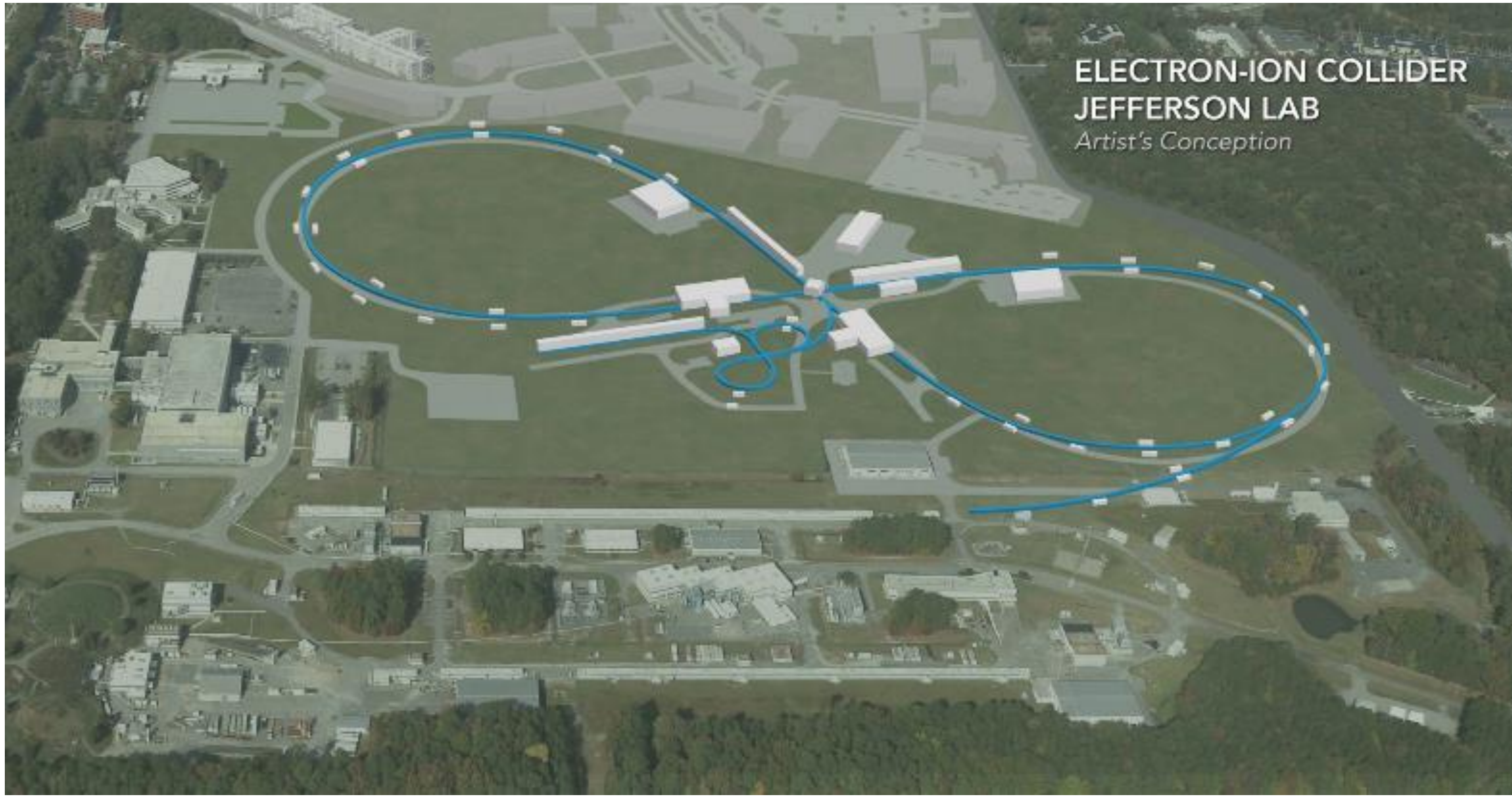
# TJNAF – Interaction Region (IR) Magnet Design Verification

Tim Michalski
Jefferson Lab




2018 Accelerator R&D PI Exchange Meeting

November 14, 2018

# TJNAF – Interaction Region (IR) Magnet Design Verification

- **Description**
  - There are 12 Final Focus Quadrupole (FFQ) and 2 Spectrometer Dipole (SD) high field, large aperture superconducting magnets located within the JLEIC interaction region.
  - Baseline parameters have been defined.
  - Modeling, simulation, and 3D layouts are required to verify designs which satisfy sound magnet design, beam transport and beam physics requirements, and detector background requirements.
- **Status**
  - Complete for this funding period.
- **Main Goal**
  - Develop valid magnet designs for a high acceptance JLEIC Interaction Region.
- **Funding**
  - Base funding for FY’17
  - FY 2018 NP Accelerator R&D FOA – Approved for FY’18/FY’19 – Base redirect
    - “Validation of EIC IR Magnet Parameters and Requirements Using Existing Magnet Results”
- **Budget**

| | FY 2017 | FY 20XX | FY 20XX |
|---|---|---|---|
| a) Funds allocated | $XXXk | | |
| b) Actual costs to date | $XXXk | | |

# TJNAF – Interaction Region (IR) Magnet Design Verification

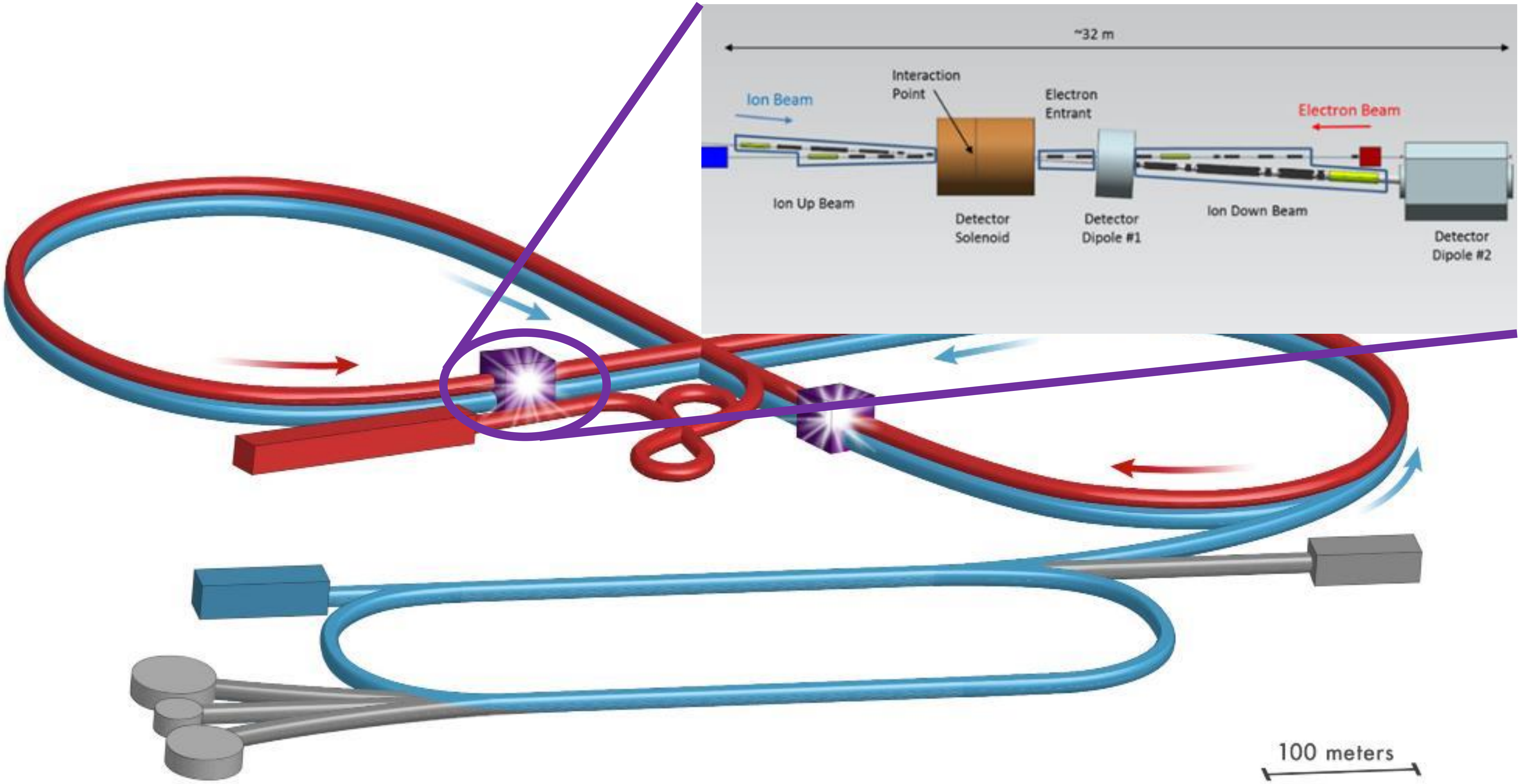
- **Milestones**

| Milestone | Schedule | Status |
|---|---|---|
| Create 3D TOSCA Models of all FFQ Magnets | August, 2018 | COMPLETE |
| Create 3D mechanical layout of the Interaction Region (IR) | August, 2018 | COMPLETE |
| Evaluate interactions between IR magnets | August, 2018 | COMPLETE |
| Evaluate structural supports and cryostats for IR magnets | August, 2018 | COMPLETE |

- **Jones Report Ranking**

| Row No. | Proponent | Concept / Proponent Identifier | Title of R&D Element | Panel Priority | Panel Sub-Priority |
|---|---|---|---|---|---|
| 1 | PANEL | ALL | Crab cavity operation in a hadron ring | High | A |
| 2 | PANEL | ALL | High current single-pass ERL for hadron cooling | High | A |
| 3 | PANEL | ALL | Strong hadron cooling | High | A |
| 4 | PANEL | ALL | Benchmarking of realist EIC simulation tools against available data | High | A |
| 5 | PANEL | ALL | Validation of magnet designs associated with high-acceptance interaction points by prototyping | High | A |
| 6 | PANEL | ALL | Polarized $^{3}$He Source | High | A |
| 7 | PANEL | LR | High current polarized and unpolarized electron | High | B |

# What part of JLEIC are we looking at?

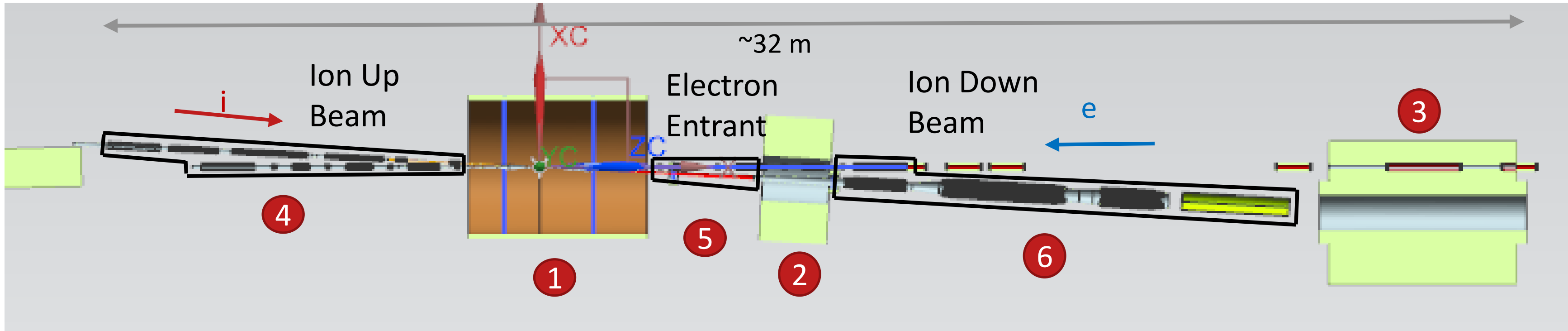


# Outline

- Interaction Region Overview Layout
- Magnet Design
- Magnet Optimization
- Magnet-Magnet Interactions
- Beam Transport Area and Cryostat Designs
- Summary and Outlook

# Interaction Region (IR) Overview Layout

- The design thus far considered six distinct areas of magnets
  1. Detector Solenoid ( 4 m)
  2. SB1 dipole (1.5 m)
  3. SB2 dipole (~4.6 m)
  4. Ion entrant side cryostat (~8.7 m)
  5. Electron entrant cryostat, between the Detector Solenoid and SB1 (~2.6 m)
  6. Ion down beam cryostat between the two spectrometer dipoles (~10.4 m)
- This talk will focus on the three beam transport sections, 4-6



# Magnet Design – Ion Magnet Parameters

- All 6 QFFB magnets require Nb3Sn due to peak field
- 3 downstream magnets are most challenging due to aperture size
- Each FFQ has a corresponding skew quadrupole. FFQ fields are too high to allow nesting in the three down beam quadrupoles.

| | | Requirements | | | | | Design | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnet Location | Magnet Type | Magnet Strength (T, T/m, T/m^2) | Magnetic length (m) | Good field region radius (cm) | Inner Radius (cm) | Outer radius (cm) | Inner radius (mm) | Coil inner radius (mm) | Coil width in radial direction (mm) | Coil outer radius (mm) | Peak field from VF (T) |
| Interaction Region (IR) Ion Quadrupole | QFFB3_US | -116 | 1 | 3 | 4 | 12 | 40 | 45.0 | 18 | 63.0 | 8.93 |
| | QFFUS03S *** | -9.9 | 1 | | 4 | 12 | 40 | 67.0 | 2 | 69.0 | 0.22 |
| | QFFB2_US * | 149 | 1.5 | 3 | 4 | 12 | 40 | 45.0 | 30 | 75.0 | 8.0 |
| | QFFUS02S *** | 5.30 | 1.5 | | 4 | 12 | 40 | 77.0 | 2 | 79.0 | 0.2 |
| | QFFB1_US | -141 | 1.2 | 2 | 3 | 10 | 30 | 34.5 | 18 | 52.5 | 7.9 |
| | QFFUS01S *** | -14.4 | 1.2 | | 3 | 10 | 30 | 57.0 | 2 | 59.0 | 0.24 |
| | QFFDS01S | 8.6 | 0.1 | | 8.5 | 17.1 | 85 | 90.8 | 10 | 100.8 | 1.6 |
| | QFFB1 ** | -88 | 1.2 | 4 | 8.5 | 17.1 | 85 | 90.8 | 43.6 | 134.4 | 11.5 |
| | QFFDS02S *** | -3.7 | 0.1 | | 12.6 | 24.7 | 126 | 133.4 | 10.0 | 143.4 | 1.8 |
| | QFFB2 ** | 51 | 2.4 | 4 | 12.6 | 24.7 | 126 | 133.4 | 45.0 | 178.4 | 10.3 |
| | QFFDS22S *** | -5.5 | 0.1 | | 12.6 | 24.7 | 126 | 133.4 | 10.0 | 143.4 | 1.8 |
| | QFFB3 | -35 | 1.2 | 4 | 14.8 | 26.7 | 148 | 155.0 | 38.0 | 193.0 | 8.5 |
| | QFFDS03S *** | 4 | 0.1 | | 14.8 | 26.7 | 148 | 155 | 10 | 165.0 | 1.84 |

| | |
|---|---|
| * | First Order Electromagnetic Optimization done and optimized design presented in rest of the paper |
| ** | First Order Electromagnetic Optimization done and optimized design presented in a separate section, magnet interaction is done without optimized design |
| *** | The peak field values are just for the skew quad alone, this value is higher when operated with the main quad |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# Magnet Design – Electron Magnet Parameters

| | | Requirements | | | | | Design | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Magnet Location | Magnet Type | Magnet Strength (T, T/m, T/m^2) | Magnetic length (m) | Good field region radius (cm) | Inner Radius (cm) | Outer radius (cm) | Inner radius (mm) | Coil inner radius (mm) | Coil width in radial direction (mm) | Coil outer radius (mm) | Peak field from VF (T) |
| Interaction Region Electron Quadrupole | Common Quad design,combined with Skew Quads | **Quad ****<br>**45** (varies from 13.63 to 44.78) | 0.6 | 3.2 | 4.5 | 8 | 45 | 49.5 | 10 | 59.5 | 3.51 |
| | | **Skew-Quad *****<br>**9.5** (varies from 1.97 to 9.3) | 0.6 | 3.2 | 4.5 | 8 | 45 | 61.5 | 3.25 | 64.8 | 1.248 |
| Electron IR Solenoid | AASOLEUS | 6 | 1.2 | | 4 | | 40 | 60 | 20 | 80.0 | 6 |
| | AASOLEDS | 6 | 1.2 | | 4 | | 40 | 60 | 20 | 80.0 | 6 |
| ION IR Solenoid | AASOLEUS | 6 | 1.2 | | 4 | | 40 | 60 | 20 | 80.0 | 6 |
| | AASOLEDS | 3.6 | 2 | | 17 | | 170 | 190 | 12 | 202.0 | 3.614 |
| Corrector | IPUSCORR1 | -0.14 By<br>-0.95 Bx | .2 | | | | | 34.5<br>50 | 9<br>3 | 43.5<br>53 | 3.06 in X coil<br>1.36 in Y coil<br>(Both coils On) |
| | IPUSCORR2 | 0.15 By<br>1.55 Bx | .2 | | | | | | | | |

| | |
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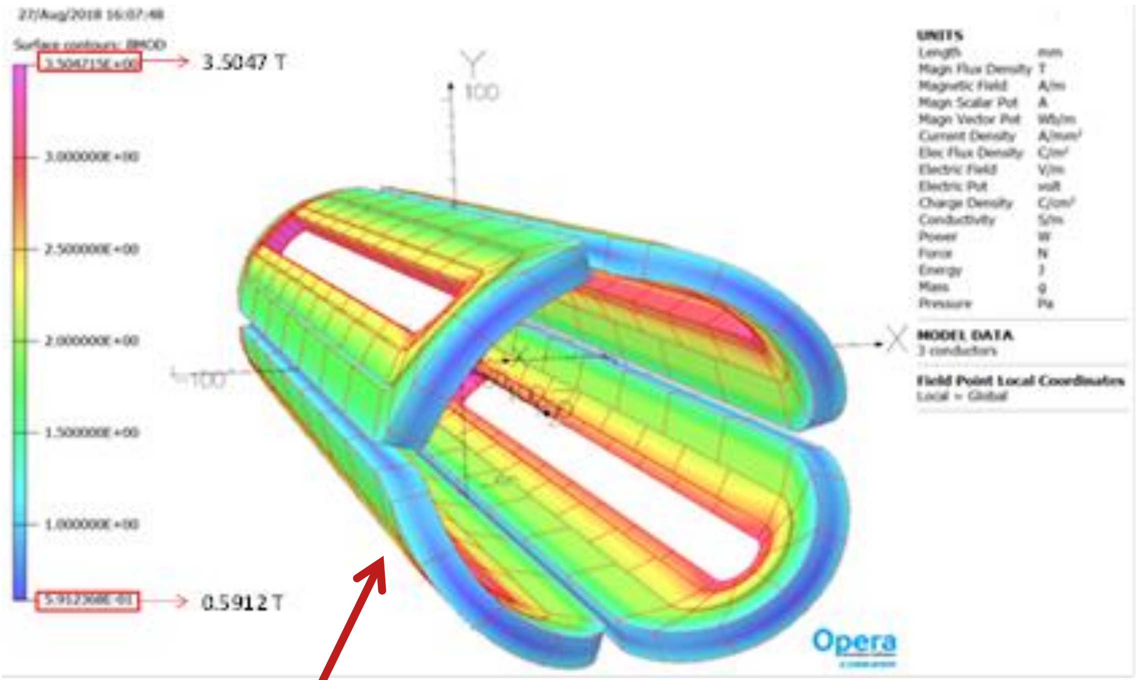
| *** | The peak field values are just for the skew quad alone, this value is higher when operated with the main quad |

Each of the quadrupoles will need a corresponding skew quadrupole.

# Magnet Design

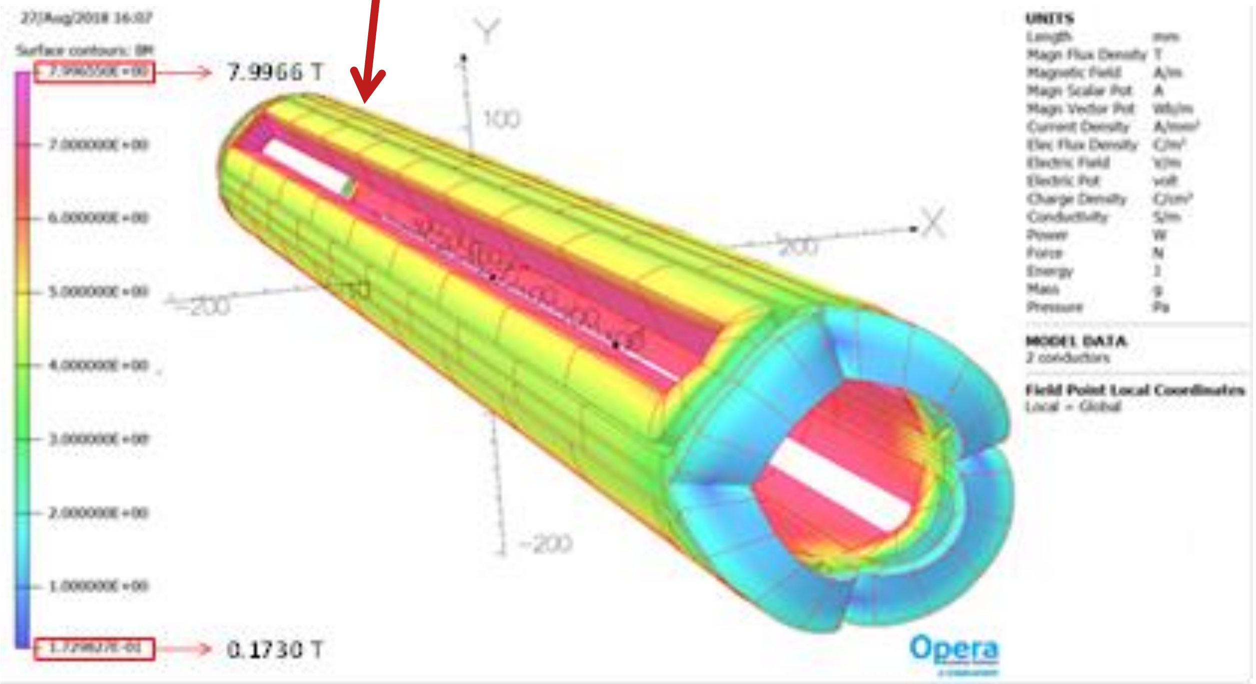
- All of the magnets for both the ion and electron beam lines are based on cold bore designs.
- This is primarily to lower the field requirements on the ion beam quadrupoles.
- The magnets in the electron beam line could be either warm or cold bore.
- The cold bore designs in the electron line do reduce the radial space needed which is a plus as you get closer to the IP.
- Expectation is to use existing, proven conductor – LARP for $Nb_3Sn$, Standard Rutherford cable for NbTi

# Magnet Design – Electron and Ion Upstream Quad



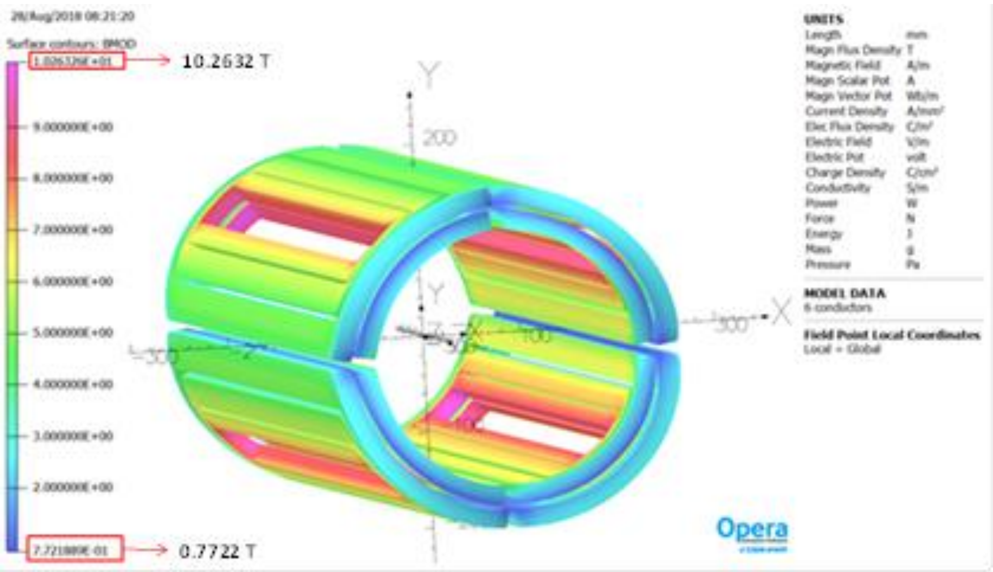

**Peak Field in Electron Quad**
The coils will be operated at 4000 A and will use 9.73 mm x 1.2 mm Rutherford cable.

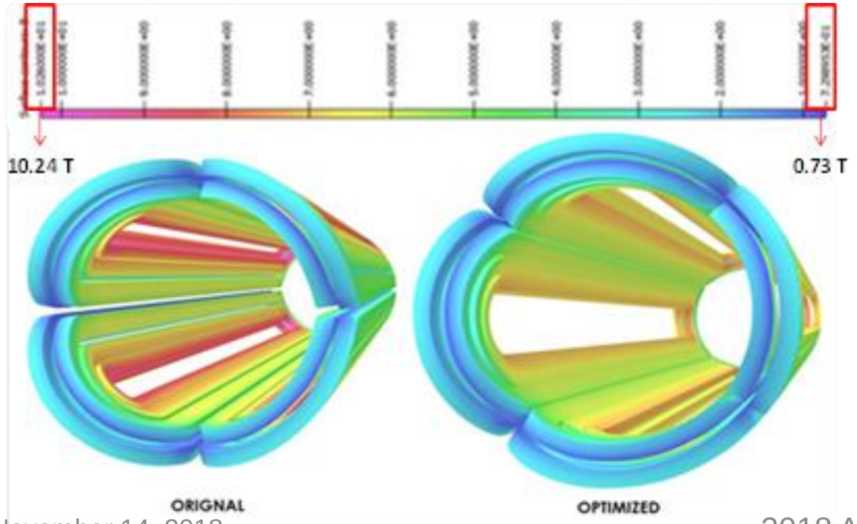
**Peak Field in Upstream Ion Quad (QFFB2_US)** The conductor is envisaged to be stranded, $Nb_3Sn$ cable with 20-30 strands per cable using 0.7 mm diameter strands. This type of $Nb_3Sn$ conductor is also being used for the LARP magnets.



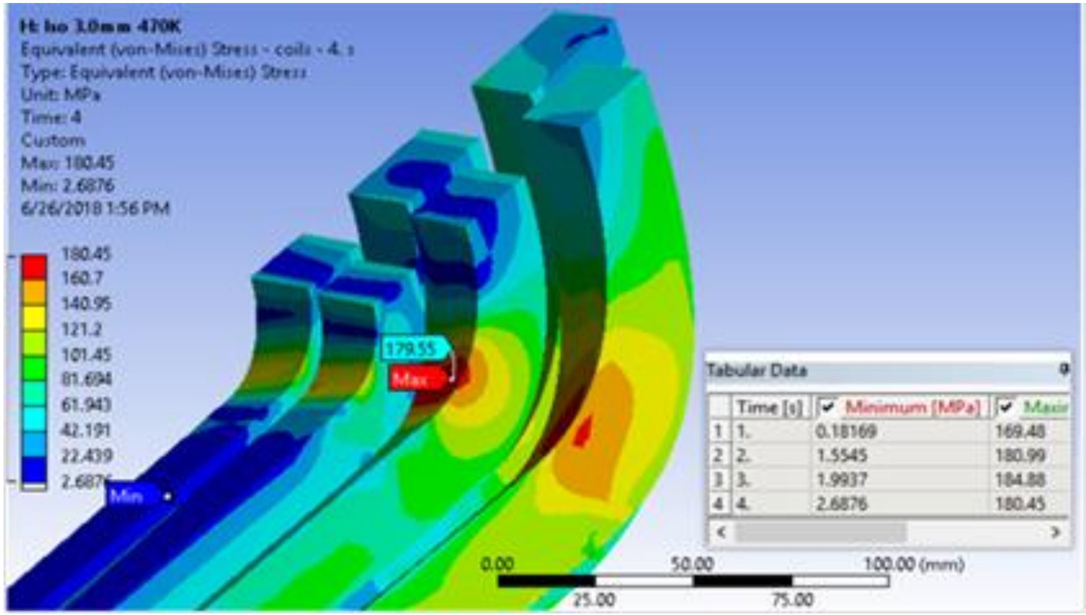
# Magnet Design – Ion Downstream Quad

Coil field in QFFB2 Before Optimization



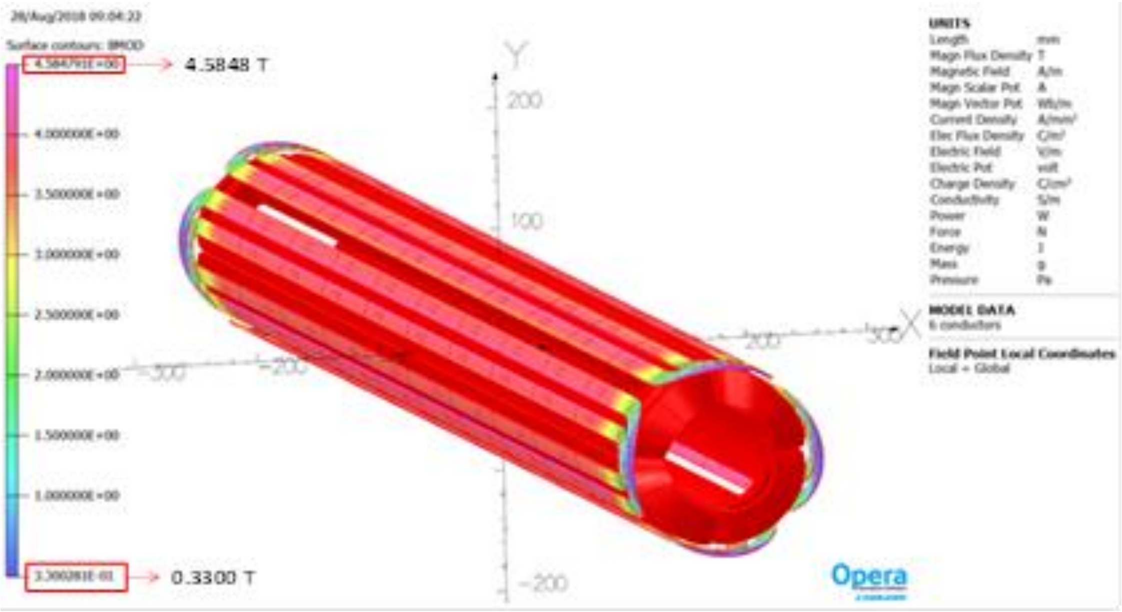

Von-Mises Stress in QFFB2 Before Optimization

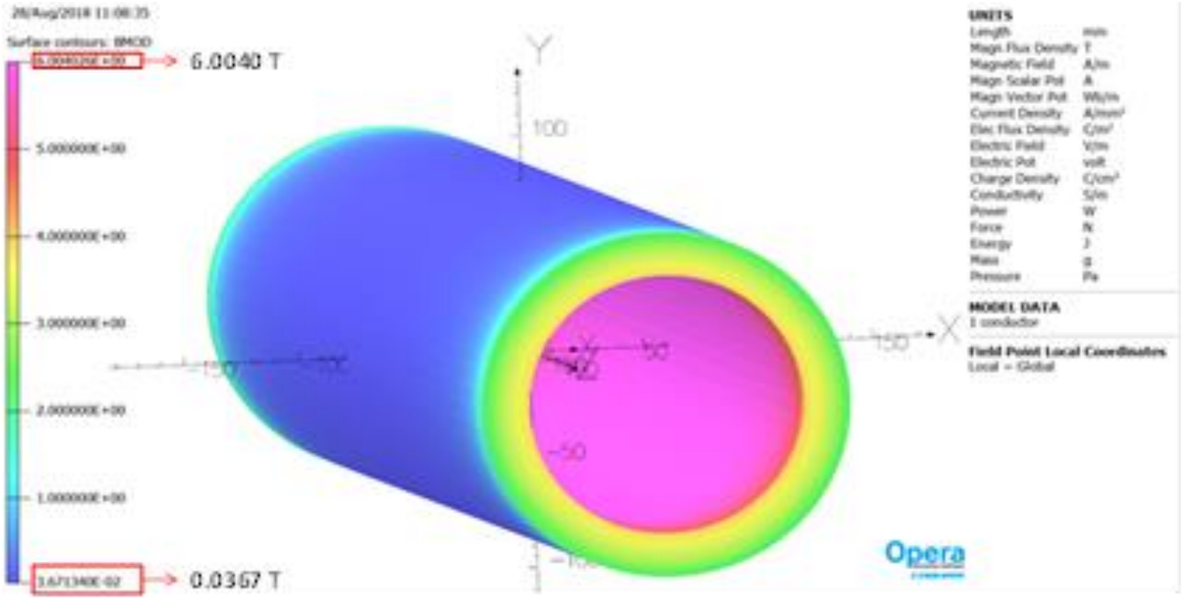


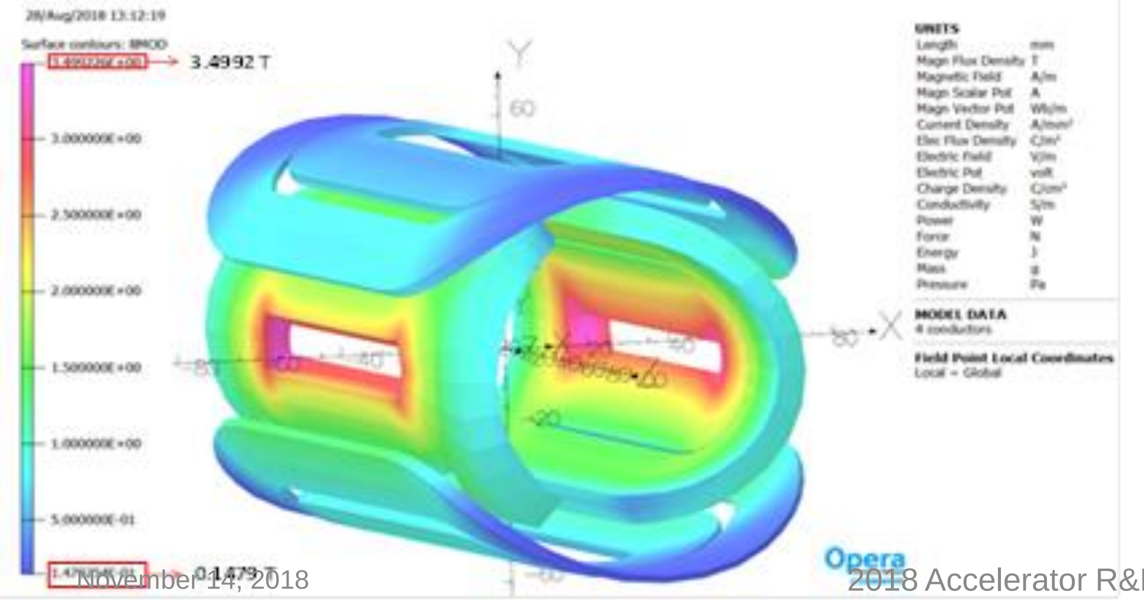

| Max Compression Stress | TEMP (K) | MQXF (MPa) | QFFB2 (MPa) |
|---|---|---|---|
| Before cool-down | 293 | -125 | -169 |
| After cool-down | 4.2 | -192 | -185 |
| With Lorentz force | 4.2 | -146 | -180 |

First Order Optimization brings the peak coil field down from 10.3 T to 8.8 T.

# Magnet Design – Skew Quad, Solenoid, Corrector Magnet



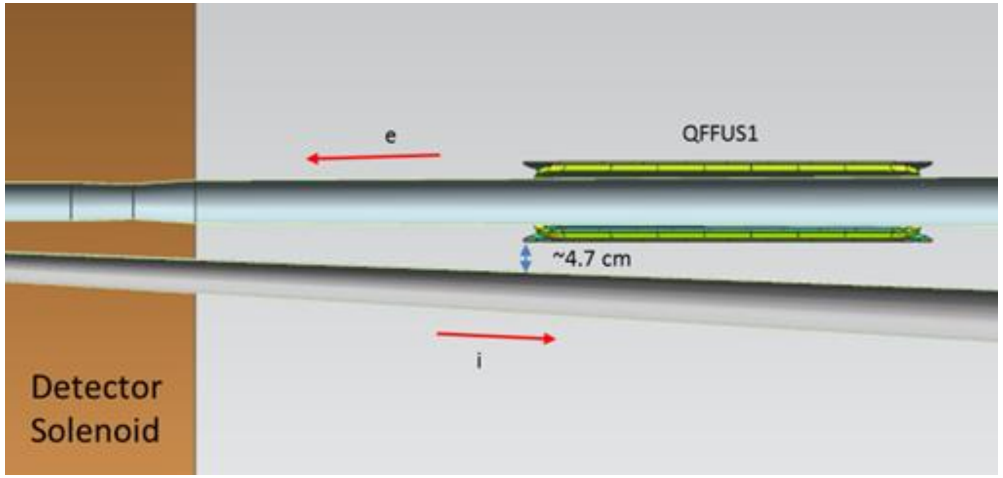



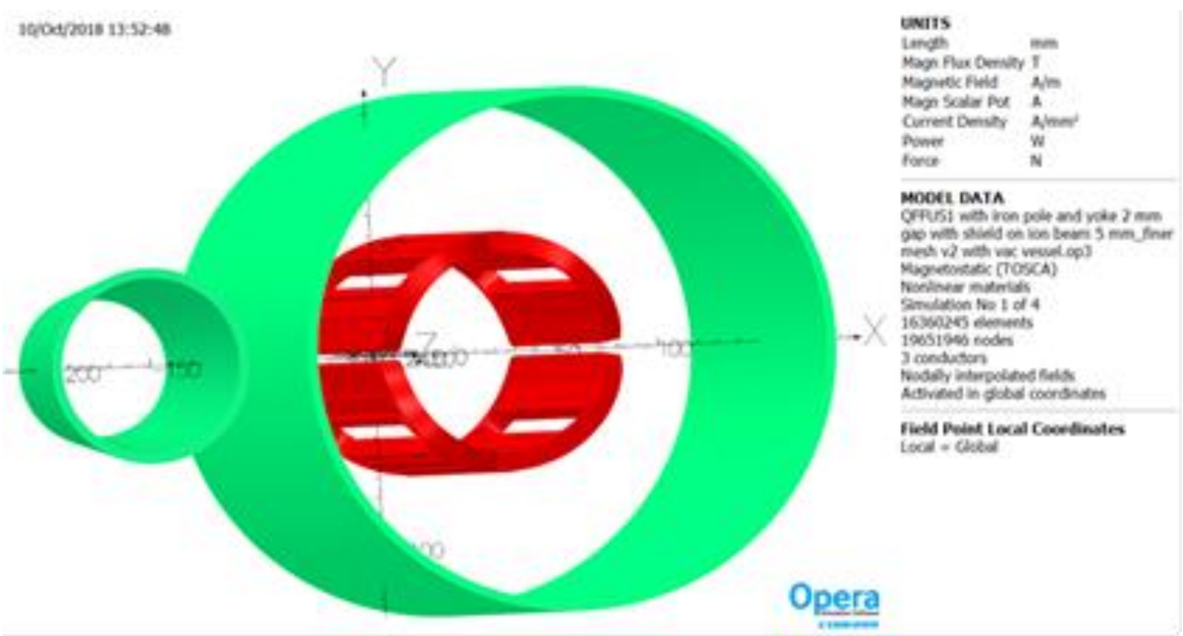

- Peak field in Skew quad is 4.6 T(this will change after optimization)
- Peak Field in the Solenoid is 6T (this will change after including the shielding)
- Peak Field in the Corrector is 3.5 T (this will change after finalizing the specification and conductor)

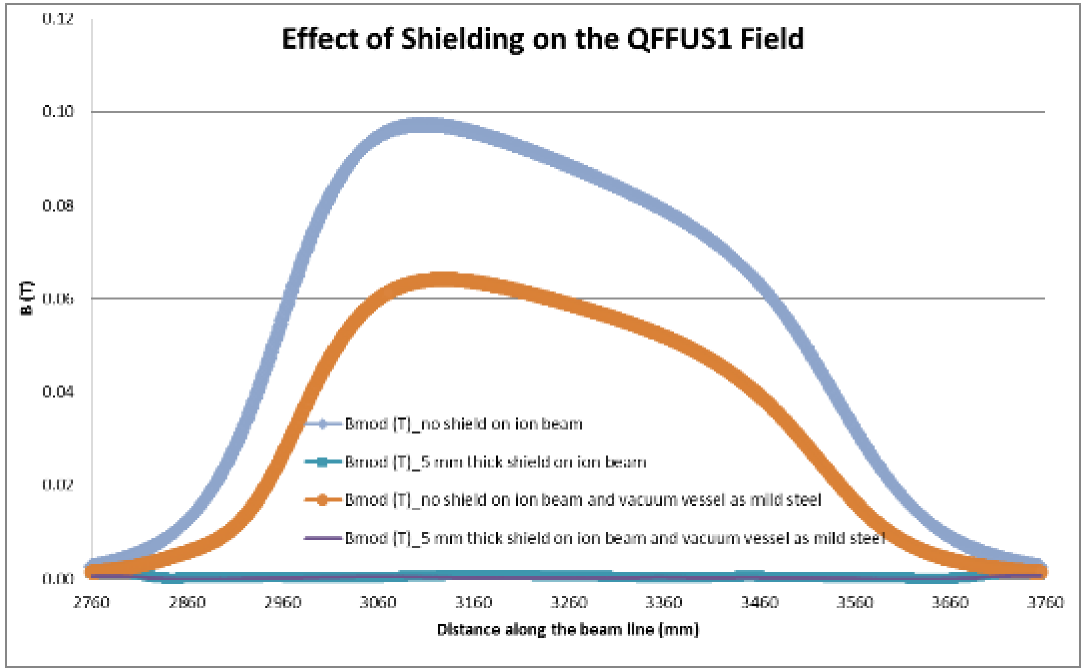
# Magnet-Magnet Interaction

- In order to study the magnet-magnet interactions, the following combinations were selected for the initial study:
  - **QFFUS1 with Ion beam line**
  - QFFB2 with electron beam line




QFFUS1- (i) ion beam tube wrapped with 5 mm mild steel passive shield (ii) the vacuum vessel for the QFFUS1 is assumed to be made of mild steel, and (iii) a combination of the above two options

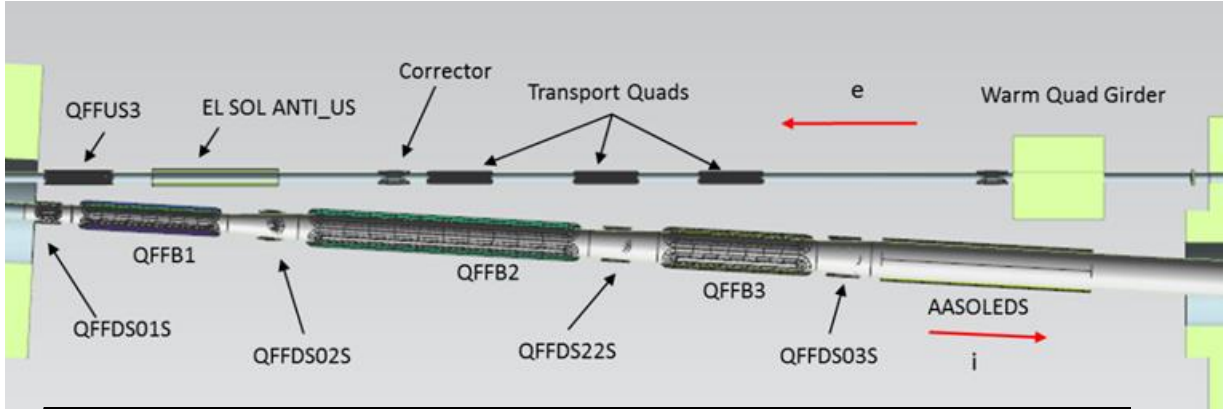


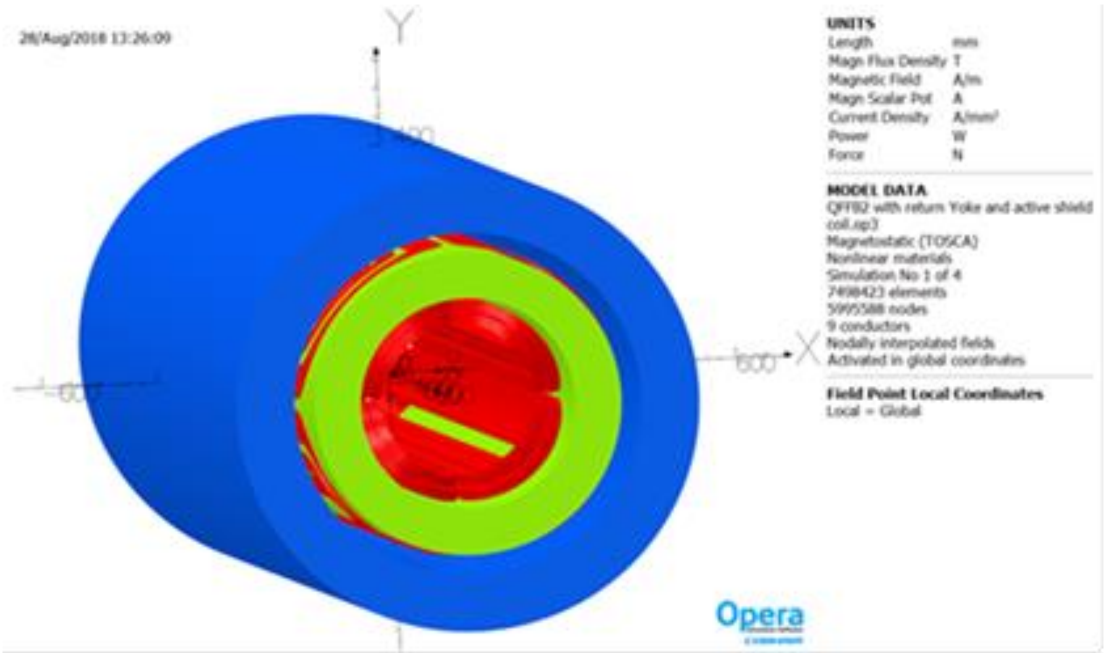
# Magnet-Magnet Interaction

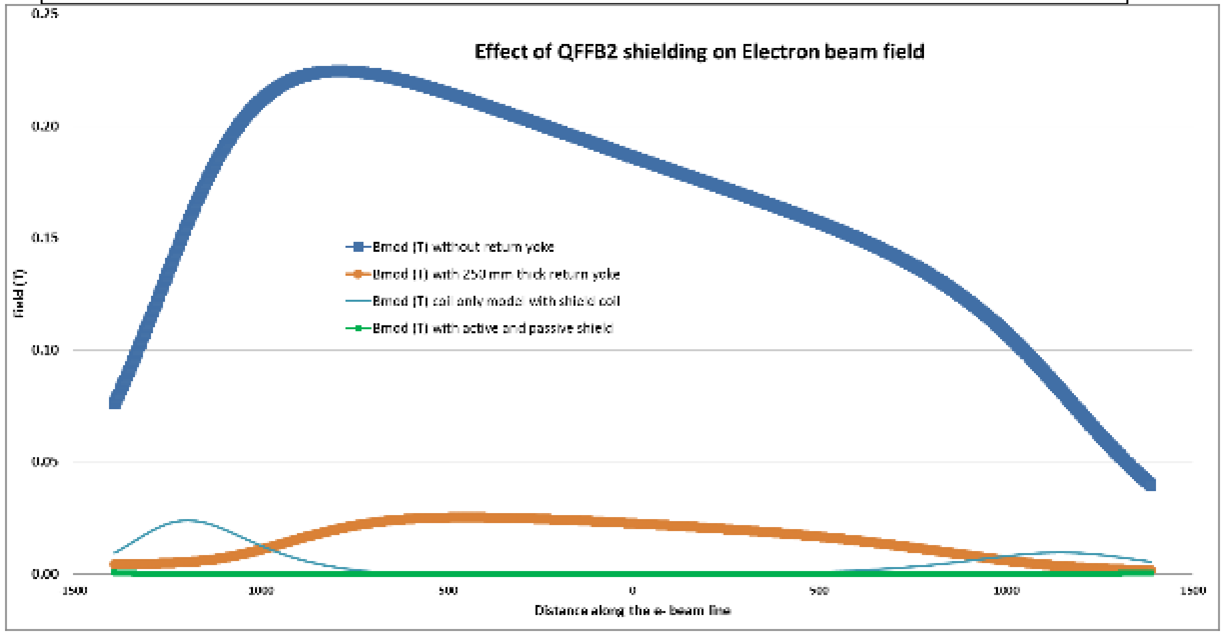
- In order to study the magnet-magnet interactions, the following combinations were selected for the initial study:
  - QFFUS1 with Ion beam line
  - **QFFB2 with electron beam line**

QFFB2- This magnet is simulated with return yoke thicknesses of 200 mm and 250 mm around the magnet, active shield around the magnet, a combination of iron yoke and an active shield coil



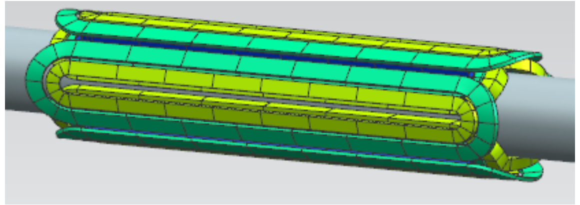

Corrector magnet and 2 transport quadrupoles have not been simulated with QFFB2 for now



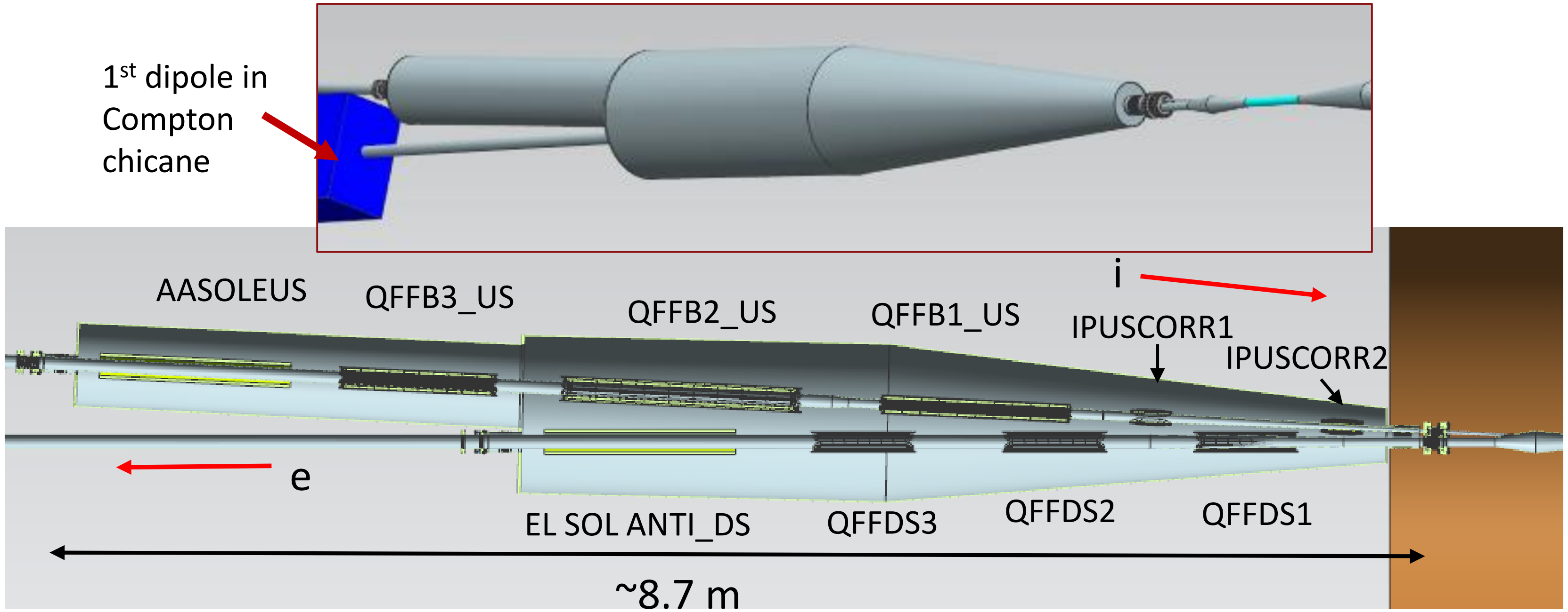



# Ion Up Beam Area

- 'Z' spacing of the magnets
  - Reserve 10 cm on each magnet end for field optimization, coil clamps, etc.
  - Reserve 30 cm for a warm to cold transition and 10 cm for a bellows at the end of the cryostats
- Eighteen plus multipole correctors and shielding coils in a single ~8.7 m long cryostat
  - Three identical quads in electron line with nested skew quads
  - Three quads in ion line with nested skew quads
  - 1.2 m solenoid in each line (same design)
  - Two horizontal/vertical correctors in ion line near IP
- Both the cryostat and cold mass will be supported in at least three locations with a minimum of twelve typical support rods on the cold mass.
- A thermal shield will be included inside of the vacuum vessel and surround the entire cold mass.
- The cryogenic feed and magnet lead can will be positioned on one side of the cryostat away from the detector elements.

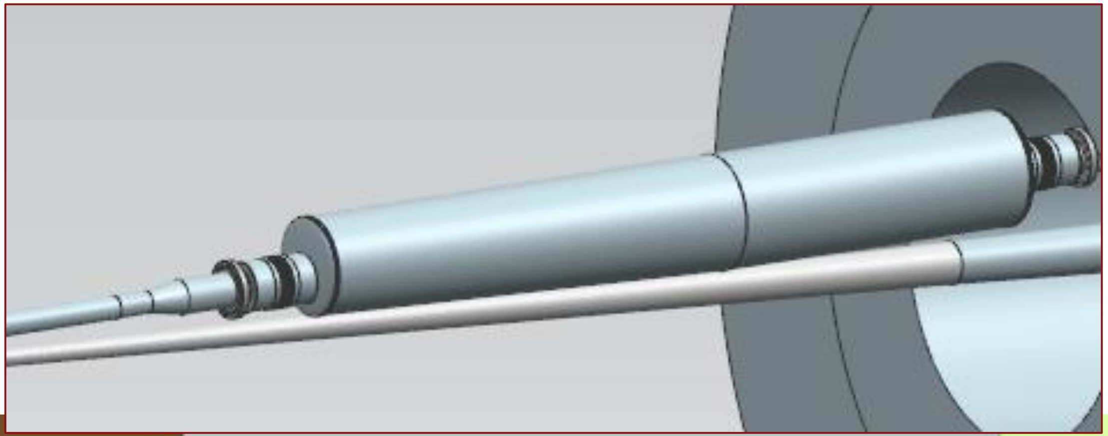


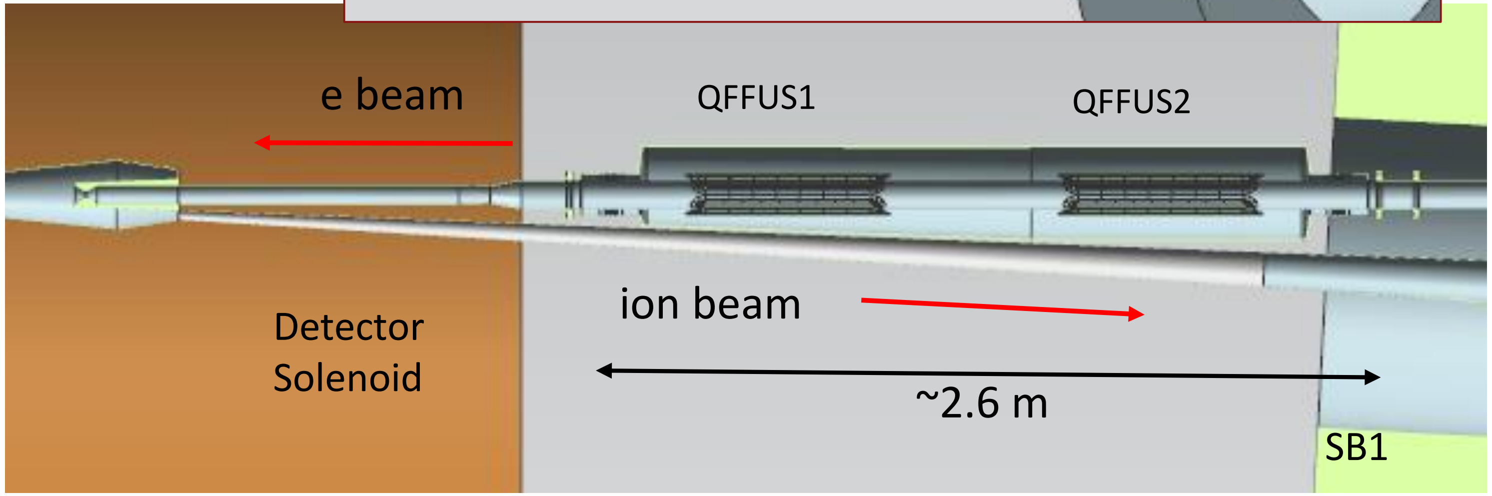
Quad with nested skew quad



# Electron Entrant Area

- Four magnets plus shield coils in a ~2.6 m long cryostat
- The cryostat will be tapered near the IP to avoid interference with the ion vacuum beam line and to allow for the maximum acceptance angle for the detector elements.
- To avoid interference with the ion beam vacuum line, the vacuum vessel and thermal shield will centered eccentrically from the cold mass.
- The warm to cold transition will extend into the detector dipole on one end and stop just short of the detector solenoid on the other.
- Intercept needed for synchrotron radiation in the electron line
  - We can move the synchrotron intercept outside of the warm to cold transition area
  - The cold bore heat loads appear to be acceptable

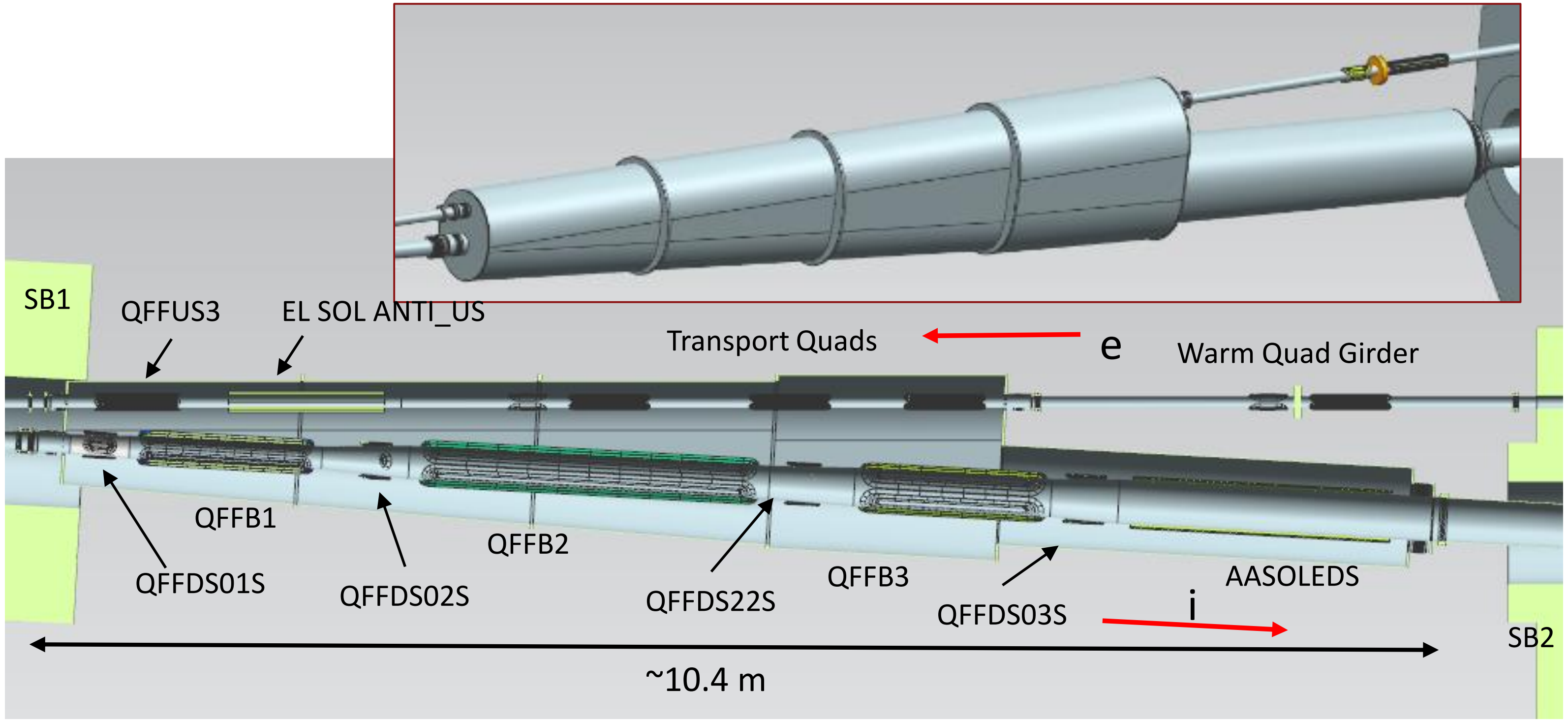




# Ion Down Beam Area

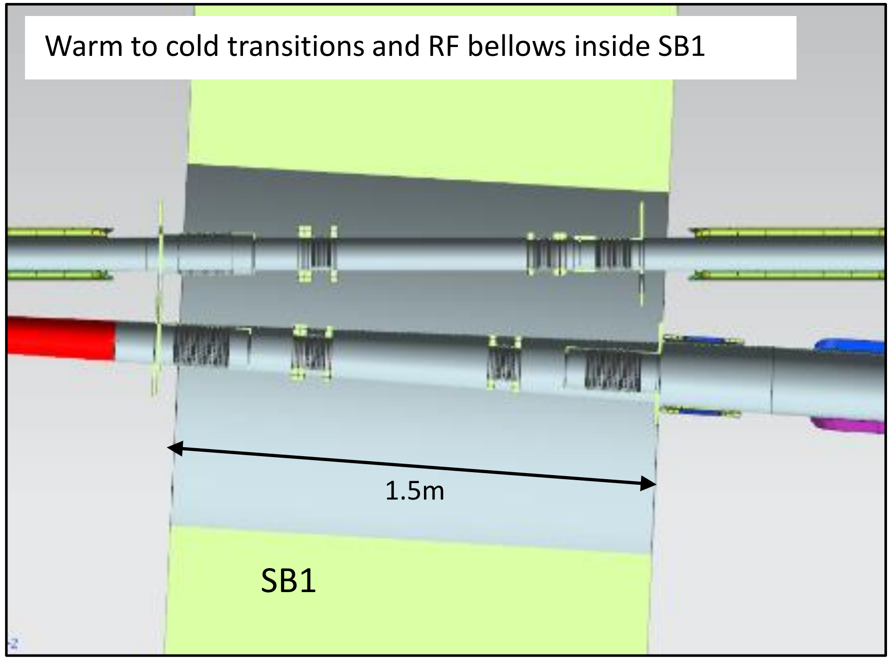
Fourteen magnets plus multipole correctors and shield coils in a single ~10.4 m long cryostat

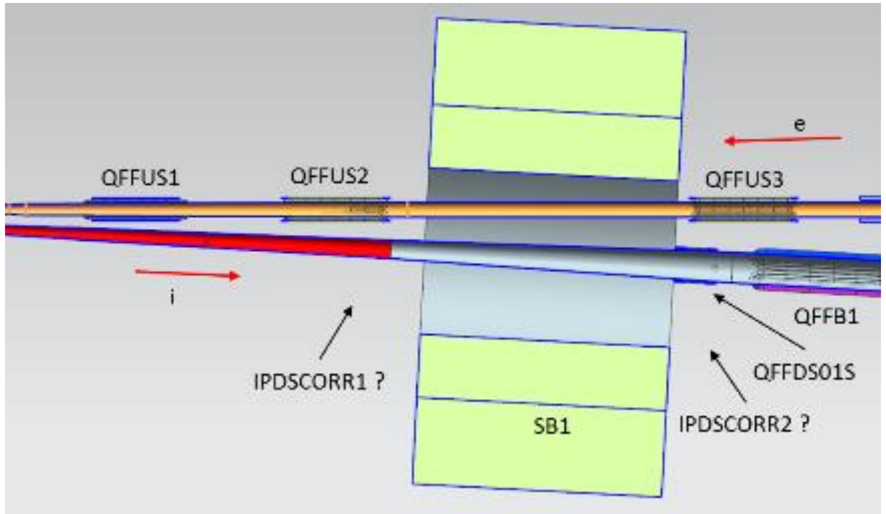
- Transport quads are superconducting as warm magnets impinge on the radial space of the ion beamline – same design as the other electron FFQs
- Three large bore, high strength quads in ion line (QFFB1, 2, 3)
- Large bore solenoid in ion beam line (AASOLEDS)
- Four separate skew quads in ion line – (QFFDS01S, 02S, 22S, 03S)
- Looking at shielding design and magnet support structure near the QFFB2 magnet



# Integration with detector dipole

- Designs of beamlines will be closely coupled to the SB1 spectrometer dipole design
- Two H/V correctors (IPDSCORR1&2) still to be placed in ion beam line
  - Combined dipole/corrector specification and location selection in progress
- In the preliminary designs both cryostat beam lines extended into the SB1
  - This will probably change as we incorporate the new corrector requirements
- Physics detectors are also desired between this magnet bore and the vacuum beam line.
- The adjacent electron beam line will also require shielding from this combined function magnet.



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# Summary and Outlook

- A thorough first layout and magnet analyses have been performed on all IR magnets.
- Further review of the shielding requirements is underway.
- Cryostat definition is also underway in order to outline space available for detectors.
- Additional cryostat detail is required to insure magnets can be supported, accommodate cooldown, withstand magnetic loads, and integrate into detector space designs
- Continue work on shielded bellows concepts that can be used for beam impedance studies
- Possibly add shielded bellows inside the cryostats to ease assembly and alignment.
- Work on shielded vacuum pump designs that can be used in the area that would be compatible with the physics detectors.
- A separate group is studying the vacuum requirements within the IR needed to limit background noise on the detectors.

- The information presented here is for $\sqrt{s}$ = 65 GeV.  Further modifications are required to accommodate $\sqrt{s}$ = 100 GeV.  The main alteration will be to double the length of the ion IR quadrupole magnets.

**Thank you for your attention.**

**Are there any questions?**