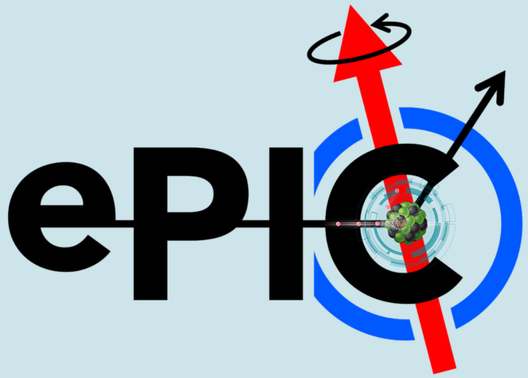


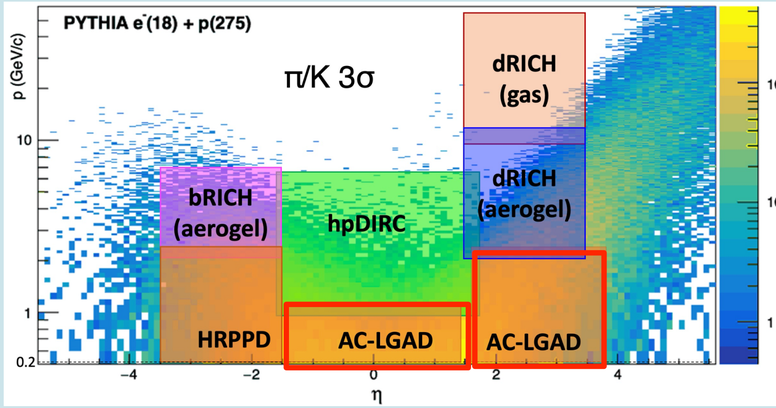
ePIC TOF

Satoshi Yano

Hiroshima University SKCM²

TOF in the ePIC detector

- TOF is a main PID detector covering low-p_T at mid-rapidity



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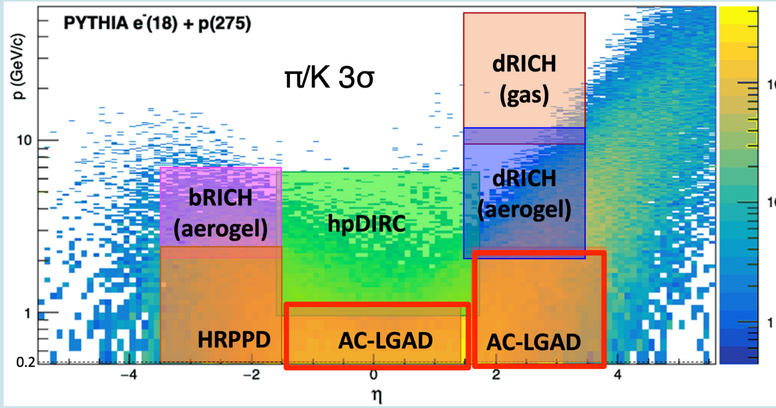

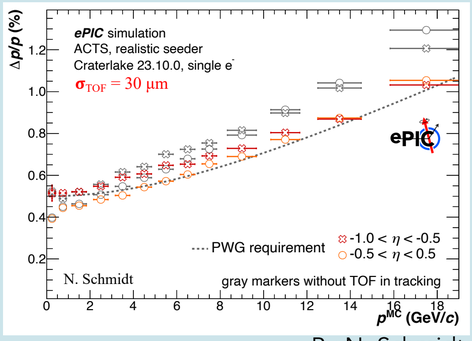

By N. Schmidt

TOF in the ePIC detector

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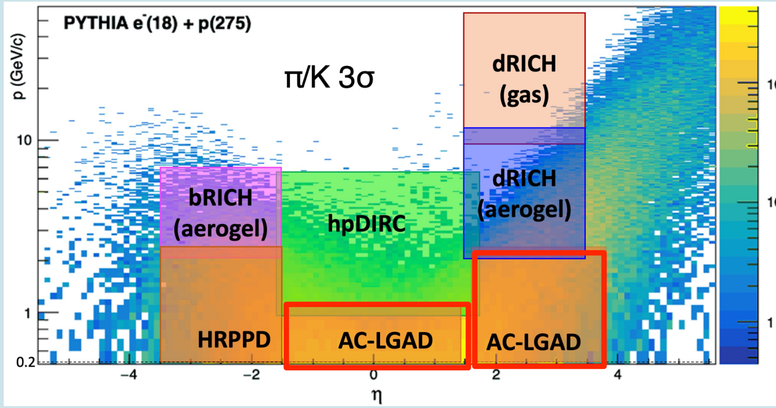
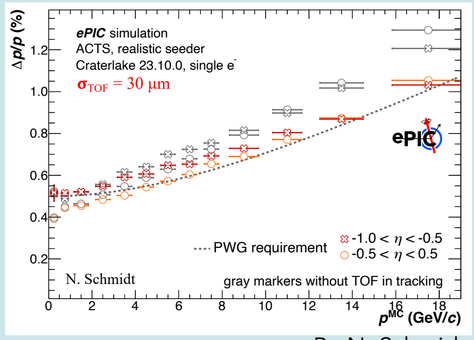
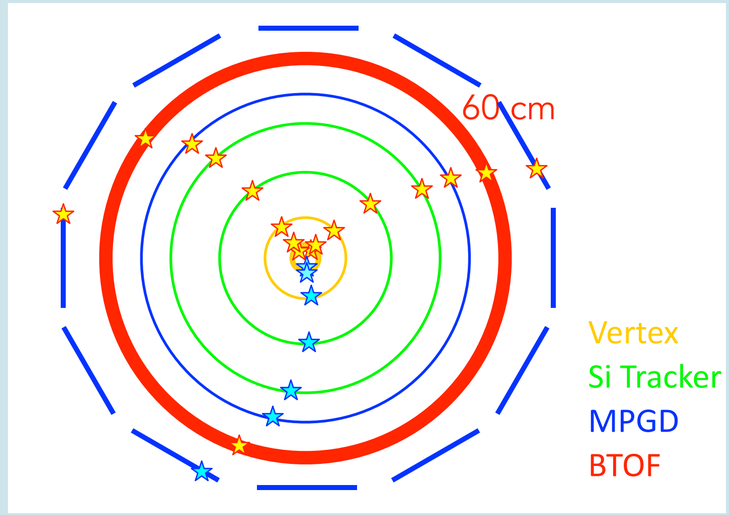




By N. Schmidt

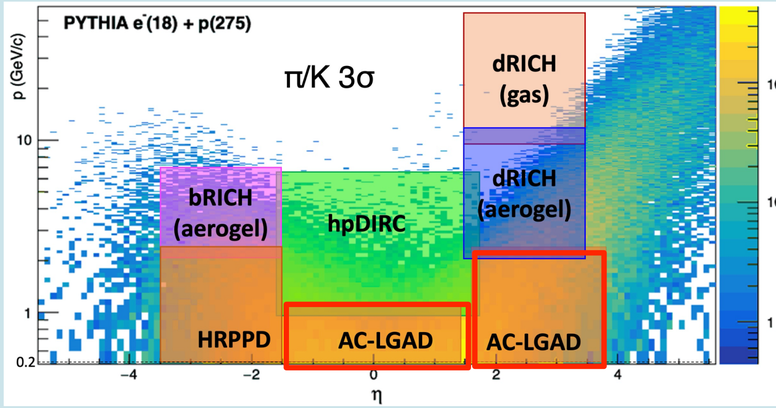
Tracking detectors in ePIC

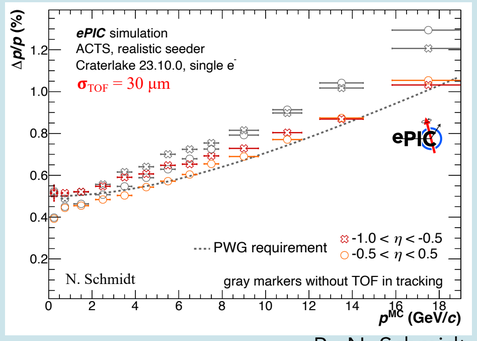


TOF in the ePIC detector

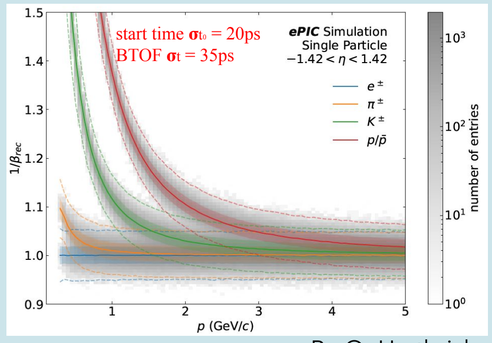
- TOF is a main PID detector covering low-p_T at mid-rapidity
- High momentum particle momentum resolution is improved by TOF
- Beam-induced background can be rejected by timing information

- Timing resolution of 35 ps and spatial resolution of 30 um is required
  - 3 sigma π/K separation up to ~1.2 GeV/c

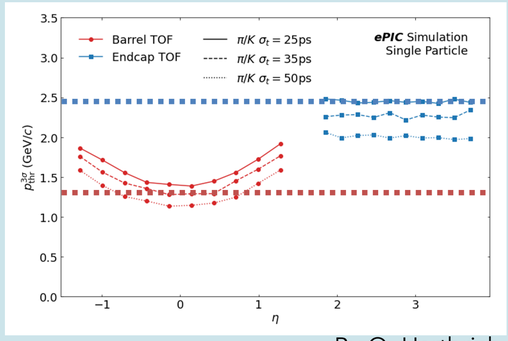




By N. Schmidt



By O. Hartbrich



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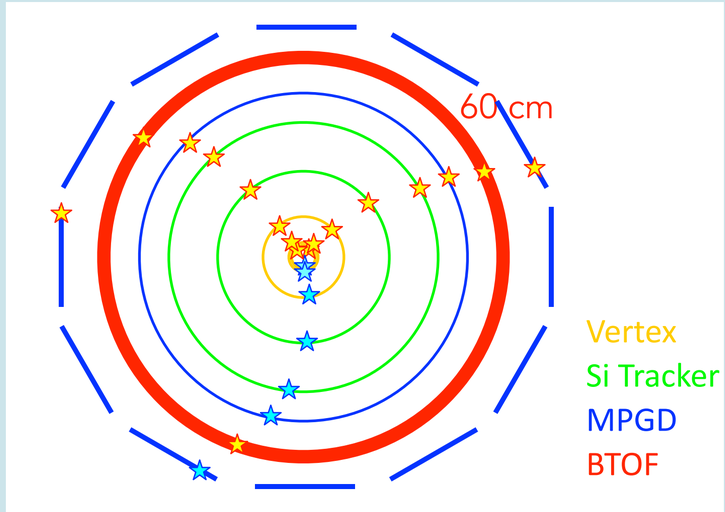
Tracking detectors in ePIC



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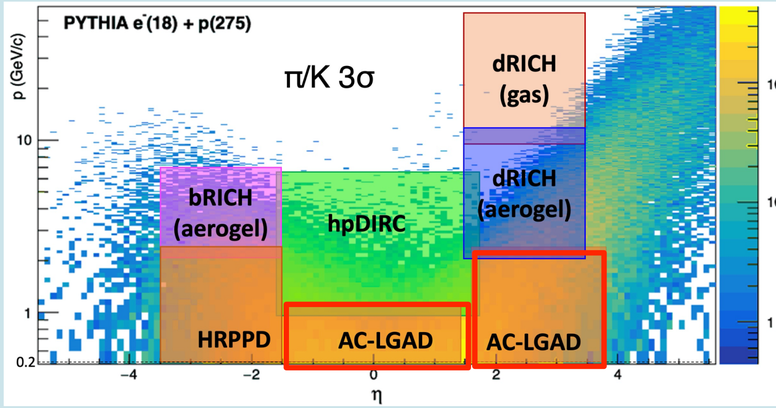
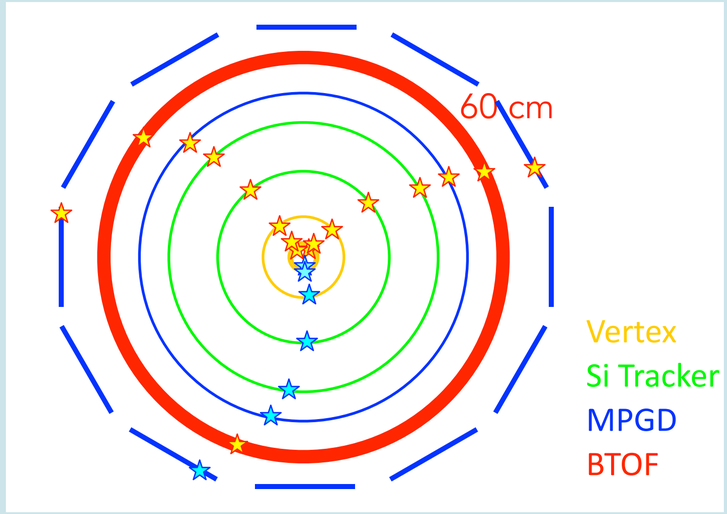
- TOF is a main PID detector covering low-p_T at mid-rapidity
- High momentum particle momentum resolution is improved by TOF
- Beam-induced background can be rejected by timing information

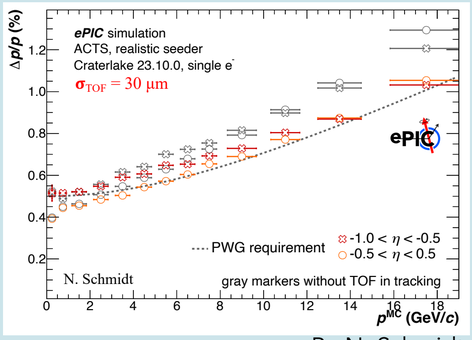
- Timing resolution of 35 ps and spatial resolution of 30 um is required
  - 3 sigma π/K separation up to ~1.2 GeV/c

- AC-LGAD technology meets the requirements
  - To reduce total readout channels, strip and pixel type AC-LGAD will be adopted for BTOF and FTOF, respectively

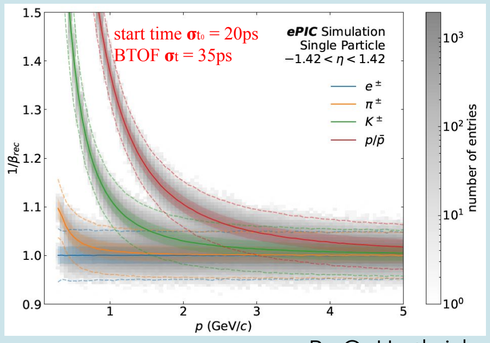


Tracking detectors in ePIC





By N. Schmidt



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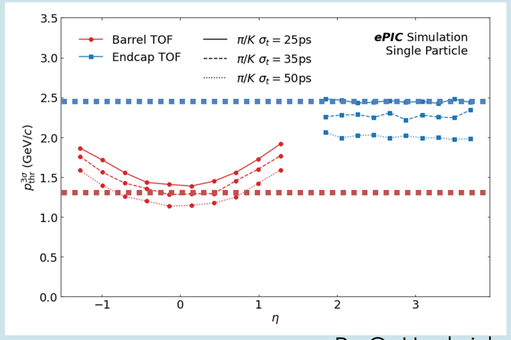
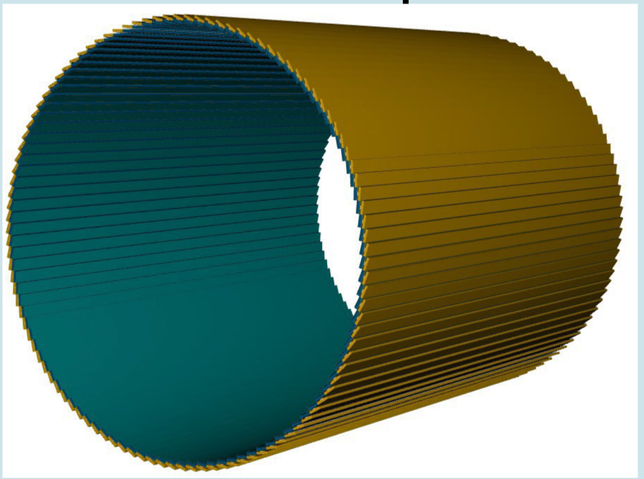


By O. Hartbrich

Detector Layout of BTOF

- BTOF is composed of 144 modules to make a cylindric

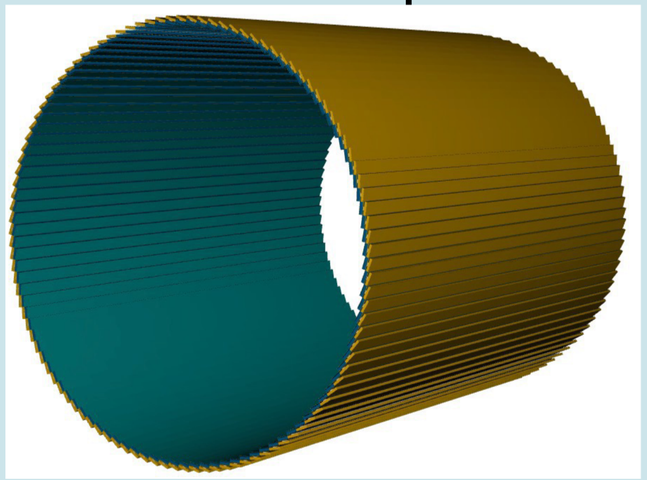
BTOF shape



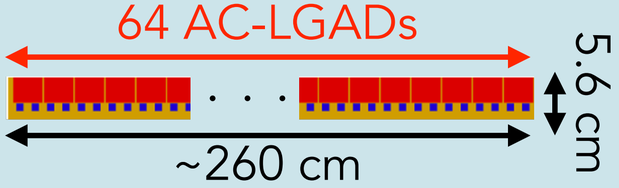
Detector Layout of BTOF

- BTOF is composed of 144 modules to make a cylindric
- 64 AC-LGAD strip sensors are attached to one module
  - ASIC place is under discussion (depending on the ASIC pixel geometry)

BTOF shape



Module top view



Module cross section

Detector Layout of BTOF

- BTOF is composed of 144 modules to make a cylindric
- 64 AC-LGAD strip sensors are attached to one module
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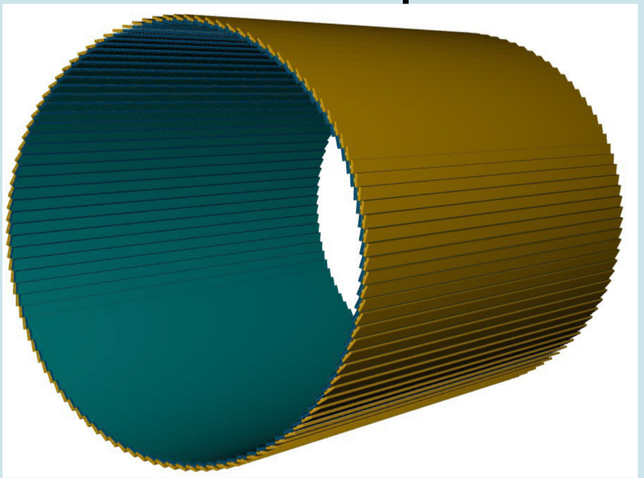
- Radius is 60 - 63 cm from the beam pipe covering $-1.42<\eta<1.77$

BTOF shape



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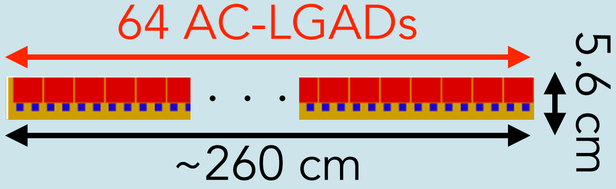
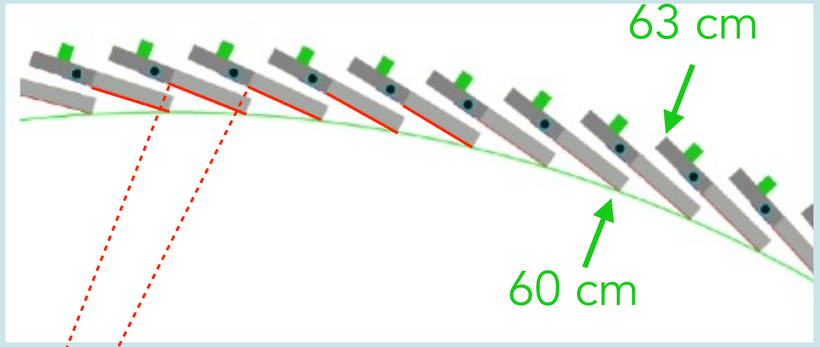


Module cross section

Cylindrical structure by modules

3 mm overlap in ϕ



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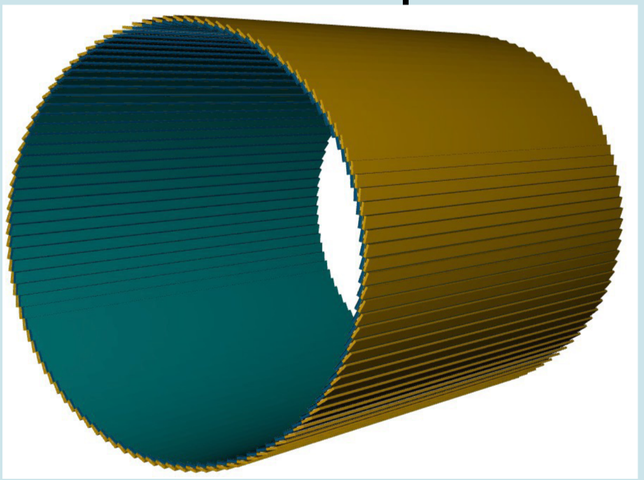
- Total material budget in acceptance is ~0.01 X/X_0

BTOF shape



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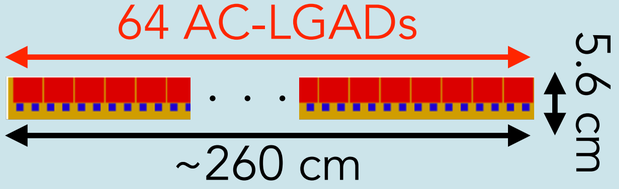

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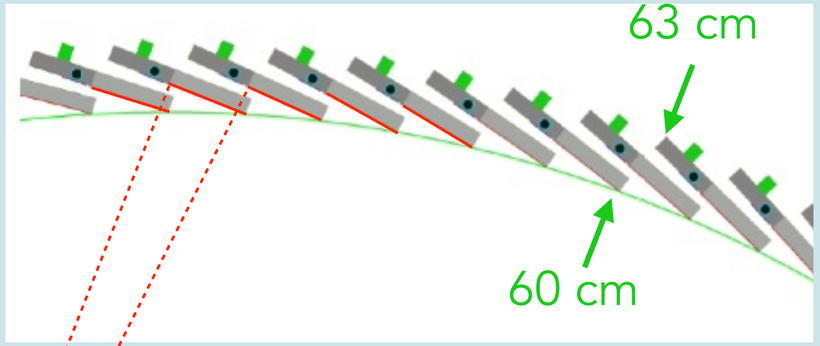
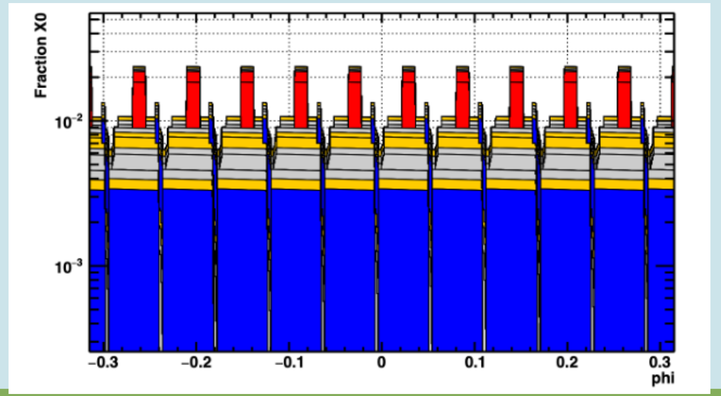


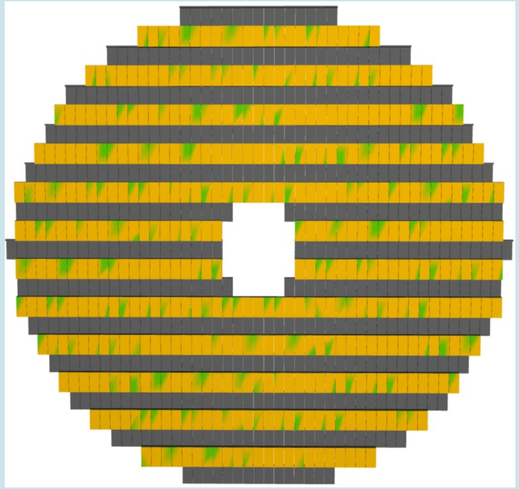
Material budget



Detector Layout of FTOF

- BTOF is composed of 1816 modules to make a disk

BTOF shape



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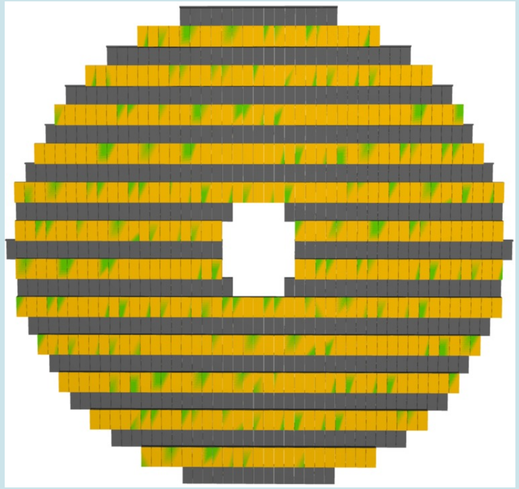
BTOF shape



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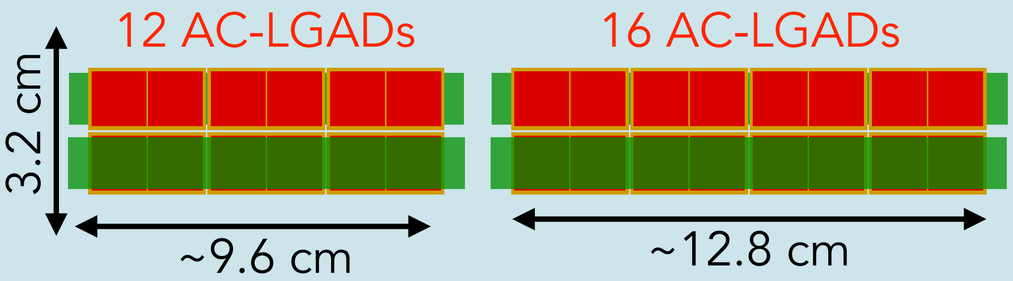

Detector Layout of FTOF

- BTOF is composed of 1816 modules to make a disk
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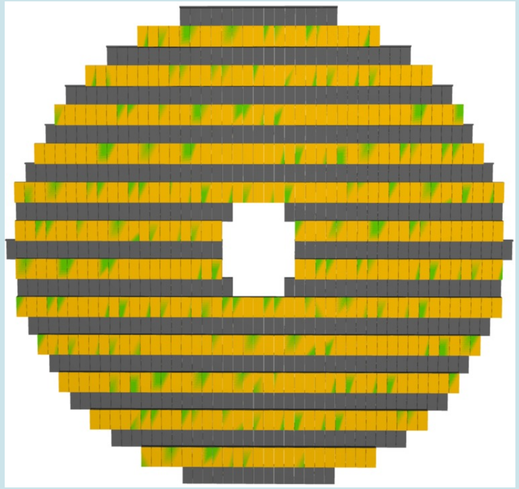
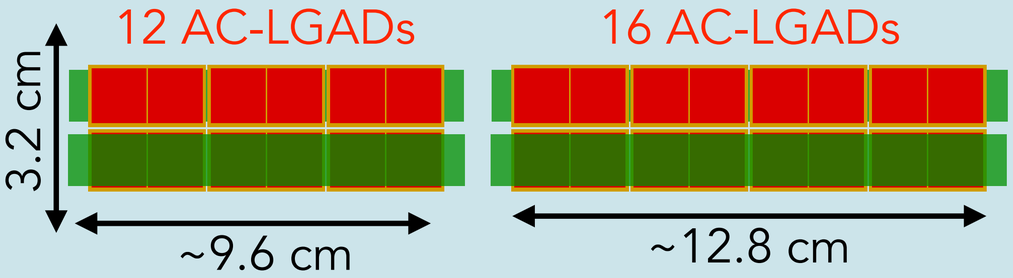
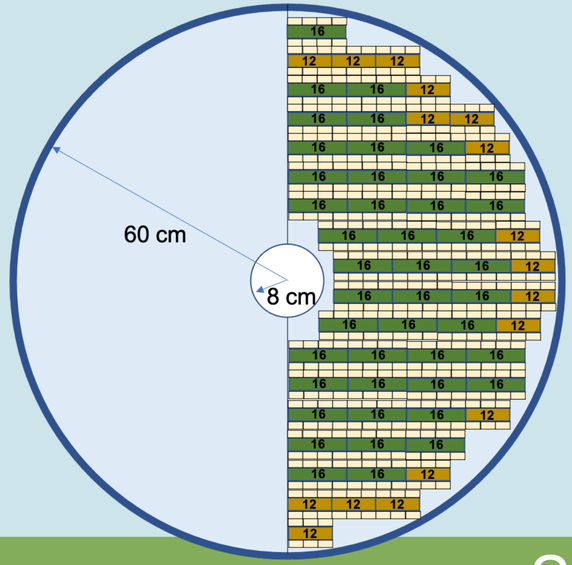
- Radius is 8 - 60 cm from the beam pipe covering 1.86<η<3.85

BTOF shape



Module top view





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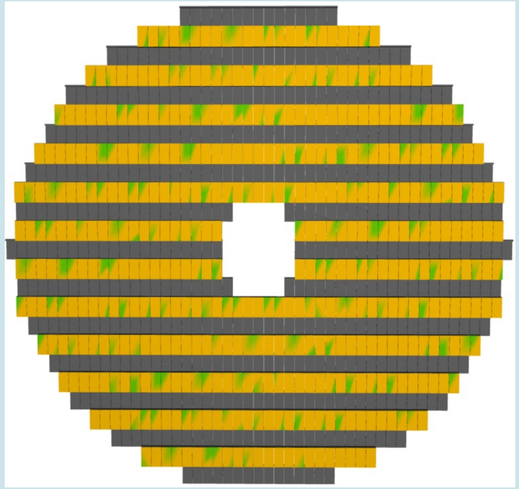
BTOF shape



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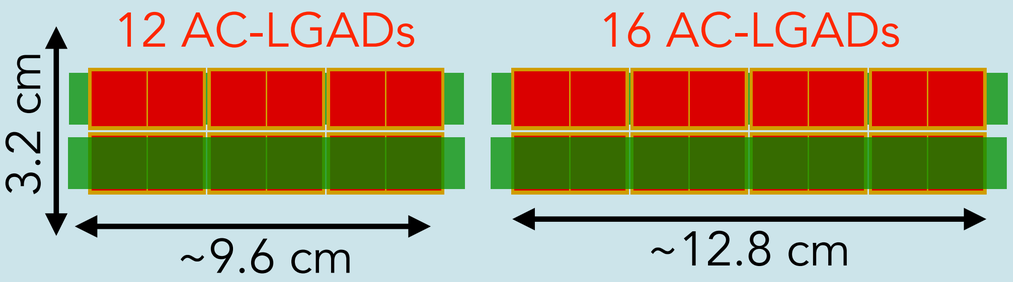
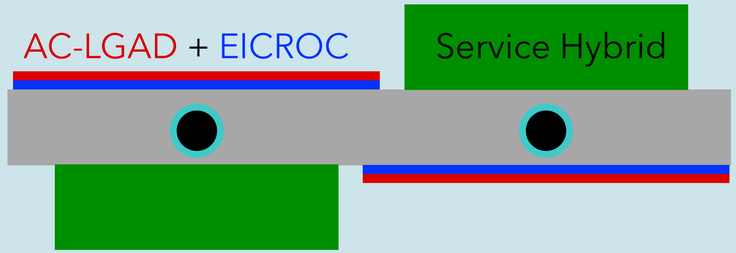
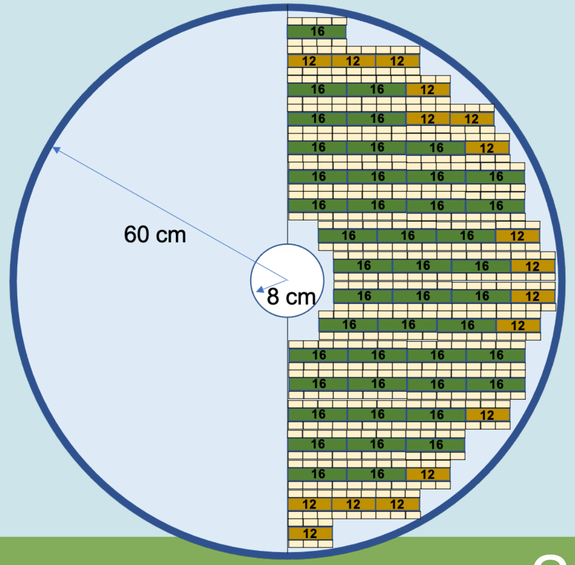


Module cross section





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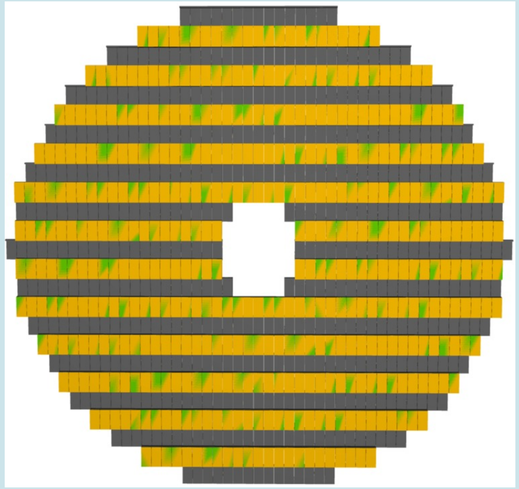
- Total material budget in acceptance is ~0.025 X/X_0

BTOF shape



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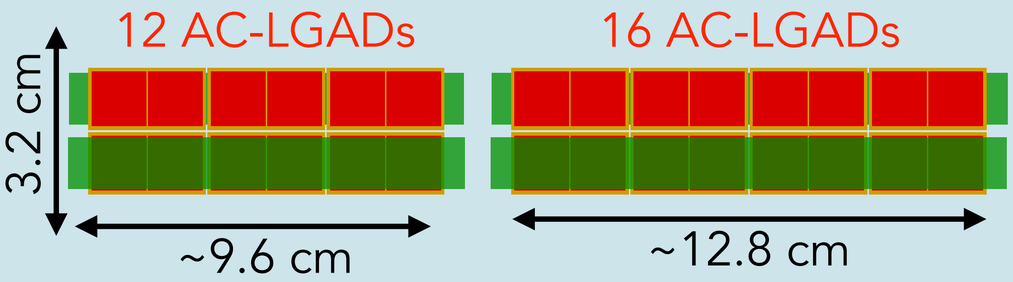

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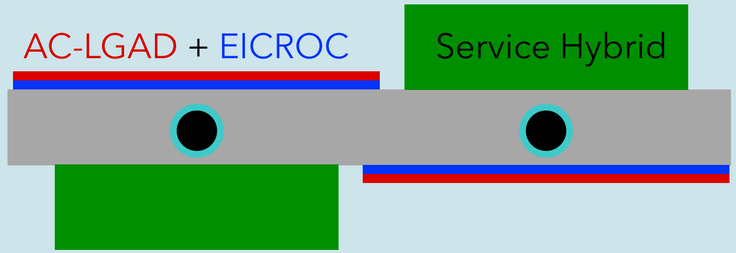

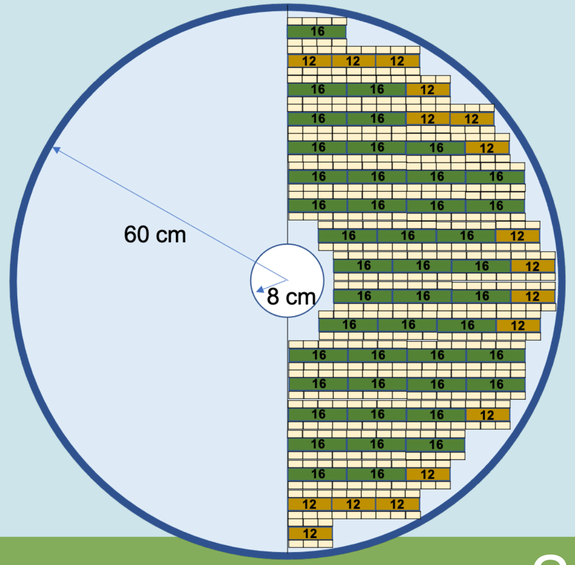

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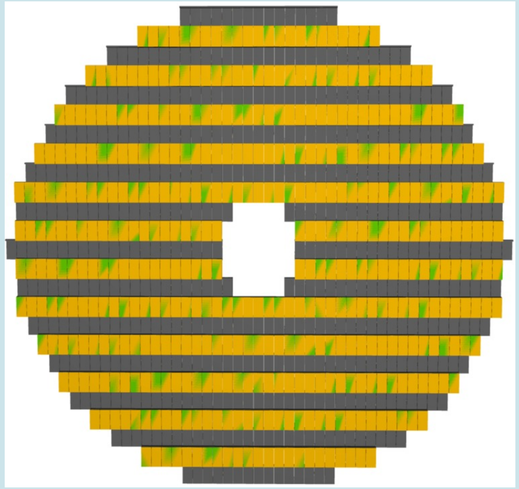
- Service hybrid, readout board + power board, is placed in front of sensors
- Total material budget in acceptance is ~0.025 X/X_0
- Service hybrid and cooling system design is important for FTOF

BTOF shape



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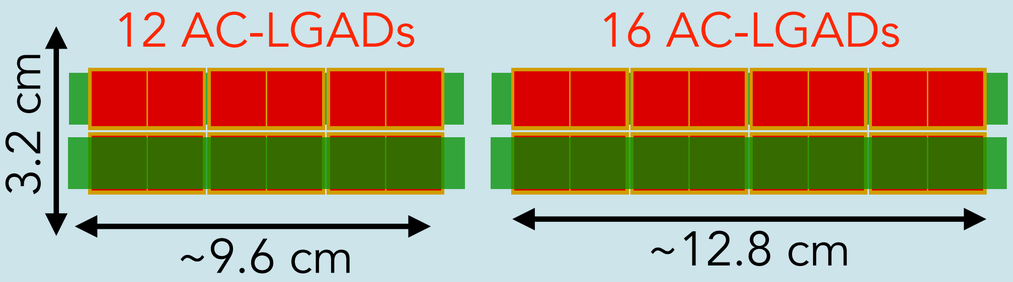
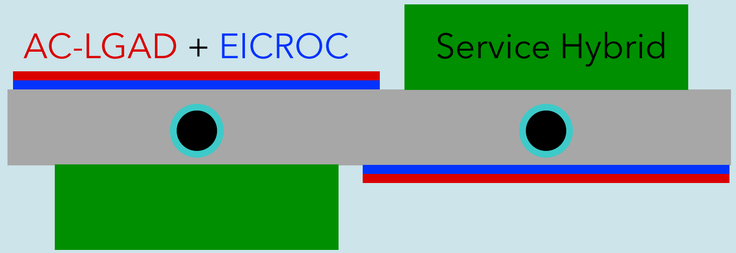
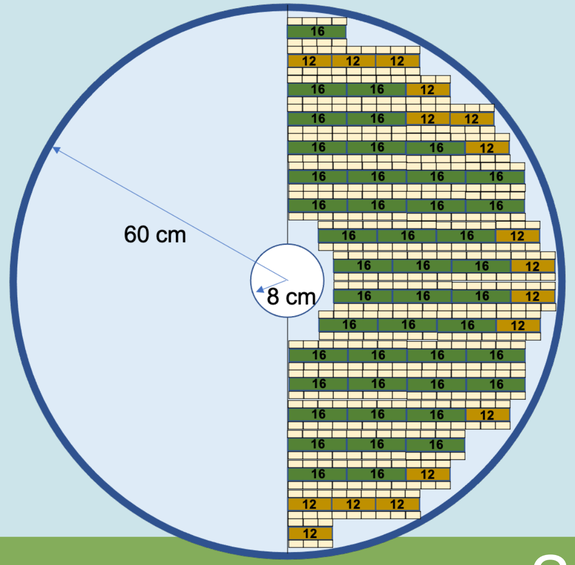


Module cross section

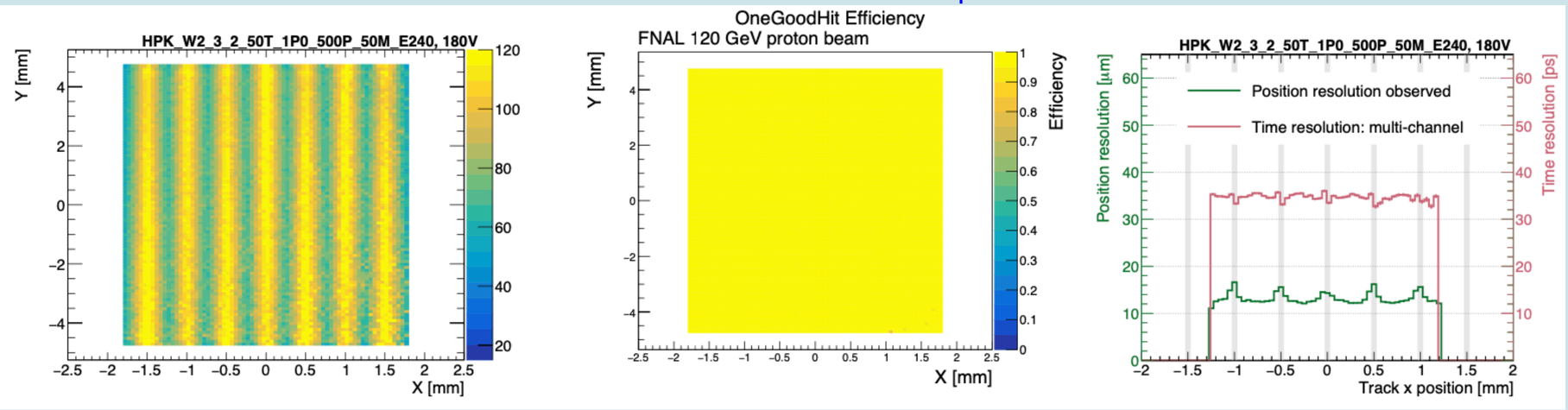




BTOF AC-LGAD sensor

- AC-LGAD technology meets the strict spatial and time resolution requirements

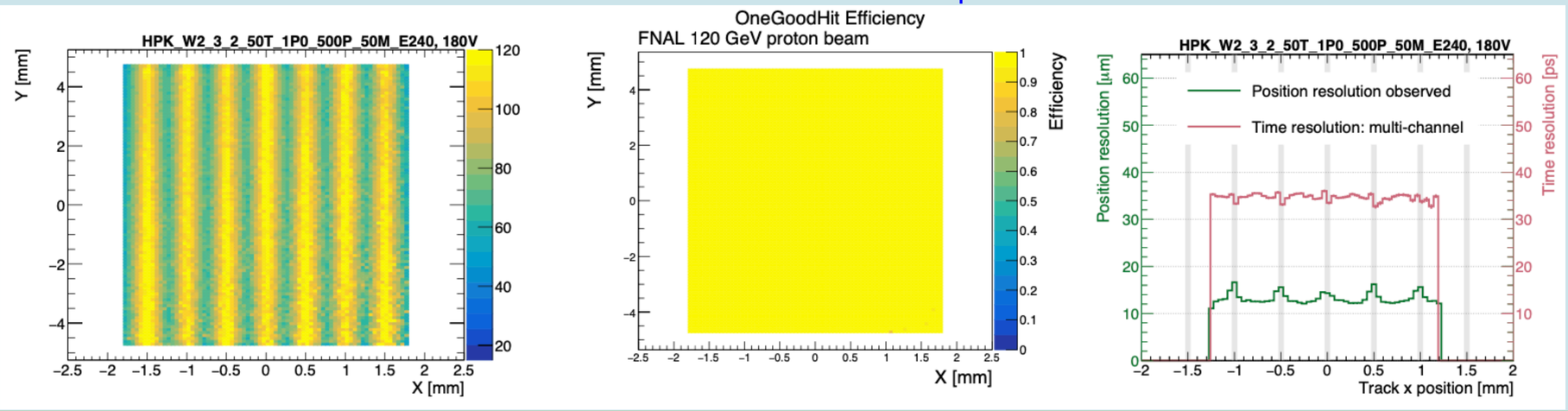
[eRD112 FY24 Proposal]

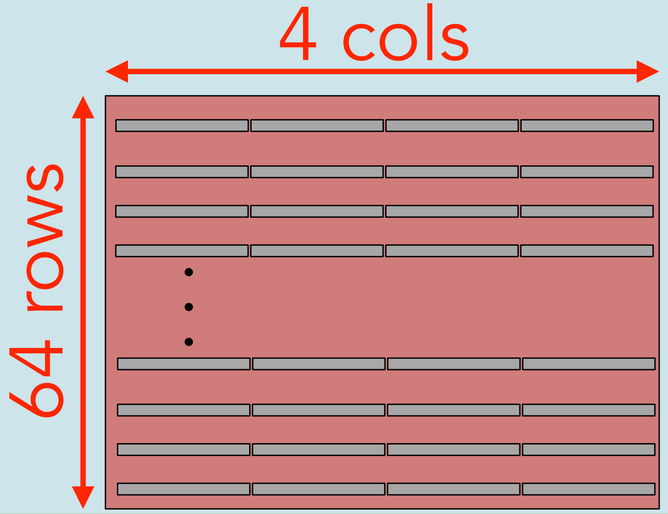


BTOF AC-LGAD sensor

- AC-LGAD technology meets the strict spatial and time resolution requirements
- Strip-type sensor, 3.2 x 4 cm^2 sensor size with 0.05 x 1 cm^2 metals, is used in BTOF
  - The readout metal geometry in a sensor is 64 x 4 and 256 channels each

[eRD112 FY24 Proposal]

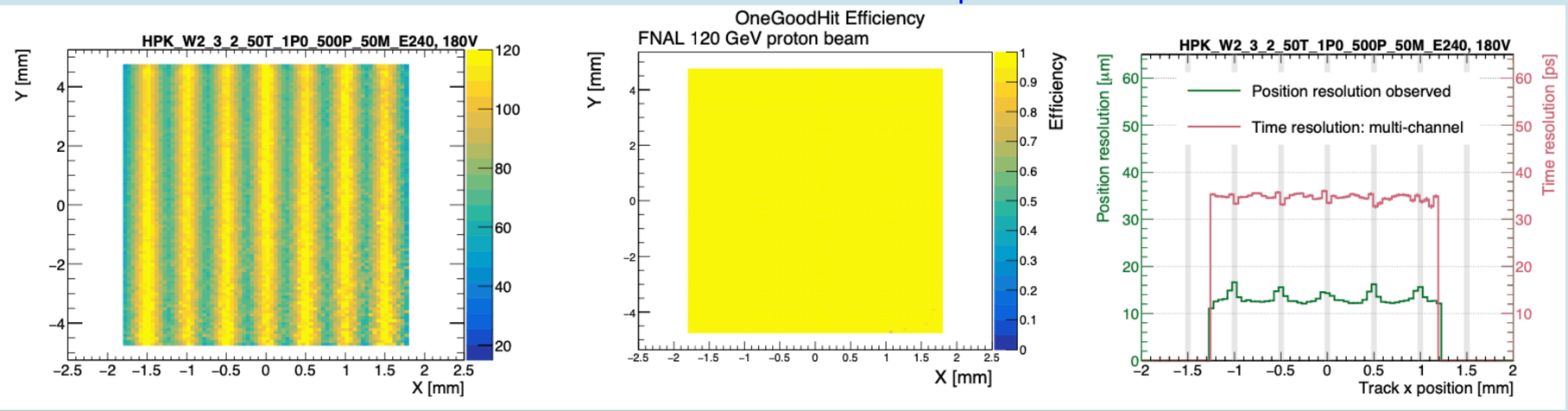


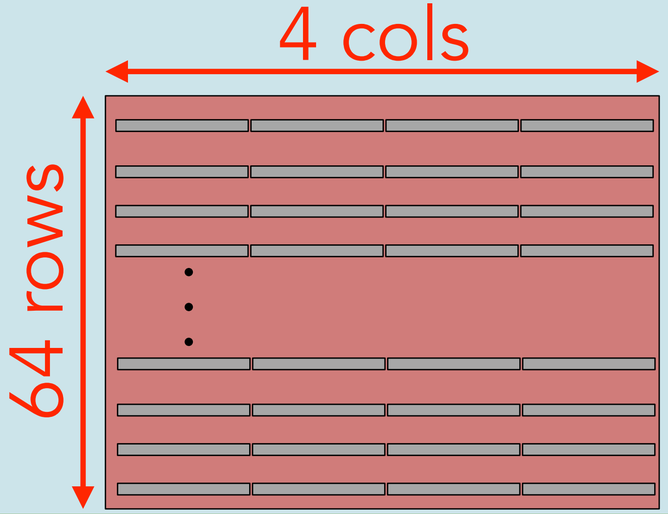


BTOF AC-LGAD sensor

- AC-LGAD technology meets the strict spatial and time resolution requirements
- Strip-type sensor, 3.2 x 4 cm^2 sensor size with 0.05 x 1 cm^2 metals, is used in BTOF
  - The readout metal geometry in a sensor is 64 x 4 and 256 channels each
- 2 ASICs are attached for each with wire bonding

[eRD112 FY24 Proposal]





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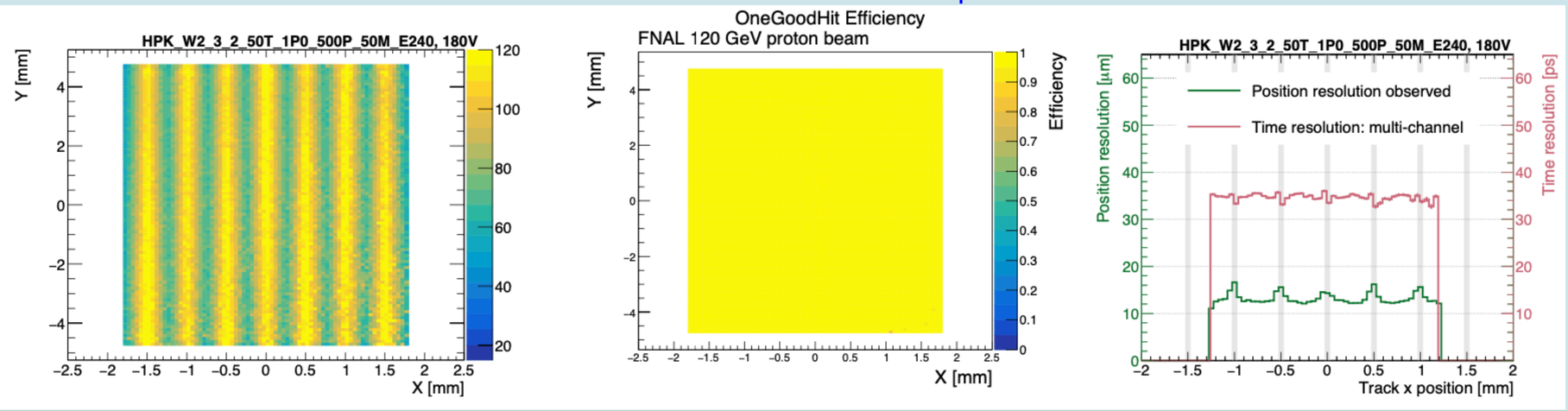
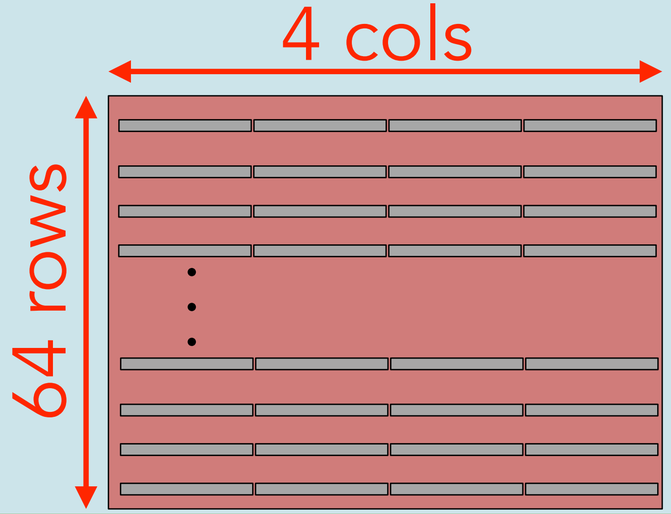
- Total information
  - **9216 sensors**
  - **10 m^2**
  - **2.4 M readout channels**

[eRD112 FY24 Proposal]

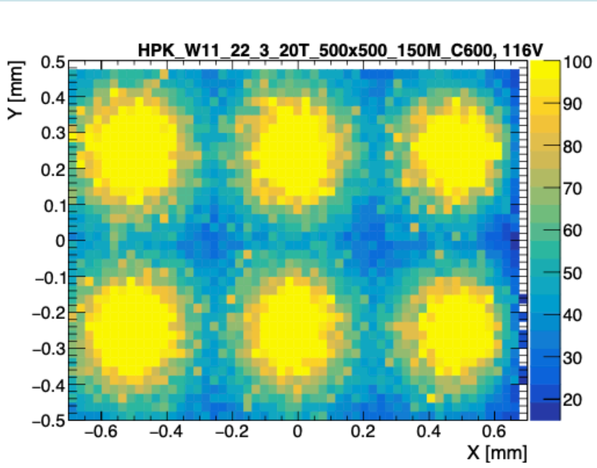


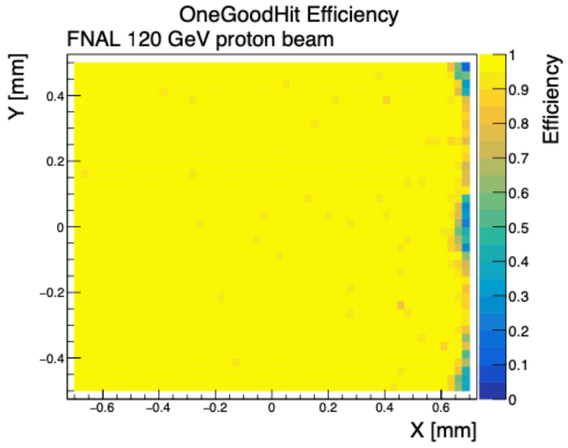


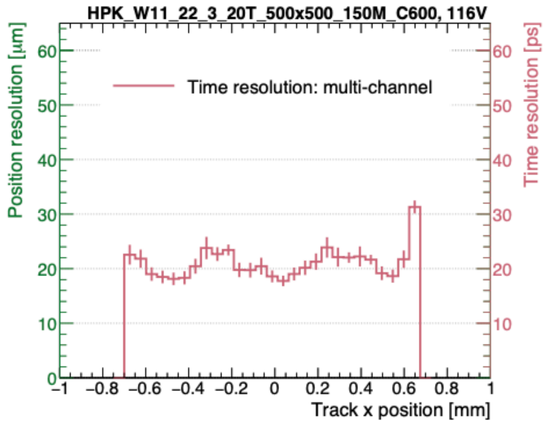
FTOF AC-LGAD sensor

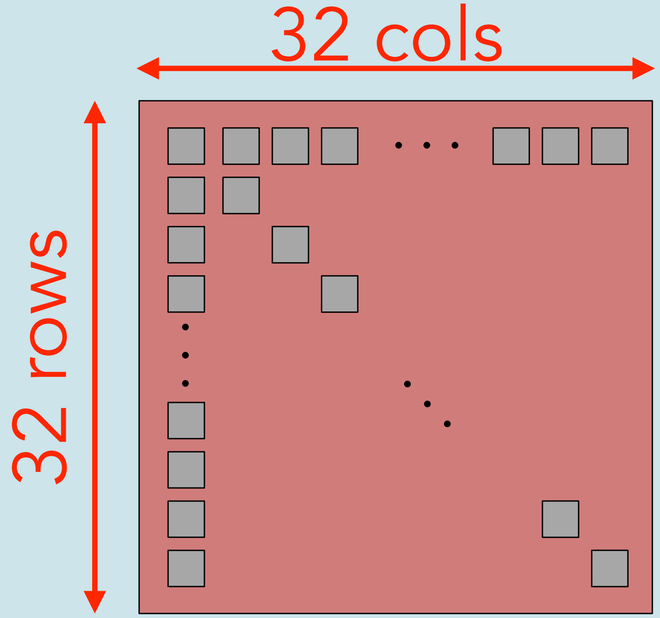
- Pixel-type AC-LGAD sensor, 1.6 x 1.6 cm^2 sensor size with 500 x 500 μm^2 pitch, is used in FTOF
  - The readout metal geometry in a sensor is 32 x 32 and 1024 channels each

[eRD112 FY24 Proposal]





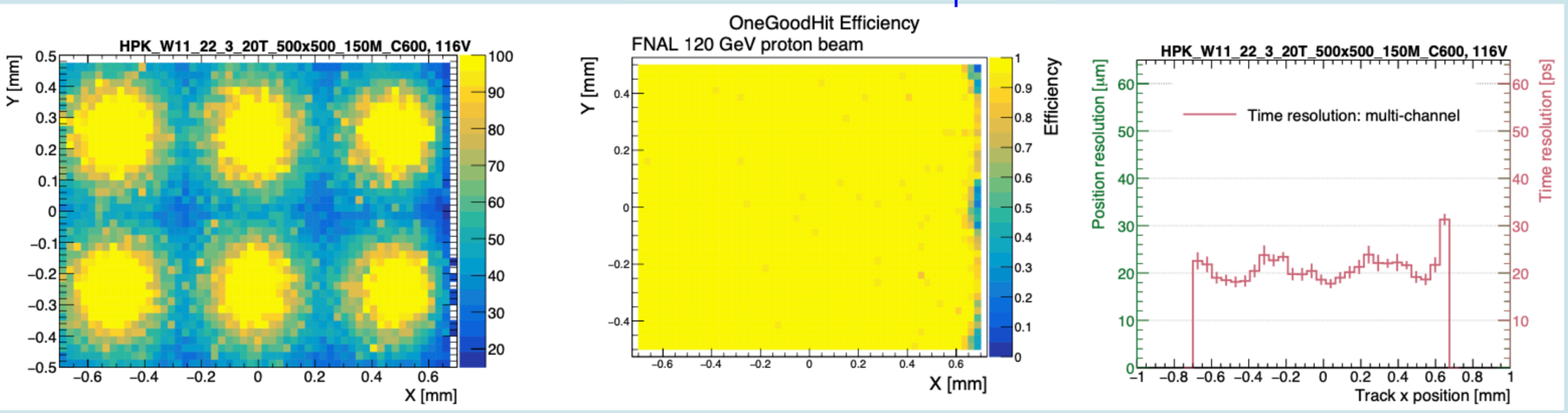


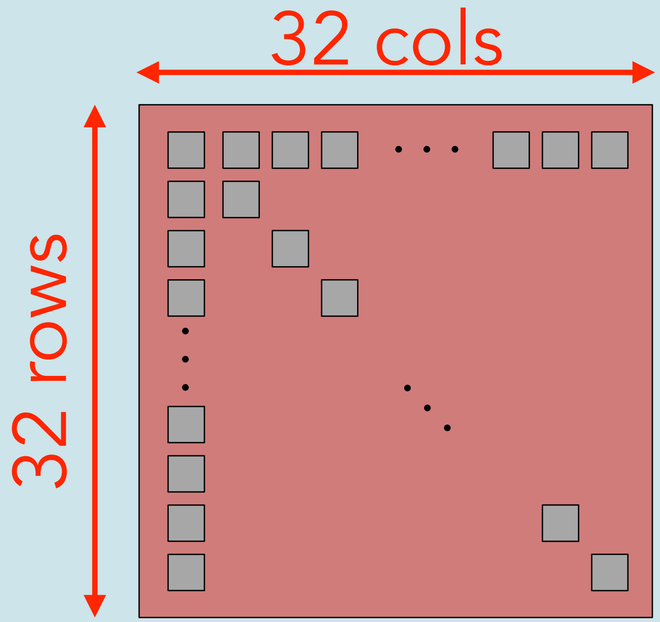


FTOF AC-LGAD sensor

- Pixel-type AC-LGAD sensor, 1.6 x 1.6 cm^2 sensor size with 500 x 500 μm^2 pitch, is used in FTOF
  - The readout metal geometry in a sensor is 32 x 32 and 1024 channels each
- One ASIC (2D 32x32) is attached to the one sensor

eRD112 FY24 Proposal





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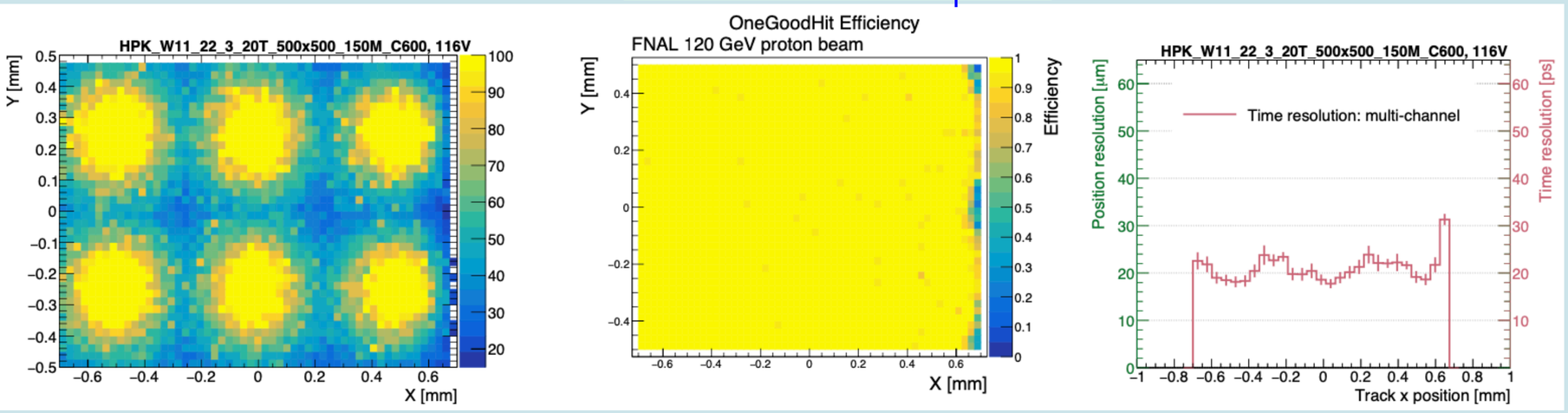
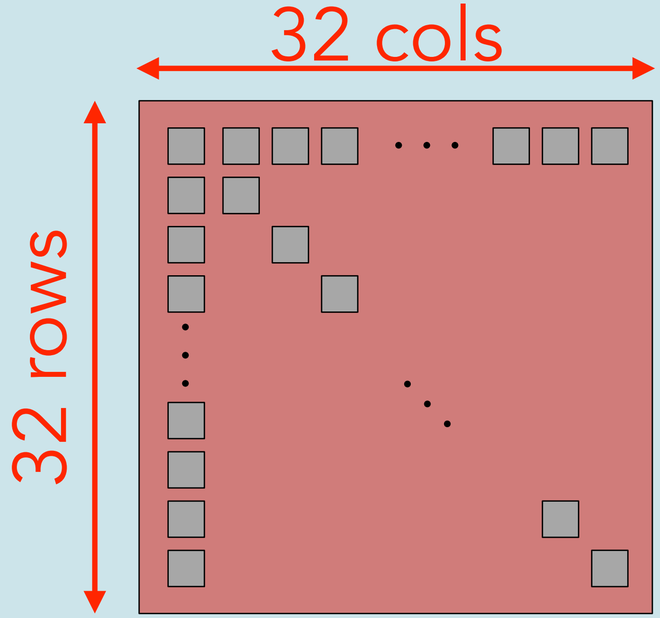
- One ASIC (2D 32x32) is attached to the one sensor
- Bump bonding is planned for soldering to ASIC

[eRD112 FY24 Proposal]





FTOF AC-LGAD sensor

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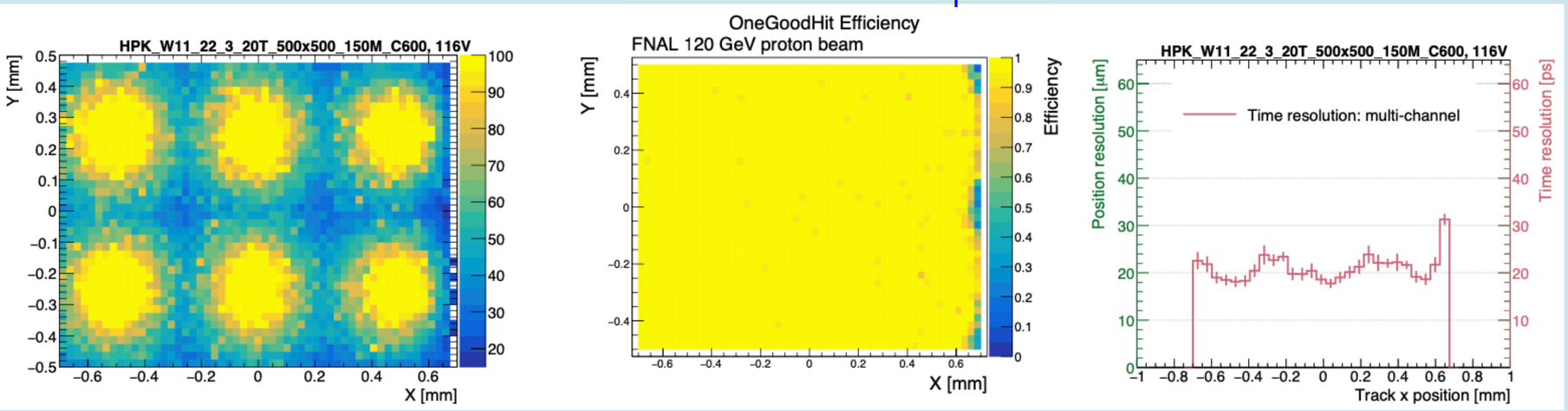
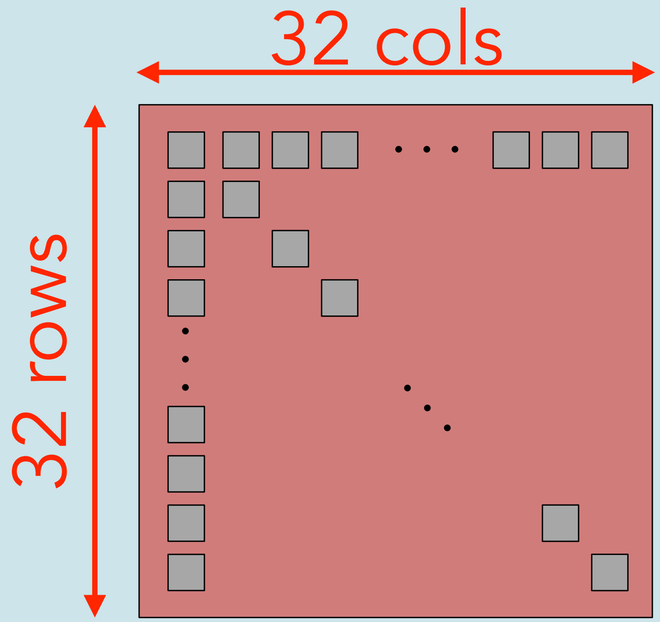
  - The readout metal geometry in a sensor is 32 x 32 and 1024 channels each
- One ASIC (2D 32x32) is attached to the one sensor
- Bump bonding is planned for soldering to ASIC

- Total information
  - **3632 sensors**
  - **1.4 m^2**
  - **3.6 M readout channels**

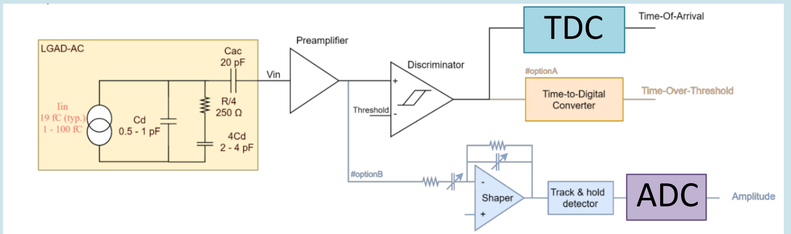
[eRD112 FY24 Proposal]





TOF ASIC

- Not only high-time resolution TDC (TOA) but also ADC must be measured
- Due to the large capacitance and readout geometry characteristics caused by the strip type, care must be taken when selecting an ASIC



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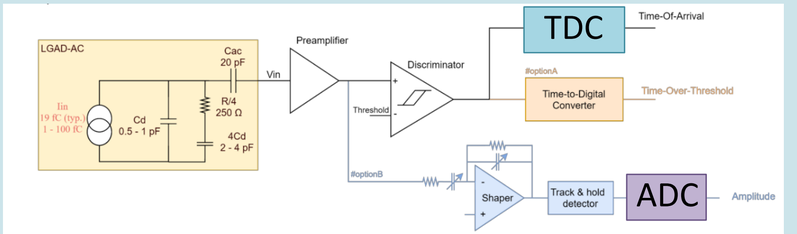
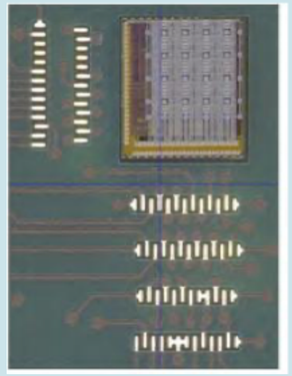


- EICROC (32x32) is one of the common ASICs used in ePIC
  - Design focuses on pixel AC-LGAD readout (tuned for low capacitance)
  - 10-bit TDC and 8-bit ADC is now available (EICROC0)
  - Modification is necessary to read higher capacitance sensor (strip AC-LGAD)

EICROC0



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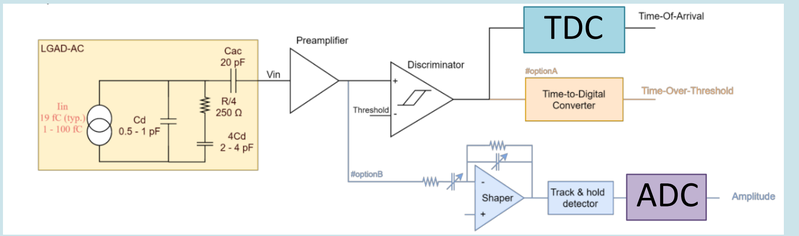

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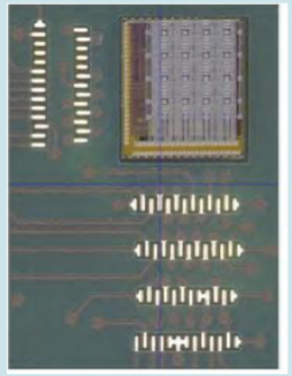
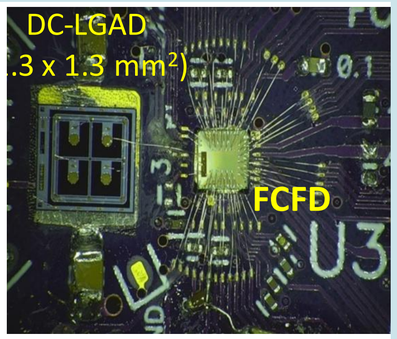
- FCFD is a new ASIC to use strip AC-LGAD readout
  - FCFD can read higher capacitance AC-LGAD sensor
  - Multiple-channel analog is available for FCFDv1

EICROC0



FCFDv0



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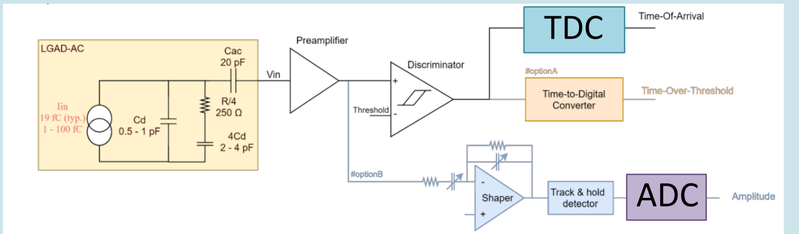

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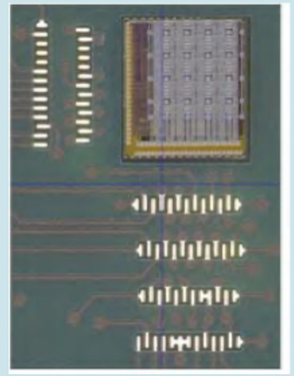
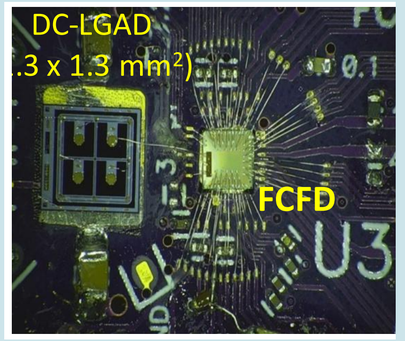
EICROC0



FCFDv0



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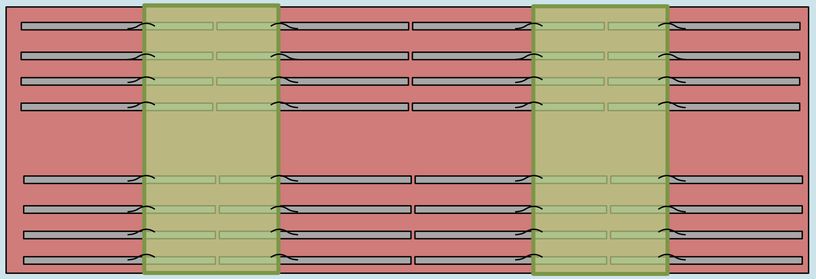
ASIC



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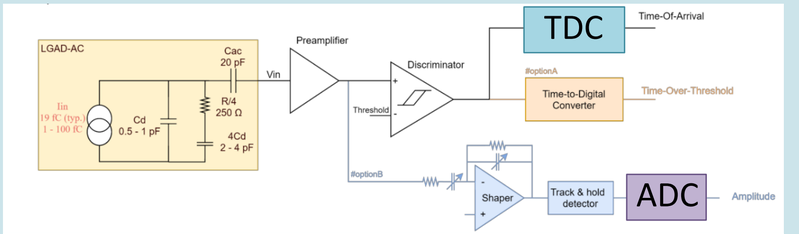

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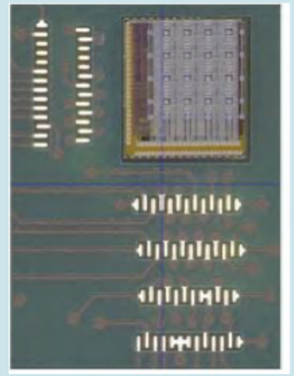
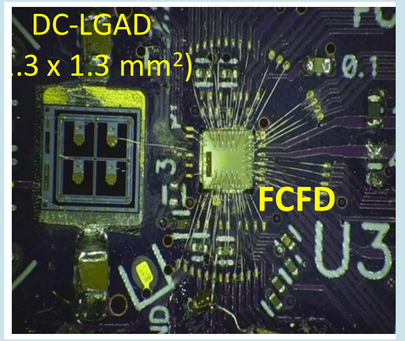
EICROC0



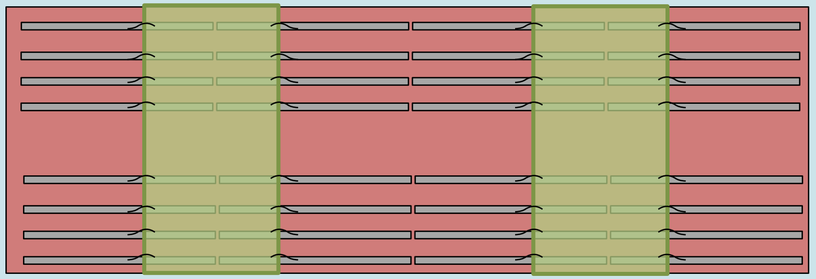
FCFDv0



- FCFD is a new ASIC to use strip AC-LGAD readout
  - FCFD can read higher capacitance AC-LGAD sensor
  - Multiple-channel analog is available for FCFDv1

- The possibility of HGCROC has begun to be discussed
  - It can measure ADC, TOA, and TOT
  - We have to investigate the possibility of the chip as soon as possible and make collaboration with the experts

ASIC



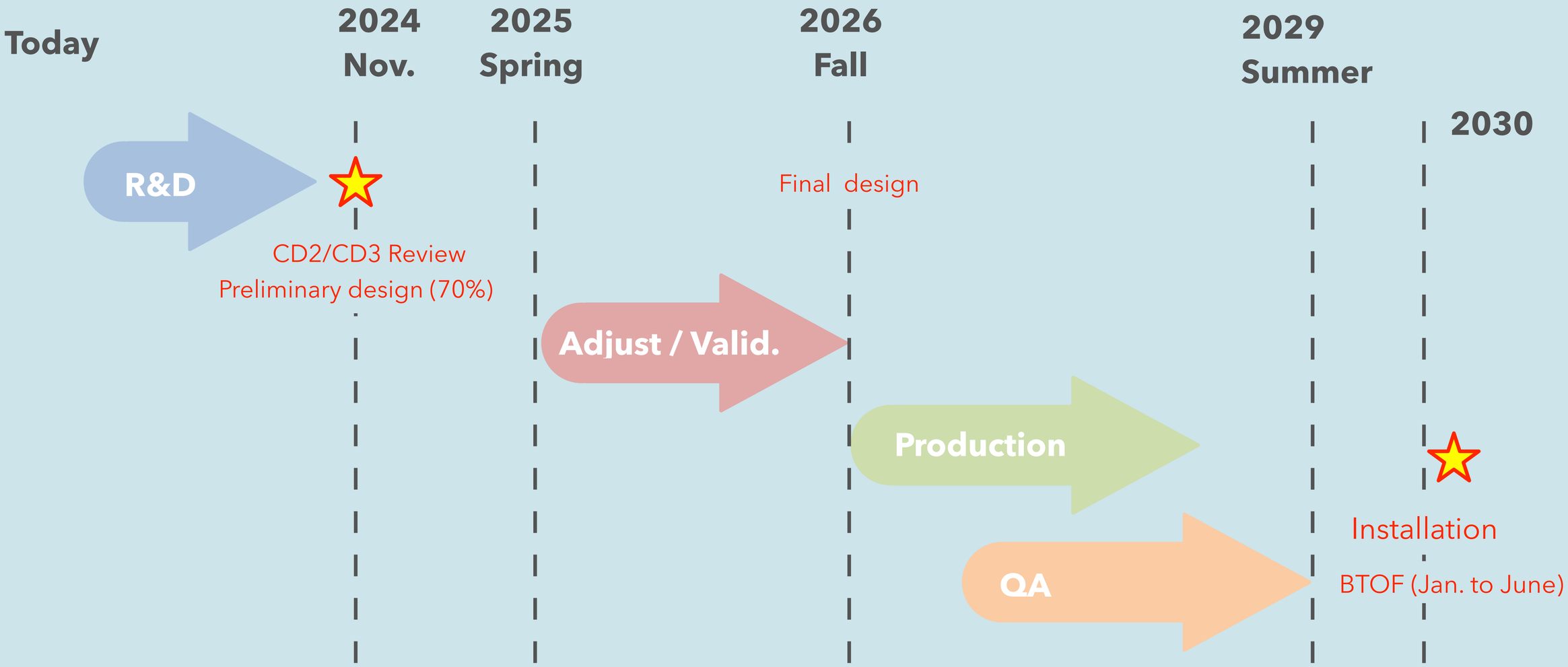
Institutes in TOF tasks (official)

- Brookhaven National Laboratory (USA)
- Fermi National Accelerator Laboratory (USA)
- Rice University (USA)
- Oak Ridge National Laboratory (USA)
- Ohio State University (USA)
- Purdue University (USA)
- University of California Santa Cruz (USA)
- University of Illinois at Chicago (USA)
- Hiroshima University (JP)
- RIKEN (JP)
- Shinshu University (JP)
- Nara Woman University (JP)
- National Chen-Kung University (TW)
- National Taiwan University (TW)
- IJCLab (FR)

Tasks in BTOF

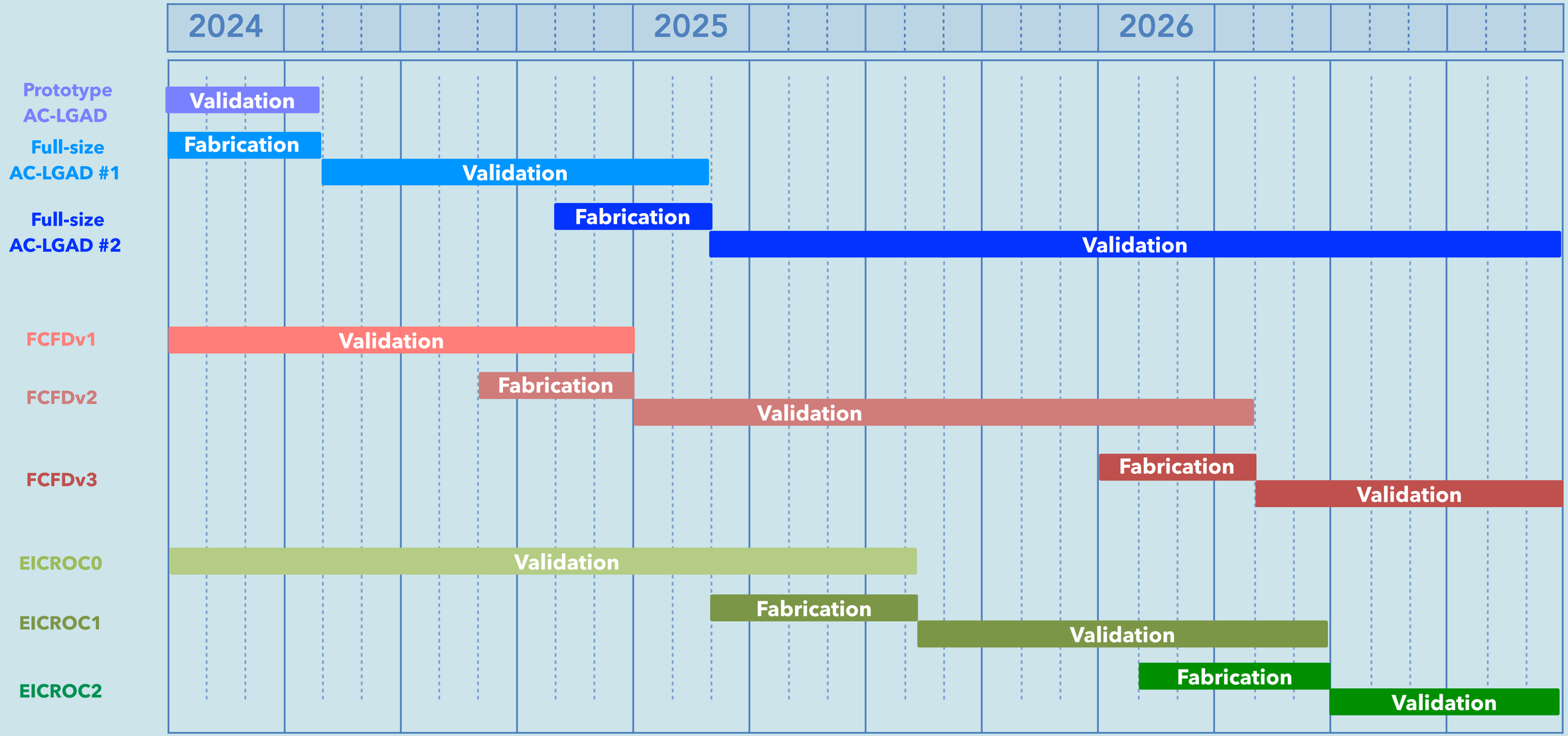
- **AC-LGAD sensor**
  - BNL
  - ORNL
  - Univ. of California, Santa Cruz
  - Univ. of Illinois, Chicago
  - Hiroshima University
  - Shinshu University
- **Frontend ASIC**
  - Fermilab
  - Rice University
  - ORNL
  - Hiroshima University
  - National Taiwan University
  - IJCLab
- **Sensor-ASIC integration**
  - BNL
  - ORNL
  - Univ. of California, Santa Cruz
  - Univ. of Illinois, Chicago
  - National Taiwan University
- **Module structure**
  - Purdue University
  - National Cheng-Kung University
- **Module assembly**
  - BNL
  - ORNL
  - Ohio State University
  - Univ. of California, Santa Cruz
  - Hiroshima University
  - RIKEN
  - Nara Woman University
  - National Taiwan University
- **Flex PCB**
  - ORNL
- **Service Hybrid**
  - Rice University
- **Backend electronics**
  - BNL

TOF schedule and cost estimation



Total cost: $11M + α (Sensors: $5M ASIC: $5M Module: $1)

Important elements (Sensor + ASIC)



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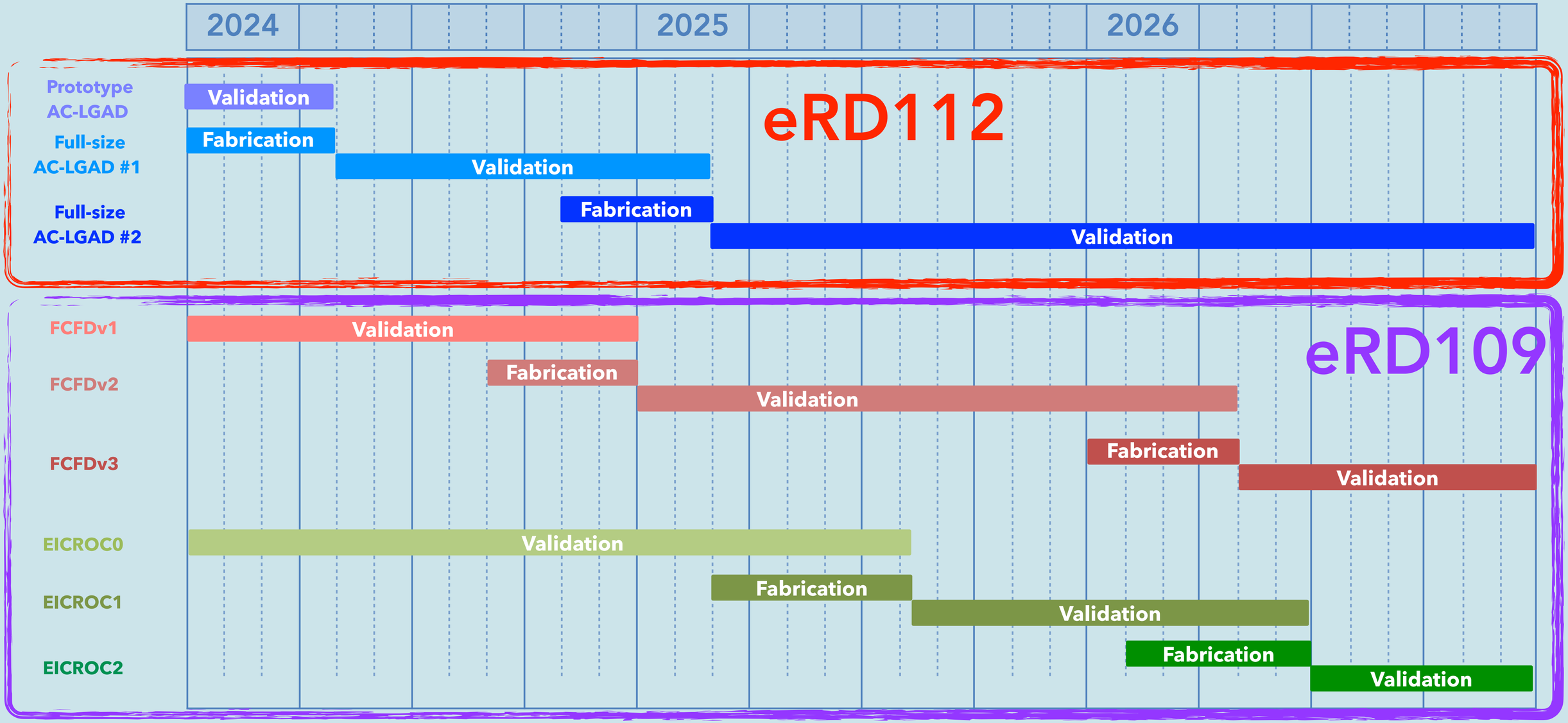

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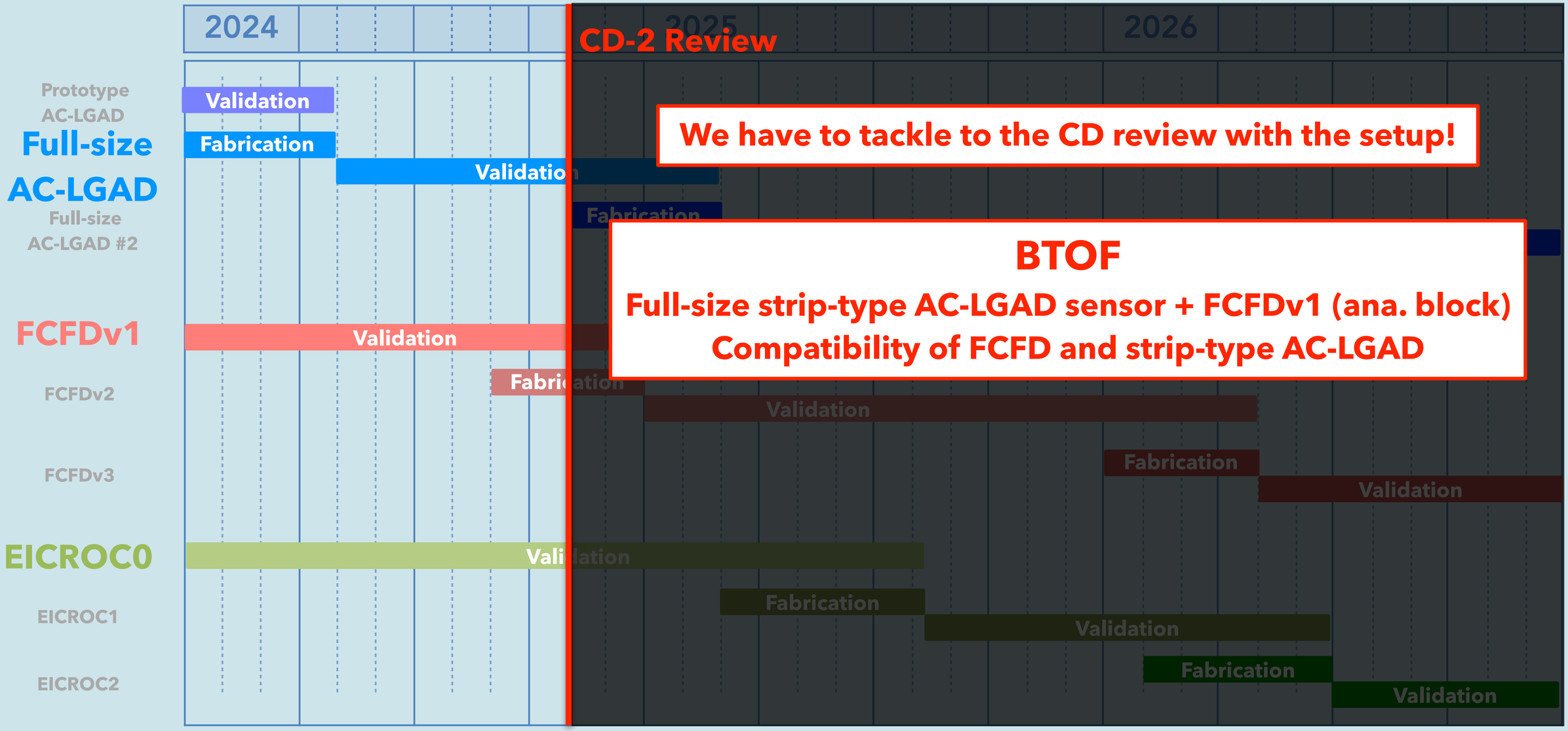

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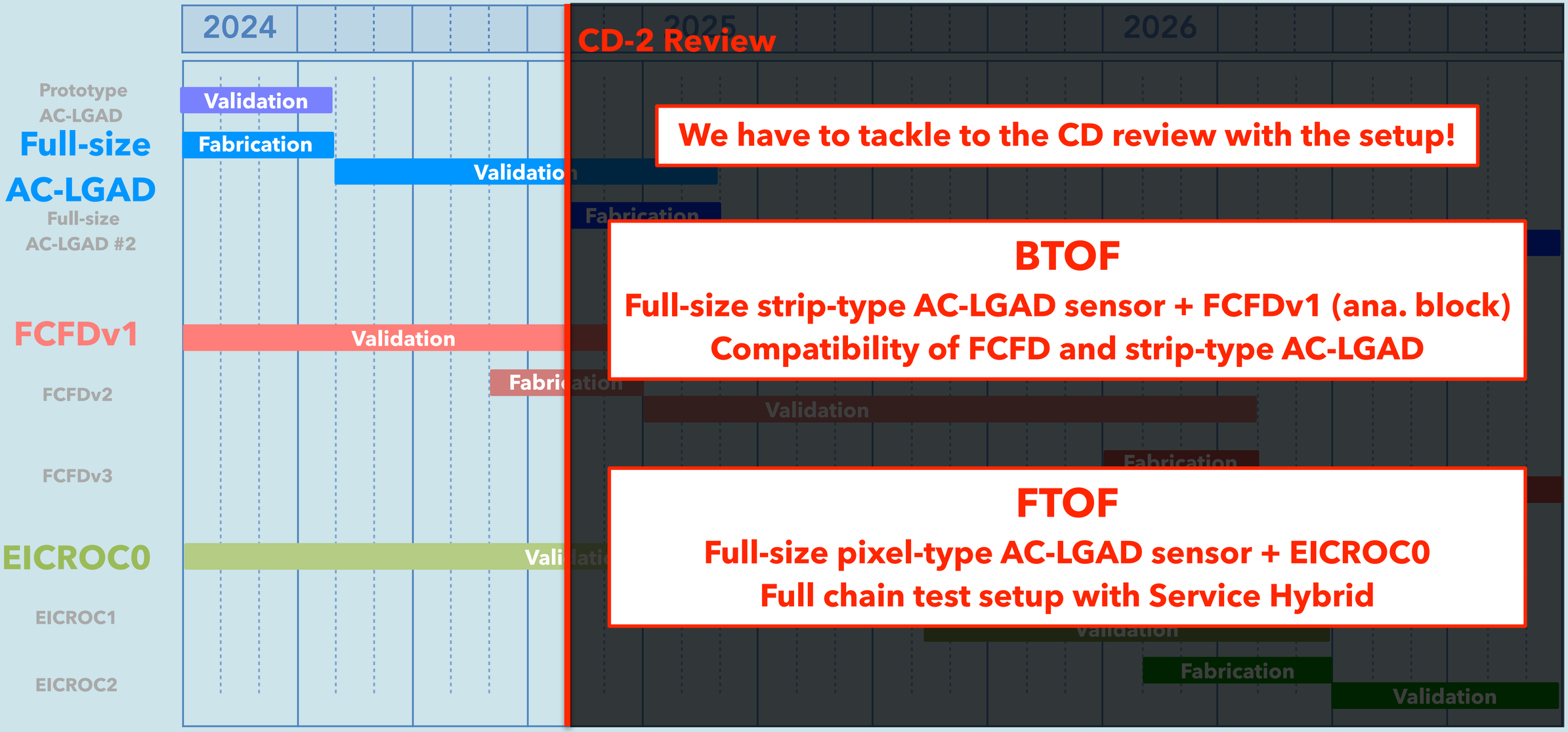

Institutes interested in ePIC-TOF in Asia

★ **Participated in ePIC-TOF project officially**

Sorted by institutes

- **China**
  - University of Science and Technology of China (AC-LGAD, Frontend ASIC)
- **Japan**
  - ★ Hiroshima University (AC-LGAD, Frontend ASIC, Sensor-ASIC integration, Simulation)
  - ★ Nara Woman's University (Frontend ASIC, Module Assembly, Stave Assembly)
  - ★ RIKEN (Module Assembly, Stave Assembly)
  - ★ Shinshu University (AC-LGAD, Frontend ASIC)
  - ★ University of Tokyo (DAQ, Reconstruction)
- **Korea**
  - Korea University (AC-LGAD)
  - Kyungpook National University (AC-LGAD)
- **Taiwan**
  - ★ National Cheng Kung University (Cooling System, Support Structure, Module Structure)
  - ★ National Taiwan University (Sensor-ASIC integration, frontend ASIC, Module Assembly)
  - ★ National Central University (Simulation)

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Sorted by activities

- **AC-LGAD**
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  - Korea University
  - Kyungpook National University
  - Shinshu University
  - University of Science and Technology of China
- **Frontend ASIC**
  - Hiroshima University
  - Nara Woman's University
  - Shinshu University
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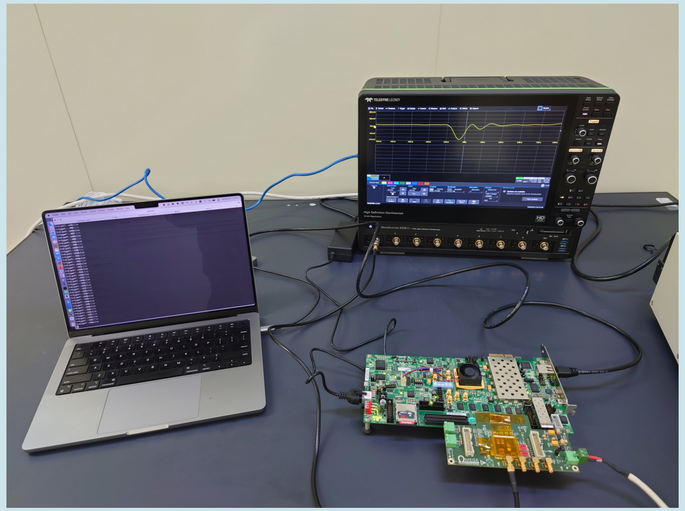
- **Sensor-ASIC integration**
  - Hiroshima University
  - National Taiwan University
- **Support and Module structure, Cooling**
  - National Cheng Kung University
- **Module Assembly**
  - Nara Woman's University
  - National Taiwan University
  - RIKEN
- **Stave Assembly**
  - Nara Woman's University
  - National Taiwan University
  - RIKEN
- **Power Supply**
  - National Cheng Kung University
- **Simulation**
  - Hiroshima University
  - National Central University
- **DAQ and Reconstruction**
  - University of Tokyo

TOF activity in Hiroshima University (JP)

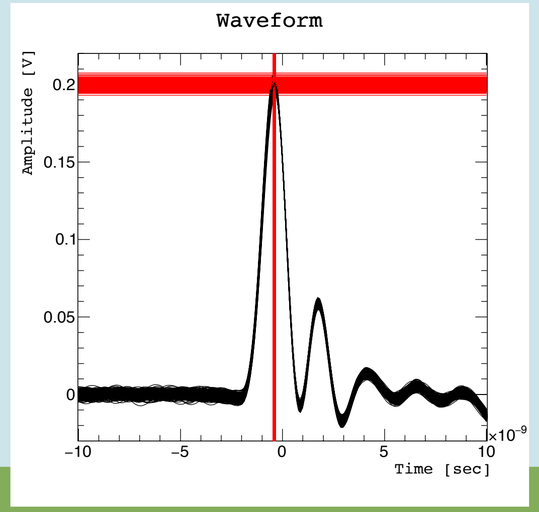
- AC-LGAD sensor R&D
  - We have started AC-LGAD R&D for ePIC (pixel and strip) in Japan
  - The R&D setup is being built at HU
  - The next batch (full-size sensor) will be tested at HU

- Frontend ASIC (EICROC) R&D
  - We have started EICROC R&D with IJCLab/Omega and BNL teams
  - The R&D setup has been built at HU

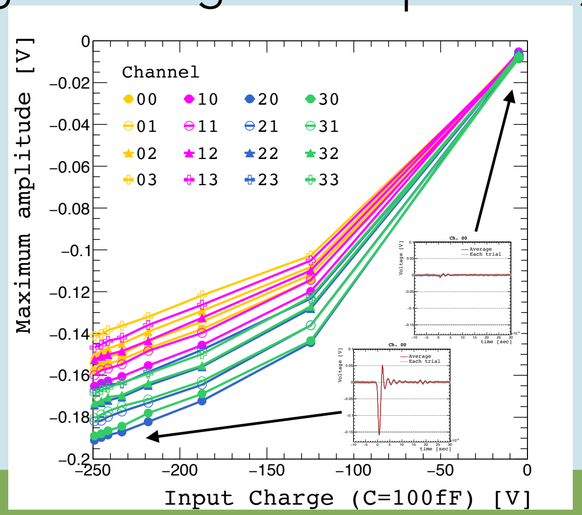
R&D setup at HU

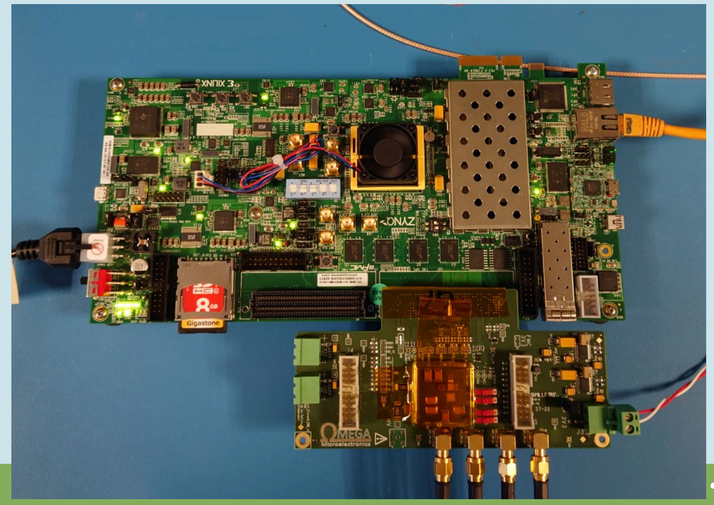


Waveform



Signal strength v.s. input charge

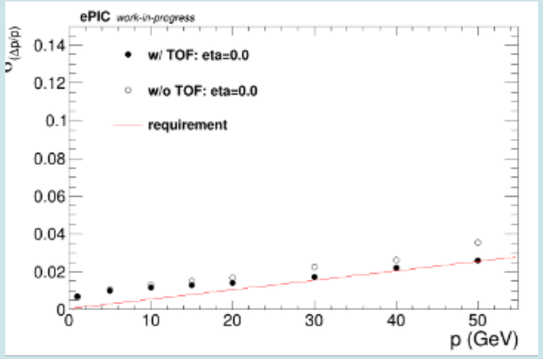


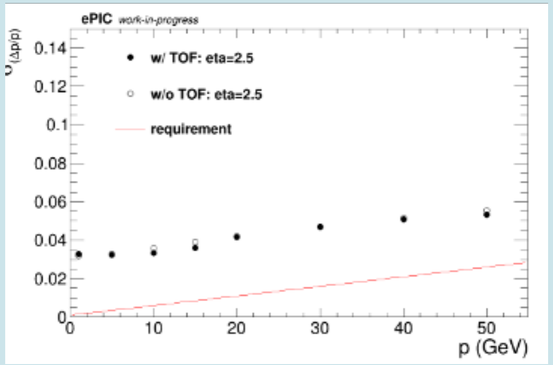


TOF activity in Taiwan

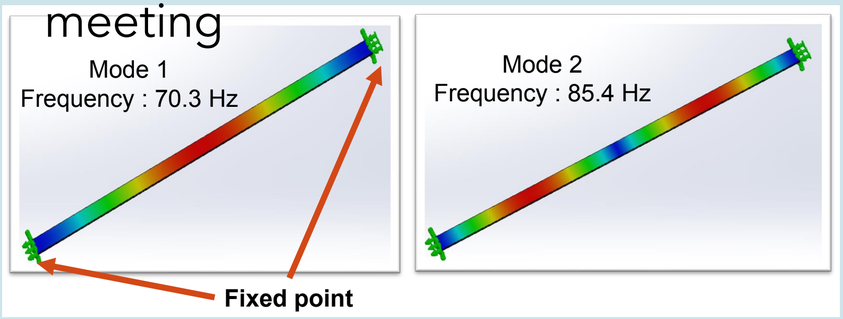
- National Central University group has started the simulation study
  - I encourage them to present the nice results at the general TOF meeting

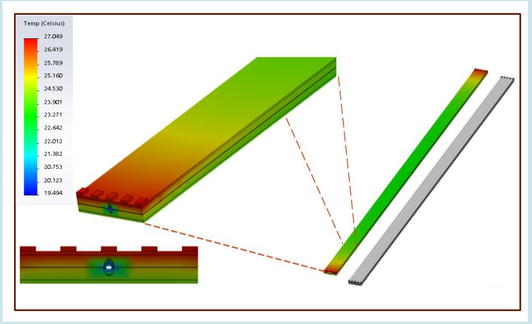
- National Cheng Kung University (NCKU) is working on the support structure design
  - Simulation study of the frequency and thermal analysis
  - Thermal test will be conducted at NCKU





From Yu-Tang Wang (NCKU) presentation at the general TOF meeting





Contribution from sPHENIX INTT Group

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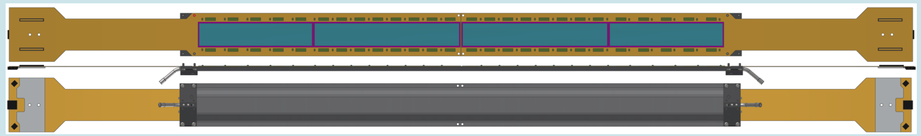

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  - Silicon sensor R&D and production
  - Carbon stave R&D and production
  - PCB R&D and production
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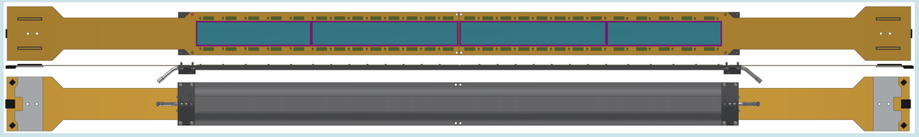

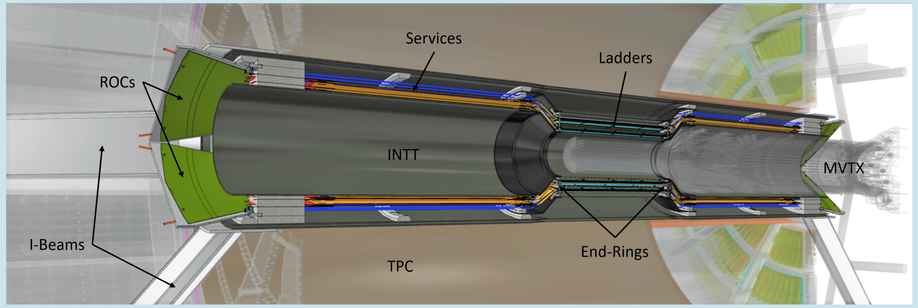

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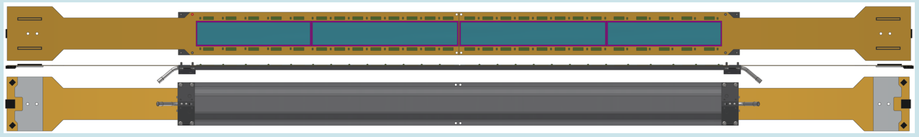

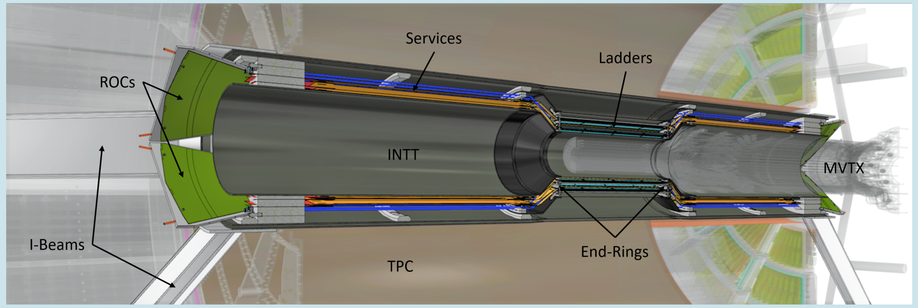

- **Their technologies and experiences must make the ePIC-TOF project more robust**

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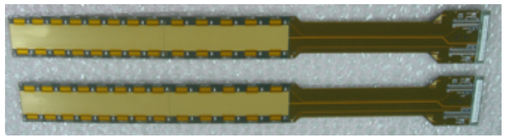
- **sPHENIX INTT Japan**

Bas extender

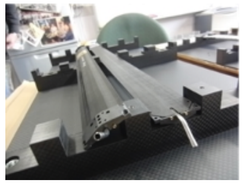
PDK
プリント電子研究所

FPC



YAMASHITA MATERIALS

Staves



ASUKA Co., Ltd.

Silicon sensor

HAMAMATSU
PHOTON IS OUR BUSINESS

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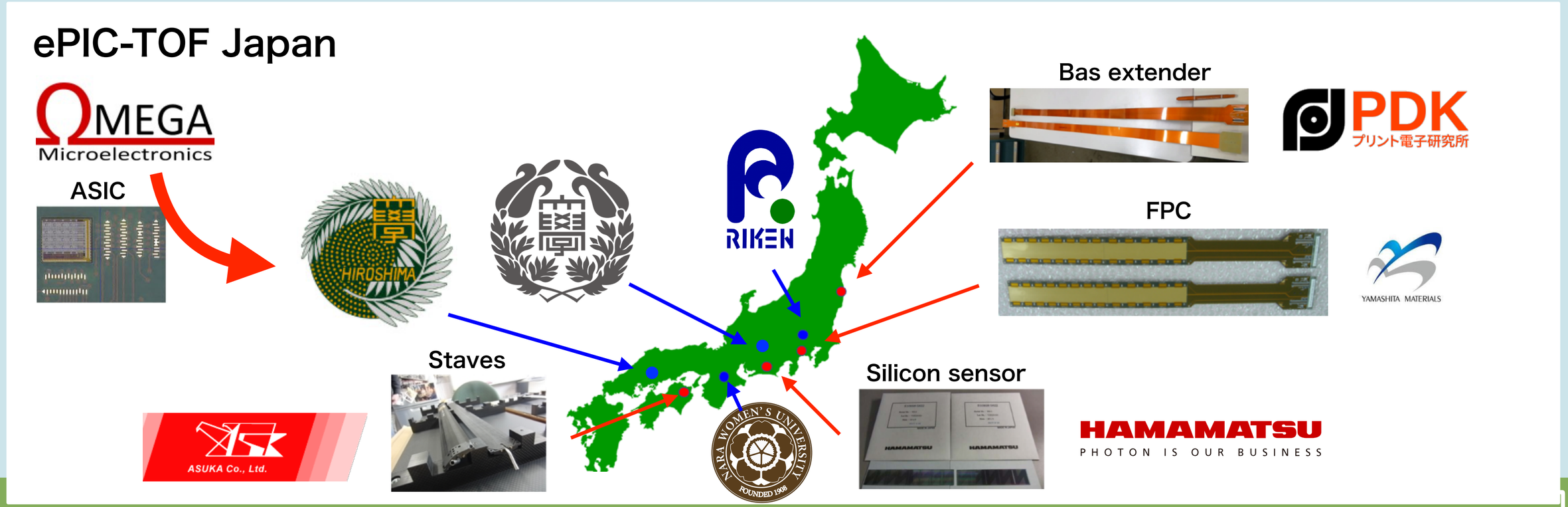

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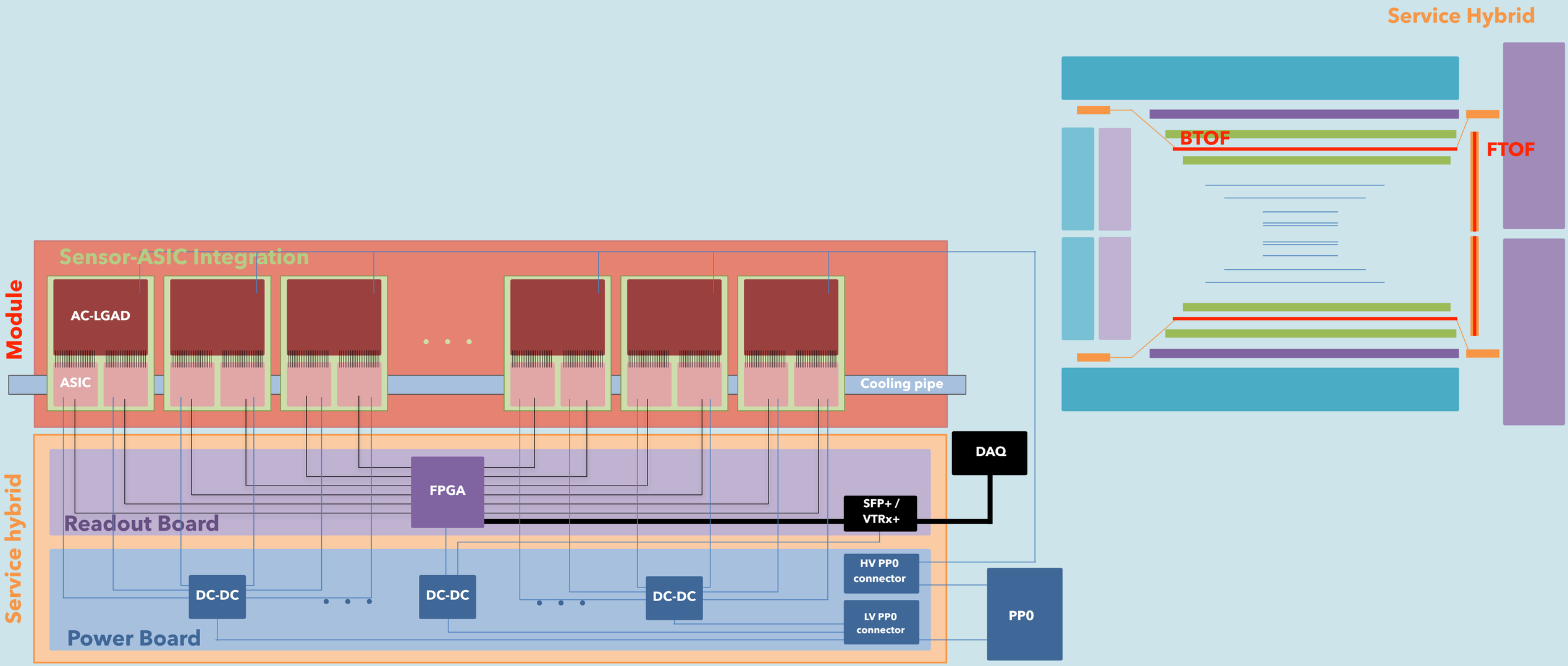
- Collaboration with the sPHENIX INTT makes the TOF project more robust
- More contribution from the Asian community is mandatory and expected in the coming months

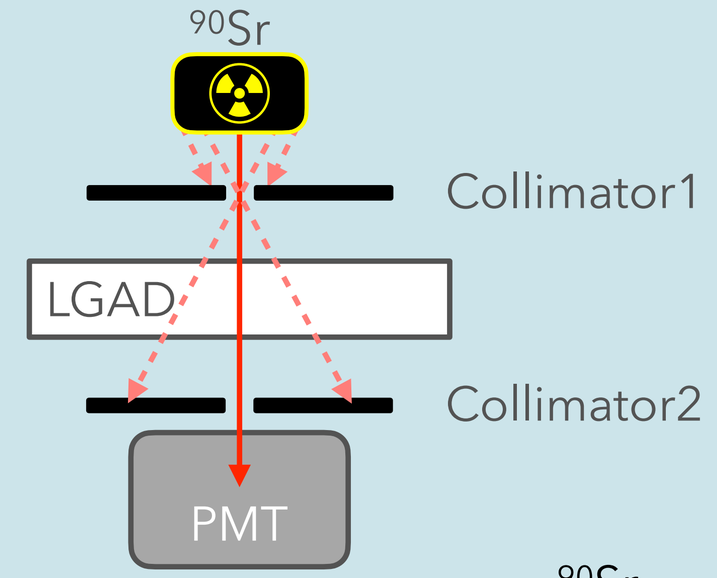
Backup

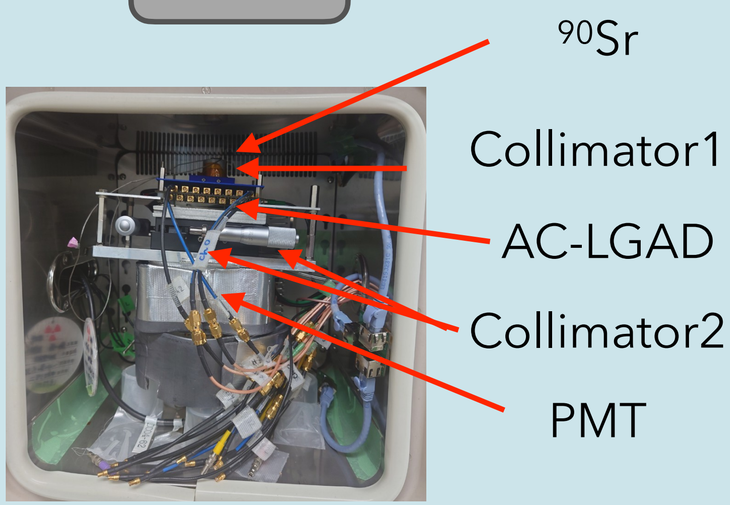
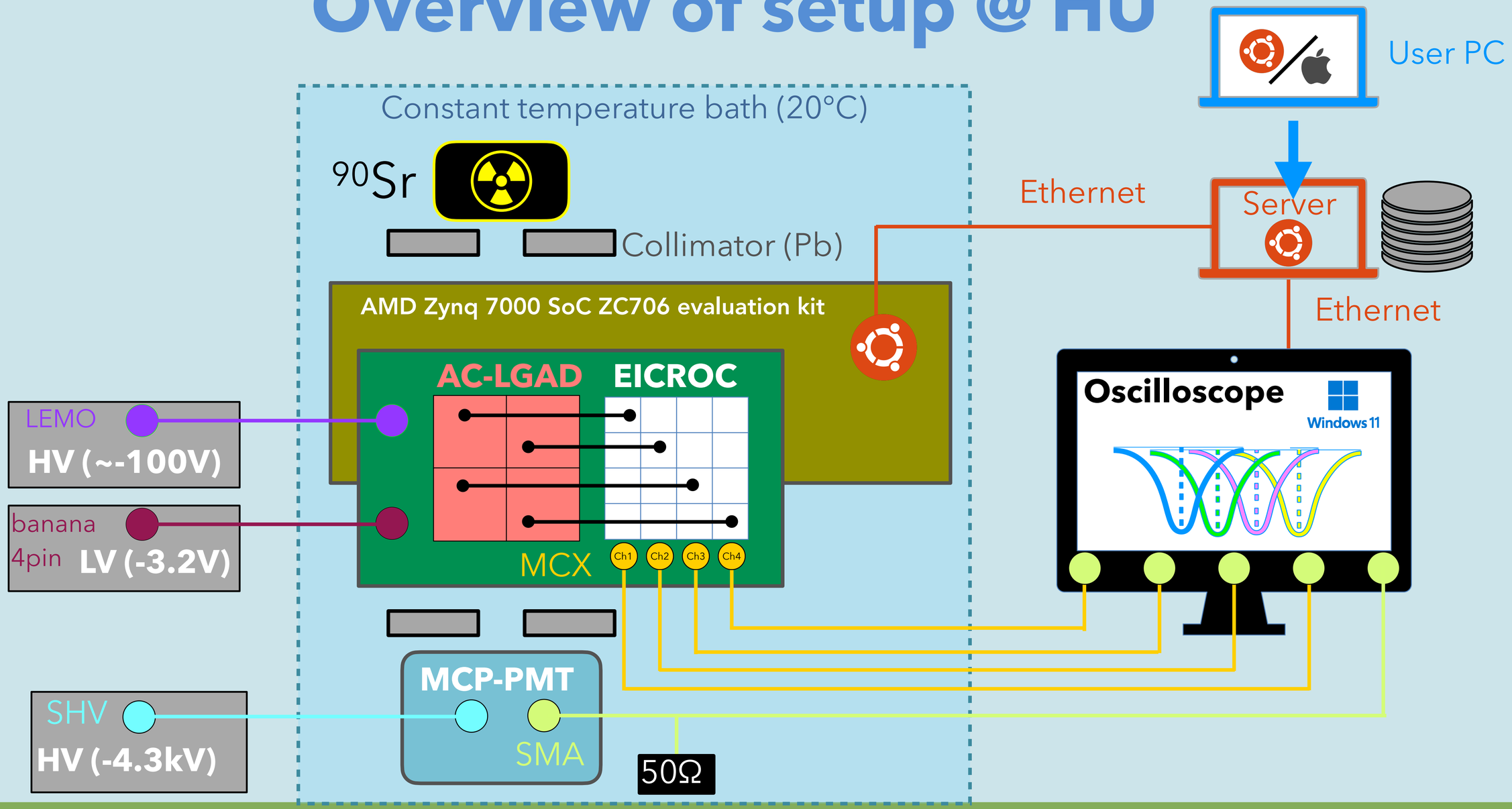
BTOF system structure



Improve radiation source test with collimators

- If the path length problem can be solved the radiation source method can measure accurate timing resolution easily
- Collimators can restrict beta radiation path length
  - σ_{timing} = 40 ps → 28 ps (analysis in progress)
- The trigger rate with ^{90}Sr (1M Bq), collimator1 and PMT is ~400 Hz, but adding collimator2 is *O*(1) Hz
- Design of the test bench with collimators by using GEANT4 is crucial to speed up the AC-LGAD R&D





Overview of setup @ HU