Advanced Detectors and Data Pipelines for Next Generation Light Sources

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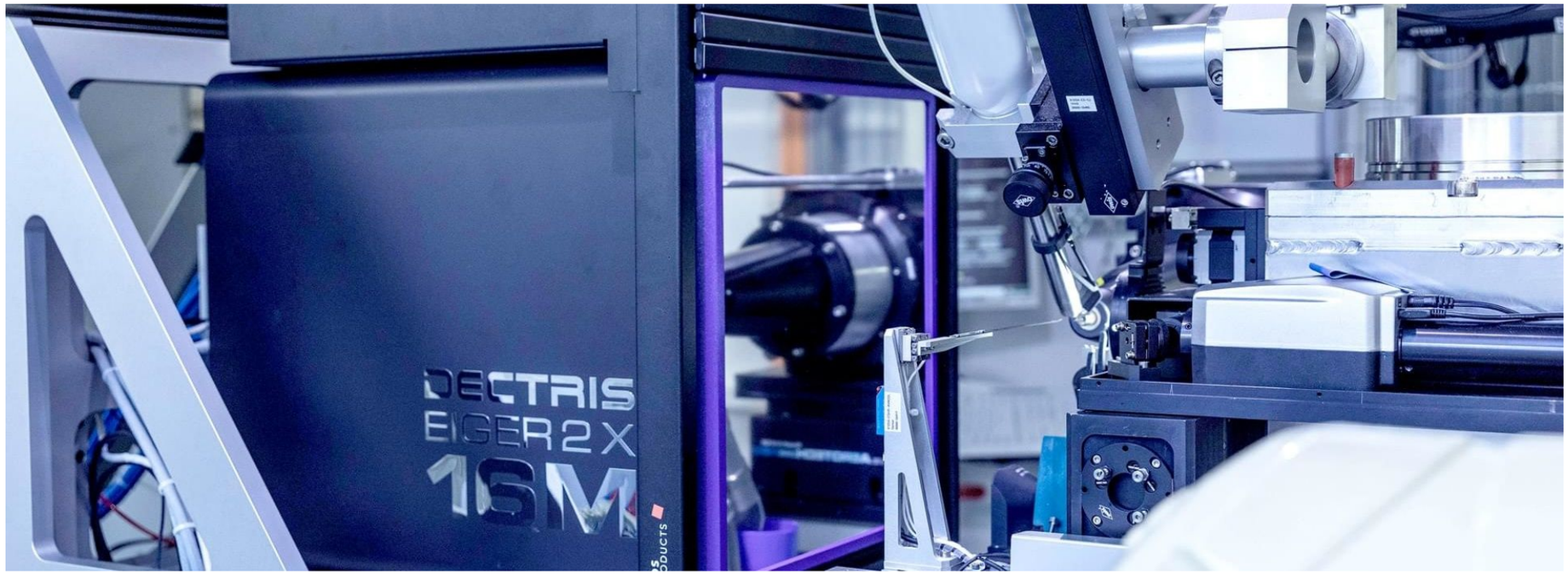
LEAPS INNOV WP7 meeting 8.4.2024

DECTRIS - Detecting the future

Our Purpose

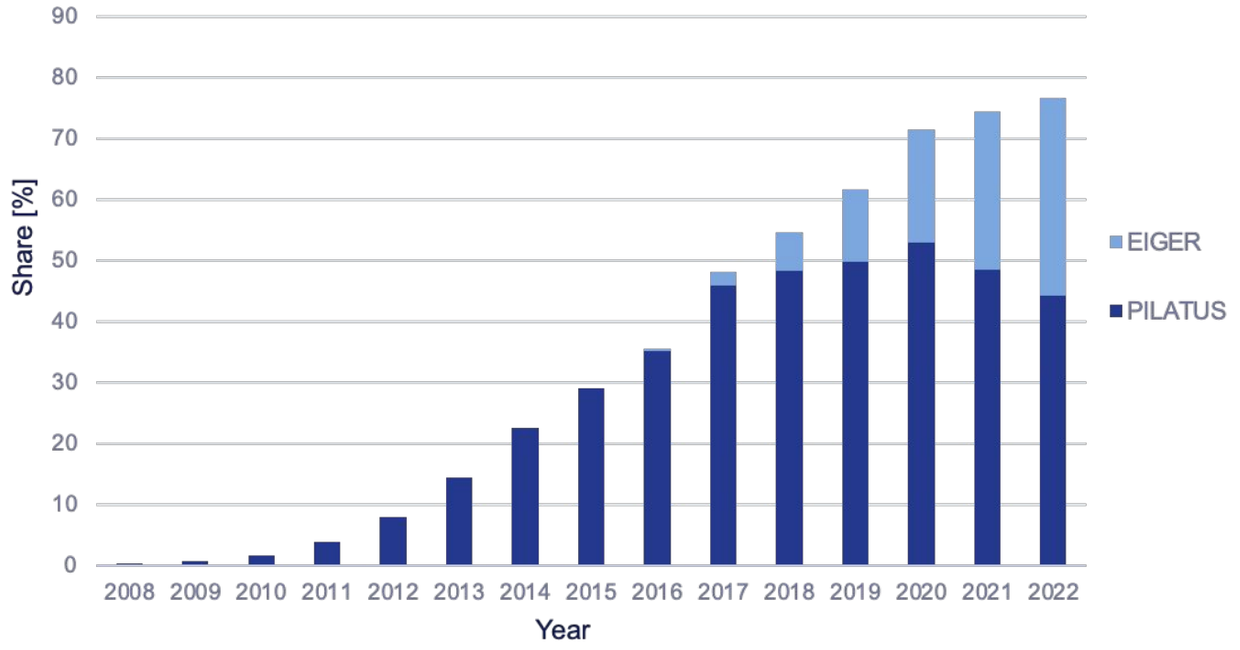
is to serve present and future generations in mastering society’s most important challenges by **enabling scientific and technological breakthroughs**



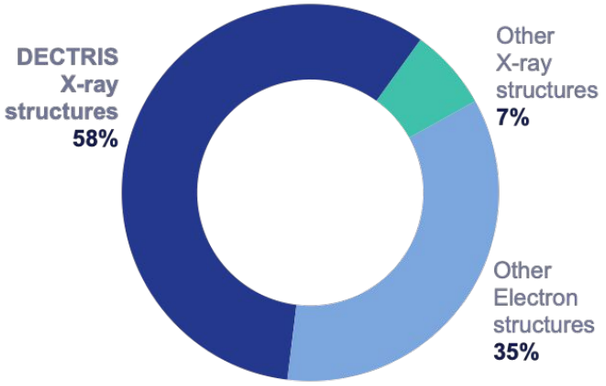
DECTRIS enabling scientific breakthroughs

DECTRIS detectors for Protein Crystallography

Protein Crystallography structures in PDB determined **with DECTRIS detectors**



SARS-COV2 protein **structures** in PDB determined with **DECTRIS Detectors**



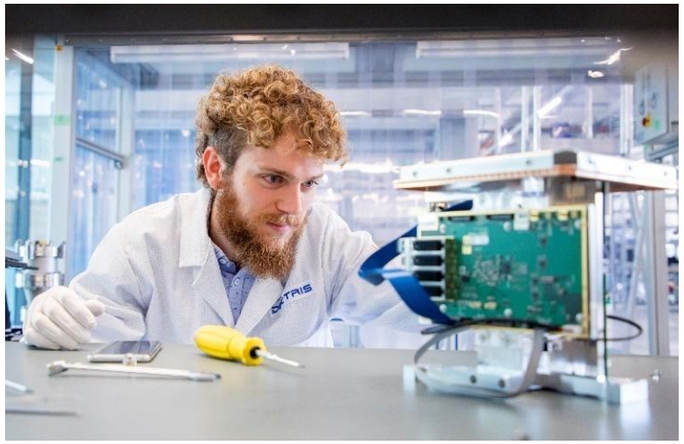
DECTRIS accelerates modern drug development

Made in Switzerland - From R&D to Product

1000 m² Cleanroom

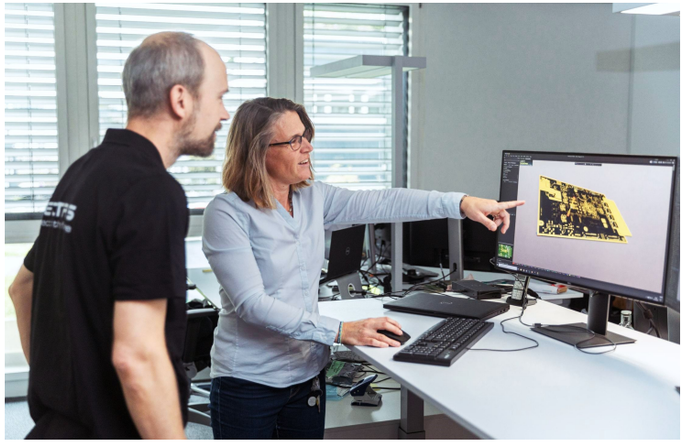
- Photolithography
- Microtechnology & Packaging
- Components assembly and testing

1000 m² Assembly Hall



- System Assembly
- Calibration
- Service, Training & Repair

Research Meets Industry



- Sensor design
- ASIC design
- Firmware development
- Software development
- Hardware development

Large Area Detectors for Synchrotron

EIGER2

75 um pixels

450 um Si sensors, 750 um CdTe sensor

2 thresholds

500k to 16M pixels

700 Hz - 4.5 kHz frame rates (XE)

98 kHz lines ROI

PILATUS4

150 um pixels

450 um Si sensors, 1000 um CdTe sensor

4 thresholds

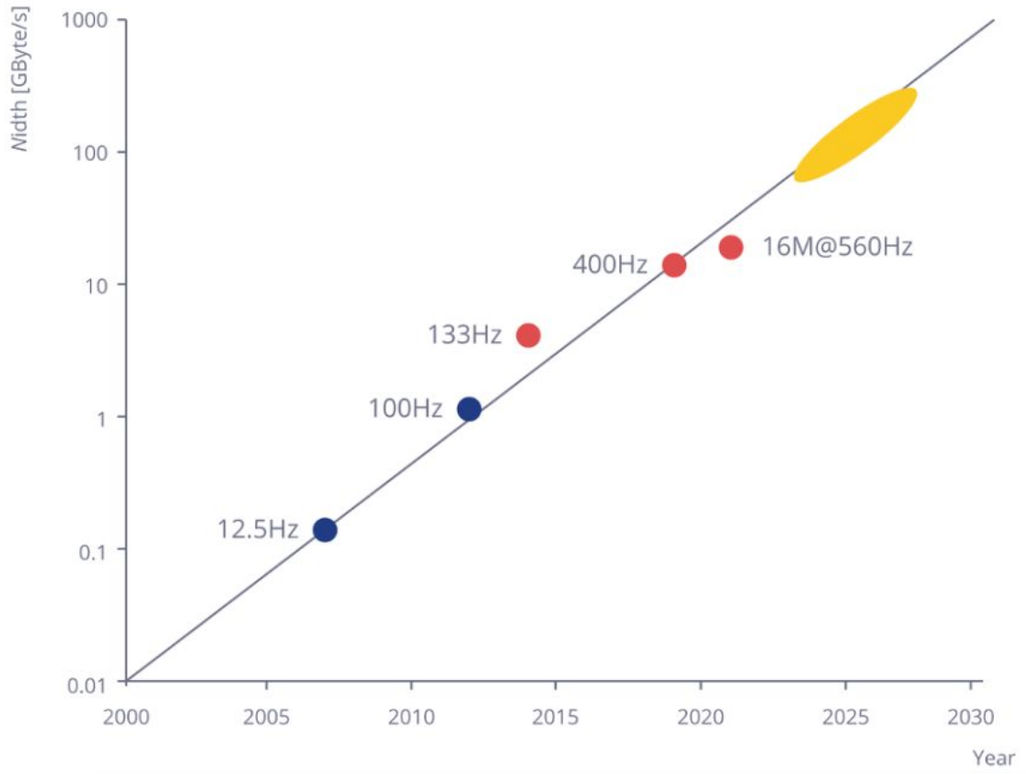
1M - 4M pixels

4.5 kHz frame rate (XE)

Evolution of Data Rates

PILATUS

2007: 0.14 Gbyte/s of Raw Data



Prototype detectors in development (Jungfrau, Citius,)

EIGER2/PILATUS4

2022: 18 Gbyte/s of Raw Data

Moore's Law for X-Ray detectors

Advancing Detector & Pipeline Design

More than just one element

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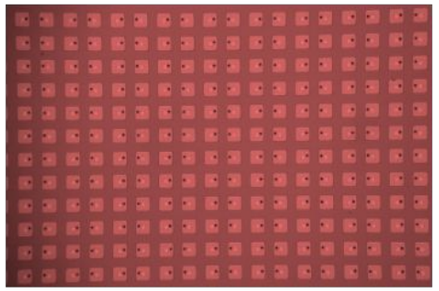
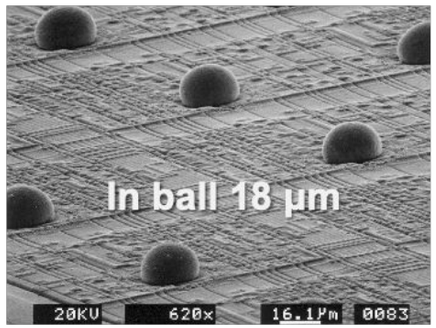
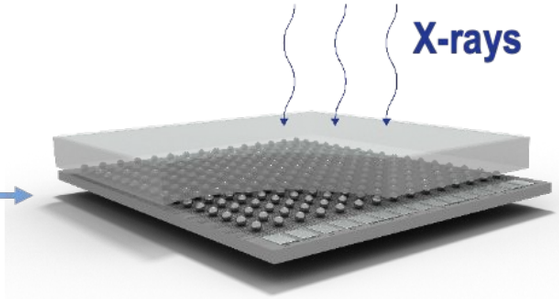
Hybrid photon counting (HPC)

Sensor
Si and CdTe

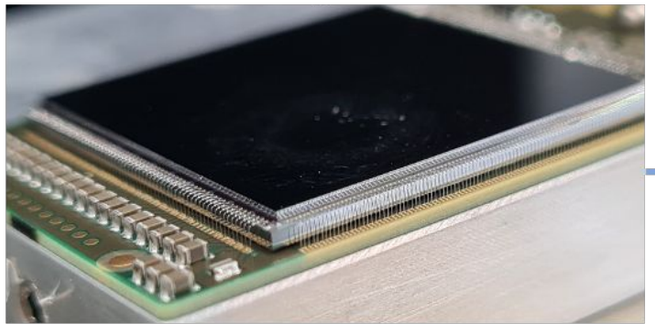


CMOS Readout Chip





Ball-Bonding



Wire Bonding

Module / Electronics

Detector Control Unit

Detector

Detectors and Pipelines

Detector Head
e.g. EIGER2 XE 16M

160 Gbit/s

Detector Control Unit (DCU)

Data Interfaces

STREAM2
ZMQ: high BW, low latency

FILEWRITER
h5: high BW, medium latency

MONITOR
TIFF: low BW, medium latency

- Readout of Pixel Data
  (8 or 16 Bit UINT)
- Send/Route data to DCU

- Assembling images
- Applying corrections
- Adding image Metadata
- Compression of images
- Packaging into .h5

- Application specific processing

Data flow

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What is all data reduction?

Detector Control Unit (DCU)

Auto-Summation

- High count rates require summing up of images
- e.g.: counting 1E7 ph/s/pix with 16 Bit requires >150 Hz

e.g.: EIGER2: internal summation & correction of images

Threshold Difference Mode

- Output subtracted threshold images
- 1 instead of 2 images per exposure

Compression

- BSLZ4 compression on assembled images per default
- Compression ratios: 5-100

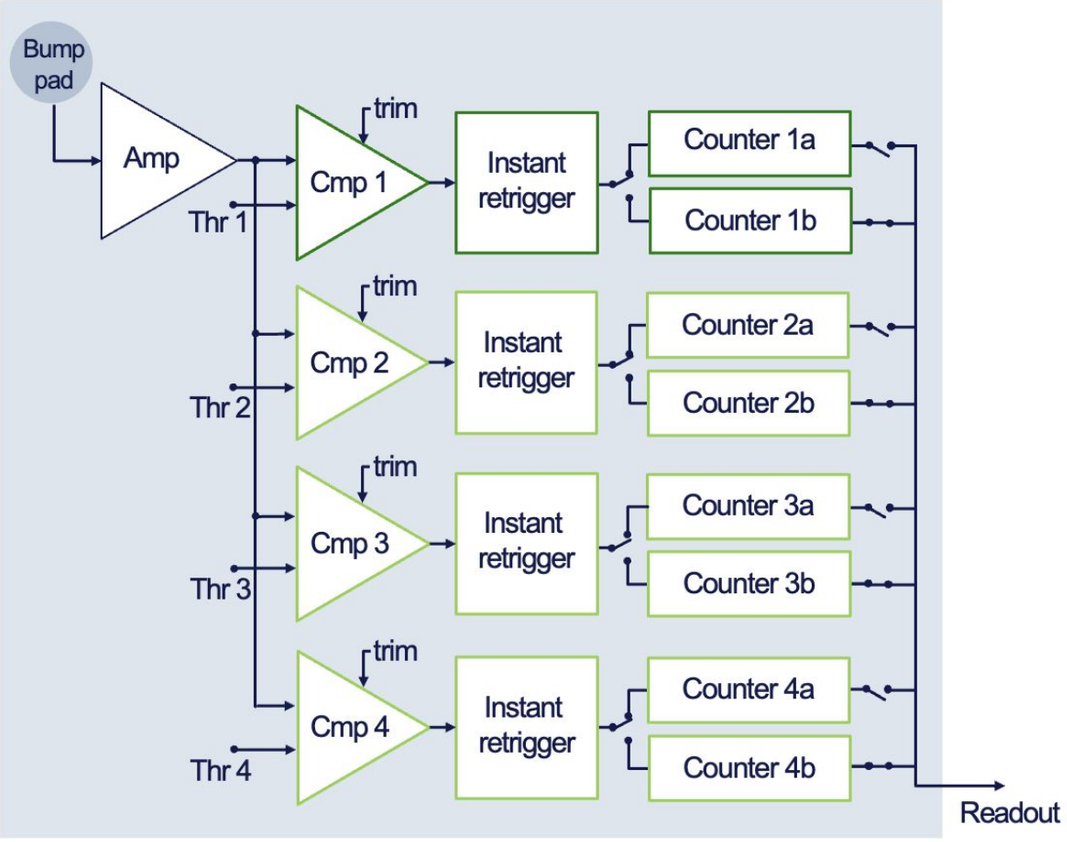
EIGER2: only achieves full specifications if images are compressed

Adaptive output

- Bit depth of output image depends on image
- Varies: 8, 16 or 32 Bit

EIGER2: Adaptive output image Bit-depth

PILATUS4 @ 4 kHz



Hybrid photon counting
150 × 150 µm^2 pixel

Number of energy thresholds
1 – 4, independently adjustable

DECTRIS Instant Retrigger
>1 × 10^7 ph/s/pixel, non-paralyzable counting

Two counters per threshold
Continuous readout (duty cycle >99.9%)

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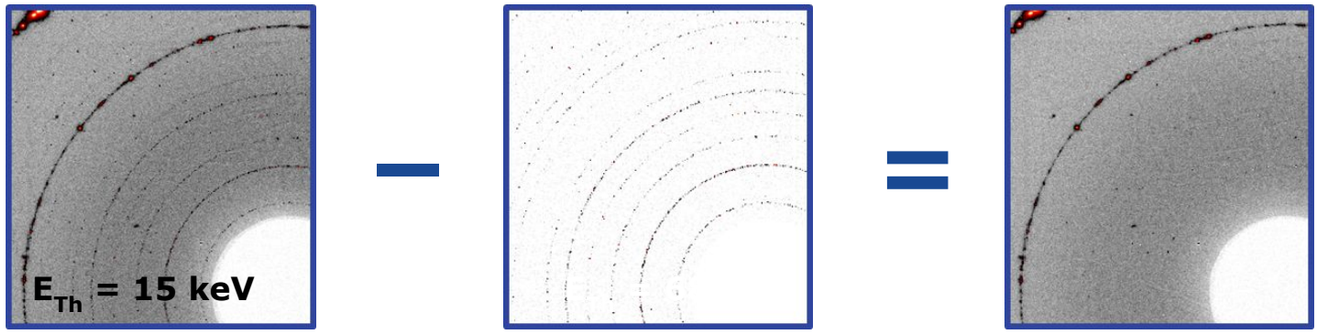
Dual Threshold Application Example

compatible with

All E2 and P4 Detectors

HIGHER-HARMONIC SUPPRESSION

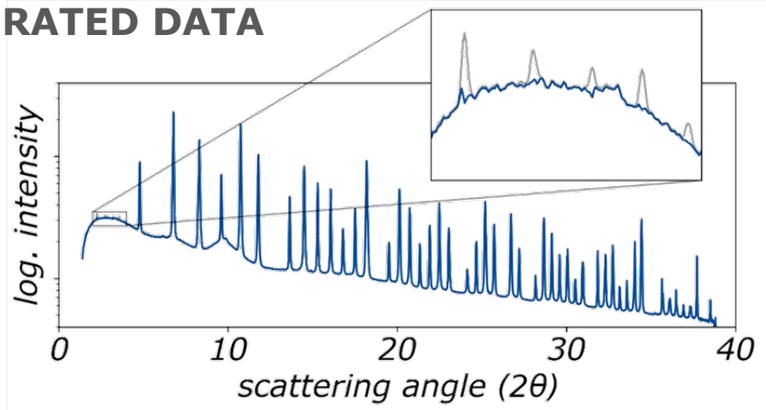
THRESHOLD 1 − **THRESHOLD 2** = **DIFFERENCE**



EXPERIMENTAL CONDITIONS

- PI: Michael Hanfland
- BL: ESRF, ID15B
- Detector: **EIGER2 X CdTe 9M**
- X-ray energy: 30 keV
- Higher-Harmonic en.: 90 keV
- Technique: LaB6 X-ray powder diffraction

INTEGRATED DATA



advanced functionality

cleaner and less data

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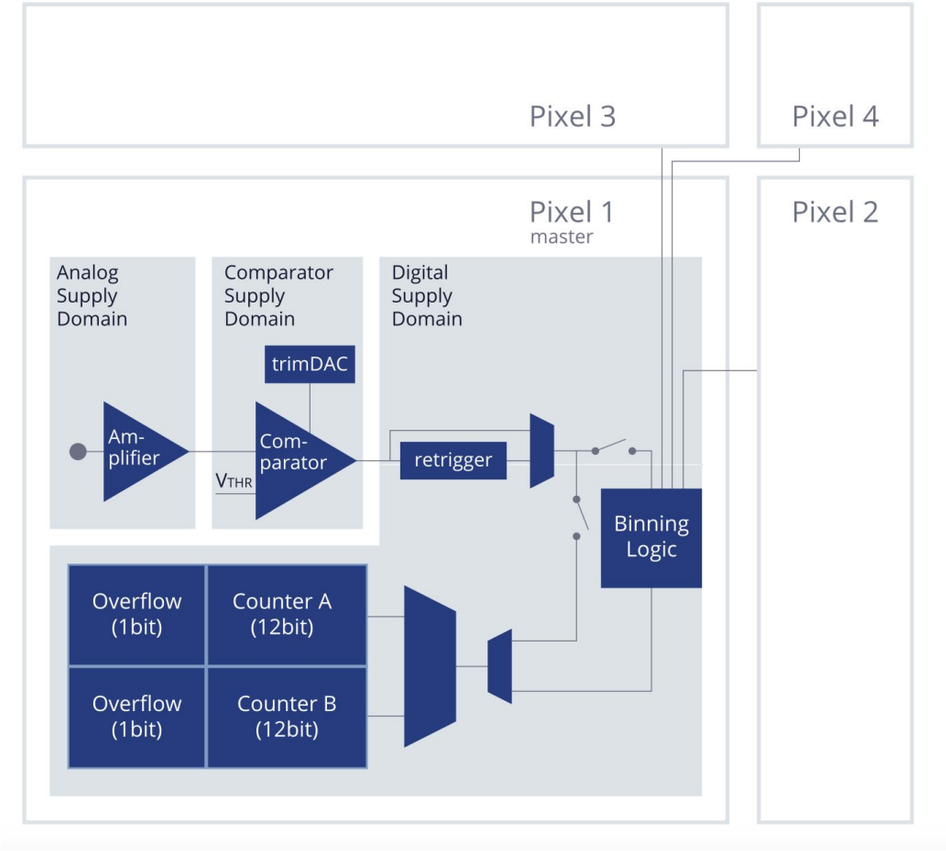
DECTRIS Fast ASIC



Pixel size
100 µm × 100 µm

Pixel array
192 × 192 pixels

Count rate
> 20 Mcts/pix/s

Readout modes
Full frame / 2 × 2 pixel digital binning

Counter encoding
12-bit integer / 8-bit floating-point

Instant Retrigger technology &
Room temperature operation

See P.Zambon, et.al. (2023), doi:10.1016/j.nima.2022.167888

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8-bit Floating-Point Compression

Standard 12 Bit UINT counter:

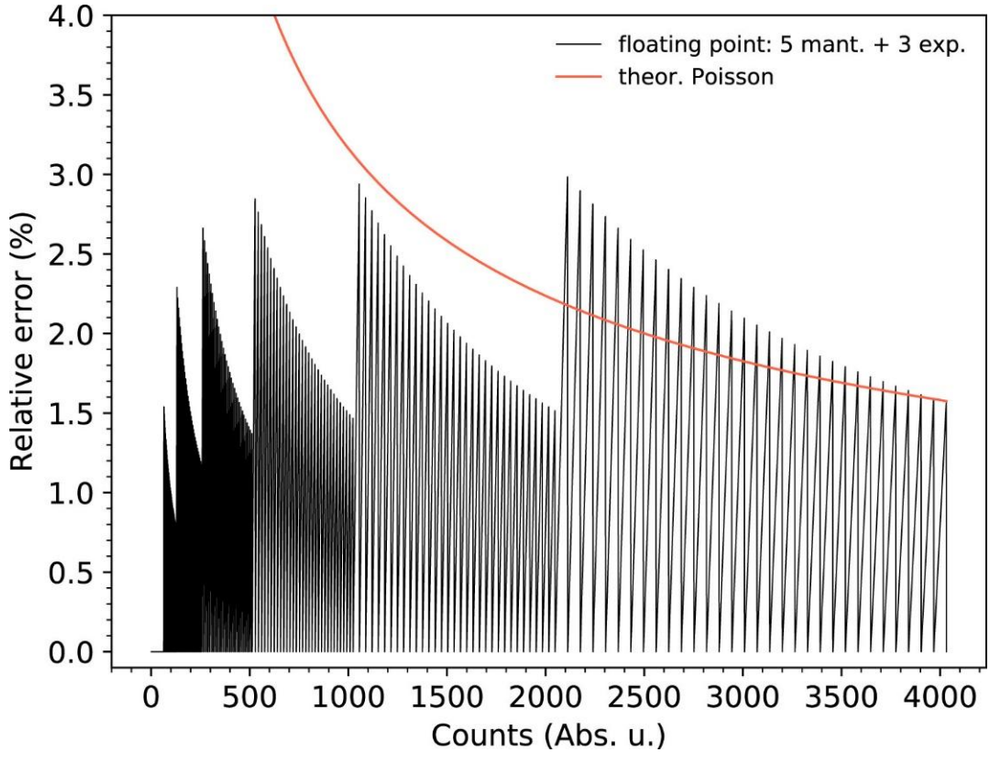
Range: 4’095 Cnts
Precision: 1 Cnt

8 Bit Floating-Point counter:

Range: 4’032 Cnts
Precision: depends on signal

exponent *mantissa*

Floating Point Rounding Error



See P.Zambon, et.al. (2023), doi:10.1016/j.nima.2022.167888

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FP Compression & Binning

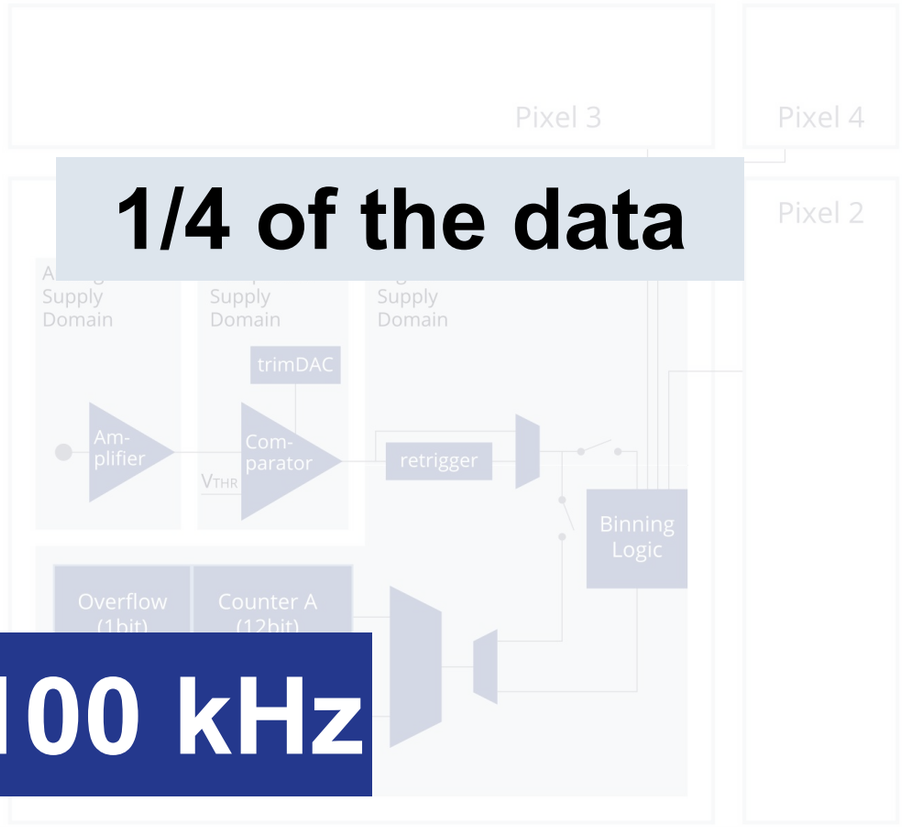
Standard 12 Bit UINT counter:

0 0 0 0 0 1 1 0 1 1 0 0

33% data rate reduction

8 Bit Floating-Point counter:

~~0 0 0 0~~ 0 1 1 0 1 1 0 0



1/4 of the data

Frame rate > 100 kHz

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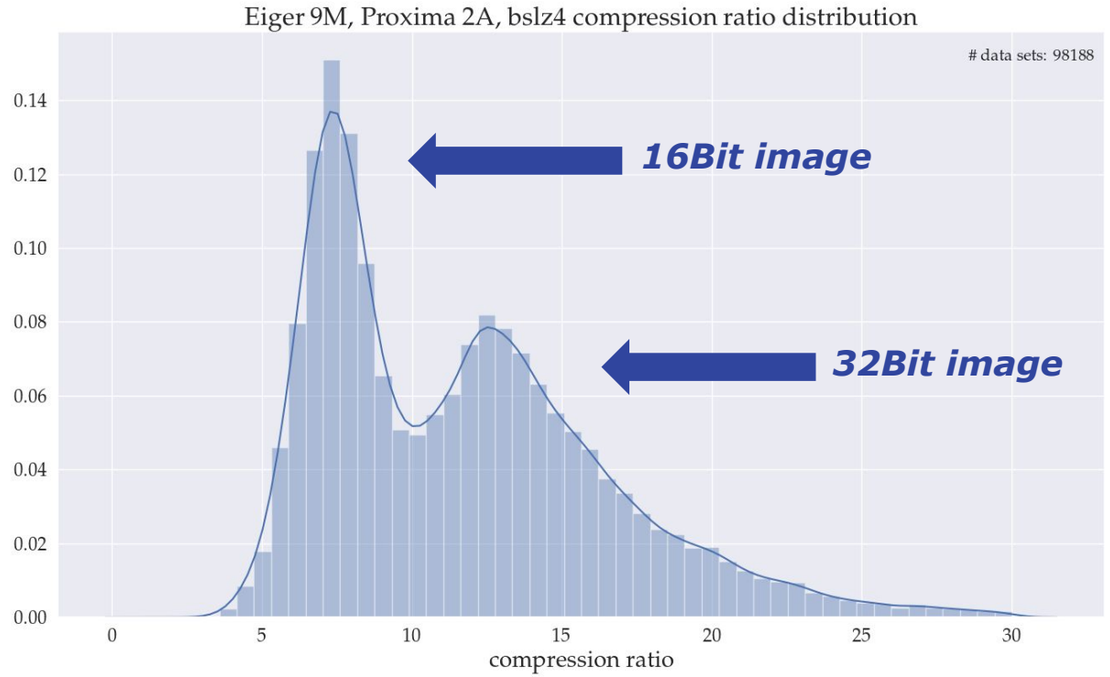
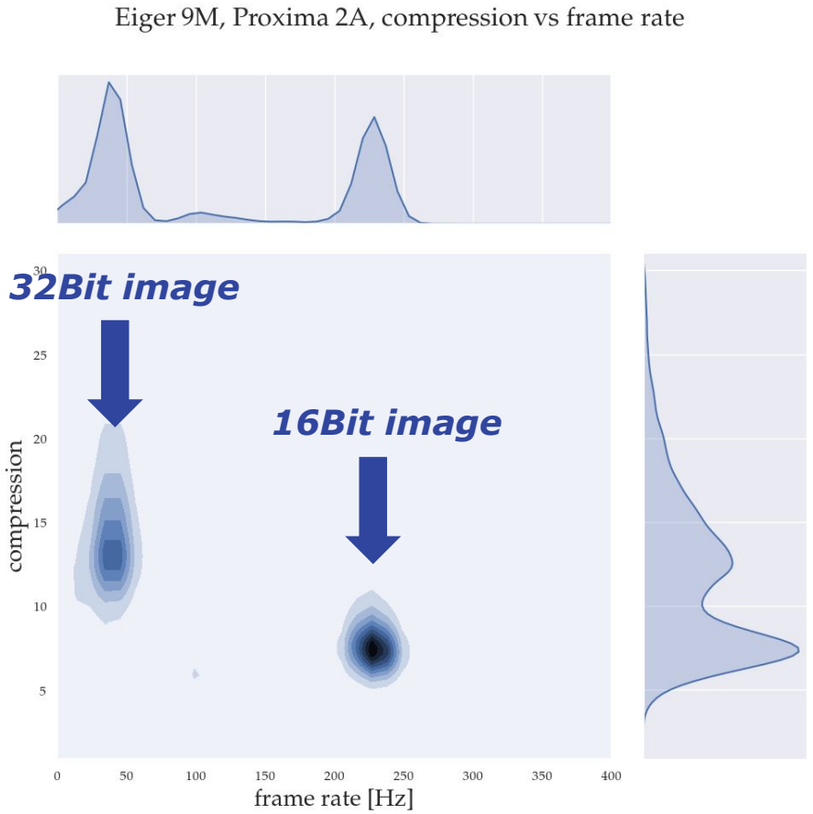
EIGER2: Current Data Output MX

Analysis of ~100’000 MX datasets





Curtesy of Martin SAVKO (SOLEIL, Proxima BL)

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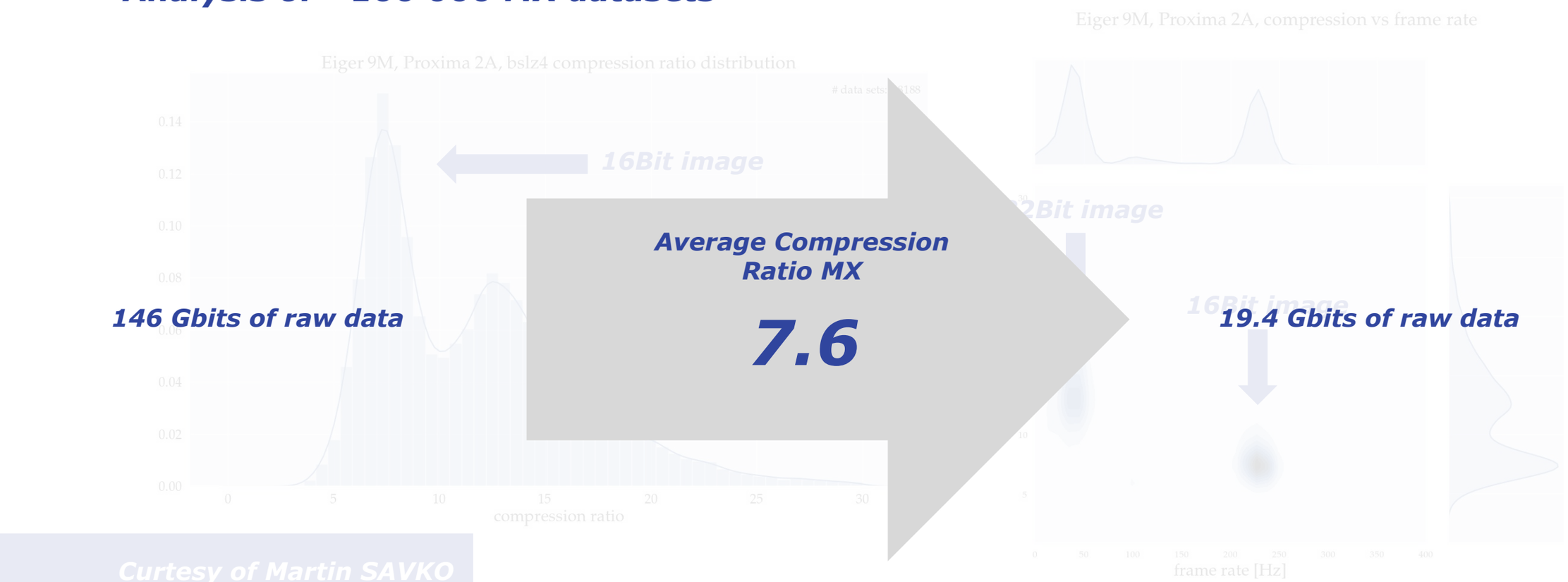


146 Gbits of raw data

Average Compression Ratio MX

7.6

19.4 Gbits of raw data

Curtesy of Martin SAVKO (SOLEIL, Proxima BL)

BitShuffle Compression

New, highly optimized BitShuffle implementation for modern processors

- Implemented in C99
- Optimized with SIMD instructions including SSE2, AVX2, and AVX-512
- Does not allocate memory
- Support for all major compilers and operating systems

Typical **speedup** between **1.3x and 10x** depending on the CPU architecture, function, and arguments

see github.com/dectris/compression/

Test by John Wright, ESRF: **speedup up to >40%** for the entire "bslz4" decode operation

see https://github.com/jonwright/bslz4_to_sparse/issues/1

Pipeline Design

Detector Head
e.g. EIGER2 XE 16M

160 Gbit/s

Detector Control Unit (DCU)

- Assembling images
- Applying corrections
- Adding image Metadata
- Compression of images
- Packaging into .h5

Can we do more?

Data Interfaces

STREAM2
ZMQ: high BW, low latency

FILEWRITER
h5: high BW, medium latency

MONITOR
TIFF: low BW, medium latency

- Readout of Pixel Data (8 or 16 Bit UINT)
- Send/Route data to DCU

- Application specific processing

Data flow

Edge Computing

Collaboration Project:

Started in April 2023

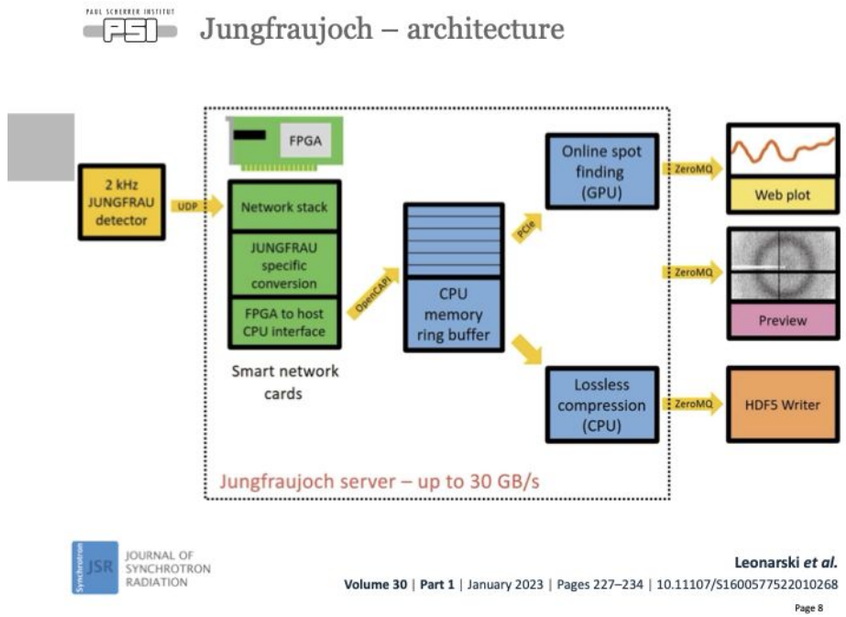
Innosuisse

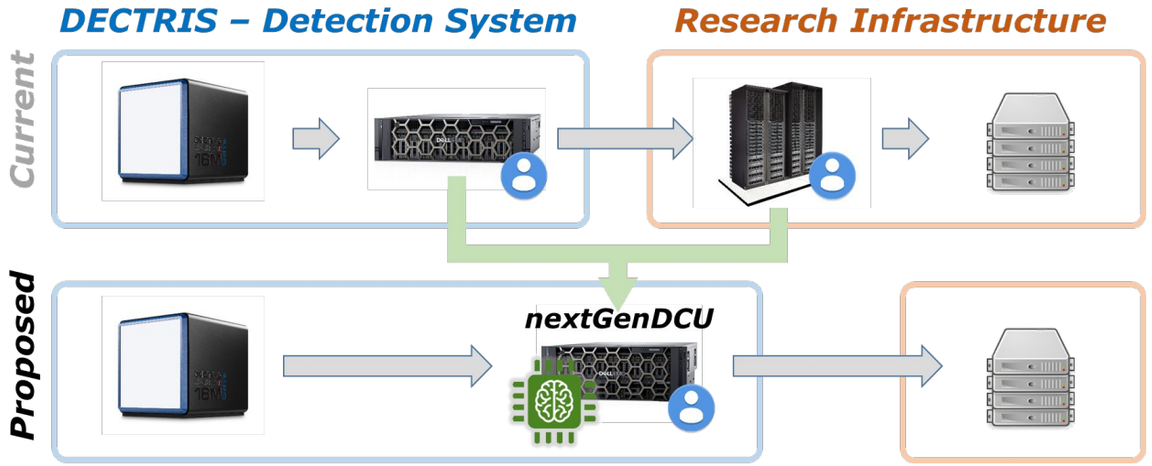
PAUL SCHERRER INSTITUT PSI

Radial integration, spot positions, indexing

Aim: no (millisecond) latency
for EIGER2 & PILATUS4

Experiment requires live feedback





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MX Image Scoring

Curtesy of Filip LEONARSKI (PSI, SLS)

on CPU

Spot finding
Peakfinder8: 25-50 ms/image

Indexing
Xgandalf (fast): 100 ms/image

on GPU/FPGA

Spot finding
COLSPOT on GPU: < 200 µs

Indexing
Fast-feedback indexer on GPU: < 1 ms

Image scoring is faster than detector framerate

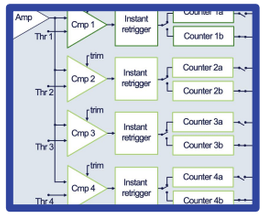
Summary & Acknowledgement

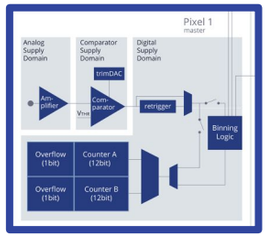
New detector design

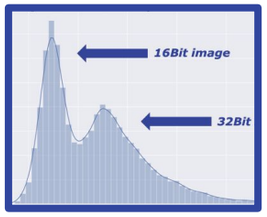
Compression
- implementing new ways
  - e.g. In-pixel compression

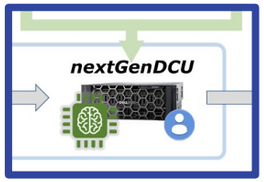
- improving current methods
  - e.g. Bit Shuffle algorithm

Edge computing









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