

PhotonPix™ for high timing accuracy single photon detection from low to high flux rates

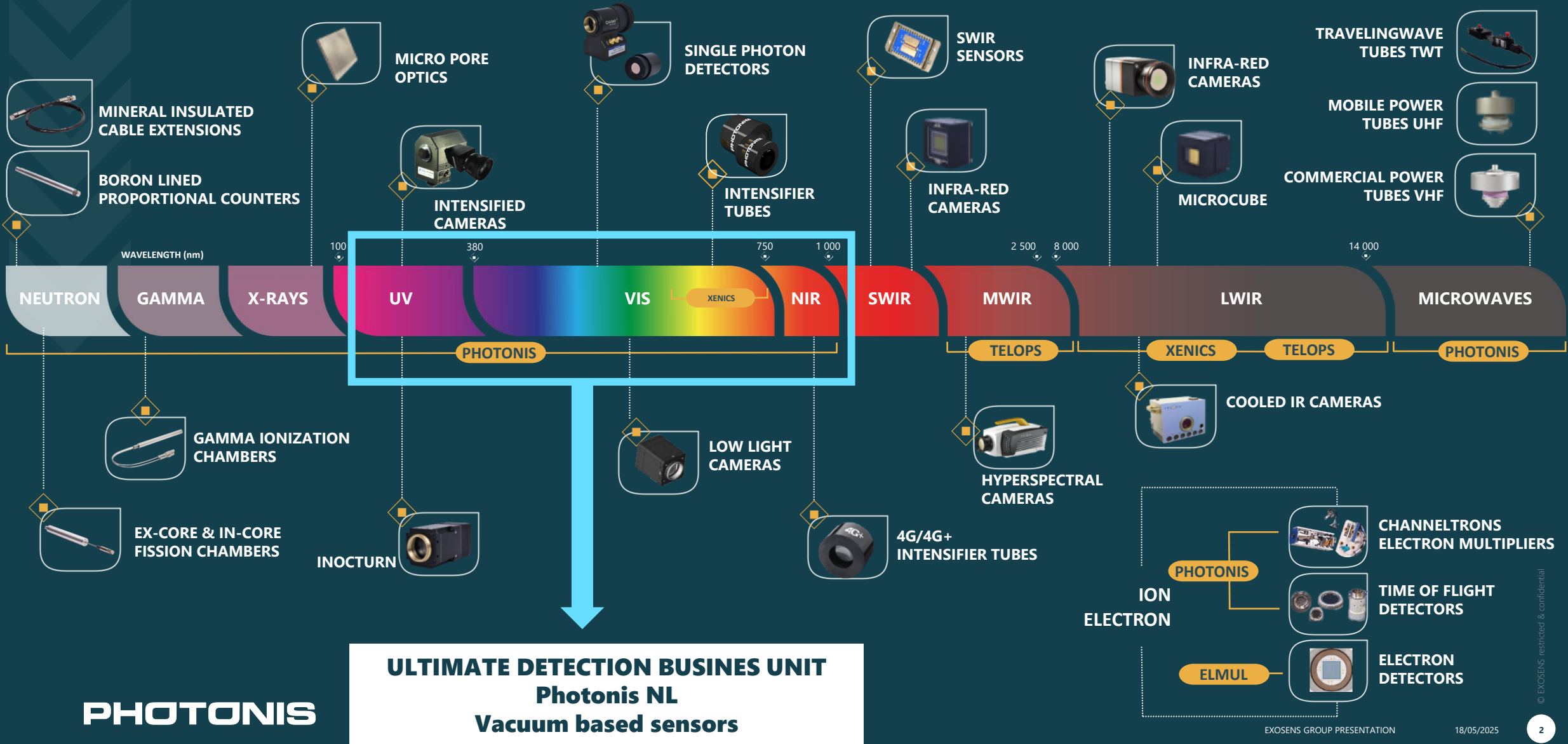
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EXOSENS TECHNOLOGICAL PLAYFIELD

FROM GAMMA TO MICROWAVES



PHOTONIS

ULTIMADE DETECTION NL BUSINESS UNIT

Vacuum tube technology for low light detection

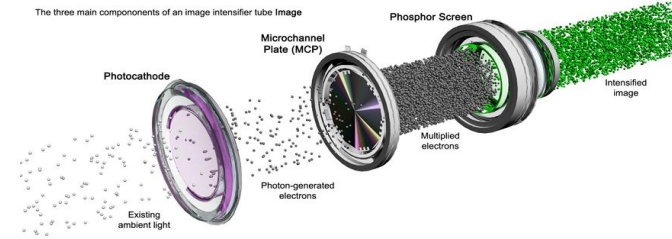
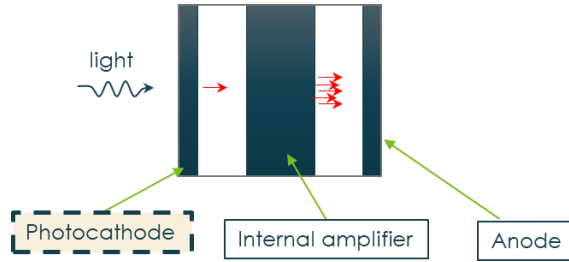
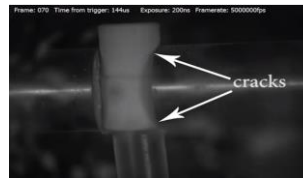


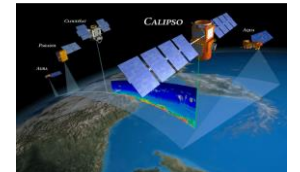
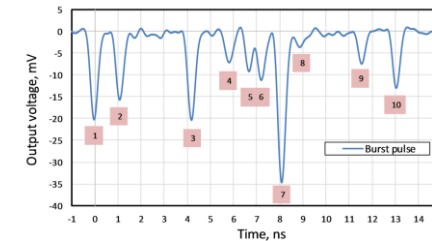
Image intensifiers with P43, P46, P47 anode

Low light detection
Resolution: 10 μm
High speed imaging (sub-ns gating)



Single/multi pixel MCP-PMT

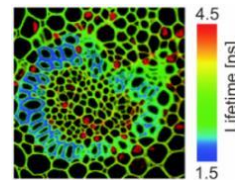
Single photon time-correlated counting
Timing: TTS=12 ps;
Rate: up to few 100 MHz (GHz in burst mode)



Single photon imaging (Cricket + TimePix³ / ASI):
Timing: 1.6ns; Pixel: 55x55 μm ; Event rate: few MHz
Multi-photon event detection



MCP-PMT with resistive anode for
Single photon imaging (LINCcam / Photonscore)
Timing: TTS (FFWHM)=40 ps;
Spatial resolution: 17 μm
Max rate: 1 MHz



FT-MCP-PMT



PhotoPixTM

Photon (IN),
NIM-logic (OUT)



PhotonPix™

It is plug-and-play solution optimized for low and high-rate applications requiring exceptional timing precision

IN: Photon
OUT: NIM-logic

Sensor: FT-8 MCP-PMT

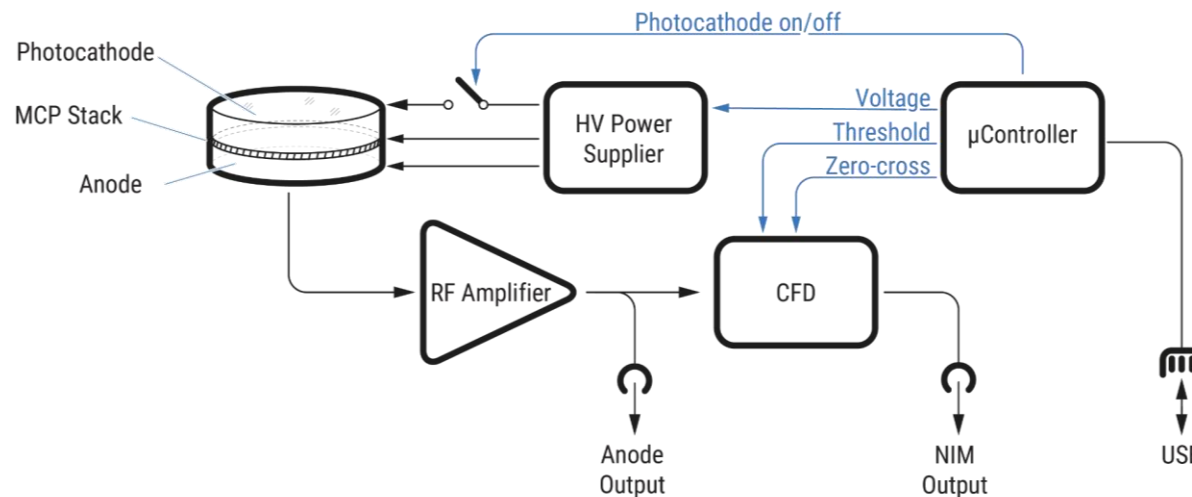
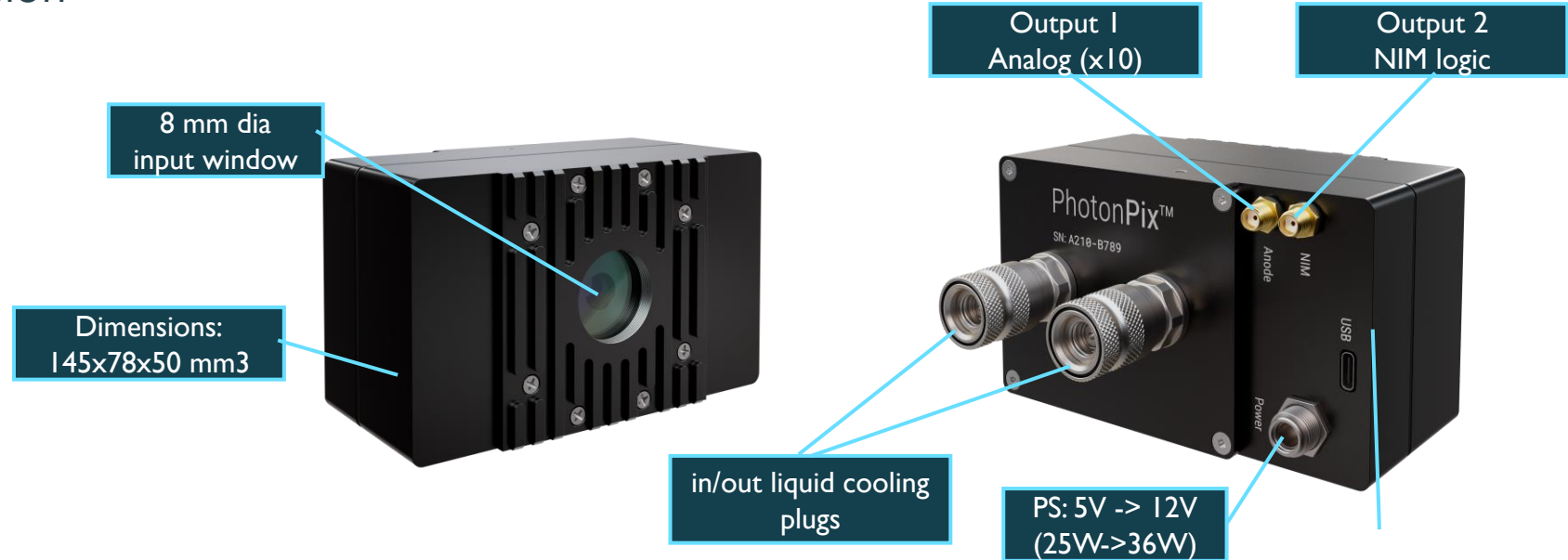
Timing: FWHM < 30 ps

Rate: few 100 MHz
Dead time: 1.6 ns

Dark rates: <30 (typical)

Cooling: Peltier (down to -22C)

Overheat and overexposure protection

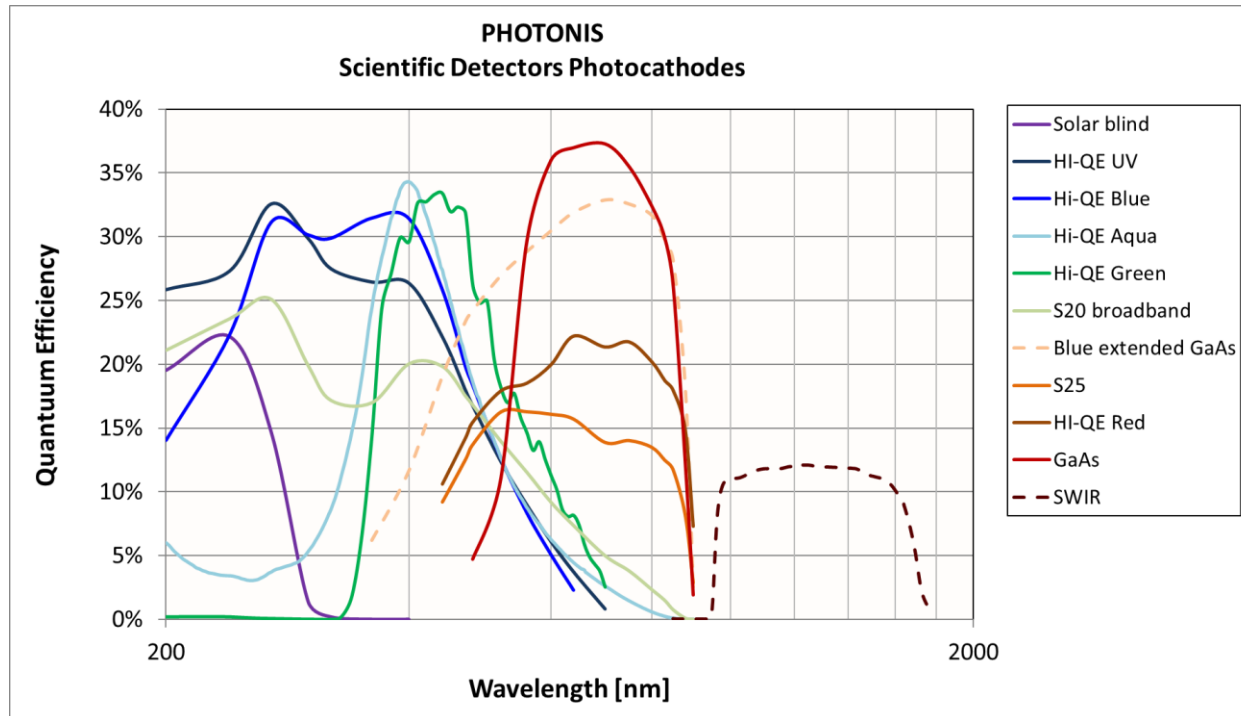


USB-C -> μControl:
Voltage (gain)
PK on/off
CFD zero-cross, threshold

FT8 MCP-PMT sensor

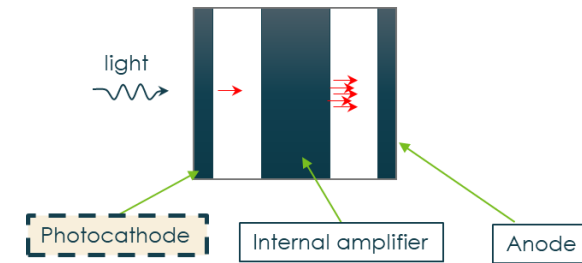
Quantum Efficiency & Dark count rates

Photonis photocathodes avenue



←→ **LOW DARK RATE**
 QE > 30 %
 < 50 cps/cm²

←→ **Hi-QE Red**
 QE ~ 20 %
 ~ 50 kcps/cm²



- Large panel of available wavelength
- State-of-the-art sensitivities

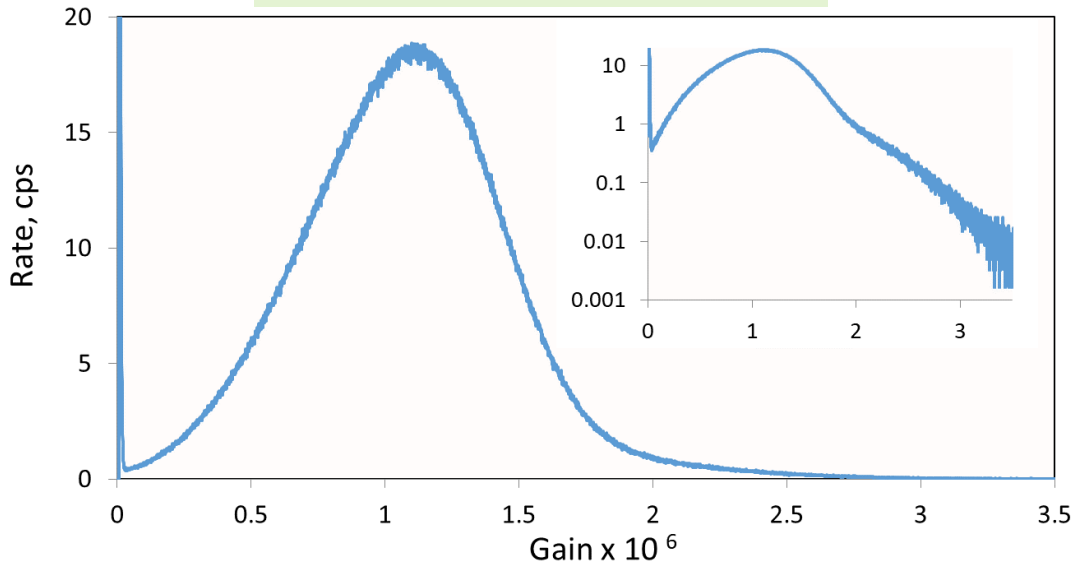
FT8 MCP-PMT sensor

Pulsed Height Distribution &

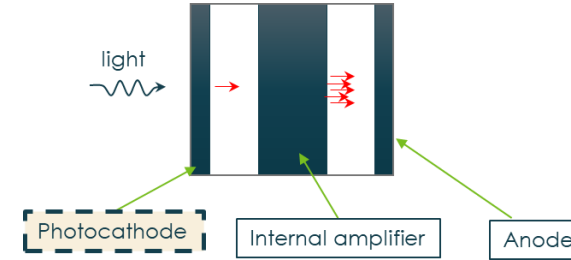
Collection Efficiency



G = 1.1E6 P/V=54 FWHM/G=0.77



PHD: Well-define shape (P/V and FWHM/G)
High Detection Quantum Efficiency



MCP Collection Efficiency (CE):
Mostly defined by first hit + OAR (MCP web contribution)

$$DQE = QE \times CE$$

Photonis MCPs:
6/8 um, appr. 72% OAR

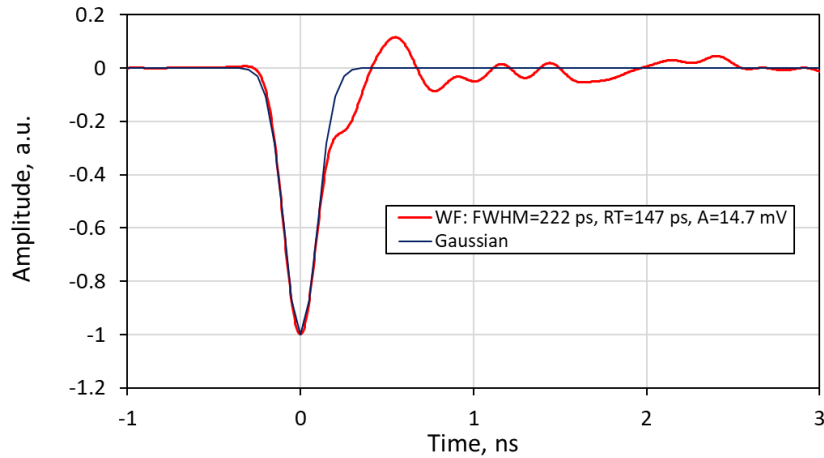
CE \approx 0.8 (LOW SY coating)
Best timing properties.

CE $>$ 0.95 (High SY web coating)
Timing slightly degraded (due to back scattered electrons)
(shorter PK-MCP distance, high bias voltage)

FT8 MCP-PMT sensor

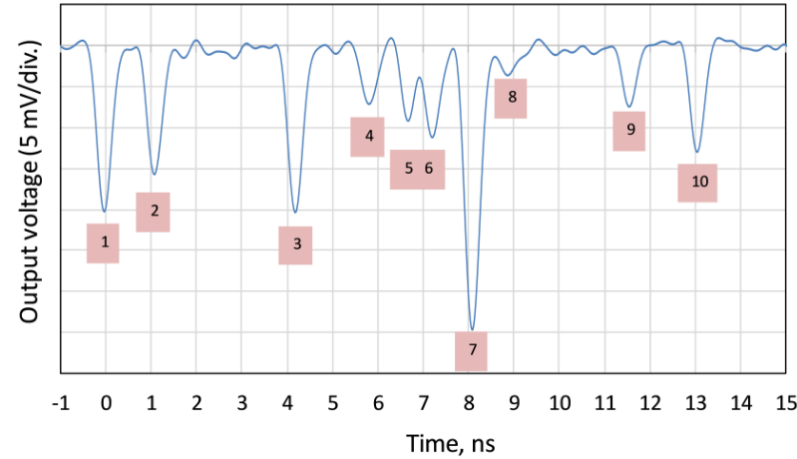
Timing properties FT-8 MCP-PMT

Waveform: Single Photon response



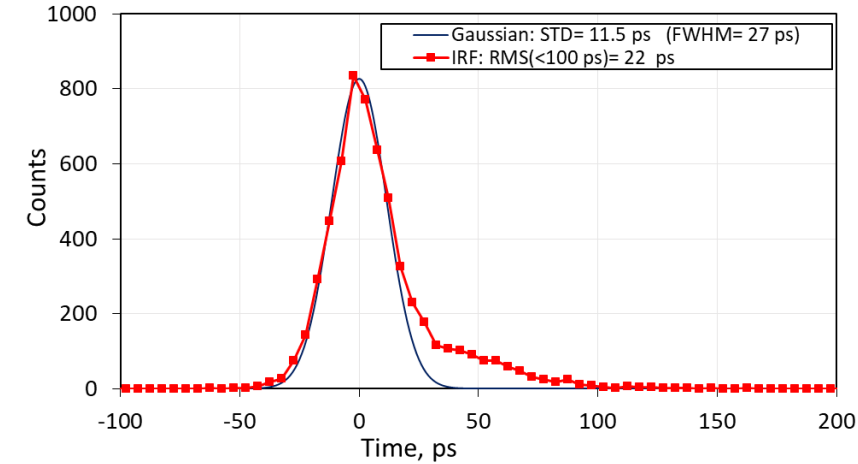
Good waveform:
Rise time < 150 ps
FWHM < 300 ps
low ringing

Waveform: Burst excitation response



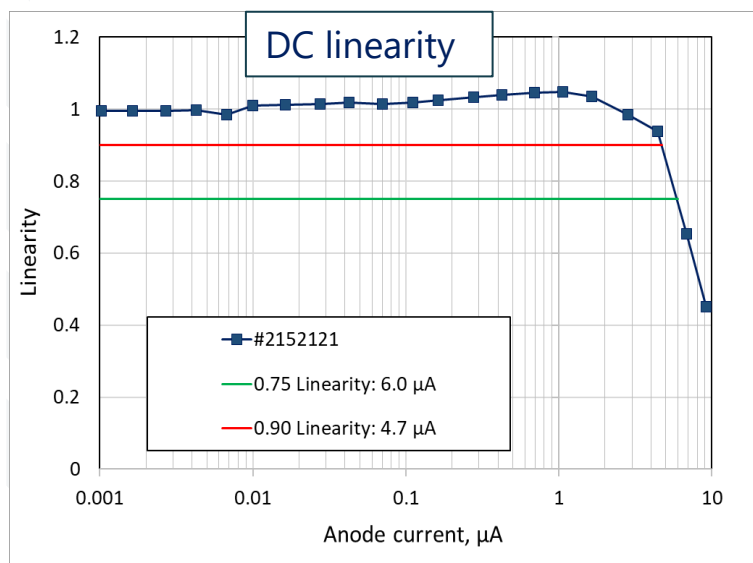
Small dead time
< 0.5 ns

Time resolution (FT-8 series)



Excellent temporal resolution
25 ps (FWHM)

Linearity

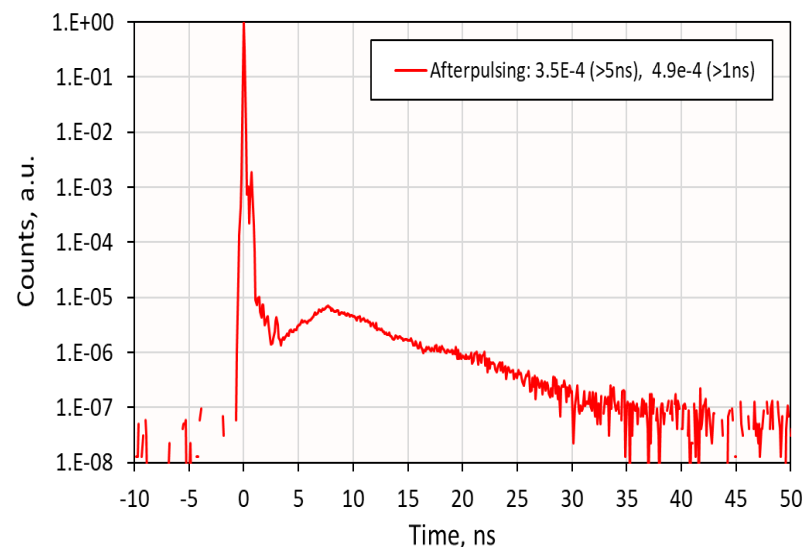


Example: FT-18 long-lifetime MCP-PMT, 13 μA strip current, Gain=2.4E5

At high illumination flux the extracted charge from MCP is high and can not be compensated fully by recharging the MCP channels resulting in decrease of electrical field and drop of the gain.

Typical linearity threshold 5-20% of MCP resistance.

Aferpulsing



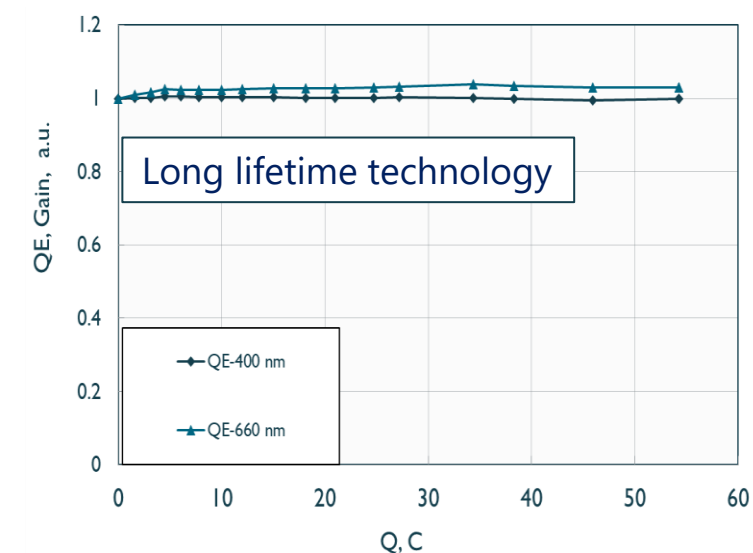
Photonis MCP-PMT

Low afterpulsing: $<5e-4$

Short time: <40 ns

Afterpulsing is caused (mostly by electron stimulated ion desorption from MCP channel. Positive ions travel back, hit the photocathode surface resulting in electron(s) emission that creates afterpulse.

Lifetime



With long lifetime MCP technology the photocathode lifetime is increased from 5 C to 50C+

100 C \rightarrow 10 MHz x 10 year

Reduction of lifetime is (typically) due to molecule and ion stimulated desorption induced by electron avalanche developed in MCP.

Typically lifetime is measured in total charge collected at anode.

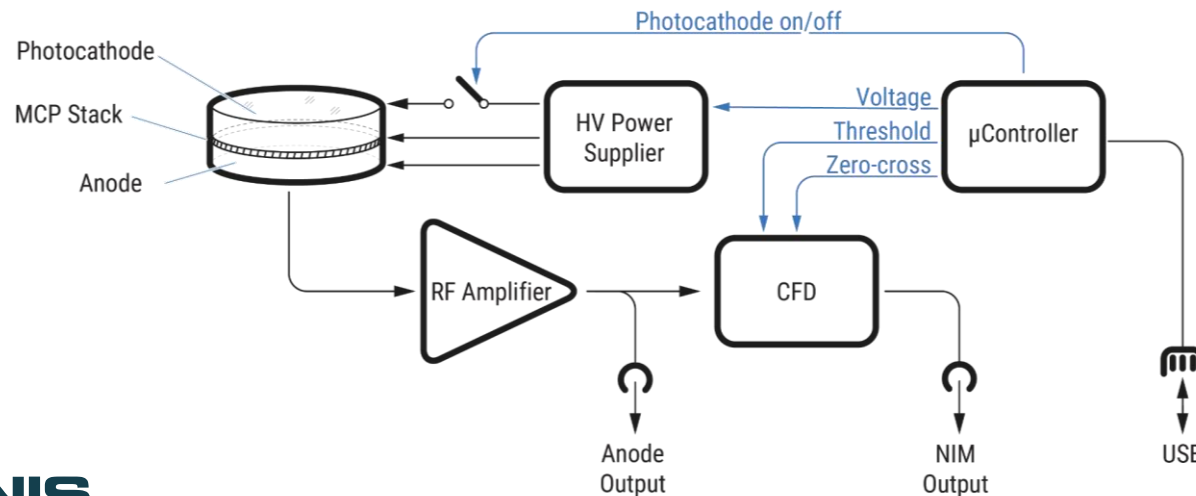
From FT-8 MCP sensor to PhotonPix™ detector

It is plug-and-play solution optimized for low and high-rate applications requiring exceptional timing precision

Timing properties will be discussed below (see next slides)

Remark for cooling impact:

- Stabilization for electronics
- Decrease PK temperature resulting in very low dark rates
 - < 10 cps with 5V PS (for all PK except Red)
 - <200 cps (from 50-80 kcps for the RED, with 12 V PS, appr. -20 C)



PhotonPix™ Characterization at low and high rates

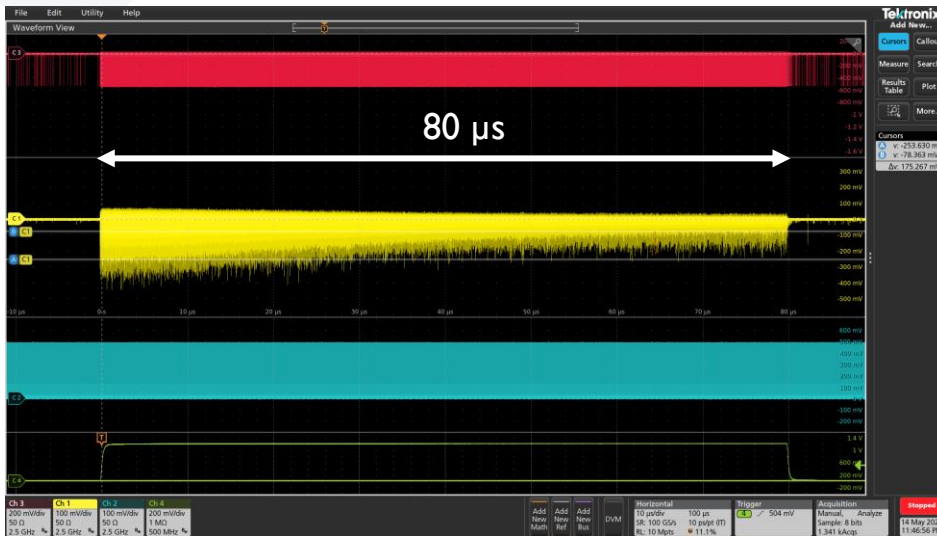


NIM logic output

Analog (x10 amp,) output

Probe laser REF: 65 MHz 80fs 515nm:
PE laser induced rate is adjusted to be about 1 MHz

LED REF: duration and power is adjustable:
e.g. 15 μs (up), 80 μs (down) or continuous

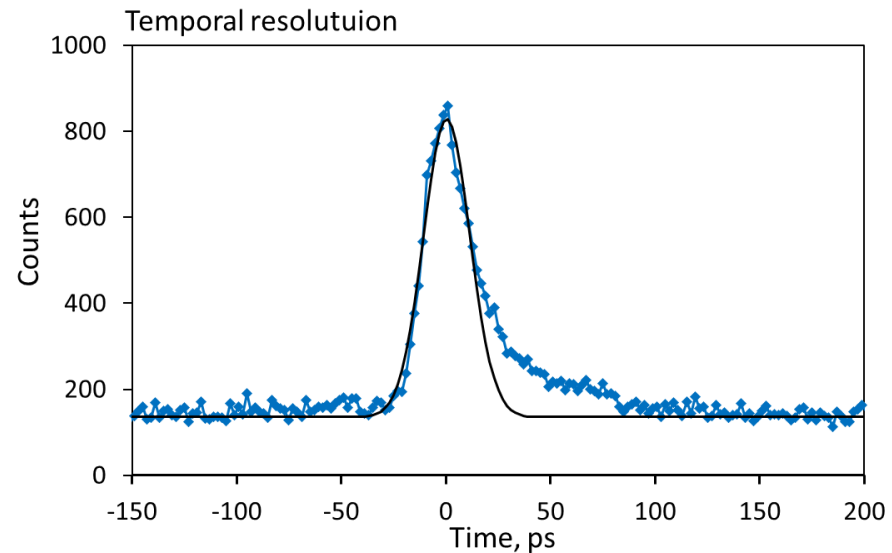
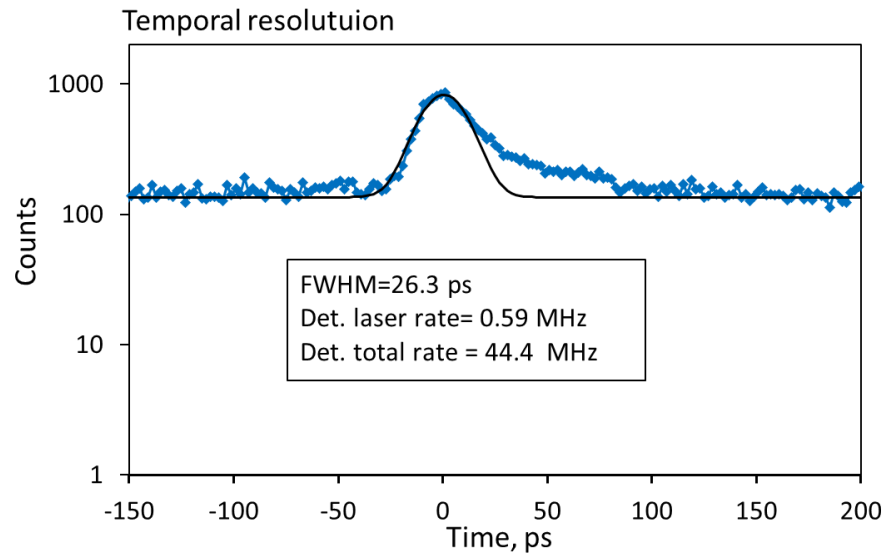
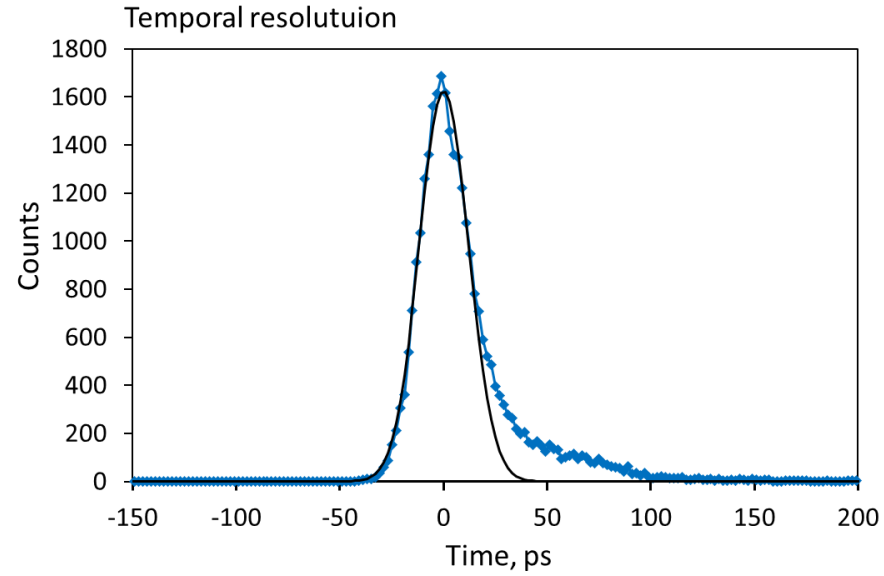
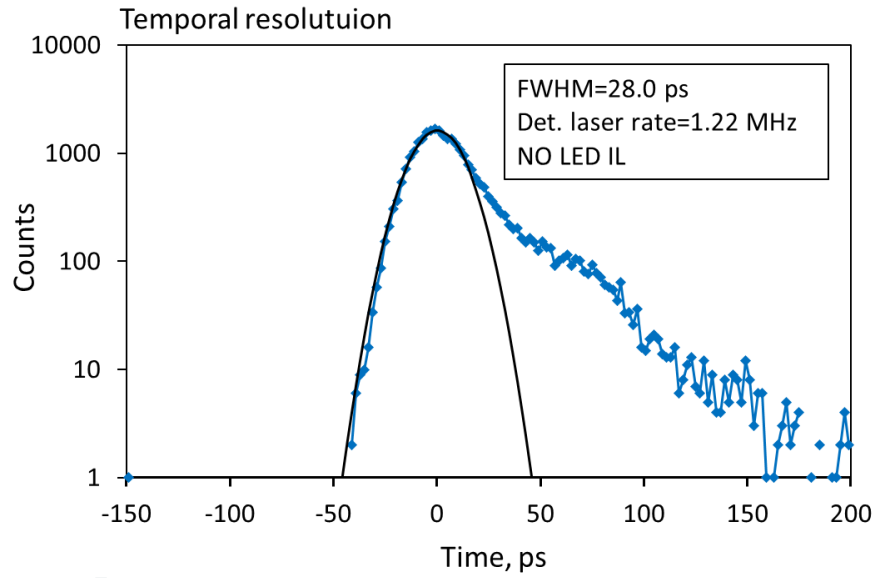


Two illumination regimes were studied

- 1) Continuous LED illumination: High rate operation is limited by MCP saturation resulting in strong drop of the pulse amplitude;
- 2) Burst mode operation: short LED illumination appr. 10 μs. For the used power no limitation caused by MCP-saturation. Dead time of electronics is a limit.

PhotonPix™ timing properties

Continuous illumination

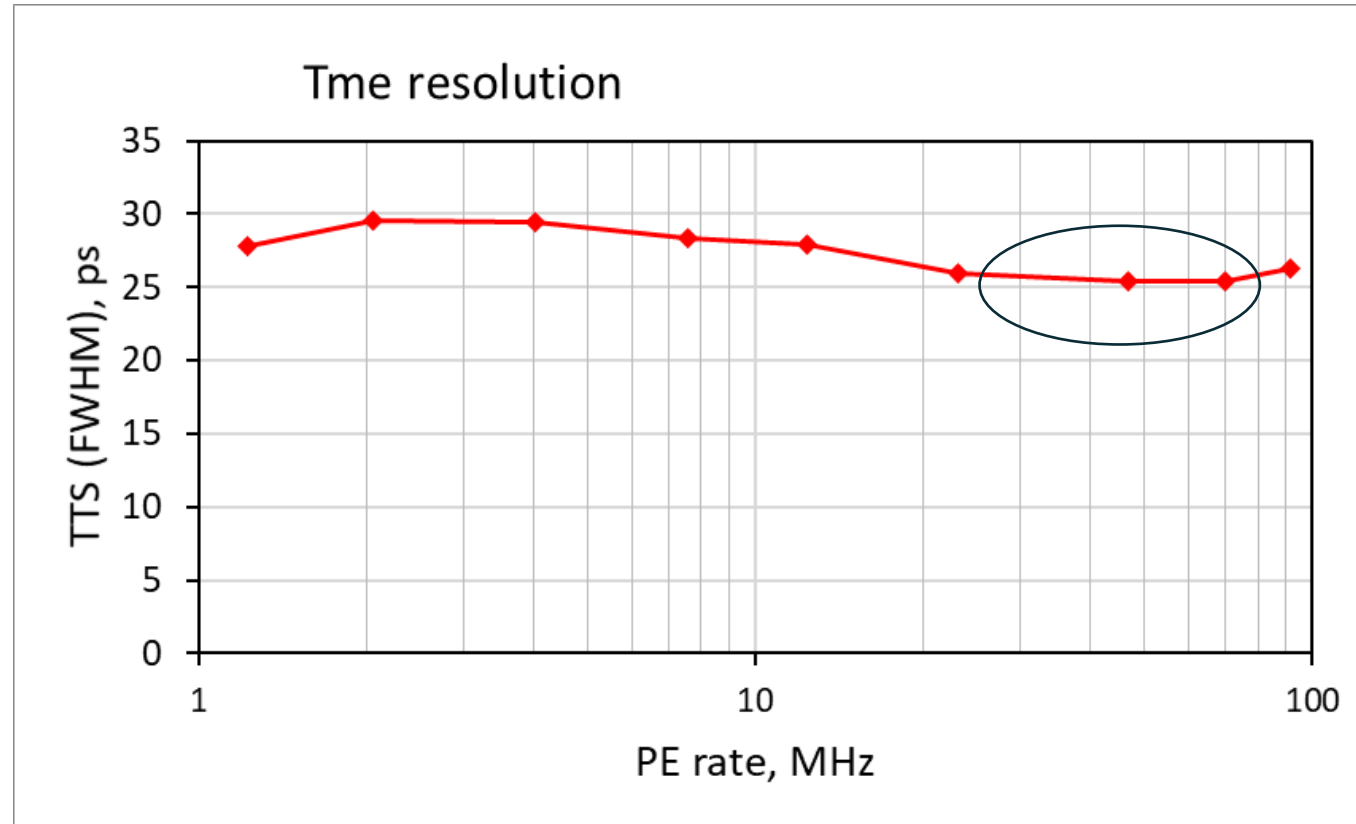


From low to high LED intensity

- Temporal resolution
- Counting efficiency
- Time Walk difference

PhotonPix™ timing properties

Continuous illumination

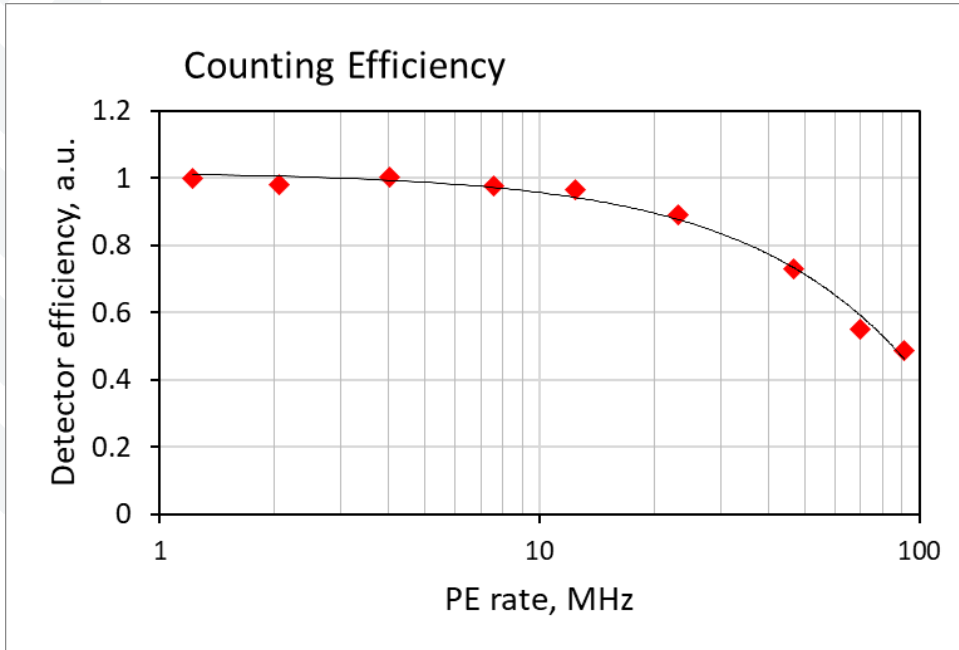


Excellent time resolution (<30 ps) with max PE rate to be about 100 MHz

Small improvement in time resolution at high rate:
Cutting low-energy pulses with worse time resolution?
To be confirmed with more measurements...

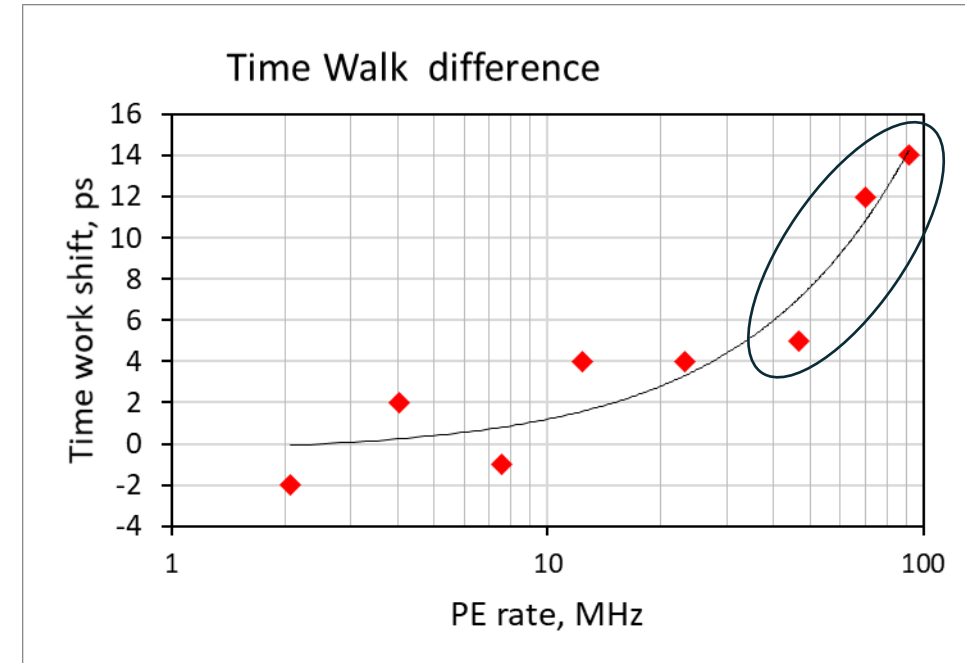
PhotonPix™ timing properties

Continuous illumination



Good linearity: 50 % drop of counting efficiency at about 80 MHz photoelectron rate

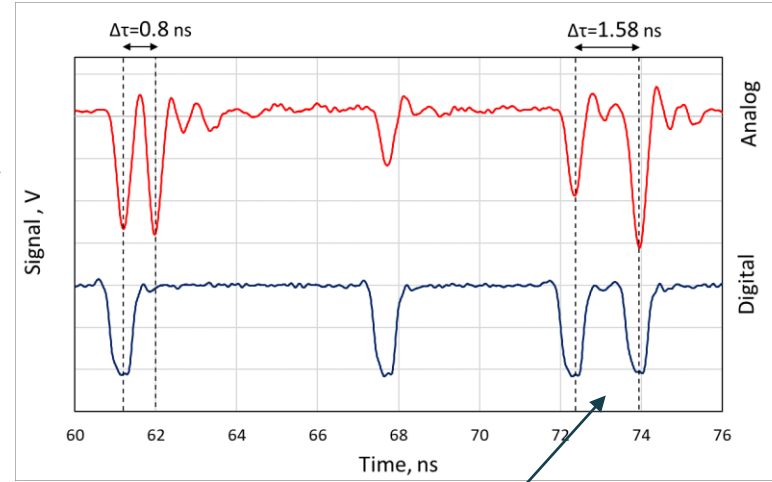
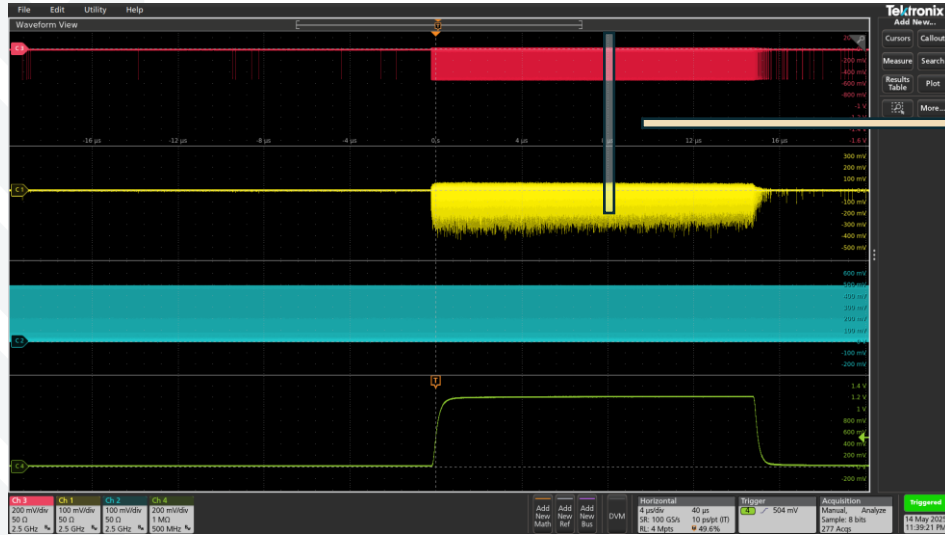
Estimated anode current at 80 MHz PE (assuming 100% current linearity) is about the value of the strip current! Drop of pulse amplitude is factor of 3-5.



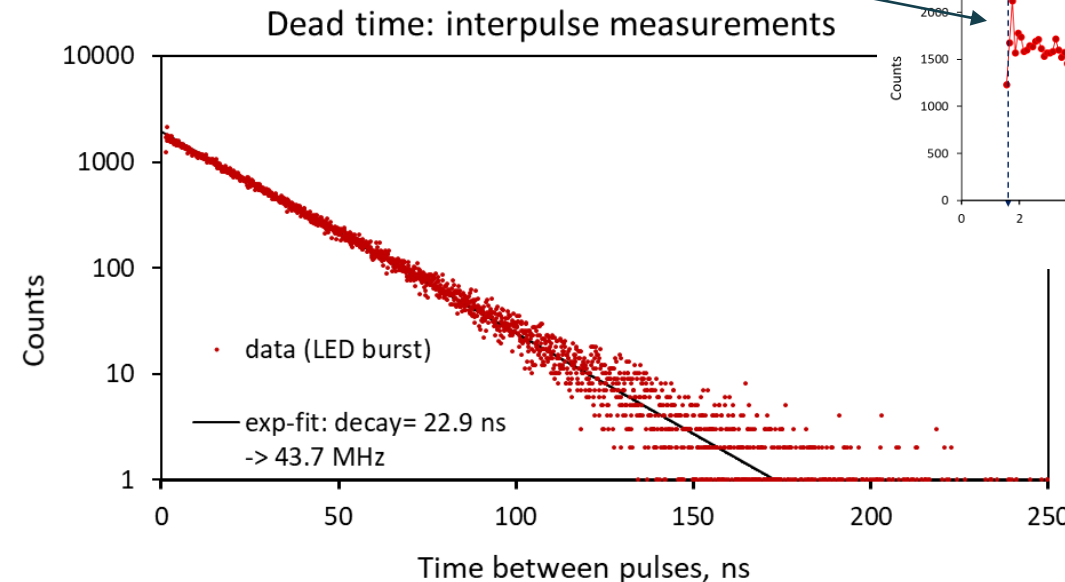
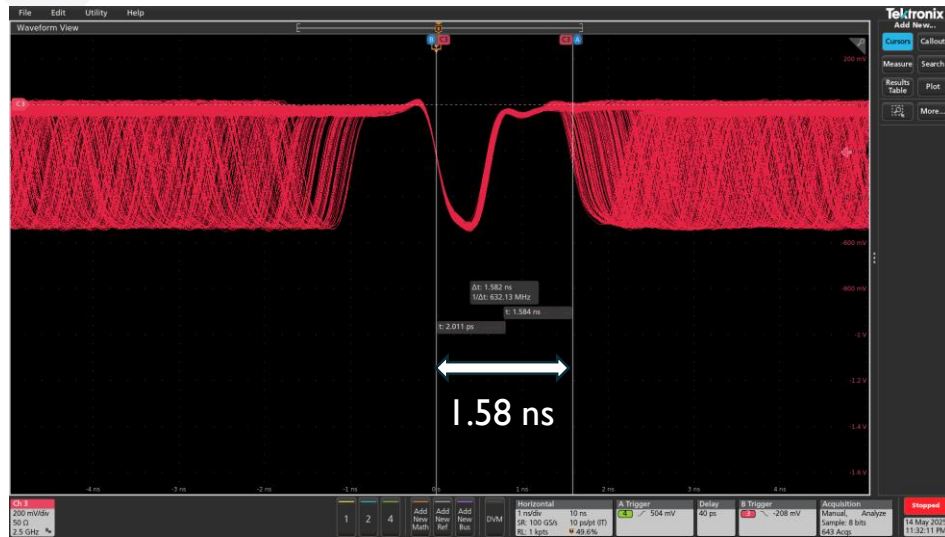
Time walk is measured between ref. laser and NIM pulses
Very stable (measurements took 8 hours)

Small shift of time walk at highest rates is probably due to imperfection of CFD with pulse amplitude to be strongly decreased.

PhotonPix™ : Dead time <2 ns

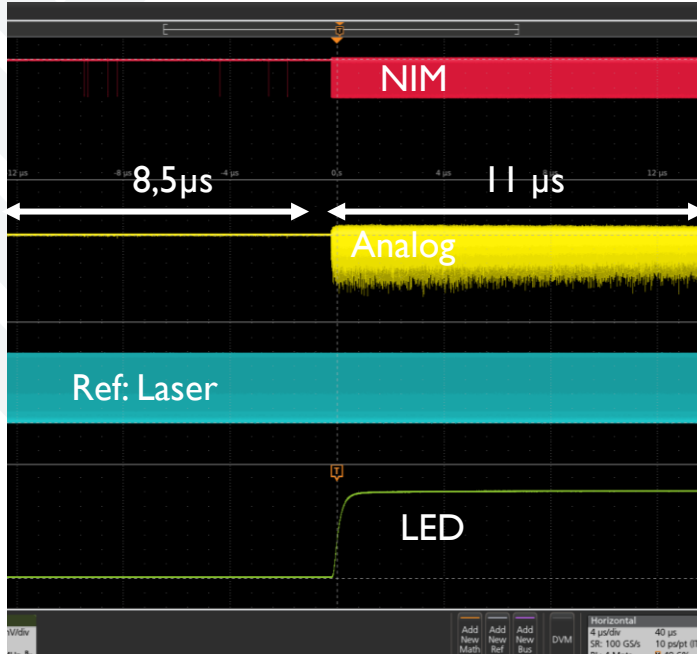


Dead time of about 1.58 ns is recorded



PhotonPix™ PhotonPix™ timing properties

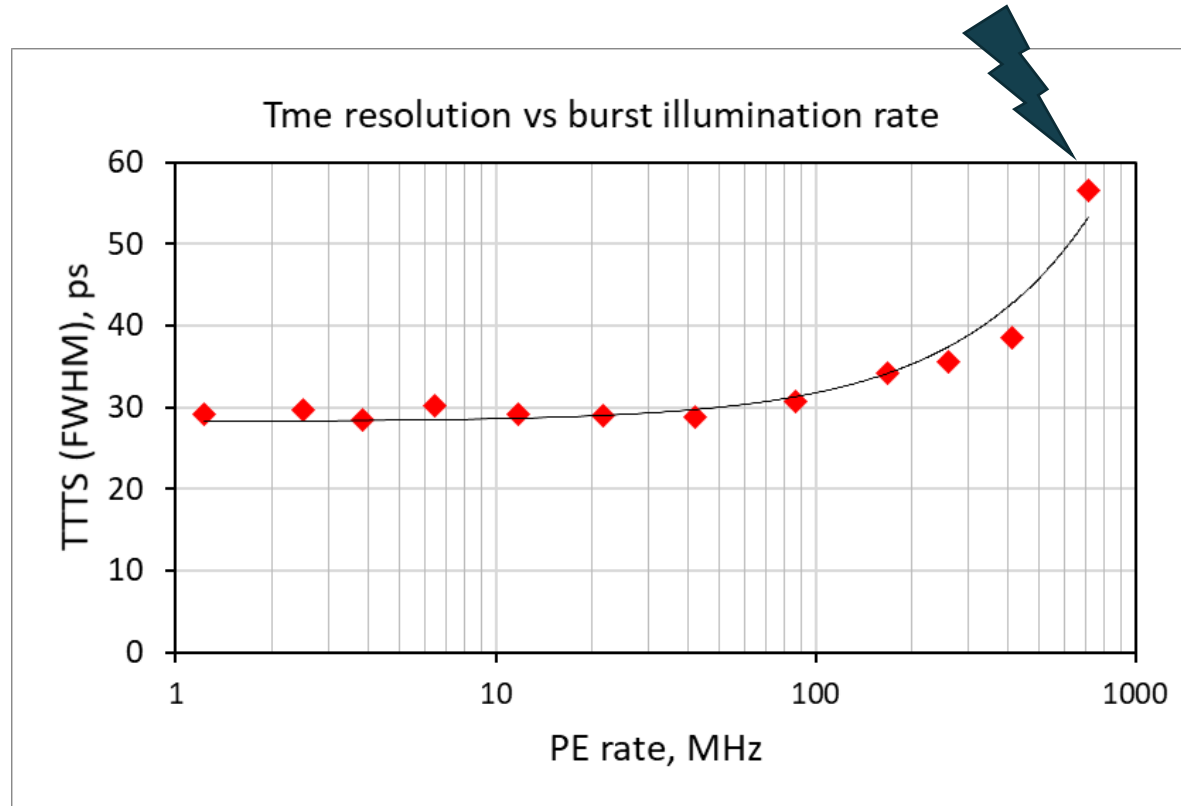
Burst mode illumination



- Data analysed in 2 regions:
 - [0-8.5µs] – only laser before the LED pulse
 - [9-20µs] - LED (11µs x 20Hz) + laser
- Temporal resolution
- Counting efficiency
- Time Walk difference

PhotonPix™ timing properties

Burst mode illumination

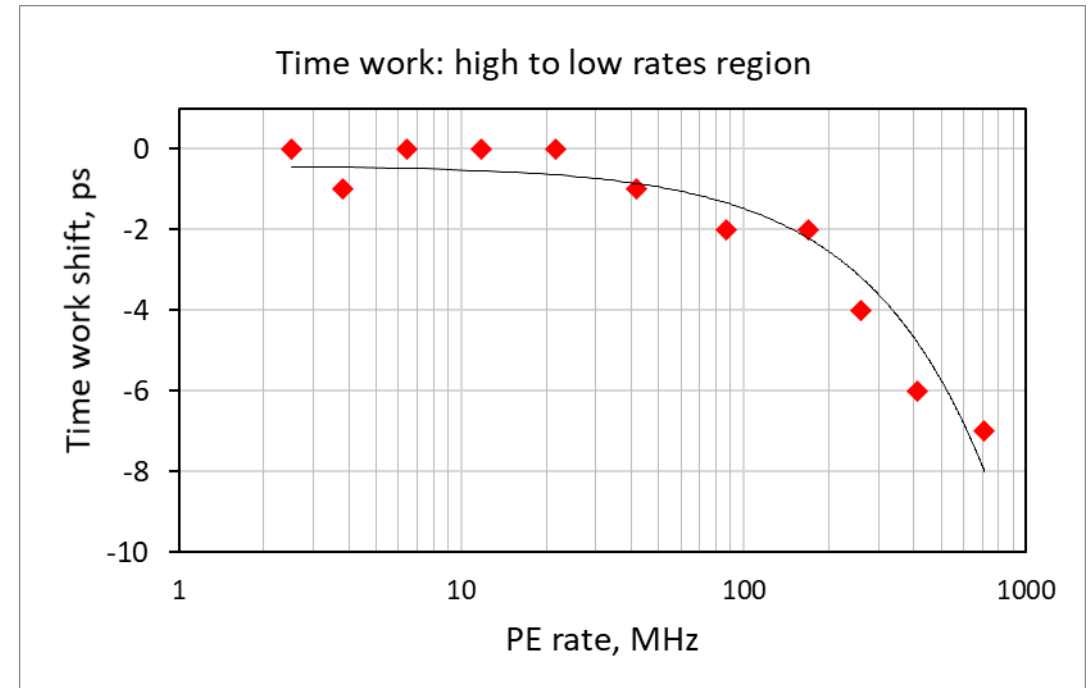
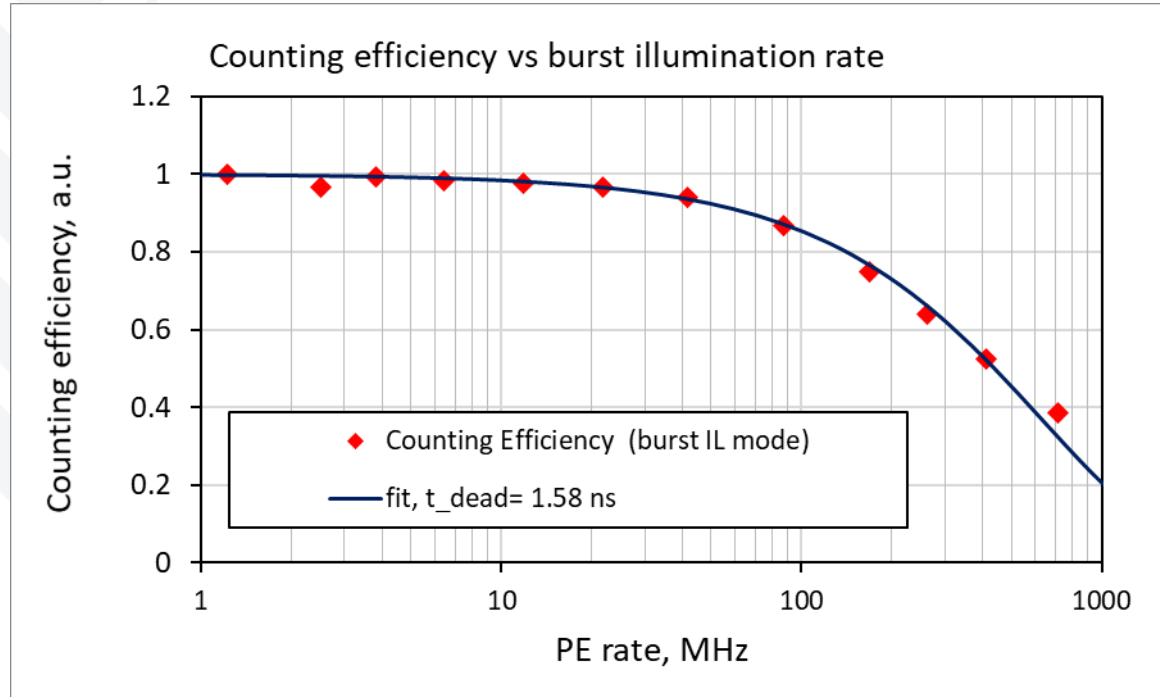


Excellent time resolution up to about 400-500 MHz photoelectron rate

Time resolution drops down to about 50-60 ps at highest used rate (at this rate about 60% of counted pulses are lost due to dead time)

PhotonPix™ timing properties

Burst mode illumination



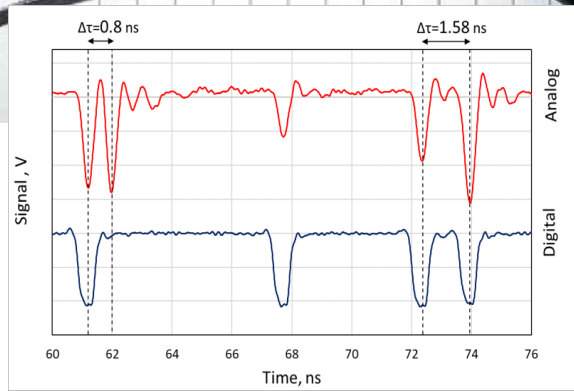
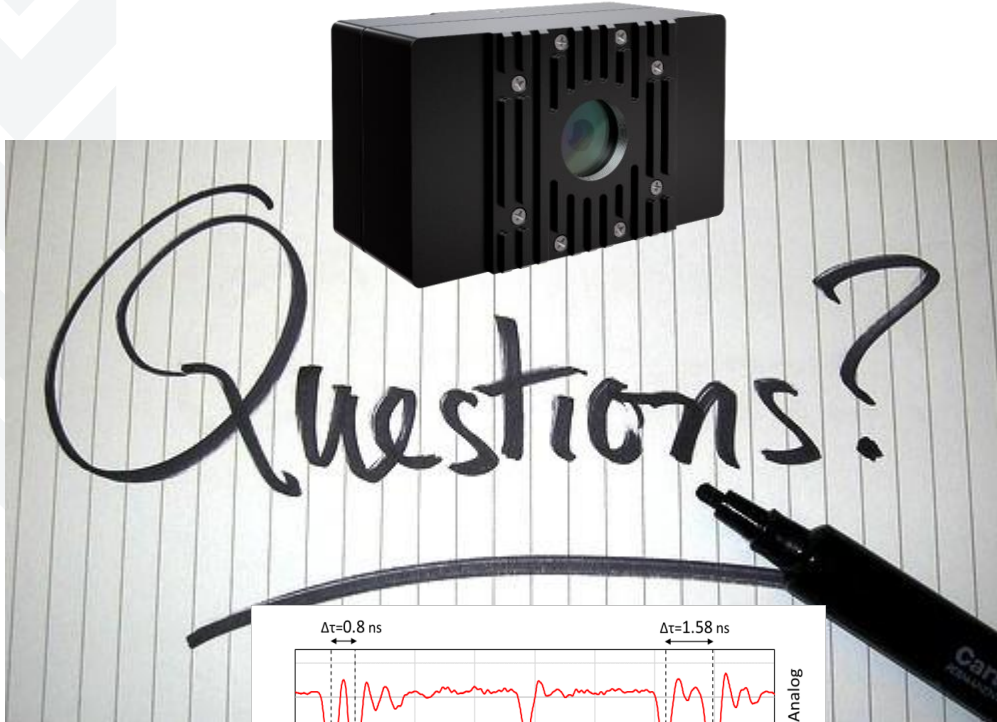
Good linearity: 50 % drop of counting efficiency at about 400 MHz photoelectron rate

Decrease of counting efficiency due to dead time with a fitting curve (black line) corresponding to $\tau_{\text{dead}} = 1.58 \text{ ns}$

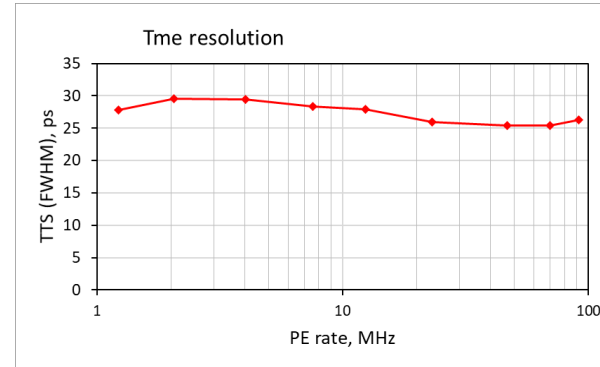
Time walk is measured between ref. laser and NIM pulses
Stable within few ps up to 200 MHz

Small negative shift is observed at higher rates.
CFD? Drift of base line?
To be clarified...

Thank you for attention!



Continuous



Burst

