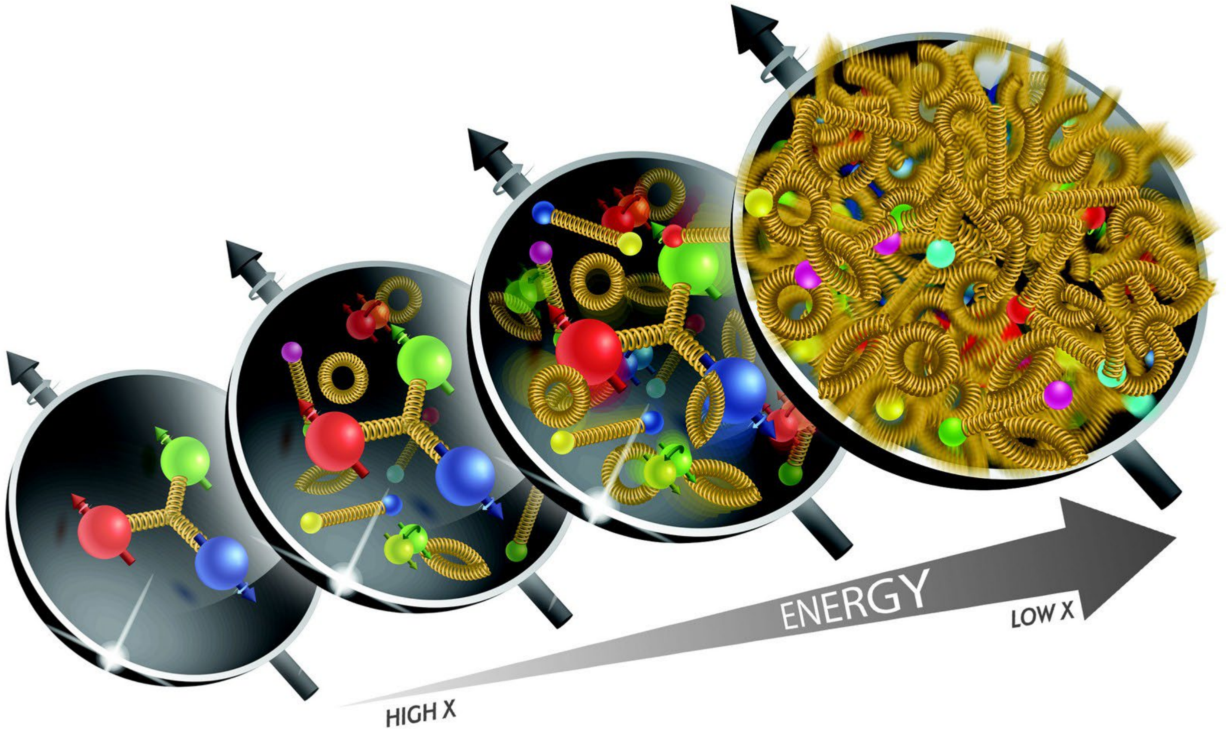
The EIC and the ePIC Detector

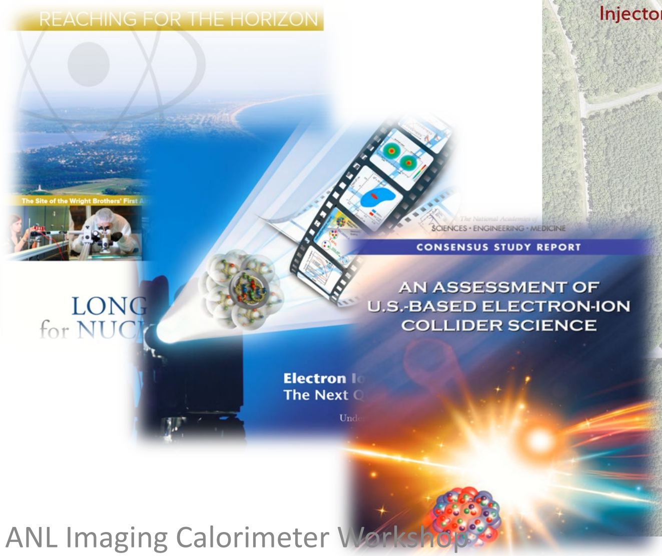
John Lajoie

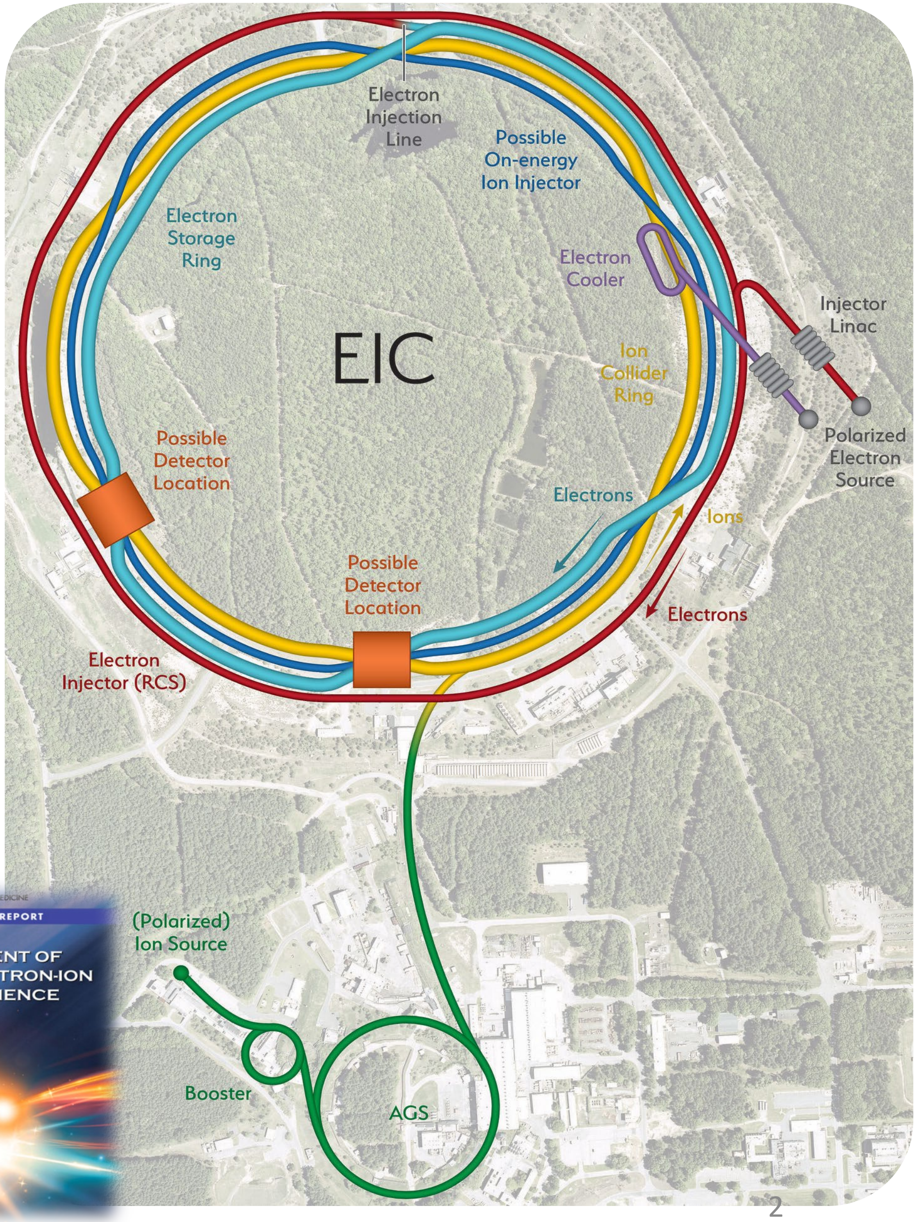


ANL Imaging Calorimeter Workshop

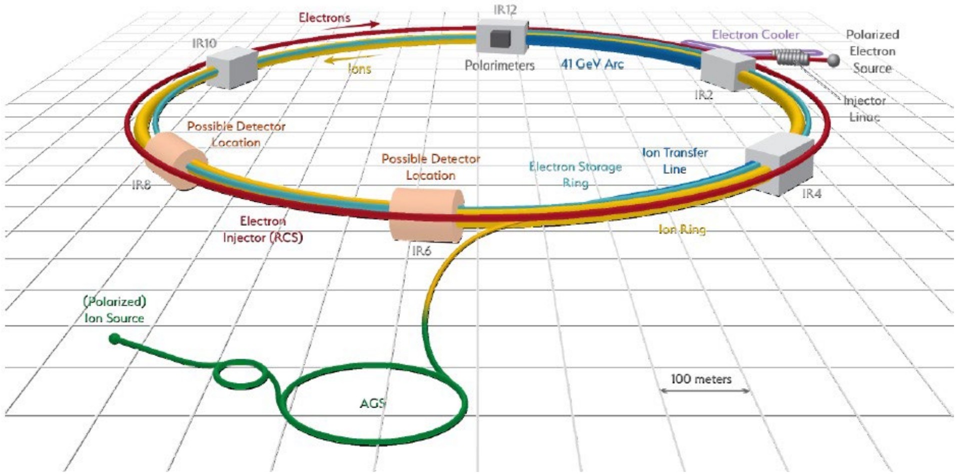
The Electron-Ion Collider (EIC)

- 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

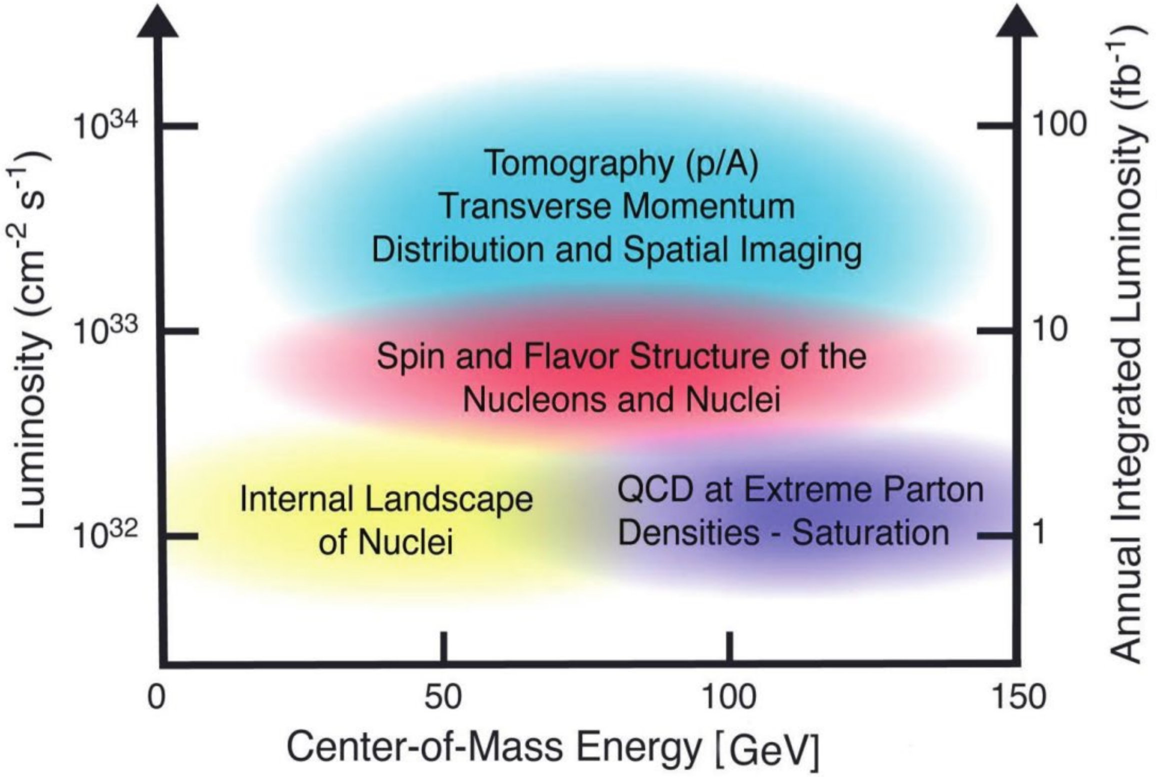




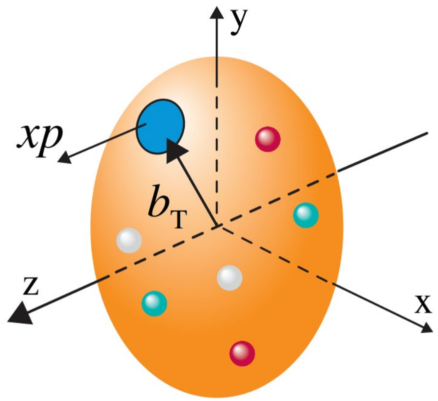
EIC Machine Parameters



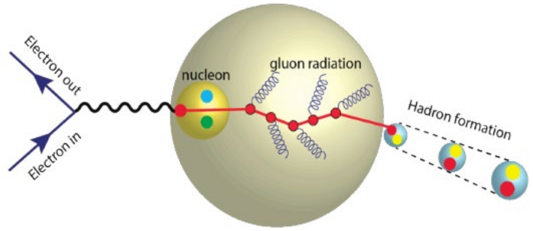
- Center of mass energy: 20 – 140 GeV
  - Electrons: 2.5 – 18 GeV
  - Protons: 40 – 275 GeV (ions: Z/A x E_{proton})
- Luminosity: 10^{34} /cm^2/sec
- Polarization: <70% (both electron and ion)
- Ion Species: proton - Uranium
- Detectors: up to 2 interaction regions with (almost) complete coverage

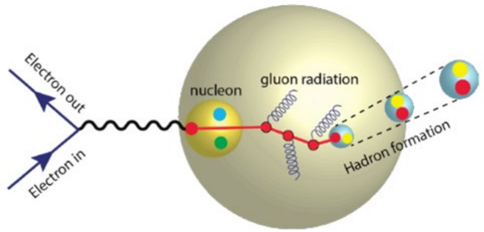


The EIC Science Mission

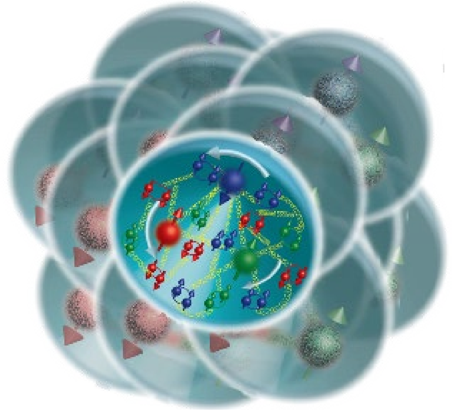


- How do the **nucleon properties like mass and spin emerge** from quarks and their interactions?
- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?





- 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?

Studying Internal Structure

Scattering of protons on protons is like colliding Swiss watches to find out how they are built.

R. Feynman

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p+p/p+A/A+A
(RHIC/LHC)

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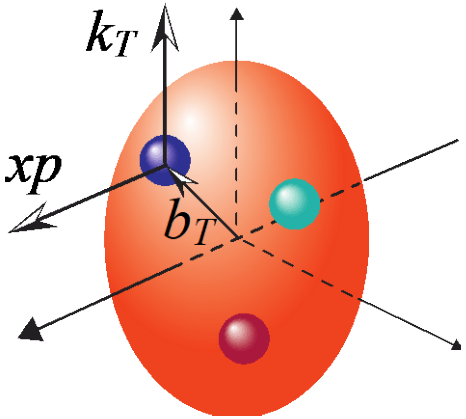
p+p/p+A/A+A (RHIC/LHC)

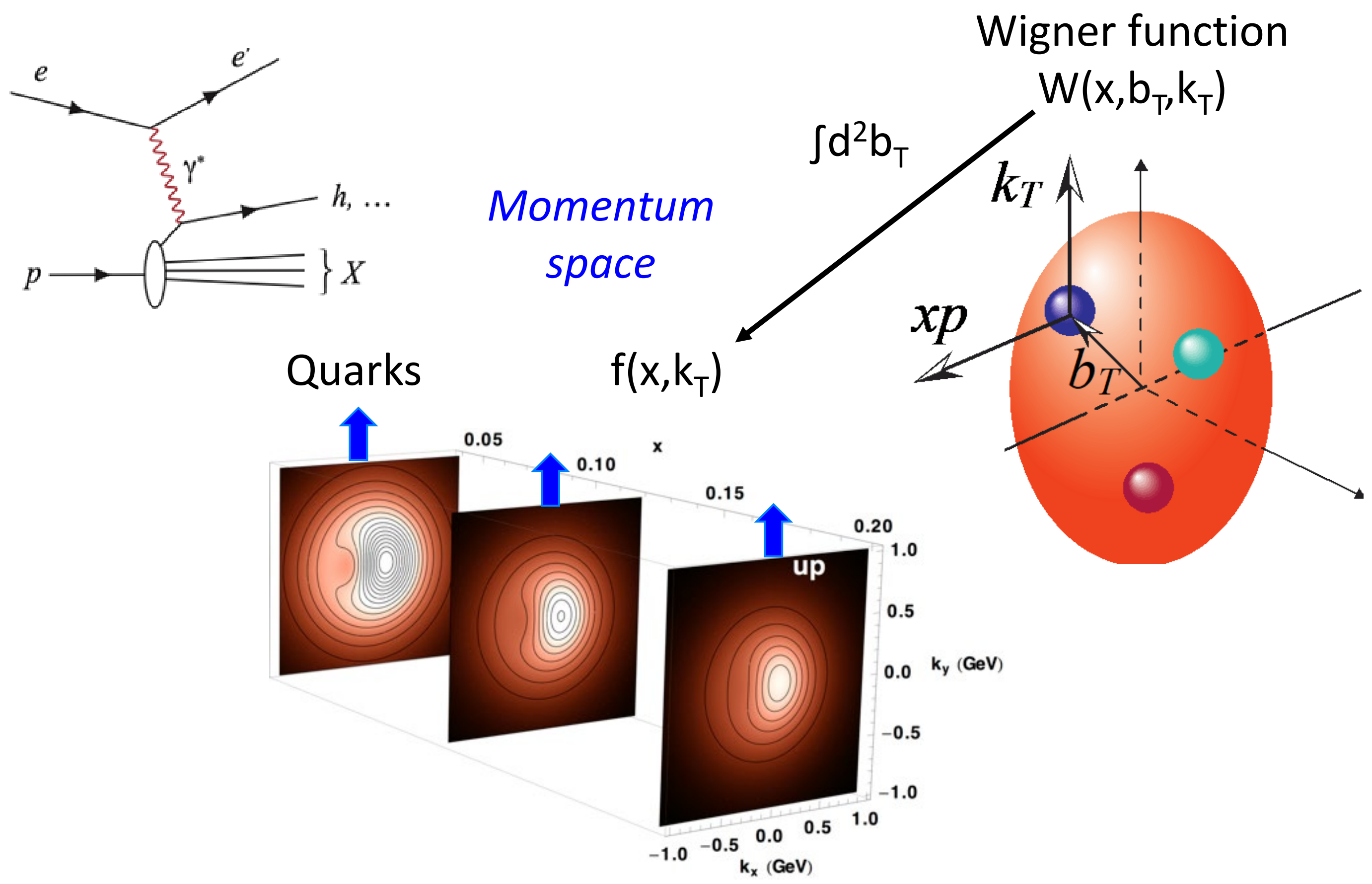
Inclusive/Semi-Inclusive DIS

Multidimensional Imaging of Quarks

Wigner function
W(x,b_T,k_T)



Multidimensional Imaging of Quarks



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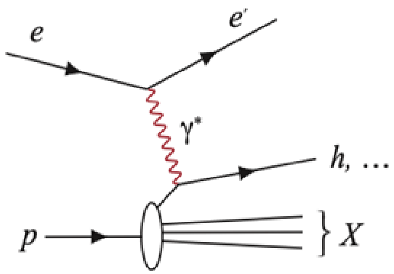
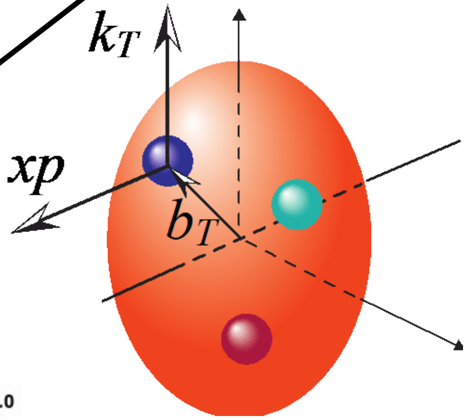


Momentum space

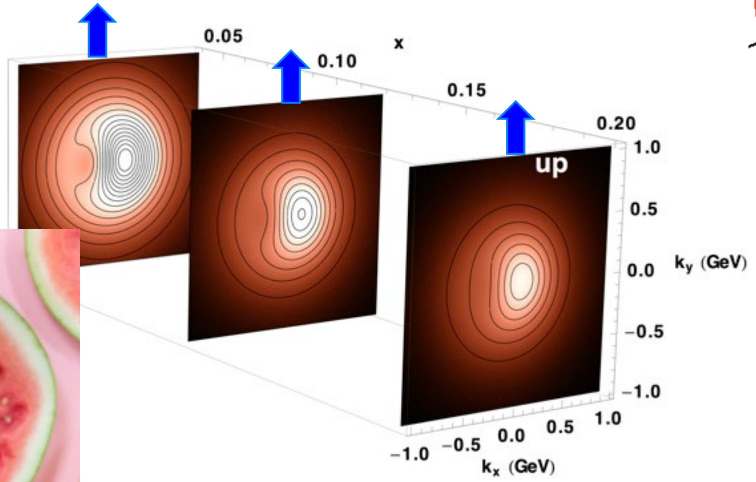
Wigner function
$W(x,b_T,k_T)$

$\int d^2b_T$

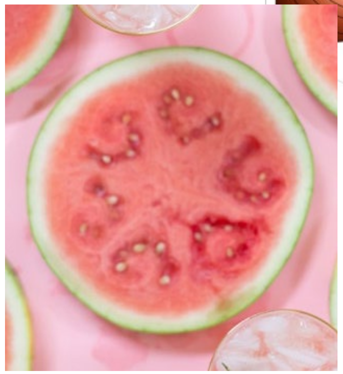


Quarks

$f(x,k_T)$



watermelon
slice



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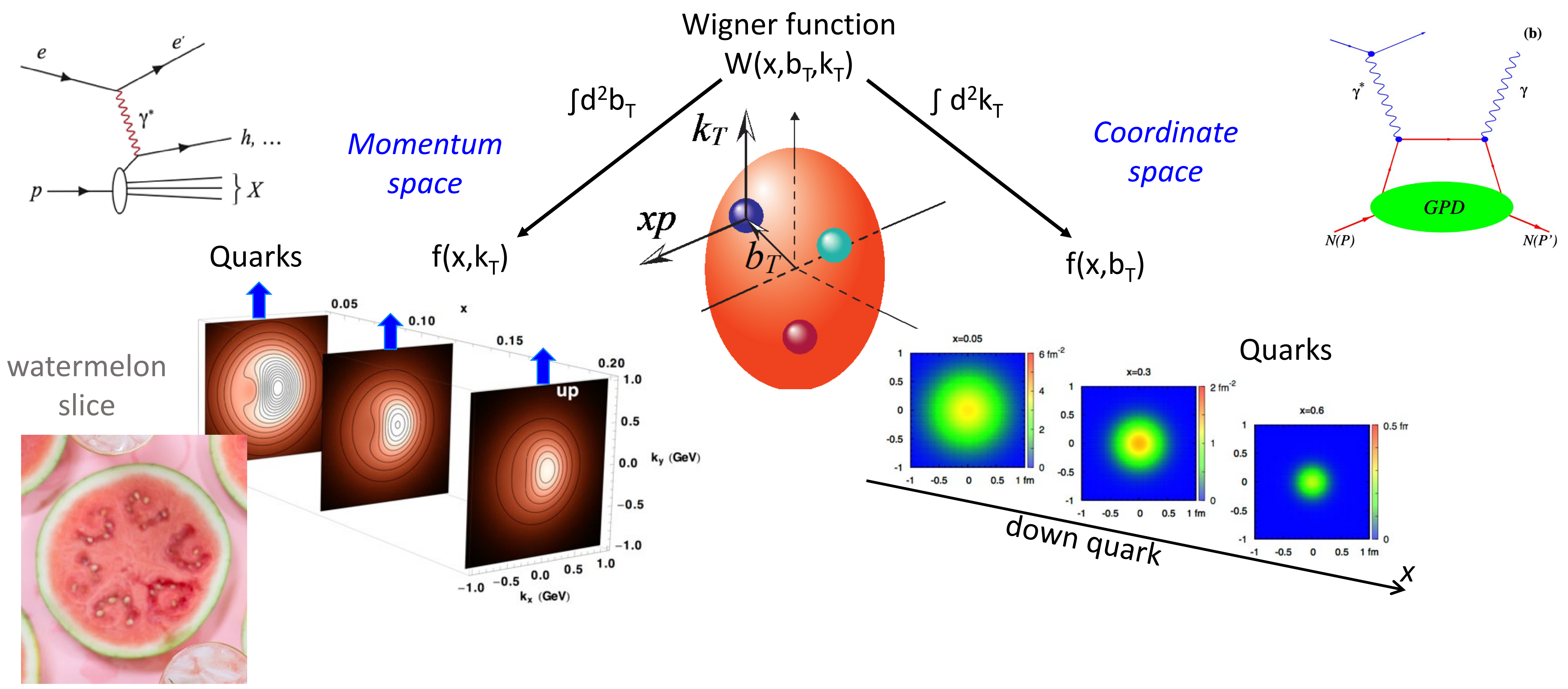
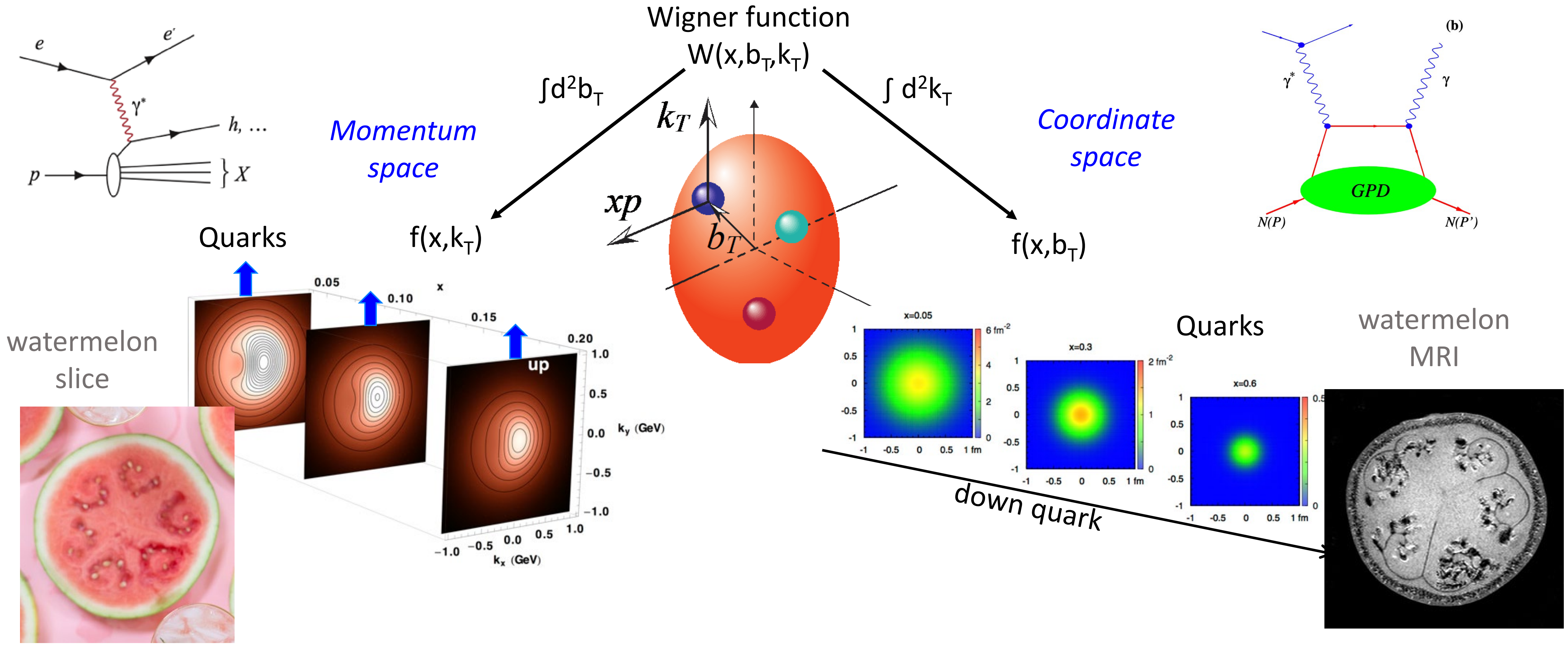
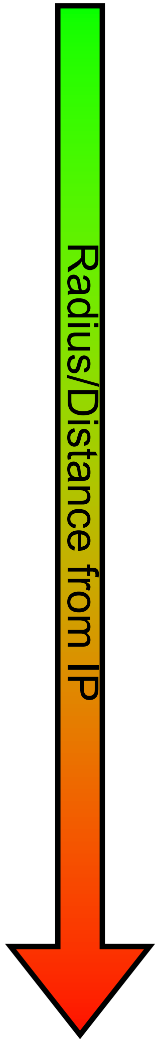


Multidimensional Imaging of Quarks



EIC Detector Requirements



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 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

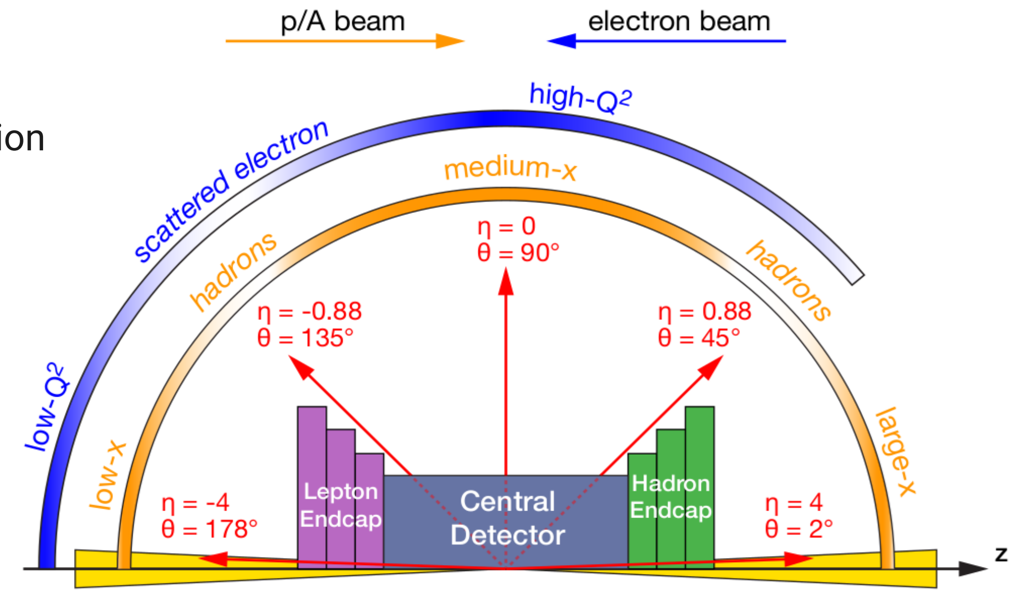
- RICH detectors (RICH, DIRC)
- Time-of-Flight high resolution timing detectors (LAPPDs, LGAD)
- Novel photon sensors: MCP-PMT / LAPPD

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

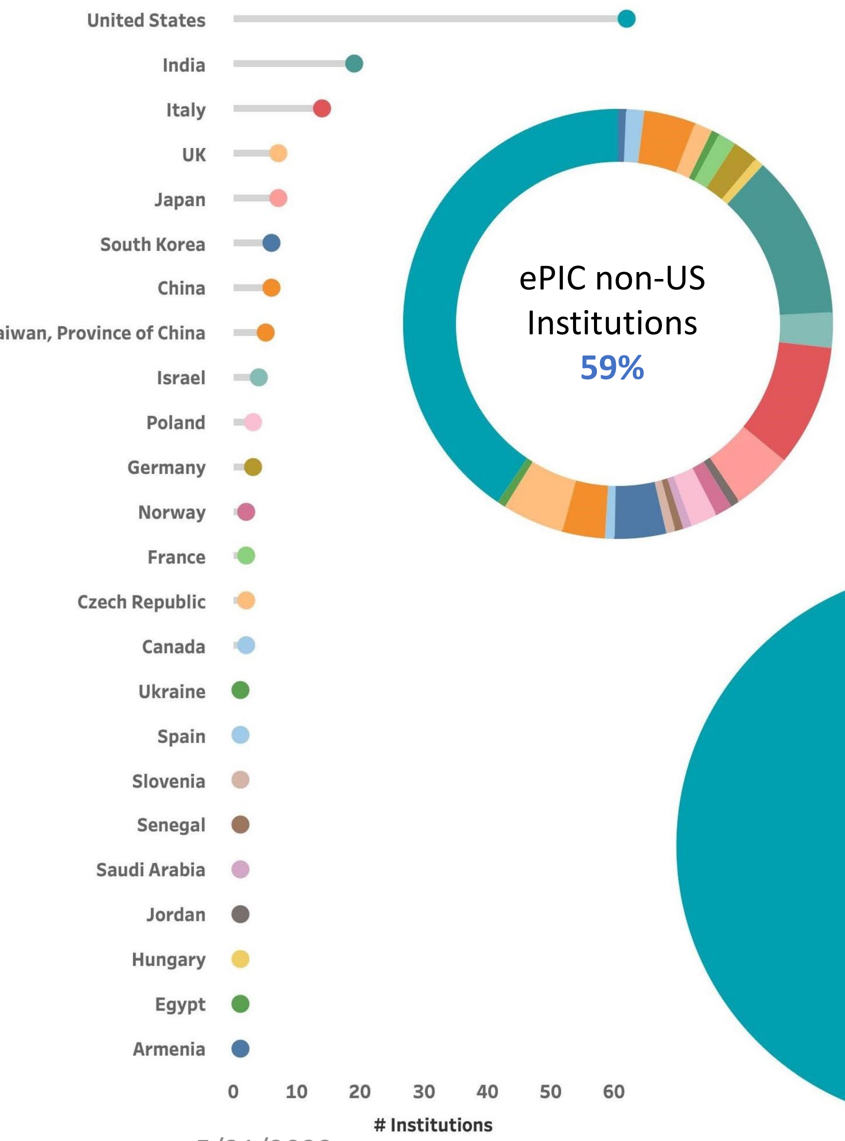


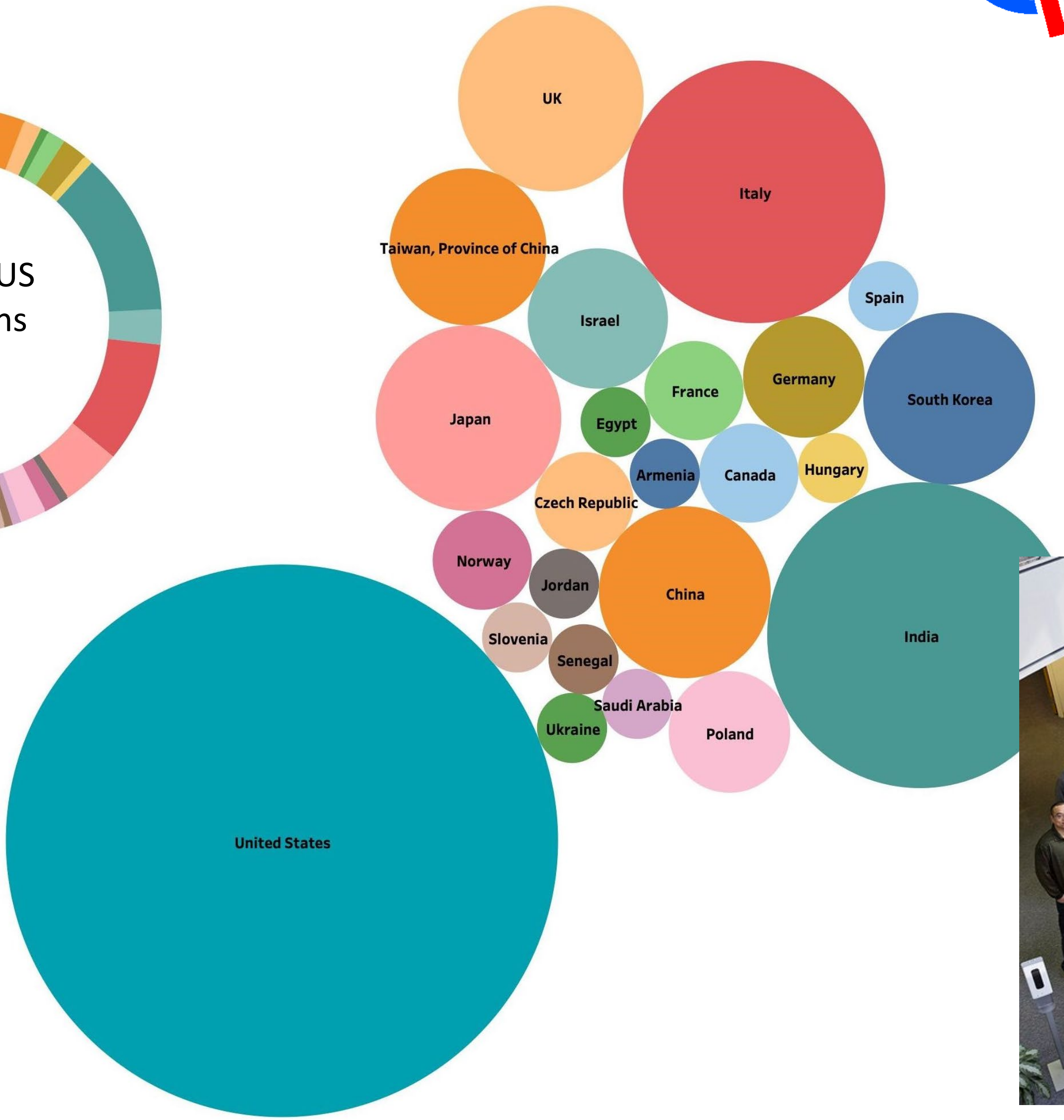
Very forward and backward detectors → Large acceptance for diffraction, tagging, neutrons from nuclear breakup

- 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 ePIC Collaboration



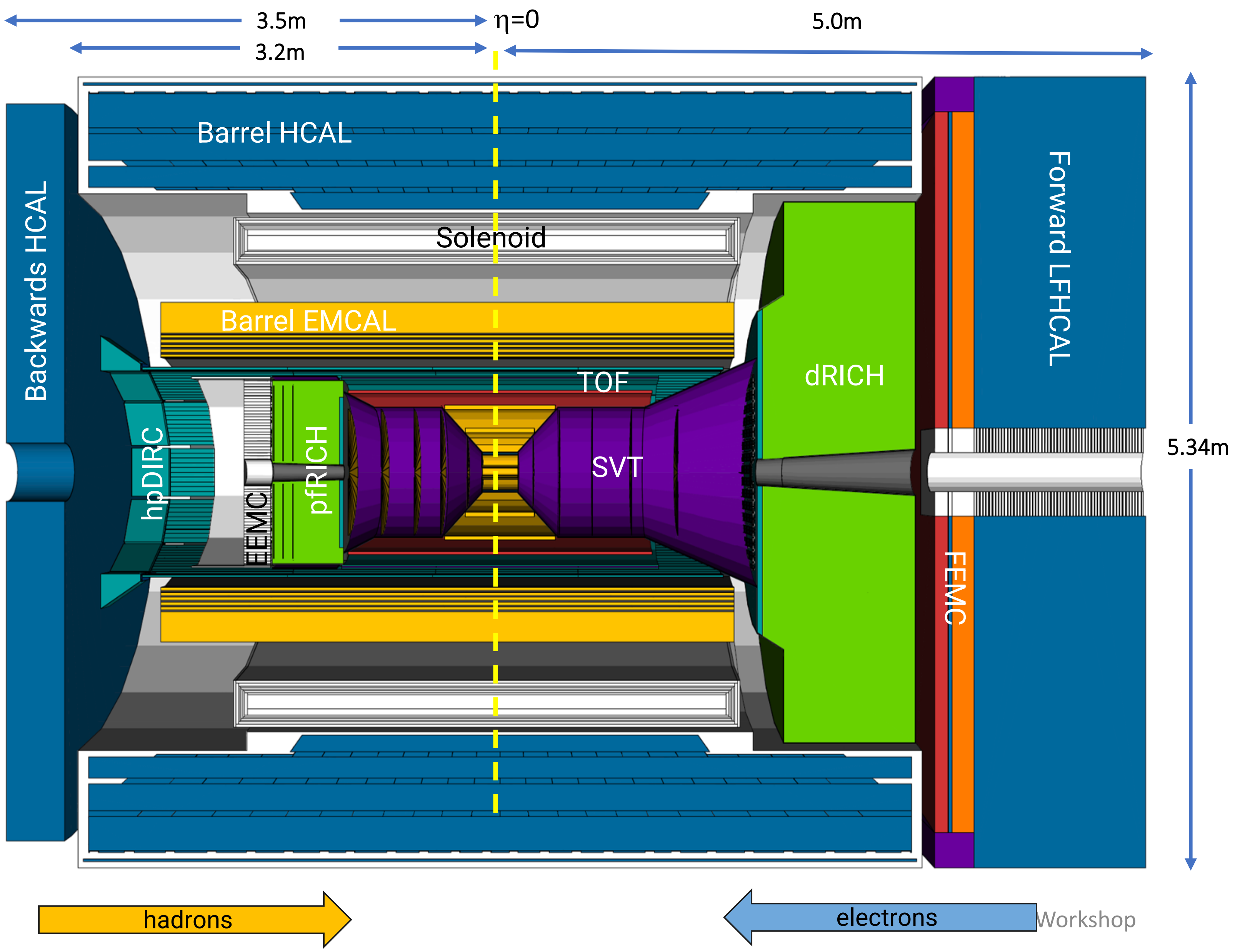


160+ institutions
24 countries

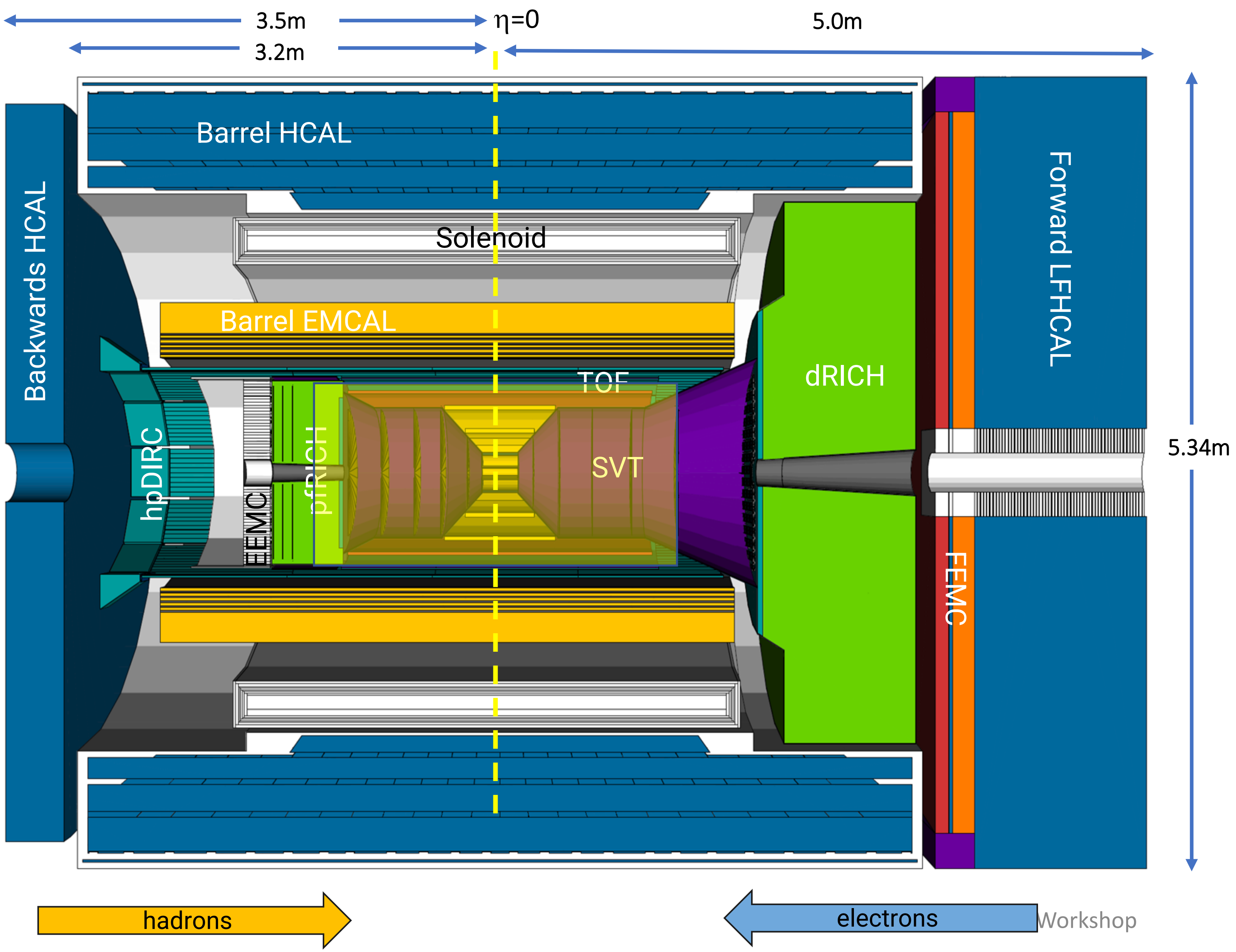
500+ participants

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

ePIC Detector Design



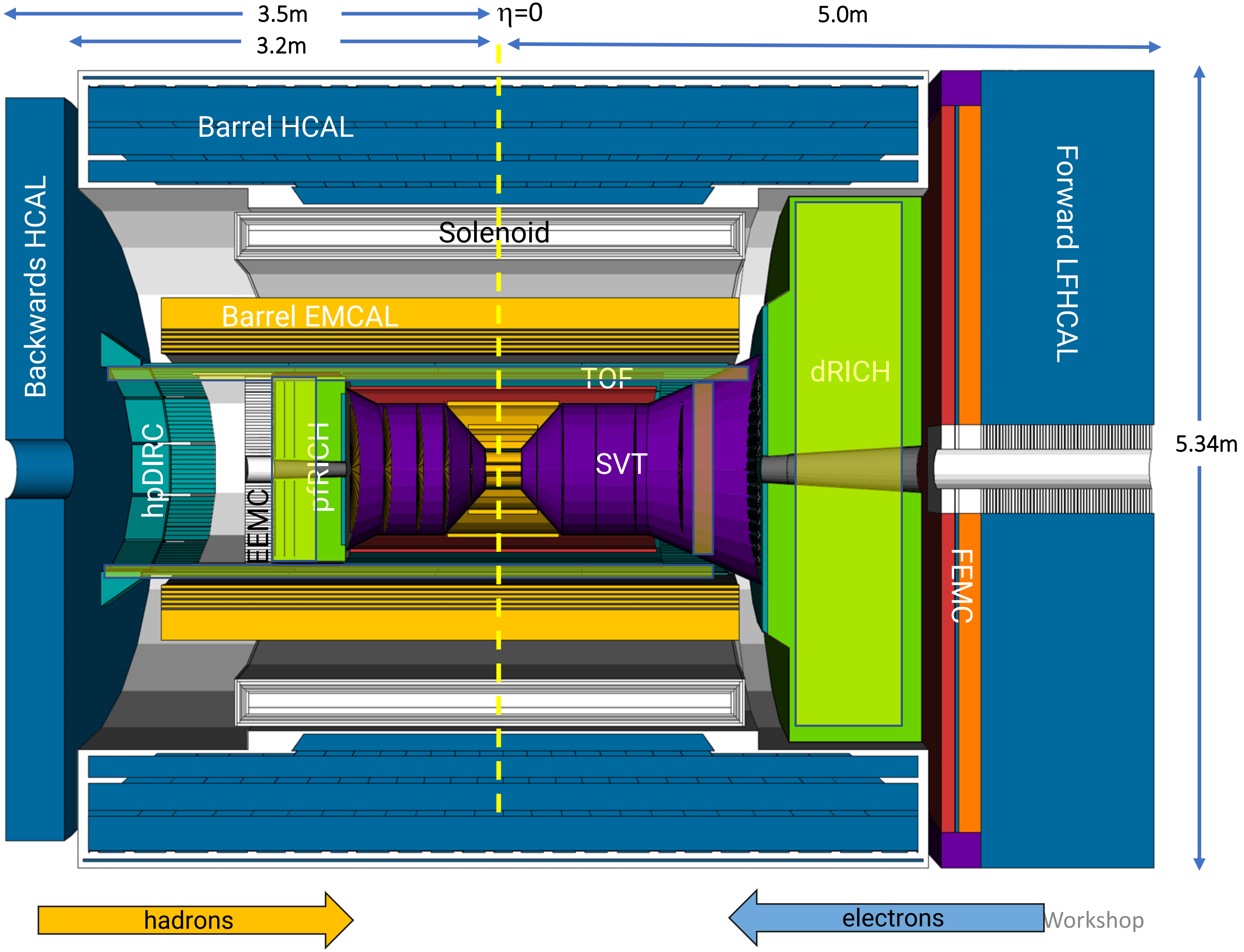
ePIC Detector Design



Tracking:

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

ePIC Detector Design



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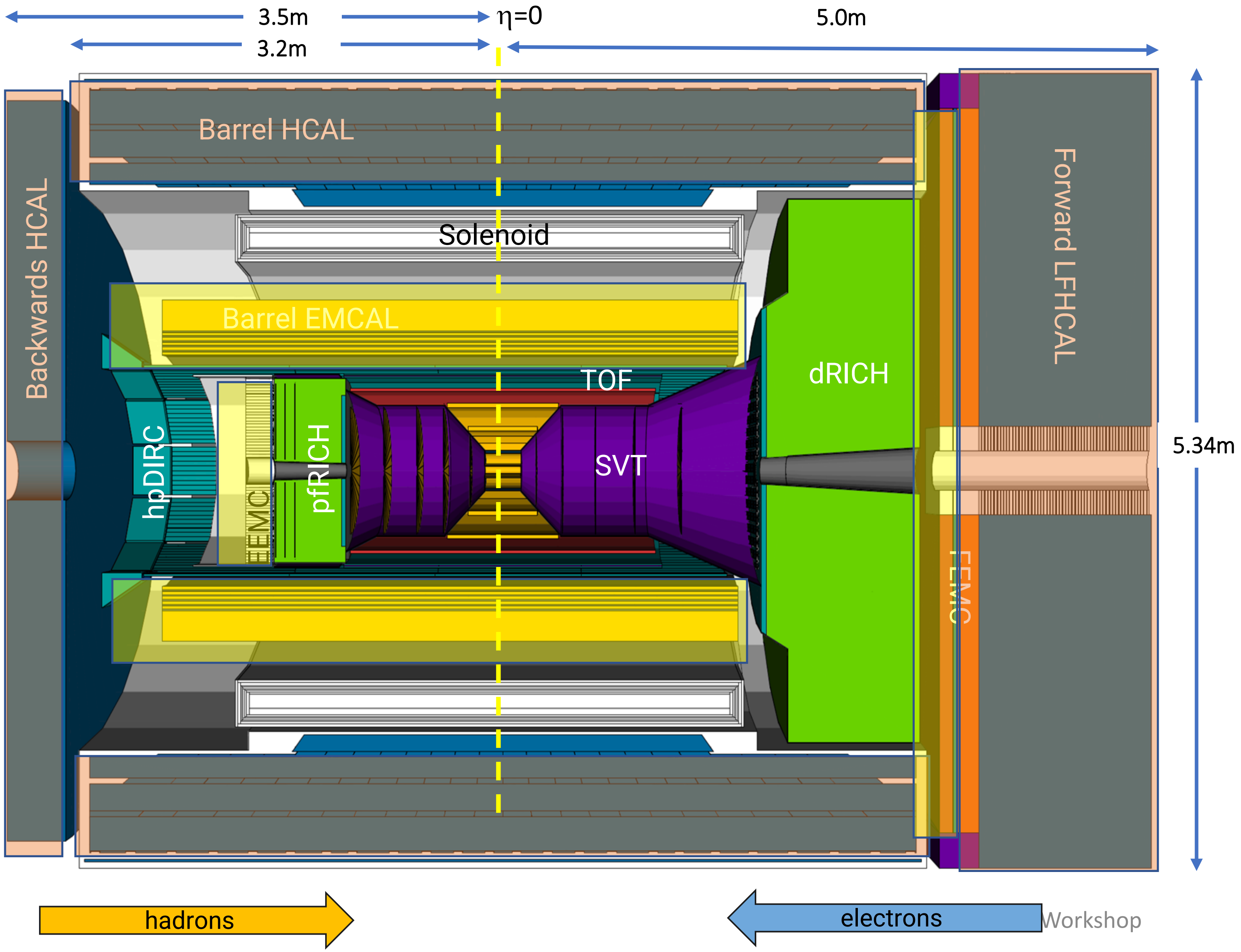
PID:

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

ePIC Detector Design



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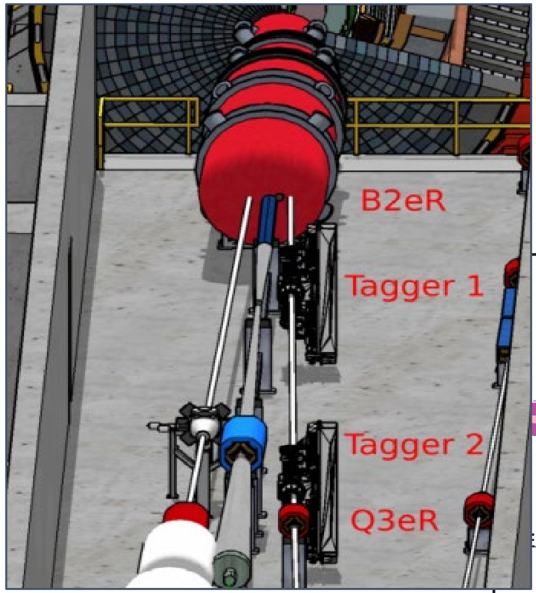
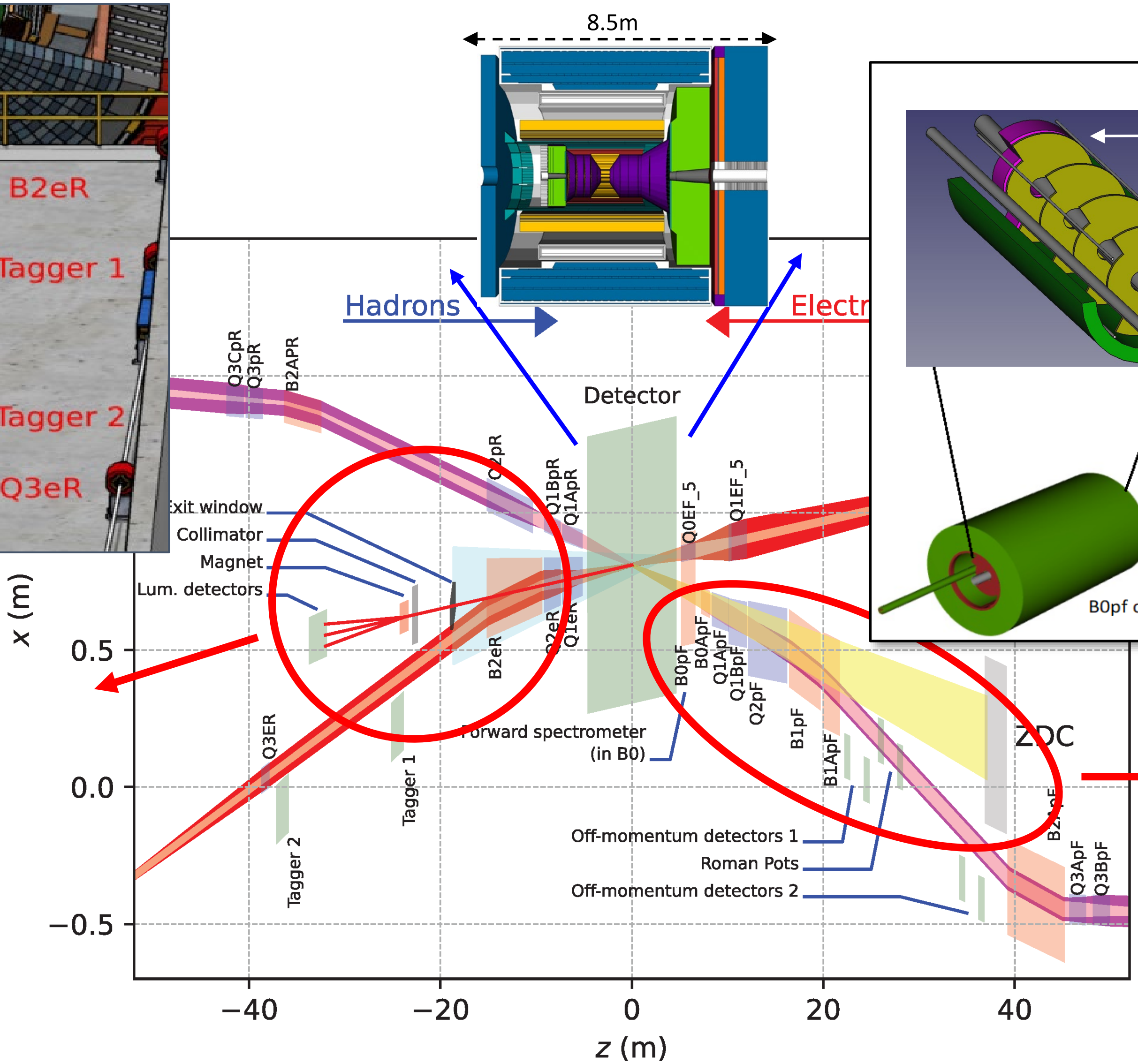
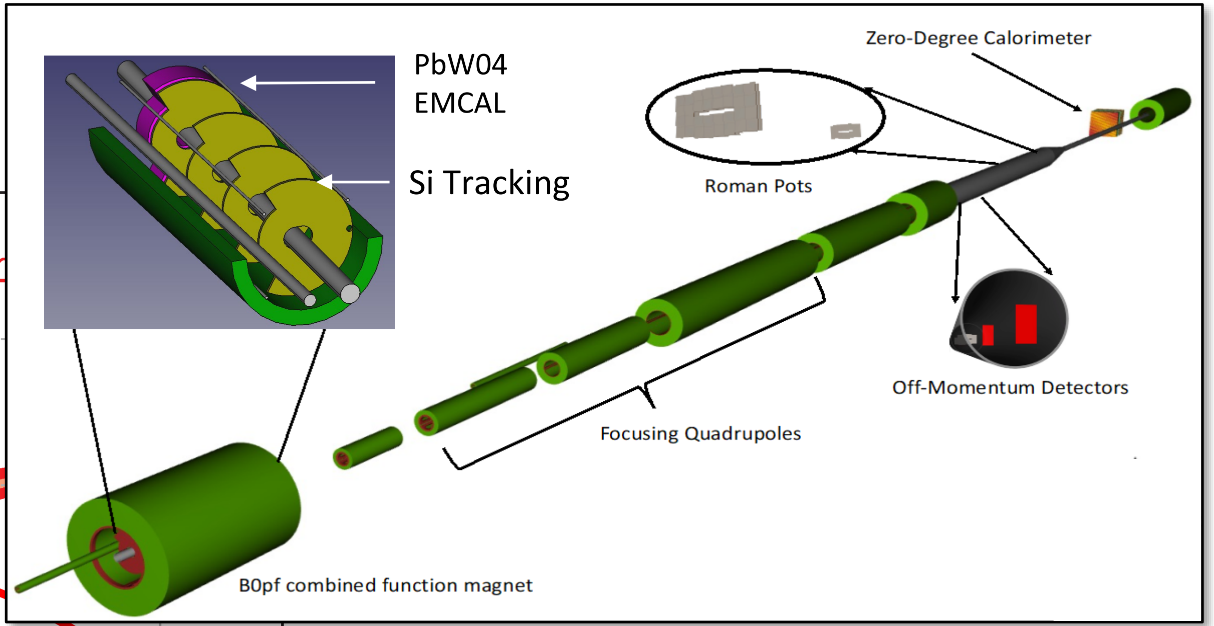
Calorimetry:

- 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







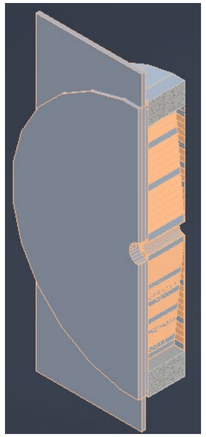
Far-Backward Detectors

- Luminosity monitor
- Low-Q^2 Tagging Detectors

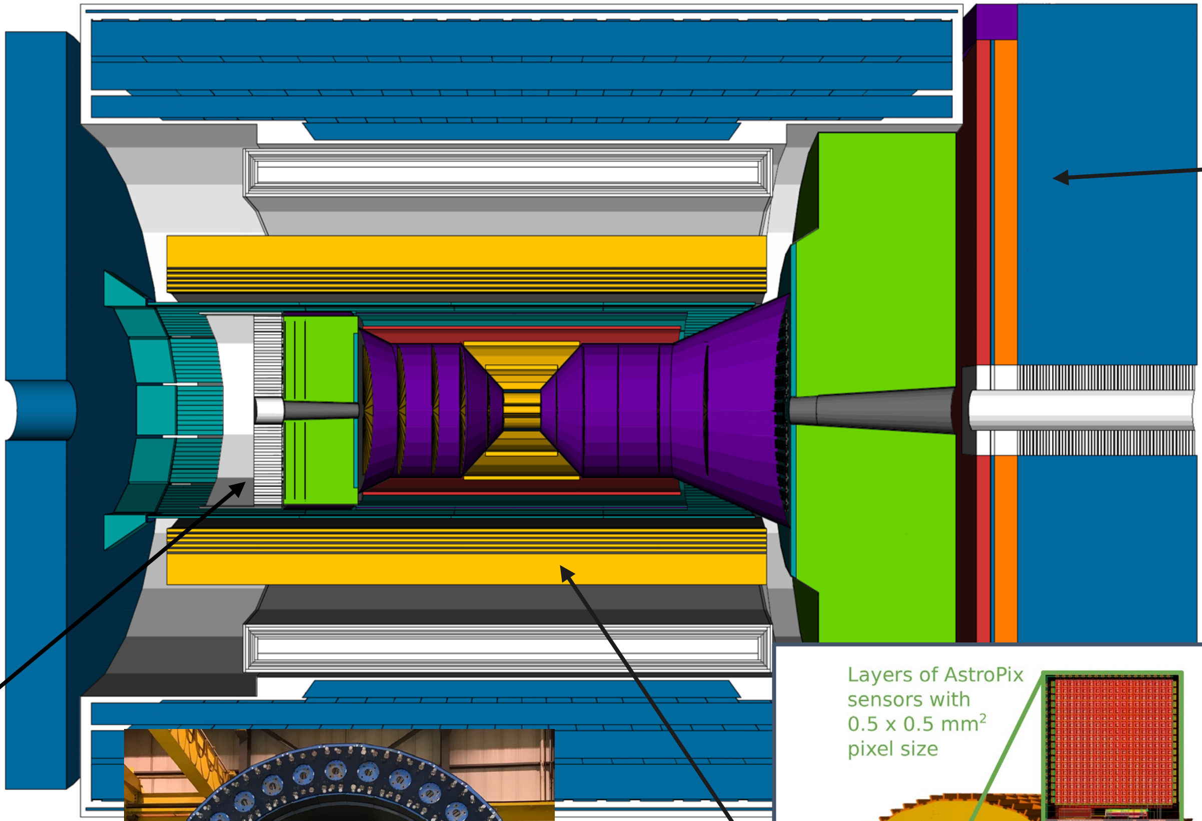
Far-Forward Detectors

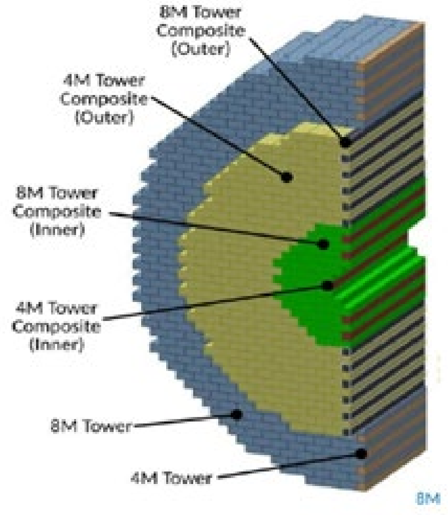
- B0 Tracking and Photon Detection
- Roman Pots and Off-Momentum Detectors
- Zero-Degree Calorimeter

Calorimetry

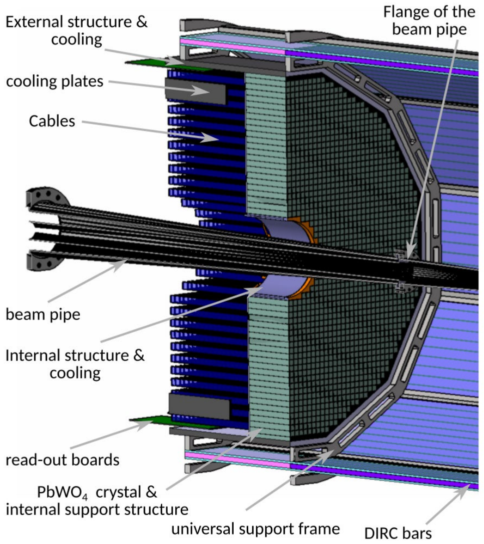


Backwards HCal
Steel/Sc Sandwich
tail catcher



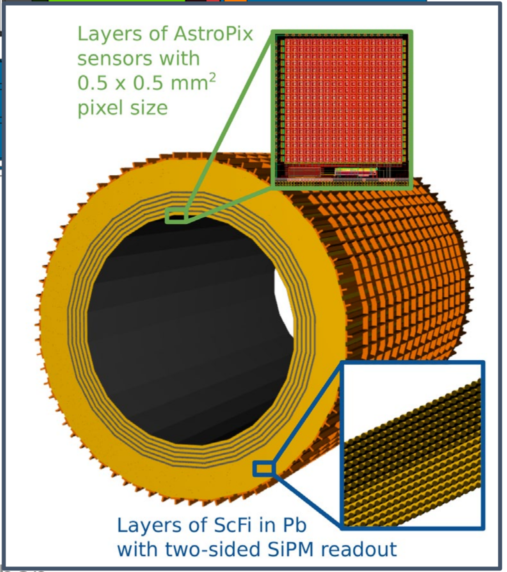


High granularity
W/SciFi EMCal
Longitudinally separated
HCAL with high-η insert



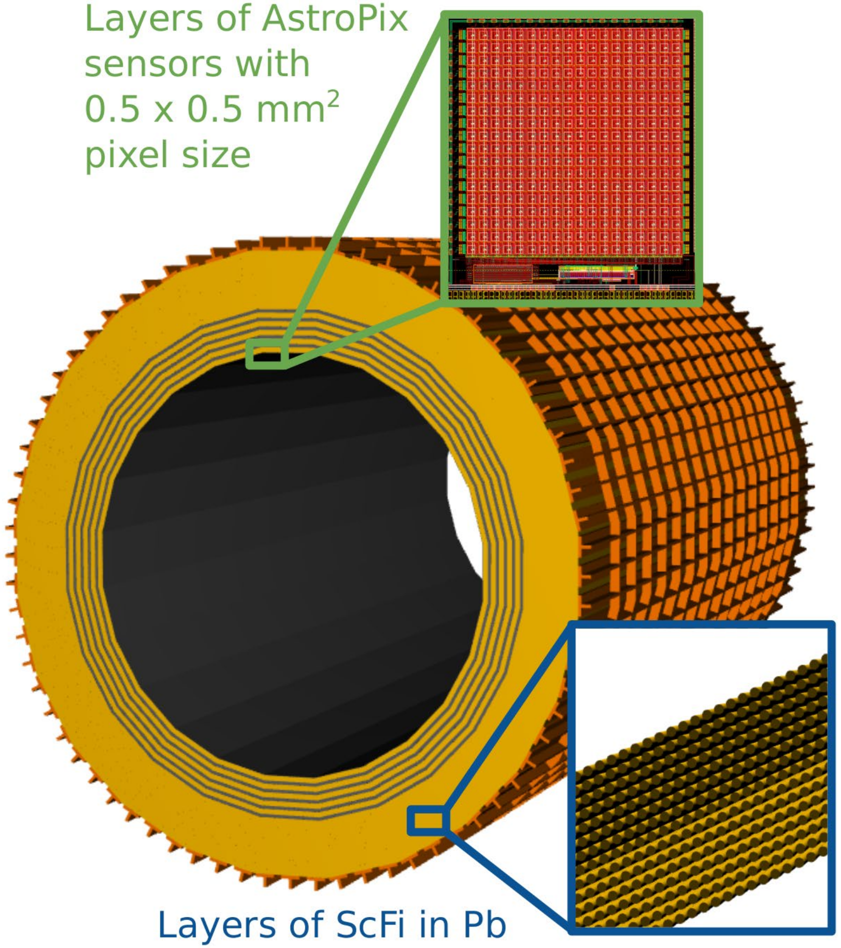
Backwards EMCal
PbW04 crystals

Barrel HCAL
(sPHENIX re-use)



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 deep Pb/ScFi section
- Total radiation thickness for EMCAL of ~20 X_0
- Detector coverage: $-1.7 < \eta < 1.3$ which overlaps with "electron-going" side endcap

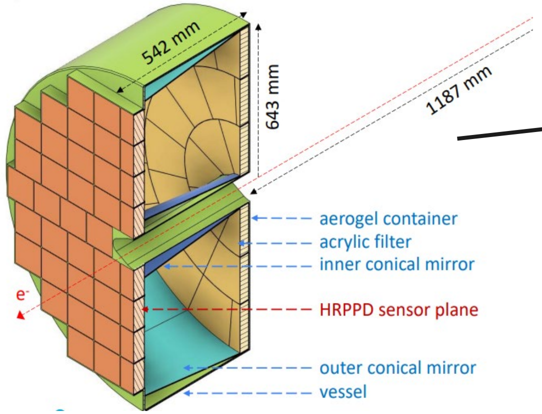


Energy resolution - SciFi/Pb Layers: $5.3\% / \sqrt{E} \oplus 1.0\%$
Position resolution - Imaging Layers (+ 2-side SciFi readout): with 1st layer hit information ~ pixel size

Particle ID

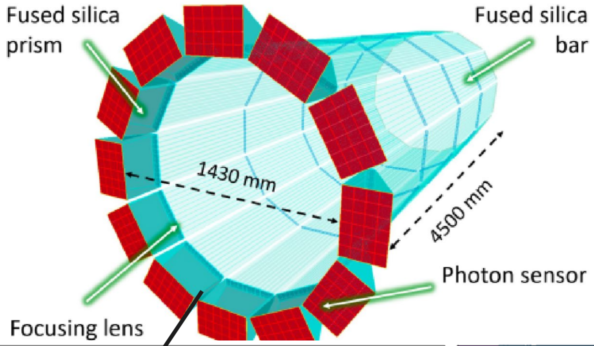
Proximity Focused (pfRICH)*

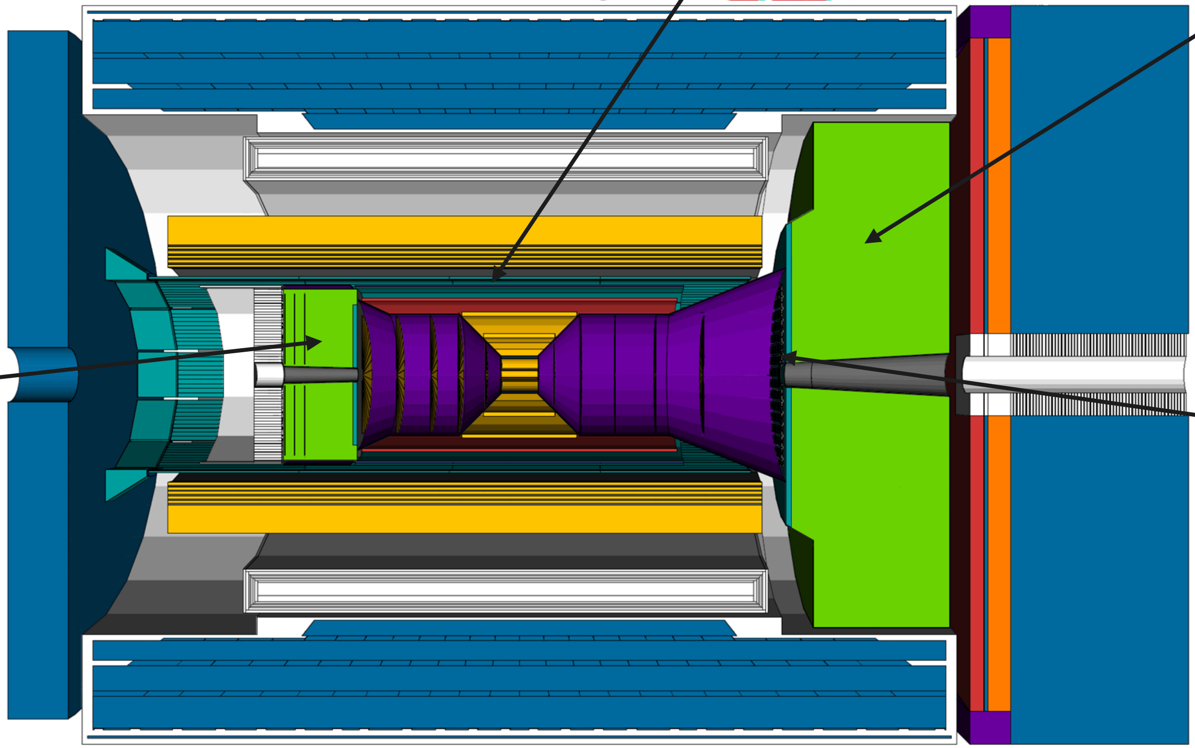
- Long proximity gap (~40 cm)
- Sensor: LAPPDs
- up to 9 GeV/c 3б π/K sep.



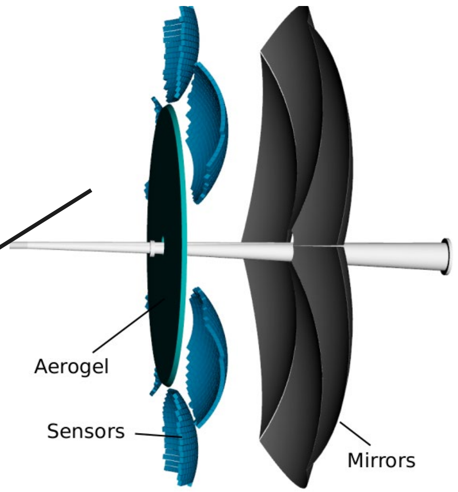
High-Performance DIRC

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

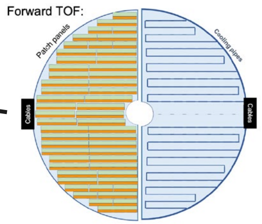




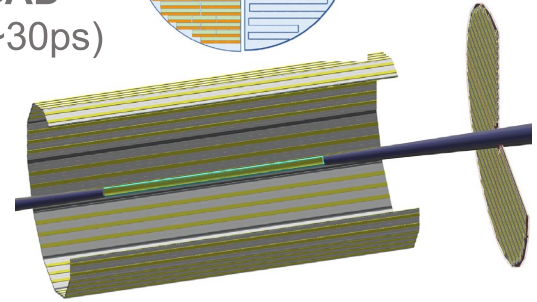
Dual-Radiator RICH(dRICH)



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

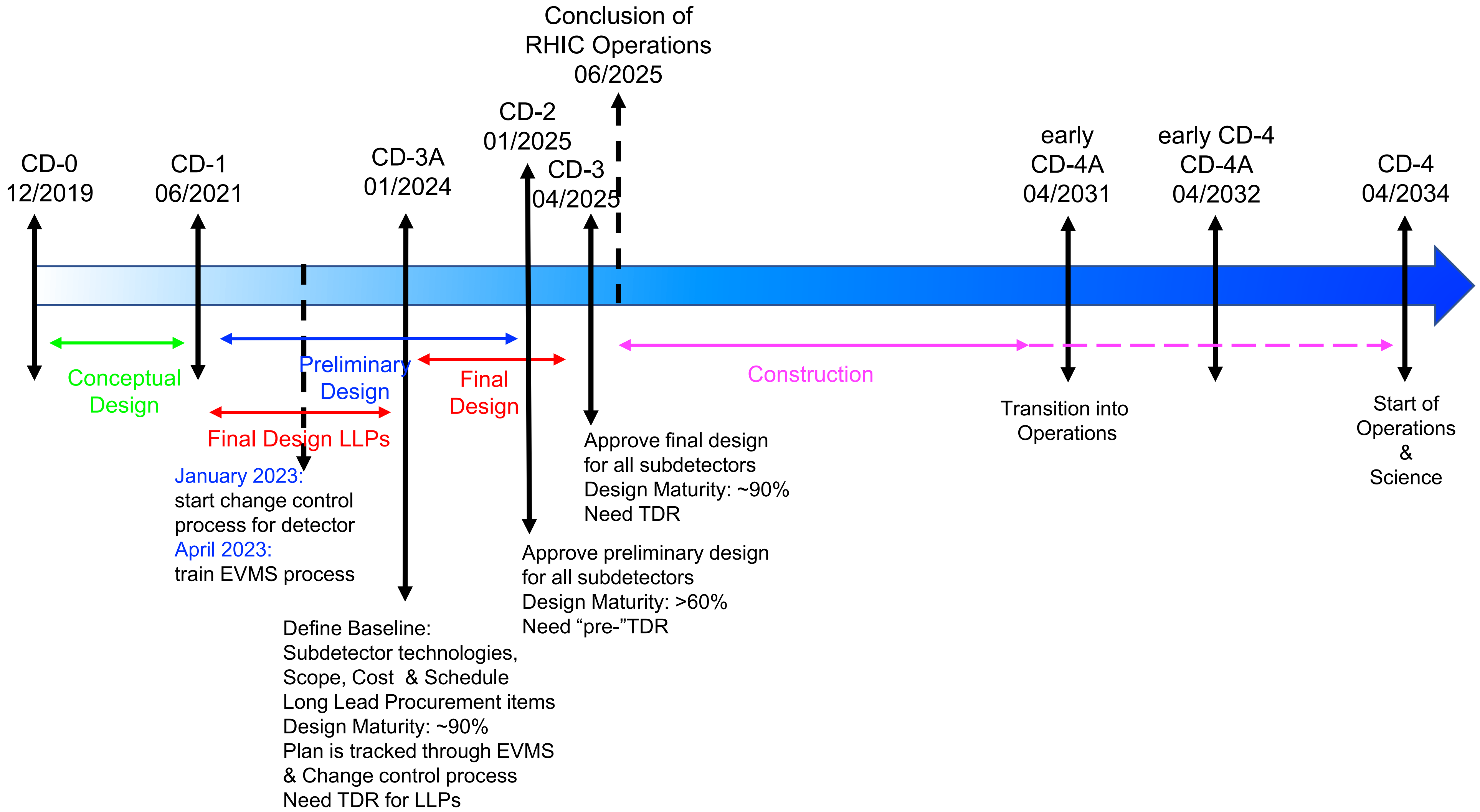


AC-LGAD TOF (~30ps)

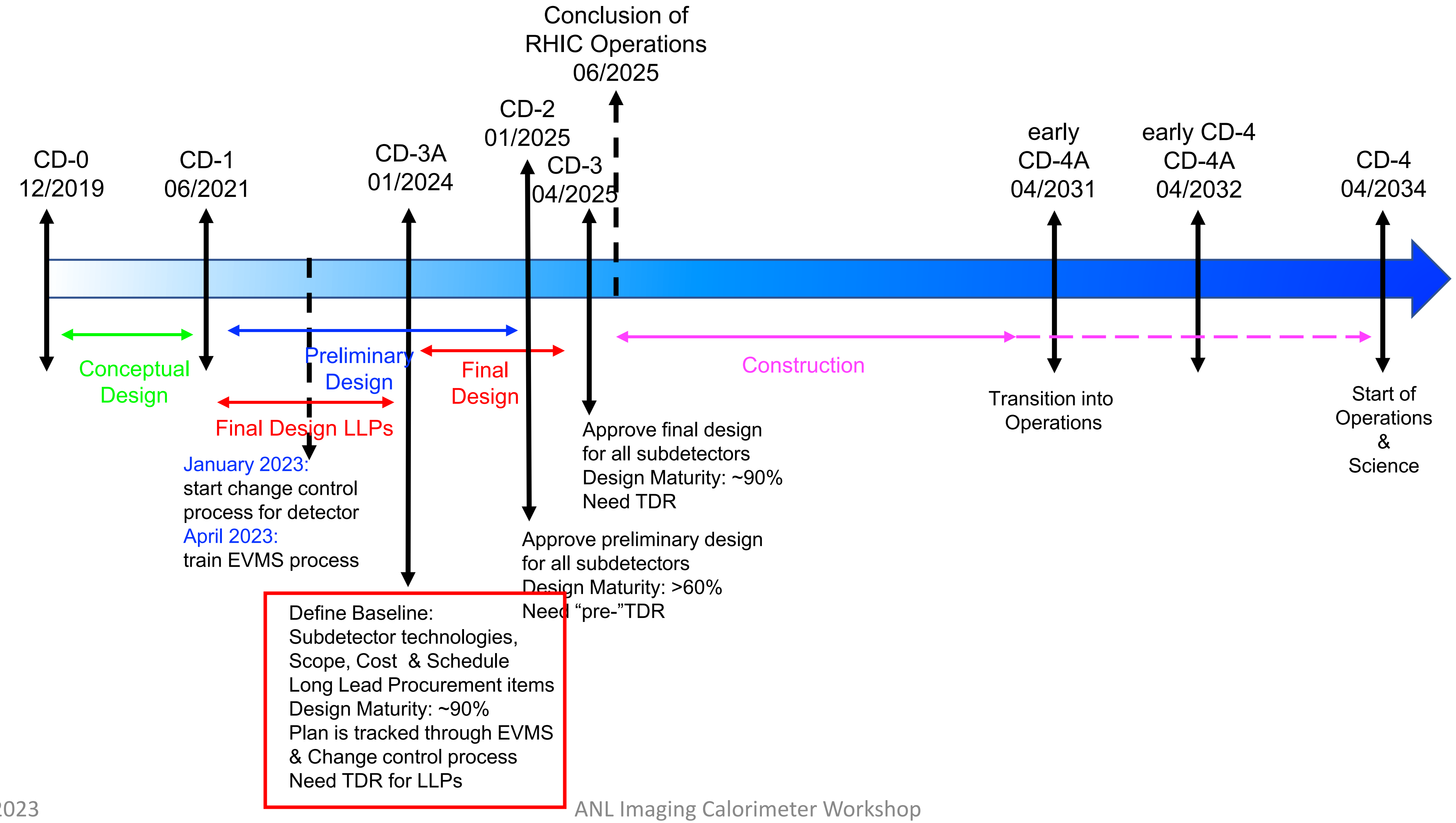


- Accurate space point for tracking
- forward disk and central barrel

EIC Project Schedule

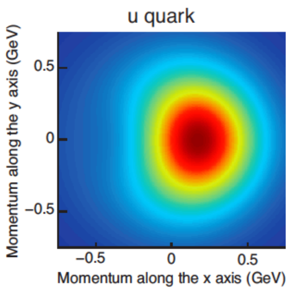


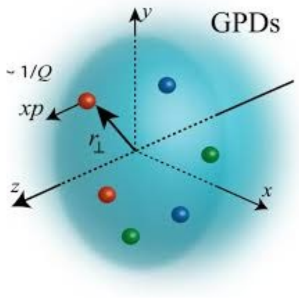
EIC Project Schedule



Summary

- The EIC is a new QCD laboratory designed to elucidate:
  - Origin of Nucleon Mass & Spin
  - Confinement
  - Nucleon / Nuclear Femtography
  - Dense Gluon States
  - BSM physics





- The EIC science goals are a natural extension of QCD studies at JLab and in RHI (RHIC and LHC)

- The ePIC Detector is maturing into a detailed technical design to pursue the EIC science program
  - EIC detectors are an enormous undertaking that will require participation and expertise from both the RHIC and JLab communities, as well as key international contributions!


"New directions in science are launched by new tools much more often than by new concepts."
Freeman Dyson


BACK UP