Higgs Factory Magnet Protection and Machine-Detector Interface

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Outline

- MDI Efforts
- Building Higgs Factory Collider, Detector and MDI Unified MARS Model
- Protecting HF Superconducting Magnets
- Optimizing MDI
- Reducing Background Loads and Improving Background Rejection in VXD and Tracker
- Plans

“MDI Efforts”: Much Broader than MDI itself

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

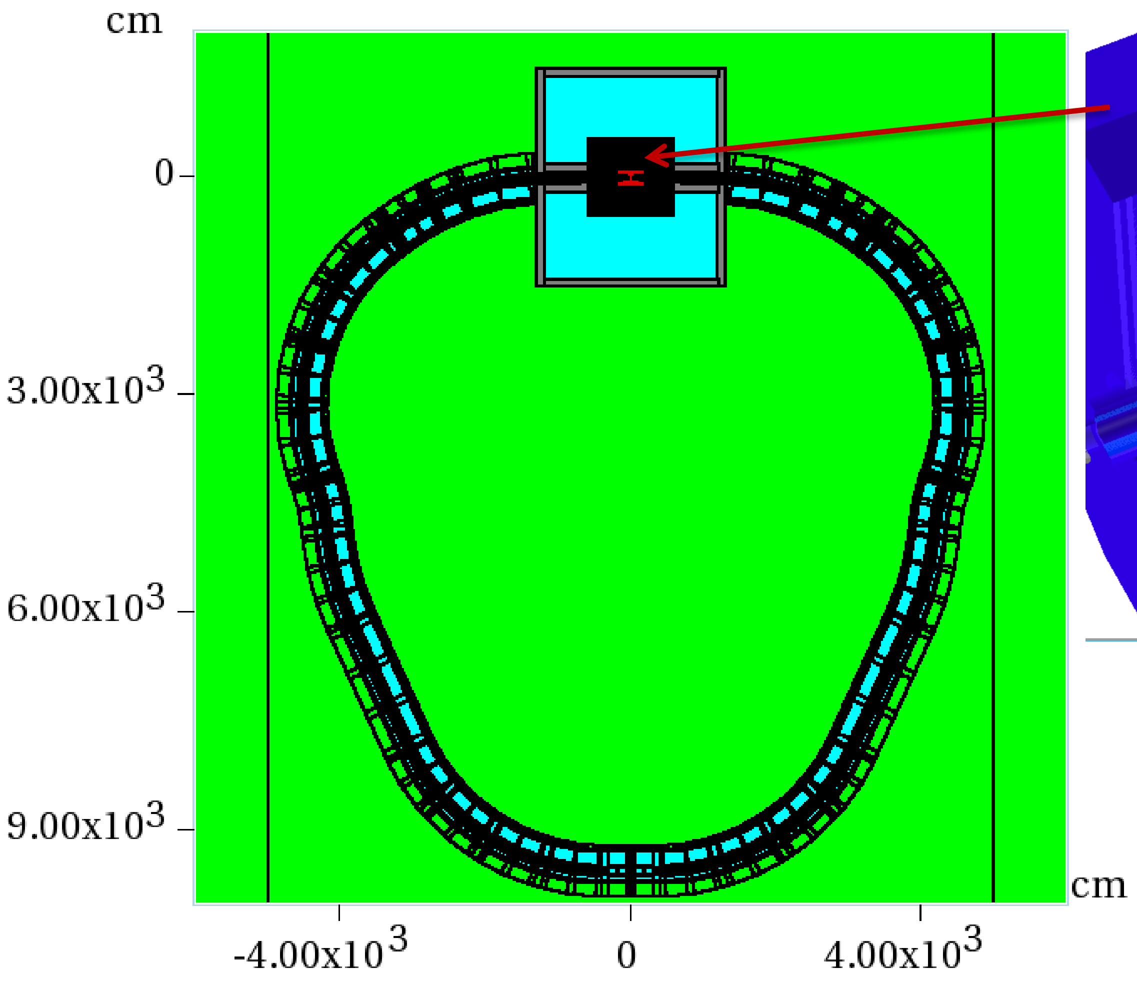
- Building unified MARS model of Interaction Region (IR), entire ring (source of backgrounds can be as long as 1/3 of the ring), magnets and other machine components along with corresponding collider detector.

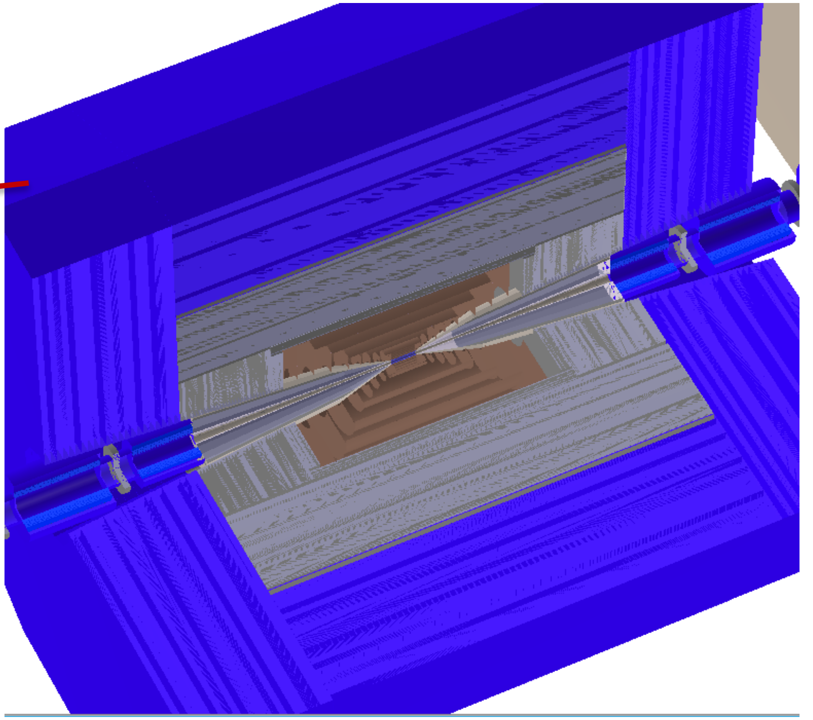
- Optimization design studies of Machine-Detector Interface (MDI) and MC magnets. The goal is two-fold:
  - ❖ Design SC magnet protection system that reduces heat loads to the tolerable limits and helps decrease background.
  - ❖ Further reduce background loads on detector components to manageable levels 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 total energy	GeV	62.5
Number of muons / bunch	10^{12}	2
Normalized emittance, $\varepsilon_{\perp N}$	π·mm·rad	0.3
Long. emittance, $\varepsilon_{\|\|N}$	π·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

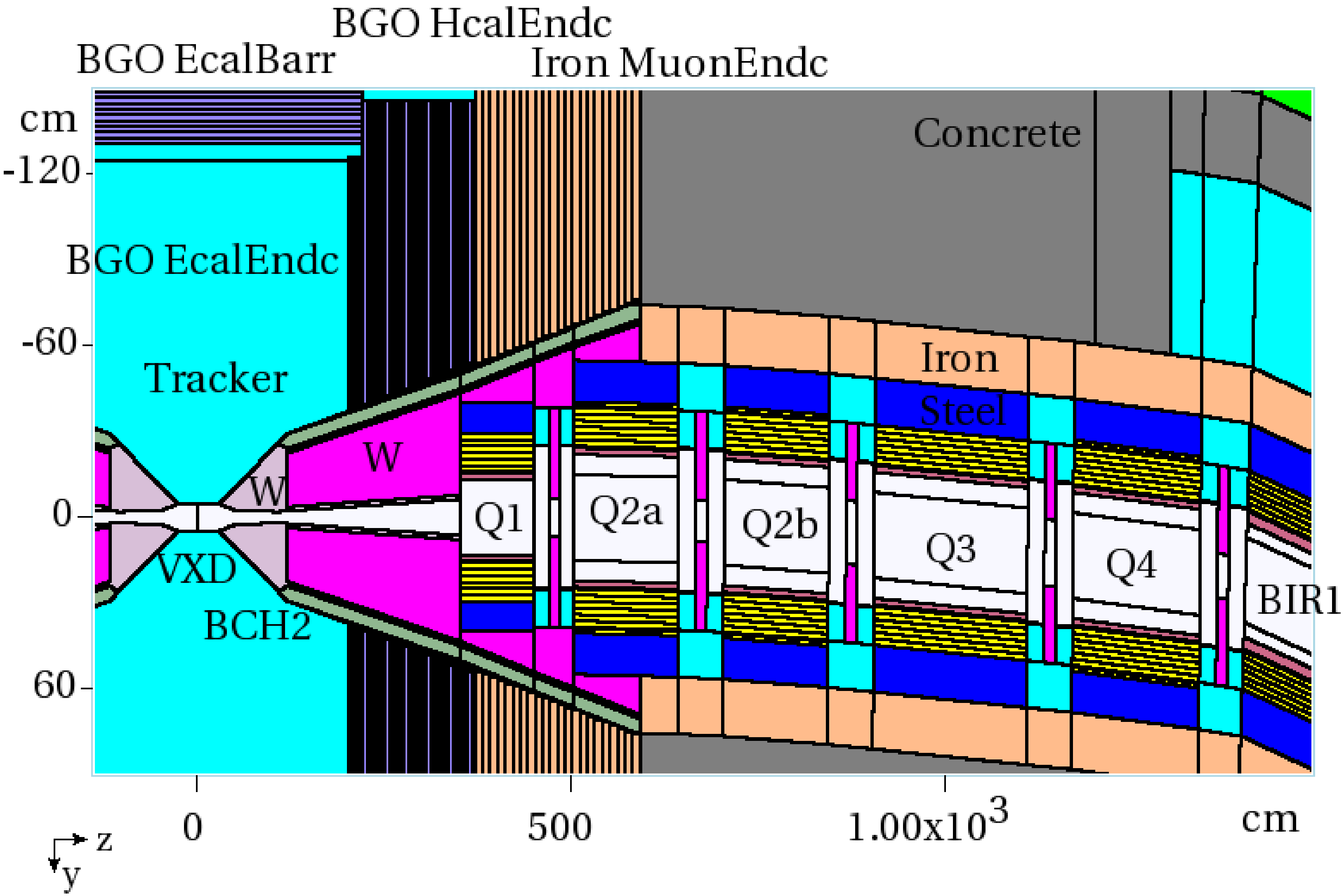
MC Higgs Factory MARS15 Model



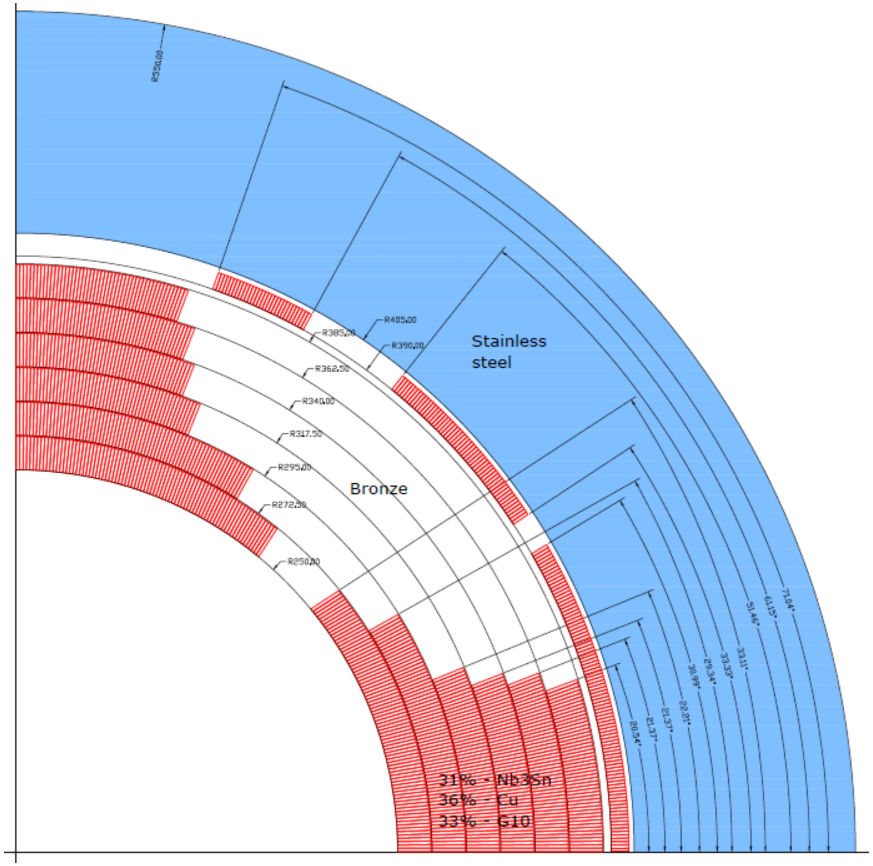


MARS model of SiD-like detector with CMS upgrade-type tracker

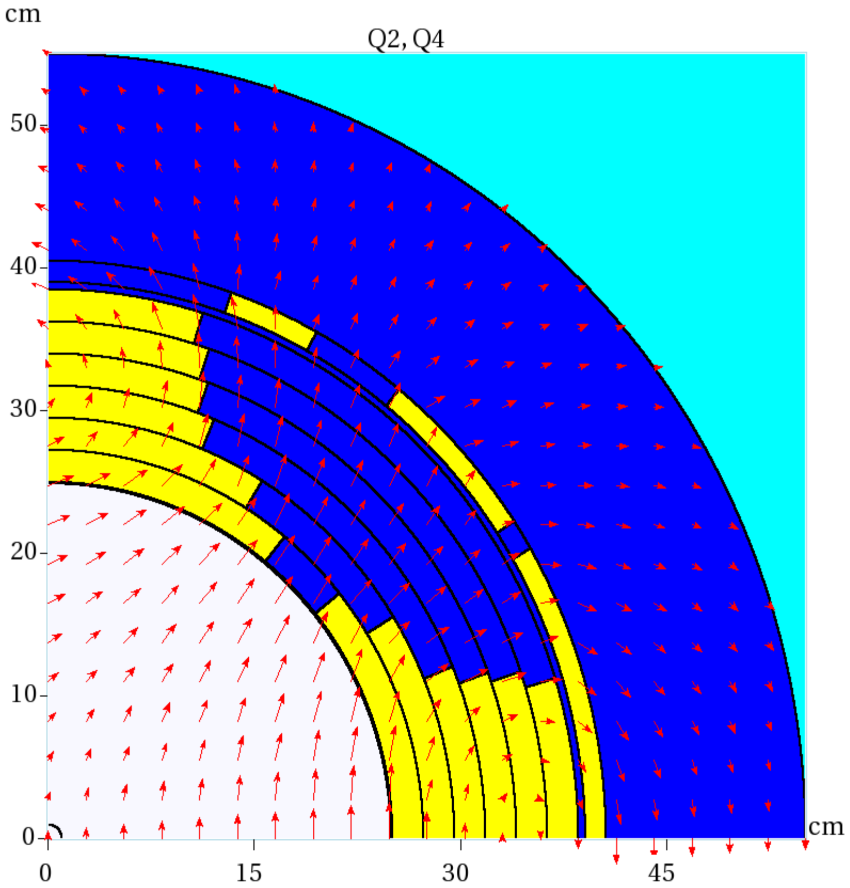
HF MDI in MARS15



50-cm ID IRQ2 and IRQ4



MARS15 Model

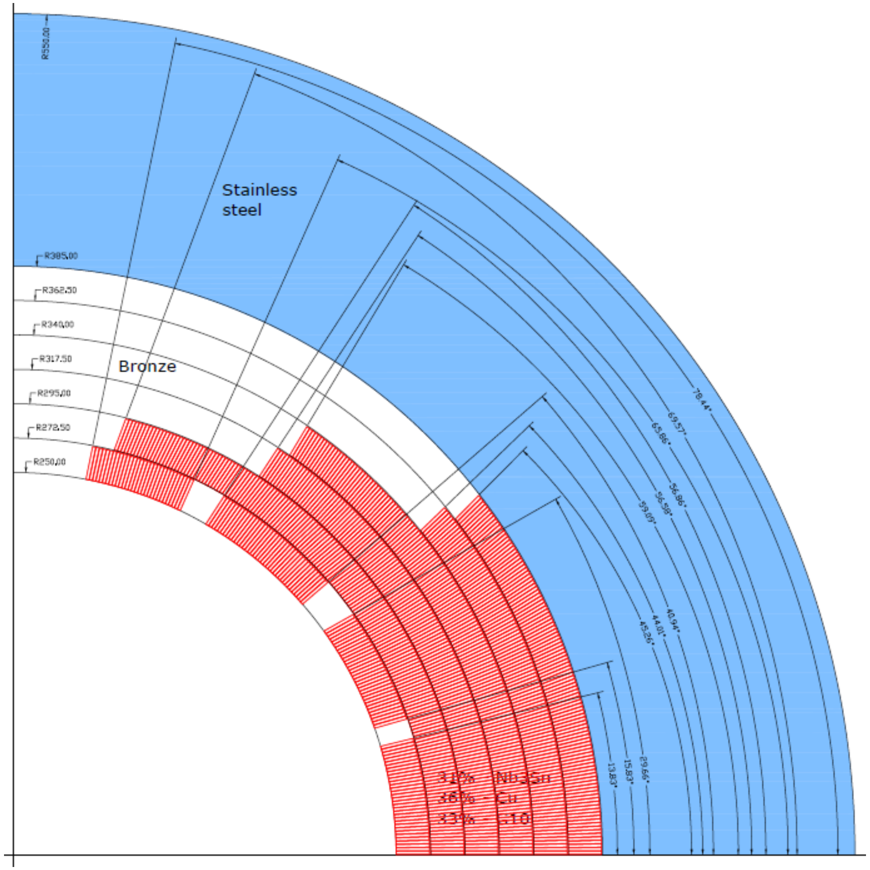


Nb$_3$Sn cos-theta **combined function** IR quadrupole Q2 and Q4 design

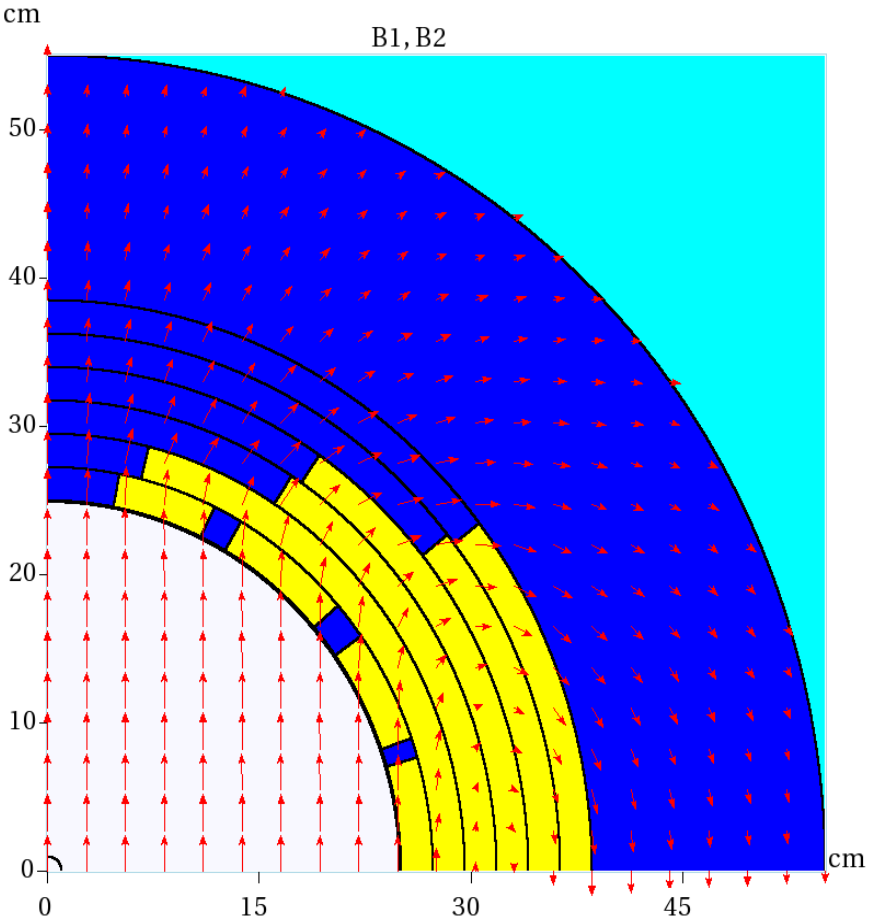
HF collider quad lengths: 0.5 ≤ L ≤ 2.05 m

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

50-cm ID 8-T IR Dipoles



MARS15 Model



HF collider dipole lengths: 2.25 ≤ L ≤ 4.1 m

HF dipole coil ID (cm) = 50 (BIR1,2), 27 (CCS) and 16 (MS and Arc)

HF Muon Decays: Background and Heat Load

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

→ **4.8×10^8 decays in IR per bunch xing responsible for majority of detector background**

3.08×10^{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

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

Note:

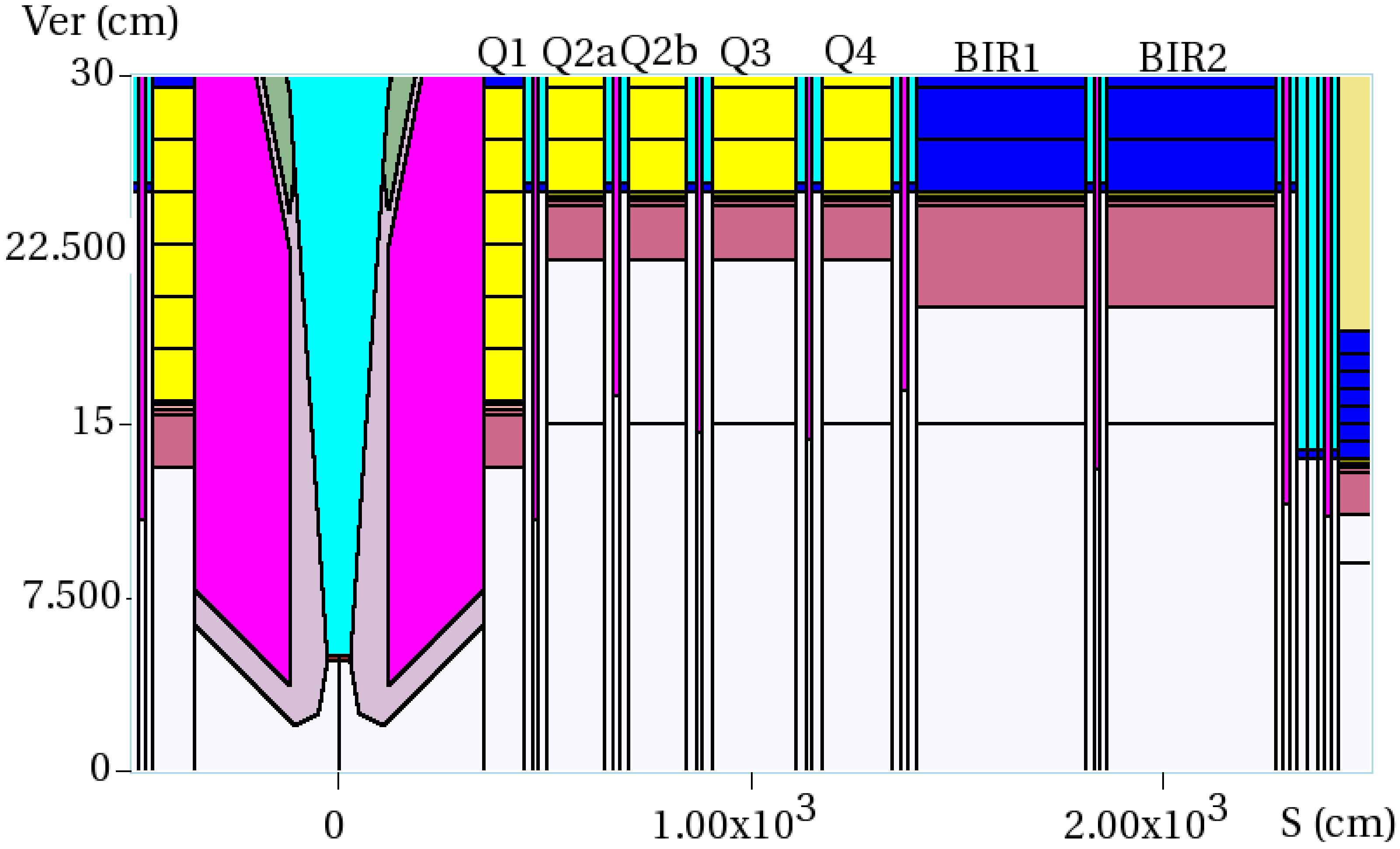
Large-aperture high-field magnets (large β_{max} and ε_t, reduced good field region) → huge physical aperture in IP vicinity → increased loads on detector

Tight Tungsten Liners and Masks

- 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 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

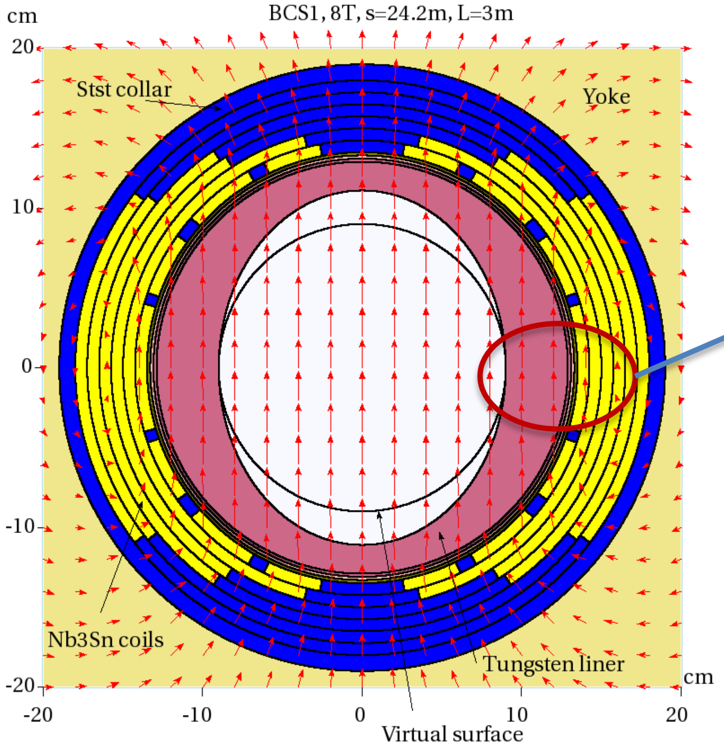
Tungsten Liners and Masks

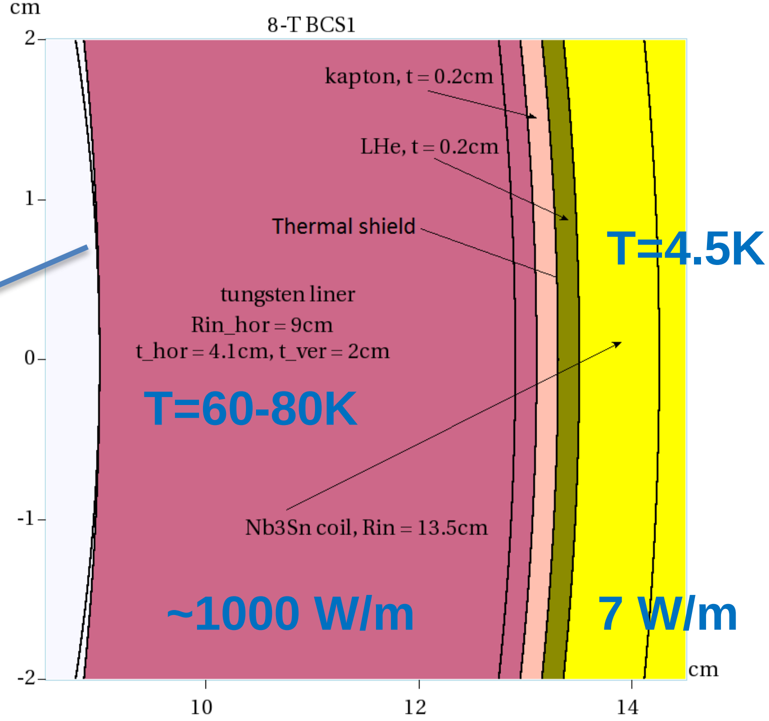
Optimized individually in each magnet in the ring



Vertical plane

BCS1 8-T Dipole with Elliptical Tungsten Liner





T=4.5K

T=60-80K

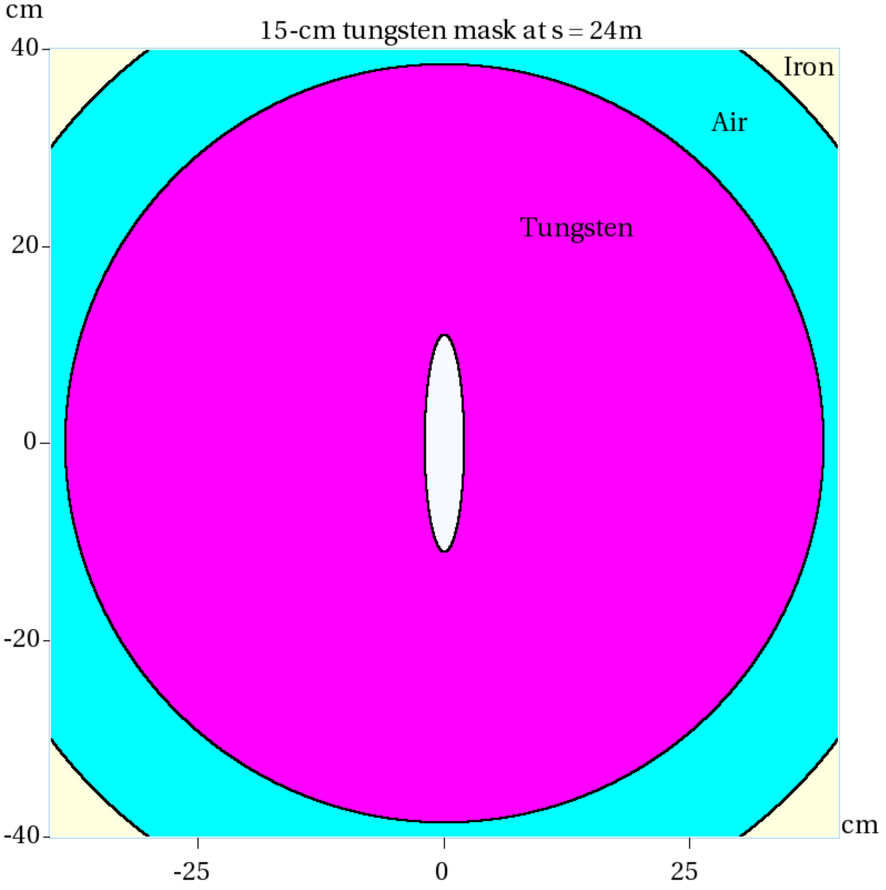
~1000 W/m

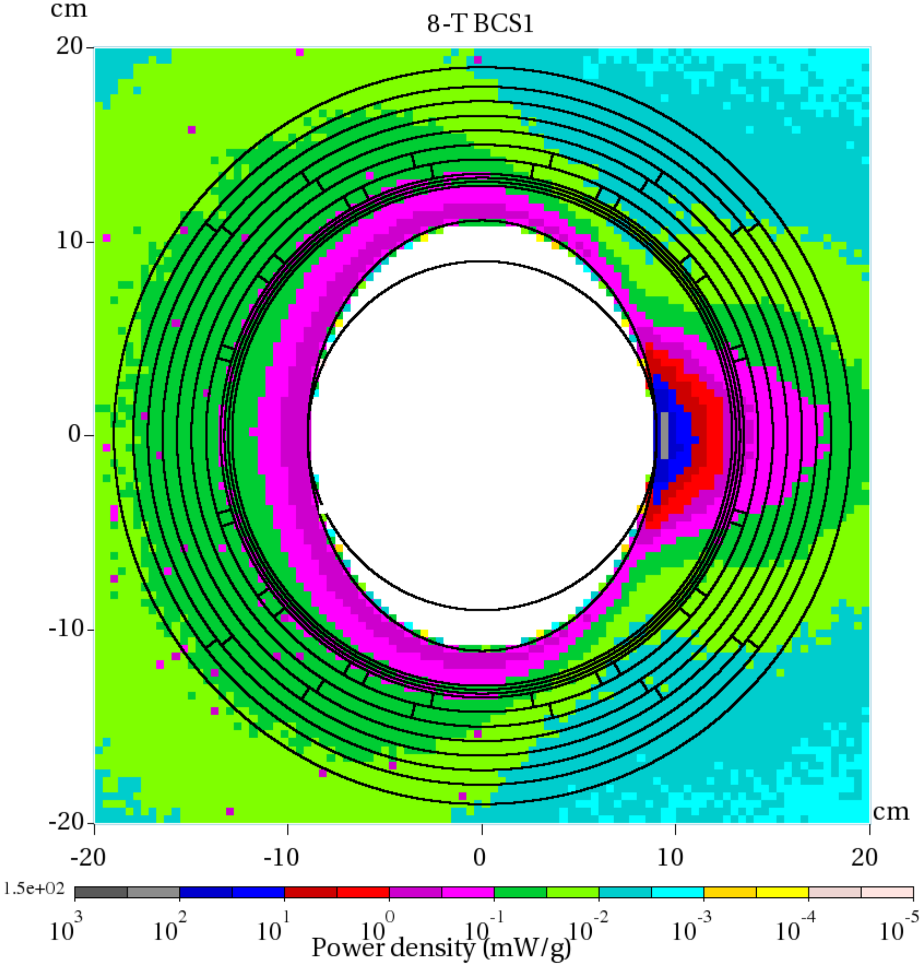
7 W/m

BCS1: Tungsten Mask and Power Density

Geometrically tightest tungsten mask (L = 15cm)
at the IP end of BCS1 dipole

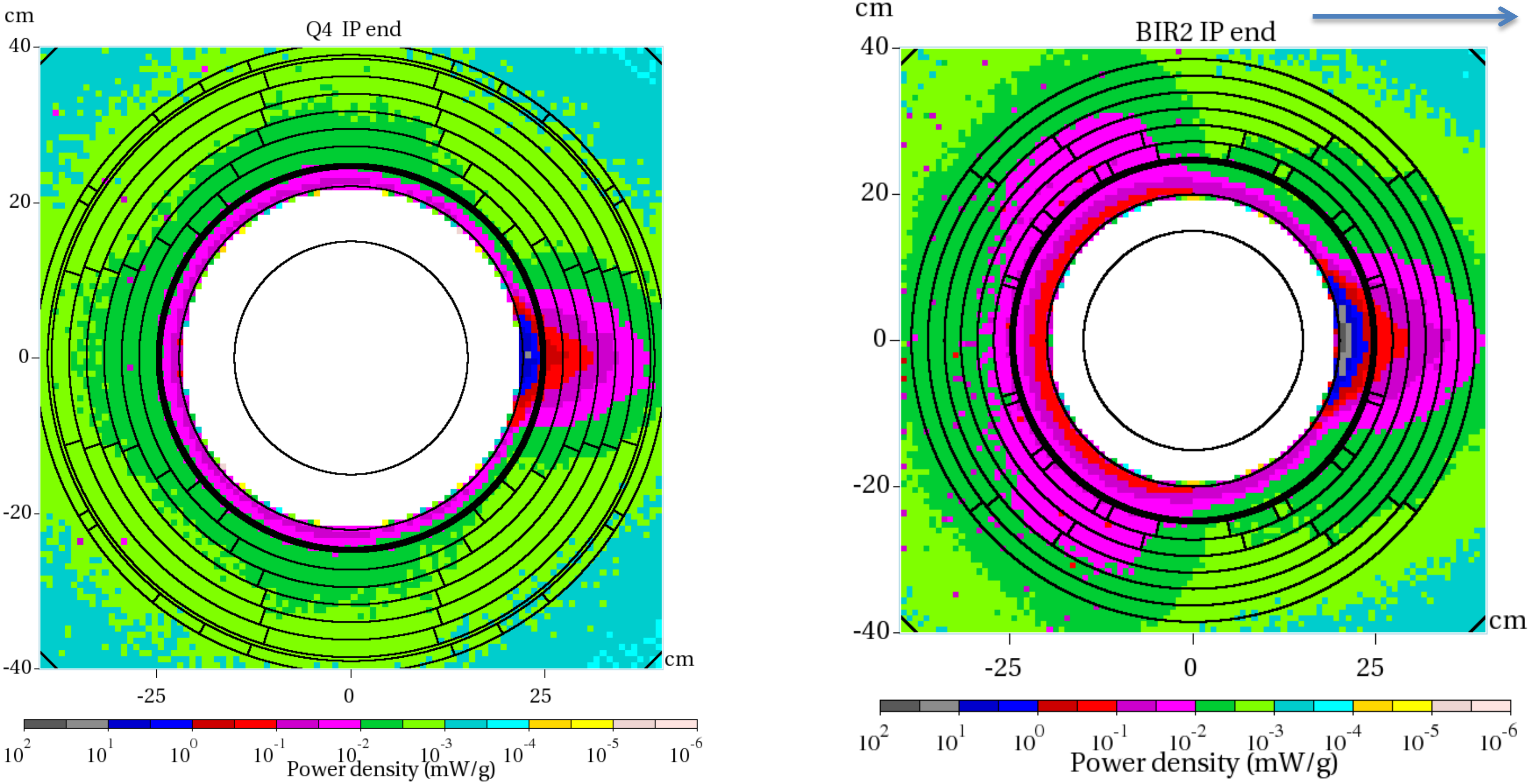
Ring center →





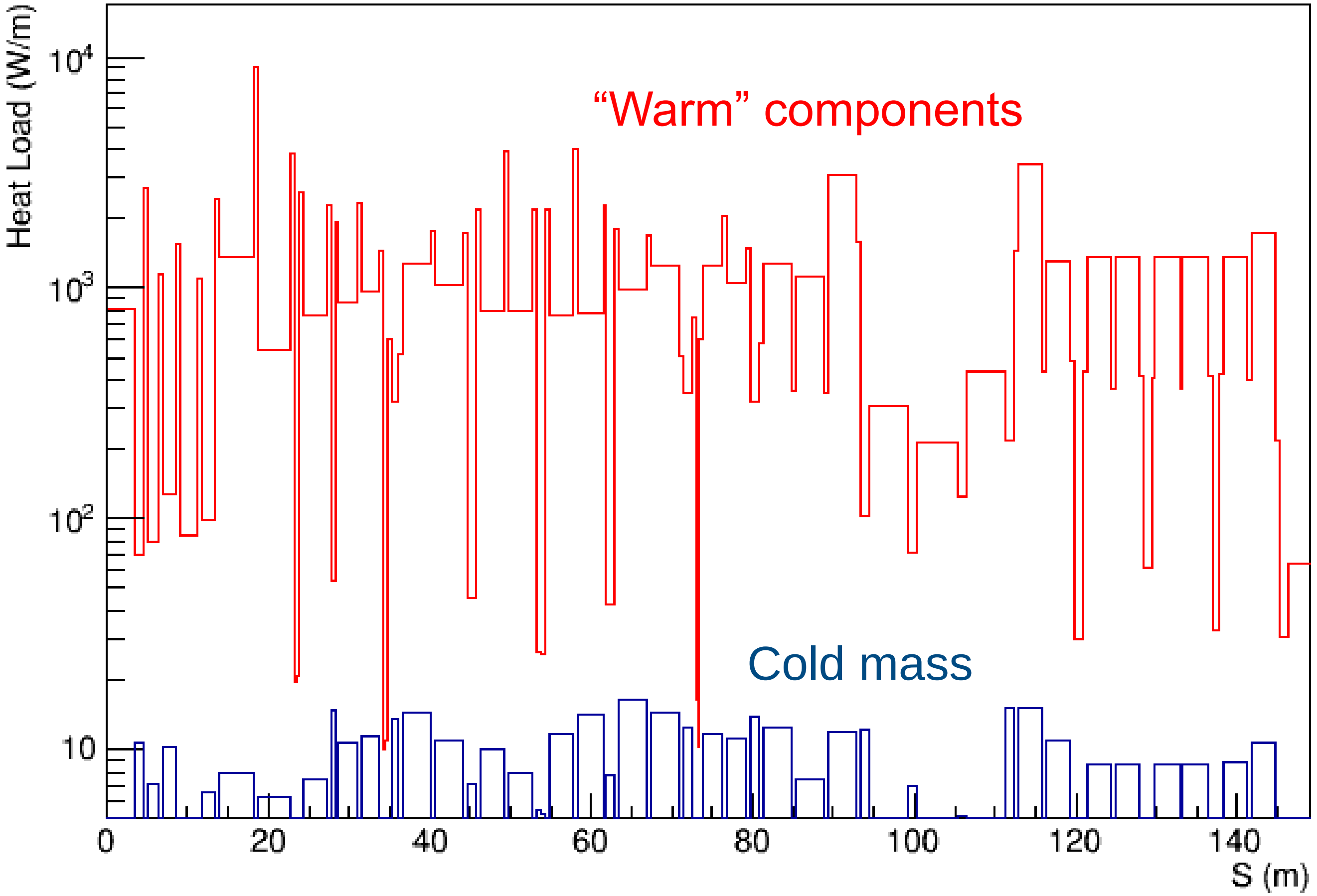
Optimized individually for each magnet interconnect region in the ring

Peak Power Density in SC Coils



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

Dynamic Heat Load on Cold Mass

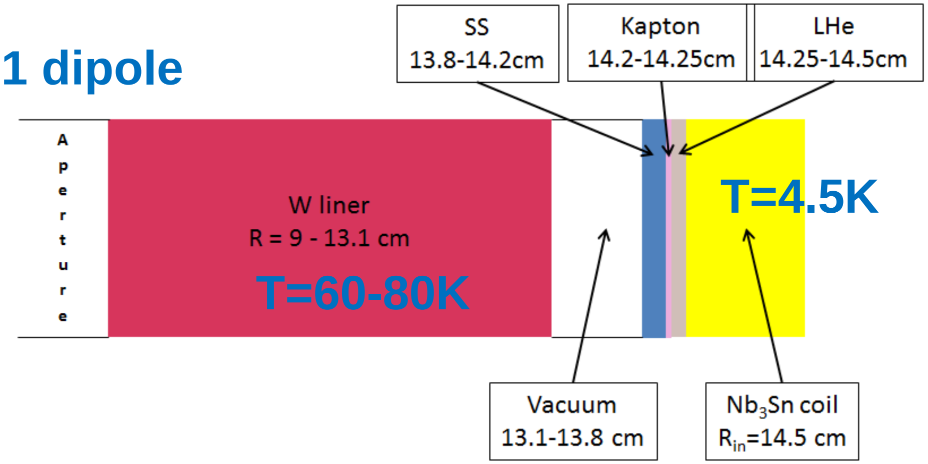


Design goal is met: 1000 W/m ⟶ ~10 W/m

Two Developments Since Winter 2014' MuPAC and DOE Reviews

1. Liner: Towards engineering design (A. Zlobin)

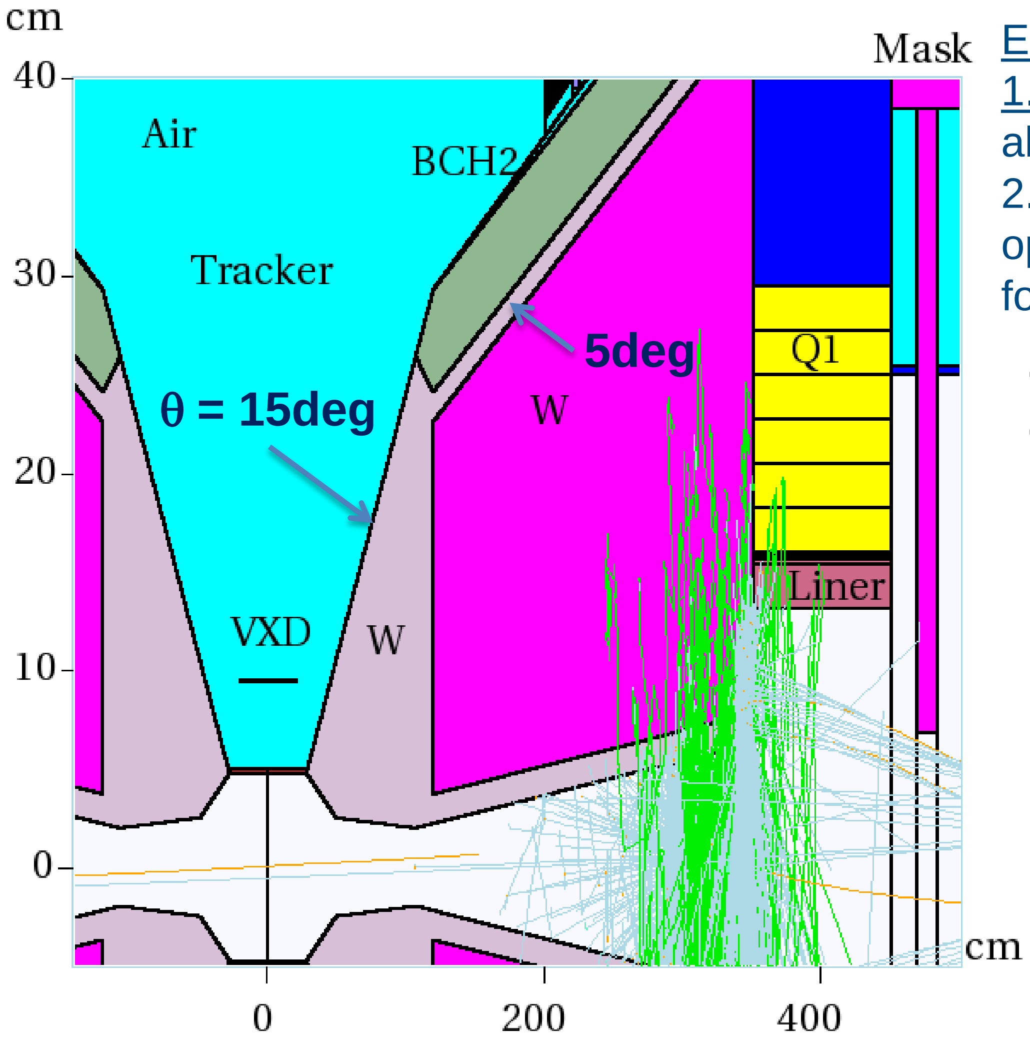
Example: BCS1 dipole



2. Resistive wall impedance and beam stability (A. Burov)

- **Transverse plane:** a few percent of growth of an initial perturbation after 1000 turns, so there is a safety factor about one hundred for the transverse plane instabilities.
- **Longitudinal plane:** one should expect up to ~30% of the energy widening. This effect could be probably reduced by means of the second harmonic RF.

Higgs Factory Nozzle Design



Expect poorer performance compared to 1.5-TeV MC: geometrically larger aperture, almost twice shorter, substantially thinner, 2.5 times shorter trap and 3.5 longer tip-to-tip open region ($\pm 2\sigma_z$ plus no extra shadowing for collision products)

A dozen of configurations studied in full MARS Monte-Carlo:

V1. θ = 7.6deg, aperture radius R = 5σ, bare tungsten (UCLA HF WS, 03/13)

V2. θ = 15deg, aperture radius R = 4σ, BCH2 cladding (MAP13, 06/13)

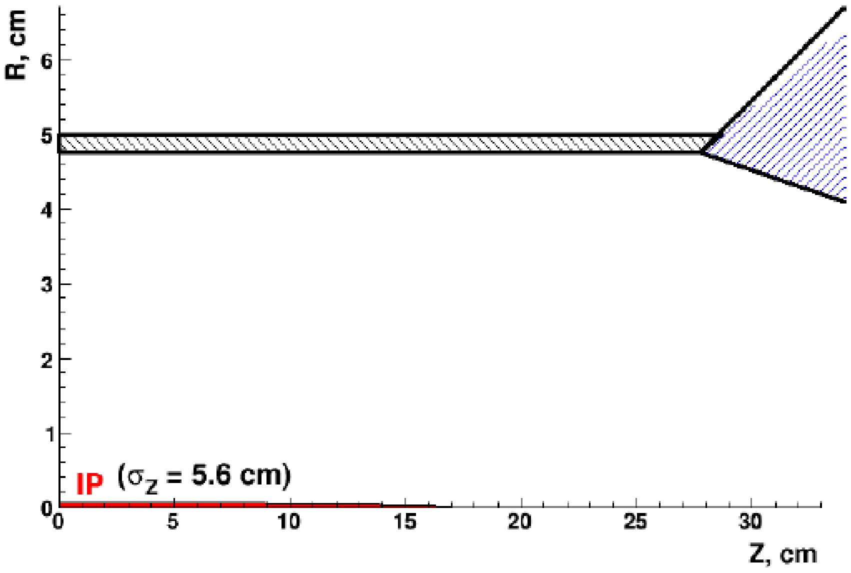
...

Be pipe radius increased from 3 to 5cm, thoroughly optimized nozzle inner shape, additional W/Fe/Concrete shielding at MDI, tighter/thicker masks and magnet inner absorbers (liners)

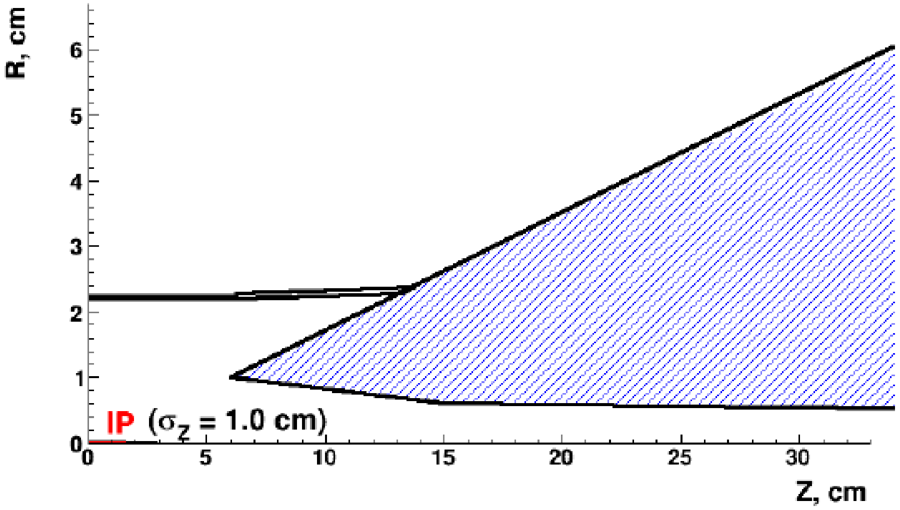
…

V7x2s4. Winter-Spring 2014

Nozzle: 125-GeV HF *vs* 1.5-TeV MC



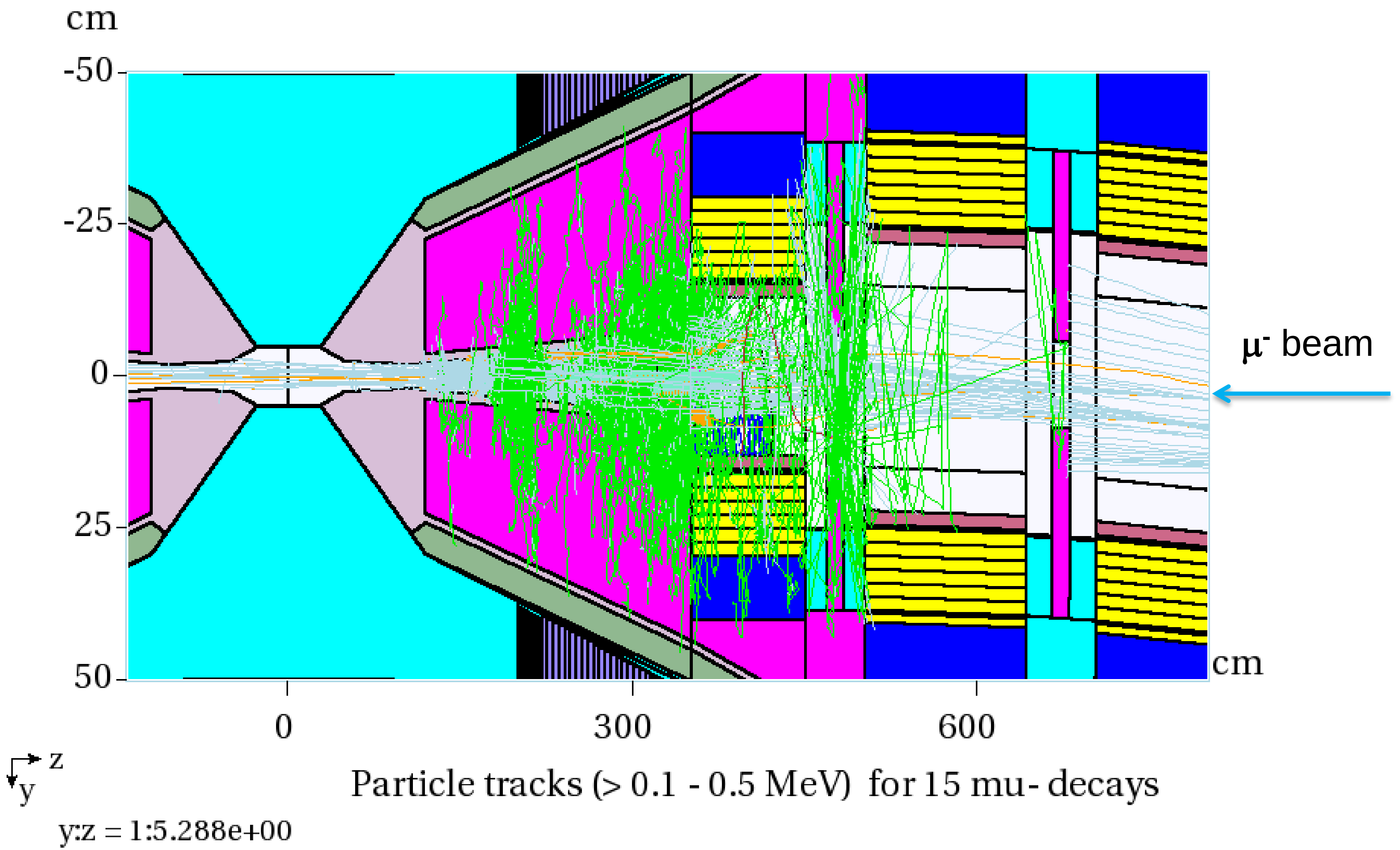
15^0 nozzle, HF MC



10^0 nozzle, 1.5 TeV MC

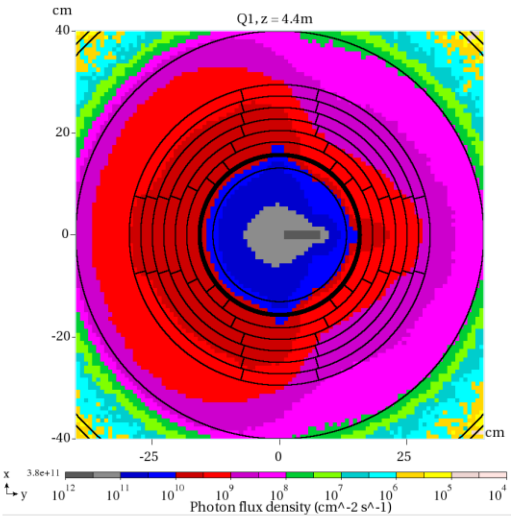
- Distance between tips ~5 times larger (due to σ_z)
- Aperture: R=1.95cm at z=108cm and R=6.34cm at z=350cm (HF) *vs* R=0.3cm at z=100cm and R=1.78cm at z=600cm (1.5 TeV MC)
- Occupies: 30 < z < 350 cm (HF) *vs* 6 < z < 600 cm (1.5-TeV MC)
- Beam-pipe radius ~ 2 times larger

HF MDI Design Efficiency Visually

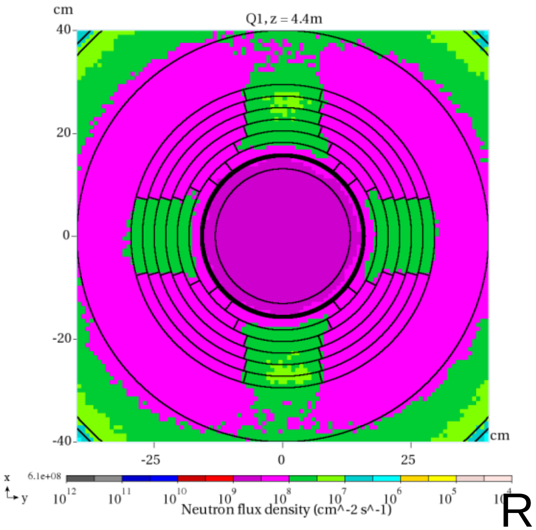


Particle tracks (> 0.1 - 0.5 MeV) for 15 mu- decays

Particle Flux and Power Density in Q1 at z = 4.4m

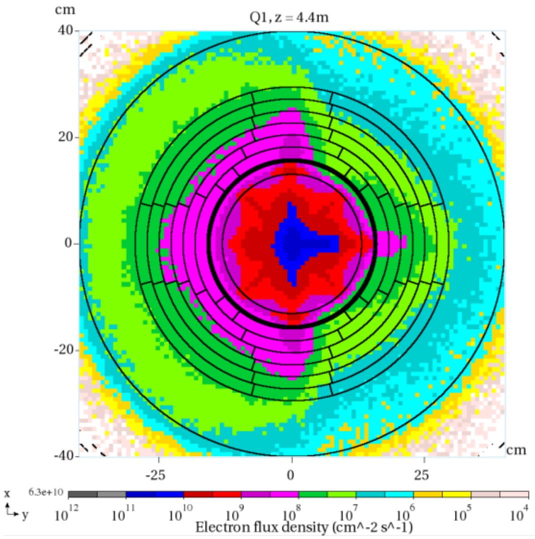


γ

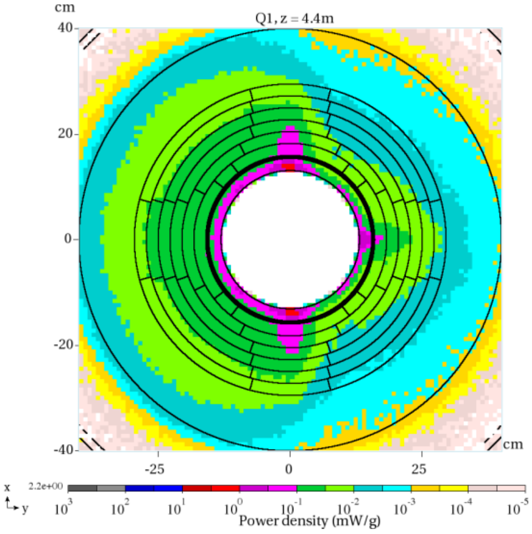


n

Ring center

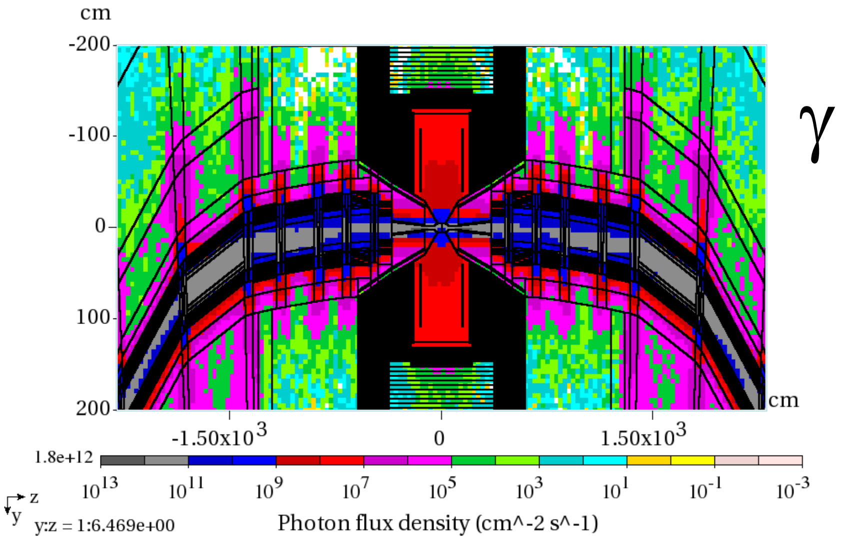


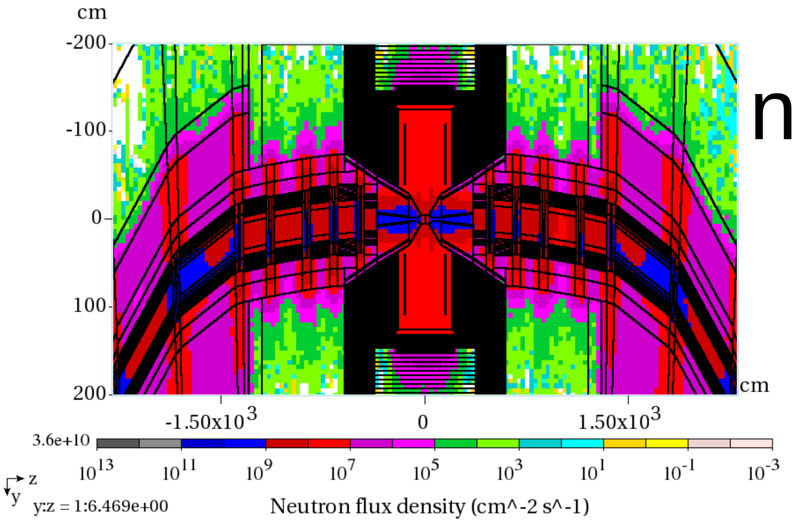
e±

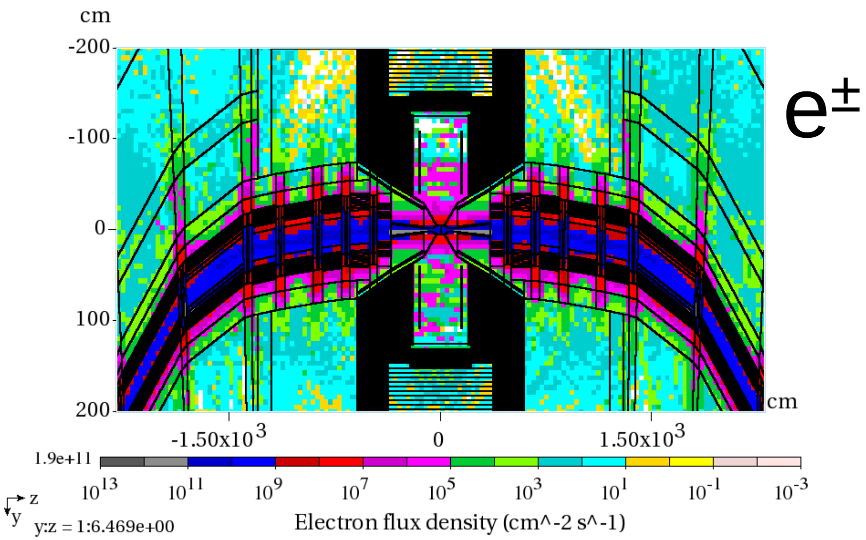


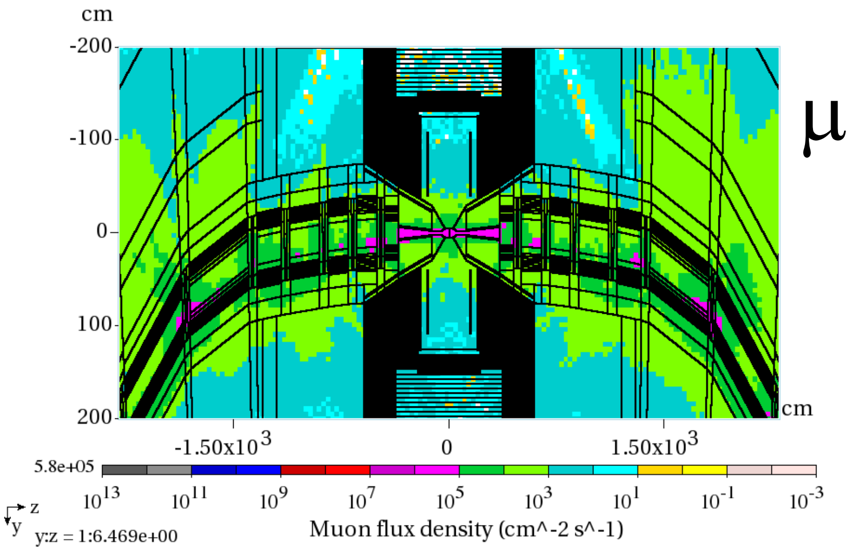
mW/g

MDI Particle Flux Density

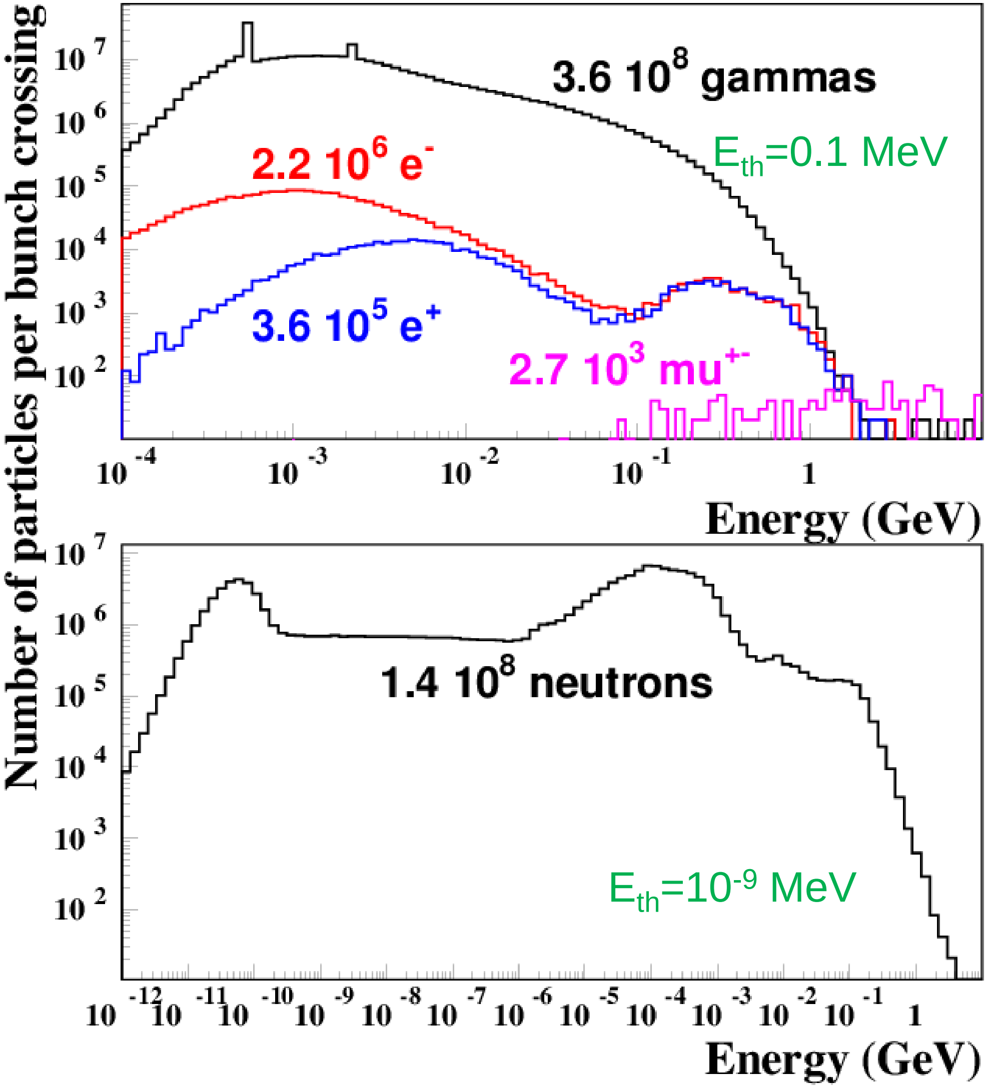








Feeding Detector Community



To feed detector simulation community, typical background source terms at the MDI surface are generated in MARS15 runs for a few % of a bunch crossing.

For a full HF bunch crossing, one needs about 14,000 core-days and up to 100 GB of disk storage space.

Particle Backgrounds Entering Detector

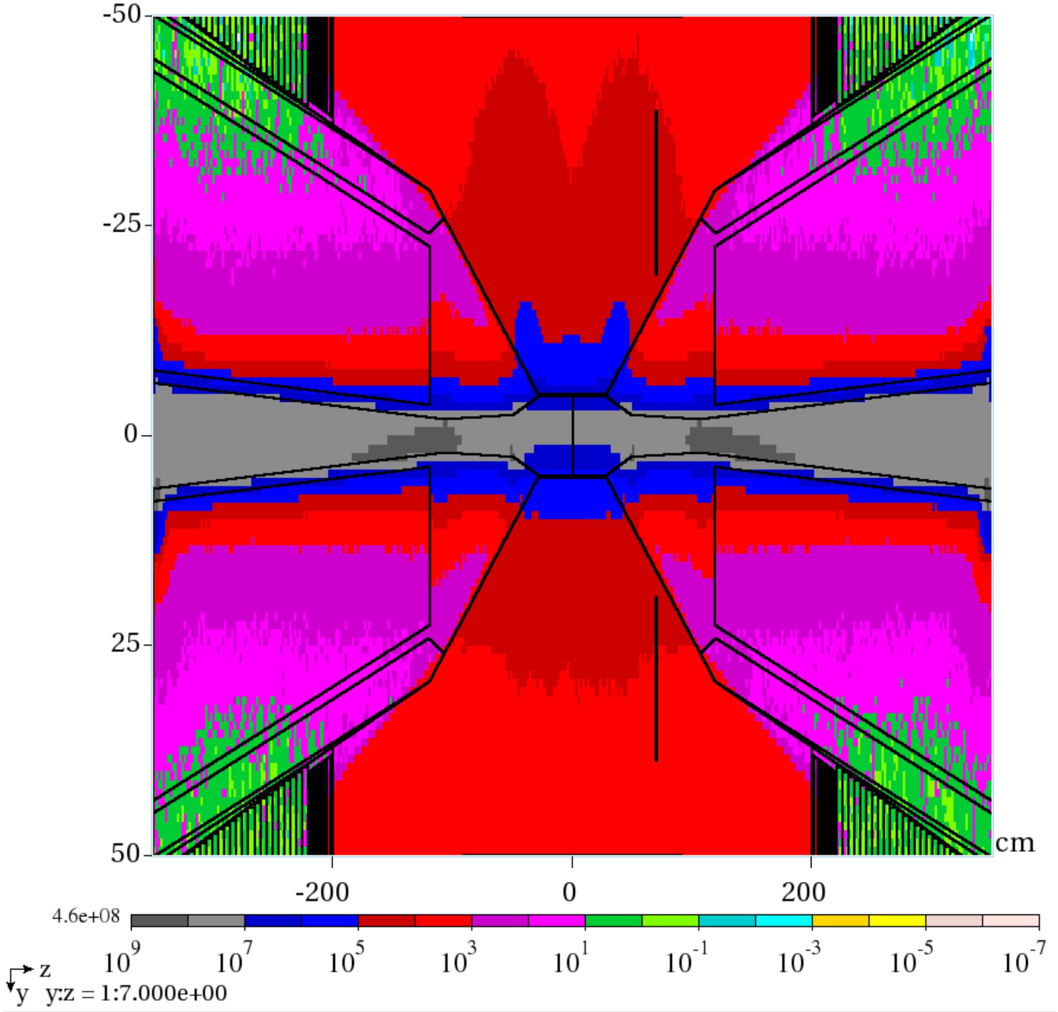
Number of particles **N** (E > 0.1-1 MeV) and energy flux **E** (TeV) entering detector per bunch crossing

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 <E>=0.9 MeV	12000	2200 <E>=8 MeV
Electron	**N**	1.0×10^6	1.2×10^8	2.0×10^6
	E	5.8 <E>=6 MeV	9000	32 <E>=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 <E>=23 GeV		8.2 <E>=3 GeV

~1/50

Photon Fluence at IP

v7x2s4

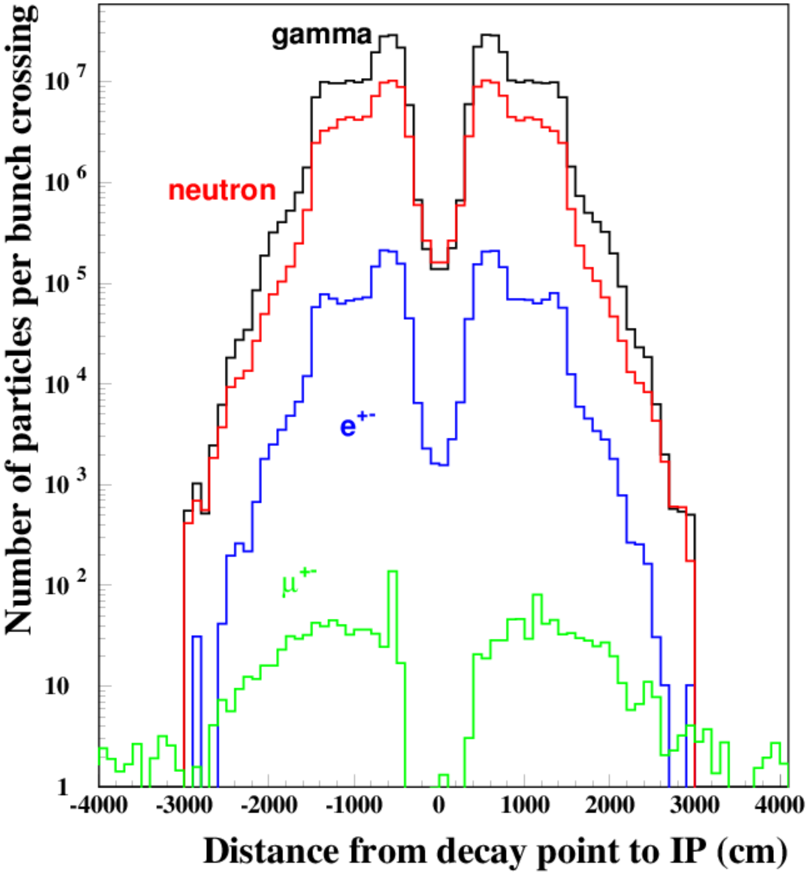


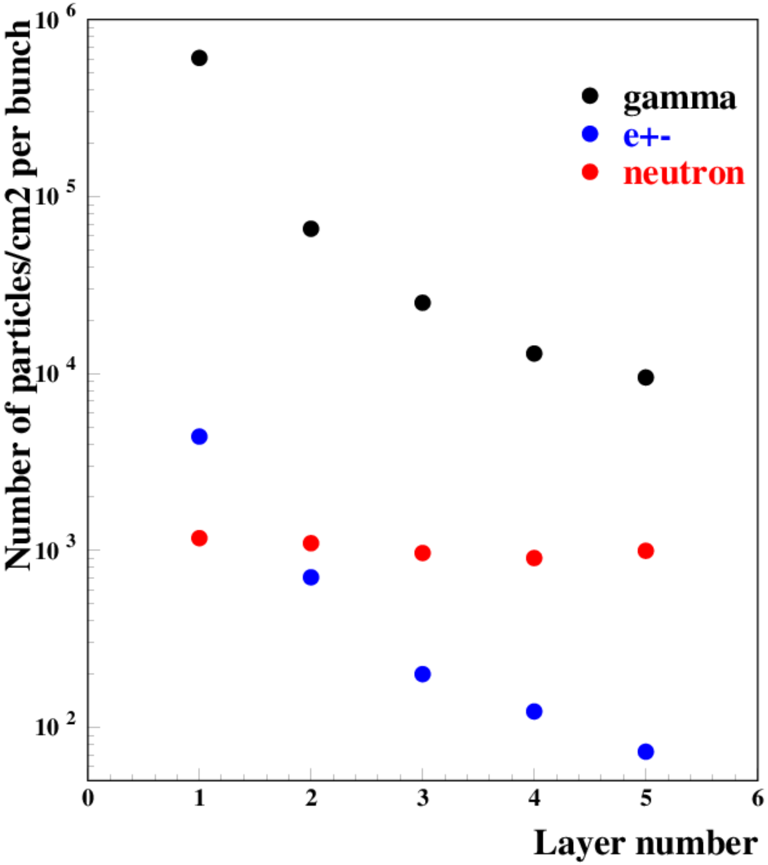
Ring center

Photon fluence (cm^{-2}) per bunch crossing

Tagged Decays; Loads on VXD Barrel

v7x2s4: >10 peak reduction for γ and e± compared to v2





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

Background Rejection in VXD and Tracker

Carnegie Mellon University studies with ILCroot4MuC-4.1.0 and Geant4-9.8.01 using MARS source files

With the MDI fully optimized for minimization of background loads, timing is the main way to reject the remaining background rates in the detector components. Inefficiency of IP muon hits and surviving fraction of MARS background particle hits in VXD and Tracker Si detectors were studied versus width of timing gate for the hit time resolution of 0.5 ns for both 1.5-TeV MC and HF.

For example, the 4-ns gate provides a factor of hundred or more background rejection while maintaining >99% efficiency for hits from IP muons.

Use of energy deposition threshold of ~20-50 keV improves rejection by additional factor of 2. The double-layer criteria based on the hit cluster concept are currently studied.

(Post-P5) MDI Plans

Higgs Factory:

- Upgrade the unified MARS model with new engineering constraints in magnets, improved timing and hit scoring algorithms.
- Re-run MARS for magnet protection & background files and perform studies on background rejection in detector components.
- Document results on magnet protection and detector backgrounds.

3-TeV Muon Collider:

- Complete building MARS model of collider, magnets and MDI. Perform initial studies of heat loads and detector backgrounds. Document results.

TBD:

- Refocus MDI effort to energy deposition studies on Front End and muon acceleration.