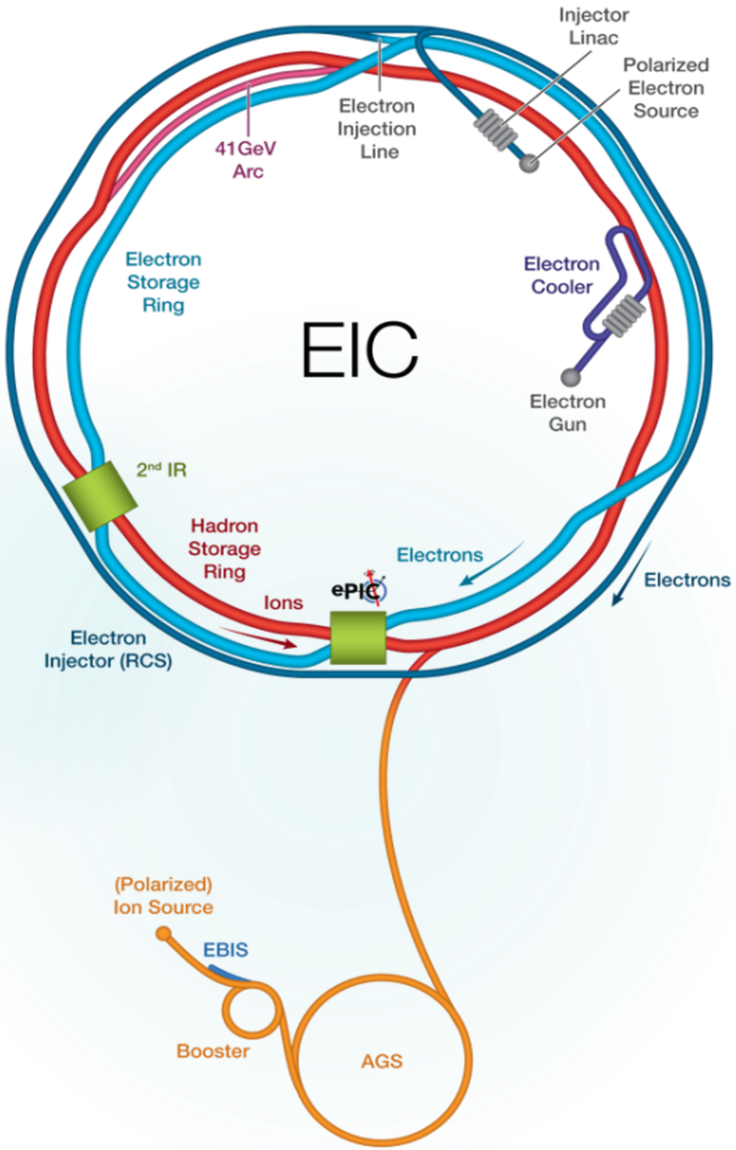
Highlights from detectors for EIC

TAKU GUNJI

CENTER FOR NUCLEAR STUDY

THE UNIVERSITY OF TOKYO

Electron-Ion Collider

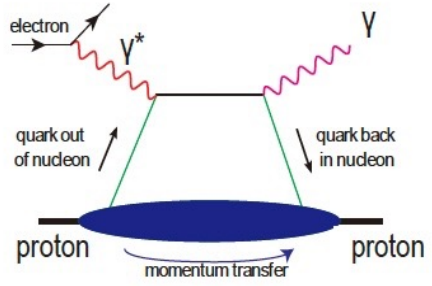


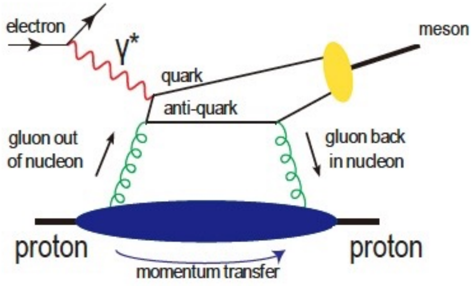
EIC = a machine that will unlock the secrets of the strongest force in Nature

- **the major US project in the field of nuclear physics**
- **the world's first collider for polarized electron and polarized proton (and light ions) and electron-nucleus collisions**

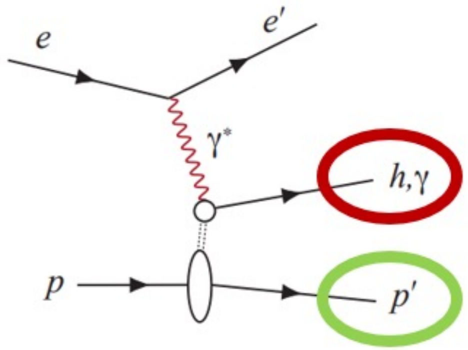
- EIC hosted at Brookhaven National Laboratory
- 80% polarized electrons from 5-18 GeV
- 70% polarized protons from 40-275 GeV
- Ions from 40-110 GeV/u
- Polarized light ions 40 -184 GeV (He^3)
- 100-1000 x HERA luminosities:10^{33}-10^{34} $cm^{-2}s^{-1}$
- CMS energies: $\sqrt{s}$ = 29–140 GeV
- foreseen to start operation in early 2030's

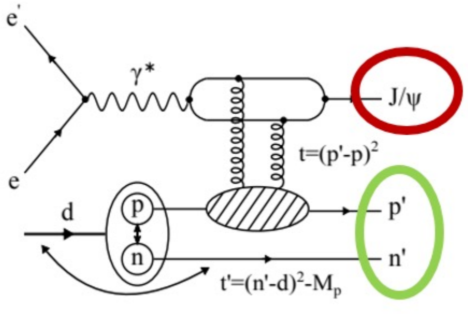
Electron-Ion Collider





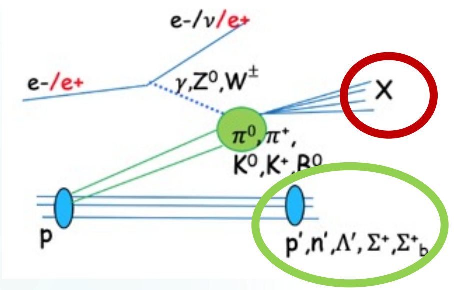
Deep Exclusive DIS

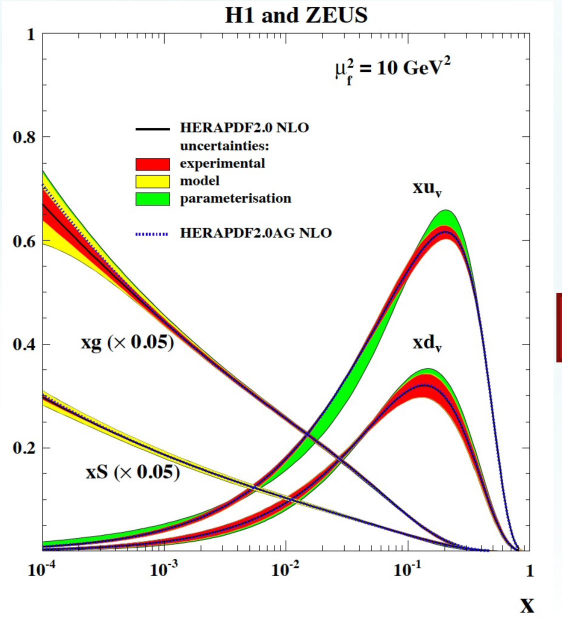


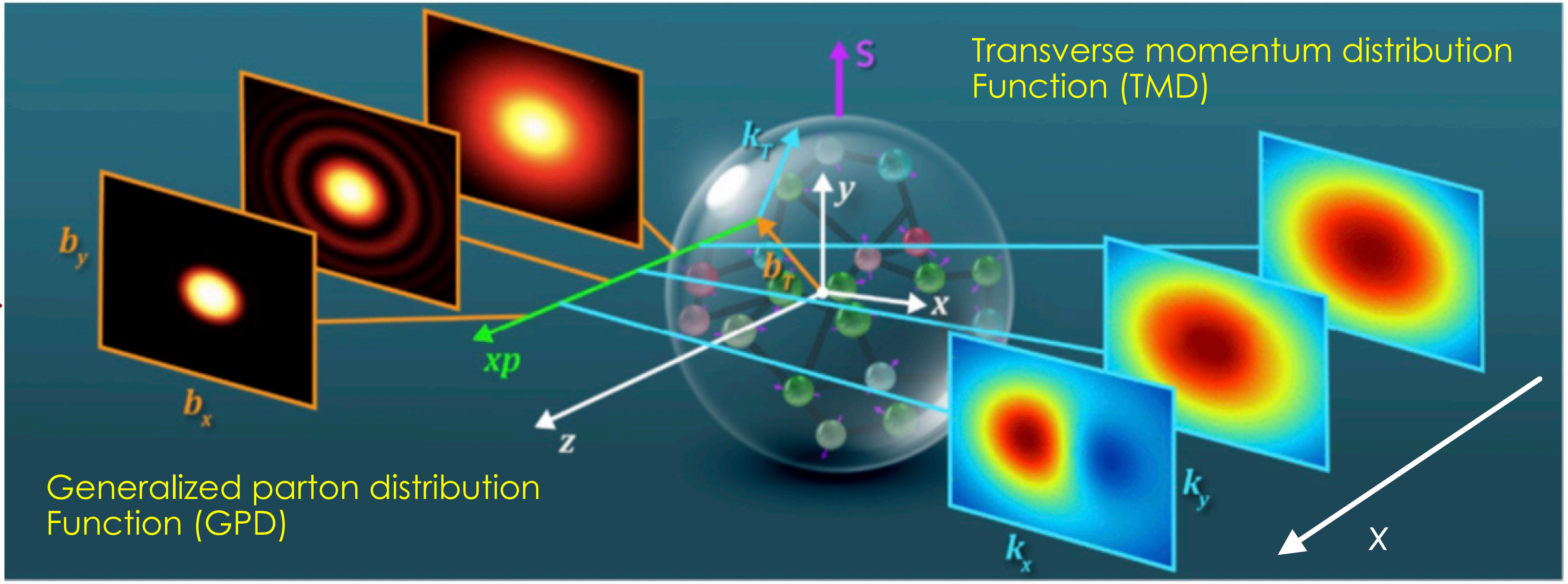


Semi-Inclusive DIS

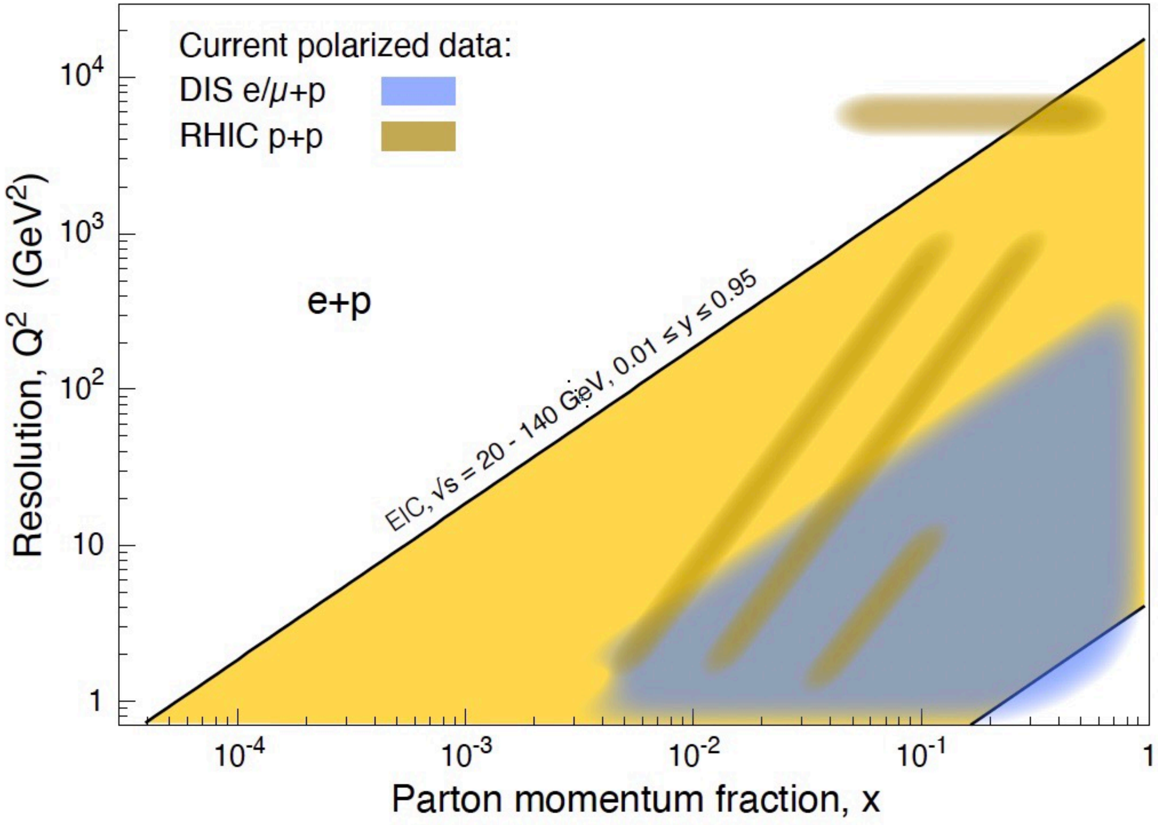
Sullivan process

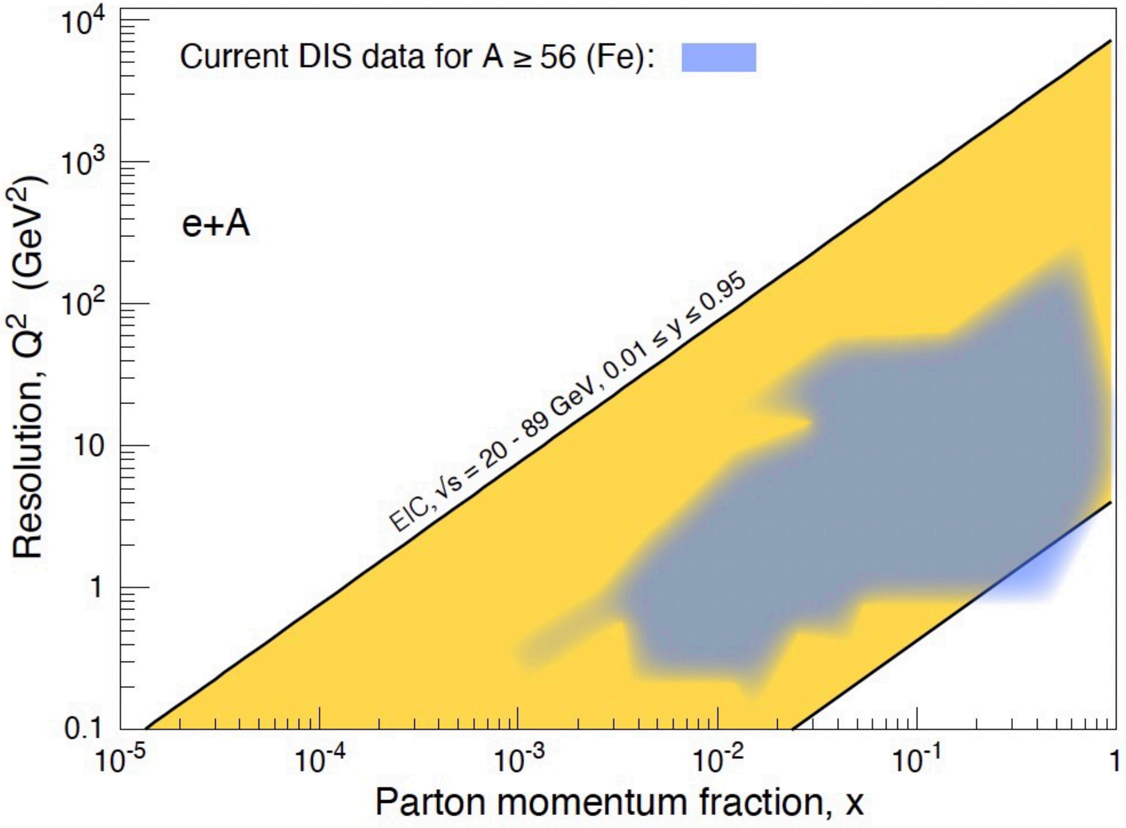






Electron-Ion Collider





Science Goal of EIC

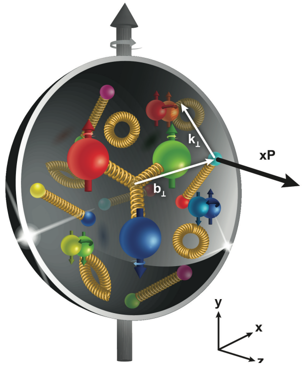
SPIN is one of the fundamental properties of matter.
All elementary particles, but the Higgs carry spin.
Spin cannot be explained by a static picture of the proton
It is the interplay between the intrinsic properties and interactions of quarks and gluons

The EIC will unravel the different contribution from the quarks, gluons and orbital angular momentum.

Does the mass of visible matter emerge from quark-gluon interactions?

Atom: Binding/Mass = 0.00000001
Nucleus: Binding/Mass = 0.01
Proton: Binding/Mass = 100

For the proton the EIC will determine an important term contributing to the proton mass, the so-called "QCD trace anomaly

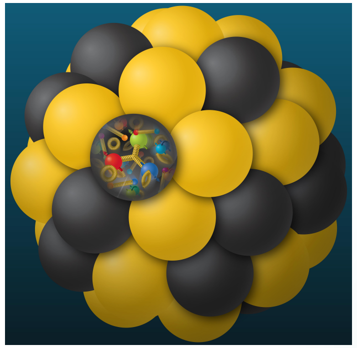


How are the quarks and gluon distributed in space and momentum inside the nucleon & nuclei?

How do the nucleon properties emerge from them and their interactions?

How can we understand their dynamical origin in QCD?

What is the relation to Confinement?

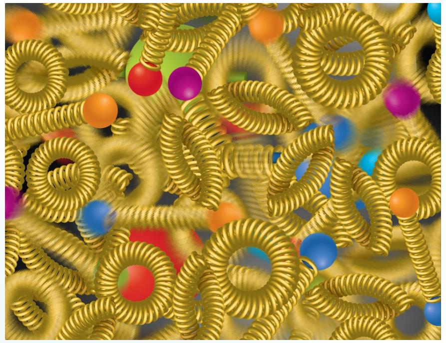


Is the structure of a free and bound nucleon the same?

How do quarks and gluons, interact with a nuclear medium?

How do the confined hadronic states emerge from these quarks and gluons?

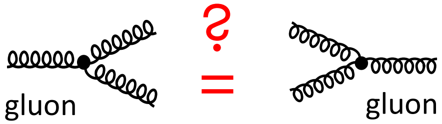
How do the quark-gluon interactions create nuclear binding?



How many gluons can fit in a proton?

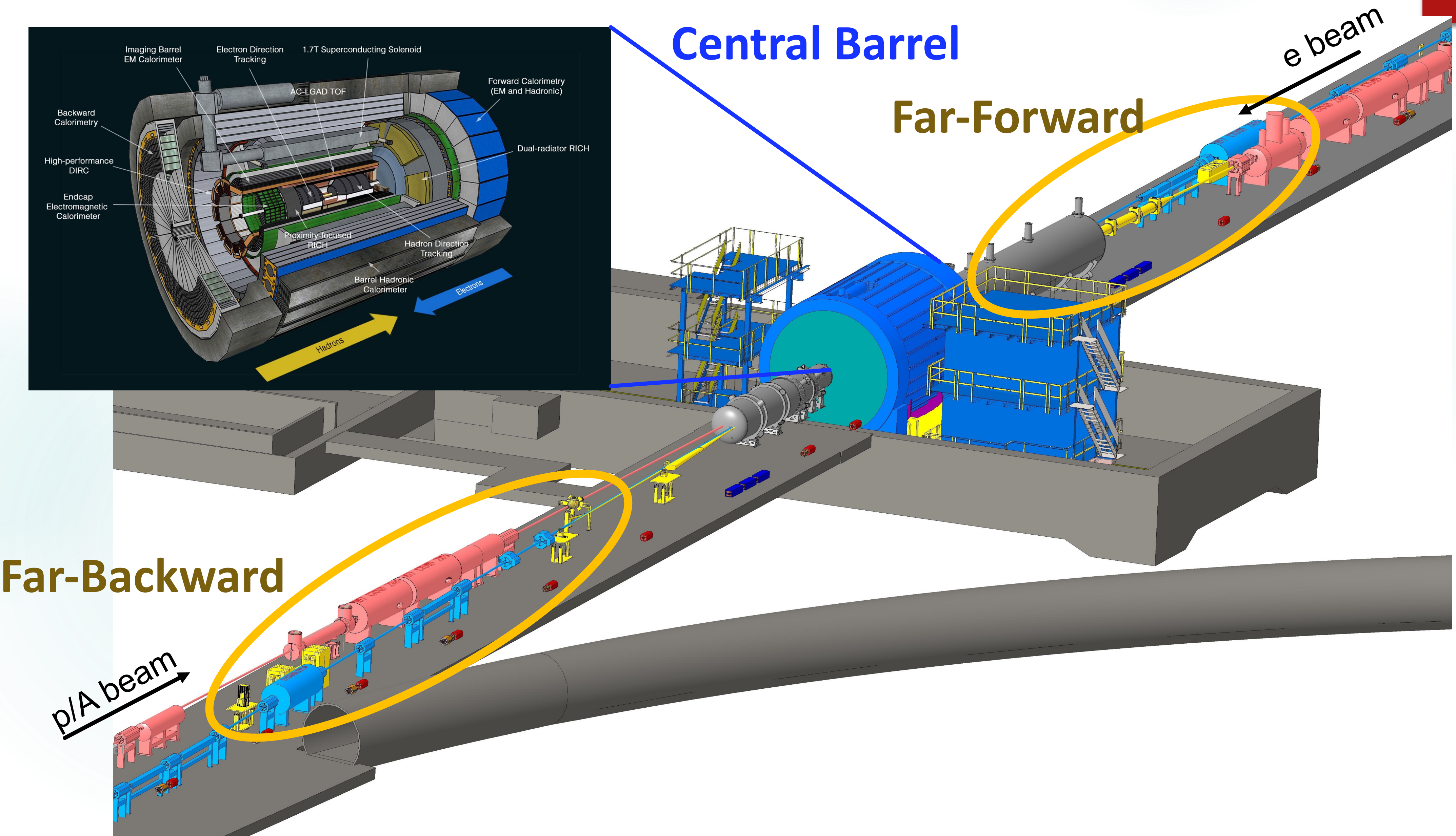
How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

What happens to the gluon density in nuclei? Does it saturate at high energy?



gluon splitting ?= gluon recombination

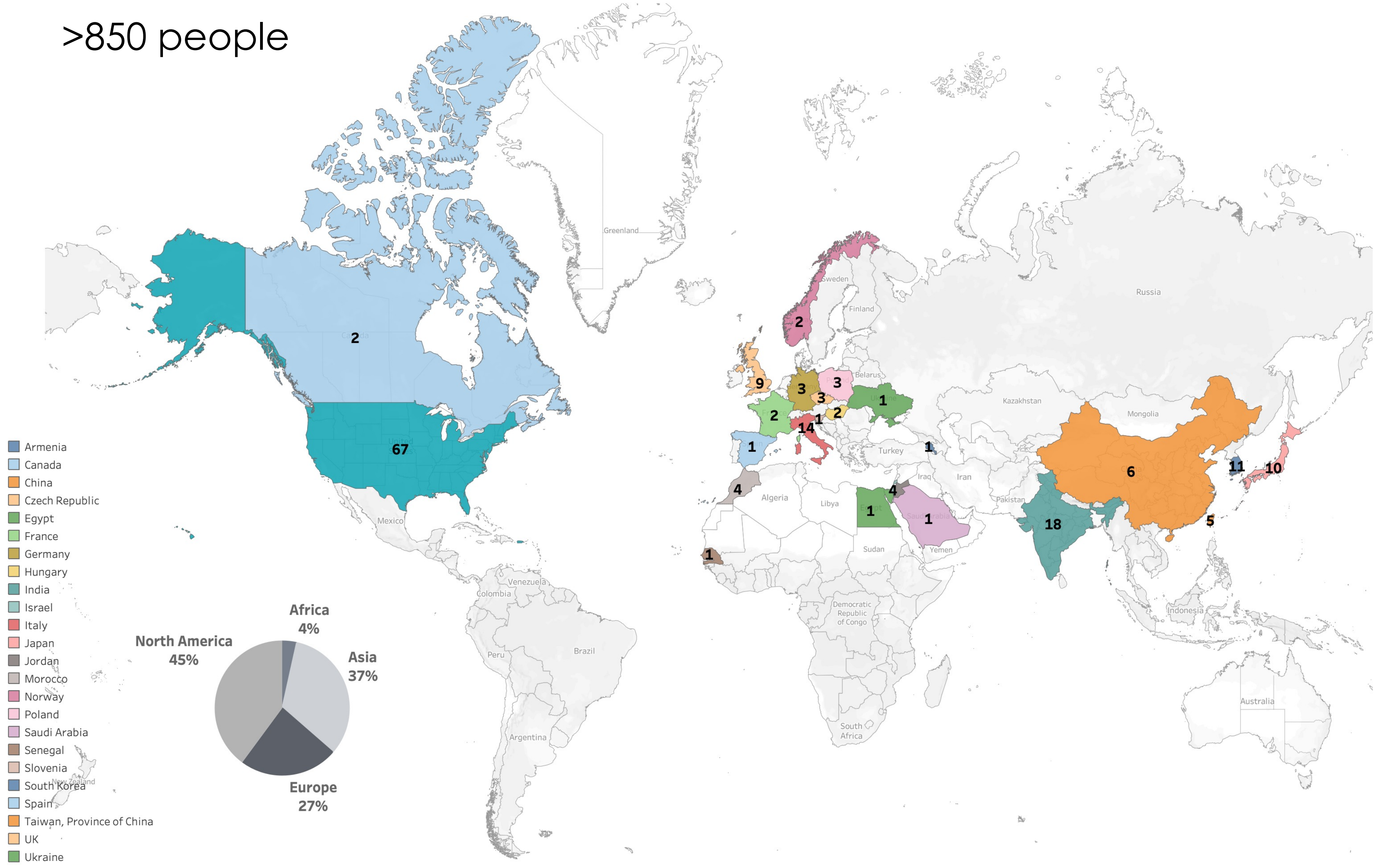
ePIC experiment



ePIC experiment collaboration

ePIC Institutions	ePIC Countries	ePIC World Region
173	25	4

>850 people



YAMAGATA UNIVERSITY 山形大学

RIKEN NISHINA CENTER — RIKEN Nishina Center for Accelerator-Based Science

NIHON UNIVERSITY

Center for Nuclear Study, The University of Tokyo

University of Tsukuba

National University Corporation Tsukuba University of Technology

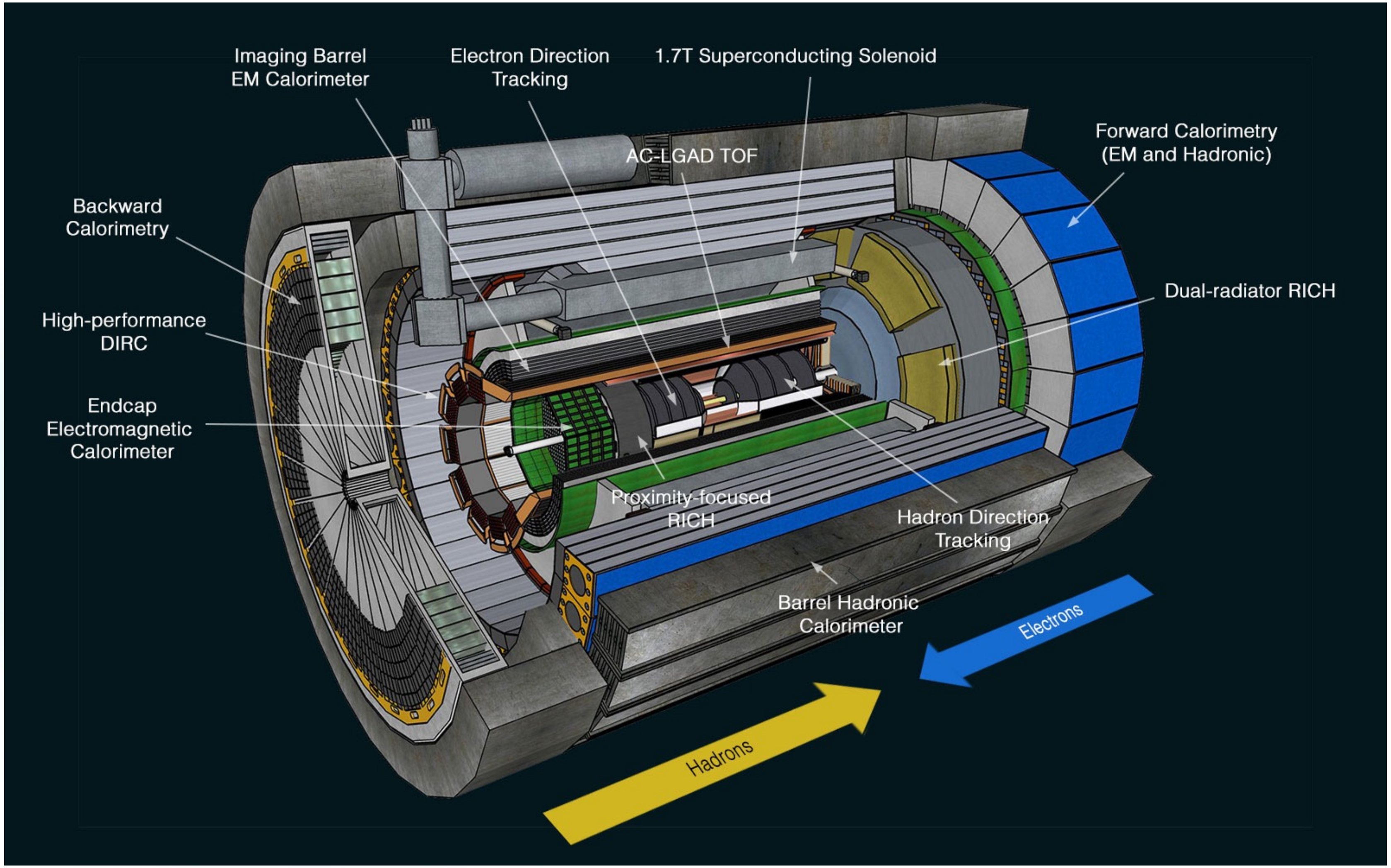
国立大学法人 奈良女子大学 Nara Women's University

HIROSHIMA UNIVERSITY

SHINSHU UNIVERSITY

KOBE UNIVERSITY

Central Barrel

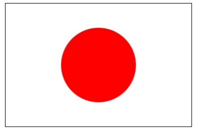


Tracking:

- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:

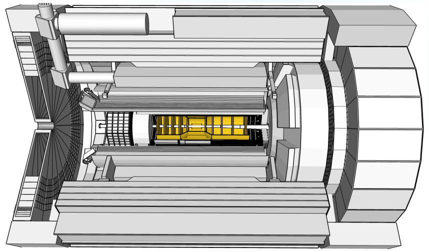
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

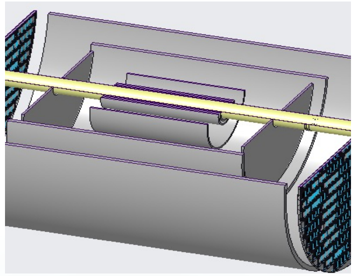
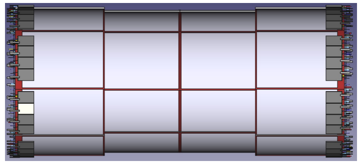
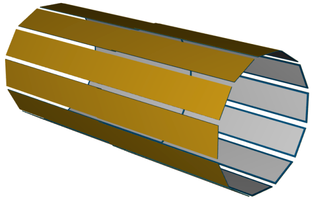
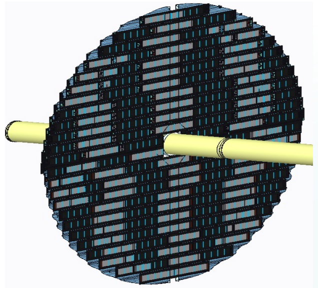
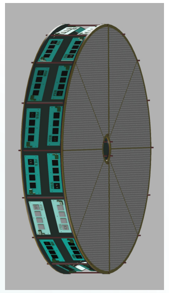
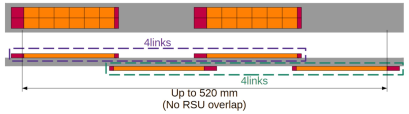
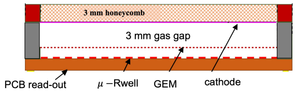


Calorimetry:

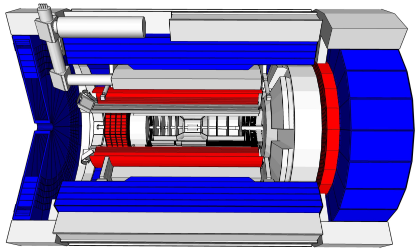
- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

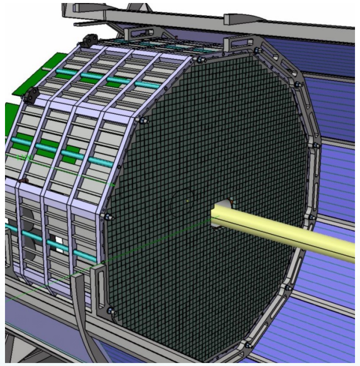
Technologies : Tracking

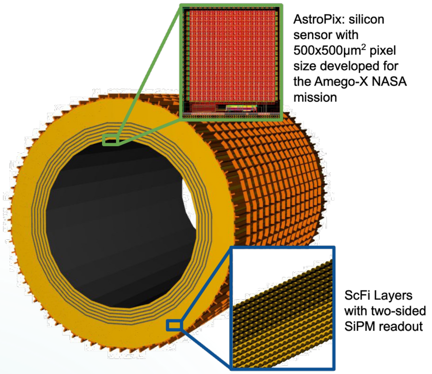


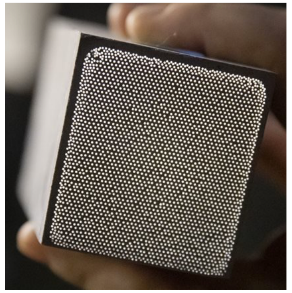
μVertex Tracker	Barrel Tracker	Outer Barrel MPGD Tracker		EndcapTracker	
		 MicroMegas Tracker	 μRWELL Tracker	 MAPS Disks	 μRWELL Disks
Main Function					
Excellent momentum 0.05%pT⊕0.5% and spatial resolution 20μm/pT⊕ 5μm		Provide redundancy and pattern recognition for tracking	Tracking close to hpDIRC detector to improve angular and space point resolution. Redundancy and pattern recognition for tracking	Excellent momentum 0.05 (0.10)% pT⊕1.0 (2.0)% and spatial resolution 30μm/pT⊕ (20 – 40) μm	Provide redundancy and pattern recognition for tracking
Displaced vertex reconstruction					
Proven Technology					
Monolithic Active Pixel Sensor → ALICE ITS3 MOSAIX sensor (65 nm) small pixels (~18 mm) and power consumption (<20 mW/cm^2)		Cylindrical resistive Micromegas technology Used: ATLAS NSW, CLAS12, SPHENIX, MINOS& T2K TPC			
	EIC Large Area Sensor (LAS), modification of ITS3 sensor with 5 or 6 RSU forming staves as the basic building elements for the Outer Barrel		world's first at ePIC 24 planar Thin-gap & double amplification (GEM & μRWELL) modules & 2D-strip readout	EIC Large Area Sensor (LAS), staves as the basic building elements for the MAPS disks	GEM- μRwell hybrid configuration with increased gain 

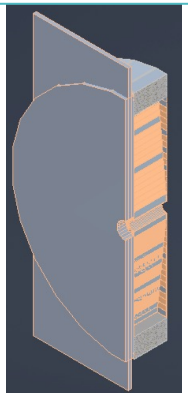
Technologies : Calorimeters

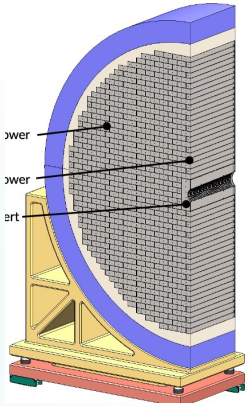






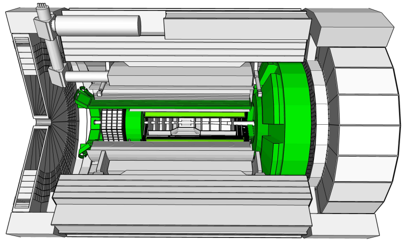




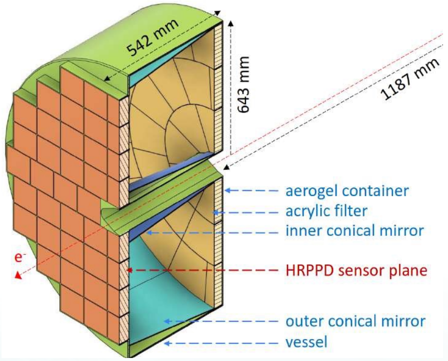


	Backward ECal	Barrel ECal	Forward ECal	Backward HCal	Barrel HCal	Forward HCal
Main Function	scattered lepton detection → very high-precision	scattered lepton and g detection, hadronic final state characterization	lepton and g detection, hadronic final state characterization → π^0, γ separation	muon and neutral detection → improved jet Energy reconstruction	muon and neutral detection → improved jet Energy reconstruction	particle-flow measurements
Proven Technology	PbWO4 – crystals → long lead procurement	Pb/SciFi sampling part using SiPMs combined with imaging section (6 layers) interleaving Pb/SciFi with ASTROPIX	Tungsten-powder + SciFi SPACAL design Developed through EIC R&D and applied successfully in sPHENIX	Steel + Scintillator SiPM-on-tile	Steel + Scintillator design re-used from sPHENIX	longitudinal segmented Steel + Scintillator SiPM-on-tile Pioneered by CALICE analog HCal High resolution insert next to beam-pipe
world's first at ePIC	SiPM as Photonsensors	Use of ASTROPIX in Calorimetry				first-time full-size CALICE like calorimeter in collider experiment

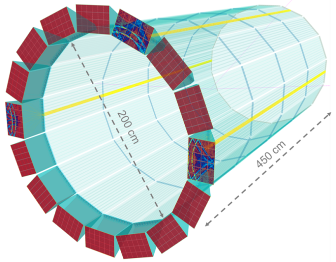
Technologies : PID



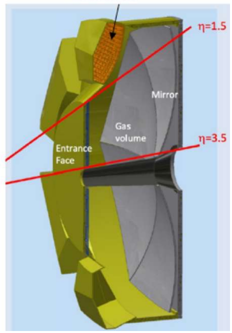
Backward RICH



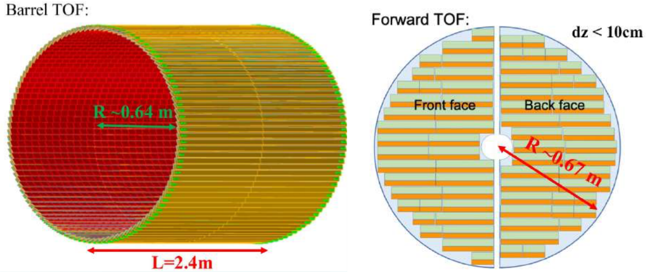
Barrel DIRC



Forward RICH



Time-of-Flight (Barrel, Forward)



Main Function

Backward RICH
- e, π, K, p separation

→ π /K 3σ sep. up to 9 GeV/c and 10-20 ps timing → ToF

Barrel DIRC
- e, π, K, p separation

→ π /K 3σ sep. at 6 GeV/c

Forward RICH
- e, π, K, p separation

→ π/K 3σ sep. up to 50 GeV/c

Time-of-Flight
- e, π, K, p separation through 20-35 ps ToF

Barrel: $0.15 < p_T < 1.5$ GeV/c

Forward: $0.15 < p_T < 2.5$ GeV/c
- Accurate space point for tracking

Proven Technology

Backward RICH: Classical single volume proximity focusing aerogel RICH with long proximity gap (~30 cm)

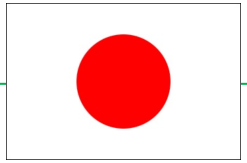
Barrel DIRC: High Performance DIRC
- Quartz bar radiator
  → Reuse of BaBAR DIRC bars
- light detection with MCP-PMTs
- Fully focused

Forward RICH: Dual Radiator RICH
- Aerogel and C_2F_6 gas
- Spherical Mirrors (6 Azimuthal Sectors)
- Photon-Sensors tiled on spheres

world's first at ePIC

Backward RICH: Photonsensors: HRPPDs for Time-of-Flight

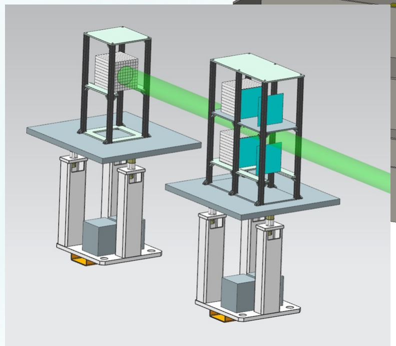
Forward RICH: First use of SiPMs as Photonsensors in a RICH



Time-of-Flight: First time use of AC-LGAD (Low Gain Avalanche Detector) in collider detector

Far-Forward/Backward

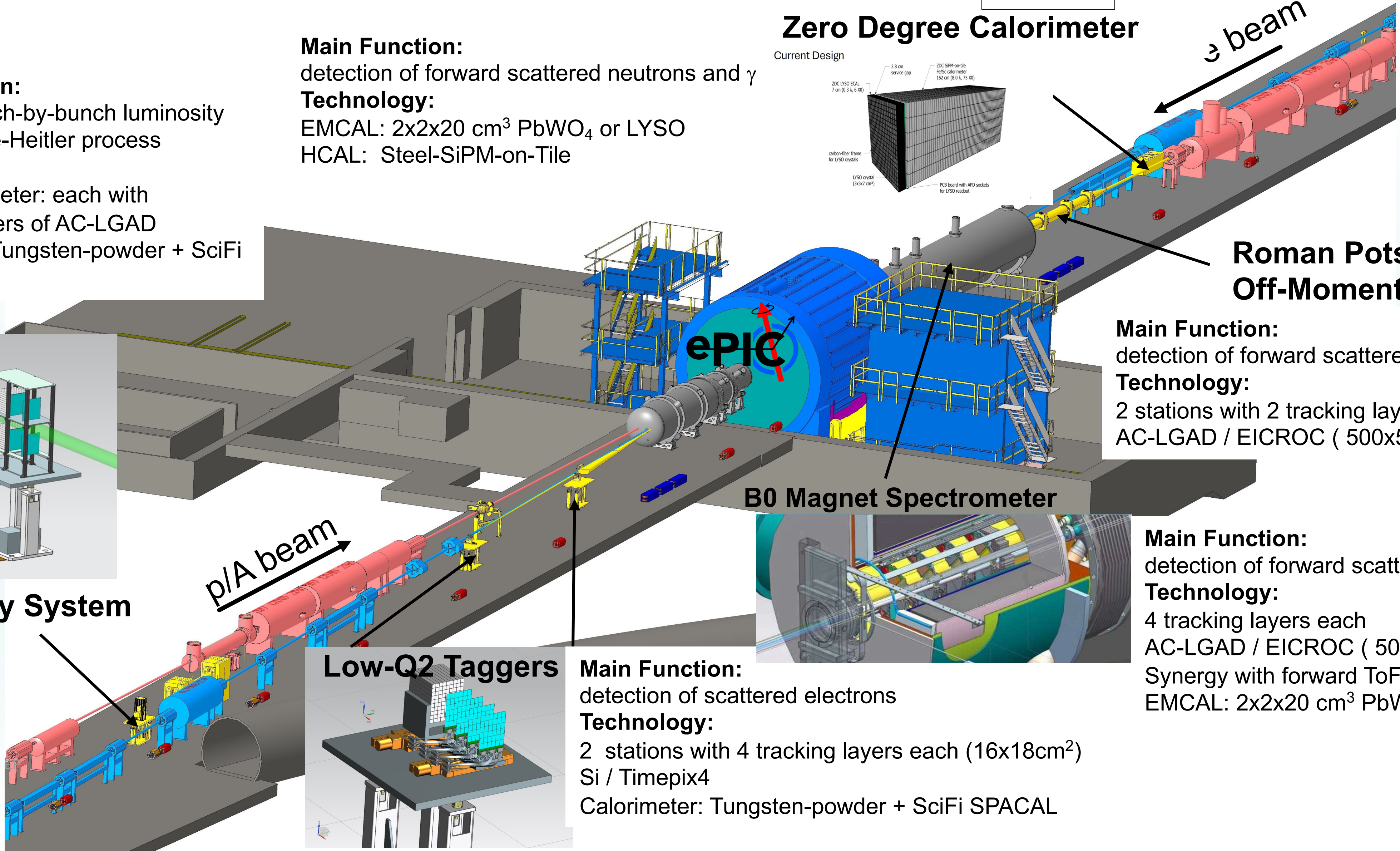
Main Function:
measure bunch-by-bunch luminosity through Bethe-Heitler process
Technology:
Pair-spectrometer: each with
2 tracking layers of AC-LGAD
Calorimeter: Tungsten-powder + SciFi SPACAL

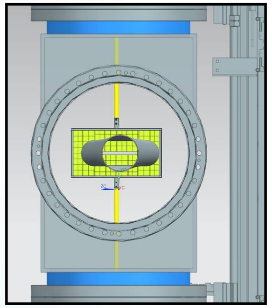


Luminosity System

Main Function:
detection of forward scattered neutrons and γ
Technology:
EMCAL: 2x2x20 cm^3 $PbWO_4$ or LYSO
HCAL: Steel-SiPM-on-Tile

Zero Degree Calorimeter





Roman Pots and Off-Momentum Detectors

Main Function:
detection of forward scattered protons and nuclei
Technology:
2 stations with 2 tracking layers each
AC-LGAD / EICROC (500x500 μm^2 pixel)

B0 Magnet Spectrometer

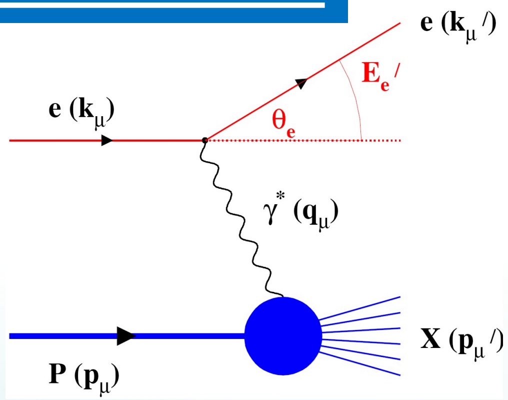
Main Function:
detection of forward scattered protons and and γ
Technology:
4 tracking layers each
AC-LGAD / EICROC (500x500 μm^2 pixel)
Synergy with forward ToF
EMCAL: 2x2x20 cm^3 $PbWO_4$ calorimeter

Low-Q2 Taggers

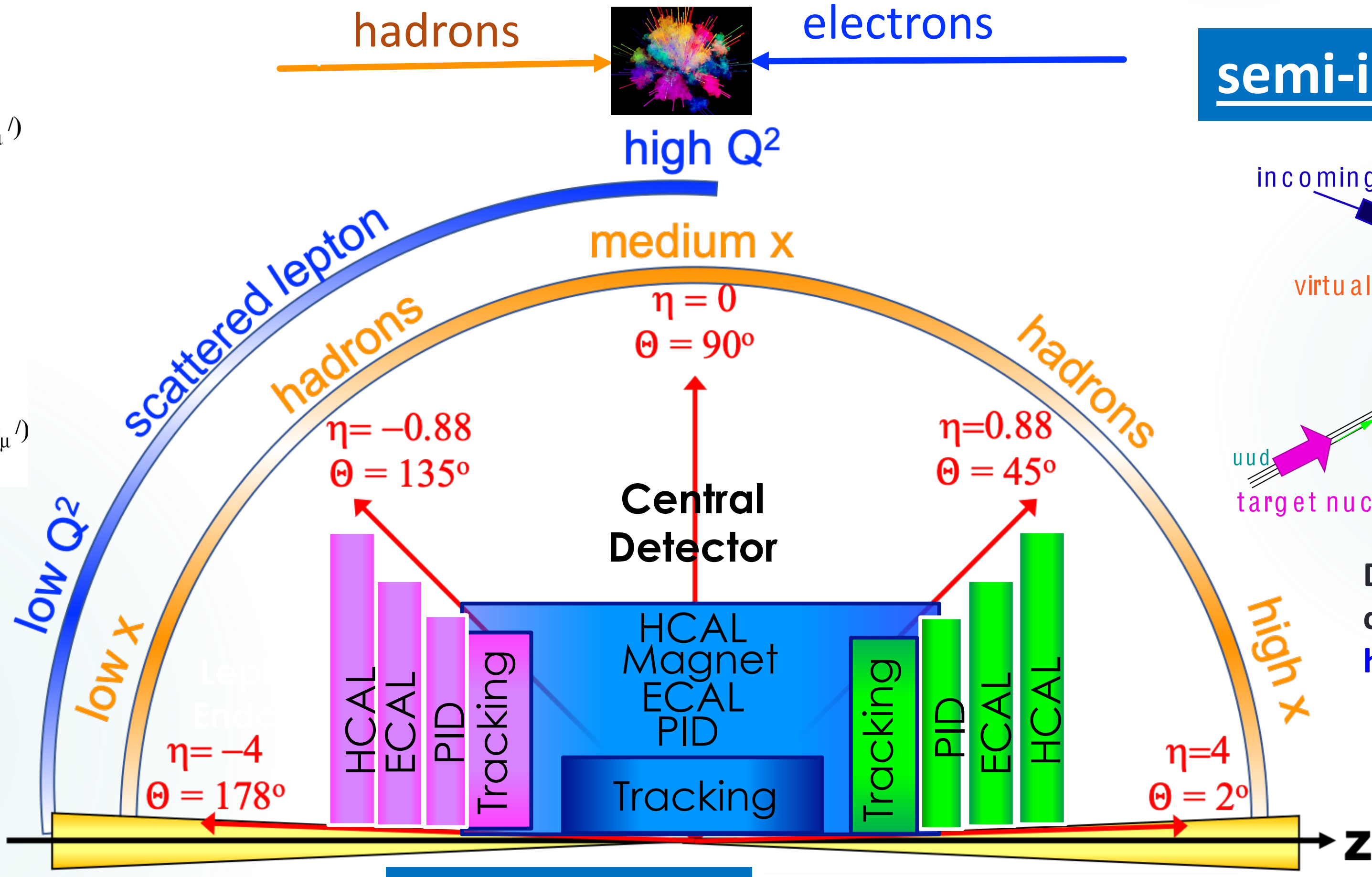
Main Function:
detection of scattered electrons
Technology:
2 stations with 4 tracking layers each (16x18cm^2)
Si / Timepix4
Calorimeter: Tungsten-powder + SciFi SPACAL

Coverage of ePIC

inclusive DIS:



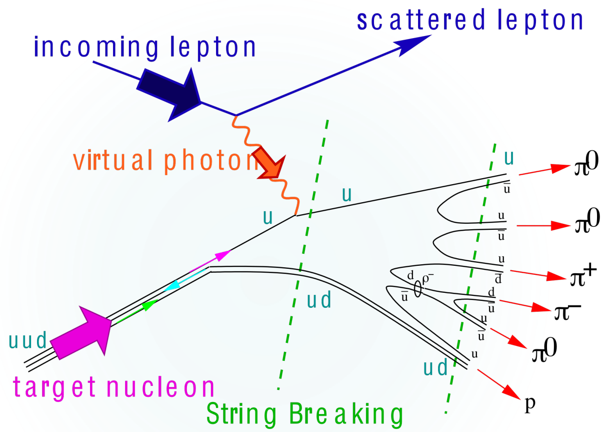
Detect only the scattered lepton in the detector



very low Q^2
scattered lepton
Bethe-Heitler photons
for luminosity

Luminosity Detector
Low Q^2-Tagger

semi-inclusive DIS



Detect the scattered lepton in coincidence with identified hadrons/jets

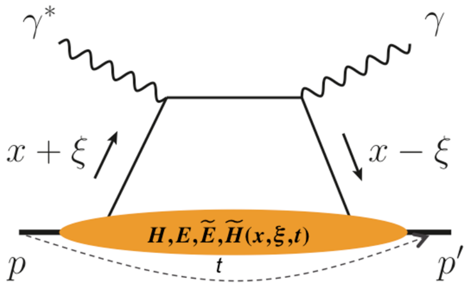
particles from nuclear breakup and
from diffractive reactions

ZDC

Forward Tracking

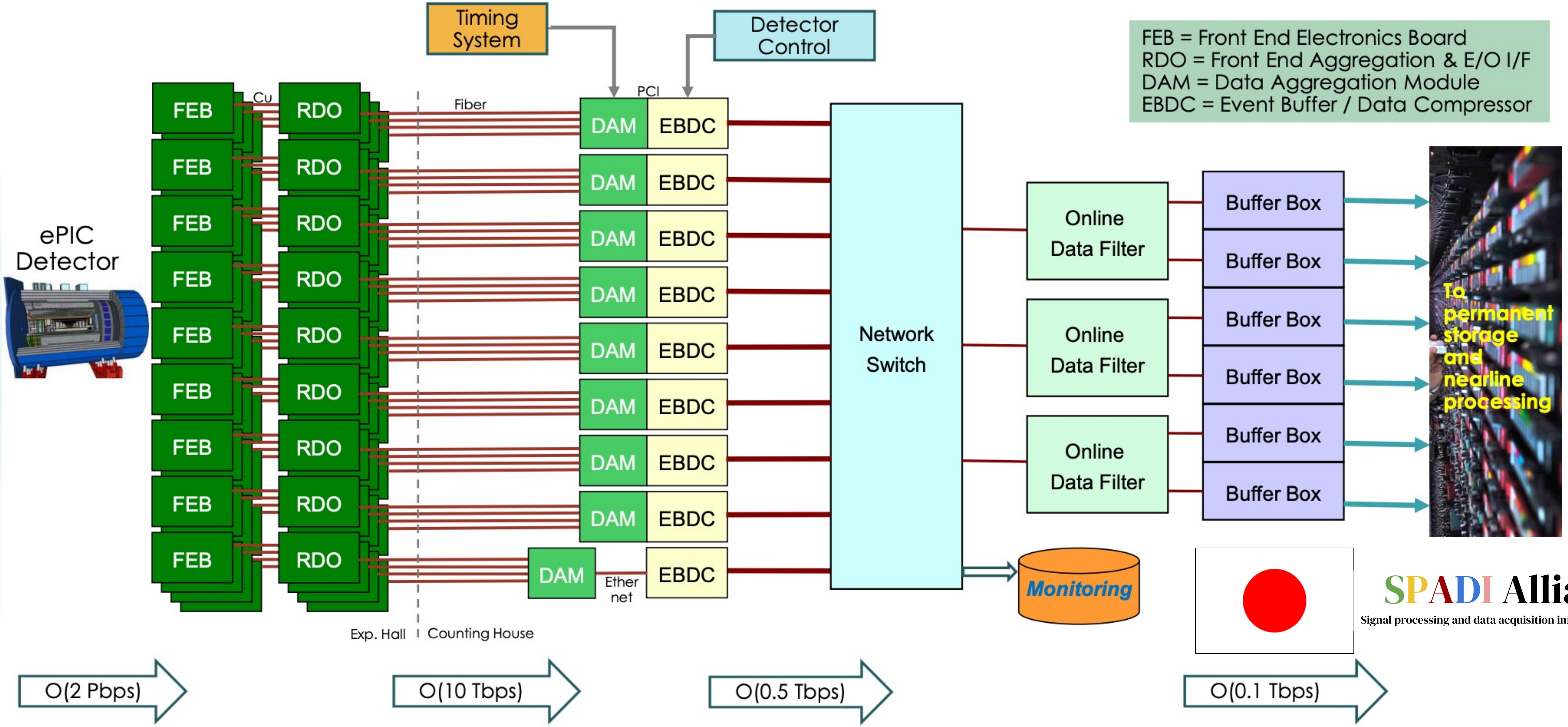
exclusive DIS

Detect scattered lepton, identify produced hadrons/jets and target remnants



Streaming DAQ

- No External trigger
- All collision data digitized but aggressively zero suppressed at FEB
- Low / zero deadtime
- Collision data flow is independent and unidirectional-> no global latency requirements
- Avoiding hardware trigger avoids complex custom hardware and firmware
- Data volume is reduced as much as possible at each stage ensuring that biases are controlled
- Integrate AI/ML as close as possible to subdetectors → cognizant Detector



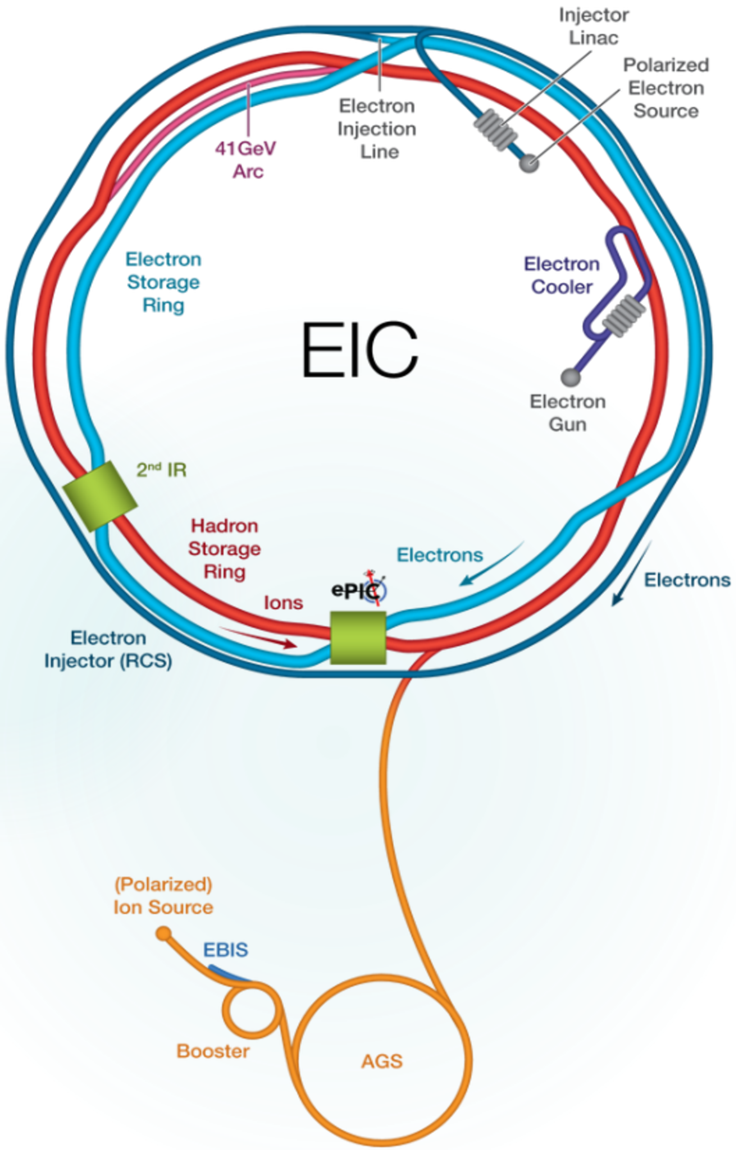
SPADI Alliance
Signal processing and data acquisition infrastructure alliance

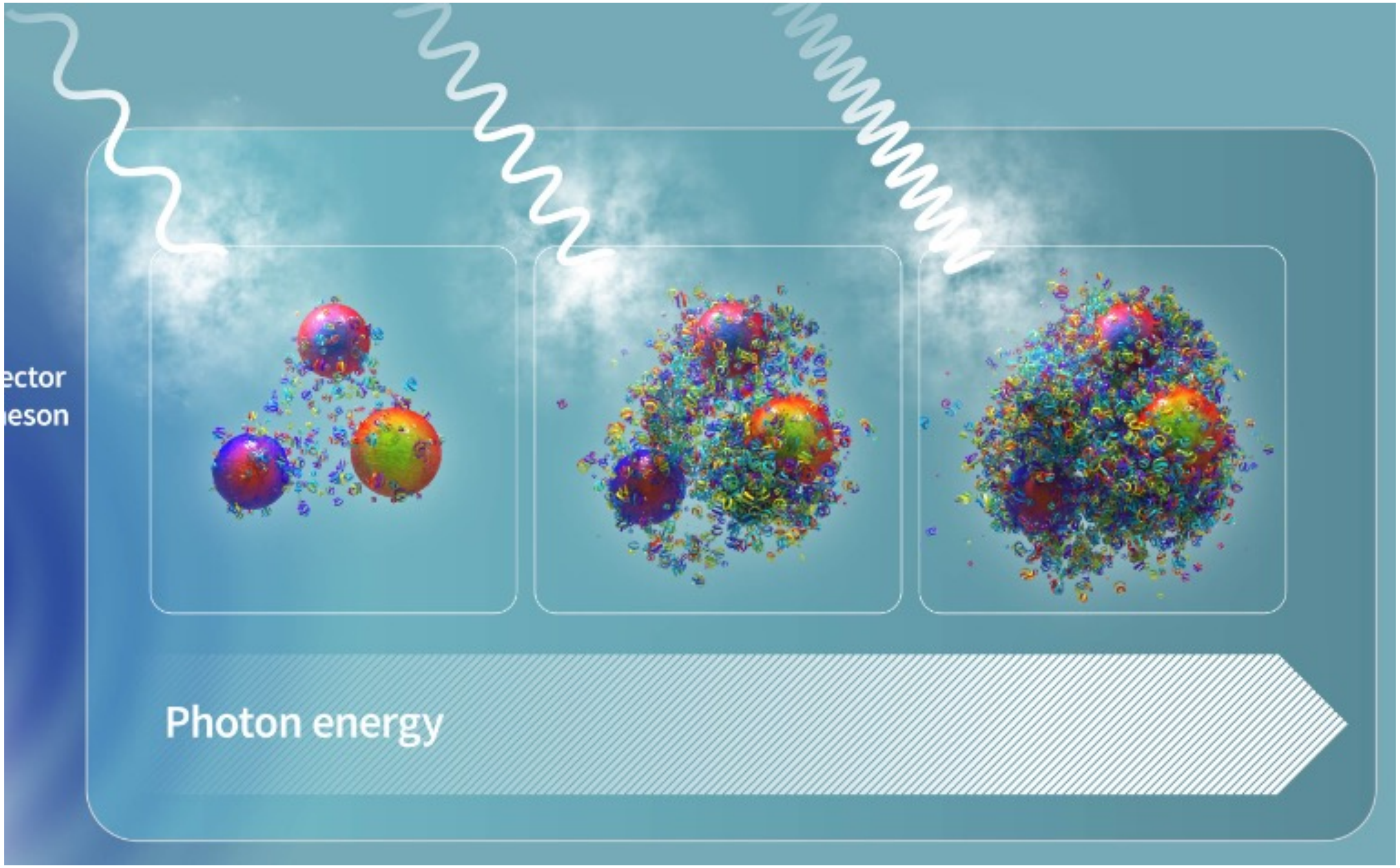
Summay

- EIC = a machine that will unlock the secrets of the strongest force in Nature
  - the world's first collider for polarized electron and polarized proton (and light ions) and electron-nucleus collisions
  - Detailed studies of 3D structure of nucleons and nuclei, origin of spin and mass, emergent properties of dense gluonic matter
- ePIC Collaboration launched to build the detectors in EIC
  - Cutting-edge technologies in various fields (MAPS, AC-LGAD, photo-sensors, ASIC, streaming readout & DAQ, AI/ML technologies)
  - Start construction from 2026 and will start commissioning from 2030. Early science will begin from 2032 or 2033.
- Synergies with HEP community in detector developments (and some of the science)

Backup

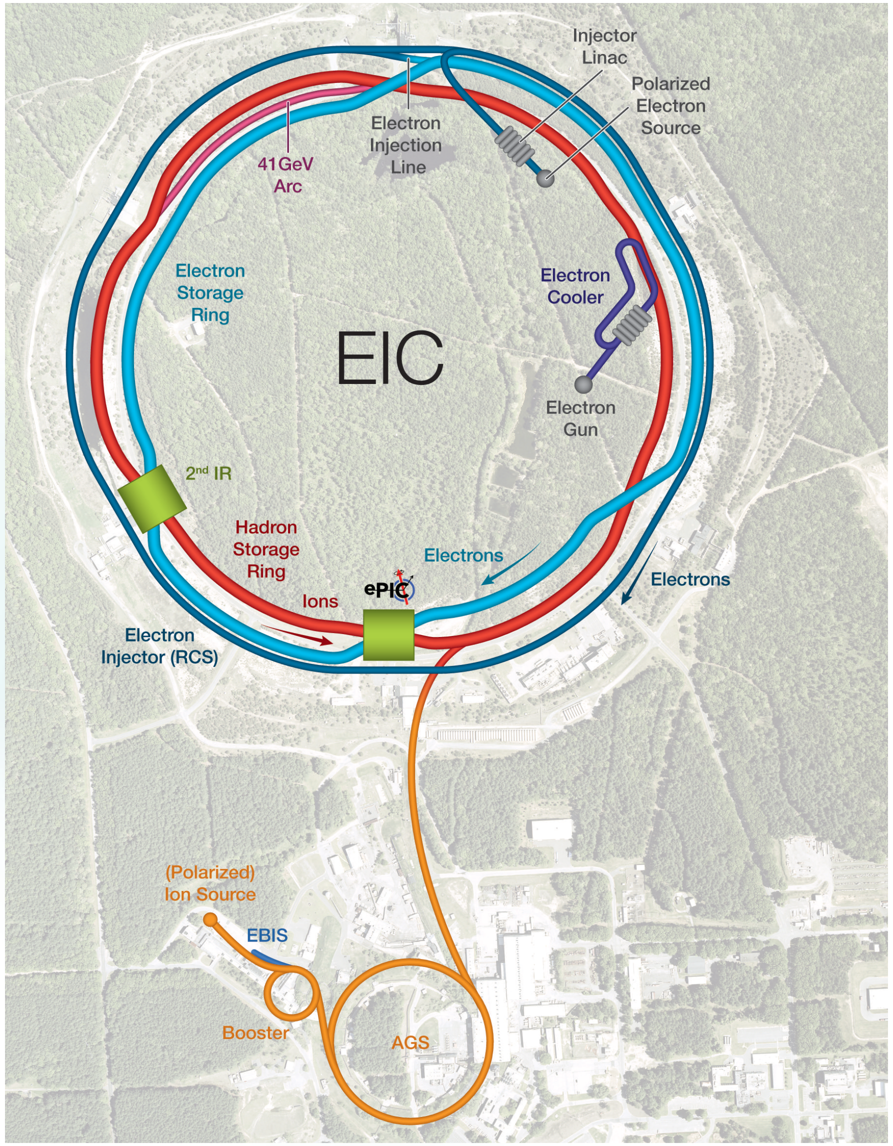
Electron-Ion Collider

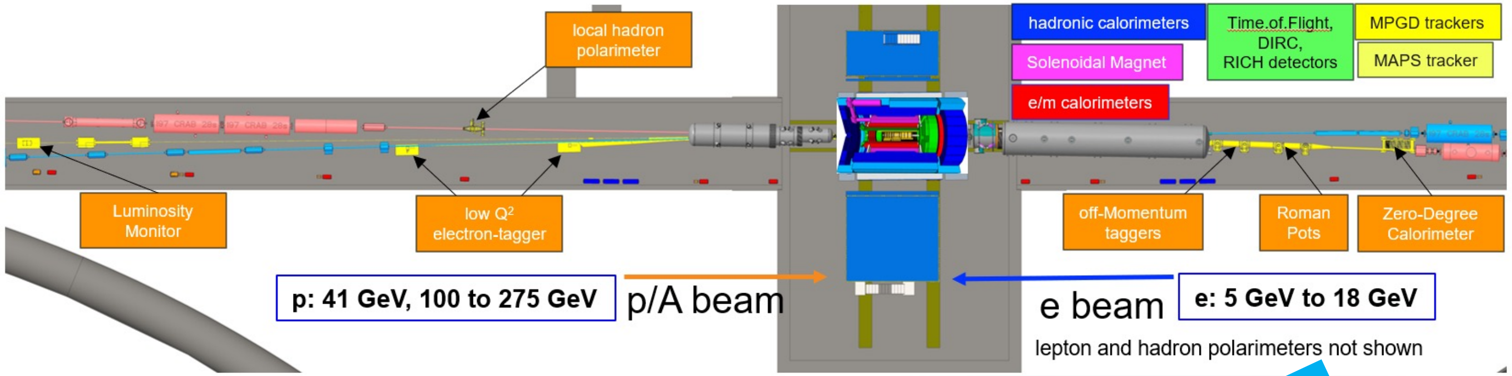


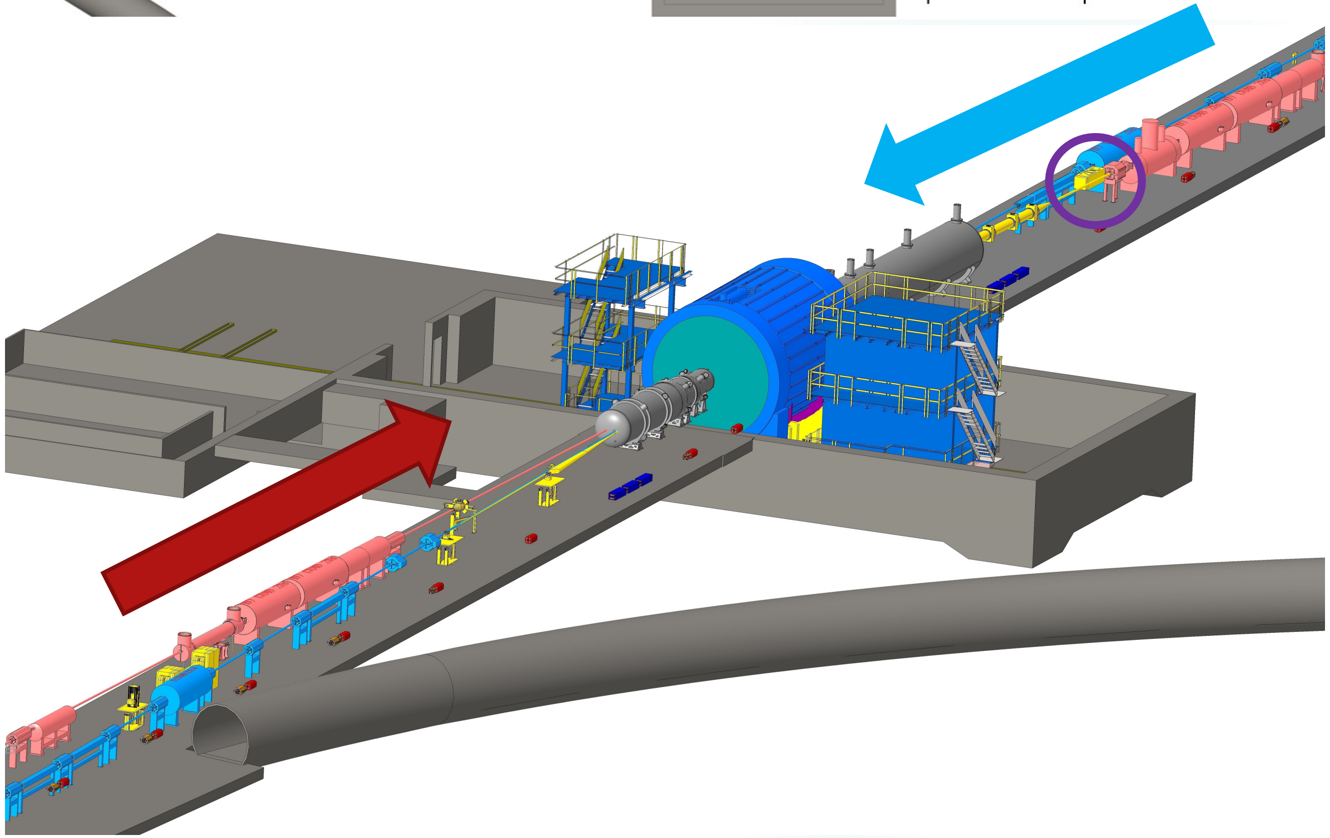


https://alice-collaboration.web.cern.ch/2023_ALICE_UPC

ePIC experiment





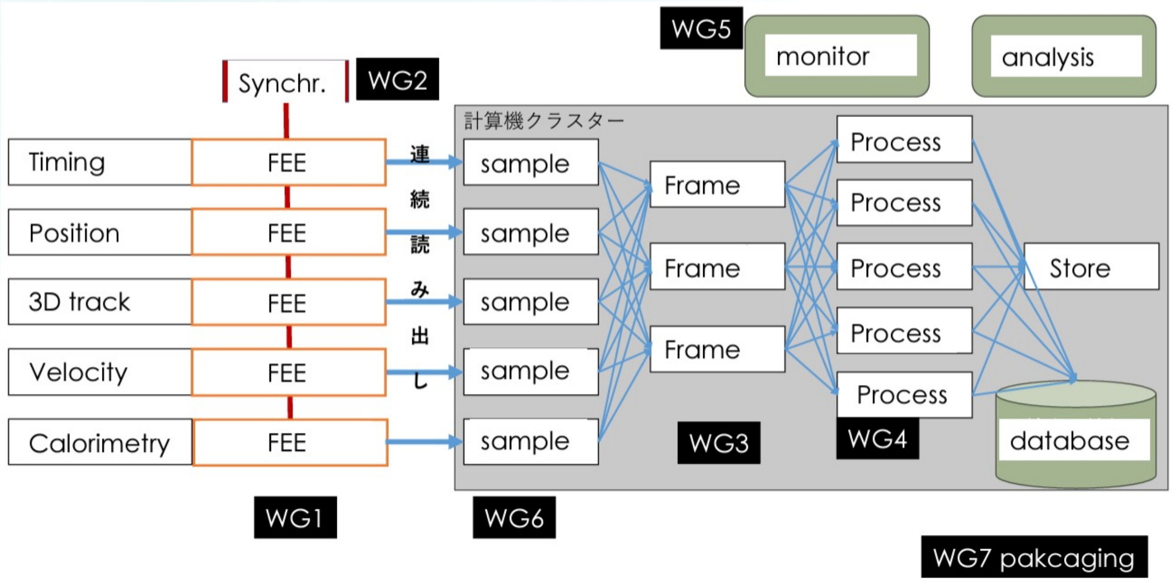


SPADI-Alliance

SPADI Alliance

Signal processing and data acquisition infrastructure alliance

- **7 working groups**
  - **FEE, timing distribution, streaming SW,**
  - **Online processing (including hardware accelerators, AI/ML)**
  - **UI, Computing, Packaging, Analysis SW**



WG1
Frontend Electronics
Streaming type
Charge ASD board
Voltage ASD board
WF Digitizer board
Control Firmware dev.

WG2
Clock synch. / Data Transfer
General Clock Synch.
High throughput
Intra-board transfer

WG3
Acquisition software framework (NestDAQ + …)
Streaming type
FairMQ-based Scalable DAQ
Sampling, Time frame build,
Event build, Monitoring…
Format

WG4
Event processing
Acceleration using GPU/FPGA
Zero suppression
Calibration, Clustering,
Tracking, PID,

WG5
User Interface
Control, Monitor, Configure,

Trial with
SlowDash

WG6
Computing infrastr.
High throughput
Large volume
Flow and Archive
Power consumption
Interconnect
Networking
…

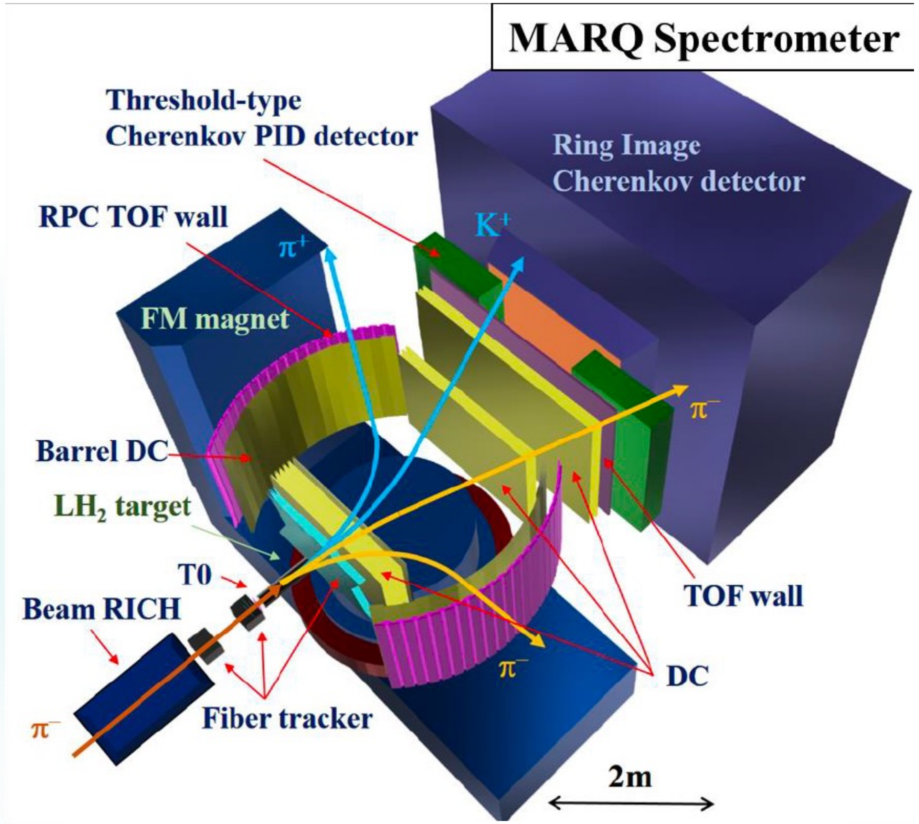
WG7
Packaging
Standalone system
Popularization
Standardization
Market research
User feedback

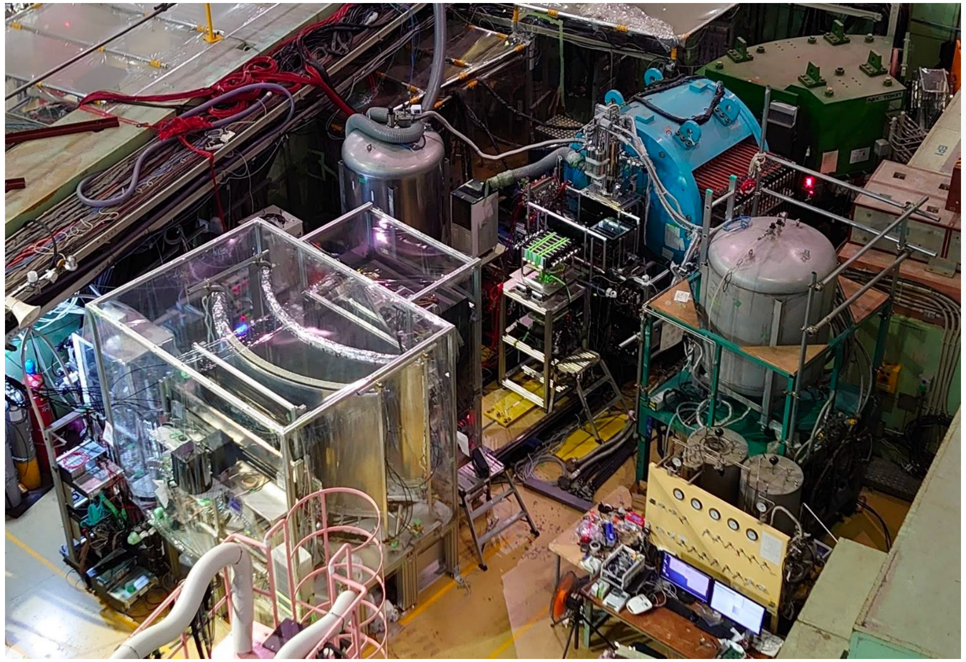
Analysis

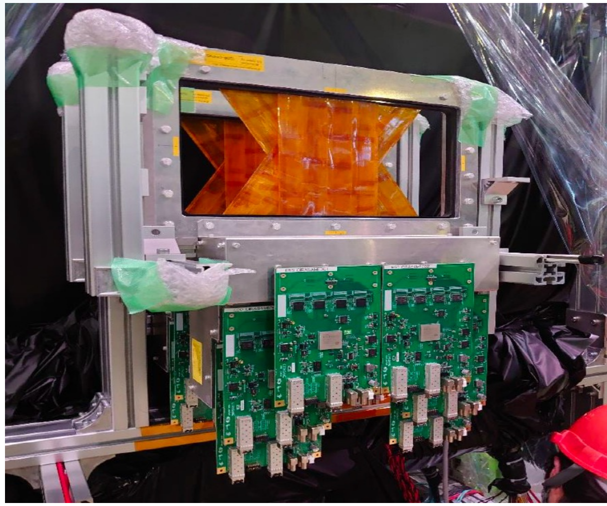
Trial with
Artemis

Streaming DAQ and computing

- **Streaming DAQ performance evaluation by using J-PARC E50 (May. 2024)**







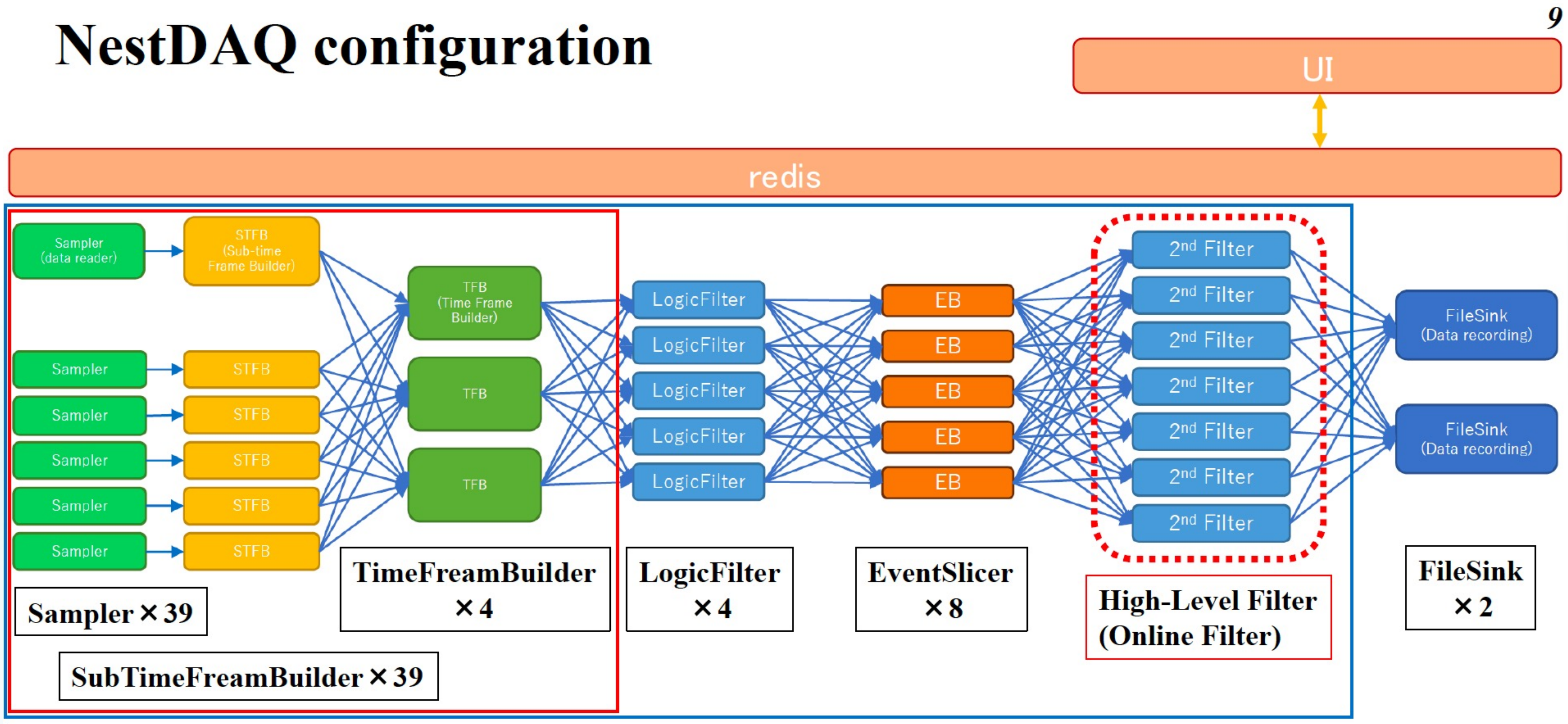
- Total detector channel ~25,000 ch

⇒ Streaming DAQ: Only TDC w/ TOT
  - FEE: 1G/10Gbps network (Optical link)
    - Streaming TDC: AMANEQ
    - MPPC module: CIRASAME
  - Timing synchronization (MIKUMARI system)

Beam intensity ~30 MHz (60 M/2.0 sec. spill, 4.2 sec. cycle)
⇒ ~1.5 MHz reaction rate (4 g/cm2 LH2 target)

Total expected data rate: ~13 GB/sec. (~100 Gbps during extraction)

Streaming DAQ and computing



- **No Filter**: Sampler → STFB → TFB → FileSink
- **Filtered**: TFB → LogicFilter → EventSlicer → High-level Filter → FileSink

Electron-Ion Collider

Wigner distribution function

$$W(x,\vec{k}_\perp,\vec{b}_\perp) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\vec{b}_\perp\cdot\vec{\Delta}_\perp} \int \frac{dz^- d^2 z_\perp}{16\pi^3} e^{ixP^+z^- - i\vec{k}_\perp\cdot\vec{z}_\perp} \langle P - \frac{\Delta}{2} | \bar{q}(-z/2)\gamma^+ q(z/2) | P + \frac{\Delta}{2} \rangle$$

5D

$\int d\vec{b}_\perp$ → TMD $f(x,\vec{k}_\perp)$

$\int d\vec{k}_\perp$ → GPD $f(x,\vec{b}_\perp)$

3D

$f(x,\vec{k}_\perp)$ $\int d\vec{k}_\perp$ → $f(x)$ PDF

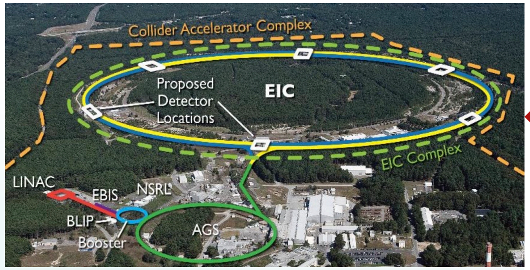
$f(x,\vec{b}_\perp)$ $\int d\vec{b}_\perp$ → $f(x)$ PDF

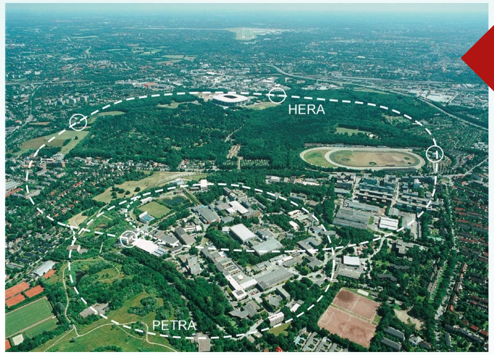
$f(x,\vec{b}_\perp)$ $\int dx$ → $F(\vec{b}_\perp)$ Form factor

1D

$f(x)$ $\int dx$ → Q charge

$F(\vec{b}_\perp)$ $\int d\vec{b}_\perp$ → Q charge





Courtesy of
Y. Hatta