MUON COLLIDER INTERACTION REGION AND MACHINE-DETECTOR INTERFACE

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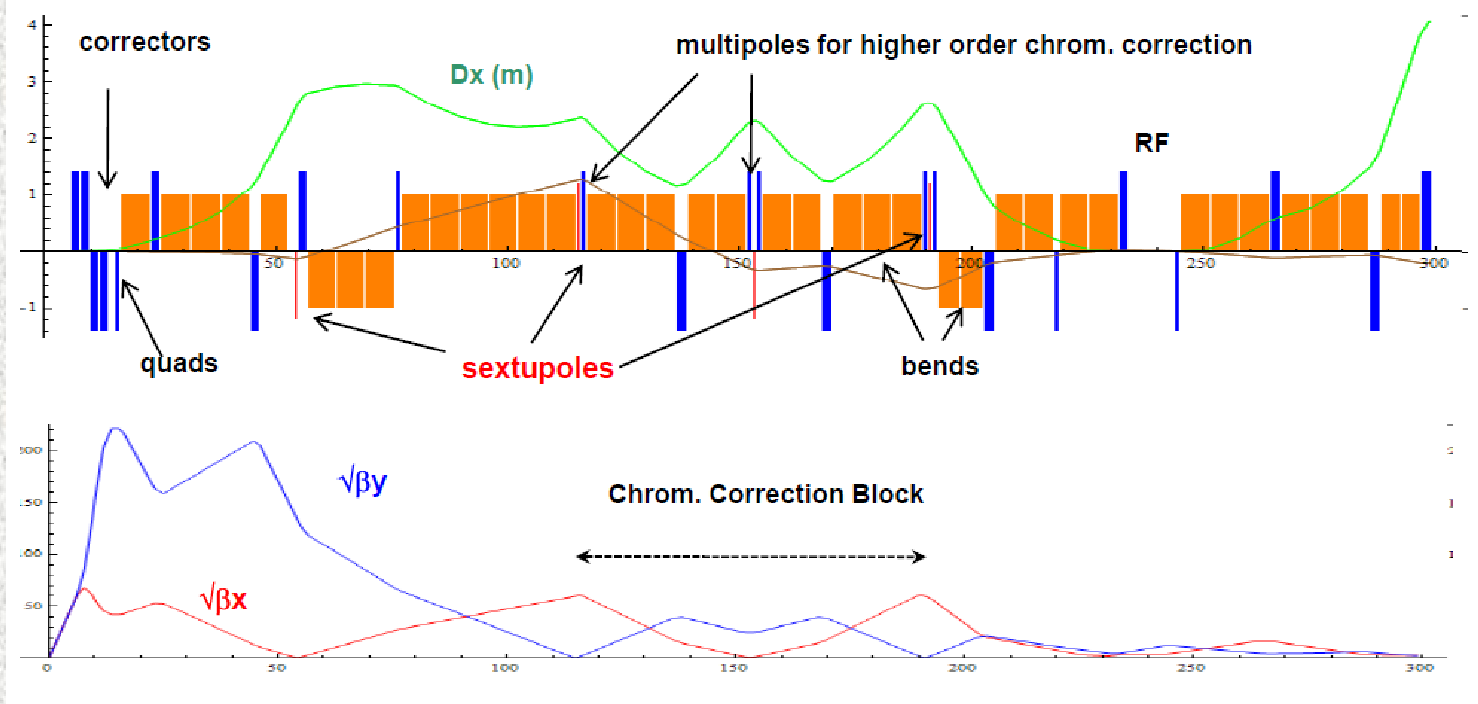
Introduction

Physics goals of a Muon Collider (MC) can only be reached with appropriate design of the ring, interaction region (IR), high-field superconducting magnets, machine-detector interface (MDI) and detector. All - under demanding requirements, arising from the short muon lifetime, relatively large values of the transverse emittance and momentum spread, unprecedented dynamic heat loads (0.5-1 kW/m) and background particle rates in collider detector.

Muon Collider Parameters

E_{cms}	TeV	1.5	4
f_{rep}	Hz	15	6
n_b		1	1
Δt	μs	10	27
N	10^{12}	2	2
$\varepsilon_{x,y}$	μm	25	25
L	$10^{34}\ cm^{-2}s^{-1}$	1	4

IR & Chromatic Correction Section



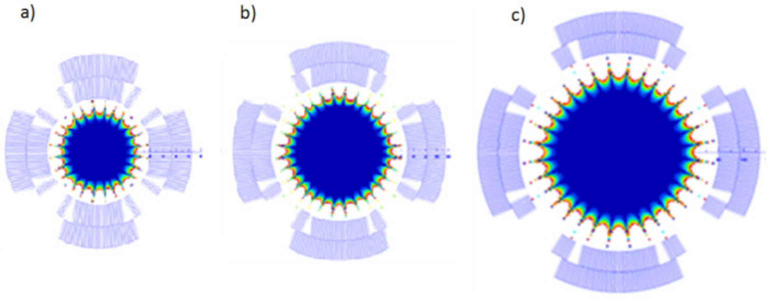
8-T dipoles in IR to generate large D at sextupoles to compensate chromaticity and sweep decay products; momentum acceptance 1.2%; dynamic aperture sufficient for transverse emittance of 50 μm; under engineering constraints.

Iterative studies on lattice and MDI with magnet experts:
High-gradient (field) large-aperture short Nb_3Sn quads and dipoles.

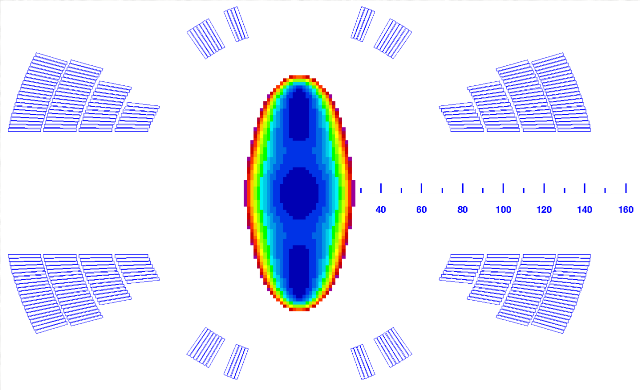
Magnet Requirements/Issues

- Dipoles in IR do an excellent job in spreading decay electrons thus reducing backgrounds in detector; split them in 2-3 m modules with a thin liner inside and tungsten masks in interconnect regions
- Full aperture A = 10 σ_{max} + 2cm
- Maximum tip field in quads = 10T (G=200T/m for A=10cm)
- B = 8T in large-aperture dipoles, = 10T in the arcs
- IR quad length < 2m (split in parts if necessary) with minimal or no shielding inside
- Serious quadrupole, dipole and interconnect technology and design constraints

IR Magnets



Quadrupoles: on limits of current state-of-the-art Nb_3Sn technology; with tungsten liners in some of them



Dipoles: open midplane – field quality and stresses are an issue.

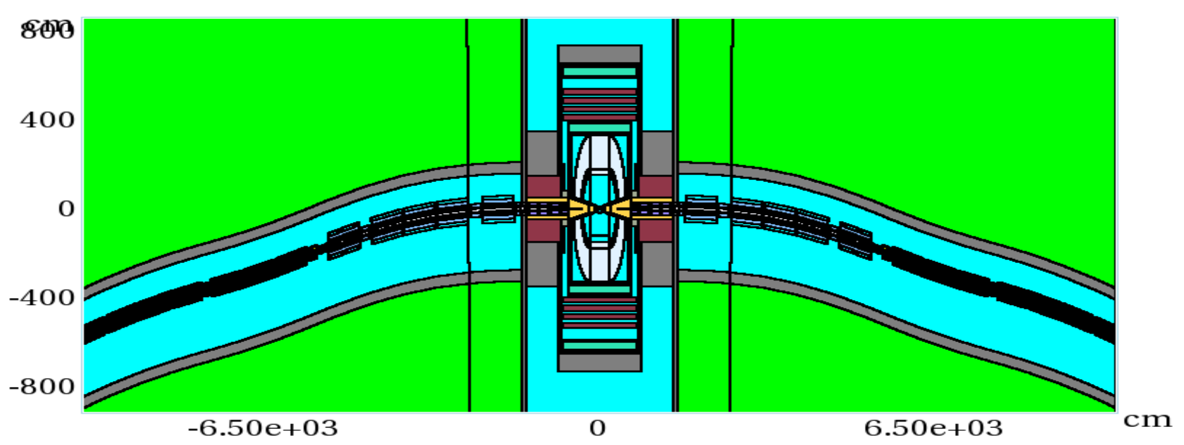
160-mm coil aperture, 55-mm gap with Al-spacers, L=6m, B=8 T. Tungsten rods cooled at LN2.

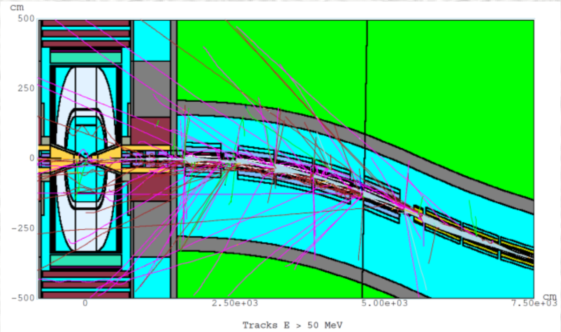
Magnet interconnects: up to 50 cm for end parts, multipole correctors and tight 20-cm 5σ tungsten masks (don't forget neutrino hazard for TeV beams).

Sources of Background and Dynamic Heat Load

1. **IP $\mu^+\mu^-$ collisions:** Production x-section 1.34 pb at $\sqrt{S}$ = 1.5 TeV (negligible compared to #3).
2. **IP incoherent e^+e^- pair production:** x-section 10 mb which gives rise to background of 3×10^4 electron pairs per bunch crossing (manageable with nozzle & detector B)
3. **Muon beam decays:** Unavoidable bilateral detector irradiation by particle fluxes from beamline components and accelerator tunnel – **major source** at MC: For 0.75-TeV muon beam of 2×10^{12}, 4.28×10^5 dec/m per bunch crossing, or 1.28×10^{10} dec/m/s for 2 beams; 0.5 kW/m.
4. **Beam halo:** Beam loss at limiting apertures; severe, can be taken care of by an appropriate collimation system far upstream of IP.

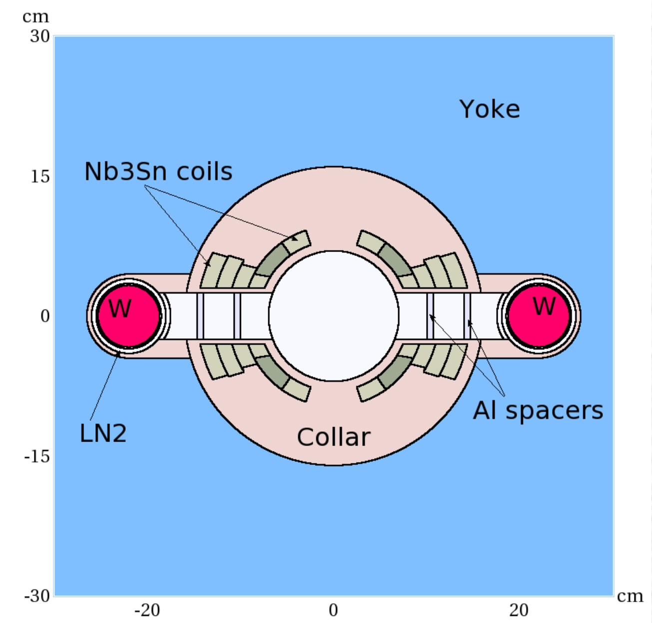
MARS15 Modeling



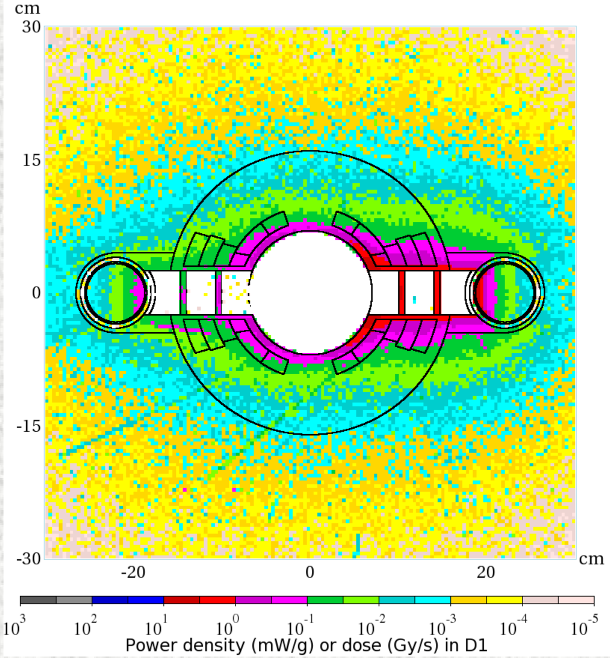


- Detailed magnet geometry, materials, magnetic fields maps, tunnel, soil outside and a simplified experimental hall plugged with a concrete wall.
- Detector model with B_z = 3.5 T and tungsten nozzle in a BCH_2 shell, starting at ±6 cm from IP with R = 1 cm at this z.
- 750-GeV bunches of 2×10^{12} μ^- and μ^+ approaching IP are forced to decay at $|S| < S_{max}$, where S_{max} up to 250 m at 4.28×10^5 / m rate, 1000 turns.
- Cutoff energies optimized for materials & particle types, varying from 2 GeV at ≥100 m to 0.025 eV (n) and 0.2 MeV (others) in the detector.

Energy Deposition in IR Dipoles



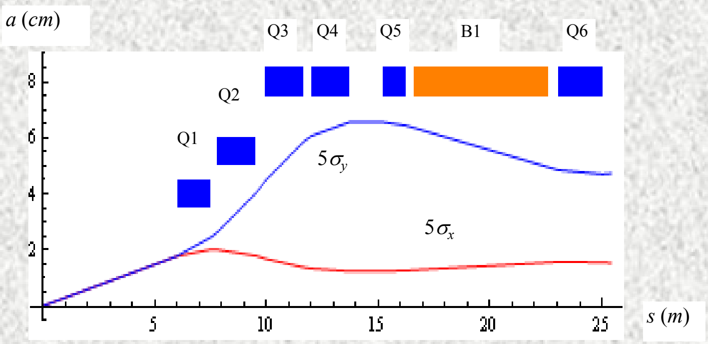
Dynamic heat load
W-rods: 200 W/m
1.9-K LHe: 245 W/m



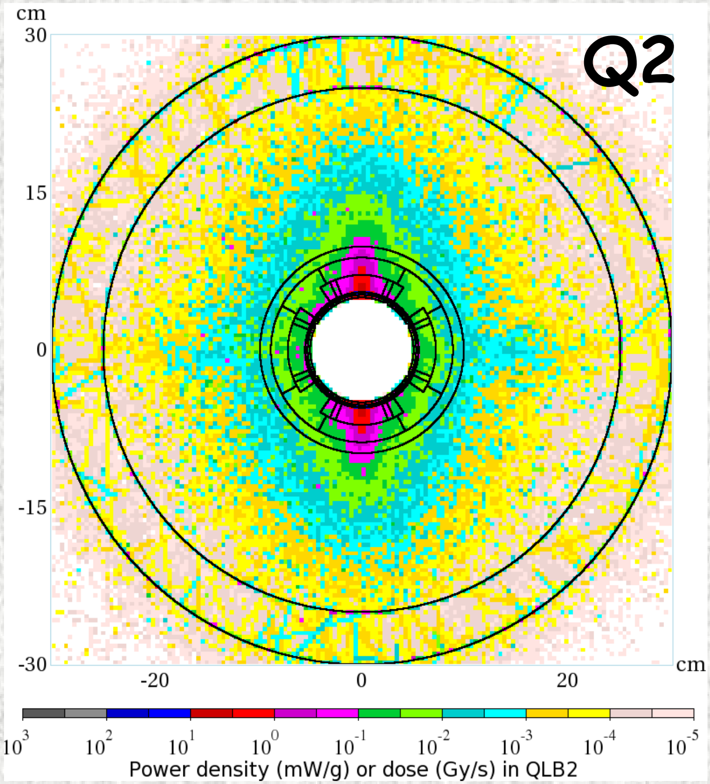
The open midplane design for the dipoles provides for their safe operation. The peak power density in the IR dipoles is about 2.5mW/g, safely below the quench limit for the Nb_3Sn superconductor based coils at the 1.9-K operation.

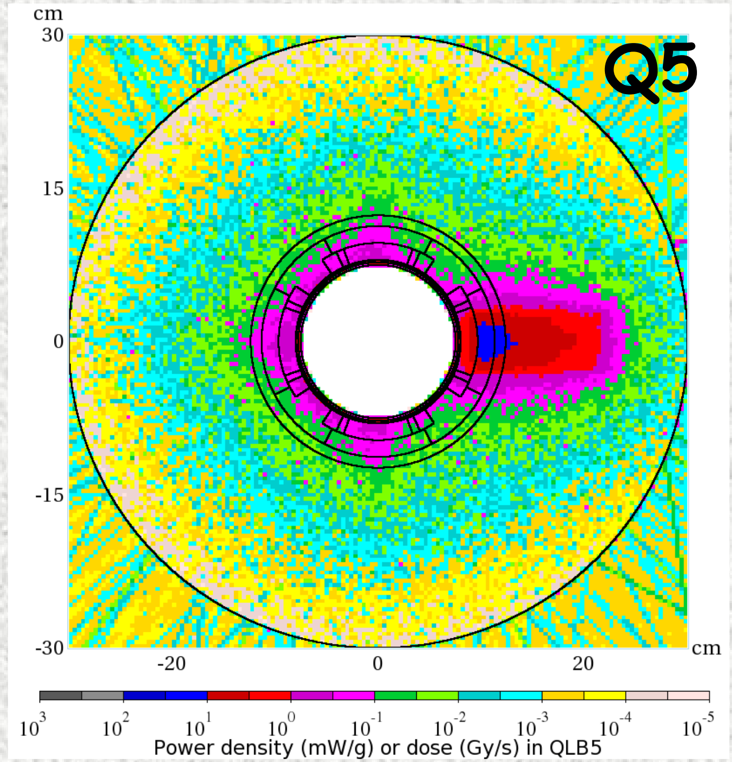
Four 7-mm wide aluminum spacers in the gap are found to have a minimal impact on the coil heating.

Energy Deposition in IR Quadrupoles



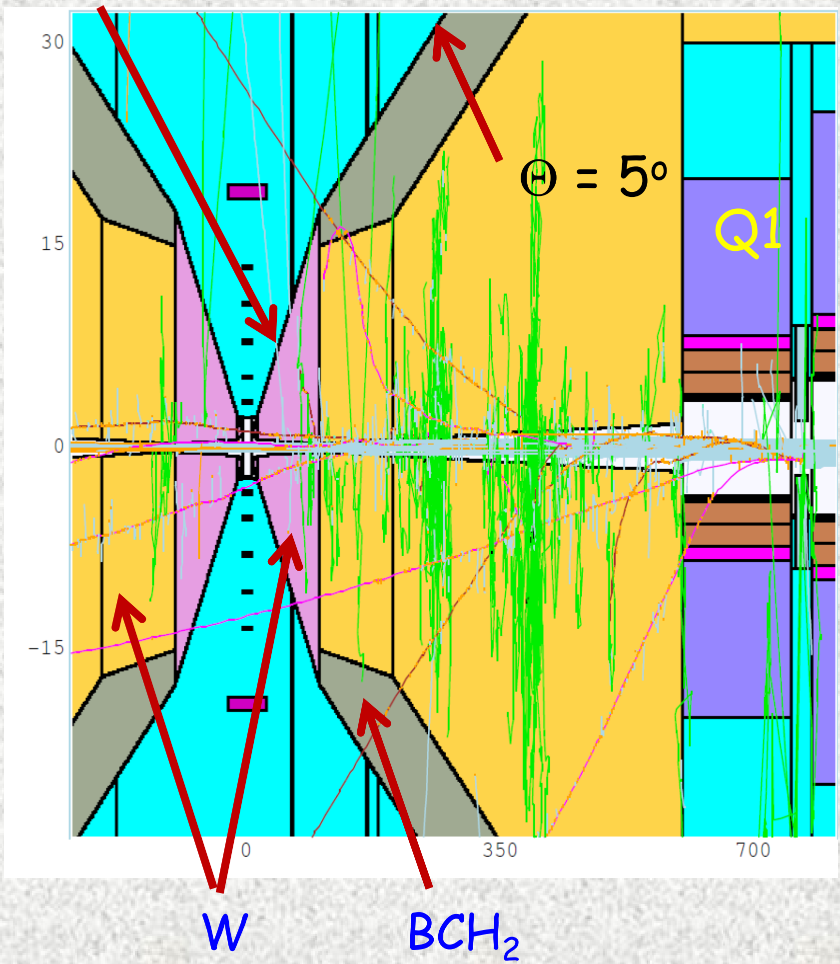
First 4 quadrupoles are operationally stable, while the level in next three IR quadrupoles is 5 to 10 times above the limit. This heat load could be reduced by a tungsten liner in the magnet aperture

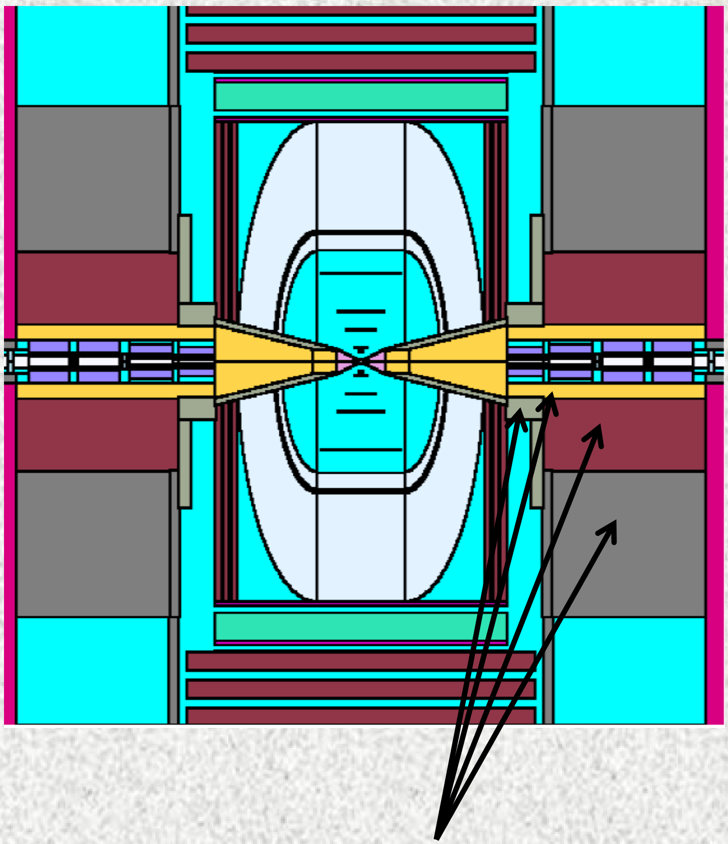




Machine-Detector Interface

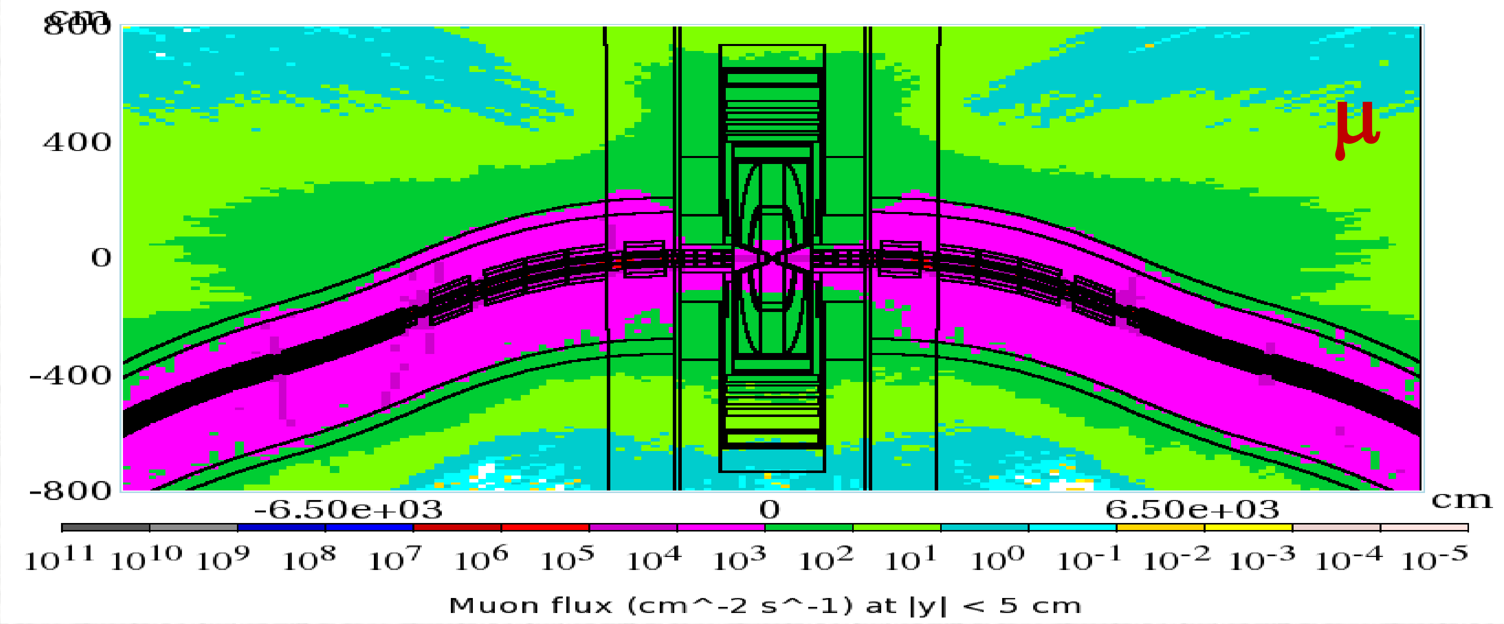
$\Theta = 10^o$ $6 < z < 600$ cm $x:z = 1:17$





Sophisticated shielding:
W, iron, concrete & BCH_2

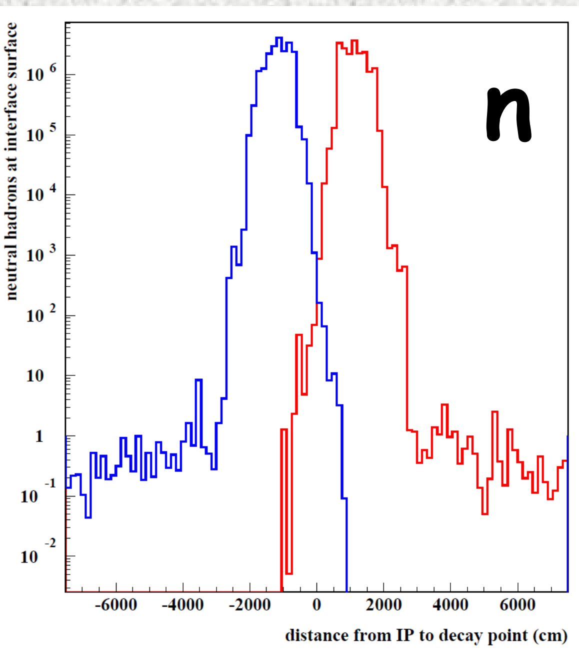
Background Suppression

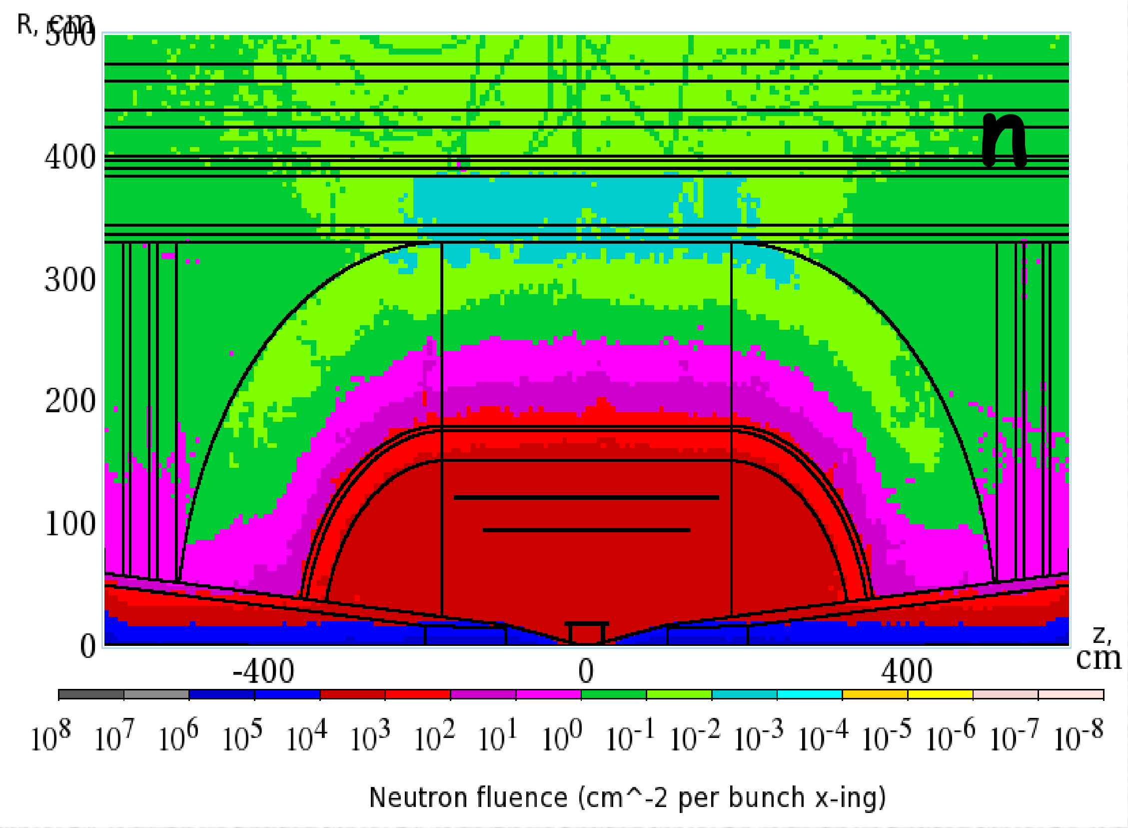


Dipoles close to the IP and tungsten masks in each interconnect region help reduce background particle fluxes in the detector by a substantial factor. The tungsten nozzles, assisted by the detector solenoid field, trap most of the decay electrons created close to the IP as well as most of incoherent e^+e^- pairs generated in the IP. With additional MDI shielding, total reduction of background loads by more than three orders of magnitude is obtained.

Background Loads in Detector

Source:
Muons from |S| < 200 m
Others from |S| < 30 m





Maximum neutron fluence and absorbed dose in the innermost layer of the silicon tracker for a one-year operation are at a 10% level of that in the LHC detectors at the luminosity of 10^{34} $cm^{-2}s^{-1}$

Summary

• A consistent IR lattice, which satisfies all the requirements from the beam dynamics point of view, has been designed for a 1.5-TeV muon collider with luminosity of 10^{34} $cm^{-2}s^{-1}$.

• Required IR magnets can be built using Nb_3Sn technology.

• Design solutions have been found and tested in simulations to provide IR magnet quench and mechanical stability as well as minimize dynamic heat load to 1.9-K cryogenics.

• Detector background simulations are advancing well, MDI optimization is underway, detector physics modeling in presence of the machine backgrounds has been started.

• More work is needed on all of the above directions.