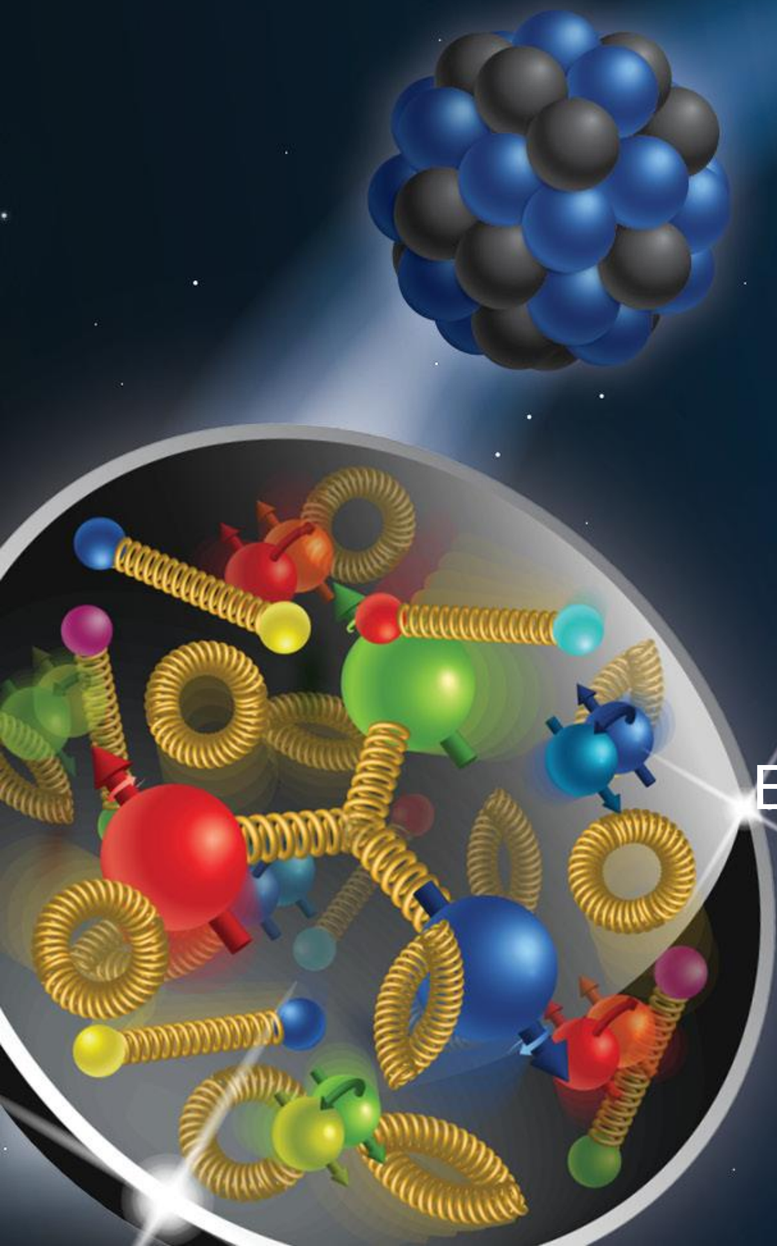


Overview IR and Magnet Requirements

H. Witte, BNL

EIC Accelerator Partnership Workshop

October 26, 2021

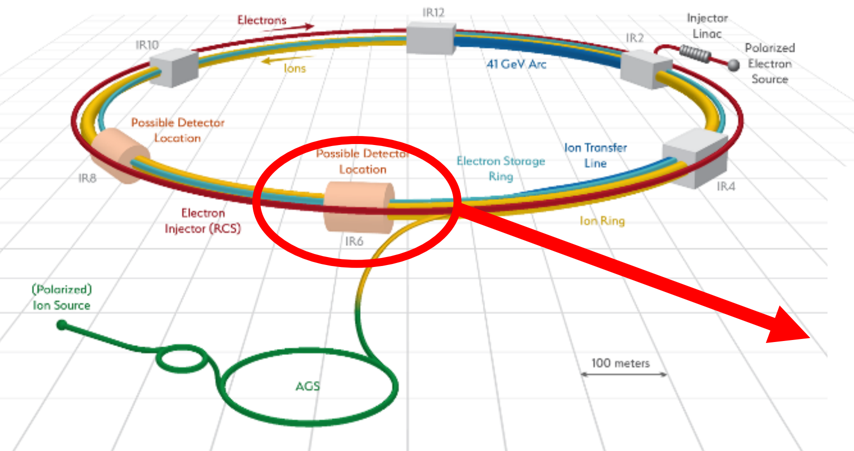
Electron-Ion Collider

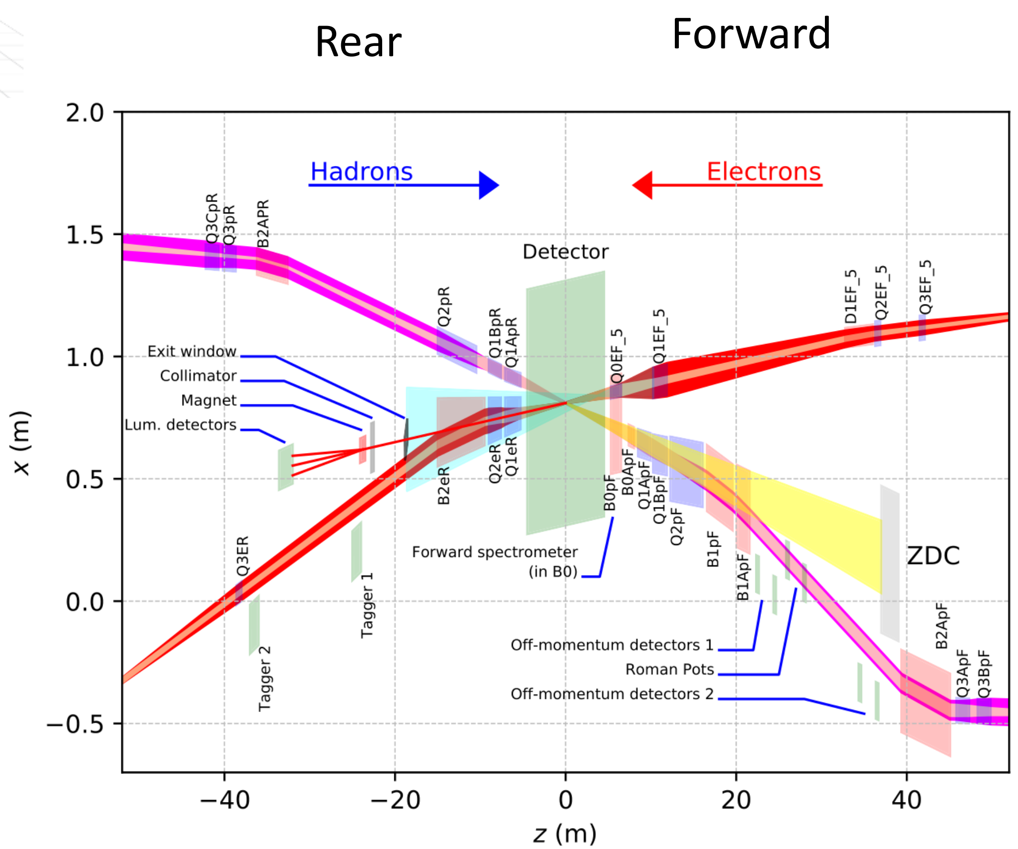
BROOKHAVEN NATIONAL LABORATORY
Jefferson Lab
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- EIC IR
- Magnet Requirements
  - Inner IR
  - Matching Magnets
  - Superconducting Solenoids
  - Rutherford Cable
- Summary

EIC IR: Overview





Hadron storage ring (HSR): 4 yellow and 2 blue RHIC arcs

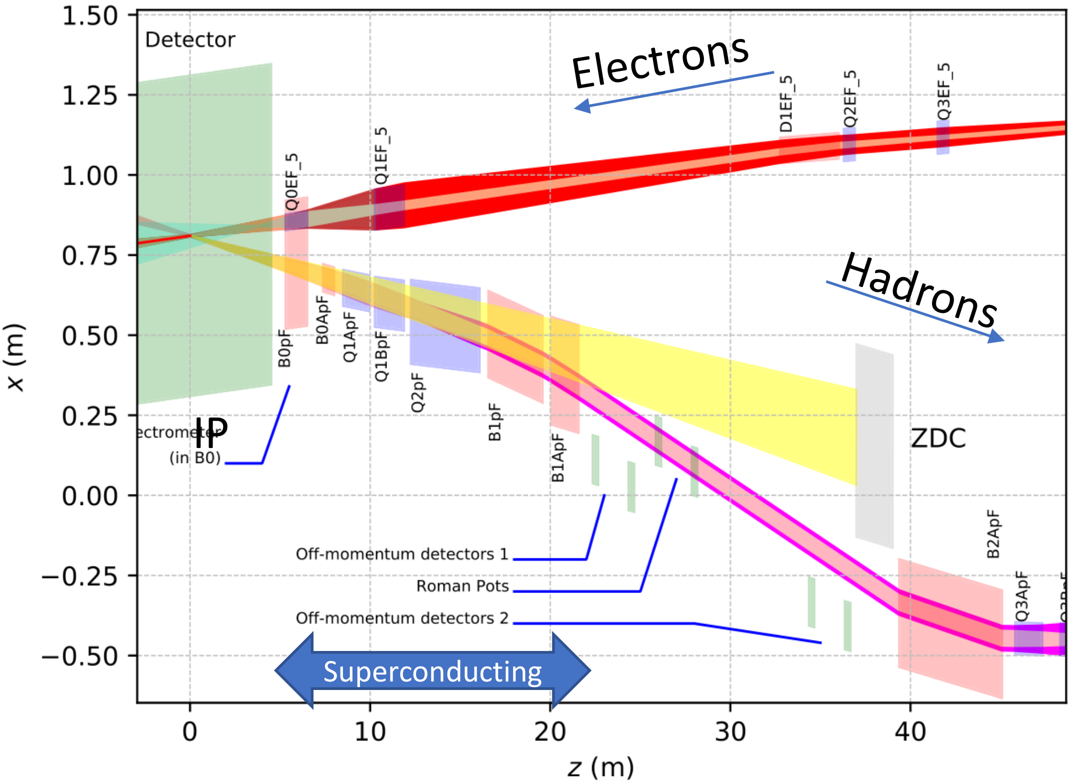
Add electron storage ring (ESR) in existing tunnel (and the RCS)

IR location: IR6

IR Requirements

- EIC IR designed to meet physics requirements
  - **Machine element free region**: -4.5m/5m main detector
  - ZDC: 60cm x 60cm x 2m @ ~30 m
  - **Scattered proton/neutron detection**
    - Protons 0.2 GeV < p_t < 1.3 GeV
    - Neutron cone +/- 4 mrad
- Machine requirements
  - Small β^*_y: quads close to IP, high gradients for hadron quads
  - **Crossing angle**: as small as possible to minimize crab voltage and beam dynamics issues
    - Choice: 25 mrad
  - **Synchrotron radiation** background
    - No bending upstream for leptons (up to ~35m from IP)
    - Rear lepton magnets: aperture dominated by sync fan

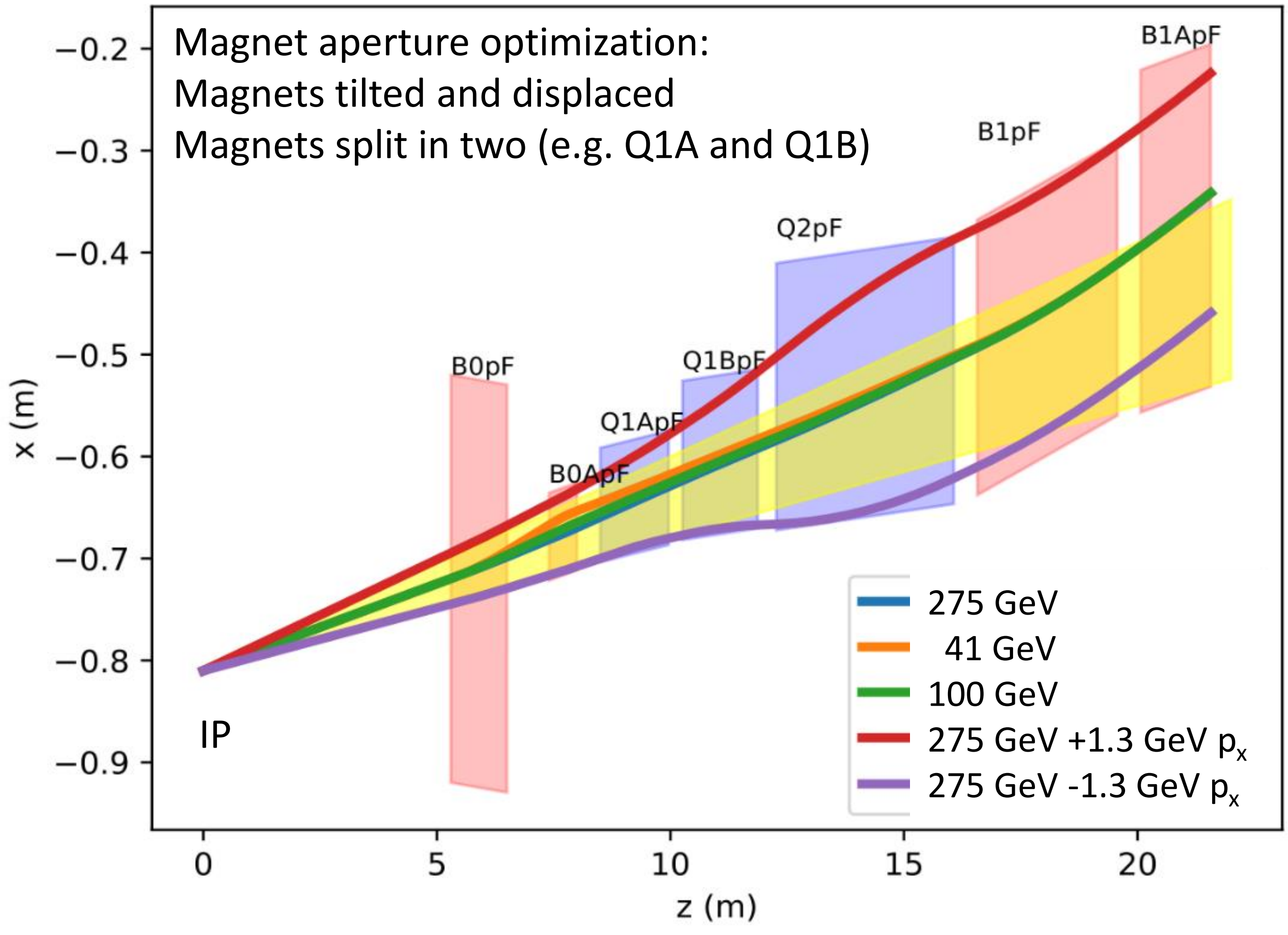
EIC IR: Forward Direction



Name	R1	length	B	grad	B pole
	[m]	[m]	[T]	[T/m]	[T]
B0ApF	0.043	0.6	-3.3	0	-3.3
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

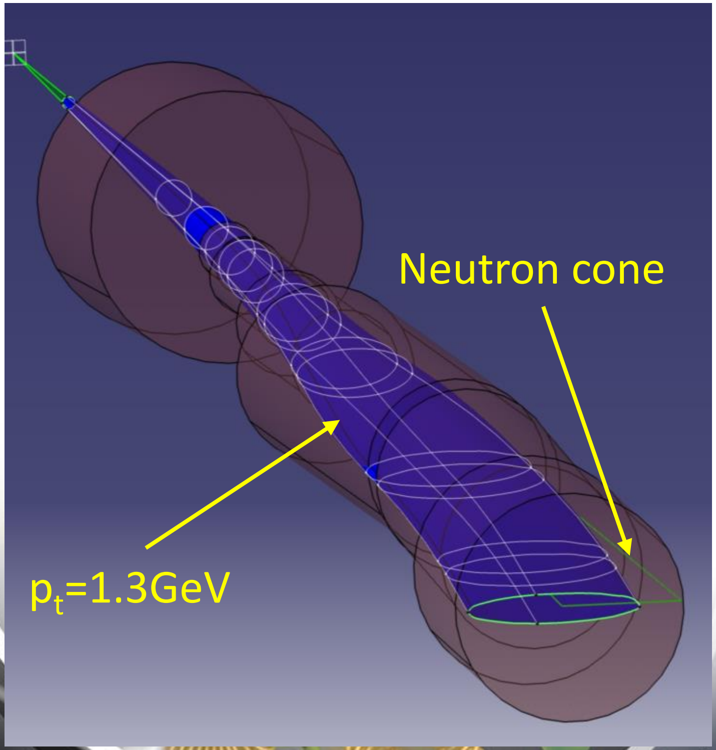
- Interleaved magnet scheme
  - Adding magnets is challenging
- Why are these magnets difficult?
  - Required field
  - Aperture
  - Geometric constraints
- Field
  - Accelerator physics
  - Hall/ring geometry
  - Magnet technology constraints
- Large apertures of magnets
  - Proton forward: physics
  - Rear electron: Synrad

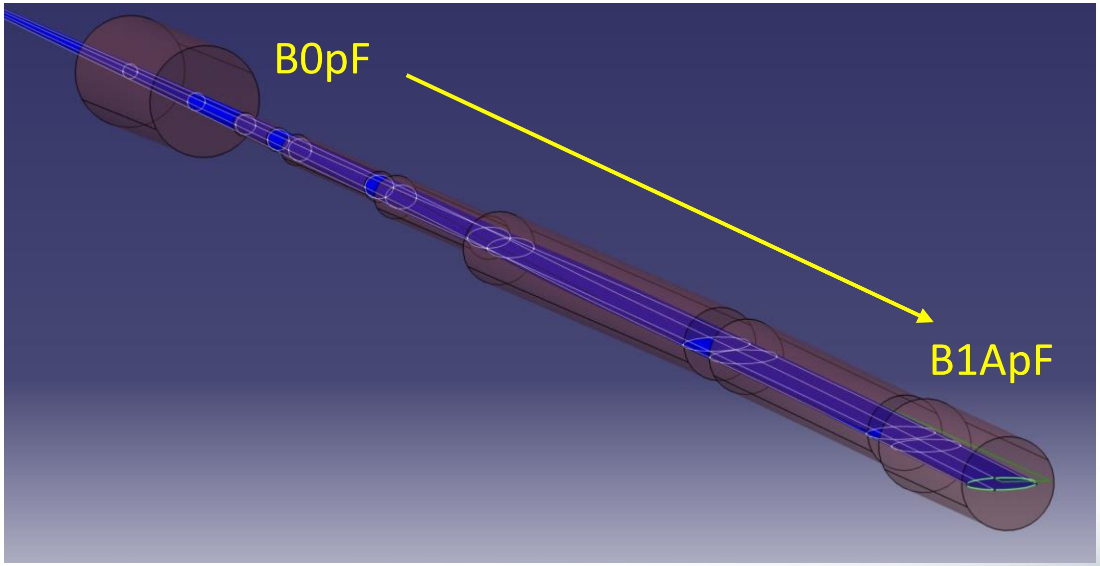
Hadron Forward - Apertures



Acceptance Studies

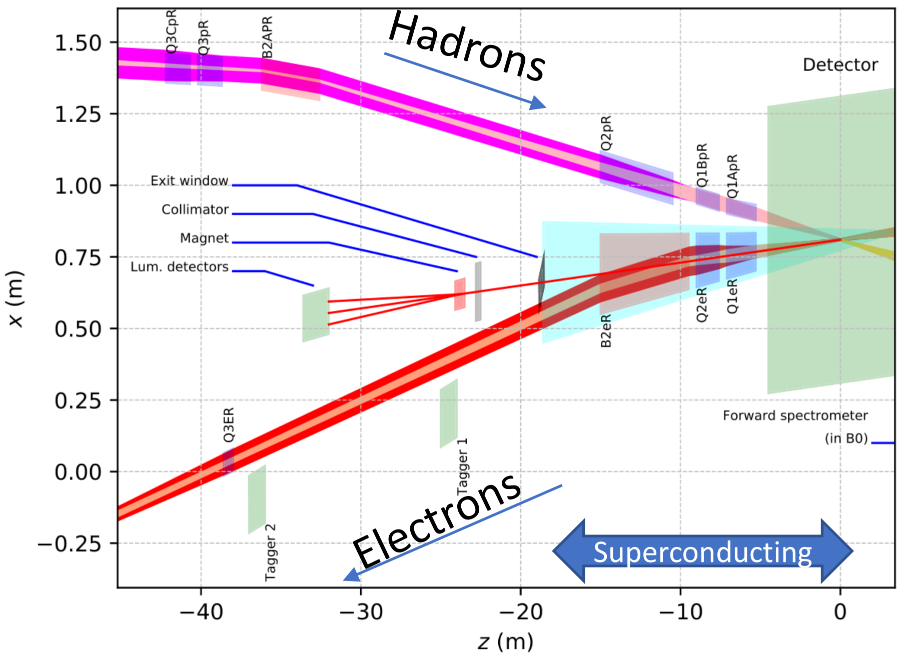
- Checked with two codes
  - BMAD – general purpose tracking code
  - Geant4 (friends from Physics)
- Cross-check allowed to identify error
  - Now perfect agreement





Generate cone for particles with p_t=1.3GeV
Rendered in CAD program with magnet apertures

EIC IR: Rear Direction



- 2-in-1 magnets
  - Common yokes
- Main issue: space between magnets
  - Crossing angle
- Large aperture due to synrad fan
  - Comes from low-beta quads

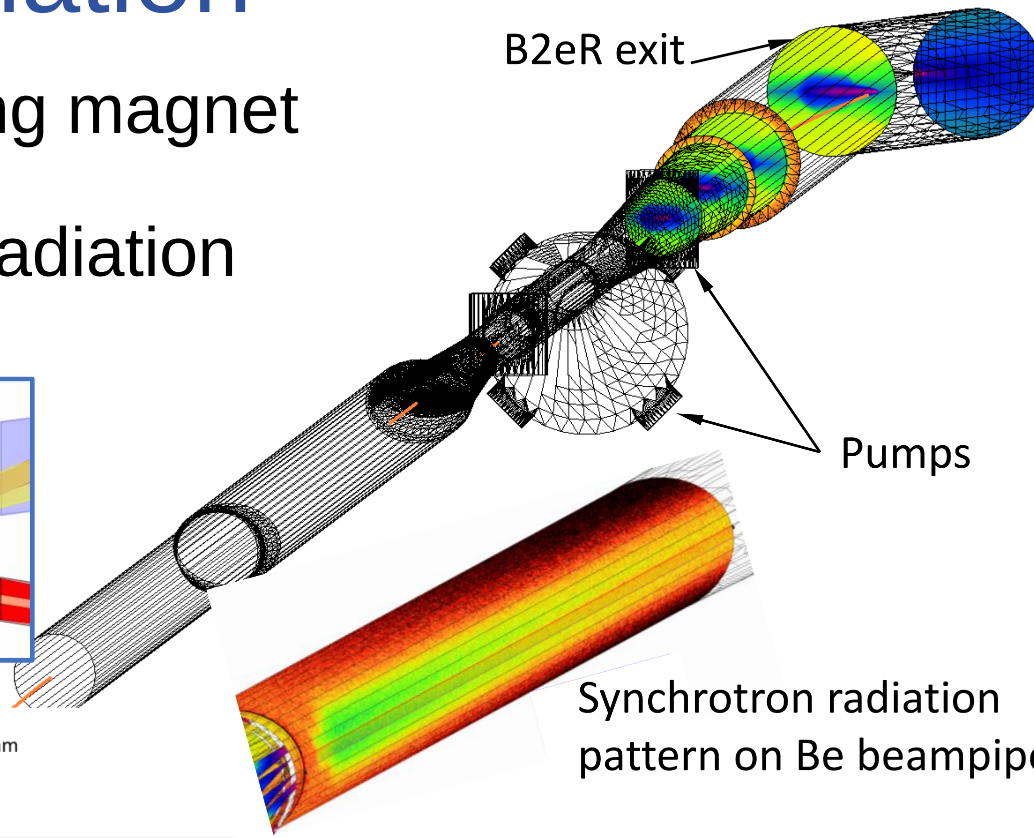
Name	R1	R2	length	grad	B pole
	[mm]	[mm]	[m]	[T/m]	[T]
Q1ApR	20	26	1.8	78.4	2.0
Q1BpR	28	28	1.4	78.4	2.2
Q2pR	54	54	4.5	33.8	1.8

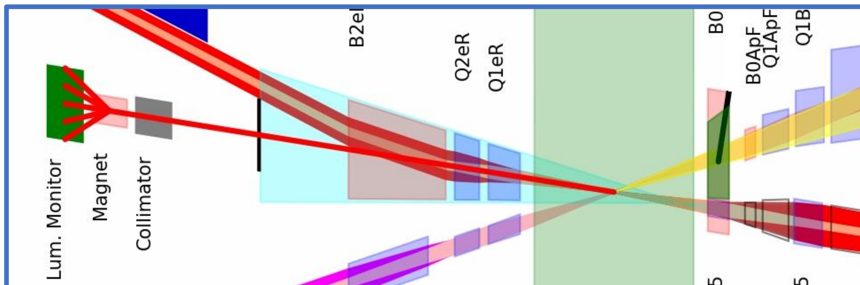
Name	R1	R2	length	B	grad	B pole
	[mm]	[mm]	[m]	[T]	[T/m]	[T]
Q1eR	66	79	1.8	0	14	-1.1
Q2eR	83	94	1.4	0	14.1	1.3
B2eR	97	139	5.5	0.2	0	-0.2

For technical reasons B2eR will be split into two magnets

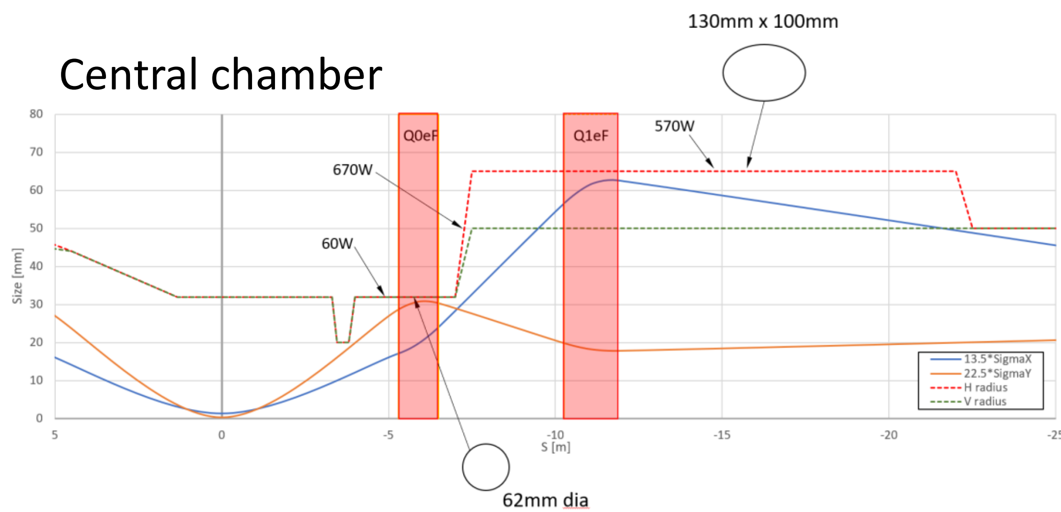
Synchrotron Radiation

- Origin: quads and bending magnet upstream
- Tails: can produce hard radiation
  - Non-Gaussian





Synchrotron radiation pattern on Be beampipe



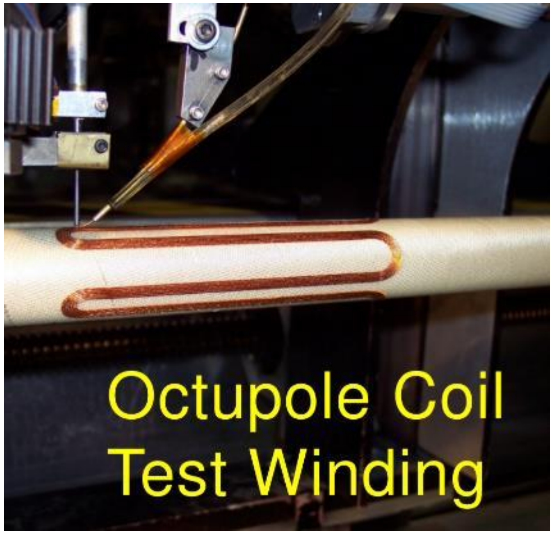
Beam pipe envelope and synrad heating

Even with masking: significant heating to deal with

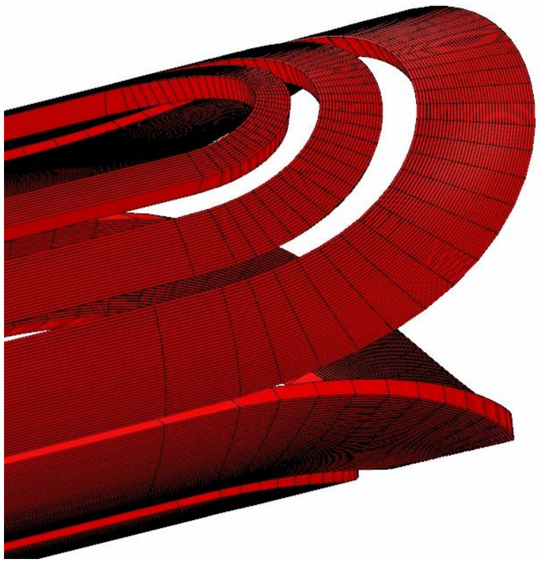
Courtesy C. Hetzel

IR Magnets - Overview

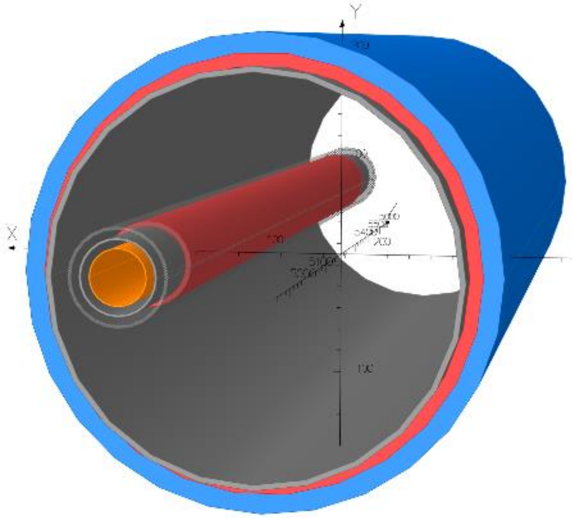
- Three groups of superconducting magnets
  - All NbTi
  - Forward direction: 2K
  - Rear direction: 4K



10 Direct Wind Magnets (S-MD)



5 Collared Magnets

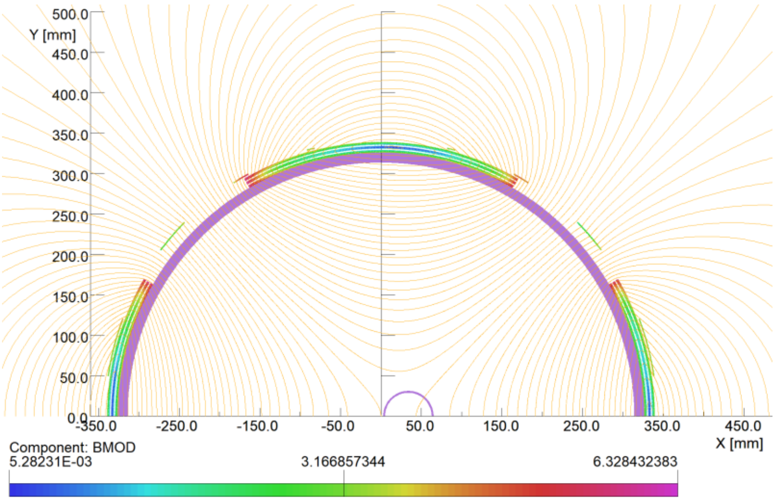


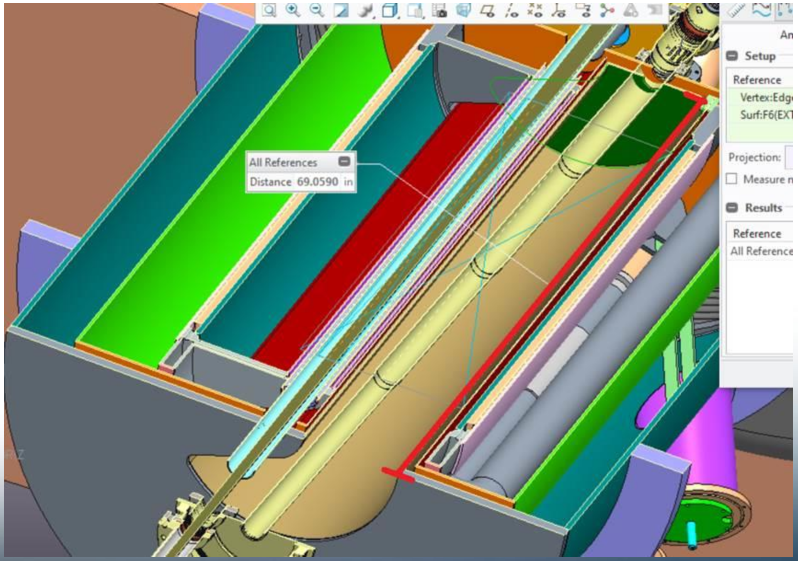
1 Special Magnet

See talk by K. Amm: EIC IR Magnet Designs and BNL Magnet Capabilities

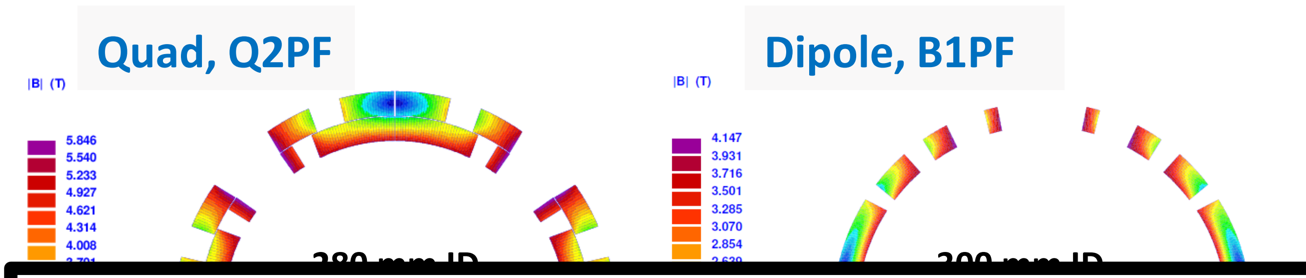
Forward Spectrometer

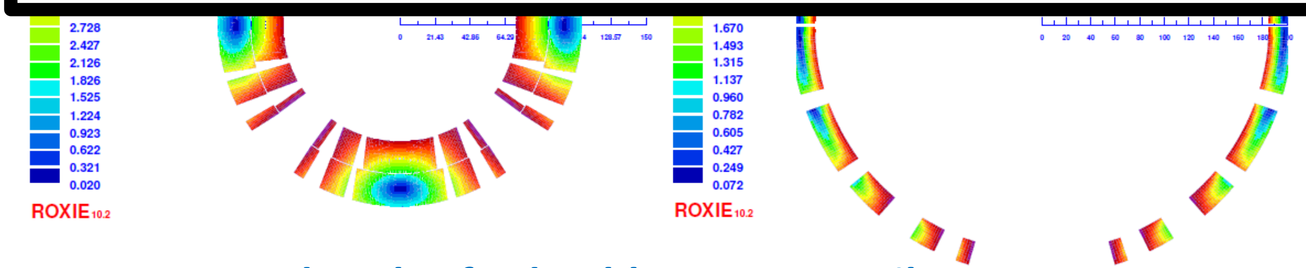
- Beams share magnet aperture
  - Hadrons: 1.3T field
  - Electrons: 14T/m gradient
- Implementation: combined function magnet
  - Large aperture quadrupole; zero field axis shifted with dipole
- Space constraints/large aperture
  - Requires 2K
- Courtesy of B. Parker (BNL)





Hadron Forward Rutherford Cable Magnets



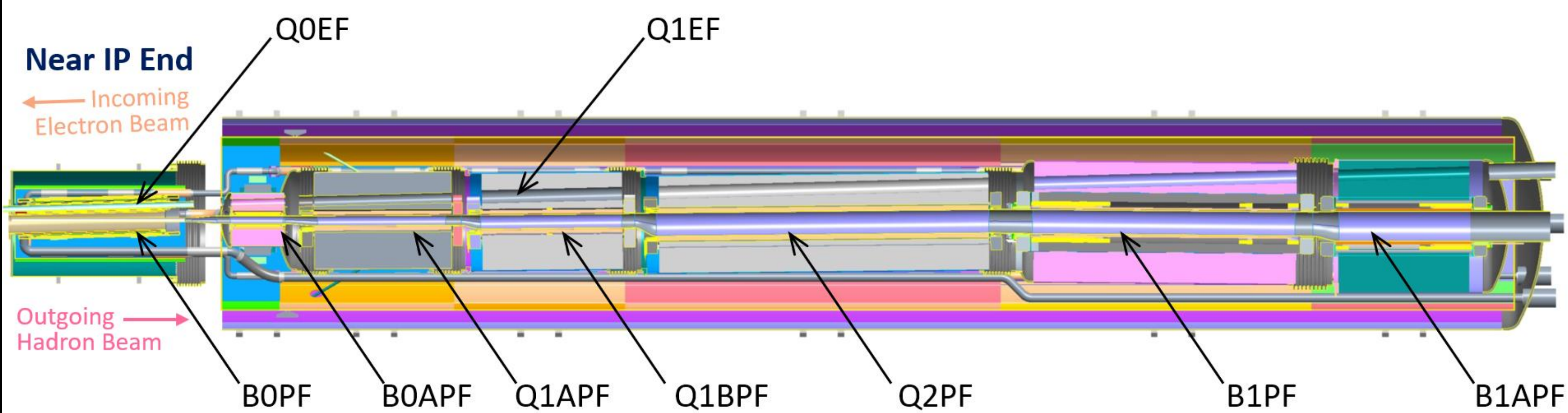


Some Forward Rutherford Cable Magnet Coils

- These designs require 2K cooling in order to reduce cross talk between the electron and hadron beam.
- Cross talk is acceptable

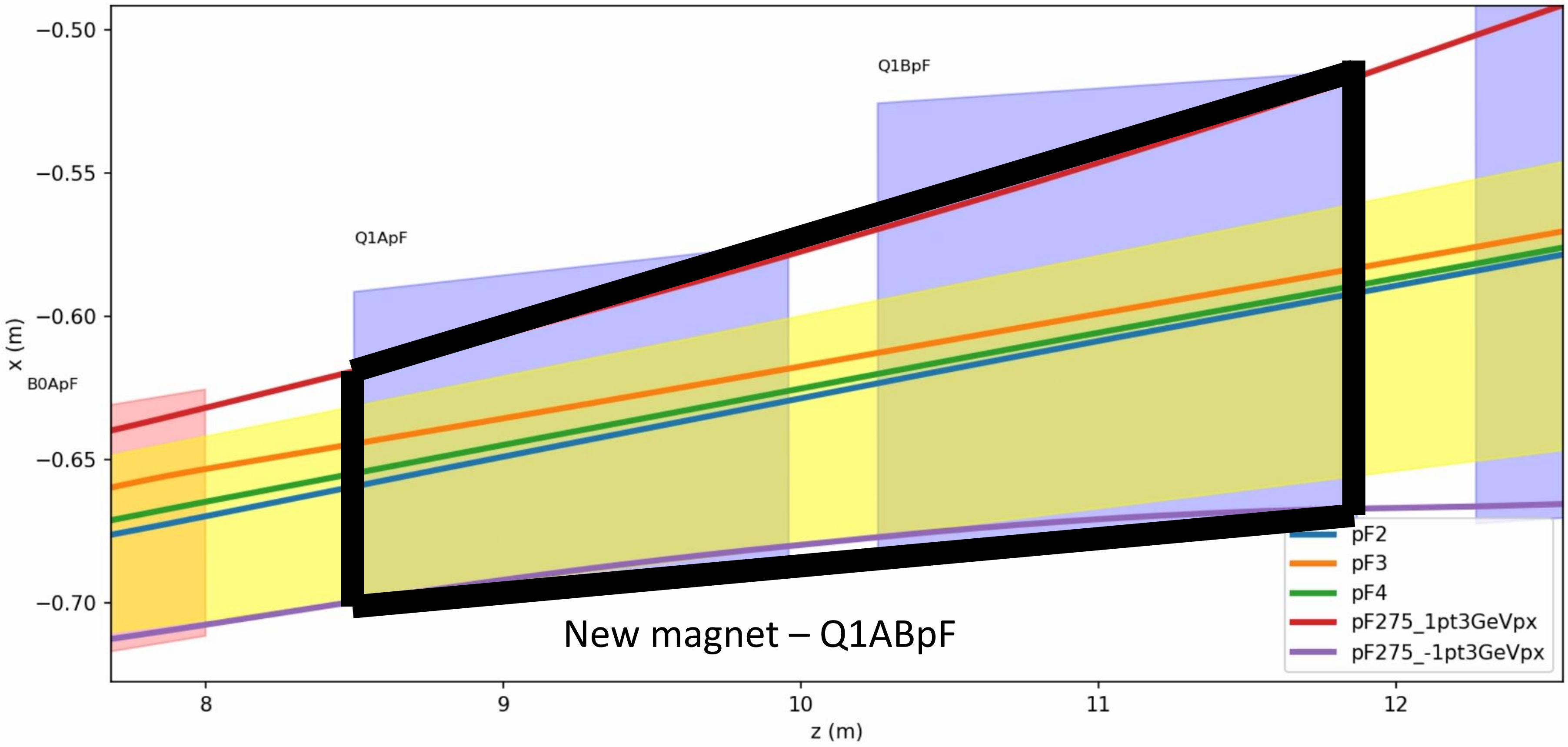
Forward side: two cryostats.

Courtesy Superconducting Magnet Division, BNL



Q1ABpF – New Magnet Concept

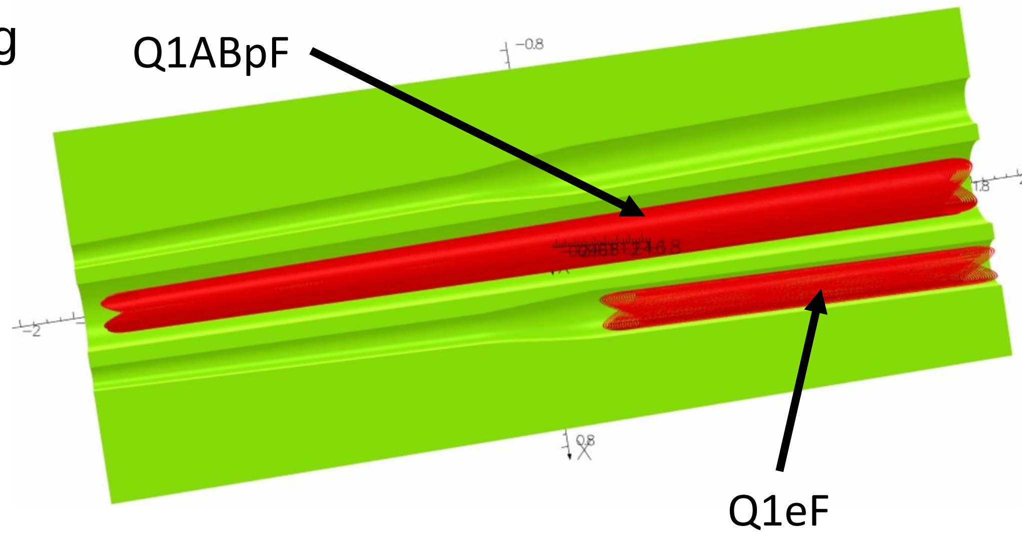
Recombining Q1ApF and Q1BpF

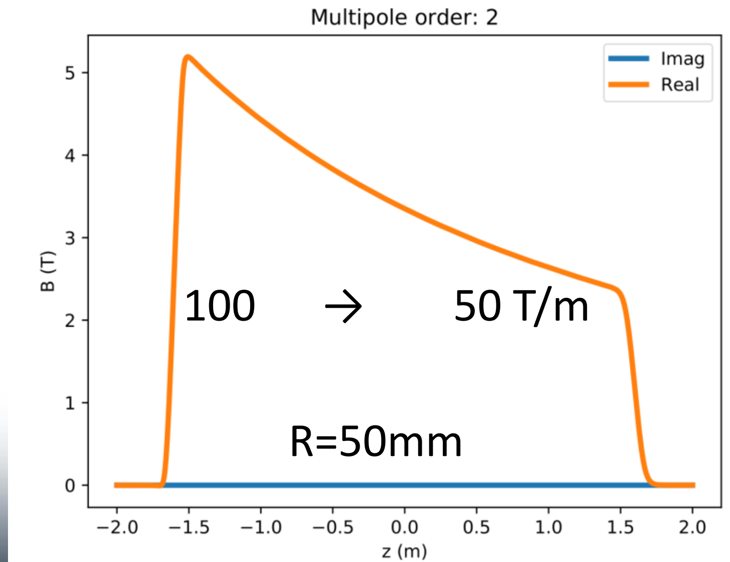


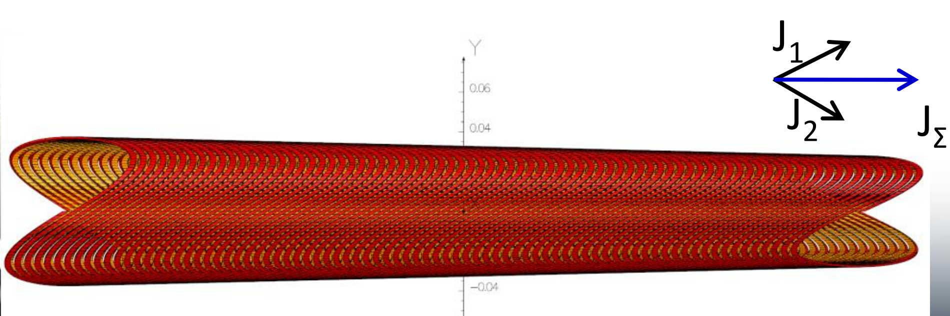
Advantages: No end plates, making use of additional space between magnets
Smaller aperture at IP side

Resolves Several Issues

- Implementation:
  - Canted Cosine Theta winding pattern
  - (or double-helix)
  - Two wires, intersecting at an angle
  - Creates desired current distribution
- Helps crosstalk / field quality
- Frontloading of gradient
  - Helps optics
- Challenges
  - Need to prove that this works mechanically

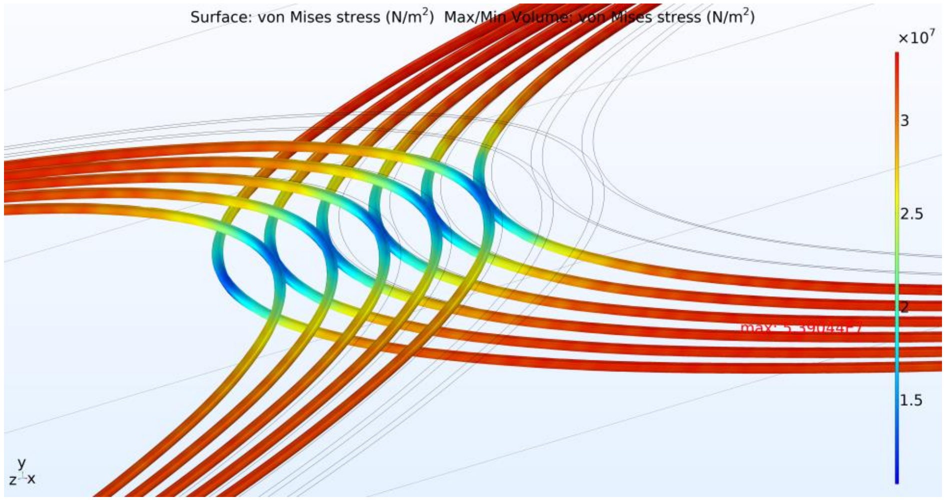


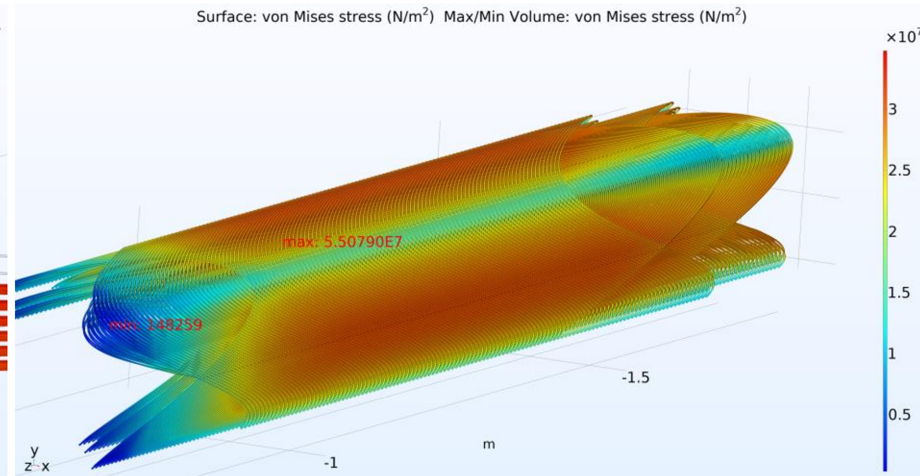


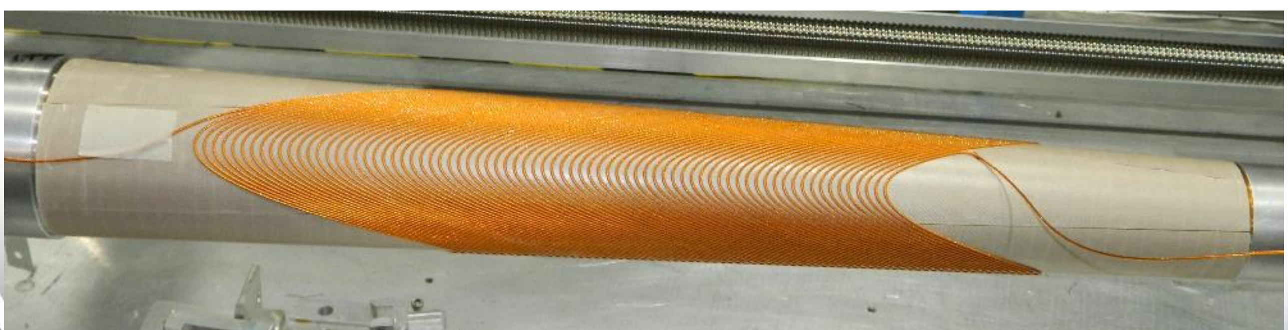


Mechanical Analysis

- Issue: complexity
  - 3D problem, need to model each strand/cable



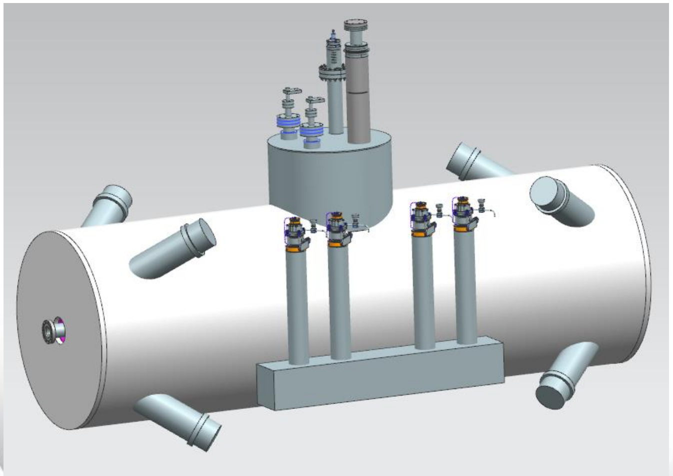


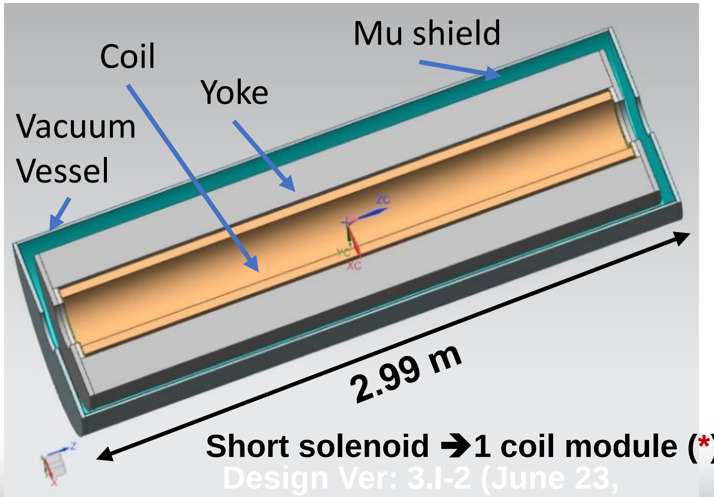


- Proof-of-principle
  - 7/16/2020
- BNL LDRD
- Implemented using direct-wind

Spin Rotator Magnets

- Required for spin rotator section, part of IR
- Short and long solenoid sections (3m and 9m)
  - Long solenoid: three short solenoids
- WBS: Includes all labor and materials for superconducting electron spin rotator solenoids for 18 GeV operation
  - Design, fabricate, test & measure
- Included: magnet cryostats & supports and girders
- See talk by T. Michalski: EIC Superconducting Spin Rotators





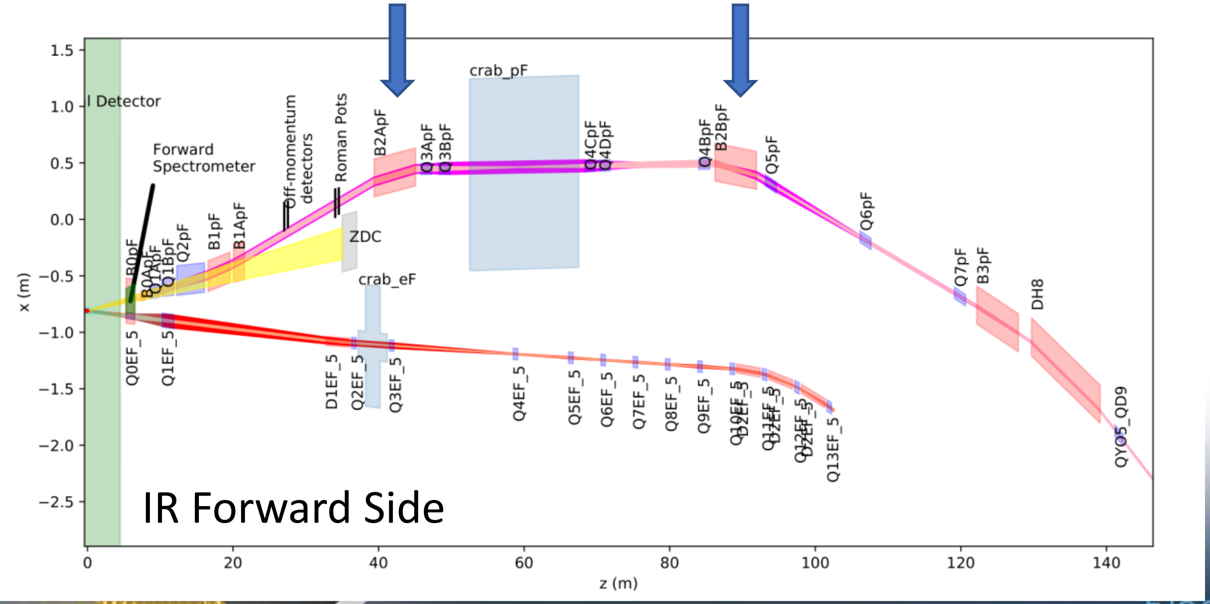
Short solenoid ➔1 coil module (*)

Design Ver: 3.I-2 (June 23, 2020)

Electron Spin Rotator	
Parameter	**Value**
	EM design
Operating current (At)	14,589,342
Central field (T)	6.79
Integrated field (Tm)	18.33
Magnetic length (m)	2.7
Peak field in the coil winding (T)	6.794
Magnetic Stored Energy (MJ)	3.37

Matching Magnets

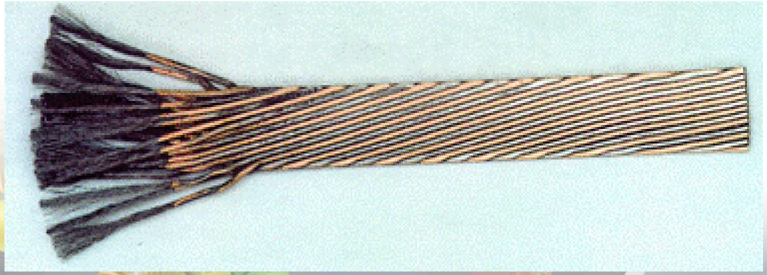
- Hadron beam needs to be matched into existing RHIC ring
- Using mostly existing RHIC magnets
  - Re-location/re-cryostating of magnets
- Need two new dipole magnets
  - 5T, 4.5m long
  - Aperture: 100mm diameter



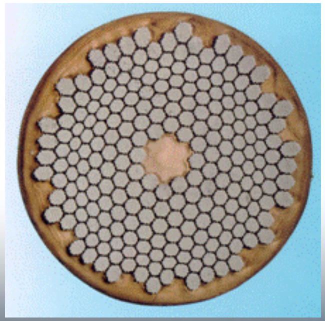
Rutherford Cable

- Short-term: R&D magnet
- All IR Magnets: 15 km
  - Strand procurement
  - Cable manufacturing
  - Strand and cable test
  - Keystoned (two variants)
- Also: 15km for detector solenoid
  - No keystone

Rutherford cable



NbTi Strand



Preliminary specs:
Strand dia =1.065 mm
Cu/Sc =1.6
Cable: 36 strands
Cable geometry:
19.4x1.773 (2.027) mm^2

Summary

- EIC: challenging IR
  - Geometric constraints
  - Driven by physics needs
- Superconducting magnet requirements
  - IR magnets
  - Superconducting spin rotator solenoids
  - Matching magnets
- IR magnets: collared, direct wind, CCT
  - NbTi
  - 2K and 4K
- R&D programme
  - Collared magnet
  - Tapered CCT magnet

Acknowledgements

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… and many more!

Additional Slides

Forward Hadron Magnets

	Length	**IR1**	**Pole tip field R1**	**Dipole Field**	**Gradient**
	m	cm	T	T	T/m
B0pF	1.2	17		-1.3	
B0ApF	0.6	4.3		3.3	
Q1ApF	1.46	5.6	4.07	0	-77.903
Q1BpF	1.61	7.8	5.16	0	-63.028
Q2pF	3.6	11.3	5.36	0	39.736
B1pF	3	13.5		3.4	
B1ApF	1.5	16.8		2.7	

IR1: inner radius (= clear aperture) at coil beginning
Pole tip field R1: IR1*gradient

Collared coils, apart from B0pF and B0ApF (direct wind)

Forward Electron Magnets

	Length	IR1	IR2	Pole tip field R1	Pole tip field R2	Gradient
	m	cm	cm	T	T	T/m
Q0eF	1.2	2.5	2.5	0.4	0.4	13.5
Q1eF	1.61	6.3	6.3	0.5	0.5	8.1

IR1: inner radius (= clear aperture) at coil beginning
IR2: inner radius (= clear aperture) at coil end
Pole tip field R1: IR1*gradient
Pole tip field R2: IR2*gradient

All direct wind coils

Rear Hadron Magnets

	Length	IR1	IR2	Pole tip field R1	Pole tip field R2	Gradient
	m	cm	cm	T	T	T/m
Q1ApR	1.8	2.0	2.56	1.56	2.	78
Q1BpR	1.4	2.8	2.8	2.184	2.184	78
Q2pR	4.5	5.4	5.4	1.84	1.84	34

IR1: inner radius (= clear aperture) at coil beginning
IR2: inner radius (= clear aperture) at coil end
Pole tip field R1: IR1*gradient
Pole tip field R2: IR2*gradient

All direct wind coils
Q1ApR: tapered

Rear Electron Magnets

	Length	IR1	IR2	Pole tip field R1	Pole tip field R2	Dipole Field	Gradient
	m	cm	cm	T	T	T	T/m
Q1eR	1.8	4.76	5.57	0.67	0.78	0	14
Q2eR	1.4	6.43	6.43	0.91	0.91	0	14.1
B2eR	5.5	9.5	9.5	0	0	0.2	0

IR1: inner radius (= clear aperture) at coil beginning
IR2: inner radius (= clear aperture) at coil end
Pole tip field R1: IR1*gradient
Pole tip field R2: IR2*gradient

All direct wind coils
Q1eR: tapered double-helix coil