Lifetime of Microchannel-Plate Photomultipliers

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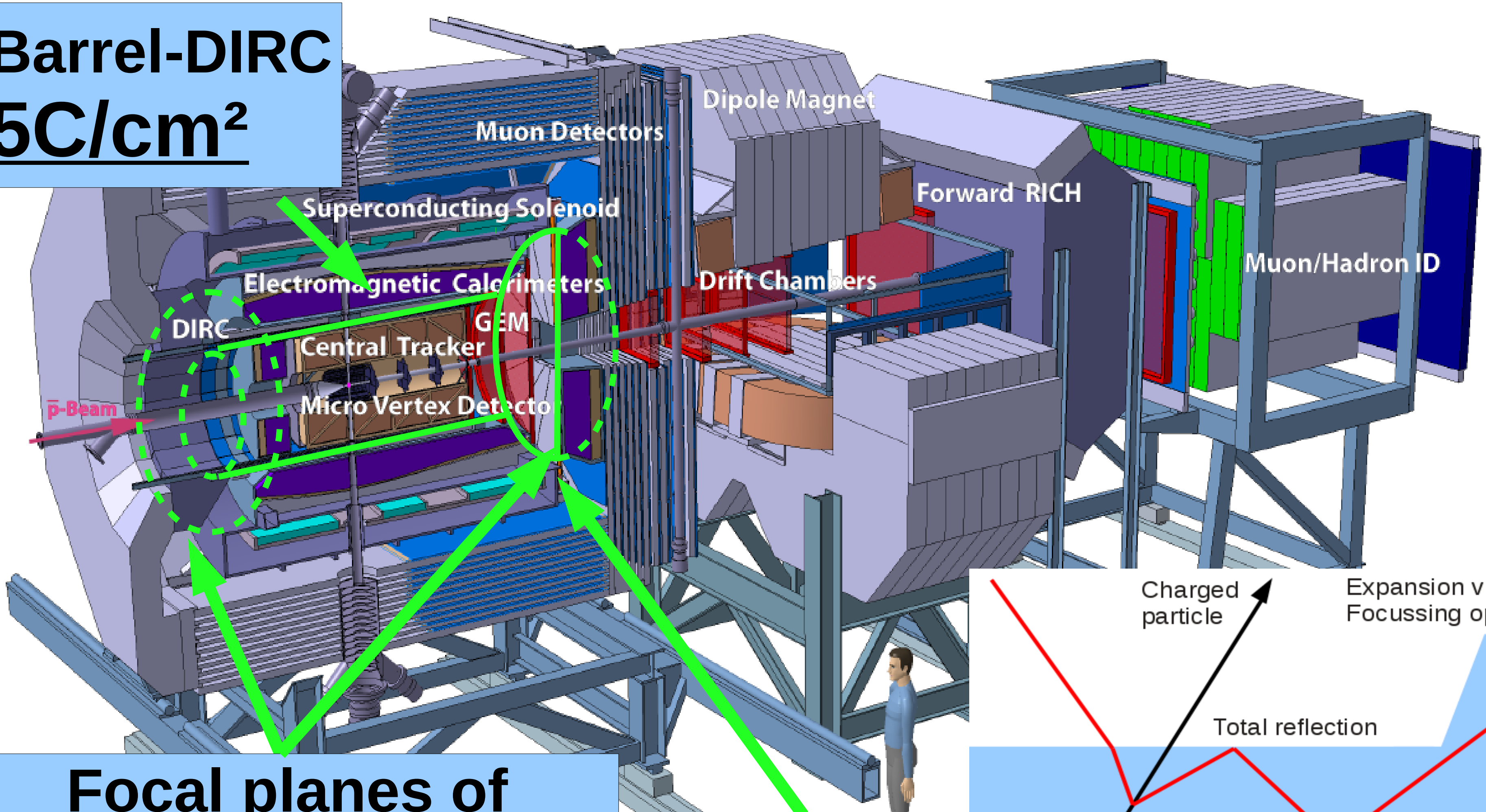
supported by

Overview

- 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

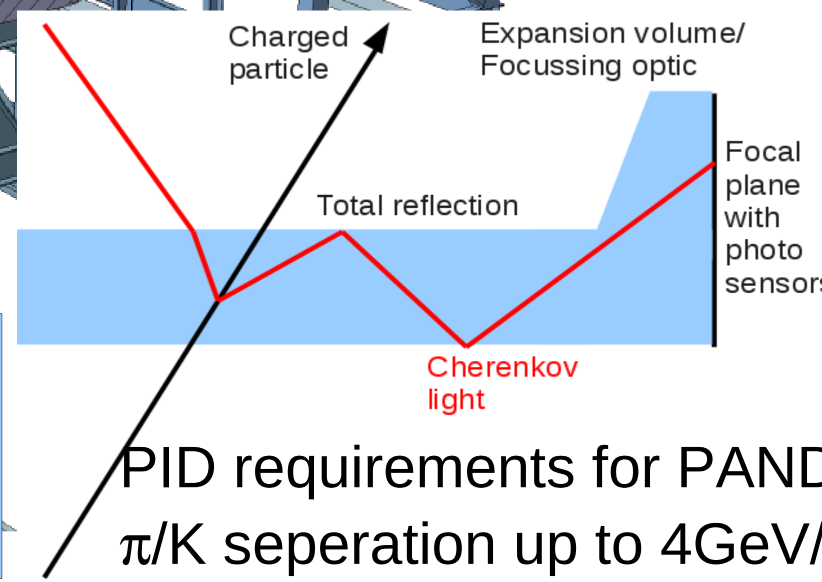
The PANDA-Detector



Barrel-DIRC
5C/cm²

Focal planes of both DIRC detectors are inside magnetic field

Disc-DIRC
>5C/cm²

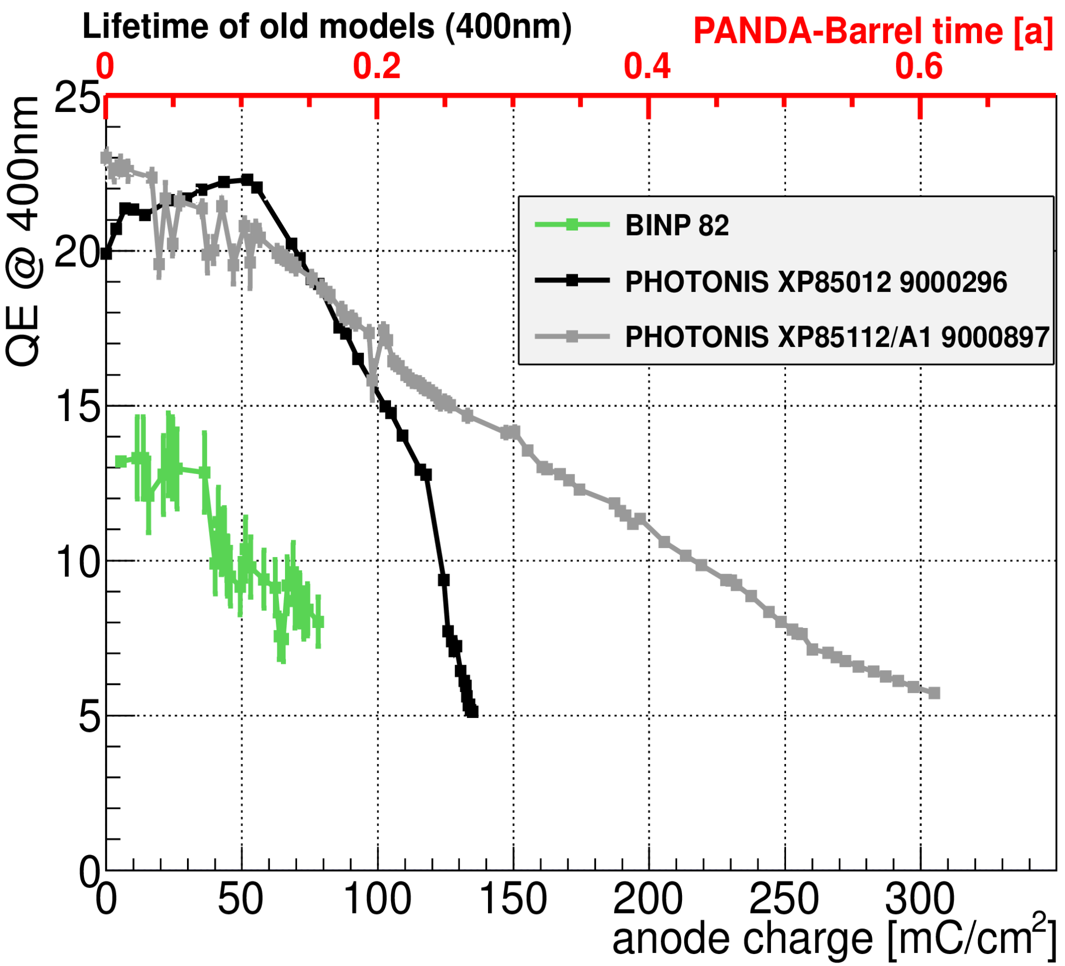


PID requirements for PANDA:
π/K seperation up to 4GeV/c

Photosensor requirements

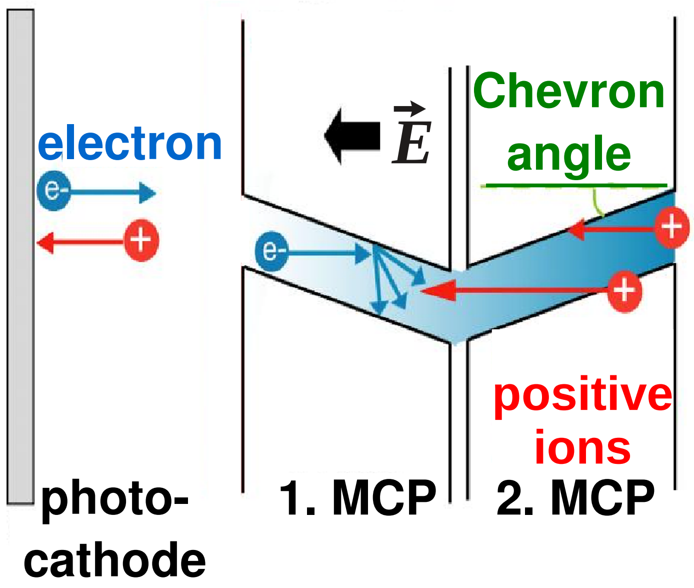
	PMTs	MCP-PMTs	SiPMs
Magnetic field resistance up to 2T (Disc DIRC)	X	✓	✓
Gain > $5*10^5$ (s.p.e.)	✓	✓	✓
Time resolution: $\sigma < 100$ps	X	✓	✓
Spatial resolution	✓	✓	✓
High geometrical efficiency	✓	✓	✓
High photon rates 200kHz/cm² (Barrel), >200 kHz/cm² (Disc)	✓	✓	✓
Radiation hardness	✓	✓	X
Darkcount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

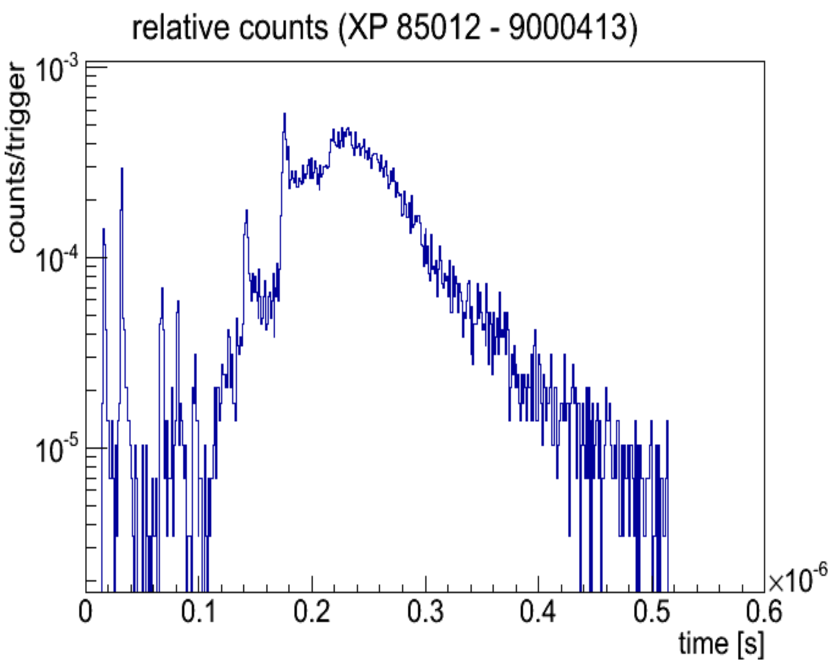
Lifetime of standard MCP-PMTs



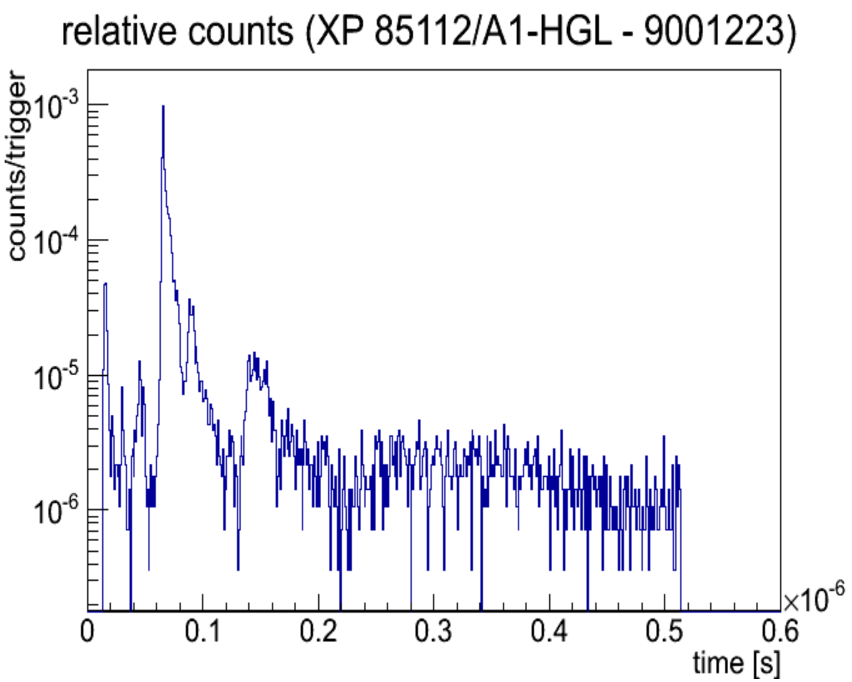
- QE @ 400nm drops to 50% of starting value within 50 – 200mC/cm²
- Corresponding PANDA-Barrel time ≤ 0,4 years
- Lifetime of standard MCP-PMTs is not sufficient for usage under PANDA conditions!
- No other models available ~3 - 4 years ago

Aging of photo cathode



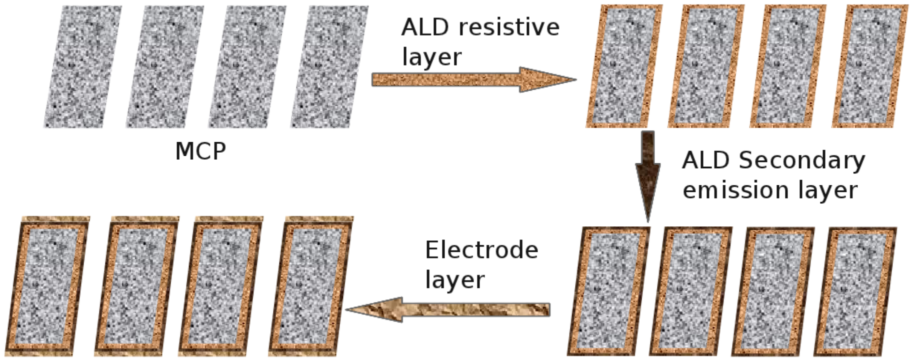


- Photocathode of older MCPs are more damaged due to impact of havier ions:
  - Chemical reactions, Adsorption
  - Cluster/lattice/surface defects
- Reduce flux of (heavy) ions
- Make cathode more "robust"



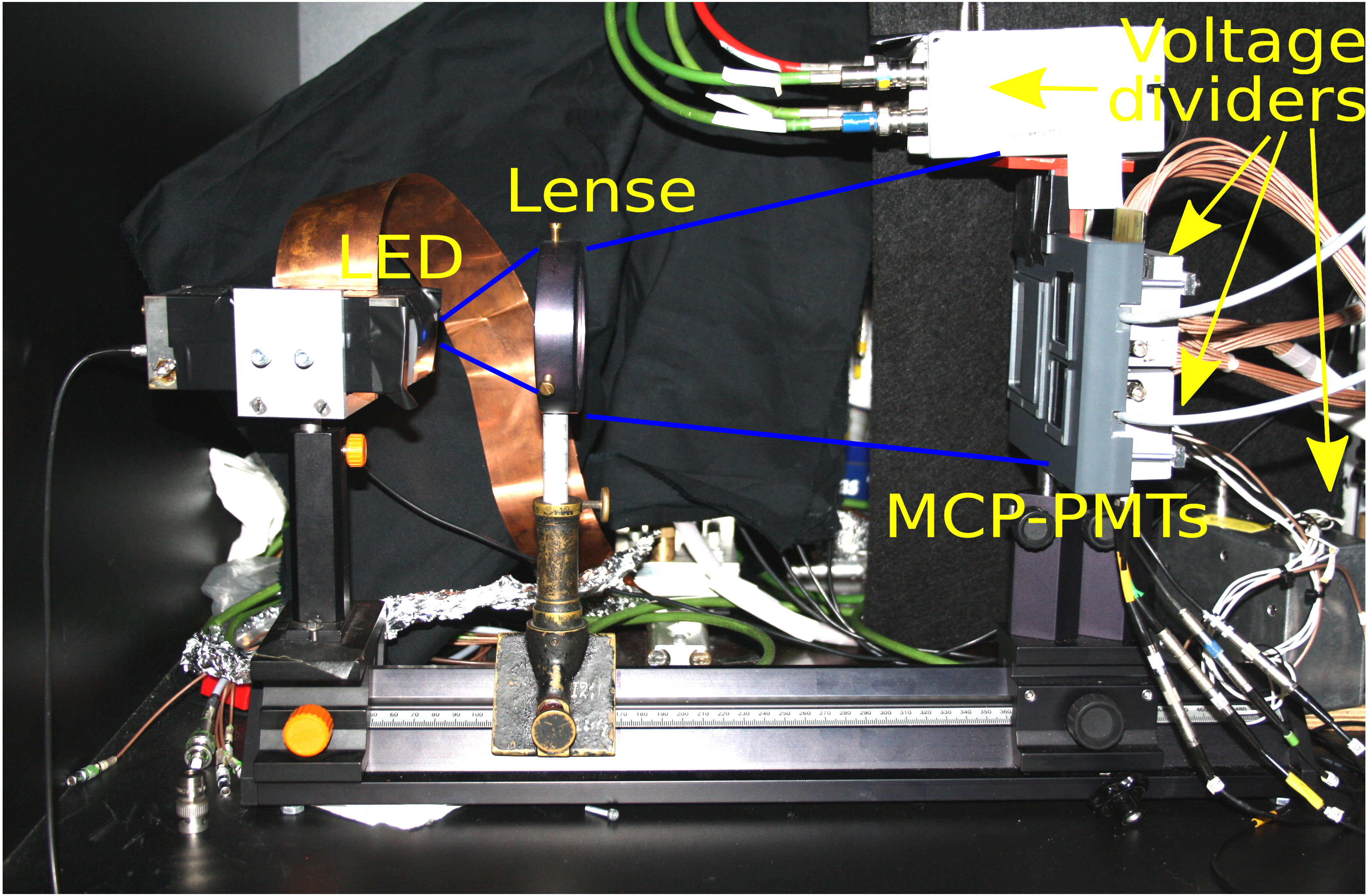
Methods to increase lifetime

- 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)



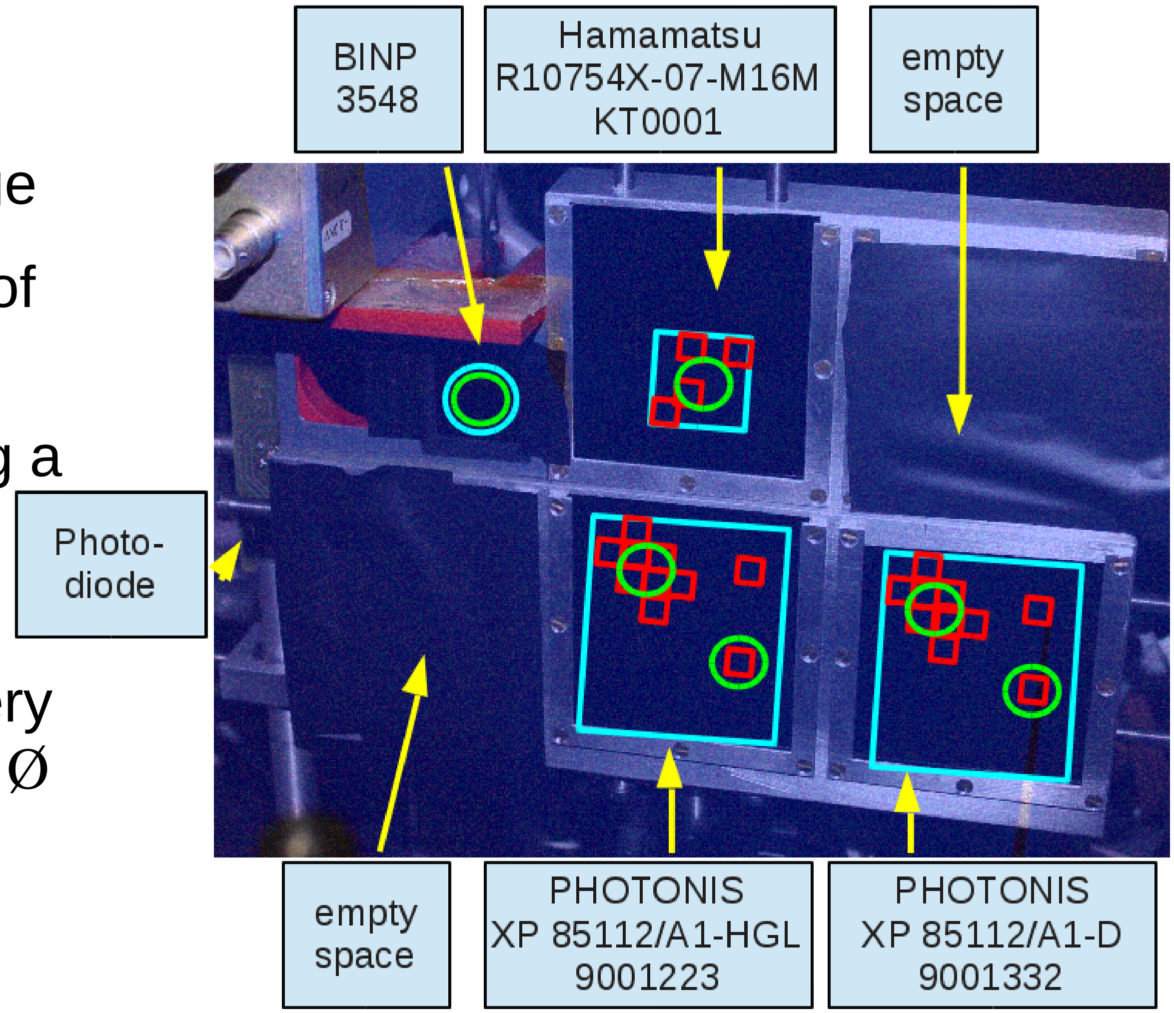
- Ceramic sealing between MCPs and metal walls (Ham. R10754X-01-M16)
- Treatment of MCP surfaces:
  - Electron scrubbing (PHOTONIS, BINP #1359, #3548)
  - **Atomic layer deposition** (PHOT. XP85112/A1-HGL, XP85112/A1-D, Ham. R10754X-07-M16M)

Setup



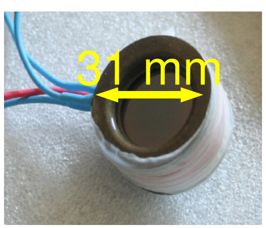
Lifetime measurement procedure

- Constant illumination of all MCPs within same lightspot
  → **permanent monitoring** to calculate collected anode charge
- Every few days: Measurement of **Gain**, **darkcount** and **QE**
- QE is measured seperatly using a Xenon arc lamp with mono-chromator ($\Delta\lambda$ = 1nm)
- QE surface scans are done every 2-4 months with PiLas (372nm, Ø ~1mm)
- Simultanous measurements of several different MCP-PMTs under same conditions as the PANDA-DIRCs

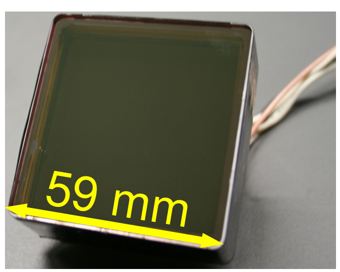


Overview of latest MCP-PMTs

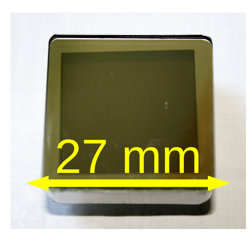
	BINP	PHOTONIS	Hamamatsu	Hamamatsu
	1359 / 3548	XP85112/A1-HGL 1223 / 1332	R10754X-01-M16 JT0117	R10754X-01-M16M KT0001 / KT0002
Pore size (µm)	7	10	10	10
Number of pixels	1	8x8	4x4	4x4
Active area (mm²)	$9^2\pi$	53x53	22x22	22x22
Geom. Efficiency (%)	36	81	61	61
Photo cathode	Multi-alkali	Bi-alkali	Multi-alkali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



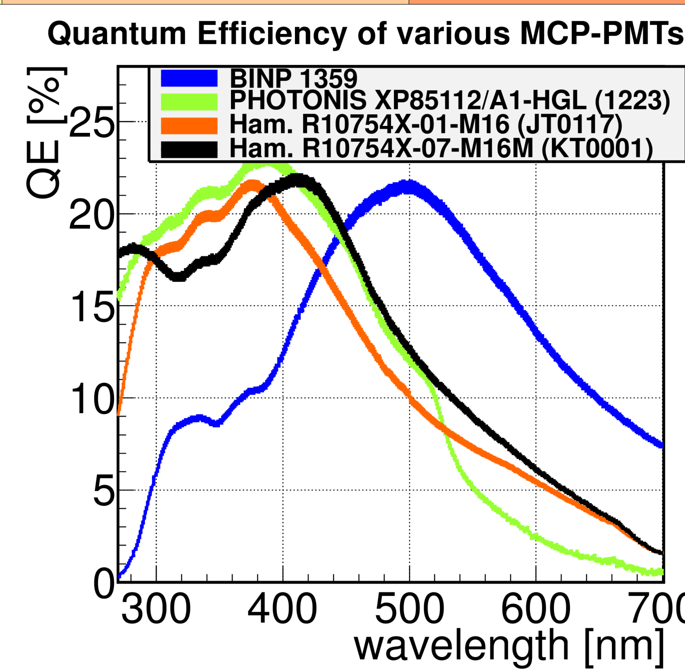
BINP
1359/3548



PHOTONIS
XP85112/A1-HGL



Hamamatsu
R10754X-01-M16

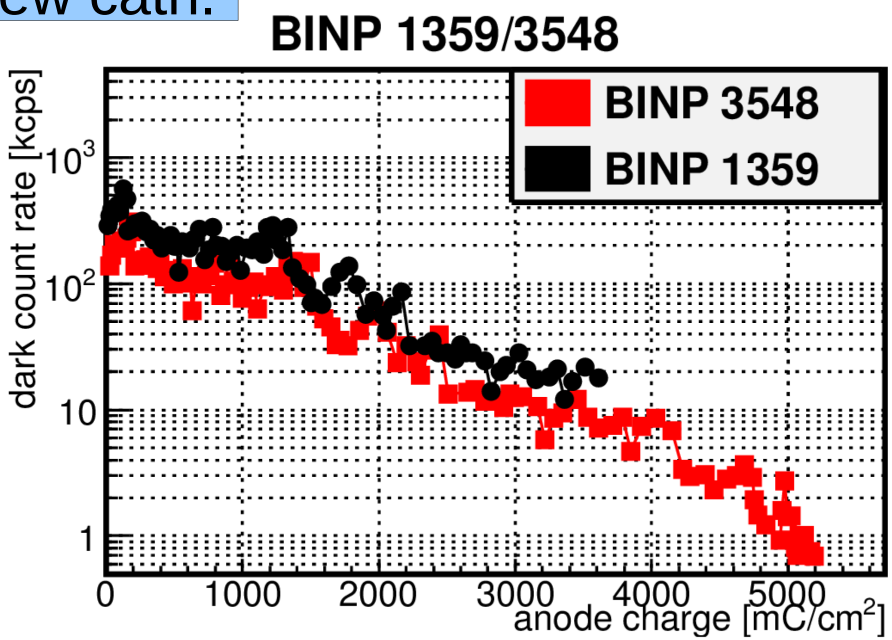


Illumination overview

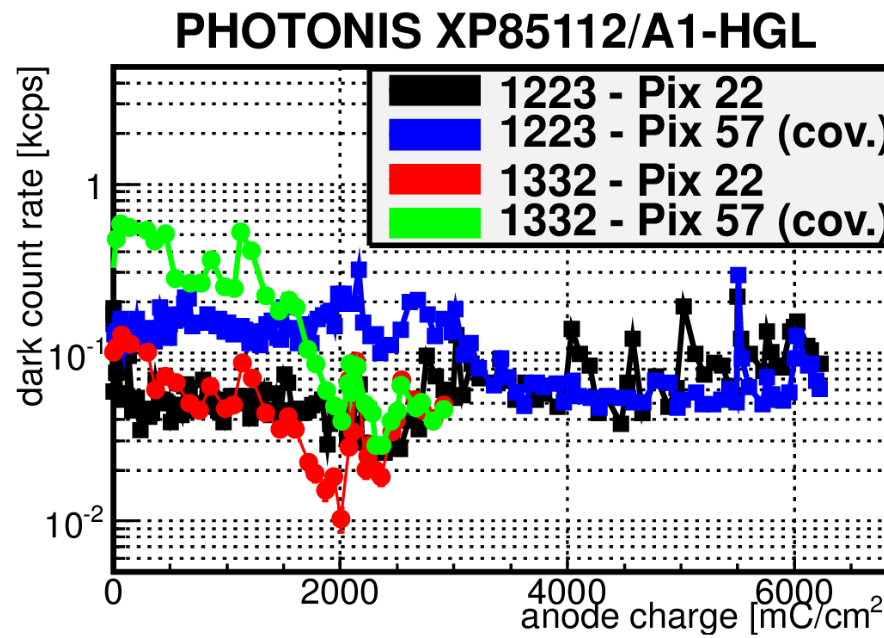
	BINP 1359/3548	PHOTONIS XP85112/A1-HGL 1223 / 1332	Hamamatsu R10754X-01-M16 JT0117	Hamamatsu R10754X-07-M16M KT0001 / KT0002
Int. Collect. Charge (Feb. 25th) [mC/cm²]	**3060 / 5195**	**6240 / 2915**	**2085**	**1225 / 490**
Max applied current per anode [nA]	315 / 346	56 / 59	45.3	71.4 / 40.3
Specified 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**	**14.1**	**19.3 / 10.9**
Number of QE-Scans	8 / 9	13 / 5	7	3 / 3
Anode area per pixel (cm²)	2.54	0.36	0.32	0.32
Measured Channels	1	8 + 2 (unexposed) + MCP-Out	8	4
Illuminated area	100%	**50%**	100%	100%
Applied voltage (V) using voltage divider	3100 (+100)	2050 / 2000 2100 / 2050 illum.	3300	2400 / 2600

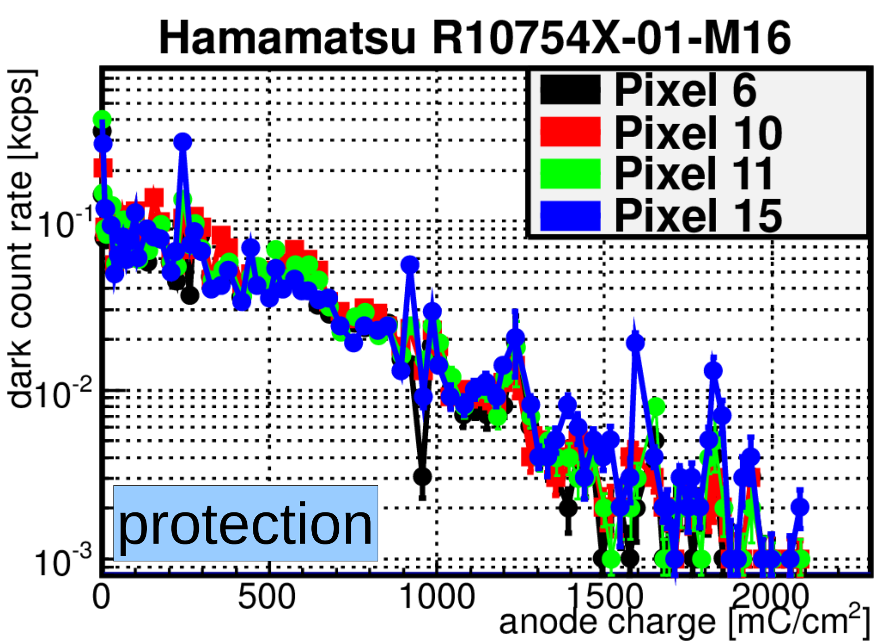
Dark count rate

new cath.

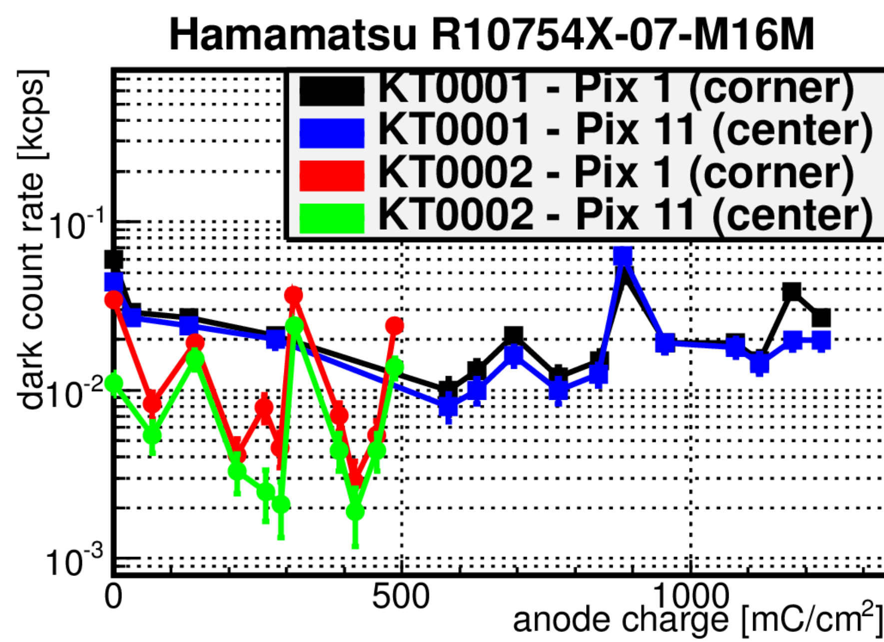


ALD



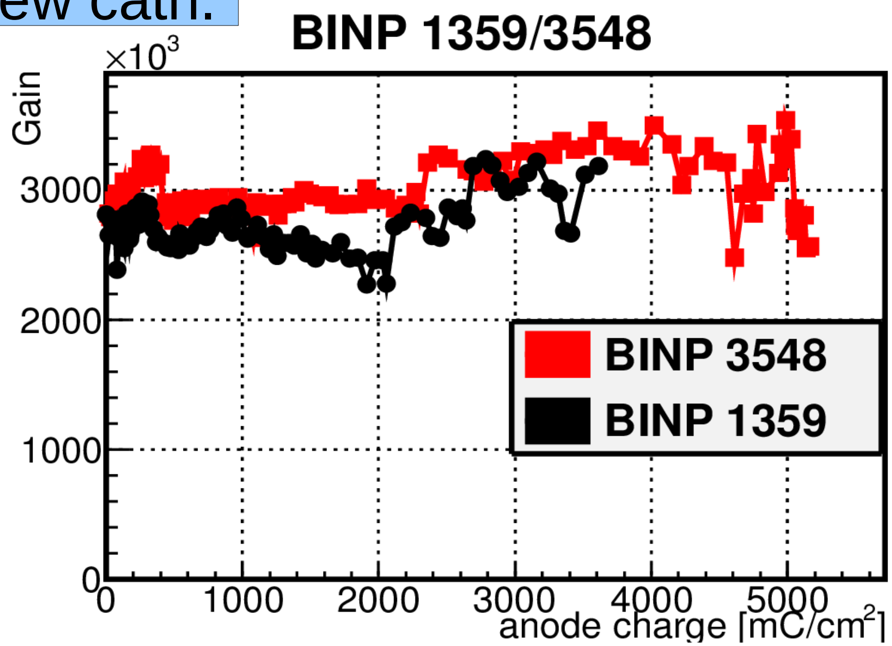


ALD

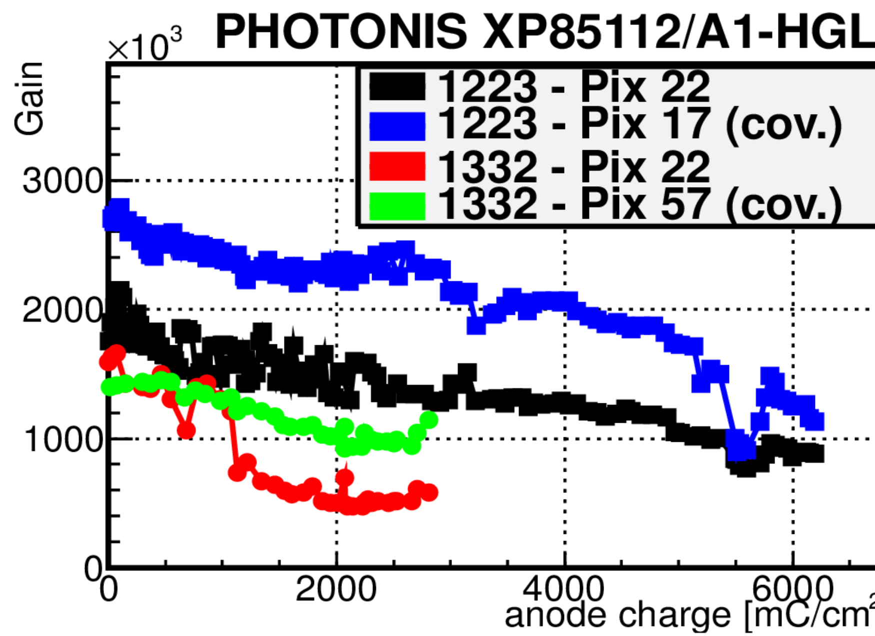


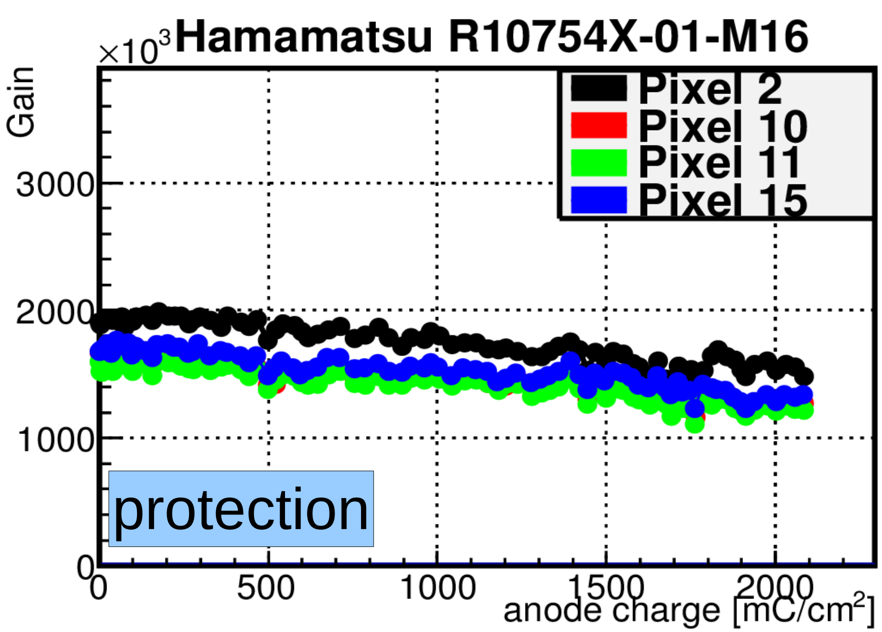
Gain

new cath.

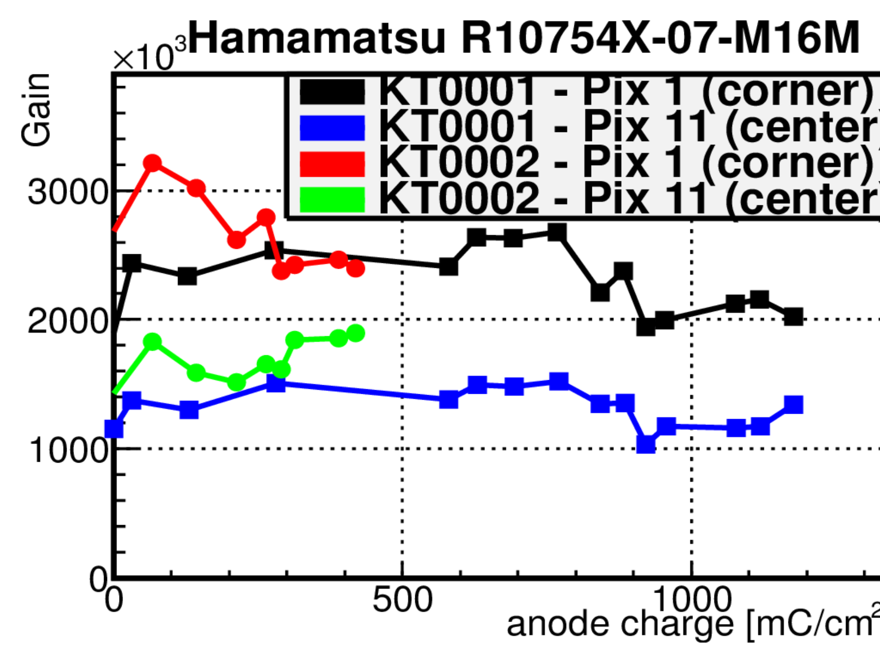


ALD



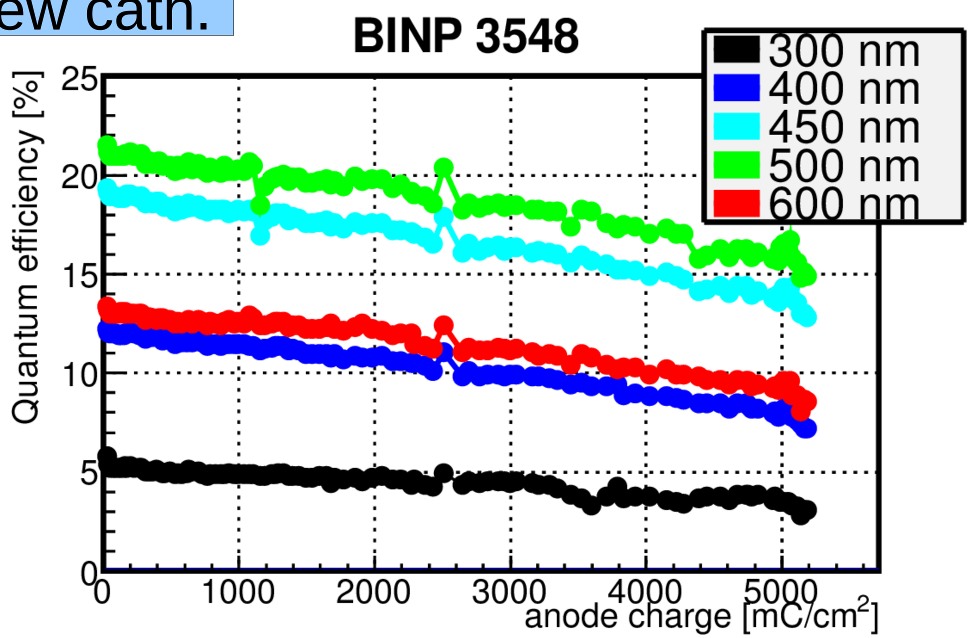


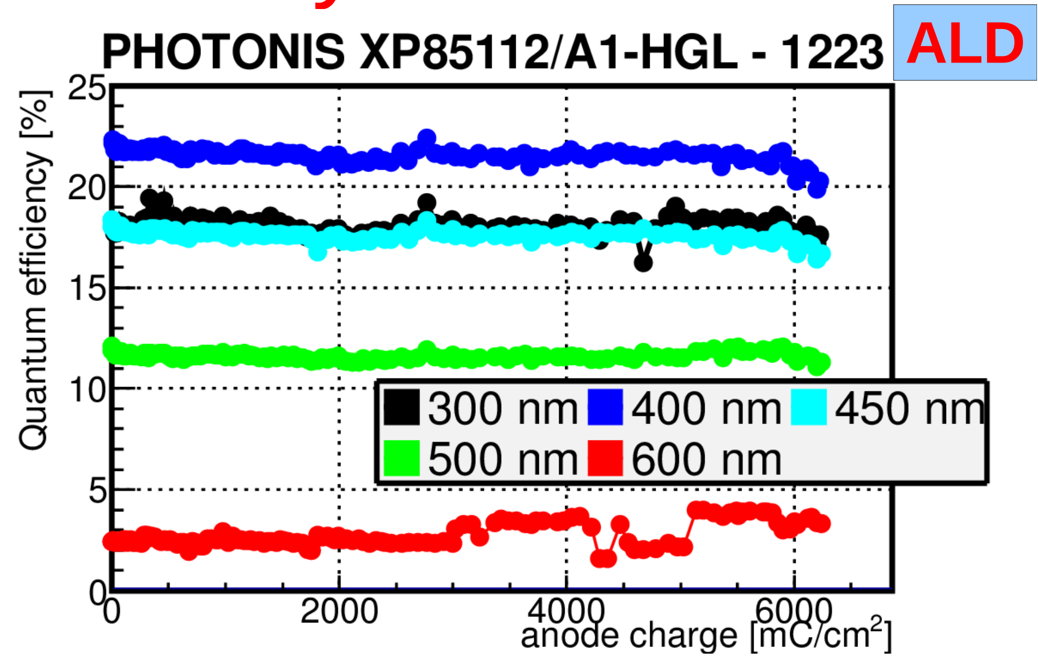
ALD

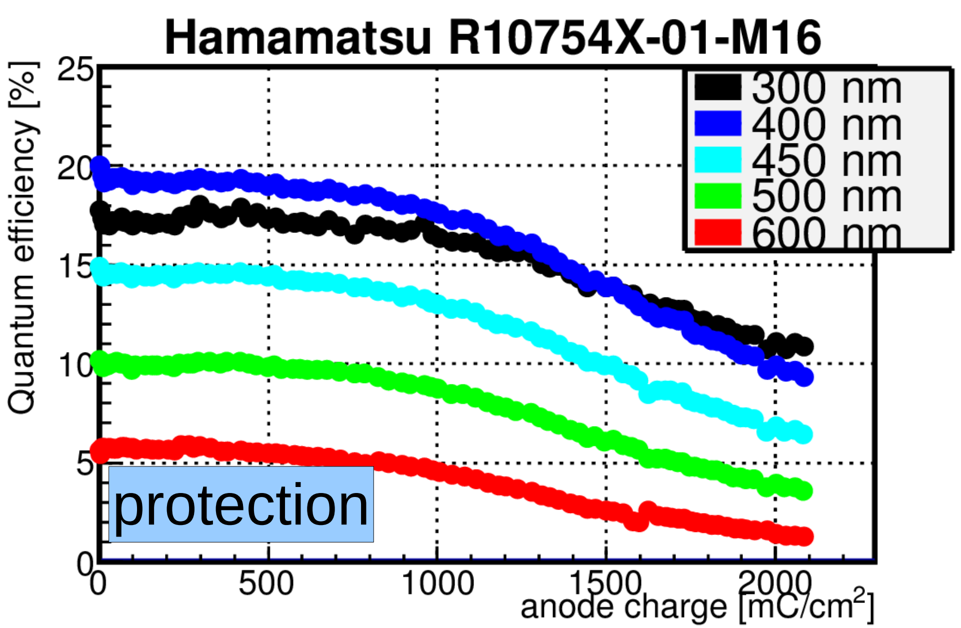


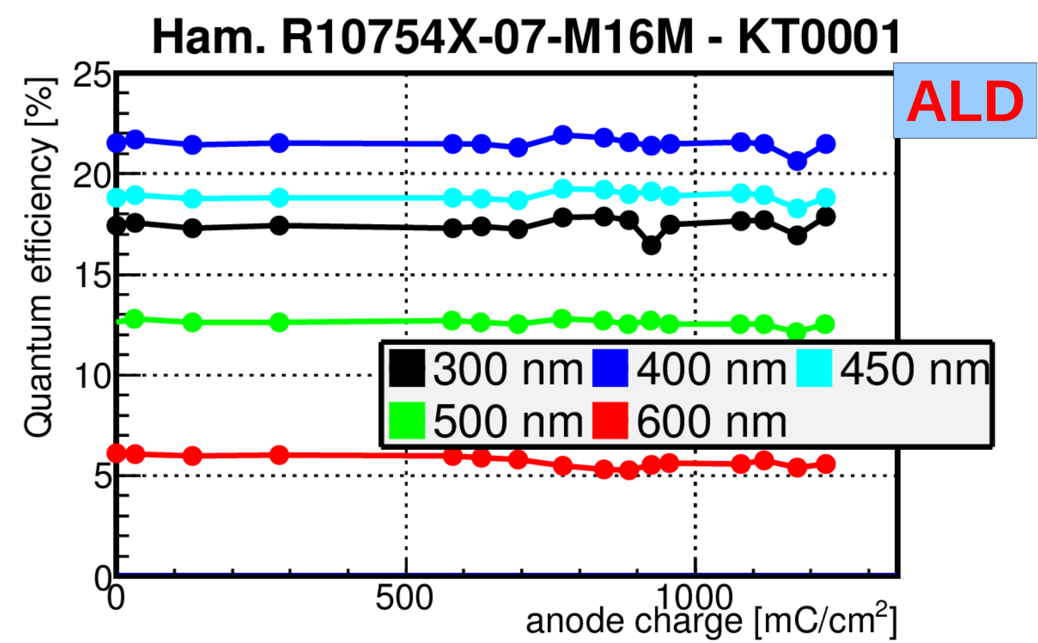
Spectral Quantum Efficiency

new cath.





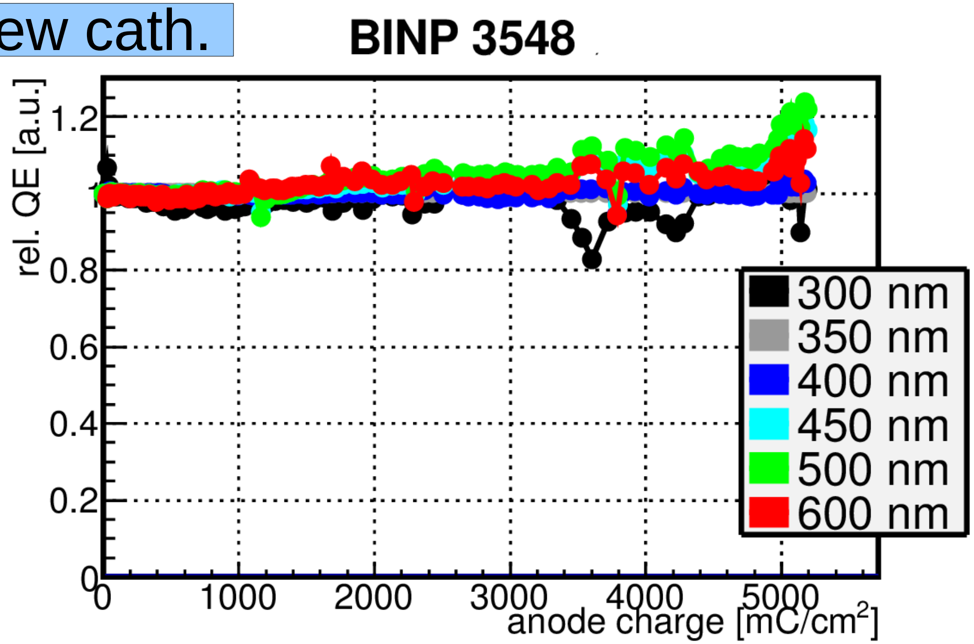




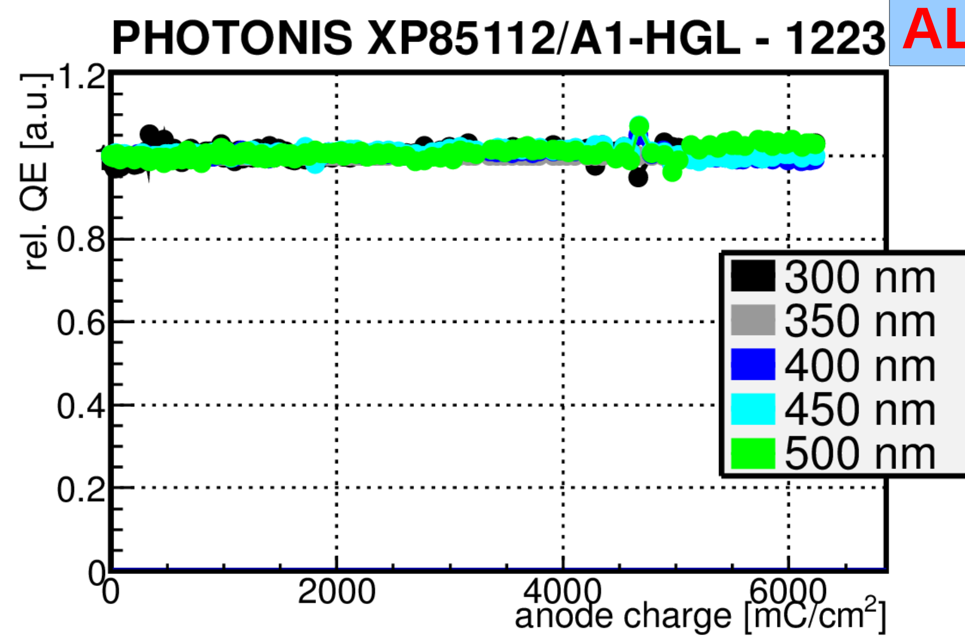
Relative QE

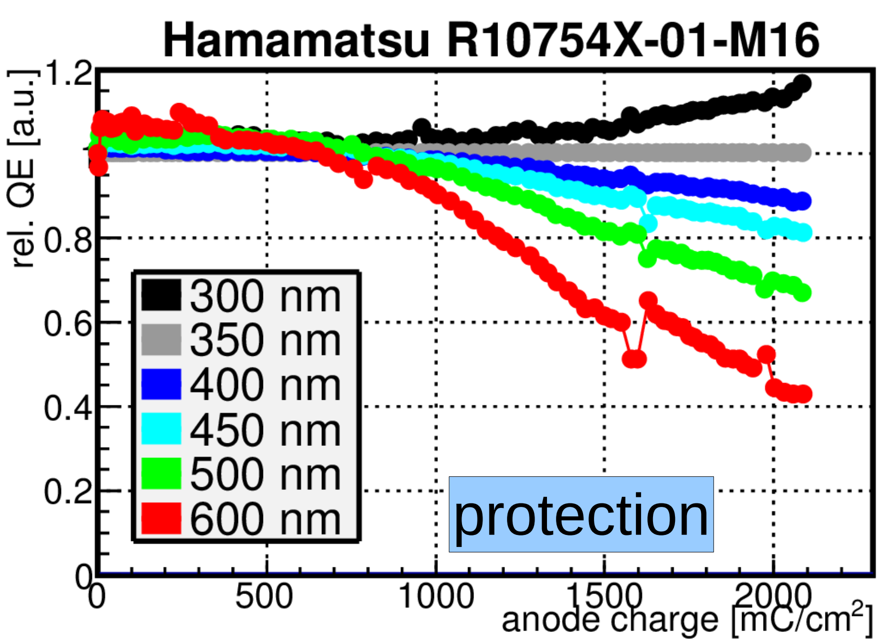
$$rel.QE.:=\frac{QE(\lambda)}{QE_{Q=0}(\lambda)}/\frac{QE(\lambda_0)}{QE_{Q=0}(\lambda_0)};\lambda_0=350\text{nm}$$

new cath.

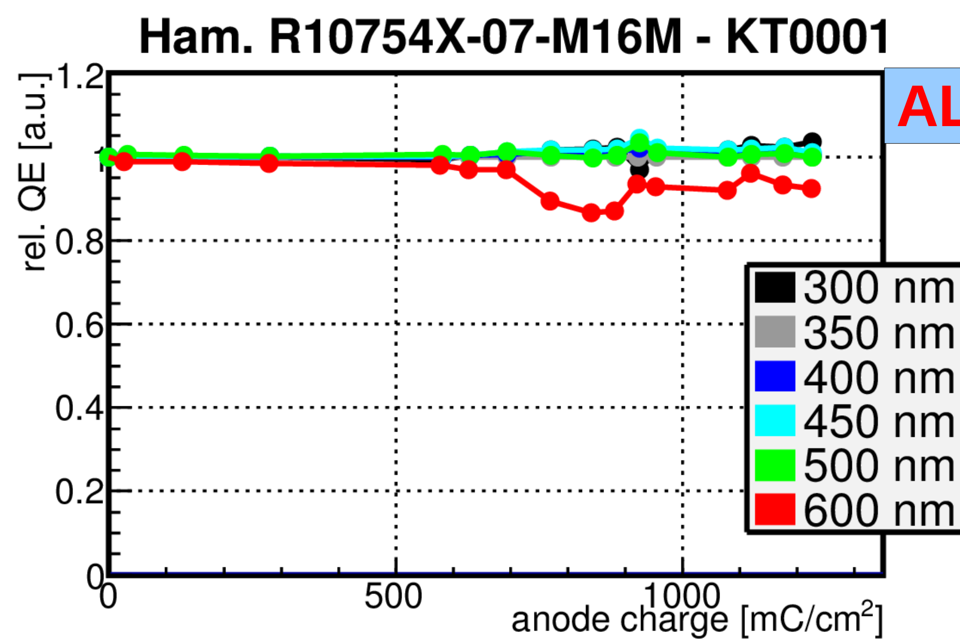


ALD



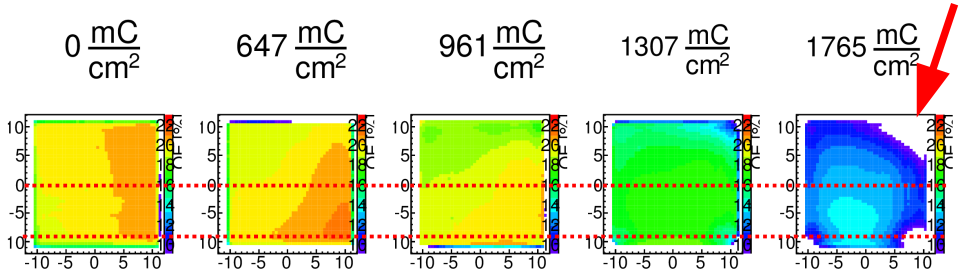


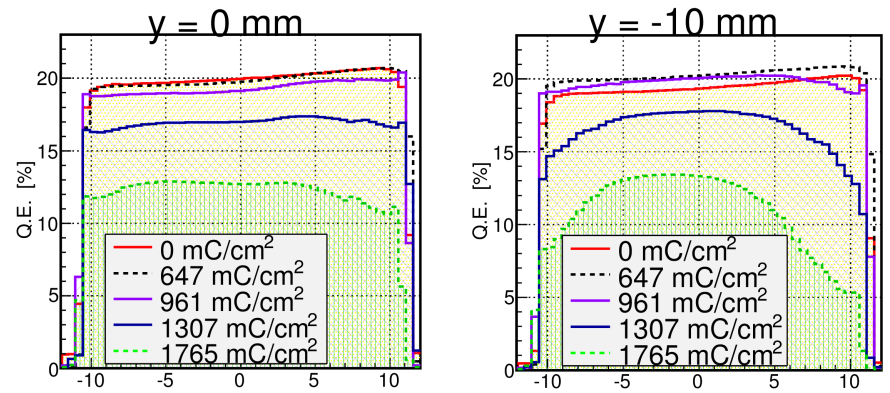
ALD



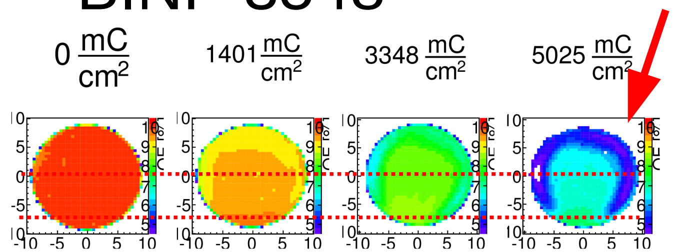
QE surface scan

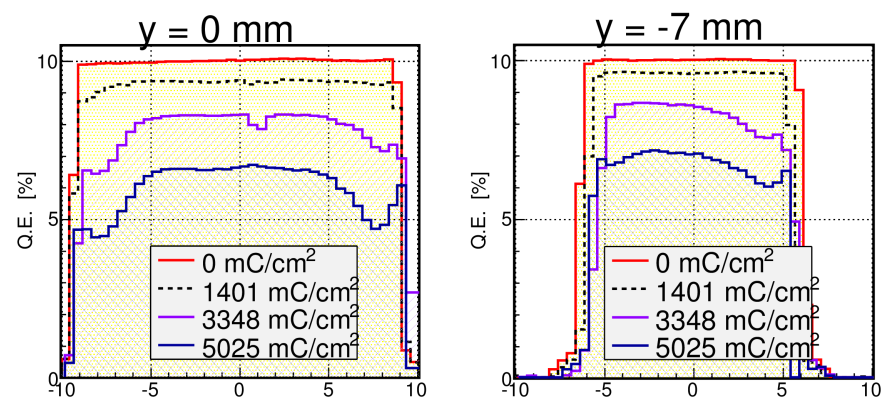
Hamamatsu R10754X-01-M16





BINP 3548

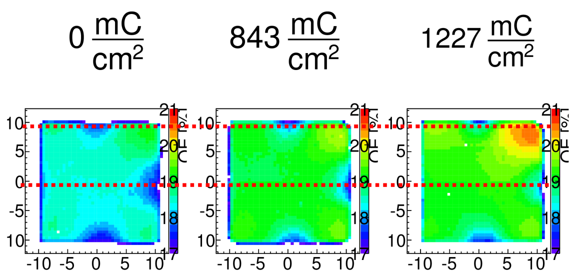


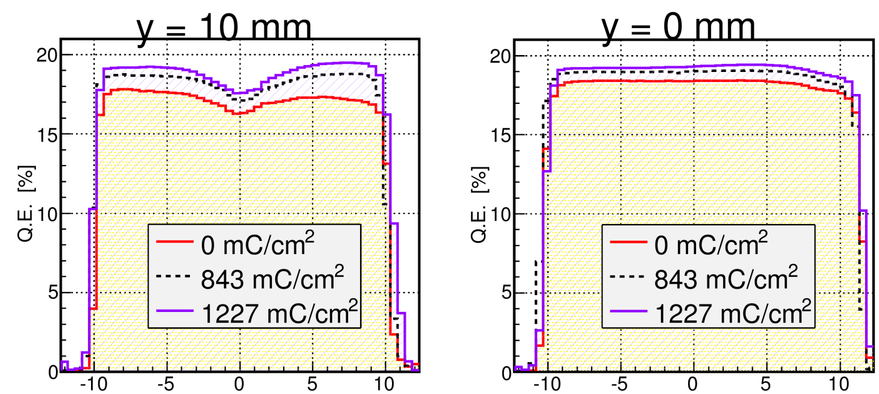


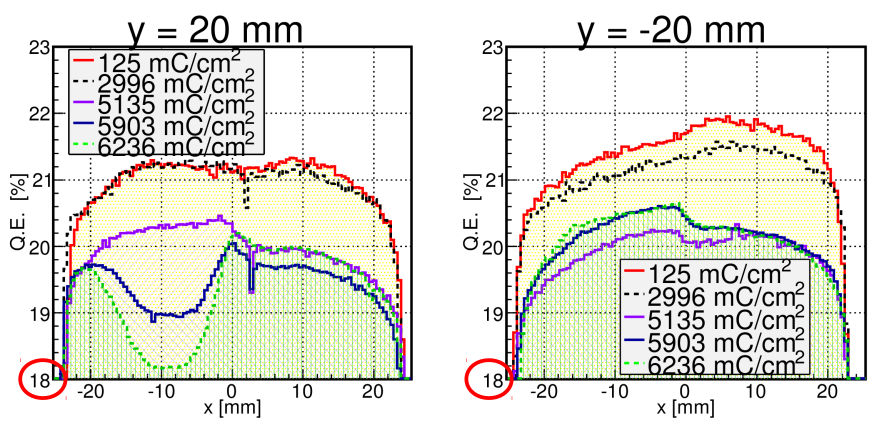
- Size scaled to relative area sizes
- Laser spot size: ~1mm, 372nm
- Aging starts at corners (M16) or rim (BINP 3548)

QE surface scan (2)

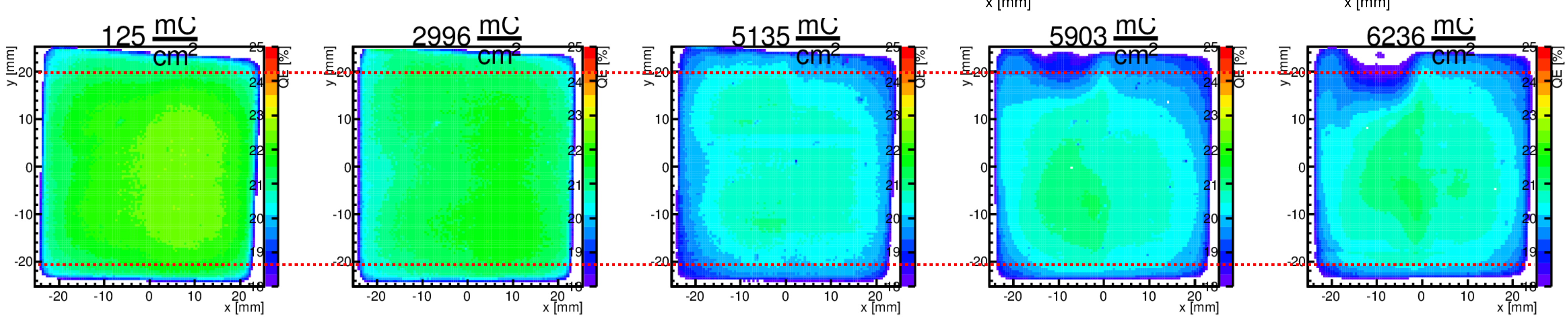
Hamamatsu
R10754X-01-M16M - KT0001



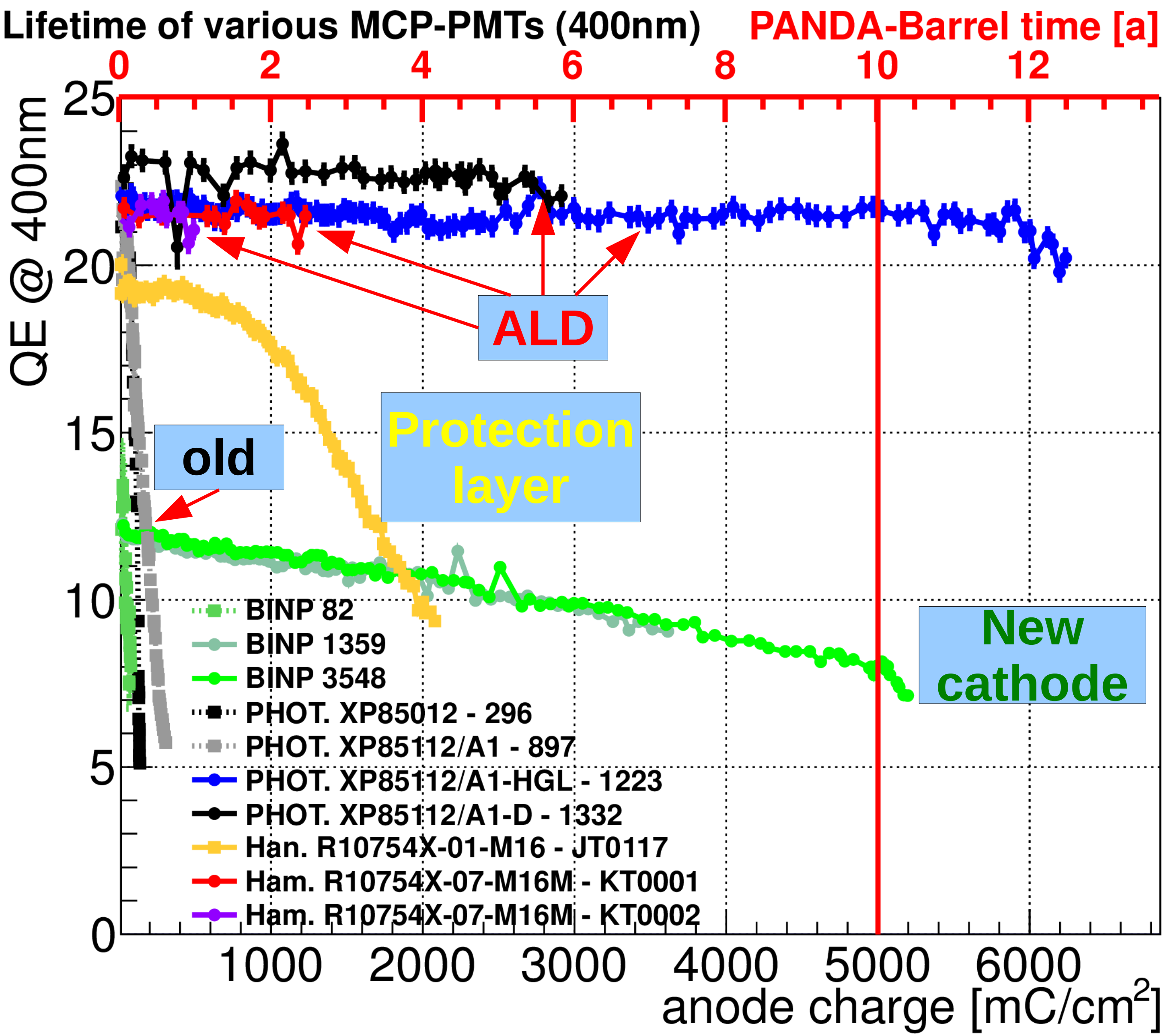




PHOTONIS
XP85112/A1-HGL - 1223



Comparison with older MCP-PMTs

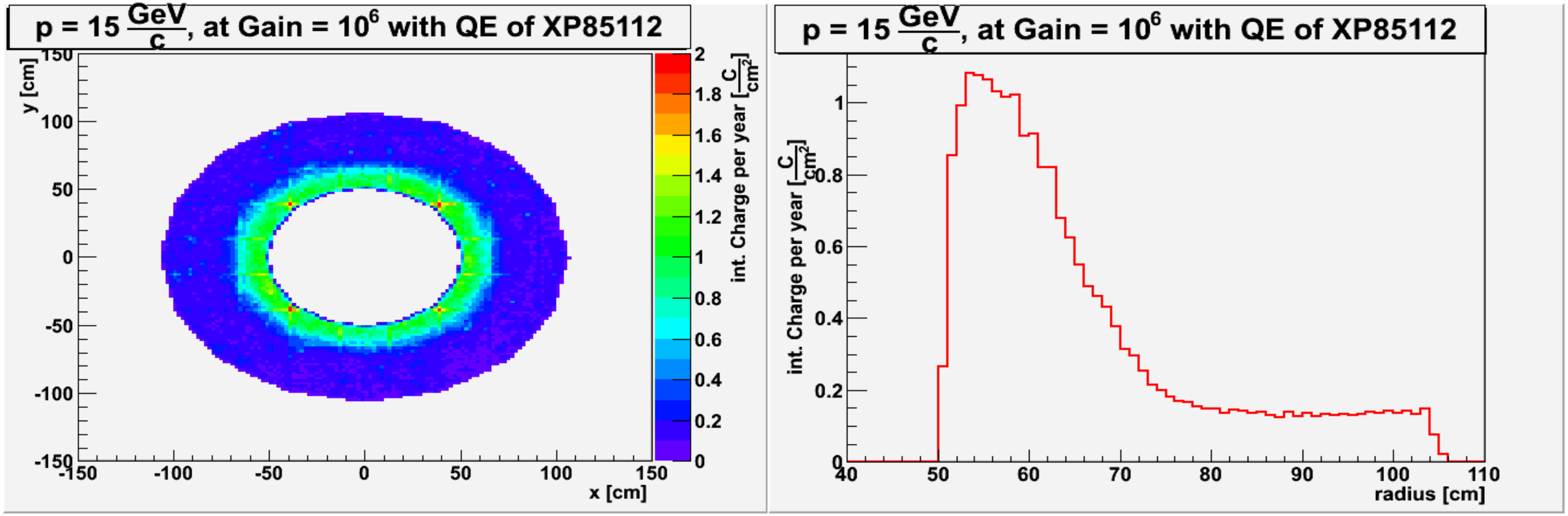


- No degradation for XP85112/A1-HGL – 1223, until 12 PANDA Barrel-Years. Decline recently started.
- XP85112/A1-D – 9001332 has already passed 6 PANDA Barrel-Years!
- More data for Ham. ALD coated MCP-PMTs needed!
- Performance of BINP 3548 is still good
- **ALD is most promising technique**

Summary and Outlook

- Requirements: **5C/cm²** (50% duty, 10 years), Disc-DIRC even more
- Results of lifetime measurements:
  - XP85112/A1-HGL - 1223 has passed ~6.2C/cm² (~12.5 PANDA Barrel-years), aging has started just recently at ~6.0C/cm² → currently checked with another device (1332)
  - More data for Ham. R10754-07-M16M needed, but promissing so far
  - All other devices show more significant aging effects
  - Surface scans reveal faster aging areas:
    - Aging of R10754X-01-M16 and BINPs starts from the corners/edges
    - R10754X-07-M16M needs more data
    - XP85112/A1-HGL - 1223 aging has started at upper rim
- Lifetime of MCP-PMTs has substantially increased (~50 - 100):
  - **ALD** is most promising technique
  - Maybe even better: ALD + new cathode?
  - XP85112/A1-HGL seems to be usable for PANDA Barrel-DIRC

Requirements for PANDA Barrel-DIRC



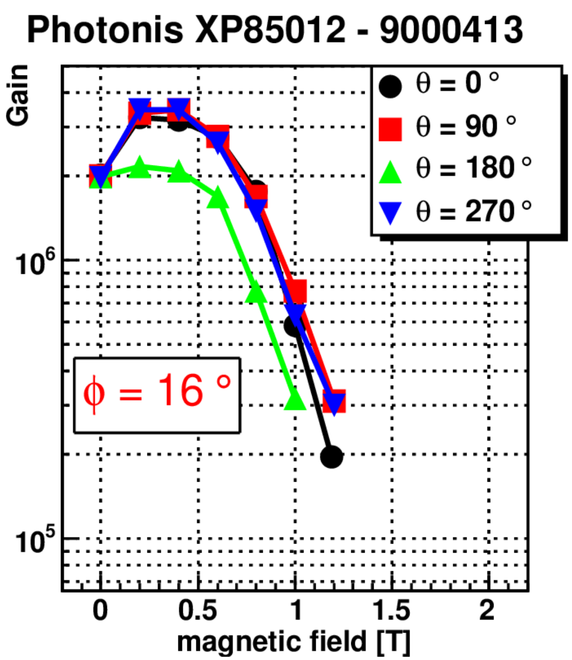
Assumptions:

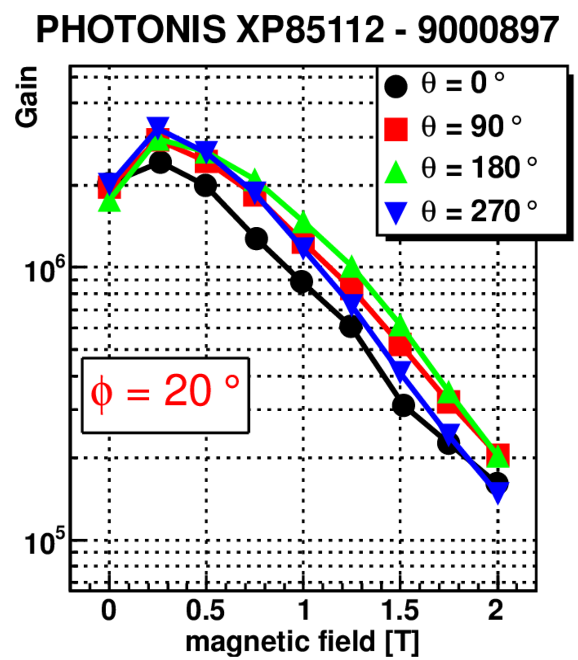
- PANDA high luminosity mode: $2*10^{32}cm^{-2}s^{-1}$
  → p-pbar reaction rate: 20MHz
- QE of XP85112
- **1 year of 100% duty cycle!**

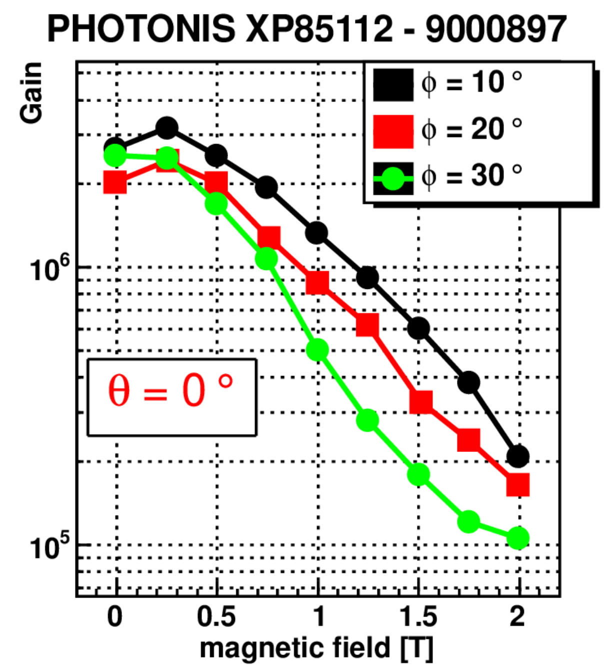
results:

- **Int. Charge is radial dependent**
- $1\frac{\mathbf{C}}{\mathbf{cm}^2*\mathbf{a}}$ at focal plane
- Assuming 50% duty cycle and 10 years operation time
  → **5C/cm² needed!**

Magnetic field performance

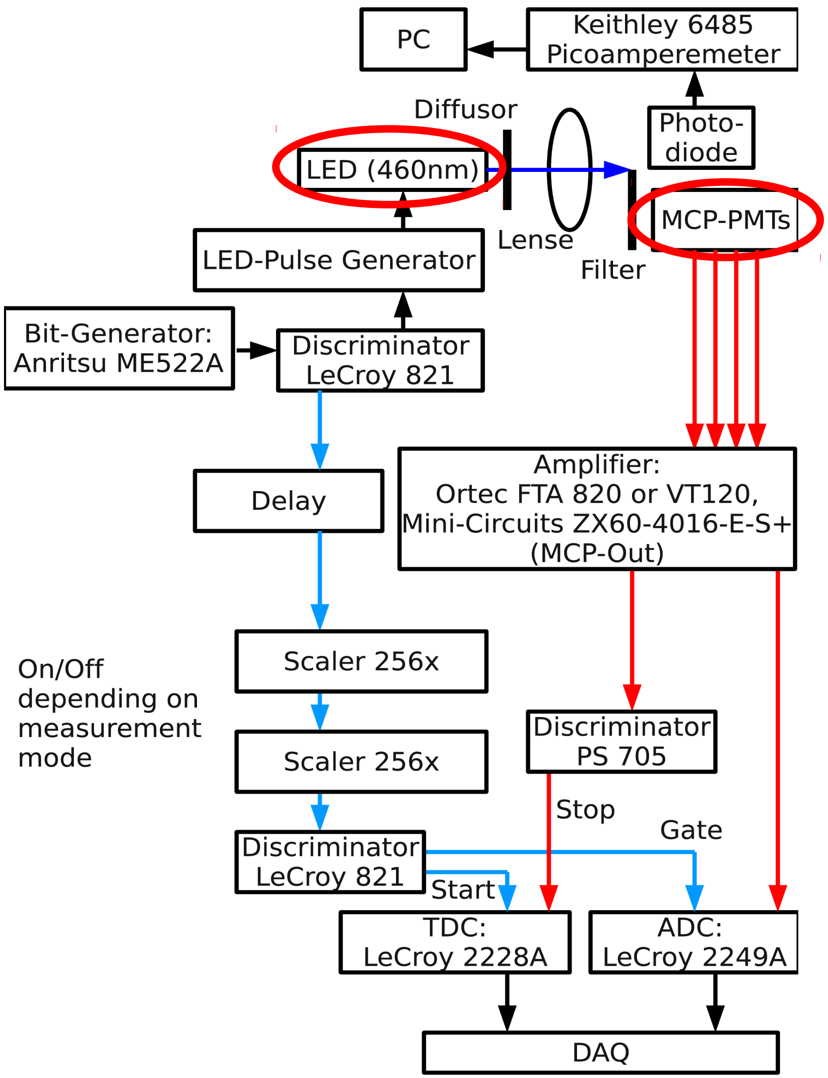






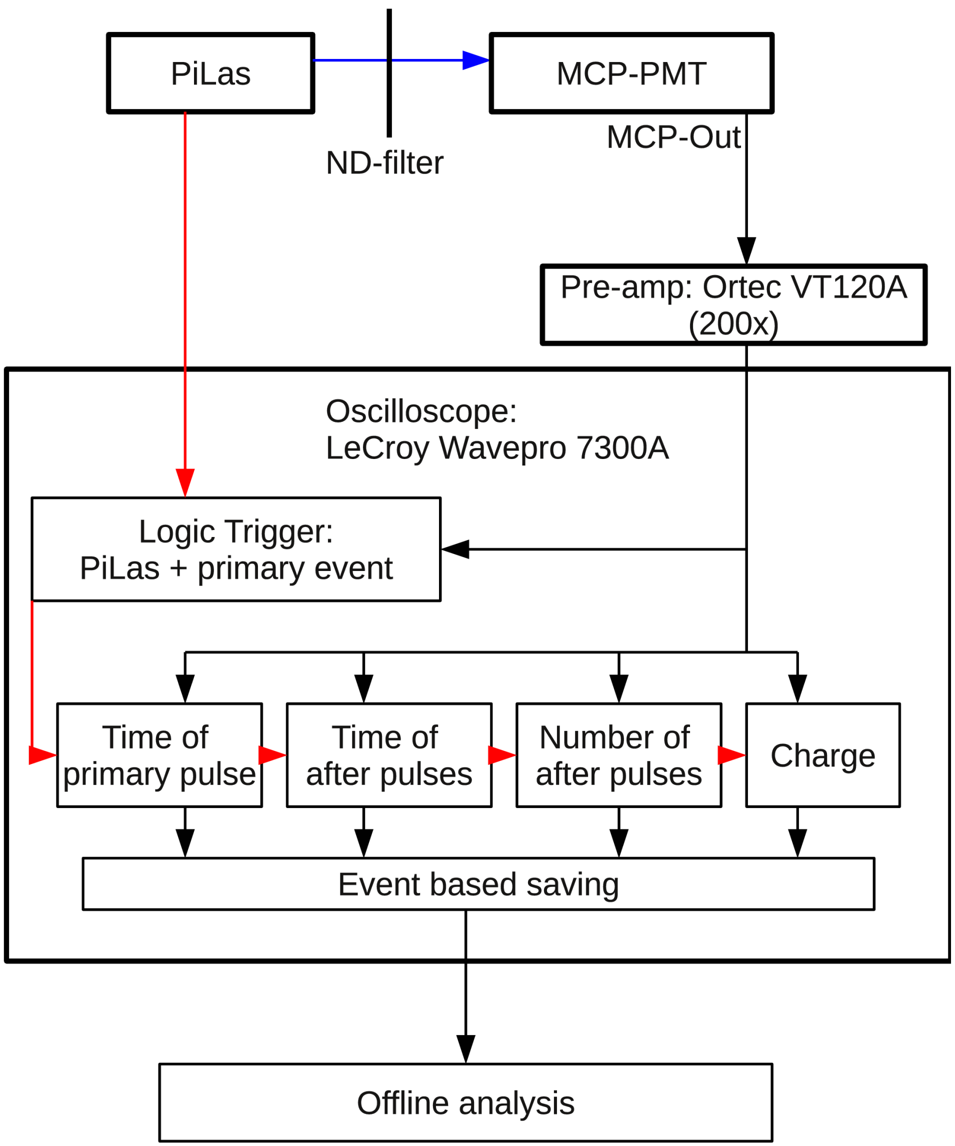
- Lamor radi of electrons determine maximum magnetic field
  → 10µm or less required for 2T
- Gain decreases drastically, if B-field is parallel to chevron angle
- Gain drops for larger tilt angle

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

After pulse



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

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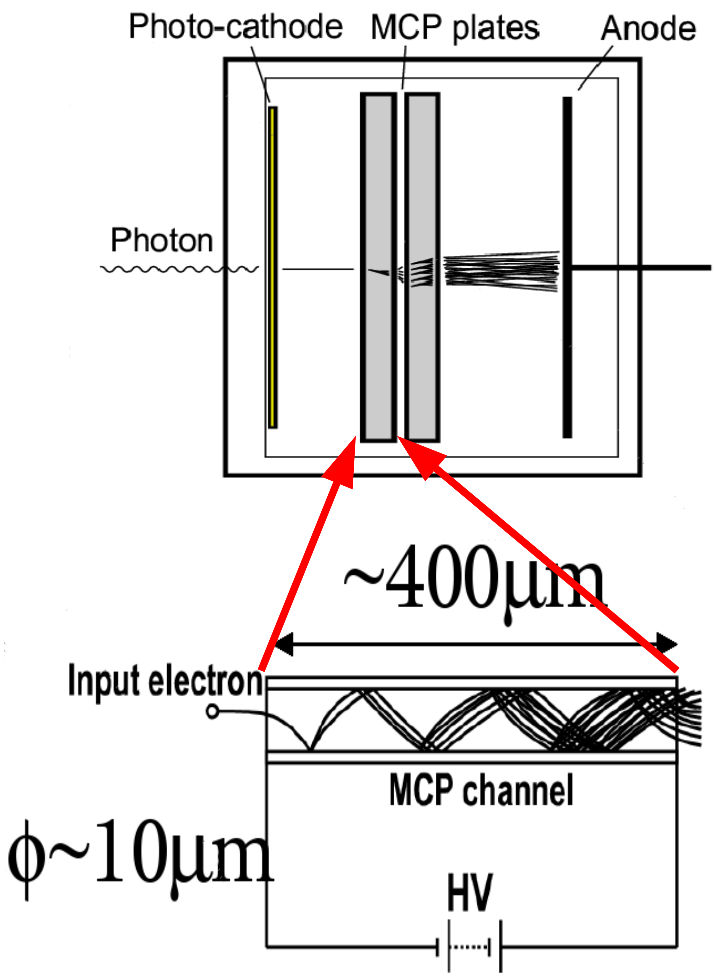
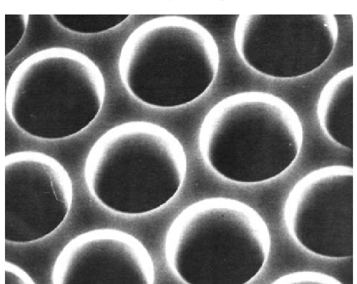
Microchannel-Plate PMTs





- 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!**