Opportunities with a 2nd EIC detector at IP8

Wenliang (Bill) Li, on behalf of the 2nd detector WG @ RHIC & AGS Annual Users’ Meeting

Aug 4, 2023
Why do we need a 2nd detector?

Needed to unlock the full discovery potential of the EIC

- Implies a general-purpose collider detector able to support the full EIC program
- **Cross checks** of key results are essential!

Complementary design features (to ePIC)

- Combined systematics (as for H1 and ZEUS)
- Phase-space coverage
- The EIC will high statistics, uncertainties for the envisioned measurements will be systematics limited.

New physics opportunities

- Take advantage of much-improved near-beam hadron detection enabled by a 2nd focus,
- Impacts, for instance, exclusive / diffractive physics; greatly expands the ability to measure recoiling nuclei and fragments from nuclear breakup.
- New ideas beyond the NAS and Yellow Report scope (EW and BSM)?
Opinions on the 2nd Detector

- Two documented opinion pieces on the subject:

  Opinion 1: Rolf Ent and Richard Milner el. al. for EICUG SC

  Opinion 2: P. Grannis and H. Montgomery

**Motivation for Two Detectors at a Particle Physics Collider**

Paul D. Gramis and Hugh E. Montgomery

(Dated: March 27, 2023)

It is generally accepted that it is preferable to build two general purpose detectors at any given collider facility. We reinforce this point by discussing a number of aspects and particular instances in which this has been important. The examples are taken mainly, but not exclusively, from experience at the Tevatron collider.

Good cases were made for both nuclear and particle physics experiment
Prime Example of Cross Check Power

144 GeV Resonance? No!

- A talk given by H. Montgomery: https://indico.cern.ch/event/1238718/sessions/495759/
  - Result verification
  - Mass determination
  - Veto false signals
- A slide stolen from Mont’s talk at EICUG 2023 on vetoing false signal
- My person take: EIC carries the potential for discovery level physics: **would anyone believe our result without cross-check?**

- 2011 CDF study of dijet mass distributions in $W + \text{jets}$ measurement.
- Statistically significant ($p$-value $7.6 \times 10^{-4}$, $3.2 \sigma$) excess
- Fit to extra Gaussian with width scaled to dijet resolution $\rightarrow$ mass $144 \pm 5 \text{ GeV}$, $\sigma_{\text{BR}} = 4 \text{ pb}$.

Crosscheck!!

- 2011 $D\emptyset$ study gives no excess, with likelihood of $145 \text{ GeV}$ resonance of $\sigma_{\text{BR}} = 4 \text{ pb}$ of $8.10^{-6}$
- Rejection $4.3 \sigma$, $95\%$ CL UL $1.9 \text{ pb}$
Organization and Effort to date

● A detector 2 WG under EIC User Group
  ○ Group Page: https://eicug.github.io/content/wg.html#detector-iiip8-group
  ○ Physics sub-WG
  ○ Detector sub-WG
  ○ Conveners: Klaus Dehmelt (CFNS/SBU), Charles Hyde (ODU), Sangbaek Lee (ANL), Simonetta Liuti (UVA), Pawel Nadel-Turonski (CFNS/SBU), Bjoern Schenke (BNL), Ernst Sichtermann (LBL), Thomas Ullrich (BNL), Anselm Vossen (Duke/JLab)
  ○ General mailing list: eic-det2-l@lists.bnl.gov
  ○ Convener mailing list: eic-det2-conveners-l@lists.bnl.gov

● Meetings:
  ○ Preparation meeting (SBU CFNS):
    ■ https://indico.bnl.gov/event/17693/
  ○ 1st International Workshop on A 2nd Detector for the EIC (Temple U.)
    ■ https://indico.bnl.gov/event/18414/
  ○ EICUG 2023 (Warsaw, Poland)
    ■ https://indico.cern.ch/event/1238718/
Aspirational goals for a 2nd EIC detector

- **MAGNETIC FIELD** – Solenoid field up to 3T, allowing for high resolution momentum reconstruction for charged particles.
- **EXTENDED COVERAGE** for precision electromagnetic calorimetry – important for DVCS on nuclei.
- **MUONS** – enhanced muon ID (not only MIPs) in the barrel and (possibly) backward region.
- **BACKWARD HADRONIC CALORIMETER** – Low-x physics, reconstruction of current jets in the approach to saturation.
- **SECONDARY FOCUS** – tagging for nearly all ion fragments and extended acceptance for low-pT/ low-x protons. Enables detection of short-lived rare isotopes.

See the talk from SANGBAEK LEE for detector and technology:
Official Project Information

- **e-p crossing angle 35 mRad**
- **A short space allocated for the central detector**
  - Less space than ePIC
  - Hard decision needs to be made to meet the design goal (backward angle PID)

  - Contact person: Bamunuvita Gamage (randika@jlab.org)
  - Further optimization is needed! (See example in later slides)
IP6 vs IP8: Similar But Different

IP6 beamline

B0 Trackers + Calorimeter
B0pf Dipole
Q1pf quadrupole
B0apf Dipole
Q2bpf quadrupole
B1apf Dipole
B1apf Dipole

Roman Pots
Hadron Beam after IP
Off Momentum

IP8 beamline

B0 Trackers + Calorimeter
BXSP01 Dipole
QFFDS01A Quadrupole
QFFDS01B Quadrupole
QFFDS02A Quadrupole
QFFDS02B Quadrupole
BXDS01A Dipole

Roman Pots
Hadron Beam after IP
Off Momentum
IP6 vs IP8: similar but different

**IP6:**
- 25 mrad e+p crossing angle
- ZDC Acceptance: -4.5 to +5.5

**IP8:**
- 35 mrad e+p crossing angle
- Second focus
- ZDC Acceptance: ±5
Roman Pots

- **Primary consideration:**
  - Slit opening 10σ wider than the beam width.

<table>
<thead>
<tr>
<th></th>
<th>Slit width</th>
<th>Slit height</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP6 RP 1&amp;2</td>
<td>8.8 cm</td>
<td>1.2 cm</td>
</tr>
<tr>
<td>IP8 1&amp;2</td>
<td>6.2 cm</td>
<td>0.8 cm</td>
</tr>
<tr>
<td>IP8 3&amp;4 (2nd focus)</td>
<td>0.7 cm</td>
<td>0.2 cm</td>
</tr>
</tbody>
</table>

Image by A. Jentsch, BNL

A Closer Look at the 2nd Focus Area and PID

2nd Focus Roman Pots

QDS01 Quadrupole

BXDS01B Dipole

ZDC

2nd Focal Point

RP Layer 3
RP Layer 4
RP Layer 5

QDS01

QDS02

4 m

Quartz fingers

- Z-Tagging Mini DIRC (C. Hyde)
  - Photon counter

\[
\frac{dN}{dX} \approx z^2 (0.013/\text{cm}) = \frac{106}{\text{cm}} \quad \text{for } z = 90
\]
<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>PHYSICS</th>
<th>DETECTOR II OPPORTUNITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffractive dijet</td>
<td>Wigner Distribution</td>
<td>detection of forward scattered proton/nucleus + detection of low $p_T$ particles</td>
</tr>
<tr>
<td>DVCS on nuclei</td>
<td>Nuclear GPDs</td>
<td>High resolution photon + detection of forward scattered proton/nucleus</td>
</tr>
<tr>
<td>Baryon/Charge Stopping</td>
<td>Origin of Baryon # in QCD</td>
<td>PID and detection for low $p_T$ pi/K/p</td>
</tr>
<tr>
<td>$F_2$ at low $x$ and $Q^2$</td>
<td>Probes transition from partonic to color dipole regime</td>
<td>Maximize $Q^2$ tagger down to 0.1 GeV and integrate into IR.</td>
</tr>
<tr>
<td>Coherent VM Production</td>
<td>Nuclear shadowing and saturation</td>
<td>High resolution tracking for precision t reconstruction</td>
</tr>
</tbody>
</table>

Based original slide by R. Fatemi

- Please note that these were selected to illustrate particular opportunities
- You are most welcome to add your favorite process!
Exclusive di-jets studies (Complementarity)

5D Image

\[ \Delta = 0 \quad \int d^2 \vec{k}_\perp \]

3D

GTMDs \((x, \vec{k}_\perp, \Delta)\)

TMDs \((x, \vec{k}_\perp)\)

GPDs \((x, \Delta)\)

PDFs \((x)\)

FFs \((\Delta)\)

1D

GTMDs contain new physics (beyond TMDs & GPDs)

<table>
<thead>
<tr>
<th>Study by S. Bhattacharya, Y. Hatta, et. al.</th>
</tr>
</thead>
</table>

- \(d\sigma\) is sensitivity to the gluon Orbital Angular Momentum
- GTMDs are “disentangled” through suitable linear combination of Polarization Observables

\[ d\sigma \approx \sin(\phi_{P_\perp} - \phi_{N_\perp}) L_g(x) \int d^2 q_\perp q_\perp^2 O(x, q_\perp) \]

- Sinusoidal angular modulation
- OAM
- “Odderon”

Exclusive di-jets studies (Complementarity)

- **Scattered electron** ($e'$): $\eta \to -\infty$, far backward region, low $Q^2$ tagger
- **Recoiled** $p$: $\eta \sim 6$, far forward region
- **Jet 1 (J1) and Jet 2 (J2)**: $-3.5 < \eta < -1.5$, Central detector
- **“Complementarity”**
  - ePIC has to have an edge over the detector 2 central detector design
    - backward HCal (ECCE design lacks backward HCal)
    - ePIC has full backward angle PID
Nuclei give control over the spin:
- Spin-0 2 GPD; Spin-1/2 8 GPDs; Spin-1 18 GPDs
- Half of these intervene in DVCS

In the nucleus two processes
- Coherent and incoherent channel
- Probe the whole nucleus and the bound nucleons

A perfect tool to study the EMC effect
- Coherent DVCS gives access to the full nucleus
  - Including non-nucleonic degrees of freedom
- Incoherent DVCS gives access to the bound nucleon
  - To test modifications of the bound nucleon structure

Measurement at higher -t is feasible

Why ePIC has difficulty for this measurement?
Exclusive $e^+^4He$ DVCS (Complementarity)

- Gluon exchange (specially at low $Q^2$) induced a “gentle tap” will not deflect interacted $^4He$ (at low -$t$) to be detected by the Roman Pots.
- 2nd focus will significantly improve the -$t$.

Active area is 10σ away horizontally.
e$^+$\(^4\)He DVCS at IP8

- For light nuclei, the 2nd focus enables detection with essentially 100% acceptance down to \(p_T = 0\).

- The study on the left shows the importance of the photon energy resolution of the barrel EMcal:
  - PbWO4 with 1-2% resolution
  - ePIC’s GlueX-like EMcal would fall in-between the PbWO4 (black) and 12% (red) points.
**Vector Meson Production via Coherent diffractive Process with $^{90}$Zr**

- Extended forward photon detection is synergetic with the 2nd focus in IR8.
- $^{90}$Zr is ideal for benchmarking:
  - The ability to tag A-1 nuclei in the 2nd focus and detect a large fraction of nuclear photons has the potential to significantly improve the suppression of incoherent backgrounds in coherent diffraction.
  - The photon detection will also help to distinguish reactions where the final nucleus was in the ground state or an excited state.
- The figures on the left show the photons and A-1 fragments from $^{90}$Zr
- The figures on the right show the additional suppression at high $t$ from the 2nd focus

*Study by M. Baker and others*
Simulations of coherent diffraction with $^{90}$Pb

- Diffractive Processes (no color exchange)
  - Coherent and incoherent: shape of heavy nuclei.

Further detail see Bjorn’s talk early today:
A-1 tagging with 2nd focus using a $^{90}\text{Zr}$ beam

A similar study will be completed on Uranium

https://arxiv.org/abs/2208.14575

Study by Mark Baker
Exclusive Vector Meson production

18 GeV e on A

- **Scattered electron (e')**: $\eta \rightarrow -\infty$, far backward region, low $Q^2$ tagger
- **Decayed J/ψ → e⁺e⁻**: $-1.5 < \eta < 3.5$, Central detector
- **Recoiled A (A')**: $\eta \sim 6$, far forward region
What does $A'$ do in the Beam Pipe? (Opportunities)

- eA Diffractive study, forward detector must:
  - Tag $A'$
  - Veto events due to neutron evaporation and gamma de-excitation
A’ Decay is not all bad!

- Evaporated neutron energy deposition study by Niseem Magdy, Y. Jia, et. al.

- Direct measurement of final nuclei, including rare isotopes, and associated de-excitation gamma photons study by B. Moran, et. al.
EIC far-forward acceptance with and without a 2nd focus

Nuclear fragments detection at Roman Pot

Order-of-magnitude improvement in forward acceptance

Most event have a proton carrying a large fraction of the initial momentum and small Pt
Software Tools

● Consensus: not to reinvent the wheel at this stage
● Make best use of ePIC development
  ○ DD4HEP as geometry description
  ○ Podio and EDM4hep as data model
  ○ EIC-recon as reconstruction
● Detail is to be developed
Conclusion

- Three pillars of 2nd Detector
  - Cross-check
  - Complementarity
  - Opportunities

- Enthusiasm from the community with drive the project forward
  - Your input is extremely valuable
Acknowledgement and Advertisement

- Detector 2 is a new opportunity, require input from the community.

- If you would like to share your idea, please reach out to any of the WG conveners directly:
  - [https://eicug.github.io/content/wg.html#detector-iiip8-group](https://eicug.github.io/content/wg.html#detector-iiip8-group)
Backup
In terms of Far Forward Acceptance: B0 is the Key

- The increase to ZDC acceptance from +-5 to +-7 marginally increases the recoil nucleon acceptance:
  - e+p 5x41 GeV pion structure study: 20% increase in terms of nucleon detection efficiency

- Instrumentation of a full calorimeter inside B0 will significantly boost the forward acceptance: from +- 5 mrad to +-28 mrad!

- Due to special constraints, full Calorimeter might be a “no-go”
## IP8 Forward Detector Suggestion

<table>
<thead>
<tr>
<th>Detector</th>
<th>Acceptance</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZDC</td>
<td>$\theta &lt; 5.5$ mrad ($\eta &gt; 6$)</td>
<td>35%/$\sqrt{E}$\n~1mm position resolution</td>
</tr>
<tr>
<td>RP 1&amp;2</td>
<td>$0.0^\ast &lt; \theta &lt; 5.0$ mrad ($\eta &gt; 6$)</td>
<td></td>
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<td>RP 3&amp;4</td>
<td>$0.0^\ast &lt; \theta &lt; 5.0$ mrad ($\eta &gt; 6$)</td>
<td></td>
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<tr>
<td>Off Momentum</td>
<td>$0.0^\ast &lt; \theta &lt; 5.0$ mrad ($\eta &gt; 6$)</td>
<td></td>
</tr>
<tr>
<td>B0 tracker + Calorimeter</td>
<td>$5.5 &lt; \theta &lt; 25.0$ mrad ($4.6 &lt; \eta &lt; 5.9$)</td>
<td>Full Calorimeter</td>
</tr>
<tr>
<td>PID at 2nd focus</td>
<td>$0.0^\ast &lt; \theta &lt; 5.0$ mrad ($\eta &gt; 6$)</td>
<td>Z tagger photon counter</td>
</tr>
</tbody>
</table>
Off Momentum Tracker

- Roman pot without slits.
- Offsetted to one direction
- Protons tagging:
  - $123.75 < E < 151.25 \text{ GeV}$
  - $45\% < p_{z,\text{proton}} / p_{z,\text{beam}} < 55\%$
- Tagging decay remnants from $\Lambda$ or $\Sigma$

Image by A. Jentsch, BNL
Thank you for your attention!
Zero Degree Calorimeter

Image by engineers, BNL

- **ZDC**
  - Sensitive to soft photon and neutron
  - IP6 ZDC $\pm$-5mrad acceptance
  - IP8 benefit from higher acceptance?
Ideas: Adding PID? Z-Tagging Mini DIRC Concept (C. Hyde)

2nd Focal Point

- Z-Tagging Mini DIRC (C. Hyde)
  - Photon counter

\[
\frac{dN}{dX} \approx z^2 (0.013/\text{cm}) = \frac{106}{\text{cm}} \text{ for } z = 90
\]

Ray trace simulation by C.Hyde and R. Dzhyagdlo
In terms of PD acceptance

Rigidity fraction of eA diffractive process:
- with 2nd focus: black + red
- without 2nd focus: black

Study by M. Baker and others

Nuclear fragments detection at Roman Pot

Study by B. Moran and others