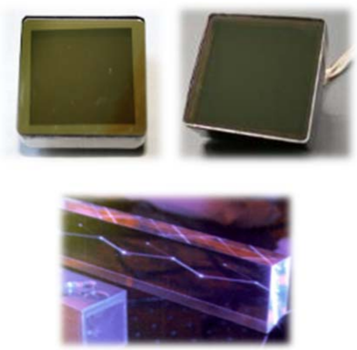
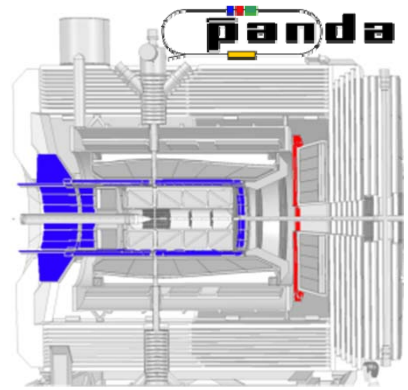
BREAKTHROUGH IN THE LIFETIME OF MICROCHANNEL-PLATE PMTS



Jochen Schwiening

GSI

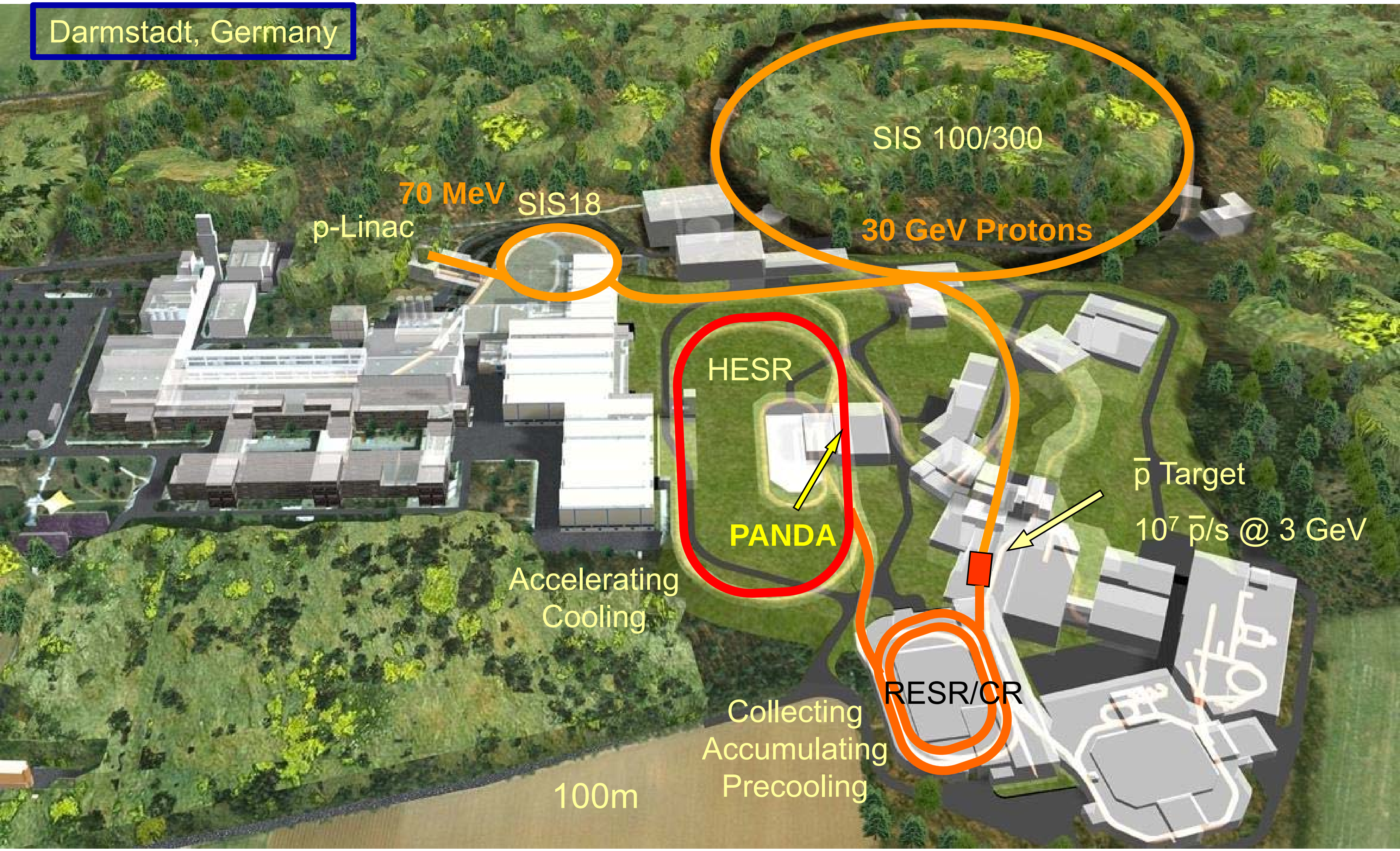
for the PANDA Cherenkov Group



- CONTEXT: DIRC DETECTORS FOR PANDA AT FAIR
- CHALLENGE: STATUS IN 2011
- MCP-PMT LIFETIME IMPROVEMENT
  - APPROACHES
  - AGING TESTS
- SUMMARY AND OUTLOOK

For more detail see
A. Lehmann's talk at LIGHT14
https://conference.mpp.mpg.de/light-14/

PANDA AT FAIR



PANDA AT FAIR

DIRCs in PANDA

PANDA: rich program of QCD studies using anti-proton beam with unique intensity and precision.

*For more info on the Barrel DIRC see M. Zühlsdorf talk **N41-8** today*

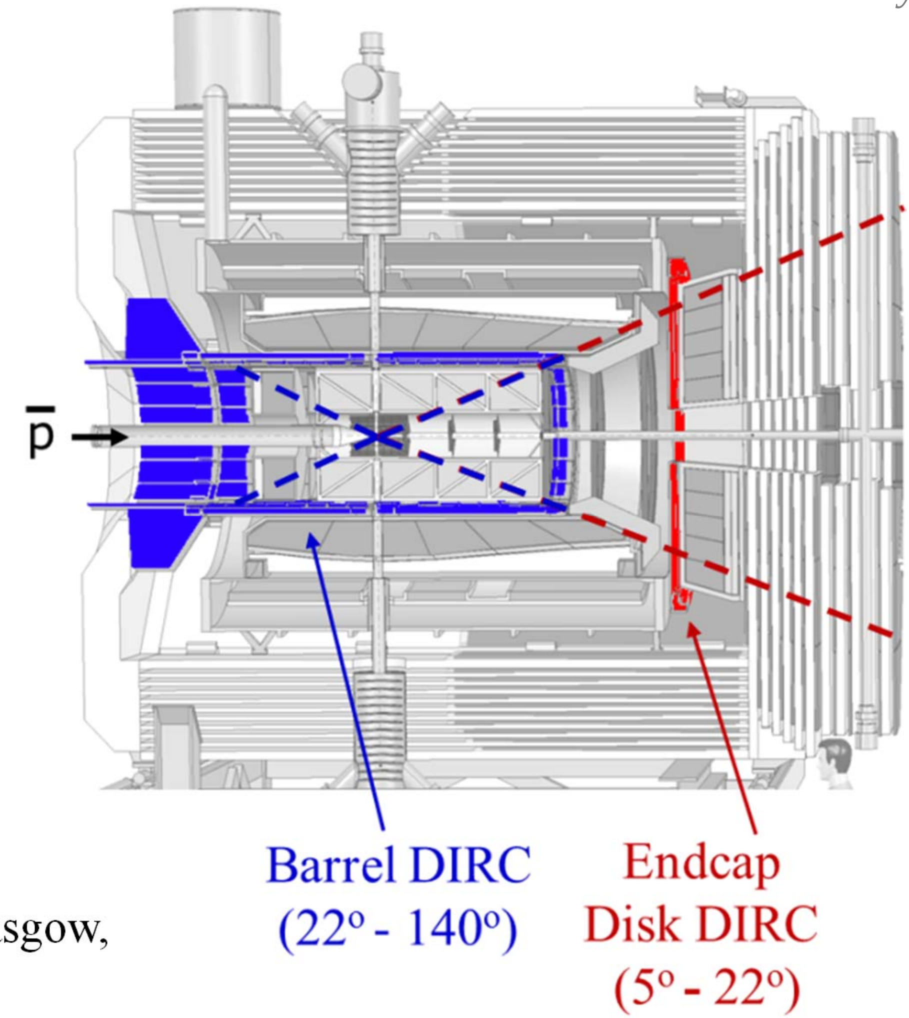
Hadronic Particle ID: two DIRC detectors

- Barrel DIRC – similar to BABAR DIRC with several key improvements.

  Goal: 3σ π/K separation for p=0.5…3.5 GeV/c.

- Novel Endcap Disk DIRC

  Goal: 3σ π/K separation for p=0.5…4.0 GeV/c.



PANDA Cherenkov Group:

JINR Dubna, FAU Erlangen-Nürnberg, JLU Gießen, U. Glasgow, GSI Darmstadt, HIM and JGU Mainz, SMI OeAW Vienna.

DIRC SENSOR CHALLENGES

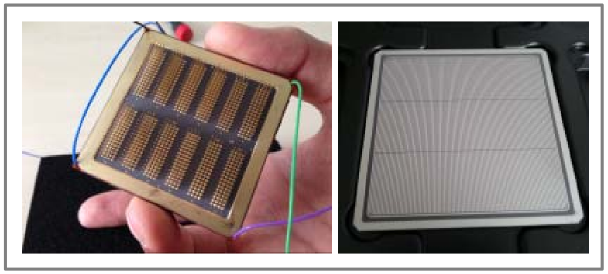
PANDA DIRCs require compact, fast multi-pixel sensor with single photon sensitivity in strong magnetic field with trigger-less DAQ and 20MHz average interaction rate.

- Good geometrical resolution over a large surface

  multi-pixel sensors with ~5x5 mm anodes

  *(much finer segmentation needed for Endcap Disk DIRC, 0.5mm anode pitch prototype being tested, see J. Rieke, poster **N24-31**)*

Hamamatsu 6x128 PHOTONIS 3x100



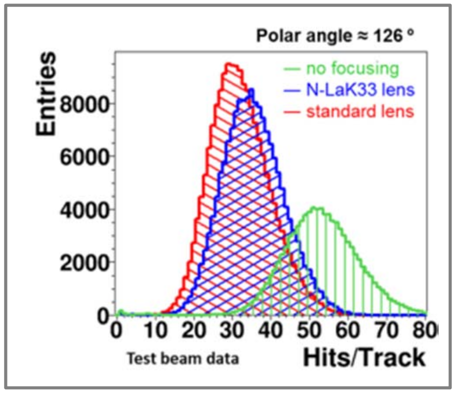
- Single photon detection inside B-field

  high gain (> 5×10^5) at 1-2 Tesla

- Time resolution for photon time of propagation and/or dispersion correction

  very good time resolution of <100 ps for single photons

PANDA Barrel DIRC Prototype



- Few photons per track

  high detection efficiency PDE = QE * CE * GE

  low dark count rate

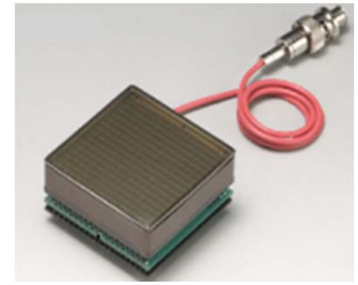
- Photon rates in the MHz regime

  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

DIRC Sensor Candidates

- Multi-anode Photomultipliers (MaPMTs)

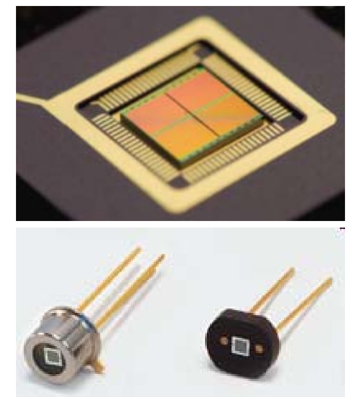


used successfully in DIRC prototypes,

was sensor of choice for SuperB FDIRC

ruled out by 1T magnetic field

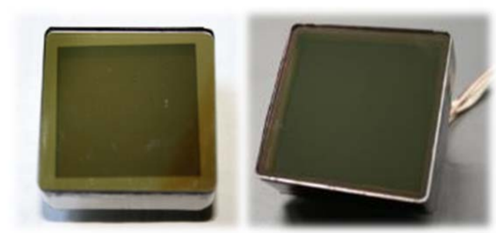
- Geiger-mode Avalanche Photo Diodes (SiPMs)



high dark count rate problematic for reconstruction (trigger-less DAQ)

radiation hardness an issue in PANDA environment

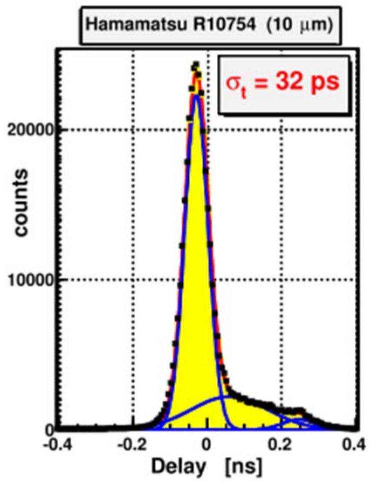
- Micro-channel Plate Photomultipliers (MCP-PMTs)

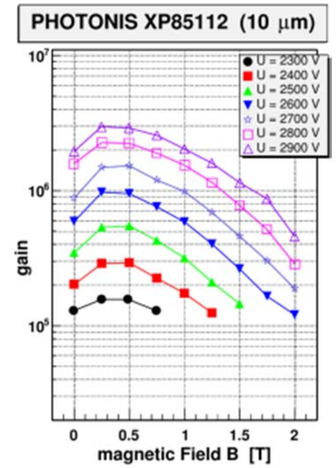


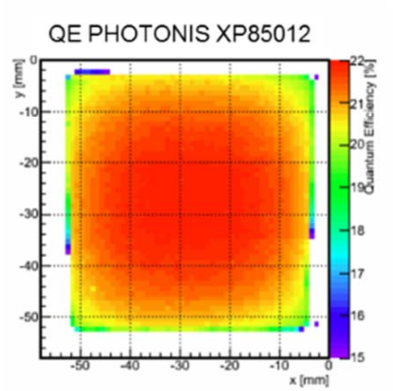
good PDE, excellent timing and magnetic field performance

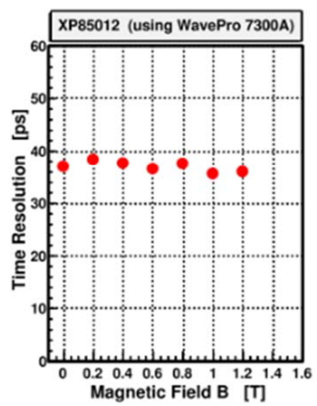
issues with rate capability and aging

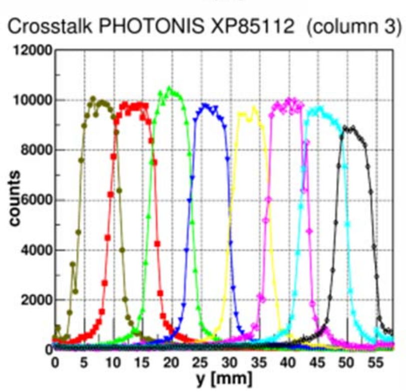
MCP-PMT Performance Examples

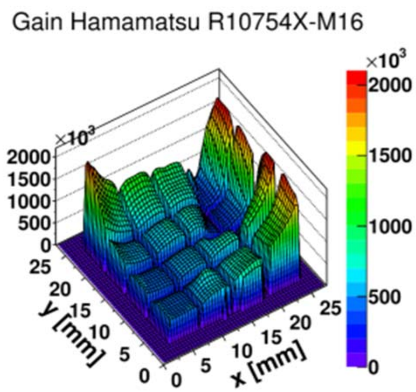








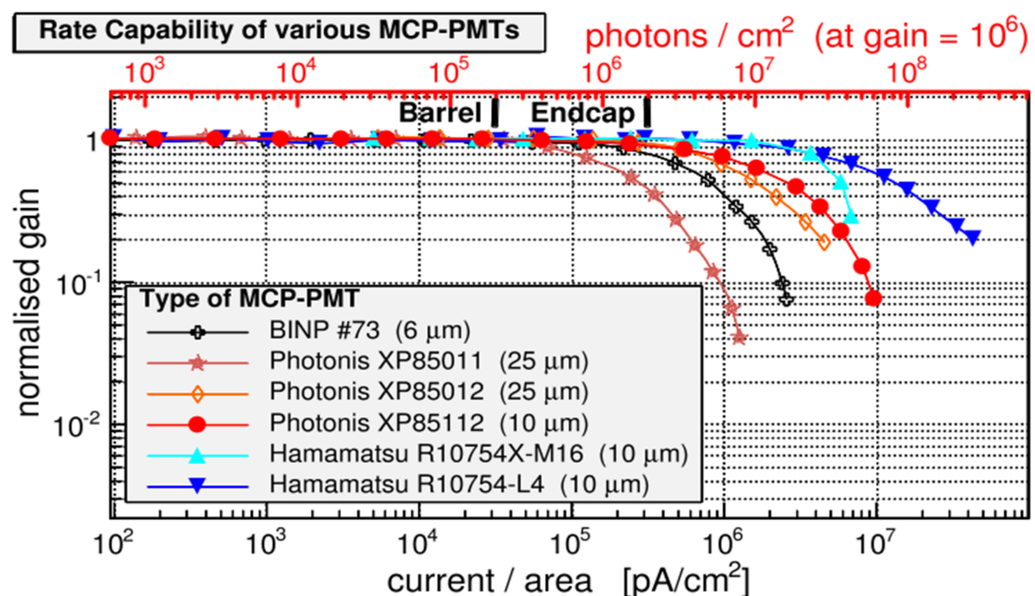




Detailed study of MCP-PMT performance:

- prototypes from BINP, PHOTONIS, Hamamatsu
- single photon time resolution
- gain and quantum efficiency scans
- charge sharing/cross-talk
- rate capability
- tests with and without magnetic field

MCP-PMTs meet *most* PANDA DIRC goals.

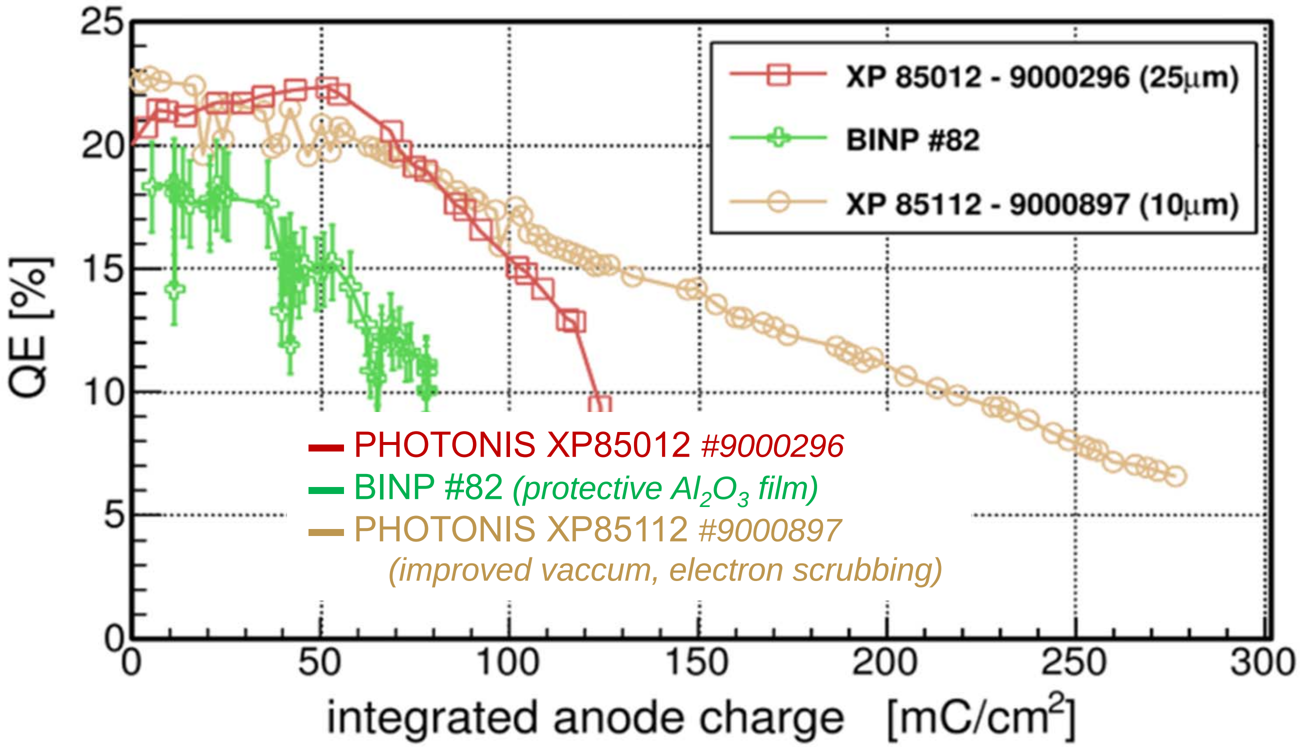


MCP-PMT LIFETIME IN 2011

The main issue with using MCP-PMTs for PANDA DIRCs:

aging of photocathode

Status of our MCP-PMT lifetime measurements in 2011



Quantum efficiency reduced by 50% or more at only <200 mC/cm^2

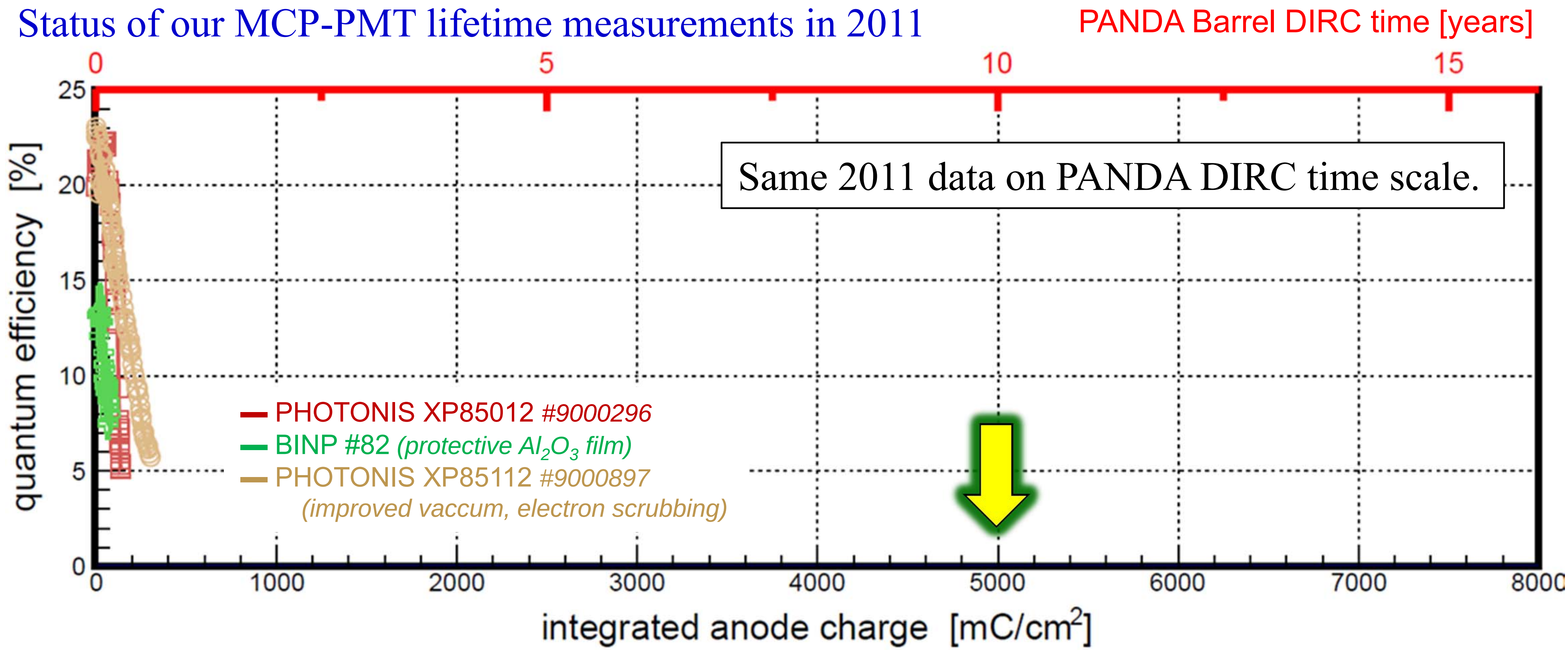
But: PANDA DIRCs require lifetime of 5-10 C/cm^2

MCP-PMT LIFETIME IN 2011

The main issue with using MCP-PMTs for PANDA DIRCs:

aging of photocathode

Status of our MCP-PMT lifetime measurements in 2011



None of the MCP-PMTs in 2011 would have survived for more than 2 months in PANDA.

→ needed factor ~50 ("breakthrough") improvement in MCP-PMT lifetime

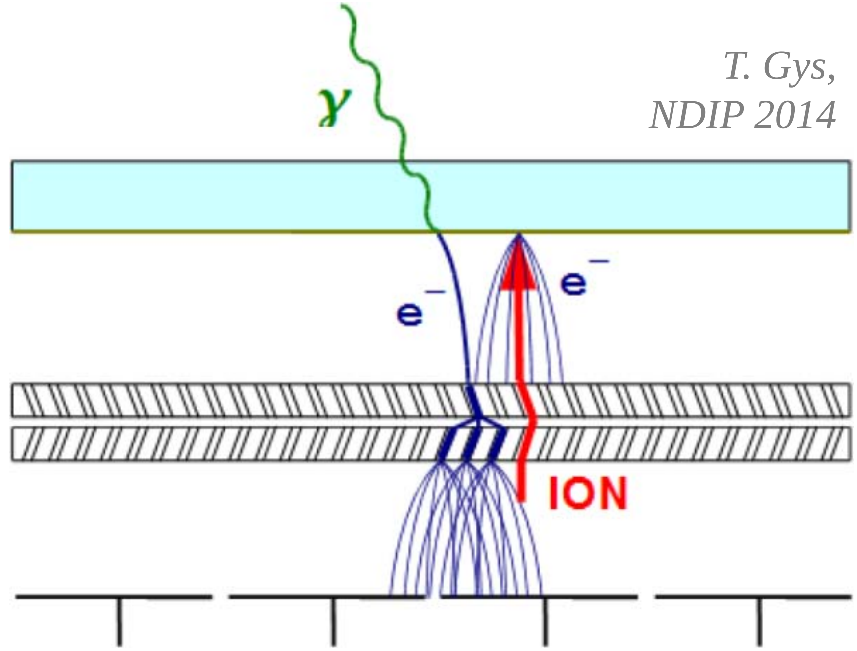
Ion feedback

Amplification process causes

- Ionization of residual gas atoms
- Desorption of atoms from MCP material (especially H and Pb)
- Damaging of MCP surfaces → gain may change

Ions accelerated towards photo cathode

- Production of secondary pulse
- Ions may react with PC
- PC gets damaged and work function may gradually change
- Degradation of Quantum efficiency (QE)

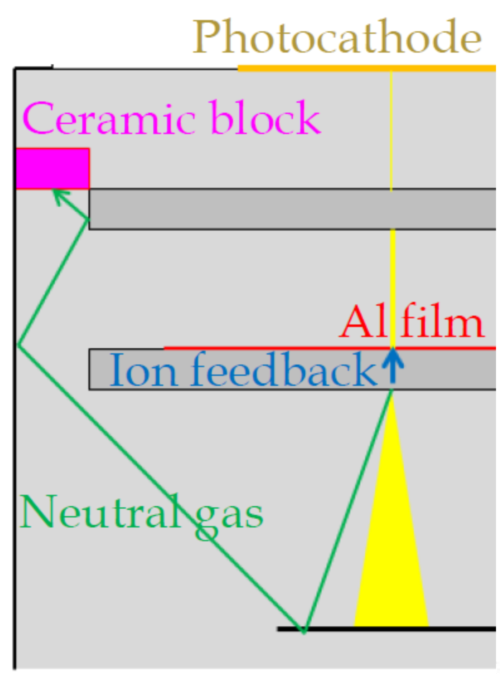


T. Gys, NDIP 2014

Neutral molecules from residual gas

Passing between MCPs and walls

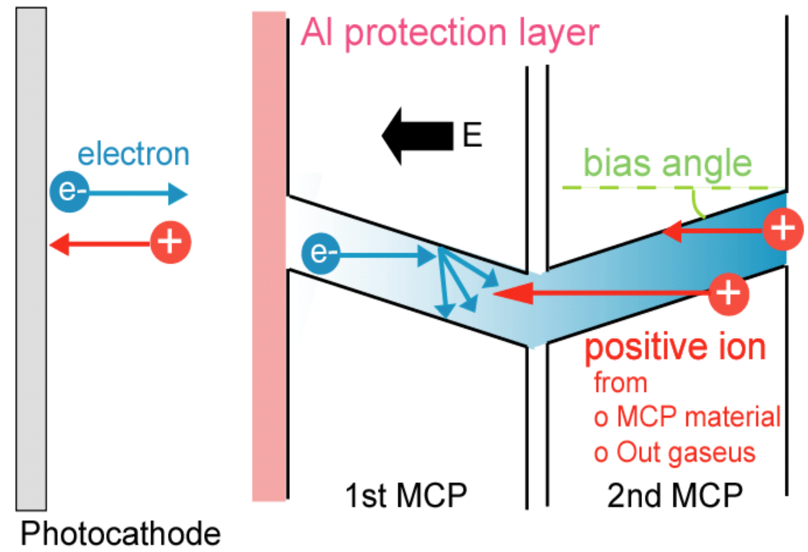
CO_2, O_2 and H_2O react with PC

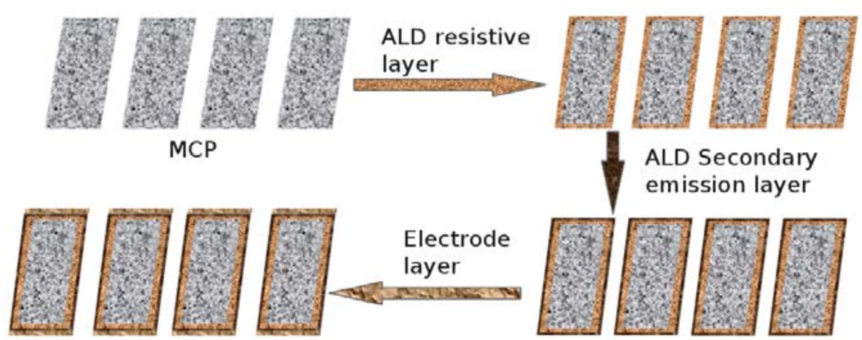


K. Matsuoka, RICH 2013

MCP-PMT Aging Countermeasures

- Stop feedback ions by thin Al_2O_3 film (5-10 nm)
  - Initially in front of first MCP layer (loss of CE)
  - Later between MCP layers (need higher HV)
- Improve vacuum quality
- Improve cleaning of MCP surfaces
  - Electron scrubbing
- Improve ceramics, seal off anode region
  - Block flow of neutral molecules from anode region
- More resistant photocathode
  - $Na_2KSb(Cs)$, $Na_2KSb(Cs)+Cs$, $Na_2KSb(Cs)+Cs_3Sb$
- Deposition of ultra-thin atomic layer
  - (MgO, Al_2O_3) on MCP substrate (ALD)
- Use of alternate substrate material?
- Ion suppression grid between MCP and photocathode?





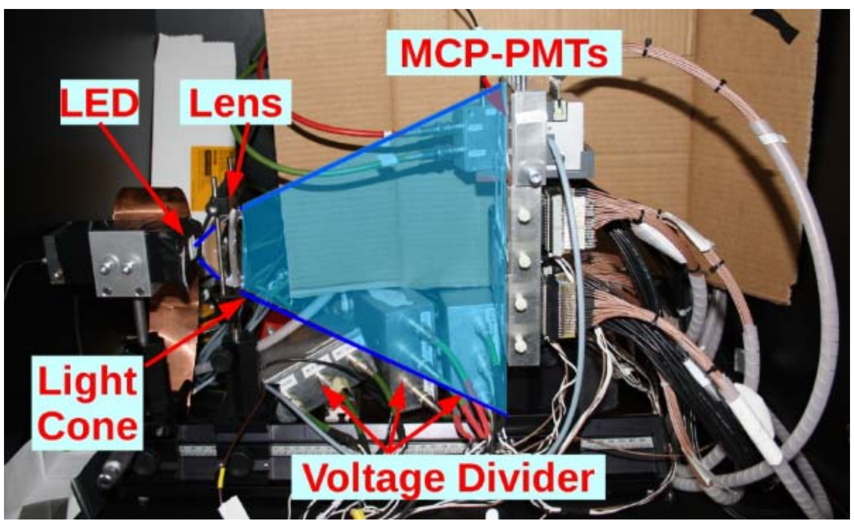
NIM A639 (2011) 148

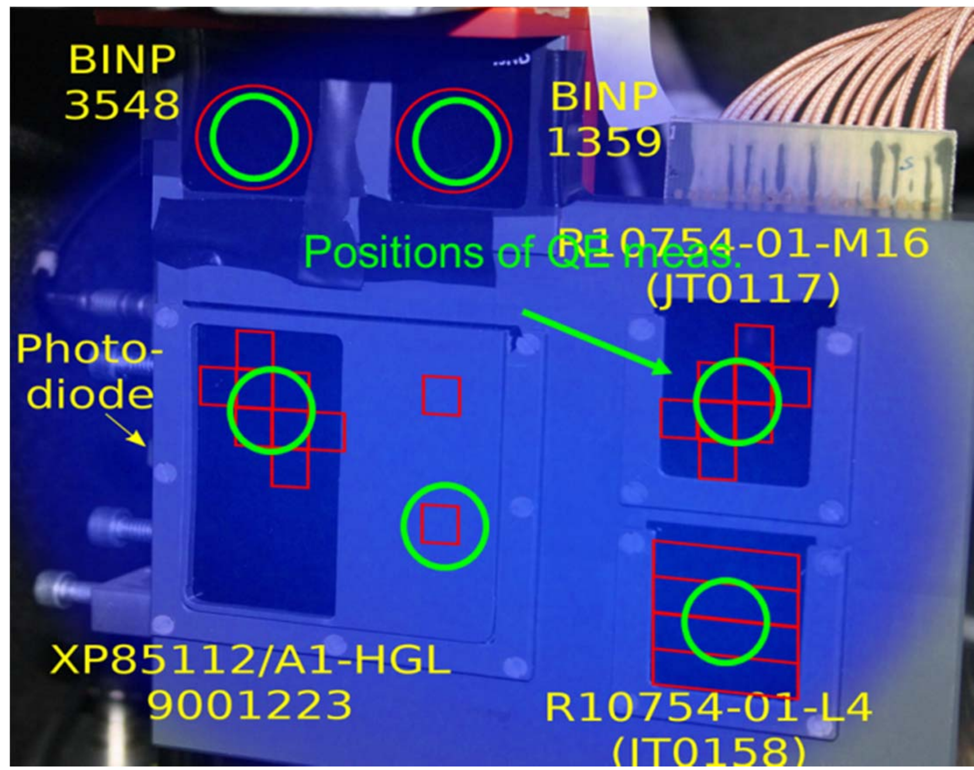
Simultaneously age all MCP-PMTs at rates comparable to PANDA DIRC environment

- common systematics, results easy to compare and interpret
- continuous illumination (460nm LED, 0.25-1MHz rate, single photon level)
- permanent monitoring (MCP pulse heights, LED intensity)
- frequent QE mesurements (250-700nm, monochromator)
- setup in operation for more than three years

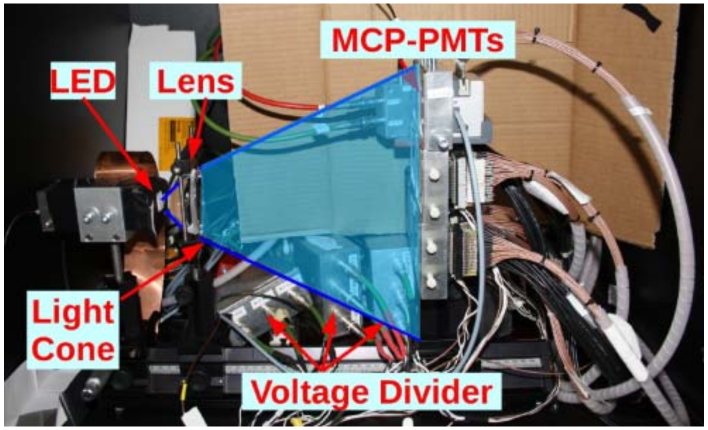
  started with standard MCP-PMTs

  lifetime-improved MCP-PMTs ~3 years ago

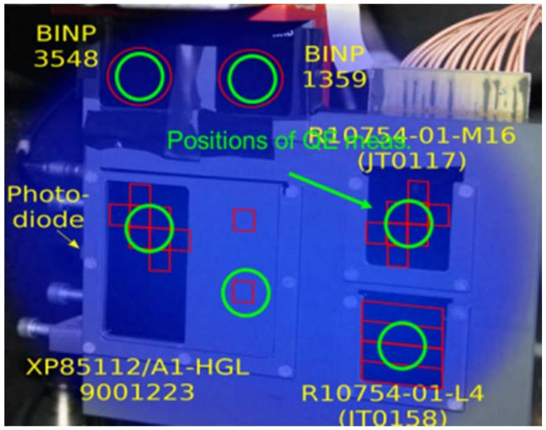


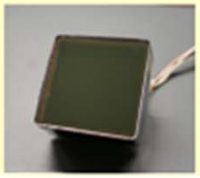


MCP-PMT Aging Measurements

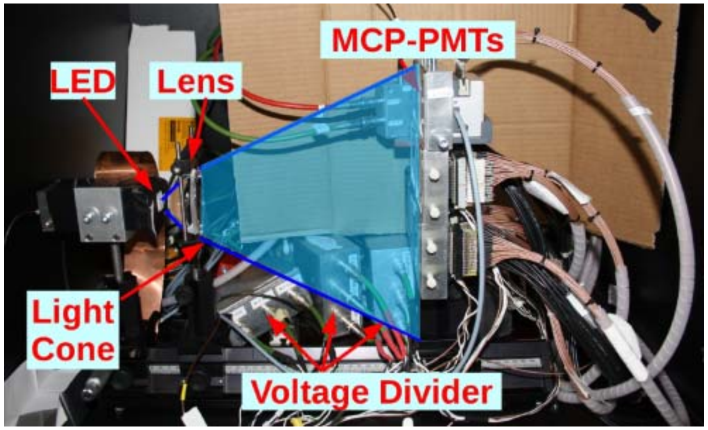


Summary of MCP-PMTs measured in setup

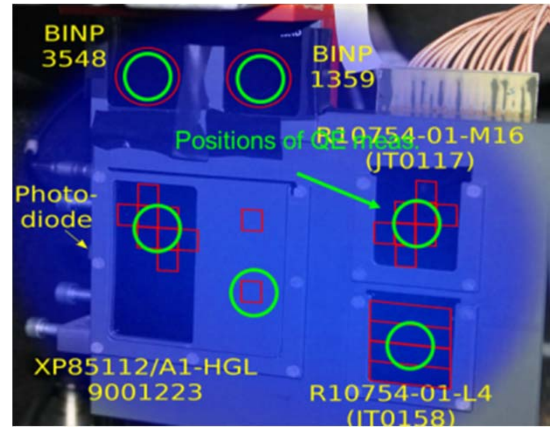


	BINP		PHOTONIS			Hamamatsu	
			XP85012	XP85112	XP85112	R10754X-01-M16	R10754X-07-M16M
pore size (µm)	6	7	25	10	10	10	10
number of pixels	1	1	8x8	8x8	8x8	4x4	4x4
active area (mm²)	$9^2\pi$	$9^2\pi$	53x53	53x53	53x53	22x22	22x22
total area (mm²)	$15.5^2\pi$	$15.5^2\pi$	59x59	59x59	59x59	27.5x27.5	27.5x27.5
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	3	1 (+1 L4)	2
							

MCP-PMT Aging Measurements

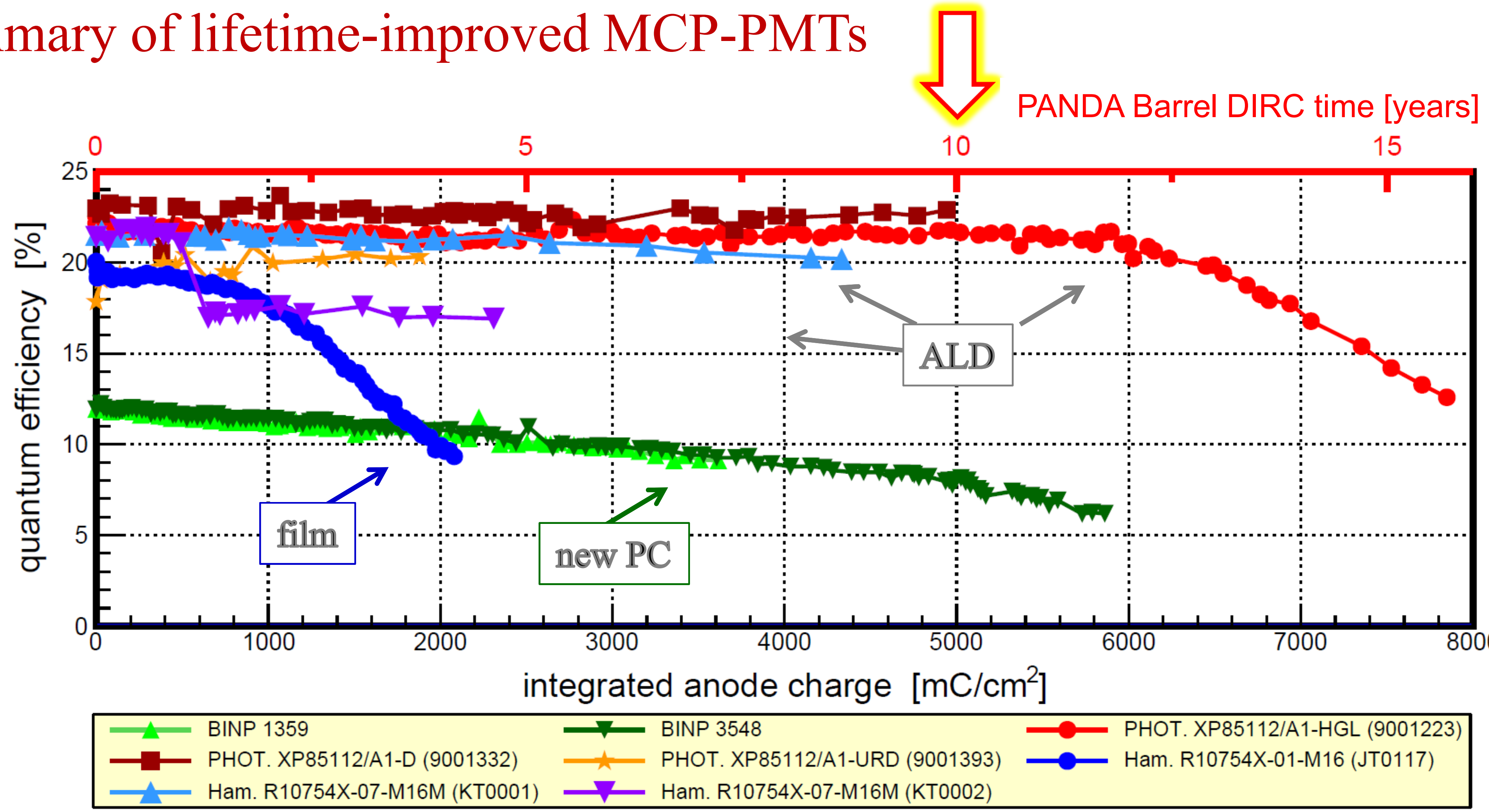


Summary of MCP-PMTs measured in setup



	Sensor ID	Integrated charge (as of Oct. 1, 2014) [mC/cm^2]	Diff. charge (maximum) [mC/cm^2/d]	# of measurements	# of QE scans	Comments
PHOTONIS XP85112	9001223	**7852**	13.5	151	14	Start: 23 Aug. 11 ongoing
	9001332	**4948**	21.8	55	7	Start: 12 Dec. 12 ongoing
	9001393	**1879**	11	19	3	Start: 23 Jan. 14 ongoing
Hamamatsu R10754X	JT0117 (M16)	**2086**	14.1	86	7	Start: 23 Aug. 11 Stop: 24 Jul. 12
	KT0001 (M16M)	**4331**	30.1	31	5	Start: 20 Aug. 13 ongoing
	KT0002 (M16M)	**2312**	20.1	26	6	Start: 21 Oct. 13 ongoing
BINP	1359	**3616**	10.6	90	8	Start: 21 Oct. 11 Stop: 06 May 13
	3548	**5925**	11.8	128	11	Start: 21 Oct. 11 ongoing

Summary of lifetime-improved MCP-PMTs



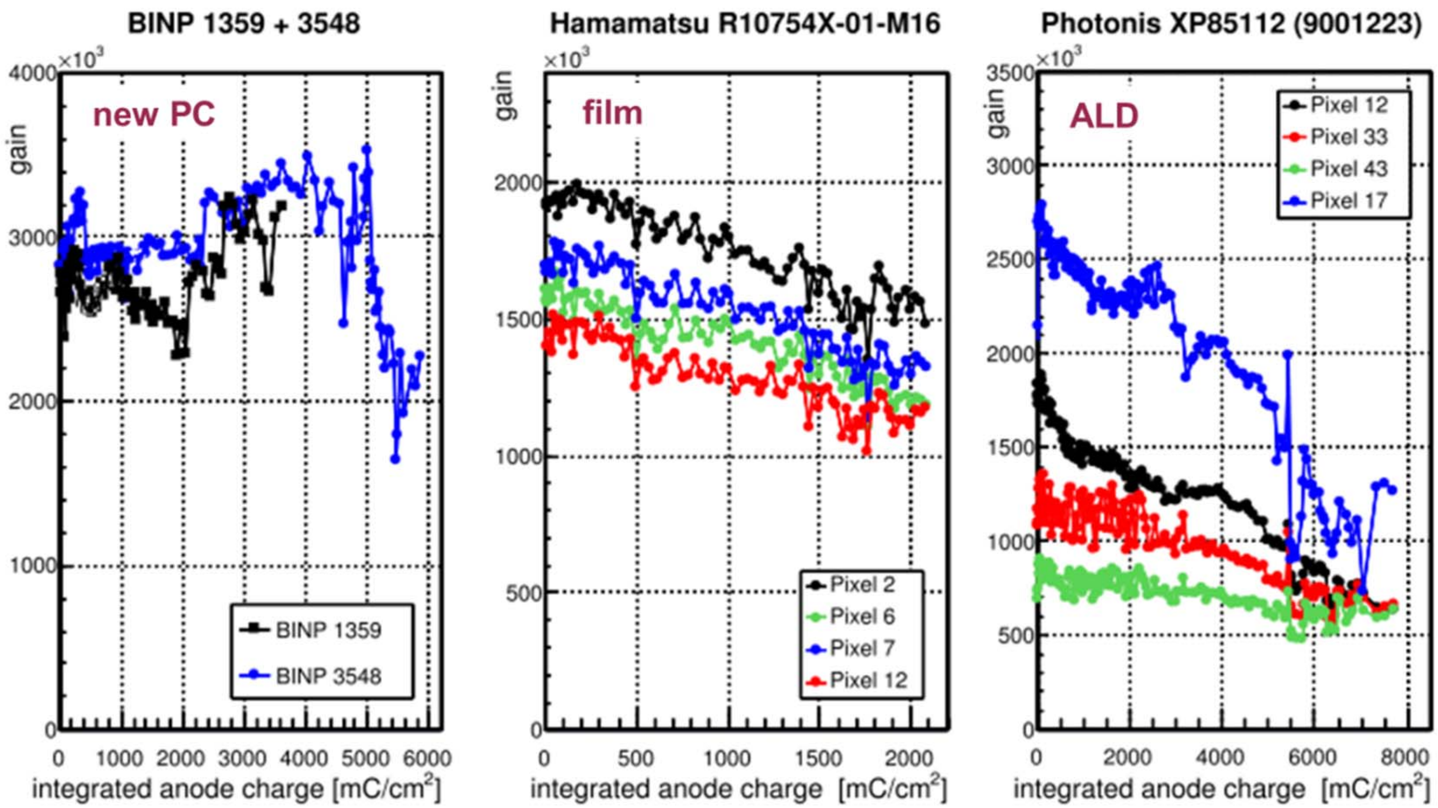
Latest MCP-PMTs with ALD technique
meet all requirements for the PANDA Barrel DIRC.

Impossible to describe all our results (3+ years) or the excellent MCP-PMT lifetime studies by Belle II and TORCH groups in this talk.

For a more complete review:
A. Lehmann's talks at
RICH 2013 and at LIGHT14

In the remaining time: a few highlights

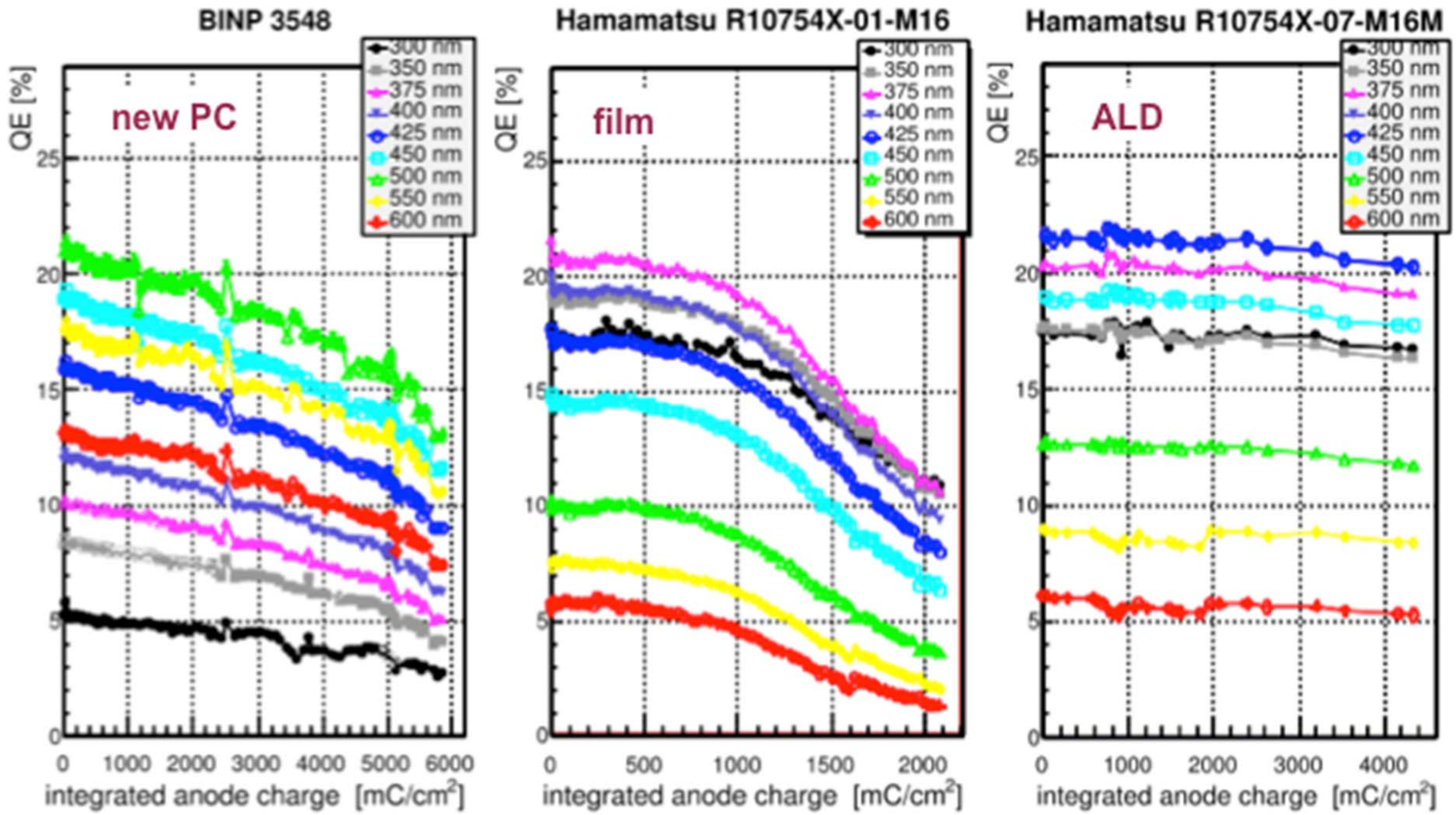
Gain vs. integrated anode charge



→ Only moderate gain changes, can be recovered by raising HV

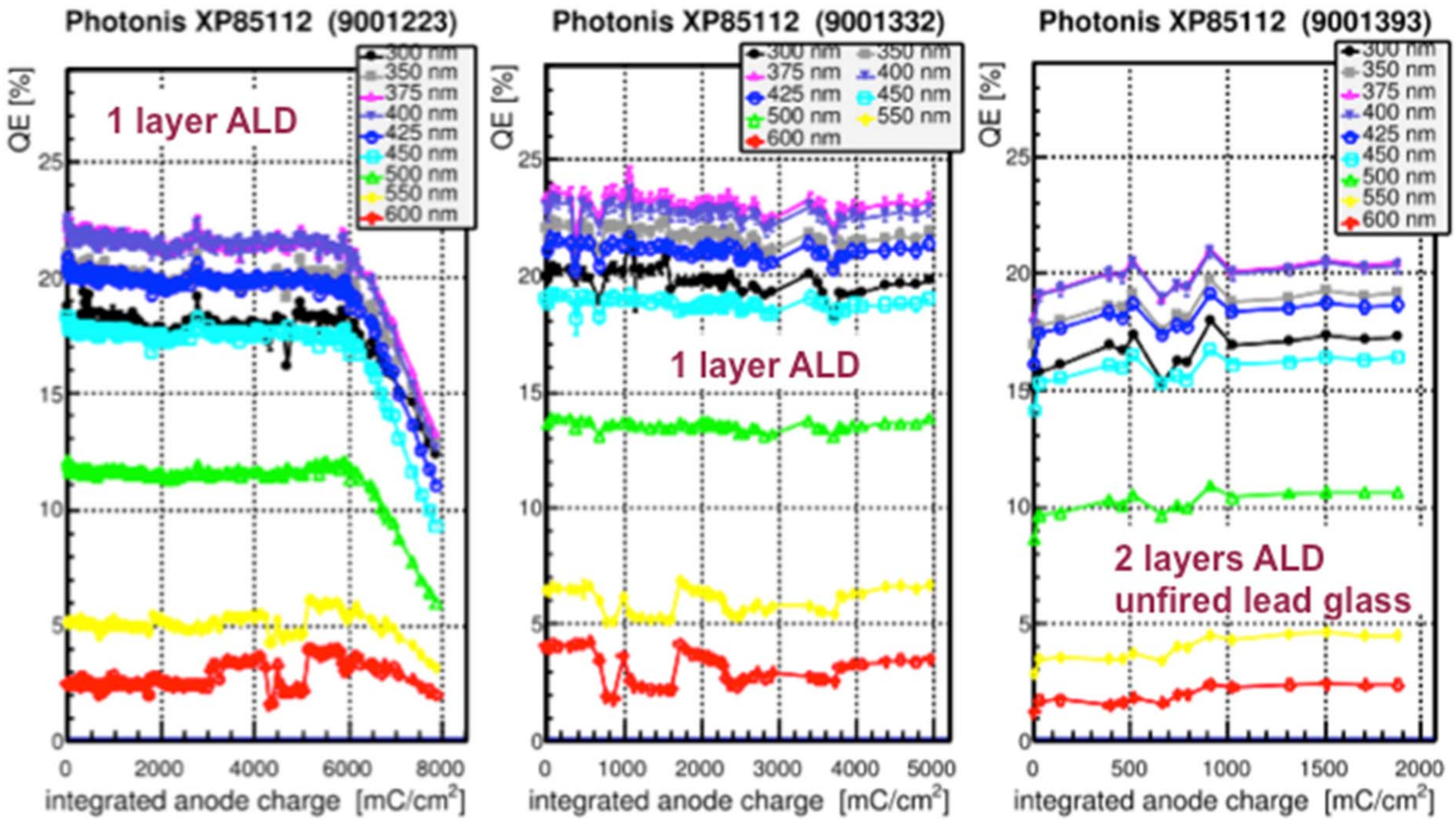
MCP-PMT LIFETIME RESULTS

Quantum efficiency for different wavelengths vs. integrated charge



BINP new PC:	continuous QE degradation
Hamamatsu film:	QE drops significantly after ~1 C/cm^2
Hamamatsu ALD:	only minor QE degradation at >4 C/cm^2

Quantum efficiency for different wavelengths vs. integrated charge



PHOTONIS Planacon with 1 layer ALD: no QE loss up to 5 C/cm^2

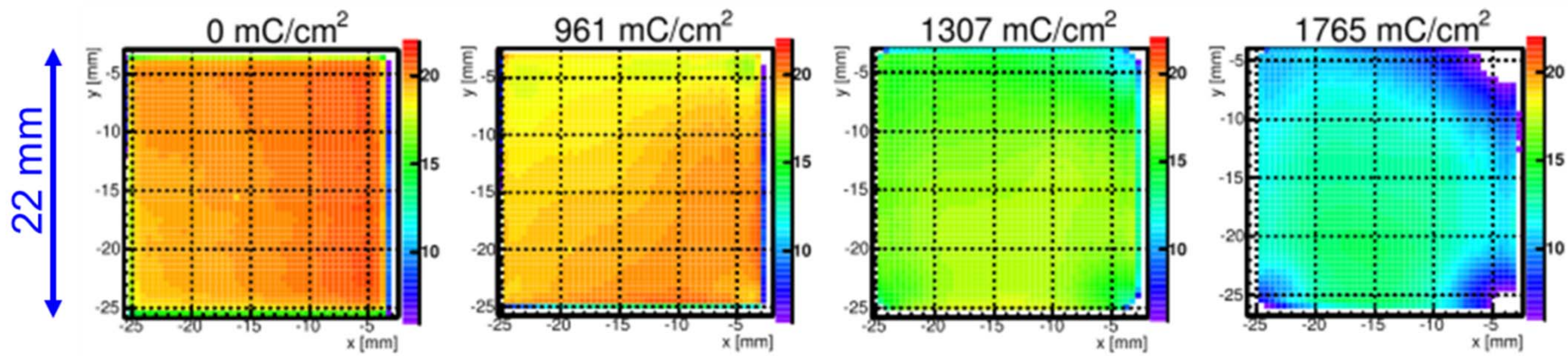
#9001223: steep QE drop after 6 C/cm^2

Latest Planacon with unfired lead glass, 2-layer ALD process: no QE loss yet at 2 C/cm^2.

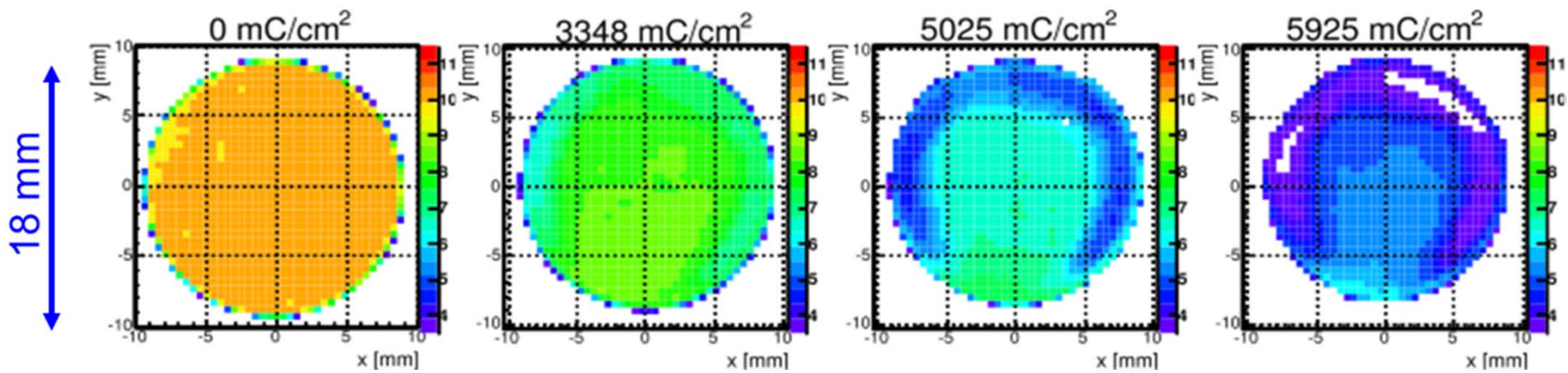
MCP-PMT LIFETIME RESULTS

Quantum efficiency scans (372nm) for different integrated charges

film **Hamamatsu R10754X-M16**

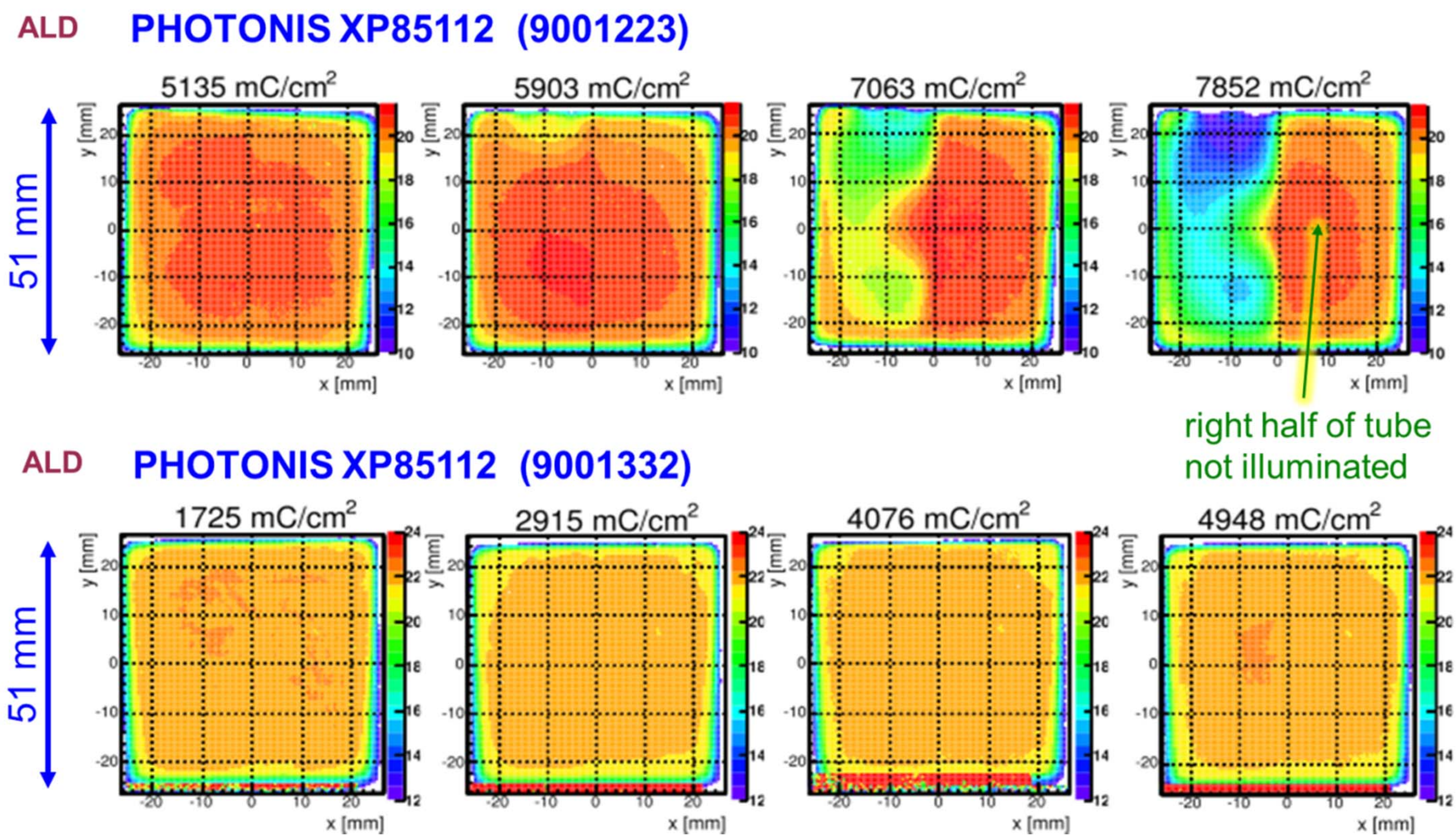


new PC **BINP 3548**



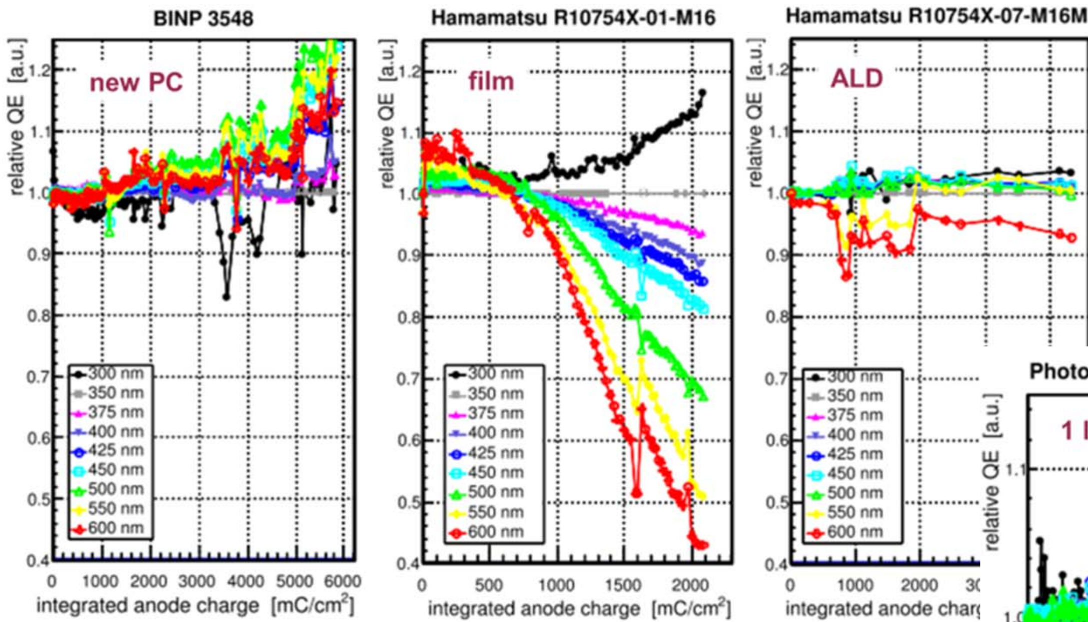
→ QE degradation evolves from rims and corners, both film and new PC fail.

Quantum efficiency scans (372nm) for different integrated charges



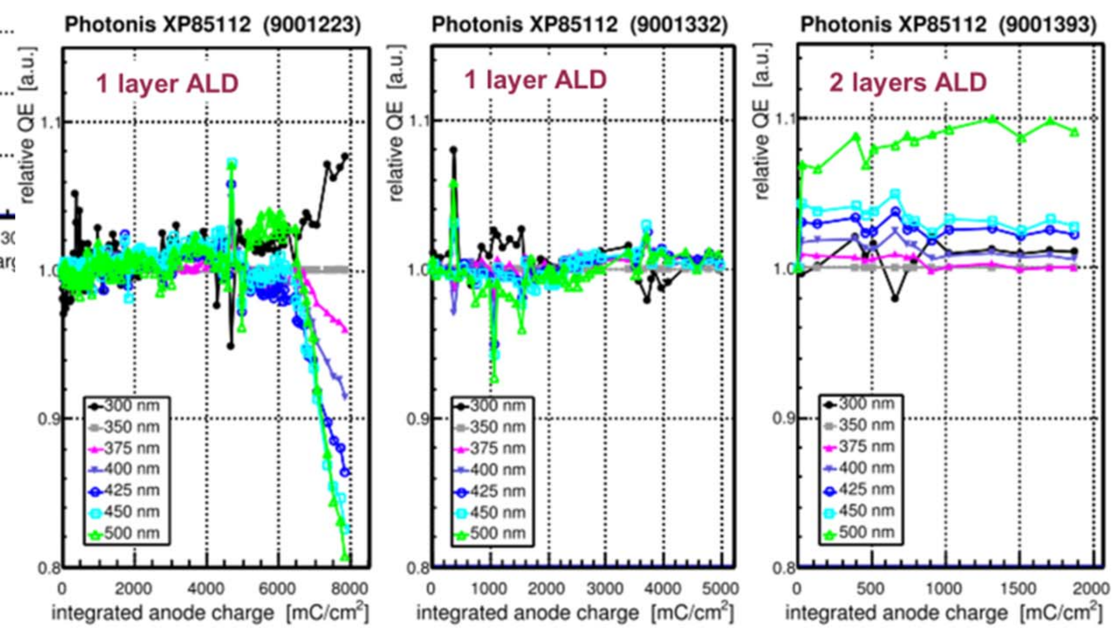
→ no visible QE degradation up to 6C/cm^2, loss limited to illuminated half.

Relative quantum efficiency for different wavelengths vs. integrated charge



New PC and ALD: loss ~constant.

Film: loss starts in red – work function

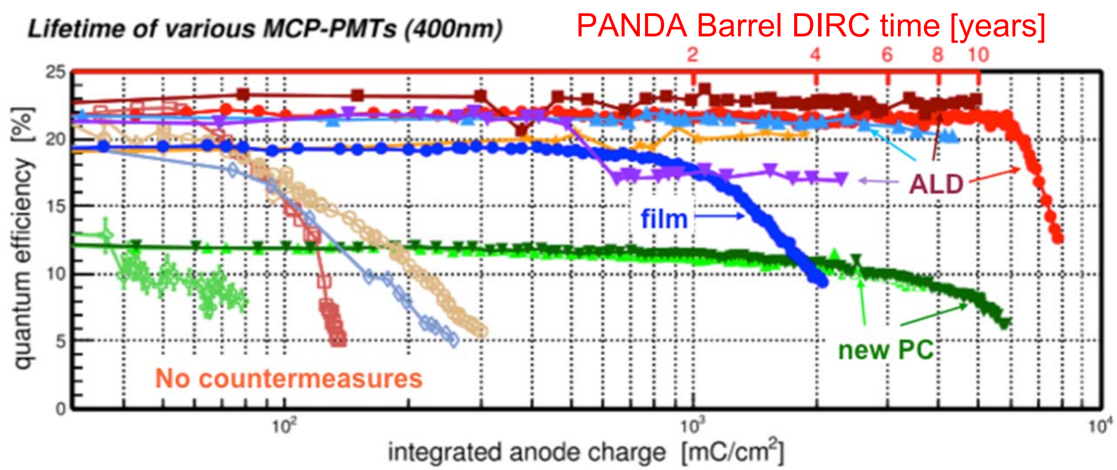


→ Clear difference in wavelength-dependent aging between different methods.

SUMMARY AND OUTLOOK

Spectacular lifetime increase of latest MCP-PMTs due to recent design improvements.

Equipping the two PANDA DIRCs and other high rate RICH counters (TOP, TORCH, DIRC@EIC,...) with MCP-PMTs seems possible.



Factor >25 improvement

Application of ALD technique appears to be most promising single step (>5 C/cm^2 anode charge now feasible).

Similar good performance observed in R&D for Belle II TOP and for TORCH.

See presentations at RICH 2013 K. Matsuoka, T. Gys, J. Milnes

Further improvements could possibly be reached by combining ALD with

- modified photo cathodes (see BINP tubes);
- MCP materials with less outgassing (e.g. borosilicate glass instead of lead glass).