Results of QA Measurements of MCP-PMTs 9002232 – 9002237 and Update on Lifetime Measurements

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

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FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG
NATURWISSENSCHAFTLICHE FAKULTÄT

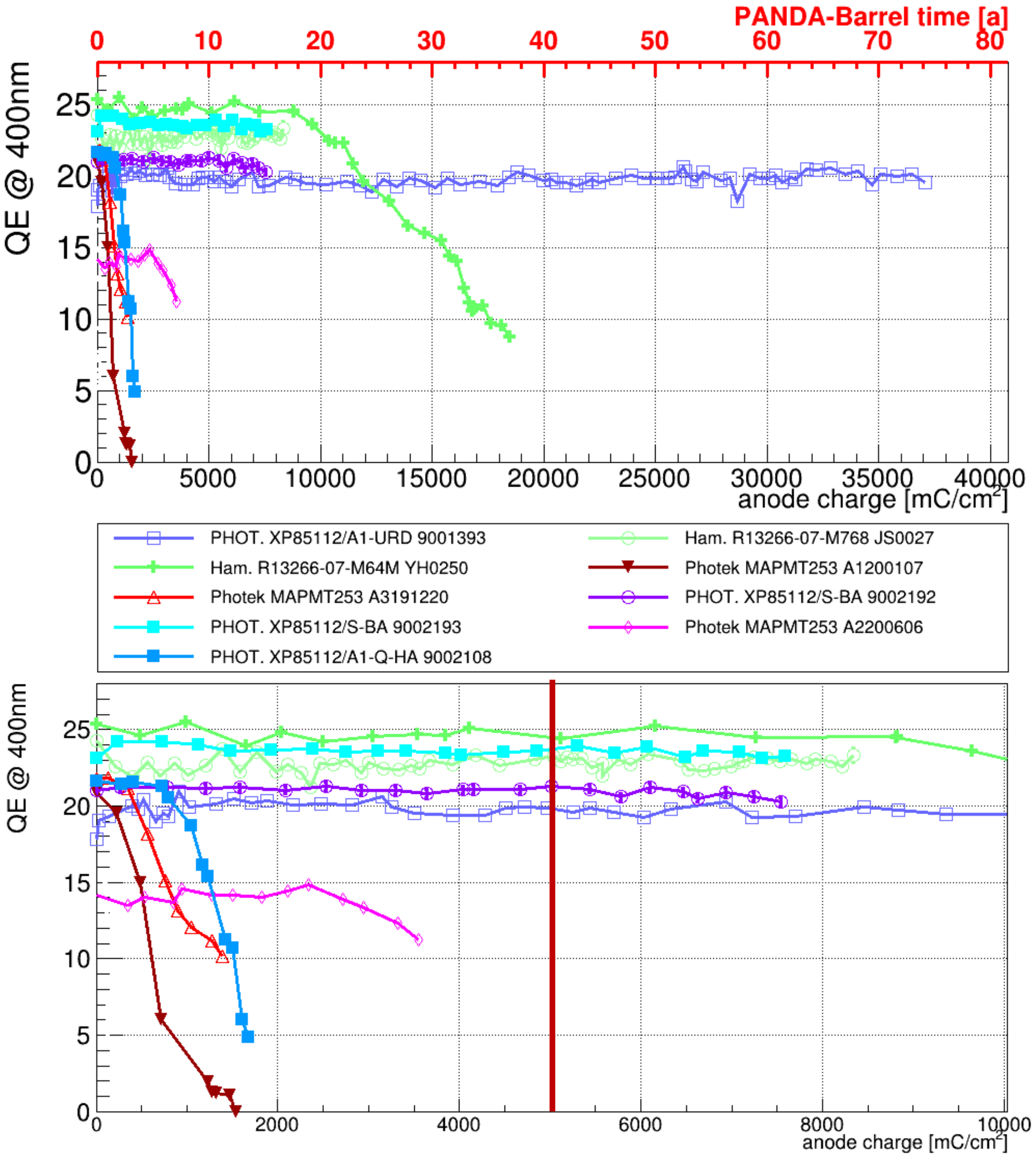
Lifetime data of latest MCP-PMTs

Constant illumination with 1 MHz single photons while permanently monitoring the integrated anode charge (IAC)

Every few weeks: measurement of the spectral QE

- Most sensors with ALD coated MCPs have **lifetime > 5 C/cm²** (10 years PANDA operation time)
- 9001393 (2 ALD-layers) at >70 years of PANDA (permanently illuminated since >10 years)

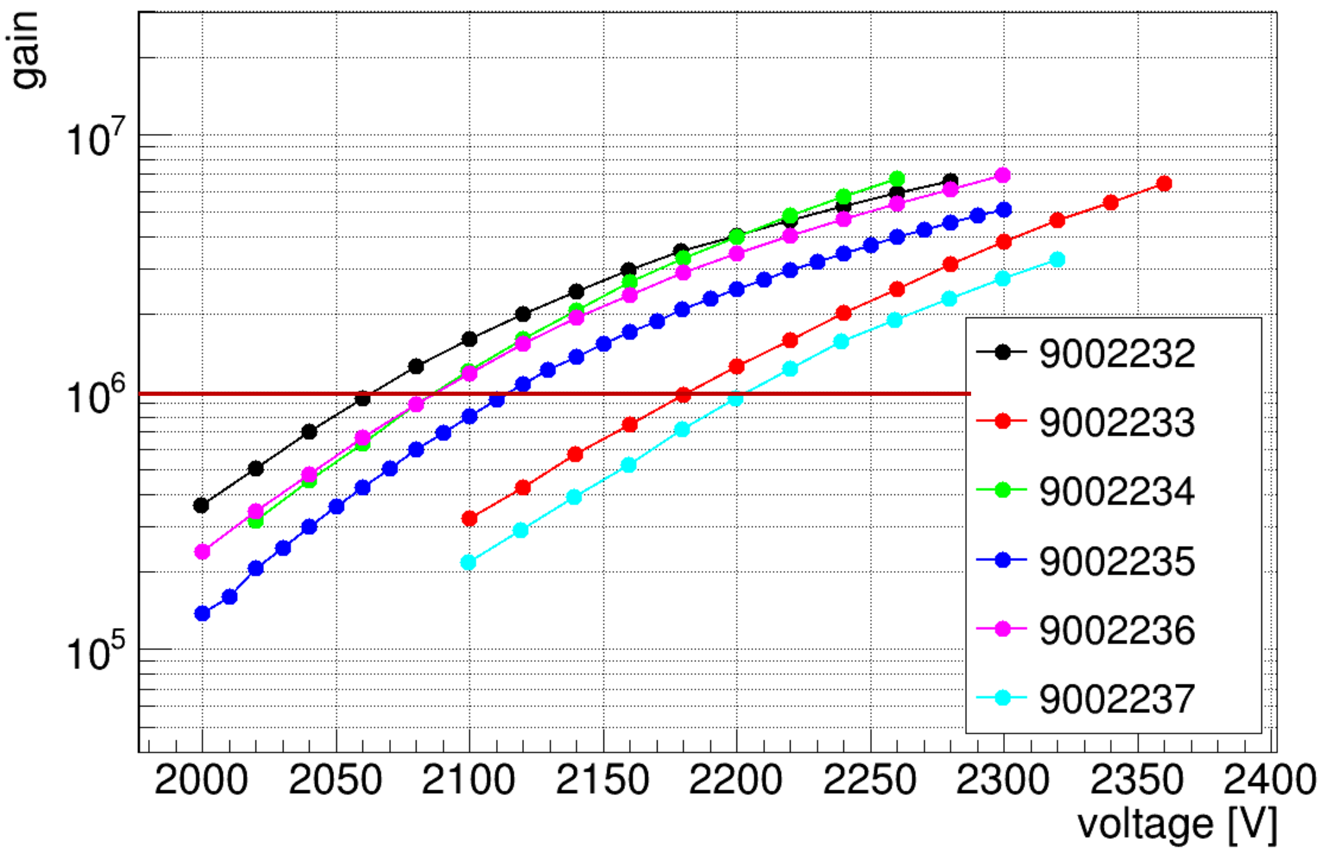
- Photonis 9002192, 9002193 (same type as serial production tubes) are at over **7 C/cm²** with minor loss
- Photek A1200107 and A3191220: QE loss (even without illumination) from the beginning due to micro leaks
- Photek A2200606 started to drop at **~2 C/cm²**



Gain vs voltage

- Measurements with 4:10:1 voltage divider
- Gain of 10^6 reached in first measurement
- Escalation still occurring at high gains
- 9002235 and 9002237 escalate in later measurements already at $\sim 10^6$

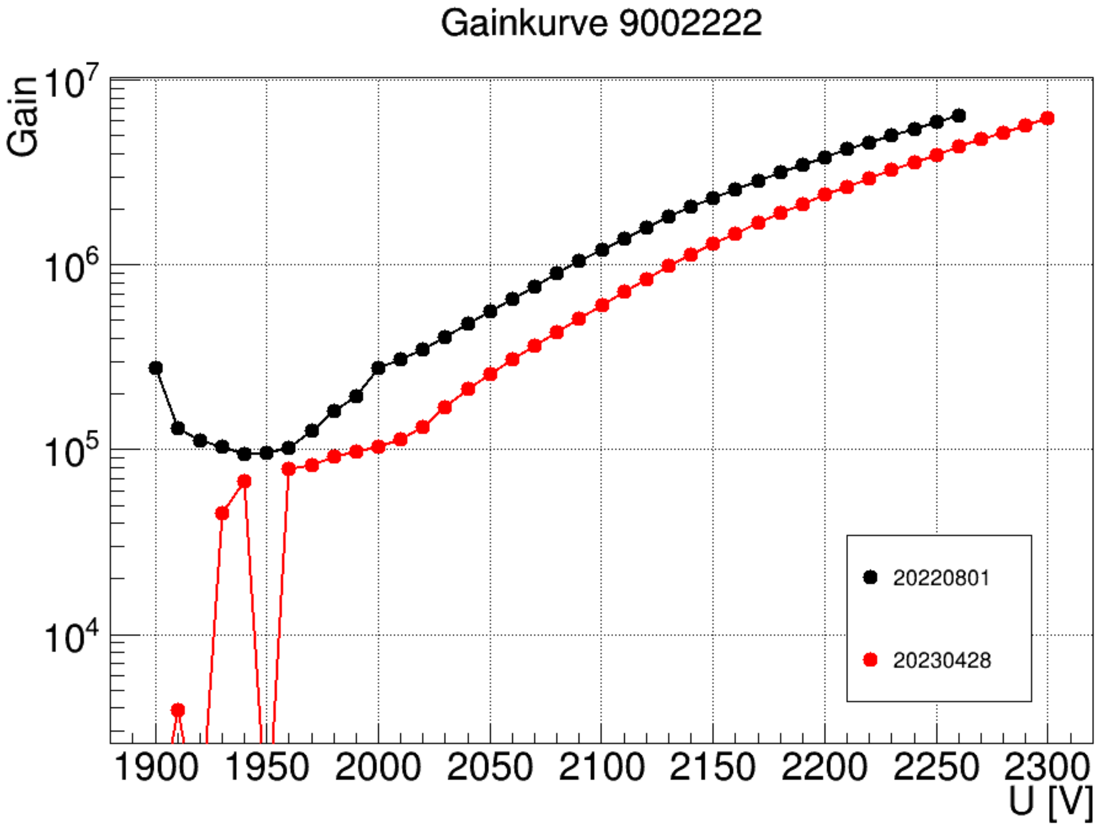
Sensor	MCP-resistance at 0V [MΩ]
9002232	52
9002233	29.5
9002234	52
9002235	49.5
9002236	48
9002237	17.7

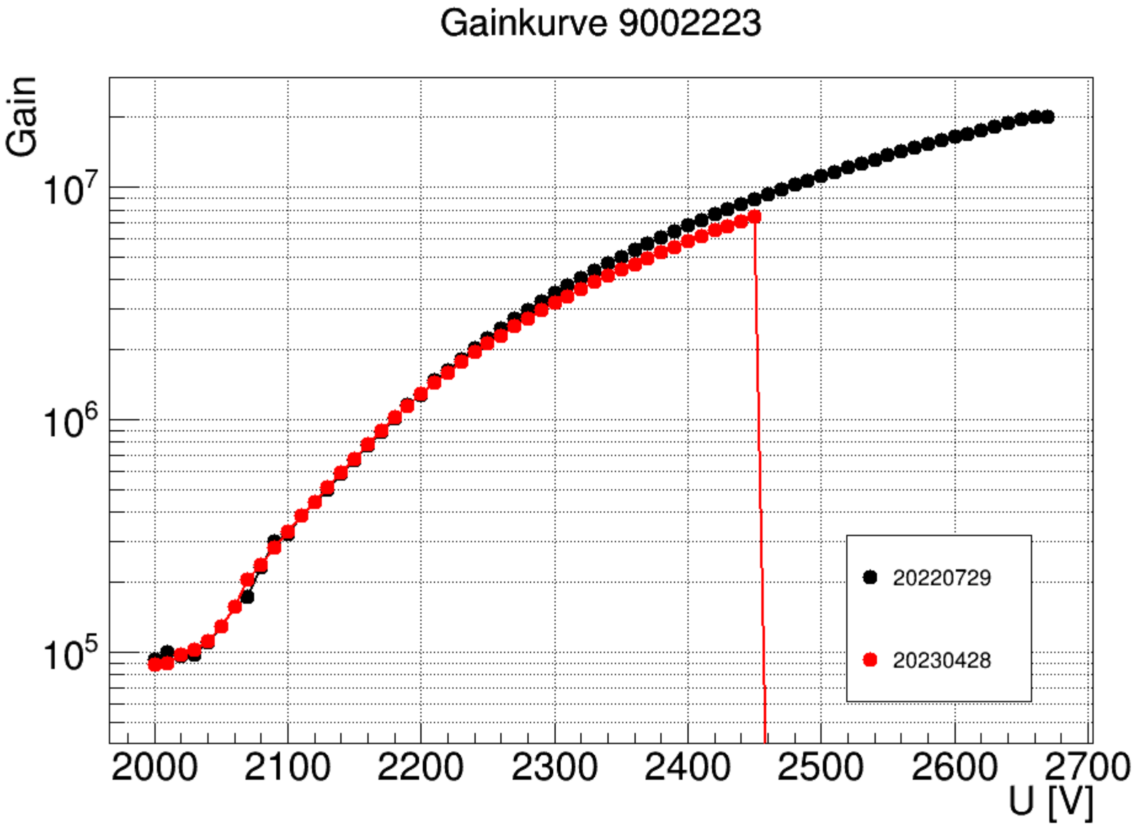


Datasheet: subspec (due to bad gain homogeneity)

Gain behaviour with time

- Comparison of gain curves shortly after receiving the tubes (black) and now (red)
  - Gain seems to decrease with time for most tubes: less then factor ~3
  - Most tubes enter escalation mode at lower gains
- No detailed investigation of temporal behaviour done yet

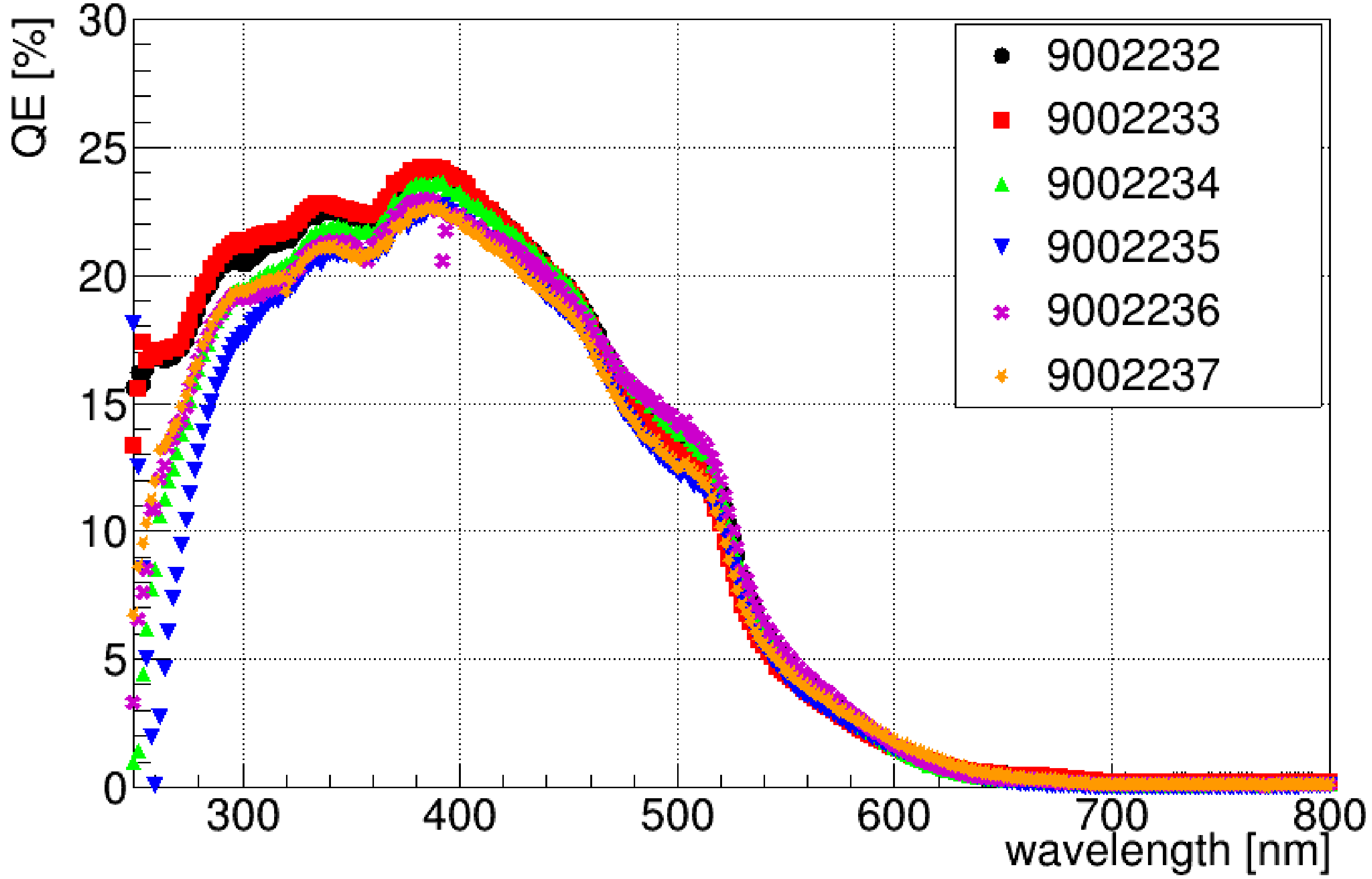




QE vs wavelength

- QE vs wavelength @ central PC position (x4 y5, ~5 mm spot)
- Peak QE of ~23% at ~390 nm

Sensor	Peak QE [%]
9002232	24.1
9002233	24.2
9002234	23.6
9002235	22.7
9002236	23.0
9002237	22.6



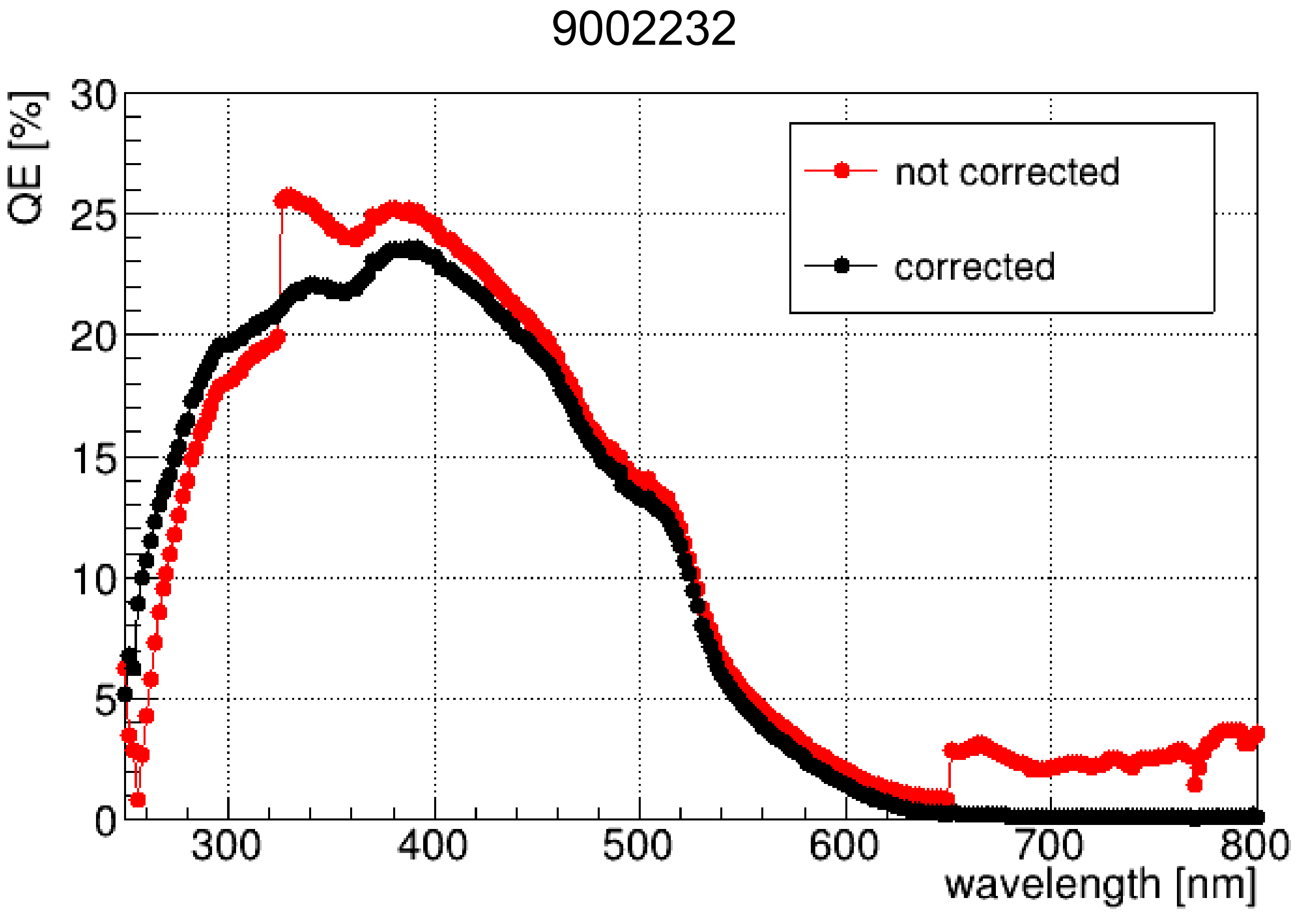
Solving of problem with jumps

- Problem (see talk Krauss PANDA 2022/3):
  - jump at 325 nm and 650 nm (red curve, extreme example)
  - bigger change in dark current ΔDC (measured before and after taking data) → bigger effect

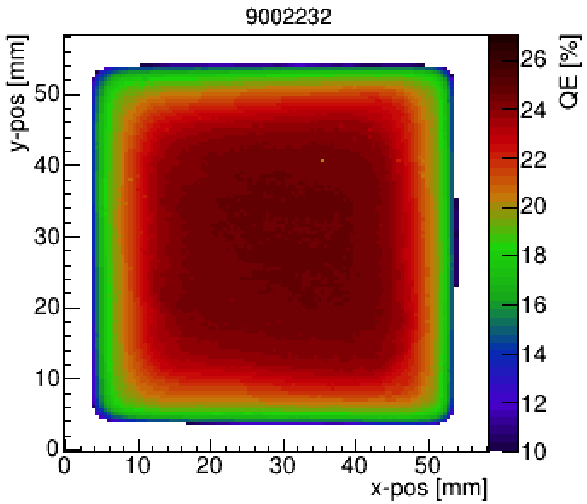
- Reason: Integer division in dark current correction

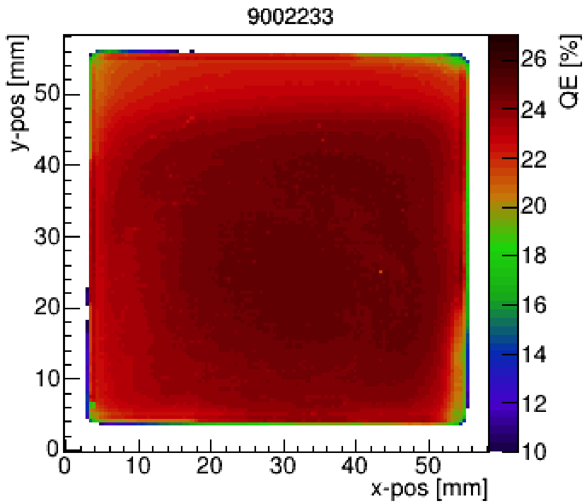
→ Instead of interpolating the dark current:
  - < 325 nm: no correction
  - 325nm<λ<650nm: subtraction of $1 \cdot \Delta\mathrm{DC}$
  - >650nm: subtraction of $2 \cdot \Delta\mathrm{DC}$

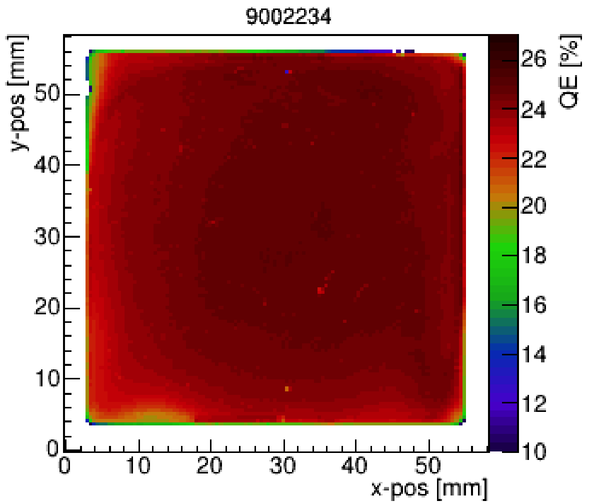
- Now: correct interpolation → Problem solved
- Previous measurements can be corrected (black curve)

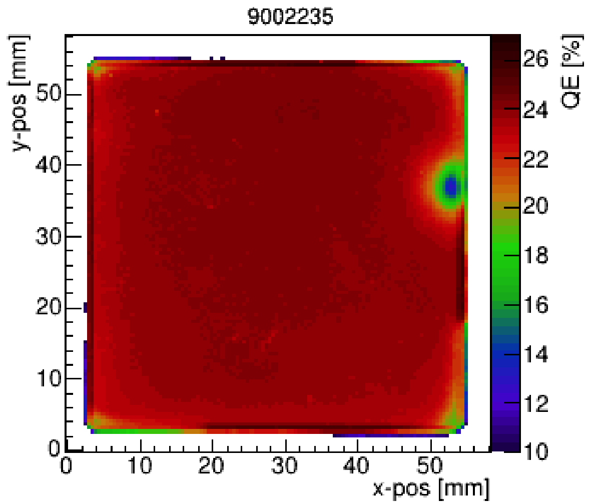


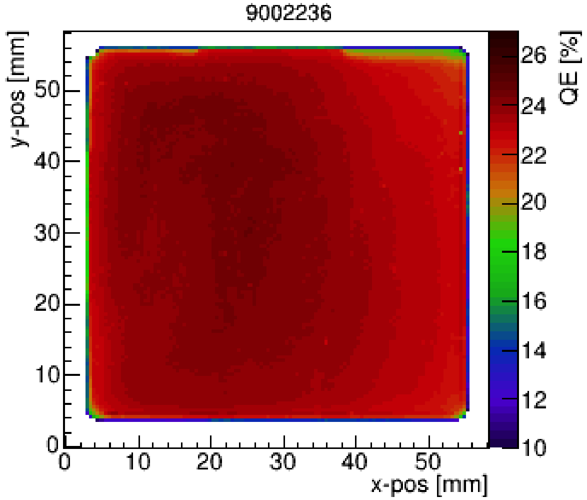
QE uniformity

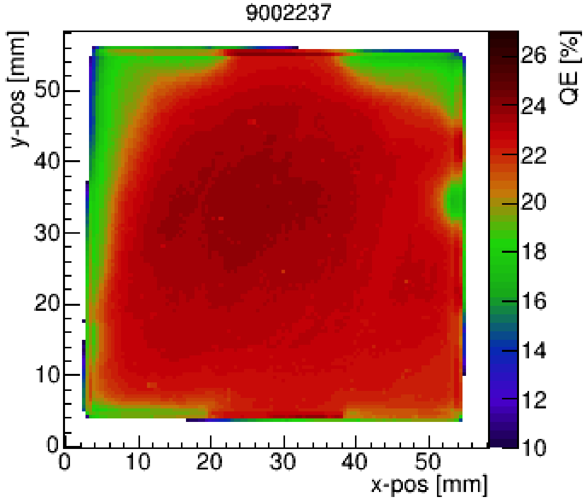


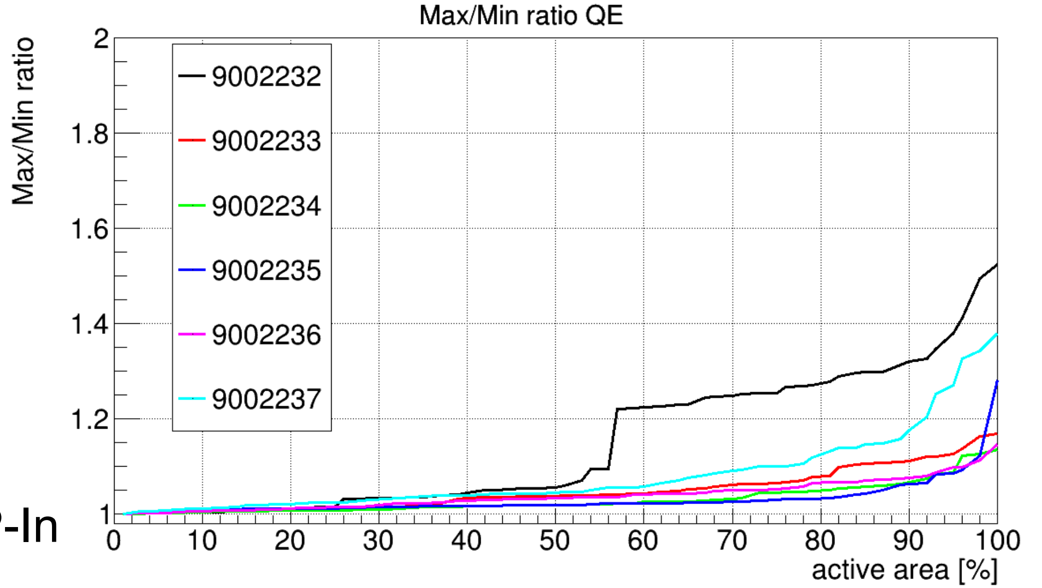












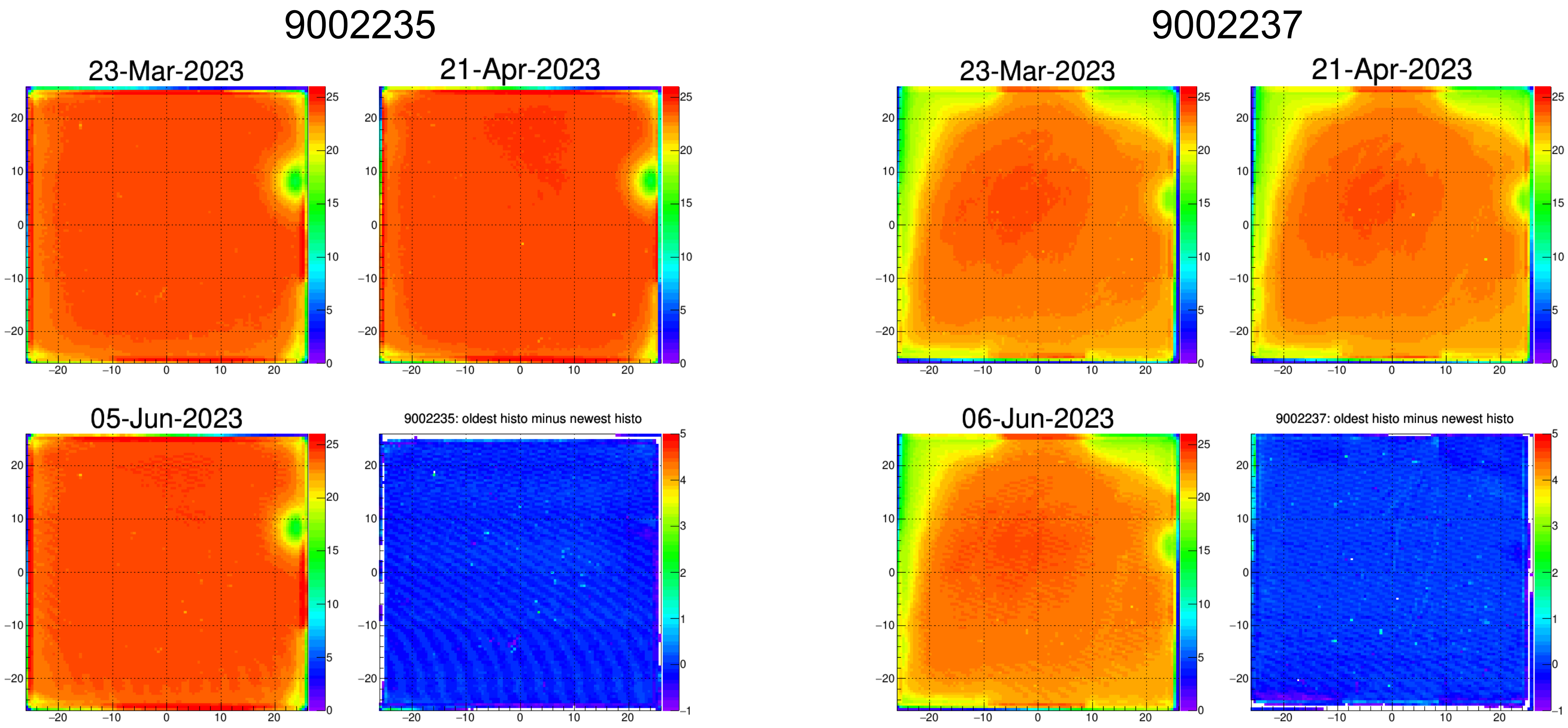
- QE surface scans @ 372nm with 200V between PC and MCP-In
- Uniformity below 1.5 for 100% active area for all tubes
- 9002235: jump at ~55% active area due to lower QE at the rims

QE holes

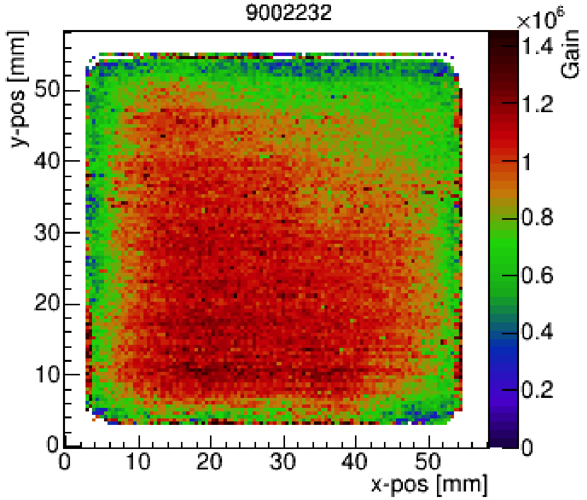
- QE holes in some of the newest sensors (9002235, 9002237) → QE loss?

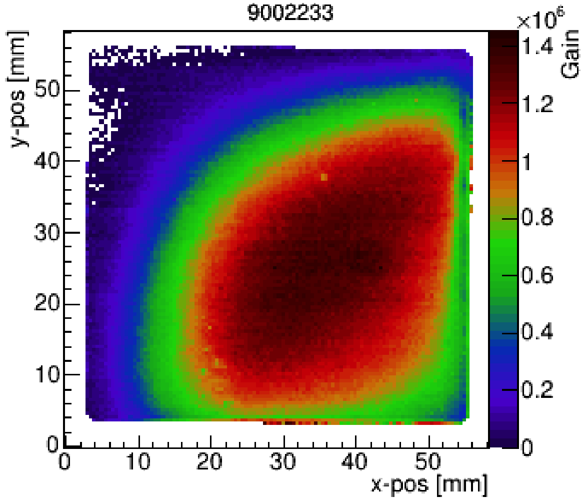
→ QE scans at different times (March, April, June)

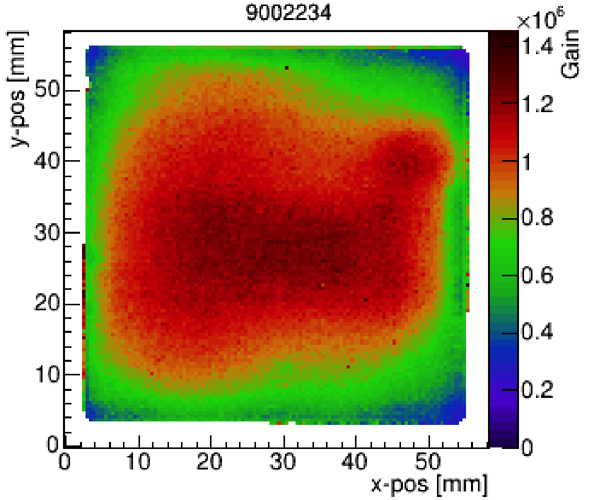
- Lower right corner: subtraction of newest to oldest scan → no further QE loss observed

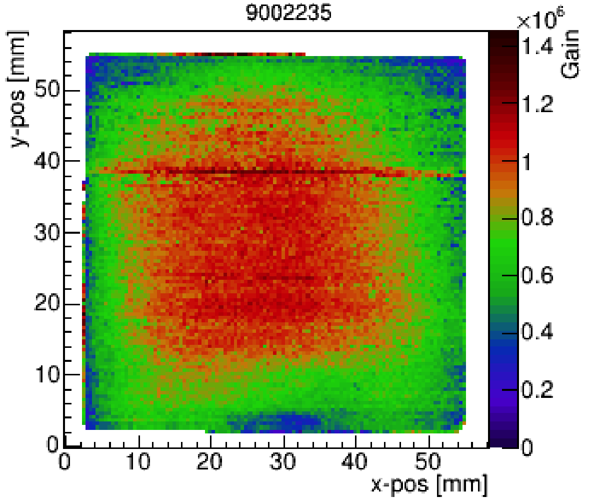


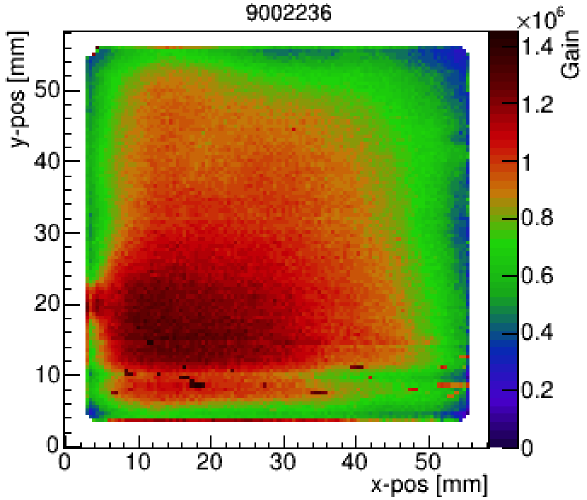
Gain uniformity

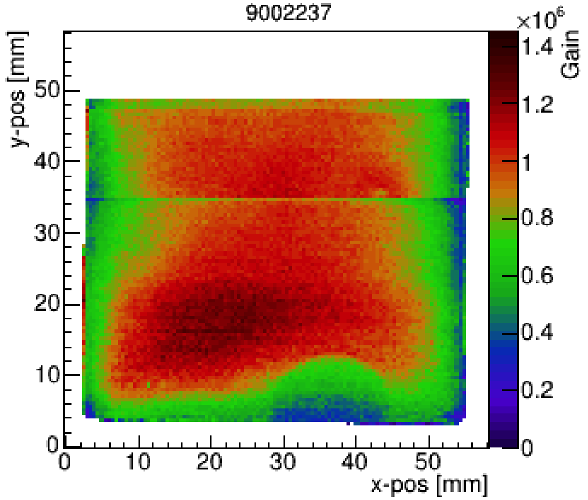


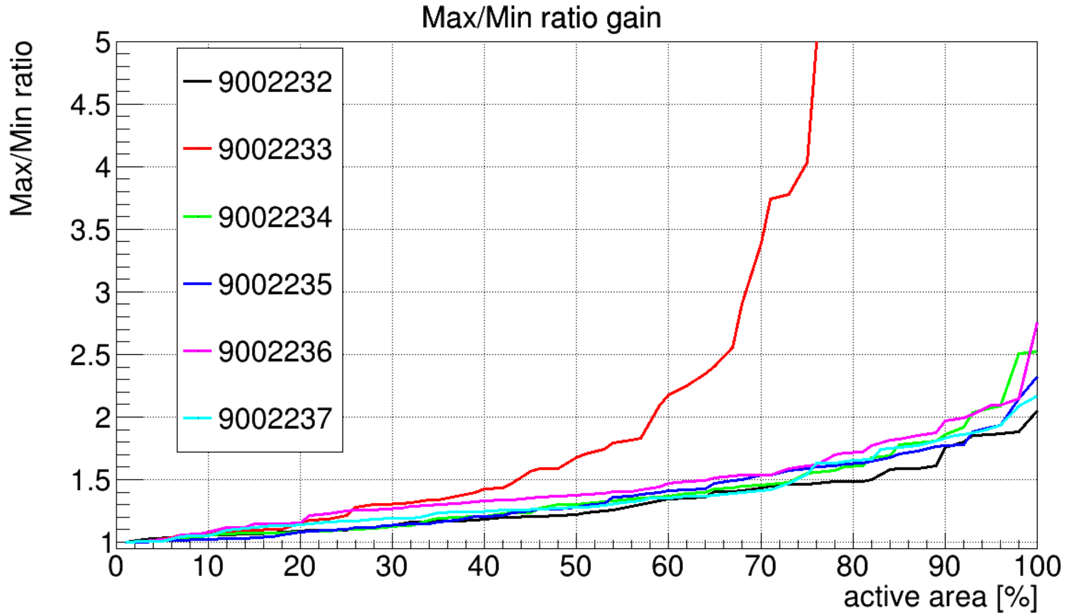










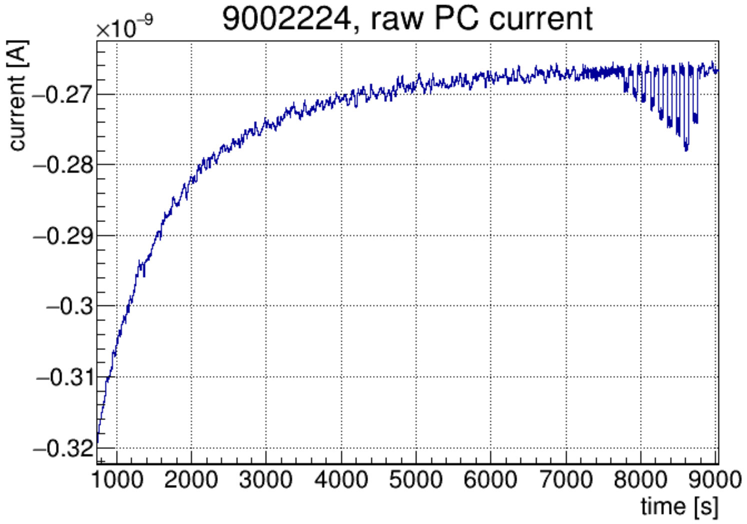


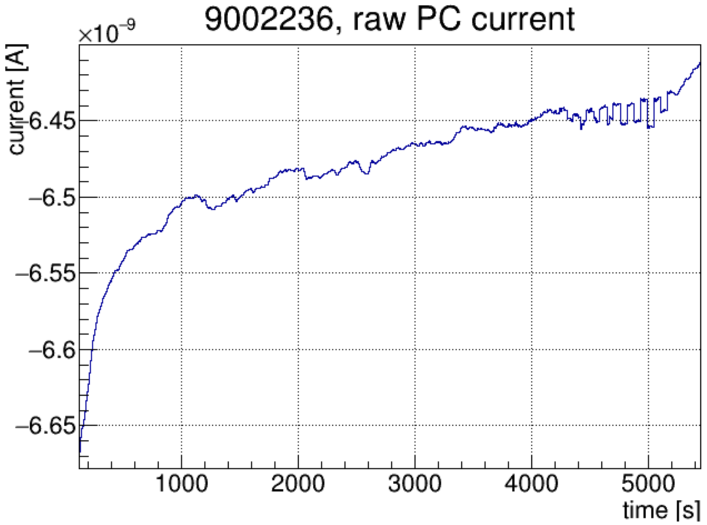
- Gain surface scans @ 372nm with 4:10:1 divider
- Uniformity less than 3 for > 90% active area for all tubes, better than older tubes (except 9002233)
- High dark currents → noisy measurements

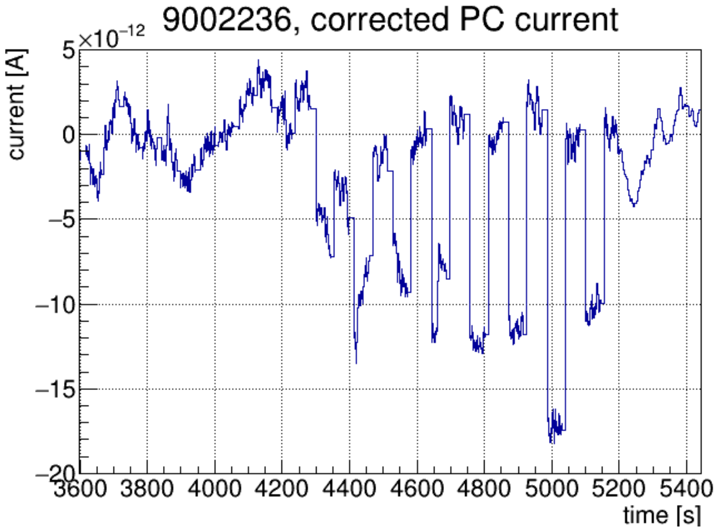
- 9002237 couldn‘t be measured completely due to escalation (even with 100 V below 10^6 gain ($\sim 2 \cdot 10^5$))
- 9002235 measured at 20 V below 10^6 ($\sim 9 \cdot 10^5$)

CE & DQE

	9002232	9002233	9002234	9002235	9002236	9002237
QE @ 372nm & x4 y5 [%]	24.7	24.6	24.9	24.0	24.4	23.8
CE [%] (4:10:1)	95.7	91.4	99.9	99.3	92.8	97.2
DQE [%]	23.6	22.5	24.9	23.8	22.6	23.1





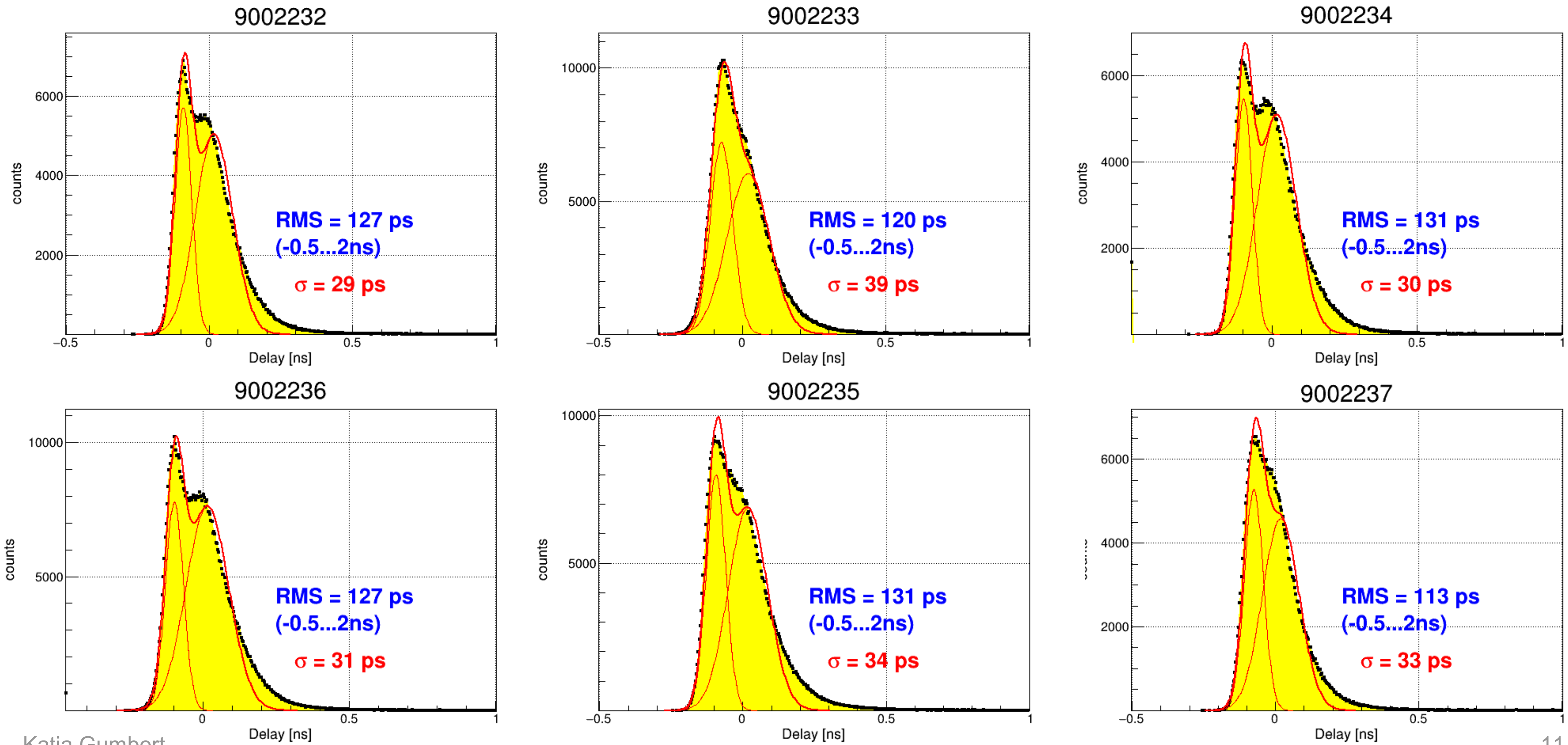


- CE > 90% for all tubes
- Measurement of QE current difficult due to high instable leakage currents (especially 9002236)

Time resolution measured with oscilloscope

	9002232	9002233	9002234	9002235	9002236	9002237
RMS [ps] (-0.5…2ns)	127	120	131	131	127	113
Sigma [ps]	29	39	30	34	31	33

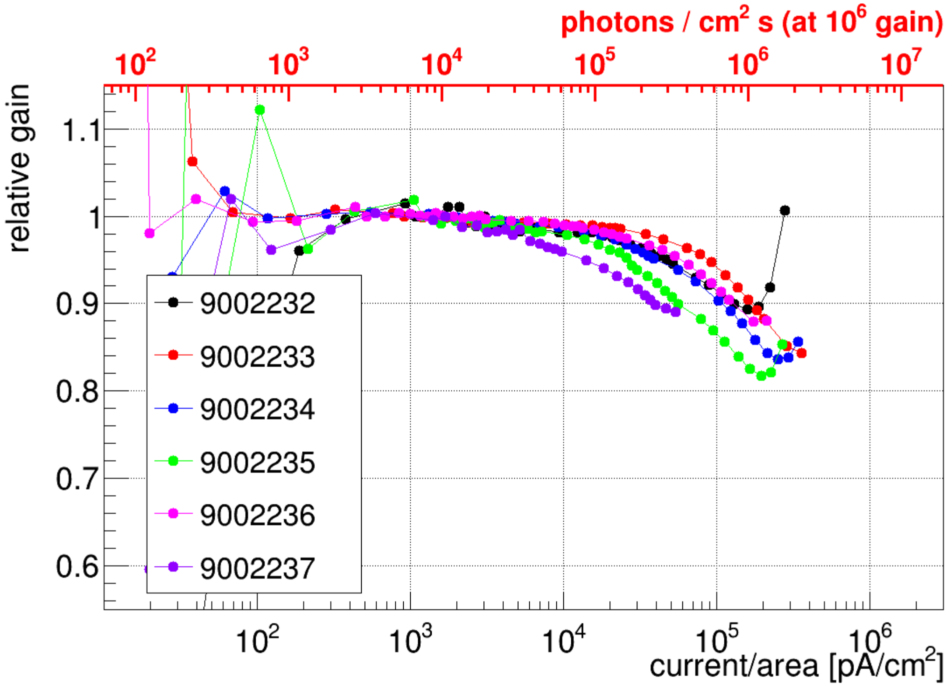
- 4:10:1 divider
- Illumination of pixel 44
- RMS < 130ps
- Sigma ~30ps
- Fits not perfect



Rate capability in current and pulse mode

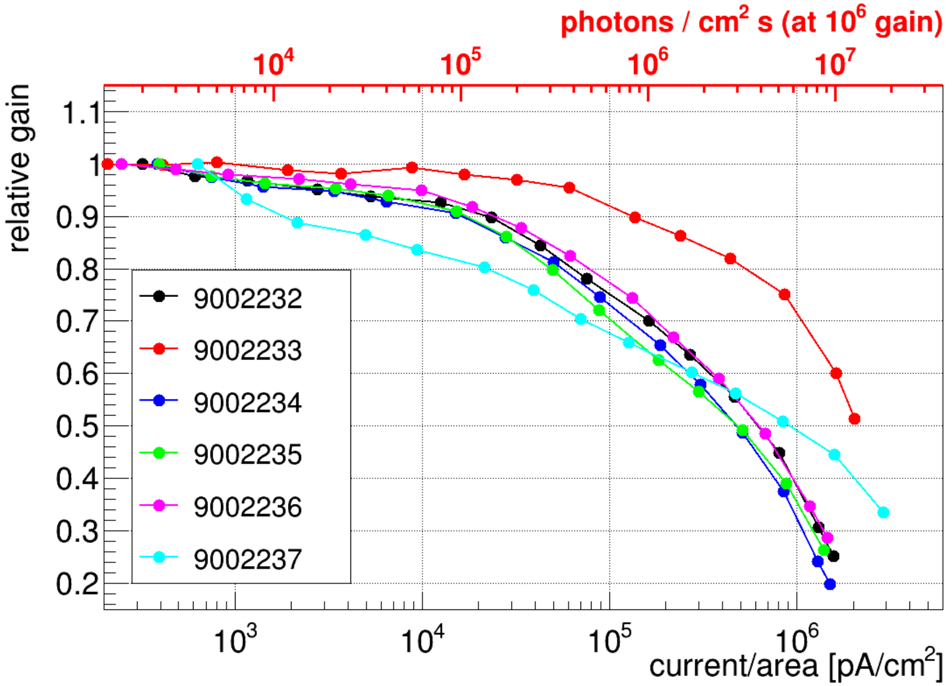
Current mode:

- Illumination of whole sensor surface
- Measurement of anode current of all shorted pixels



Pulse mode:

- Illumination of pixel 44
- Measurement of charge spectra with scope

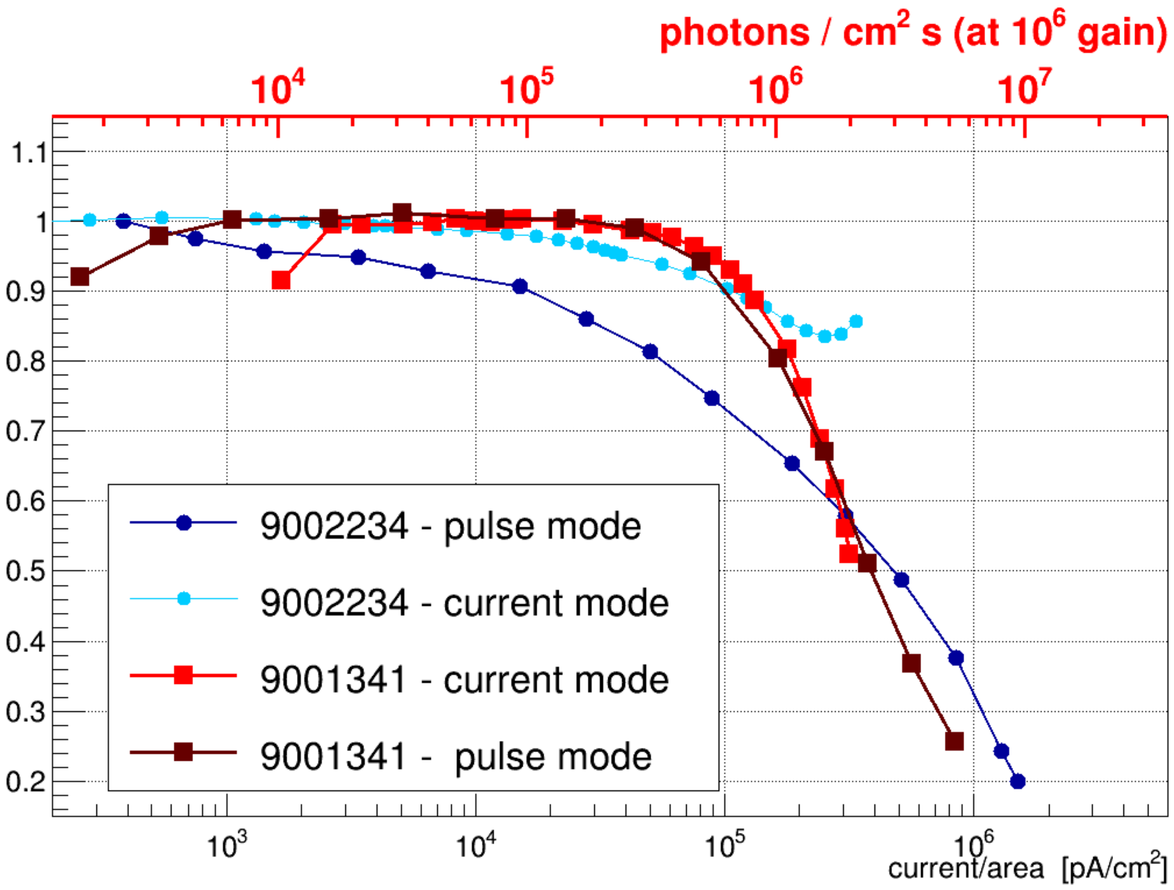


- Very different behaviours comparing pulse and current mode and different sensors (also seen in previous tubes)
  → still not understood

- 9002220 and 9002227 send to Photonis for further investigation

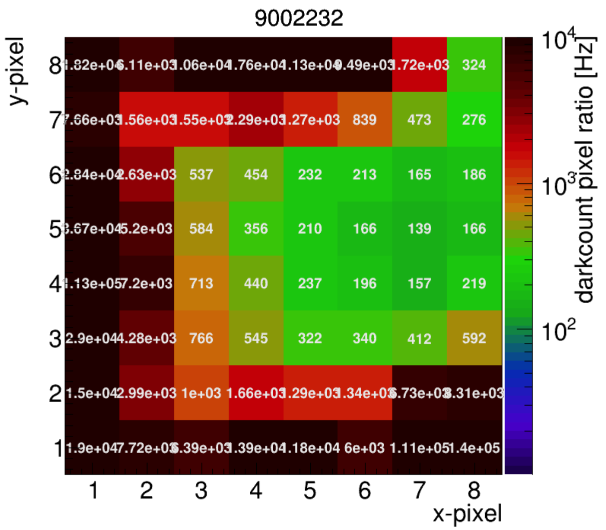
Rate capability comparison

- Comparison of 9002234 to 9001341 in current and pulse mode
- Recent measurements with same setup and analysis for both tubes
- 9001341:
  - Pulse and current mode very similar
- 9002234:
  - Different behavior in current and pulse mode

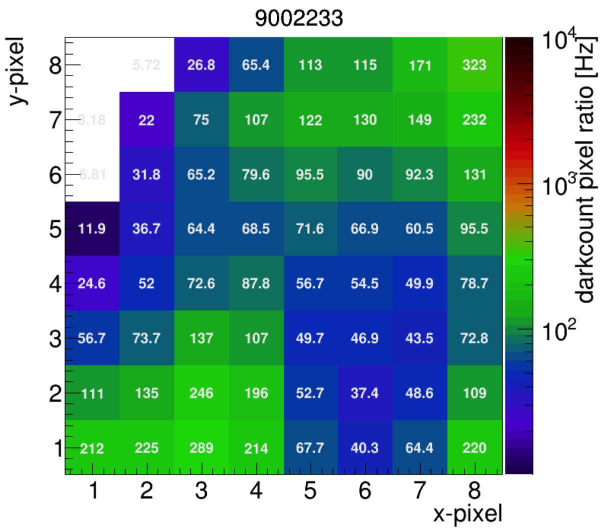


Dark count rates with TRB/DiRICH DAQ

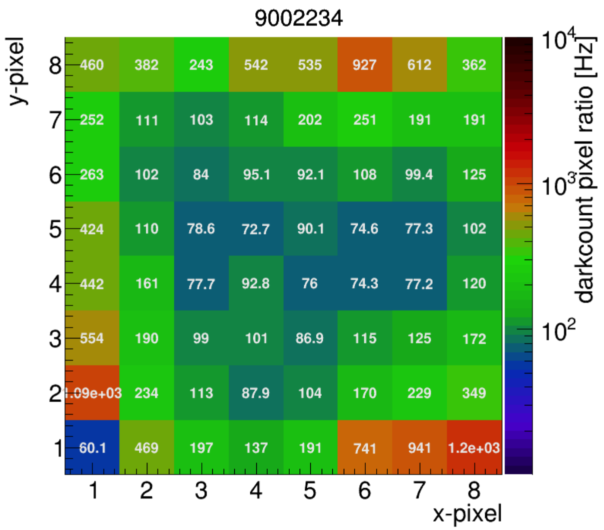
9002232



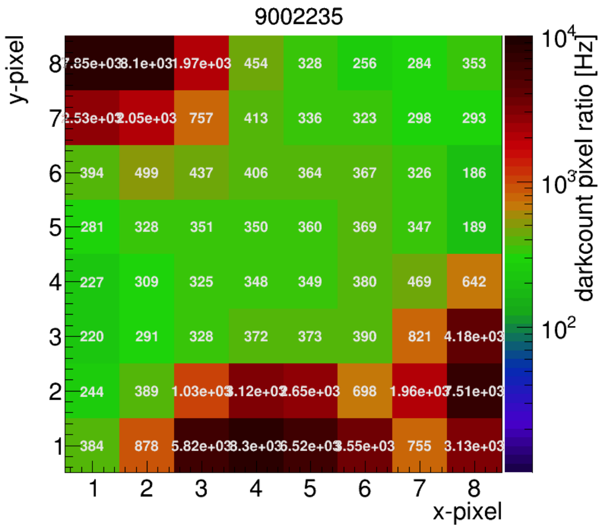
9002233



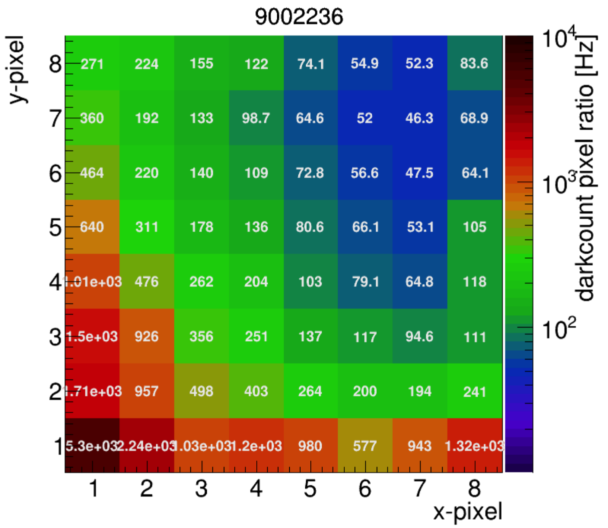
9002234



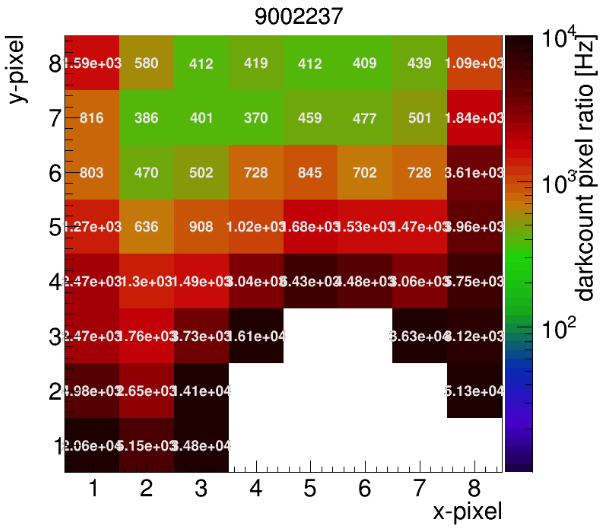
9002235



9002236



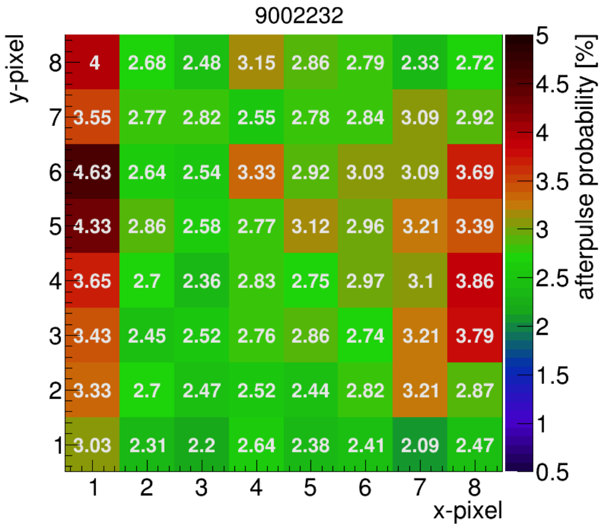
9002237



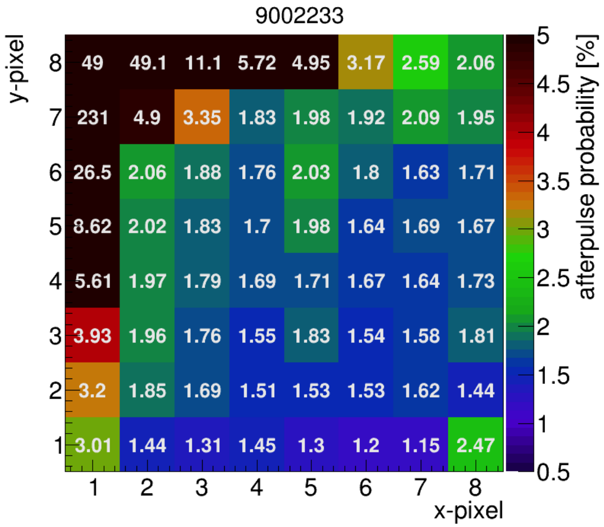
- 4:10:1 divider
- Dark count rates measured with TRB/DiRICH DAQ
- **Important: logarithmic z-scale!**
- Typical hot pixels at rims
- 9002237:
  many noisy pixels in lower right corner (>100kHz)
  → these pixels are switched off
- 9002233: white pixels with DC<10 Hz (limit of z-range)

Afterpulse ratio with TRB/DiRICH DAQ

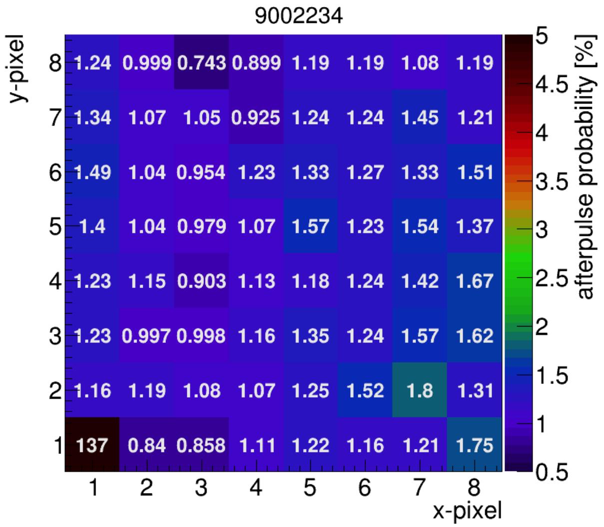
9002232



9002233

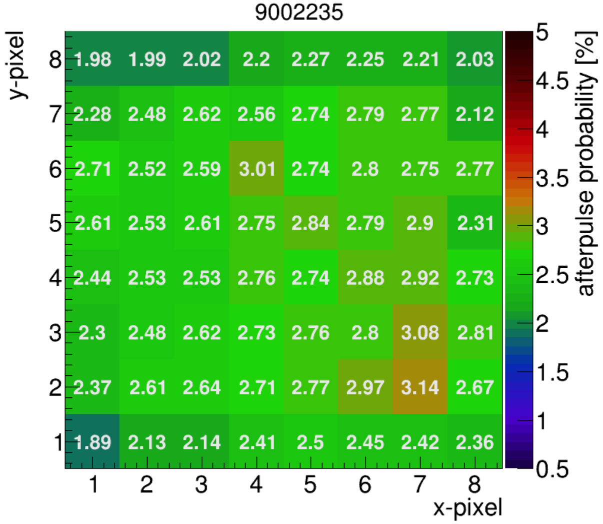


9002234

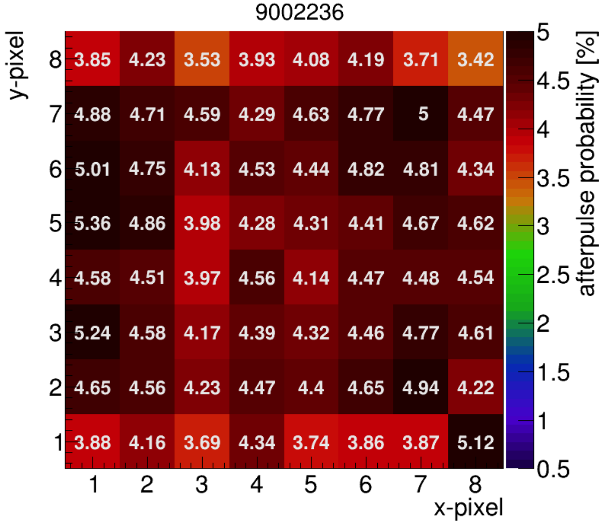


- 4:10:1 divider
- Afterpulse ratio measured with TRB/DiRICH DAQ
- Afterpulse ratio: probability of feedback ion producing a signal
- Typically: mean AP ratio ~1-3%

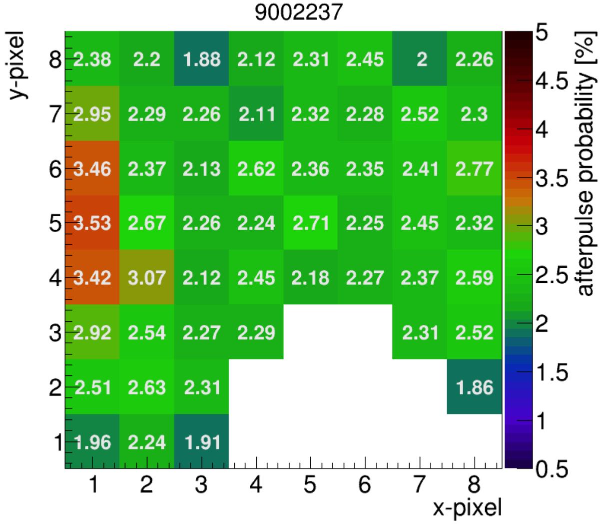
9002235



9002236

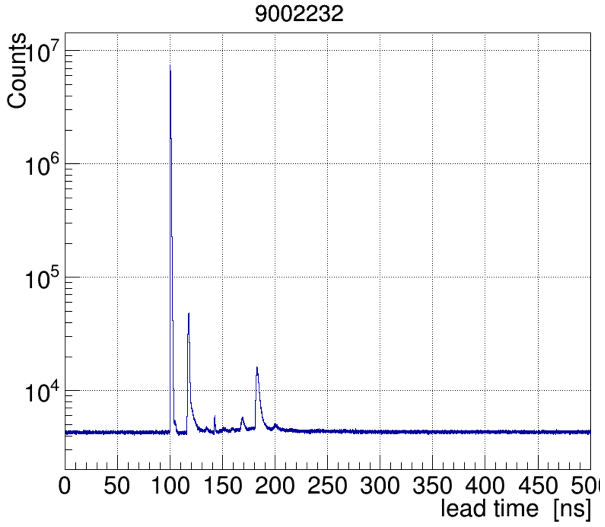


9002237

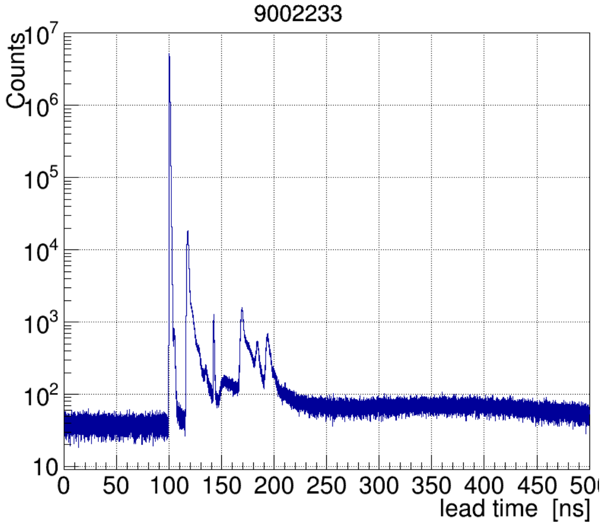


Time spectra with TRB/DiRICH DAQ

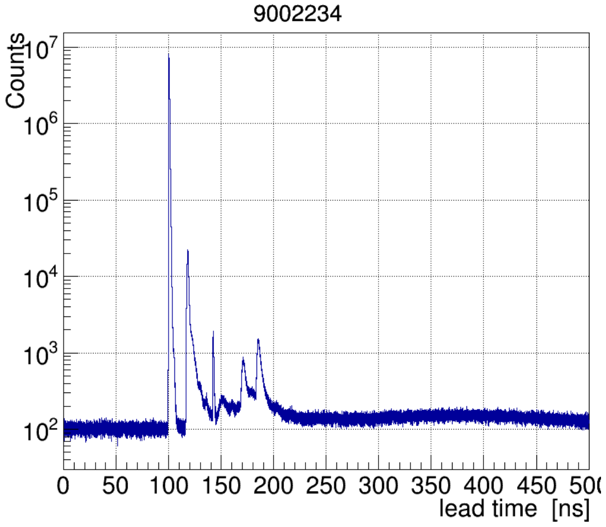
9002232



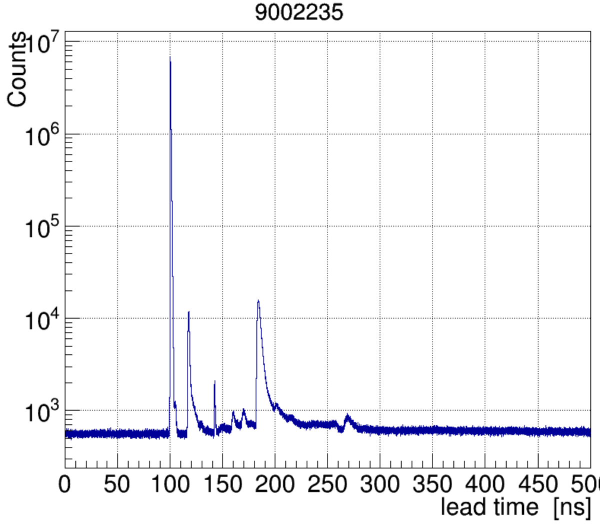
9002233



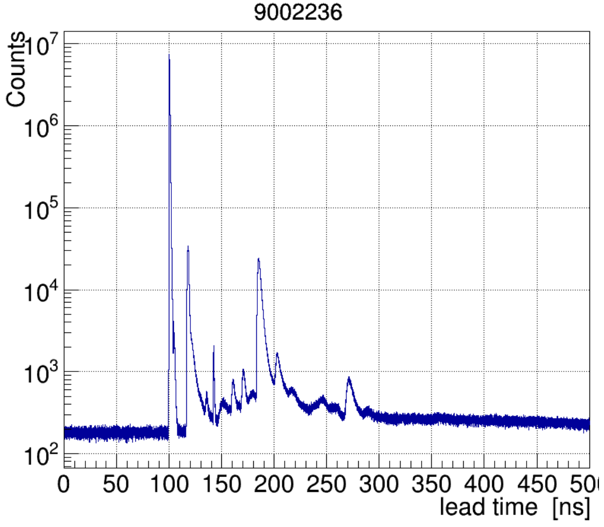
9002234



9002235



9002236



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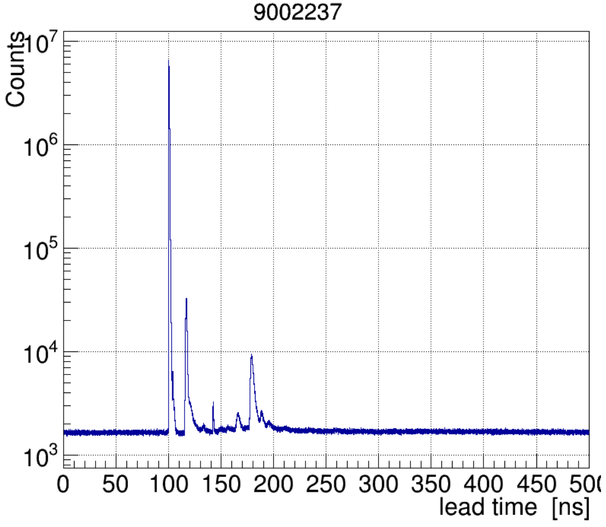
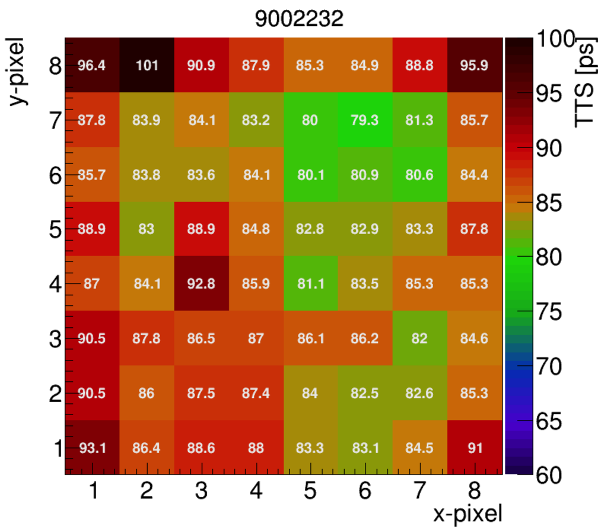


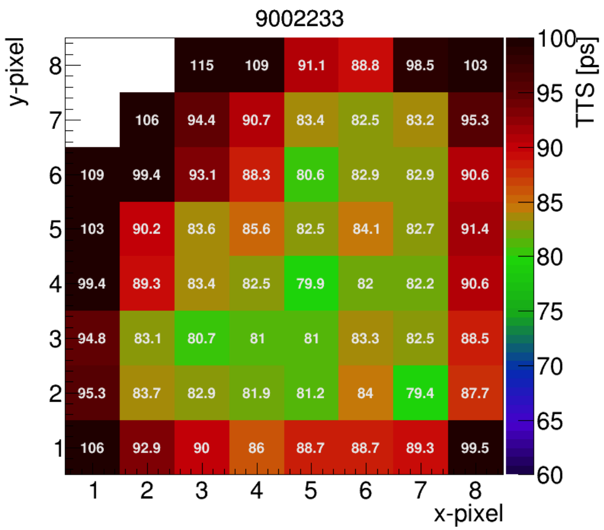
- Time spectra measured with TRB/DiRICH DAQ
- see talk by Daniel Miehling

σ_{TTS}-time resolution with TRB/DiRICH DAQ

9002232



9002233



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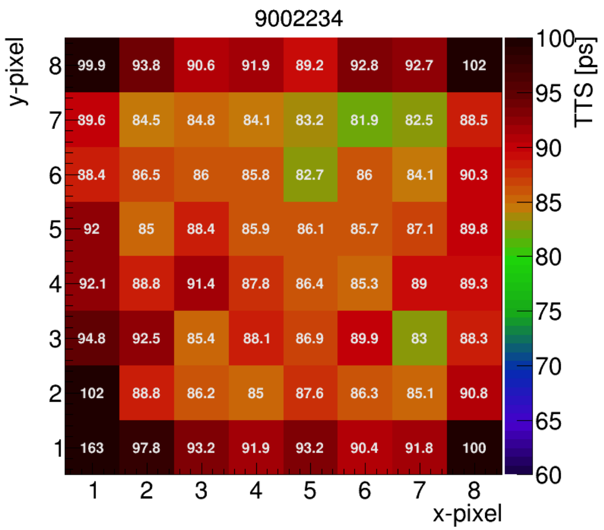

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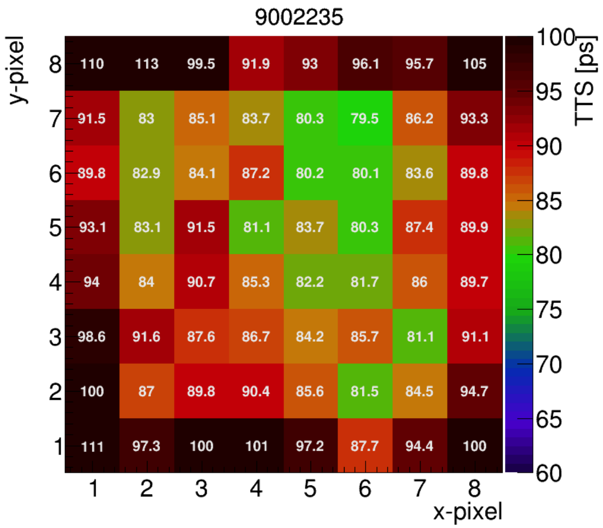
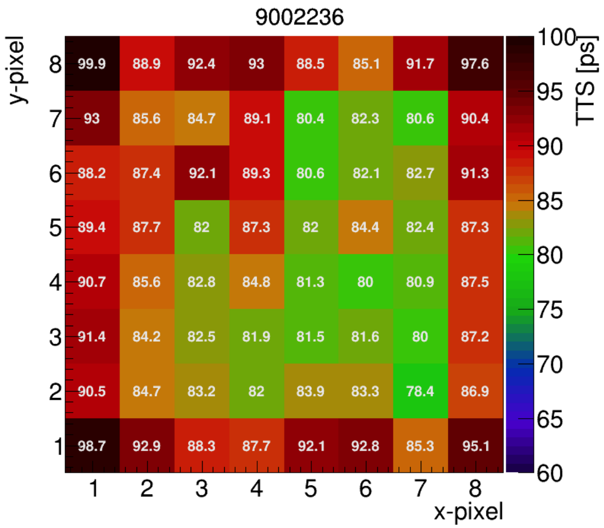
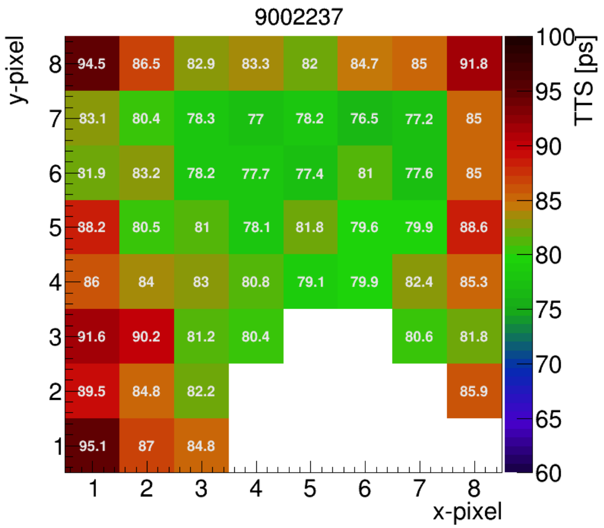


9002236

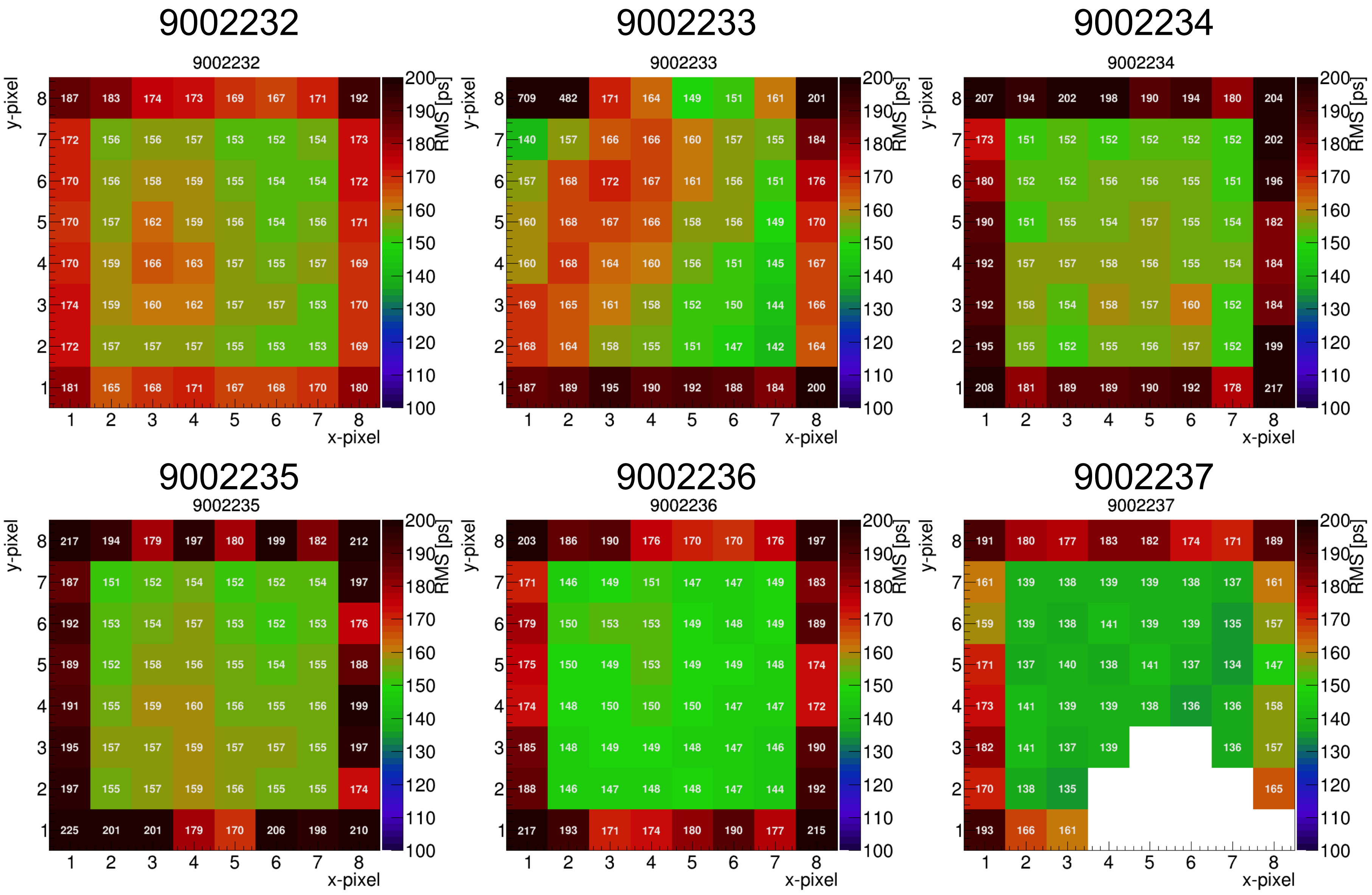


9002237



- 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 across full pixel area

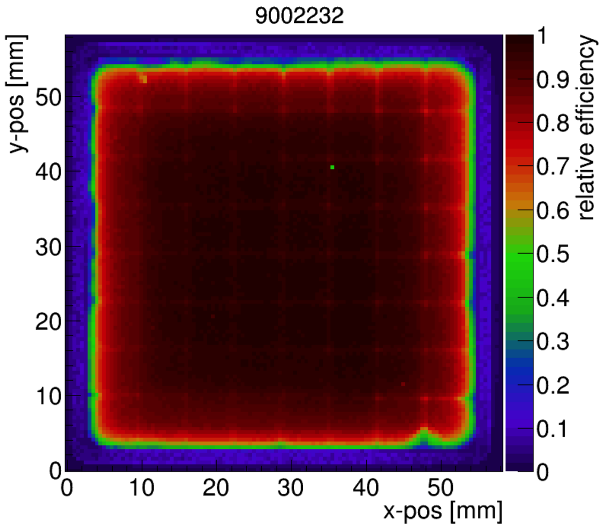
RMS timing with TRB/DiRICH DAQ



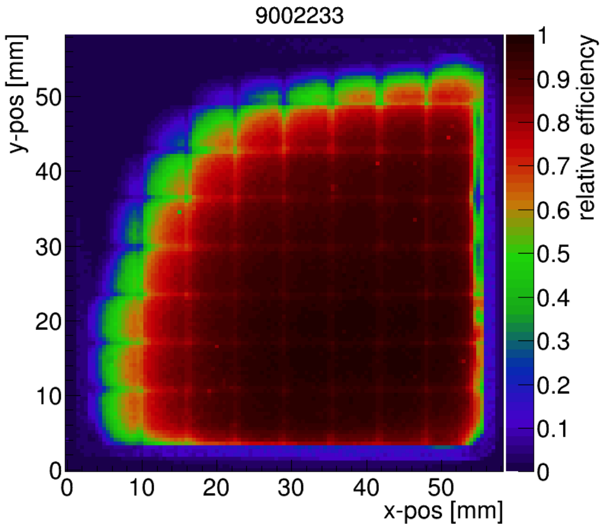
- 4:10:1 divider
- RMS timing measured with TRB/DiRICH DAQ
- Time window:
  -0.5 – +2 ns around main peak
- RMS timing **<200 ps** for >95% of all pixels for combined tube-DAQ system and over full pixel area

Efficiency plots with TRB/DiRICH DAQ

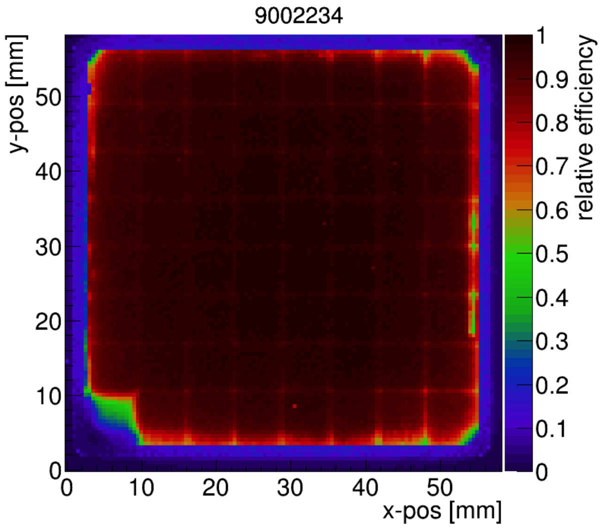
9002232



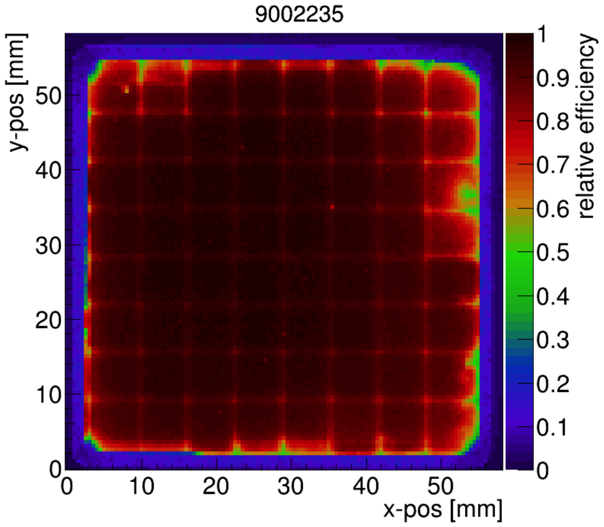
9002233



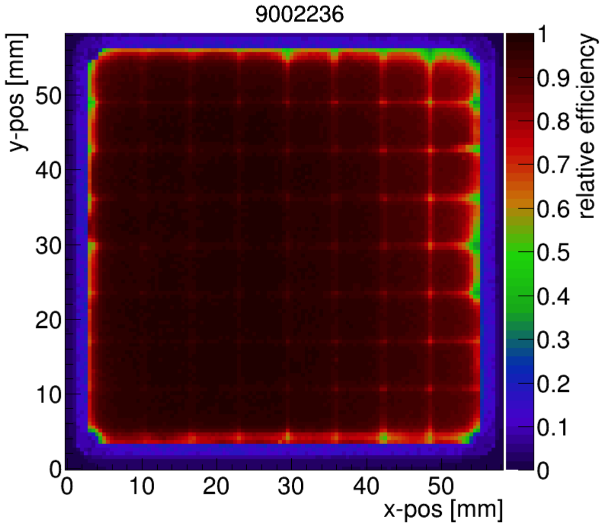
9002234



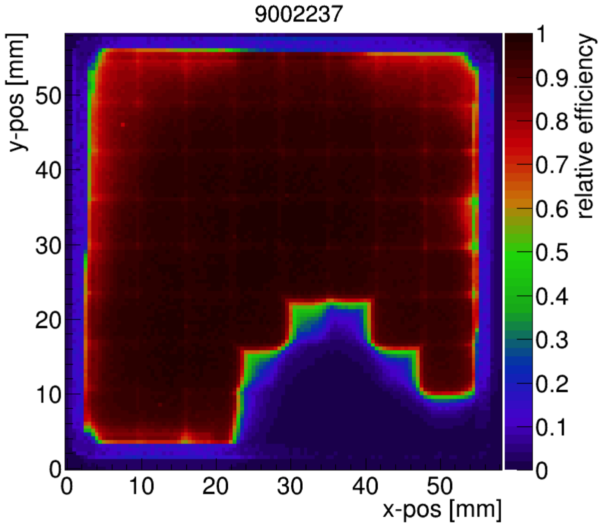
9002235



9002236



9002237



- 4:10:1 divider
- For every position: $\frac{\#\text{measured laser signals}}{\#\text{expected laser signals}}$ normalized to the highest ratio
- Threshold: ~20% of s.p.p at pixel x4 y5
- Important for experimental setup: combination of CE, gain and threshold

Summary

- Good gain uniformity except 9002233
- High CE → DQE of ~23%
- Time resolution fulfills requirements
- Good QE uniformity apart from some holes (no QE loss yet)

But:

- In general quite high afterpulse probability
- Inconsistent measurements of the rate capability
  → search for possible reason is ongoing (two tubes send to Photonis)
- 9002235 and 9002237 escalate at 10^6 gain
- Escalation begins earlier than in very first measurement

	QE [%] (@372nm)	QE-ratio [full area]	Gain-ratio [full area]	CE [%] (4:10:1)	DCR [Hz/cm²]	AP-Fraction [%]	TTS [ps] (TRB)	RMS [ps] (TRB)
DIRC specs	>18	<1.5	<3	>65	<1000	<2	<50 (scope)	<200 (scope)
9002220	21.7	1.24	3.96	99.1	2100.3	2.0	86	165
9002221 (APF)	23.8	1.29	4.54	82.5 (1:10:1)	2195	18.8	91	163
9002222	21.5	1.32	2.52	94.6	1869.7	1.8	90	171
9002223	19.1	1.39	3.58	99.6	247.2	0.7	92	166
9002224	21.5	1.31	2.04	97.3	558.1	0.7	88	166
9002225 (QE)	20.2	2.68	2.35	95.3	142.9	1.3	94	158
9002226 (QE)	20.4	1.44	3.15	96.9	2602.4	2.0	97	169
9002227 (APF)	22.1	1.33	4.04	96.7	6609.5	39.5	87	158
9002228	21.3	1.14	2.21	98.8	1061.1	7.4	83	155
9002229	21.1	1.2	2.7	96.6	109.9	1.0	85	155
9002230	25.4	1.55	3.1	96.3	228.1	3.2	85	156
9002231	24.6	1.14	2.5	98.6	403.2	2.4	82	149
9002232 (DC)	24.7	1.52	2.05	95.7	25181.2	2.9	86	164
9002233 (gain)	24.6	1.17	75.7	91.4	224.1	4.2	88	170
9002234	24.9	1.14	2.52	99.9	604.8	1.2	90	171
9002235 (esc)	24.0	1.28	2.32	99.3	1392.2	2.6	90	172
9002236	24.4	1.15	2.76	92.8	447.4	4.4	87	164
9002237 (esc)	23.8	1.38	2.17	97.2	4934.0 (53 pix)	2.4	83	152