ePIC Experiment Overview

*Satoshi Yano Hiroshima University EIC*で展開する新たな素粒子・原子核物理

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A complete understanding of how quarks and gluons form nuclei is essential to the realization of "Fermtotechnology"

Femtotechnology

How to "see" inner structure of nucleus/nucleon

• DIS (Deep Inelastic Scattering) is a clean method to "see" the inner structure of nucleus and

nucleon

- nucleon **Table 2.1:** Different categories of processes measured at an EIC (Initial state: Colliding electron (*e*), proton (*p*), and nuclei (*A*). Final state: Scattered electron (*e*0), neutrino (*n*), photon
	- **QED+pQCD** plays a main role in the process

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How to "see" inner structure of nucleus/nucleon *CHAPTER 2. PHYSICS MEASUREMENTS AND REQUIREMENTS* 7

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Second photon. In this case of the virtual photon. In this case of the virtual parties of the virtual photon. I $t = \frac{1}{\sqrt{2\pi}} \sum_{i=1}^{n} \frac{1}{i}$ *W* $\big\} X$ ין
י $\sum_{n=0}^{\infty}$ \overline{f} for all processes to determine the event kinematics.

Neutral Current DIS

Detection of scattered electron with highprecision eyant kinematics $R_{\text{factor}} = \frac{V}{\sqrt{2\pi}}$ which reflection of scattered measurement of \mathcal{L} event with ϵ

*e*ʹ

Semi-Inclusive DIS

Precise detection of scattered electron in coincidepce with at the $least 1 h$ agron *p e e*ʹ *h,*γ *p*ʹ $\frac{1}{2}$ and $\frac{1}{2}$ does a dense nuclear environment affect the dynamics of $\frac{1}{2}$ different affect the dynamics of $\frac{1}{2}$ different affect the dynamics of $\frac{1}{2}$ different affect the dynamics of $\frac{1}{2}$ di atics correlations, and the gluon state h_N $\frac{d}{dx}$ denote the nucleir in $\frac{d}{dx}$ at $\frac{d}{dx}$ rise to gluonic matter at $\frac{d}{dx}$ rise to gluonic matter $\frac{d}{dx}$ λ ith at the ϵ

p

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scattered electron, but needs to be reconstructed from $\mathcal O$ to be reconstructed from $\mathcal O$

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- The process can be categorized as follows,

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How to "see" inner structure of nucleus mucleon Charged-current Inclusive DIS: *e* + *p*/A ! *n* + *X*; at high enough momentum transfer *Q*2, the electron*e* ν **Semi-inclusive DIS:** *^e* ⁺ *^p*/A ! *^e*⁰ ⁺ *^h±*,0 ⁺ *^X*, which *e* requires measurement of *at least one* identified hadron *e*ʹ **Neutral-current Inclusive DIS:** *e* + *p*/A ! *e*⁰ + *X*; for this process, it is essential to detect the scattering \mathcal{L} *e e*ʹ

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> $\overline{1}$ $\left\{ \right.$ \int

X $\begin{matrix} \end{matrix}$ $\left\{ \right.$ \int

 $\frac{1}{2}$ **S** $\frac{1}{2}$ **p** $\frac{1}{2}$ **p** event requires measurement of *at least one* identified hadron

Event kinematic *fr*om final state particles (Jacquet-Blondel měthod) *e*ʹ

Deep Exclusive DIS

Charged Current DIS

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The physics accessible in each process is different Exhaustive measurements can reveal how nuclei and nucleons are composed of partons *p X* $\begin{matrix} \hline \end{matrix}$ $\left\{ \right.$ ⎭ *p p*ʹ $\{X\}$ The physics accessible in each process is different $\begin{array}{c} \begin{array}{c} \end{array} \end{array}$ $\left\{ \right\}$ \int $p \longrightarrow \leftarrow \leftarrow \leftarrow \leftarrow \leftarrow$

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- World's first polarized electron-proton and electron-nucleus collider
	- For e-p/A collisions at the EIC
		- Polarized beams: e, p/d/3He…Cu/Au/U (Wide range of nuclei)
		- Luminosity $\sim 10^{33}$ 10^{34} cm⁻²s⁻¹ = 10 100 fb⁻¹/year
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- EIC Critical Decision (CD) Plan
	- 2020: Approve Mission Need (CD-0)
	- 2021: Approve Alternative Selection and Cost Range (CD-1)
	- 2024: Approve Performance Baseline (CD-2)
	- 2025: Approve Final Design (CD-3)
	- 2032: Start Mission (CD-4)

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The EIC is a unique project, the world's only one approved for the ultimate understanding of QCD Most likely, the only novel high-energy collider in the next 15-20 years

Major Nuclear Physics Facilities for the Next Decade Report of the NSAC Facilities Subcommittee accepted on April 26, 2024, by NSAC

"The EIC will be a new world-leading DOE facility at the forefront of scientific discovery. The Subcommittee ranks the EIC as (a) absolutely central in its potential to contribute to world-leading science in the next decade."

"Concerning readiness of the facility for construction, we rank the EIC in category (a) ready to initiate construction."

- ePIC is the only experiment approved for construction at EIC
	- electron-Proton/Ion Collider = ePIC
	- >650 members, 177 institutes, 26 countries
	- 45% North America, 37% Asia, 27% Europe, 4% Africa

ePIC Initiated in **July 2022**

Currently: >850 collaborators (from 2024 Institutional Survey)

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The ePIC collaboration is the strongest team from all over the world to achieve all possible physical targets at EIC

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ePIC Detector Concept

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Proton/Ion beam

Backward Forward

Electron beam

ePIC Detector Concept Backward Collision Point Forward

Proton/Ion beam

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electron, *e*0 , with high precision. All other final state particles (*X*) are ignored. The scattered electron is critical for all processes to determine the event kinematic session of the event kinematics. in coincidence with the scattered electron. We conclude $\frac{1}{2}$

density in nuclei? Does it saturate at high energy, giving rise to gluonic matter

p e ν *W e e*ʹ *h,* … $p \longrightarrow$ *p e h,*γ *p*ʹ • How does a dense nuclear environment affect the dynamics of quarks and event with high precision. ons? **Exclusive DIS:** *e* + *p*/A ! *e*⁰ + *p*⁰ /*A*⁰ + *g*/*h±*,0/*VM*, which requires the measurement of all particles in the measurement of all particles in the measurement of \mathbb{R} *p e e*ʹ $\mathcal{P} \longrightarrow \left\{ \begin{array}{cc} \mathbf{p} & \mathbf{p} \end{array} \right.$ and denote the dynamics of \mathbf{p} gluons, the correlations, and the gluons, and density in the saturate at high energy, giving rise to gluonic matter at high energy, giving rise to gluonic ma \sim and \sim and \sim and \sim and \sim and \sim and even in \sim and even in \sim \mathcal{H} does a dense nuclear environment affect the dynamics of \mathcal{H} gluons, the interactions, and the gluons, and their interactions, and the gluons, and the gluons, $\frac{1}{2}$ $\mathcal{L}(\mathbf{t})$ is saturate at $\mathcal{L}(\mathbf{t})$. Does it saturate at high energy, giving rise to gluonic matter \mathbf{t} $\sum_{i=1}^n a_i$ and $\sum_{i=1}^n a_i$ in all nuclei and even in all nuclei and even in nuclei and even in nuclei and even in a_i ons?

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Produced particles (incl. jets) $mid \sim$ forward n

Electron beam

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EP hadron beam Far-forward <2.1° (~37 mrad)

- BOT Length: 340 cm • BOT Radius: 72.5 cm
	-
- Outer Length: 84 cm
- Outer Radius: 42 cm
	-
- ToF: Part of PID

AC-LGAD Endcap

AC-LGAD Barrel

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AC-LGAD Barrel

Silicon Vertex Tracker (SVT):

- Small pixels (20 μm) 65nm MAPS tech.
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AC-LGAD Endcap rel single π^{\pm} $-2.50 < \eta < -1.00$ π - ePIC (24.02.1/1.11.0 **PWG Requiremen** \bullet π - ePIC (24.02.1/1.11.0

Backward EMCal (-3.5<η<-1.7) PbWO4 crystal

Scattered electron reconstruction

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Scattered electron reconstruction

Imaging Barel EMCal (-1.7<η<1.4) 6 layers of Si sensors with SciFi/Pb layers

with two-sided SiPM readout

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EMCal $(1.4 < \eta < 3.7)$ W/ScFi blocks π/γ separation

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Steel/Sci sampling <20 GeV neutron

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LFHCal **Calorimeter Design** $(1.4 < \eta < 3.7)$ Steel/Sci sampling <20 GeV neutron 4M Towe **Steel Structur HCAL Detector** ECAL Detector 8M EMCal $(1.4 \leq n \leq 3.7)$ W/ScFi blocks π/γ separationImaging Barel EMCal (-1.7<η<1.4) 6 layers of Si sensors with SciFi/Pb layers Layers of AstroPi AstroPix: silicon ensors with sensor with $500x500\mu m^2$ pixel 0.5 mm² size developed for the Amego-X NASA mission **Barrel HCal** sPHENIX re-use *Motion to initiate the change control process (from

- EMCal plays a very important role in scatted electron measurement
	- e' distributes η<-2 region with E>10 GeV

Calorimeter Performance electrons in barrel correspond to the c
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 $\frac{1}{0.8}$
1 / $\sqrt{E \text{ (GeV)}}$

 $50 -$

 $\frac{1}{0.2}$

 $\overline{0.4}$

 $\frac{1}{0.6}$

 \bigcirc EN \bigcirc

- measurement
	-
- γ merging from $π⁰$ starts $p~35$ GeV/*c* with the imaging EMCal

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No strong ⌘ or ' performance dependence

Proximity Focused RICH (pfRICH)

11

~40 cm proximity gap Aerogel + HRPPD sensor (t0) PID by timing information π/K separation up to 10 GeV/c e/π separation up to 2.5 GeV/c

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Dual-Radiator RICH (dRICH)

C2F6 Gas / Aerogel + SiPMs π/K separation up to 50 GeV/c

High-Performance DIRC (hpDIRC)

Quartz bar radiator (reuse BaBar) + MCP-PMTs π/K separation up to 6 GeV/c

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• Electron identification, electron-pion separation at low momentum (high-y) complementary to the

electromagnetic calorimeter

- electromagnetic calorimete
- Hadron identification, pion-

Hyperon decay hadron kinematics

- electromagnetic calorimete
-

- electromagnetic calorimete
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Far-Forward Detector Design

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B0 detector

4 AC-LGAD layers PbWO4 EMCal

B0 detector

Roman Pods

Far-Forward Detector Design $+$ $($ γ∗ $\overline{1}$ $\left\{ \right.$ \int

B0 detector

4 AC-LGAD layers PbWO4 EMCal

> 1st: Si layers + PbWO4/LYSO 2nd: W/Si Imaging EMCal 3rd: Pb/Sci HCal $θ < 5.0$ mrad (η>6.0)

Roman Pods

Zero Degree Calorimeter

2 stations with 2 AC-LGAD layers each /*A*⁰ + *g*/*h±*,0/*VM*,

- B0 detector can reconstruct charged particles and photons at 4.6<η<5.9 region by using a bending magnet
	- Parent particles can be reconstructed

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• BO detector can reconstruct charged par $\frac{2}{9}$ 1.4 $\frac{2}{5}$ $4.6 < \eta < 5.9$ region by using a bending magnetic 1.2 1.4 (GeV)

 $\mathbf{0.2}$

e Parent particles can be reconstructed and $\begin{array}{ccc} \begin{array}{ccc} \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \end{array} \end{array}$

0

 $0.2\Box$

 $0.4\overline{$

 $0.6₊$

 0.8

1

and *^t* = (*p*⁰ *^p*)² (middle) for the 5 ⇥ 41 GeV and 18 ⇥ 275 GeV (right) collision energies.

e

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1 1.2 14 \widetilde{R} Og $4.6 <$ η<5.9 region by using a bending magnet by a state of $\frac{1}{2}$ • BO detector can reconstruct charged particles and photons $at_{41\text{ GeV}}$

0

0.2

0.4

η

and *^t* = (*p*⁰ *^p*)² (middle) for the 5 ⇥ 41 GeV and 18 ⇥ 275 GeV (right) collision energies.

• RPs can detect 60 - 95% momentum, proton

e Parent particles can be reconstructed and $\begin{array}{ccc} \begin{array}{ccc} \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \end{array} \end{array}$

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Far-Forward/Backward Detector Performance \mathbf{g} instead of the virtual photon. In this case of the virtual photon. In this case of the virtual photon. In this case, \mathbf{g} in patikward petettor *p W X* ⎫ $\left\{ \right\}$ \int

 $0.8⁺$ 1 1.2 14 \widetilde{R} Og $4.6 <$ η<5.9 region by using a bending magnet by a state of $\frac{1}{2}$ • BO detector can reconstruct charged particles and photons $at_{41\text{ GeV}}$ e Parent particles can be reconstructed and $\begin{array}{ccc} \begin{array}{ccc} \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \end{array} \end{array}$

assumptions of the contract of
The contract of the contract o B0 tracking reso.

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0.4

and *^t* = (*p*⁰ *^p*)² (middle) for the 5 ⇥ 41 GeV and 18 ⇥ 275 GeV (right) collision energies.

• RPs can detect 60 - 95% momentum, proton

• OMD can detect 40%~65% momentum proton w.r.t steering magnet

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- BO detector can reconstruct charged par $\frac{2}{9}$ 1.4 $\frac{2}{5}$ $4.6 < \eta < 5.9$ region by using a bending magnetic e Parent particles can be reconstructed and $\begin{array}{ccc} \begin{array}{ccc} \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \end{array} \end{array}$ $0.8₁$ 1.2 1.4 (GeV)
- OMD can detect $40\%~65\%$ momentum $\frac{0.6}{0.45}$
- RPs can detect 60 95% momentum, prc

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- $0.8¹$ 1 1.2 14 \widetilde{R} Og 4.6<η<5.9 region by using a bending magnet • BO detector can reconstruct charged particles and photons $at_{41\text{ GeV}}$ – Parent particles can be reconstructed
- 0.4 • OMD can detect 40%~65% momentum proton w.r.t steering magnet
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- V ZDC Can detect heution/photon = 0 2 4 • ZDC can detect neutron/photon

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ePIC-Japan team

- Nucleon structure
	- Yamagata University
	- RIKEN
	- Nihon University

• Member institutes in Japan

– High-energy nuclear physics

- University of Tsukuba
- University of Tokyo
- Nara Woman's University
- Hiroshima University

High-energy particle physics

- Shinshu University
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- Data acquisition
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Japanese team is involved in AC-LGAD TOF, ZDC, and Data Acquisition

Central Detector Non-DOE Interest & In-Kind

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The EIC is a significant experiment that will satisfy our intellectual curiosity and create a new era for mankind!

Thank you!

Neutral Current DIS **Referrion of scattered discussions** electron with highprecision event kinematics f scattered **Event kinematic from final** Parton Distributions in nucleons and nuclei QCD at Extreme Parton Densities - $\frac{1}{e^{\lambda}}$ Saturation ~ 1 fb⁻¹ $\sim h_{\text{max}}$ 1 fb⁻¹ $\frac{1}{2}$ h_{max} and dynamics $\sim 10 \text{ fb}^{-1}$ *p e* **Example DIS:** Predictal Current DIS: Early Charged Constitution District DIS: Prediction District District DIS

Semi-inclusive District Dist *X* լ
| $\left\{ \right.$ \int **Semi-inclusive DIS:** *^e* ⁺ *^p*/A ! *^e*⁰ ⁺ *^h±*,0 ⁺ *^X*, which *e e*ʹ γ∗ *h,* … $\overline{1}$ $\left\{\right.$ \int $p \longrightarrow \Big| \Longrightarrow \Big| X$ electron with the scattered electron. \sum_{μ} and the gluons, and their interactions, and their interactions, and the gluons, and $\frac{d}{dx}$ is a high energy in the saturate at high energy p and p **Example 1 e** + *p* + *p* + *e* + which require the measurement of all particles in the measurement of all particles in the measurement of \mathcal{L} *p* γ∗ *h,*γ

or a gluonic phase with universal properties in all nuclei and even in p *p*ʹ

tron (*e*), proton (*p*), and nuclei (*A*). Final state: Scattered electron (*e*0), neutrino (*n*), photon the event kinematic cannot be reconstructed from the event from the \sim scription anto be recorded from the final state particles. The final state particles in the state particle state particles in the state par ical for all processes to determine the event kinematics. *p* $\begin{matrix} \end{matrix}$ $\left\{ \right\}$ ⎭

Requirements for an EIC detector 20 *2.11. SUMMARY OF DETECTOR REQUIREMENTS*

 $\overline{\varkappa}$

ferent *^x ^Q*² regions over the detector polar angle / pseudorapidity coverage. semi-inclusive $\text{max}_{\text{max}}/\text{cm}^2$ at HL-LHC. For the following summary, and throughout this document, the beams' directions Expected radiation 10¹⁰ n_{eq}/cm² at EIC (10 $^{15\text{-}16}$ n $_{\rm eq}$ /cm 2 at HL-LHC)

armatic deservation (pseudorapidity) Precise vertex, tracking, PID, and calorimetry, **hermetic** detector system (lη|>0, lφ|<π) going "backward" or in the "rear" direction" or in the "rear" direction. The "rear" direction. The "rear" direct
The "rear" direction. The "rear" direction" direction. The "rear" direction. The "rear" direction" direction.

- Precise primary and secondary vertex determination
	- Heavy flavor hadron and hyperon reconstruction
- Precise low-mass tracking at an extensive range
	- Good low momentum resolution
- Particle identification at an extensive range
	- π / K / p separation
- High-resolution EMCal covering a very wide rapidity region
	- Scattered electron identification and kinematic determination
- Reasonable resolution HCal covering a very wide rapidity region
	- Neutral hadron, n / $K⁰_L$ identification for PFA (full jet reco.)
- Far-Forward and Far-Backward detectors
	- Large acceptance for diffraction, tagging neutrons from nuclear breakup
	-

Requirements for an EIC detector

10x275GeV e+p @ 500.0 kHz, 1 fb⁻¹ min-bias integrated lumi. \rightarrow -1.50 < y < 1.50 cm (1 bin)

