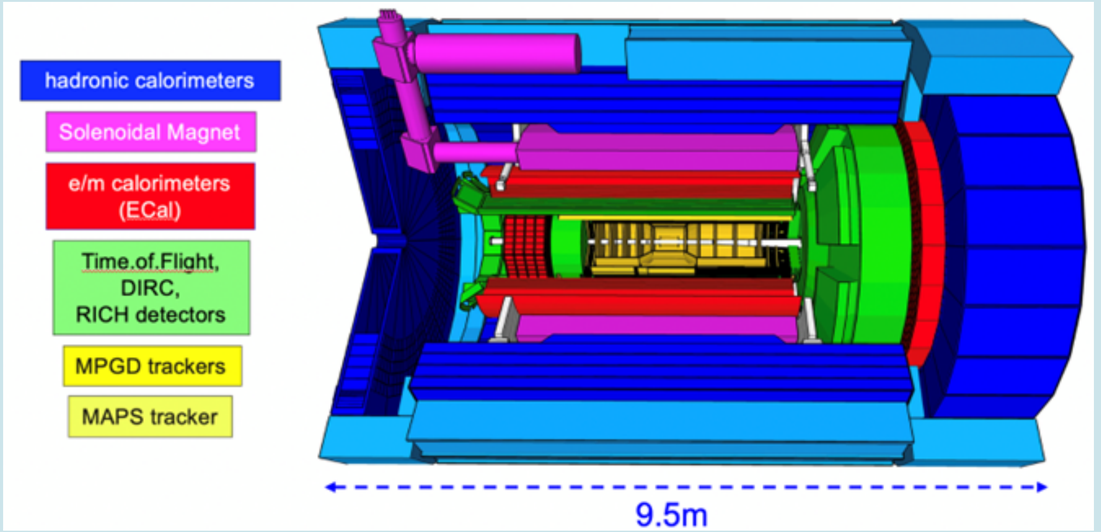
# AC-LGAD TOF

*Satoshi Yano (Hiroshima University)*

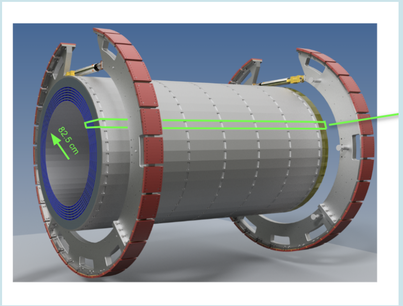
*EIC-ASIA meeting on 12/12/2024*

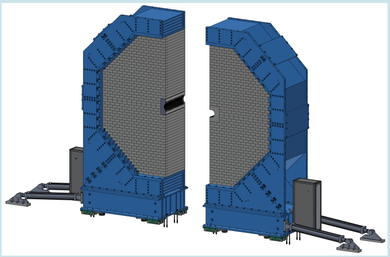
# The ePIC detector

## ePIC is the “encapsulated” detector

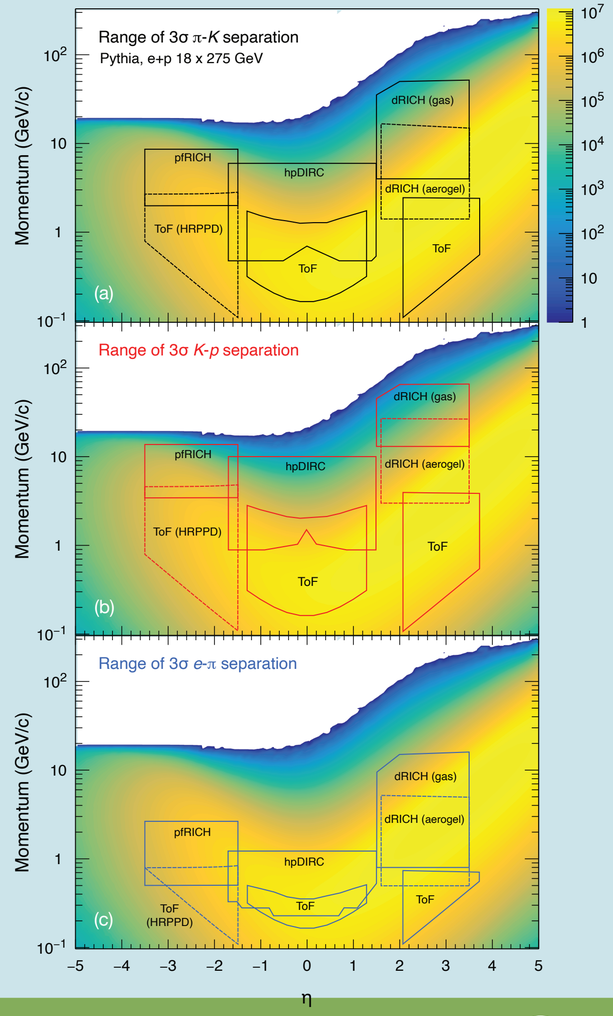



## EM & Hadron Calorimeter

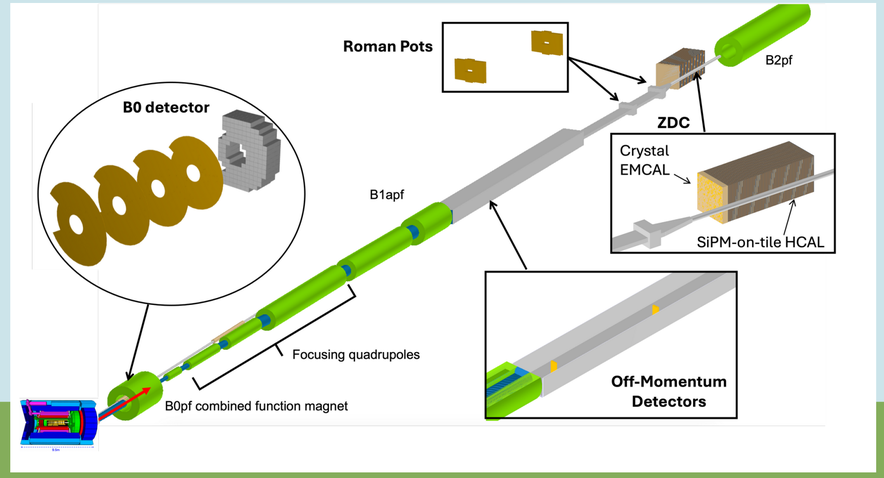




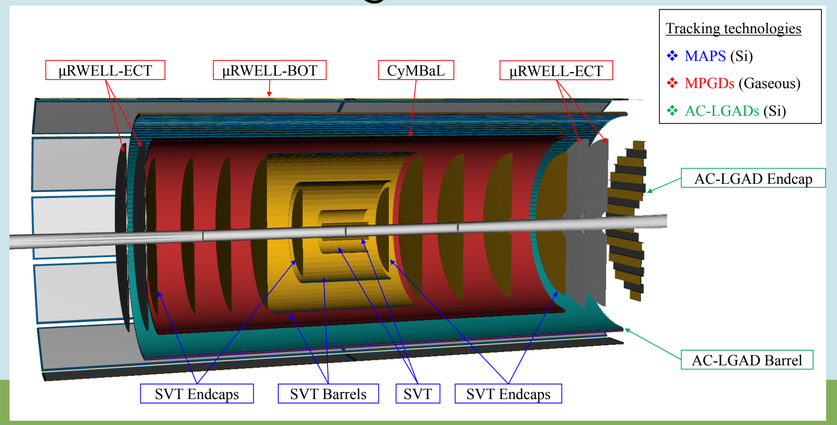
## PID detectors




## Far-forward detectors




## Tracking detectors

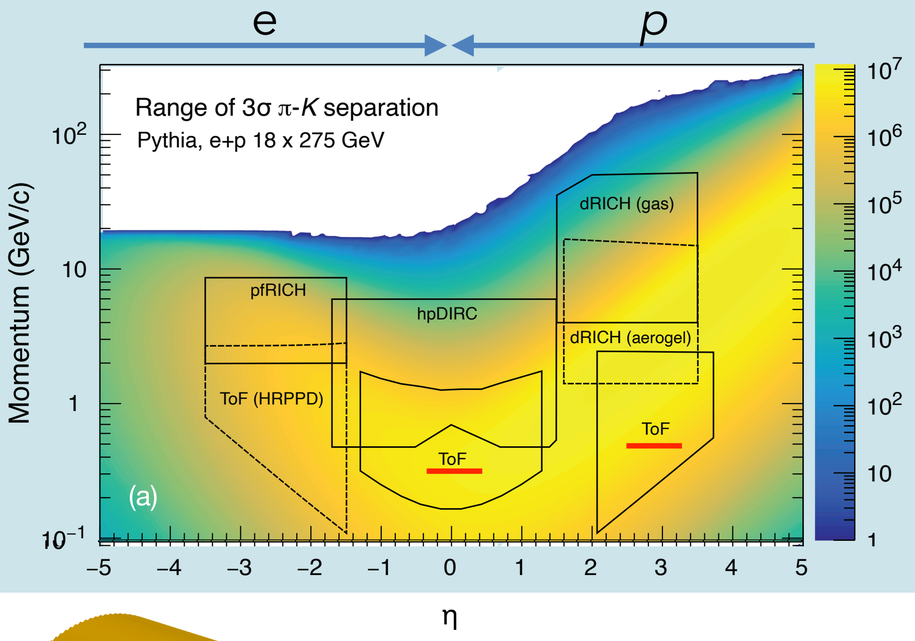


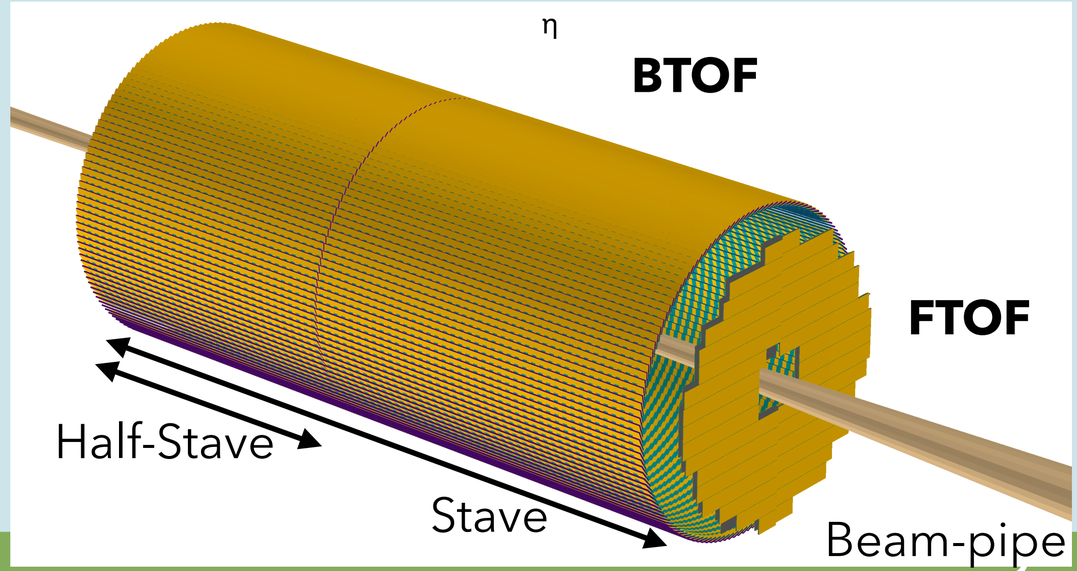
# AC-LGAD TOF in ePIC

- Two types of AC-LGAD TOF, BTOF and FTOF, are installed for the low-p PID
  - Complementary to the Cherenkov detectors

- BTOF covers mid-rapidity (-1.2<η<1.6) composed of tilted 144 staves (288 half-staves)
  - π/K separation below 1.2 GeV/c is performed
  - Strip-type AC-LGAD sensor is used
  - It is placed at ~64 cm from the beam-pipe

- FTOF covers forward-rapidity (1.9<η<3.9), hadron going direction
  - π/K separation below 2.5 GeV/c is performed
  - Pixel-type AC-LGAD sensor is used

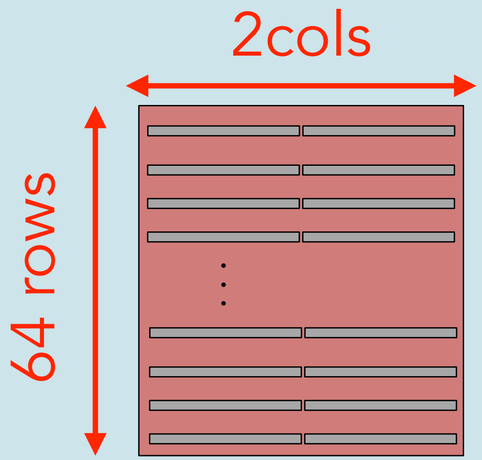


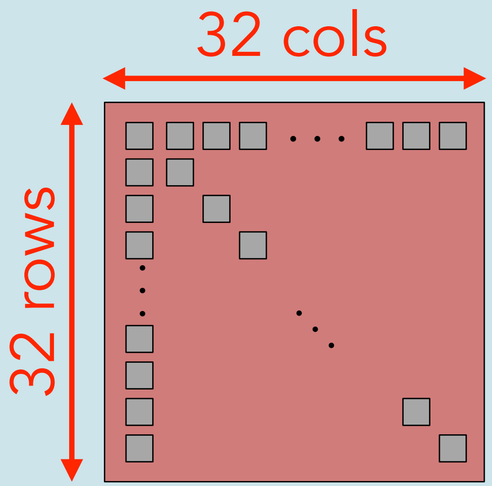
# AC-LGAD for BTOF and FTOF

- **Strip-type** sensor, ~~3.2 x 4 cm$^2$~~ 3.2 x 2 cm$^2$ sensor size with 0.005 x 1 cm$^2$ metals with 0.05 cm pitch, is used in **BTOF**
- The readout metal geometry is ~~64 x 2~~ 64 x 2 and ~~256~~124 channels in total each
- 1 ASICs are attached to each sensor with wire bonding

- **Pixel-type** AC-LGAD sensor, 1.6 x 1.6 cm$^2$ sensor size with 0.05 x 0.05 cm$^2$ metals, is used in **FTOF**
- The readout metal geometry is 32 x 32 and 1024 channels in total each
- 1 ASIC (2D 32x32) is attached to the one sensor




- BTOF strip sensor
  - **18432 sensors**
  - **12 m$^2$**
  - **2.4 M readout channels**



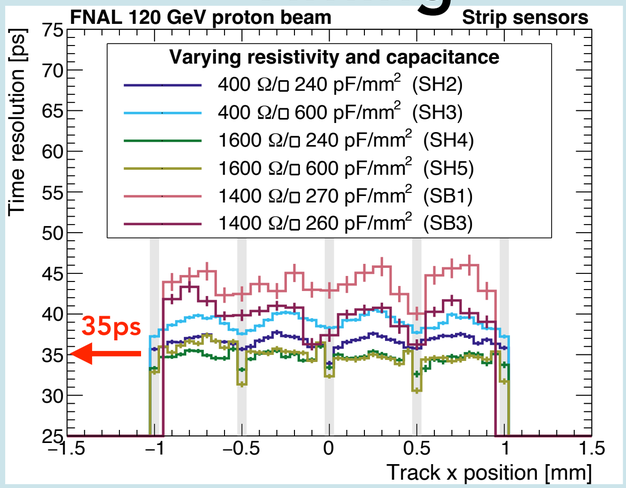

- FTOF pixel sensor
  - **3632 sensors**
  - **1.1 m$^2$**
  - **3.6 M readout channels**

# Latest sensor performance

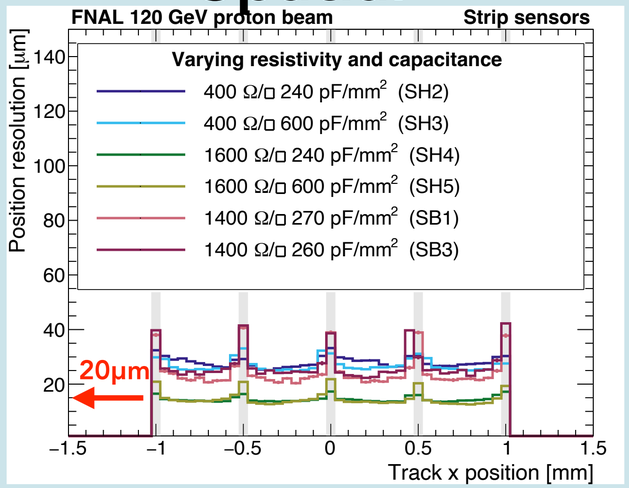
## Beam test result at FNAL (from eRD112 FY24 report by FNAL, LBNL)

### Strip type results

#### Timing

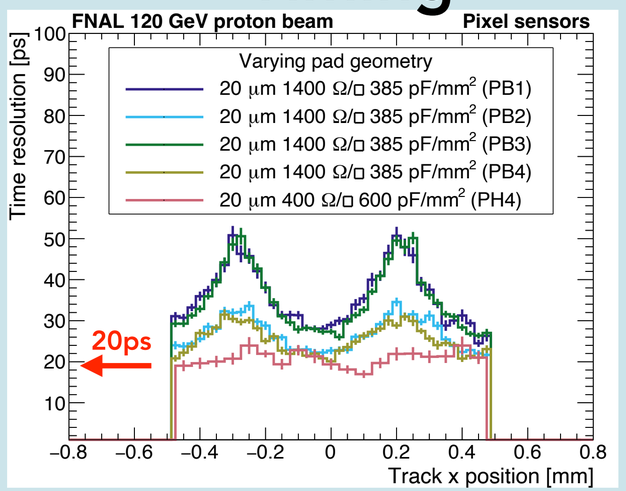



#### Spatial

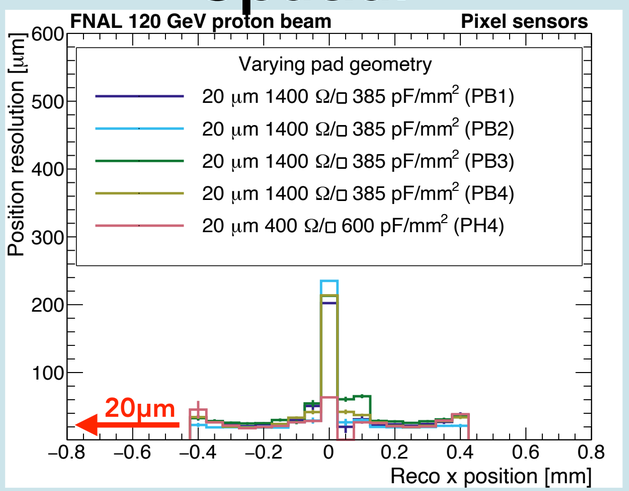



### Pixel type results

#### Timing



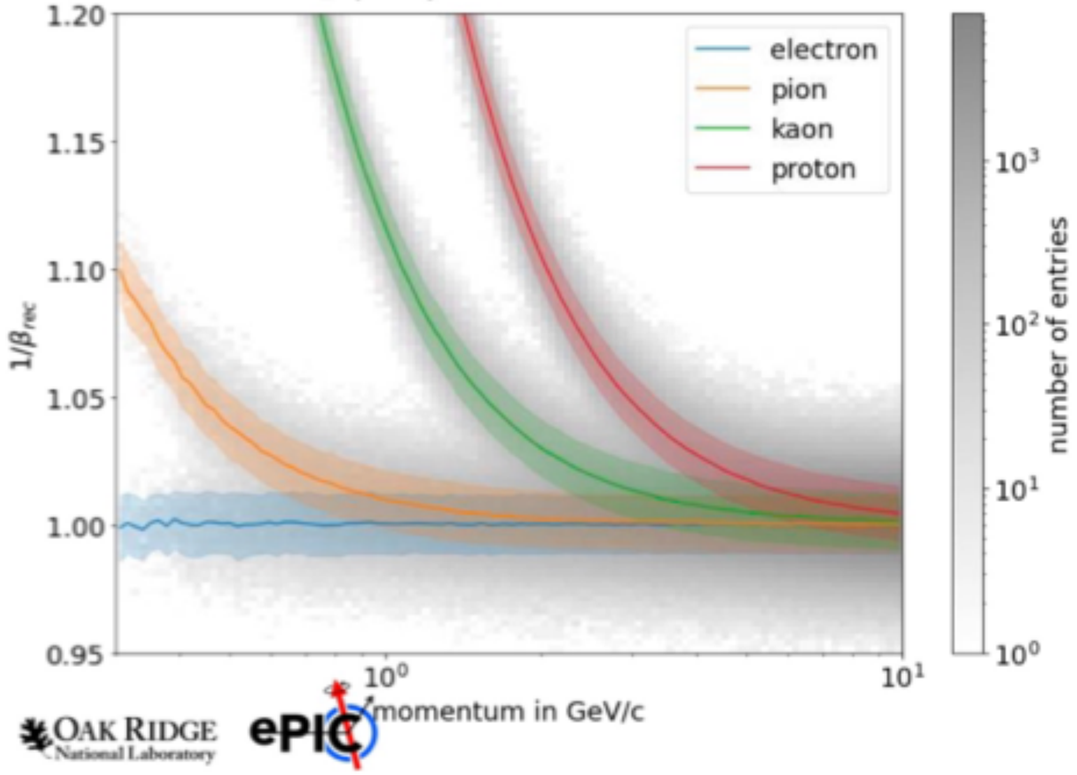

#### Spatial



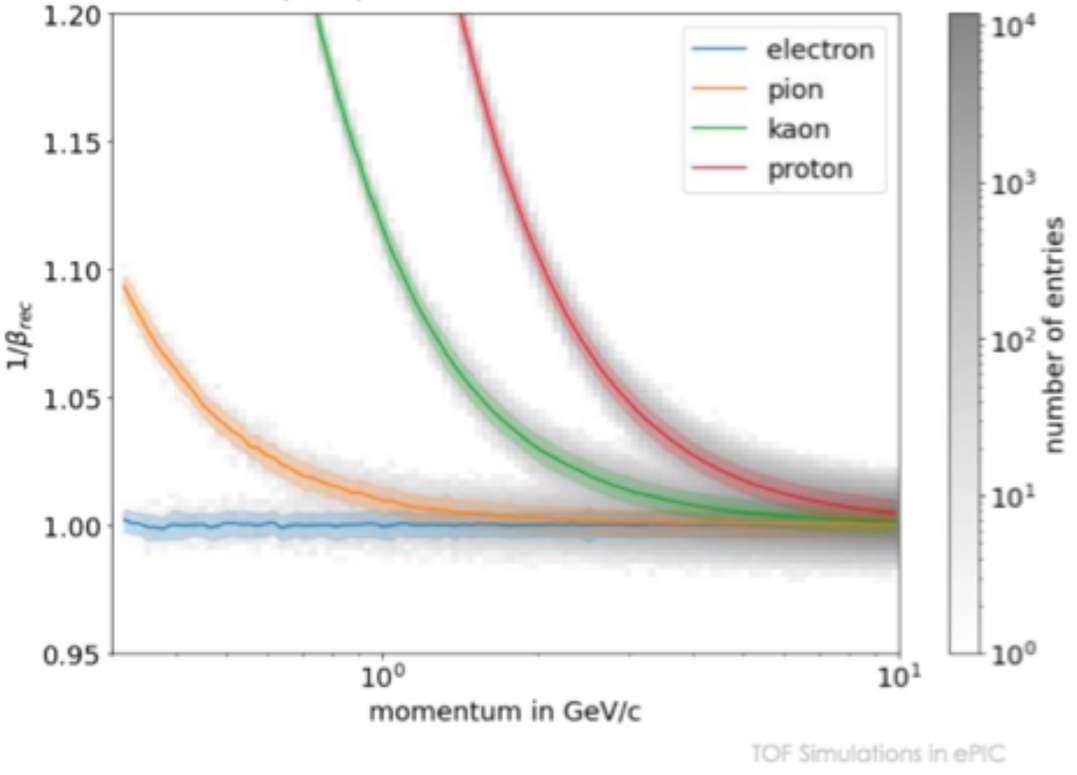

- HPK and BNL sensors show reasonable results in both strip and pixel types with the “BEST” bias voltage
  - The higher performance of time resolution should be achieved when considering the electronics jitter and T0 resolution
- The performances are under control and the next prototypes will have higher performance
- The sensors are still smaller than the sensors used in the experiment

# PID performance by AC-LGAD TOF

- Barrel Region
  - e/pi up to 0.5 GeV/c
  - pi/K up to 1.9 GeV/c
  - K/p up to 3.1 GeV/c




- Endcap Region
  - e/pi up to 0.8 GeV/c
  - pi/K up to 2.7 GeV/c
  - K/p up to 4.6 GeV/c




TOF Simulations in ePIC

OAK RIDGE National Laboratory ePIC

# ASIC

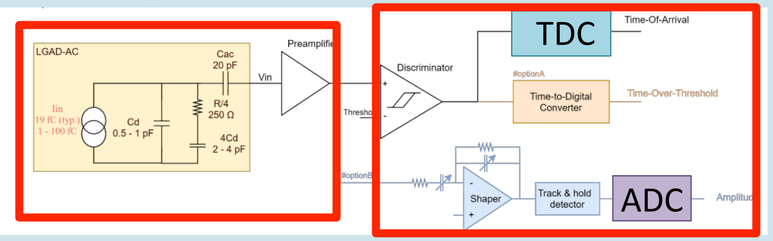
- EICROC (32x32 = 1024ch) is one of the common ASICs used in ePIC
  - Design suits to pixel-type AC-LGAD readout (for low input capacitance)
  - 10-bit TDC and 8-bit ADC is now available (EICROC0)

- We have several options for the strip-type AC-LGAD readout
  - The strip type has a large input capacitance of ~10 pF
    - "Standard" EICROC should be modified if it is used for the strip type
  - FCFD and modified HGCROC are the candidates
    - FCFDv1 with the analog block is available and FCFDv2 with digital block will be available beginning of next year
    - HGCROC has been developed for CMS Calorimeter and is ready
    - ETROC (CMS ASIC) will be used for the coming electronics development

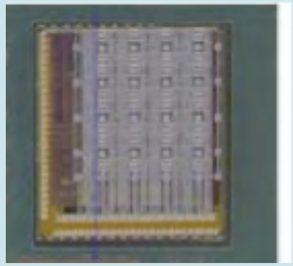
- It is very welcome to join the ASIC development
  - We are discussing how to collaborate with eRD109 (electronics R&D consortium)

Analog block

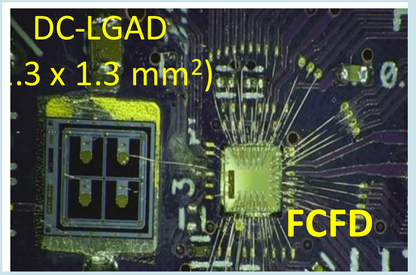
Digital block



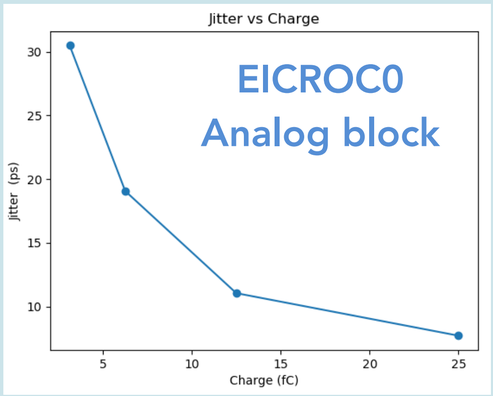

EICROC0

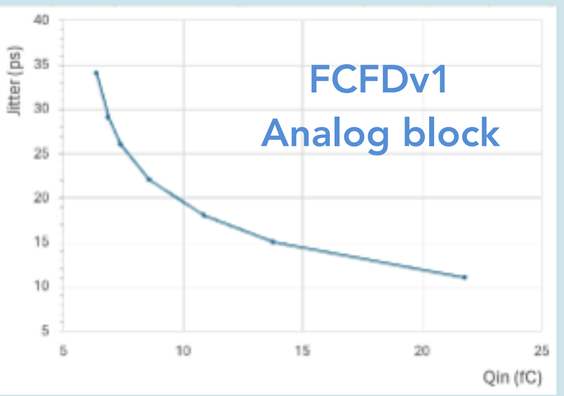


FCFDv1




HGCROC3



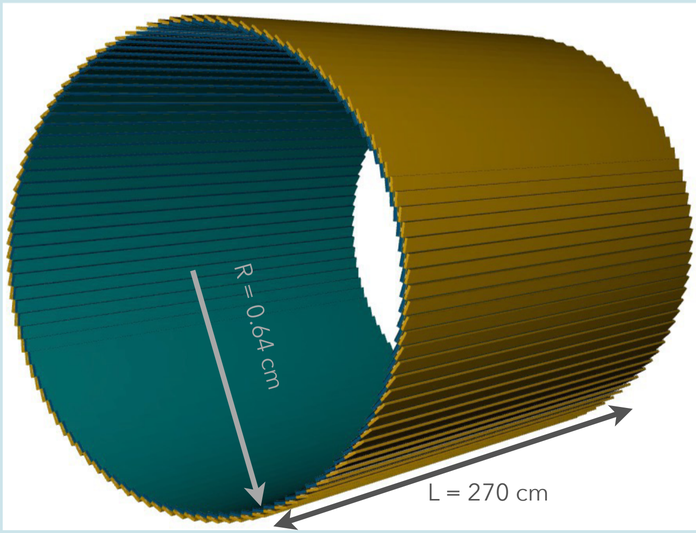



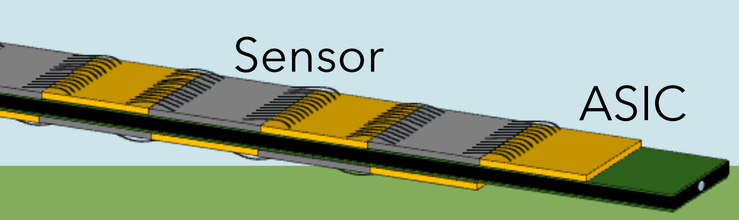
# Challenging points other than sensor and ASIC

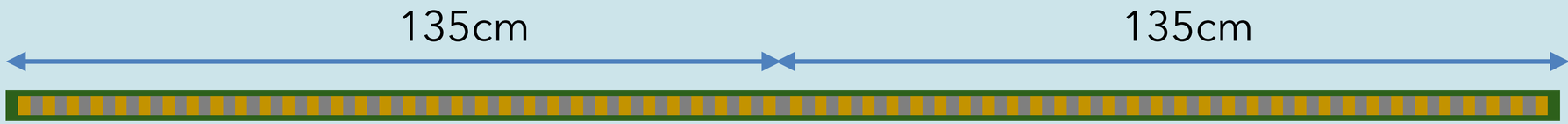
- BTOF is composed of long stave structures with a low material budget ~3% X/X0
  - ~0.5% X/X0 material budget with 135 cm must be developed
  - We have never developed such a long and low material FPC!
  - Due to the restriction, the cooling system design flexibility is limited

- Temperature control of the sensor is one of the most challenging and important points to realize BTOF
  - AC-LGAD is very sensitive to its temperature

- To avoid the acceptance hole and enhance the cooling capability, the double-side design is the baseline
  - The procedure of assembling and construction plays a key role in enhancing the yield

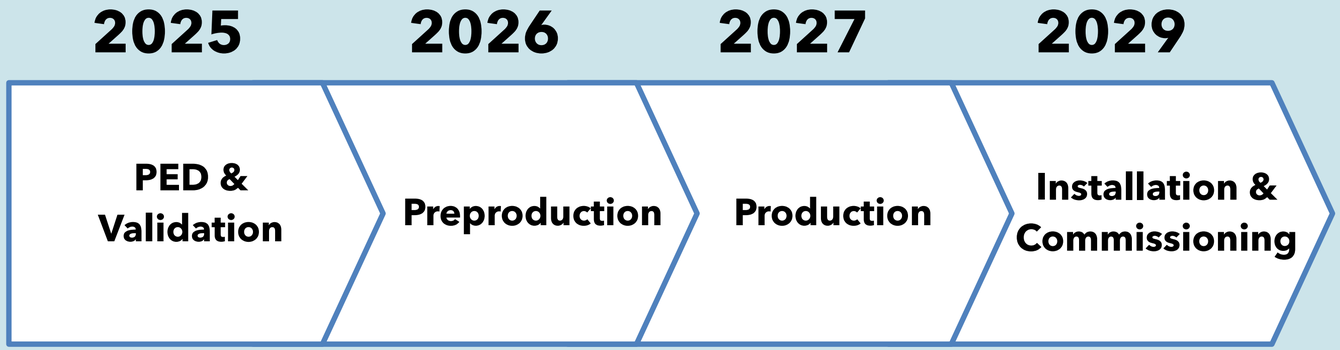


# The AC-LGAD TOF collaboration and schedule

| Institute | Contact Person | NOW (TDR->Project) |
|---|---|---|
| Brookhaven National Laboratory | Prithwish Tribedy tribady@bnl.gov | DAQ readout chain readout, sensor-ASIC integration, sensor with FF AC-LGAD; EICROC testing |
| Fermi National Accelerator | Artur Apresyan Artur.Apresyan@cern.ch | FCFD ASIC (no ePIC) |
| OMEGA | Dominique Marchand dominique.marchand@ijclab.in2p3.fr | EICROC |
| Los Alamos National Laboratory | Xuan Li xuanli@lanl.gov | |
| Rice University | Wei Li wl33@rice.edu | B/FTOF FEE?, Backend electronics (postdoc) , simulation and reconstruction |
| Oak Ridge National Laboratory | Oskar Hartbirch hartbricho@ornl.gov | sensor-ASIC integration, frontend electronics (waffle probing), module assembly |
| Ohio State University | Daniel Brandenburg Brandenburg.89@osu.edu | BTOF/FTOF: module assembly; backend electronics |
| Purdue University | Andreas Jung anjung@purdue.edu | Module assembly |
| Univ. of California, Santa Cruz | Simone Mazza simazza@ucsc.edu | Sensor, sensor-ASIC integration, module assembly (no in-kind) |
| University of Illinois at Chicago | Olga Evdokimov mailto:evdolga@uic.edu | |
| Hiroshima University | Kenta Shigaki shigaki@hiroshima-u.ac.jp | FTOF EICROC testing, sensor testing (30%), simulation |
| RIKEN | Yuji Goto. goto@bnl.gov | BTOF: module assembly |
| Shinshu University | Kentaro Kawaide kawade@shinshu-u.ac.jp | Sensor testing, simulations |
| University of Tokyo | Taku Gunji gunji@cns.s.u-tokyo.ac.jp | DAQ streaming readout |
| South China Normal University | Shuai Yang syang@scnu.edu.cn | |
| Univ of Sci. and Tech. of China | Yanwen Liu | |
| Indian Institute of Tech., Mandi | Prabhakar Palni prabhakar.palni@unigoa.ac.in | FTOF Module Assembly/QA, sensor testing |
| National Inst. of Sci. Edu. Res. | Ganesh Tambave ganesh.tambave@niser.ac.in | Module Assembly |
| National Central University | | FF AC-LGAD (sensor QA) |
| National Cheng-Kung University | Yi Yang yiyang@ncku.edu.tw | Mechanics and cooling systems |
| National Taiwan University | Rong-Shyan Lu rslu@phys.ntu.edu.tw | FF AC-LGAD; module assembly |
| Univ. Técnica Federico Santa María | | Simulations |
| LBNL | Zhenyu Ye yezhenyu2003@gmail.com | BTOF ASIC testing; SH |
| Kent State University | Zhangbu Xu zxu22@kent.edu | Simulation, readout test, machine shop (in-kind) |
| Nara | Takashi Hachiya hachiya@cc.nara-wu.ac.jp | BTOF module assembly/validation/FPCB |

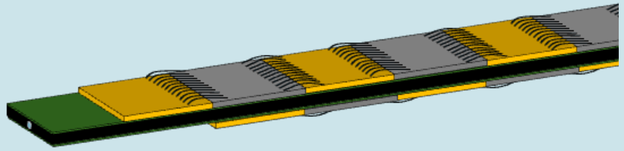



- The schedule is based on the data-taking start in 2032
- I am not sure, but it will be behind the schedule by 2 years?

# Organization of TOF-Japan


- The Japanese community has committed to the AC-LGAD TOF project
  - Especially, we focus on the BTOF part
- Recently, Tohoku University has participated in the project officially
- The institutes are working on,
  - Simulation (background & material budget)
  - Long FPC design
  - Sensor R&D
  - Assembling & Construction
- TOF-Japan meeting (link) is held every Wednesday (10:00JST → 20:00EST)

# Assembly building & Resource in Japan



- Construction has begun on a new building to house TOF's development and assembling room
  - The building is scheduled to be completed by the end of 2025
- There is one 100 $m^2$ 1,000 ~ 10,000 class clean room that we can use for BTOF
  - Wire bonding machine, probe station, laser system and other equipment will be installed here
- We are discussing whether to build another site at RIKEN
  - The site will be used not only by BTOF but also by ZDC activities

- We requested a large amount of grant for our government to succeed in the ePIC project
  - BTOF is one of the main projects in the plan ($10s M)
  - The official conclusion will be public this December

[News link (English)]

**Japan to Join Electron-Ion Collider Accelerator Construction Project; Potential Boost for Quantum Computer Technology**

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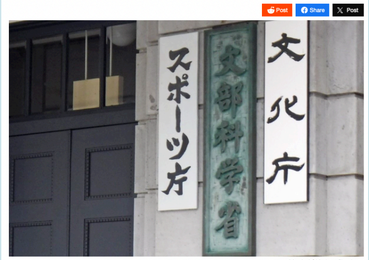



Yomiuri Shimbun file photo
The Education, Culture, Sports, Science and Technology Ministry building in Tokyo

**The Yomiuri Shimbun**
15:47 JST, May 15, 2024

Japan will participate in a U.S. project to build a large electron-ion collider (EIC), a particle accelerator capable of observing the world at the level of one trillionth of a millimeter, it has been learned.

The EIC is expected to shed new light on the physical laws governing the subatomic world and contribute to the practical application of advanced technologies such as quantum computers.

The Education, Culture, Sports, Science and Technology Ministry plans to announce soon its intention to participate in the plan, with the goal of starting operations in 2032.

The state-of-the-art EIC accelerator, a circular experimental facility about 3.8 kilometers in circumference, will be built by Brookhaven National Laboratory (BNL) in New York, part of the U.S. Department of Energy.

BNL plans to replace the existing accelerator in the basement of the building. Construction is scheduled to begin in 2026, with operations beginning in 2032.

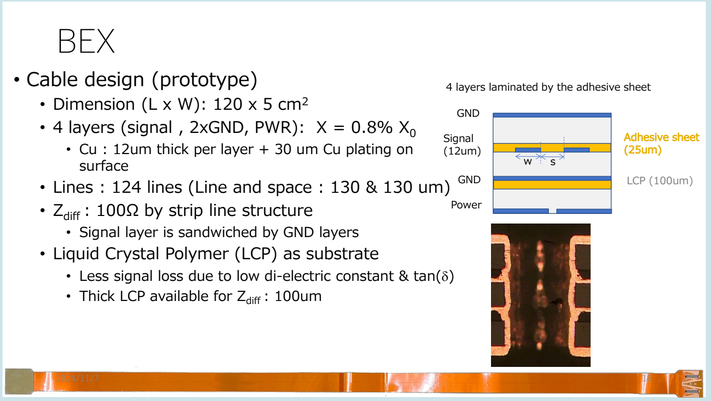
# Other items

- Takashi Hachiya (NWU) is working on the FPC design
  - FPC design is still difficult despite relaxed conditions
  - The first one is designed with ETROC2

- We visited HAYASHI-REPIC CO. Ltd. to discuss how to cooperate with the AC-LGAD TOF project
  - The company made the long & low material FPC of sPHENIX
  - The mass production of the ATLAS Strip tracker for the upgrade is ongoing

- We are planning to have a meeting with HPK engineers next week
  - The strategy for the coming sensor production will be discussed

- We are preparing the test beam at Tohoku University
  - Masashi Kaneta (Tohoku University) plays a key role in the test




# Summary

- AC-LGAD TOF is an important PID doctor for low-p region at mid and forward rapidity
- BTOF uses the strip type, and FTOF uses the pixel-type sensor
  - The covering area of BTOF and FTOF is 12 $m^2$ and 1.1 $m^2$, respectively
- The spatial resolution is already above the requirement, but the higher timing resolution is necessary to get 35 ps timing resolution with the whole system
- Tohoku University has joined the project and they play in very important role in the coming test beam in Japan
- Our government decision for the grant is about to be public soon (this month)