# EIC AC-LGAD R&D FY23 Report and FY24 Proposal


**eRD112 (this talk)**

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**Los Alamos National Laboratory**: X. Li, E. Renner
**National Cheng Kung University/Academia Sinica (Taiwan)**: W.-C. Chang, P.-J. Lin, Y. Yang
**Purdue University**: S. Karmarkar, A. Jung
**University of California, Santa Cruz**: M. Gignac, S. Mazza, J. Ott, A. Seiden, S.H. Sadrozinski, B. Schumm
**University of Illinois at Chicago**: O. Evdokimov, S. Nanda, D. Shekar, Z. Ye

**eRD109 (Fernando's talk)**

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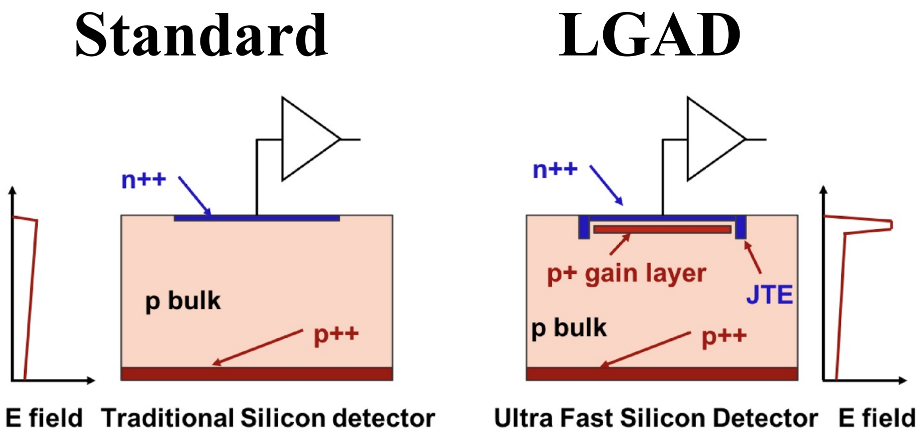
**University of Illinois at Chicago**: O. Evdokimov, S. Nanda, D. Shekar, Z. Ye

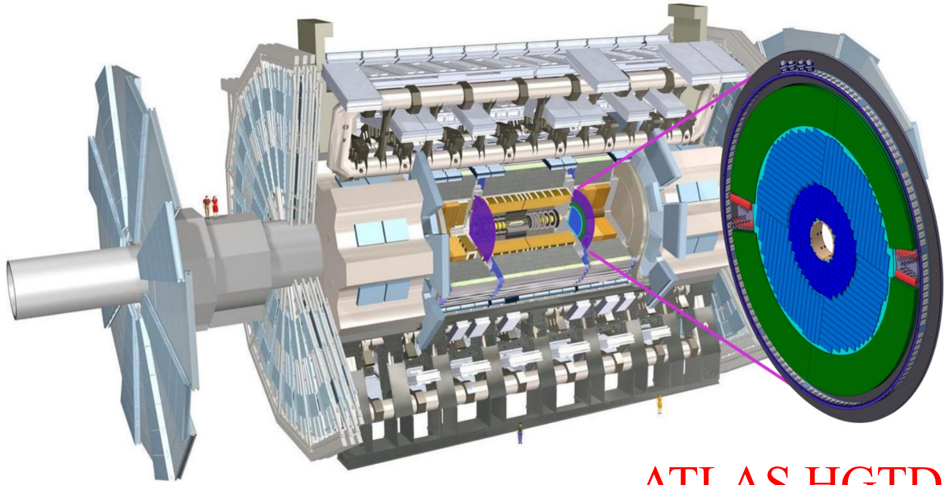
**Institutions seeking external resources:**

**University of Science and Technology of China (China), National Institute of Sci. Edu. and Research (India)**
**Hiroshima University (Japan), Nara Women's University (Japan), RIKEN (Japan), Univ of Tokyo (Japan)**

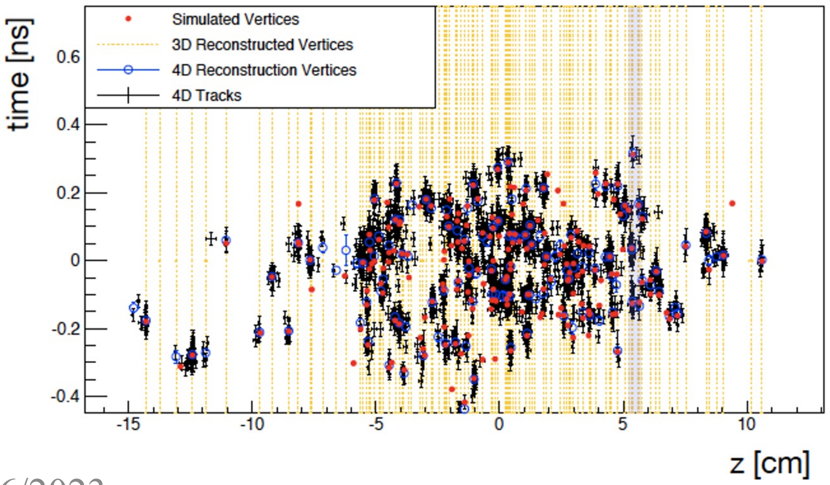
# Low Gain Avalanche Diode

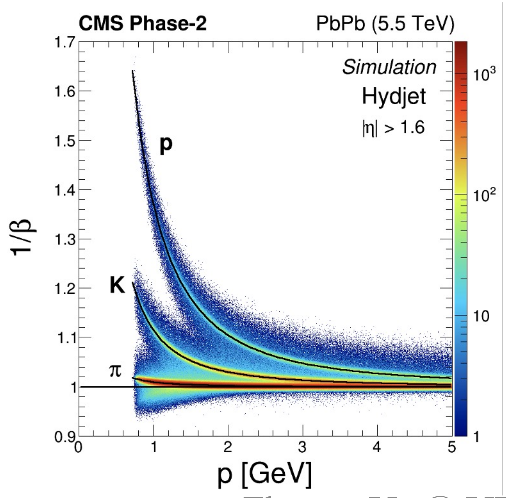
- Utilizing synergies to LGAD detectors at ATLAS (6 $m^2$) and CMS (14 $m^2$) for HL-LHC.

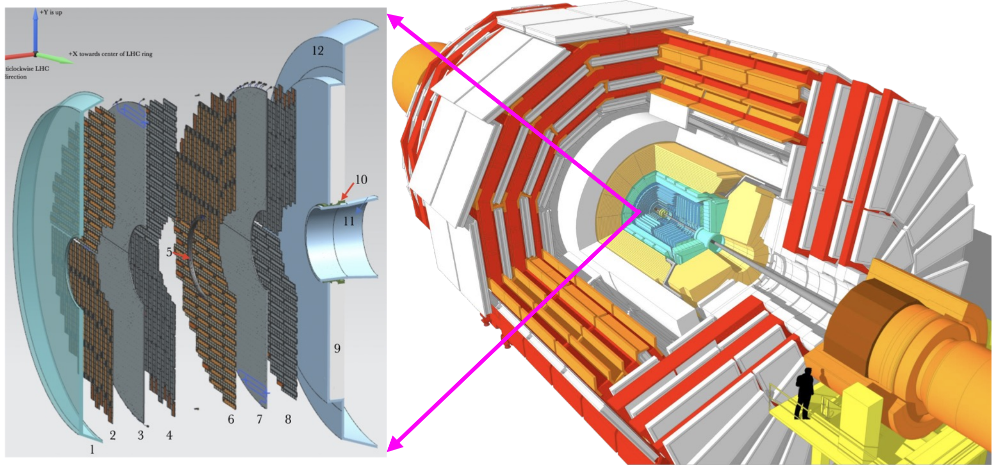


ATLAS HGTD



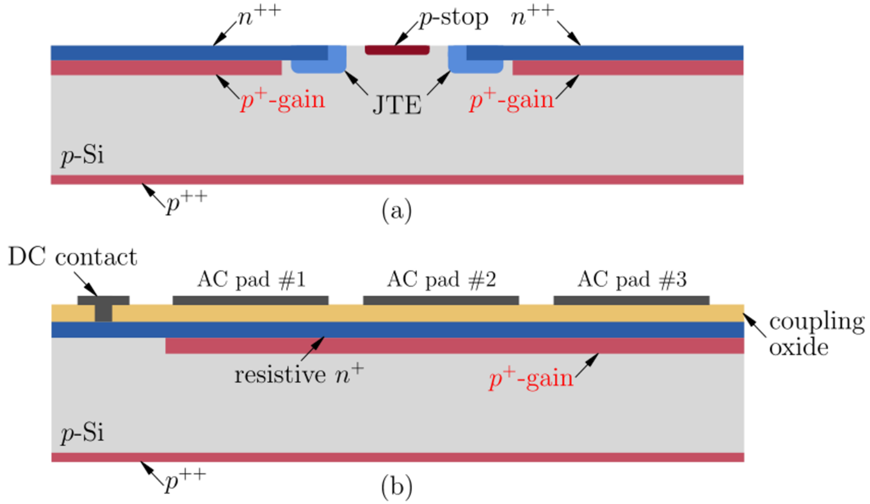
CMS ETL

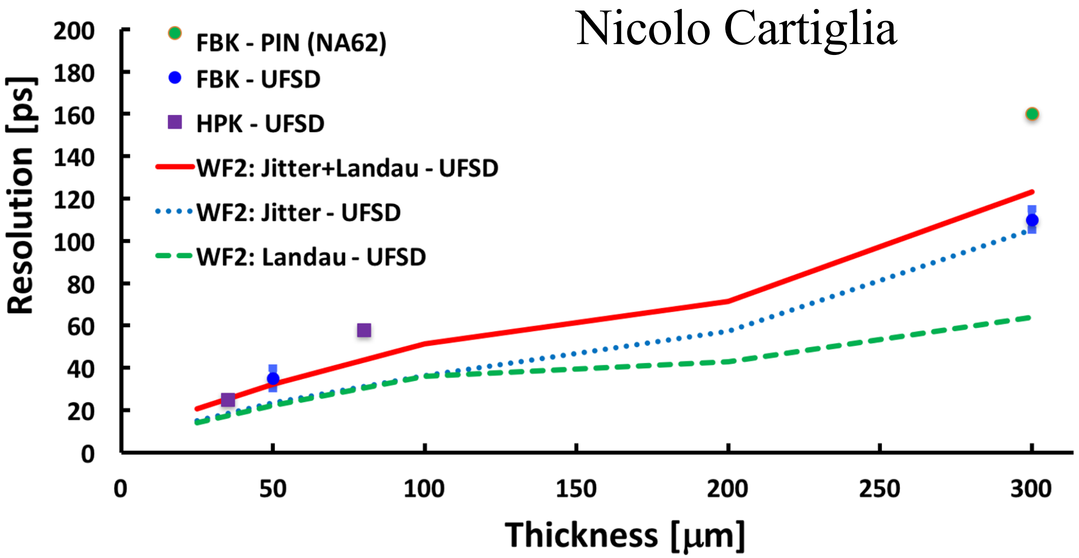
# AC-coupled LGAD

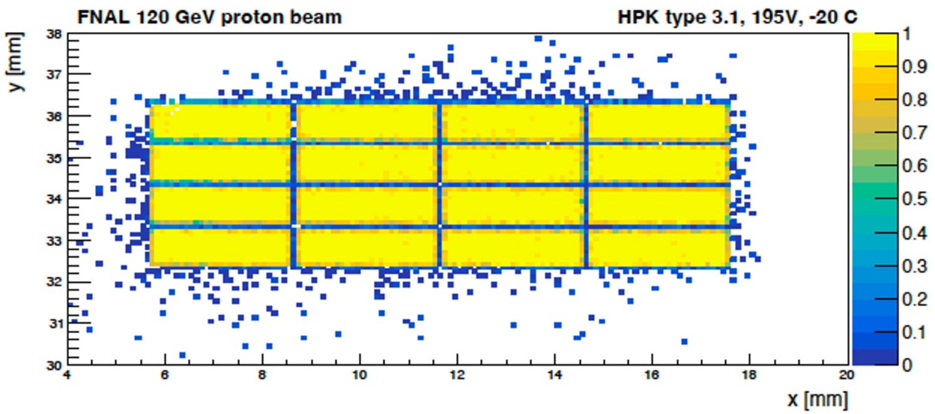
- AC-LGAD provides not only precise timing resolution, but also ~100% fill factor and much better spatial resolution than DC-LGAD.

(DC-)LGAD

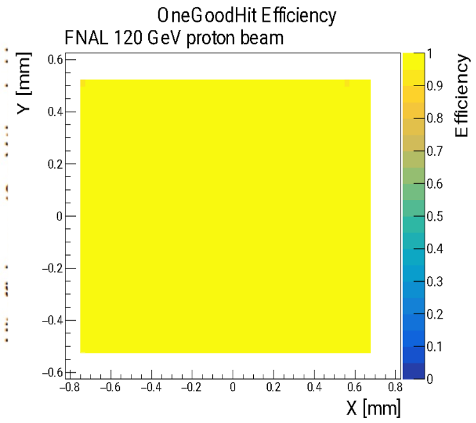
AC-LGAD



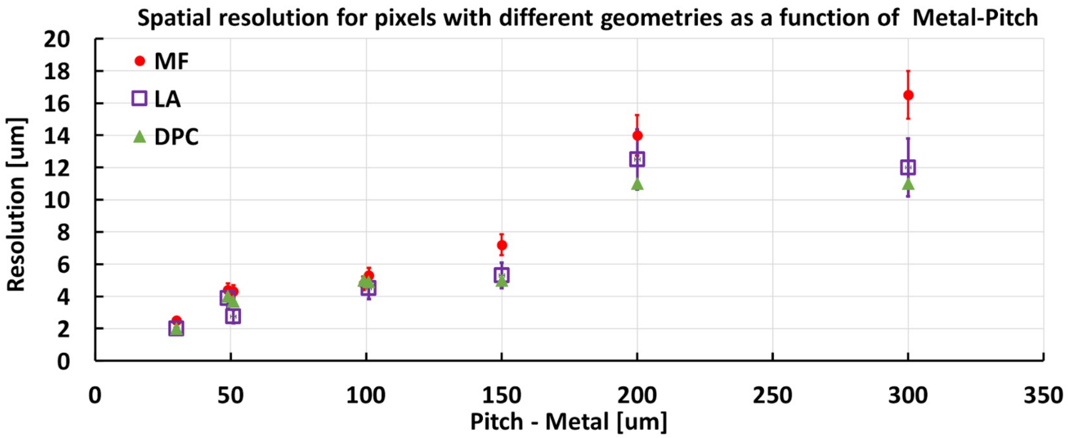




DC-LGAD

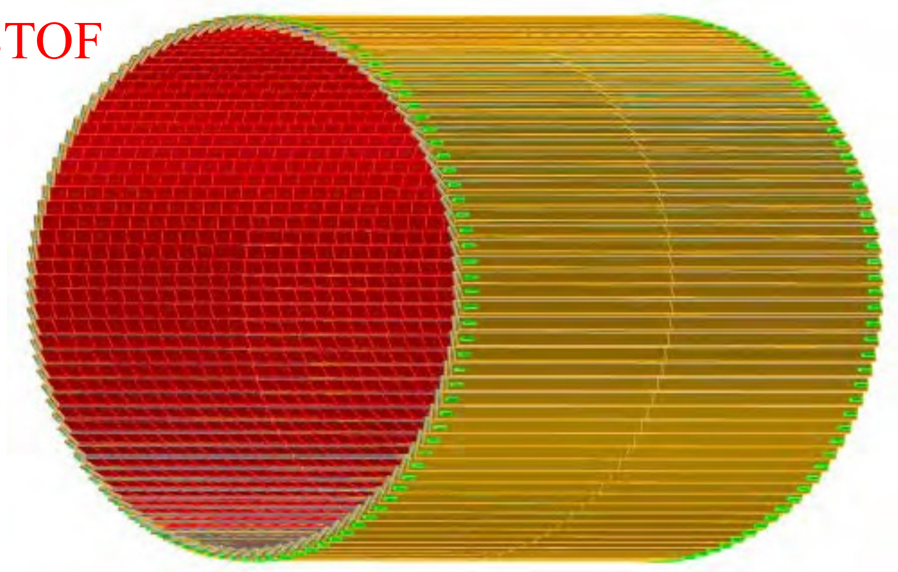



AC-LGAD

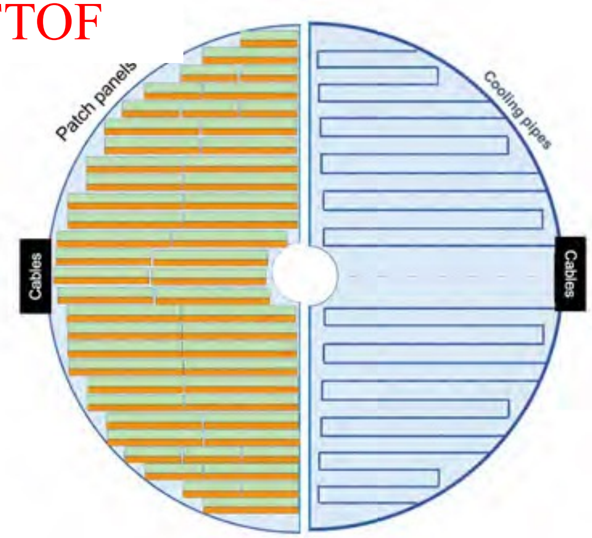


# ePIC AC-LGAD Detector Requirements (Last Year)

BTOF



FTOF



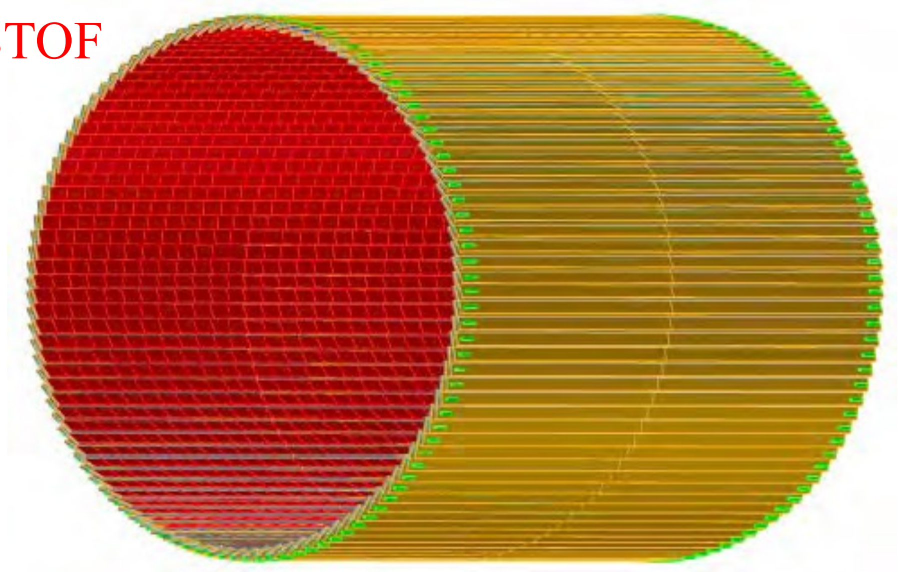

Roman Pots

| | Area ($m^2$) | Channel size ($mm^2$) | # of Channels | Timing Resolution | Spatial resolution | Material budget |
|---|---|---|---|---|---|---|
| Barrel TOF | 10 | 0.5*10 | 2.4M | 30 ps | 30 $\mu m$ in $r \cdot \varphi$ | 0.01 $X_0$ |
| Forward TOF | 1.4 | 0.5*0.5 | 5.6M | 25 ps | 30 $\mu m$ in x and y | 0.08 $X_0$ |
| B0 tracker | 0.07 | 0.5*0.5 | 0.28M | 30 ps | 20 $\mu m$ in x and y | 0.01 $X_0$ |
| RPs/OMD | 0.14/0.08 | 0.5*0.5 | 0.56M/0.32M | 30 ps | 140 $\mu m$ in x and y | no strict req. |

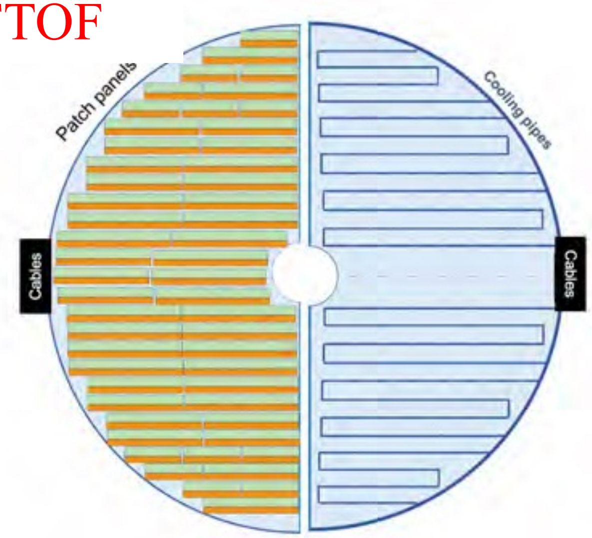
Requirements on timing and spatial resolutions and material budget are still being evaluated and are subject to change as the design matures, and we will continue to explore common designs for these detectors where possible to reduce cost and risk.

# ePIC AC-LGAD Detector Requirements (Current)

BTOF



FTOF



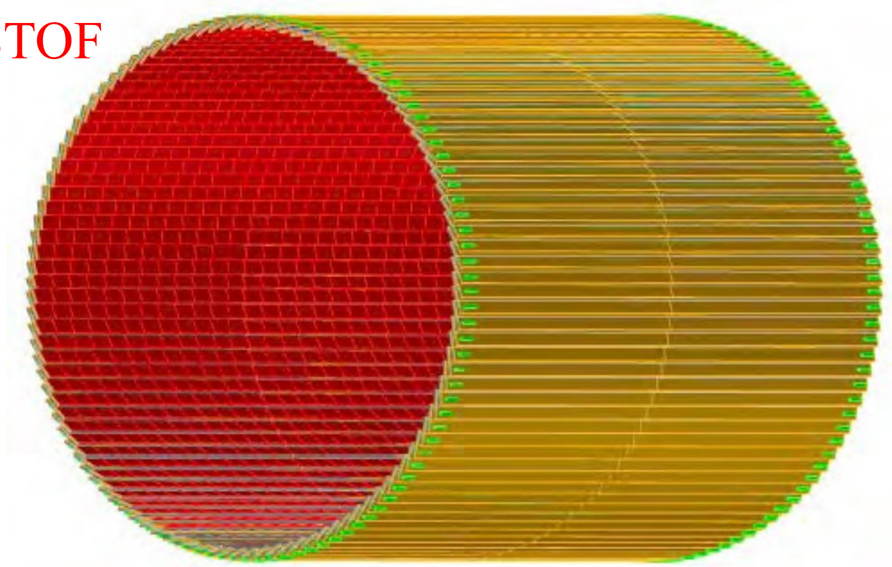

Roman Pots

| | Area ($m^2$) | Channel size ($mm^2$) | # of Channels | Timing Resolution | Spatial resolution | Material budget |
|---|---|---|---|---|---|---|
| Barrel TOF | 10 | 0.5*10 | 2.4M | 30 → 35 ps | 30 $\mu m$ in $r \cdot \varphi$ | 0.01 $X_0$ |
| Forward TOF | 1.4 | 0.5*0.5 | 5.6M | 25 ps | 30 $\mu m$ in x and y | 0.08 → 0.025 $X_0$ |
| B0 tracker | 0.07 | 0.5*0.5 | 0.28M | 30 ps | 20 $\mu m$ in x and y | 0.01 → 0.05 $X_0$ |
| RPs/OMD | 0.14/0.08 | 0.5*0.5 | 0.56M/0.32M | 30 ps | 140 $\mu m$ in x and y | no strict req. |

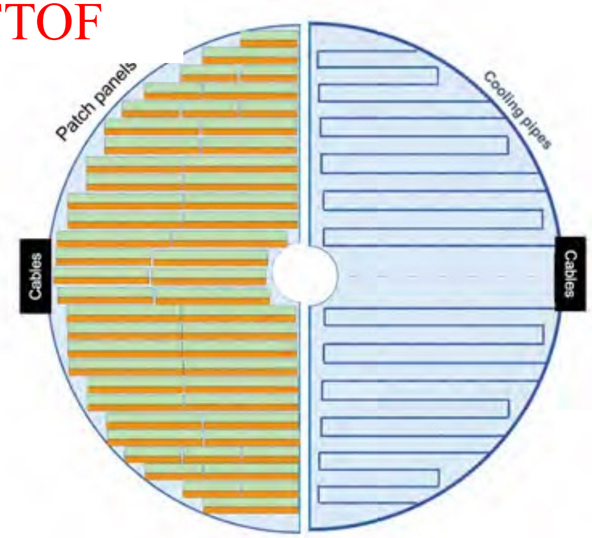
Requirements on timing and spatial resolutions and material budget are still being evaluated and are subject to change as the design matures, and we will continue to explore common designs for these detectors where possible to reduce cost and risk.

# ePIC AC-LGAD Detector Module Designs

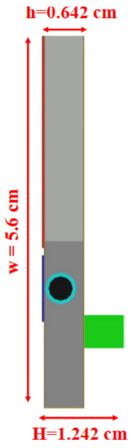
BTOF

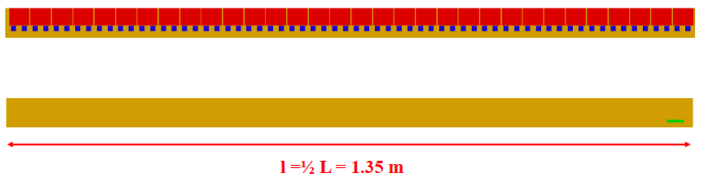


FTOF

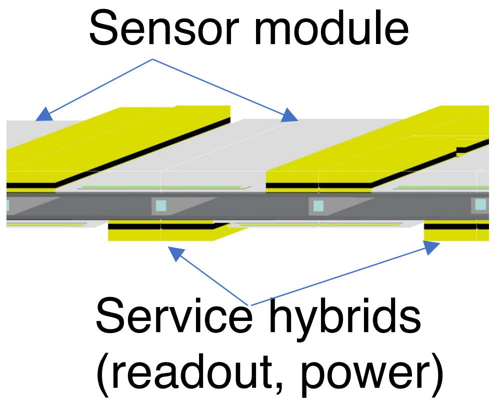


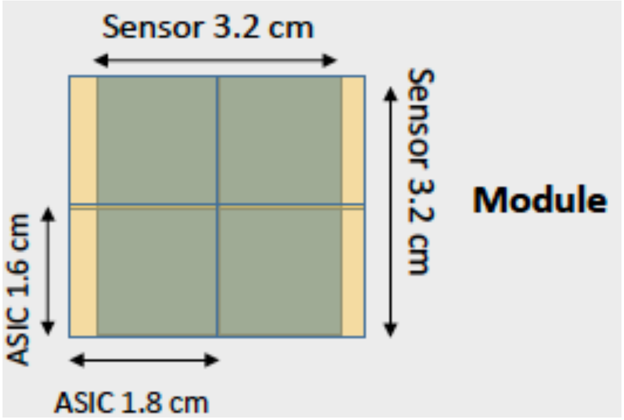

Roman Pots



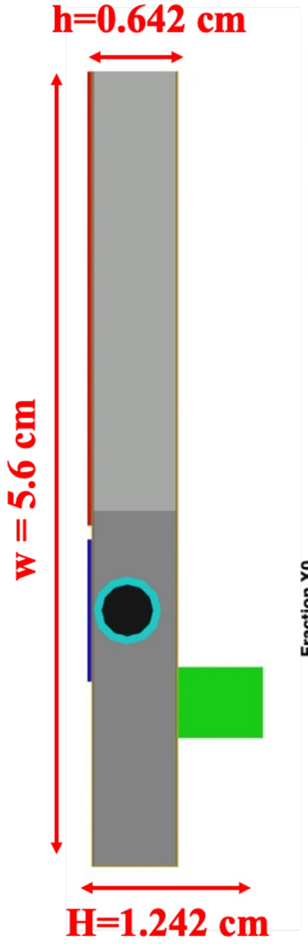

- 32 AC-LGAD sensors, each 3.2*4 cm² read out by 2 ASICs
- Low mass flexible Kapton PCB distributes power and I/O signals from a low mass connector(s) at the edge
- **Liquid coolant** in Al cooling tube takes away heat from the ASICs

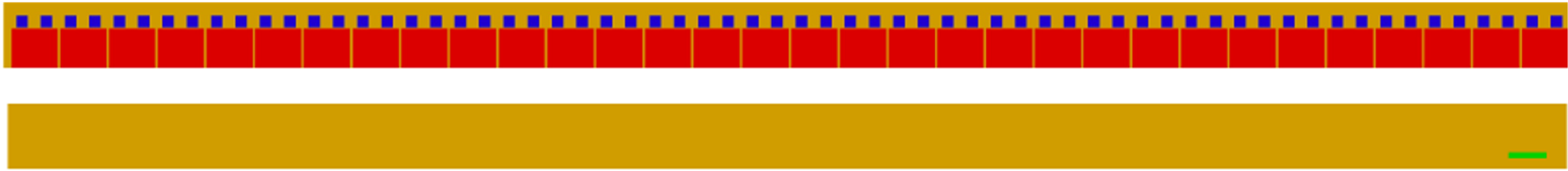


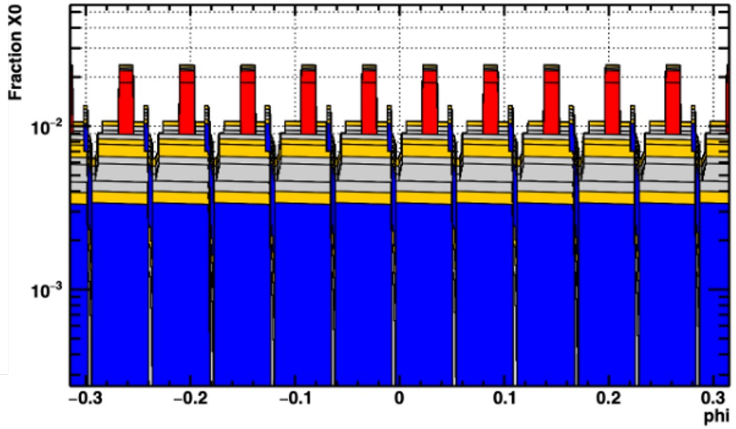

Key components -> detector module -> integration and services

# ePIC BTOF Detector Module Conceptual Design



- **64 AC-LGAD strip sensors**, each 3.2*4 $cm^2$ read out by **2 ASICs**
- **Low mass flexible Kapton PCB** distributes power and I/O signals from connector
- **Liquid coolant** in **Al tube** embedded in CF light-weight structure for heat removal

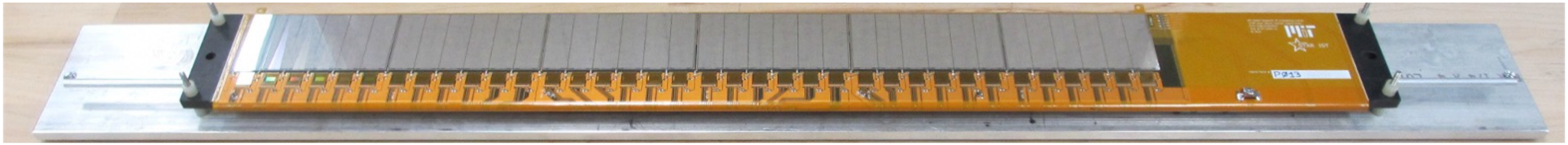


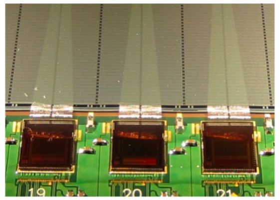

144 modules, each with 2 readout boards with 2 LV+HV cables, 2 DAQ fiber, and 1 cooling line

Power consumption: ~4 kW (2.4kW for ASIC, 1 kW for DC-DC, 0.6kW for sensors+cable)

Total weight: ~70 kG

**STAR IST**





# Key Components for AC-LGAD Detectors

- **AC-LGAD sensor:**
  - Goal: large area sensors that meet timing/spatial resolution requirements with minimal # channels
  - Approach: utilize BNL IO to optimize the sensor design (pitch, electrode width, n-layer doping density, active volume thickness); engage commercial vendors to verify sensor quality and production cost/yield
- **Sensor/ASIC integration:**
  - Goal: cost-effective way to establish reliable electrical and mechanical connections between sensor and ASIC
  - Approach: bump-bonding, wire-bonding, interposer
- **Mechanical structure with cooling:**
  - Goal: light-weight structure with cooling that meet the material budget, thermal and mechanical requirements
  - Approach: finite element analysis and prototyping with carbon-fiber composite and/or PEEK materials
- **Frontend ASIC:**
  - Goal: low jitter (<15 ps) and low power (~1 mW/channel), streaming readout with TDC and ADC outputs
  - Approach: custom-designed EICROC and FCFD, ASICs from 3rd party institutions
- **Frontend readout electronics:**
  - Goal: low jitter clock (<5 ps), low $X_0$ flexible module PCB, service hybrid (readout and power board)
  - Approach: design a precise clock distribution system in concert with EPIC DAQ group, design and prototype flexible PCB that meet the requirements; design and prototype service hybrid

# eRD112 FY23 Report

$461k requested, $250k approved in 2/2023

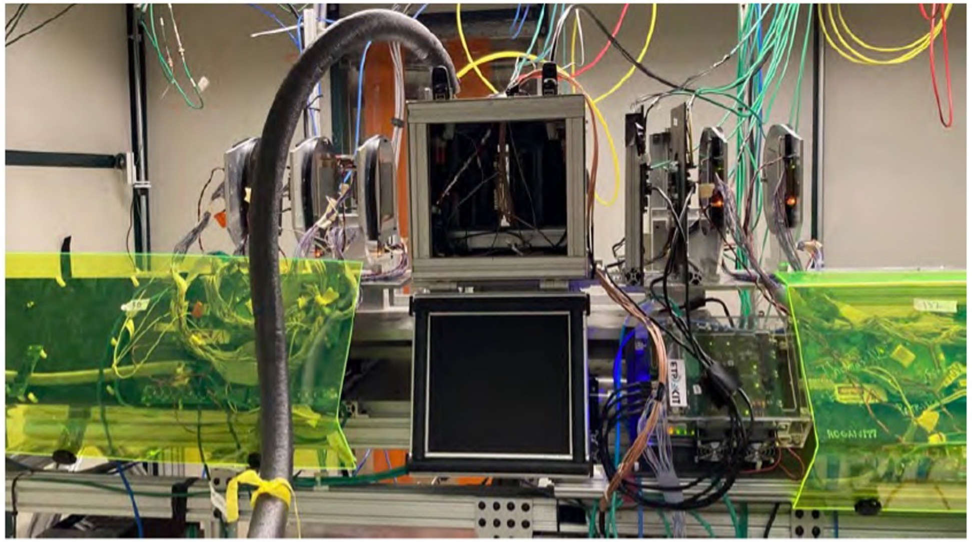
- AC-LGAD Sensor
  - ✓TCAD simulation
  - ✓Productions by BNL IO and HPK/~~FBK~~
  - ✓Sensor characterization in the lab/beam
  - ~~Irradiation test~~
- ~~Sensor/ASIC integration~~
  - ~~Interposer to connect pixelated ASICs with strip sensors, or pixel sensors with various pitch~~
- Mechanical structure
  - ✓Light-weight structure made from carbon-fiber composite materials and/or PEEK

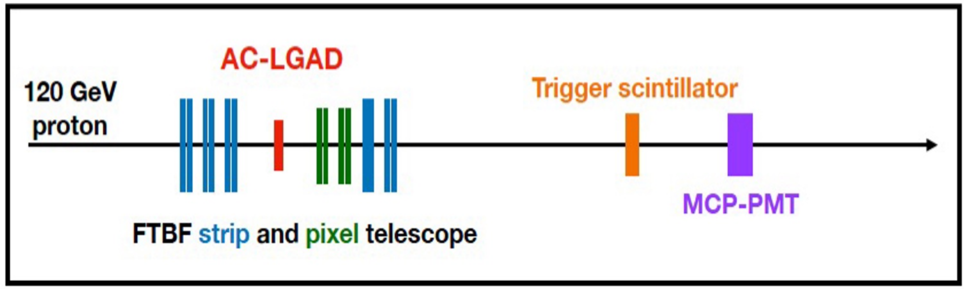
# eRD112 FY23 Deliverables - Sensor

- **Sensor**
  - Sensors with different configurations produced by BNL-IO and Hamamatsu, and tested with 120GeV protons
  - Prototype strip sensors with ~34 ps time resolution and 12-15 um spatial resolution for BToF.
  - Prototype pixel sensors with ~20 ps time resolution and ~20* um spatial resolution for FToF, B0, RPs/OMD.

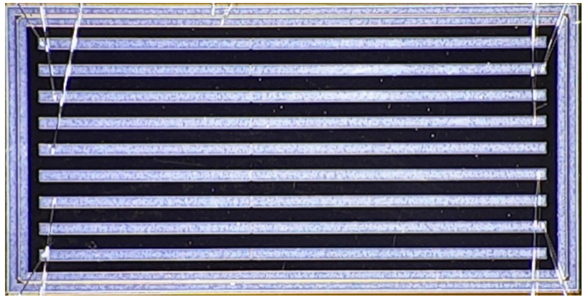
* ~50 um under the metal eletrode. To be improved

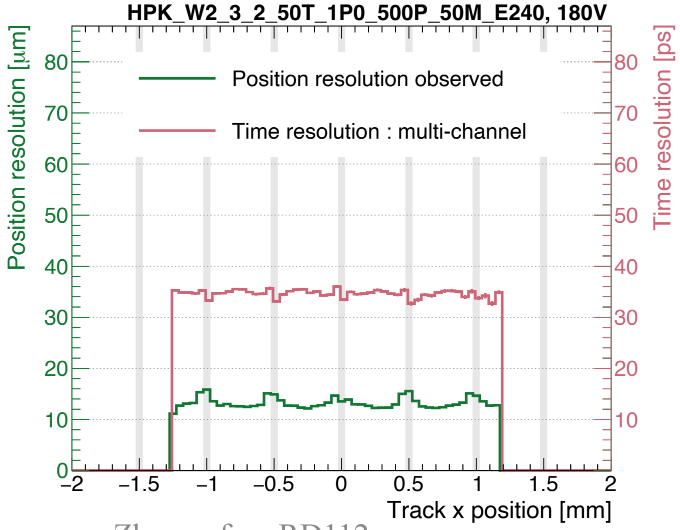
## Fermilab Test Beam Setup



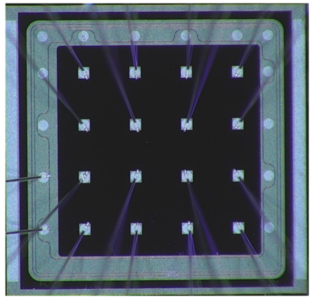


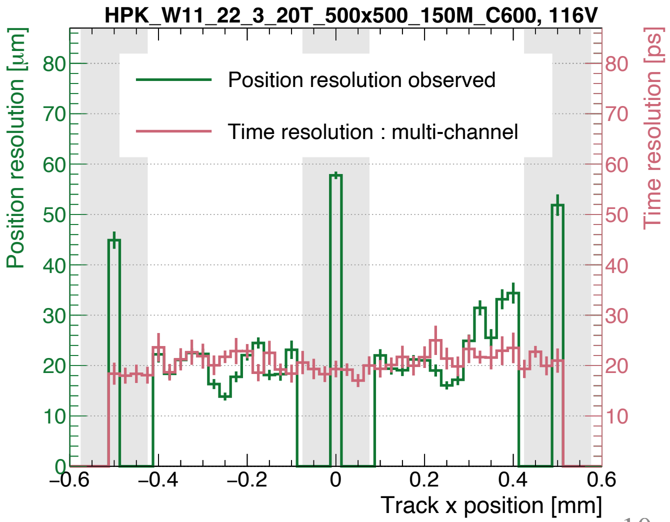

## HPK Strip Sensor (4.5x10 mm$^2$)





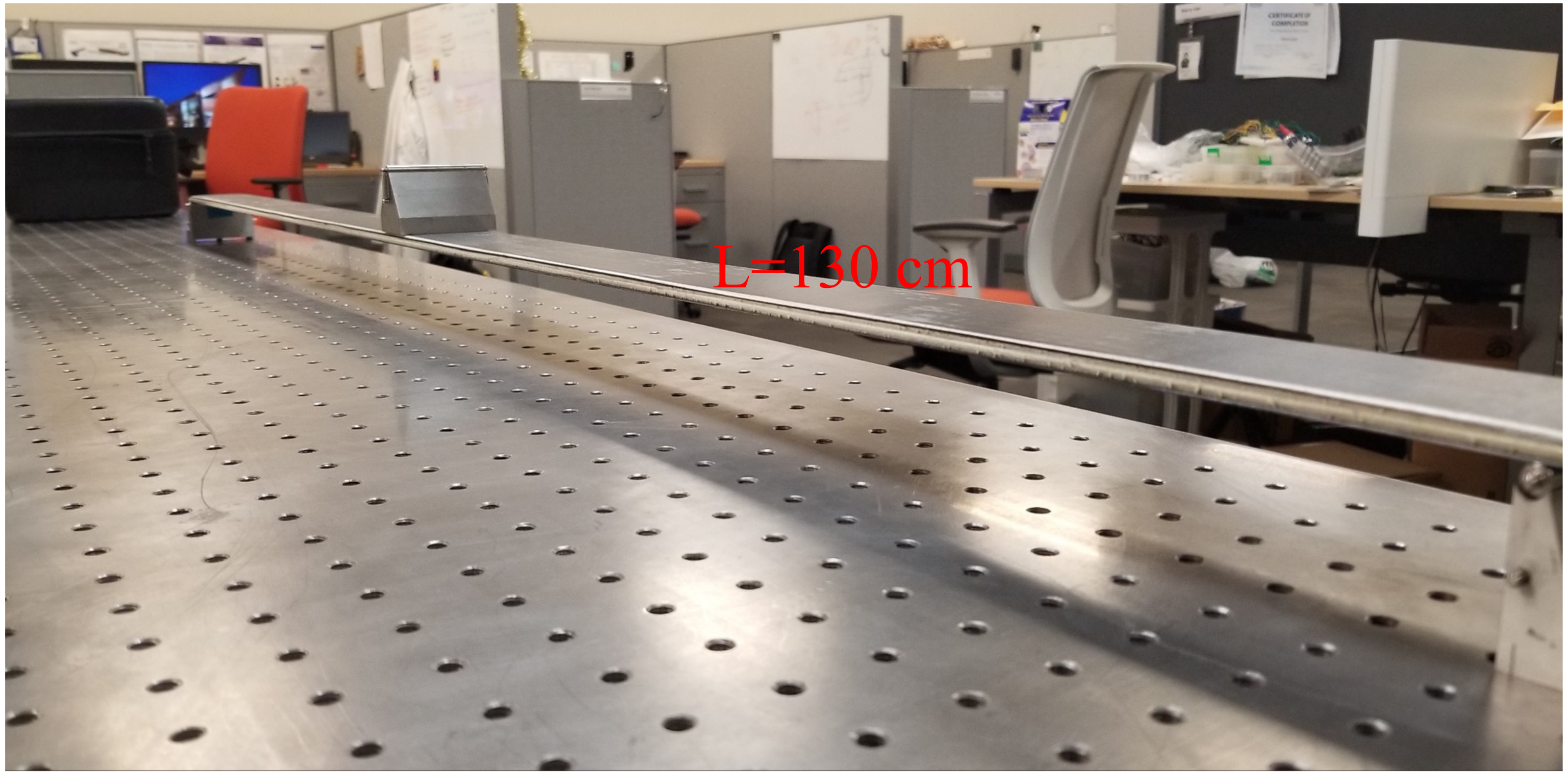

## HPK Pixel Sensor (2x2 mm$^2$)

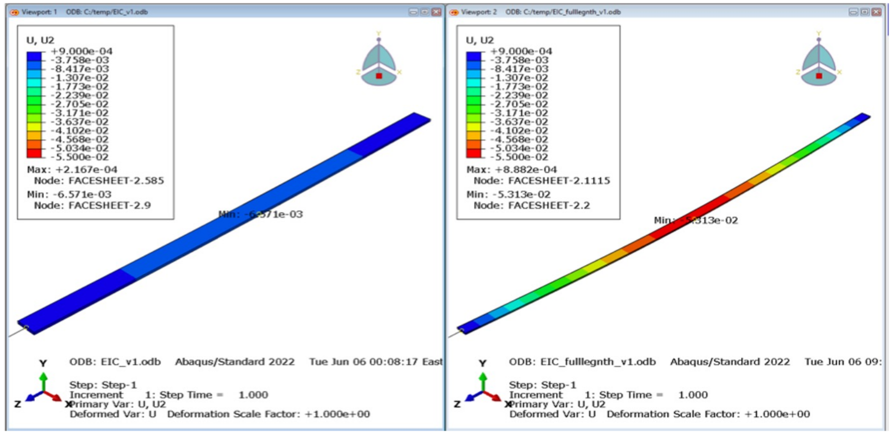


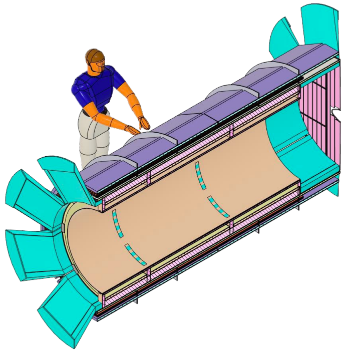


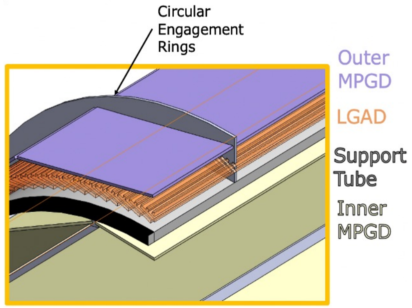
# eRD112 FY23 Deliverables - Mechanical Structure

- **Mechanical structure:**
  - Prototype of light-weight module structure for BTOF made with Carbon-Fiber foam/sheets by Purdue.
  - In the process of producing a few more prototypes with embedded cooling tube by the end of 2023







# eRD112 FY24 Proposal

- AC-LGAD Sensor
  - Productions by BNL IO, HPK and FBK
  - Sensor characterization in the lab/beam
  - TCAD simulation
  - Irradiation test

Further optimize sensor design and produce prototypes that meet ePIC requirements, including timing and spatial resolution, irradiation tolerance, and reasonably large size for module assembly

- Sensor/ASIC integration
  - Interposer to connect pixelated ASICs with strip sensors, or pixel sensors with various pitch

Investigate reliable and cost-effective mechanical and electrical sensor-ASIC connections with interposer

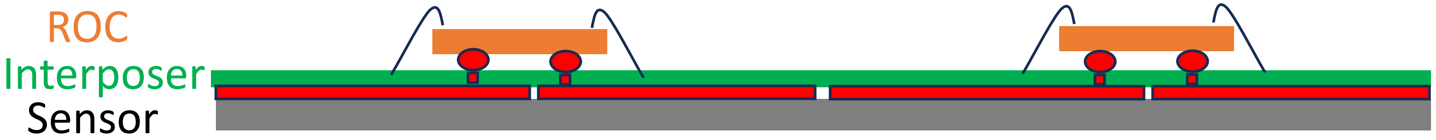
- Mechanical structure
  - Light-weight structure for FTOF

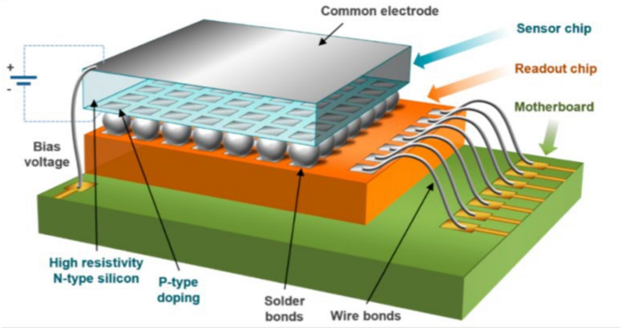
Develop light-weight mechanical structures for FTOF

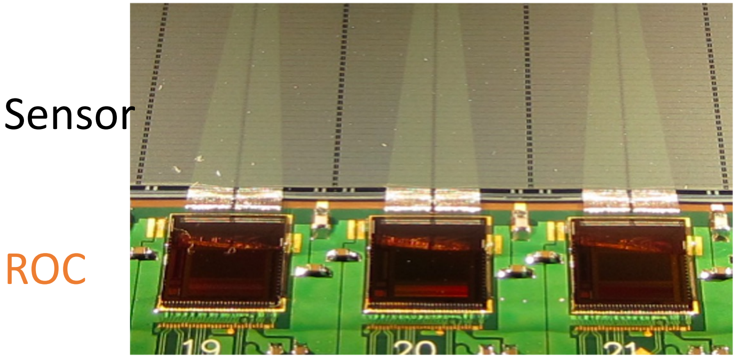
Sensor + ASIC demonstrator (prototype module) for EIC and testing with particle beam

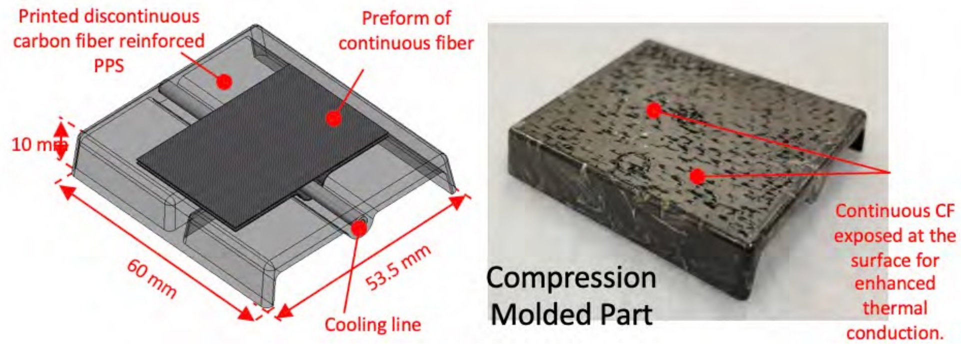
# eRD112 FY24 Proposal

- Sensor (346k) further optimize sensor design, determine final size and yield, verify radiation tolerance
  - TCAD simulation and sensor irradiation test (20k)
  - Sensor production and characterization: BNL IO (75k+46k), HPK (80k+40k), FBK (70k+15k)
- Sensor/ASIC integration (15k)
  - Interposer to connect pixelated ASICs with strip sensors, or pixel sensors with various pitch
- Mechanical structure (53k)
  - Light-weight structure made from CF composite materials using compression or injection molding for FTOF



# eRD112 FY24 Deliverables

- Optimized sensor design and final prototypes that meet ePIC requirements, including timing and spatial resolution, irradiation tolerance, and reasonably large size for module assembly
- Prototypes of interposer for mechanical/electrical connections between strip sensor and ASIC
- Prototypes of light-weight module mechanical structures for both barrel and forward TOF
- Sensor + ASIC demonstrator for EIC applications and testing with particle beam.

**eRD112 (414k)**
- Sensor R&D (346k$)
  - BNL, HPK/FBK productions
  - TCAD, lab/beam/irradiation tests
- Sensor/ASIC integration (15k$)
  - Interposer
- Mechanical structure ($53k)
  - Light-weight structure with cooling

**eRD109 (Fernando's talk)**
- Frontend ASICs
  - EICROC, FCFD
- Frontend electronics
  - Low Jitter Clock
  - Low-mass flexible PCB
  - Service hybrid

**EPIC Simulation**
- Geometry model, digitization and reconstruction
- Requirements on spatial, timing resolutions, and material budget

**Project Engineering Design**
- Engineering design for pre-TDR
- Integration & services

**Sensor** **ASIC** **Sensor-ASIC integration** **Services** **Prototype Module**

# Summary

## FY23 Report:

- AC-LGAD requirements have evolved with improved knowledge from ePIC simulation.
- Prototype HPK sensors are promising to meet the timing/spatial resolution requirements
- Development of light-weight mechanical structures for Barrel TOF staves has started

## FY24 Proposal:

- Continue sensor development to further optimize and finalize design and specifications
- Develop interposer for sensor-ASIC integration
- Develop light-weight mechanical structures for Forward TOF