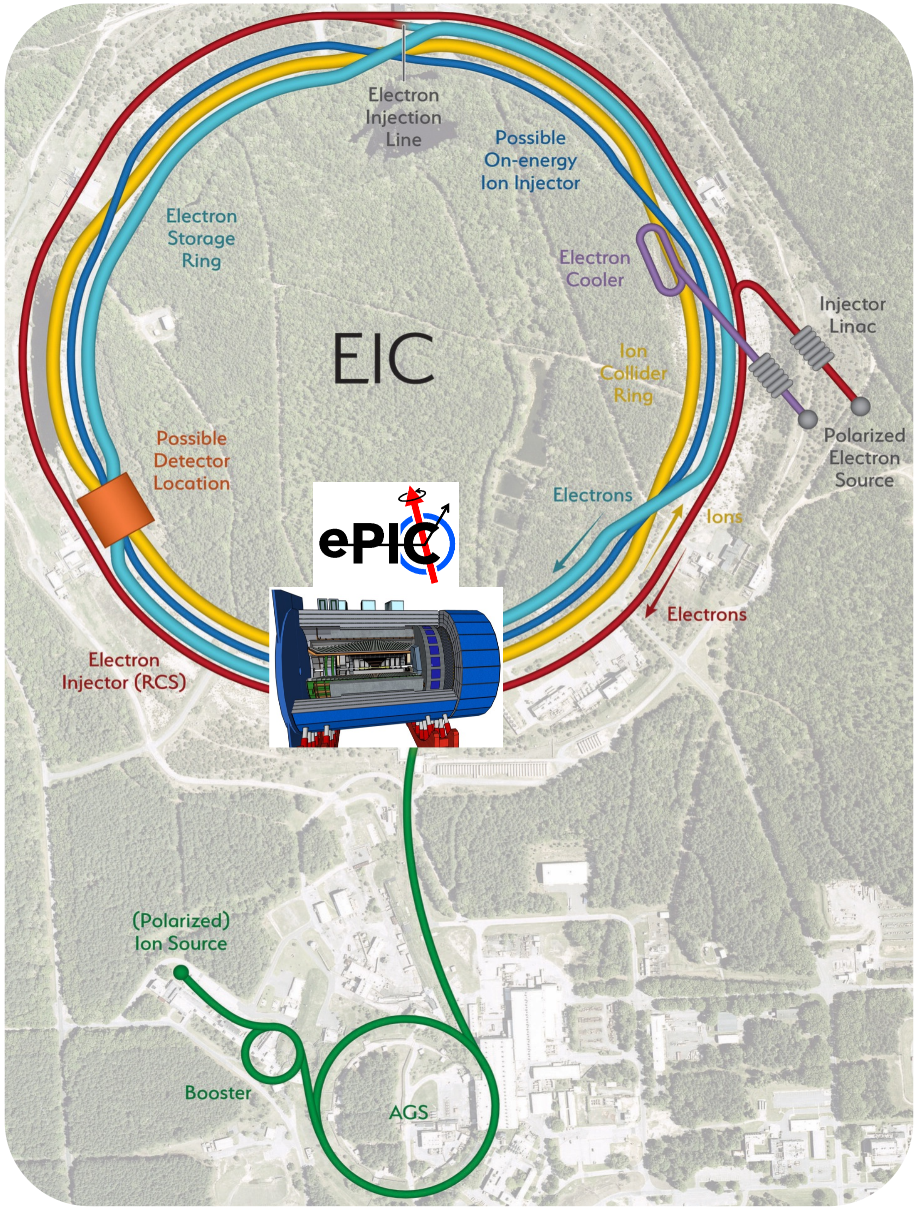
The ePIC Detector

An Overview

- Physics Motivation
- ePIC Detector
- The Path Forward

Richard Milner

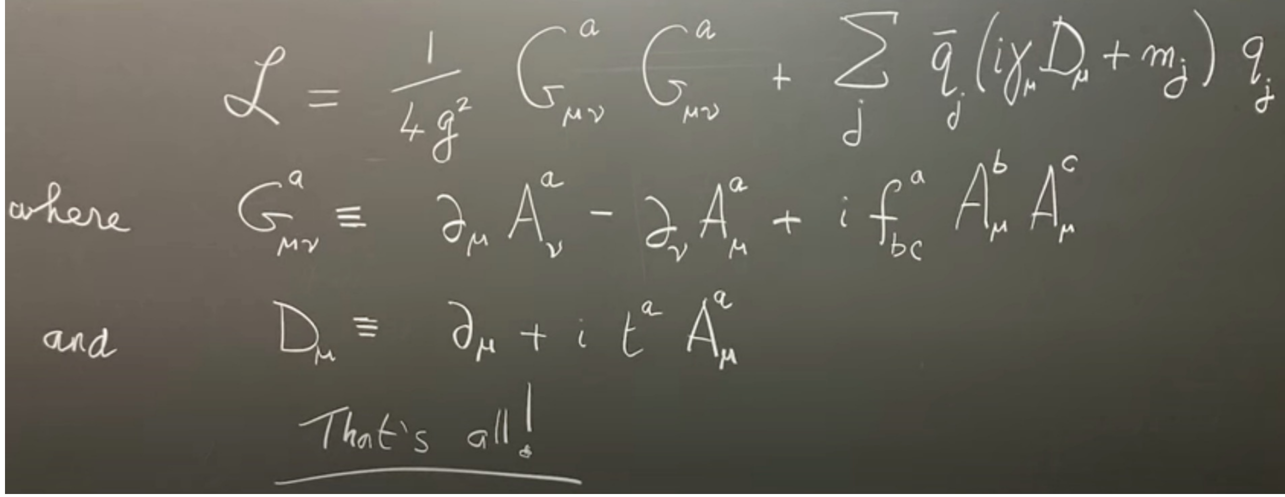
for the ePIC Collaboration



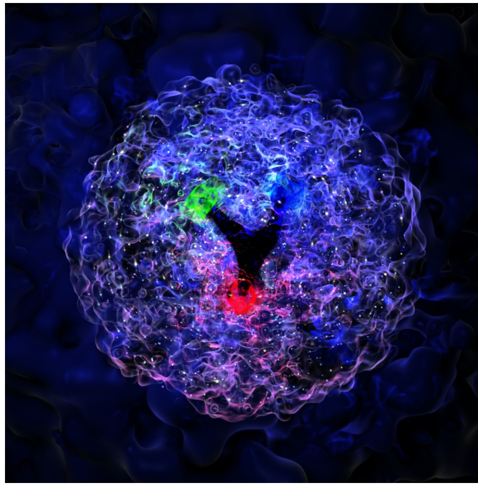
With thanks to:
John Lajoie

U.S. DEPARTMENT OF ENERGY
Office of Science

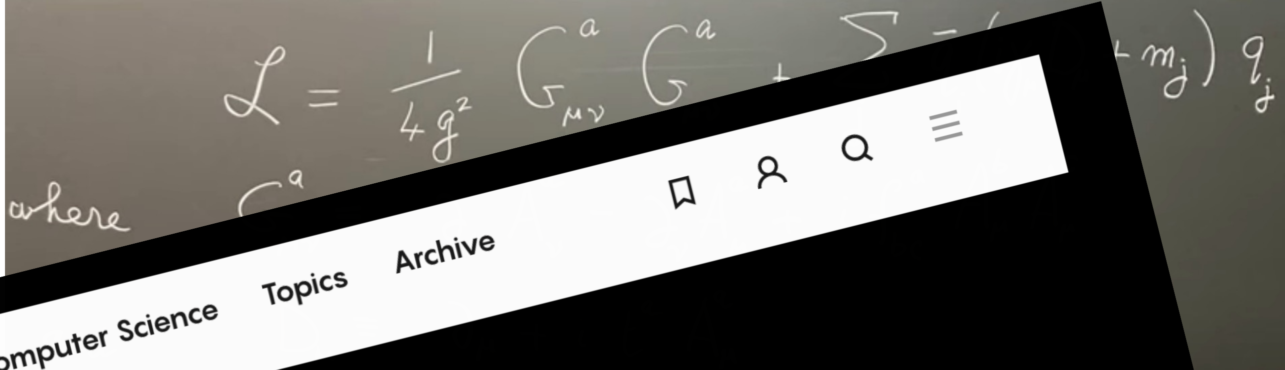
Electron-Ion Collider: The 21st Century QCD Laboratory



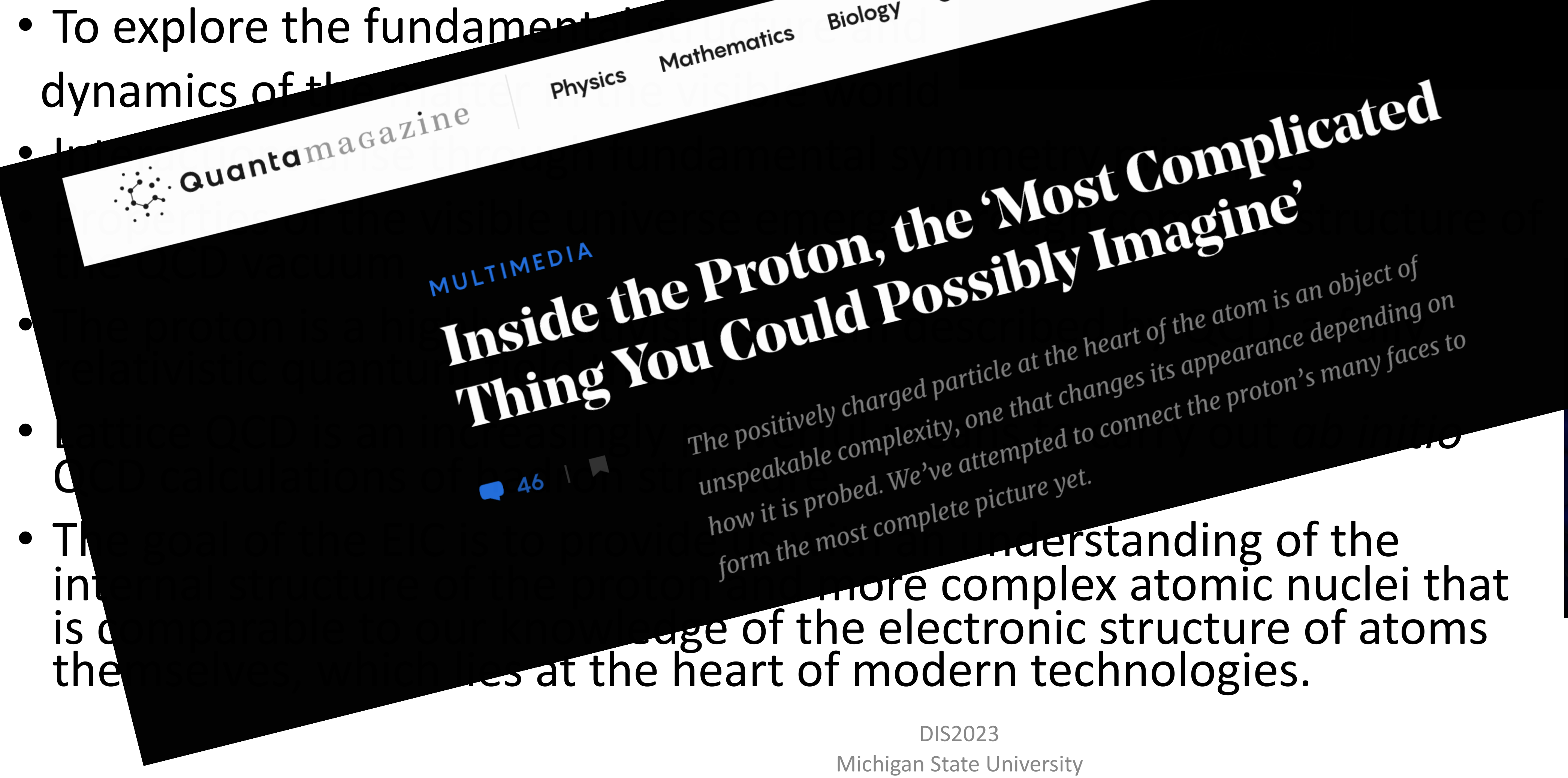
- To explore the fundamental structure and dynamics of the matter in the visible world.
- Interactions arise through fundamental symmetry principles.
- Properties of the visible universe emerge through the complex structure of the QCD vacuum.
- The proton is a highly relativistic system described by QCD, a fully relativistic quantum field theory.
- Lattice QCD is an increasingly powerful means to carry out *ab initio* QCD calculations of hadron structure.
- The goal of the EIC is to provide us with an understanding of the internal structure of the proton and more complex atomic nuclei that is comparable to our knowledge of the electronic structure of atoms themselves, which lies at the heart of modern technologies.



Electron-Ion Collider: The 21st Century QCD Laboratory



- To explore the fundamental … dynamics of the …
- …
- …
- …
- …understanding of the … more complex atomic nuclei that is … of the electronic structure of atoms … at the heart of modern technologies.



Quanta magazine

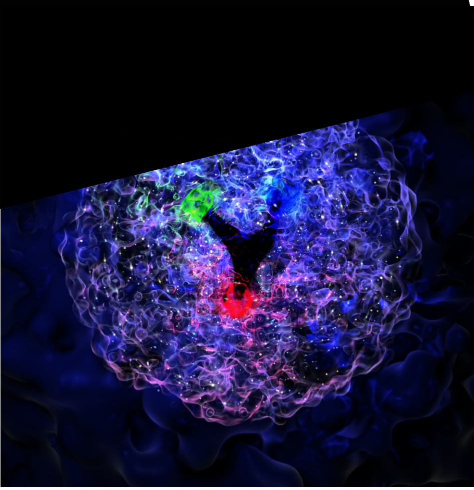
Physics Mathematics Biology Computer Science Topics Archive

MULTIMEDIA

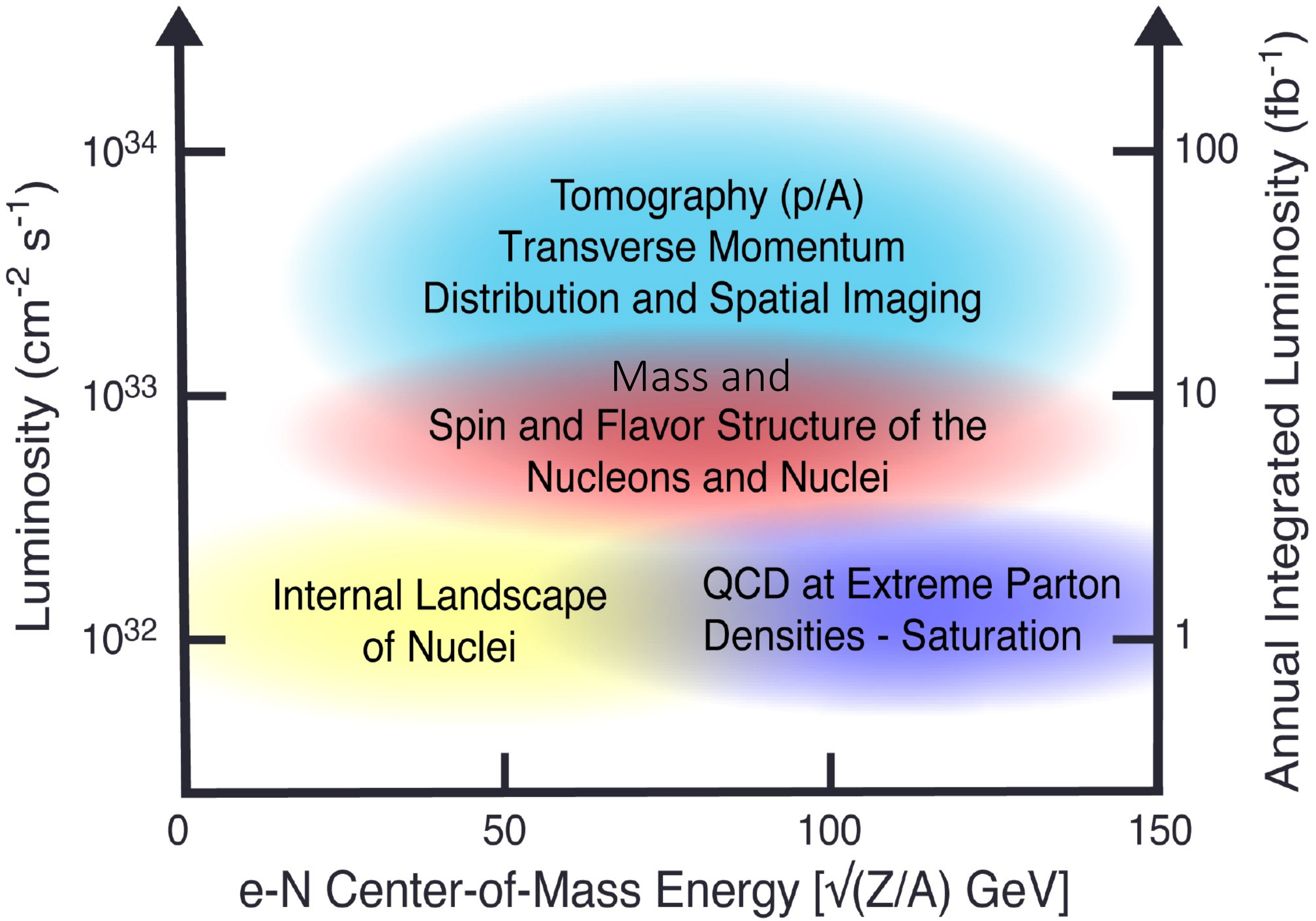
Inside the Proton, the 'Most Complicated Thing You Could Possibly Imagine'

The positively charged particle at the heart of the atom is an object of unspeakable complexity, one that changes its appearance depending on how it is probed. We've attempted to connect the proton's many faces to form the most complete picture yet.

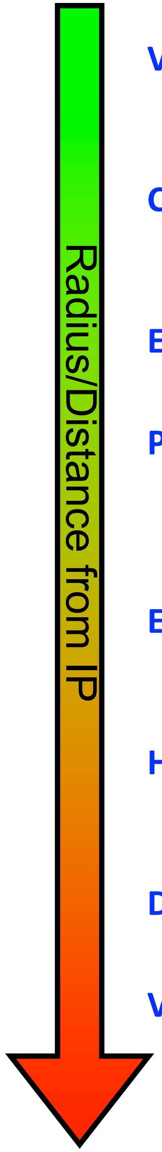
46



Collider Specifications from Science



Requirements for an EIC Detector



Vertex detector → Identify primary and secondary vertices,
Low material budget: 0.05% X/X_0 per layer;
High spatial resolution: 10 mm pitch CMOS Monolithic Active Pixel Sensor

Central tracker → Measure charged track momenta
MAPS – tracking layers in combination with micro pattern gas detectors
MPGD: μRWell or MicroMegas

Electron and hadron endcap tracker → Measure charged track momenta
MAPS – disks in combination with micro pattern gas detectors

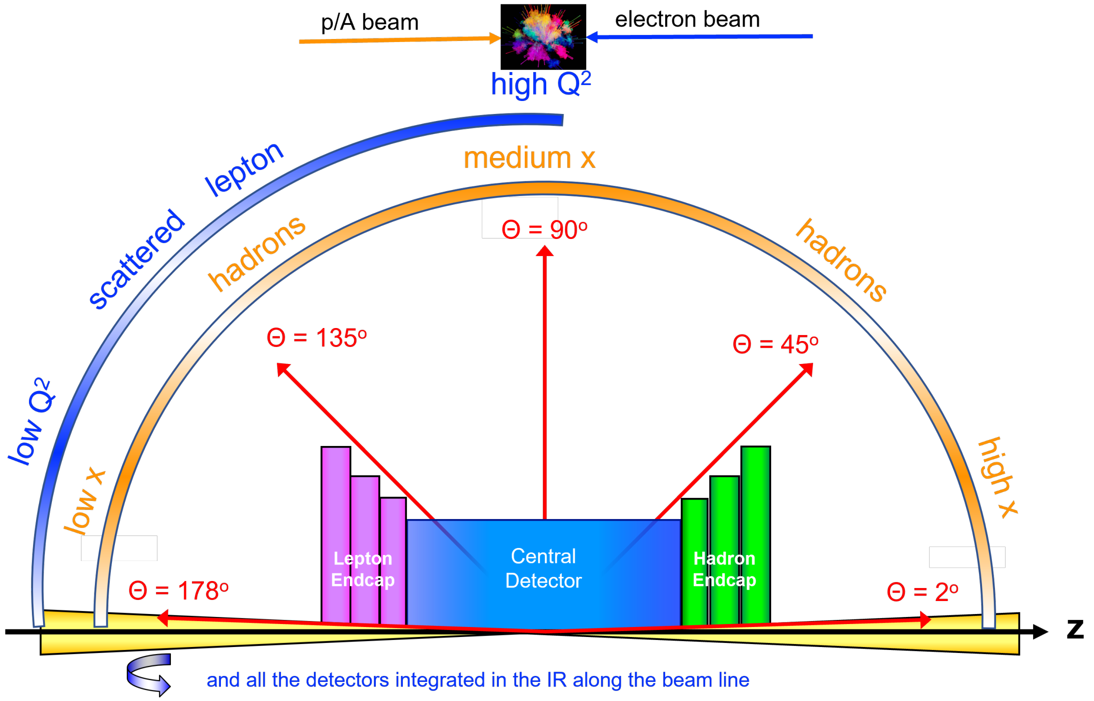
Particle Identification → pion, kaon, proton separation on track level
RICH detectors (modular and dual radiator RICH, DIRC) & Time-of-Flight
high resolution timing detectors (LAPPDs, LGAD) 10 – 30 ps
novel photon sensors: MCP-PMT / LAPPD

Electromagnetic calorimeter → Measure photons (E, angle), identify electrons
$PbWO_4$ Crystals (backward), W/SciFi Spacal (forward)
Barrel: Pb/SciFi+imaging part or new Scintillating glass

Hadron calorimeter → Measure charged hadrons, neutrons and K_L^0
challenge achieve ~50%/$\sqrt{E}$ + 10% for low E hadrons (<E> ~ 20 GeV)
Fe/Sc sandwich with longitudinal segmentation

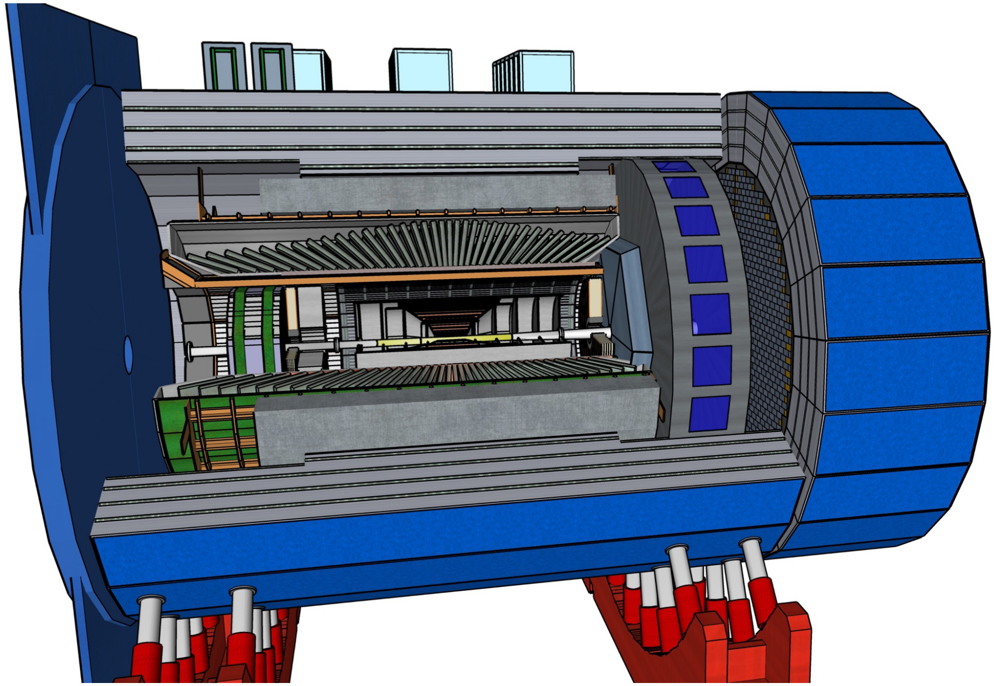
DAQ & Readout Electronics: trigger-less / streaming DAQ
Integrate AI into DAQ → cognizant Detector

Very forward and backward detectors → scattered particles under very small angles
Silicon tracking layers in lepton and hadron beam vacuum
Zero – degree high resolution electromagnetic and hadronic calorimeter



A Brief Timeline

- EICUG Yellow Report (2020-21)
- Call for proposals issued jointly by BNL and JLab in March 2021
  - Proposals due Dec. 1, 2021
  - ATHENA, CORE and ECCE proposals submitted
- Public DPAP meetings Dec. 13-15, 2021
  - Presentations from proto-collaborations
  - Panel-assigned homework questions
- Second DPAP session Jan. 19-21, 2022
- DPAP closeout March 8th, 2022
  - Final report available March 21st, 2022
  - ECCE proposal chosen as basis for first EIC detector reference
- Spring/Summer 2022 – ATHENA and ECCE form joint leadership team
  - Joint WG's formed and consolidation process undertaken
  - Coordination with EIC project on development of technical design
- Collaboration formation process started July, 2022
  - First IB Meeting July 18th
  - Charter writing committee formed and active – DE&I built in from start!
- First ePIC Collaboration meeting July 26-29, 2022
- ePIC Charter approved Dec. 14th, 2022
- ePIC collaboration leadership elected Feb. 14, 2023



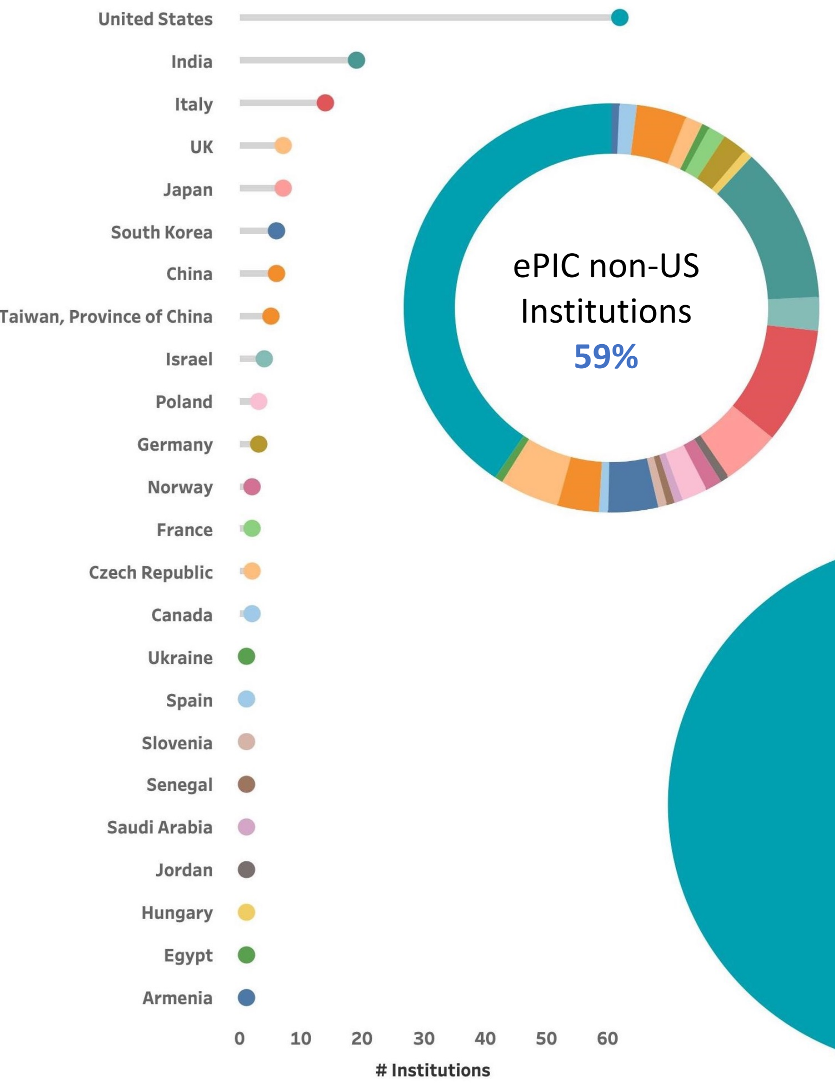
ePIC Detector
- To be sited at IP6 (25mr crossing angle)
- Addresses EIC science program as outlined in the EIC white paper and NAS report
- Must be ready for Day-1 EIC operations
- Working towards pre-TDR and CD-2/3A

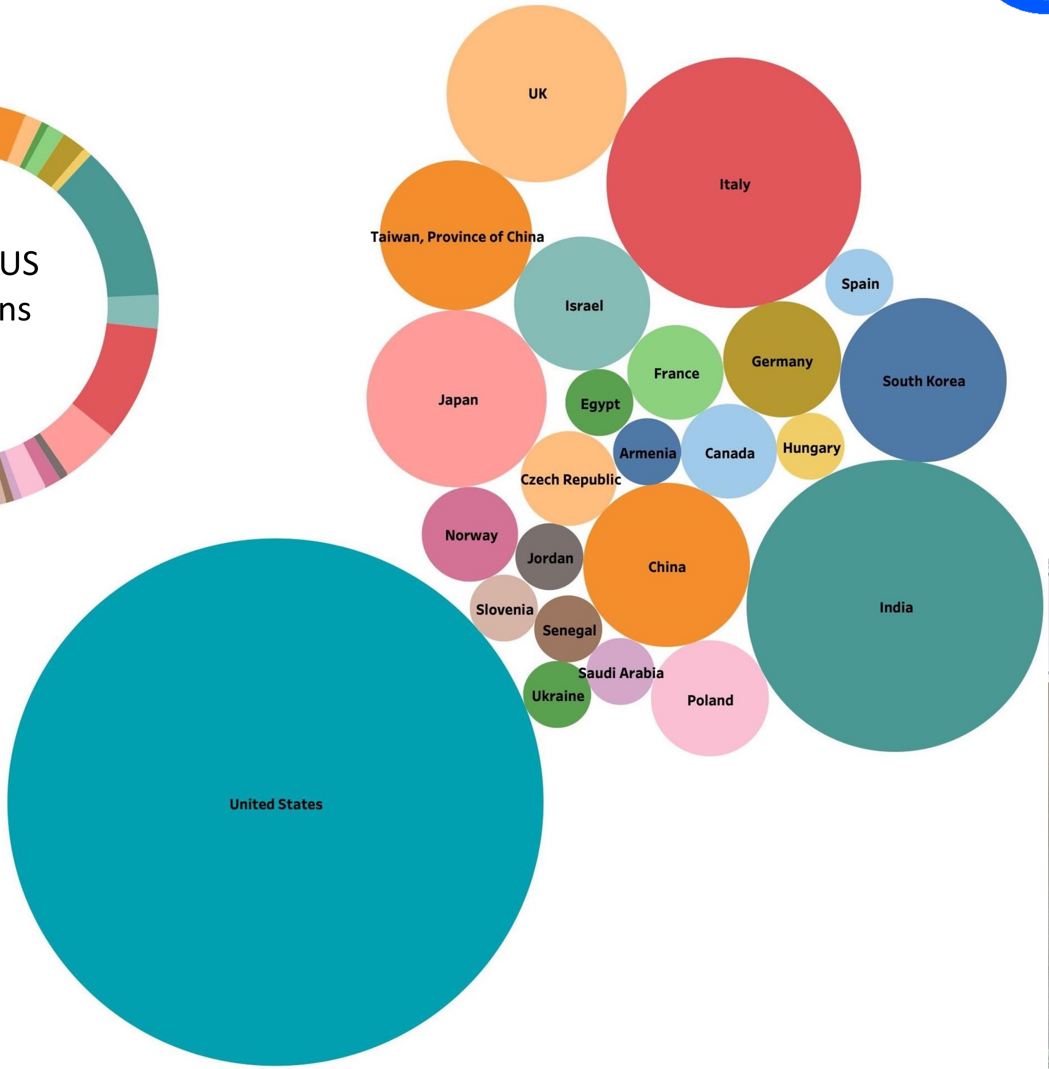
The ePIC Collaboration

160+ institutions
24 countries

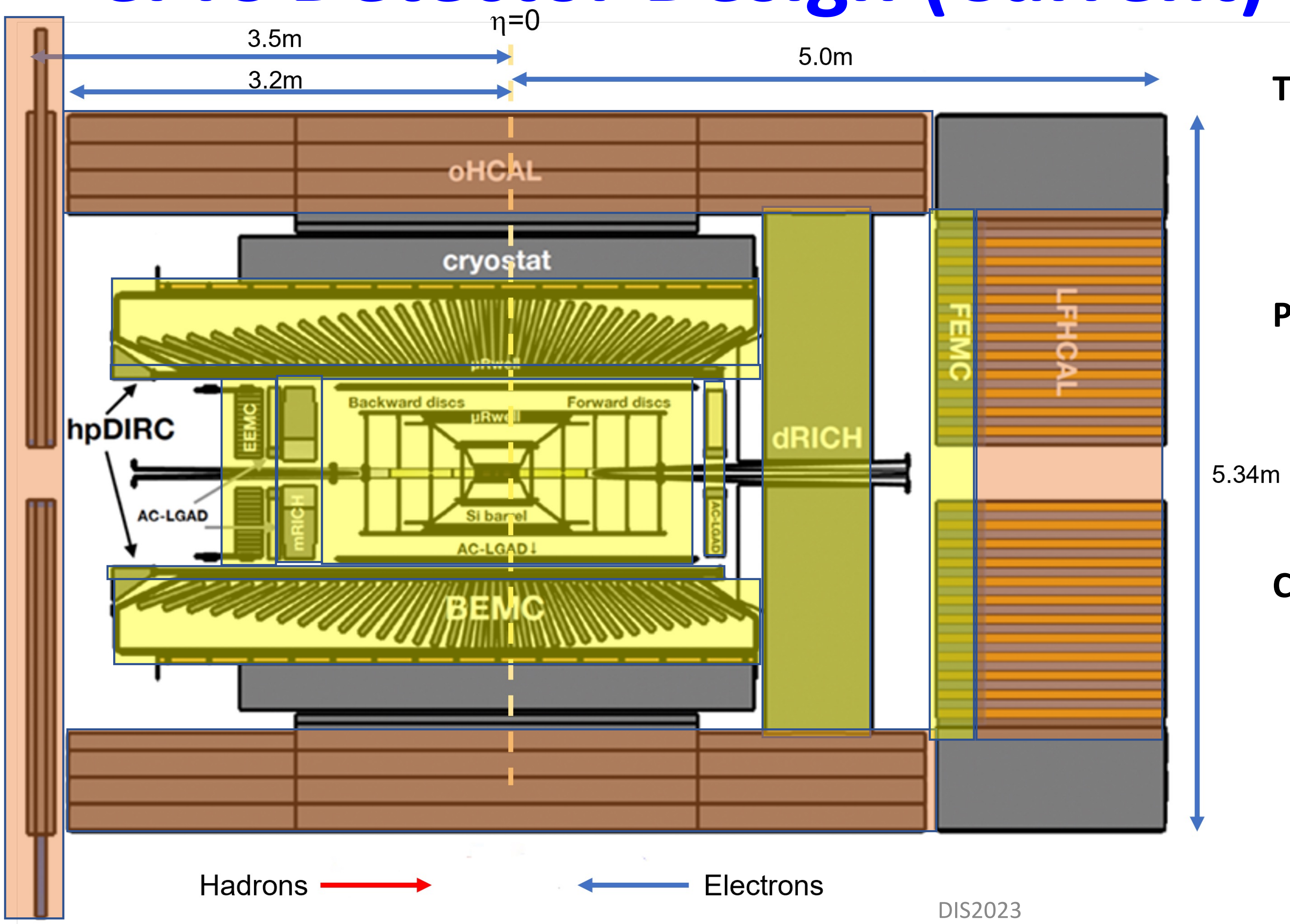
500+ participants

A truly global pursuit for a new experiment at the EIC!





ePIC Detector Design (Current)

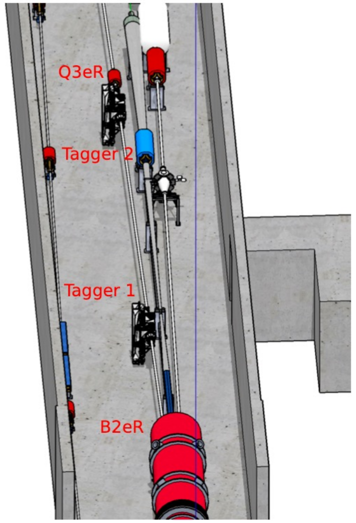


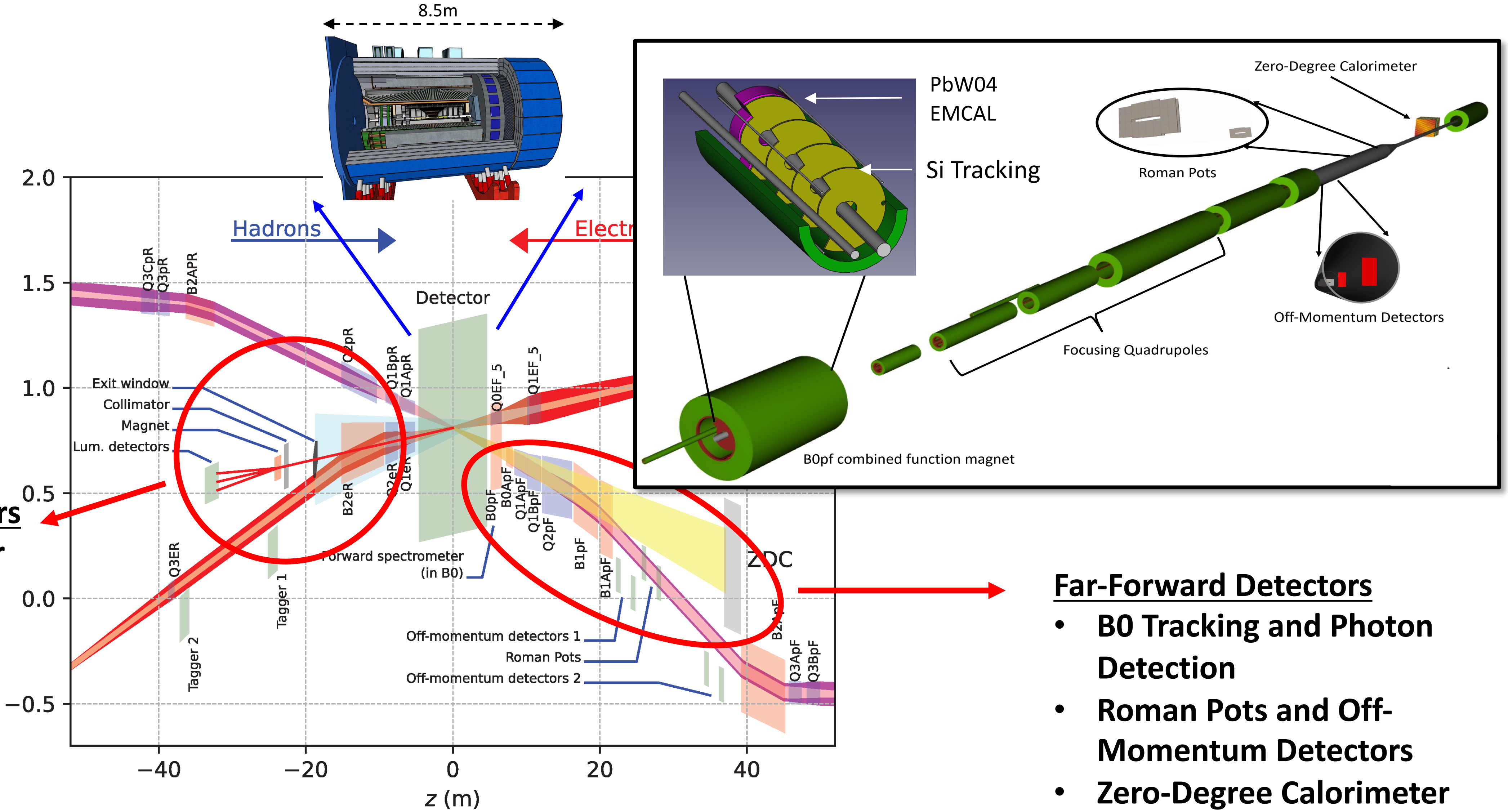
Tracking:
- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:
- hpDIRC
- mRICH/pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:
- SciGlass/Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

Far-Forward and Far-Backward Detectors





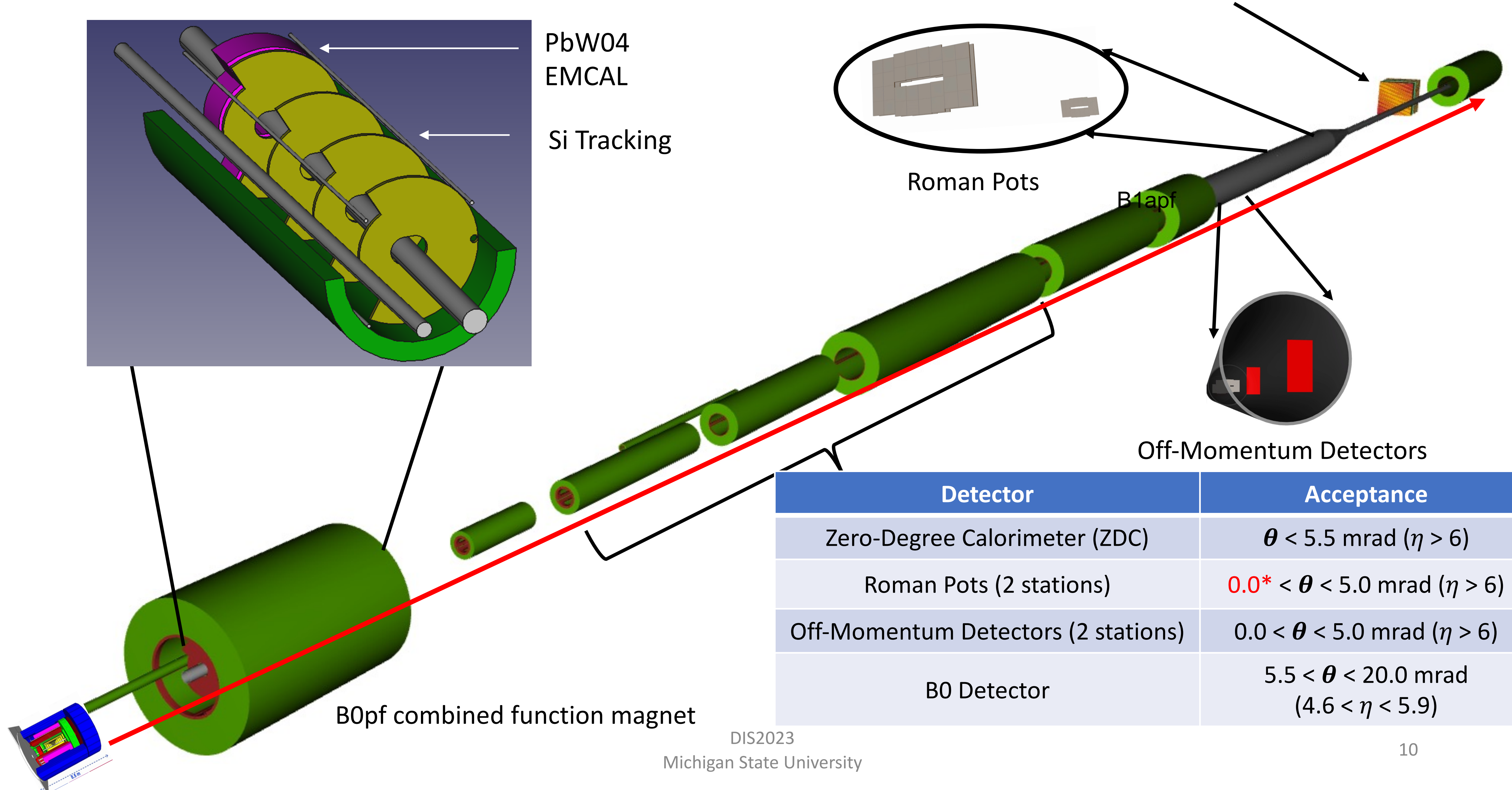
Far-Backward Detectors

- Luminosity monitor
- Low-Q^2 Tagging Detectors

Far-Forward Detectors

- B0 Tracking and Photon Detection
- Roman Pots and Off-Momentum Detectors
- Zero-Degree Calorimeter

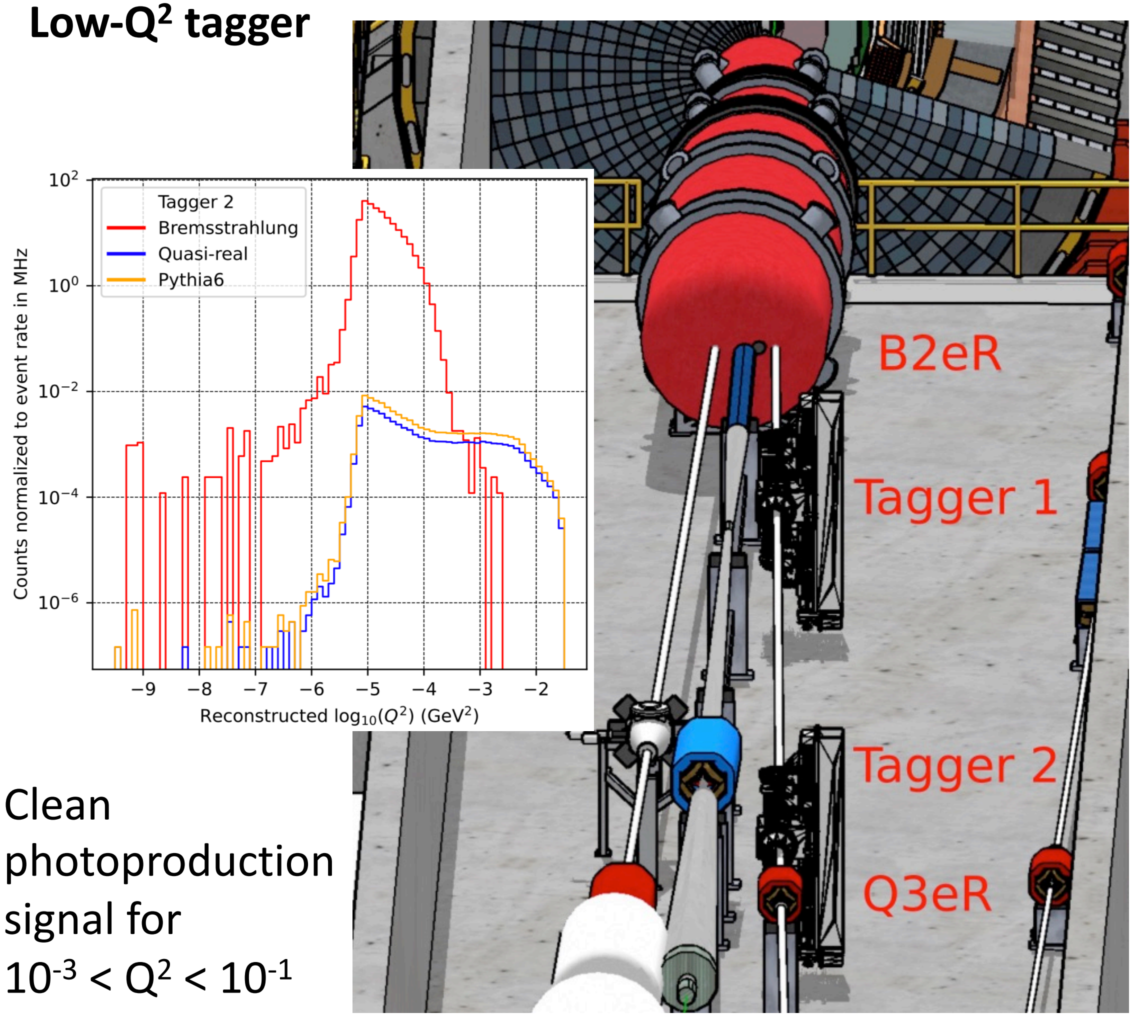
The Far-Forward Detectors



Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	$\boldsymbol{\theta} < 5.5$ mrad ($\eta > 6$)
Roman Pots (2 stations)	0.0* $< \boldsymbol{\theta} < 5.0$ mrad ($\eta > 6$)
Off-Momentum Detectors (2 stations)	$0.0 < \boldsymbol{\theta} < 5.0$ mrad ($\eta > 6$)
B0 Detector	$5.5 < \boldsymbol{\theta} < 20.0$ mrad ($4.6 < \eta < 5.9$)

Far Backwards Detectors

Low-Q^2 tagger

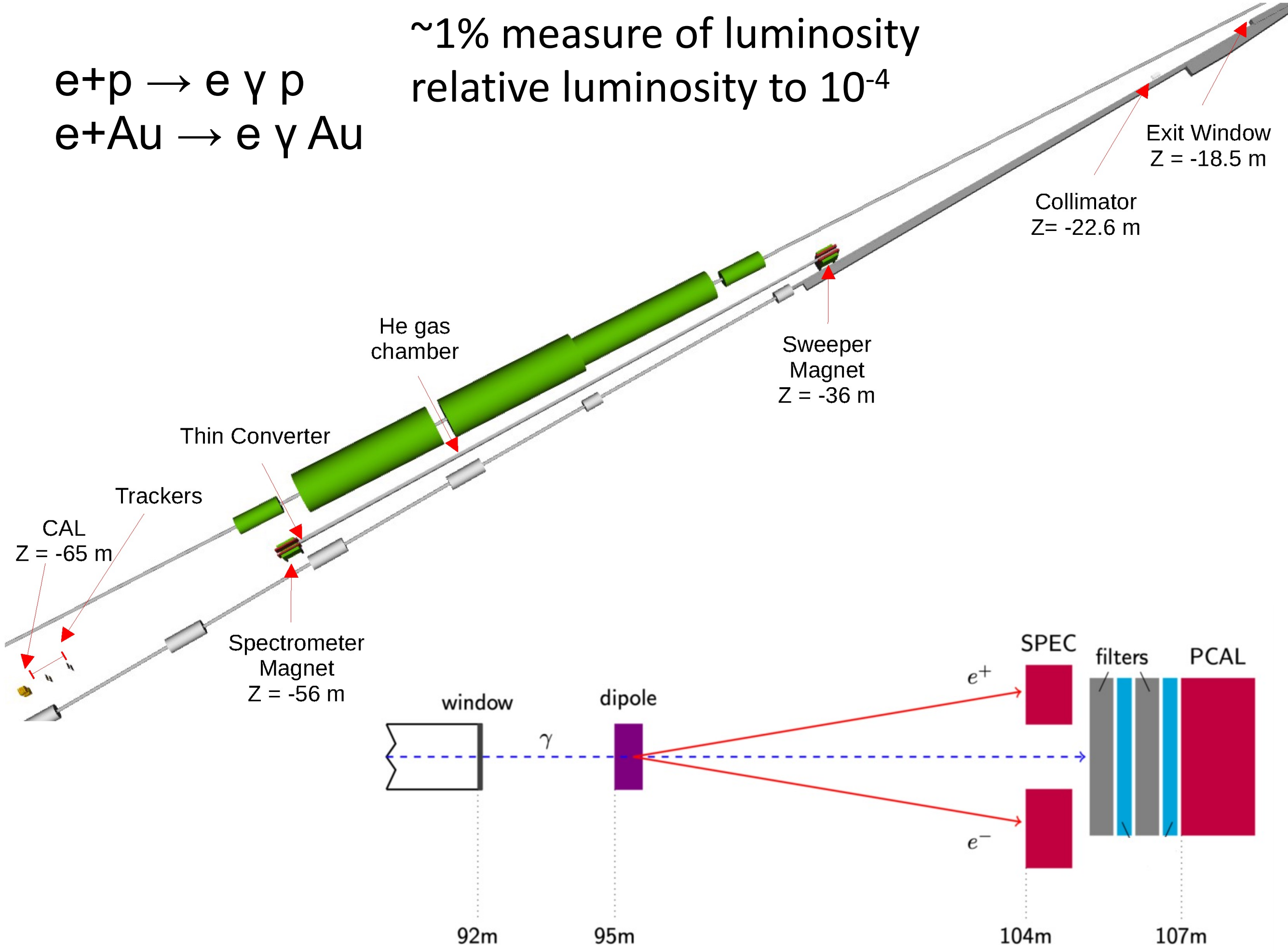


Clean photoproduction signal for $10^{-3} < Q^2 < 10^{-1}$

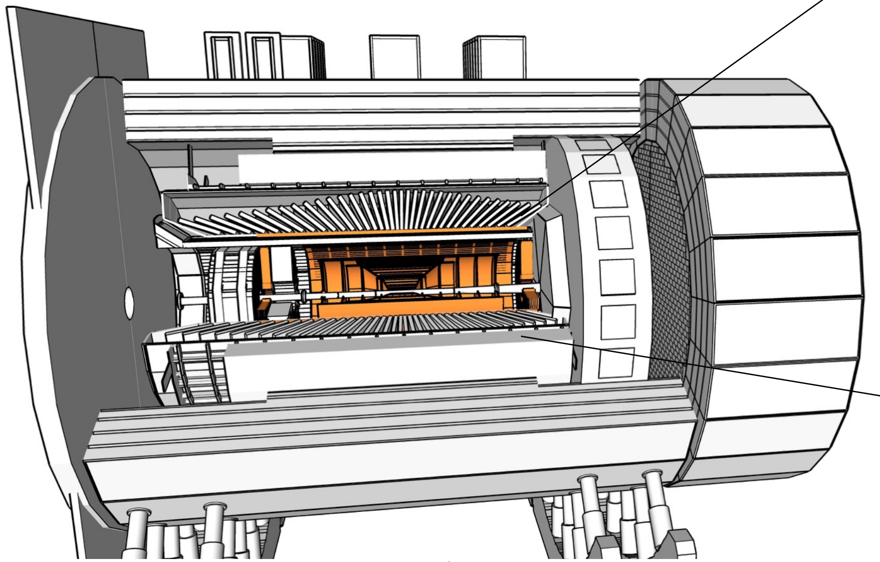
Luminosity Spectrometer

$e+p \rightarrow e\ \gamma\ p$
$e+Au \rightarrow e\ \gamma\ Au$

~1% measure of luminosity
relative luminosity to 10^{-4}

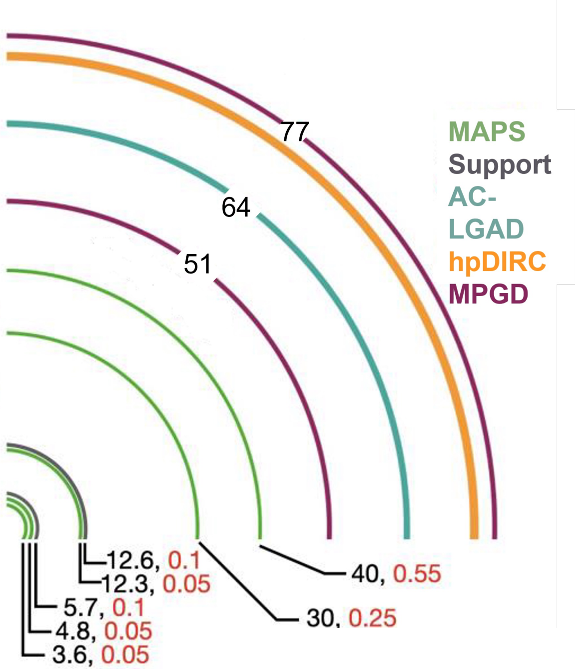


Tracking



Black numbers are radii in cm

Red numbers are material in % X0

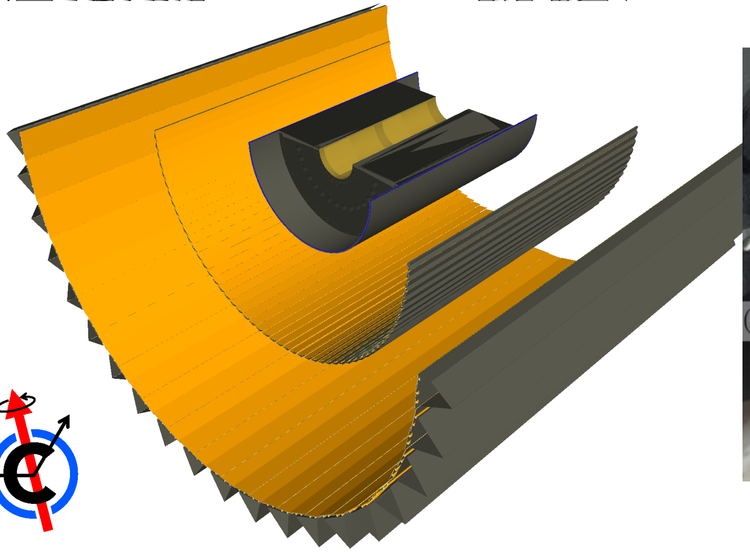


Si Tracker based on ALICE ITS3 65nm MAPS sensors.

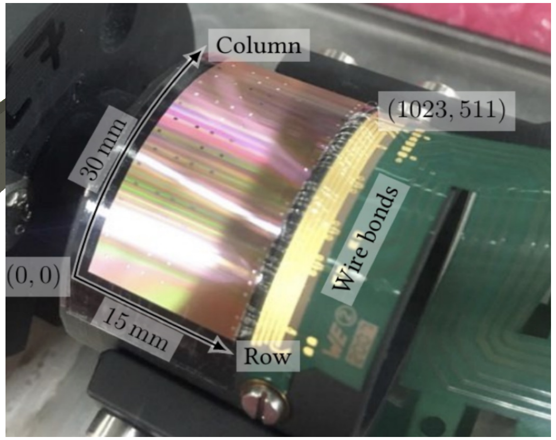
Five layers in barrel, supplemented by MPGDs for pattern recognition.

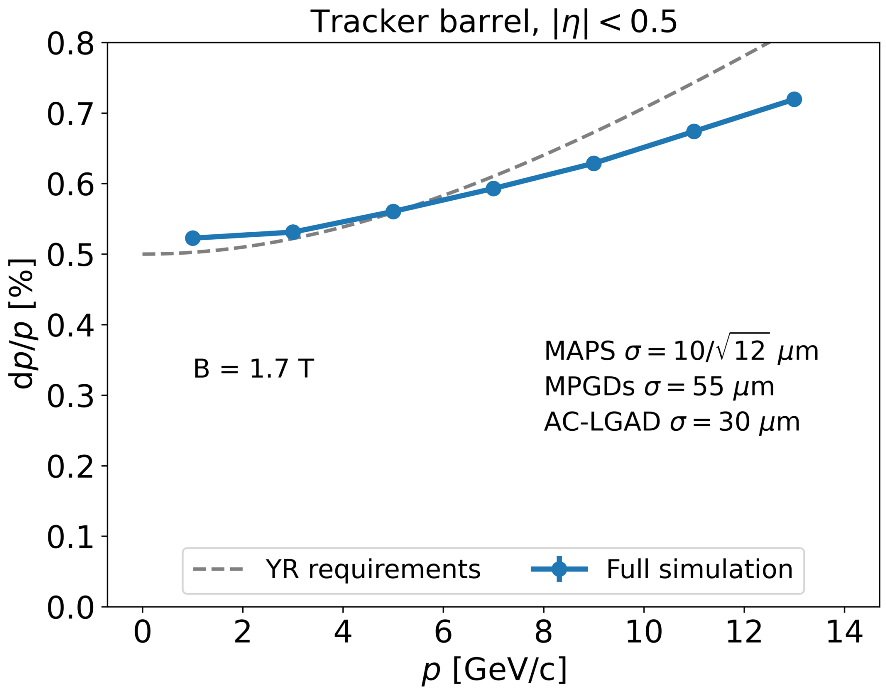
Five discs in forward/backward directions (+MPGD in forward)

Meets EICUG Yellow Report design requirements.

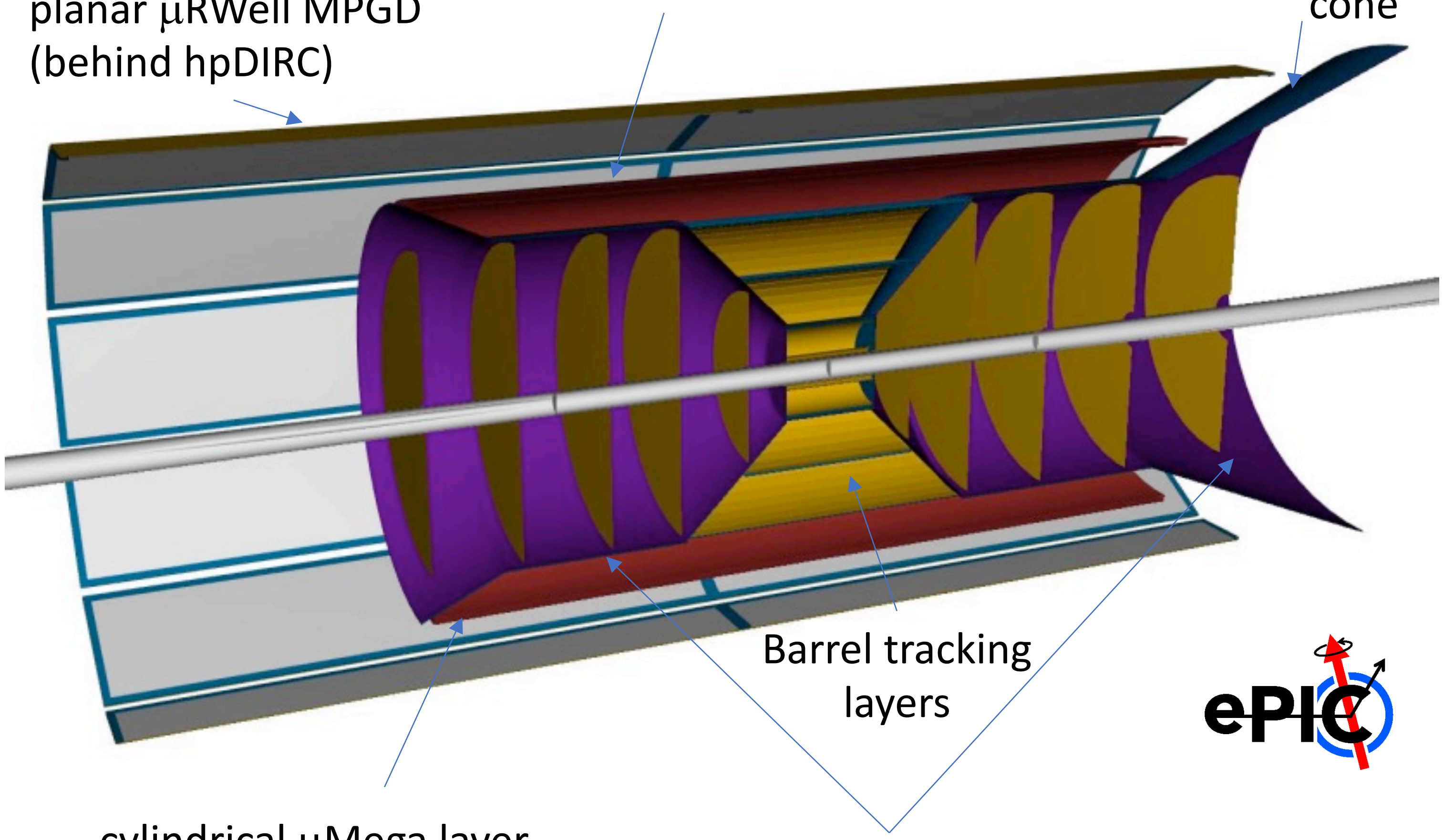


First “µITS3” assembly at CERN





Tracking



ePIC

Inner two vertex layers optimized for beam pipe bakeout and ITS3 sensor size.

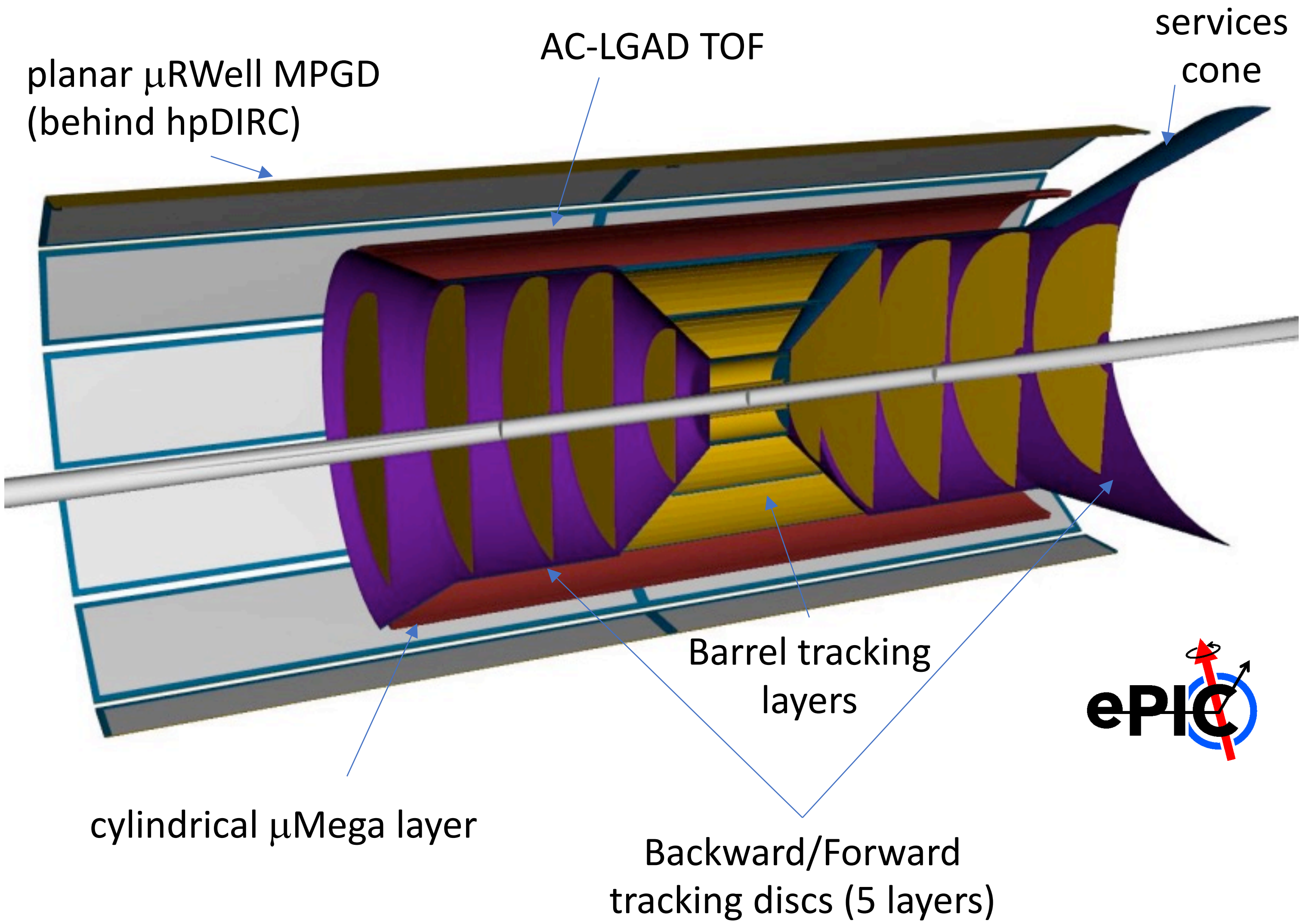
Third layer dual-purpose (vertex + sagitta)

Cylindrical µMega/TOF provide pattern recognition redundancy

µRWell behind hpDIRC provides ring seed direction, space point for pattern recognition

BARREL	r [mm]	l [mm]	X/X0 %
Si vertex layer 0	36	270	0.05
Si vertex layer 1	48	270	0.05
Si layer 2	**120**	270	**0.05**
Si sagitta layer 3	**270**	540	**0.25**
Si sagitta layer 4	**420**	840	0.55
Cyl.Micromegas layer	550	2300	0.5
AC-LGAD layer	640	2400	1.0
µRWELL behind DIRC	**730**	3420	~1.0%

Tracking



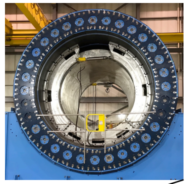
Five discs in forward/backwards direction (ITS-3 based large area sensor design)

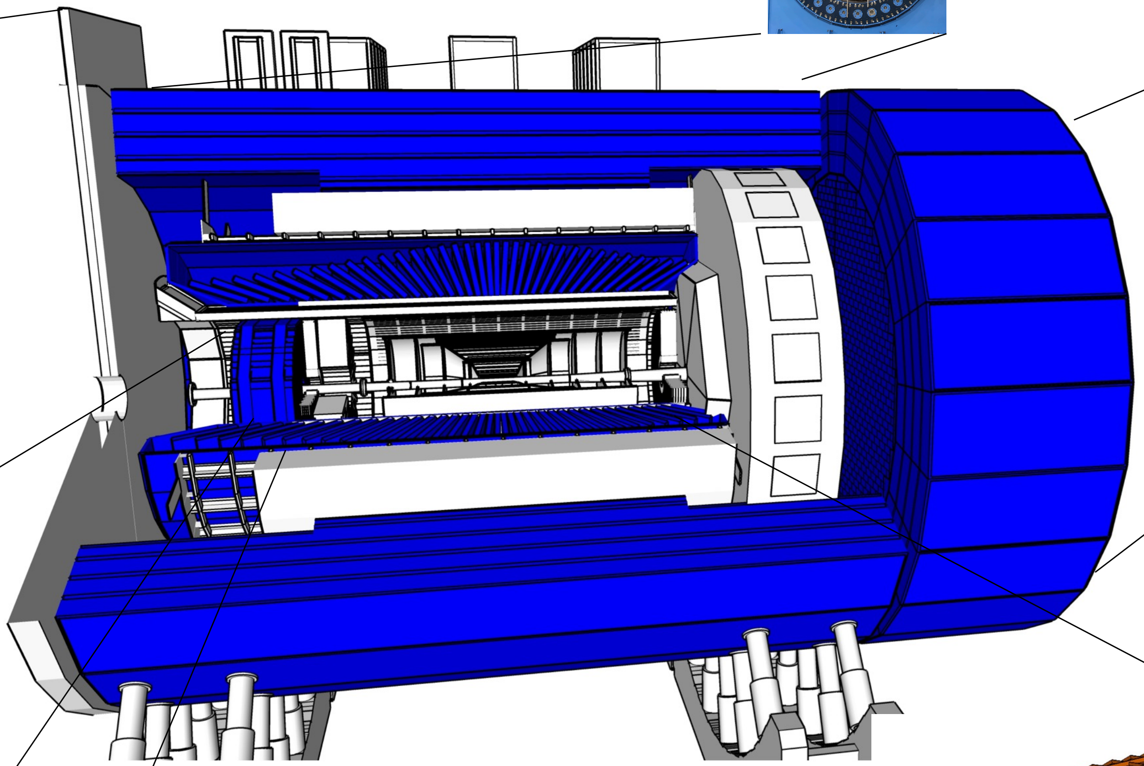
Increase lever arm by maximizing tracker extent in z (ongoing optimization)

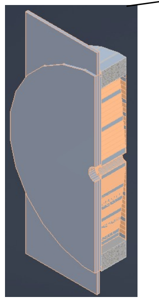
DISKS	+z [mm]	-z [mm]	X/X0 %
Disk 1	250	-250	0.24
Disk 2	450	-450	0.24
Disk 3	700	-650	0.24
Disk 4	1000	-900	0.24
Disk 5	**1350**	**-1150**	0.24

Calorimetry

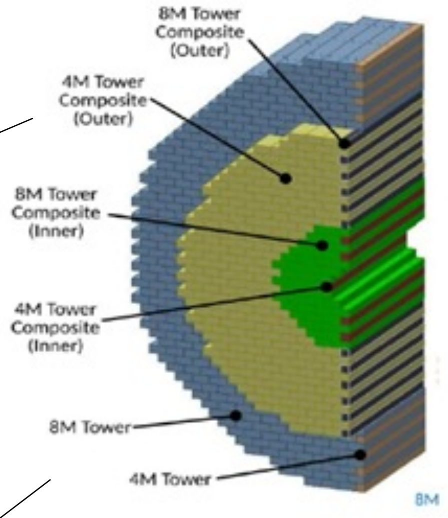
Barrel HCAL
(sPHENIX re-use)



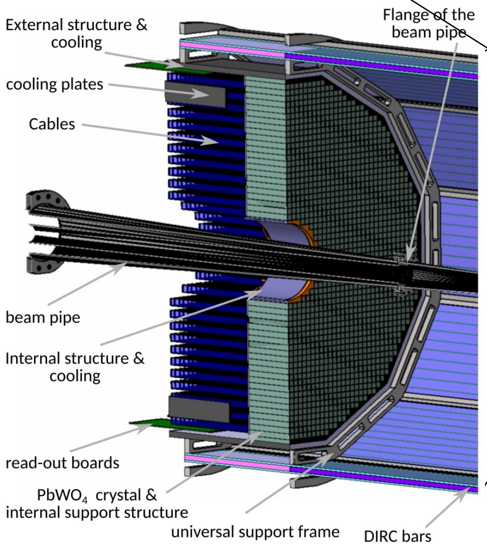




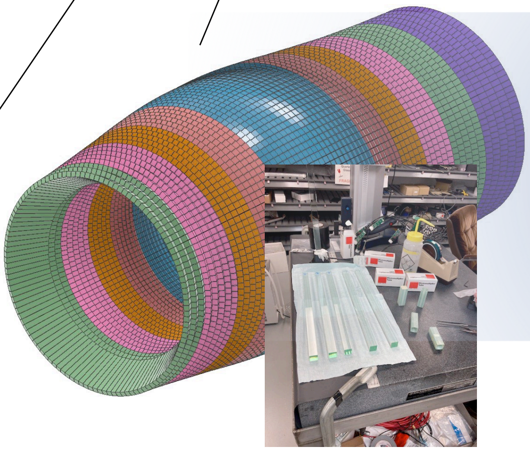
Backwards HCal
Steel/Sc Sandwich
tail catcher



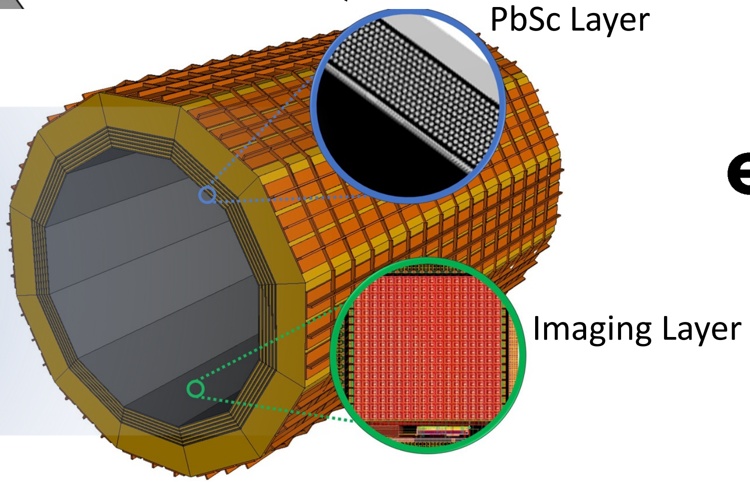
High granularity
W/SciFi EMCal
Longitudinally separated
HCAL with high-η insert



Backwards EMCal
PbW04 crystals

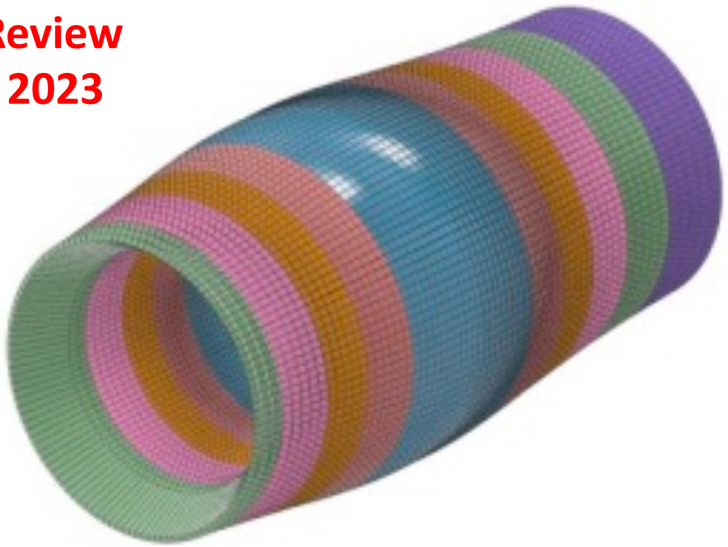


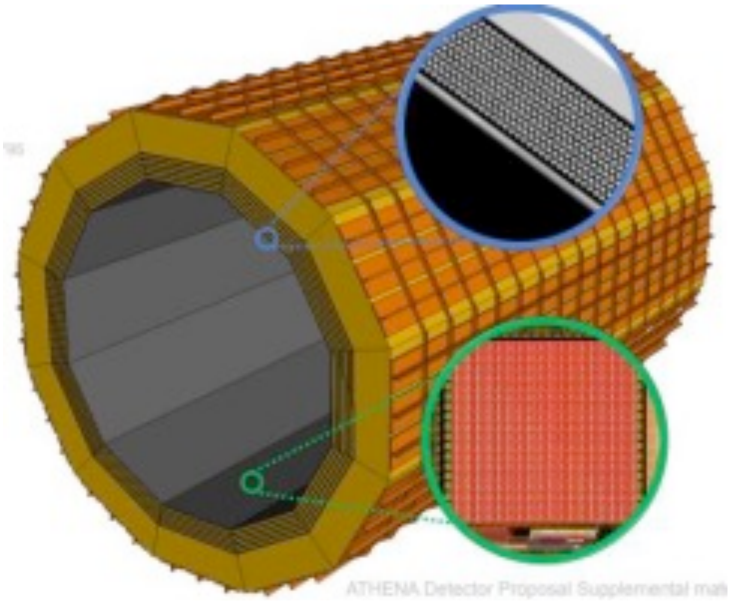
Complementary
options for BECAL:
SciGlass or
Imaging Calorimeter



Barrel ECal Technology Selection

ePIC Internal Review
March 13-14, 2023



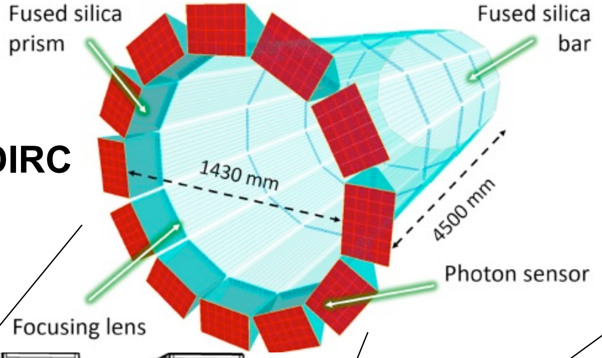


Homogeneous Calorimeter:
- SciGlass: cost-effective radiator
- Geometry and mechanical design based on PANDA
- Anticipated readout with SiPM matrices

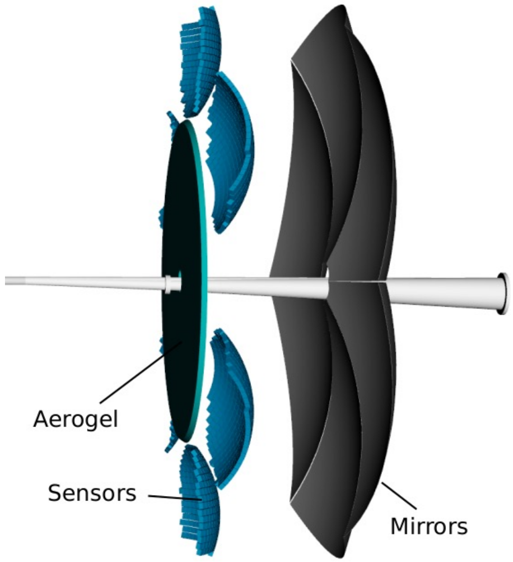
Hybrid Design:
- Imaging calorimetry based on monolithic silicon sensors (AstroPix)
- 6 layers of imaging Si sensors interleaved with 5 SciFi/Pb layers
- Followed by a large section of SciFi/Pb (can serve as inner HCAL)

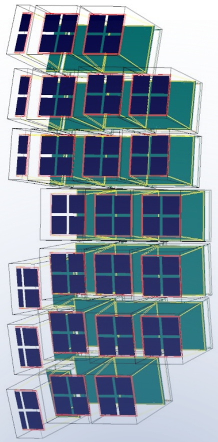
Particle ID

High-Performance DIRC

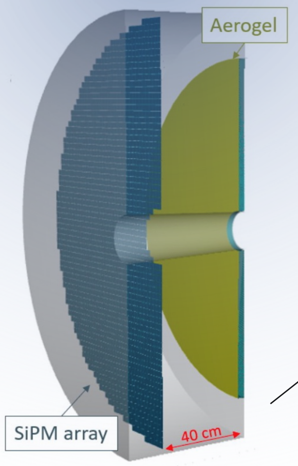


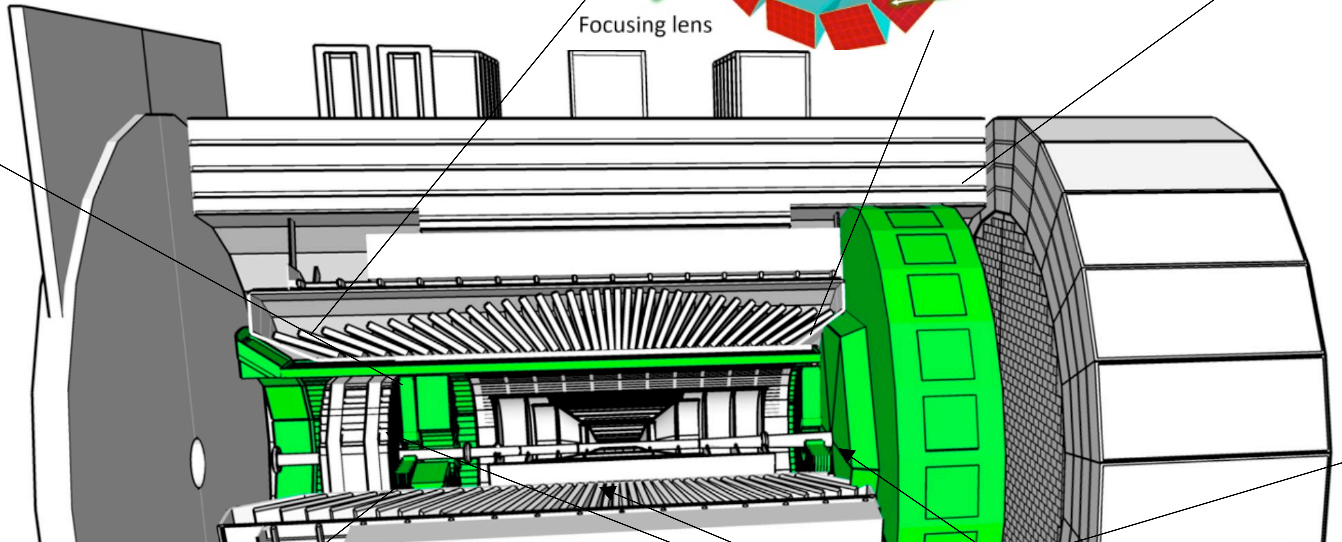
Dual-Radiator RICH (dRICH)

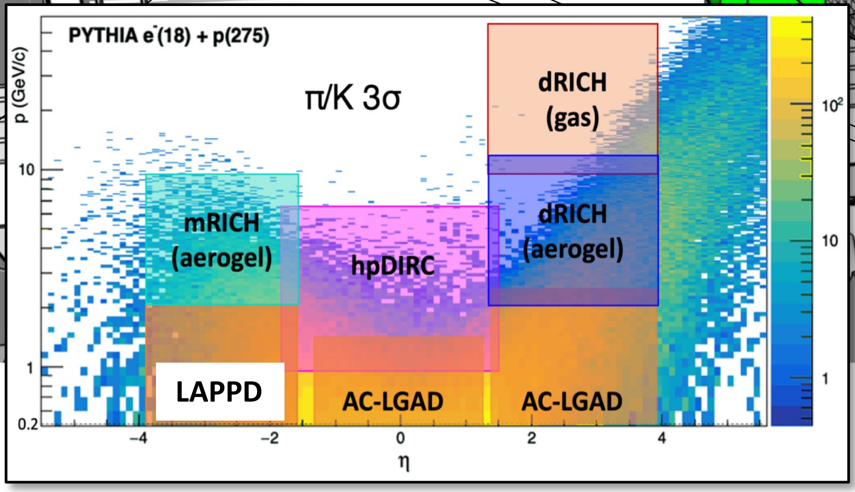




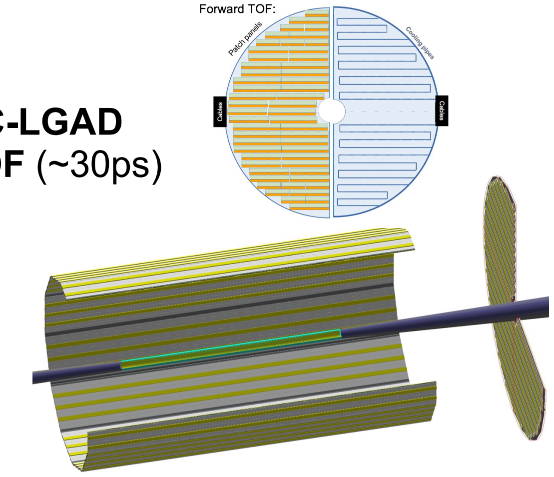
Modular (mRICH)
or Proximity Focused
(pfRICH)





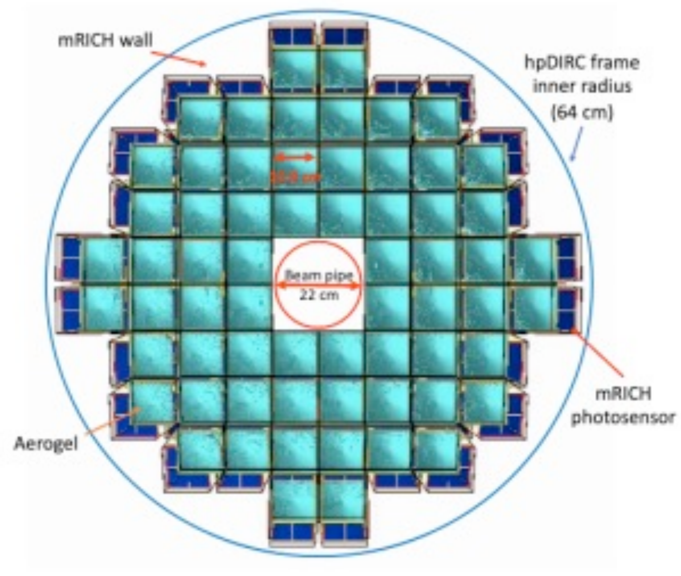


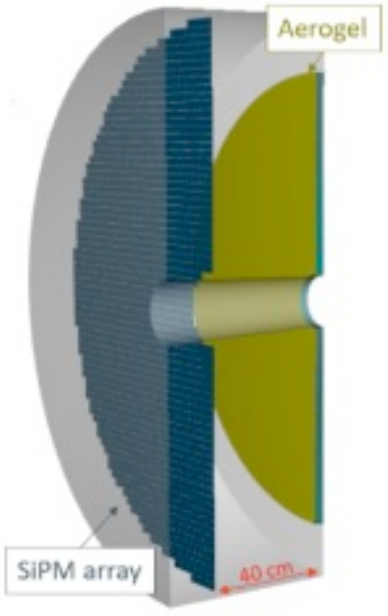
AC-LGAD
TOF (~30ps)



Backwards PID Technology Selection

ePIC Internal Review
March 20-21, 2023



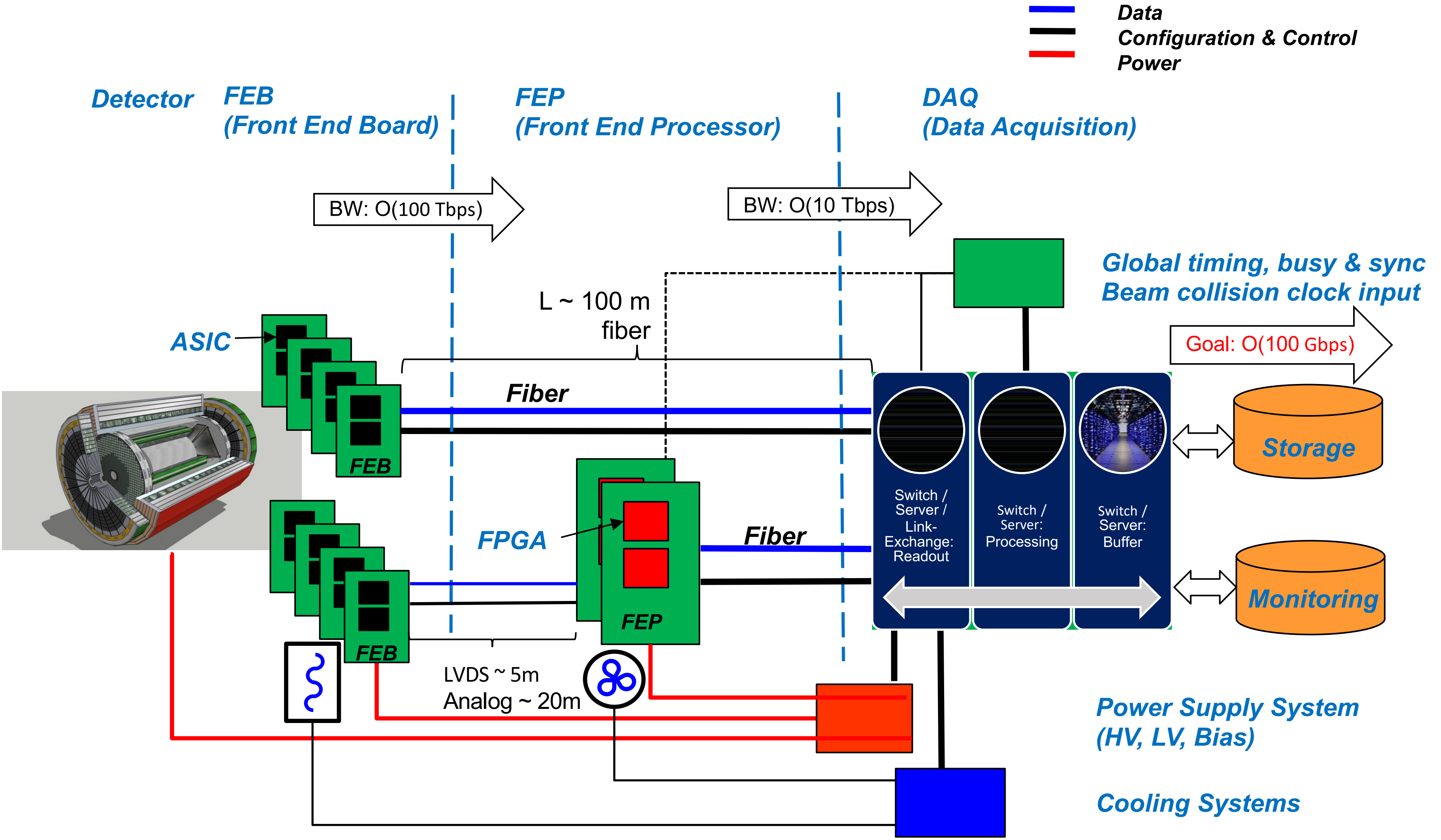


Modular RICH (mRICH)
- Aerogel radiator
- Longitudinally compact due to Fresnel lens focusing
- Modules have dead area

Proximity Focusing RICH (pfRICH)
- Aerogel radiator
- Gas threshold-based electron ID
- Requires expansion volume

Both with use LAPPD/HRPPD readout to provide additional timing information.

ePIC Streaming DAQ



- No External trigger
- All collision data digitized but aggressively zero suppressed at FEB
- Low / zero deadtime
- Event selection can be based upon full data from all detectors (in real time, or later)
- Collision data flow is independent and unidirectional-> no global latency requirements
- Avoiding hardware trigger avoids complex custom hardware and firmware
- Data volume is reduced as much as possible at each stage

EIC Project R&D Activities

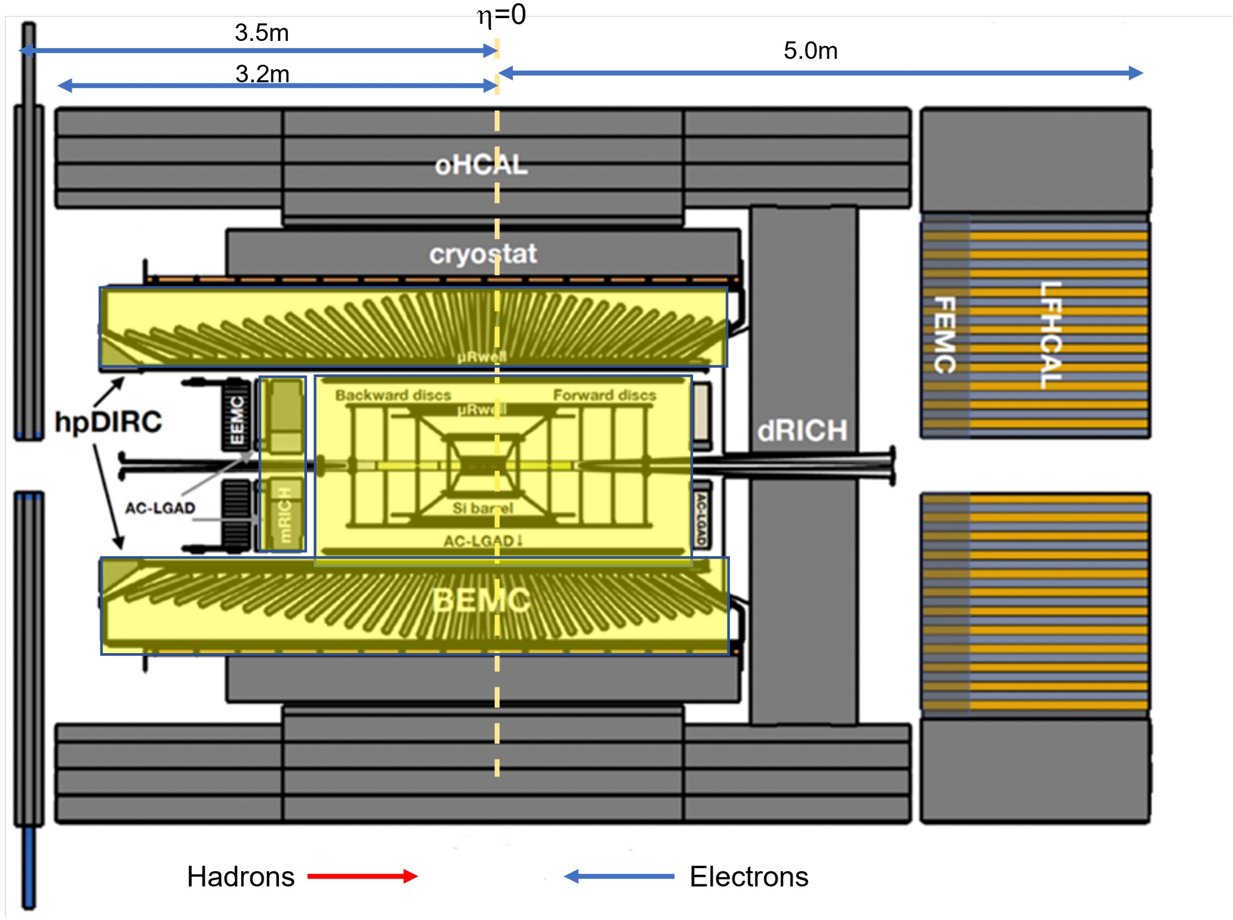
https://wiki.bnl.gov/conferences/index.php/ProjectRandDFY23

2023													
Project:	**eRD101**	**eRD102**	**eRD103**	**eRD104**	**eRD105**	**eRD106**	**eRD107**	**eRD108**	**eRD109**	**eRD110**	**eRD111**	**eRD112**	**eRD113**
Title:	mRICH	dRICH	hpDIRC	Silicon Service reduction	SciGlass	Forward ECal	Forward HCal	Cylindrical MPGD	ASIC/Electronics	Photosensors	Si-Vertex	AC-LGAD	Si-Sensor Development and Characterization
Contact:	X. He (GSU), M.Contalbrigo (U. Ferrara)	E. Cisbani (INFN-RM1), M.Contalbrigo (U. Ferrara), A. Vossen (Duke)	G. Kalicy (CUA), J. Schwiening (GSI)	L. Gonella (B'ham)	T. Horn and .L. Pegg (CUA)	H.Z. Huang (UCLA), O. Tsai (UCLA)	Friederike Bock (ORNL)	K. Gnanvo (UVA)	Fernando Barbosa (JLab)	Y. Ilieva (SC), C. Zorn (JLab), J. Xie (ANL), A. Kiselev (BNL), Pietro Antonioli (INFN)	Nicole Apadula (LBNL)	Zh. Ye (UIC)	Grzegorz Deptuch (BNL)
Proposal:	v1 (pdf)	v1 (pdf)	v1 (pdf), v2 (pdf)	v1 (PDF) v2 (pdf)	v1 (pdf)	v1 (pdf)	v1 (pdf), v2 (pdf)	v1 (pdf)	v1 (pdf), v2 (pdf), v3 (pdf)	v1 (pdf)	v1 (pdf) v2 (pdf)	v1 (pdf)	v1 (pdf) v2 (pdf)

See also EIC generic detector R&D: https://www.jlab.org/research/eic_rd_prgm

Work Underway on ePIC Design

- Tracking optimization
  - Achieve a realistic, low-mass design with good performance
    - Efficiency/seeding studies w/backgrounds
    - MPGD configuration
    - Integrate support and services
- Alternative technologies for barrel EMCal
- PID in backwards region (competing implementations)

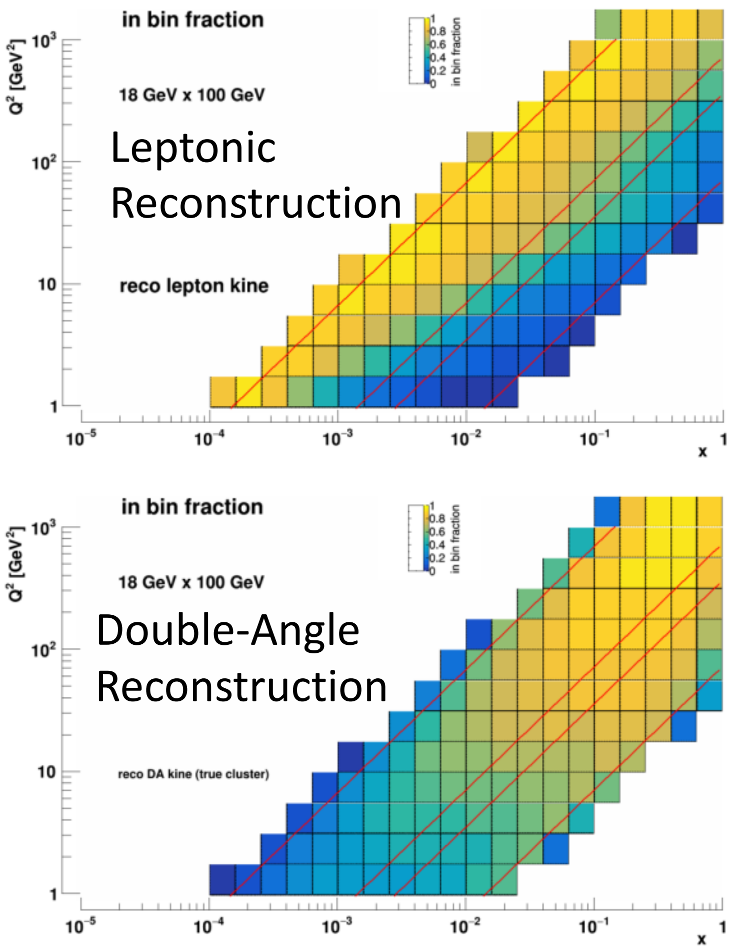


Process is driven by physics performance!

Iterative process between ePIC Collaboration and EIC Project

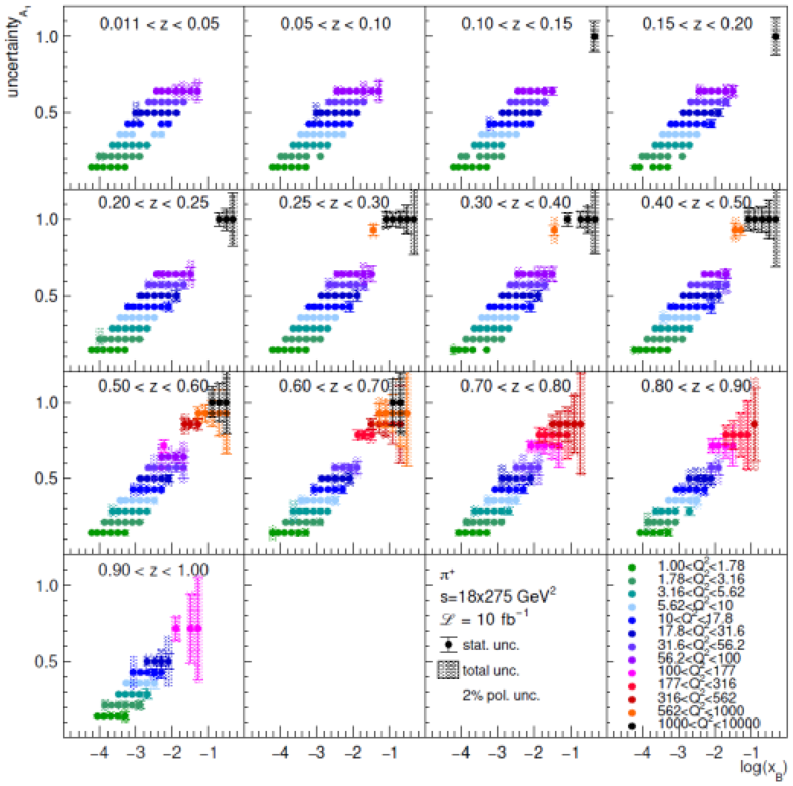
ePIC Physics Studies

First large-scale simulation campaign completed
Anticipate full simulation campaigns every quarter

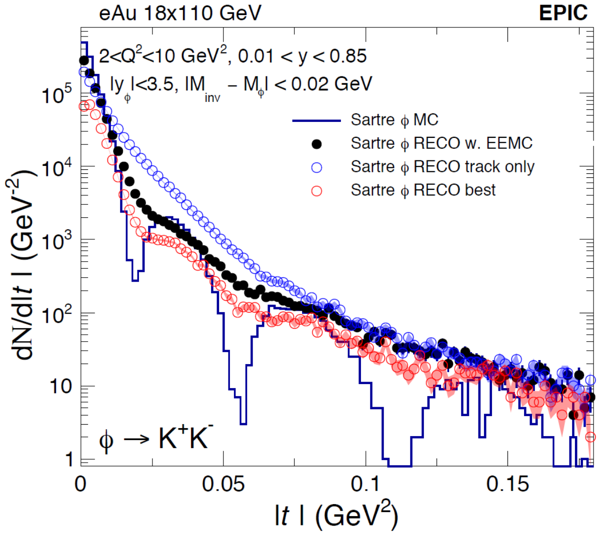


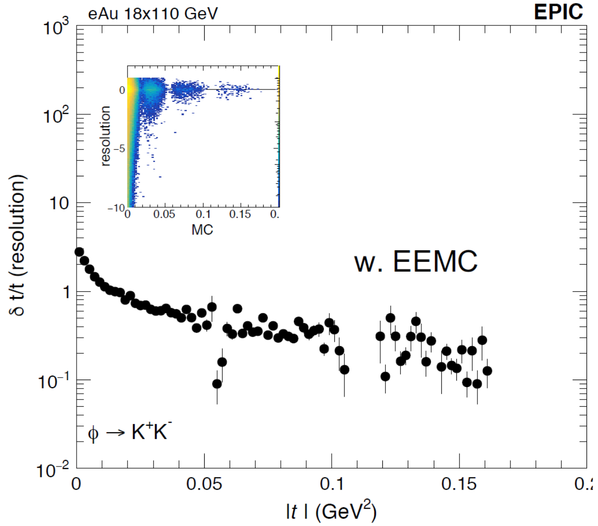
Ralf Seidl

Projected A_1 Uncertainties



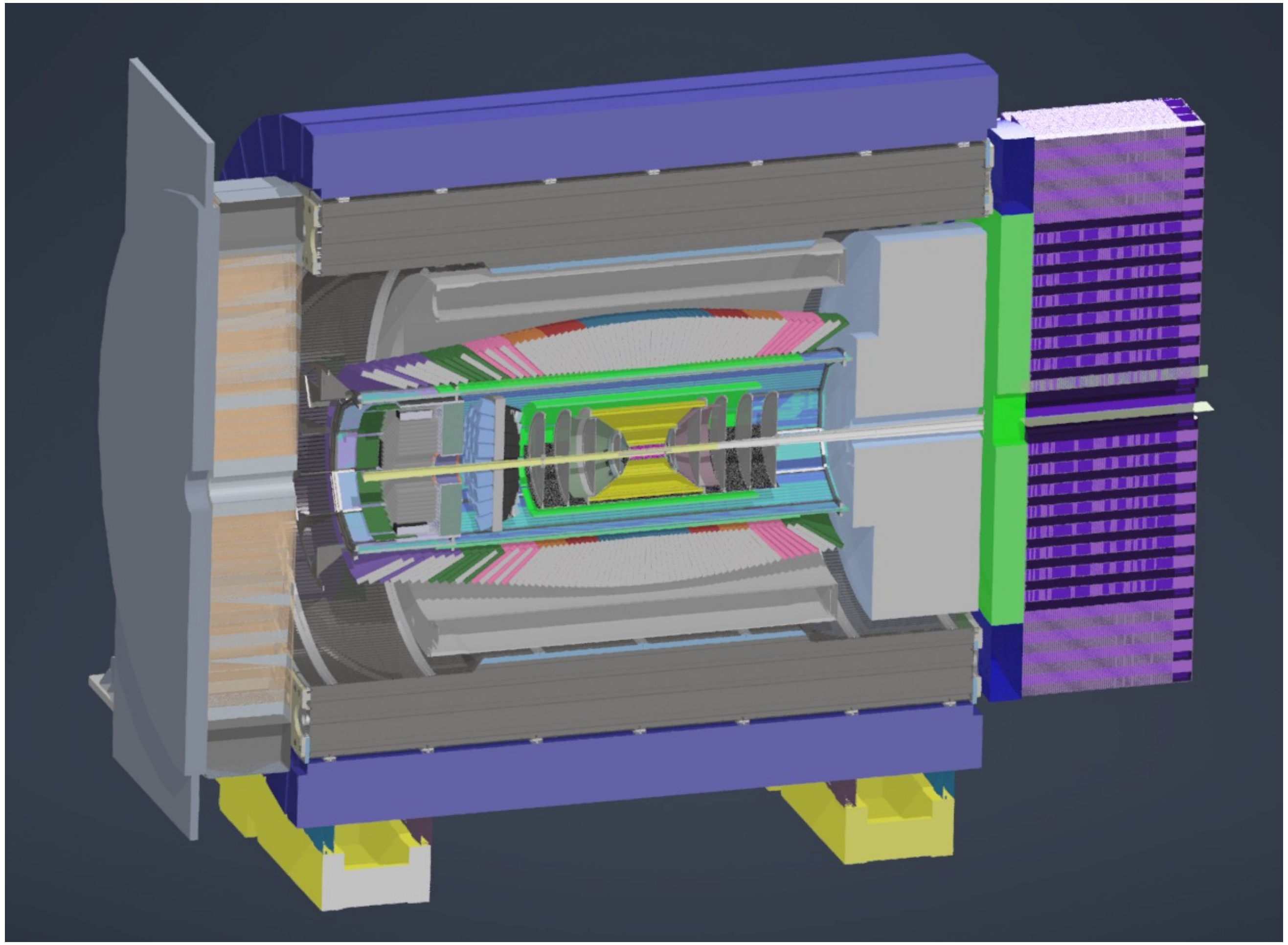
Charlotte Van Hulse



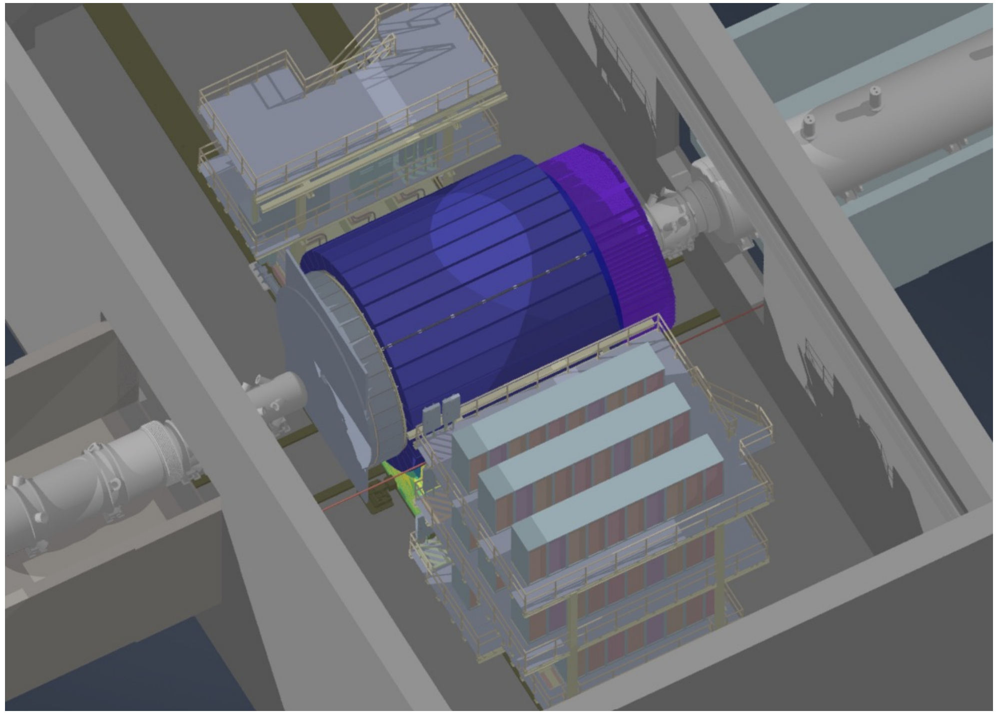


Kong Tu

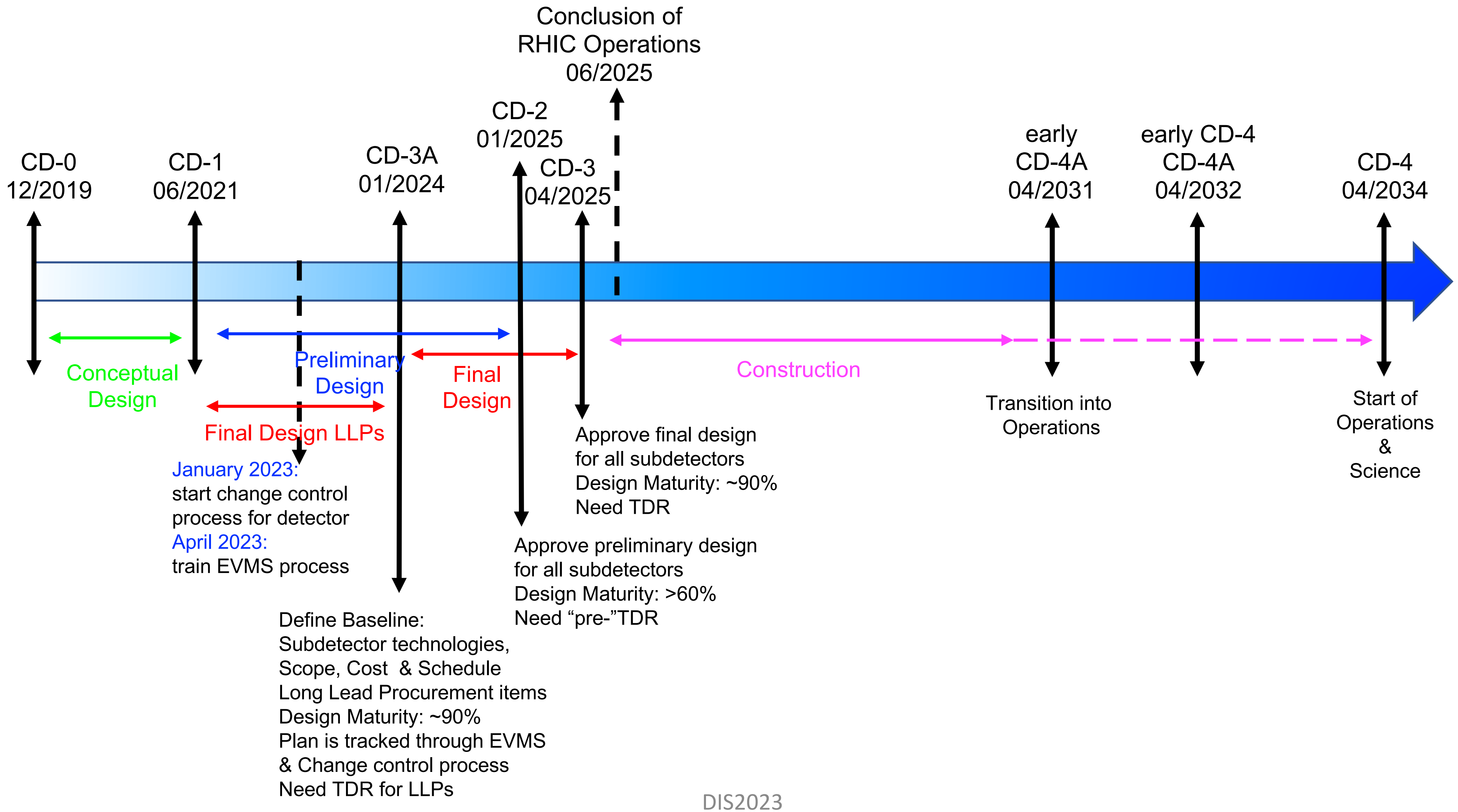
Engineering Design



Full CAD design of ePIC ongoing to facilitate *realistic* detector integration, including cabling and services.



EIC Project Schedule



NSAC Long Range Plan - QCD Town Hall

Recommendation 2: EIC Project

We recommend the expeditious completion of the EIC as the highest priority for facility construction.

The Electron-Ion Collider (EIC) is a powerful and versatile new accelerator facility, capable of colliding high-energy beams ranging from heavy ions to polarized light ions and protons with high-energy polarized electron beams. In the 2015 Long Range Plan the EIC was put forward as the highest priority for new facility construction and the expeditious completion remains a top priority for the nuclear physics community. The EIC, accompanied by the general-purpose large-acceptance detector, ePIC, will be a discovery machine that addresses fundamental questions such as the origin of mass and spin of the proton as well as probing dense gluon systems in nuclei. It will allow for the exploration of new landscapes in QCD, permitting the “tomography”, or high-resolution multidimensional mapping of the quark and gluon components inside of nucleons and nuclei. Realizing the EIC will keep the U.S. on the frontiers of nuclear physics and accelerator science and technology.

- Building on the recent EIC project CD-1 approval, the community-led Yellow-Report, and detector proposals, the QCD research community is committed to continue the development and timely realization of the EIC and its first detector, ePIC. We recommend supporting the growth of a diverse and active research workforce for the ePIC collaboration, in support of the expeditious realization of the first EIC detector.

- We recommend new investments to establish a national EIC theory alliance to enhance and broaden the theory community needed for advancing EIC science and the experimental program. This theory alliance will contribute to a diverse workforce through a competitive national EIC theory fellow program and tenure-track bridge positions, including appointments at minority serving institutions.

Summary

- The ePIC Collaboration has kicked-off:
  - Charter and elected leadership in place
  - Second collaboration meeting Jan. 9-11, 2023
    - https://indico.bnl.gov/event/17621/
  - Next collaboration meeting at annual EICUG meeting in Warsaw, Poland in July 2023.
  - Ongoing WG meetings focused on developing the ePIC technical design for CD-2/3A
    - Forum to focus community and R&D consortium expertise
  - Strong support and participation from EIC community
- The ePIC Detector is maturing into a detailed technical design
  - EIC detectors are an enormous undertaking that will require participation and expertise from both the RHIC and JLab communities
  - Detailed reviews in progress of calorimeter and RHICH technologies
  - International participation is key!
  - Progress towards DOE milestones: CD-3A review in 2023.