ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Breakthrough in the Lifetime of Microchannel-Plate Photomultipliers

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

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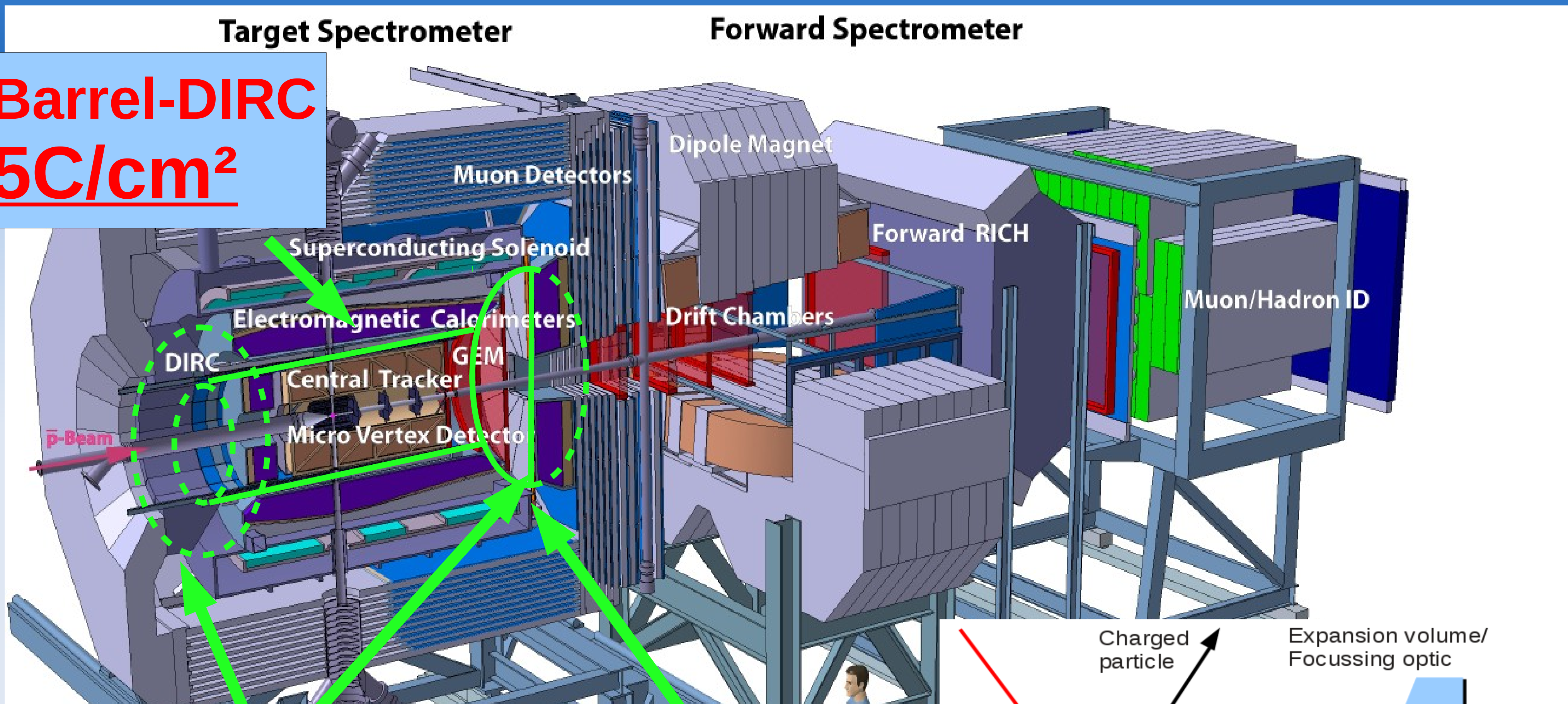
Outline

- Motivation
- Properties of MCP-PMTs and lifetime constraints
- Setup of lifetime measurements under PANDA conditions
- Results of the latest measurements for various devices concerning:
  - Darkcount rate
  - Gain
  - Quantum Efficiency measurements
  - QE surface scan
- Comparison with previous measurements
- Summary and outlook

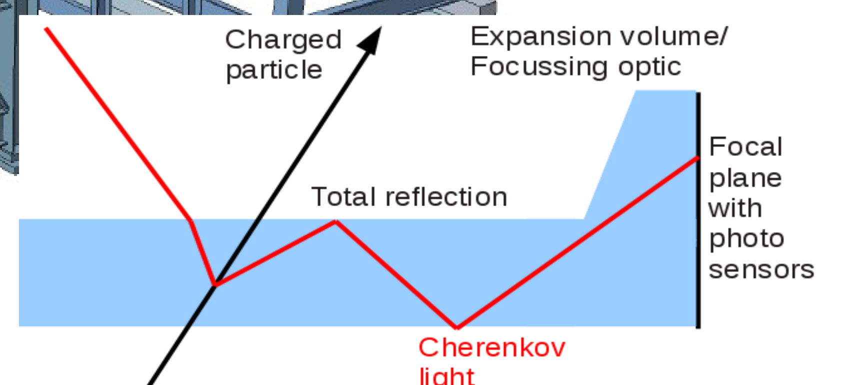
The PANDA-Detector



Barrel-DIRC
5C/cm²

Focal planes of both DIRC detectors are inside magnetic field

Disc-DIRC
>5C/cm²

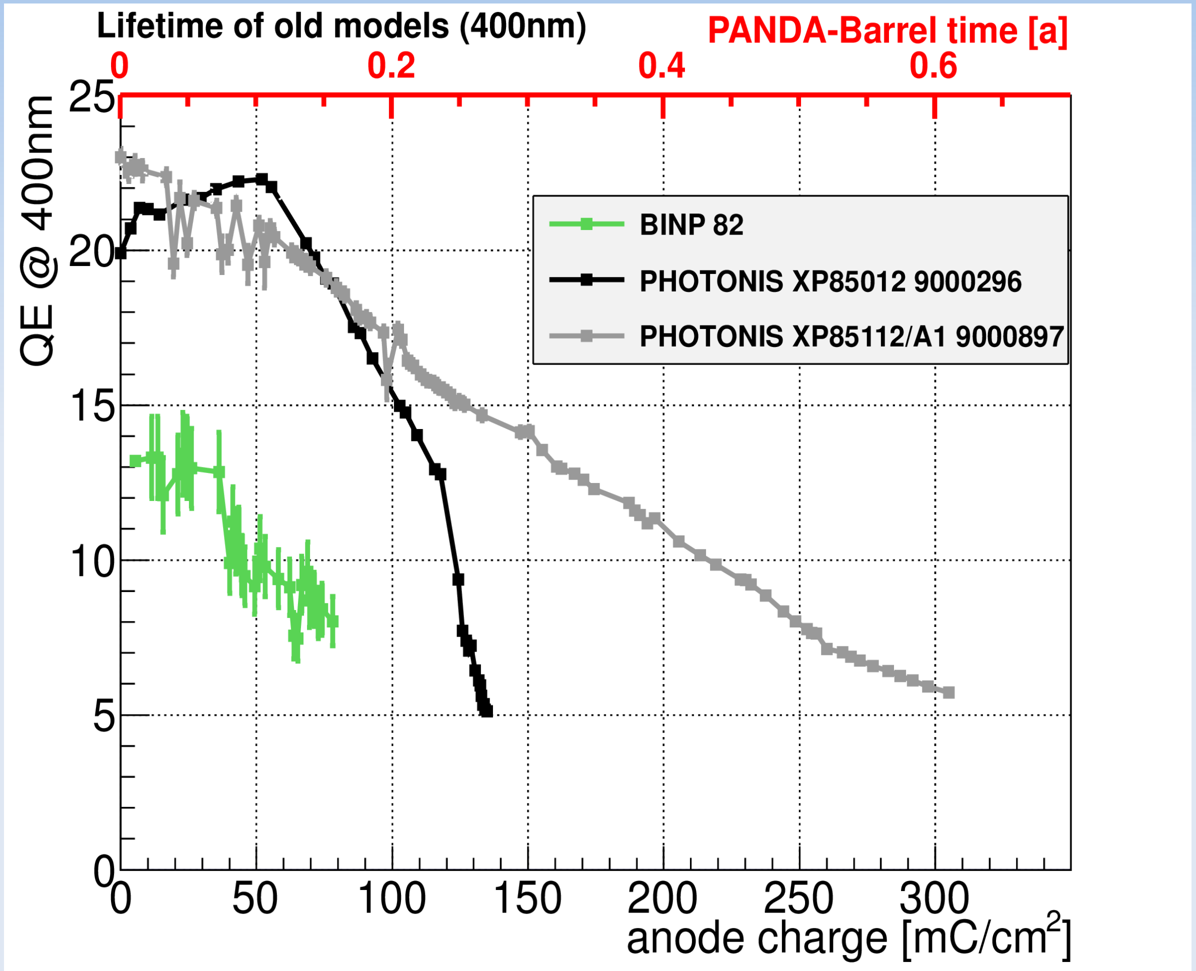


PID requirements for PANDA:
π/K seperation up to 4GeV/c

Photosensor requirements

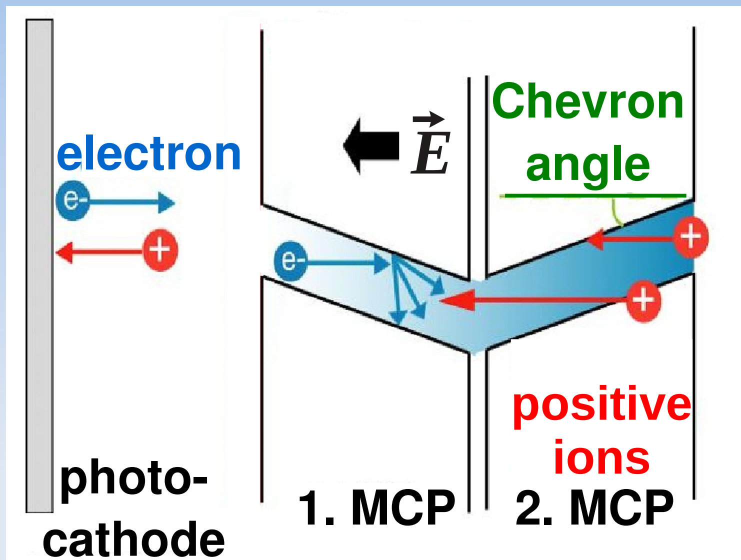
	PMTs	MCP-PMTs	SiPMs
Magnetic field resistance up to 2T (Disc DIRC)	X	✓	✓
Gain > $5*10^5$ (single photons)	✓	✓	✓
Time resolution: $\sigma < 100$ps	X	✓	✓
Spatial resolution	✓	✓	✓
High geometrical efficiency	✓	✓	✓
High photon rates 200kHz/cm² (Barrel), >200 kHz/cm² (Disc)	✓	✓	✓
Radiation hardness	✓	✓	X
Darkcount rate	✓	✓	X
Lifetime: >5C/cm² for 10 year PANDA operation (50% duty, Gain = 10^6) at high luminosity ($2*10^{32}cm^{-2}s^{-1}$)	✓	? ✓	?

Lifetime of MCP-PMTs (~ 4 years ago)



- QE @ 400nm drops to 50% of starting value within 50 – 200mC/cm²
- Corresponding PANDA-Barrel time ≤ 0.4 years
- Lifetime of standard MCP-PMTs is not sufficient for usage under PANDA conditions!
- No other models available ~ 3 - 4 years ago

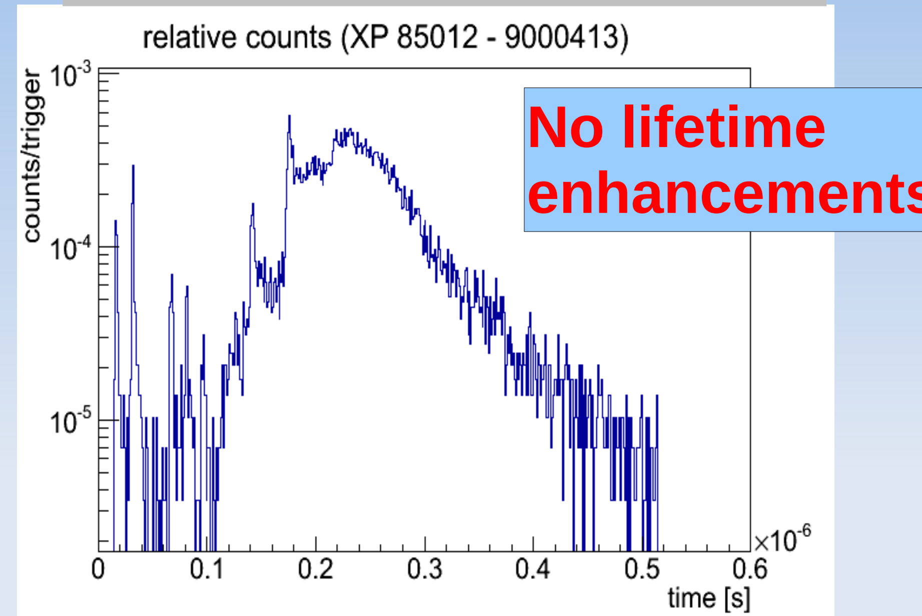
Aging of photo cathode

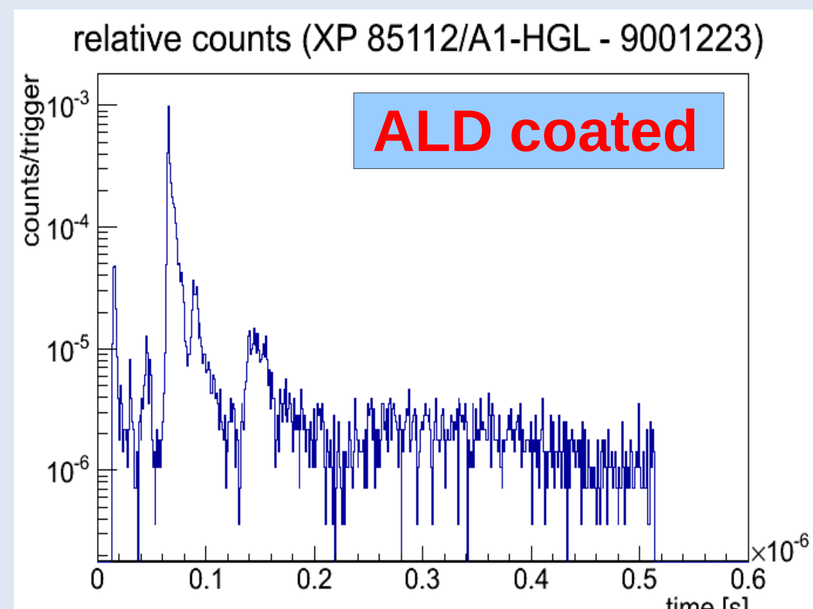


- Photocathodes of older MCPs are more damaged due to impact of (heavy) ions:
  - Chemical reactions, Adsorption
  - Cluster/lattice/surface defects

- Possible solutions:
  - Make cathode more ”robust”
  - Reduce flux of (heavy) ions

Afterpulsing measurements

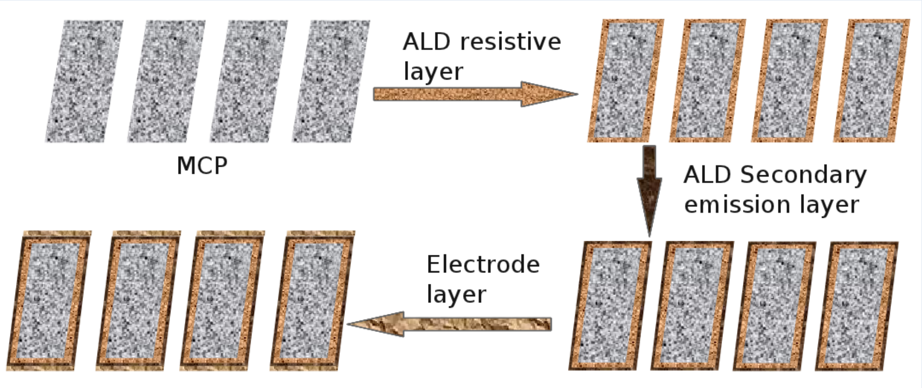




Methods to increase lifetime

- Improved vacuum (PHOTONIS, BINP #1359, #3548)
- New photo cathode, Cs/Sb -vapor (BINP #1359, #3548)
  → **Problem: higher darkcount rate**
- Protection layer:
  - In front of first MCP layer (old Ham. MCP-PMTs, BINP #82)
    → **Problem: reduction of collection efficiency**
  - Between MCP layers

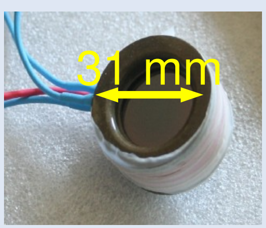
    (Ham. R10754X-01-M16)



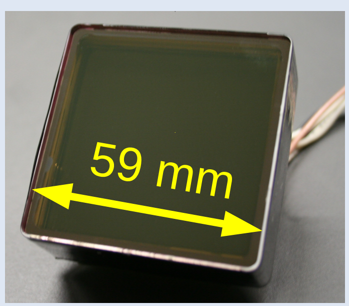
- Treatment of MCP surfaces:
  - Electron scrubbing (PHOTONIS, BINP #1359, #3548)
  - **Atomic layer deposition** (PHOT. XP85112/A1-HGL, XP85112/A1-D, Ham. R10754X-07-M16M) → Company Arradiance (www.arradiance.com)

Overview of latest MCP-PMTs

	BINP	PHOTONIS	Hamamatsu	Hamamatsu
	1359 / 3548	XP85112/A1-HGL 1223 / 1332	R10754X-01-M16 JT0117	R10754X-01-M16M KT0001 / KT0002
Pore size (µm)	7	10	10	10
Number of pixels	1	8x8	4x4	4x4
Active area (mm²)	$9^2\pi$	53x53	22x22	22x22
Geom. Efficiency (%)	36	81	61	61
Photo cathode	Multi-alkali	Bi-alkali	Multi-alkali	Multi-alkali
Peak Q.E.	495	390	375	375
comments	$Na_2KSb(Cs)+Cs_3Sb$ cathode	**ALD**	Prot. layer between 1. and 2. MCP	**ALD**

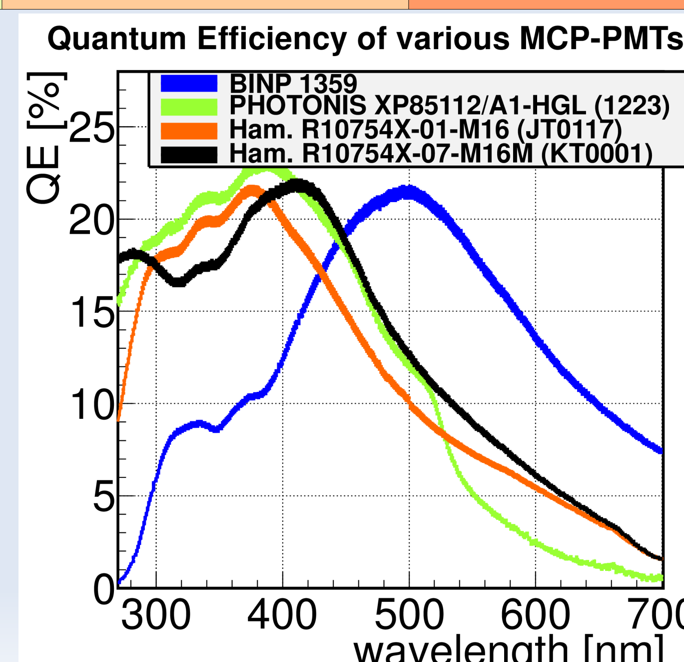


BINP
1359/3548

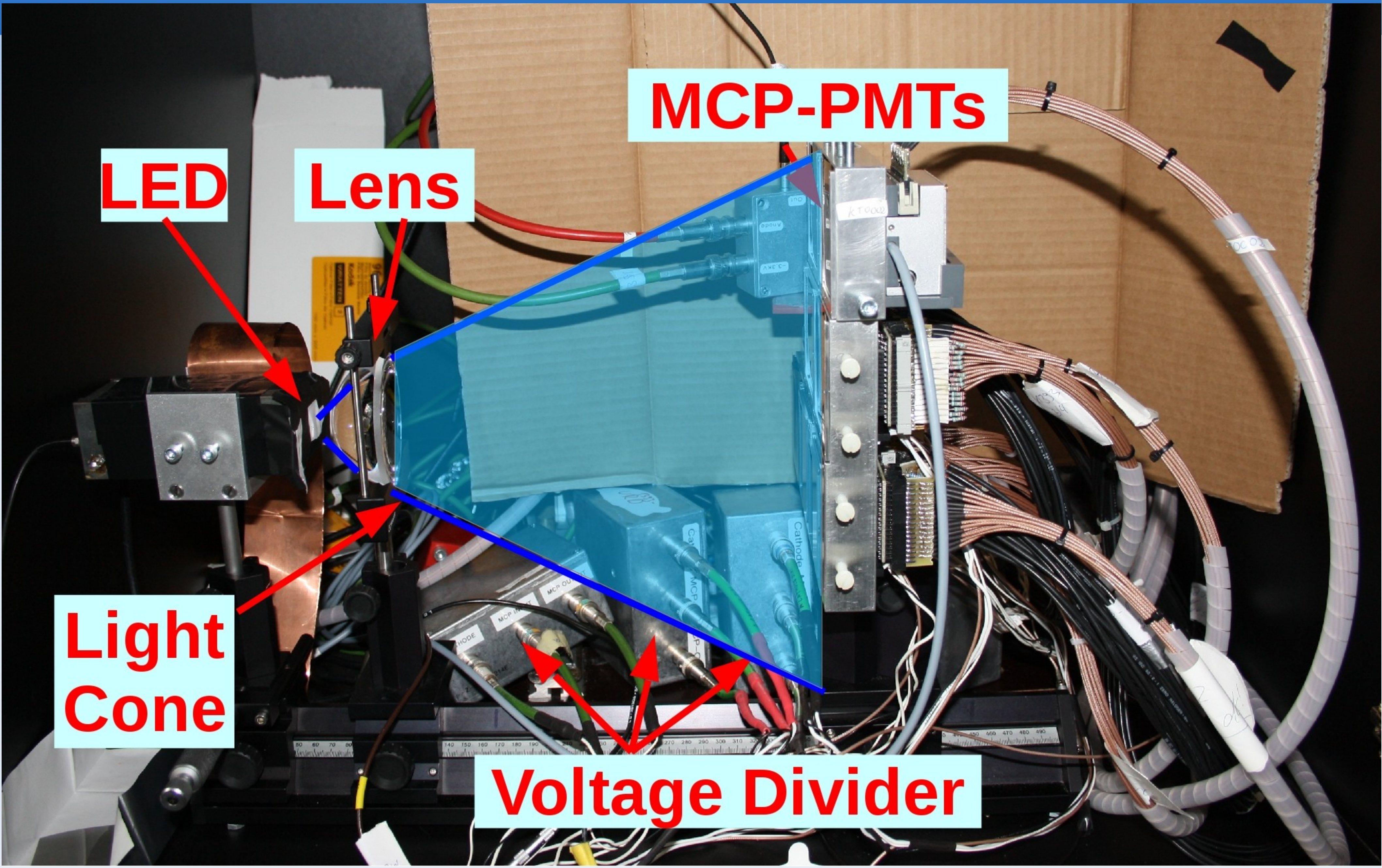


PHOTONIS
XP85112/A1-HGL

Hamamatsu
R10754X-01-M16

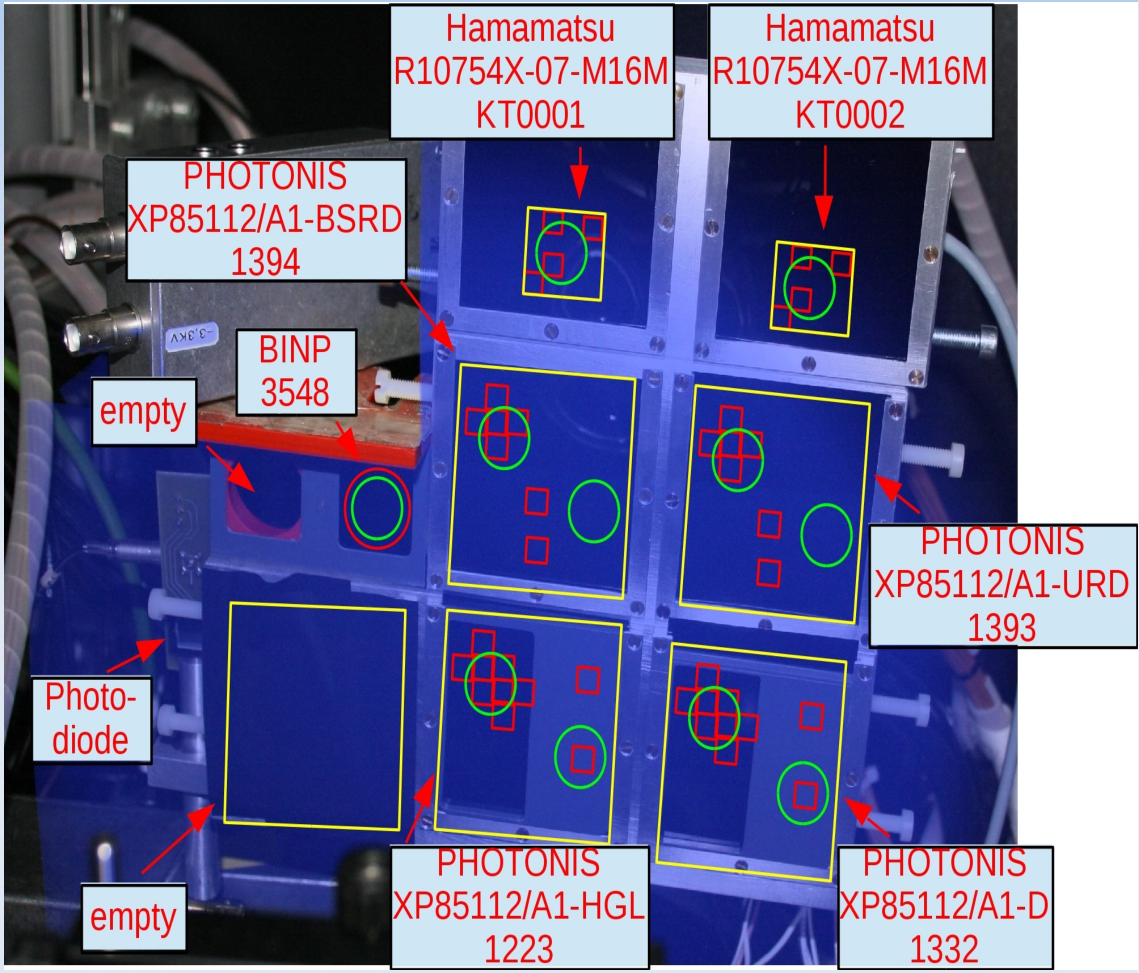


Setup



Lifetime measurement procedure

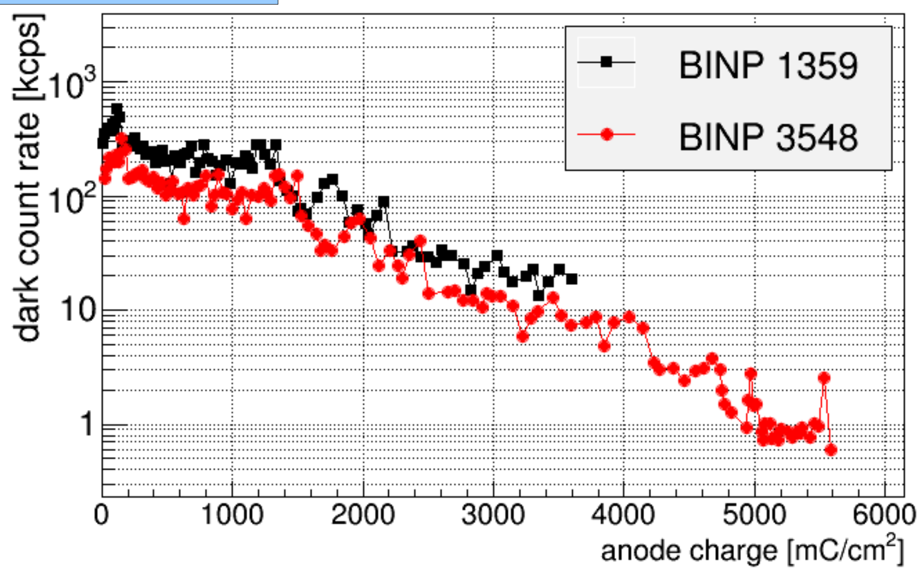
- Simultanous measurements of several different MCP-PMTs under similar conditions as at the PANDA-DIRCs
- Constant illumination (1 MHz single photons) of all MCPs within same lightspot→ **permanent monitoring** to calculate collected anode charge
- Every 7-14 days: Measurement of **Gain**, **darkcount** and **QE**
- QE is measured seperatly using a Xenon arc lamp with monochromator (Δλ = 1nm, 250-700nm)
- QE surface scans are done every 2-4 months with PiLas (372nm, Ø ~1mm)



Dark count rate

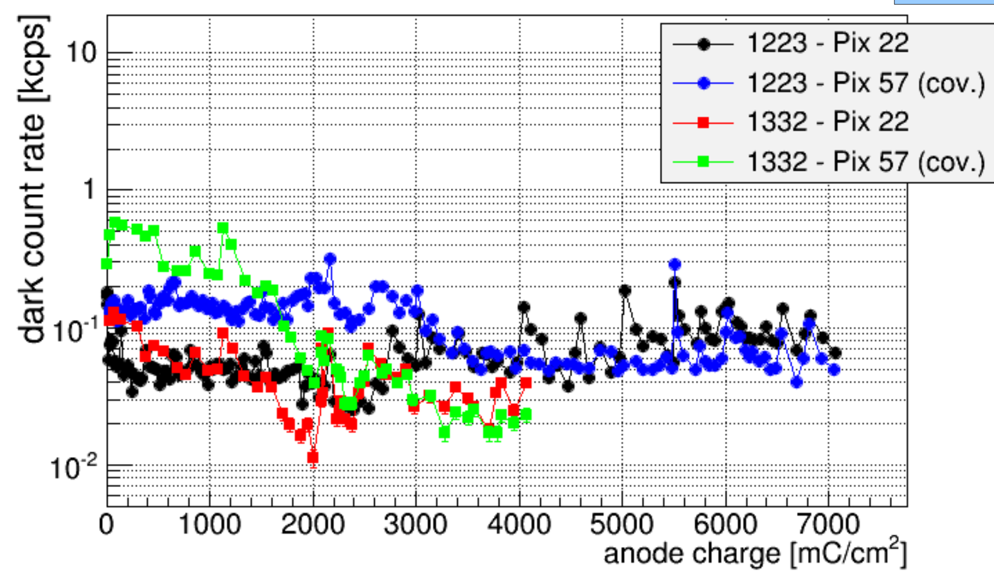
new cath.

BINP 1359/3548

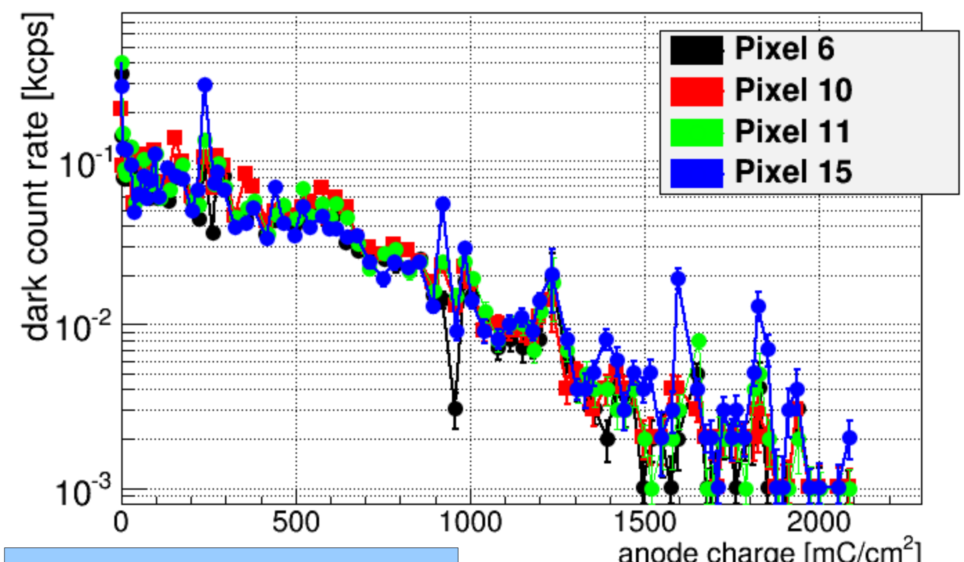


ALD

PHOTONIS XP85112/A1-HGL

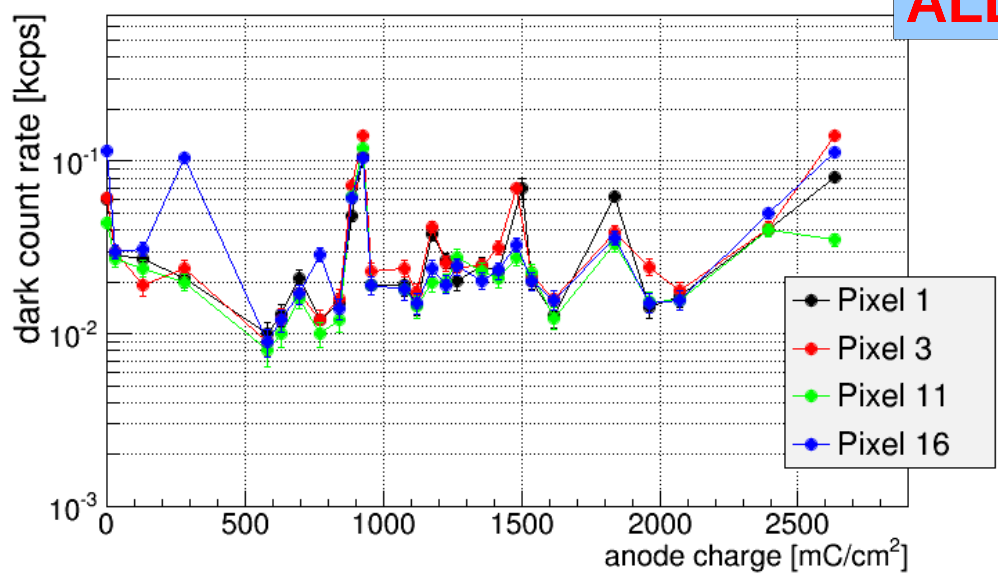


Hamamatsu R10754X-01-M16



Hamamatsu R10754X-07-M16M

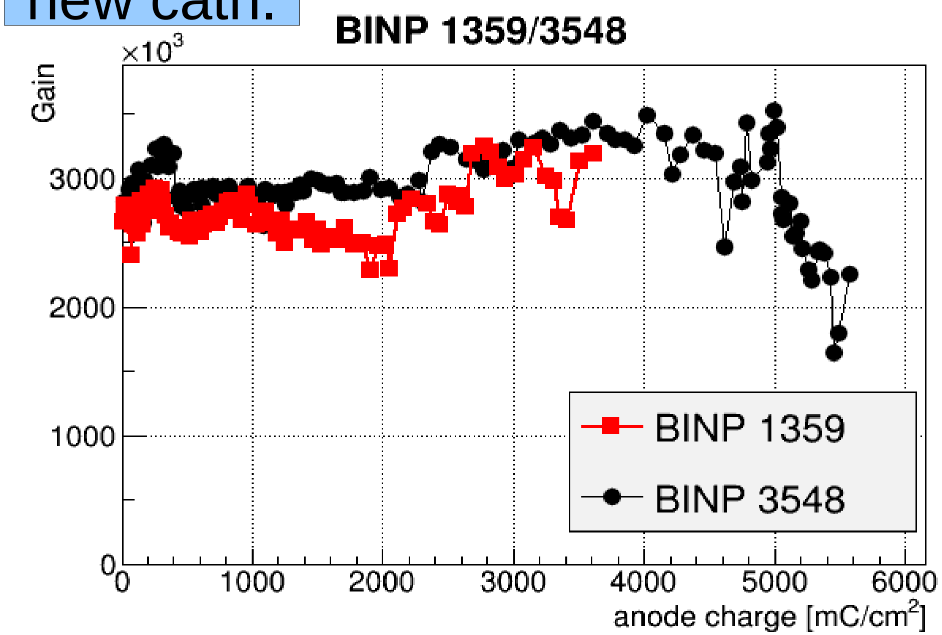
ALD



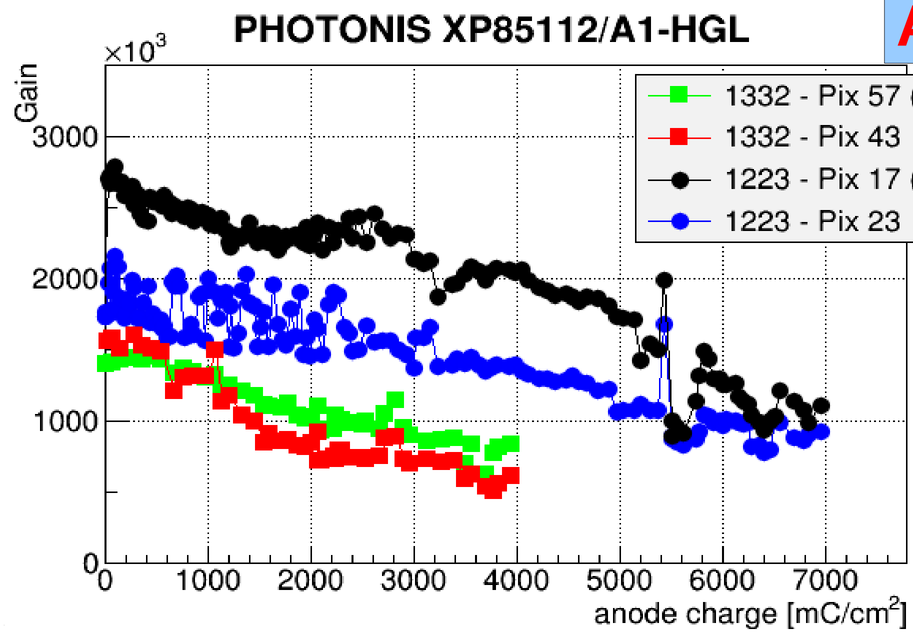
protection layer

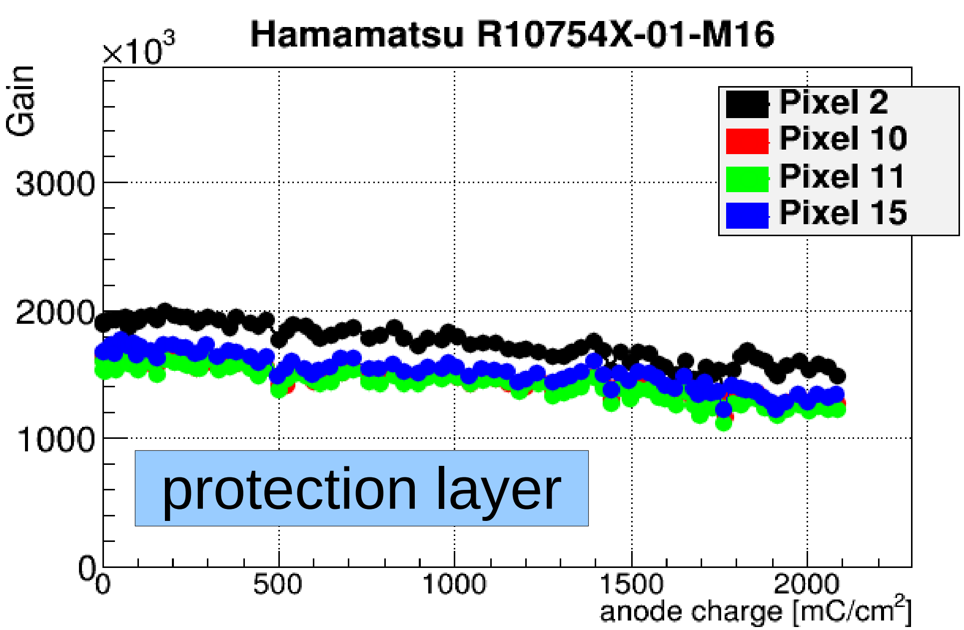
Gain

new cath.



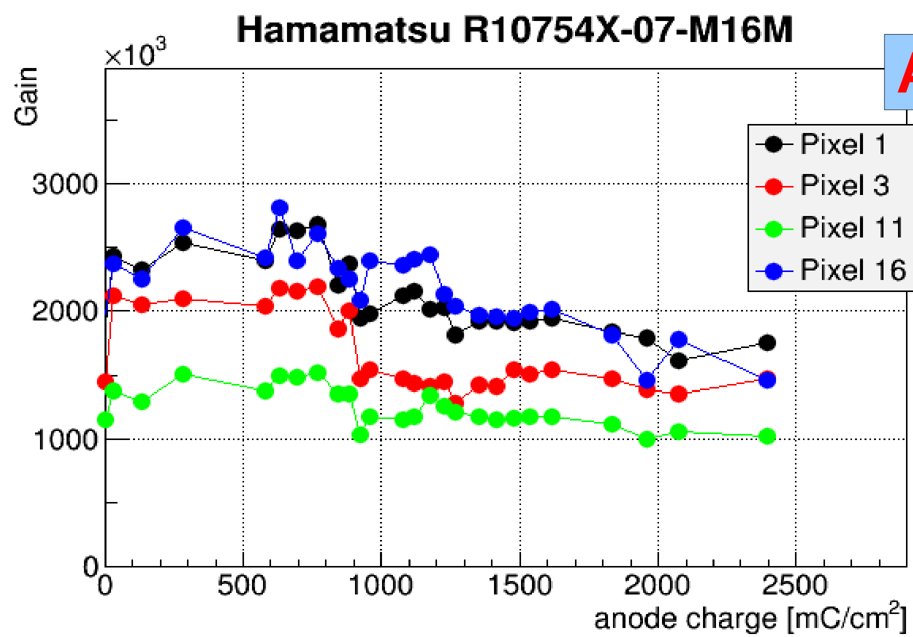
ALD





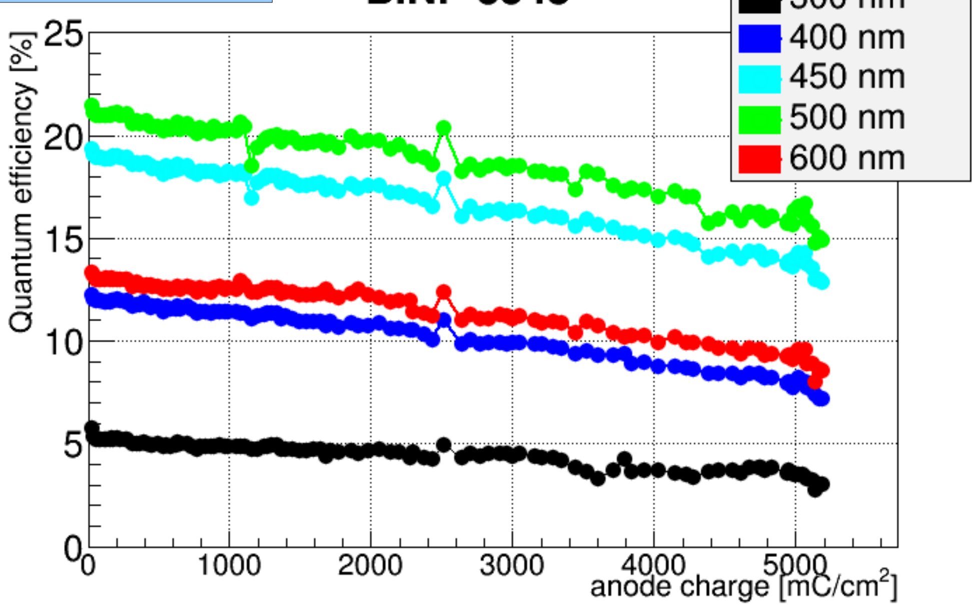
protection layer

ALD

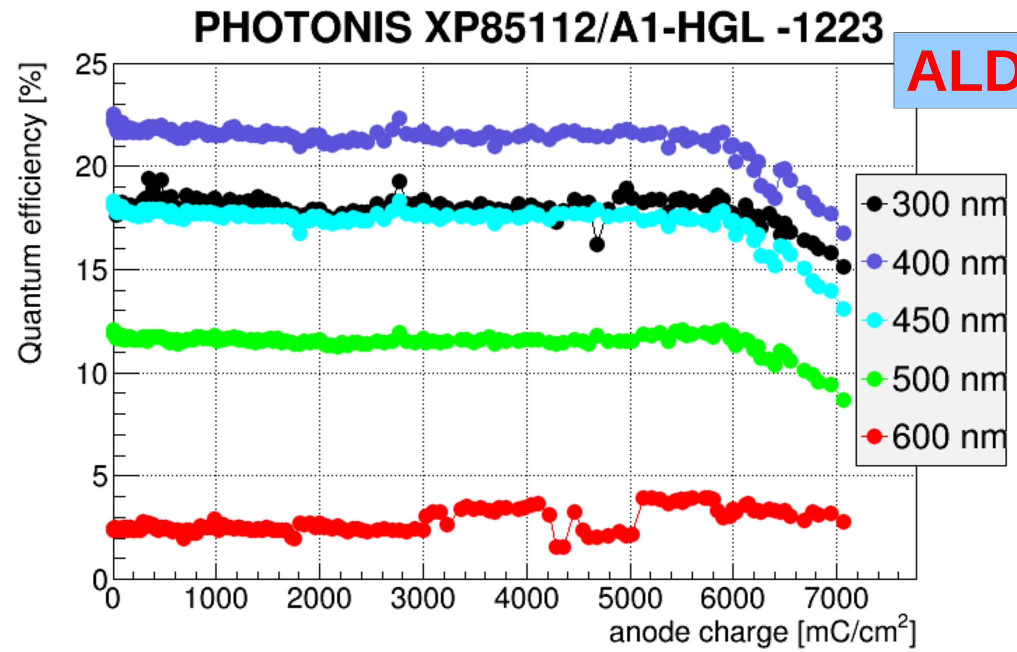


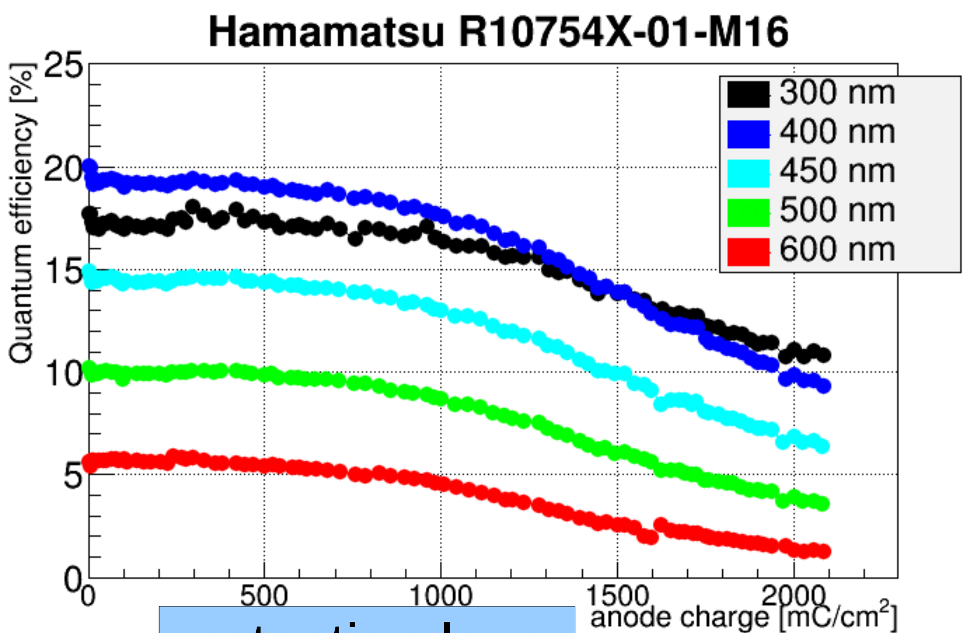
Spectral Quantum Efficiency

new cath.



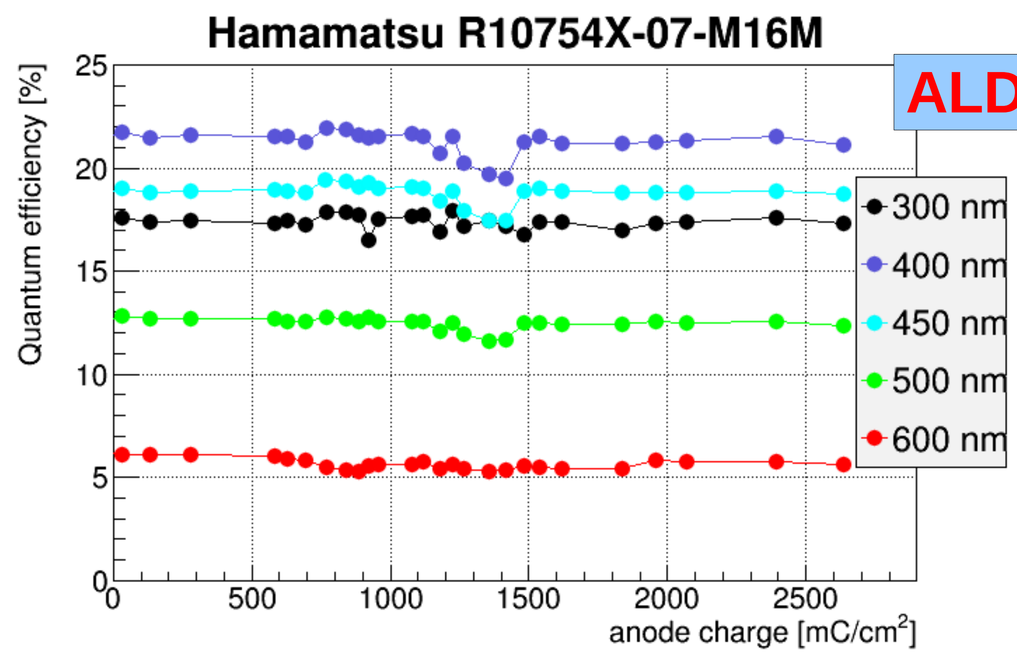
ALD





protection layer

ALD

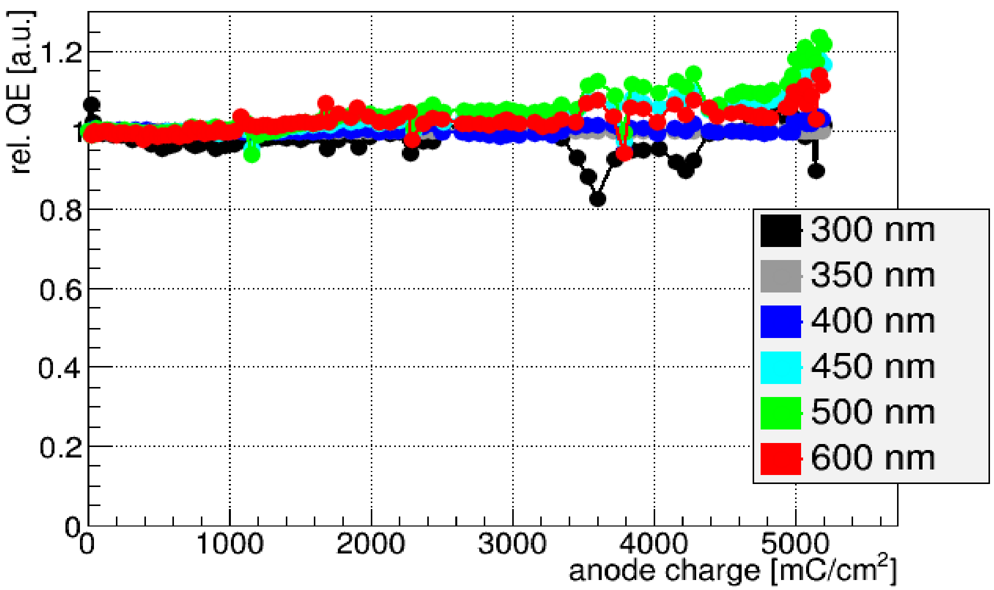


Relative QE

$$rel.\,QE.:=\frac{QE(\lambda)}{QE_{Q=0}(\lambda)}/\frac{QE(\lambda_0)}{QE_{Q=0}(\lambda_0)}\;;\lambda_0=350\text{nm}$$

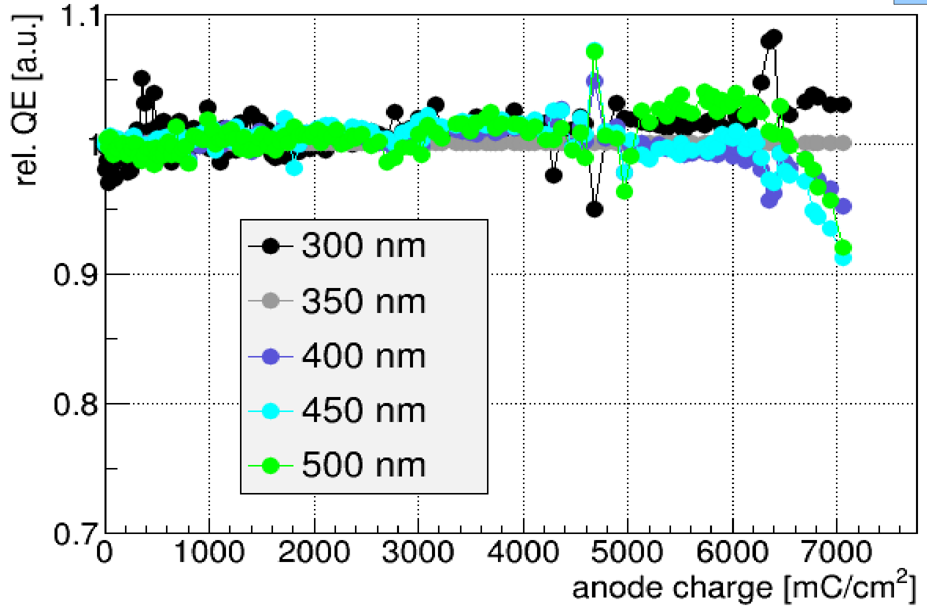
new cath.

BINP 3548

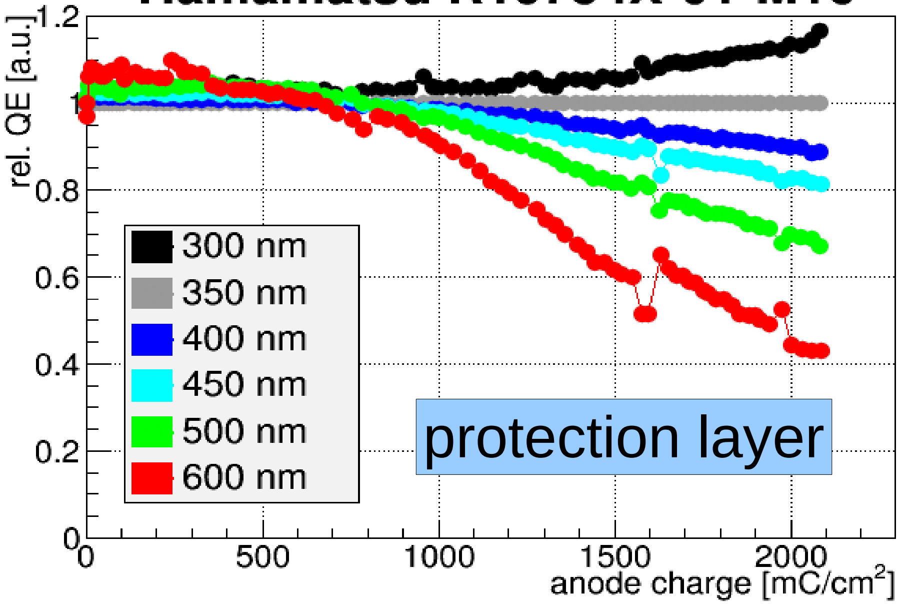


PHOTONIS XP85112/A1-HGL

ALD

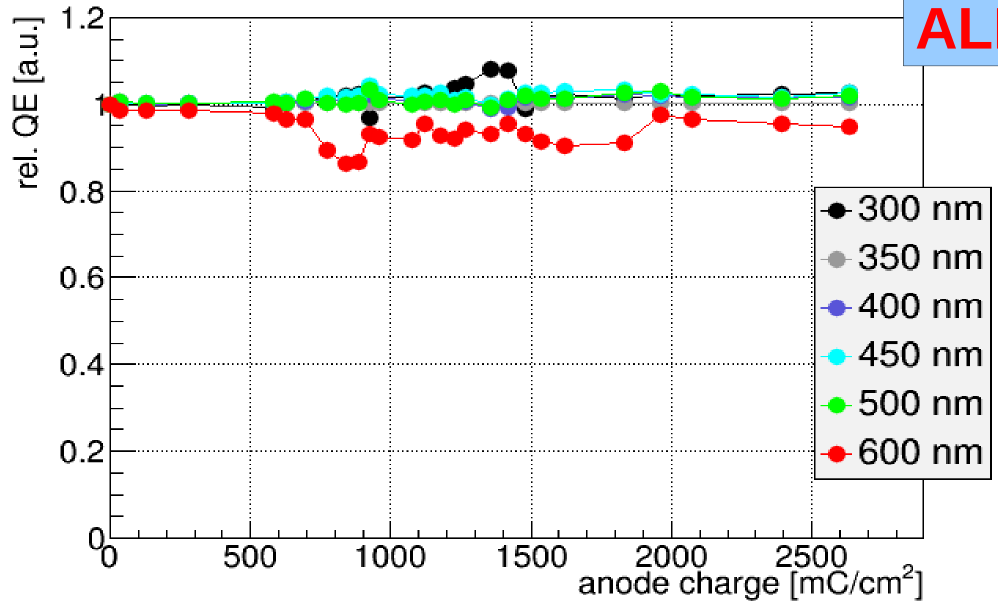


Hamamatsu R10754X-01-M16



Hamamatsu R10754X-07-M16M

ALD

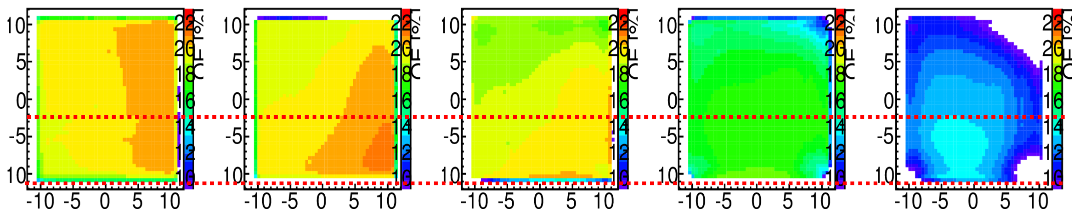


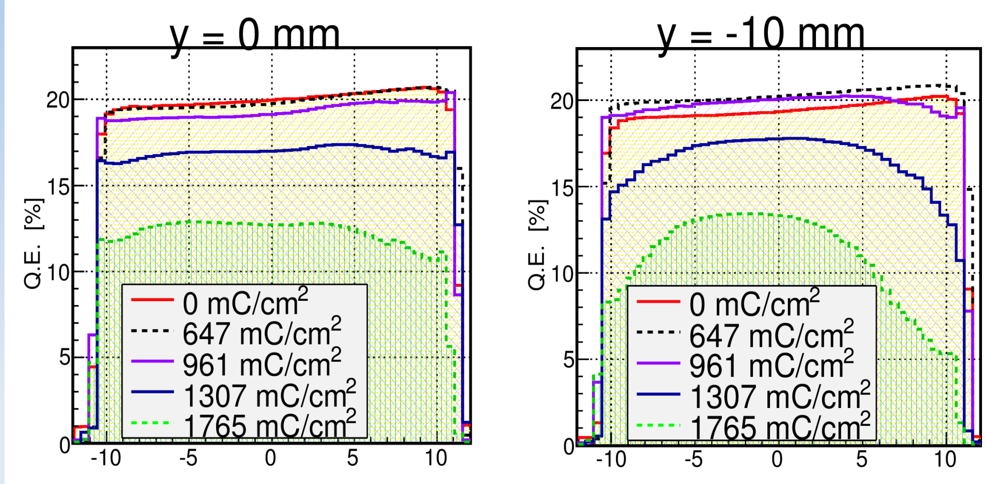
QE surface scan

protection layer

Hamamatsu R10754X-01-M16

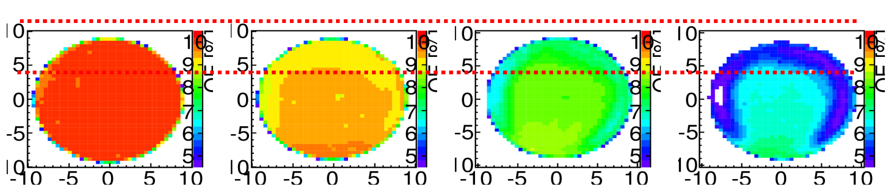
0 mC/cm² | 647 mC/cm² | 961 mC/cm² | 1307 mC/cm² | 1765 mC/cm²

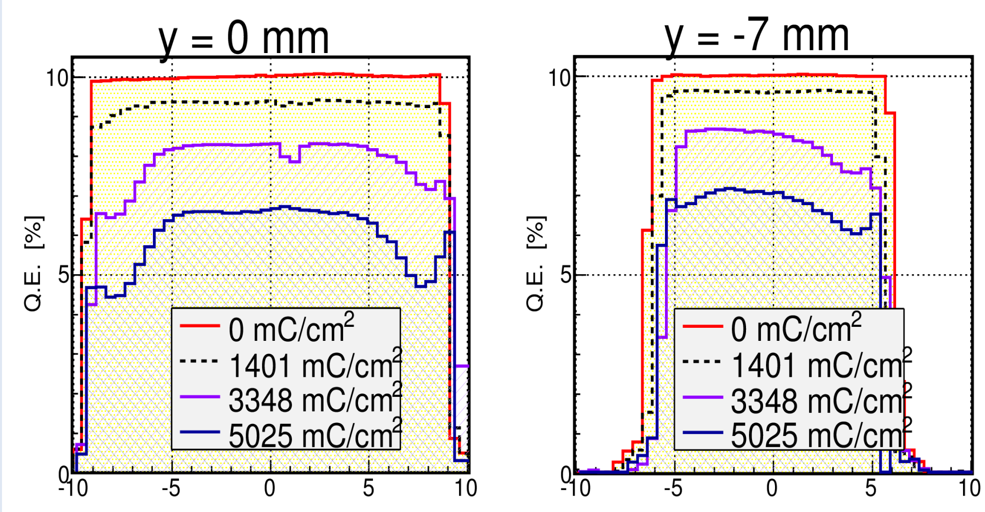




new cath. BINP 3548

0 mC/cm² | 1401 mC/cm² | 3348 mC/cm² | 5025 mC/cm²

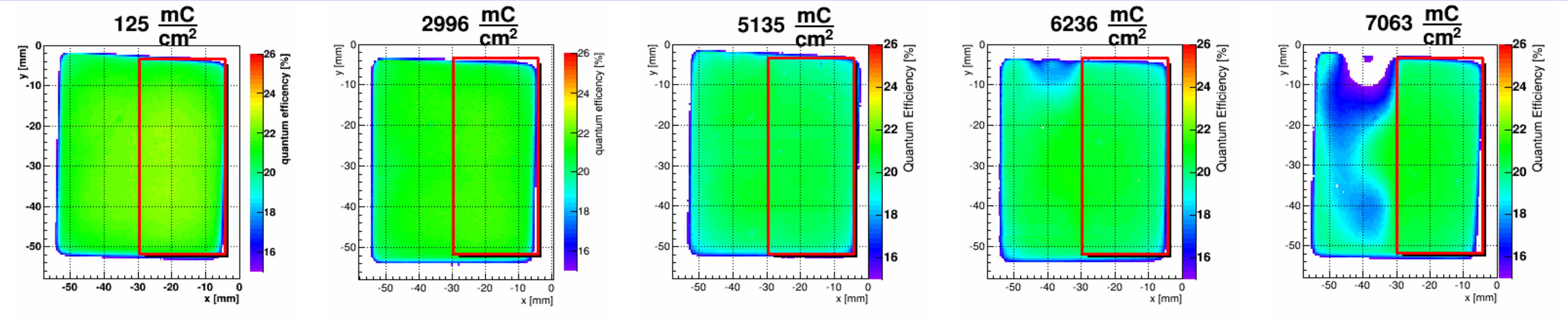




- Laser spot size: ~1mm, 372nm
- Aging starts at corners (M16) or rim (BINP 3548)

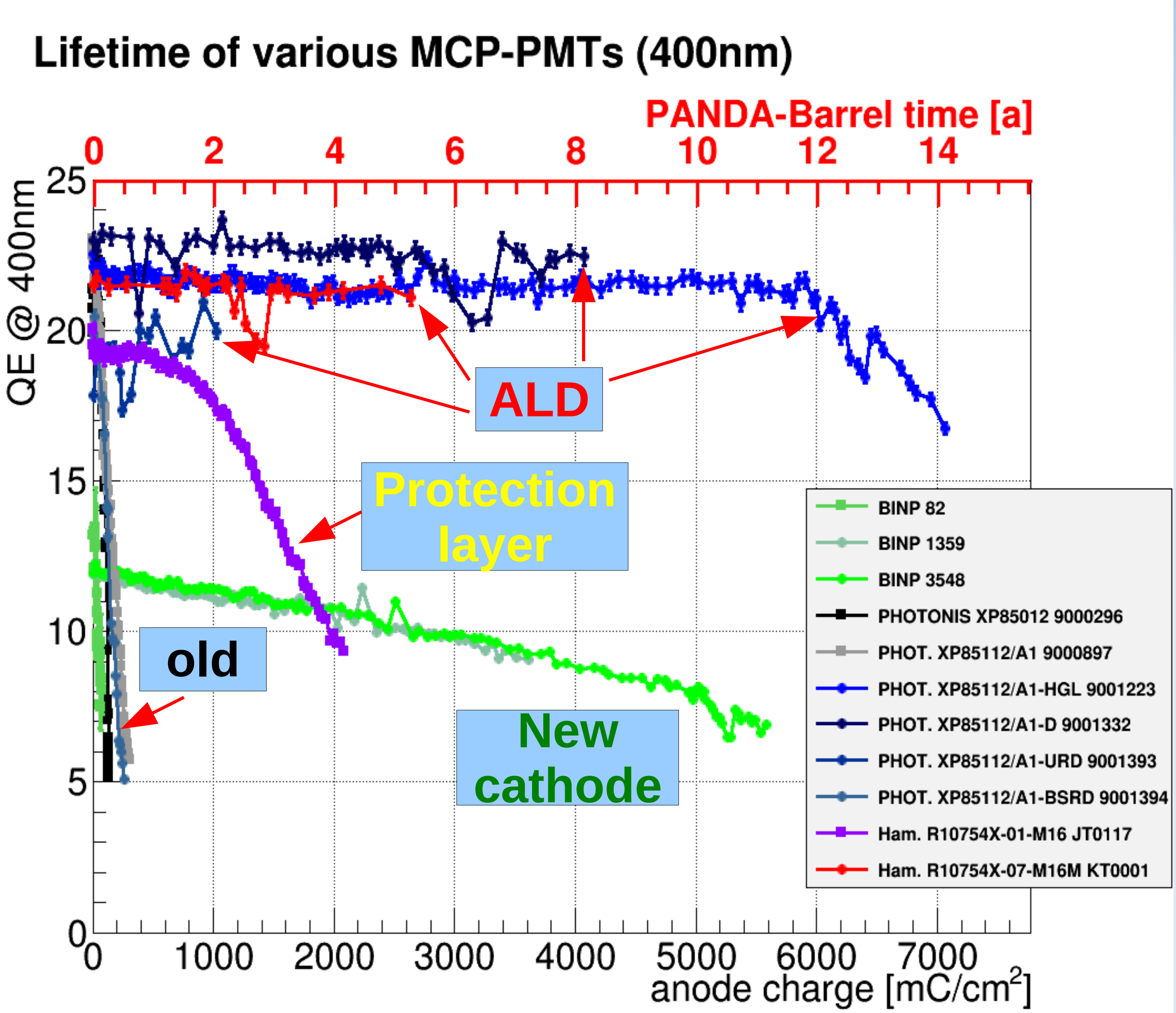
QE surface scan (2)

PHOTONIS
XP85112/A1-HGL - 1223



- red area is **not** illuminated
- aging starts at the edge after 6C/cm²
- difference between covered (right) and illuminated (left) area clearly visible at >7C/cm²

Comparison with older MCP-PMTs



- Aging of XP85112/A1-HGL – 1223 has started after 6C/cm²
- XP85112/A1-D – 9001332 has collected over 4C/cm² with no degradation
- Ham. ALD coated MCP-PMT shows no aging effects (2.6C/cm²)
- Performance of BINP 3548 acceptable
- **ALD is most promising technique**

Summary and Outlook

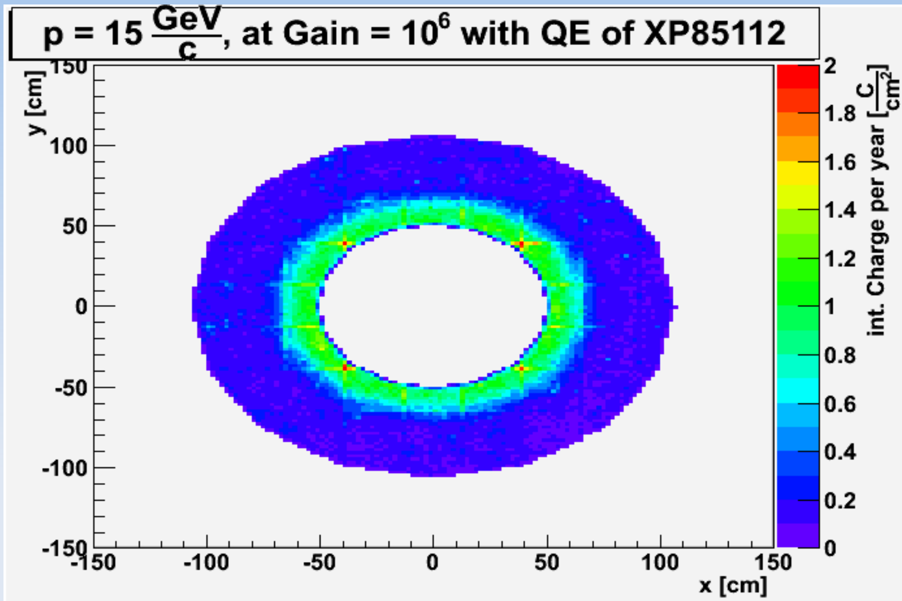
- Requirements: **5C/cm²** (50% duty cycle, 10 years), Disc-DIRC even more
- Lifetime of MCP-PMTs has substantially increased:
  - ALD coated devices show best performance
  - Surface scans show that aging starts at the corners/edges
  - XP85112/A1-HGL - 1223 has passed ~7C/cm², first aging effects visible at ~6.0C/cm²

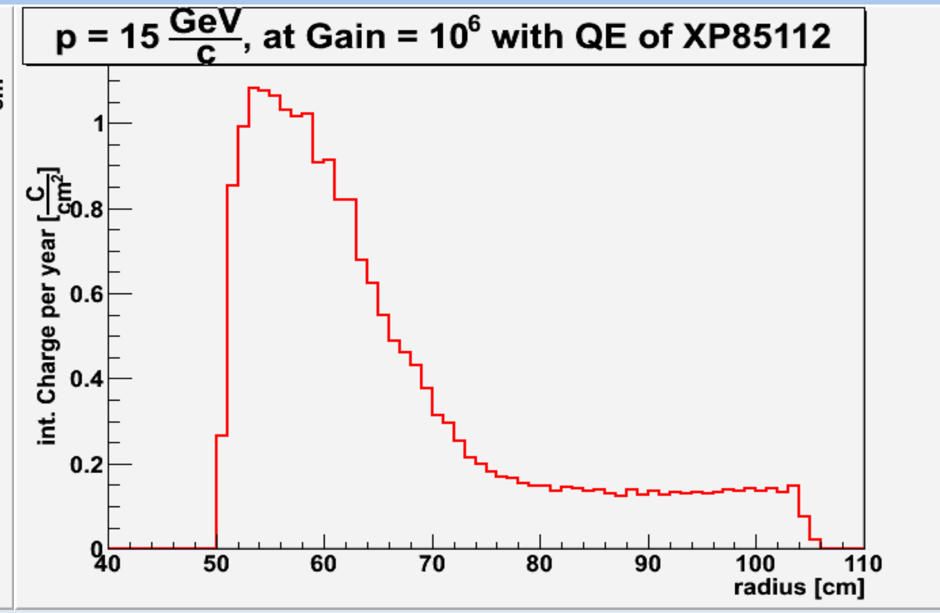
    → currently checked with other devices (1332, 1393)
- Future improvements:
  - ALD + new cathode?
  - Change MCP material (leadglas → borosilicateglas)

Illumination overview

	BINP 1359/3548	PHOTONIS XP85112/A1-HGL 1223 / 1332 /1393	Hamamatsu R10754X-01-M16 JT0117	Hamamatsu R10754X-07-M16M KT0001
Int. Collect. Charge (Jun. 25th) [mC/cm²]	**3615 / 5587**	**7062 / 4076 / 1026**	**2085**	**2633**
Max applied current per anode [nA]	315 / 346	56 / 59 / 59	45.3	71.4 / 40.3
Specified max. DC anode cur. [nA]	1000	47 (64 Chans.) 94 (32 Chans.)	100	100
Max Diff. Charge [mC/cm²/d]	**10.7 / 11.7**	**13.5 / 13.6 / 13.6**	**14.1**	**19.3 / 10.9**
Anode area per pixel (cm²)	2.54	0.36	0.32	0.32
Measured Channels	1	8 + 2 (unexposed) + MCP-Out / 7 chans 1393	8	4
Illuminated area	100%	**50% / 100% (1393)**	100%	100%
Applied voltage (V) using voltage divider	3100 (+100)	2050 / 2000 2100 / 2050 illum.	3300	2400 / 2600

Requirements for PANDA Barrel-DIRC





Assumptions:

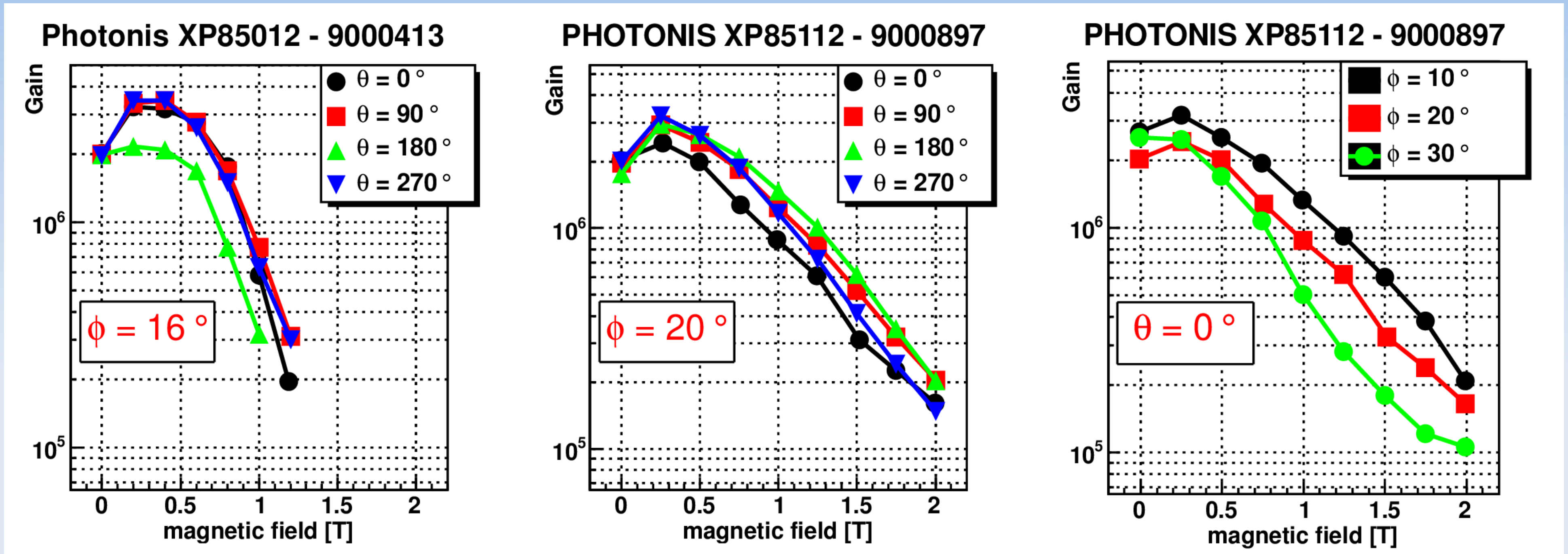
- PANDA high luminosity mode: $2*10^{32}\text{cm}^{-2}\text{s}^{-1}$
  → p-pbar reaction rate: 20MHz
- QE of XP85112
- **1 year of 100% duty cycle!**

results:

- **Int. Charge is radial dependent**
- $1\frac{\mathbf{C}}{\mathbf{cm^2*a}}$ at focal plane
- Assuming 50% duty cycle and 10 years operation time →

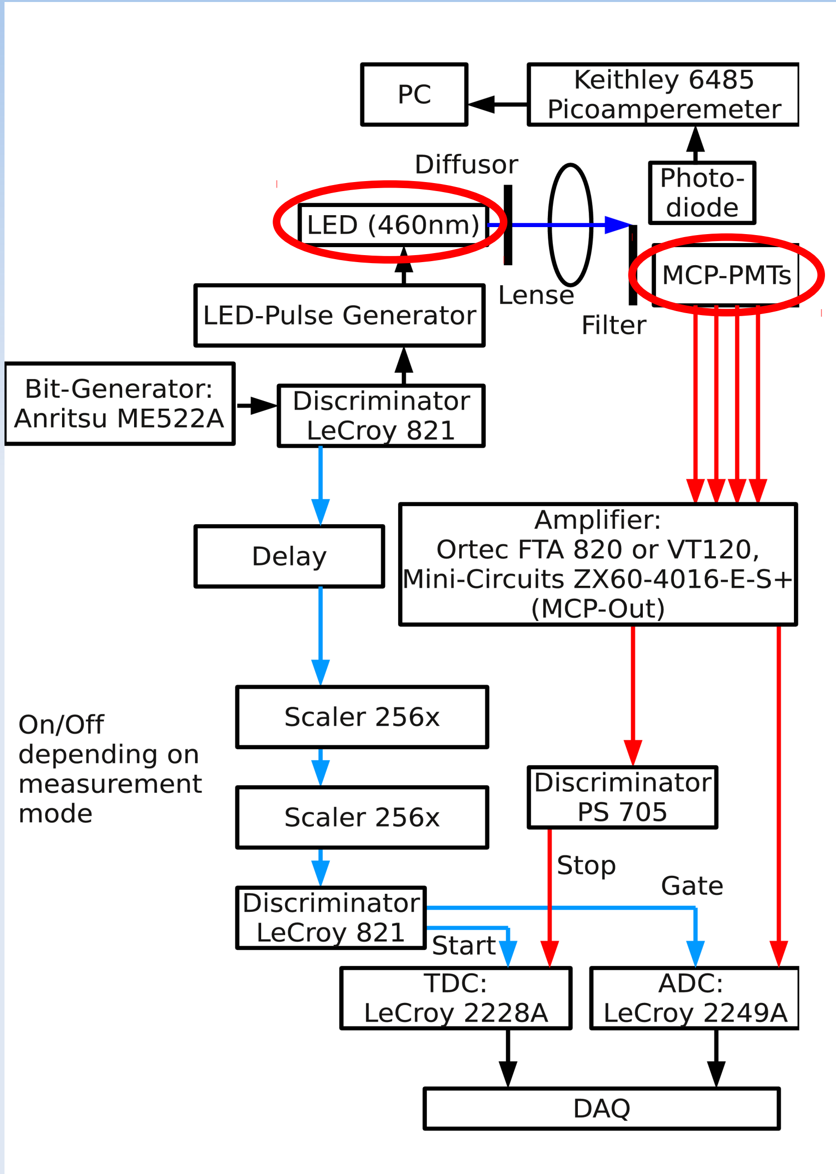
5C/cm² needed!

Magnetic field performance



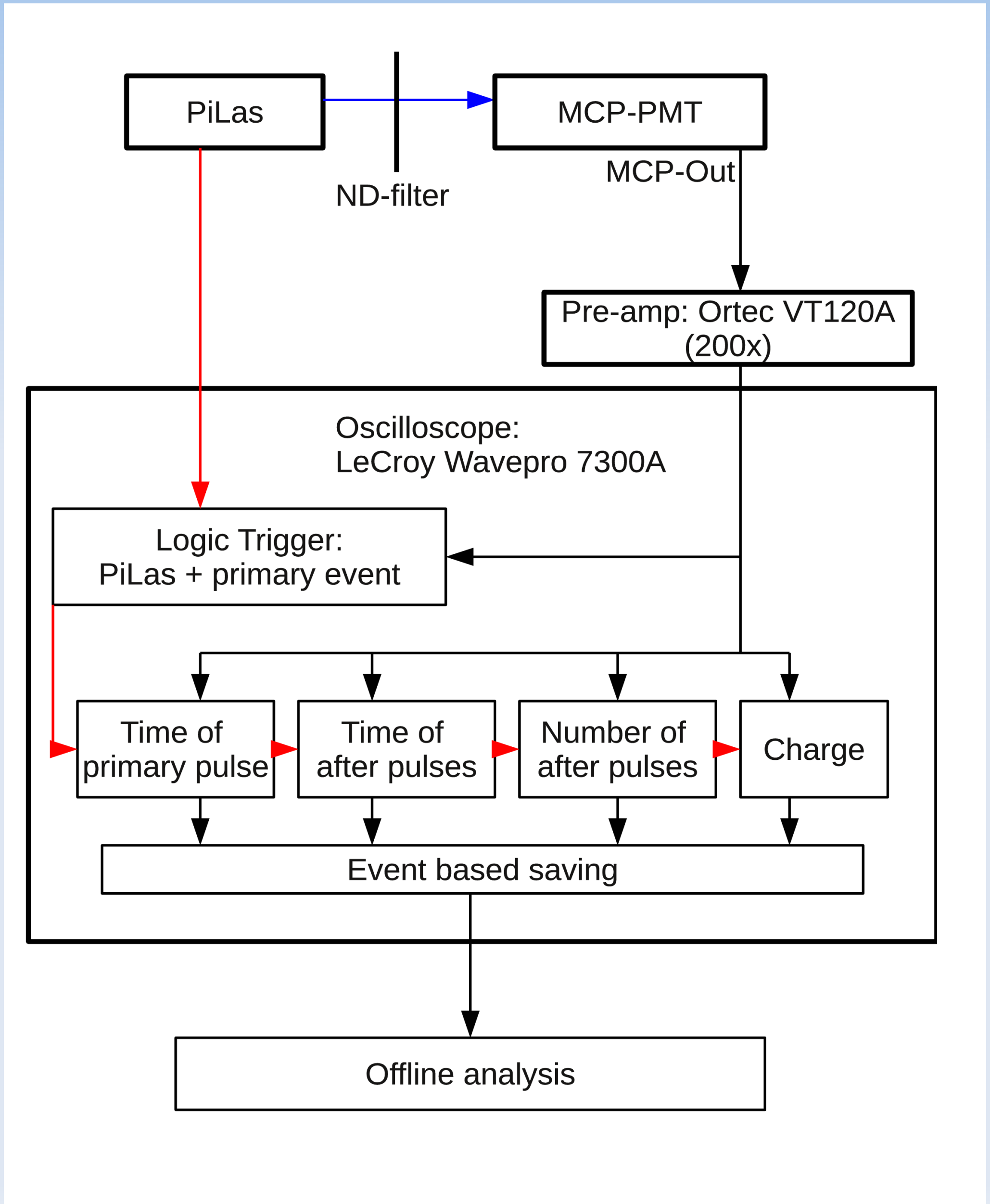
- Lamor radi of electrons determine maximum magnetic field → 10µm or less required for 2T
- Gain decreases almost instantly, if B-field is parallel to mcp channels
- Gain drops faster for larger tilt angles > 20°

Illumination setup



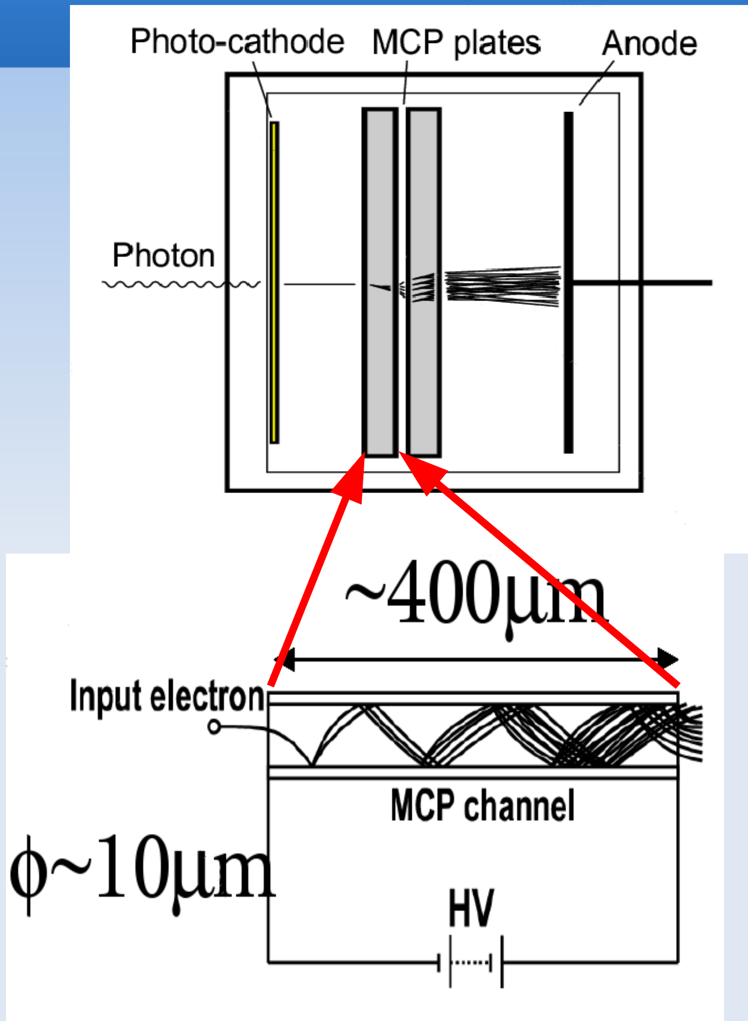
- LED-Lightspot is expanded on all MCPs
- Trigger rate: 272kHz – 1MHz
- Scaler: event reduction for monitoring
- TDC used for crosstalk and pedestal supression
- Stability of LED is measured with photodiode

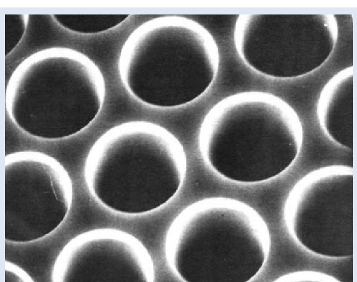
Afterpulse



- Goal: Determine mass/kind of backscattered ions and estimate their amount
- Absolute time can be calculated by time difference of primary and after pulse
- Classical approach for estimating m/q

Microchannel-Plate PMTs





- Typical pore sizes: 6 – 25µm
- Very fast signals:
  - Rise time: 0.5 – 1.5ns
  - TTS < 50ps
- Gain > 10^6 with 2 MCP stages
- Low dark count rate
- Usable in B-fields of up to 2T → Standard PMTs not usable in PANDA
- **Problems:**
  - Price
  - **Aging → QE drops!**