Photon counting soft X-ray detector capable of gated operation at extremely high input fluxes

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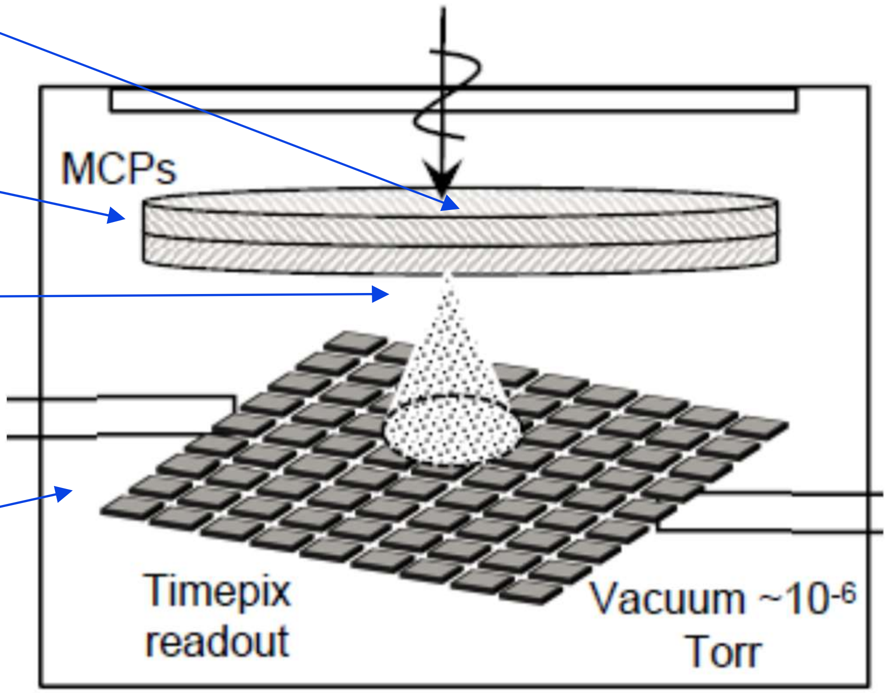
MCP detector configuration for soft X-ray applications

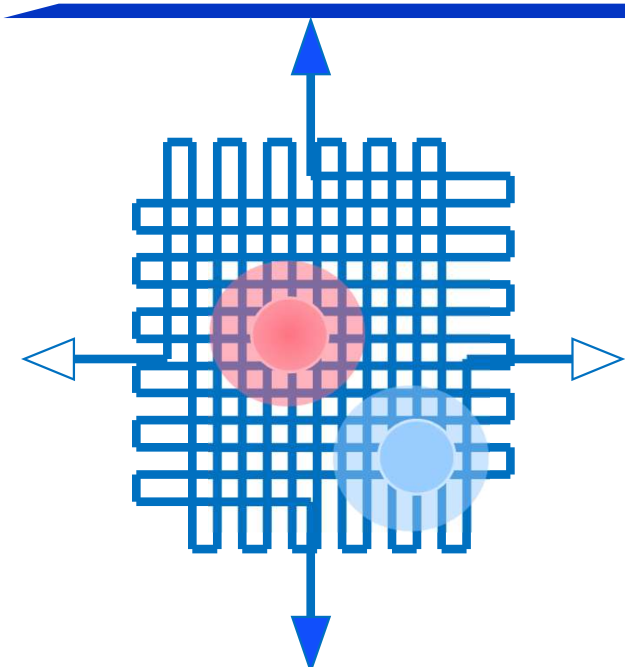
- Photocathode converts photon to electron
- MCP(s) amplify electron by 10^3 to 10^7
- Rear field accelerates electrons to readout
- Different readouts can be used, optimized for particular application

Photocathode is deposited directly on MCP



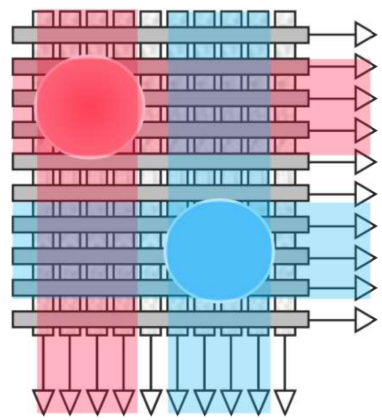
No ideal detector fitting all applications.
Compromises are always to be found.

Types of readout



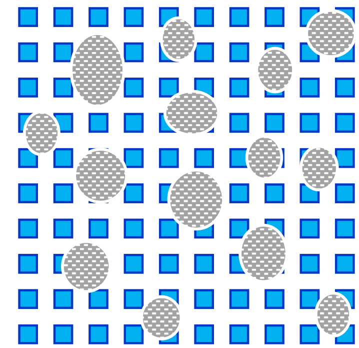
Cross Delayline (XDL)

4 amps
Gain ~ 10^7
Rate < 1MHz
Δt ~ 50 ps rms



Cross Strip (XS)

2 x N amps
Gain ~ 10^6
Rate ~10 MHz
Δt ~ 100 ps rms

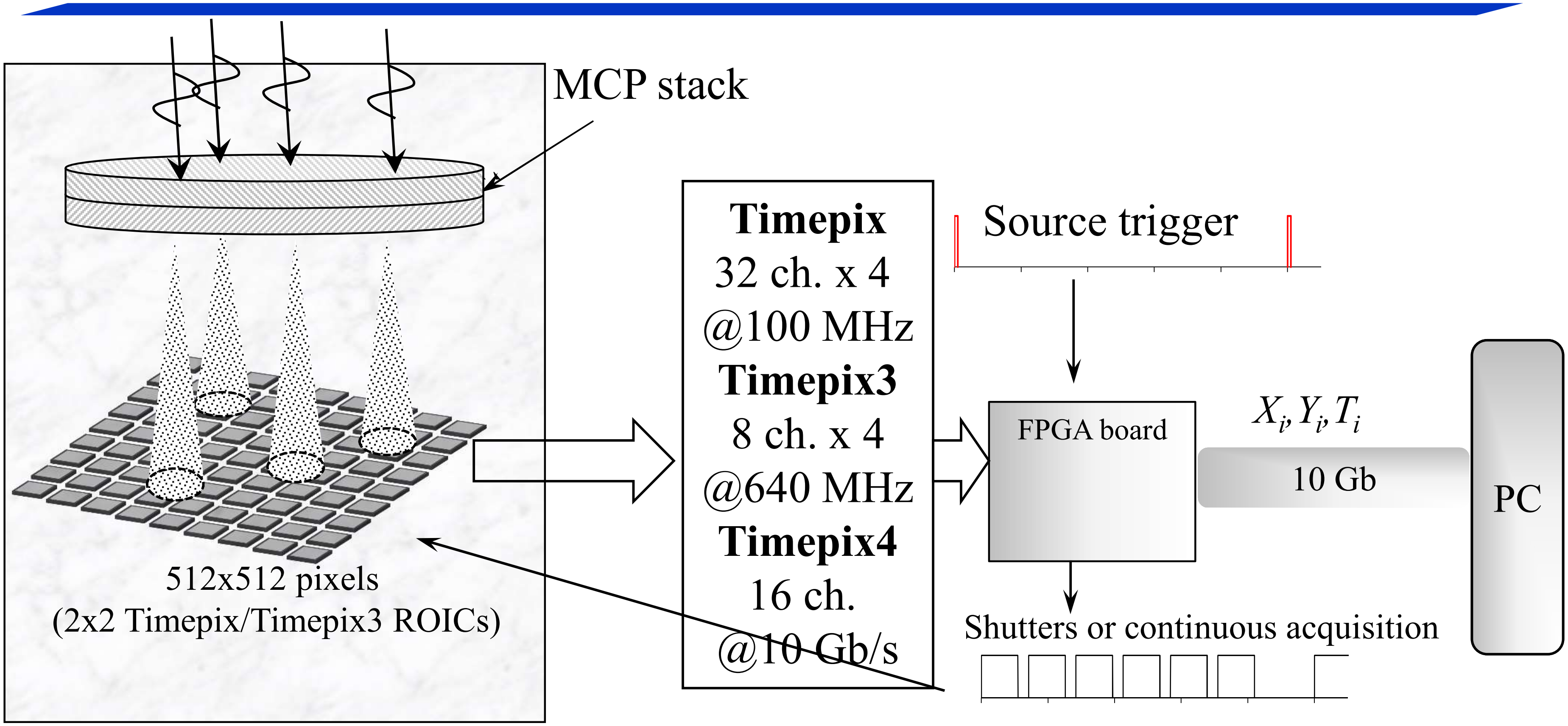


Medipix/Timepix ASIC

N x N amps
Gain ~ 10^4-10^5
Rate > 500MHz
Δt ~ 1.6 ns
(200 ps with Timepix4)

Nucl. Instrum. Meth. A **949** (2020) 162768

MCP detector with Timepix readout for soft X-ray applications

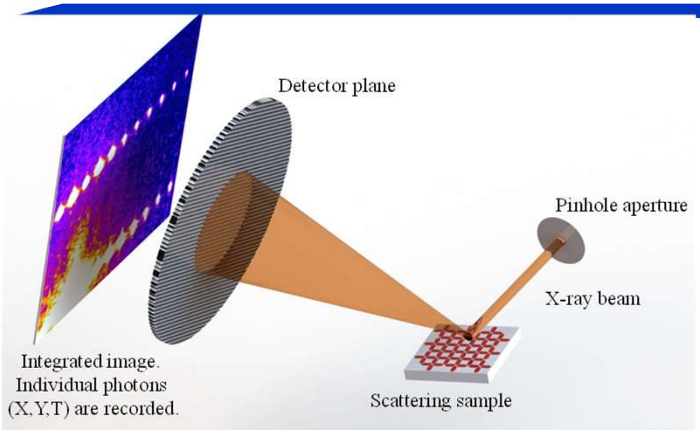


Multiple simultaneous photons can be detected.

Spatial resolution is limited by the MCP pore (~ 6 μm).

Timing resolution: Timepix ~10-20 ns, Timepix3 ~ <2 ns, Timepix4 ~ 200 ps

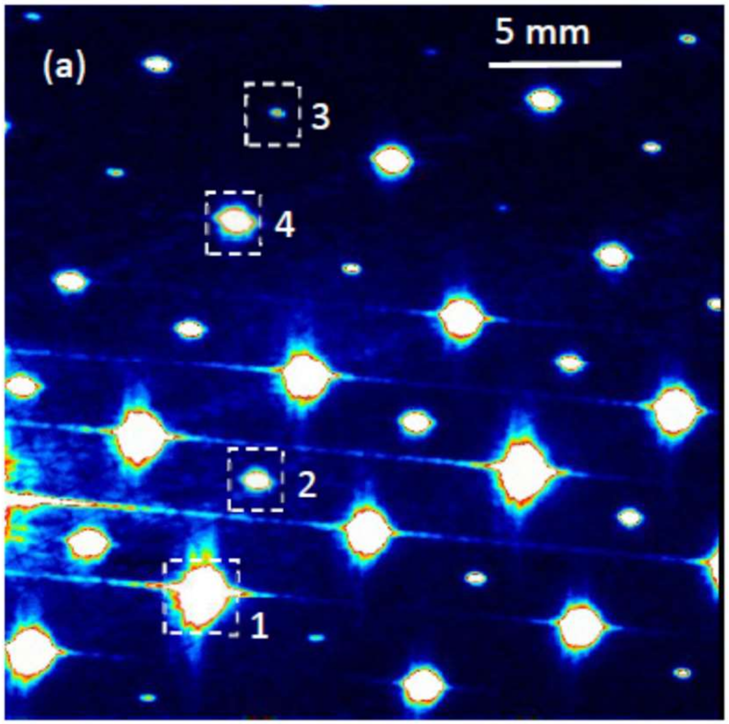
High dynamic rate photon counting with MCP/TPX detector

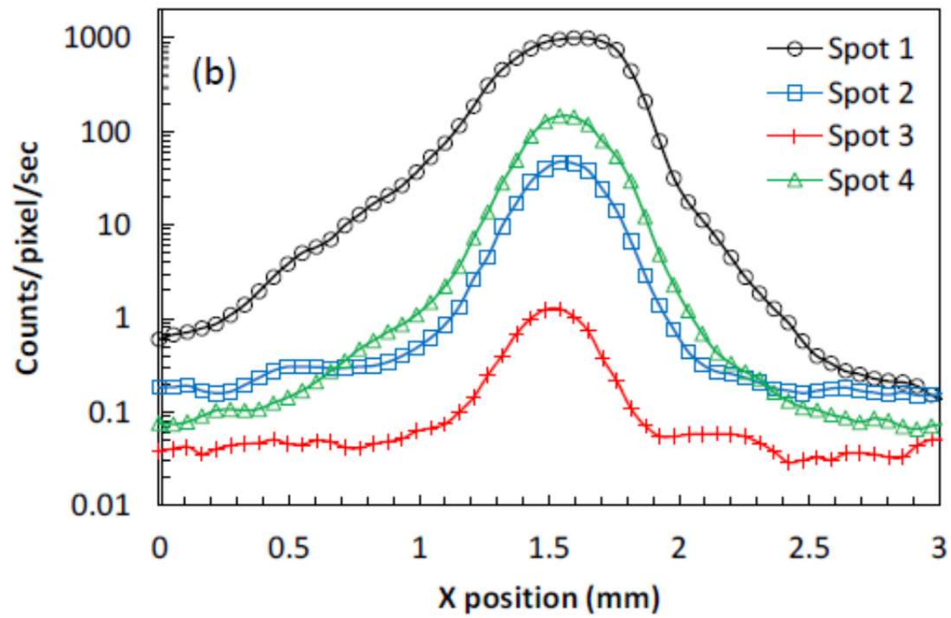


Beamline experiments on the MCP optimization

- MCP/Timepix detectors enable operation at a very large dynamic range (photon counting within very bright and very dim spots at the same time).

- The count rate within different spots in that image

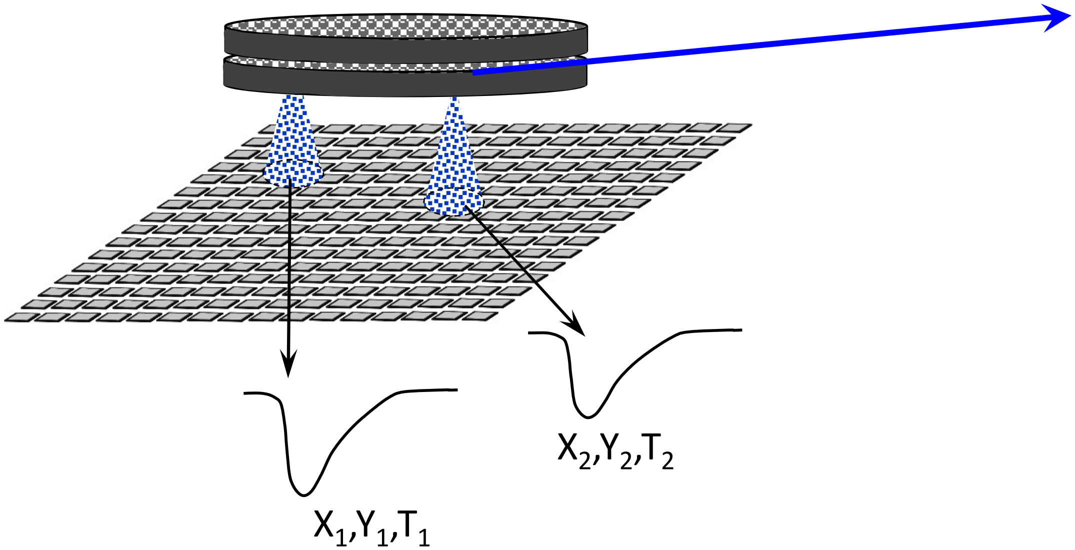


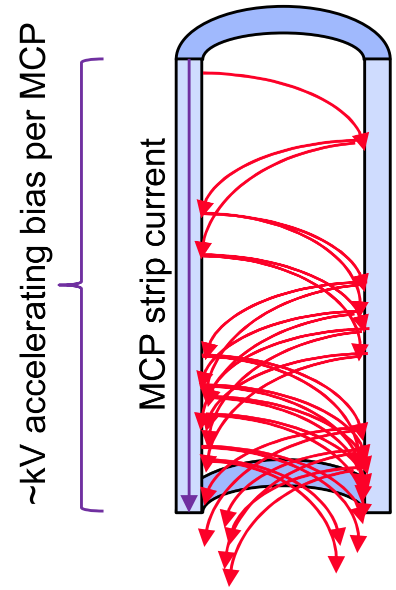


J. Synchrotron Rad. **28** (2021) 1069

MCP count rate saturation at high input rates

Many events can be detected in a short time period.
Each extracts charge Q from the MCP.

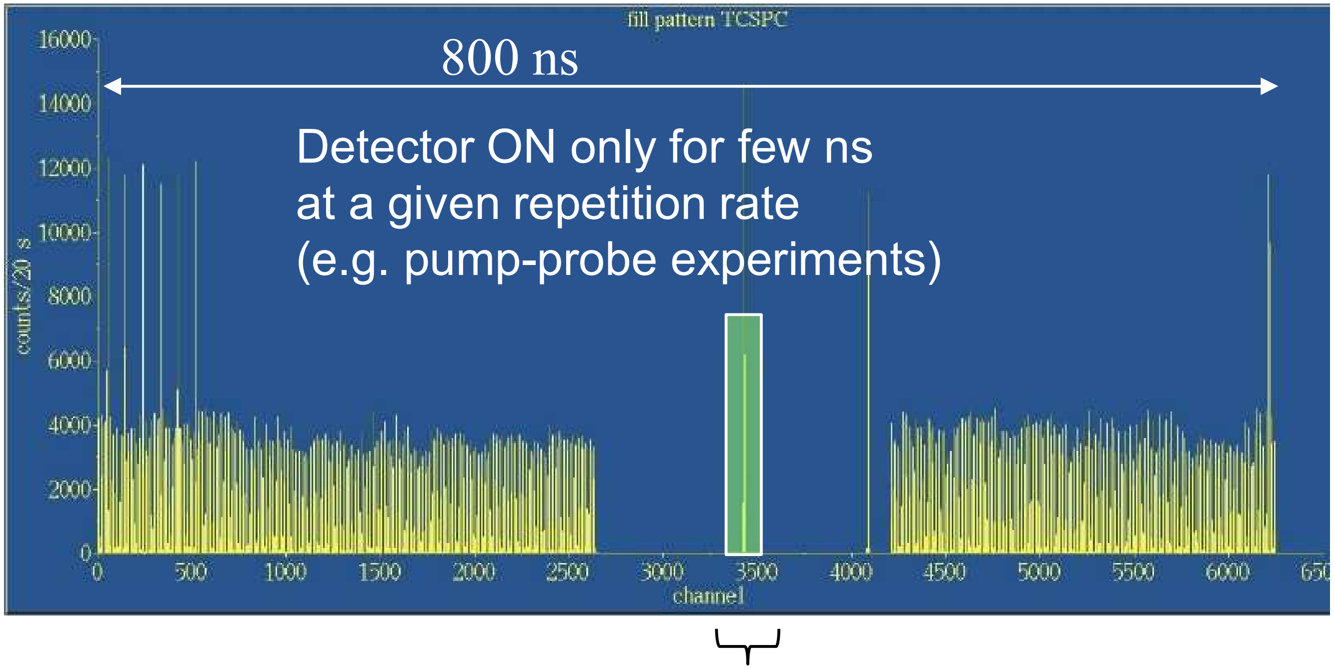


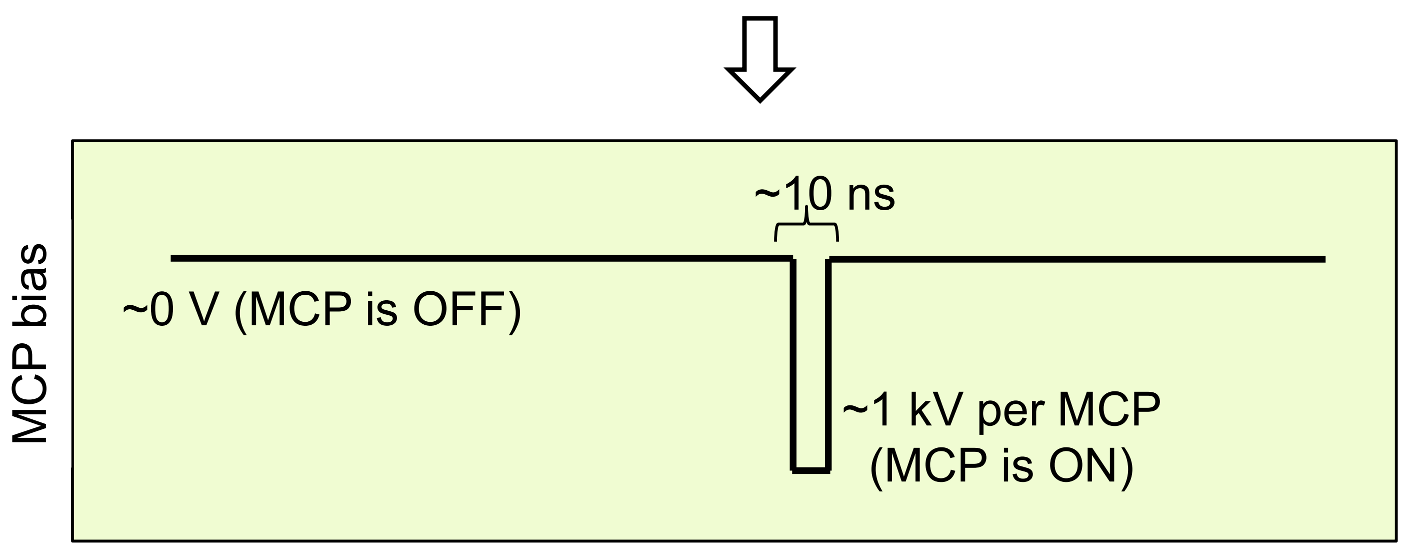


- Charge Q is extracted from the pore
- Pore does not provide an adequate gain if not recharged
- Need to resupply that charge
- MCP strip current defines the speed of charge replenishment
- Negative thermal coefficient of resistance limits the maximum MCP strip current
- At very high input rates MCP amplification drops to very low values

Solution: gating the MCP accelerating bias

Beam intensity vs. time

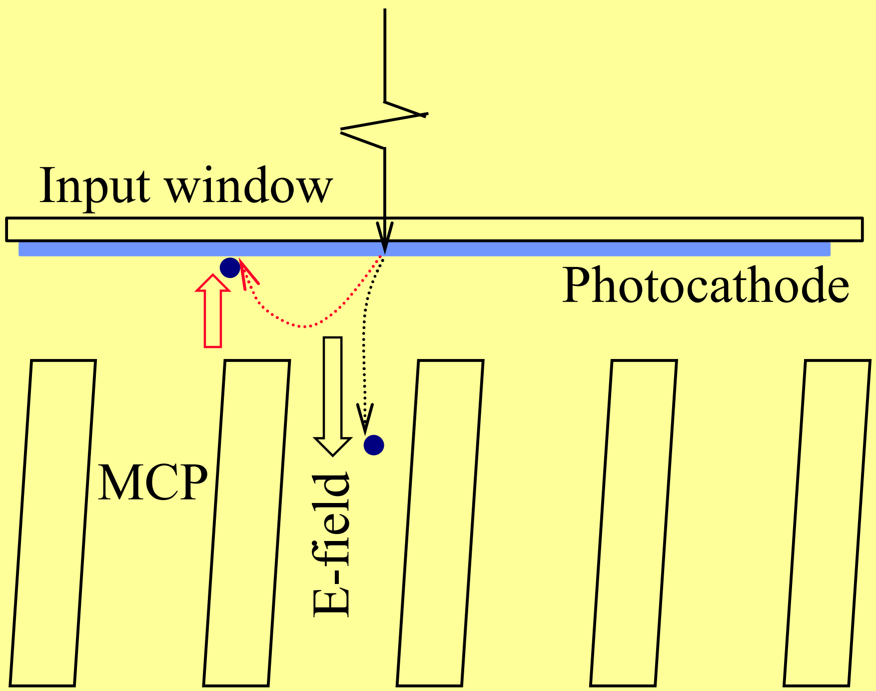




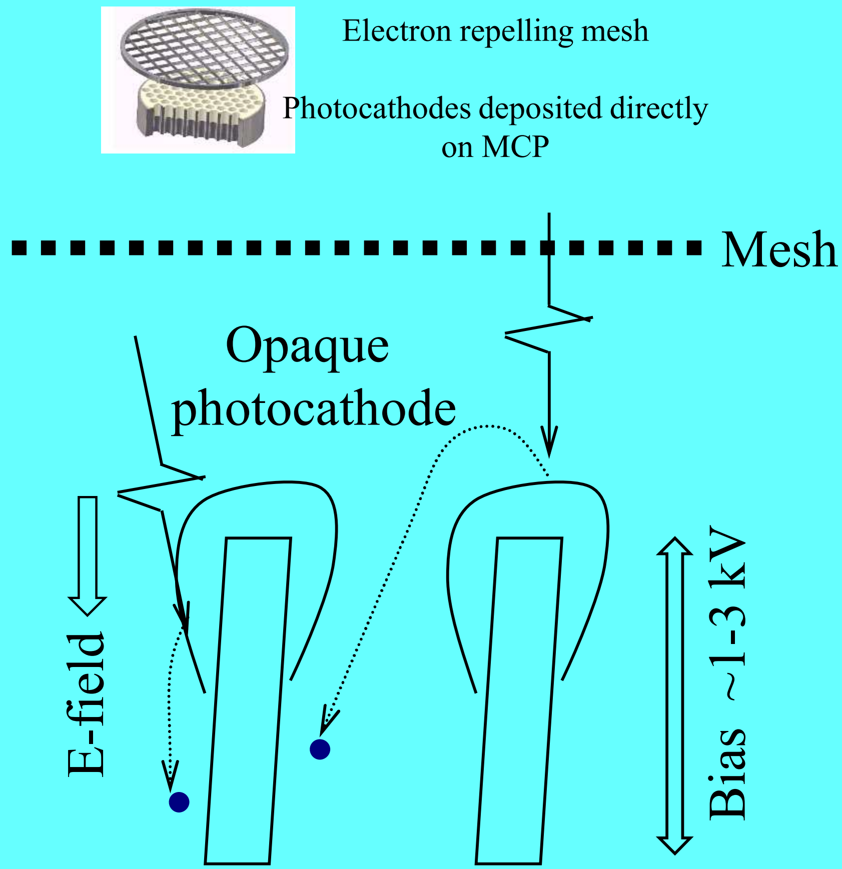
Time gating MCP detectors

Image intensifiers
(visible photons):
photocathode is gated at ~ns scales.
Photoelectrons have ~eV energies, easy to stop them by reversing the electric field

(<100 V bias jumps, almost no current)

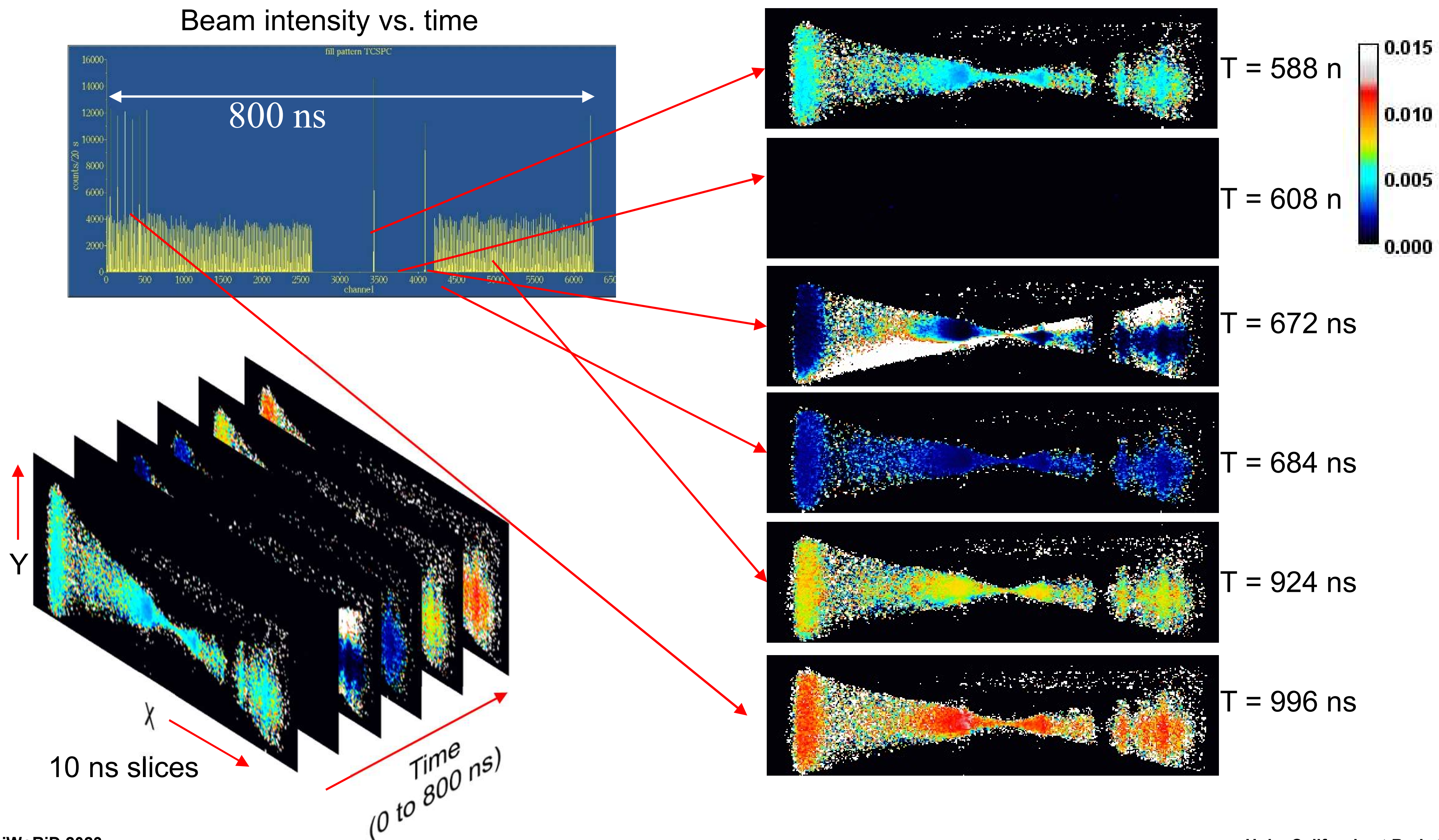


Soft X-ray detectors with opaque photocathodes:
need to turn the MCP OFF (bias ~kV scale)
large strip currents (tens of μA)



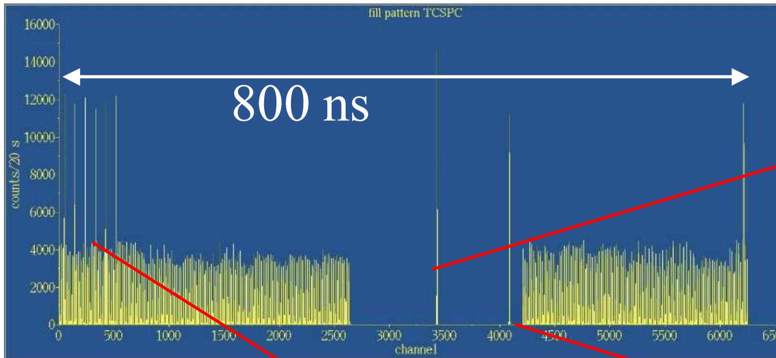
Images at different phases of the ring

Images within 10 ns time window, normalized by the average intensity image.

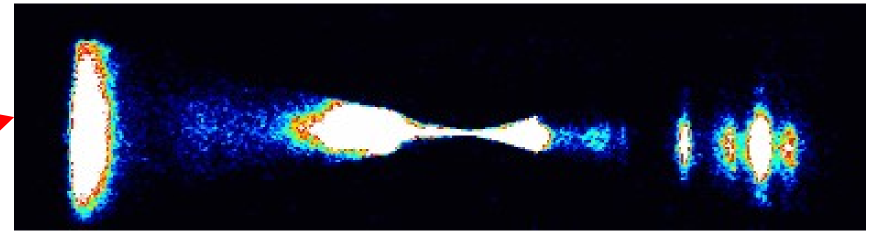


Images at different phases of the ring

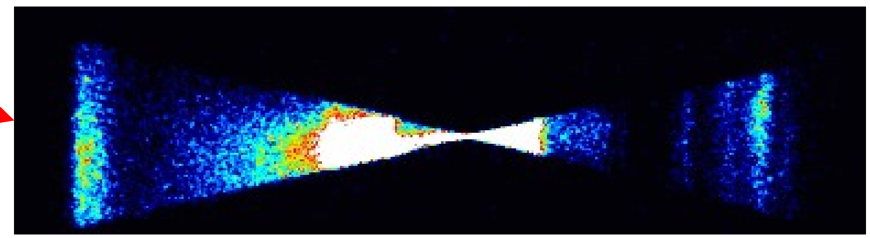
Beam intensity vs. time



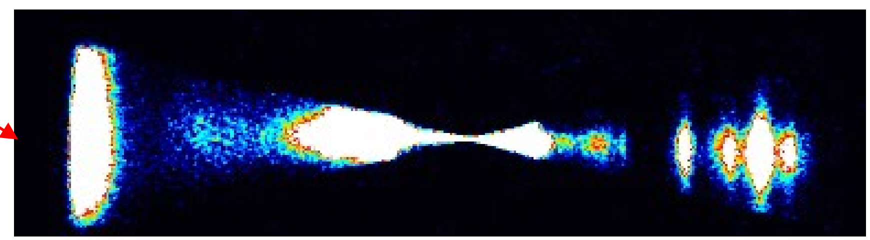
T = 588 ns

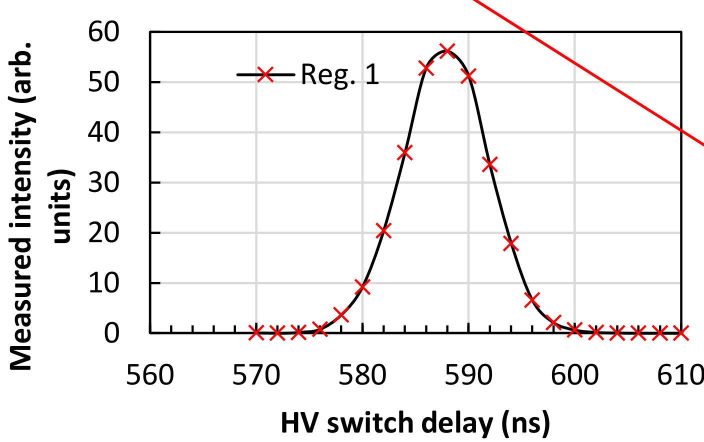


T = 672 ns



T = 966 ns

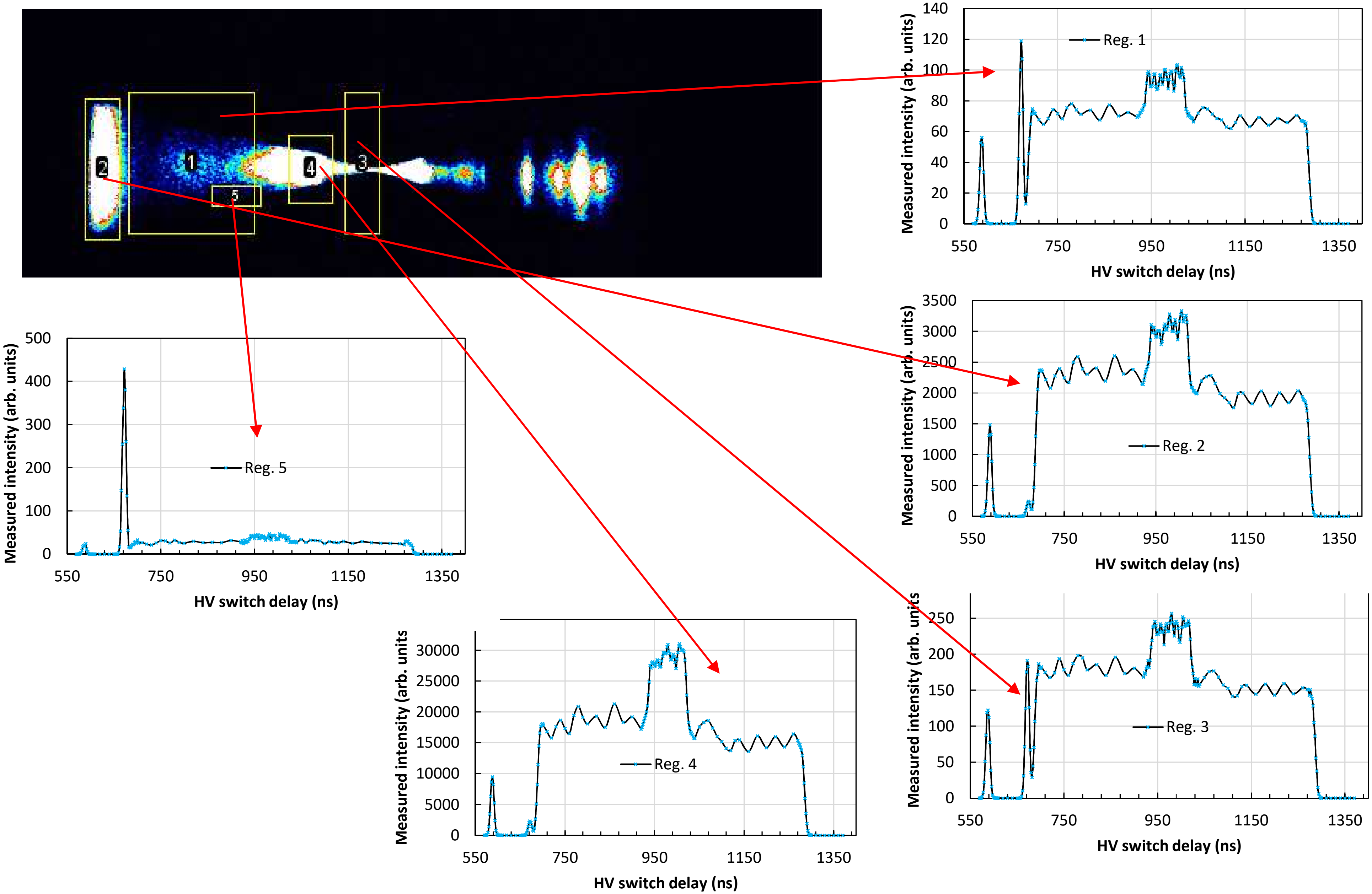




Intensity distribution is different for different phases of the storage ring cycle.

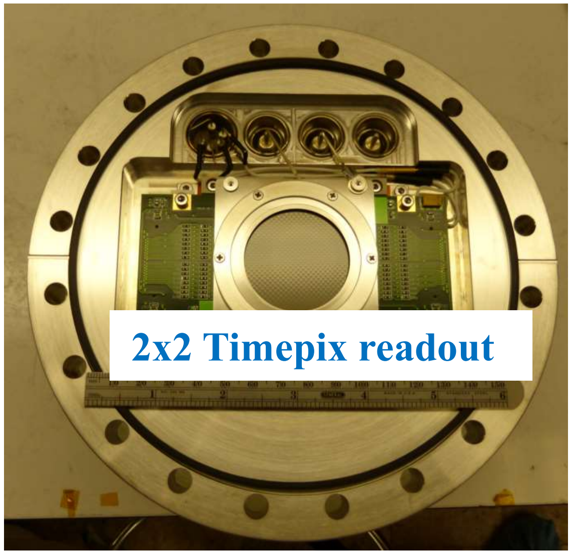
Can image them independently from each other, all in one measurement.

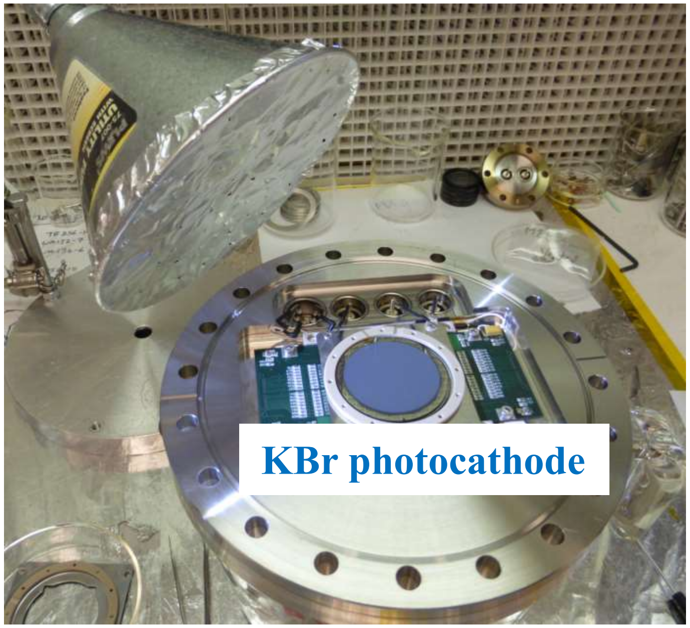
Intensity vs time at different spatial locations



Improvement of Detection Efficiency

- The MCPs with 12 or 5 um pores, L/D=60:1, 8 degree pore bias are used.
- Grid mesh is used to increase the QE by directing electrons emitted in the interchannel area.
- Detector with 28x28 mm^2 active area is used in test.
- **KBr photocathode** is deposited on the input surface of MCP.





Detection efficiency vs pore bias

CsI 281, 109, 48, 21 eV

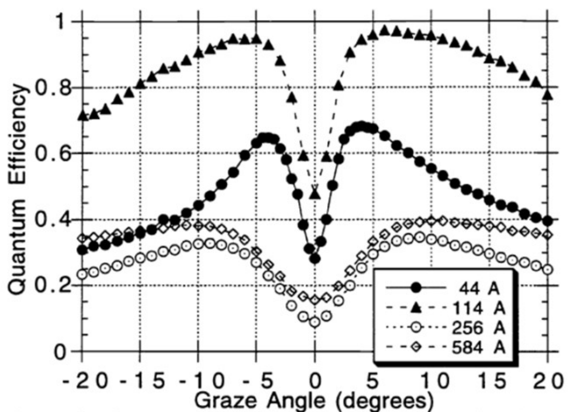


Figure 2. Quantum efficiency v.s. graze angle of incidence to the MCP pores for CsCl.

44 A = 281 eV
114 A = 109 eV
256 A = 48 eV
584 A = 21 eV

Proc. SPIE **2808** (1996) "EUV, X-Ray, and Gamma-Ray Instrumentation for Astronomy VII

CsI photocathode, 277 eV

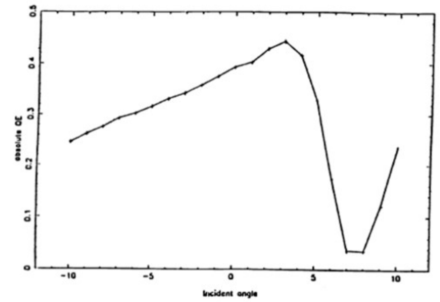


Figure 4: Absolute QE measurement of CsI coated Phillips MCPs at 277 eV and 0° azimuthal angle.

Proc. SPIE **2808** (1996) "EUV, X-Ray, and Gamma-Ray Instrumentation for Astronomy VII"

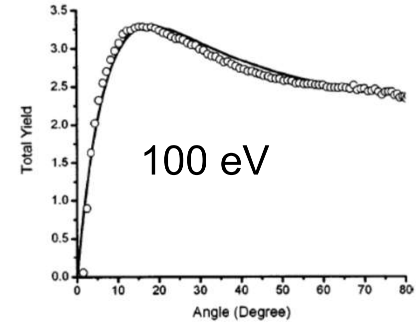
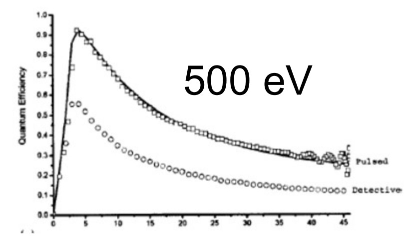
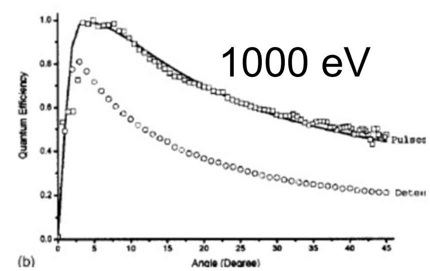


FIG. 4. TEY from 1000 Å thick CsI photocathode excited by 100 eV photons. F=1 kV/mm. The solid line was calculated using Fraser's model.[7]



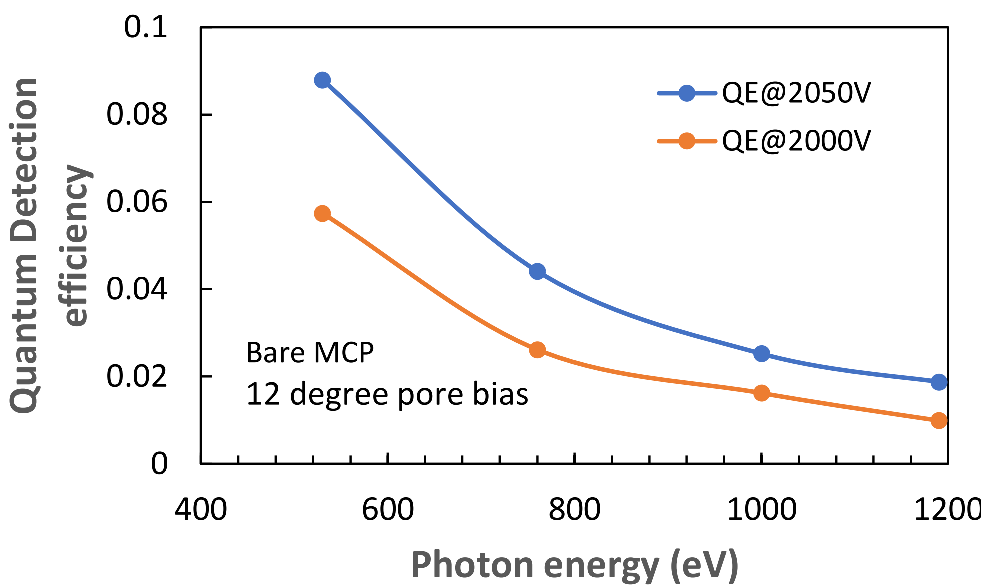


Rev. Sci. Instrum. **75** (2004) 3131

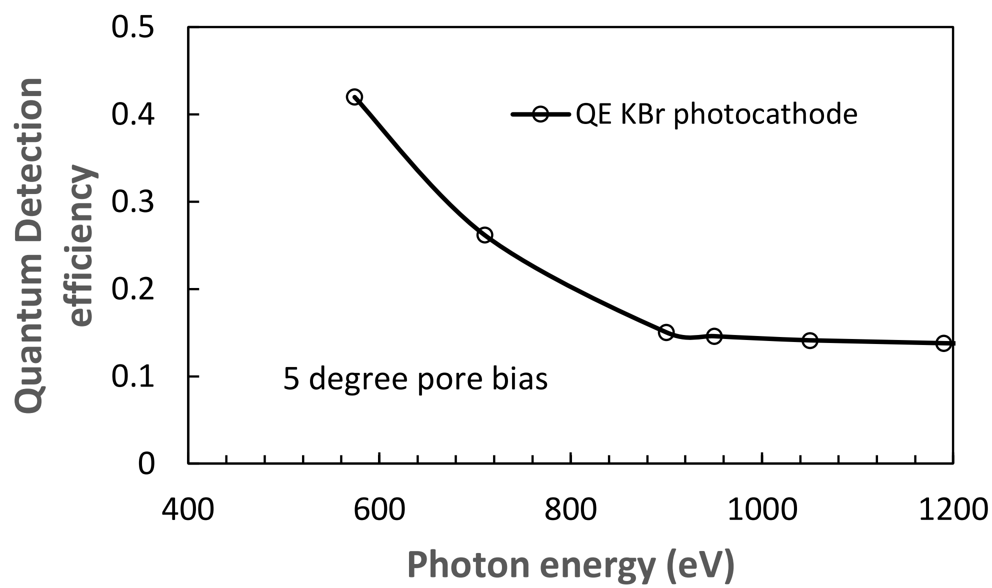
~5 degree bias is optimal for few hundred eV photons

Measured detection efficiency at BESSY

Generation 1
No photocathode.
MCP with 12 pore degree bias

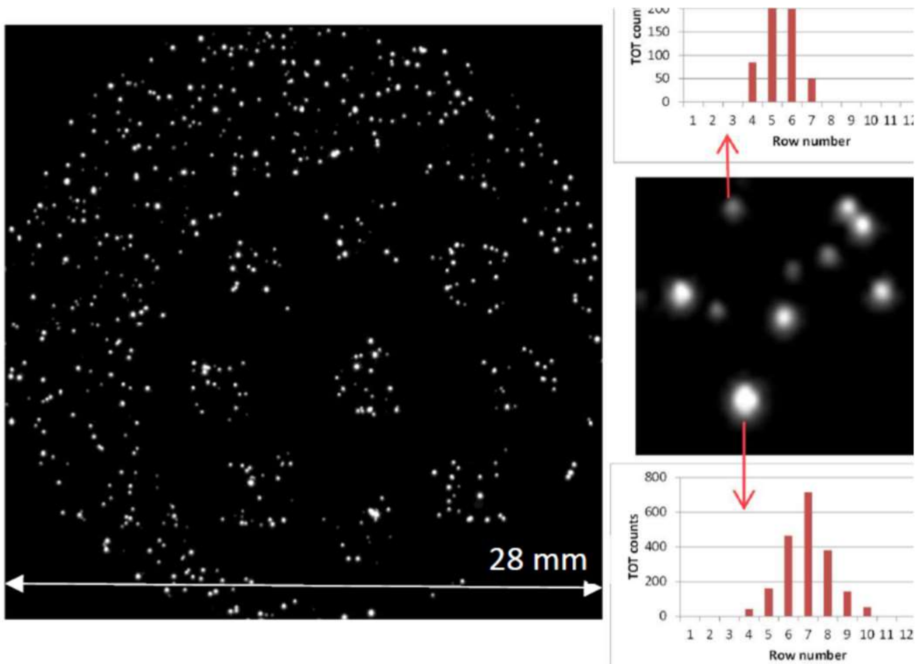


Generation 2
KBr photocathode.
MCP with 5 pore degree bias

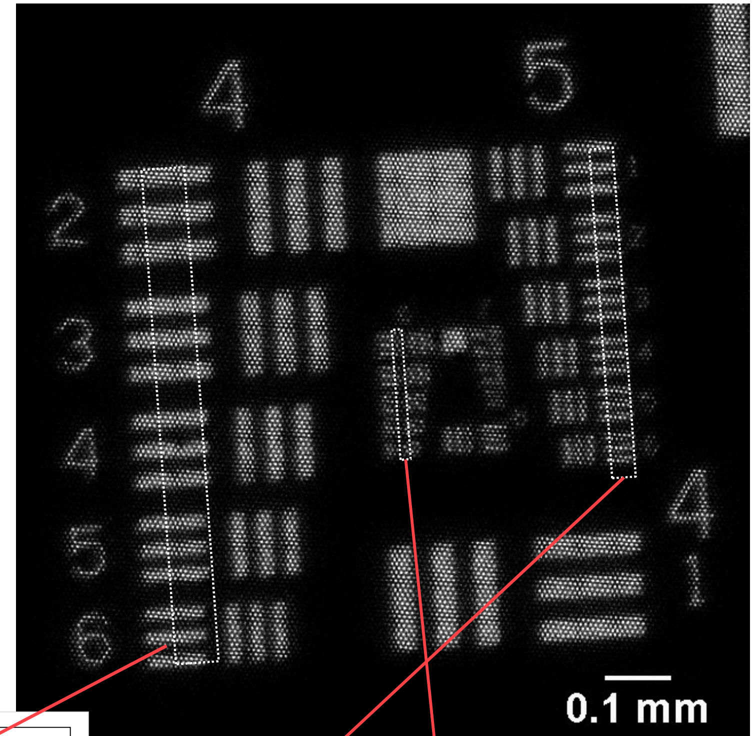


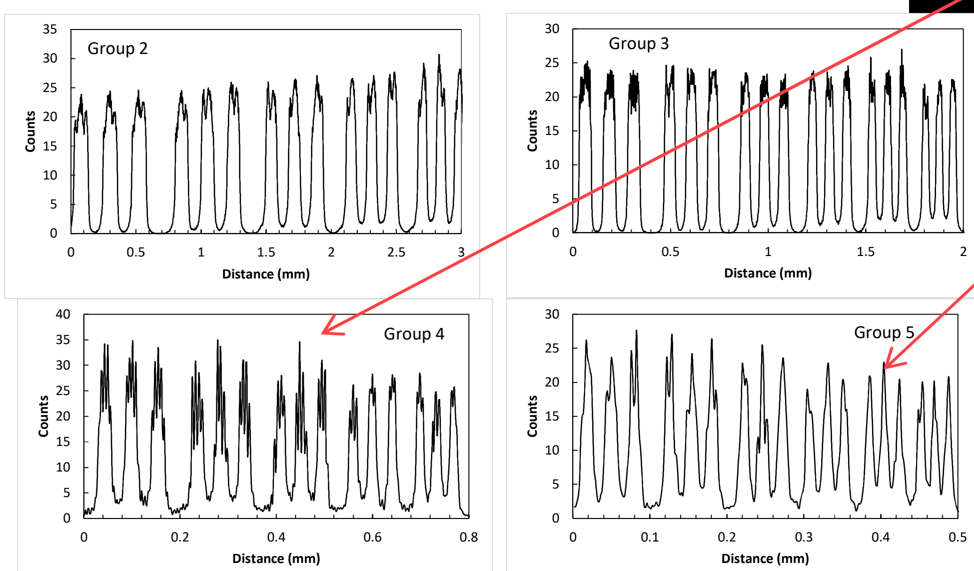
Optimized pore bias and KBr photocathode substantially improve detection efficiency

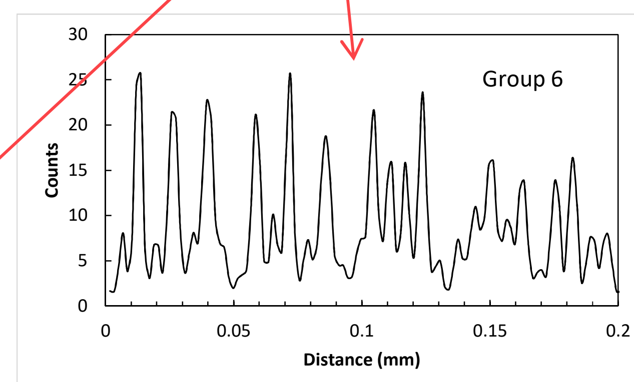
Spatial resolution with event centroiding: ~6 μm resolution



Cross sections through resolution mask



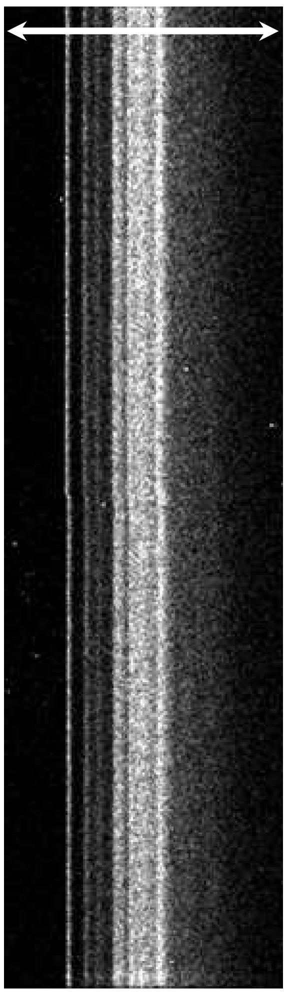




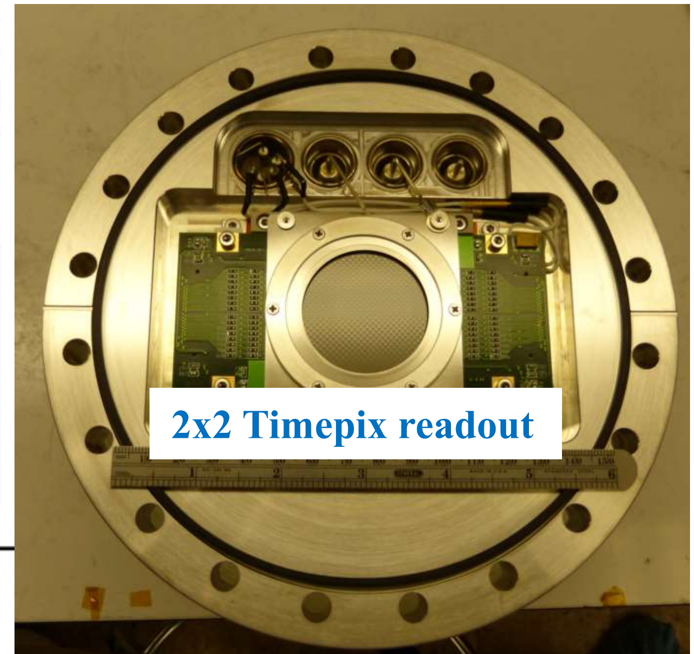
JINST **13** (2018) C11005

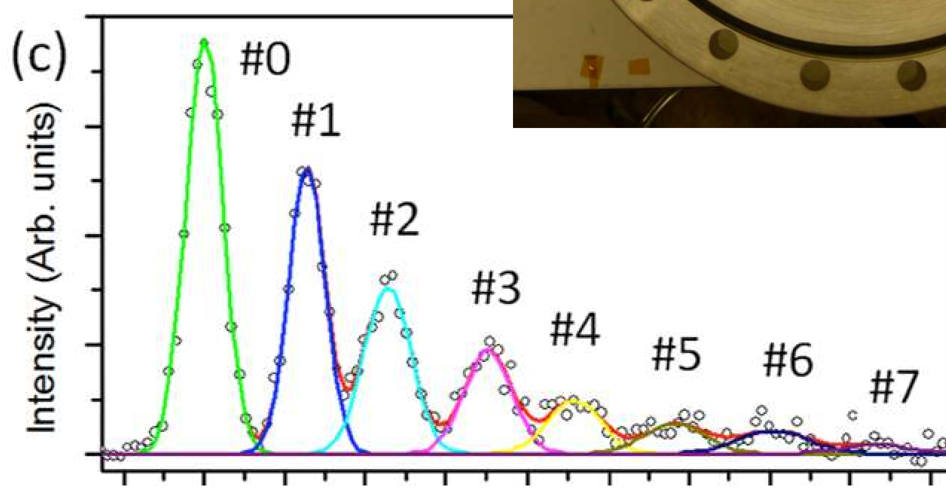
MCP/TPX detectors at ALS and LCLS

~8.5 mm



Raw image

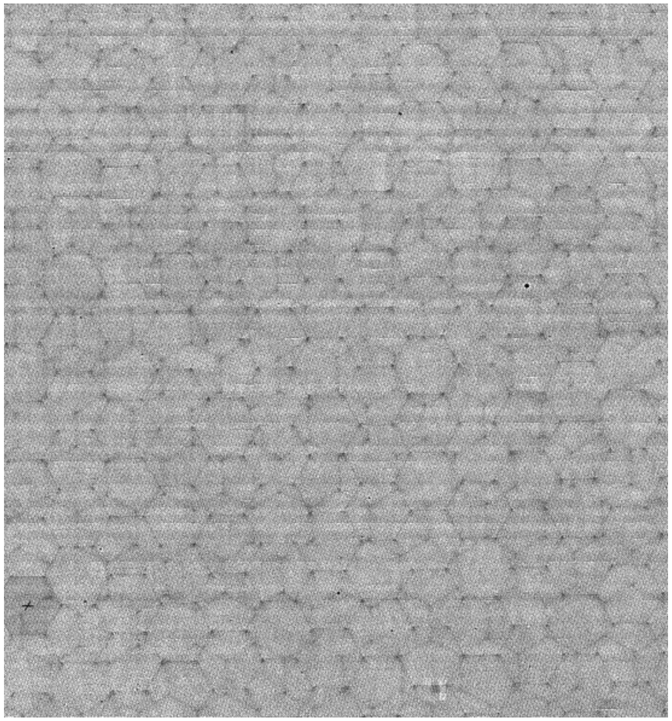


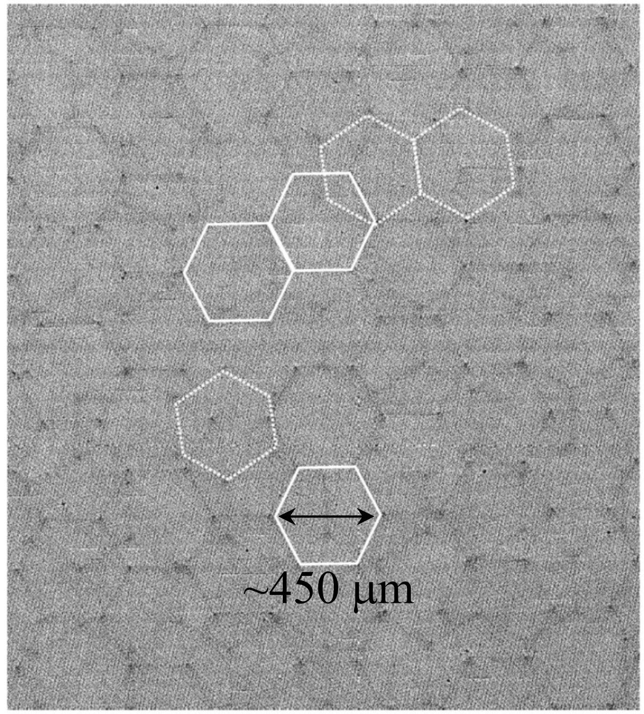


HOPG elastic peak vibronic coupling

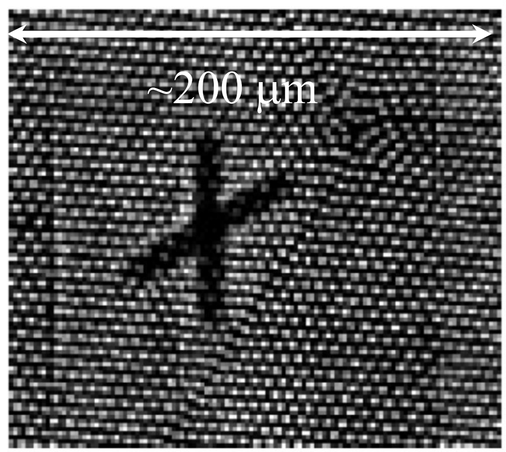
X. Feng et al., Phys. Rev. Let 125, 116401 (2020)

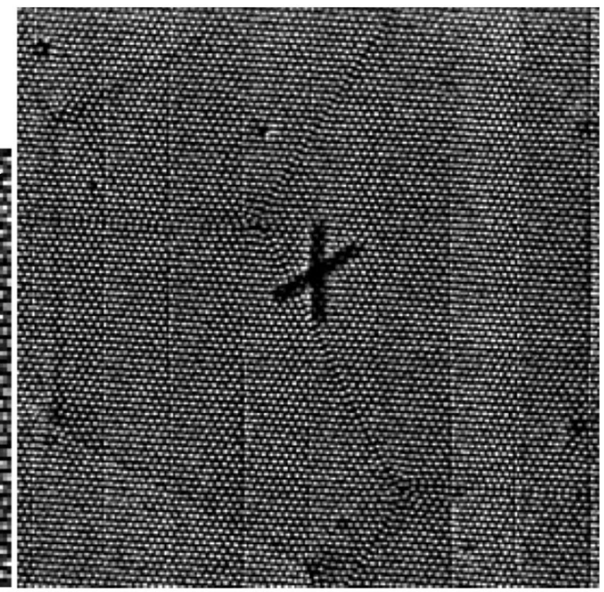
High resolution through event centroiding





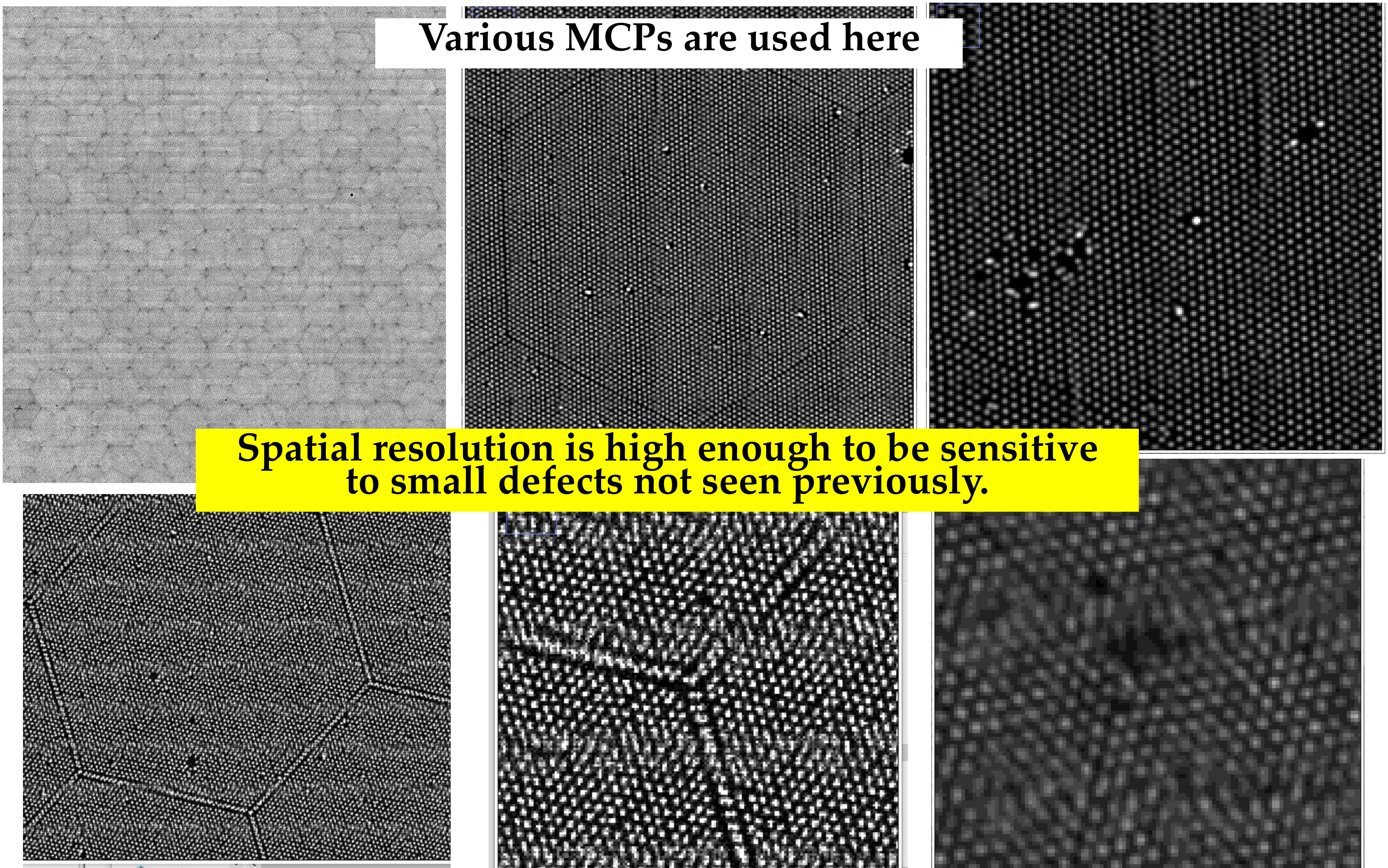
Multifibers from both MCPs are visible





Dots in the image are single pores (5 µm diameter, ~6 µm hex spacing)

Importance of MCP uniformity at ~6 μm scales



Various MCPs are used here

Spatial resolution is high enough to be sensitive to small defects not seen previously.

MCP/Timepix soft X-ray detector generations

Gen. 2 (used now)

- **Spatial resolution** 55 μm with 10 ns timing resolution
- **Either** high spatial resolution (~6 μm), **or** high timing resolution
- **Count rate** in high spatial resolution (~6 μm), is **limited to ~3 MHz**
- **Count rate** with 10 ns and 55 μm is ~ **30 MHz**
- **320 μs** readout time (**dead time)** per frame
- **Power dissipation** ~1W/chip

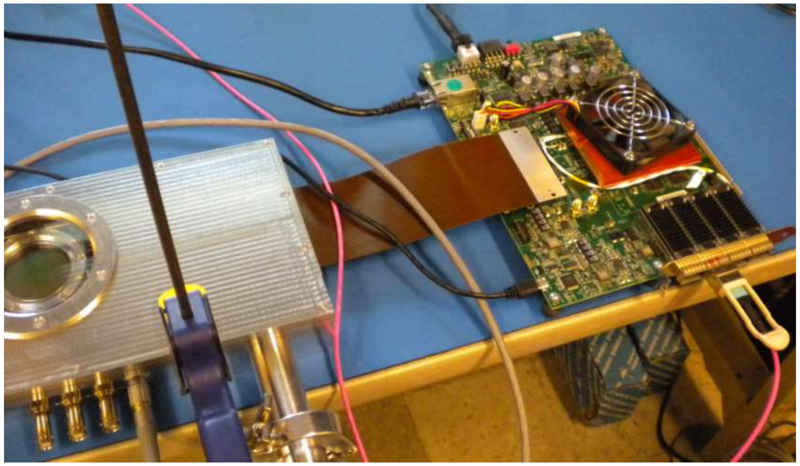
Gen. 3

- **Timing resolution improved to <2 ns**
- **Both high spatial** (~6 μm) **and timing resolution** (<2 ns) are possible
- **No dead time for readout: event driven readout**
- **80 Mhits/s rate per chip**
- **More heat generated in vacuum** (power dissipation ~2 W/chip); power options can be optimized
- **Longer cable out of vacuum** (LVDS signal output)

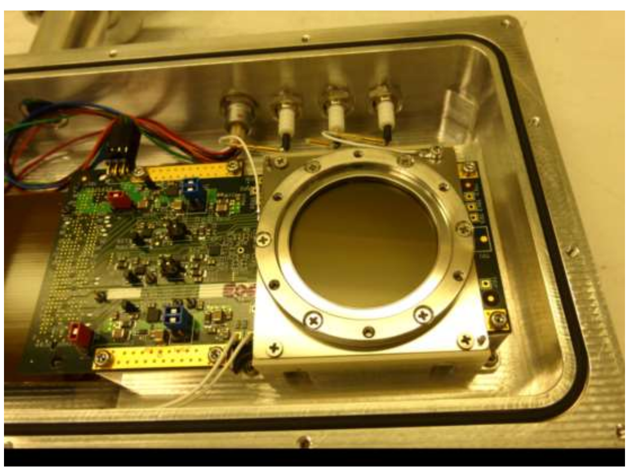
Gen. 4

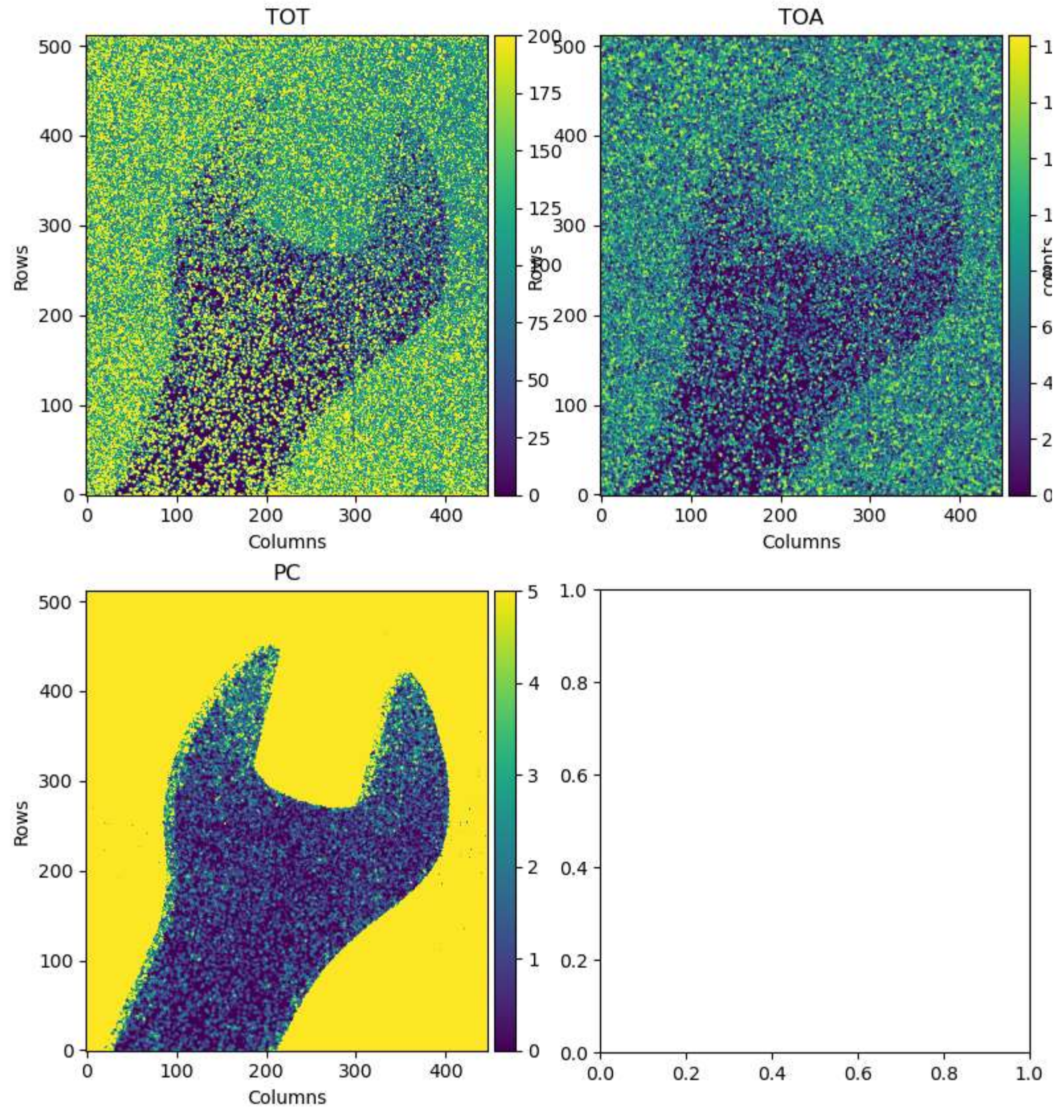
- **Timing resolution improved to ~200 ps**
- **Larger area per chip** (512x488 pixels, 55 μm each)
- **4-side buttable** (TSVs)
- **Very high data output rates** (up to 160 Gb/s)

Our first image of MCP/Timepix4 detector: June 2023



**Vacuum enclosure
with MCP/Timeix4 assembly**





Thank you for your attention!

This work was supported in part by DOE through award #RoyTimepixDetector.

MCP/Timepix development at UCB were supported in the past by NASA, DOE, NNSA.

The work on MCP/Timepix detector was done within the Medipix collaboration.

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