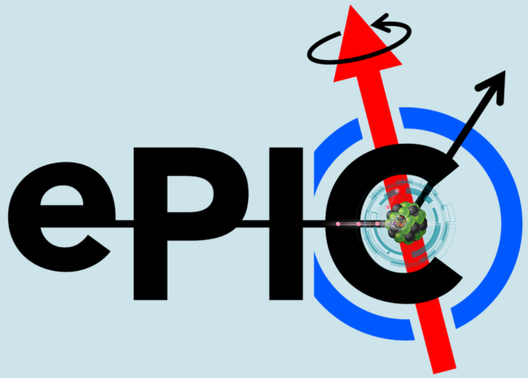


# TOF

*Satoshi Yano (Hiroshima University)*

# New TOF DSC organization

- New TOF organization members
  - DSL: Zhangbu Xu (Kent state Univ.), Deputy DSL: Satoshi Yano (Hiroshima University)
  - DSTC
    - BTOF: Matthew Gignac (UC Santa Cruise)
    - FTOF: Mathieu Benoit (ORNL)

- Work packages have been created
  - Sensors: Simone Mazza (US Santa Cruise), Japanese colleague (Satoshi Yano)
  - Frontend Electronics: Wei Li (Rice Univ.), TBD
  - Module integration and assembly: Mathieu Benoit (ORNL),  Matthew Gignac (UC Santa Cruise)
  - System tests and validation: Takashi Hachiya (Nara Woman Univ.), (FF Liaison) Prithwish Tribedy (BNL)
  - Mechanical structure: Andy Jung (Purdue Univ.), Yi Yang (National Cheng-Kung Univ.)
  - DAQ & Clock distribution: Tonko Ljubicic (BNL)
  - Power system, Detector slow control, monitor and safety system: Frank Geurts (Rice Univ.)
  - Simulations, software & calibration: Kantaro Kawade (Shinshu Univ.), (depty) Tommy Tsang (Kent state Univ.)

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**Asian community member**

- Work packages have been created
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**The TOF DSC general meeting is held every Wednesday at 10:30 (EST)**

# Contribution from the Asian community

- We are surveying to determine which institutions can give in-kind contributions and how well they can do it.

## Survey results at October 2023

| Institution | Working Group and Tasks |
|---|---|
| Brookhaven National Laboratory | **BTOF:** sensor, sensor-ASIC integration, module assembly; **CS**: backend electronics; **DP**: simulation and reco. |
| Fermi National Accelerator | |
| Los Alamos National Laboratory | **FTOF**: sensor, module assembly; **CS**: cooling system and support structure; **DP**: simulation and reco. |
| Rice University | **BTOF/FTOF**: Front-end electronics; **CS**: backend electronics; **DP**: simulation and reconstruction |
| Oak Ridge National Laboratory | **BTOF/FTOF: s**ensor, sensor-ASIC integration, frontend electronics, module assembly |
| Ohio State University | **BTOF/FTOF:** module assembly; **CS**: backend electronics, alignment; **DP**: simulation and reco. |
| Purdue University | **BTOF/FTOF**: module structure; **CS:** cooling system and support structure |
| Univ. of California, Santa Cruz | **BTOF**: sensor, sensor-ASIC integration, module assembly |
| University of Illinois at Chicago | **BTOF/FTOF**: sensor, sensor-ASIC integration, module assembly; **DP**: simulation and reconstruction |
| Hiroshima University | **BTOF/FTOF**: sensor, module assembly; **DP**: simulation and reconstruction |
| RIKEN | **BTOF/FTOF:** module assembly |
| Shinshu University | **BTOF/FTOF:** sensor |
| University of Tokyo | **CS:** streaming readout; **DP**: online reconstruction |
| South China Normal University | |
| Univ of Sci. and Tech. of China | |
| Indian Institute of Tech., Mandi | **DP**: simulation and reconstruction |
| National Inst. of Sci. Edu. Res. | |
| National Central University | **DP:** simulation |
| National Cheng-Kung University | **BTOF/FTOF**: module structure; **CS**: cooling system and support structure |
| National Taiwan University | **BTOF**: sensor-ASIC integration, frontend electronics, module assembly |
| Univ. Técnica Federico Santa María | **FTOF:** module assembly; **DP:** simulation and reconstruction |

- We are making the latest table and estimating the in-kind contribution from each institute
- Please contact us which task you are interested in, and let us know the expected in-kind contribution

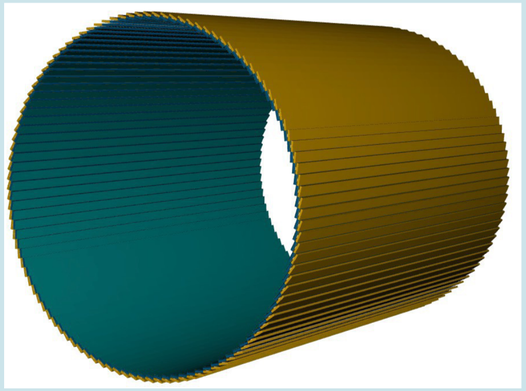
# Expected contribution from the Asian community

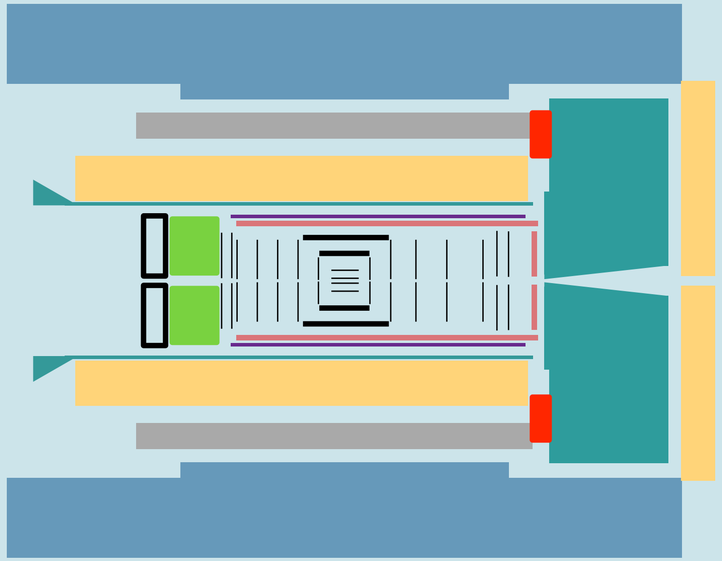
| Institute | In-kind contributions to tasks |
|---|---|
| Hiroshima University | BTOF/FTOF: ASIC test, sensor test, simulation |
| Shinshu University | BTOF/FTOF: Sensor test, simulation |
| Nara Woman University | BTOF: Module FPC, system test, module assembly |
| University of Tokyo | BTOF/FTOF: readout, online reconstruction |
| Riken | BTOF: module assembly |
| National Central University | BTOF/FTOF: sensor QA |
| National Cheng-Kung University | BTOF/FTOF: module structure, cooling system, support structure |
| National Taiwan University | BTOF: sensor test, module assembly |
| Indian Institute of Tech. Mandi | FTOF: module assembly, sensor-ASIC integration |

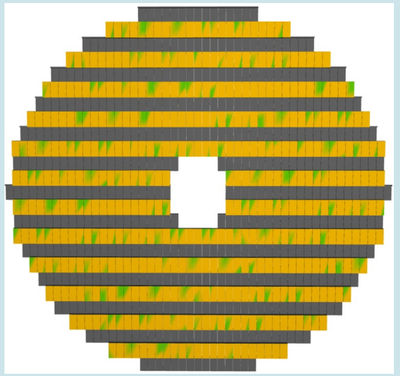
- The table is being updated
- Please correct me if you find any mistake
- **For the other institutes not listed in the table, please let us know as soon as possible which task you will contribute**
- I proposed the EIC-Asia TOF regular meeting and the poll is prepared
  - https://www.when2meet.com/?24082382-AapNr
- I would like to have the meeting once per month

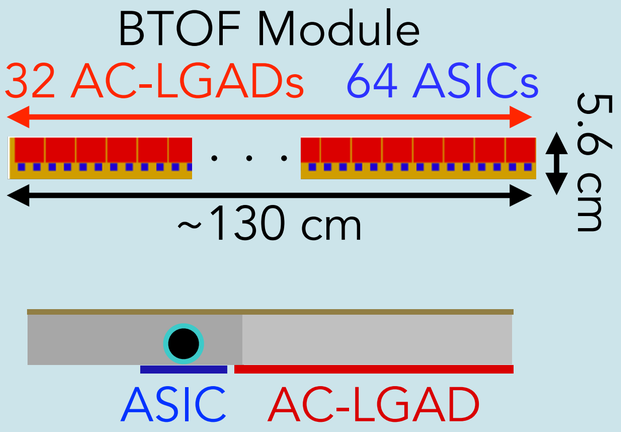
# Backup

# Recap of BTOF and FTOF

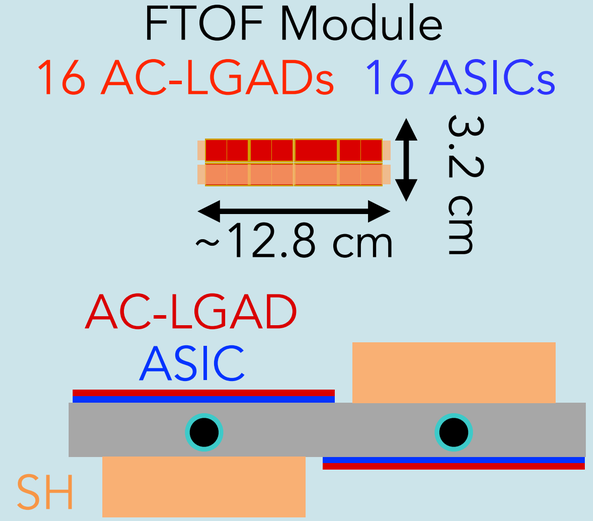









Required performance
Timing resolution ~ 30 ps
Spatial resolution ~ 30 μm

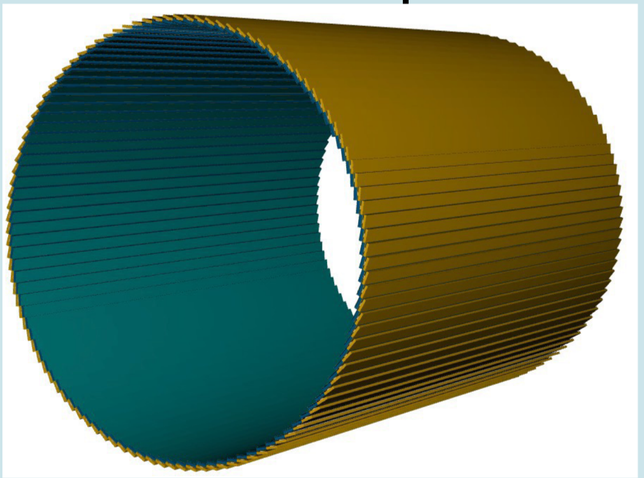



- Strip-type and pixel-type AC-LGAD are used for BTOF and FTOF, respectively
- FCFD and EICROC are used for strip-type and pixel-type AC-LGAD, respectively
- BTOF SH is placed in a different place from sensor+ASICs, but FTOF SH is placed in front of sensor+ASICs

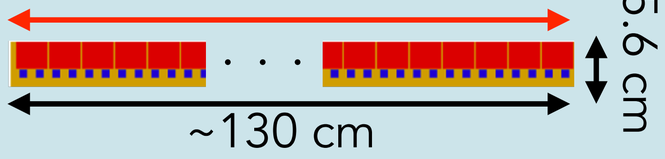
# Detector Layout of BTOF

- 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)
- Radius is 60 - 63 cm from the beam pipe covering $-1.42<\eta<1.77$
- Total material budget in acceptance is ~0.01 $X/X_0$

**BTOF shape**



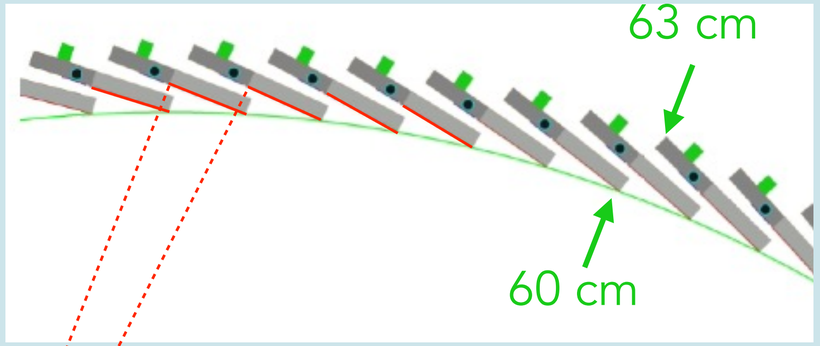
BTOF Module



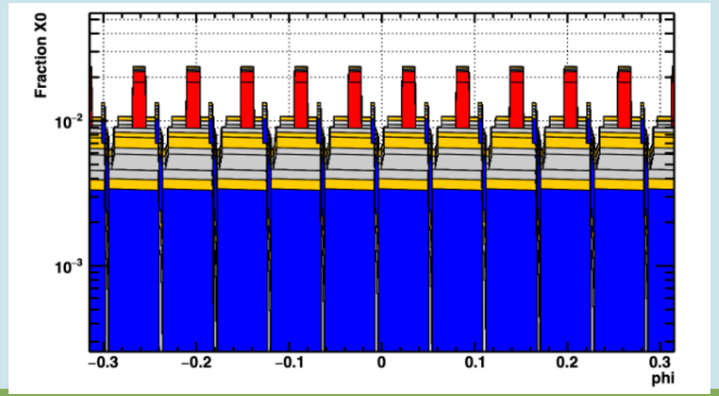

**Module cross section**

**Cylindrical structure by modules**

3 mm overlap in Φ



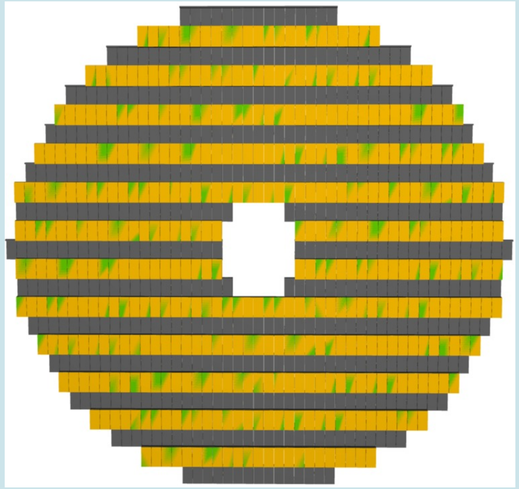

**Material budget**



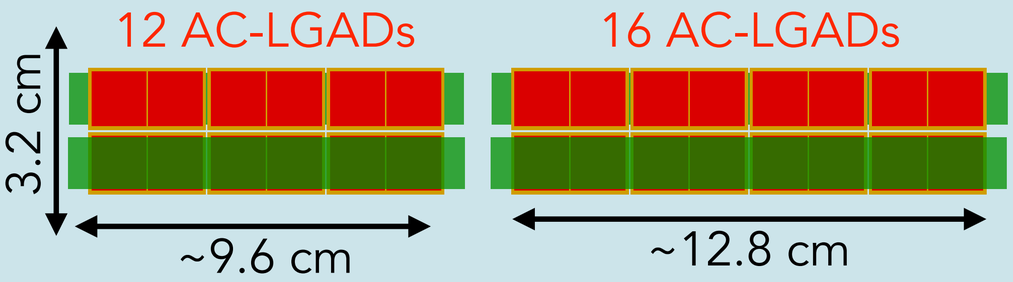
# Detector Layout of FTOF

- FTOF is composed of 1816 modules to make a disk
- 12 or 16 AC-LGAD pixel sensors are attached to one module
- Radius is 8 - 60 cm from the beam pipe covering $1.86<\eta<3.85$
- 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

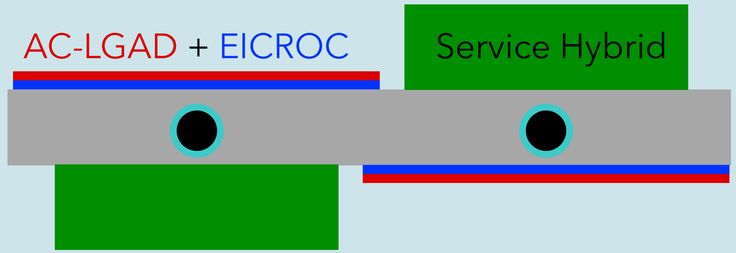
**BTOF shape**

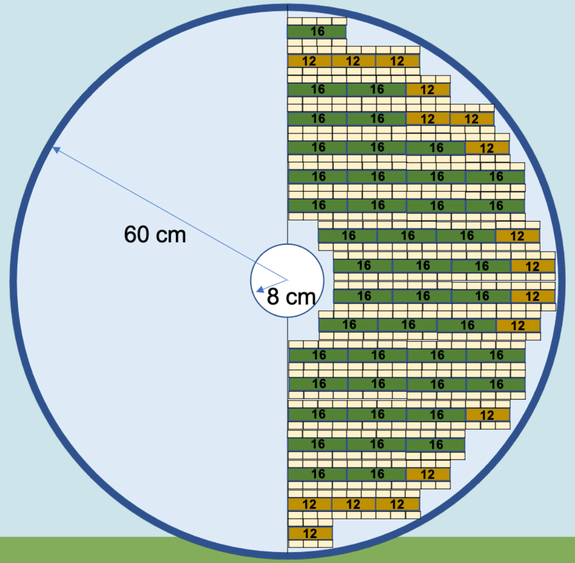


**Module top view**




**Module cross section**



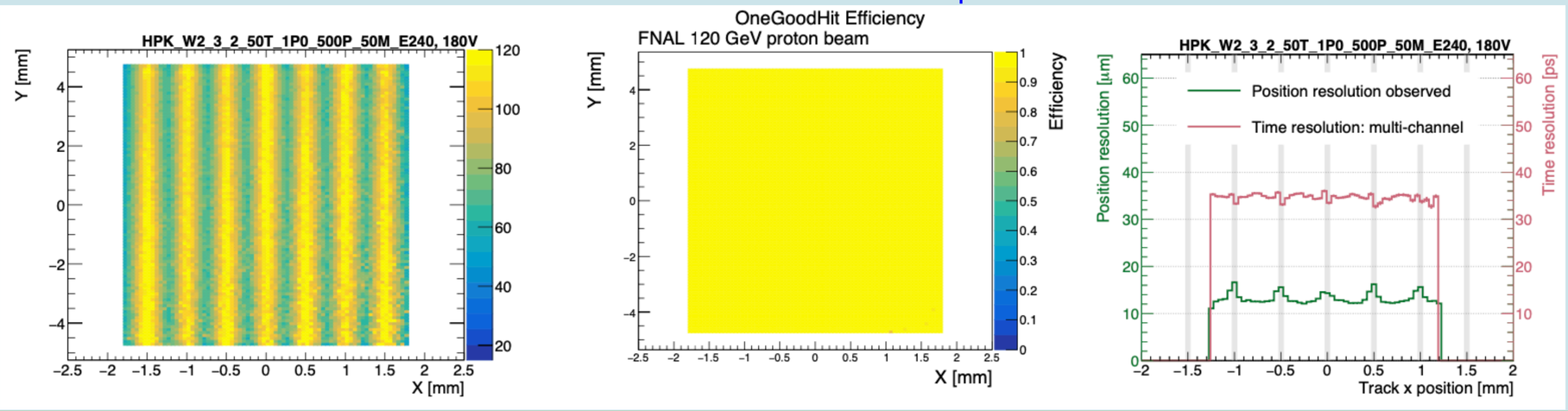



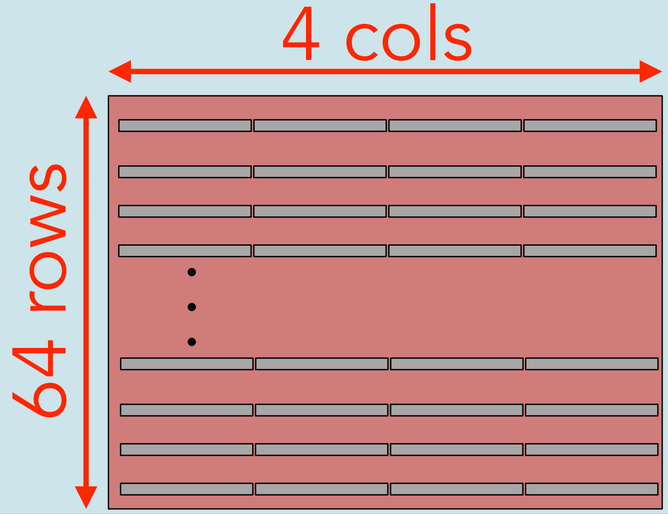
# BTOF AC-LGAD sensor

- 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

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

[eRD112 FY24 Proposal]



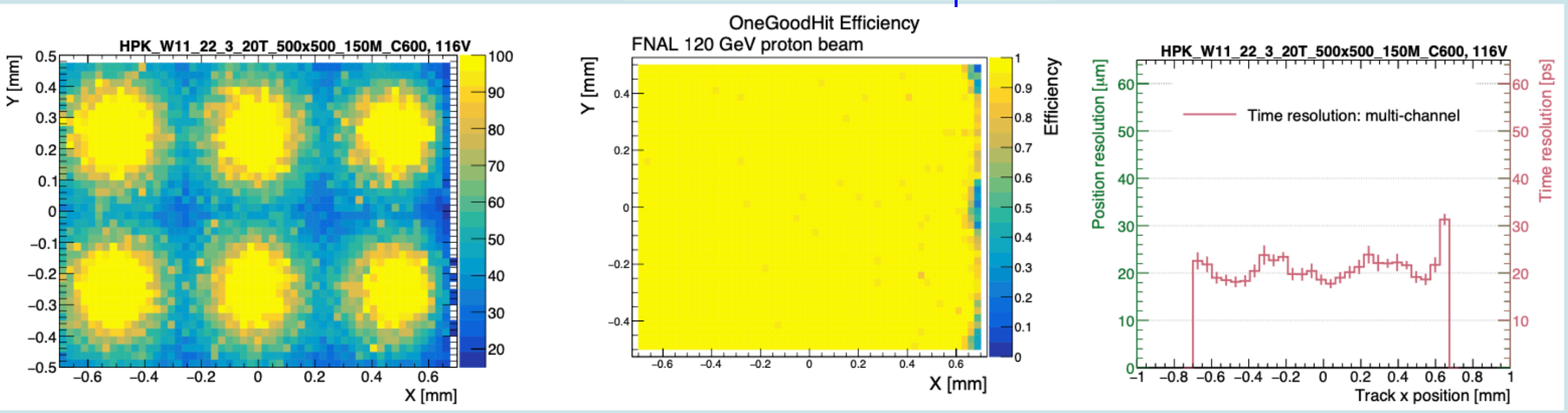



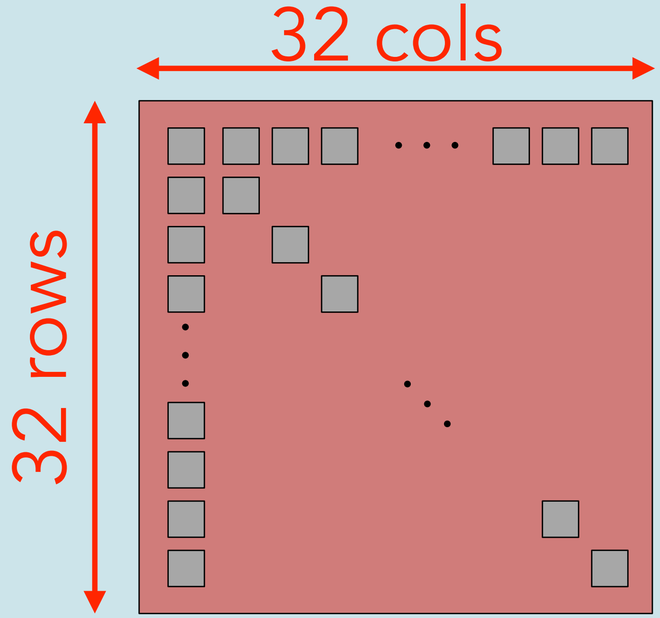
# FTOF AC-LGAD sensor

- Pixel-type AC-LGAD sensor, 1.6 x 1.6 $cm^2$ sensor size with 500 x 500 $\mu m^2$ 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
- Bump bonding is planned for soldering to ASIC

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

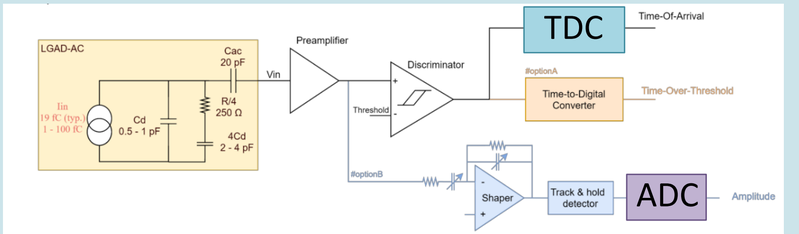
[eRD112 FY24 Proposal]



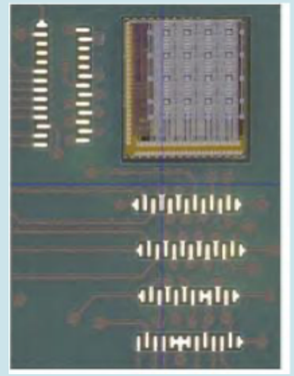
# TOF ASIC

- 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

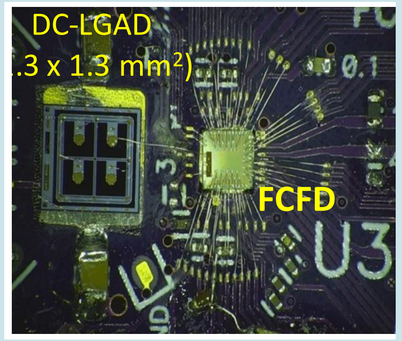



- EICROC (32x32) is one of the common ASICs used in ePIC
  - Design focuses on pixel AC-LGAD readout (tuned for low capacitance)
  - 10-bit TDC and 8-bit ADC is now available (EICROC0)
  - Modification is necessary to read higher capacitance sensor (strip AC-LGAD)

EICROC0



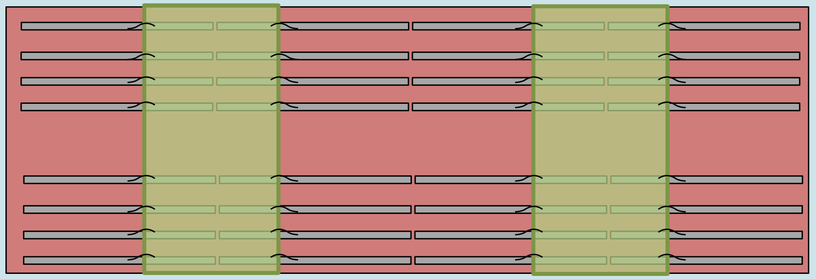
FCFDv0



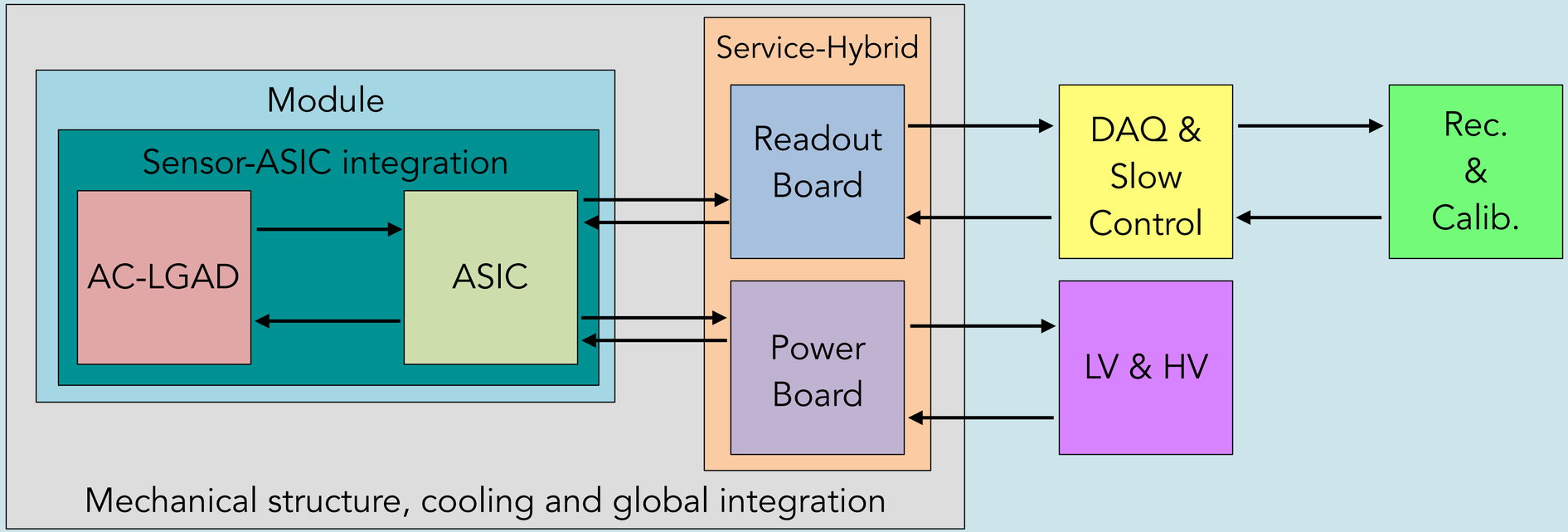

- FCFD is a new ASIC to use strip AC-LGAD readout
  - FCFD can read higher capacitance AC-LGAD sensor
  - Multiple-channel analog is available for FCFDv1

- 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



# TOF structure




- **Barrel-TOF (BTOF)**
  - Strip-type AC-LGAD
  - ASIC (FCFD)
  - Sensor-ASIC integration
  - Module
  - Service-Hybrid
  - Mechanical structure
  - Global integration
- **Forward-TOF (FTOF)**
  - Pixel-type AC-LGAD
  - ASIC (EICROC)
  - Sensor-ASIC integration
  - Module
  - Service-Hybrid
  - Mechanical structure
  - Global integration
- **Common system**
  - DAQ
  - Cooling
  - Software (Rec. & Calib.)
  - HV & LV
  - Slow control

# Non-labor cost of each sub-system

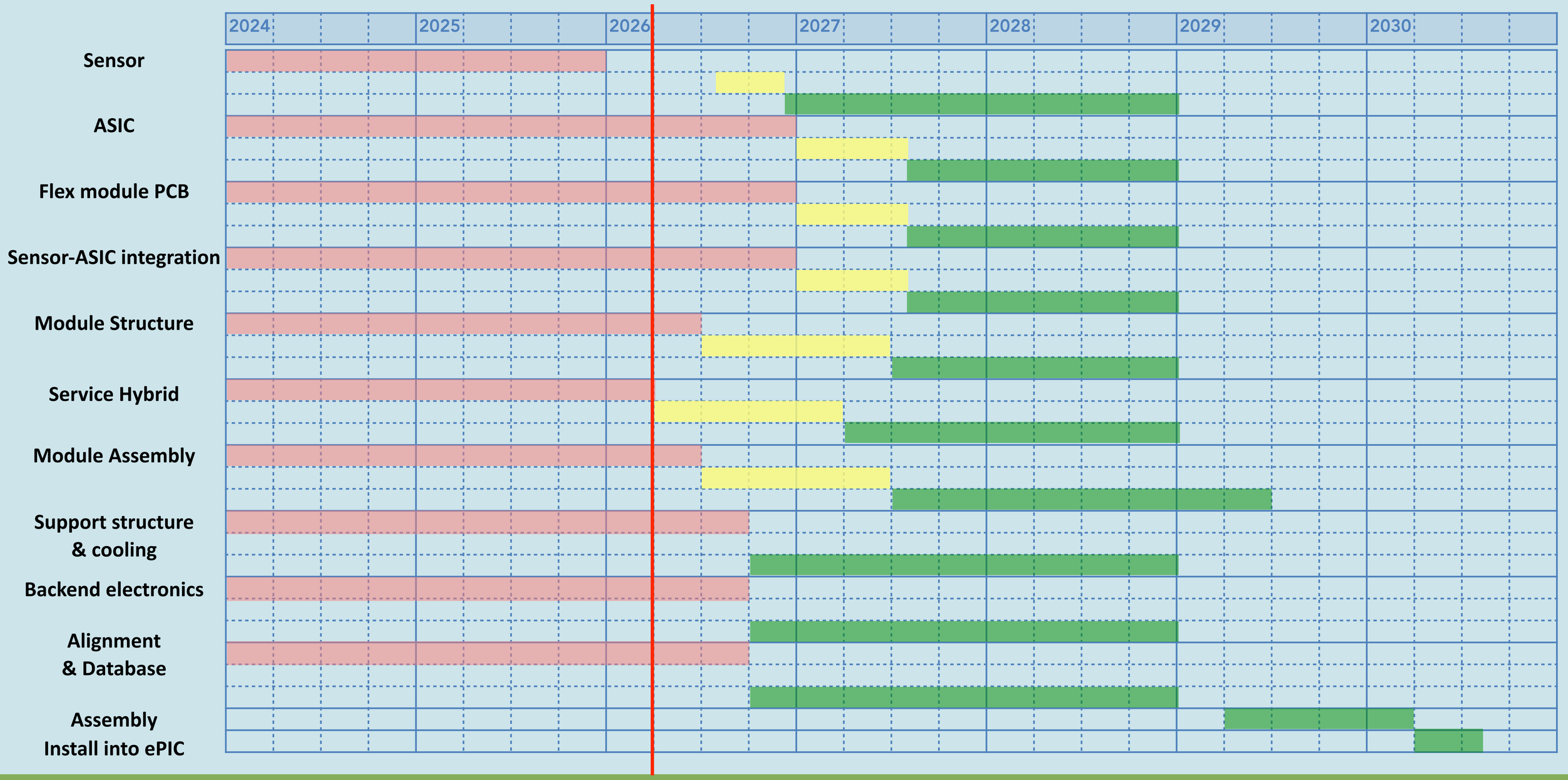
- **Total BTOF cost: $10,760,800 ($9,126,300)**
  - Sensor: $4,907,500
    - R&D: $407,500
    - Pre-production (10%): $450,000
    - Production (90%): $4,050,000
  - ASIC: $2,125,000
    - R&D: $870,000
    - Pre-production (20 wafers): $835,000
    - Production (120 wafers): $420,000
  - Sensor ASIC integration: $1,061,600
    - R&D: $120,000
    - Pre-production (10%): $99,600
    - Production (90%): $842,000
  - Flex module PCB: $1,520,000
    - R&D: $80,000
    - Pre-production (10%): $160,000
    - Production (90%): $1,280,000
  - Module structure: $252,700
    - R&D: $15,000
    - Pre-production (10%): $50,000
    - Production (90%): $187,700
  - Service Hybrid (Power+Readout board): $532,000
    - R&D: $142,000
    - Pre-production (10%): $40,000
    - Production (90%): $350,000
  - Module assembly: $362,000
    - Pre-production: $50,000
    - Production: $150,000

- **Total FTOF cost: $3,056,558 ($1,886,458)**
  - Sensor: $765,500 ($358,000)
    - (!) R&D: $407,500
    - Pre-production (10%): $37,000
    - Production (90%): $321,000
  - ASIC: $768,600 ($451,000)
    - R&D: $317,600
    - Pre-production (20 wafers): $292,600
    - Production (120 wafers): $158,400
  - Sensor ASIC integration: $318,000 ($268,000)
    - R&D: $50,000
    - Pre-production (10%): $28,000
    - Production (90%): $240,000
  - Flex module PCB + Service Hybrid: $582,200 ($432,200)
    - R&D: $150,000
    - Pre-production (10%): $174,210
    - Production (90%): $257,990
  - Module structure: $119,258 ($104,258)
    - R&D: $15,000
    - Pre-production (10%): $12,500
    - Production (90%): $91,758
  - Module assembly: $503,000 ($273,000)
    - R&D: $230,000
    - Pre-production (10%): $27,300
    - Production (90%): $245,700

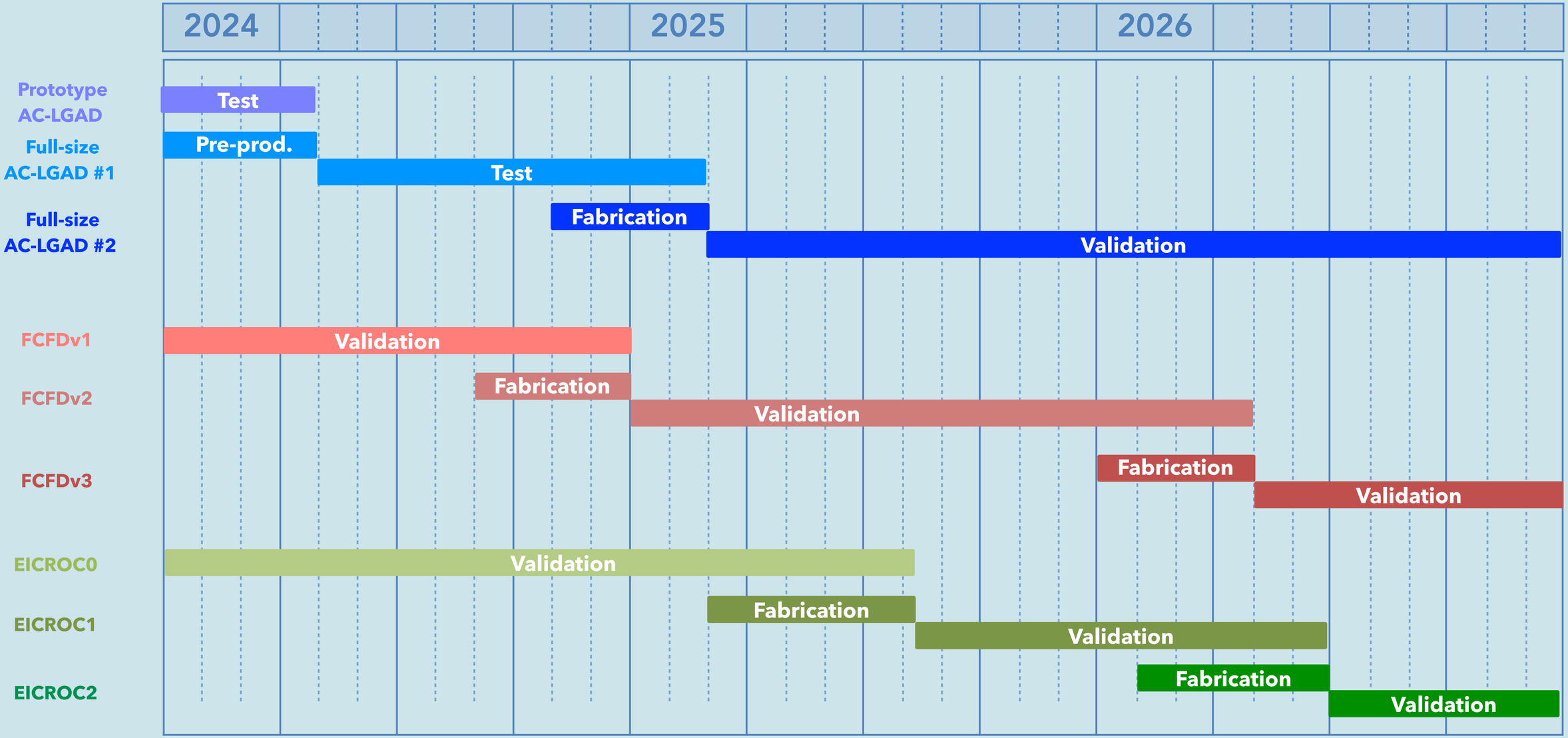
- **Total common system cost: $1,749,000 ($1,585,500)**
  - Support structure: $106,000 ($42,500)
    - R&D: $63,500
    - Production: $42,500
  - Cooling system: $300,000
  - Backend electronics: $1,243,000

- **TOTAL**
  - **R&D + Production: $15,566,358**
  - **Production: $12,598,258**

## New clean room (100m²) @ HU



# Schedule of sensor and ASIC



# Power budget of TOF

- BTOF power consumption is larger than the FTOF due to the size difference
- Sensors+ASICs and SH of FTOF are placed on the same board, so the cooling power is designed for the sum of the consumption
- SH of BTOF is located in a different place than sensors + ASICs

BTOF

| | Power |
|---|---|
| Sensors | 4kW |
| FCFD | 9.4kW |
| DC-DC | 3.3kW |
| FPGA | 1kW |
| Total | 17.7kW |

SH = 4.3kW

FTOF

| | Power |
|---|---|
| Sensors | 0.3kW |
| EICROC | 3.6kW |
| DC-DC | 2.5kW |
| FPGA | 1kW |
| Total | 7.4kW |

# 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, OMEGA, CEA-Saclay (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/OMEGA/CEA-Saclay
- **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
  - Nara Woman University
- **Service Hybrid**
  - Rice University
- **Backend electronics**
  - BNL