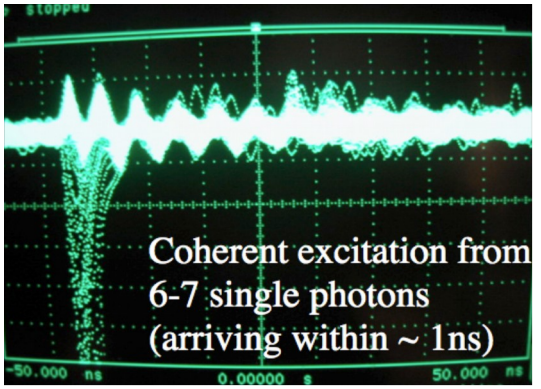
Origin of Time-over-Threshold (ToT) Multi-Peaks

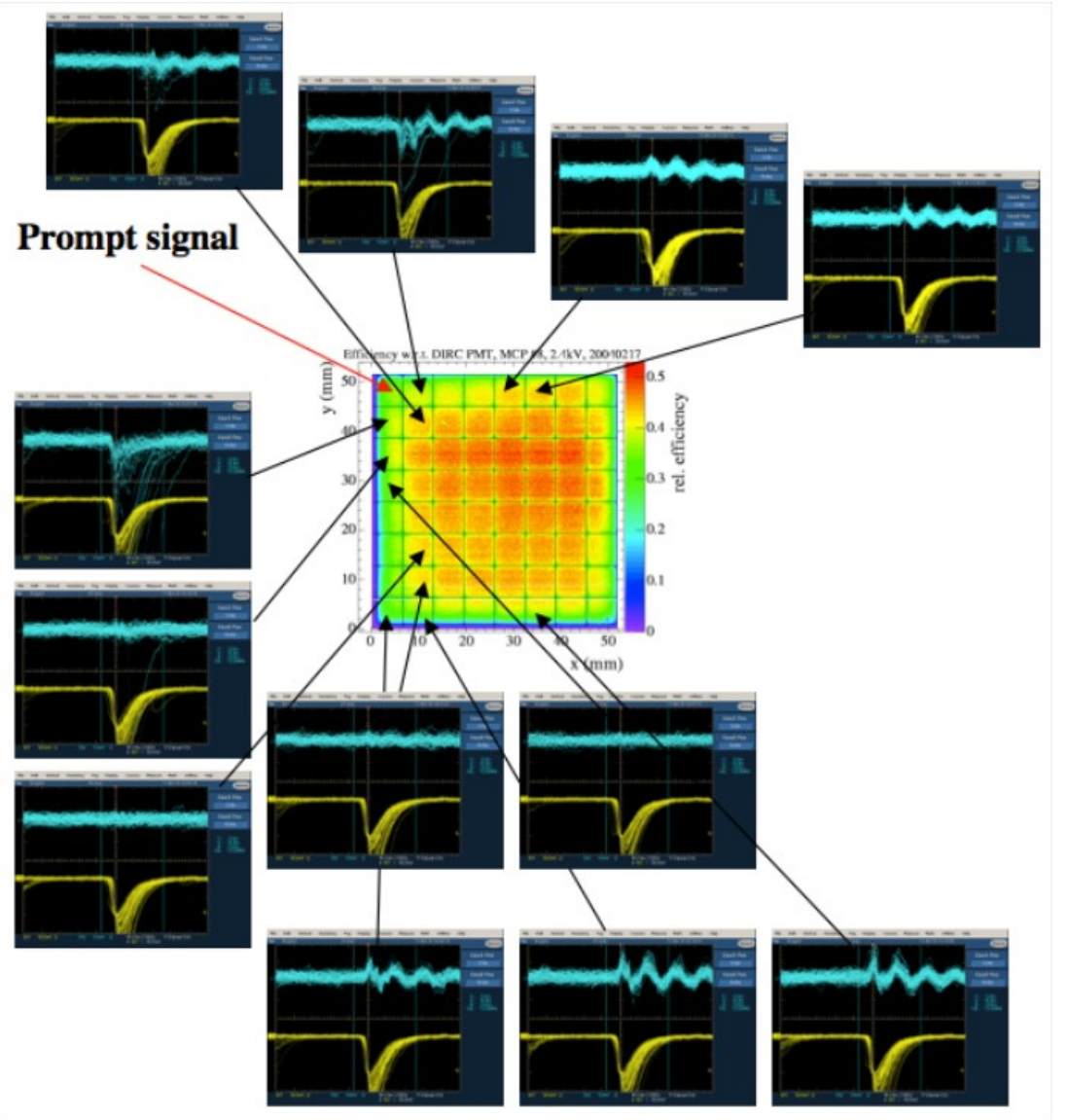
A. Lehmann, M. Böhm, M. Pfaffinger, S. Stelter
and the students D. Mieling, M. Nemeth-Csoka, N. Schwarm

- Crosstalk measurements of Jerry Va'vra
- First ringing tests with different ND filters (1 pixel, whole PC)
- Quantification of crosstalk (ringing) effects
- Effects of ringing on pulse widths (or ToT)

Jerry Vavra's Planacon Measurements

- Old Burle Planacon MCP-PMT (2-inch, 8x8 pixels) for FDIRC
- Right figure: shining single photons to pad #1 (upper left) → observes crosstalk also at rather distant pixels
- Lower figure: illuminate entire detector plane with diffuse light → going from single photons to 6-7 p.e's per entire PC plane → "coherent excitations"



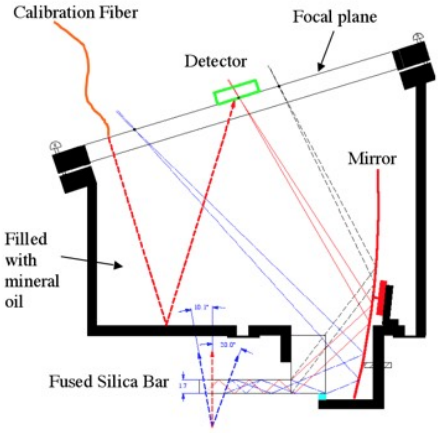


Jerry's Conclusion (Argonne Talk 2018)

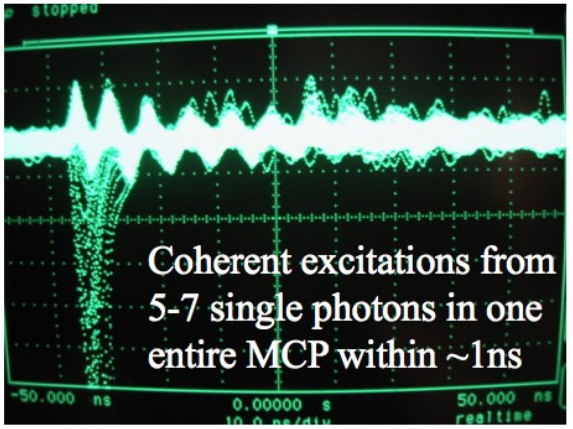
Cross-talk causing coherent excitations

J.V., MCP-PMT log book #1, p.18, 2005, and FDIRC#1 beam test log book #3, p. 34, 2005

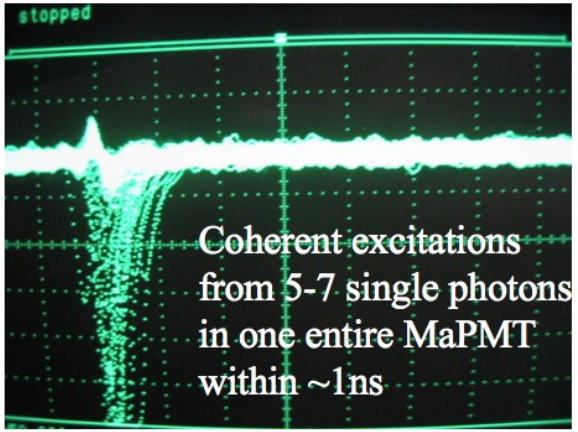
Method to do it:



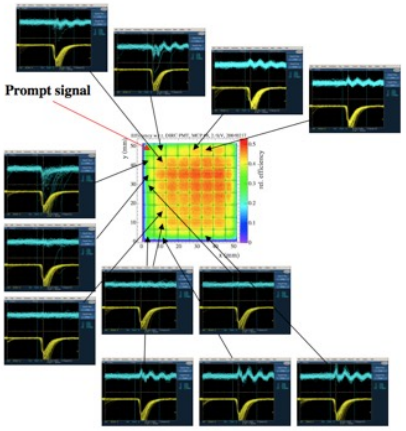
Planacon MCP-PMT:



H-8500 MaPMT:



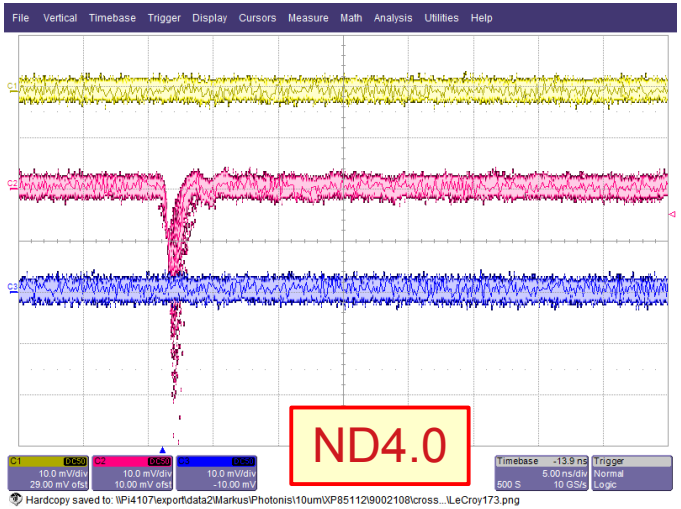
A cross-talk in the old Burle Planacon was very complicated:

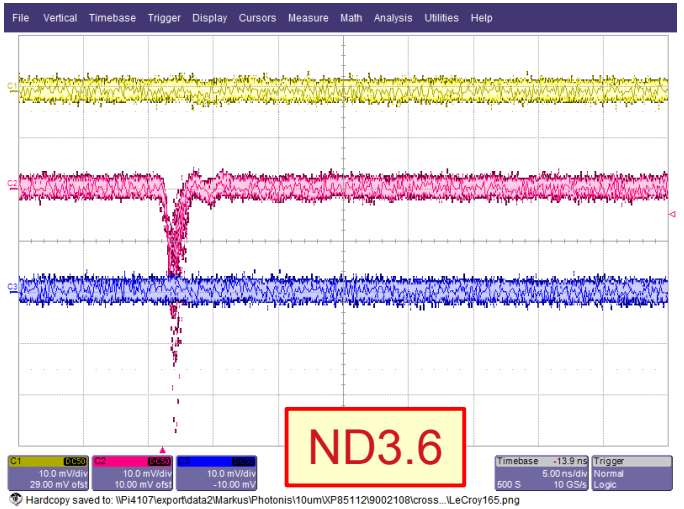


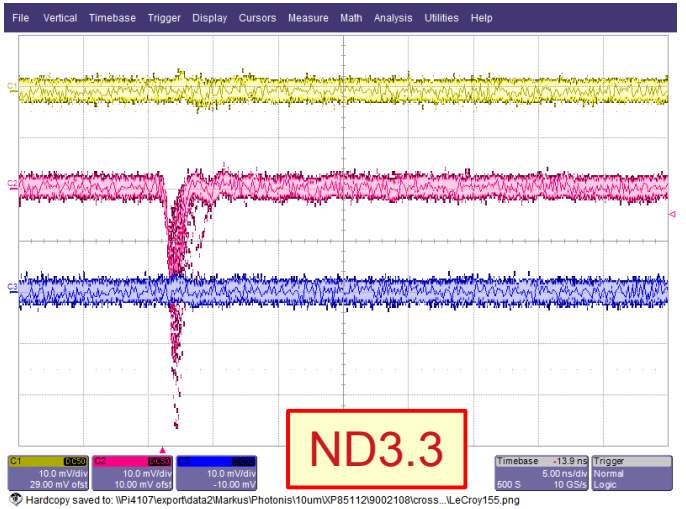
- **The cross-talk in the Planacon MCP-PMT was related to MCP backplane issues. This problem affected the timing resolution. H-8500 MaPMT was OK.**

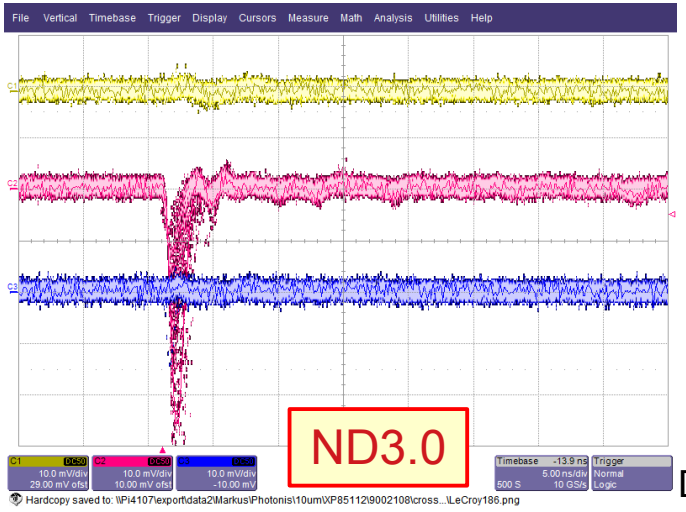
PHOTONIS XP85112-Q-HA (9002108)

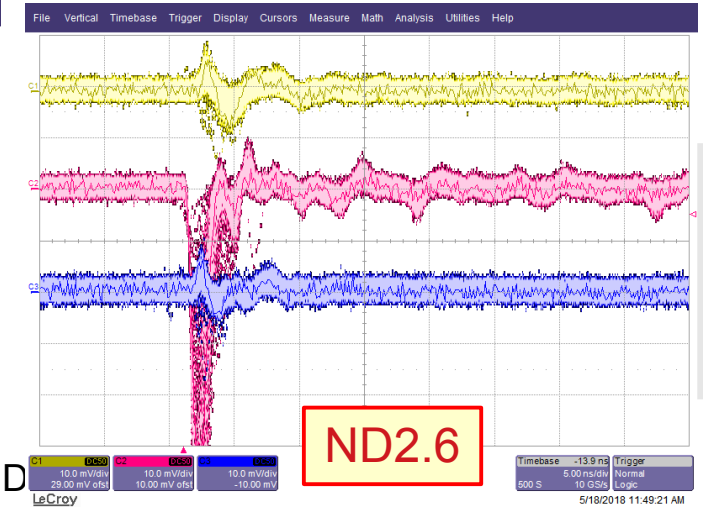
- 2 inch x 2 inch, 8 x 8 pixels, 10 µm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; focused **illumination of pixel 44 only**











x: 5 ns/div
y: 10 mV/div

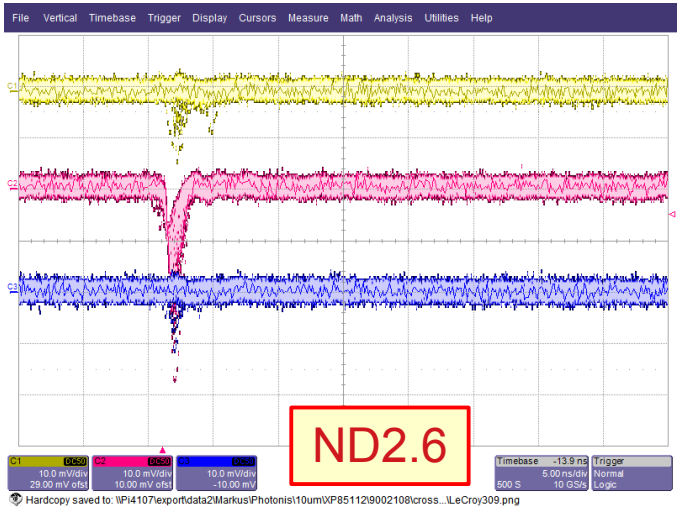
Trigger:
Laser * px44

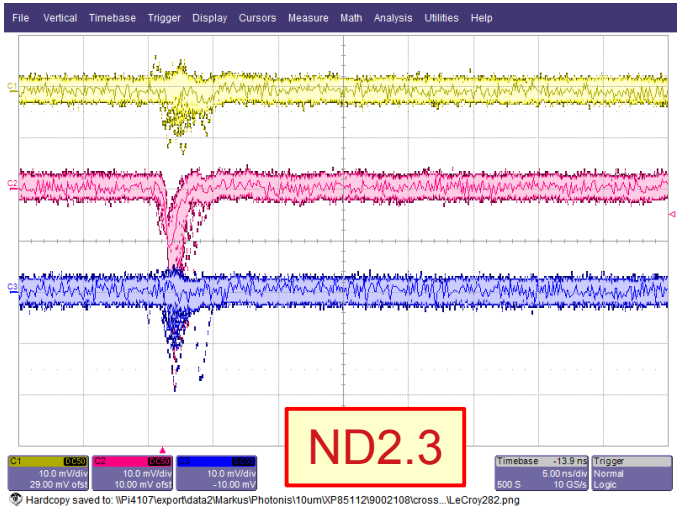
Pixel's read out

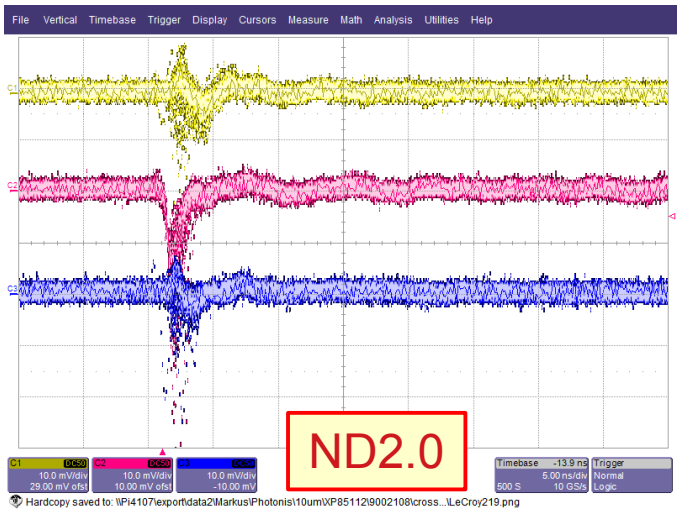
11	12	13	14	15	16	17	18
21	22	23	24	25	26	27	28
31	32	33	34	35	36	37	38
41	42	43	44	45	46	47	48
51	52	53	54	55	56	57	58
61	62	63	64	65	66	67	68
71	72	73	74	75	76	77	78
81	82	83	84	85	86	87	88

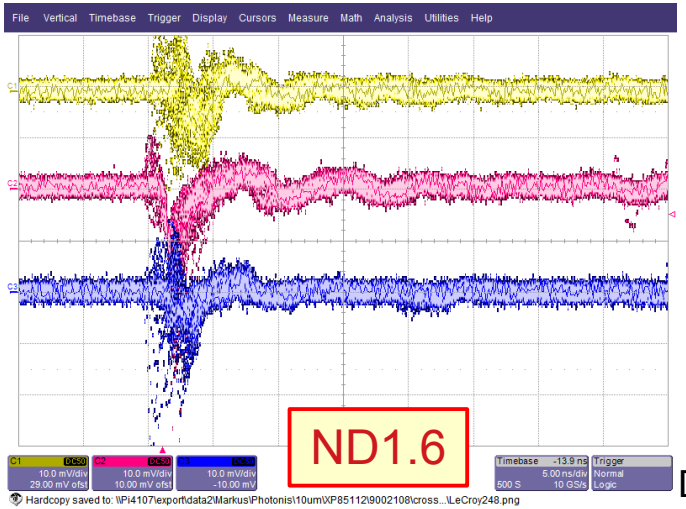
PHOTONIS XP85112-Q-HA (9002108)

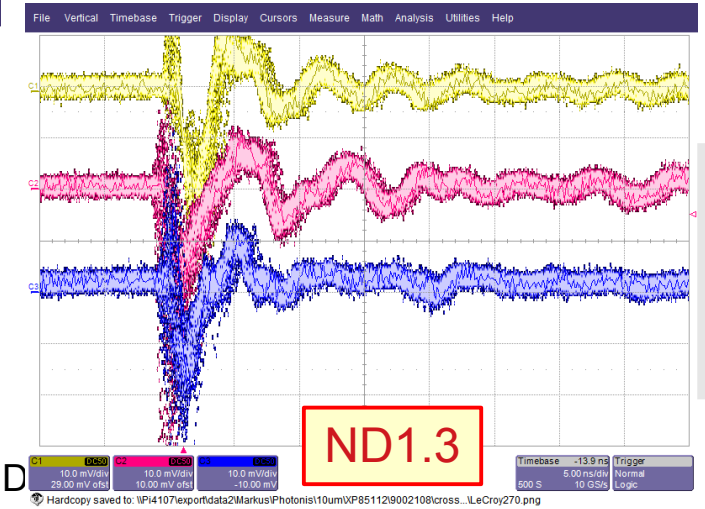
- 2 inch x 2 inch, 8 x 8 pixels, 10 µm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; diffuse **illumination of full PC area**











x: 5 ns/div
y: 10 mV/div

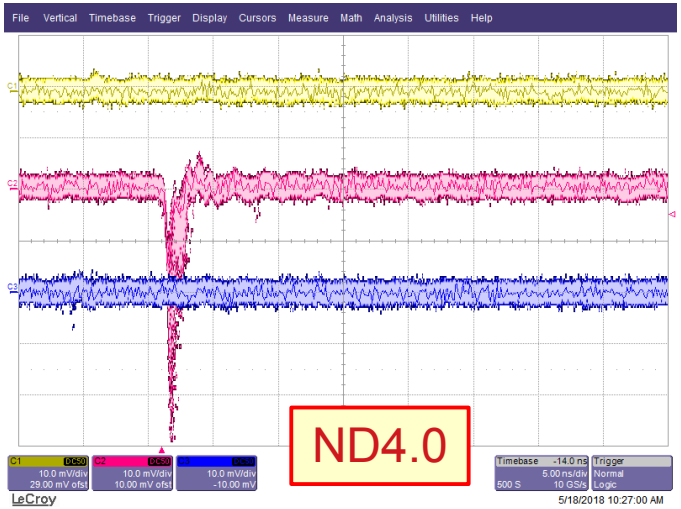
Trigger:
Laser * px44

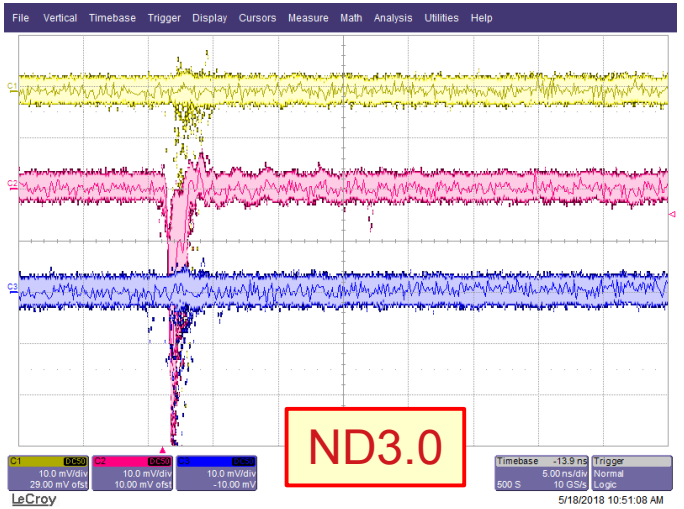
Pixel's read out

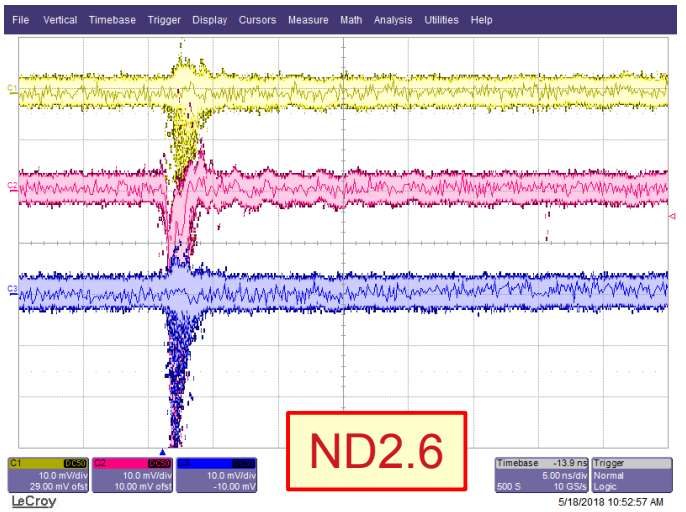
11	12	13	14	15	16	17	18
21	22	23	24	25	26	27	28
31	32	33	34	35	36	37	38
41	42	43	44	45	46	47	48
51	52	53	54	55	56	57	58
61	62	63	64	65	66	67	68
71	72	73	74	75	76	77	78
81	82	83	84	85	86	87	88

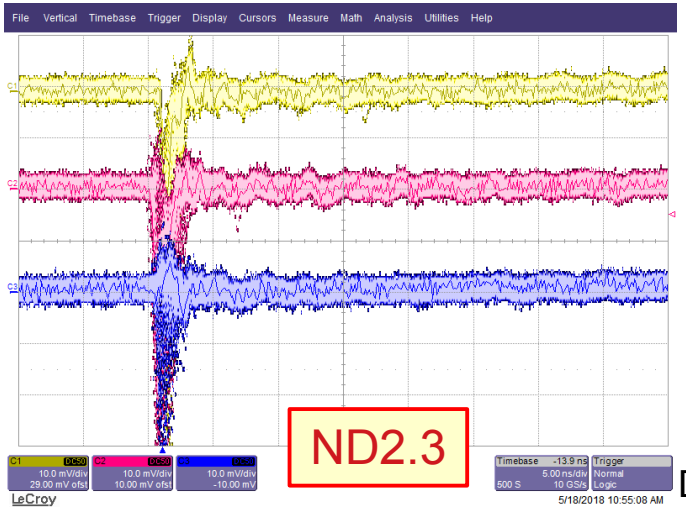
Hamamatsu R13266-07-M64M (YH0250)

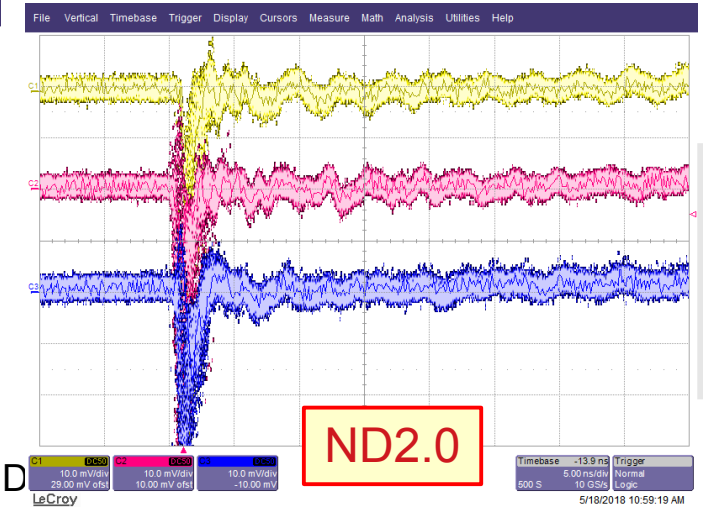
- 2 inch x 2 inch, 8 x 8 pixels, 10 μm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; diffuse **illumination of full PC area**







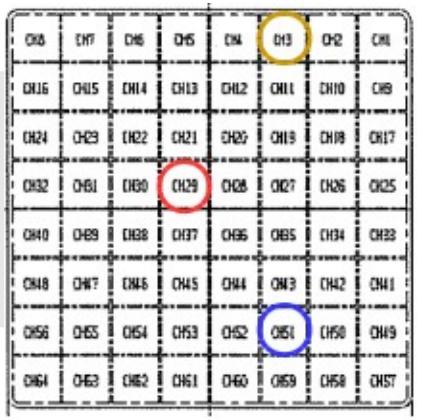




x: 5 ns/div
y: 10 mV/div

Trigger:
Laser * CH29

Pixel's read out



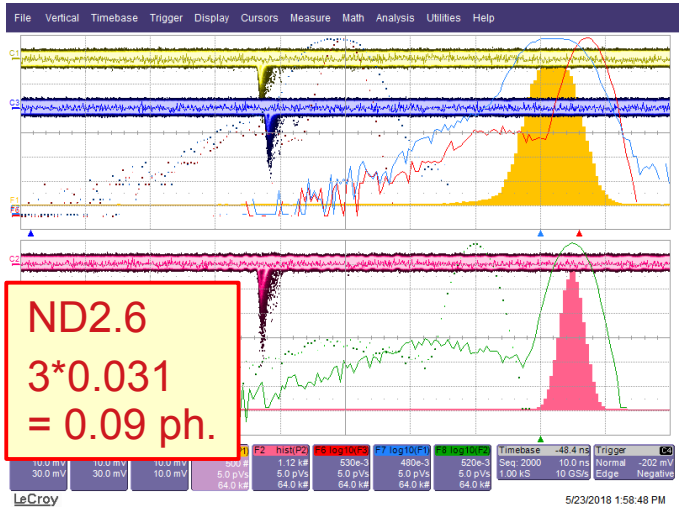
First Conclusions

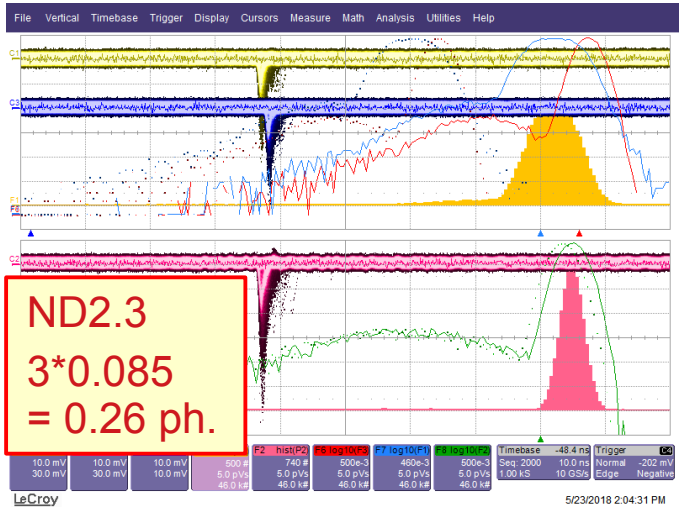
- We observe a similar ringing effect with the latest PHOTONIS MCP-PMT as Jerry has seen >10 years ago with Burle Planacon
- Qualitative findings of these first tests
  - The ringing gets more with the amount of measured single photons (hitting different pixels) per MCP-PMT
  - The ringing gets also more with an increasing pulse height (this means that events with several photons per pixel also cause ringing even if just one pixel is illuminated)
  - Clearly there is also ringing in the latest 2-inch Hamamatsu tubes with similar findings as above, but with a different frequency as in the Photonis tubes
- More quantification of this effect is needed
  - Diffuse illumination of whole PC area with different light intensities (ND filters)
  - Measure above signals but with **masks** for different amount of open pixels
  - determine amount of photo electrons (N_{pe}) per pixel from pulse height histos:

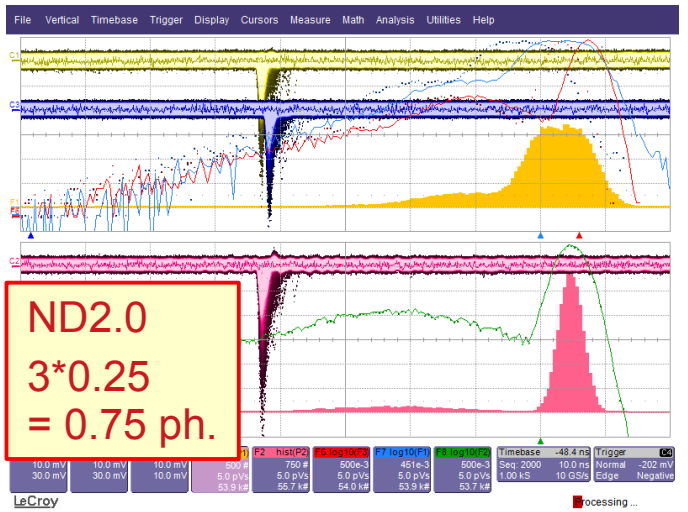
$$\mathbf{N_{pe} = \lambda = -\ln(N_0/N_{all})} \qquad \text{with} \quad N_k = \lambda^k \cdot e^{-\lambda} / k! \quad \text{and} \quad N_{all} = \Sigma\, N_k$$

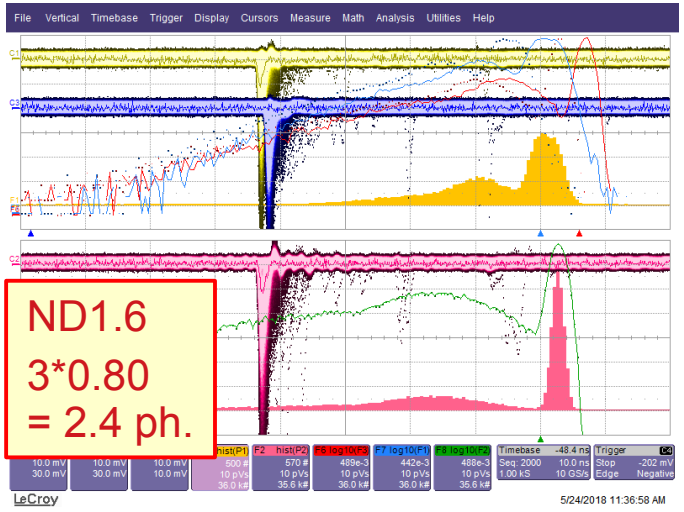
PHOTONIS 9002108 – low intensity

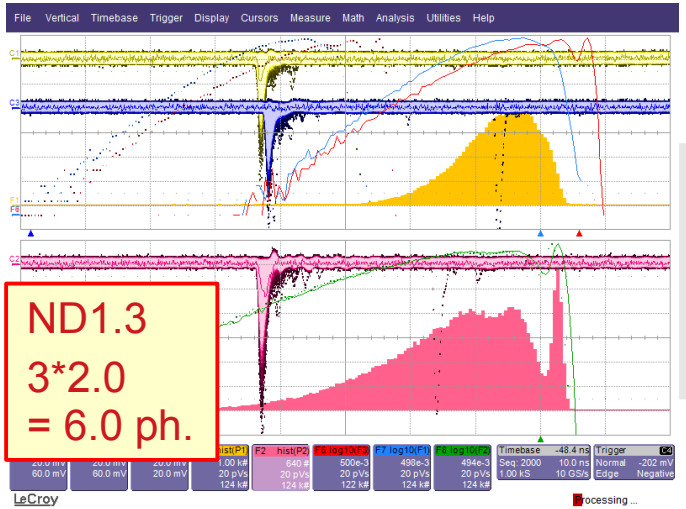
- 2 inch x 2 inch, 8 x 8 pixels, 10 µm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; illumination of **3 pixels** of PC area







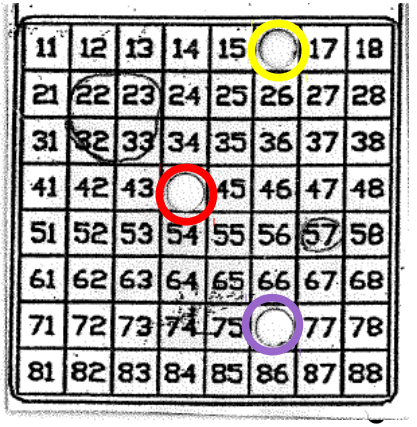




x: 5 ns/div
y: 10 mV/div

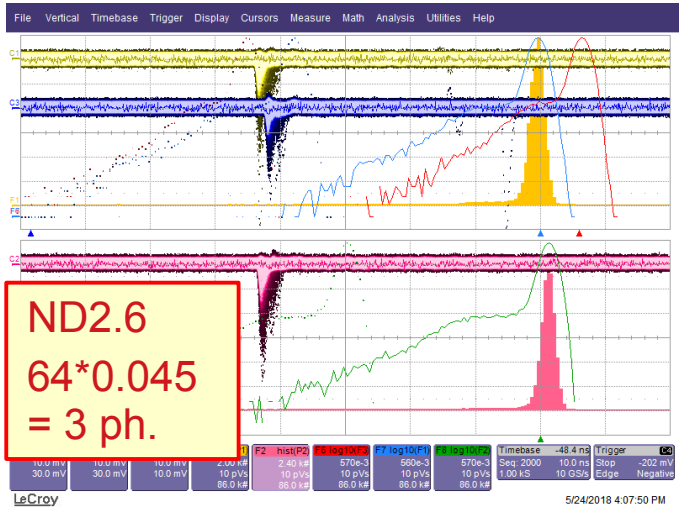
Trigger:
Laser pulse

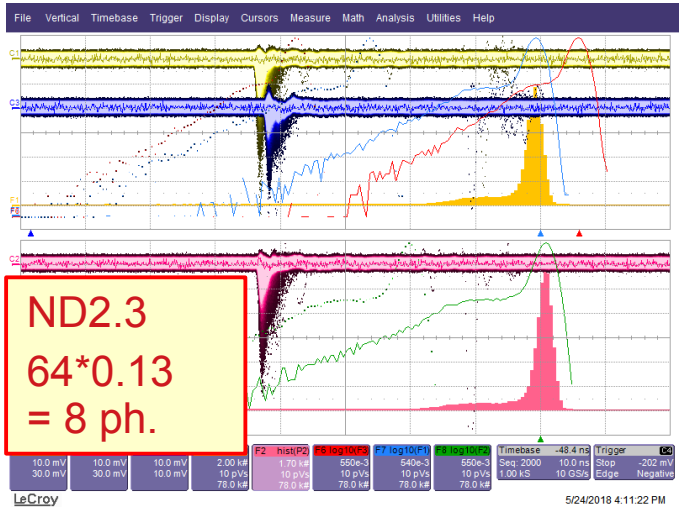
Pixel's read out

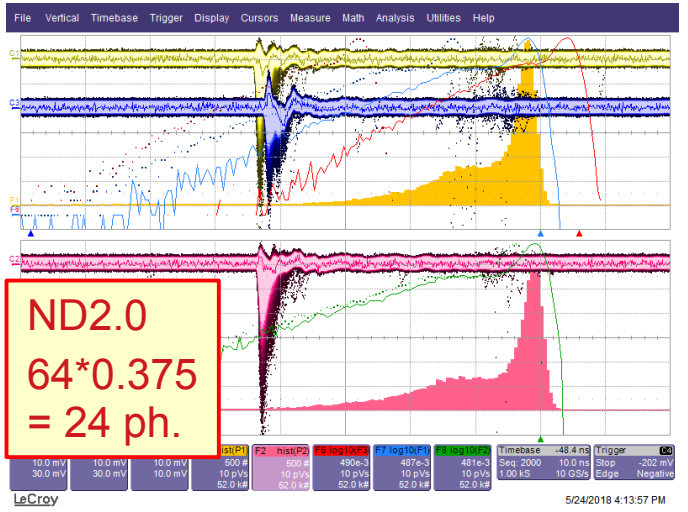


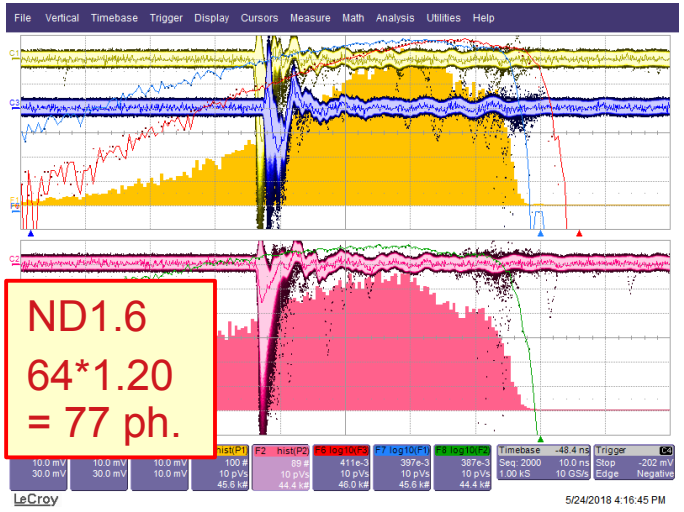
PHOTONIS 9002108 – high intensity

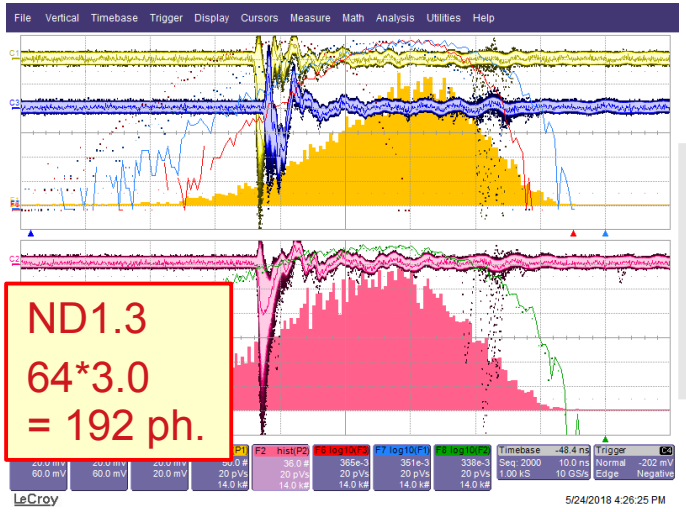
- 2 inch x 2 inch, 8 x 8 pixels, 10 µm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; illumination of **full PC area (no mask)**







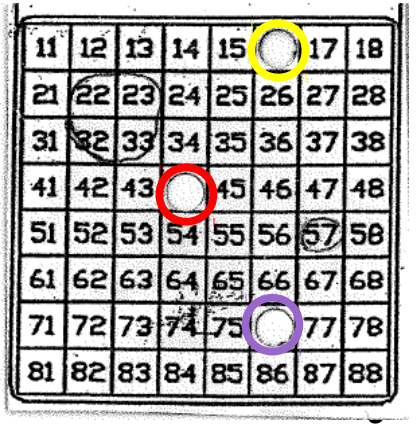




x: 5 ns/div
y: 10 mV/div

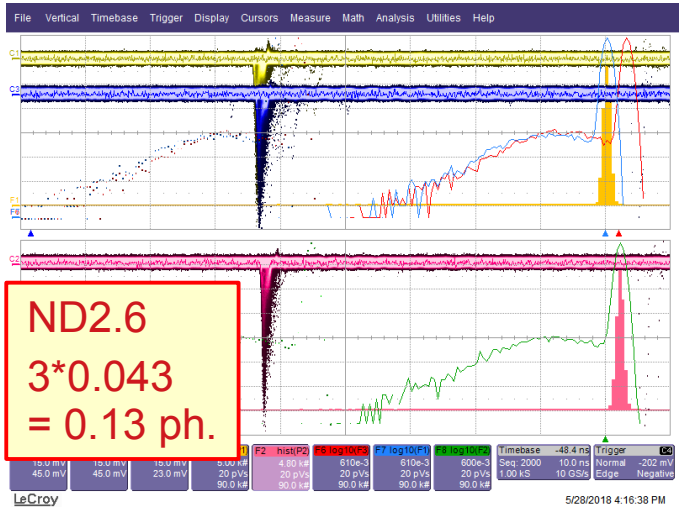
Trigger:
Laser pulse

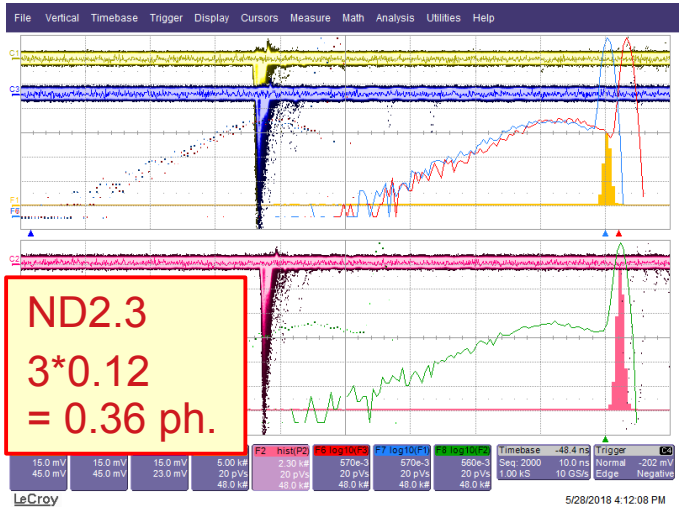
Pixel's read out

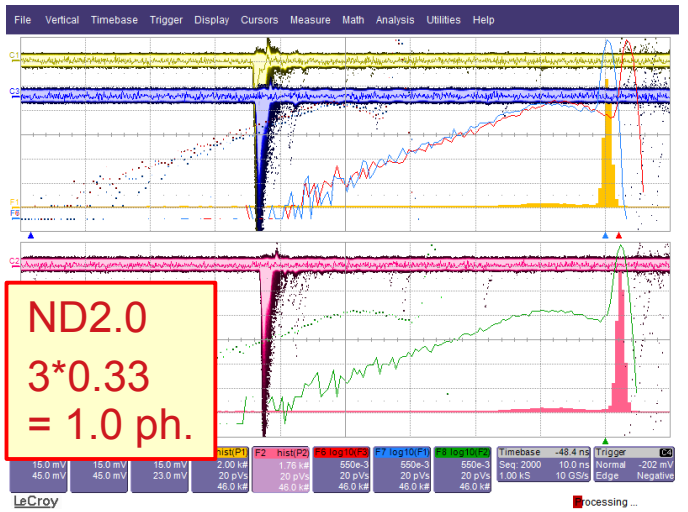


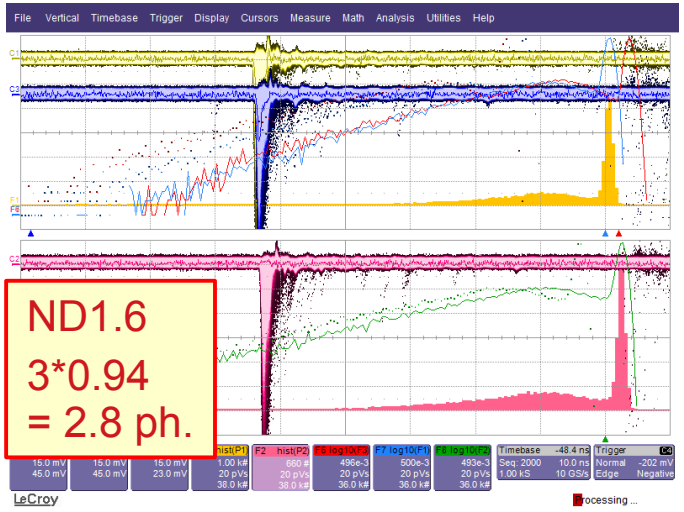
Hamamatsu YH0250 – low intensity

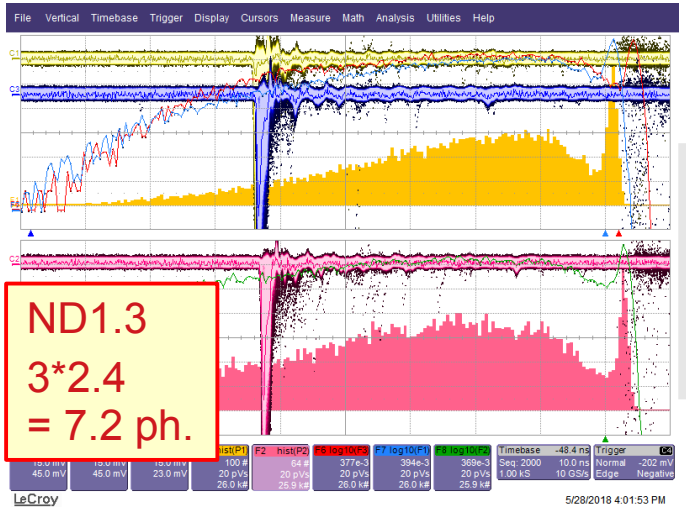
- 2 inch x 2 inch, 8 x 8 pixels, 10 µm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; illumination of **3 pixels** of PC area







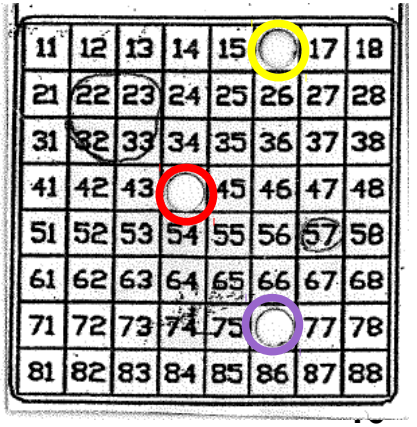




x: 5 ns/div
y: 15 mV/div

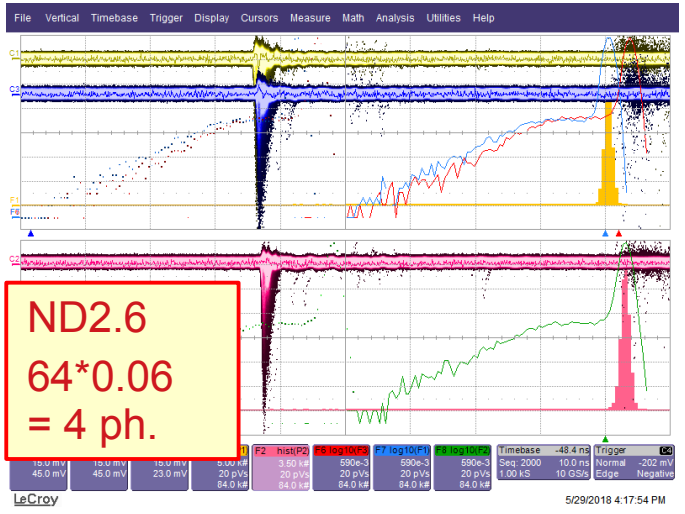
Trigger:
Laser pulse

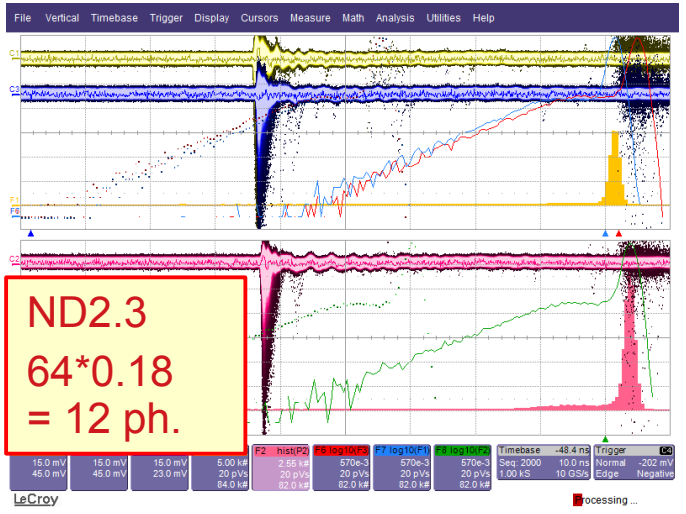
Pixel's read out

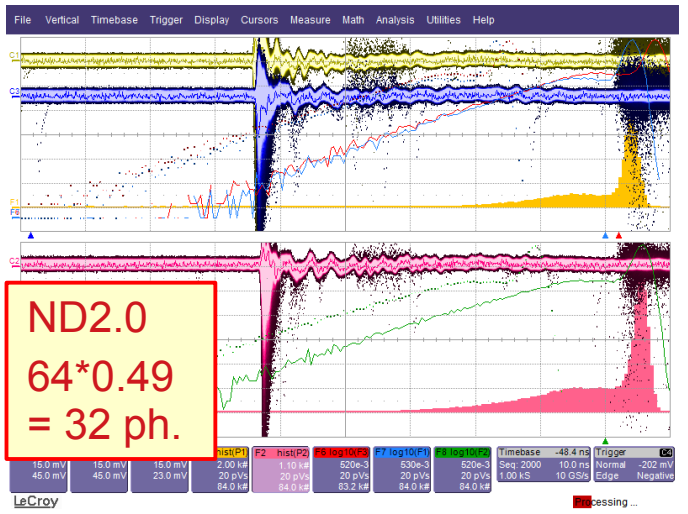


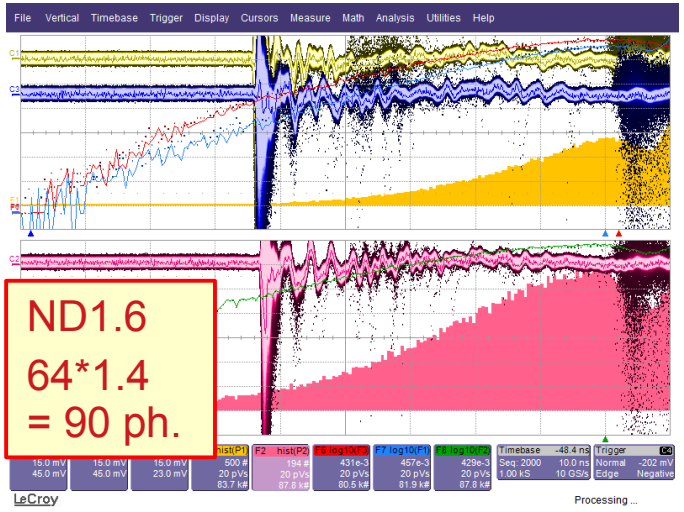
Hamamatsu YH0250 – high intensity

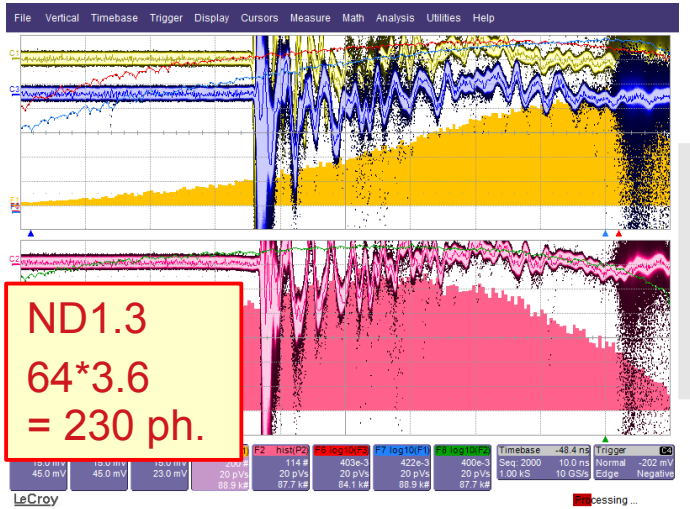
- 2 inch x 2 inch, 8 x 8 pixels, 10 µm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; illumination of **full PC area (no mask)**







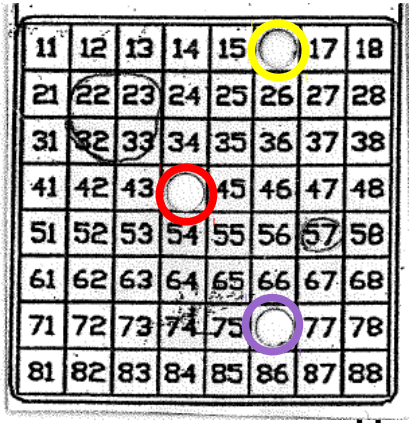




x: 5 ns/div
y: 15 mV/div

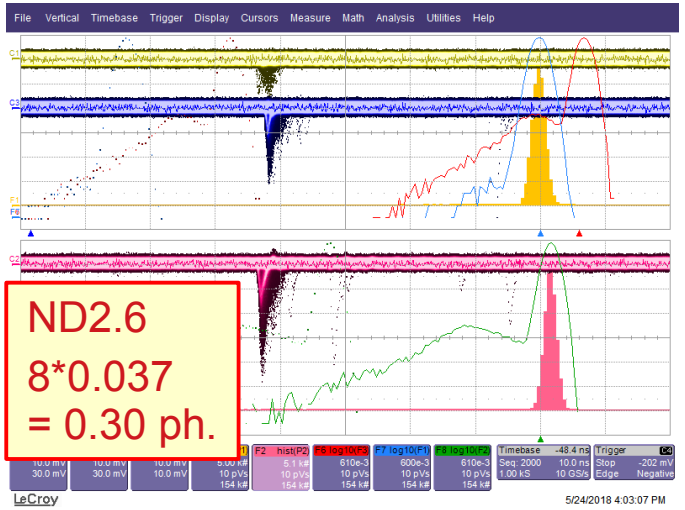
Trigger:
Laser pulse

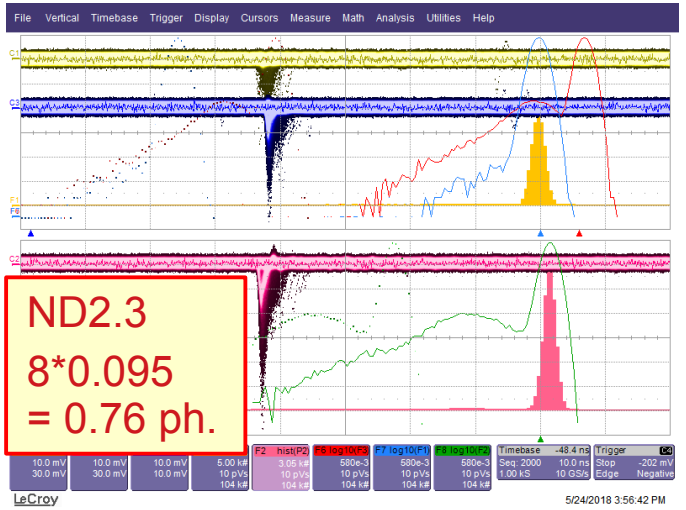
Pixel's read out

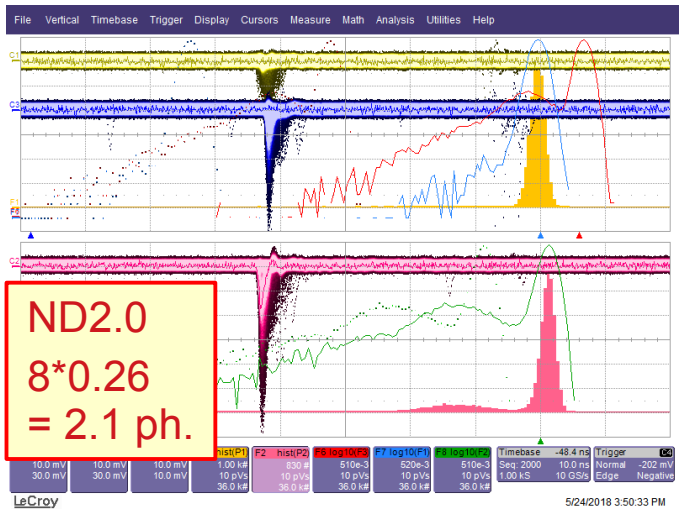


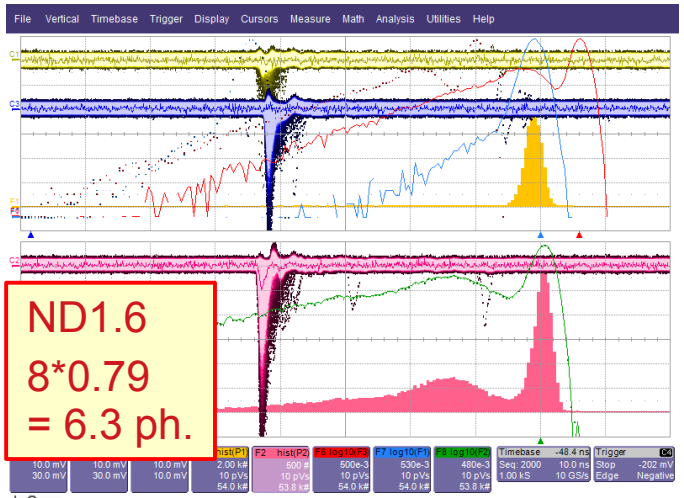
PHOTONIS 9002108 – Cherenkov ring

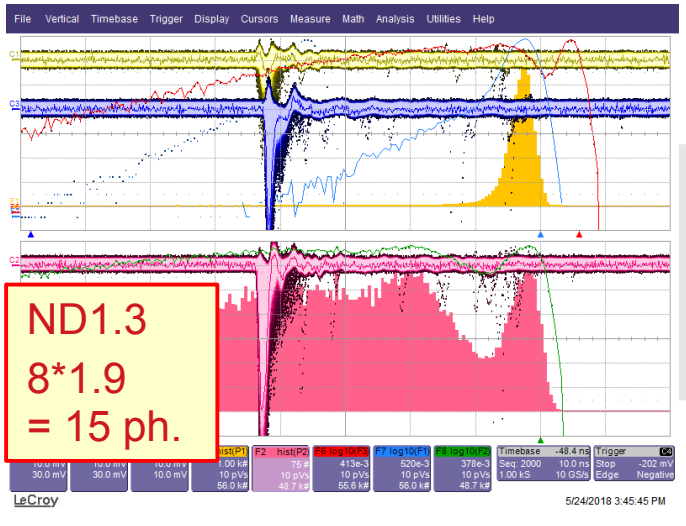
- 2 inch x 2 inch, 8 x 8 pixels, 10 µm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; illumination of **8 pixels** of PC area







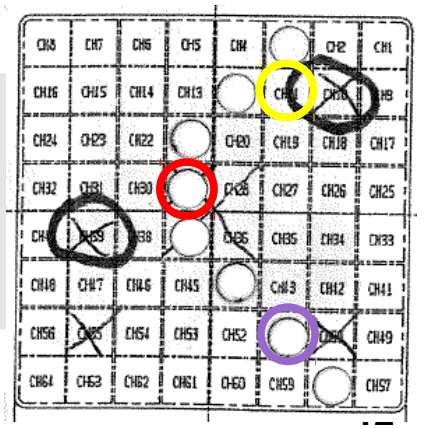




x: 5 ns/div
y: 10 mV/div

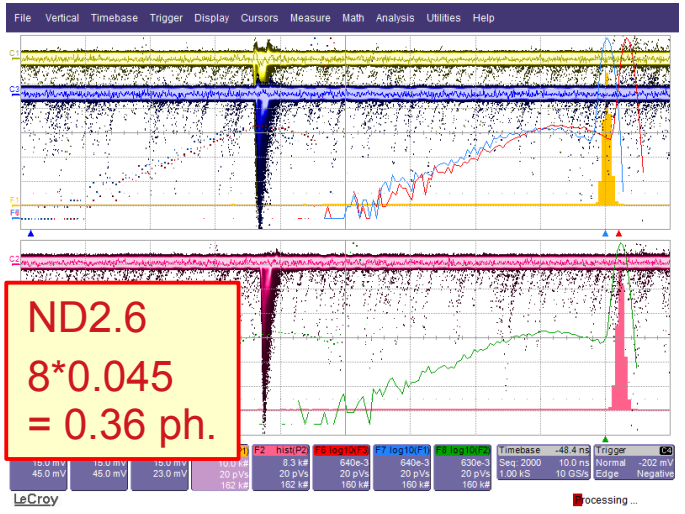
Trigger:
Laser pulse

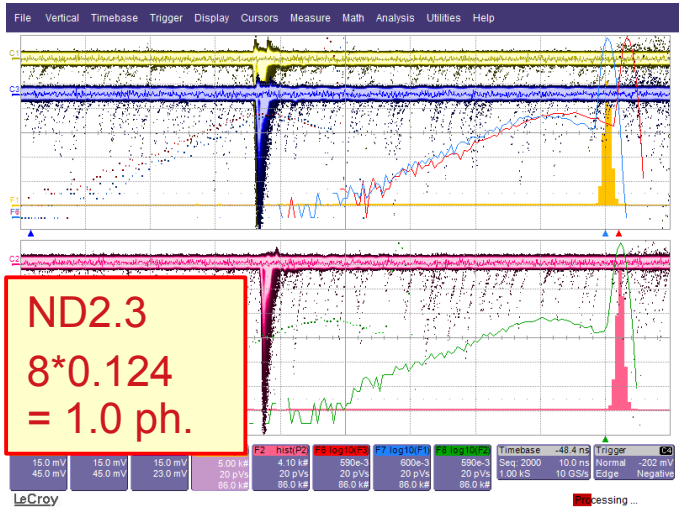
Pixel's read out

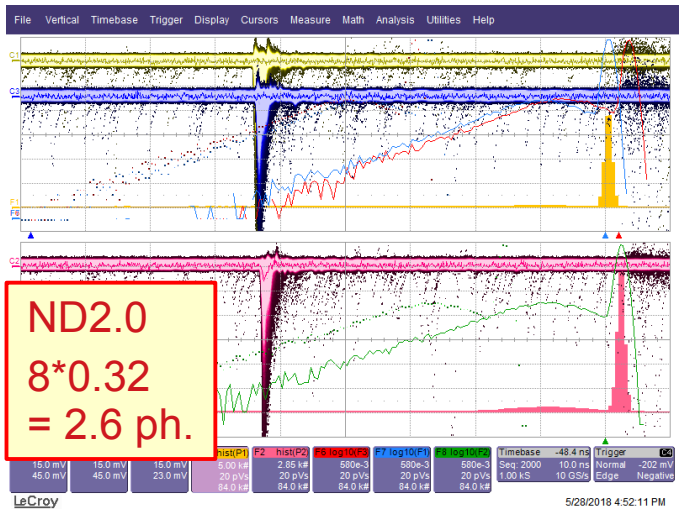


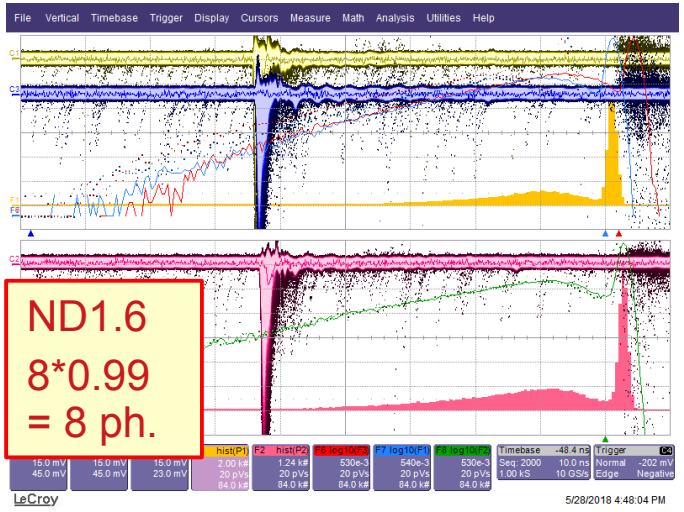
Hamamatsu YH0250 – Cherenkov ring

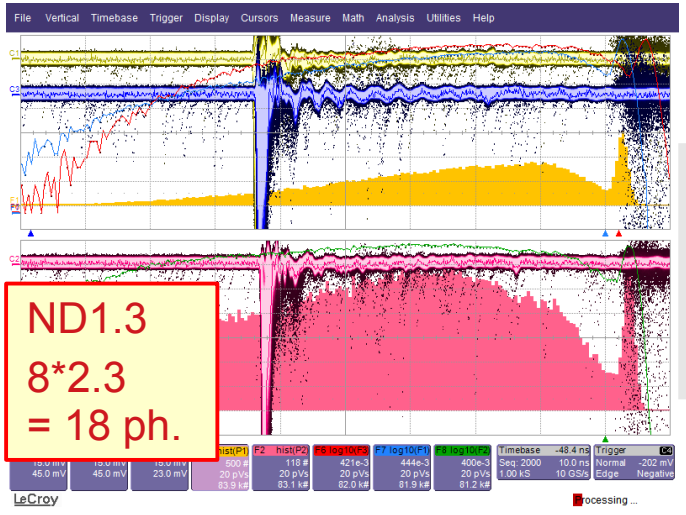
- 2 inch x 2 inch, 8 x 8 pixels, 10 μm pores with ALD coating, 10^6 gain
- Blue (372 nm) PiLas; 15 kHz; illumination of **8 pixels** of PC area







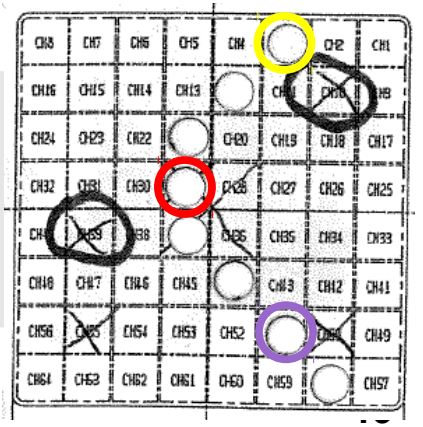




x: 5 ns/div
y: 15 mV/div

Trigger:
Laser pulse

Pixel's read out

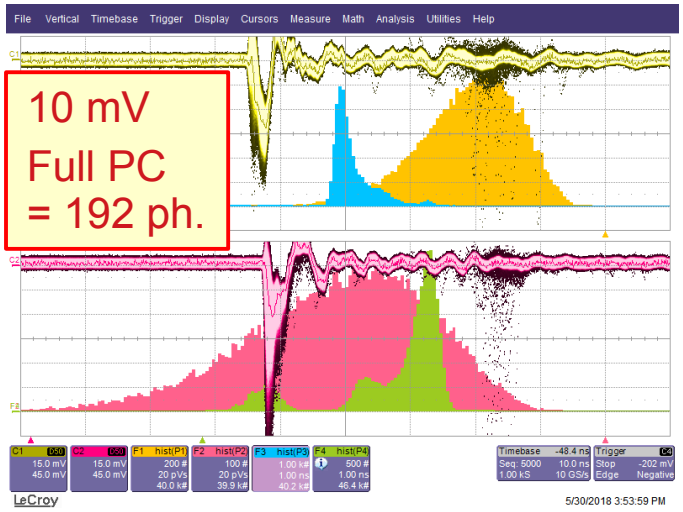


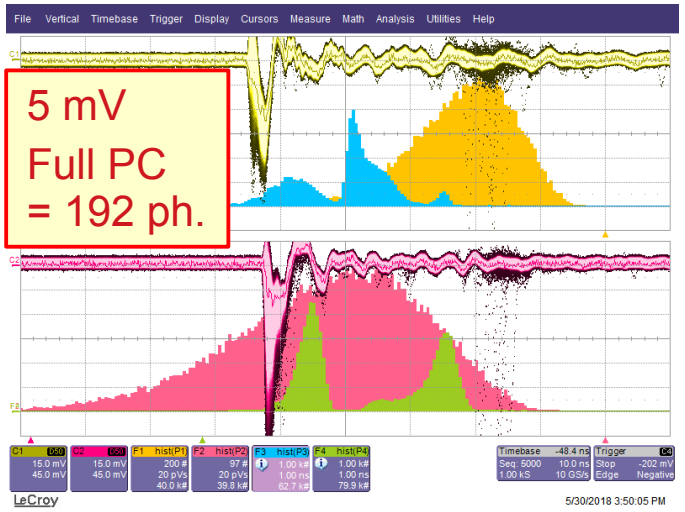
Second Conclusions

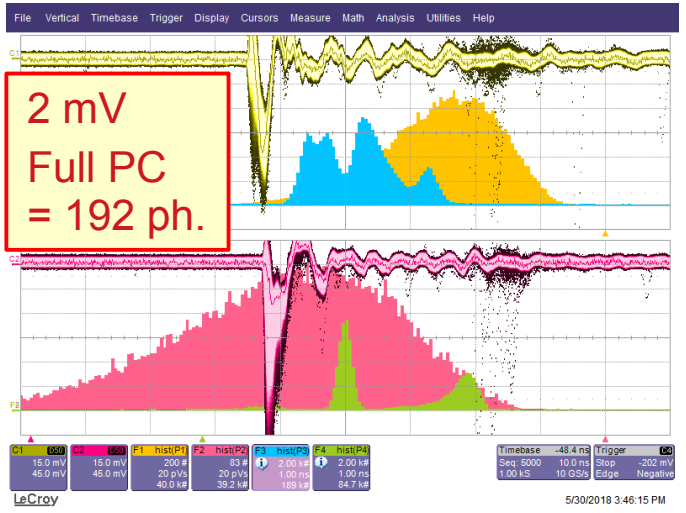
- Measured pulse distributions and pulse height spectra for different ND filters (→ number of photo electrons per pixel) and illuminated pixels (→ number of photo electrons per sensor)
- Quantitative results
  - 3 non-adjacent pixels illuminated: no ringing seen up to 6-7 photons (Hama?)
  - Full sensor illuminated:
    - No problem up to 3-4 photons (per sensor)
    - Ringing starts at ~10 photons (per sensor)
    - Significant increase of oscillations with more photons (per sensor)
  - Cherenkov ring (8 pixels hit, some adjacencies): ringing starts at 6-8 photons
- 2-inch Hamamatsu looks worse than new Photonis MCP-PMT
- Ringing seems to get worse when adjacent pixels are hits

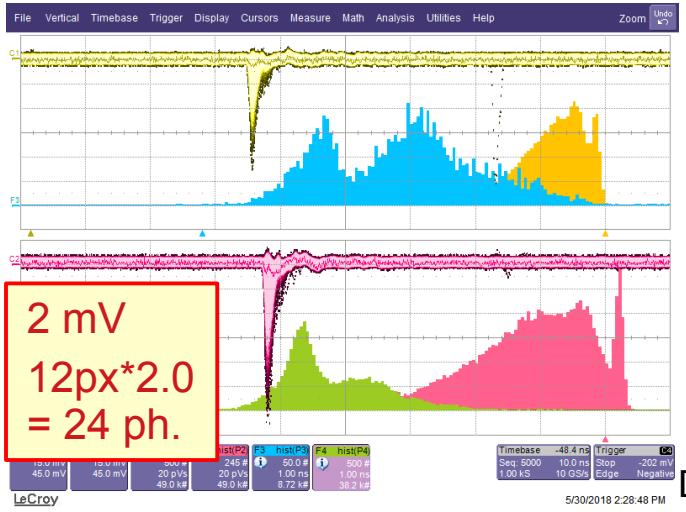
PHOTONIS 9002108 – Pulse widths

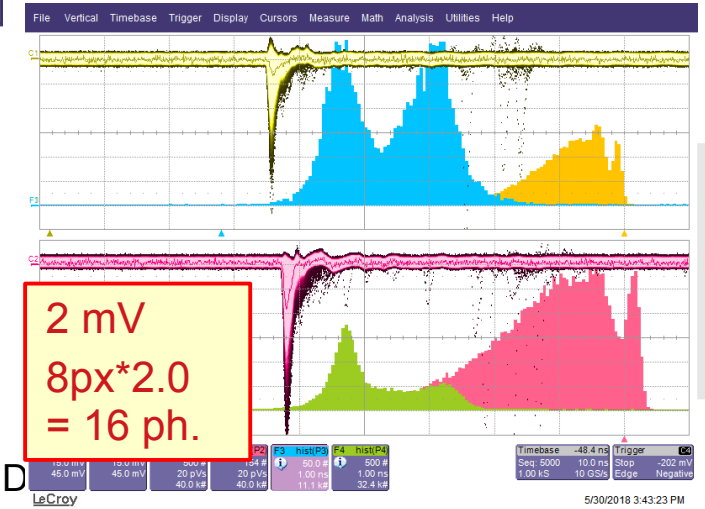
- Pulse widths at different thresholds; **high and medium intensity**
- illumination **with ND1.3; 10, 5, 2 mV thr. (upper) and 2 mV (lower)**
- Pixel 16 (upper plot, blue histo); pixel 44 (lower plot, green histo)











x: 5 ns/div
y: 10 mV/div

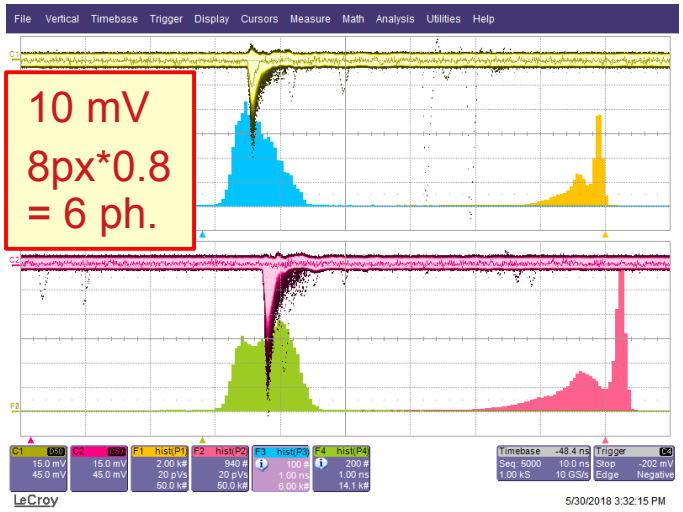
Trigger:
Laser pulse

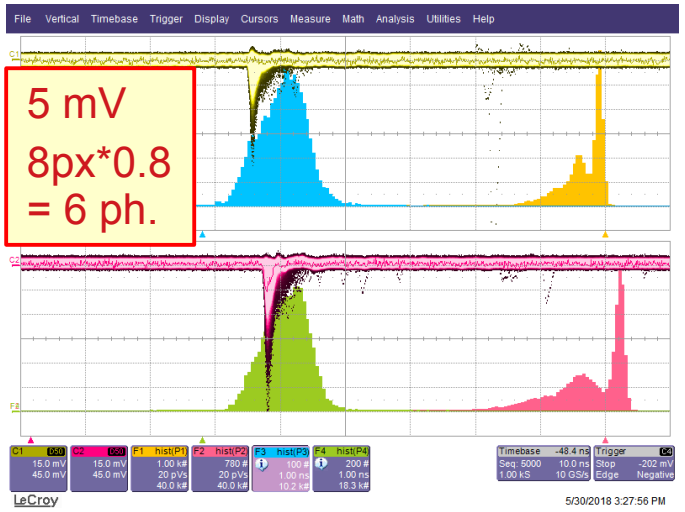
Pixel's read out

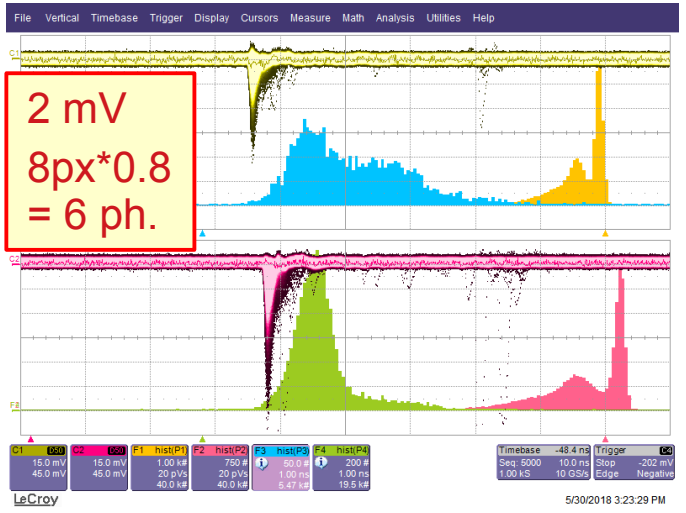
11	12	13	14	15	16	17	18
21	22	23	24	25	26	27	28
31	32	33	34	35	36	37	38
41	42	43	44	45	46	47	48
51	52	53	54	55	56	57	58
61	62	63	64	65	66	67	68
71	72	73	74	75	76	77	78
81	82	83	84	85	86	87	88

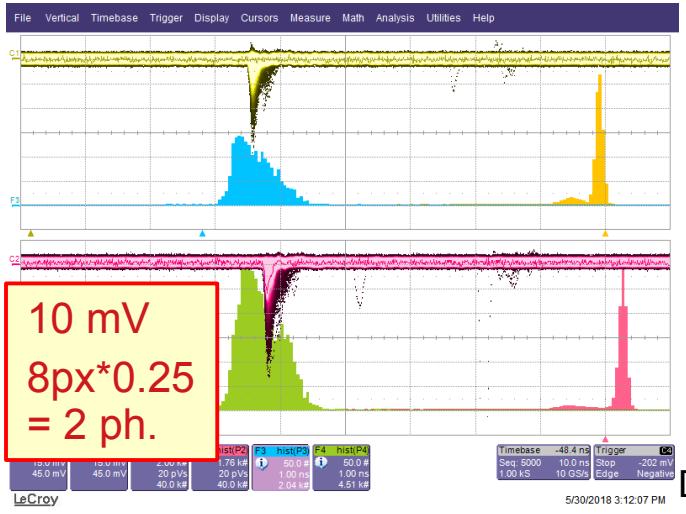
PHOTONIS 9002108 – ToT

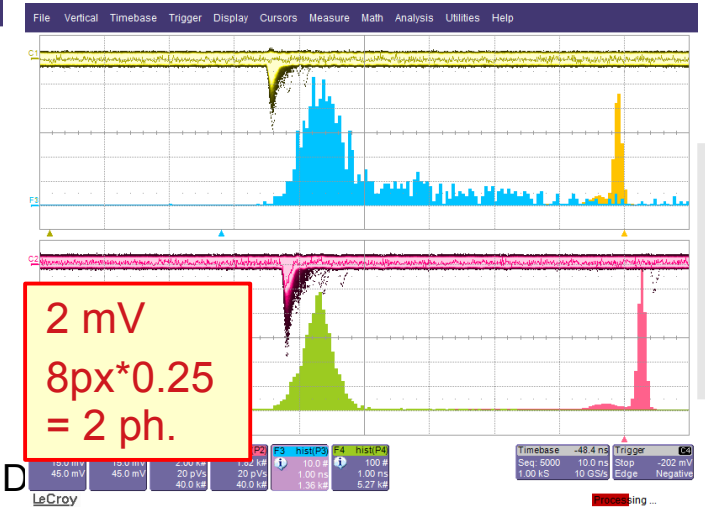
- Pulse widths at different thresholds; **8 open pixels**
- illumination **with ND1.6 (upper row) and ND2.0 (lower row) filter**
- Pixel 16 (upper plot, blue histo); pixel 44 (lower plot, green histo)







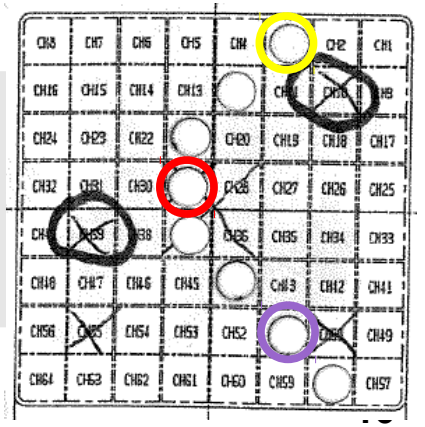




x: 5 ns/div
y: 10 mV/div

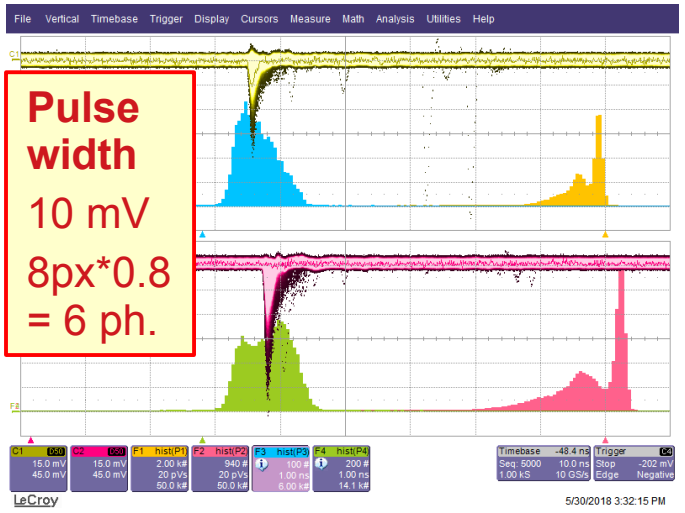
Trigger:
Laser pulse

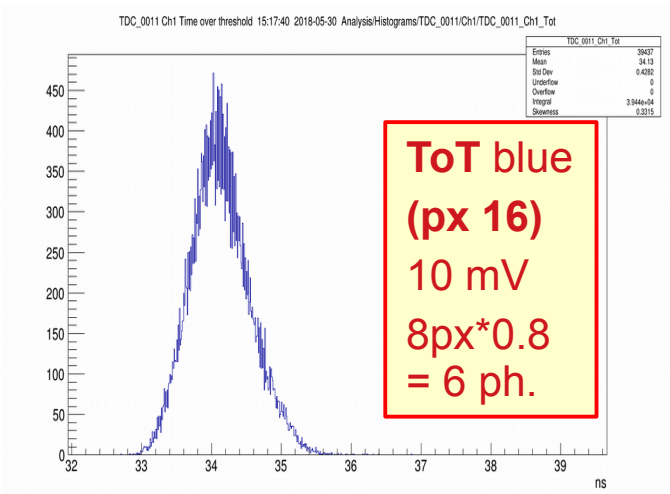
Pixel's read out

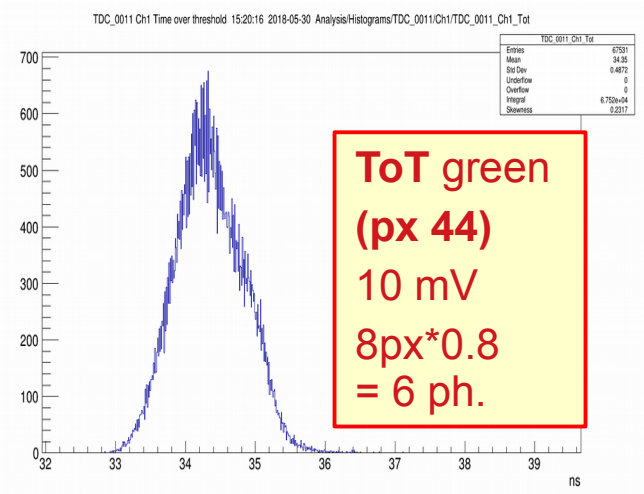


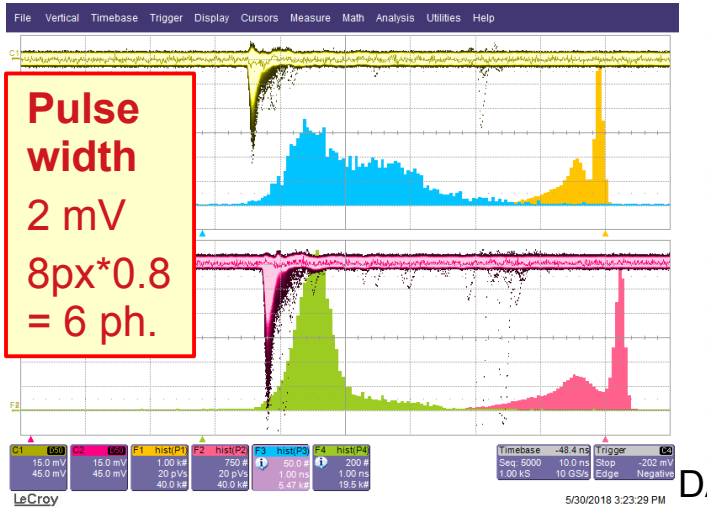
PHOTONIS 9002108 – Width vs ToT

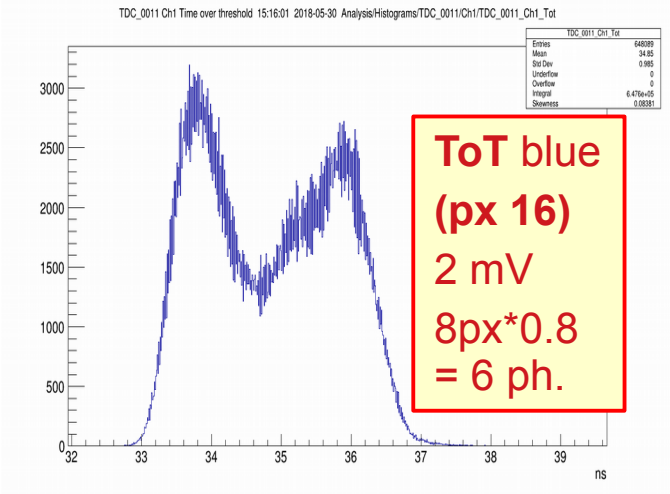
- Pulse widths and ToT at 2 and 10 mV thresholds; **8 open pixels**
- ND1.6 filter; **osci:** pulse width (left); **PADIWA/TRB:** ToT (right)
- Pixel 16 (upper plot, blue histo); pixel 44 (lower plot, green histo)

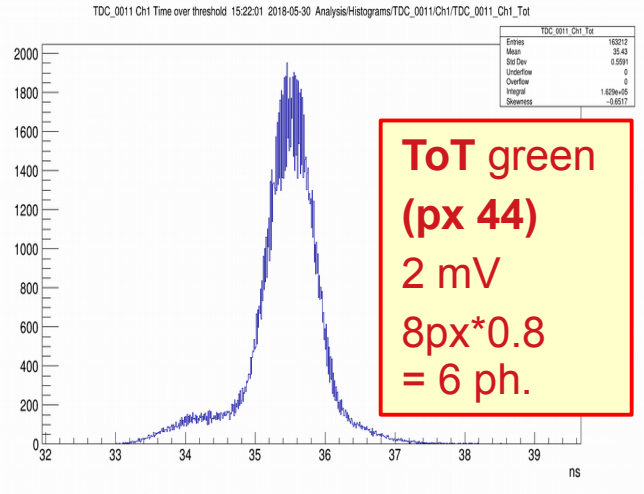






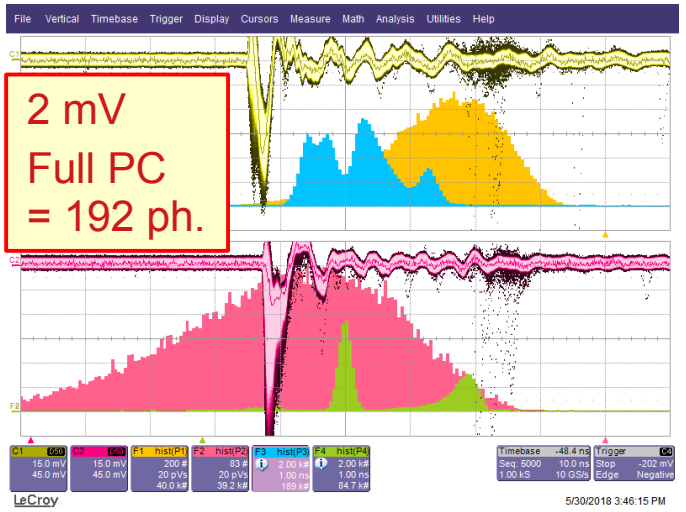


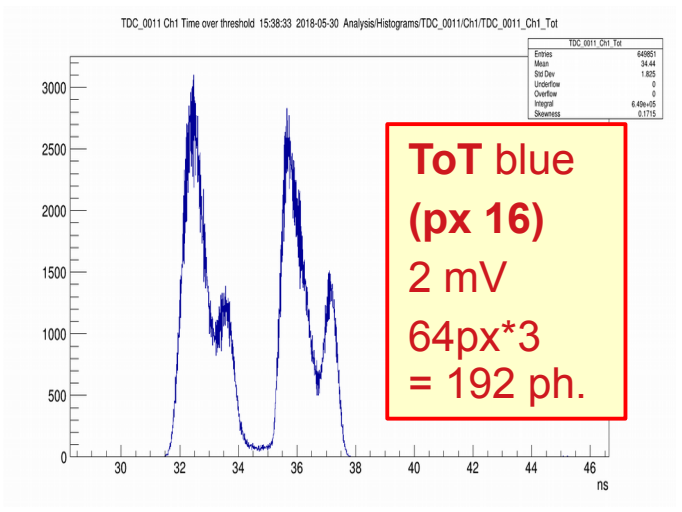


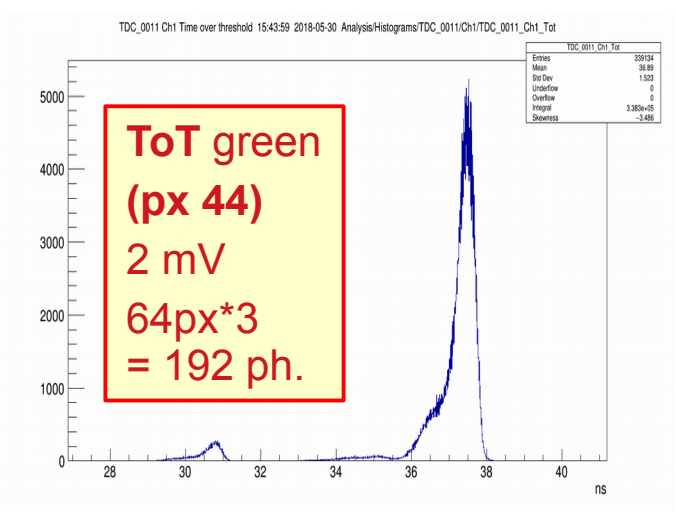


PHOTONIS 9002108 – Pulse widths

- Pulse widths and ToT at 2 mV threshold; **full illumination of PC**
- ND1.3 filter; **osci:** pulse width (left); **PADIWA/TRB:** ToT (right)
- Pixel 16 (upper plot, blue histo); pixel 44 (lower plot, green histo)







- Pulse width and ToT distributions show similar shapes and structures
- Strong indication that multi-peaks in ToT spectra are already caused in MCP-PMTs (probably only when several photons are detected)
- Most likely cause is the ringing produced by (electronic) crosstalk and/or reflections at the backplane

Conclusion

- Jerry's observation of ringing (he calls it coherent excitations) in the Burle Planacon MCP-PMTs is still visible in the new Photonis tubes and also in the 2-inch Hamamatsu PMTs
- The problem seems to slowly start at 6-8 photo electrons produced at the same time (within ~1 ns) in the PC
- 2-inch Hamamatsu looks even worse than new Photonis MCP-PMT
- When ringing is there low thresholds create multi-peaks in TRB ToT and osci pulse heights → how is timing affected?
- Most likely cause: MCP-PMT backplane (bad circuit design?)
- **We have to test different backplane designs to see if effect can be reduced → experts available?**
- However: in Hamamatsu SL10 the whole second MCP was split!