The EIC Community: Path Towards Detectors

Thomas Ullrich
JLUO Annual Meeting
June 22-24, 2020
The Long Path to EIC Detectors
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Big Questions & Physics Case
White Paper 2012 & NAS Report
The Long Path to EIC Detectors

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First Detector Ideas & Concepts
The Long Path to EIC Detectors

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R&D, Prototypes
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Detailed Detector Requirements & Concepts

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Mature Detector Design

R&D, Prototypes
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White Paper 2012 & NAS Report

EIC User Group (formal since 2016)

First Detector Ideas & Concepts

Detailed Detector Requirements & Concepts

Mature Detector Design

R&D, Prototypes
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EIC Detector R&D Program (> 2011)

R&D, Prototypes
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First Detector Ideas & Concepts

Detailed Detector Requirements & Concepts

Yellow Report Initiative (2020)

Mature Detector Design

EIC Detector R&D Program (> 2011)

R&D, Prototypes
EIC User Group

• Involved community collaborating on EIC issues since early 2000
  ‣ Focussed around “QCD Community” BNL & JLab and few universities
  ‣ Substantial boosts in interest around 2007 & 2015 NSAC Long Range Plans
• First “User Meeting” at in Stony Brook, June 2014 (161 participants)
• Formation of a formal EIC User Group in 2014/2015
  ‣ Charter approved June 2016
  ‣ Institutional Board
  ‣ Steering Committee
  ‣ http://eicug.org
  ‣ Organization of user meetings, newsletter, talks committees, working groups
EIC User Group in Numbers and Graphs

- 1081 members (252 JLab)
- 224 institutions
- 31 countries

- 60% experimentalists
- 25% theorists
- 14% accelerator scientists
- 1% administration, computing

Graph showing the number of new members per year from 2014 to 2020.
EIC User Group is International

- N. America: 61%
- Europe: 26%
- Asia: 10%
- S. America: 2.5%
- Oceania: 0.8%
- Africa: 0.5%

Interesting Comparison:
~25% US participants in large LHC collaborations
- 20% in ATLAS
- 30% in CMS
Still work to do …

- Behind the curve!

Male (84%)
Female (13%)
Unspecified

Percent of PhDs Awarded to Women in Specified Fields, Classes of 1920 through 2016

- All Fields
- Physical Sciences
- Physics

aip.org/statistics
Current Activities

- Yellow Report Initiative (later)
- New charter
  - require new charter after CD-0/CD-1 (phase II/III)
  - charter writing committee in place
- Elections
  - International Representative on the EICUG Steering Committee
- Coordination of EIC efforts at Snowmass 2021
  - In-depth process by U.S. particle physics community to define the most important questions for our field and to identify the most promising opportunities to address these questions in a global context.
  - Coordinate with EIC community and Snowmass WGs
- Next EIC User Meeting July 15-17, 2020 (remote)
  - https://indico.bnl.gov/event/7352/
EIC Machine Overview

EIC design will meet NSAC and NAS requirements

- Design using much of existing RHIC facility
- 3 accelerator rings:
  - Existing RHIC yellow ring (275 GeV)
  - New Rapid Cycling electron Synchrotron (18 GeV)
  - New Electron Storage Ring (18 GeV)
- 2 injector complexes:
  - Hadron injectors (existing)
  - Electron Injectors
- 2 detector halls
- Hadron Cooling Facility

\[ \sqrt{s} = 20 - 141 \text{ GeV} \]
\[ \mathcal{L}_{\text{max}} = 10^{34} \text{ cm}^{-2}\text{s}^{-1} \]

\[ \text{P(e & p)} = 80\% \]

\[ A = \text{p to Uranium} \]
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EIC: Not Your Standard Collider Setup

Constraining IR features, asymmetric beam energies, synchrotron backgrounds, crossing angle, and wide range of energies impact detector acceptance and detector technologies considerably.
• Hermetic detector, low mass inner tracking
• Electron measurement & jets in wide rapidity range
• Good momentum resolution \((x, Q^2)\)
• Good impact parameter resolution (heavy flavor)
• Excellent EM resolution, especially e-going direction
• Good hadronic energy resolution in h-going direction
• Excellent PID \(\pi/K/p\)

- Forward: up to 50 GeV/c
- Central: up to 7 GeV/c
- Backward: up to 8 GeV/c
Vital: Early Generic EIC Detector Concepts

- Early concepts indicate
  - first feasibility test of measurements
  - estimate of achievable resolutions (and shortcomings)
  - mass distribution - hints were minimizing $X/X_0$ is needed
  - available space for subsystems
  - the need for R&D
Generic EIC Detector R&D Program

- Started 2011 in association with BNL, JLab and the DOE Office of NP
- Funded by DOE through RHIC operations funds
- Program explicitly open to international participation
- Standing EIC Detector Advisory Committee consisting of internationally recognized experts in detector technology

Current: Marcel Demarteau (chair, ANL), Carl Haber (LBNL), Peter Krizan (Ljubljana), Ian Shipsey (Oxford), Rick Van Berg (UPenn), Jerry Va’vra (SLAC), Glenn Young (JLab)

- Typical 10-11 projects supported per FY
- Consortia for Calorimetry, Tracking, PID
- Over 190 participants from 49 institutions (16 non-US)
  - not all are in the EICUG, e.g. colleagues from HEP

URL: https://wiki.bnl.gov/conferences/index.php/EIC_R%2525D
Examples: Calorimetry

- Scintillating fibers embedded in W-powder composite absorber, a.k.a W-SciFi
  - Development led to working prototypes with good energy & position resolutions that would result in a capable EM calorimeter for the barrel and hadron-going directions at an EIC
- Shashlik Calorimeters
- Lead Tungstate (PbWO4) crystals
- Scintillating Glasses
  - Similar to lead glass in many properties but exhibit $>10\times$ the light yield per GeV
  - Allows doping: Gd, Yb, Ce, …
  - Can now make reliably 20 cm bars
- Hadron Calorimetry (beginning)
- SiPM testing
Examples: Tracking

- GEMs & multi-layer GEMs & GEM + MMG
- Low-mass GEM tracker
- Resistive micro-well detector (μRWELL) detector
- Mini-TPC
  - Triple GEM stack with a small drift region
- Cherenkov-TPC
- Gaseous single-photon detection with MPGDs for high-p RICH - new photocathode based on NanoDiamond (ND) particles coupled to MMG
- TPC Readout Chambers, Zig-Zag RO boards
Examples: Particle ID

- **DIRC** (Detection of Internally Reflected Cherenkov light) for barrel region
- **mRHIC**: Compact aerogel RICH covering up to 10 GeV/c ($\pi/K/p$)
- **dRICH**: RICH with two radiators (gas + aerogel) to cover the full momentum range: more than 3 s.d. separation for $\pi/K/p$ over 3-50 GeV/c in forward region (up to 15 GeV for $e/\pi$)
- **Photosensors** (SiPMT, MCP-PMT, LAPPD)
- **High field tests**
- **Time-of-Flight** (LGAD, LAPPD)
The Yellow Report Initiative

Name borrowed from CERN Yellow Reports series which includes reports on detectors and technical papers, criteria being that the audience should be large and the duration of interest long.

- The purpose is to advance the state and detail of:
  - documented physics studies with focus on detector requirements
  - detector concepts to match the requirements including the complementarity of two detectors towards future technical design reports
- Kick off meeting at MIT, Dec 12-13, 2019
- Timeline ~ 1 year driven by (among others):
  - CD-1: March 2021
  - CD-2: September 2022
- Expect effort to facilitate the formation of collaborations
- 4 Working Group Meetings in 2020
  - March (Temple), May (Pavia), September (CUA), November (UCB)
Organization of Yellow Report

Physics WG
Conveners:
- Adrian Dumitru (Baruch)
- Olga Evdokimov (UIC)
- Andreas Metz (Temple)
- Carlos Muñoz Camacho (Orsay)

Detector WG
Conveners:
- Ken Barish (UC Riverside)
- Tanja Horn (CUA)
- Peter Jones (Birmingham)
- Silvia Dalla Torre (Trieste)

EIC UG Steering Committee

Subgroups:
- Inclusive Reactions
- Semi-Inclusive Reactions
- Exclusive Reactions
- Jets & Heavy Flavor
- Diffractive Reactions & Tagging

Subgroups have 2-5 conveners each.
42 conveners in total

- Weekly meeting of each WG & joint meetings
- Regular meetings between PWG and DWG
- Many collaborative tools deployed by EICUG, BNL & JLab to support process: Indico, Email-groups, Dropbox, Wiki, Google calendar, Github, computing resources, …
Physics Working Group Efforts

- Established simulation baseline parameters
  - $e_p, e_{A_{\text{light}}}, e_{A_{\text{heavy}}}, E_e + E_h$ range, $\int L dt = 10 \text{ fb}^{-1}$ and $100 \text{ fb}^{-1}$, $P_{e/p} = 70\%$

- Break-down physics deliverables into “physics objects” (PO): $e$, $h$, jets, …
  - map out kinematics for each PO
  - Cross-check PO maps across physics subgroups to determine the most challenging constraints in terms of detector design;

- Focus on fast simulations
  - determine the optimal/acceptable detector performance
  - confirm/check resulting impact on the rest of the measurements

- Many channels are under study, progressing well
- Many kinematic maps for physics objects completed/near completion
- Fast simulations of many channels are well underway
- Initial constraints on detectors are starting to come out (and being communicated to the DWG)
Physics Working Group - Examples

Inclusive WG: Charged Current

Highest momentum gamma go down the proton (+z) beamline.

Mid-range momentum photons from pion decay contribute in the forward (mid-forward eta) region.

Peaked backward (-z) direction gamma come from e-radiation.

High momentum hadrons from the beam remnant go down the beampipe (+z).

Fragmentation hadrons from scattered quark are produced at mid-range (mid-forward eta) region.

Need detector to be pushed as far forward as possible.

Semi-Inclusive WG: Gluon Sivers

Results for Gluon Sivers: kinematics

Jets & HF WG: D & B mesons

Example: in fast simulation 18 GeV electron + 100 GeV proton int. luminosity at 1 fb^-1.

Track pseudorapdity cut: 1 to 3.

Assumption a hybrid design of MAPS (0.4%X0) and HV-MAPS (0.8%X0) – forward tracker

• Vertex spatial resolution smeared.
• Pseudorapidity dependent tracking momentum and spatial resolution smeared.
• 95% tracking efficiency.
• 100% PID identification.

Exclusive WG: Diffractive dijet production

(Diffraction & Tagging WG: Diffractive production)

\[ \Upsilon \text{ events in EICRoot All-Silicon detector} \]

- LBNL All-Silicon Detector (Developed by LBNL’s eRD16 generic EIC detector project)
  - Silicon Tracker
    - 6 layers
  - Silicon Endcap Disks
    - 6 disks

\[ \text{Upsilon peaks are still distinguishable with a lower B-field} \]

Diffraction & Tagging WG: Diffractive \( \Upsilon \) production

\[ 10 \text{ fb}^{-1} / 197 \]

1.5 Tesla

3.0 Tesla
Main mandate of the Yellow Report is to consider and compare all possible technologies for two EIC detectors

YR timeline short ⇒ balance between full Geant4 simulations and parametrizations

Interactive Detector Matrix

- Official set of physics requirements and technology parameters
## Tracking
- Hot: All-silicon vs hybrid (silicon & gaseous) trackers
- Compare technologies

<table>
<thead>
<tr>
<th>Barrel region</th>
<th>TPC + Fast MPGD Layer</th>
<th>Cylindrical MPGD (Micromegas, µRWell)</th>
<th>Drift Chambers / Straw Tubes</th>
<th>Planar MPGDs (GEM, Micromegas, µRWell)</th>
<th>Small TGCs</th>
<th>MPGD-TRDs</th>
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<td>- momentum res.;</td>
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<td>Pros:</td>
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<td>- additional dE/dx;</td>
<td>- Space point &amp; angular res.;</td>
<td>- momentum res.;</td>
<td>- Alternative to cylindrical MPGDs</td>
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<td>- cost</td>
<td>- Time resolution (&lt; 10 ns)</td>
<td>- additional dE/dx;</td>
<td>arrangement in polygons</td>
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<td>Radiator size</td>
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<td>- Low material in barrel</td>
<td></td>
<td>- cost</td>
<td>- Easier fabrication</td>
<td>Radiator size</td>
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<td>Cons:</td>
<td>- End cap material</td>
<td>Cons:</td>
<td>Cons:</td>
<td>Cons:</td>
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<td>- calibration space</td>
<td>- Momentum res.</td>
<td>- End cap material</td>
<td>- Momentum res.</td>
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<td>- charge distortion</td>
<td>- Fabrication challenges</td>
<td>- calibration</td>
<td>- Detector space barrel</td>
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<td></td>
<td></td>
<td>- Material budget in barrel</td>
<td>- Stability issues</td>
<td>- Material budget in barrel</td>
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<td>- Momentum &amp; angular res.</td>
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<td>- Low material (&lt;0.4%)</td>
<td>- Cost &amp; robustness</td>
<td>- Material budget</td>
<td>- Material budget</td>
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<td>- ?</td>
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<td>Electro End Cap</td>
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## Detector Working Group - Examples

### Tracking
- Hot: All-silicon vs hybrid (silicon & gaseous) trackers
- Compare technologies

### PID
- Many option established in R&D program

<table>
<thead>
<tr>
<th></th>
<th>P Range</th>
<th>Contr. $\sigma_c$</th>
<th>Param.</th>
<th>Pro/Con</th>
<th>Ext. Const</th>
<th>MONTECARLO Sim.</th>
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<td>~YES</td>
<td>YES</td>
<td>~ YES</td>
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<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES (Simplied)</td>
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<td>constant w/</td>
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<td>YES (Simplified)</td>
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<td>(Emission)</td>
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<td>Multipliers)</td>
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<td>DIRC</td>
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- Calorimetry
  - Study many options including crystals, glass, W/SciFi, Shashlyk, Pb/Sc, PbGl, etc.

<table>
<thead>
<tr>
<th>$\eta$</th>
<th>Nomenclature</th>
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<th>HCal</th>
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<td>-3.5 : -2</td>
<td>backward</td>
<td>2/$\sqrt{E}$</td>
<td>3/$\sqrt{E}$</td>
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<tr>
<td>-2 : -1</td>
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<td>7/$\sqrt{E}$</td>
<td>3(6)/$\sqrt{E}$</td>
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<td>-1 : 1</td>
<td>barrel</td>
<td>(10-12)/$\sqrt{E}$</td>
<td>3/$\sqrt{E}$</td>
</tr>
<tr>
<td>1 : 3.5</td>
<td>forward</td>
<td>(10-12)/$\sqrt{E}$</td>
<td>3/$\sqrt{E}$</td>
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</tbody>
</table>

*Technology selection depends on the space available
Several other technologies are under consideration
e/\pi: pion suppression depends on the energy, and the energy and momentum resolutions

EIC Calorimetry overview
Several options including crystals, glass, W/SciFi, Shashlyk, Pb/Sc, PbGl, etc.

Material in front will affect the resolution
Detector Working Group - Examples

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- All DWG are making fantastic progress - more input from PWG is coming
Take Away Message

- EIC User Group
  - Vibrant, international, active, steadily increasing community
  - Good communication with project, labs, and DOE
  - Coordination of European and US Strategy efforts
  - Seed for collaborations
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  - The EIC R&D program is a vital part of the EIC efforts with many active participants making good progress on many components vital for an EIC detector
  - Was essential for many aspects of Yellow Report effort
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- Yellow Report
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  - Very encouraging vibrant collaboration between all parts of QCD community
  - On track to provide mature detector concepts
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Then we only have to built it - but this is another (much longer) talk