1. Results of the B-field measurements
2. Comparison of the MCP-PMTs for Barrel-DIRC tendering process

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Online Meeting, 27.10.2020

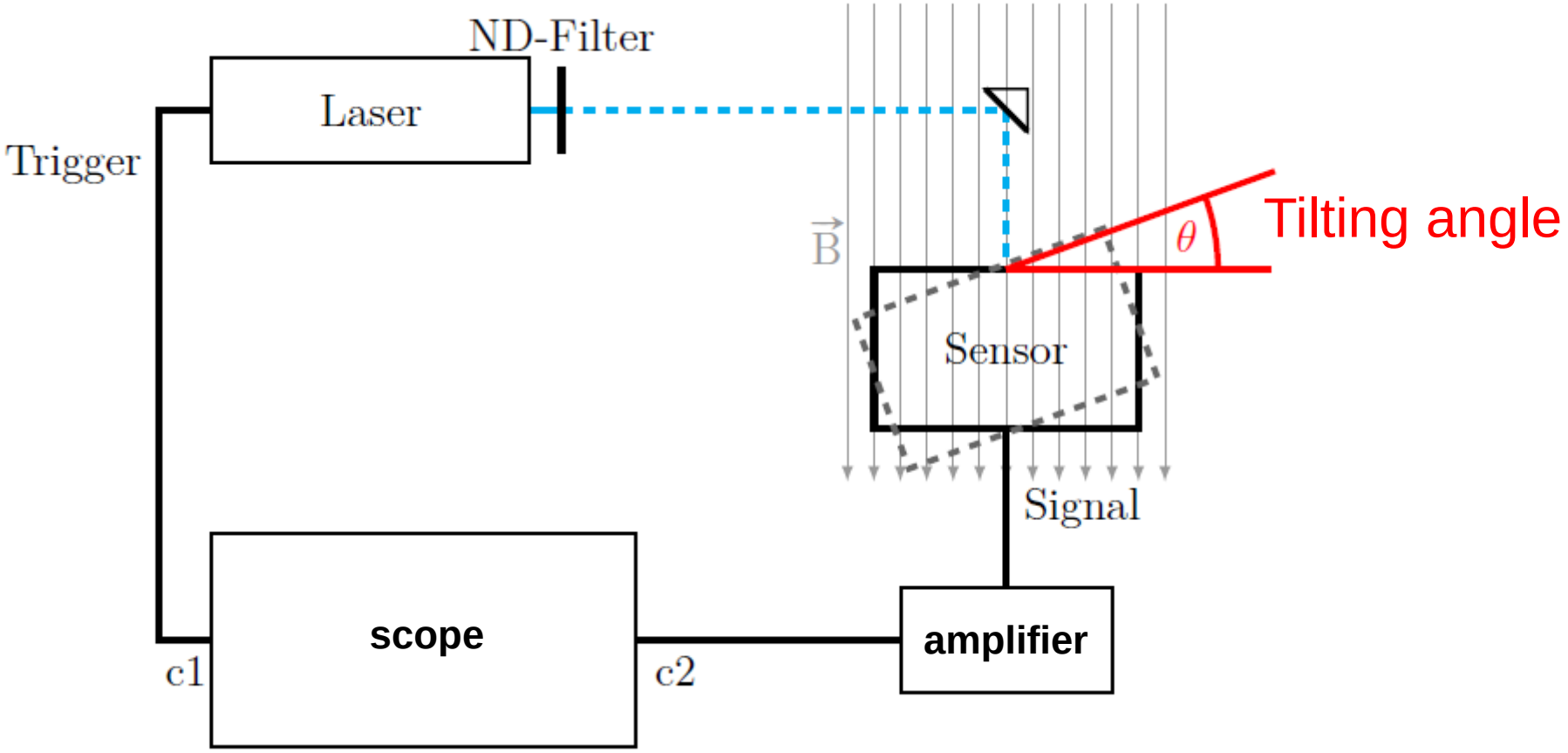
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

B-field measurements Jülich

	Tube	Tilt angle (all 5° steps)	Gain range @ 0T	Voltage (100 V steps)
Photonis 8x8:	**9002192** **9002193**	**0° - 17.5°**	**1,3e6 – 5,8e6** **1,5e6 – 5,1e6**	**2500 – 2700** **2400 – 2600**
Photek 8x8:	**A1200107** A1200116 A2200606 **A3191220**	**0° - 20°**	**1,4e6 – 5,8e6** 8e5 – 4,5e6 1,5e6 – 5e6 **5,8e5 – 2,4e6**	**2400 – 2600** 2560 – 2760 2700 – 2800 **2200 – 2400**

- Marked tubes are official tendering tubes
- Different tilting angles due to size of tubes (Photonis 8x8 thicker than Photek)

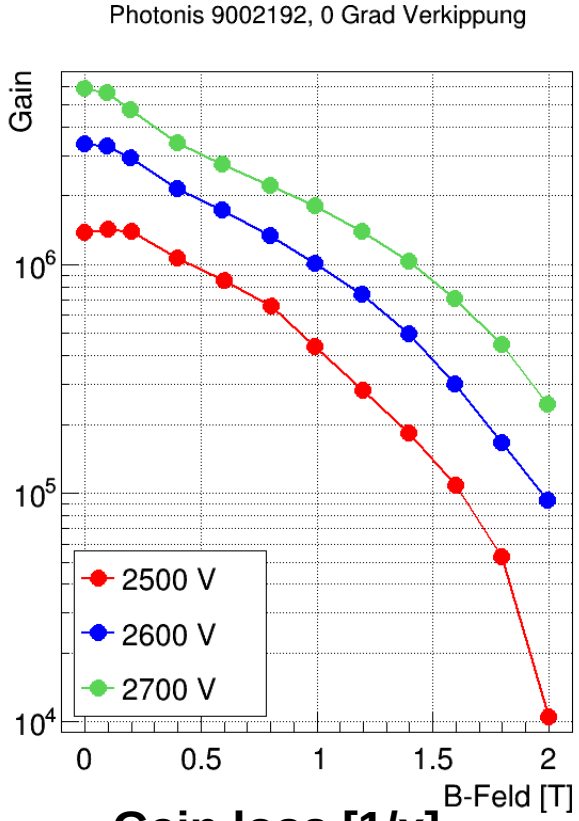
B-field measurements - Setup

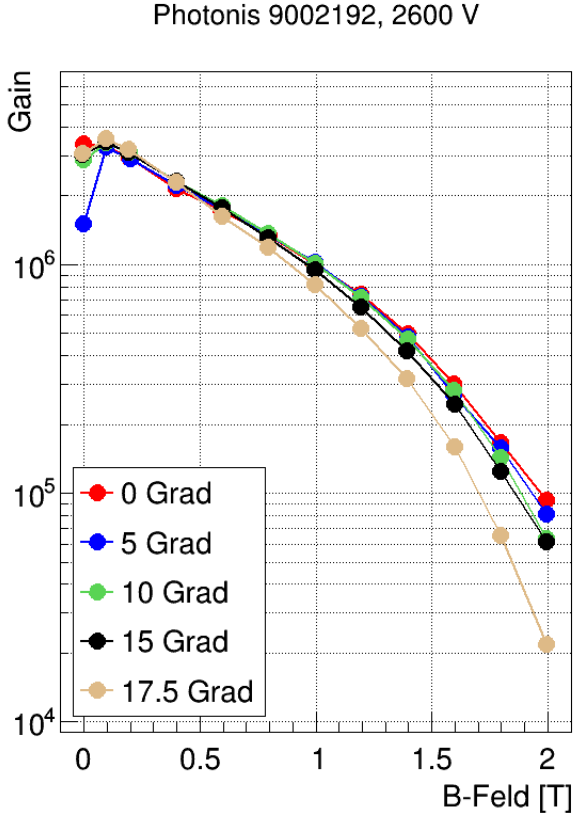


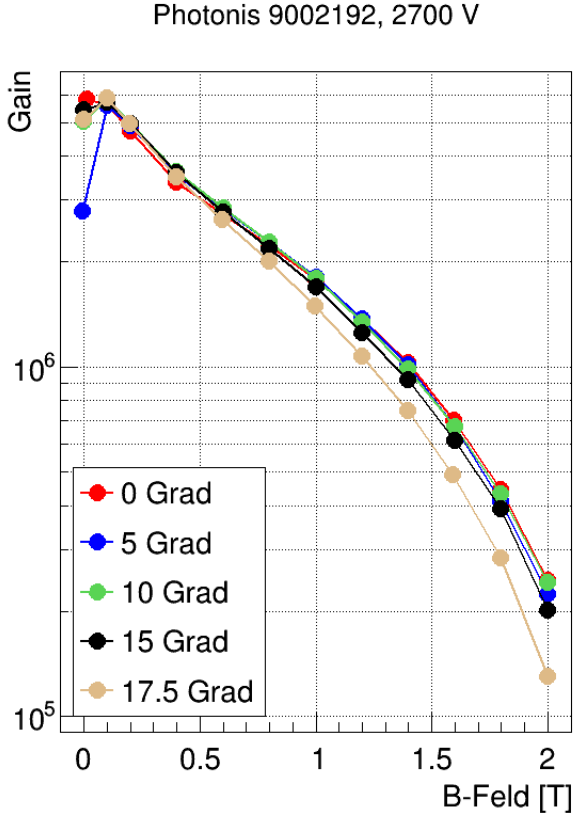
Measuring pulseheight distribution → calculating gain

Photonis 9002192 (8x8):

B-field measurements – results





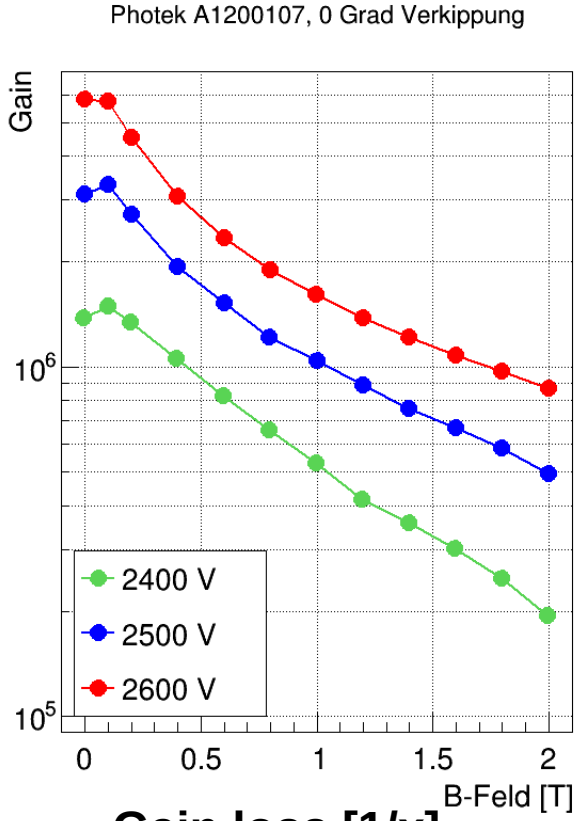


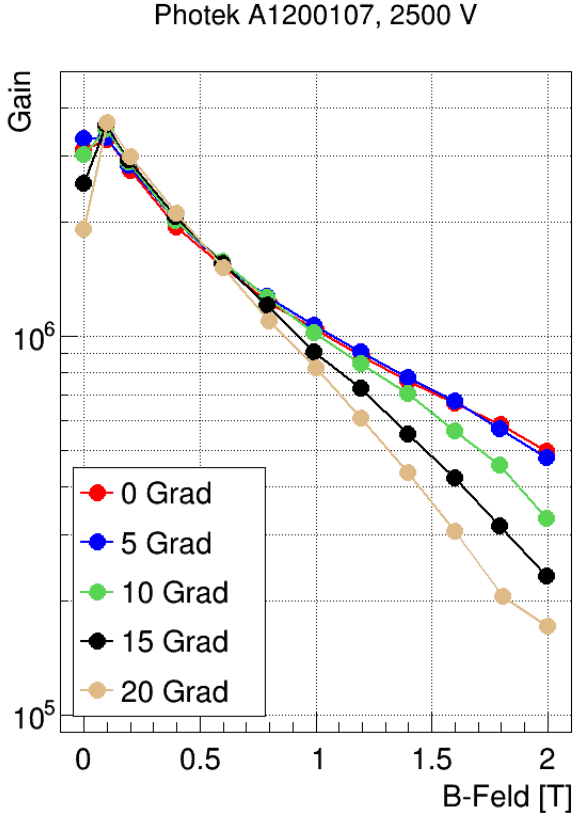
Gain loss [1/x]:

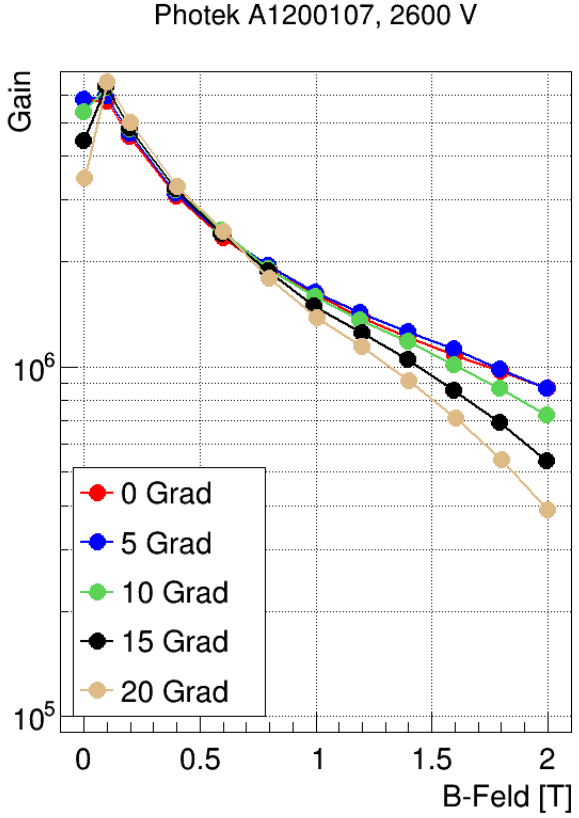
Tube	0 - 1T, 0°	1 - 2T, 0°	1T, 0 - 17.5°	2T, 0 - 17.5°
9002192	3,3	20	1,2	3,1
9002193	2,7	16	1,2	1,9

Photek A1200107 (8x8):

B-field measurements – results







Gain loss [1/x]:

Tube	0 - 1T, 0°	1 - 2T, 0°	1T, 0 - 20°	2T, 0 - 20°
A1200107	3,1	2,2	1,2	2,6
A3191220	1,9	2,3	1,2	2

TRB-Scans Jülich part 1

- We did some TRB-Scans in b-field, not analysed yet
- In the following describing the days of TBR-Measurements

- Some big problems occured:
  - Did xy-DiRICH scan with applied b-field for Photek A1200107
  - After switching off the b-field the countrates increased from few kHz to few MHz → all used DiRICH boards were destroyed (4 in total)

Measured spikes of 1 - 2 V amplitude
→ Reason for DiRICH dying

TRB-Scans Jülich part 2

- Switching to Padiwa 3 FEE, countrates still magnitude of MHz per pixel !!
- Changing MCP-PMT, now A1200116 used → all measurements worked well, no escalating

- Now switched to Photonis 9002193
- After switching on an off b-field countrates increased to some MHz, no explanation (checked light, different boards, cables, HV,…)
- Changed tube → Photonis 9002192
- At first no problems → did xy-scan with magnet switched off
- Switched on magnetic field, countrates still okay → x-scans, xy-scans
- Switch off b-field → after few minutes countrates increased to MHz
- Switch on b-field (1 – 1.5 T) → after few minutes countrates decreased to normal values (some kHz)
- Slowly decreasing b-field and watching countrates → stable for fields to 20 mT
- But 0 mT → countrates increasing to MHz

TRB-Scans Jülich part 3

- Switched off tube and b-field for few hours → no change in countrates for 0mT
- Put tube out of measuring box and rebuilt in → no change in countrates for 0mT
- Changed polarity of b-field → no change
- Tried to scan on a desk ~ 2 meters distance from magnet → no change

- Back in Erlangen did xy-scan about 1 week after Jülich for 9002192 & 9002193 → scans worked well

- BUT!! CE after Jülich (showed by Daniel) decreased of factor 3 – 4
- Conclusion:
  - No idea what happened with tubes in b-field!
  - Perhaps Jülich incidents and decreased CE after Jülich are correlated?!?

- **We will further analyse and investigate but are confused**

Summary B-field measurements

- Photonis 8x8:
  - Behaving like older 10 µm ald-coated MCP-PMTs, as expected
  - Strange behaviour after putting on and off magnetic field, no idea why
  - Will be under investigation, maybe reason for CE loss?!?

- Photek 8x8:
  - 6 µm MCPs no significant improvement for small magnetic fields (0 – 1T)
  - But much better in the range of higher fields up to 2 T

Pass/no pass criteria for Barrel DIRC tubes

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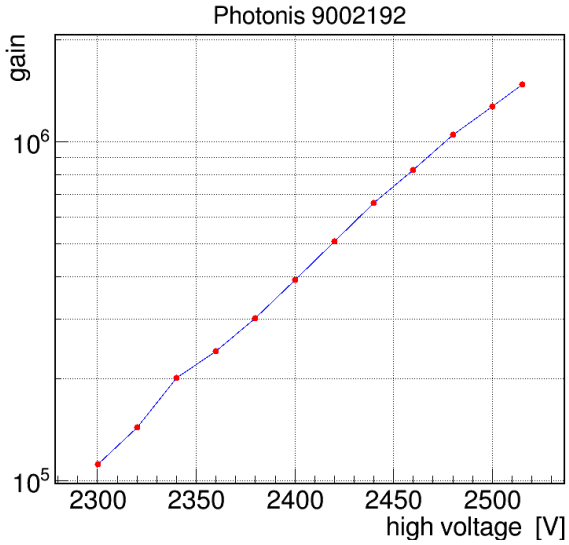
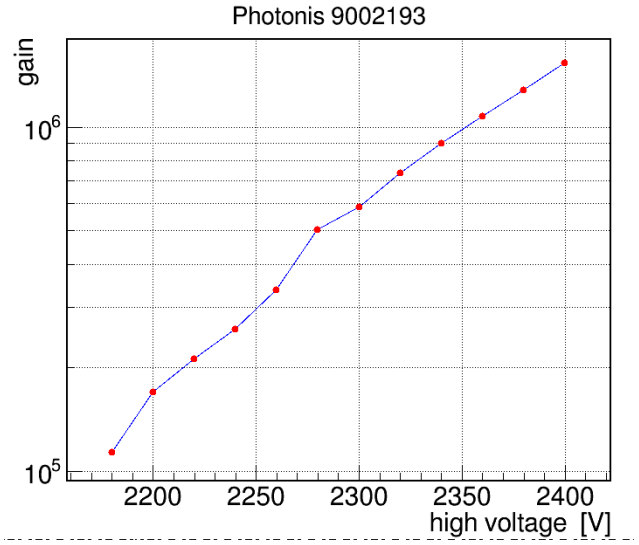
In the following just not passed parameters will be shown and explained why not passed

		Values					
		Second offer		Evaluation samples			
		Photek	Photonis	A1200107	A3191220	9002192	9002193
Active area ratio	>72%	OK	OK	74,1	74	76,6	79,8
Useful area	2''x2''	OK	OK	28,1	27,6	26,5	27,6
Number of pixels	64 (8x8)	OK	OK	OK	OK	OK	OK
Outer dimension	58mm x 58mm up to 62mm x 62mm	OK	OK	61,4x61,9	60,3x61,8	58,8x58,8	58,8x58,8
Front window material	sapphire of fused silica	OK	OK	OK	OK	OK	OK
Spectral range	starting at 290nm	OK	OK	>20%	>20%	>20%	>20%
Dark count rate	< 1kHz/cm^2	OK	OK	262,9	69	24	183
TTS	<= 50ps	OK	OK	40	36	26	27
RMS timing precision	150-200ps or better in -0.5…+2ns time window around main peak at standard operating voltage (less than 3.0 kV at B=0T)	OK	OK	215	199	109	109
Low afterpulsing	< 2% @10^6 gain	OK	OK	0,14	0,49	1,74	0,79
Gain	**at least 10^6 @ standard operating voltage (less than 3.0 kV at B=0T)**	**OK**	**OK**	**max Voltage**	**not reachable**	**2350V**	**2450V**
Rate capability	10% max gain loss at 0.5 MHz/cm^2@10^6 gain	OK	OK	1; 0,8	1; 0,95	0,92; 0,95	0,93; 0,95
Pulse height distribution	typical P/V>3 measured on the total area @10^6 gain (0T; 1T)	OK	OK	2,7; 7,1	2,2; 6	2,6; 3,6	3,2; 2,8
Peak quantum efficiency (QE) in 300-400 nm range	>= 18%	OK	OK	24,37	25,02	22,16	24,66
Collection efficiency (CE)	>= 65%	OK	OK	95,1	71,5	75,6	75,2
Detective quantum efficiency DQE = CE * QE	>= 12%	OK	OK	23,2	17,9	16,8	18,5
Gain uniformity	max/min ratio 3 or better	OK	OK	7,7	12,5	4,2	3,1
QE uniformity at peak wavelength	max/min ratio up to 1.15 in central sensor region (inner 2x2 pixels), up to 3 elsewhere	OK	OK	1,02; 1,92	1,04; 8,33	1; 1,28	1,01; 1,35
High magnetic field compatibility	≤10µm pores MCPs	OK	OK	6	6	10	10
Lifetime	<5% QE drop after 2 C/cm2 and <10% QE drop after 5 C/cm2 of integrated anode charge (IAC) at 400 nm (comment: will not be measured to full IAC during this evaluation)	OK	OK	-1,62	-1,94		

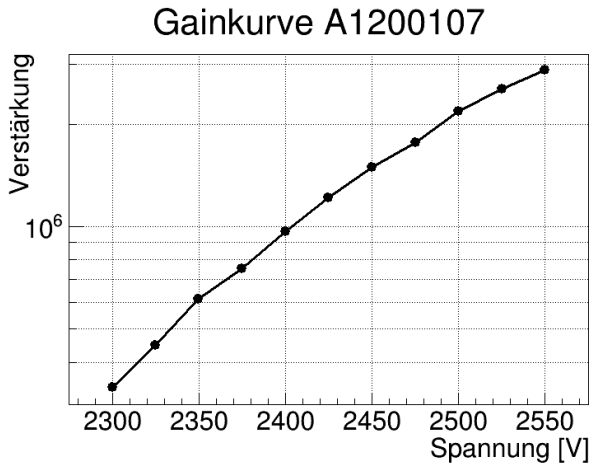
Gain vs voltage

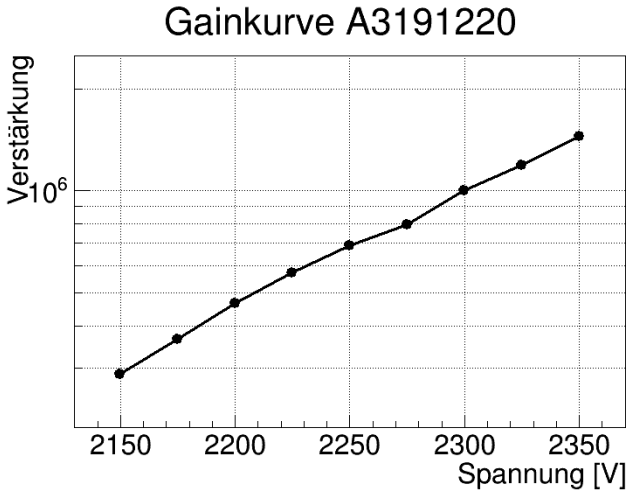




- Measured with scope at pixel x4 y5 (center pixel)

Tube	10^6 gain
9002192	2480 V
9002193	2350 V
A1200107	2400 V
A3191220	**2300 V**





Tube	Max U
9002192	2800 V
9002193	2800 V
A1200107	2550 V
A3191220	**2350 V**

Pass/no pass criteria for Barrel DIRC MCP-PMTs

		Values					
		Second offer		Evaluation samples			
		Photek	Photonis	A1200107	A3191220	9002192	9002193
Active area ratio	>72%	OK	OK	74,1	74	76,6	79,8
Useful area	2''x2''	OK	OK	28,1	27,6	26,5	27,6
Number of pixels	64 (8x8)	OK	OK	OK	OK	OK	OK
Outer dimension	58mm x 58mm up to 62mm x 62mm	OK	OK	61,4x61,9	60,3x61,8	58,8x58,8	58,8x58,8
Front window material	sapphire of fused silica	OK	OK	OK	OK	OK	OK
Spectral range	starting at 290nm	OK	OK	>20%	>20%	>20%	>20%
Dark count rate	< 1kHz/cm^2	OK	OK	262,9	69	24	183
TTS	<= 50ps	OK	OK	40	36	26	27
RMS timing precision	150-200ps or better in -0.5...+2ns time window around main peak at standard operating voltage (less than 3.0 kV at B=0T)	OK	OK	215	199	109	109
Low afterpulsing	< 2% @10^6 gain	OK	OK	0,14	0,49	1,74	0,79
Gain	at least 10^6 @ standard operating voltage (less than 3.0 kV at B=0T)	OK	OK	max Voltage	re[illegible]	2450 V	2350 V
Rate capability	**10% max gain loss at 0.5 MHz/cm^2@10^6 gain**	**OK**	**OK**	**1; 0,8**	**1; 0,95**	**0,92; 0,95**	**0,93; 0,95**
Pulse height distribution	typical P/V>3 measured on the total area @10^6 gain (0T; 1T)	OK	OK	2,7; 7,1	2,2; 6	2,6; 3,6	3,2; 2,8
Peak quantum efficiency (QE) in 300-400 nm range	>= 18%	OK	OK	24,37	25,02	22,16	24,66
Collection efficiency (CE)	>= 65%	OK	OK	95,1	71,5	75,6	75,2
Detective quantum efficiency DQE = CE * QE	>= 12%	OK	OK	23,2	17,9	16,8	18,5
Gain uniformity	max/min ratio 3 or better	OK	OK	7,7	12,5	4,2	3,1
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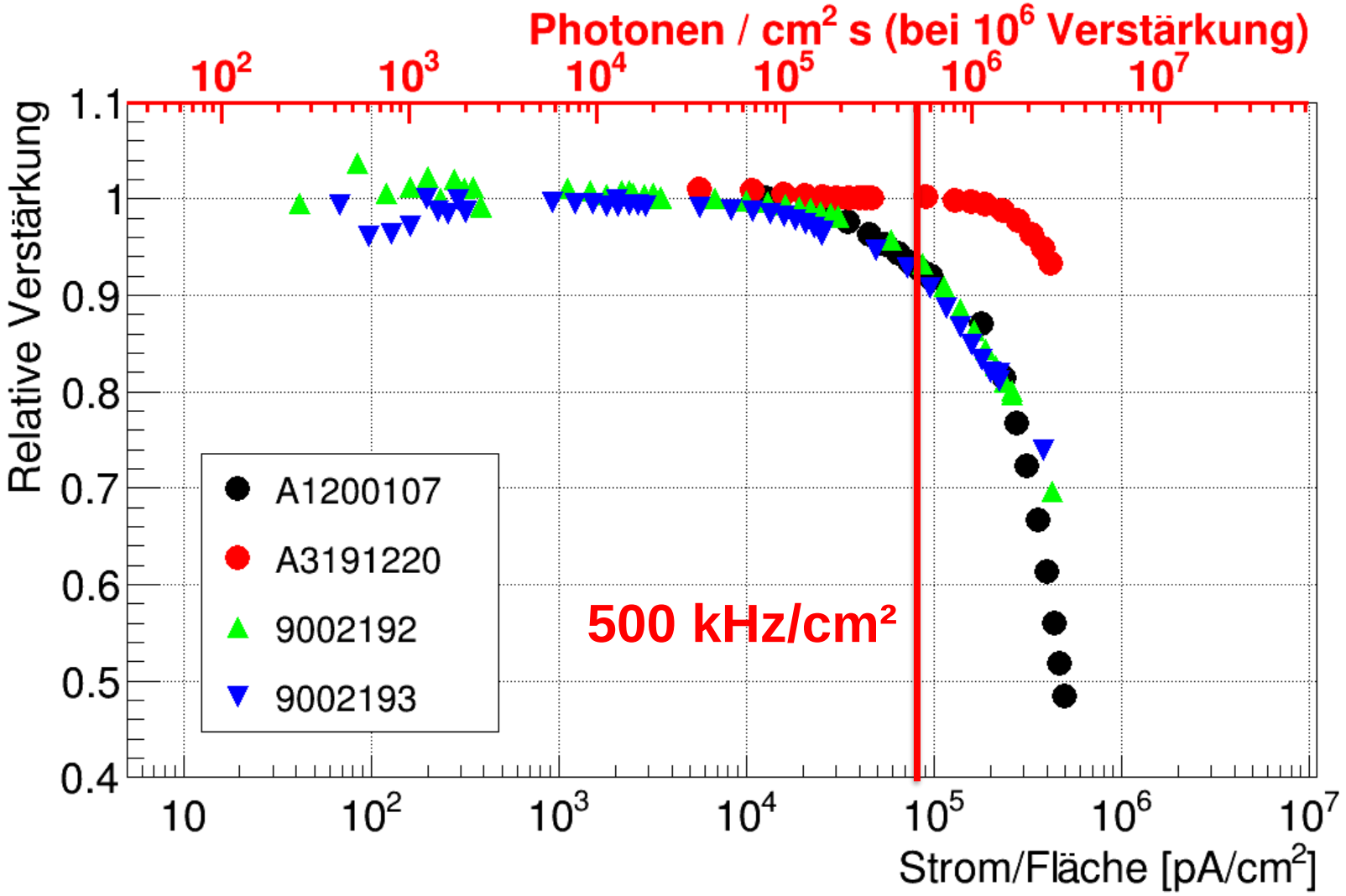
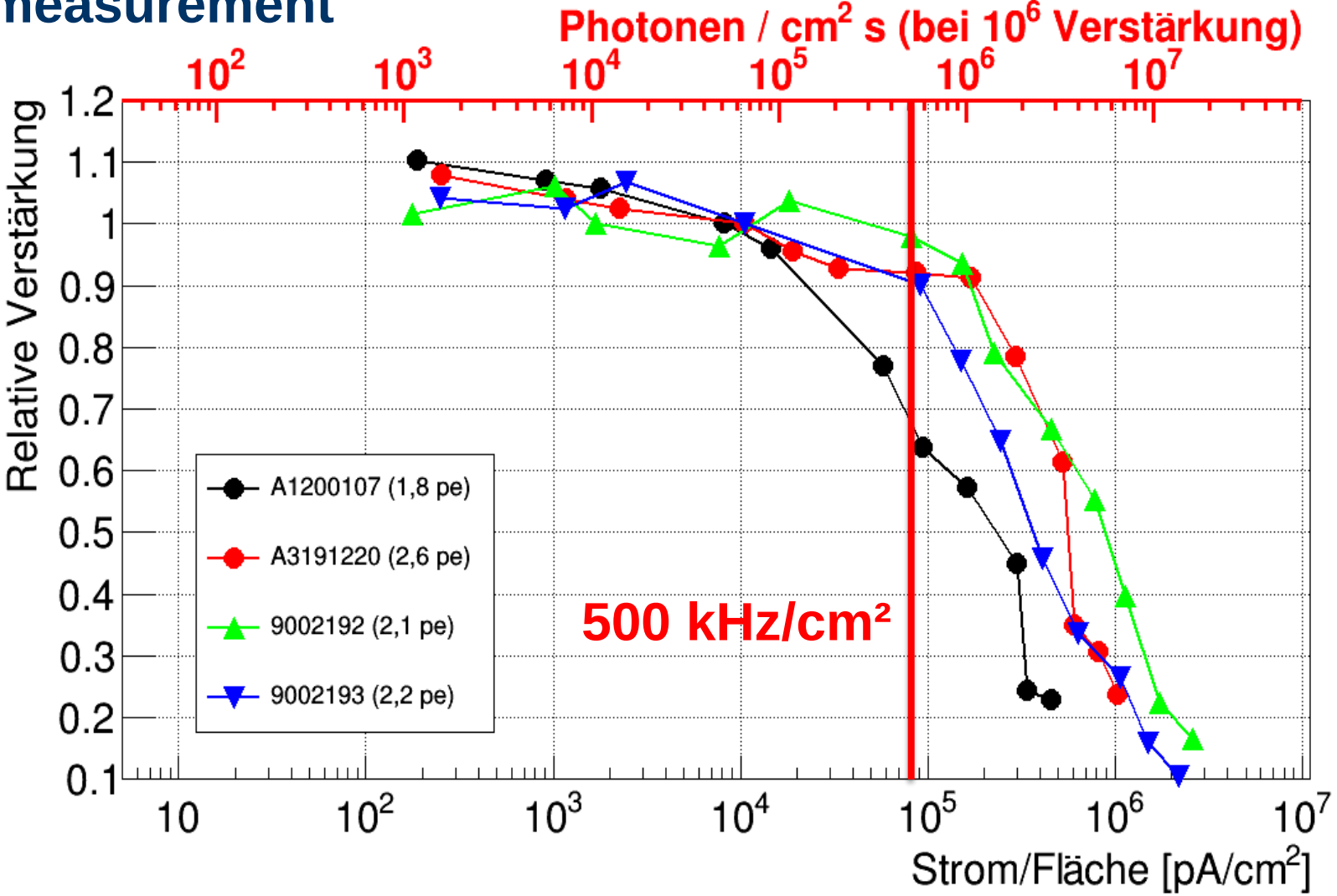
High magnetic field compatibility	≤10µm pores MCPs	OK	OK	6	6	10	10
Lifetime	<5% QE drop after 2 C/cm2 and <10% QE drop after 5 C/cm2 of integrated anode charge (IAC) at 400 nm (comment: will not be measured to full IAC during this evaluation)	OK	OK	-1,62	-1,94		

Rate capability whole tube, current measurement



Rate capability center pixel (pix x4 y5) pulse measurement



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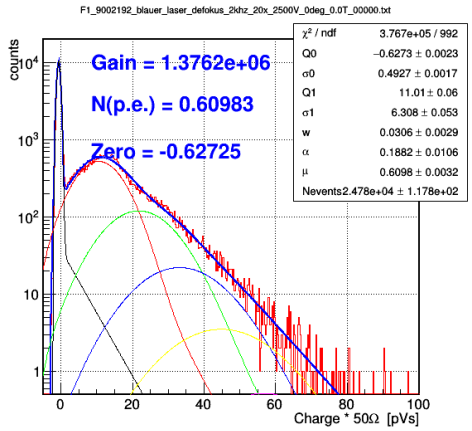
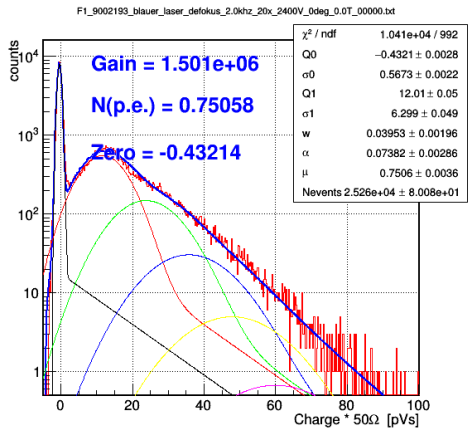
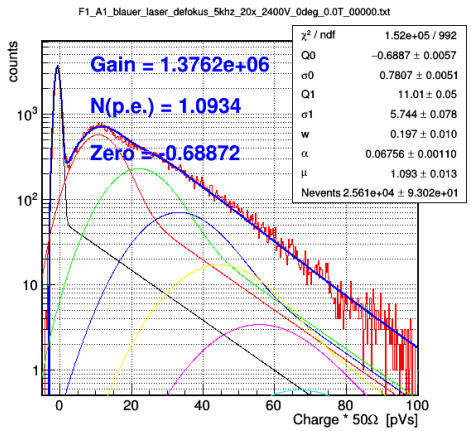
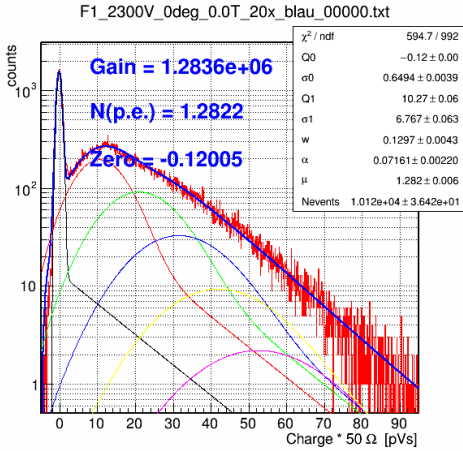
Pulse height distribution (Peak to valley ratio), 0 Tesla 0°





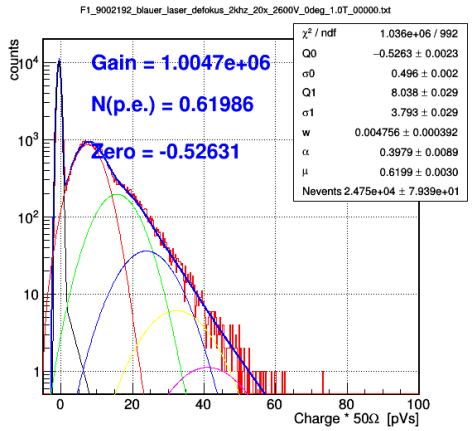


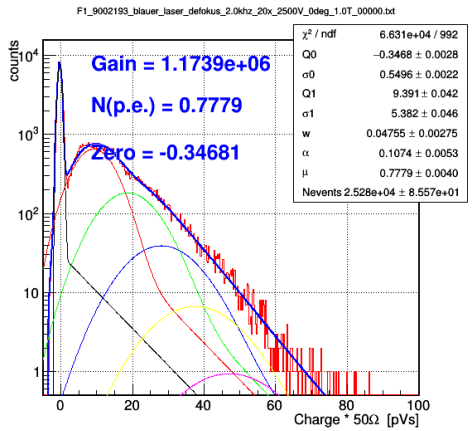


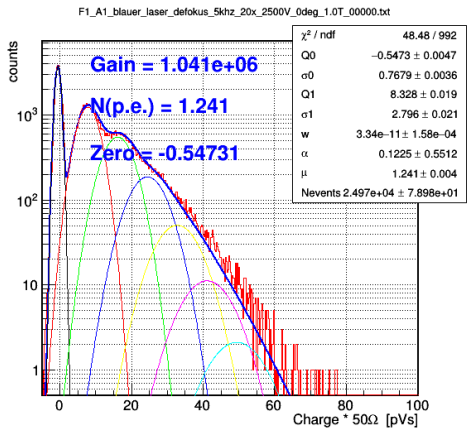
9002192 9002193 A1200107 A3191220

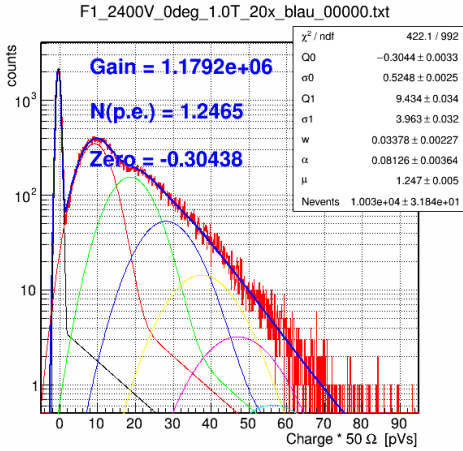
Tube	Voltage	Pixel	Gain	N_pe	Peak	Valley	P/V ratio
9002192	2500 V	x4 y7	1,3e6	0,6	600	230	2,61
9002193	2400 V	x4 y7	1,5e6	0,75	625	195	3,21
A1200107	2400 V	x4 y5	1,4e6	1,1	702	263	2,67
A3191220	2300 V	x5 y5	1,3e6	1,3	267	124	2,15

Pulse height distribution (Peak to valley ratio), 1 Tesla 0°









9002192 9002193 A1200107 A3191220

Tube	Voltage	Pixel	Gain	N_pe	Peak	Valley	P/V ratio
9002192	2600 V	x4 y7	1e6	0,62	936	262	3,57
9002193	2500 V	x4 y7	1,2e6	0,78	721	261	2,76
A1200107	2500 V	x4 y5	1e6	1,24	1302	184	**7,08**
A3191220	2400 V	x5 y5	1,2e6	1,25	392	65	**6,03**

Pass/no pass criteria for Barrel DIRC MCP-PMTs

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Front window material	sapphire of fused silica	OK	OK	OK	OK	OK	OK
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Rate capability	10% max gain loss at 0.5 MHz/cm^2@10^6 gain	OK	OK	~~1~~	1; 0,95	0,92; 0,95	0,93; 0,95
Pulse height distribution	typical P/V>3 measured on the total area @10^6 gain (0T,1T)	OK	OK	~~7~~; 7,1	~~2~~; 6	~~2~~; 3,6	3,2; ~~2~~
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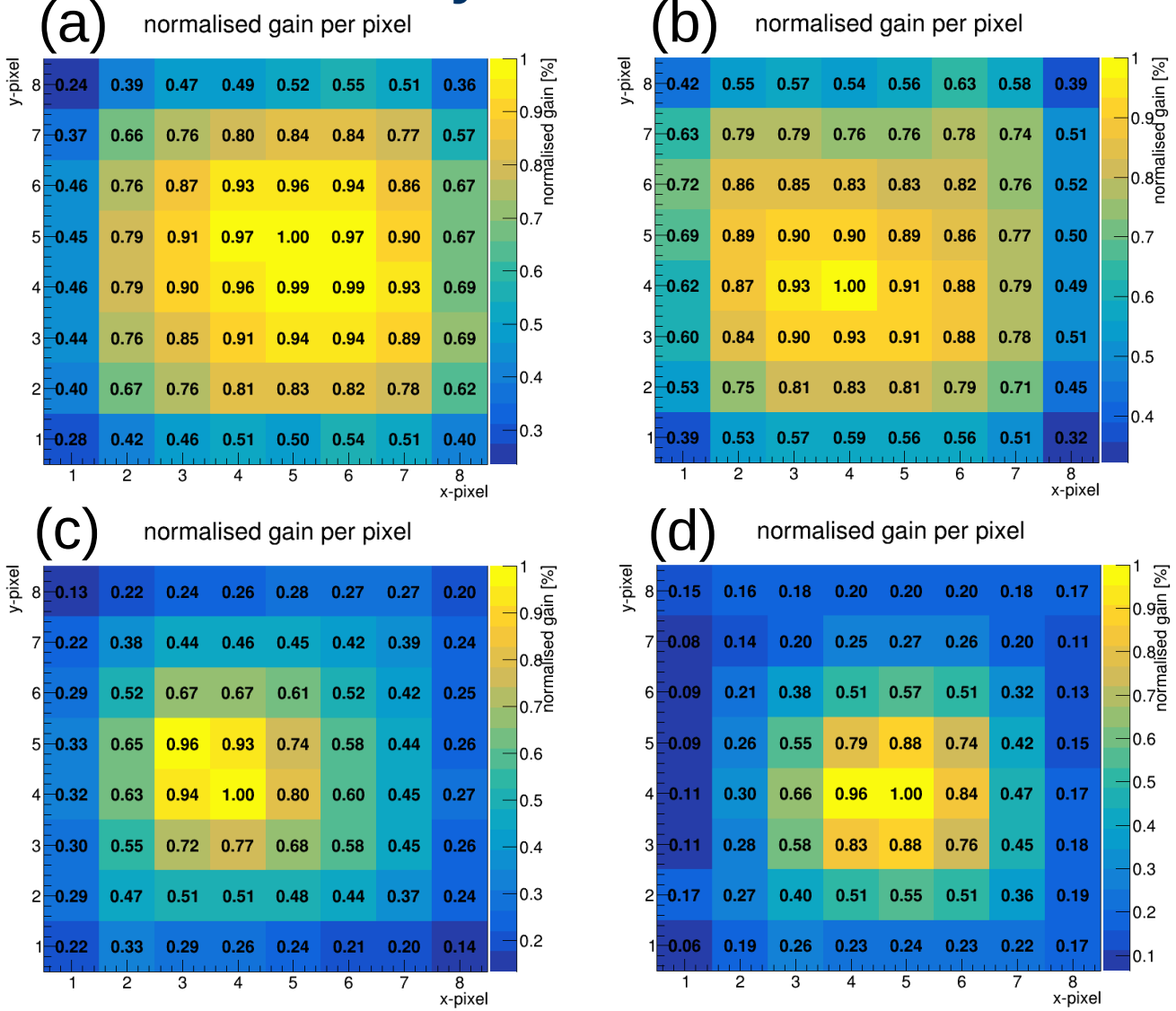
QE uniformity at peak wavelength	max/min ratio up to 1.15 in central sensor region (inner 2x2 pixels), up to 3 elsewhere	OK	OK	1,02; 1,92	1,04; 8,33	1; 1,28	1,01; 1,35
High magnetic field compatibility	≤10µm pores MCPs	OK	OK	6	6	10	10
Lifetime	<5% QE drop after 2 C/cm2 and <10% QE drop after 5 C/cm2 of integrated anode charge (IAC) at 400 nm (comment: will not be measured to full IAC during this evaluation)	OK	OK	-1,62	-1,94		

Gain uniformity



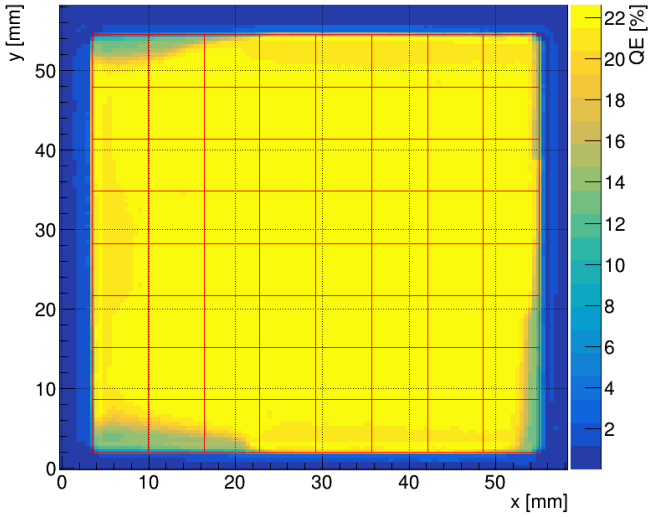
Tube	Max/Min ratio (all)
Photonis 9002192 (a)	4,2
Photonis 9002193 (b)	3,1
Photek A1200107 (c)	7,7
Photek A3191220 (d)	12,5

Pass/no pass criteria for Barrel DIRC MCP-PMTs

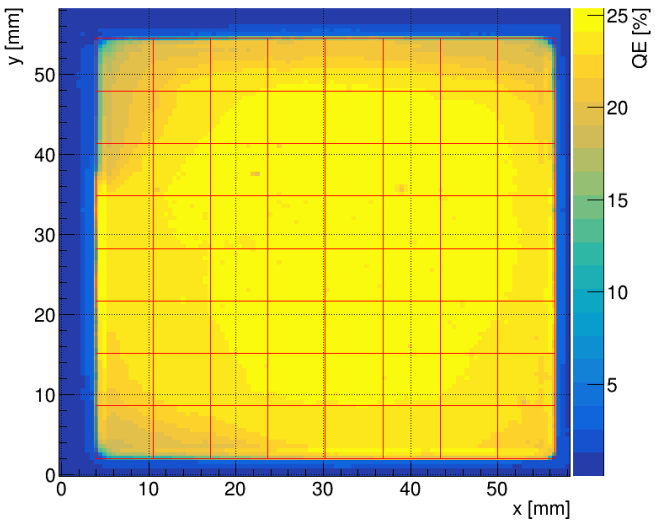
		Values					
		Second offer		Evaluation samples			
		Photek	Photonis	A1200107	A3191220	9002192	9002193
Active area ratio	>72%	OK	OK	74,1	74	76,6	79,8
Useful area	2''x2''	OK	OK	28,1	27,6	26,5	27,6
Number of pixels	64 (8x8)	OK	OK	OK	OK	OK	OK
Outer dimension	58mm x 58mm up to 62mm x 62mm	OK	OK	61,4x61,9	60,3x61,8	58,8x58,8	58,8x58,8
Front window material	sapphire of fused silica	OK	OK	OK	OK	OK	OK
Spectral range	starting at 290nm	OK	OK	>20%	>20%	>20%	>20%
Dark count rate	< 1kHz/cm^2	OK	OK	262,9	69	24	183
TTS	<= 50ps	OK	OK	40	36	26	27
RMS timing precision	150-200ps or better in -0.5...+2ns time window around main peak at standard operating voltage (less than 3.0 kV at B=0T)	OK	OK	215	199	109	109
Low afterpulsing	< 2% @10^6 gain	OK	OK	0,14	0,49	1,74	0,79
Gain	at least 10^6 @ standard operating voltage (less than 3.0 kV at B=0T)	OK	OK	max Voltage	re[illegible]le	2450 V	2350 V
Rate capability	10% max gain loss at 0.5 MHz/cm^2@10^6 gain	OK	OK	1	1; 0,95	0,92; 0,95	0,93; 0,95
Pulse height distribution	typical P/V>3 measured on the total area @10^6 gain (0T; 1T)	OK	OK	2[illegible]; 7,1	[illegible]2; 6	[illegible]6; 3,6	3,2; 2[illegible]
Peak quantum efficiency (QE) in 300-400 nm range	>= 18%	OK	OK	24,37	25,02	22,16	24,66
Collection efficiency (CE)	>= 65%	OK	OK	95,1	71,5	75,6	75,2
Detective quantum efficiency DQE = CE * QE	>= 12%	OK	OK	23,2	17,9	16,8	18,5
Gain uniformity	max/min ratio 3 or better	OK	OK			[illegible]	3,1
QE uniformity at peak wavelength	**max/min ratio up to 1.15 in central sensor region (inner 2x2 pixels), up to 3 elsewhere**	**OK**	**OK**	**1,02; 1,92**	**1,04; 8,33**	**1; 1,28**	**1,01; 1,35**
High magnetic field compatibility	≤10µm pores MCPs	OK	OK	6	6	10	10
Lifetime	<5% QE drop after 2 C/cm2 and <10% QE drop after 5 C/cm2 of integrated anode charge (IAC) at 400 nm (comment: will not be measured to full IAC during this evaluation)	OK	OK	-1,62	-1,94		

QE uniformity 0 Coulomb integrated Anode Charge

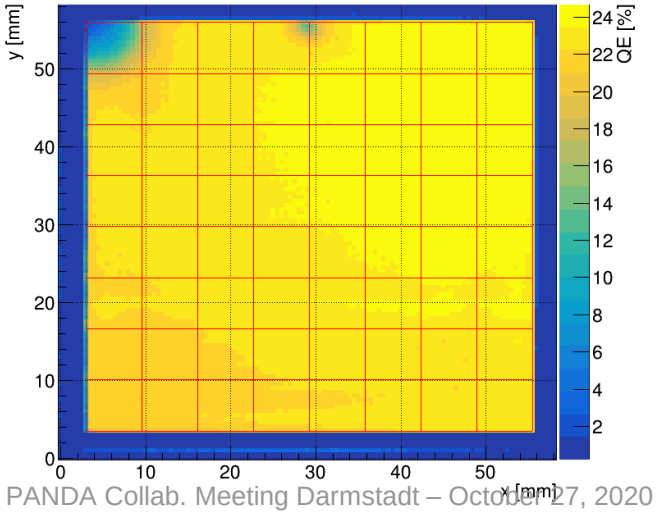
9002192_QE_pixelcut



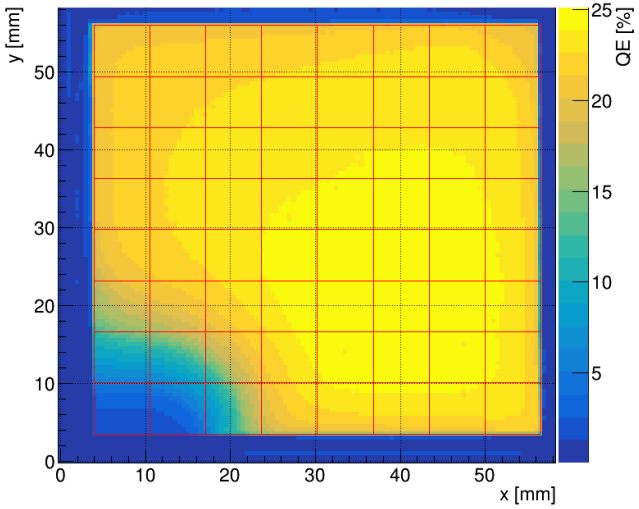
9002193_QE_pixelcut



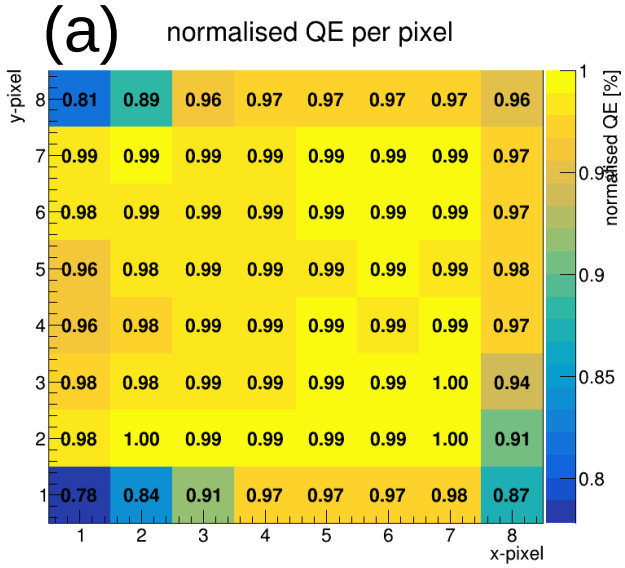
Photek_A1200107

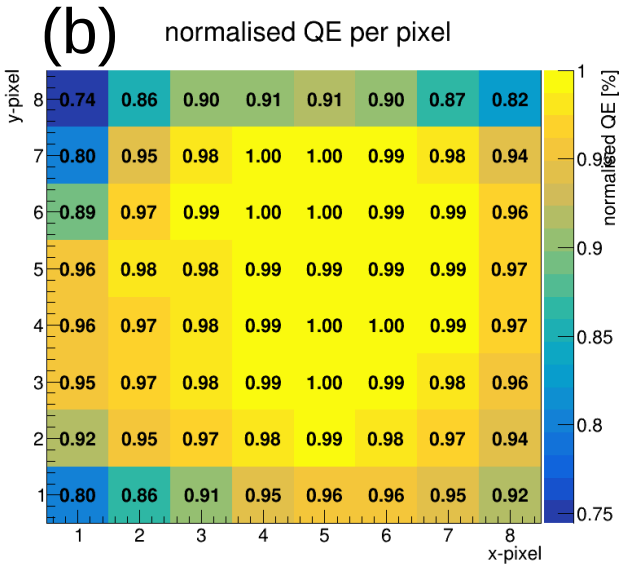


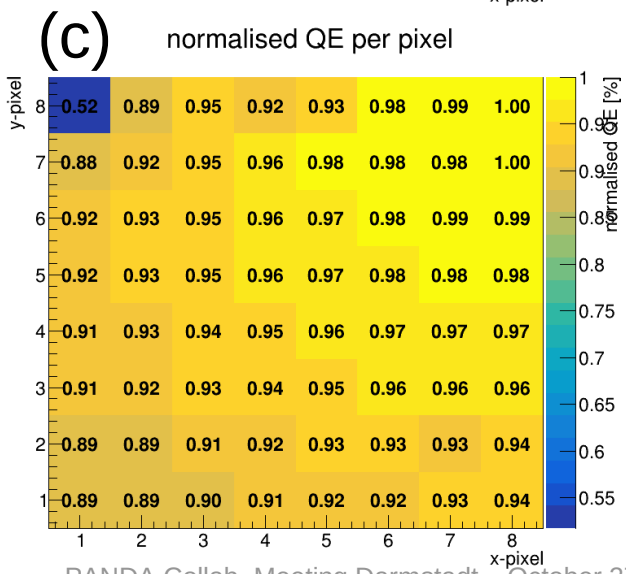
Photek_A3191220

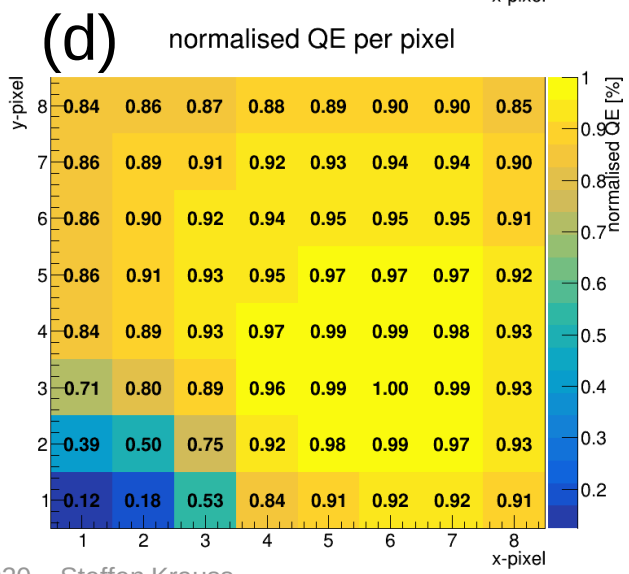


QE uniformity









Tube	Max/Min ratio (2x2; full)
9002192 (a)	1; 1,28
9002193 (b)	1,01; 1,35
A1200107 (c)	1,02; 1,92
A3191220 (d)	1,09; 8,33

Summary of all passed/ not passed criteria

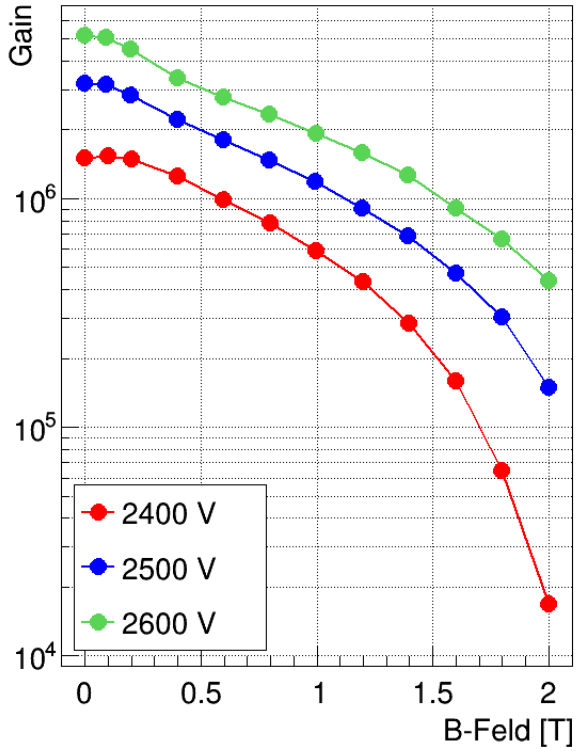
- Open for explainig/discussing all measured values
- Pretty clear which tubes are favourites

		Values					
		Second offer		Evaluation samples			
		Photek	Photonis	A1200107	A3191220	9002192	9002193
Active area ratio	>72%	OK	OK	74,1	74	76,6	79,8
Useful area	2''x2''	OK	OK	28,1	27,6	26,5	27,6
Number of pixels	64 (8x8)	OK	OK	OK	OK	OK	OK
Outer dimension	58mm x 58mm up to 62mm x 62mm	OK	OK	61,4x61,9	60,3x61,8	58,8x58,8	58,8x58,8
Front window material	sapphire of fused silica	OK	OK	OK	OK	OK	OK
Spectral range	starting at 290nm	OK	OK	>20%	>20%	>20%	>20%
Dark count rate	< 1kHz/cm^2	OK	OK	262,9	69	24	183
TTS	<= 50ps	OK	OK	40	36	26	27
RMS timing precision	150-200ps or better in -0.5...+2ns time window around main peak at standard operating voltage (less than 3.0 kV at B=0T)	OK	OK	215	199	109	109
Low afterpulsing	< 2% @10^6 gain	OK	OK	0,14	0,49	1,74	0,79
Gain	at least 10^6 @ standard operating voltage (less than 3.0 kV at B=0T)	OK	OK	max Voltage	re[illegible]le	2450 V	2350 V
Rate capability	10% max gain loss at 0.5 MHz/cm^2@10^6 gain	OK	OK	[illegible]	1; 0,95	0,92; 0,95	0,93; 0,95
Pulse height distribution	typical P/V>3 measured on the total area @10^6 gain (0T; 1T)	OK	OK	[illegible]; 7,1	[illegible]; 6	[illegible]; 3,6	3,2; [illegible]
Peak quantum efficiency (QE) in 300-400 nm range	>= 18%	OK	OK	24,37	25,02	22,16	24,66
Collection efficiency (CE)	>= 65%	OK	OK	95,1	71,5	75,6	75,2
Detective quantum efficiency DQE = CE * QE	>= 12%	OK	OK	23,2	17,9	16,8	18,5
Gain uniformity	max/min ratio 3 or better	OK	OK			4,2	3,1
QE uniformity at peak wavelength	max/min ratio up to 1.15 in central sensor region (inner 2x2 pixels), up to 3 elsewhere	OK	OK	1,02; 1,92	1,[illegible]33	1; 1,28	1,01; 1,35
High magnetic field compatibility	≤10µm pores MCPs	OK	OK	6	6	10	10
Lifetime	<5% QE drop after 2 C/cm2 and <10% QE drop after 5 C/cm2 of integrated anode charge (IAC) at 400 nm (comment: will not be measured to full IAC during this evaluation)	OK	OK				

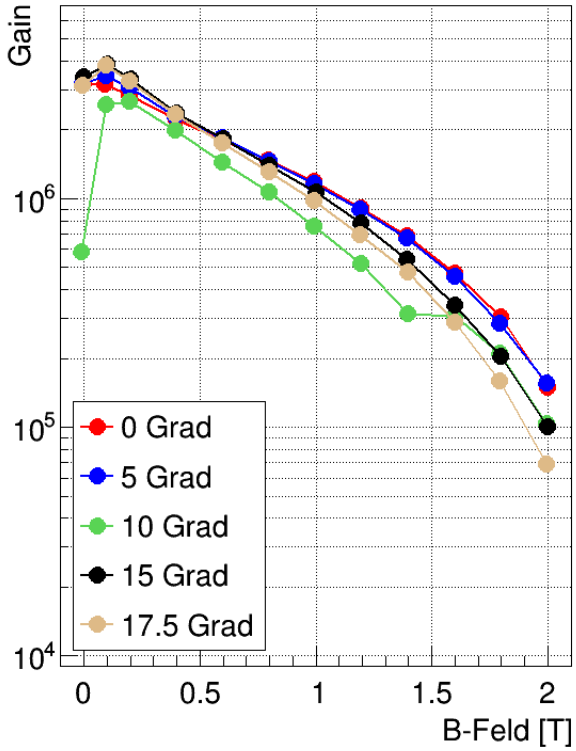
Backup

B-field measurements – results

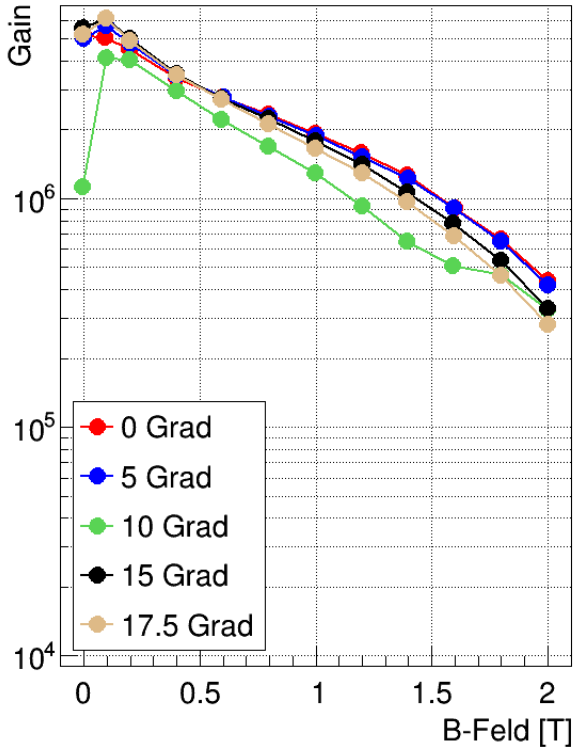
Photonis 9002193, 0 Grad Verkippung



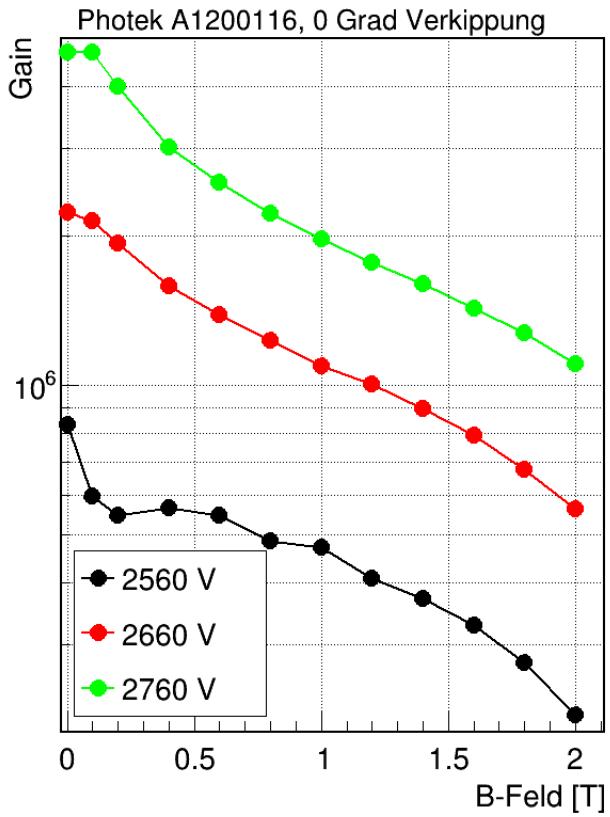
Photonis 9002193, 2500 V

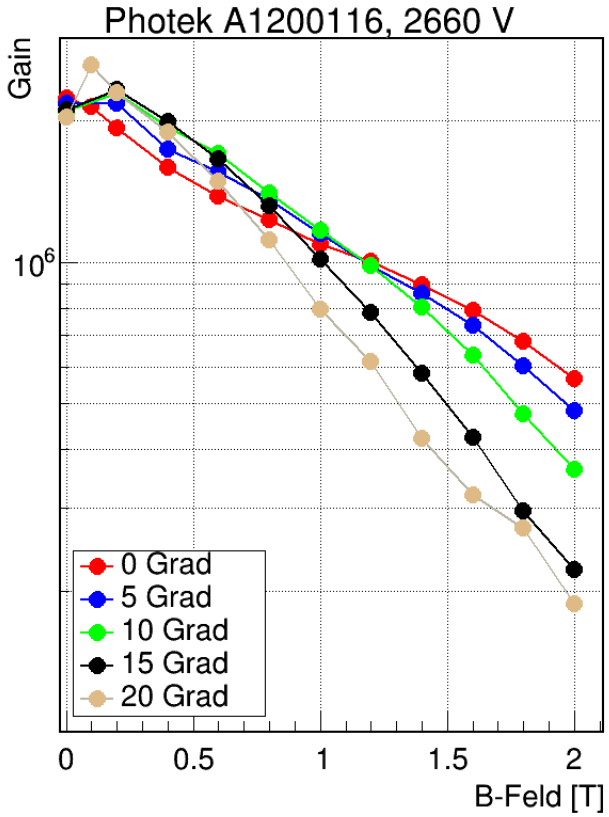


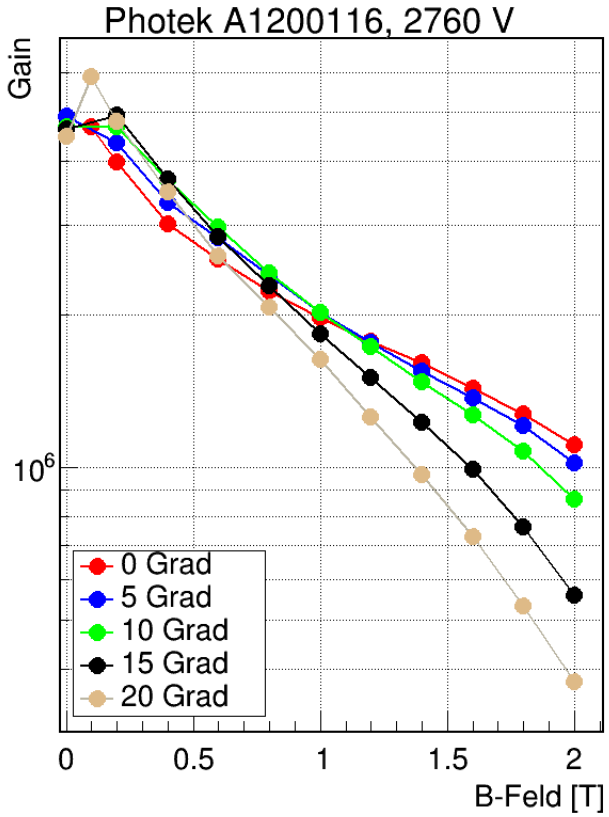
Photonis 9002193, 2600 V



B-field measurements – results

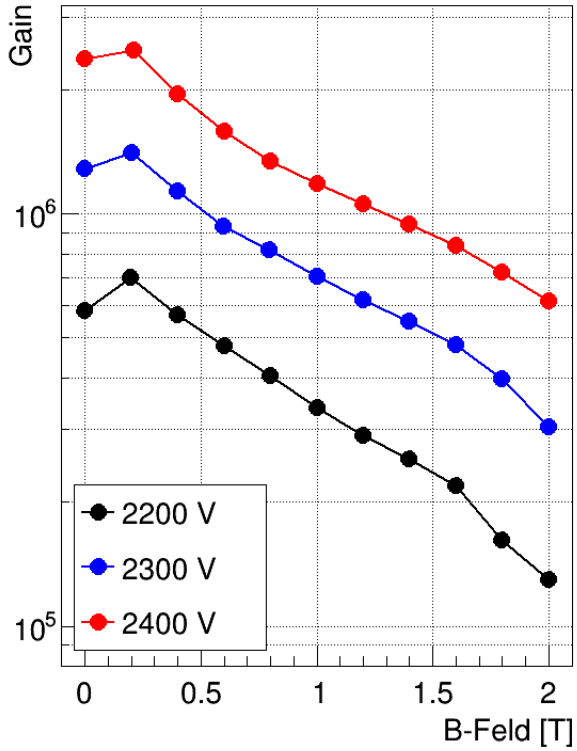




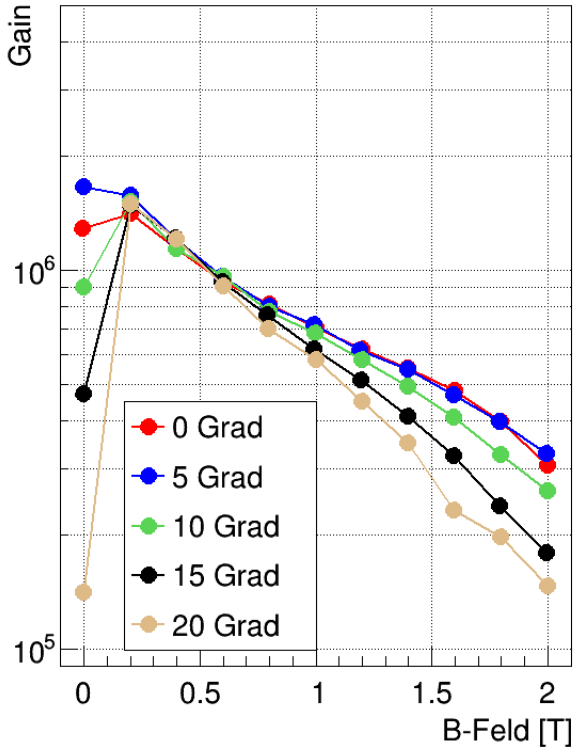


B-field measurements – results

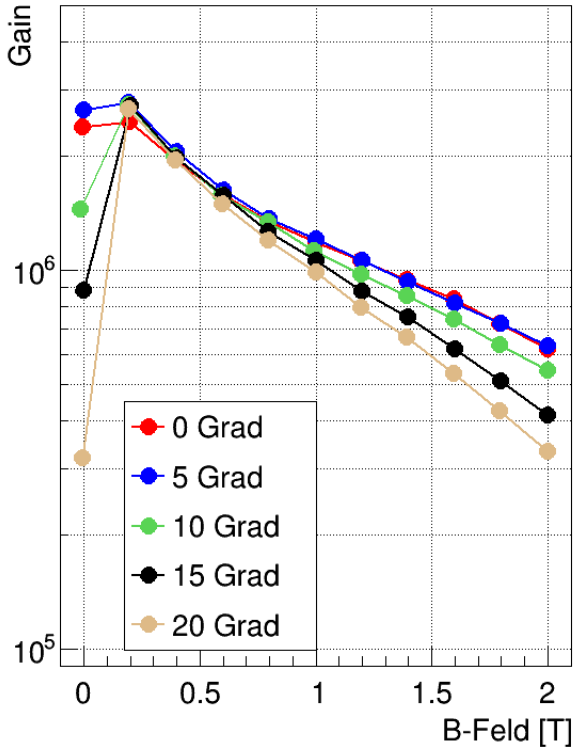
Photek A3191220, 0 Grad Verkippung



Photek A3191220, 2300 V

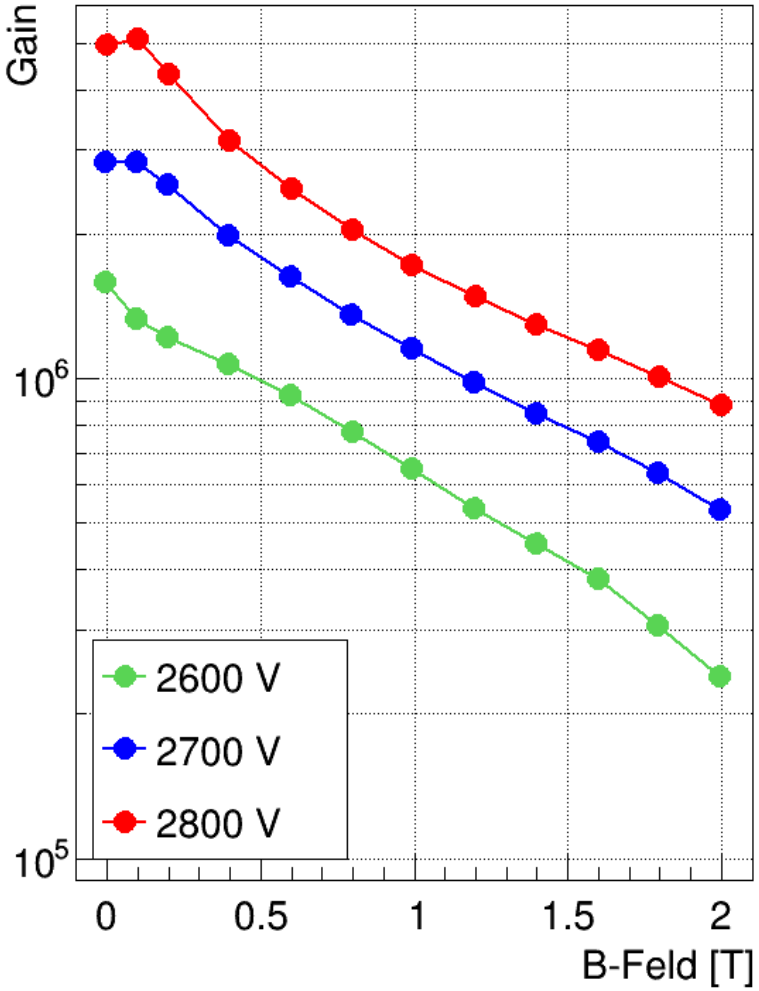


Photek A3191220, 2400 V

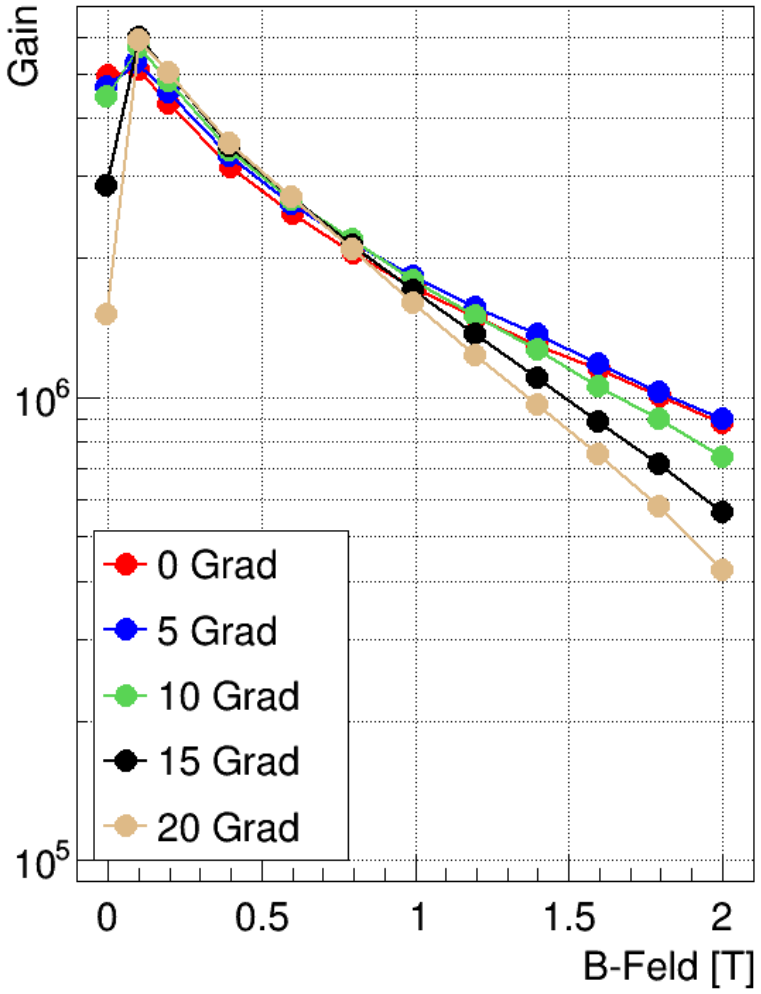


B-field measurements – results

Photek A2200606, 0 Grad Verkippung



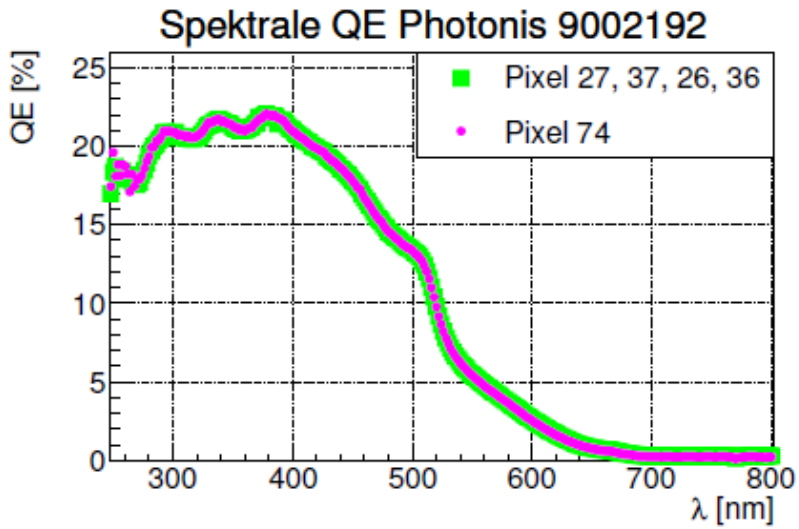
Photek A2200606, 2800 V

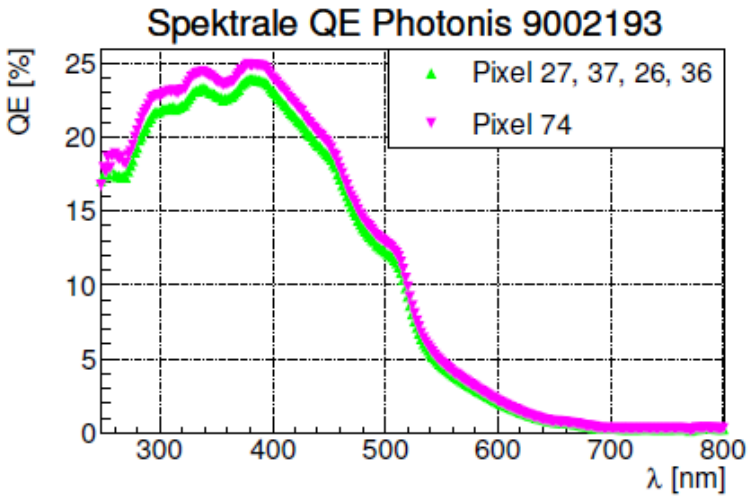


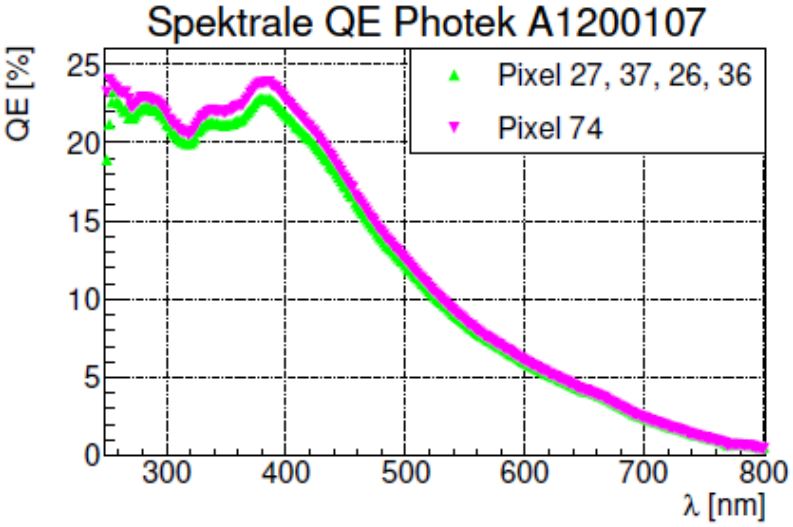
Pass/no Pass parameter	A1200107	A3191220	9002192	9002193
Active area ratio	74,1	74	76,6	79,8
Useful area [mm](from QE distr.)	53 x 53	52,5 x 52,5	51,5 x 51,5	52,5 x 52,5
Number of pixels	64	64	64	64
Outer dimension	61,4 x 61,9	60,3 x 61,8	58,8 x 58,8	58,8 x 58,8
Front window material	sapphire	sapphire	Not mentioned	Not mentioned

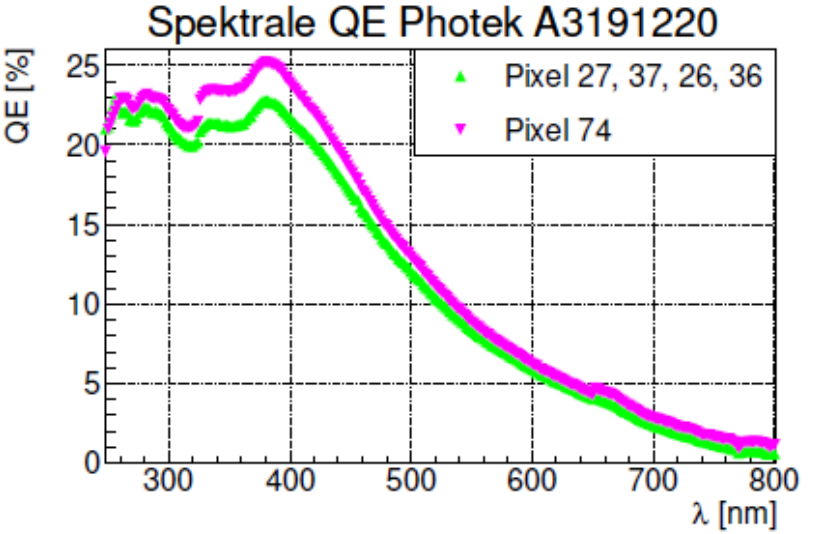
Spectral range

QE vs. wavelength dependency

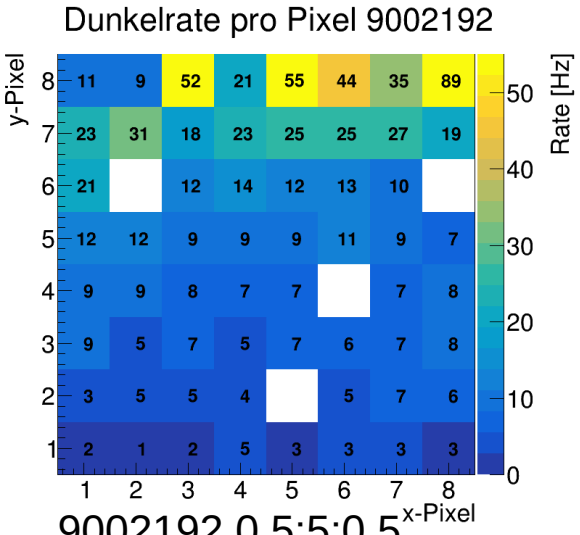




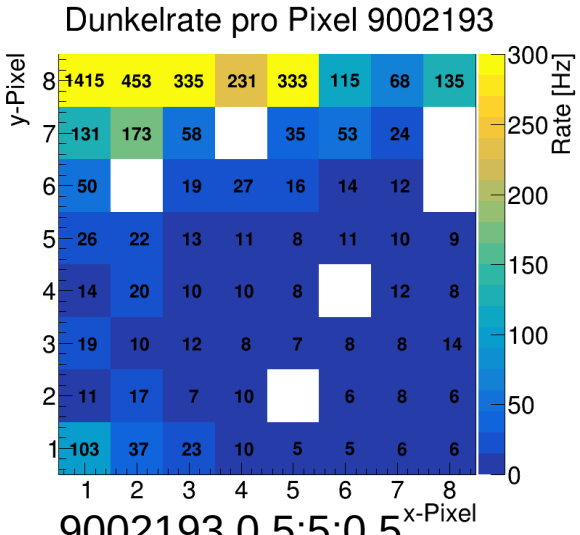




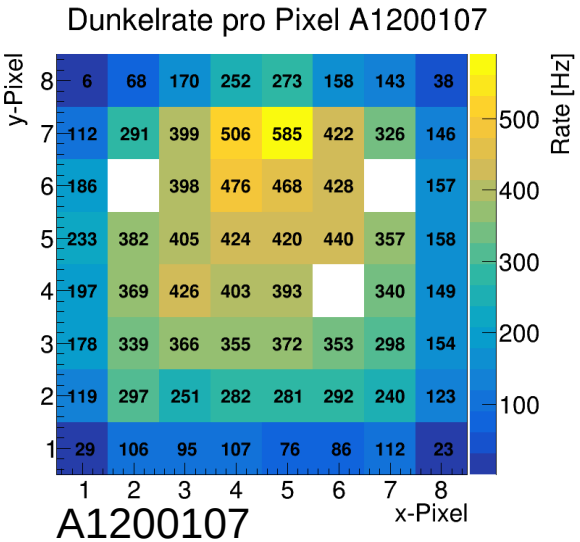
Darkcount rates



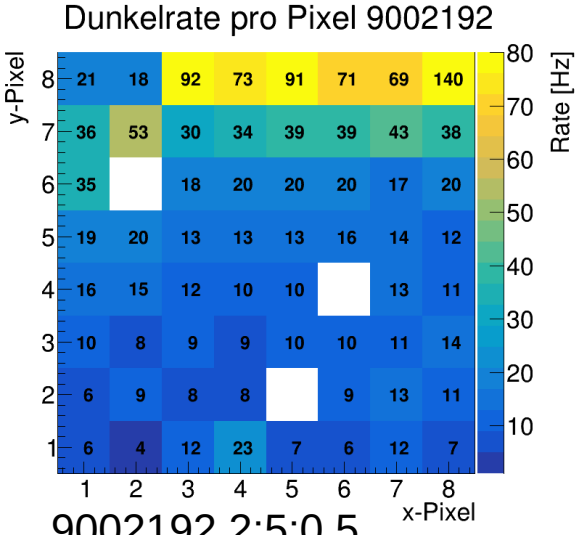
9002192 0,5:5:0,5



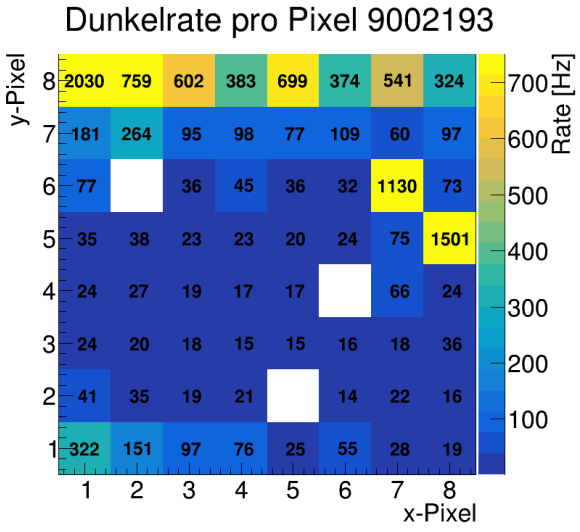
9002193 0,5:5:0,5



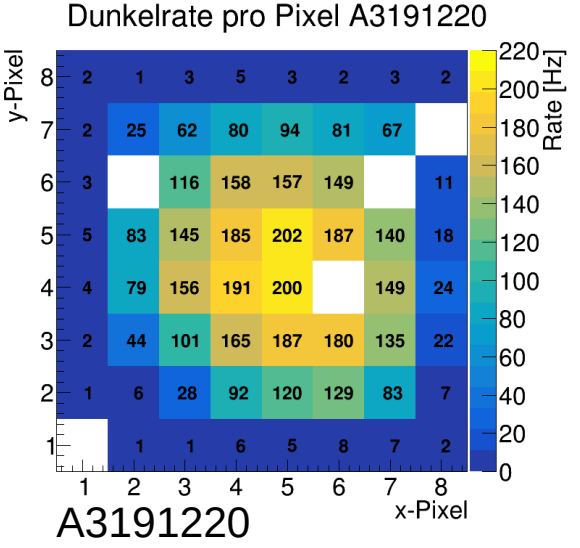
A1200107



9002192 2:5:0,5



9002193 2:5:0,5



A3191220

DiRICH Scans Darkcounts

tube	A1200107	A3191220	9002192		9002193	
Voltage divider [MΩ]	delivered	delivered	0,5:5:0,5	2:5:0,5	0,5:5:0,5	2:5:0,5
threshold (50% s.p.p.)	1375	1750	1500	1500	1750	1750
10^6 voltage	2400 V	2300 V	1970 V	2480 V	1880 V	2400 V
darkcounts [Hz/pixel] full tube	262,9	69	13,9	24	70,8	182,9

Time resolution:
TTS & RMS (-0.5 to 2 ns)

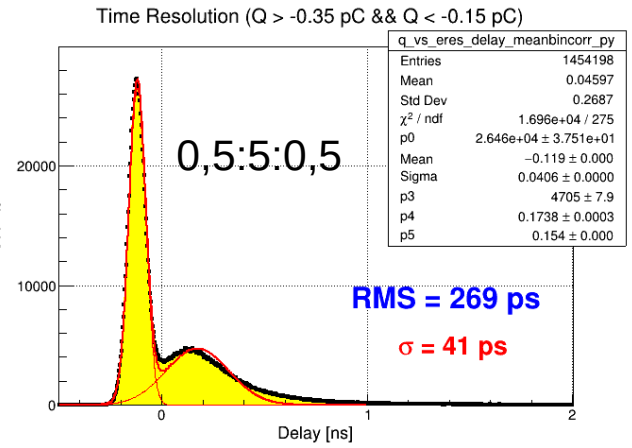
ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

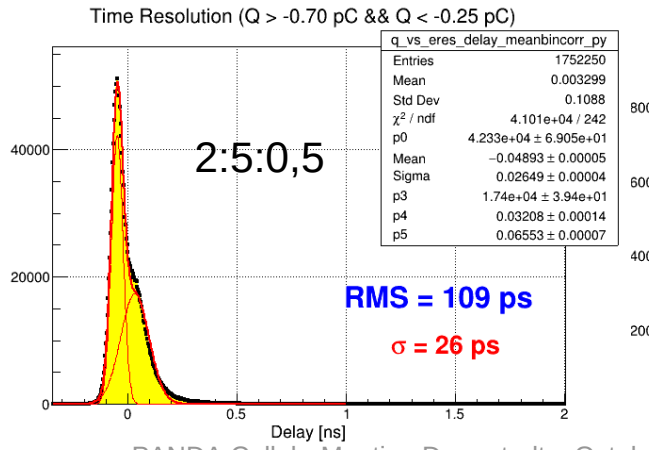
FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

Photonis

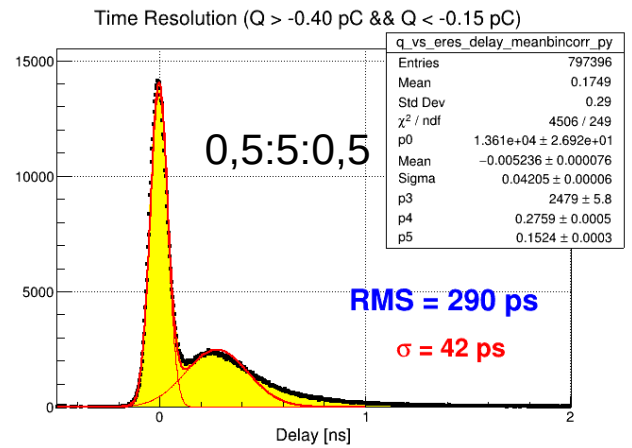
- measured with scope
- at pixel x4 y5 (center)

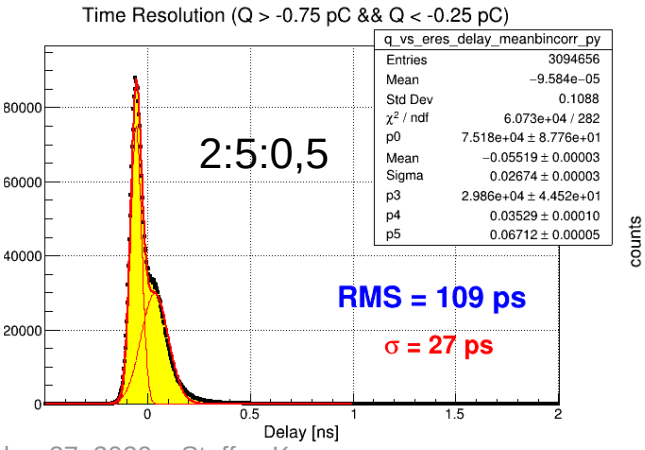
9002192



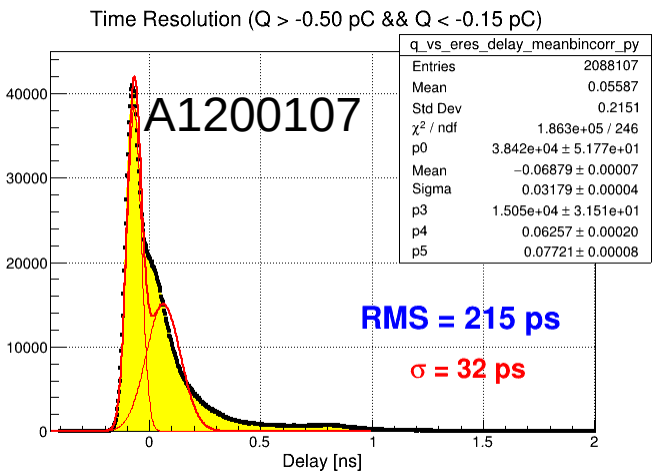


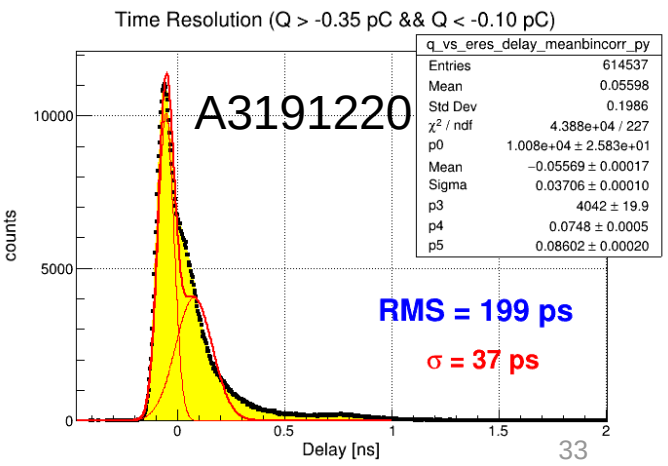
9002193





Photek





QE Homogenität verschiedene Flächen Max/Min Ratio + DQE

Fläche	9002192	9002193	A1200107	A3191220
2 x 2 Pixel	1	1,01	1,02	1,04
4 x 4 Pixel	1	1,02	1,05	1,12
6 x 6 Pixel	1,02	1,05	1,11	2
overall	1,28	1,35	1,92	8,33

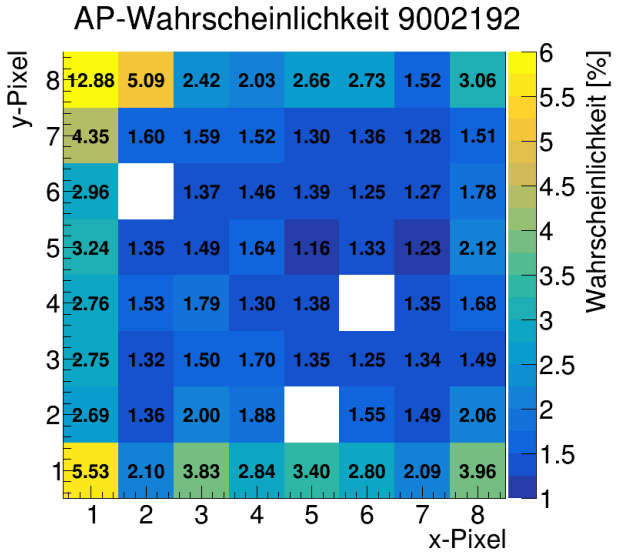
DQE immer auf Pixel x4 y5 gemessen

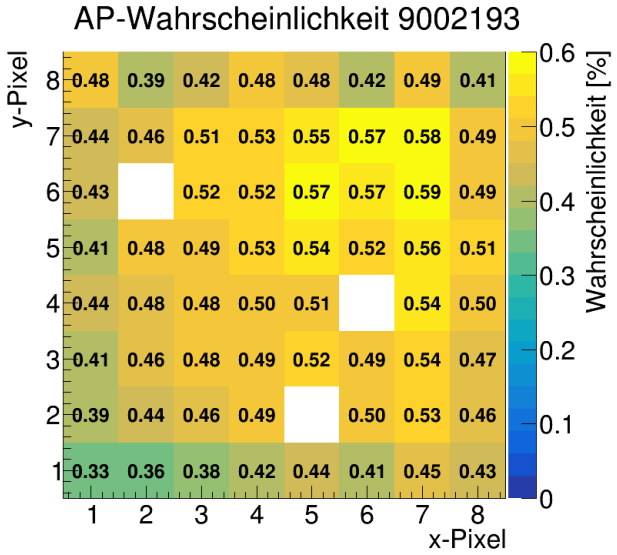
[%]	9002192	9002193	A1200107	A3191220
QE	22,16	24,66	24,37	25,02
CE	75,6	75,2	95,1	71,5
DQE	16,8	18,5	23,2	17,9

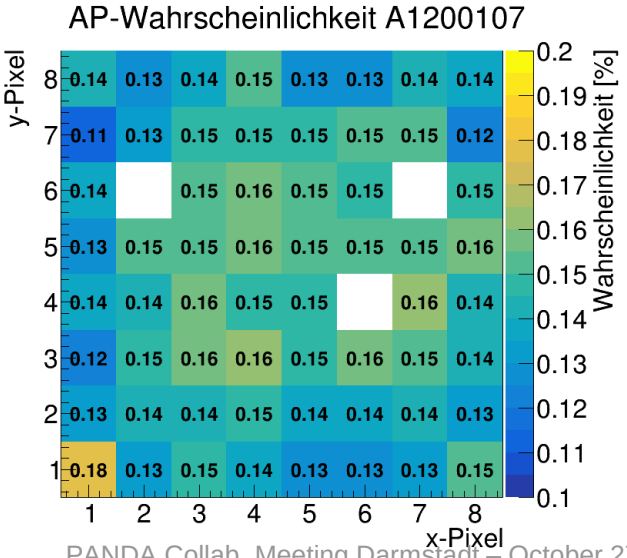
Setup parameters TRB-DiRICH-scan

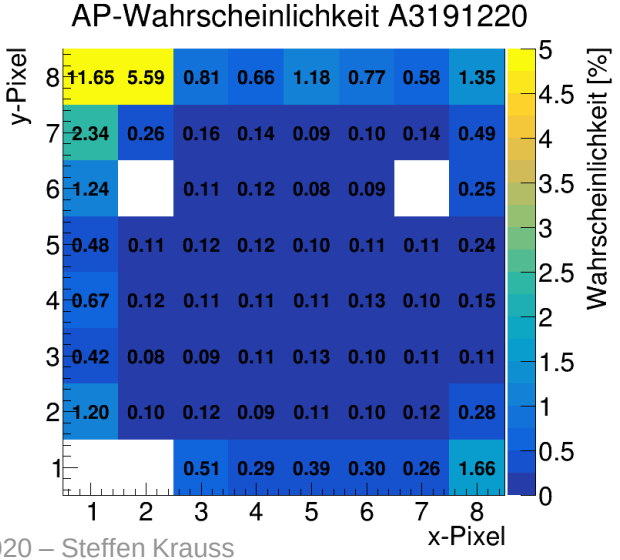
tube	A1200107	A3191220	9002192		9002193	
voltage divider [MΩ]	delivered	delivered	0,5:5:0,5	2:5:0,5	0,5:5:0,5	2:5:0,5
threshold (s.p.p.)	50%	50%	25%	25%	25%	50%
stepsize	0,5 mm	0,5 mm	0,5 mm	0,5 mm	0,5 mm	0,5 mm
10^6 voltage	2400 V	2300 V	1970 V	2515 V	1880 V	2350 V
gain (pix: x4 y5)	1e6	1e6	1e6	>1e6	1e6	1e6

DiRICH Scans afterpulsing









tube (Photonis 25%s.p.p)	**AP in % p. pixel**
Photonis 9002192	1,74
Photonis 9002193	0,79
Photek A1200107	0.14
Photek A3191220	0,49; w.o. upper left, much better