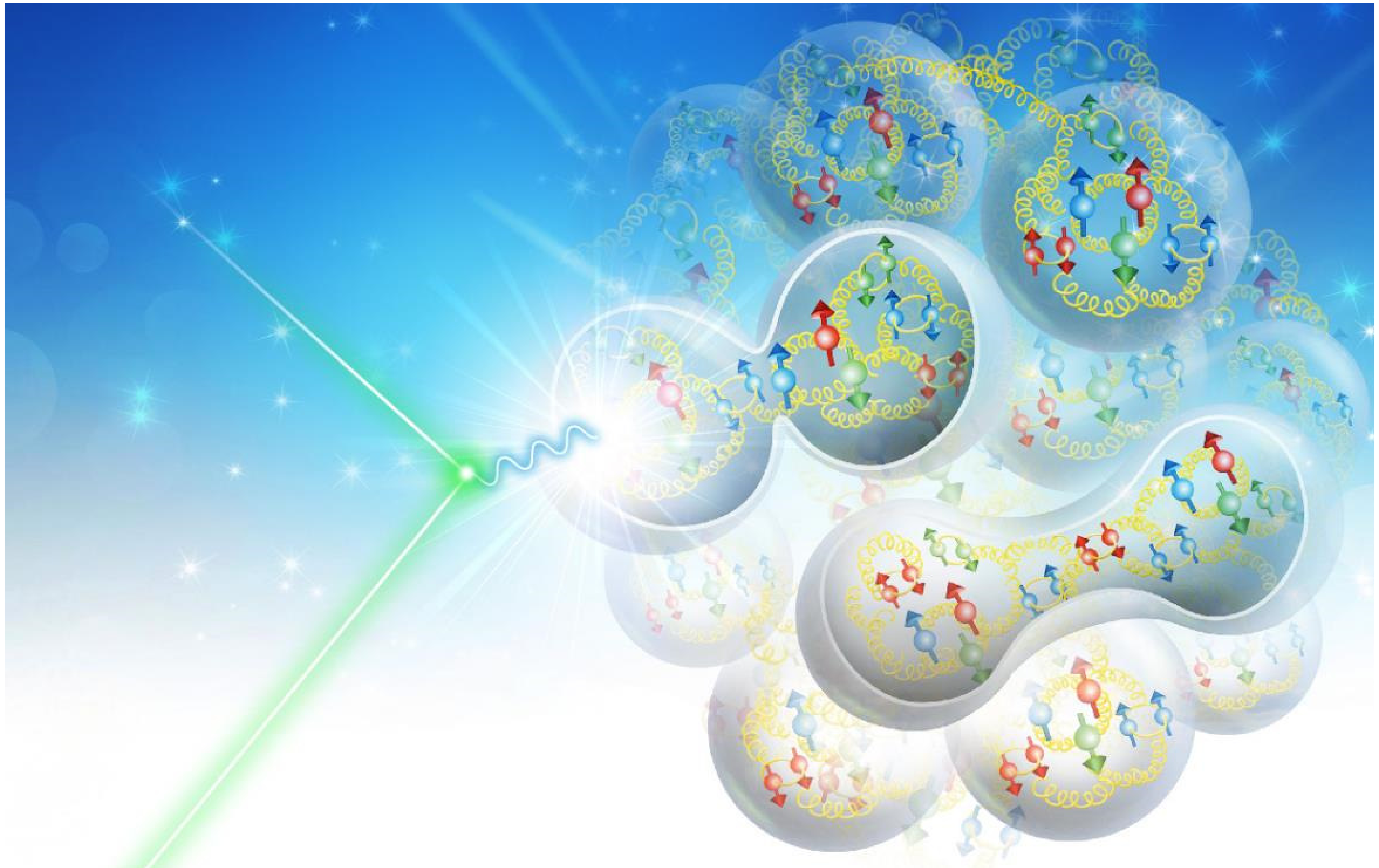
IR Magnet Design and Engineering Considerations



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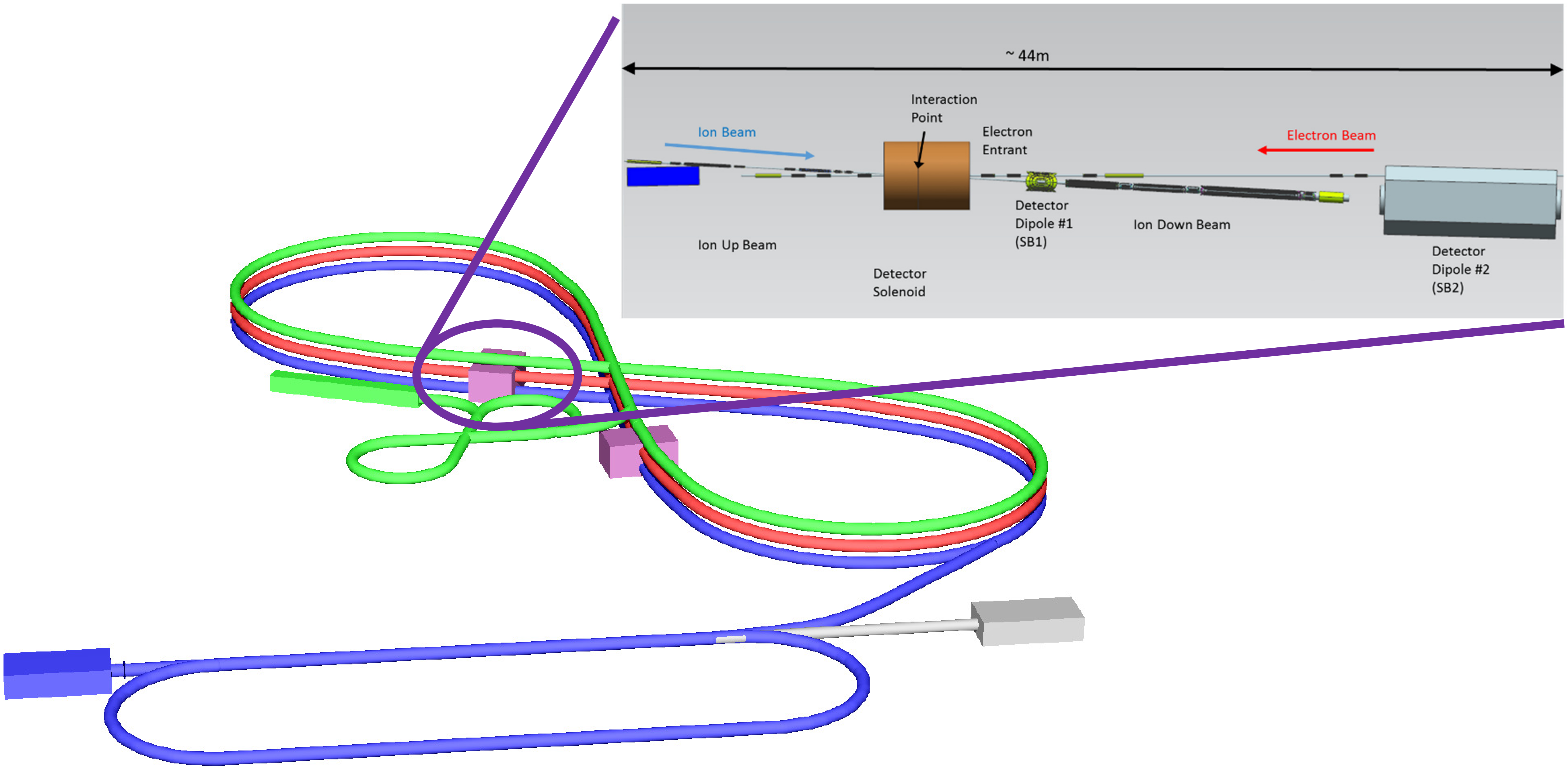
Interaction Region (IR) Magnet Design Verification (FY'18-19 Base R&D)

- **Description**
  - There are 12 Final Focus Quadrupole (FFQ) and 3 Spectrometer Dipole (SD) high field superconducting magnets located within the JLEIC interaction region.
  - There are 14 Skew Quadrupoles (some integrated with FFQs), 4 anti-solenoids, and 6 corrector magnets
  - Baseline parameters have been defined; updated for 200 GeV ions.
  - 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.
- **Goals**
  - Each of the IR magnets is designed and analyzed in 3D TOSCA to verify the design is feasible and required performance parameters are attainable. Optimization of iQDUS1a in Roxie by LBL.
  - 3D models representing the magnet designs are added to the JLEIC layout for verifying space allocation, mechanical support, and cryostat placement.
  - Beam studies and detector background simulations of the resultant designs will define any required changes.
  - Iterations on designs will be performed such that all involved groups agree on an acceptable design solution.
- **Deliverables**
  - 3D TOSCA models for all magnet designs shall be generated to demonstrate field strength, magnet size, impact to the adjacent beam, magnet current, etc.
  - 3D CAD models for all magnet designs shall be generated to demonstrate space allocation, structural support, and IR vacuum space for background simulations.
  - Iterations of specific magnet designs will be performed as required.

What part of JLEIC are we looking at?



Outline

- Magnet Design
- Magnet-Magnet Interactions
- Beam Transport Area and Cryostat Designs
- Summary and Outlook

Magnet Design – Ion Magnet Parameters

- All FFQ magnets are NbTi
- Ion FFQ lengths have been increased for 200 GeV
- 3 downstream magnets are most challenging due to aperture size
- Four skew quadrupoles in the upstream and downstream lines, two are nested with the FFQ quadrupoles.

Specifications											Design			
Element name	Type	Length [m]	Good field half-aperture [cm]	Inner Half-A [cm]	Outer Radius [cm]	Dipole field [T]		Quadrupole field [T/m]		Solenoid [T]	Coil Inner radius (mm)	Coil Outer Radius (mm)	Coil Width in Radial Direction	Peak Field in the coil (T)
Upstream elements						Bx	By	Normal	Skew					
iASUS	SOLENOID	1.6	3	4	12	0	0	0	0	2	60	67	7	2.01
iQUS3S	QUADRUPOLE	0.5	3	4	12	0	0	0	3.38	0	45	47	2	0.30
iQUS2	QUADRUPOLE	2.1	3	4	12	0	0	94.07	0	0	45	78	33	5.70
iQUS2S	QUADRUPOLE	0.5	2	3	10	0	0	0	-9.26	0	35	40	5	0.55
iQUS1b	QUADRUPOLE	1.45	2	3	10	0	0	-97.88	0	0	34.5	49.5	15	5.12
iQUS1S	QUADRUPOLE	0.5	2	3	10	0	0	0	16.42	0	35	44	9	0.89
iQUS1A	QUADRUPOLE	1.45	2	3	10	0	0	-97.88	-3.08	0	34.5	57.5	23	5.12
iCUS1	KICKER	0.3	2	3	10	-3.90	0.076	0	0	0	34.5	52.5	18	6.34
iCUS2	KICKER	0.3	2	3	10	4.50	-0.019	0	0	0				
iDSUS	SOLENOID	1.6	2	160	210	0	0	0	0	-2				
Downstream elements														
iDSDS	SOLENOID	2.4	2	160	210	0	0	0	0	-2				
iBDS1a	RBEND	0.75	4.0	38.5	48.5	0.2	1.32	0	0	0	410	441	31	5.73
iBDS1b	RBEND	0.75	4.0	38.5	48.5	-0.2	1.32	0	0	0				
iQDS1a	QUADRUPOLE	2.25	4.0	9.2	23.1	0.0	0	-37.23	-1.23	0	130	171	41	6.43
iQDS1S	QUADRUPOLE	0.5	4.0	9.9	24.8	0.0	0	0	14.85	0	130	142	12	3.91
iQDS1b	QUADRUPOLE	2.25	4.0	12.3	31.0	0.0	0	-37.23	0	0	130	163	33	6.38
iQDS2S	QUADRUPOLE	0.5	4.0	13.0	32.7	0.0	0	0	-7.83	0	136	145	9	2.29
iQDS2	QUADRUPOLE	4.5	4.0	17.7	44.4	0.0	0	25.96	0	0	182	215	33	6.95
iQDS3S	QUADRUPOLE	0.5	4.0	18.4	46.2	0.0	0	0	0.63	0	200	202	2	0.38
iASDS	SOLENOID	1.2	4.0	19.8	49.7	0.0	0	0	0	4	225	240	15	4.01
iBDS2	RBEND	8.00	4.0	40.0	90.0	0.0	-4.42	0	0	0				
iBDS3	RBEND	6.50	4.0	4.0	30.0	0.0	5.44	0	0	0	50	81	31	6.73
iQDS4	QUADRUPOLE	0.8	3	4	30	0	0	144.14	0	0				

Magnet Design – Electron Magnet Parameters

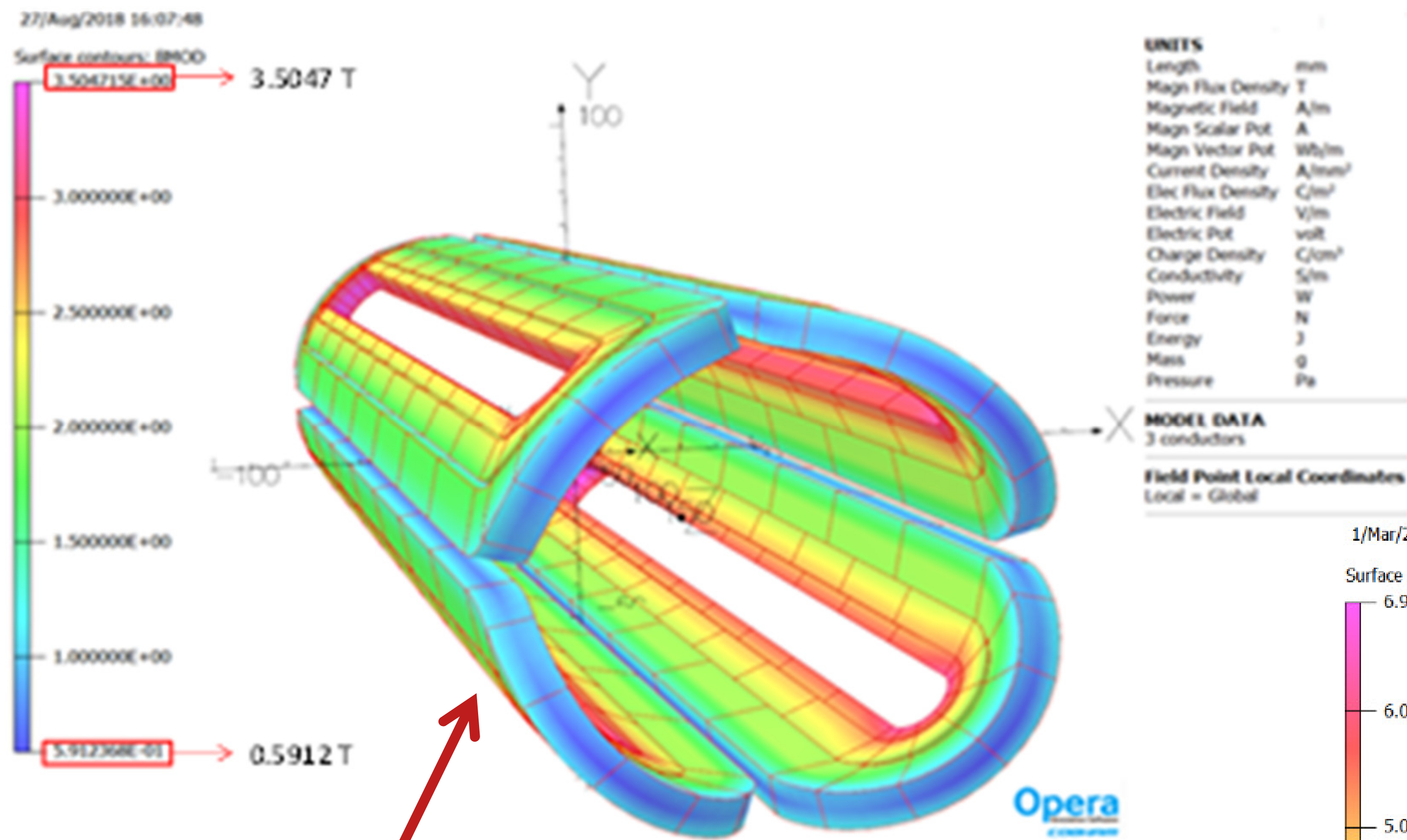
- Electron FFQ designs have not changed.
- All the quads and skew-quads are designed the same for 45 T/m main quad strength and 9.5 T/m for skew-quad strength. These quads can be optimized further to reduce space or reduce peak field in the coils.

Element name	Type	Length [m]	Good field half-aperture [cm]	Inner Half-A [cm]	Outer Radius [cm]	Dipole field [T]		Quadrupole field [T/m]		Solenoid [T]	Coil Inner radius (mm)	Coil Outer Radius (mm)	Coil Width in Radial Direction	Peak Field in the coil (T)
Upstream elements						Bx	By	Normal	Skew					
eASDS	SOLENOID	1.2	2.2	4.5	11	0	0	0	0	-4	65	80	15	4.00
eQDS3	QUADRUPOLE	0.6	2.4	4.5	10	0	0	-18.72	-2.71	0				
eQDS2	QUADRUPOLE	0.6	2.8	4.5	8.5	0	0	36.22	5.25	0	49.5	65	15.5	3.58
eQDS1	QUADRUPOLE	0.6	1.7	4.5	8	0	0	-33.75	-4.89	0				
eDSDS	SOLENOID	1.6	2	160	210	0	0	0	0	-2				
Downstream elements														
eDSUS	SOLENOID	2.4	2	160	210	0	0	0	0	-2				
eQUS1	QUADRUPOLE	0.60	2.0	4.5	10.0	0.0	0.00	-36.94	8.10	0				
eQUS2	QUADRUPOLE	0.60	3.2	4.5	11.0	0.0	0.00	33.66	-7.38	0	49.5	65	15.5	3.58
eQUS3	QUADRUPOLE	0.6	1.5	4.5	11.0	0.0	0	-20.80	4.56	0				
eASUS	SOLENOID	1.8	2.2	4.5	11.0	0.0	0	0	0	-4	65	80	15	4.00

Magnet Design

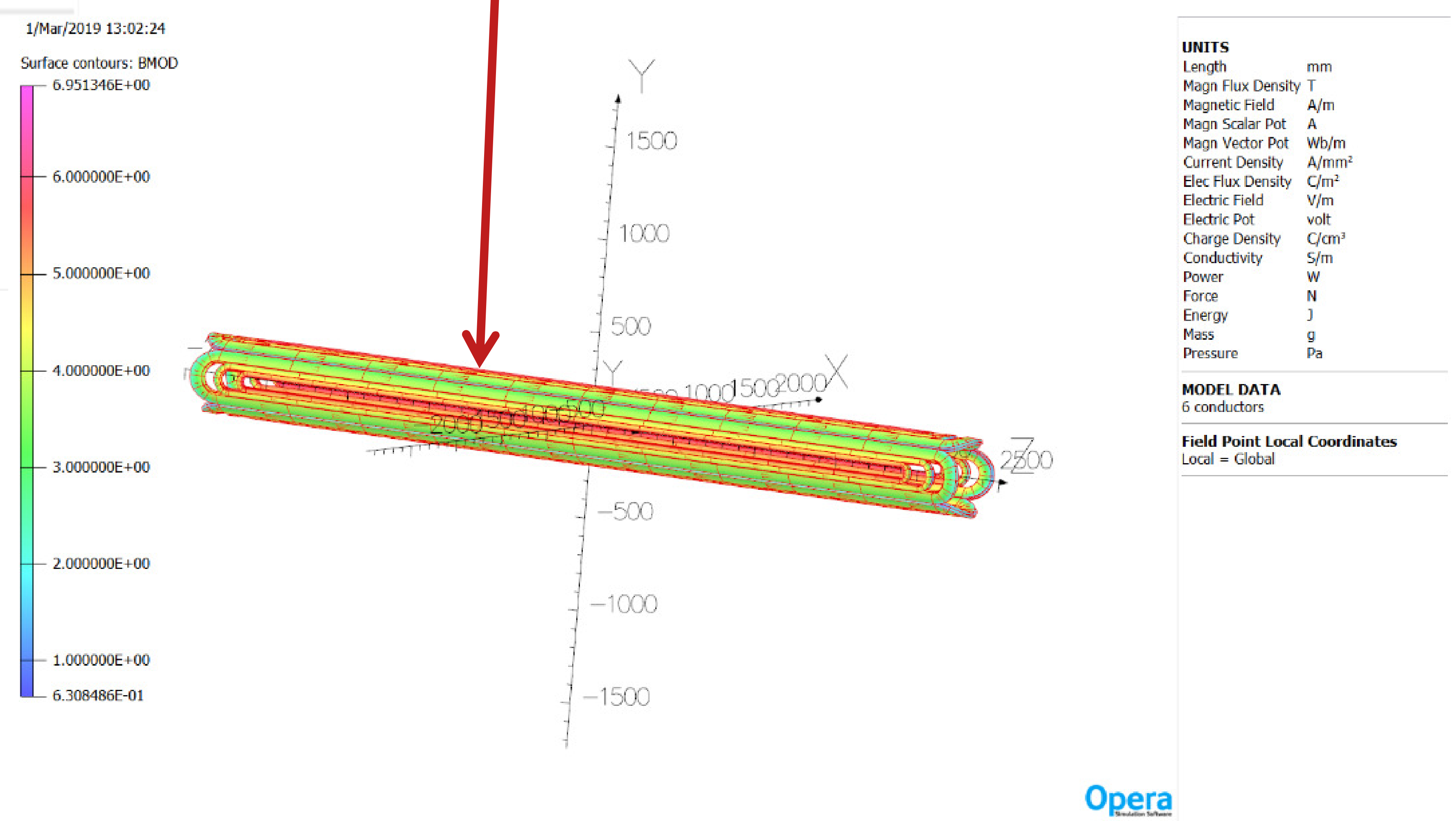
- All of the magnets for both the ion and electron beam lines are based on cold bore designs.
- This is primarily to lower the field requirements on the ion beam quadrupoles.
- The magnets in the electron beam line could be either warm or cold bore.
- The cold bore designs in the electron line do reduce the radial space needed which is a plus as you get closer to the IP.
- A design limit of 4.6T pole tip field has been set. This maintains field in the coils within the regime for NbTi @ 4.5K.

Magnet Design – Electron and Ion Upstream Quad

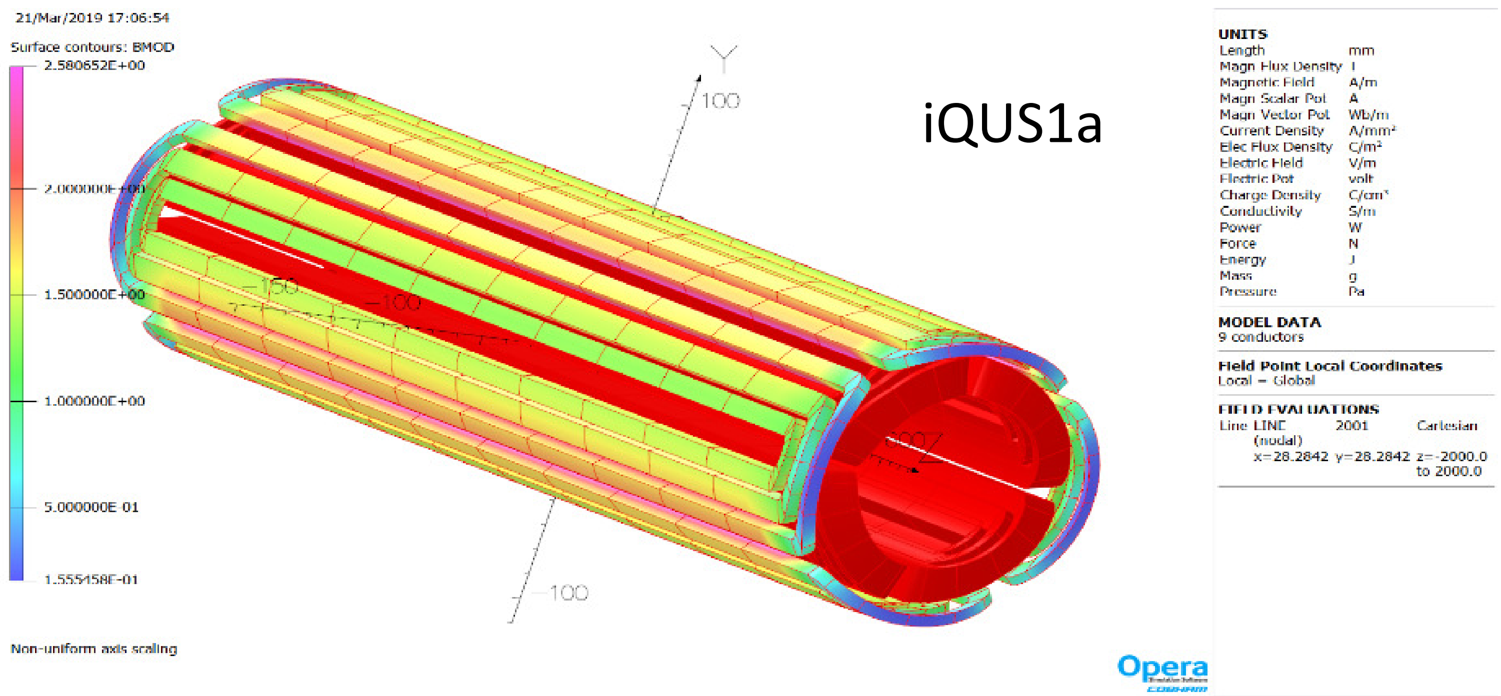


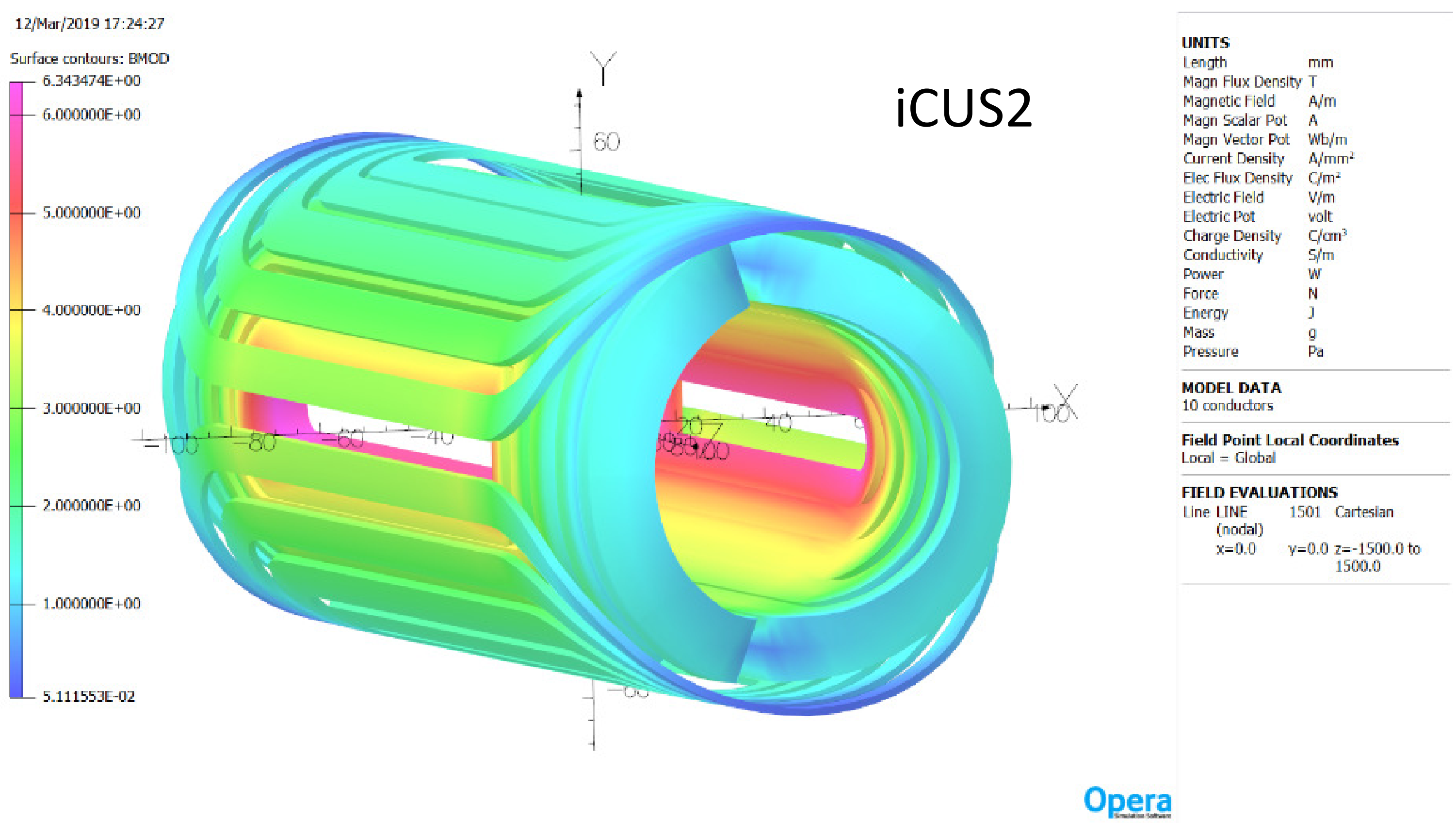
Peak Field in Electron Quad = 3.5T
The coils will be operated at 4000 A and will use 9.73 mm x 1.2 mm Rutherford cable.

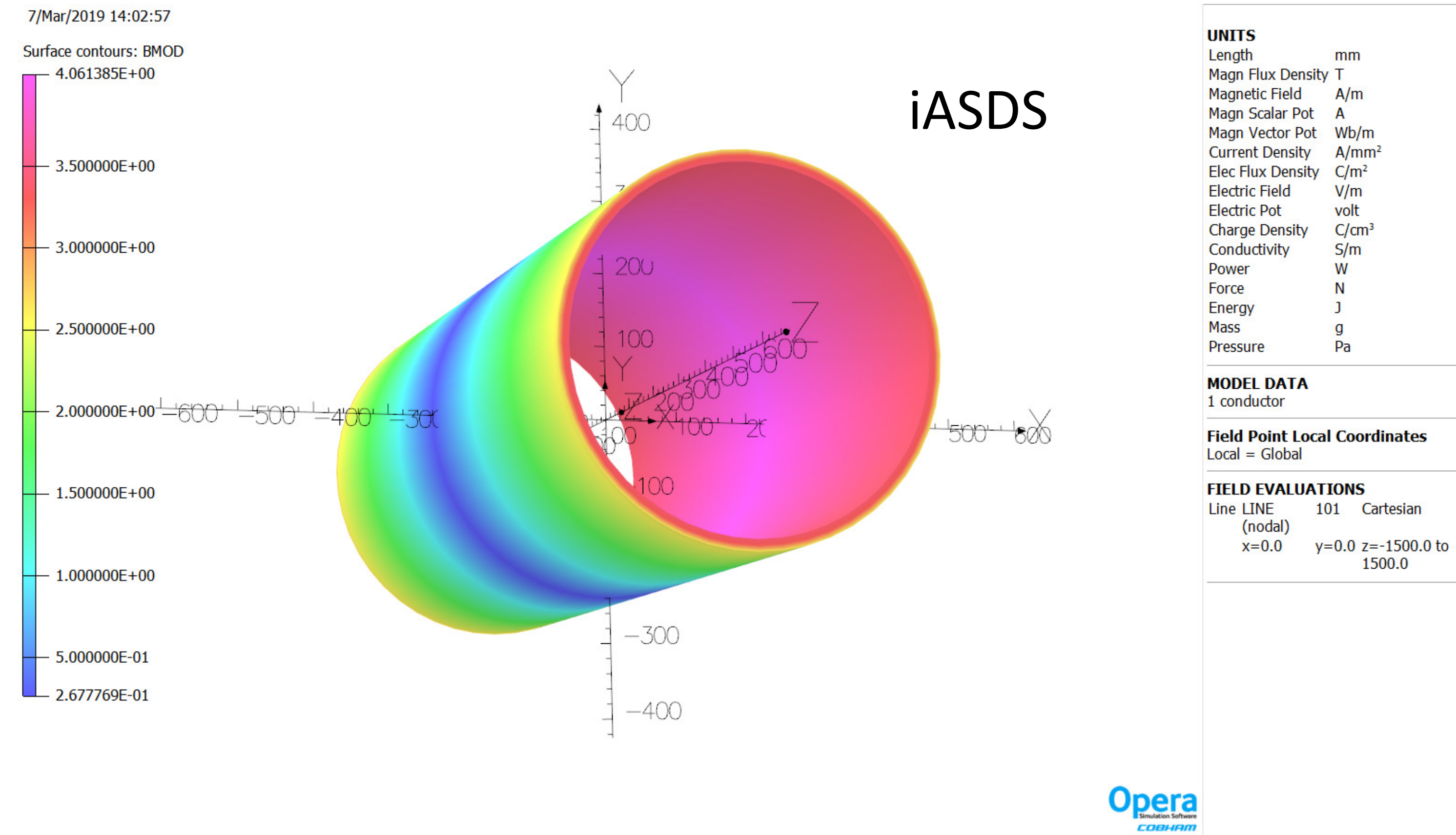
Peak Field in Upstream Ion Quad (iQDS2) = 6.95T
The conductor is envisaged to be stranded, NbTi cable with 20-30 strands per cable using 0.7 mm diameter strands.



Ion Magnet Designs – Skew Quad, Solenoid, Corrector (Kicker)

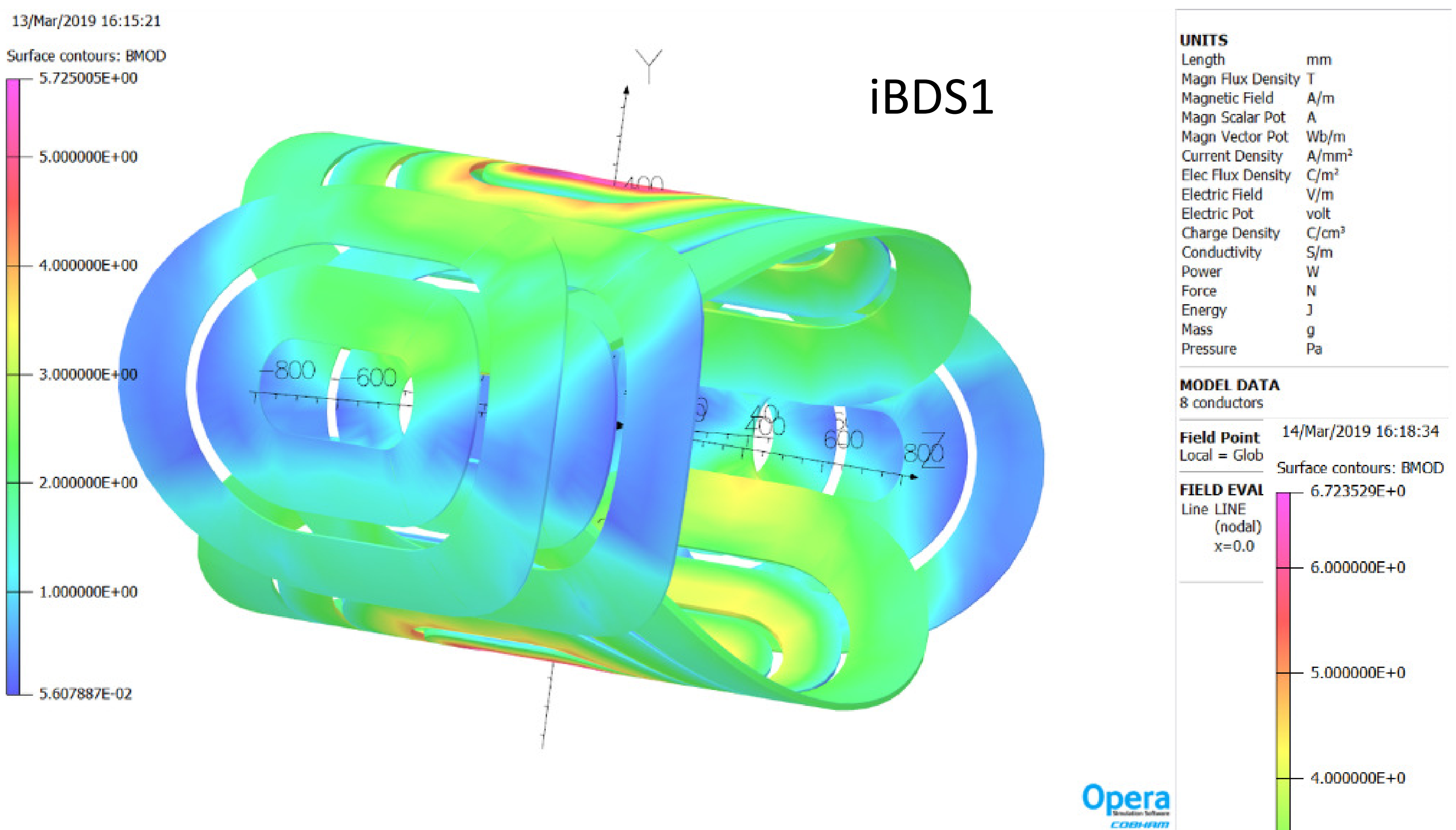




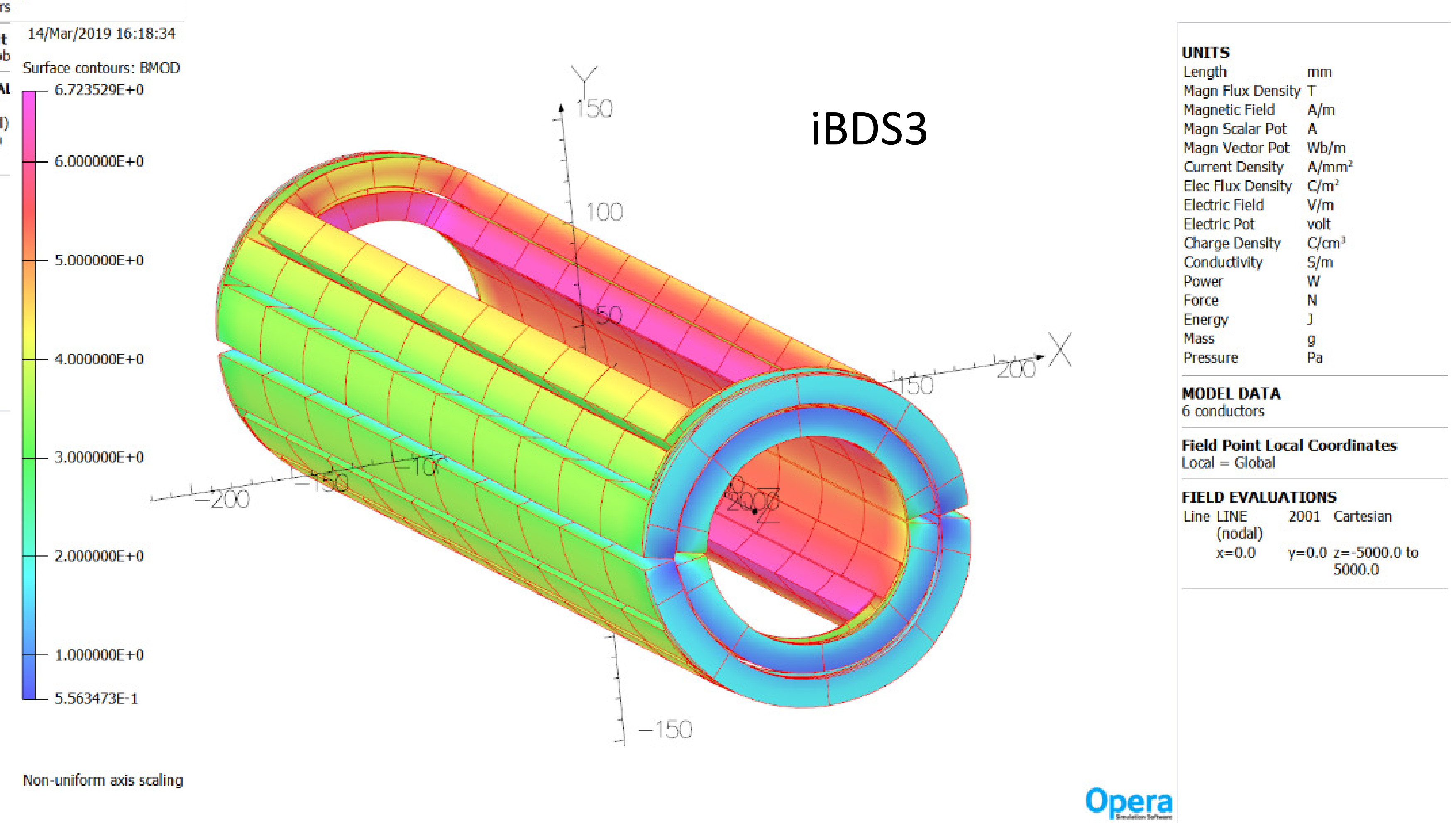


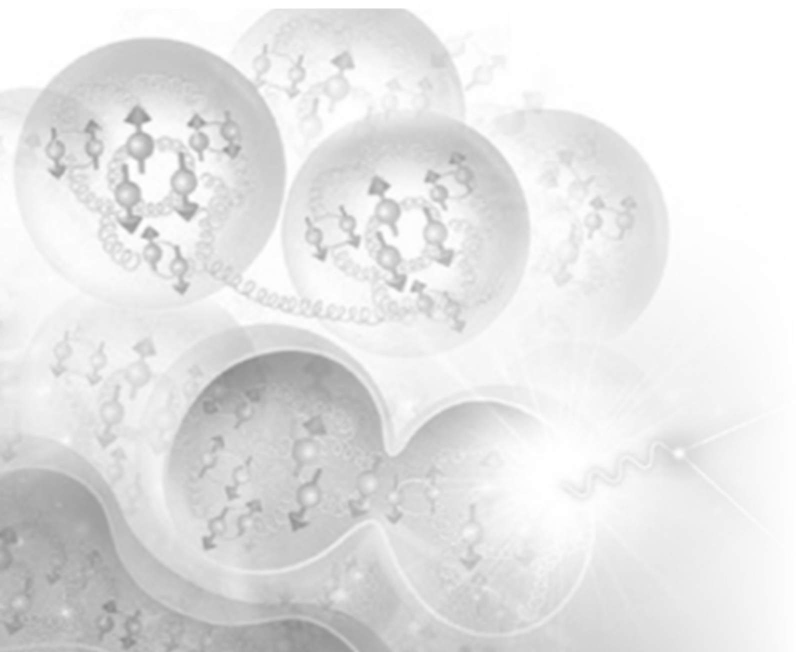
- Peak field in the iQUS1a Skew quad is 2.6 T
- Peak field in the iASDS Solenoid is 4 T
- Peak field in the iCUS2 Corrector is 6.3 T

iBDS1 & iBDS3 Designs



- Peak field in the iBDS1 coil is 5.73 T
  - Single horizontal bend plus two vertical bend coils
- Peak field in the iBDS3 dipole coil is 6.73 T
  - Start of ion beam transport after the detector

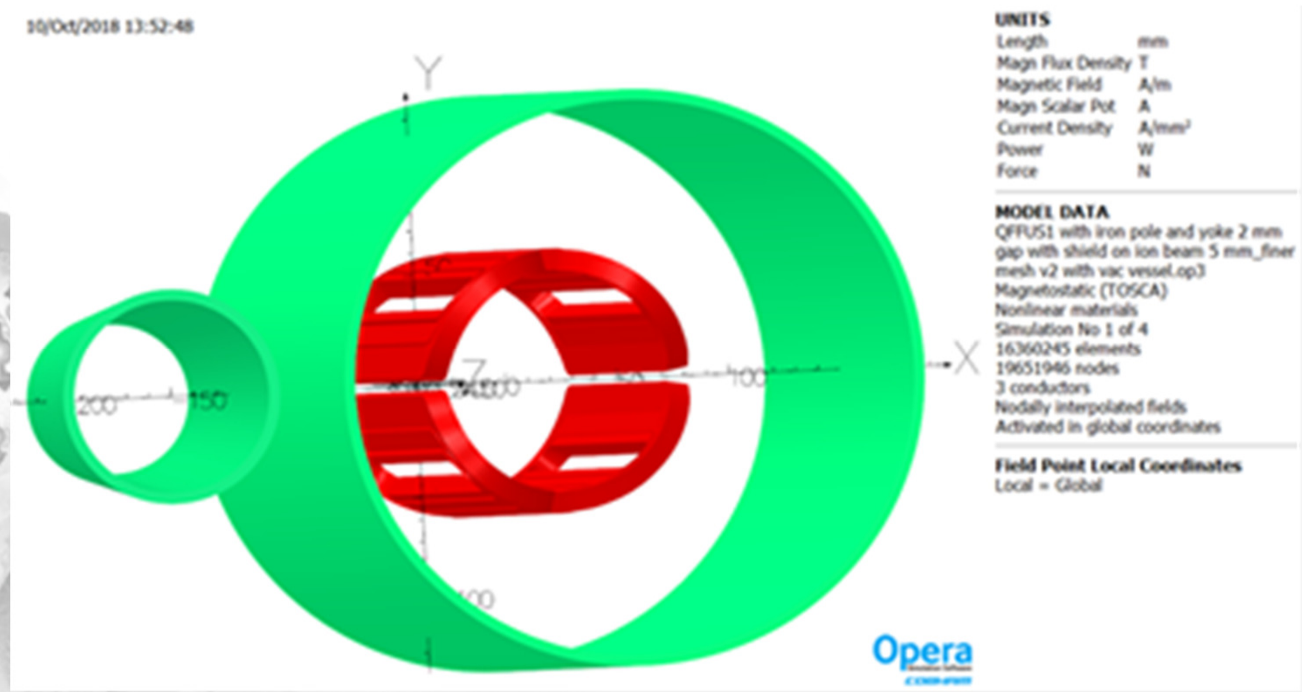


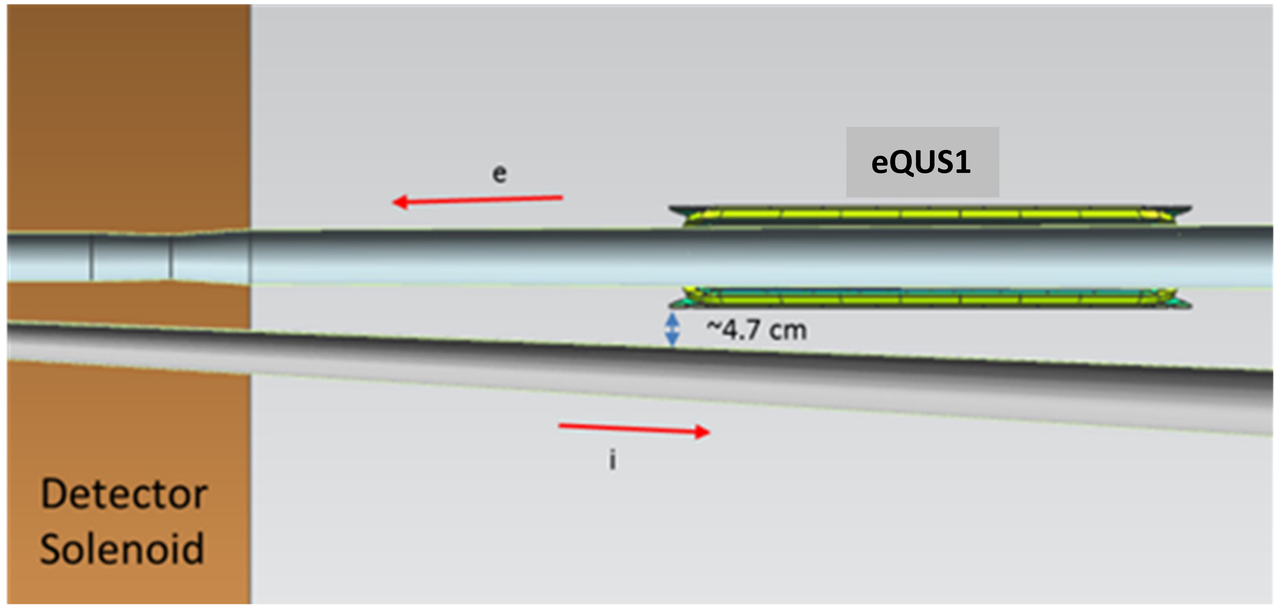


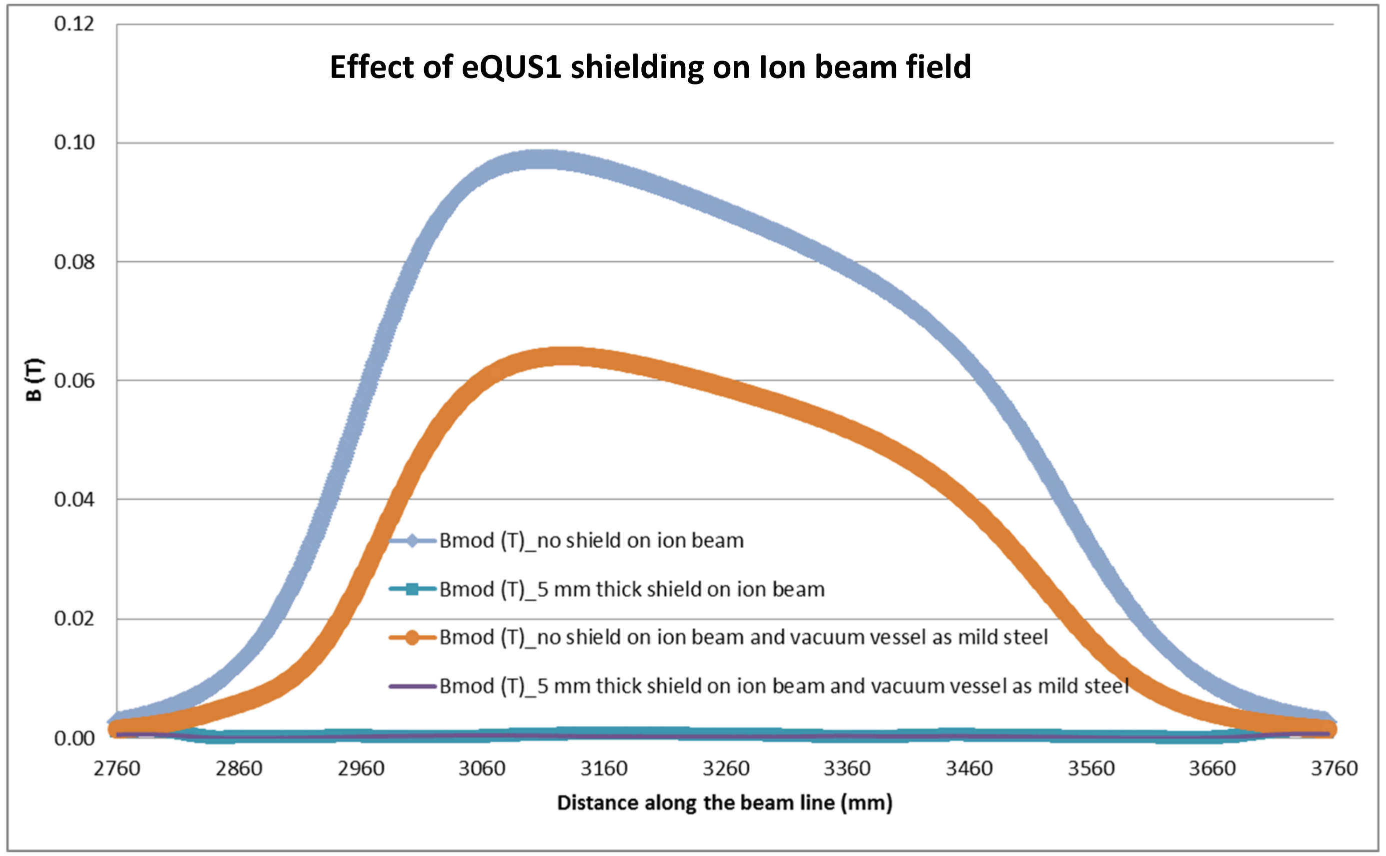
Magnet-Magnet Interaction – (previous design, will be updated for 200 GeV ions)

- In order to study the magnet-magnet interactions, the following combinations were selected for the initial study:
  - **eQUS1 with ion beam line (shown)**
  - eQUS1 with ion beam line (pending)
  - iQDS1a, eQUS3 and eASUS (pending)
  - eQUS2 and iQUS1a (pending)

eQUS1- (i) ion beam tube wrapped with 5 mm mild steel passive shield (ii) the vacuum vessel for the eQUS1 is assumed to be made of mild steel, and (iii) a combination of the above two options

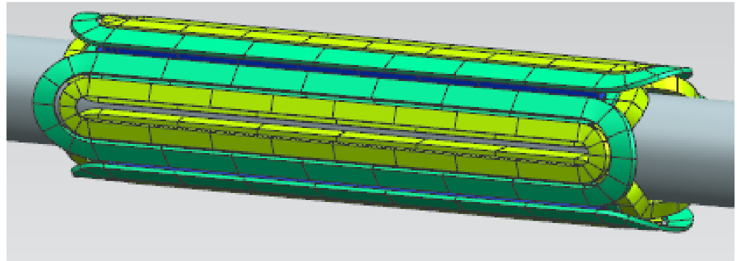






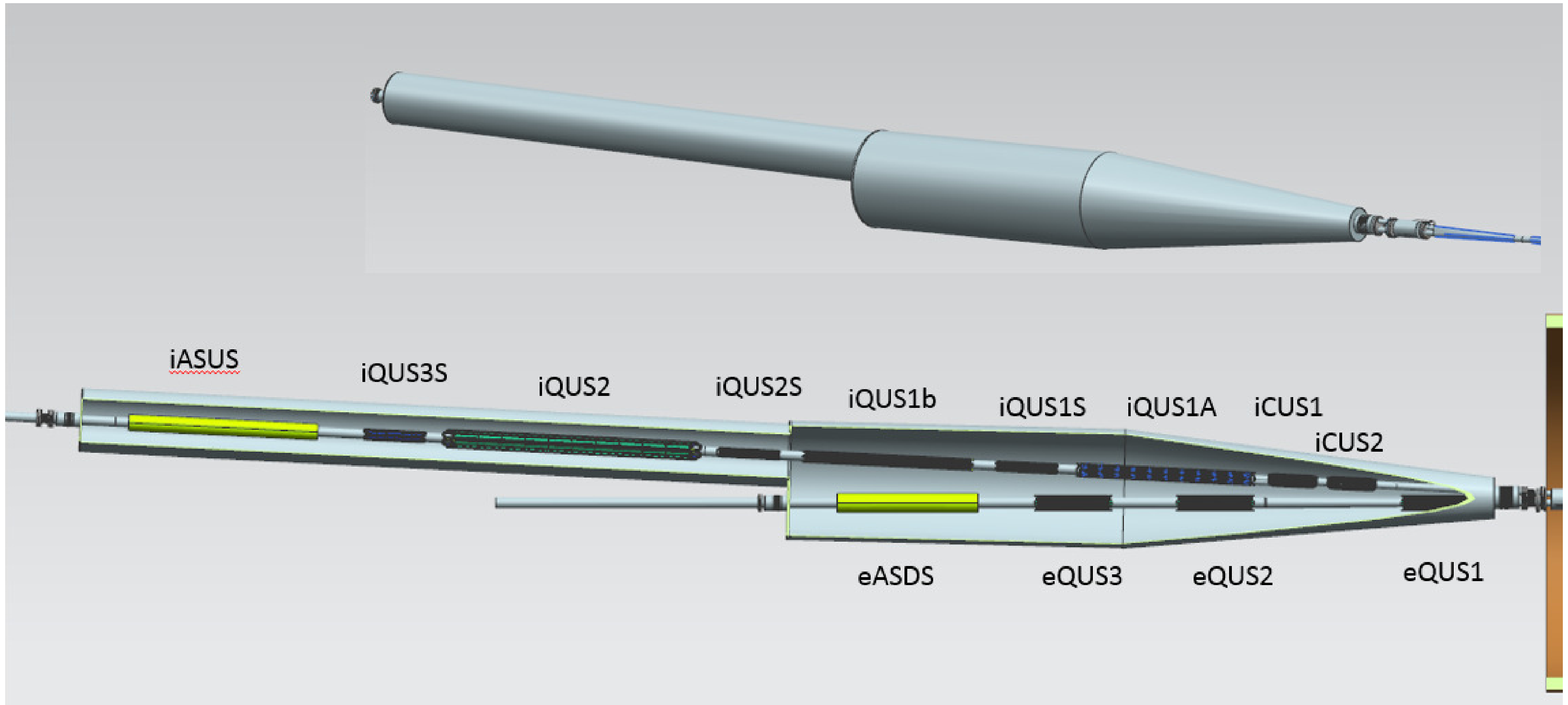
Ion Up Beam Area

- '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
- Twenty magnets plus multipole correctors and shielding coils in a single, long cryostat
  - Three identical quads in electron line with nested skew quads
  - Three quads in ion line plus four skew quads
  - One solenoid in each line
  - Two horizontal/vertical correctors in ion line near IP



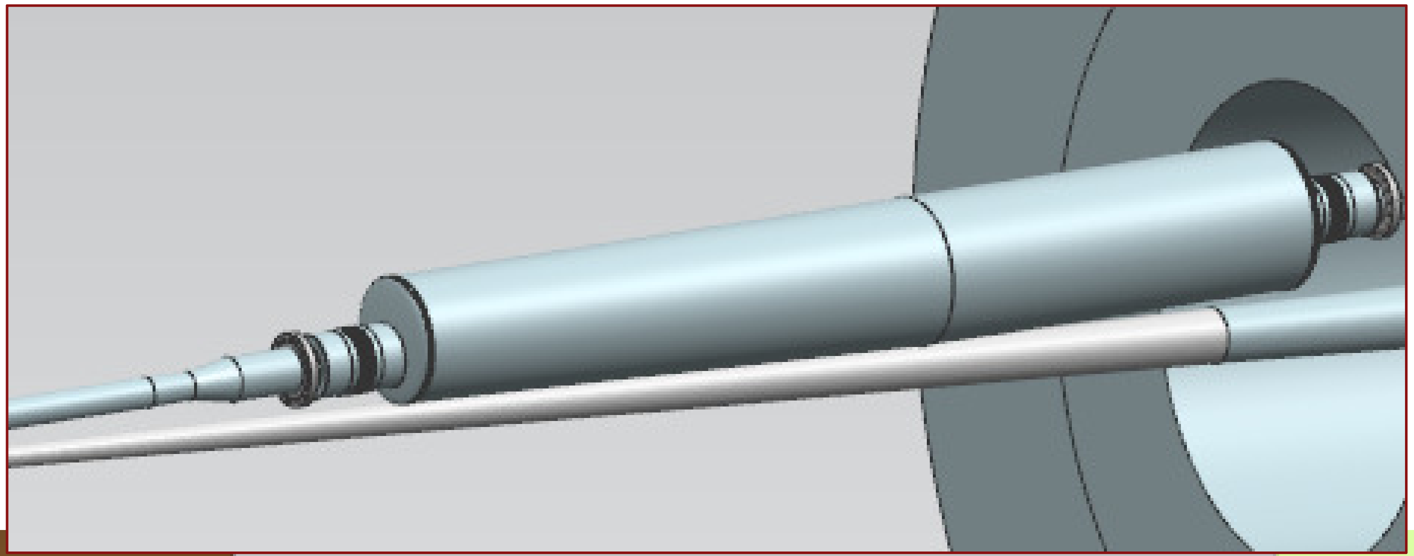
Quad with nested skew quad

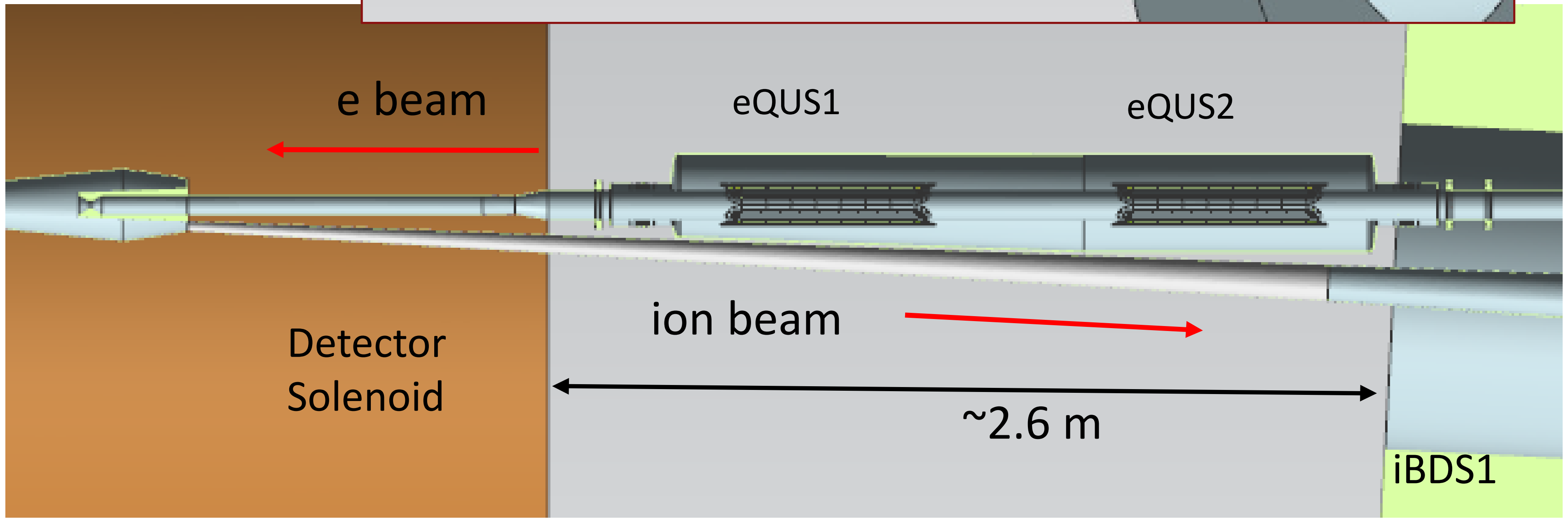
- Both the cryostat and cold mass will be supported in at least three locations with a minimum of twelve typical support rods on the cold mass.
- A thermal shield will be included inside of the vacuum vessel and surround the entire cold mass.
- The cryogenic feed and magnet lead can will be positioned on one side of the cryostat away from the detector elements.



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 may be needed for synchrotron radiation in the electron line
  - Initial cold bore heat loads appeared to be acceptable
  - Need to update the SR loads with the new electron beam lattice

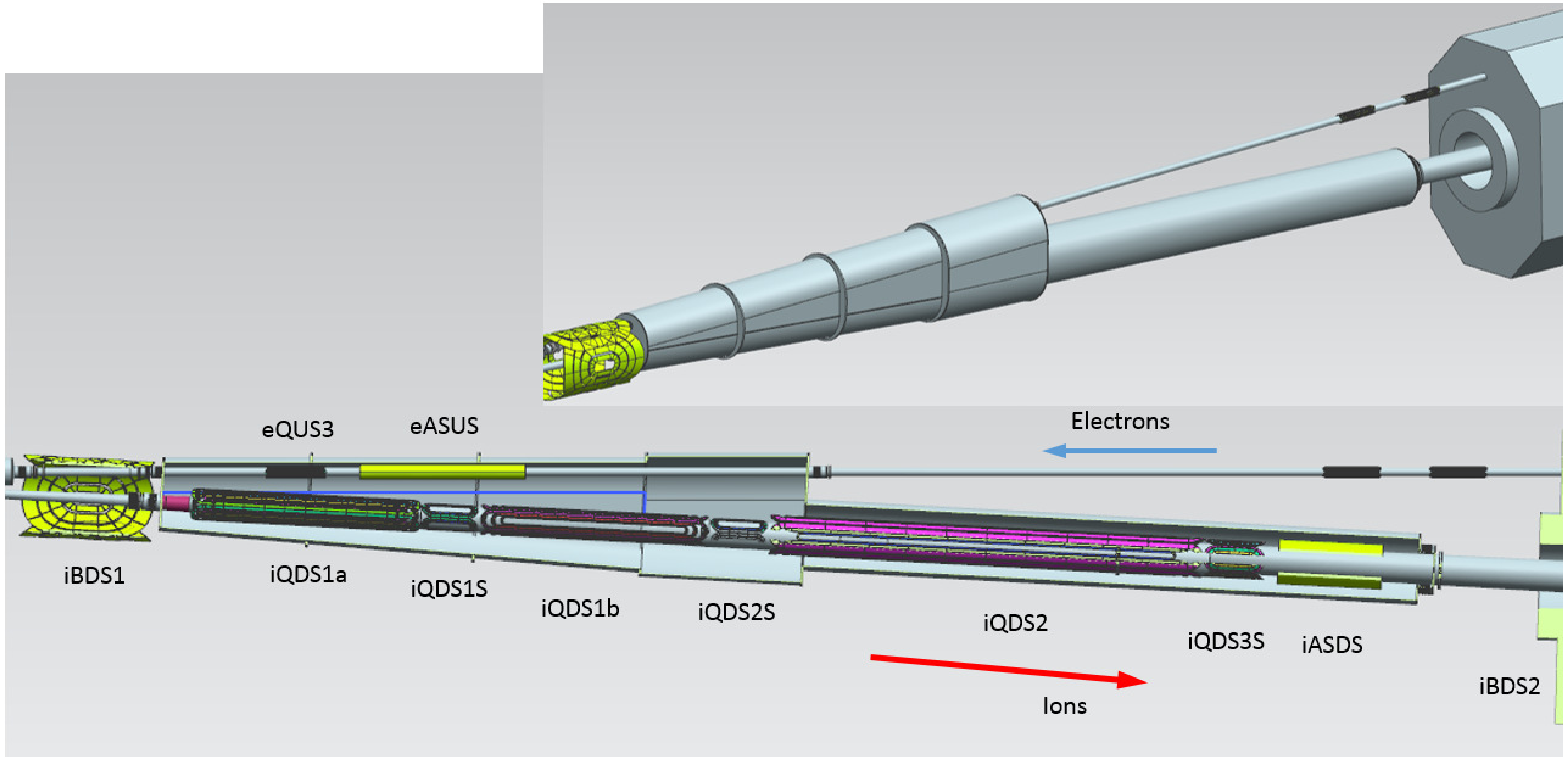




Ion Down Beam Area

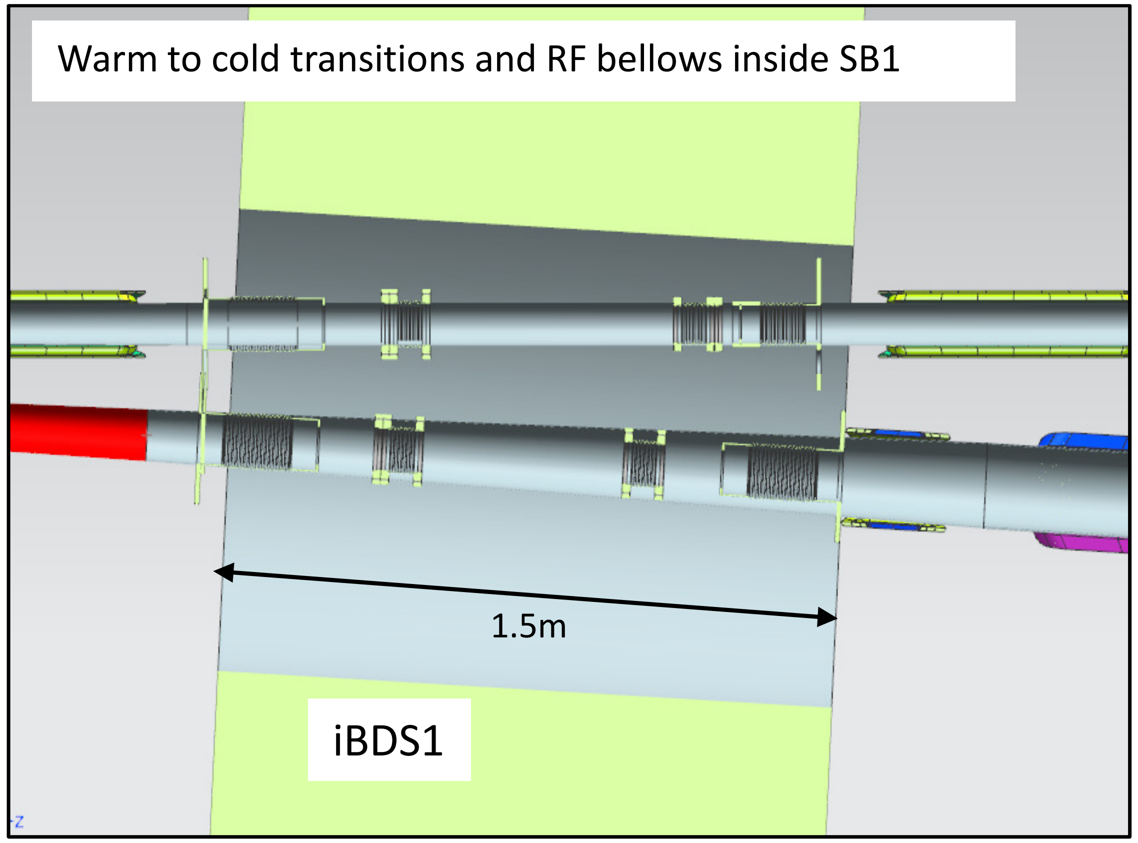
- Eleven magnets plus multipole correctors and shield coils in a single, long cryostat
- In addition, some transport quads will probably have to be superconducting as warm magnets impinge on the radial space of the ion beamline – same design as the other electron FFQs

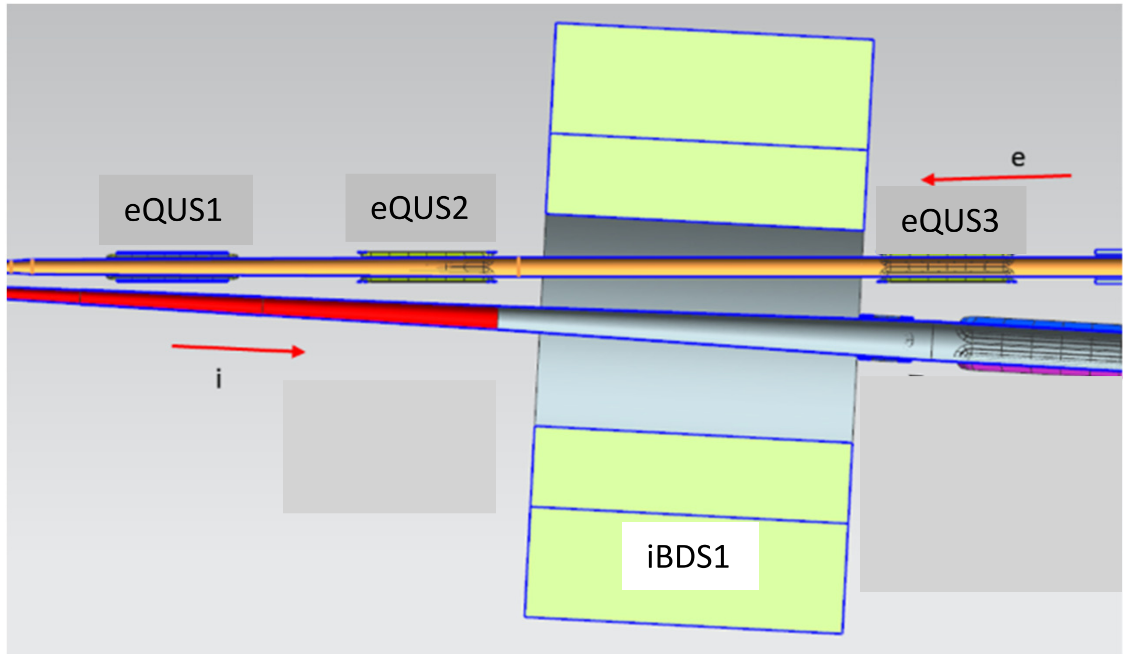
- Large bore solenoid in ion beam line (iASDS)
- Four skew quads in ion line – (IQDS1aS, iQDS1S, IQDS2S, IQDS3S)
- Long cryostat with minimal space between magnets presents challenges to packaging, alignment, instrumentation, diagnostics, etc.



Integration with detector dipole

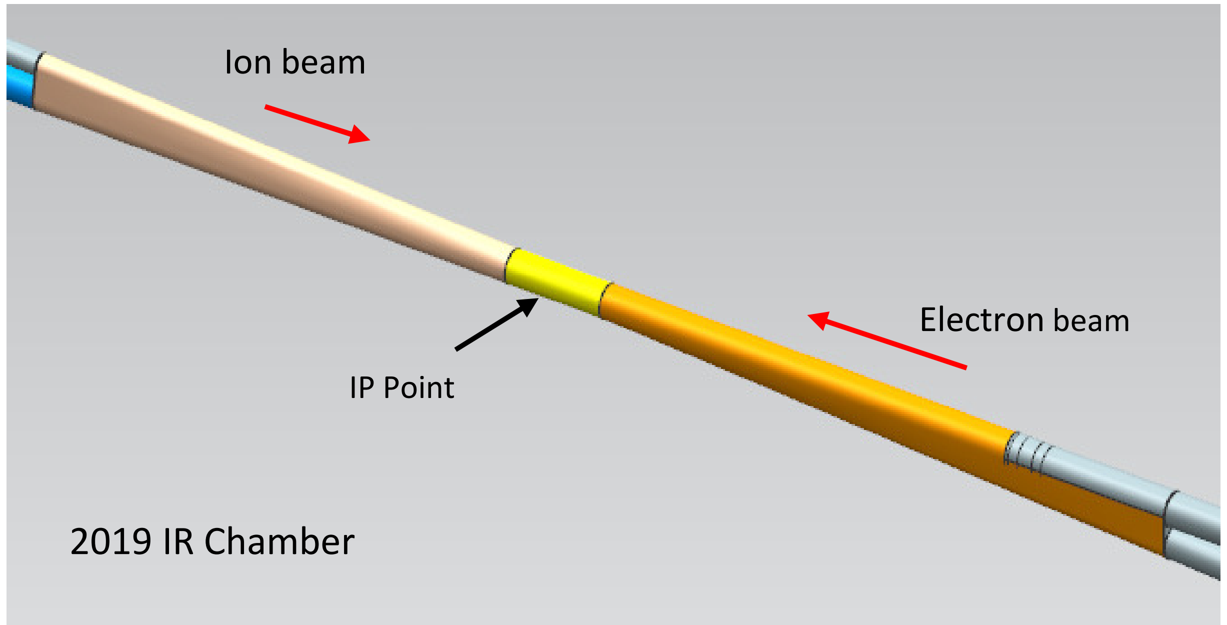
- Designs of beamlines will be closely coupled to the iBDS1 spectrometer dipole design
- In the preliminary designs (shown in figures) both cryostat beam lines extended into the dipole
- The new dipole design is a combined function magnet for the ion beam line
  - Single horizontal bend dipole
  - Two vertical bend correctors
- The electron beam line will require shielding from this combined function magnet.
- Physics detectors are also desired between this magnet bore and the ion vacuum beam line.

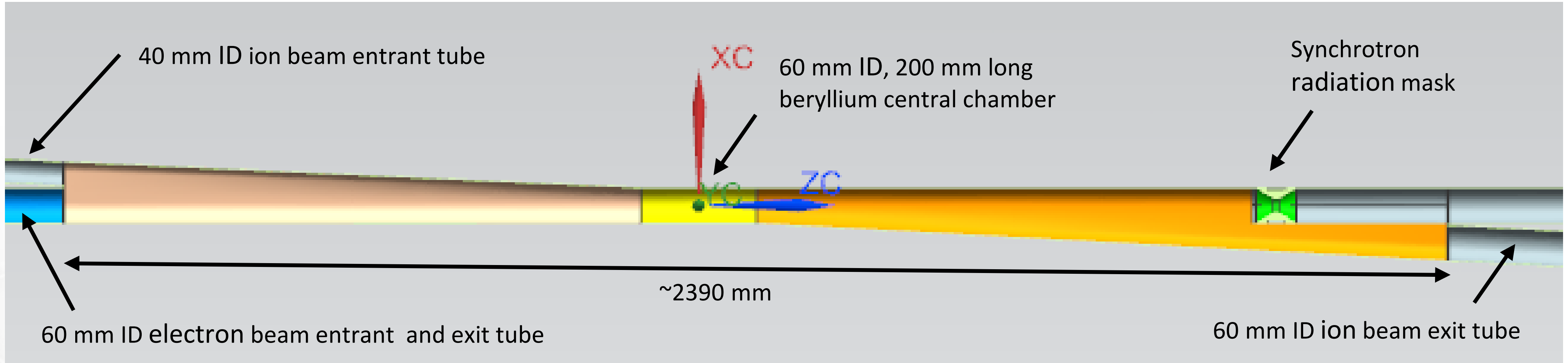




IR Beam Pipe Design

- This is the second generation design. It has been updated for both detector background and beamline impedance considerations.
- 2018 IR vacuum chamber had large beam impedance (Calculation by F. Marhauser)
- 2019 IR vacuum chamber
  - "Cone like" transitions from beam tubes to the central beryllium IR chamber
  - Synchrotron mask unchanged (1000 mm from IP, 24 mm ID/10 mm long)
  - Design in progress and impedance calculations still to be done





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Summary and Outlook

- A thorough 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. Longitudinal space is a challenge.
- Continue work on shielded vacuum pump designs for the region, compatible with the physics detectors.
- A separate group is studying the vacuum requirements within the IR needed to limit the impact from background noise on the detectors.

Thank you for your attention.

Are there any questions?