Systematic Studies of Microchannel Plate PMTs

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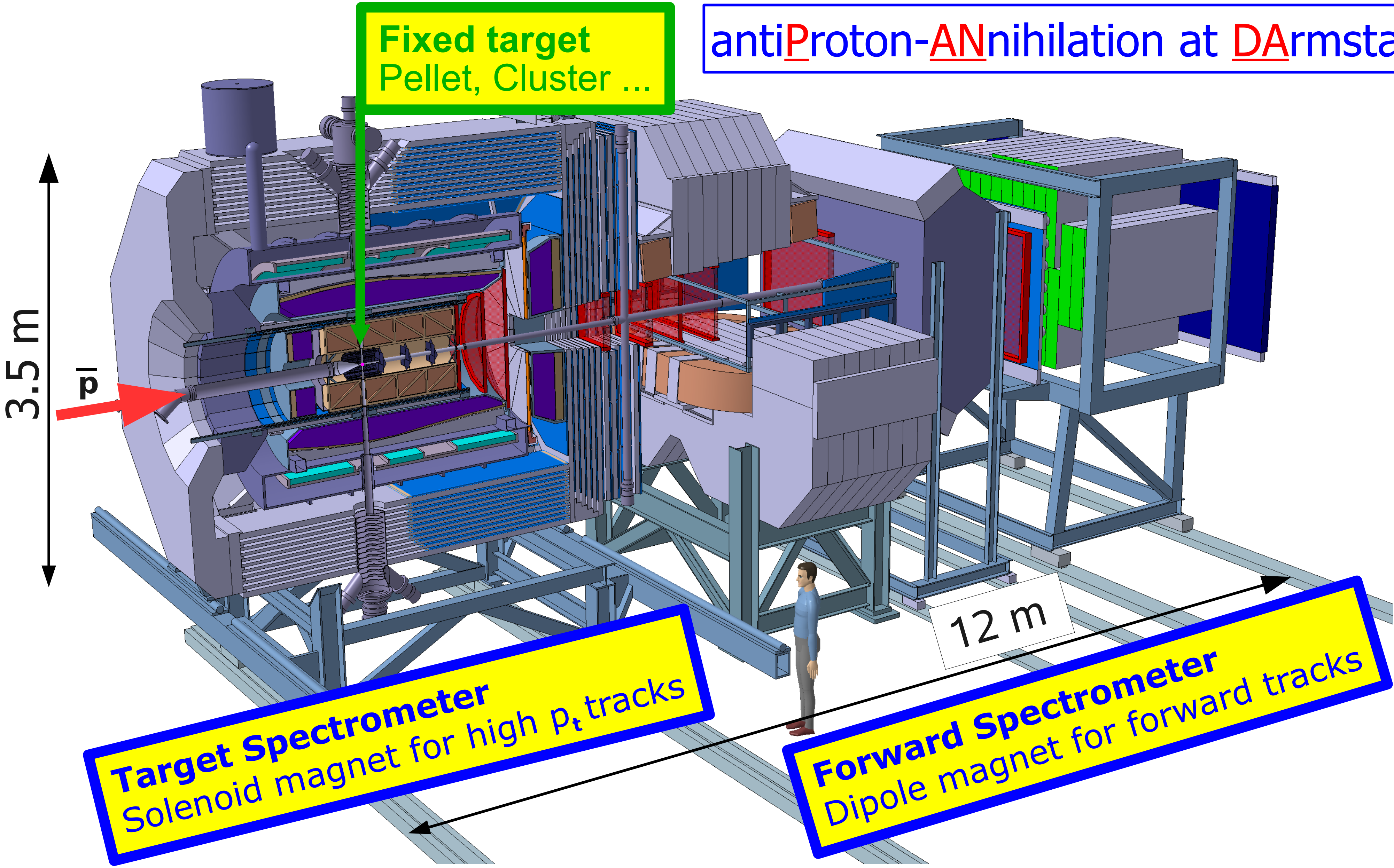
on behalf of the PANDA Cherenkov group

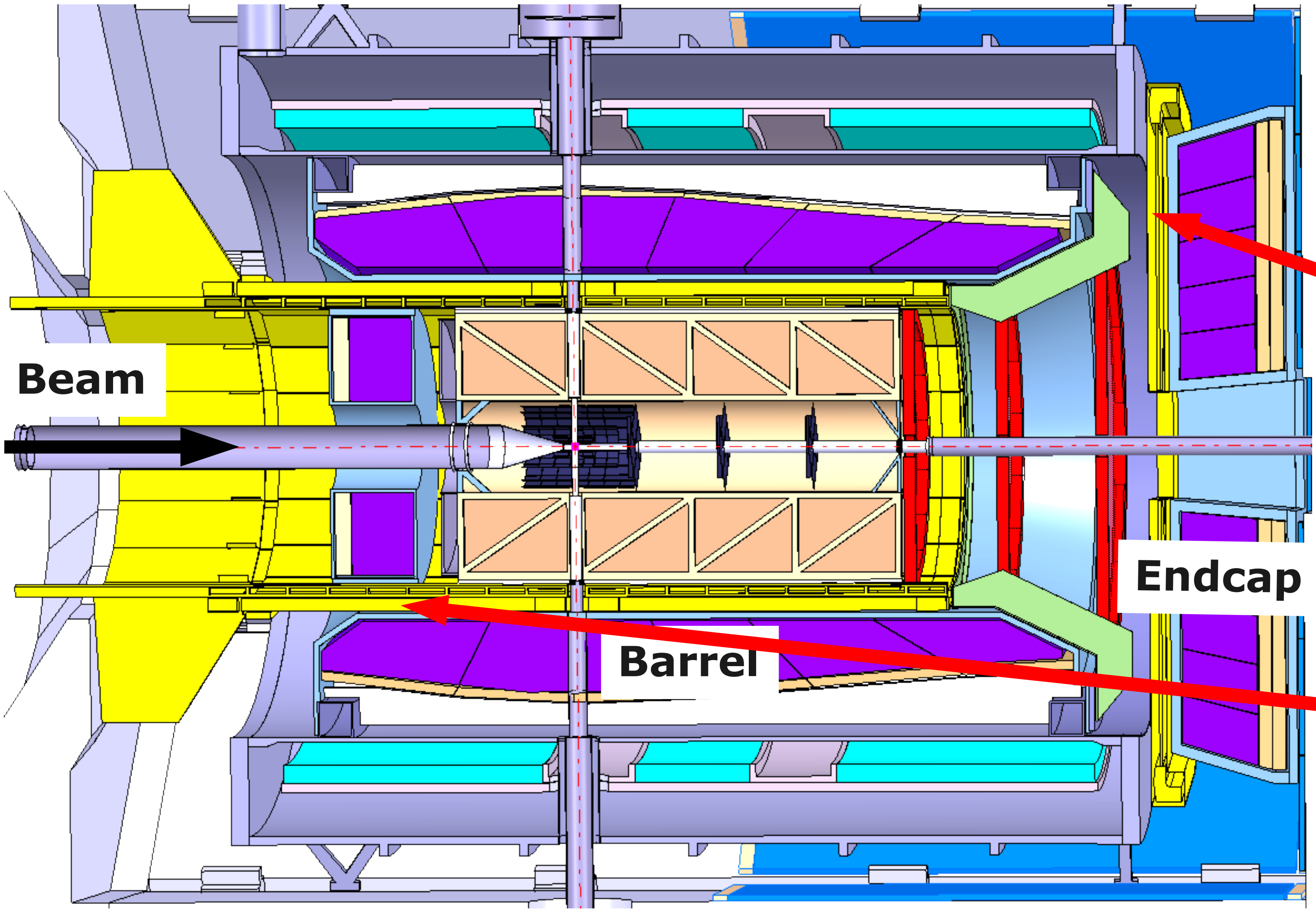
- Motivation
- Experiences with various MCP-PMTs
  - dark count
  - behaviour in magnetic fields
  - time resolution
  - gain variation of pixels and crosstalk
  - rate stability
  - lifetime

PANDA Detector

antiProton-ANnihilation at DArmstadt



Cherenkov Detectors



Overview Talk, Carsten Schwarz

20 MHz
$\bar{p}$-p annihilations

All image planes inside a magnetic field of 1-2 Tesla

Challenges to Photon Sensors

- 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 stability** (rates of several MHz/cm^2)
  - **long lifetime**

Sensor Candidates

good geometrical resolution over a large surface needed
→ **multi-pixel sensors**

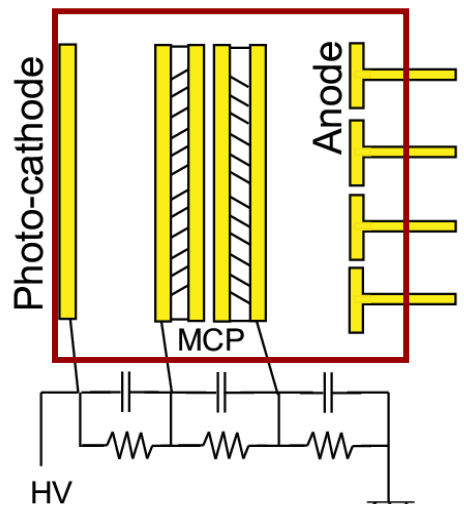
- multi-anode photomultipliers (MaPMTs)
  - (more or less) ruled out by magnetic field
- Geiger-mode avalanche photo diodes (SiPMs)
  - huge noise is very problematic
- **micro-channel plate photomultipliers** (MCP-PMTs)
  - main problems are lifetime and rate stability
- others?

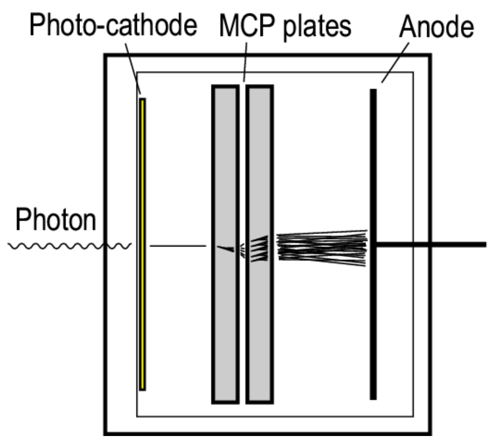
Poster,
Johann Marton

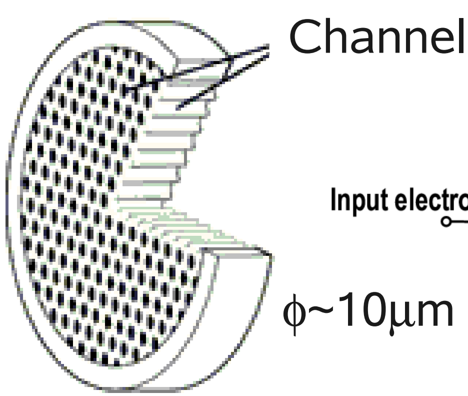
There is not yet an ideal sensor for the PANDA DIRCs !

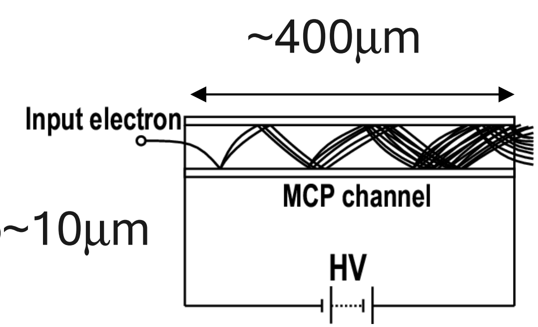
Microchannel Plate PMT

electron multiplication in glass capillaries (∅ ≈ 10-25 μm)





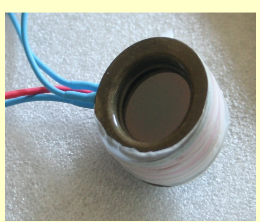
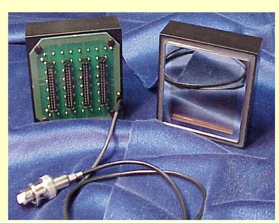
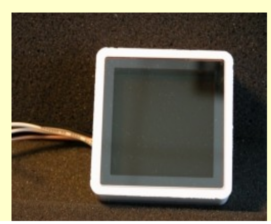




- very fast time response:
  - signal rise time = 0.3 – 1.0 ns
  - TTS < 50 ps
- high gain:
  - $>10^6$ with 2 MCP stages
  - single photon sensitivity
- usable in high magnetic fields
- low dark count rate
- quantum efficiency comparable to that of standard vacuum PMTs
- multi-anode PMTs possible
-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

Investigated MCP-PMTs

	BINP		Burle-Photonis			Hamamatsu
		XP85011	Prototype	XP85013	XP85012	R10754-00-L4
pore size (μm)	6 or 8	25	10	25	25	10
number of pixels	1	8x8	8x8	8x8	8x8	4x1
active area (mm²)	9^2 π	51x51	51x51	53x53	53x53	22x22
total area (mm²)	15.5^2 π	71x71	69.5x69.5	59x59	59x59	27.5x27.5
geom. efficiency (%)	36	52	54	81	**81**	61
peak Q.E.	22% @ 480 nm	--	--	--	21% @ 380 nm	20% @ 300 nm
comments	5-10 nm Al_2O_3 protection layer	--	--	larger active area ratio	better vacuum, polished surfaces	protection layer planned

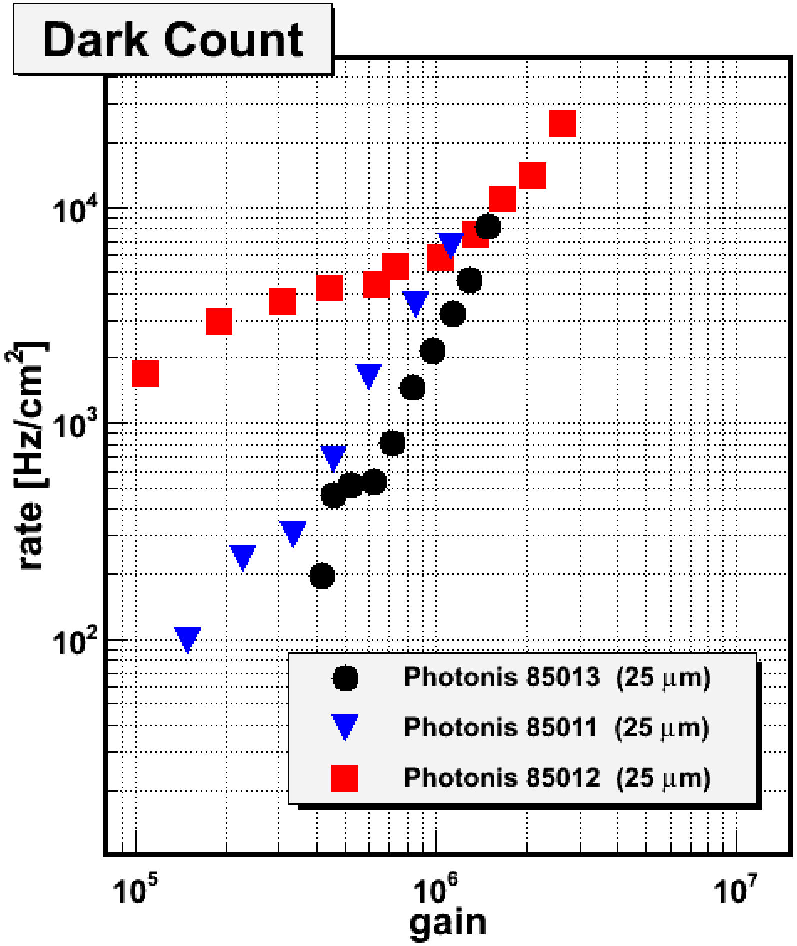

- this work: comparison of several identical models of MCP-PMTs
  - 3x BINP, 3x Photonis XP85012 and 4x Hamamatsu R10754-00-L4

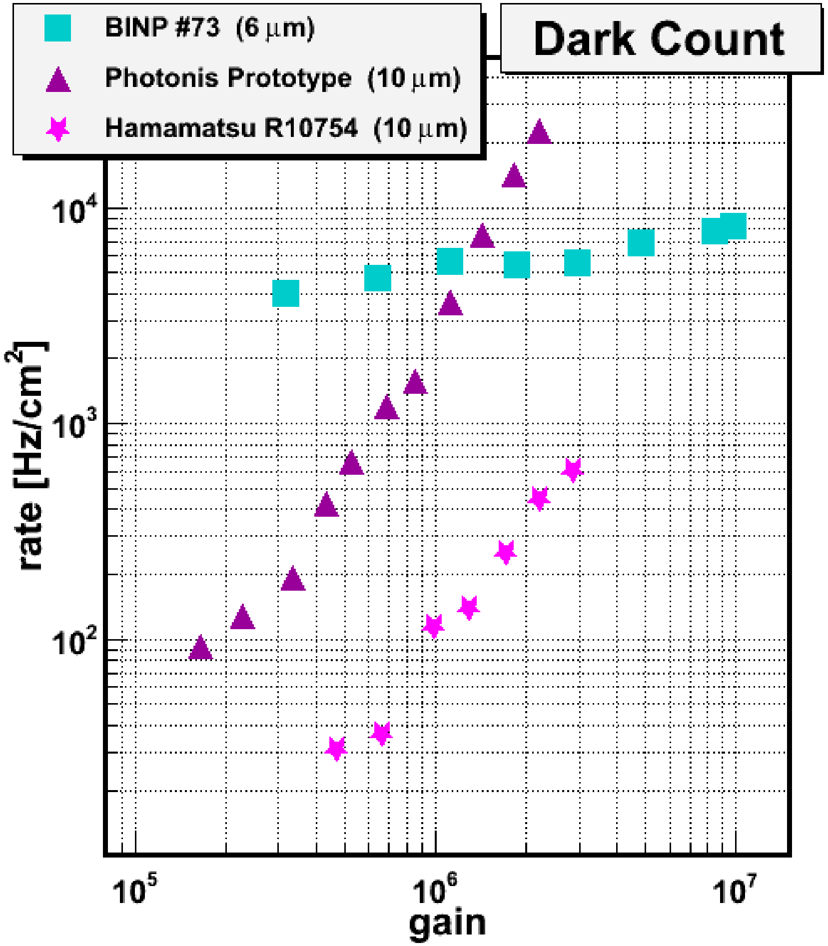
Tools for MCP-PMT Studies

- Light source
  - PiLas light pulser (pulse width 14 ps (σ); λ = 372 nm)
  - light transport through glass fibers, micro lenses and gray filters
- Fast oscilloscope
  - LeCroy WavePro7300 (3 GHz; 20 Gs/s)
  - very useful for precise time resolution measurements
- Dipole magnet
  - homogeneous field up to 2.2 T (6 cm pole shoe gap)
- XY-Scanner
- Setup for quantum efficiency measurements
  - halogen lamp (λ = 300-800 nm) and monochromator (Δλ = 1 nm)
  - Si photo diode as reference sensor (Hamamatsu S6337-01)

Dark Count Rates of MCP-PMTs

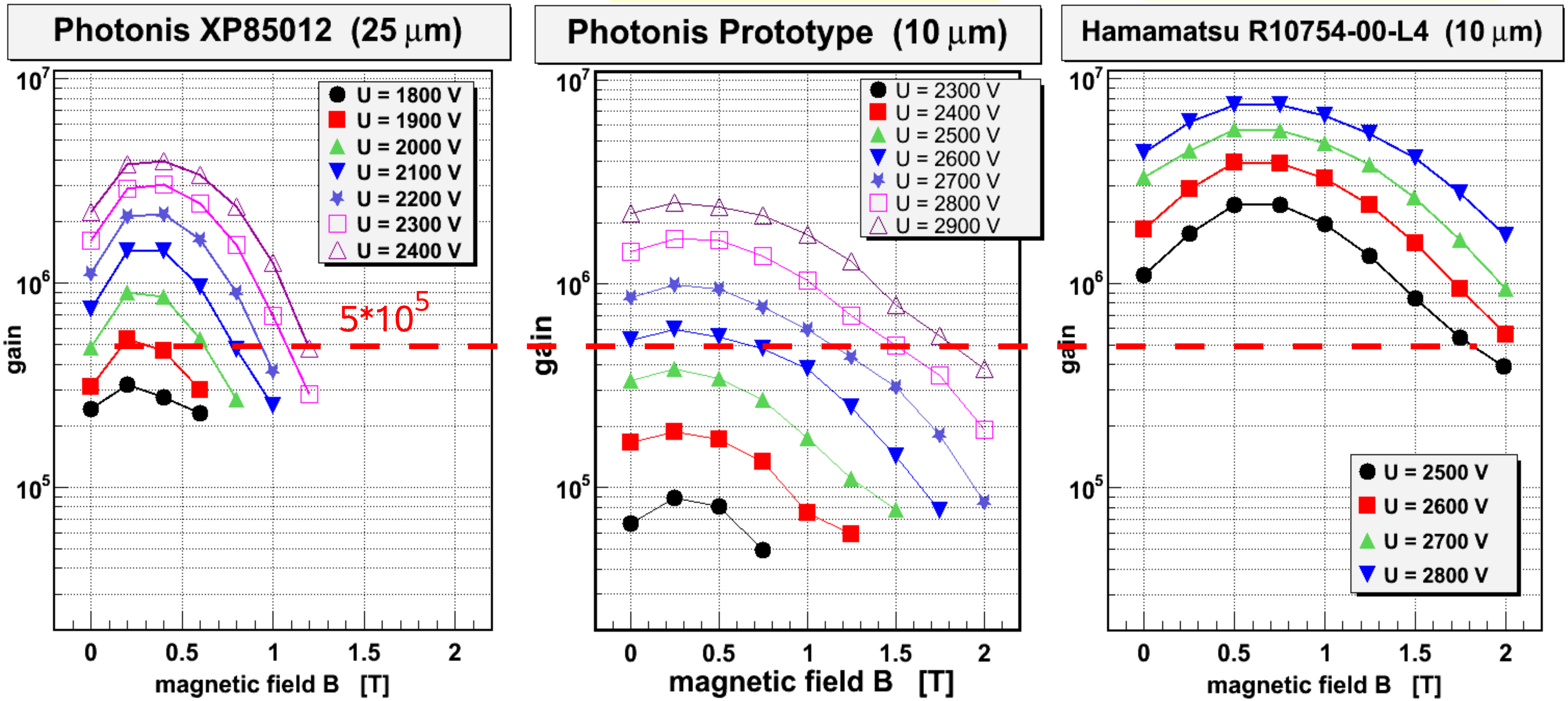
- Typical dark count rate: ~5 kHz/cm^2 at 10^6 gain
- Hamamatsu R10754 with much lower rate: ~100 Hz/cm^2





Gain in Magnetic Field

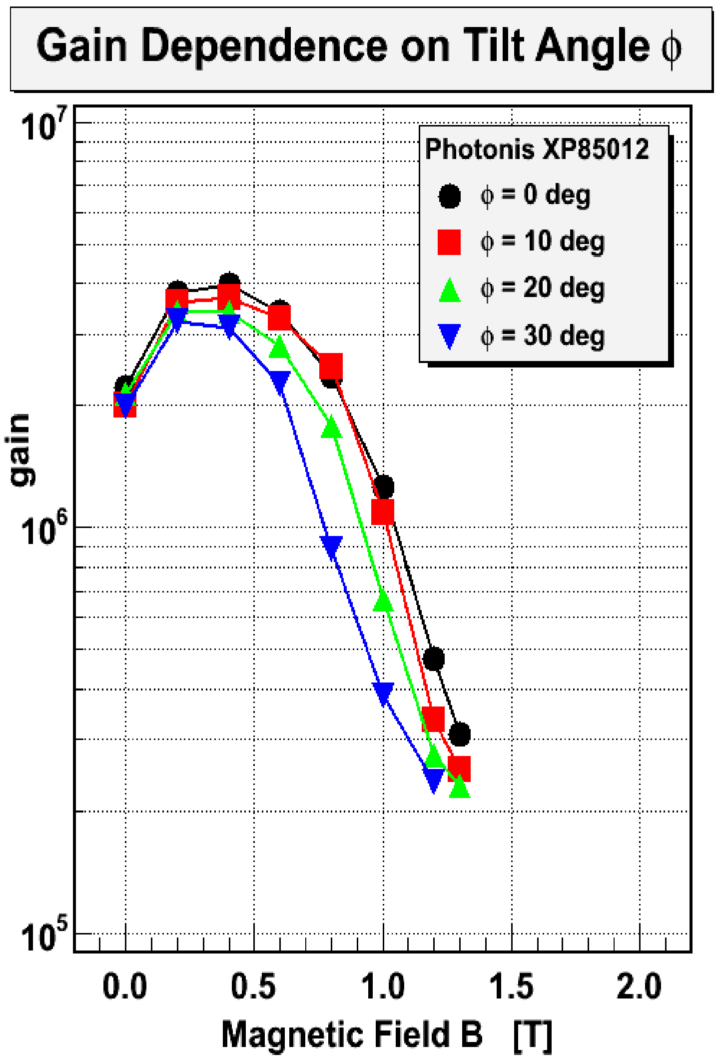
XP85012 (25 µm) | Prototype (10 µm) | R10754 (10 µm)

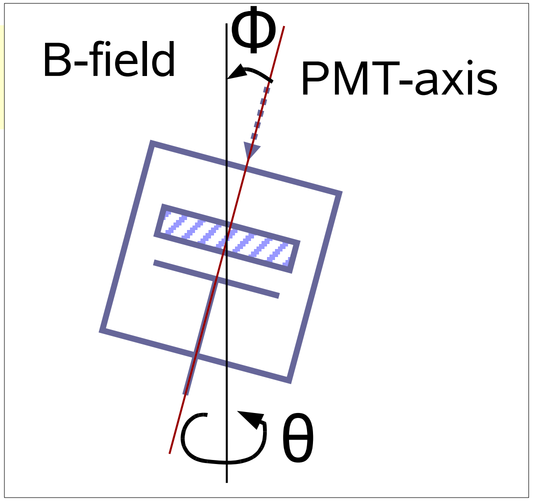


- 25 µm MCP gain breaks down at ~1 T → marginal for Barrel DIRC
- 10 µm MCPs will be suitable for both Endcap and Barrel DIRC

Gain and Direction of B-Field (Φ)

Photonis XP85012 (25 μm)



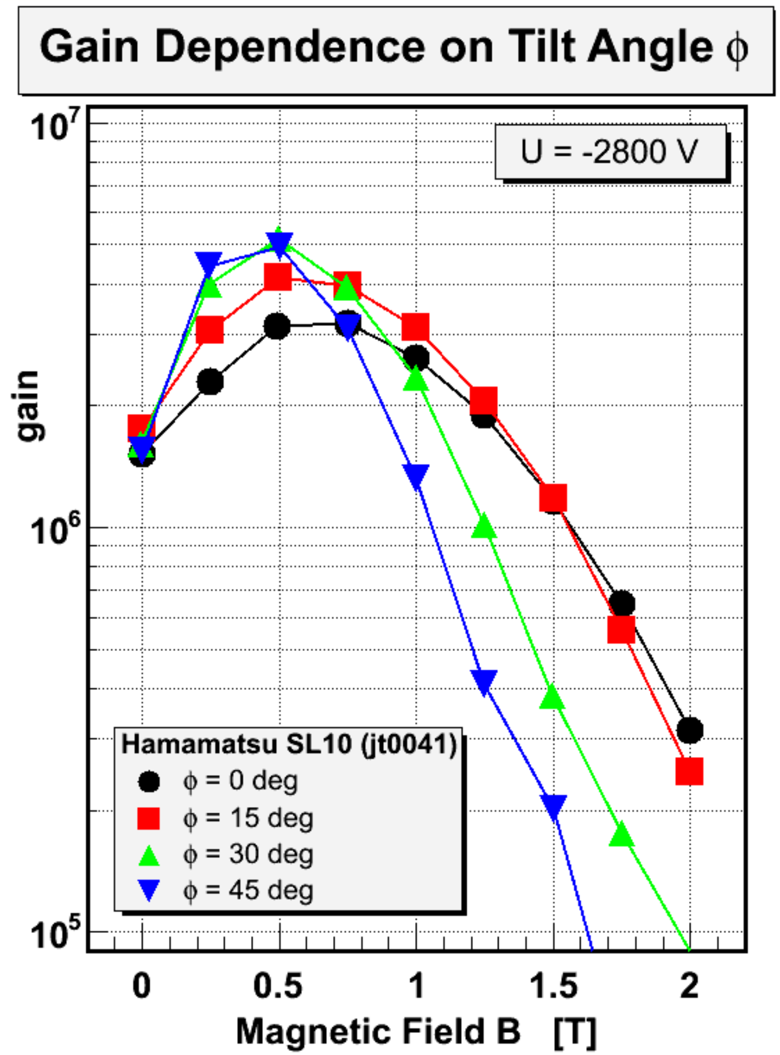


ϕ = tilt angle between B-field direction and PMT-axis

θ = rotation angle of PMT around B-field direction

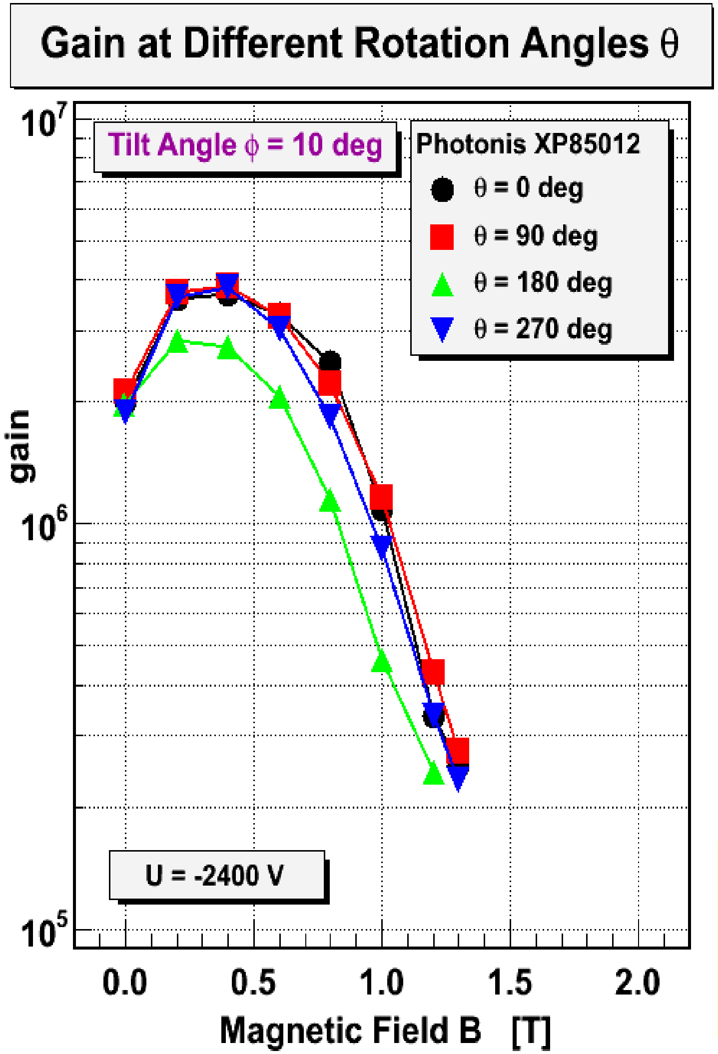
Significant gain loss at high B-field and large ϕ-angles

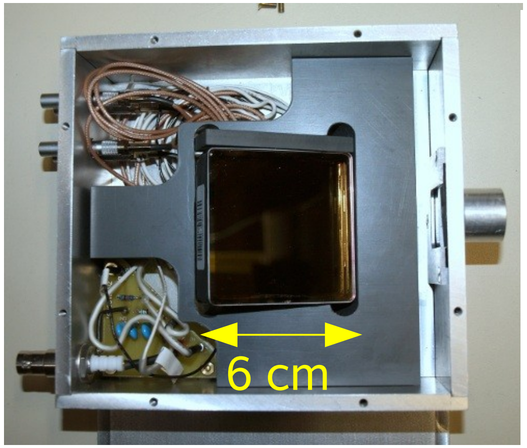
Hamamatsu R10754 (10 μm)



Gain and Direction of B-Field (θ)

Photonis XP85012 (25 μm)

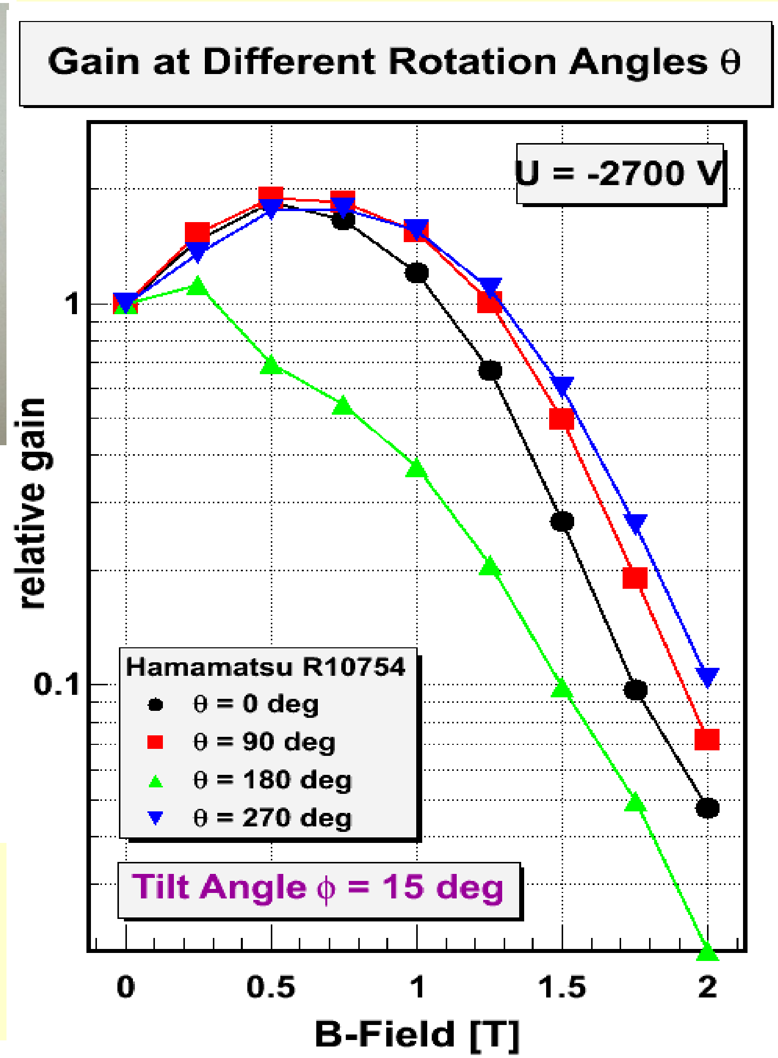




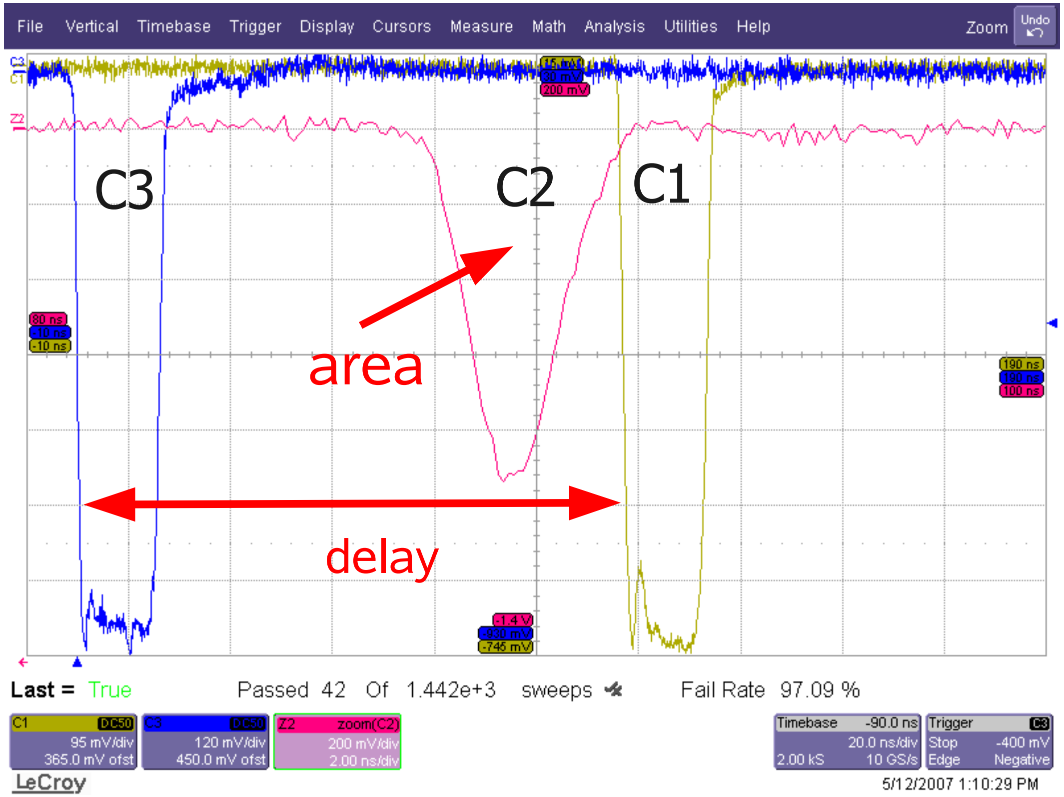
PMTs built with some ferromagnetic material → rotation and tilting of PMT inside B-field with special inserts in alubox

gain slope changes rapidly when pores point along B-field

Hamamatsu R10754 (10 μm)

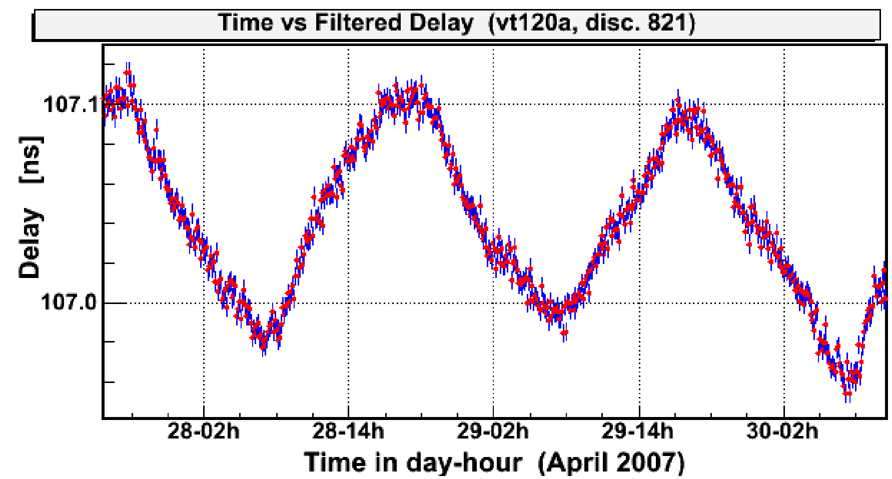


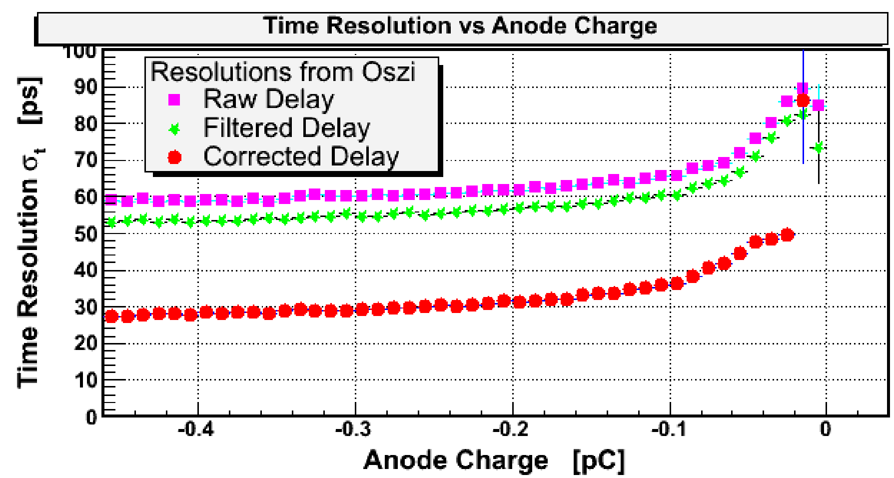
Time Resolution Measurements



- 3 GHz / 20 Gs oscilloscope
- measure area (C2)
- measure delay of PiLas reference pulse C3 to MCP pulse C1
  $\Rightarrow$ jitter $\equiv$ time resolution

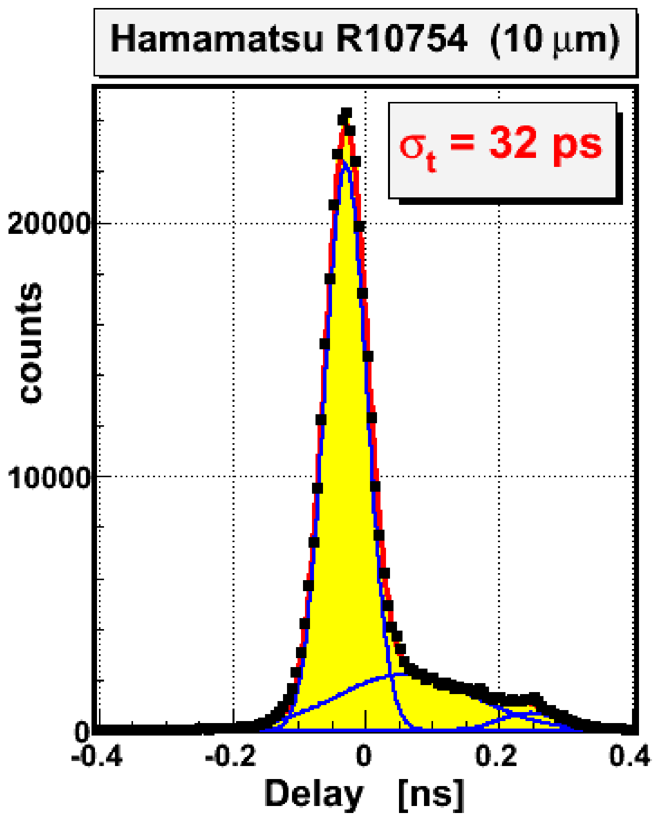
- timewalk to be corrected for
  - sampling noise of oszilloscope
  - longterm drifts in delay

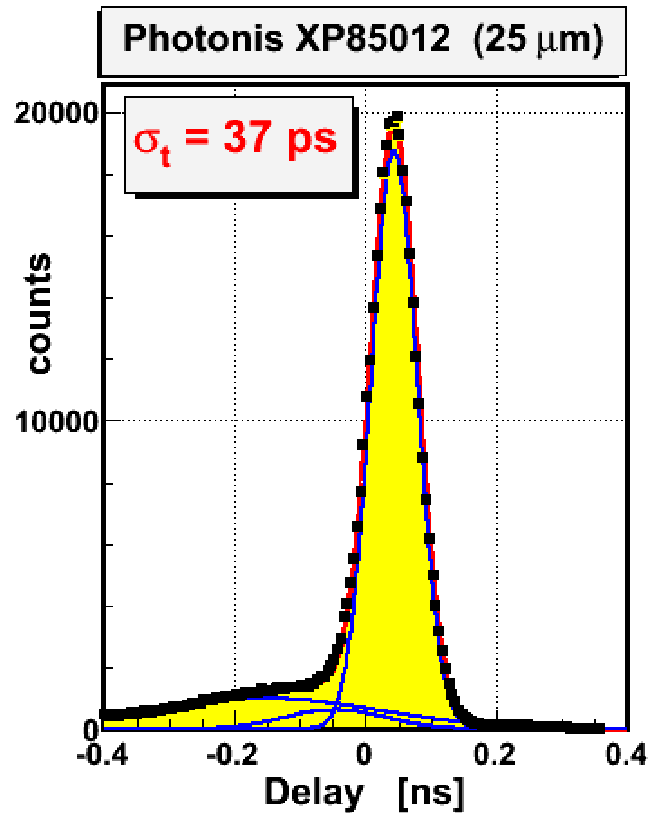


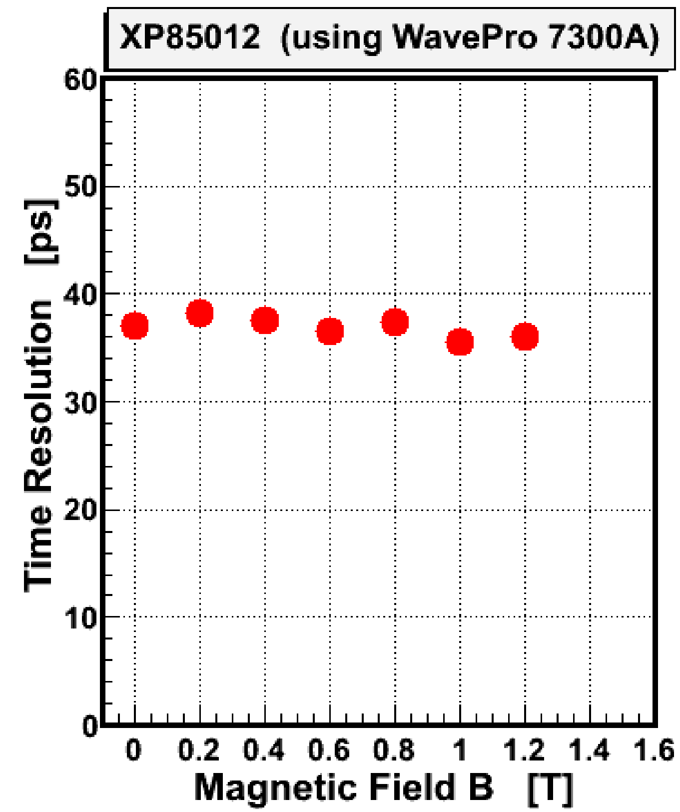


Single Photon Time Resolution

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





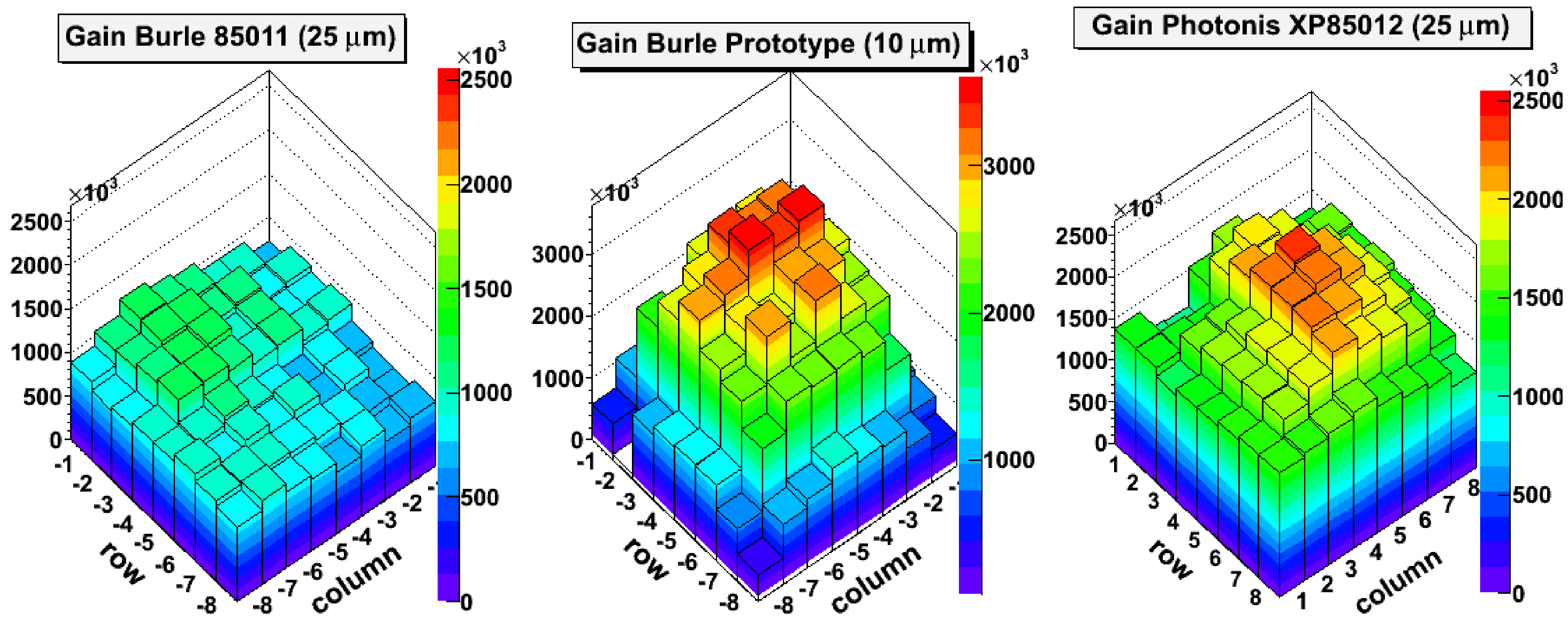


BINP	Photonis				Hamamatsu
#73	XP85011	XP85012	XP85013	Prototype	R10754
6 μm	25 μm	25 μm	25 μm	10 μm	10 μm
27 ps	**49 ps**	**37 ps**	**51 ps**	**41 ps**	**32 ps**

- time resolution of all MCPs 50 ps and better
- **no dependence on the B-field**

Gain of Photonis MCP-PMTs

- **factor 2 gain variations** between pixels of 25 μm MCPs
- large gain fluctuations in 10 μm MCP (prototype)



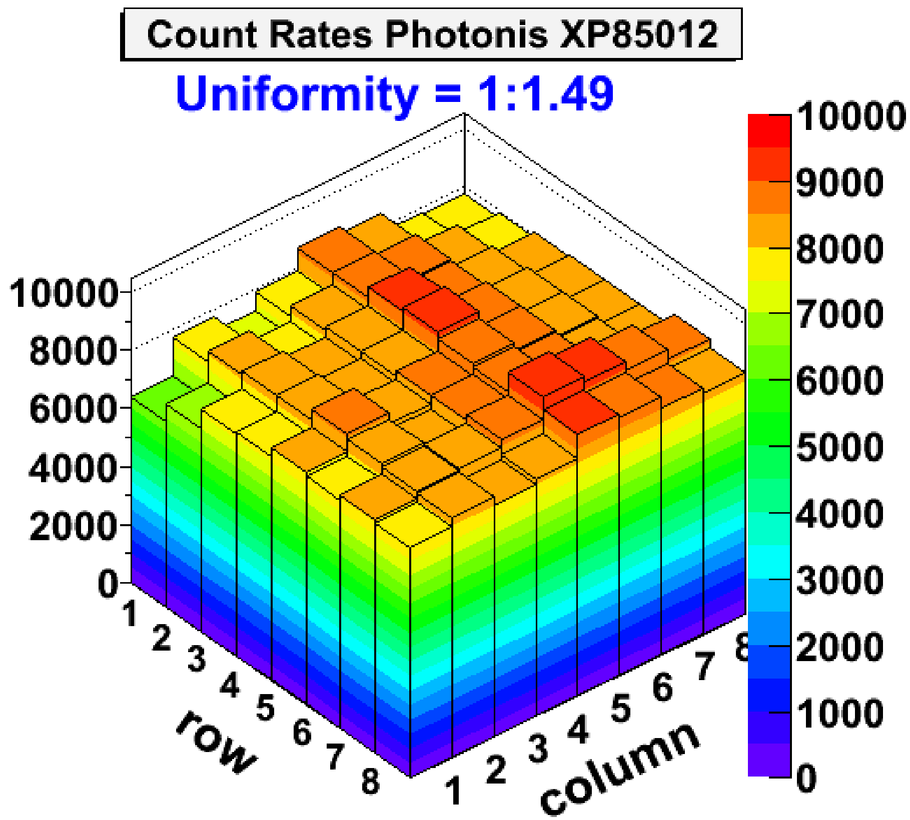
Uniformity = 1:1.87

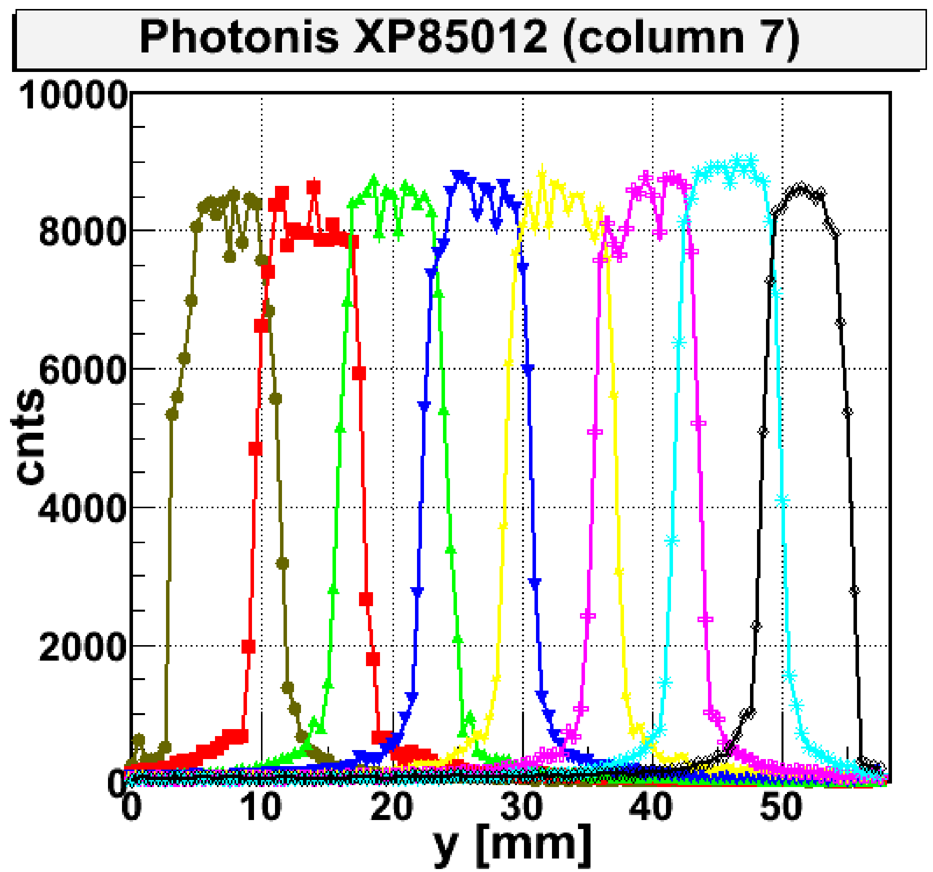
Uniformity = 1:8.07

Uniformity = 1:2.20

Homogeneity and Crosstalk of Photonis XP85012

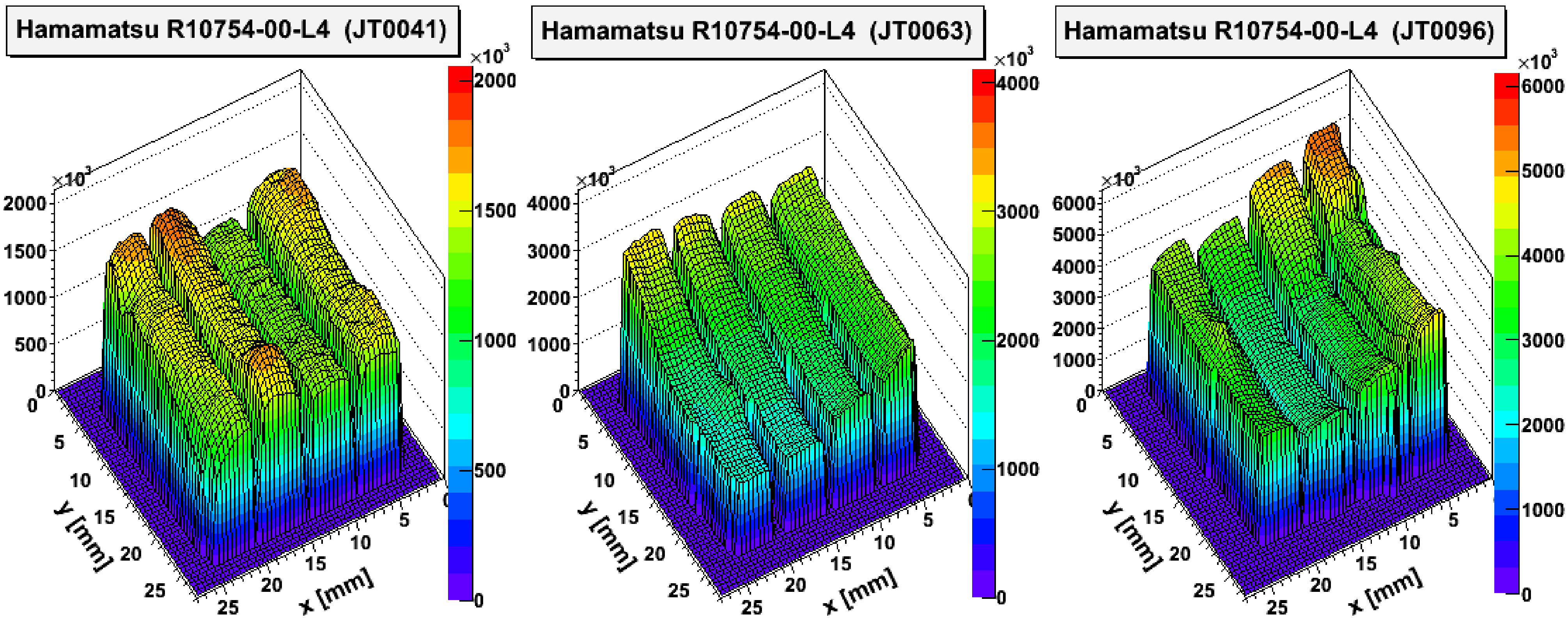
- fairly flat response with **factor 1.5 variations** between pixels
- crosstalk is clearly visible but appears managable



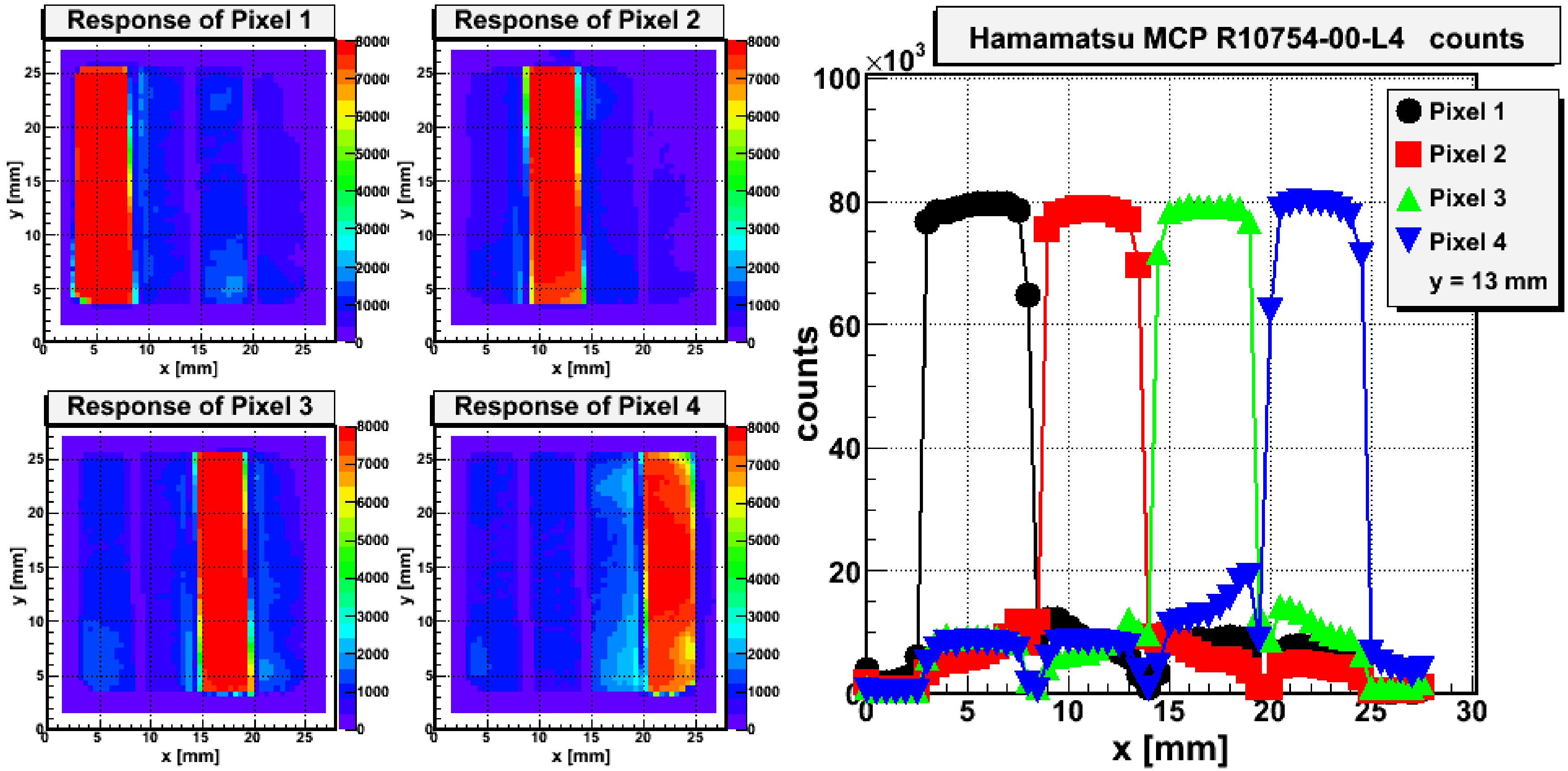


Gain of Hamamatsu MCP-PMTs

- gain variations of factor 2 even within the same pixel
- rather different gain behaviour for each of the MCP models

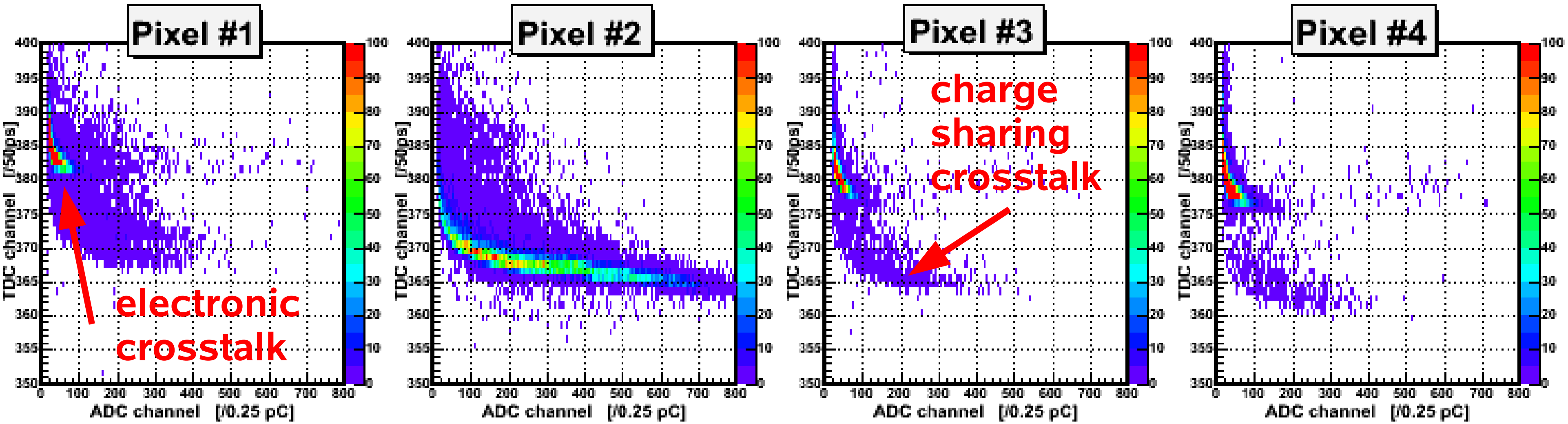


Homogeneity and Crosstalk of Hamamatsu R10754-00-L4

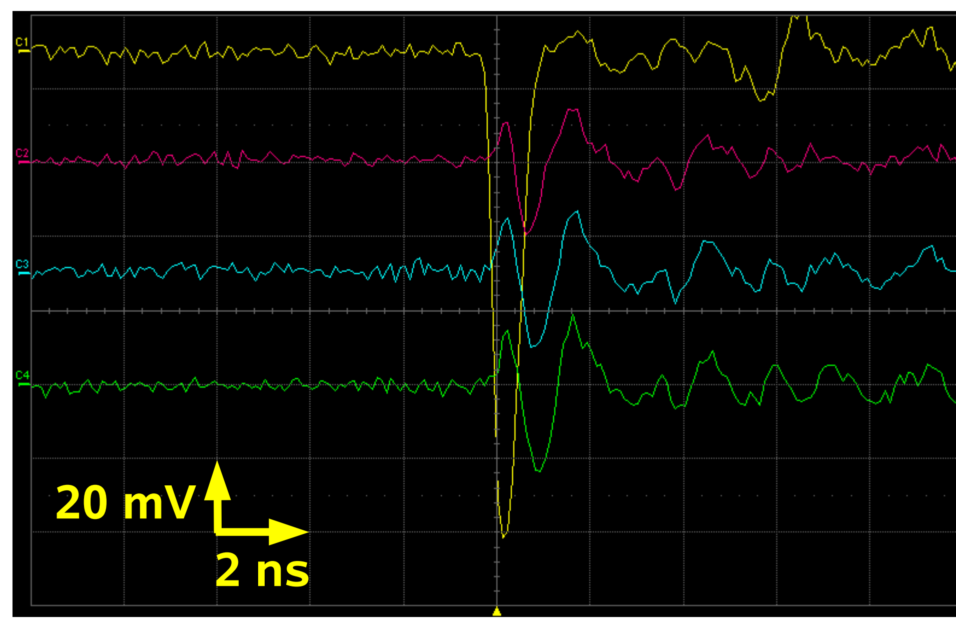


- very **homogeneous response** of the individual channels
- significant **crosstalk** between the channels: can it be reduced?

Crosstalk of Hamamatsu R10754



- two components in timewalk distributions
  - crosstalk from charge sharing
  - electronic crosstalk
- components separated in time
- electronic crosstalk from both voltage divider and MCP-PMT



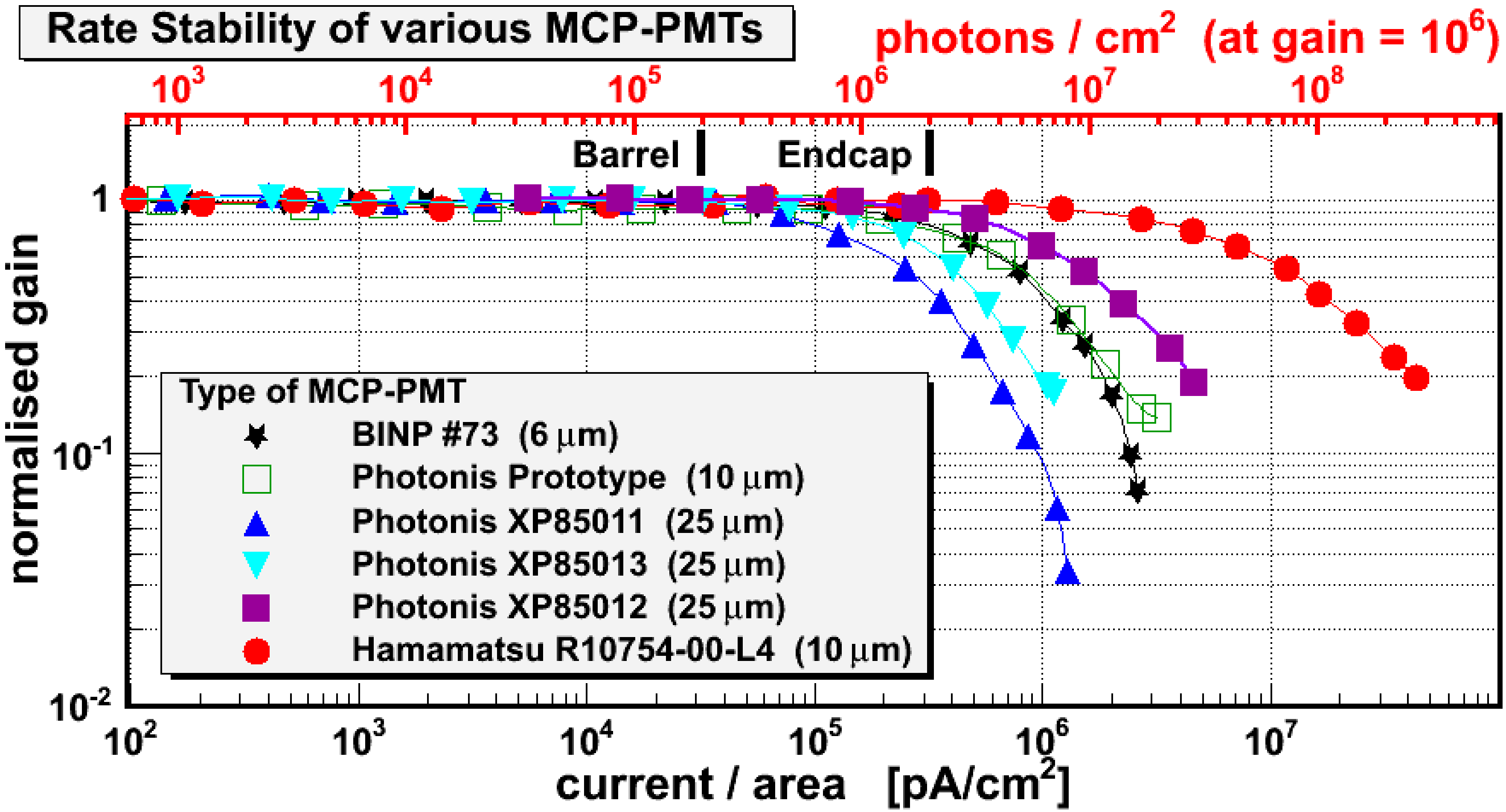
Rate and Charge Estimates

- **rate stability and lifetime are the most critical issues** for the application of MCP-PMTs in high-rate particle physics experiments
- expected rates and anode charges of the PANDA DIRCs:

	total rate	anode rate (after Q.E.)	integrated anode charge
	[MHz/cm^2]	[MHz/cm^2]	[C/cm^2/year] at 10^6 gain
Barrel DIRC			
at end of radiator	*60*	*5.6*	*28*
at readout plane	1.7	**0.16**	**0.8**
Endcap DIRC			
TOP	19	**1.9**	**9.6**
focussing	7.5	**0.76**	**3.8**

- Endcap DIRC with 5-10x higher photon rate than Barrel DIRC → very challenging

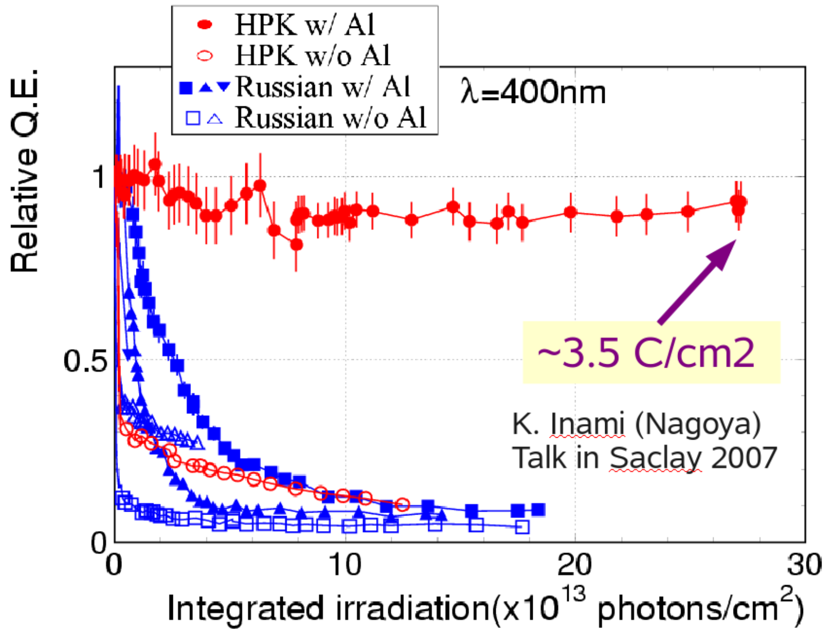
Rate Stability

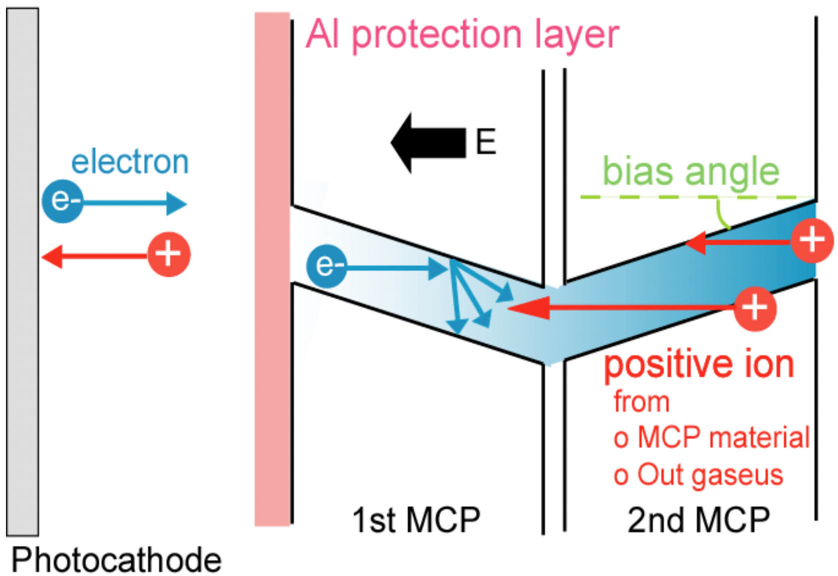


- most MCP-PMTs show stable operation to ~200-300 kHz/cm^2 single photons (at gain 10^6)
- R10754 and XP85012 seem suitable for both PANDA DIRCs

Approaches to Increase Lifetime

- Protection layer (BINP and Hamamatsu)



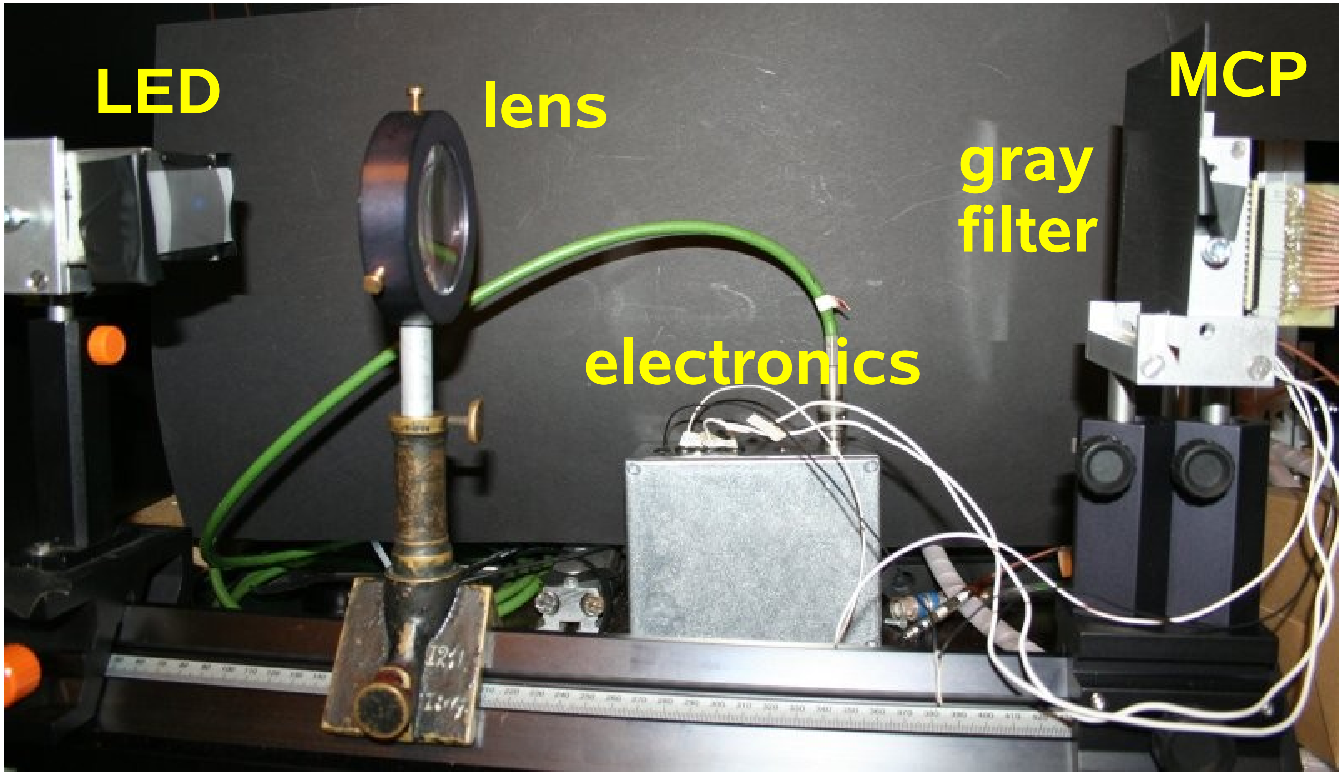


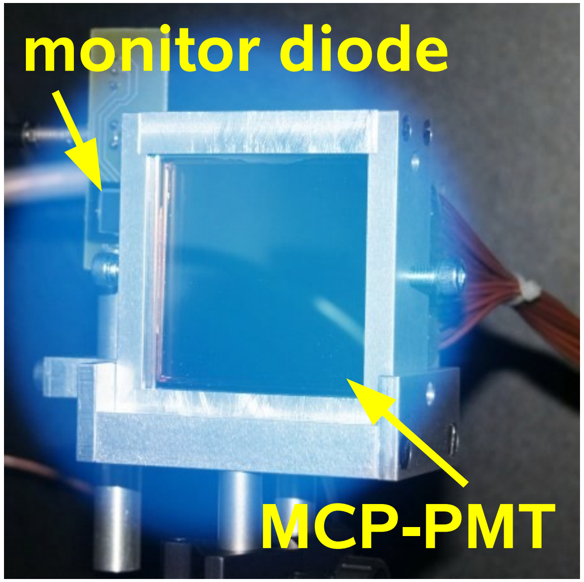
  - disadvantage: lower collection efficiency
  - no Q.E. drop up to 3.5 C/cm^2 integr. anode charge (Nagoya)
- Surface treatment + better vacuum (Photonis)
  - advantage: no reduced collection efficiency

How to Measure MCP Lifetime

- Continuous illumination
  - 460 nm LED at 272 kHz rate attenuated to single photon level
  - ~0.4 photo electrons (ph.e.) per pixel → ~3.5 mC/cm^2/day
- Permanent monitoring
  - record MCP pulse heights at highly prescaled rate using CAMAC DAQ
  - measure LED light intensity using the current of a photo diode
- [Ir]regular quantum efficiency (Q.E.) measurements
  - 300–800 nm wavelength band with 1 nm monochromator resolution
  - measure current of calibrated reference diode [Hamamatsu]
  - measure current of shorted (2 MCPs and anode) MCP-PMT
- Analysis
  - calculate Q.E. from current ratio of MCP-PMT and reference diode
  - extract gain and number of ph.e. from pulse height spectra

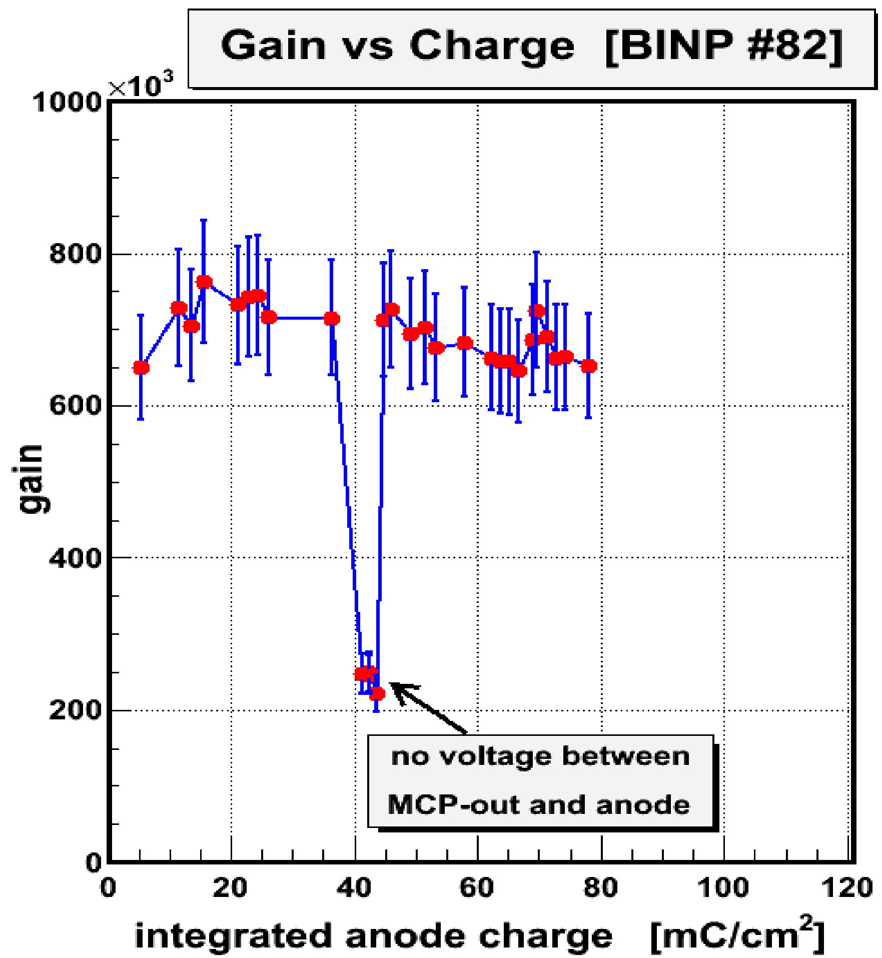
Setup for Illumination

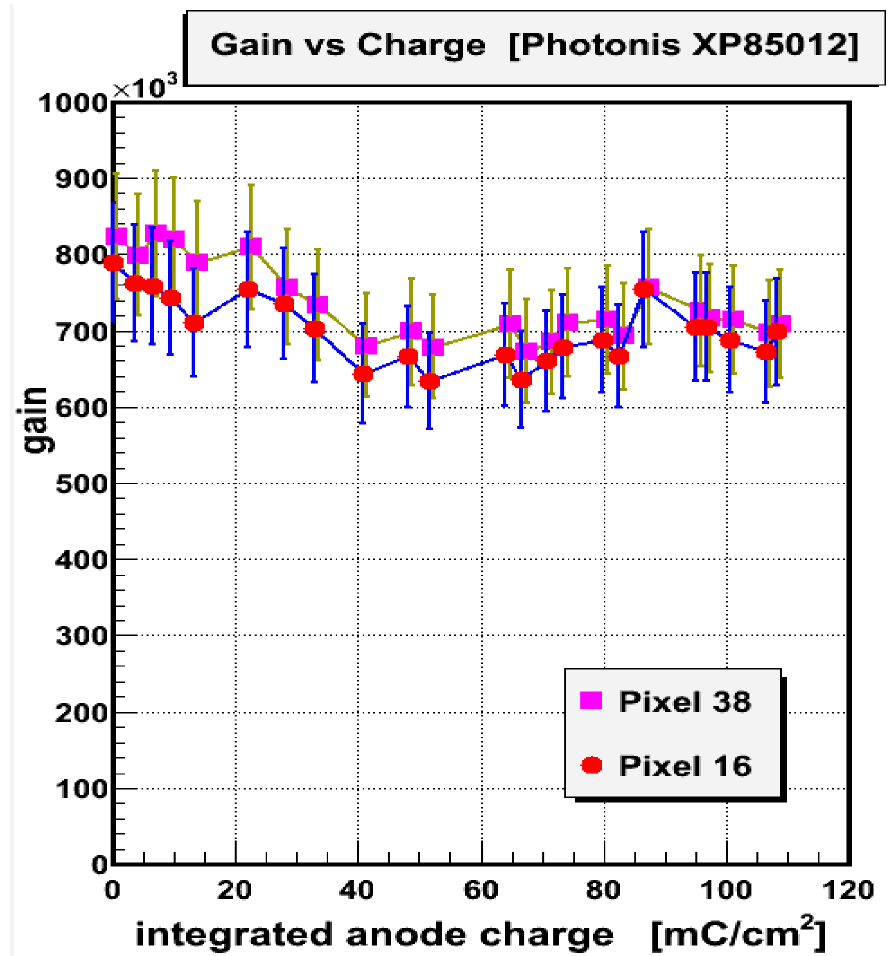




- importance of solid and repeatable setup (often taken apart)
- lens creates roughly parallel light of the LED spot
- homogeneous illumination of whole MCP (blue area of light) and monitor diode

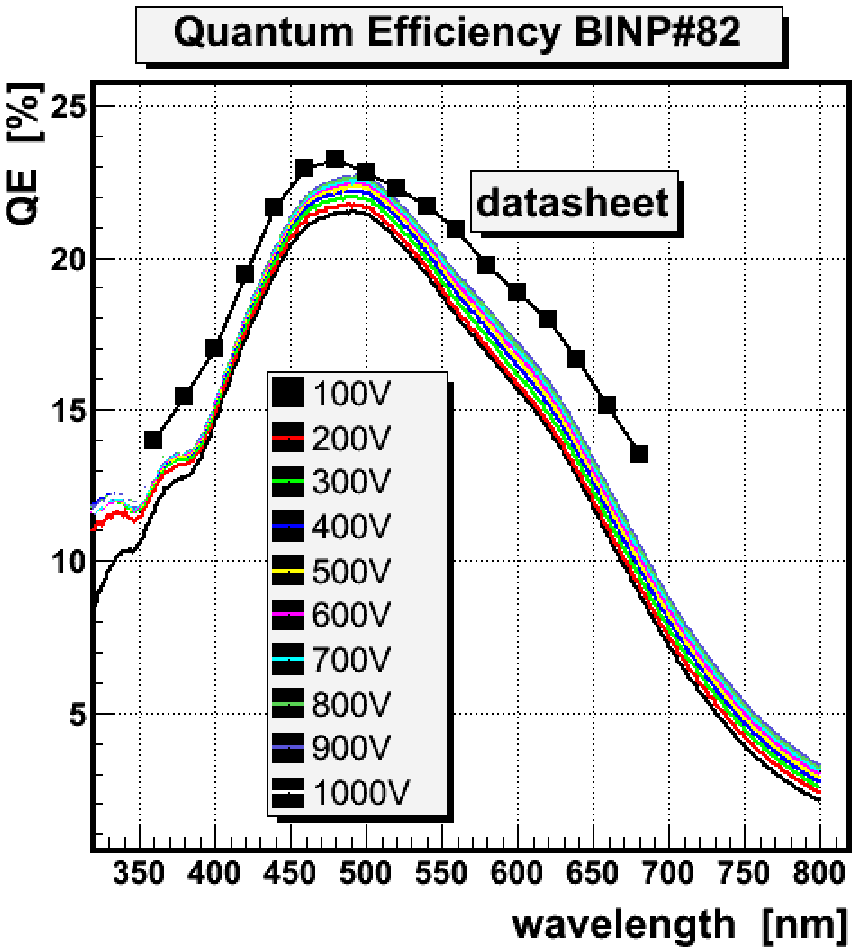
Gain after Illumination

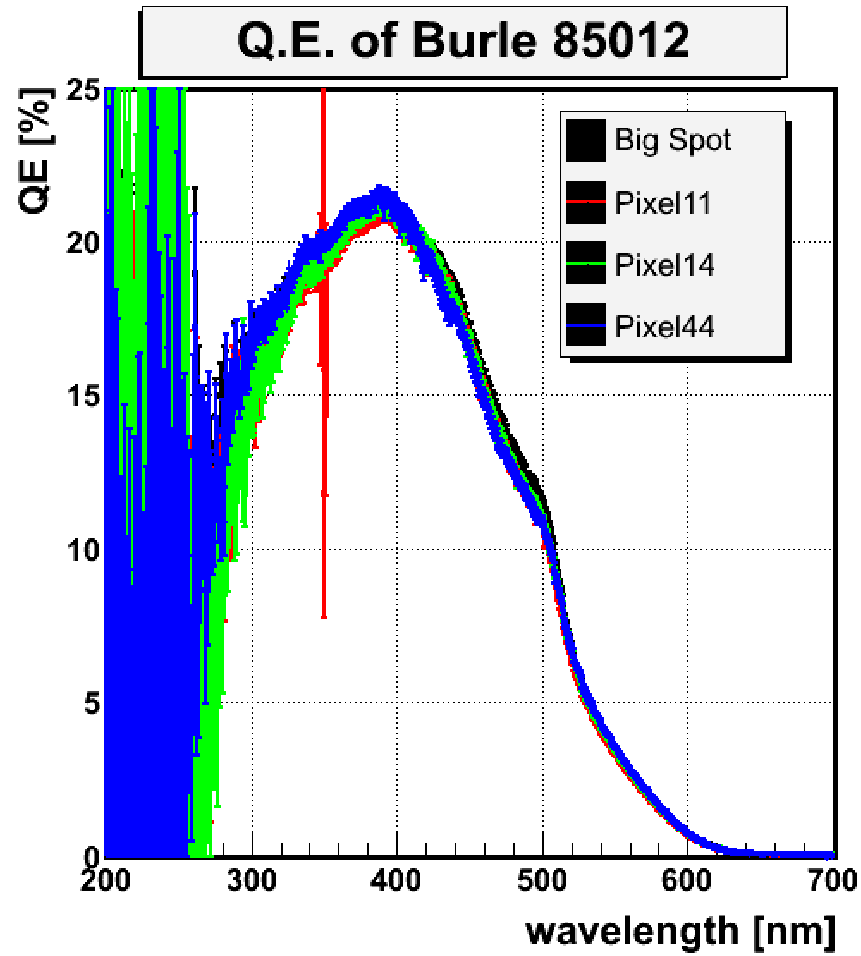




- only moderate gain variations for BINP #82 and Photonis XP85012

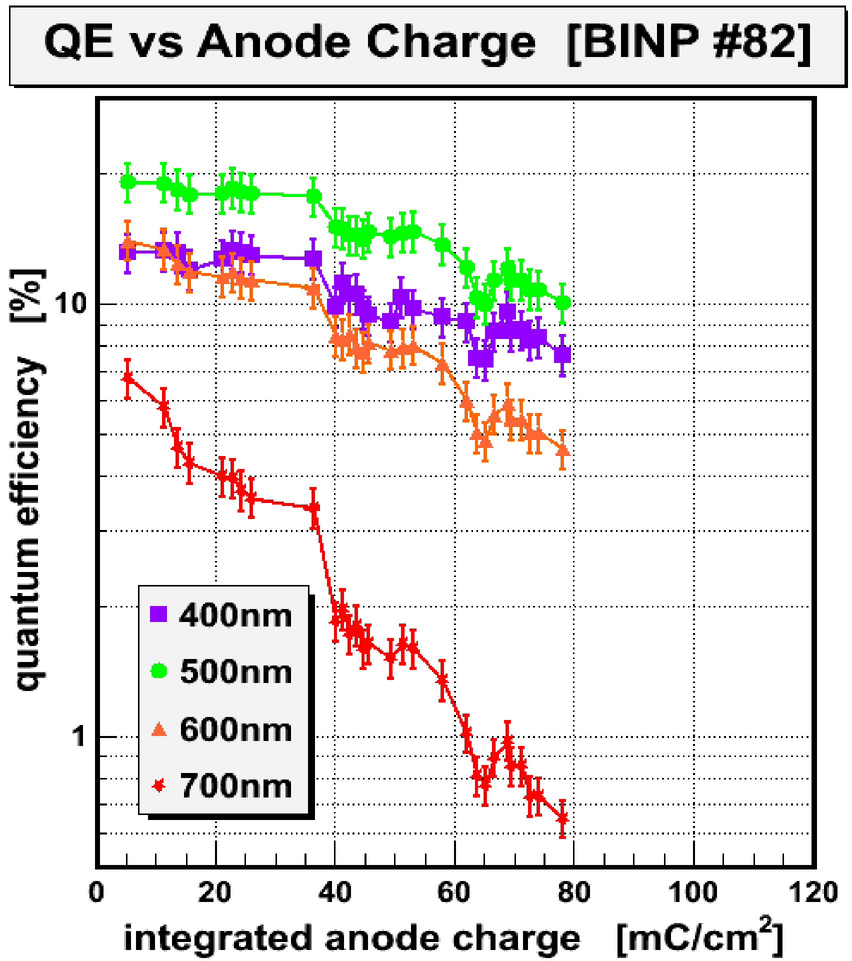
Q.E. before Illumination

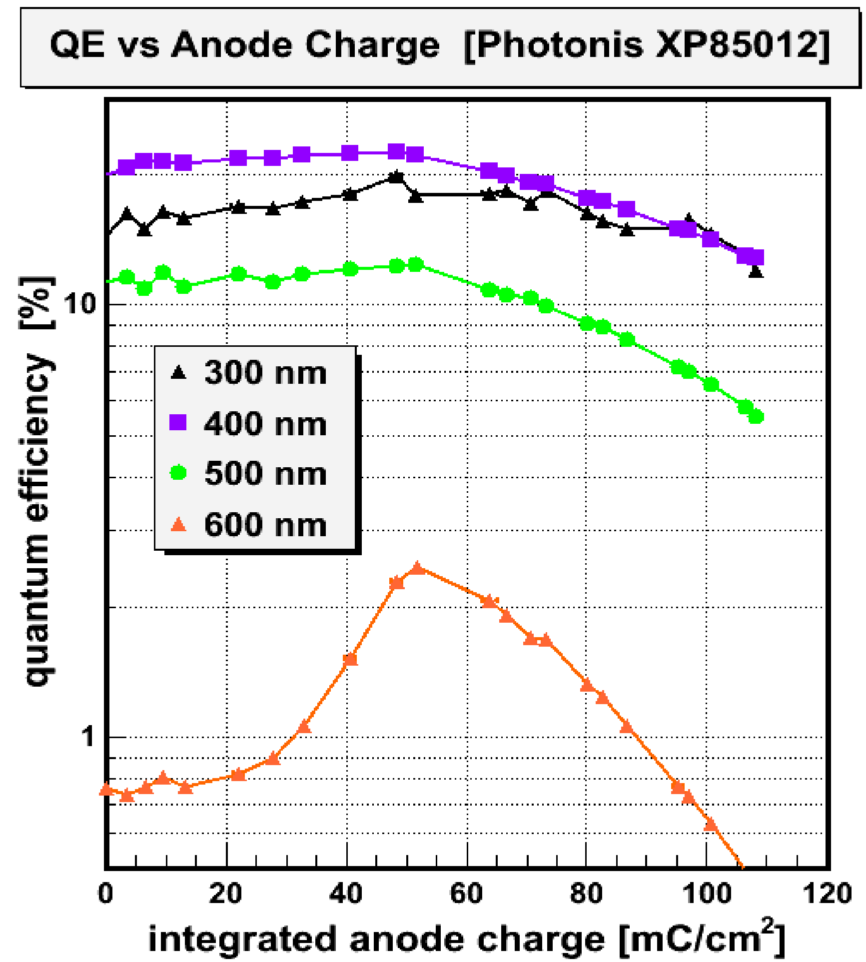




- maximum Q.E. at 480 nm (BINP) and 380 nm (Photonis)
- Q.E. does not depend on illumination position and voltage

Q.E. after Illumination





- **BINP:** decrease of Q.E. depends upon wavelength
- **XP85012:** first slight increase of Q.E. then it starts dropping

Summary and Outlook

	Barrel DIRC	Endcap DIRC	XP85012	R10754
Gain [*10^6]	> 0.5 @ 1 T	> 0.5 @ 2 T	barrel ok	endcap ok
Time resolution [ps]	< 100	< 50	37	32
Rate stability [MHz/cm^2]	0.2	2	> 1	> 5
Lifetime [C/cm^2/year]	~ 1	4 – 10	barrel in reach	w. prot. layer: maybe endcap in reach

- Latest models of MCP-PMTs fulfil most specifications for PANDA DIRC except lifetime.
- Recent developments have increased lifetime of MCPs significantly, but further improvements will be needed.