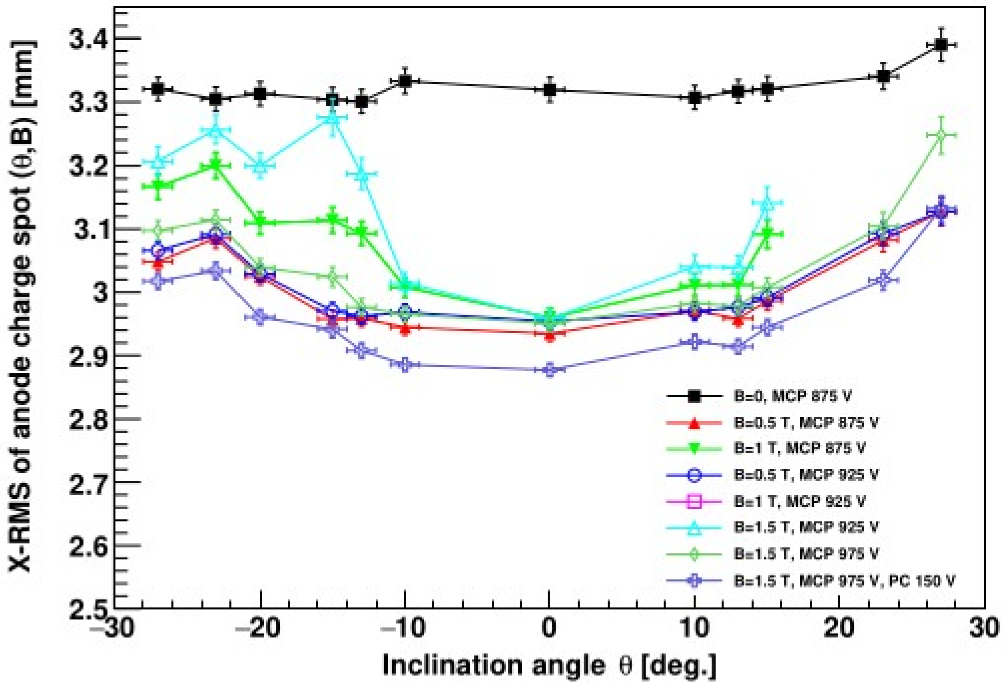
$$\lambda(B,\theta) = -\ln\left[1 - p(B,\theta)\right] \simeq p(B,\theta) \ . \tag{4}$$

Since the number of observed PE is proportional to the Photon Detection Efficiency (PDE), the relative efficiency of LAPPD in magnetic field can be estimated by:

$$\varepsilon_r(B,\theta) \simeq \frac{\lambda(B,\theta)}{\lambda(B=0)} \ . \tag{5}$$

Charge spot position vs. B-field inclination (θ)





One PDE scan - HRPPD ageing studies