High-Energy nuclear physics in Japan and view on EIC

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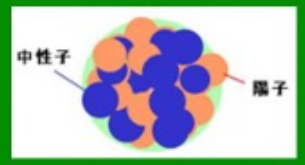
Outline

- Goals of high-energy nuclear physics
- Our past, current, and future activities
- View on EIC
- International high-energy QCD frontier initiative
- Summary

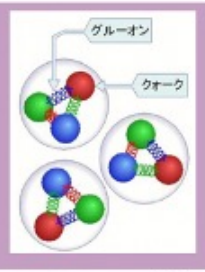
Nuclear Physics

low energy (MeV) → middle energy (GeV) → high energy (TeV)

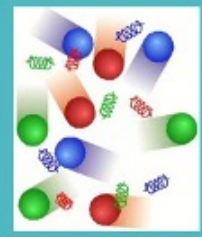
Nucleons /Nucleus



Hadrons



Quark and Gluons



- Superheavy element
- α cluster
- Nuclear structure
- Nucleon pair condensation
- Nucleon pair superfluid
- Nuclear matterr
- Tetra neutrons
- Exotic hadrons
- Partial Restoration of chiral symmetry @ nuclear deensity
- hyper-nucleus
- Y-N/Y-Y interactions、
- Strangness nuclear matter
- Color Confinment
- Hadron stucture and Mass
- QCD vacuum
- Partial Restoration of chiral symmetry
- Quark Gluon Plasma
- Quark and Gluon distributions in nuclei and nucleon
- High-dense Gluonic matter

RIBF, FRIB,RAON, HIAF | **J-PARC, J-Lab, FAIR** | **RHIC, LHC, EIC**

~200 (JP) ~100 (JP) ~70 (JP)

Japanese version of LRP

原子核研究 Genshikaku Kenkyu

TOP | お知らせ | 本誌について | 著者の方へ | 購読 | 編集委員 | バックナンバー | リンク

バックナンバー一覧に戻る

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日本の核物理の将来レポート

unstable nuclear physics

precision nuclear physics

hyper-nucleus, strangeness

hadron physics

high-energy heavy-ion physics

nucleon structure

fundamental physics

computational physics

http://genshikaku.jp/backnumber.php?vol=57&issue=sp2

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nuclear physics

nuclear matter physics

unstable nuclear physics

hyper-nucleus, strangeness

hadron physics

high-energy heavy-ion physics

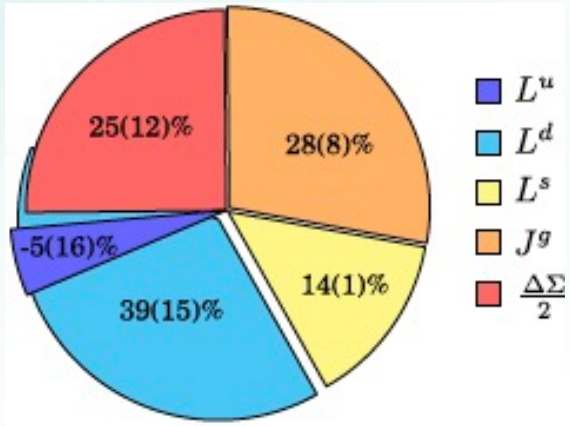
nucleon structure

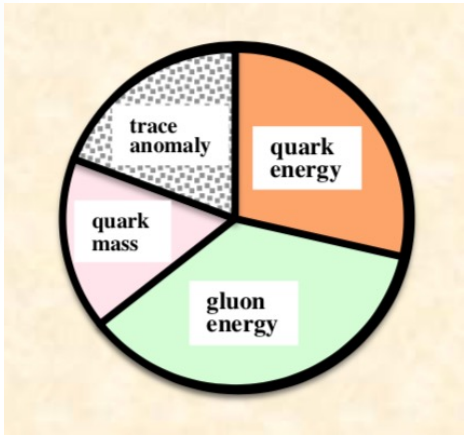
fundamental physics

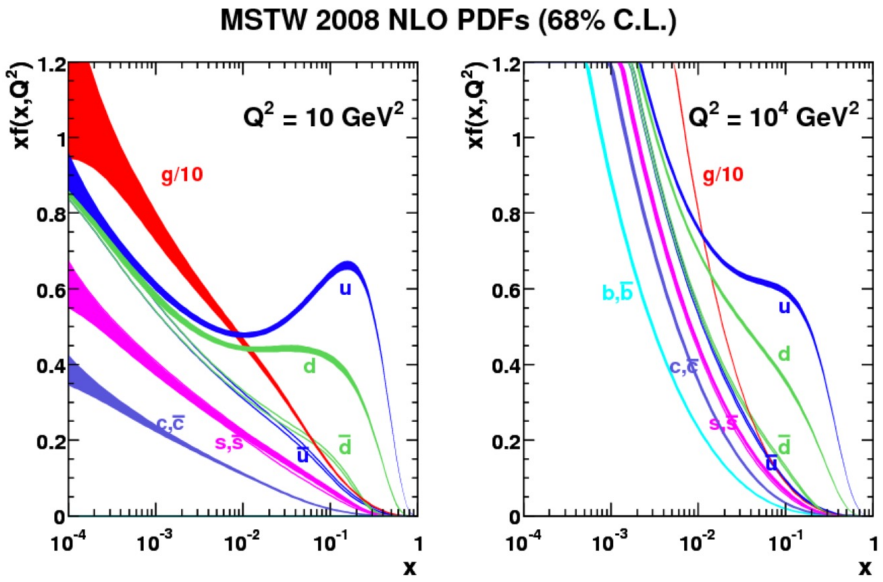
http://kakudan.rcnp.osaka-u.ac.jp/jp/researcher/kakukon/futurerep2021/futurerep2021.html

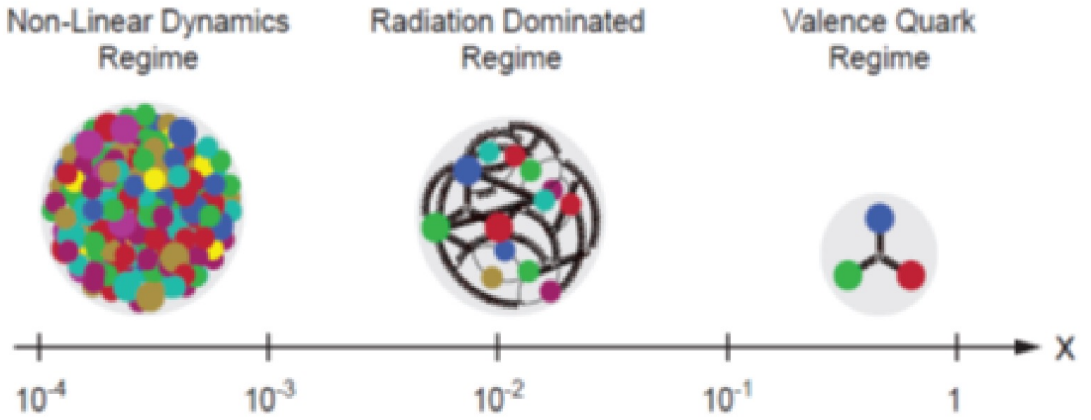
Goals of high-energy nuclear physics

- Understanding of the dynamics of quarks and gluons in nucleons (nucleons as the simplest constituents of matter)
  - Emergence of quarks and gluons from nucleons
  - 3D structue of partons in nucleon/nuclei (k_T, $\vec{x}$)
  - Origin of proton spin, mass, and charge
  - High dense gluons (gluon saturation) at high-energy



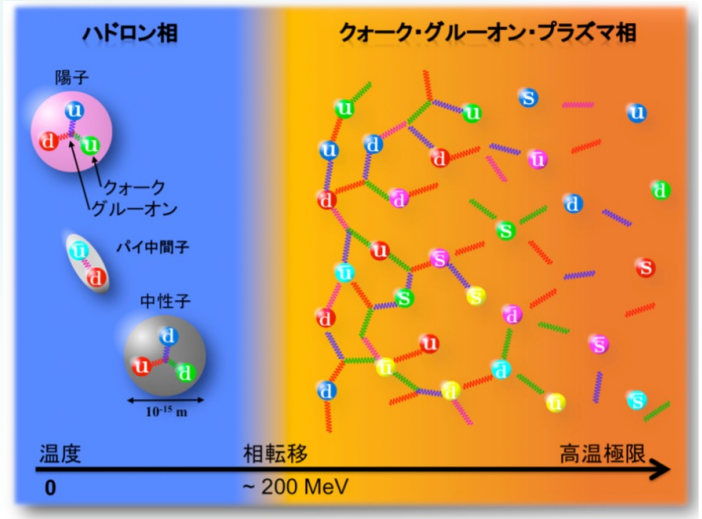




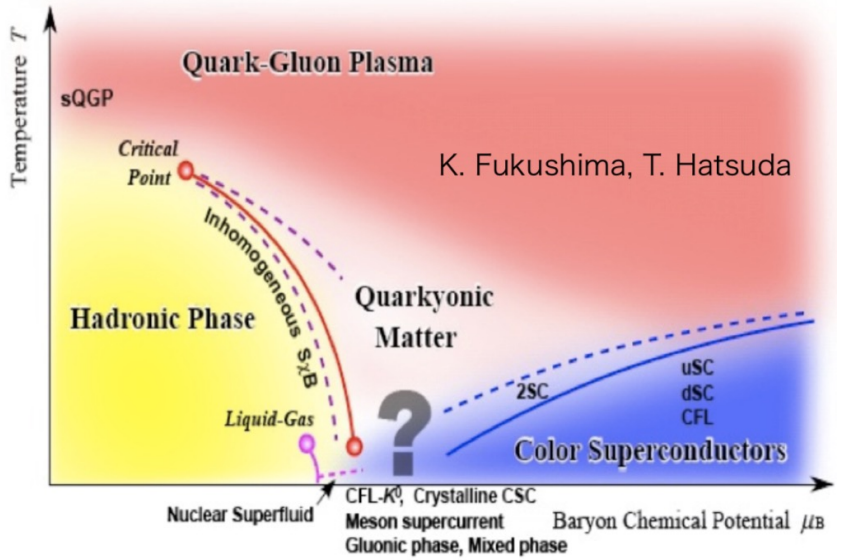


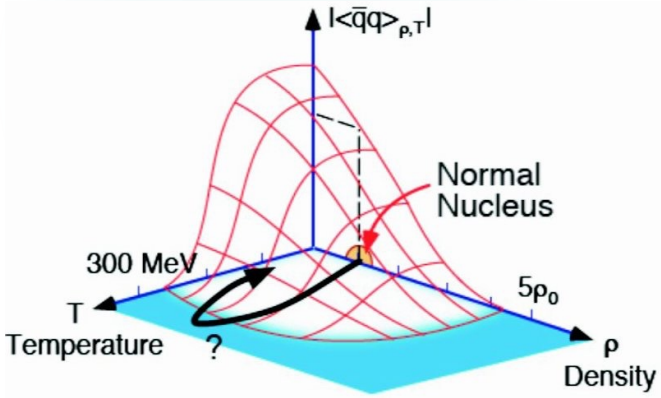
Goals of high-energy nuclear physics

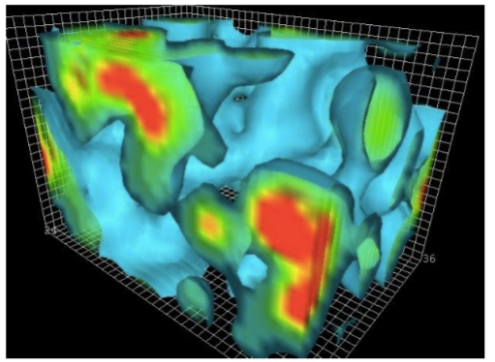
- Understanding of the dynamics of quarks and gluons in many-body systems composed of nucleons or partons under extreme conditions
  - Phase transtion from hadrons to Quark-Gluon Plasma
  - QCD Phase Diagram
  - QCD Vacuum structure



http://tkynt2.phys.s.u-tokyo.ac.jp/~maezawa/intro_my_study/research_lattice.html







Japan contributed Projects

Brookhaven National Laboratory

CERN

Fermilab

KEK

2000 2010 2020

PHENIX

sPHENIX

STAR

ALICE

COMPASS

AMBER

SeaQuest

SpinQuest

Belle

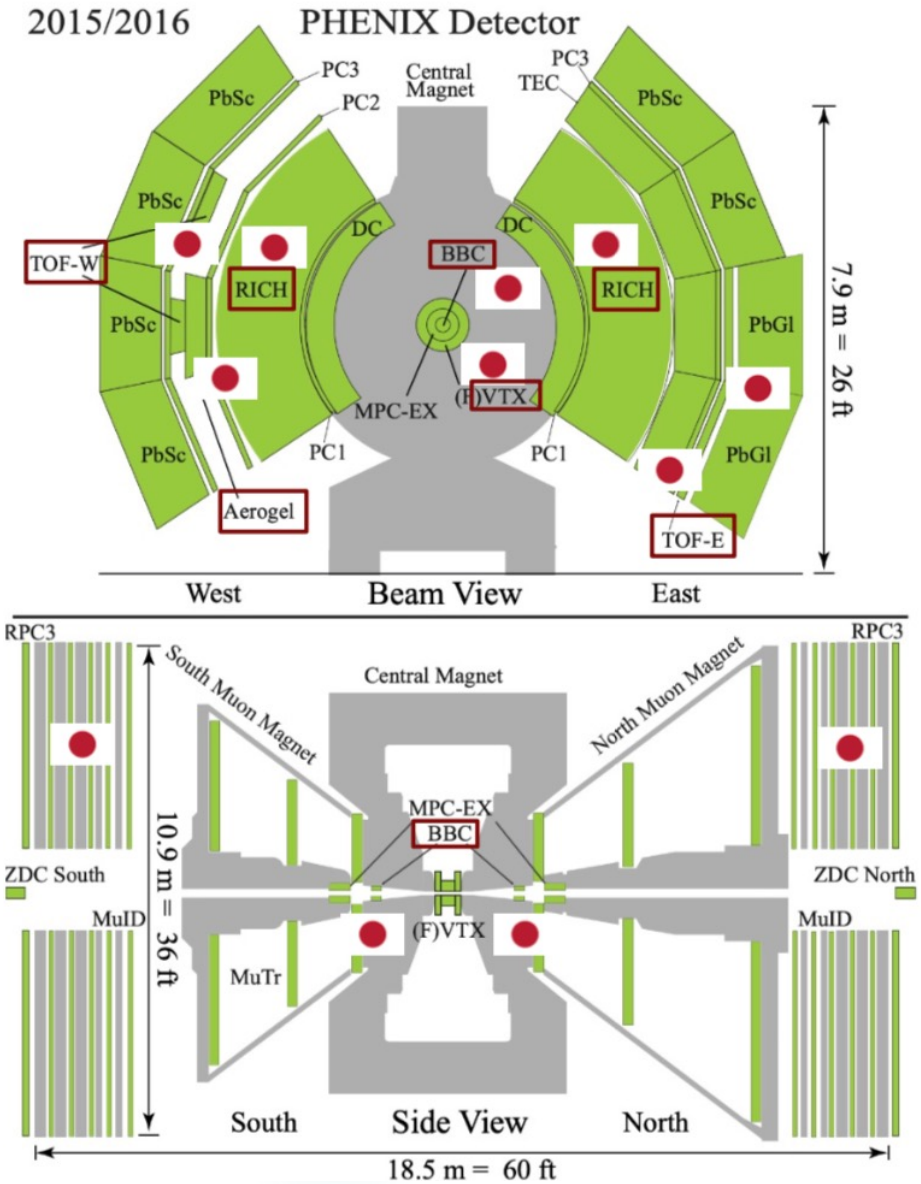
Belle-II

E50

大強度陽子加速器施設 J-PARC Japan Proton Accelerator Research Complex

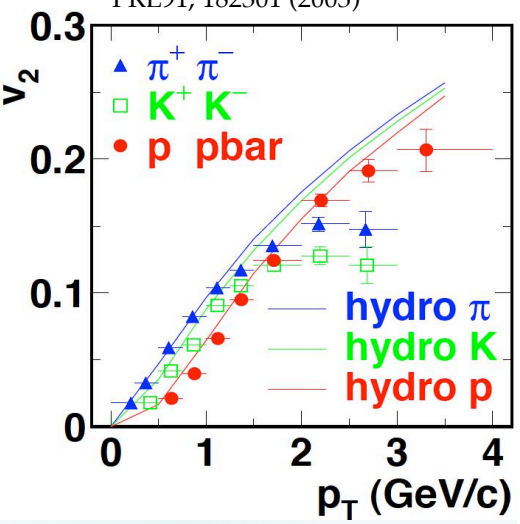
RHIC-PHENIX

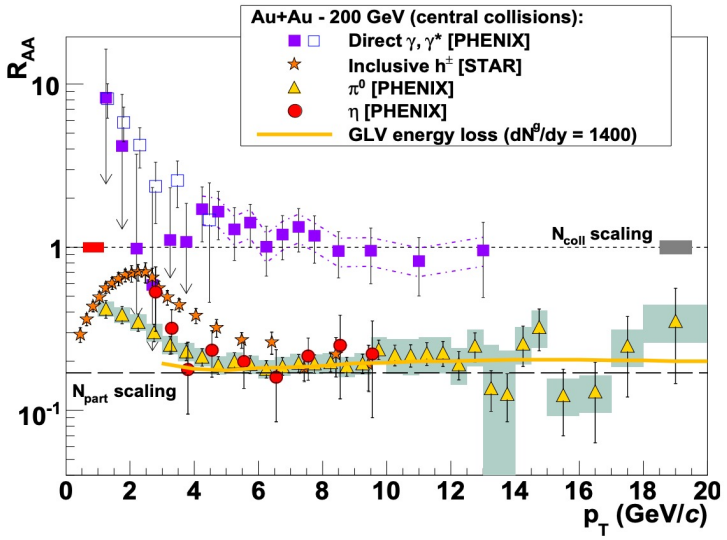
- 75 institutes, >500 members
- Data taking: 2000-2016
- Spokesperson:
  - Shoji Nagamiya, Yasuyuki Akiba
- Japan members (~100, 20% of PHENIX)
  - >10 institutes
- Core roles in the collaboration
  - Spokespersons, PWG Conveners, EC members, Detector projects
- Many contributions for detectors, computing, and physics analysis
  - ~10 subsystems
  - CCJ (computing center Japan) in RIKEN
  - ~ 100 papers (Japanese members are in PPG) out of 230 papers
  - ~50 PhD students
- Supported by U.S.-Japan Science and Technology Cooperation Program in High Energy Physics and RIKEN



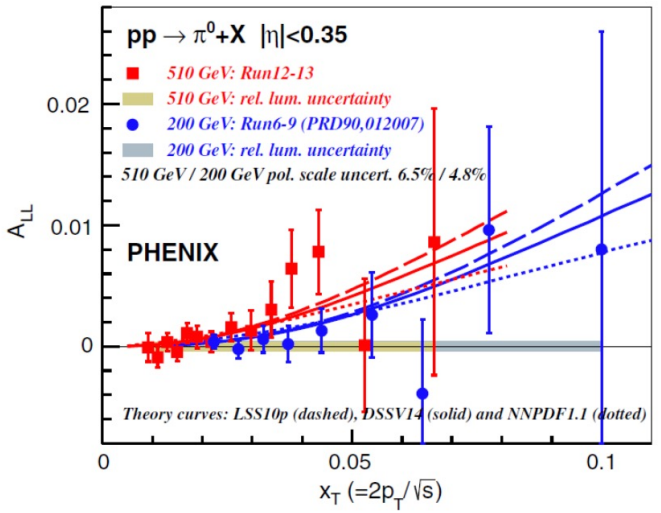
Highlights of RHIC-PHENIX

PRL91, 182301 (2003)

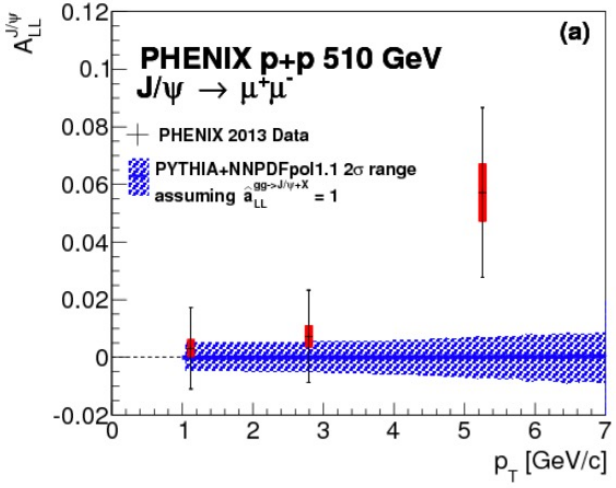


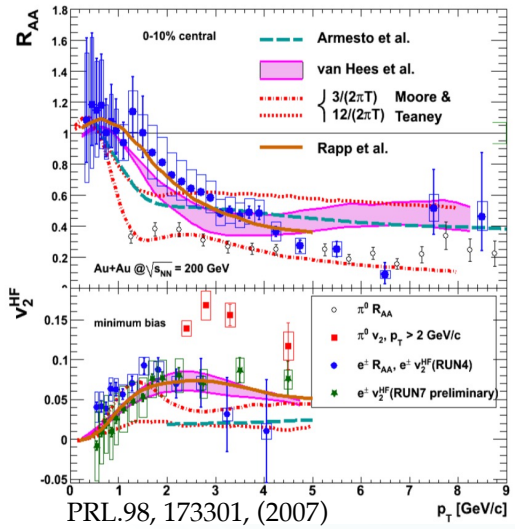


PRL 103, 012003 (2009), Phys. Rev. D.93.011501

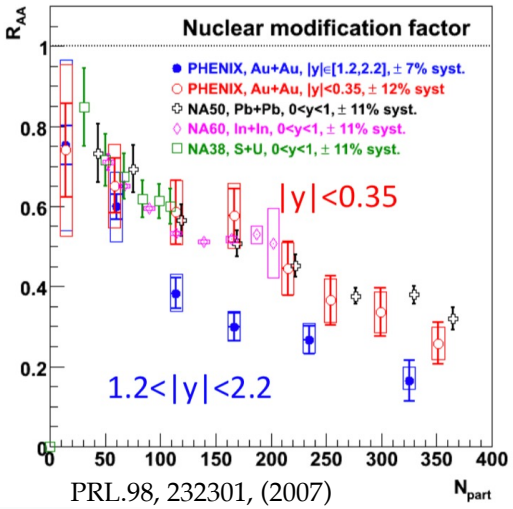


Phys. Rev. D 94, 112008 (2016)

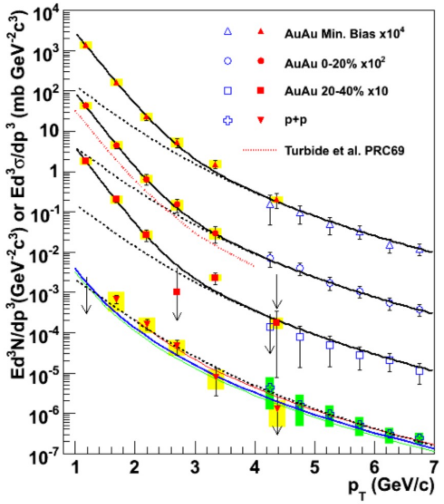


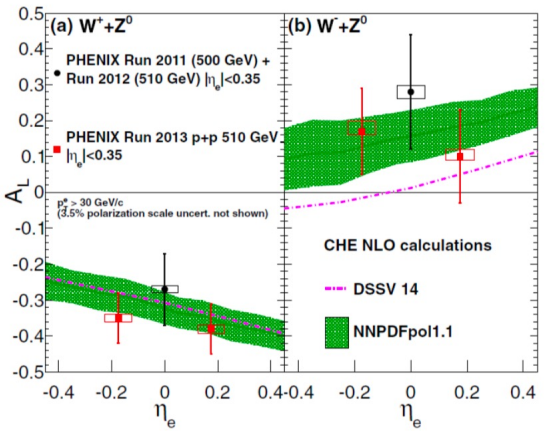


PRL.98, 173301, (2007)

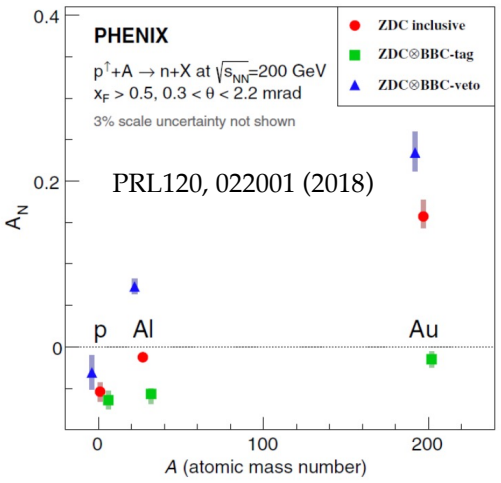


PRL.98, 232301, (2007)





PRD93, 051103 (2016)



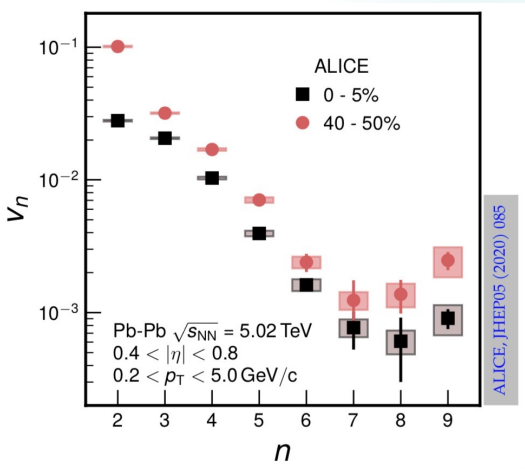
PRL120, 022001 (2018)

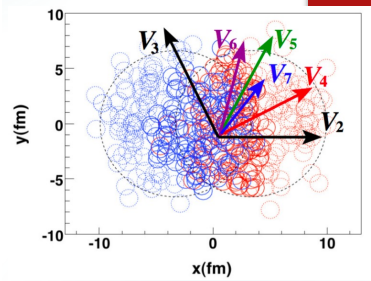
LHC-ALICE

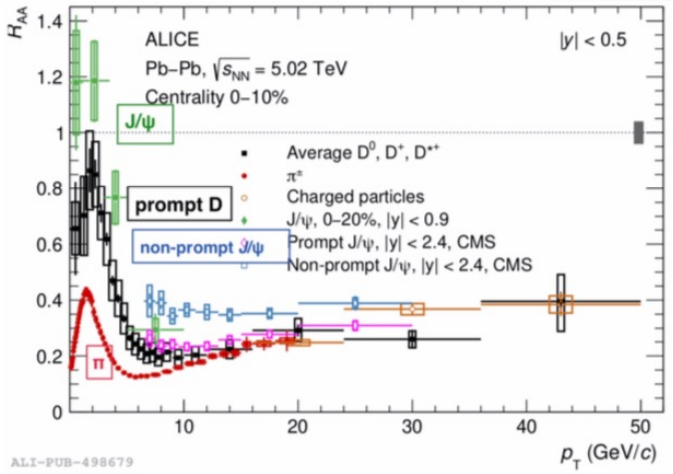
Detailed characterizatio of the QGP

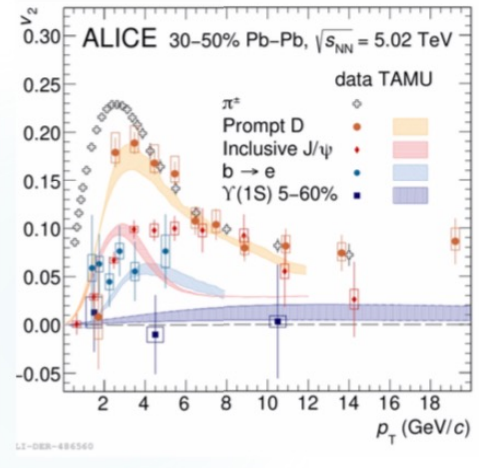
- Japan members (6 institues, ~60 = 3% of ALICE)
- Core roles in the collaboration
  - Deputy CB chairs, Run Coordinator
  - PWG Convener
- 5 detector projects contributed
- ~ 25 papers (Japanese members are in PC) out of 415 papers
- ~13 PhD students

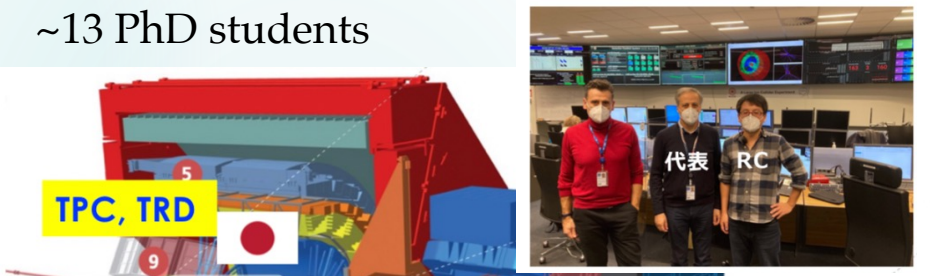
Tokyo, Tsukuba, Hiroshima, Nara, Nagasaki, Saga (RIKEN as associate member)



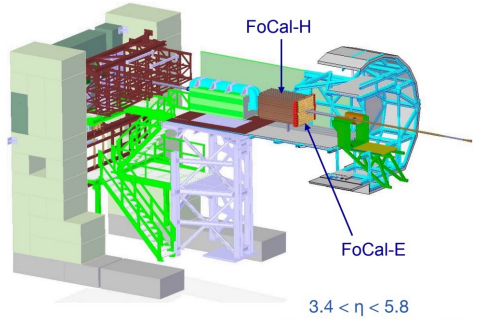


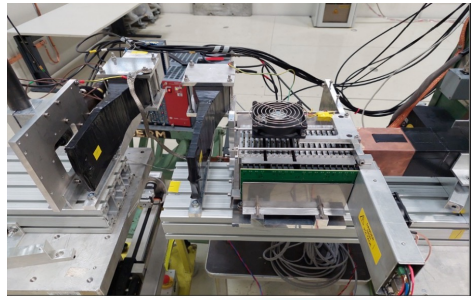




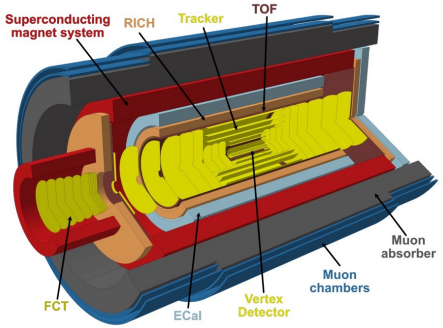


Forward Calorimeter upgrade (Run4 -)



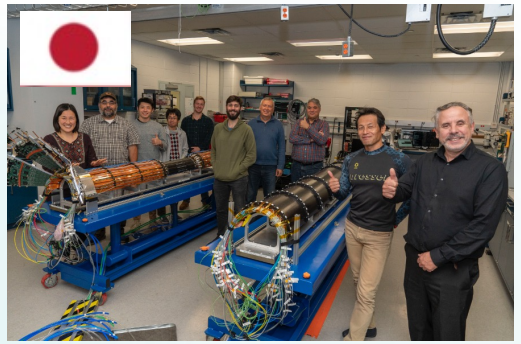


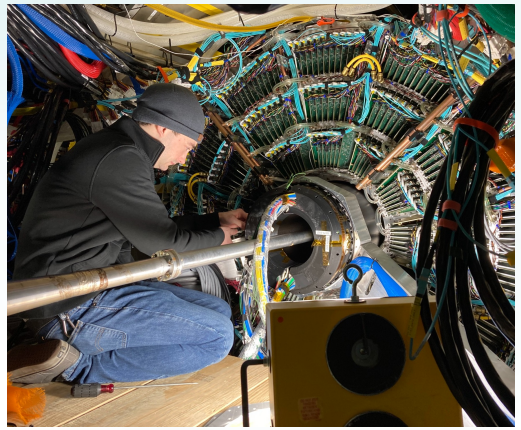
ALICE 3 (Run5 -)



sPHENIX, STAR, FAIR-CBM

- sPHENIX for precision QGP studies
  - INTT construction and installation
- Data taking will start this year





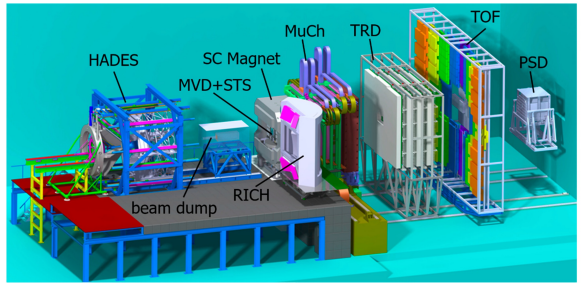
RIKEN, Nara

- STAR
  - QCD phase diagram, CEP

Tsukuba (>2016)

  - Analysis Coordinator, PWG convener
  - Analysis of C_6/C_2, v_n, Λ polarization …
  - 23 papers from Japanese members
- FAIR-CBM
  - QCD phase diagram
  - Plans to contribute STS and PSD projects

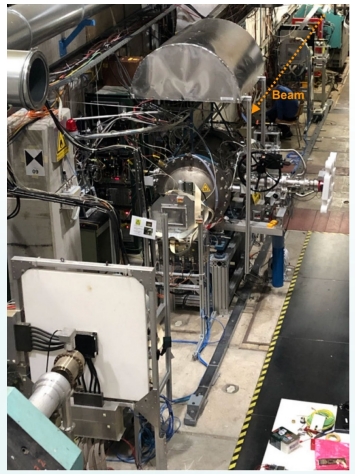
Tsukuba as associate member

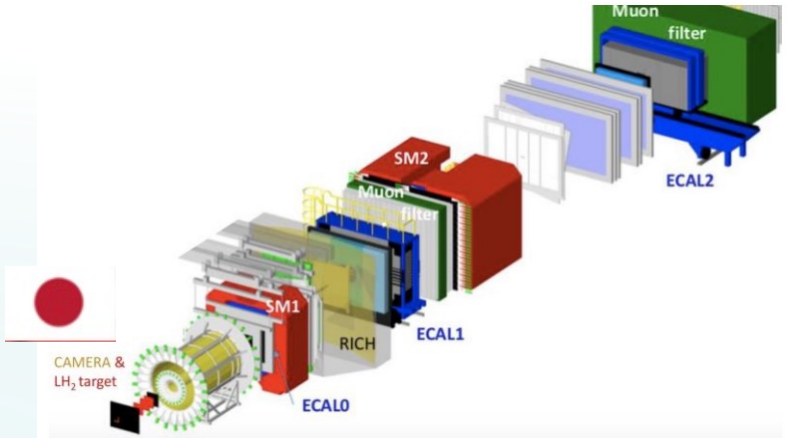


STS for J-PARC E16

AMBER and SpinQuest

- **AMBER** CERN-SPSC-2019-003 **Yamagata**
  - Successor experiment of COMPASS





Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s^{-1}]	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware additions
muon-proton elastic scattering	Precision proton-radius measurement	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pressure H2	2022 1 year	active TPC, SciFi trigger, silicon veto,
Hard exclusive reactions	GPD E	160	$2 \cdot 10^7$	10	$\mu^\pm$	$NH_3^\uparrow$	2022 2 years	recoil silicon, modified polarised target magnet
Input for Dark Matter Search	$\overline{p}$ production cross section	20-280	$5 \cdot 10^5$	25	p	LH2, LHe	2022 1 month	liquid helium target
$\overline{p}$-induced spectroscopy	Heavy quark exotics	12, 20	$5 \cdot 10^7$	25	$\overline{p}$	LH2	2022 2 years	target spectrometer: tracking, calorimetry
Drell-Yan	Pion PDFs	190	$7 \cdot 10^7$	25	$\pi^\pm$	C/W	2022 1-2 years	
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	~100	10^8	25-50	$K^\pm, \overline{p}$	$NH_3^\uparrow$, C/W	2026 2-3 years	"active absorber", vertex detector
Primakoff (RF)	Kaon polarisability & pion life time	~100	$5 \cdot 10^6$	> 10	K^-	Ni	non-exclusive 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	≥ 100	$5 \cdot 10^6$	10-100	$K^\pm$ $\pi^\pm$	LH2, Ni	non-exclusive 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5 \cdot 10^6$	25	K^-	LH2	2026 1 year	recoil TOF, forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	$5 \cdot 10^6$	10-100	$K^\pm, \pi^\pm$	from H to Pb	2026 1 year	

Table 2: Requirements for future programmes at the M2 beam line after 2021. Muon beams are in blue, conventional hadron beams in green, and RF-separated hadron beams in red.

PHASE-1

Conventional hadron and muon beams

2022 ➔ 2025 and beyond

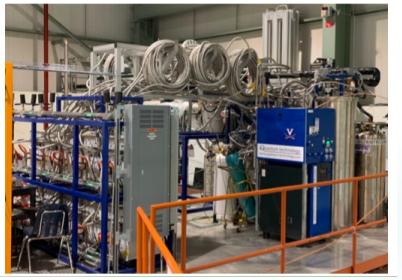
PHASE-2

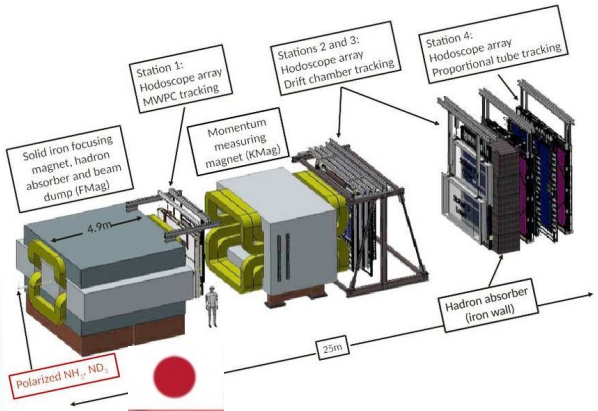
Conventional and RF-separated Hadron/Hadron and muon beam

2026 and beyond

- **SpinQuest@FermiLab**
  - Physics run (2023-2025)
    - Spin asymmetry (J/ψ and DY)

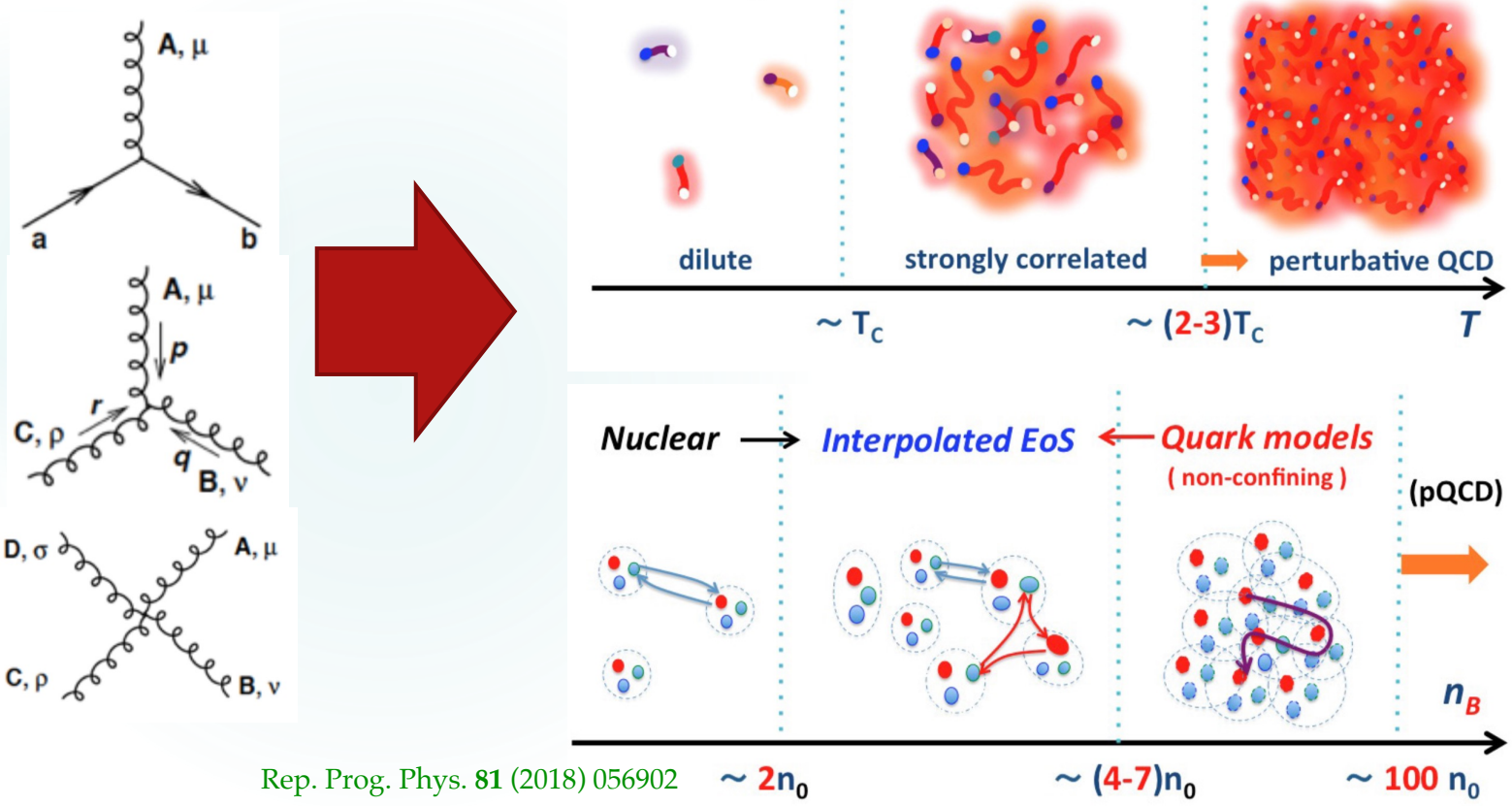
Yamagata, RIKEN, KEK

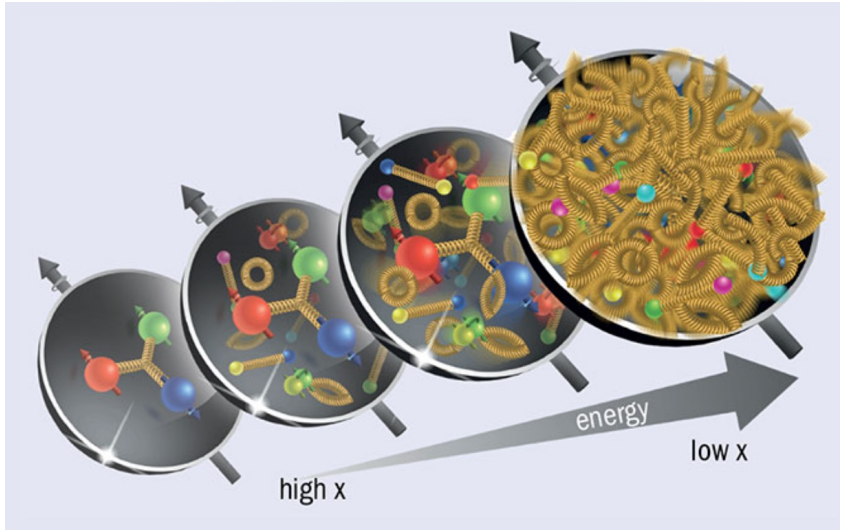




View on EIC

- QGP physics and nucleon/nuclei structure physics are complement
  - Microscopic QCD strong interactions → emergent propertices under various conditions

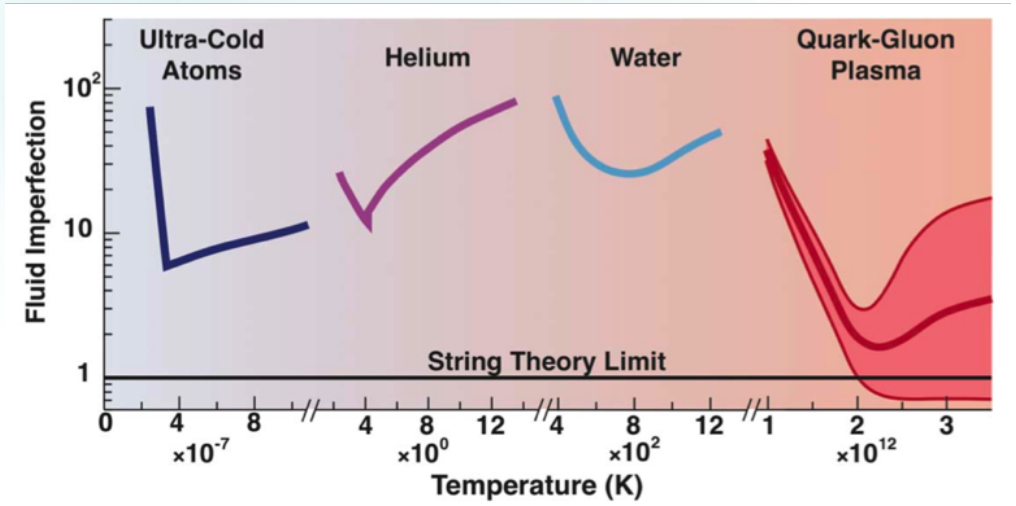


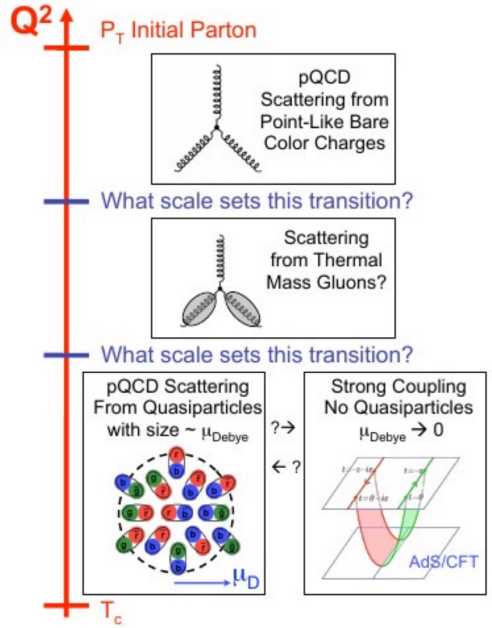


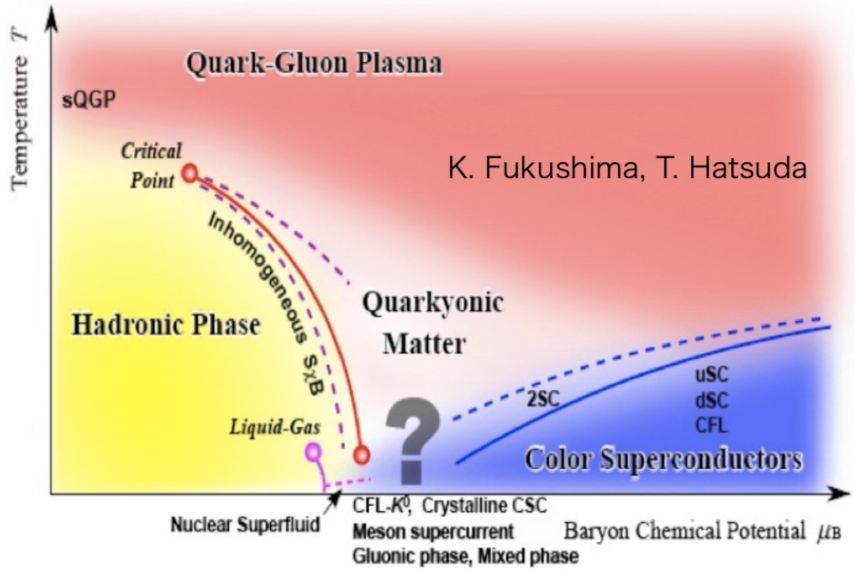
Rep. Prog. Phys. **81** (2018) 056902

View on EIC

- **Goals of QGP physics for next decades**
  - Characterize the macroscopic long-wavelength **QGP** properties precisely (η/s, D_s)
  - Understand the microscopic structure and parton dynamics underlying the **QGP** properties
  - Characterize the changes of the degree of freedom between **hadrons** and **QGP** (phase transition : deconfinemeent and chiral symmetry restoration)
  - Characterize the phase diagram and search for new state of matter (**wQGP, CSC**)





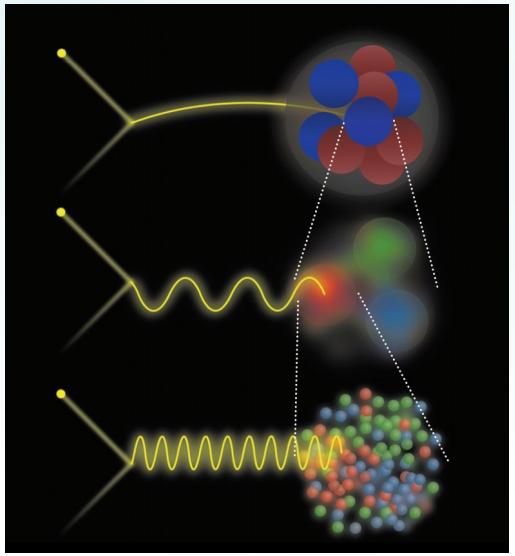


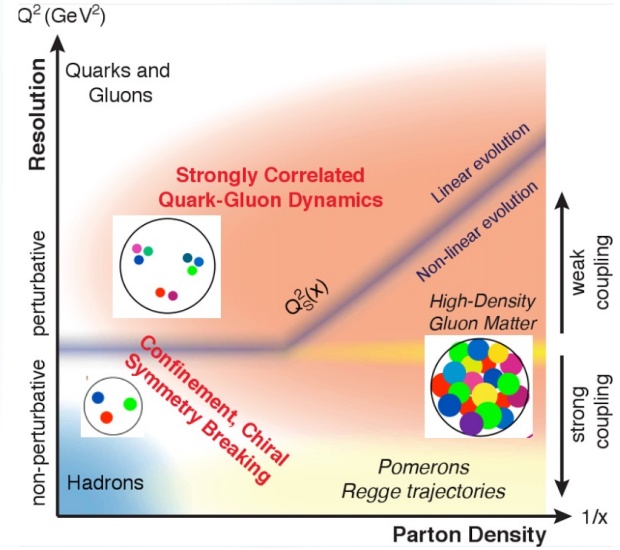
View on EIC

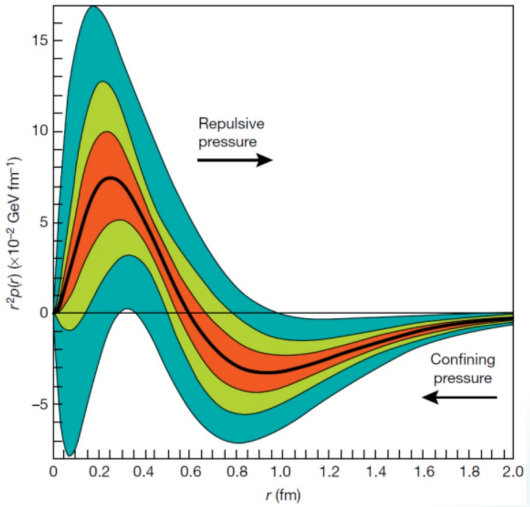
- **Goals of EIC physics**

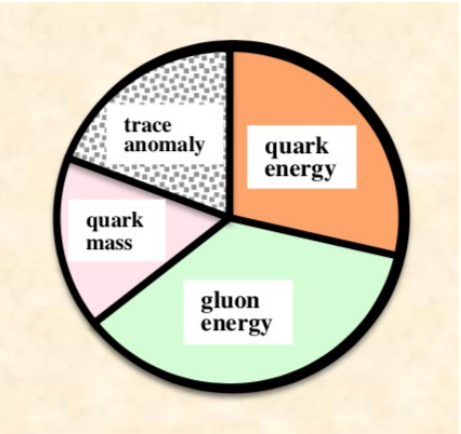
Replace "QGP" with "nucleon/nuclei"

  - Characterize the macroscopic long-wavelength **nucleon/nuclei** properties precisely (**radius, mass, spin, charge**)
  - Understand the microscopic structure and parton dynamics underlying the **nucleon/nuclei** properties (**ex, constituent quark pictures → quark and gluon dynamics**)
  - Characterize the changes of the degree of freedom between **nucleons** and **quark & gluons**
  - Characterize the phase diagram and search for new state of matter (**gluon saturation**)







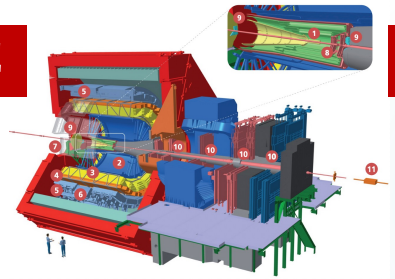


International QCD Frontier Initiative

- **“Frontier of international high-energy quantum science: QCD research at overseas facilities”** proposed to Science Council of Japan (2022)

CERN-LHC, BNL-RHIC

ALICE



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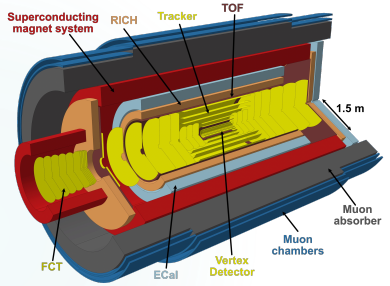
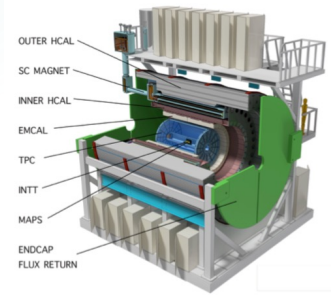
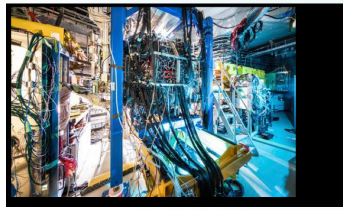


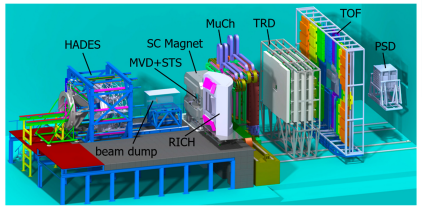
sPHENIX



FAIR(2029-)

GSI





WASA-FRS HypHI

CBM

High temperature QCD

High density QCD

High energy QCD

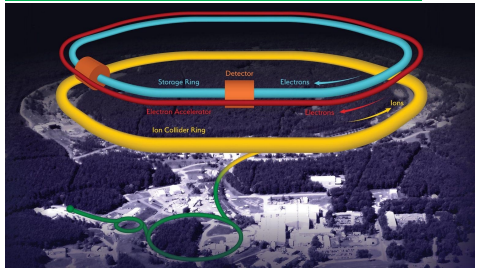
International QCD Frontier

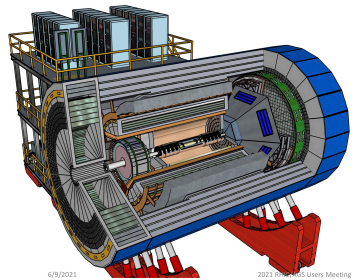
“emergence of the QCD”

QCD theory

Computational QCD

EIC(CD1、2032-)





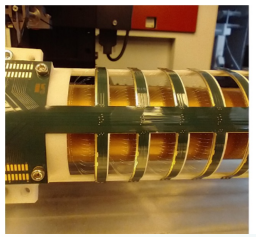
ePIC

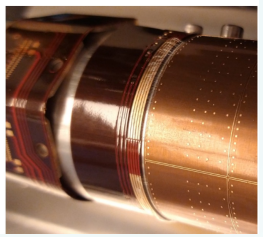
Brookhaven National Laboratory

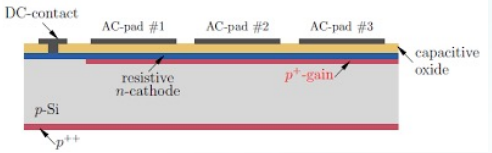
International QCD Frontier Initiative

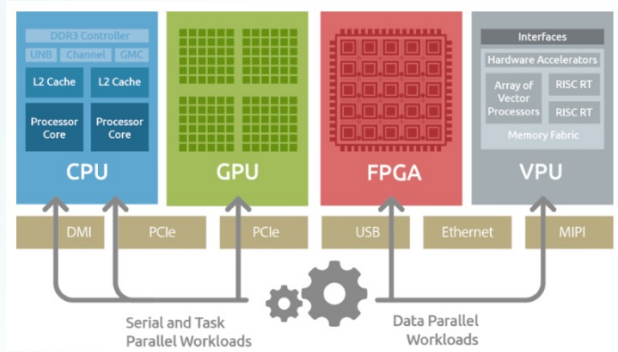
- Leading long-term international joint experimental research at overseas facilities
- Unify and strengthen Japanese teams from different projects and establish the collaboration according to project timelines/needs
- Human resource development for the next generation

- state-of-the-art common technology development
  - 4D (MAPS) Si pixel development
  - Heterogeneous computing









出展 ADLINK

Summary and Outlook

- **A lof of contributions to various experiments fom Japanese high-energy nuclear physics community**
  - PHENIX & STAR at RHIC, ALICE at LHC, COMPASS at SPS, SeaQuest at FNAL, …
- **Much deeper understandings of the QCD will be achieved:**
  - sPHENIX, ALICE-FoCAL, ALICE3, FAIR-CBM, AMBER, SpinQuest
  - **Electron Ion Collider**
- **"International QCD Frontier Initiative" Plan**
  - Unify and strengthen the Japanese teams from various experiments and work together coherently by sharing expertise and resources.