Requirements and R&D for a Detector at the Future Electron-Ion-Collider (EIC)

Thomas Ullrich
VCI2022, February 21, 2022
EIC Physics (= QCD Physics)

Investigate with precision universal dynamics of gluons to understand the emergence of hadronic and nuclear matter and their properties

Central Questions:

• How are sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties emerge from them and their interactions?

• How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

• What happens to the exploding gluon density at low-x in hadronic matter? Does it saturate at high energy, giving rise to a gluonic matter with universal properties?
Deep Inelastic Scattering (DIS)

\[ Q^2 \approx x \cdot y \cdot s \]

- \( Q^2 \): resolution power, virtuality
- \( s \): center-of-mass energy squared
- \( x \): momentum fraction of nucleon’s momentum carried by parton (0 < x < 1)
- \( y \): inelasticity (0 < y < 1)

DIS:
- As a probe, electron beams provide unmatched precision of the e.m. interaction
- Direct, model independent, determination of kinematics of physics processes

Gluons dominate matter for \( x < 0.1 \)
Access to gluon dominated region and wide kinematic range in $x$ and $Q^2$

- Large center-of-mass energy range $\sqrt{s} = 20 - 140$ GeV

Access to spin structure and 3D spatial and momentum structure

- Polarized electron and proton and light nuclear beams $\geq 70\%$ for both

Accessing the highest gluon densities ($Q_s^2 \sim A^{1/3}$)

- Nuclear beams, the heavier the better (up to U)

Studying observables as a fct. of $x$, $Q^2$, $A$, etc.

- High luminosity (100x HERA): $10^{33-34}$ cm$^{-2}$ s$^{-1}$
The Community Behind the EIC

The EIC User Group: http://eicug.org

- Formation of a formal EIC User Group in 2014/2015
- 1307 members, 265 institutions, 36 countries
- EIC Science Centers at JLab (EIC²) and BNL/Stony Brook University (CFNS)
- Networks in many countries (e.g. EIC-Net in Italy)
2015: US Nuclear Physics Long Range Plan:
“We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.”

2018: National Academy EIC Review
“The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely.”

December 2019/January 2020:
After science, cost, and host review DoE gives EIC CD-0 (Approve Mission Need) and selects BNL as the hosting site. BNL and JLab are the hosting labs. Project management officially started 4/1/2020.

January/February 2021: Release of CDR, CD-1 Review

July 2021: CD-1 (Approve Alternative Selection and Cost Range) received.
Original cost estimate: $2 - 2.6 B
$100M from New York State towards infrastructure
DOE’s Critical Decision (CD) milestones:

**Aggressive Time Schedule:**
- **CD-2/3a:** April 2023
- **Performance baseline**
- **CD-3:** July 2024
- **Start construction**
- **CD-4a (early):** July 2030
- **CD-4a:** July 2031
- **Start operation**
- **CD-4 (early):** July 2031
- **CD-4:** July 2033
- **Full RF Power Installed**
EIC Machine Overview

EIC is using part of RHIC facility at BNL which is operating at its peak.
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Three Ring Design

• Hadron storage ring 40-275 GeV (existing)
  ‣ Many bunches, 1160 @ 1A beam current
  ‣ Need strong cooling

• Electron storage ring (2.5–18 GeV, new)
  ‣ Many bunches
  ‣ Large beam current (2.5 A) → 10 MW S.R. power
  ‣ S.C. RF cavities

• Electron rapid cycling synchrotron (new)
  ‣ 1-2 Hz
  ‣ Spin transparent due to high periodicity

• High luminosity interaction region(s) (new)
  • \(L = 10^{34}\text{cm}^{-2}\text{s}^{-1}\)
  • Superconducting magnets
  • 25 mrad crossing angle with crab cavities
EIC Machine Overview

- Key parameters
  - $\sqrt{s} = 20 - 140$ GeV
  - $L_{\text{max}} = 10^{34}\text{cm}^{-1}\text{s}^{-1}$
  - Polarization $e$ & $p = 70\%-80\%$
  - hadron beam $A = p$ to $U$

- Requires very complex IR designed to meet physics requirements

- EIC is not your standard Collider Setup
  - asymmetric beam energies, boosted kinematics
  - crossing angle (25 mrad)
  - synchrotron backgrounds
  - machine element free region: $\sim 9.5$ m for detector
  - wide range of energies affect detector acceptance and detector technologies considerably
Detector Planning

- The DOE-NP supported EIC Project includes **one** detector and **one** IR in the reference costing.
- The EIC is capable of supporting a science program that includes **two** detectors and **two** interaction regions.
- The community (EIC User Group) is strongly in favor of two general purpose detectors
  - Complementarity, cross-checks, reduction of systematics
- **EIC User Group “Yellow Report” Effort**
  - Initiative to advance the state and detail of requirements and detector concepts in preparation for the realization of the EIC.
  - 1 year effort concluded in March 2021 with a comprehensive “Yellow” Report
  - 902 Pages, 414 authors from 121 institutions, 675 figures
  - arXiv:2103.05419

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### Detector Planning

- **Tracking Electrons and Photons**
  - HCAL
  - Muons
- **Resolution**
  - Relative Momentum
  - Allowed $X/X_0$
  - Minimum $p_T$ (MeV/c)
  - Transverse Pointing Res.
  - Longitudinal Pointing Res.
  - Resolution
  - $m_{E/E}$
  - PID
  - Min $E$
- **Photon $p$-Range Separation Energy**
  - $< -4.6$ Low-$Q^2$ tagger
  - $-4.6$ to $-4.0$ Not Accessible
  - $-4.0$ to $-3.5$ Reduced Performance
- **Muons** useful for background suppression and improved resolution
  - $-3.5$ to $-3.0$ Forward Detector
  - $m_{p/p}$ ~ $0.1\% \times p^{2\%}$
  - $-2.5$ to $-2.0$ Forward Detector
  - $m_{p/p}$ ~ $0.02\% \times p^{1\%}$
  - $-2.0$ to $-1.5$ Forward Detector
  - $m_{p/p}$ ~ $0.02\% \times p^{5\%}$
  - $-1.5$ to $-1.0$ Forward Detector
  - $m_{p/p}$ ~ $0.1\% \times p^{2\%}$ up to $5\%$ or less
  - $-1.0$ to $-0.5$ Forward Detector
  - $m_{p/p}$ ~ $0.1\% \times p^{2\%}$ up to $1\%$
  - $0.0$ to $0.5$ Forward Detector
  - $m_{p/p}$ ~ $50\% / E_{\gamma}$
  - $0.5$ to $1.0$ Forward Detector
  - $m_{p/p}$ ~ $10\% / E_{\gamma}$
  - $1.0$ to $1.5$ Forward Detector
  - $m_{p/p}$ ~ $50\% / E_{\gamma}$
  - $1.5$ to $2.0$ Barrel
  - $m_{p/p}$ ~ $50\% / E_{\gamma}$
  - $2.0$ to $2.5$ Barrel
  - $m_{p/p}$ ~ $50\% / E_{\gamma}$
  - $2.5$ to $3.0$ Forward Detectors
  - $m_{p/p}$ ~ $50\% / E_{\gamma}$
  - $3.0$ to $3.5$ Forward Detectors
  - $m_{p/p}$ ~ $50\% / E_{\gamma}$
  - $3.5$ to $4.0$ Forward Detectors
  - $m_{p/p}$ ~ $50\% / E_{\gamma}$
  - $> 4.6$ Proton Spectrometer
  - $0.0$ to $4.5$ Neutral Detection
  - $m_{p/p}$ ~ $50\% / E_{\gamma}$
Measurement categories to address EIC physics:

- **Inclusive DIS ($e'$)**
  - fine multi-dimensional binning in $x$, $Q^2$

- **Semi-inclusive DIS / SIDIS (fwd hadrons)**
  - 5-dimensional binning in $x$, $Q^2$, $z$, $p_T$, $\theta$

- **Exclusive processes (hermeticity)**
  - 4-dimensional binning in $x$, $Q^2$, $t$, $\theta$ to reach $|t| > 1$ GeV$^2$

\[ \int L \, dt \]

- 1 fb$^{-1}$
- 10 fb$^{-1}$
- 10-100 fb$^{-1}$

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**Category of Processes to Study**

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**Machine & detector requirements**
The energy and angle of scatter electron gives key variables $x, y, Q^2$.
Inclusive (All): Scattered Electron Requirements

The energy and angle of scatter electron gives key variables $x, y, Q^2$

Measurements with $A \geq 56$ (Fe):
- $eA/\mu A$ DIS (E-139, E-665, EMC, NMC)
- $\nu A$ DIS (CCFR, CDHSW, CHORUS, NuTeV)
- DY (E772, E866)

20 GeV on 100 GeV, $0.1 < Q^2 < 1 \text{ GeV}^2$, $3 \times 10^{-5} < x < 2 \times 10^{-4}$
The energy and angle of scatter electron gives key variables $x, y, Q^2$

Measurements with $A \geq 56$ (Fe):
- $eA/\mu A$ DIS (E-139, E-665, EMC, NMC)
- $vA$ DIS (CCFR, CDHSW, CHORUS, NuTeV)
- DY (E772, E866)

20 GeV on 100 GeV, $0.1 < Q^2 < 1$ GeV$^2$, $5 \times 10^{-4} < x < 3 \times 10^{-3}$
The energy and angle of scatter electron gives key variables $x, y, Q^2$.
Inclusive (All): Scattered Electron Requirements

The energy and angle of scatter electron gives key variables $x, y, Q^2$

Measurements with $A \simeq 56$ (Fe):
- $eA/\mu A$ DIS (E-139, E-665, EMC, NMC)
- $\nu A$ DIS (CCFR, CDHSW, CHORUS, NuTeV)
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20 GeV on 100 GeV, $7 < Q^2 < 70$ GeV$^2$, $3 \cdot 10^{-2} < x < 1 \cdot 10^{-1}$
The energy and angle of scatter electron gives key variables \( x, y, Q^2 \).
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- $e'$ Measurement Requires:
  - excellent electron identification ($e/h$)
  - equal rapidity coverage for tracking and calorimeter
  - low material budget to reduce bremsstrahlung
  - momentum/energy and angular resolution are critical

![Graph showing data points for $Q^2$ values between 200 and 1000 GeV$^2$ with $0.1 < x < 1$]
SIDIS: Hadron Identification Requirements

- Physics Requirements
  - \( \pi^\pm, K^\pm, p^\pm \) separation over a wide range \(|\eta| \leq 3.5\)
  - Strong Momentum–\( \eta \) correlation
    - \(-5 < \eta < 2: 0.2 < p < 10\) GeV/c
    - \(2 < \eta < 5: 0.2 < p < 50\) GeV/c
Particle ID (PID) Techniques

- EIC will need for most of the physics a resolution of
  - $\pi/K \sim 3 - 4\sigma$
  - $K/p > 1\sigma$

- Need more than one technology to cover the entire momentum ranges at different rapidities

- Need absolute particle numbers at high purity and low contamination

- EIC PID needs are more demanding than at most collider detector
Magnet

- Cannot affect the $e$ beam to avoid synchrotron radiation $\Rightarrow$ Solenoidal Field (common in HEP)
- Downside is missing bending power $\int B \cdot dl$ in forward and backward region putting extreme requirements on tracking (h) and calorimetry (e)

Services

- Central detector will contain > 16 different subsystems
- Substantial integration challenge for power, cooling, and data services
- Hermeticity?!
Hermetic detector, low mass inner tracking

- Moderate radiation hardness requirements

- Electron measurement & jets in approx. $-4 < \eta < +4$

- Good momentum resolution
  - central: $\sigma(p)/p = 0.05 \% p \oplus 0.5 \%$
  - fwd/bkd: $\sigma(p)/p = 0.1\% \oplus 0.5\%$

- Good impact parameter resolution: $\sigma = 5 \oplus 15/p \sin^{3/2} \theta (\mu m)$

- Excellent EM resolution
  - central: $\sigma(E)/E = 10 \% / \sqrt{E}$
  - backward: $\sigma(E)/E < 2 \% / \sqrt{E}$

- Good hadronic energy resolution
  - forward: $\sigma(E)/E \approx 50 \% / \sqrt{E}$

- Excellent PID $\pi/K/p$
  - forward: up to 50 GeV/c
  - central: up to 8 GeV/c
  - backward: up to 7 GeV/c

- Low pile-up, low multiplicity, data rate $\sim 500$kHz (full lumi)

Hermeticity, low mass, and PID requirements makes EIC detector design challenging
Detector Proposals

- March 6, 2021, BNL & JLab released the Call for Collaboration Proposals for Detectors with expected proposal submission deadline of December 1, 2021.
- Location: IP6 (in project scope), IP8
- EIC Detector Proposal Advisory Panel (DPAP) chaired by Rolf Heuer (CERN) and Patty McBride (FNAL) + 8 members
- The call was answered by 3 proto-collaborations: ATHENA, CORE, ECCE

Review Meeting
- Cover: Design, technology, performance, collaboration/organization, cost, schedule
  - December 13–15, 2021
  - January 19-21, 2022
- DPAP supported by EIC Detector Advisory Committee (DAC) on all technical aspects
- Report to be released March 1, 2022

Proposed Detectors

• ATHENA and ECCE quite similar in design
  ‣ differences due to size and B field
  ‣ tracking and PID very similar
  ‣ calorimeter technologies differ
• Example: ATHENA
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  ‣ Solenoid
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• Example: ATHENA
  ‣ Solenoid
  ‣ Barrel tracking
    ▪ vertex - wafer-scale stitched MAPS
    ▪ inner - MAPS layers
    ▪ outer - cylindrical Micromegas layers
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  › Endcap Tracking
    ○ MAPS Disks
    ○ Planar GEMs/$\mu$RWell with annular shape
    ○ $\mu$RWell disk
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  ‣ Particle Identification
    ○ dual RICH (aerogel + gas)
    ○ proximity focussing RICH (aerogel)
    ○ high-performance DIRC
    ○ Time-of-Flight with *AC-LGAD* sensors
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- EM Calorimetry
  - forward: W-Powder/Scintillating Fiber
  - backward: PbWO$_4$, SciGlass
  - barrel: Astropix imaging layers & Pb/SciFi layers
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- Hadron Calorimetry
  - Fe/Sci sandwich
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- Support Structure & Platforms
• Many of the considered subsystems were developed and matured in the Generic EIC Detector R&D Program.
• Program was supported through funds provided to BNL by the DOE Office of Nuclear Physics and was running for 10 years (2011 - 2021).
• FY21: 281 participants from 75 institutions (37 non-US).
• Many PIs and participants of this program now active in detector working groups of the proto-collaborations.
• Generic R&D is now replaced by Project R&D aims at achieving the maturity required to carry out final design and construction.
• Currently, this program is not specific to any proto-collaboration and focuses on those technologies that are common to all experiments.
• The community is eager to restart a generic R&D program to work on potential future upgrades and technologies that are considered in a 2nd detector - work in progress.

# Generic R&D Projects 2014-2021

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<th>Topic</th>
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<td>eRD2</td>
<td>A Compact Magnetic Field Cloaking Device</td>
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<td>eRD3</td>
<td>Design and assembly of fast and lightweight forward tracking prototype systems</td>
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<td>eRD6</td>
<td>Tracking and PID detector R&amp;D towards an EIC detector</td>
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<td>eRD10</td>
<td>(Sub) 10 Picosecond Timing Detectors at the EIC</td>
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<td>eRD11</td>
<td>RICH detector for the EIC’s forward region particle identification - Simulations</td>
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<td>eRD12</td>
<td>Polarimeter, Luminosity Monitor and Low Q2-Tagger for Electron Beam</td>
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<td>eRD14</td>
<td>An integrated program for particle identification (PID)</td>
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<td>eRD15</td>
<td>R&amp;D for a Compton Electron Detector</td>
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<td>eRD16</td>
<td>Forward/Backward Tracking at EIC using MAPS Detectors</td>
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<td>eRD17</td>
<td>BeAGLE: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing/Saturation Regime</td>
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<td>eRD18</td>
<td>Precision Central Silicon Tracking &amp; Vertexing</td>
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<td>eRD19</td>
<td>Detailed Simulations of Machine Background Sources and the Impact to Detector Operations</td>
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<tr>
<td>eRD20</td>
<td>Developing Simulation and Analysis Tools for the EIC</td>
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<td>eRD21</td>
<td>EIC Background Studies and the Impact on the IR and Detector design</td>
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<td>eRD22</td>
<td>GEM based Transition Radiation Tracker R&amp;D</td>
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<td>eRD23</td>
<td>Streaming Readout for EIC Detectors</td>
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<td>eRD24</td>
<td>Silicon Detectors with high Position and Timing Resolution as Roman Pots at EIC</td>
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<tr>
<td>eRD25</td>
<td>Si-Tracking</td>
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<tr>
<td>eRD26</td>
<td>Pulsed Laser System for Compton Polarimetry</td>
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<tr>
<td>eRD27</td>
<td>High Resolution ZDC</td>
</tr>
<tr>
<td>eRD28</td>
<td>Superconducting Nanowire Detectors</td>
</tr>
<tr>
<td>eRD29</td>
<td>Precision Timing Silicon Detectors for combined PID and Tracking System</td>
</tr>
</tbody>
</table>

**Categories:** Tracking, PID, Calorimetry, Software/Simulations, Other
### Project R&D Projects 2022

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<th>Project</th>
<th>Topic</th>
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<td>eRD101</td>
<td>mRICH / aerogel RICH</td>
</tr>
<tr>
<td>eRD102</td>
<td>dRICH</td>
</tr>
<tr>
<td>eRD103</td>
<td>hpDIRC</td>
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<tr>
<td>eRD104</td>
<td>Service reduction</td>
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<tr>
<td>eRD105</td>
<td>SciGlass</td>
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<tr>
<td>eRD106</td>
<td>Forward EMCAL</td>
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<tr>
<td>eRD107</td>
<td>Forward HCAL</td>
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<tr>
<td>eRD108</td>
<td>Cylindrical &amp; Planar MPGD</td>
</tr>
<tr>
<td>eRD109</td>
<td>ASICs/Electronics</td>
</tr>
<tr>
<td>eRD110</td>
<td>Photosensors</td>
</tr>
<tr>
<td>eRD111</td>
<td>Si-Tracker (no sensors)</td>
</tr>
<tr>
<td>eRD102</td>
<td>ToF with AC-LGAD</td>
</tr>
</tbody>
</table>

- Currently R&D funding not available due to Continuing Resolution in the US
- R&D plan will have to be adjusted depending on the outcome of proposal selection program
Example: Crystals and Glasses (eRD1 & eRD105)

- EIC: e-going direction needs high precision calorimetry ($\approx 2%/\sqrt{E}$)
- Typically requires Lead Tungstate (PbWO4) crystals
- Crystals are expensive, few vendors (SICCAS, CRYTUR)
  - Quality and QA issues
  - Moderate production capacity, raw material shortage

- New effort R&D: Scintillating glasses (CUA/Vitreous State Laboratory)
  - Similar to lead glass in many properties but exhibit $>30\times$ the light yield per GeV
  - Nano-sized particles of BaSi$_2$O$_5$
  - Allows doping: Gd, Yb, Ce, …
  - Efforts combined in EEEMCAL consortium
Steady progress due to R&D program and Small Business Innovation Research (SBIR) funding

- 40cm long bars will match PbWO₄ resolution required & achieved
- Radiation test very positive
- SBIR phase-II to start large-scale production (40+ cm, rectangular and projective shapes)
- Path to inexpensive high resolution EM calorimeters
Example: Photosensors (eRD14 & eRD110)

- EIC requires highly-pixilated photodetectors working at 1.5-3 T. This problem is most critical for RICH detectors and is not fully solved yet.

- Currently
  - Calorimetry ➞ SiPM (~OK)
  - RICH detectors ➞ SiPM (noise, mitigation strategies)
  - hpDIRC ➞ MCP PMT (~OK but expensive, field resistance on edge)

- MCP-PMTs
  - On market: Photonis/Photek
  - Characterization of performance in eRD14
  - Not tolerant to magnetic fields (angle!)
  - OK for hpDIRC (readout in low B region)
  - No collaboration with vendor

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  - On market: Photonis/Photek
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- Our past studies of single-anode MCP PMTs suggest smaller pore size yields higher-B immunity.

- Details of performance depend on orientation.

<table>
<thead>
<tr>
<th>B (T)</th>
<th>Average Charge (a.u.)</th>
<th>G (×10^5)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>1.4</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>2.79</td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td>2.6</td>
</tr>
</tbody>
</table>

- Photonis PP0365G

- HV=2.79 kV
- 99.6% of HV_max

- HV=2.6 kV
- 98% of HV_max

- 6 μm pore size
- HV=-2.79 kV
- 99.6% of HV_max

- 6 μm pore size
- HV=-2.6 kV
- 98% of HV_max

- Photonis PP0365G
Example: Photosensors (cont.)

**SiPM**

- **Pros:** high photon efficiency, good time resolution, insensitive to magnetic field
- **Cons:** large dark count rates (data rate!), not radiation tolerant
- $10^{11}$ (1-MeV) neq/cm at dRICH sensor location reached after 10 years

**Mitigation:**

- Cooling ($T < -30^\circ$) & annealing cycles ($T > 120^\circ$), anneal-in-place needed
- Variations in devices from different providers → detailed characterization
- Lots of synergy with efforts in Italy (INFN) & collaboration with FBK
- Unclear how to modify SiPM design to achieve better radiation hardness
Example: Photosensors (cont.)

- **LAPPD/HRPPD** potential solution for EIC
  - Photon detector + ~10 ps ToF detector at the same time
- **Large-Area Picosecond PhotoDetector (LAPPD)**
  - Microchannel plate (MCP) based large area picosecond photodetector
  - Original LAPPD-Collaboration (HEP), now INCOM (Gen-II)
    - Promising but still not fully applicable for EIC needs
      - good but not sufficient field resilience
      - no pixelization
    - Efforts at ANL to develop pixelized more field resistant version in collaboration with INCOM
- **High-Resolution Picosecond PhotoDetector (HRPPD)**
  - In development by manufacturer (INCOM)
  - Novel multi-anode direct readout
  - Reduced gap spacing for improved timing resolution and B-Field tolerance
  - DOE SBIR support
Example: ITS3 MAPS Sensors (eRD25, eRD111)

**EIC Vertex & Tracking Requirements:**
- Spatial resolution: ~5 µm, material budget < 0.3% X/X₀ per layer, integration time ~2 µs, low power consumption (air cooling)
- Consensus that technology of choice is MAPS (used in ALICE, STAR)
- None of the existing MAPS sensors meets all of the requirements

**EIC MAPS**
- EIC Si Consortium joined forces with ITS3 collaboration developing novel MAPS sensor for an upgrade of the inner tracking system of the ALICE experiment at CERN
- Goal is to develop Large-area, wafer-scale, stitched sensors bent around beam pipe using latest 65 nm MAPS technology
- EIC sensor development needs to fork-off later to develop an ITS3-derived sensor for outer layers (non stitched wafer-scale sensors)
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Radiator gases for EIC RICH detectors are fluorocarbons that exhibit extremely high Global Warming Power: $\text{GWP(C}_2\text{F}_6) \sim 10000$, $\text{GWP(CO}_2) = 1$.

Increasingly prohibited across the world.

Where used:
- Complex and expensive close circulation systems needed.
- Increasing procurement issues expected.

RICH performance is preserved when fluorocarbons at atmospheric pressure are replaced with argon pressurized at a few bar.

The challenge is to design a vessel that allows:
- Safe high-pressure operation.
- Minimizing its impact on the overall detector material budget.
- Engineering in progress - awaiting results.
Take Away Message

• An Electron-Ion Collider will contribute profoundly to the understanding of matter and be an important component in our suite of tools to revolutionize our knowledge in the next decades

• Detector requirements are established in Yellow Report (arXiv:2103.05419)

• EIC Detectors are unique and challenging to realize
  ‣ Hermiticity, PID, high precision, low material, complex IR

• Three proto-collaboration compete for two IR’s
  ‣ Despite different efforts EIC User Group is healthy, collaborative community
  ‣ March is decision month on detector concepts/designs

• Instrumentation challenges: Photodetectors, high resolution EM calorimetry, wafer-scale stitched sensors MAPS, $\mu$RWell, replacement of global warming gases

• Sound generic R&D program from 2011-2021, new project R&D program in place to reduce remaining risks
Backup Slides
Example: Cylindrical and Planar $\mu$RWell (eRD6, eRD108)

- Barrel (cyl.) and endcap (planar) tracking using MPGDs
- $\mu$RWell technology is recent development
- Use instead GEMs or Micromegas
  - combines the advantages of GEM and Micromegas
  - easier detector construction, no stretching as for GEMS
    - lower material budget
    - save around 25% in material cost
- Envision capacitive-sharing pad readout: Vertical stack of pads layers → transfer of initial charge from MPGD by capacitive coupling
- Has not yet been adopted in any experiment
ATHENA - A Totally Hermetic Electron Nucleus Apparatus

https://athena-eic.org
Chapter 2: The ECCE Detector

This chapter presents a description of the ECCE detector, including the central detector (barrel, forward electron endcap and backward hadron endcap), and the far-forward and far-backward systems. A high-level description is provided in the first section, to highlight the integrated design. Detailed descriptions of each ECCE region are then found in the following sections.

2.1 ECCE detector overview

The ECCE detector consists of three major components: the central detector, the far-forward system, and the far-backward region. The ECCE central detector has a cylindrical geometry based on the BaBar/sPHENIX superconducting solenoid, and has three primary subdivisions: the barrel, the forward endcap, and the backward endcap (Fig. 2.1). Henceforth "forward" is defined as the hadron/nuclear beam direction and backwards the electron beam direction. We will use electron or backward, and hadron or forward interchangeably when describing the endcaps.

Table 2.1 lists the physics requirements in the ECCE central detector, the technical challenges associated with its realization, and the ECCE solutions that achieve the stated goals. Comments about future upgrade paths are included in the notes.

Backward Endcap
- Tracking:
  - ITS3 MAPS Si discs (x4)
  - AC-LGAD
- PID:
  - mRICH
  - AC-LGAD TOF
  - PbWO₄ EM Calorimeter (EEMC)

Barrel
- Tracking:
  - ITS3 MAPS Si (vertex x3; sagitta x2)
  - μRWell outer layer (x2)
  - AC-LGAD (before hpDIRC)
  - μRWell (after hpDIRC)
- h-PID:
  - AC-LGAD TOF
  - hpDIRC
- Electron ID:
  - SciGlass EM Cal (BEMC)
- Hadron calorimetry:
  - Outer Fe/Sc Calorimeter (oHCAL)
  - Instrumented frame (iHCAL)

Forward Endcap
- Tracking:
  - ITS3 MAPS Si discs (x5)
  - AC-LGAD
- PID:
  - dRICH
  - AC-LGAD TOF
- Calorimetry:
  - Pb/ScFid shashlik (FEMC)
  - Longitudinally separated hadronic calorimeter (LHFCAL)

Figure 2.1: Principal components of the ECCE central detector: backward/electron endcap (left), barrel (center), and forward/hadron endcap (right).

The ECCE detector size is determined by the reuse of the BaBar magnet and sPHENIX HCAL, and further EIC detector needs:
- Needs +5 m on proton/ion side.
- Needs less space (-3.5 m) on electron side.
- The detector radius is 2.7 meter, with the RCS beam at 3.35 meter.

https://www.ecce-eic.org
CORE: a COmpact detector for the EIC

FIG. 2. View of CORE created using “SketchUp” 3D modeling software.

The detector is built around a Si pixel tracker (2.4 m long and 44 cm in radius) with excellent vertex and momentum resolution (shown in Fig. 20). The tracker makes efficient use of the magnetic field, taking up 19% of the 7.8 m³ volume of the solenoid. The small radius of the tracker and the proximity of the DIRC and barrel EMcal, which are located directly outside of the tracker, allow particles with lower pT to reach the PID systems even when operating at 3 T. This reduces the need to divide up the beam time between different solenoid field settings. The silicon tracker is complemented by a MPGD tracker in-between the dual-radiator RICH and EMcal in the hadron endcap.

Particle identification is provided by three systems. For particles detected in the hadron endcap, the dual-radiator RICH (aerogel + gas) provides 3⇡/K separation up to 50 GeV/c and e/⇡ up to 15 GeV/c (with better separation at lower momenta). It has a gas depth of 1.2 m and ample space for the photosensors. In the barrel outside the tracker there is a high-performance DIRC (0.5 mm radius). The baseline option is to re-use radiator bars from the BaBar DIRC [5]. The small size of the CORE DIRC would also make it affordable to build new, thinner bars—although this would require some additional R&D for validation. The thin bar option is discussed in section V C 2. For the baseline bar option, the DIRC can provide 3⇡/K separation up to 6-7 GeV/c, and better at lower momenta. For momenta in the 0.2-0.5 GeV/c range (|p|, not pT), the DIRC can operate in a "threshold mode" (pions give a strong signal while kaons and protons are below Cherenkov threshold), extending the coverage down to the lowest momenta. A similar mode of operation is also available for the dual-radiator RICH, although the kaon threshold in the aerogel is 2 GeV/c (due to the lower index of refraction). The DIRC also provides timing information with an ⌘-dependent resolution, reaching about 20 ps closest to the electron endcap. In the electron endcap, CORE will use an AC-LGAD TOF system with 25 ps resolution located...