ePIC Collaboration Meeting, July 25-29, 2023, University of Warsaw

# Barrel and Forward TOF: AC-LGAD

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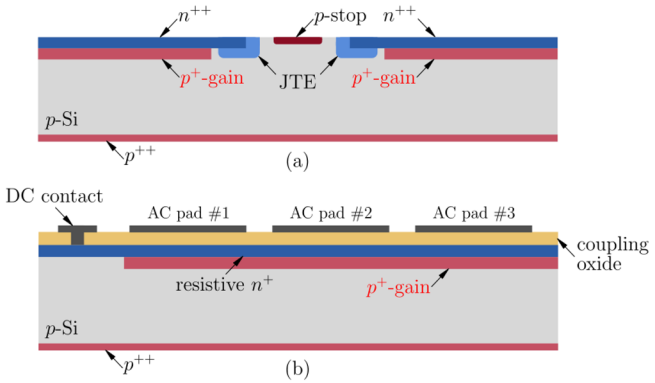
U.S. DEPARTMENT OF ENERGY | Office of Science

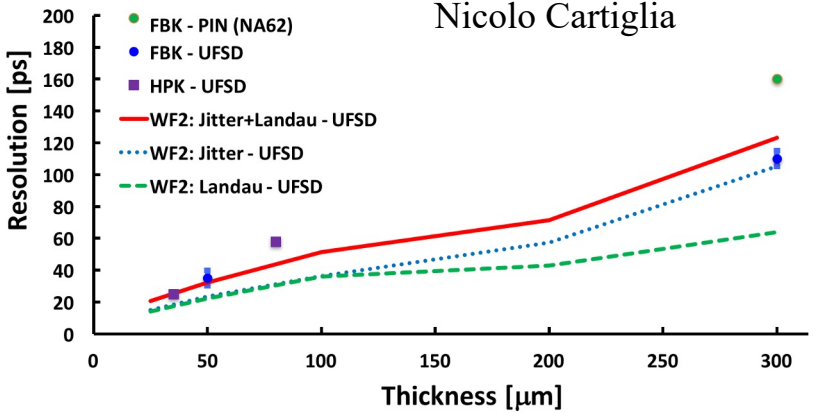
# AC-LGAD Technology

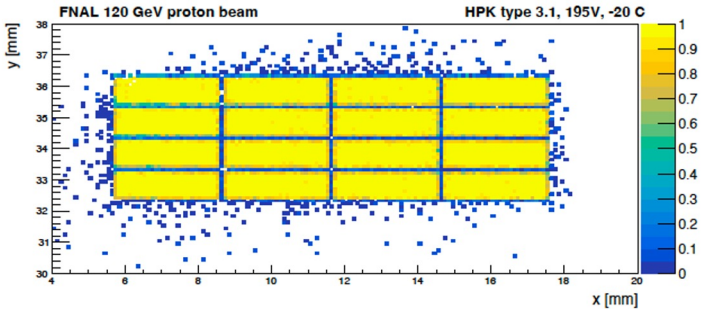
- AC-LGAD provides not only precise timing resolution, but also ~100% fill factor and much better spatial resolution than DC-LGAD.

(DC-)LGAD

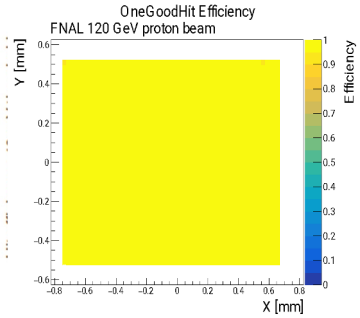
AC-LGAD



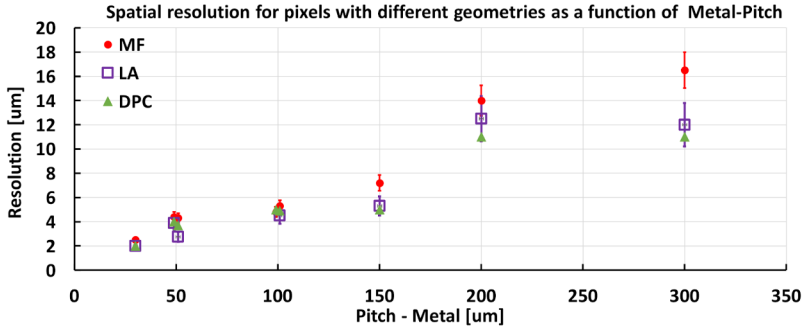




DC-LGAD




AC-LGAD



# AC-LGAD TOF for ePIC

**Tracking and Vertexing:**

- MAPS (3-5 μm)
- **AC-LGAD (30 μm)**
- MPGD (150 μm)

**PID:**

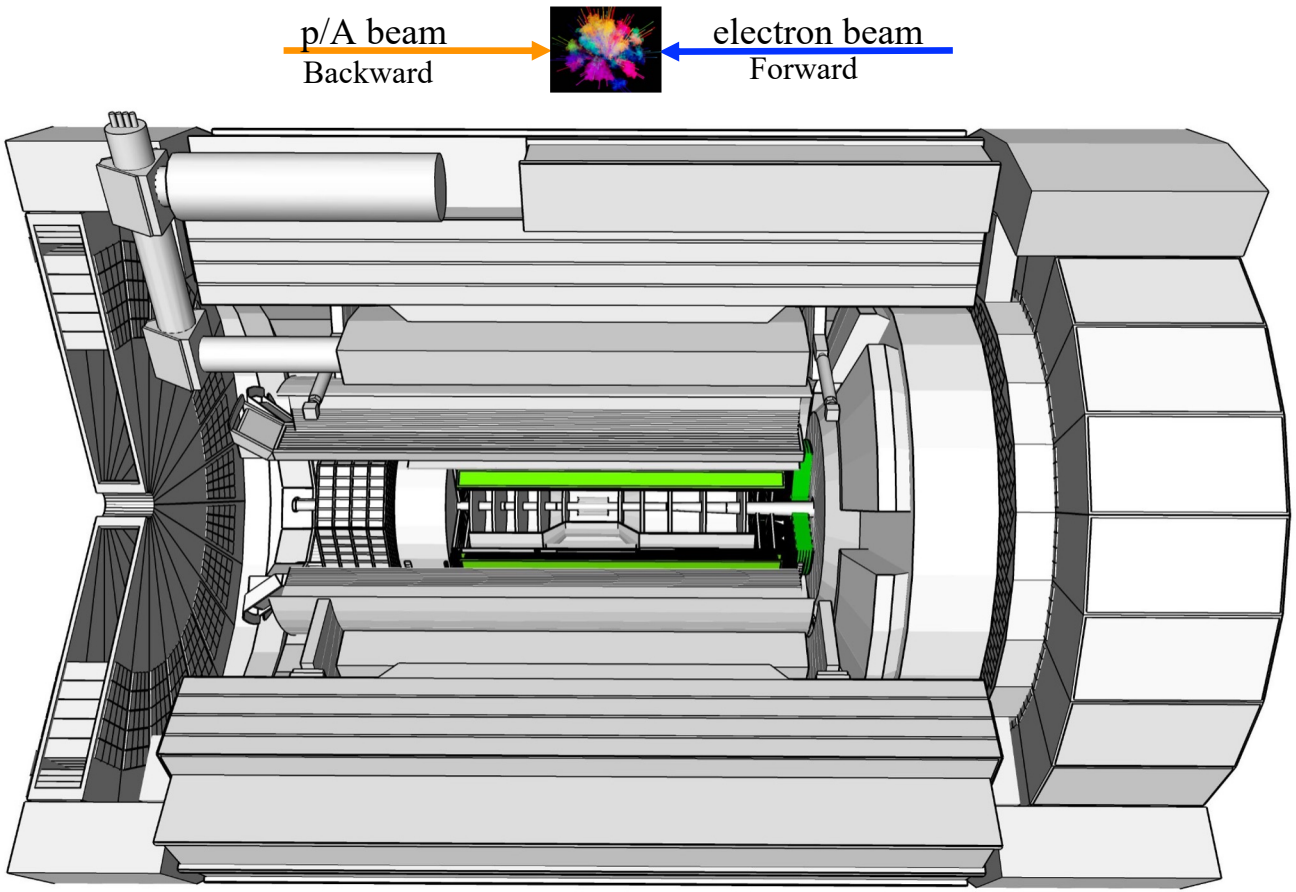
- hpDIRC
- pfRICH
- dRICH
- **AC-LGAD TOF (25/35 ps)**

**Calorimetry:**

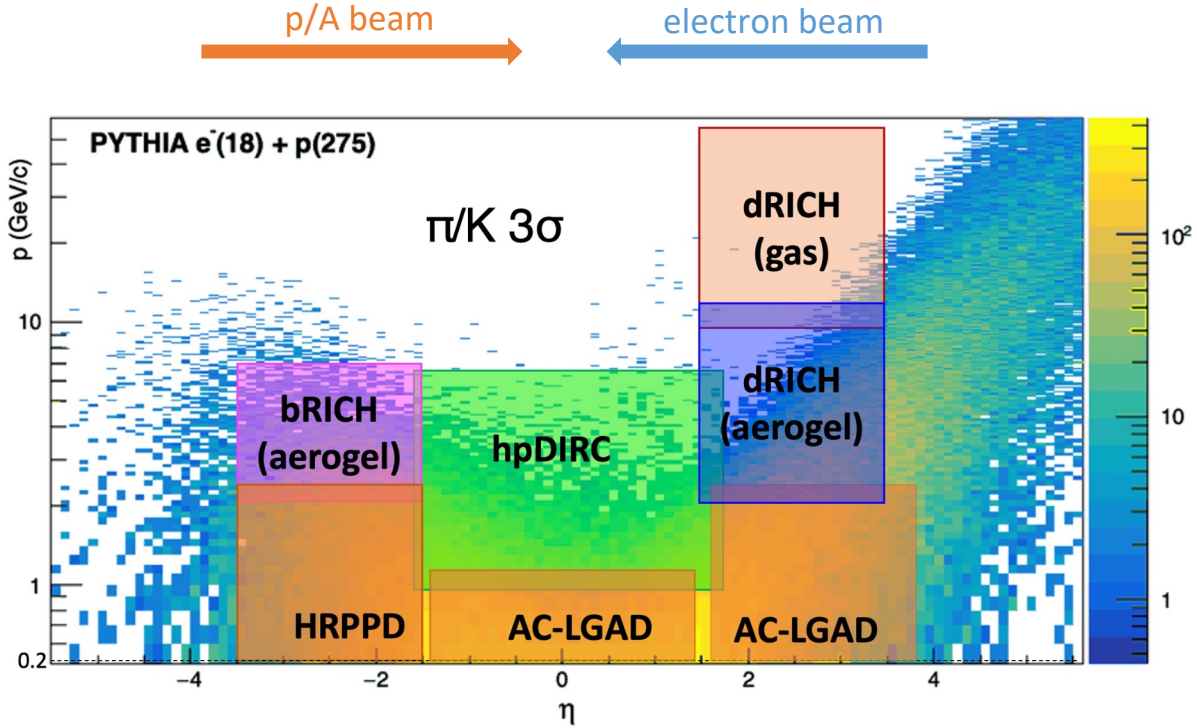
- PbWO EEMCal
- Fe/Sc Backward HCAL
- Pb/SciFi Barrel EMCal with Imaging
- Barrel HCal (sPHENIX re-use)
- W/SciFi FEMC
- Fe/Sc&W/Sc LFHCAL

**Far-Forward/Backward:**

- AC-LGAD for B0 tracker and RPs
- ZDC …



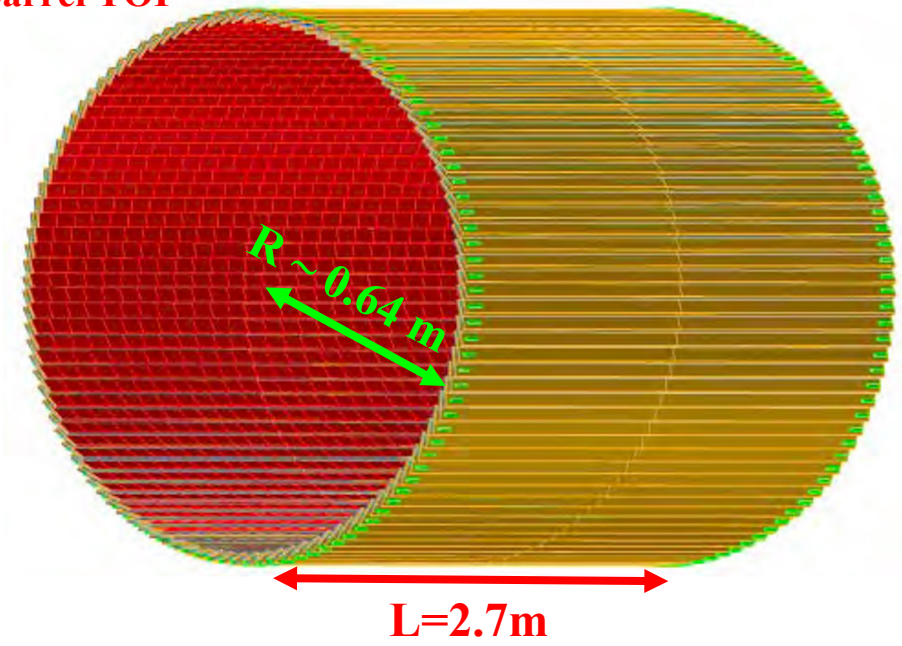
# AC-LGAD TOF for ePIC



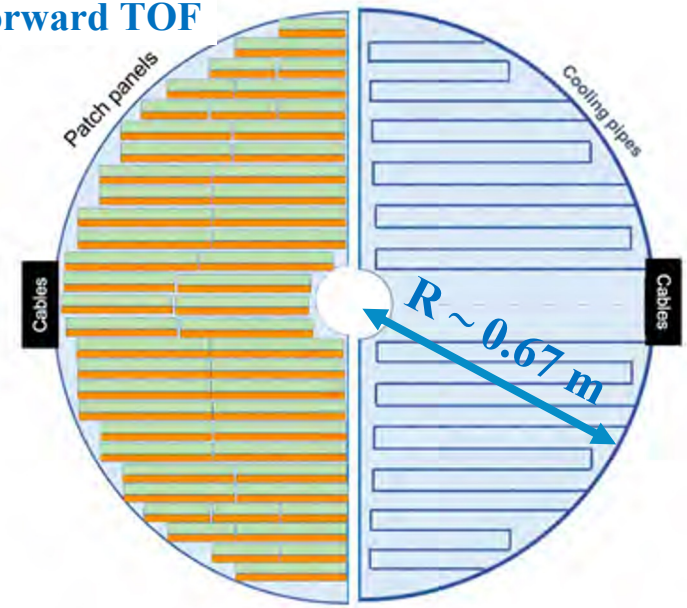

| Detector | r (cm) | z (cm) | Rapidity coverage | Momentum range for 3$\sigma$ $\pi$/K separation |
|---|---|---|---|---|
| Barrel TOF | 63<r<66 | -120<z<120 | -1.40<η<1.40 | 0.2 < $p_T$ < ~1.2 GeV/c |
| Forward TOF | 8<r<67 | 180<z<190 | 1.74<η<3.83 | 0.2 < p < ~2.3 GeV/c |

# AC-LGAD TOF Detector Specifications

**Barrel TOF**



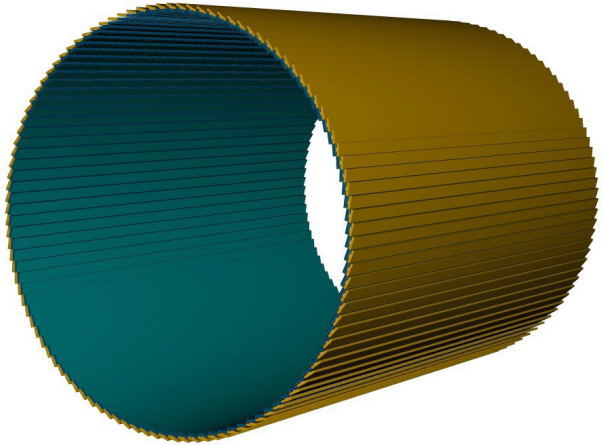

**Forward TOF**



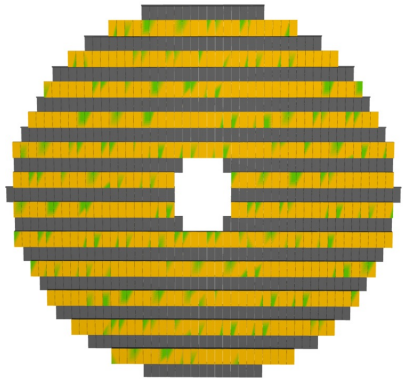

| Detector | Area ($m^2$) | Channel size ($mm^2$) | Number of channels | Time resolution (ps) | Spatial resolution (μm) | Material budget ($X_0$) | Total Power (kW) |
|---|---|---|---|---|---|---|---|
| BTOF | ~10 | 0.5x10 | ~2.4M | 35 | 30 in r·φ | ~1% | 4 |
| FTOF | ~1.4 | 0.5x0.5 (0.7x0.7?) | ~6M (3M?) | 25 | 30 in x and y | ~5% (2.5%?) | 13 (7?) |

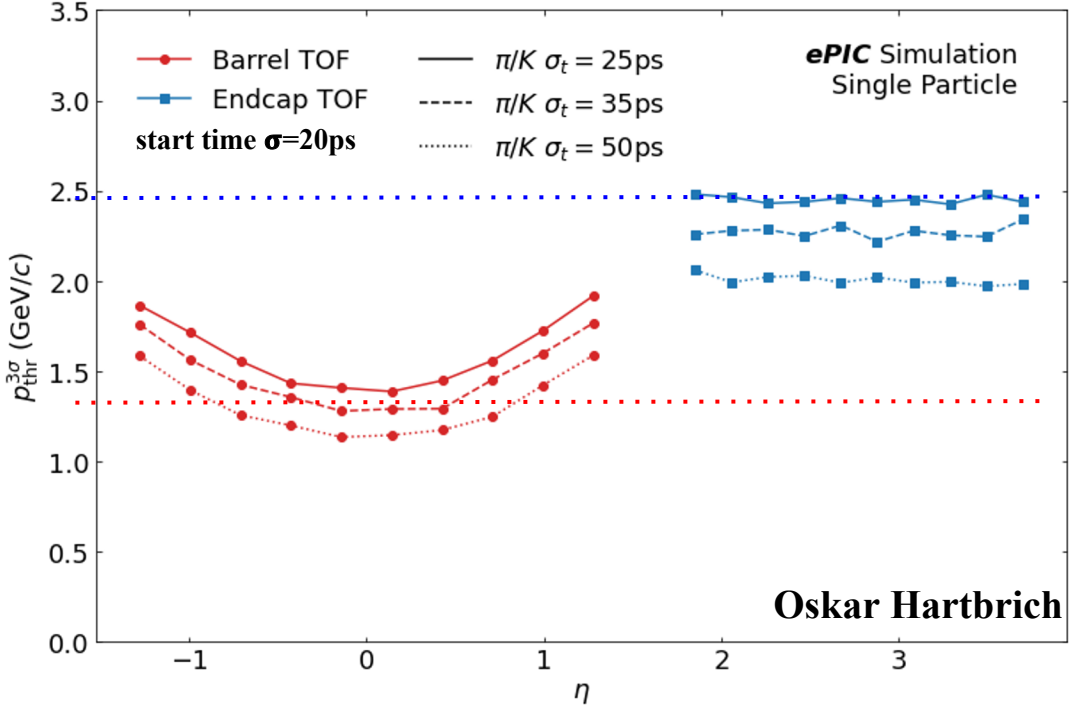
# AC-LGAD TOF for PID in ePIC Simulation

**BTOF in DD4HEP (Zhenyu Ye)**



**FTOF in DD4HEP (Nicolas Schmidt)**

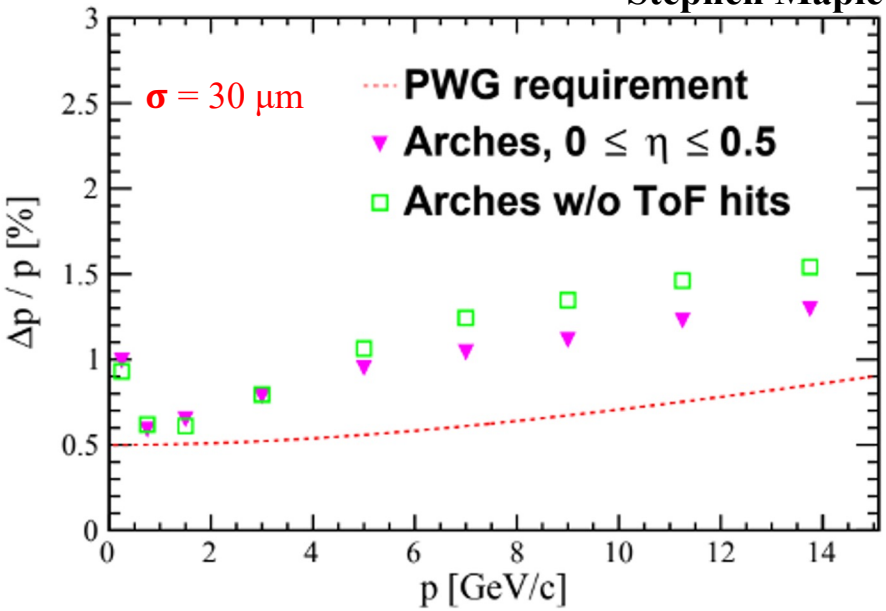


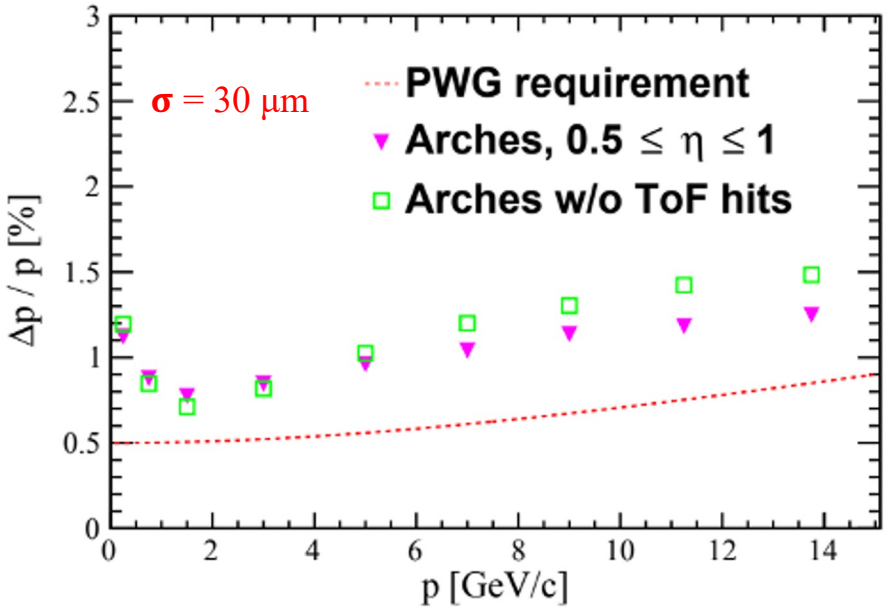



- BTOF with timing resolution of 35 ps provide 3$\sigma$ $\pi$/K separation up to ~1.3 GeV/c
- FTOF with timing resolution of 25 ps provide 3$\sigma$ $\pi$/K separation up to ~2.4 GeV/c

# AC-LGAD TOF for Tracking in ePIC Simulation

Stephen Maple



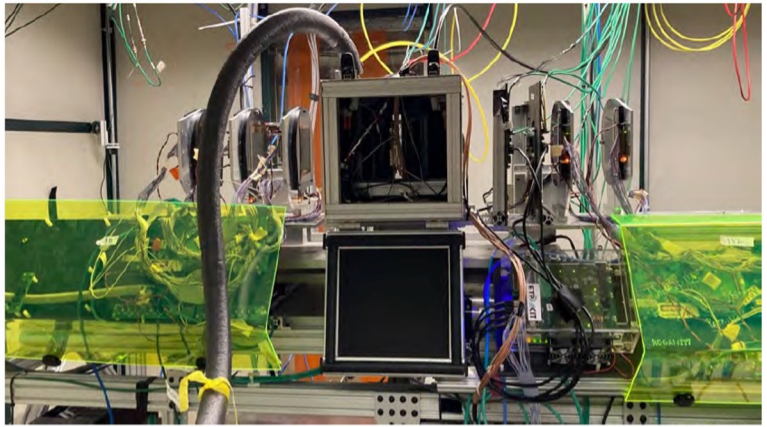



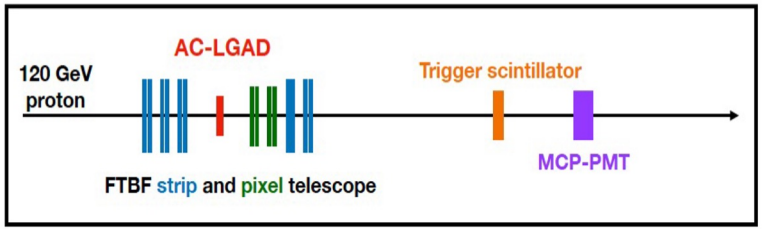

- BTOF with a spatial resolution of 30 μm improves momentum resolution at high p
- TOF helps track reconstruction by rejecting beam background and pileup hits in SVT

# AC-LGAD Sensor Development

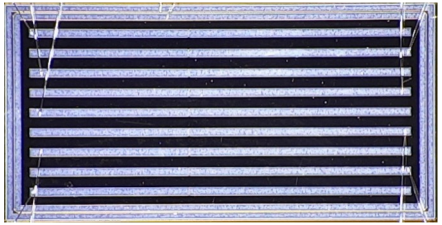
- Goal: large area sensors that meet timing/spatial resolution requirements with minimal # of channels
- Status: prototype sensors produced by BNL IO and HPK and tested in the lab/beam by BNL/FNAL/UCSC/UIC
- Plan: new productions to optimize sensor design for better timing and less # of channels, verify irradiation tolerance
  validate sensor size and sensor-ASIC integration for module assembly

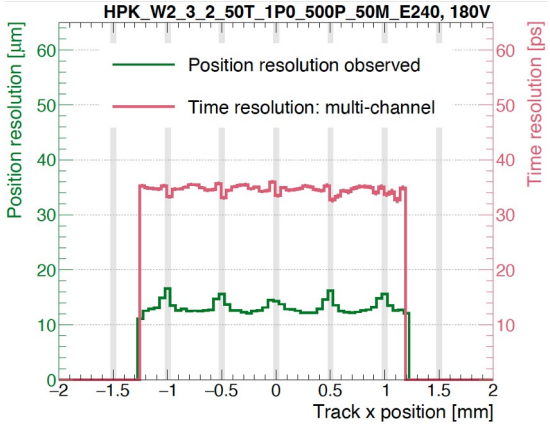
**Fermilab Test Beam Facility**



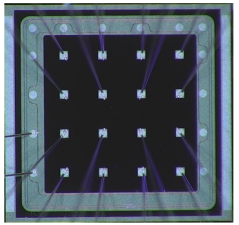


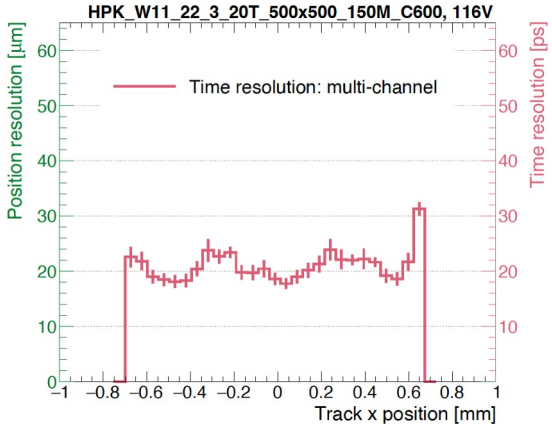

**HPK Strip Sensor for BTOF**






**HPK Pixel Sensor for FTOF**





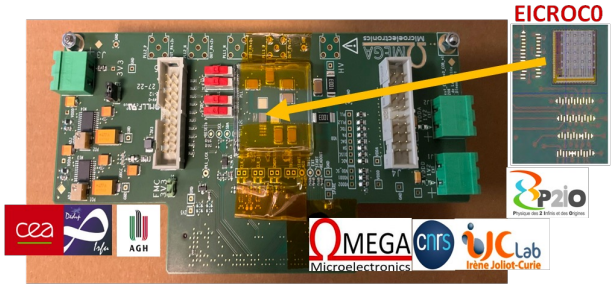
# Frontend Readout Electronics

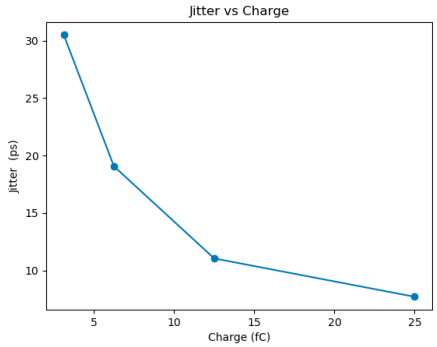
- Goal: develop ASIC and other components that meet requirements on timing/spatial resolutions and power consumption
- Status/Plan:

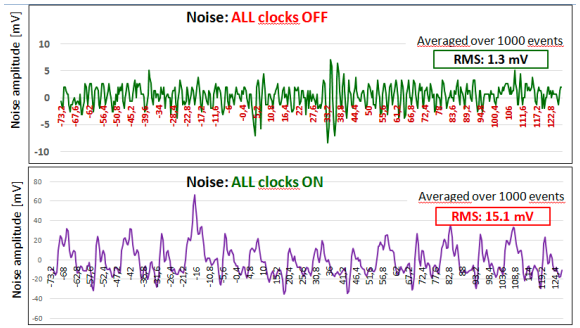
  ASIC: IJCLab/Omega/CEA-Irfu EICROC0->0_1/1; FNAL FCFDv0->1->2; UCSC HPSoCv1->2, ASROC, FAST2->3

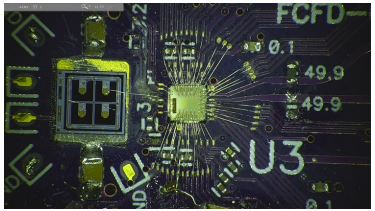
  Low mass flexible PCB: ORNL proof of concept prototypes -> full scale functional prototype

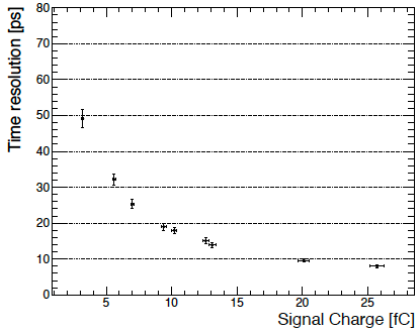
  Service hybrid: BNL/Rice/UIC prototype readout boards

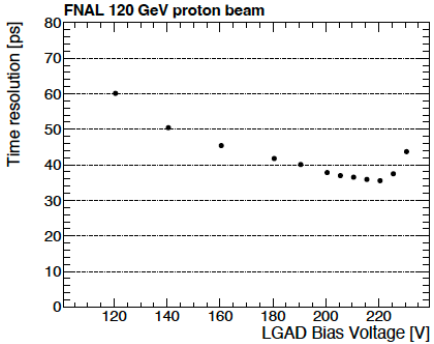


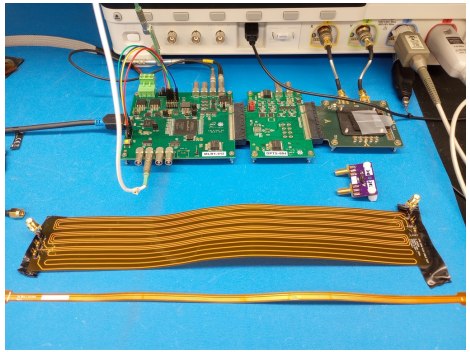



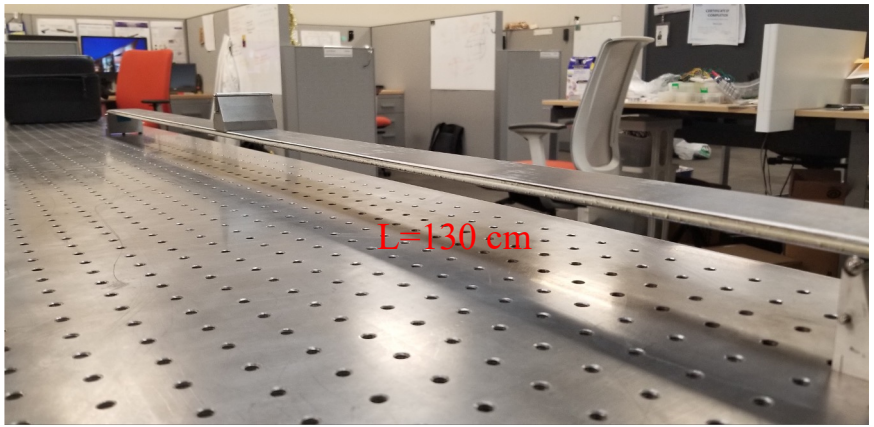



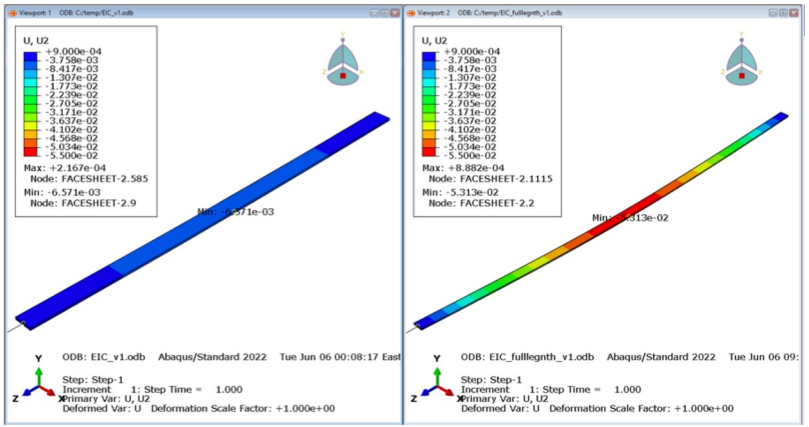



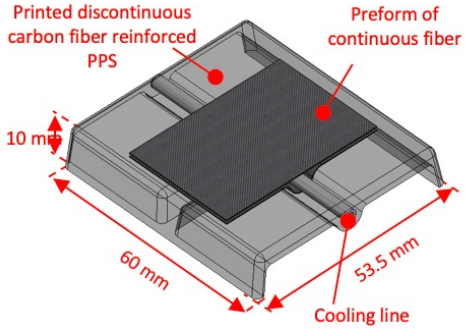



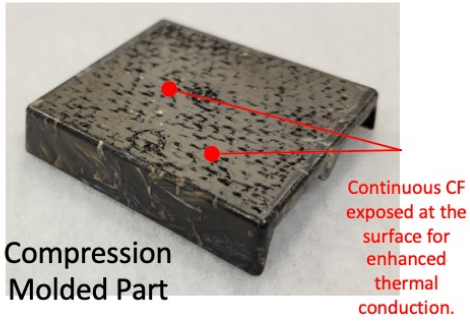
# Lightweight Mechanical Structure

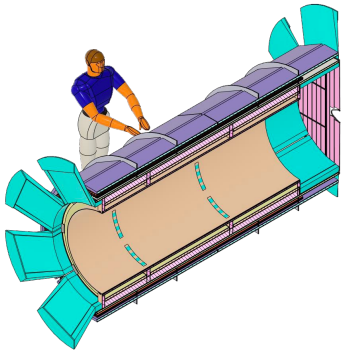
- Goal: light-weight structure with cooling that meet the material budget, thermal and mechanical requirements
- Status: first BTOF prototype produced with CF sheet + form at Purdue, detailed analysis and measurement in progress
- Plan: produce BTOF/FTOF prototypes, and look into support structure and cooling system design by Purdue/NCKU

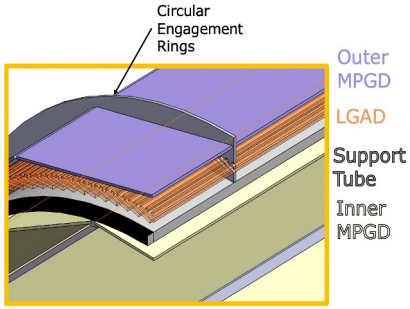


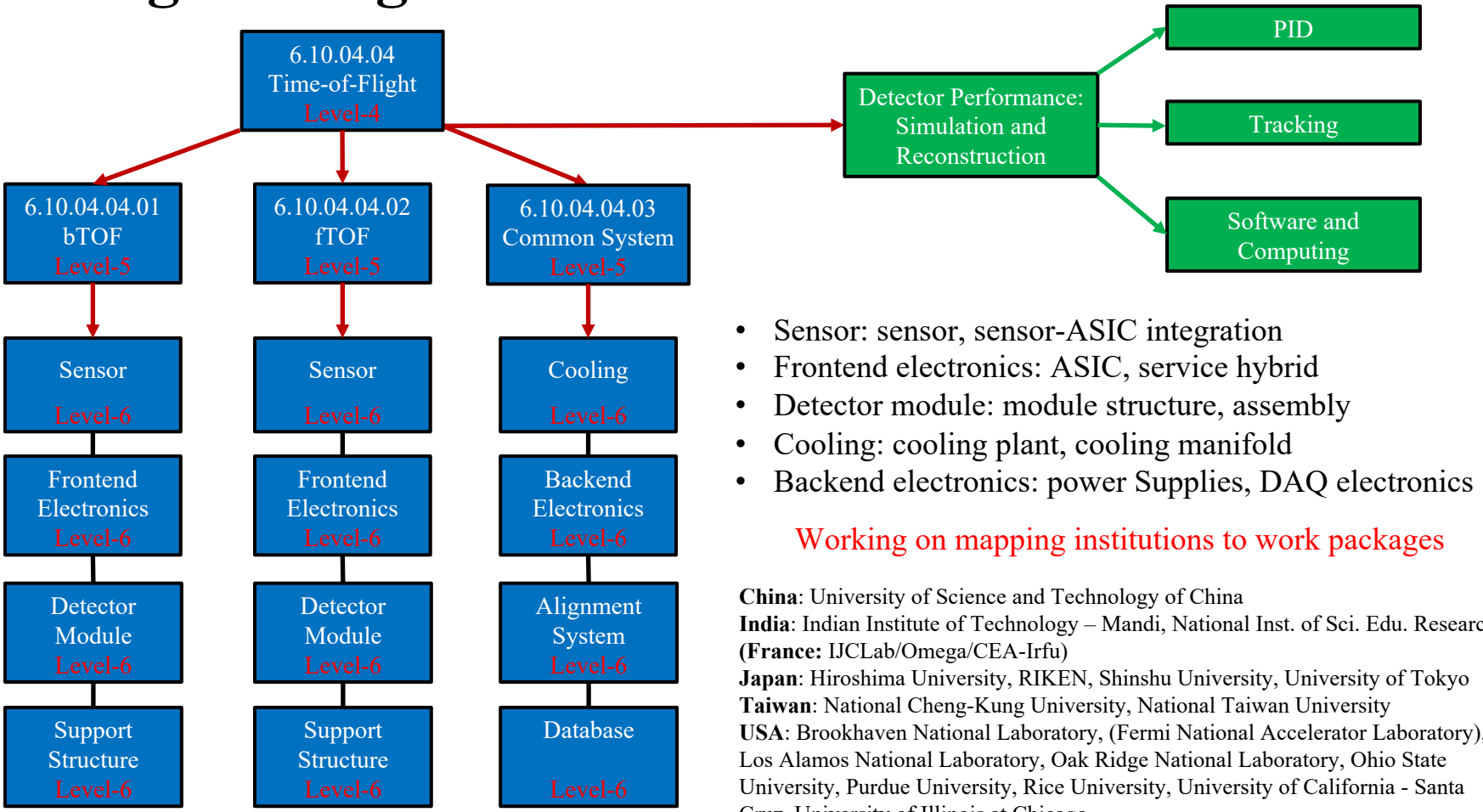





# Working Packages




- Sensor: sensor, sensor-ASIC integration
- Frontend electronics: ASIC, service hybrid
- Detector module: module structure, assembly
- Cooling: cooling plant, cooling manifold
- Backend electronics: power Supplies, DAQ electronics

Working on mapping institutions to work packages

**China**: University of Science and Technology of China
**India**: Indian Institute of Technology – Mandi, National Inst. of Sci. Edu. Research
**(France:** IJCLab/Omega/CEA-Irfu)
**Japan**: Hiroshima University, RIKEN, Shinshu University, University of Tokyo
**Taiwan**: National Cheng-Kung University, National Taiwan University
**USA**: Brookhaven National Laboratory, (Fermi National Accelerator Laboratory), Los Alamos National Laboratory, Oak Ridge National Laboratory, Ohio State University, Purdue University, Rice University, University of California - Santa Cruz, University of Illinois at Chicago

# Summary and Outlook

1. AC-LGAD TOF detectors will provide low $p_T$ PID and aid track reconstruction at ePIC
   - BTOF at r~64 cm with 35 ps timing resolution provide 3$\sigma$ $\pi$/K separation upto ~1.3 GeV/c
   - FTOF at z~185 cm with 25 ps timing resolution provide 3$\sigma$ $\pi$/K separation upto ~2.4 GeV/c
   - Fast (<3ns) and high precision (~30 μm) spatial points provided by AC-LGAD aid track reconstruction through background rejection and momentum resolution improvements
2. BTOF and FTOF design based on existing detectors
   - BTOF follows STAR Intermediate Silicon Tracker with strip sensors wire-bonded to ASIC
   - FTOF follows CMS Endcap Timing Layer with pixel sensors bump-bonded to ASIC
   - Active R&D on key components with progresses made in individual components including sensor, ASIC, low mass Kapton flexible PCB, and lightweight support structure. Plan to also study sensor-ASIC integration, module assembly, readout boards, and cooling system in the coming year
3. Fabrication and assembly plan based on experience with multiple domestic and international institutions with strong technical capabilities and interests. No major integration issue found in initial study. More detailed study of services and integration will be done in coming months
4. Work on mapping institutions and work packages, fix cost estimate and schedule with CAM

# More Information about AC-LGAD TOF DSC

- **AC-LGAD TOF DSC**
  - Mailing list: eic-projdet-tofpid-l@lists.bnl.gov
  - Indico page: https://indico.bnl.gov/category/414
  - Wiki page and task list: https://wiki.bnl.gov/eic-project-detector/index.php/TOFPID
  - Meeting time: Tuesday 9:00am ET

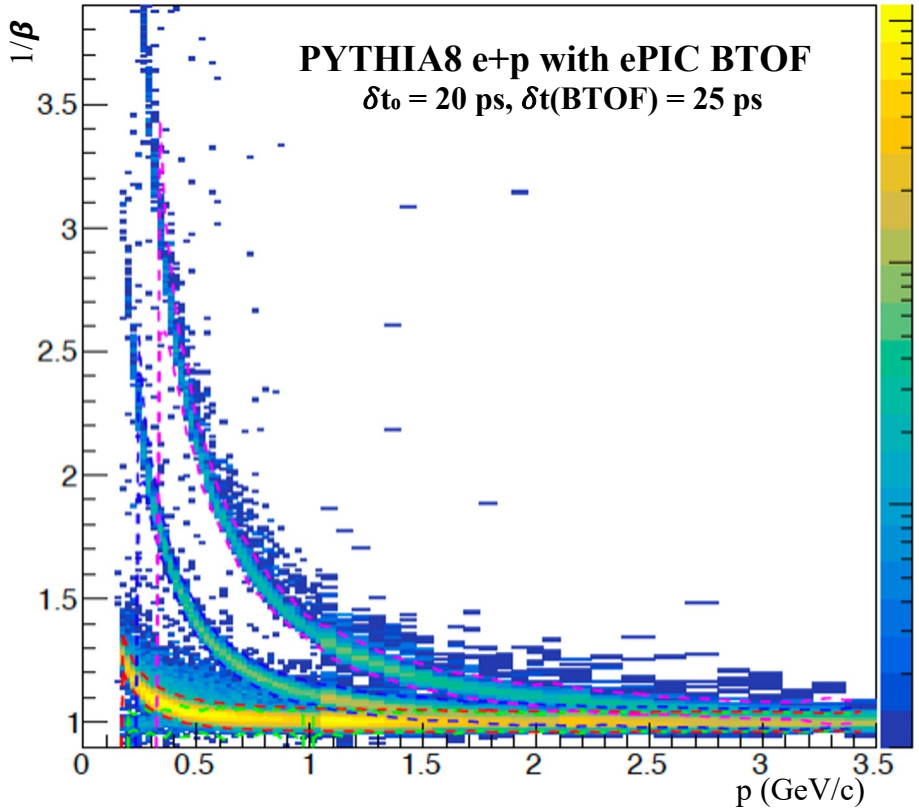
- **eRD112/eRD109/LGAD Consortium:**
  - Mailing list: https://mailman.rice.edu/mailman/listinfo/lgads-eic
  - Indico page: https://indico.bnl.gov/category/323/
  - EIC project R&D proposals: https://wiki.bnl.gov/conferences/index.php?title=Proposals
  - Meeting time: Tuesday 9:00am ET

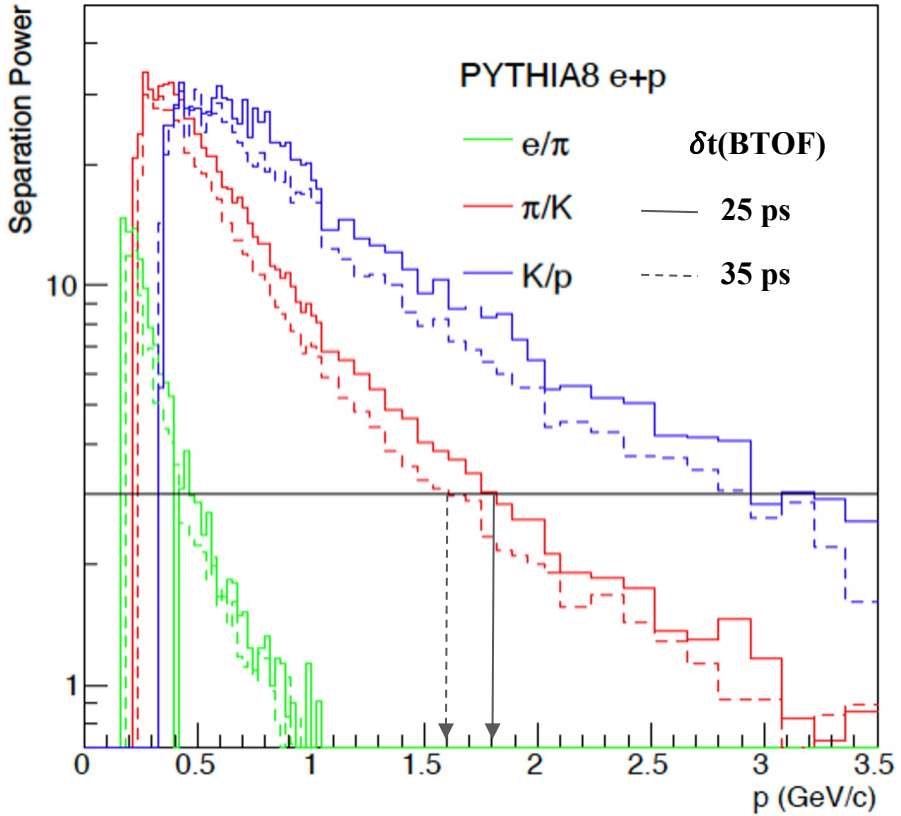
- **New institutions and collaborators are very welcome to join.**

# Backup

# BTOF for Particle Identification in Simulation

Zhenyu Ye

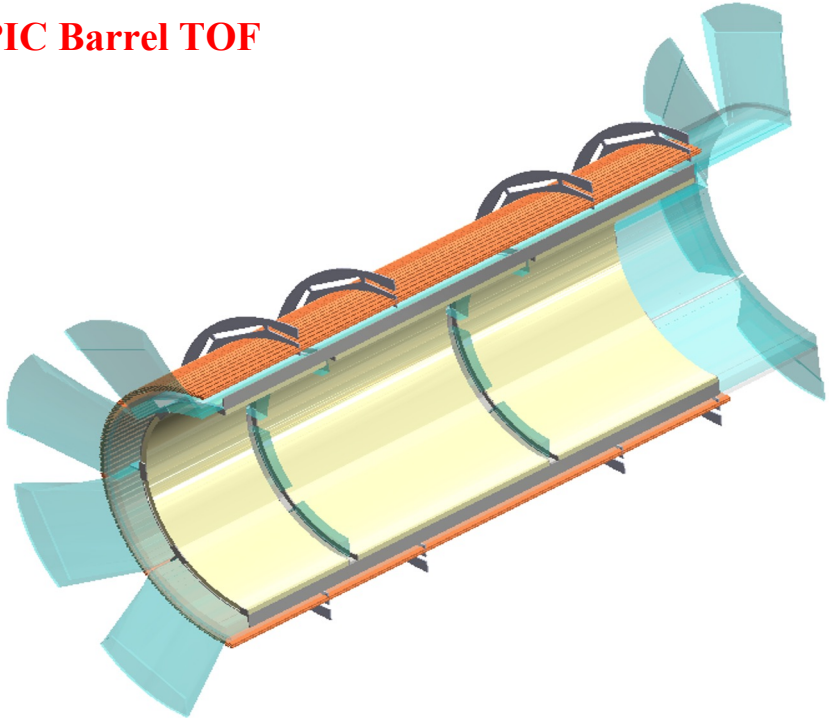


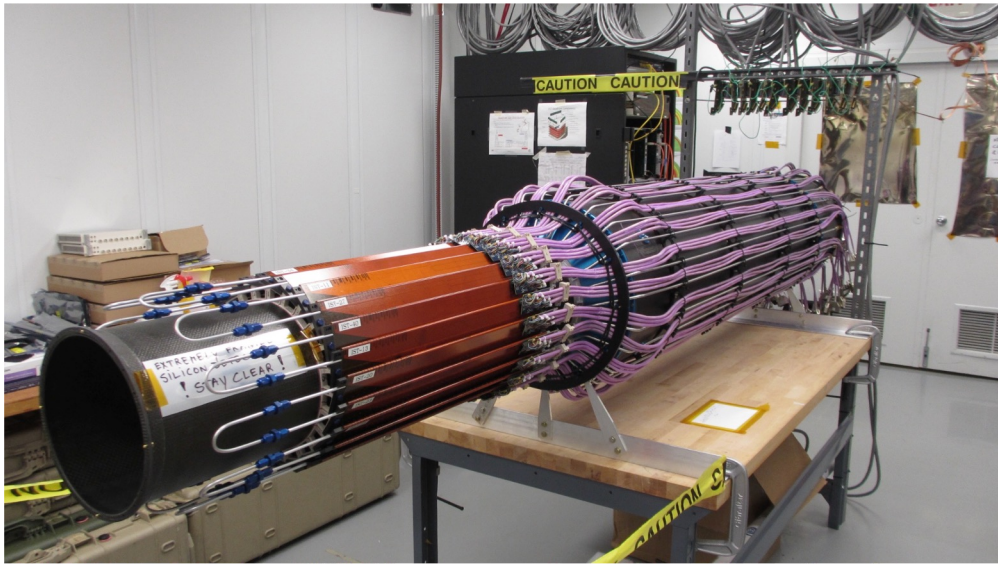

- BTOF with timing resolution of 35 (25) ps can achieve 3$\sigma$ $\pi$/K separation upto 1.6 (1.8) GeV/c

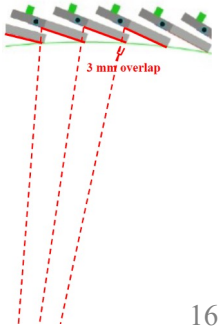
# BTOF Detector Layout

**ePIC Barrel TOF**



**STAR Intermediate Silicon Tracker**

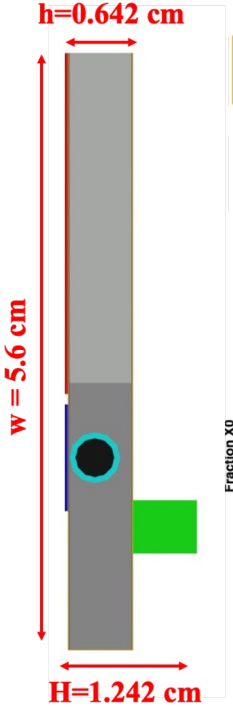


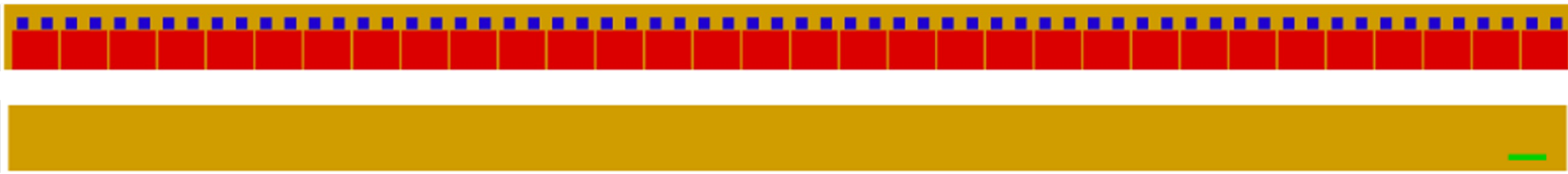




ePIC BTOF follows cylindrical silicon tracker design (e.g. STAR IST)

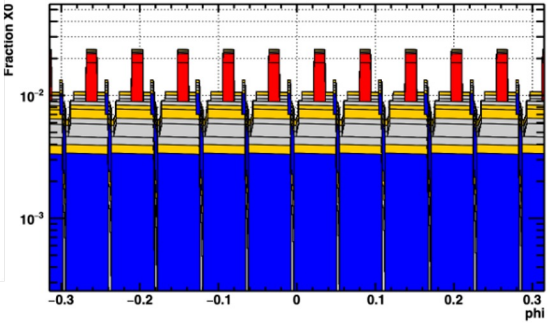
- Tilted stave modules overlap in phi to fully cover the azimuthal 2π angle
- Readout boards connected to the end of staves are outside of the BTOF acceptance (see next talk)
- Cooling tubes with liquid coolant at room temperature to take the heat generated by frontend ASIC

# 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

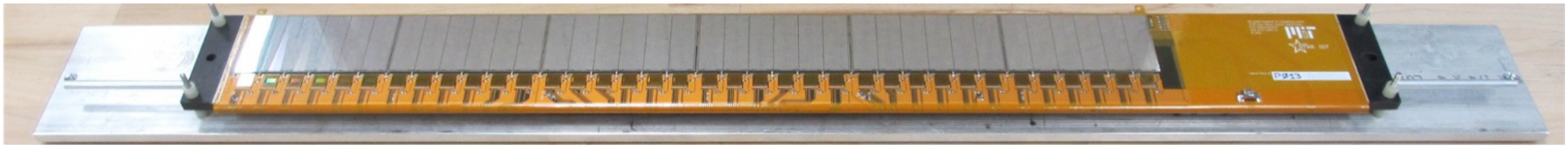


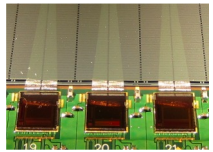

144 modules, each with 2 readout boards with 2 LV+HV cables, 2 DAQ fiber, and 1 cooling line

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

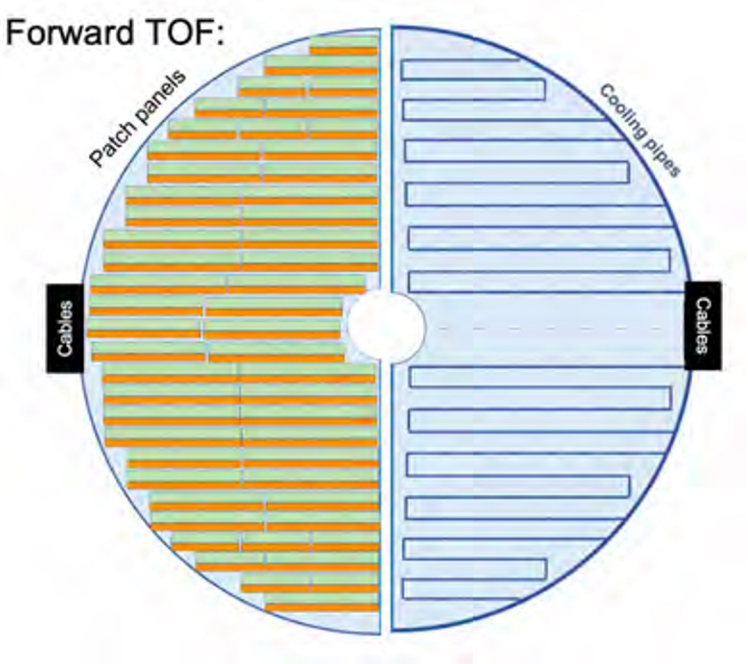
Total weight: ~70 kG

**STAR IST**

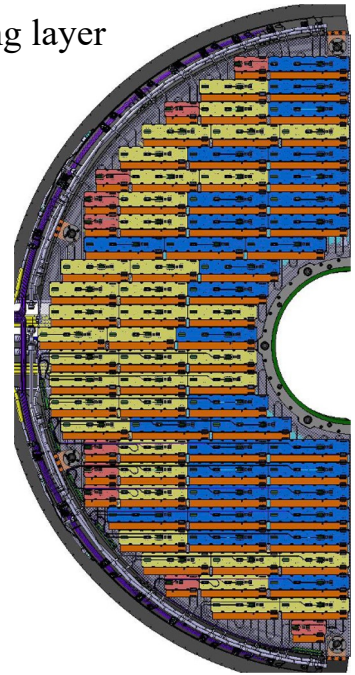




# FTOF Detector Layout



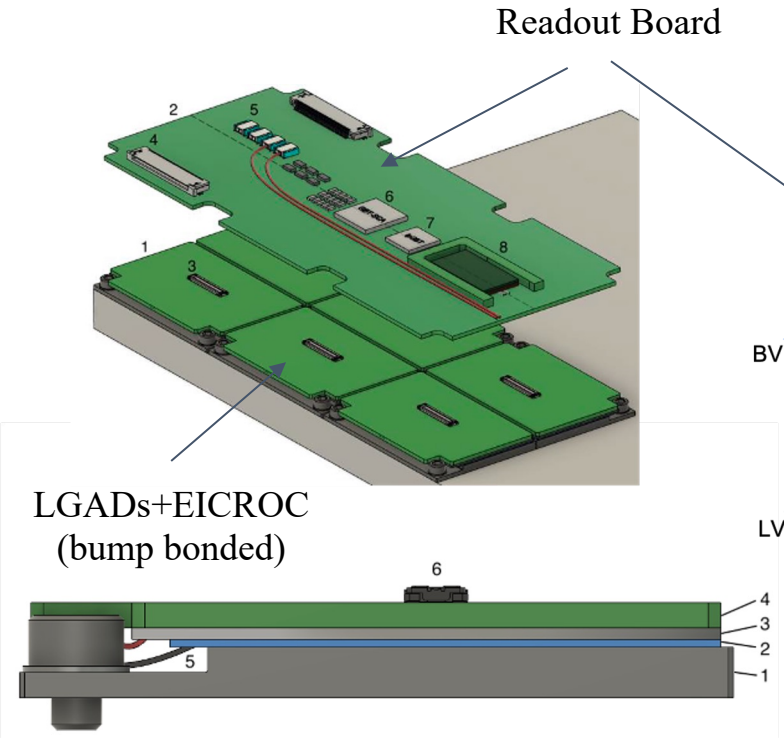

CMS endcap timing layer



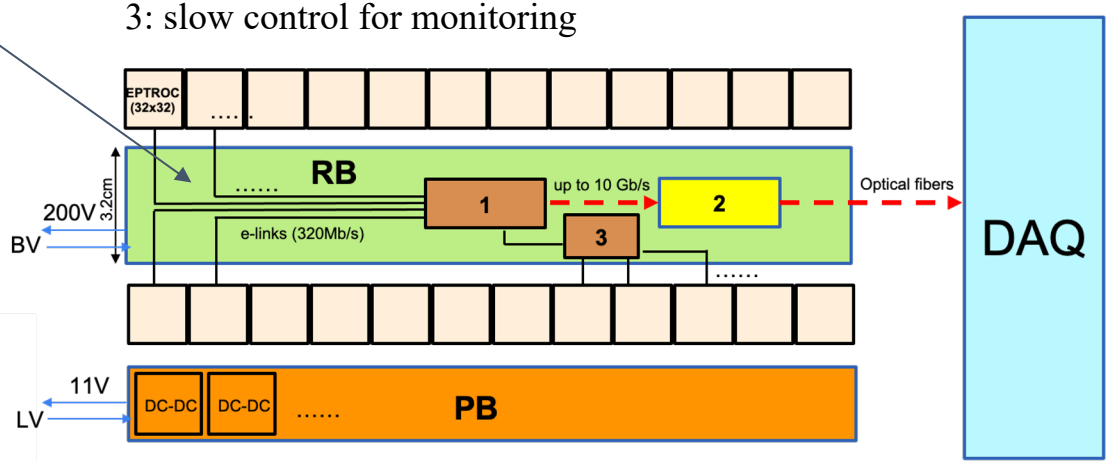
Forward TOF layout, based on the CMS ETL design:

- Two halves DEEs made of light-weight (carbon fiber) support structure, tiled by rectangular modules of three types with different lengths
- Cooling tubes with coolant at room temperature to take the heat generated by frontend ASICs and other electronic elements

# FTOF Detector Module Conceptual Design




1: data transceiver FPGA chip
2: optical link module (e.g., CERN VTRx+)
3: slow control for monitoring

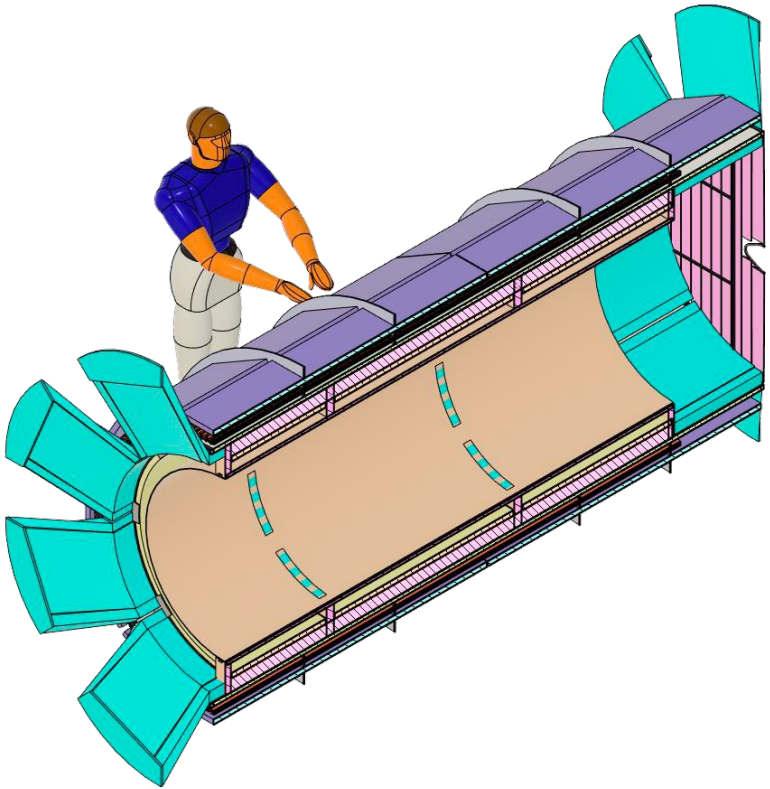


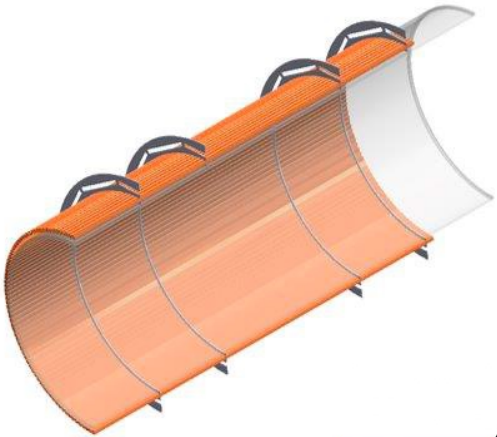

212 readout boards, each has: 1 fiber to DAQ, 2 LV cables (1 supply, 1 return) and 2 BV cables (1 supply, 1 return)

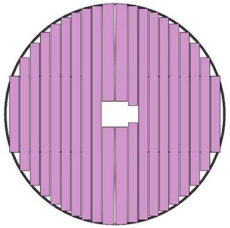
Power consumption: ~13 kW (8.5kW for ASIC, 3.5 kW for DC-DC, 1kW for sensors+cable)

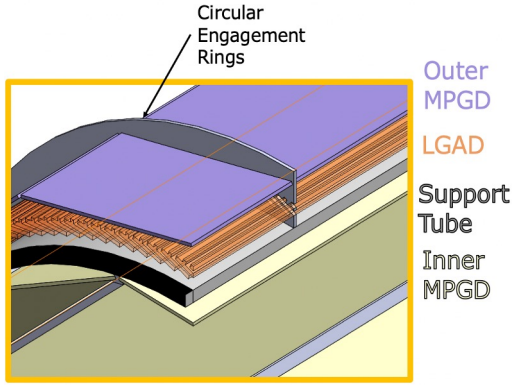
- Considering 0.7x0.7 mm$^2$ sensor design, which reduces the power budget by ~50%

# Integration and Services









# Schedule and Timeline

Charge #4