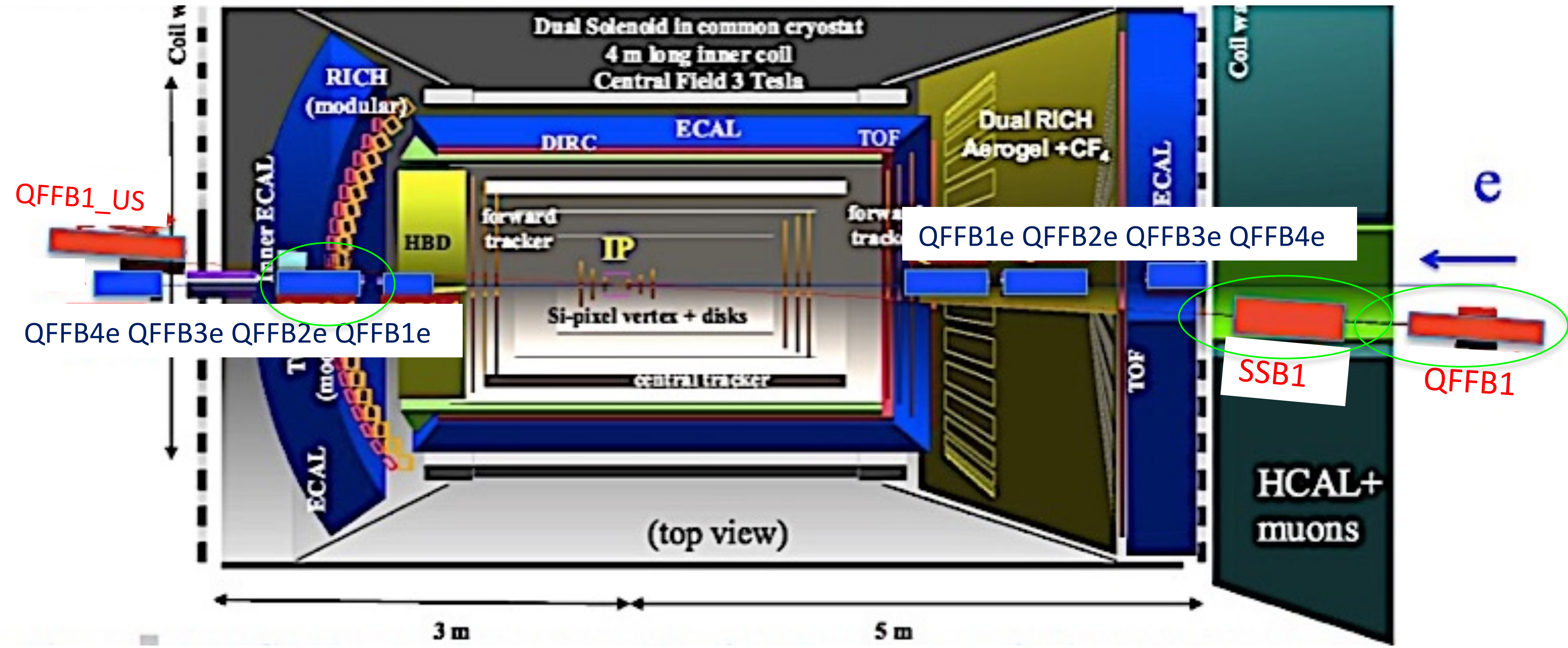
CIC Magnets for IR region of EIC



- Quadrupoles must operate in the fringe field of the ~3 T detector solenoid.
- The FF magnets must operate over a large range of beam energies: no PM.
- FF quads must focus ions after IP collision must match to the collider lattice, but must have large aperture to pass scattered. QF1 requires 12 T in windings.
- E, ion quads are close to one another, must not produce field on the other beam.
- All FF magnets must operate with high rad damage & heat load from losses.

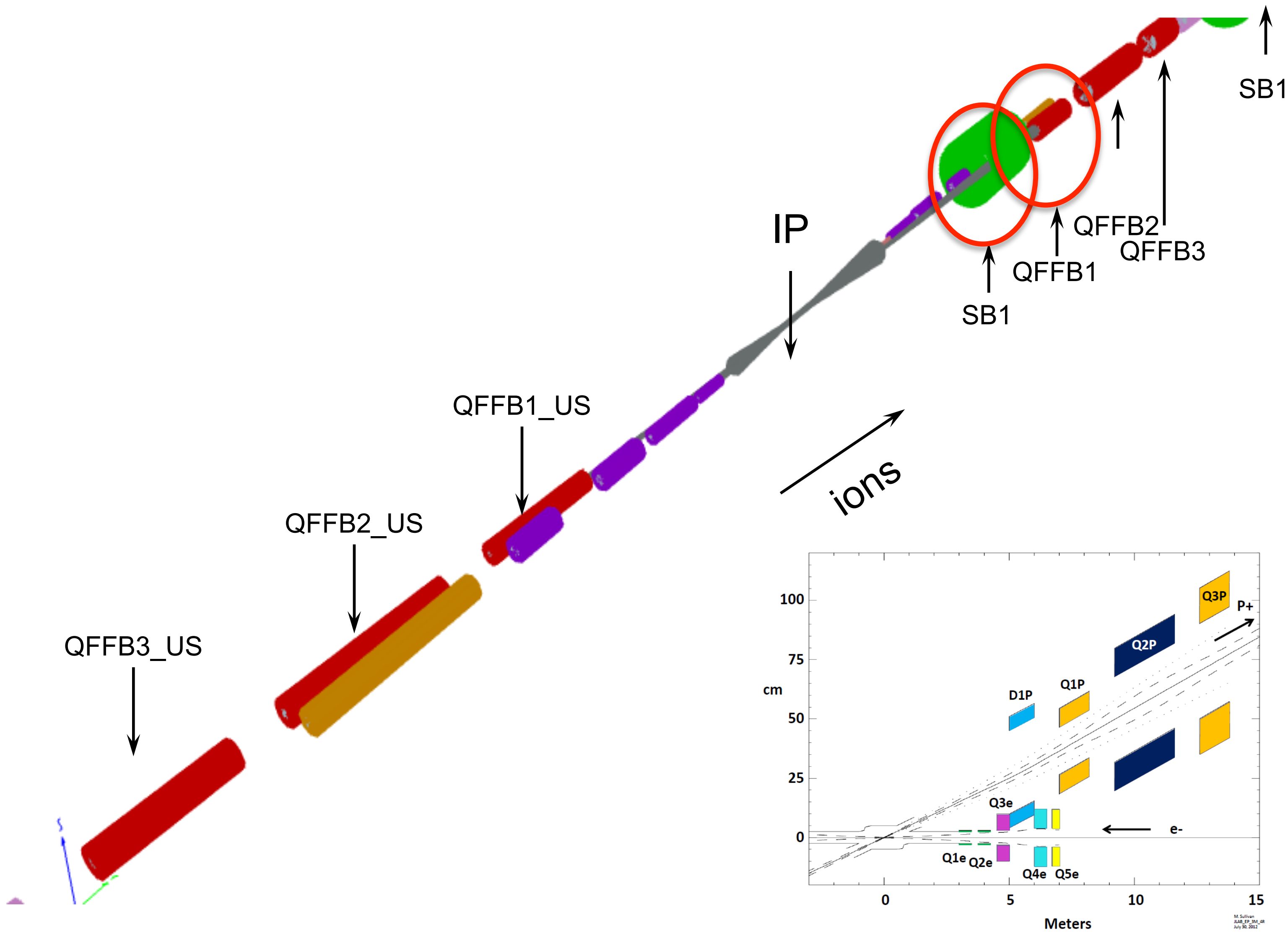
We have prepared conceptual designs for the four most difficult IR magnets

Ion Beam: **QFFB1:** 90 T/m, 9 cm half-aperture, 36 cm from e-beam
SB1: 2 T, 340 mm aperture, 25 cm from the electron beam

Electron beam: **QFFB2e:** 58 T/m gradient, 3 cm half-aperture, 10.5 cm from the ion beam
QFFB1e, QFFB2e are immersed in fringe field of spectrometer solenoid

- All designs utilize CIC conductor.
  - adaptable for challenging coil geometries
  - compact end windings
- Utilize MgB_2 or REBCO superconductor for temperature margin in high radiation loss in QFFB1e, QFFB2e.
- Utilize Nb_3Sn superconductor for high gradient in QFFB1.
- Utilize sheath solenoid winding to cancel external flux from spectrometer solenoid.

Interaction Region: Ion Beam Magnets

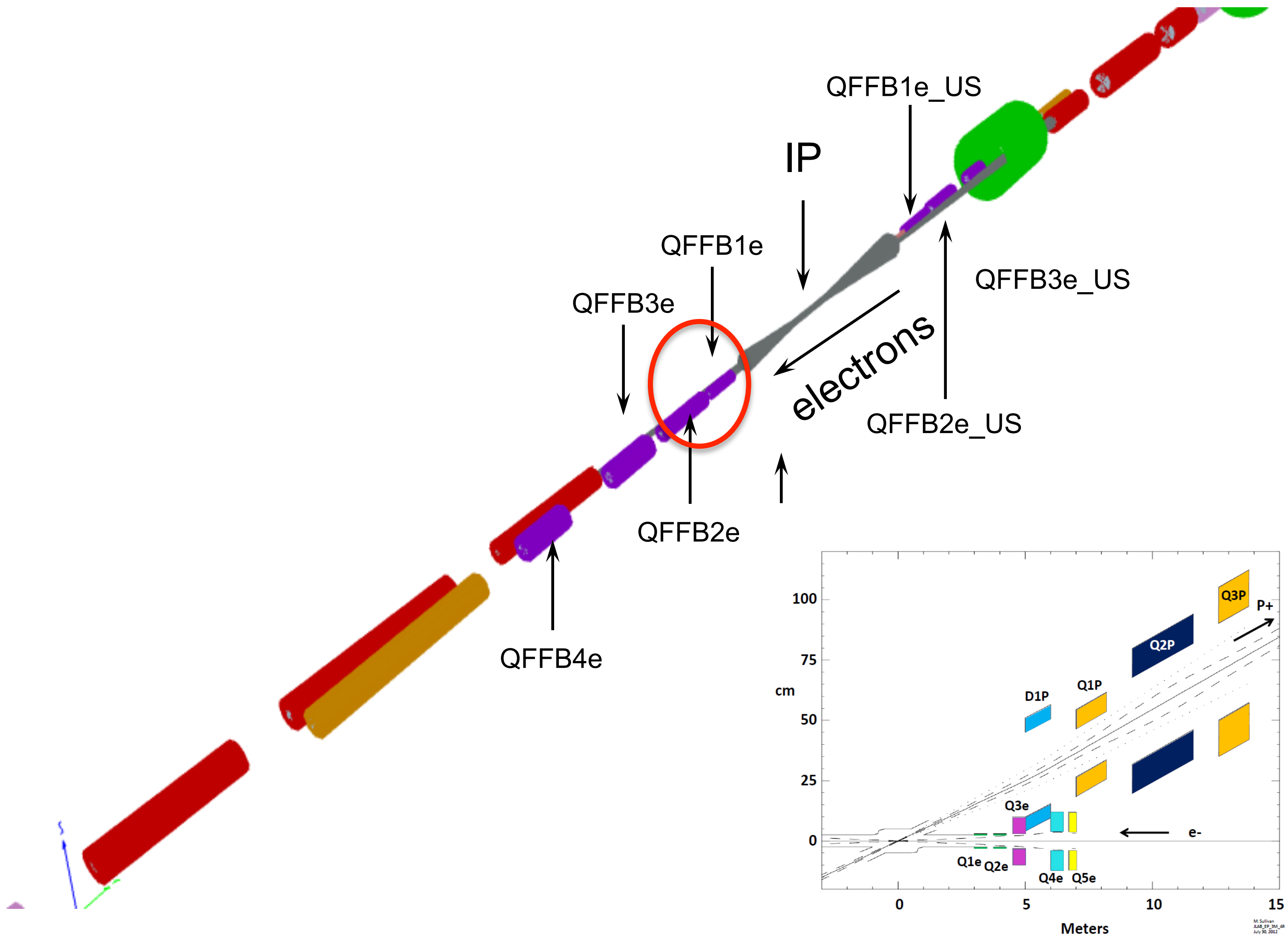


IR Ion Magnet Parameters

- Assuming 100 GeV/c
- Parameters are determined primarily by detection requirements rather than beam dynamics
- Bottom-up study of multipole requirements in progress
- Note: parameters are still being fine-tune but no major changes

Name	Type	Length [m]	Good-field radius [cm]	Inner radius [cm]	Outer radius [cm]	Min. beam separation [cm]	Strength [T or T/m]	Pole-tip field [T]
QFFB3_US	Quad [T/m]	1	3	4	12	36.0	-116	-4.6
QFFB2_US	Quad [T/m]	1.5	3	4	12	26.5	149	6
QFFB1_US	Quad [T/m]	1.2	2	3	10	18.0	-141	-4.2
SB1	Dipole [T]	1	4	17	24	25.0	-2	-2
QFFB1	Quad [T/m]	1.2	4	9	17.1	35.9	-88	-8
QFFB2	Quad [T/m]	2.4	4	15.7	24.7	48.2	51	8
QFFB3	Quad [T/m]	1.2	4	17	26.7	67.2	-35	-6
SB2	Dipole [T]	4	4	40	90	102	4.7	4.7

Interaction Region – e-Beam Magnets



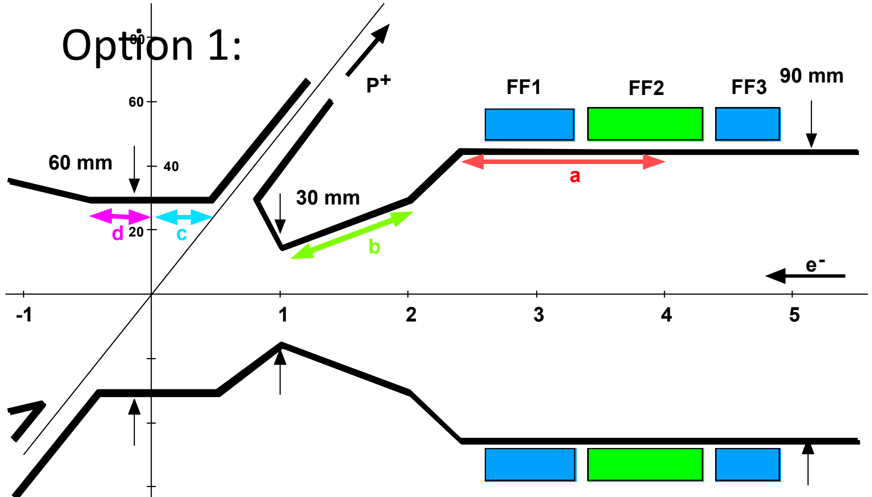
IR Electron Magnet Parameters

- Assuming 10 GeV
- Parameters are determined primarily by beam size and available space
- Multipole tolerance study has not been done yet
- One has to consider effect of the solenoid fringe field
- Note: parameters are still being fine-tune but no major changes

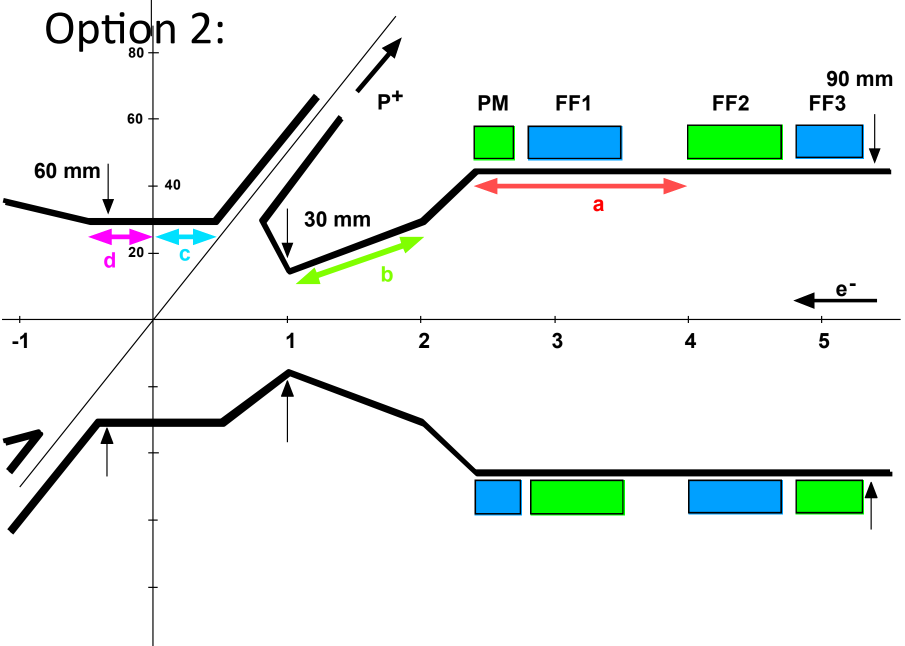
Name	Type	Length [m]	Good-field radius [cm]	Inner radius [cm]	Outer radius [cm]	Min. beam separation [cm]	Strength [T/m]	Pole-tip field [T]
QFFB4e	Quad	0.5	4	5	11	21	-3.1	-0.16
QFFB3e	Quad	0.58	4	5	11	15	47.9	2.39
QFFB2e	Quad	0.7	2	3	8	10.5	-57.7	-1.73
QFFB1e	Quad	0.4	1.2	2	6	8	24.4	0.49
QFFB1e_US	Quad	0.7	2	3	7	12	-43.9	-1.32
QFFB2e_US	Quad	0.7	4	5	10	16	45.5	2.28
QFFB3e_US	Quad	0.5	4	5	10	22	-16.4	-0.82

Synchrotron Light is a Major Challenge

Option 1:



Option 2:



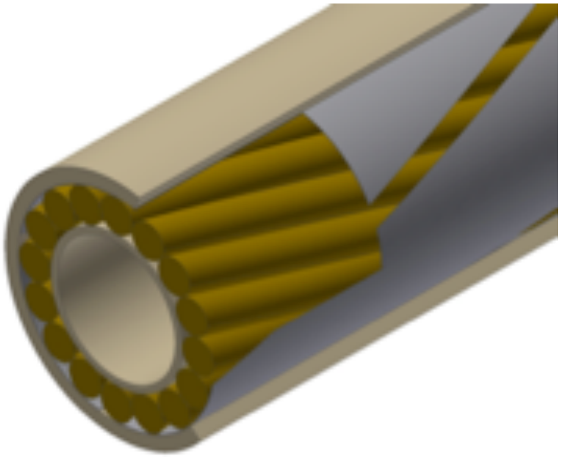
Surface a (5 GeV)

5 GeV	>10 k	>50 k	W
Bas. High Emit.	0.0	0.0	0.0
Opt 1 High Emit.	0.0	0.0	0.0
Opt 2 High Emit.	3.56e6	1.28e5	9.3
Bas. Red. Emit.	0.0	0.0	0.0
Opt 1 Red. Emit.	0.0	0.0	0.0
Opt 2 Red. Emit.	7.15e5	2.23e4	1.7

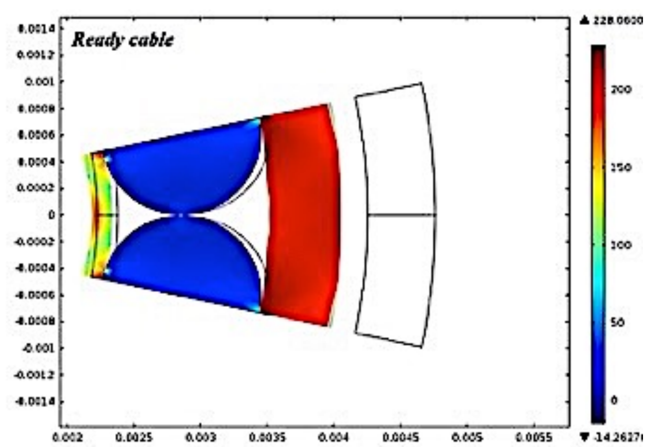
Surface a (10 GeV)

10 GeV	>10 k	>50 k	W
Bas. High Emit.	8039	3096	<.1
Opt 1 High Emit.	1.01e6	4.14e5	5.5
Opt 2 High Emit.	4.85e6	2.09e6	27.9
Bas. Red. Emit.	0.0	0.0	0.0
Opt 1 Red. Emit.	0.0	0.0	0.0
Opt 2 Red. Emit.	1.03e6	4.09e5	5.3

The same CIC cable we are using for the Ion Ring dipoles has unique capability for the IR challenge



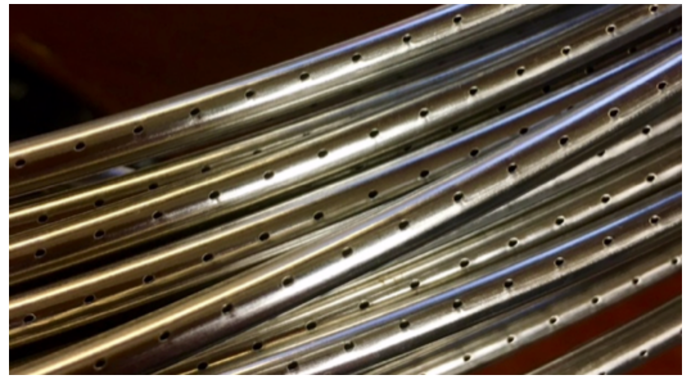
Superconducting wires are cabled onto a perforated center tube.



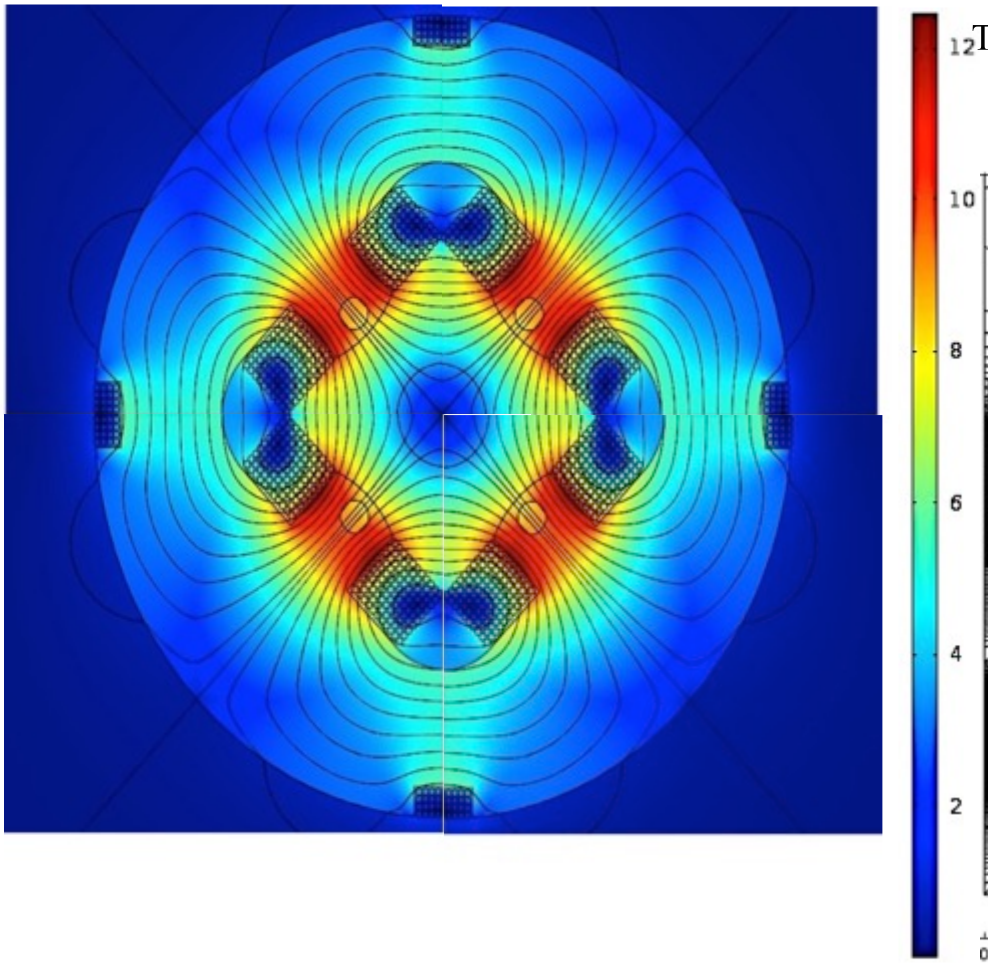
The cable is inserted in a sheath tube, and the sheath is drawn onto the cable to just compress the wires against the center tube.

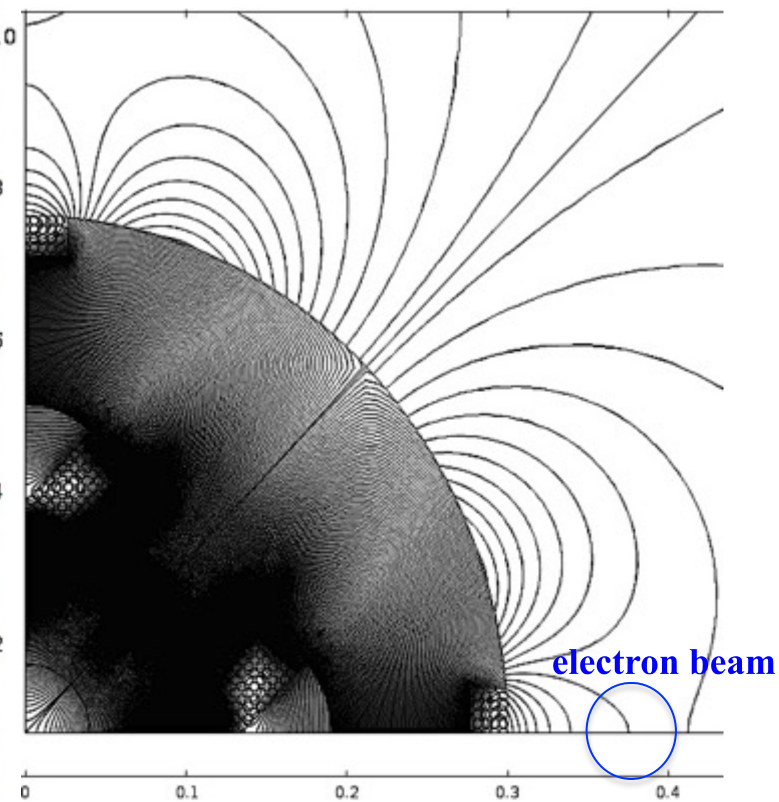
For the IR magnets, use Nb_3Sn and MgB_2 wires instead of NbTi to optimize for each magnet.

All of the materials, fabricated components, tooling, expertise that we developed for the CIC dipole is useful for the IR magnets.



Ion beam quad QFFB1: 90 T/m, 9 cm half-aperture, 36 cm from e-beam



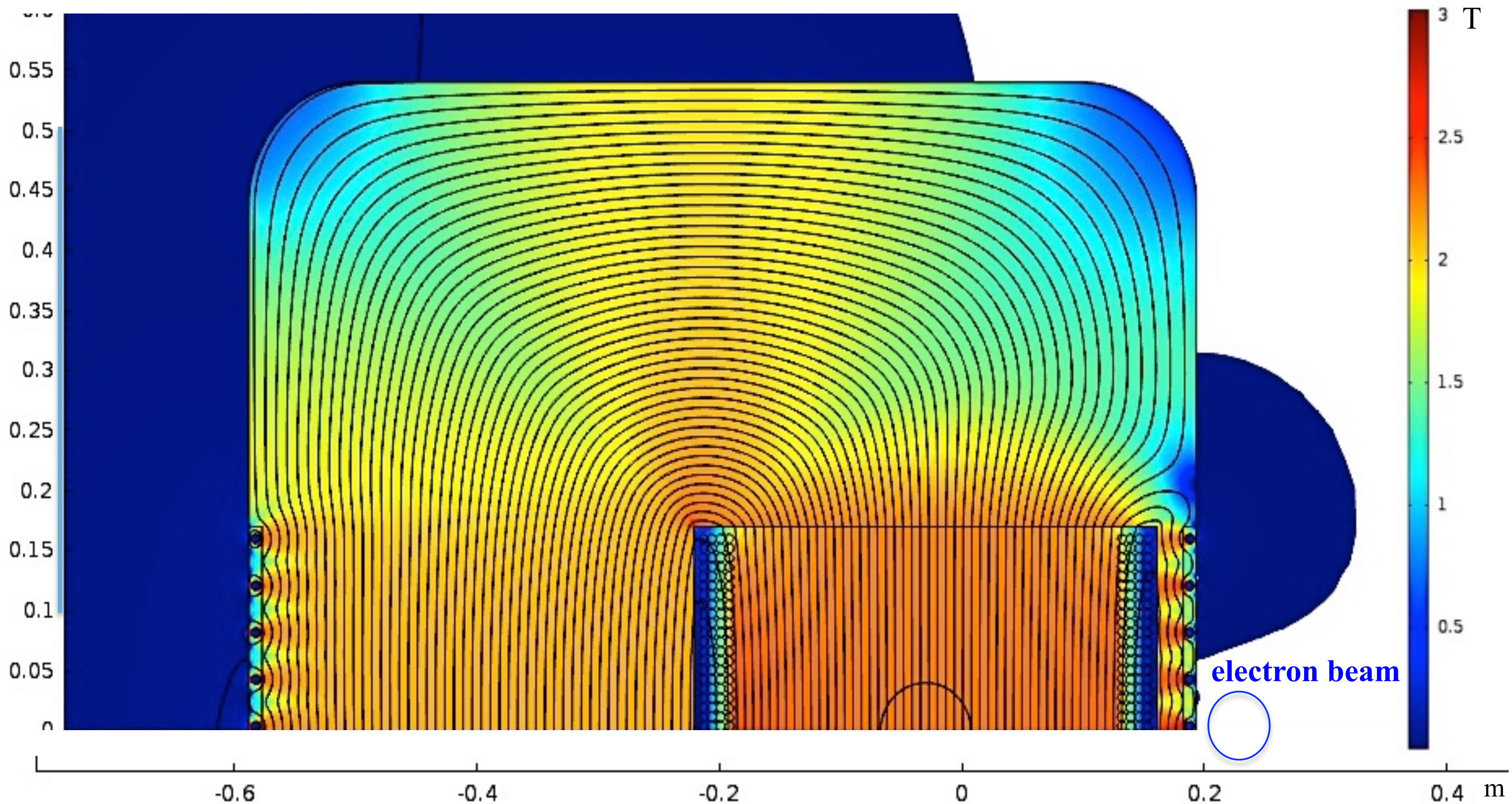


Reverse-current winding kills fringe field at the location of the electron beam.

9 kA cable current

Nb_3Sn windings, 4.2 K

Dipole SB1: 2 T, 340 mm aperture, 25 cm from the electron beam

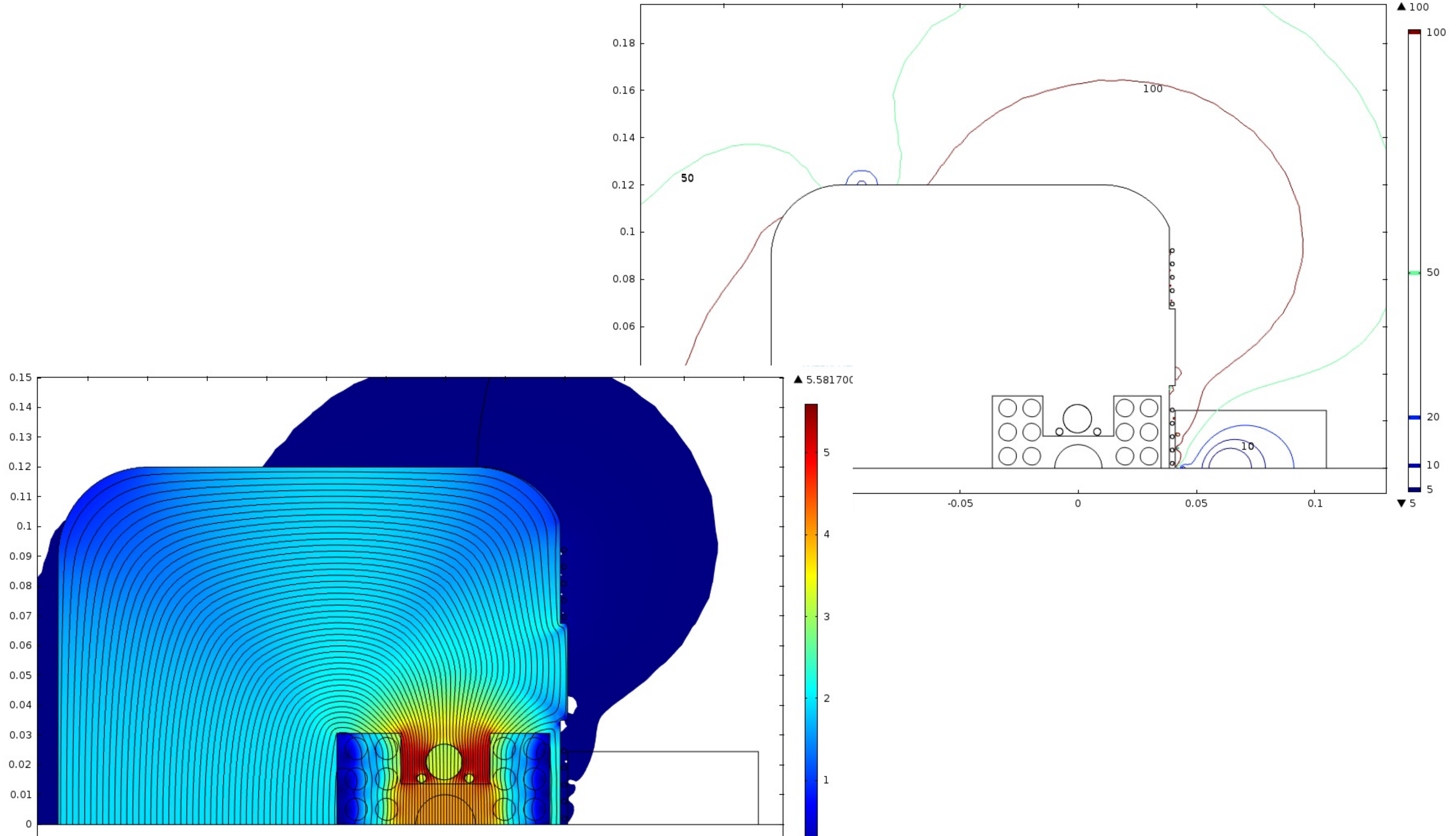


Window-frame C-geometry dipole configured as a Lambertson septum to suppress fringe field at electron beam.

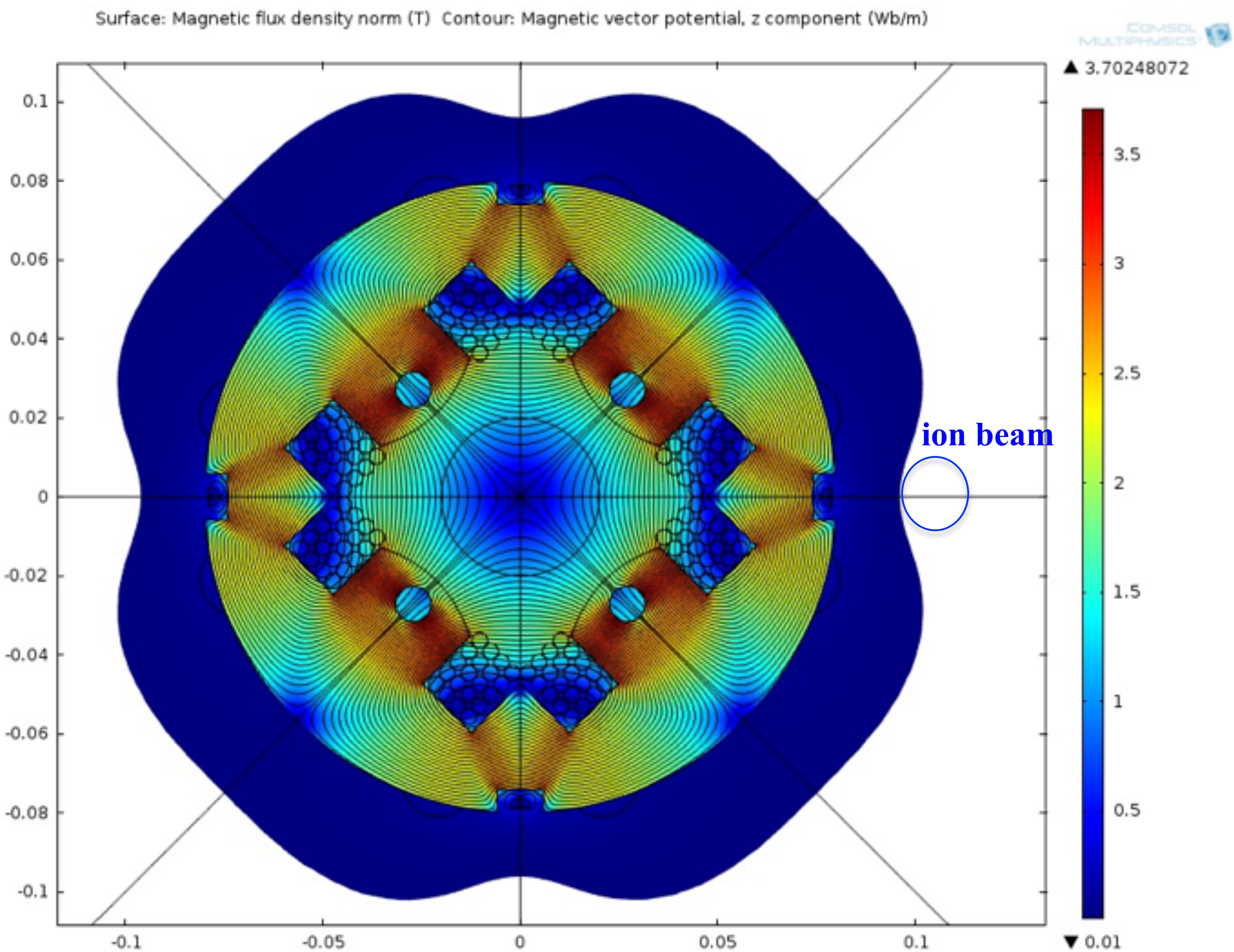
4 kA cable current

MgB_2 windings, 10 K

CERN has asked me to design a 4 T septum for slow extraction from LHC for transfer to FCC

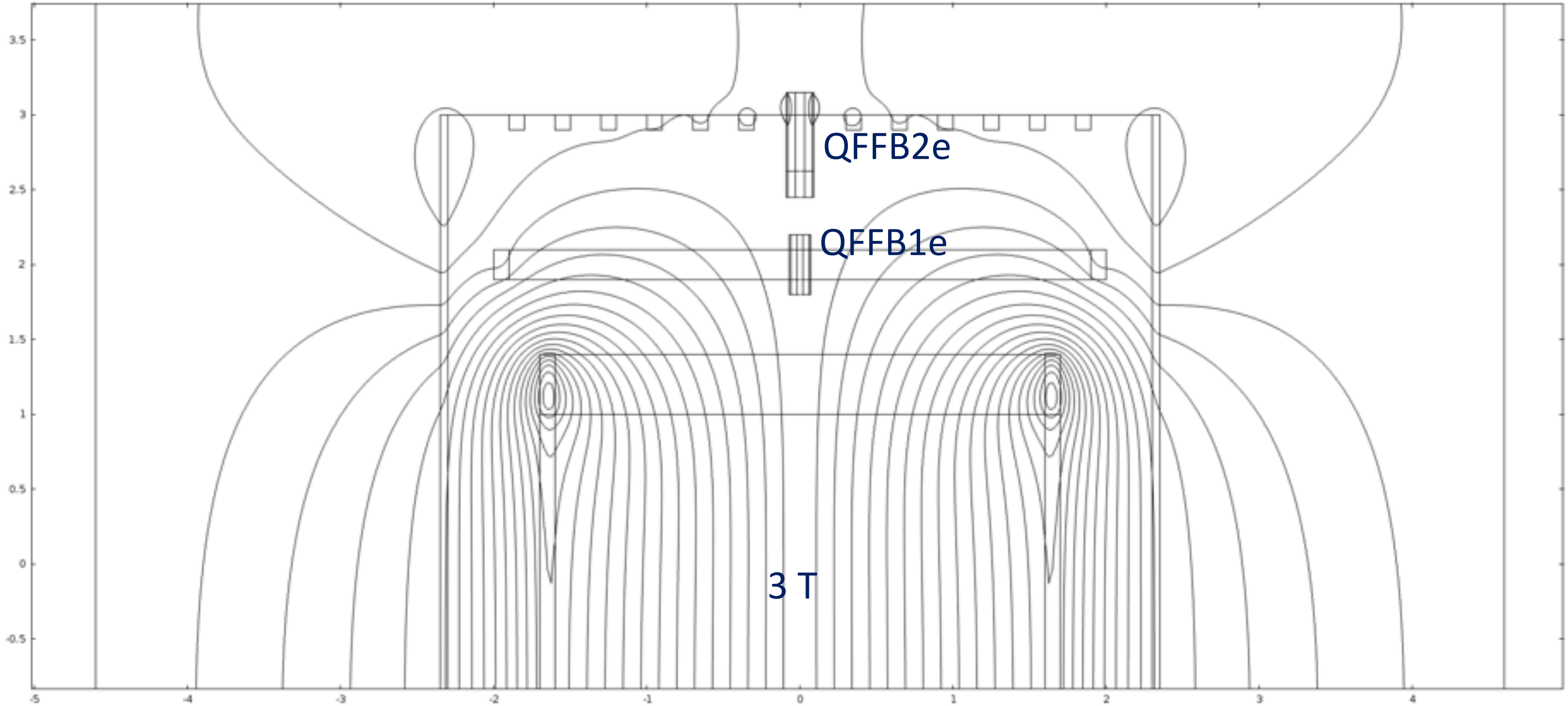


Quadrupole QFFB2e: 58 T/m gradient, 3 cm half-aperture, 10.5 cm from the ion beam



MgB$_2$ windings @ 10 K

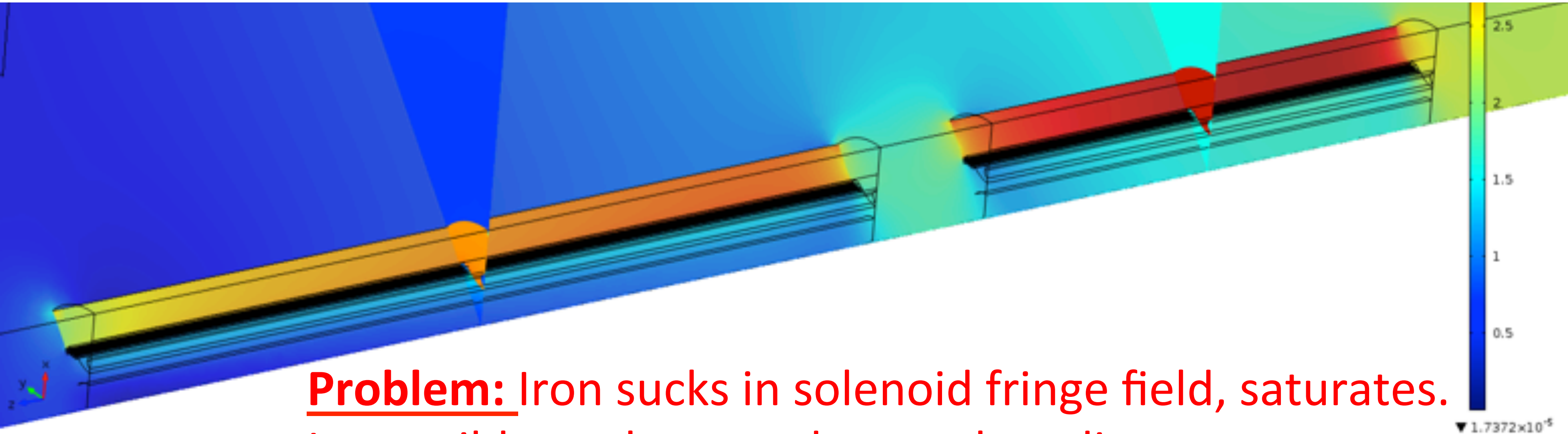
QFFB1e - Quad with Iron Flux Return: Cancel flux from 3 T spectrometer solenoid



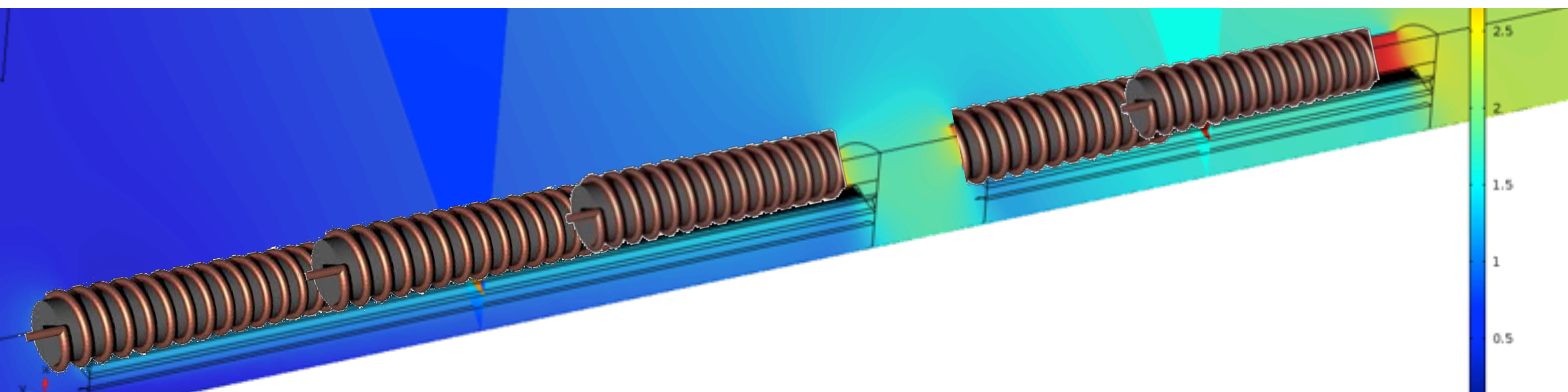
The problem:

- Need superconducting quads (not PM quads) in e-beam FF to be able to operate with range of electron energies, tune the FF optics for optimum dynamic aperture.
- Superconducting quad needs iron flux return, but iron pulls in fringe flux from spectrometer solenoid and saturates.

Stealth magnetics: exclude fringe field

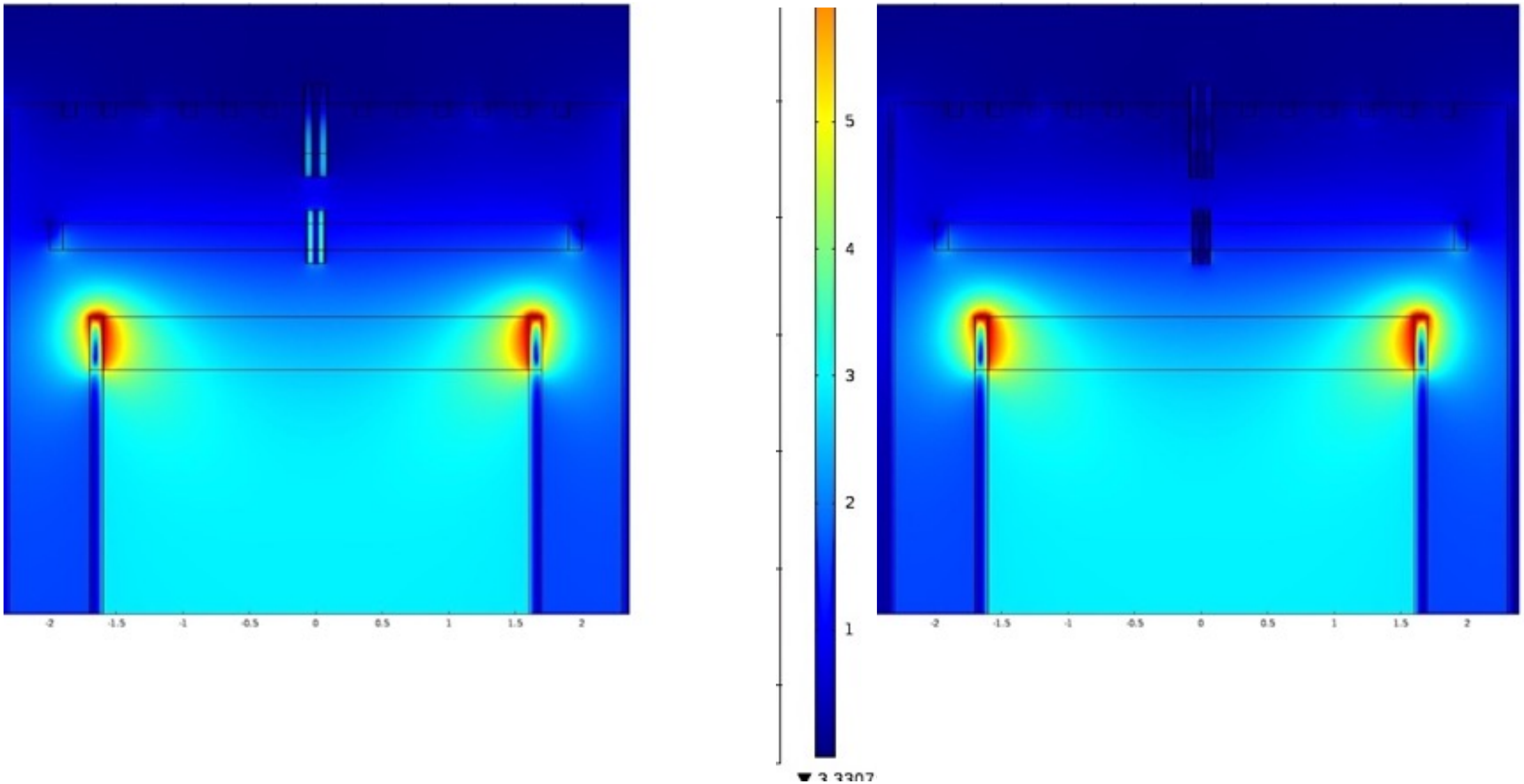


<u>Problem:</u> Iron sucks in solenoid fringe field, saturates.
Impossible to shape and control gradient.



<u>Solution:</u> wrap superconducting solenoid winding on flux return.
Adjust K(z) to exclude flux from spectrometer.

QFFB1e, QFFB2e with and without suppression of solenoid fringe



By adjusting K(z) we can exclude the fringe field of the spectrometer solenoid, so that the iron-clad quads operate in the normal fashion.

Conclusions

- We have made preliminary magnetic designs that can achieve the requirements for all of the special magnets for the IR region.
- CIC windings provide flexibility to meet the requirements with compact structure, suppress fields at close-lying neighbor beam.
- CIC windings make it possible to use Nb_3Sn, MgB_2 superconductor to provide thermal headroom.
- Stealth magnetics can be used to operate superconducting quads in fringe field of spectrometer.

2017 Proposal for IR magnet R&D

- **Technical goals**
- Prepare detailed conceptual designs for three example superconducting magnets for the requirements of inner quadrupoles and forward dipoles for EIC IR requirements.
- Develop Nb_3Sn cable-in-conduit with parameters suitable for a sub-scale model quadrupole for QFFB1.
- Develop a stealth solenoid capable of sheathing to the model quadrupole so that it can be operated in the fringe field region of an existing large solenoid as a first test of stealth magnetics.

Scope of work

- **Conceptual designs for the three IR magnets.**
- Obtain design specifications from both JLEIC and eRHIC for example specifications for the three magnets discussed above. We have first specs from the JLEIC team; we will obtain revised specs from both teams and endeavor to define a set of specs that are closely common in the two designs.
- Prepare further-detailed designs per those specifications, with conceptual mechanical drawings of the magnets and first estimates of systematic and random multipoles for the integrated fields on the beam that passes through the magnet and on the beam that passes close beside.
- Evaluate issues pertinent to fabrication that should be priority considerations in a follow-on effort to build/test model dipoles.
- **Development and testing of sample lengths of CIC conductor for QFFB1**
- Fabricate sample lengths of CIC cable, following closely the procedures we are using in the current development of continuously formed sheath on NbTi cable (with Hyper Tech). We prepare sample CIC cables containing one superconducting strand, all other strands made of silicon bronze of same diameter. We form bends with radius appropriate for the target winding application, then heat-treat the cable. We then test the single superconducting strand to its short-sample limit (much more readily done since SS current of one wire is < 1 kA) to establish whether CIC fabrication and bending the CIC cable deteriorate the short-sample performance of constituent strands.
- **Build a sub-scale model of NbTi-based QFFB2e including stealth winding**
- Design and build a short-body ½-transverse-scale model of the QFFB2e quadrupole, including the reverse-current shielding windings and the solenoid winding. This task may not be completed in the FY17 effort, since it is a multi-winding assembly. The intent is to progress as far as possible to prepare for testing the sub-scale model in the fringe field of an existing detector solenoid during FY18, in order to put the ideas for stealth magnetics to a first experimental test. There are many such detector solenoids at various laboratories around the world, several are not currently in operational service, others are but have lengthy periods when the beams or experiments they serve are down for long scheduled intervals (one such is the former LASS spectrometer at JLab). Seek to identify a window of opportunity during which we could test the sub-scale magnet.

12-month Budget

Total cost \$300K

Outcomes:

Coil-wind strategies for the end geometry of IR magnets

Nb_3Sn CIC for high-gradient quad

Subscale stealth solenoid suitable to install in existing solenoid, test stealth strategy in practice

Category	% E Requ FTE mo.	Task 1 Design IR magnets	Task 2 Build/test Nb3Sn CIC samples FTE mo.		Task 3 Build sub-scale stealth solenoid FTE mo.		Tasks 1-3
A. Sr Personnel							
PI: Peter McIntyre		17,432		-		-	17,432
Fringe Benefits		3,798		-		-	3,798
							-
Sr. Res. Assoc.: Dr. Akhdiyor Sattarov		13,248		-	2.0	13,248	26,496
Fringe Benefits		3,748		-		3,748	7,496
							-
Subtotal Salaries Senior Personnel		**30,680**		**-**		**13,248**	**43,928**
Subtotal Benefits Senior Personnel		**7,546**		**-**		**3,748**	**11,294**
Subtotal Senior Personnel		**38,226**		**-**		**16,996**	**55,222**
							-
B. Other Personnel							-
Lab Supervisor: Timothy Elliott		-	2.0	12,566		-	12,566
Fringe Benefits		-		3,627		-	3,627
Research Instrument Specialist: Raymond Garrison		8,989		-			8,989
Fringe Benefits		2,990		-		-	2,990
Technician: Jeffrey Breitschopf		-		-		-	-
Fringe Benefits		-		-		-	-
							-
Grad Student: James Gerity		6,000		-			6,000
Fringe Benefits		3,153		-		-	3,153
Student worke Katie O'Quinn, Scott Bannert		-	3.0	2,000	3.0	-	2,000
Fringe Benefits		-		202		-	202
Subtotal Salaries Other Personnel		**14,989**		**14,566**		**-**	**29,555**
Subtotal Benefits Other Personnel		**6,143**		**3,829**		**-**	**9,972**
Subtotal Other Personnel		**21,132**		**18,395**		**-**	**39,527**
							-
Total Salaries		**45,669**		**14,566**		**13,248**	**73,483**
Total Benefits		**13,689**		**3,829**		**3,748**	**21,266**
Total Personnel Costs		**59,358**		**18,395**		**16,996**	**94,749**
OTHER DIRECT COSTS							
Materials & Supplies							10,000
Total Supplies		**-**		***15,000***		**-**	***15,000***
Subcontracts							
Physics Dept. Shop				5,000			5,000
Total Subcontracts		**-**		***5,000***		**-**	***5,000***
Domestic Travel							
Total Travel		***4,000***		***4,000***			***8,000***
Modified Total Direct Costs (MTDC)		**63,358**		**42,395**		**16,996**	**122,749**
							-
EXEMPT COSTS							-
							-
Salaries & wag captitalized in connection with fabrication of subscale stealth quad, which will beome an item of TAMU capital equipment							
Subtotal Other Personnel		**-**		**-**		**66,244**	**66,244**
							-
Total Salaries		**-**		**-**		**46,926**	**46,926**
Total Benefits		**-**		**-**		**19,319**	**19,319**
Total Personnel Costs		**-**		**-**		**66,244**	**66,244**
Capitalized M&S							
Total Capitalized M&S						**13,000**	**13,000**
Capitalized Subcontracts							
Total Capitalized Subcontracts						**13,000**	**13,000**
		9,000					
Total exempt costs		**9,000**		**15,000**		**101,244**	**125,244**
TOTAL DIRECT COST		**72,358**		**57,395**		**118,241**	**247,993**
							-
INDIRECT COST	MTI	**30,729**		**20,561**		**8,243**	**59,533**
							-
TOTAL PROJECT COST (TPC)		**103,087**		**77,956**		**126,484**	**307,527**

SBIRs that benefit our development of the ring dipoles <u>and</u> the IR magnets

HyperTech:

- Phase 2 for development of continuous tube forming of sheath tube onto the cable for long-length CIC cable.
- Phase 1 for development of CIC cable containing Nb_3Sn and MgB_2 wires.