Stress management for high-energy MC SR and IR magnets

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Introduction

- Conceptual design studies of MC SRs and IRs with muon beam energy of 0.75 and 1.5 TeV have been performed in the U.S. in 2010-2012
- Studies included beam optics, magnet design concepts and radiation shielding ➔ Tungsten internal absorber ≥ 50 mm is required + vacuum insulation + helium channel
- It was shown that large-aperture shell-type magnet coils produce better properties than block-type coils and/or open mid-plane coils
- The next two slides will show conceptual designs and parameters of SR and IR magnets based on Nb_3Sn technology for 3 TeV (1.5×1.5 TeV) MC

3 TeV MC SR magnets

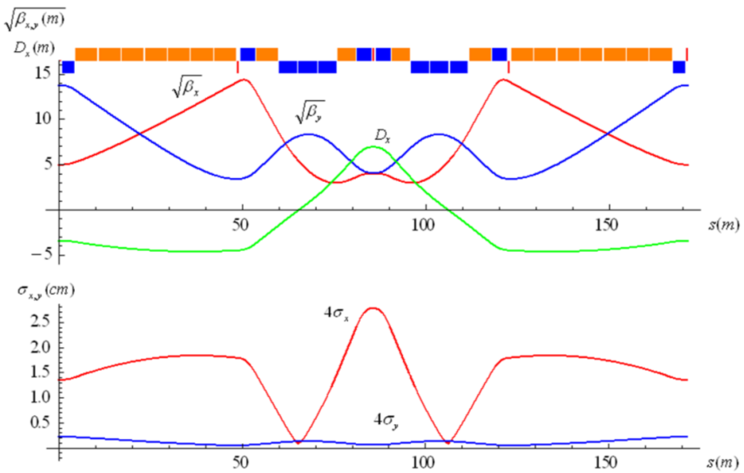


Figure 1: MC arc cell concept and beam size in magnets.

High-Field Combined-Function Magnets for a 1.5×1.5 TeV Muon Collider Storage Ring
V.V. Kashikhin, Y.I. Alexahin, N.V. Mokhov, A.V. Zlobin, Fermilab, Batavia, IL, IPAC2012

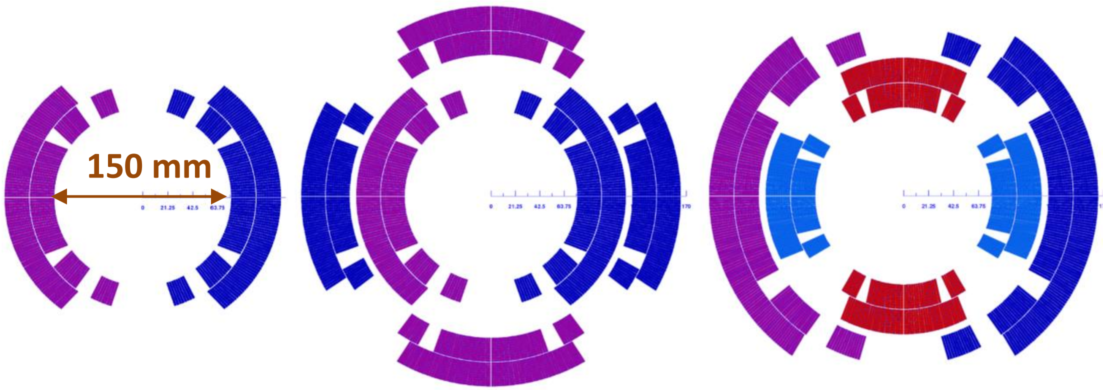
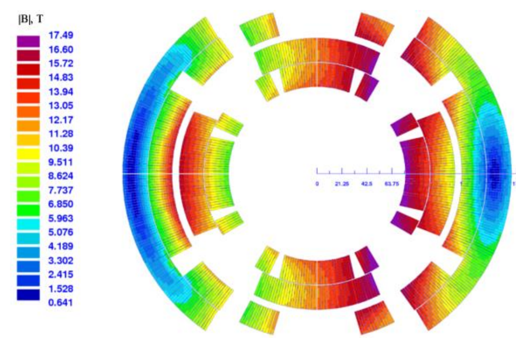


Table 4: Parameters of Arc Dipole and Combined-Function Quadrupole at T_{op}=4.5 K.

Parameter	Arc dipole D	D/Q QDA1/3	Q/D QDA1/3	Q/D QFA2/4
Maximum field in coil (T)*	15.7	16.8/16.7	16.5/17.5	
Maximum field or gradient in aperture (T or T/m)*	14.4	9.3/76.7	12.0/72.5	
Operating field or gradient in aperture (T or T/m)*	10.4	9.0/35.0	9.0/35.0	8.0/85.0
Fraction of SSL at the operating field*	0.72	0.75/0.61	0.70/0.64	0.75/0.86
Inductance L_{self} (mH/m)*	18.2	16.0/20.6	44.2/6.9	
Stored energy E at the operating field (MJ/m)*	1.7	1.5/0.5	2.9/0.1	2.3/0.6
Horizontal Lorentz force F_x at the operating field (MN/m)*#	5.8	7.7/-0.1	7.2/2.2	6.1/5.5
Vertical Lorentz force F_y at the operating field (MN/m)*#	-2.4	-4.5/-1.6	-4.0/-0.3	-4.5/-1.5

* the first value is for dipole coils, the second one is for quadrupole coils; # totals per 1st quadrant in dipole and per 1st octant in quadrupole.



- Large aperture, high field, operation margin, Lorentz forces

3 TeV MC IR magnets

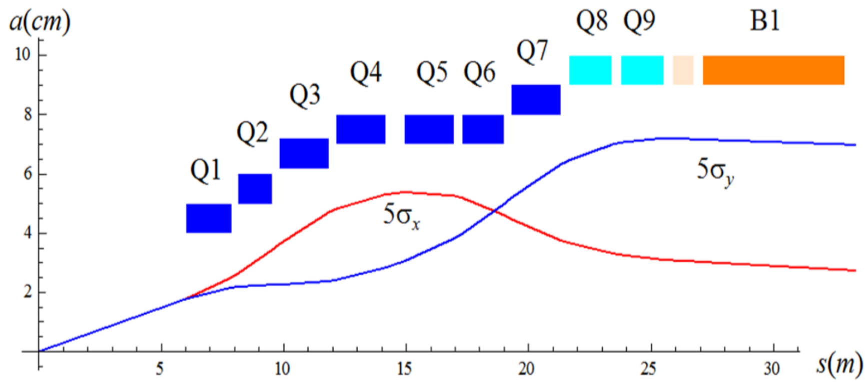
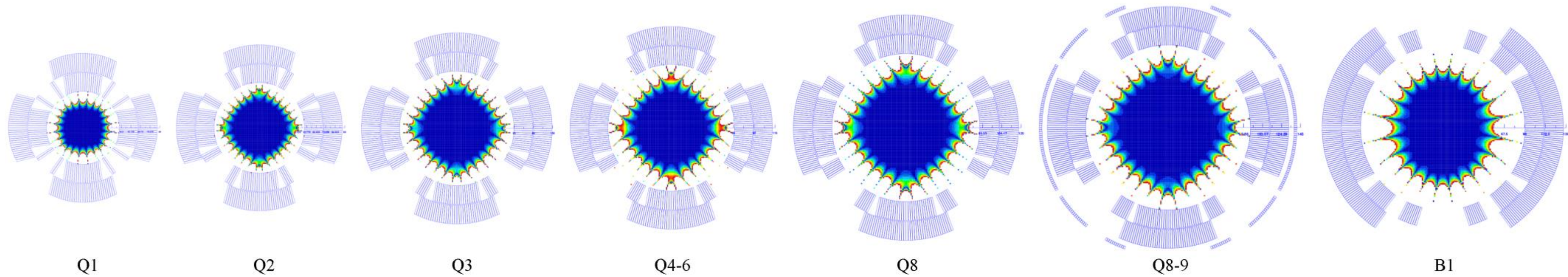


Figure 1: MC IR layout and beam size in magnets.

Magnets for Interaction Regions of a 1.5×1.5 Tev Muon Collider
V.V. Kashikhin, Y.I. Alexahin, N.V. Mokhov, A.V. Zlobin, Fermilab, Batavia, IL, IPAC2012

Table 2: IR Magnet Parameters.

Parameter	Q1	Q2	Q3	Q4-6	Q7	Q8-9	B1
Apert. (mm)	80	100	124	140	160	180	180
G_{op} (T/m)	250	200	161	144	125	90	0
B_{op} (T)	0	0	0	0	0	2	8
Length (m)	1.85	1.40	2.00	1.70	2.00	1.75	5.80



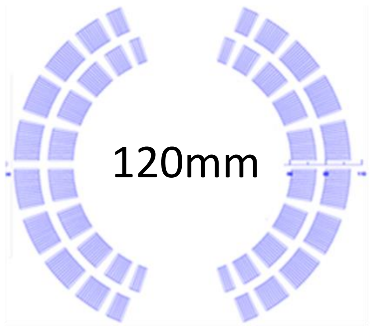
- Large aperture, high field, operation margin, Lorentz forces

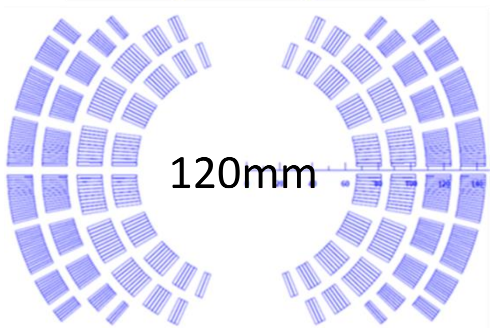
MC SR and IR magnet general features

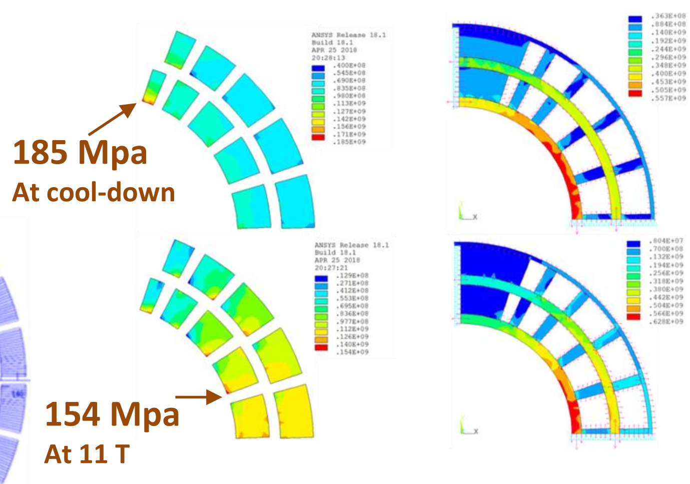
- Large aperture – up to 180 mm
  - larger aperture will be needed for higher muon beam energies to use thicker absorber
- High field level – ~8-10T (aperture)/~14-17.5T (coil)
  - within the limit of Nb_3Sn technology
  - higher operation fields will require HTS/Nb_3Sn hybrid coils
- Large operation margin ≥ 30%
- ***<u>Large Lorentz forces</u>***

Stress management for high-field large-aperture magnets

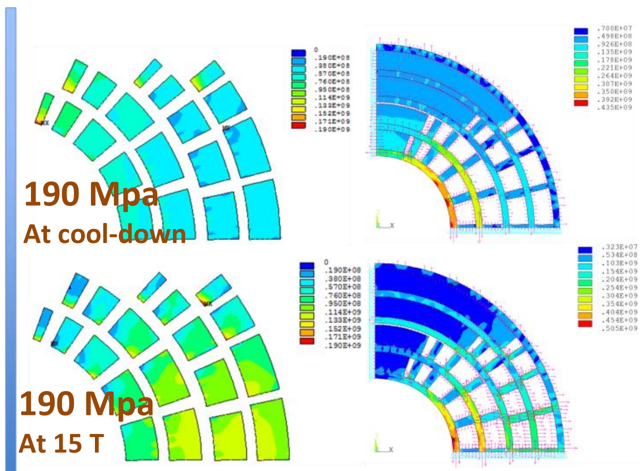
LARGE-APERTURE HIGH-FIELD Nb_3Sn DIPOLE MAGNETS
A.V. Zlobin, V.V. Kashikhin, I. Novitski (Fermilab, Batavia, IL) , IPAC2018







Equivalent stress (Pa) in the coil (left) and the coil support support structure (right) of Design 1 after cool-down (top) and at 11 T bore field (bottom).



Equivalent stress (Pa) in the coil (left) and the coil support support structure (right) of Design 2 after cool-down (top) and at 15 T bore field (bottom).

Parameter	Design 1	Design 2
Number of layers	2	4
Bore field, T	12.10	15.42
Peak field, T	14.18	15.88
Current, A	13.06	12.50
Inductance, mH/m	22.47	64.94
Stored energy, MJ/m	1.92	5.07
F_x, MN/m/quadrant	7.59	12.38
F_y, MN/m/quadrant	-3.17	-8.01

- Studies have shown that stress management is critical for HF/LA magnets
- It is even more important for HF/LA combined Q/D magnets used in MC
- ***Future conceptual magnet design studies for MC need to consider this concept***

Conclusion

- SR and IR in HE MC 3+ TeV will use SC magnets with large aperture (~200 mm) and high fields (15-20 T) for highest luminosity
  - Nb_3Sn or HTS/LTS hybrid technologies
- Stress management is a critical coil design concept which needs serious theoretical and experimental studies
- This is an important part of the U.S. Magnet Development Program
- There is possible synergy also with Europe, for instance CSI is also working on this concept