Event Driven Readout

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DESY – FS-DS

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

CFEL SCIENCE

MT MATTER AND TECHNOLOGIES

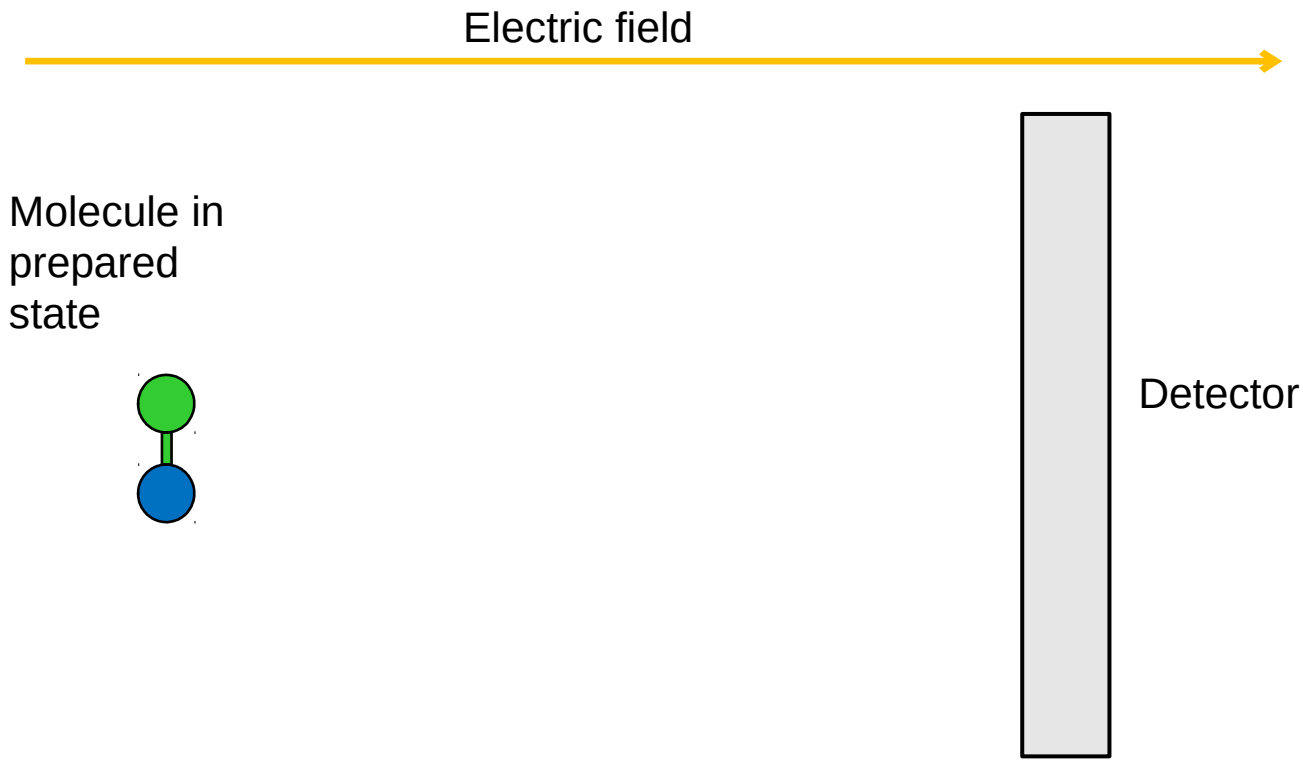
DESY.

Outline

- Scientific Motivation
- Frame Driven vs. Event Driven
- Challenges
- Outlook

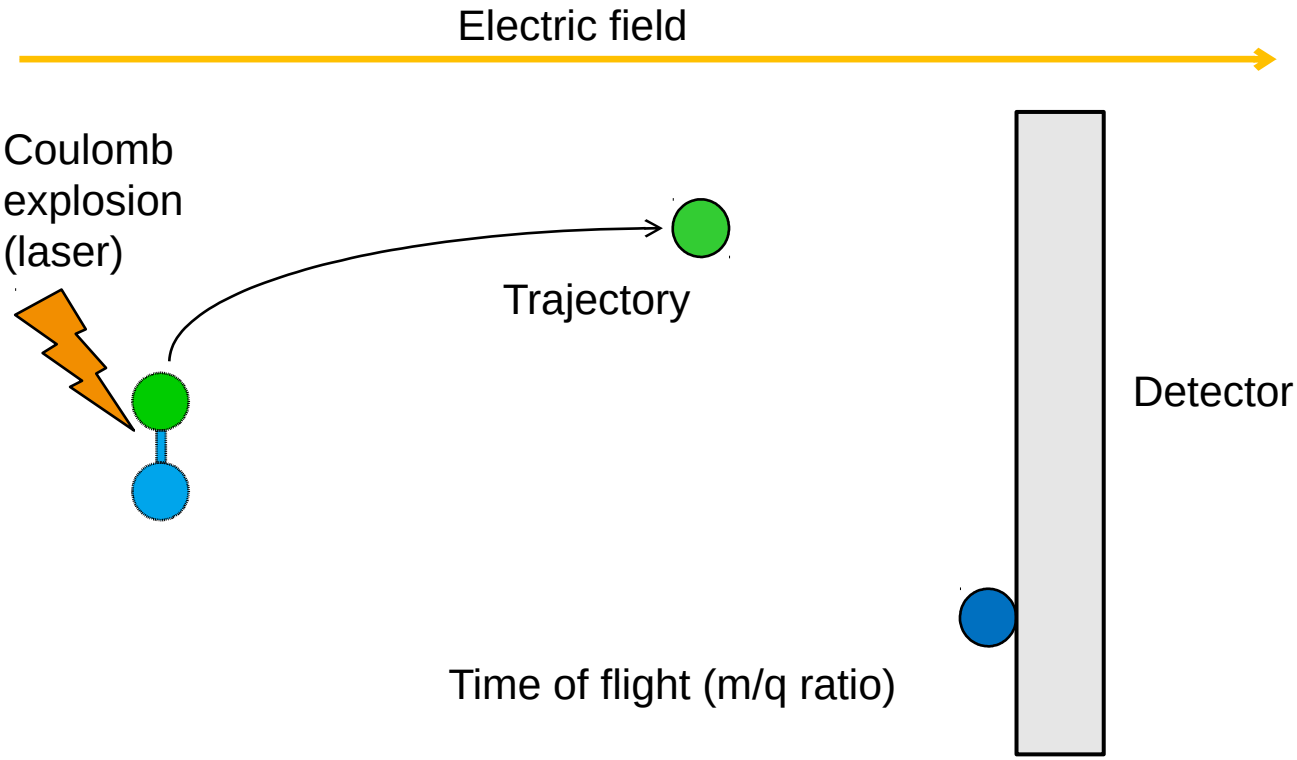
Timepix3

Scientific Case: Ion Detection @ CFEL-CMI



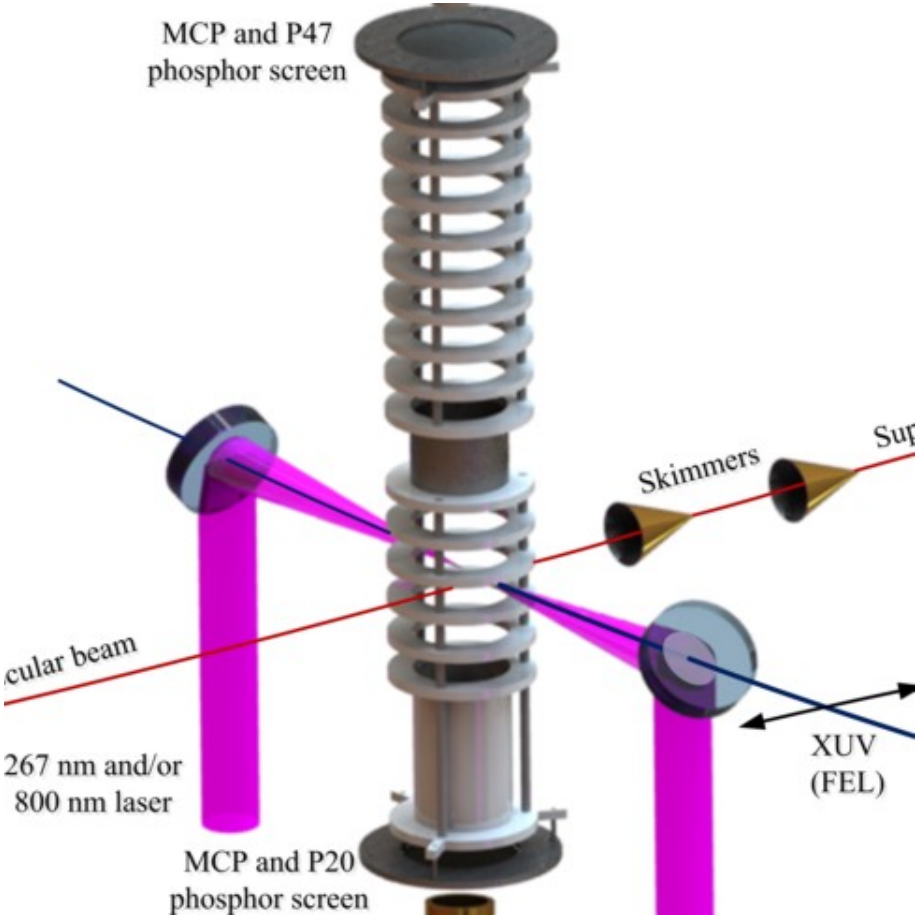
Timepix3

Scientific Case: Ion Detection @ CFEL-CMI



Timepix3

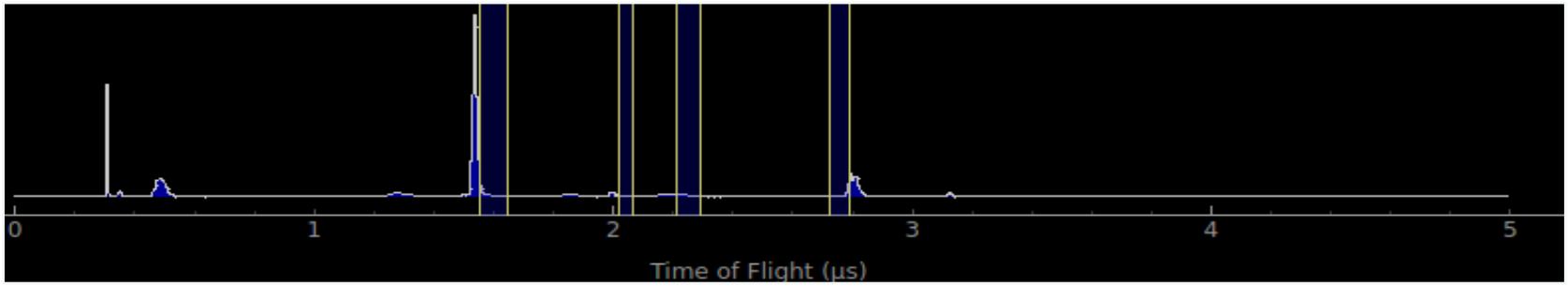
Scientific Case: Ion Detection @ CFEL-CMI

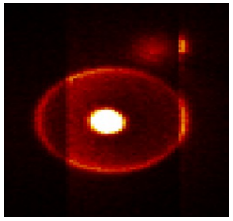


- High time resolution
- Several Mhits/cm^2/s
- Vacuum preferred

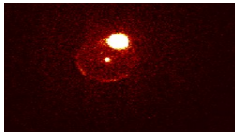
Timepix3

Scientific Case: Ion Detection @ CFEL-CMI

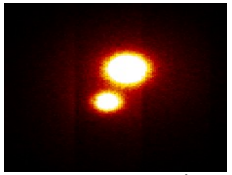




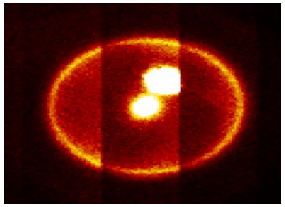
(Pyrrole- H^+)



(Pyrrole)$^{2+}$



$(C_3H_3)^+$

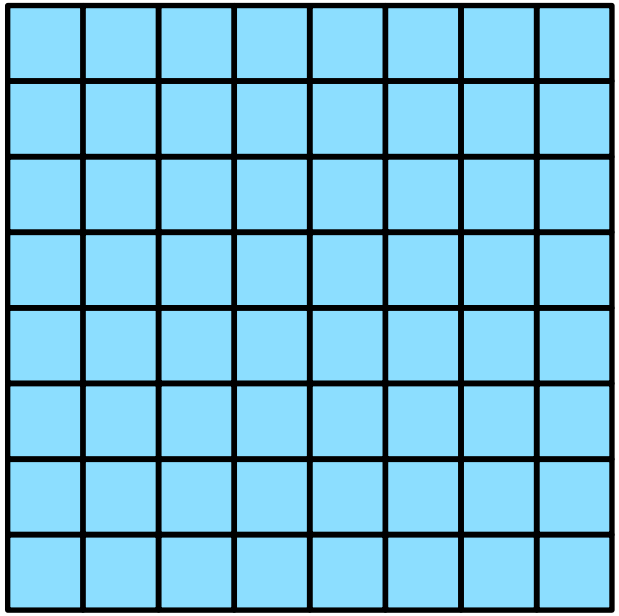


$(H_3O_3)^+$

Investigating the fragmentation processes of singly hydrogen bonded systems via **P**hoto-**I**on-**P**hoto-**I**on **C**oincidences(**PIPICO**) Imaging

Frame Driven Readout

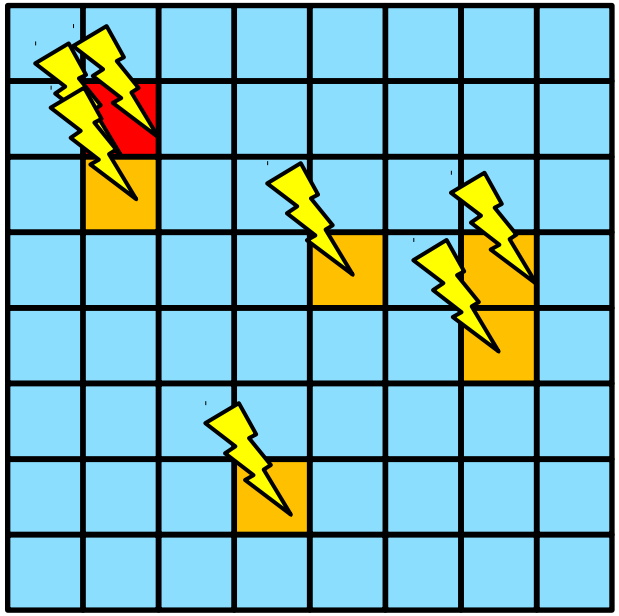
How does it work?



Detector

Frame Driven Readout

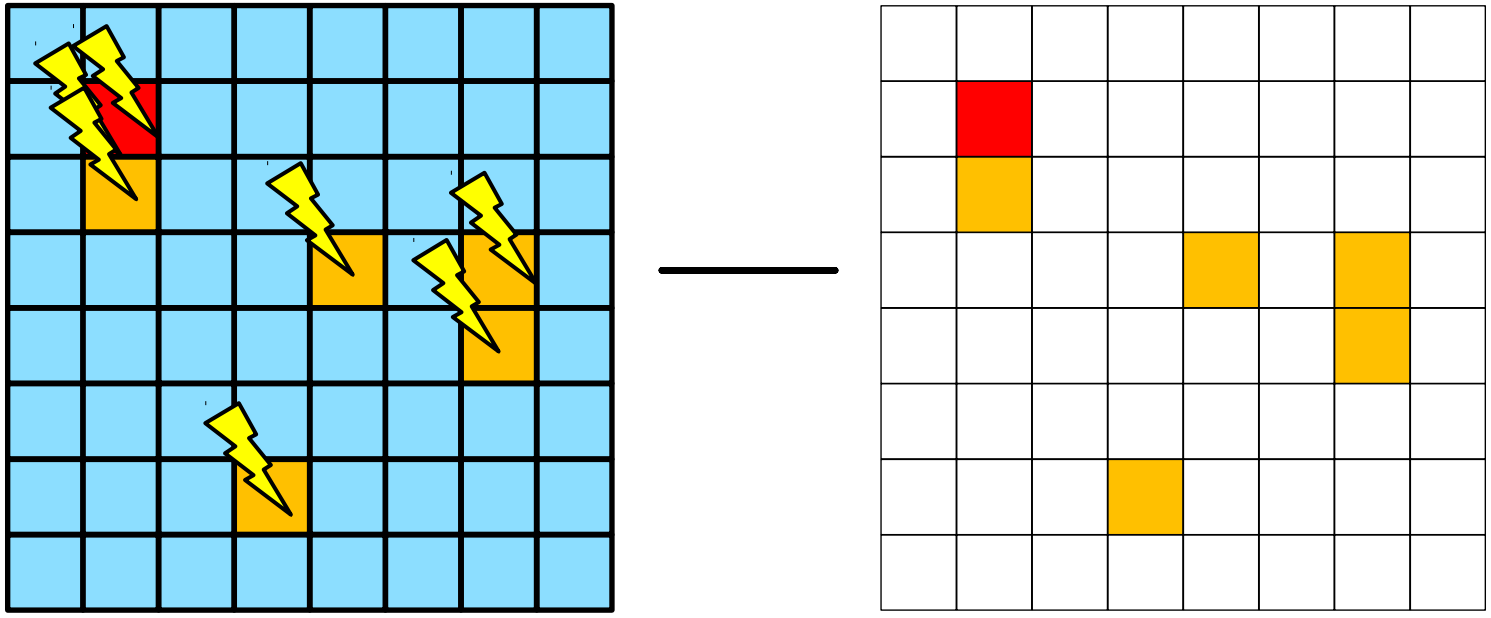
Image Acquisition



Detector

Frame Driven Readout

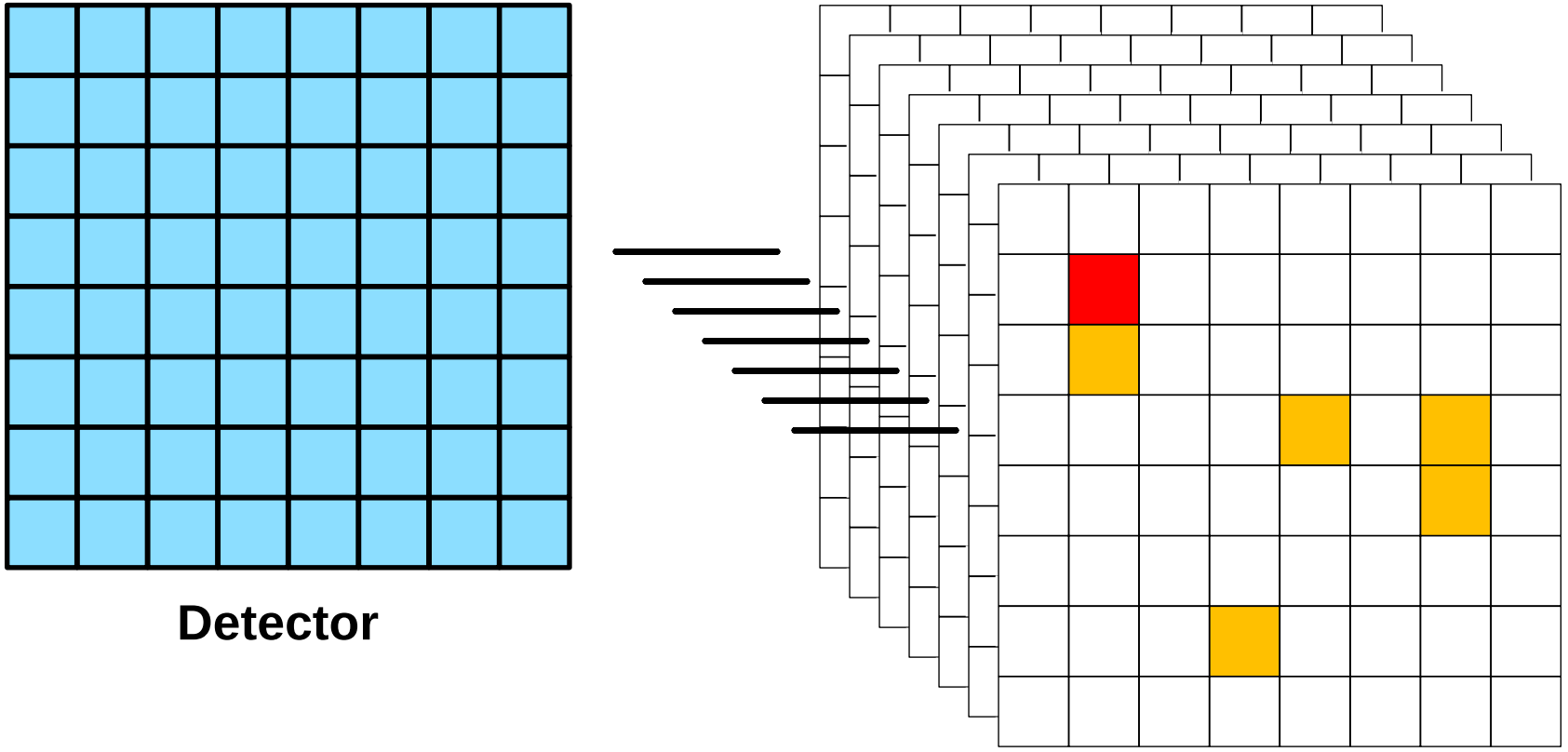
Image Readout



Detector

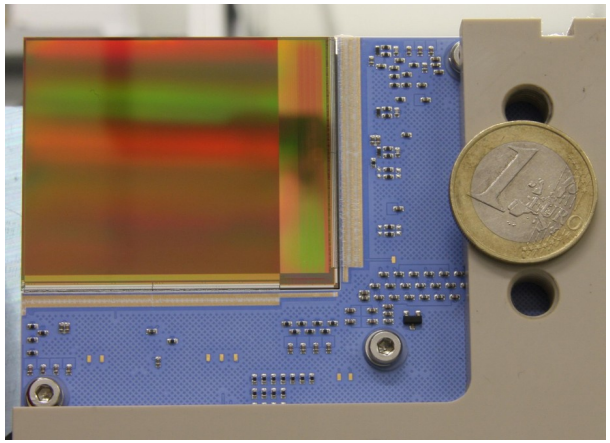
Frame Driven Readout

Image Readout

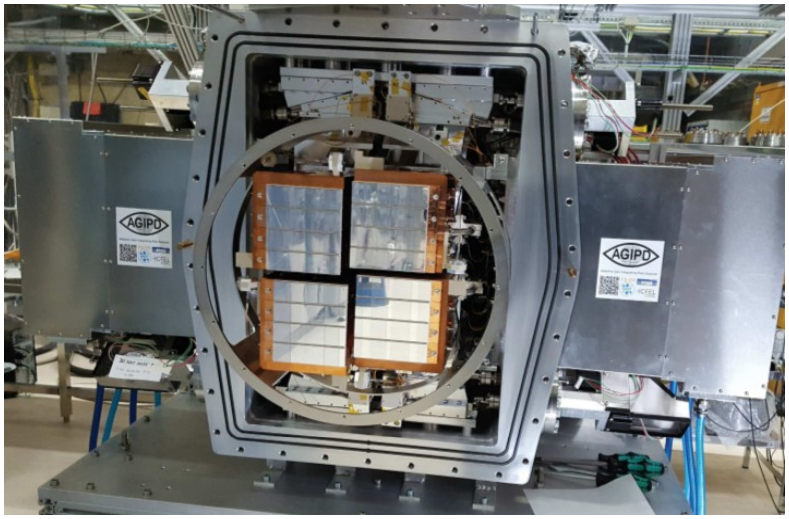


Frame Driven Readout

Examples developed by the FS-DS



PERCIVAL: CMOS Detector for Soft X-rays



AGIPD: Integrating Detector for the XFEL.eu

LAMBDA: Photon Counting Detector

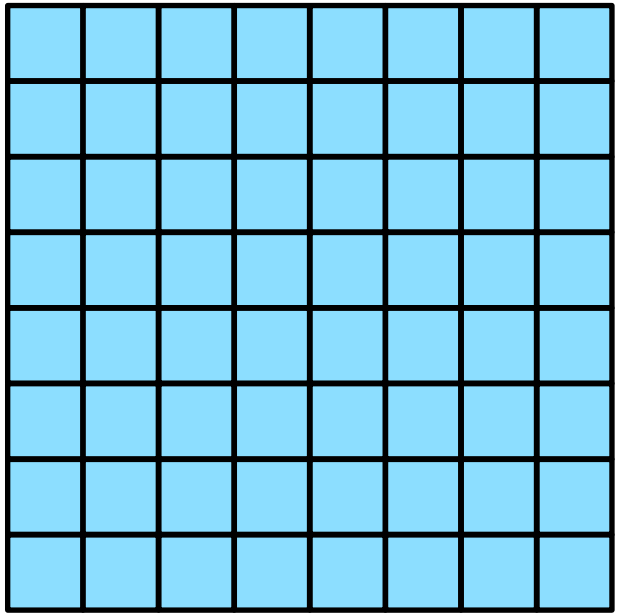
Frame Driven Readout

In short

- Many photons can be recorded per image
- For continuous time resolution, a high frame rate is needed
- 1 kHz readout of 1 Mpixel detector:
  - 10^9 pixel readouts
  - ~ 2 Gigabytes per second

Event Driven Readout

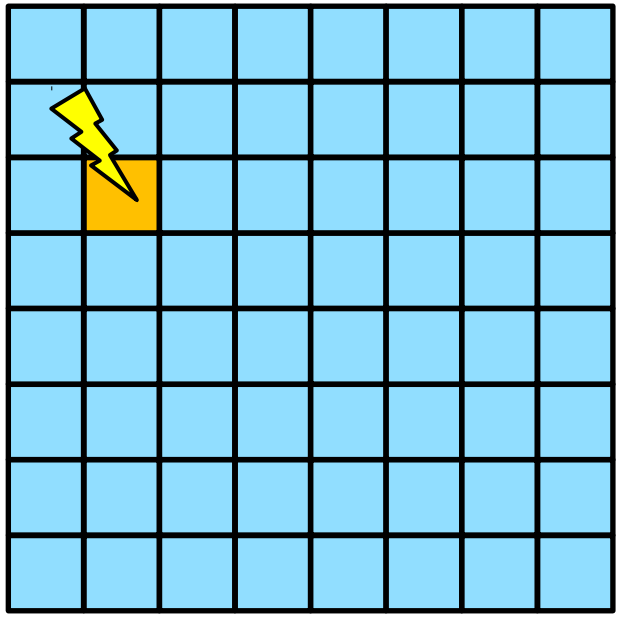
How does it work?



Detector

Frame Driven Readout

Continuous readout of hits



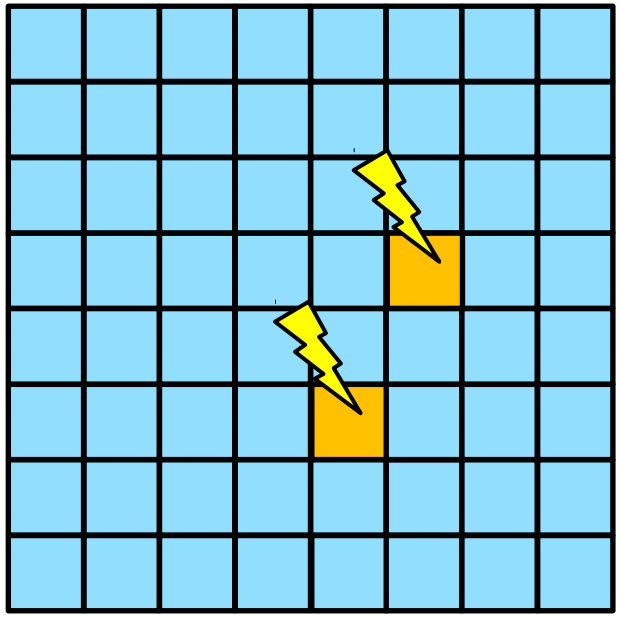
Detector

Pixel (2,6)
Energy ~10 keV
Time 125 ns

Data packet

Frame Driven Readout

Continuous readout of hits



Detector

Pixel (5,3)
Energy ~15 keV
Time 725 ns

Pixel (6,5)
Energy ~10 keV
Time 725 ns

Data packets

Event Driven Readout

In short

- One data packet per hit on the detector
  - Hit time, energy measurement, pixel co-ordinates
- Data rate is proportional to hit rate
  - 10^8 hits ~ 1 Gigabyte/s
- Advantageous at moderate hit rates
  - ~ 1.56 ns time resolution with Timepix3
  - Energy discrimination
  - Potential sub-pixel position resolution (signal sharing)

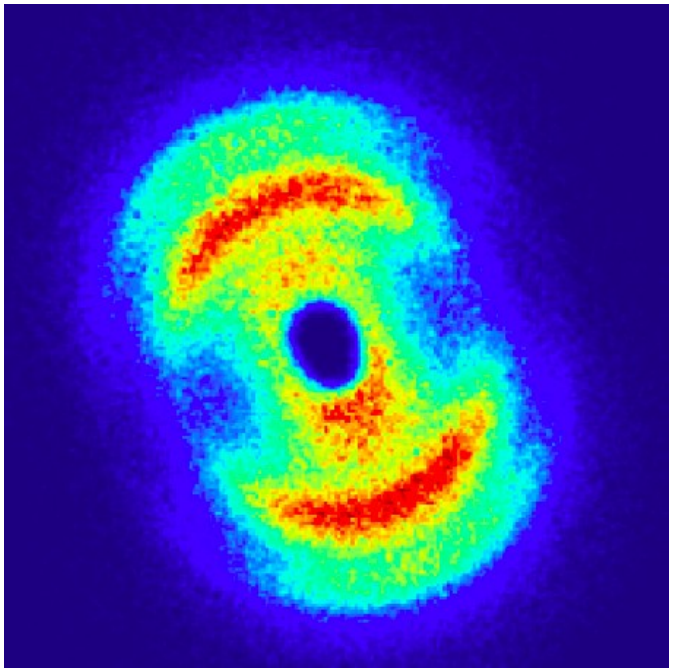
Timepix3

Specifications

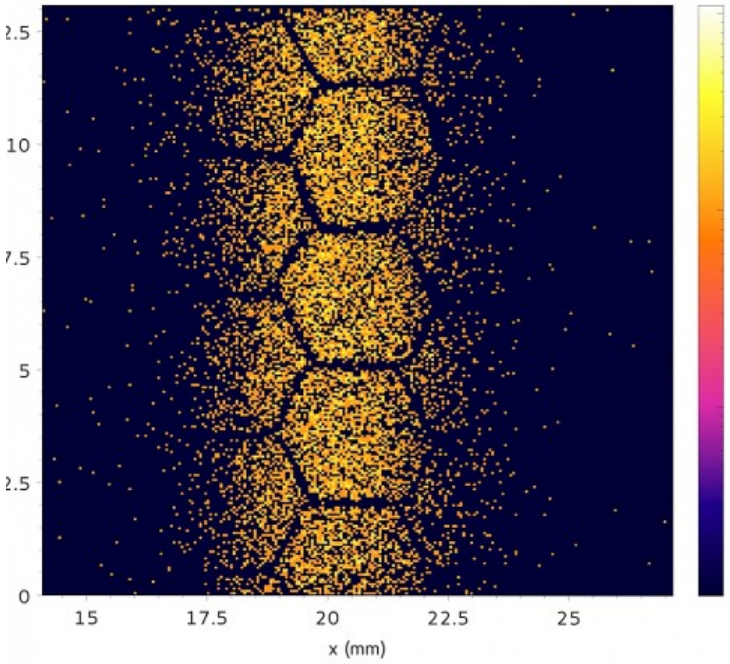
			Timepix3 (2013)
Technology			IBM 130nm – 8 metal
Pixel Size			55 x 55 µm
Pixel arrangement			3-side buttable 256 x 256
Sensitive area			1.98 cm^2
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA
		Event Packet	48-bit
		Max rate	< 43 $Mhits/cm^2/s$
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)
		Frame	Zero-suppressed (with pixel addr)
		Max count rate	82 $Ghits/cm^2/s$
TOT energy resolution			< 2KeV
Time resolution			1.56ns
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)
Target global minimum threshold			<500 e^-

Timepix3

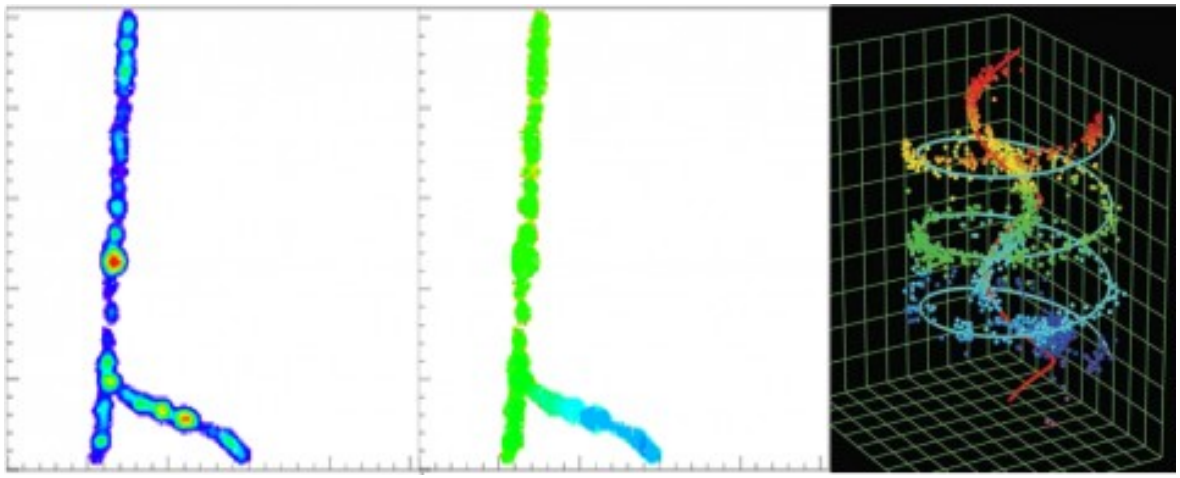
Applications



Ion imaging



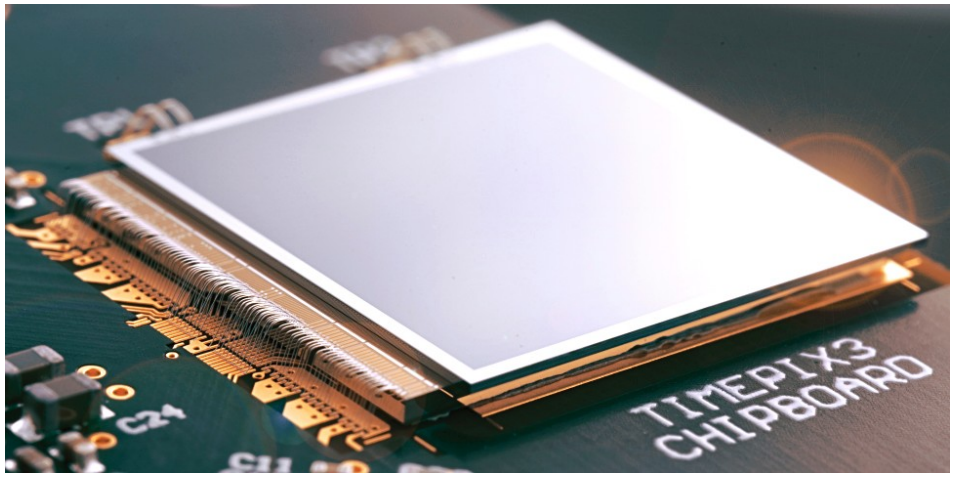
Beam Gas Ionisation (BGI) for monitoring



3D charge particle tracking

Timepix3

Limitations



- Overall hit rate
  - $4e^7$ hits/chip/s chip design (reliable rate)
  - $1.5e^7$ hits/chip/s with current readout card

- Pixel recovery in 1 us (standard mode)
  - ~ 200,000 hits/pixel/s
  - Can speed up to 0.5 us in time only mode (poorer time resolution)

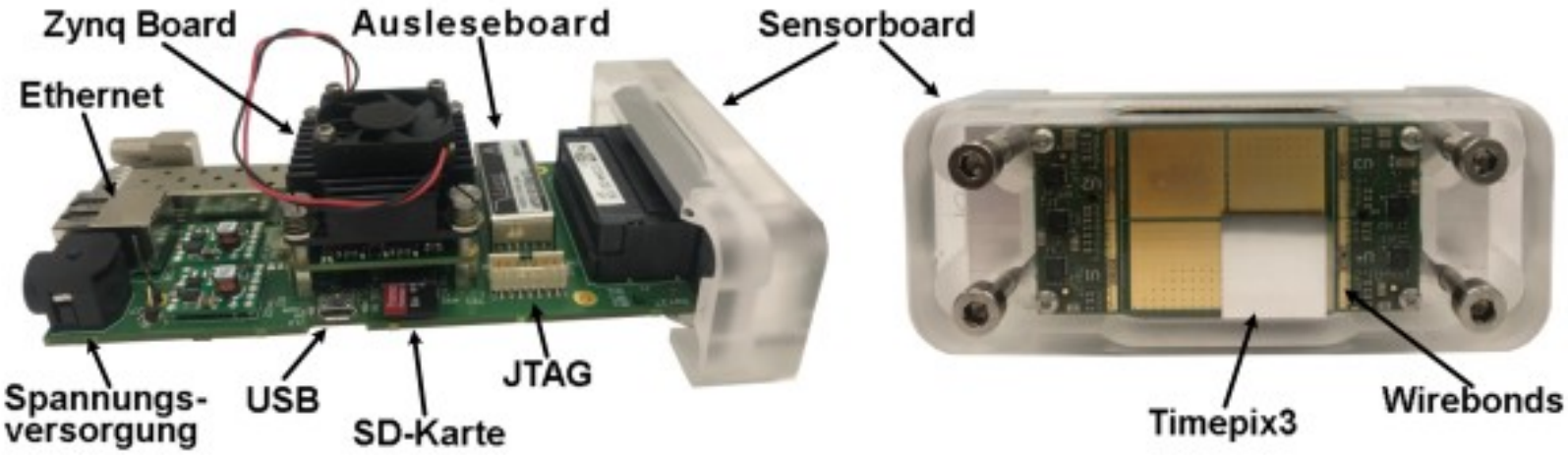
Timepix4

Specifications

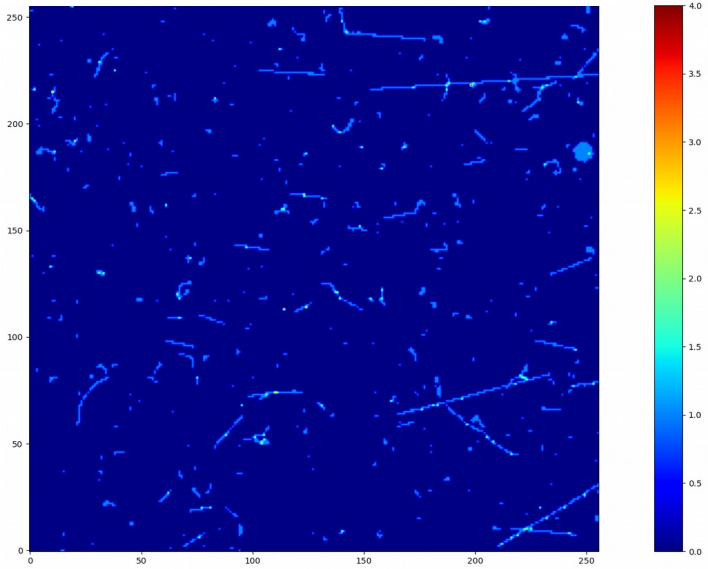
			Timepix3 (2013)	Timepix4 (2018/19)
Technology			IBM 130nm – 8 metal	TSMC 65nm – 10 metal
Pixel Size			55 x 55 µm	55 x 55 µm
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448 **3.5x**
Sensitive area			1.98 cm^2	6.94 cm^2
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	
		Event Packet	48-bit	64-bit **33%**
		Max rate	< 43 Mhits/cm^2/s	178.8 Mhits/cm^2/s **4x**
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr)
		Max count rate	82 Ghits/cm^2/s	~800 Ghits/cm^2/s **10x**
TOT energy resolution			< 2KeV	< **1Kev** **2x**
Time resolution			1.56ns	**~200ps** **8x**
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	≤81.92 Gbps (16x @5.12 Gbps)
Target global minimum threshold			<500 e^-	<500 e^-

Timepix3

Readout System developed at DESY (Fabian Borstel, CFEL-FSDS)

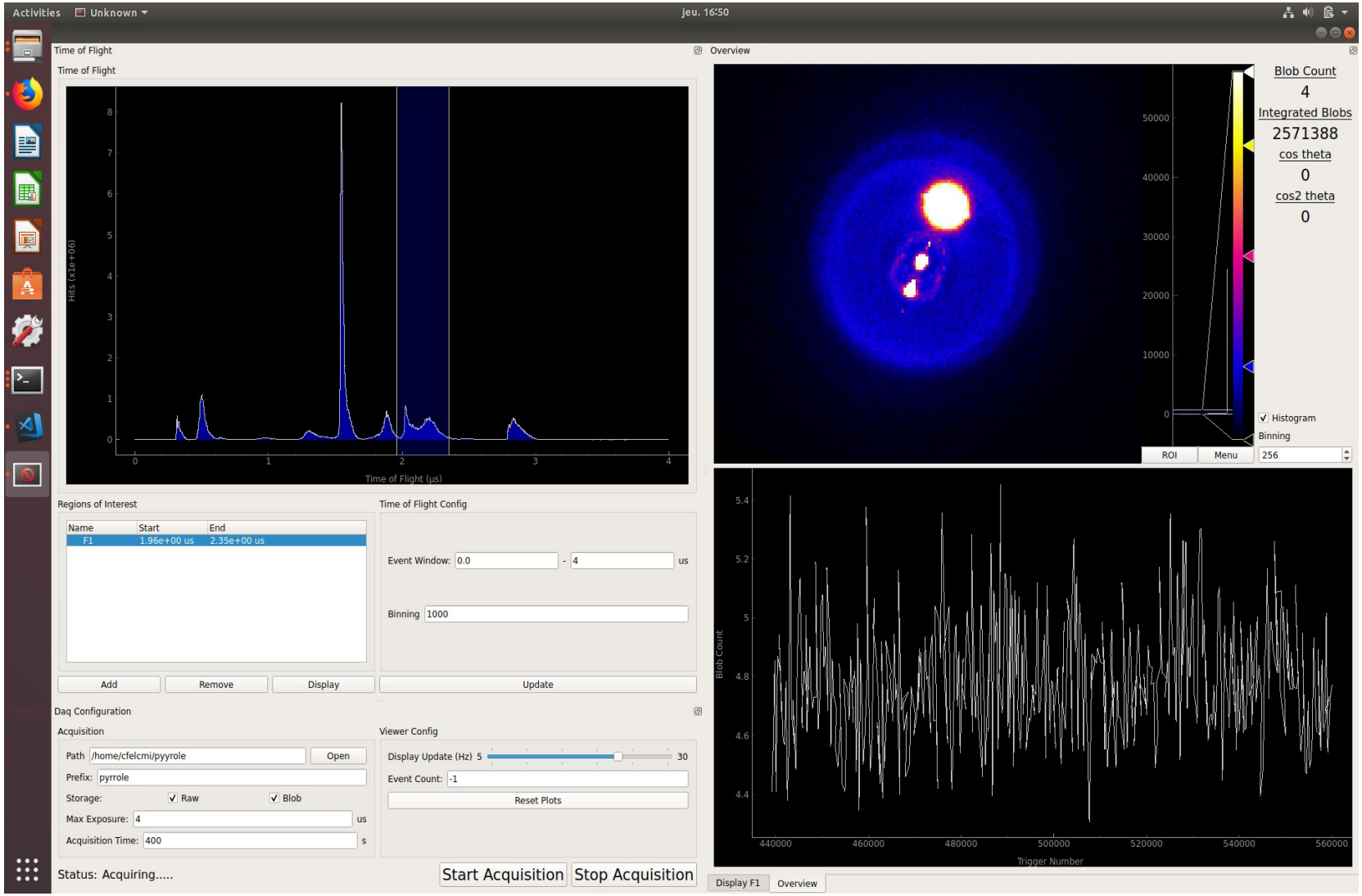


- Bachelor Thesis
  - Use of Zynqs Ultrascale+
  - Development of in-house know-how.



Timepix3

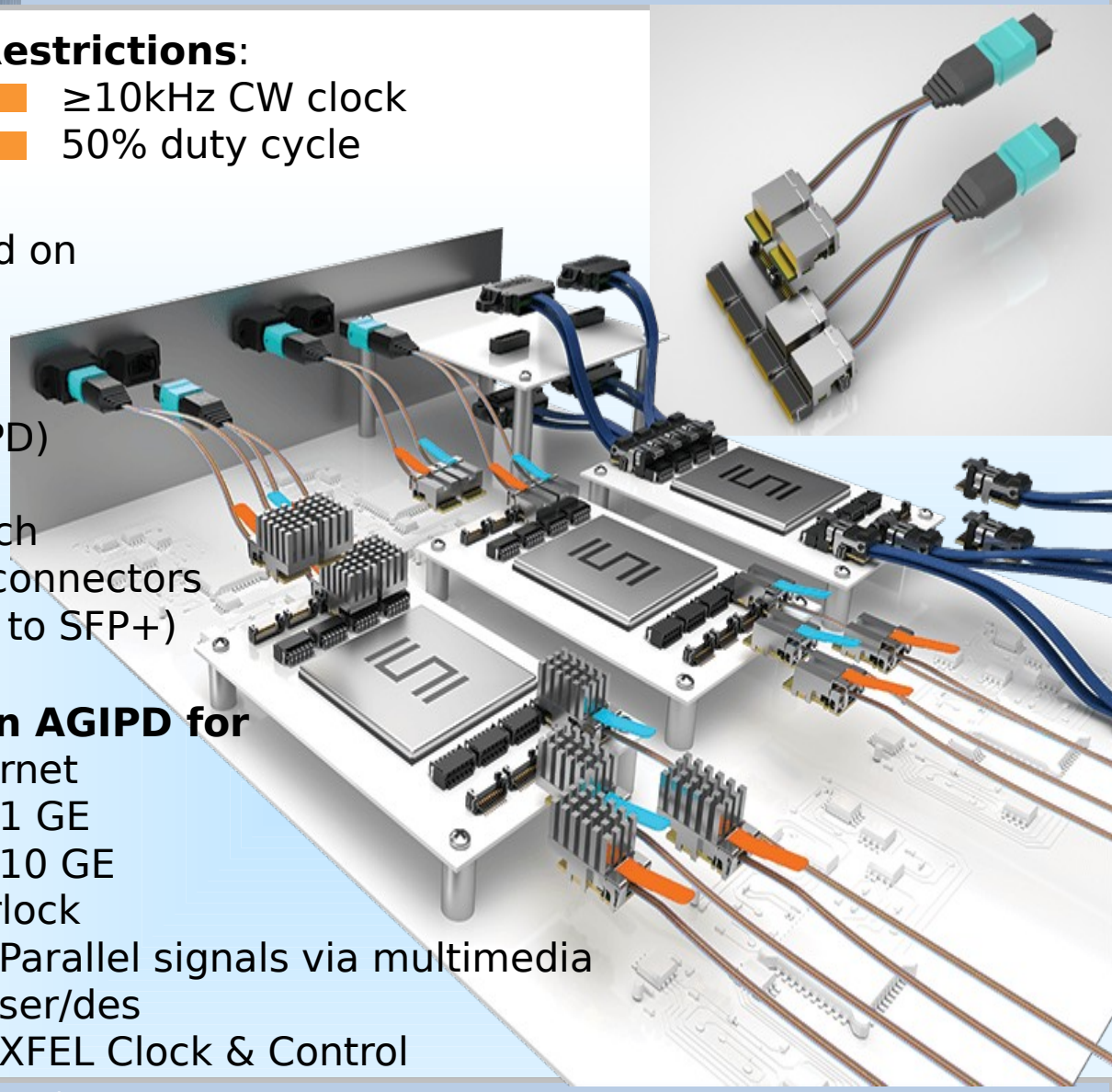
Python Library developed at DESY (Ahmed Al-Refaie, CFEL-CMI)

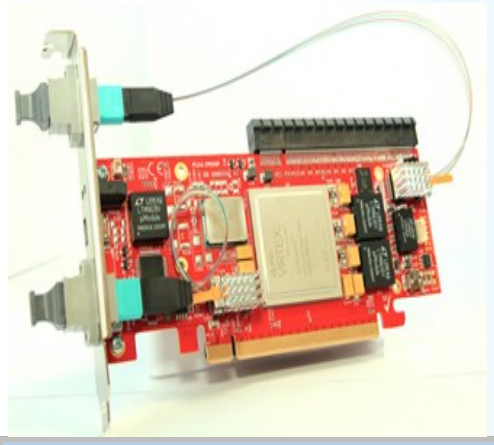


FireFly Optical Data Transmission

- Footprint: 2 cm ╳ 2 cm
- 3 Flavours
  - 12 ch TX
  - 12 ch RX
  - 4 ch RX + 4 ch TX (used on AGIPD)
- Speed
  - 10 Gb/ch
  - 14 Gb/ch (used on AGIPD)
  - 28 Gb/ch (available)
  - Plans for up to 128 Gb/ch
- Adapts to commercial MPT connectors
- Individual splice cables (e.g to SFP+)

- **Restrictions**:
  - ≥10kHz CW clock
  - 50% duty cycle

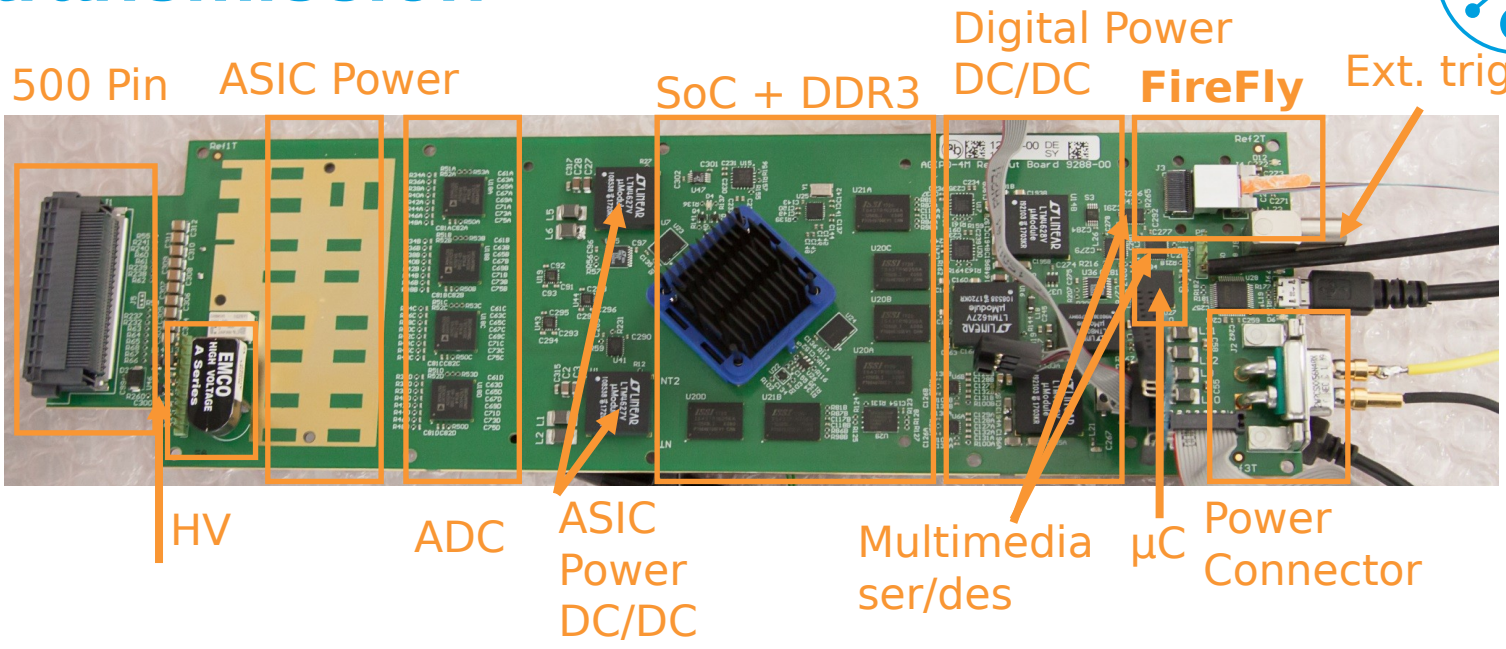




Used on AGIPD for

- Ethernet
  - 1 GE
  - 10 GE
- Interlock
  - Parallel signals via multimedia ser/des
  - XFEL Clock & Control

Data transmission



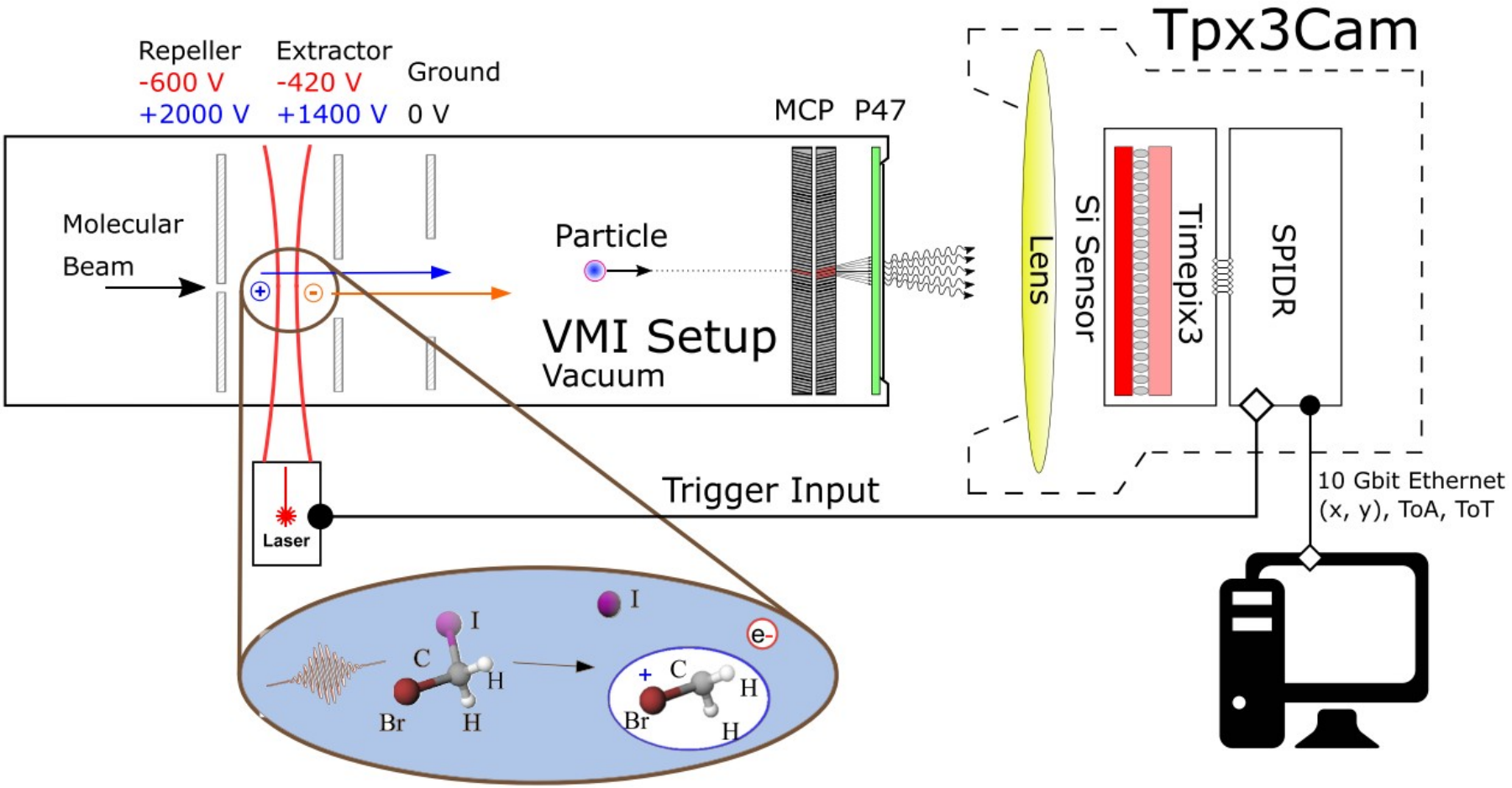
- Main challenges remain ‘before’ and ‘after’ the optical links:
  - RF-PCB design
  - Bandwidth of DAQ system
  - Real time visualisation

Outlook

- Several scientific cases identified
  - Ion imaging at FELs
- Timepix3 is a major player
  - It can reach 1.56 ns time resolution.
  - Limitations have been found for some applications
- Timepix4 is coming up
  - First chips in hand by the end of the year
  - Knowledge in house but several challenges remain open

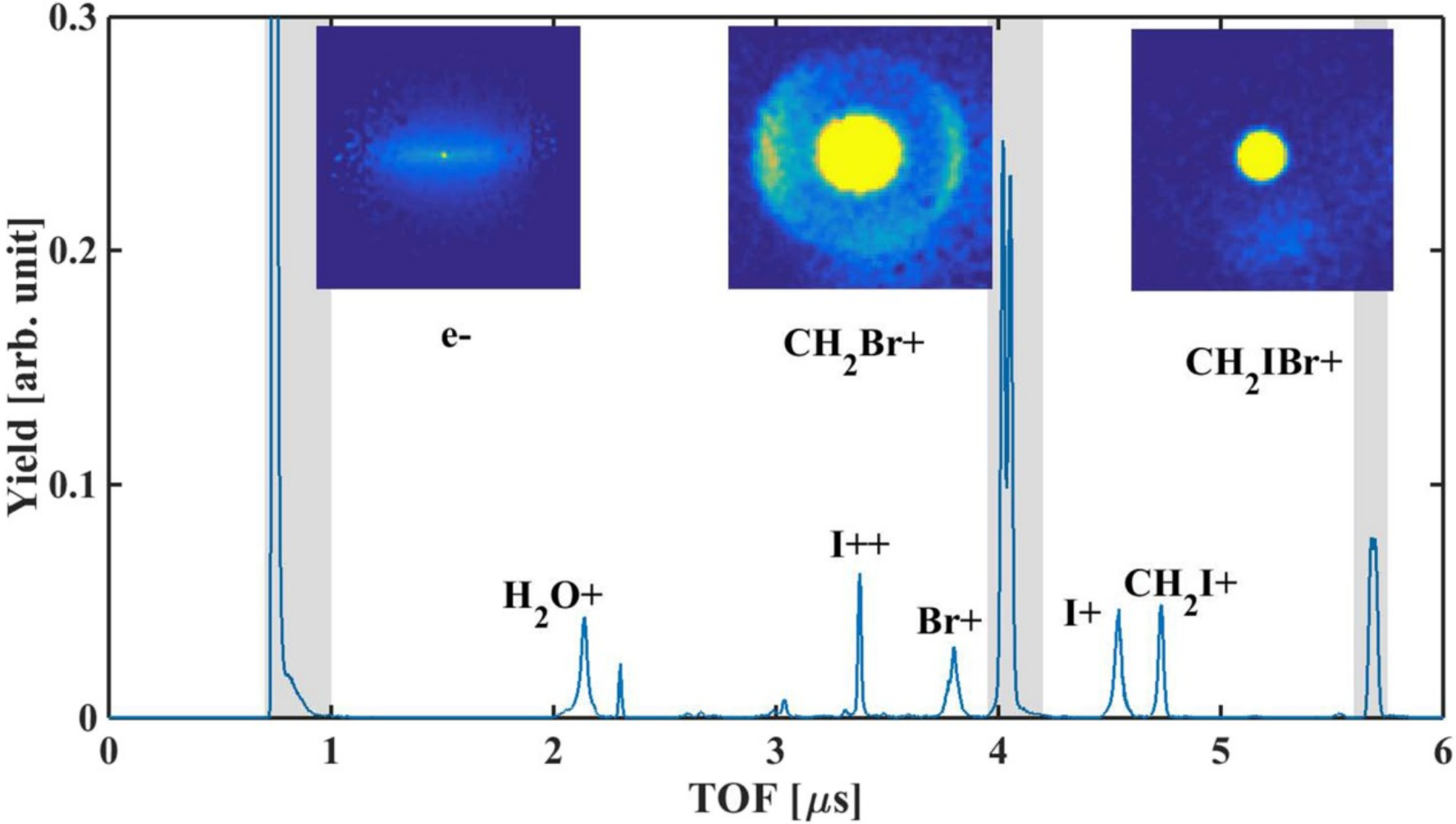
Backup

Ion Imaging



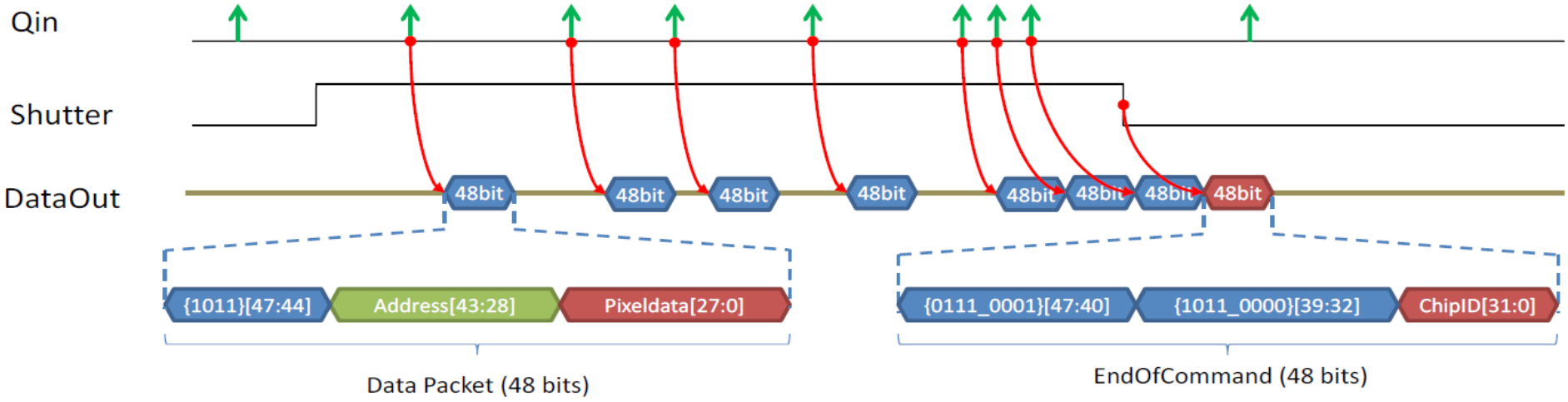
Backup

Ion Imaging



Backup

Readout System developed at DESY (Fabian Borstel, CFEL-FSDS)



Structure of a data package:

- 4-bit header, indicates the start and package type.
- 16-bit address, indicates the location of each of the 65536 pixels.
- 28-bit data payload, which depending on the operation mode, contains information on ToA, ToT, the number of hits or a combination of those.