Design and Simulation of $\mu^+\mu^-$ Higgs Factory Machine-Detector Interface

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Muon Accelerator Program
Collaboration Meeting (MAP13)
Fermilab
June 19-22, 2013

Outline

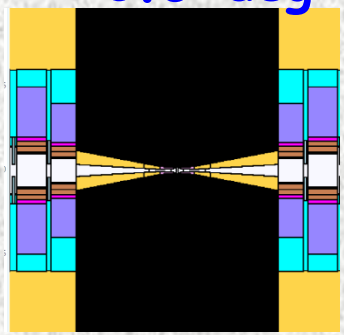
- Decay Related Rates in IR and Detector
- Code Improvements
- IR Magnets and Lattice MARS Models
- Improved MDI Design
- HF Detector Backgrounds
- Energy Deposition in IR Magnets
- Conclusions

Machine Background Load to 1.5-TeV MC Detector

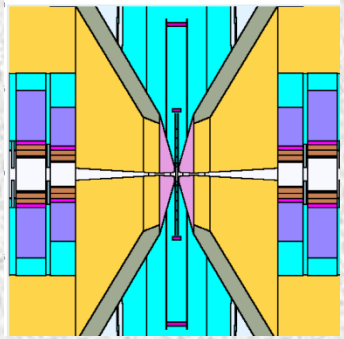
MARS-calculated total number of particles per bunch crossing entering detector

Particle	Minimal 0.6-deg	10-deg
Photon	1.5×10^{11}	1.8×10^{8}
Electron	1.4×10^{9}	1.2×10^{6}
Muon	1.2×10^{4}	3.0×10^{3}
Neutron	5.8×10^{8}	4.3×10^{7}
Charged hadron	1.1×10^{6}	2.4×10^{4}

0.6-deg



10-deg



No time cuts here

X:Z=1:20

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

HF Muon Decays: Backgrounds and Heat Loads

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

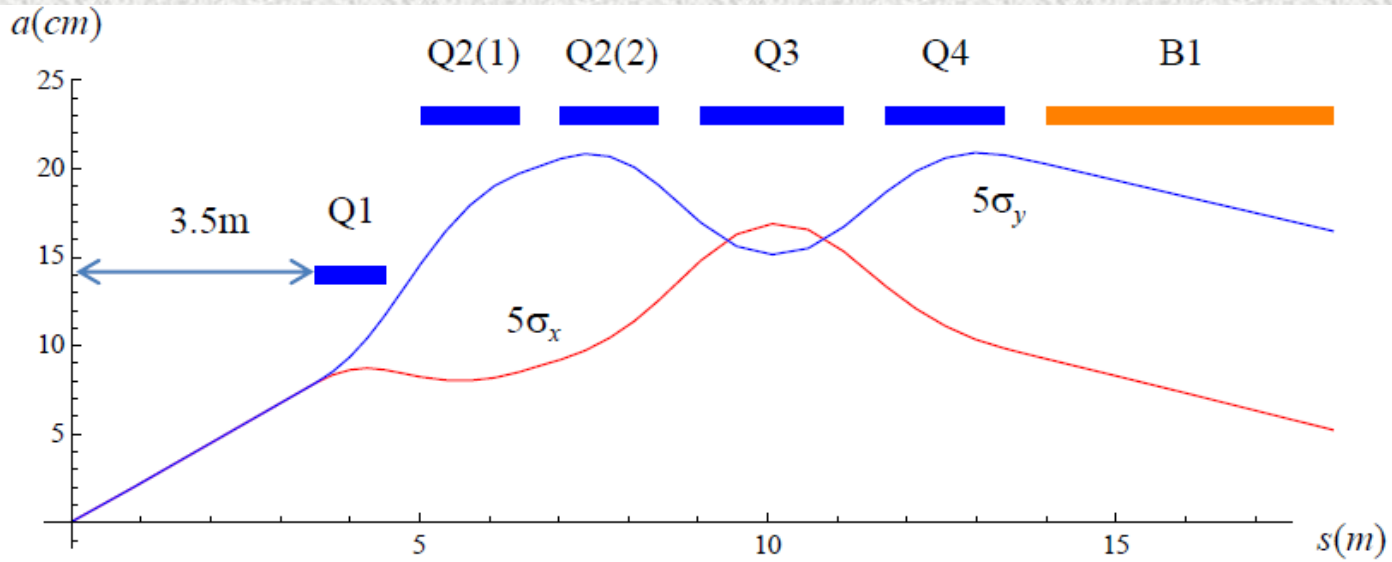
HF Detector Related Code Developments

- MARS15 Low-energy electromagnetic physics description improved and extended; as a result, e/γ minimal energy can now be as low as 1 keV (compared to previous 200 keV), same as for charged hadrons, muons and heavy ions; minimal neutron energy is 0.001 eV.

- Inclusive, hybrid and exclusive modeling of all physics process in MARS15. The latter provides "unity-weight" option.

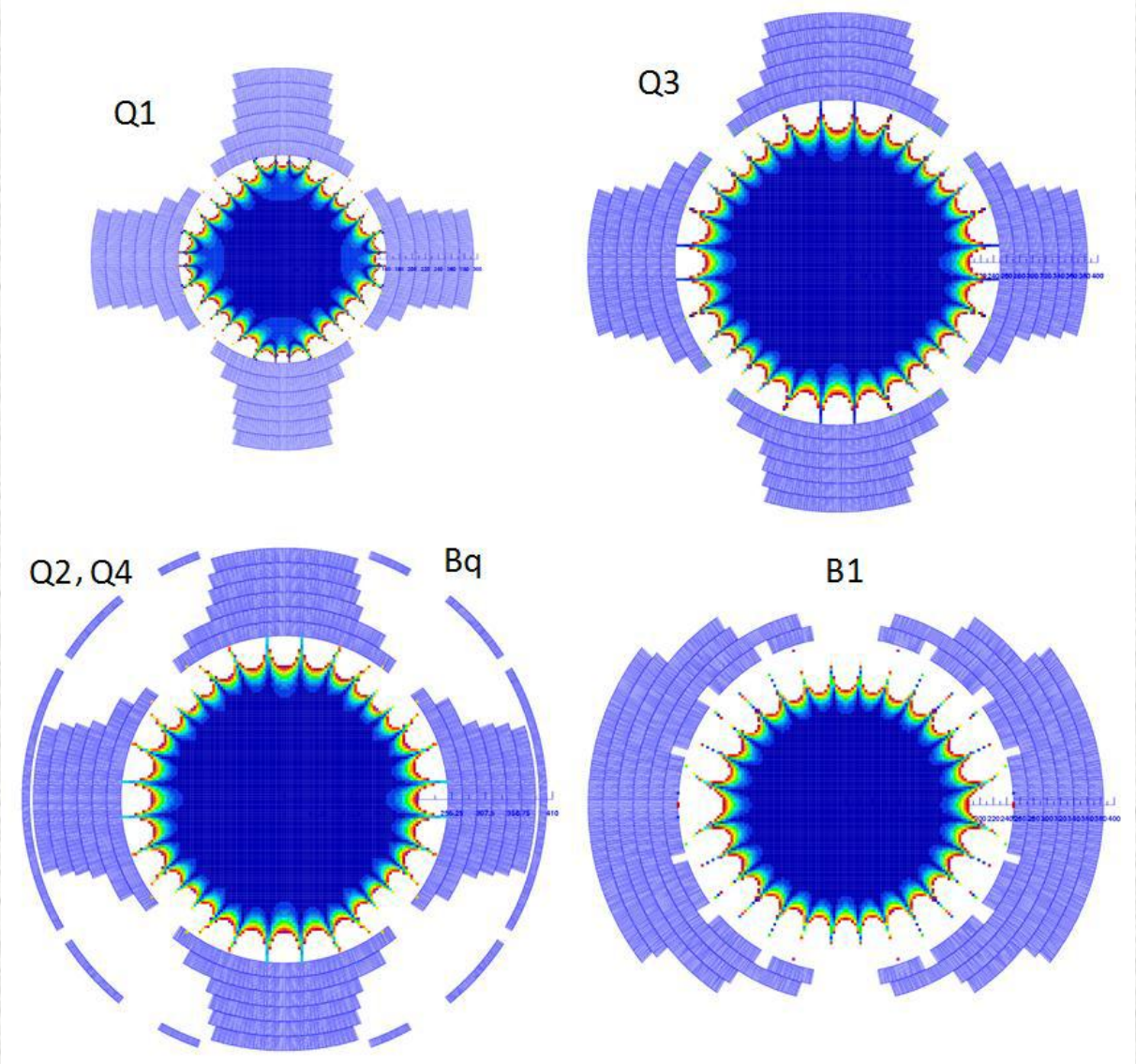
- ROOT geometry and visualization implemented to MARS15; import & export of GDML geometries; lcsim SiD implemented to a unified HF IR/MDI/detector MARS model, with lcsim stdhep files converted to aida and ROOT formats; new ROOT-MAD-MARS Beam Line Builder.

HF Final Focus

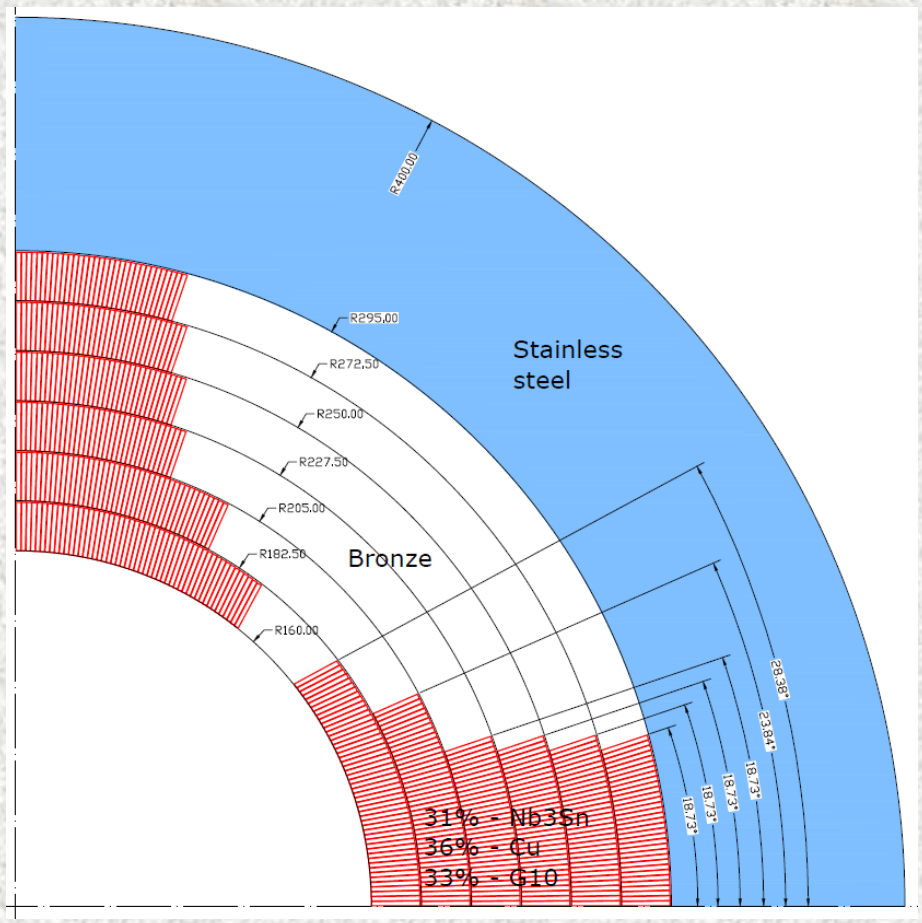


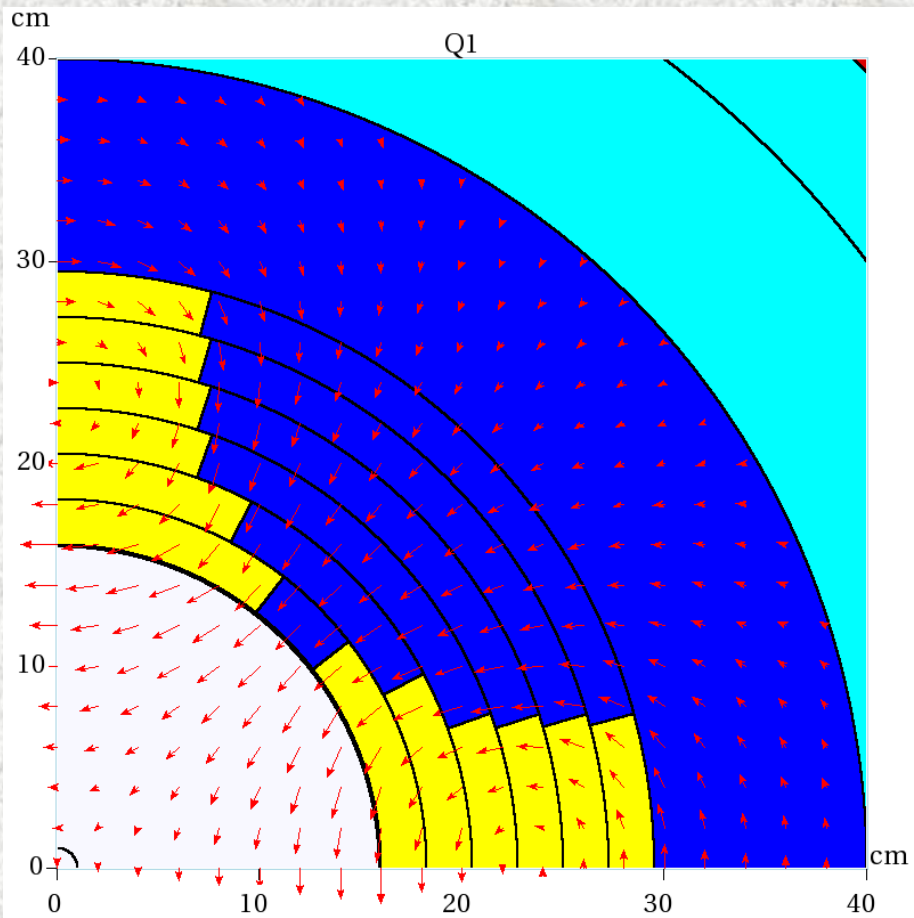
	Q1	Q2	Q3	Q4	B1
aperture (cm)	27	45	45	45	45
gradient (T/m)	74	-36	44	-25	0
dipole field (T)	0	2	0	2	8
length (m)	1.0	1.4	2.05	1.7	4.1

HF IR Magnets



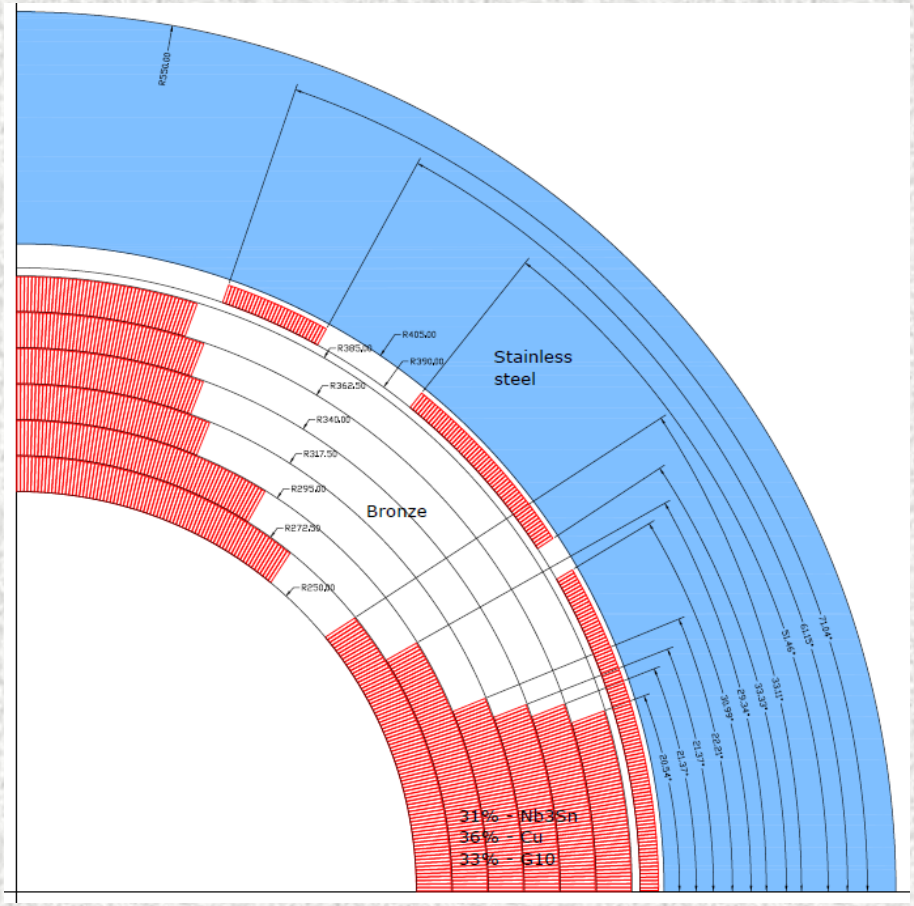
320-mm IRQ1 MARS15 Model

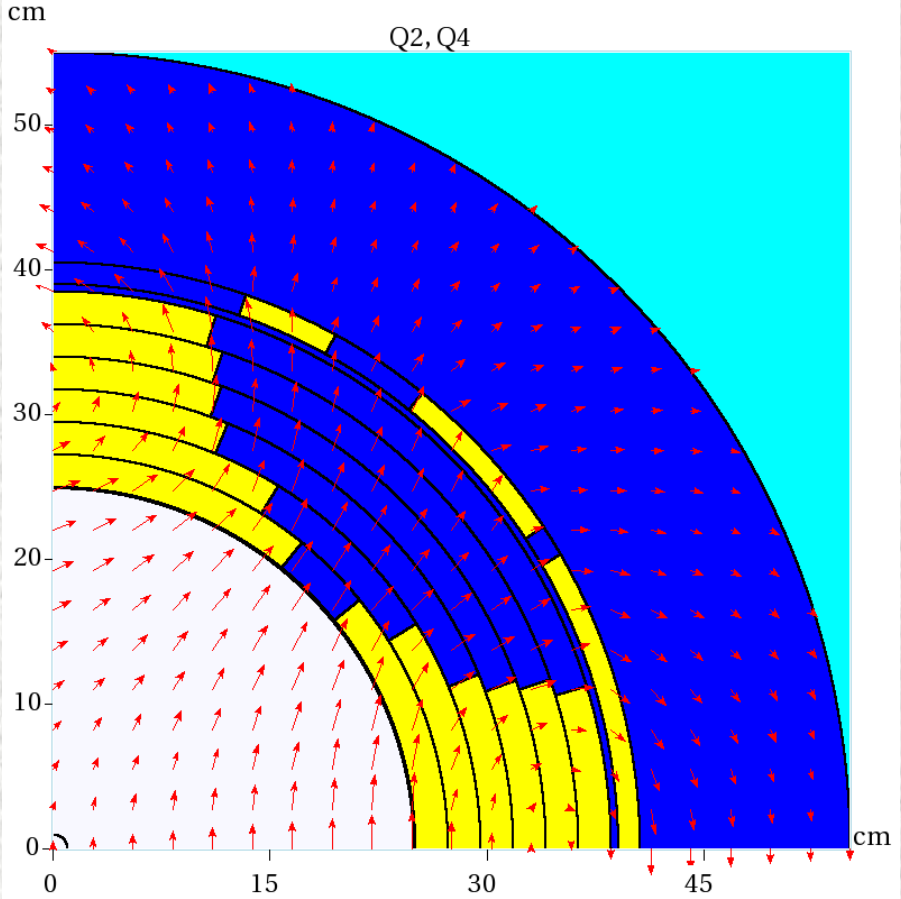




Nb_3Sn cos-theta 74 T/m IR quadrupole design

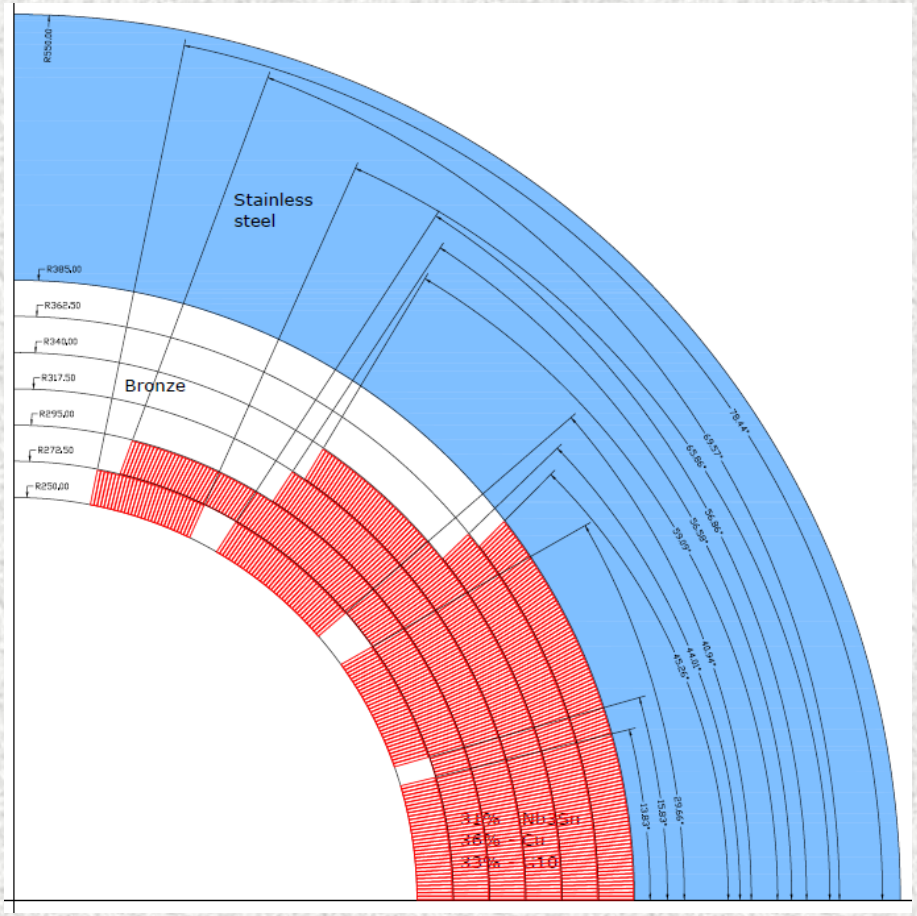
500-mm IR Q2 and Q4 MARS15 Model

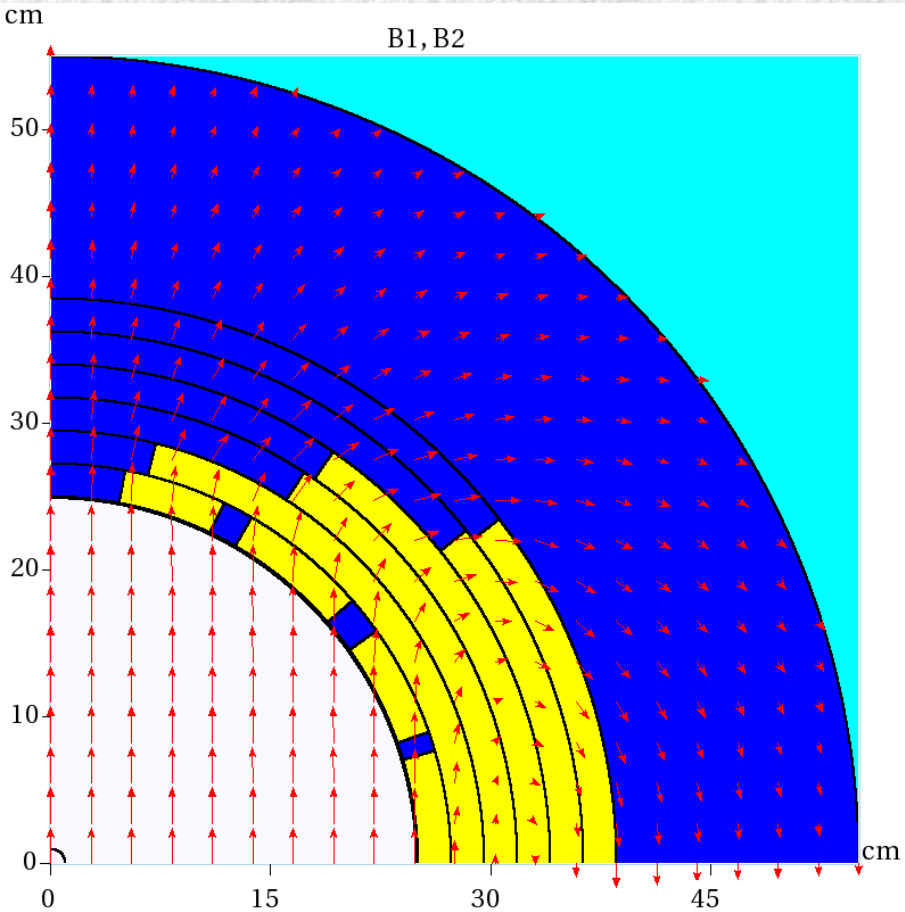




Nb_3Sn cos-theta combined function IR quadrupole design.

500-mm 8-T B1 and B2 Dipole MARS15 Model





HF Nozzle Design

Design principles

1. Inner aperture: 5σ radius
2. Minimal outer angle θ without overlap with tracker and calorimeter
3. Tip-to-tip: $\pm 2\sigma_z$ plus no extra shadowing for collision products
4. Minimal trap, both longitudinally and laterally
5. BCH_2 cladding in V2.

HF: Almost twice shorter, substantially thinner, 3.5 longer tip-to-tip open region and 2.5 times shorter trap compared to the 1.5-TeV MC design:
Expect poorer performance!

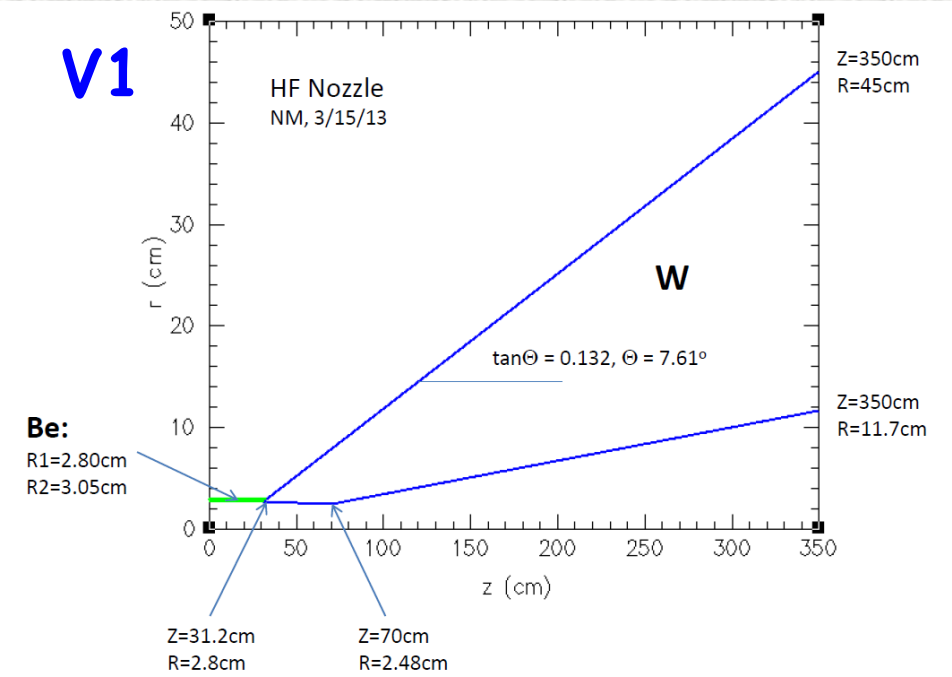
Two HF MDI Versions Considered So Far

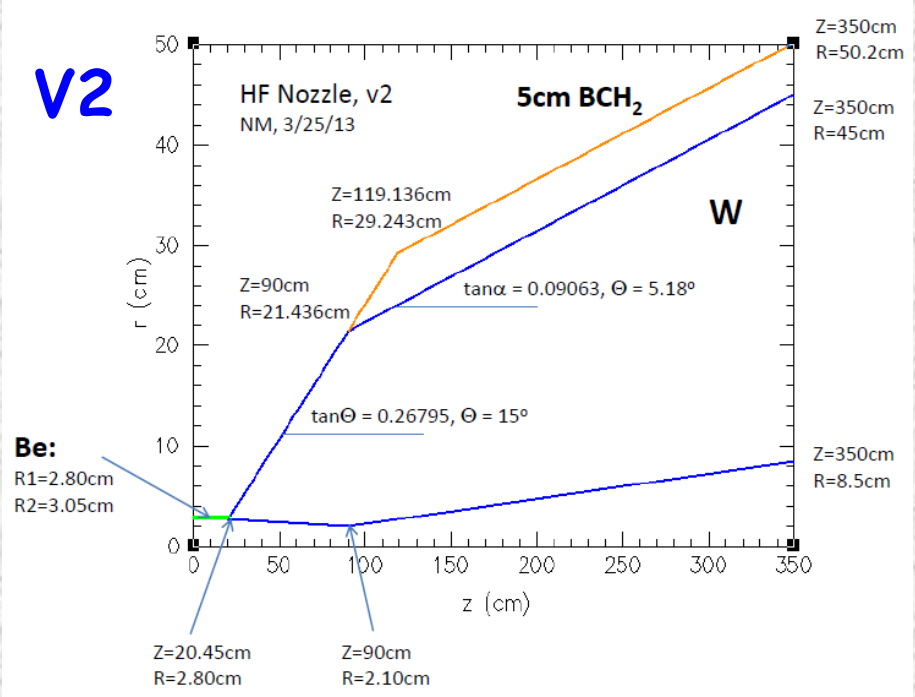
V1: Minimal 7.6-deg, 5σ aperture radius, bare tungsten nozzles, results presented at UCLA HF workshop, March 2013.

V2: Thicker/tighter 15deg/4σ optimized tungsten nozzles in BCH_2 cladding, presented at MAP13, June 2013.

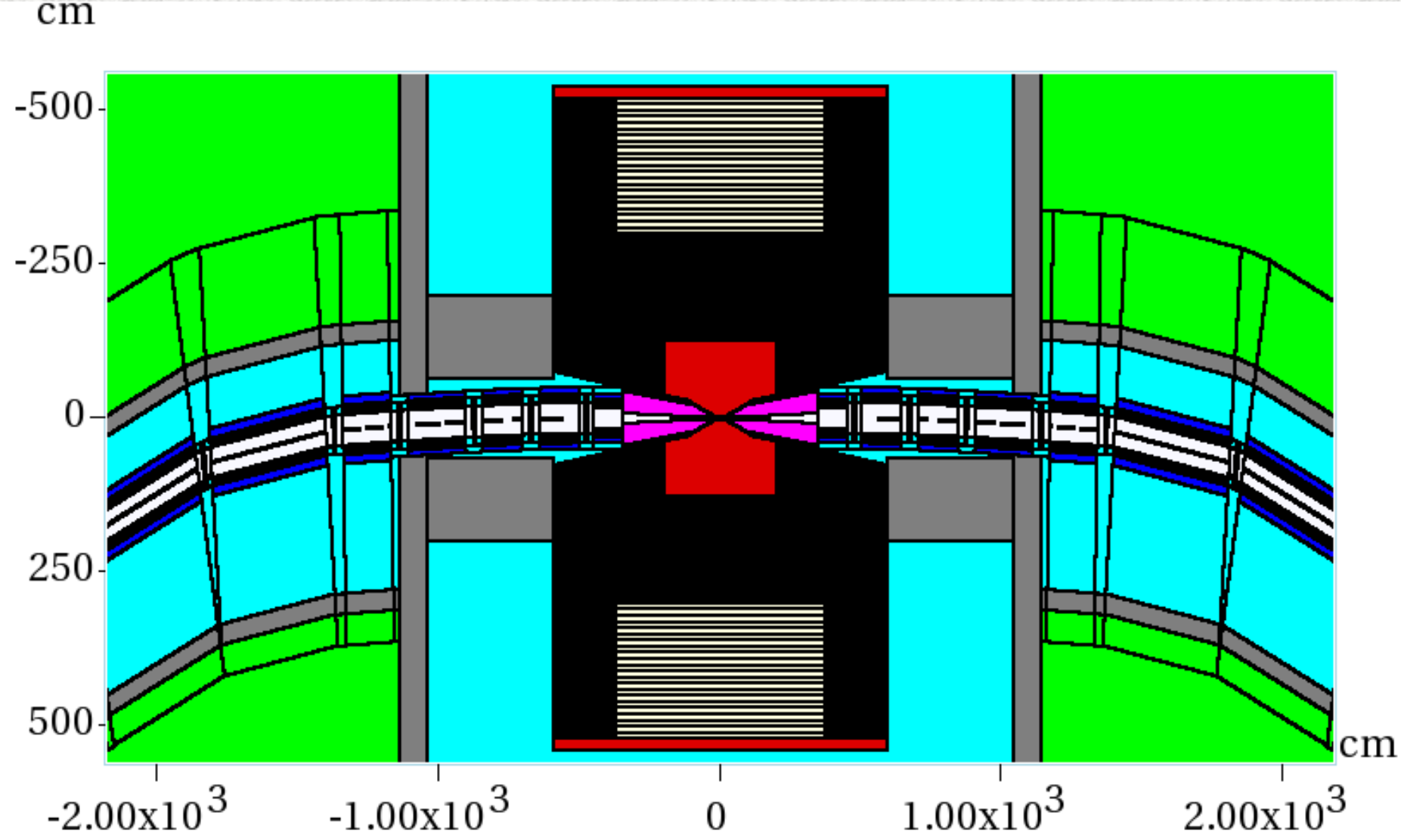
In both cases: minimal (5σ aperture radius, 10 cm thick) tungsten collimators in magnet interconnect regions, concrete collars around Q2-Q3 in experimental hall, concrete plug at the tunnel mouth.

HF Nozzle Design: From V1 to V2

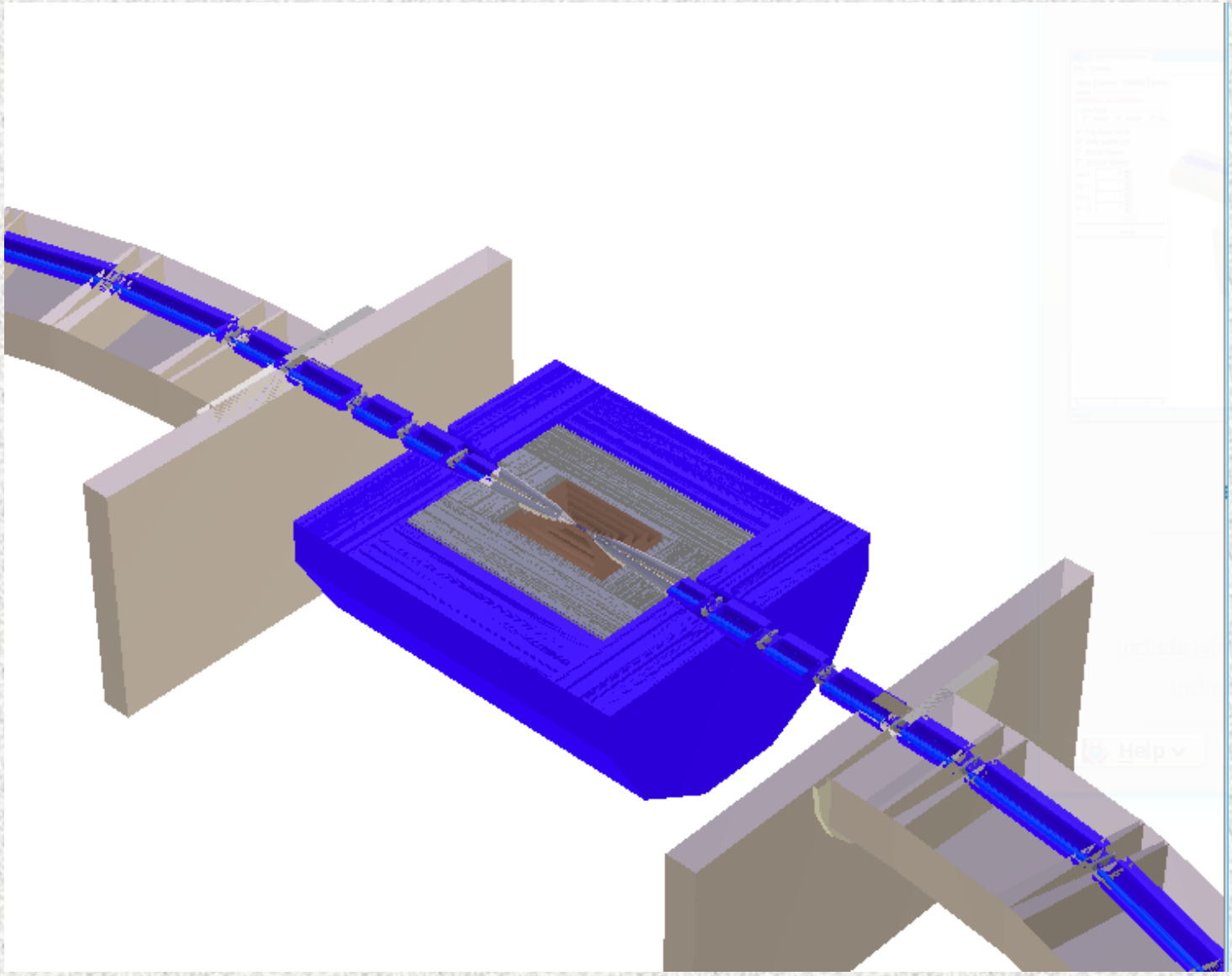




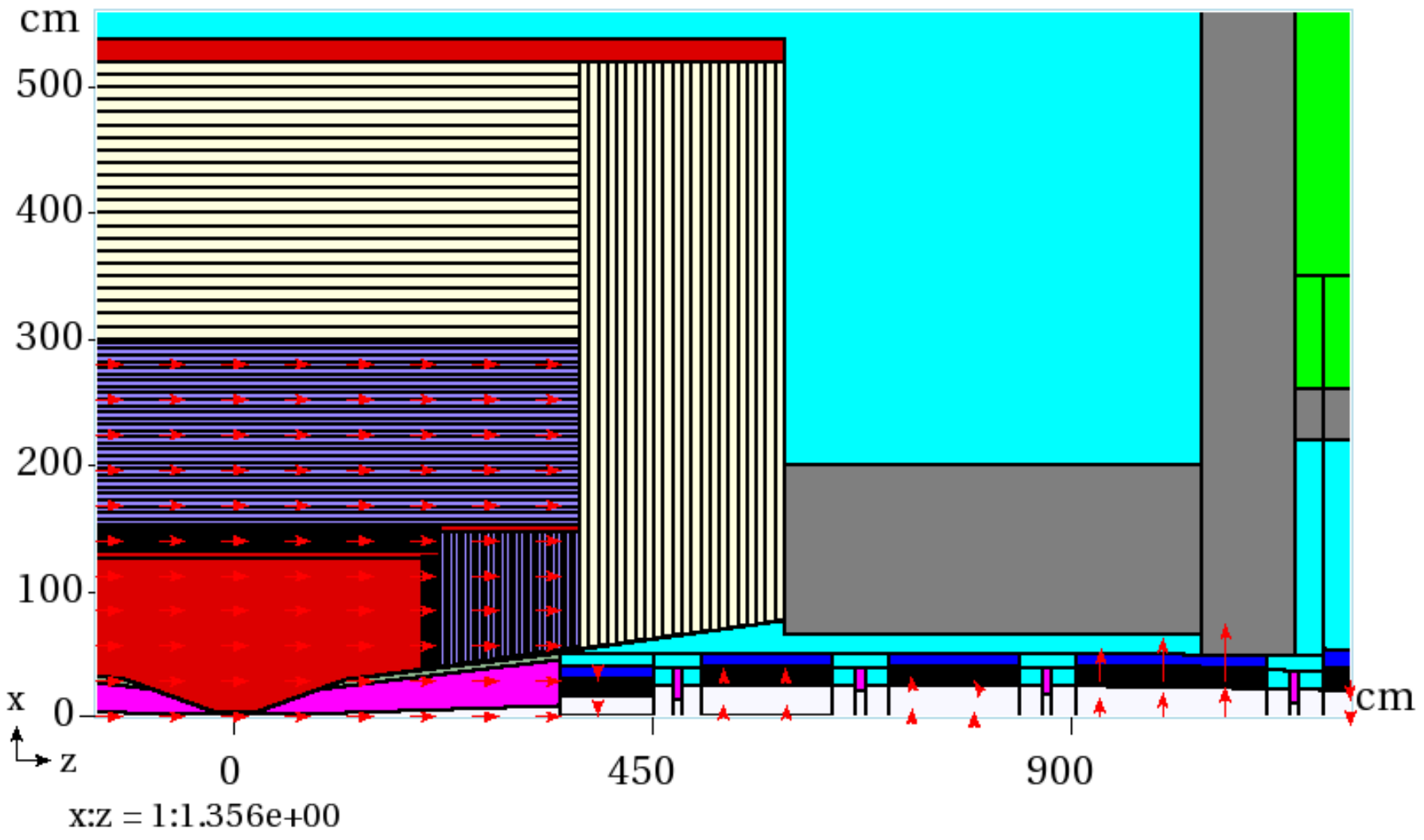
HF IR MARS15 Model: 2D View



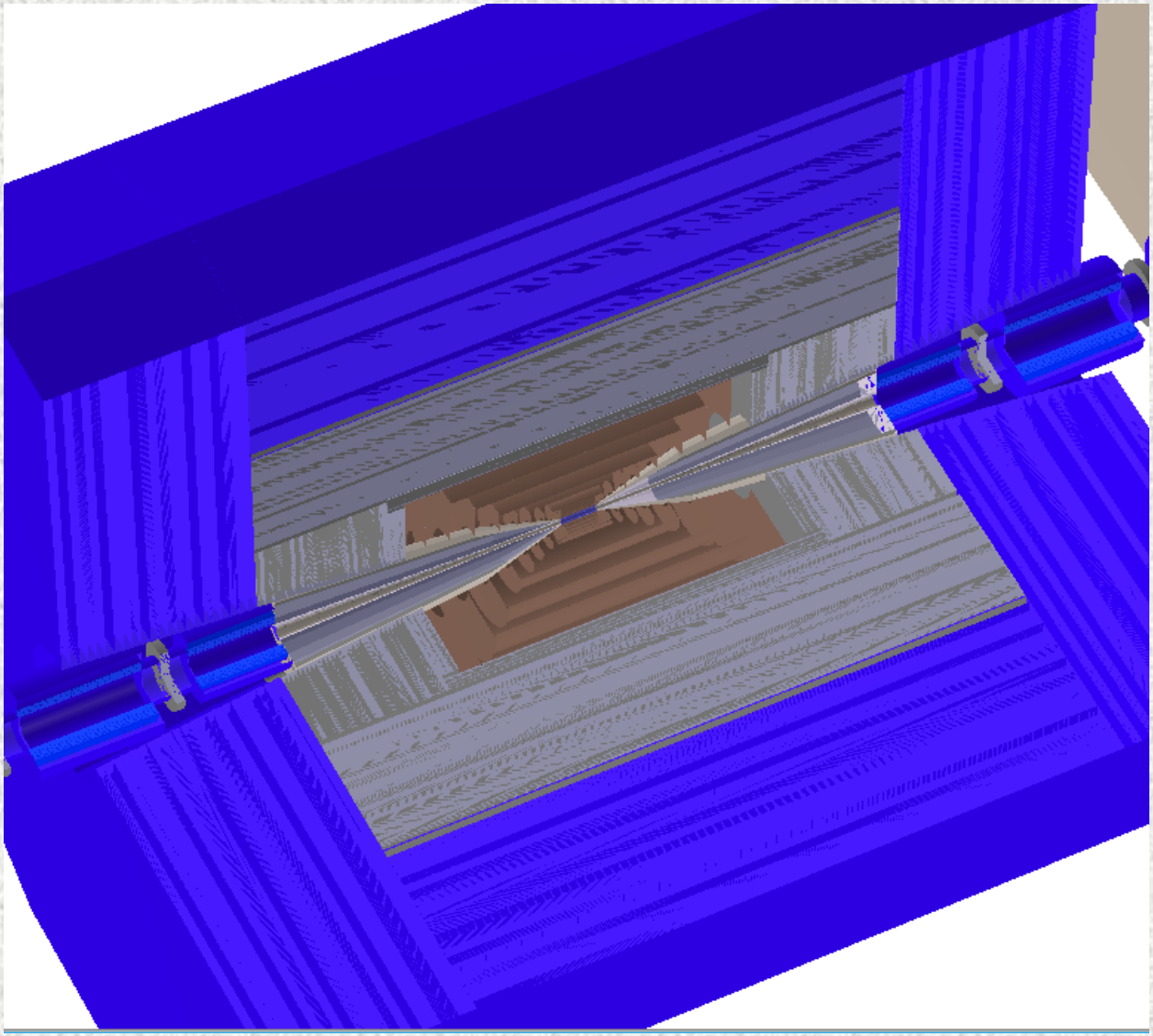
HF IR MARS15 Model: 3D View



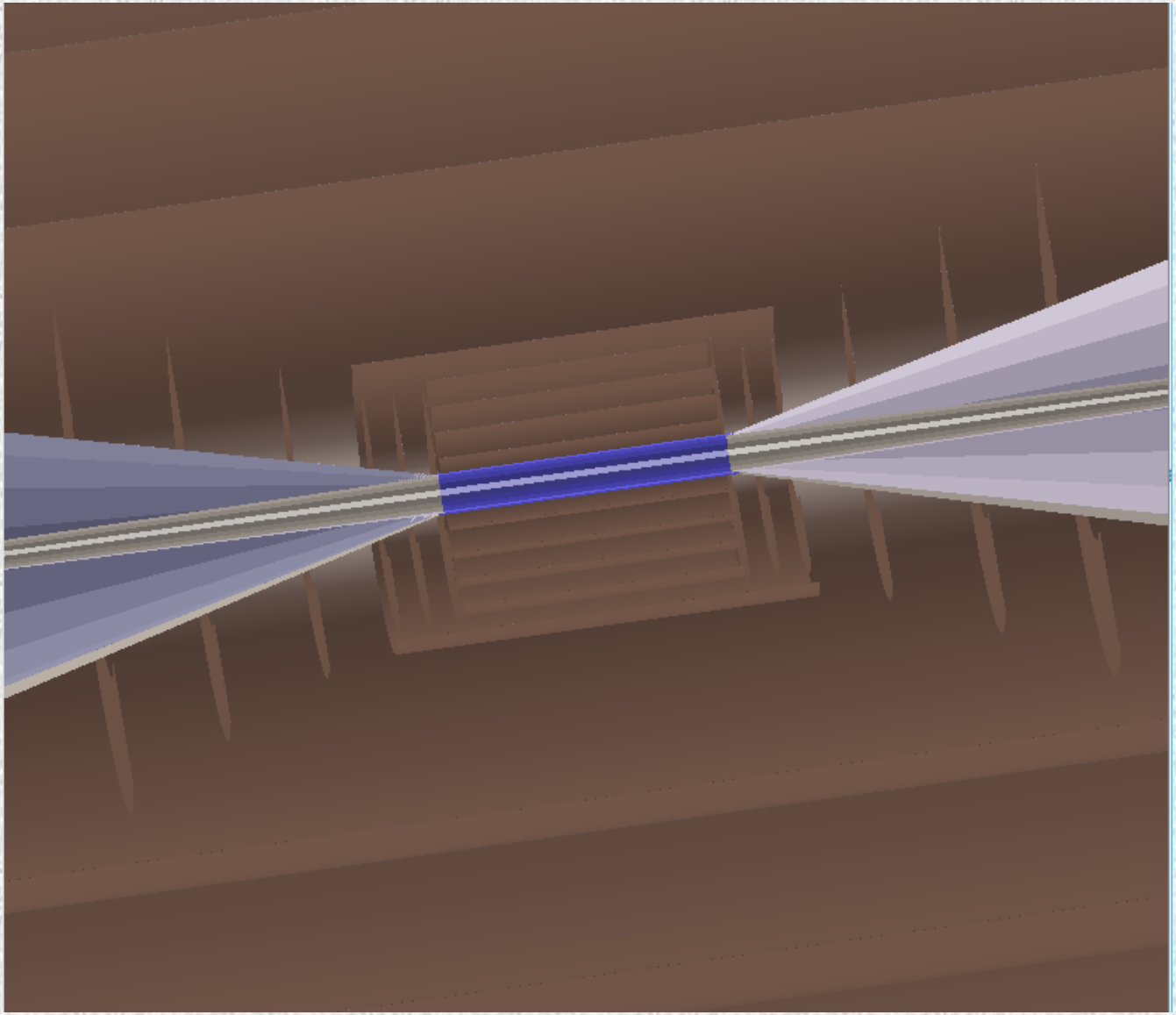
HF MDI MARS15 Model: 2D View



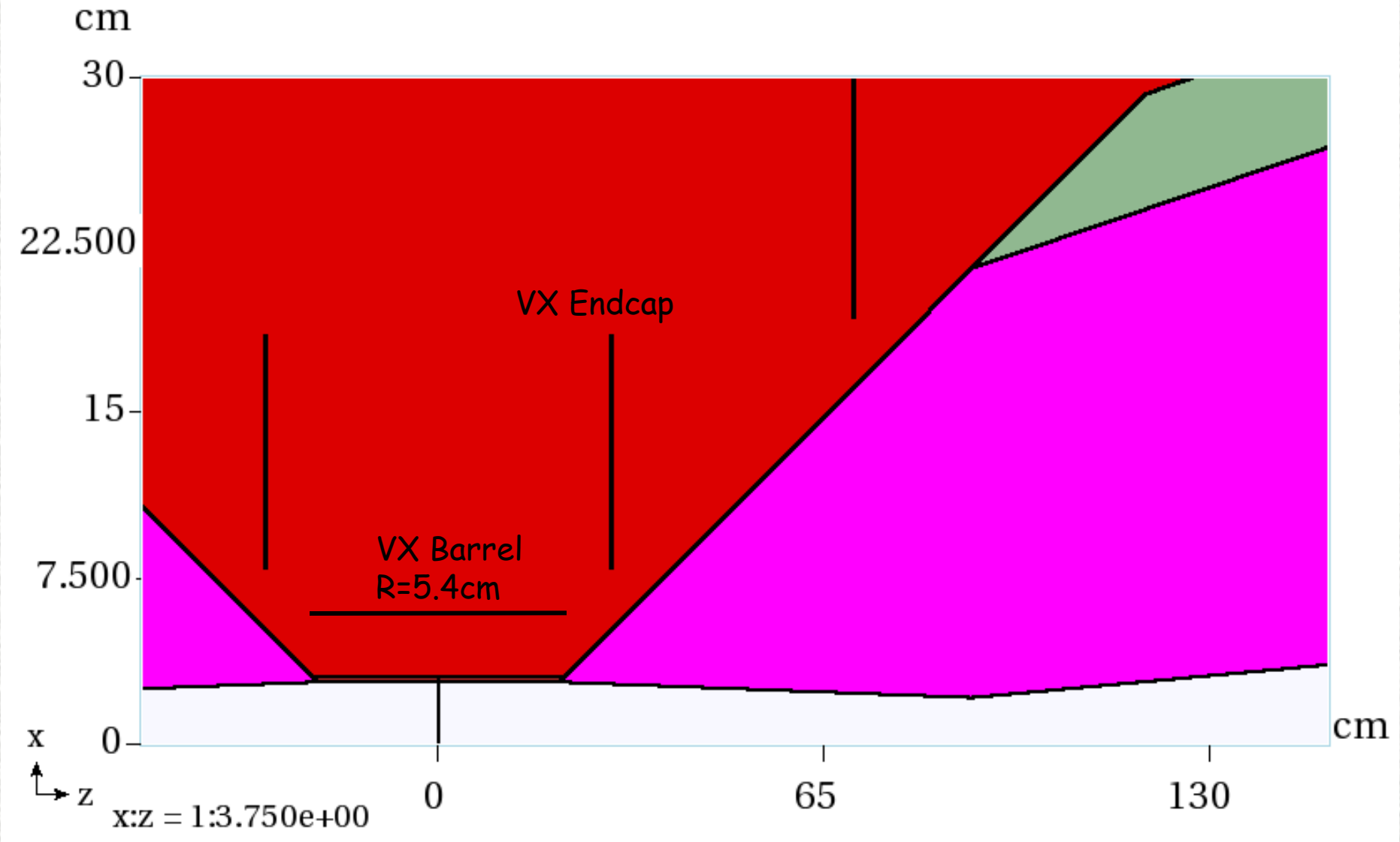
HF MDI MARS15 Model: 3D View



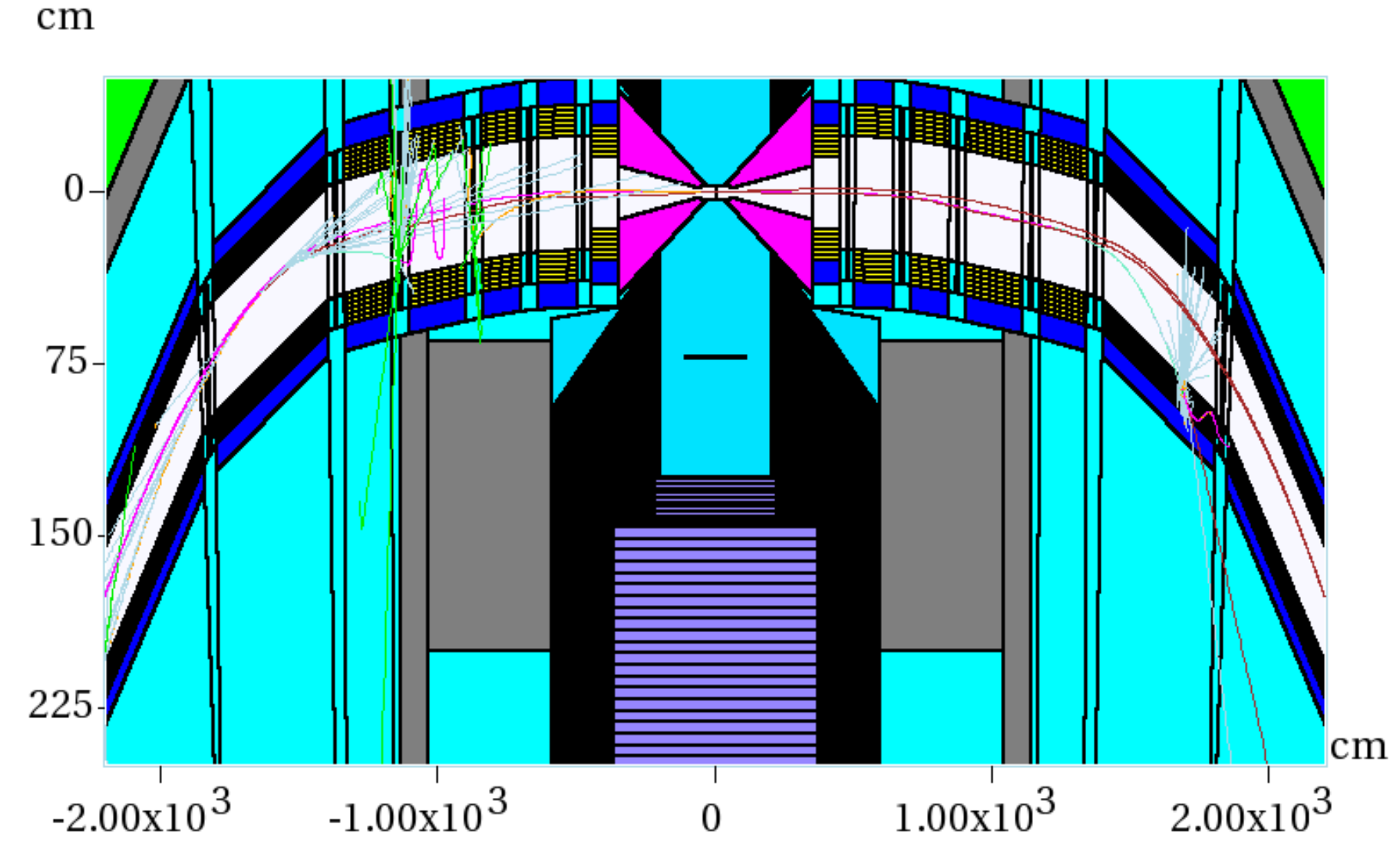
Vertex, Tracker and Nozzle



Vertex Detector Hottest Components

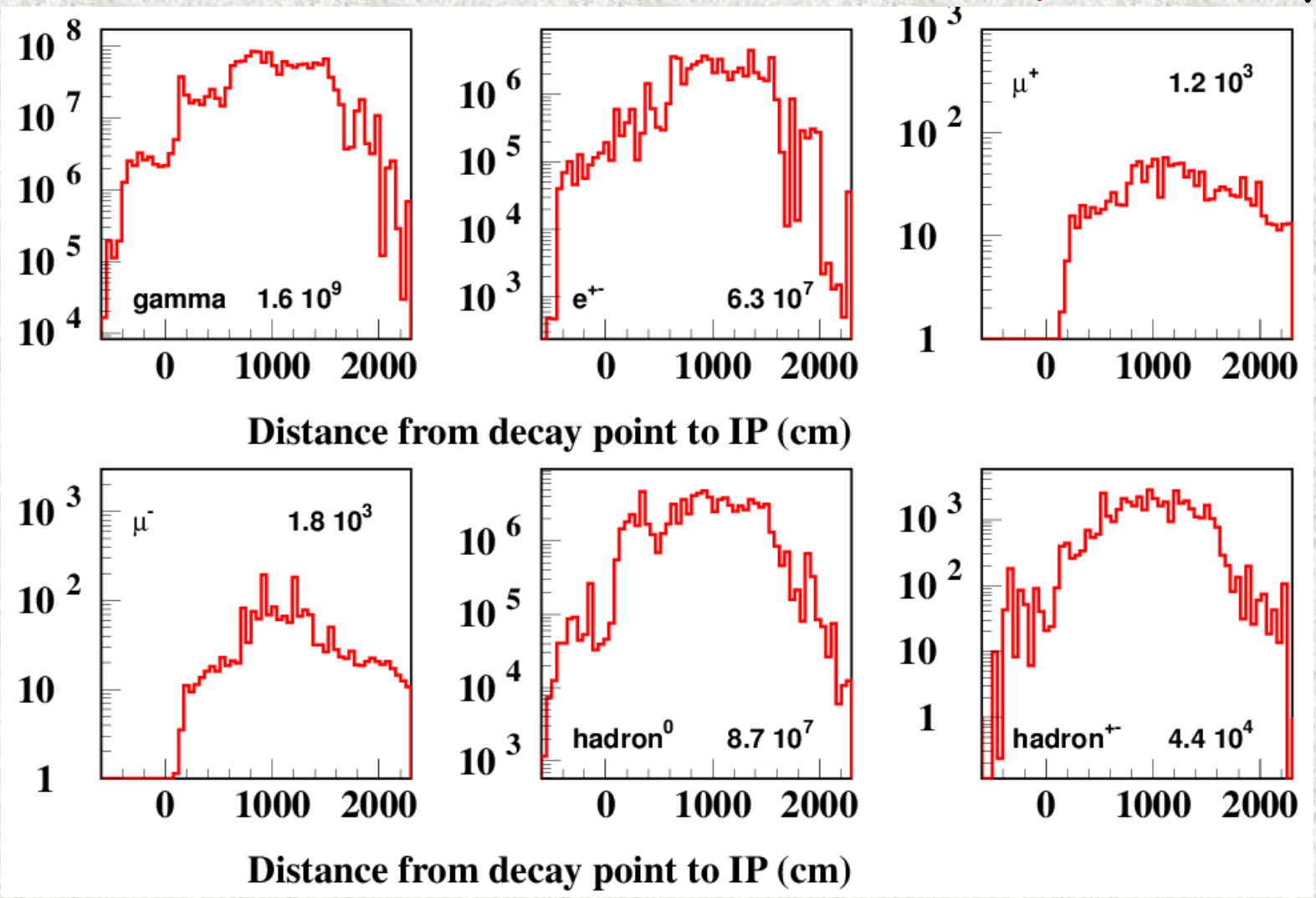


$\mu^+\mu^-$ Decays in HF IR, V1

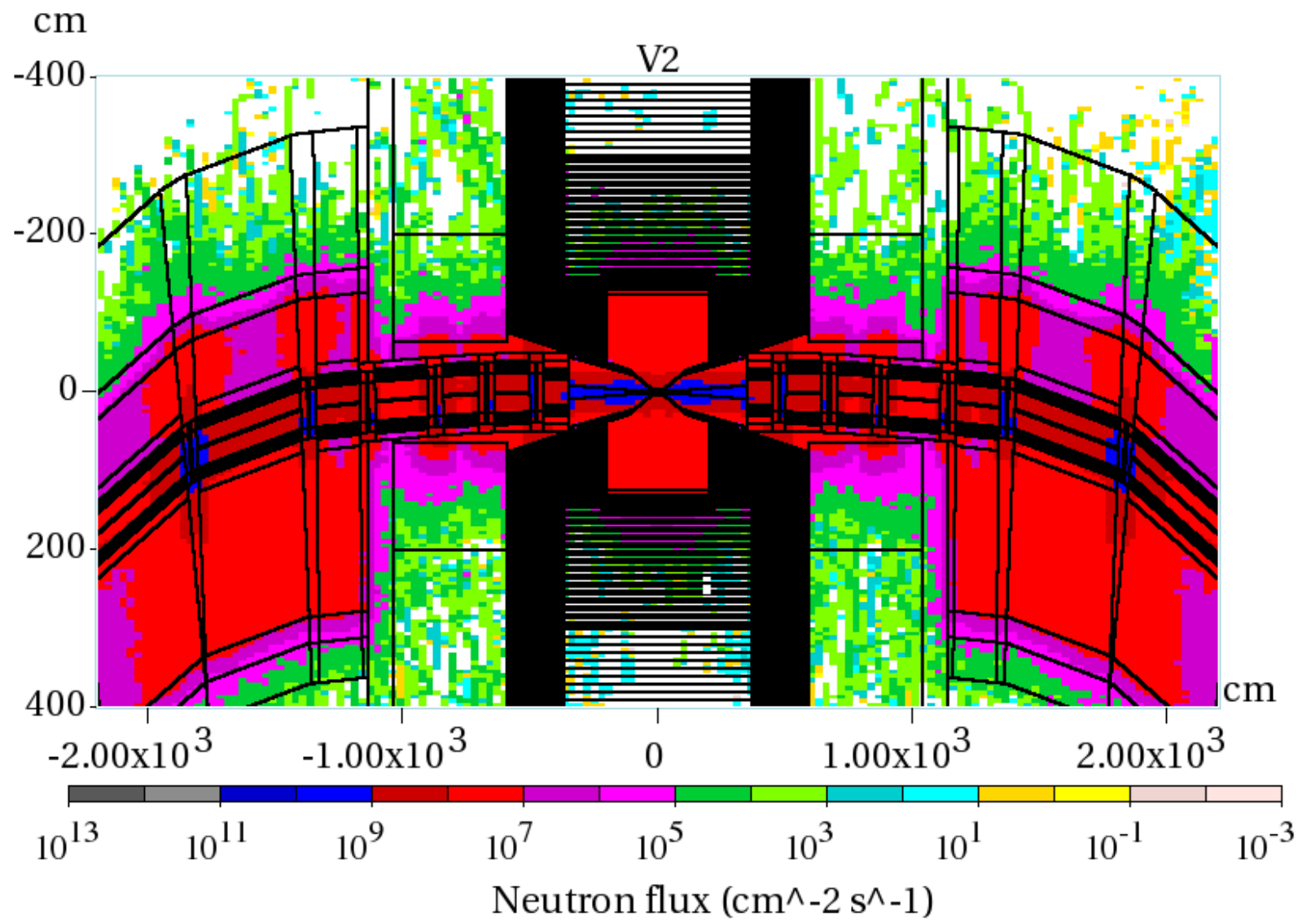


Tagging Decays for Particles Entering Detector

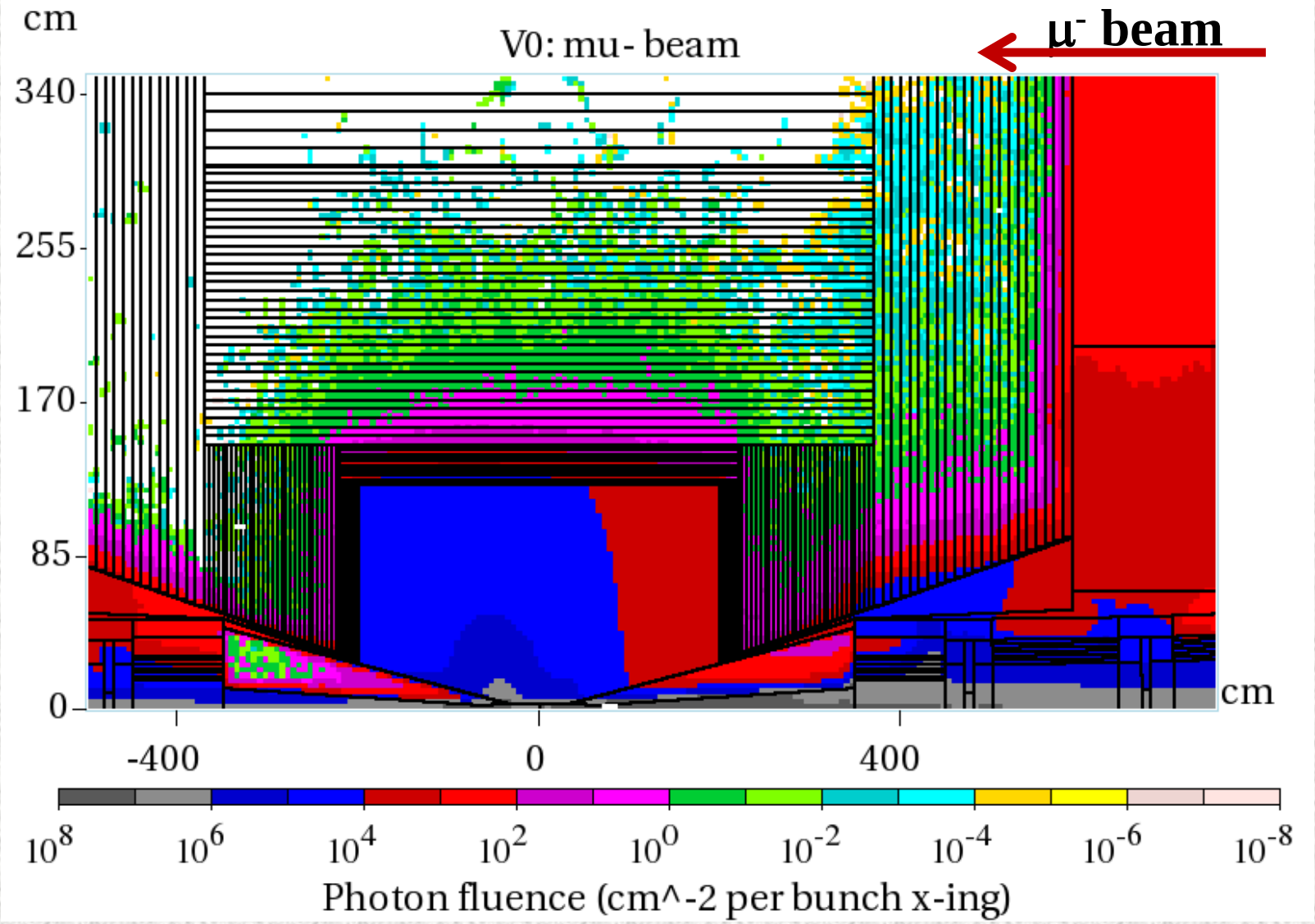
~99% from S = ± 23.2m (up to B2) ← μ^- beam



Neutron Flux in HF IR

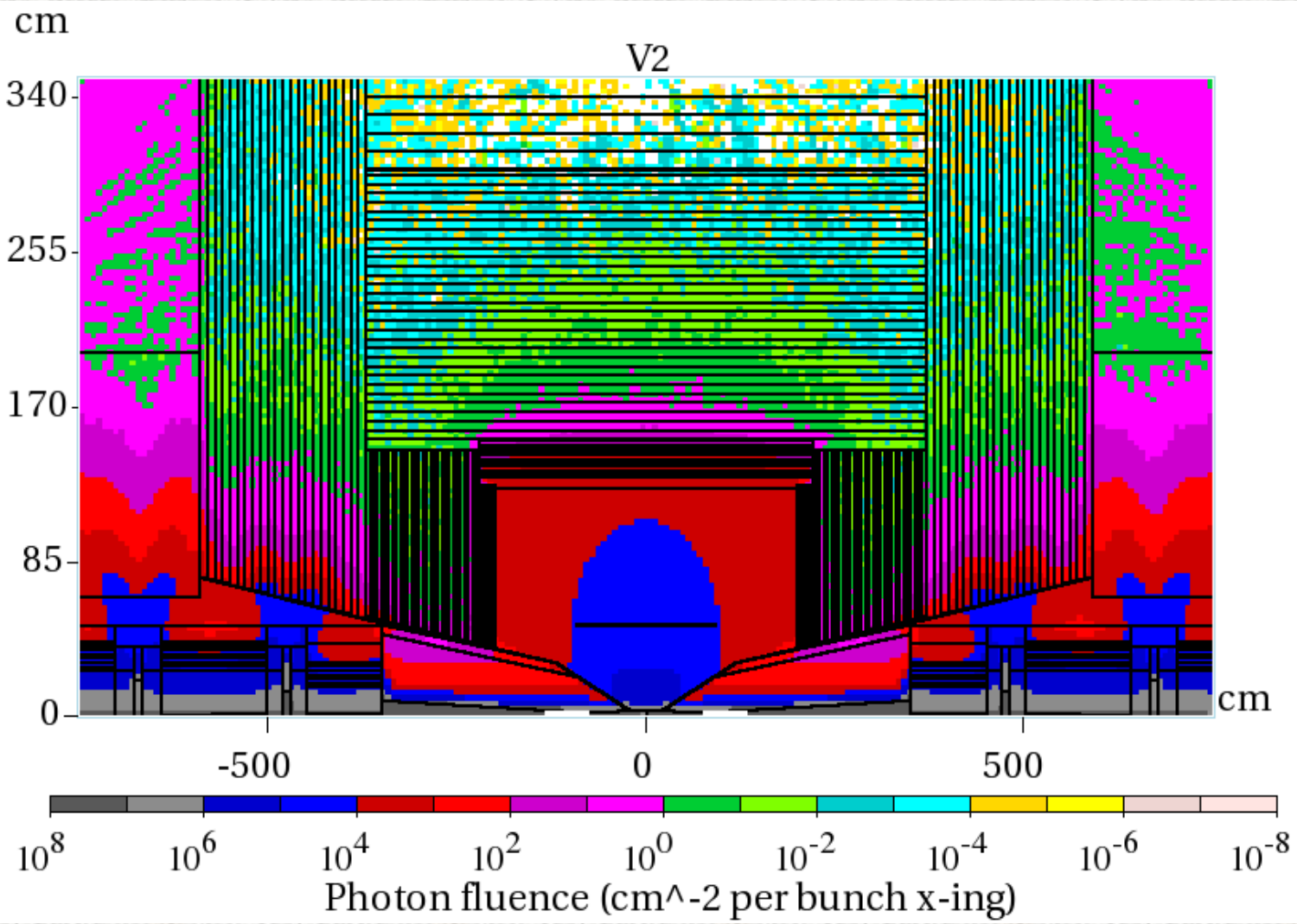


HF Photon Background, V1



Peak ~100 times that at 1.5 TeV MC

Photon Fluence in Detector: MDI V2



Peak in VB

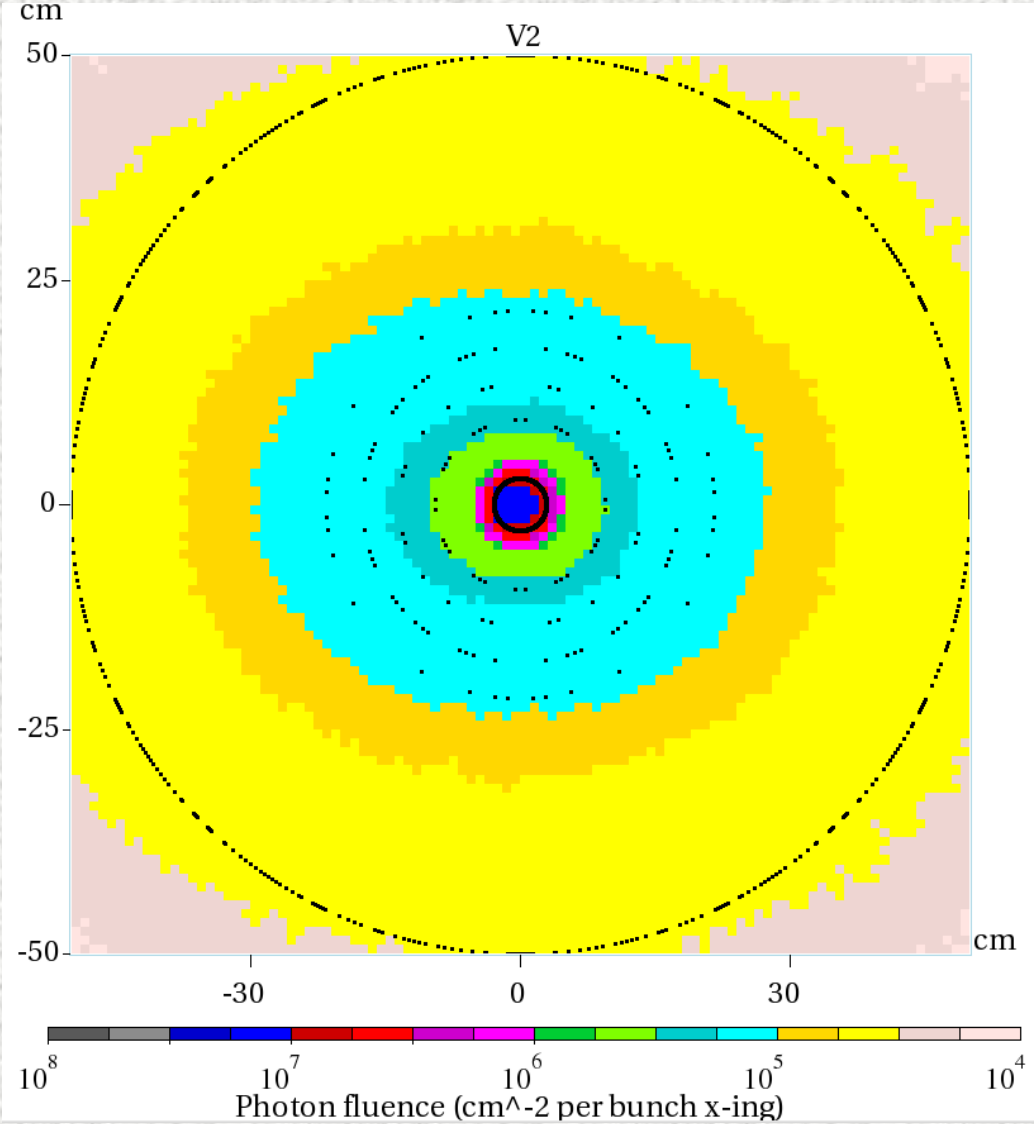
V2: 1.3e6
V1: 1.5e7

Without timing

×10 1.5TeV MC

Noticeably higher than that in the LHC CMS at 10^{34} also true for dose

Photon Fluence at IP: MDI V2

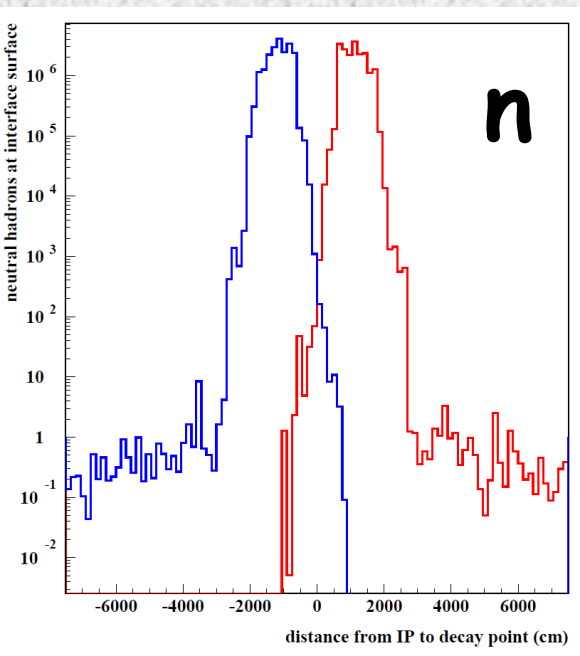


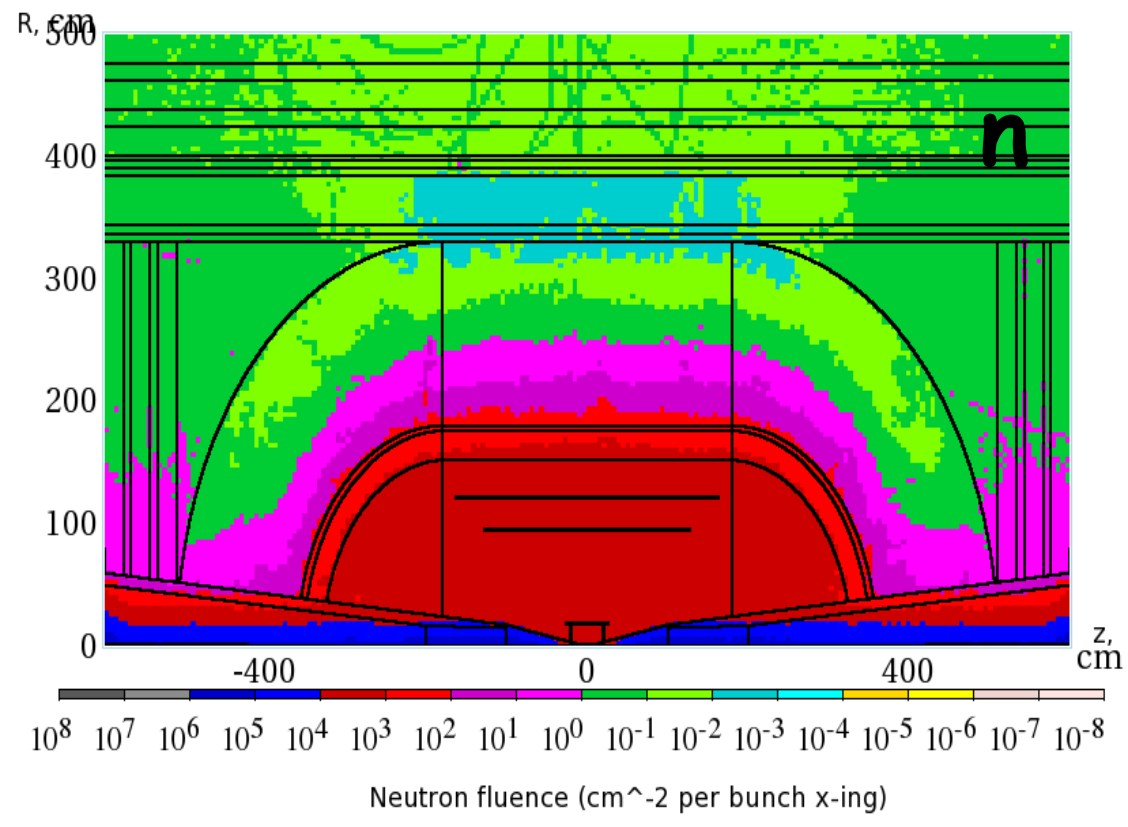
Neutron Background in 1.5-TeV MC Detector

Source:

Muons from |S| < 200 m

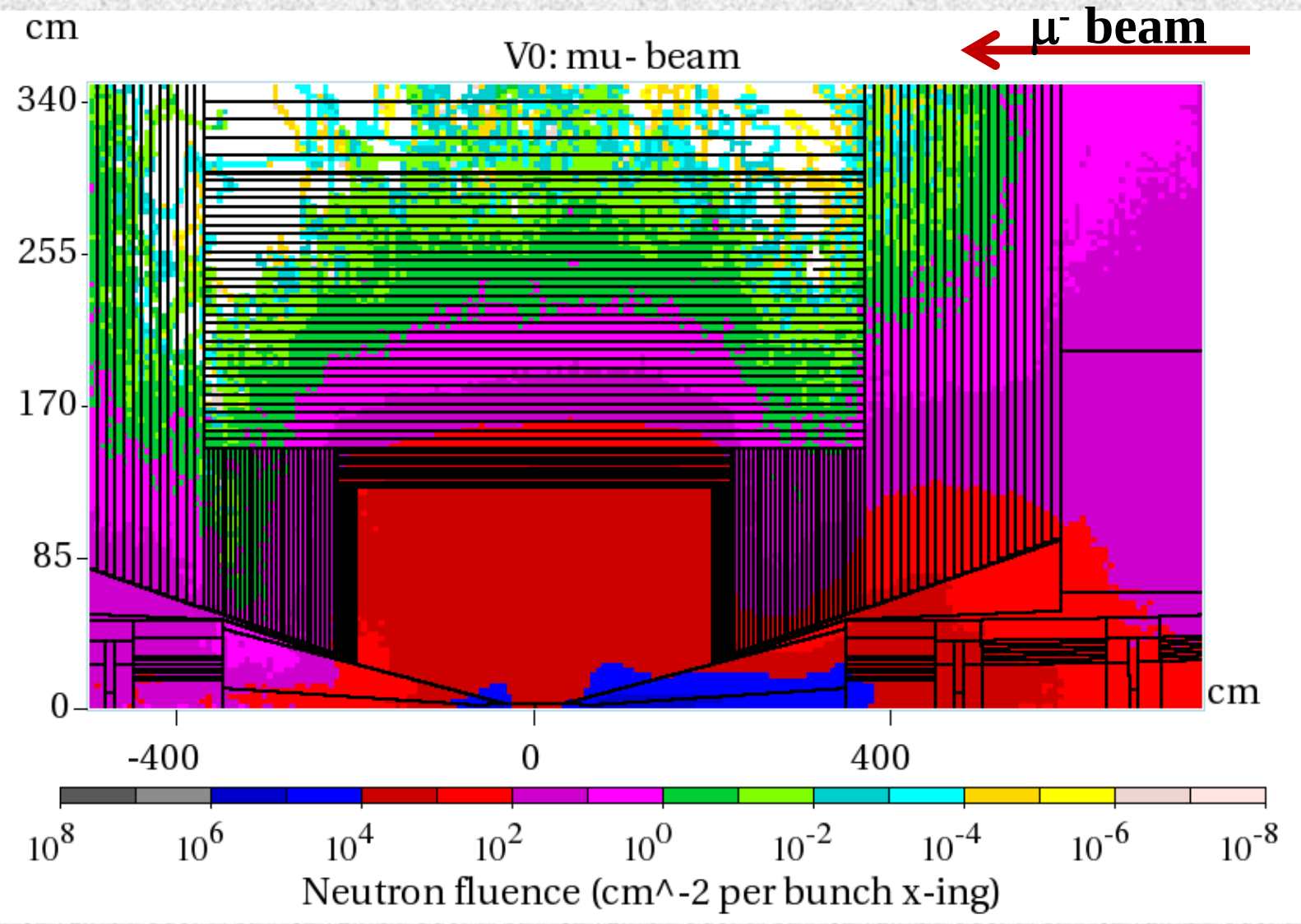
Others from |S| < 30 m





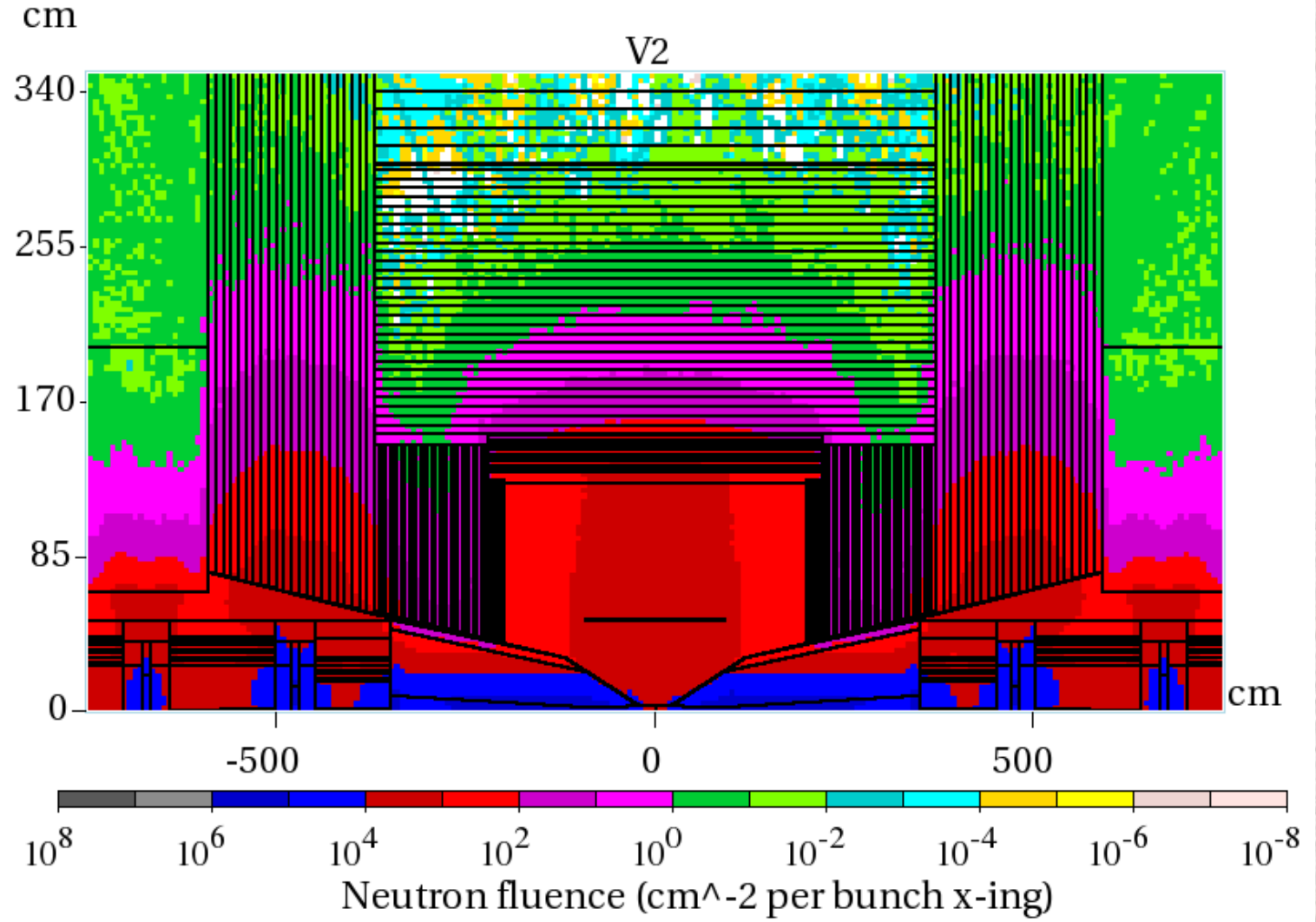
Maximum neutron fluence in the innermost layer of the silicon tracker is at a 10% level of that in the LHC CMS at luminosity of 10^{34} $cm^{-2}s^{-1}$. Yearly absorbed dose for a one-year operation in the point is 50% of that in CMS.

HF Neutron Background, V1



Peak close to that at 1.5 TeV MC

Neutron Fluence in Detector: MDI V2



Peak in VB

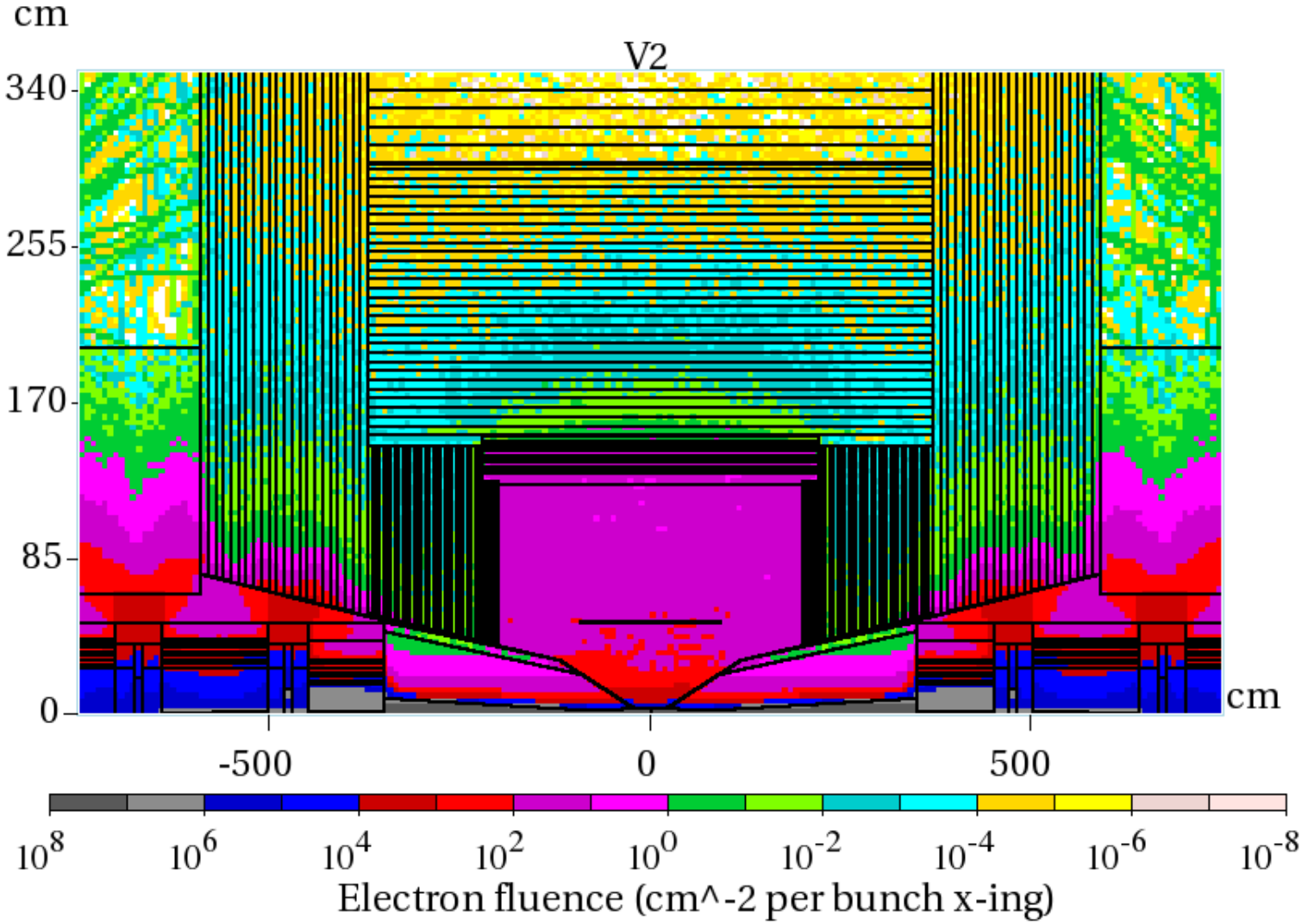
V2: 1.2e4
V1: 1.2e5

Without timing

×0.1 1.5TeV MC

Noticeably lower than that in the LHC CMS at 10^{34}

Electron Fluence in Detector: MDI V2

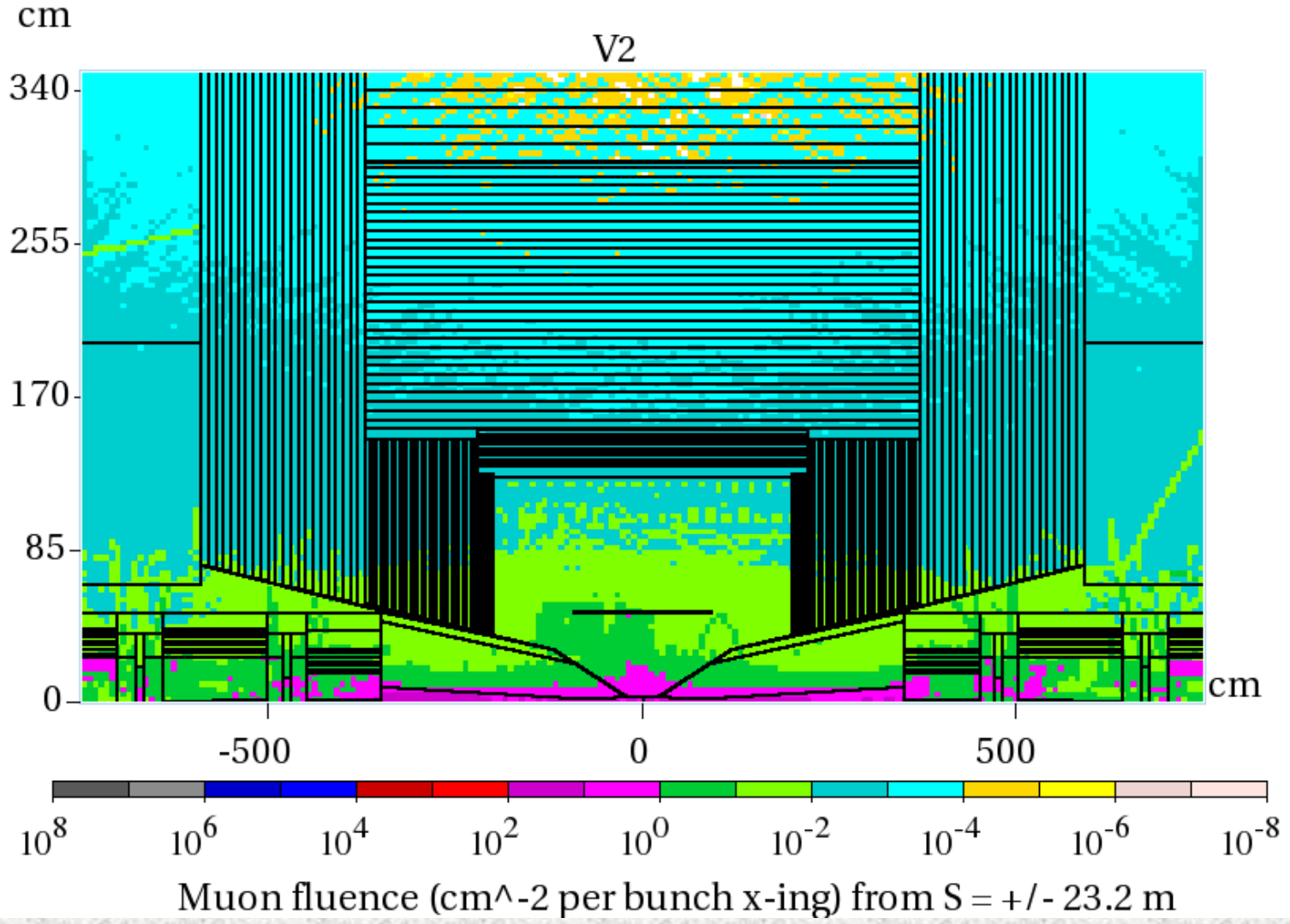


Peak in VB

V2: 3e4

Without timing

Muon Fluence in Detector: MDI V2

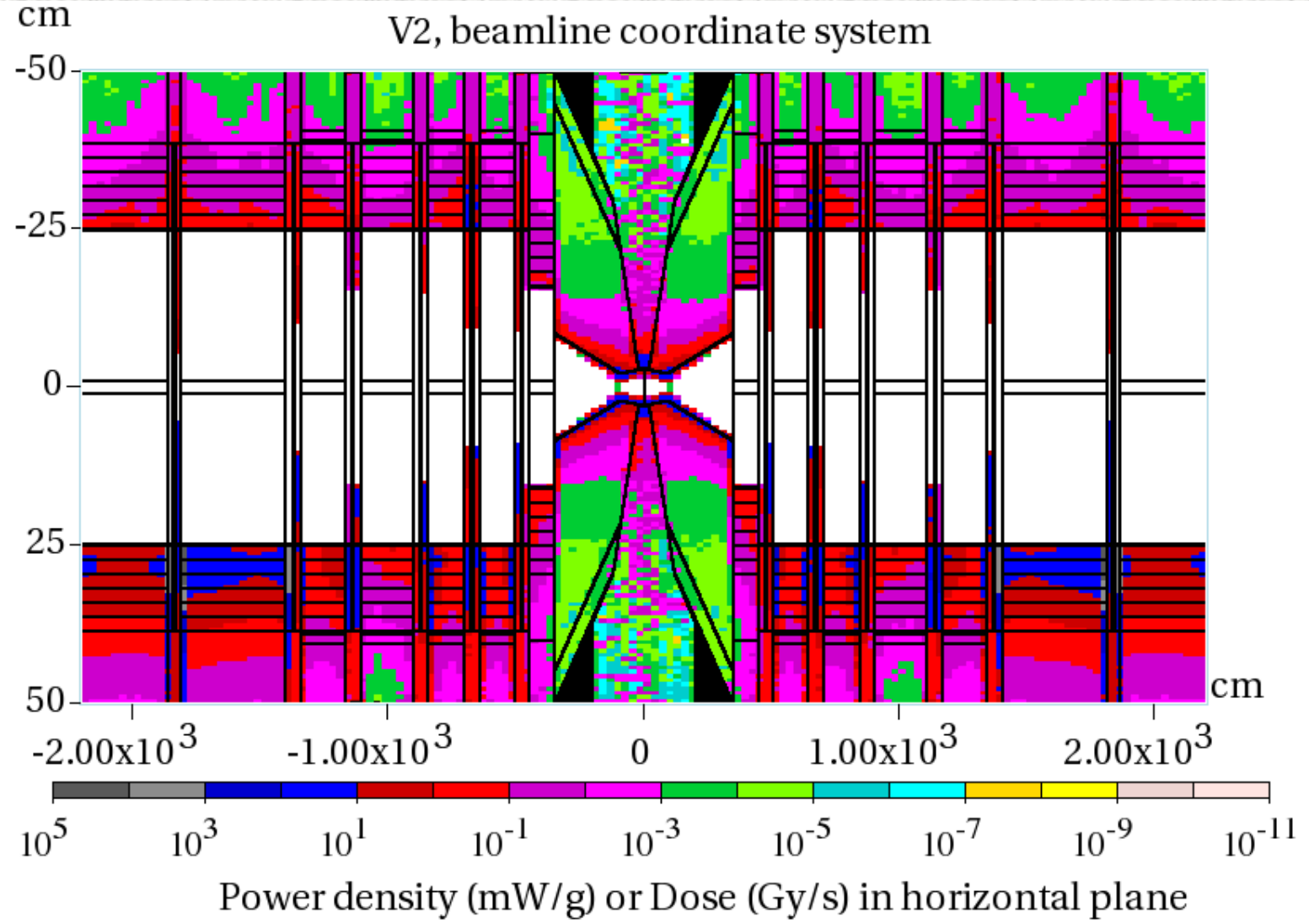


Peak in VB

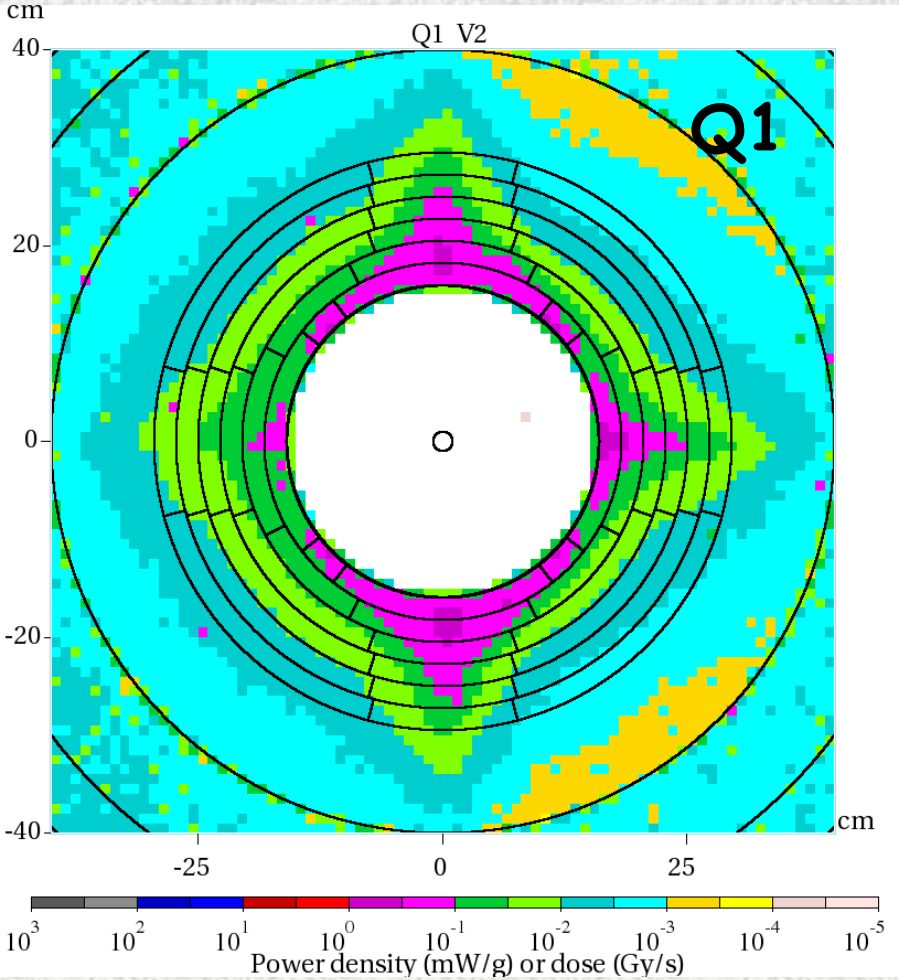
V2: 3.2

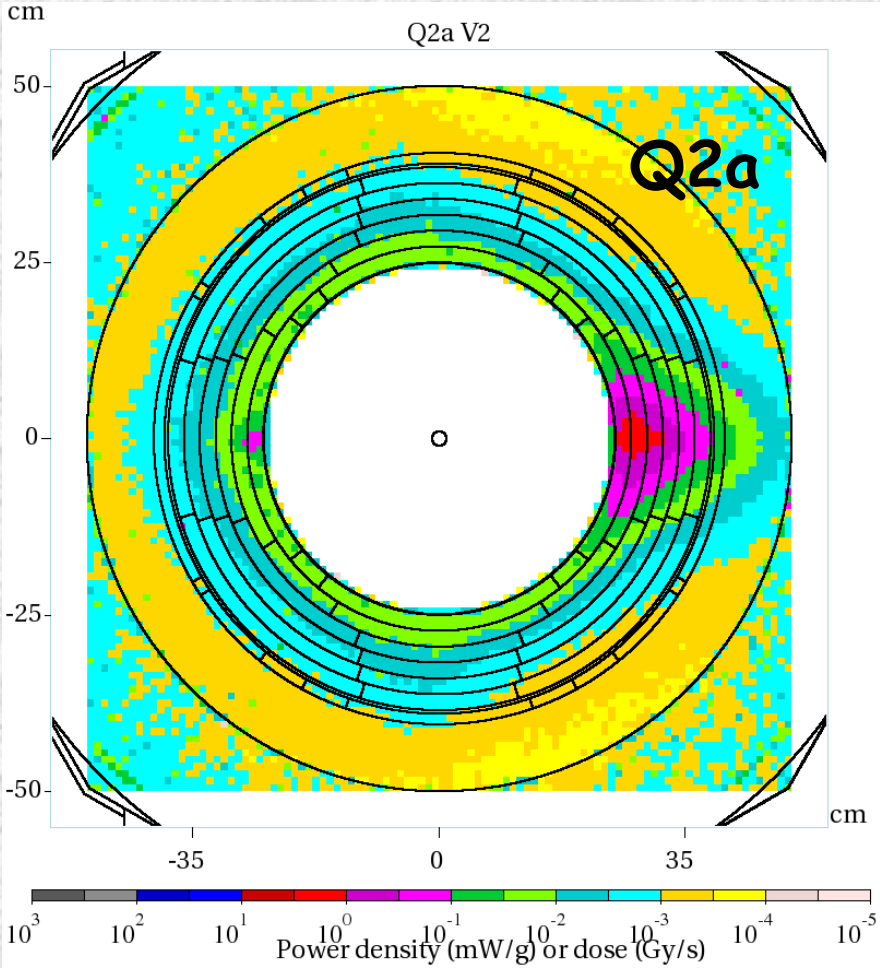
Expect increase at large radii From decays at |S| > 23.2 m

Power Density and Dose in IR V2

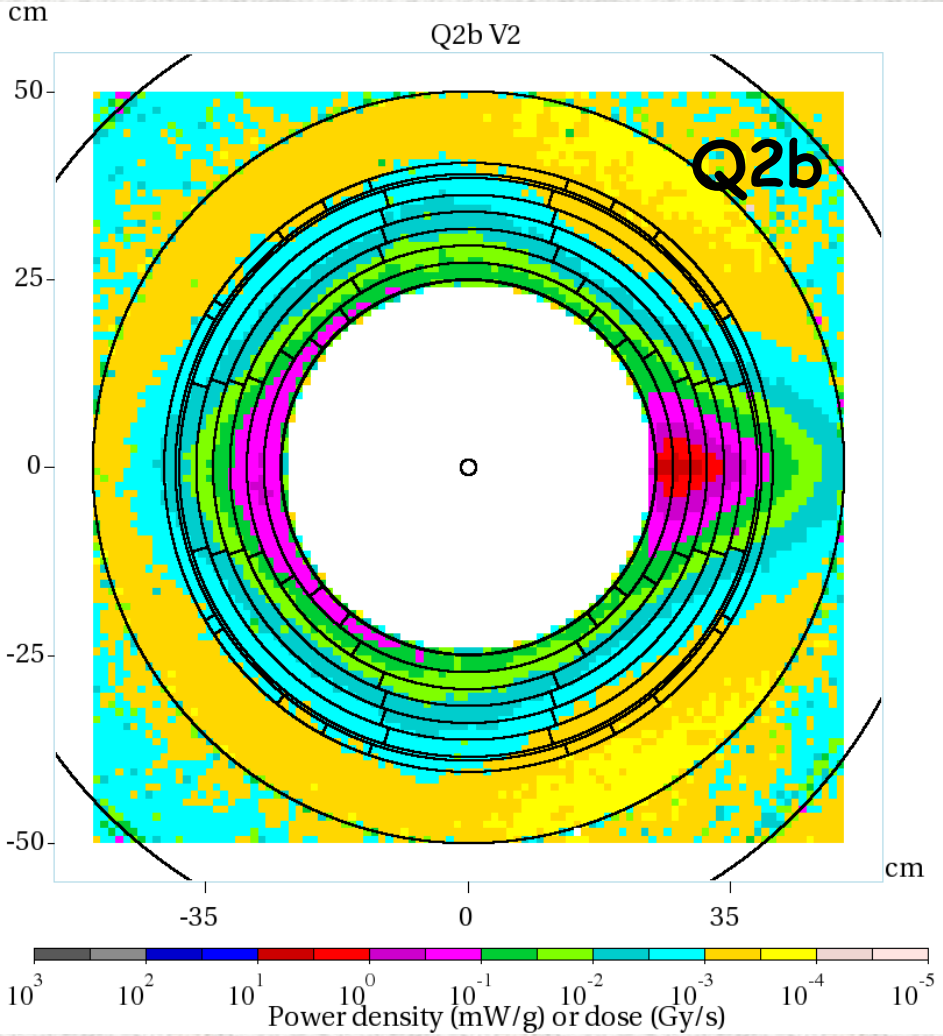


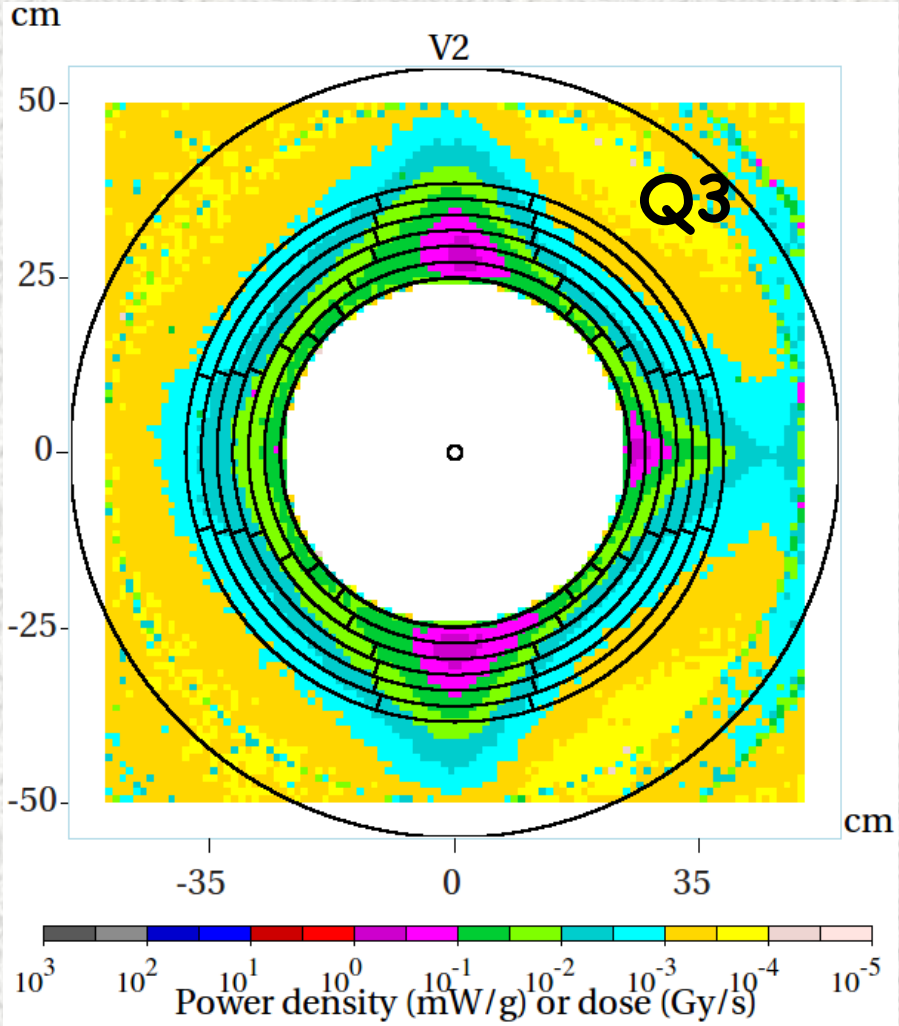
Power Density in IR Magnets V2: Q1 and Q2a



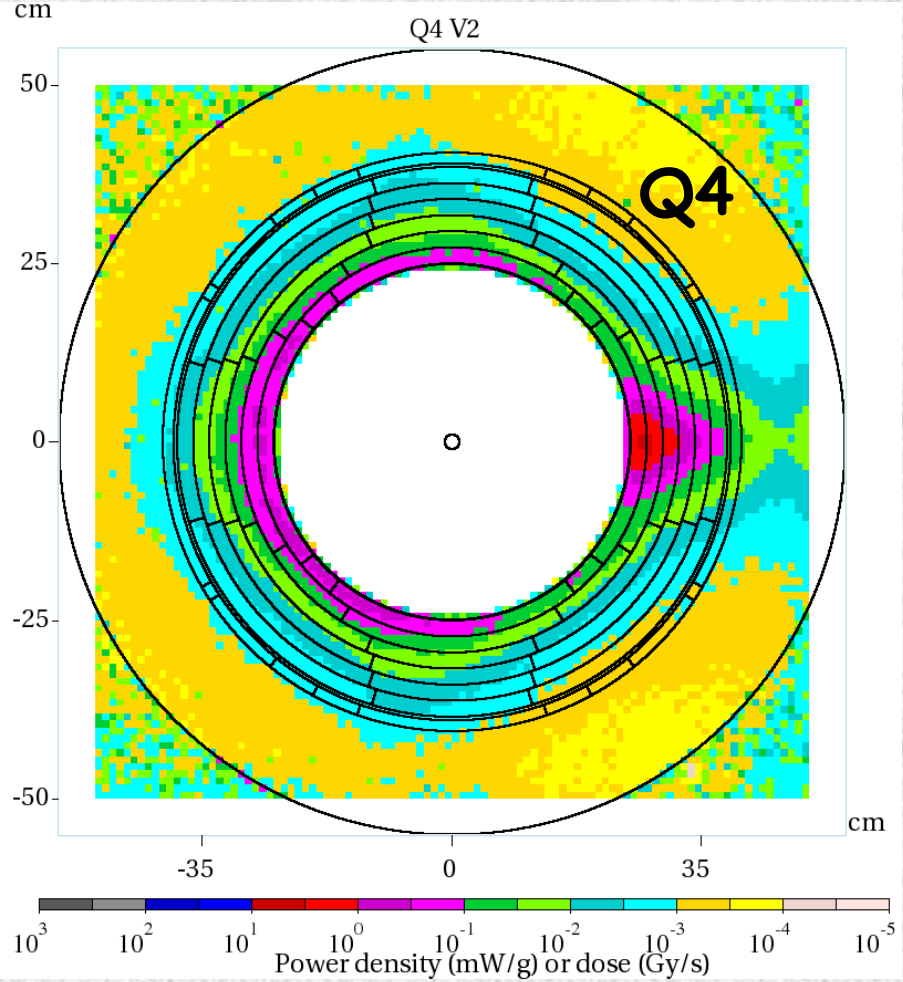


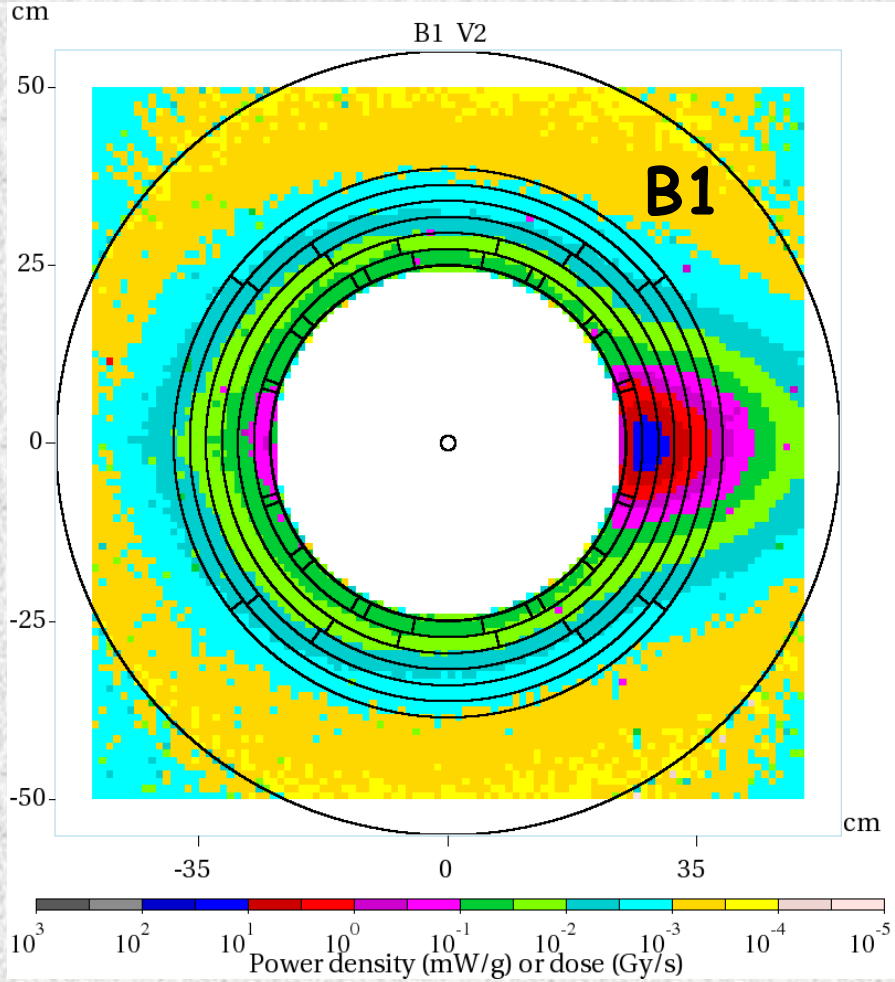
Power Density in IR Magnets V2: Q2b and Q3





Power Density in IR Magnets V2: Q4 and B1





Peak Power Density in IR Magnets, V2

Magnet	Q1	Q2a	Q2b	Q3	Q4	B1
mW/g	0.4	2.5	7.5	7.5	3.5	19

Started from up to 80 mW/g…

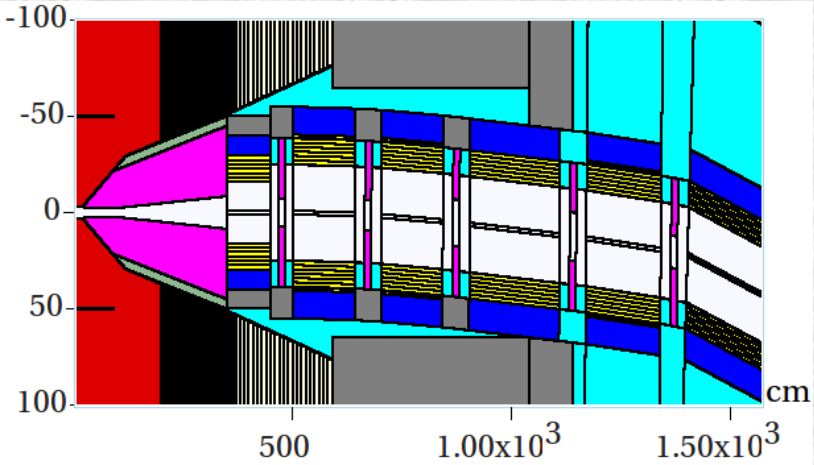
Quench limit for Nb_3Sn coils is 5 mW/g

Remember 1 kW/m average dynamic heat load!

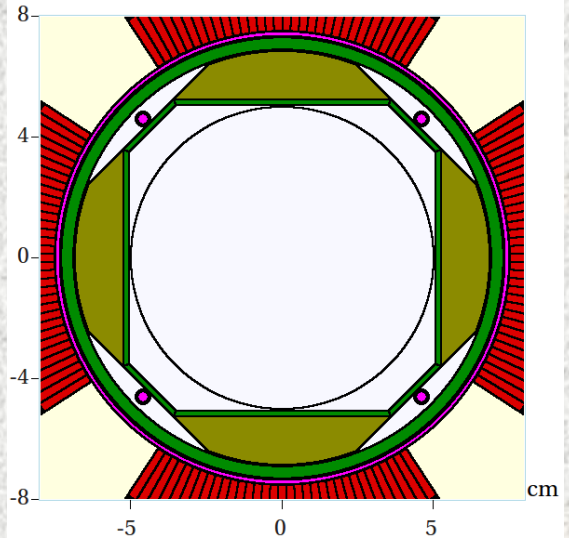
Next Steps: V2 → V3

Improved masks in interconnect regions:

- Smaller aperture
- Thicker
- Plugs outside



Segmented W-absorbers in hot magnets, as we do for HiLumi LHC upgrade



Conclusions

- Consistent MARS15 model of Muon Collider HF IR and MDI with large aperture Nb_3Sn magnets and SiD lcsim detector built, with results on muon-decay detector backgrounds and heat loads to IRQ calculated.
- MDI configuration further optimized matching SiD detector, with new nozzle etc.
- Next steps: further improve tracking in strong magnetic fields; extend the MARS IR model to account for all Bethe-Heitler muons; MDI shielding optimization.
- Produce background source files and launch HF detector response simulations with the MARS-generated source.