Funding support:

Office of Science
U.S. Department of Energy

ePIC capabilities and possible upgrades

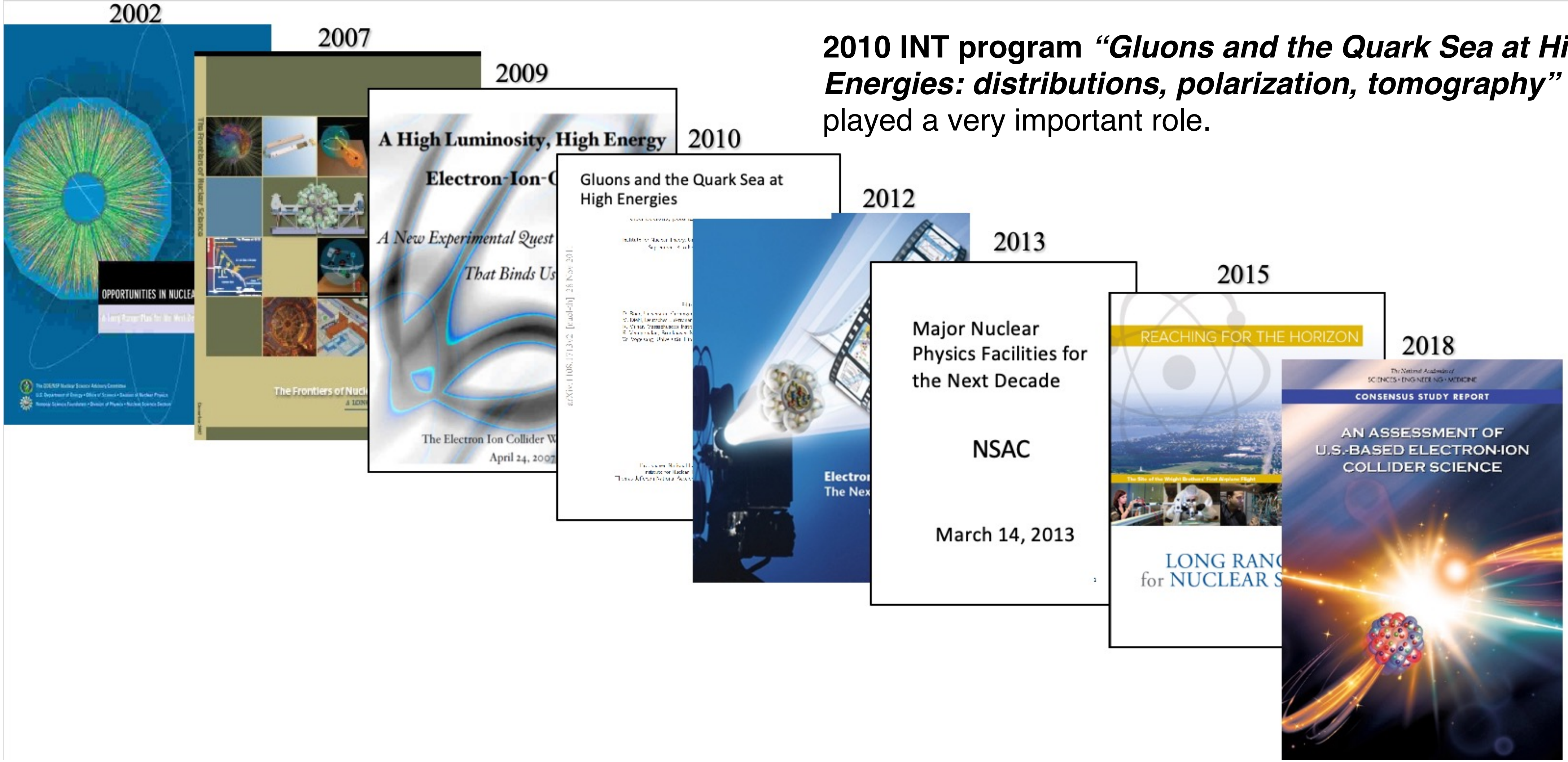
EIC project detector capabilities and a peek beyond

Ernst Sichtermann (LBNL)

INT Workshop INT-24-87W
Electroweak and Beyond the Standard Model Physics at the EIC
Seattle Washington, February 12—16, 2024

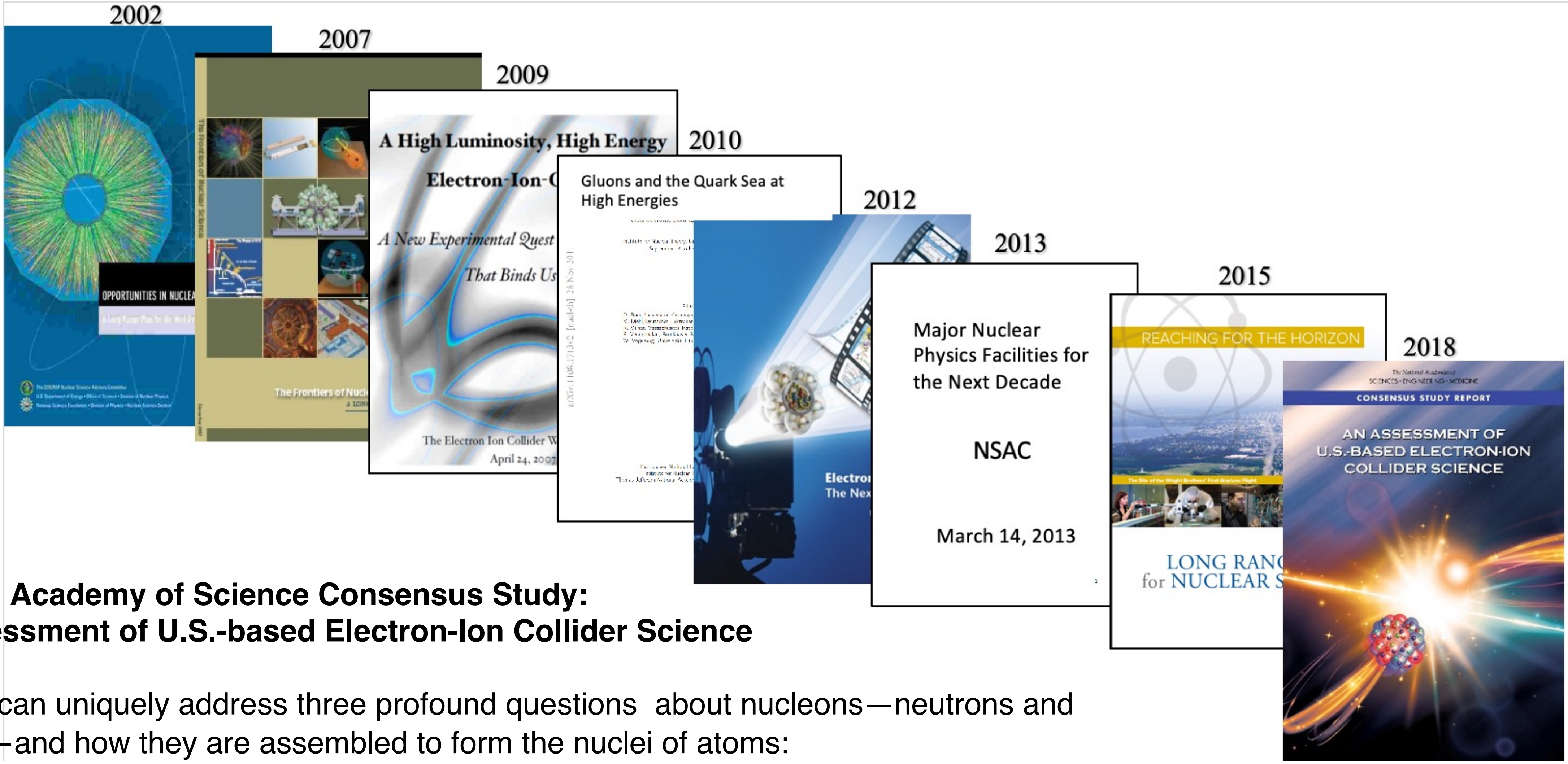
Berkeley Lab

How did we get to the EIC?



2010 INT program ***"Gluons and the Quark Sea at High Energies: distributions, polarization, tomography"*** played a very important role.

How did we get to the EIC?

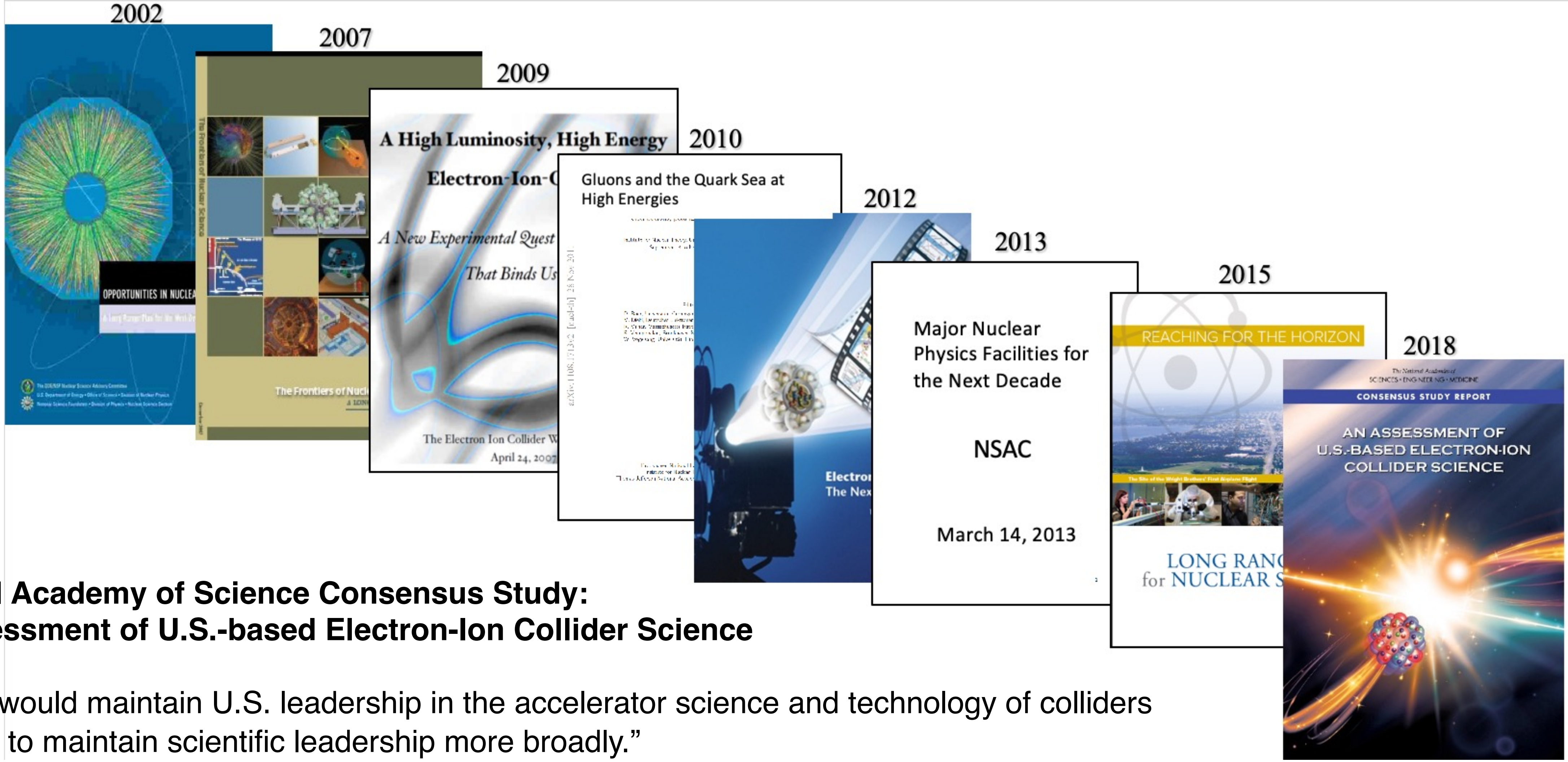


National Academy of Science Consensus Study:
An Assessment of U.S.-based Electron-Ion Collider Science

"An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

- **How does the mass of the nucleon arise?**
- **How does the spin of the nucleon arise?**
- **What are the emergent properties of dense systems of gluons?"**

How did we get to the EIC?



National Academy of Science Consensus Study:
An Assessment of U.S.-based Electron-Ion Collider Science

“An EIC would maintain U.S. leadership in the accelerator science and technology of colliders and help to maintain scientific leadership more broadly.”

How did we get to the EIC?

2023 Long Range Plan for Nuclear Science:

... "Next, we reaffirm the exceptionally high priority of the following two investments in new capabilities for nuclear physics. The Electron–Ion Collider (EIC), to be built in the United States, will elucidate the origin of visible matter in the universe and significantly advance accelerator technology as the first major new advanced collider to be constructed since the LHC. Neutrinoless double beta decay experiments have the potential to dramatically change our under- standing of the physical laws governing the universe."

RECOMMENDATION 2

As the highest priority for new experiment construction, we recommend that the United States lead an international consortium that will undertake a neutrinoless double beta decay campaign, featuring the expeditious construction of ton-scale experiments, using different isotopes and complementary techniques.

RECOMMENDATION 3

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

Courtesy E.C. Aschenauer, https://indico.desy.de/event/41404/

Facility context:

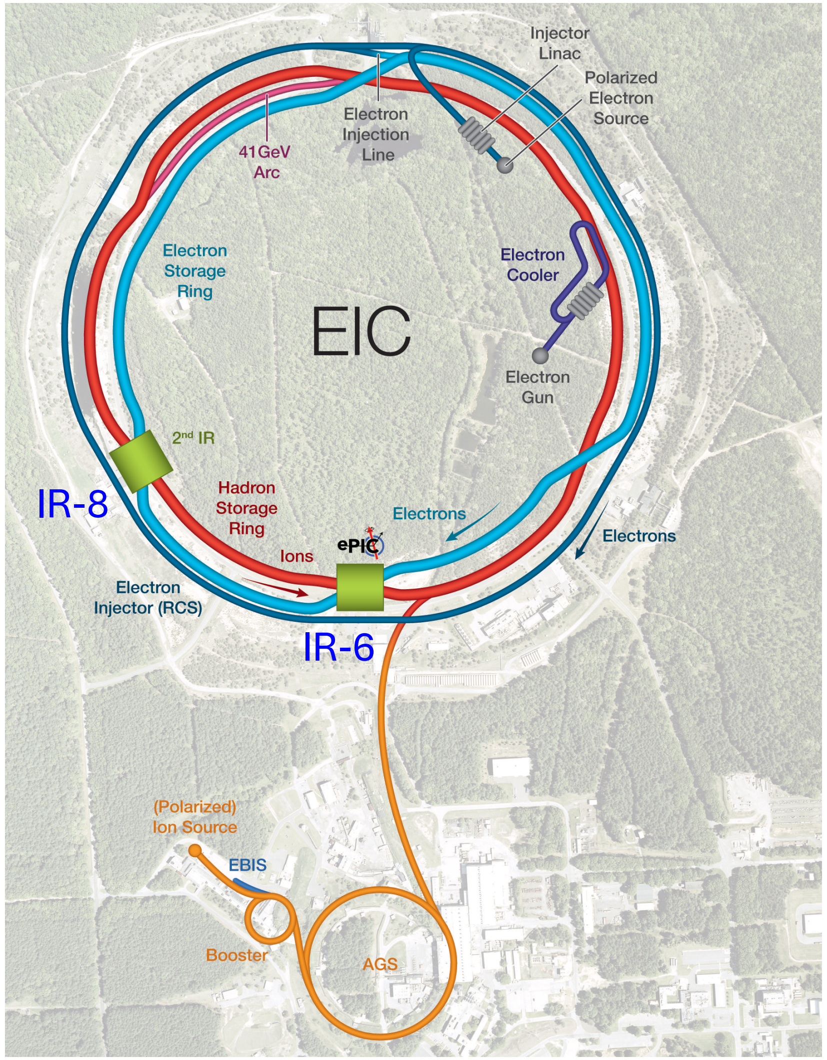
Project Design Goals

- High Luminosity: L= 10^{33} – 10^{34}cm^{-2}sec^{-1}, 10 – 100 fb^{-1}/year
- Highly Polarized Beams: 70%

  → requires high precision polarimetry
- Large Center of Mass Energy Range: E_{cm} = 29 – 140 GeV

  → Large Detector Acceptance
- Large Ion Species Range: protons – Uranium

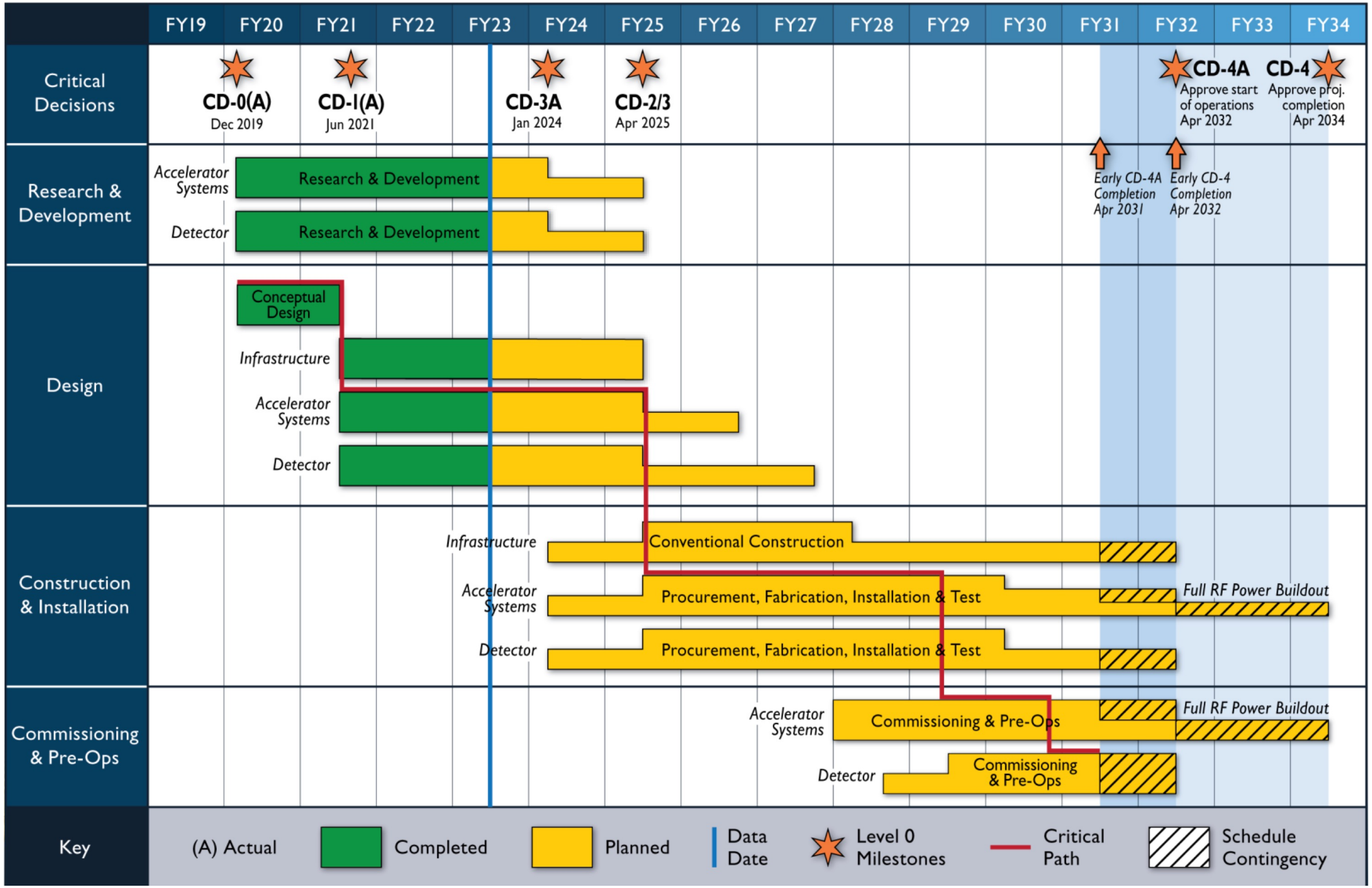
  → Requires forward detectors integrated in beam lattice
- Good Background Conditions
- Accommodate a Second Interaction Region (IR) → IR-8



p: 41 GeV, 100 to 275 GeV → p/A beam

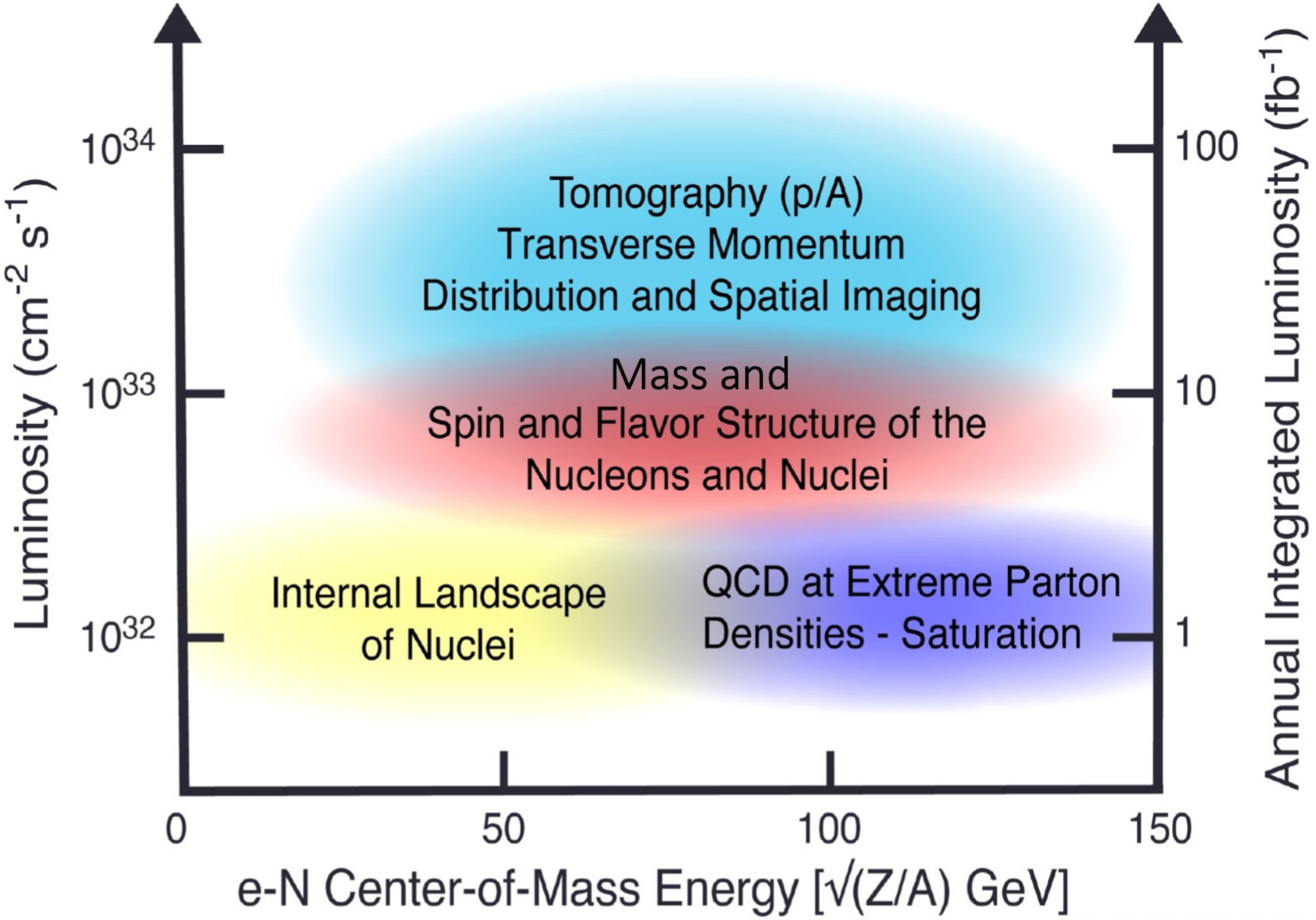
e beam ← e: 5 GeV to 18 GeV

Project context:



Source: J. Yeck, 2023 EIC User Group Meeting — https://indico.cern.ch/event/1238718/

Energy – Luminosity context:



Towards Detector Requirements:

Internal Landscape of Nuclei

QCD at Extreme Parton Densities Saturation

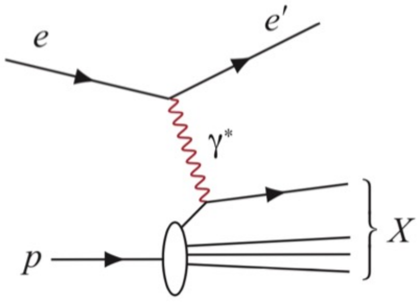
Mass, Spin, Flavor Structure of the Nucleons and Nuclei

Tomography Transverse Momentum Distribution Spatial Imaging

QCD at Extreme Parton Densities Saturation

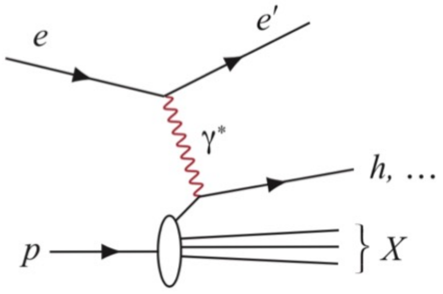
Tomography Transverse Momentum Distribution Spatial Imaging

Inclusive DIS



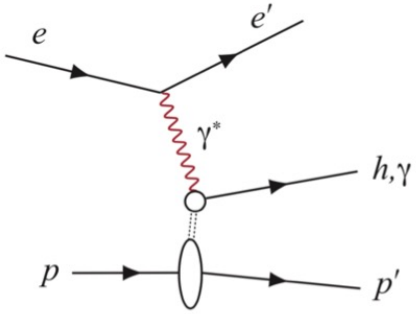
- High performance electron identification and reconstruction

Semi-inclusive DIS



- Tracking and hadronic calorimetry
- Heavy flavors identification from vertexing
- Light flavors from dedicated PID detectors

Exclusive DIS

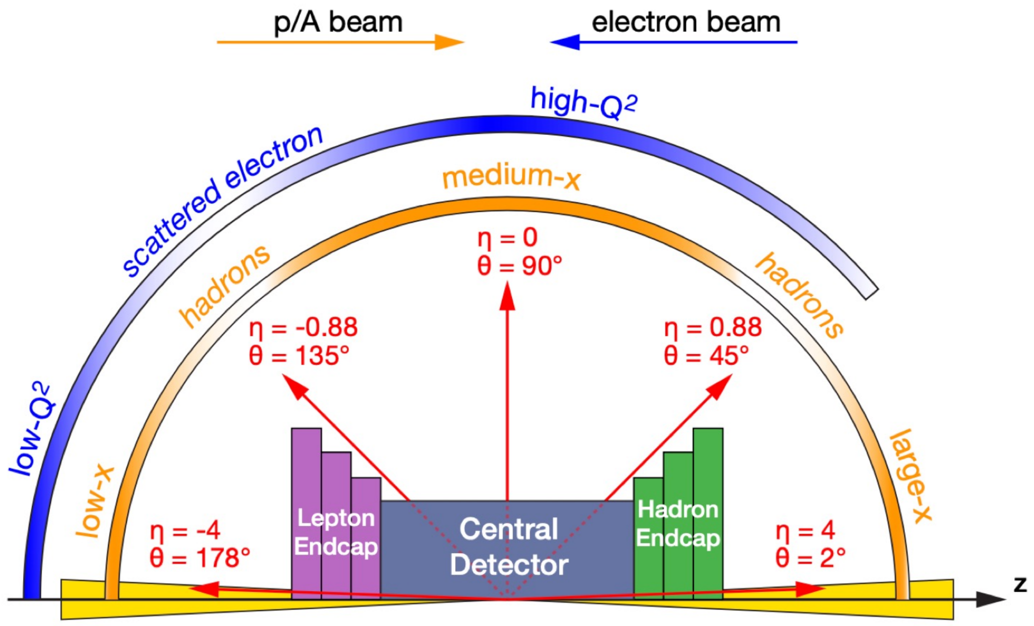


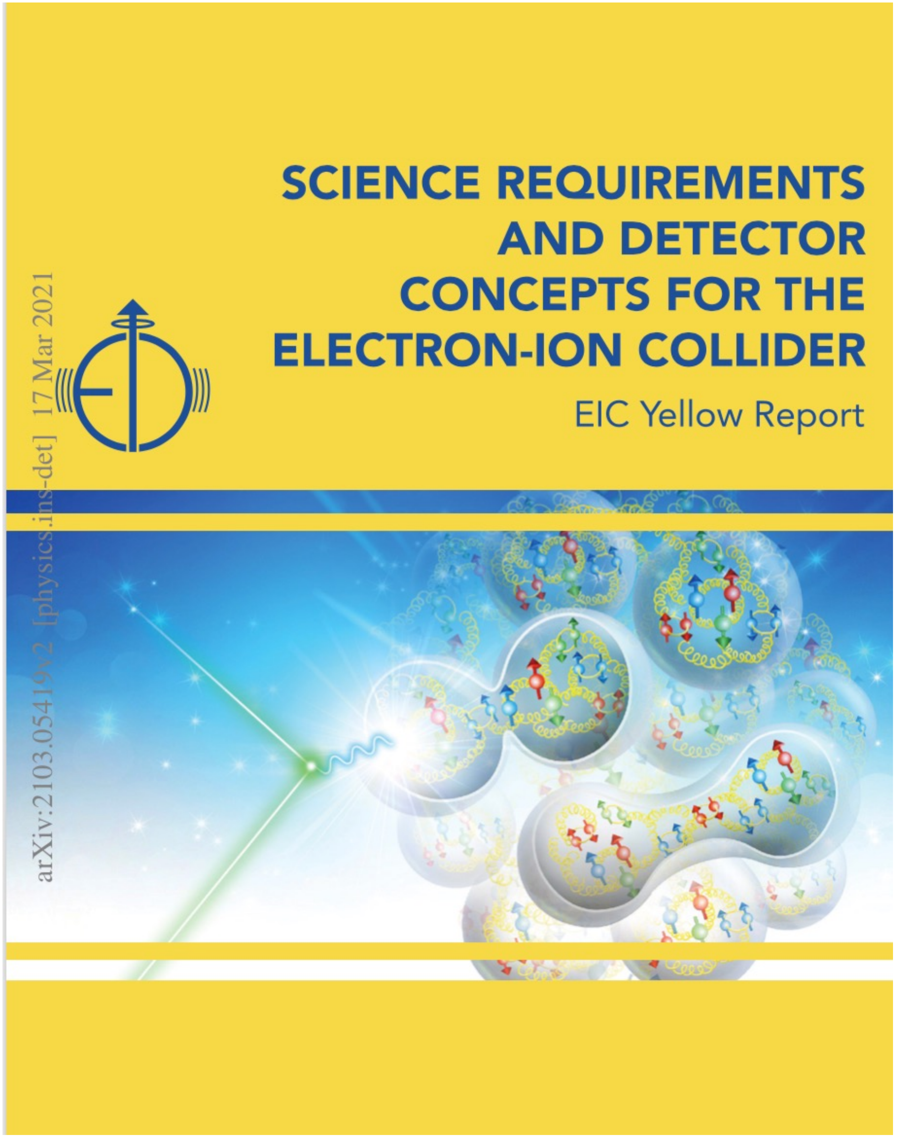
- Efficient proton tagging
- Cover full acceptance range

Community Detector Requirements:

arXiv:2103.05419, NPA 1026 (2022) 12447

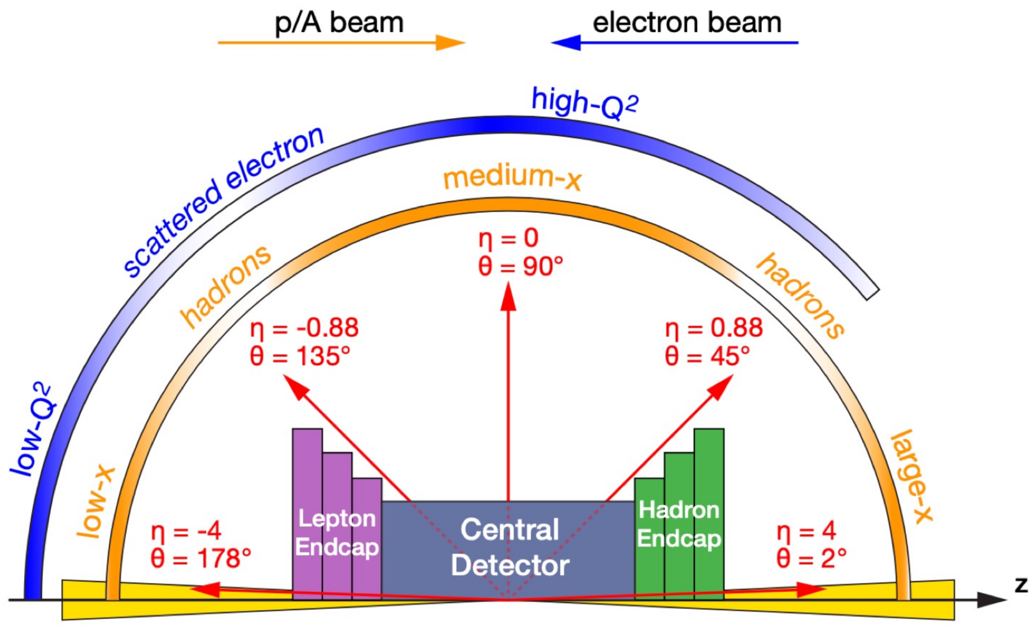
2021 Yellow Report — works out initial requirements,
two detector reference designs
identifies further physics opportunities
led (in-)to call for detector proposals.

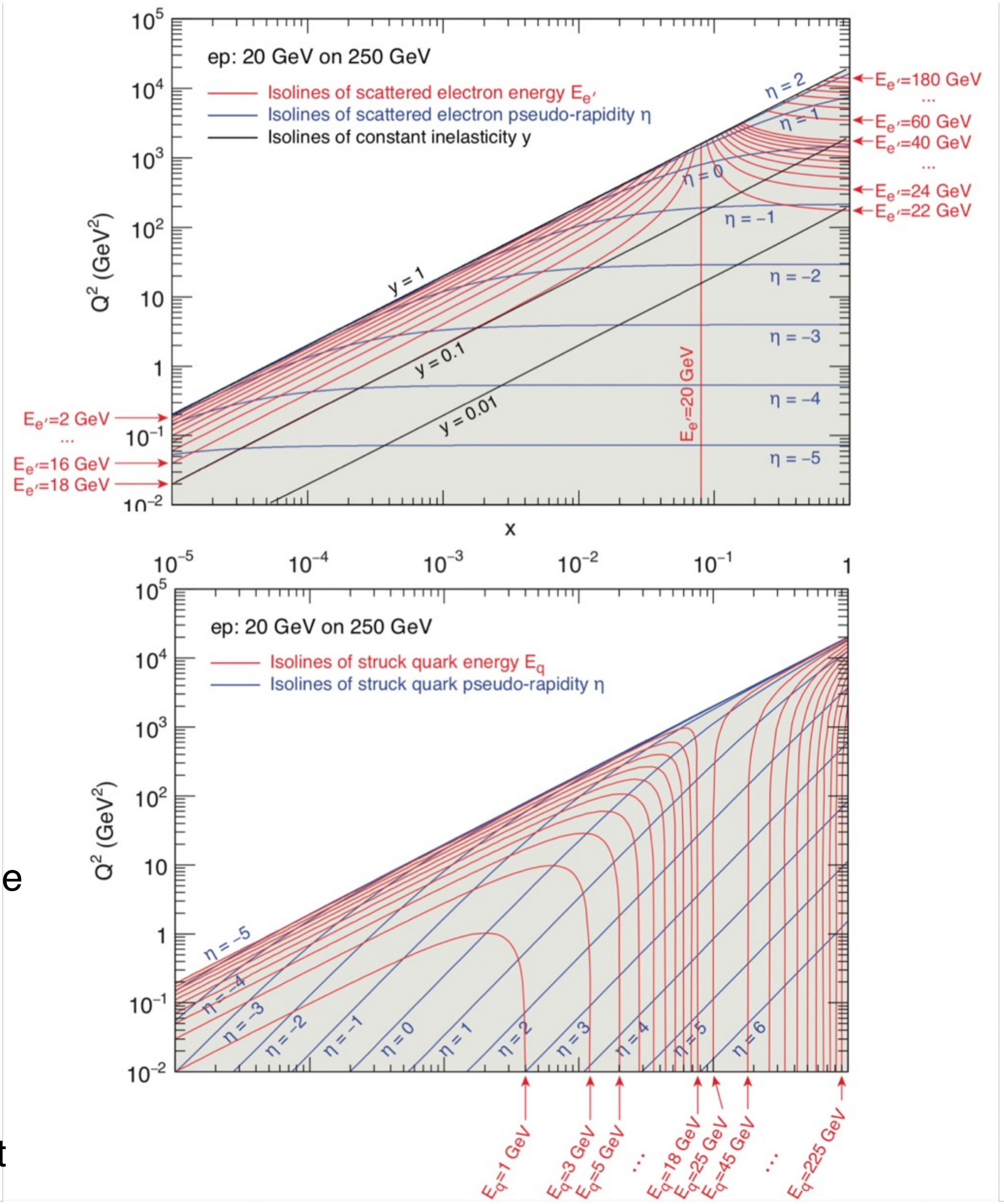




High luminosity drives the need for a compact device, ~ 9m along the beam axes,
Large acceptance required by the science drives the need for (very) careful integration,
Combination with calorimetry and PID drives the need for a compact tracking subsystem,

Detector Requirements:





High luminosity drives the need for a compact device, ~ 9m along the beam axes,

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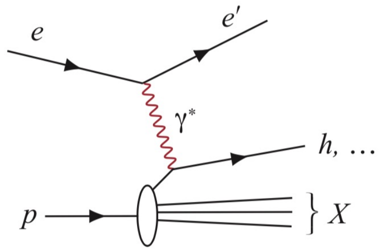
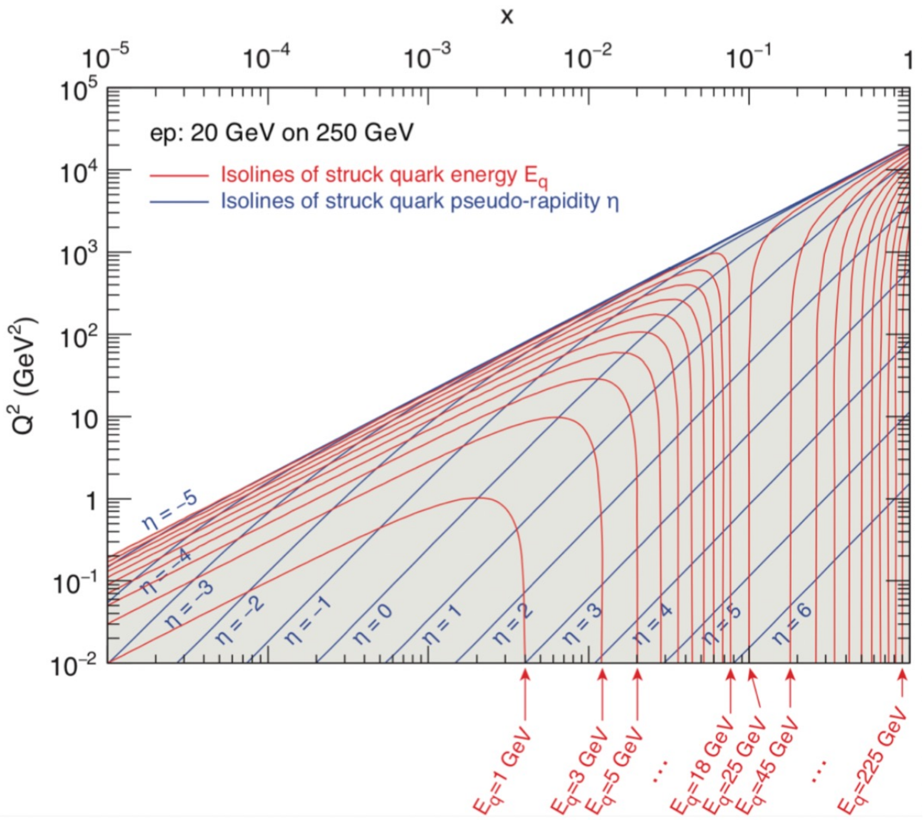
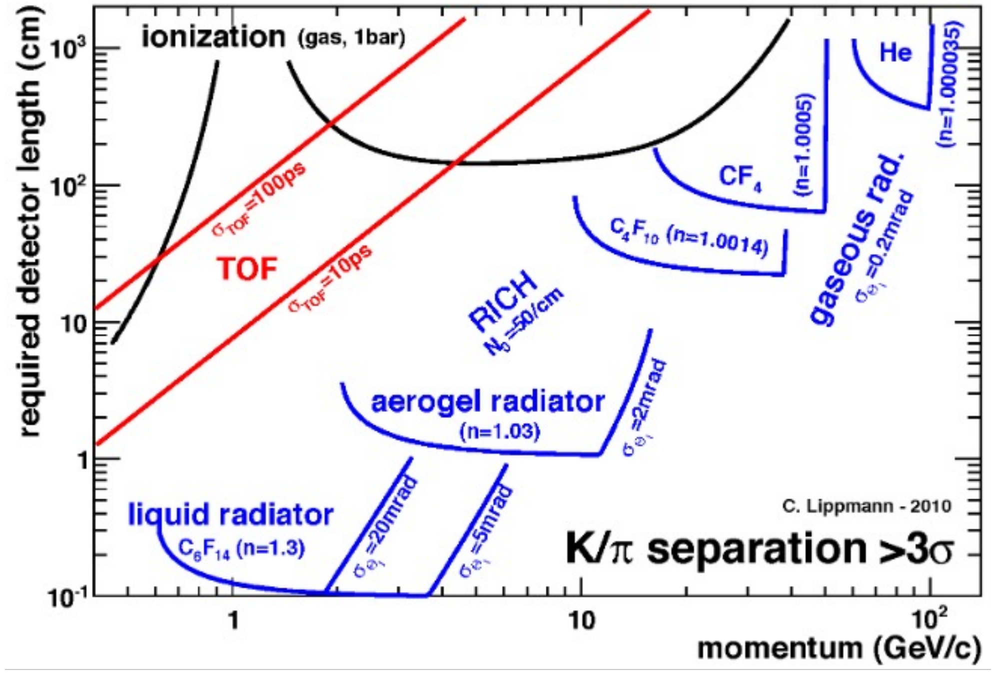
From Detector Requirements to Technologies:

SIDIS, as an example:

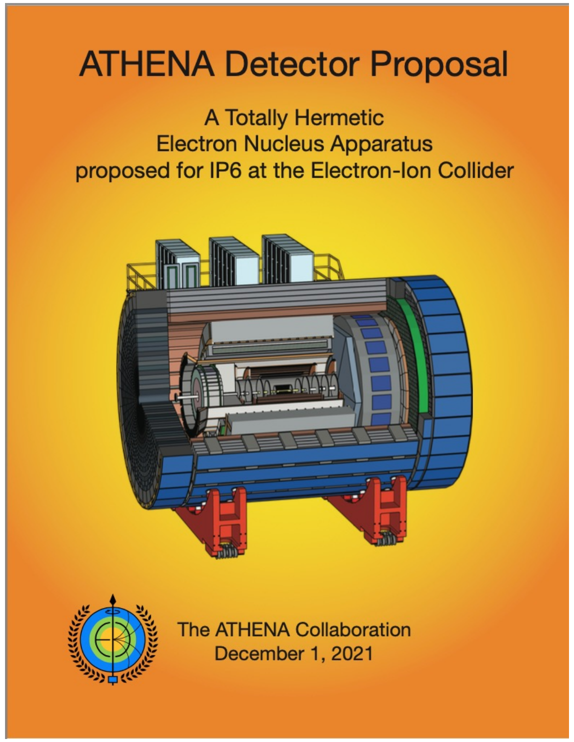




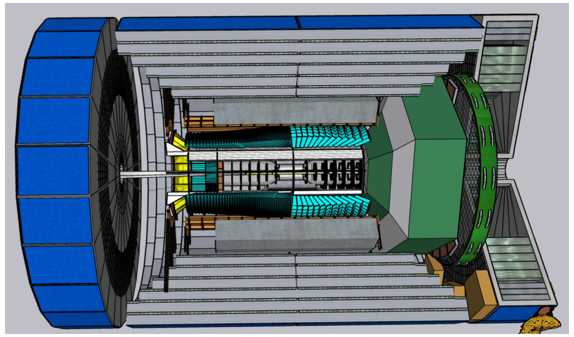


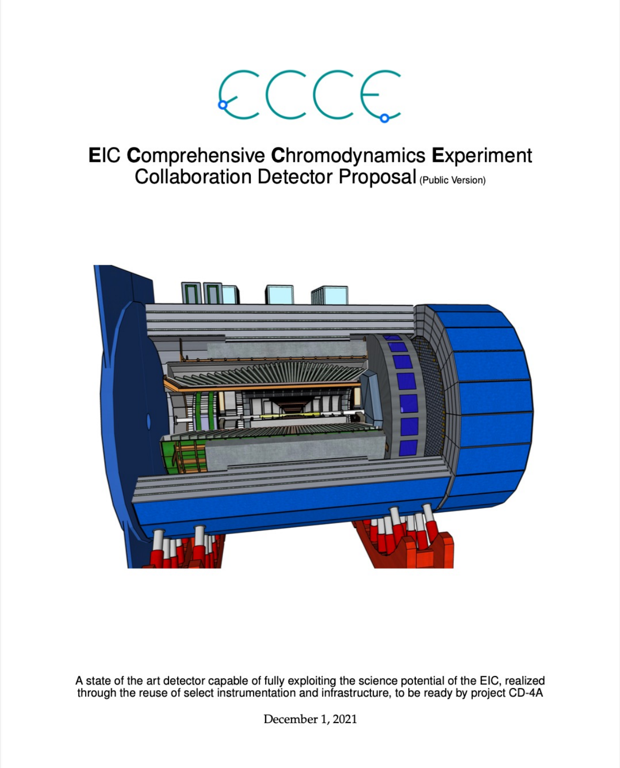
Wide range of hadron momenta necessitates multiple identification technologies/techniques

Detector Proposals and DPAP:



CORE





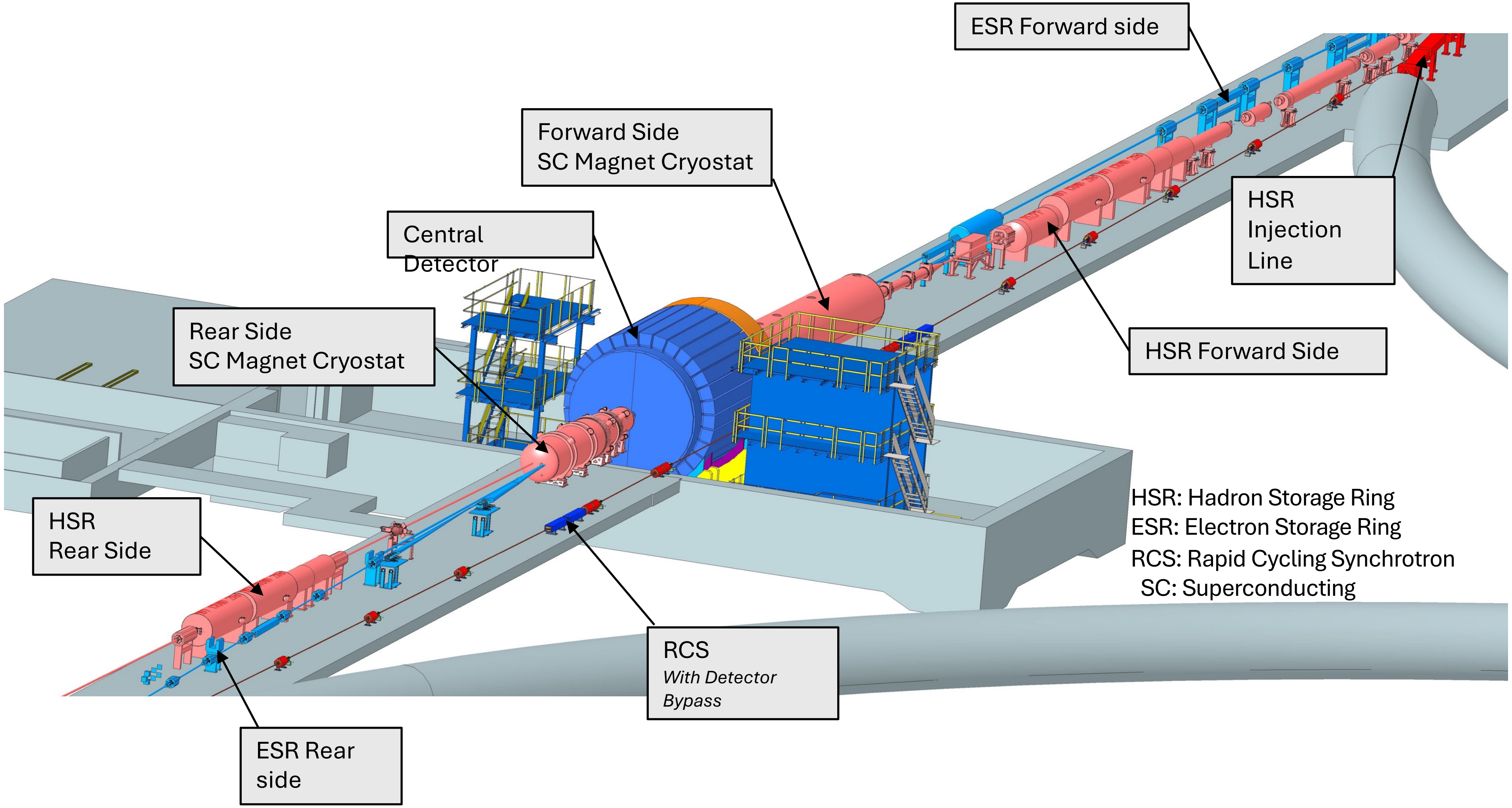
Detector Proposal Advisory Panel (DPAP) reviewed three proposals; ATHENA, CORE, and ECCE,

Finds that ATHENA and ECCE fulfill all requirements for a Detector 1, i.e. NAS science case,
none of the collaborations is strong or large enough to develop Detector 1 for Day 1

Recommended ECCE as Detector 1 in Spring 2022 – adopted by the EIC Project as Reference,

“Right language” for a Detector 2, but no language on an actual concept, technology, etc.

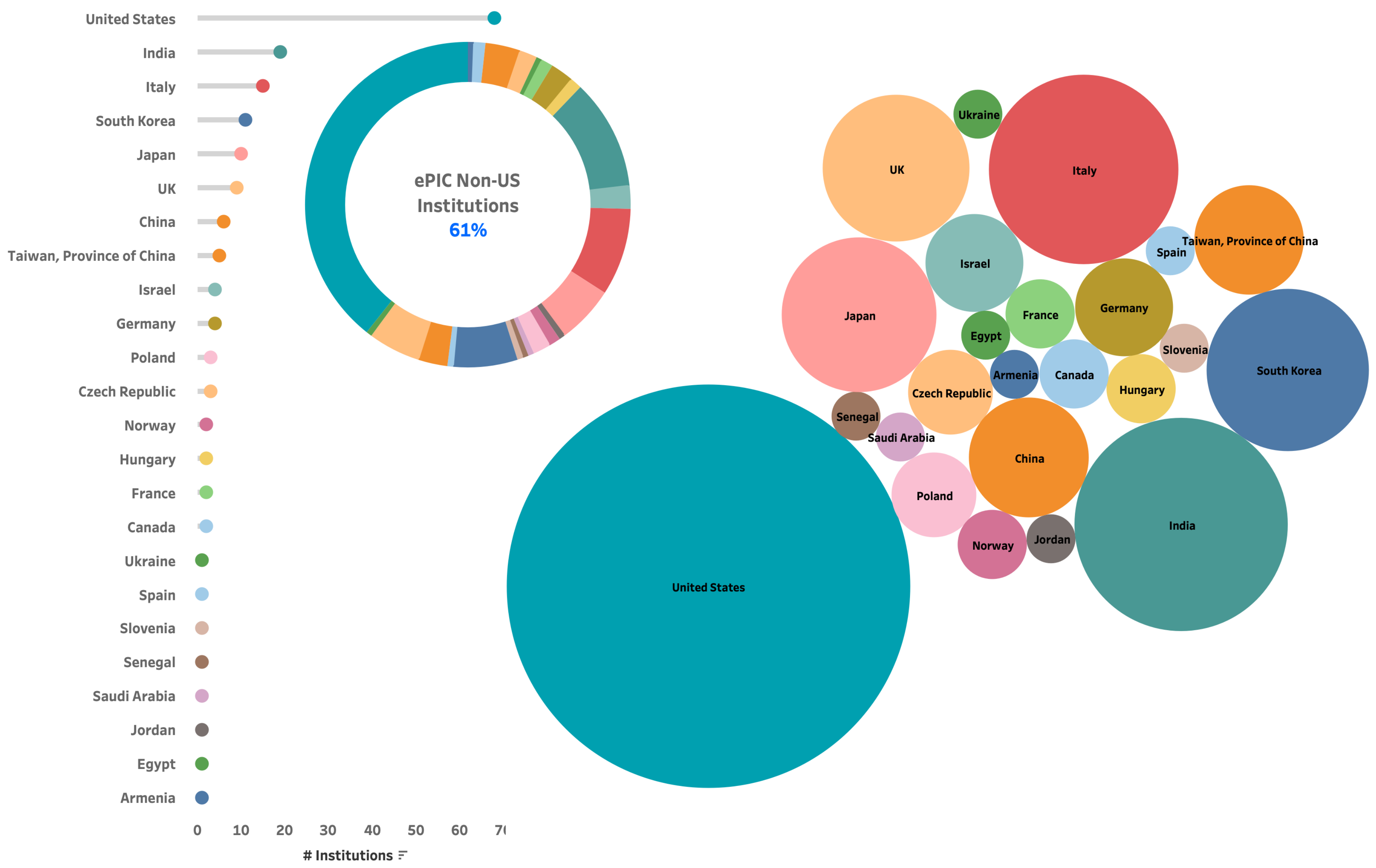
A *lot* has happened since DPAP



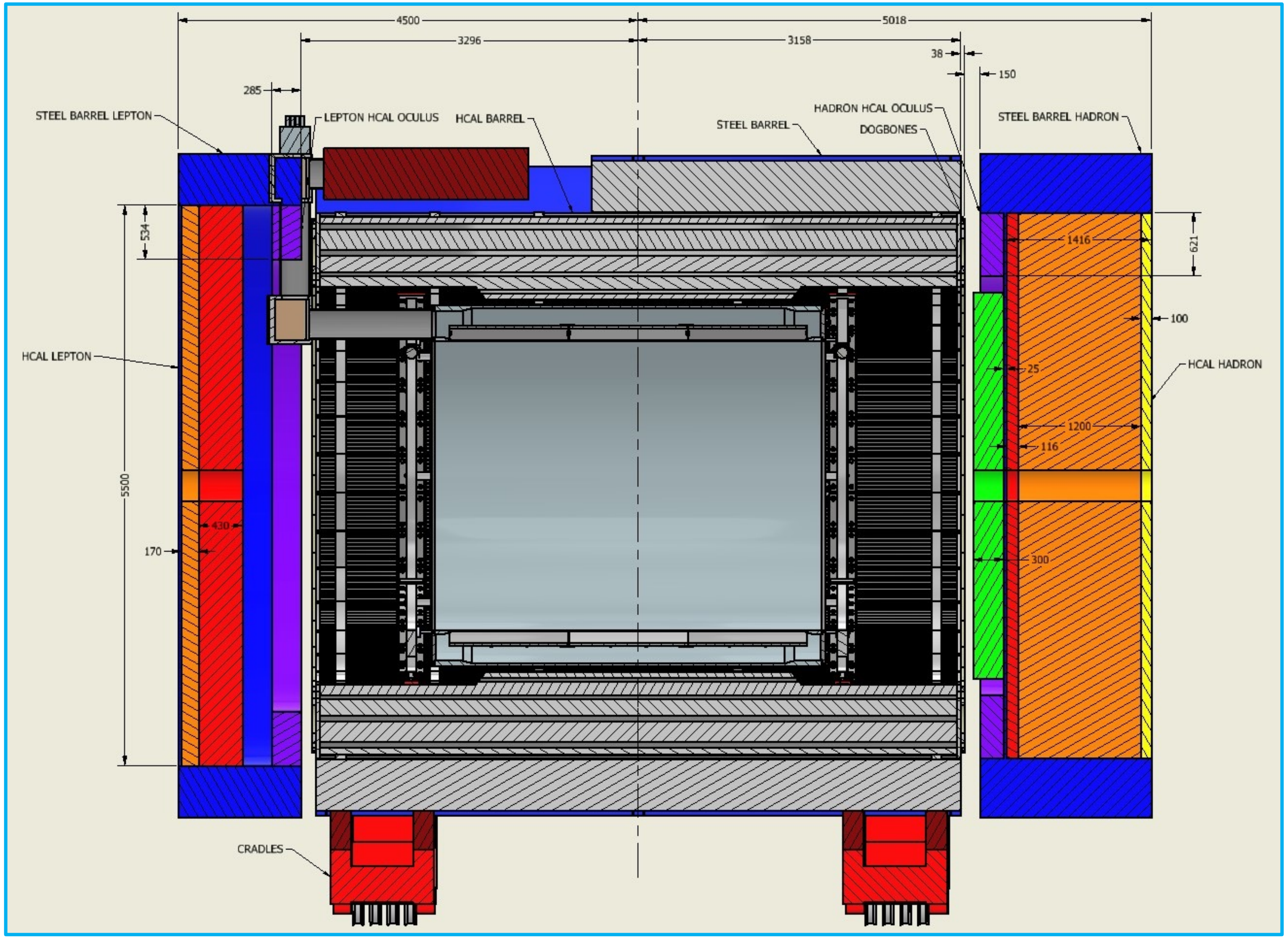
HSR: Hadron Storage Ring
ESR: Electron Storage Ring
RCS: Rapid Cycling Synchrotron
SC: Superconducting

And *lots* of work remains.

ePIC - A global pursuit for a new EIC experiment at IP6 at BNL



A new magnet for the central instrument:



One of *the* most important decisions for any collider experiment…

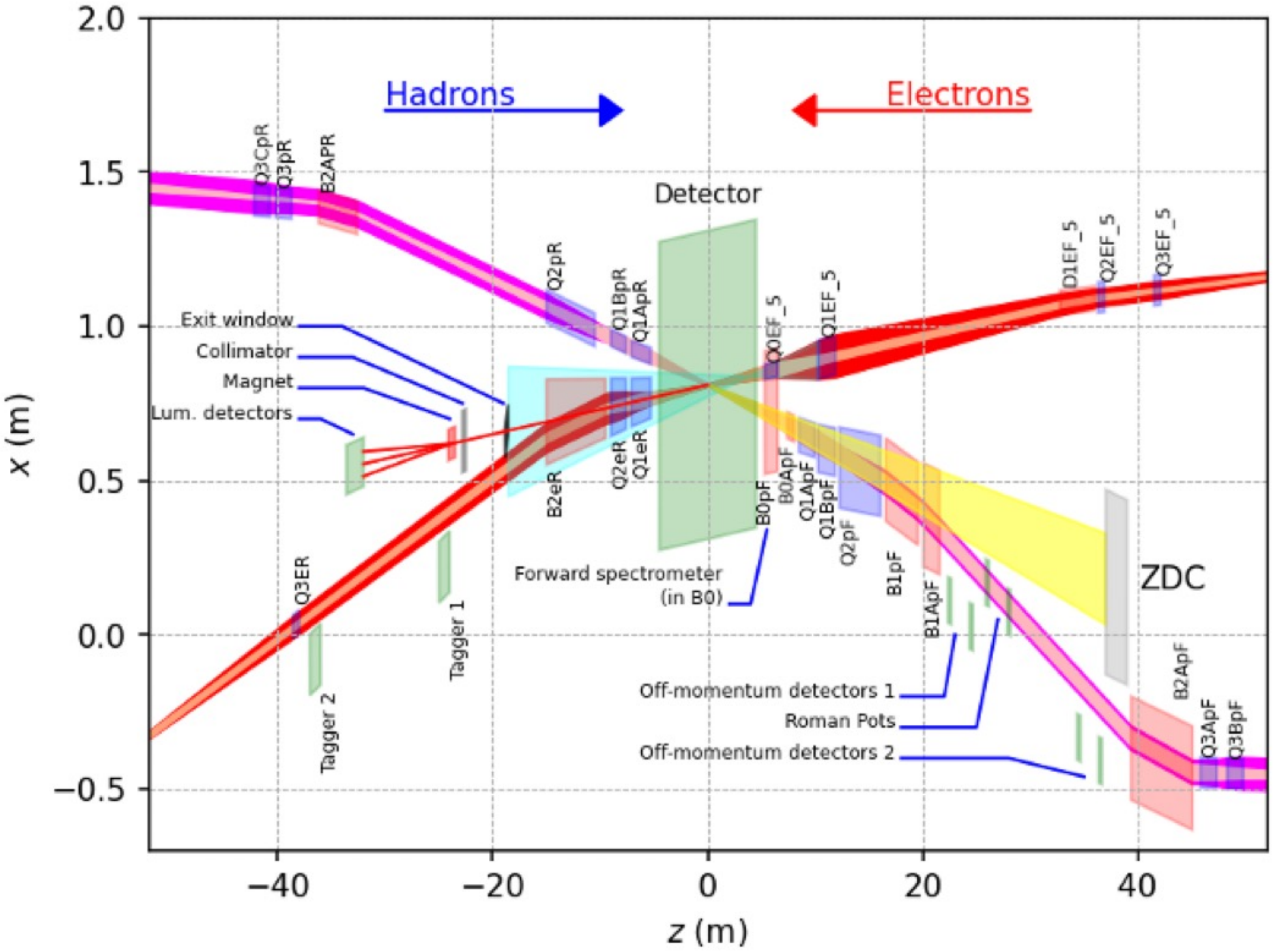
1.7 T solenoidal field strength

BaBar geometry

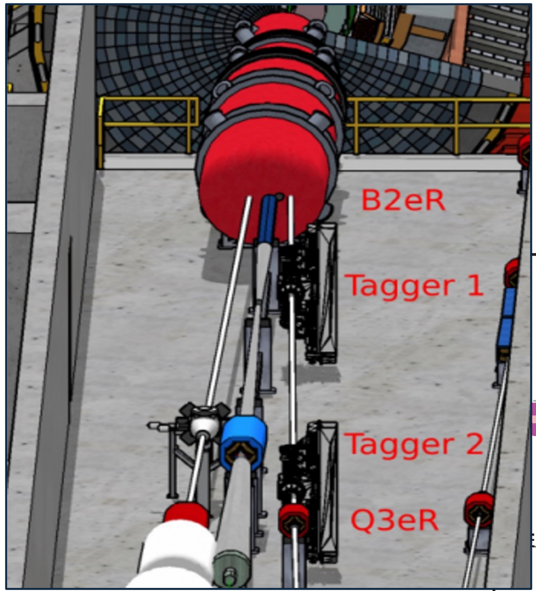
Coupled system; returns, service gaps, etc.

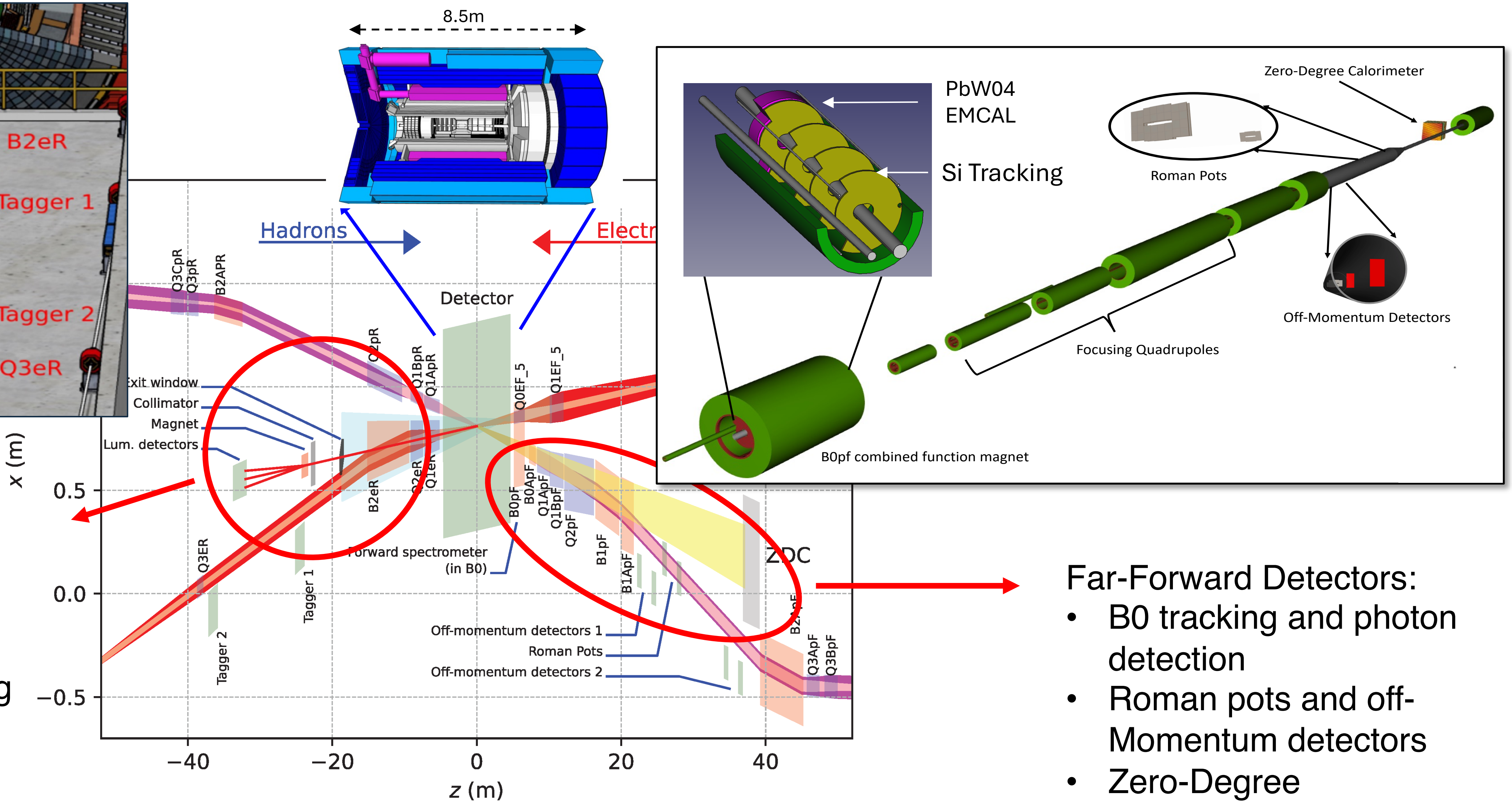
Courtesy R. Rajput-Ghoshal

Interaction region:



Instrumenting the Interaction Region:





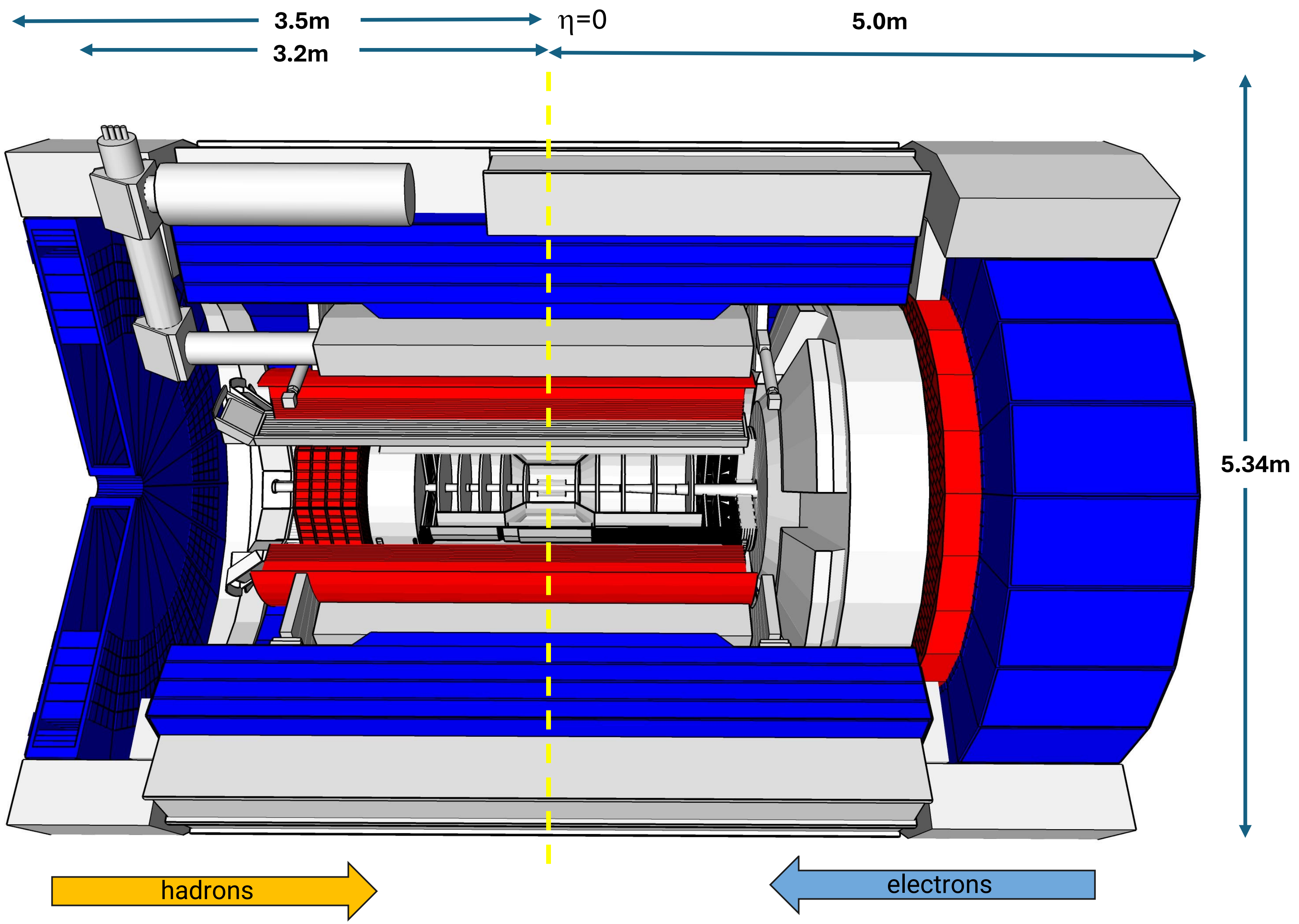
Far-Backward Detectors:

- Luminosity monitor
- Low-Q^2 tagging detectors

Far-Forward Detectors:

- B0 tracking and photon detection
- Roman pots and off-Momentum detectors
- Zero-Degree Calorimeter

Central Detector:



Tracking:

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

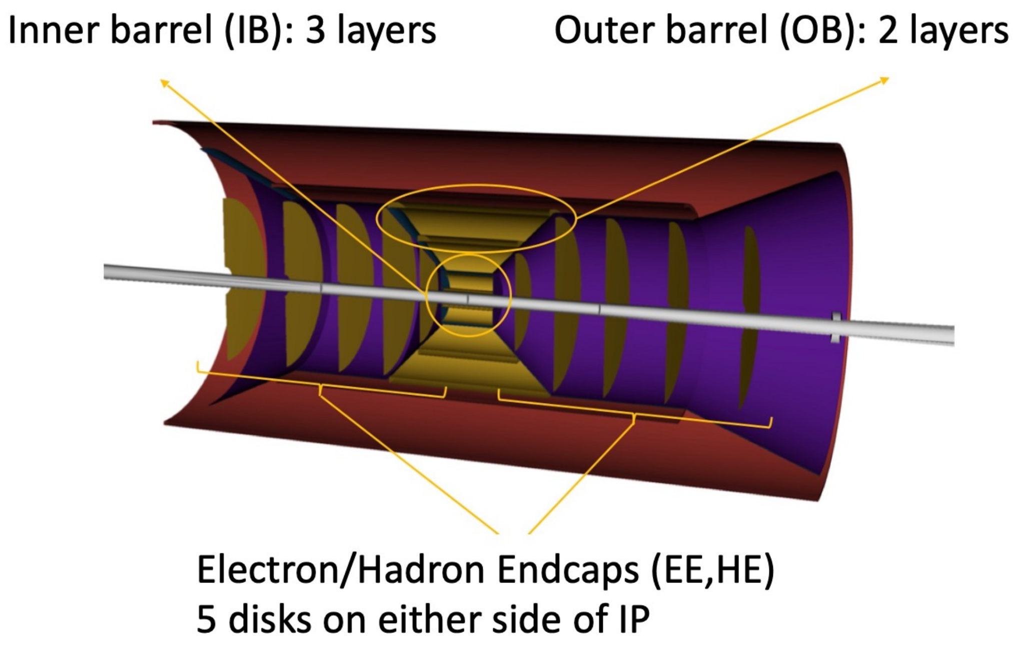
PID:

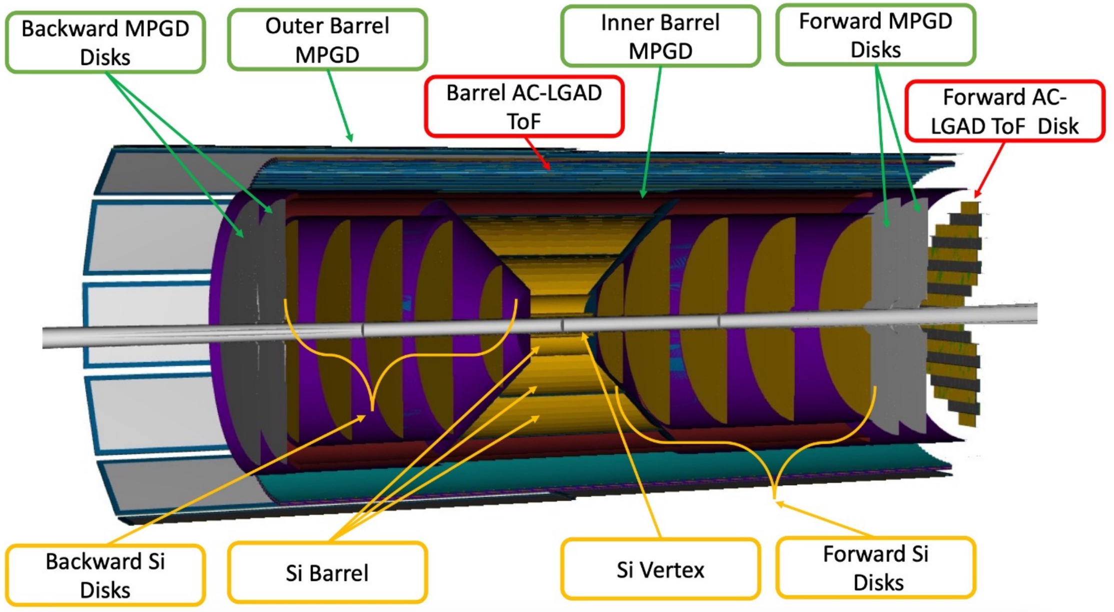
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps ToF)

Calorimetry:

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

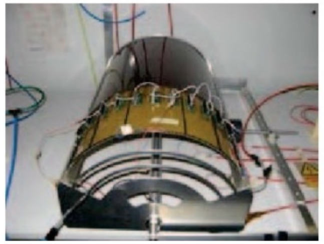
Central Detector – tracking:



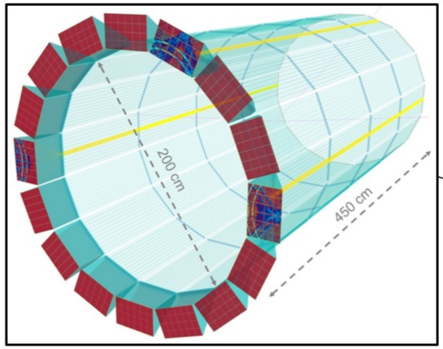


- one technology: MAPS @ 65 nm (ALICE ITS3)
- IB: First layer @ R ~ 3.6 cm - Material: 0.05% X/X_0 / layer
- OB: Material: 0.55% X/X_0 / layer
- EE/EH Material: 0.24% X/X_0 / layer
- pixel size O(10x10 μm^2)
- Total area 8.5 m^2

- additional hit points for track reconstruction (~150 μm)
- fast timing hits for background rejection (~10-20 ns)
- provide hit point over large angular range for PID
- new ASIC SALSA for readout (derived from ALICE SAMPA for TPC



Central Detector – particle identification:

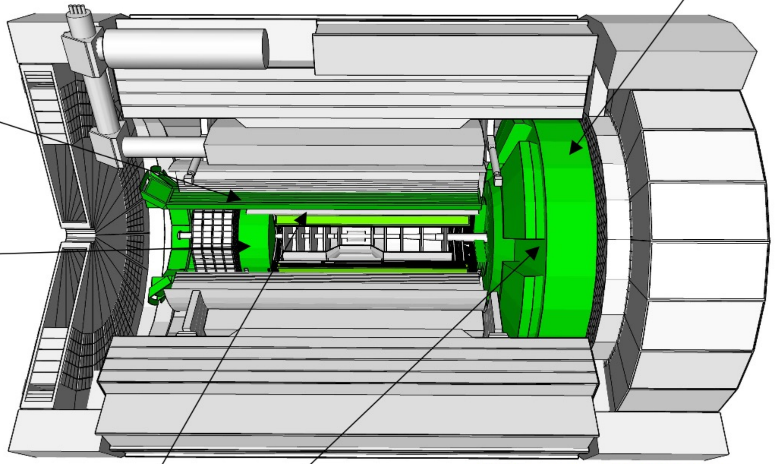


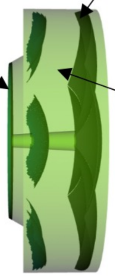
hpDIRC (High Performance DIRC)
- Quartz bar radiator → Reuse of BaBAR DIRC bars
- photosensor: MCP-PMTs
- p/K 3s sep. at 6 GeV/c

dual radiator Forward RICH: dRICH

Aerogel z: 4cm
radius: 110 cm
0.3 mm acrylic filter

Spherical Mirrors
6 Azimuthal Sectors

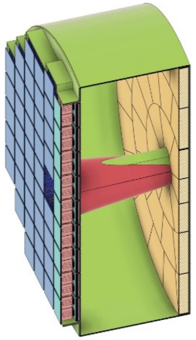




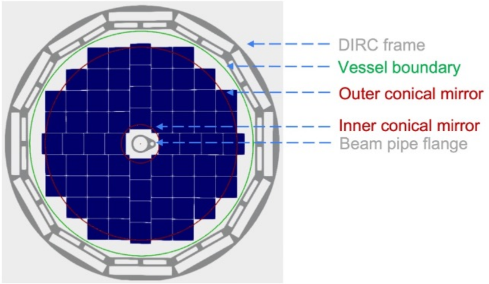
C_2F_6 Gas Volume
120 cm length
radius: 185 cm

Photosensor: **SiPMs**

Backward RICH: pfRICH
- Aerogel Cherenkov Det.
- e, π, K, p separation → π/K 3σ sep. at 10 GeV/c
- Photosensor:: **HRPPDs** to include TOF
- RICH with long proximity gap (~30 cm)

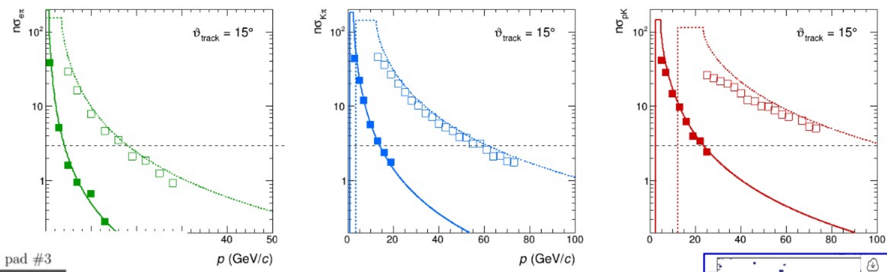


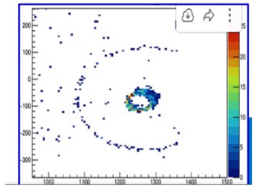
Sensor plane tiling scheme



π/K 3σ sep. at 50 GeV/c–

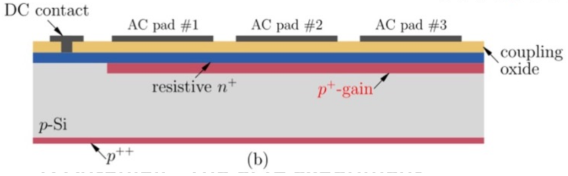
dRICH sim.



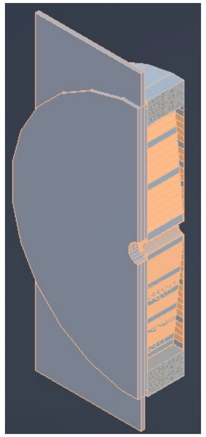


TOF

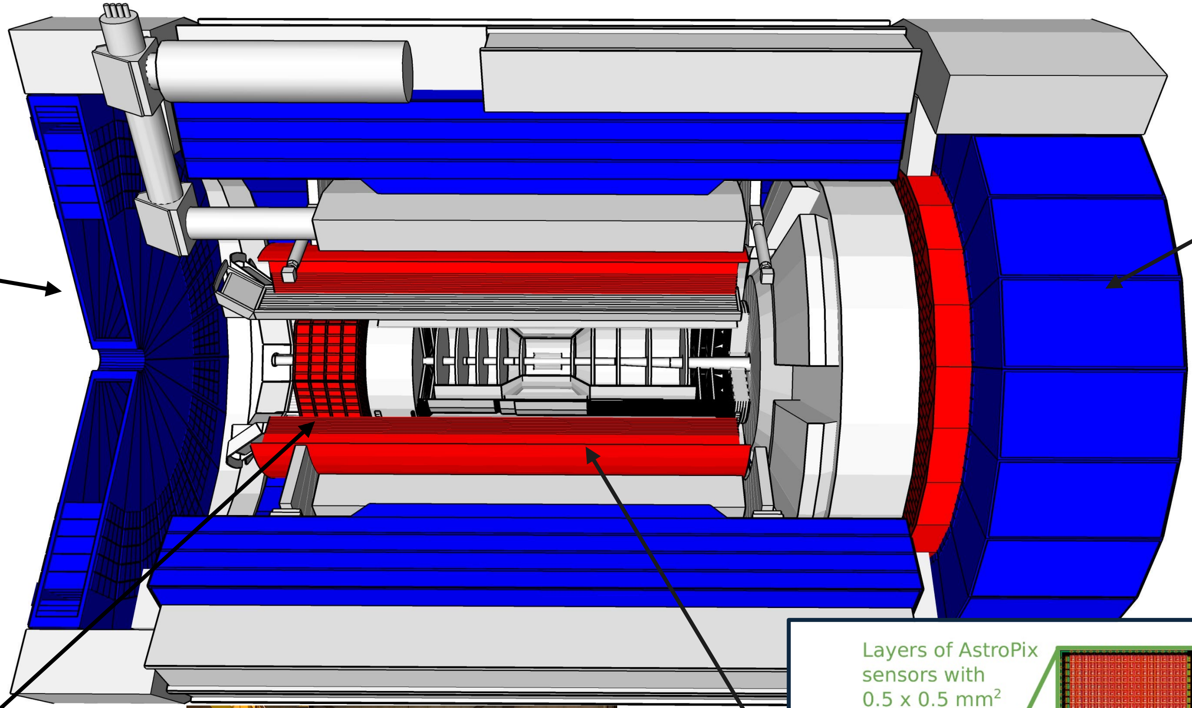
AC-LGAD (Low Gain Avalanche Detector)
- 20-35 psec / σ=30 μm
- Accurate space point for tracking
- forward disk and central barrel

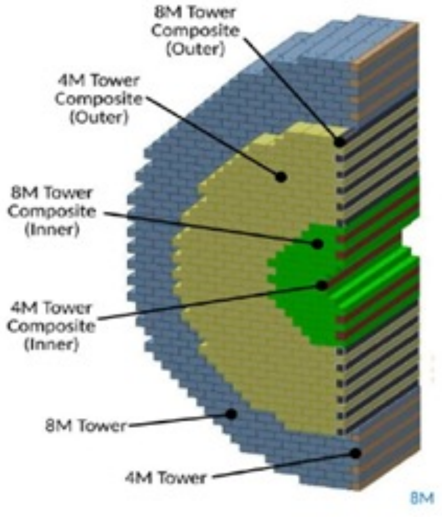


Central Detector – calorimetry:

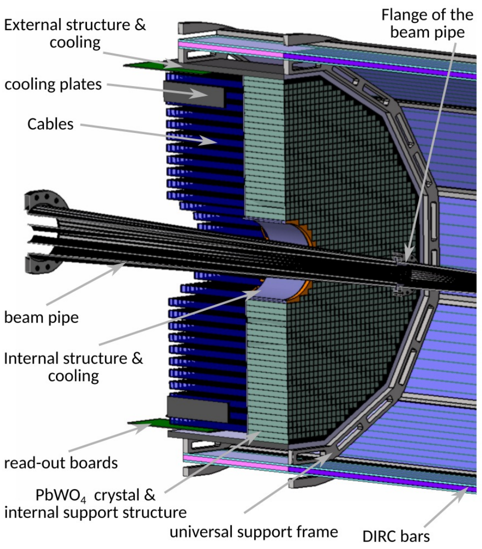


Backwards HCal Steel/Sc Sandwich tail catcher



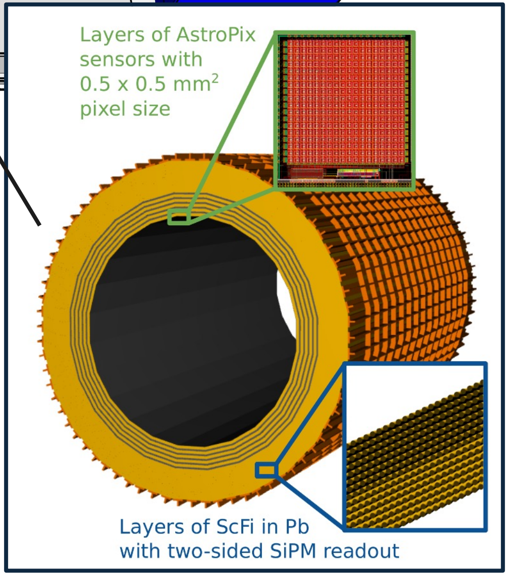


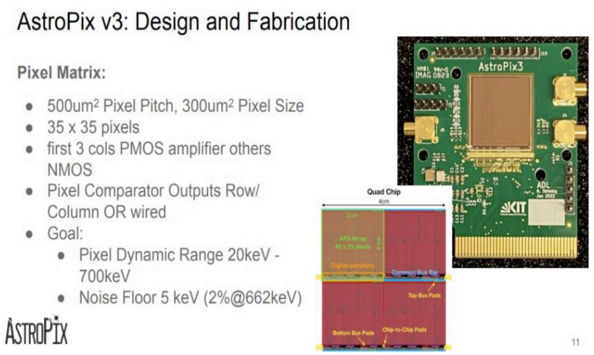
High granularity W/SciFi EMCal Longitudinally separated HCAL with high-η insert



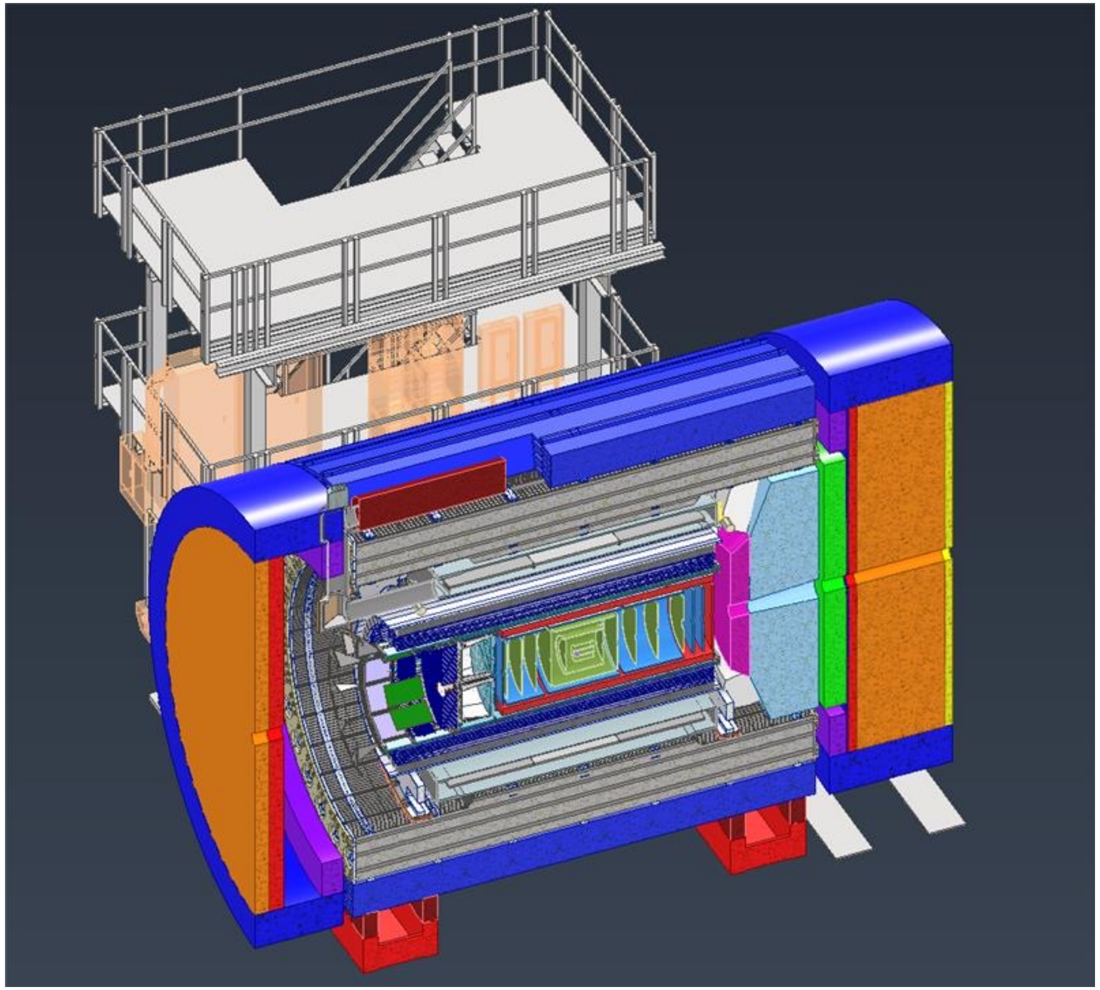
Backwards EMCal PbW04 crystals, SiPM photosensor

Barrel HCAL (sPHENIX re-use)

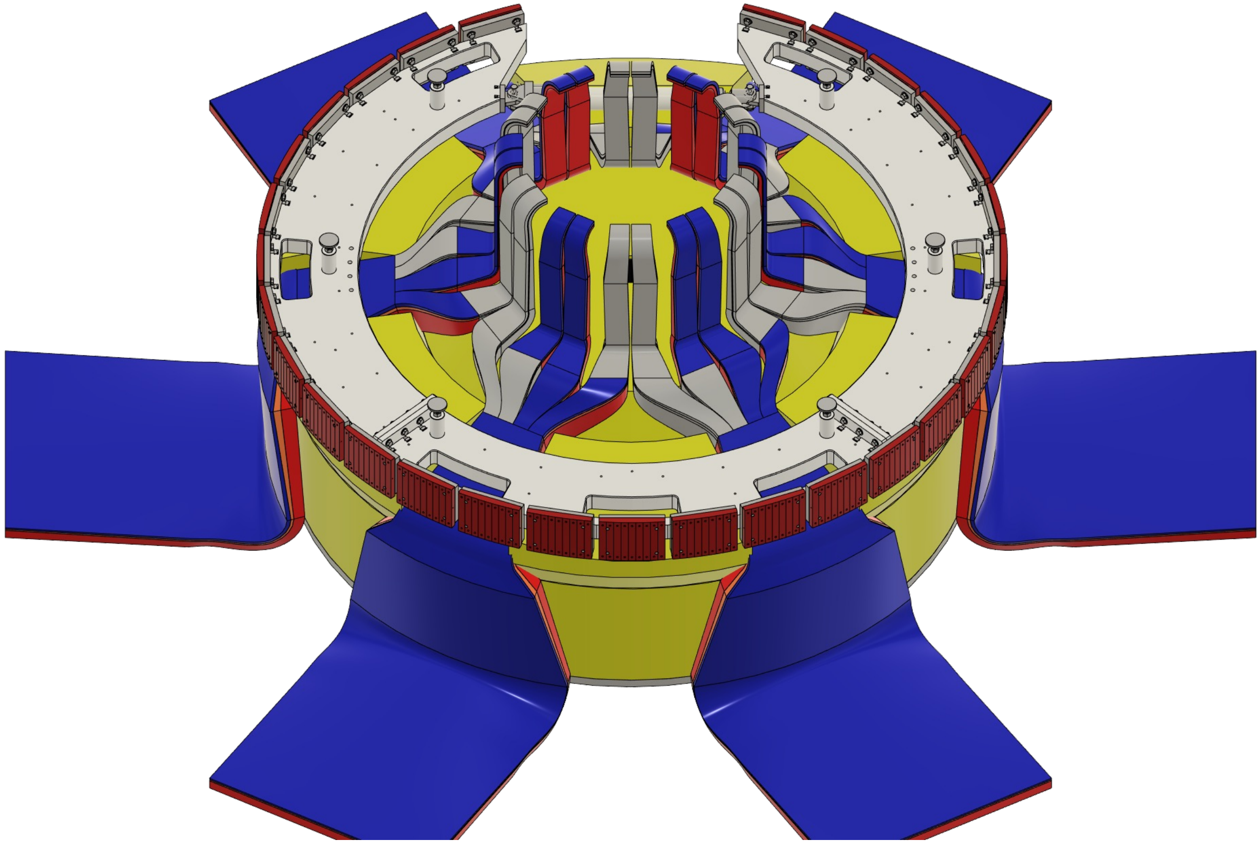




Central Detector – integration:

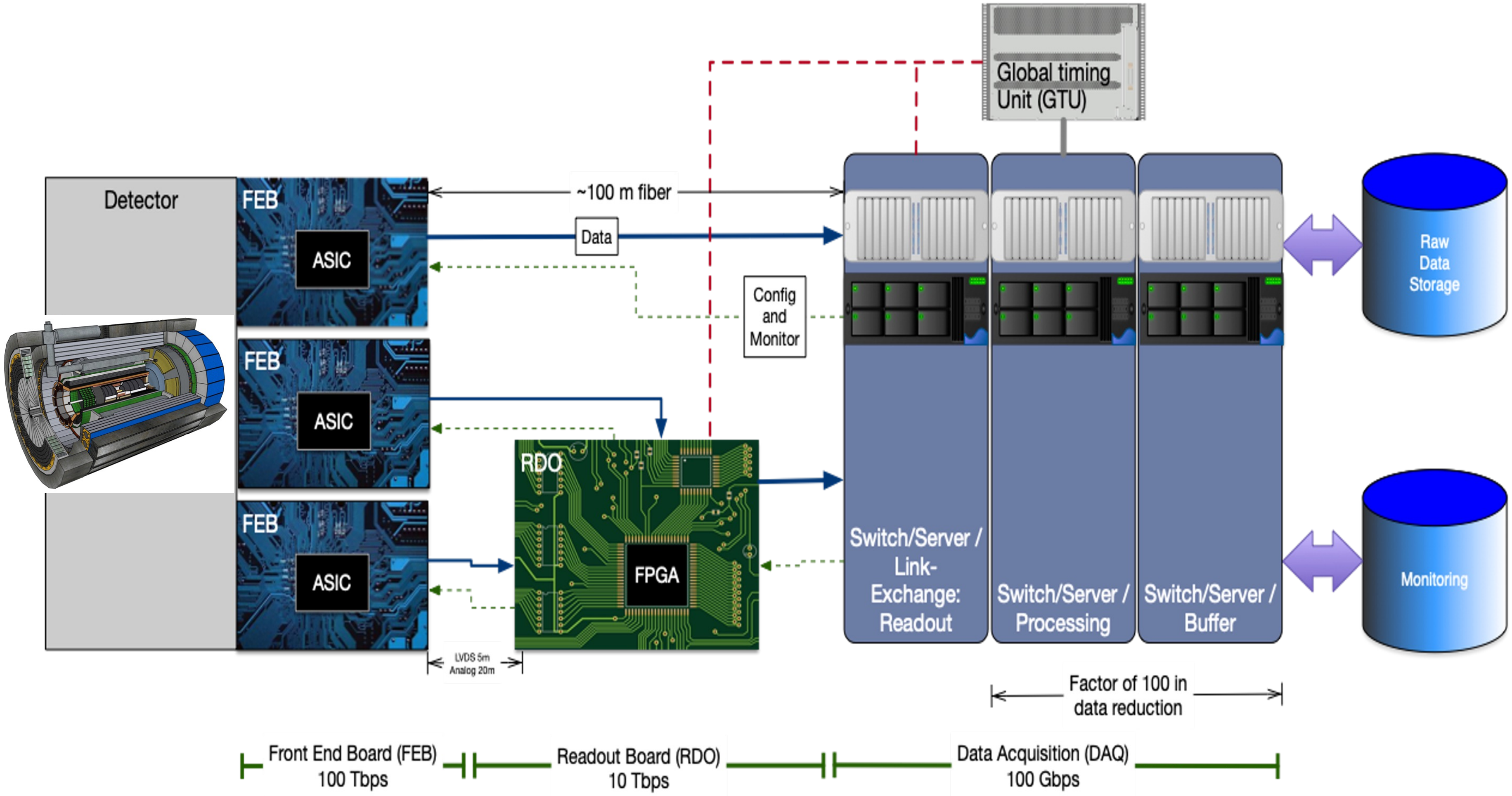


dRICH vessel, end rings, and service paths, as just one example of integration puzzles:



Streaming Readout and DAQ:

Bunch Crossings every ~10 ns or ~100 MHz
Collision Rate ~ 2 us or 500 kHz



- No external trigger,
- Avoids complex custom hardware and firmware associated with traditional triggered systems,
- All collision data digitized,
- Data volume is reduced as much as possible early on,
- Low-to-no dead-time
- Event selection can be based on data from all subsystems in real-time or after-the-fact.

And the software and computing model and approach to enable rapid analyses.

Closing comments

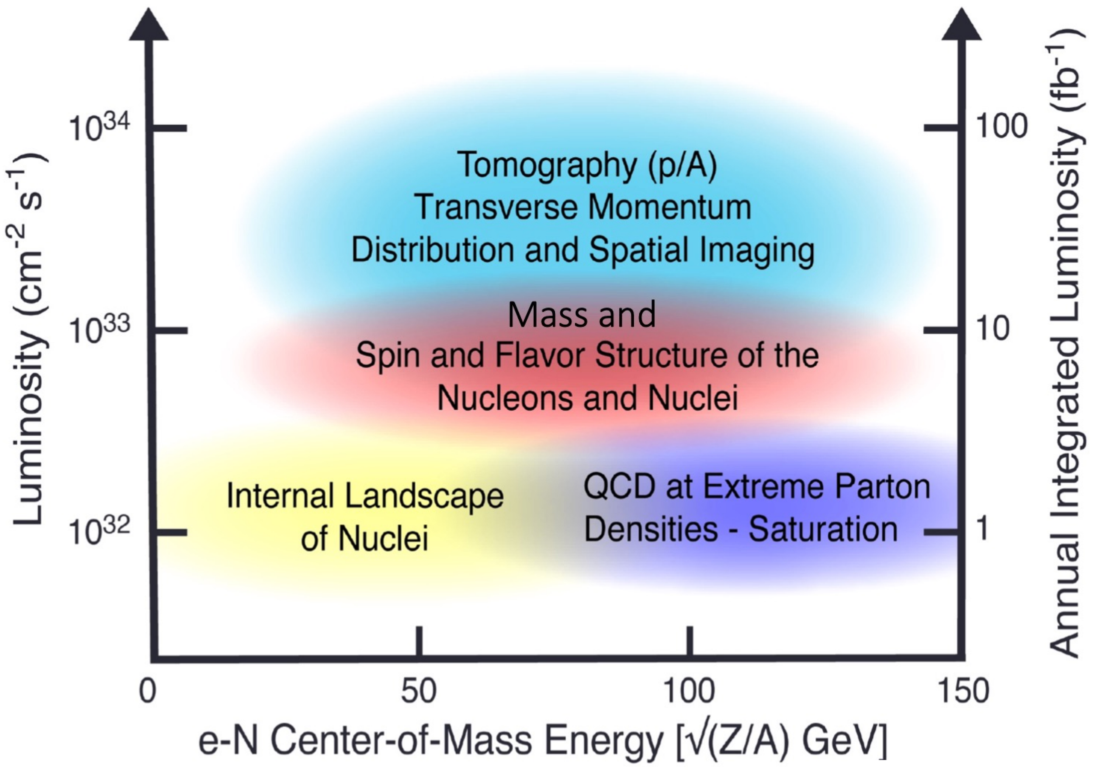
EIC project is well on track,

Project includes both collider and (one) detector,

Recent focus on long-lead-time items,

Technical Design Report is next,

~2030 is closer than it may appear…



Circling back to the workshop,

EW physics is not put usually front and center but has been part from the very beginning and continues to be so – a recent example is e.g. M. Arratia et al, PRD 103 (2021) 074023

Obvious missing detector capability: muons – https://www.jlab.org/research/eic_rd_prgm

Thank you for your attention!

And thanks to our many colleagues who are making it happen.