

EIC activities in Japan

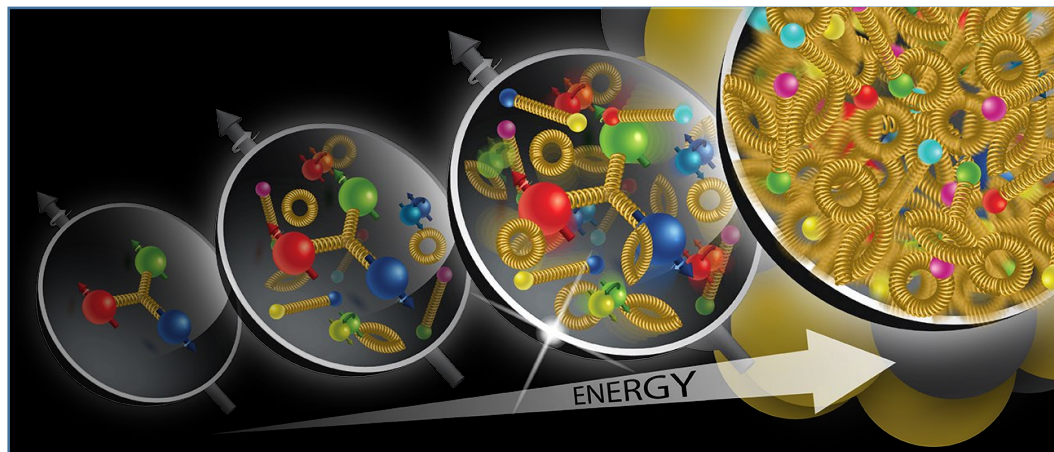
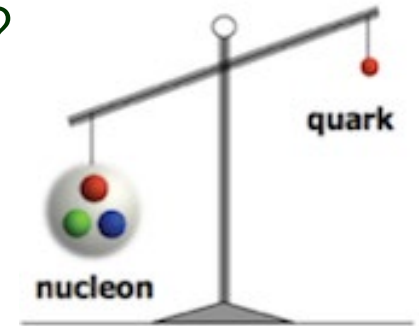
2nd APCTP Workshop on the Physics of EIC:
ePIC Physics and Detectors

November 30 (Thu), 2023

Yuji Goto (RIKEN)

Physics at EIC

- How does the mass of the nucleon arise?
 - The Higgs mechanism accounts for only $\sim 1\%$ of the mass of the proton.
- How does the spin of the nucleon arise?
 - The spin of the quarks accounts for only one-third of the spin of the proton.
- What are the emergent properties of dense system of gluons?
 - The gluon saturation describes a new state of matter at extreme high density.

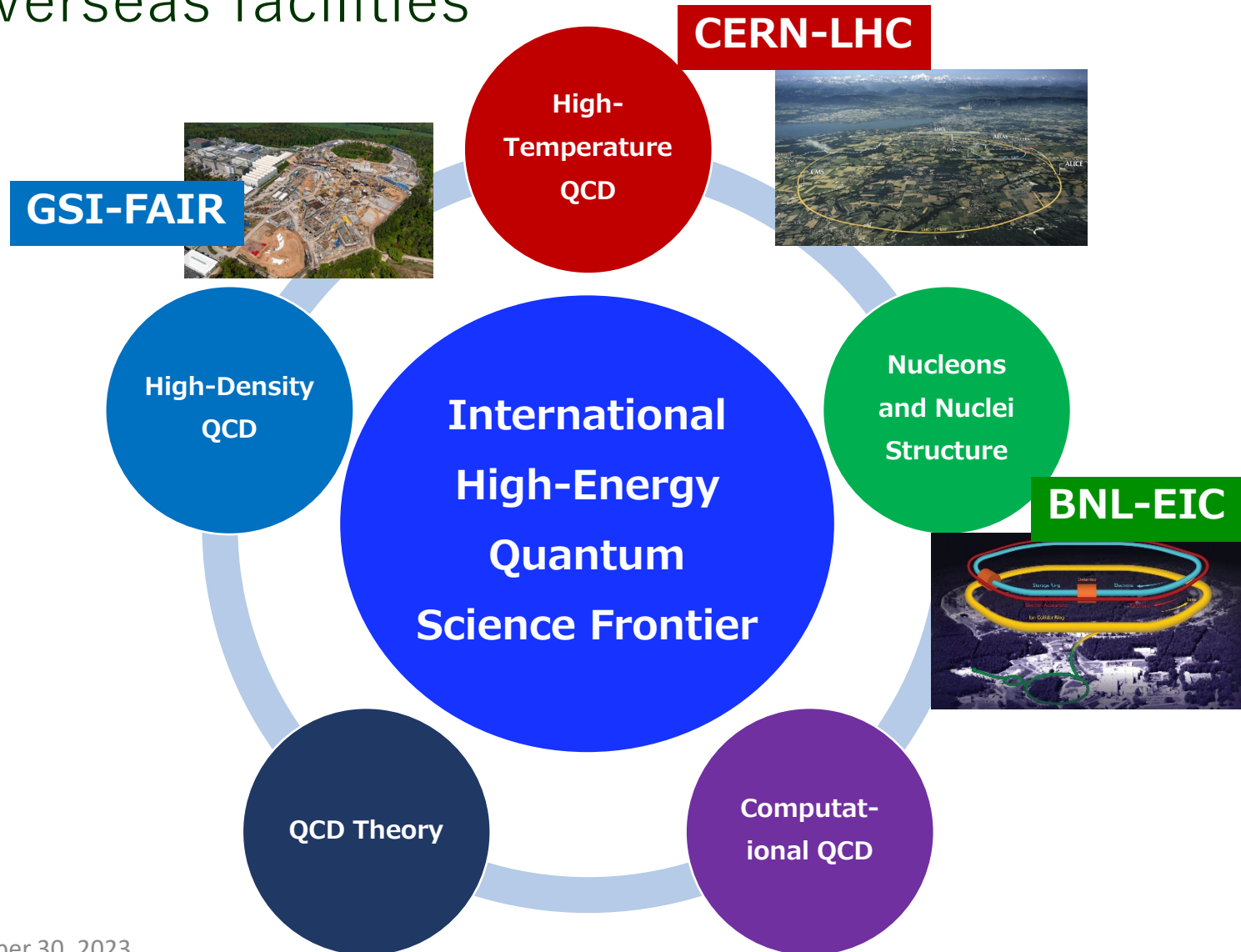


EIC-Japan activities

- 2019: Science Council of Japan Master Plan 2020 proposal of EIC
 - Collaboration including nuclear-physics community and high-energy community
 - Core institutions: Yamagata and RIKEN
 - Participating institutions: Kobe, Nihon, KEK, etc.
- 2020: Yellow Report
- 2020.5: eRD27 “developing a high resolution ZDC for the EIC”
- 2020.11: Expression of Interest (EOI) from EIC-Japan
- 2021.3-12: Call for detector proposal from the EIC project
 - EIC-Japan group participates in the ECCE detector consortium
- 2022: Science Council of Japan “Medium- and Long-term Research Strategy for Science” for “Future Science Promotion Initiative”
 - EIC project proposal submitted as a part of the “International High-Energy Quantum Science Frontier: QCD research at overseas facilities”
 - Prof. Gunji (CNS, Univ. of Tokyo) leading the proposal
 - Including LHC, FAIR, EIC, etc. and Theory

International High-Energy Quantum Science Frontier

- Promote QCD research to be developed at overseas facilities

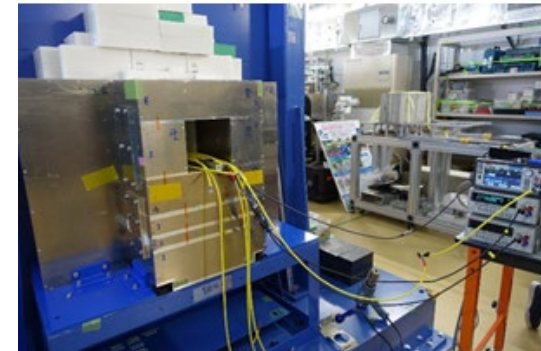
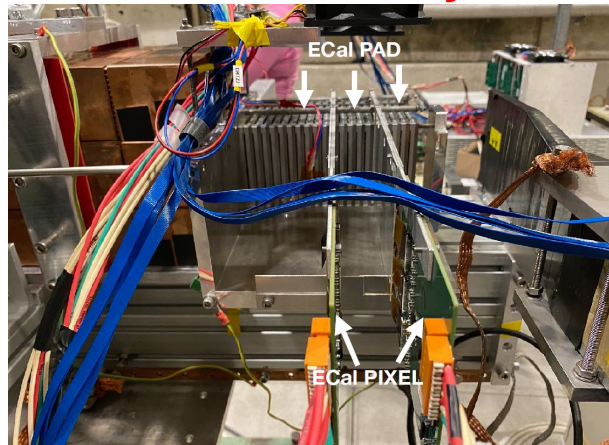
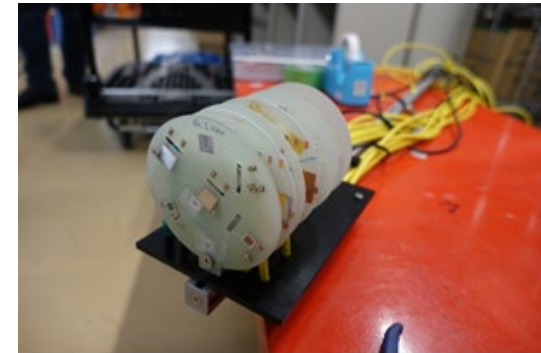


EIC-Japan activities

- 2023: This proposal was endorsed as a third pillar in Japanese Nuclear Physics Committee along with J-PARC extension and RIBF upgrade to the Science Council of Japan
 - Science Council of Japan selected “Exploring the basic laws of nature and origin of the universe and matter” as the Grand Vision #19 including our proposal
- **Discussion of cooperation with Asian groups**
 - 2022.11.2-4 APCTP Workshop on the Physics of EIC in Incheon, Korea
 - 2022.11.18 EIC Meeting at NCU in Taiwan
 - 2023.3.16-18 EIC Asia Workshop at RIKEN in Wako, Japan
 - 2024.1.29-31 EIC Asia Workshop at NCKU in Tainan, Taiwan

Interest in contributing to ZDC

- ECCE/EPIC ZDC (Zero-Degree Calorimeter) design
 - Simulation, performance evaluation
- ALICE-FoCal-E technology: Tungsten/Silicon
 - Led by Univ. of Tsukuba (Prof. Chujo)
 - Development and evaluation with test beams
- Radiation tolerance test by neutron irradiation
- RIKEN, Tsukuba, Tsukuba Tech, Kobe, Shinshu, Yamagata, JAEA, Nihon, Kyushu, KEK



ECCE/EPIC ZDC

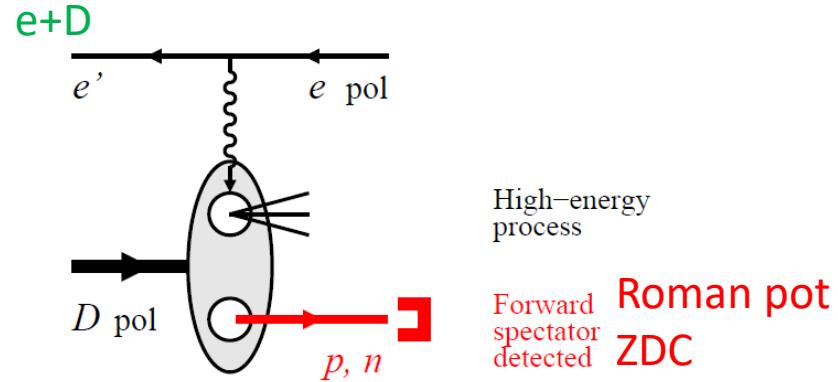
ALICE FoCal-E R&D
with test beams

Neutron irradiation
at RIKEN RANS

Far-forward physics at EIC

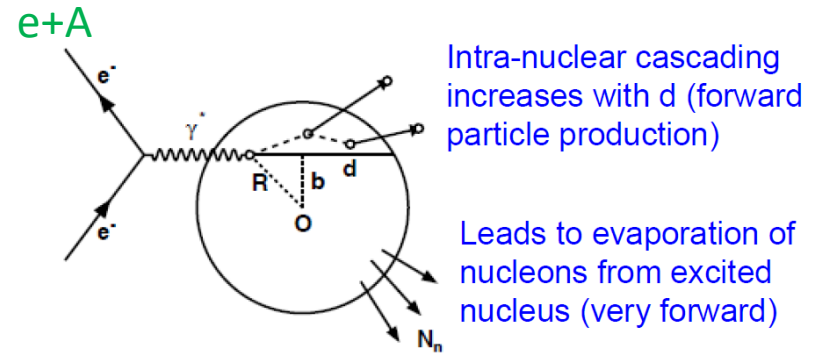
- Spectator tagging in $e+d/{}^3\text{He}$ collisions

- Neutron structure
 - Neutron spin structure, S & D waves



- $e+A$ collisions at zero degree

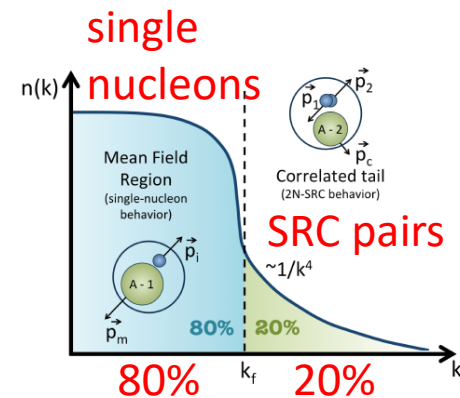
- Breakup determination of the excited nucleus
 - Veto with evaporated neutrons and photons from de-excitation



- Geometry tagging in $e+A$ collisions

- Event-by-event characterization of collision geometry
- Study of nuclear medium effects
- Short-range correlation (SRC) and EMC effect
 - Nuclear PDF significantly modified by SRC pairs

Nucleon Momentum Distribution



Far-forward physics at EIC

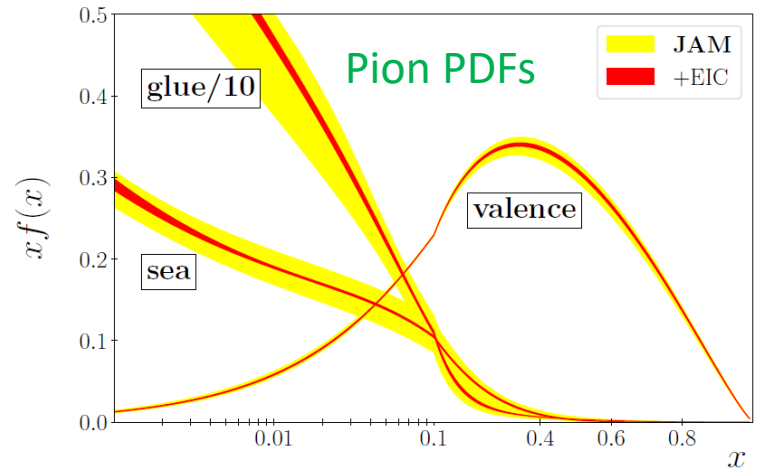
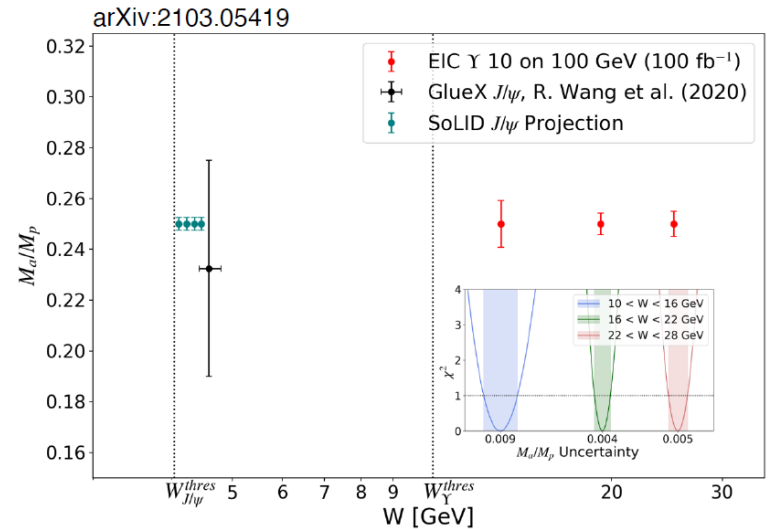
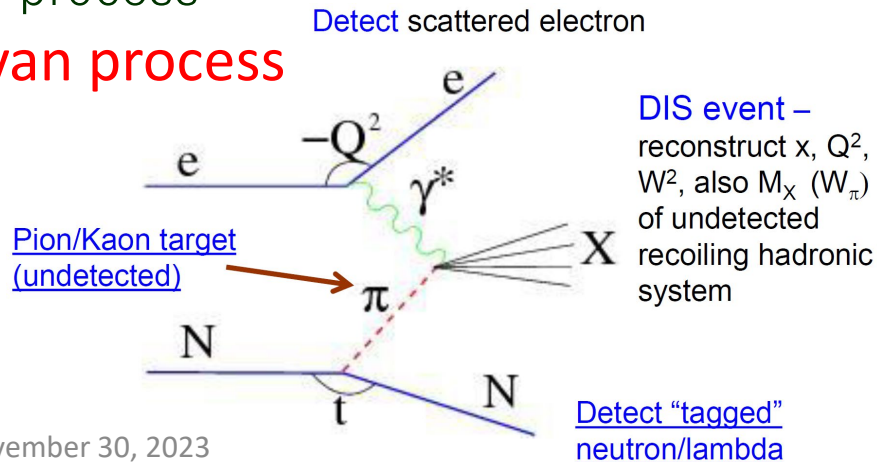
- Mass of the proton, pion, kaon

$$M = E_q + E_g + \chi m_q + T_g$$

X. Ji, PRL 74 1071 (1995)

- Proton
 - Determination of an important term contributing to the proton mass, the so-called “QCD trace anomaly”
 - Through dedicated measurements of exclusive production of J/ψ and Υ close to the production threshold
- Pion and kaon
 - Determination of the quark and gluon contribution to mass with the Sullivan process

Sullivan process

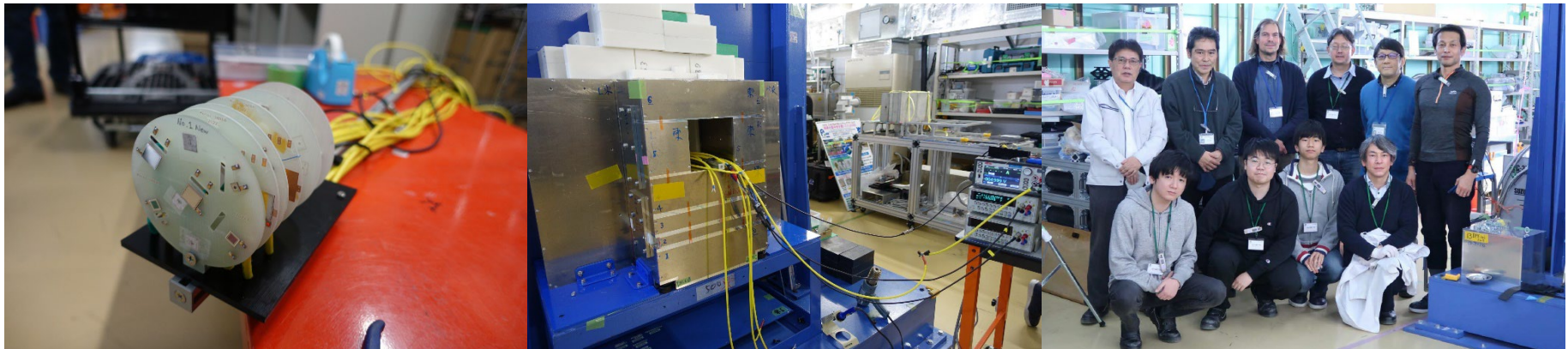


Requirements to ePIC ZDC

- Large acceptance
 - Large aperture → large ZDC
- Soft photon detection of $O(100)$ MeV
 - Detection efficiency more than 90%
- Neutron measurement
 - Energy up to 275 GeV (beam energy)
 - Energy resolution $50\%/\sqrt{E(\text{GeV})} + 5\%$
 - Position resolution $3 \text{ mrad}/\sqrt{E(\text{GeV})}$
- Photon measurement
 - Soft photon with 20-30% energy resolution
 - 20-40 GeV photon with $35\%/\sqrt{E(\text{GeV})}$ energy resolution and 0.5-1 mm position resolution
- Radiation tolerance
 - $O(10^{13}) n_{\text{eq}}/\text{cm}^2$ (1MeV neutron eq.) in several years

RANS Neutron Irradiation Test

- RIKEN RANS
 - 7MeV proton beam, $100\mu\text{A}$, 6×10^{13} proton/s
 - Maximum current stable produced about $40\mu\text{A}$
 - Neutron 5MeV max, 10^{12} neutron/s from the Be target
 - 2cm from the target: 10^8 neutron/cm²/s
- 2022.3.3-4 first irradiation test
- 2023.3.7-8 second irradiation test
 - Tested FoCal-E Pad p-type/n-type baby-chip/MPD, APD/SiPM for readout of crystal calorimeter
 - Monitored by MPD from Kyushu Univ., Indium foil, and thermistor

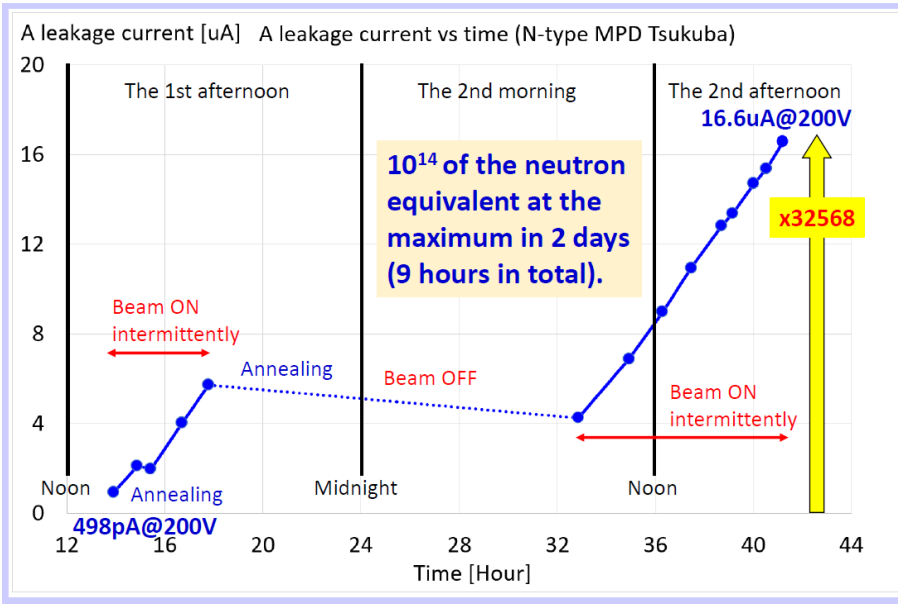


RANS neutron irradiation test

- 10^{14} neutron/cm² at the maximum in 2 days, 9 hours in total
- Recorded online a leakage current of the n-type MPD (monitor photo-diode)
- Comparison of the C-V characteristics of the n-type MPD before and after the irradiation
 - Full-depletion voltage: 35V → 85V

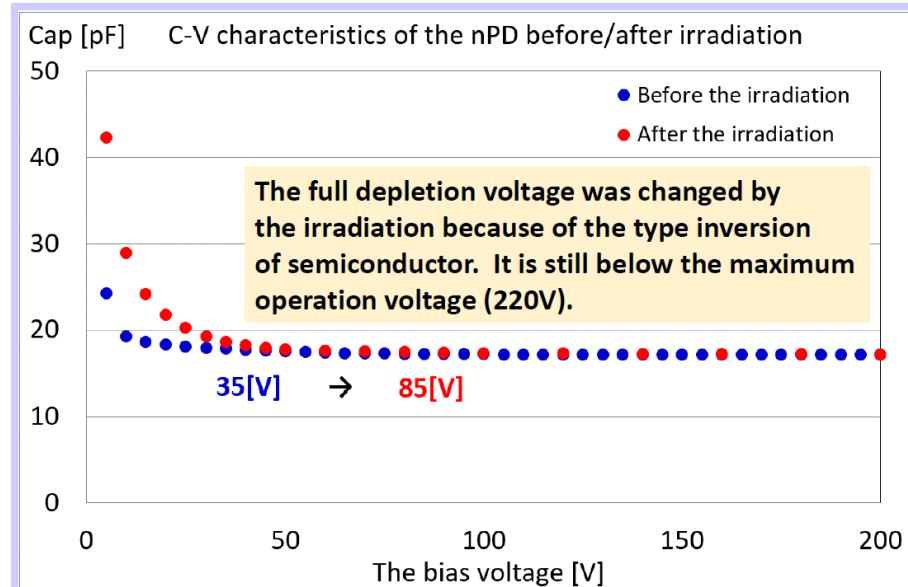
Inaba-san's slides

The n-substrate monitor PD



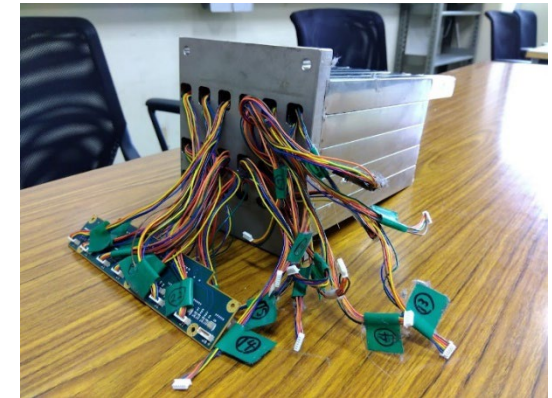
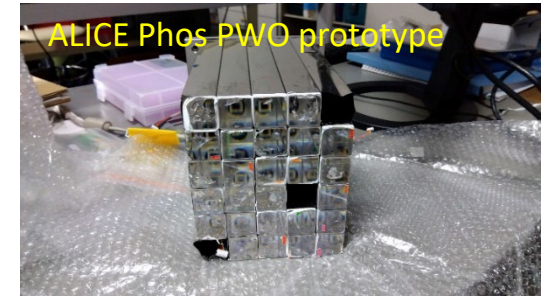
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The C-V characteristics of n-substrate MPDs

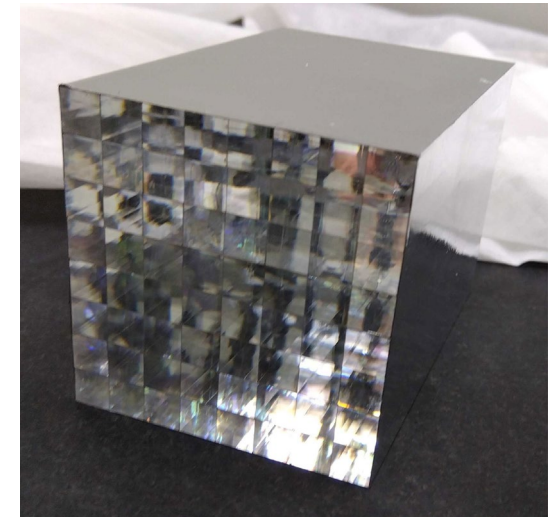


Crystal Calorimeter

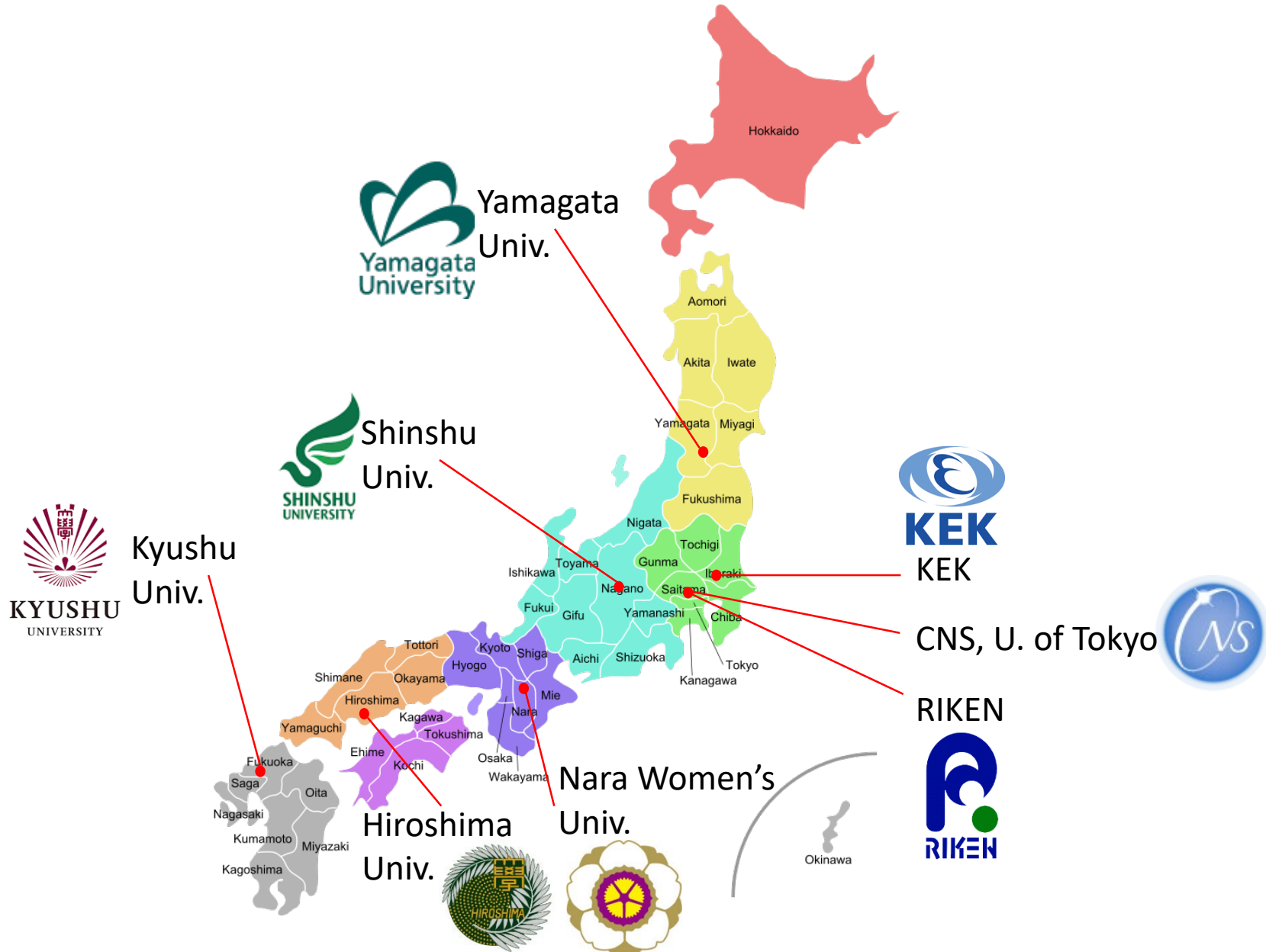
- ALICE-Phos PWO prototype
 - Hiroshima Univ.
 - 2cm x 2cm x 18cm
 - APD readout
 - Shipped to RIKEN



- LYSO crystal by Taiwan group
 - Offer from Taiwan Group for test module production, simulation calculation, etc.
- Test beam at ELPH, Tohoku Univ. in Japan in February, 2024

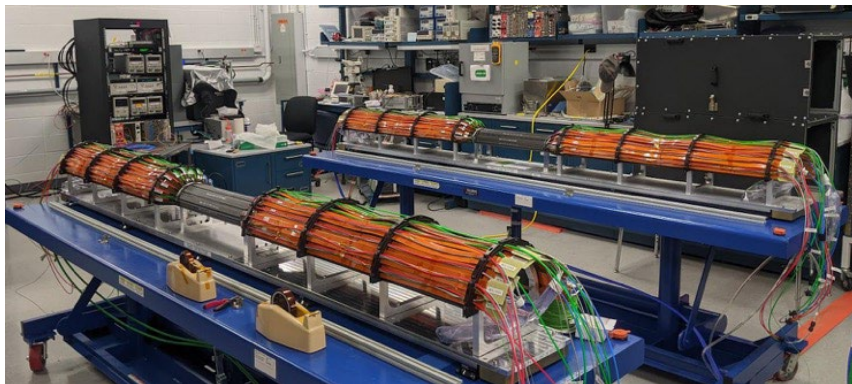


Interest in contributing to AC-LGAD Barrel



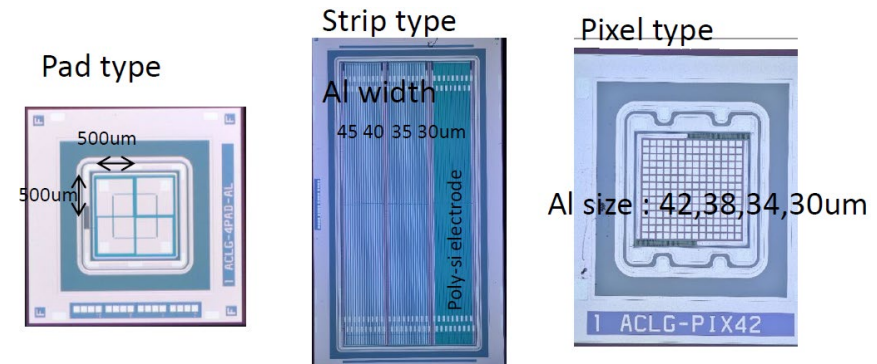
Interest in contributing to AC-LGAD Barrel

- 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
- HPK LGAD development by KEK group (Prof. Nakamura)
 - To be combined with some readout ASIC
- RIKEN, Hiroshima, Nara Women's, Shinshu, Yamagata, CNS Tokyo, Kyushu, KEK



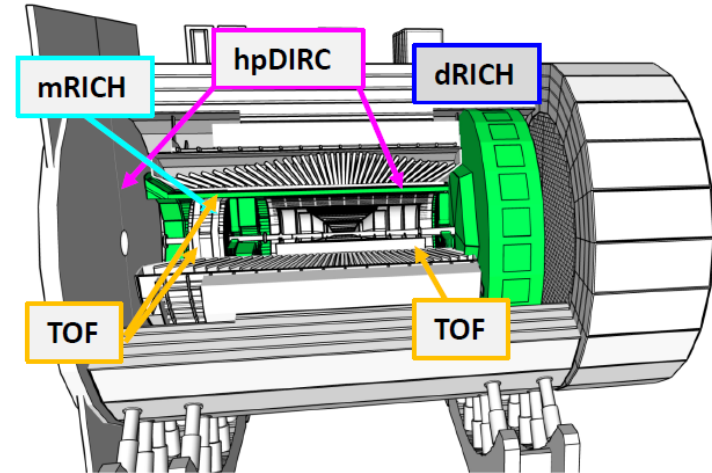
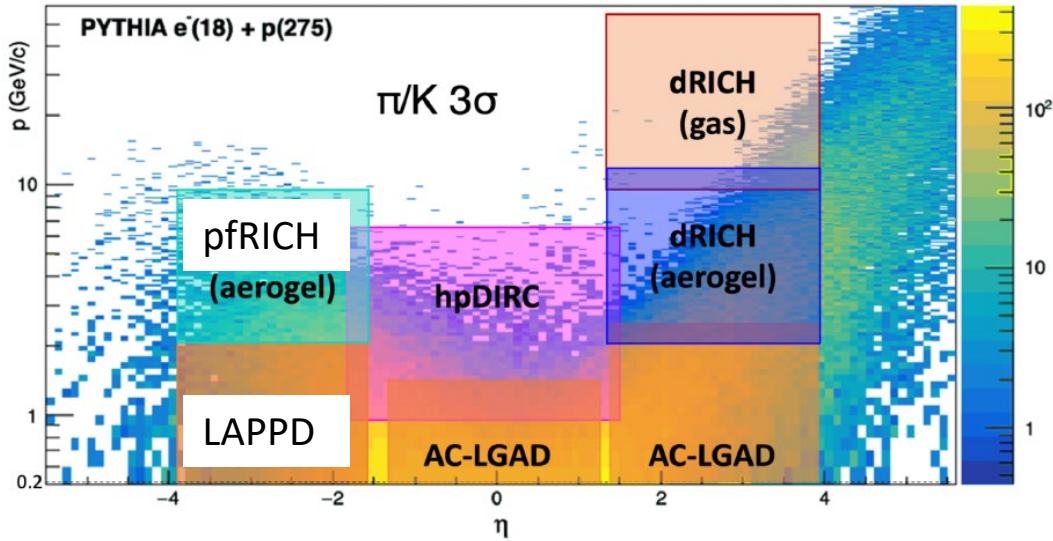
sPHENIX INTT construction

November 30, 2023



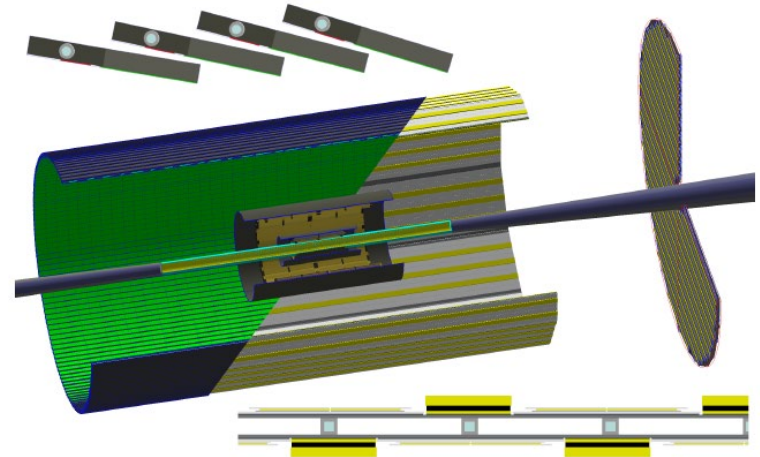
HPK LGAD development

Charged particle ID



- Need to separate:
 - Electrons from photons
 - Electrons from charged hadrons
 - Calorimeter
 - Charged pions, kaons and proton from each other
 - TOF and Cherenkov
- AC-LGAD based TOF system
 - Hadron PID in momentum range below the thresholds of the Cherenkov detectors

AC-LGAD TOF (~ 25 ps)



AC-LGAD discussion

- 2022-2023 Discussion of the US-Japan Science and Technology Cooperation Program in High Energy Physics
 - Dr. Tricoli to provide test boards to Hiroshima Univ, RIKEN, and Taiwan group (coming soon)

AC-LGAD Test Setup

To be provided from BNL

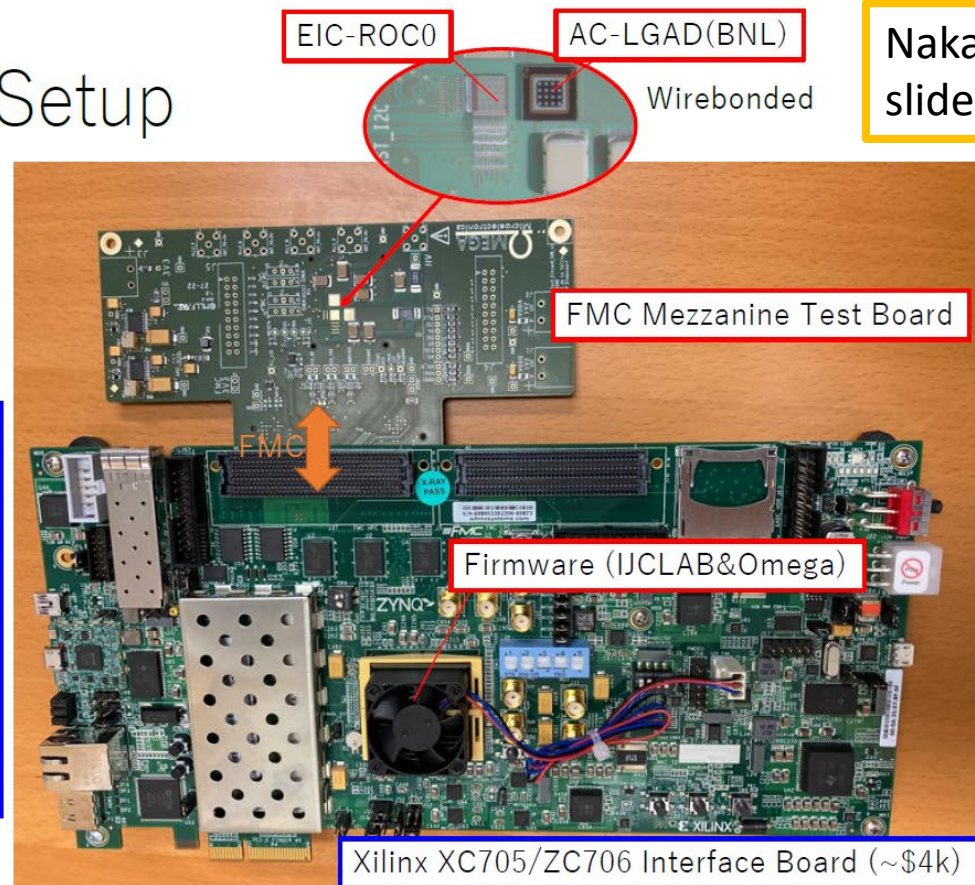
To be prepared by users

Nakagawa-san's slides

PC Ubuntu 22.04
Python or C/C++
TCP/IP Client

C/C++ base DAQ software
(IJCLAB&Omega)
Ubuntu 22.04

Ethernet



AC-LGAD discussion

- BNL Facility Tour by Dr. Tricoli



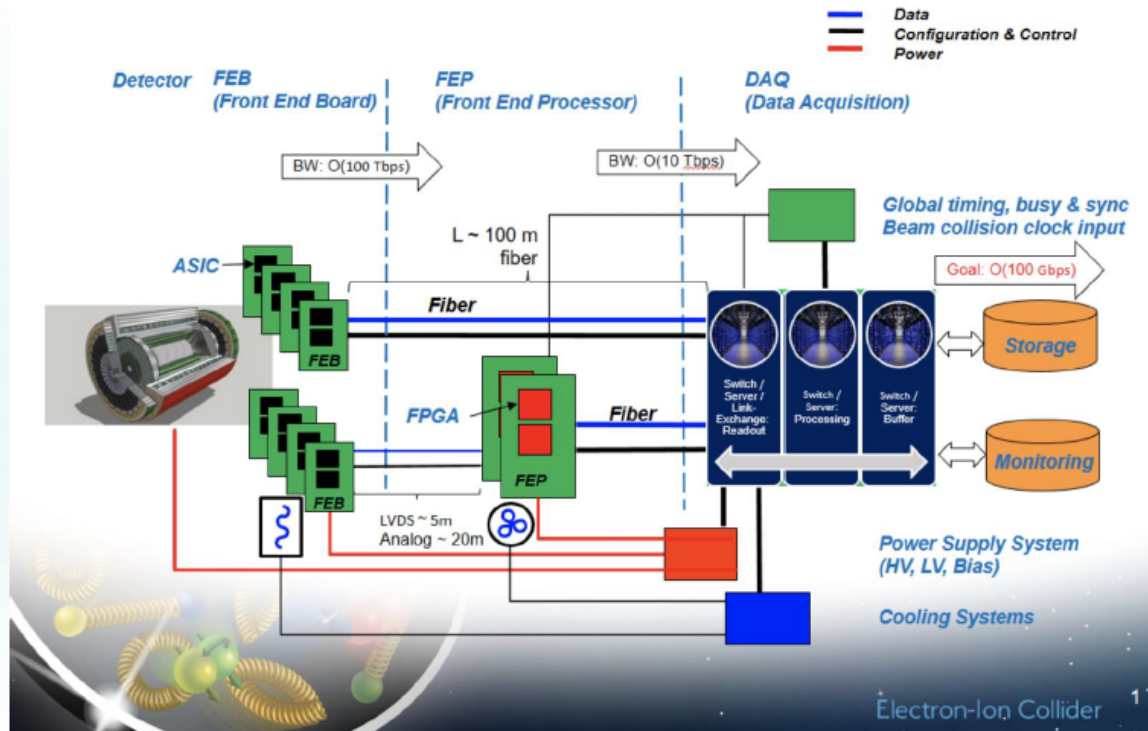
- KEK Facility Tour by Prof. Nakamura (KEK)



Interest in contributing DAQ

- ▶ Free Streaming Readout and (near) real-time processing
 - ▶ Will be a future standard DAQ system

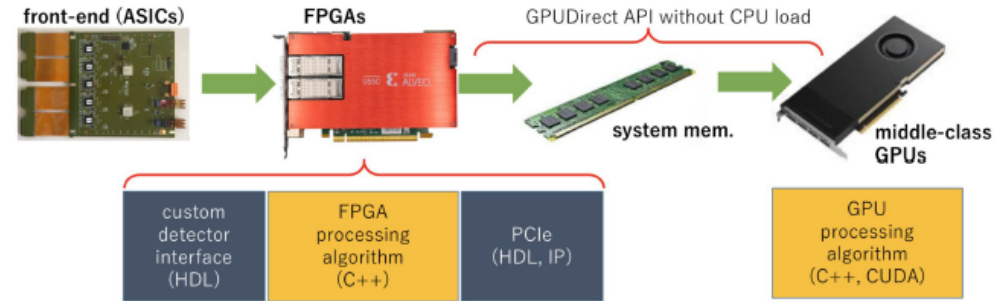
EIC Streaming Readout Architecture



Interest in contributing DAQ

Plans for ePIC

- Data processing and software trigger using hardware acceleration (FPGA, GPU, CPU)



EPIC Electronics / DAQ Standard Component Names and Functions

	Sensor	Adapter	Front End Board (FEB)	Readout Board (RDO)	Data Aggregation Module (DAM)	Computing
Name	Sensor	Adapter	Front End Board (FEB)	Readout Board (RDO)	Data Aggregation Module (DAM)	Computing
Sharing	Detector Specific	Detector Specific	Detector Specific	Few Variants	Common	Common
Function	-Multi-Channel Sensor	-HV/Bias distribution -HV divider -Interconnect routing	-Amplification -Shaping -Digitization -Zero Suppression	-Communication -Aggregation -Formatting -Data Readout -Config & Control -Clock & Timing	-Computing Interface -Aggregation -Software Trigger -Clock & Timing -Config & Control	-Data buffering and sinking -Run Control -Calibration Support -QA / Scalers -Collider Feedback -Event ID/Building? -Software Trigger -Monitoring
Attributes	-MAPS -AC-LGAD -MCP-PMT -SIPM -LAPPD	-Sensor Specific -Passive	-ASIC/ADC -Discrete -Serial Link	-FPGA -Fiber Link	-Large FPGA -PCIe -Potentially Ethernet	

Any collaboration is more than welcome!

Summary

- 2022: Science Council of Japan “Medium- and Long-term Research Strategy for Science”
 - EIC project proposal submitted as a part of the “International High-Energy Quantum Science Frontier: QCD research at overseas facilities”
- 2023: This proposal was endorsed as a third pillar in Japanese Nuclear Physics Committee along with J-PARC extension and RIBF upgrade to the Science Council of Japan
 - Science Council of Japan selected “Exploring the basic laws of nature and origin of the universe and matter” as the Grand Vision #19 including our proposal
- Discussion of EIC cooperation with Asian groups
- Contributing from Japan
 - ZDC
 - ALICE-FoCal-E technology: Tungsten/Silicon
 - Development and evaluation with test beams at CERN-PS & SPS and ELPH, Tohoku Univ.
 - RANS neutron irradiation test at RIKEN
 - LYSO crystal by Taiwan group
 - AC-LGAD
 - Discussion of the US-Japan Science and Technology Cooperation Program in High Energy Physics
 - Test boards to Hiroshima Univ, RIKEN, and Taiwan group
 - Streaming DAQ system of the ePIC experiment