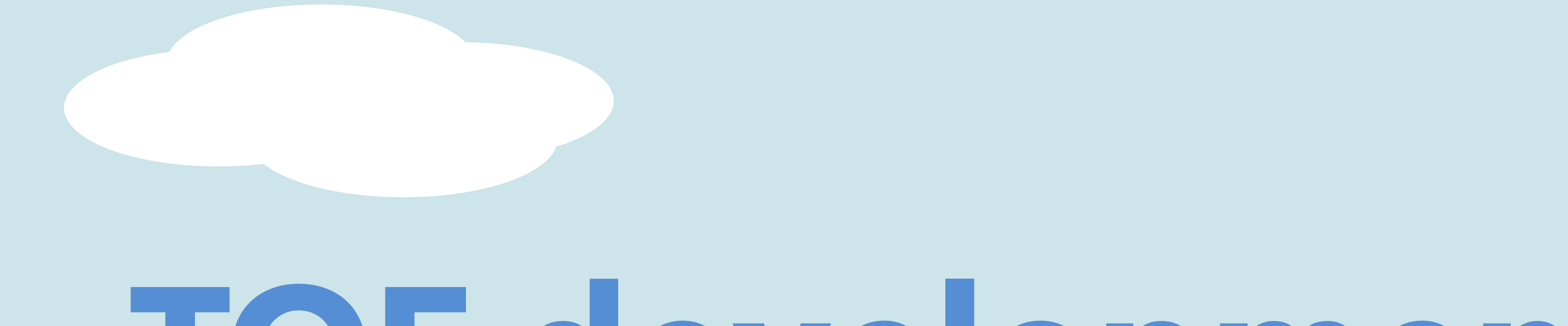
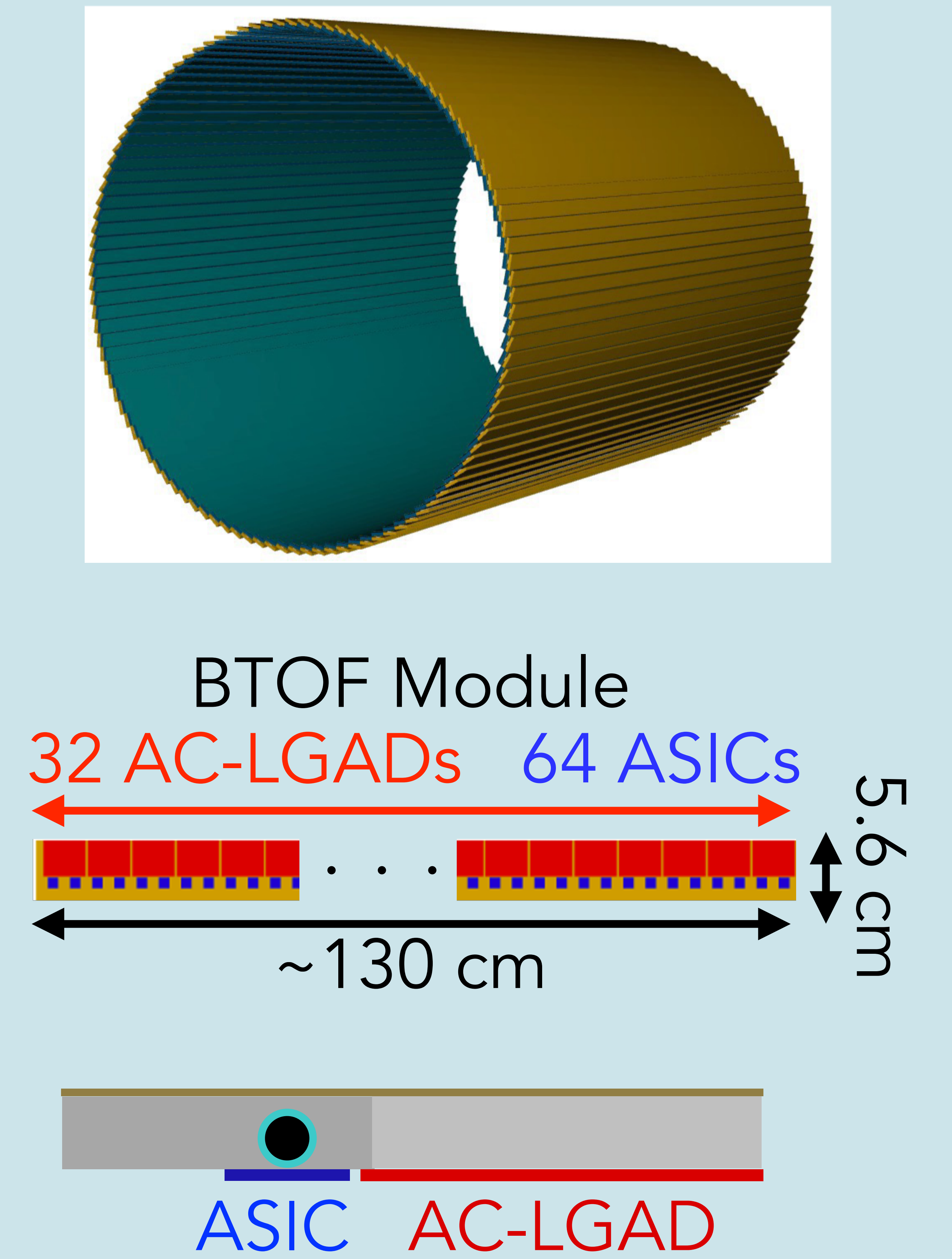
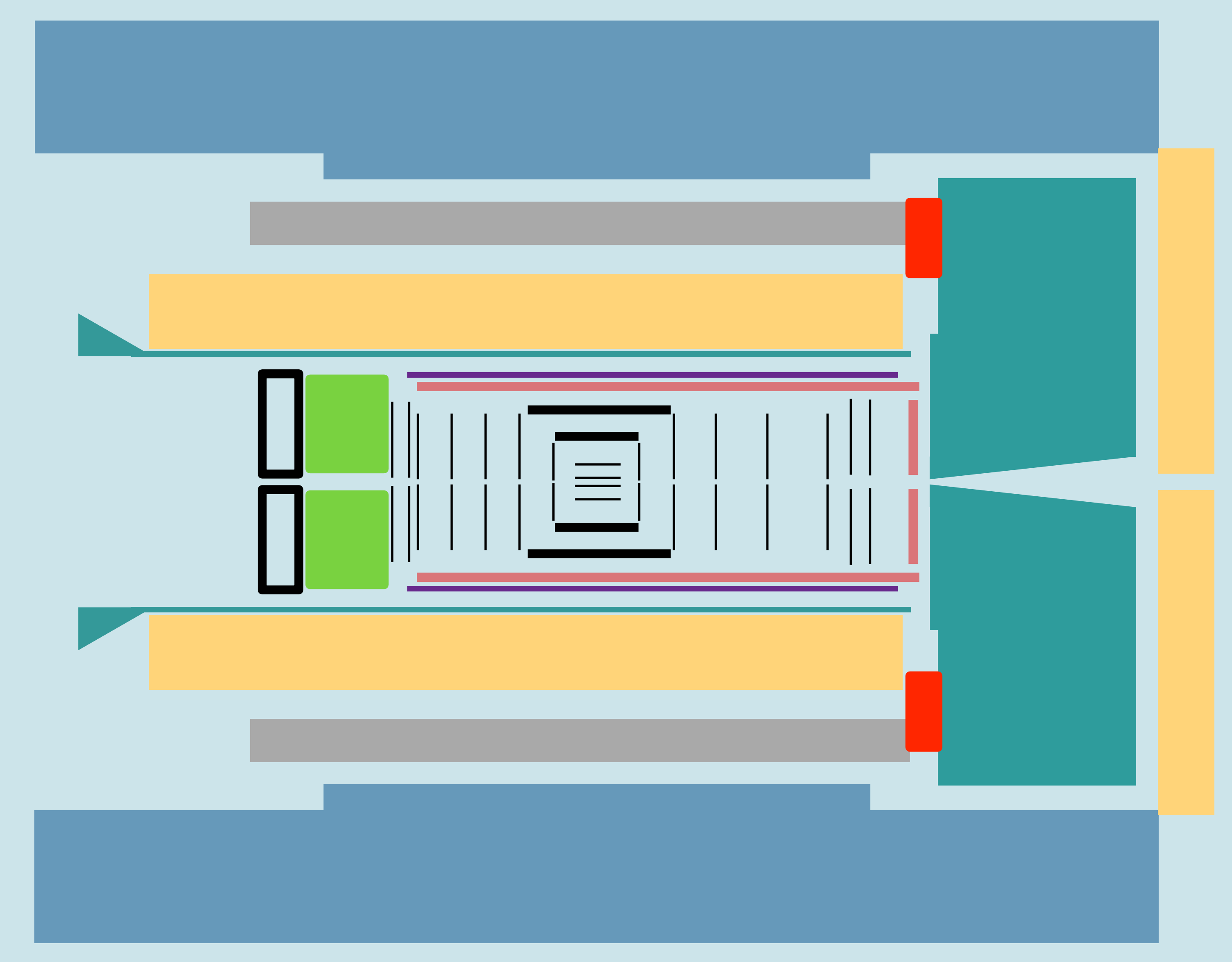


TOF development in Asia

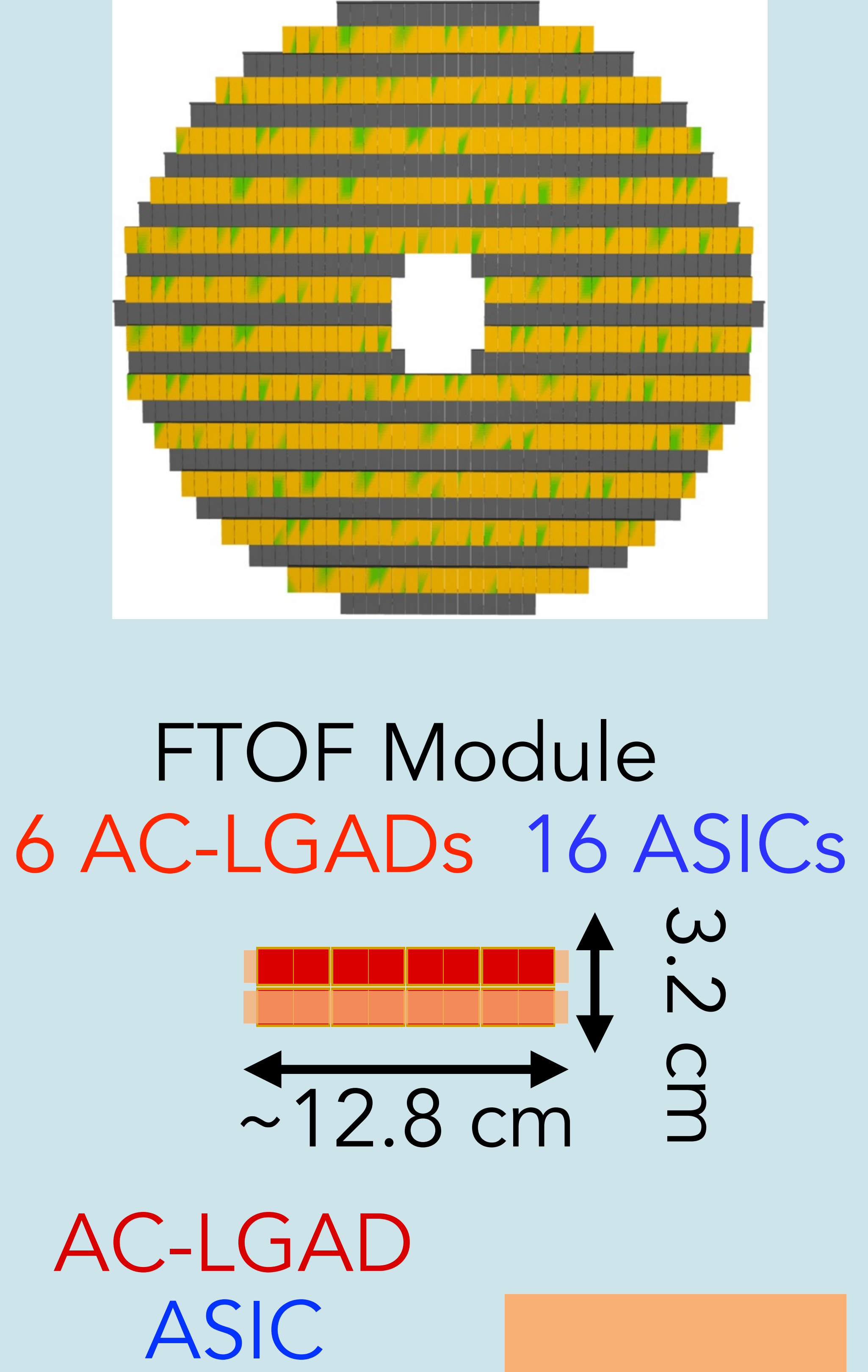
Satoshi Yano (Hiroshima University)

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

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), Satoshi Yano (Hiroshima Univ.)
  - 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.)

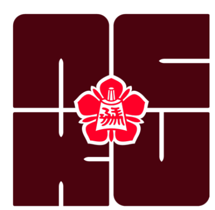
New TOF DSC organization

- 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)

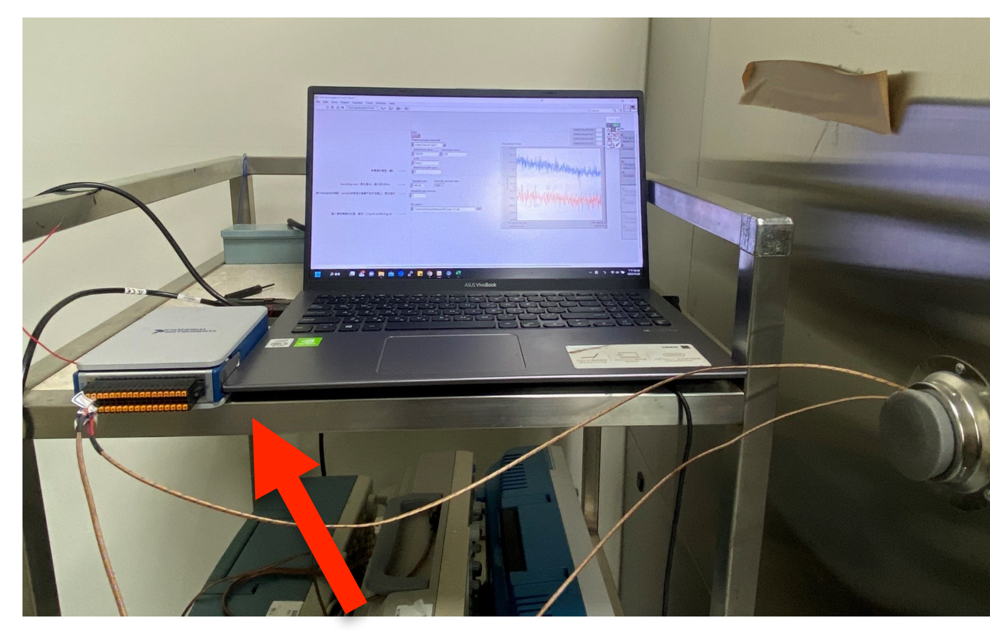
- Work packages have been created
  - Sensors: Simone Mazza (US Santa Cruise), **Satoshi Yano** (Hiroshima Univ.)
  - Frontend Electronics: Wei Li (Rice Univ.), TBD
  - Module integration and assembly: Mathieu Benoit (ORNL), Matthew Gignac (UC Santa Cruise)
  - System tests and validation: **Takashi 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.)

Recent activity in Asia
National Cheng Kung University (TW)

Yi Yang's presentation



Test Setup



NI 9213 DAQ
- 16 channels
- Accuracy:
  - High-resolution mode : <0.02 °C
  - High-speed mode : <0.25 °C

Environmental chamber
- Inner dimensions: 40 x 50 x 60 cm^3
- Temperature: -40 °C ~ 100 °C (± 0.2 °C)
- Humidity: 10% ~ 98% (± 2.5%)

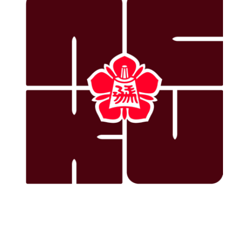
Cooling system
- Temperature: 3 °C ~ 32 °C

Heat source
- Ceramic plate (5Ω): ~500°C

Thermocouple
- Type E: -250°C ~ 900°C

Recent activity in Asia
National Cheng Kung University (TW)

Yi Yang's presentation



First Test

Source 0
Source 1
Heat source
Honeycomb
Foam
Ch 4
Ch 5

source 0
Tc - T (ºC)
T (ºC)
source 0
Wout - Win

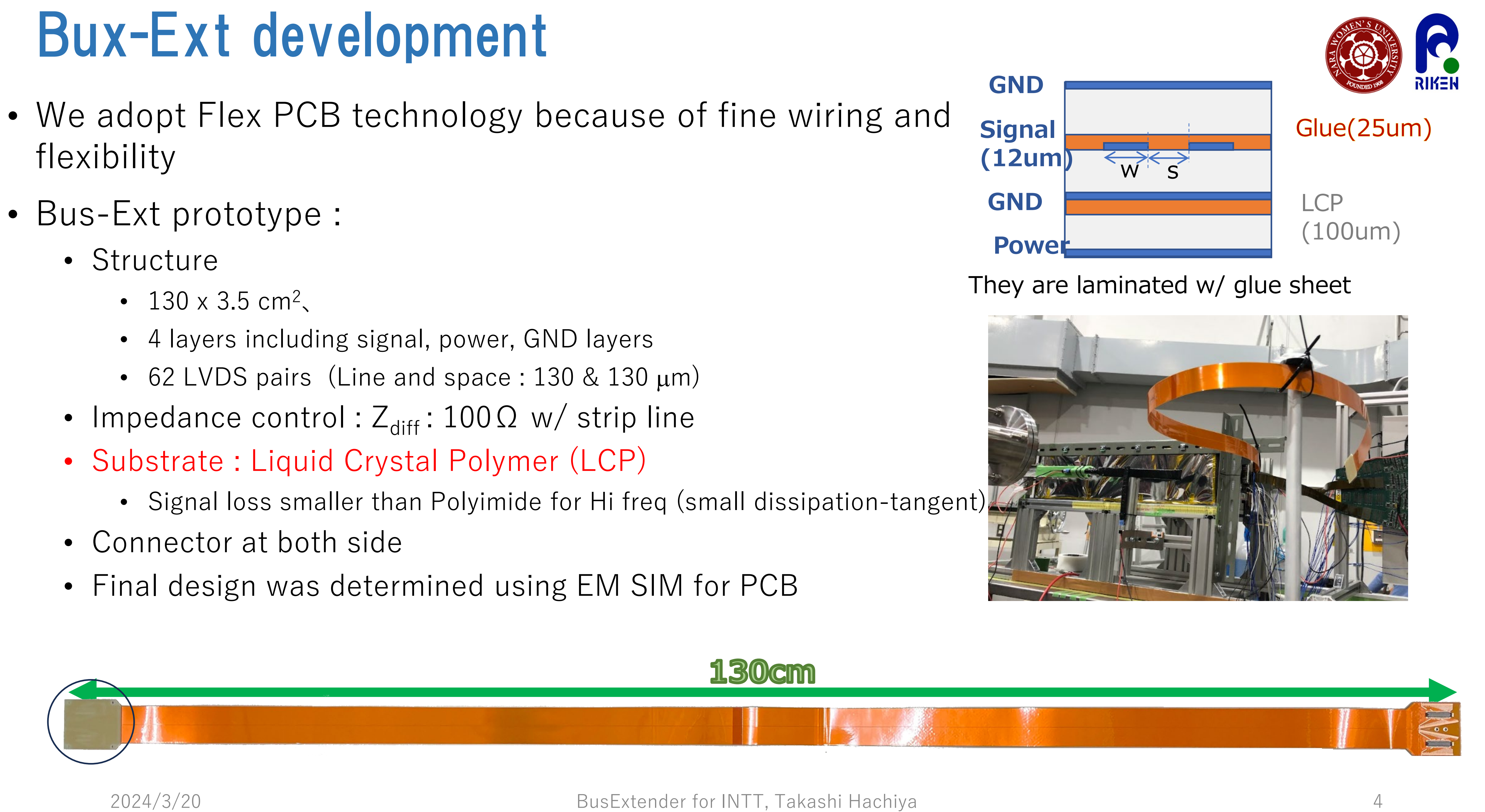
source 1
Tc - T (ºC)
T (ºC)
source 1
Wout - Win

ch 4(S0)
Tc - T (ºC)
T (ºC)
ch 4(S0)
Wout - Win

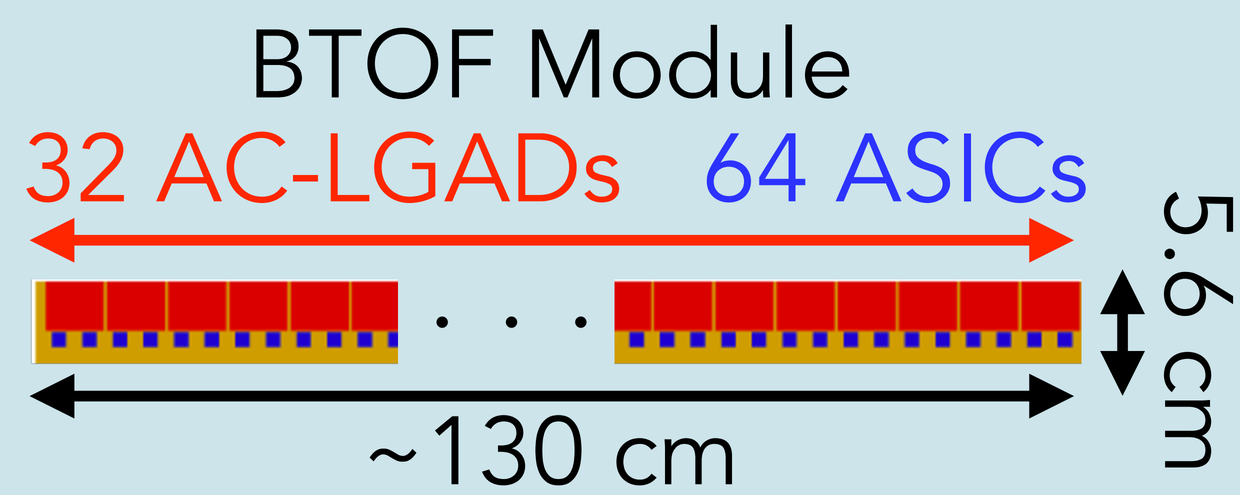
ch 5(S1)
Tc - T (ºC)
T (ºC)
ch 5(S1)
Wout - Win

Recent activity in Asia
Nara Woman's University (JP)

- R&D of Long Flexible Printed Circuit (FPC)
  - BTOF uses 130cm long FPCs
- Nara Woman's University has experience to develop ~130cm FPC for sPHENIX INTT
  - Their knowledge will surely be utilized in the development



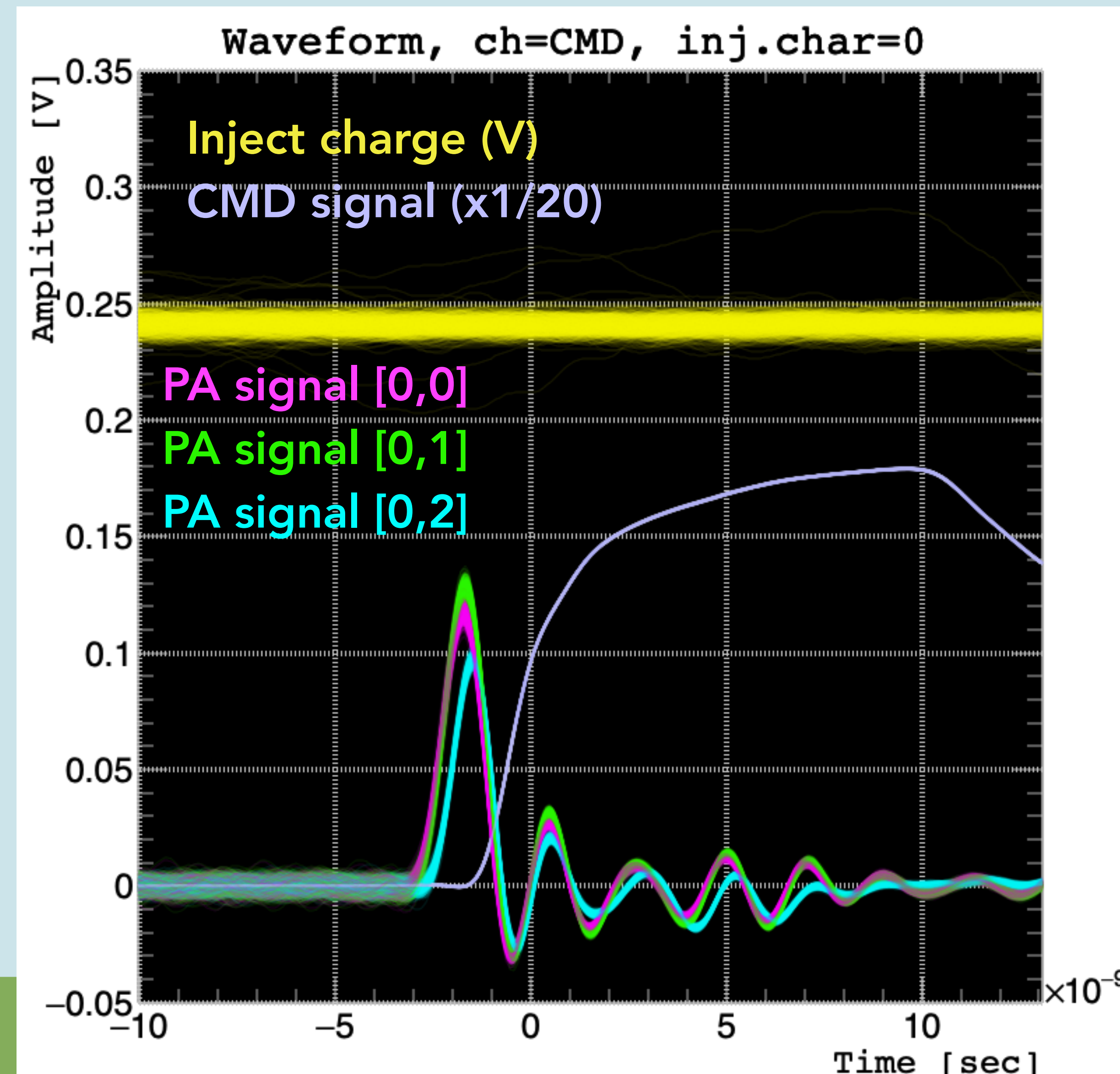
Takashi's presentation

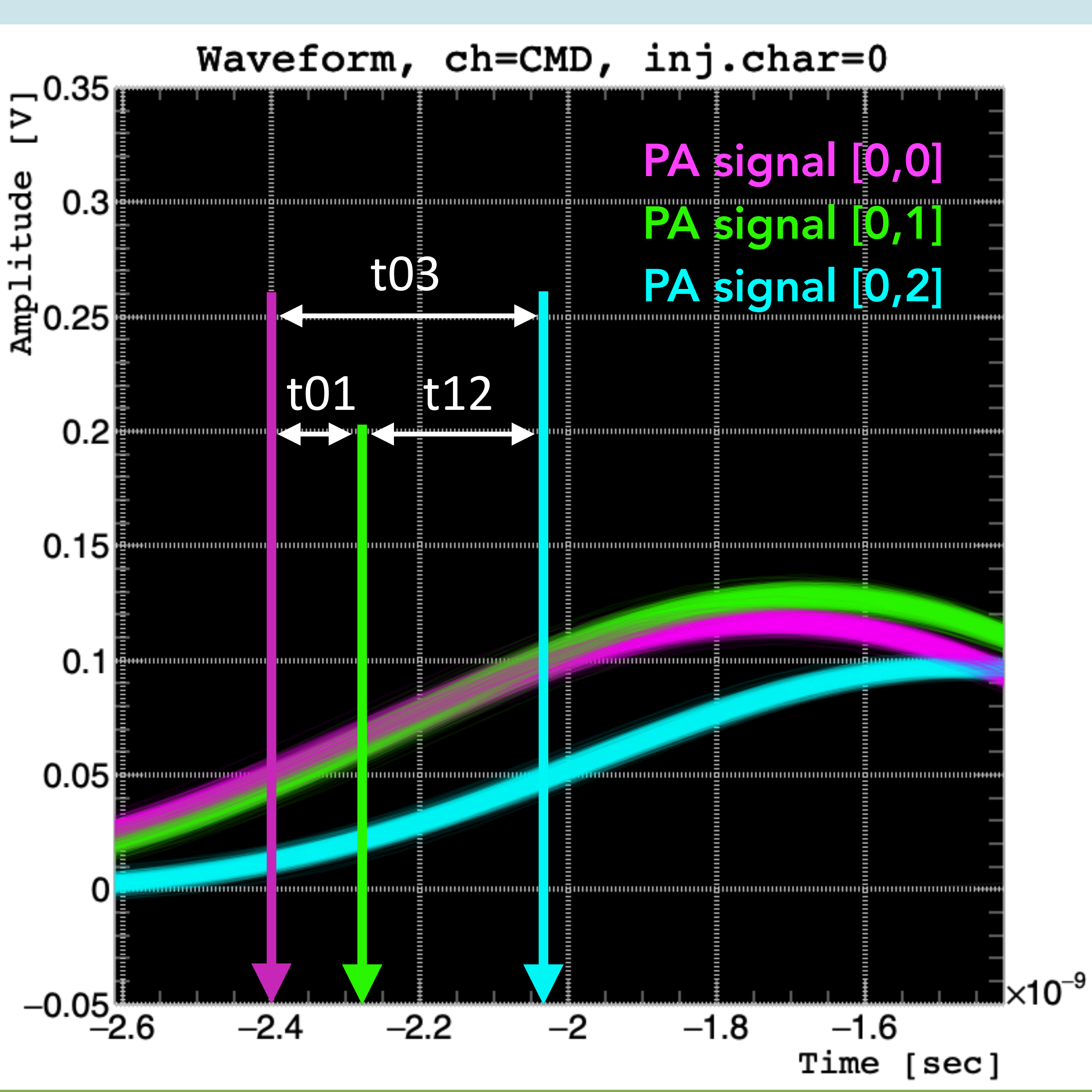


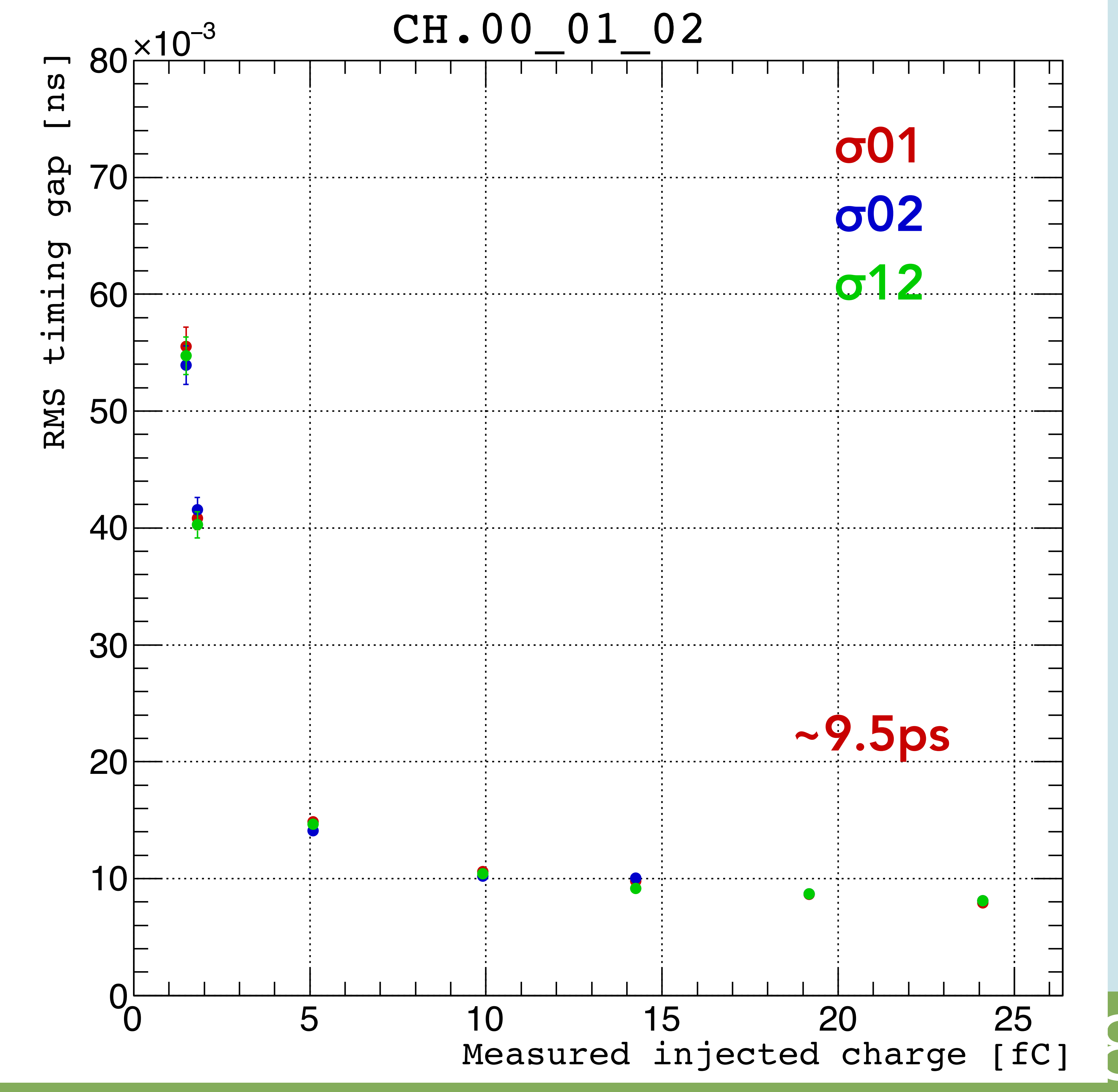
Recent activity in Asia
Hiroshima University (JP)

- EICROC0 characterization
  - Performance evaluation of analog block is being conducted

- The analog signal response with injected charges is used
  - Timing resolution has been calculated by signal timing differences







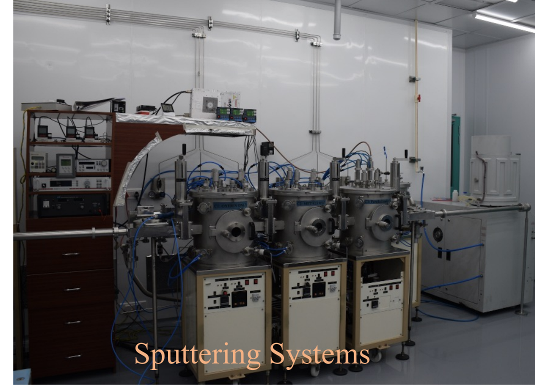
New institute interested in TOF

- The Indian Institute Of Technology, Mandi (IIT Mandi) is interested in the TOF project
- They have state-of-the-art instrumentation facilities utilized for the TOF project

Infrastructure at IIT Mandi C4DFED

Centre For Design & Fabrication of Electronic Devices (C4DFED) [21 fabrication instruments]

- Unique world-class facility for multidisciplinary research on electronic device design and fabrication
- Center has class 100, Class 1000 & Class 10000 laboratories where high-end sophisticated electronic device design, fabrications, and characterizations tools are installed & housed

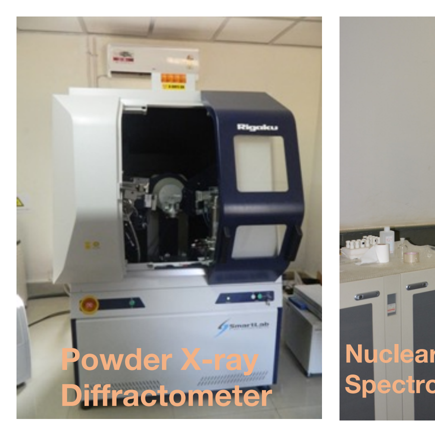


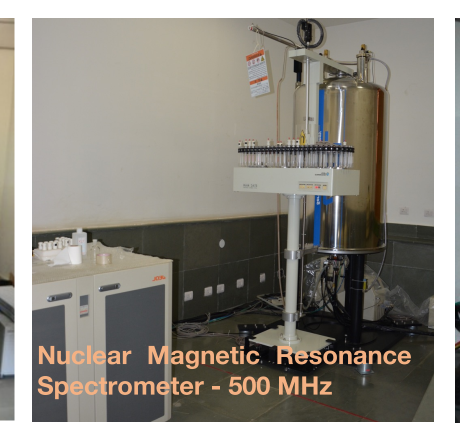
prabhakar@iitmandi.ac.in; amal@iitmandi.ac.in

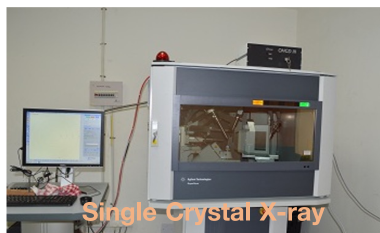
Infrastructure at IIT Mandi AMRC

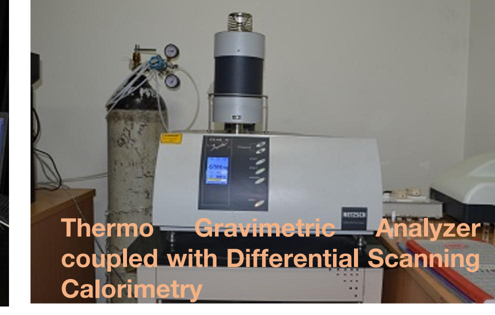
Advanced Material Research Center (AMRC)

- A state-of-the-art instrumentation facility, housing more than 46 ancillary equipment, some of them are:









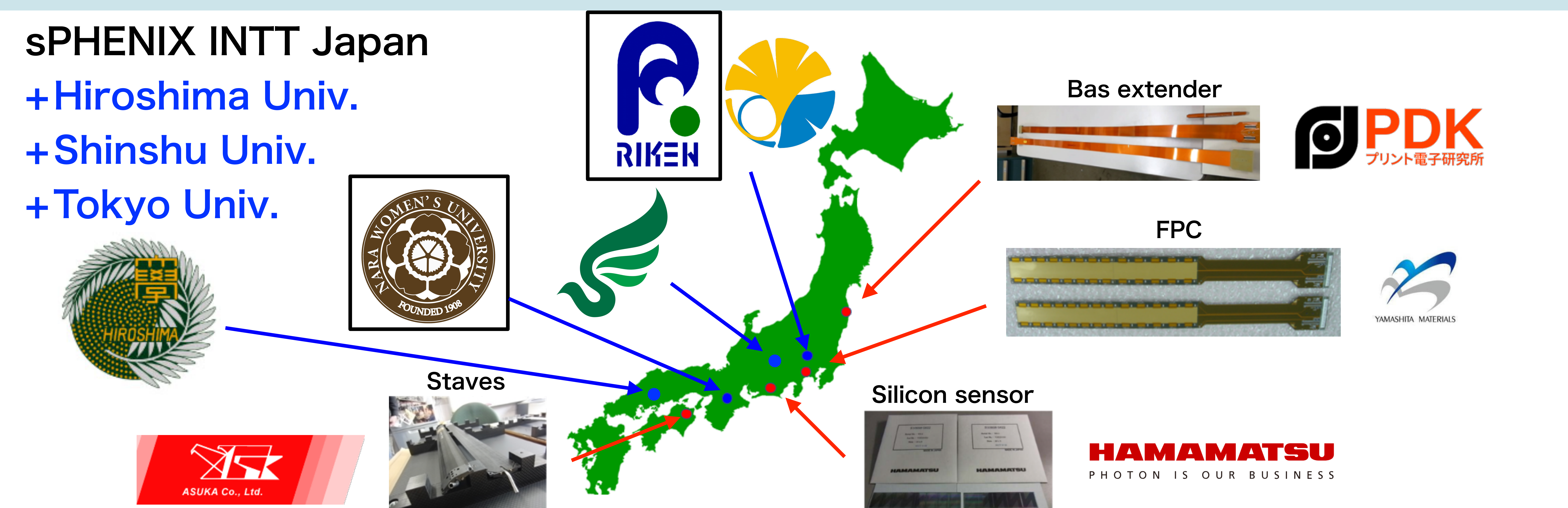
prabhakar@iitmandi.ac.in; amal@iitmandi.ac.in

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

Japanese team plan

- Major contributions are expected from the Japanese community
- We are planning to give an in-kind contribution to BTOF
  - Hiroshima University will have a 120m^2 area of clean room for BTOF assembling (in early 2026)
  - We are requesting the budget for FY2025 for equipment and sensors etc for assembling and procurement (pre-production/production)



Summary

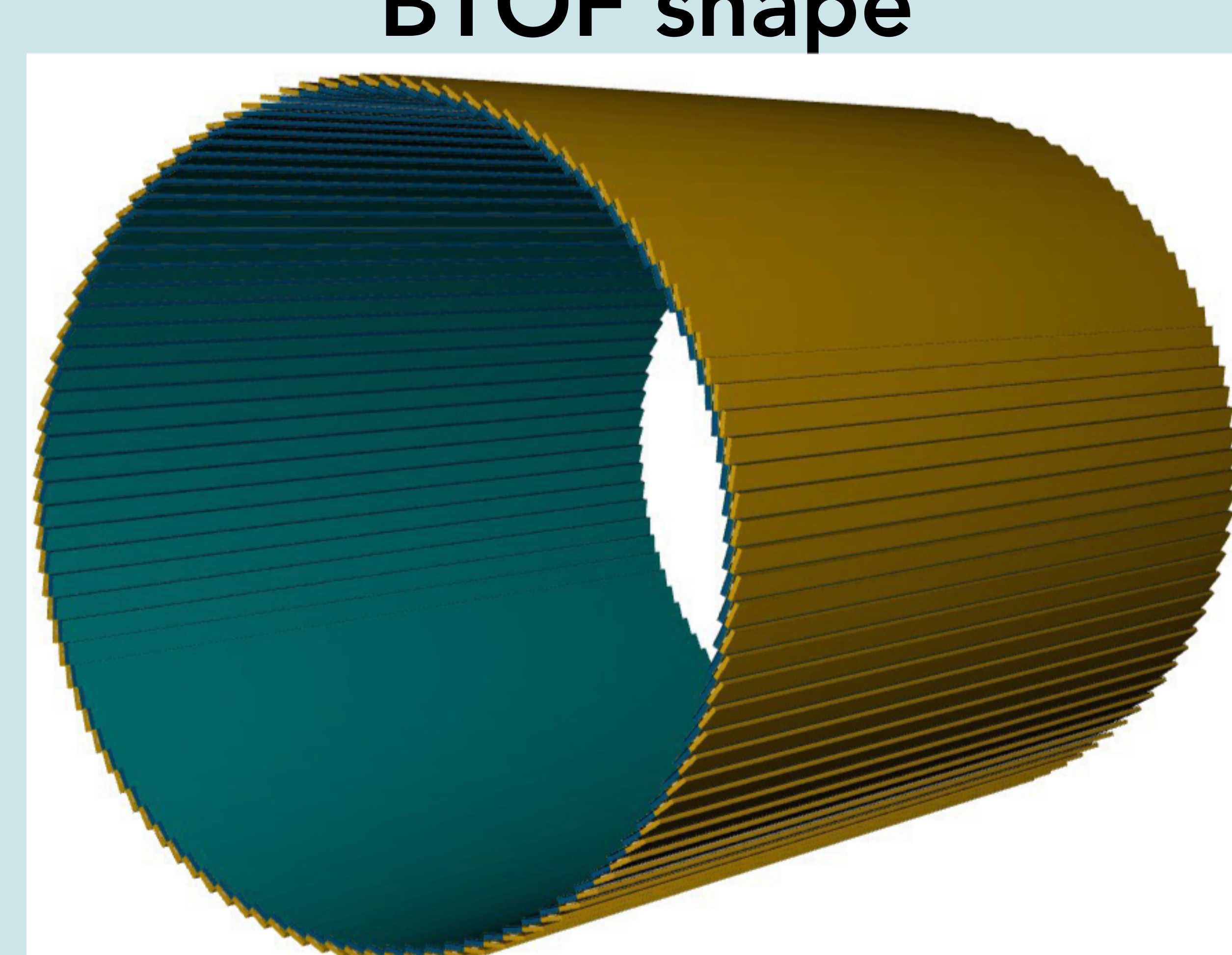
- The new organizational structure has been made
  - Many members from Asia are involved in the structure
- National Cheng Kung University released the first thermal test results of mechanical structure
- Nara Woman's University who has the experience to develop the long PCB is involved in our project
- Hiroshima University participates in the development of EICROC
- New Indian institute is interested in TOF project
- Japan is planning an in-kind-contribution of BTOF

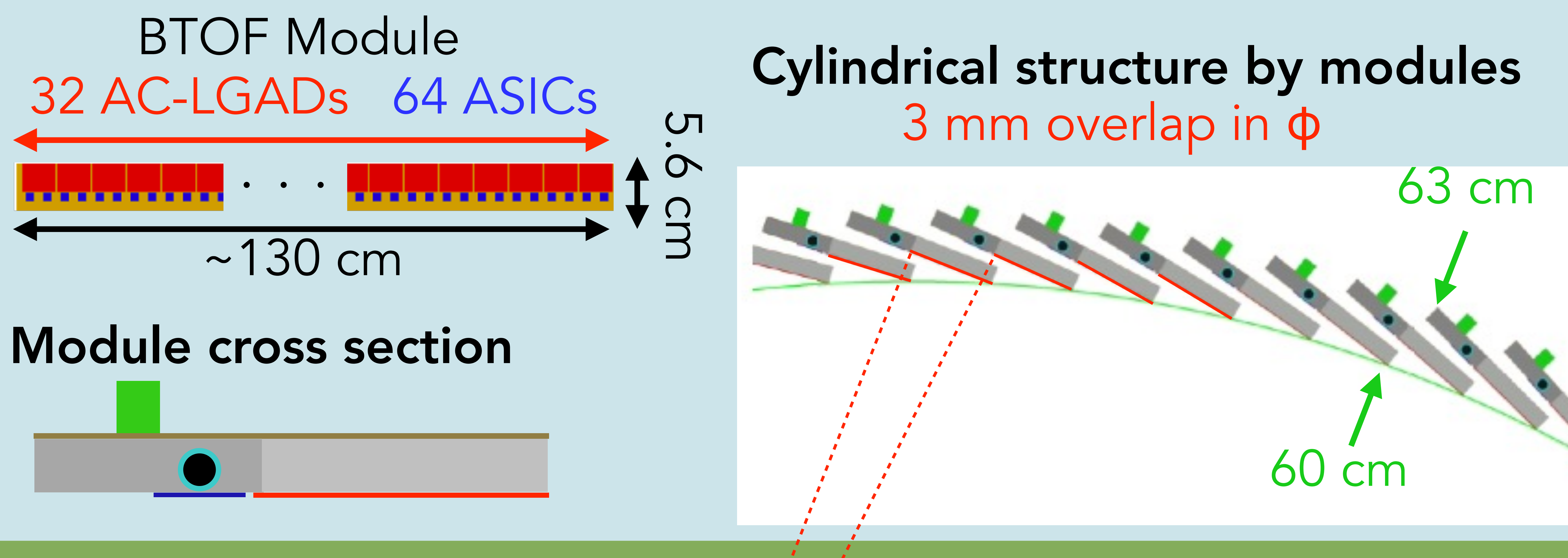
Backup

Detector Layout of BTOF

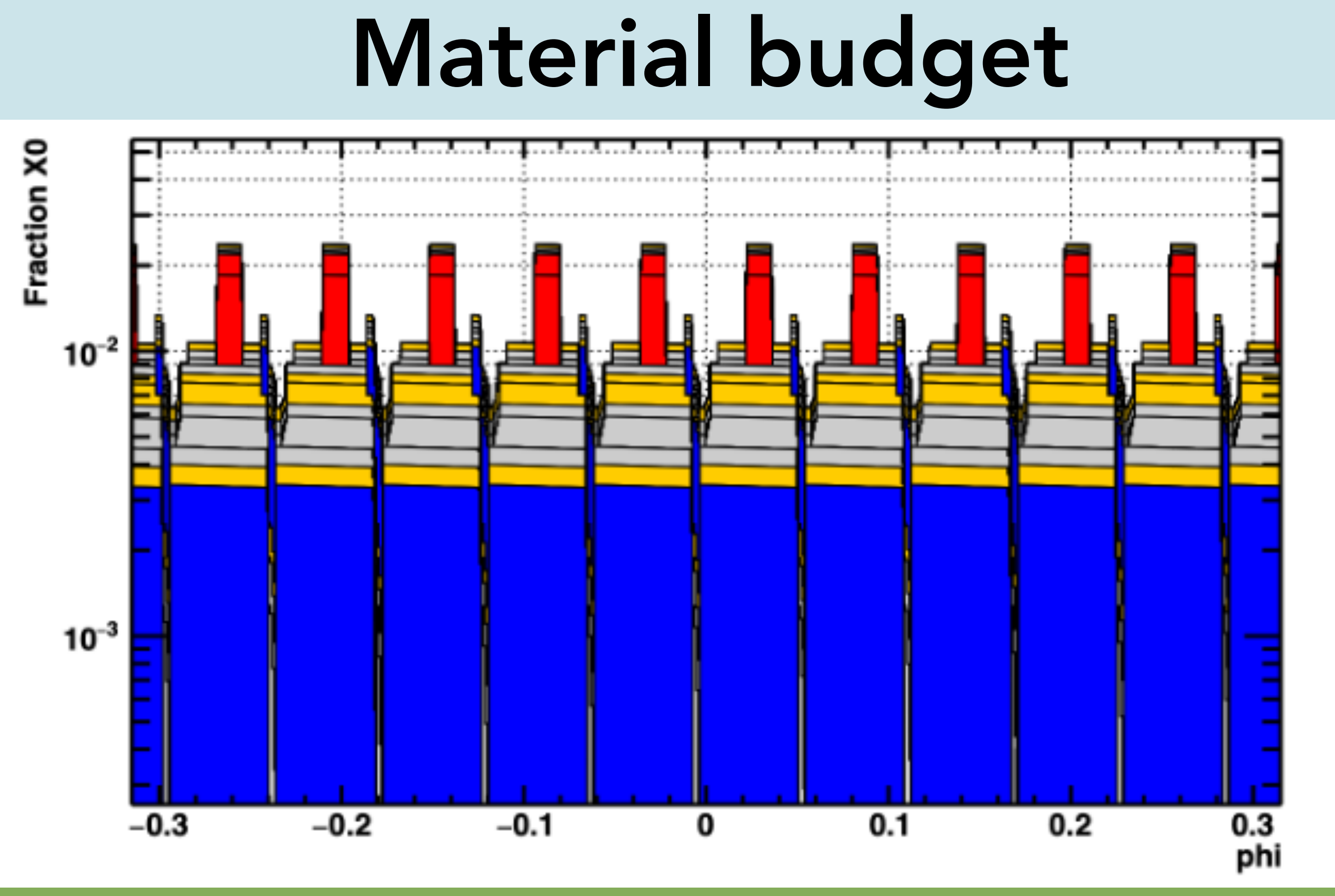
- BTOF is composed of 144 modules to make a cylindric
- 64 AC-LGAD strip sensors are attached to one module
  - ASIC place is under discussion (depending on the ASIC pixel geometry)
- Radius is 60 - 63 cm from the beam pipe covering $-1.42<\eta<1.77$
- Total material budget in acceptance is ~0.01 X/X_0

BTOF shape





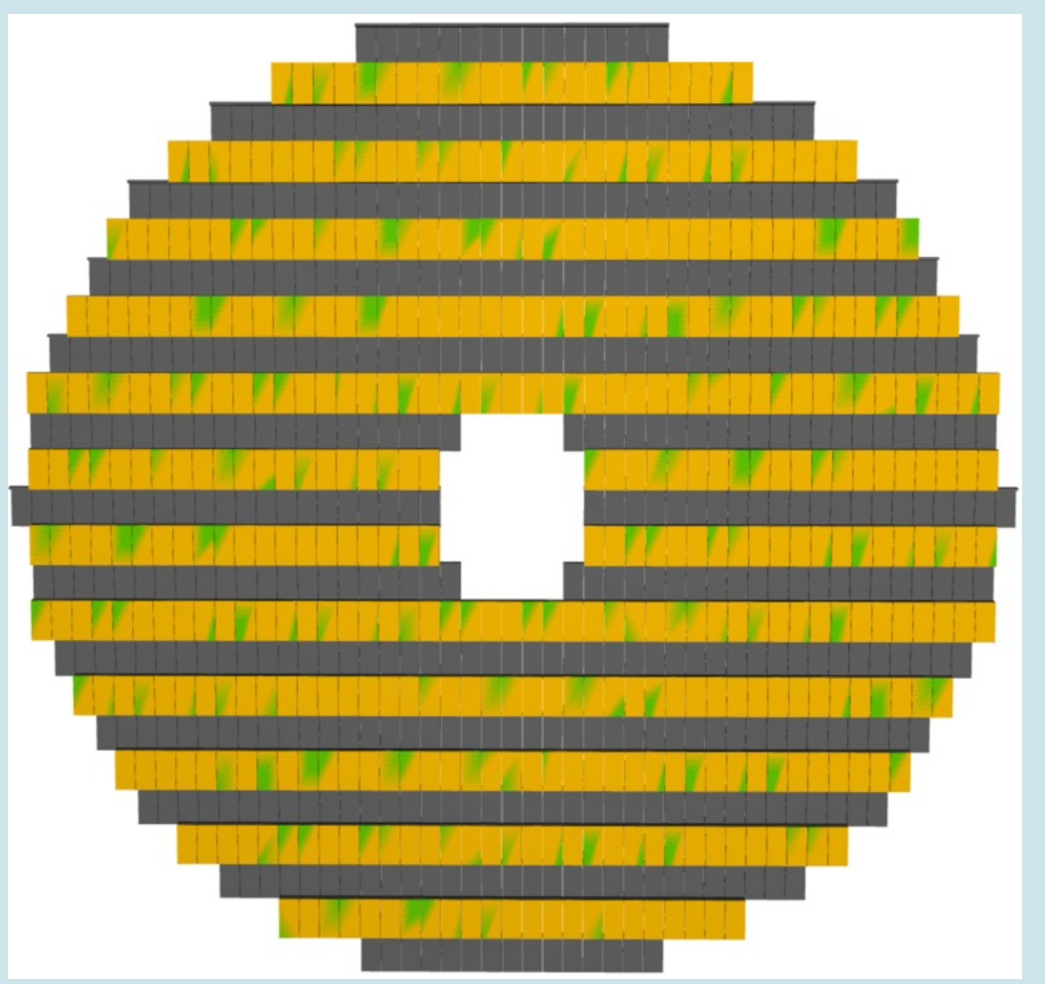
Material budget

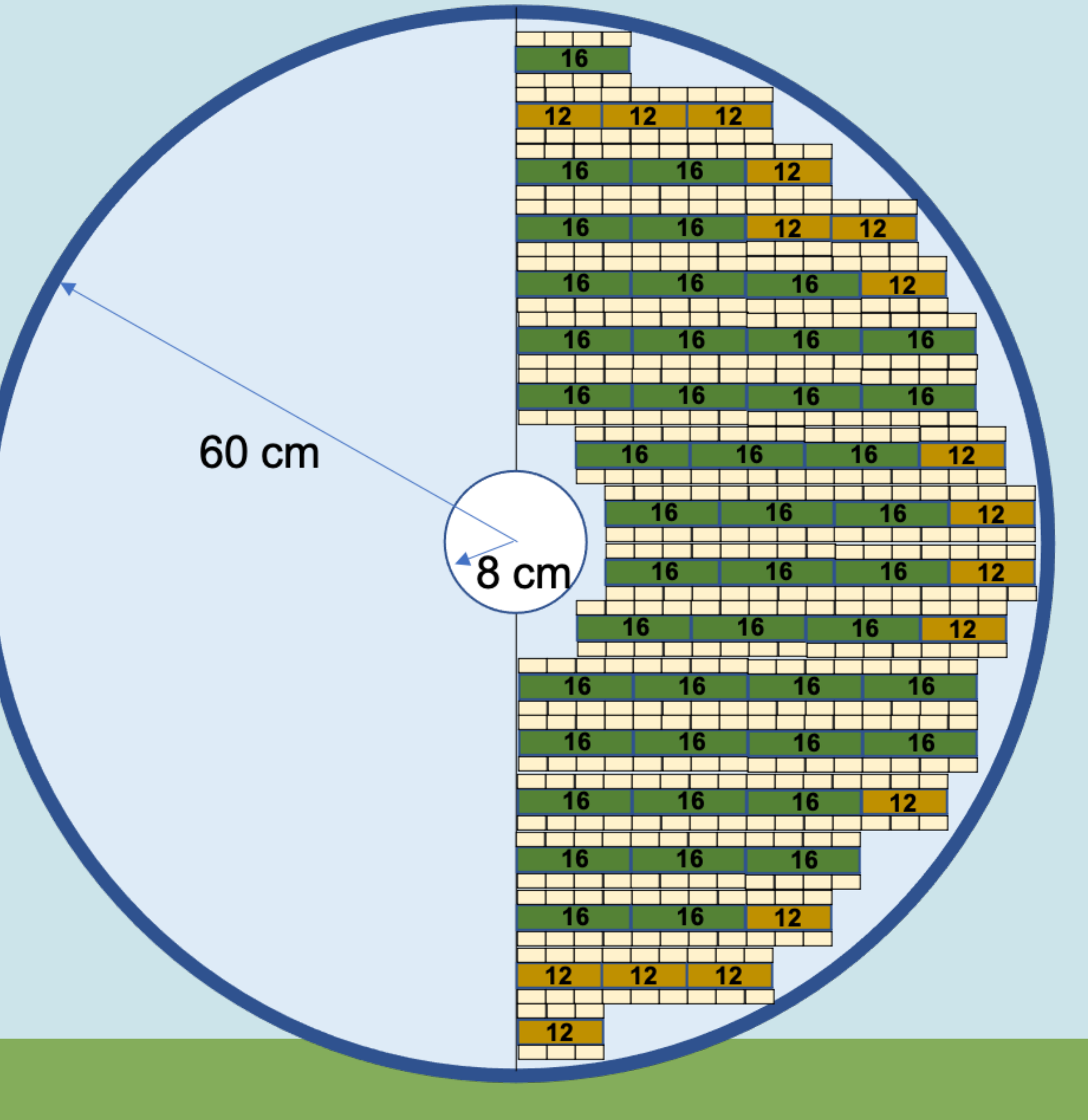


Detector Layout of FTOF

- 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

12 AC-LGADs

16 AC-LGADs

3.2 cm

~9.6 cm

~12.8 cm

Module cross section

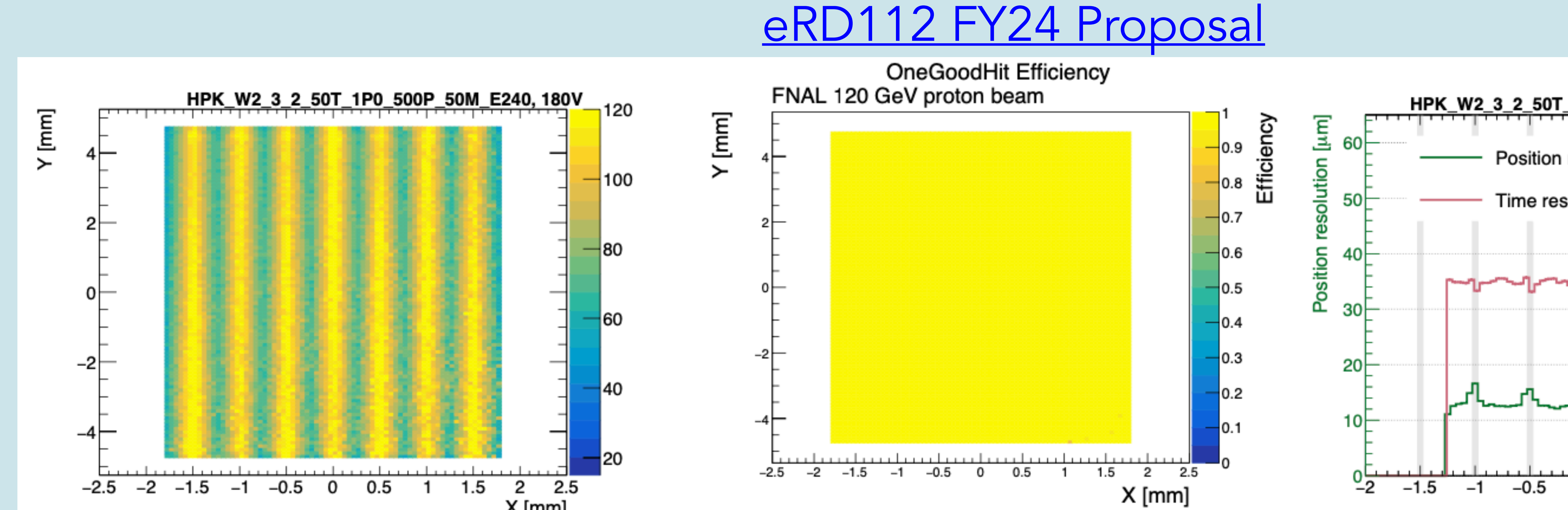
AC-LGAD + EICROC

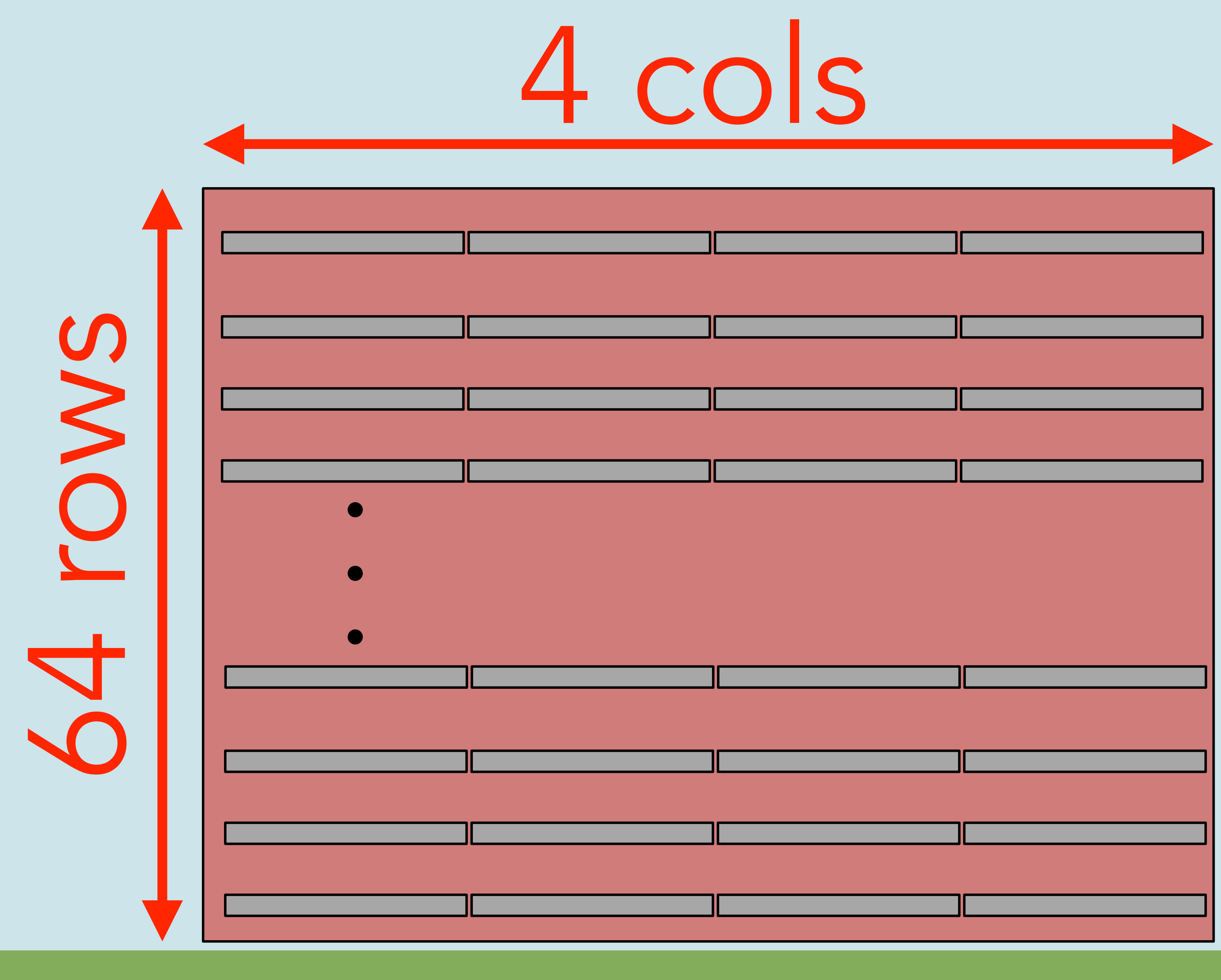
Service Hybrid

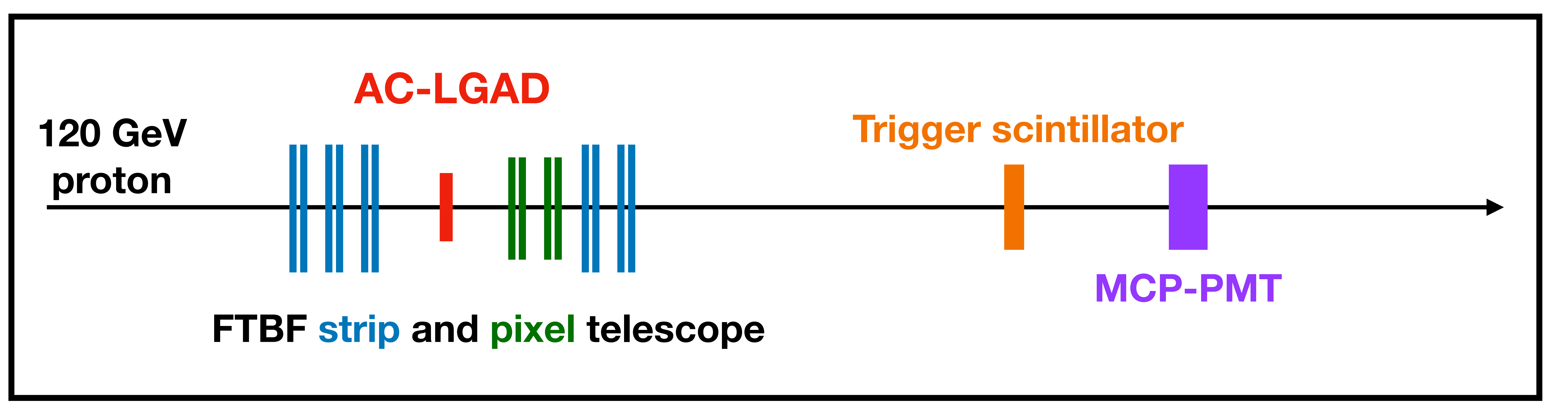
- AC-LGAD technology meets the strict spatial and time resolution requirements
- Strip-type sensor, 3.2 x 4 cm^2 sensor size with 0.05 x 1 cm^2 metals, is used in BTOF
  - The readout metal geometry in a sensor is 64 x 4 and 256 channels each
- 2 ASICs are attached for each with wire bonding

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

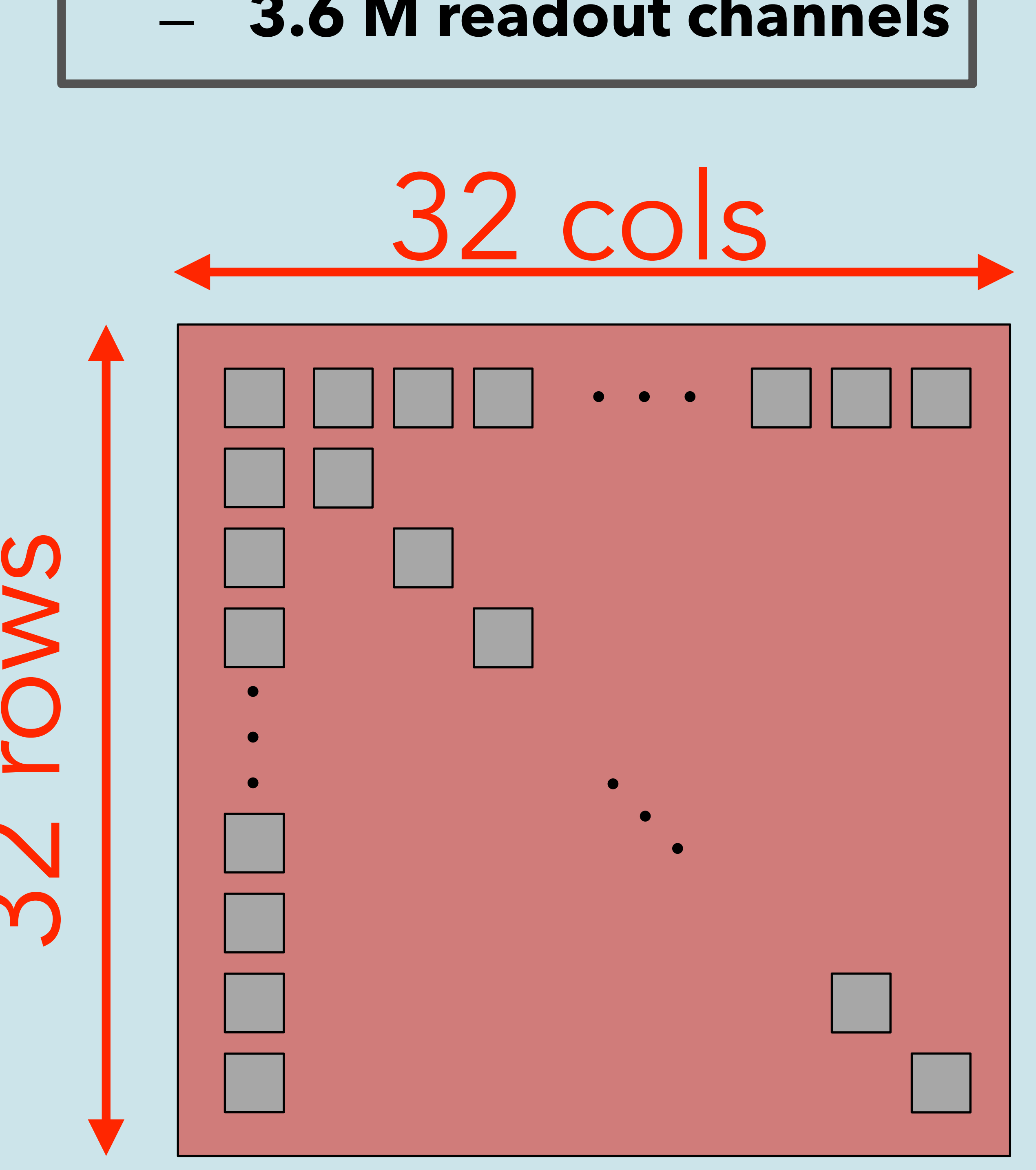
eRD112 FY24 Proposal







- Total information
  - **3632 sensors**
  - **1.4 m²**
  - **3.6 M readout channels**



[eRD112 FY24 Proposal]

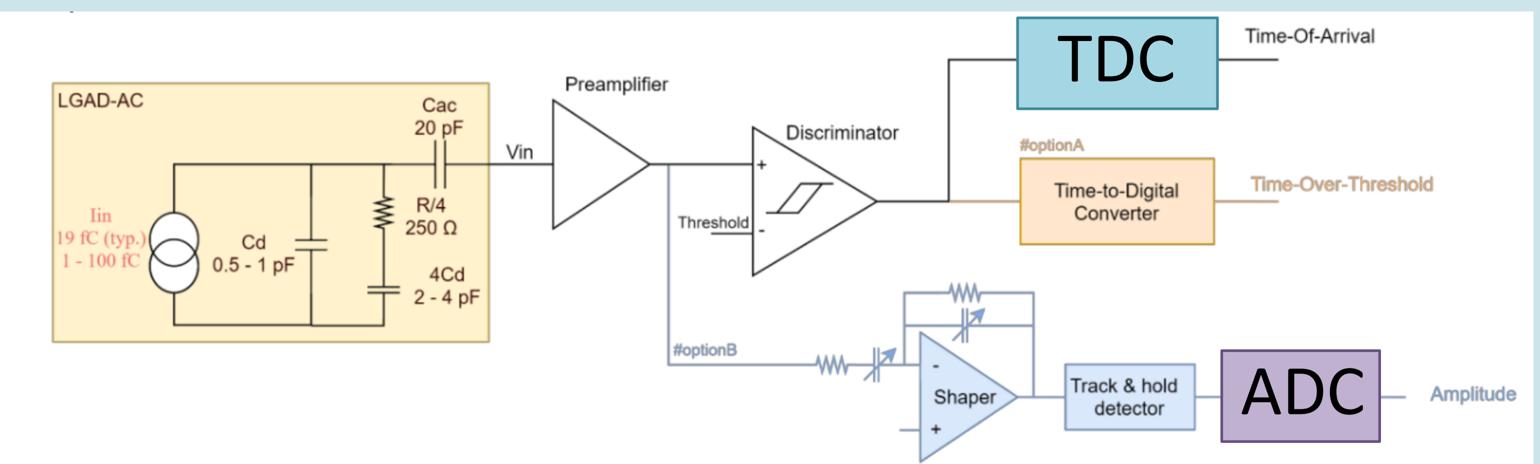
TOF ASIC

- 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

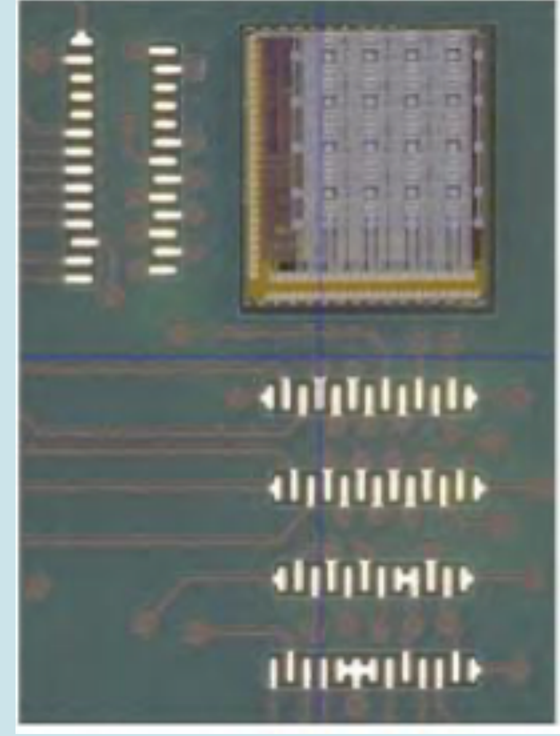
- EICROC (32x32) is one of the common ASICs used in ePIC
  - Design focuses on pixel AC-LGAD readout (tuned for low capacitance)
  - 10-bit TDC and 8-bit ADC is now available (EICROC0)
  - Modification is necessary to read higher capacitance sensor (strip AC-LGAD)

- 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

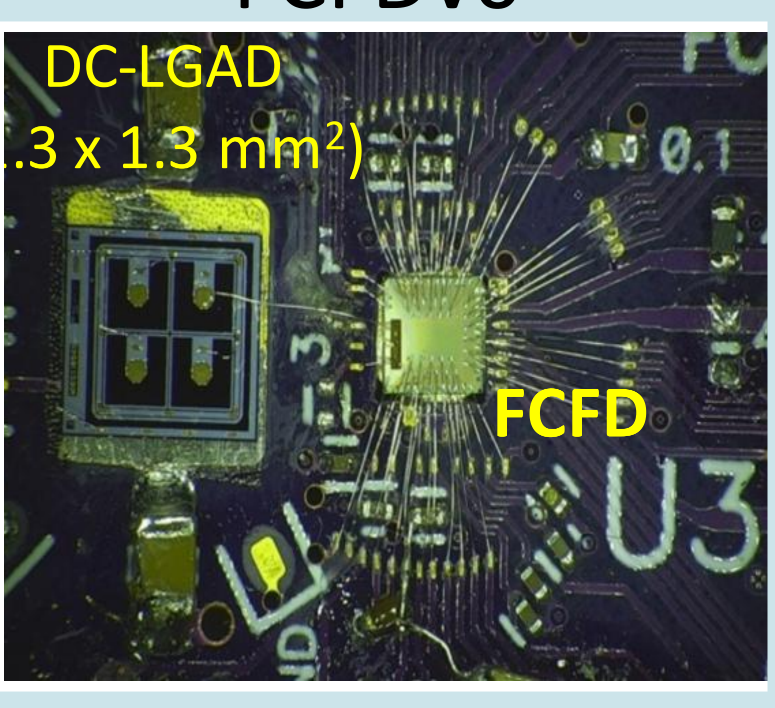
- The possibility of HGCROC has begun to be discussed
  - It can measure ADC, TOA, and TOT
  - We have to investigate the possibility of the chip as soon as possible and make collaboration with the experts



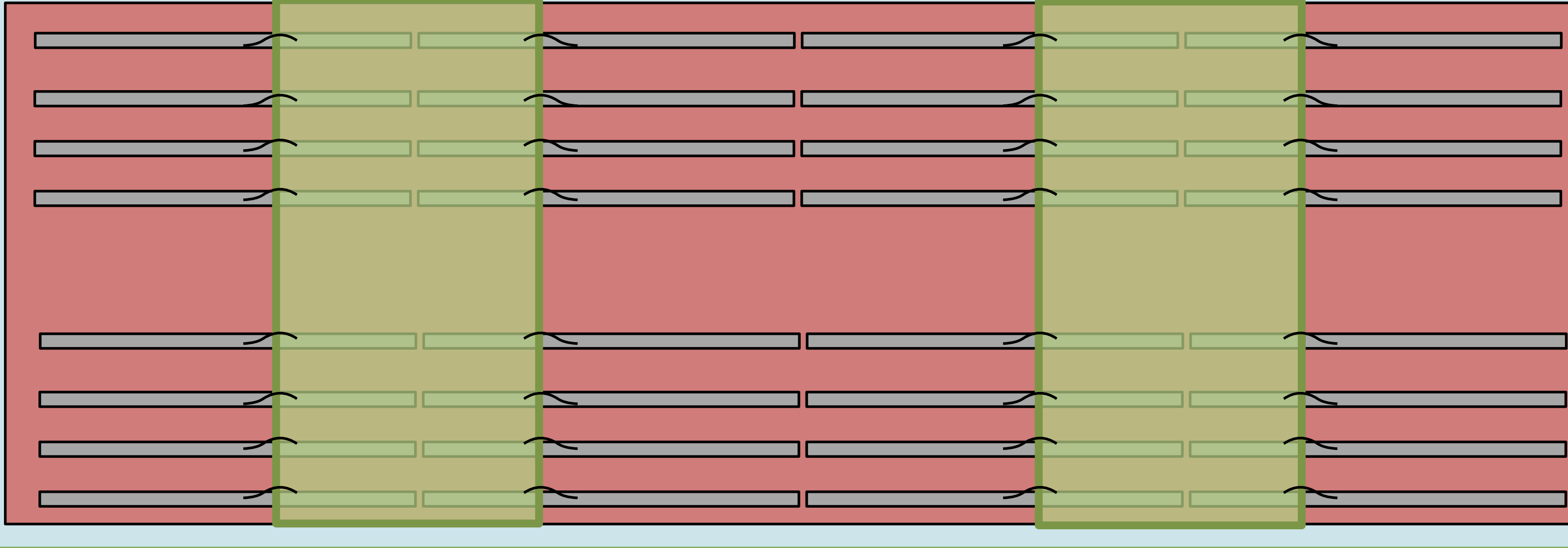
EICROC0



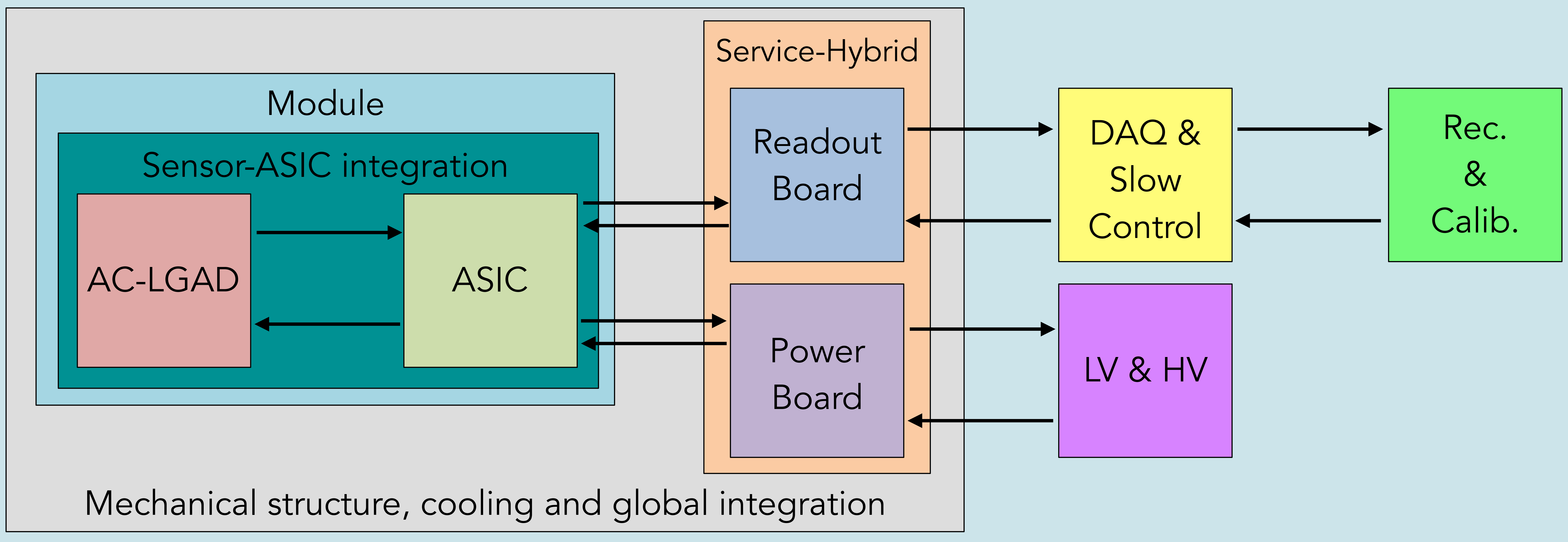
FCFDv0



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

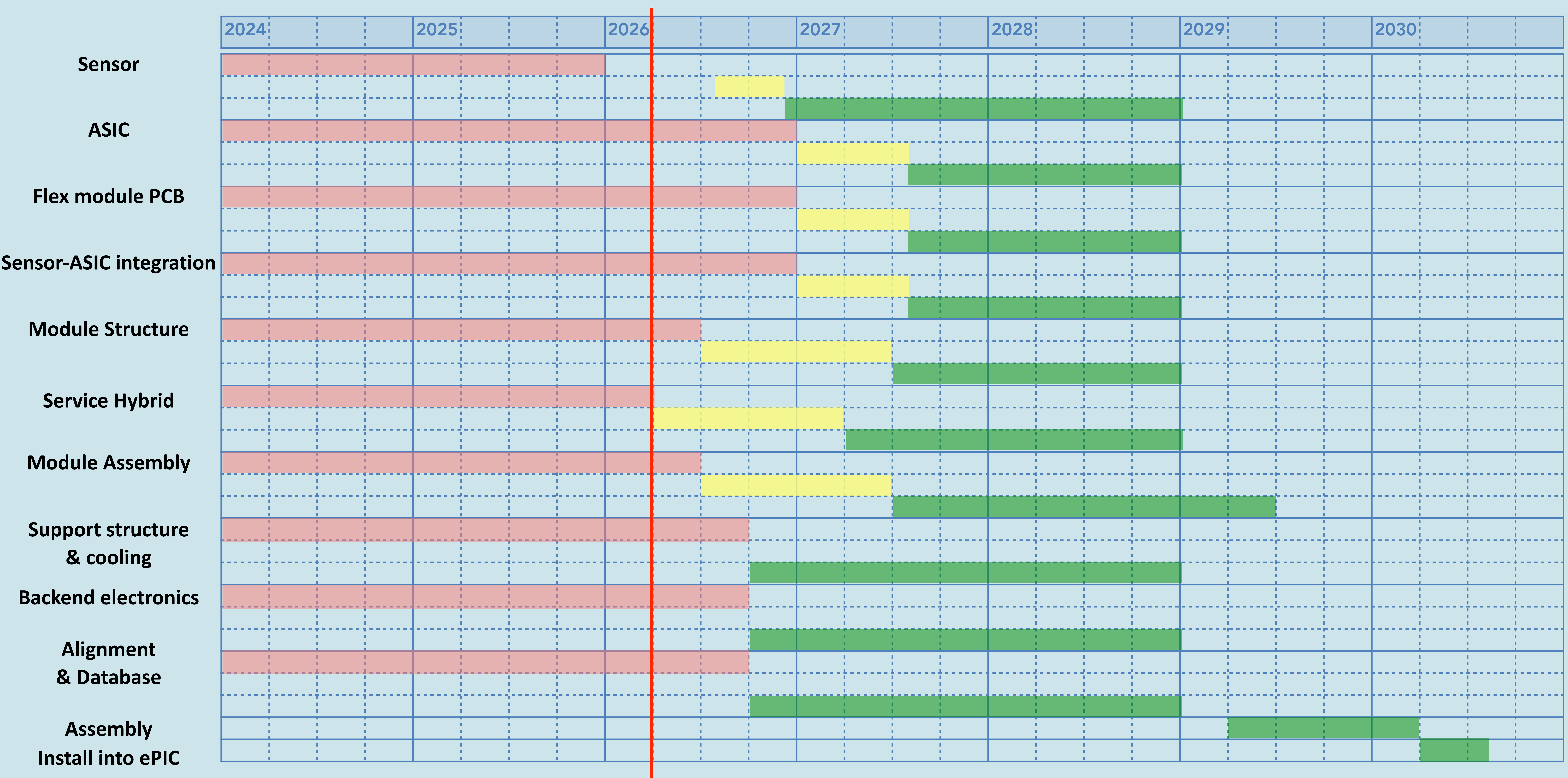
Non-labor cost of each sub-system

- **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

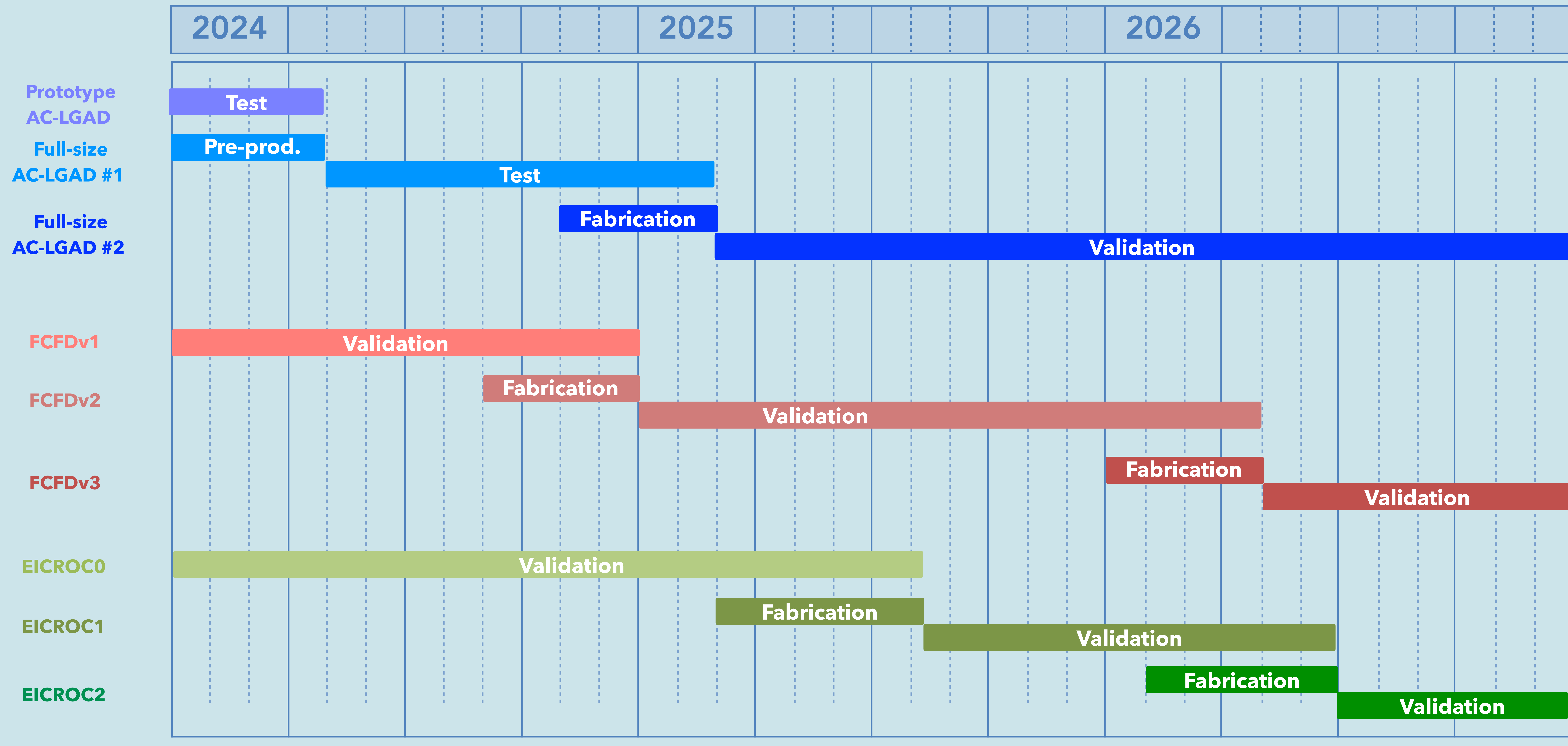
- **Total FTOF cost: $3,056,558 ($1,886,458)**
  - Sensor: $765,500 ($358,000)
    - (!) R&D: $407,500
    - Pre-production (10%): $37,000
    - Production (90%): $321,000
  - ASIC: $768,600 ($451,000)
    - R&D: $317,600
    - Pre-production (20 wafers): $292,600
    - Production (120 wafers): $158,400
  - 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
2024
2025
2026
2027
2028
2029
2030
Sensor
ASIC
Flex module PCB
Sensor-ASIC integration
Module Structure
Service Hybrid
Module Assembly
Support structure & cooling
Backend electronics
Alignment & Database
Assembly
Install into ePIC

Schedule of sensor and 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, 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