# EIC Central Detector Solenoid

## Superconducting Detector Magnets Workshop


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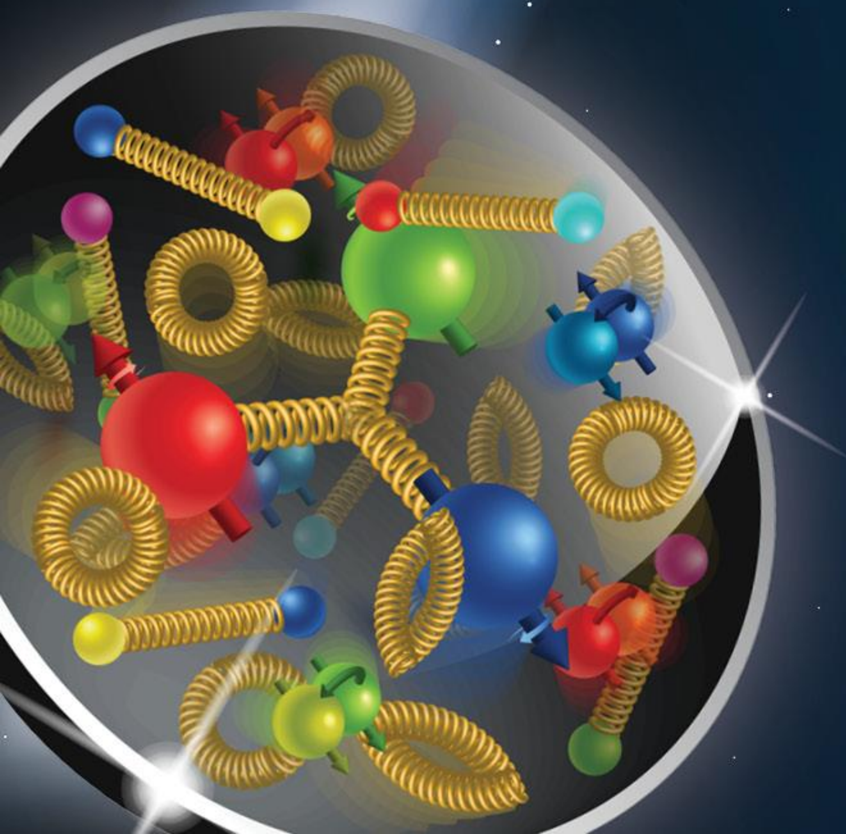

Electron-Ion Collider

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# JLab- An Introduction

- JLab is one of the Department of Energy's 17 National Laboratories, Created to build and operate the Continuous Electron Beam Accelerator Facility (CEBAF), world-unique facility for Basic Research in Nuclear Physics:
    - Mission is to gain a deeper understanding of the structure of matter
    - In operation since 1995
    - 1,623 Active Visiting Scientist Participants
    - ~200 Completed Experiments to-date
    - 150 patents produced
    - Produces ~1/3 of US PhDs in Nuclear Physics
    - ~800 Staff and ~1700 users
    - K-12 Science Education program serves as national model
    - Site is 169 Acres

# JLab- Magnet group and Magnet expertise at Lab

**<u>Magnet Group</u>**:

- 2 Magnet Engineers
  - ~ 60 years cumulative experience from industry and lab:

    *Oxford Instruments, Scientific Magnetics and General Electric*
- 3 mechanical engineers with significant SC magnet experience.
- 3 Mechanical designers with significant magnet experience

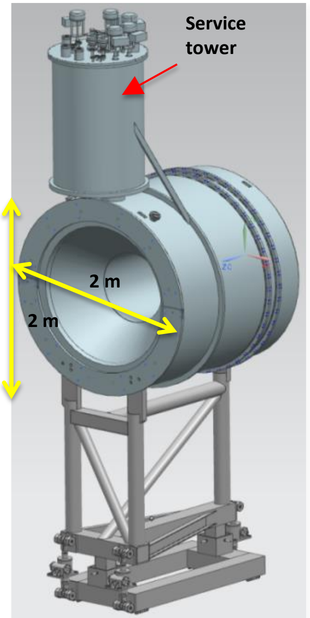
**<u>Other Technical Staff</u>**:

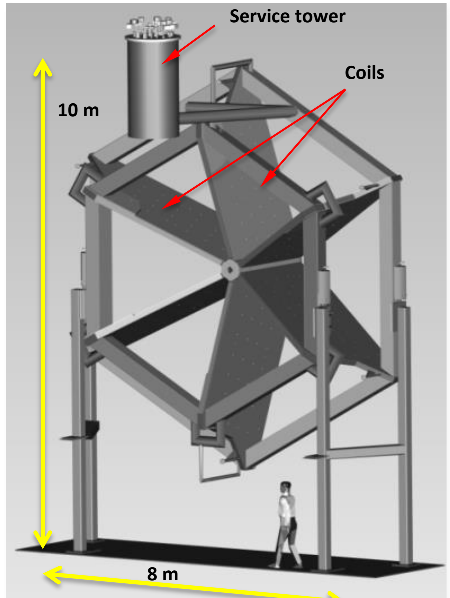
- Numerous technicians and designers (electrical, mechanical, vacuum, cryogenics, etc)
- A magnet measurement lab with various measuring capabilities

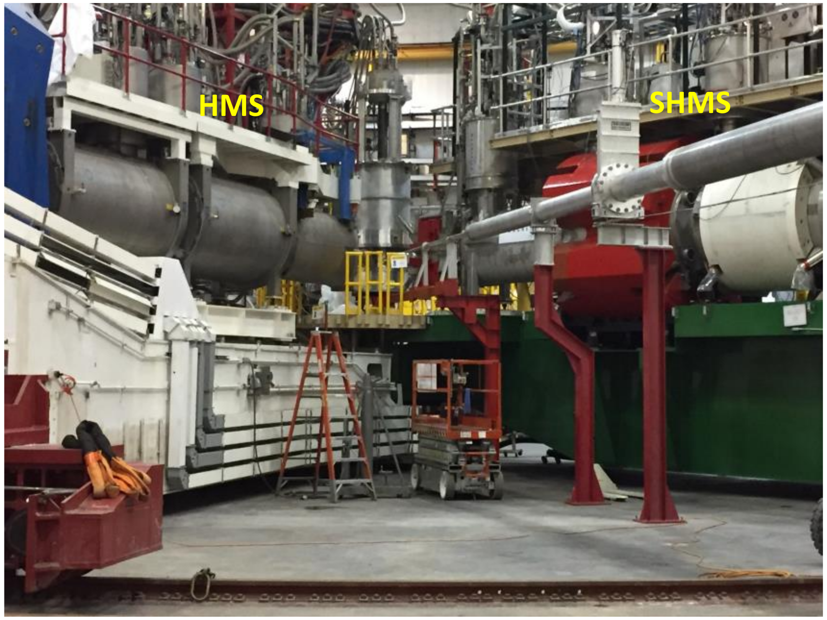
# Superconducting magnet at JLab

- Hall A
  - There are two spectrometers, each with 3 superconducting magnets
    - Q1 (resistive) - Q2 (SC) - Dipole (SC) - Q3 (SC)
      - NbTi cable (30 strands of 1.64mm x 14.7 mm) wrapped in Kapton and glass for Q2 and Q3
      - NbTi cable (36 strands of flattened Rutherford cable, 2.5mm x 19mm) for Dipole, insulated stainless steel strip co-wound with conductor for mechanical stability
- Hall B
  - Hall B has one spectrometer and utilizes two large superconducting magnets, a 6-coil Torus and a 5-coil actively shielded Solenoid (5T central field), SSC outer conductor soldered in Cu channel was used for these magnets
- Hall C
  - Hall C houses a High Momentum Spectrometer and a Super High Momentum Spectrometer (SHMS), SHMS utilizes 5 SC superconducting magnets; HB, 3 quadrupoles and dipole (3.9 T), SSC outer conductor was used for all the magnets and it was soldered in Cu channel for 2 Quads and one dipole.
- Hall D
  - One large superconducting magnet, the magnet was built in 70s at SLAC, repurposed to used at JLab
- Others
  - CLEO magnet reuse for some other experiments at Hall A
  - There are some standard SC magnets bought from various vendors

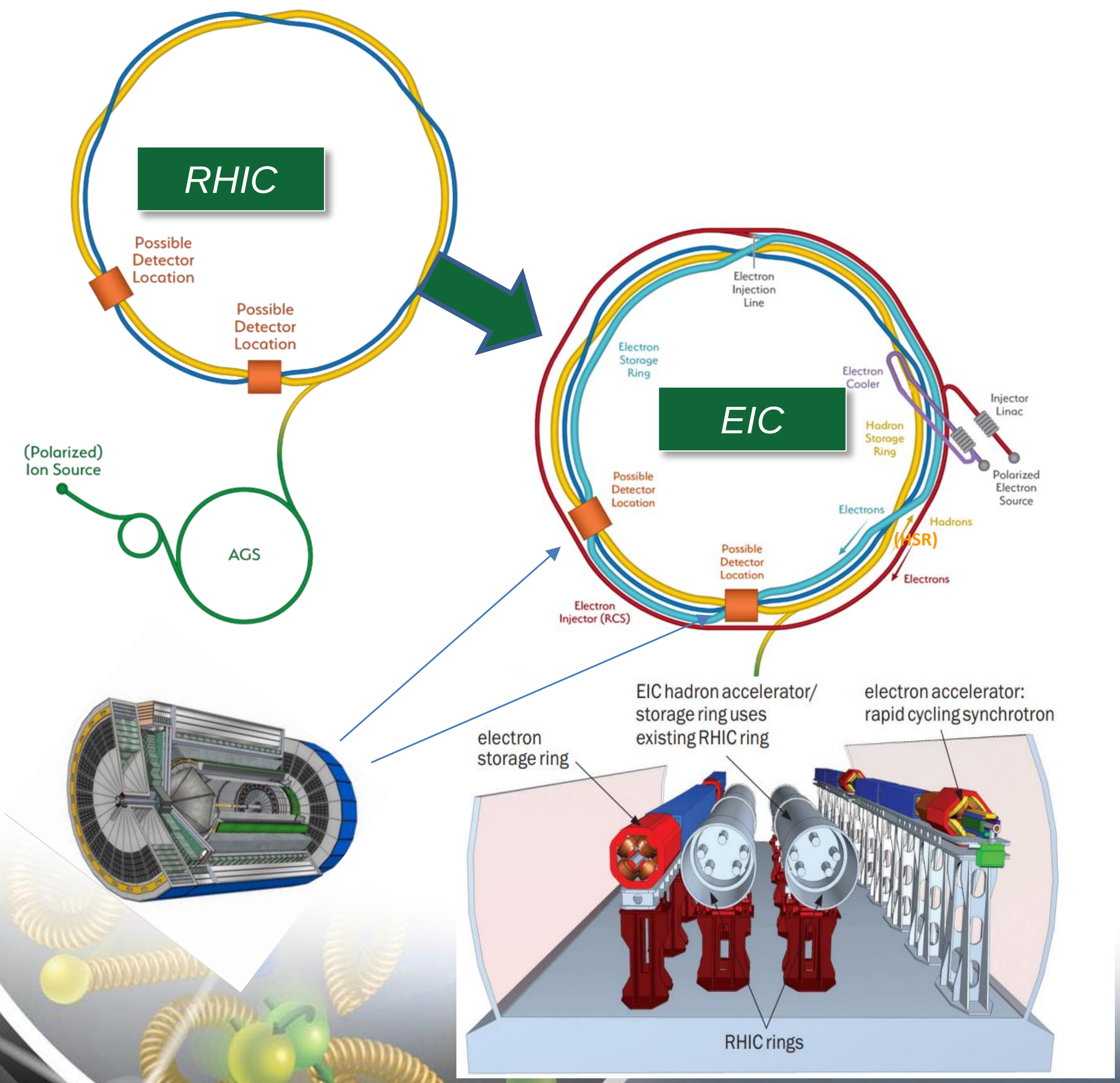
# Superconducting magnet at JLab




# Electron Ion Collider (EIC)

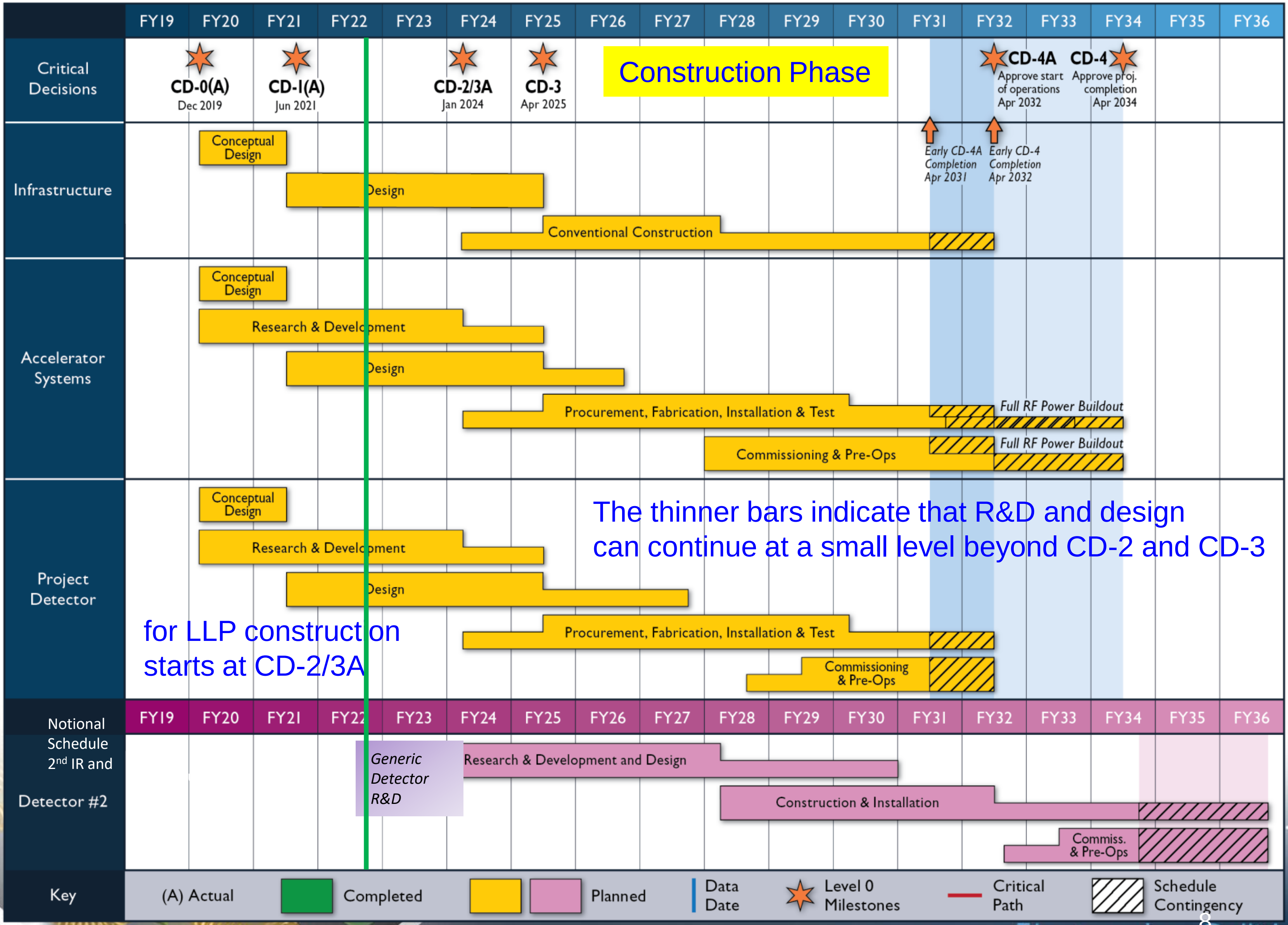



**The EIC will be a discovery machine for unlocking the secrets of the "glue" that binds the building blocks of visible matter in the universe.**

The EIC at Brookhaven Lab will reuse key infrastructure RHIC and build on discoveries at RHIC and CEBAF at Jefferson Lab. But the EIC will have new features that greatly expand the ability to explore the building blocks of visible matter.

The EIC will be at Brookhaven Lab and JLab is a major partner in this project.

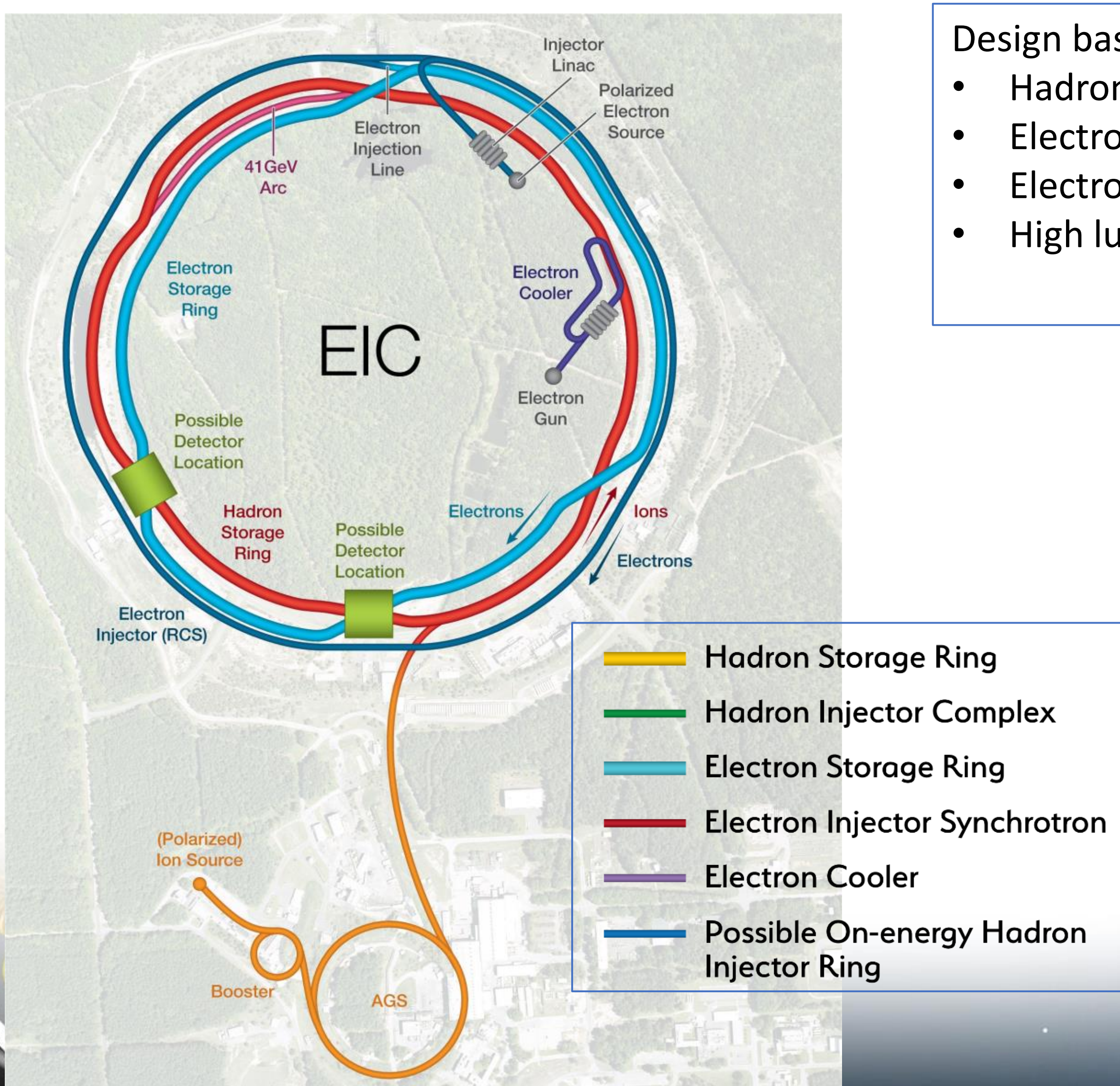
# EIC High Level Schedule





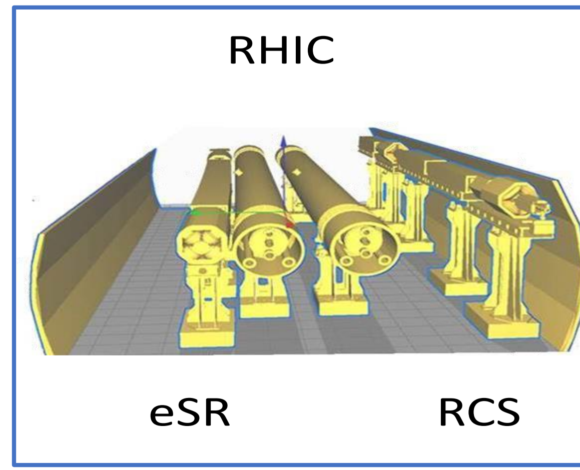

Electron-Ion Collider

# EIC- High Level View

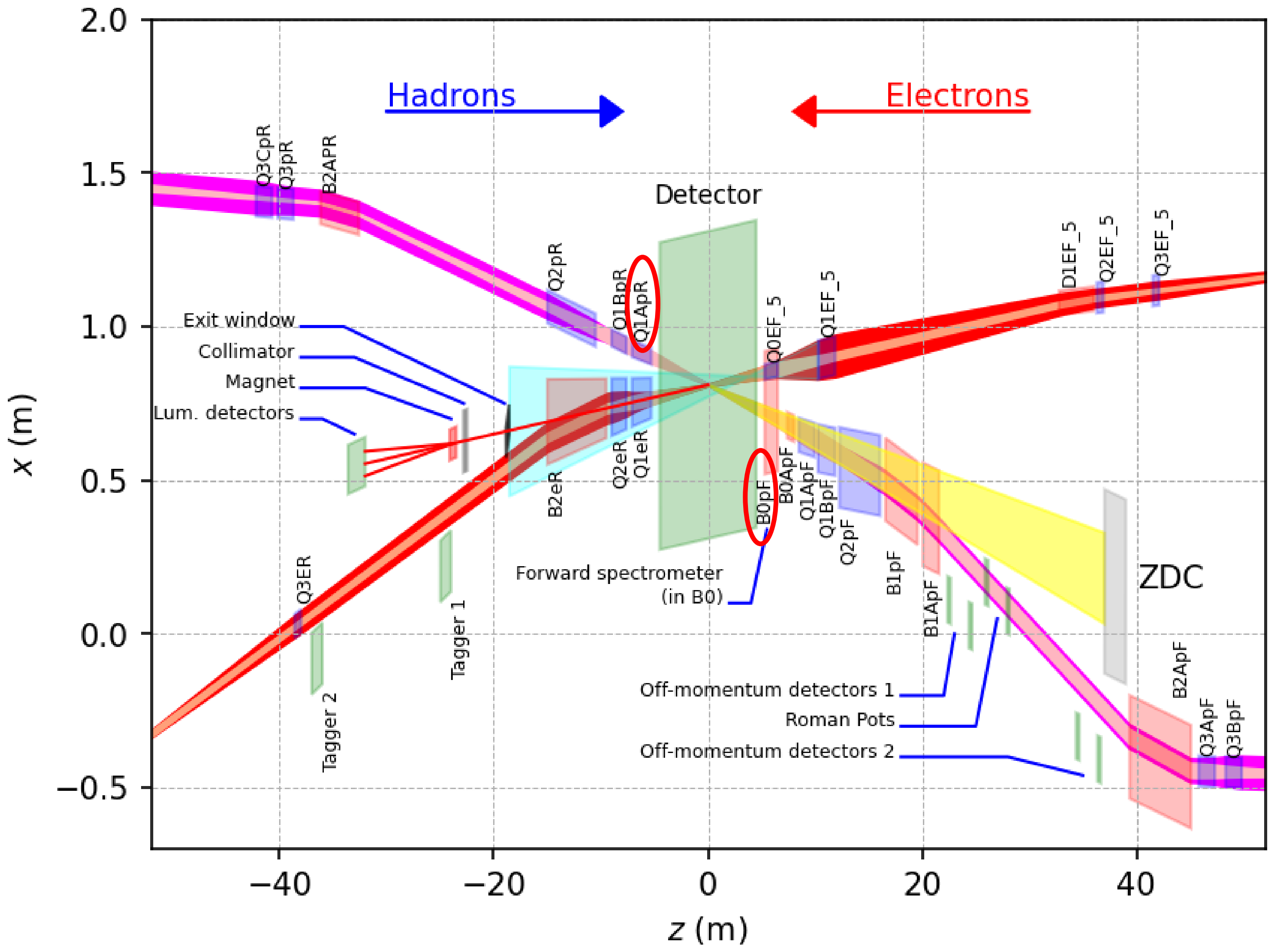



Design based on **existing** RHIC

- Hadron storage ring 40-275 GeV (existing)
- Electron storage ring (2.5–18 GeV (new))
- Electron rapid cycling synchrotron (new)
- High luminosity interaction region(s) (new)



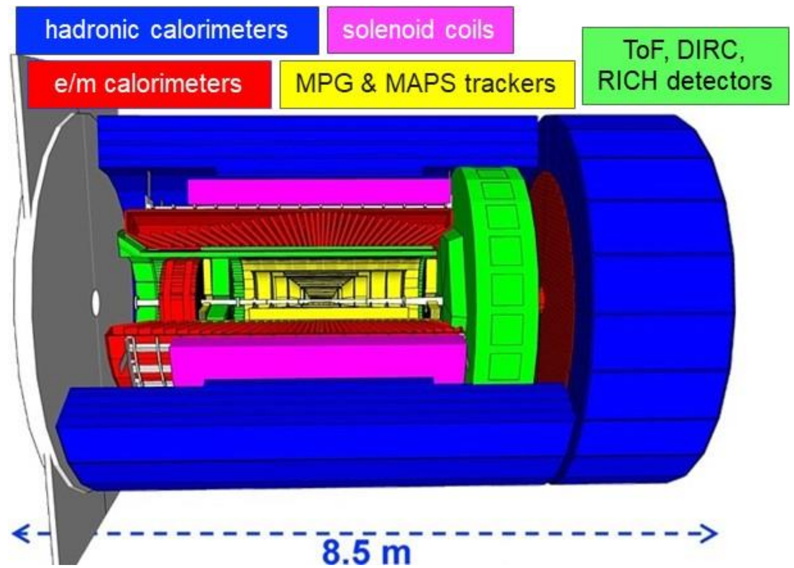
# Interaction Region



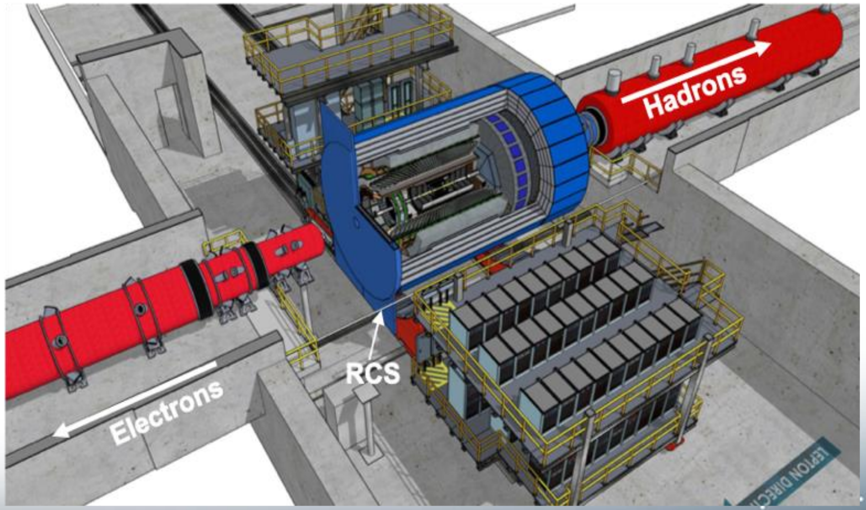

RCS is not shown in this view

# Detector Solenoid Overview

Superconducting Detector solenoid
- 3.5m long coil, 2.84 m room temperature bore diameter, 2T on-axis field
    - Old BaBAR/SPHENIX magnet as contingency
- Operating Temperature  4.5 K
- Conductor: Copper Cladded, Rutherford Cable made with  NbTi superconducting strands




Detector solenoid Design:
- The Detector solenoid is foreseen as a long-lead procurement item.
- In order to be ready for a long-lead procurement for the magnet at CD-2/3A, we need to complete the reference design, reference drawings and a SOW for the vendor by CD-2/3A
- CEA, Saclay  is our collaborator for the design phase.



# Detector Solenoid New Magnet Specifications

| Parameter | Detector 1-Solenoid |
|---|---|
| Central Field (T) | 1.5 |
| Coil length (mm) | 3512 |
| Warm bore diameter (m) | 2.84 |
| Polarity | Bipolar |
| Lowest operating field (T) | 0.5 |
| Flat Field area | ± 100 cm around center<br>80 cm radius |
| Field uniformity in Flat field Area (%) | 12.5 |
| RICH area | From z=+180 cm to 280 cn |
| Projectivity in RICH Area (mrad@30GeV/c)<br>Projectivity in RICH Area (A/Tmm$^2$) | 0.1<br>10 |
| Stray field requirement | <10G @ z=-5.3 m, @z=+7.4 m, and @R=3.4 m |
| Cryostat length (m) | <3.85 |
| Cryostat outer diamter (m) | <3.54 |
| Charging voltage (V) | 10 |
| Fast discharge voltage maximum (V) | 500 |
| Quench hot spot temperature (K) | <150 |
| Temperature margin (K) | >1.5 |
| Current margin (%) | >30 |
| Charging time (hr) | 2-3 |
| Cooldown time (weeks) | 3-4 |
| Cooling scheme | Thermosiphon |
| Conductor | ~~Al Stabilized NbTi Rutherford Cable~~<br>Cu Stabilized NbTi Rutheford Cable |
| Operating Temperature | 4.5 |

Accelerator fringe field requirements, under further study.

# Magnet- Area of interest

The solenoid Field specification document is finalized . There are three areas of importance from the magnetic field point of view, these are:

- Flat Field Area
- RICH detector Area
- Stray field limitation at IR magnets and RCS

**Flat Field Area:** This are is 200 cm long and 80 cm in radius around the IP, the field uniformity required in this area is 12.5%

**Stray Field:**

The detector solenoid has neighboring IR magnets, in order to reduce the effect of solenoid magnet on IR magnets, there is a requirement of stray field less than 5G at B0ApF and Q1ApR magnets, these magnets extends from z= 7.4 m to 8 m and z=-5.3 m to -7.1 m respectively.

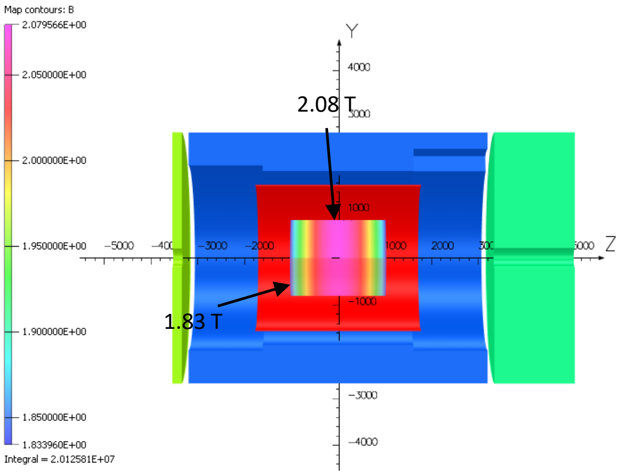
The RCS is radially 335.2 cm from the magnet central axis and stray field requirement there is <0.007 Tm

**RICH detector Area:** To maximize the RICH performance based on the gas radiator it is critical to minimize the bending of the tracks in the volume of the gas radiator. For this one needs to shape the field that it is parallel to the different scattering angles of particles covered by the RICH. The RICH area extends from z=+180 cm to +280 cm.

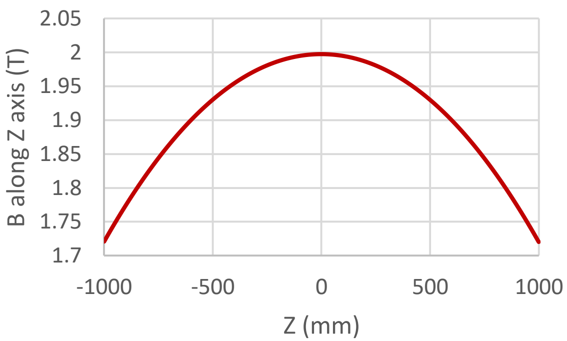
# 3D Magnetic Preliminary Design Results

| Parameter | Parameter Value | Units | Validation |
|---|---|---|---|
| Coil $R_{in}$ | 1509.5 | mm | OK |
| Coil $R_{out}$ | 1543.1 | mm | OK |
| Coil Length | 3492.0 | mm | OK |
| **3D RESULTS** | | | |
| B @ (0,0,0) | 2.000 | T | OK |
| Bpeak+self field | 2.602 | T | |
| Stored Energy | 45.7 | MJ | |
| B @ (0,0,-5300) | 61 | G | Tbd |
| B @ (0,0,7200) | 37 | G | Tbd |
| B @ (3400,0,0) | 62 | G | Tbd |
| Projectivity | 2.41 | $T/Amm^2$ | OK |
| Homogeneity | 12.3 | % | Validated by physics group |

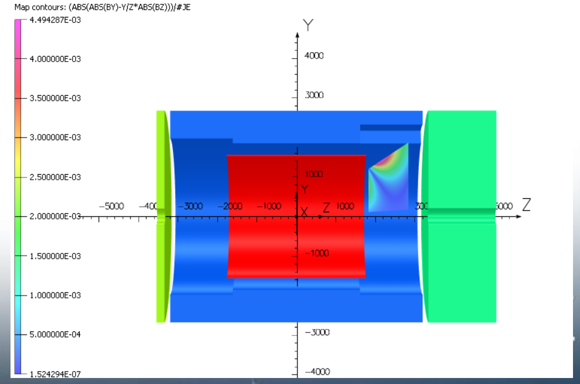
*Homogeneity region*




*B field along Z axis*

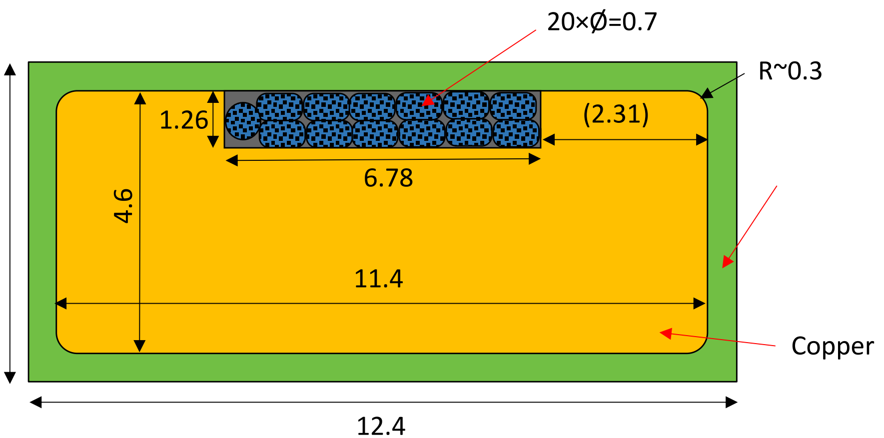



*RICH Projectivity*



# EIC Solenoid Conductor

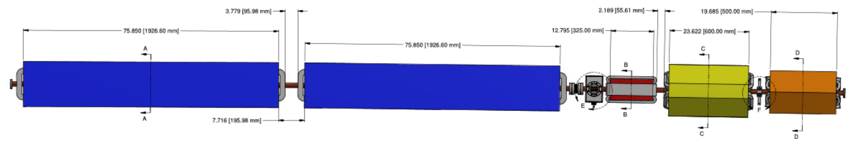
| | Parameters | Values | Units |
|---|---|---|---|
| Conductor | Nominal current | 3906 | A |
| | $B_0$ | 2 | T |
| | $B_{peak}$ | 2.6 | T |
| | Operating temperature ($T_{op}$) | 4.5 | K |
| | Max. conductor temperature ($T_m$) | 4.7 | K |
| | Temp. margin @ 2.6T & 4.7K | 2.5 | K |
| | Hot spot Temperature | 67.3 | K |
| | $\sigma_{0.2\%}$ | >165 | MPa |
| | Unit length (supposed) | 2 | km |
| | Total length | 16.2 | km |
| | Coils weight (impregnated) | 7.9 | t |
| Strand | Strand diameter | 0.7 | mm |
| | Cu/NbTi | 1.3 | |
| | Ic @ 2.6T & 4.7K | >680 | A |
| | Filament diameter | <70 | µm |
| | RRR Cu | >80 | |
| Cable | Nb strands | 20 | |
| | Transposition pitch | 50 | mm |
| Channel | RRR Cu | >100 | |
| | Copper section (Final) | 43.7 | $mm^2$ |



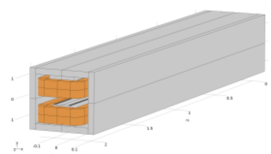

*Dimensions are in mm*

# Other Magnets in EIC

| RCS | Dipole | Quads | Sextupole | Corrector |
|---|---|---|---|---|
| Qty. | 384 | 534 | 420 | 276 |
| Length (m) | 4.24 | 0.6 | 0.5 | 0.27 |

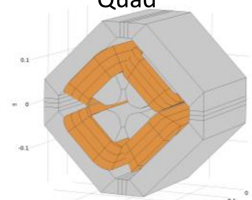


Dipole



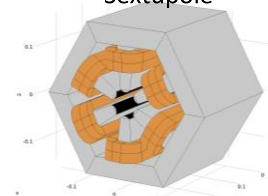
B=0.234T

Quad



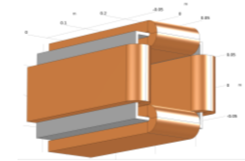
G=22.2 T/m

Sextupole



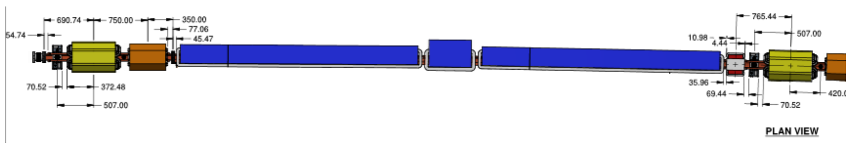
$G_s$=280 T/m$^2$
(63mT at 15mm)

Corrector



$B_{dipole}$=6.5 mTm

| ESR | D1/D3 | D2 | Quads | Sextupole | Corrector |
|---|---|---|---|---|---|
| Qty. | 504 | 252 | 494 | 308 | 247 |
| Length (m) | 3.25 | 0.6 | 0.6 | 0.5 | 0.25 |



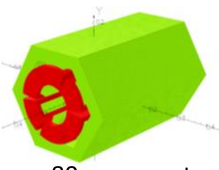

Dipoles

52 mm gap
B=0.252/0.7T

Quad

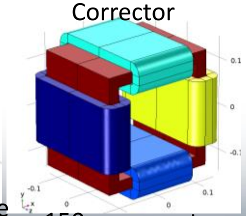
74 mm aperture
G=18T/m

Sextupole



80 mm aperture
$G_s$=360T/m$^2$
(81mT at 15mm)

Corrector



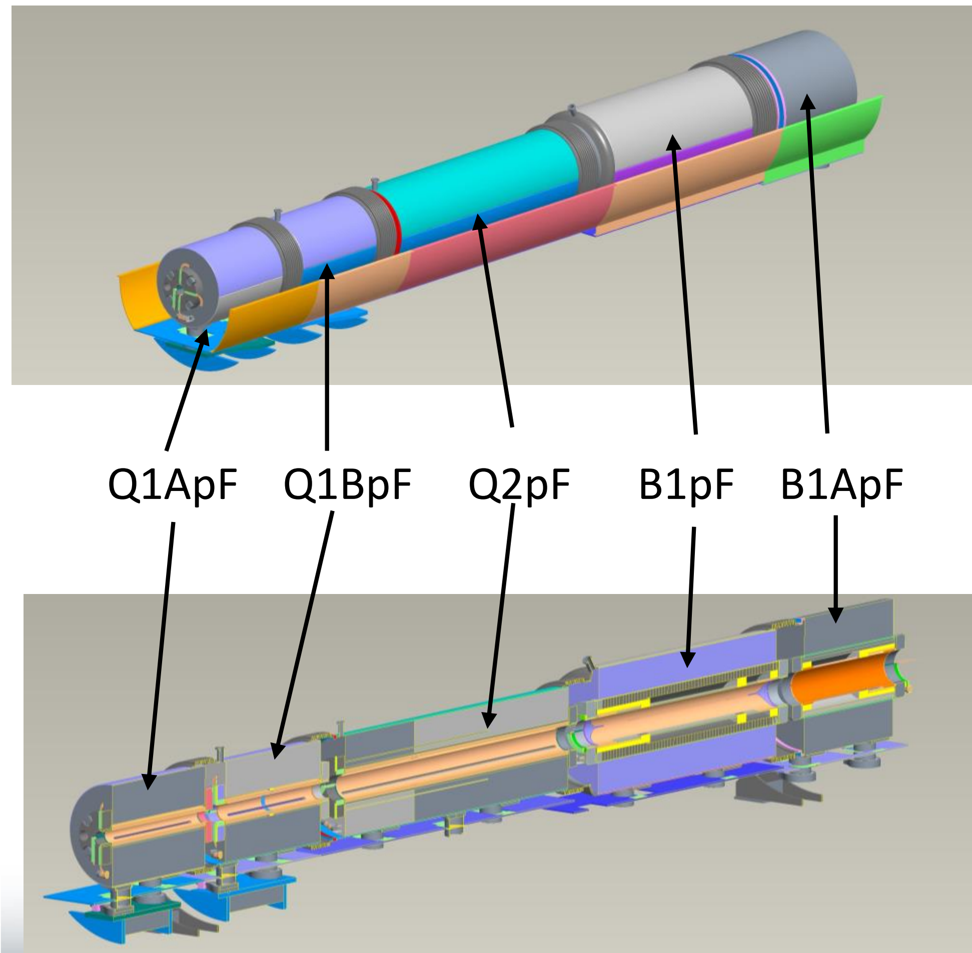
150 mm aperture
$B_{dp}$=6mTm

Courtesy Holger Witte, BNL

# Other Superconducting Magnets

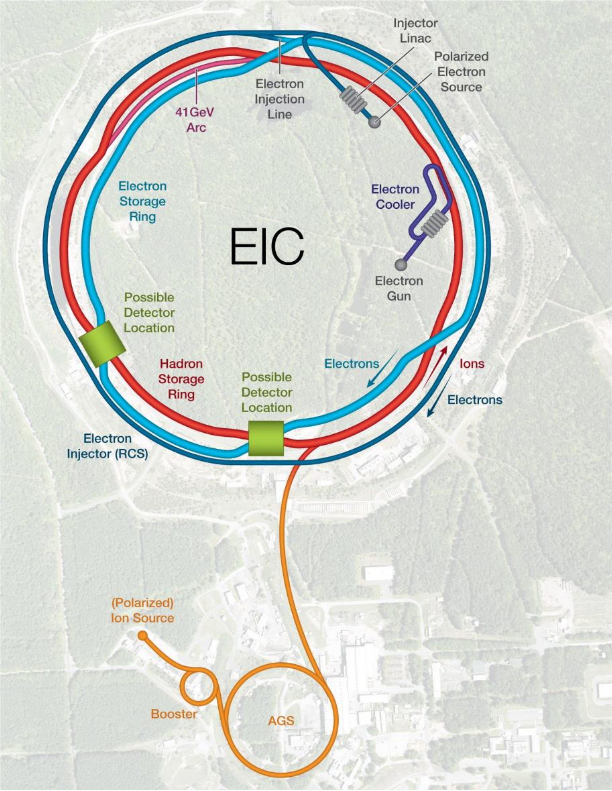
- Spin Rotator Solenoids (not shown here)
  - 16 modules, 3m long, 7T on-axis field
- IR Magnets
  - Five collared magnets
    - Dipoles and quads
    - Based on Rutherford cable
  - NbTi, 2K operation
  - Cold mass only
    - One cryostat for all magnets
  - Additionally: Matching dipoles
    - 5T dipoles, 4m long

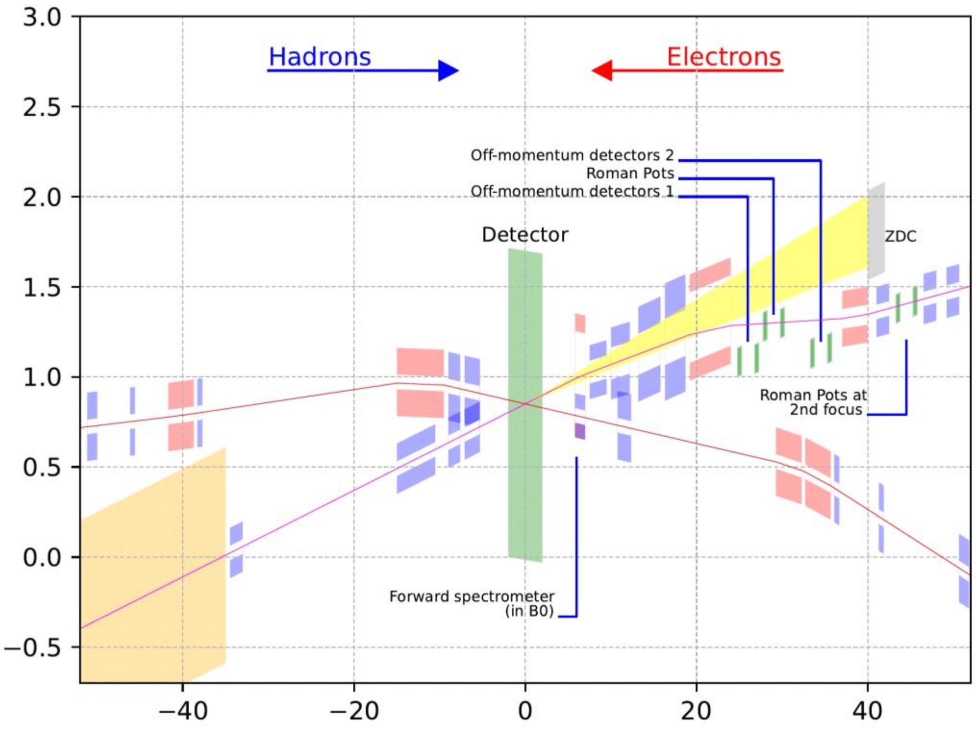
Courtesy Holger Witte, BNL




| Name | R1 | length | B | grad | B pole |
|---|---|---|---|---|---|
| | [m] | [m] | [T] | [T/m] | [T] |
| Q1ApF | 0.056 | 1.46 | 0 | -72.608 | -4.066 |
| Q1BpF | 0.078 | 1.61 | 0 | -66.18 | -5.162 |
| Q2pF | 0.131 | 3.8 | 0 | 40.737 | 5.357 |
| B1pF | 0.135 | 3 | -3.4 | 0 | -3.4 |
| B1ApF | 0.168 | 1.5 | -2.7 | 0 | -2.7 |

# 2nd IR

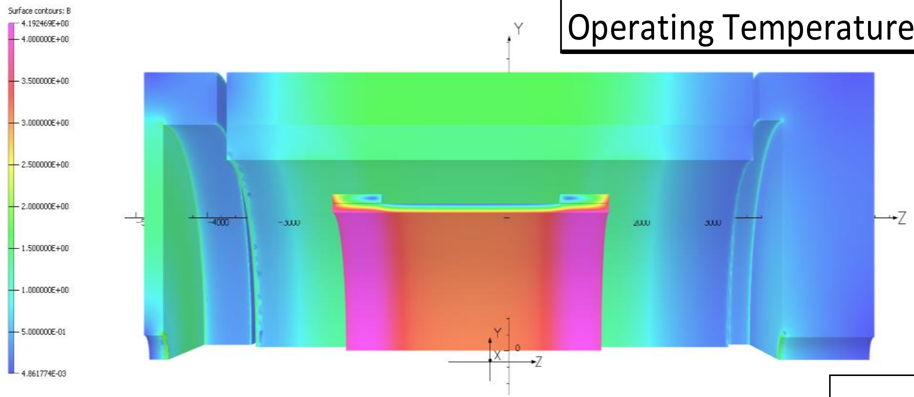



- 2nd ID and 2nd Detector is not in the funded scope as of now.
- One of the next levels of detailed design relevant to physics performance is detector solenoid integration is in progress
- Solenoid field could be higher (~3T)
- Solenoid will probably need Al-Stabilized Rutherford cable

# 3T Solenoid Design

| Parameter | Requirement |
|---|---|
| Central Field (T) | 3 |
| Coil length (m) | 3.6<br>(to fit in 3.84 m long cryostat) |
| Warm bore diameter (m) | 3.2 |
| Conductor | NbTi in Cu Matrix- Aluminum Stabilized |
| Operating Temperature (K) | 4.5 |




| Thickness/Nuclear interaction length | | | |
|---|---|---|---|
| Material | BaBAR | Marco (2T) | ATHENA/SOCRATE (3T) |
| Al | 0.34 | 0.00 | 0.65 |
| Cu | 0.01 | 0.17 | 0.17 |
| SS | 0.00 | 0.24 | 0.42 |
| NbTi | 0.01 | 0.01 | 0.02 |
| | | | |
| Total | 0.36 | 0.42 | 1.26 |

# Summary

- EIC is a DoE (Department of Energy) funded project and most of the sub-systems are in advanced stage of design.
- CD2/3A is scheduled in January 2024, long lead procurement can start after CD2/3A.
- Detector solenoid for the first detector is in advance stage of design.
- Design is expected to be complete by October 2023.
- Copper stabilized Rutherford cable is required for this magnet
- The 2nd IR conceptual design work is progressing well, 2nd detector might need higher field solenoid, that will be need Aluminum stabilized Rutherford cable.
- There are other superconducting and resistive magnets required for this project.

# Acknowledgement

I would like to thank my team members for all the work, EIC detector solenoid team is spread over 3 main institutes. All the team members are:

- JLab:
    - Rolf Ent, Walter Wittmer, Mitch Laney, Giuseppina (Jessie) Tenbusch, Probir Ghoshal, Eric Sun, Sandesh Gopinath, Dan Young, and Kaiyi Hall
- BNL:
    - Elke Aschenauer, Roberto Than, Holger Witte, Alexander Kiselev, Rahul Sharma and Roland Wimmer
- CEA, Saclay:
    - Lionel Quettier, Valerio Calvelli, Christophe Berraud, Francesco Stacchi, Francois-Paul Juster, Hugo Reymond, Michel Segreti, Jean-Pierre Lotin, and Damien Simon