Muon Collider SR and IR Magnets

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May 29, 2014

Charge

- Review the current activities in your area and summarize key advances
- Provide a prioritized list of activities
- Provide a list of activities that will be completed by the end of this fiscal year
- Present activities that, in your opinion, should be transferred to GARD

Outline

- Goals, milestones, organization
- Magnet needs & requirements
- Baseline magnet technology and approach
- Status of SR and IR magnet studies for
  - 1.5 TeV MC
  - 3 TeV MC
  - 125 GeV HF
- Magnet scale up to 5-6 TeV MC
- Nb_3Sn magnet modeling status and needs
- Higher field magnets and R&D issues
- Summary

Goals, Milestones and Organization

- Main goals of MC SR and IR magnet studies
  - provide realistic input for the lattice and IR design analysis and optimization, beam dynamics and radiation protection study
  - identify key magnet issues to be addressed during an R&D phase
- Milestones
  - FY10-11 – 1.5 TeV MC
  - FY12-13 – 3 TeV MC
  - FY13-14 – 125 GeV HF
  - FY14-15 – 5-6 TeV MC
- Organization
  - Task 29M.03.03.01.01 "FNAL: General Magnet Design WP"
  - Small effort ~0.3 FTE/year
  - Close collaboration with MAP Collider (Yu. Alexahin) and MDI (N. Mokhov) working groups

Magnet needs & Requirements

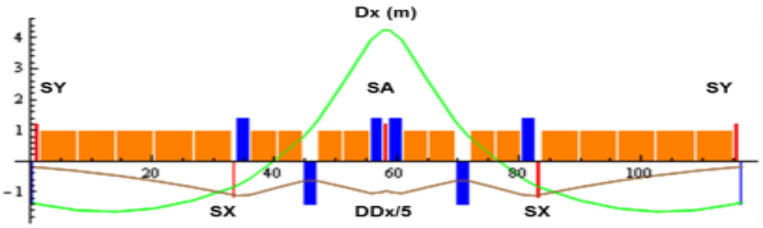
- MC SR includes Interaction Regions, Chromaticity Correction Section, Matching Section and Arc
- Key machine requirements for MC SR magnets
  - High *nominal fields* to achieve highest possible luminosity
  - Sufficient *operation margin* to work at high dynamic heat load
  - *Accelerator field quality* in beam area at operation fields
  - *Dipole field in some IR quadrupoles* to reduce the detector background
  - *Combined quadrupoles/dipoles* to spread the decay neutrino flux
  - *Appropriate aperture* to accommodate muon beams, magnet cryostat, cooling and radiation protection systems
- Magnet operation requirements
  - Coil pre-stress and *Lorentz force management*
  - Coil *cooling*
  - Magnet *quench protection*
  - Magnet *protection from radiation*

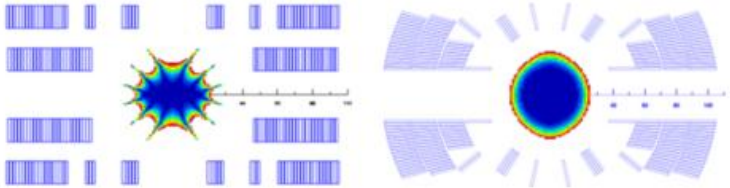
Baseline Approach

- High fields required for MC call for advanced accelerator magnet technologies beyond traditional Nb-Ti magnets limited to B_{op}~8 T
- Present focus on Nb_3Sn magnets– *baseline approach*
  - B_{nom}=10 T
  - large operation margin >20%
  - mature magnet technology (B_{op}<12 T) thanks to GARD and LARP work during past two decades
- Conductor – *present technology limit*
  - 1 mm high-J_c Nb_3Sn strand
  - wide 40-42 strand Rutherford cables

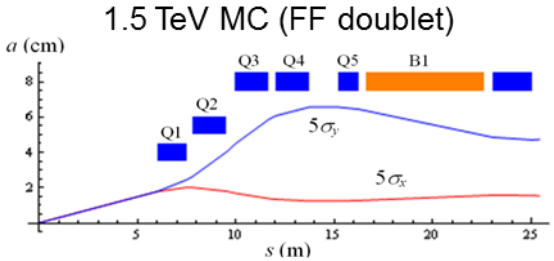
1.5 TeV MC: Arc and IR Magnets

- Arc magnets
  - B_{op}=10T, G_{op}=200 T/m, 20 mm×10 mm beam aperture
  - Open midplane D and large-aperture cos2θ Q
  - Results
    - 10 T with relatively low operation margin ~12%
    - good field quality only in ~30% of coil aperture
    - large dynamic heat load in D ~25 W/m (~5% level)
  - Open mid-plane in D does not help => internal absorber => larger aperture

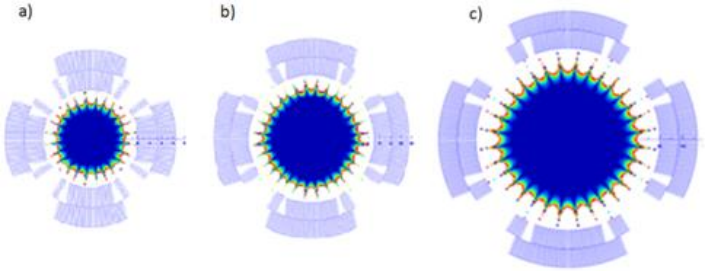




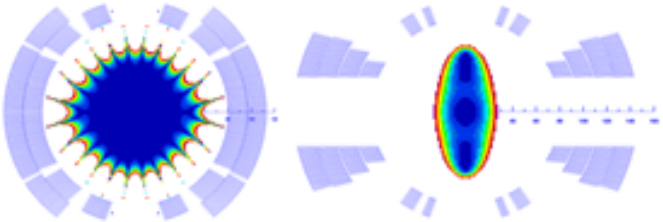
- IR magnets
  - B_{op}=8 T (D), B_{op}~11 T (Q)
  - Results
    - B_{des}=14-15 T with 2-layer coils
    - 20-30% (Q) and 45% (D) operation margin



- W masks and inner absorbers



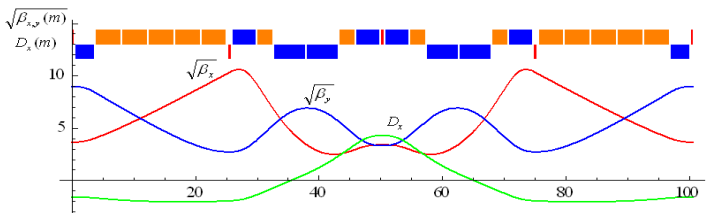
Q1, 80 mm Q2, 110 mm Q3-5, 160 mm

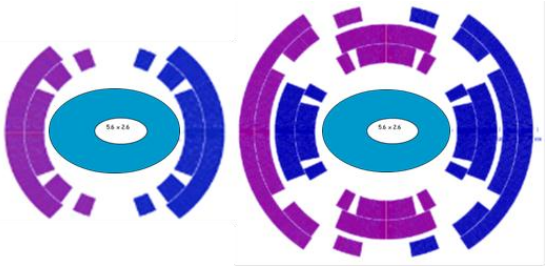


B1, 160 mm

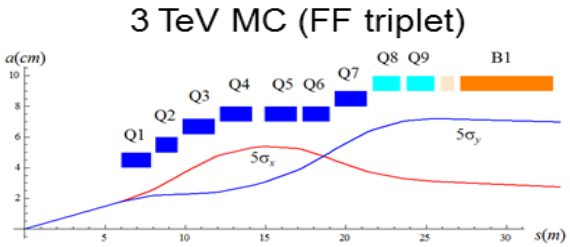
3 TeV MC: Arc and IR Magnets

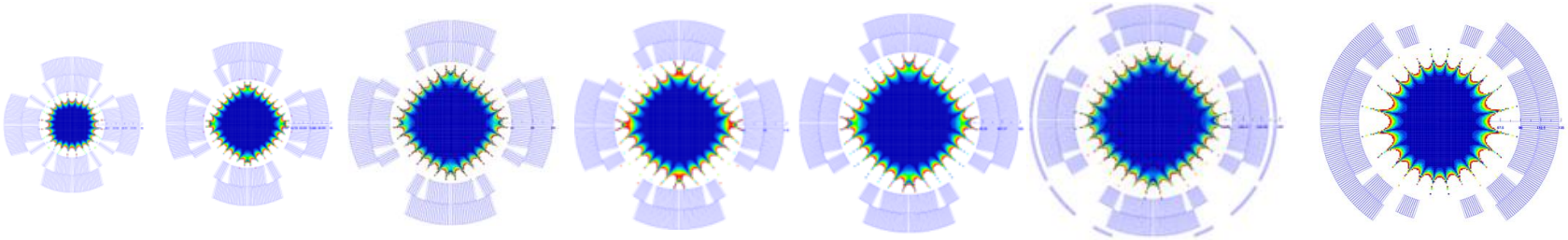
- Arc magnets
  - B_{op}=10.4 T, G_{op}=31-85 T/m, B_{op}=8-9T, 56 mm×26 mm
  - 15 cm aperture cosθ D and combined Q/D
  - Elliptical liner with shifted bore
  - Results
    - B_{op}=10.4 T with ~30% margin at 4.5 K => 2-layer coils
    - B_{op}~8-9T and G_{op}~80T/m with ~20% margin (B_{coil} ~18 T) at 4.5 K => nested Q/D with 4-layer coils
- IR magnets
  - B_{op}=8 T (D), B_{op}~11 T (Q)
  - Aperture 80-180 mm
  - Results
    - B_{des}=14-15 T with 2-layer coils
    - 20-30% (Q) and 45% (D) operation margin
- Tungsten masks and inner absorbers
- Work in progress (FY14)
  - energy deposition, absorber and coil aperture optimization





D, 150 mm Q/D, 150 mm

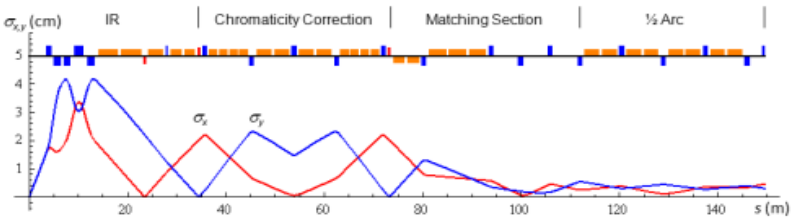


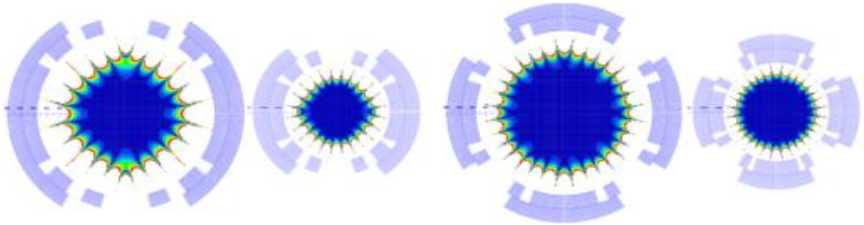


Q1, 80 mm Q2, 100 mm Q3, 125 mm Q4-6,140 mm Q7, 160 mm Q8-9, 180 mm B1, 180 mm

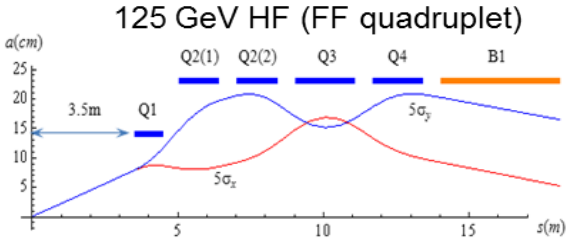
125 GeV HF: CCS, MS, Arc and IR Magnets

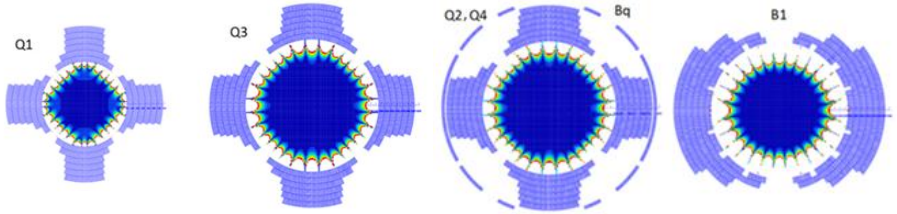
- CCS, MS and Arc magnets
  - Max B_{op}=10 T (D), max G_{op}=36 T/m (Q)
  - Beam aperture: 92 mm (Arc), 231 mm (MS,CCS)
    - defined in arc by beam sagitta in dipoles
  - Large aperture cosθ Dipoles and cos2θ Quads
  - coil ID 16 cm (Arc) and 27 cm (MS, CCS)
  - Results
    - Max B_{op}=10 T with ~30% margin at 4.5 K (B_{max}~14 T) with *2-layer dipole coils*
    - Max G_{op}~36 T/m with ~60-80% margin at 4.5 K (max B_{coil} ~15 T) with *2-layer quadrupole coils*
- IR magnets
  - IR magnet aperture is large 32-50 cm
  - Results
    - B_{des}~17-18 T requires *6-layer coils* for quench protection and to limit maximum coil stress
    - 20-50% operation margin in IR magnets
- W masks and inner absorbers





D1, 270 mm D2, 160 mm Q1, 270 mm Q2, 160 mm

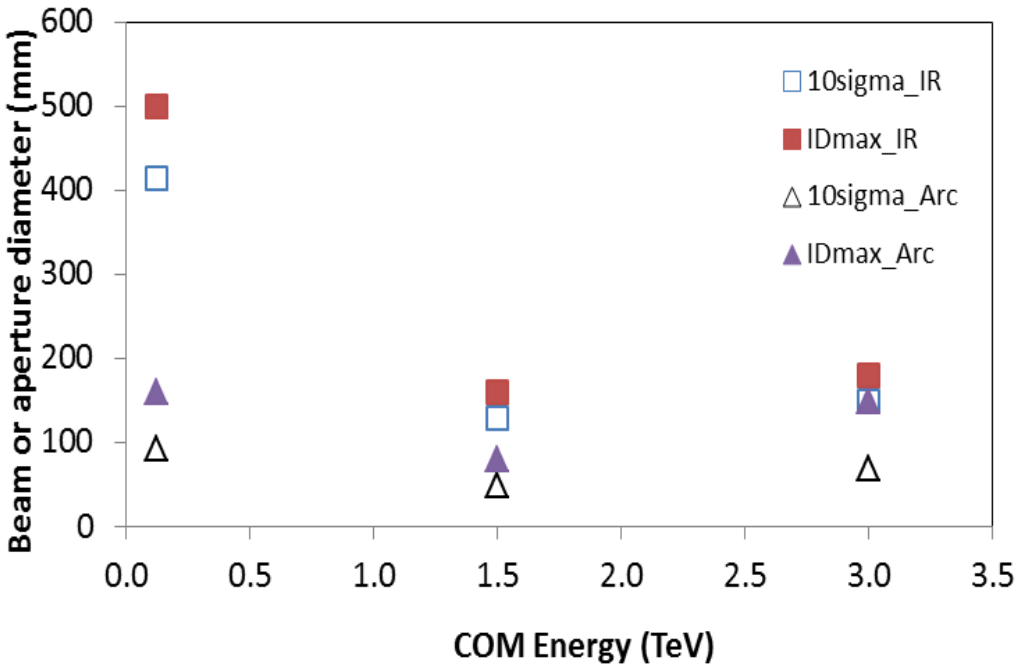




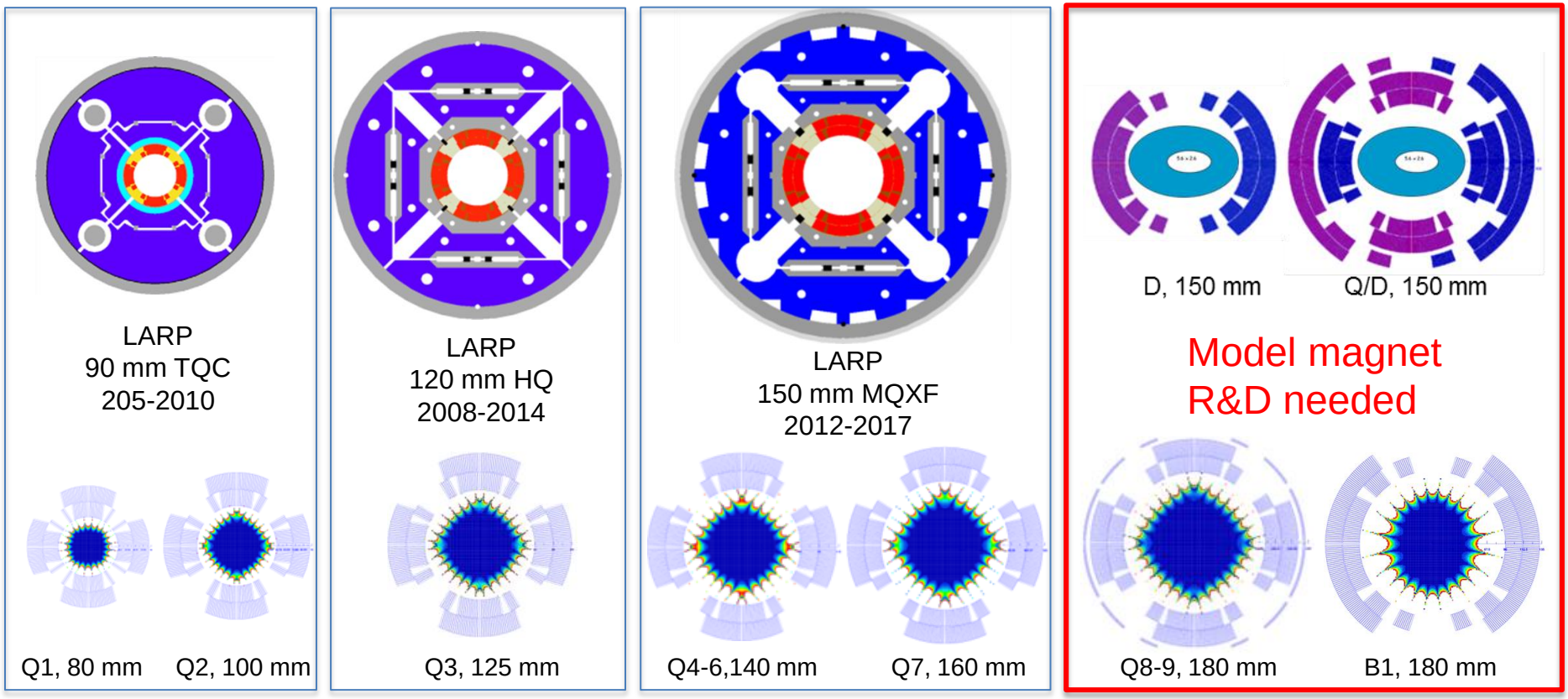
Q1, 320 mm Q3, 500 mm Q2,4, 500 mm B1, 500 mm

Magnet scale up to 5-6 TeV MC

- 125 GeV HF
  - IR magnet aperture is large – ID=32-50 cm
  - arc magnet ID=16 cm
  - CCS, MS magnet ID=27 cm
- 1.5 TeV and 3 TeV MC
  - IR magnet aperture 8-18 cm
  - arc magnet aperture ~15 cm
  - CCS, MS magnets are similar to arc and IR
- Magnet requirements for 1.5 TeV and 3 TeV are quite similar
  - replace open midplane dipoles in 1.5 TeV machine with cos-theta dipoles used in 3 TeV machine
- 5-6 TeV MC
  - Extrapolation to 5-6 TeV machine => IR and SR magnet aperture ~20 cm



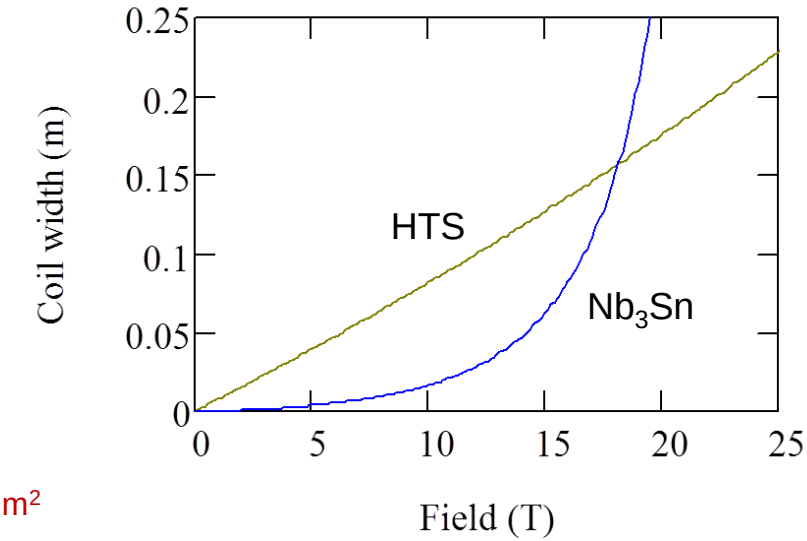
Nb_3Sn Magnet model R&D



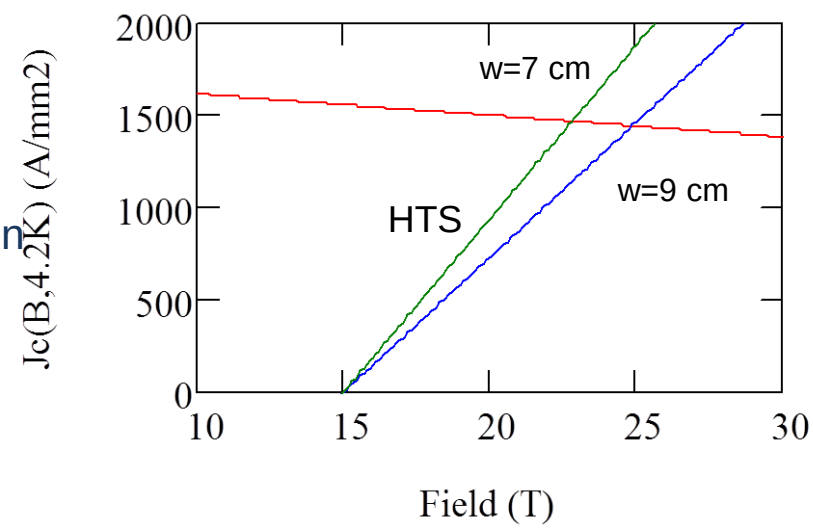
- Coil aperture: 20-30 cm
- Design field: B_{max}~15 T
- Magnet types: dipoles, quadrupoles, nested Q/D magnets
- R&D issues: mechanical structure and stress management, quench performance, field quality, quench protection, etc.

Higher Field Magnets

- Higher fields in MC SR allow higher luminosity or lower Proton Driver power
- Magnet target parameters
  - B_{op}=15-20 T, 20% margin => *B_{des}=18-25 T !!!*
- 15-20 T magnet issues
  - Large stored energy and Lorentz forces (~B^2)
    - Quench protection and stress management
  - Cost (~ *coil width*)
    - 15 T Nb_3Sn magnets: w~15 cm
      - J_c(12T,4.2K)=2.5 kA/mm^2
    - 20 T HTS/LTS magnets: w_{tot}~20-25 cm
      - 10 T HTS insert: w~7 cm for J_E(20T,4.2K)=450 A/mm^2
      - 15 T Nb_3Sn section: w~15 cm, ID~40-50 cm



- R&D directions
  - Increase Nb_3Sn and HTS conductor J_E
  - Develop high-current Nb_3Sn and HTS cables
  - Solve stress management and quench protection problems
  - Demonstrate quench performance and field quality for large-aperture Nb_3Sn and HTS magnets



Outside of MAP scope and resources!

Summary

- Magnet studies for 0.125, 1.5 and 3 TeV MC are almost complete
- Next steps
  - SR and IR magnets for 5-6 TeV machine – *small extension of the present concepts*
  - Corrector, CCS and MS magnets – *could be postponed*
  - Cryostat concept integrated with W absorbers and masks – *will be developed this FY*
- 10 T Nb_3Sn magnets – *baseline approach*
  - magnet technology is *available* from LARP and GARD
  - some *focused R&D* for ~20-30 cm aperture Nb_3Sn dipoles and nested Q/D *will be needed*
- Higher field magnets – *outside of the MAP scope and resources => GARD*
  - 15 T Nb_3Sn magnets with coil ID~20(40) cm, B_{des}~18 T – *new class of Nb_3Sn accelerator magnets*
  - 20 T HTS/LTS magnets (10 T HTS insert) with ~20 cm bore, B_{des}>25 T – *new magnet technology*
  - *significant R&D effort is needed!!!*