Update on the most recent Photonis MCP-PMTs for the PANDA Barrel DIRC

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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Status of lifetime measurements



- **Required spec:** 5 C/cm² IAC (10 years of PANDA) reached by most ALD-coated MCP-**PMTs**
- Best sensor by far: Photonis 9001393 with two ALD-layers (no QE loss up to 34 C/cm²)
- Photonis 9002108, Photek A1200107 and A3191220 had **poor lifetime**
- Photonis 9002192, 9002193 have reached 6 C/cm² IAC without PC damage or QE loss
- Latest Photek A2200606 has no sign of QE damage up to 2.5 C/cm²



QE vs wavelength



QE vs wavelength @ center point (x4 y5, ~5 mm spot)
Jump @ 330 nm not real → DAQ related → Just visible for high dark currents



QE uniformity



20

0

60

40

80

100

active area [%]



• Uniformity below 1.4 for all tubes for 100% active area

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Gain vs voltage



- Measurements with two different voltage dividers taken for each tube
 - 1-10-1: 200 V PC MCPin
 - 4-10-1: 800 V PC MCPin
- All 4-10-1 curves at slightly higher gain than other curves because of higher initial energy of photo electron
- Gain of 10⁶ safely reached by all tubes, for some even > 10⁷
- 3x10⁶ to obtain at every pixel 1x10⁶ gain due to max/min ratio of 3



Gain uniformity







Efficiency plots with TRB/DiRICH DAQ



- Normalized number of main peak events at every position
- Threshold: ~20-30%
 of single photon peak
- Important for experimental setup
- Combined information of gain, QE & CE







9002222







Threshold scan with TRB/DiRICH DAQ



- Calculated threshold for single photon peak for every pixel
- S.p.p of pixel x4 y5 taken for following surface scans on next slide
- S.p.p behaviour strongly correlated to gain distribution



Efficiency plots vs signal threshold



- Normalized number of main peak events at every position
- Different thresholds plotted for Photonis 9002223











CE & DQE



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	9002220	9002221	9002222	9002223	9002224
QE @ 372nm & x4 y5 [%]	20.2	23.8	21.5	19.1	21.8
CE [%]	95	80	88	87	90
DQE [%]	19.3	19.1	18.9	16.8	19.6

- 9002221 measured thrice ~80%
- 9002220 9002224 reach CE of 80 90%

Dark count rates with high PC-MCP voltage



- Dark count rates measured with TRB/DiRICH DAQ
- Important: different scales in z axis!
- Typical hot pixels at rims



Afterpulse ratio with high PC-MCP voltage



- Afterpulse probability measured with TRB/DiRICH DAQ
- Something wrong with 9002221?
 - Explanation shown on next slide



map

afterpulse pixel

.5

0.5

Afterpulse ratio with high PC-MCP voltage



- Afterpulse probability measured with TRB/DiRICH DAQ
- Something wrong with 9002221?
- Significantly higher count rates in afterpulse timing regime
- Additional peaks also seen with scope with completely different setup (PCBs, cables, DAQ)
- Next step: reproduce with digitizer & use of HV without divider







10² 10 50 100 150 200 250 300 350 400 450 500 550 lead time [ns]

9002224



σ timing with high PC-MCP voltage



8 -106

6

3

-87

78

82

88

2 3

9002222

90 95 85

98 95

5 6

96 101

81 78 83

85 86 100

91

99 96

82 82

83 82 83

83 84 88 86

84 93

93

map

15

95

90

85 80

75

101

x-pixel

- 4:10:1 divider
- σ timing measured with TRB/DiRICH DAQ
- σ timing <100 ps for
 >90% of all pixels for combined tube-DAQ system and over full pixel area

				v	OOLL	-0								
pixel	8 -98	94	92	91	90	90	87	93	_	120 g	pixel	8	100	100
∽	7 87	78	78	81	78	78	80	91	-	110 X	Υ	7	-86	79
	6 85	80	79	80	79	79	79	92	-	105 🔲		6	-88	81
	5 89	81	79	79	82	77	81	90	-	100 .ஜ 02		5	96	83
	4 90	81	83	79	79	80	81	93	_	90		4	89	87
	3 -98	89	82	81	82	86	81	86	-	85		3	96	88
	2 91	83	81	81	87	81	81	97	-	80		2	100	86
	1-99	89	97	94	98	93	93	108		75		1	- 110	97
	1	2	3	4	5	6	7	8 -nivol		-70			1	2
								-pixei						
				9	0022	23				100				
pixel	8 -99	94	93	97	97	97	99	117	_	120 g 115 E	pixel	8	-99	96
∽	7 98	92	90	92	88	91	88	105	-	110 .xe	~	7	-88	76
	6 92	90	96	92	85	87	90	105	-	105 g		6	-88	79
	5 -95	91	85	89	87	89	89	98	-	100 ອີ		5	93	82
	4 96	91	88	87	84	86	87	99	_	90		4	-88	83
	3 94	85	82	80	87	85	84	93	-	85		3	97	90
	2 93	86	82	80	85	88	78	96	-	80		2	-99	86

9002220

92 88 95

5

6

8

x-pixel

4

2 3

1

100	100	100	95	95	105	102	111	120 de la
86	79	86	85	84	80	85	100	-110 ×
88	81	83	87	85	87	85	97	-105 gg
-96	83	86	86	90	87	88	97	–100 [.] ⊛
-89	87	86	84	83	88	91	99	-95 -90
96	88	85	85	89	91	85	94	-85
100	86	84	85	91	87	87	99	<mark>-</mark> 80
1110	97	94	93	99	99	94	103	-75
1	2	3	4	5	6	7 X	8 -pixel	- −70

	9002224													
	-		20 <u>a</u>											
8	-99	96	94	92	86	86	93	104	-	115 ⁸				
7	-88	76	83	84	78	75	83	96		i 10 ja				
6	-88	79	81	87	82	82	82	95	- 1	05 g				
5	-93	82	89	85	87	86	88	91	1	ରି: 00				
4	-88	83	90	85	80	87	89	91	-9	95				
-						•.			-9	3 0				
3	-97	90	85	87	91	90	81	92	-	35				
2	-99	86	86	87	88	82	86	93	-8	30				
1	102	92	94	94	87	87	91	98		75				
	1	2	3	4	5	6	7	8		<i>'</i> 0				

x-pixel

σ timing with low PC-MCP voltage as comparison Panda

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x-pixel

- y-pixel sigma pixel map y-pixel • 1:10:1 divider • σ timing measured with TRB/DiRICH not measured yet DAQ • σ timing <100 ps for >90% of all pixels for x-pixel combined tube-DAQ 120 da 115 lug 110 jug 110 jug system and over full y-pixel map y-pixel 8-114 pixel pixel area sigma
- No major changes in timing



120 dam 115 110 110 sigma bixel mab 100 sigma bixel mab

x-pixel

RMS timing with high PC-MCP voltage

6 170

5 179

4 182

151 154

2

156

151 152 154 150 151 147 167

153 154 155 154 **150**

193 198 203 210

152 150 150 150 148 171

150 153 153 150 169



9002222

161 162 161 160 159 173

158 157 160 164 157 178

157 158 158 181

158 161 162 159 156

158 159 162 163 160 159 174

159 156 157 160 159 154 180

180 186 188 183 184

5 6

158 162

161

184 178 178 178 184 174

- 4:10:1 divider
- RMS timing measured with TRB/DiRICH DAQ
- Time window:
 -0.5 +2 ns around main peak
- RMS timing <200 ps for >95% of all pixels for combined tube-DAQ system and over full pixel area

9002220													
	8	189	181	183	179	175	175	181	182	220 g	lovice lovice		
	7	176	153	153	153	152	151	154	179	210 la	;		
	6	174	153	151	152	153	152	153	191	190 É			
	5	178	154	152	154	153	152	157	175	180			
	4	177	151	151	151	151	154	157	180	170			
	3	194	154	152	150	151	154	154	182	-160			
	2	175	152	150	150	151	153	154	178	-150			
	1	189	174	175	176	180	181	181	199	140			
		1	2	3	4	5	6	7 x·	8 -pixel				
					9	0022	23						
	8	192	177	191	192	179	175	180	196	220 de m	lovio		
		-								-210 -	-		

150 149 147 173

rms pix

200

190

180

170

160

150

140

176

205

8 x-pixel

207

~~~~~



9002224

| 0            | -                |     |     |     |     |     |     |        | 220 <u>_</u>      |
|--------------|------------------|-----|-----|-----|-----|-----|-----|--------|-------------------|
| . <u>×</u> 8 | 238              | 197 | 207 | 207 | 189 | 203 | 194 | 221    | na                |
| Υ-Ρ          | _                |     |     |     |     |     |     |        | -210 <del>_</del> |
| 7            | 202              | 148 | 151 | 154 | 149 | 148 | 149 | 175    | jx,               |
| ~            | 407              |     | 450 | 450 | 454 |     |     | 100    | -200 <u>s</u>     |
| 6            | =197             | 146 | 150 | 153 |     | 147 | 145 | 168    | 100 E             |
| 5            | 182              | 146 | 152 | 154 | 150 | 147 | 148 | 167    | -190              |
| 5            | - 102            | 140 | 132 | 134 |     | 147 | 140 | 107    | -180              |
| 4            | 182              | 147 | 151 | 152 | 148 | 147 | 147 | 172    | 100               |
|              |                  |     |     |     |     |     |     |        | -170              |
| 3            | 184              | 146 | 149 | 150 | 149 | 147 | 143 | 169    |                   |
|              | E                |     |     |     |     |     |     |        | -160              |
| 2            | <del>_</del> 190 | 147 | 145 | 147 | 146 | 146 | 145 | 169    |                   |
|              | Face             |     |     |     |     |     |     | 100    | -150              |
| 1            | 208              | 183 | 194 | 173 | 178 | 192 | 171 | 188    | 140               |
|              | 1                | 2   | 3   | 4   | 5   | 6   | 7   | 8      |                   |
|              |                  |     |     |     |     |     | ×۰  | -pixel |                   |

rms pixel map

210

200

190

180

170

160

150

140

8

x-pixel

#### **RMS timing with low PC-MCP voltage**





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by factor of ~2

#### Means of TRB scans



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|                                                       | 9002220 |     | 9002221 |     | 9002222 |     | 9002223 |     | 9002224 |     |
|-------------------------------------------------------|---------|-----|---------|-----|---------|-----|---------|-----|---------|-----|
| Dark count rate [Hz/cm <sup>2</sup> ]                 | 2100    |     | 2195    |     | 1870    |     | 247     |     | 558     |     |
| Afterpulseratio p. pixel [%]                          | 2.      | 0   | 18      | 8.8 | 1       | .8  | 0.7     |     | 0.7     |     |
| TTS low voltage p. pixel [ps]                         |         |     | 91      |     | 90      |     | 92      |     | 94      |     |
| TTS high voltage p. pixel [ps]                        | 8       | 6   | 91      |     | 90      |     | 92      |     | 88      |     |
| RMS low voltage p. pixel<br>(inner/ outer area) [ps]  |         |     | 330     | 343 | 307     | 354 | 304     | 329 | 305     | 341 |
| RMS high voltage p. pixel<br>(inner/ outer area) [ps] | 153     | 181 | 155     | 172 | 159     | 186 | 151     | 186 | 148     | 189 |

#### Effects seen in escalation mode summary



- B-field measurements showed strange effects ("escalation") when decreasing field to 0 T, first observed in fall 2020
- Start of "escalation" depends on gain and/or illumination conditions
- List off effects seen during "escalation":
  - Higher current across the MCPs (factor >3)  $\rightarrow$  resistivity drop
  - Seems to have no equilibrium state, steady increase of currents
  - High (dark) count rate and high anode current
  - Smaller signals  $\rightarrow$  gain drop
  - photon creation
  - Effects appear to be less serious inside magnetic field
- Escalation behaviour only appears with latest Photonis tubes

# By optimizing the ALD process Photonis was able to shift the "escalation" camera starting point to higher gains for 9002221-9002224







Reason: photon creation inside

the MCP-PMT, can be seen with camera or even bare eyes



photo of PMT before operation and during escalation mode



# Voltage divider discussion

GEFORDERT VOM



Bundesministerium für Bildung und Forschung

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#### **Rate capability**

- FRIEDRICH-ALEX pan)da UNIVERSITÄT FAKUI ΤÄΊ photons /  $cm^2$  s (at 10<sup>6</sup> gain) 10<sup>2</sup>  $10^{3}$  $10^{4}$ 2220 1:10:1 2220 4:10:1 2221 1:10:1 2221 4:10:1 0.9 2222 1:10:1 2222 4:10:1 0.8 2223 1:10:1 2223 4:10:1 0.7 2224 1:10:1 2224 4:10:1 0.6 10<sup>3</sup> 10<sup>5</sup> 10<sup>2</sup> 10<sup>4</sup> 10<sup>6</sup> 10
- Curves plotted for both voltage dividers
  Dependencies not yet visible

gain

elative

- → need to improve evaluation method
- Dips in some curves (e.g. 9002220, 4:10:1) not fully understood yet but DAQ related (about to disappear soon)

current/area [pA/cm<sup>2</sup>]

#### **Dark currents vs voltages**



- Dark current measurement for different PC & MCP voltage combinations
- At some point all tubes are switching into high dark current mode
- Further investigations ongoing







