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125-GeV Higgs Factory SC Magnet Protection and Machine-Detector Interface

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Snowmass Muon Collider Forum
125-GeV Higgs Factory
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Outline

- Machine-Induced Backgrounds (MIB) and Machine-Detector Interface (MDI)
- Building Higgs Factory Collider, Detector and MDI Unified MARS Model
- Protecting HF Superconducting Magnets
- Optimizing MDI

“MDI Efforts”: Much Broader than MDI itself

- Developments of physics, geometry and tracking modules for adequate modeling of Muon Collider (MC).

- Building unified MARS model of Interaction Region (IR), entire ring (source of backgrounds can be as long as 1/3 of the ring), magnets and other machine components along with a corresponding collider detector.

- Optimization design studies of Machine-Detector Interface (MDI) and MC magnets. The goal is two-fold:

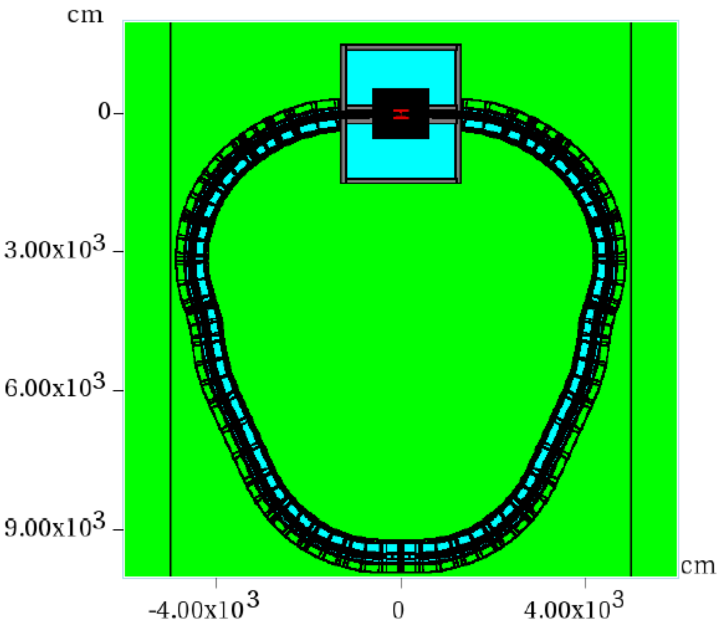
  ❖Design SC magnet protection system that reduces heat loads to the tolerable limits and helps decrease background.

  ❖Further reduce background loads on detector components to manageable levels via MDI optimization and exploitation of background rejection techniques in detector.

MDI-Related Higgs Factory Parameters

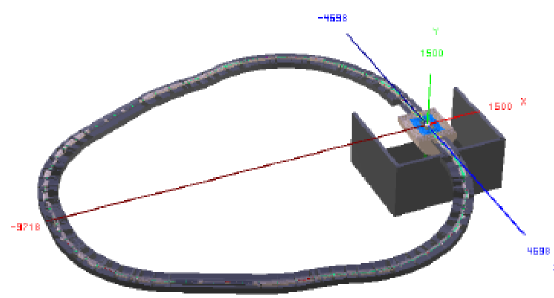
Parameter	Unit	Value
Circumference, C	m	299
β^*	cm	2.5
Muon energy	GeV	62.5
Number of muons / bunch	10^{12}	2
Normalized emittance, $\varepsilon_{\perp N}$	$\pi\cdot$mm$\cdot$rad	0.3
Long. emittance, $\varepsilon_{\|\|N}$	$\pi\cdot$mm	1.0
Beam energy spread	%	0.003
Bunch length, σ_s	cm	5.64
Repetition rate	Hz	30
Average luminosity	10^{31}/cm^2/s	2.5

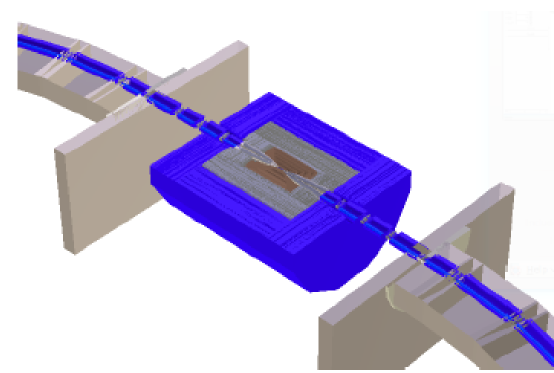
$\sqrt{S} =$ 125-GeV Higgs Factory MARS15 Model



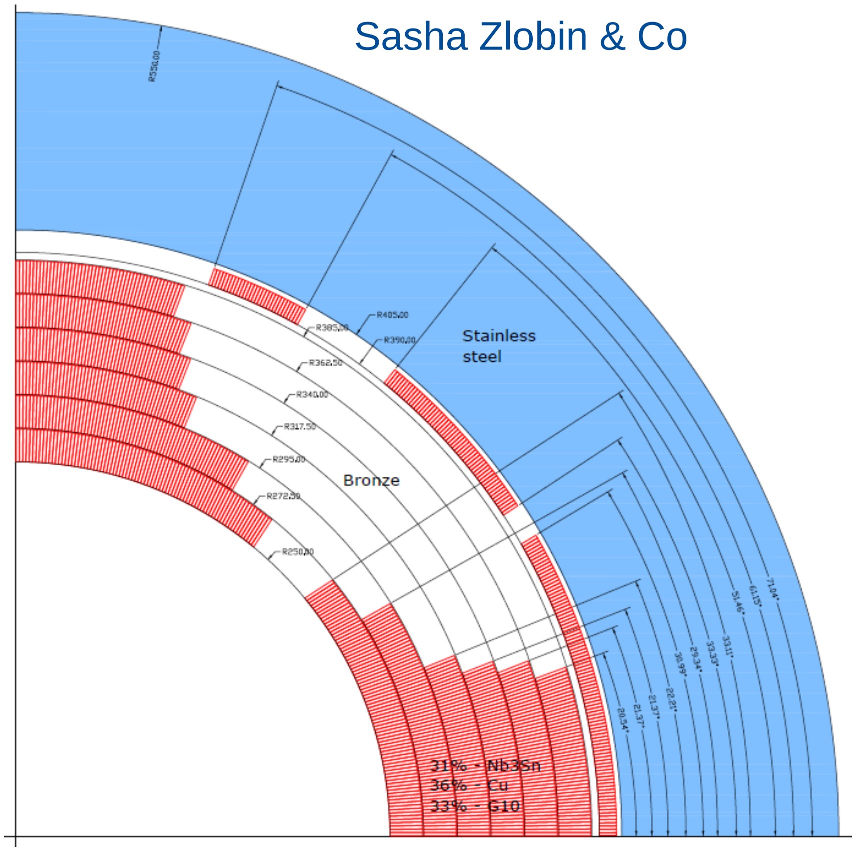
HF Muon Collider with IR, MDI and **SID-like detector with SVD and tracker model based on that of the CMS detector upgrade.** The circumference is about 300 m. Simplified tunnel and detector hall geometry.

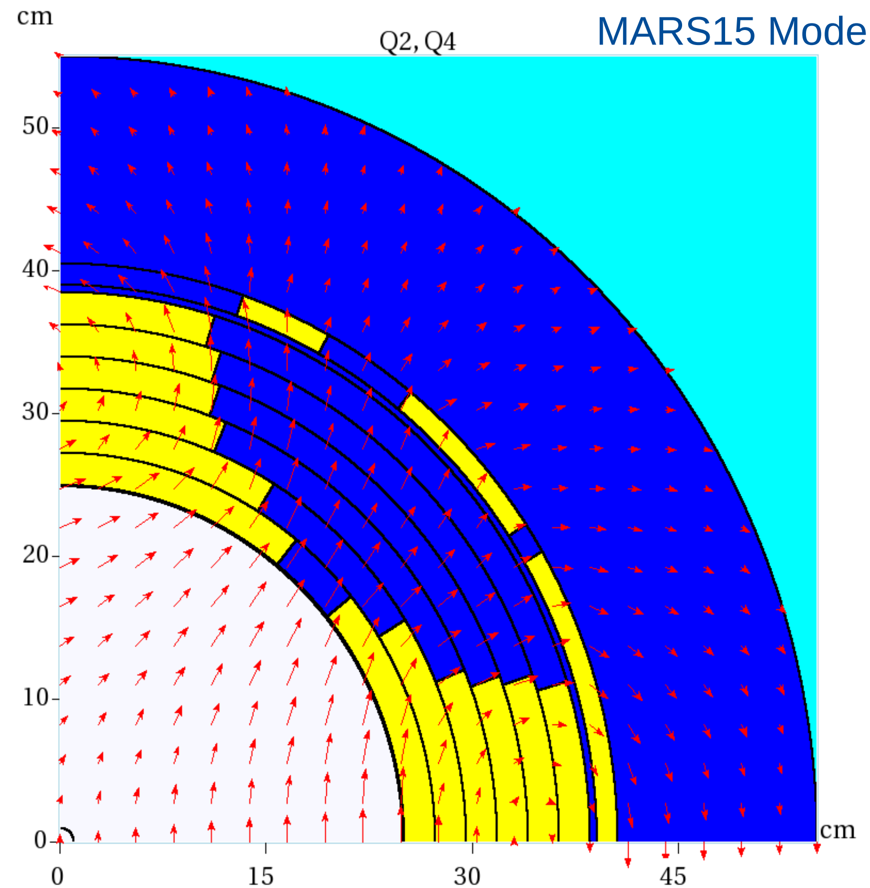
The decay length for a 62.5 GeV muon is $3.9 \cdot 10^5$ m. With $2 \cdot 10^{12}$ muons per bunch, this results in 10^7 decays per meter in a single pass. The HF ring is designed for 1000 to 2000 turns per a store with 30 stores per sec. This provides the peak luminosity of 8×10^{31} cm^{-2} s^{-1} compared to $\sim 4 \times 10^{33}$ cm^{-2} s^{-1} at 1.5 TeV MC.





50-cm ID IRQ2 and IRQ4





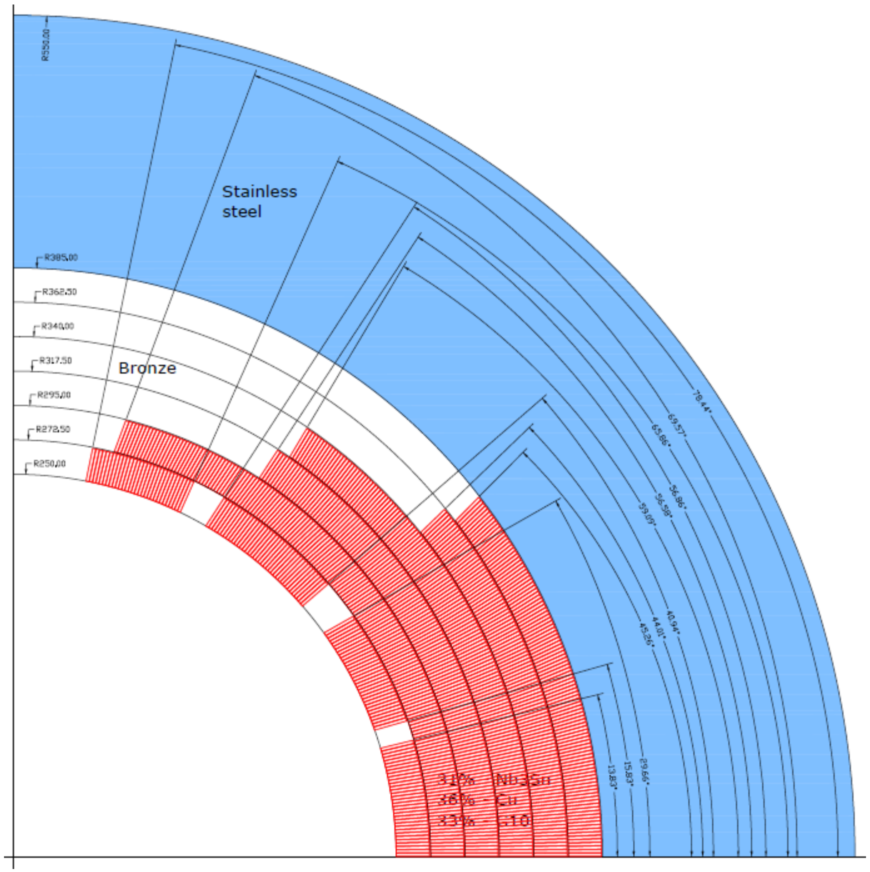
Nb$_3$Sn cos-theta **combined function** IR quadrupole Q2 and Q4 design

HF collider quad lengths: 0.5 ≤ L ≤ 2.05 m

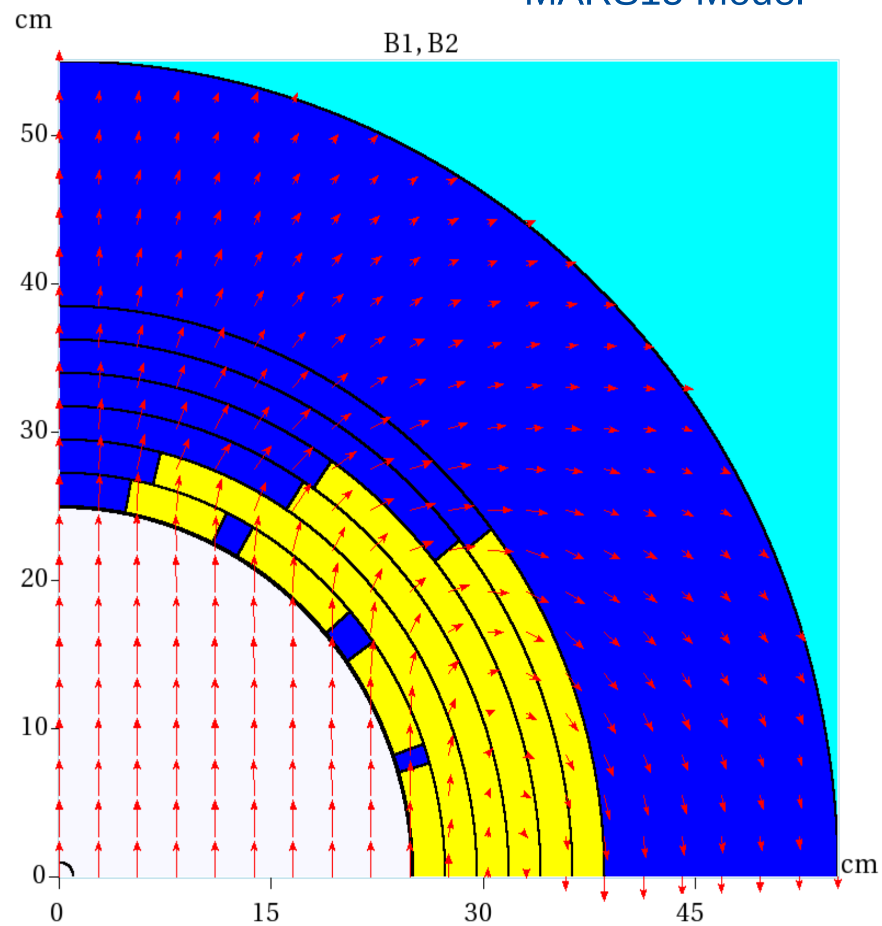
HF quad coil ID (cm) = 32 (Q1), 50 (Q2-Q4), 27 (CCS) and 16 (MS and Arc)

50-cm ID 8-T IR Dipoles

Sasha Zlobin & Co



MARS15 Model



HF Muon Decays: Background and Heat Load

λ_D = 3.896 $\times 10^5$ m, 1.0266 $\times 10^7$ decays/m/bunch xing (2 beams)

4.8 $\times 10^8$ decays in IR per bunch xing responsible for majority of detector background

3.08 $\times 10^{11}$ decays/m/s for 2 beams*

Dynamic heat load: **1 kW/m****

~300 kW in superconducting magnets

i.e. ~ multi-MW room temperature equivalent

*) 1.28 $\times 10^{10}$ decays/m/s for 1.5-TeV MC
**) 0.5 kW/m for 1.5-TeV MC

Note:
Large-aperture high-field magnets (large β_{max} and ε_t, reduced good field region) → **huge physical aperture in IP vicinity → increased loads on detector**

Tight Tungsten Liners and Masks – Optimized Individually for Each Magnet in HF

- Reduce peak power density in inner Nb_3Sn cable to below the quench limit with a safety margin, from a hundred mW/g to ~1.5 mW/g

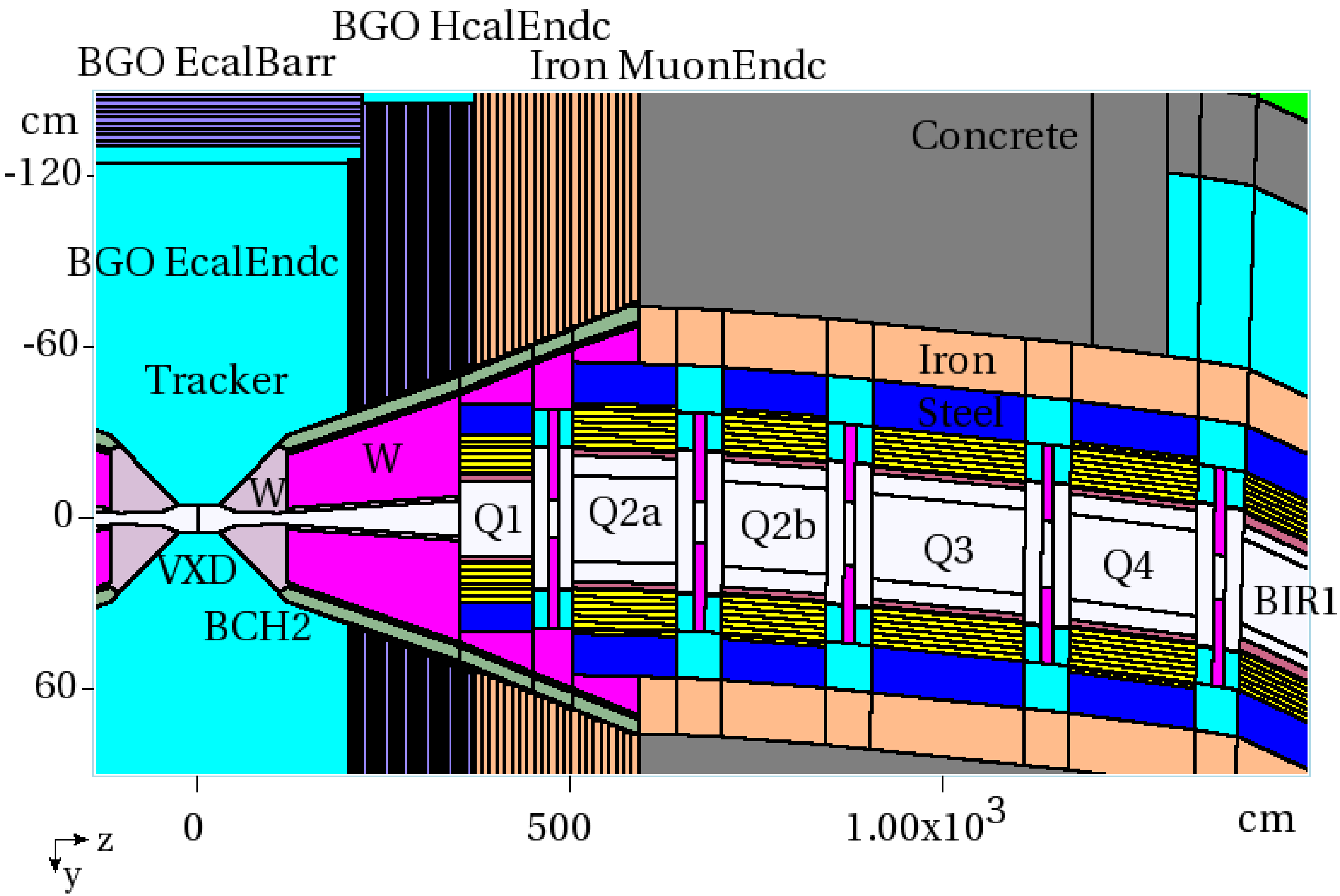
- Keep the HF lifetime peak dose in the innermost layers of insulation below ~20 MGy

- Reduce dynamic heat load to the cold mass from 1 kW/m to ~10 W/m

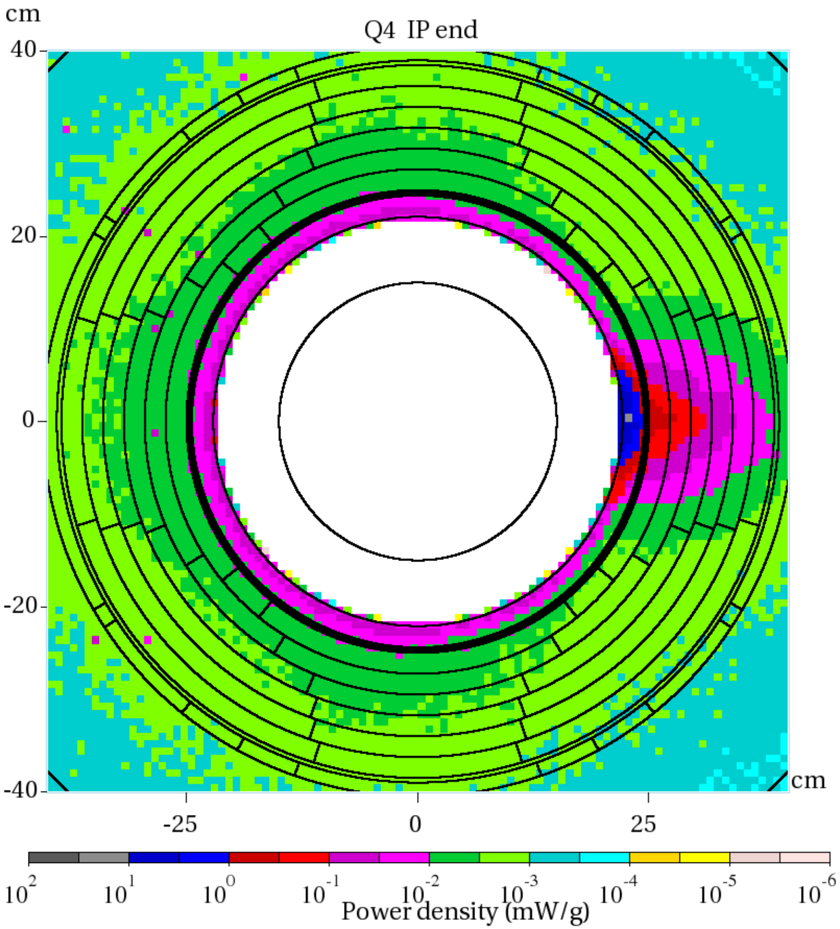
- Suppress the long-range component of detector background

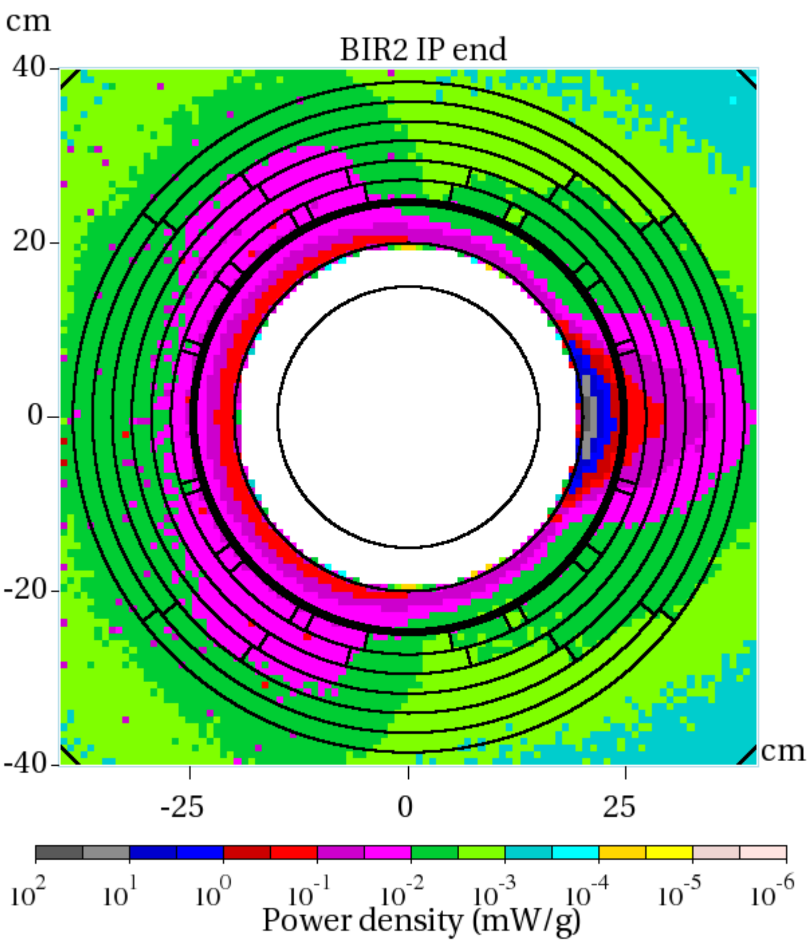
- Byproduct: already modest HF neutrino-induced radiation plume (0.1mSv/yr) can be localized on the Fermilab site

HF MDI MARS15 Optimization



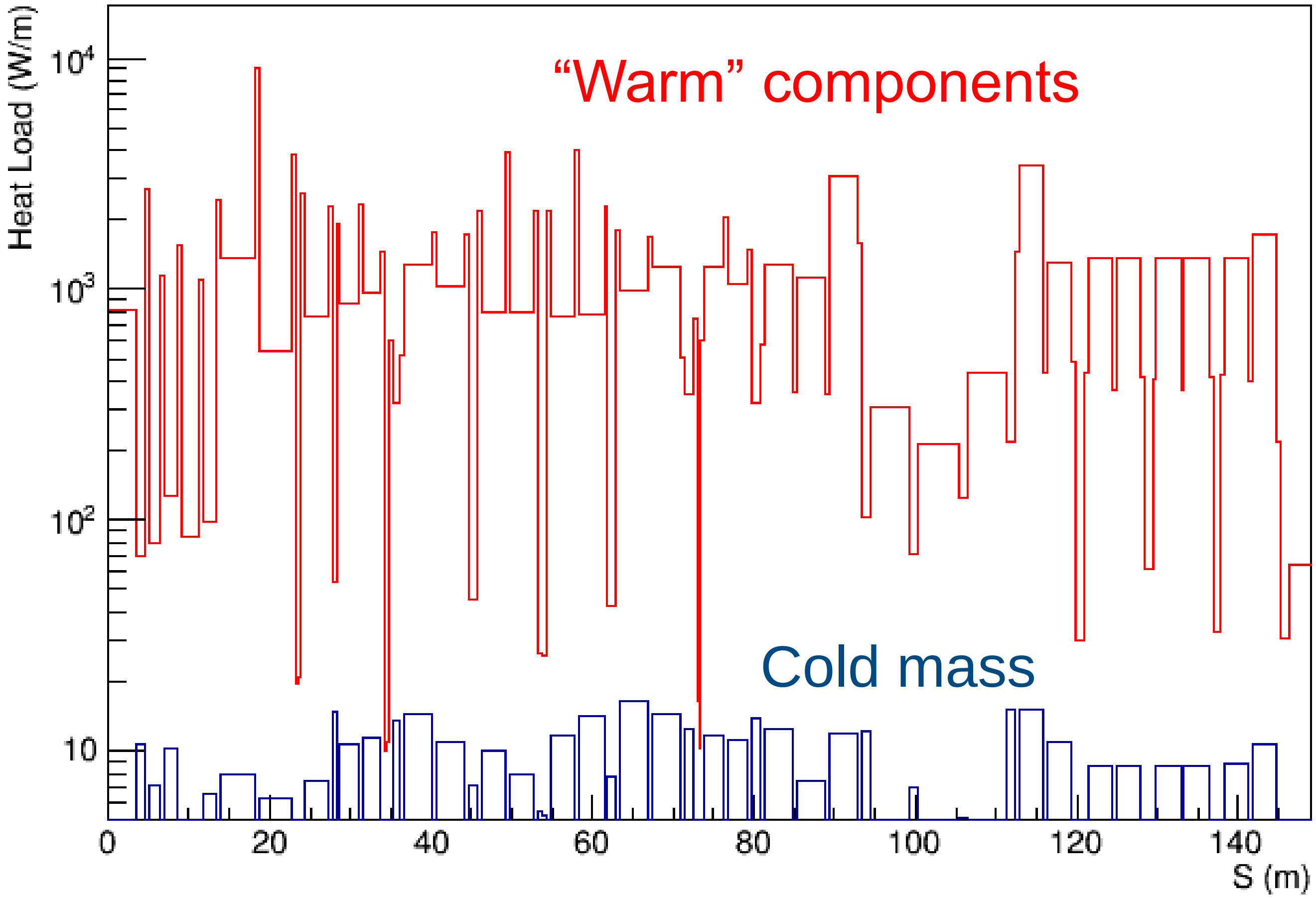
Peak Power Density in SC Coils





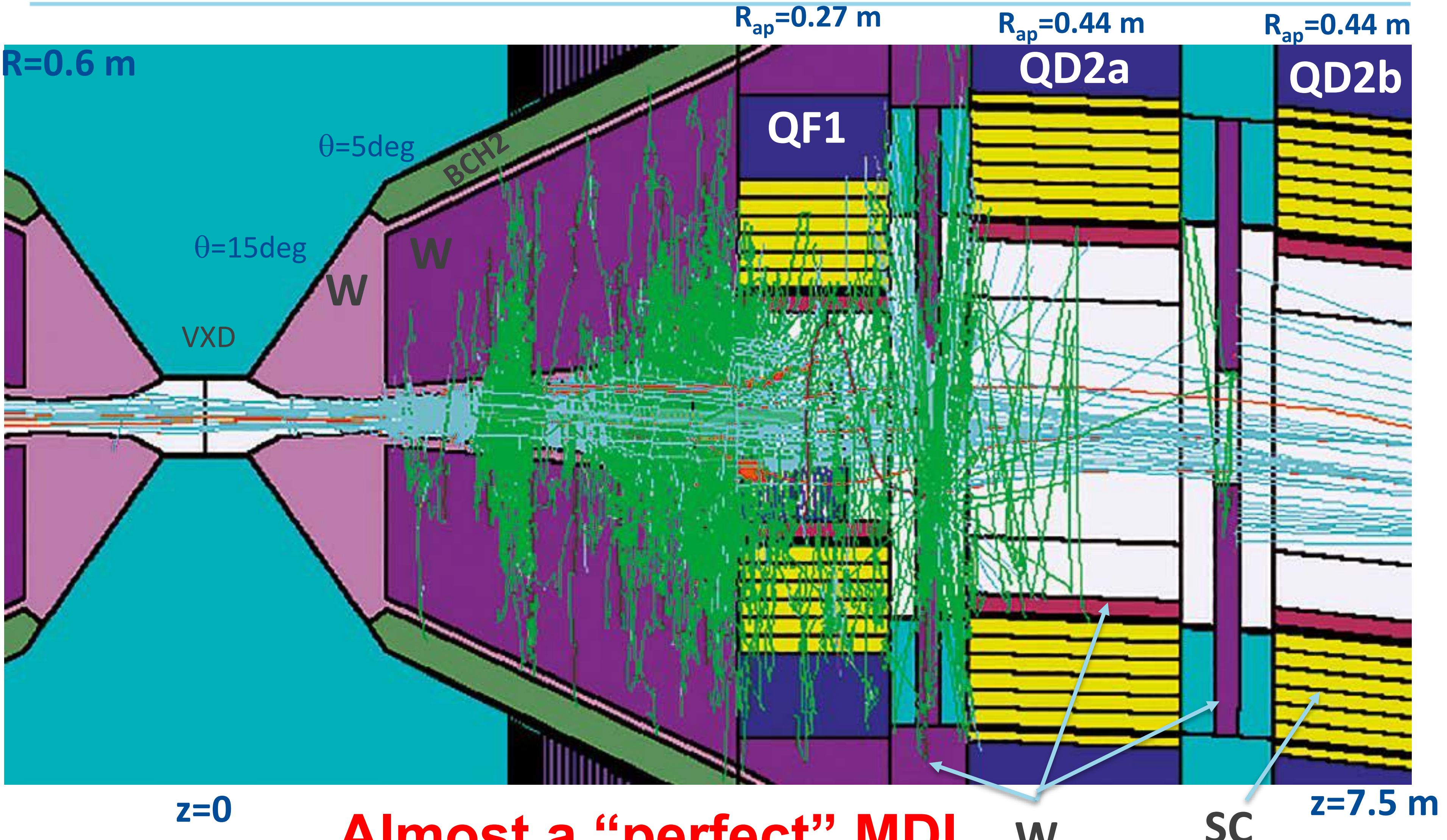
Design goal is met: 100-150 mW/g ⟶ < 1.5 mW/g

Dynamic Heat Load on Warm & Cold Mass



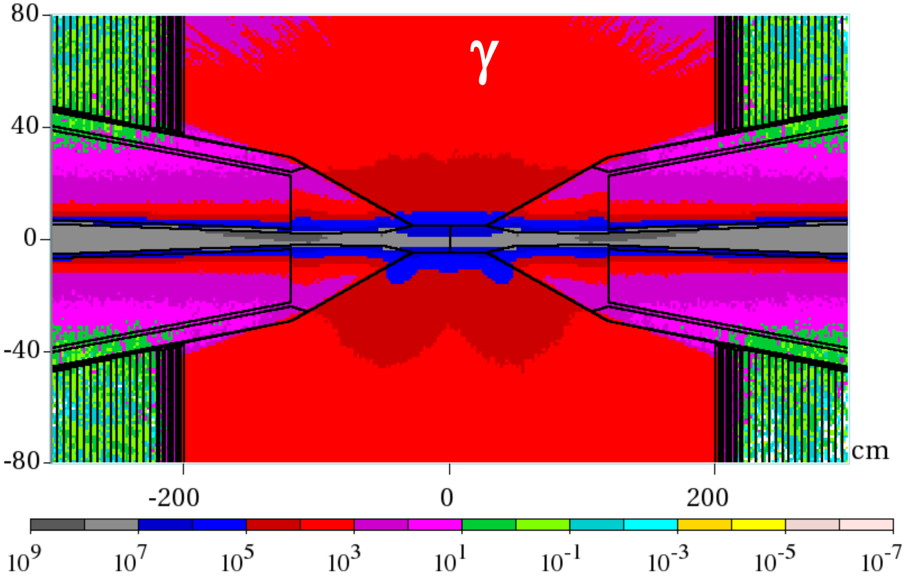
Design goal is met: 1000 W/m ⟶ ~10 W/m

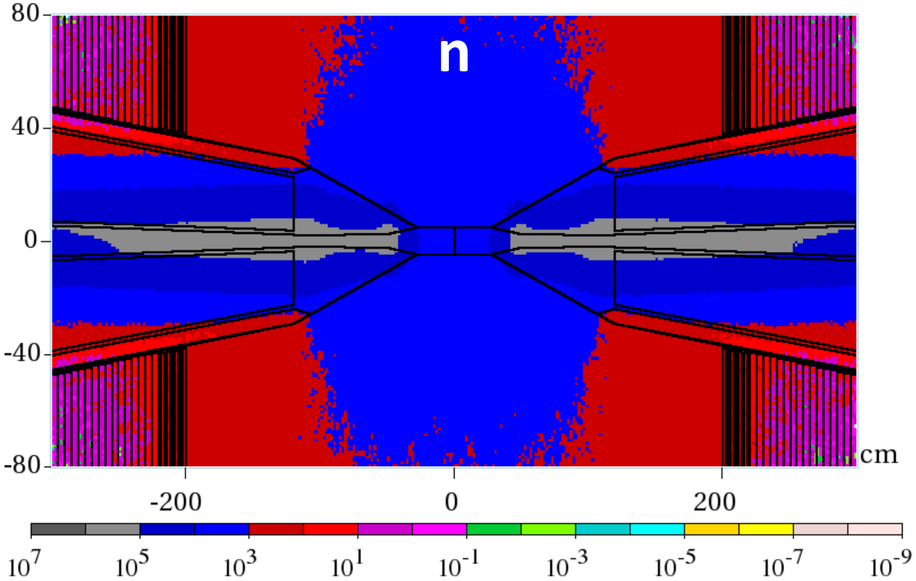
125-GeV Higgs Factory Thoroughly Optimized MDI



Almost a "perfect" MDI

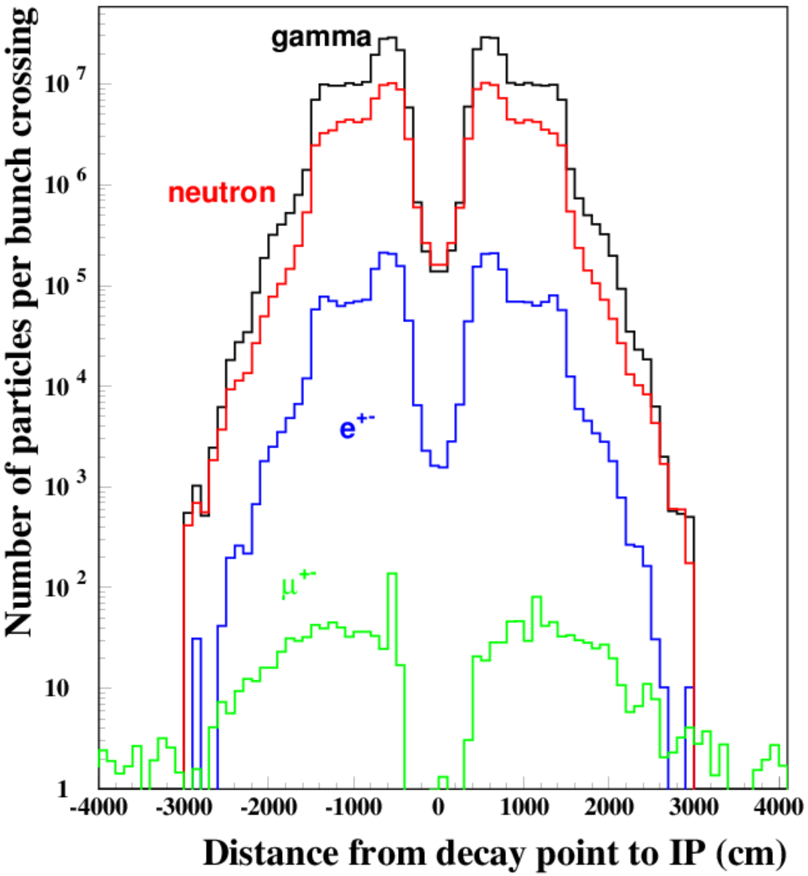
HF MC: Photon and Neutron Fluences (cm^{-2} per BX)

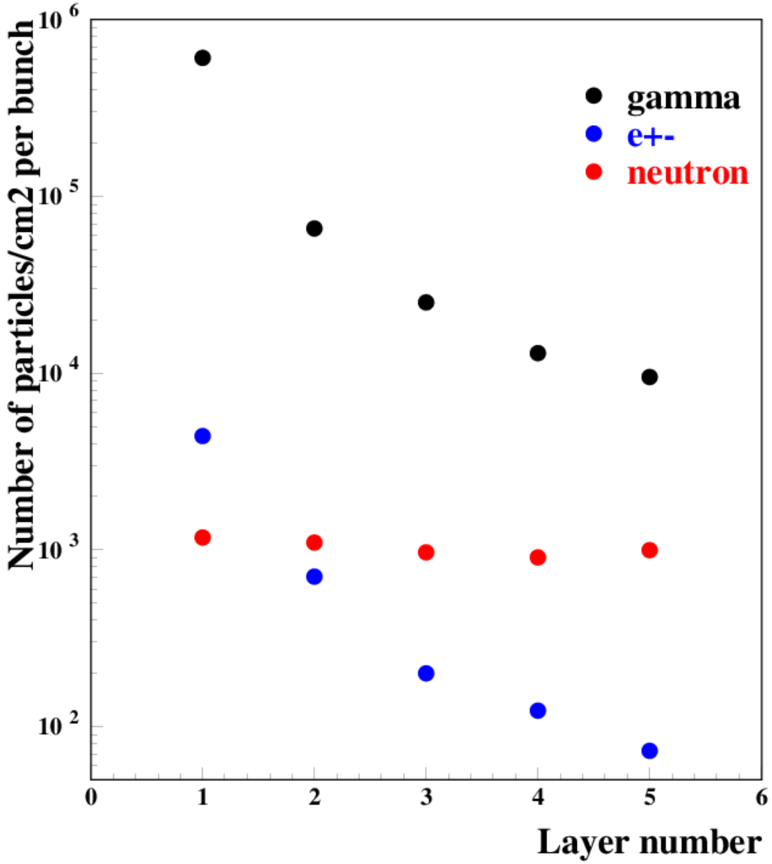




In central detector, the photon fluence is noticeably larger than in the LHC detectors while for neutrons it is much lower

HF Tagged Decays & Loads on VXD Barrel



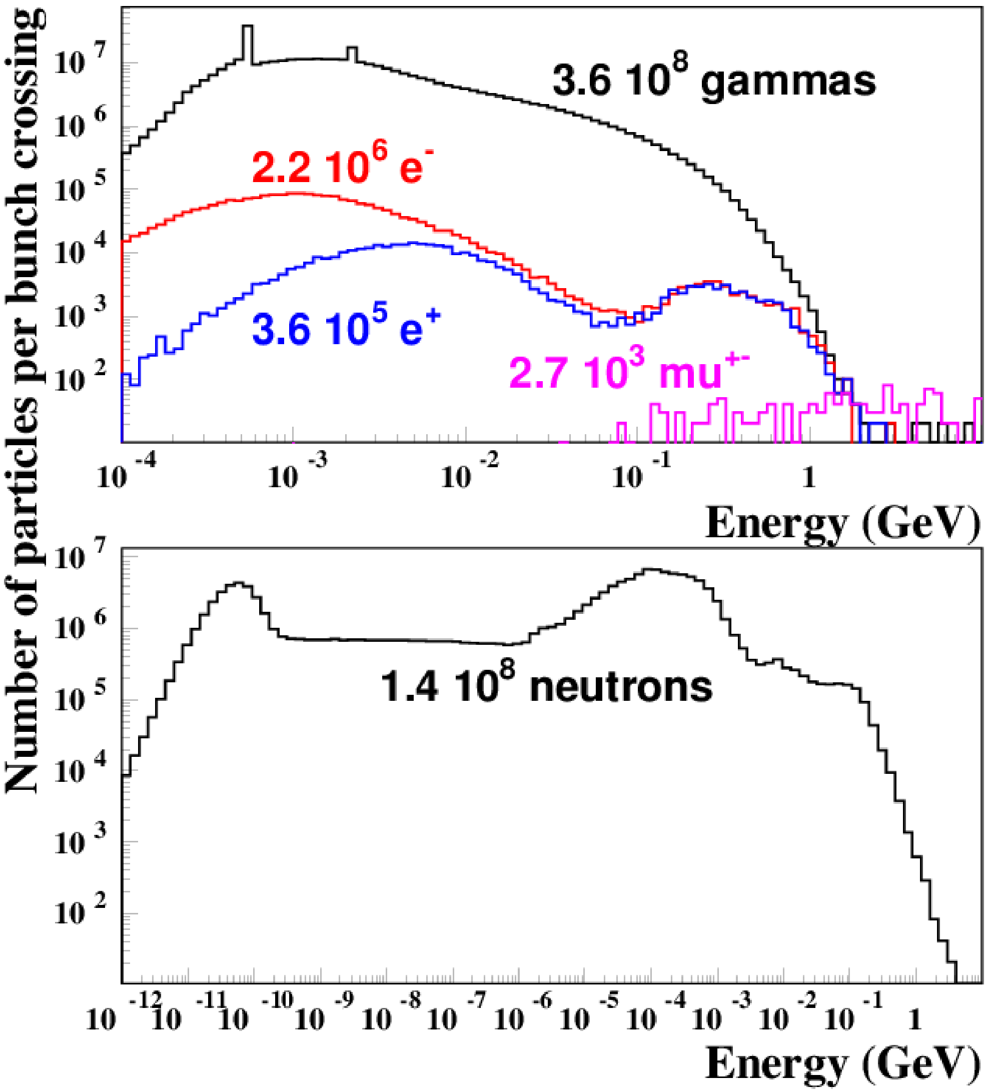


Majority of background particles entering detector are from decays at |S| < 25-30 m

Layer radii: 5.4, 9.45, 13.49, 17.55; 21.59 cm; -20 < z < 20 cm.

Here for μ^- beam only

Feeding Detector and Physics Groups



To feed detector and physics groups, typical background source terms at the HF MDI surface were generated in MARS15 runs (Jan. 2014) for a few % of a bunch crossing (weighted particles).

Machine Induced Backgrounds: HF *vs* 1.5-TeV MC

Number of particles **N** (E > 0.1-1 MeV) and energy flux **E** (TeV) entering detector per bunch crossing

Particle		1.5-TeV MC 10deg	125-GeV HF V2 (MAP13 06/13)	125-GeV HF V7x2s4 (Jan. 2014)
Photon	**N**	1.8×10^{8}	3.2×10^{9}	2.8×10^{8}
	E	160 $\langle E\rangle$=0.9 MeV	12000	2200 $\langle E\rangle$=8 MeV
Electron	**N**	1.0×10^{6}	1.2×10^{8}	2.0×10^{6}
	E	5.8 $\langle E\rangle$=6 MeV	9000	32 $\langle E\rangle$=16 MeV
Neutron	**N**	4.1×10^{7}	1.7×10^{8}	5.2×10^{7}
	E	170	300	86
Ch. Hadron	**N**	4.8×10^{4}	1.0×10^{5}	1.0×10^{4}
	E	12	26	2.3
Muon	**N**	8.0×10^{3}		2.8×10^{3}
	E	184 $\langle E\rangle$=23 GeV		8.2 $\langle E\rangle$=3 GeV

~1/50

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Summary

- Fermilab has several years of experience, tools and know-how to minimize Machine-Induced Backgrounds, protect superconducting magnets, detector and environment as well as optimize Machine-Detector Interface for the 125-GeV Higgs Factory and TeV-scale Muon Colliders.

- Thorough MARS15 simulations demonstrated a factor of 100 reduction of radiation loads on SC magnets and background levels in the HF detector.

- USA possesses unique expertise in this area.