Massachusetts Institute of Technology: MIT PixELφ Lab

Jelena Lalic, MIT

Overview

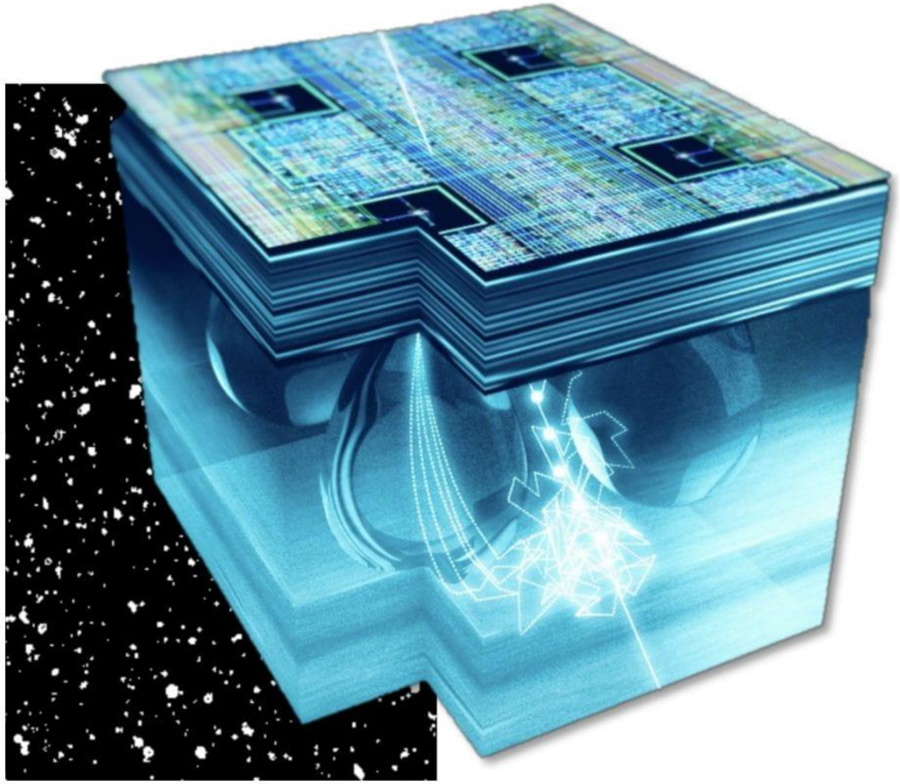
- Introduction to MIT PixELφ Lab
- Key Projects and Applications
- Future Directions

MIT PixELφ Lab: Silicon Pixel Lab for Elementary physics at MIT

- **Overview of the lab:** the MIT lab focuses on advanced sensor technologies for elementary physics research, specializing in the development and application of Monolithic Active Pixel Sensor (MAPS) technology.

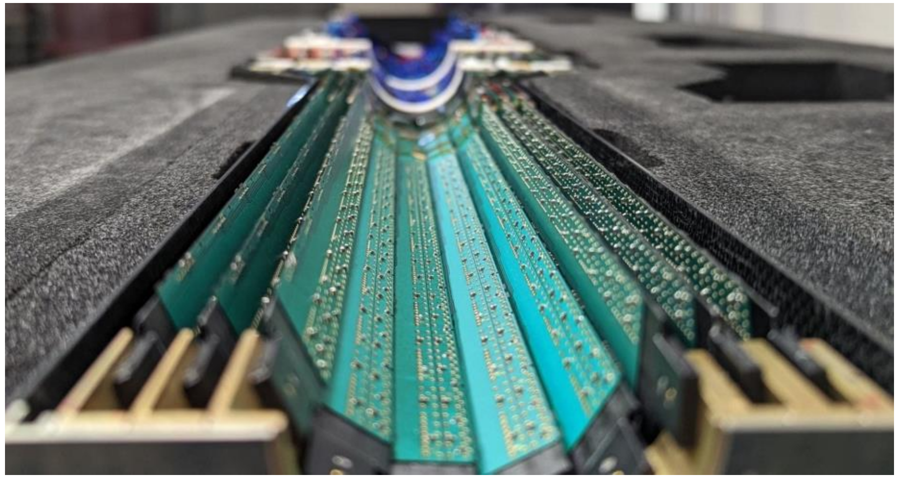
- **Mission and Vision:** Our focus is on harnessing this cutting-edge sensor technology to pioneer advanced detection systems, thereby setting new standards in precision and innovation for the field.

- **Collaborations and Lab Capabilities**
  - Strong collaboration with CERN
  - Part of the team is CERN-based
  - **Currently, CERN-based lab**
  - Mid-Long term -> MIT-based lab

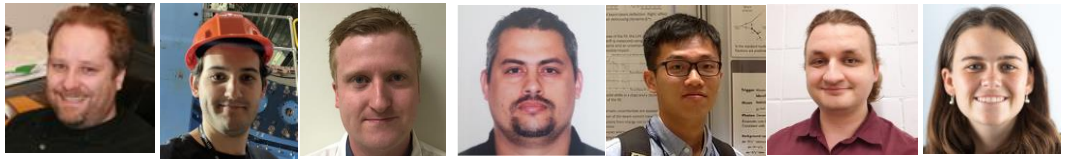


MIT PixELφ Lab: Silicon Pixel Lab for Elementary physics at MIT

- Leveraging the expertise of MIT Heavy-Ion Group.
- Lab recently formed by Prof. Gian Michele Innocenti
- For more information https://pixelphilab.mit.edu/



MVTX team



Gunther Roland
Professor

PhD Alex Patton
joined 2022

Cameron Dean
Postdoc Joined 2022

Yasser C. Morales
Research Scientist

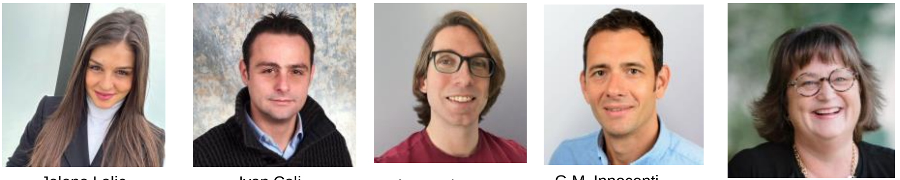
Hao Ren Jheng
Joined 2021

Michael Peters
joined 2017

Hannah Bossi
Postdoc
Joined 2023

\+

SVT/MOSAIX team



Jelena Lalic
Engineer, Joined 2024

Ivan Cali
Research Scientist

PhD Jordan Lang
joined 2023

G.M. Innocenti
Joined 2024

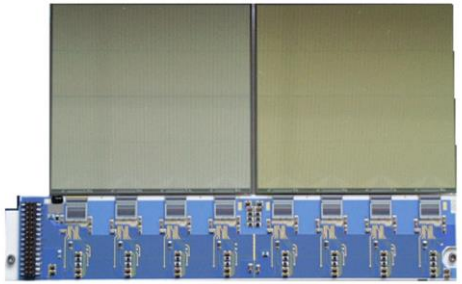
Laura Sewell
Joined 2024

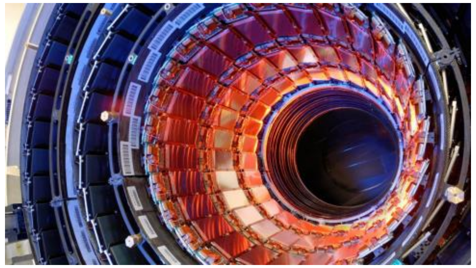
+ Bates engineers

Silicon detectors in the MIT heavy-ion group

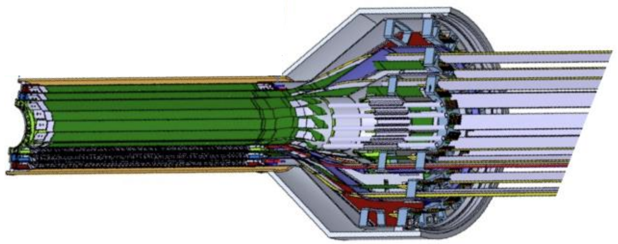
Almost 30 years of experience in pixels detectors construction and commissioning

PHOBOS experiment at RHIC
AC-coupled, single-sided, silicon pad for tracking, vertexing, and multiplicity

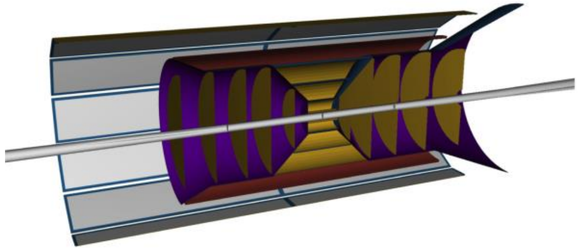




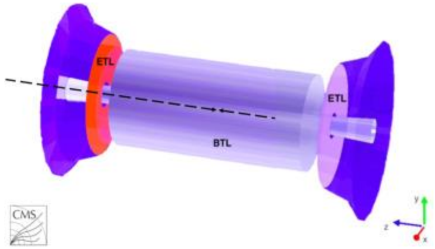
CMS tracker ("hybrid pixels")
commissioning pixel and strip detectors for heavy-ion runs



Monolithic Active Vertex Tracker (MVTX) for sPHENIX with ALICE ITS2 technology
- mechanical design, cooling, integration
- module characterization
- DCS design, installation and commissioning



Silicon Vertex Tracker for ePIC
first experiment for the upcoming EIC (Electron-Ion Collider)

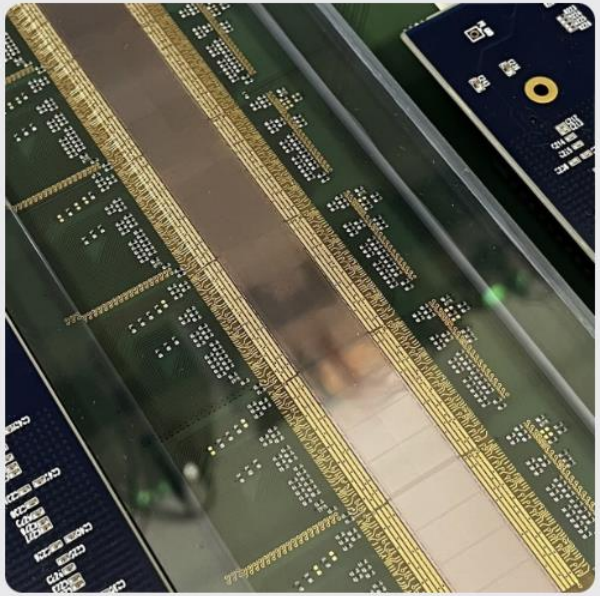


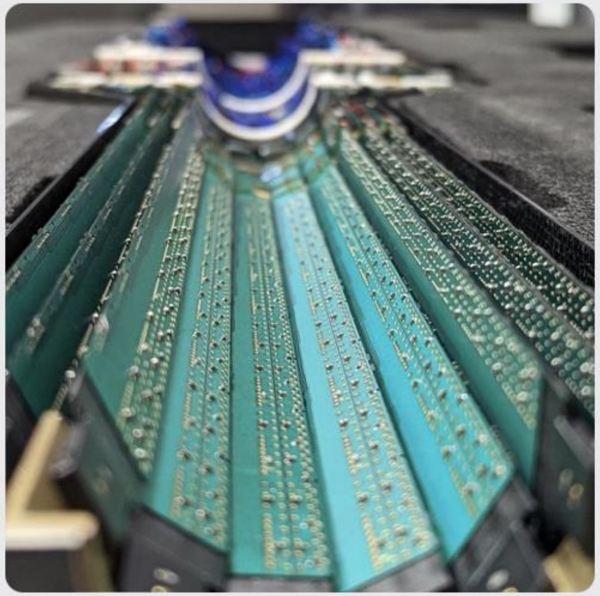
Ultra-fast silicon timing detector for CMS in Run 4

IST for STAR at RHIC

1990 2000 2010 2020 2030

Projects @ MIT PixELφ Lab:





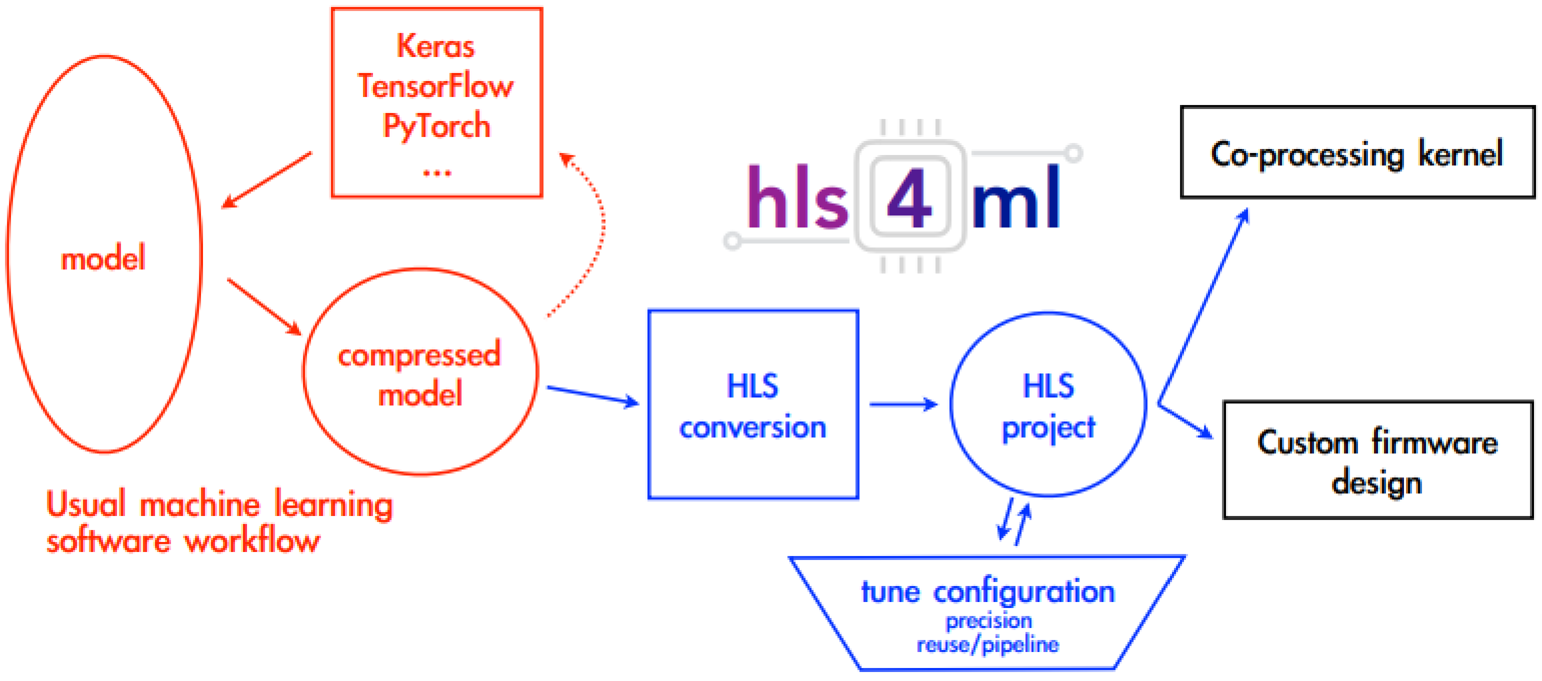
Silicon Vertex Tracker (SVT) for the ePIC experiment at the Electron-Ion Collider

MVTX for the sPHENIX experiment

Artificial intelligence with FPGA for MAPS detectors

HLS4ML: Ultra fast machine learning for FPGAs

[J. et al 2018 JINST 13 P07027]

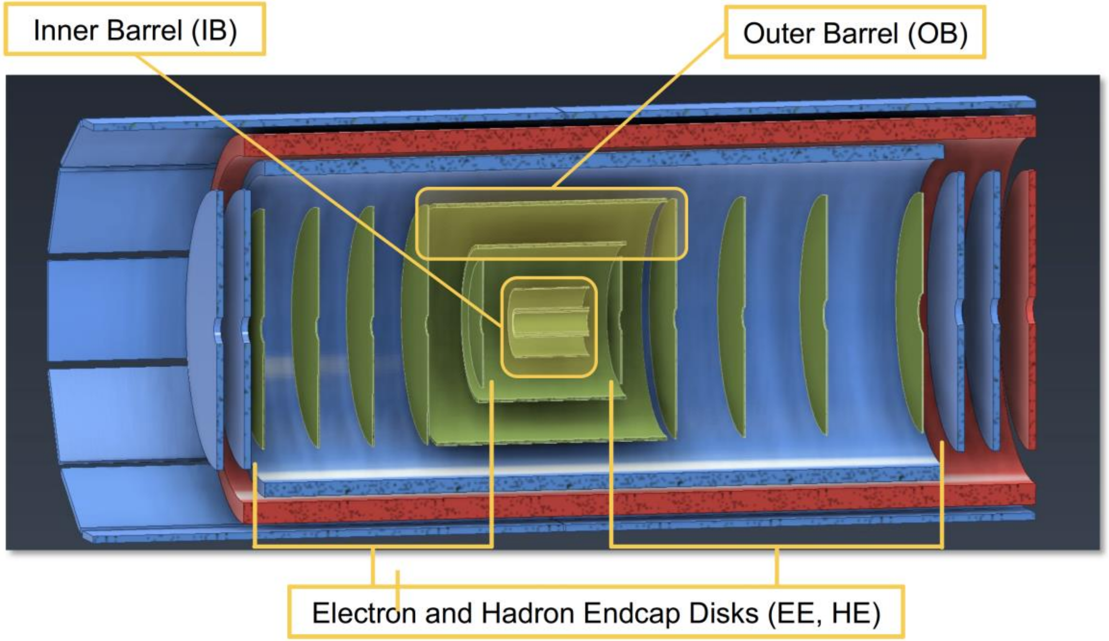


Workflow to translate a model into a FPGA implementation using hls4ml

- Python package for machine learning inference in FPGAs.
- firmware implementations of machine learning algorithms is created using a high-level synthesis language (HLS)
- Traditional open-source machine learning package models are converted into HLS that can be configured for your use-case.

Silicon Vertex Tracker (SVT) for ePIC

The **Silicon Vertex Tracker** (**SVT**) will utilize MAPS for precision tracking of charged particles.



Inner Barrel (IB)
build with bent ITS3 wafer-size sensors as the ITS3
Outer Barrel (layers 3,4 and disks)
Build with *flat* Large Area sensors derived from ITS3 sensors and further optimized

SVT AND CHALLENGES:

- Baseline sensor choice is ITS3 sensor in TowerJazz 65 nm technology being developed for the ALICE ITS3 upgrade
- ***SVT sensor area is much larger (~8m2) and* SVT has a much wider pseudorapidity coverage ->** Adapt the ITS3 MOSAIX to develop EIC-Large Area Sensors (LAS)
- strong constraints on material budget that imposes challenges for services, cooling, powering
- MIT, as a part of the SVT collaboration, is actively involved in overcoming those challenges

ITS3

ITS3

- will replace the three inner-most vertexing layers of ALICE
- Nearly massless detector based on wafer-scale sensors up to 10cm x 26cm
- Thinned down to ~40 um
- Bent into cylindrical detector layers that are held in place with carbon foam and cooled by a forced airflow
- Will be placed 2 mm from the beam pipe

ER2: MOSAIX

- MIT is involved in MOSAIX sensor design
- First time for the MIT group to get involved into sensor design itself (30 years of detector experience and commissioning but not design so far)

Stitched bent sensors for ITS3 and first three layers of the SVT

MLR1: qualification of CMOS 65nm technology, prototype for circuit blocks

ER1: stitching technology demonstrator (MOSS and MOST sensor), yield studies

ER2: fully functional sensor that satisfy ITS3 requirements

ER3: final production and design (bug fixes from ER2)

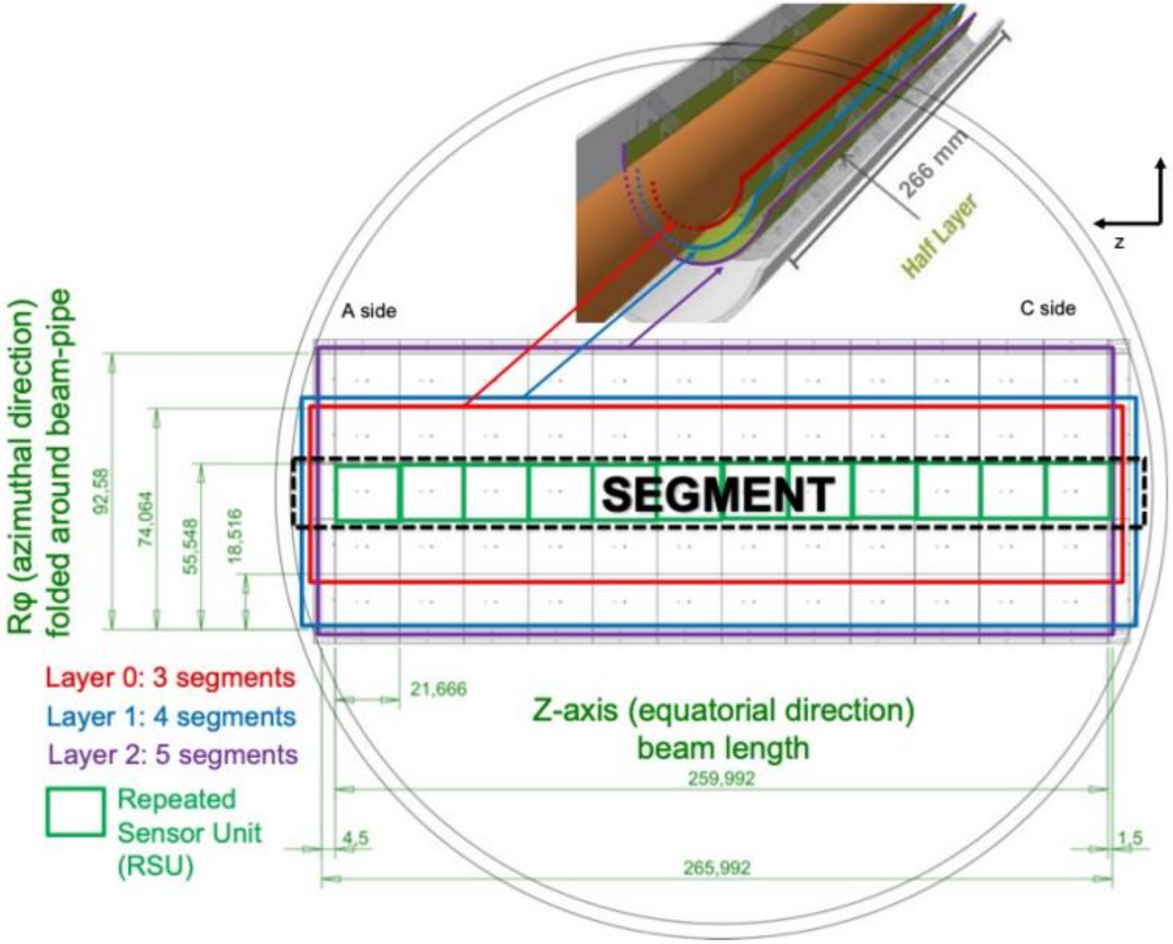
Introduction to MOSAIX

MOSAIX development

- Preproduction chip
  - Full size and full functional prototype ASIC
- ER2 Stitched sensor design
  - Wafer scale
- Will be followed by ER3 (final production)
  - Only bug fixes

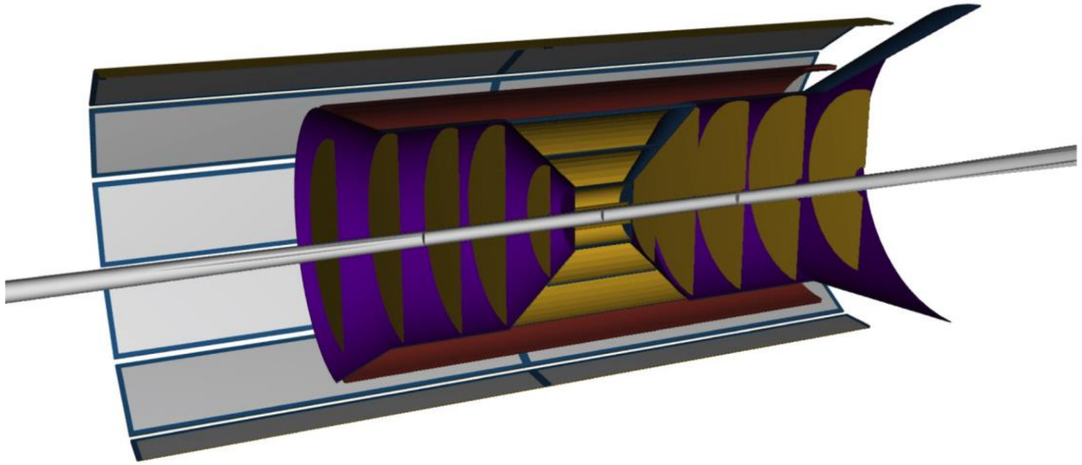
IB Layer Parameters	Layer 0	Layer 1	Layer 2
Sensor length [mm]		265.992	
Sensitive length [mm]		259.992	
Sensor azimuthal width [mm]	58.692	78.256	97.820
Radial position [mm]	19.0	25.2	31.5
Equatorial gap [mm]		1.0	
Max thickness [µm]		50	

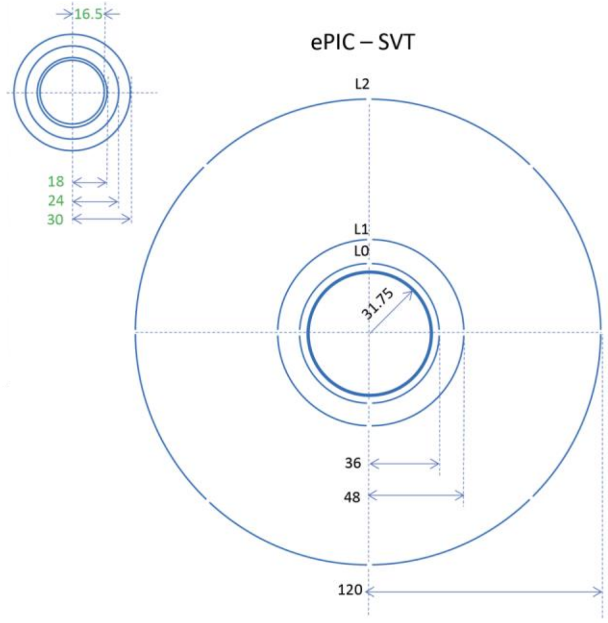
Table 3.3: Design dimensions of the sensor dies and radial position.



MIT Involvement for the SVT detector

- Sensor design for ER2/ER3
- High-frequency wafer probing characterization of large-volumes of MAPS
- Development of the readout testing setup
- Coordinating the SVT testing and characterization working group
- Testing of the data compression using FPGA multiplexing for service reduction
- Mechanics: Mechanical structure for the large-radius *bent* layer of the Layer 2→ Bates as one of the ePIC testing/construction sites





MIT contribution to MOSAIX design

- ***1 engineer (myself) working full time on design together with MOSAIX design team at CERN***
  - Started January 2024
- ***Areas of focus:***
  - RTL:
    - Serializer in the RSU periphery
  - Models and Liberate characterization
    - Stitched backbone buf, stitched backbone interface (bridged) in the LEC, REC and tile serializer
    - Modelling and integration inside the tile periphery
    - Liberate AMS characterization
  - Periphery Implementation

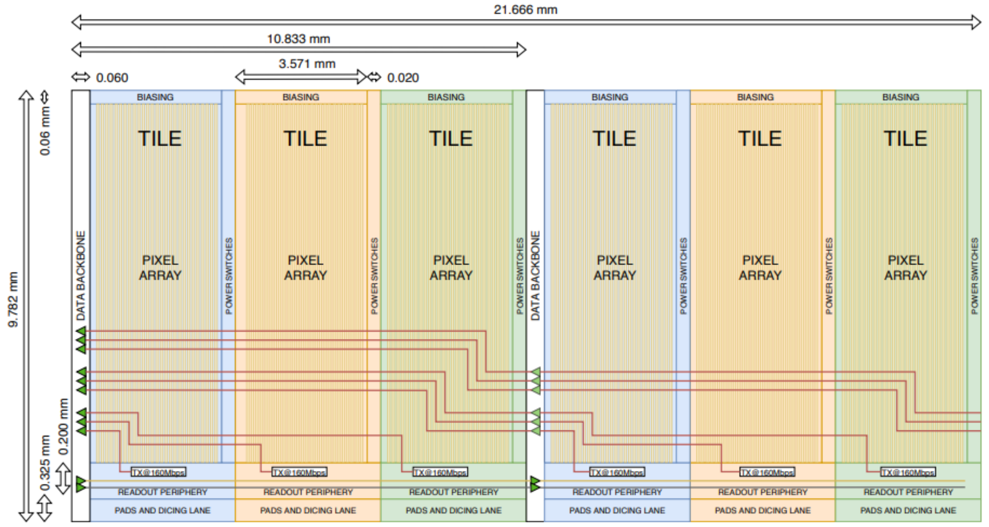
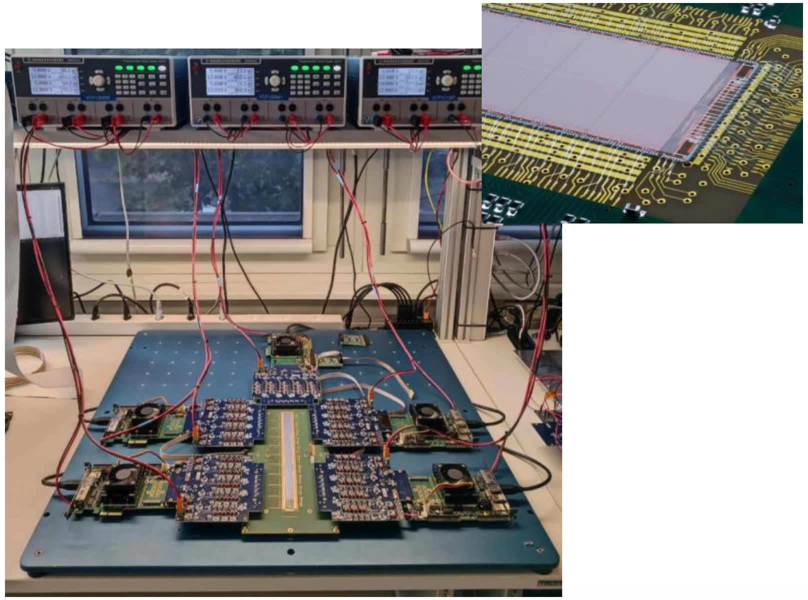


Figure 3.37: Architecture of the bottom half sensor unit (not to scale).

Joao (BNL) and myself are 2 EIC engineers within ITS3 CERN design team.

High-speed MAPS Wafer Probing



The capability of performing fast and accurate tests of large-area MAPS sensors is crucial for:

- Performing the first tests of the MOSAIX engineering runs (ER2)
- Finalizing characterization of the ER3 sensor
- Testing and characterizing the LAS design.
- **Conducting large-scale tests of the sensors during the production phase. This is especially critical for the LAS sensors that will equip the disks and the outer barrels.**

We propose a development of the high-frequency (10.24Gps) wafer-probe testing:

- Preliminary testing with existing serializer, the NKF7, which serves as a prototype for the serializer to be incorporated into the MOSAIX sensor
- Once the principle is verified, we will proceed to design and produce the setups for the ER2 and the ER3 sensors.

Unique contribution of the SVT team to the ITS3 project.
Involving new members of the SVT team to this effort.

Future activities

- Current job opening https://academicjobsonline.org/ajo/jobs/27541
- We are planning on getting new members and expanding area of work
- Will have MIT undergraduate and PhD students joining (during this summer)

- Strong interest within wider MIT community in exploring MAPS for FCC and lower energy nuclear physics
- AI in MAPS (leveraging in-house experience with AI)