ATHENA
A Totally Hermetic Electron-Nucleus Apparatus

Yulia Furletova (JLAB),
On behalf of ATHENA pre-collaboration
Kick-off meeting for EIC@IP6

with 292 register participants, attendance peak at 197, no session with less than 130 participants

Following the site selection for construction of the U.S. Electron-Ion Collider research facility by the U.S. Department of Energy (DOE) in early 2020, the EIC Users Group led a year-long Yellow Report initiative to define the detector design criteria needed to realize the EIC physics described in the EIC White Paper, supported by the National Academy of Sciences. Using the Yellow Report as input, a Reference Detector concept was presented at the recently held DOE Critical Decision-1 review of the EIC.

A Call for EIC Detector Proposals has been issued by DOE & BNL/JLab on March 6, 2021 with an expected proposal submission deadline on December 1st, 2021. The EICUG community's strong preference for two detectors has led to multiple exciting detector initiatives. We invite all interested groups and consortia to come together to plan for a detector inspired by the Yellow Report detector concept based on a new central detector magnet up to 3T, which could evolve into a concrete proposal and collaboration formation for IP6.

This message is to invite you to a kick-off meeting on March 12-13, 2021. We will review the Yellow Report's work, consider all emerging ideas for EIC detectors, encourage the formation of subsystem consortia, and organize ourselves for the next steps. The meeting is meant to enable forming a collaboration, planning timelines, and developing strategies to engage EIC community members to meet the deadline for submitting a detector proposal.

Hosted by Collaborating Universities
Kick-off meeting for EIC@IP6

the warm and wide Expressions Of Interest presentation:

1:30 PM  DAQ/Readout subsystems presentations: 3  [DAQ_Readout.pptx]
1:45 PM  Calorimetry subsystems presentations: 6  [Calorimetry.pptx]
2:15 PM  Tracking subsystems presentations: 10  [Tracking.pptx]
3:20 PM  Particle-ID subsystems presentations: 6  [PiD.pptx]
3:50 PM  Rear/Forward taggers subsystems presentations: 3  [Rear_Froward_Tag.png]
4:05 PM  Polarimetry subsystems presentations: 3  [Polarimetry.pptx]
4:20 PM  EIC Software presentations: 4  [Software.pptx]
Based on new up to 3T magnet and the YR reference detector

An initial Reference Detector concept was presented at the recently held DOE Critical Decision-1 review of the EIC and is included in the EIC-CDR 2021

It should/will cover the physics of EIC White Paper, NAS report and Yellow Report.

It will fulfill entirely the Call for Detector Proposal mandate for Detector 1

Contact to EIC Project Management: Elke Aschenauer
Structuring the collaboration

Temporary structure (still for a few weeks) needed to let the activity progress while preparing a consolidate structure. It includes:

- the coordination committee ([eic-ip6-org-l@lists.bnl.gov](mailto:eic-ip6-org-l@lists.bnl.gov)) (namely the kick-off meeting organizers).
  Silvia Dalla Torre, Abhay Deshpande, Olga Evdokimov, Yulia Furletova, Barbara Jacak, Alexander Kiselev, Franck Sabatie, Bernd Surrow
- the preliminary IB (one representative per Institution for the time being)
  * the charter in preparation by a dedicated committee (illustrated in the following slides)
- presently **94 institutions** are contributing

ATHENA pre-collaboration is open to the whole EICUG community
- Web-page: [https://sites.temple.edu/eicatip6](https://sites.temple.edu/eicatip6)
- Join EIC@IP6 on Slack: [link](https://sites.temple.edu/eicatip6)

Image design by Joanna Griffin and Shannon West of Jefferson Lab
<p>| AGH University of Science and Technology, Krakow, Poland | CUA, USA | Fudan University, China | INFN Ferrara, Italy |
| Akal University, India | A. Alikhanyan National Science Laboratory (Yerevan Physics Institute), Armenia | Goa University, India | INFN Genova, Italy |
| ANL, USA | Czech Technical University in Prague, Czechia | GSI, Germany | INFN Laboratori Nazionali di Frascati, Italy |
| Banaras Hindu University, India | DA V College, Chandigrah, India | GSU, USA | INFN Laboratori Nazionali del Sud, Italy |
| BNL, USA | Daresbury Laboratory, UK | IFJ PAN, Poland | INFN Padova, Italy |
| Brunel University, UK | Duke University, USA | IJCLab, Université Paris-Saclay, CNRS-IN2P3, Orsay, France | INFN Roma1, Italy |
| CCNU Wuhan, China | FIT, USA | INFN Bari, Italy | INFN Roma2, Italy |
| Central University of Karnataka, India | Florida International University, USA | INFN Bologna, Italy | INFN Torino, Italy |
| Central University of Tamil Nadu | Florida State University, USA | INFN Catania, Italy | INFN Trieste, Italy |
| CIAE, China | Forschungszentrum Jülich, Germany | INFN Cosenza, Italy | INFN Trieste, Italy |</p>
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<th>Indian Institute of Science Research and Education, Berhampur, India</th>
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<td>UC Berkeley, USA</td>
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The highly international team of the ATHENA pre-collaboration.

Total 94 institutions.
EIC@IP6 → ATHENA

24 naming proposals, 23 LOGO proposals open to the whole collaboration

https://sites.temple.edu/eicatip6/athena-logo-competition/
in parallel an active ad hoc committee is preparing a charter:

- Our Charter Committee:
  - Ken Barish (UC Riverside)  Zein-Eddine Meziani (ANL)  Daria Sokhan (Glasgow)
  - Olga Evdokimov (UIC)  Bedanga Mohanty (NISER)  Thomas Ullrich (BNL)
  - David Gaskell (JLAB)  Marta Ruspa (Torino)  Anselm Vossen (Duke)
  - Nicole d'Hose (CEA-Saclay)  Murad Sarsour (GSU)  Qinghua Xu (Shandong)
  - Tom Hemmick (Stony Brook)  Ernst Sichtermann (LBNL)

Meetings began on 4/23 and have made significant progress laying the foundations for the developing document.

The goal is to have a full draft available by early June, for the subsequent iterations with the IB and the adoption vote.
Developing Structure

Institutional Board
IB Chair, IB Vice-chair

Executive Board

Spokesperson(s)

Detector Subsystems
- Magnet
- Calorimetry
- Tracking
- Particle-ID
- Rear/Forward
- Polarimetry
- DAQ/Readout

Software/Simulations

Physics Validation
- Inclusive
- SIDIS
- Jets/HQ
- Diffraction/
- Tagging
- Exclusive

Collaboration Committees

Proposal Committee
Proposal Committee

- **Integration / Global design:** Bedanga Mohanty, Franck Sabatie, Alexander Kiselev, Thomas Ullrich, Silvia Dalla Torre
  - Engage in a dialog between physics WGs concerning requirements and subsystem WGs concerning performance and help realize a global detector model based on performance, cost, maturity, and institutional commitment while keeping the ATHENA community fully informed about design considerations, ensuring opportunities for feedback from collaborators.

- **Costing:** Bernd Surrow, Olga Evdokimov, Zhangbu Xu, Yulia Furletova
  - Use cost template from EIC project team and EIC reference detector costing evaluation presented to the ICR in January 2021 as a starting point for completing detector costing.
  - Communicate with subsystem WGs about costing: Subsystem template, expected cost bracket, holding regular costing meetings with a “costing” representative for each subsystem WGs.
  - Prepare full costing of detector proposal with advice/input from the EIC project team and ATHENA community.

- **Draft/ Editing:** Abhay Deshpande, Barbara Jacak, Zein-Eddine Meziani, Peter Jones
  - Prepare a draft outline for the detector proposal and present it to the ATHENA community using shared overleaf document.
  - Writing of introductory material.
  - Solicit input from WGs specifying details for each section, including costing from the costing focus group.
  - Compiling the entire document, soliciting comments, and finalizing the document.

Ex-officio / Official EIC project contact:
Elke Aschenauer
WG conveners and charge highlights

**Subsystem detector WG Conveners:**
Technology choices / Estimate of services, support + active materials / Implementation into global experimental model / Simulation of subsystem performance in the global experiment / Costing of each subsystem
- Tracking: Francesco Bossu, Domenico Elia, Laura Gonella, Matt Posik
- PID: Frank Geurts, Tom Hemmick, Roberto Preghenella
- Calorimetry: Vladimir Berdnikov, Paul Reimer, Oleg Tsai
- Far Forward: John Arrington, Alexander Jentsch
- Far-Backward: Jaroslaw Adam, Krzysztof Piotrzkowski
- DAQ: Alexandre Camsonne, Jeffery Landgraf
- Polarimetry*: Oleg Eyser*, Ciprian Gal (*we propose Polarimetry as a joint group across EIC detectors)

**Physics Validation WG Conveners:**
Identify key observables described in YR / 2-3 plots which will illustrate the ability of EIC@IP6 to address NAS report and YR / Additional physics performance plots that would give a competitive advantage for the proposal?
- Inclusive: Paul Newman, Barak Schmookler, Qinghua Xu
- Semi-inclusive: Marco Radici, Anselm Vossen
- Jets/HF/EW-BSM: Miguel Arratia, Brian Page, Stephen Sekula, Ernst Sichtermann
- Exclusive: Salvatore Fazio, Spencer Klein, Daria Sokhan

**Software WG Conveners:**
Full detector assembly / Assist detector and physics WG’s to perform simulation and detector integration / Complete and improve reconstruction software
- Whitney Armstrong, Andrea Bressan(*), Wouter Deconinck, Sylvester Joosten, Dmitry Romanov
(*): liaison to EICUG software group
## Highlights from the WGs

[https://sites.temple.edu/eicatip6/calendar/collaboration-calendar/](https://sites.temple.edu/eicatip6/calendar/collaboration-calendar/)

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### Events

- **Bi-weekly ATHENA meetings on Thrs 11-2pm EDT**
- **Monthly ATHENA meetings on Thr 8pm-11pm EDT (for ASIA)**
New Solenoid (up to 3T)

By: V. Calvelli (CEA), R. Rajput-Ghoshal (JLAB)

**Solenoidal Configuration**

Parameter | Values |
--- | --- |
$B_{IP}$ (T) | 3.15 |
$B_{\text{peak}}$ (T) | 4.35 |
Coil thickness (mm) | 200 |
Energy (MJ) | 183.9 |
$H_{\text{TCP}}$ 2 (%) | 6.61 |
$H_{\text{FLAT}}$ 1 (%) | 25.12 |
Projectivity (T/Amm²) | 14.82 |

Parameter | Goal |
--- | --- |
$B_{IP}$ (T) | 3.00 |
Bore diameter (mm) | 1600 |
Coil length (mm) | 3600 |
$H_{\text{TCP}}$ 2 (%) | 5.0 |
$H_{\text{FLAT}}$ 1 (%) | 10.0 |
Projectivity (T/Amm²) | min |

**Helmholtz Configuration**

Parameter | Values |
--- | --- |
$B_{IP}$ (T) | 2.97 |
$B_{\text{peak}}$ (T) | 4.84 |
Coil thickness (mm) | 210 |
Energy (MJ) | 235.7 |
$H_{\text{TCP}}$ 2 (%) | 4.83 |
$H_{\text{FLAT}}$ 1 (%) | 16.37 |
Projectivity (T/Amm²) | 17.51 |

**On the Interaction Point $r \theta$ plane**

$proj = \frac{B_z \tan \theta - B_r}{f_E}$

If $proj = 0$ everywhere, particles are not deflected from the original trajectory (same as $\frac{dB}{dt} = 0$)

$H_{\text{TCP}} = \frac{B_z}{B_{IP}} \leq 5\%$

$H_{\text{FLAT}} = \frac{B_{\text{max}} - B_{\text{min}}}{B_{IP}} < 10\%$

Mostly difficult to reach before the RICH

Due to the short length of the magnet

Current version ONGOING
Magnetic field map released 28/05/2021

Version for full analysis
Magnetic field map released 07/05/2021

9 June 2021
Silicon vertex and tracking detector

Primary and secondary vertex reconstruction + momentum measurement in combination with gas based tracking system at larger radii and Z (see next slides)

Currently two configurations studied:
"YR hybrid" and "YR all-silicon"
- Both based on ALICE ITS3 65 nm MAPS sensor
- Ongoing layout optimisation: # of vertex layers and disks, integration of barrel region with disks, overall integration with MPGD tracking detector, ...

<table>
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<th># layers/disks</th>
<th>Vertex</th>
<th>Barrel</th>
<th>Endcaps</th>
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<td>YR Hybrid</td>
<td>3+2</td>
<td>2</td>
<td>7 fwd + 7 bwd</td>
</tr>
<tr>
<td>YR All-silicon</td>
<td>2</td>
<td>2+2</td>
<td>5 fwd + 5 bwd</td>
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10µm pixel pitch

\( x/X_0 = 0.05\% \) per vertexing layer

\( x/X_0 = 0.55\% \) per tracking layer

\( x/X_0 = 0.24\% \) per disk

9 June 2021
Momentum performance

Results from the YR studies compared with Physics WG (PWG) requirements:

**All-Silicon**

**Hybrid (Si+TPC)**

Babar (1.4 T)
Beast (3.0 T)
- PWG Requirements

1.5T, 3.0T, PWG requirement
(Uniform B-fields)
End Cap Trackers

End cap trackers can be relatively large. MPGD based tracking detectors can cover large areas and provide tracking information at a reasonable cost.

Hardware R&D work within eRD6 and eRD22

- Large area GEM for forward / backward trackers
  - Large area (1 m × 0.5m) & Low mass GEMs (~0.5% X/X0)
- High performance & low channels count anode readout for MPGD
  - Zigzag strips, Capacitive-sharing readout
- GEM-based transition radiation detector (GEM-TRD)
  - Prototyping and Gas system
  - Provide e/π discrimination and tracking
- Resistive Micro-Well (μRWELL) technology
  - Develop large area μRWELL with capacitive-sharing readout
All-Silicon and Hybrid Concepts

Current detector concepts have general layouts and technologies. Discussions of specific choices now underway within tracking WG.

- **All-Silicon concept**
  - Vertex/Barrels and disks
    - EIC Silicon consortium

- **Hybrid concept**
  - MPGD end cap: (GEMs or micro R-Wells)
    - Florida Tech., Temple, UVa
  - MPGD barrel
    - Micromegas – Saclay
    - Micro R-Well – Florida Tech, Temple, UVa
  - Silicon vertex/barrels and disks
    - EIC Silicon consortium
  - Large z MPGD-TRD
    - BNL, Florida Tech. Jlab, Temple, UVa, Vanderbilt
Low momentum PID with GridPix

Known and Proven Technology for GridPix
- GridPix is a 55 μm × 55 μm pixel readout for a gaseous TPC
- First Timepix3 based GridPix test beam (2017)
- Quad module performance from test beam (2018)
- Investigations of the 8 quad detector (2020)

Ultimate dE/dx Device
- Avalanche grid in front of 55 x 55 μm² pixels.
- Greater than 90% efficiency for single electrons.

Goal:
- Enough diffusion to get every electron into a different hole
- Count electrons one-by-one.
- Three generations of development and continuing.
- Large area is VERY expensive, but this proposal is small area.

4-sided buttable pixel arrangement
- Model 4 replaces wires bond with bump bond (improves active area) (93.7% -> 99.5% active area)
- DAQ interface by Through-Silicon-Vias (TSV).

Current Group Members:
Tom Hemmick, Klaus Dehmelt, Sanghwa Park, Prakhar Garg (SBU)
Nikolai Smirnov (Yale)
Jochen Kaminski (Bonn)
**HPDIRC FEATURES**

**Concept:**
- Fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction
- Innovative 3-layer spherical lenses, compact fused silica expansion volumes
- Fast photon detection using small-pixel MCP-PMTs ($eRD14$) and high-density readout electronics ($eRD14$)

**Excellent performance over wide angular range:**
- $\geq 3$ s.d. $\pi/K$ up to 6 GeV/c, $\geq 3$ s.d. $e/\pi$ up to $\sim 1.2$ GeV/c
- Low momentum $\pi/K$ identification in “veto mode” down to 0.2-0.3 GeV/c

**Features:**
- Radially compact (8-10 cm; impact on cost of post-DIRC systems)
- Flexible design (to deal with sensor in B-field and detector integration)
- Low demand on detector infrastructure (no cryogenic cooling, no flammable gases)
- R&D at advanced stage (PID performance estimate based on test beam results, excellent agreement between detailed simulation and prototype data, fast simulation available)

**Involved institutions:** CUA, GSI, BNL, W&M, USC, SBU, UH, JLab, ODU

[Image of 3-layer spherical lens]
**dRICH Overview**

Radiators:
- Aerogel: 4 cm, $n_{(400nm)}>1.02 + 3$ mm acrylic filter
- Gas: 1.6 m (1.1 m ePHENIX), $n_{C_2F_6}≈1.0008$

6 identical Open Sectors (Petals):
- Large Focusing Mirror with $R≈2.9$ m (~2.0 m ePHENIX)
- Optical sensor elements: ~4500 cm²/sector, 3 mm pixel size, UV sensitive, out of charged particles acceptance

Optimized for JLEIC, preliminary implementation in ePHENIX

**Phase Space:**
- Polar angle: 5-25 deg
- Momentum: 3-50 GeV/c

**Typical contributions to angular errors**

**Photon Detectors**

- Aerogel + Acrylic Filter
- Charged particle
- Beam pipe(s)
ATHENA Calorimetry at a glance.

- High Resolution EndCaps.
- Technologies developed during EIC generic detector R&D. Well established and spread in the EIC users community.
- Barrel Calorimeters – being optimized, depends on design of the new SC magnet.

- WScFI EM section of Hadron EndCap.
- Technology pioneered at UCLA.
- Very Compact with good EM resolution.
- Similar technology now used in construction of sPHENIX emcal.

STAR Forward Calorimeter System.

Constructed in 2020 with new, very efficient method.

HCal Fe/Sc, similar technology for EIC reference detector.

Expected performance of ATHENA hadron endcap (improved version of STAR FCS).
High resolution electron arm ECAL. EEEEmCal.

- PbWO4 crystals (inner)
  - compact, radiation hard, luminescence yield to achieve high energy resolution, including the lowest photon energies
  - Sensor: SiPMs (TBC)
- SciGlass (outer)
  - EIC eRD1
  - radiation hard, luminescence yield similar or better than crystals depending on longitudinal length
  - Sensor: SiPMs (TBC)
ATHENA Far-Forward Detectors

- Roman pots and ZDC cover the normal diffractive proton tagging and neutron/photon tagging from nuclear breakup.
- OMD required for tagging protons and pions from nuclear breakup and lambda since they will have a different magnetic rigidity in the beamline than the beam itself.
- B0 required for tagging protons at higher angles (especially important for lower beam energies).

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<td>Zero-Degree Calorimeter (ZDC)</td>
<td>$\theta &lt; 5.5 \text{ mrad (}\eta &gt; 6)$</td>
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<tr>
<td>Roman Pots (2 stations)</td>
<td>$0.0^* &lt; \theta &lt; 5.0 \text{ mrad (}\eta &gt; 6)$ (*)depends on beam optics</td>
</tr>
<tr>
<td>Off-Momentum Detectors (OMD)</td>
<td>$0.0 &lt; \theta &lt; 5.0 \text{ mrad (}\eta &gt; 6)$</td>
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<tr>
<td>B0 Sensors (4 layers, evenly spaced)</td>
<td>$5.5 &lt; \theta &lt; 20.0 \text{ mrad (}\eta &lt; 5.9)$</td>
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ATHENA Far-Forward Detectors

- Combination EMCal and HCAL with high granularity and resolution.
- Design starting point is ALICE FoCal.

Interested parties: eRD27, Kansas, RIKEN

- Requires high granularity silicon tracking with high spatial resolution.
- Timing layer(s) required.
- Also need compact EM preshower or EMCal for tagging photons.

Interested parties: eRD24, LGAD Consortium (both comprise many institutions)

- Both can rely on use of AC-LGAD technology for fast (~20-30ps) timing and good spatial resolution.
- Roman Pots require special care since we plan to go with “potless” design to maximize acceptance.

Interested parties: LANL, and others
We aim to measure the EIC luminosity with a precision better than 1% using the electron-ion bremsstrahlung:

Dedicated detectors will measure “zero-degree” photons, and the design effort started from the challenging design of the photon exit window, hit by a SR fan.

A fraction of the scattered electrons in bremsstrahlung will be measured too, and the electron detectors will also be used to tag low-$Q^2$ Events (photoproduction) in ATHENA:

See more about the EIC luminosity measurement later this morning:
https://indico.bnl.gov/event/11322/#day-2021-06-09

Interested groups in this ATHENA project:
AGH UST (Kraków), BNL, Glasgow Univ., IFJ PAN (Kraków), Temple Univ.
Polarimetry (joint with EICUG WG)

- **Hadron Polarimeter at IP6 (elastic recoil)**
- **pC for relative polarimetry**
- **Inside of spin rotators / crab cavities**
- **Confirmation of polarization vector (start of fill)**
- **Polarization bunch profile (after crab rotation)**
- **Ultra-thin Carbon fiber targets may not be suitable for high bunch repetition rate at EIC**

- **Electron Polarimeter at IP6 (Compton scattering)**
- **Backscattered photon needs feedthrough for some magnets**
- **Available acceptance, effect of beam pipe/exit window**
- **Cross talk between longitudinal/transverse asymmetries**

EIC UG working group on polarimetry/luminosity
https://indico.bnl.gov/category/280/
Monthly meetings → higher frequency for proposal specific topics
Software & Computing WG

Software & Computing Conveners:
Whitney Armstrong, Andrea Bressan(*), Wouter Deconinck, Sylvester Joosten, Dmitry Romanov
(*)-liaison to EICUG software group

Day 0 WG support:
Kolja Kauder, Miguel Arratia, Stephen Sekula, Dmitry Romanov, Yulia Furletova, Andrea Bressan

Full simulation/reconstruction team
Whitney Armstrong, Miguel Arratia, Wouter Deconinck, Sylvester Joosten, Jihee Kim, Chao Peng, Tomas Polakovic, Dmitry Romanov, Marshall Scott, Zhenyu Ye, Ziyue Zhang, Maria Żurek
...and a rapidly growing amount ATHENA collaborators!

User support and documentation
Documentation portal: doc.athena-eic.org
Full simulation tutorial
eic-ip6-software-l@lists.bnl.gov
#software-helpdesk at Slack

Bi-weekly software meeting: Thursday 12:00pm EDT
ATHENA detector implementation well underway

- Full geometry based on reference detector implemented in DD4hep
- Reasonable detail in central detector tracking
  - Detailed geometry and services for silicon tracker
  - µRWEL detectors around the DIRC
  - TRD in forward region
  - Various ECAL and HCAL options with support structures
  - Latest Solenoid geometry and beamline setup
- Working with PID working group to enhance implementations of dRICH, mRICH and DIRC systems.
- Working with Far Forward and Far Backward WGs to implement the full beamline and near-beamline detector system.

Next step: validate tracking geometries and reconstruction performance (Gaudi+ACTS) together with tracking WG
The DD4HEP community

ATHENA@EIC

Production

CLIC

Production

FCC

Production Run 3

LHCb

Under investigation Run 3

RHIC

Super Charm Tau Factories

Production

“framework for providing a complete solution for full detector description (geometry, materials, visualization, readout, alignment, calibration, etc.)"
ATHENA is international pre-collaboration, currently includes 94 institutions.

To join: send email to eic-ip6-org-l@lists.bnl.gov

Stay connected: subscribe to public mail eic-ip6-public-l@lists.bnl.gov or join Slack: link or webpage https://athena-eic.org/meetings-and-events/

ATHENA detector

- It is based on the EICUG reference detector
- The Yellow Report physics studies show that it meets the requirements
- A new 3 T magnet matching this configuration is being designed.
- The detector includes a variety of different technologies for tracking, calorimetry, particle identification and ancillary detectors along the beam line
- The technology choice is largely determined by the EIC Detector R&D Program

A concrete configuration will be defined shortly in the detector proposal drafting process, based on the groups joining the effort, within the available cost range

The detailed Geant4 simulations will be conducted for this coherent detector setup (DD4HEP implementation)
Thank you!
Backup
### Vertex/tracking performance

Results from the YR studies compared with PWG performance summary:

#### all-silicon

<table>
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<tr>
<th>$\eta$</th>
<th>Tracking performance (All-silicon concept, B = 3 T)</th>
<th>Transverse pointing res.</th>
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#### Hybrid (Si+TPC)

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9 June 2021