Muon Collider Machine-Detector Interface: Recent Results and Plans

Nikolai Mokhov

FNAL MDI team

Y. Alexahin, V.Y. Alexakhin, E. Gianfelice-Wendt, C. Johnstone, V.V. Kashikhin, NM, S. Striganov, A. Zlobin

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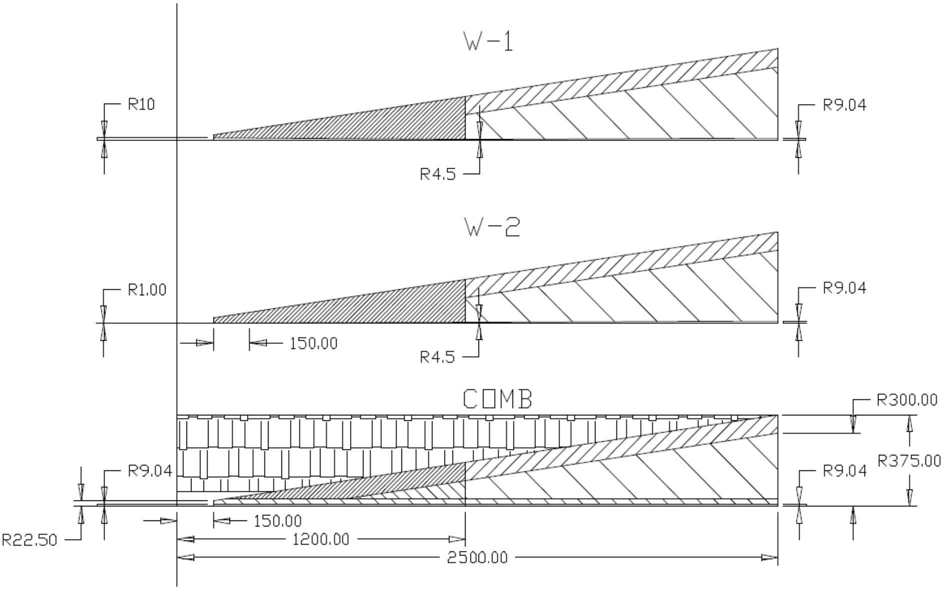
OUTLINE

- Background Sources (see my previous talk)
- Collimating Nozzle and Dipoles in IR
- MARS15 Modeling in IR and Detector, November 2009
- IP versus Machine Backgrounds
- MARS15 Modeling and Magnet Design, January 2010
- MDI Issues and Work to Do

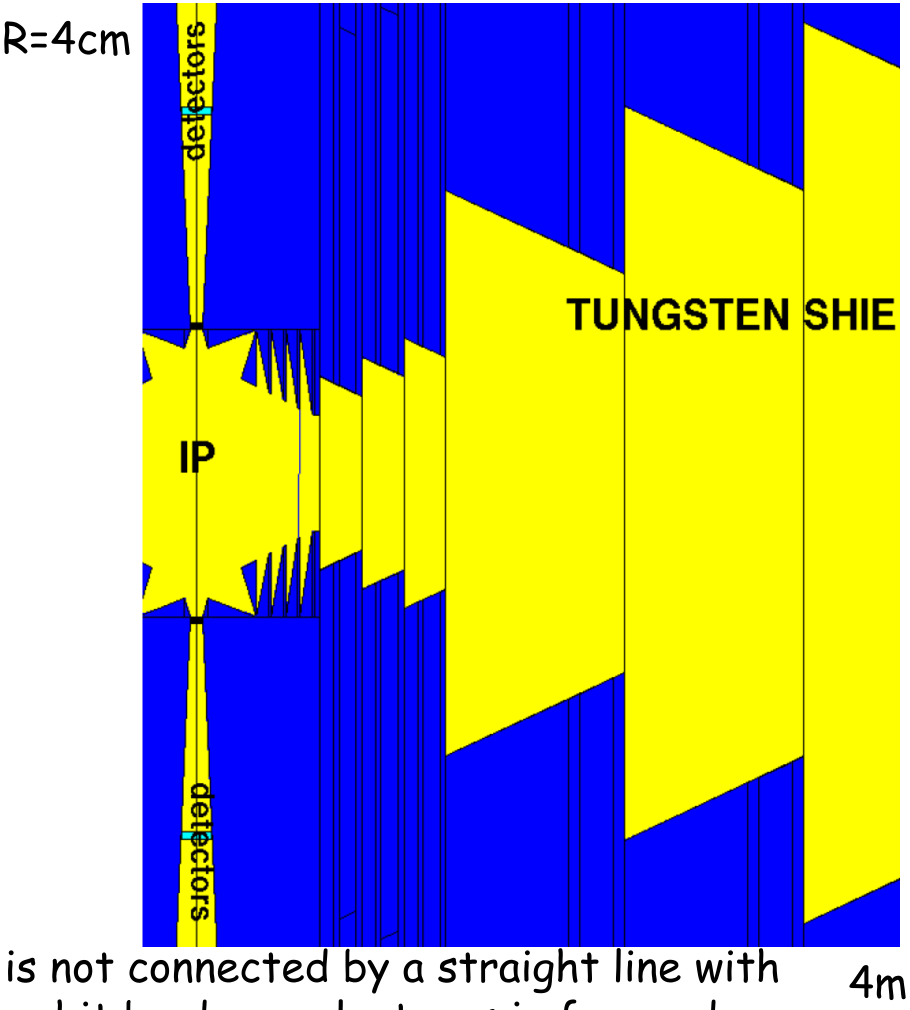
Collimating Nozzles at IP

As was found, the most effective collimation includes a limiting aperture about one meter from the IP, with an interior conical surface which opens outward as it approaches the IP. These collimators have the aspect of two nozzles spraying electromagnetic fire at each other, with the charged component of the showers being confined radially by the solenoidal magnetic field and the photons from one nozzle being trapped (to whatever degree possible) by the conical opening in the opposing nozzle.

Nozzle Concepts



B. Foster & N. Mokhov (1994):
Background reduction 30 to 500 times



Detector is not connected by a straight line with any surface hit by decay electrons in forward or backward directions (I. Stumer, 2001)

Spreading Decay Electrons Along IR

SC sweep dipoles with tungsten masks between IR elements, proposed by Carol and myself in 1996, implemented in a consistent lattice with required momentum acceptance and DA by Yury and Eliana I 2009, a factor of seven reduction of backgrounds.

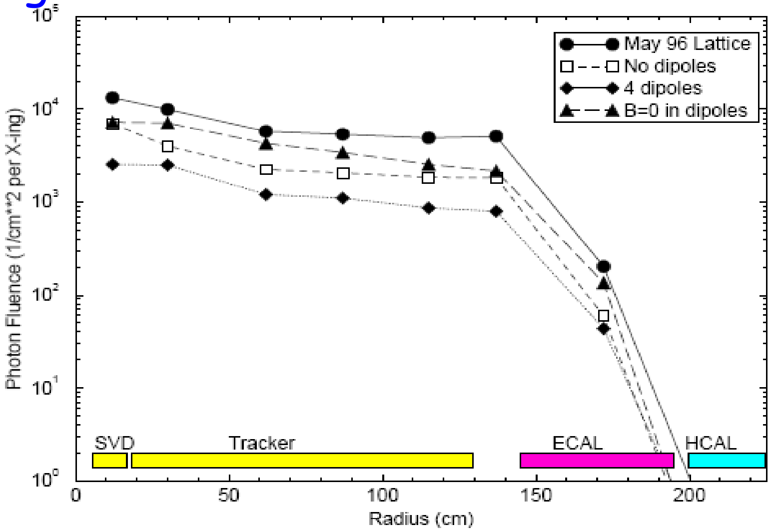


Figure 7: Radial dependence of photon fluence in the ±1.2 m central detector region around the IP per 2 × 2 TeV $\mu^+\mu^-$ bunch crossing for different IR scenarios due to muon beam decays.

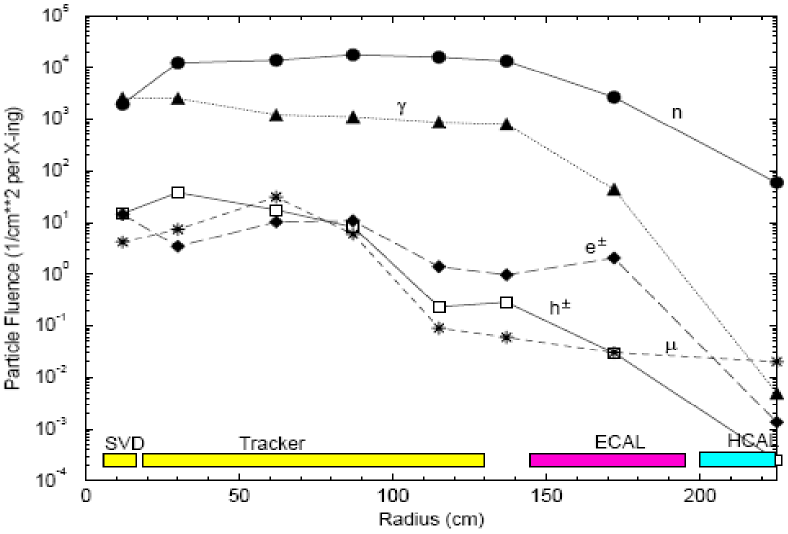
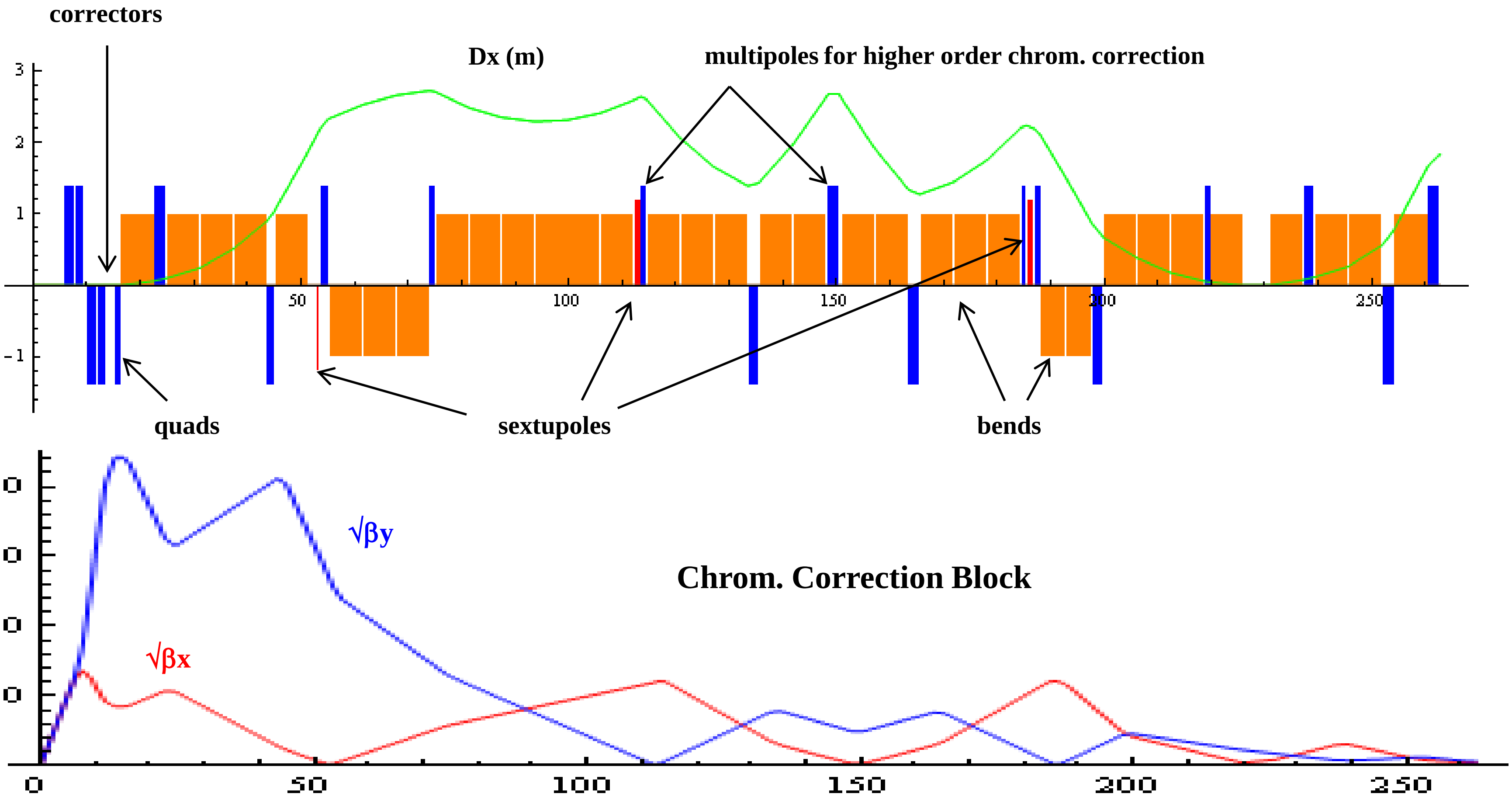


Figure 8: Radial dependence of particle fluence in the ±1.2 m central detector region around the IP per 2 × 2 TeV $\mu^+\mu^-$ bunch crossing for the best IR configuration considered.

Helps suppress Bethe-Heitler muons which cause significant fluctuations in transverse energy and missing transverse energy due to energy spikes in deep inelastic interactions of such muons.

IR Design by E.Gianfelice-Wendt & Y.Alexahin (2009)



Tungsten Cone in BCH_2 Shell

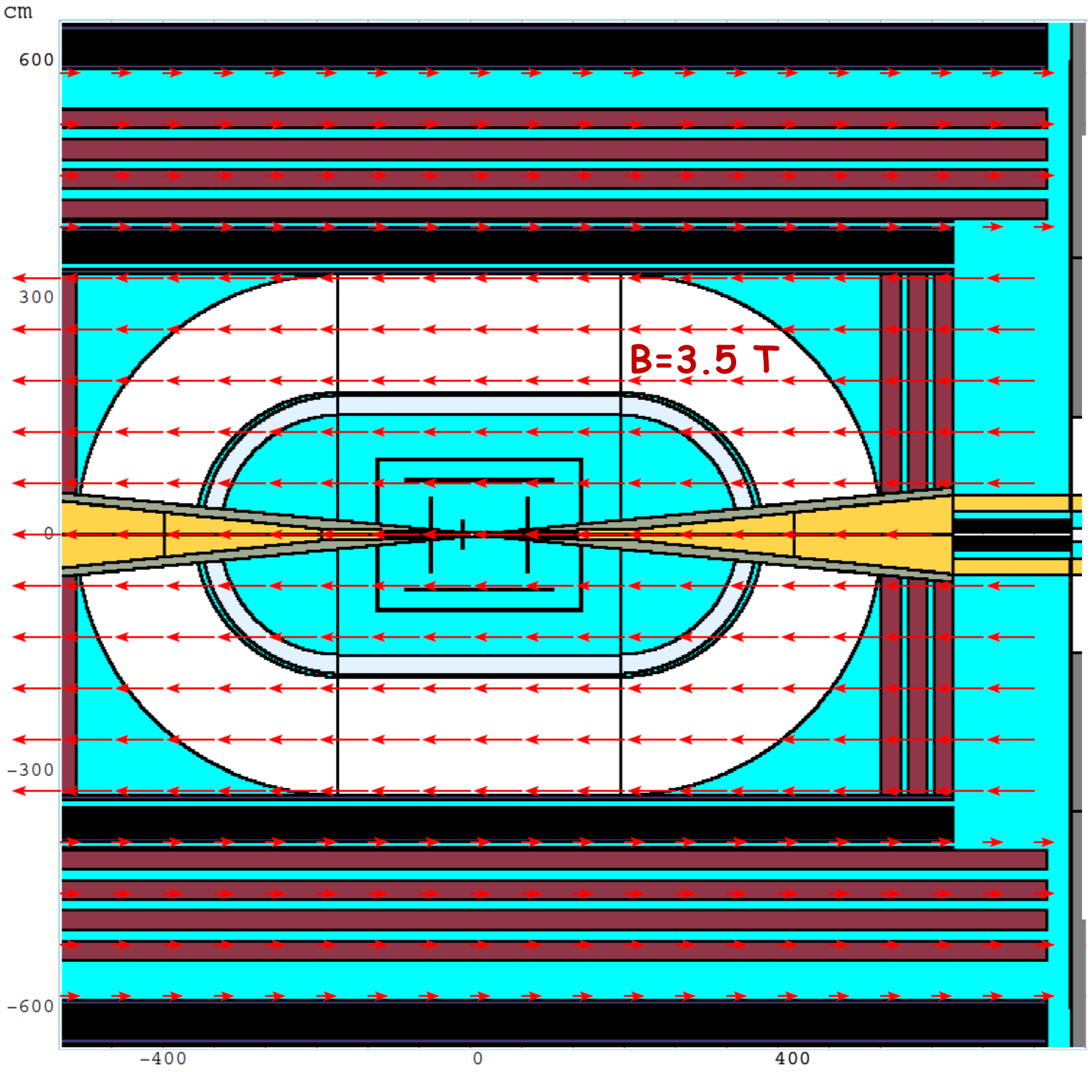
1. **Minimize it** as much as possible (20^0 to $6\text{-}9^0$) because of limitations on possible physics:
   - Top production in forward regions as CoM energy goes up
   - Asymmetries are more pronounced in forward regions
   - Z' => ttbar
   - Final states with many fermions (like ordinary SM tt events) are hardly ever contained in the central detector

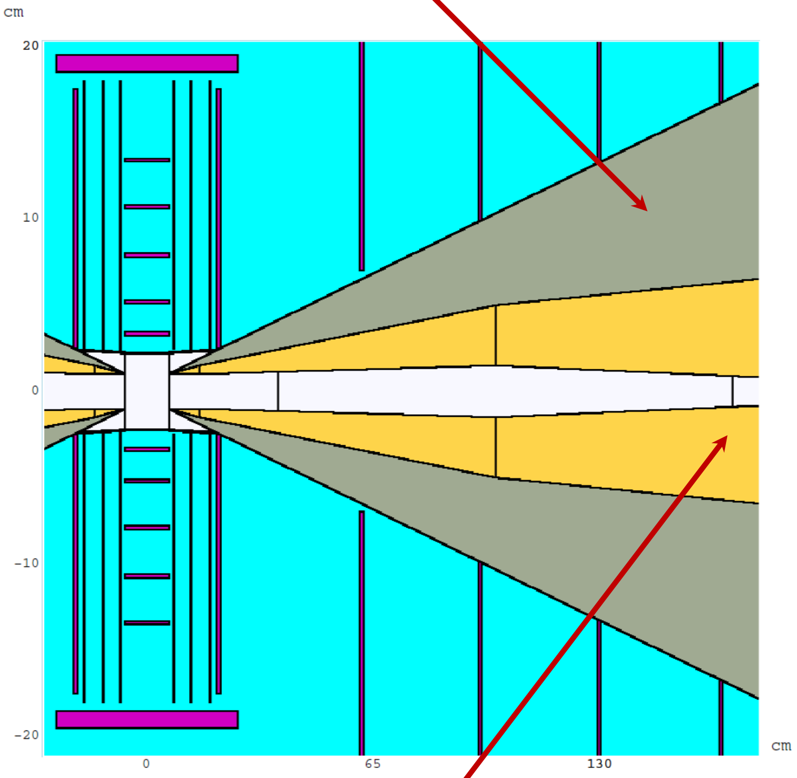
2. **Instrument it**:
   - Forward calorimeter
   - Lumi-cal a'la ILC – 40-140 mrad for precise measurement of the integrated luminosity ($\Delta L/L \sim 10^{-3}$)
   - Beam-cal at smaller angles for beam diagnostics

MARS15 Modeling

- 250-m segment of the lattice implemented in MARS15 model with cosθ and dipoles and quads.
- Model includes rather detailed magnet geometry, materials, magnetic fields (maps and simplified descriptions), tunnel, soil outside and a simplified experimental hall plugged with a concrete wall; no masks in interconnect regions.
- It includes 4th concept ILC detector with B_z=3.5 T and tungsten nozzle in a BCH_2 shell (6° cone, Nov. 2009), starting at ±6cm from IP with R=1 cm at this z.
- 750-GeV bunch of 2×10^{12} μ^- approaching IP is forced to decay at -10 to 200 m at 4.28×10^5 per meter rate.
- Cutoff energy is optimized for materials & particle types, varying from 2 GeV at ≥100 m to 0.025 eV in the detector.

4th Concept Detector at MC: MARS15 Model



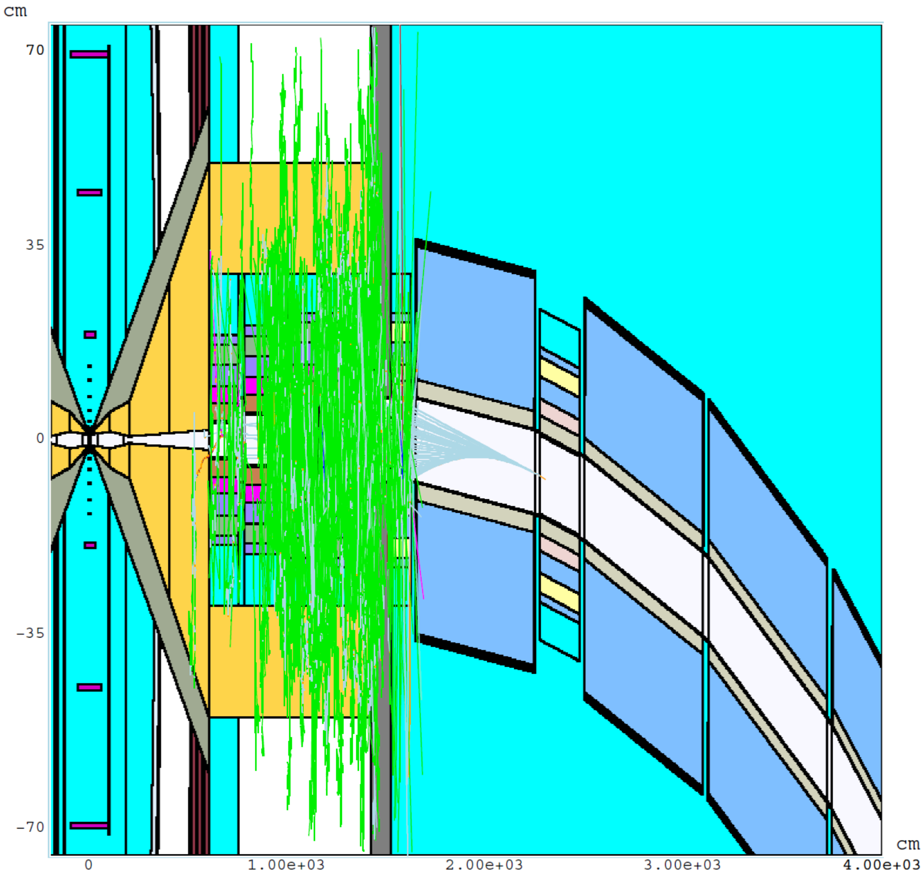


Borated poly

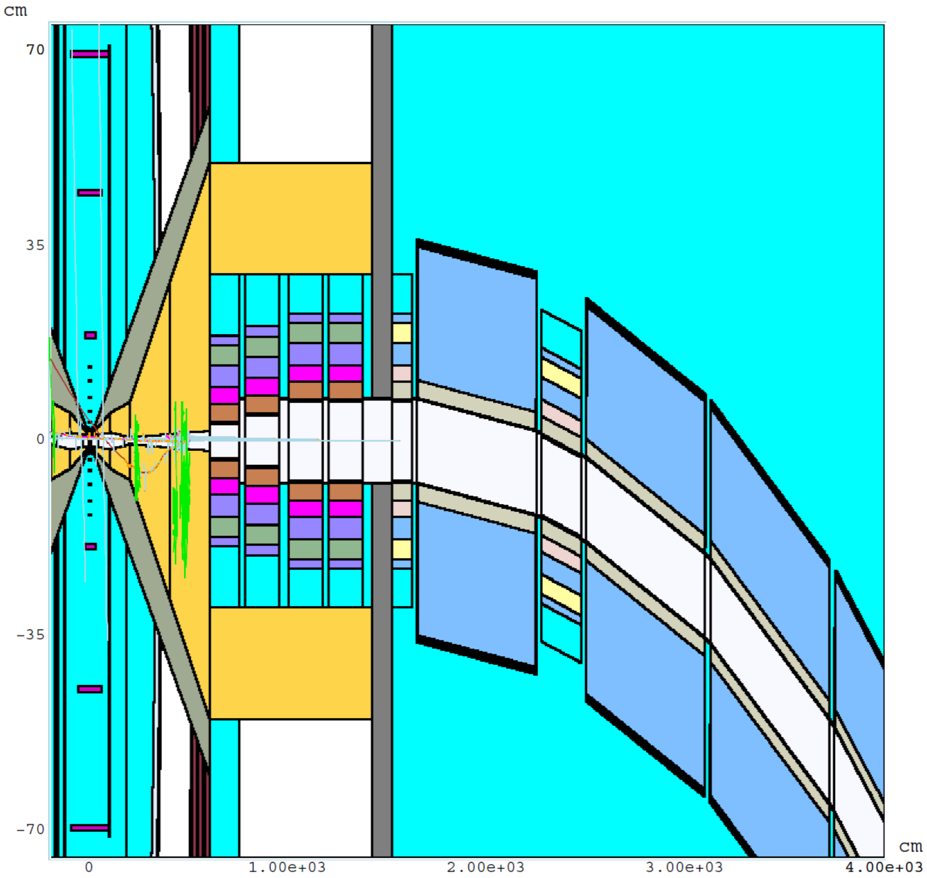
Tungsten

Two Decay Event Displays

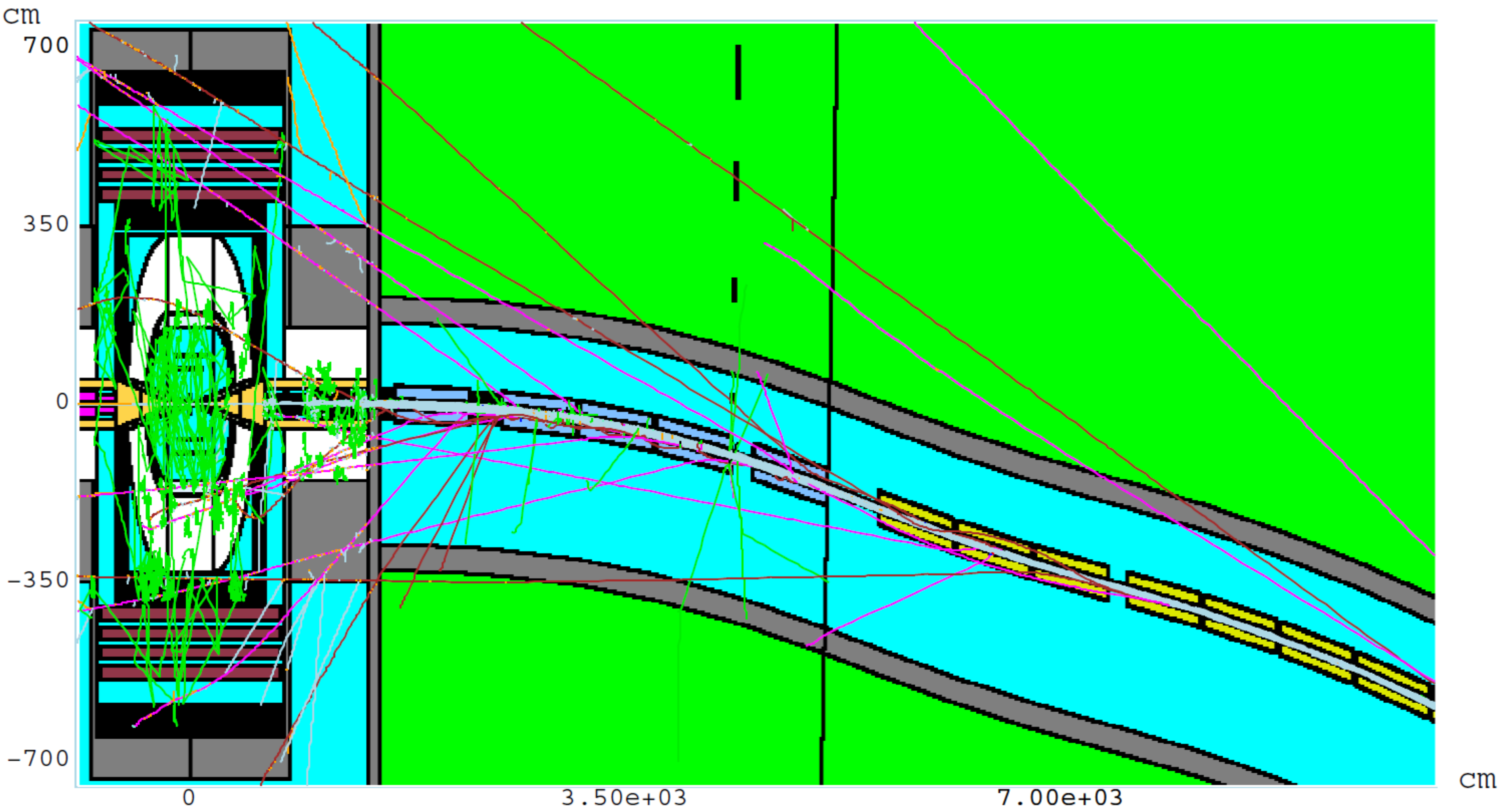
First event



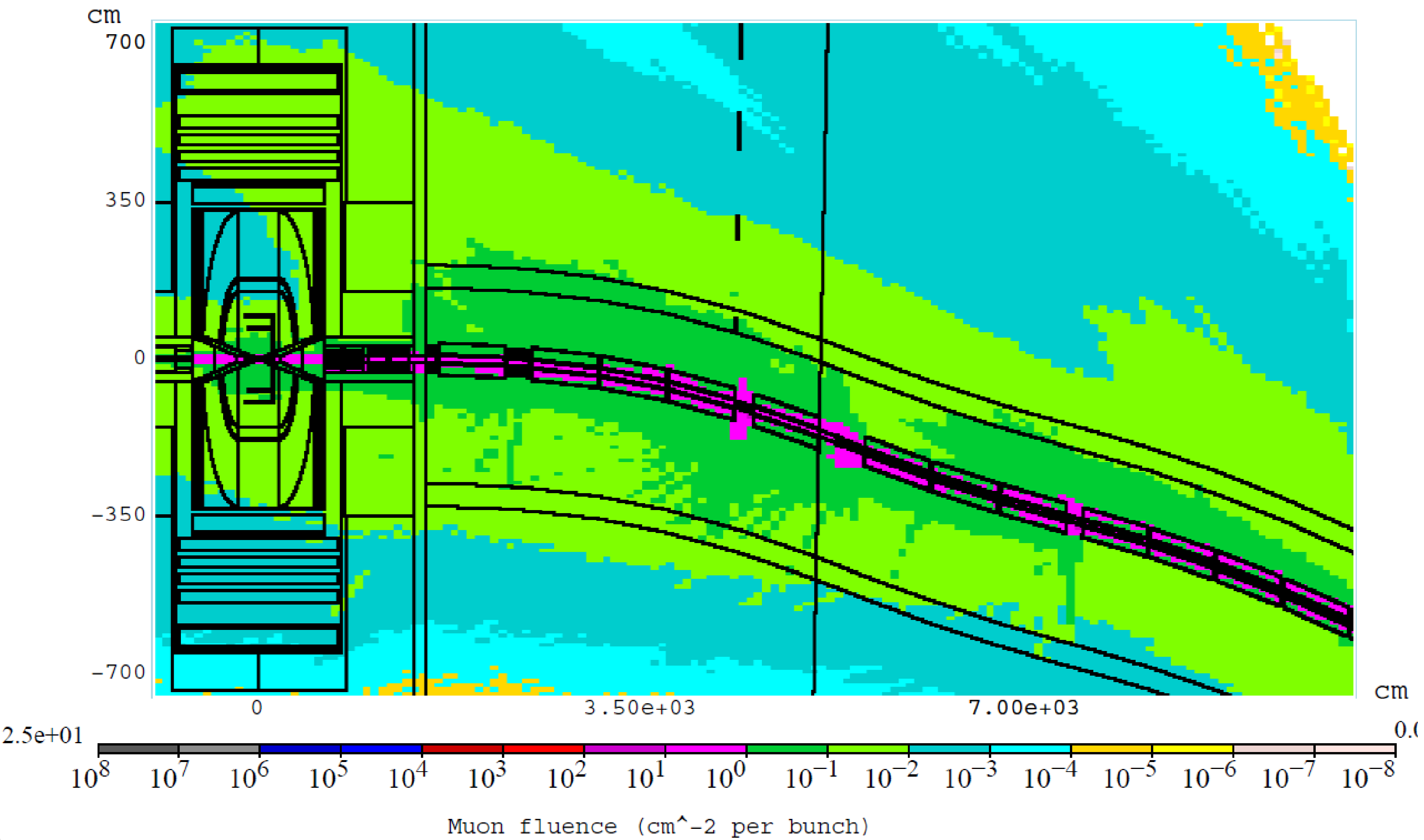
Second event



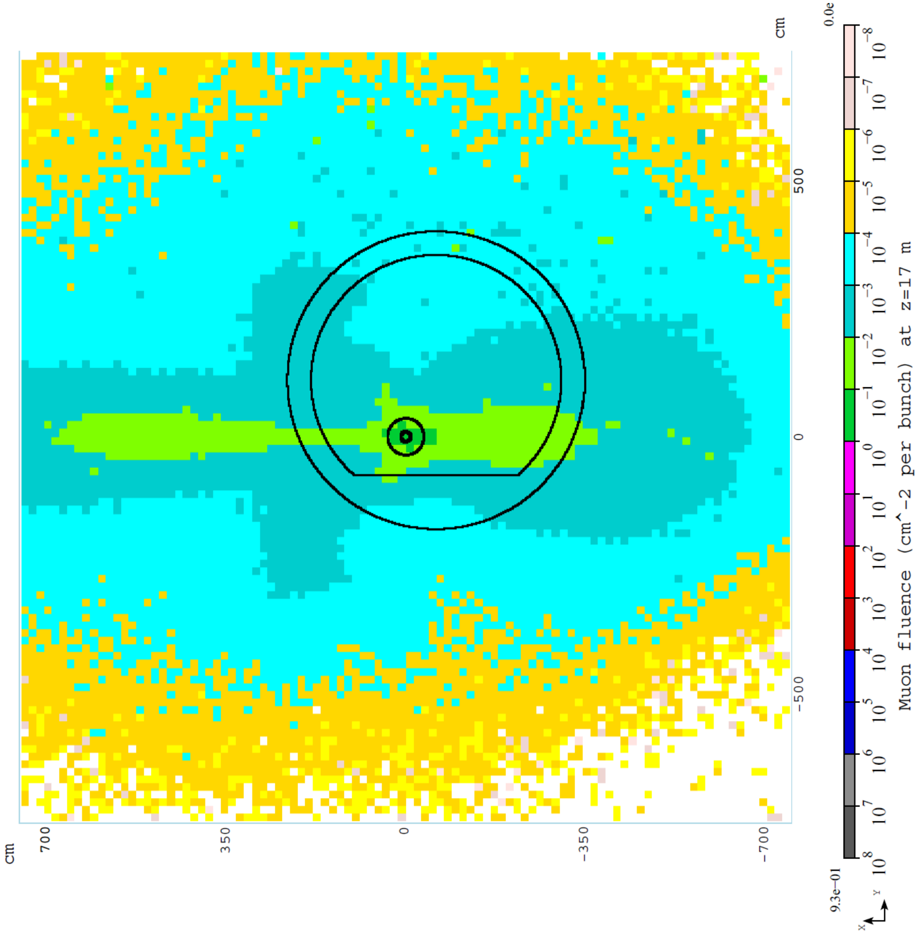
Tracks in IR

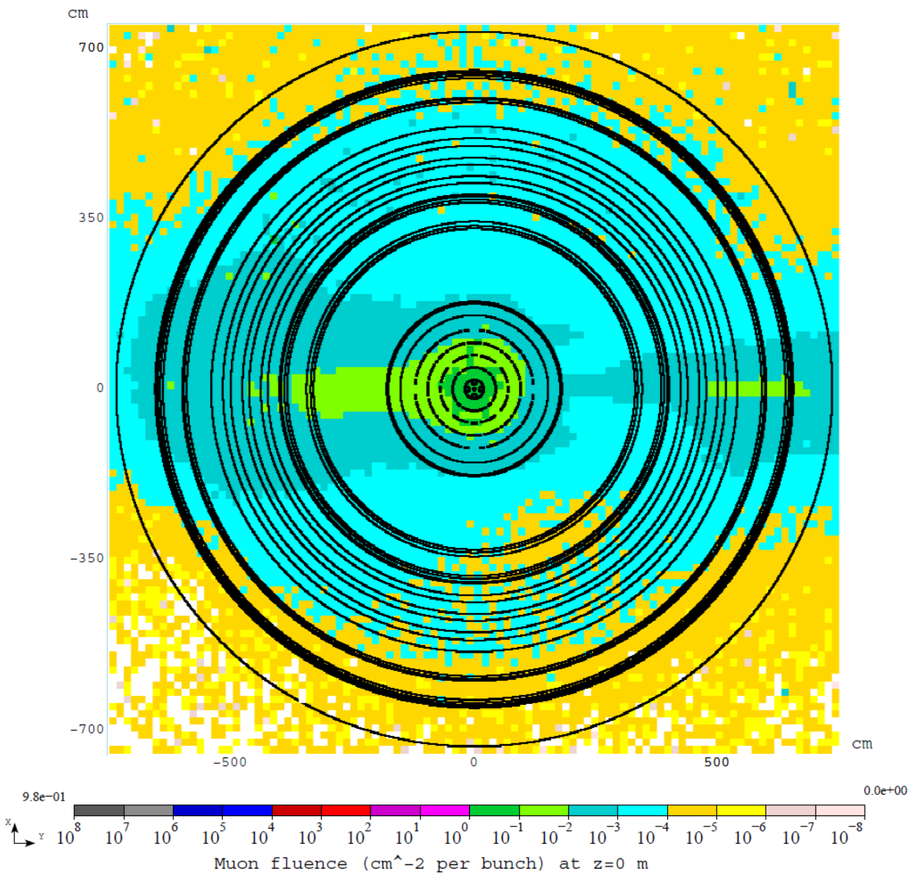


Muon Fluence in Orbit Plane

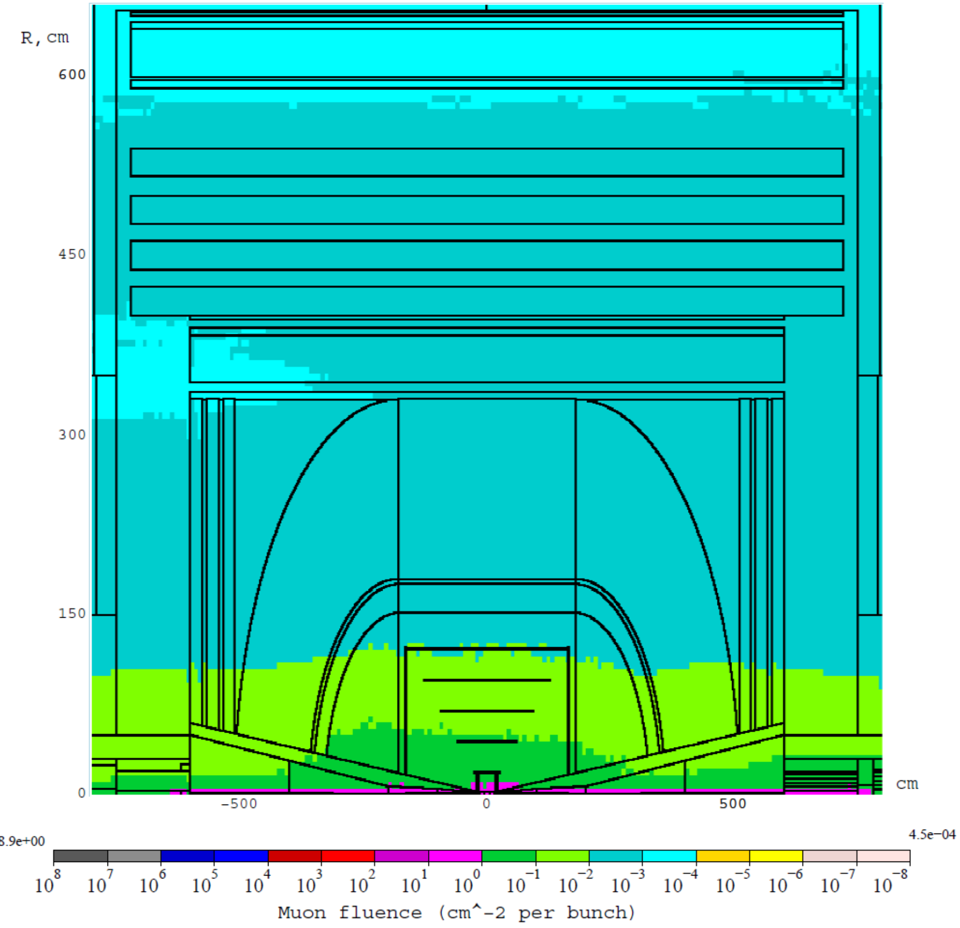


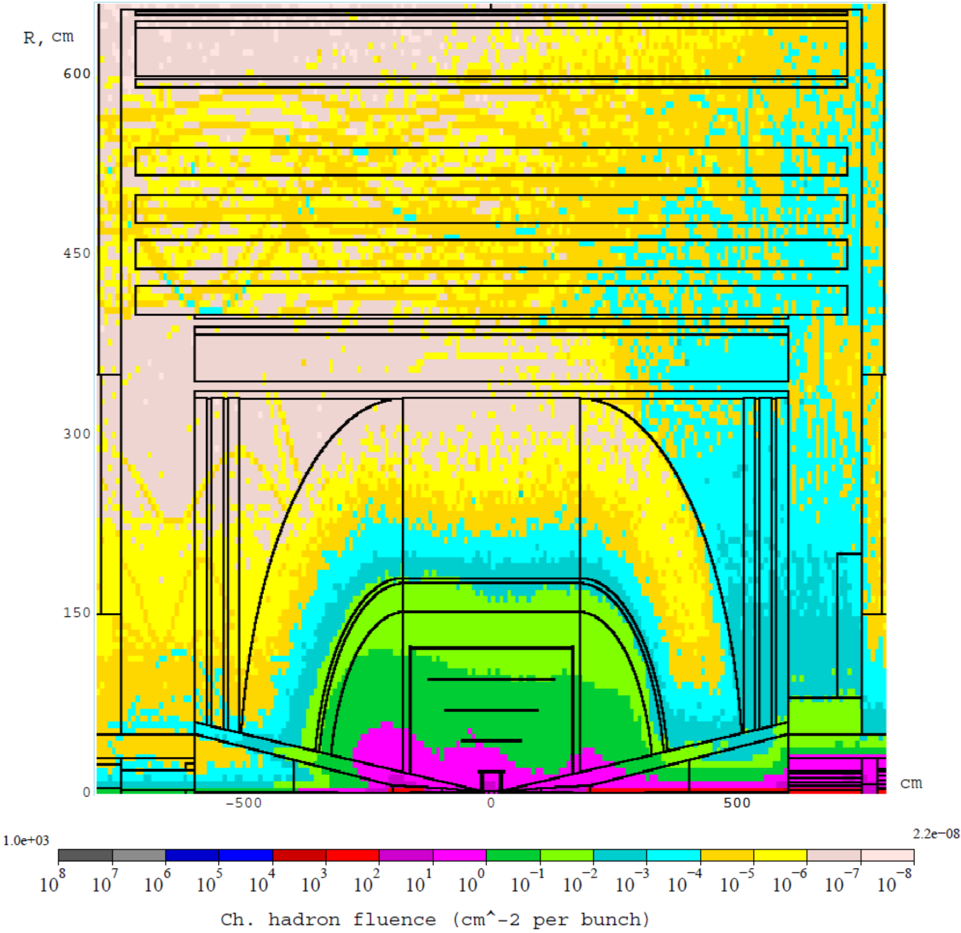
Muon Fluence at z=17 m and z=0



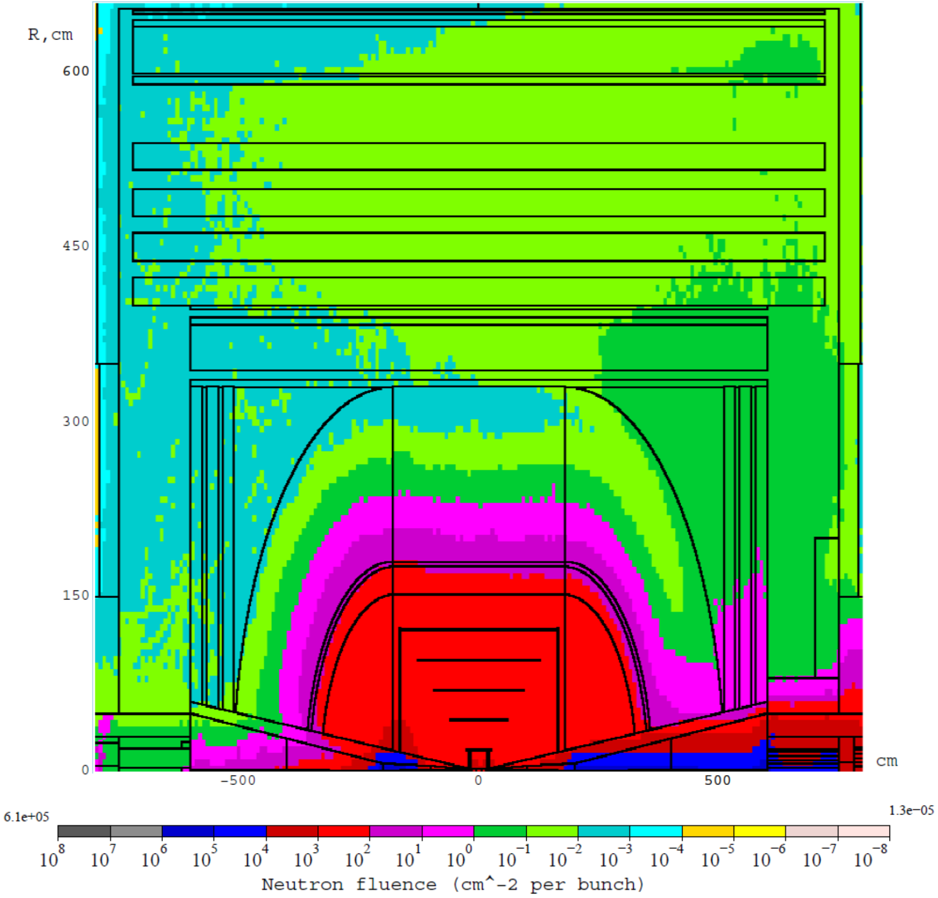


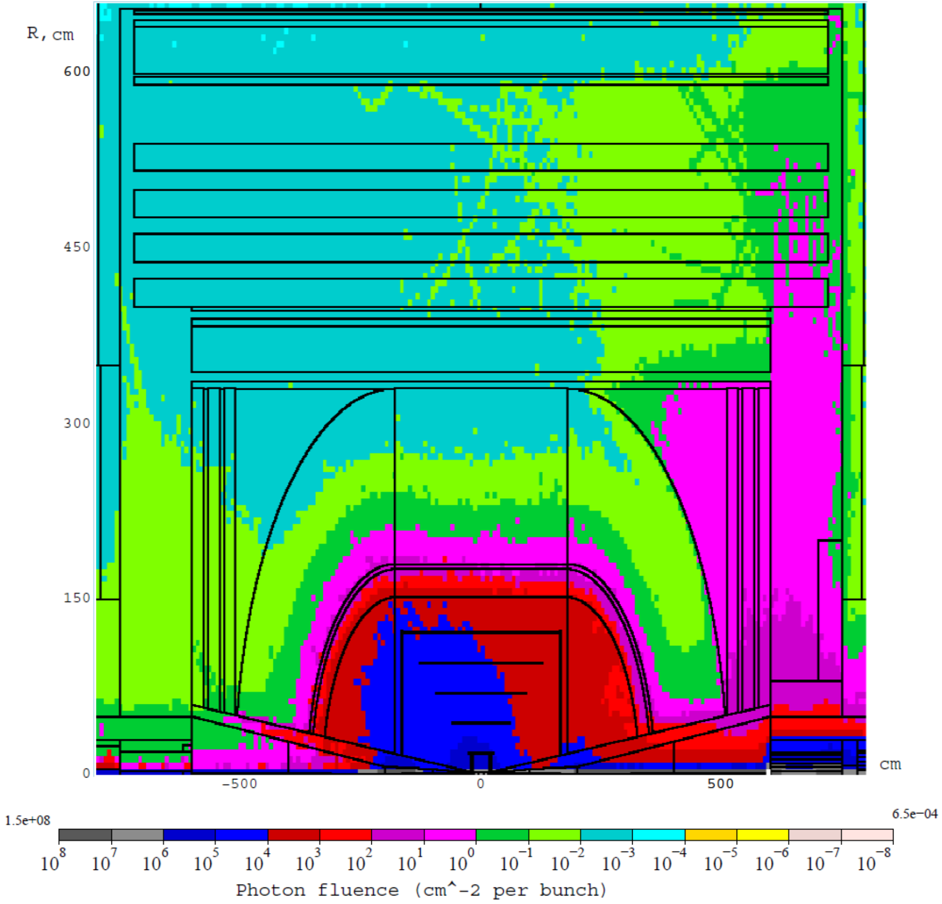
Muon and Charged Hadron Fluence



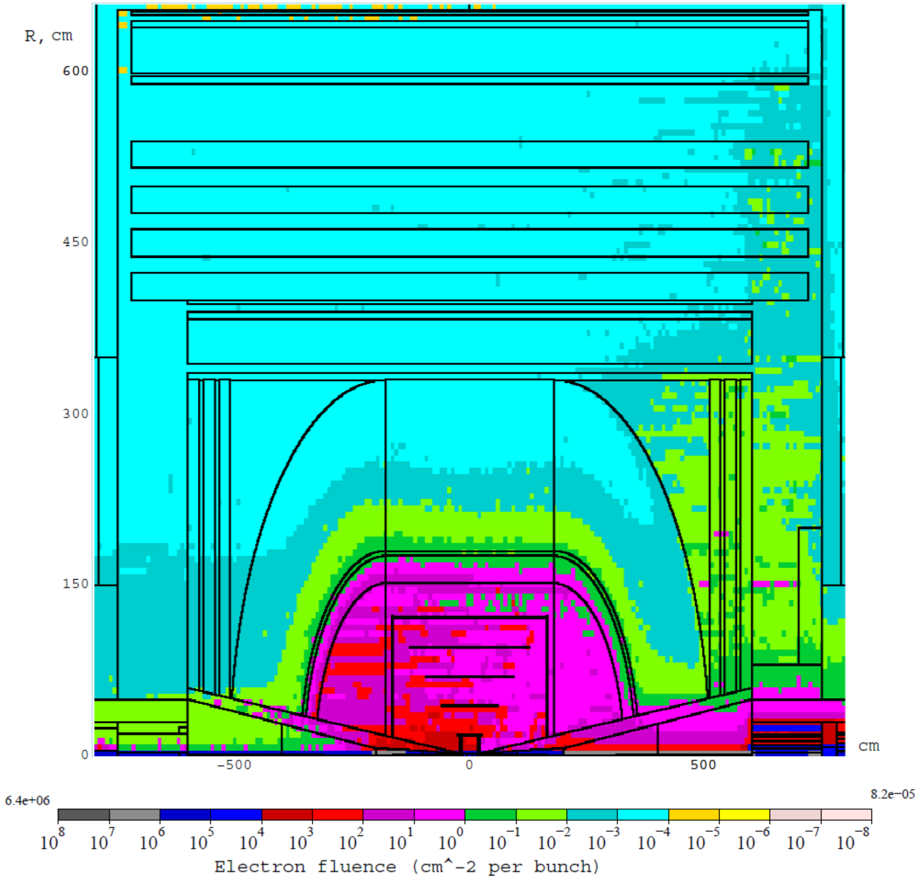


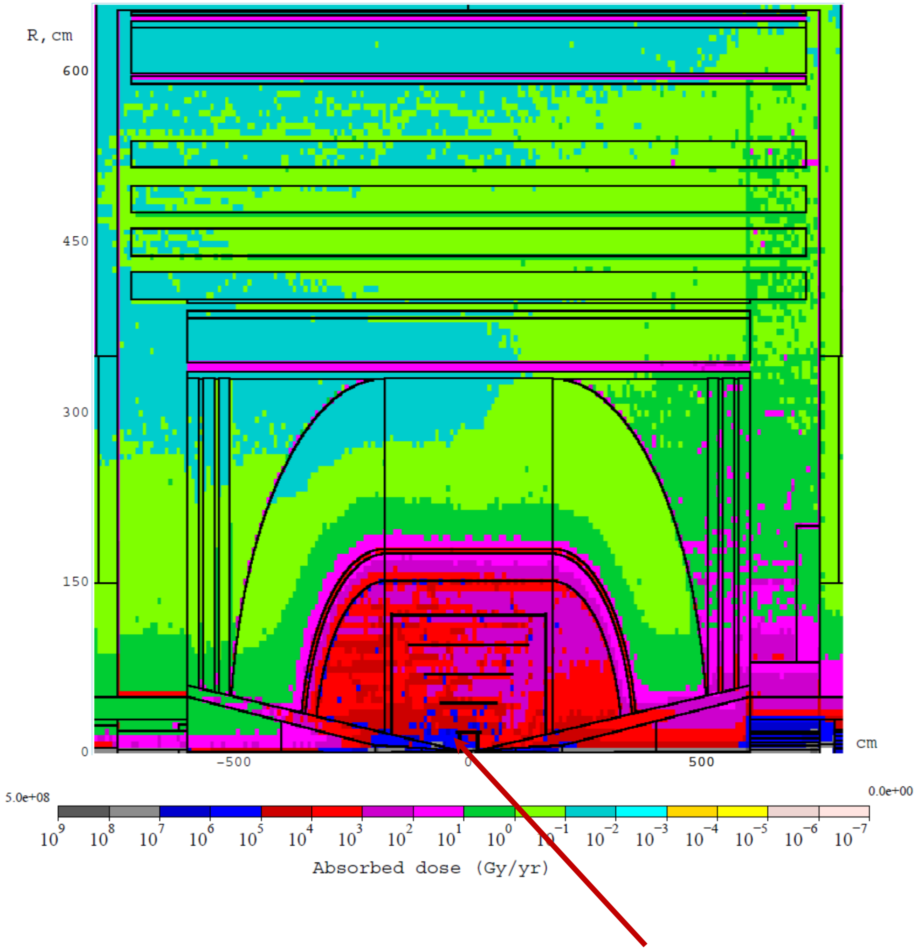
Neutron and Photon Fluence





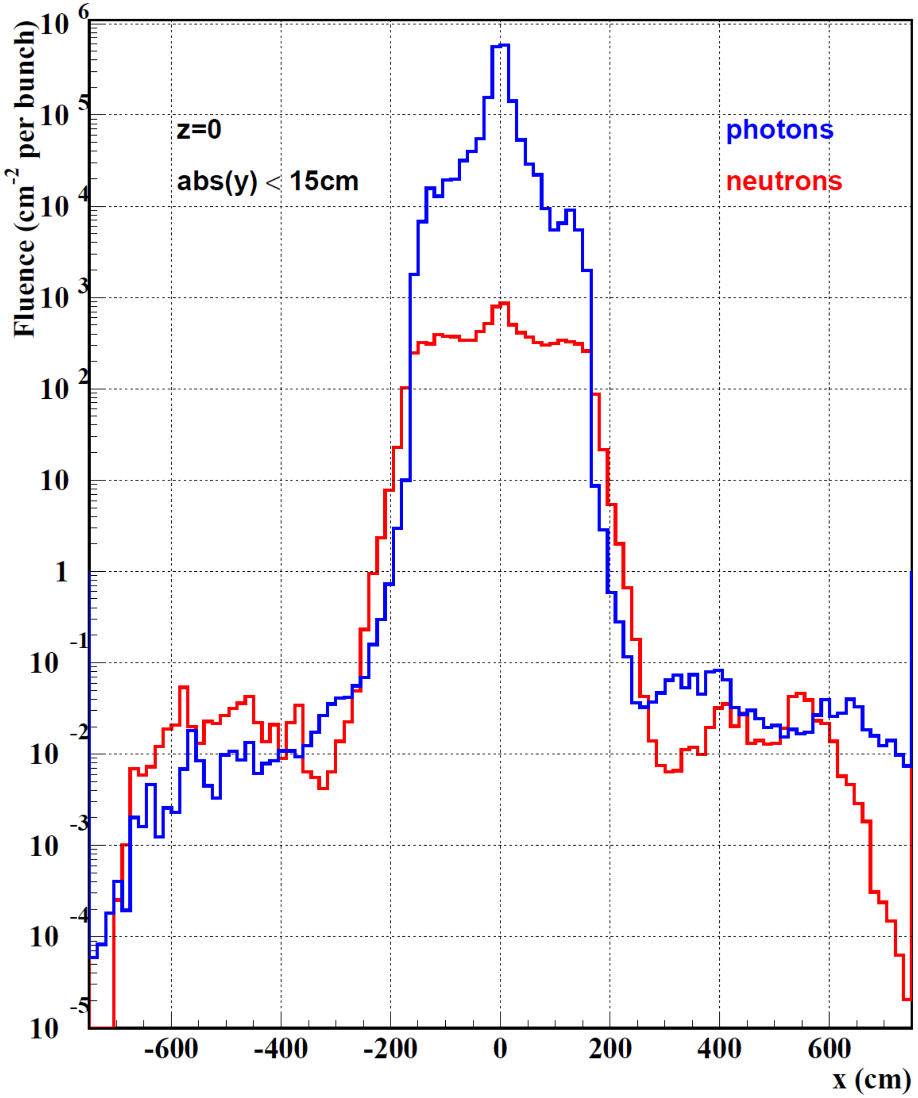
Electron Fluence and Total Dose per Year

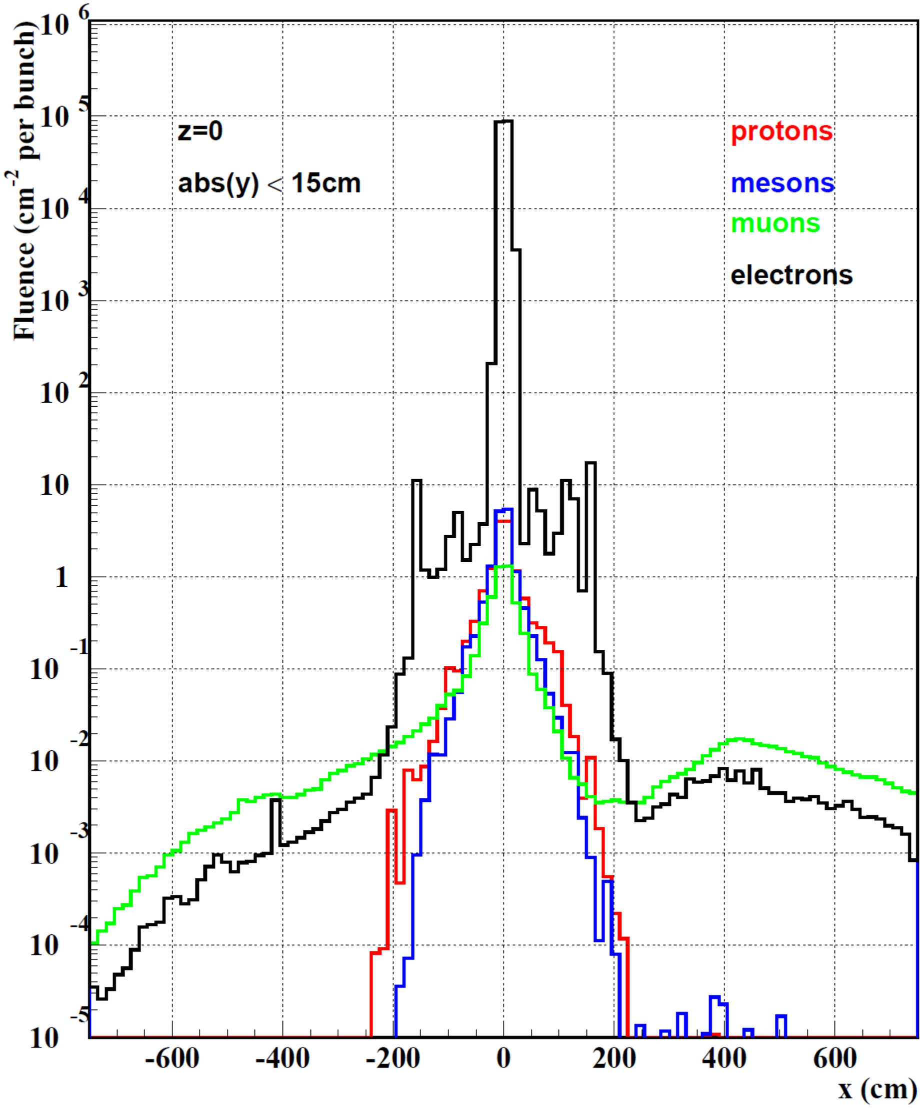




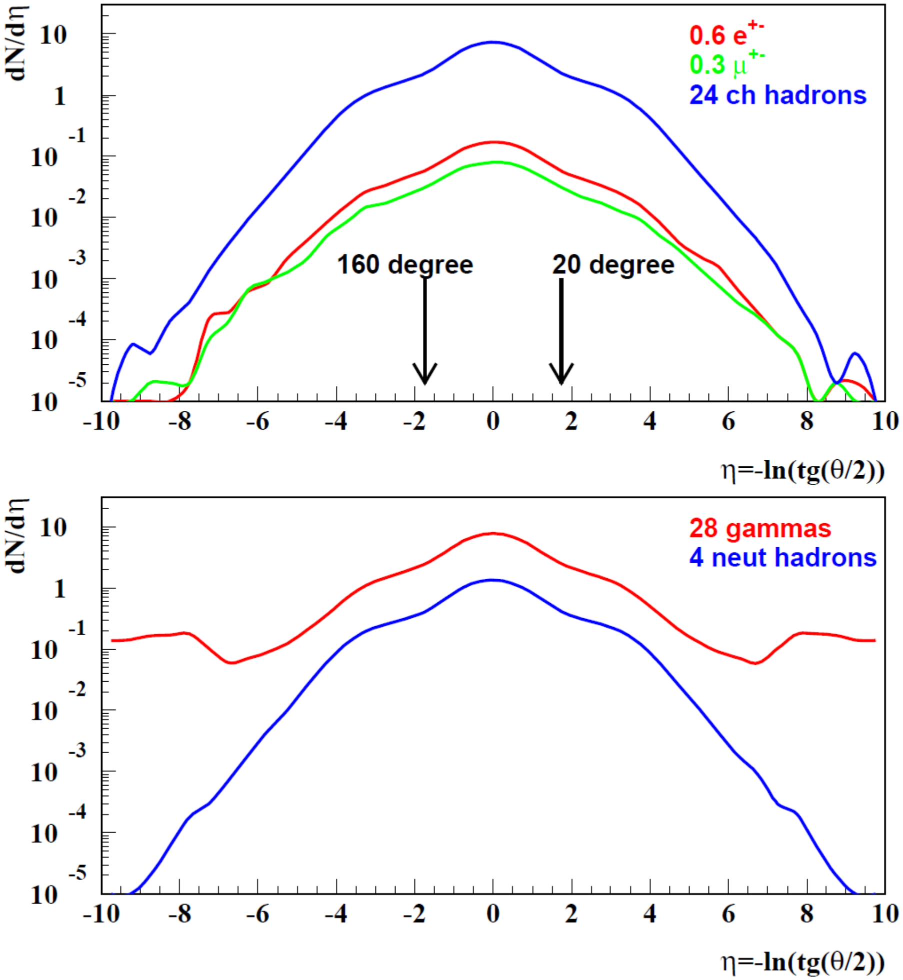
~1 MGy/yr for 2 beams

Particle Fluence in Horizontal Plane at z=0

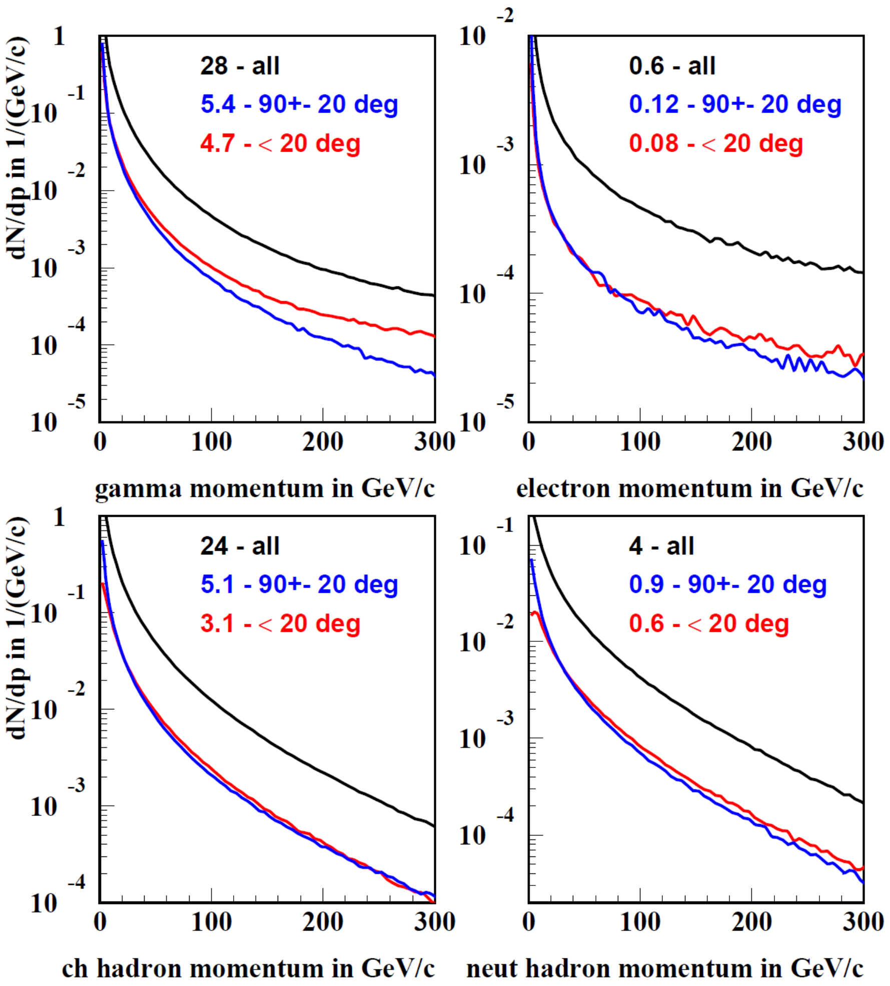




Rapidity and Momentum Spectra from $\mu^+\mu^-$ Collision



$\mu^+\mu^- \rightarrow \gamma^*/Z^0$ at 1500 GeV (1.34 pb)



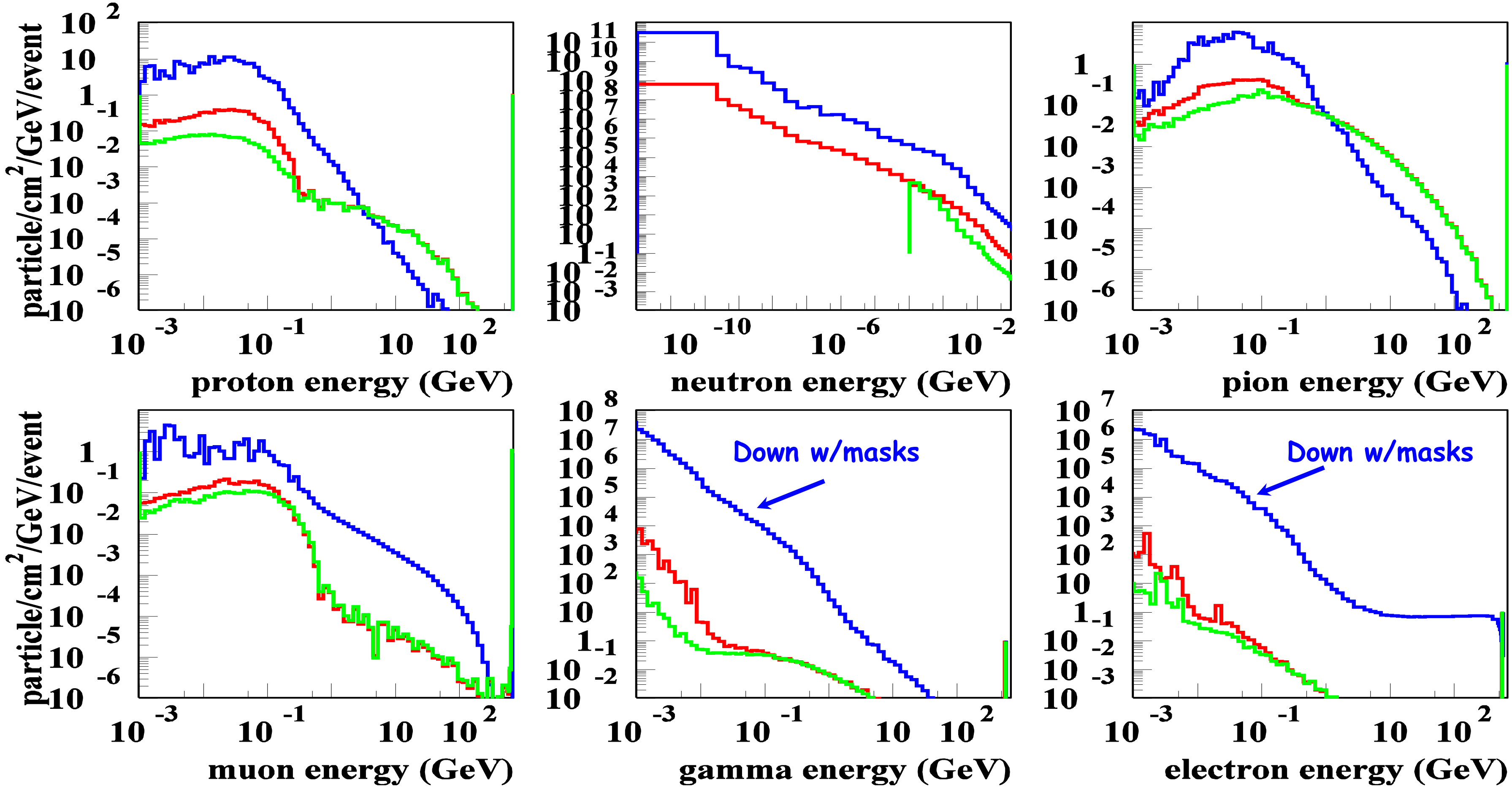
$\mu^+\mu^- \rightarrow \gamma^*/Z^0$ at 1500 GeV (1.34 pb)

PYTHIA calculations

Machine vs Vertex Backgrounds in Tracker

Energy spectra in tracker (+-46x46x5cm)

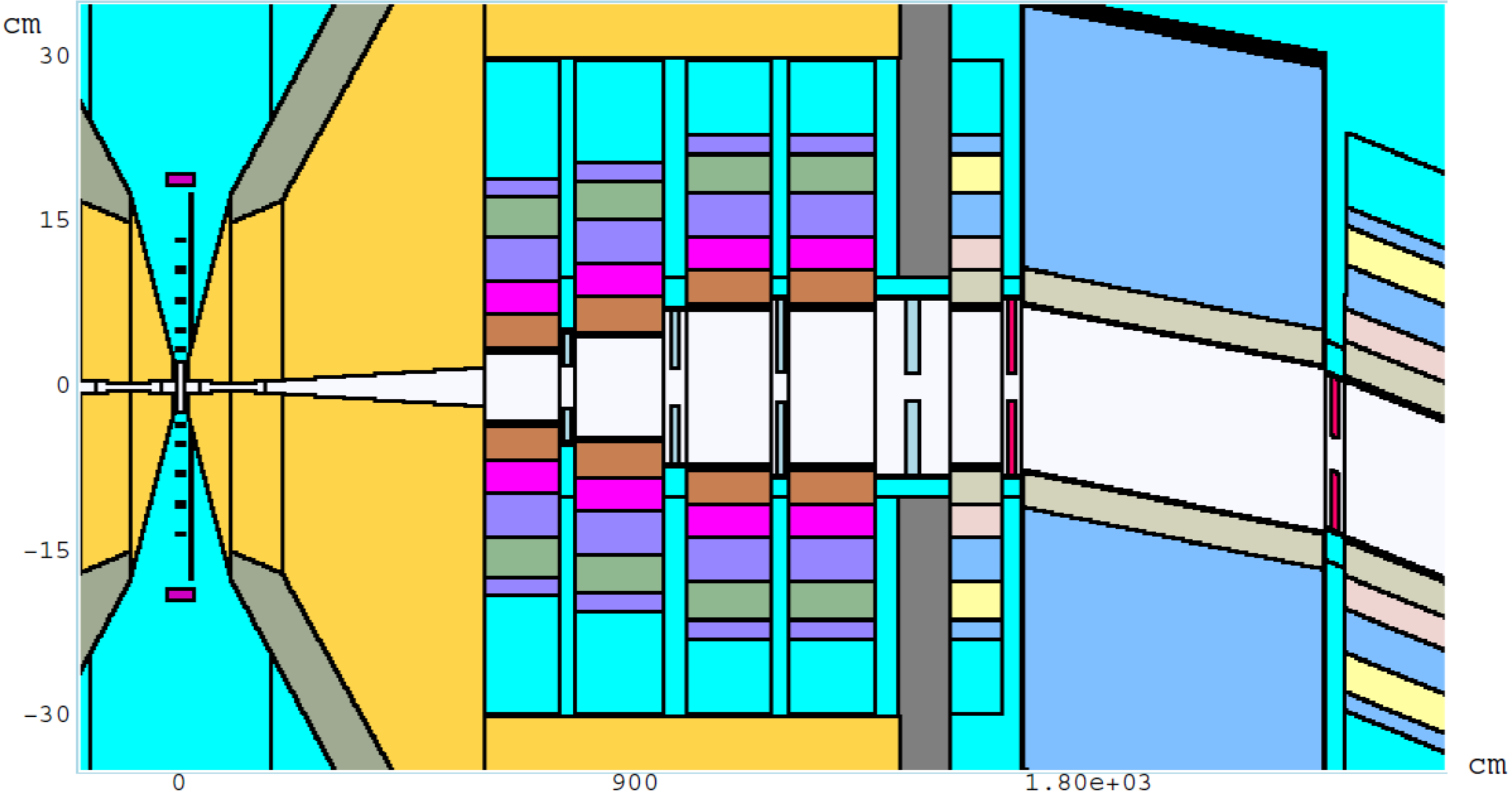
Blue lines - from machine, red lines – Z0 events, green lines - Higgs events



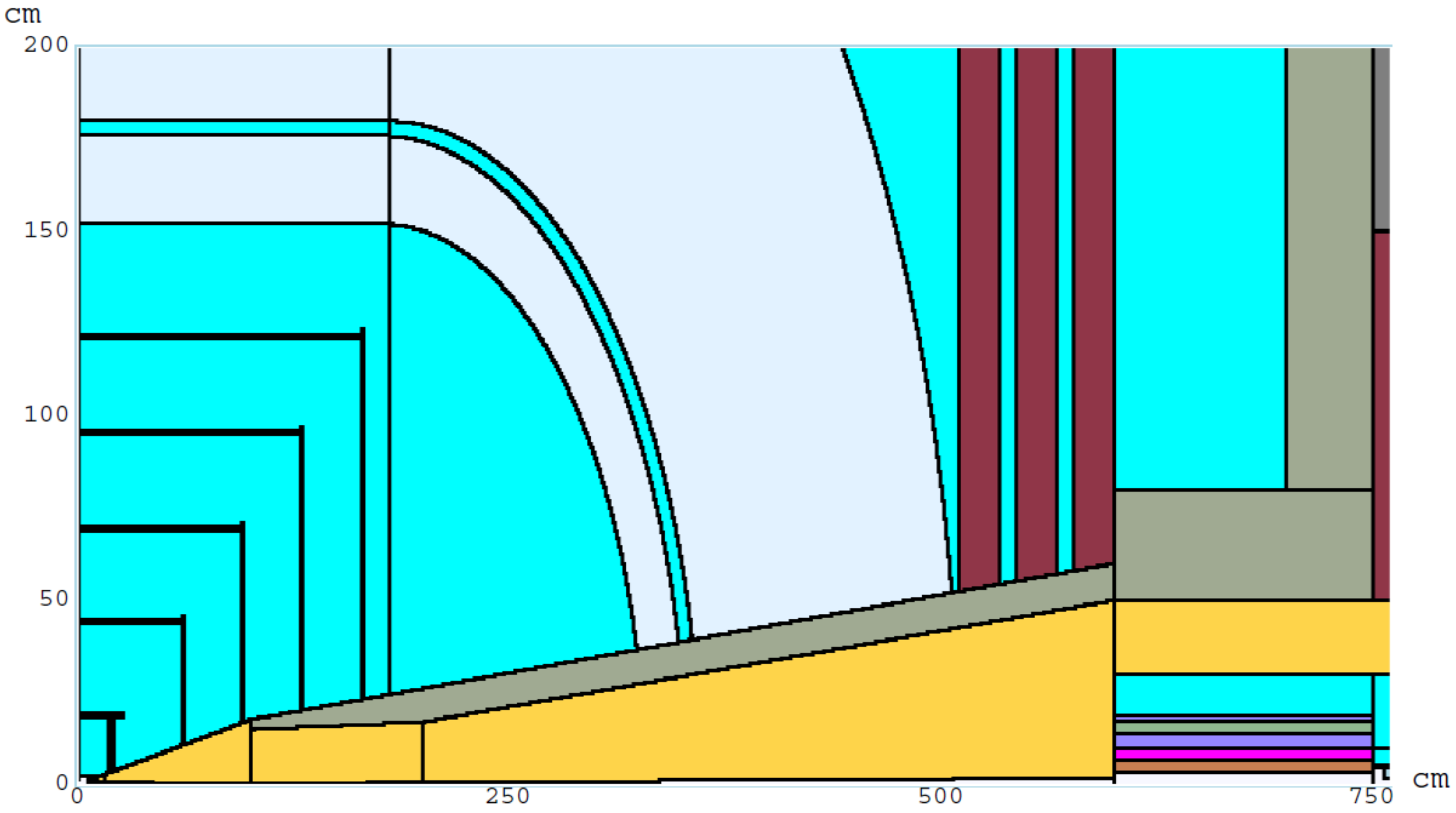
MARS15 Modeling (January 2010)

- Updated IR lattice with magnet interconnect constraints fulfilled and 5σ 10-cm tungsten masks between quads.
- Further refined geometry of MDI and 4th concept ILC detector with B_z=3.5 T, with shielding and BCH_2 liners wherever needed.
- Tungsten nozzle starting at ±6cm from IP with R=1 cm at this z, BCH_2 shell (re-optimized). Variation of its outer angle (6, 10, 15 and 20 degrees). Optimization of its opening shape.
- 750-GeV bunch of 2×10^{12} μ^- approaching IP is forced to decay at -10 to 200 m at 4.28×10^5 per meter rate. To speed up calculations, some optimizations were done with z_{max}=35 m or 75 m rather than 200 m.
- Conceptual design of open midplane dipoles and a family of quads fulfilling IR constraints; their realistic geometry and magnetic field maps implemented into MARS model; simulations to start next week.

MARS15 MDI Model (January 2010)

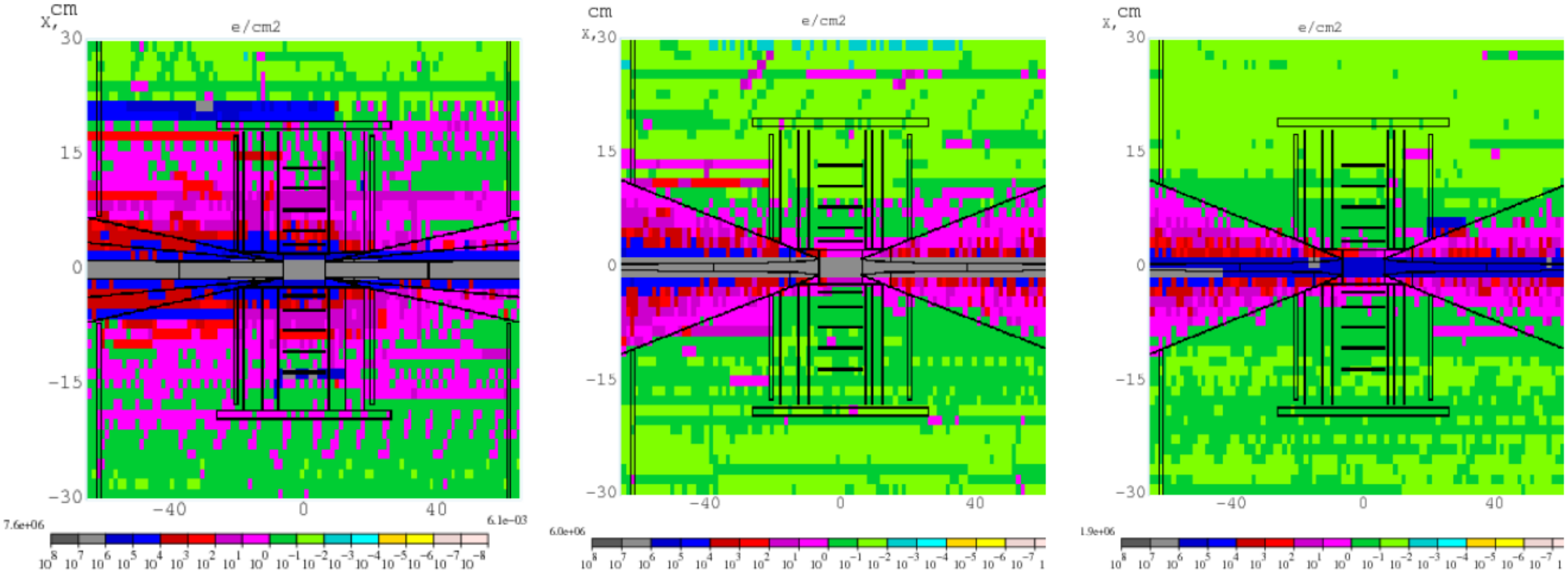


MARS15 MDI Model (January 2010)



Electron Flux (preliminary)

At CL and r=5cm: **1** **~1/300** **~1/200**



Left: Initial cone configuration (6°, 5σ inner radius up to 2m from IP), as reported at the November workshop at FNAL

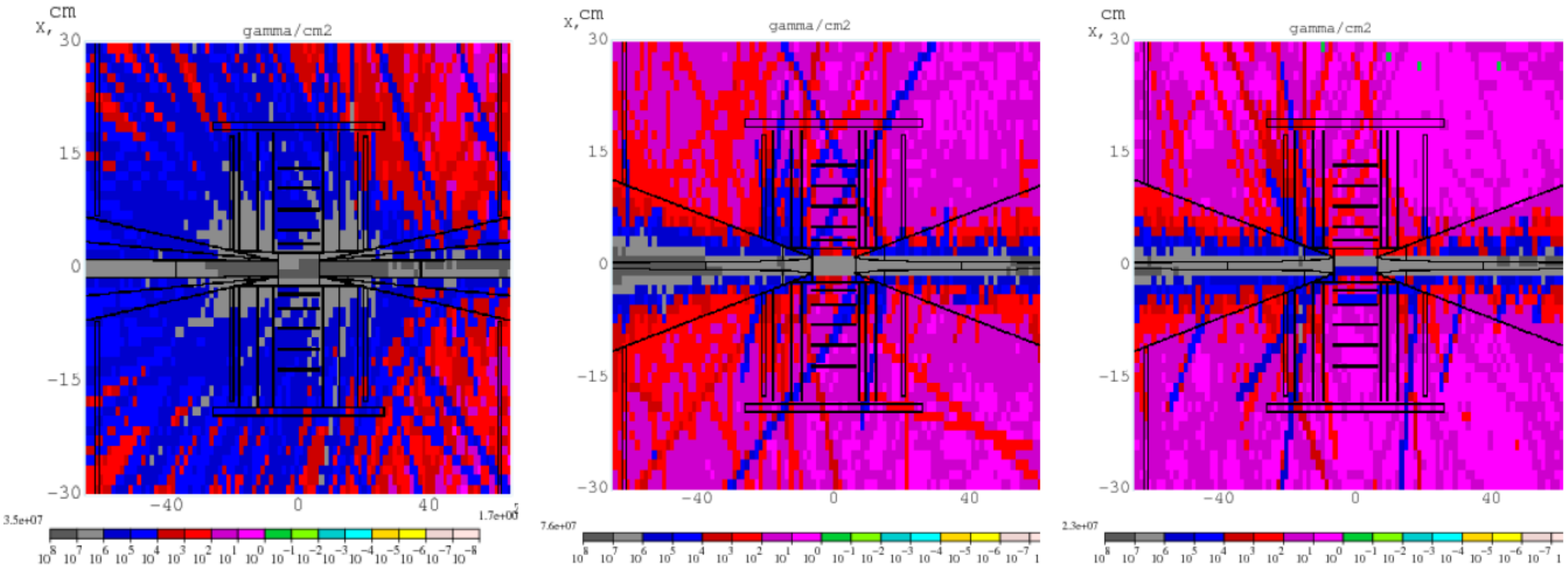
Central: Cone angle increased to 10 °, 5σ inner radius up to 1m from IP, 5σ masks inserted between FF quads

z_{max}=75 m

Right: Same, plus FF quads displaced by 1/10 of the aperture (2-T dipole component helps mitigate neutrino radiation problem)

Photon Flux (preliminary)

At CL and r=5cm: **1** **~1/20** **~1/300**



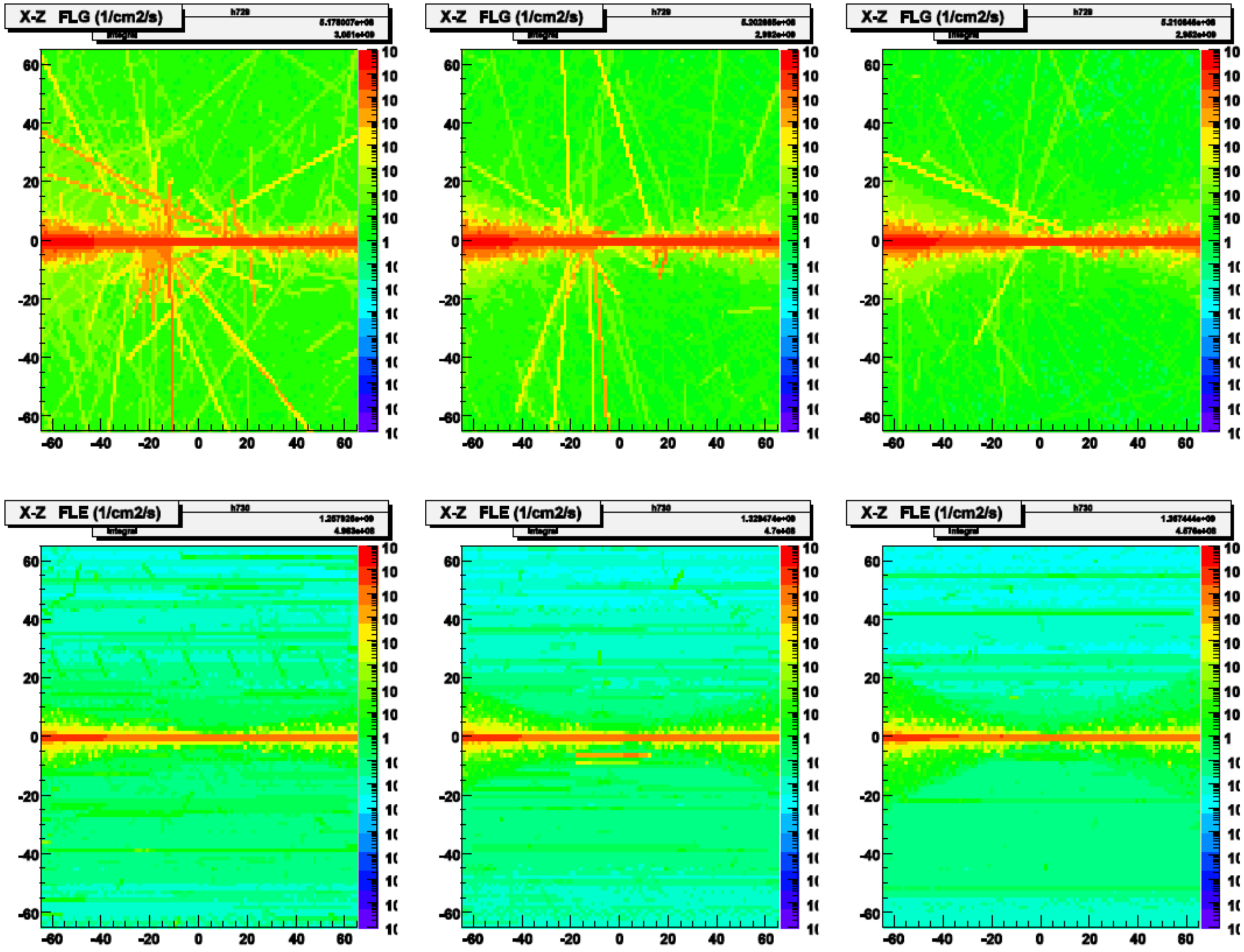
Left: Initial cone configuration (6°, 5σ inner radius up to 2m from IP), as reported at the November workshop at FNAL

Central: Cone angle increased to 10 °, 5σ inner radius up to 1m from IP, 5σ masks inserted between FF quads

Right: Same, plus FF quads displaced by 1/10 of the aperture

z_{max}=75 m

Cone Outer Angle: 10°(L), 15°(C), 20°(R),



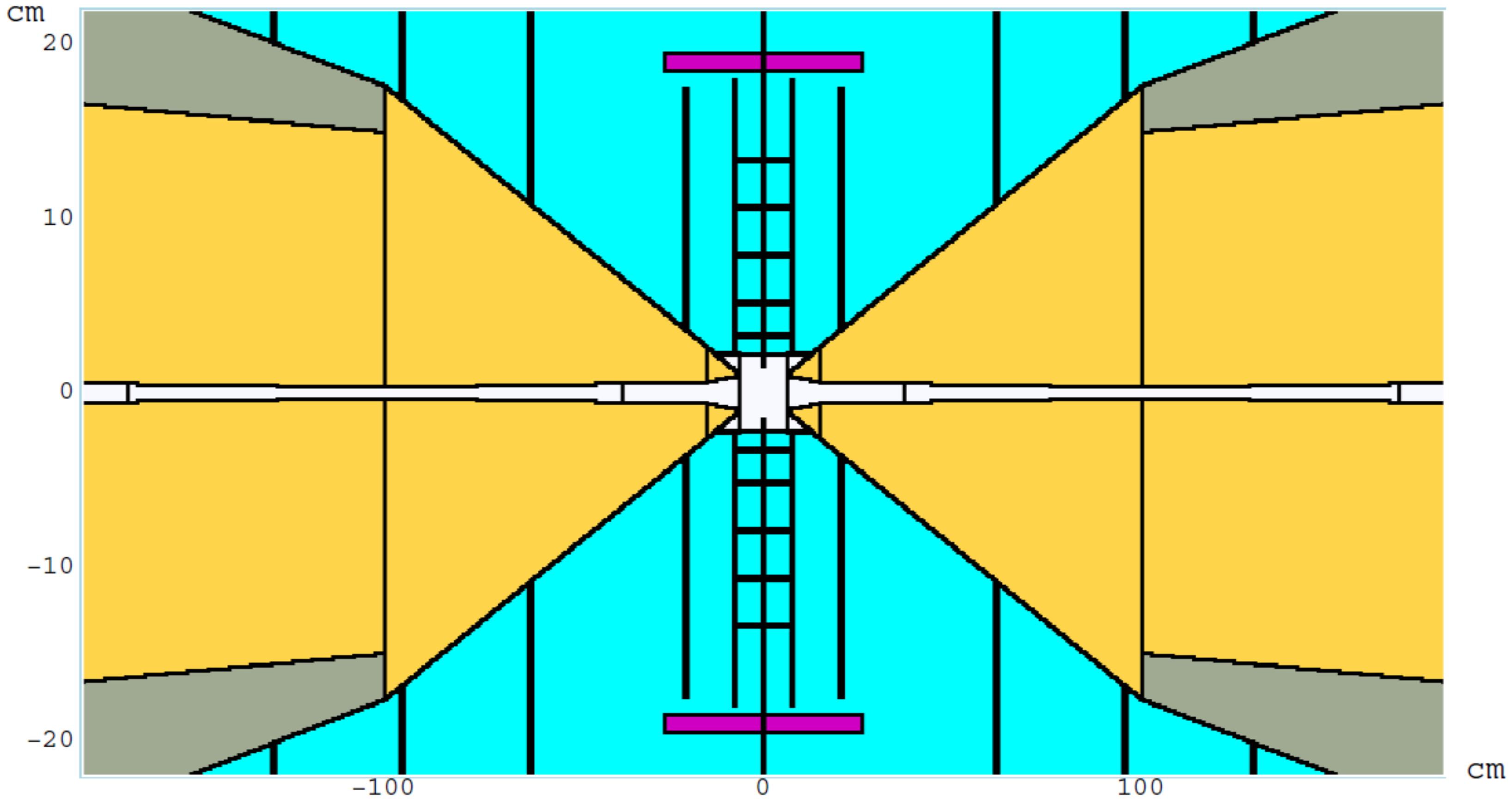
Photons

Electrons

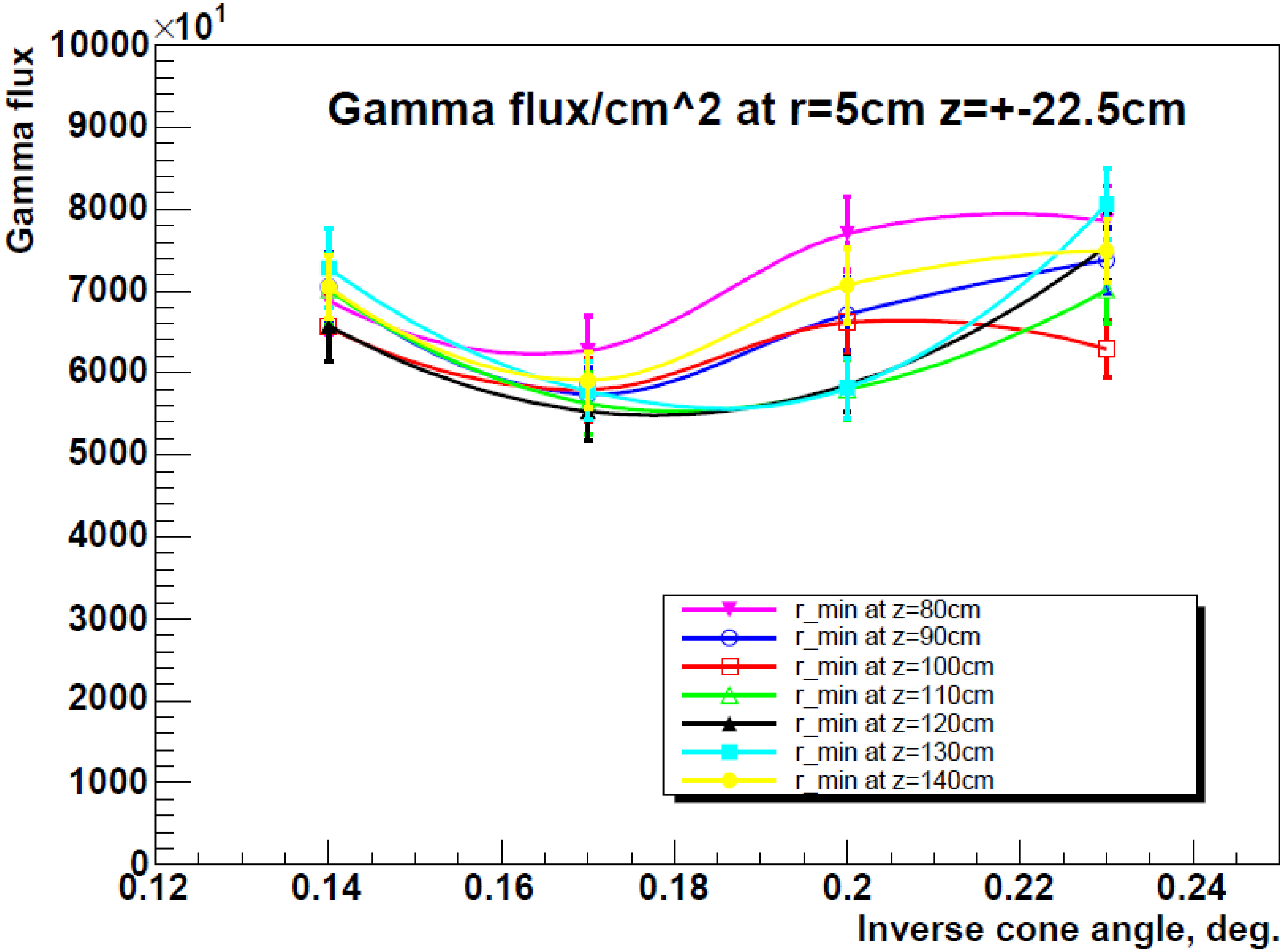
z_{max}=75 m

Preliminary: 10 degree cone is OK

Cone Opening Optimization



Inner Cone Shape Optimization



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Optimum:
z~120 cm
with r=3.6mm
at this z.

z_{max}=35 m

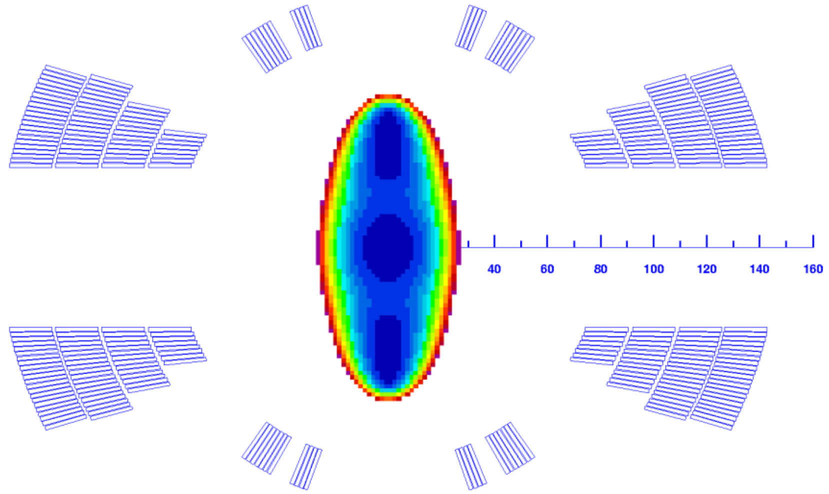
IR Magnets

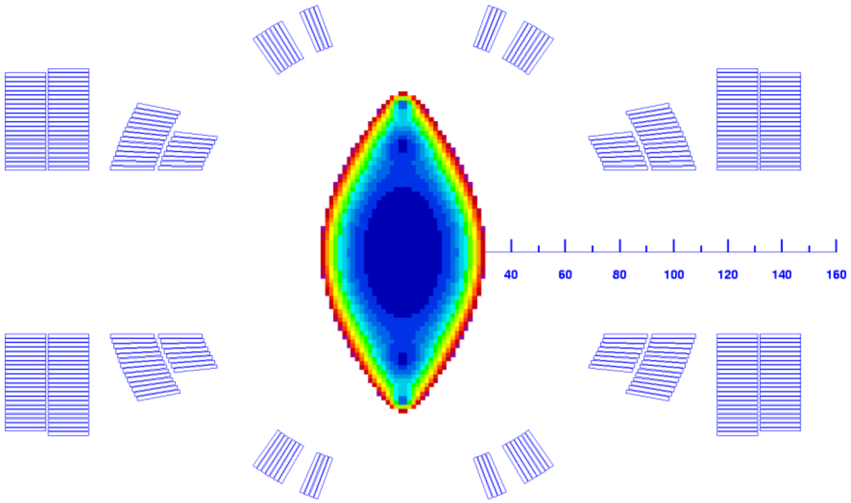
The show-stopper in MC MDI studies is detector backgrounds. That is why in these new-wave efforts we are first focusing on this issue. The ways are known to deal with high energy deposition levels in coils related to three critical problems in SC magnets: peak power density (quench stability), dynamic heat loads (cryogenics) and radiation damage (lifetime).

Some of them are already implemented in the MDI design (short magnets with masks in between, liners, open mid-plane dipoles). Their optimization as well as consideration of additional possibilities suggested (exotic materials, permanent magnets etc.) will be done iteratively along the road.

Note: power load on lattice elements by decay products is about 0.5 kW/m for 1.5 TeV MC. Manageable level for LHe cryogenics is ~10 W/m, i.e. almost all the load is on the catching components (masks, liners and rods in open mid-plane dipoles) which therefore need to be cooled at LN2 or room temperature.

IR BE1 Open-Midplane Dipole





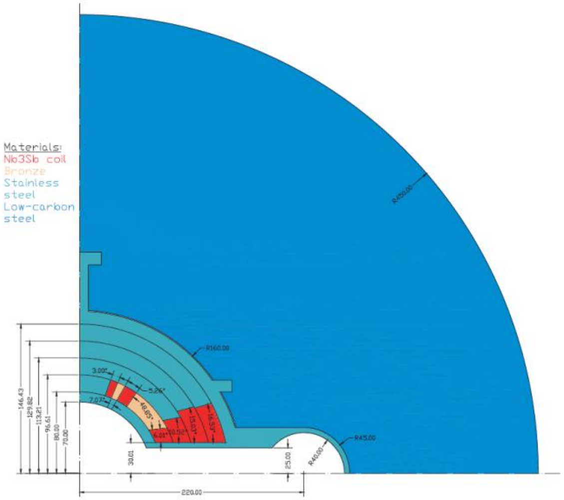
- One of the most challenging magnets in the list: large midplane gap and unusual aperture requirements
- Same concept as for the ring dipole, but field quality optimized for the vertically elongated beam
- Two double-shells or shell/block hybrid
- B_{op} ~ 8T with ~22% margin at 4.5K in either case.
- Midplane gap:

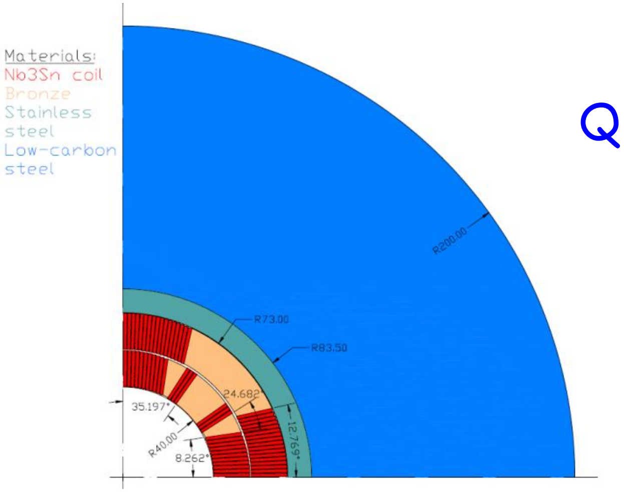
Coil-coil – 60mm

Clear – 50mm

New IR Magnet Design and Implementation in MARS

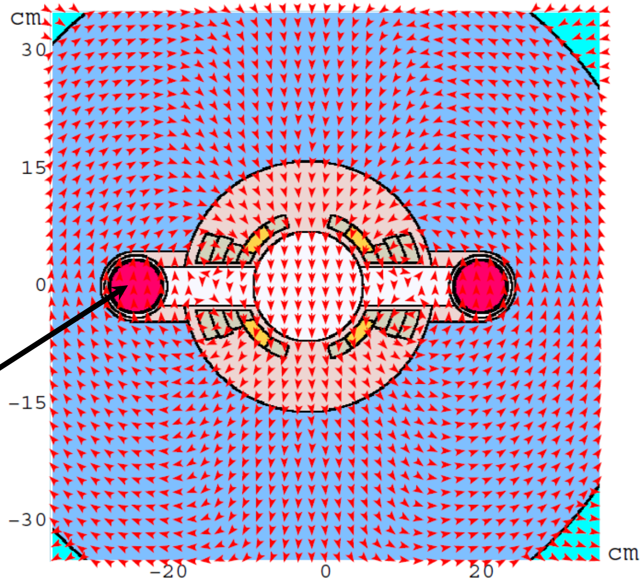
BE1: VK



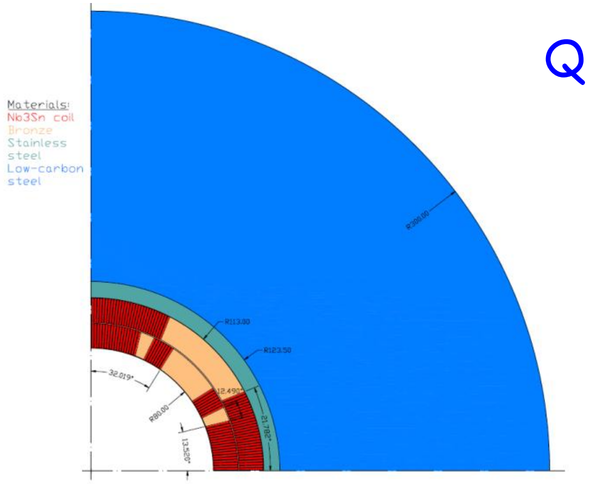


Q1: ID 80mm,
G=250 T/m

BE1: MARS



Tungsten rods
cooled by LN2



Q3: ID 160mm,
G=130 T/m

Detector-MDI Task Force

FNAL-INFN proposal of December 15, 2009, for a Task Force Simulation Group on studies for the feasibility of a high-energy physics experiment at a muon collider. Two-year 3-phase working plan on software development (MARS15 and ILCroot), and detector and MDI simulations.

MDI Issues and Work to Do (1)

1. Dealing with 0.5-1 kW/m loss rate in magnets (dynamic heat load and quench stability).
2. ~10 T dipoles: open midplane versus conventional $\cos\theta$ (splitted in ~3m long pieces with masks in between and modest high-Z liners). Put significant effort into open mid-plane dipole designs to get field quality, handle the forces and enclose the beam dumps so that radiation is controlled in the tunnel.
3. Alternative technologies for short IR quads: permanent high-gradient quads very close to IP, holmium/gadolinium liners in quads, novel adhesive-free approach. Explore higher gradient quadrupoles and determine if a lower beta star is feasible. If this is possible, evaluate whether to use the gain to raise the luminosity or reduce N raise f and thus reduce the detector background.
4. Add more realistic geometry and magnetic field maps to MARS model.

MDI Issues and Work to Do (2)

5. Interconnect regions: 40-50 cm needed, seems OK for optics, backgrounds and neutrino radiation for 750-GeV muon beams; need to keep them as short as possible with energy going up.
6. Design a ring for 3 TeV and compare the background problems with 1.5 TeV.
7. Explore if short 20-30 T solenoid(s) from the last bend to the IP (with gaps for the quadrupoles) would help backgrounds.
8. For each design, determine how much shielding is needed inside the final quadrupoles.

MDI Issues and Work to Do (3)

9. ☆ Continue the optimization of detector background, balancing advantages of smaller nozzle angle vs effects of the greater background if it has a smaller angle, not sacrificing physics; consider its instrumentation (Lumical and other ILC experience).
10. Investigate if such an optimal cone confines incoherent pairs with the detector 3.5-T field.
11. ☆ Establish an MDI Task Force with a very tight connection between accelerator, magnet and detector groups.
12. Model detector response to physics signal in presence of IP and machine backgrounds. To first order, the backgrounds will drive critical parameters of the MC detector design, not the physics.
13. Revisit beam scraping schemes for 0.75 and 1.5-TeV muon beams.