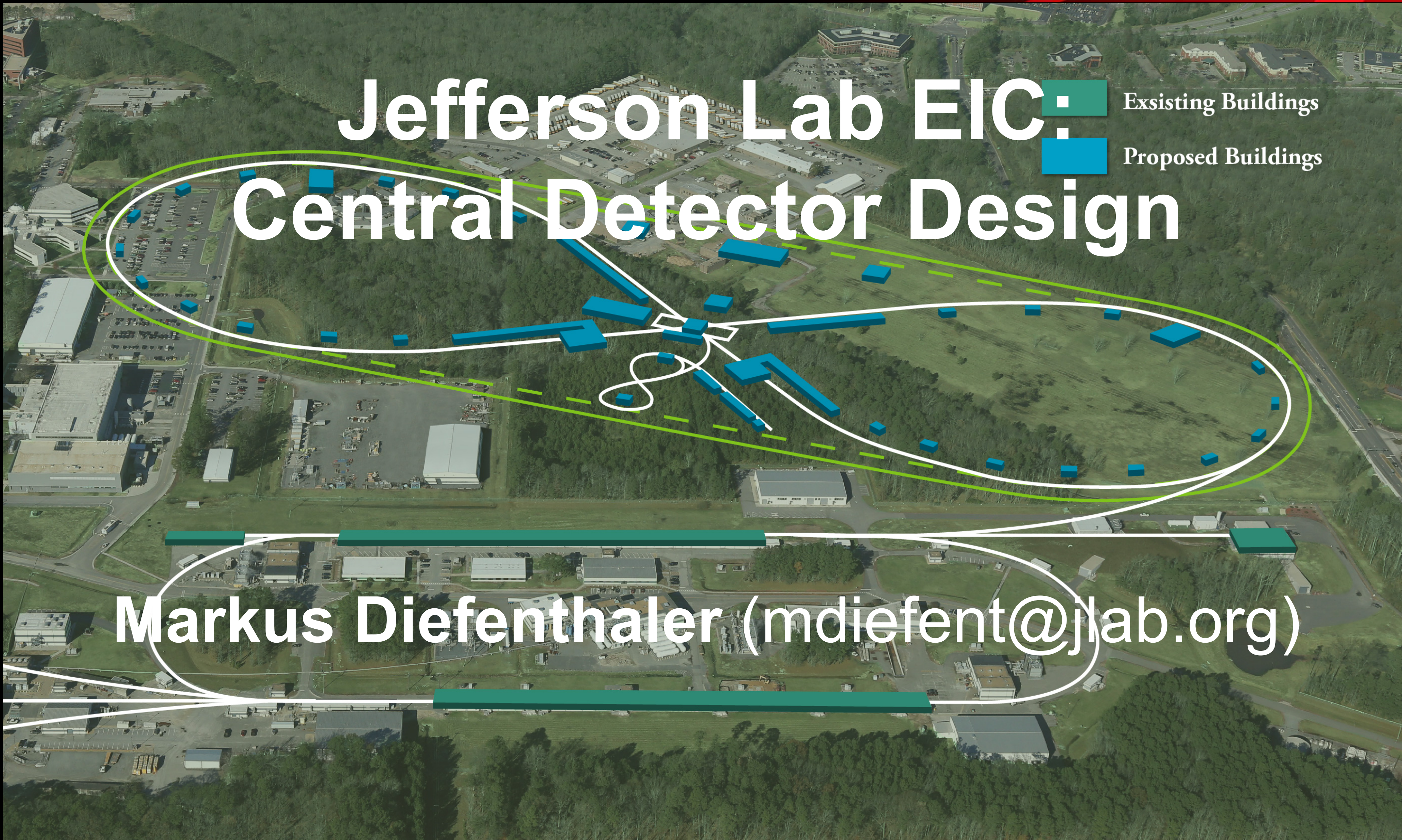
Jefferson Lab EIC: Central Detector Design



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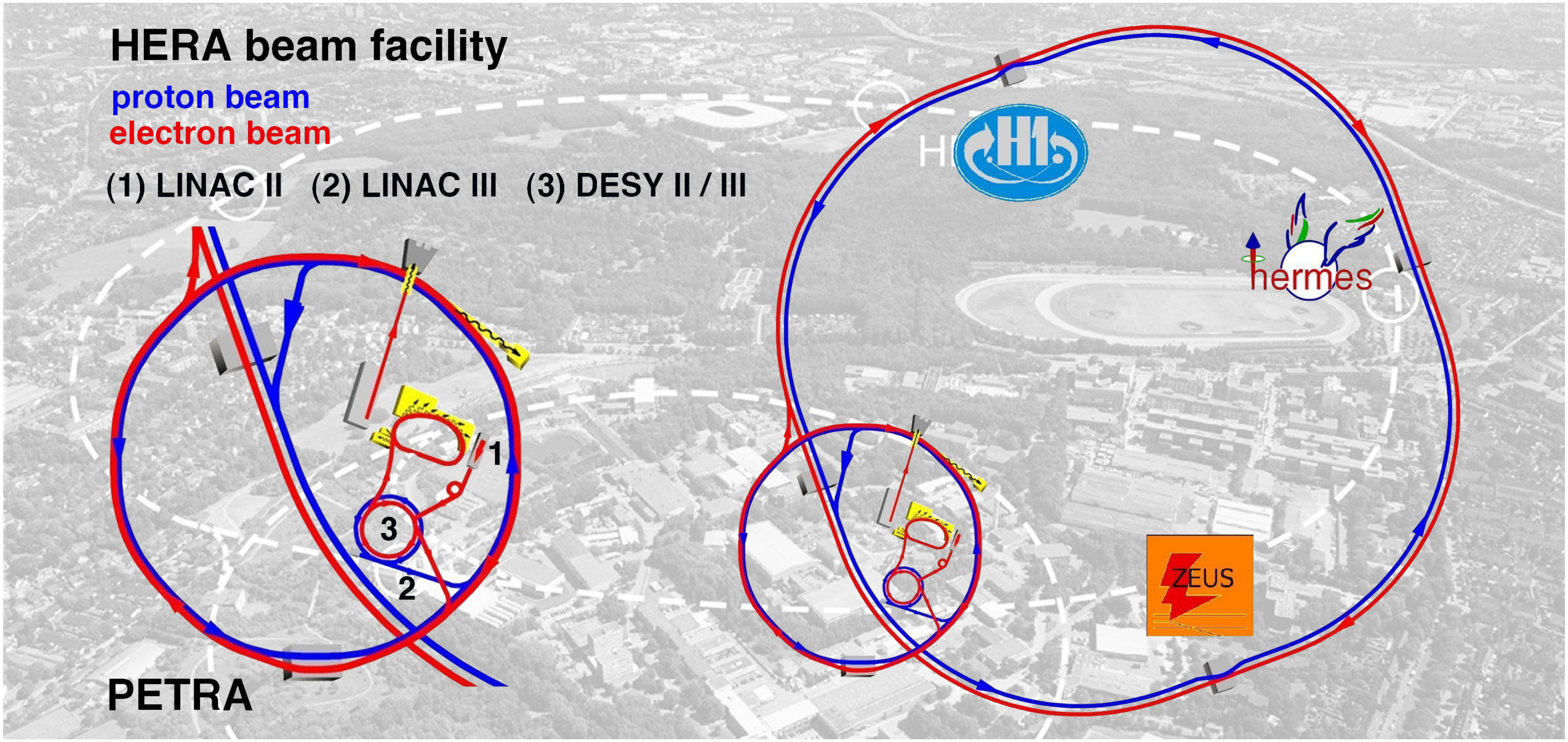
DIS 2016
April 13th 2016

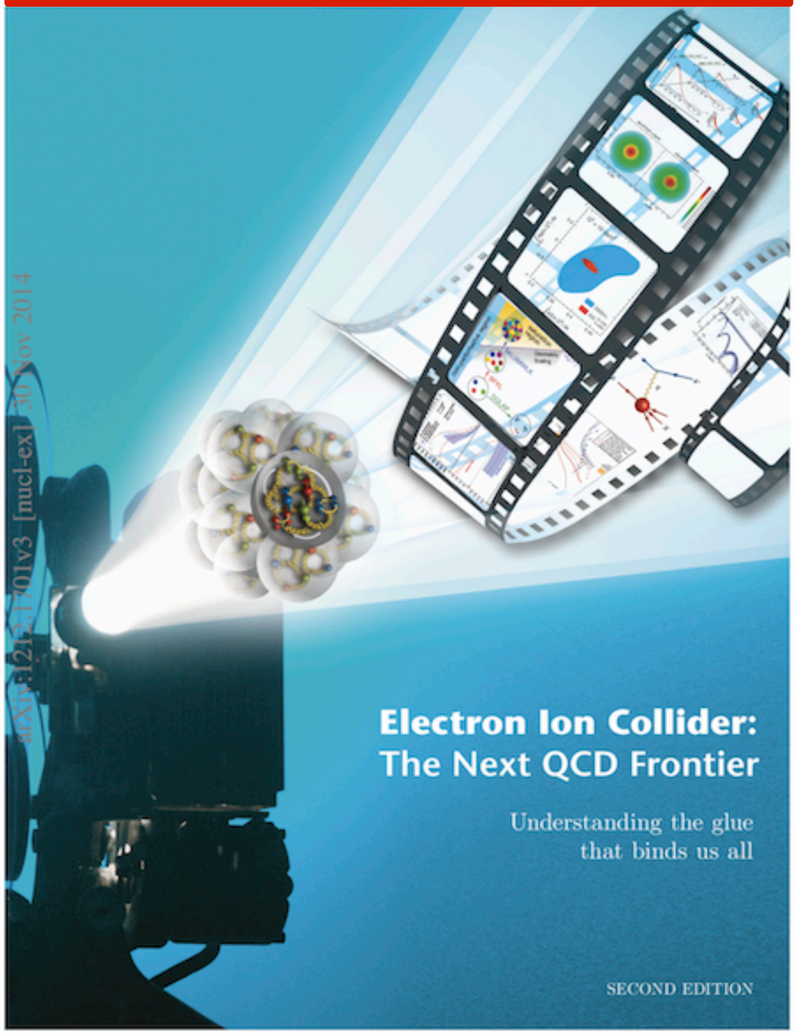
Jefferson Lab
Thomas Jefferson National Accelerator Facility

HERA – The first Electron-Ion Collider



Electron-Ion Collider (EIC)

EIC White Paper: The glue that binds us all (**arXiv:1212.1701**)



World's first collider of:

- **polarized electrons** and **polarized protons/light ions**
- **electron-nucleus collider**

Realization of the science case:

- eRHIC at BNL
- **Jefferson Lab EIC** (this presentation)

For e-N collisions at the EIC:

- Polarized beams: **e, p, d, ^{3}He**
- **e** beam: 3-10 GeV
- **p** beam: 20-100 GeV
- $L_{ep} \sim 10^{33\text{-}34}$ cm^{-2}s^{-1} ($10^{2} - 10^{3}$ times HERA)
- variable CM energy

For e-A collisions at the EIC:

- wide range in nuclei
- luminosity per nucleon same as **e-p**
- variable CM energy

EIC: ideal facility for studying QCD

High luminosity:

- high precision for various measurements in various configurations
- resulting requirement for systematic uncertainties ≤ 1%

Transverse and longitudinal polarization of light ions (p, d, ^{3}He):

3D imaging in space and momentum:

- parton flavor and spins separated
- TMD measurements requires high luminosity (multidimensional binning) and broad PID range
- DVCS measurements requires high luminosity and hermeticity
- spectator tagging requires zero degree calorimeter, far-forward spectrometer

High CM energy:

- broad Q^2 range for studying evolution, separate leading-twist from higher-twist observables
- access to low Bjorken-x in the DIS region (Q^2 > 1GeV^2): map transition from DGLAP evolution to gluon saturation

broad range in A from hydrogen to uranium isotopes:

- hadronization in the nuclear medium, spectator multiplicities (see left box)
- 3D imaging (see left box)
- gluons EMC effect: high precision, requires high luminosity
- gluon saturation: access to low Bjorken-x in the DIS region

[229] Wim Cosyn - Next-generation nuclear DIS with spectator tagging at EIC

JLEIC Design strategy: High luminosity and polarization

[163] Yuhong Zhang - JLEIC – A High Luminosity Polarized Electron-Ion Collider at Jefferson Lab

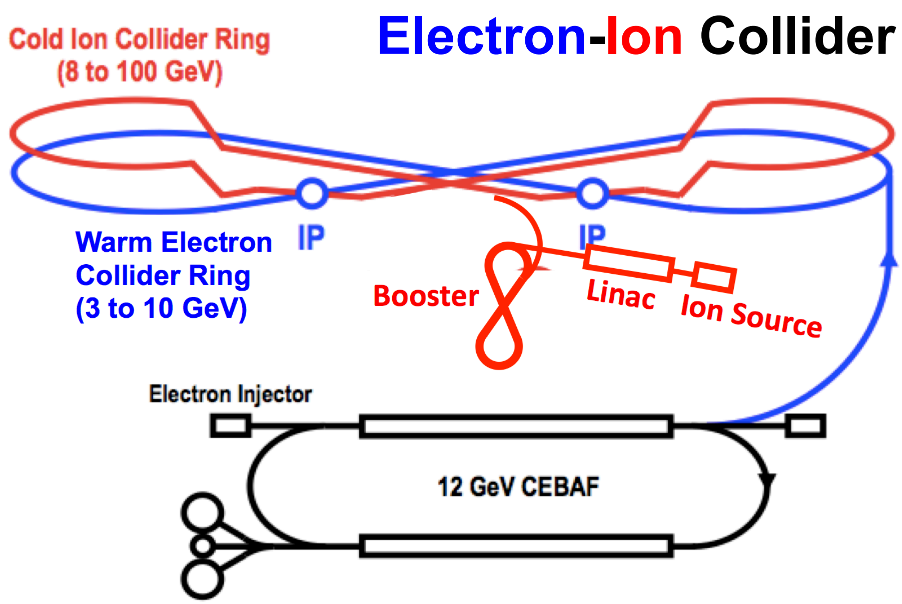
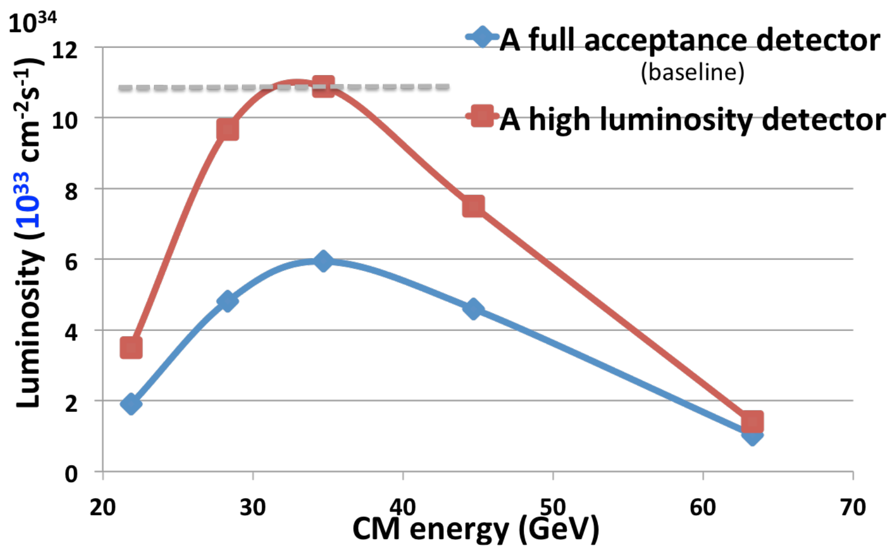


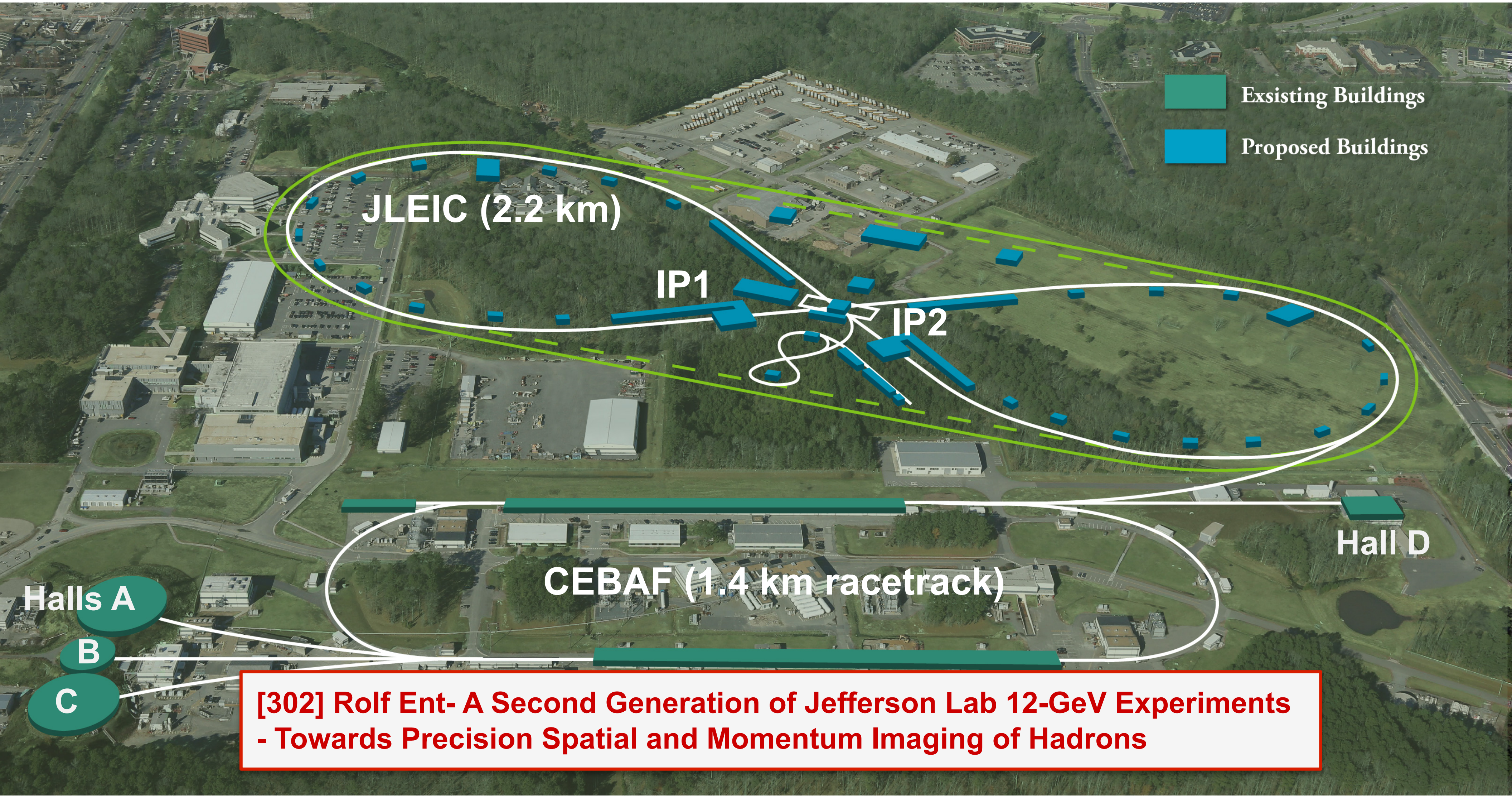
Figure-8 shaped ring-ring collider:
- **spin precessions** in left and right ring parts cancel exactly
- zero **spin tune** (net spin precession)
- energy-independent **spin tune**
- **polarization** easily preserved and manipulated:
  - by small solenoids
  - by other compact spin rotators



High luminosity:
- high-rate collision of short bunches
  - with small emittance
  - with low charge
- **ion beam:** high-energy electron cooling (R&D)
- **electron beam:** synchrotron radiation damping

arXiv:1504.07961

JLEIC site plan



Complementary detector scenarios

- two detectors optimized for different capabilities and using complementary technologies allow better performance and improved cost-effectiveness
- complementary sensitivity to physics, backgrounds and fake effects
- cross-checks on discoveries and important physics results
- combine results for precision measurements:
  - a combined reduction of systematics
  - in a ring-ring collider: detector luminosities can be added
- higher efficiency of operation
- increase scientific productivity

IP1: multi-purpose, full acceptance detector (this presentation)

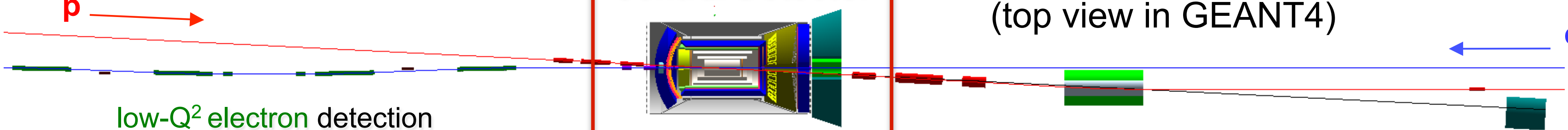
- focus on single track reconstruction and PID
- optimized to support the broad physics program in the white paper

IP2: complementary, smaller detector

- focus on jet reconstruction and calorimetry

Design of a Full-Acceptance Detector

[280] Rik Yoshida - JLEIC forward detector design and performance



[179] Dave Gaskell - Electron Polarimetry at JLEIC

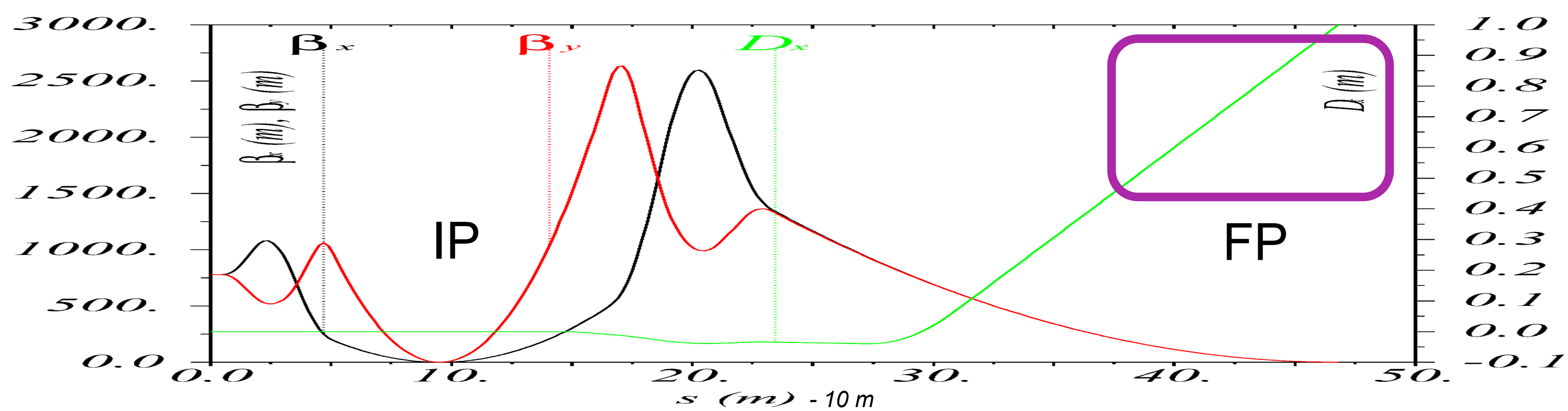
Design goals

1. **Detection/identification of complete final state including spectators and remnants**
2. **Spectator p_T resolution << Fermi momentum**
3. **Low-Q^2 electron tagger for photoproduction**
4. **Compton polarimeter with e^- and γ detection**

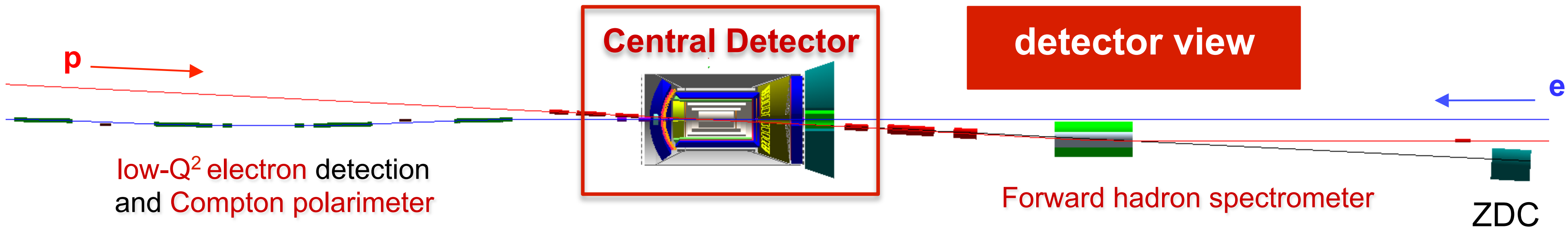
Hadron detection in three stages:

1) Endcap with 50 mrad crossing angle
2) Small dipole covering angles to a few degrees
3) Ultra-forward up to one degree, for particles passing accelerator quads

Beam line functions as spectrometer: $dp/p < 3\times10^{-4}$



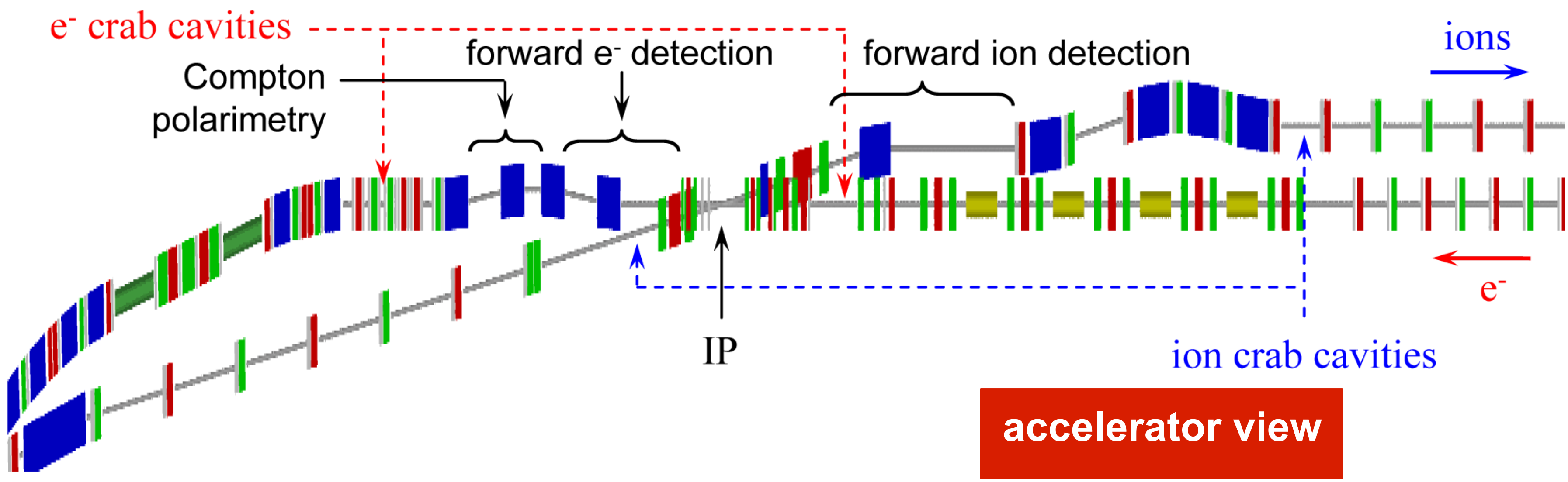
Detector and interaction region



Extended detector: 80m

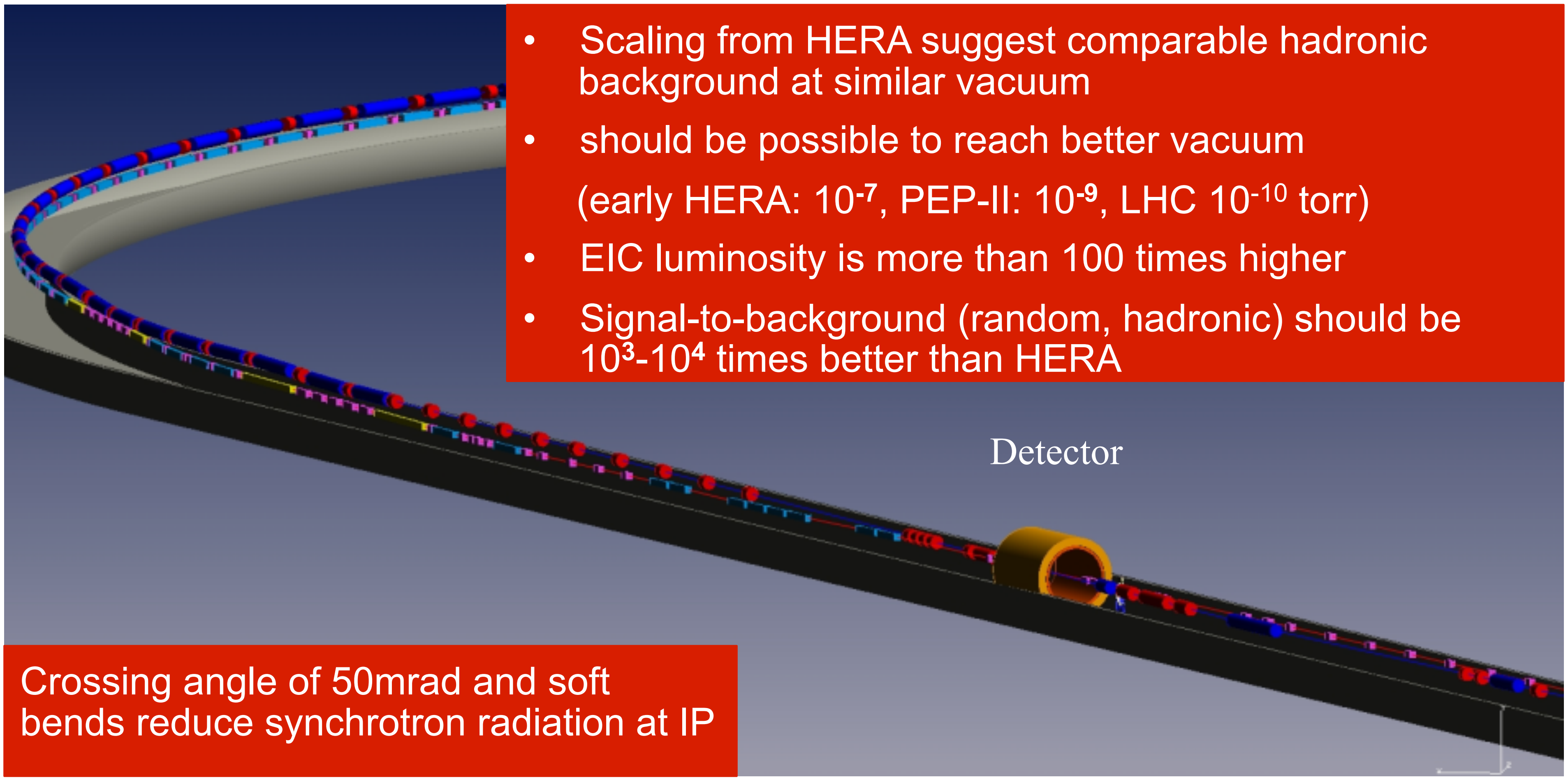
30m for multi-purpose chicane, 10m for central detector, 40m for the forward hadron spectrometer

fully integrated with accelerator lattice



Detector locations and backgrounds

- **Far** from arc where electrons exit ➔ reduce background from synchrotron radiation
- **Close** to arc where ions exit (see below) ➔ reduce beam-gas interaction straight upstream of detector
- background limited to *near* sources (e.g. synchrotron radiation from quadrupoles)



- Scaling from HERA suggest comparable hadronic background at similar vacuum
- should be possible to reach better vacuum

  (early HERA: 10^{-7}, PEP-II: 10^{-9}, LHC 10^{-10} torr)
- EIC luminosity is more than 100 times higher
- Signal-to-background (random, hadronic) should be 10^3-10^4 times better than HERA

Crossing angle of 50mrad and soft bends reduce synchrotron radiation at IP

Design considerations for the central detector

Focus on reconstruction and identification of individual particles

Important for 3D structure (exclusive, SIDIS), heavy flavor, low-multiplicity jets, …

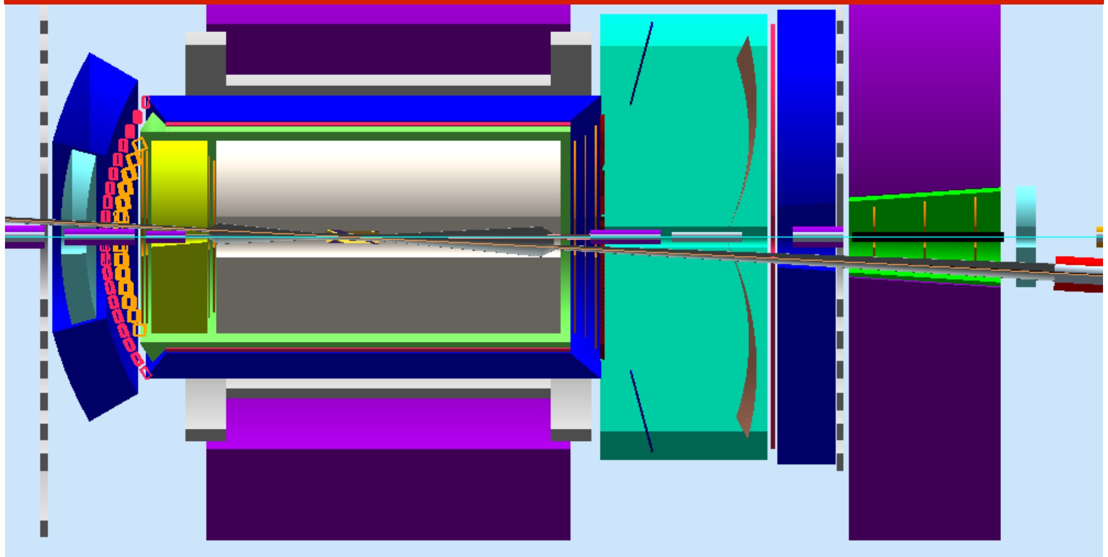
EIC physics requires very good PID

- most challenging requirement
- drives layout and size of the central detector

Modular design

- compatible with CLEO and BaBar 1.5 T solenoids,
- or a new 3 T solenoid (4 m long coil, 3 m diameter)
- compatible with 4π Hcal (focus of IP2 detector design)

IP1 detector: 10.5 m quad-to-quad



Luminosity ~ *1 / (total distance)* between ion quadrupoles

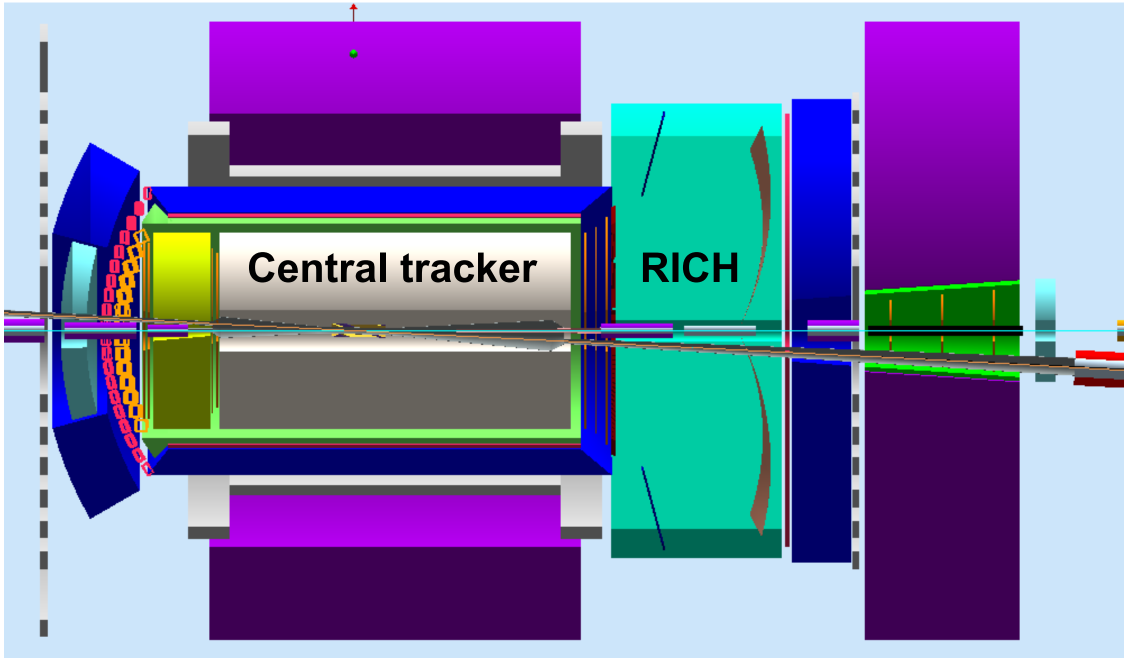
- stat. error ~ √(distance)
- important, but not at the 10% level
- endcap space allocation should be driven by physics, not accelerator design

Key features for the central detector

- **doubly asymmetric IP location** within solenoid and different endcaps

maximize angular acceptance in forward electron direction

more space for PID and calorimeters for high-momentum particles



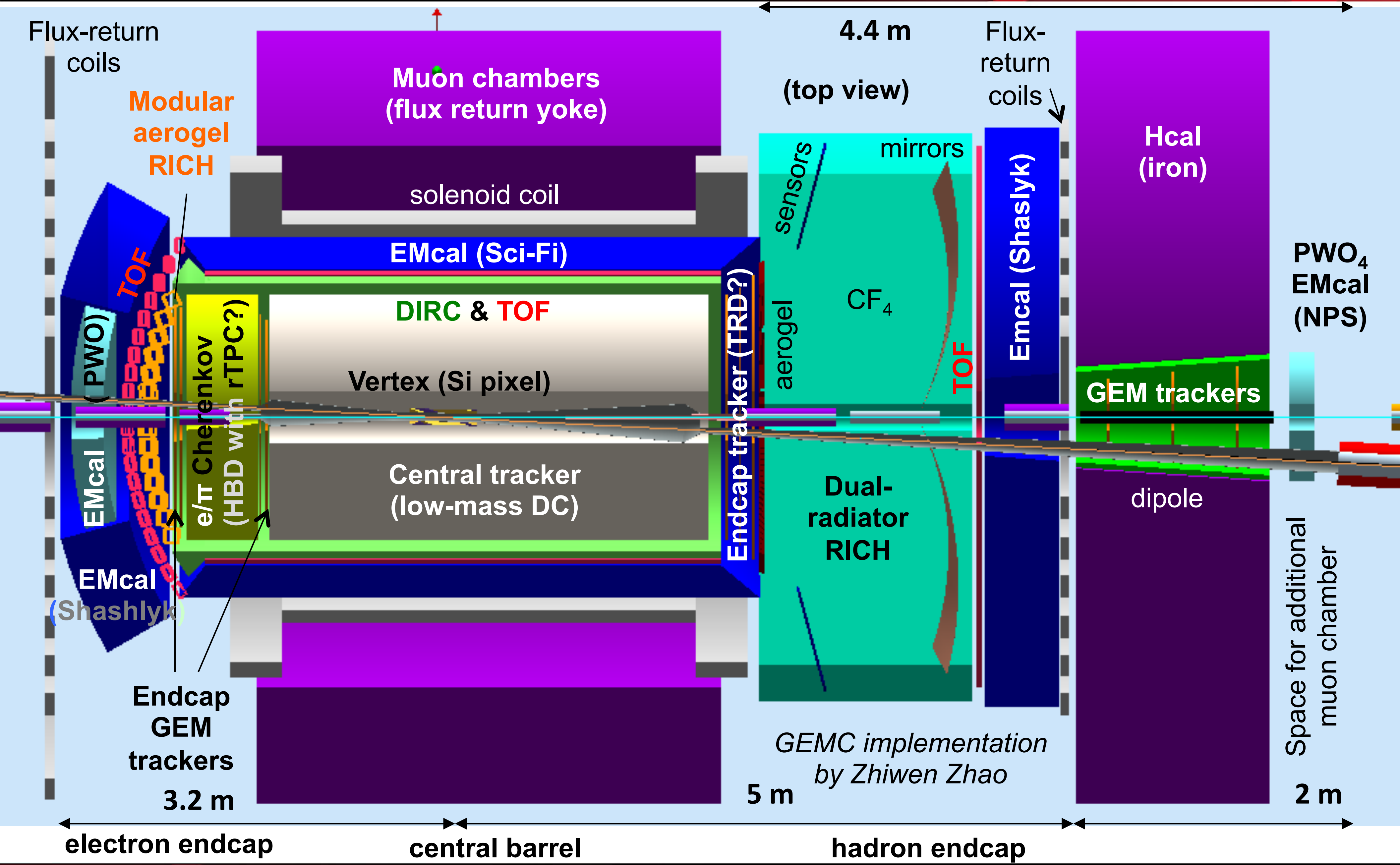
Integration with accelerator lattice

- makes full use of 50 mrad crossing angle
- solenoid field can be adjusted independently of the beam energies

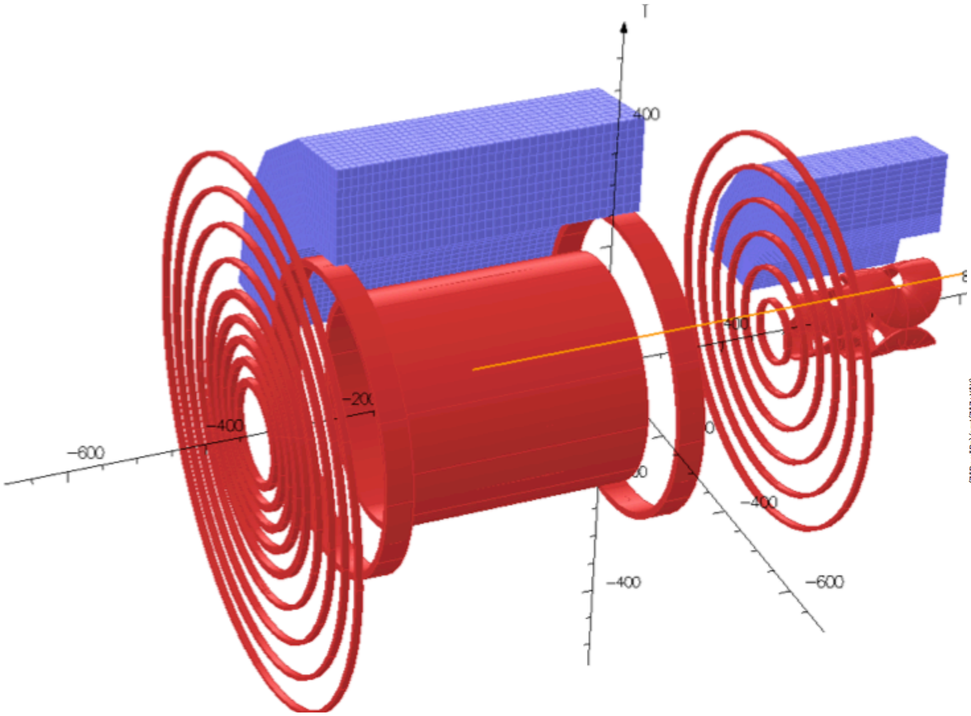
Magnet design

- solenoid and dipole fields satisfy both tracker and RICH requirements

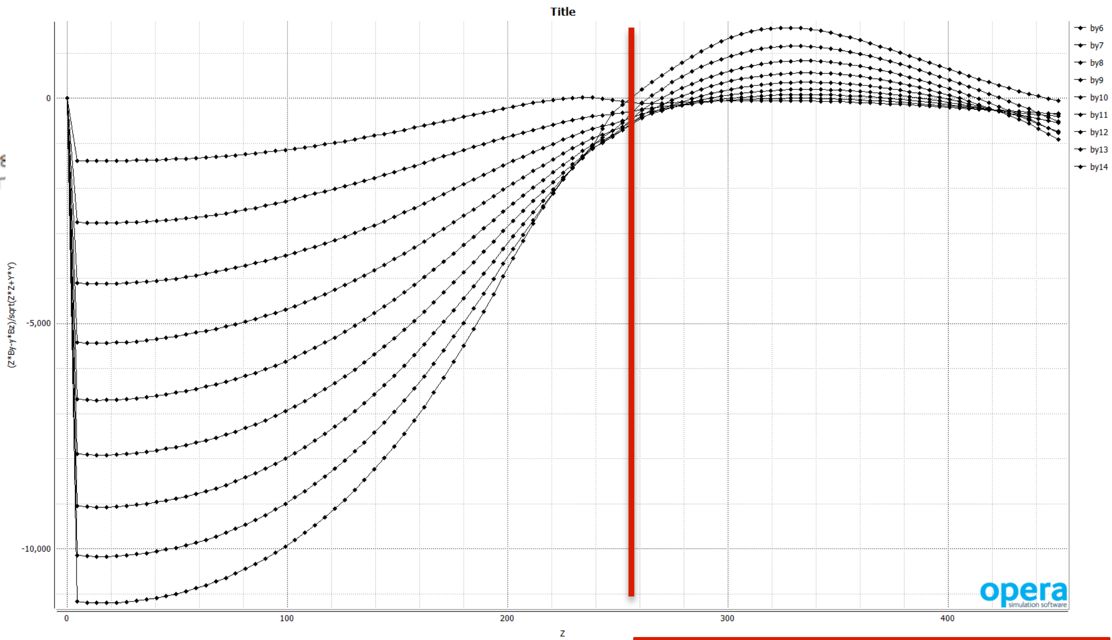
Central detector overview



Central detector solenoid and dipole design

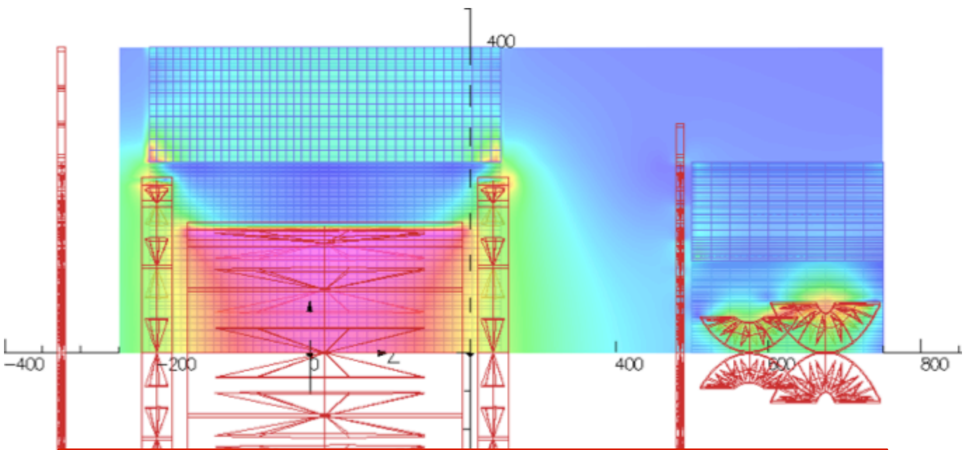


field perpendicular to line of sight from IP



central tracking

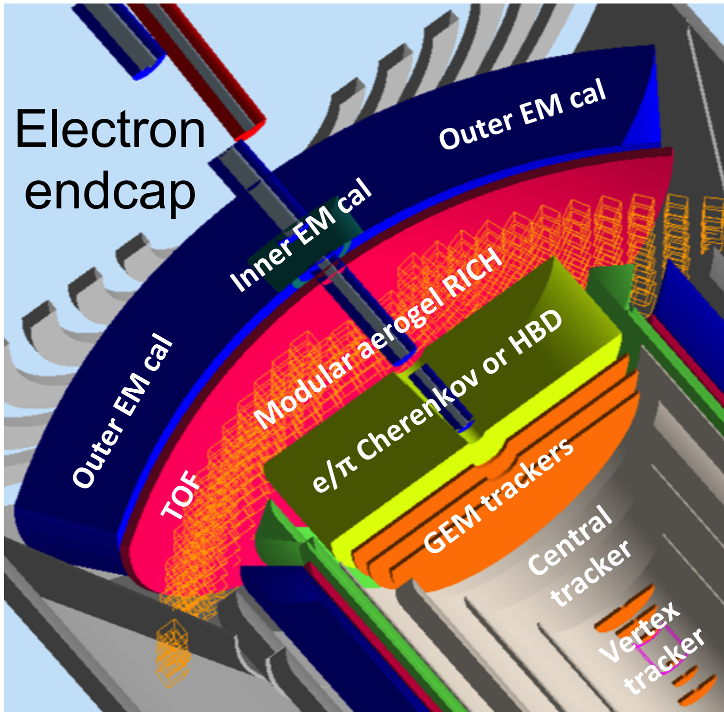
dual-radiator RICH

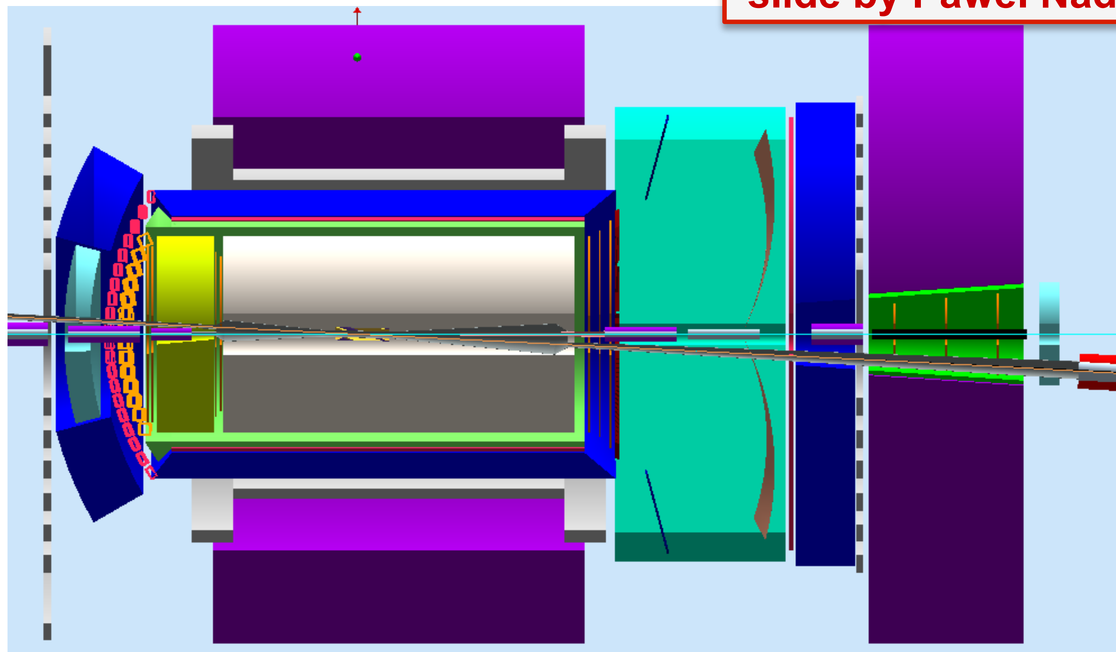


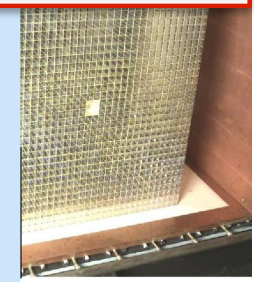
magnitude of magnetic field

Generic EIC detector R&D program

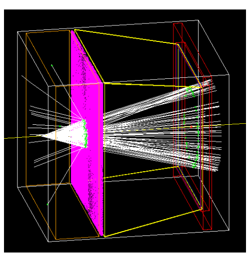
slide by Pawel Nadel-Turonski



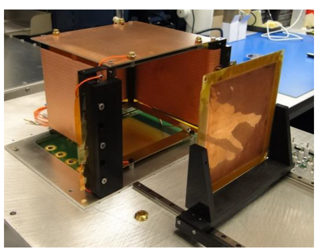




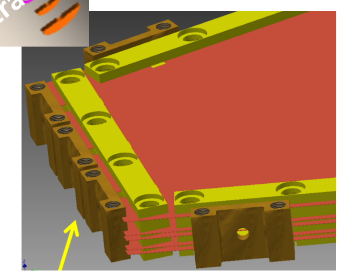
eRD1 – PWO_4 small-angle EMcal



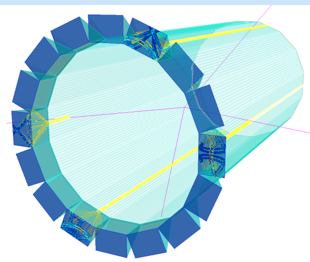
eRD14 – modular aerogel RICH



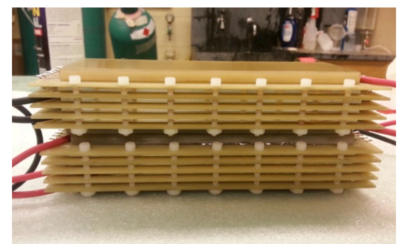
eRD6 – HBD/TPC?



eRD3 & eRD6 – GEM trackers



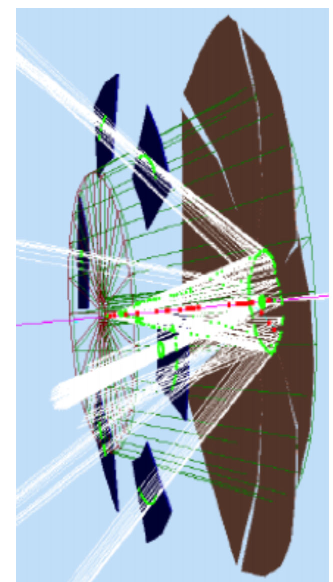
eRD14 – DIRC



eRD14 – MRPC TOF

eRD14 – photosensors

eRD14 – dual-radiator RICH



BNL & JLab staff and users actively participate in the program

JLab detector implements many of the projects in its baseline

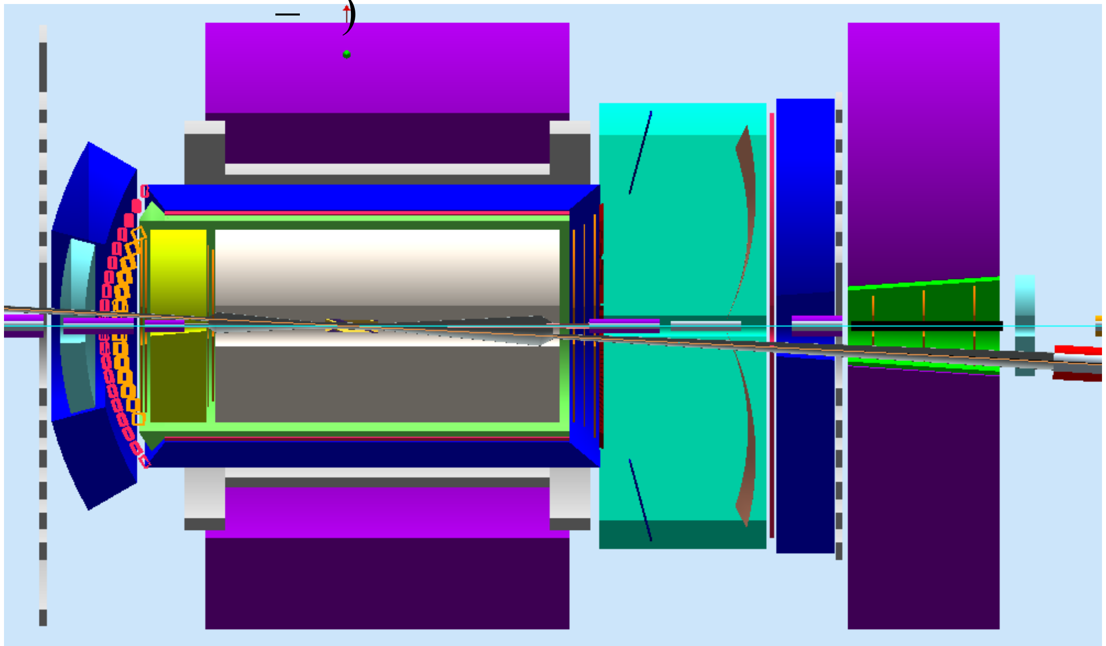
Program is managed by T. Ullrich (BNL) and open to everyone

Hadron identification requirements

slide by Pawel Nadel-Turonski

- e-endcap: momentum range driven by *electron* beam energy.
  - Need to cover range up to almost full electron energy
- A (modular) aerogel RICH can do π/K up to 10 GeV

- h-endcap: momentum range driven by *proton* beam energy.
  - Need to cover significant fraction
- A dual-radiator RICH can do π/K up to 50 GeV



- 4π TOF coverage is needed for bunch identification
  - and coincidence with small-angle detectors
- Time resolution of 30-50 ps also gives limited hadron ID

- barrel: required momentum range for π/K is about half the electron beam energy.
- A DIRC can cover π/K up to at least 4 GeV
  - R&D ongoing to extend the momentum range to 6 GeV/

Electron identification requirements

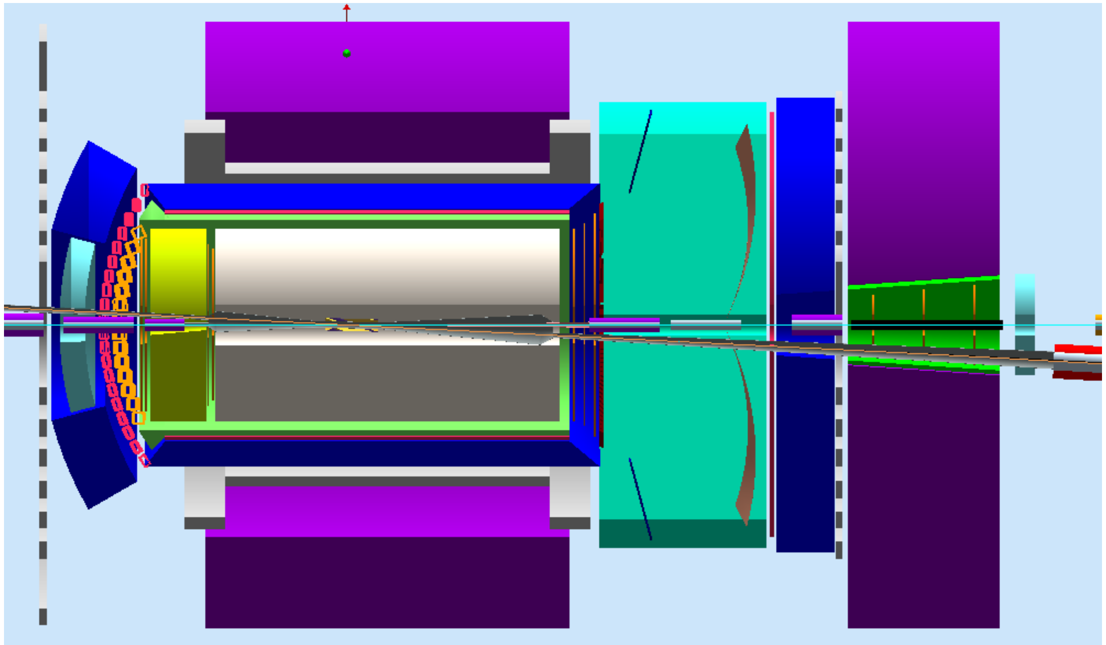
slide by Pawel Nadel-Turonski

- Pion backgrounds are large at small angles (endcaps) and low energies.
  - Need suppression at the $10^3 - 10^4$
  - EMcal alone not enough

- e-endcap: EMcal covers full range
- A Hadron Blind Detector (Cherenkov) provides additional additional e/π ID up to 4 GeV.

- Inner PWO_4 has 2%/√E resolution vs 5-6%/√E for the outer Shashlyk
- Important for reconstruction of electron momentum at small angles

- h-endcap: EMcal + Hcal cover full range
  - CF_4 RICH can provide additional e/π ID at low energy
- An additional TRD would help suppress backgrounds for leptonic decays of reaction products (ofen high energies)



- barrel: Pion backgrounds smaller.
- GlueX-like Sci-Fi EMcal provides factor 100 suppresion
- A high-performance DIRC can provide additional e/π ID up to 1.8 GeV (which corresponds to 6 GeV for π/K)

Design summary

- design of full acceptance detector at the JLEIC ring-ring collider
- multi-purpose detector for the broad physics program of the EIC
- fully integrated with JLEIC ring-ring collider
- central detector optimized for semi-inclusive and exclusive processes with excellent PID capabilities
- detector R&D in progress
- great opportunity for collaboration on:
  - detector design and
  - detector R&D