MCSR Magnet Options

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MCSR mini-workshop,
Fermilab, May 19-20, 2011

Outline

- Basic requirements
  - aperture , nominal field, radiation heat load
  - field quality, stresses, cooling, quench protection
- Magnet designs:
  - open midplane dipole (OMD) vs. large aperture dipole (LAD)
- Mechanical design and stress analysis
  - OMD
  - LAD with shifted beam pipe
- Summary

Basic Requirements

- The MC storage ring is based on 10 T dipole magnets.
  - margin - TBD
- The small transverse beam size (σ~0.5 mm) requires a small aperture only ~10-20 mm in diameter.
- 0.5 kW/m dynamic heat load from muon decay particles localized mainly in the horizontal direction on the inner side of the storage ring
  - to be intercepted outside of the magnet helium vessel on a safe distance from primary beams.

Y. Alexahin et al.,IPAC'2010

MCSR OMD (2001)

Proceedings of the 2001 Particle Accelerator Conference, Chicago

MAGNETS FOR A MUON STORAGE RING*

B. Parker[†], M. Anerella, J. Escallier, A. Ghosh, R. Gupta, M. Harrison, J. Schmalzle, J. Sondericker and E. Willen, BNL, Upton, NY 11973, USA

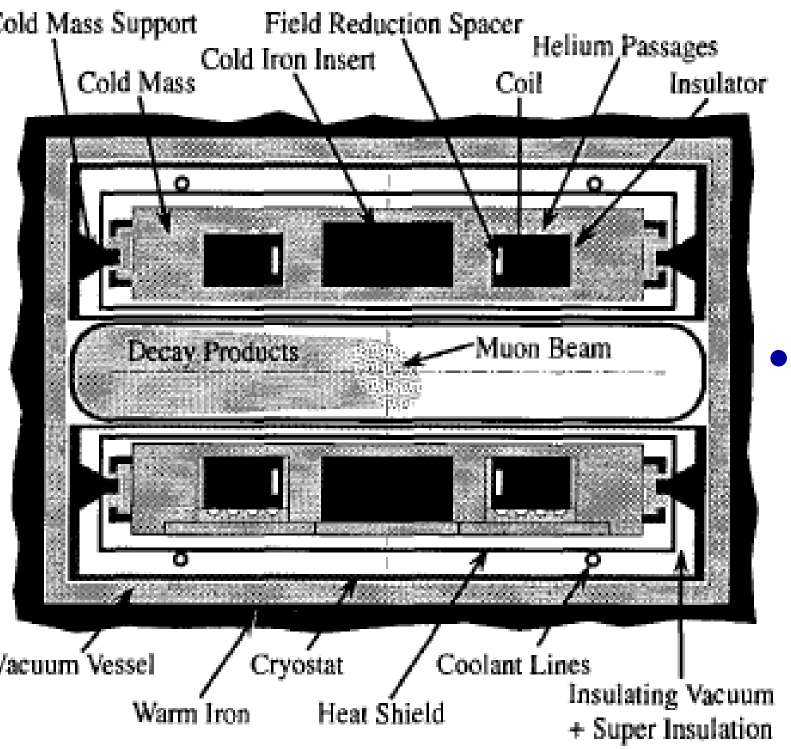


Figure 1: Cross section, with main features labeled, of neutrino factory muon storage ring magnet that avoids decay particles directly hitting superconducting coils.

- Bq=8 T, Smax~70 MPa

LHC IR OMD (2005)

Presented at the 2005 Particle Accelerator Conference at Knoxville, Tennessee, May 16-20, 2005.

OPTIMIZATION OF OPEN MIDPLANE DIPOLE DESIGN FOR LHC IR UPGRADE*

R. Gupta#, M. Anerella, A. Ghosh, M. Harrison, J. Schmalzle and P. Wanderer, BNL, NY, U.S.A.
N. Mokhov, FNAL, Batavia, IL, U.S.A.

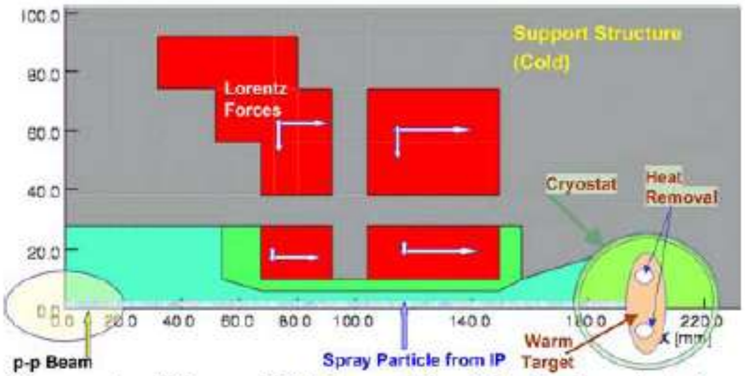


Figure 1: *"Open Midplane Dipole"* design that has essentially no conductor or structure at the midplane.

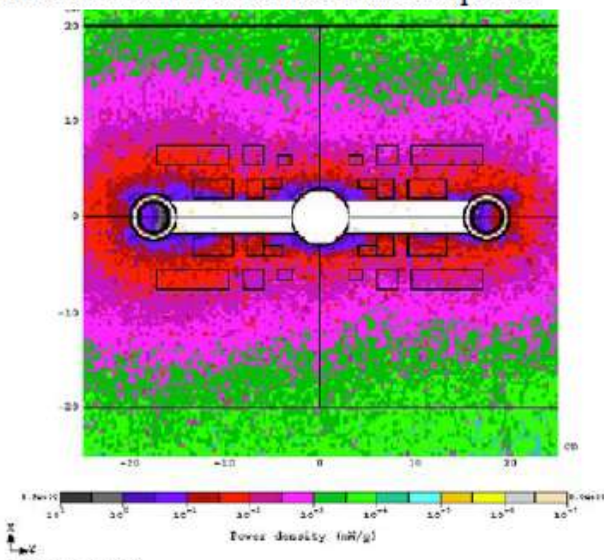


Figure 4: Power density isocontours at the non-IP end of the D1B.

Table 1: Summary of Design Iterations

	A	B	C	D	E	F
H(mm)	84	135	160	120	80	120
V(mm)	33	20	50	30	34	40
V/H	0.39	0.15	0.31	0.25	0.43	0.33
B_o(T)	13.6	13.6	13.6	13.6	15	13.6
B_{ss}(T)	15	15	15	14.5	16	15
J_c(A/mm^2)	2500	3000	3000	3000	3000	3000
Cu/Sc	1	1,1.8	0.85	0.85	0.85	1
A(cm^2)	161	198	215	148	151	125
R_i(mm)	135	400	400	320	300	300
R_o(mm)	470	800	1000	700	700	700
E(MJ/m)	2.2	4.8	9.2	5.2	4.1	4.8
F_x(MN/m)	9.6	10.1	12.3	9.5	10.4	9.6
F_y(MN/m)	-3.0	-6.8	-8.7	-7.0	-5.1	-5.4

Table 3: Heat loads (W) to the system components

D1A (1.5 m)

Superconductor	3.6
Collar	26.6
Yoke	4.6
Tungsten Rod	1.6

D1B (8.5 m)

Superconductor	24.1
Collar	177.2
Yoke	15.0
Tungsten Rod	52.2
Pipes	7.2

- 13.6 T D1-1.5 m, D2-8.5 m

Superconductor & Magnet Technology

- The expected level of magnetic fields in magnets 10 T (+ ?% margin) suggests using Nb_3Sn superconductor.
- This superconductor has the most appropriate combination of the critical parameters including the critical current density J_c, the critical temperature T_c, and the upper critical magnetic field B_{c2}.
- Cu-stabilized multi-filament Nb_3Sn strands with J_c(12T, 4.2K)~3000 A/mm^2, strand diameter 0.7-1.0 mm and Cu/nonCu ratio~0.9-1.1 are commercially produced at the present time by industry in long length.
- Magnet technology has matured during the past decade.

OMD Concepts

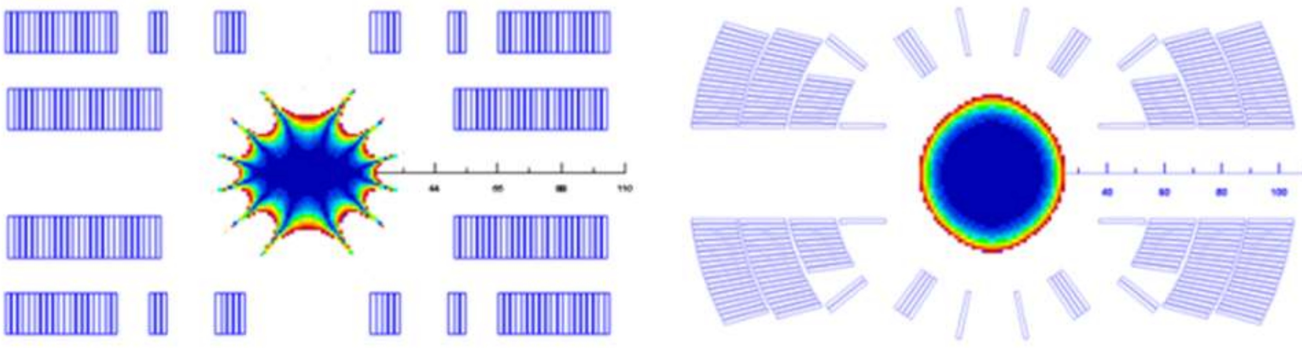


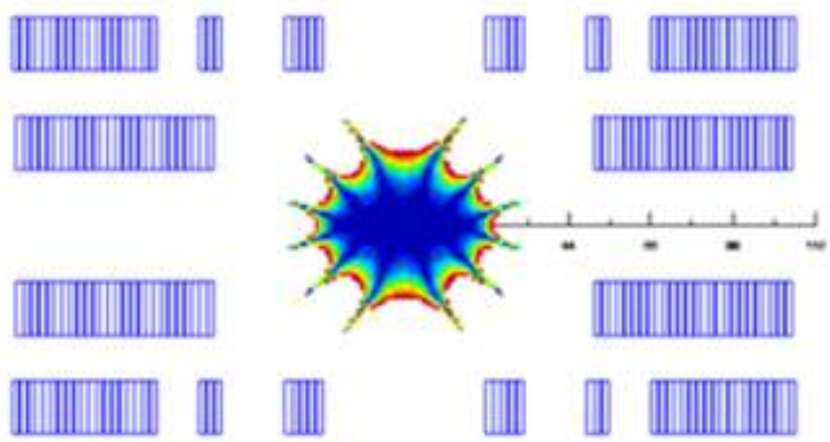
Figure 2: MC Storage Ring dipole based on 4-layer block-type coil (left) or 4-layer shell-type coil (right).

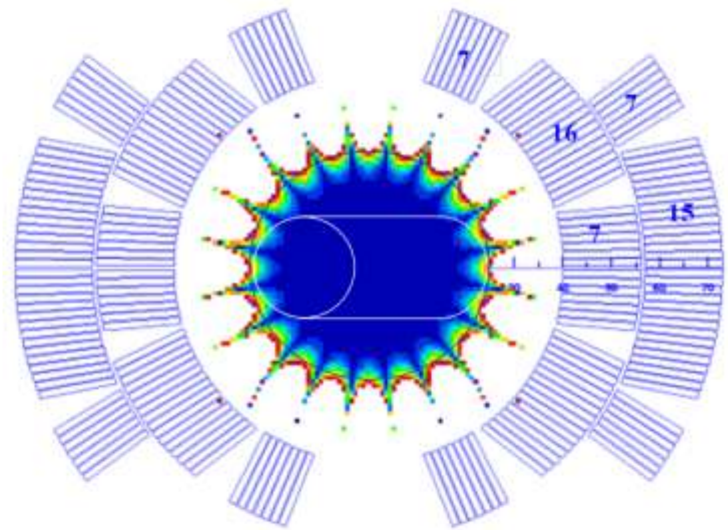
Table 4: Storage Ring Dipole Parameters.

Parameter	Block design	Shell design
B_{max} coil at 4.5K (T)	13.37	13.13
B_{max} at 4.5 K (T)	11.24	11.24
B_{op} (T)	10.0	10.0
Inductance at B_{op} (mH/m)	6.72	9.52
Stored energy at B_{op} (kJ/m)	1280	1100
F_x at B_{op} (kN/m)	4084	3990
F_y at B_{op} (kN/m)	-2216	-1870

A. Zlobin et al.,IPAC'2010

OMD vs. LAD





Parameter	Open mid-plane design	Shell-type design
B_{max} in coil at 4.5K (T)	13.5	13.7
B_{max} in bore at 4.5 K (T)	11.2	12.5
B_{op} (T)	10.0	10.0
F_x at B_{op} (kN/m)	3796	3033
F_y at B_{op} (kN/m)	-1694	-1498

I. Novitski et al., *ASC'2010*

Field Quality

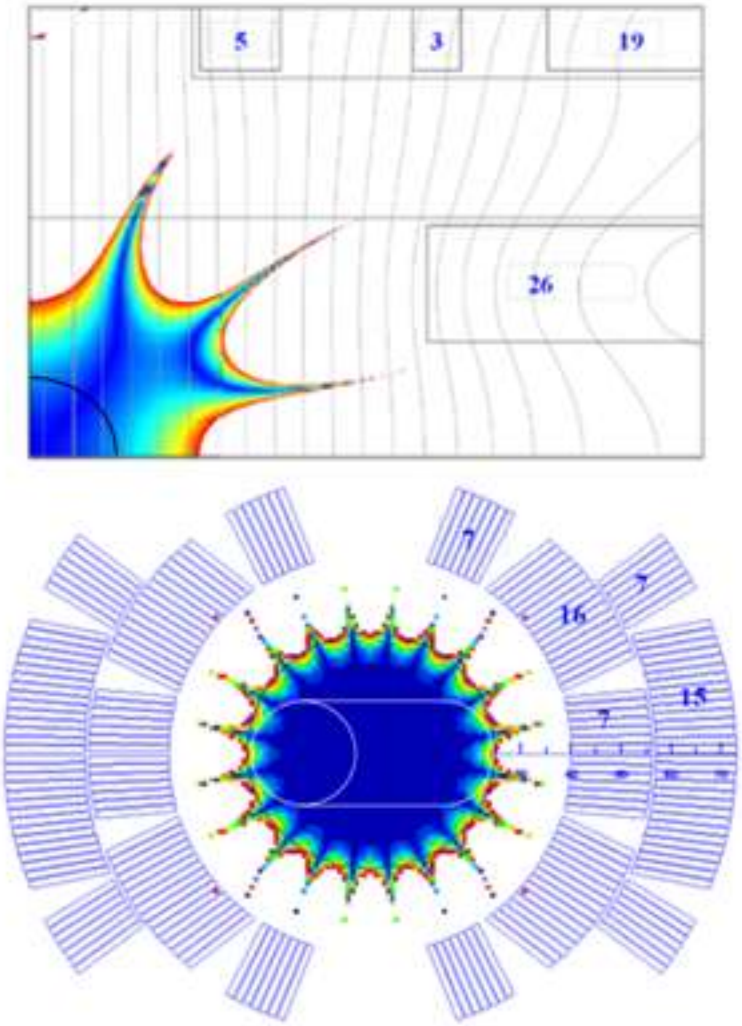
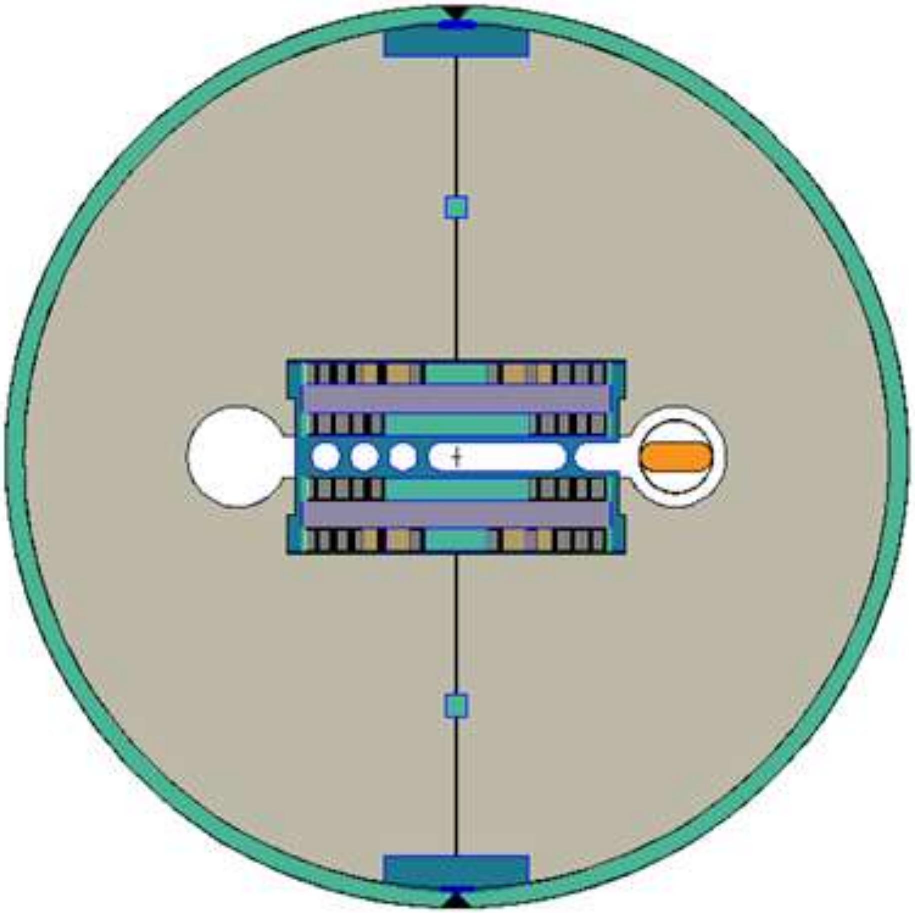


Fig. 2. Field quality in the MC Storage Ring dipole based on open mid-plane (top) or large-aperture (bottom) design. Dark areas correspond to dB/B<10⁻⁴.

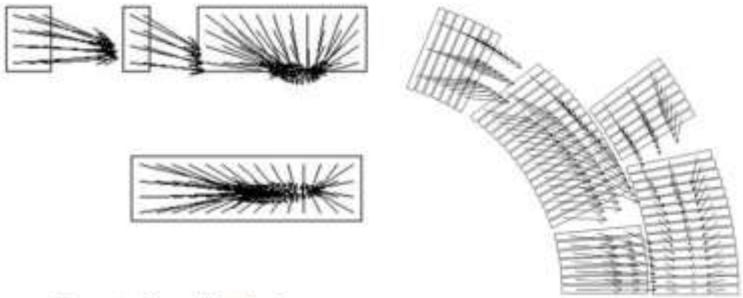
- Geometrical field harmonics in both designs are small.
- Structure and coil deformations, saturation of the iron yoke and magnetization of cable and coil components and coil support structure will contribute to b_3.
- However, due to the fact that these magnets will operate at a constant field gradient all these components can be easily compensated by appropriate tuning the coil geometry.

OMD Mechanical Structure

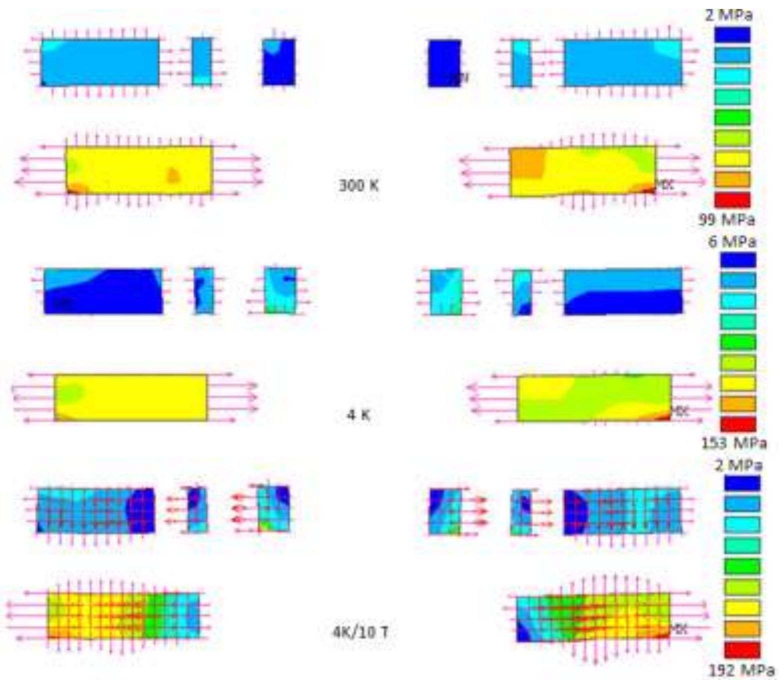


- Two double-pancake coils, a vertically split iron yoke, and a thick stainless steel skin with two alignment keys and two control spacers.
- Two double pancake block-type coils, wound around Ti poles with 22 mm thick interlayer stainless steel plates, are placed inside an Al cage.
- The cage provides the required vertical coil separation and contains holes for cooling pipes on one side and a slot for the beam pipe and an escape pass for the decay particles to the absorber placed in one of the two holes in the iron yoke.

OMD Stress Analysis

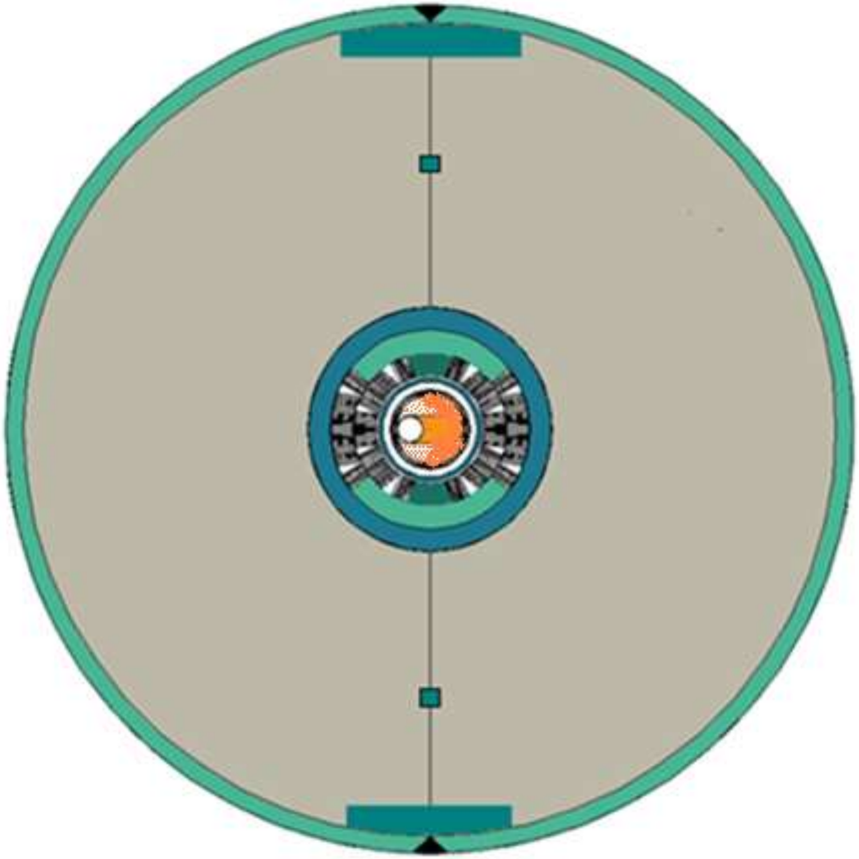


Lorentz force distributions



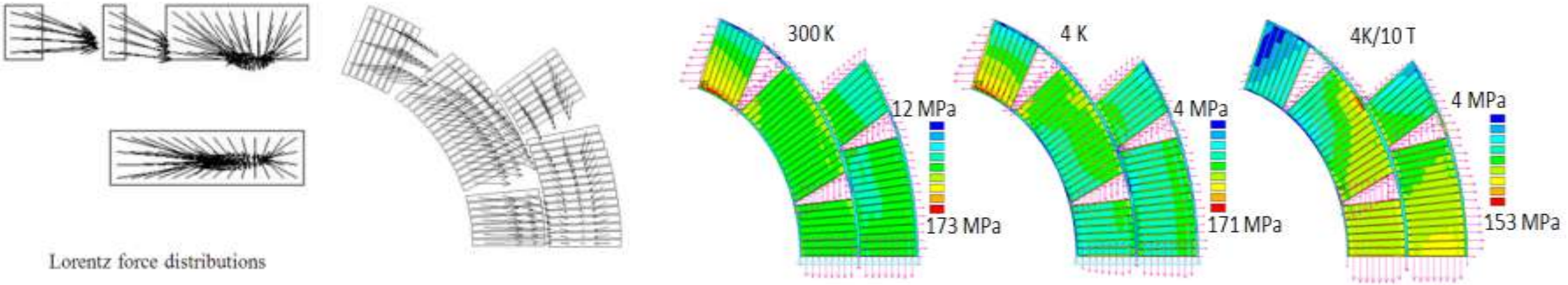
- Coil pre-stress is provided by the yoke and skin during only in x-direction.
- The x-component of the Lorentz force is supported by the iron yoke and skin.
- The vertical Lorentz force is supported by the thick stainless steel plates and Al cage.
- The average coil pre-stress at 300K of ~80 MPa.
- The maximum coil stress195 MPa is concentrated in the corner of the mid-plane block.
- The maximum coil deformations at the nominal field <60 microns.
- Removing the support blocks significantly increases the coil and structure deformations as well as the stress concentrations in the coil.

LAD Mechanical Structure



- Two double-layer cos-theta coils, vertically split iron yoke, and thick stainless steel skin with two alignment keys and two control spacers.
- The coils are separated from the iron yoke by thin stainless steel collars. A similar support structure was successfully used in Fermilab's high-field 90-mm Nb_3Sn quadrupole models .

LAD Stress Analysis



- The initial coil azimuthal pre-stress and geometry control is provided by the collar blocks. The final coil pre-stress and radial support is provided by the yoke and skin.
- The average inner-layer coil pre-stress at room temperature of ~120 MPa keeps the coil blocks under compression and in contact with the pole blocks up to the magnet nominal operating field.
- The maximum coil stress does not exceed 175 MPa. The maximum coil stress could be further reduced by optimizing the radial stress distribution on the pole turns.
- The maximum coil stress in the shell-type design is lower than in the open mid-plane dipole described above, allowing operation of this magnet type at higher magnetic fields.

Conclusions

- The Nb_3Sn magnets are designed to operate at 4.5 K and provide the specified nominal operating field of 10 T with 12-25% margin, accelerator field quality in the magnet aperture occupied with beams.
- Both designs have attractive and difficult features.
- The study and optimization of magnet operating margin, field quality and other key parameters for both designs need to be completed by constructing and testing of a series of magnet models.

Open Midplane Dipole

- The open mid-plane dipole concept in principle allows the decay electrons to dissipate their energy in the absorber hidden in the iron yoke and cooled by at higher temperature (78 or 300 K).
- However,
  - Substantial fraction (~50%!!) of the heat is deposited in magnet cold mass. Together with the static heal load from the absorber it provide quite large heat load on the 4.5 K level (>200 W/m !!!)
  - the need to support the coils in the gap reduces the efficiency of this approach. Managing the vertical Lorentz force component is the main challenge of the open mid-plane design.
  - Moreover, this magnet design requires an indirect coil cooling scheme which introduces additional complications in magnet design and its operation.

Large Aperture Dipole

- The traditional cos-theta approach requires a large aperture coil which must accommodate both the beam pipe and the absorber. This leads to a large coil volume and large stored energy.
- However,
  - excellent field quality in the large area inside the coil bore and asymmetric distribution of the heat load from decay electrons in principle allow a significant reduction of the magnet aperture.
  - the Lorentz force level is noticeably lower and the operating margin is substantially higher in the traditional large-aperture magnet with respect to the open mid-plane magnet.
  - Coil cooling and quench protection for this design are based on the well known traditional schemes used in accelerator magnets.
  - The efficiency of the internal absorber is much better reducing the heat load in the cold mass to static heat from the absorber
    - ➢ Optimized absorber with variable density

Acknowledgements

- Yu. Alexahin - MCSR magnet requirements
- N. Mokhov – radiation studies
- V.V. Kashikhin – magnet magnetic analysis
- I. Novitski – mechanical analysis