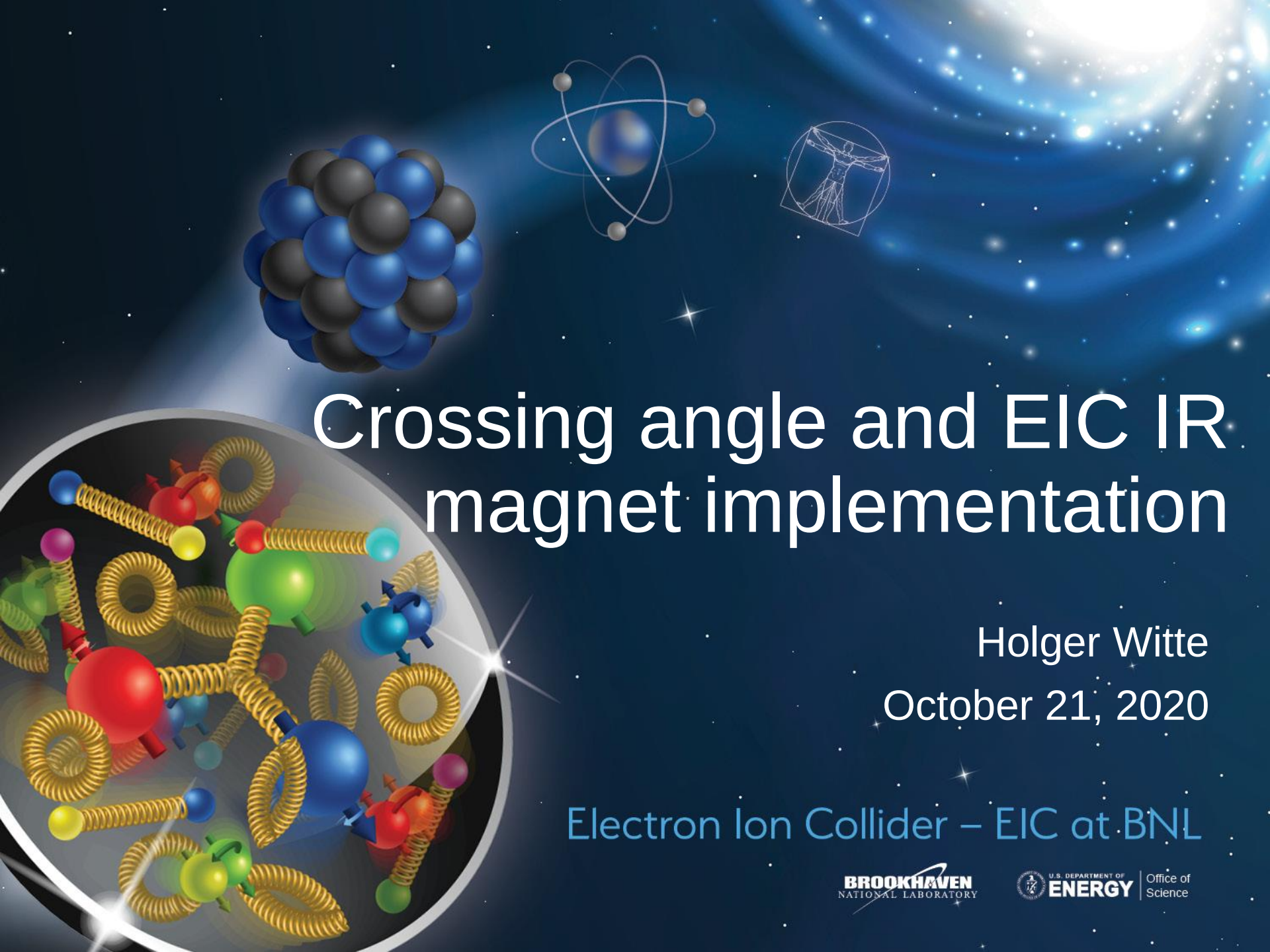


Crossing angle and EIC IR magnet implementation

Holger Witte

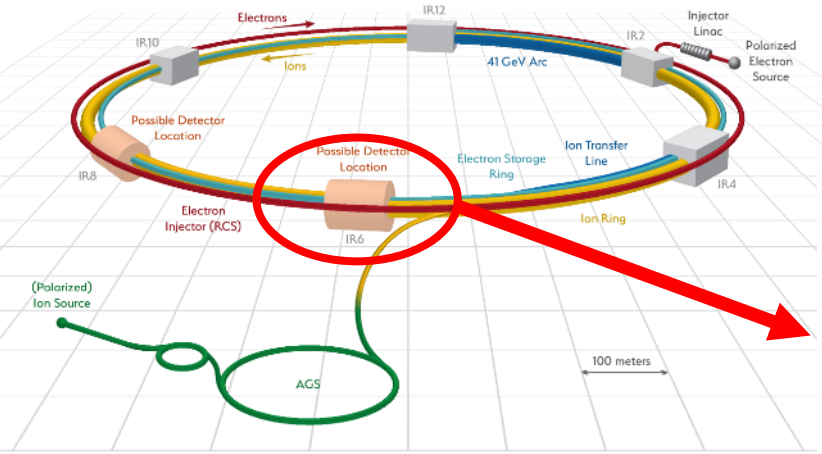
October 21, 2020

Electron Ion Collider – EIC at BNL

BROOKHAVEN NATIONAL LABORATORY

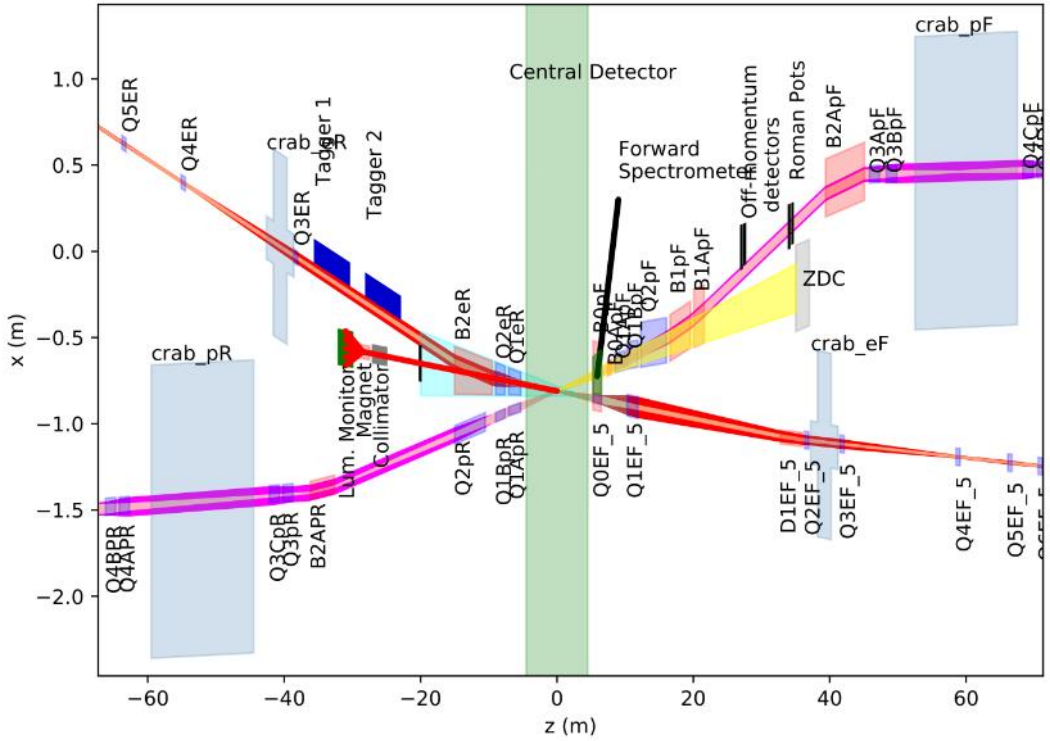
U.S. DEPARTMENT OF ENERGY | Office of Science

EIC IR: Overview



Rear

Forward



RHIC yellow ring: EIC hadron ring

Add electron storage ring in existing tunnel

Possible IR location: IP6

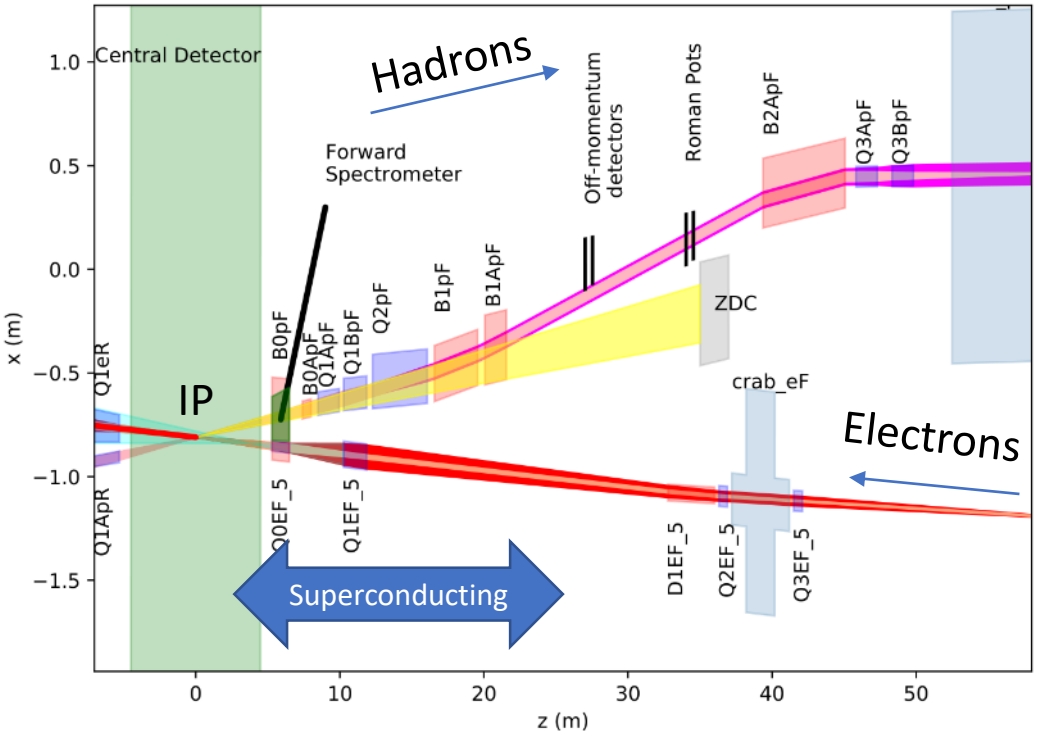
Considerations

- Geometry
  - RHIC tunnel (injection, RHIC magnets, RCS, eSR)
  - Experimental hall (IP6?)
  - Space for detector
- Physics considerations
  - See slide at end
- Accelerator/optics
  - Match into existing tunnel
  - Dispersion, chromaticity

Considerations (cont.)

- Crab cavities
  - Location
  - Geometry
  - Phase advance
- Engineering
  - Magnets: feasibility
  - Cryostating
  - Utilities
- Project
  - Cost, risk
  - R&D required
  - Vendors

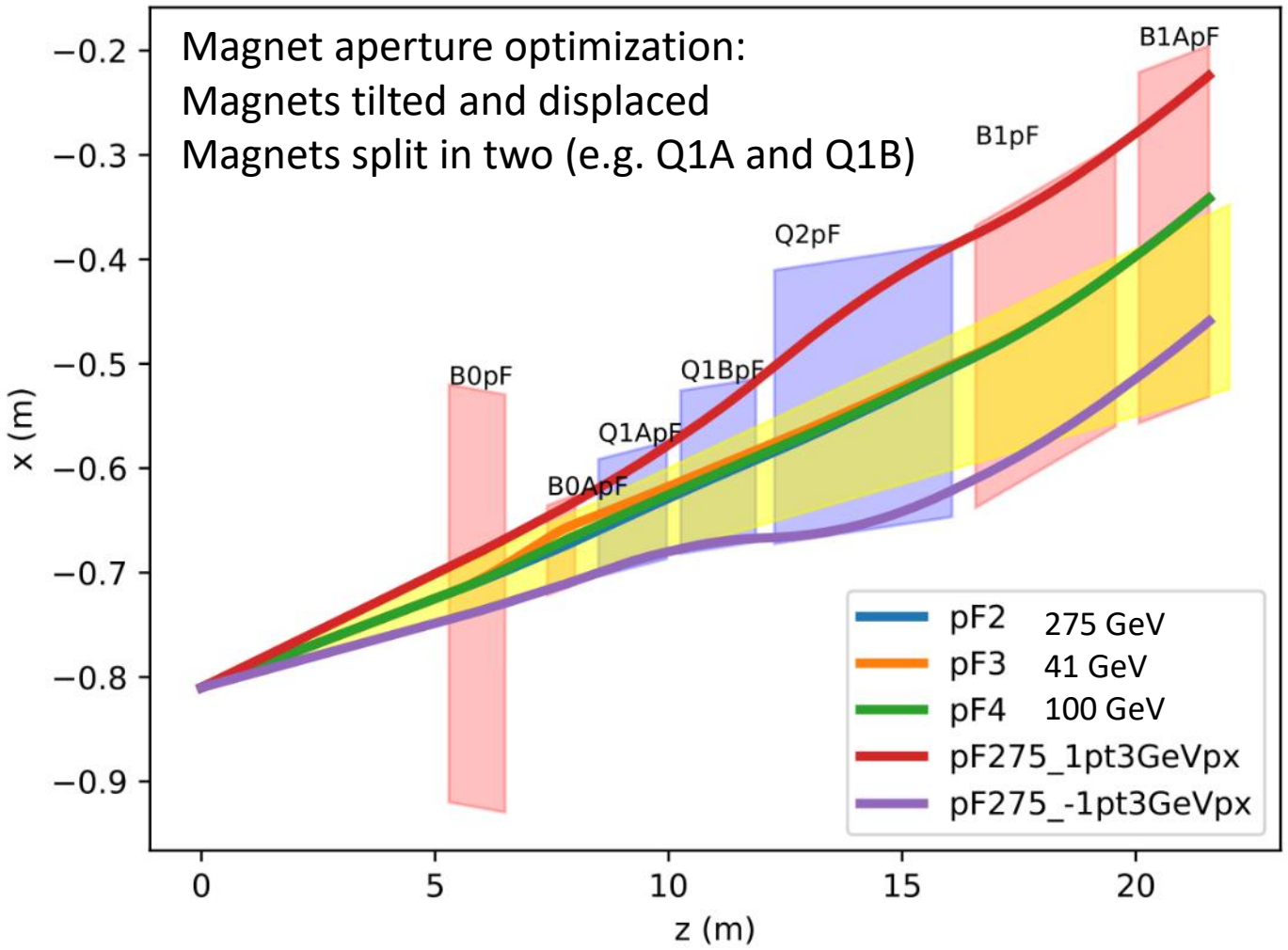
EIC IR: Forward Direction



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

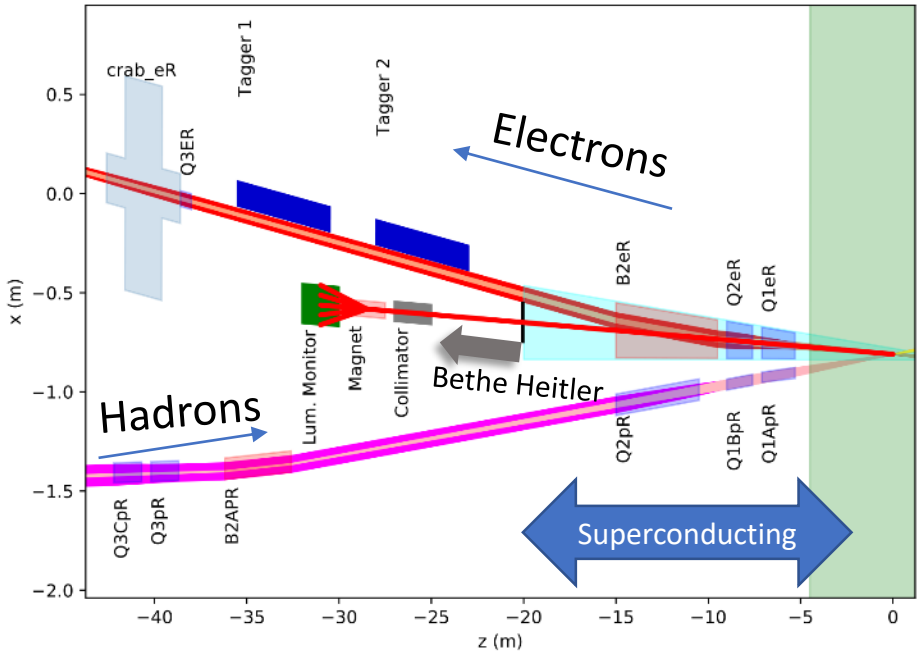
- Interleaved magnet scheme
  - Adding magnets is challenging
- Why are these magnets difficult?
  - Required field
  - Aperture
  - Geometric constraints
- Field
  - Accelerator physics
  - Hall/ring geometry
  - Magnet technology constraints
- Large apertures of magnets
  - Proton forward: physics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

Hadron Forward - Apertures



Also: making magnets longer makes this worse

EIC IR: Rear Direction

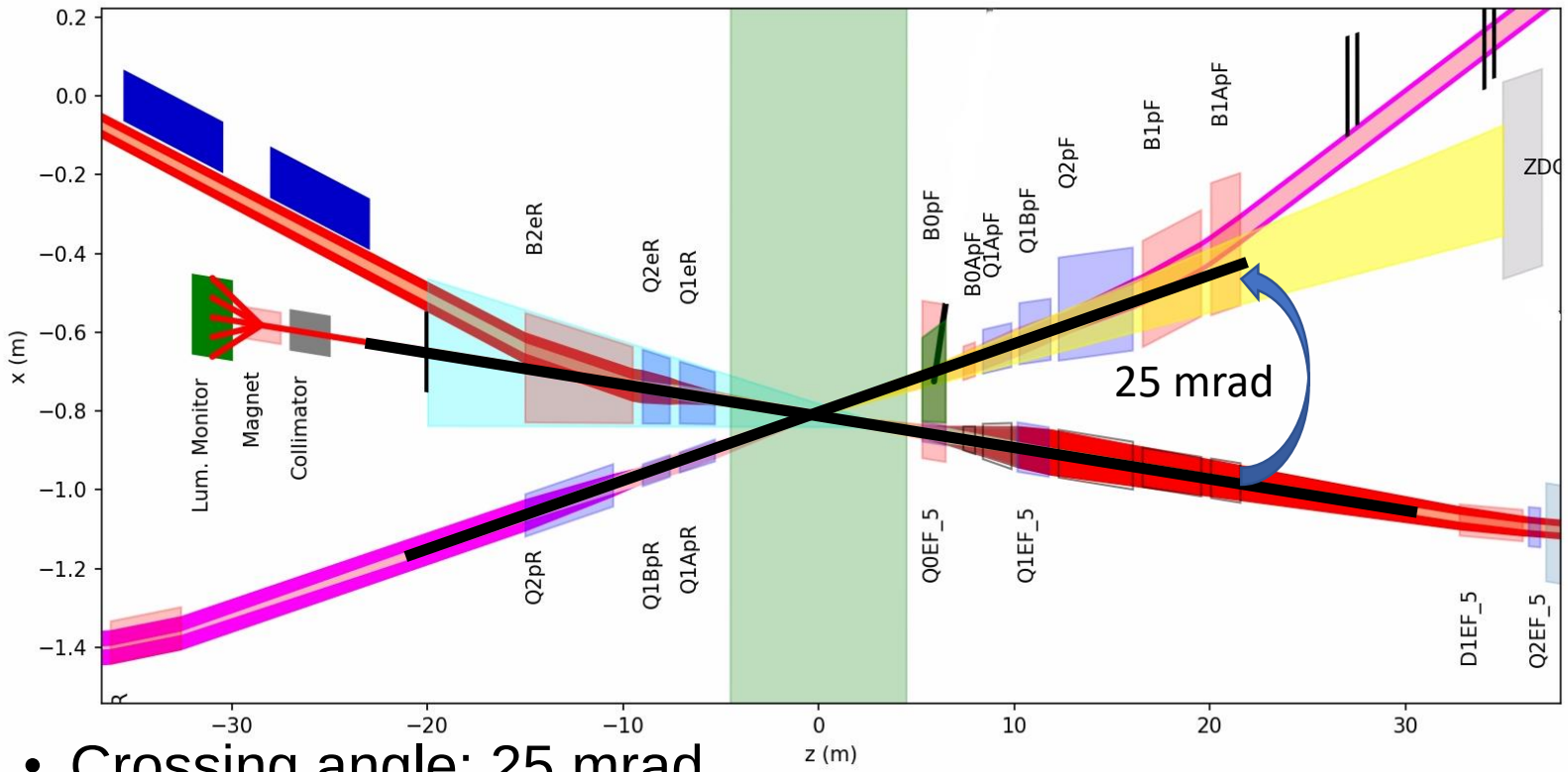


- 2-in-1 magnets
  - Common yokes
- Main issue: space between magnets
  - Crossing angle
- Large aperture due to synrad fan
  - Comes from low-beta quads
  - Linked to β*

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

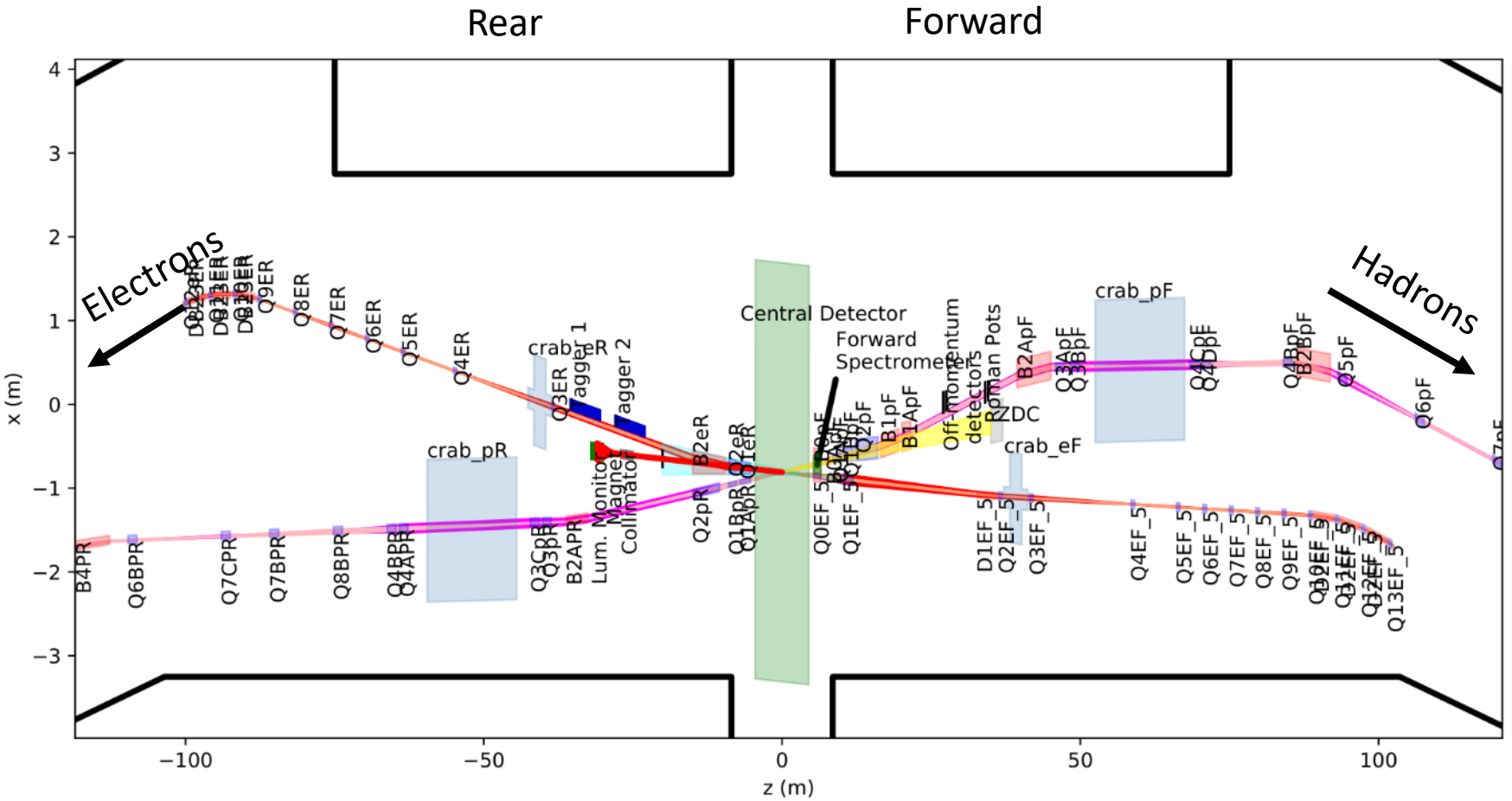
Crossing Angle



- Crossing angle: 25 mrad
  - Hadrons: 17 mrad
  - Electrons: 8 mrad
- Smaller crossing angle: beams less separated, magnet issues
- Larger crossing angle: magnet issues, crab cavities, beam dynamic issues

EIC IR

Note: magnet cryostats are 94” dia



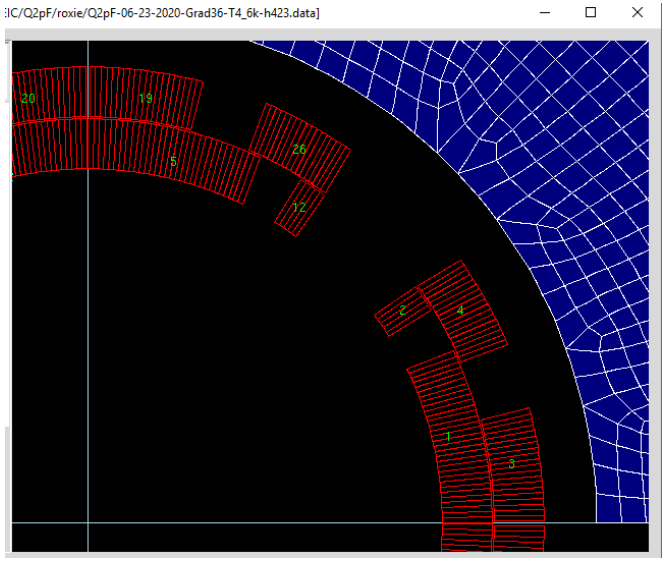
Larger crossing angle:

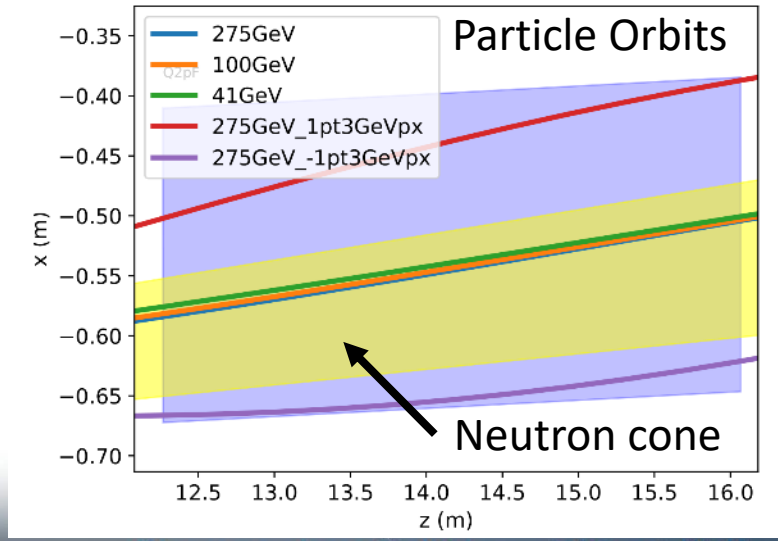
Cannot do more in hadron line (field/space issues)

Electrons: Synrad issues

Q2pF – Collared Magnet

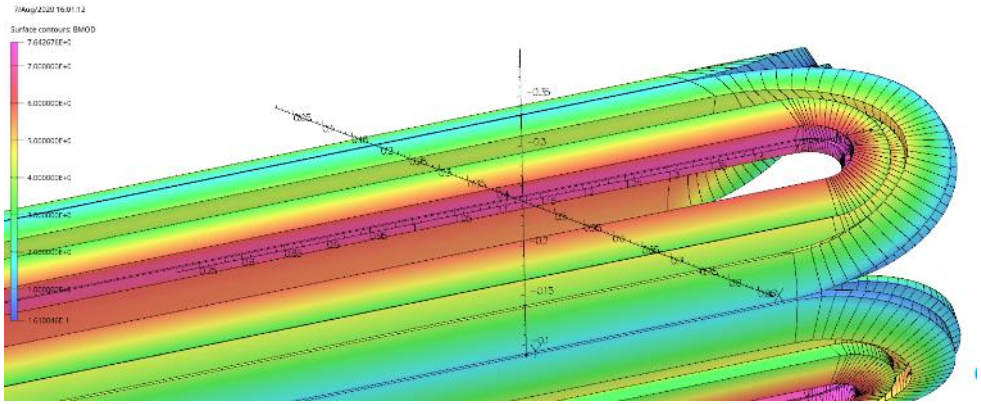
- Hadron quadrupole
  - Gradient: 41 T/m
  - 3.8m long
  - Aperture 262 mm
    - Coil R=140mm
    - Pole tip field: 5.74T
  - e-beam: 36-42cm distance
- Field-free region for electrons
- Magnet limitations
  - Gradient/field
  - Aperture
  - Stray field



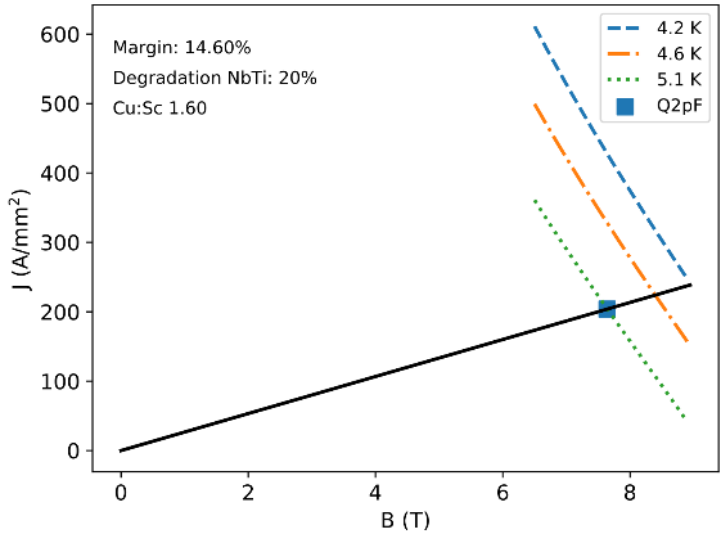


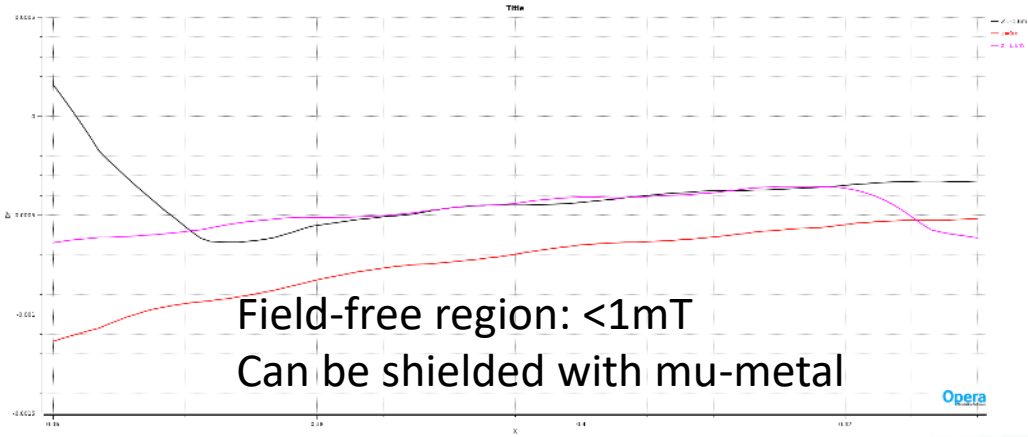
Q2pF Simulation Results

Peak field on wire: 7.6T



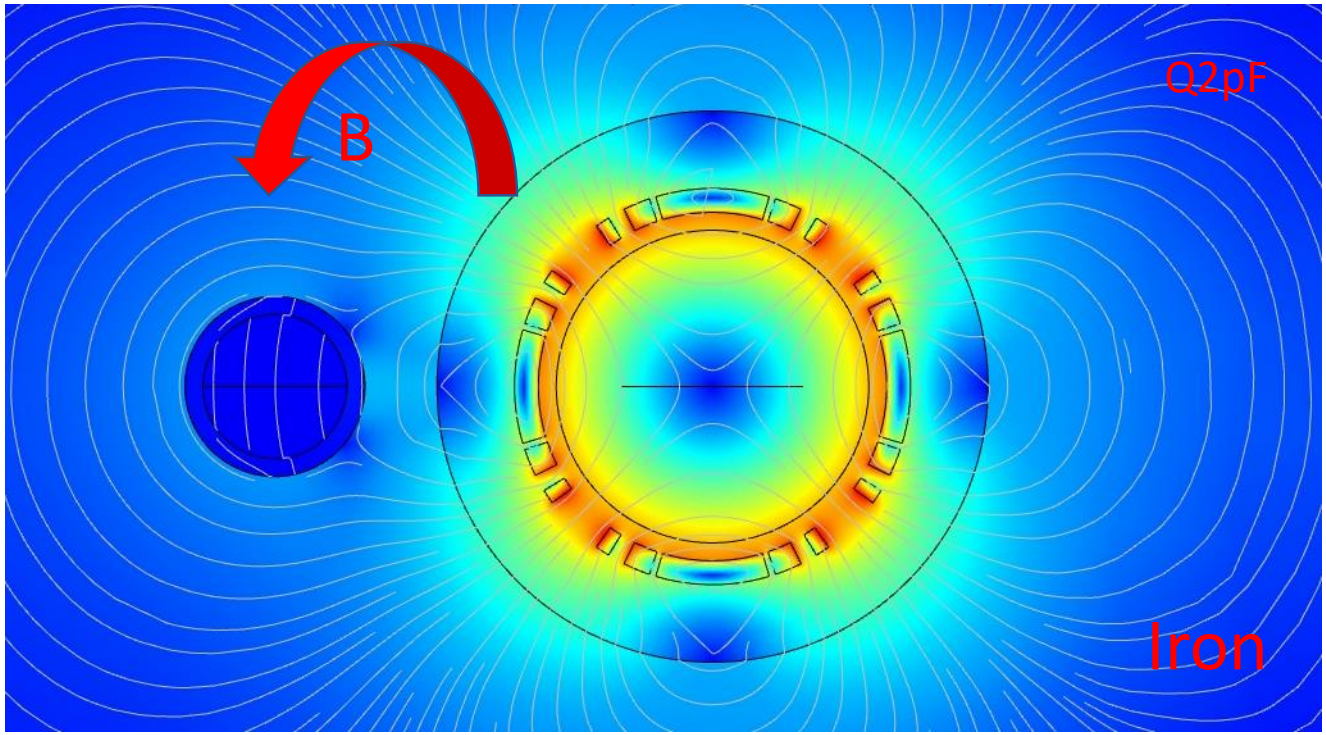
```
NORMAL 3D INTEGRAL RELATIVE MULTIPOLES (1.D-4):
b 1:      -0.00000   b 2:   10000.00000   b 3:       0.00000
b 4:       0.00788   b 5:       0.00000   b 6:      -0.32418
b 7:       0.00000   b 8:       0.00003   b 9:      -0.00000
b10:       0.62188   b11:       0.00000   b12:      -0.00013
b13:       0.00000   b14:      -0.22462   b15:      -0.00000
b16:       0.00001   b17:       0.00000   b18:       0.01234
b19:       0.00000   b20:       0.00000   b

SKEW 3D INTEGRAL RELATIVE MULTIPOLES (1.D-4):
a 1:      -0.00000   a 2:      -0.00000   a 3:      -0.00000
a 4:       0.00000   a 5:       0.00000   a 6:      -0.00000
a 7:      -0.00000   a 8:       0.00000   a 9:      -0.00000
a10:       0.00000   a11:      -0.00000   a12:      -0.00000
a13:       0.00000   a14:      -0.00000   a15:      -0.00000
a16:      -0.00000   a17:       0.00000   a18:       0.00000
a19:       0.00000   a20:       0.00000   a
```





Crosstalk

Electrons: field free Hadrons: quadrupole magnet

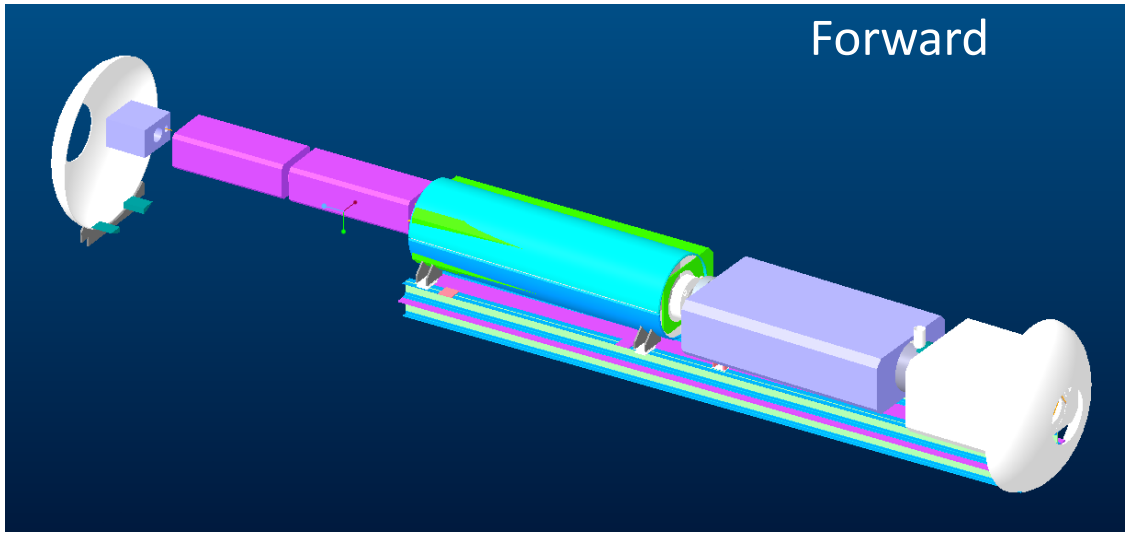


≈40 cm

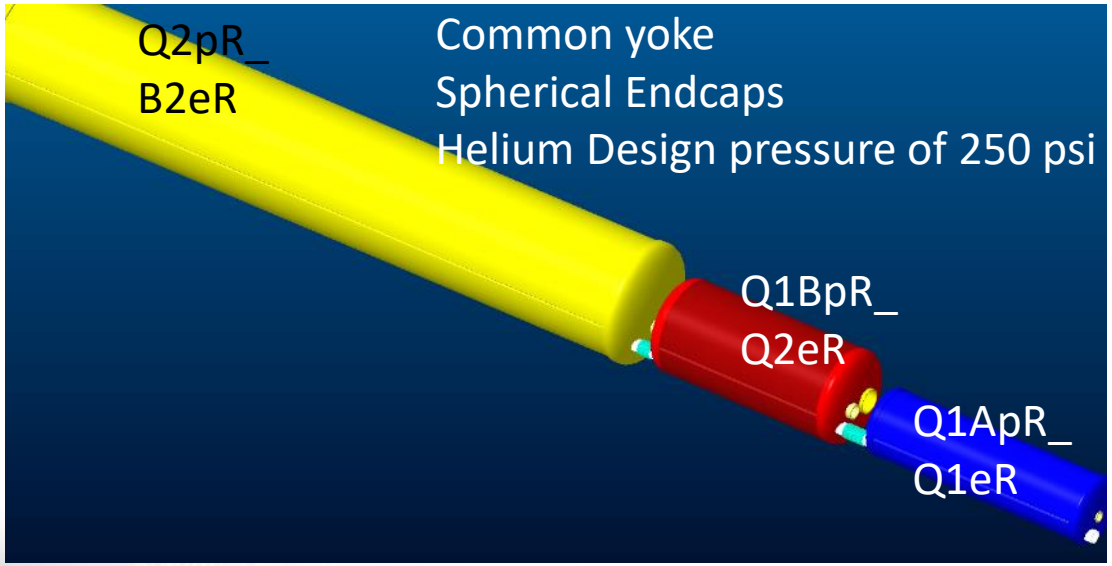
Refers to flux from one magnet leaking into the other
Leads to field quality issues
Depends on geometry and field/flux

Common issue for all IR magnets

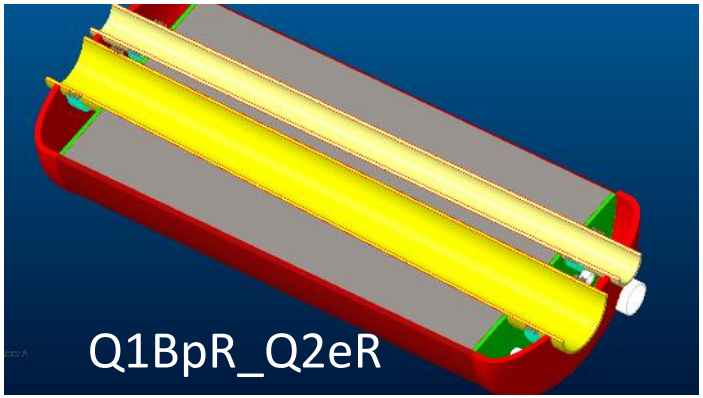
Magnet Engineering



- Just about enough space between magnets

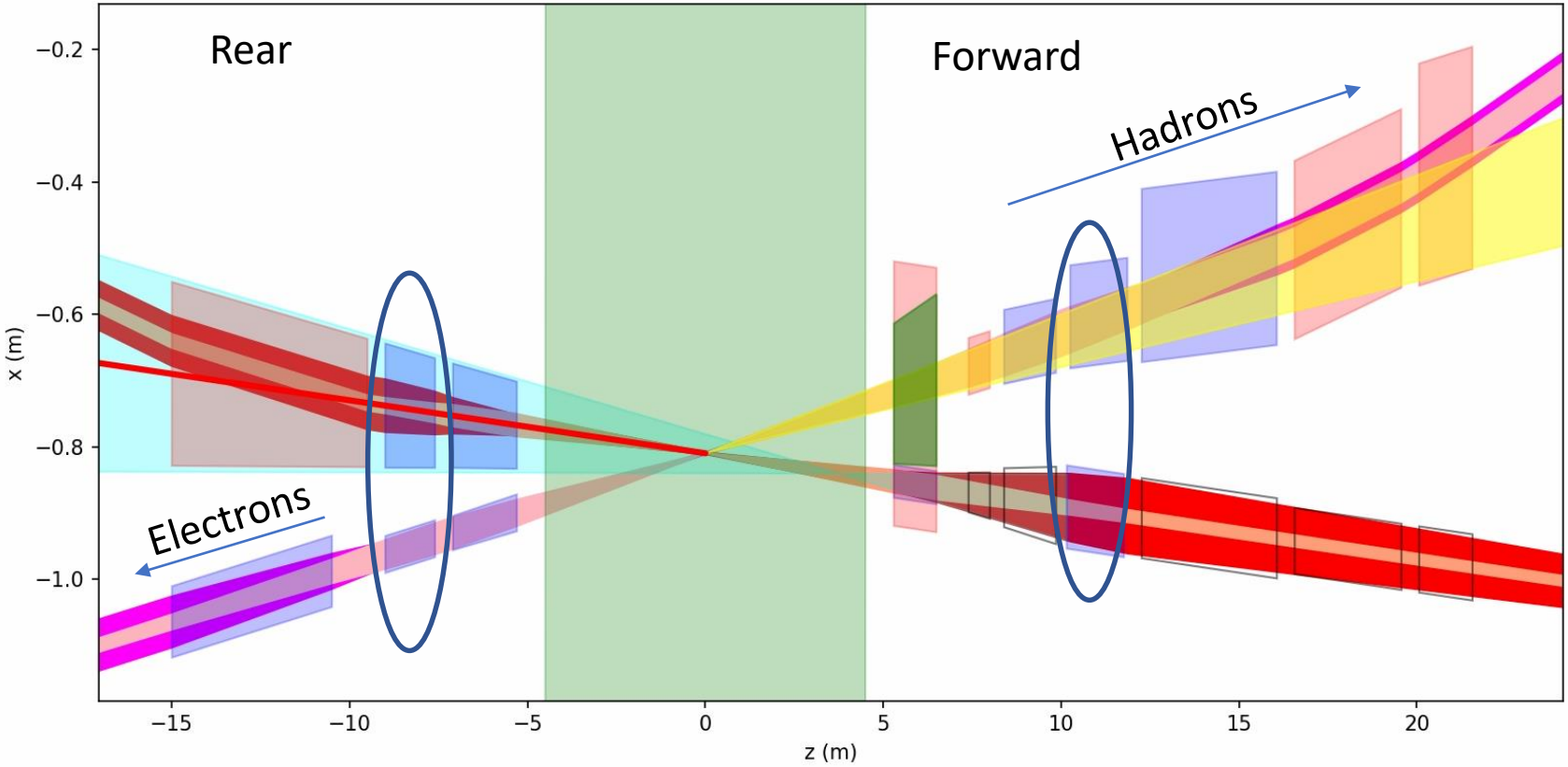


Rear Side



IR Layout

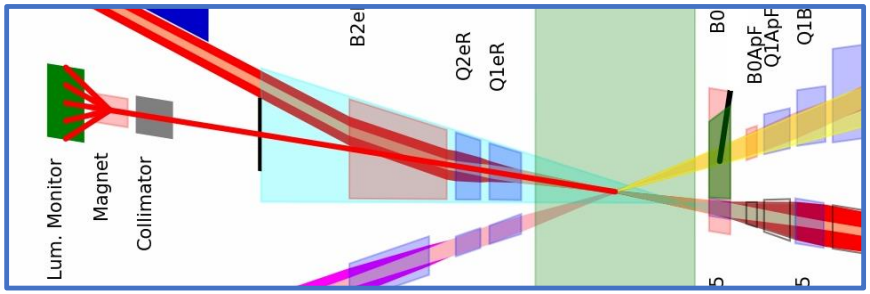
IR sectors not independent of each other



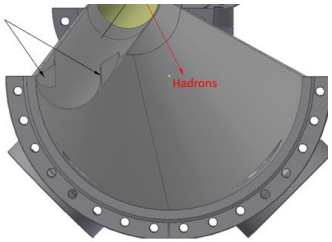
Changing one sector implies changing another one

Also: need to get back to RHIC ring

Synchrotron Radiation

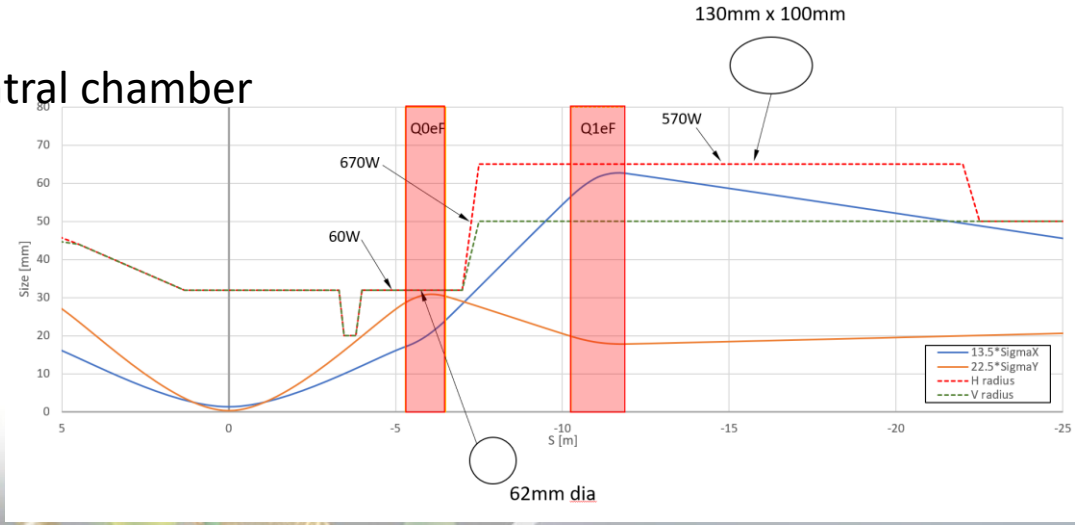


FPA



- Generated by quads and bending magnet upstream
- Tails: can produce hard radiation
  - Non-Gaussian
- Even with masking: significant heating to deal with

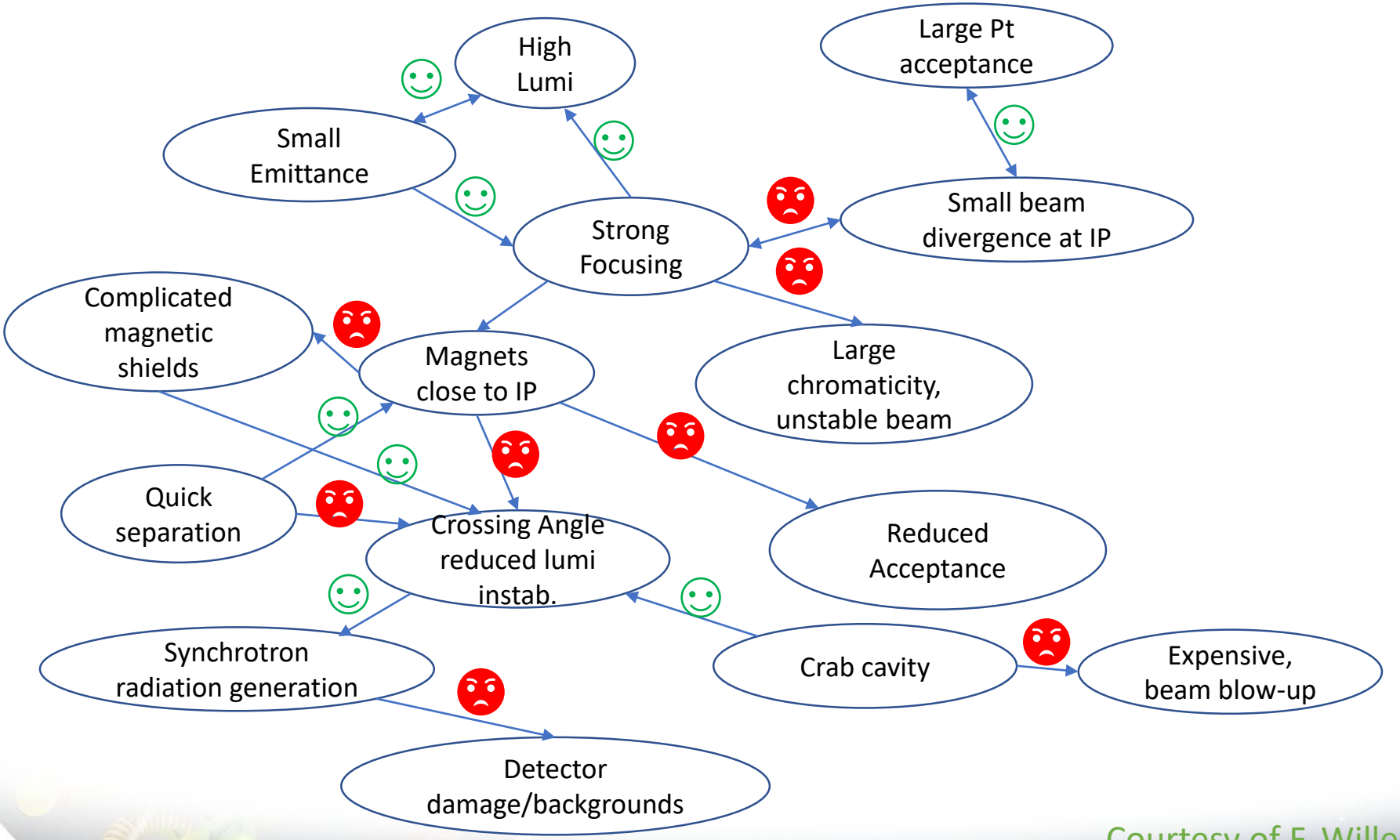
Central chamber



Beam pipe envelope and synrad heating

Courtesy C. Hetzel

IR Design Choices



Courtesy of F. Willeke

Summary

- IR developed in collaboration with BNL Physics
  - Meets requirements of ‘white paper’
  - Is there anything we have been missing?
- Many considerations went into this IR
  - Geometric constraints
  - Engineering feasibility
  - Magnets, cryostating

Acknowledgements

Mike Anerella, Elke Aschenauer, J Scott Berg, Alexei Blednykh, John Cozzolino, Dave Gassner, Karim Hamdi, Charly Hetzel, Doug Holmes, Henry Hocker, Alex Jentsch, Alexander Kiselev, Henry Lovelace III, Gary McIntyre, Christoph Montag, Guillaume Robert-Demolaize, Brett Parker, Bob Palmer, Stephen Plate, Mike Sullivan (SLAC), Steve Tepikian, Roberto Than, Peter Thieberger, Qiong Wu

Additional Slides

Considerations

- Geometry
  - RHIC tunnel (injection, RHIC magnets, RCS, eSR)
  - Experimental hall (IP6?)
  - Space for detector
- Physics considerations
  - See slide at end
- Accelerator/optics
  - Match into existing tunnel
  - Dispersion, chromaticity