

# Event Driven Readout

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DESY – FS-DS

**HELMHOLTZ** RESEARCH FOR  
GRAND CHALLENGES

**DESY.**

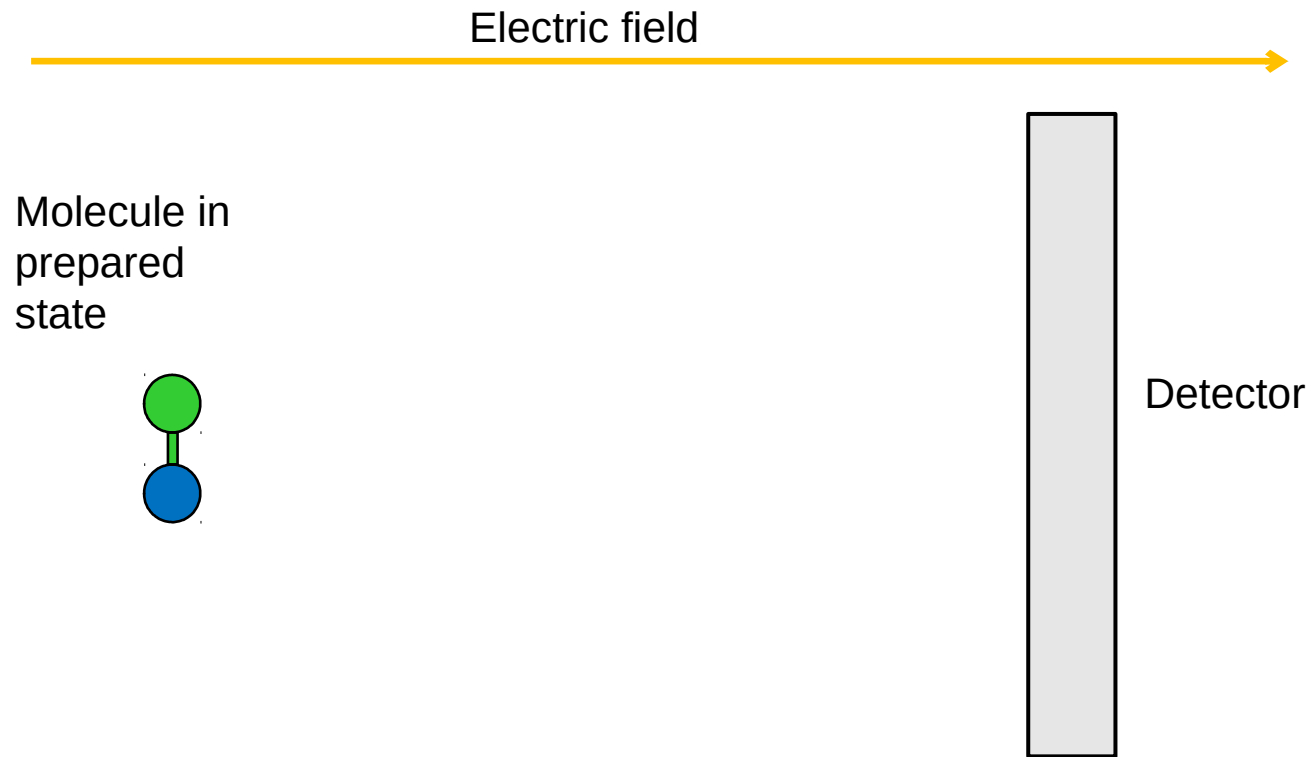


# Outline

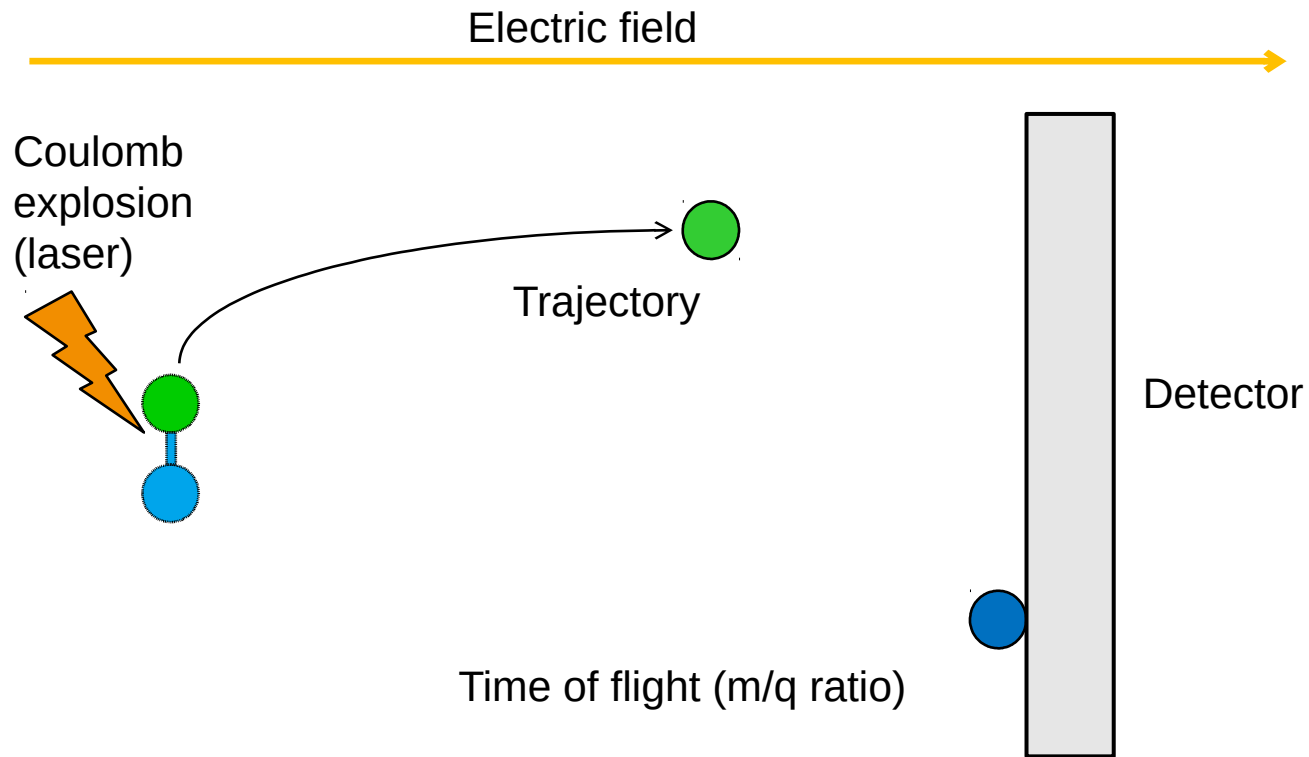


- Scientific Motivation
- Frame Driven vs. Event Driven
- Challenges
- Outlook

## Scientific Case: Ion Detection @ CFEL-CMI



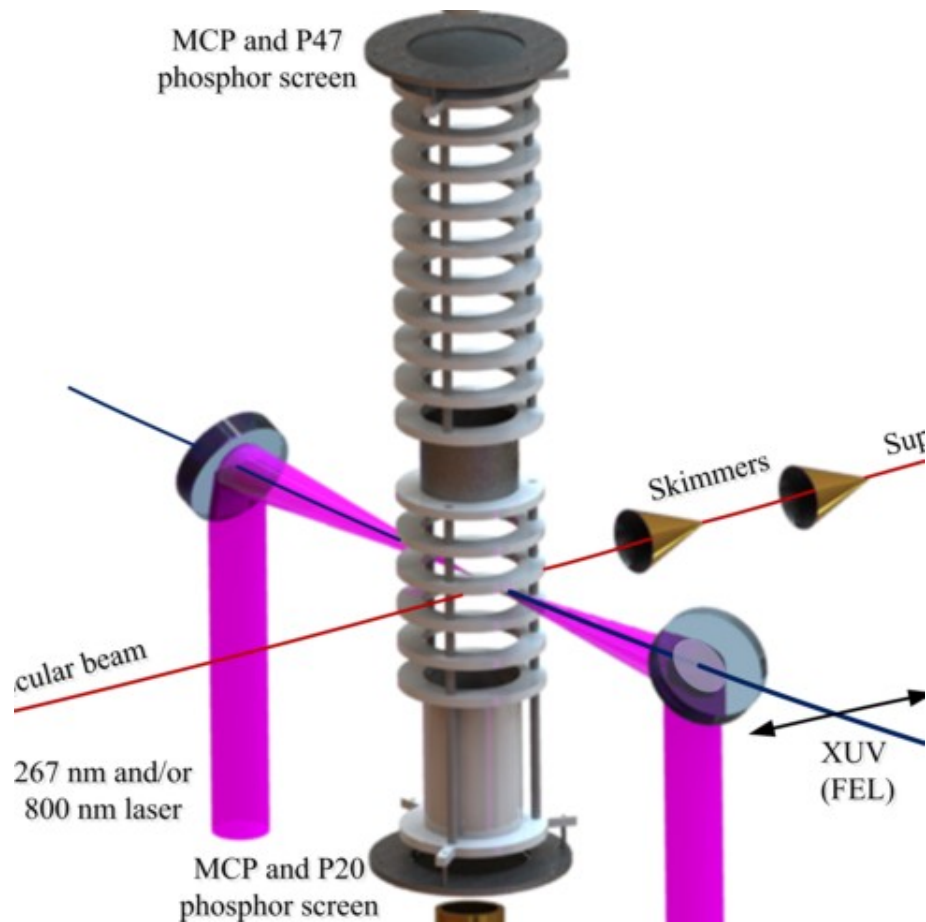
## Scientific Case: Ion Detection @ CFEL-CMI



# Timepix3

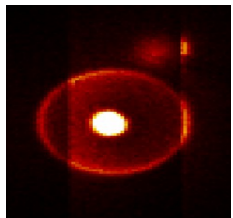
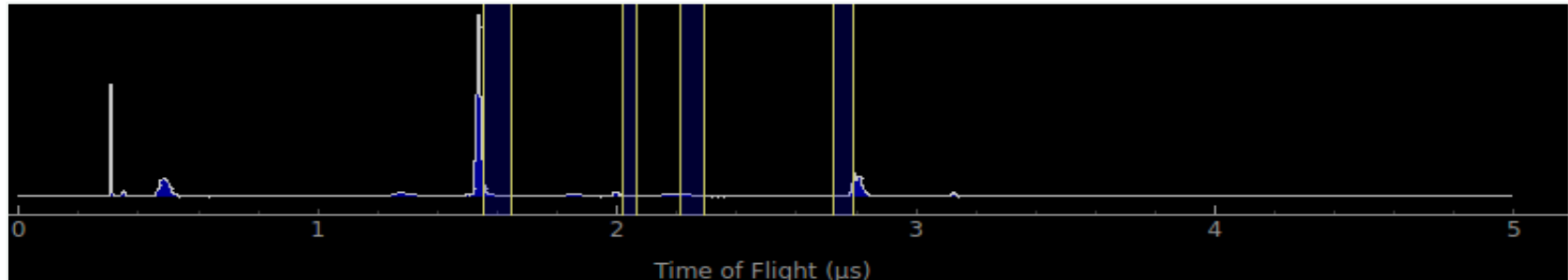


## Scientific Case: Ion Detection @ CFEL-CMI

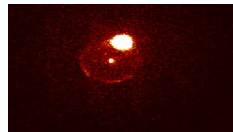


- High time resolution
- Several Mhits/cm<sup>2</sup>/s
- Vacuum preferred

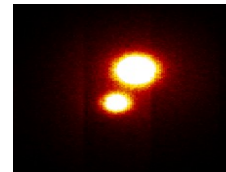
## Scientific Case: Ion Detection @ CFEL-CMI



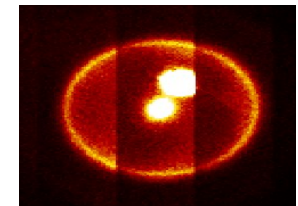
(Pyrrole-  $\text{H}^+$ )



(Pyrrole) $^{2+}$



( $\text{C}_3\text{H}_3$ ) $^+$

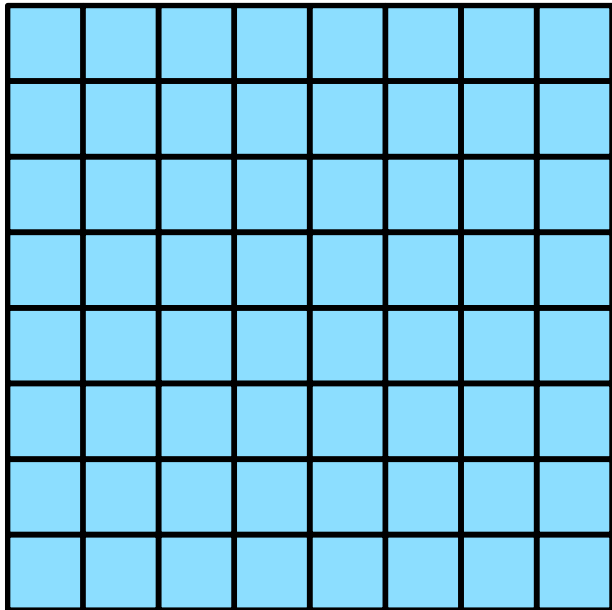


( $\text{H}_3\text{O}_3$ ) $^+$

Investigating the fragmentation processes of singly hydrogen bonded systems via **Photo-Ion-Photo-Ion Coincidences (PIPICO)** Imaging

# Frame Driven Readout

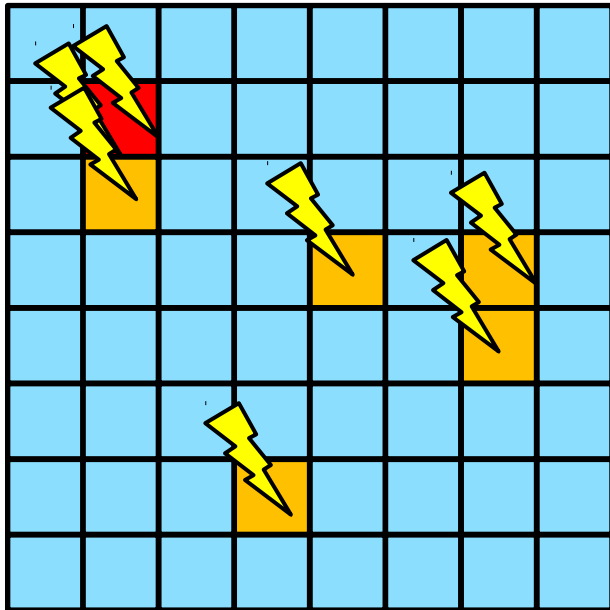
How does it work?



**Detector**

# Frame Driven Readout

## Image Acquisition

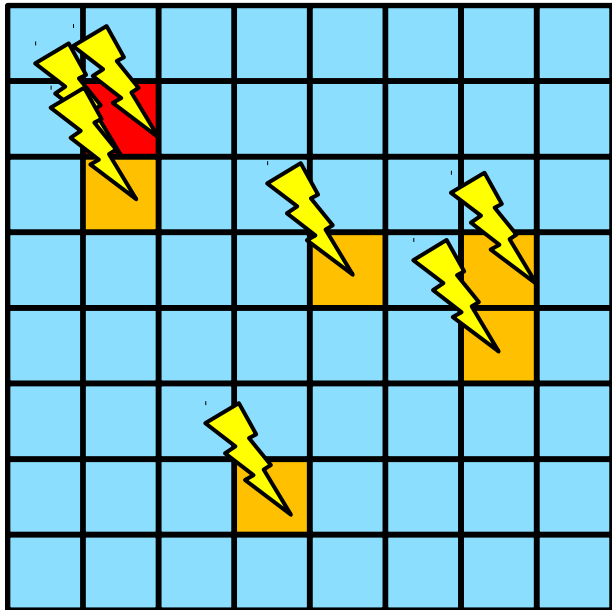


**Detector**

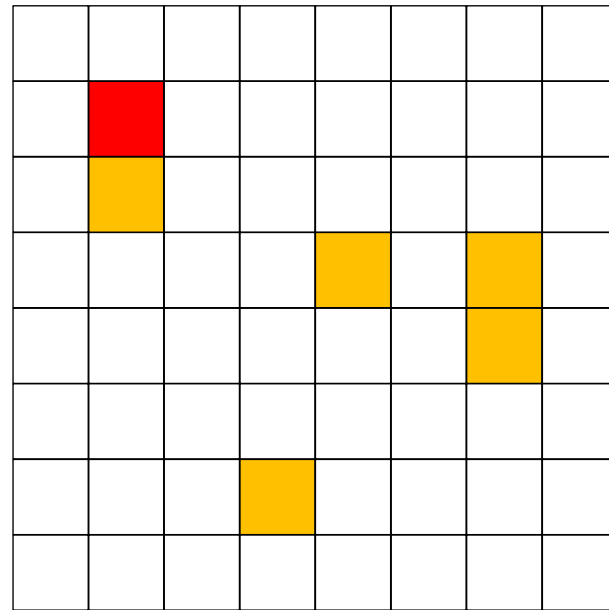


# Frame Driven Readout

## Image Readout

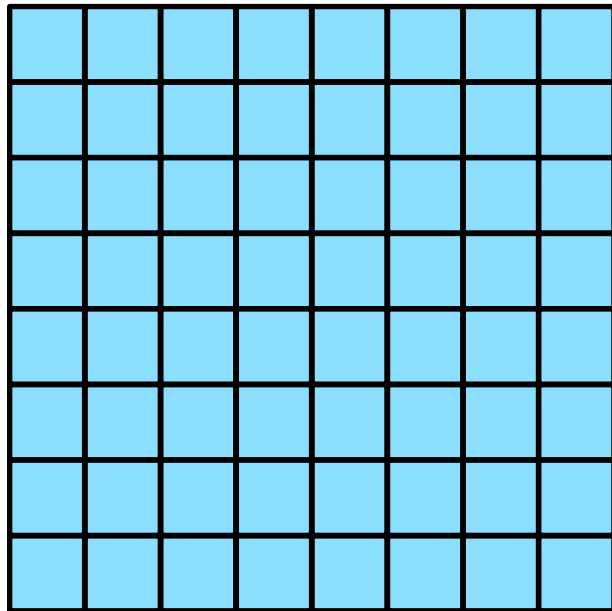


**Detector**

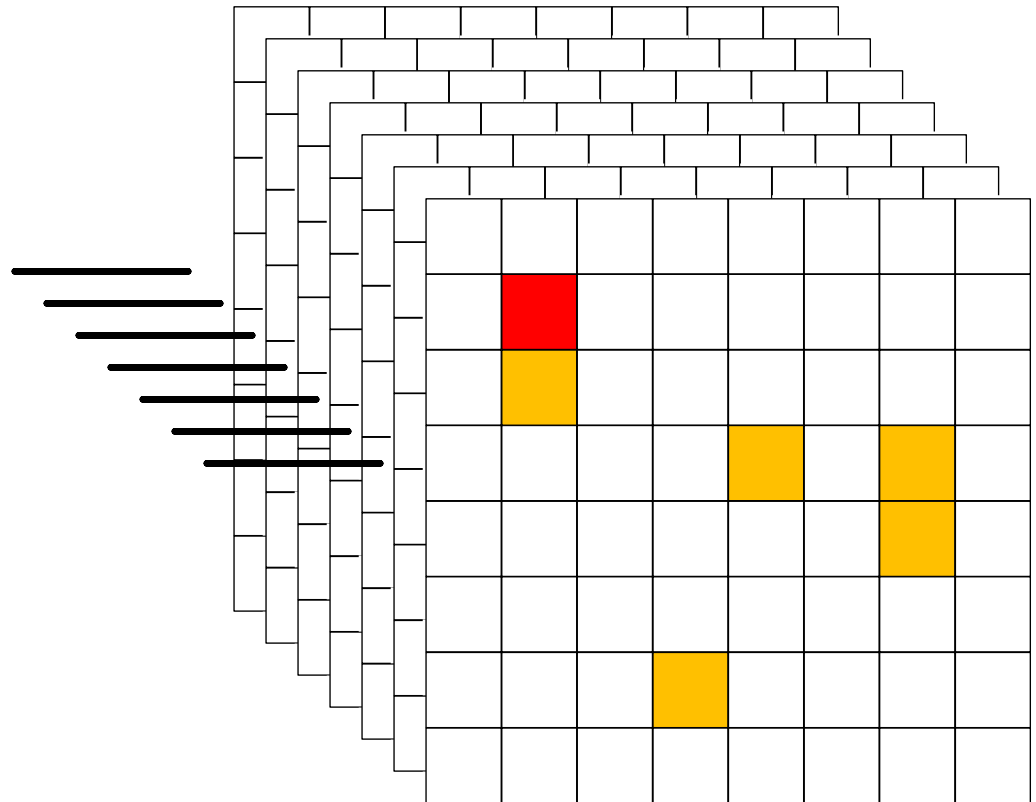


# Frame Driven Readout

## Image Readout

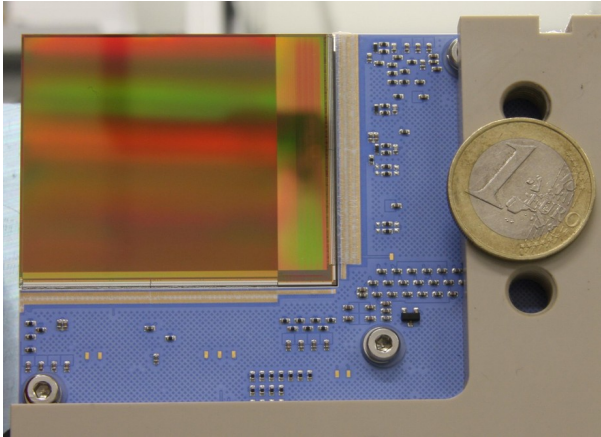


**Detector**

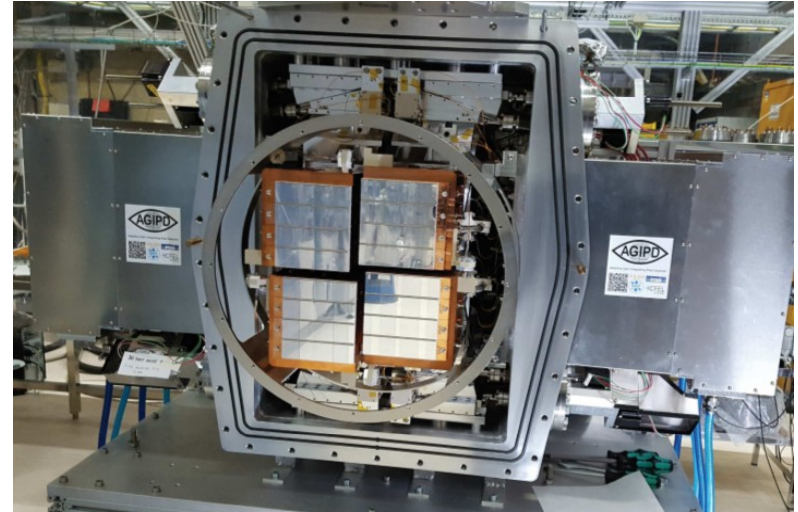


# Frame Driven Readout

Examples developed by the FS-DS



PERCIVAL: CMOS Detector for Soft X-rays



AGIPD: Integrating Detector for the XFEL.eu



LAMBDA: Photon Counting Detector

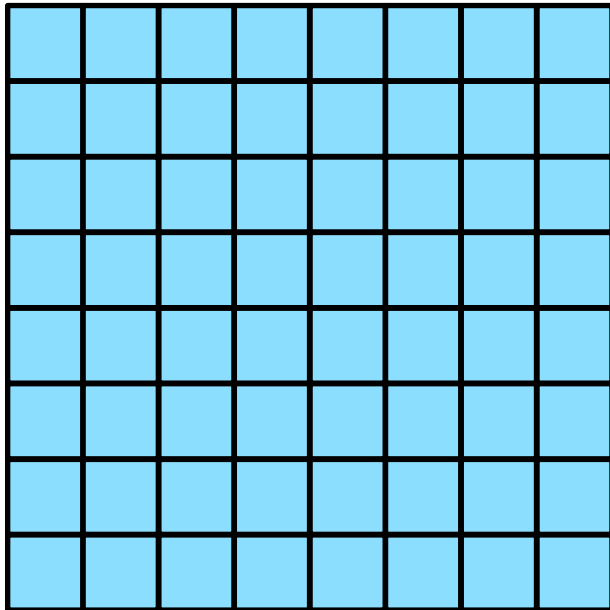
# Frame Driven Readout

## 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

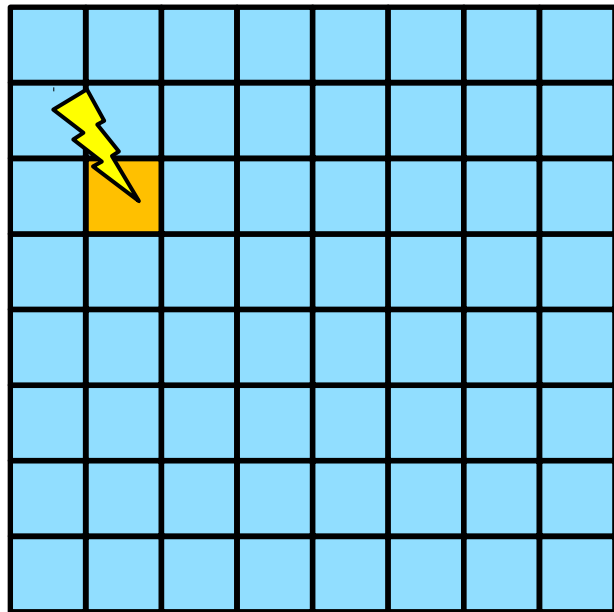
How does it work?



**Detector**

# Frame Driven Readout

Continuous readout of hits



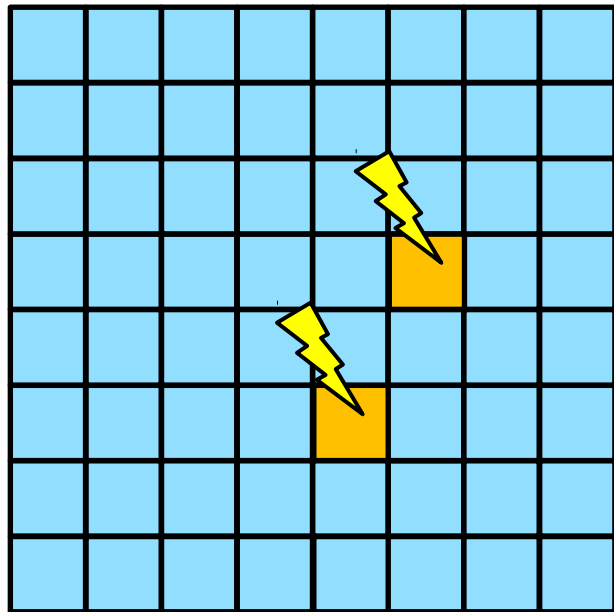
**Detector**

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  $\sim$  1 Gigabyte/s
- Advantageous at moderate hit rates
  - $\sim$  1.56 ns time resolution with Timepix3
  - Energy discrimination
  - Potential sub-pixel position resolution (signal sharing)



# Timepix3

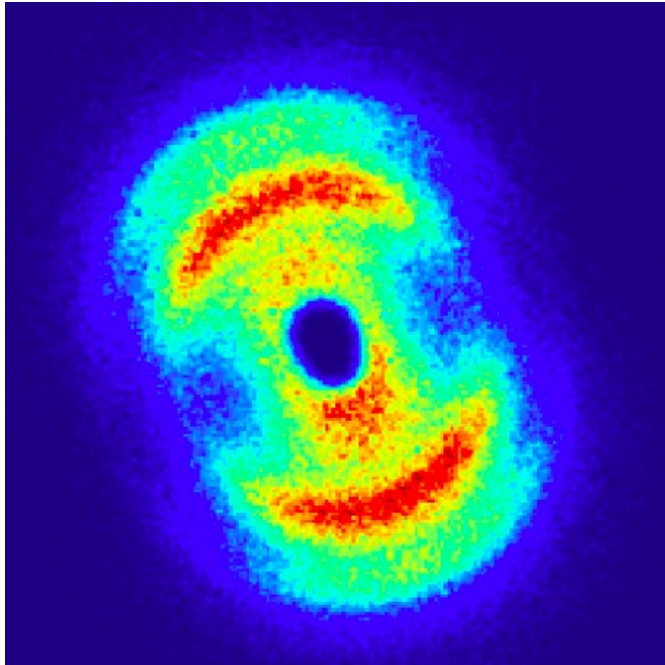
## Specifications



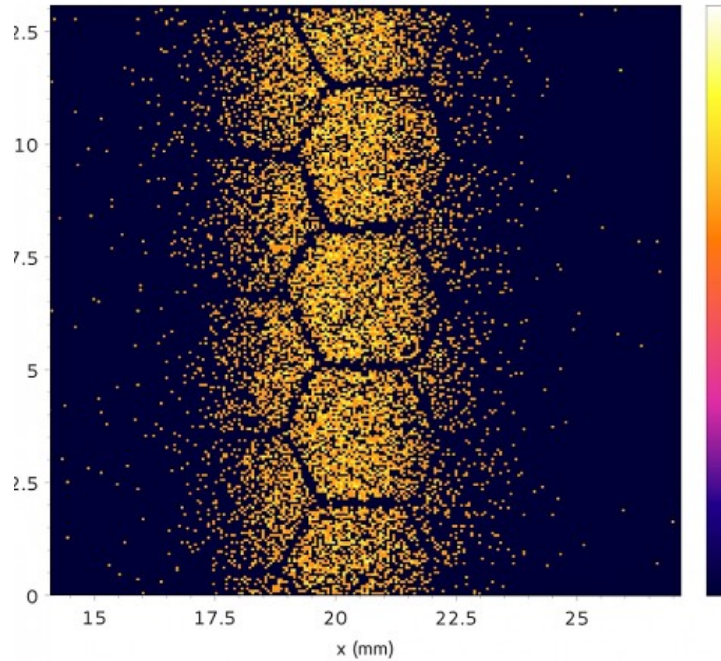
			<b>Timepix3 (2013)</b>
<b>Technology</b>			IBM 130nm – 8 metal
<b>Pixel Size</b>			55 x 55 $\mu\text{m}$
<b>Pixel arrangement</b>			3-side buttable 256 x 256
<b>Sensitive area</b>			1.98 $\text{cm}^2$
<b>Readout Modes</b>	Data driven (Tracking)	Mode	TOT and TOA
		Event Packet	48-bit
		Max rate	< 43 Mhits/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

# Timepix3

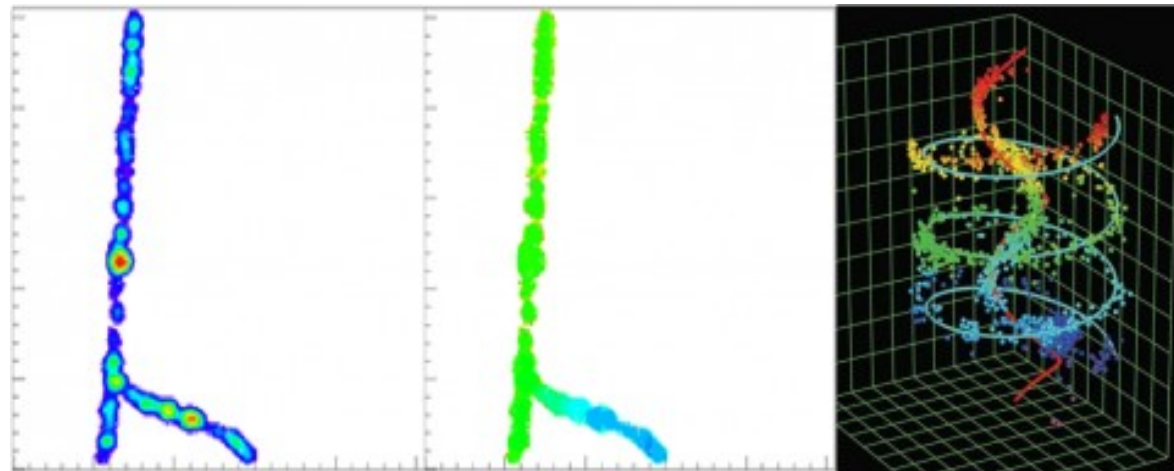
## Applications



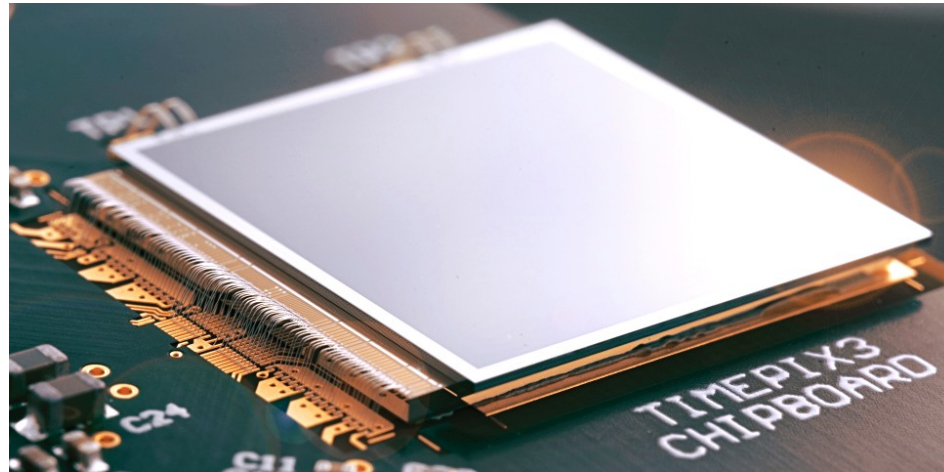
Ion imaging



Beam Gas Ionisation (BGI) for monitoring



3D charge particle tracking



- 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)
  - $\sim 200,000$  hits/pixel/s
  - Can speed up to 0.5 us in time only mode (poorer time resolution)

# Timepix4

## Specifications

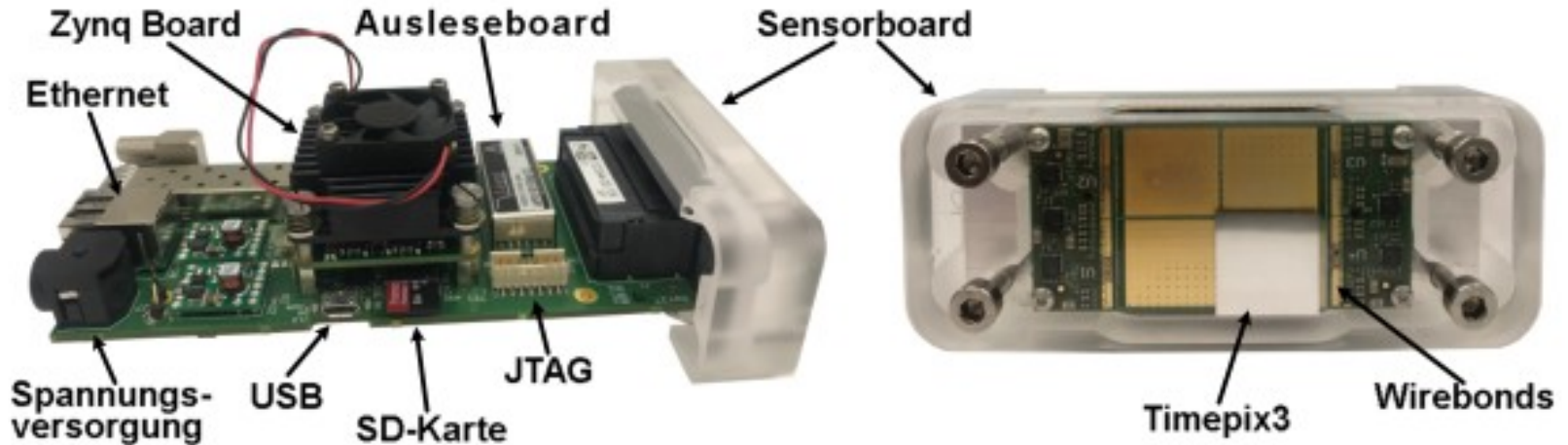


			Timepix3 (2013)	Timepix4 (2018/19)	
<b>Technology</b>			IBM 130nm – 8 metal	TSMC 65nm – 10 metal	
<b>Pixel Size</b>			55 x 55 $\mu\text{m}$	55 x 55 $\mu\text{m}$	
<b>Pixel arrangement</b>			3-side buttable 256 x 256	4-side buttable 512 x 448 <b>3.5x</b>	
<b>Sensitive area</b>			1.98 $\text{cm}^2$	6.94 $\text{cm}^2$	
<b>Readout Modes</b>	Data driven (Tracking)	Mode	TOT and TOA		
		Event Packet	48-bit	64-bit <b>33%</b>	
		Max rate	< 43 Mhits/ $\text{cm}^2/\text{s}$	178.8 Mhits/ $\text{cm}^2/\text{s}$ <b>4x</b>	
	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/ $\text{cm}^2/\text{s}$	~800 Ghits/ $\text{cm}^2/\text{s}$	<b>10x</b>
<b>TOT energy resolution</b>			< 2KeV	< 1Kev <b>2x</b>	
<b>Time resolution</b>			1.56ns	~200ps <b>8x</b>	
<b>Readout bandwidth</b>			$\leq 5.12\text{Gb}$ (8x SLVS@640 Mbps)	$\leq 81.92\text{Gbps}$ (16x @5.12 Gbps)	
<b>Target global minimum threshold</b>			<500 $e^-$	<500 $e^-$	

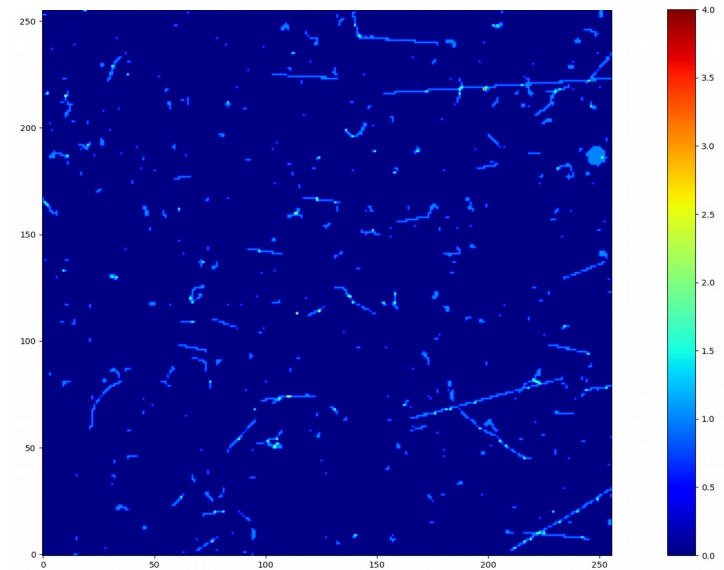
# Timepix3



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



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

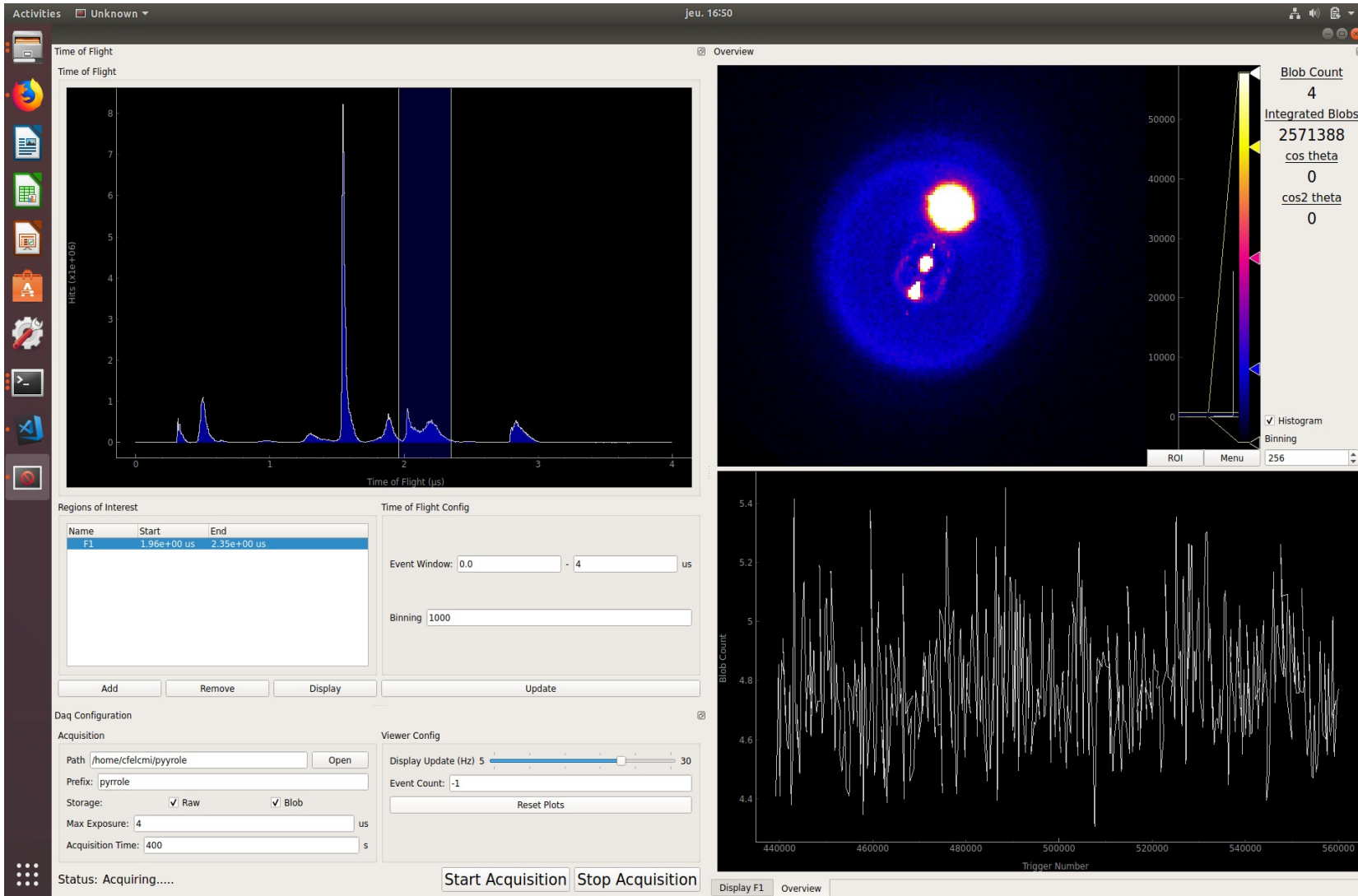




# Timepix3



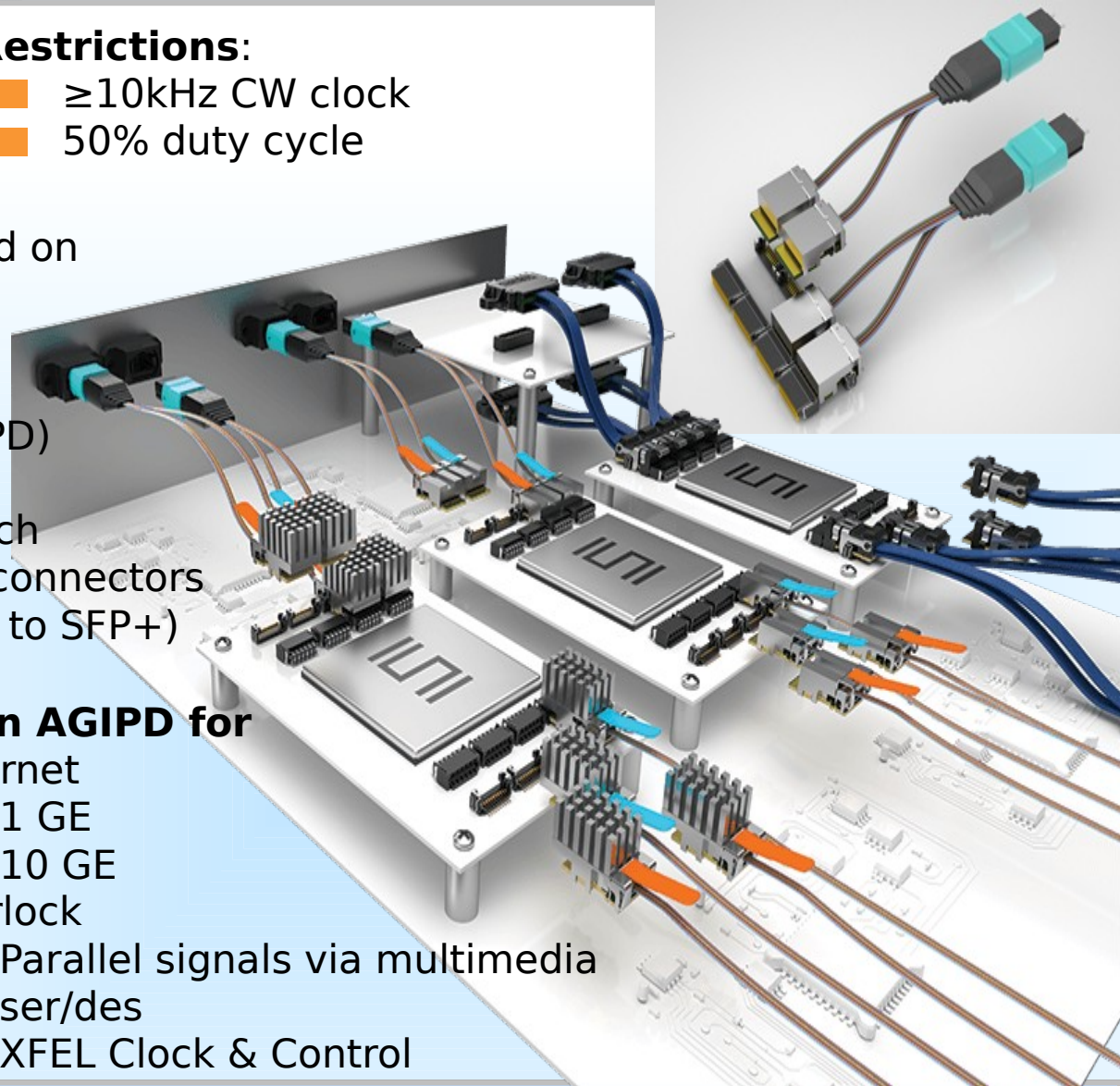
Python Library developed at DESY (Ahmed Al-Refaie, CFEL-CMI)



# FireFly Optical Data Transmission

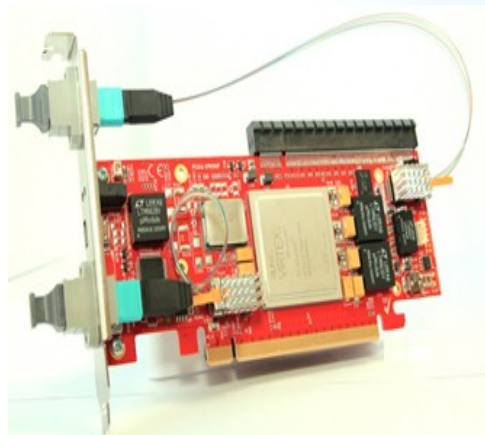


- Footprint: 2 cm X 2 cm
  - 3 Flavours
    - 12 ch TX
    - 12 ch RX
    - 4 ch RX + 4 ch TX (used on AGIPD)
  - Speed
    - 10 Gb/ch
    - 14 Gb/ch (used on AGIPD)
    - 28 Gb/ch (available)
    - Plans for up to 128 Gb/ch
  - Adapts to commercial MPT connectors
  - Individual splice cables (e.g to SFP+)
- Restrictions:**
- $\geq 10\text{kHz}$  CW clock
  - 50% duty cycle

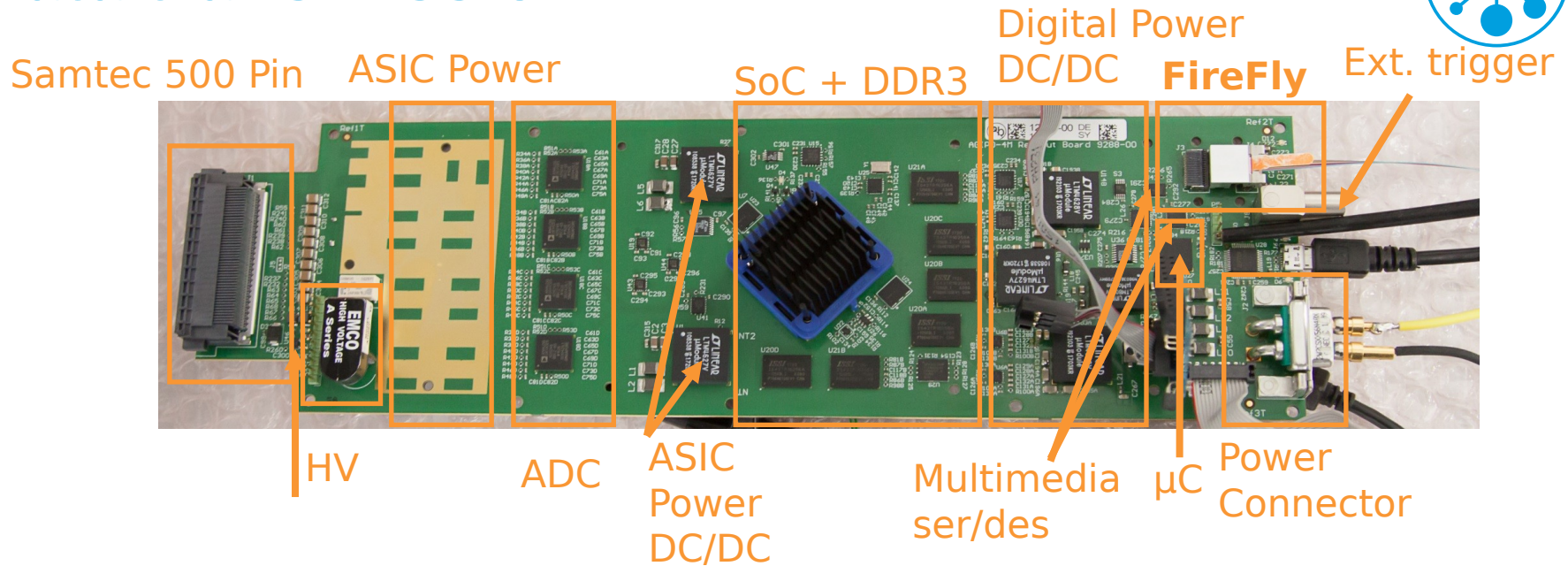


## Used on AGIPD for

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



# Data transmission



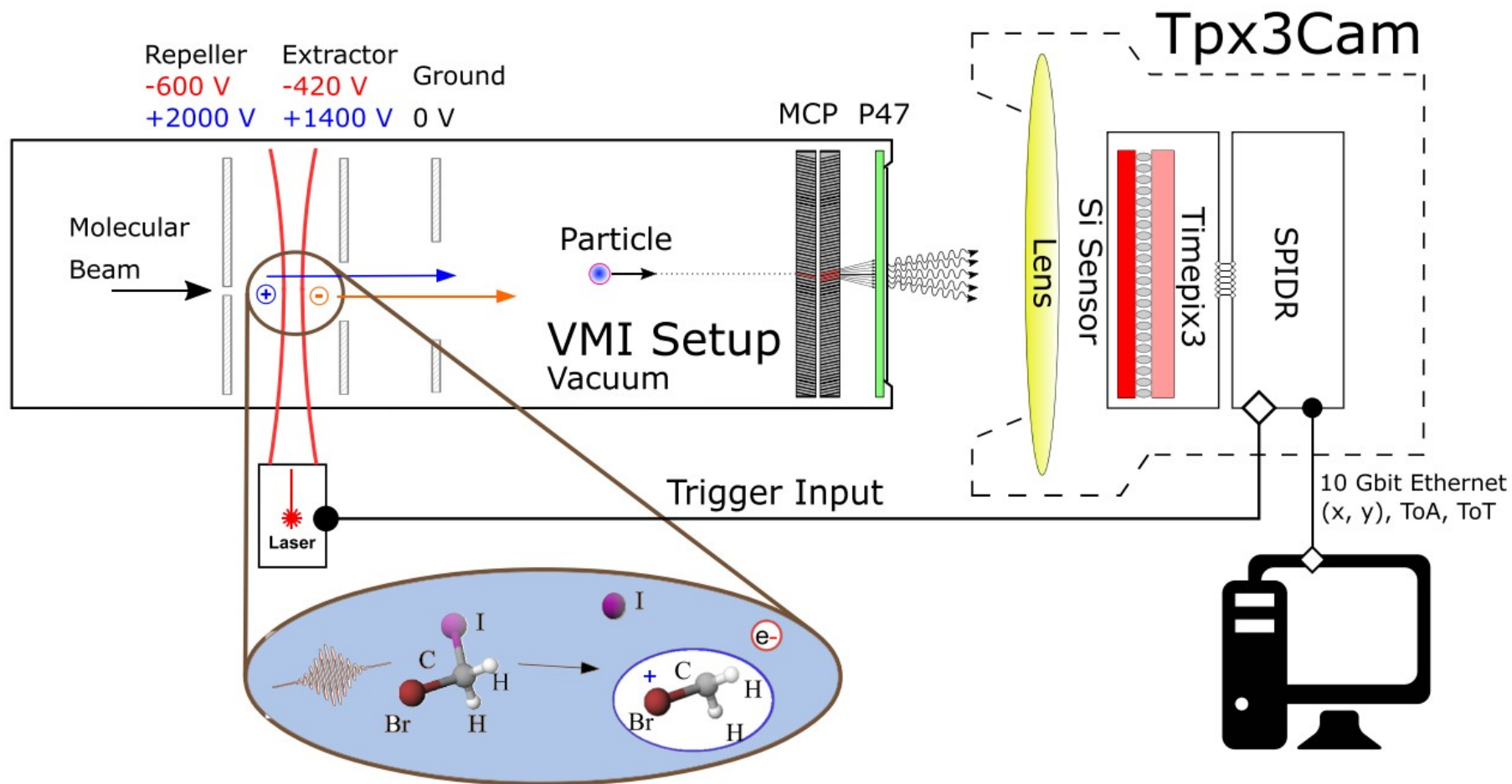
- Main challenges remain ‘before’ and ‘after’ the optical links:
  - RF-PCB design
  - Bandwidth of DAQ system
  - Real time visualisation



- 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

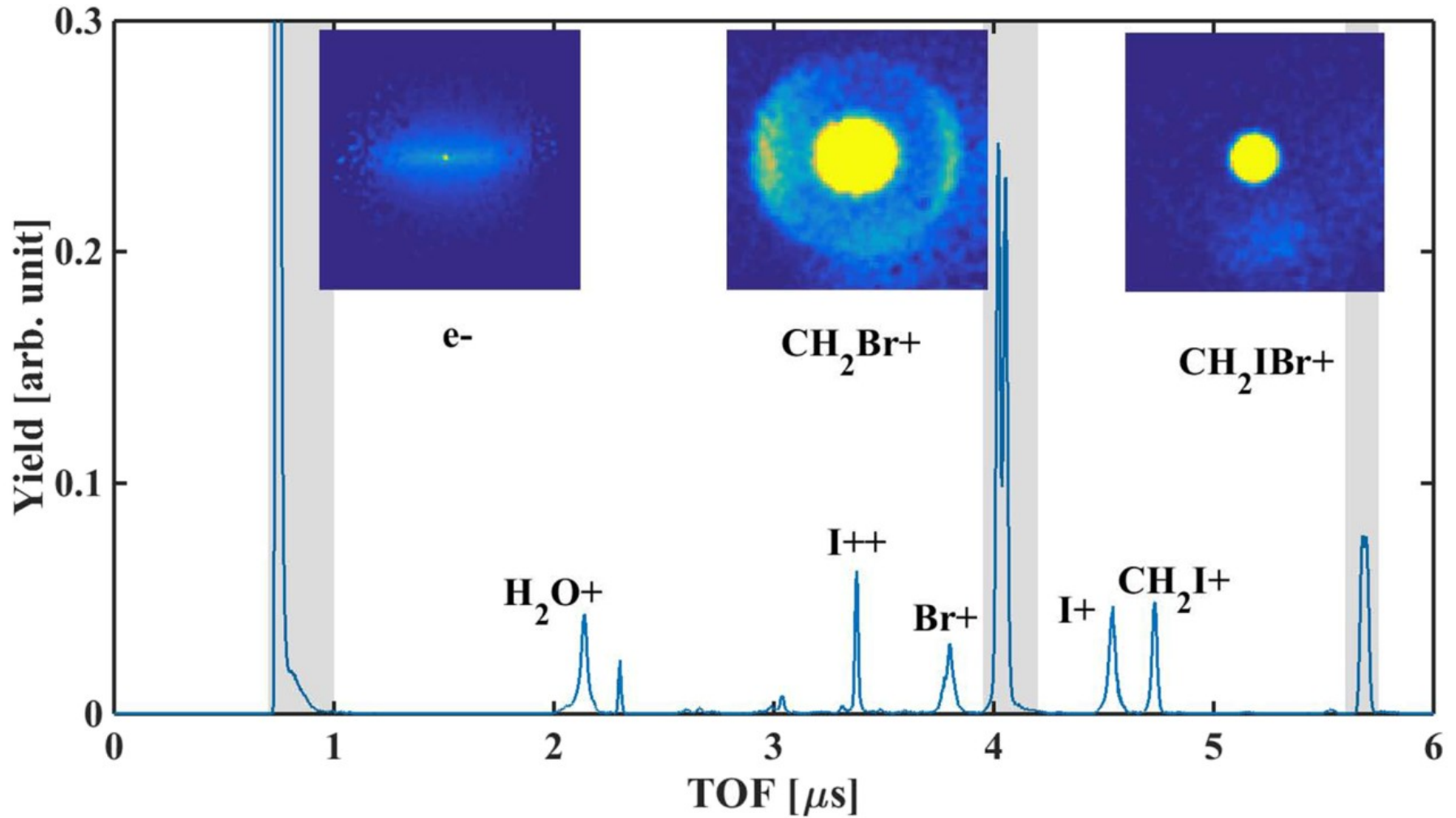
## Ion Imaging



# Backup

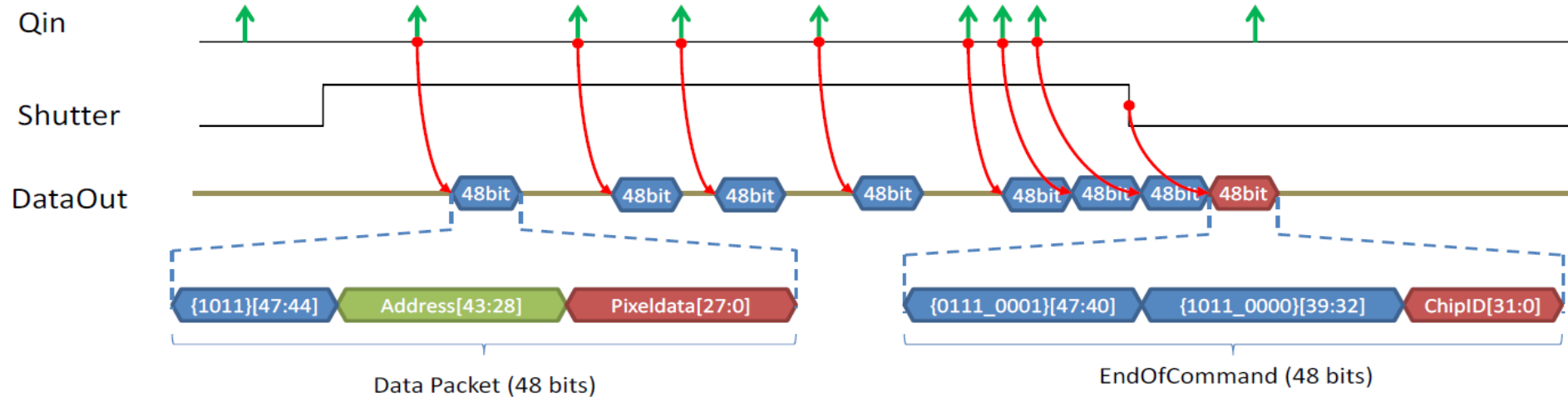


## Ion Imaging



# 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.