Tristan10M detector: Characterization of a large area detector for time resolved experiments based on Timepix3 chip

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1 Introduction

- The Tristan 10M project aims at building a large area (16 cm × 23 cm) detector for time resolved experiments based on the Timepix3[1] chip.
  - 10 modules in a 2x5 matrix for a total of 160 Timepix3 ASICs running in parallel
- The Timepix3 offers better properties for time resolved experiments compared to conventional photon counting ASICs[2].
  - High granularity (55µm pixel pitch)
  - Event driven mode (time stamp and location of an event sent out for any occurrence), rather than in frame based mode
  - Sufficient time resolution (1.56 ns) without gating the detector
- This work presents the detector characterization results, setup calibration at Diamond's beamline I19, as well as the assessment of inter-module alignment.

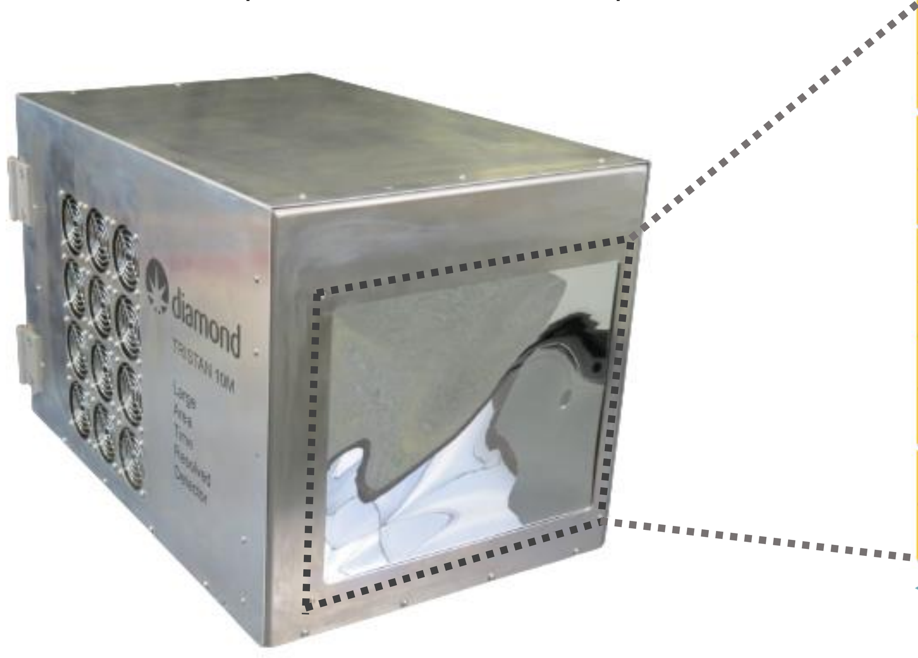
2 Exploded View of Tristan 10M

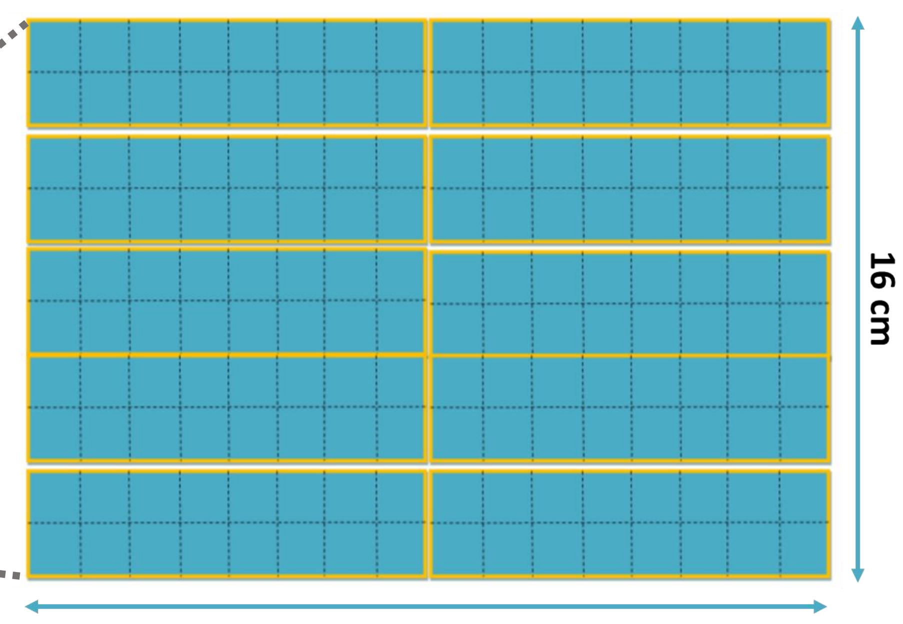
Tristan 10M detector

- 10,485,760 pixels
- 55 µm x 55 µm pixel pitch
- Active area 317 cm^2
- 40 Mhits/cm^2/s
- Time resolution 8 ns without gating the detector
- Data driven output, allows continuous acquisition.

Detector Layout

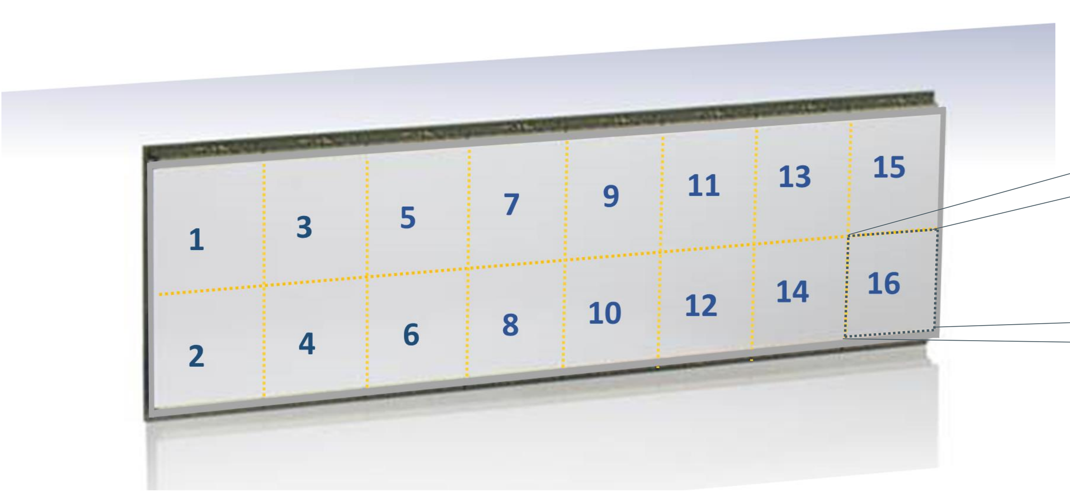
The Tristan 10M detector is organized in a 5 x 2 module matrix, each module being made up of sixteen Timepix3 chips bump-bonded to a monolithic pixelated silicon sensor.





Single Module

The single module is being made up of 8 x 2 Timepix3 chips bump-bonded to a 500µm thick monolithic pixelated silicon sensor.



Timepix3 Chip

The Timiepix3 ASICs perform the measurements of photon events within complex pixel electronics.

Timepix3 physical description[3]

Pixel arrangement	256 × 256
Pixel size	55 μm^2
Chip active area	1.98 cm^2
Total chip area	2.29 cm^2
Dead time per pixel	475 ns
Notional timing resolution	1.5625 ns
Minimum detectable charge	500 e^-

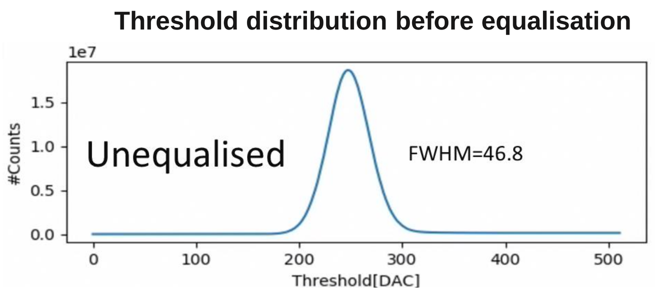
3 Characterisation

In this section, the charactorization results of one in 16 modules (16 Timepix3 chips) are presented. All other modules follow the same charactorization protocol.

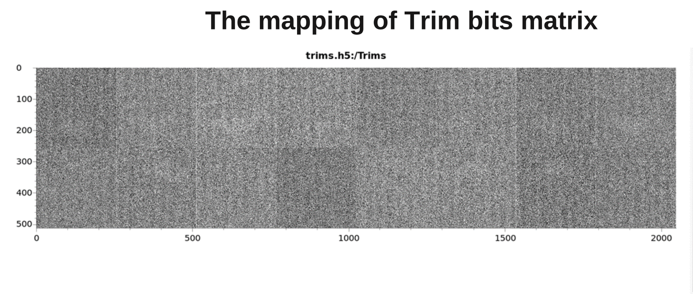
Threshold equalisation

The equalisatiion procedure is implemented for all pixels, dispersion of threshold has been reduced from a FWHM of 46.8 DAC units to 17.5. The mapping and distribution of equalised Trim bits also shown below.

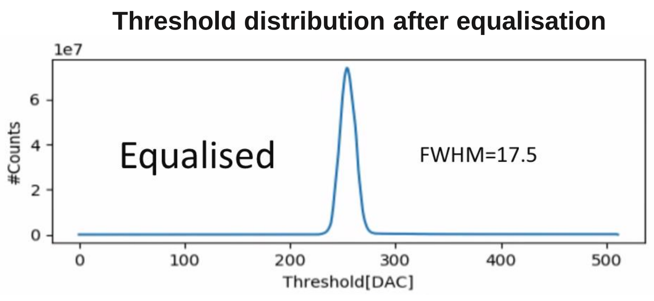
Threshold distribution before equalisation



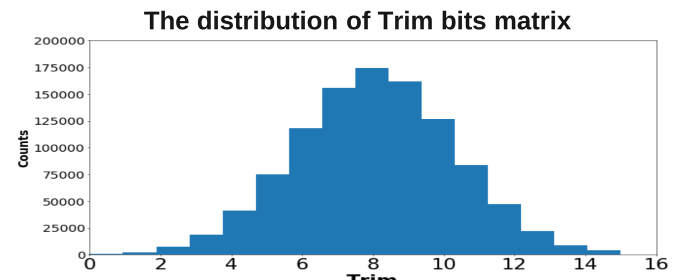
The mapping of Trim bits matrix



Threshold distribution after equalisation

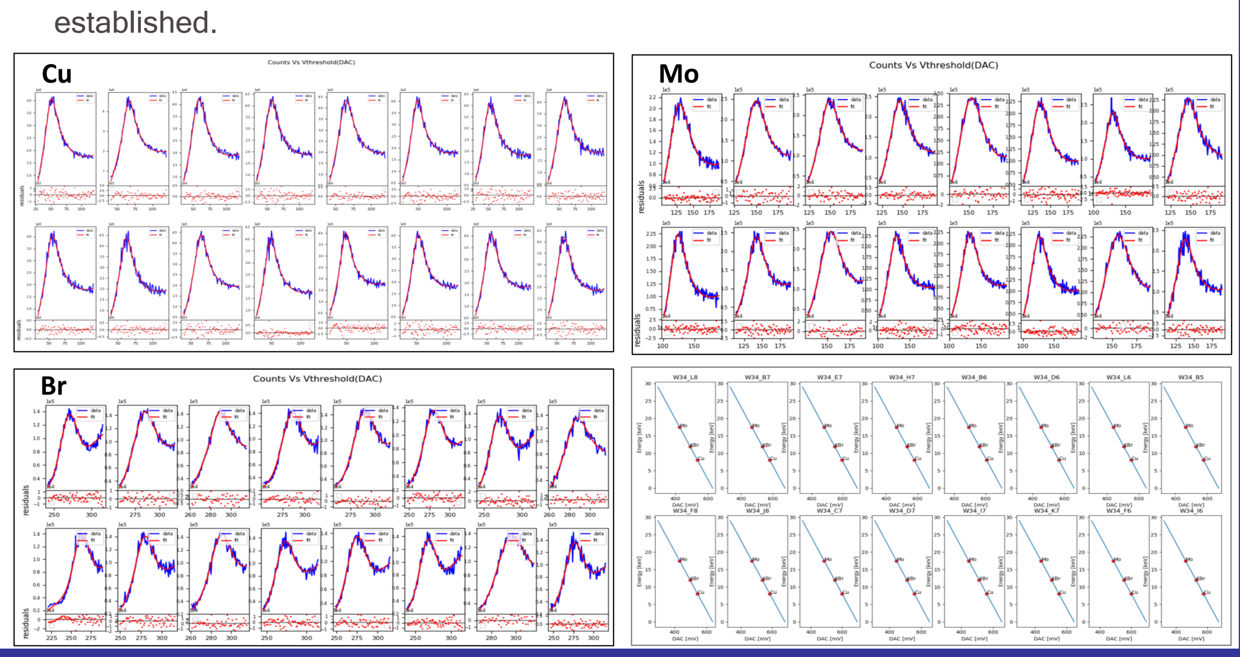


The distribution of Trim bits matrix



Energy calibration

- The threshold has been calibrated in energy by using the fluorescence of 3 elements Cu, Mo, and Br.
- The threshold DAC scans focussed around the peak from all three materials were measured for each pixel across the module pixel matrix, as shown below.
- Linear regression analysis was performed to calibrate the recorded peak DAC value to the incident X-ray energy, the relationship between threshold DAC and energy was established.



Masked pixels

The masked pixels consist of five different types, each type is encoded and saved in HDF5 format, so that the masked pixel type can be easily identified for subsequent data processing.

Pixel Mask Specification

bit 0: gaps — (Chip gaps and module gaps) — value "1" in HDF5
bit 1: dead pixels — (masked from equlisation step) — value "2" in HDF5
bit 2: under-responding* — (masked from flat-fielding step) — value "4" in HDF5
bit 3: over-responding* — (masked from flat-fielding step) — value "8" in HDF5
bit 4: noisy — (from dark image step) — value "16" in HDF5

* The pixels' counts fall out of three standard deviations of the average counts.

The Masked pixels in one module

```
Total masked pixels (%)=  967 ( 0.0922% )
Dead/0count masked pixels (%)=  819 ( 0.0781% )
under performing masked pixels (%) =  49 ( 0.0047% )
Over performing masked pixels (%) =  99 ( 0.0094% )
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	chip01	chip02	chip03	chip04	chip05	chip06	chip07	chip08
0count/dead pixels	61	28	35	61	83	17	60	59
Under performance pixels	0	3	2	1	2	0	5	10
Over performance pixels	3	3	1	7	10	0	4	6
Total masked pixels	64	34	38	69	95	17	69	75

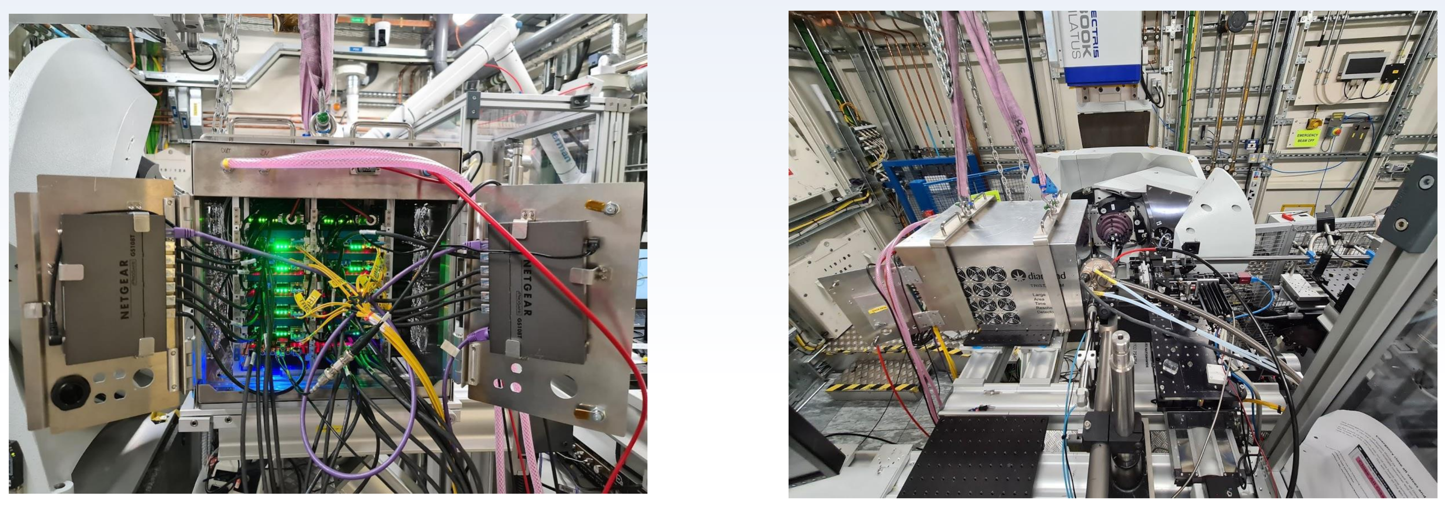
	chip09	chip10	chip11	chip12	chip13	chip14	chip15	chip16
0count/dead pixels	45	42	34	60	63	38	105	28
Under performance pixels	2	0	1	13	0	0	10	0
Over performance pixels	6	0	0	8	2	2	9	38
Total masked pixels	53	42	35	81	65	40	124	66

The total Masked pixels in 10M detector

Masked Pixel Type	#	%
Dead/ 0 count	11976	0.1142
Under-performing	469	0.0045
Over-performing	890	0.0085
Noisy	8192	0.0781
Total	21527	0.2053

4 Beamline Commissioning

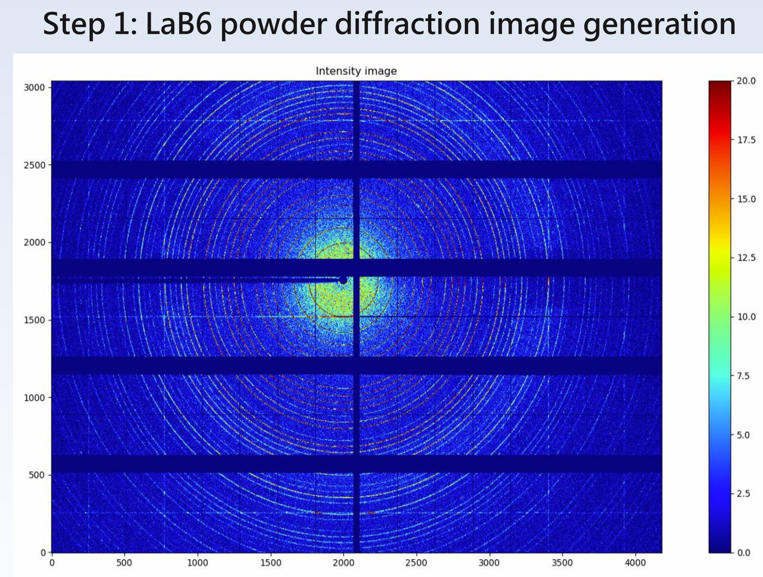
- The Tristan project was recently completed with the delivery of a Tristan10M system to Diamond's Small-Molecule Single-Crystal Diffraction beamline (I19) and commissioned with a time-resolved experiment in March 2021.
  - **Beamline**: i19 EH2
  - **Wavelength**: Ag edge, 0.4859 Å, 25.5140 KeV
  - **Diffractometer**: four circle newport diffractometer



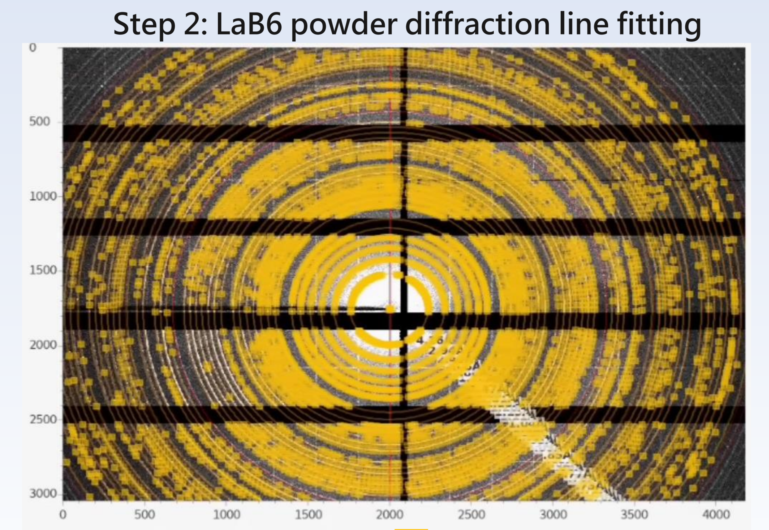
Tristan 10 M mount setup on beamline

- LaB6 powder diffraction pattern was measured by Tristan10M on beamline I19 for sample-to-detector distance and detector centre calibration during the detector commissioning.

Step 1: LaB6 powder diffraction image generation

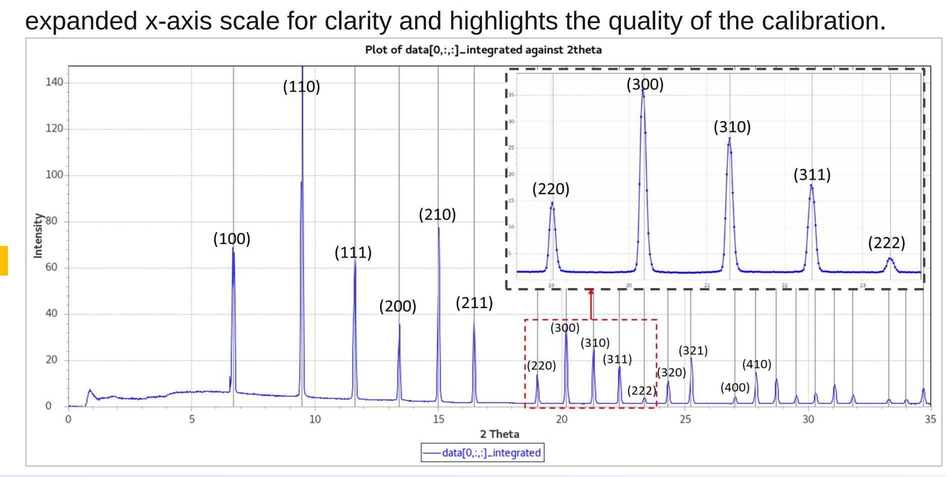


Step 2: LaB6 powder diffraction line fitting



Step3: Run the calibration

The integrated pattern shows that all peak positions are in perfect agreement with the calculated 2 Theta of LaB_6. The inset shows the patterns on an expanded x-axis scale for clarity and highlights the quality of the calibration.

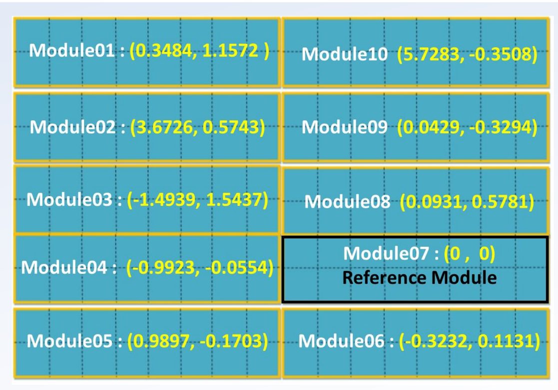


Step 4: Calibration results

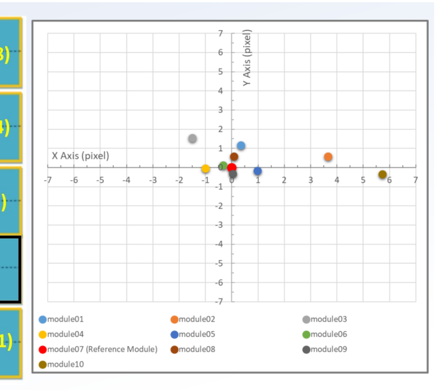
The sample-to-detector distance and detector centre was calibrated as below.

Six independent parameters	Value
Wavelength (Å)	0.2859 (fixed)
Distance (mm)	111.4279
Beam centre X (pixel)	2002.073
Beam centre Y (pixel)	1756.918
Tilt (degrees)	-0.1398
Tilt Angle (degrees)	-114.6

- Module alignment calibration in the detector on per-sensor basis.
  - Pick a module to be the reference. This will be given the coordinates (0,0).
  - Fix the distance to the value obtained from the full 10M calibration fit. Go through the beam centre calibration steps above for each module separately. All beam centre (x, y) numbers will be expressed as relative to the reference module's beam centre (x, y) coordinate.
  - The data will be given to collaborators for their correction.



Beam centre calibration results on per-module basis



Module offset from ideal position

References & Acknowledgment

1. Poikela T. et al. Timepix3: A 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout. J. Instrum. 9, C05013–C05013 (2014). DOI: 10.1088/1748-0221/9/05/C05013
2. Yousef H. et al. Timepix3 as X-ray detector for time resolved synchrotron experiments. Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip. 845, 639–643 (2017). DOI: 10.1016/j. nima.2016.04.075
3. Crevatin, Giulio, et al. Development of a Timepix3 readout system based on the Merlin readout system. Journal of Instrumentation 10.03 (2015): C03042. DOI: 10.1088/1748-0221/10/03/C03042

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5 Conclusion

- Tristan10M detector was fully characterised and total masked pixels of around 0.2% was achieved, the encoded mask strategy provides convenience for follow-up data processing.
- The Tristan 10M detector has been delivered to the beamline I19 and is fully functional.
- The detector also showed good alignment of the modules based on the LaB_6 powder diffraction data on per-module basis, most modules are less than 1 pixel size deviation.