LAPPD/HRPPD Studies

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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 response in magnetic fields – CERN, October 2023 and March 2024
  J. Agarwala, et al., NIMA (2024) 170122
  - Motivation
  - Detector characteristics and schematics
  - Experimental setup and results

- HRPPD ageing studies – Trieste laboratory 2025 (Preparation at final stage)
  - Motivation
  - Experimental setup and measurement protocol

Context and Motivation

Large **A**rea **P**icosecond **P**hoton **D**etectors
High **R**ate **P**icosecond **P**hoton **D**etectors

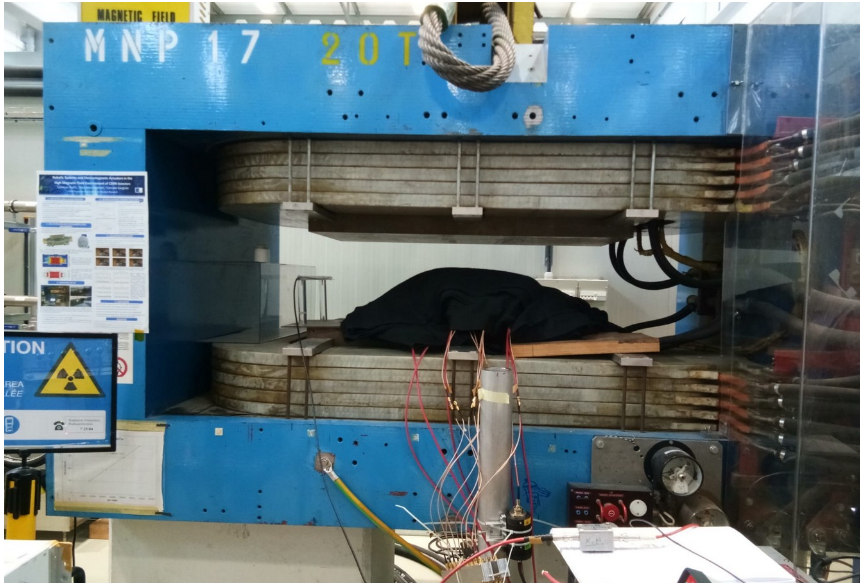
→ Large sensitive area
Micro-**C**hannel **P**late-PMT technology

- HRPPDs - photosensor candidates for pfRICH sub-detector in ePIC
- PfRICH application requires about 1.4 T magnetic field tolerance
- Response of MCP-PMT based detectors get affected in magnetic fields

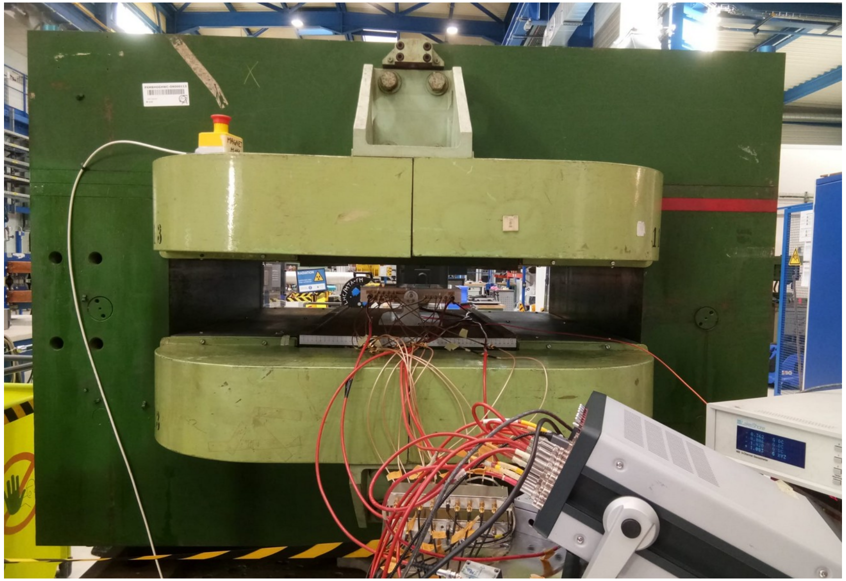
- We measured (up to 1.5 T)
  - Degradation in gain and relative **P**hoton **D**etection **E**fficiency (PDE) as a function of **B**-field strength and angular distribution
    - ✓ Partial recovery by increasing MCP bias voltages
  - Geometrical effect on the anode charge spot
  - Time response (delay in **B**-fields)

Studies at CERN

- Vertical dipole magnets, Current to **B**-field converter, water cooling system
- Operation in room temperature
- 3D Hall probe to check the field strength



- MNP-17, 0.5 T, field direction - UP
- 30 cm aperture allows ~ $\pm 40^0$

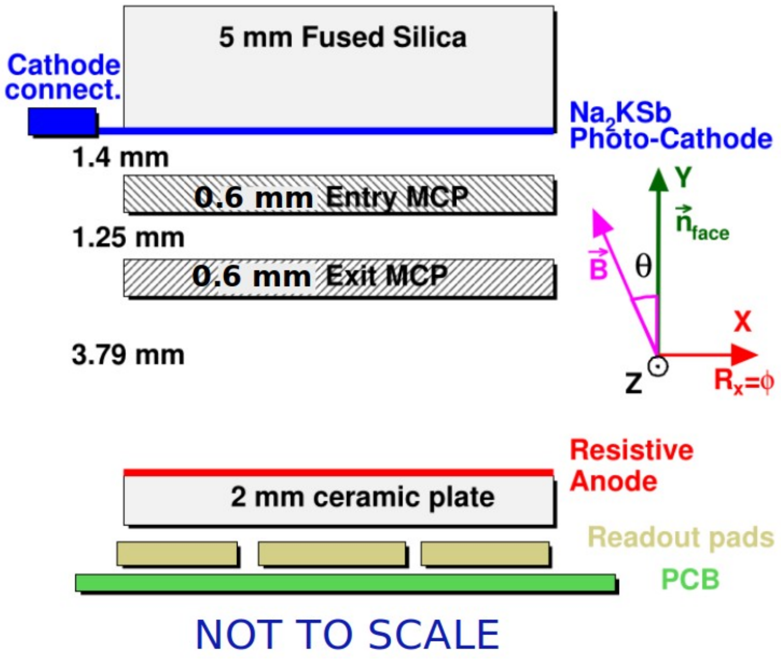


- M113, 1.5 T, field direction – Up & Down
- 17 cm aperture allows ~ $\pm 27^0$

LAPPD #153 (Gen. II) - characteristics and schematics

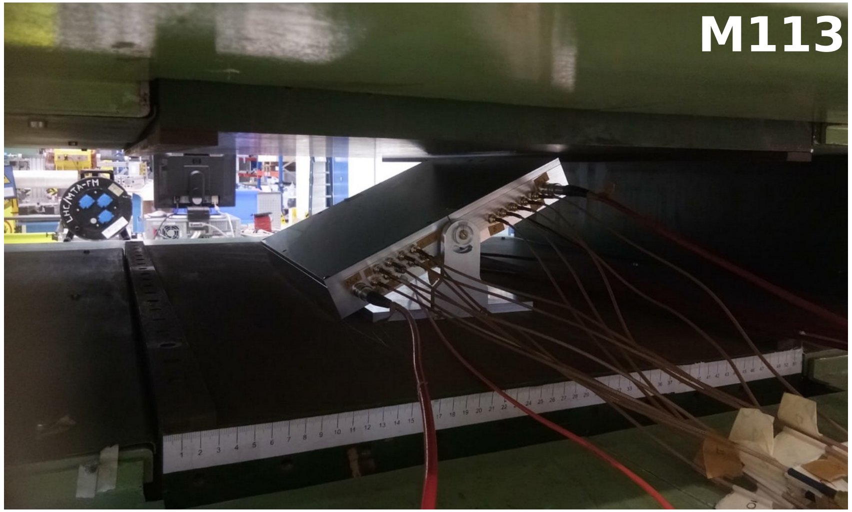
https://incomusa.com

- ~ 200 x 200 x 15 mm^3, short stack
- Two MCPs in Chevron pair of 13^0, 10 µm capillary
- HV bias: ROP of 200-875-200-875-50V
- Gain @ ROP: ~7.5 x 10^6
- <QE> @405 nm: 18.0%, Max. @365 nm ~25%
- Dark Count Rates (2.1 kHz/cm^2 at ROP, threshold 4 mV)

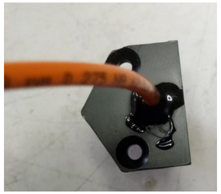


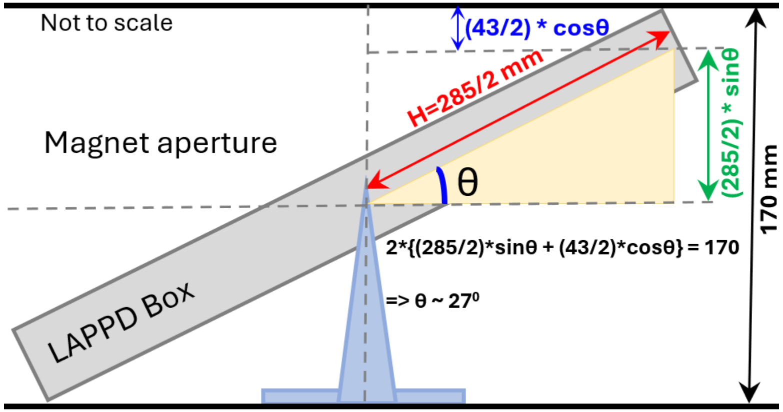
θ is in Chevron plain
θ is +ve when **B**-field is along the capillaries of Entry MCP

Experimental setup



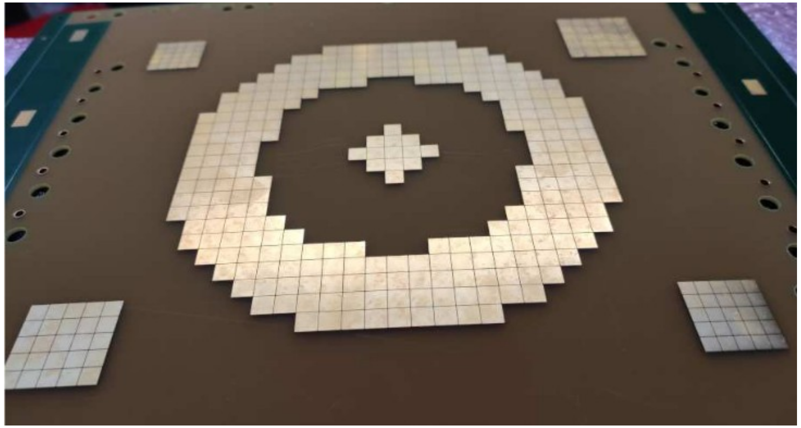
Light propagation from laser to box through Multi-mode fibre

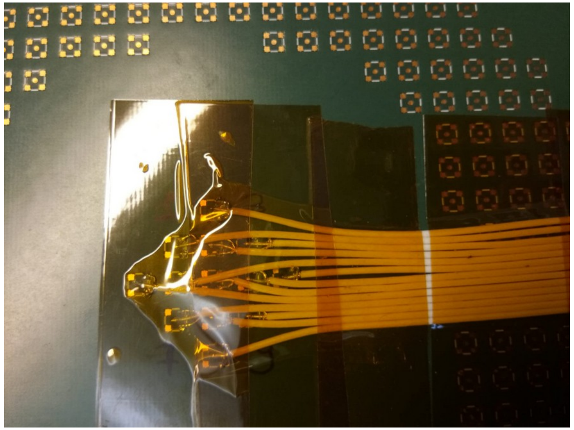


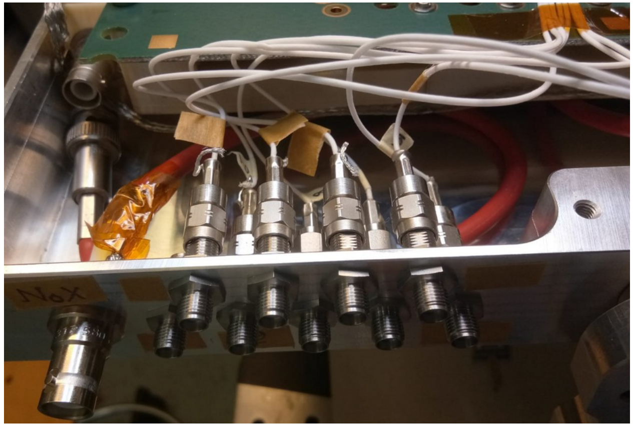


- Darkbox (380 x 285 x 43 mm^3), external support facilitates inclined configuration
- PicoQuant pulsed laser (λ=405 nm) driven by PDL 800-D, external trigger mode
- Synchronisation output pulse of laser controller used as the fast trigger for DAQ
- CAEN V1742 digitizer module installed in a VME crate
- DTE1415 CAEN power supply

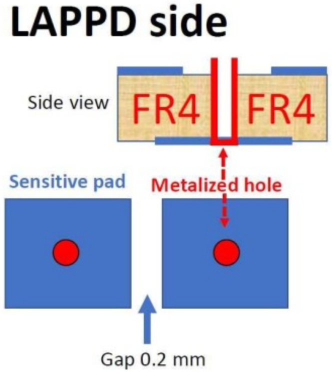
Readout





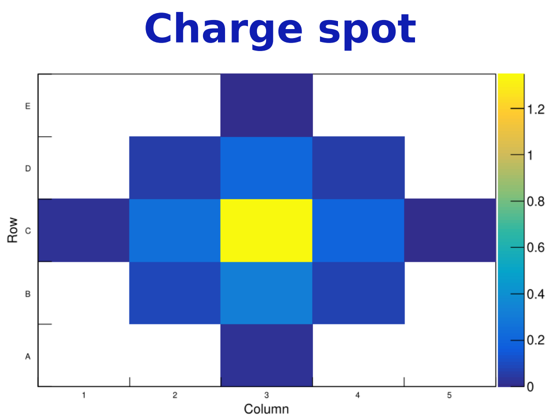


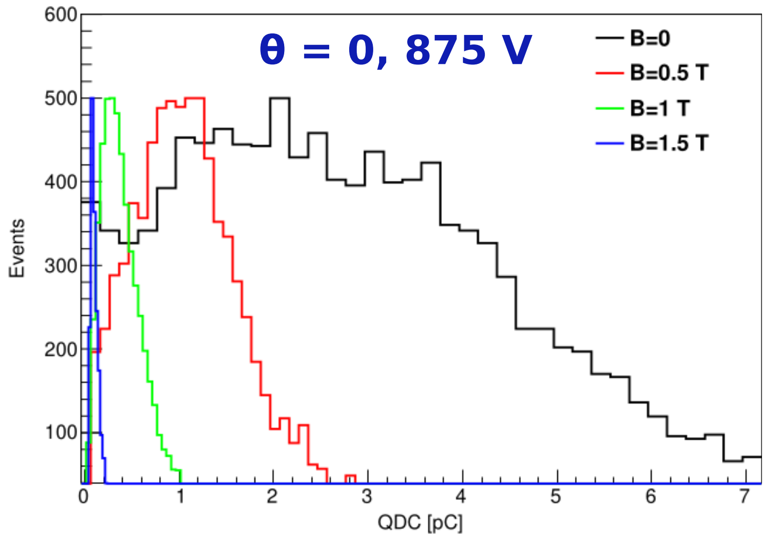
- LAPPD capacitively coupled with custom-designed (INFN-GE) RO PCB
- Central 13 pads (6 mm x 6 mm)
- Coaxial cables (SMA connector on one side) soldered on the pads
- Custom-designed (INFN-GE) amplifiers 1 GHz, 20 dB gain, 0.22 mV noise, <0.2% cross-talk

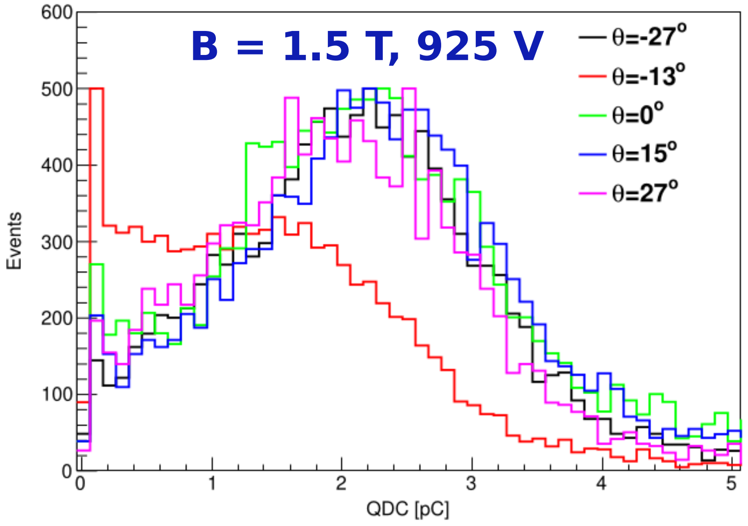


Integrated charge distributions

Evident SPE peaks

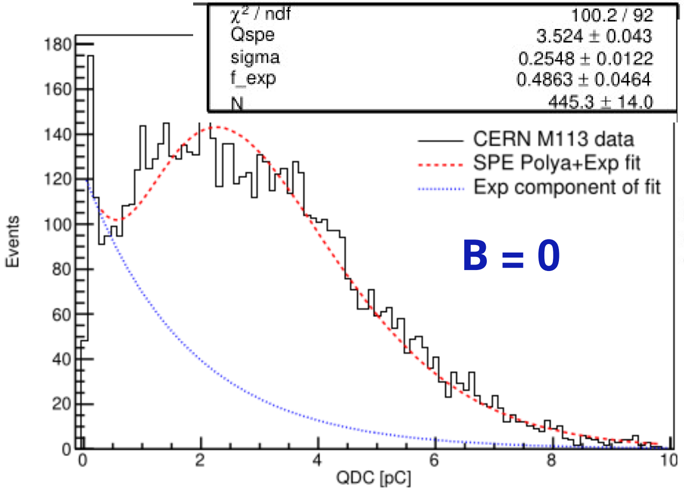


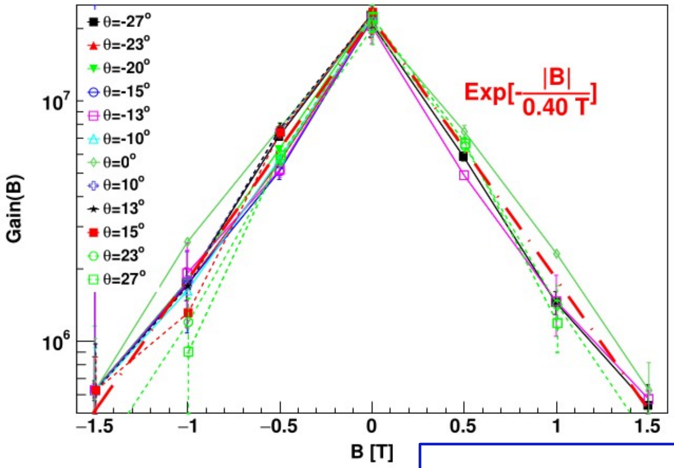


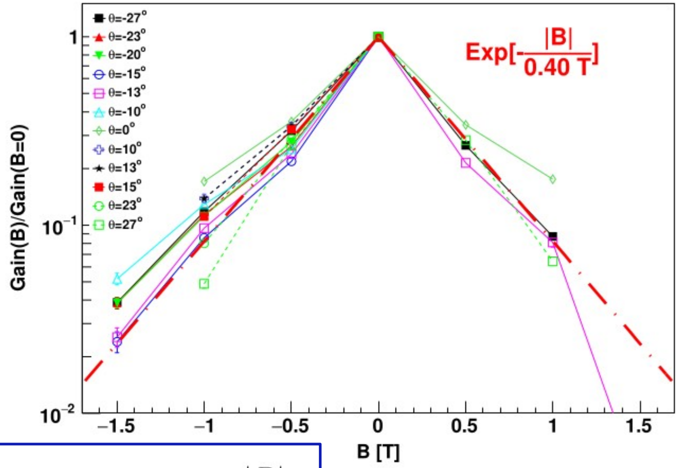


- Collection of charge on all pads
- Signal amplitude integrated over 3 ns, converted in pC by normalising to the load resistance of 50 Ω and by scaling for amplifier gain
- Integrated charge supression - SPE peaks shift towards zero in **B**-fields
- At **B** = 1.5 T and MCPs at 925 V, weak angular dependence except at $\theta = -13^0$

Gain vs. B-field strength





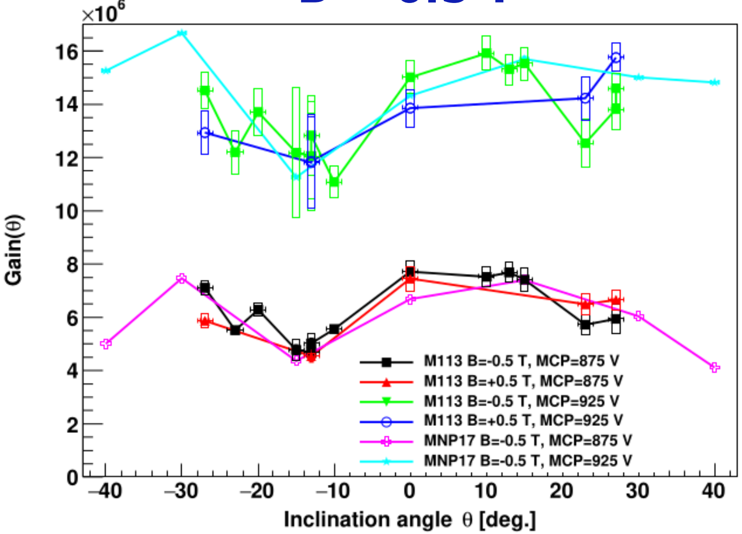


$$\boxed{Gain(B) = Gain(0) \times e^{-\frac{|B|}{0.40\ T}}}$$

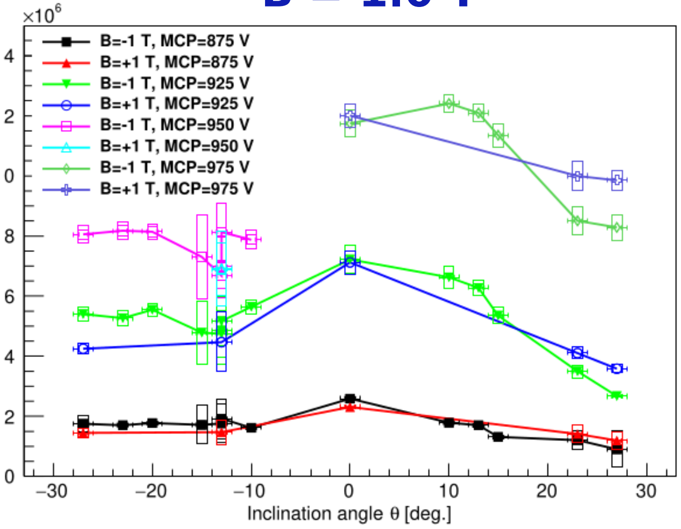
- Charge spectra fitted with a sum of a Polya and an exponential distribution
- Mean of the fit provides effective SPE gain
- Absolute gain/relative gain drop exponentially with **B**-field strengths
- From 0.5 T to 1.5 T, relative gain drops by ~ one order of magnitude

Gain vs. B-field rotation (θ)

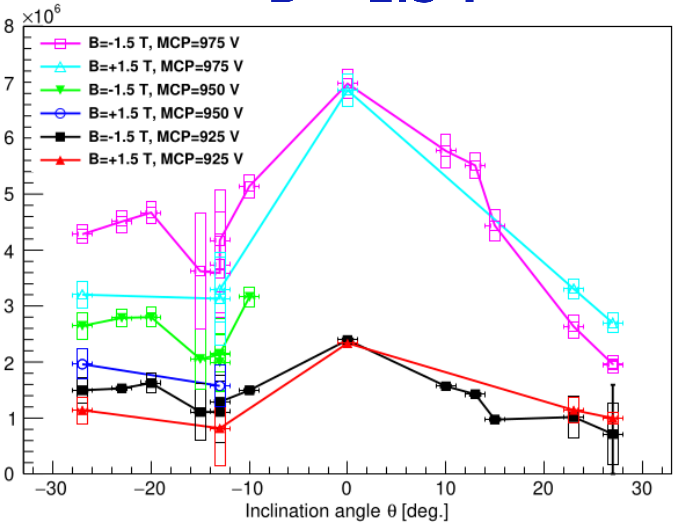
B = 0.5 T



B = 1.0 T



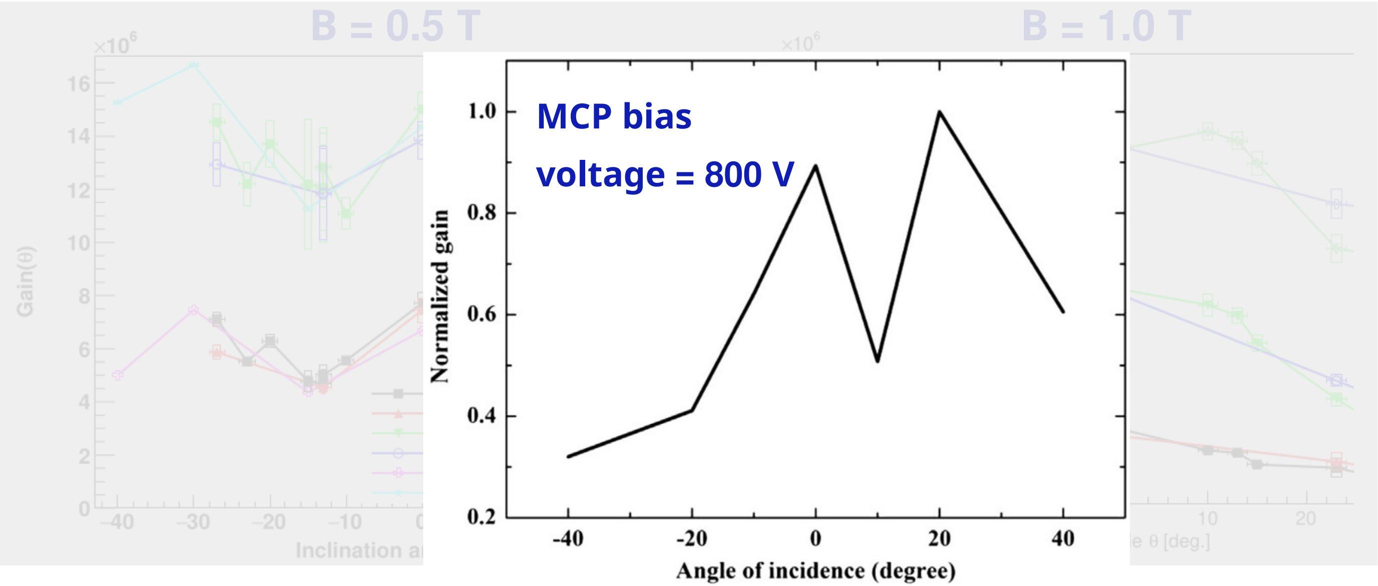
B = 1.5 T



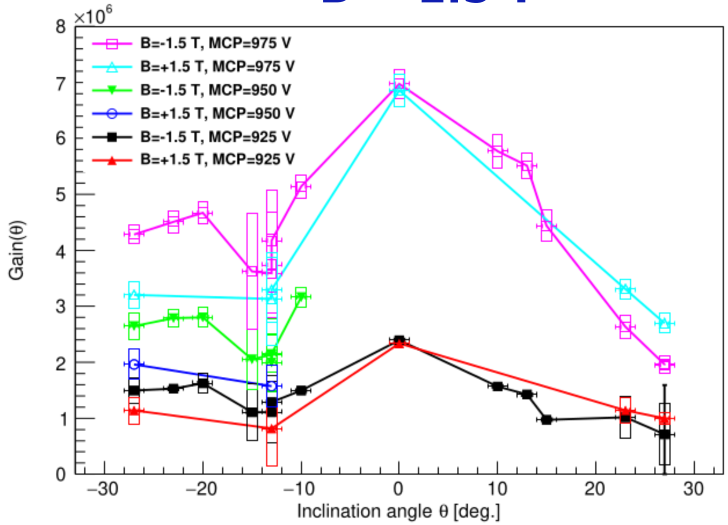
- Very small angular dependence at **B** = 0.5 T
- Some dependence at $\theta > 20^0$ and **B** ≥ 1.0 T
- <u>Dips at -13^0</u> are observed

Gain vs. B-field rotation (θ)

Simulation vs. Data



B = 1.5 T

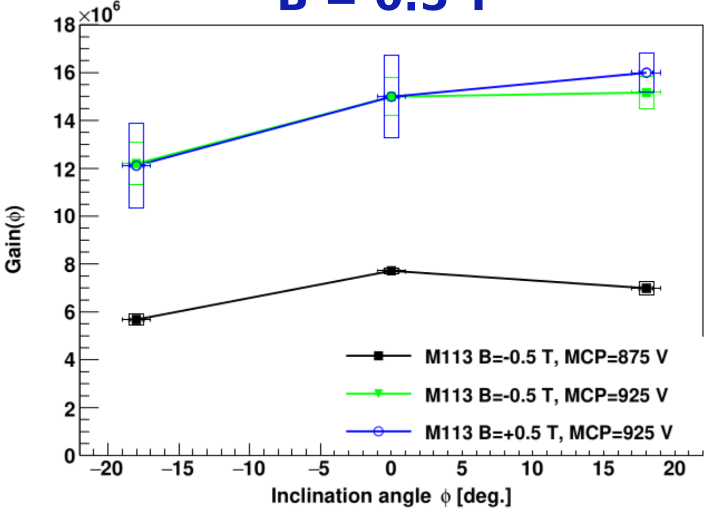


- Simulation with one MCP (of +10⁰) of 10 µm capillaries for Juno experiment
- In simulation, no magnetic field was applied, but photo-electron inclination was considered
- Dip at MCP bias angle present
- Good agreement between simulation and data (Exit MCP)

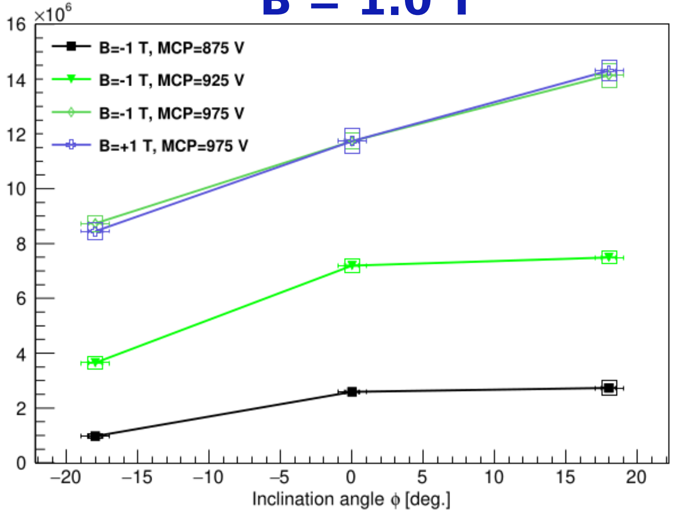
Gain vs. B-field rotation (ϕ)

Inclination in transverse plane
Out of Chevron plane

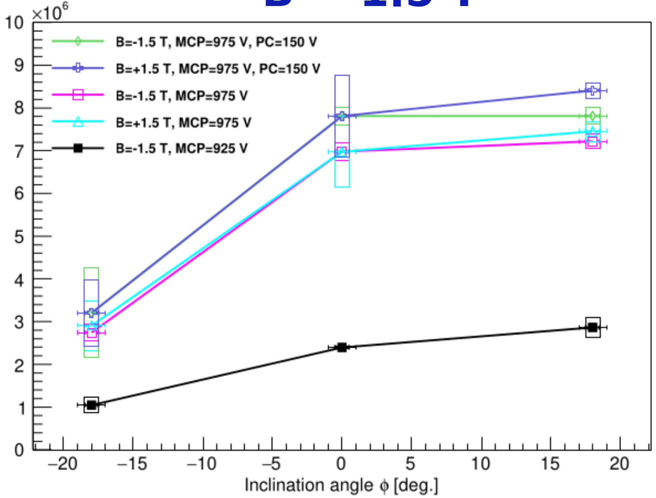
B = 0.5 T



B = 1.0 T



B = 1.5 T

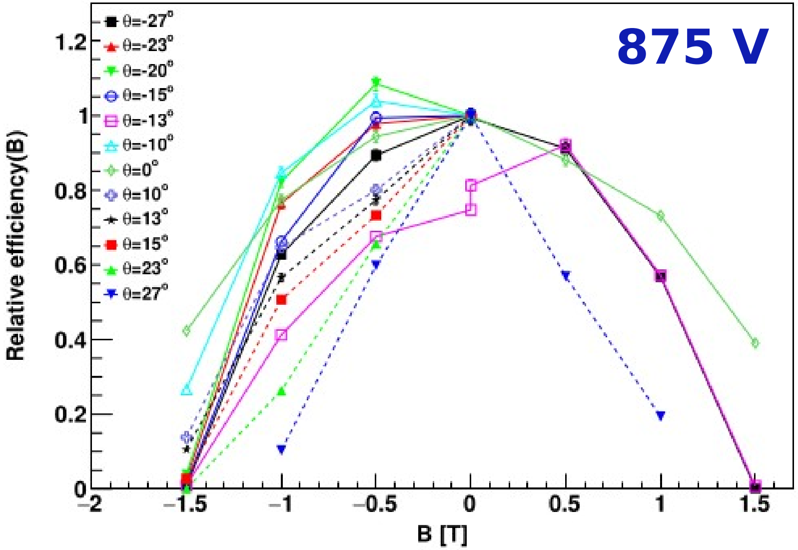


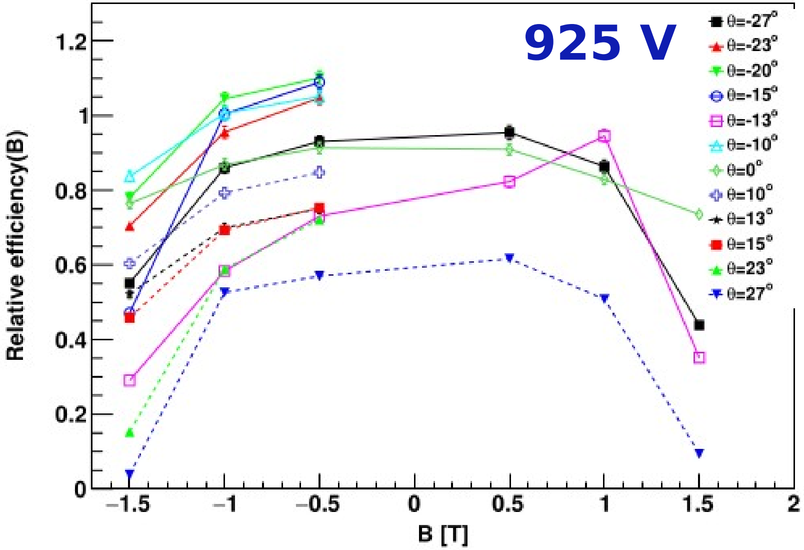
- Non-symmetric behaviour though the LAPPD geometry is symmetric!
- Absolute gain suppression by ~factor 2, at – 18^0 for B = 1.5 T
- Geometrical mismatch between Entry and Exit MCPs??

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

Efficiency vs. B-field strength

Recovered upto 1 T





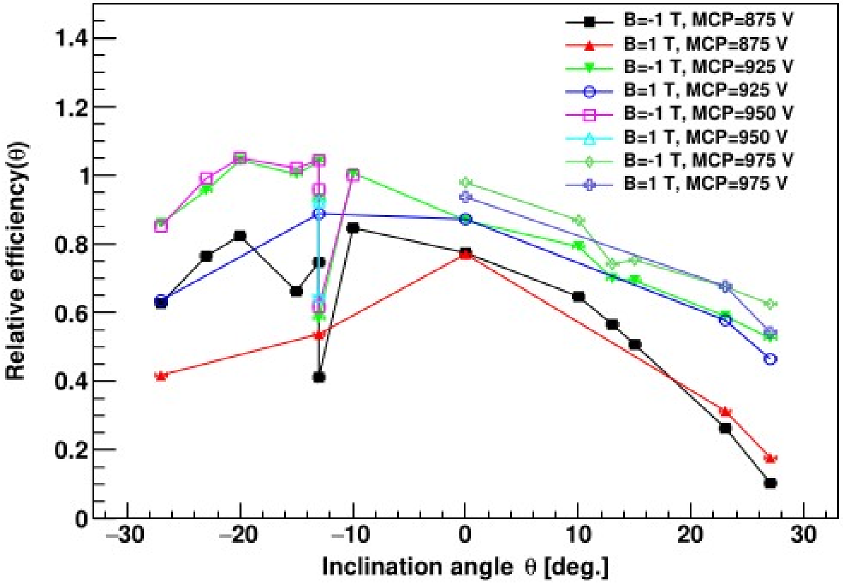
$$\varepsilon_r(B,\theta) \simeq \frac{\lambda(B,\theta)}{\lambda(B=0)}$$

λ = <# of PE/pulse>

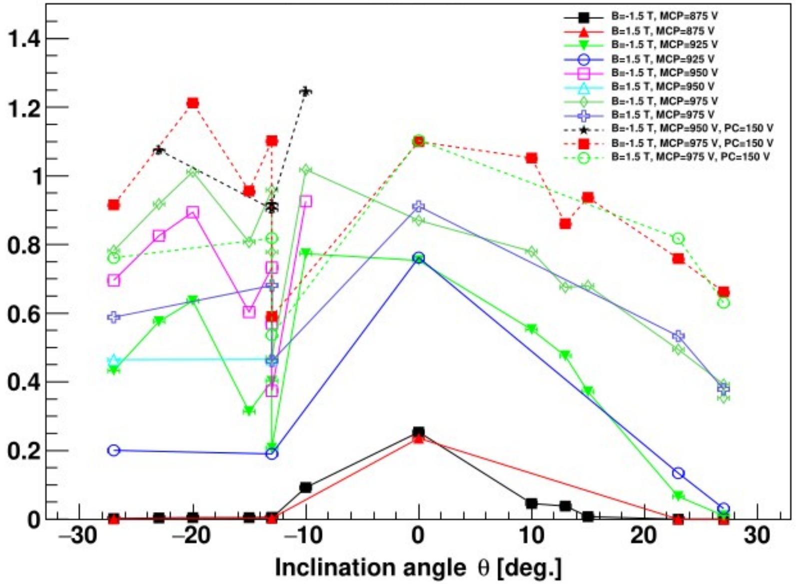
- Relative efficiency strongly depends on **B**-field strengths, ~ 30% suppression from 0.5 T to 1.0 T@ 875 V
- Strong dependence on MCP bias, gain compensation by 50 V increase across MCPs and upto **B** = 1.0 T

Efficiency vs. B-field rotation (θ)

B = 1.0 T

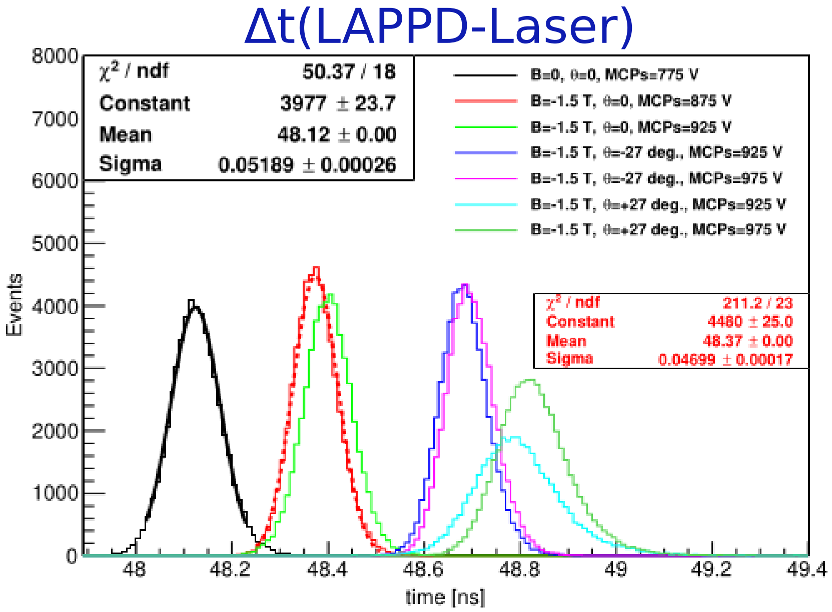


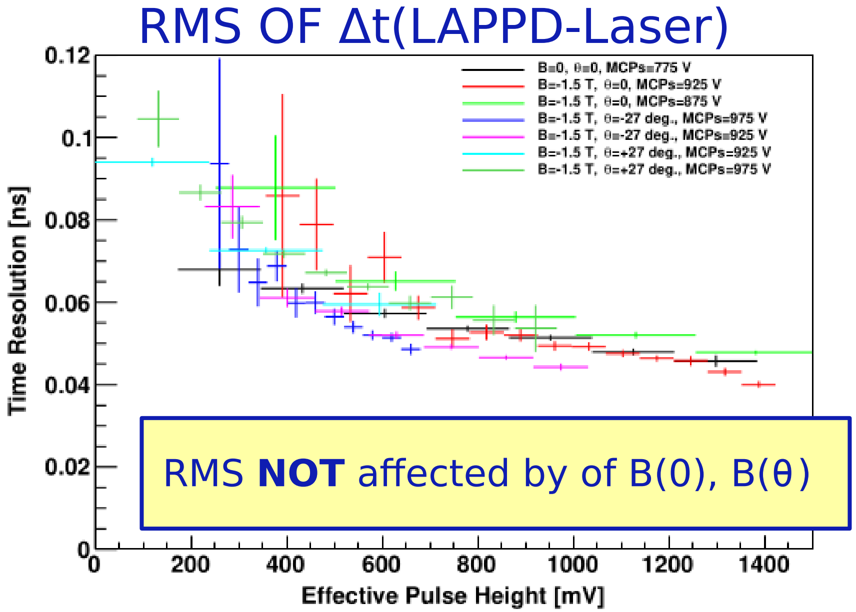
B = 1.5 T



- Clear dip at -13^0 for all points in angular distribution
- At -13^0 lower production of secondaries - electrons follow the **B**-field lines and don't hit the capillary walls
- Higher PC bias (increment by 100 V) recover the efficiency by ~15%

Timing response in B-field

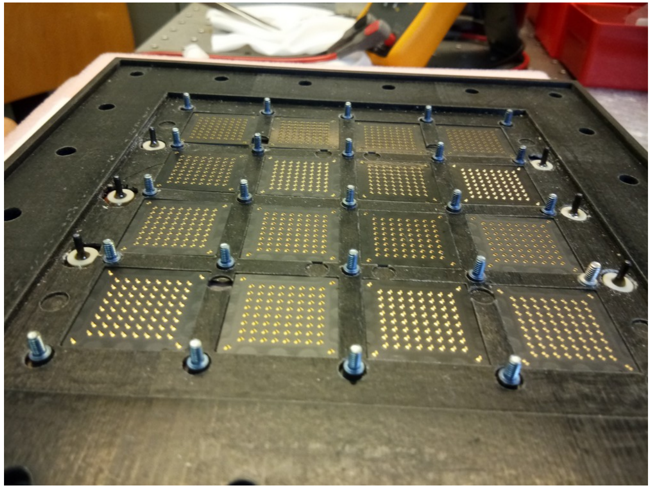


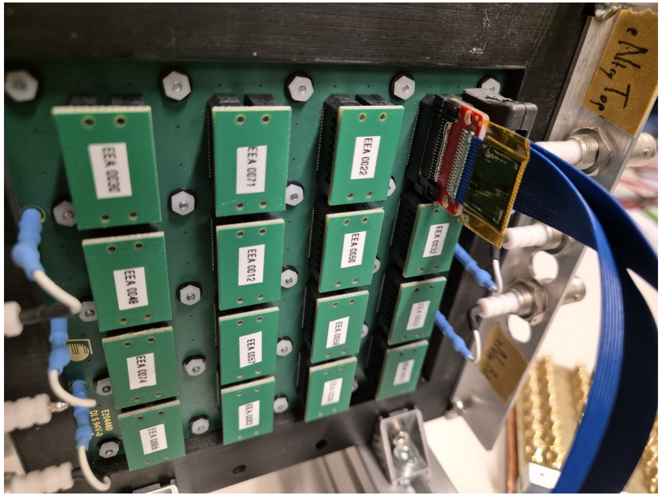


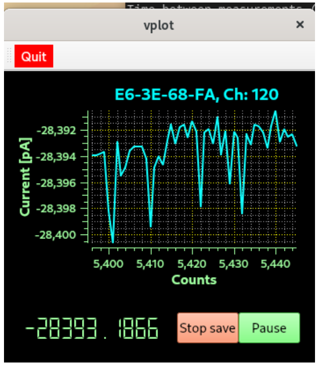
B	θ	Signal delay
1.5 T	0^0	250 ps
1.5 T	-27^0	557 ps
1.5 T	$+27^0$	665 ps

- Measured for few photo-electrons (Not SPE)
- **B**-field introduces delay in LAPPD signals
- Further delay for inclined **B**-fields (longer paths for e^-)

Ageing Studies on an HRPPD unit

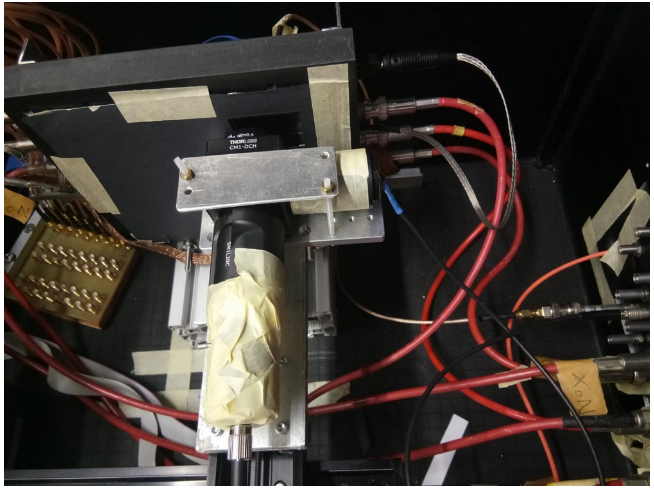






Motivation

- High radiation environments for the HRPPDs installed near the beampipe
  - Photocathode lifetime affected
  - (MCP performances deteriorated)



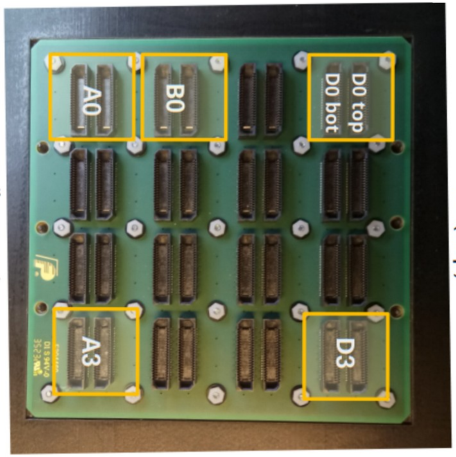
- Three HRPPD-ageing test stands at BNL, INFN, Jlab

- Accelerated and localised ageing on an HRPPD unit in Trieste laboratory (10^{14} photon flux in 10 days, ~ 1 cm^2 surface area)

Strategy for ageing studies

Darkbox top

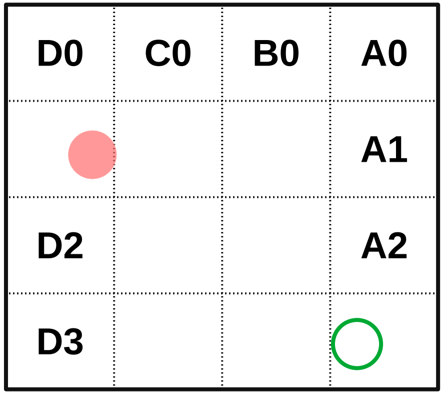
G (bottom)



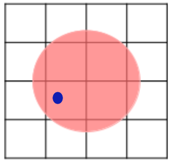
PC (Top)

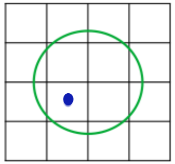
Backplane
Rear-end view

Darkbox top



Window
Frontview





3 mm x 3 mm pixels

Pixelated Anode pads
Directly-couple to Readout pads

Ageing spot

HRPPD characterisation + irradiation

- Defocalised spot (d ~ 10 mm)
- Central 2 x 2 pads irradiated
- 4 x 4 pads under study

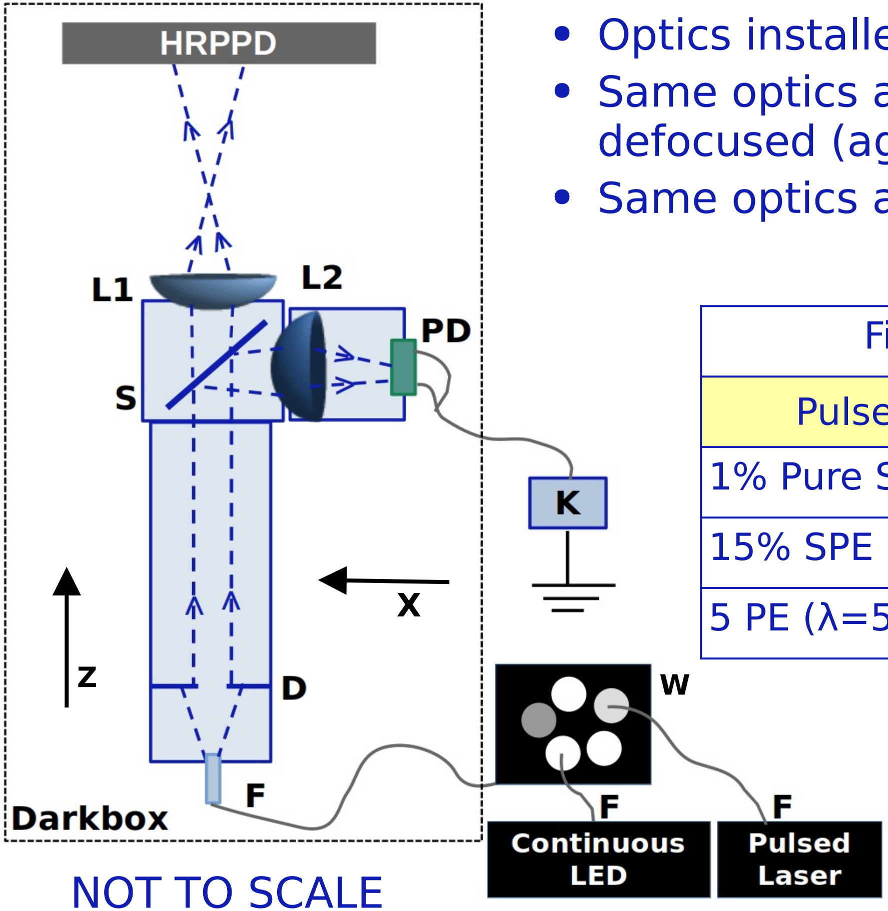
Reference spot

HRPPD characterisation

- Focalised spot (d ~ 1 mm)
- 2 x 2 pads under study

Protection of reference spot using black shielding during high illumination on ageing spot

Optics set-up



NOT TO SCALE

- Optics installed on a movable (XYZ) system
- Same optics at two different Z positions – focused (measurements)/ defocused (ageing) spots
- Same optics at two different X positions – ageing/reference spots

Five configurations (different optics outside darkbox)	
Pulsed Laser + ND filters(wheel)	Continuous LED
1% Pure SPE (λ=0.01) **measurements**	Direct for **QE**
15% SPE (λ=0.1) **measurements**	Via wheel (empty) **Ageing**
5 PE (λ=5) **measurements**	

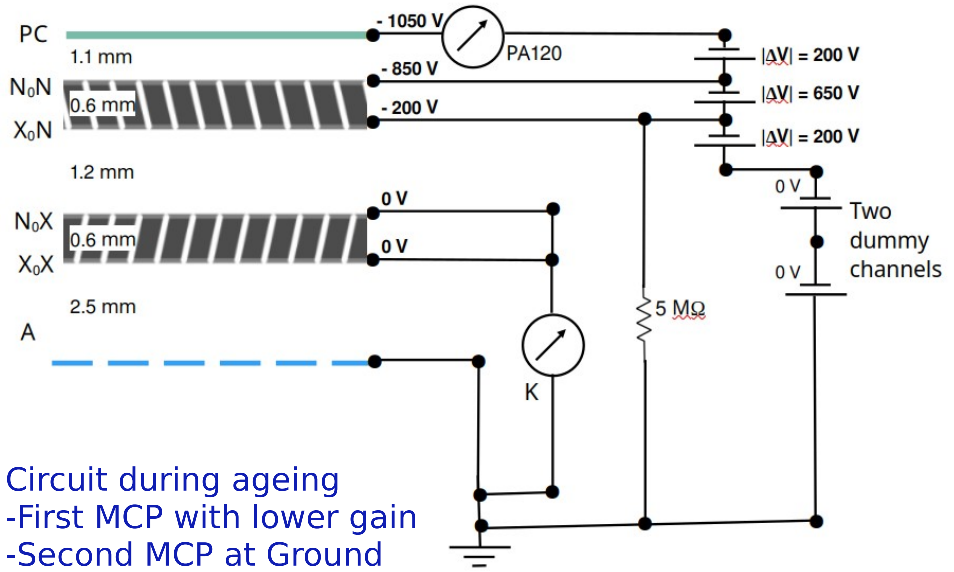
L1 Lens (20 mm), **L2** Lens (50 mm), **S** splitter, **PD** Photo-Diode, **K** Keithley, **D** Diaphragm, **F** Fibre, **W** motorised wheel

Measurement protocol

Measurements before, after and at a few intermediate stages of illumination

At ROP: 200_700_200_700_200 V
- SPE responses (1%, 10% non-empty events) in terms of gain, PDE
- Dark Count Rates
- After Pulse Rates

PC at -50V, First MCP at Keithley, 2nd MCP at floating
- QE/Photo-current measurements



Circuit during ageing
-First MCP with lower gain
-Second MCP at Ground

During irradiation monitoring of:
- Photon fluence by Photo-Diode current (keithley)
- Total integrated charge at second MCP (Keithley)
- Photocathode current (custom-designed PA)
- First MCP currents by CAENLOGS

✓ PDE, QE scans over pads as a function of photon flux and total integrated charge
✓ Effect on DCR, APR, Gain

Conclusion

- We studied the response of the LAPPD #153 in magnetic fields at CERN.
  J. Agarwala, et al., NIMA (2024) 170122.
  - ✓ LAPPD gain drops exponentially with **B**-field strength.
  - ✓ Gain has mild dependence on **B**-field inclination.
  - ✓ Reduction in effective PDE.
  - ✓ Both the gain and PDE are partially recovered with 50/100 V increase across the two MCPs.
  - ✓ Time delay for normal (~200 ps) and inclined **B**-fields (~500 ps)

- Preparation for ageing studies with an HRPPD unit is at its final stage.
  - ✓ Regular, dedicated Global HRPPD ageing Meet: https://indico.bnl.gov/category/605/
  - ✓ Optics, electrical set-up and measurement protocol well defined.
  - ✓ Measurements will start soon.

Thank you!

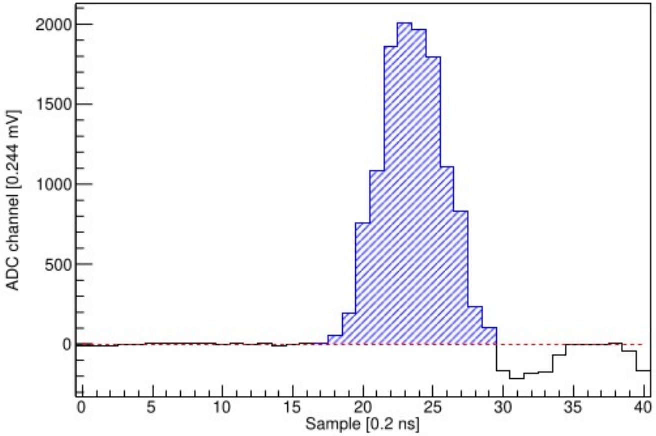
Extra slides

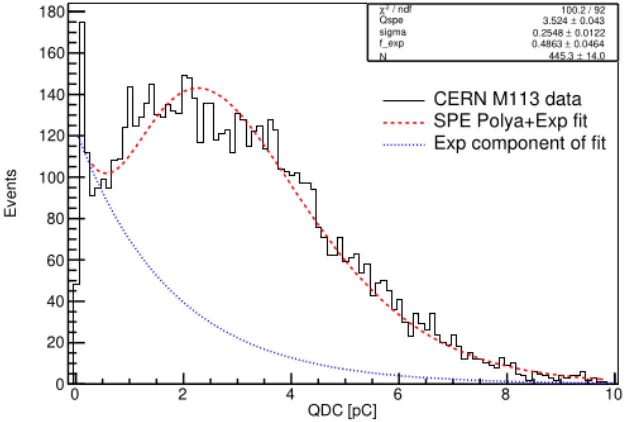
LAPPD #153 MCP features & performance

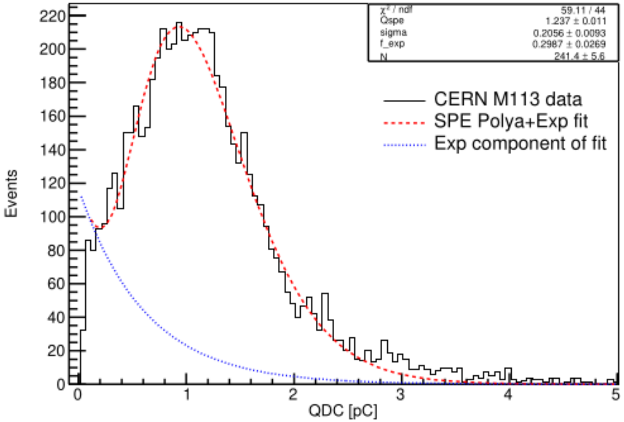
LAPPD 153 Microchannel Plate (MCP) Features & Performance

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.

Collected charge and gain





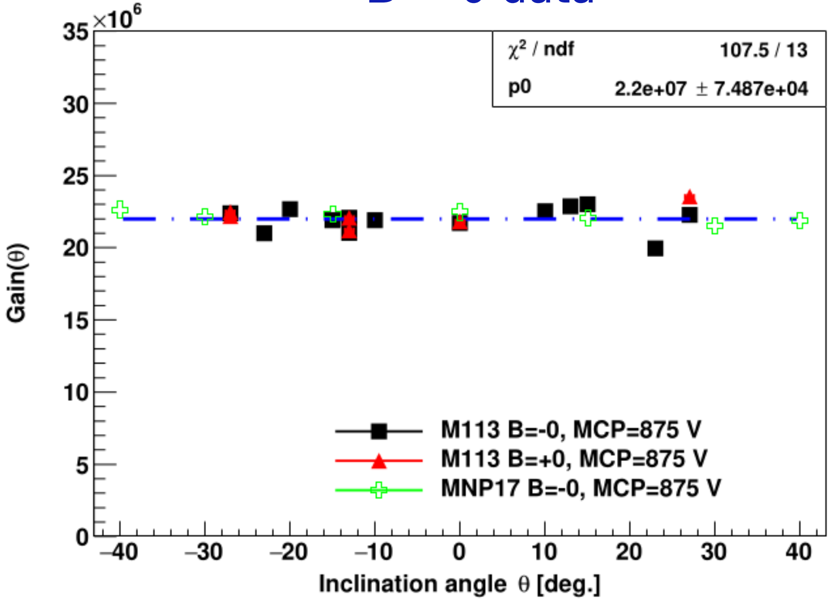


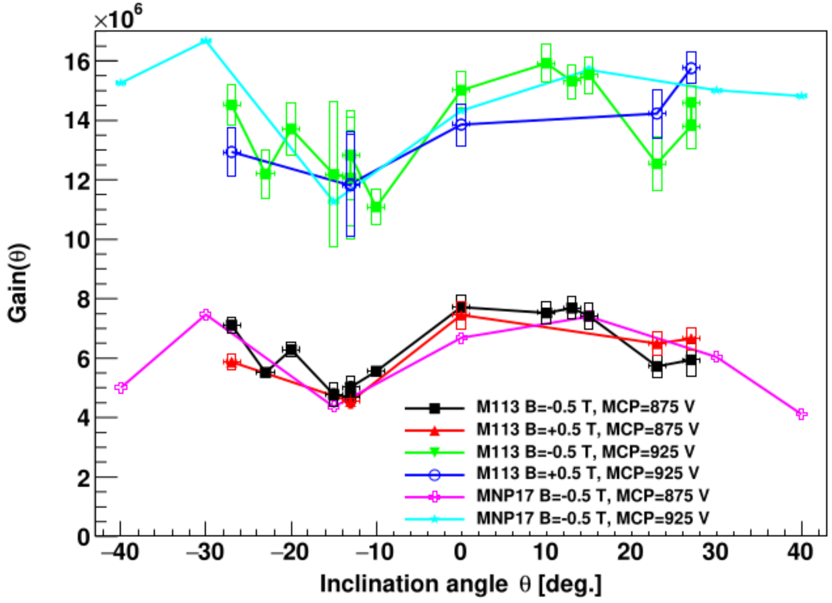
Threshold 10 mV, 0.05 pC
Red line shows average base line

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

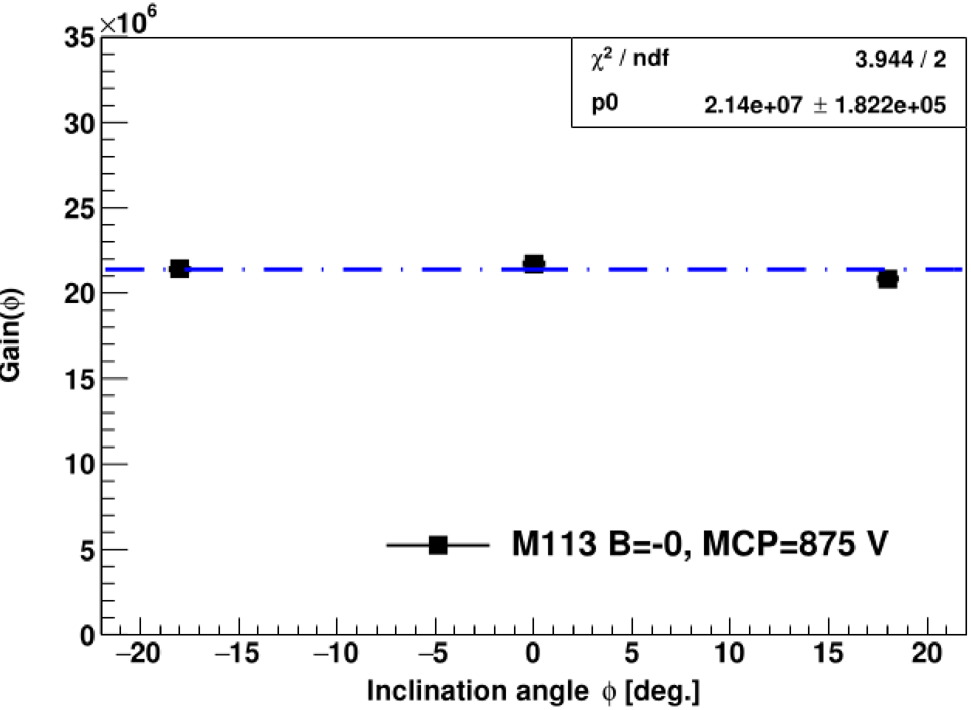
Gain vs B-field angular distribution

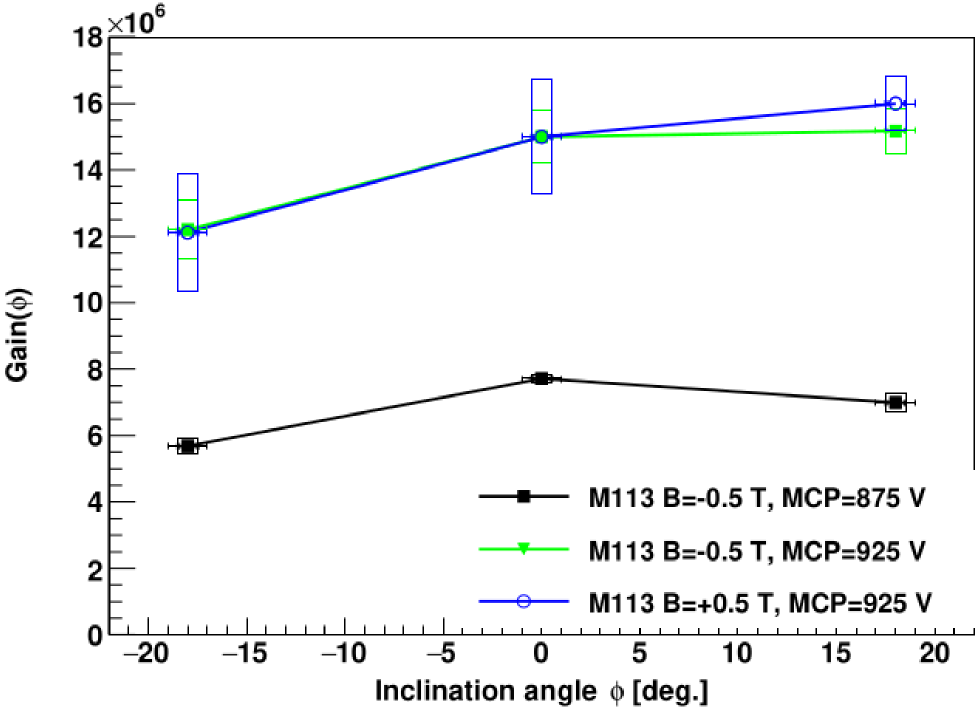
B = 0 data





Gain vs. B-field rotation (ϕ)





Efficiency definition

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

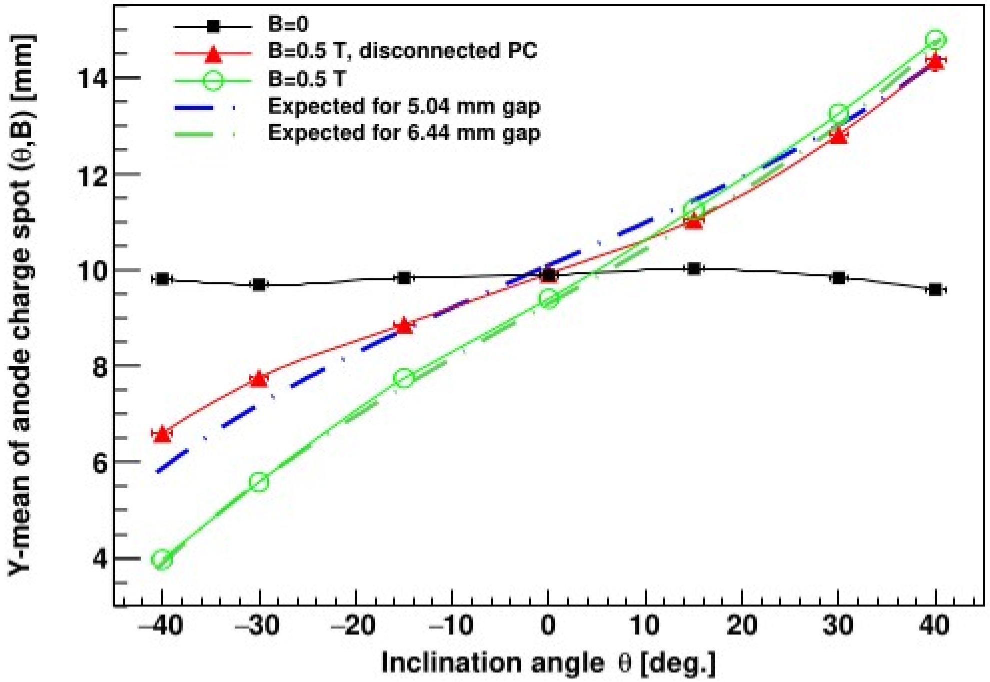
From the probability above we can estimate the mean number of PE per laser pulse:

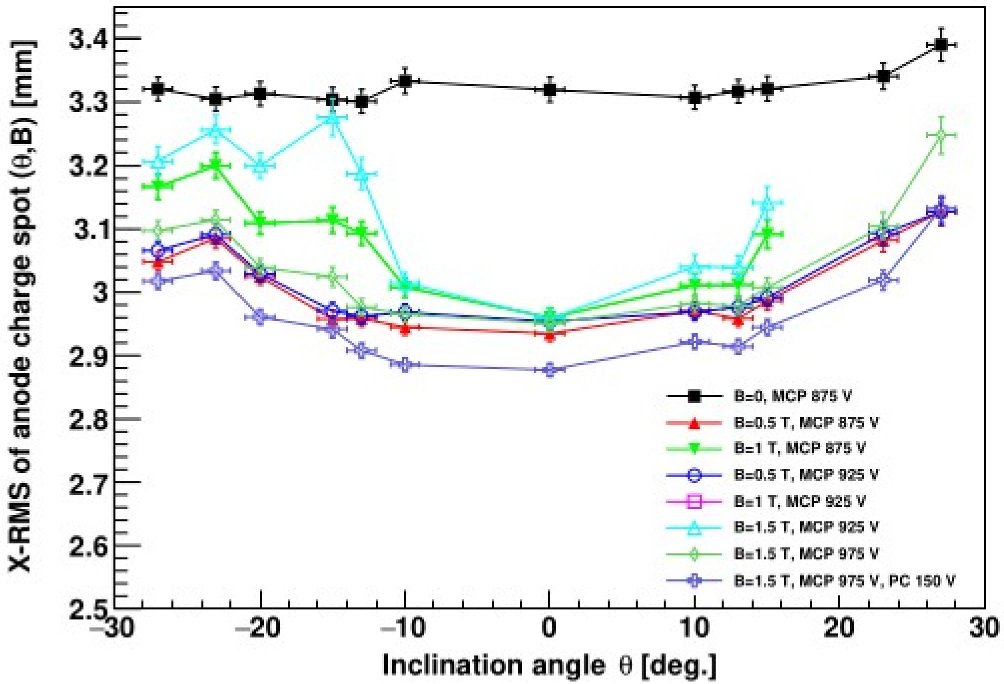
$$\lambda(B,\theta) = -\ln\left[1 - p(B,\theta)\right] \simeq p(B,\theta) \ . \tag{4}$$

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)





Simulation - efficiency vs. angle

No dip observed for simulated data (Juno experiment)

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

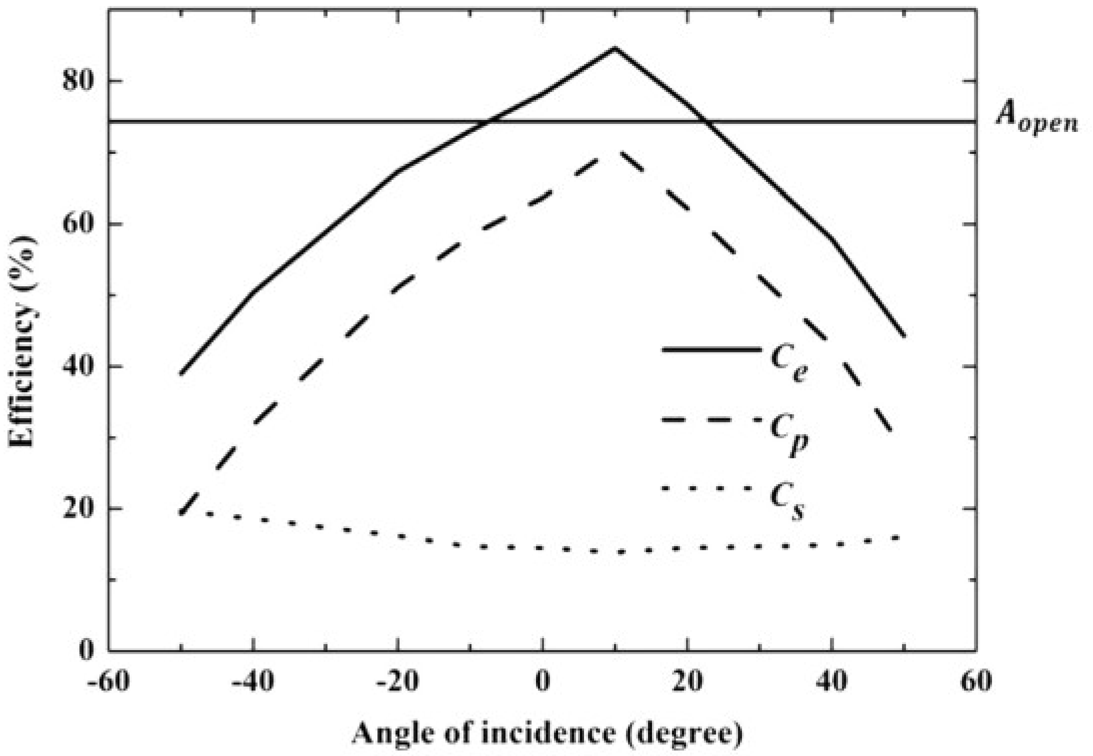
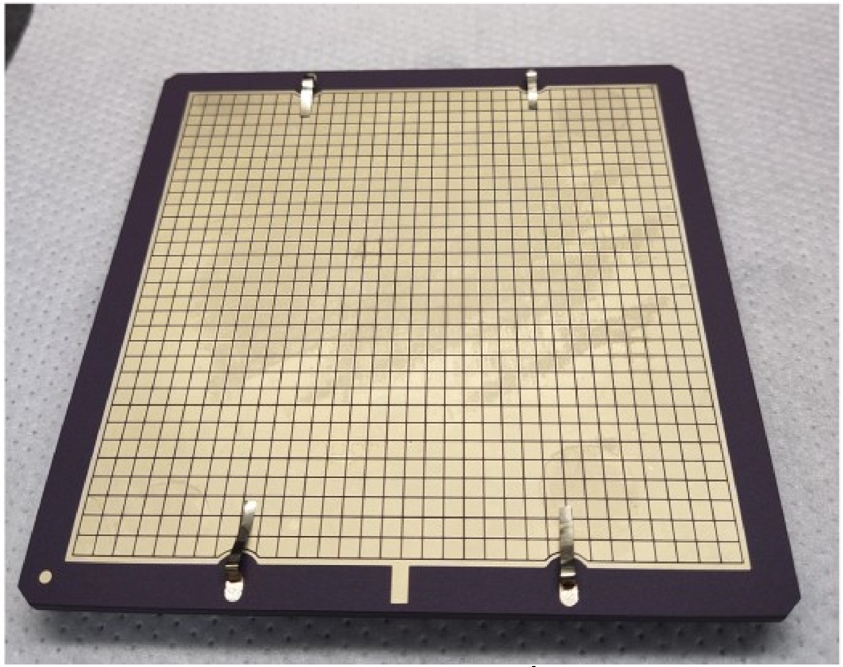
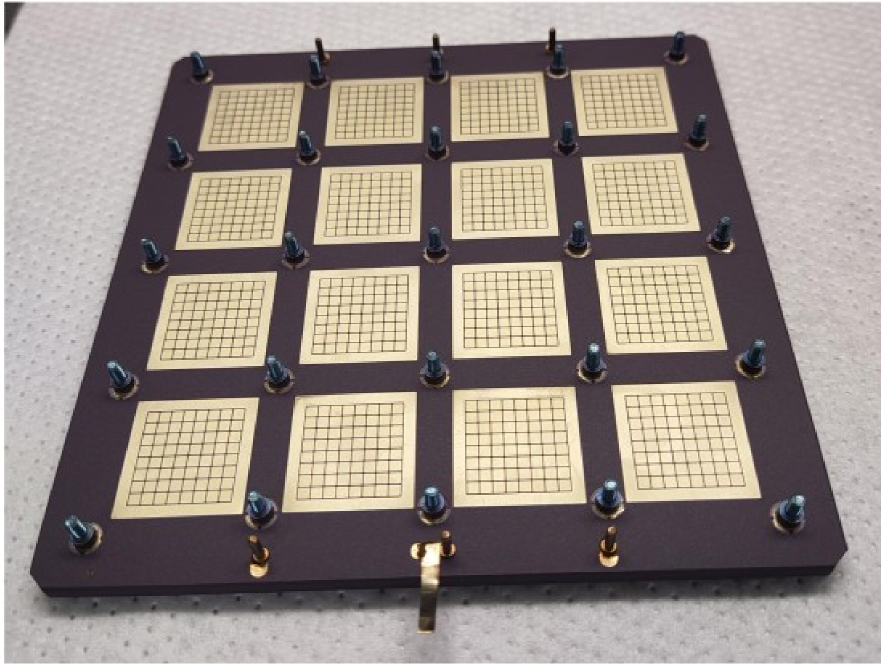


Fig. 8. Efficiencies as functions of θ at U=200 V and E=500 eV. The MCP bias voltage is 800 V. C_e, C_p and C_s are represented by the solid line, the dashed line and the dotted line respectively. A_{open} represented by the horizontal line is 74.1%.

HRPPD

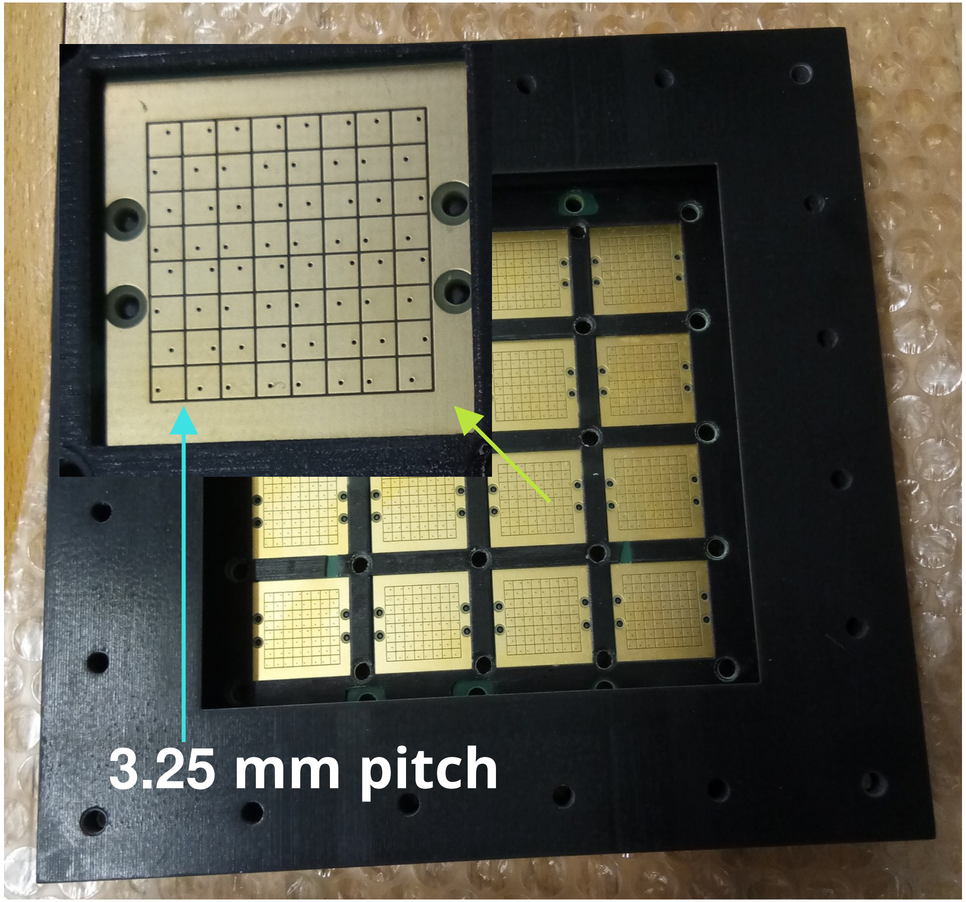


1024, 3 mm pixels

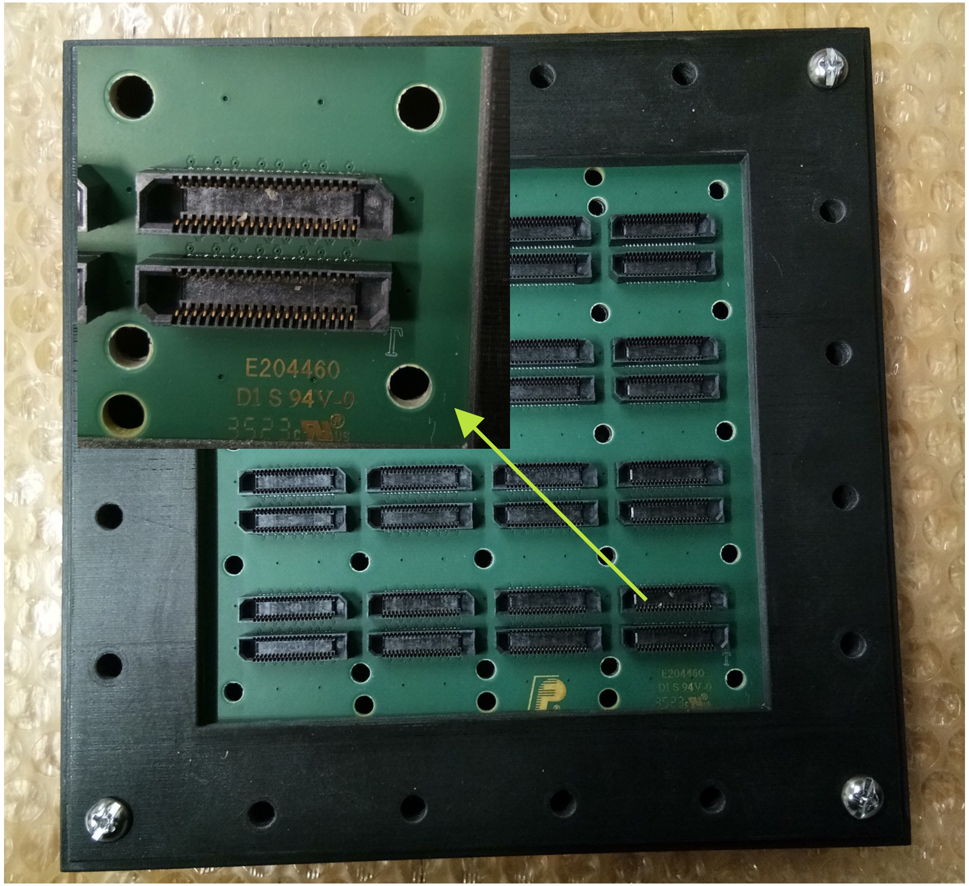


Anode plate vacuum side (left), air side (right)

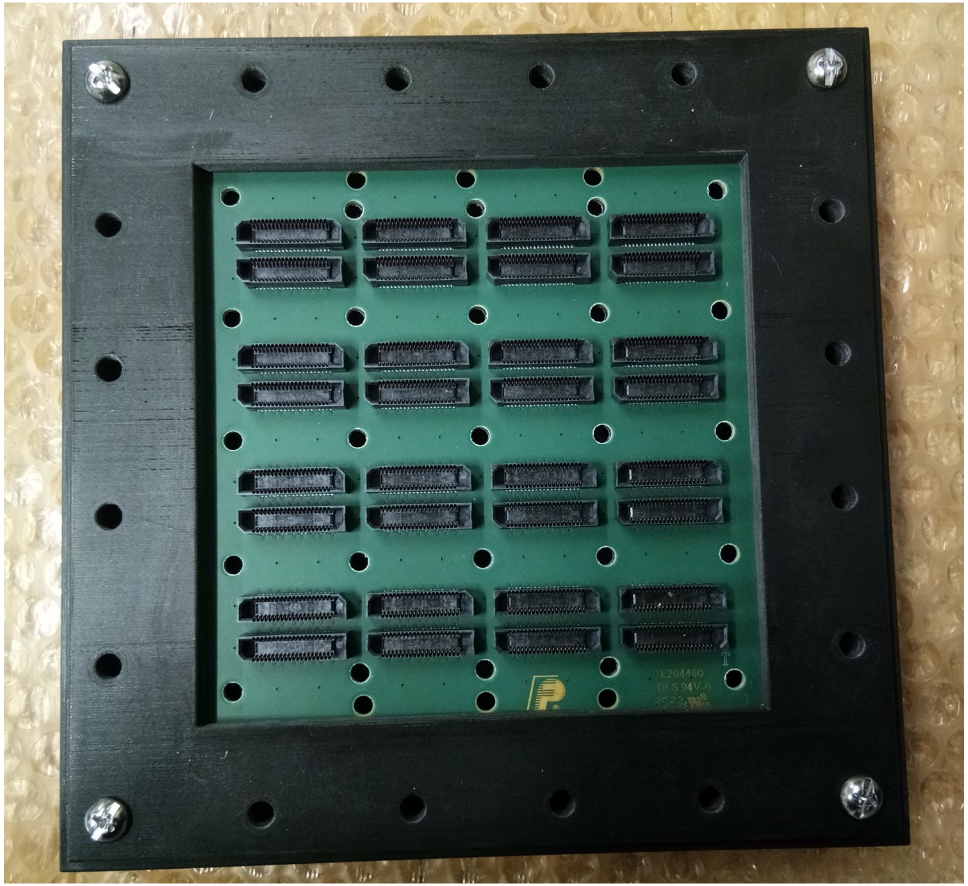
Passive interface arrived in Trieste



Inner side
(matches HRPPD rear side)

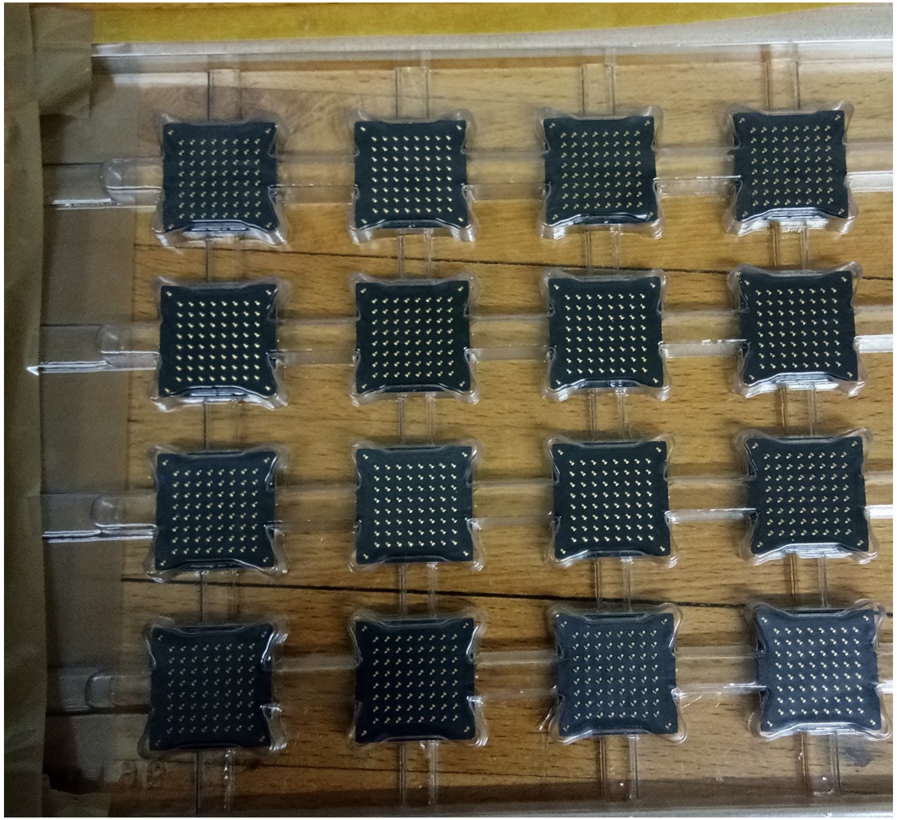


Outer side
32x Samtec ERF8 connectors/sockets



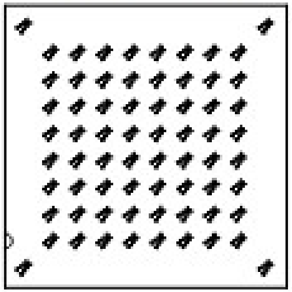
Grounding caps

Compression interposers arrived in Trieste

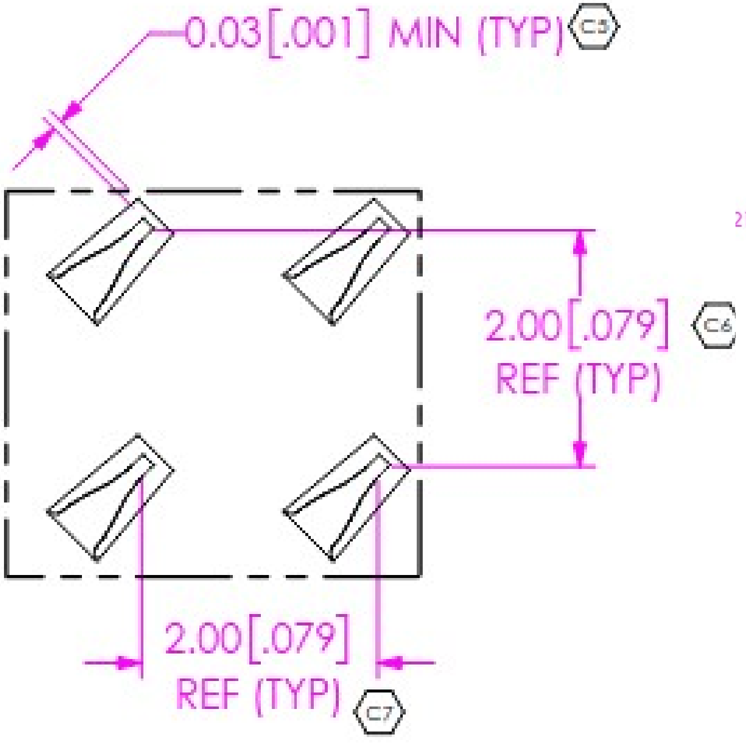


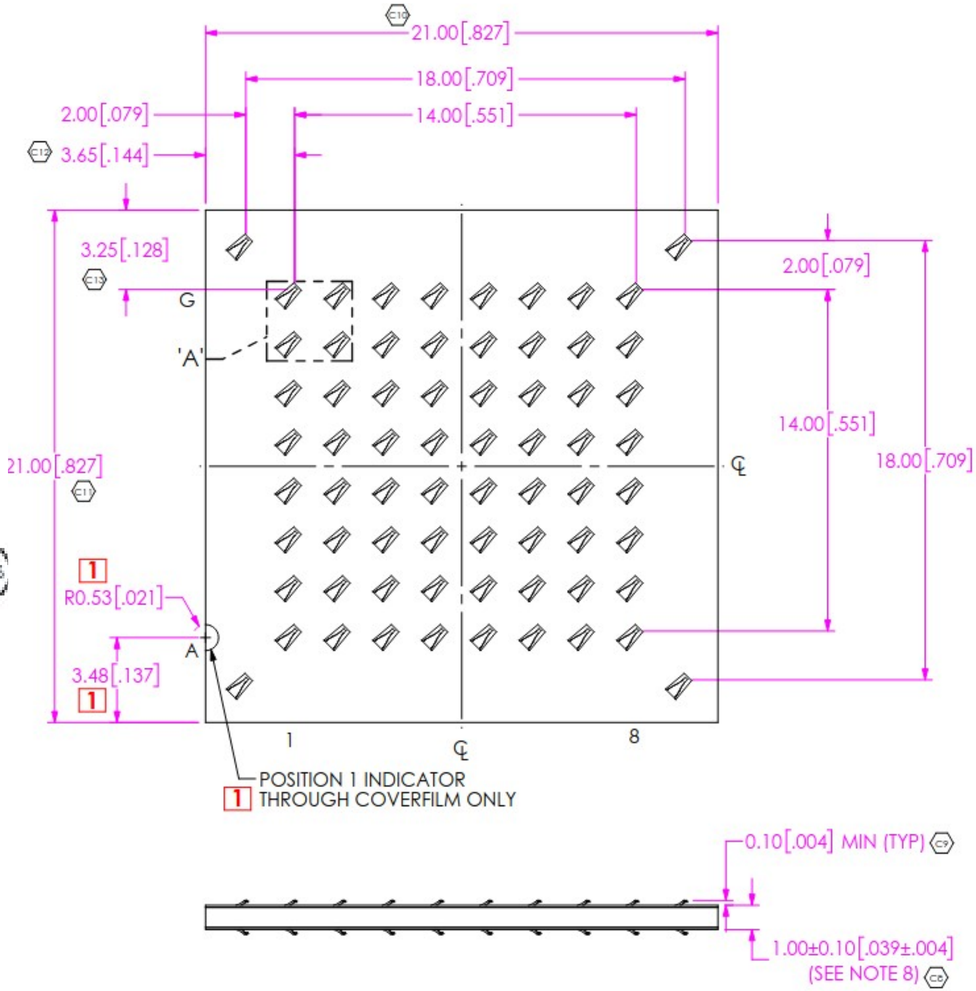
Direct connection between
HRPPD rear side and passive interface

Mechanical design of interposers

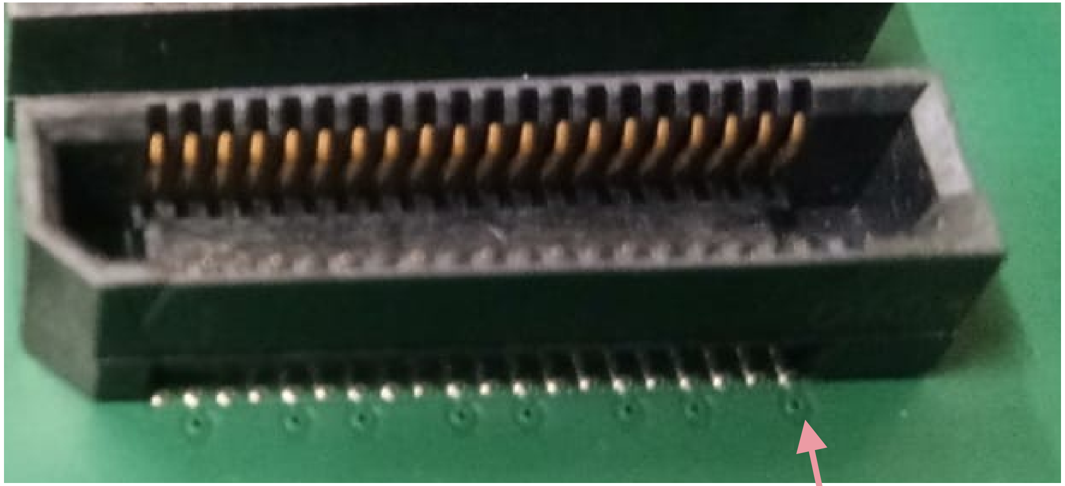


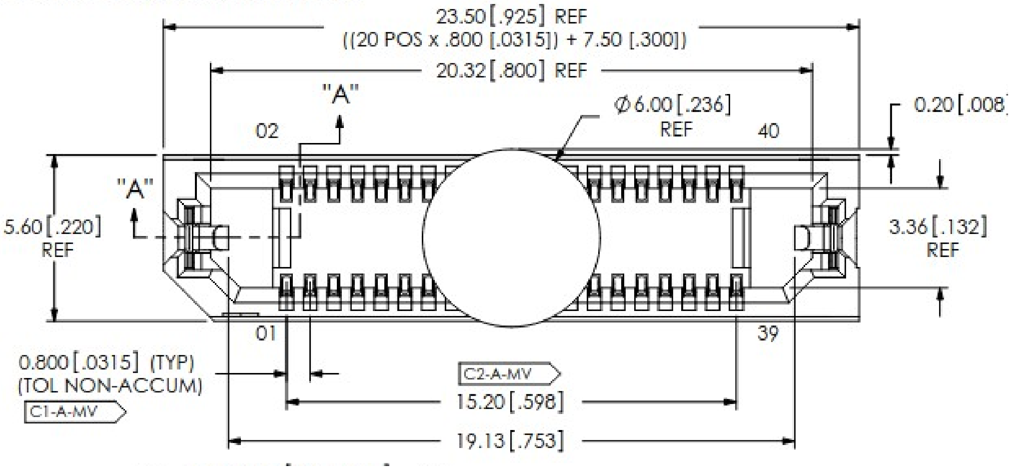
Designed and dimensioned in mm [inches]





ERF8 sockets

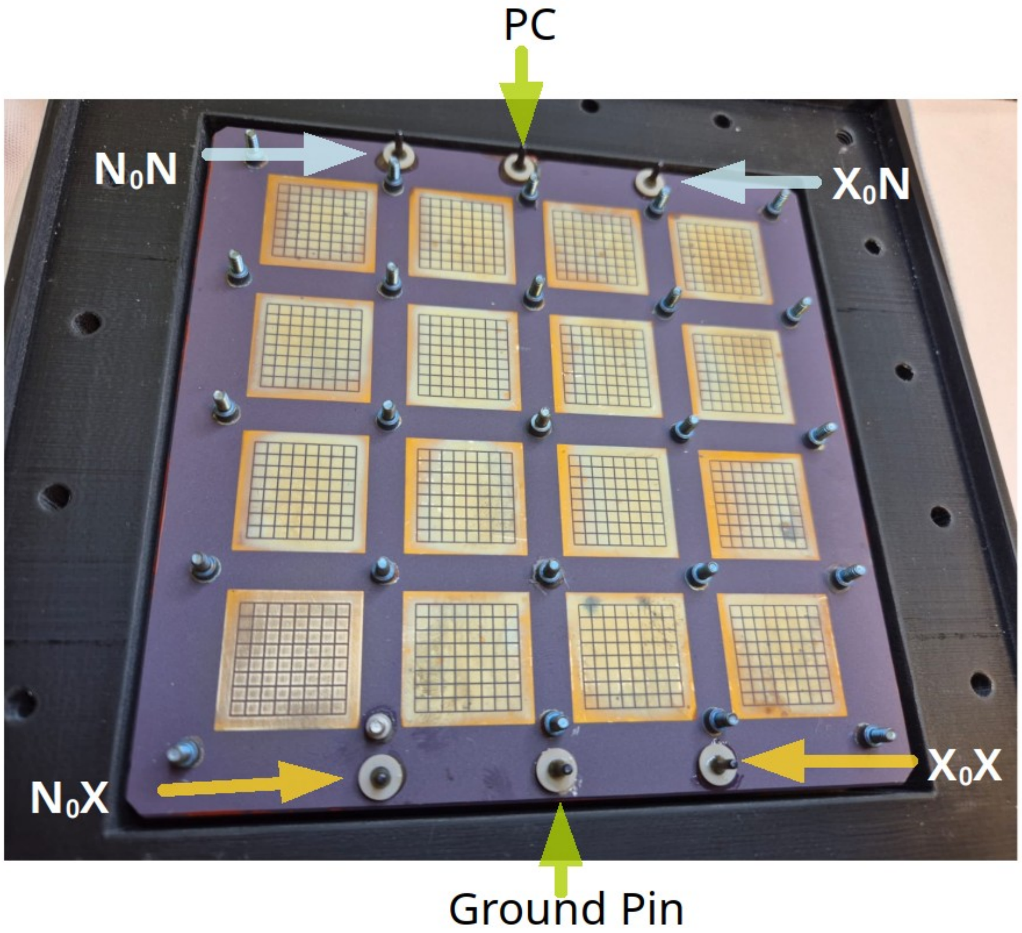




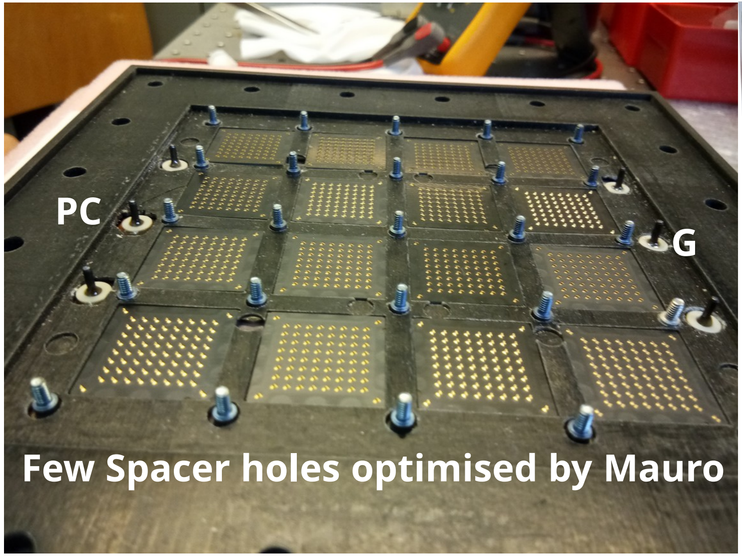
Used for 32 pads

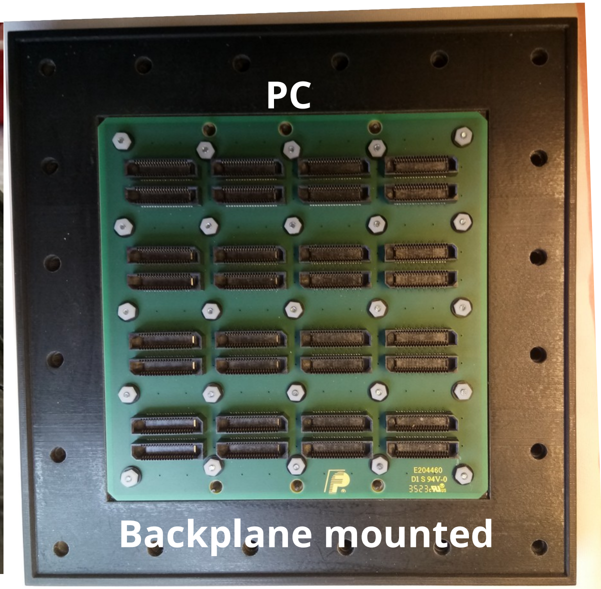
2 x 20 pins, 8 extras, 2 x 8 marked

HRPPD #25

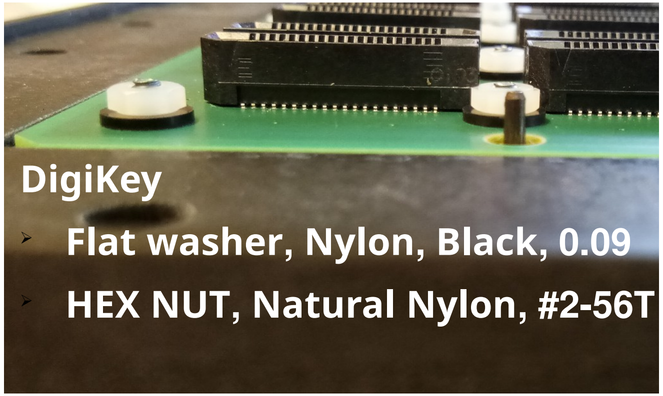


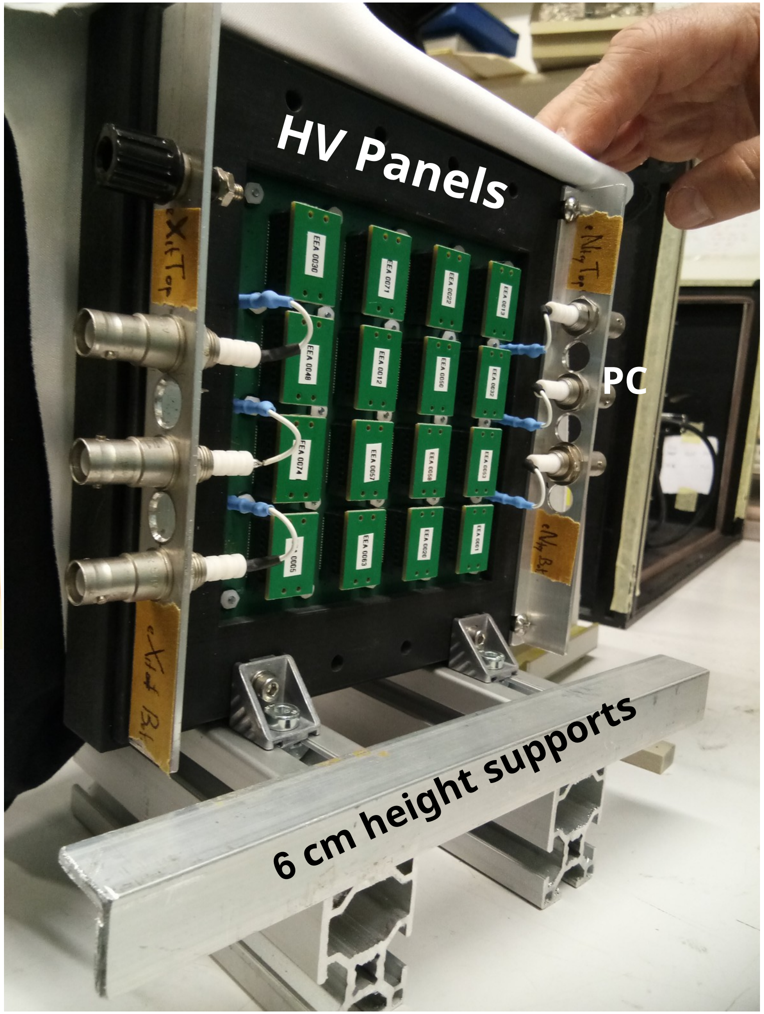
Assembling of HRPPD #25



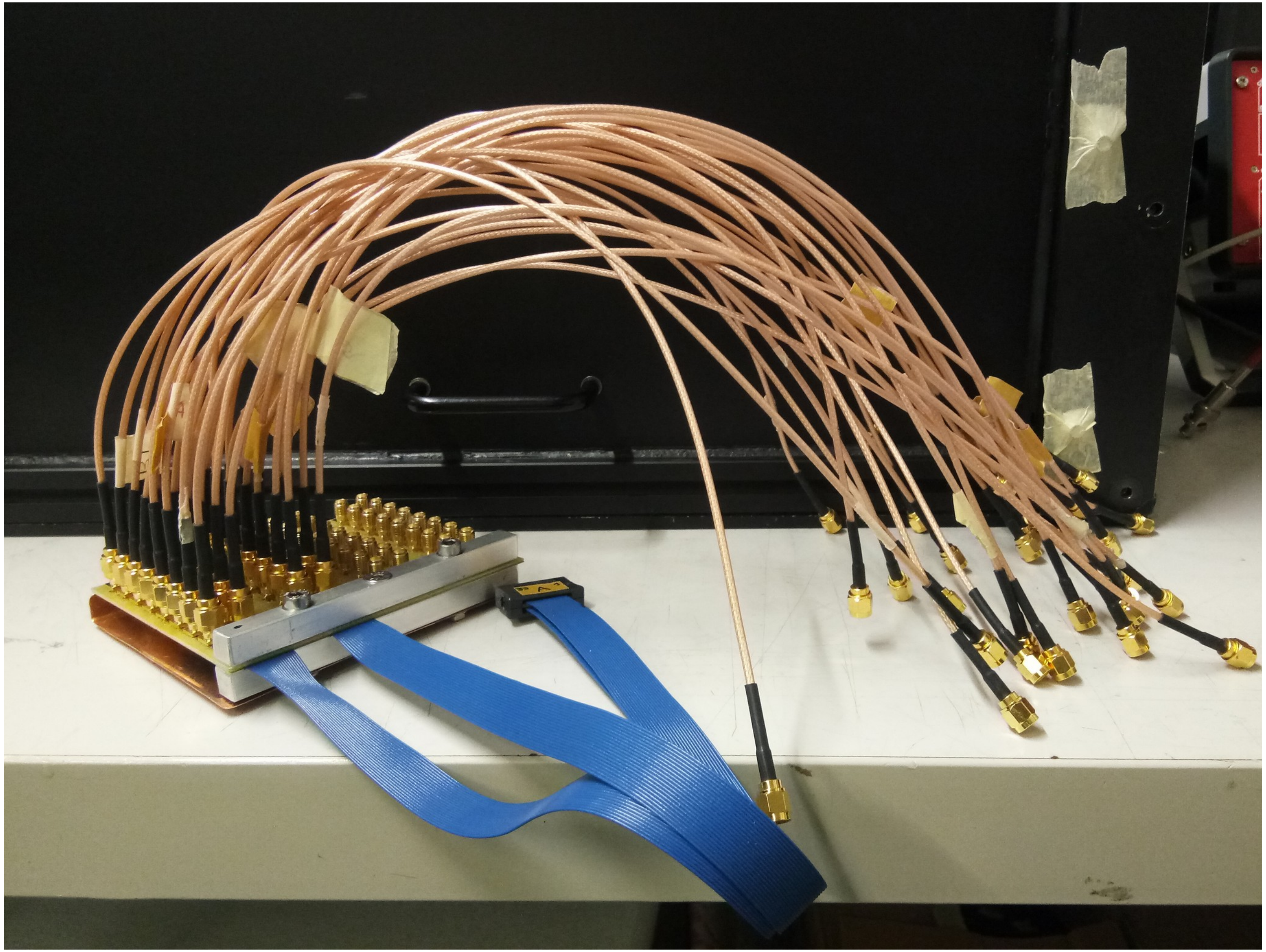


Planarity O (100 µm)
~100 µm bump – top to bottom





Readout preparation

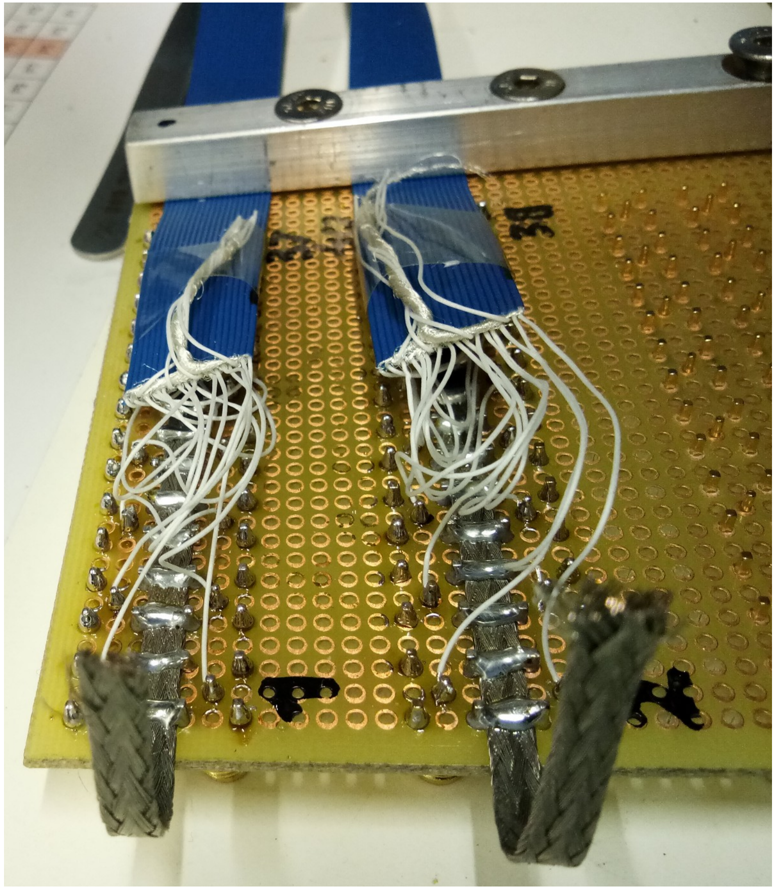


Breadboard (32 RO channels)

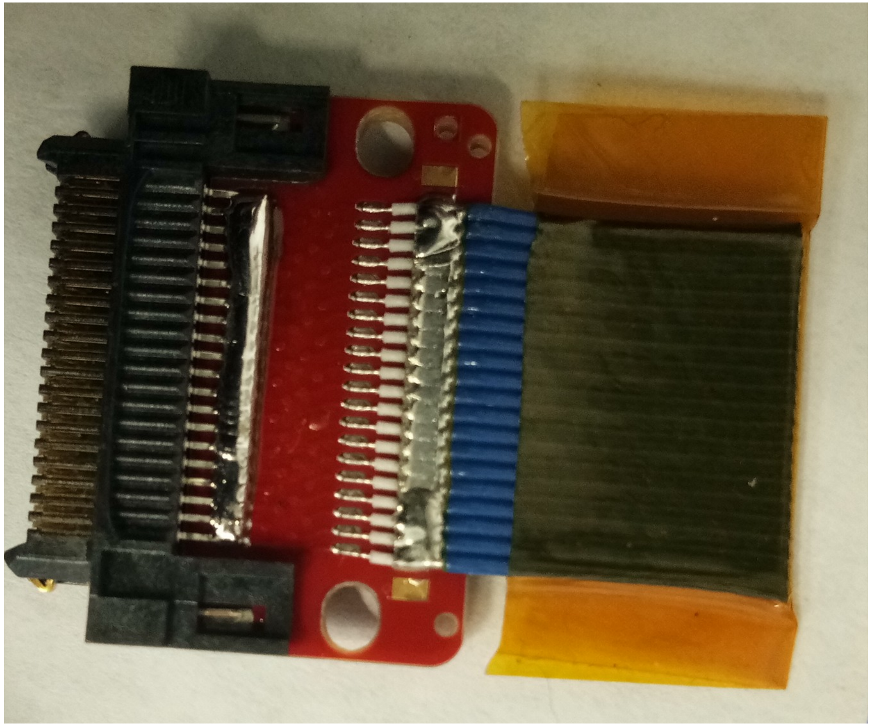
- Prepared
- Connections checked
- Cabling with labeling done

Mauro’s bread board - updates

32 readout channels

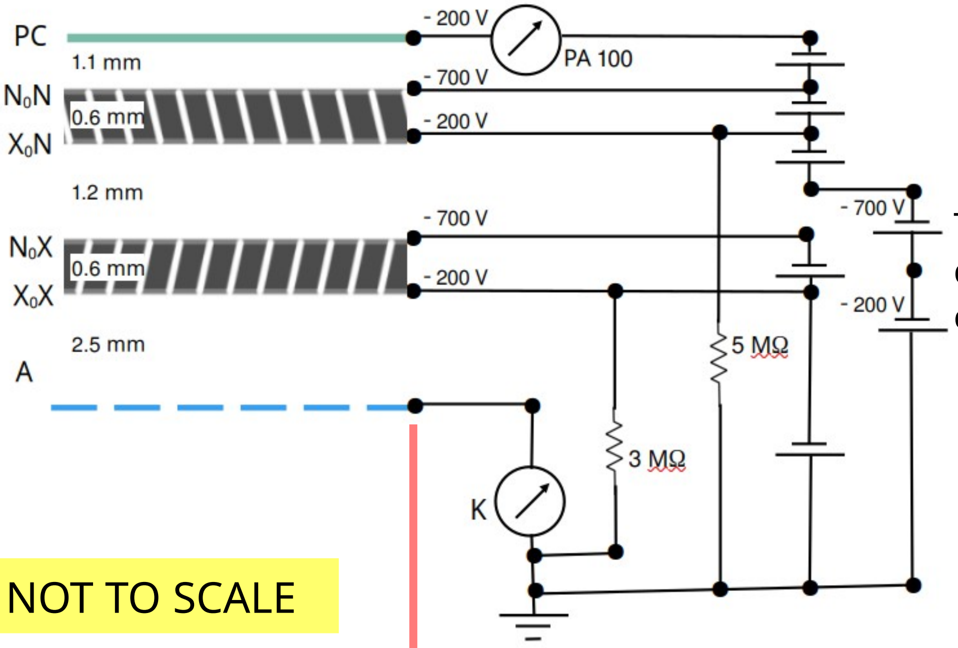


Grounding: 32 channels



Electrical circuits

HV power supply
7 Channels in Daisy chain



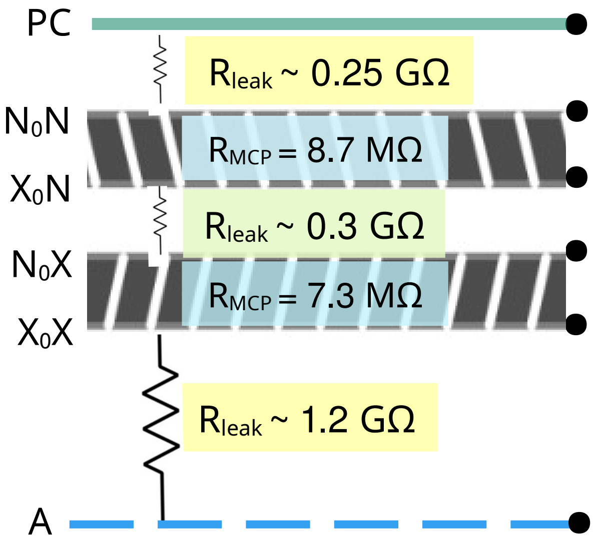
Two dummy channels

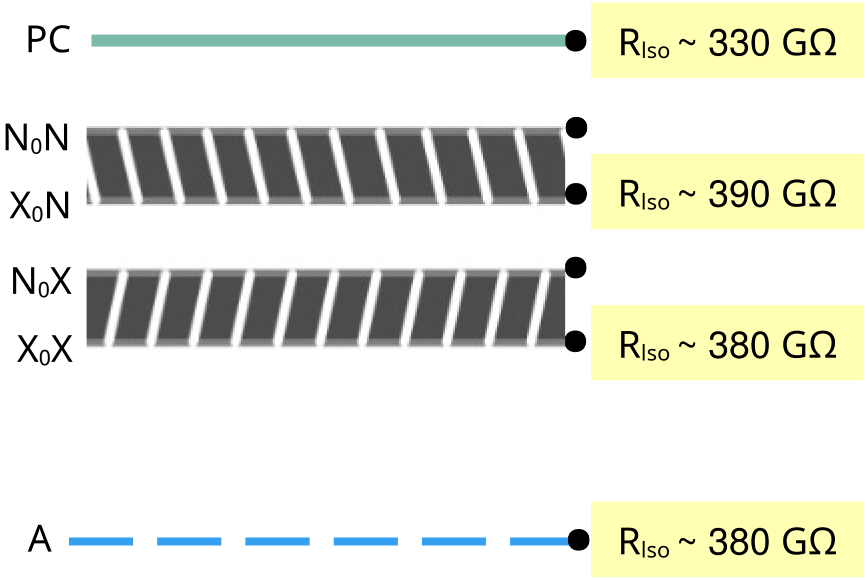
NOT TO SCALE

HV Ground Pin
either to Keithley or Oscilloscope

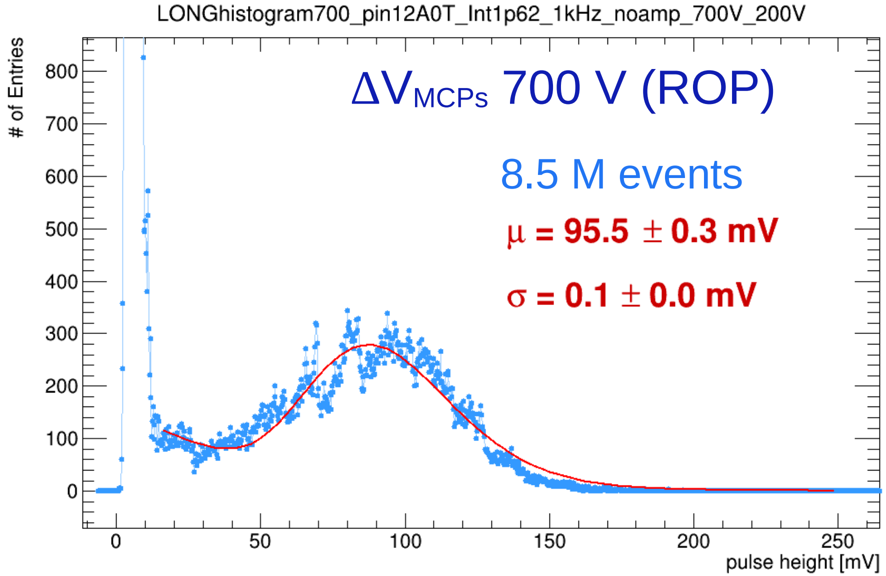
- CAEN DT1415ET HV power supply
  - GECO 2020 software
- 2.5 GHz Oscilloscope (waverunner 9254)

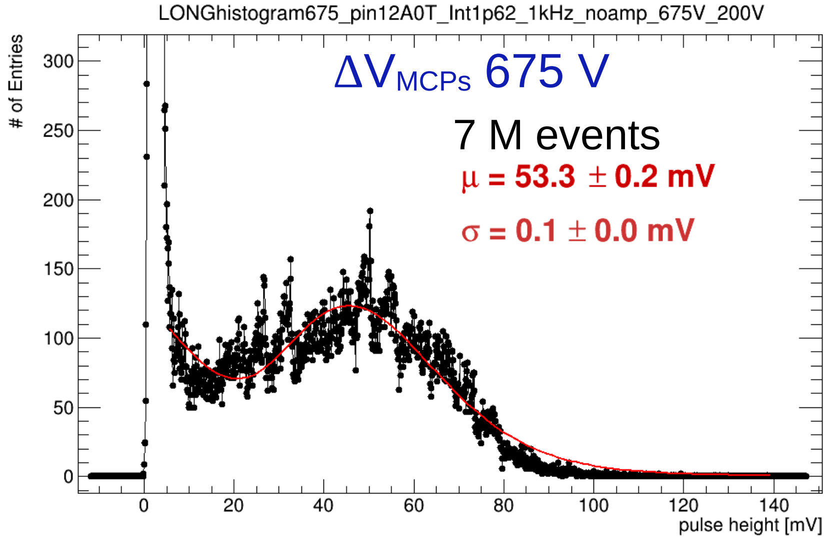
Measurement of Leaks/Isolation

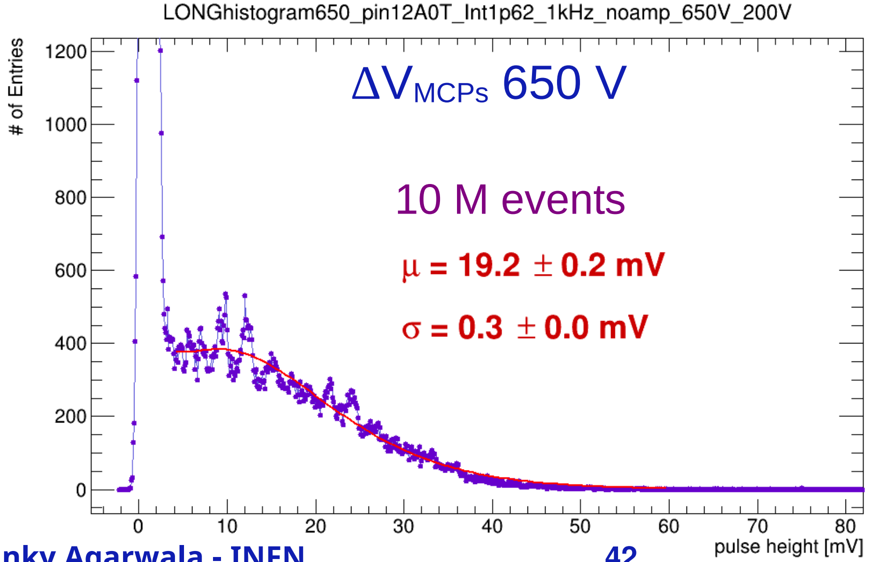




SPE responses, longruns

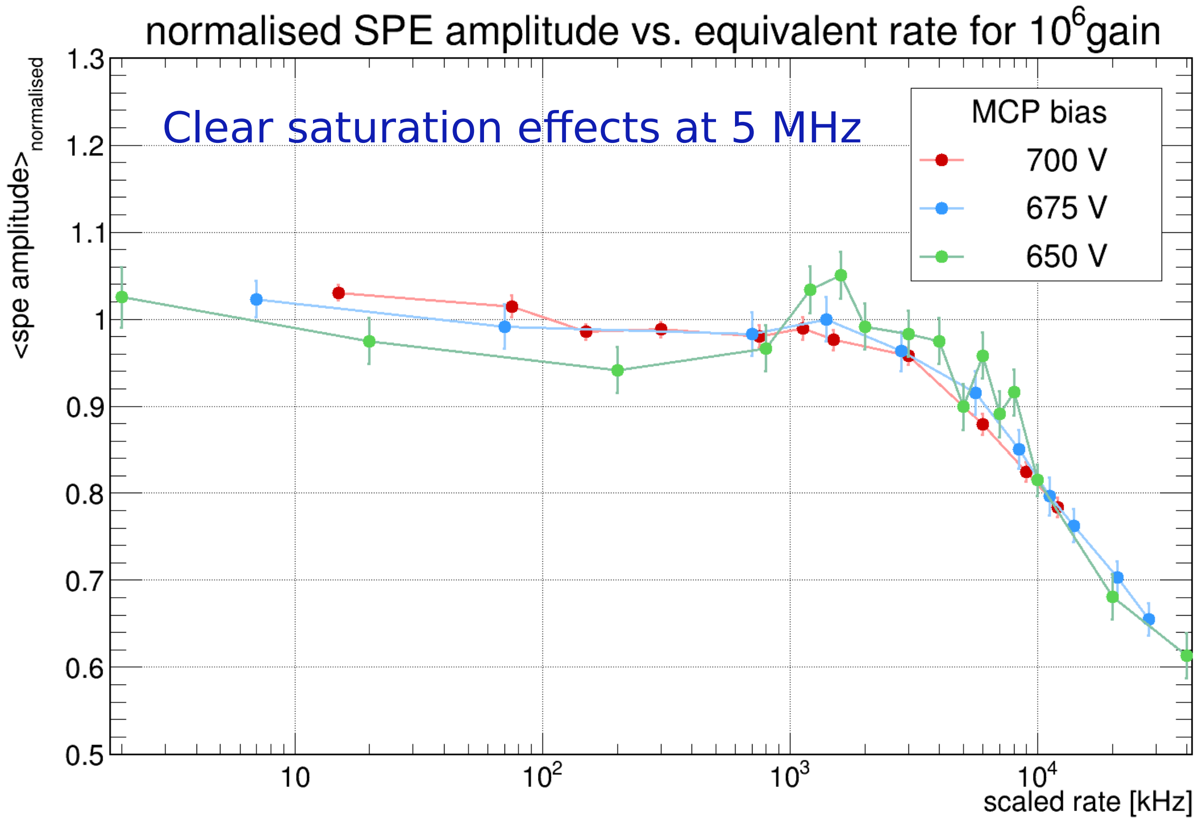






Normalised amplitude vs. scaled rate

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



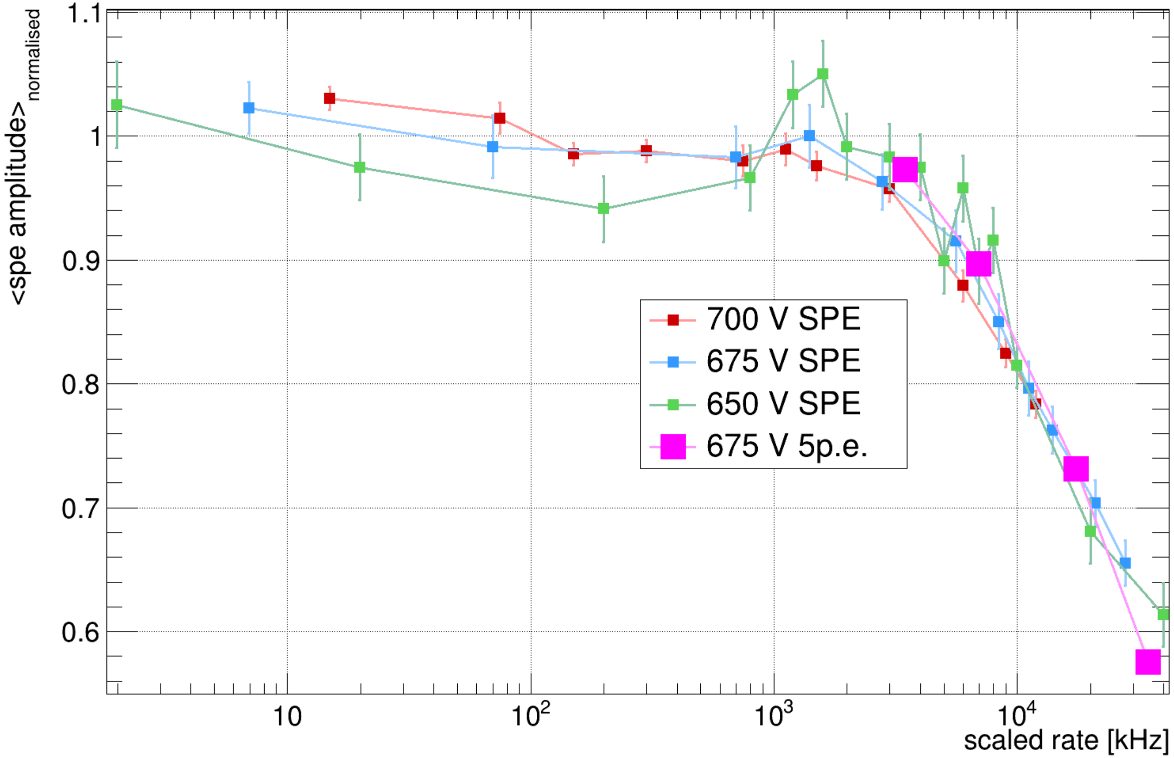
$$\text{Scaled rate} = \frac{\text{Rate x Gain } \textbf{(datasheet)}}{10^6}$$

ΔV [V]	Scaling factor
700	15
675	7
650	2

Normalised amplitude vs. scaled rate

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

675 V, Int. 3.5 (5 p.e.), without amplifier

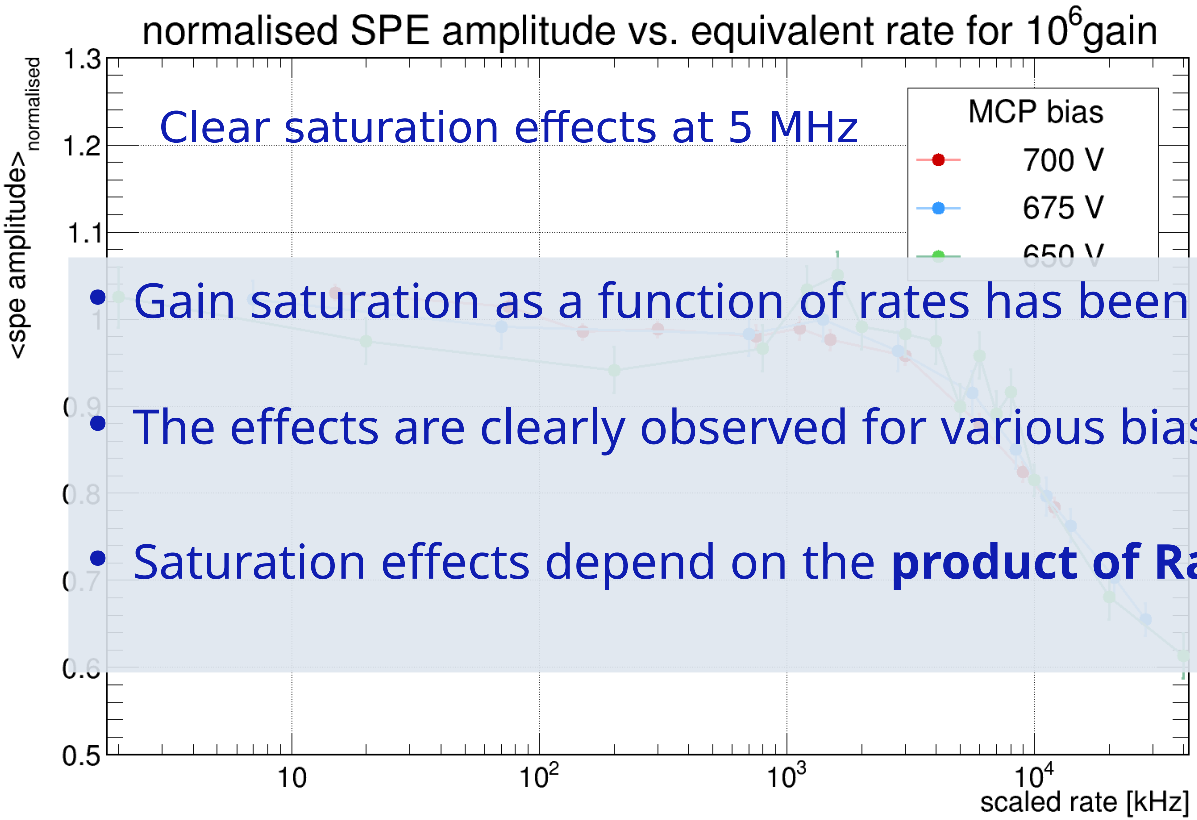


$$\text{rate} = \frac{\text{Rate x Gain } \textbf{(datasheet)}}{10^6}$$

ΔV [V]	Scaling factor
700	15
675	7
650	2

Normalised amplitude vs. scaled rate

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

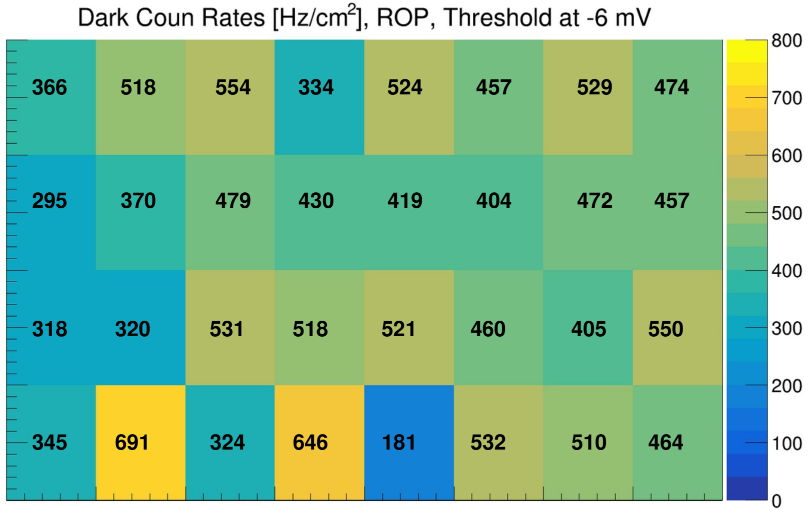


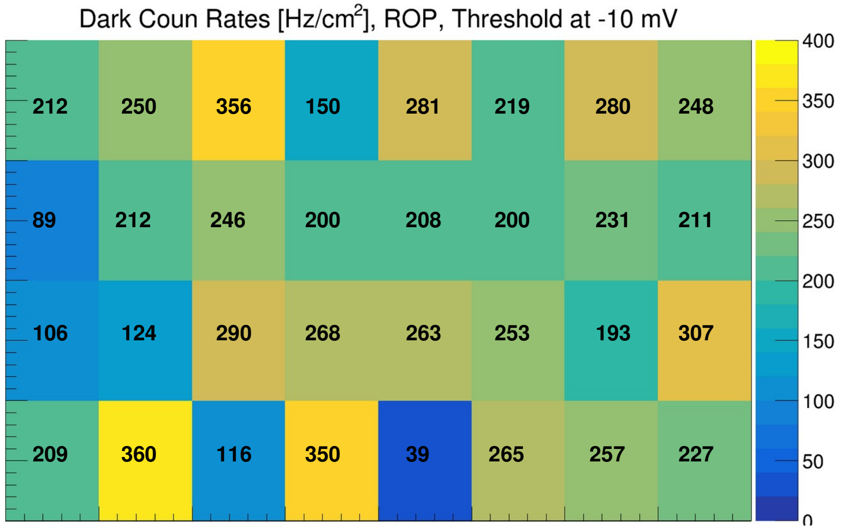
$$\text{Scaled rate} = \frac{\text{Rate x Gain } \textbf{(datasheet)}}{10^6}$$

- Gain saturation as a function of rates has been measured (SPE responses).
- The effects are clearly observed for various bias voltages across the MCPs.
- Saturation effects depend on the **product of Rate and Gain** (universal curve).

ΔV [V]	Scaling factor
700	15
675	7
650	2

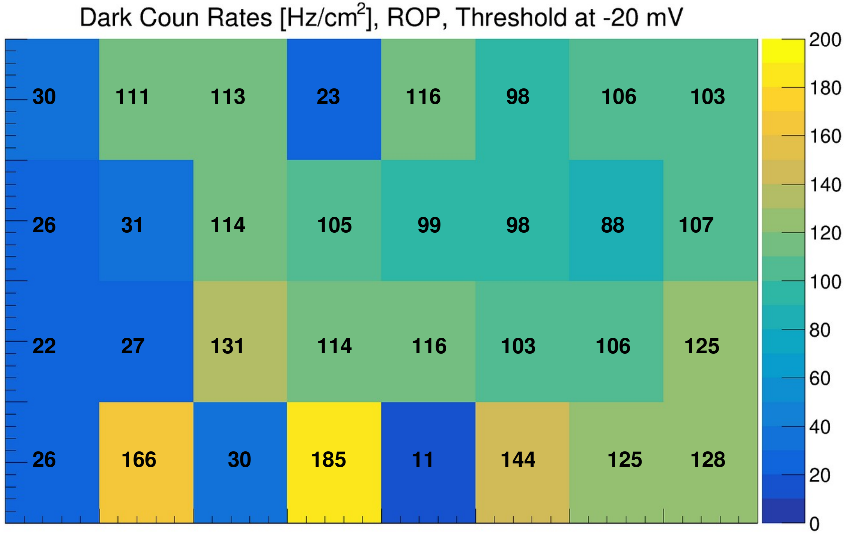
Dark Count Rates





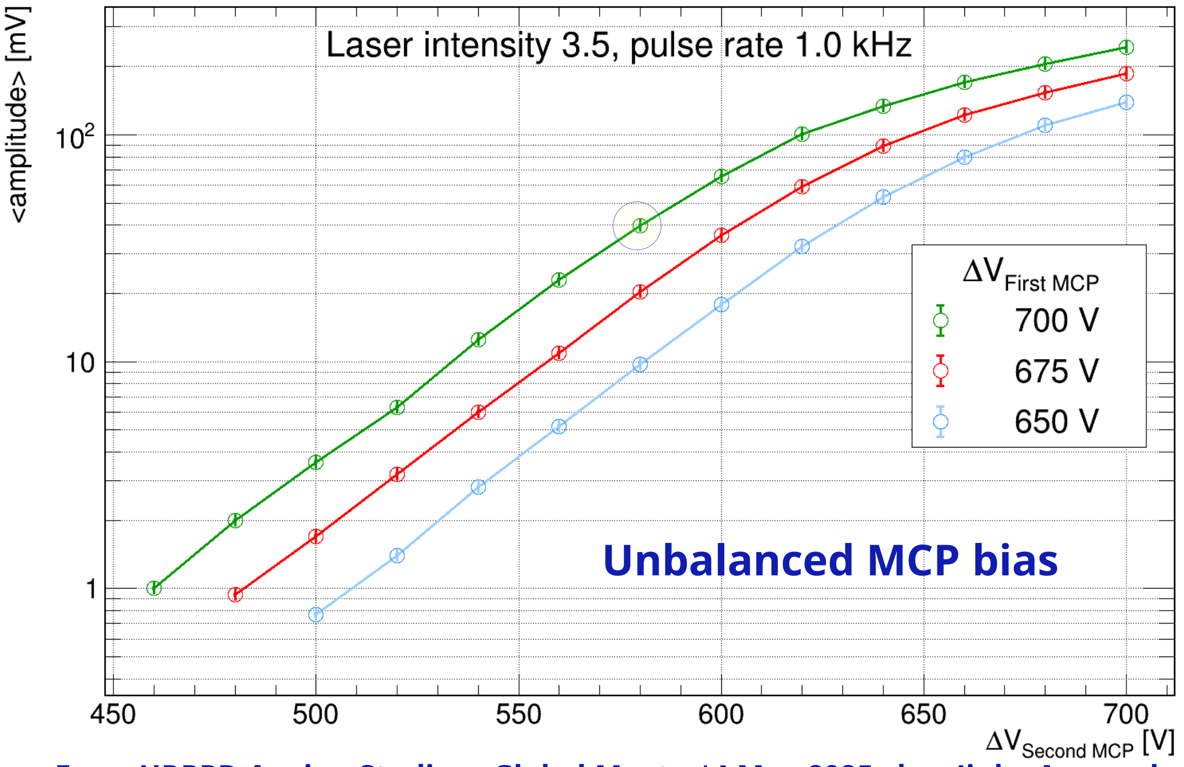
37	27	33	?	19	14	11	9
34	39	29	24	20	13	3	10
30	40	31	21	17	7	4	1
38	28	32	22	?	8	12	2

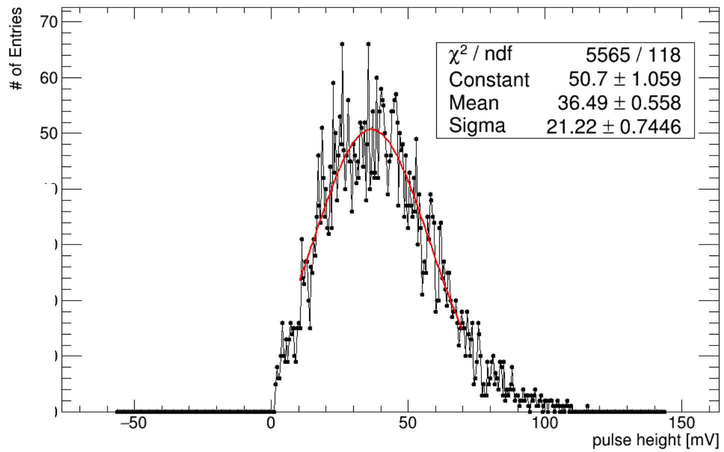
? D isconnected pins (#23, 18)



Amplitude vs. 2nd MCP bias

HV: -200_**varying-ΔV$_{MCP2}$** _-200_fixed-ΔV$_{MCP1}$ _-200 V
Trigger on Sync pulse, Int. 3.5; 1.0 kHz
Without amplifier; Pin #12 A0Top



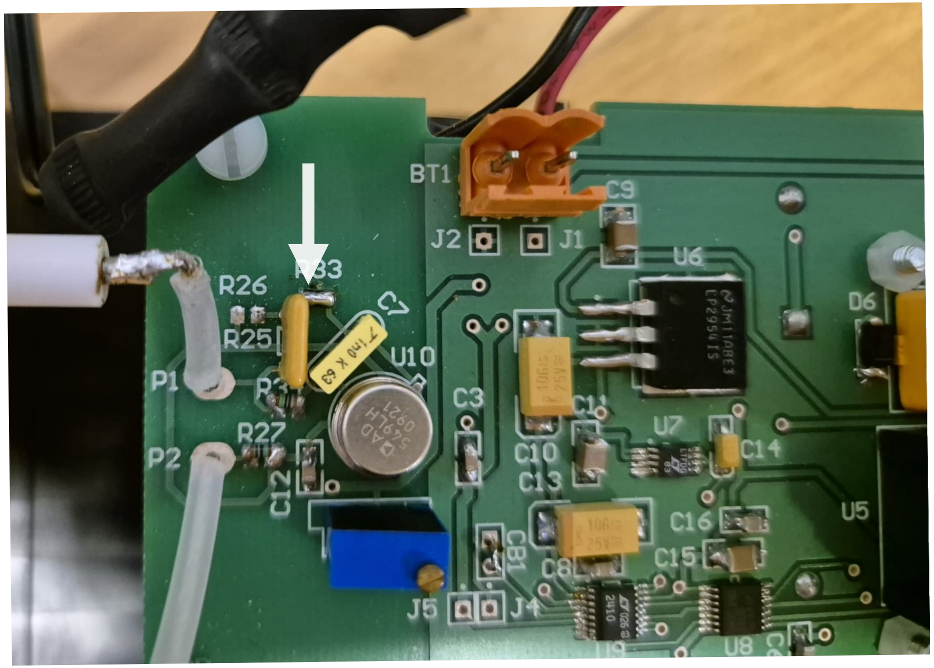


- Fixed slope for <a> < 50 mV
  - ΔV ~ 75 V corresponds to a factor 10 in amplitude

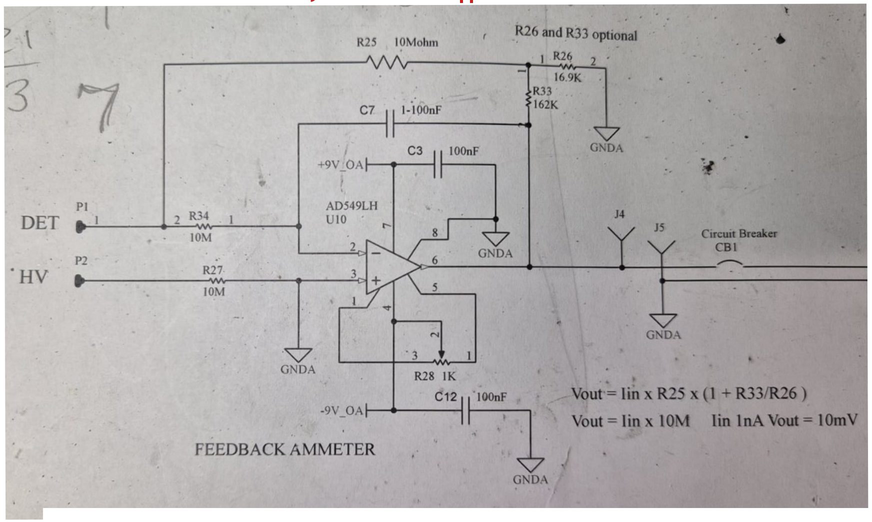
Modified picoammeter

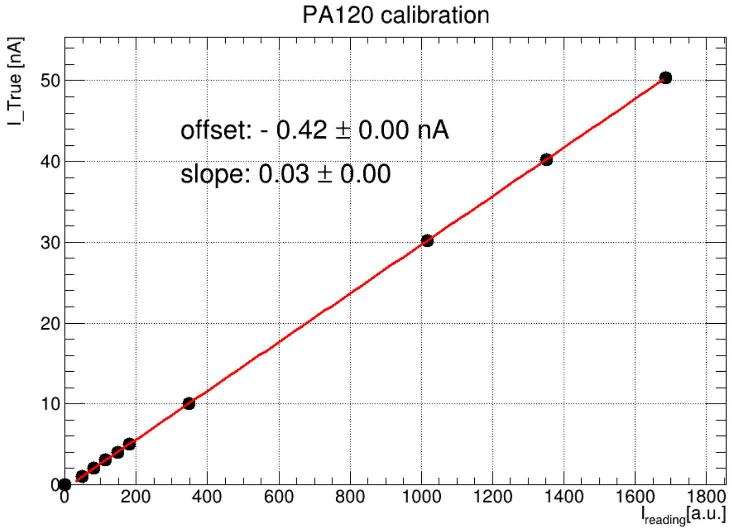
PA120

330 kΩ added in parallel to the 10 MΩ



R25, 10 MΩ || 0.33 MΩ





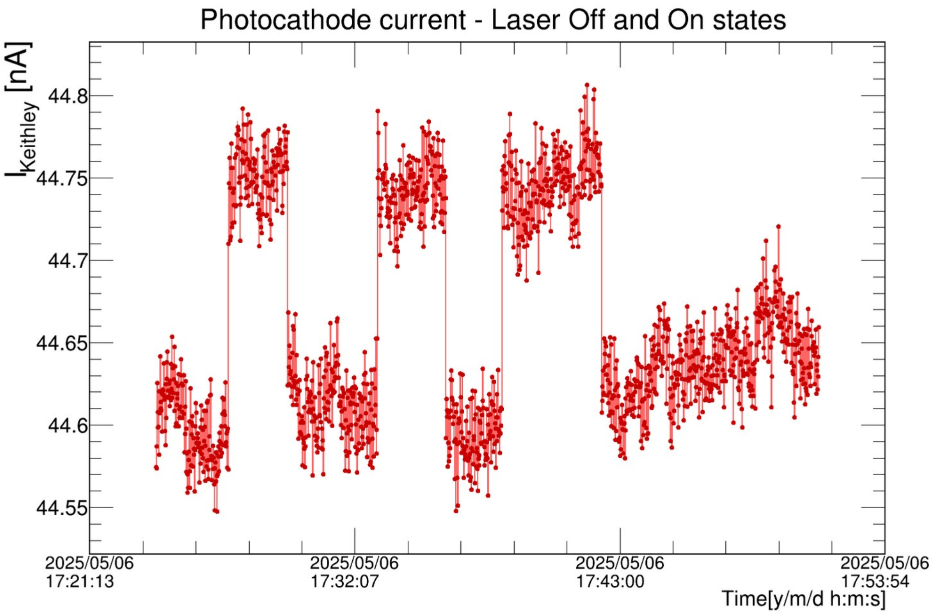
I_{Max} for 10 MΩ: ~46 nA

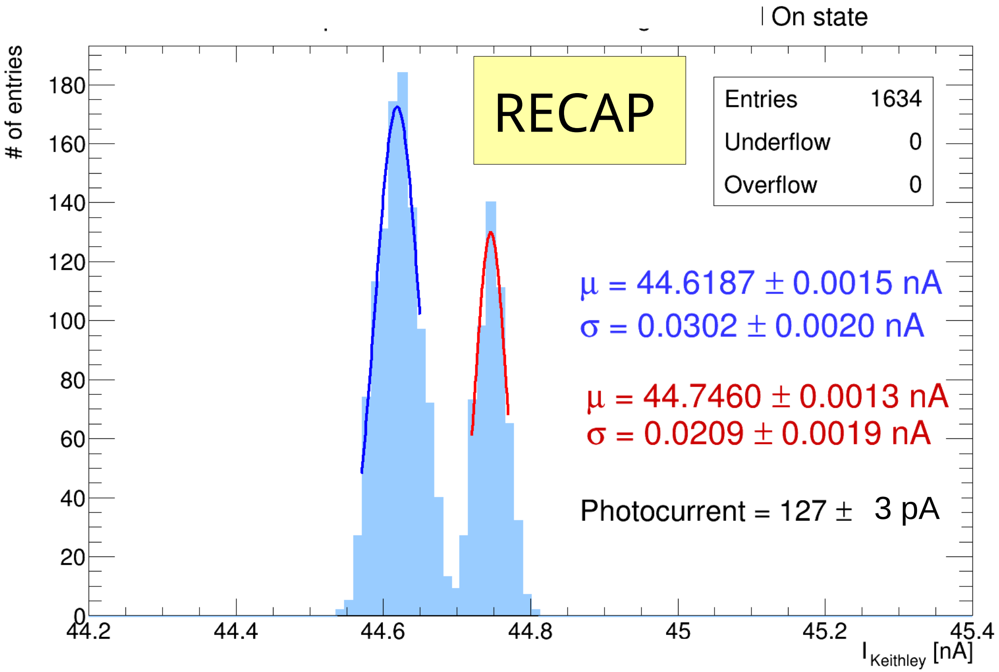
I_{Max} for PA120: ~1.5 μA

QE measurement strategy

Preliminary

Light On state: Intensity 3.5, Internal Trigger 40 MHz
NoN at +10 V



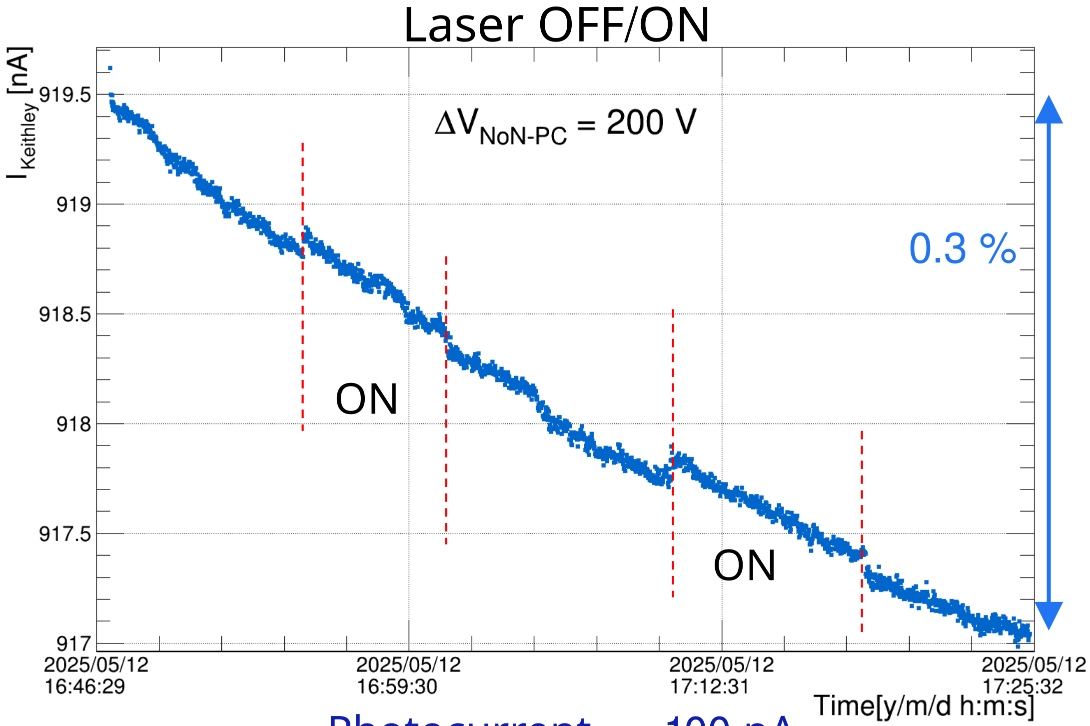


8×10^8 p.e./sec

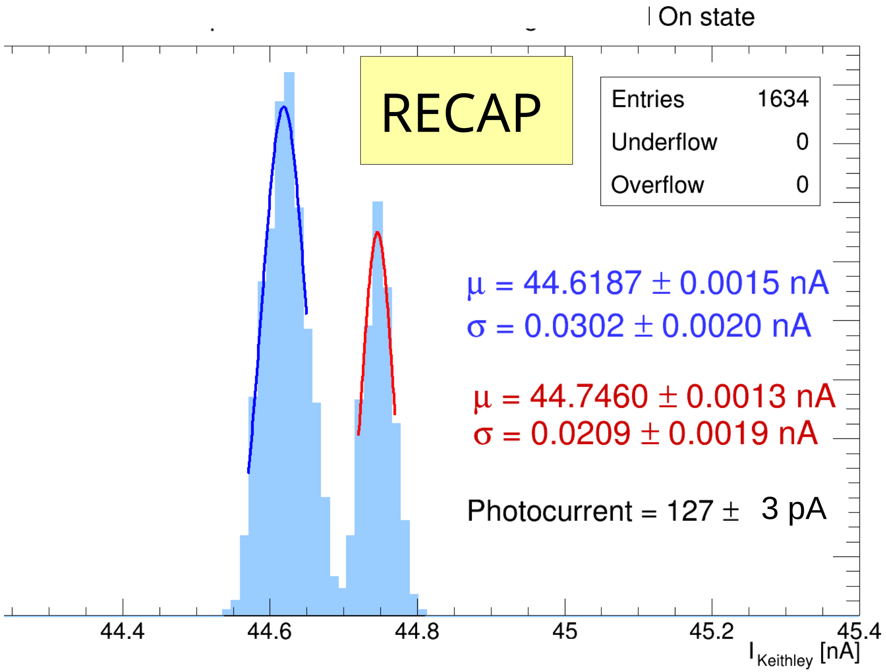
QE measurement strategy

Preliminary

Light On state: Intensity 3.5, Internal Trigger 40 MHz
NoN at +10 V vs. 200 V



Photocurrent = ~100 pA



8×10^8 p.e./sec