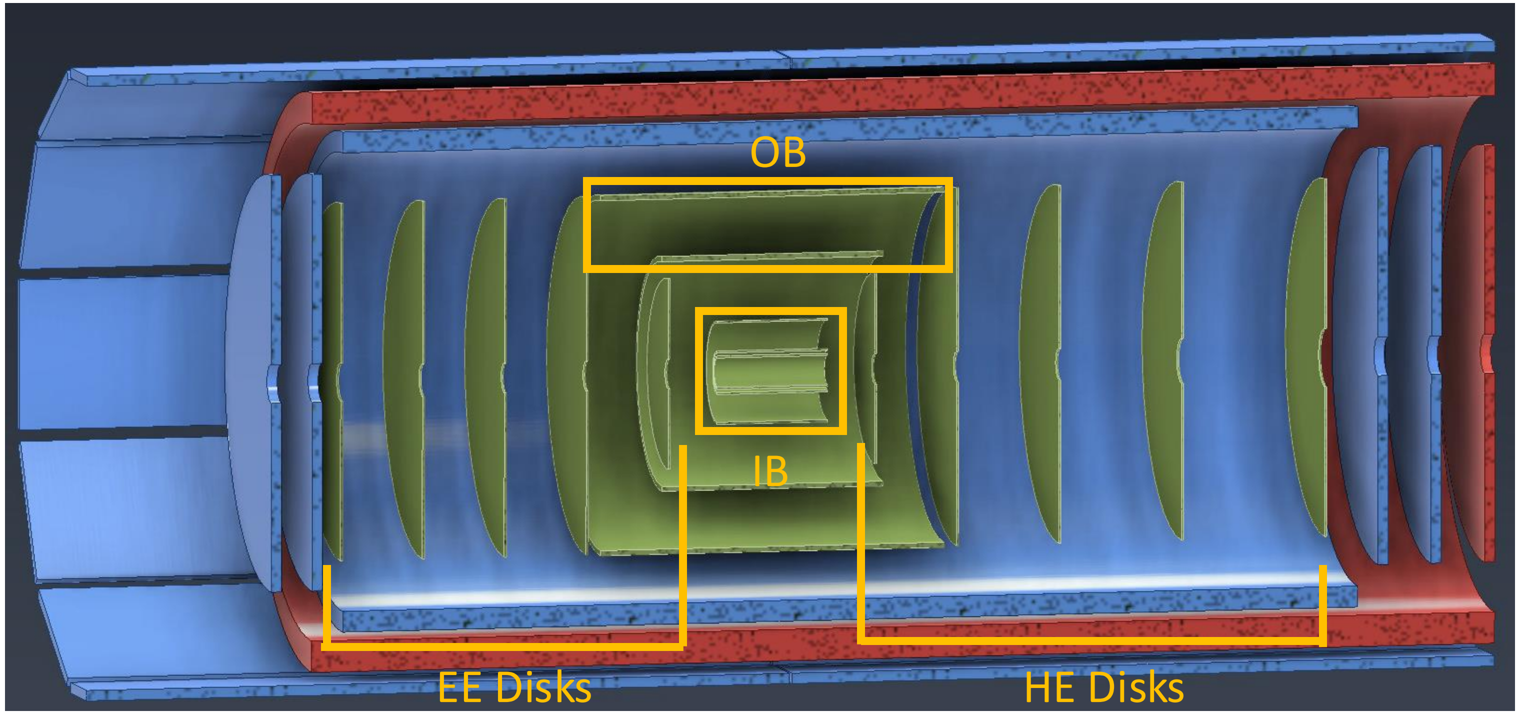
Sensor Development for ePIC Silicon Vertex Tracker

Zhenyu Ye
LBNL

ePIC Silicon Vertex Tracker



	Momentum Resolution	Spatial Resolution
Backward (-3.5 to -2.5)	~0.10%×p⊕2.0%	~ 30/pT µm ⊕ 40 µm
Backward (-2.5 to -1.0)	~ 0.05%×p⊕1.0%	~ 30/pT µm ⊕ 20 µm
Barrel (-1.0 to 1.0)	~0.05%×p⊕0.5%	~ 20/pT µm ⊕ 5 µm
Forward (1.0 to 2.5)	~0.05%×p⊕1.0%	~ 30/pT µm ⊕ 20 µm
Forward (2.5 to 3.5)	~0.10%×p⊕2.0%	~ 30/pT µm ⊕ 40 µm

Inner Barrels (L0, L1, L2):
- ITS3 sensor
- Radii of 3.6, 4.1, and 12 cm
- Length of 27 cm
- X/X_0 ~0.05%

Outer Barrels (L3, L4):
- EIC large area sensors with modified design based on ITS3, mounted on more conventional staved CF structure with integrated liquid or air cooling
- Radii of 27 and 42 cm
- Lengths of 42 and 84 cm
- X/X_0 ~0.25% and 0.55%

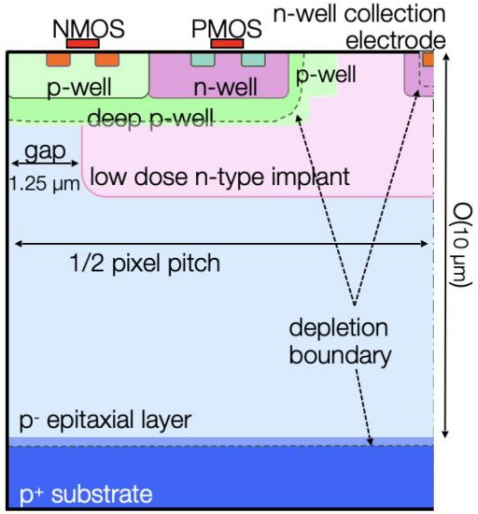
Endcap Disks (5 EE, 5 HE):
- EIC-LAS sensors on conventional structures with integrated air cooling
- Outer radii of 25 and 40 cm
- X/X_0 ~0.25%

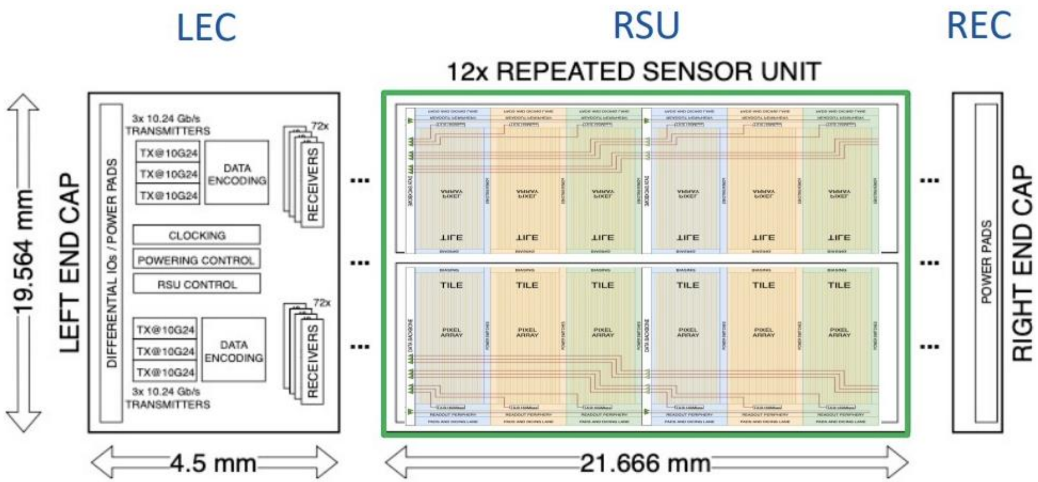
Crucial to achieve EIC physics requirements

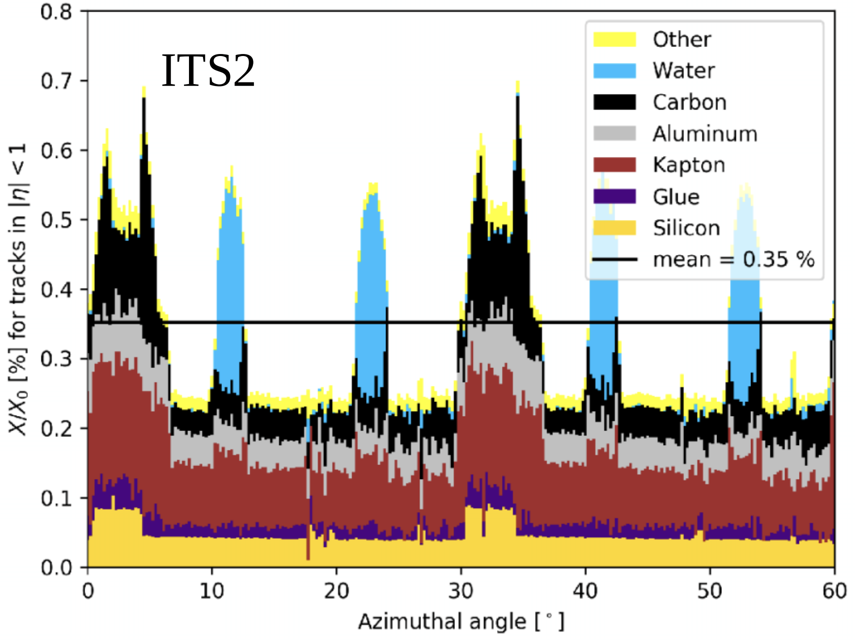
ePIC Silicon Vertex Tracker – Inner Barrels

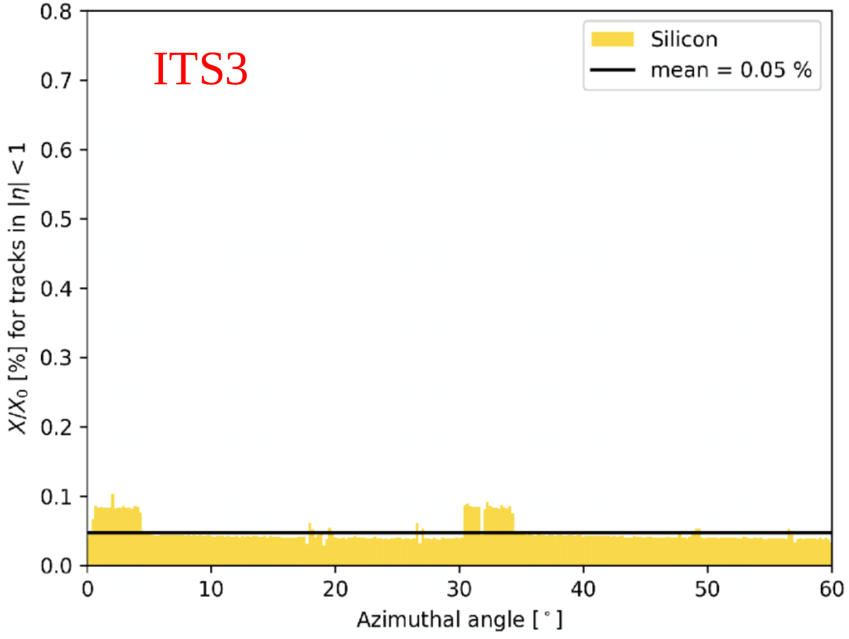
ALICE ITS3

- Thinned, curved, self-supporting wafer-scale MAPS sensors based on TPSCo 65nm CMOS Imaging Technology
- X/X_0~0.05% (air cooling, minimal support and no services in active area)
- Pixel pitch O(20×22.5) μm^2
- Power consumption 40 mW/cm^2
- Integration time 2 μs
- Radii of 1.9, 2.52, 3.15 cm
- Length of 27 cm









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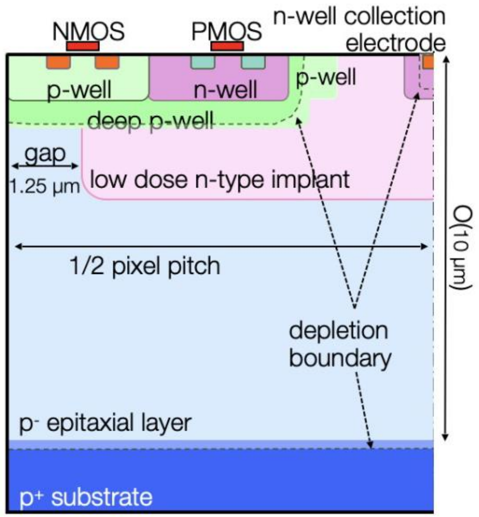
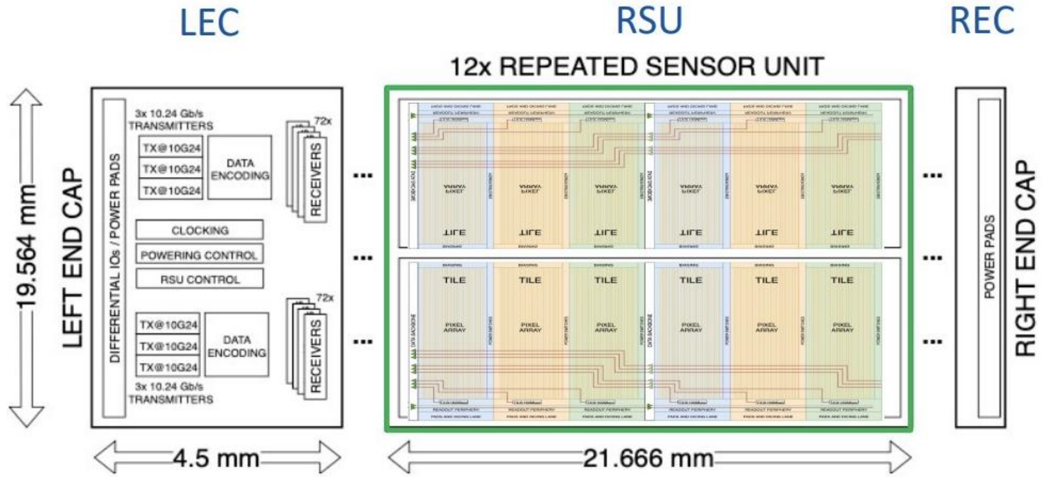
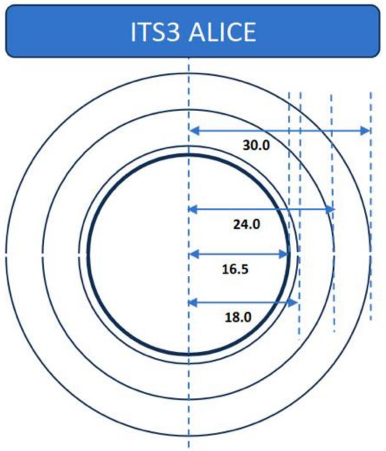
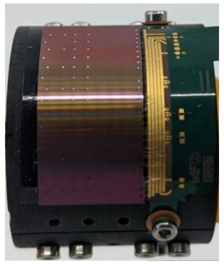


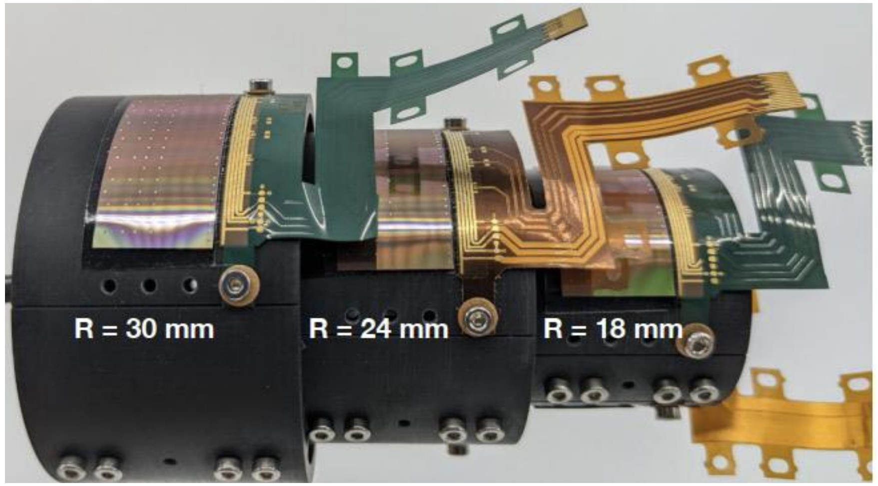


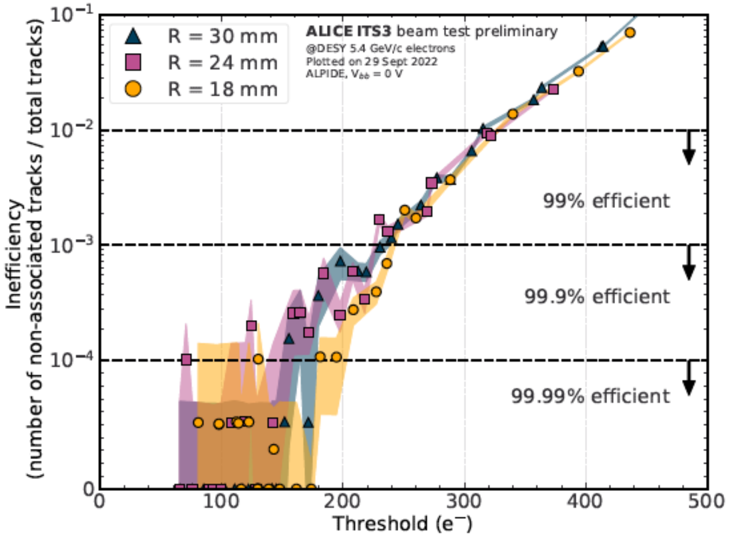
CERN-LHCC-2024-003 ; ALICE-TDR-021



ALPIDE bent to 18mm radius







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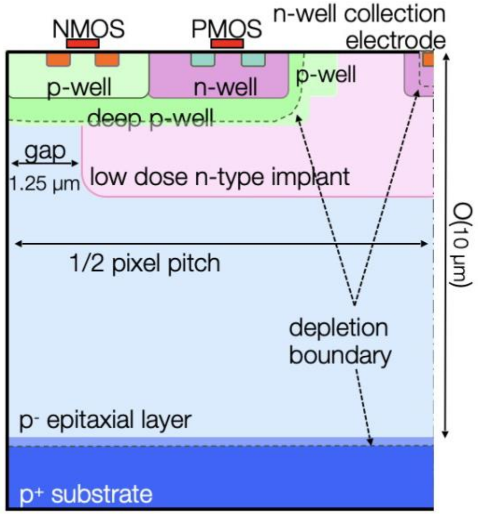


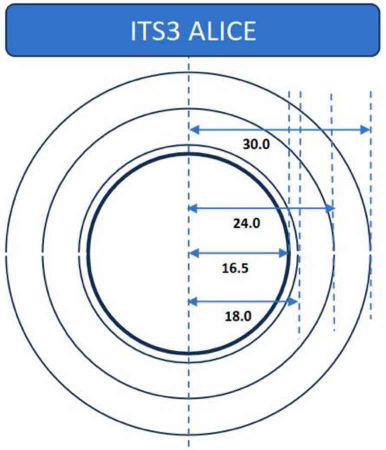
ePIC Silicon Vertex Tracker

Inner barrels (L0-L2) inspired by ITS3

- Same design as ALICE ITS3
- Radii of 3.6, 4.8, and 12 cm
- Length of 27 cm

-> Partner between ALICE ITS3 and ePIC (BNL/**LBNL**/MIT/UK)

CERN-LHCC-2024-003 ; ALICE-TDR-021



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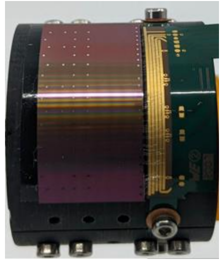
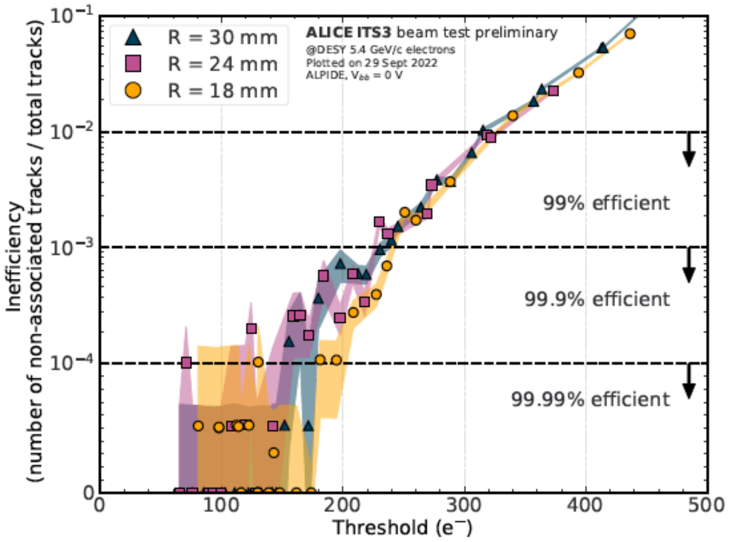
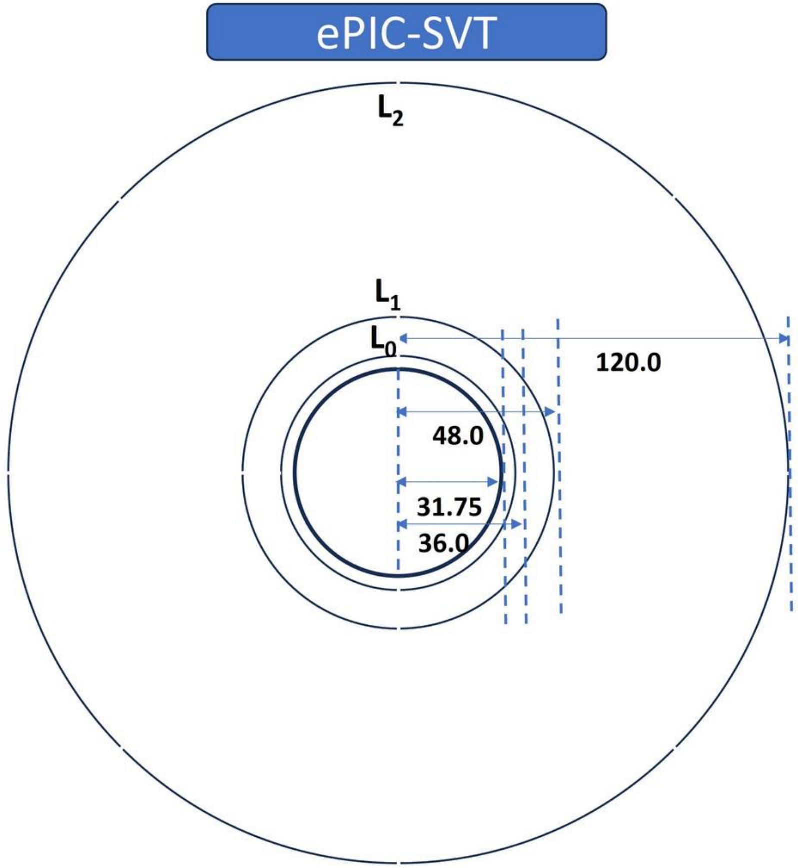
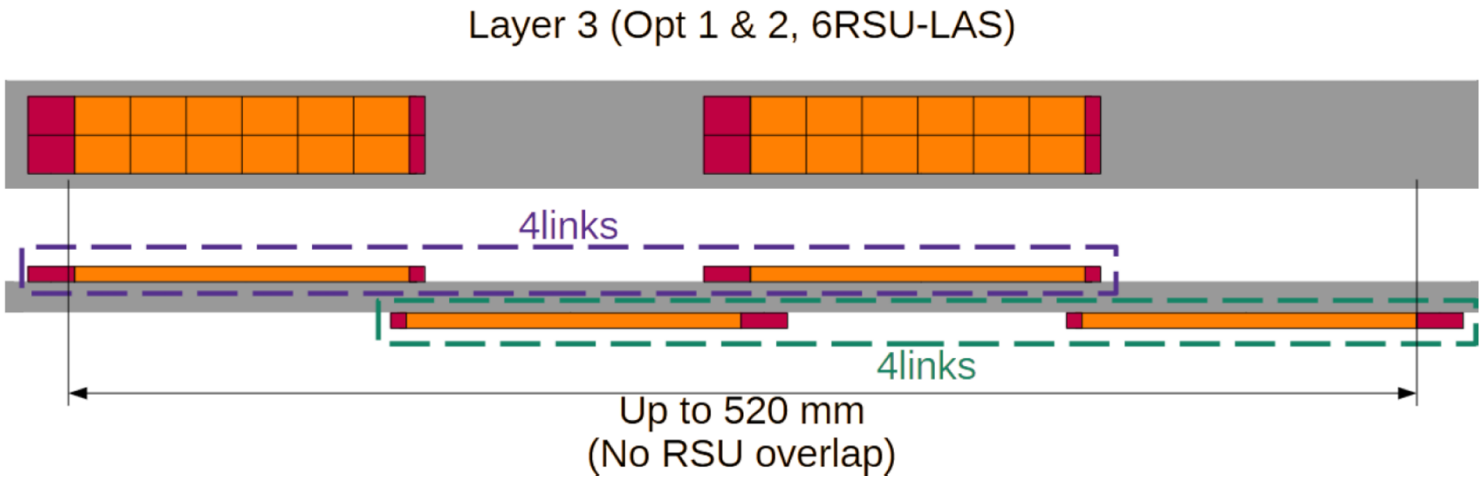
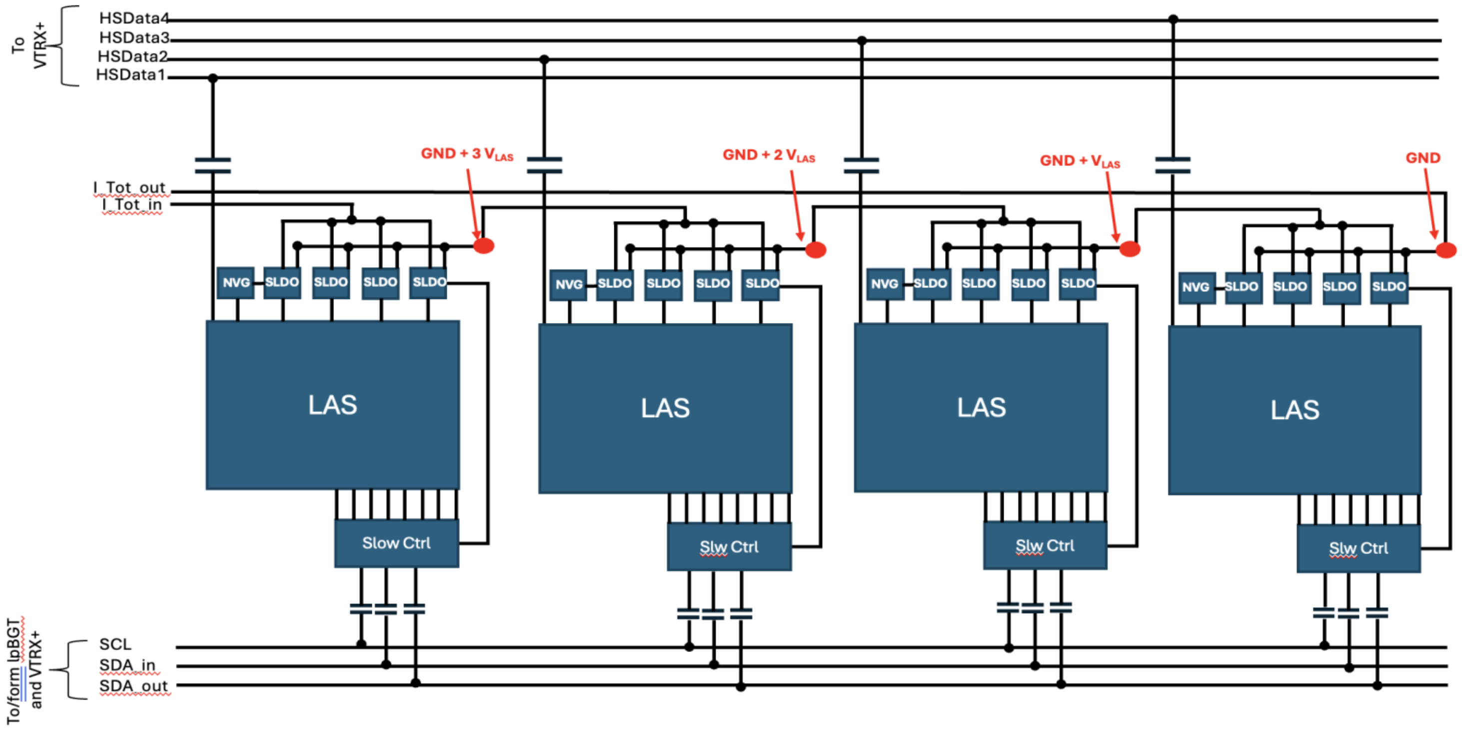






ePIC Silicon Vertex Tracker – Outer Barrels and Disks





ePIC SVT OB and disks will have

- An optimized sensor design for ePIC
  - Reduced number of RSUs (5-6)
  - Reduced number of data links
  - Power and read out only from one side

  -> Work pending on BNL-CERN agreement to get access to ITS3 sensor design library

- An ancillary IC that will provide up to 4 EIC-LAS sensors
  - Negative bias voltage (BNL)
  - Slow control signal (BNL/**LBNL**)
  - Serial power (**LBNL**/UK)

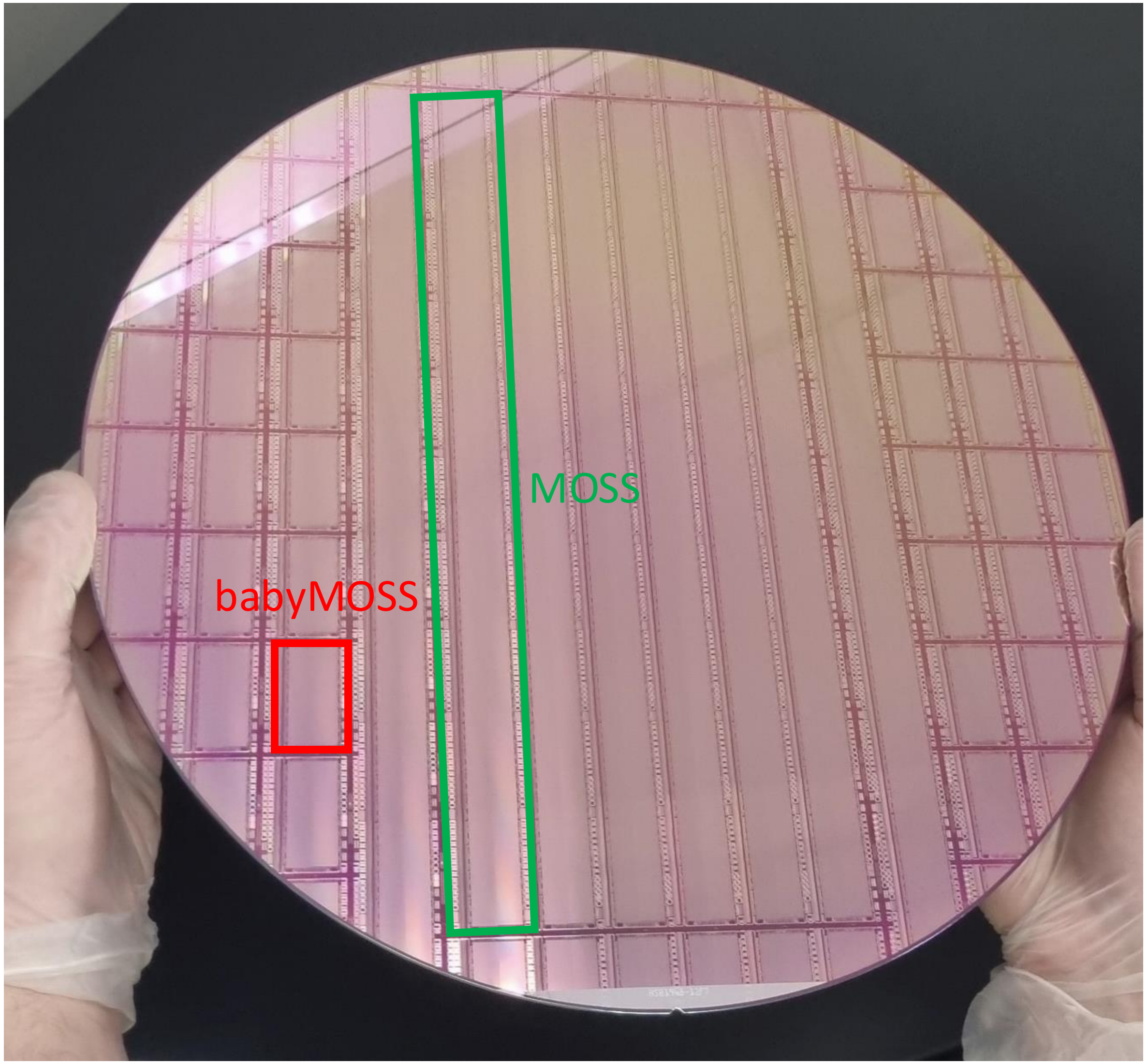
  -> Work on-going

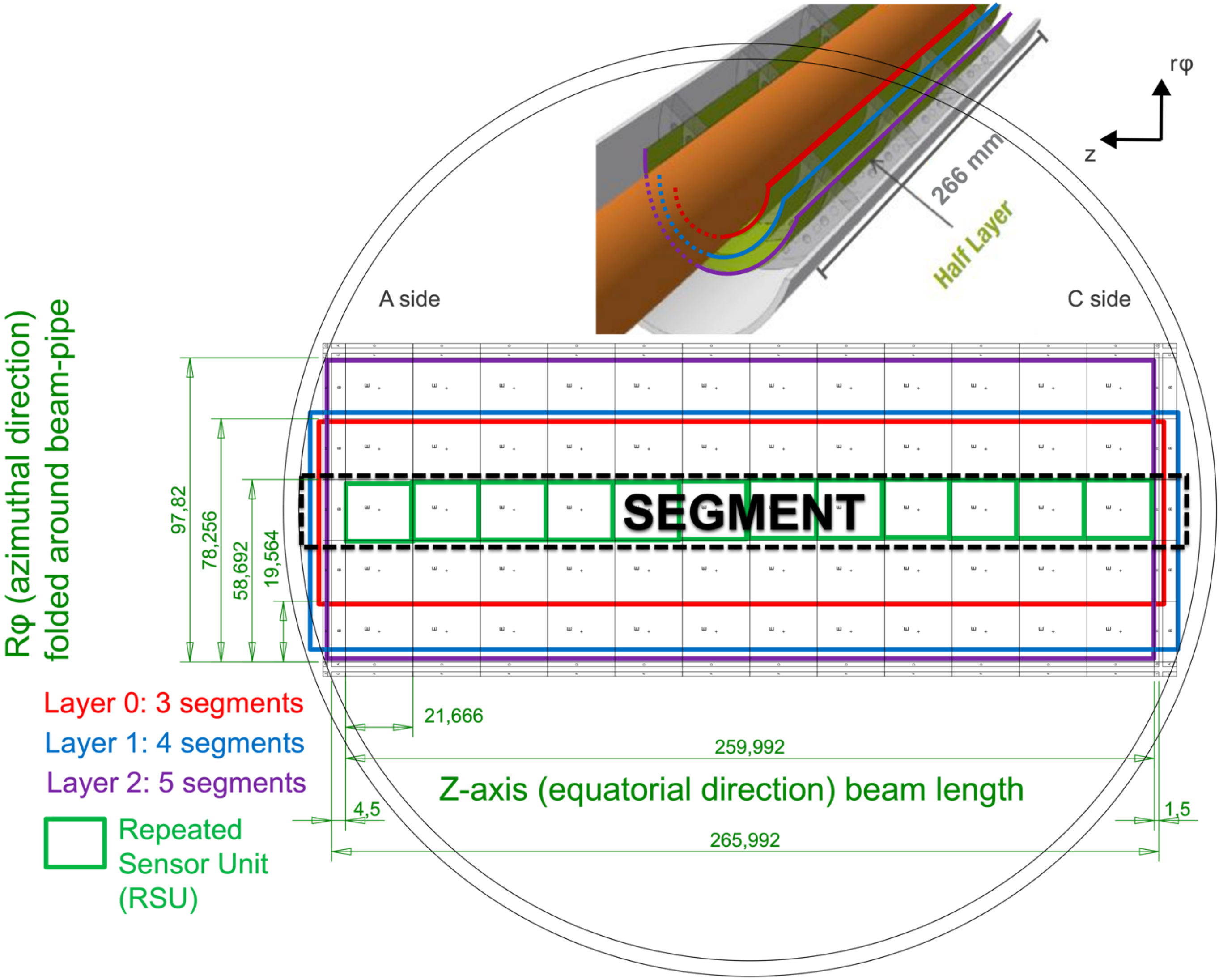
ePIC SVT Sensor Development Schedule

Today

- ✓ ITS3 feasibility study on TPSCo 65 nm CMOS technology (MLR1) 2021-2022
- ITS3 feasibility study on wafer scale sensor production based on stitching technique (ER1) 2022-2024
- ITS3 wafer scale sensor development (ER2, ER3) for IB 2024 – 2026,
- EIC-LAS development for OB and disks complete and ready for production start in Q4 2026,
- Ancillary IC development for EIC-LAS complete and ready for production start in Q2 2026.

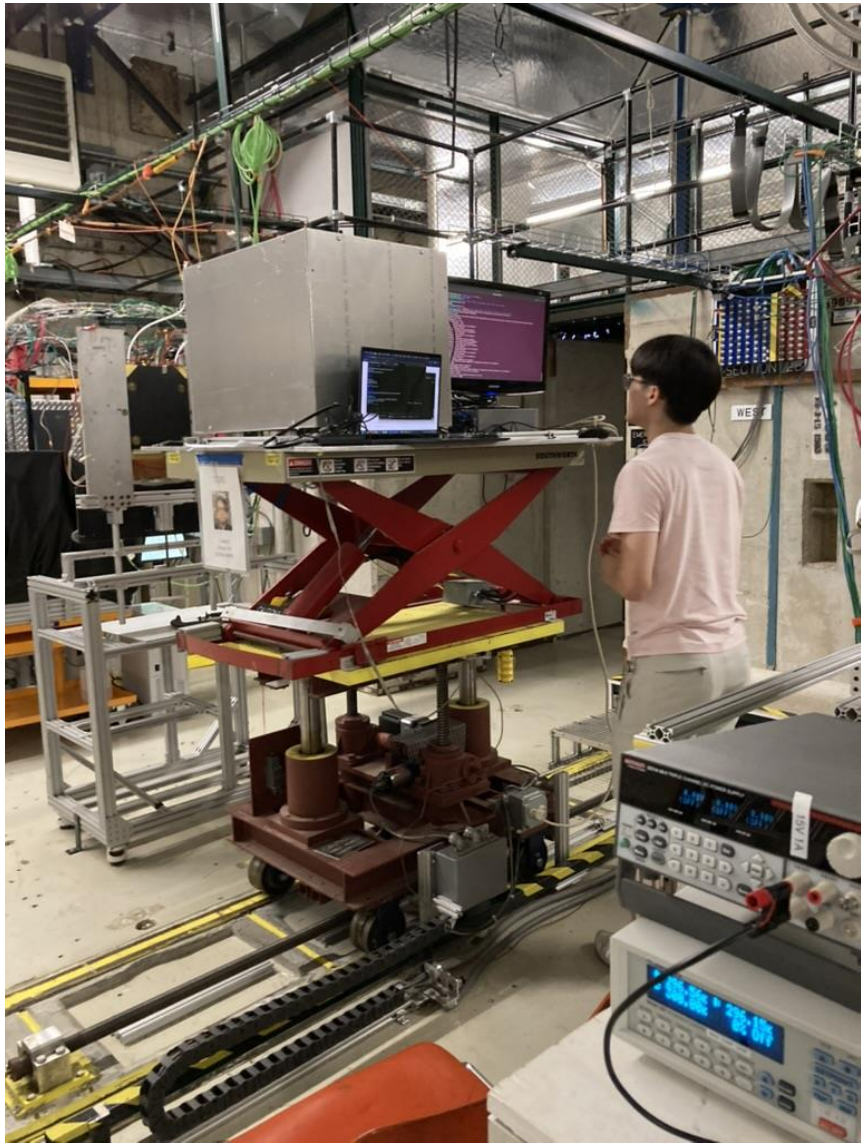
ALICE ITS3 ER1 – MOSS and babyMOSS Sensors

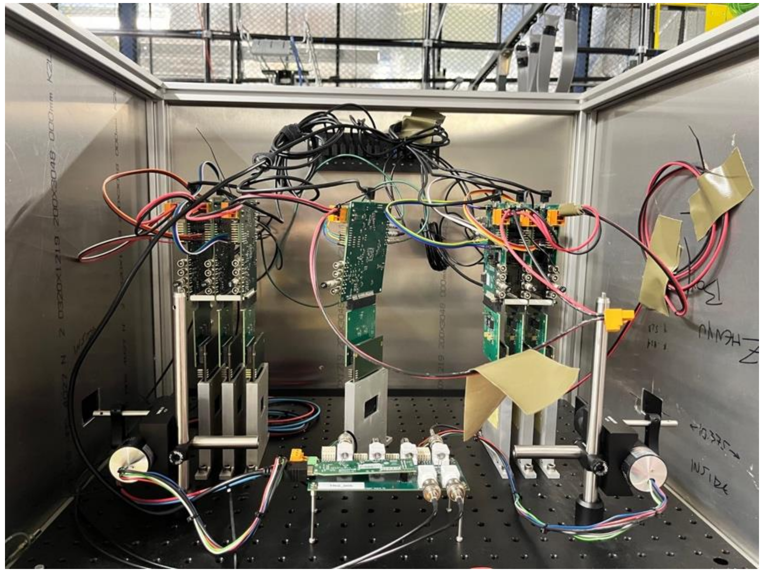


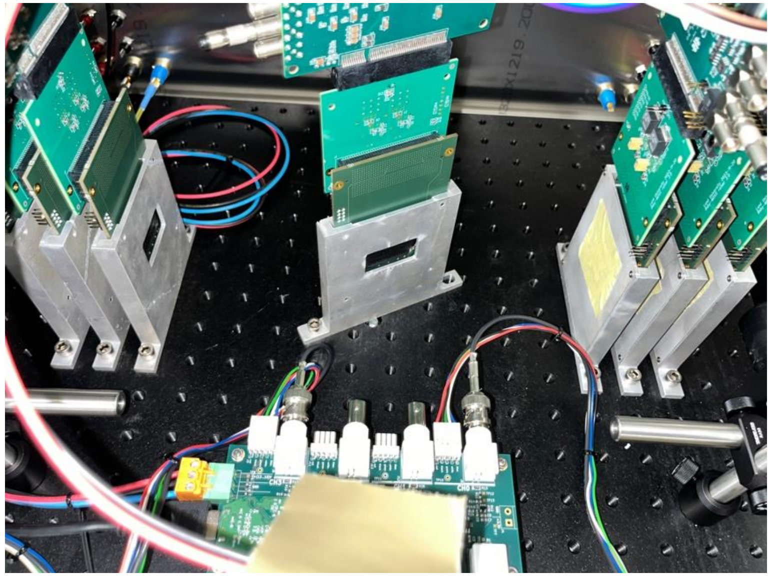


BabyMOSS Beam Tests at FTBF

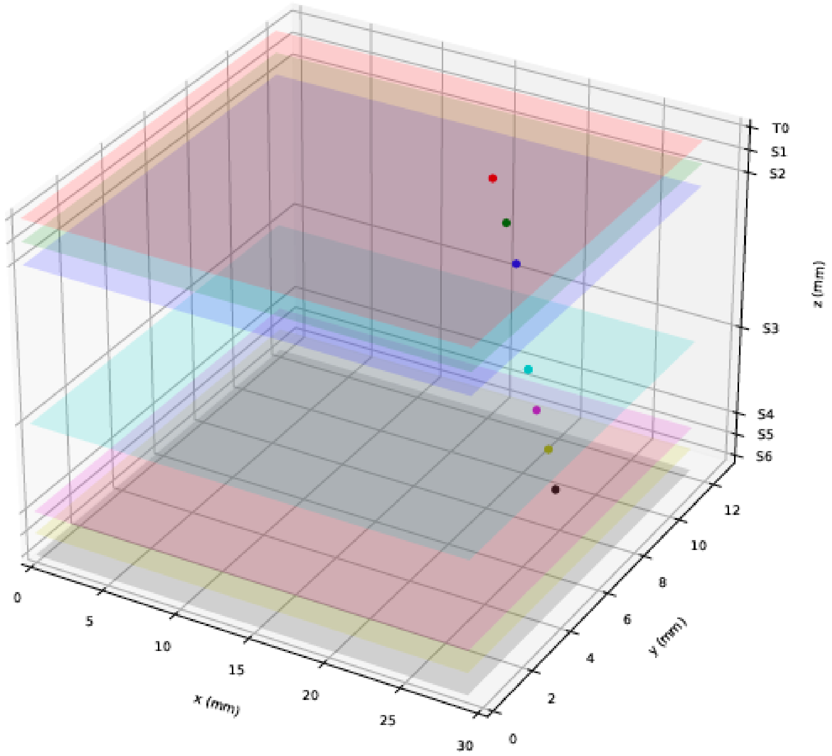
babyMOSS Telescope at Fermilab Test Beam Facility

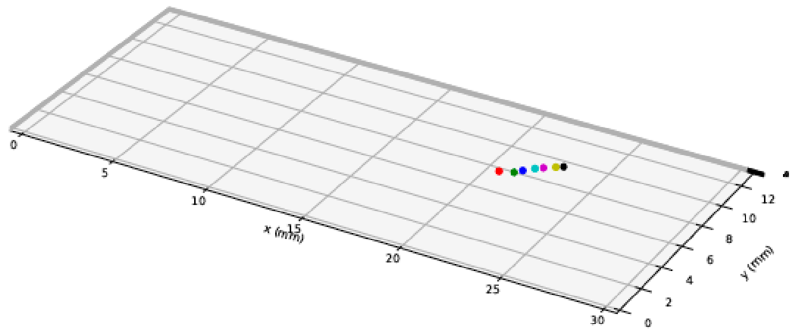






A 120 GeV proton beam event





LBL/UCB: Tucker Hwang, Zhenyu Ye; **UIC:** Danush Shekar

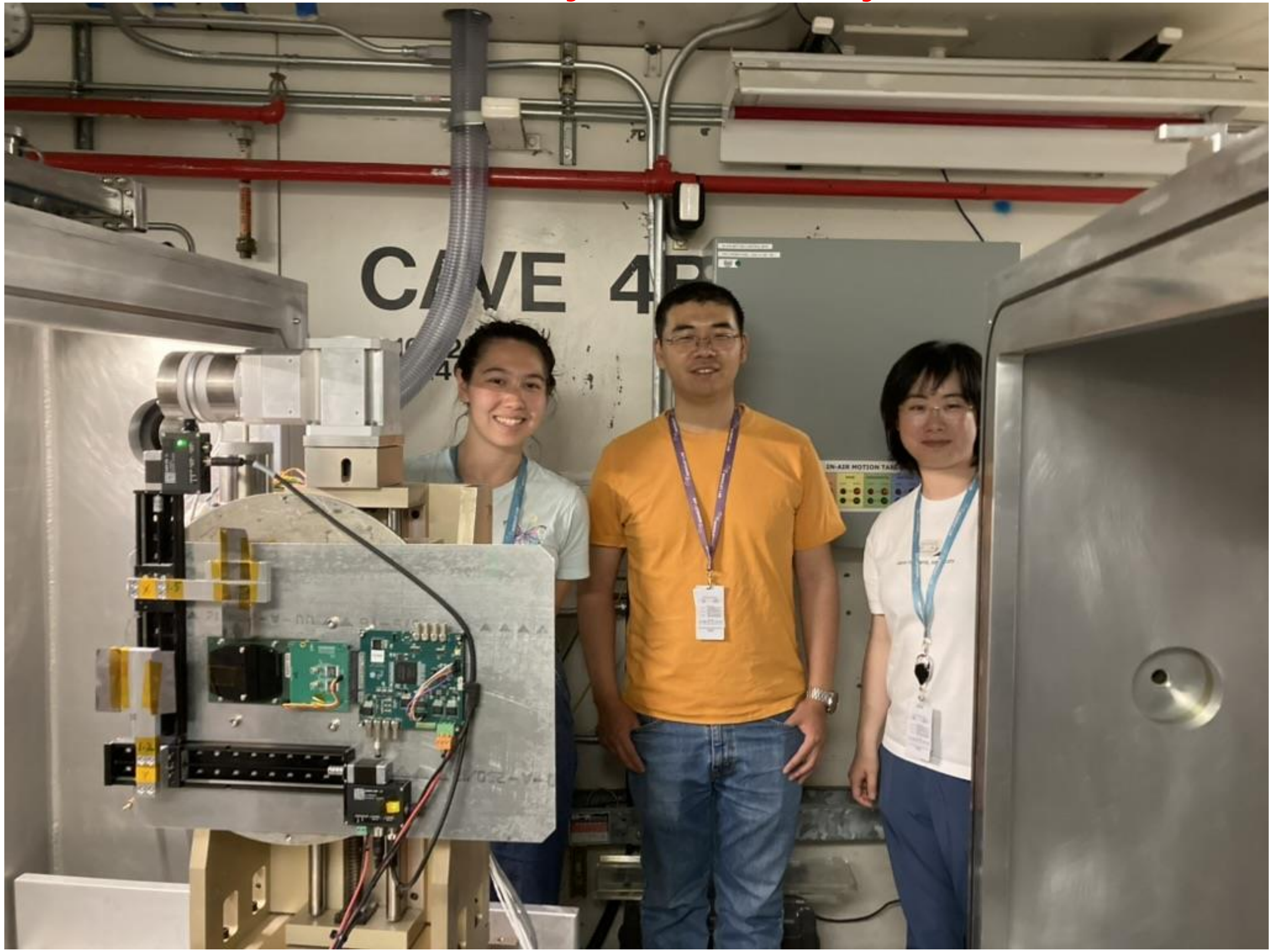
babyMOSS Beam Tests at FTBF

LBL/UCB: Tucker Hwang, Zhenyu Ye; **UIC:** Danush Shekar

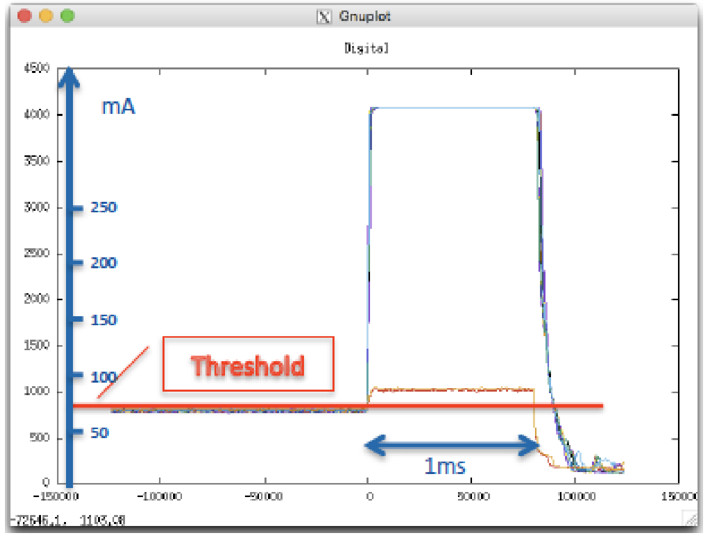
- May 22-June 4: commissioned a 7-plane babyMOSS telescope with 120 GeV protons
  - Took data to study the sensor performance with different incident angles between 0-75 degree
  - Issues:
    - Intermittent power loss that led to interruptions to data taking
    - Synchronization loss of the DUT that compromised the efficiency calculation
    - Significant secondary particles in the DUT holder at large incident angles that led to higher occupancy in the reference planes after the DUT
- June 26-July 12: took data with an improved setup at FTBF
  - Fixed the power cable connection that led to intermittent power losses
  - Reduced secondary particle production with modified babyMOSS holders
  - Got rid of synchronization losses with improved data taking and analysis procedures
  - Data analysis is nearly complete to extract efficiency, resolution, cluster size vs incident angle and threshold

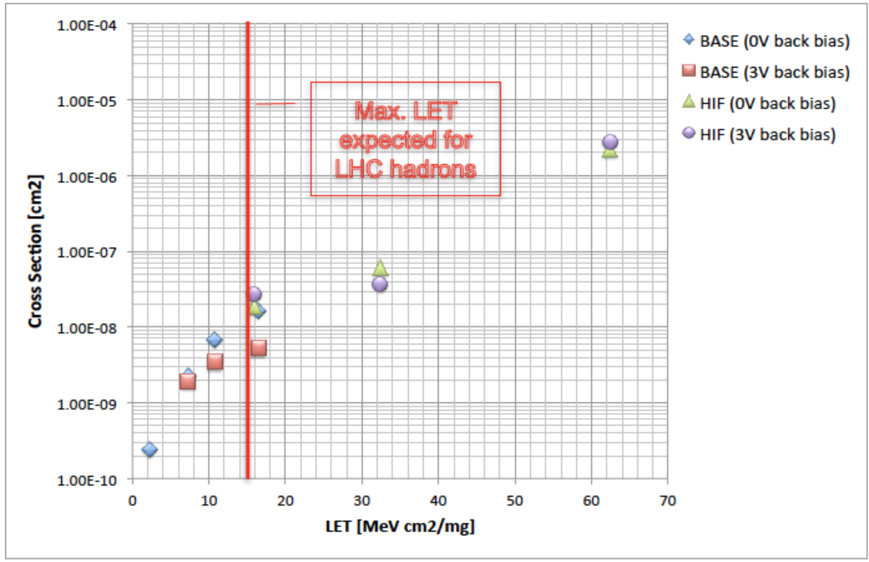
BabyMOSS SEE Tests at BASE

New members joined for July 1 test



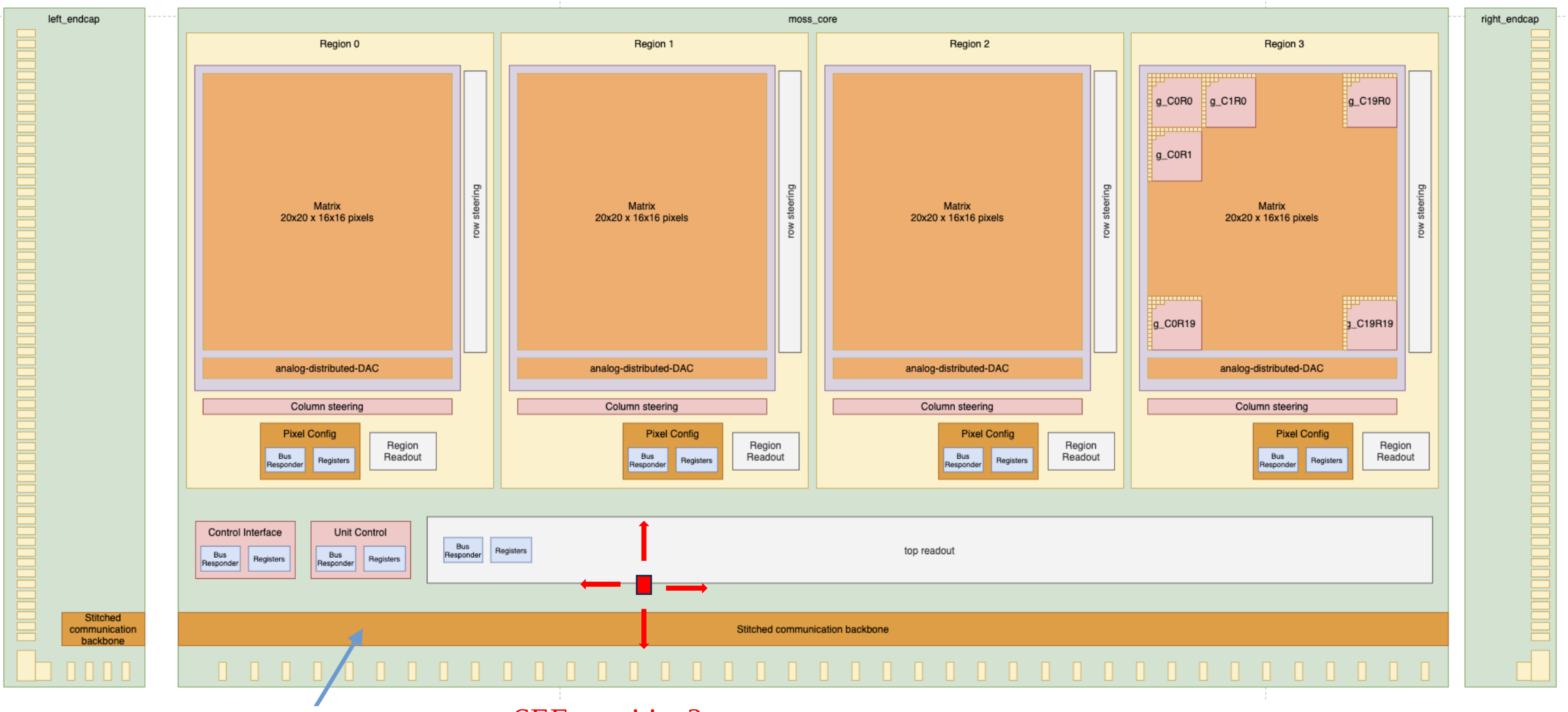
ALIPIDE for ITS2





LBL/UCB: Yu Hu, Barbara Jacak, Beatrice Liang-Gilman, Shujie Li, Anjali Nambrath, Emma Yeats, Zhenyu Ye;
CERN: Hartmut Hillemanns; **KU:** Nicola Minafra; **UC Riverside:** Barak Schmookler

BabyMOSS SEE Tests at BASE



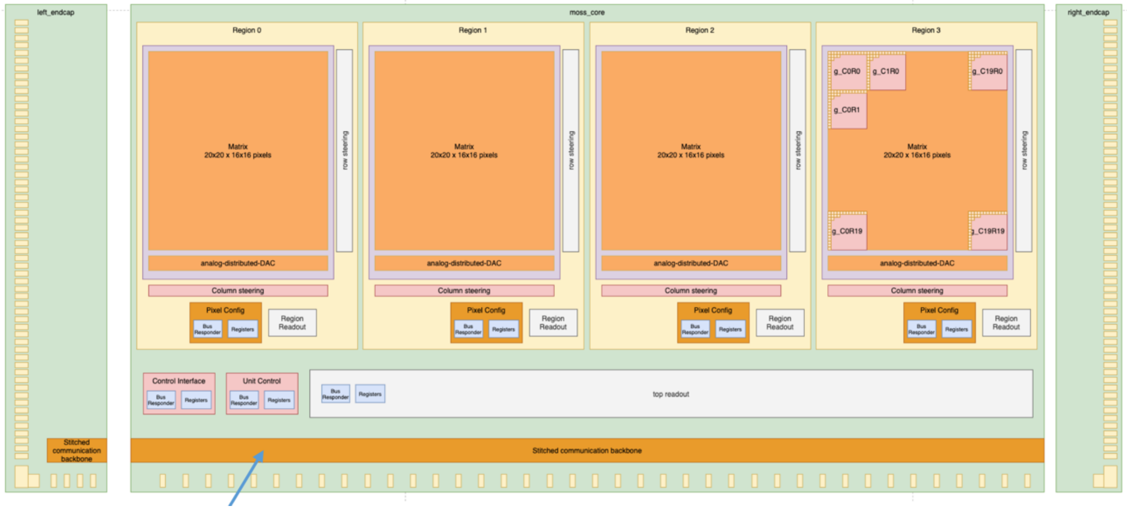
SEE sensitive?

BabyMOSS SEE Tests at BASE

LBL/UCB: Yu Hu, Barbara Jacak, Beatrice Liang-Gilman, Shujie Li, Anjali Nambrath, Emma Yeats, Zhenyu Ye;

CERN: Hartmut Hillemanns; **KU:** Nicola Minafra; **UC Riverside:** Barak Schmookler

- May 22-23:
  - Initial commission of the setup with motion-controlled collimators
  - Scan in X and Y to search for SEL-sensitive circuits with 1.5 (1.2) mm gap collimator in X (Y)
  - Scan in X and Y to search for SEL-sensitive circuits with 0.2 mm gap collimators
- July 1:
  - Measure the SEL and DAC SEU cross-section as a function of LET
  - Scan in Y to search for SEL-sensitive circuits with 0.2 mm gap collimator
- Data analysis is nearly complete to extract cross-sections and locations of sensitive circuits on babyMOSS



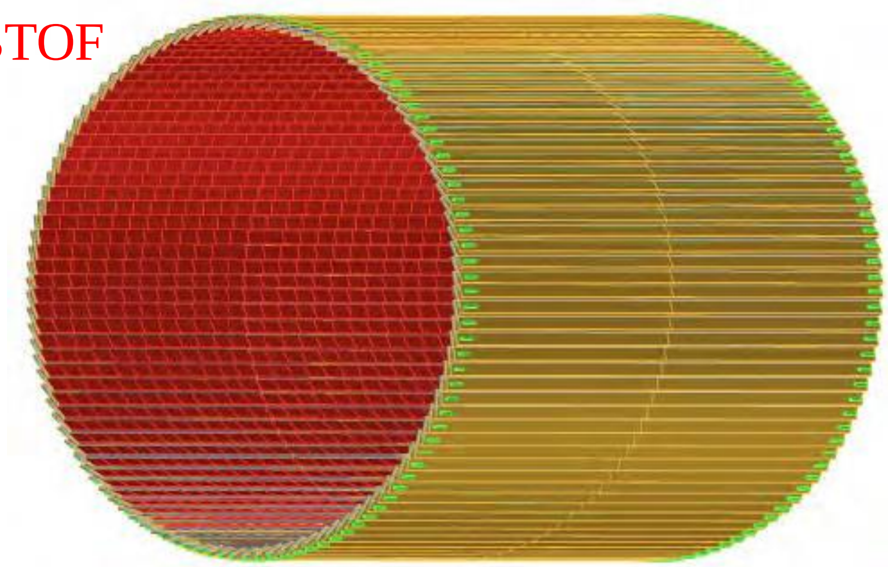
Summary and Outlook

- **Sensor Design**
  - Main sensor: contributed to Design-for-Manufacturing standard cell library for ER2 submission
  - Ancillary IC: serial powering, slow control (IC designer from Engineering, new RNC SEA start today)
- **Sensor Characterization**
  - **MLR1 sensor temperature dependence with a climatic chamber at LBL (Barak from UC Riverside)**
  - **ER1 sensor beam tests at Fermilab Test Beam Facility**
    - Assembled and commissioned a 7-plane babyMOSS telescope with 120 GeV protons
    - Studied the dependence of sensor performance on incident angle
  - **ER1 sensor SEE tests at Berkeley Accelerator Space Effects Facility**
    - Measured babyMOSS SEL and DAC register SEU cross-sections as a function of LET
    - Searched for SEL-sensitive circuits on babyMOSS with motion-controlled collimators
  - **ER1 sensor tests in winter 2024/Spring 2025:**
    - Irradiate babyMOSS sensors and study the temperature dependence in the lab and with beam
- **Extensive R&D and construction work planned on sensor and Ancillary IC for SVT, in combination with readout electronics, mechanics and module assembly in 2024-2027.**
- **R&D work also planned for AC-LGAD detectors**

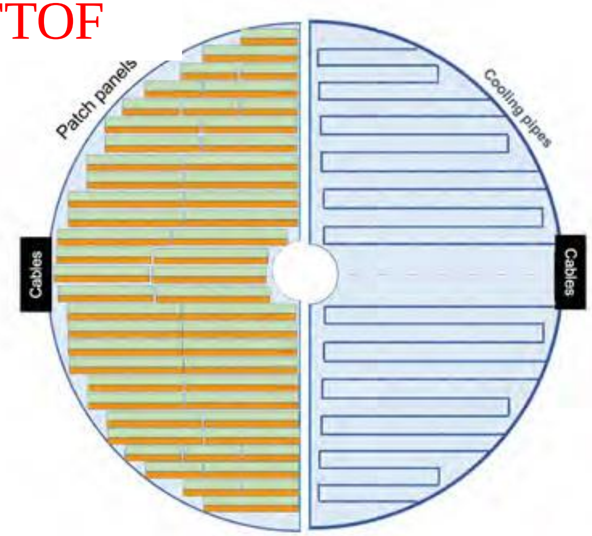
Backup

ePIC AC-LGAD Detector Specifications

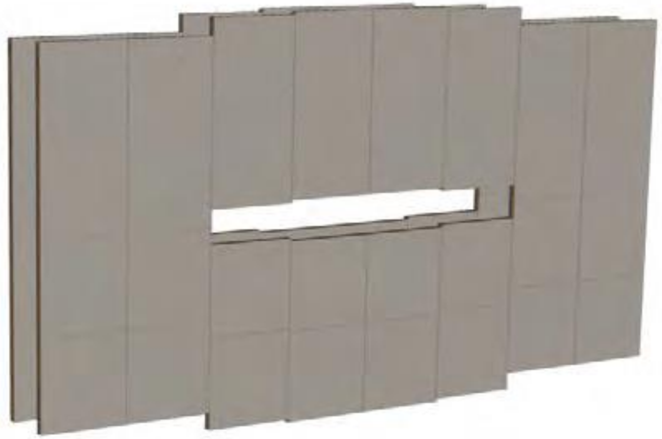
BTOF



FTOF



Roman Pots



	Area (m^2)	Channel size (mm^2)	# of Channels	Timing Resolution	Spatial resolution	Material budget
Barrel TOF	12	0.5*10	2.4M	35 ps	30 μm in $r \cdot \varphi$	0.01 X_0
Forward TOF	1.1	0.5*0.5	4.5M	25 ps	30 μm in x and y	0.05 X_0
B0 tracker	0.07	0.5*0.5	0.28M	30 ps	20 μm in x and y	0.05 X_0
RPs/OMD	0.14/0.08	0.5*0.5	0.56M/0.32M	30 ps	140 μm in x and y	no strict req.
LUMI Tracker	0.32	0.5*10	64k	35 ps	30 μm in x or y	0.01 X_0

Requirements on timing and spatial resolutions and material budget are still being evaluated and are subject to change as the design matures, and we will continue to explore common designs for these detectors where possible to reduce cost and risk.

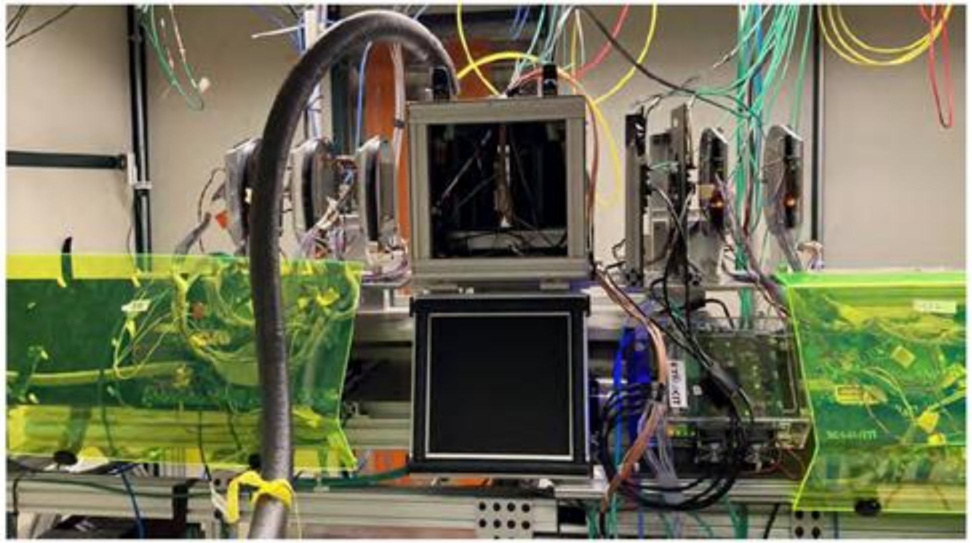
Prototyping for ePIC AC-LGAD Detectors

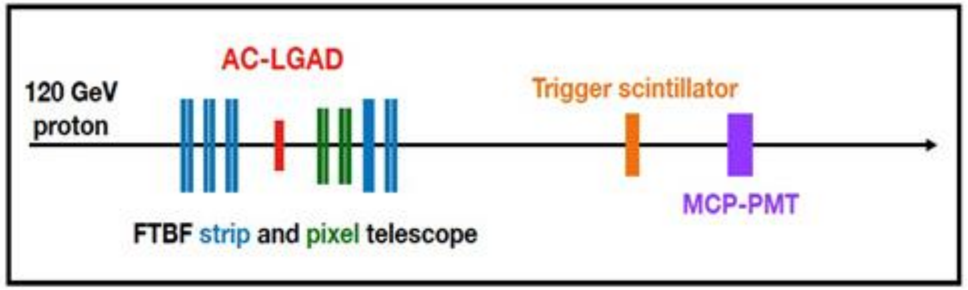
[1] Journal of Instrum. (2023)
[2] submitted to NIMA (2024)

- Sensors produced by BNL-IO and HPK for EIC, and tested with 120GeV protons [1,2]
  - Prototype strip sensors with ~35 ps time resolution and <15 um spatial resolution
  - Prototype pixel sensors with ~20 ps time resolution and ~20* um spatial resolution.

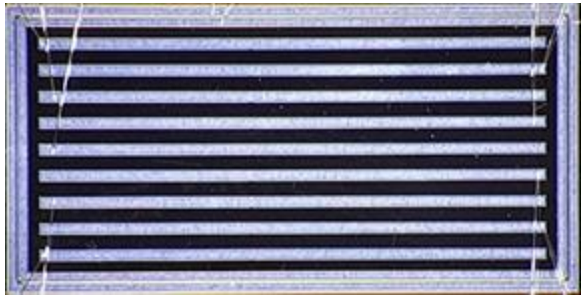
* ~50 um under metal electrodes. To be improved

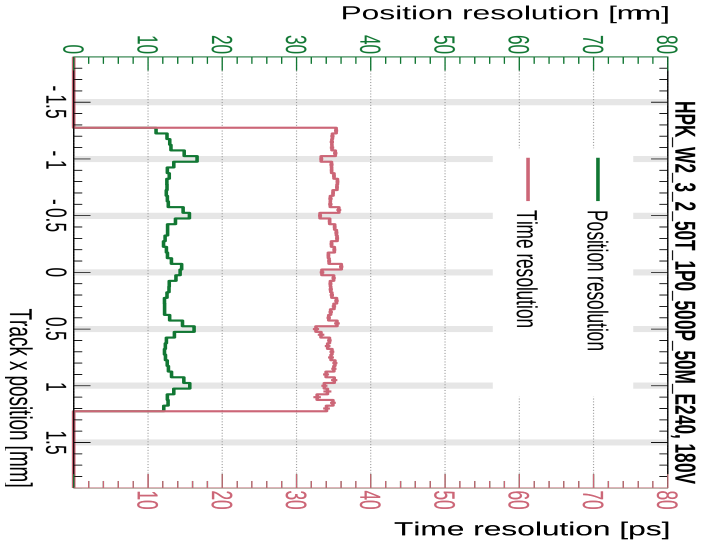
Fermilab Test Beam Setup



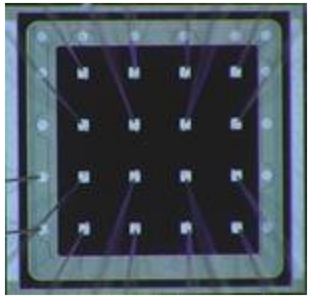


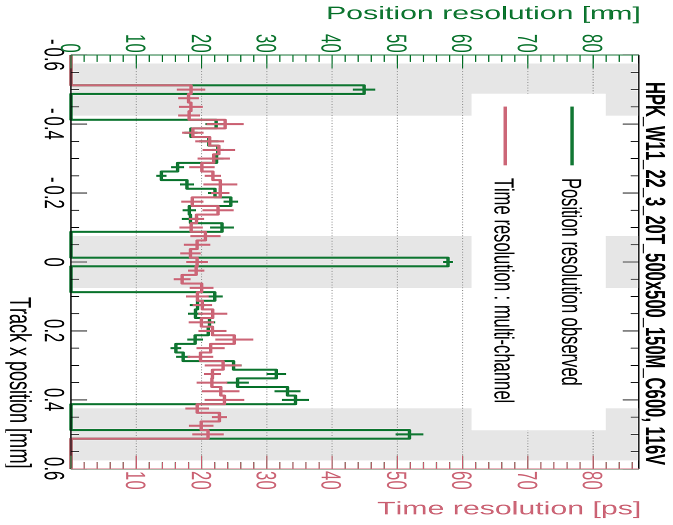
HPK Strip Sensor (4.5x10 mm^2)





HPK Pixel Sensor (2x2 mm^2)





Beam Tests for AC-LGAD Detector Prototypes