Understanding visible matter via the electron-Proton and Ion Experiment at the EIC

Kong Tu (BNL) for the ePIC Collaboration
Seeing is believing – the power of imaging

38 billion km ($\sim 10^{12}$ m)

First-ever image of a black hole - *Event Horizon Telescope*

a few centimeter ($\sim 10^{-2}$ m)

CT scan sequence of a patient with a *glioblastoma*.

10-100 nanometer ($\sim 10^{-9}$ m)

3D images of myelin - the insulation coating our nerve fibres

Astronomical scale

CT scan sequence of a patient with a *glioblastoma*.

Imaging: one of the most convincing scientific methods to understand our nature!
“Seeing” the fundamental structure of matter

Big questions in QCD confinement and its manifest in:
- Origin of mass and spin
- 3D structure of nucleon and nuclei
- Gluon saturation at high energy
- ...
The Electron-Ion Collider will probe the fundamental structure of matter with unprecedented precision.

RHIC tunnel will be reused by the EIC and become the first electron-ion collider.

- $\sqrt{s} \Rightarrow 20 - 141$ GeV
- $\mathcal{L}_{\text{max}} \Rightarrow 10^{34}$ cm$^{-2}$ s$^{-1}$
- Electron, proton, and light nuclei beams can be polarized.
ePIC experiment

➢ electron-Proton-Ion Collider experiment (ePIC) is at IP6.
➢ ePIC experiment is designed to fulfill the requirements of the EIC Yellow report and the NAS report.
ePIC detector subsystem overview

- e/m calorimeters
- MAPS & MPGD trackers
- solenoid coils
- hadronic calorimeters
- PID detectors

1.7 T solenoid magnet

~9.5 meter
MAPS and MPGD trackers

Silicon Vertex Tracker (SVT):
- Monolithic Active Pixel Sensor (MAPS): ~20x20um
- 3 vertex barrels: ITS3 curved wafer-scale sensor, 0.05% X/X0
- 2 outer barrels: ITS3 based Large Area Sensors (EIC-LAS), 0.55%X/X0
- 5 disks (forward/backward), EIC-LAS, 0.25% X/X0
Multi Pattern Gas Detectors (MPGD):
10 ns time resolution, 150 um spatial resolution
- 2 GEM-microRwell endcaps (forward/backward) with 1-2% X/X0.
- Inner Micromegas barrel with 0.05% X/X0.
- Outer GEM-microRwell planar layer
AC-coupled Low Gain Avalanche Diode (AC-LGAD)
• A PID Time of Flight detectors to cover PID at low pT
• Also provide time and spatial info for tracking
• Resolution: ~30 ps, 30 um (with charge sharing)
Barrel (BTOF): 0.05 x 1 cm strip, 1% X/X0
Forward disk (FTOF) : 0.05 x 0.05 cm pixel, 2.5% X/X0
The tracking system from inside out: vertex, Si Tracker, MPGD, BTOF
Tracking is the core of ePIC

Tracking performance based on single particle studies

- Single particle
  - Includes AC-LGAD layers
  - Extreme $\eta$ regions will require use of other ePIC sub detector information
  - Follows requirements elsewhere

Forward and backward regions are challenging to meet the requirement alone by tracking; will need help from other subsystems.
Particle Identification Detectors in ePIC

- **High-performance Detection of Internally Reflected Cherenkov light (hpDIRC)**
- **Proximity-focusing Ring Cherenkov detector (pfRICH)**
- **Dual radiator RICH (dRICH)**

9.5m
Barrel PID detector - hpDIRC

hpDIRC

- 10 long bars
- flat mirrors on far end
- MCP-PMT Sensors
- Reconstruction based on geometrical and/or time info (TOF from AC-LGAD)
- >3sigma pi/k separation power
Backward electron-going PID detector - pfRICH

- **Aerogel**: Three radial bands; Opaque dividers
- **Vessel**: Honeycomb carbon fiber sandwich
- **HRPPD photosensors with timing capability**: 120 mm size
  - Tiled with a 1.5mm gap
  - 68 sensors total

**Performance:**
- Coverage: $-3.5 < \eta < -1.5$
- Uniform performance in \{\eta, \phi\} range
- $\pi/K$ separation: above $3\sigma$ up to 9.0 GeV/c
Forward hadron-going PID detector - dRICH

dRICH:
- for high momentum PID at forward region ~ 50 GeV/c for pi/K separation.
- $1.5 < \eta < 3.5$ coverage
- 4cm aerogel + C2F6 gas
- 6 spherical mirrors to focalize photons
- SiPM based sensors for photon detection
Calorimeter

Calorimeters with wide range of acceptances (backward, barrel, forward) and different technologies:

• Electromagnetic Calorimeter.
• Hadronic Calorimeter.
EM Calorimeter

**Backward**
- PbWO4 crystals
- excellent energy resolution and high pion suppression for electron reconstruction

**Barrel**
- 6 layers of imaging Si sensors (AstroPix) interleaved with 5 SciFi/Pb layer
- Followed by a large section of SciFi/Pb

**Forward**
- W/SciFi blocks beehive with fiber good pi/gamma separation
- Tracking+pECal+LFHCAL for optimized HF jets
- SiPMs as photonsensors
Hadronic Calorimeter

- Low-x hadronic final state important for gluon saturation, typically backward-going
- Exact design still in progress

- Reuse from sPHENIX
- Upgrade electronics to HGCROC
- Increase segmentation by reading out each tile individually

- Forward Hcal: Steel + Scintillator SiPM-on-tile
- Forward insert calorimeter to further improve acceptance ($3.2 < \eta < 4$)
Far-forward and far-backward system

**Far-forward**: Detect particles from nuclear breakup and exclusive processes
- B0 tracker/Calorimeter
- Roman pots
- off-momentum detector
- Zero-degree calorimeter

**Far-backward**:  
- Two low Q² electron taggers  
- luminosity monitor
Far-backward detectors

- **Low Q^2 taggers:**
  - ✓ Pixel-based 4 trackers (Timepix4), with rate capability of > 10 tracks per bunch
  - ✓ Calorimeters (for calibration)
- **Challenges:** high, non-uniform Brem. background

**Luminosity monitor:**
Precise luminosity determination (<1%), from Bremsstrahlung processes \( ep \rightarrow e\gamma p \)

- ✓ Tracker: AC-LGAD strips with 20um resolution
- ✓ Calorimeter: Scintillating Fiber, 23X₀
Far-forward detectors

<table>
<thead>
<tr>
<th>Detector</th>
<th>Acceptance</th>
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</thead>
<tbody>
<tr>
<td>Zero-Degree Calorimeter (ZDC)</td>
<td>$\theta &lt; 5.5$ mrad ($\eta &gt; 6$)</td>
</tr>
<tr>
<td>Roman Pots (2 stations)</td>
<td>$0.0^* &lt; \theta &lt; 5.0$ mrad ($\eta &gt; 6$)</td>
</tr>
<tr>
<td>Off-Momentum Detectors (2 stations)</td>
<td>$0.0 &lt; \theta &lt; 5.0$ mrad ($\eta &gt; 6$)</td>
</tr>
<tr>
<td>B0 Detector</td>
<td>$5.5 &lt; \theta &lt; 20$ mrad ($4.6 &lt; \eta &lt; 5.9$)</td>
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ePIC is an international collaboration

- ePIC Initiated in July 2022
- Currently: >850 collaborators (from 2024 Institutional Survey)
- >650 members active in ePIC activities
4 collaboration meetings so far

JLab, Jan. 2023

Warsaw, July 2023

ANL, Jan. 2024

SBU, July 2022
Going full-speed towards the CD-2 (April 2025)

The thinner bars indicate that R&D and design can continue at a small level beyond CD-2 and CD-3.
ePIC experiment – a versatile detector for understanding the visible matter

✓ ePIC is the 1\textsuperscript{st} Electron-Ion Collider experiment, sitting at IP6.
✓ ePIC is a young but large international collaboration with > 850 members.
✓ ePIC is an experiment with state-of-the-art detector technologies.
Acknowledgment

The event display is provided by VIRTUE, which is made by Sean Preins (UCR), https://store.steampowered.com/app/2728380/VIRTUE/

Many thanks to my ePIC colleagues for their discussions and inputs to the slides!

Thank you!
Backup