TUPI (Timepix-based Ultra-fast Photon Imaging) Detector

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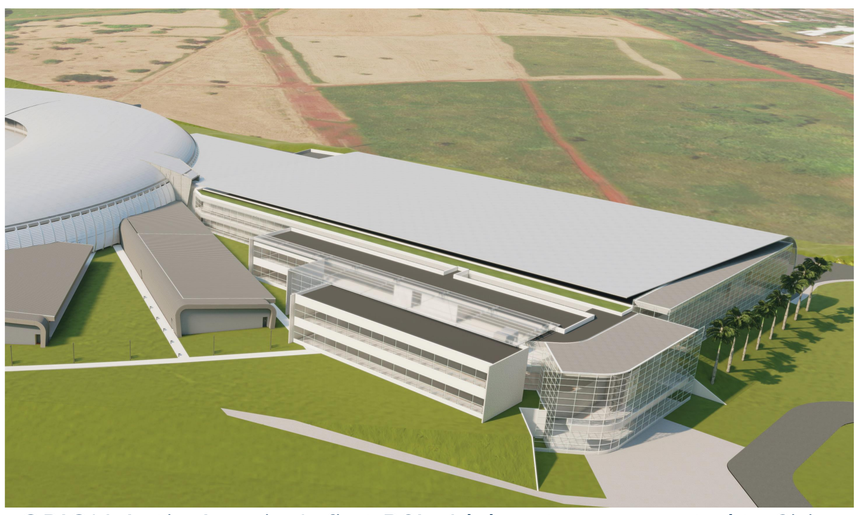
A hybrid pixel photon-counting detectors family named TUPI is proposed to meet ORION's[1] tender and hard X-rays beamlines specifications. This will be the first maximum biosafety lab ever to be attached to synchrotron beamlines. TUPI detectors will be based on an elementary module of 3x1 Timepix4[2] ASICs (Application Specific Integrated Circuit) that can be tiled to assemble larger active areas. The elementary module has 1344 x 512 pixels (55 µm pixel size), reaching more than 688 kpixels on approximately 74 mm x 28 mm area. It can achieve imaging acquisition rates up to 11 kHz in the called "Data Driven" mode (when reading ToT and ToA data) and discriminate 3 x 10^6 ph/s/mm^2 returning the deposited photons energy information in the pixels. In the photon counting mode could reach almost 44 kHz with 16-bit counting depth and could be able to discriminate hit rates up to 5 x 10^9 ph/s/mm^2.

Project Requirements



ORION, Latin America's first BSL-4 laboratory connected to Sirius Light Source [1].

TUPI detectors will be initially used for imaging in two beamlines in ORION, the new Brazilian Biosafety Level 4 (BSL-4) laboratory currently being built on the CNPEM campus attached to SIRIUS Light Source.

TIMBÓ

This tender X-ray beamline is specialized in X-ray holotomography. It is under design to generate high resolution three-dimensional nano-scale images of tissues, organoids, and arthropods infected by harmful pathogens [1]. Energy range from 5 to 20 kev.

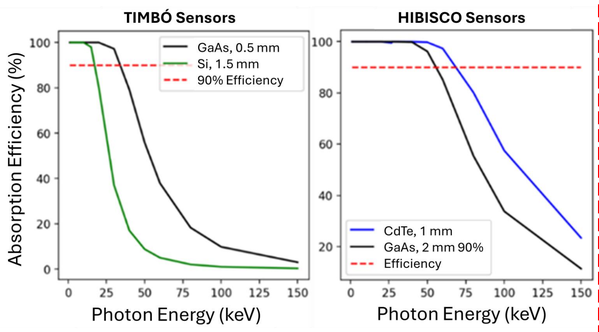
HIBISCO

It is a hard X-ray beamline dedicated to high-energy X-ray computed tomography for longitudinal studies on small animals infected with high-risk pathogens. The primary feature setting this beamline apart is the hability to produce images with millimetric resolution, approximately 100 times more detailed than standard medical tomography, while minimizing radiation dose[1].
Energy range from 16 to 45 kev. Estimated photon flux from 10^8ph/s/mm^2 with 60 x 60 mm^2 FOV.

TUPI ATTRIBUTES FOR FULFILL REQUIREMENTS

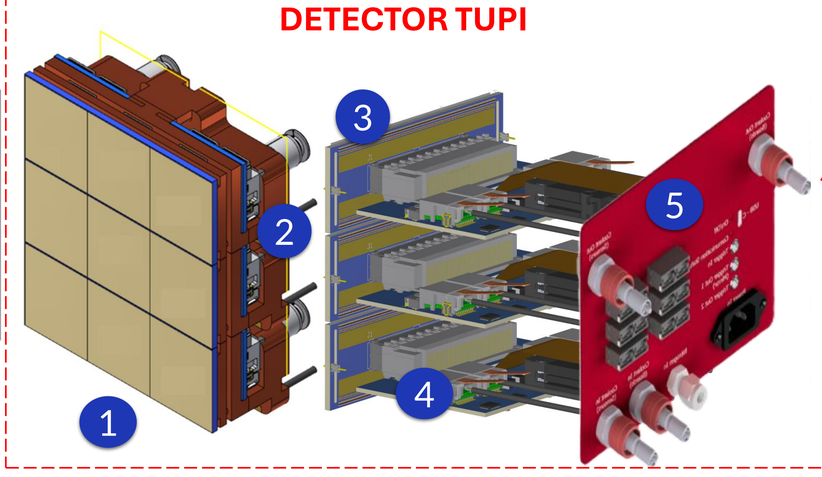
- Various sensor materials to detect energies from 3 to 50 keV;
- 3x3 Timepix4 ASICs arrangement;
- 74mm x 85mm active area;
- 1344 x 1536 pixel matrix;
- 2.06 megapixels;
- Frame rate ≈ 4000 fps @16bits counter depth;
- High speed photon counting (low dead time);
- Modularity, easy maintenance and replacement;
- Minimum gaps for maximize the active area;
- Vacuum compatible ≈10^{-3} mbar.

TUPI Detector Concepts



- TIMBÓ sensors strips of 3x1 monobloc Si slim edge sensors 1.5mm thick. Or strips of 3x1 singles GaAs slim edge sensors with 0.5mm thickness.
- HIBISCO sensors strips of 3x1 singles GaAs slim edge sensors 2 mm thick. Or strips of 3x1 singles CdTe slim edge sensors with 1 mm with thickness.
- All sensors with guard rings for electrical field equalization.
- Three pixels gaps between ASICs columns.
- 2 mm gaps between strips due to wirebonds in both sides of the ASICs.
- Each strip is replaceable.

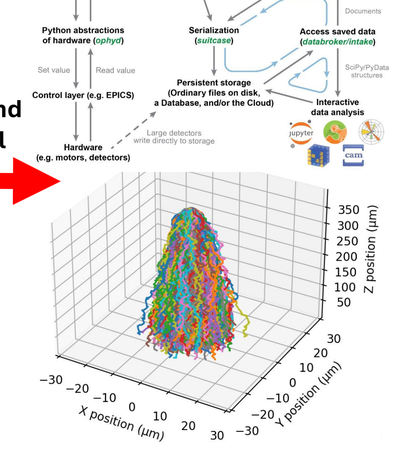
DETECTOR TUPI



1. Detector head contains three strips, each one with sensors bump bonded over three Timepix4[2] ASICs, and an environment with N2 flow to prevent humidity and dirt from affecting the sensors.
2. The electronic boards includes heat/cooling elements, water cooled heat spreaders, and a mechanical assembly for precise alignment / adjustments of each strip.
3. Three Sensor Boards[3] (blue) connect control, data, and power signals, supporting three ASICs in each strip and providing high voltage to the sensors.
4. Each Adapter Board[3] (blue at a 90-degree angle assembly) splits data, control, and power signals for interfacing with the ASICs. It converts 48 high-speed electrical data links to optical fibers using 4 FireFly™ Optical Transceivers and supplies DC voltages to the Timepix4[2] ASICs.
5. The backplane allows external connections: accommodating up to 144 FireFly™ fiber optics links for data out, cooling water connection, Ethernet control link, nitrogen gas for detector head, etc.

DETECTOR SERVER

- Server interfaces high performance FPGA boards (example, BittWare AV870p) with data receiving through FireFly™ optical fibers network links.
- Server with PCI Express X16 bus generation 5.0 to reach 504 Gbps.
- Bit-rate of 477 Gbps @16 pixel bit depth, with a maximum efetive possible frame rate: 43290 FPS.
- Direct Memory Access (DMA).
- Ethernet network for control and detector settings.



The software for TUPI detectors will perform the following functions:

- High frame rate data acquisition: It will receive the acquired data and save it for scientific processing.
- Equipment control: It will interact with the hardware and read/write process variables to control and set up the detector system.
- Procedures orchestration: It will interact with the control system to perform high-level tasks, preparing the detector for scientific use, such as calibration procedures.

Next Steps on TUPI project

In the next phase of the project these listed concepts will undergo reviewed through POCs (Proofs of Concepts), tests, and simulations.

The objective is to select the concepts with lower risk and greater viability that can meet the requirements and advance to the detailed engineering design phase. The planned target is to develop functional detector TUPI prototypes by early 2026.

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