Simulation studies and R&D status and plans in Japan for the EIC ePIC Barrel TOF with AC-LGAD

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ePIC Collaboration

The Electron Ion Collider (EIC) is a proposed particle accelerator that would collide beams of electrons, protons, and ions at 20-140GeV, and the Electron Proton Ion Collider (ePIC) is a detector to be installed at EIC.

The ePIC Collaboration includes more than 160 institutions in 24 countries and has more than 500 participants.

The ePIC Collaboration has a wide range of expertise and diverse physics interests.

The design of the detector proposed in ePIC is based on ECCE and ATHENA, and is shown in Fig1. In EIC Japan group, we are interested in contributing to ZDC, Barrel TOF with AC-LGAD. Especially, Hiroshima University group is interested in AC-LGAD Barrel.

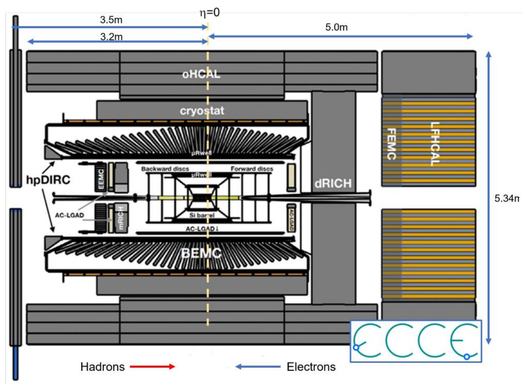


Fig.1 The design of the ECCE detector.[5]

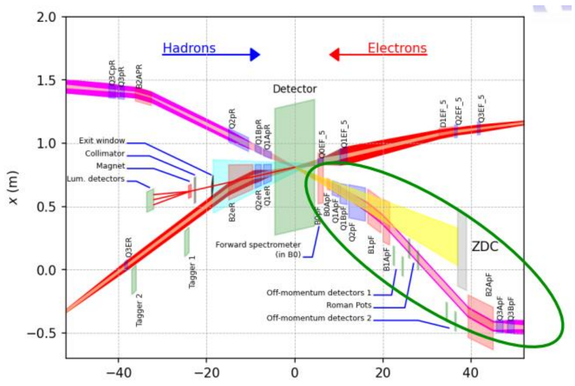


Fig.2 Image of the EIC baseline IR layout[6]

Time of Flight(TOF) in the ePIC Collaboration

TOF is a main identification detector at low- to middle-pT region. In order to accurately measure particle information in the TOF, there are several requirements.

- Requiring an excellent timing resolution due to the compact design detector at |η|<1.4(Barrel) and 1.8<|η|< ～4.0(Endcap): 30 ps (25 ps) for Barrel (Endcap)
  – Particle identification e/π/K/p separation 0.15 < p < 2 GeV/c (0.15 < p < 2.5 GeV/c)
- Requiring the spatial resolution: 30 um (30 um) for Barrel (Endcap)
  – Improve tracking (momentum) resolution

LGAD technology is the primary candidate for compliance with these requirements.

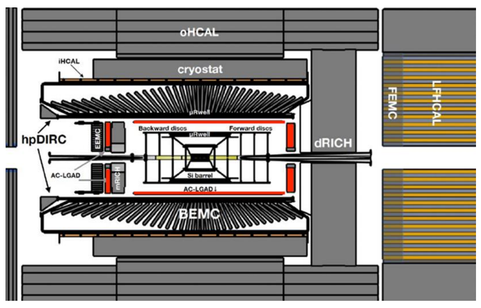


Fig.3 The design of the EIC detector. Red aria is AC-LGAD.[5]

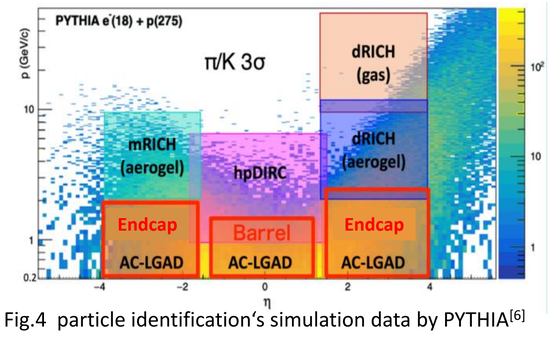


Fig.4 particle identification's simulation data by PYTHIA[6]

AC-LGAD

Construction of AC-LGAD (Low-Gain Avalanche Detector) Barrel based on our past experience of PHENIX VTX silicon detector construction and present experience of sPHENIX INTT silicon detector construction.

AC-LGAD is

– Additional oxide layer for AC-coupling readout
– 30 ps timing resolution
– One large gain layer for electrodes → 100% of fill factor
– Good spatial resolution thanks to charge sharing

EIC-Japan has higher hopes for AC-LGAD technology than DC-LGAD that is being built by ATLAS and CMS.

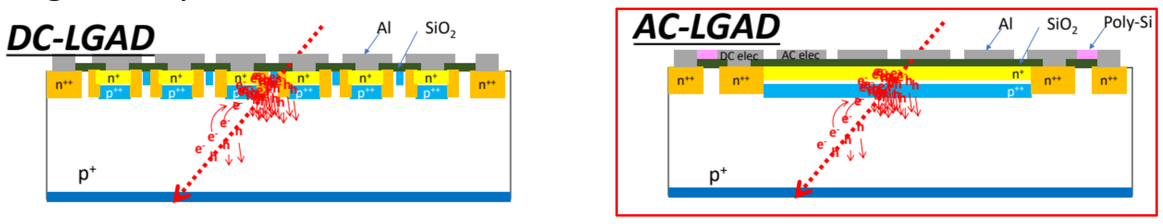


Fig.5 Comparison of AC-LGAD and DC-LGAD[7]

Reference
[1] EIC Yellow Report, BNL-220990-2021-FORE, JLAB-PHY-21-3198, LA-UR-21-20953
[2] EIC RHIC and the EIC, https://www.bnl.gov/eic/rhic-eic-comparison.php
[3] EIC Asia Workshop (held in 16-18 March 2023)
[4] EIC Japan meeting
[5] John Lajoie(Iowa State Univ.) slide in EIC Asia Workshop
[6] elke-caroline aschenauer(BNL) slide in EIC Asia Workshop
[7] First Prototype of Finely Segmented HPK AC-LGAD Detectors, JPS Conf. Proc. 34, 010016 (2021)

Simulation Studies

Since improvements are still needed to adapt AC-LGAD to EIC, S.Yano (Hiroshima Univ.) started a simulation about barrel and endcap TOF.

Detector response and data reconstruction
– ePIC detector (based on DD4Hep): https://github.com/eic/epic
– EICRecon: https://github.com/eic/EICrecon
– Pythia8 NC DIS Q2>1GeV2 in ep (18GeV electron + 275GeV proton beam) collisions (HepMC data archived in S3)
– 10,000 events
5.2(Barrel),2.8(Endcap Disc1),3.0(Endcap Disc2) hits per event
TOF detector in simulation
– Sensor segment size of barrel-TOF: 100um x 1cm
– Sensor segment size of endcap-TOF: 100um x 100um
– Sensor thickness: 300um

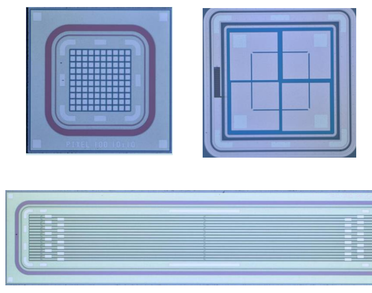


Fig.6 Sensor Type
(←Pixel, →Pad, ↓Strip)

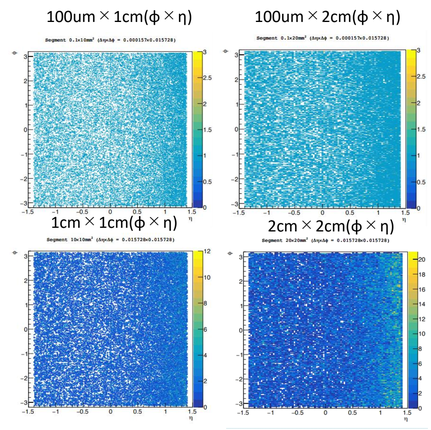
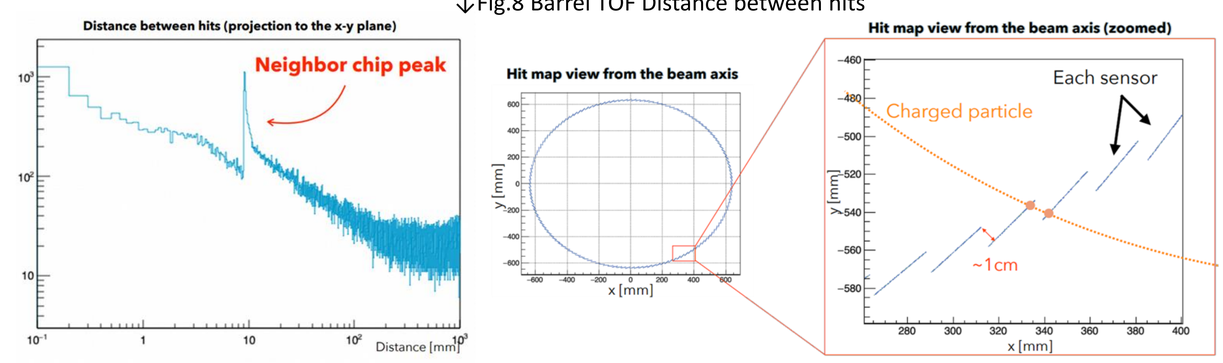


Fig.7 Barrel TOF occupancy

The maximum multiple-hit segment
– 100um x 1cm (strip-type) : $3x10^{-4}$
– 100um x 2cm (strip-type) : $3x10^{-4}$
– 1cm x 1cm (pad-type) : $12x10^{-4}$
– 2cm x 2cm (pad-type) : $20x10^{-4}$

Negligible overlapping effect per event even with O(1) cm size segment
Not necessary the high granularity segment from the particle identification point of view
⇒ Next step is to search effect on the tracking resolution

↓Fig.8 Barrel TOF Distance between hits



Cause multiple hits on different chips by one charged particle
⇒Have to search possibility of improving tracking resolution by this effect

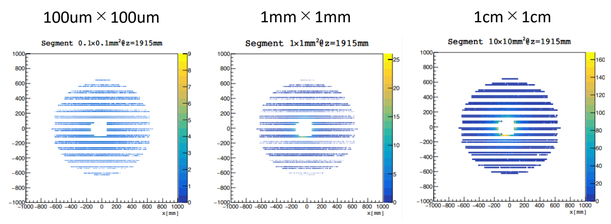


Fig.9 Endcap TOF of Occupancy of Disc1

The maximum multiple-hit segment
– 100um x 100um (pad-type) : $9x10^{-4}$
– 1mm x 1mm (pad-type) : $2.5x10^{-3}$
– 1cm x 1cm (pad-type) : $1.7x10^{-2}$

There are several unexpected inactive area but, This is happening because of a technical issue.

Test Bench at Hiroshima University

We establish a test bench at Hiroshima University to evaluate the performance of LGAD chips.

For this purpose, new equipment such as oscilloscope,FPGA and so on have been installed.

Currently, we are waiting for the chips and EICROC to arrive from BNL.

Fig.10 Oscilloscope: WaveRunner 8208HD (10GS/s, 8ch)

Fig.11 Digitizer: CAEN DT5742 (5GS/s, 16ch)

Fig.12 PMT: PHOTEK PMT240 (60 ps rising time)

Fig.13 FPGA: ZC706

Summary and R&D status in Japan

In 2019, RIKEN and Yamagata University took the lead in submitting a proposal for the Science Council of Japan Master Plan 2020 EIC. In 2022, EIC project proposal submitted Science Council of Japan.

Then, we had a couple of meetings and Workshop to cooperate with Asian group. Our interests are in contributing to ZDC, AC-LGAD Barrel TOF and free streaming DAQ system of the ePIC experiment.

10 institutions are interested in researching ZDC and are developing it with reference to ECCE/EPIC's ZDC and ALICE-FoCal-E technologies.

8 institutions(including Hiroshima Univ.) are interested in researching AC-LGAD and construction of AC-LGAD Barrel TOF based on our experience of PHENIX VTX silicon detector and sPHENIX INTT silicon detector construction. Hiroshima University will lead the research on AC-LGAD in EIC Japan group.

Hiroshima University has already started the simulation study to fine-tune the segmentation and material budget. Furthermore, since a test board will be provided to Hiroshima University soon, we will set up a test bench and R&D lab.

If anyone is interested in helping us plan for the future of EIC, we look forward to hearing from you.

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