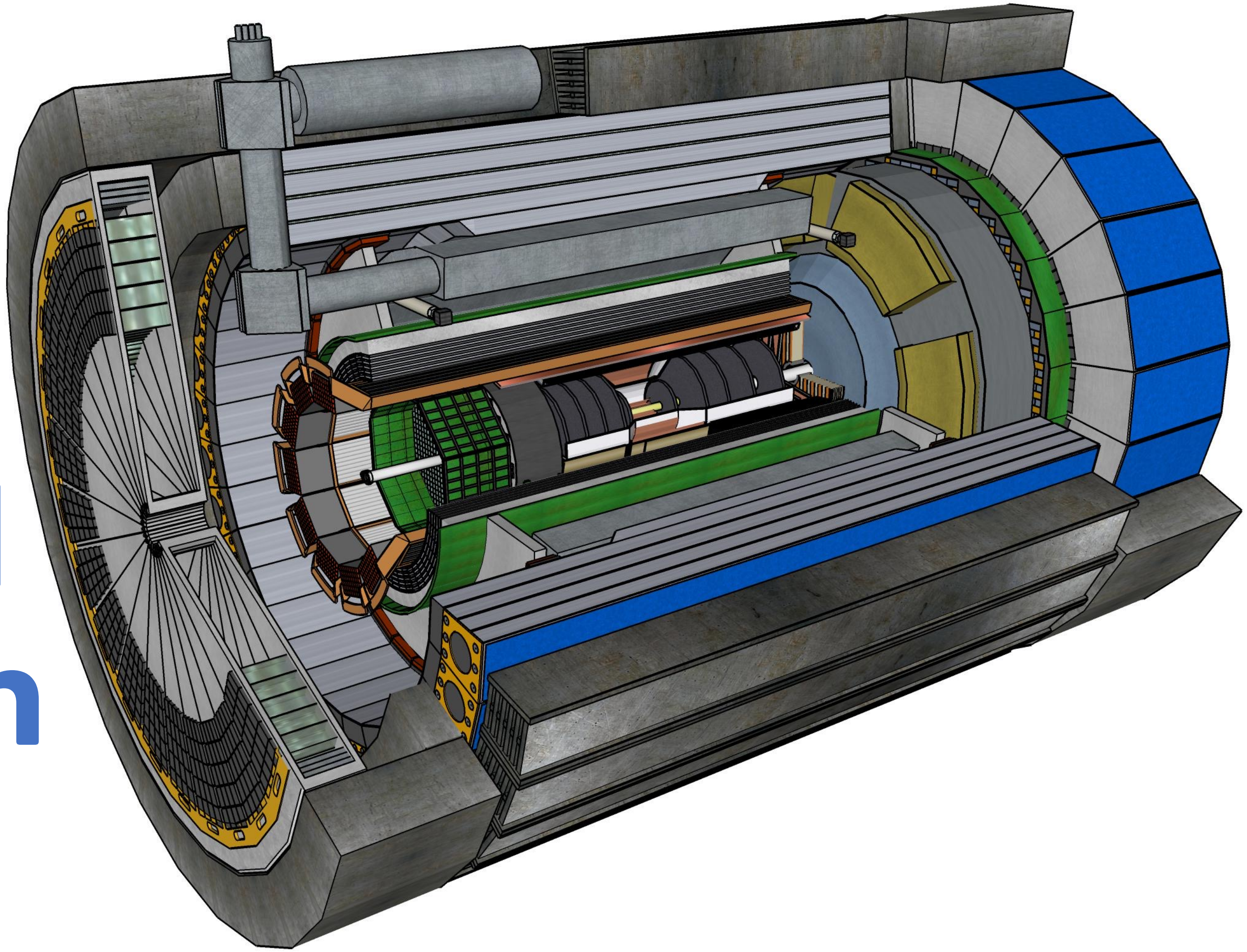
The ePIC Detector and Collaboration



Daniel Brandenburg
(Ohio State University),
for the ePIC Collaboration
2023 RHIC & AGS Users' Meeting
August 4th 2023

The Ohio State University

U.S. Department of Energy
Office of Science

Outline

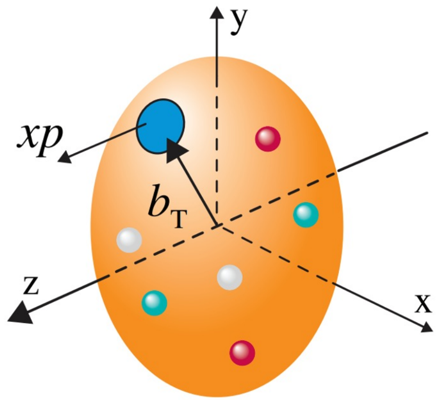
1. EIC Physics case and Detector Requirements

2. The progress and status of the ePIC Collaboration

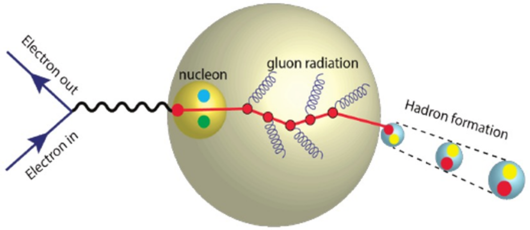
3. The ePIC detector design towards the TDR

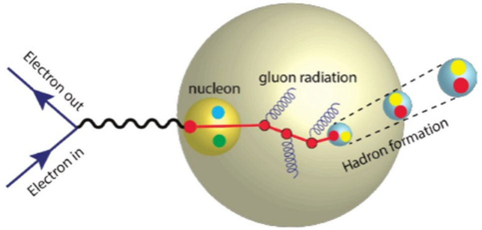
The EIC Science Mission

- How do the **nucleon properties like mass and spin emerge** from quarks and their interactions?



- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

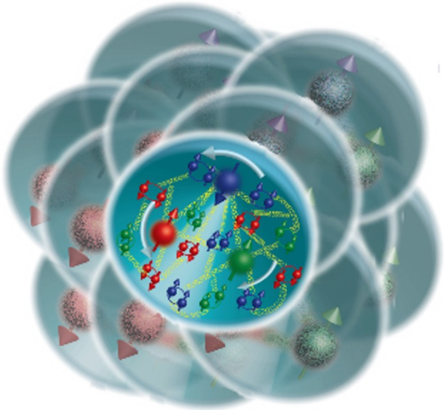




- In what manner do color-charged quarks and gluons, along with colorless jets, interact with the nuclear medium? And how do the confined hadronic states emerge from these quarks and gluons?

- What is the mechanism through which quark-gluon interactions give rise to nuclear binding?

- What impact does a high-density nuclear environment have on the interactions, correlations, and behaviors of quarks and gluons?

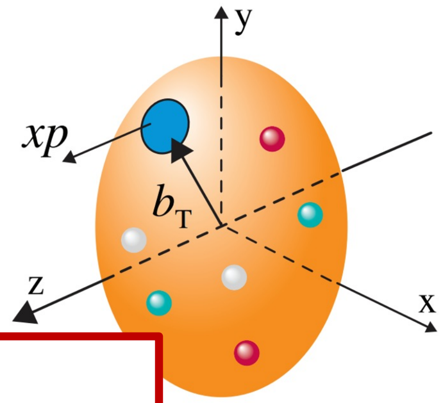


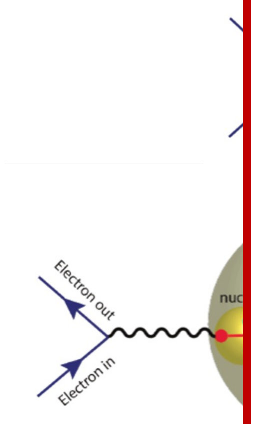
- Is there a **saturation point** for the density of gluons in nuclei at high energies, and does this lead to the **formation of gluonic matter** with universal properties across all nuclei, including the proton?

The EIC Science Mission

- How do the **nucleon properties like mass and spin emerge** from quarks and their interactions?

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?



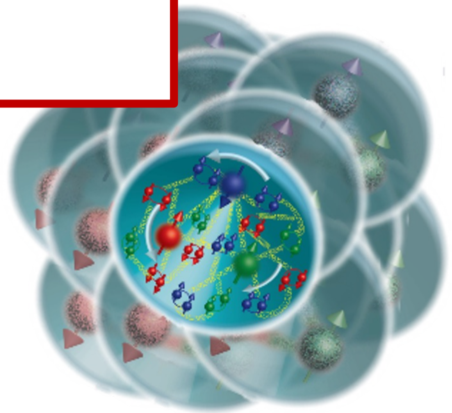


ng with
v do the
gluons?

actions give

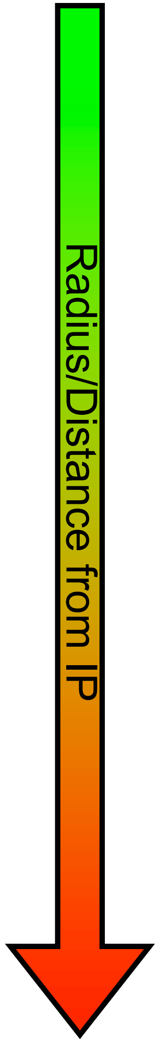
The whole EIC physics scope must be addressed by ePIC

- What impact does a high-density nuclear environment have on the interactions, correlations, and behaviors of quarks and gluons?



- Is there a **saturation point** for the density of gluons in nuclei at high energies, and does this lead to the **formation of gluonic matter** with universal properties across all nuclei, including the proton?

EIC Detector Requirements



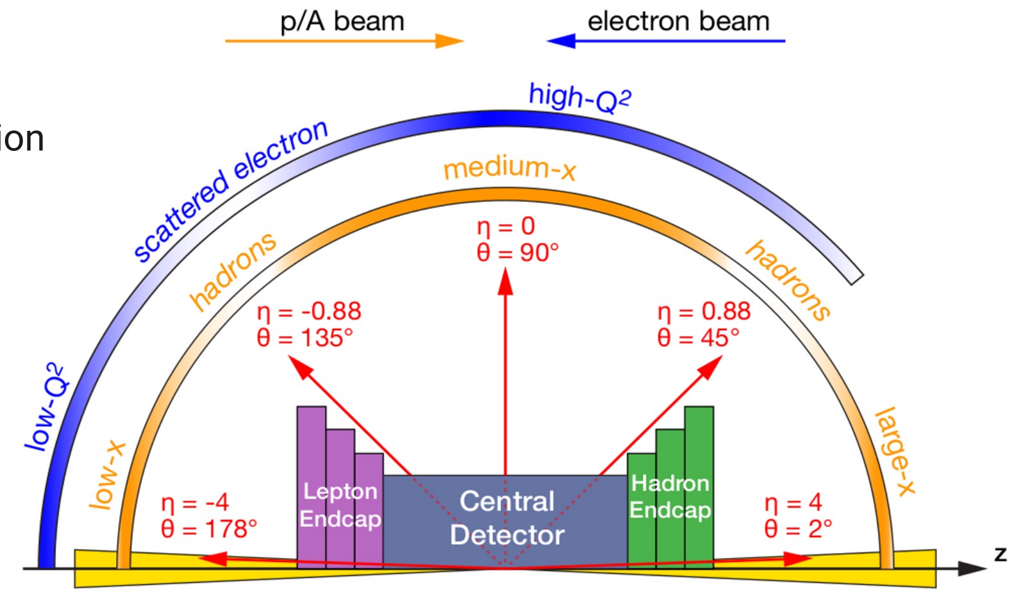
Vertex detector → Identify primary and secondary vertices,
- Low material budget: 0.05% X/X_0 per layer
- High spatial resolution: 20 μm pitch CMOS Monolithic Active Pixel Sensor

Central and Endcap tracker → High precision low mass tracking
- MAPS – tracking layers in combination with micro pattern gas detectors

Particle Identification → High performance single track PID for π, K, p separation
- RICH detectors (RICH, DIRC)
- Time-of-Flight high resolution timing detectors (HRPPDs, LGAD)
- Novel photon sensors: MCP-PMT / HRPPD

Electromagnetic calorimetry → Measure photons (E, angle), identify electrons
- $PbWO_4$ Crystals (backward), W/ScFi (forward)
- Barrel Imaging Calorimeter (Si + Pb/ScFi)

Hadron calorimetry → Measure charged hadrons, neutrons and K_L^0
- Achieve ~70%/√E + 10% for low E hadrons (~ 20 GeV)
- Fe/Sc sandwich with longitudinal segmentation



Very forward and backward detectors → Large acceptance for diffraction, tagging, neutrons from nuclear breakup
- Silicon tracking layers in lepton and hadron beam vacuum
- Zero-degree high resolution electromagnetic and hadronic calorimeters

DAQ & Readout Electronics → trigger-less / streaming DAQ, Integrate AI into DAQ

The Path To ePIC

Path to EIC is also the path to ePIC

- **White paper** (2012, 2014)
- **Long range plan** for Nuclear Science (2015)
- **The National Academy of Science assessment** (2018)
- **CD0 and site selection** (Dec 2019/ Jan 2020)
- **The Yellow Report** (2020)
- **The ECCE and ATHENA proposals** (2021)

Status 1 year ago:

- Merging of the CORE, ECCE and ATHENA Collaborations
- **Project Detector @ IP6 becomes ePIC**
- Community merging was just completed
- Structuring the ePIC collaboration just started
- Detector consolidation and optimization at a very initial stage

Now published in Nuclear Physics A

Detector and machine design parameters driven by the physics objectives

The Path To ePIC

THANK YOU !

Tracking:
Xuan Li xuanli@lanl.gov
Kondo Gnanvo kagnanvo@jlab.org
Laura Gonella <laura.gonella@cern.ch>
Francesco Bossu francesco.bossu@cea.fr

Calorimetry:
Friederike Bock Friederike.Bock@cern.ch
Carlos Munoz Camacho munoz@jlab.org
Oleg Tsai tsai@physics.ucla.edu
Paul Reimer reimer@anl.gov

Cerenkov PID:
Xiaochun He xhe@gsu.edu
Grzegorz Kalicy kalicy@cua.edu
Tom Hemmick tkhemmick@gmail.com
Roberto Preghenella <preghenella@bo.infn.it>

TOF PID (AC-LGADs):
Wei Li wl33@rice.edu
Constantin Loizides constantin.loizides@cern.ch
Franck Geurts geurts@rice.edu
Zhenyu Ye yezhenyu@uic.edu

Far Forward:
Michael Murray mjmurray@ku.edu
Yuji Goto goto@bnl.gov
Alex Jentsch ajentsch@bnl.gov
John Arrington JArrington@lbl.gov

Far Backward:
Igor Korover korover@mit.edu
Nick Zachariou nick.zachariou@york.ac.uk
Krzyzstof Piotrzkowski
krzysztof.piotrzkowski@cern.ch
Jaroslaw Adam jaroslavadam299@gmail.com

DAQ/Electronics/Readout:
Chris Cuevas cuevas@jlab.org
Jo Schambach schambachjj@ornl.gov
Alexandre Camsonne camsonne@jlab.org
Jeff Landgraf jml@bnl.gov

Computing and Software:
Cristiano Fanelli cfanelli@mit.edu
David Lawrence davidl@jlab.org
Sylvester Joosten sjoosten@anl.gov
Andrea Bressan Andrea.Bressan@cern.ch

Global/Integration:
Richard Milner milner@mit.edu
Jin Huang jhuang@bnl.gov
Thomas Ullrich thomas.ullrich@bnl.gov
Silvia Dalla Torre Silvia.DallaTorre@cern.ch
Carlos Munoz Camacho munoz@jlab.org
Joe Osborn josborn1@bnl.gov

The Joint WGs (April 22 – March 23)

Simulation Production and QA:
Joe Osborn osbornjd@ornl.gov
Wenliang (Bill) Li wenliang.billlee@googlemail.com
Zhoudunming (Kong) Tu zhoudunming@bnl.gov
Wouter Deconinck wouter.deconinck@umanitoba.ca

Inclusive:
Tyler Kutz tkutz@mit.edu
Claire Gwenlan claire.gwenlan@physics.ox.ac.uk
Barak Schmookler barak.schmookler@stonybrook.edu
Paul Newman paul.richard.newman@cern.ch

Semi-Inclusive:
Ralf Seidl rseidl@ribf.riken.jp
Charlotte Van Hulse cvanhuls@mail.cern.ch
Anselm Vossen anselm.vossen@duke.edu
Marco Radici marco.radici0@gmail.com

Exclusive, Diffraction and Tagging:
Axel Schmidt axelschmidt@gwu.edu
Rachel Montgomery Rachel.Montgomery@glasgow.ac.uk
Spencer Klein srklein@lbl.gov
Daria Sokhan Daria.Sokhan@glasgow.ac.uk

Jets and Heavy Flavor:
Cheuk-Ping Wong cpwong@lanl.gov
Wangmei Zha first@ustc.edu.cn
Miguel Arratia miguela@ucr.edu
Brian Page bpage@bnl.gov

BSM & Precision EW:
Xiaochao Zheng xiaochao@jlab.org
Sonny Mantry Sonny.Mantry@ung.edu
Yulia Furletova yulia@jlab.org
Ciprian Gal ciprian@jlab.org

Building a Collaboration: Timeline

- June 2022: Collaboration roster established via institutional survey
- July 26th-28th: Collaboration formation meeting @ Stony Brook University
- August-December 2022: Collaboration Charter
  - December 14: adoption of the charter
- December 2022 - February 2023: Nomination process & Collaboration leadership election
  - Mid February: announcement of election results
- > April 2022: forming the collaboration community
- Biweekly general meetings, alternating meeting time to account for a world-wide collaboration including 4 time-areas:
  - East Cost, West Cost, Europe, Asia
- First Collaboration Meeting: July 26-28, 2022, at Stonybrook
- Second Collaboration Meeting: January 9-11, 2023 at JLab
- Third Collaboration Meeting: July 26-29, 2023, in Warsaw

ePIC Collaboration Leadership

Formed (early career representants elected), Chair and vice elected

elected

EB formation in the pipeline for the next future

Collaboration Council
Institutional Representatives

Spokesperson's Office
Spokesperson (SP)
Deputies

Executive Board
SP & Deputies
3 members elected by CC
DE&I
Early Career
Addtl. Members Nominated by SP

Standing Committees
DE&I
Conferences and Talks
Membership
Elections
Publications

Ad-Hoc Committees

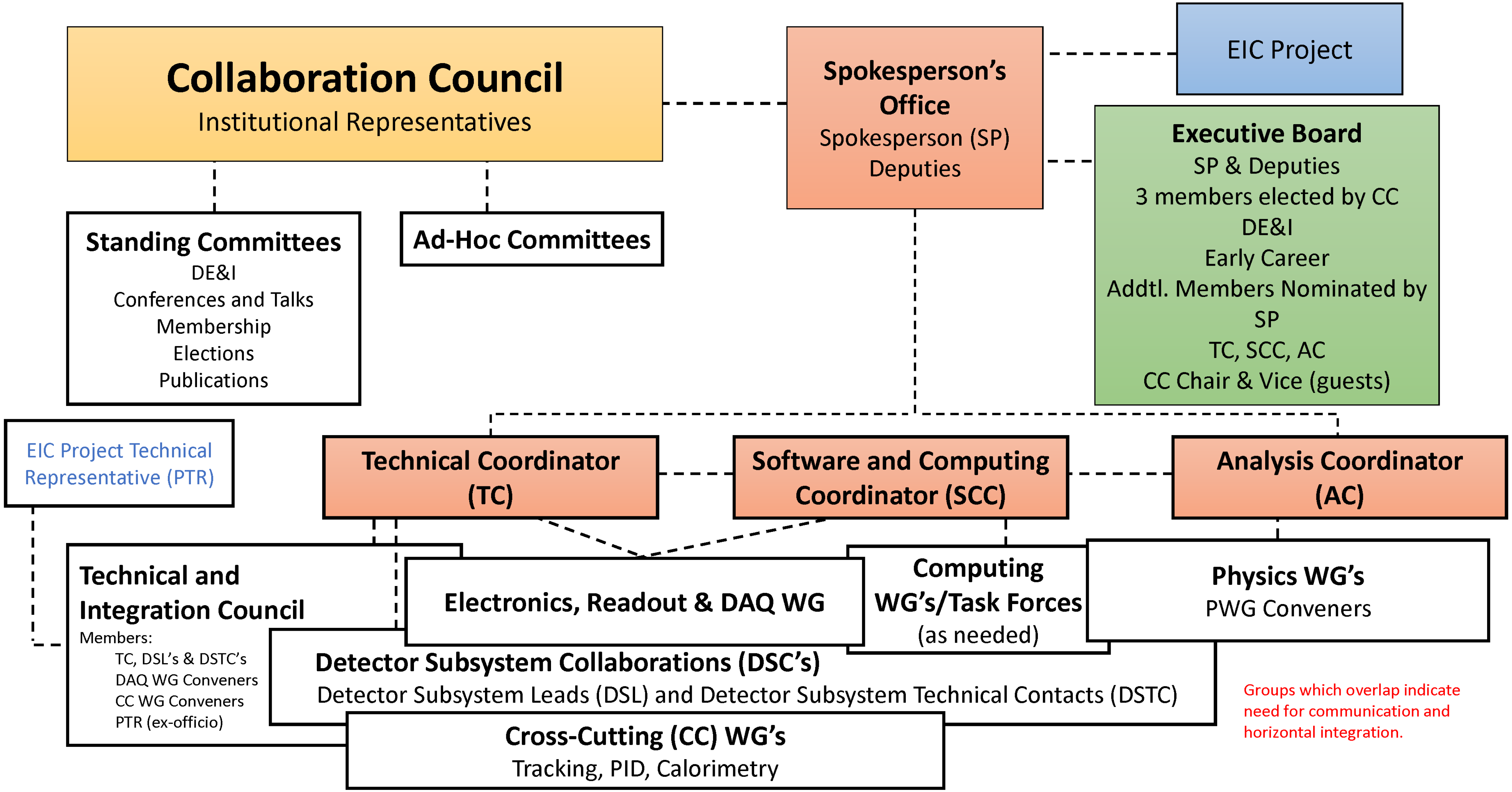
- Election Committee is in place:

John Arrington (Chair), Helen Caines, Domenico Elia, Or Hen

Ongoing the election process of chair and vice of:

- DE&I
- Conference and talks
- Membership

ePIC Collaboration: Structure



ePIC Collaboration: Structure

Working Groups

SPOKESPERSON'S OFFICE
J. Lajoie (ISU), Spokesperson
S. Dalla Torre (INFN), Deputy Spokesperson

TECHNICAL COORDINATOR
Klaus Dehmelt (SBU)

ELECTRONICS, READOUT AND DAQ
Fernando Barbosa (JLab)
Jeff Landgraf (BNL)
Jin Huang (BNL)

PID
Oskar Hartbrich (ORNL)
Thomas Ulrich (BNL)

TRACKING
Ernst Sichtermann (LBNL)
Matt Posik (Temple)

FAR FORWARD/ FAR BACKWARD
Simon Gardner (Glasgow)
Nathaly Santiesteban (UNH)

CALORIMETRY
Oleg Tsai (UCLA)

SOFTWARE AND COMPUTING COORDINATOR
Markus Diefenthaler (JLab), Coordinator
Wouter Deconinck (Manitoba), Deputy
Sylvester Joosten (ANL), Deputy
Torre Wenaus (BNL), Deputy

PRODUCTION
Sakib Rahman (Manitoba)
Thomas Britton (JLab)

PHYSICS AND DETECTOR SIMULATION
Kolja Kauder (BNL)
Chao Peng (ANL)

USER LEARNING
Holly Szumila-Vance (JLab)
Kolja Kauder (BNL)

RECONSTRUCTION
Shujie Li (LBNL)
Derek Anderson (ISU)

VALIDATION
Tori Jeske (JLab)
Dmitry Kalinkin (Kentucky)

ANALYSIS TOOLS
Kong Tu (BNL)
TBD

STREAMING COMPUTING MODEL
Marco Battaglieri (INFN Genova)
Jin Huang (BNL)

ANALYSIS COORDINATORS
Salvatore Fazio (Unical)
Rosi Reed (Lehigh)

INCLUSIVE PHYSICS
Tyler Kutz (MIT)
Claire Gwenlan (Oxford)

SEMI-INCLUSIVE PHYSICS
Charlotte Van Hulse (Alcala)
Stefan Diehl (UConn)

EXCLUSIVE, DIFFRACTION AND TAGGING
Raphael Dupre (Orsay)
Rachel Montgomery (Glasgow)

JETS AND HEAVY FLAVOR
Olga Evdokimov (UIC)
Brian Page (BNL)

BSM AND PRECISION EW
Ciprian Gal (JLab)
Michael Nycz (Virginia)

Detector Subsystem Collaborations

SPOKESPERSON'S OFFICE
J. Lajoie (ISU), Spokesperson
S. Dalla Torre (INFN), Deputy Spokesperson

TECHNICAL COORDINATOR
Klaus Dehmelt (SBU)

dRICH
DSL/DSTC: Marco Contalbrigo (INFN)

hpDIRC
DSL/DSTC: Greg Kalicy (CUA)

BACKWARD RICH
DSL/DSTC: Alexander Kislev (BNL)

FAR FORWARD
DSL: Alex Jentsch (BNL)
DSTC (B0): Zvi Citron (Ben-Gurion)
DSTC (Roman Pots/OMD): Alex Jentsch (BNL)
DSTC (ZDC): Yuji Goto (RIKEN)

FAR BACKWARD PAIR SPECTROMETER
DSL: Nick Zachariou (York)
DSTC: Dhevan Gangadharan (Houston)

FAR BACKWARD HIGH RATE CALORIMETRY
DSL/DSTC: Krzysztof Piotrzkowski (AGH)

FAR BACKWARD HIGH RATE TRACKER
DSL: Jaroslav Adam (CTU)
DSTC: Simon Gardner (Glasgow)

Si TRACKERS
DSL: Ernst Sichtermann (LBL)
DSTC: Laura Gonella (Birmingham)

BACKWARDS ECAL
DSL: Tanja Horn (CUA)
DSTC: Carlos Munhoz (IJCLab)

BACKWARDS HCAL
DSL/DSTC: Leszek Kosarzewski (CTU)

BARREL ECAL
Co-DSL: Sylvester Joosten (ANL)
Co-DSL: Hwidong Yoo (Yonsei)
Deputy DSL: Maria Zurek (ANL)
DSTC (Si): Jessica Metcalfe (ANL)
DSTC (SciFi/Pb): Zisis Papandreou (Regina)

BARREL HCAL
DSL/DSTC: John Lajoie (ISU)

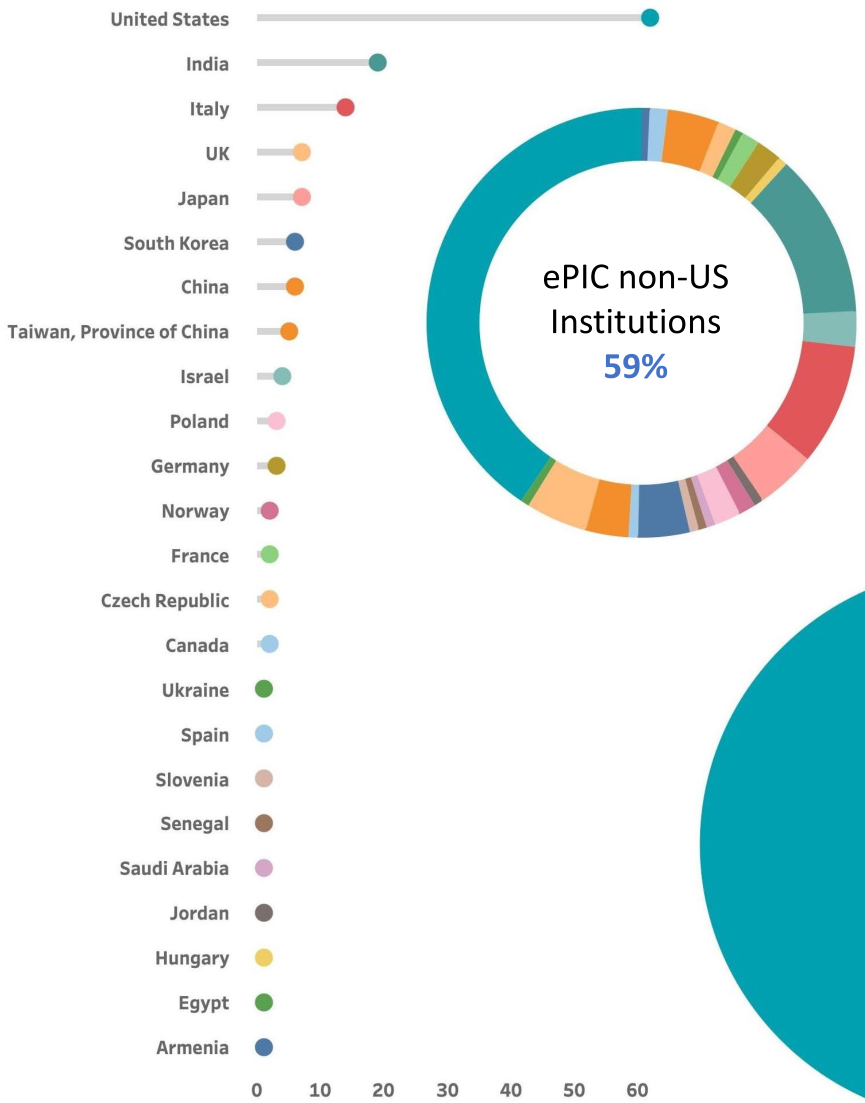
FORWARD ECAL
Co-DSL/DSTC: Oleg Tsai (UCLA)
Co-DSL: Huan Huang (UCLA)

FORWARD HCAL
DSL/DSTC: Friederike Bock (ORNL)
Deputy DSL/DSTC: Miguel Arratia (UCR)

AC-LGAD TOF
DSL: Zhenyu Ye (UIC)
Deputy DSL: Satoshi Yano (Hiroshima)

GASEOUS TRACKERS
DSL: Kondo Gnanvo (LBL)
DSTC: Maxence Vendenbroucke (Saclay)

The ePIC Collaboration

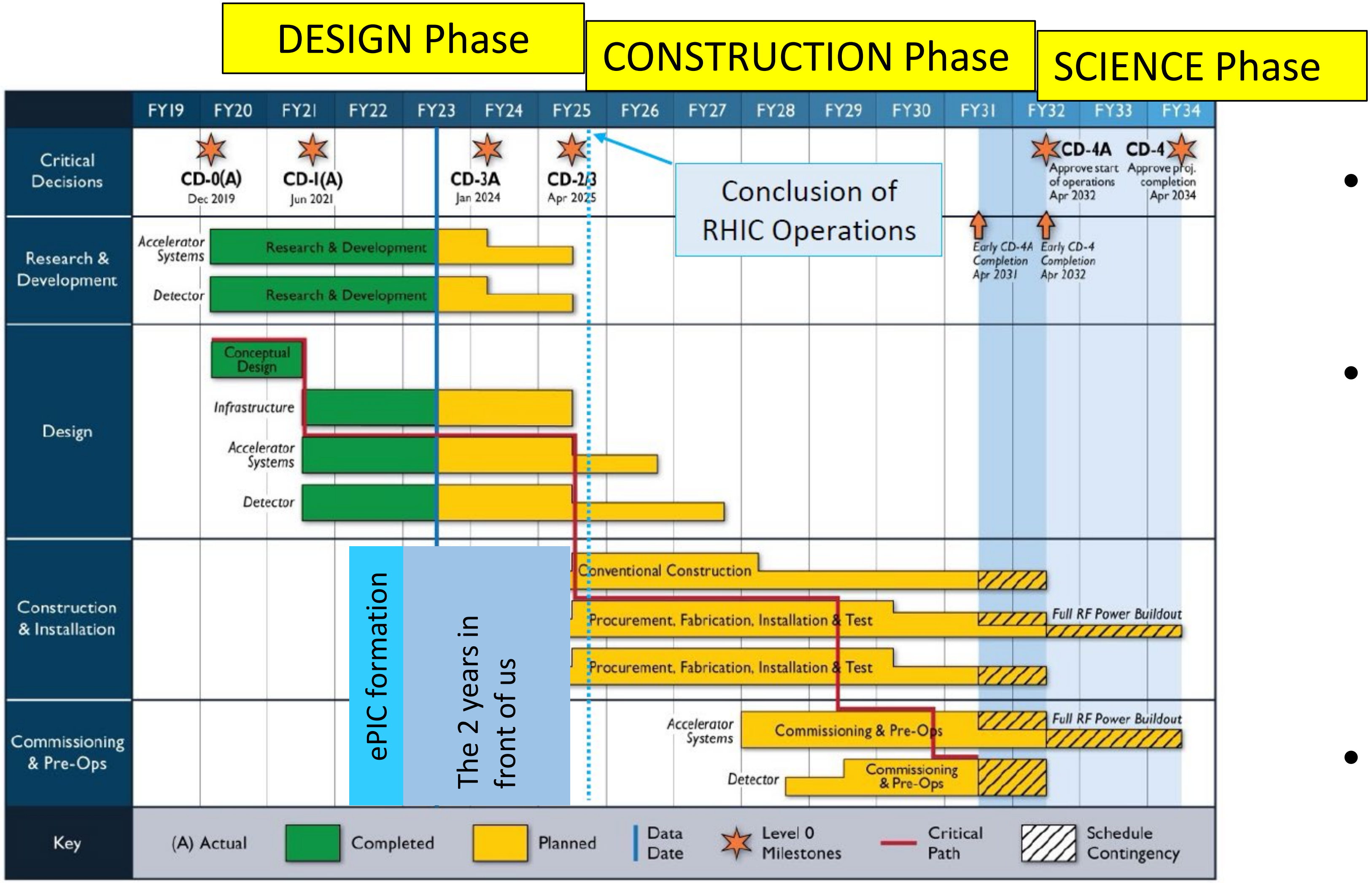


171 institutions
24 countries

500+ participants

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

ePIC Timeline and Milestones

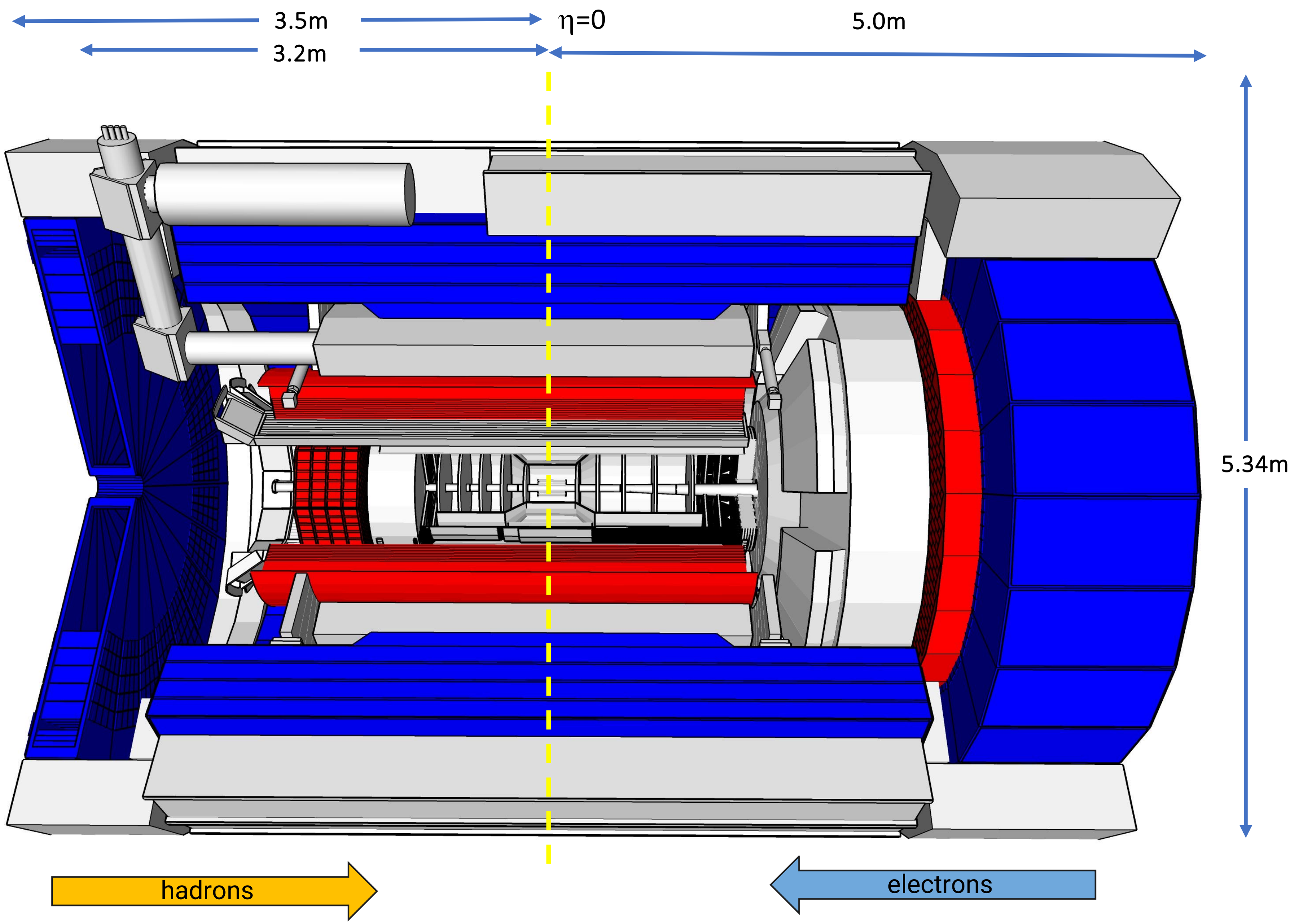


The ePIC goals for the current and next year:

- to prepare the Technical Design Report (TDR) to get CD3 approval
- To organize the Collaboration so to be ready for the construction phase at the beginning of 2025

- The ePIC management plan by the SP–office is focused on the next two-years

ePIC Detector Design



Tracking:

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

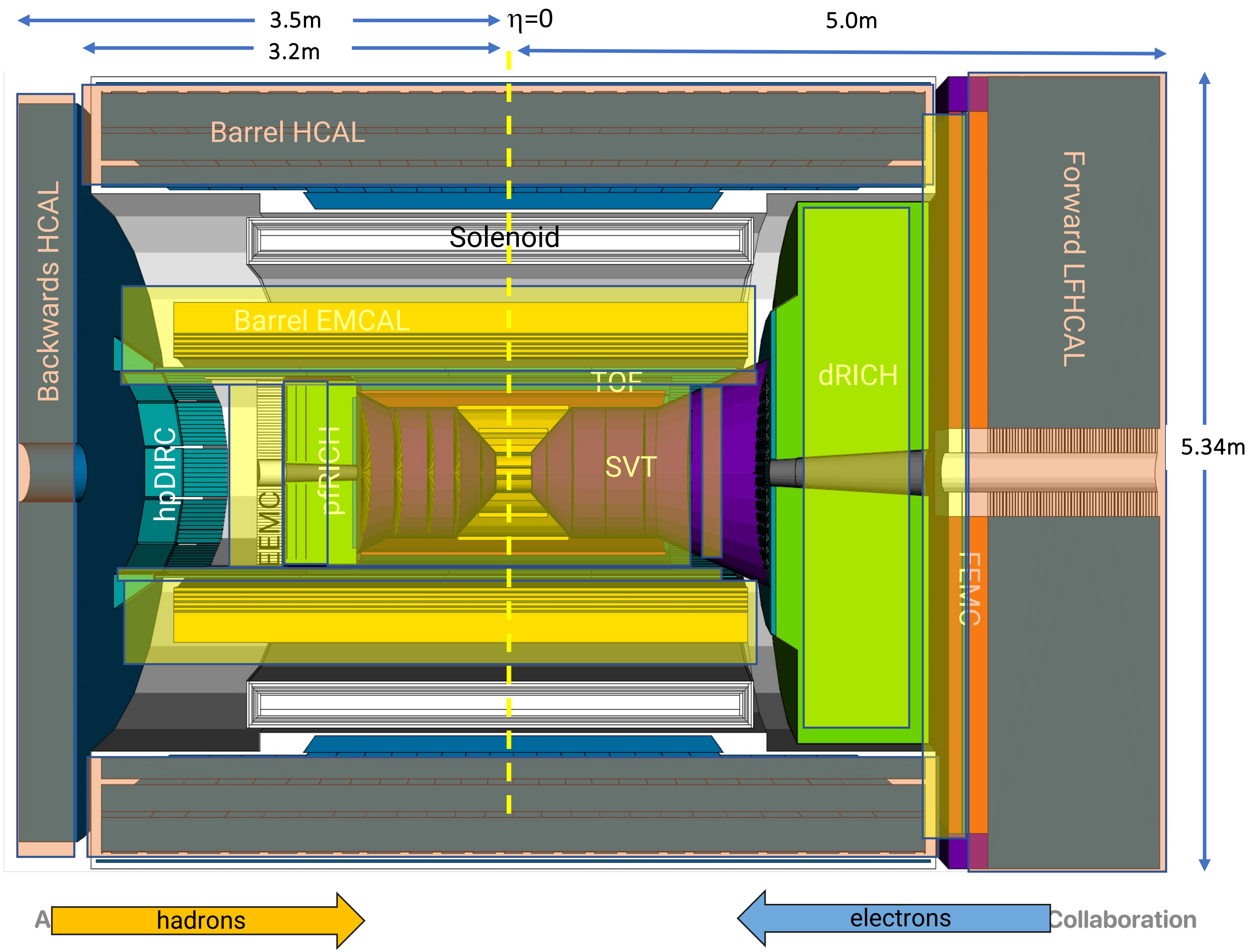
PID:

- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:

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

ePIC Detector Design



Tracking:

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

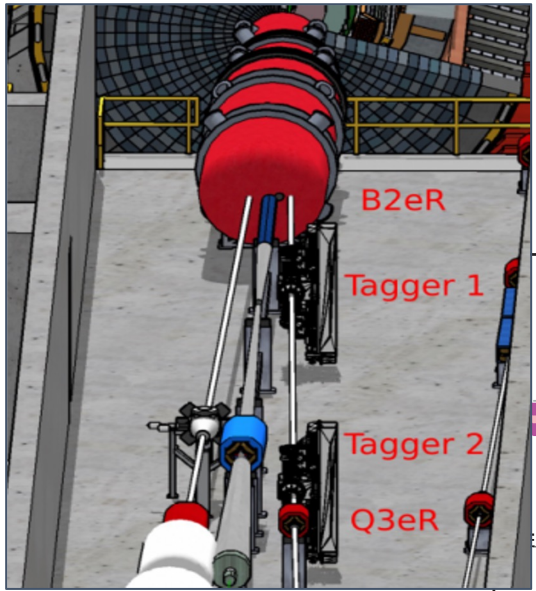
PID:

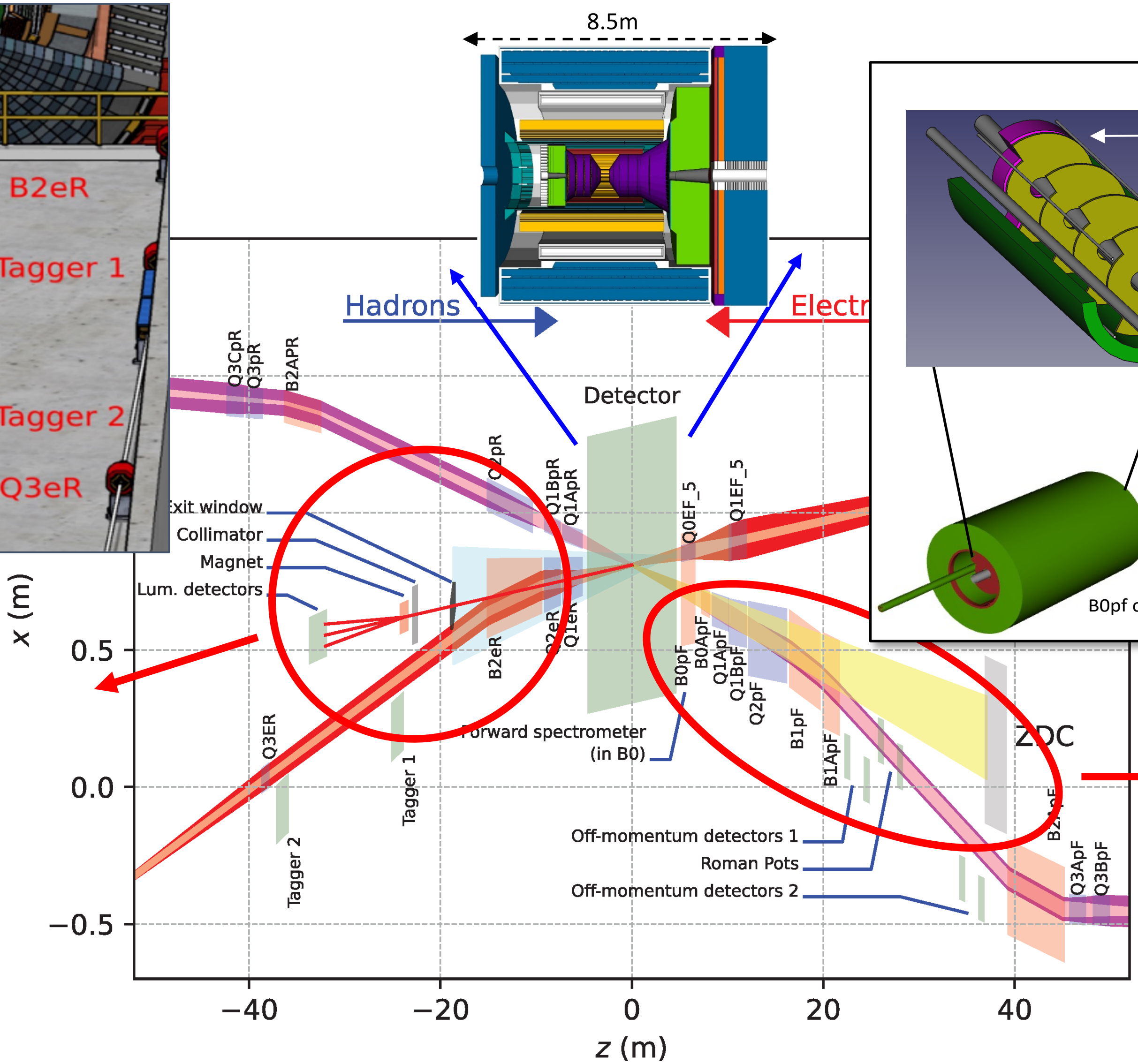
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

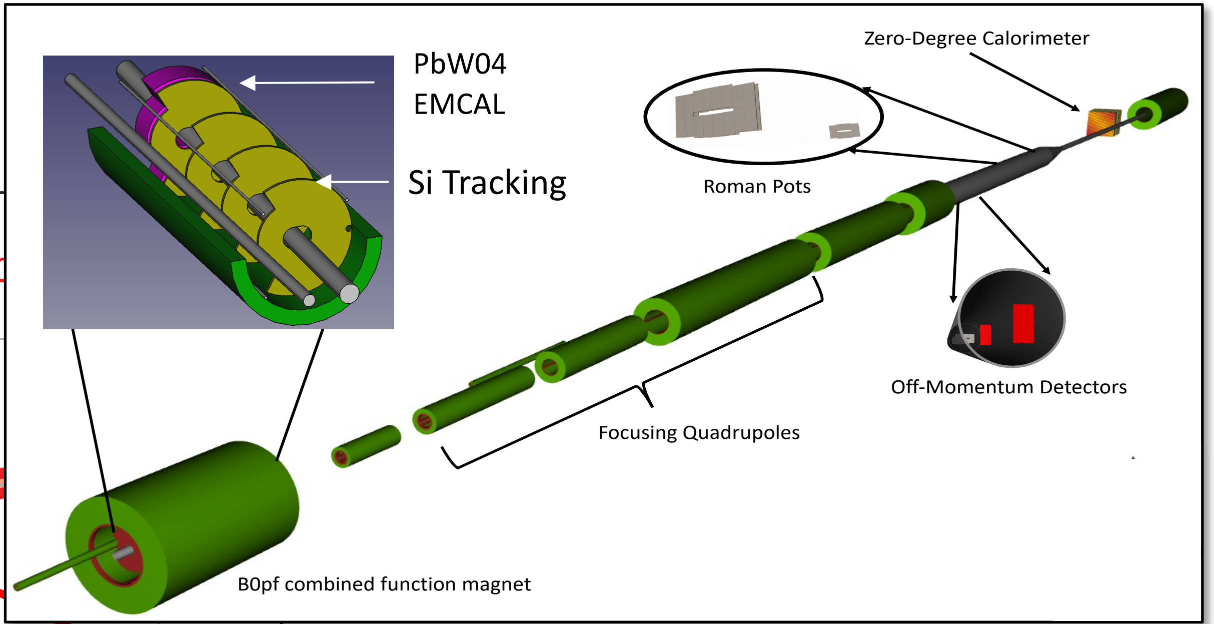
Calorimetry:

- 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







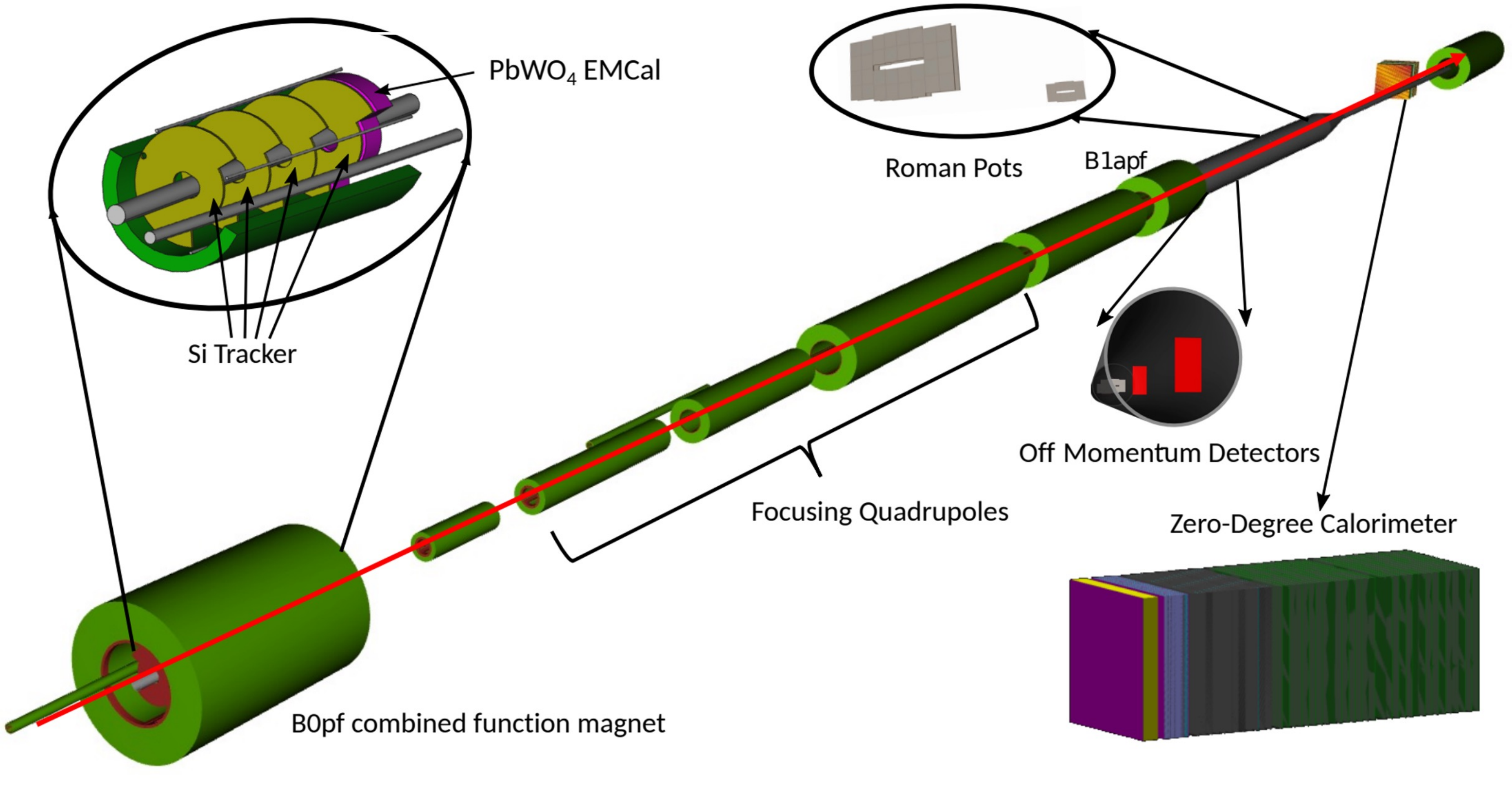
Far-Backward Detectors

- Luminosity monitor
- Low-Q^2 Tagging Detectors

Far-Forward Detectors

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

Far-Forward Detectors

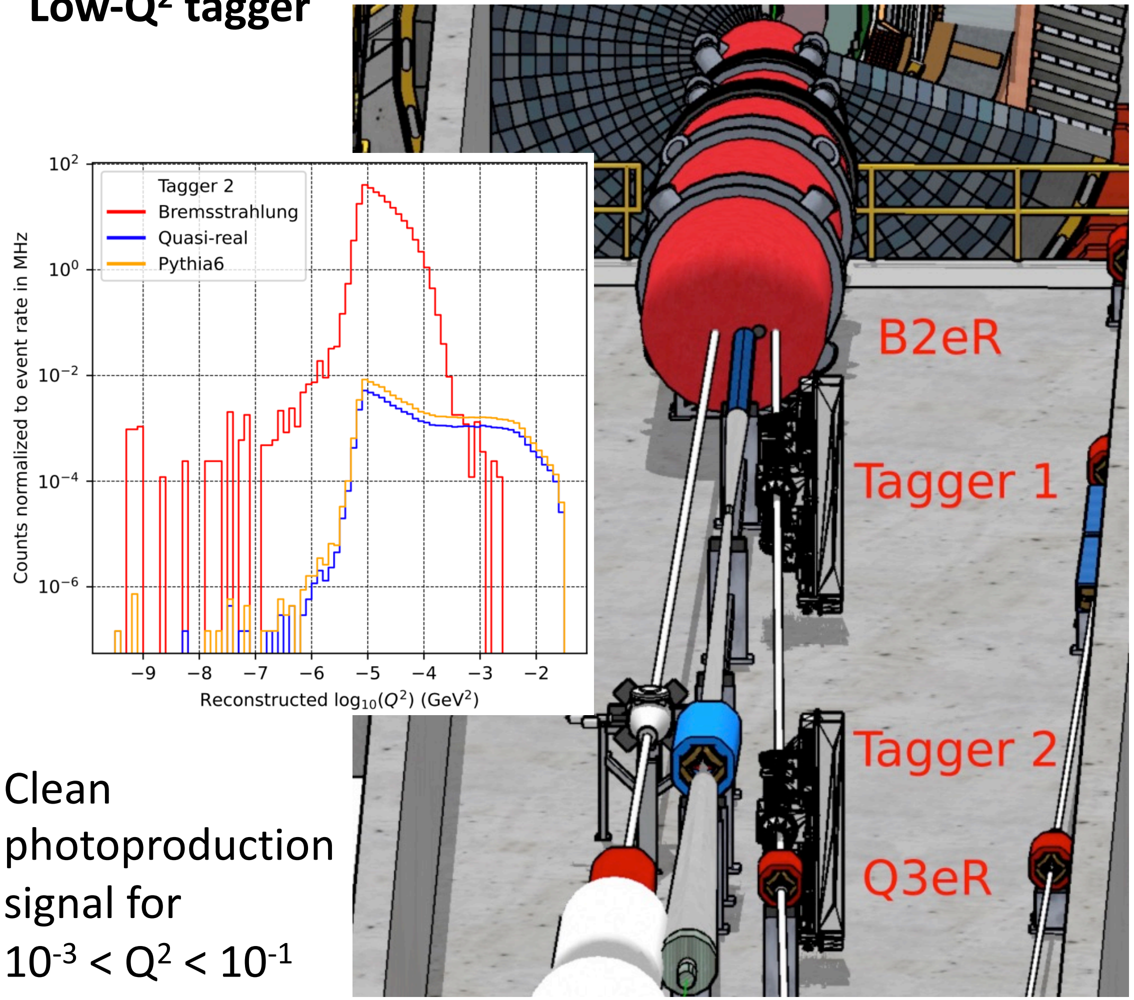


Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	$\boldsymbol{\theta}$ < 5.5 mrad (η > 6)
Roman Pots (2 stations)	0.0 < $\boldsymbol{\theta}$ < 5.0 mrad (η > 6)
Off-Momentum Detectors (2 stations)	$\boldsymbol{\theta}$ < 5.0 mrad (η > 6)
B0 Detector	5.5 < $\boldsymbol{\theta}$ < 20.0 mrad (4.6 < η 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

- **B0 system:** Measures charged particles in the forward direction and tags neutral particles
- **Off-momentum detectors:** Measure charged particles resulting from, e.g., decays and fission
- **Roman pot detectors:** Measure charged particles near the beam
- **Zero-degree calorimeter:** Measures neutral particles at small angles

Far Backwards Detectors

Low-Q^2 tagger

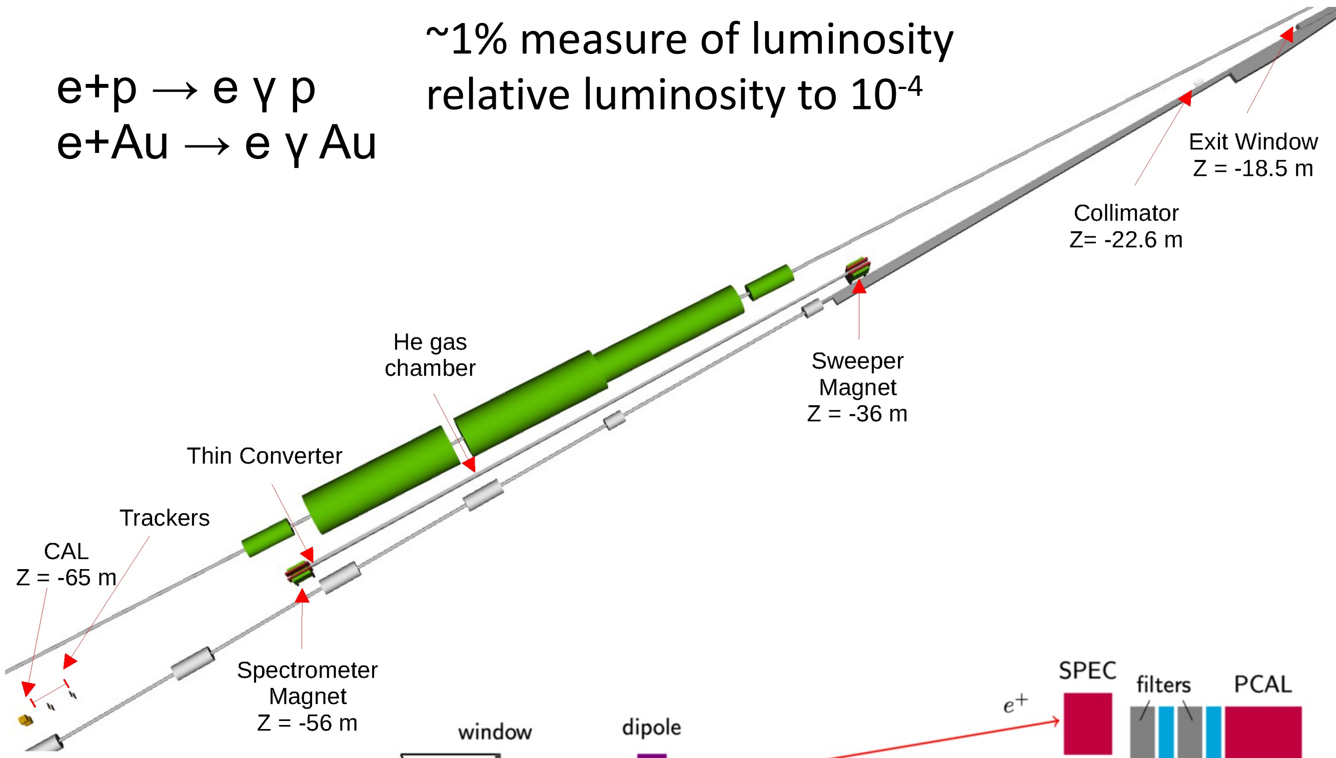


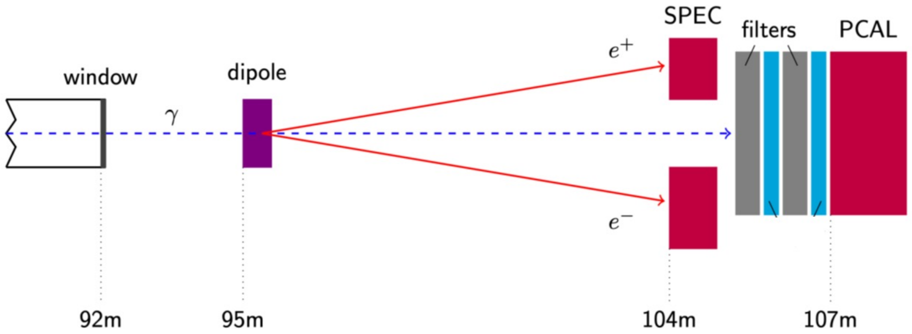
Clean photoproduction signal for $10^{-3} < Q^2 < 10^{-1}$

Luminosity Spectrometer

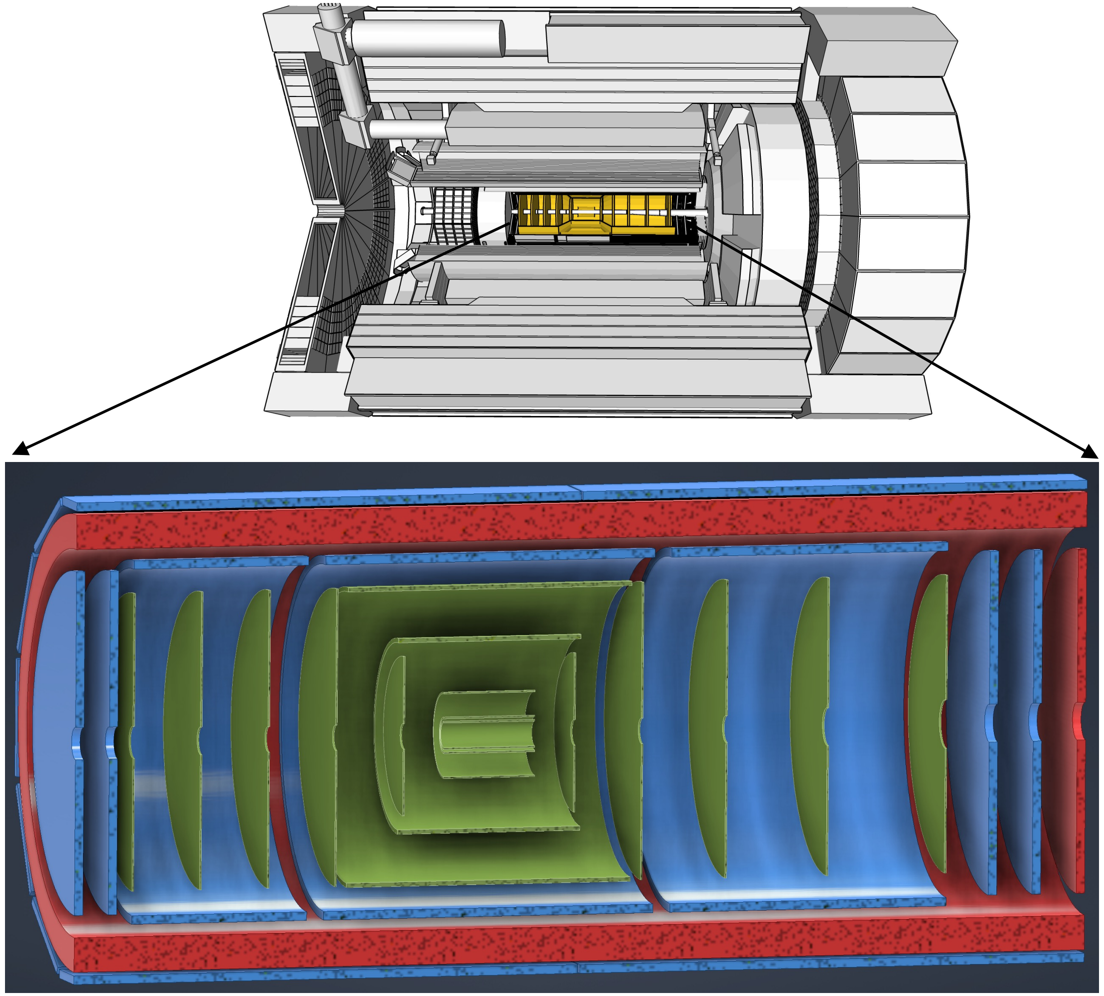
$e+p \rightarrow e\ \gamma\ p$
$e+Au \rightarrow e\ \gamma\ Au$

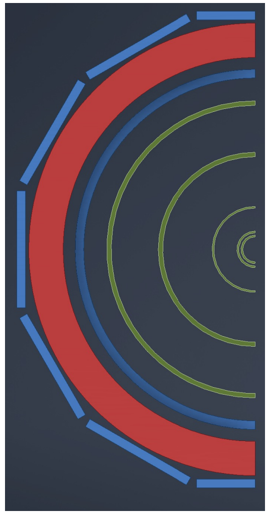
~1% measure of luminosity
relative luminosity to 10^{-4}





ePIC Tracking Detectors





- MAPS Barrel + Disks
- MPGD Barrels + Disks
- AC-LGAD based ToF

- **MAPS Tracker:**
  - Small pixels (20 μm), low power consumption (<20 mW/cm^2) and material budget (0.05% to 0.55% X/X_0) per layer
  - Based on ALICE ITS3 development
  - Vertex layers optimized for beam pipe bakeout and ITS-3 sensor size
  - Barrel layers based on EIC LAS development
  - Forward and backwards disks

world's first at ePIC

- **MPGD Layers:**
  - Provide timing and pattern recognition redundancy
  - Cylindrical μMEGAs
  - Planar μRWell's before hpDIRC
    - Impact point and direction for ring seeding

world's first at ePIC

- **AC-LGAD TOF and AstroPix (BECAL)**
  - Additional space point for pattern recognition / redundancy

Tracking Performance

Technology

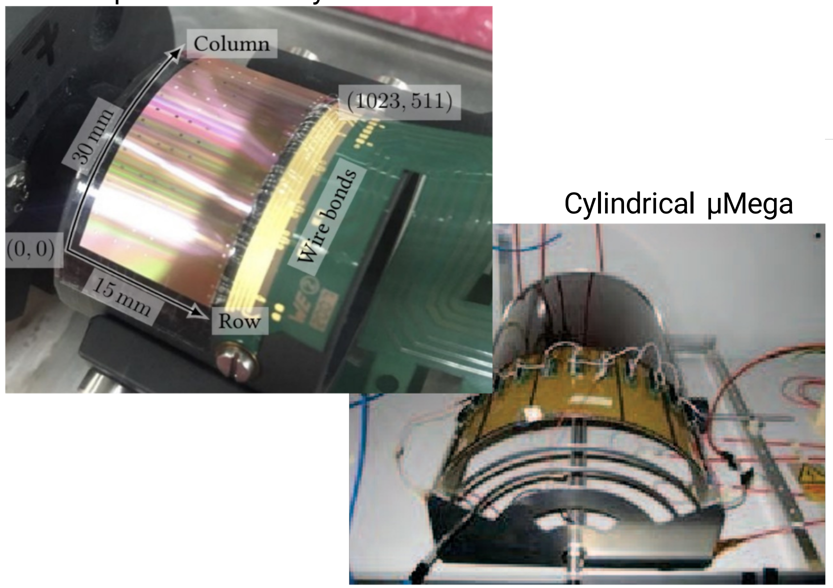
ITS3 MAPS based Si-detectors:
- O(20μm) pitch, $X/X^0 \sim 0.05$ – 0.55%/ layer

Gaseous tracker:
- σ = 55 μm, $X/X_0 \sim 0.2\%$/layer

AstroPix outer tracker layer:
- 500μm pixel pitch (σ = 144 μm)

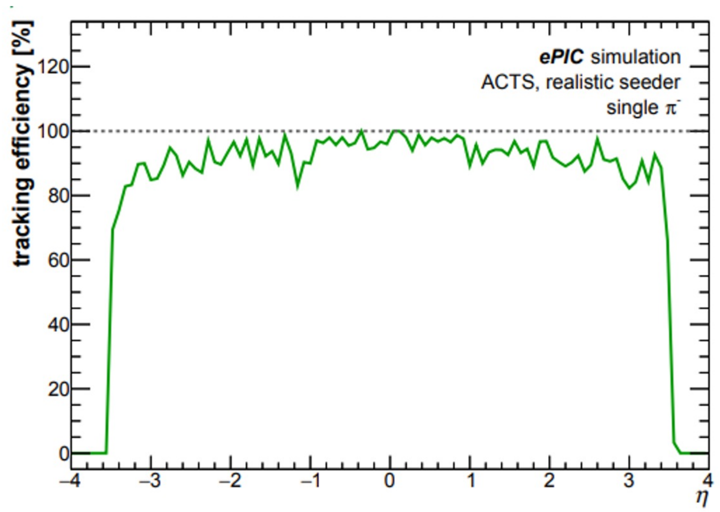
First "μITS3" assembly at CERN

Cylindrical μMega

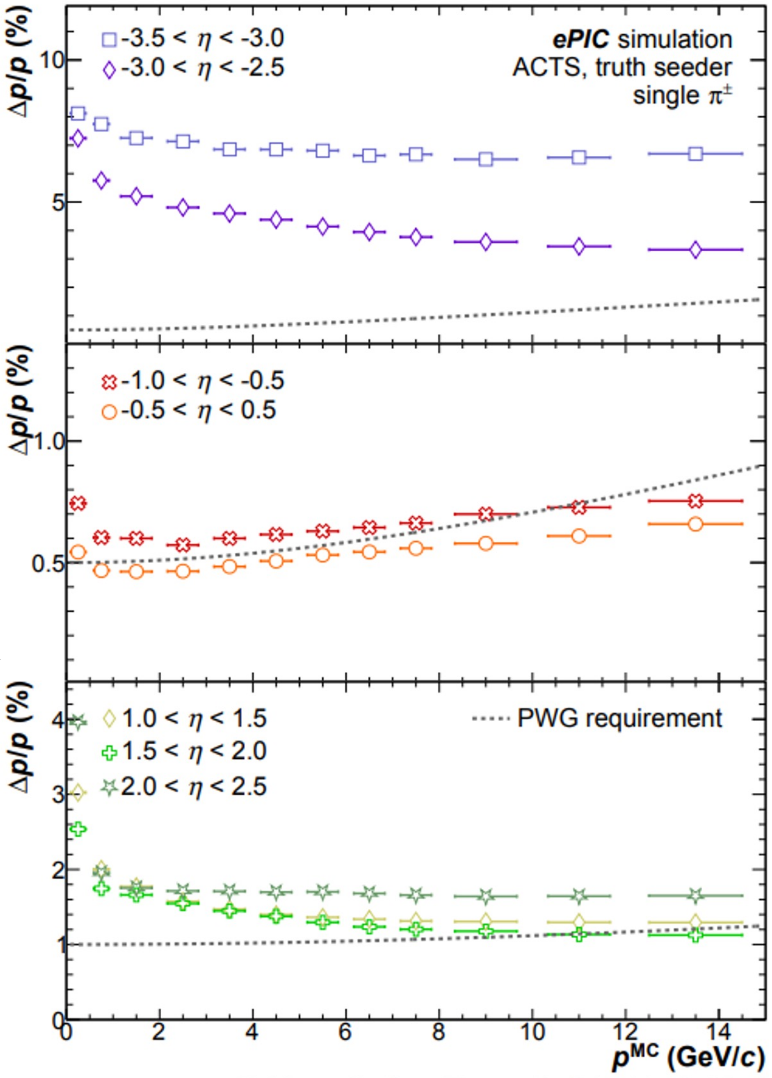


Simulated performance

F. Bock, Hard Probes 2023



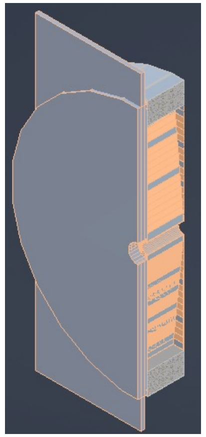
F. Bock, Hard Probes 2023



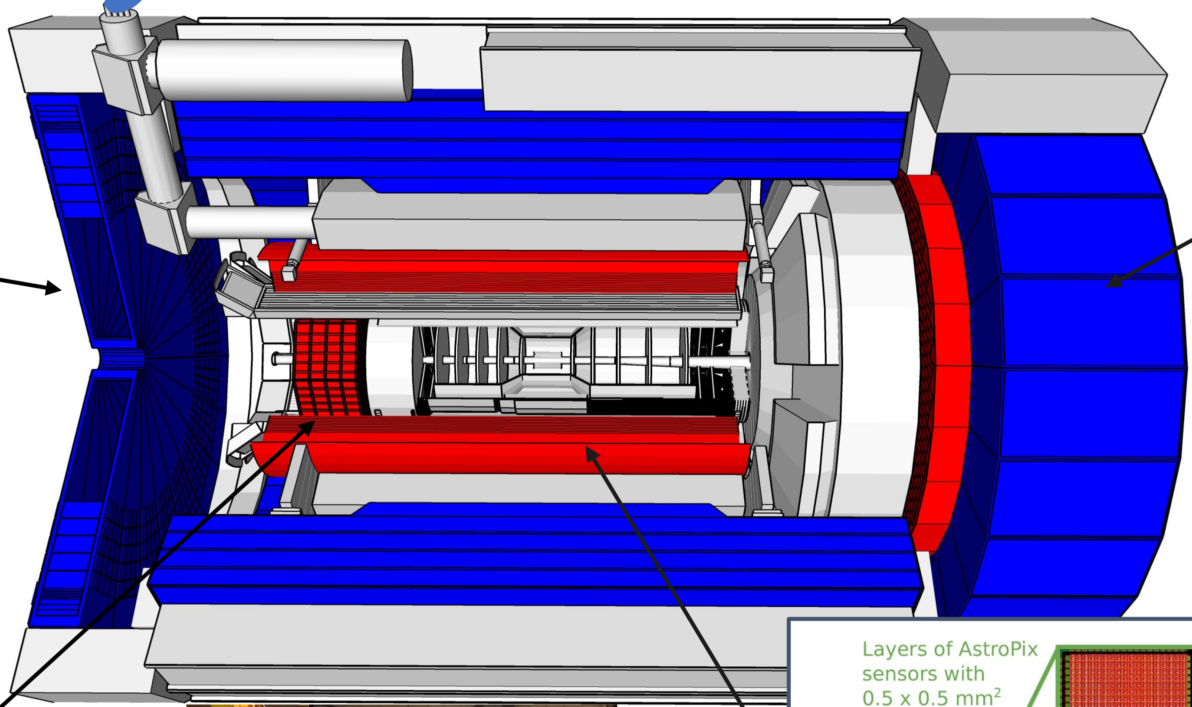
E. Yeats, R. Cruz-Torres, N. Schmidt, S. Maple

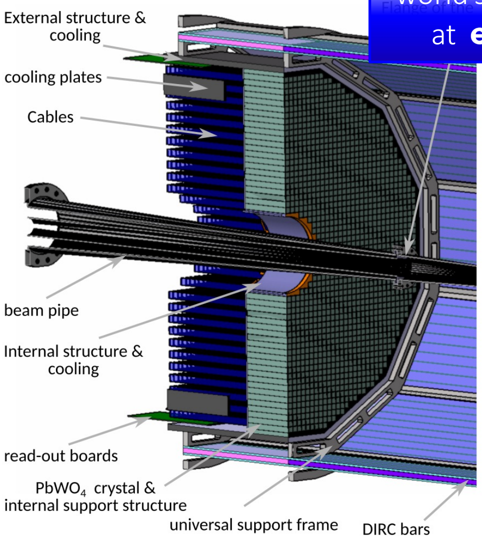
- Meets EICUG Yellow Report design requirements
- Backward momentum resolution complemented by calorimetric resolution

Calorimetry



Backwards HCal
Steel/Sc Sandwich
tail catcher

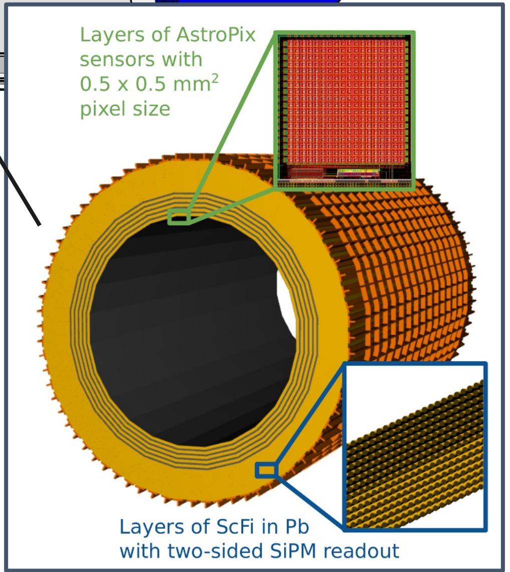


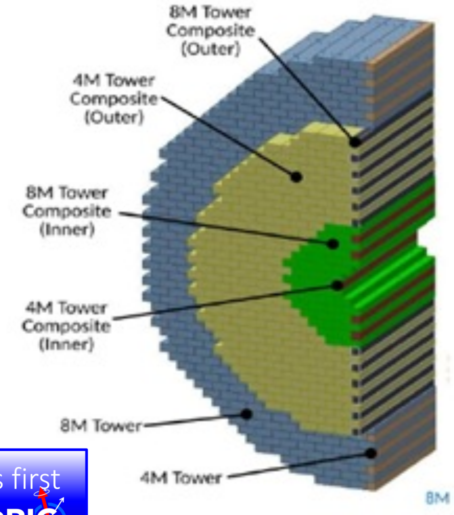


world's first at ePIC

Backwards EMCal
PbW04 crystals, SiPM
photosensor

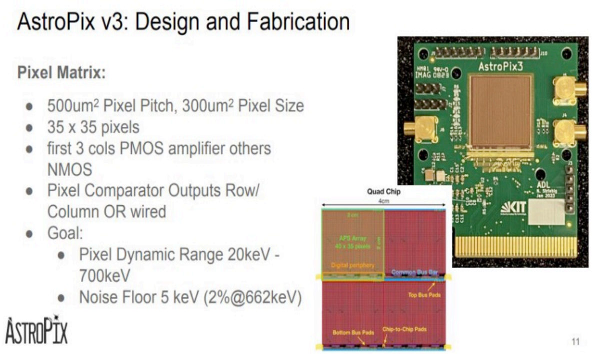
Barrel HCAL
(sPHENIX re-use)





world's first at ePIC

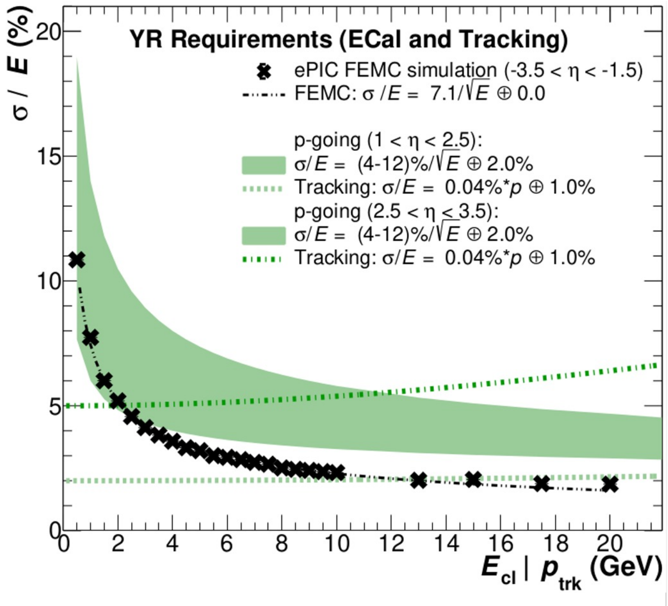
High granularity
W/SciFi EMCal
Longitudinally separated
HCAL with high-η insert

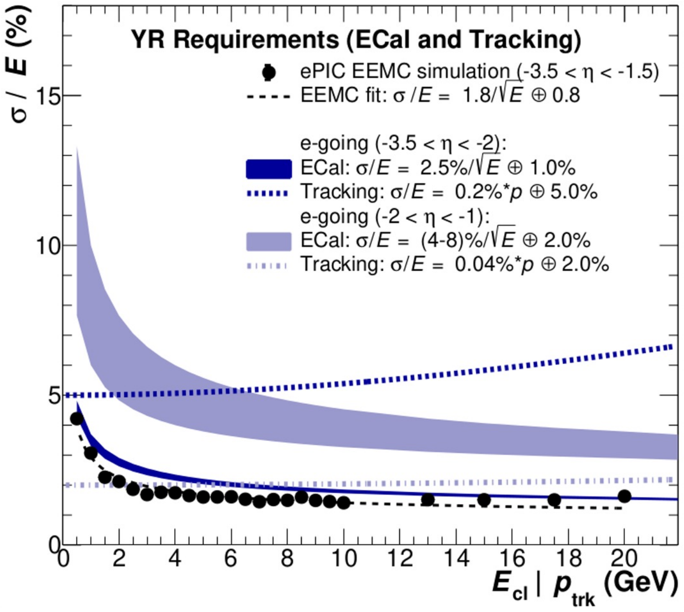


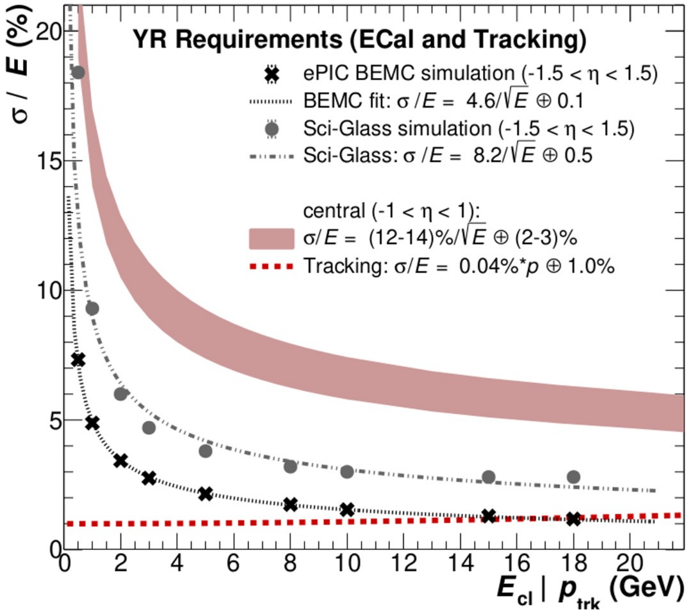
world's first at ePIC

Calorimetry Performance

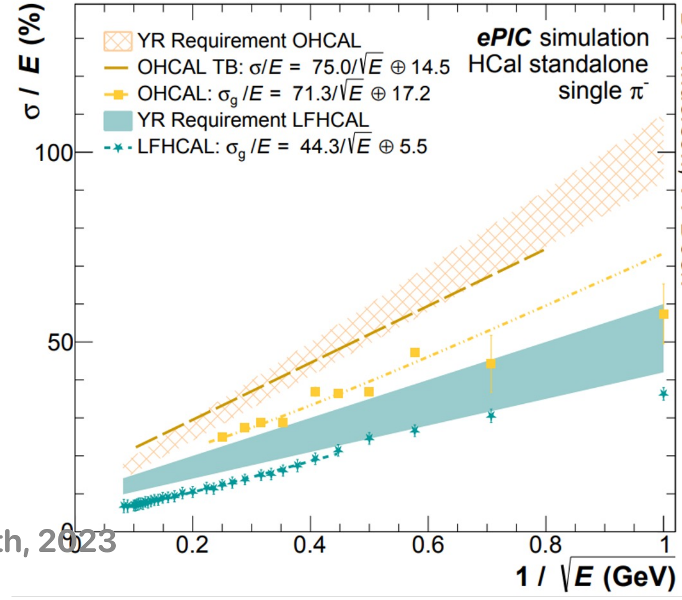
plots by N. Schmidt







F. Bock, Hard Probes 2023



D. Anderson, F. Bock

Performance on energy resolution and matching

- Technologies fulfill YR requirements on energy resolution
- Ongoing simulation studies related to overlaps between different η regions for calorimetry and reconstruction algorithms

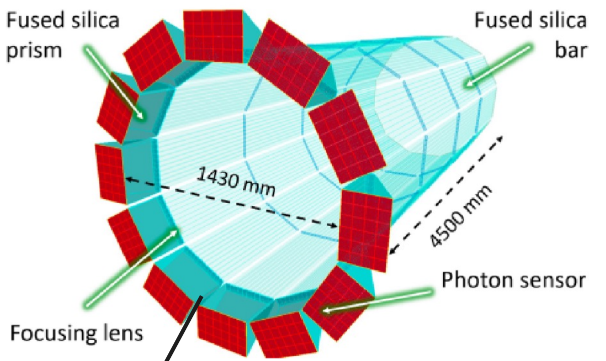
Ongoing work on Monte-Carlo validation

- Validation for high Z absorbers

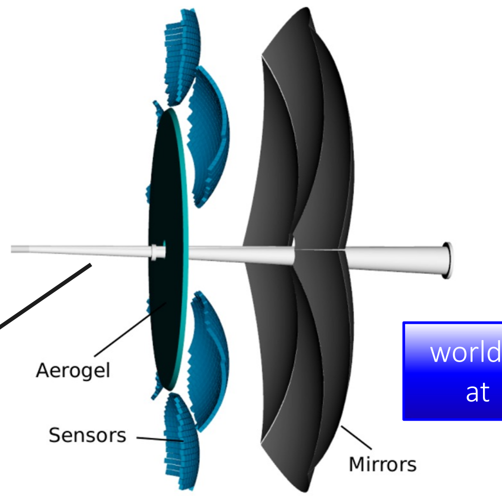
Particle ID

High-Performance DIRC

- Quartz bar radiator (BaBAR bars)
- light detection with MCP-PMTs
- Fully focused
- π/K 3б separation at 6 GeV/c



Dual-Radiator RICH(dRICH)

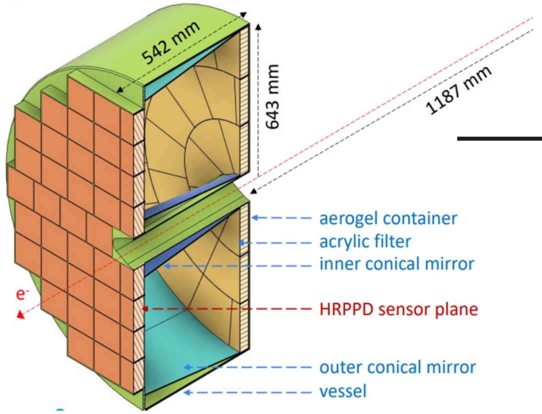


world's first at ePIC

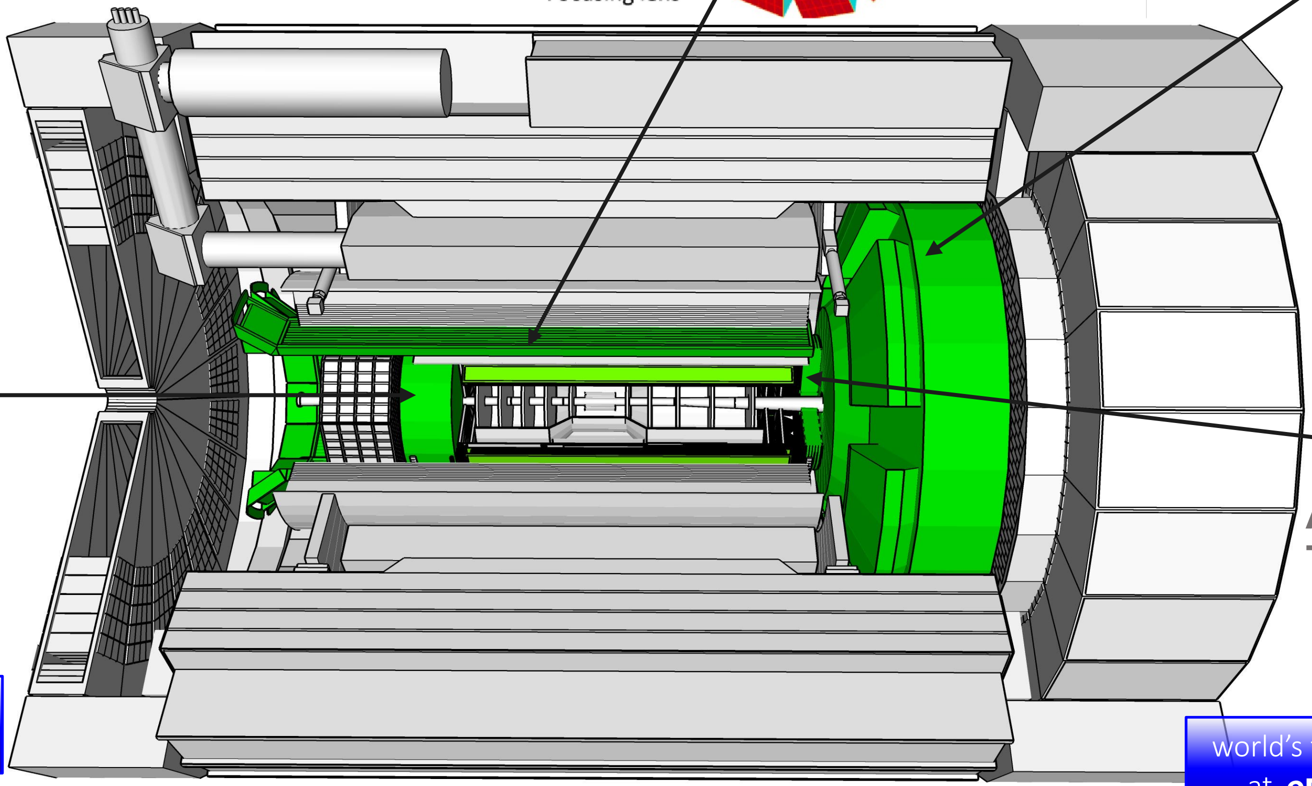
- C_2F_6 Gas Volume and Aerogel
- Sensors tiled on spheres (SiPMs)
- π/K 3σ sep. at 50 GeV/c

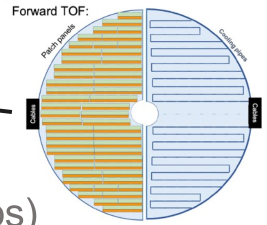
Proximity Focused (pfRICH)

- Long proximity gap (~40 cm)
- Sensor: LAPPDs
- up to 9 GeV/c 3б π/K sep.

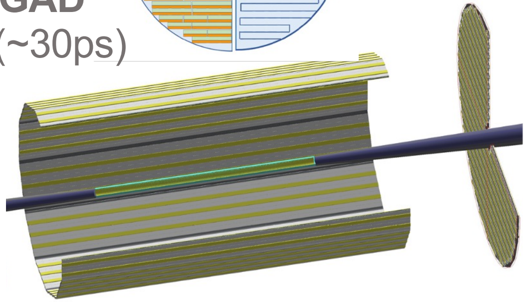


world's first at ePIC





AC-LGAD TOF (~30ps)



world's first at ePIC

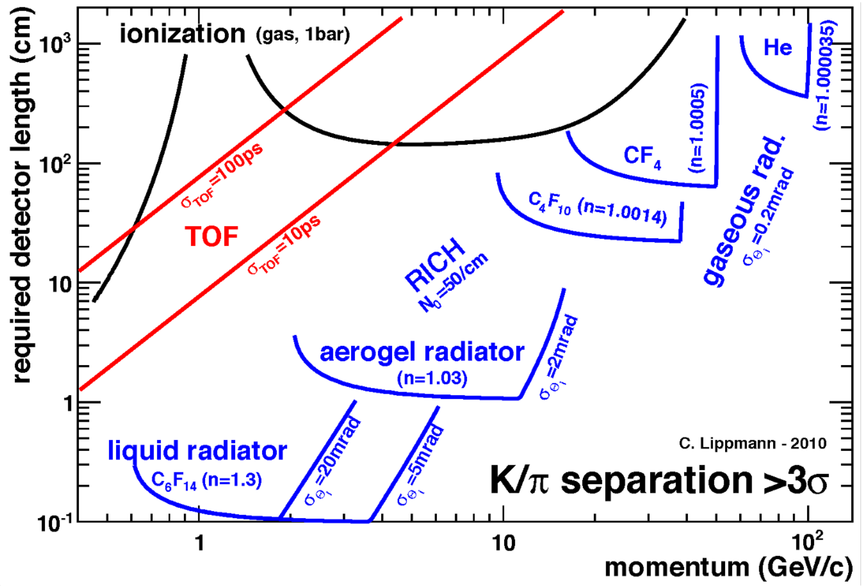
- Accurate space point for tracking
- forward disk and central barrel

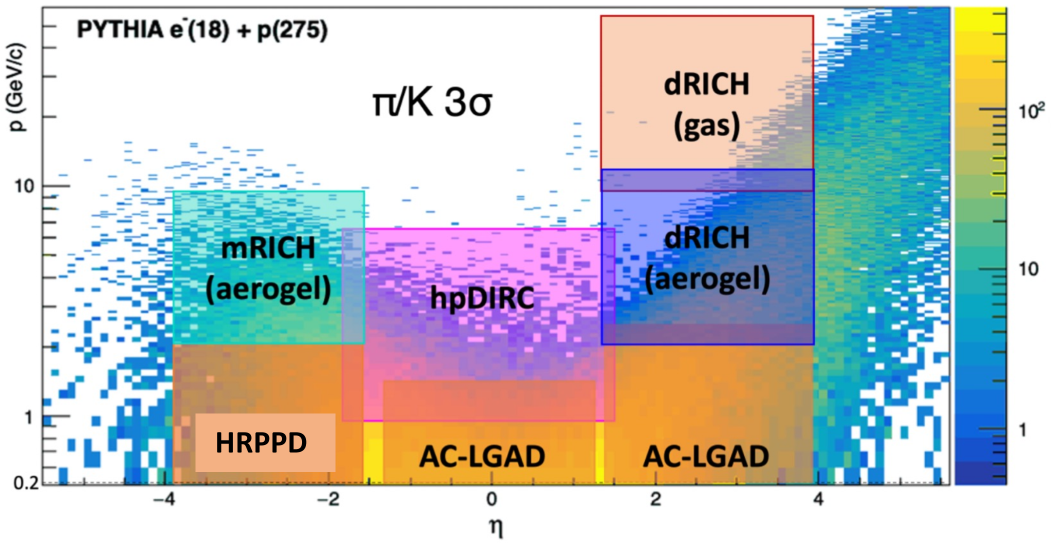
Particle ID

Particle IDentification needs

- Electrons from photons ⟶ **4π coverage in tracking**
- Electrons from charged hadrons ⟶ **mostly provided by calorimetry and tracking**
- Charged pions, kaons and protons from each other on track level ⟶ **Cherenkov detectors**
  - Cherenkov detectors, complemented by ToF

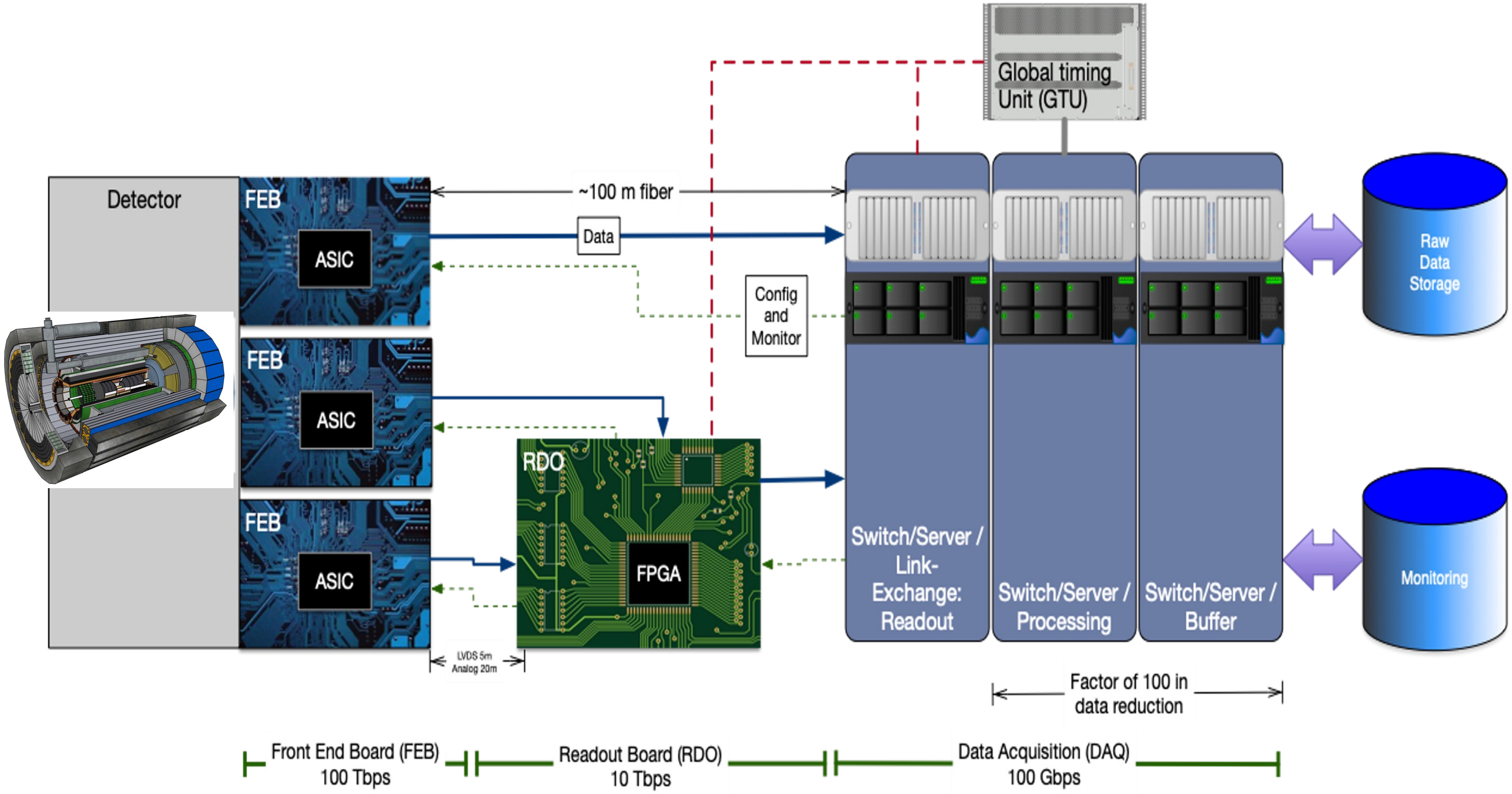
Rapidity	π/K/p and π^0/γ	e/h	Min p_T (E)
-3.5 – -1.0	7 GeV/c	18 GeV/c	100 MeV/c
-1.0 – 1.0	8-10 GeV/c	8 GeV/c	100 MeV/c
1.0 – 3.5	50 GeV/c	20 GeV/c	100 MeV/c





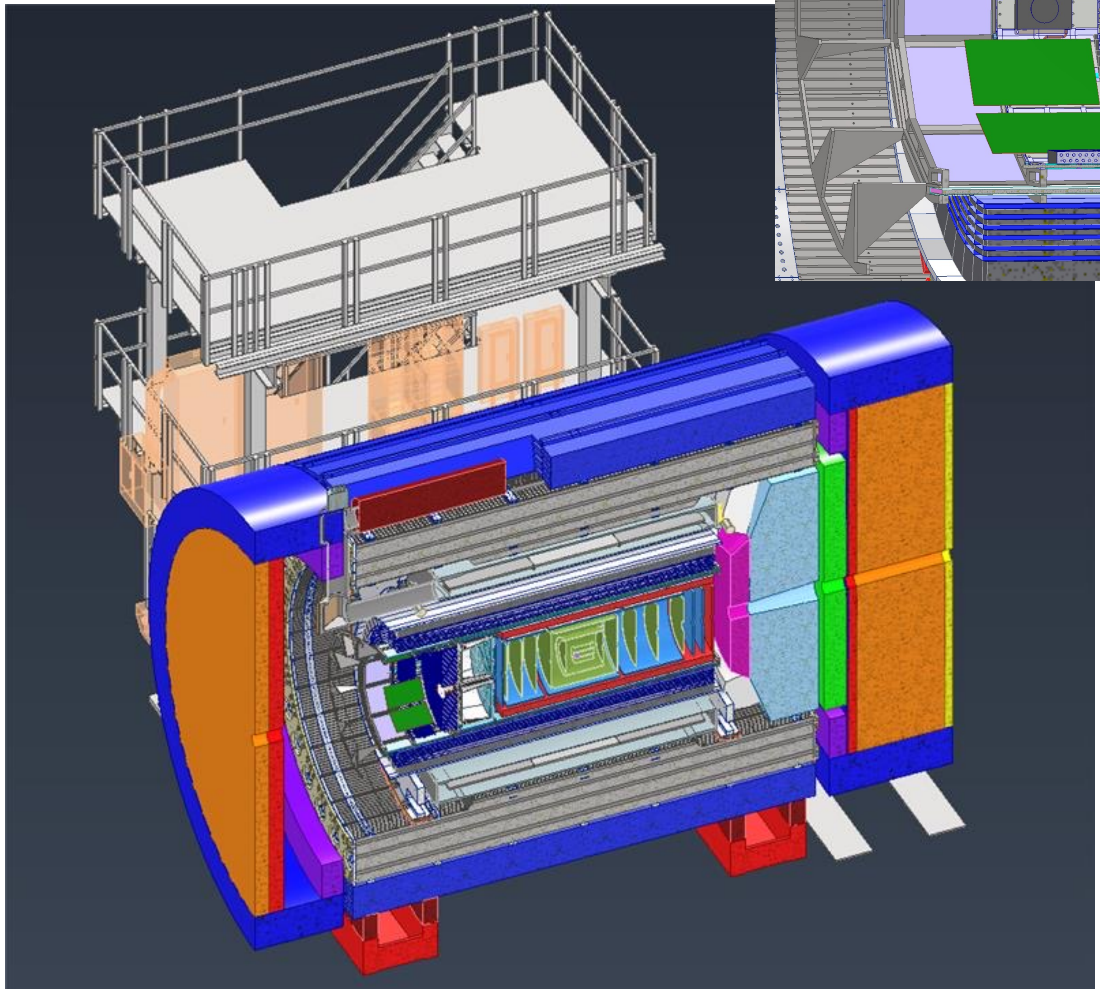
Need more than one technology to cover the entire momentum ranges at different rapidities

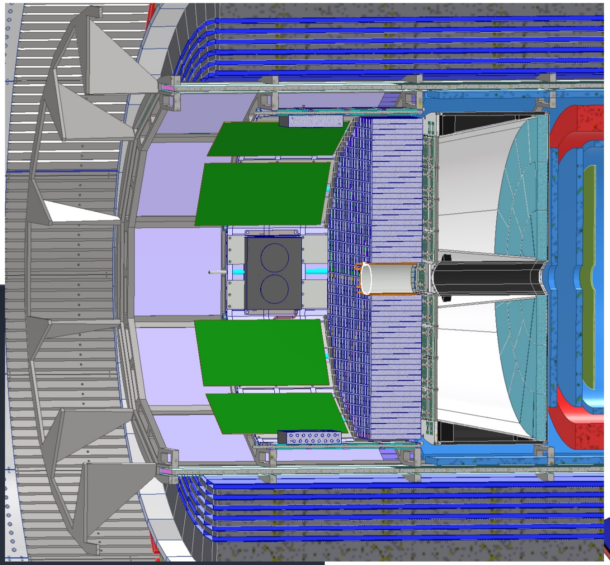
ePIC Streaming DAQ



- 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

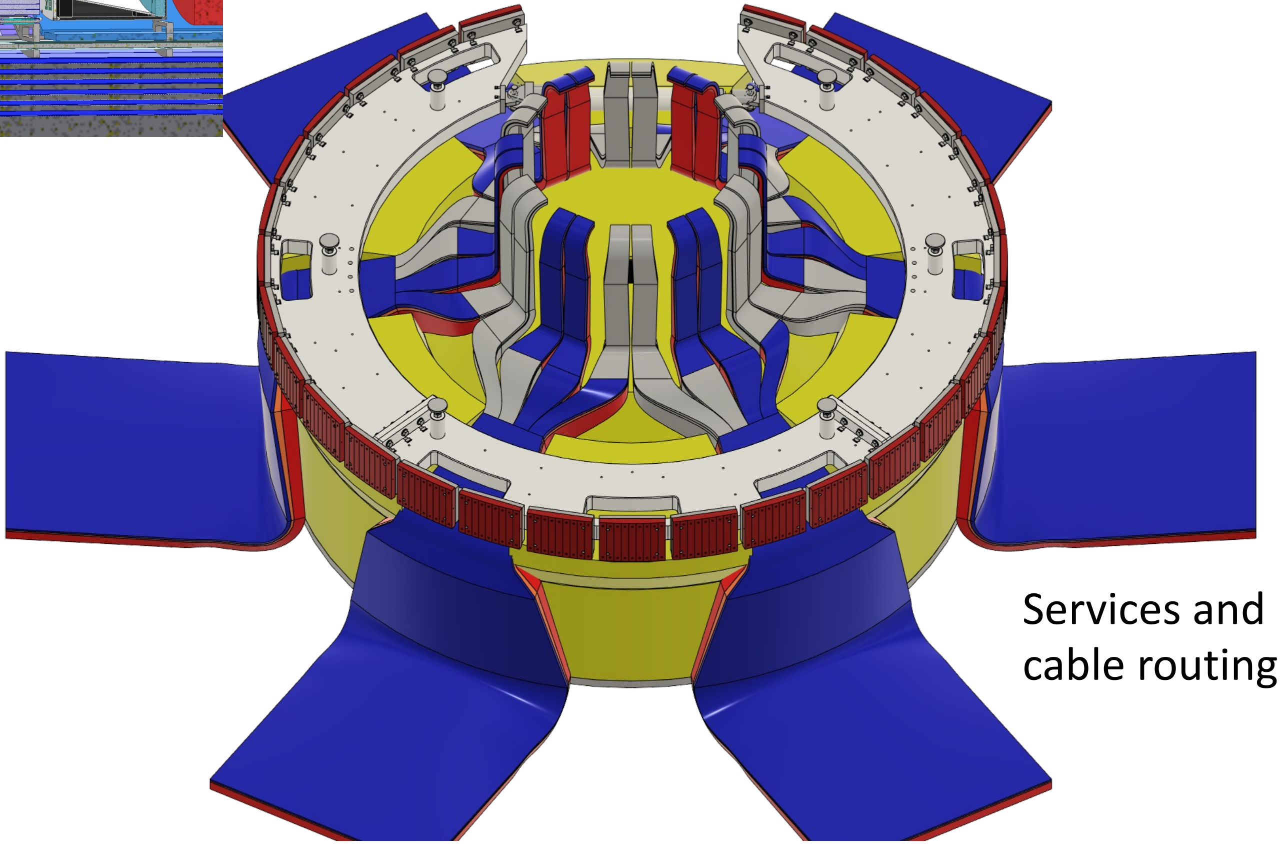
Integration





Backwards detector optimization

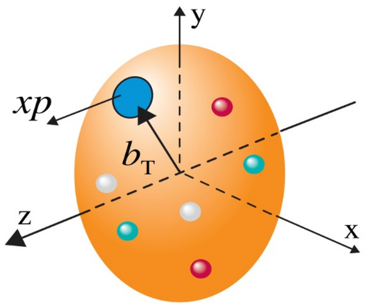
dRICH vessel, end rings, and services paths

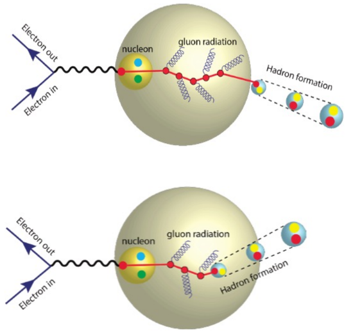


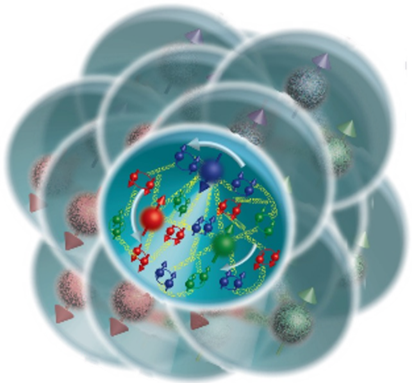
Services and cable routing

Summary & Conclusions

- The EIC is a QCD laboratory for discovery science:
  - Origin of Nucleon Mass & Spin
  - Confinement
  - Nucleon / Nuclear Femtography
  - Dense Gluon States
  - BSM physics







- Last 1 year: **Extraordinary progress for ePIC**
- Structuring collaboration
  - SP-office, CC, Coordinators, new scientific bodies, the DSCs
  - Welcoming new collaborators world-wide
- Consolidating and optimizing the detector layout
  - Tracking, calorimetry, PID, FF/FB, r-o & electronics & DAQ
- Progress towards key milestone: Technical Design Report for CD3 approval

ePIC Collaboration – Get Connected!

- Mailing Lists – https://lists.bnl.gov/mailman/listinfo
- Indico Agenda - https://indico.bnl.gov/category/402/
- Wiki - https://wiki.bnl.gov/EPIC
- ePIC Software Training:
  - https://eic.github.io/tutorial-setting-up-environment/
  - https://eic.github.io/tutorial-geometry-development-using-dd4hep/
  - https://eic.github.io/tutorial-simulations-using-ddsim-and-geant4/
  - https://eic.github.io/tutorial-jana2/
  - Recordings: https://www.youtube.com/@eicusergroup1532

QR code for Mattermost channels:

Backup

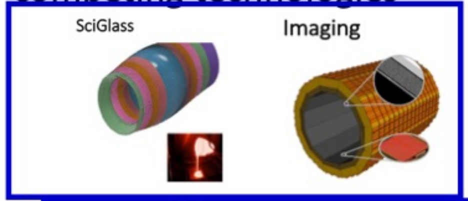
ePIC handling processes for technology choices, the barrel ECal and the backward RICH cases

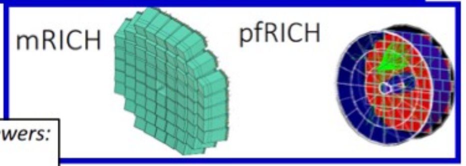
Why ?

- March 13, 2022 – EIC Project encourages proto-collaboration to "…integrate new experimental concepts and technologies that improve physics capabilities without introducing inappropriate risk."
- Spring/Summer 2022 – Barrel ECal and backwards PID identified by GD/I as consolidation items requiring additional scrutiny.

Preparatory phase

- October '22 – March '23:
  - First ePIC simulation campaign with 2 geometry concepts to support simulation studies for competing technologies
- Barrel ECal and backwards PID guidance to proponents, committee charge developed.
- External review committee members identified.
- GD/I review preparation meetings:
  - (ECal) https://indico.bnl.gov/event/17940/ ;
  - (bRICH) https://indico.bnl.gov/event/18140/, https://indico.bnl.gov/event/18221





Internal Reviews

- Barrel Ecal review: https://indico.bnl.gov/event/18517/
(at the INDICO site: charge to proponents, charge to reviewers and review report)
- Backward RICH: https://indico.bnl.gov/event/18499/
(at the INDICO site: charge to proponents, charge to reviewers and review report)

REVIEW Pannels: GD/I & external reviewers

Many thanks to our external reviewers:

Etiennette Auffray (CERN)
Tom LeCompte (SLAC)
Rainer Novotny (Univ. Giessen)

Many thanks to our external reviewers:

Ichiro Adachi (KEK)
Roberta Cardinale (U. Genova)
Carmelo D'Ambrosio (CERN)
Antonello Di Mauro (CERN)

Recommendations and motion approval

- SP-office and proto-EB → Recommendations
- April 14, 2023 : Recommendations presented at the ePIC General Meeting
- April 21, 2023 : Recommendations presented at the CC Meeting, motions to initiate the change control process presented
- May 1, 2023 : as result of a CC voting process, the motions to initiate the change control process are approved

First meeting of ePIC proto Executive Board (proto-EB):
- **Members:** J. Lajoie, S. Dalla Torre, K. Dehmelt, M. Diefenthaler, R. Reed, S. Fazio
- **CC Chair/Vice Chair (invited):** E. Sichtermann, B. Surrow *(invited, non-voting)*
- **Temporary EB Members:** B. Jacak, O. Evdokimov, T. Gunji, D. Higinbotham
- **External Input Solicited:** P. Jones, P. Newman

EICUG

Hot/Cold QCD Town Hall Recommendation

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

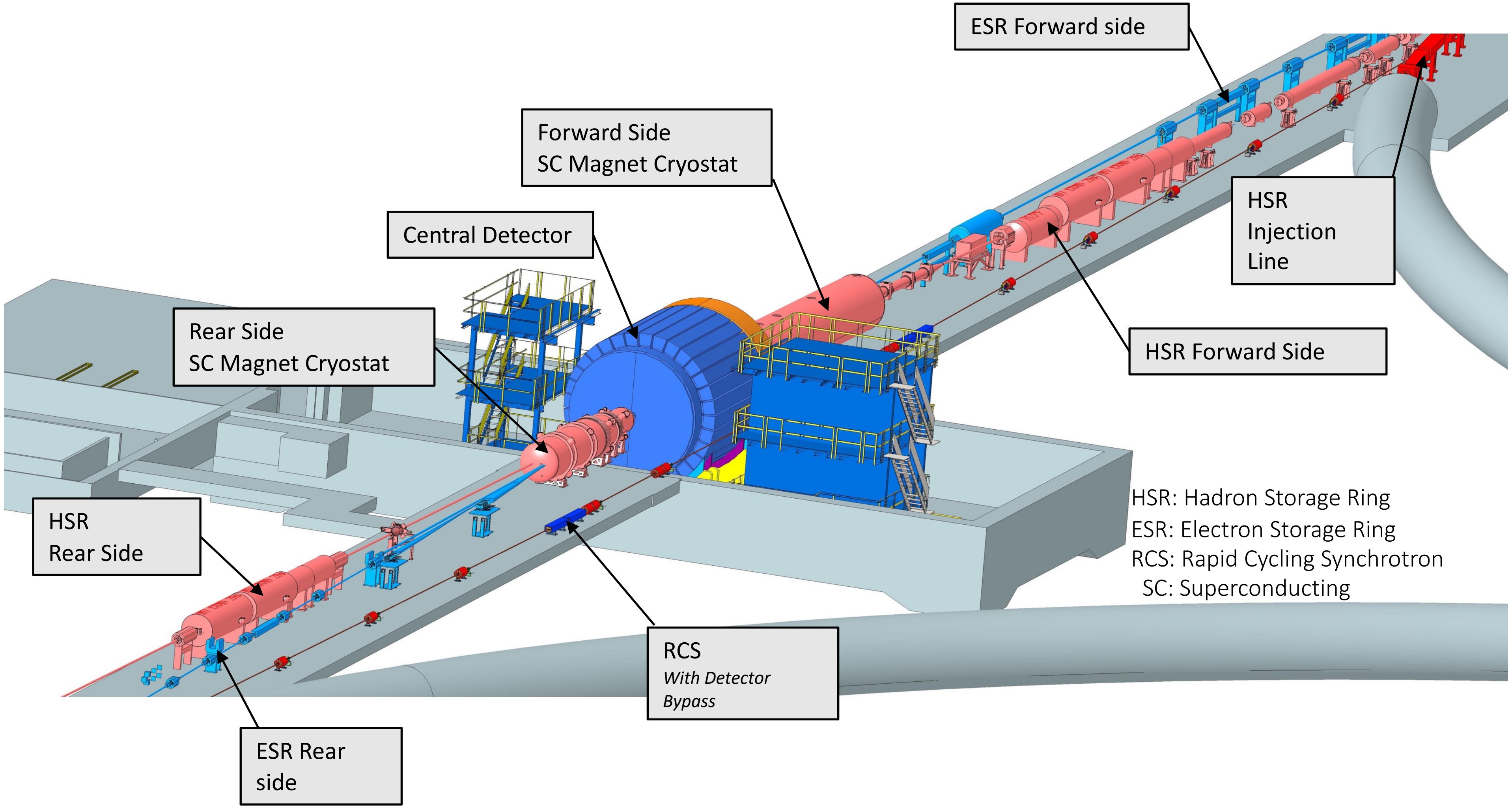
The Electron-Ion Collider (EIC) is a powerful and versatile new accelerator facility, capable of colliding high-energy beams ranging from heavy ions to polarized light ions and protons with high-energy polarized electron beams. In the 2015 Long Range Plan the EIC was put forward as the highest priority 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.

(with two sub-bullets related to support for the ePIC detector and workforce, and EIC Theory)

There is consistent and overwhelming support for EIC

EIC must continue to be a HIGH recommendation for the field

Interaction Region Integration



HSR: Hadron Storage Ring
ESR: Electron Storage Ring
RCS: Rapid Cycling Synchrotron
SC: Superconducting

Beam Backgrounds

electron beam:

- Synchrotron radiation
  - Backscattering
  - Photo desorption
  - → degradation of vacuum
- Beam gas interactions
  - Off momentum electrons
- Higher order mode losses
  - Local heating at injection and ramp (short bunches)
  - Degradation of vacuum
- Background due to de-excitation of beam if bunches are replaced

proton beam:

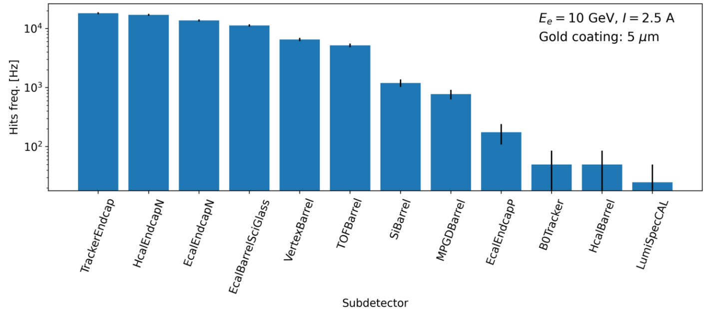
- Low beam lifetime during injection and ramping
- Beam gas interactions, large hadronic cross section
  - Secondary interactions with aperture limitations, i.e. with magnets, beam pipe, masks

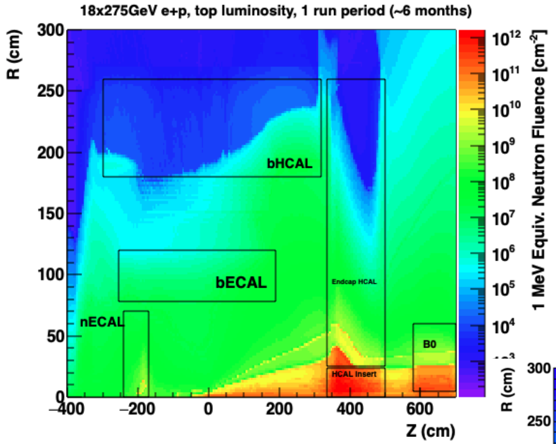
Requirements:
Keep beam backgrounds as low as possible
→ Careful design of interaction region, beam-pipe masks and photon beam dump
→ Excellent vacuum system

Important to note:
- ➢ Low multiplicity per event: < 10 tracks
- ➢ No pileup from collisions 500 kHz @10^{34} $cm^{-2}s^{-1}$ → DIS event every 200 bunches
- ➢ Radiation environment much less harsh than LHC → factor 100 less

Background and Radiation Simulations

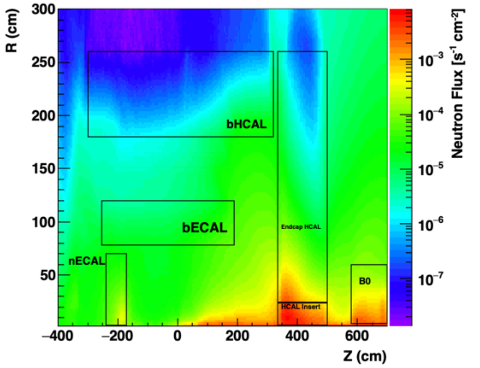
Synchrotron Radiation

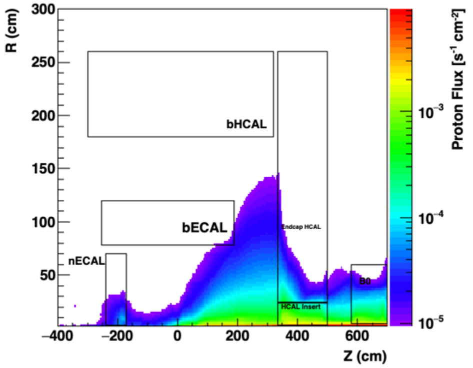


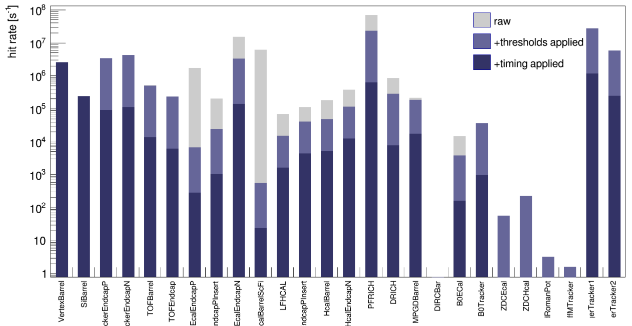


1 MeV Neutron fluence at top luminosity (500 kHz) for 18 GeV x 275 GeV

Neutron & proton flux E_{kin}>250 MeV to determine single event upsets top luminosity & 18 GeV x 275 GeV

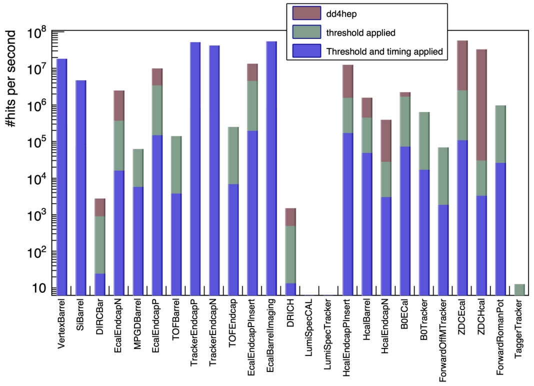




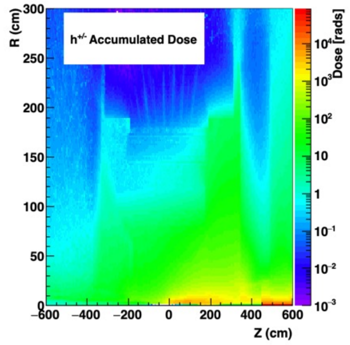


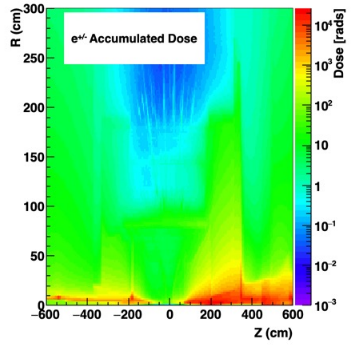
Electron Beam Gas

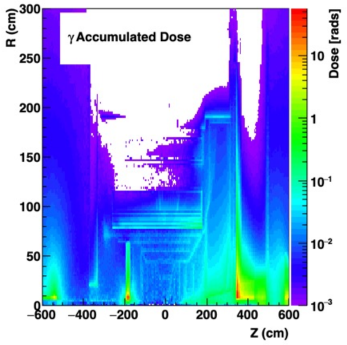
Hadron Beam Gas



Radiation dose at 18 GeV x 275 GeV for top luminosity 500 kHz







High-Level Installation Schedule

CD-3
04/2025

Oct 2028

Jan 2029

April 2029

Dec 2029

June 2030

Oct 2030

Jan 2031

early
CD-4A
04/2031

early CD-4
CD-4A
04/2032

CD-4
04/2034

Construction

IR-6 ready
for installation

Transition into
Operations

Start of
Operations
&
Science

done in beam position

done in IP-6 Assembly Hall

lower half
barrel Hcal
installed
Solenoid
delivered

Endcap HCals
completed
Solenoid
Field mapping

Barrel Ecal
ready
for installation

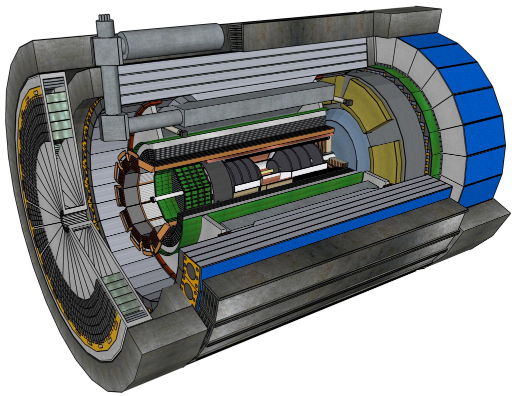
Hadron Endcap
Detectors
installed
Trackers, dRICH
ECal

- Solenoid and Barrel HCal need to be ready by Jan 2029
- All other subdetectors need to be ready between 06/29 to 06/30 depending on their location in the detector

Barrel Hcal
& Solenoid
installed
followed by low
power test

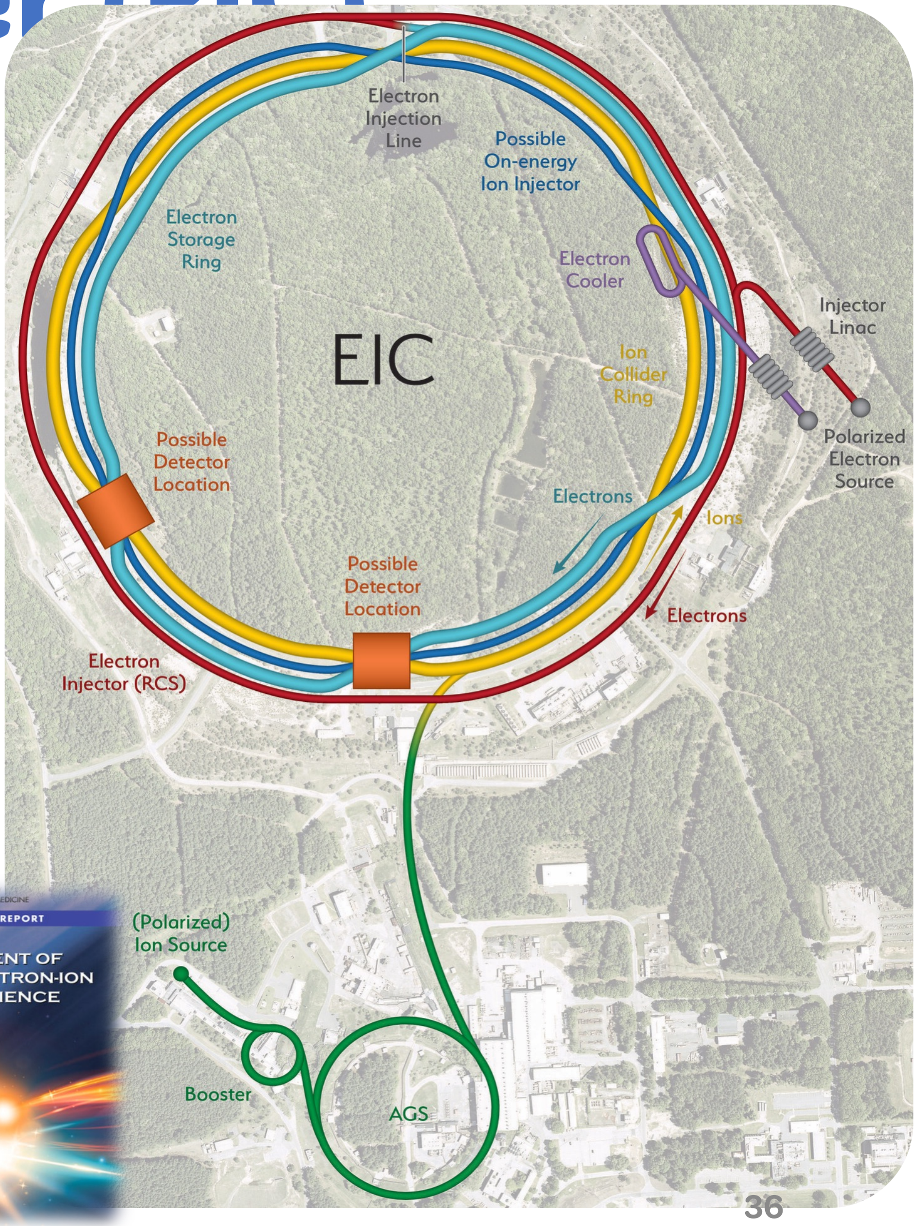
Barrel Detectors
installed
ECal, DIRC,
ToF, Trackers

Lepton Endcap
Detectors
installed
Trackers, bRICH
ECal

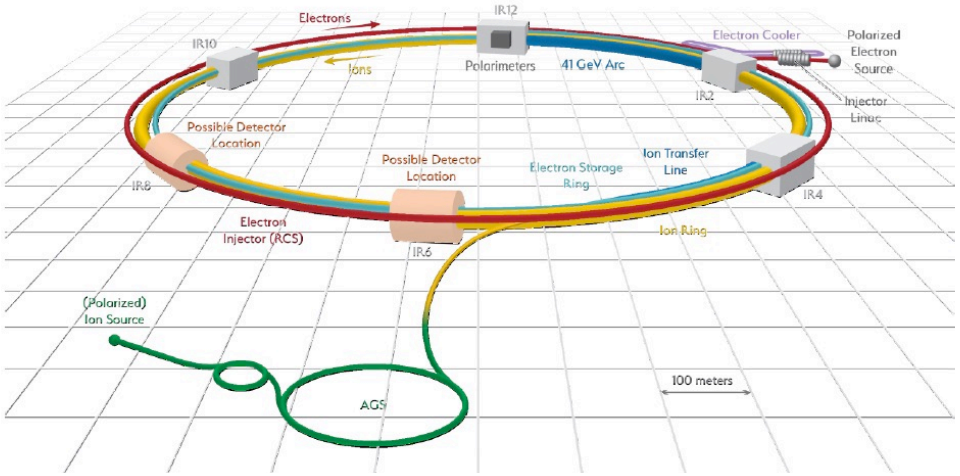


The Electron-Ion Collider (EIC)

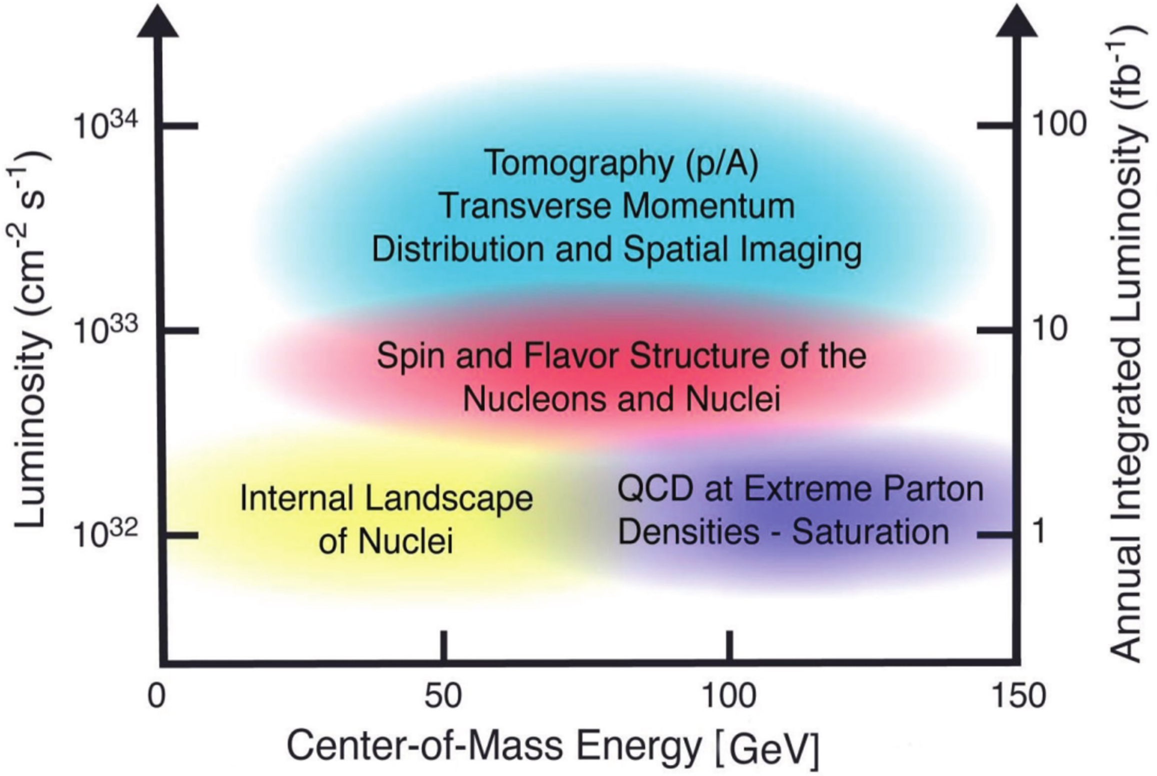
- Joint project between Brookhaven National Lab and Jefferson Lab
- $1.7-2.8B investment
  - CD-1 (2021), CD-3A (2024), CD-2/3 (2025)
- Explore the structure of matter via QCD:
  - Origin of Nucleon Mass & Spin
  - Confinement
  - Nucleon / Nuclear Femtography
  - Dense Gluon States
  - BSM
- Operations as soon as 2032



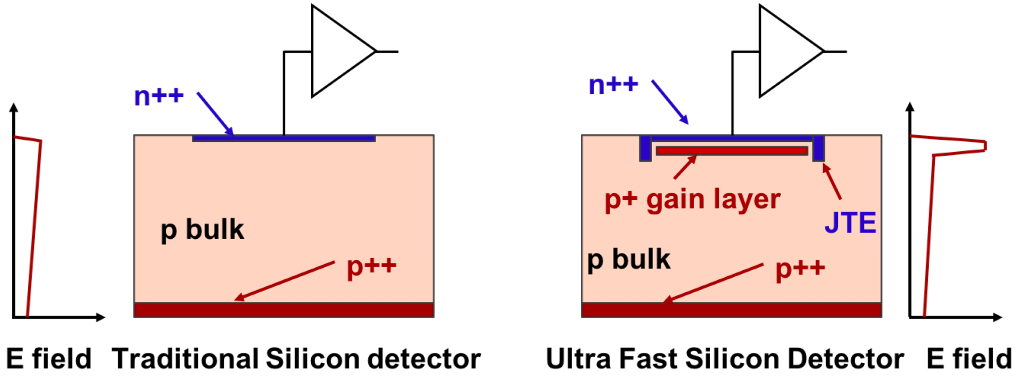
EIC Machine Parameters

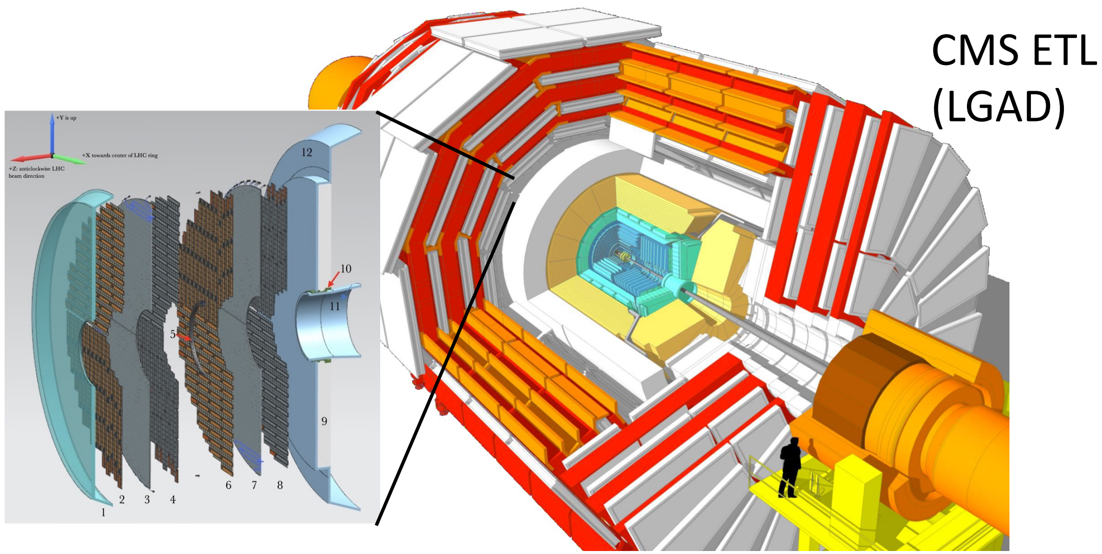


- Center of mass energy: 20 – 140 GeV
  - Electrons: 2.5 – 18 GeV
  - Protons: 40 – 275 GeV (ions: Z/A x E_{proton})
- Luminosity: 10^{34} /cm^2/sec
- Polarization: <70% (both electron and ion)
- Ion Species: proton - Uranium
- Detectors: up to 2 interaction regions with (almost) complete coverage



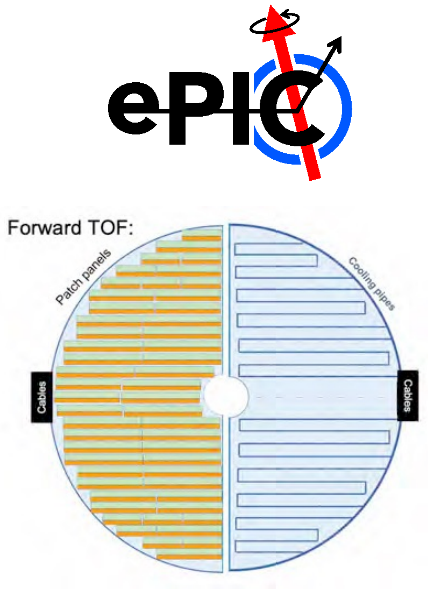
AC-LGAD TOF

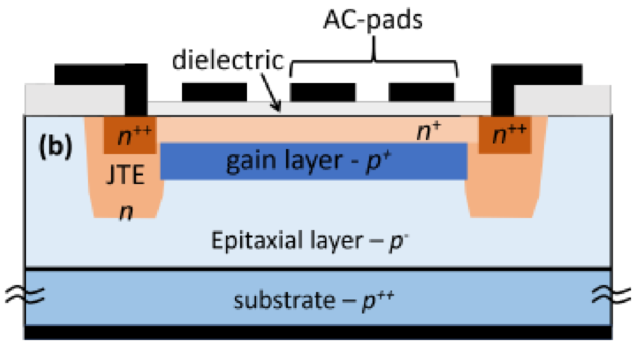


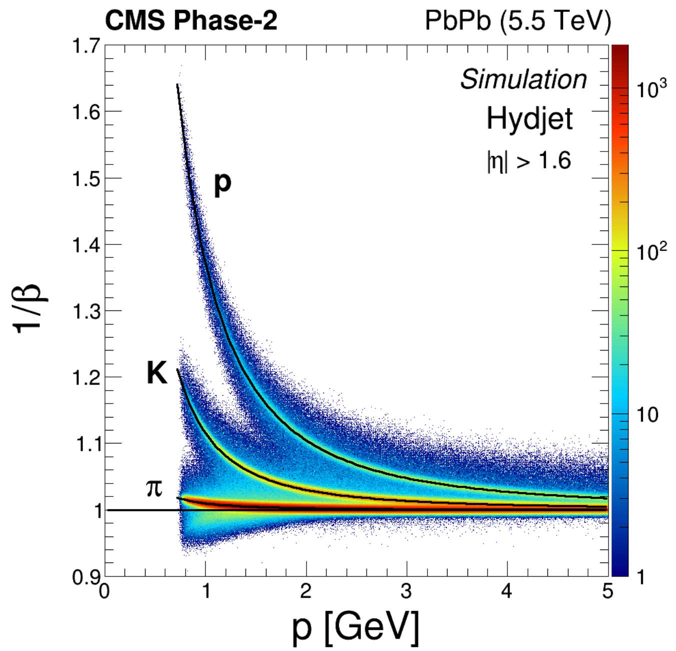


AC-LGAD detectors add an AC-coupled readout to provide both *fast timing response* and *excellent spatial resolution* (4D).

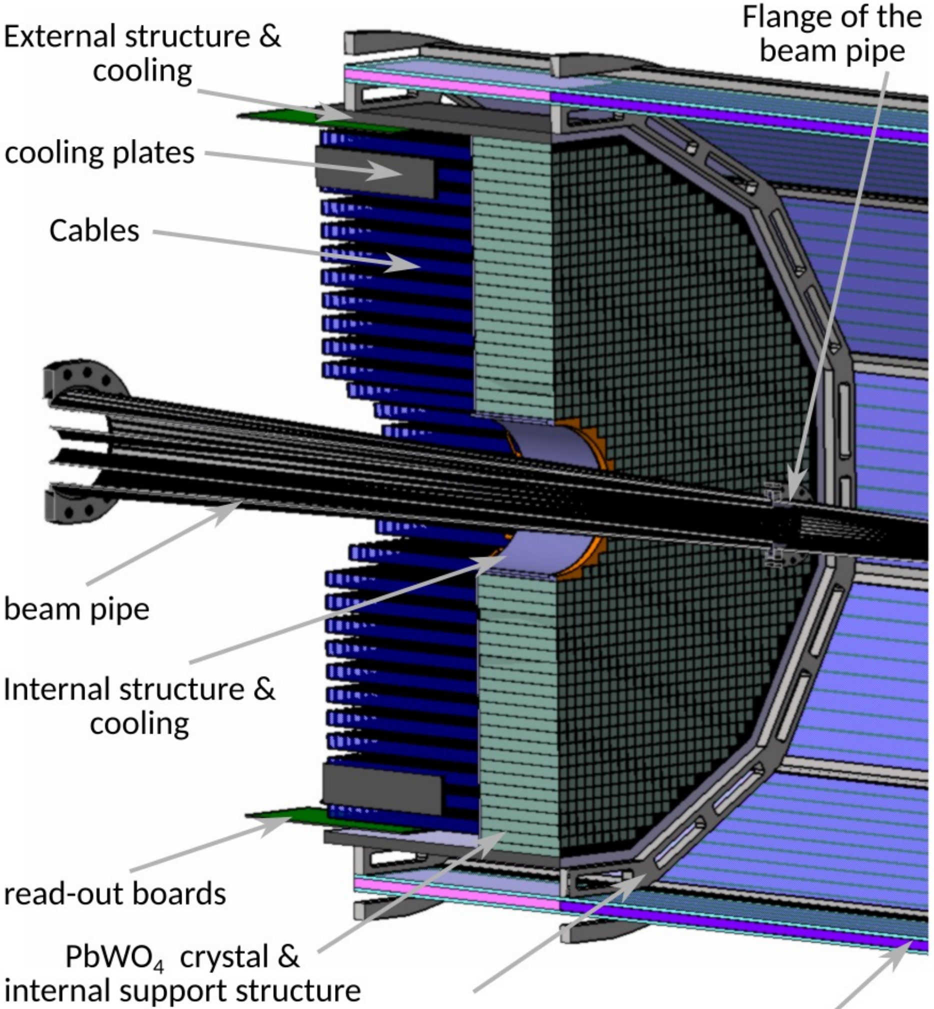
Roman pot arrays







Backward Calorimetry

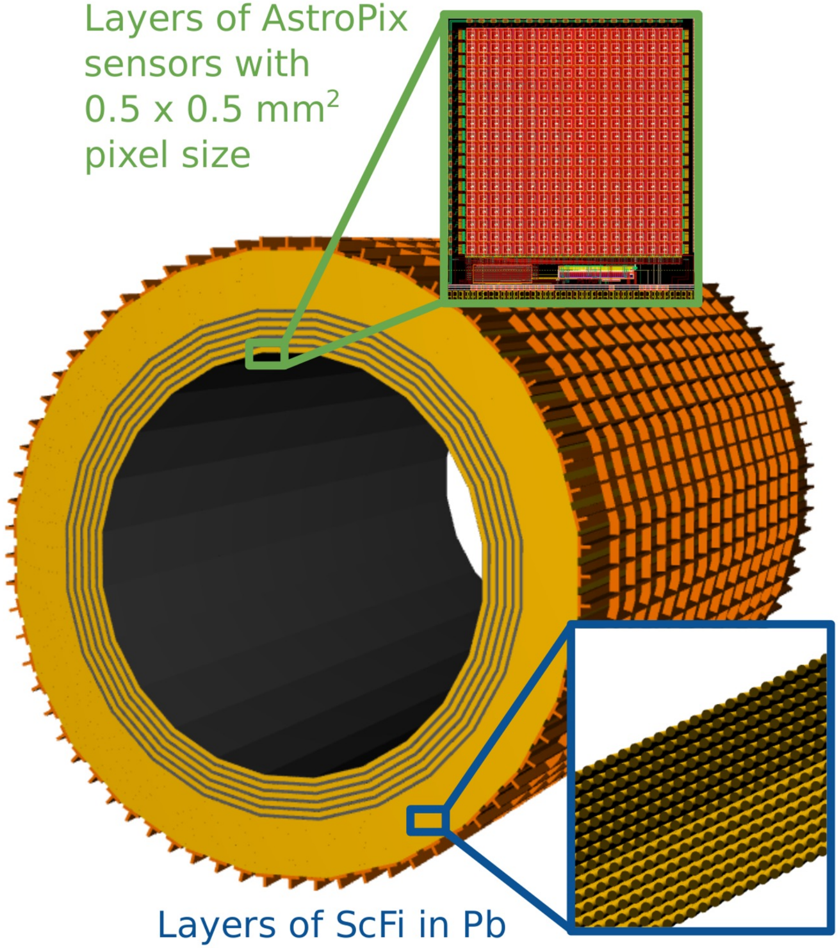


Backward EMCAL

- Non-projective **$PbWO_4$ calorimeter** (EEEMC-Consortium)
  - $2 \times 2 \times 20$ cm^3 crystals
  - Length ~$20X/X_0$, transverse size ~Molière radius
  - Located inside the inner DIRC frame
  - Preferred readout: SiPMs of pixel size 10µm or 15µm
  - Cooling to keep temperature stable within ± 0.1 °C
- Ongoing efforts advancing the design to increase coverage in η ($-3.7 < \eta < -1.5$) with inlay around beampipe

Barrel EM Calorimetry

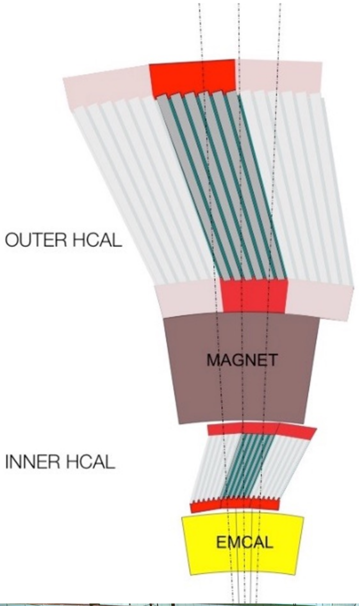
- Hybrid concept
  - Imaging calorimetry based on monolithic silicon sensors AstroPix (NASA's AMEGO-X mission) - 500 µm x 500 µm pixels Nuclear Inst. and Methods in Physics Research, A 1019 (2021) 165795
  - Scintillating fibers in Pb (Similar to GlueX Barrel ECal, 2-side readout w/ SiPMs) Nuclear Inst. and Methods in Physics Research, A 896 (2018) 24-42
- 6 layers of imaging Si sensors interleaved with 5 Pb/ScFi layers and followed by a large chunk of Pb/ScFi section (can be extended to inner HCAL)
- Total radiation thickness for EMCAL of ~20 X_0
- Detector coverage: $-1.7 < \eta < 1.3$ which overlaps with "electron-going" side endcap



Energy resolution - SciFi/Pb Layers: $5.3\% / \sqrt{E} \oplus 1.0\%$

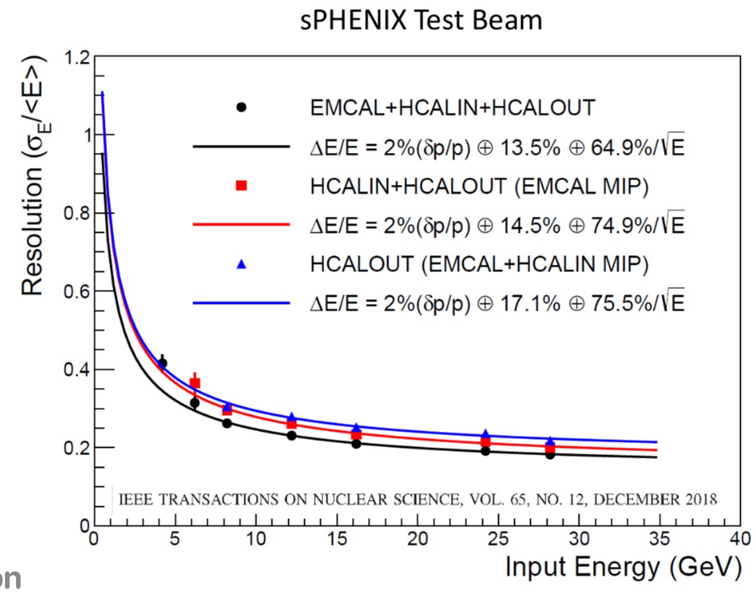
Position resolution - Imaging Layers (+ 2-side SciFi readout): with 1st layer hit information ~ pixel size

Barrel Hadronic Calorimetry

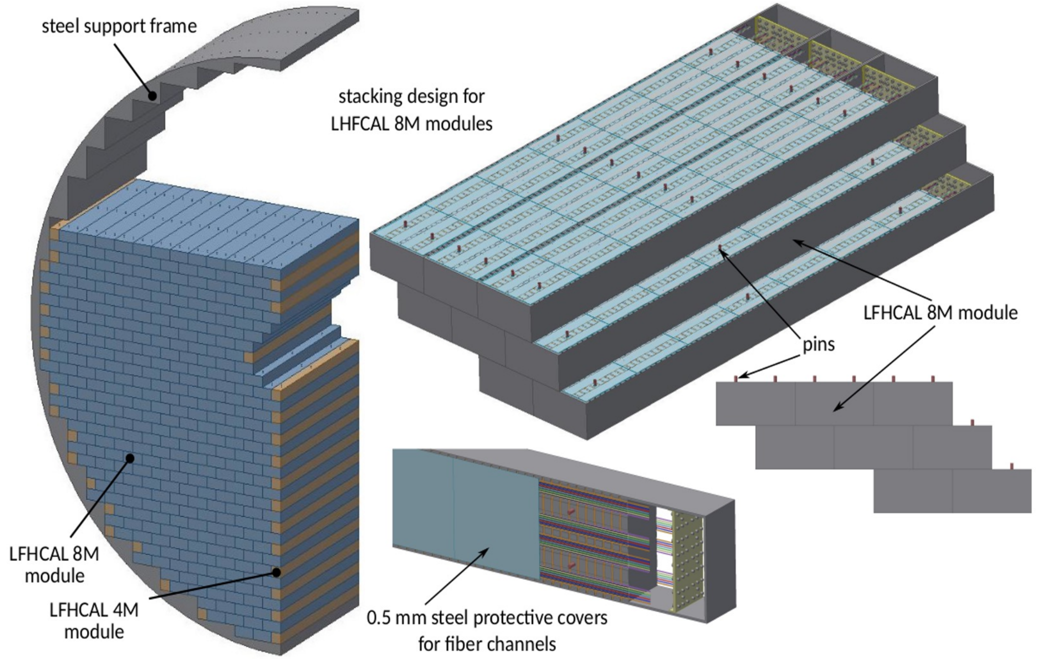


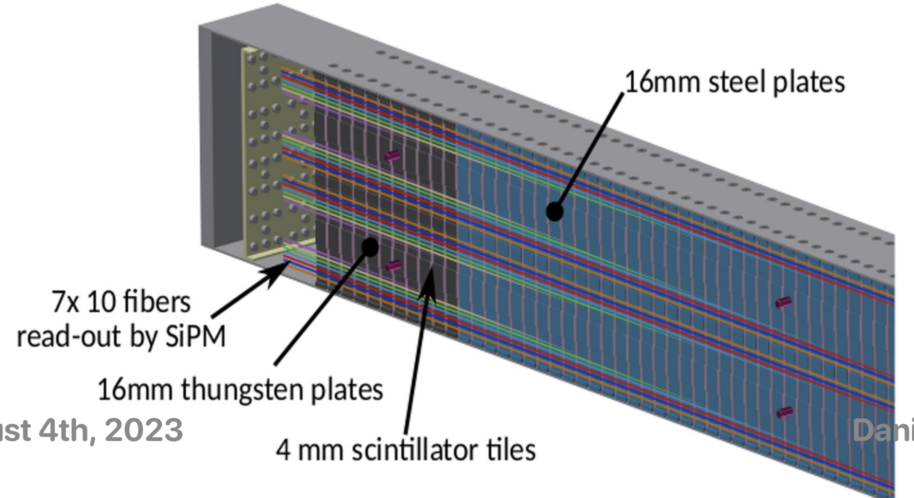
Reuse of sPHENIX outer (outside of the Solenoid) HCal ≈ 3.5λ_I

- Steel and scintillating tiles with wavelength shifting fiber
- $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$ (1,536 readout channels, SiPMs)



Forward Hadronic Calorimetry





Design based on longitudinally separated steel and scintillator tiles (ORNL)

- Inspired by Projectile Spectator Detector (CBM)
    - 60 layers of steel-sci plates + 10 layers of W-Sci plates (5 x 5 cm towers)
    - 7 signals per tower (from 10 plates)
    - λ/λ_0 = 6.9 (HCAL only, larger shower containment)

- Ongoing efforts to explore granular inlay around beampipe

Tracking Performance

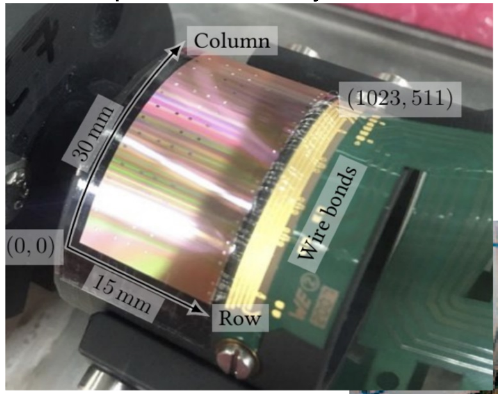
Technology

ITS3 MAPS based Si-detectors:
- O(20μm) pitch, $X/X^0 \sim 0.05 – 0.55\%$/ layer

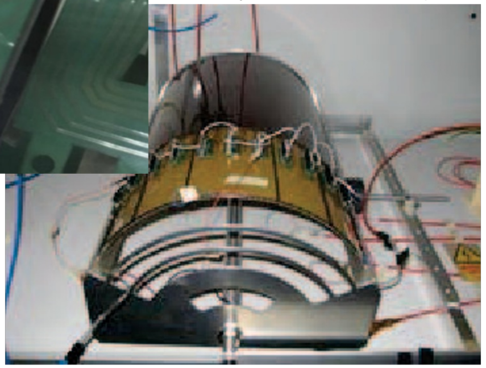
Gaseous tracker:
- σ = 55 μm, $X/X_0 \sim 0.2\%$/layer

AstroPix outer tracker layer:
- 500μm pixel pitch (σ = 144 μm)

First "μITS3" assembly at CERN

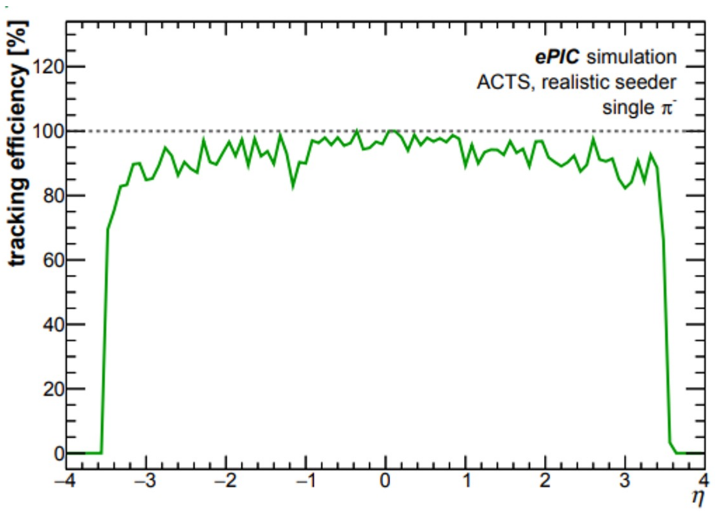


Cylindrical μMega



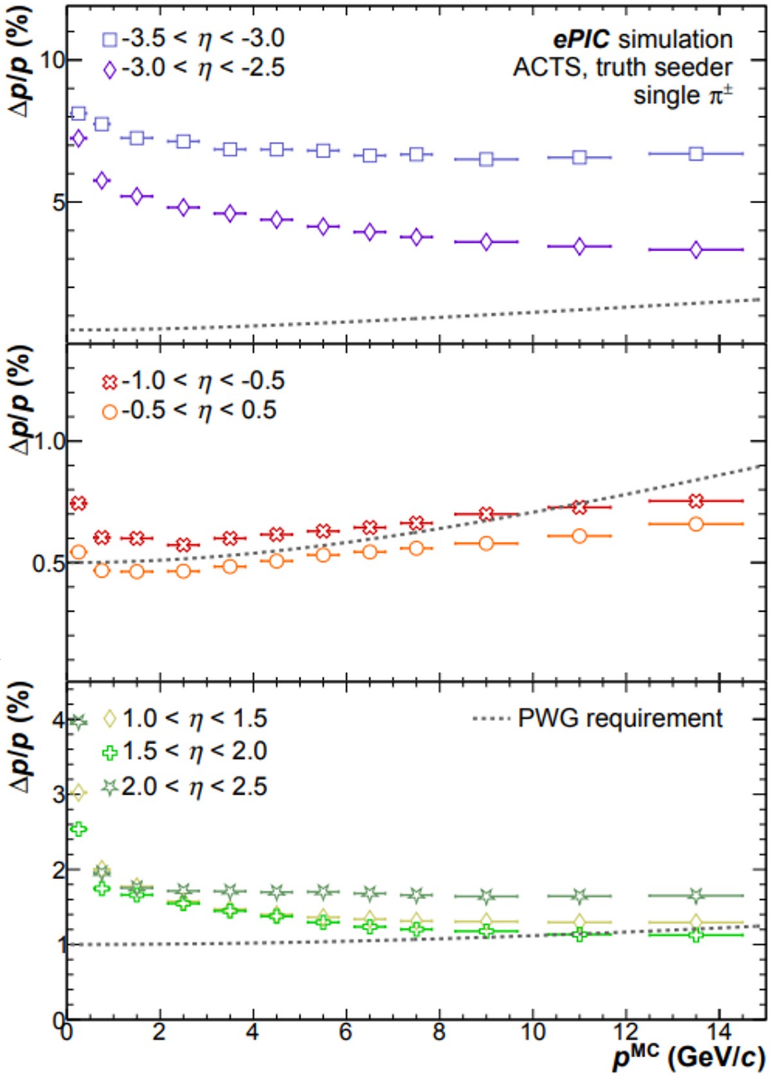
Simulated performance

F. Bock, Hard Probes 2023



- Meets EICUG Yellow Report design requirements
- Backward momentum resolution complemented by calorimetric resolution

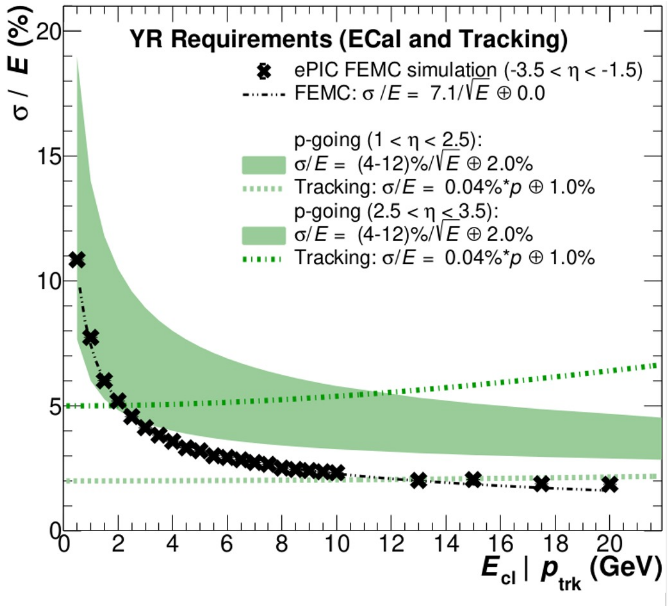
F. Bock, Hard Probes 2023

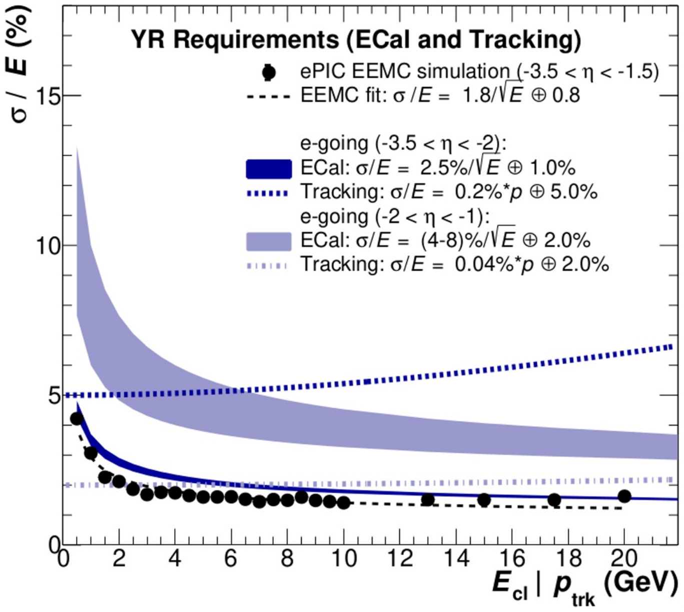


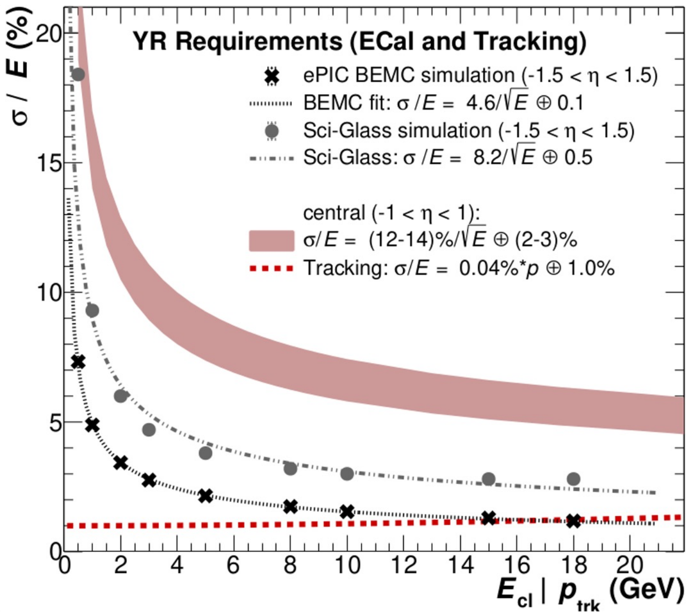
E. Yeats, R. Cruz-Torres, N. Schmidt, S. Maple

Calorimetry Performance

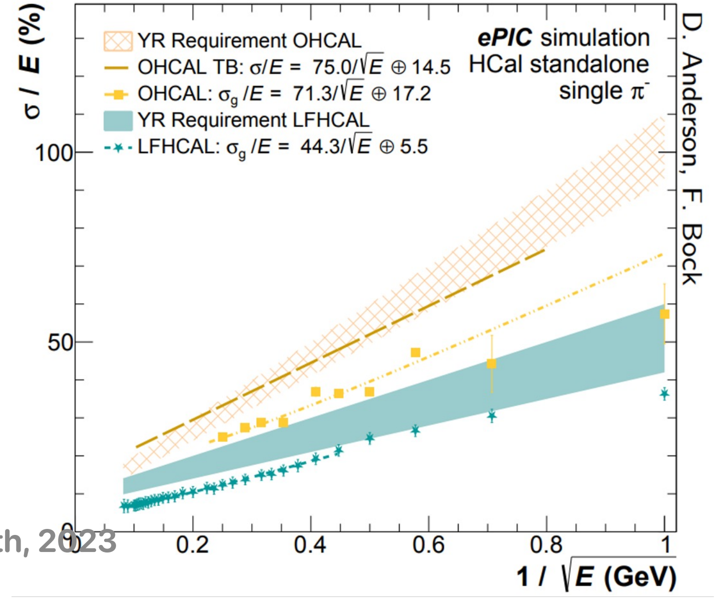
plots by N. Schmidt







F. Bock, Hard Probes 2023



Performance on energy resolution and matching

- Technologies fulfill YR requirements on energy resolution
- Ongoing simulation studies related to overlaps between different η regions for calorimetry and reconstruction algorithms

Ongoing work on Monte-Carlo validation

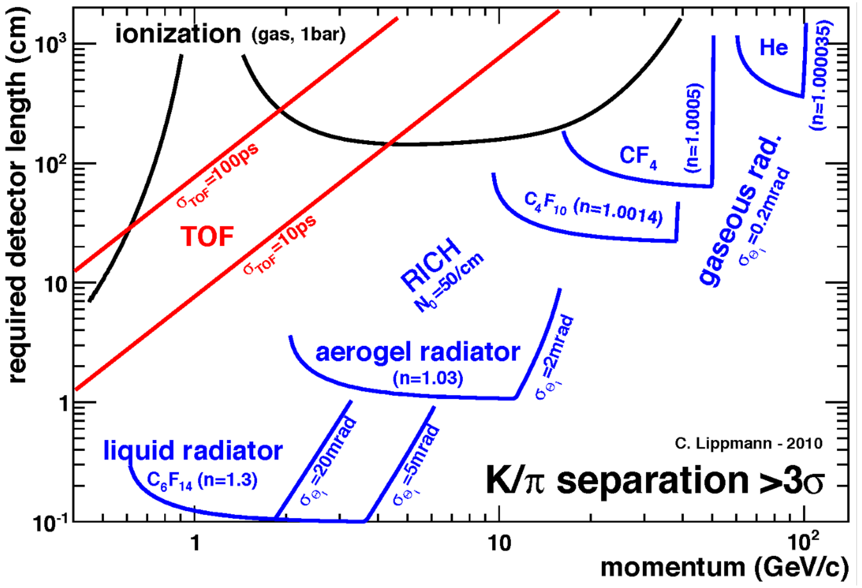
- Validation for high Z absorbers

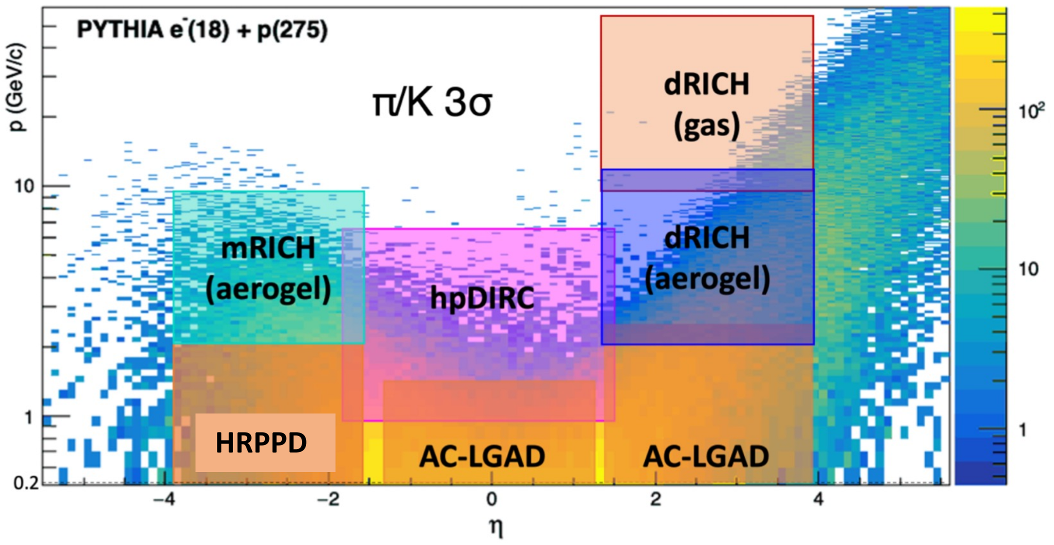
Particle ID

Particle IDentification needs

- Electrons from photons ⟶ **4π coverage in tracking**
- Electrons from charged hadrons ⟶ **mostly provided by calorimetry and tracking**
- Charged pions, kaons and protons from each other on track level ⟶ **Cherenkov detectors**
  - Cherenkov detectors, complemented by ToF

Rapidity	π/K/p and π^0/γ	e/h	Min p_T (E)
-3.5 – -1.0	7 GeV/c	18 GeV/c	100 MeV/c
-1.0 – 1.0	8-10 GeV/c	8 GeV/c	100 MeV/c
1.0 – 3.5	50 GeV/c	20 GeV/c	100 MeV/c



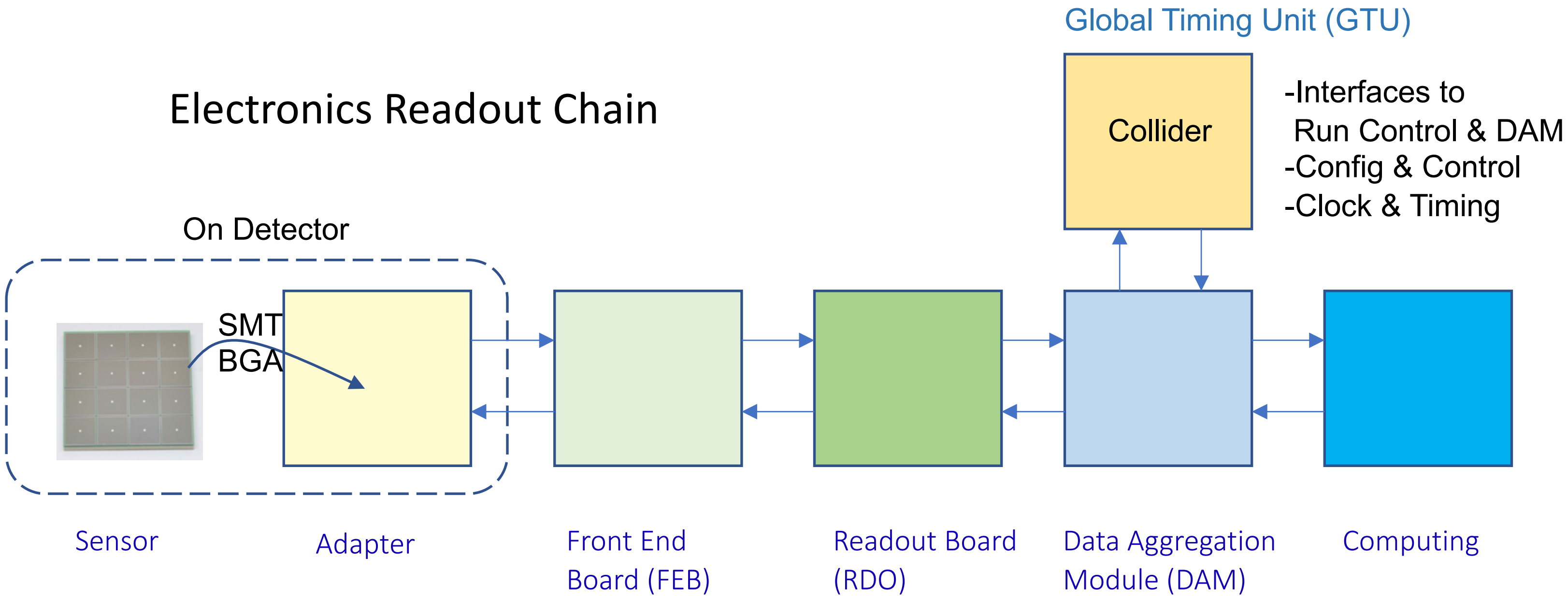


Need more than one technology to cover the entire momentum ranges at different rapidities

Electronics

- We have 23 different detector technologies in the ePIC detector
- It would be intractable if all have different readout electronics
- The goal is to minimize the number of different ASICs and use common readout solutions

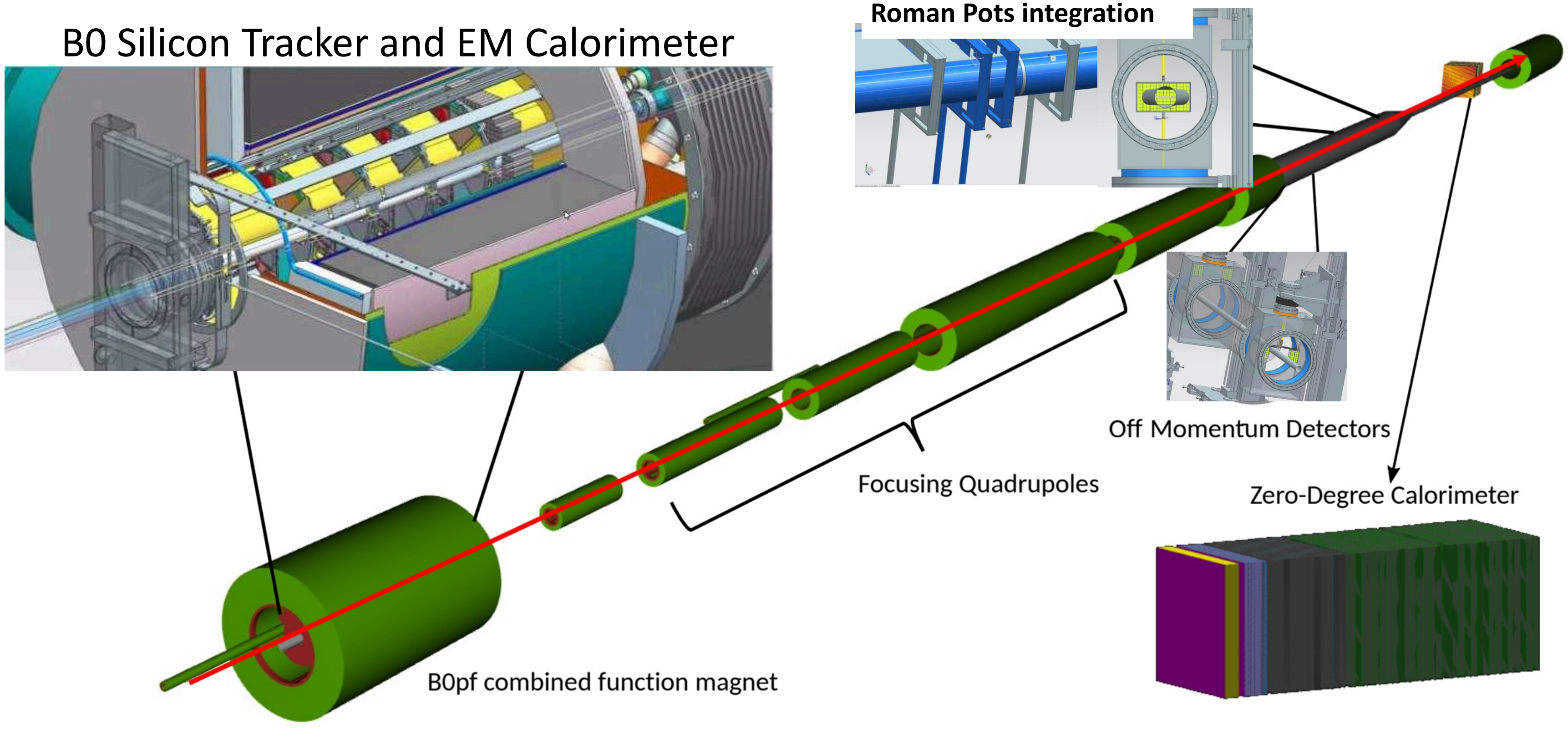
Electronics Readout Chain



Detector Group	Channels			
	MAPS	AC-LGAD	SiPM/PMT	MPGD
TOTAL	32 B	7.1M-54M	370k	100k
ASIC	ITS-3	EICROC FCFD HPsOC ASROC FAST	Discrete/COTS HGCROC3 ALCOR-EIC	SALSA

- We expect to need ITS-3, Astropix, Timepix, and 4 different **ASICs**
- Based on existing ASICs → reduce cost & time
- Much synergy with international efforts

Far-Forward Detectors

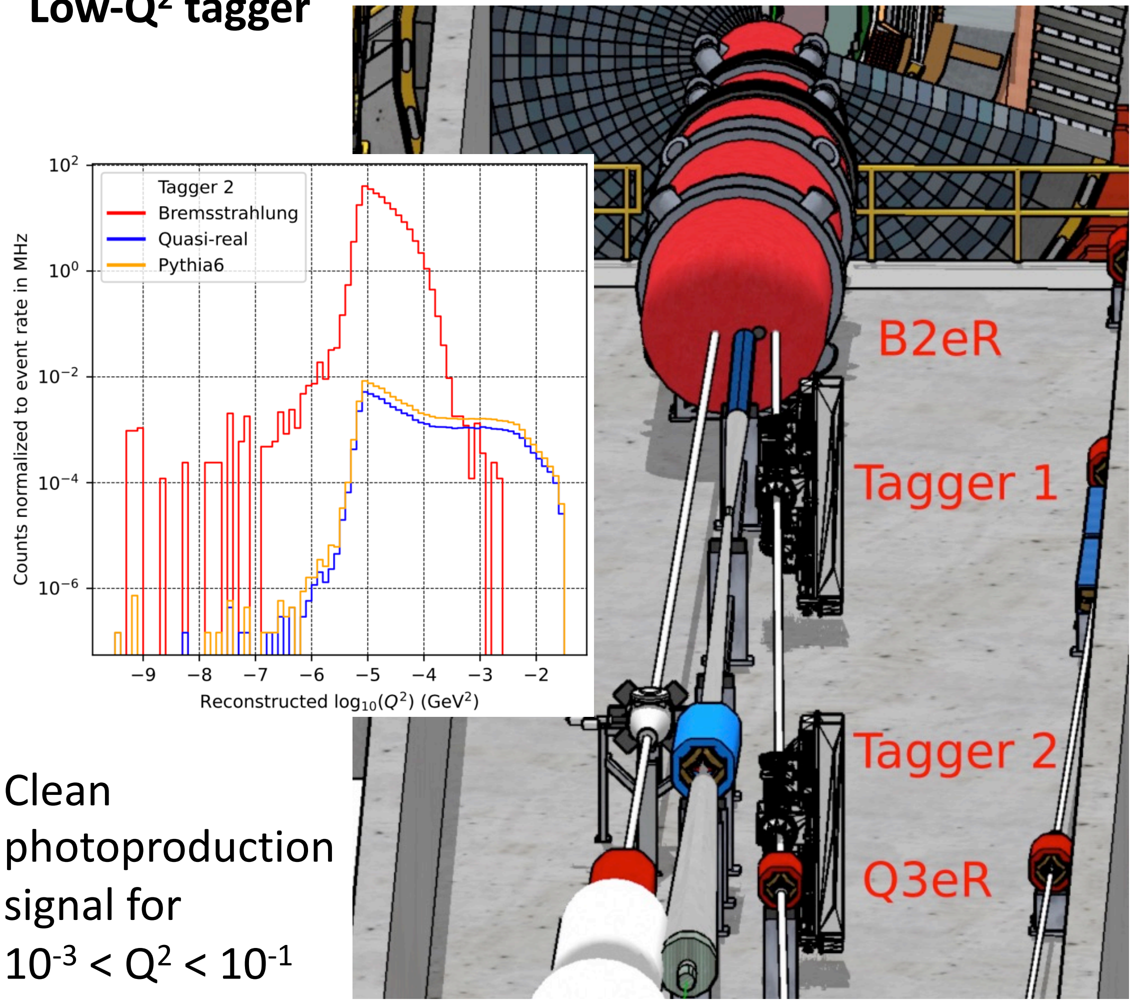


Detector	Acceptance
Zero-Degree Calorimeter (ZDC)	θ < 5.5 mrad (η > 6)
Roman Pots (2 stations)	0.0 < θ < 5.0 mrad (η > 6)
Off-Momentum Detectors (2 stations)	θ < 5.0 mrad (η > 6)
B0 Detector	5.5 < θ < 20.0 mrad (4.6 < η < 5.9)

- **B0 system:** Measures charged particles in the forward direction and tags neutral particles
- **Off-momentum detectors:** Measure charged particles resulting from, e.g., decays and fission
- **Roman pot detectors:** Measure charged particles near the beam
- **Zero-degree calorimeter:** Measures neutral particles at small angles

Far Backwards Detectors

Low-Q^2 tagger

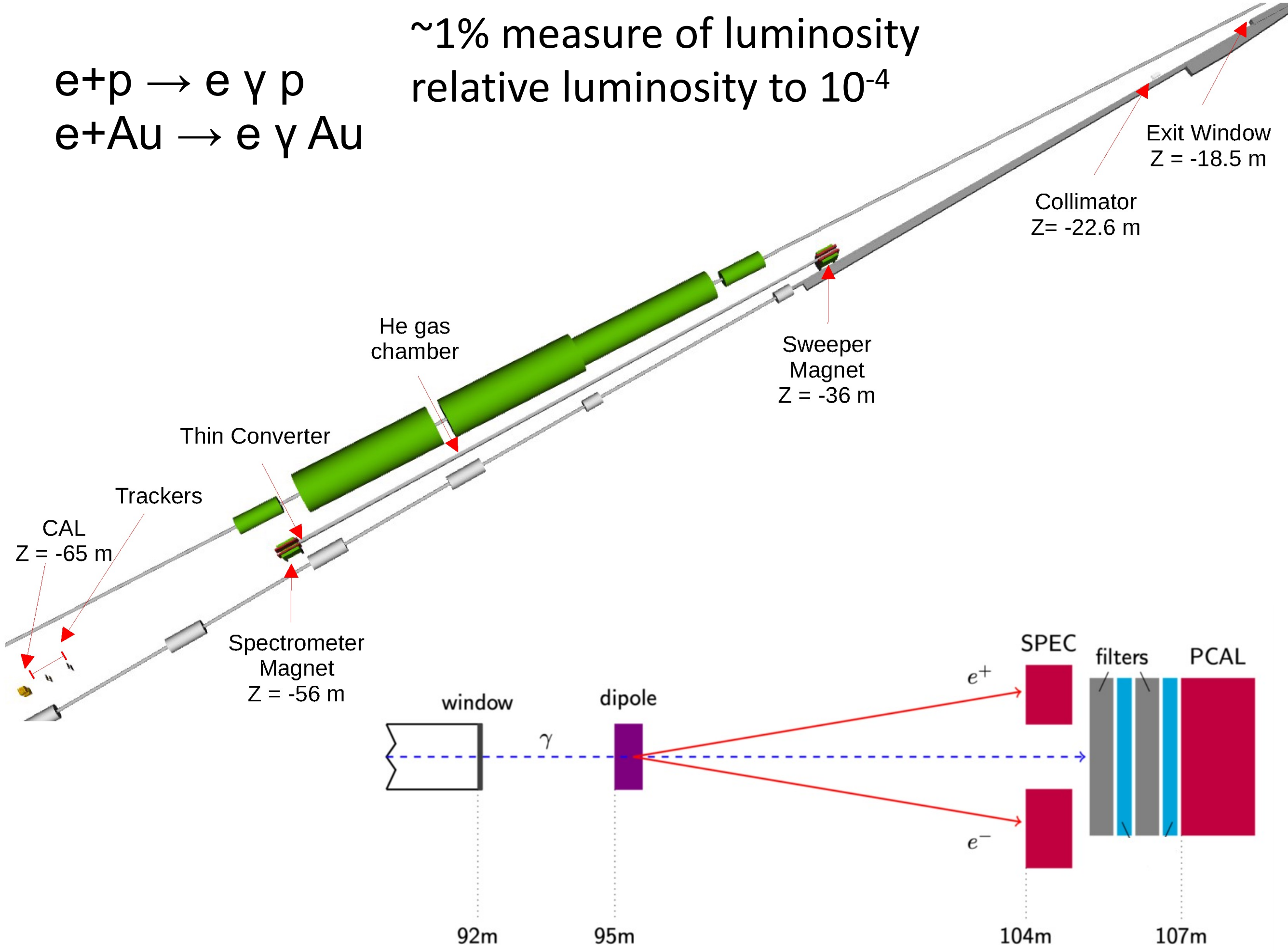


Clean photoproduction signal for $10^{-3} < Q^2 < 10^{-1}$

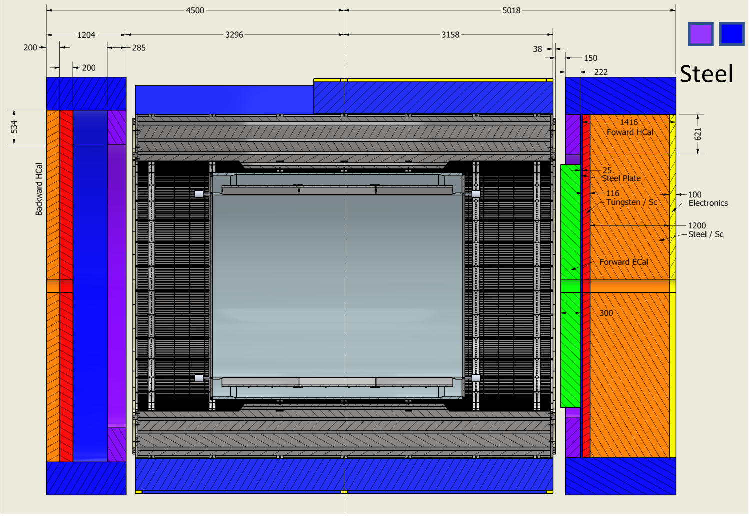
Luminosity Spectrometer

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

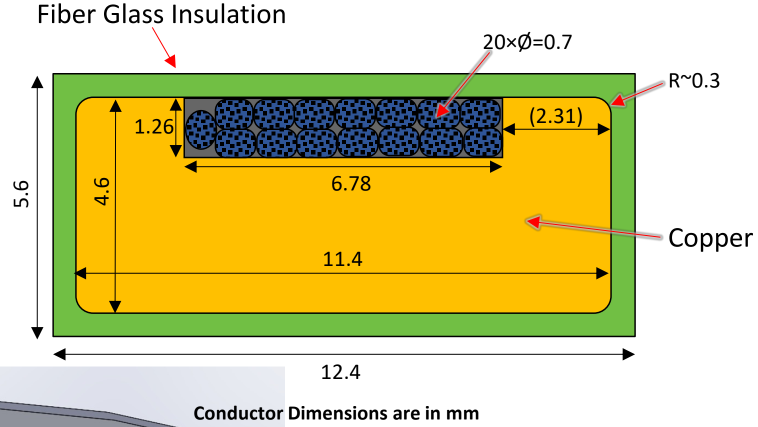
~1% measure of luminosity
relative luminosity to 10^{-4}



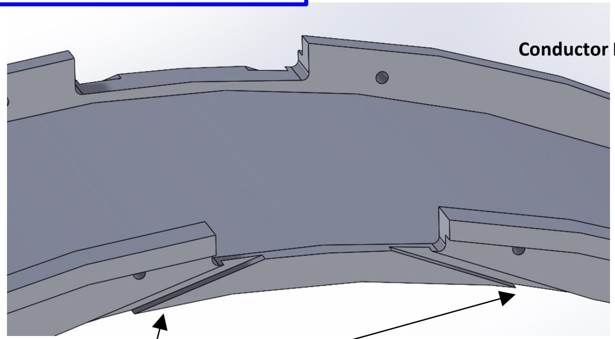
Marco Magnet Design



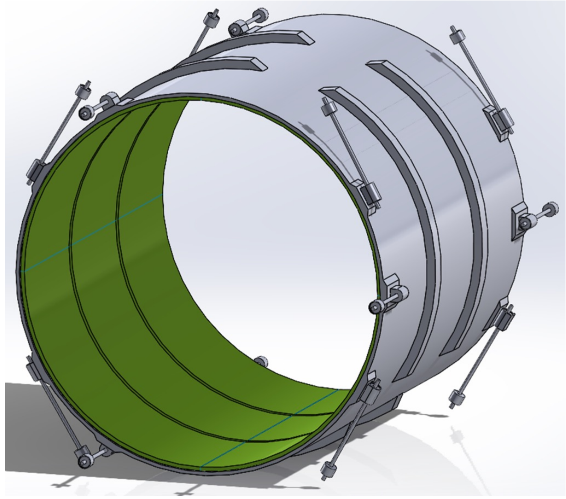
Conductor is based on CEA-Saclay experience as used for previous magnets.
Contract for conductor test samples in place with viable vendor.



Mechanical analysis undergoing final checks



Coil is divided in 3 modules with 557 Turns each. This is done mainly to accommodate possible conductor length.
Flux return steel layout fully defined to minimize forces and fringe fields (~10G)



Joint CEA-Saclay-JLab-BNL effort

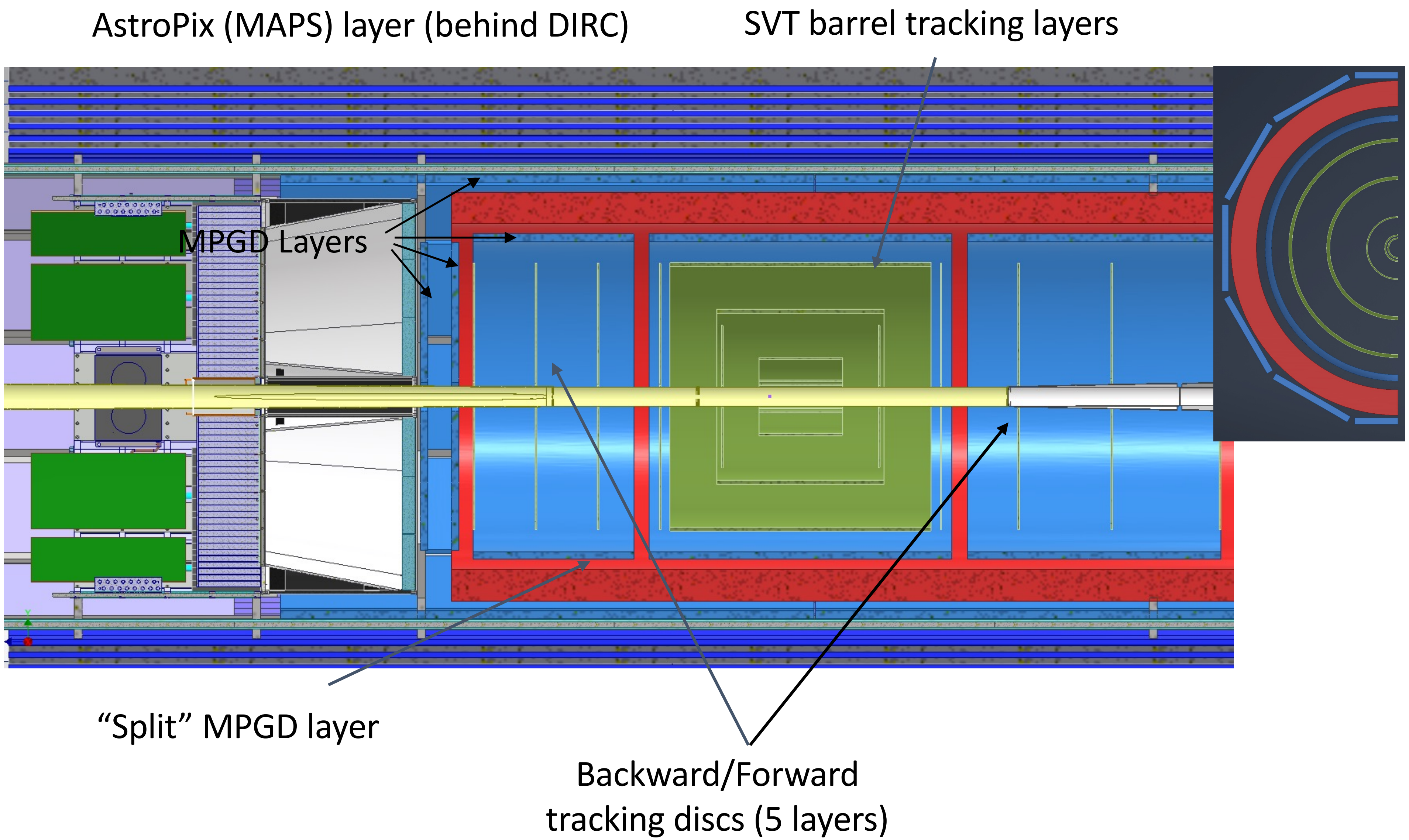
The two most important design parameters are conservative: large temperature margin and large critical current margin

B_0	1.5 T	1.7 T	2.0 T	Units
Current	2900	3296	3924	A
B_{peak}	1.925	2.187	2.602	T
Temp. margin	3.1	2.9	2.5	K
Load line margin	60.6	55.3	46.8	%
$I / Ic(T_m, B_{peak})$	17.3	21.3	28.8	%

> 1.5 K

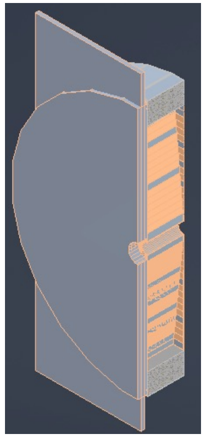
<30 %

Tracking Design Optimization

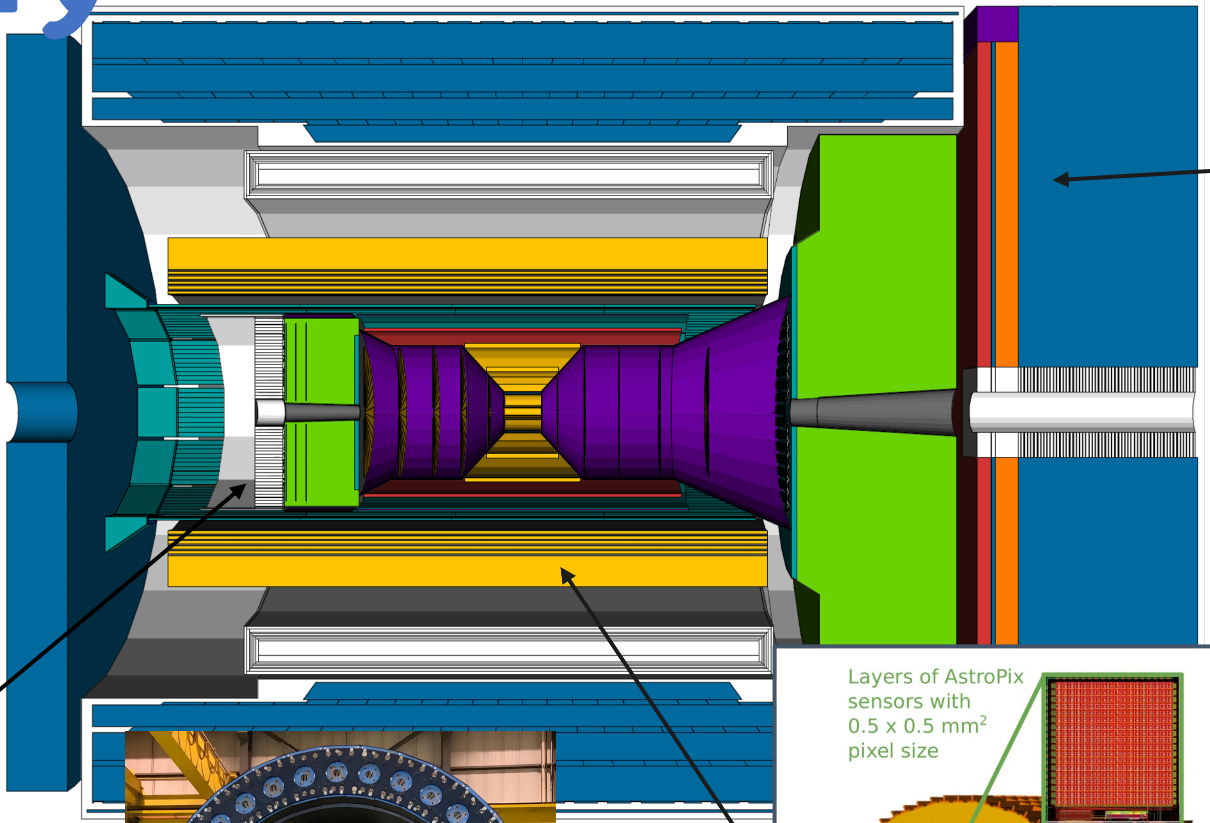


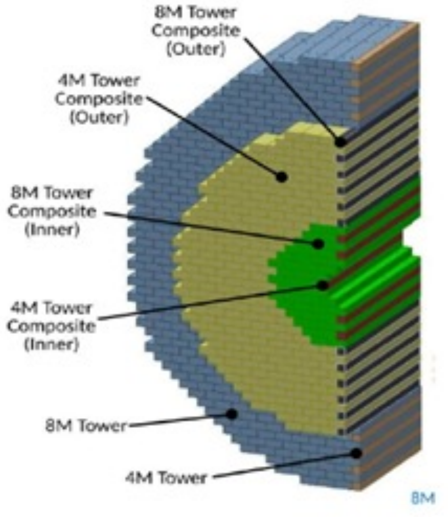
- **Inner two vertex layers** optimized for beam pipe bakeout and ITS-3 sensor size
- Third layer dual-purpose (vertex + sagitta) - **5 layers total**
- **Five discs in forward/backwards** direction (ITS-3 based large area sensor design EIC LAS)
- **MPGD's** provide pattern recognition redundancy
- **1st AstroPix layer of Barrel ECal** provides ring seed direction, space point for pattern recognition

Calorimetry

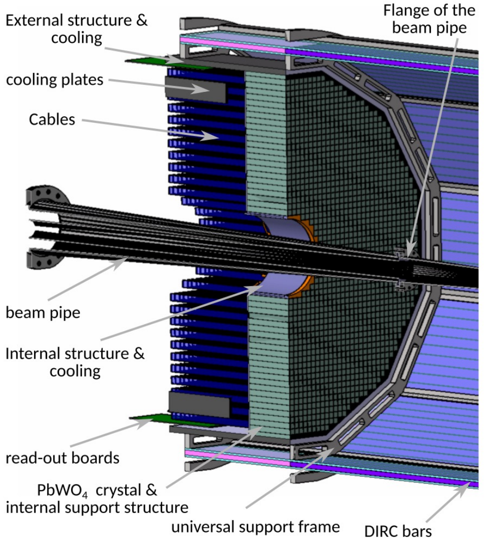


Backwards HCal
Steel/Sc Sandwich
tail catcher





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



Backwards EMCal
PbW04 crystals

Barrel HCAL
(sPHENIX re-use)