Lifetime of MCP-PMTs

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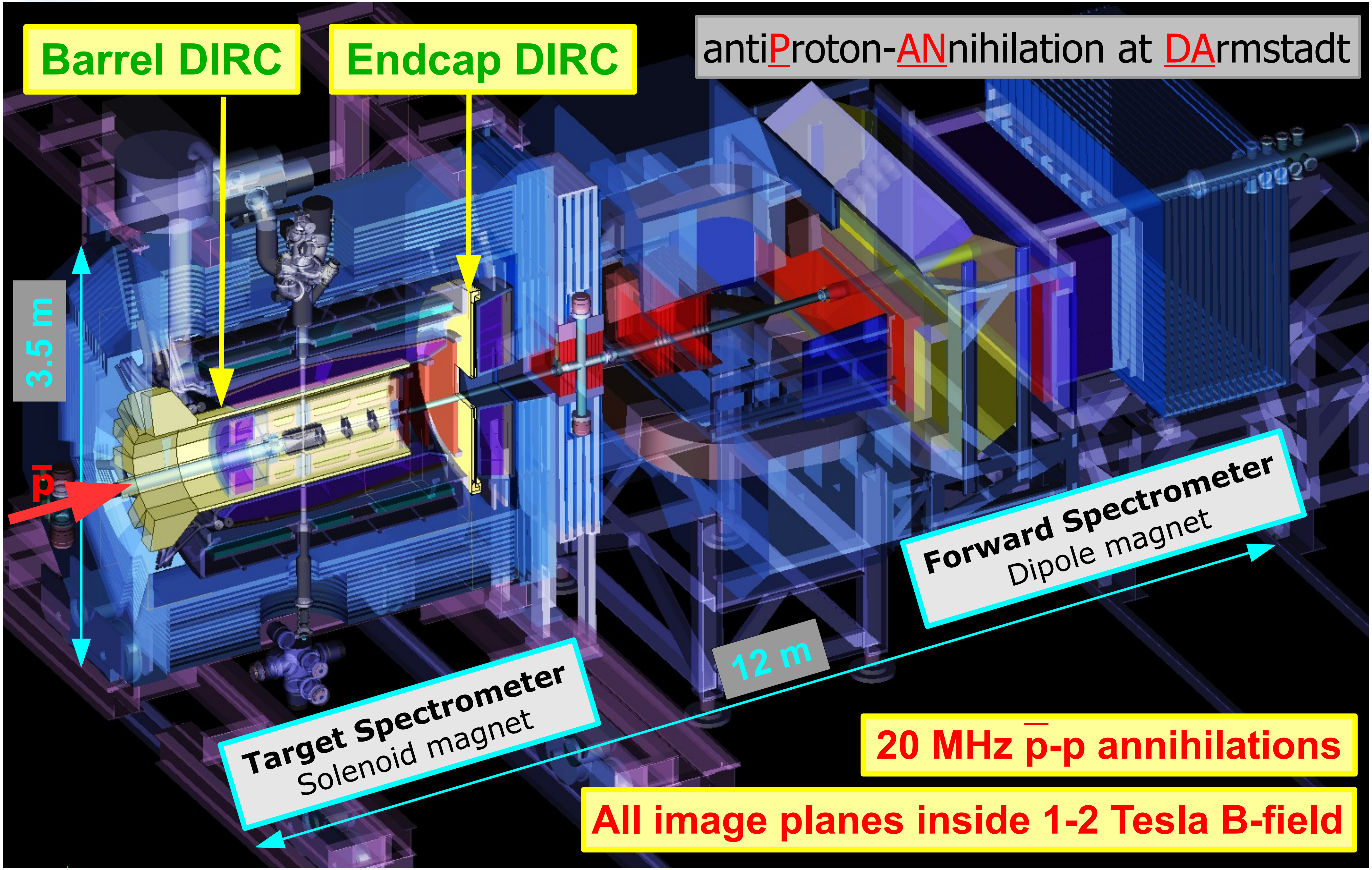
- Motivation
- A few pros and cons of MCP-PMTs
- Approaches to increase lifetime
- Results of aging tests
- Outlook and summary

$\overline{\text{P}}$ANDA Detector at FAIR



Challenges to Photon Sensors

- Good geometrical resolution over a large surface
  - multi-pixel sensors with ~5x5 mm^2 anodes (smaller for Endcap DIRC)
- Single photon detection inside B-field
  - high gain (> $5*10^5$) in up to 2 Tesla
- Time resolution for ToP and/or dispersion correction
  - very good time resolution of <100 ps for single photons
- Few photons per track
  - high detection efficiency η = QE * CE * GE
    [QE = quantum efficiency; CE = collection efficiency; GE = geometrical efficiency]
  - low dark count rate
- Photon rates in the MHz regime
  - **high rate capability** with rates up to MHz/cm^2
  - **long lifetime** with integrated anode charge of 0.5 to 2 $C/cm^2/y$

Sensor Candidates

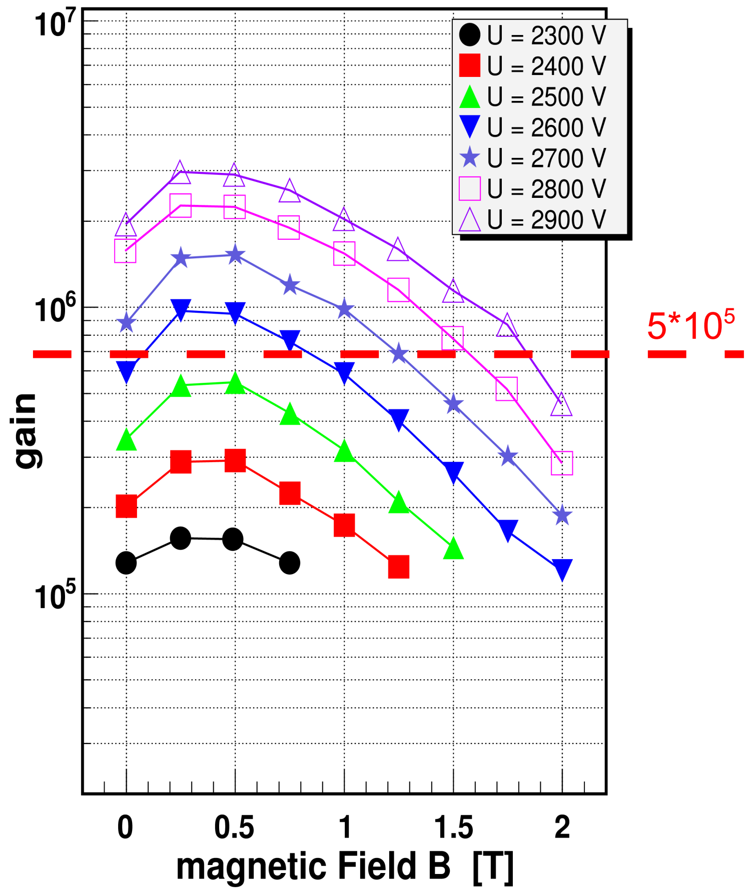
- multi-anode photomultipliers (MaPMTs)
  - ruled out by magnetic field
- Geiger-mode avalanche photo diodes (SiPMs)
  - huge noise is very problematic
  - radiation hardness unclear
- **micro-channel plate photomultipliers** (MCP-PMTs)
  - preferred choice for PANDA DIRC
  - but problems with rate capability and **aging** (mainly QE)

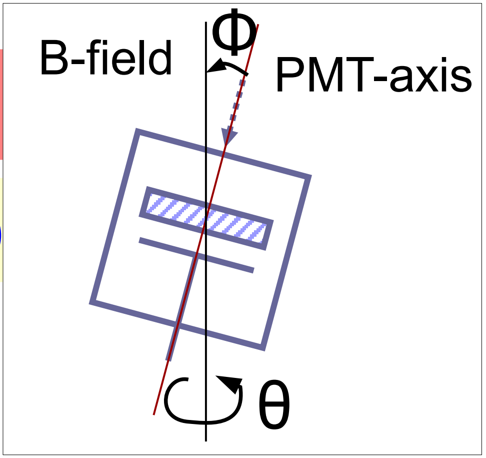
In the year 2011 there was no suitable sensor for the PANDA DIRCs !

Gain inside B-Field

10 µm pores sufficient at 2 T

PHOTONIS XP85112 (10 µm)





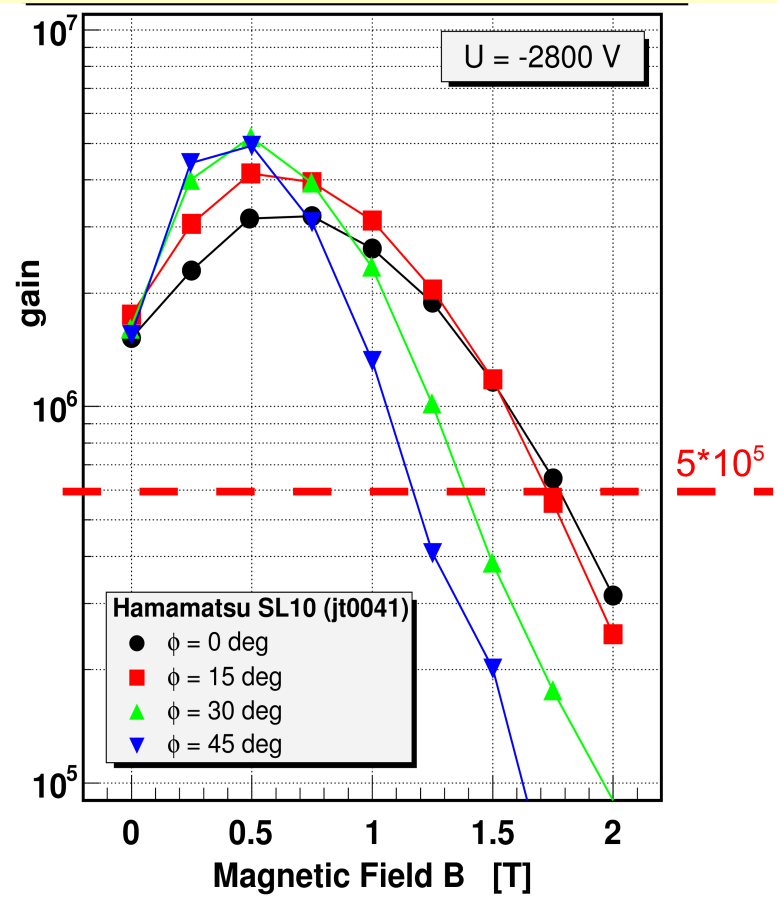
Φ = tilt angle between B-field direction and PMT-axis

θ = rotation angle of PMT around B-field direction

Gain loss at high B-fields and large Φ-angles

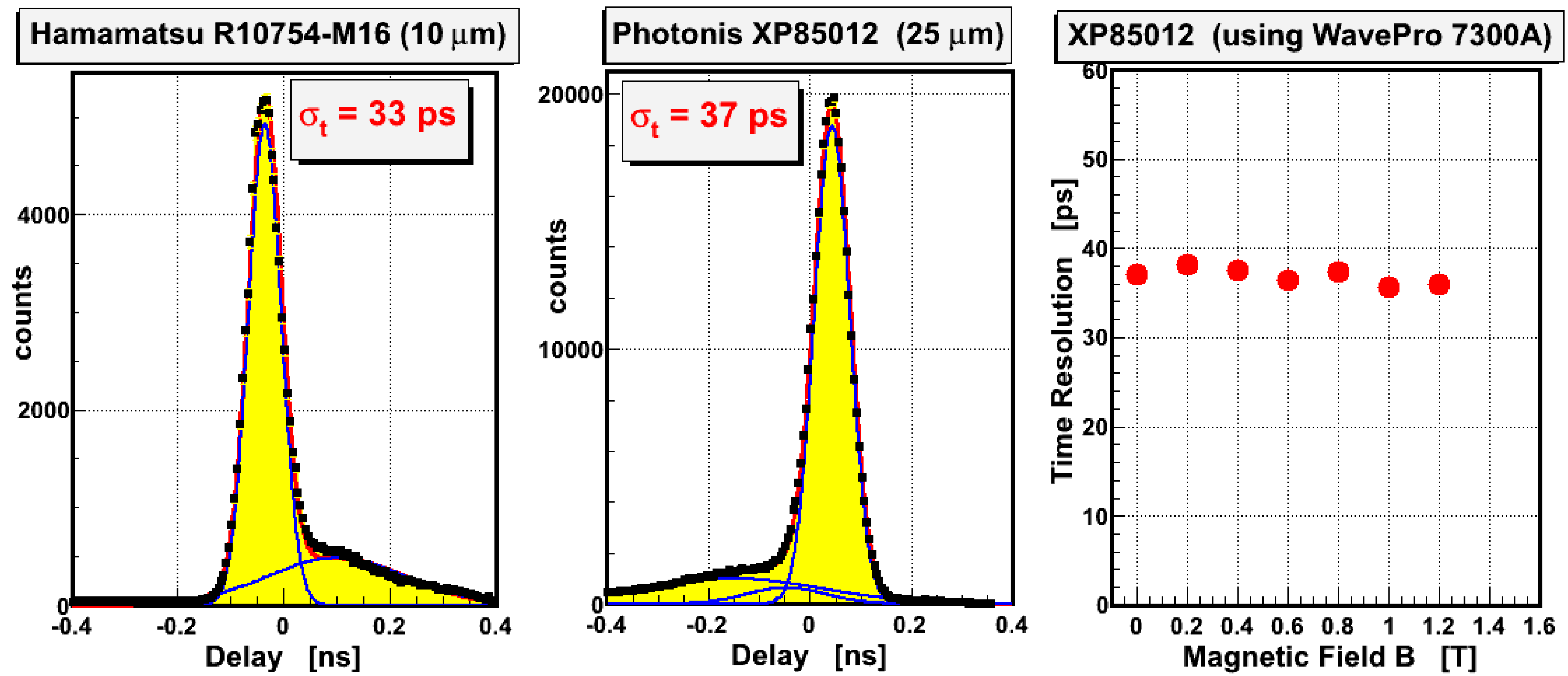
gain versus tilt angle Φ

Hamamatsu R10754 (10 µm)



Single Photon Time Resolution

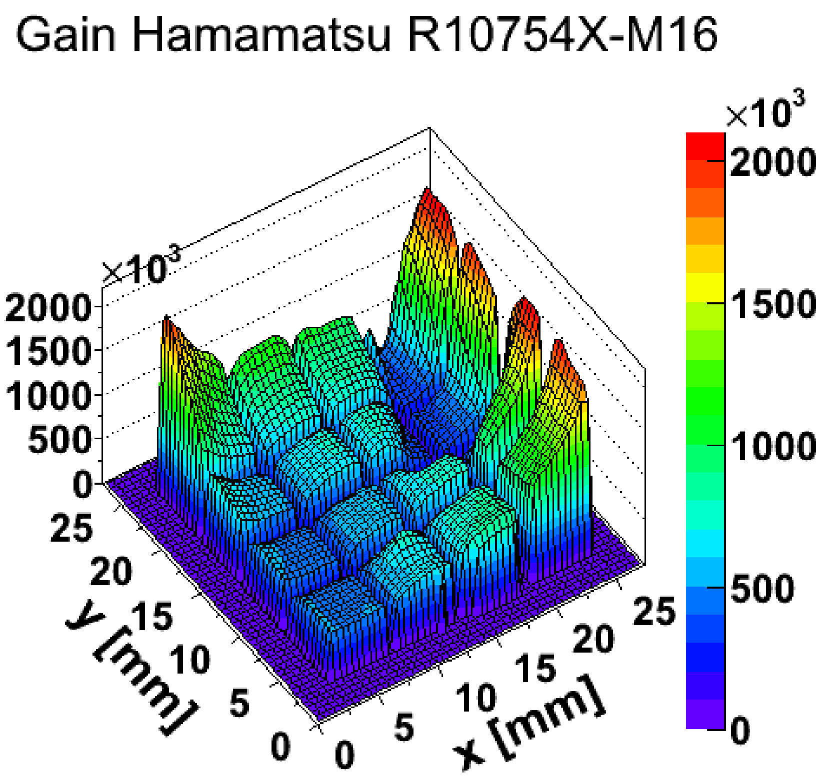
Amplifier Ortec FTA820 (x200; 350 MHz) --- Discriminator Philips Scientific 705

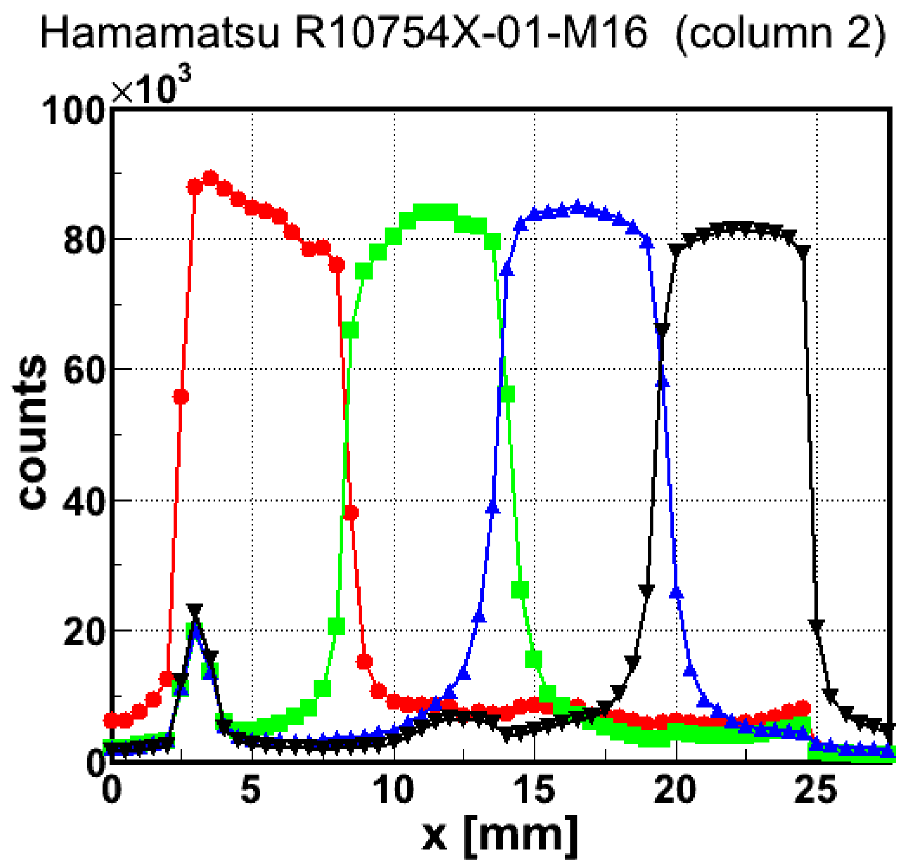


BINP	PHOTONIS				Hamamatsu		
#73	XP85011	XP85012	XP85013	XP85112	R10754	R10754X-L4	R10754X-M16
6 µm	25 µm	25 µm	25 µm	10 µm	10 µm	10 µm	10 µm
27 ps	**49 ps**	**37 ps**	**51 ps**	**36 ps**	**32 ps**	**31 ps**	**33 ps**

- time resolution of all MCP-PMTs 50 ps and better
- no dependence on the B-field

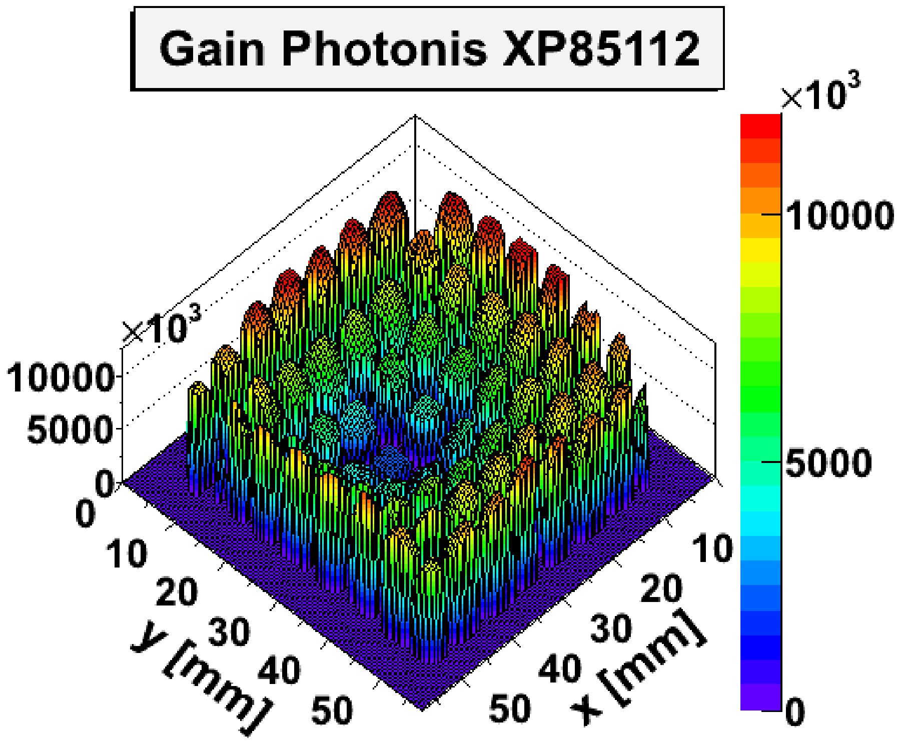
Gain and Crosstalk of R10754X-M16

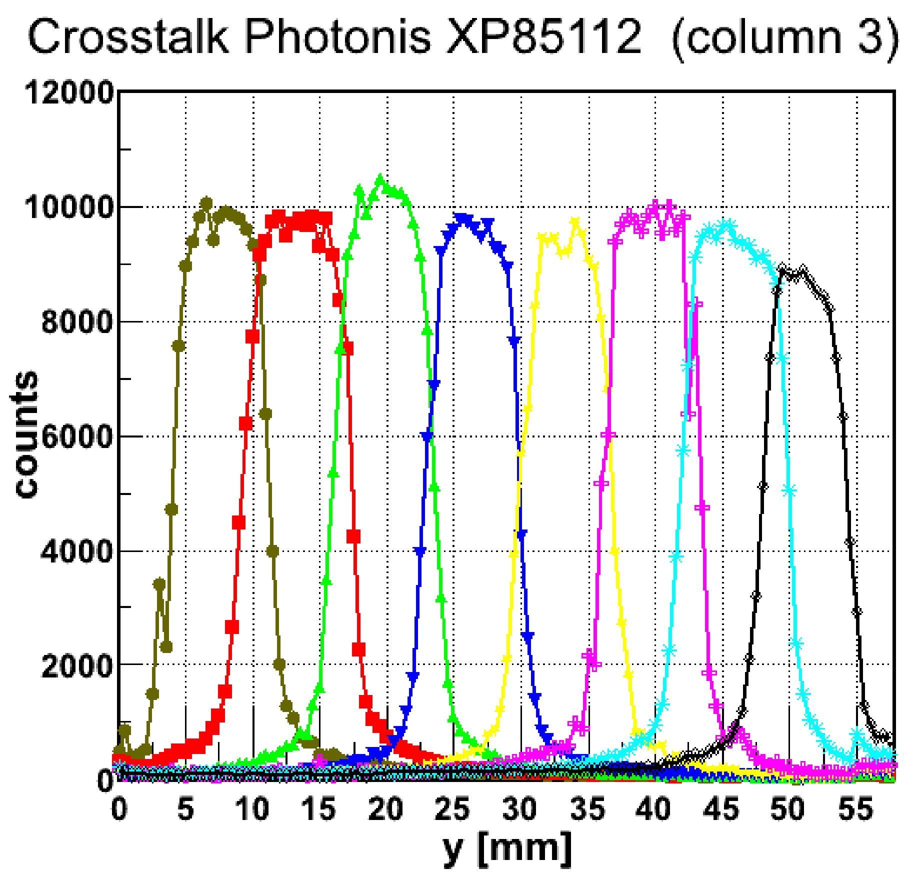




- **gain variations** of factor 3 even within the same pixel
- 50% level of crosstalk extends only little into adjacent pixel
- long tails in crosstalk are of electronic nature

Gain and Crosstalk of XP85112





- **substantial gain variations between pixels** (in center!)
- 50% crosstalk level extends ~1 mm into adjacent pixel
- but no long crosstalk tails

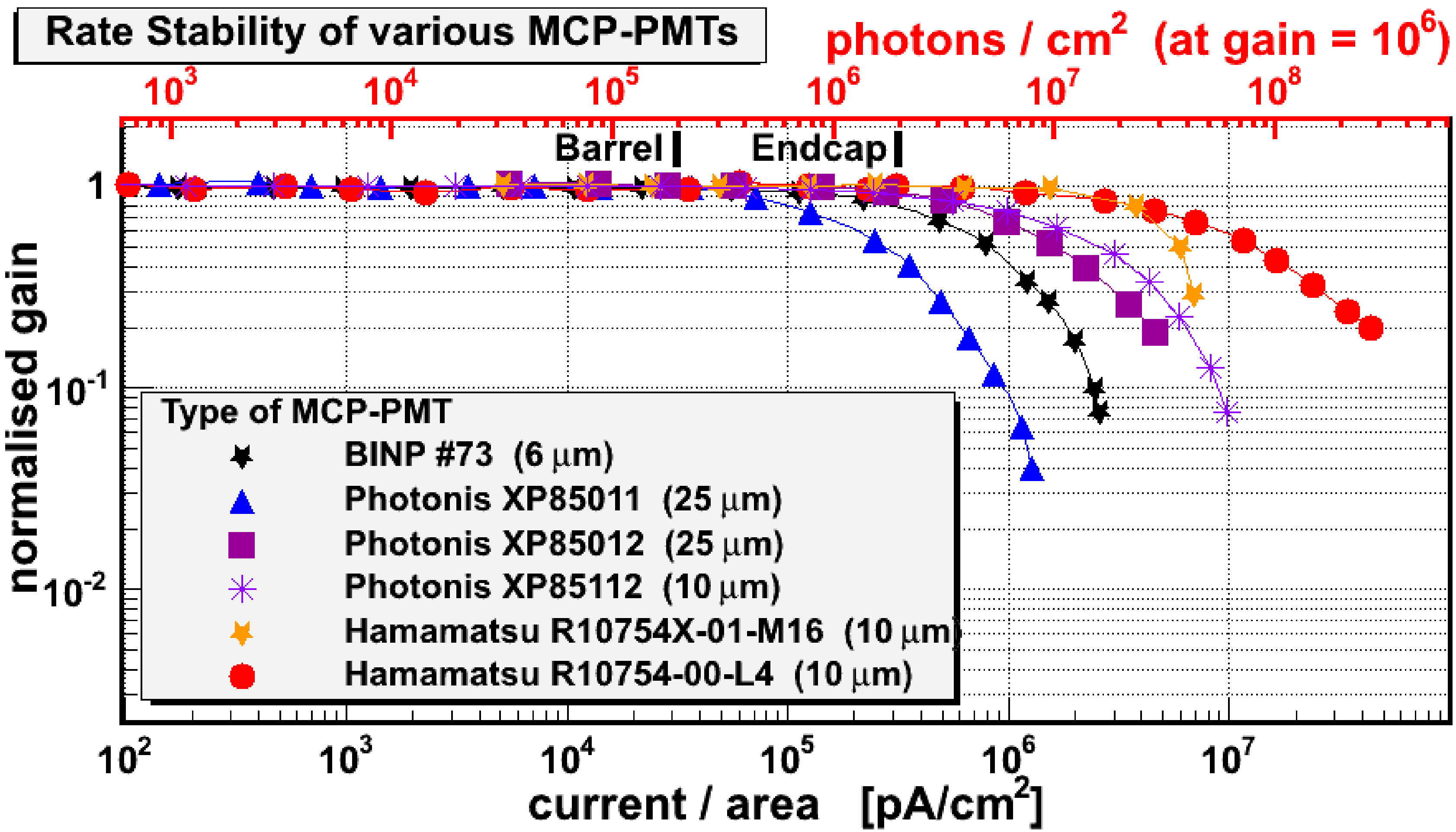
Rate Estimates for PANDA

- **rate capability and lifetime are the most critical issues** for the application of MCP-PMTs in any high-rate experiment
- expected rates and anode charges of the PANDA DIRCs:

	total rate	anode rate (after Q.E.)	integrated anode charge / year	integrated anode charge / 10 years
	[MHz/cm^2]	[MHz/cm^2]	[C/cm^2/year] at 10^6 gain (at 100% dc)	[C/cm^2] at 10^6 gain (at 50% duty cycle)
Barrel DIRC				
at end of radiator	*60*	*5.6*	*28*	
at readout plane	1.7	**0.2**	**1**	**5**
Endcap DIRC				
at rim of radiator	*19*	*2*	*10*	
focussing	7.5	**0.8**	**4**	**20**

- Endcap DIRC with much higher photon rate than Barrel DIRC → very challenging

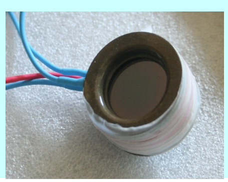
Rate Capability



- most MCP-PMTs show stable operation to ~200-300 kHz/cm^2 single photons (at gain 10^6)
- R10754X and XP85112 are suitable for both PANDA DIRCs

Lifetime-Investigated MCP-PMTs

	BINP		PHOTONIS			Hamamatsu	
			XP85012	XP85112	XP85112	R10754X-01-M16	R10754X-07-M16M
pore size (µm)	6	7	25	10	10	10	10
number of pixels	1	1	8x8	8x8	8x8	4x4	4x4
active area (mm²)	$9^2\pi$	$9^2\pi$	53x53	53x53	53x53	22x22	22x22
total area (mm²)	$15.5^2\pi$	$15.5^2\pi$	59x59	59x59	59x59	27.5x27.5	27.5x27.5
geom. efficiency (%)	36	36	81	81	81	61	61
photo cathode	multi-alkali		bi-alkali			multi-alkali	
peak Q.E.	21% @ 495 nm	21% @ 495 nm	20% @ 380 nm	23% @ 380 nm	22% @ 380 nm	21% @ 375 nm	22% @ 415 nm
comments		**better vacuum, new cathode**	better vacuum, polished surfaces	better vacuum, polished surfaces	**better vacuum, ALD surfaces**	**protection layer between MCPs**	**further improved lifetime (ALD?)**
# of tubes measured	**1**	**2**	**1**	**1**	**2**	**1 (+1 L4)**	**2**

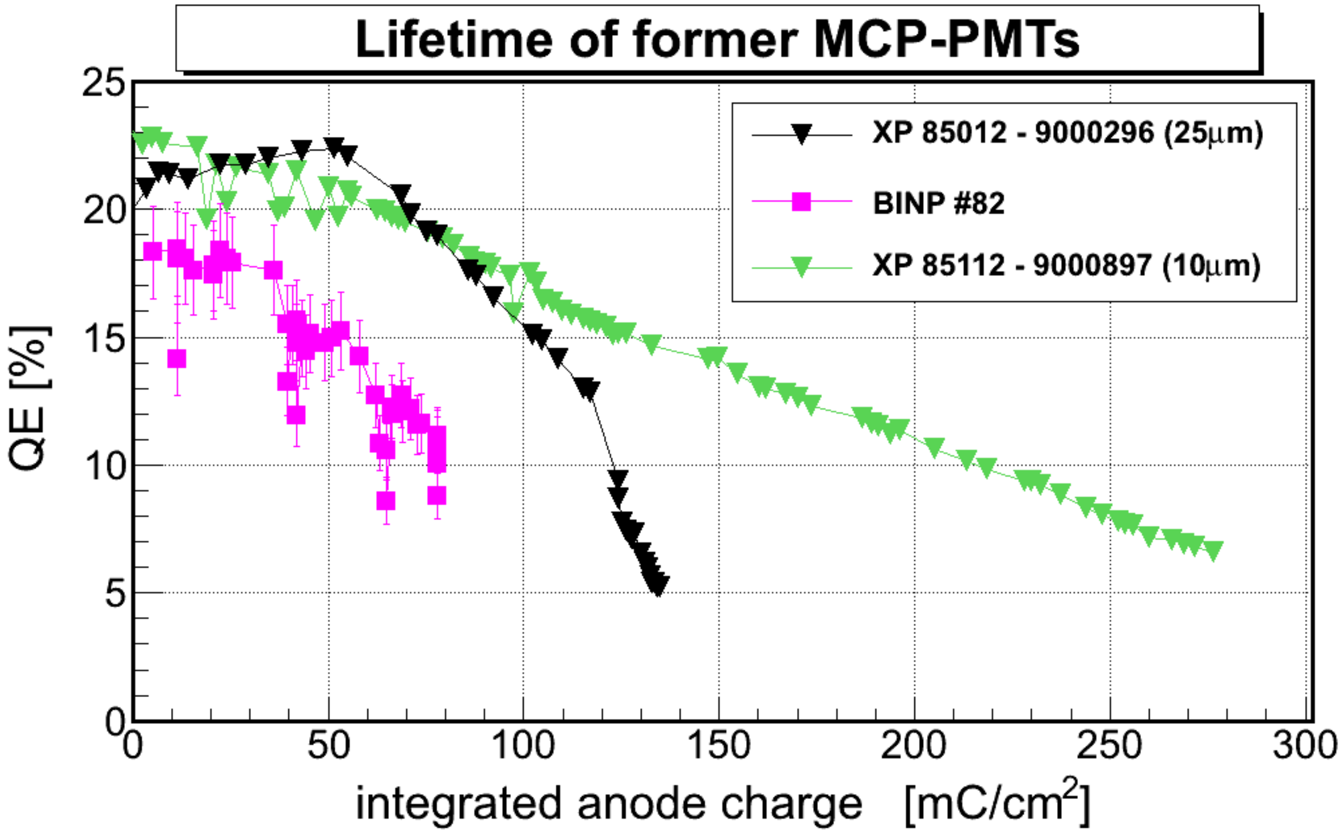


- Tubes first measured with no significant lifetime improvements
- Lifetime improved tubes currently being measured or finished
- Measurement of tube just started or not yet included in setup

Lifetime of former MCP-PMTs

Status ~2 year ago

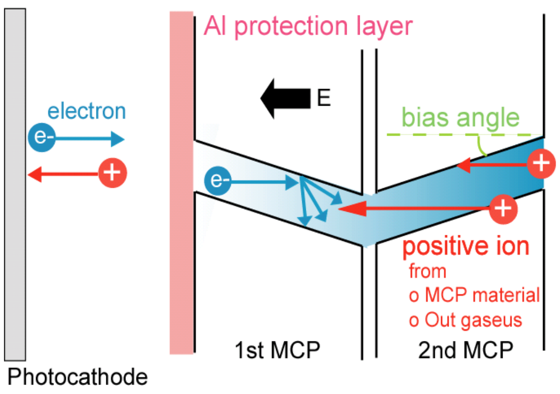
- BINP with Al_2O_3 film at MCP entrance to stop feedback ions
- PHOTONIS with improved vacuum and electron scrubbing of surfaces



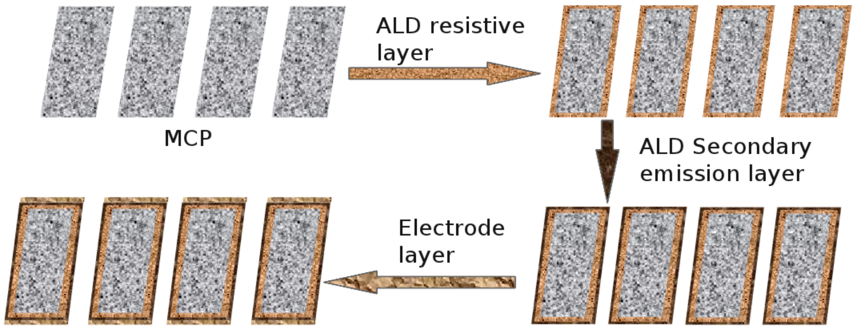
- Quantum efficiency reduced by 50% or more at <200 mC/cm^2
- By far not sufficient for PANDA

Approaches to Increase Lifetime

- Protection layer
  - In front of first MCP layer (older BINP and Hamamatsu)
    - disadvantage: reduction of collection efficiency
  - Between MCP layers (new Hamamatsu)
    - anode region is hermetically sealed from photo cathode region [NIM A629 (2011) 111]



- Improved vacuum + treatment of MCP surfaces [NIM A639 (2011) 148]
  - Electron scrubbing (older PHOTONIS and new BINP)
  - Atomic layer deposition (PHOTONIS)



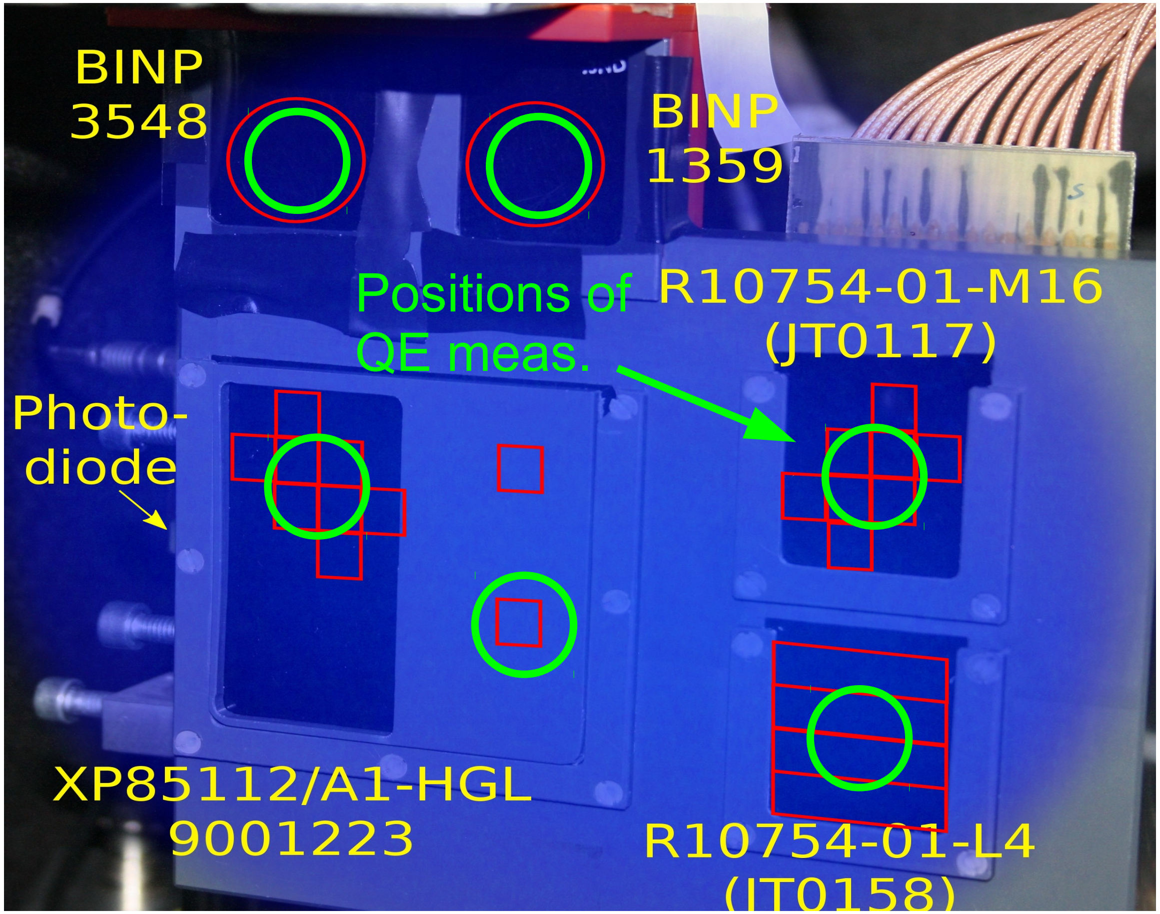
- New photo cathode [JINST 6 C12026 (2011)]
  - $Na_2KSb(Cs) + Cs_3Sb$ (new BINP)
    - disadvantage: significantly higher dark count rate

Aging of Several MCP-PMTs

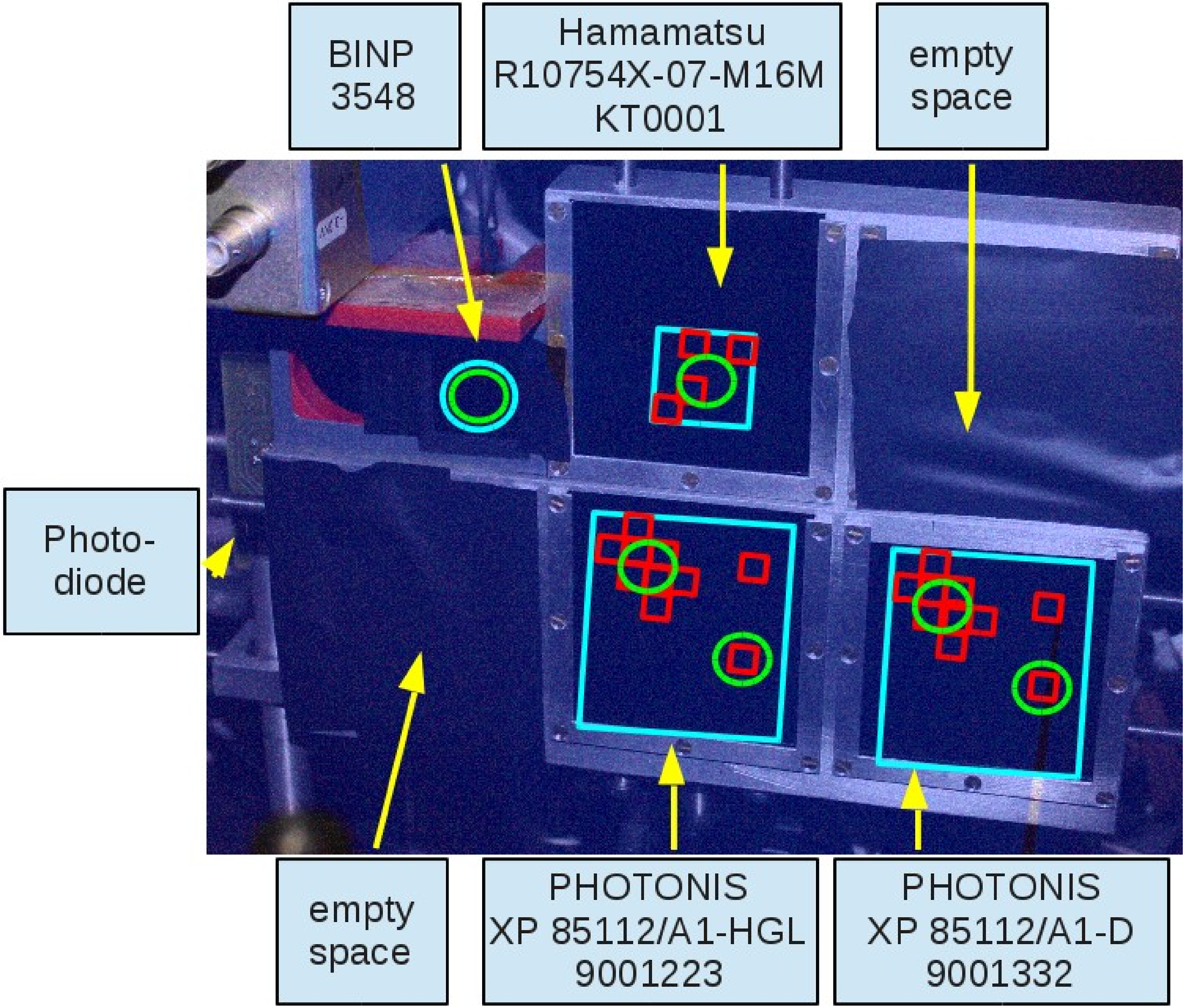
- **Problem:** The few aging tests existing were done in very different environments → results are rather difficult to compare
- **Goal:** measure aging behavior for all currently available lifetime-enhanced MCP-PMTs in same environment
- **Simultaneous illumination** with common light source → same rate
- MCP-PMTs included in aging tests of last 2 years:
  - 2x BINP
    - improved vacuum and scrubbed surfaces + new photo cathode (one finished)
  - 4x Hamamatsu R10754X
    - L4 and M16: protection layer between 1st and 2nd MCP (both finished)
    - 2x M16M: further counter measures against aging (ALD?)
  - 2x PHOTONIS XP85112
    - ALD surfaces
    - surface half covered during illumination

Measurement of MCP Lifetime

- Continuous illumination
  - 460 nm LED at 0.25 to 1 MHz rate attenuated to single photon level $\rightarrow$ 3 to 14 mC/cm^2/day
- Permanent monitoring
  - MCP pulse heights and LED light intensity
- Q.E. measurements
  - 300–800 nm wavelength band with monochromator $\Delta\lambda$ = 1 nm
  - every few days: wavelength scan
  - every several weeks: complete surface scan



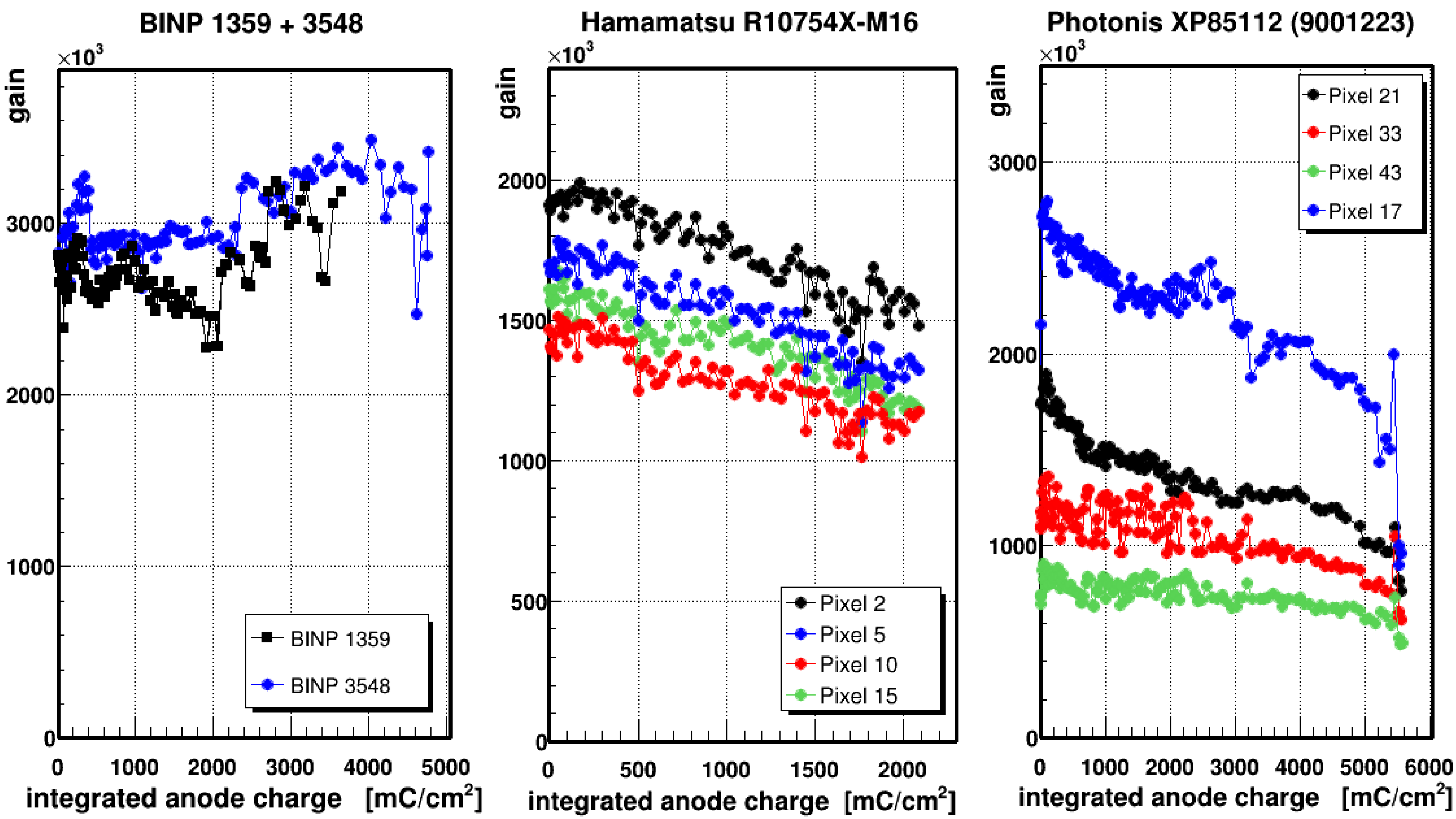
Current Setup



Illumination Overview

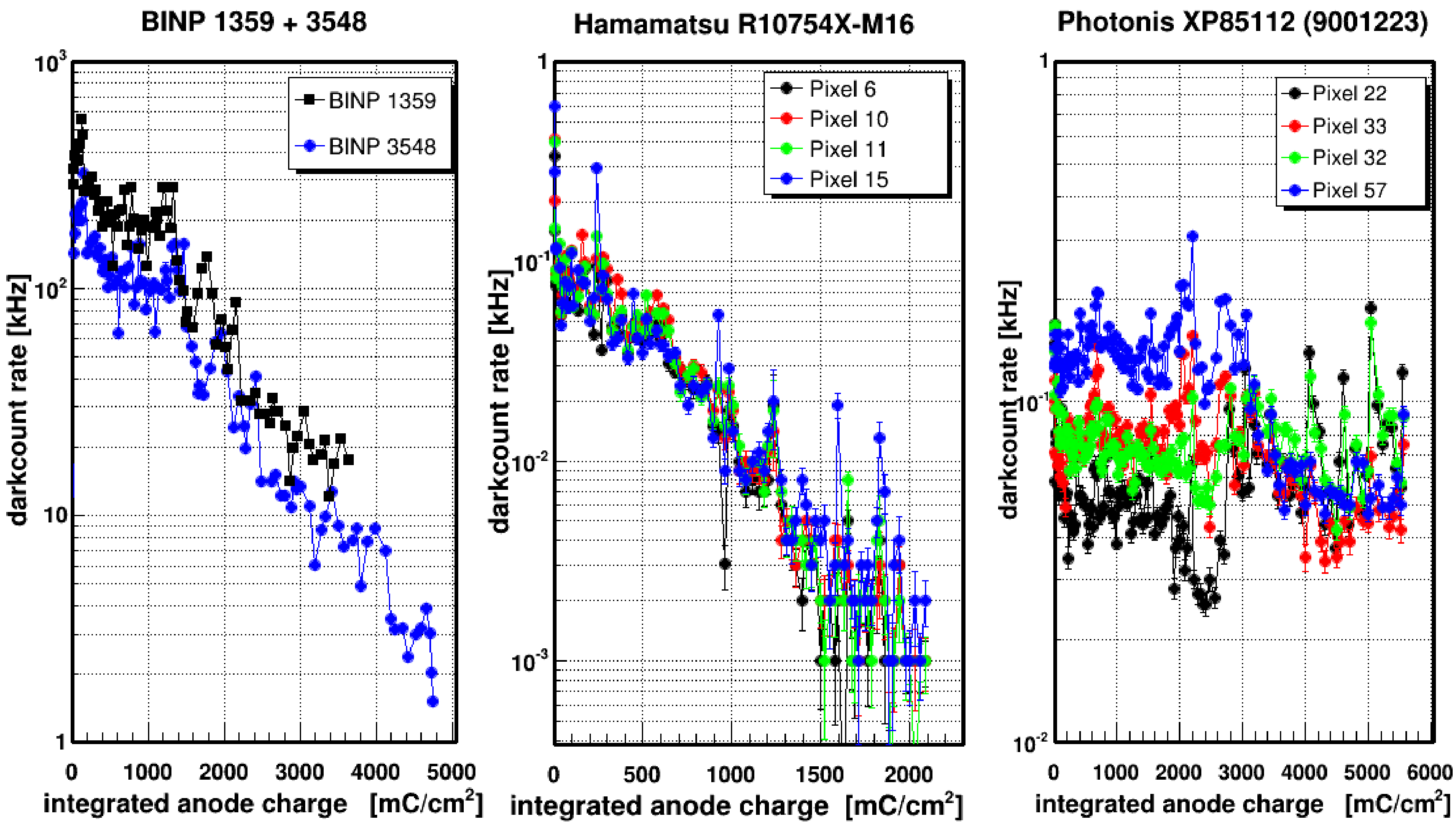
	Sensor ID	Integral charge (Sep. 2, 2013) [mC/cm^2]	Diff. charge (maximum) [mC/cm^2/d]	# of mea-surements	# of QE scans	Comments
Photonis XP85112	9001223	**5570**	13.4	123	11	Start: 23 Aug. 11 ongoing
	9001332	**2261**	14.1	27	3	Start: 12 Dec. 12 ongoing
Hamamatsu R10754X	JT0117 (M16)	**2086**	14.1	86	7	Start: 23 Aug. 11 Stop: 24 Jul. 12
	JT0158 (L4)	**649**	6.3	83	8	Start: 23 Aug. 11 Stop: 6 Aug. 12
	KT0001 (M16M)	**131**	16.7	3	1	Start: 20 Aug. 13 ongoing
	KT0002 (M16M)					not yet started
BINP	1359	**3648**	10.6	90	8	Start: 21 Oct. 11 Stop: 06 May 13
	3548	**4779**	11.7	100	8	Start: 21 Oct. 11 ongoing

Gain vs. Integrated Anode Charge



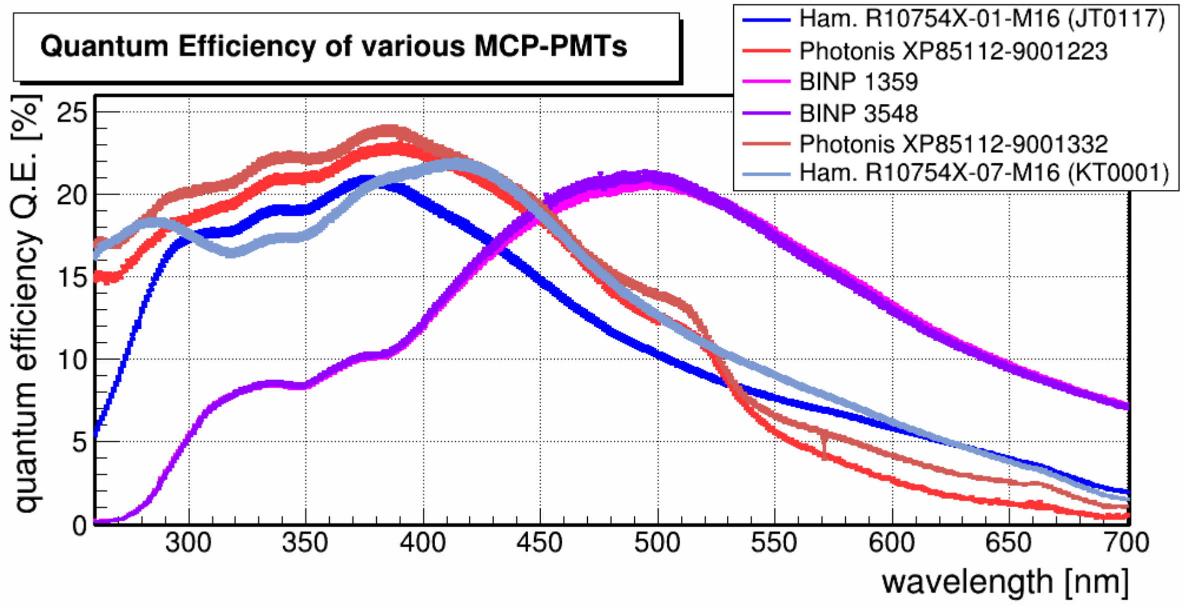
- Only moderate gain changes
- This was different in the former MCP-PMTs !

Darkcount vs. Anode Charge



- Only few changes of darkcount rate for PHOTONIS XP85112
- Big reduction in BINP and Hamamatsu R10754X

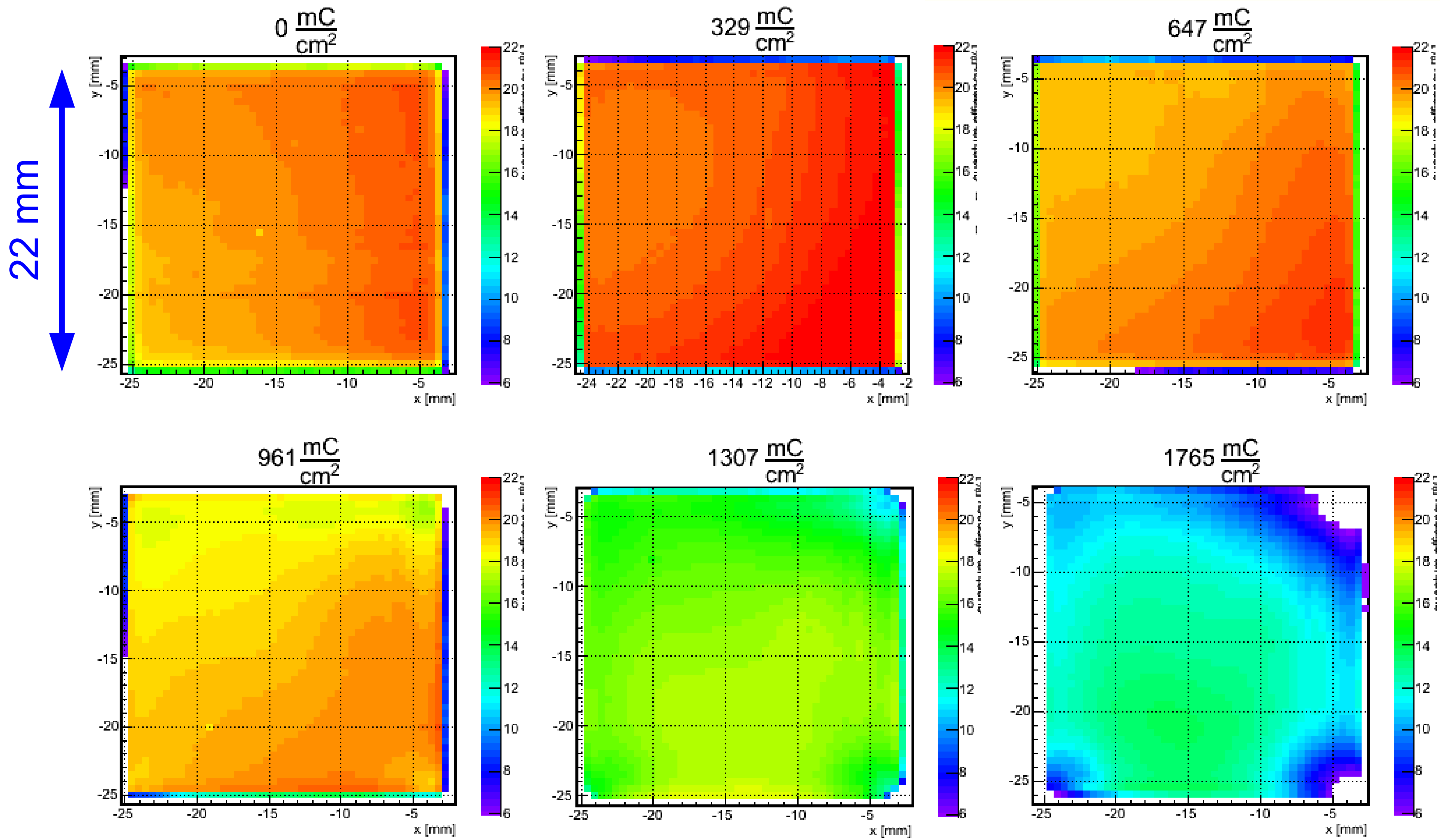
Quantum efficiency



MCP-PMT	Peak Q.E. (nm)	Photo cathode
XP85112/A1⁻HGL (1223)	390	bi-alkali
R10754X-01-M16	375	multi-alkali
R10754X-07-M16M	415	bi-alkali
BINP 1359	495	$Na_2KSb(Cs) + Cs_3Sb$
BINP 3548	495	$Na_2KSb(Cs) + Cs_3Sb$

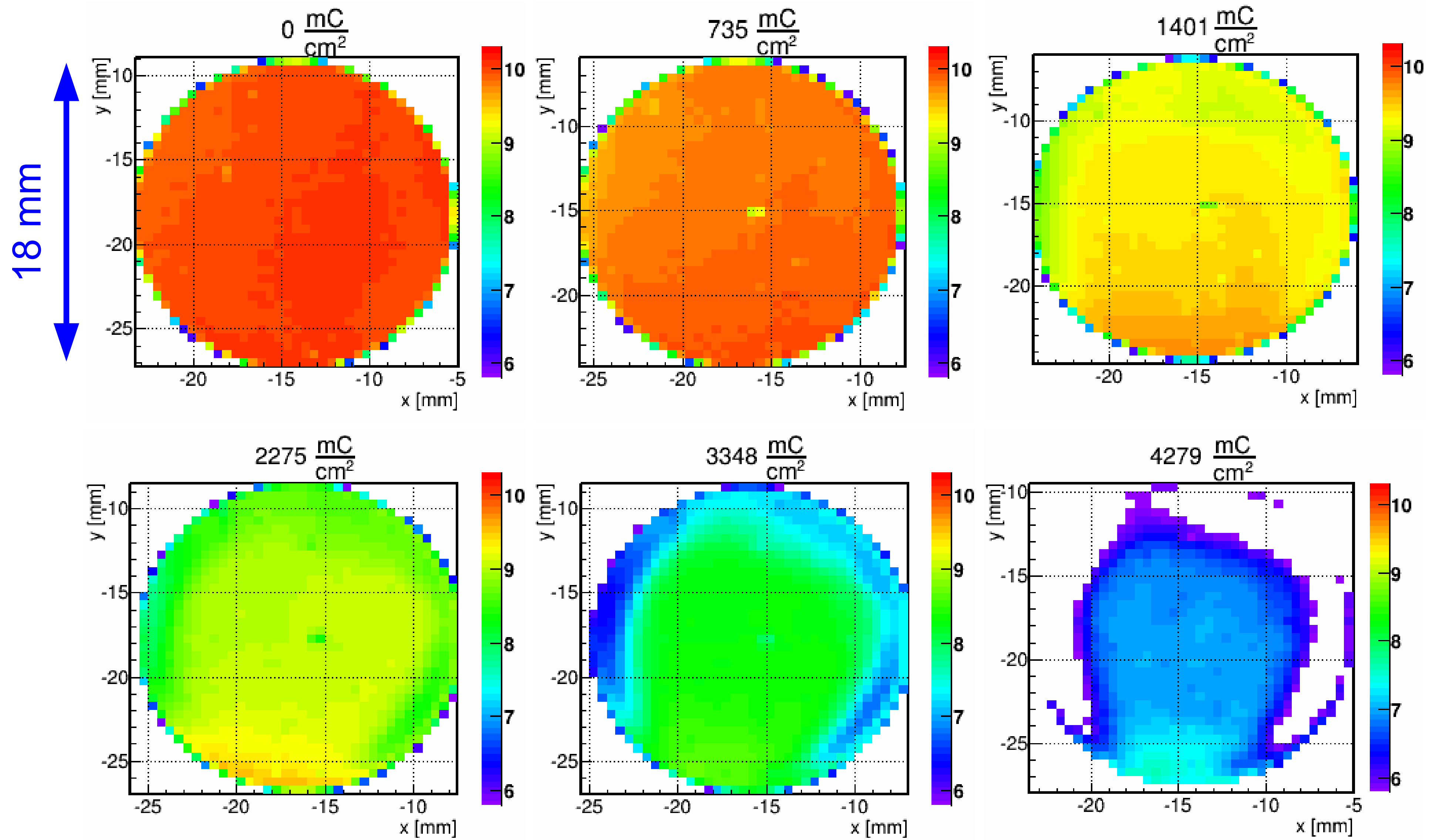
Q.E. Scans (Hamamatsu R10754X-M16)

Q.E. measured at 372 nm



Q.E. Scans (BINP 3548)

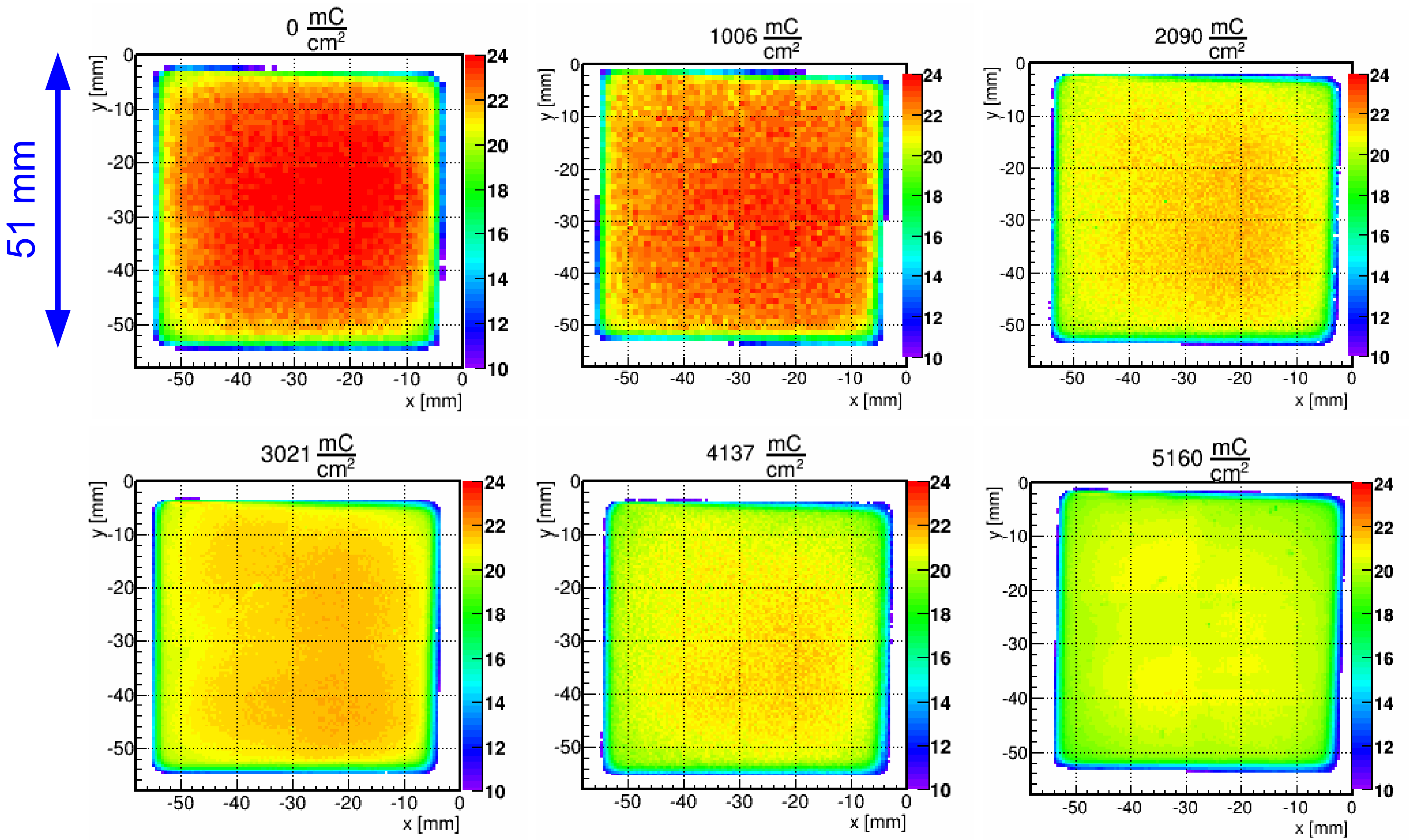
Q.E. measured at 372 nm



Q.E. Scans (Photonis XP85112)

9001223

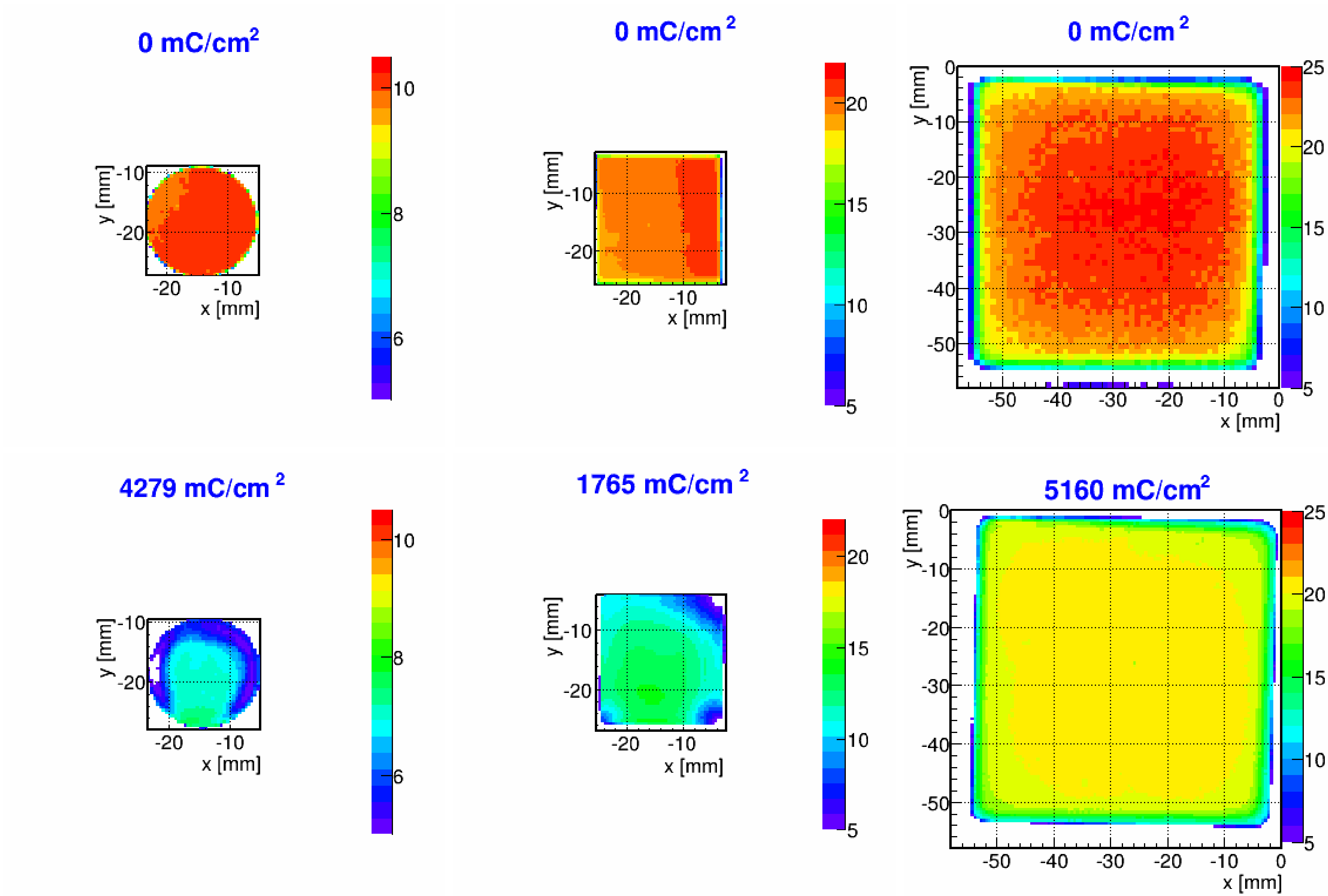
Q.E. measured at 372 nm



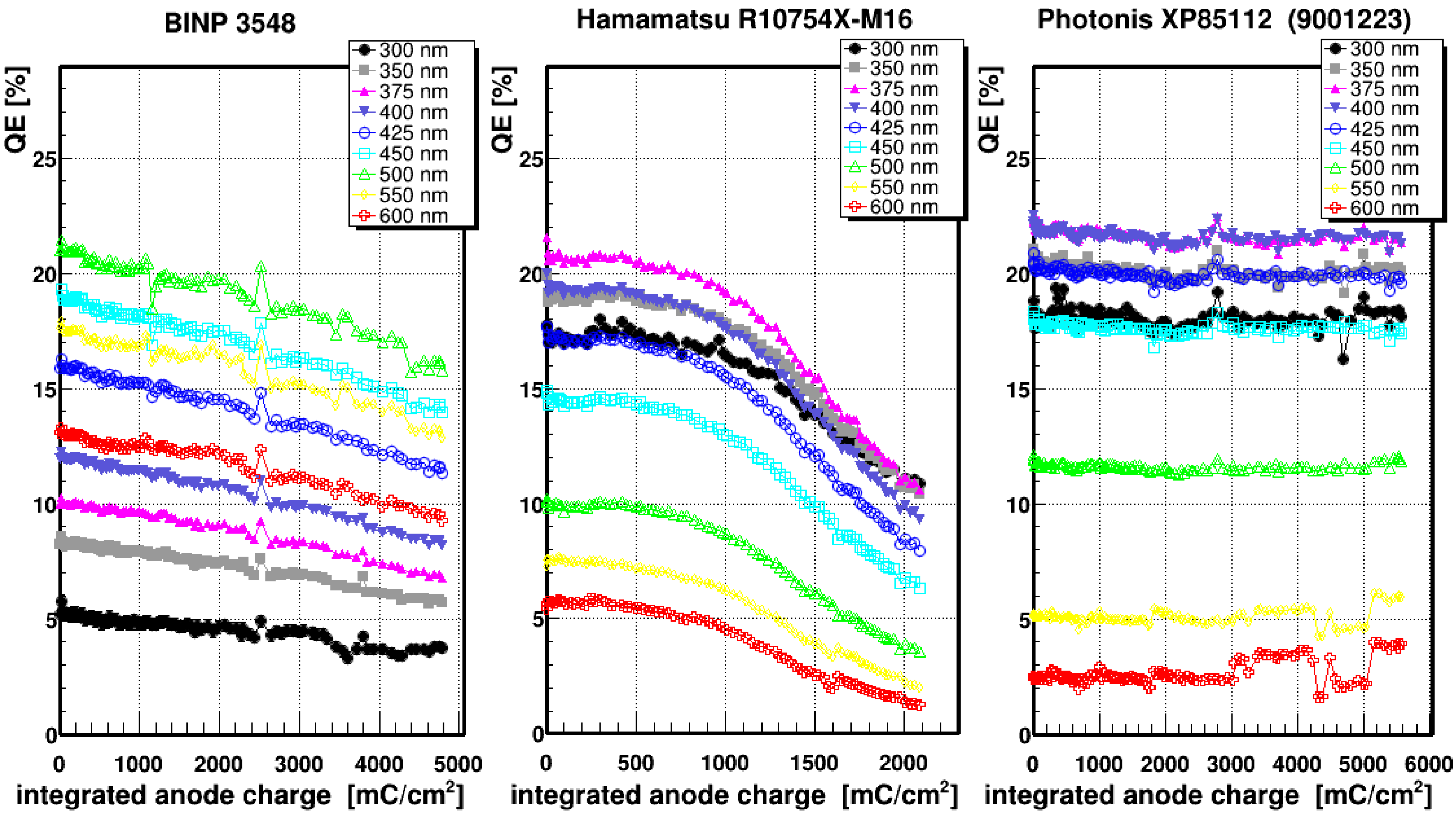
Q.E. Scans (scaled to MCP size)

Q.E. measured at 372 nm

BINP 3548 | **Ham. R10754X-M16** | **PHOTONIS XP85112**

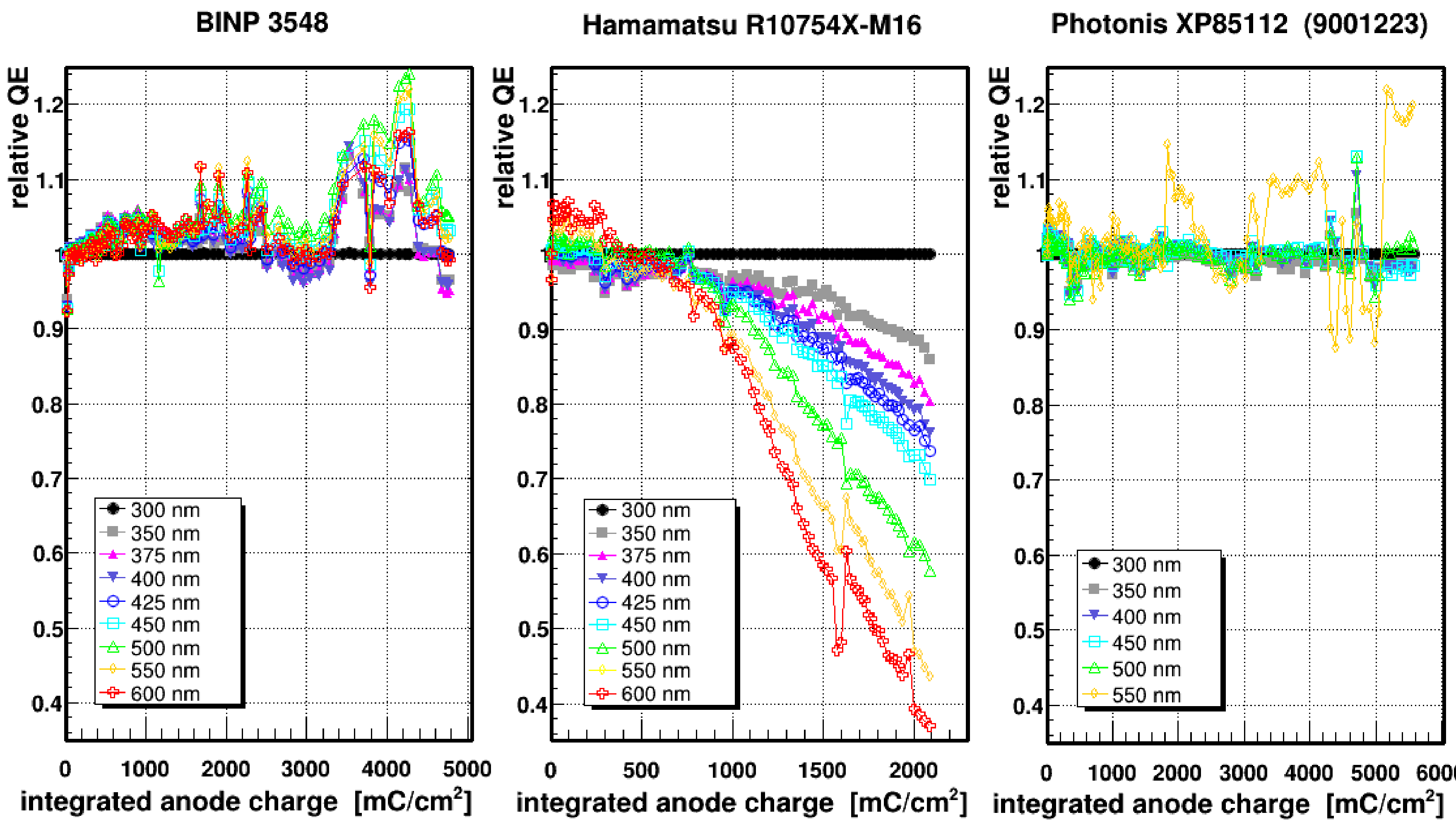


Q.E.(λ) vs. Integral Anode Charge



- Hamamatsu: Q.E. drops significantly above ~1 C/cm^2
- **PHOTONIS: if at all, only moderate Q.E. drop seen**

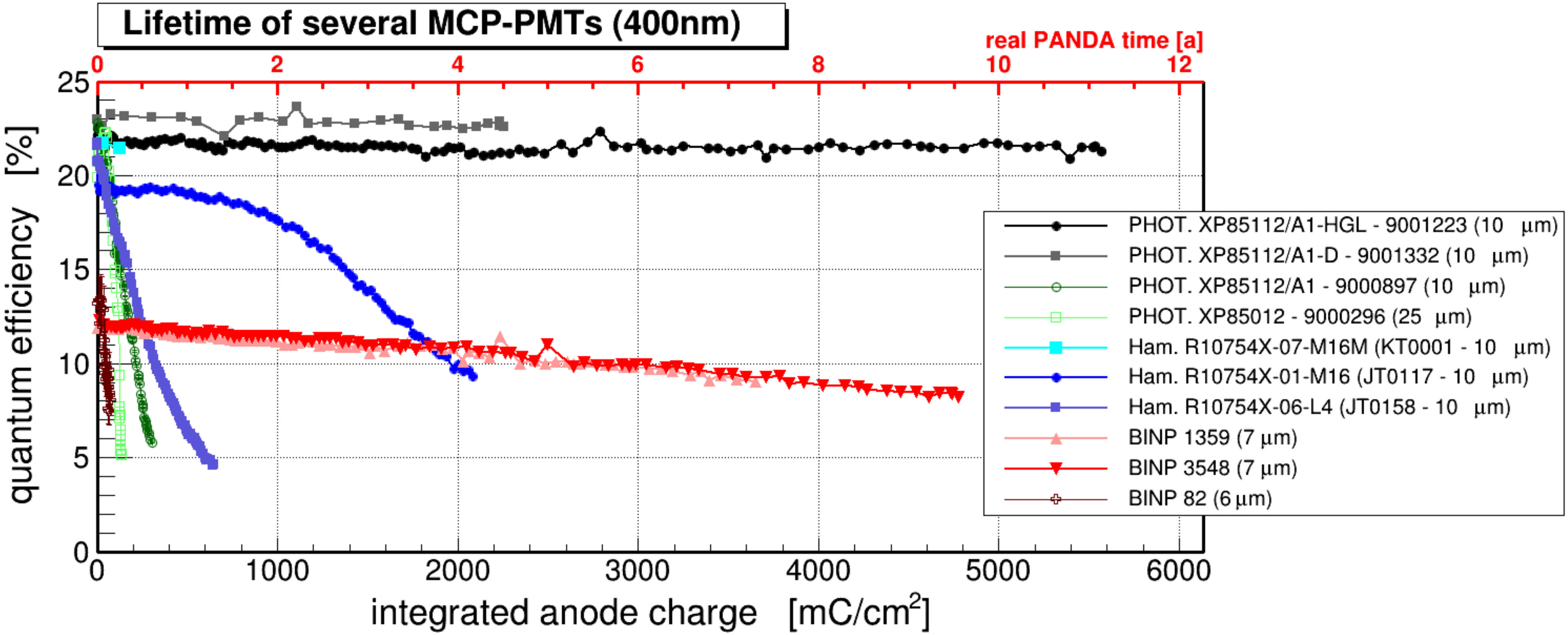
Relative Q.E.(λ) vs. Anode Charge



<u>Ham. R10754X-M16:</u> longer wavelengths drop faster than short ones

<u>BINP 3548 and PHOTONIS XP85112:</u> **no relative Q.E. degradation**

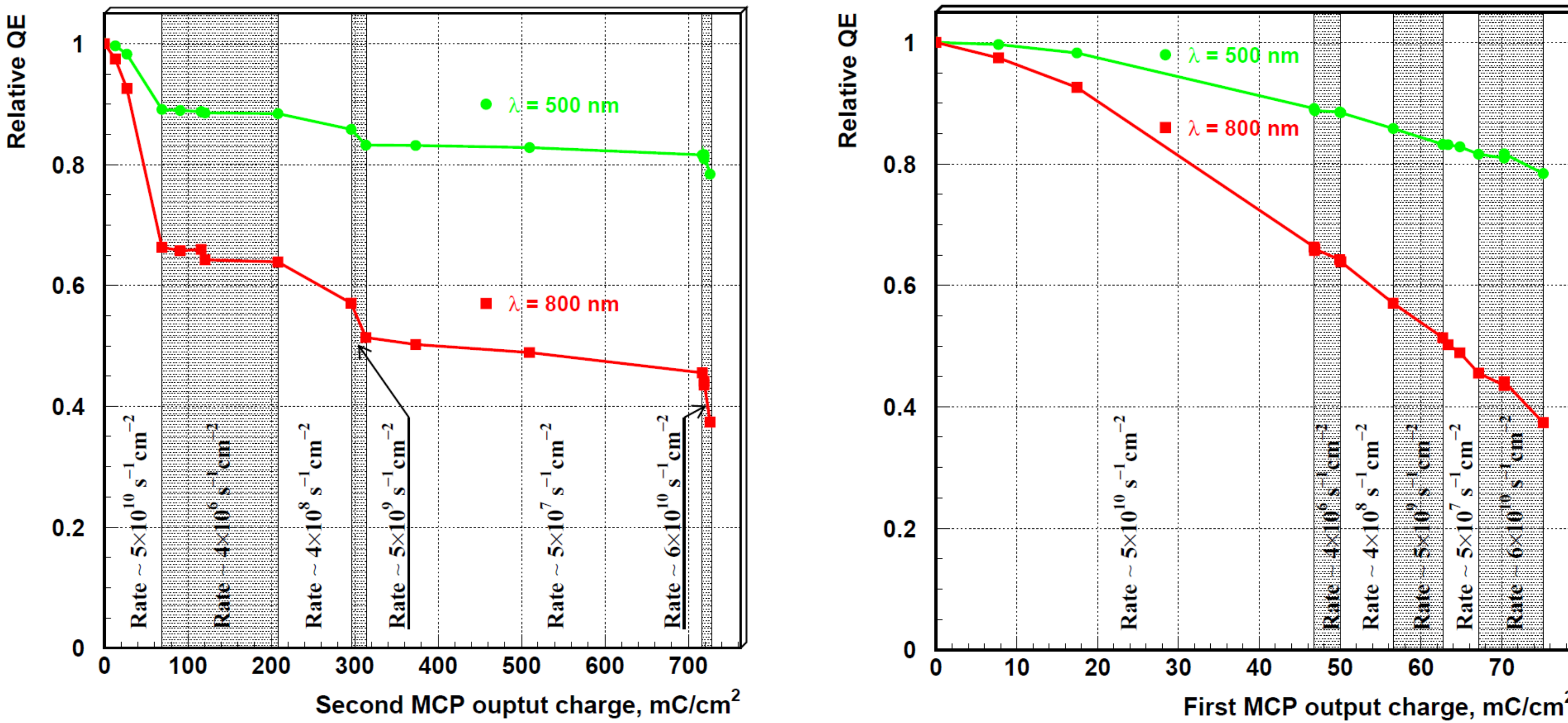
Lifetime of Different MCP-PMTs



- older BINP and PHOTONIS MCP-PMTs: rapid Q.E. degradation
- new PHOTONIS XP85112: **almost no Q.E. drop at 5.6 C/cm^2**

Accelarate Aging Measurements

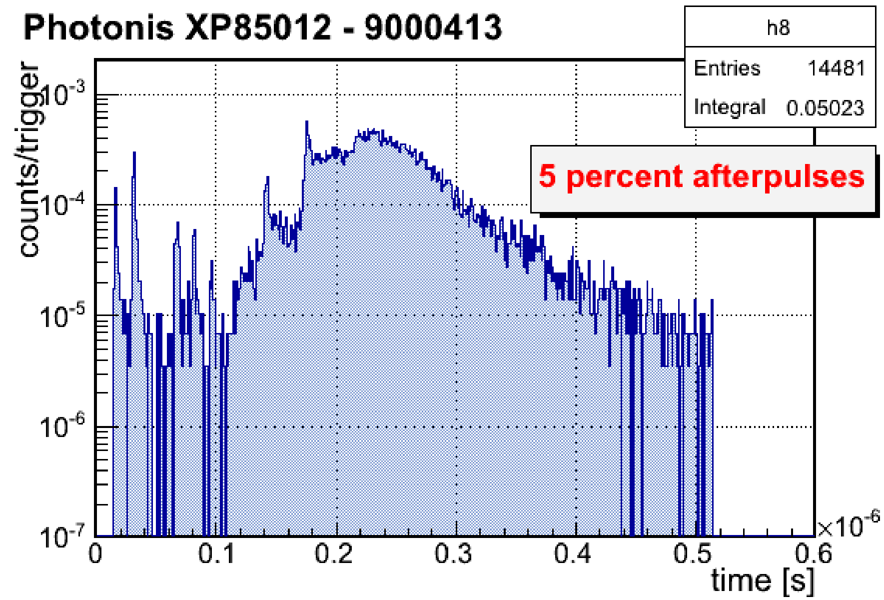
M.Yu. Barnyakov and A.V. Mironov, 2011 JINST 6 C12026

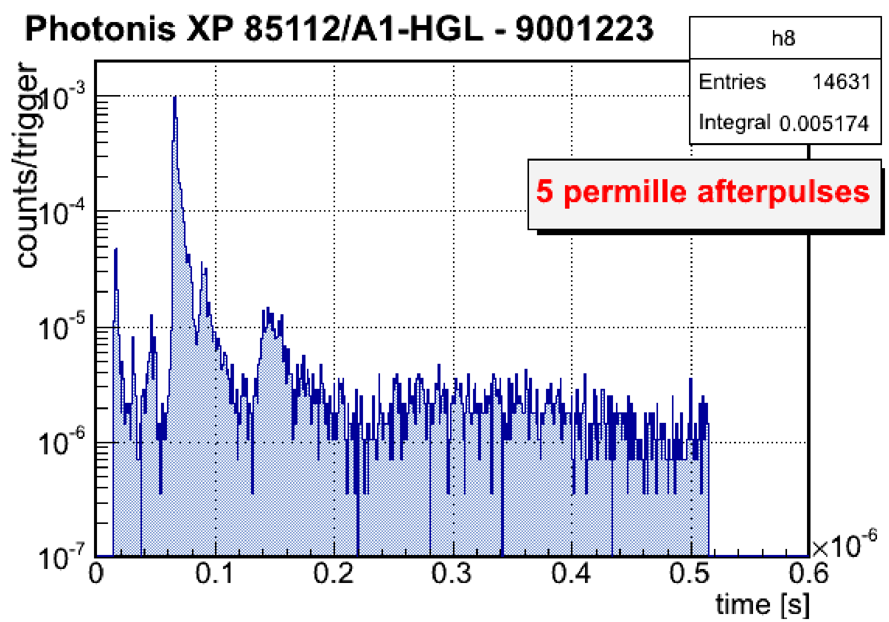


- At 2nd MCP output QE degradation rate depends on count rate
- At 1st MCP no correlation between QE degradation and count rate

Estimate Lifetime from Afterpulsing

- How to guess MCP-lifetime before (and during) aging?
- Measure fraction of pulses (p.e.) followed by an afterpulse (ion)
  - The higher the fraction of afterpulses the higher the amount of restgas inside tube
  - Time delay spectrum may allow to guess the type of ions
- New MCP-PMT with ALD surfaces shows lowest afterpulsing.
- More statistics (= PMTs) needed!



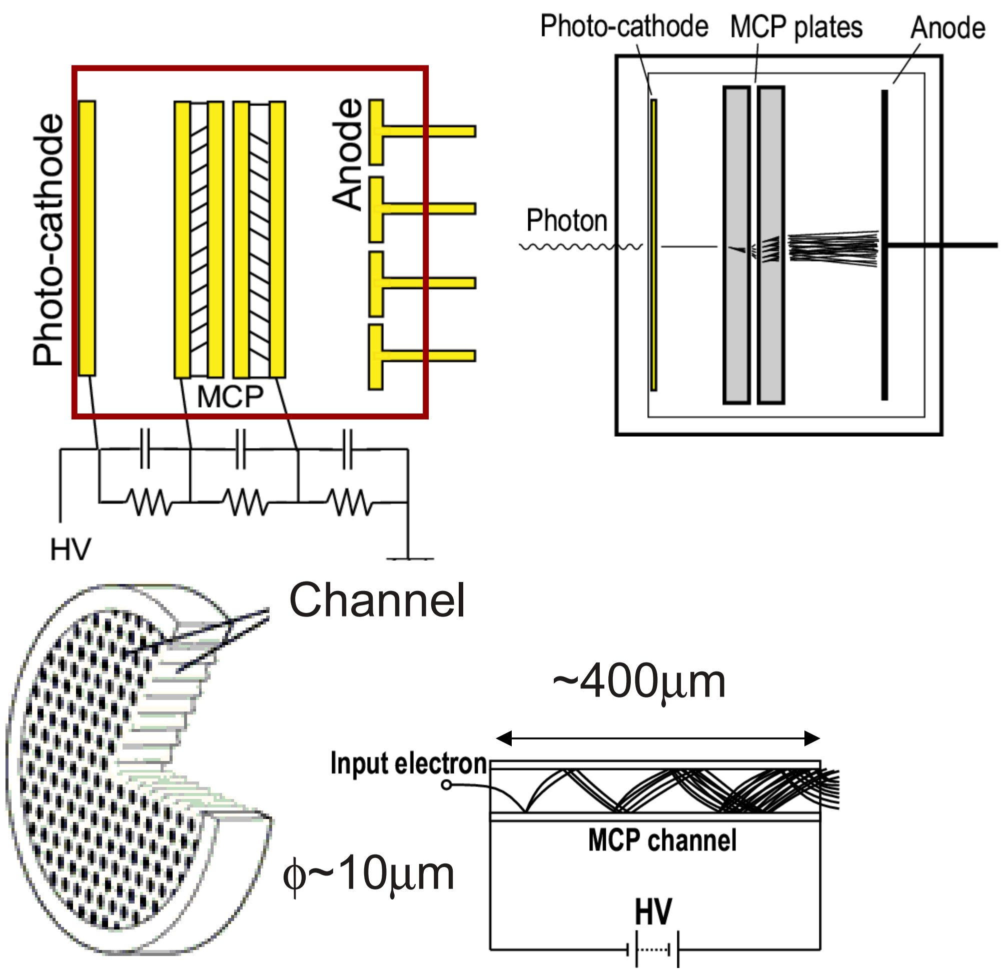


Summary

- Latest MCP-PMT models fulfill most requirements of PANDA DIRC.
- **Significant increase of lifetime of MCP-PMTs** due to the recent improvements in design
  - **huge step forward !**
  - equipping the PANDA DIRCs with MCP-PMTs seems possible
- **ALD technique appears very promising (reached ~6 C/cm^2)**
- Further improvements could possibly come from
  - modified photo cathodes (see BINP)
  - MCP materials with less outgassing
    (e.g., borsilicate glass instead of lead glass)

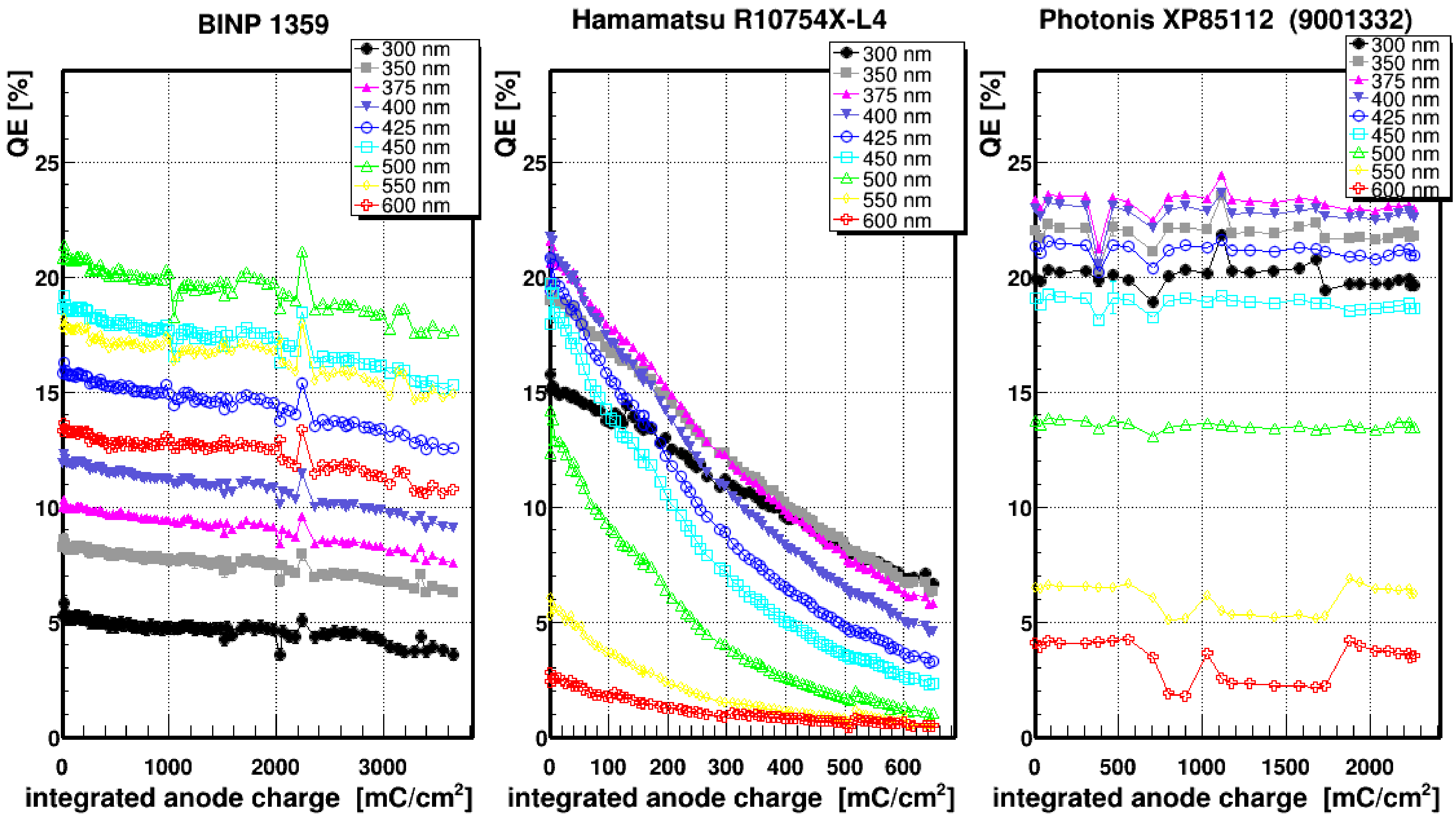
Microchannel-Plate PMT

electron multiplication in glass capillaries ($\varnothing \approx$ 10-25 μm)



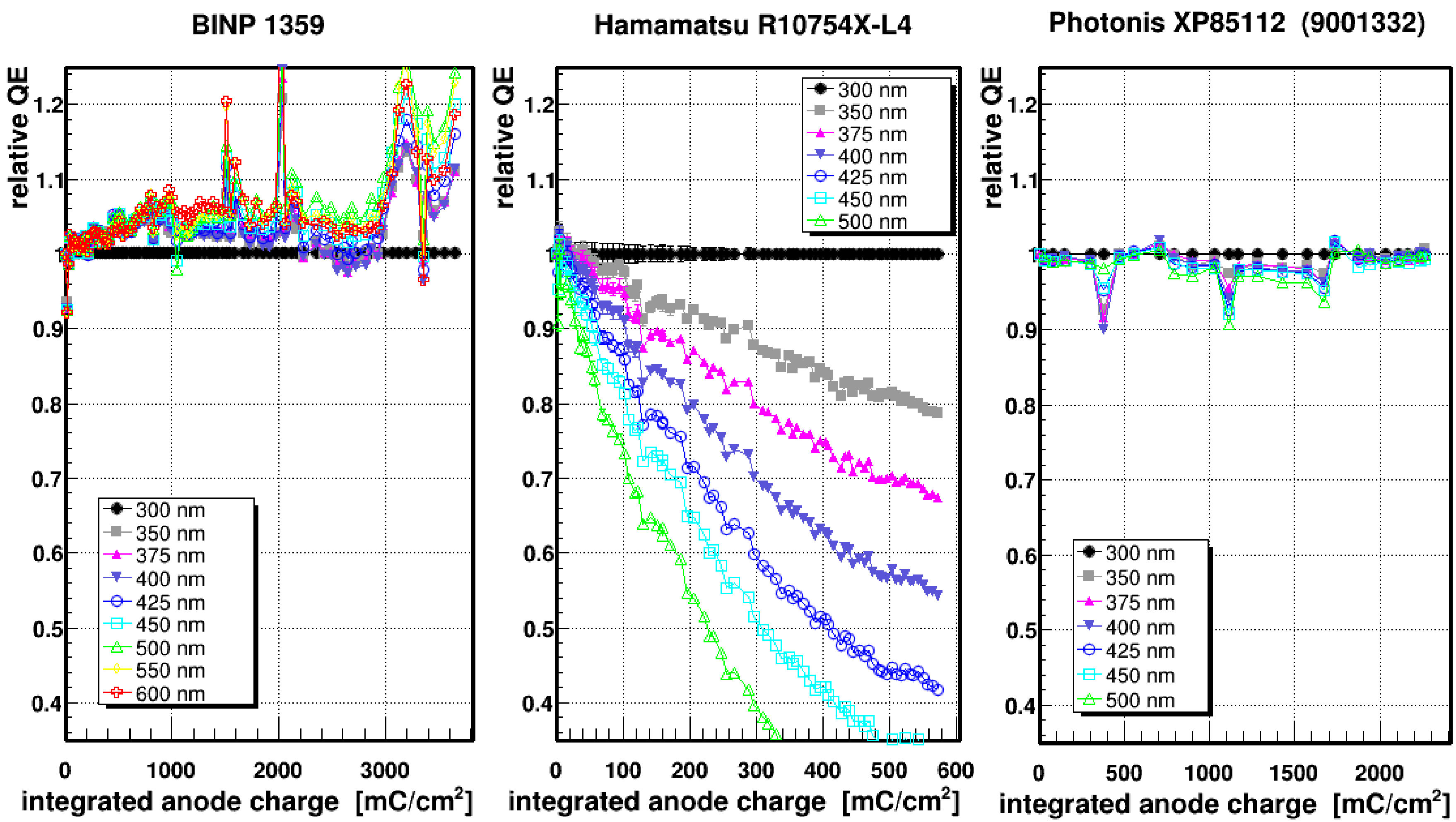
- usable in high magnetic fields
- high gain:
  - $>10^6$ with 2 MCP stages
  - single photon sensitivity
- very fast time response:
  - signal rise time = 0.3 – 1.0 ns
  - TTS < 50 ps
- low dark count rate
- quantum efficiency comparable to that of standard vacuum PMTs
- multi-anode PMTs available
- caveats:
  - lifetime (QE drops)
  - price

Q.E.(λ) vs. Integral Anode Charge



- Hamamatsu: tube was damaged before illumination
- **PHOTONIS: no Q.E. drop seen**

Relative Q.E.(λ) vs. Anode Charge



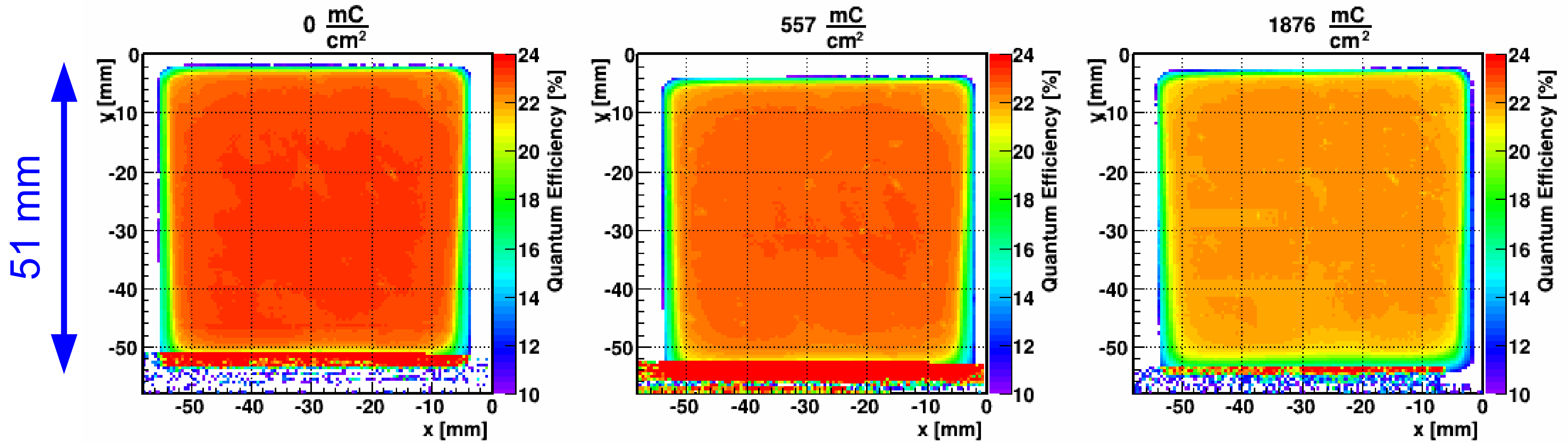
Ham. R10754X-L4: longer wavelengths drop faster than short ones

BINP 1359 and PHOTONIS XP85112: **no relative Q.E. degradation**

Q.E. Scans (Photonis XP85112)

9001332

Q.E. measured at 372 nm



Q.E. Scans (Hamamatsu R10754X-M16M)

Q.E. measured at 372 nm