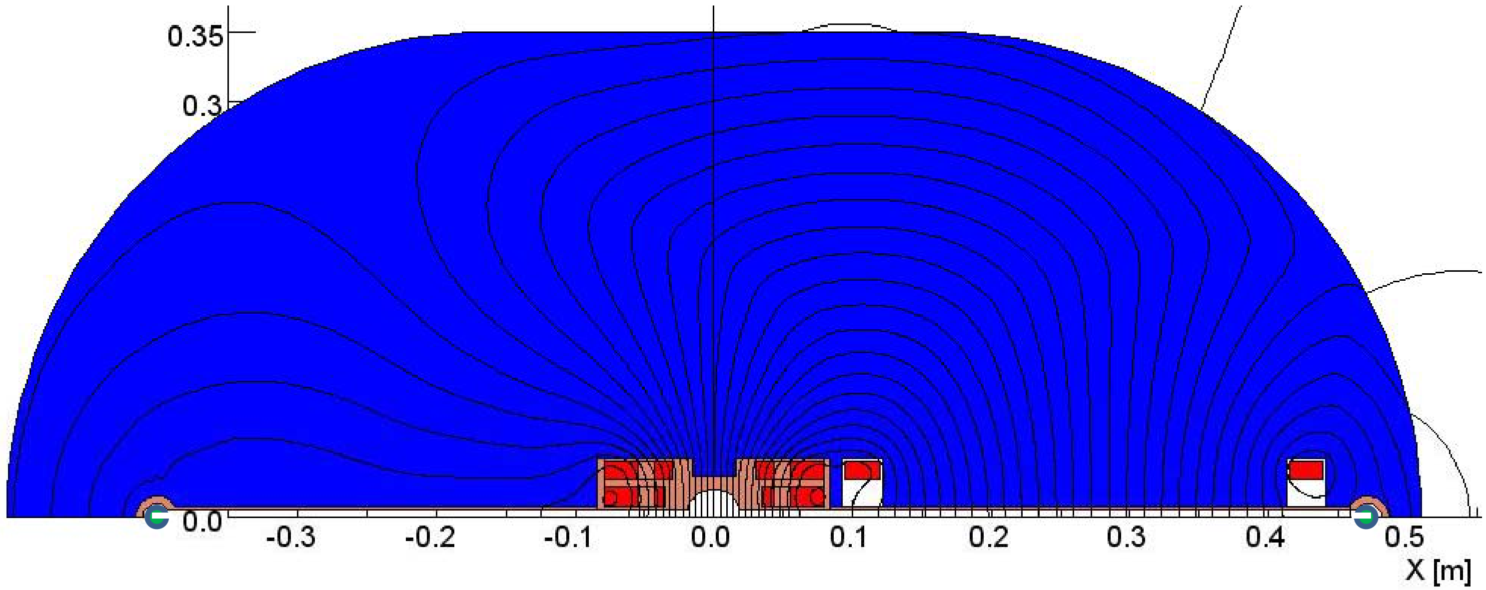
Open Midplane Active Return Dipole

How to remove ***all*** decay electrons and synchrotron light from muon collider arc dipoles



OMAR

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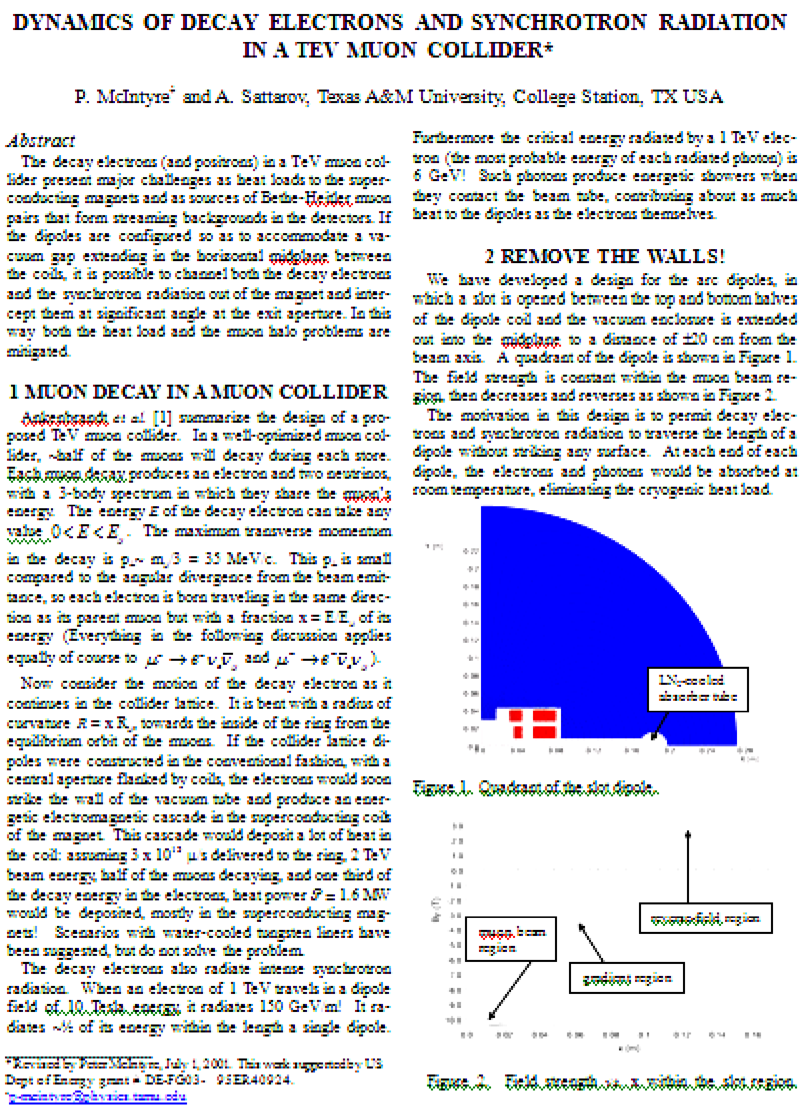
PAC 2001: We showed how to think about the dynamics of decay electrons and synchrotron light in muon collider arc dipoles.



DYNAMICS OF DECAY ELECTRONS AND SYNCHROTRON RADIATION IN A TEV MUON COLLIDER*

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Abstract

The decay electrons (and positrons) in a TeV muon collider present major challenges as heat loads to the superconducting magnets and as sources of Bethe-Heitler muon pairs that form streaming backgrounds in the detectors. If the dipoles are configured so as to accommodate a vacuum gap extending in the horizontal midplane between the coils, it is possible to channel both the decay electrons and the synchrotron radiation out of the magnet and intercept them at significant angle at the exit aperture. In this way both the heat load and the muon halo problems are mitigated.

1 MUON DECAY IN A MUON COLLIDER

Ankenbrandt *et al.* [1] summarize the design of a proposed TeV muon collider. In a well-optimized muon collider, ~half of the muons will decay during each store. Each muon decay produces an electron and two neutrinos, with a 3-body spectrum in which they share the muon's energy. The energy E of the decay electron can take any value $0 < E < E_\mu$. The maximum transverse momentum in the decay is $p_\perp \sim m_\mu/3$ = 35 MeV/c. This $p_\perp$ is small compared to the angular divergence from the beam emittance, so each electron is born traveling in the same direction as its parent muon but with a fraction $x = E/E_\mu$ of its energy (Everything in the following discussion applies equally of course to $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$ and $\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$).

Now consider the motion of the decay electron as it continues in the collider lattice. It is bent with a radius of curvature $R = x R_\mu$ towards the inside of the ring from the equilibrium orbit of the muons. If the collider lattice dipoles were constructed in the conventional fashion, with a central aperture flanked by coils, the electrons would soon strike the wall of the vacuum tube and produce an energetic electromagnetic cascade in the superconducting coils of the magnet. This cascade would deposit a lot of heat in the coil: assuming 3×10^{12} μ/s delivered to the ring, 2 TeV beam energy, half of the muons decaying, and one third of the decay energy in the electrons, heat power $\mathcal{P}$ = 1.6 MW would be deposited, mostly in the superconducting magnets! Scenarios with water-cooled tungsten liners have been suggested, but do not solve the problem.

The decay electrons also radiate intense synchrotron radiation. When an electron of 1 TeV travels in a dipole field of 10 Tesla energy, it radiates 150 GeV/m! It radiates ~½ of its energy within the length a single dipole. Furthermore the critical energy radiated by a 1 TeV electron (the most probable energy of each radiated photon) is 6 GeV! Such photons produce energetic showers when they contact the beam tube, contributing about as much heat to the dipoles as the electrons themselves.

2 REMOVE THE WALLS!

We have developed a design for the arc dipoles, in which a slot is opened between the top and bottom halves of the dipole coil and the vacuum enclosure is extended out into the midplane to a distance of ±20 cm from the beam axis. A quadrant of the dipole is shown in Figure 1. The field strength is constant within the muon beam region, then decreases and reverses as shown in Figure 2.

The motivation in this design is to permit decay electrons and synchrotron radiation to traverse the length of a dipole without striking any surface. At each end of each dipole, the electrons and photons would be absorbed at room temperature, eliminating the cryogenic heat load.

LN₂-cooled absorber tube

Figure 1. Quadrant of the slot dipole.

muon beam region

gradient region

reverse field region

Figure 2. Field strength vs. x within the slot region.

*Revised by Peter McIntyre, July 1, 2001. This work supported by US Dept of Energy grant # DE-FG03- 95ER40924.

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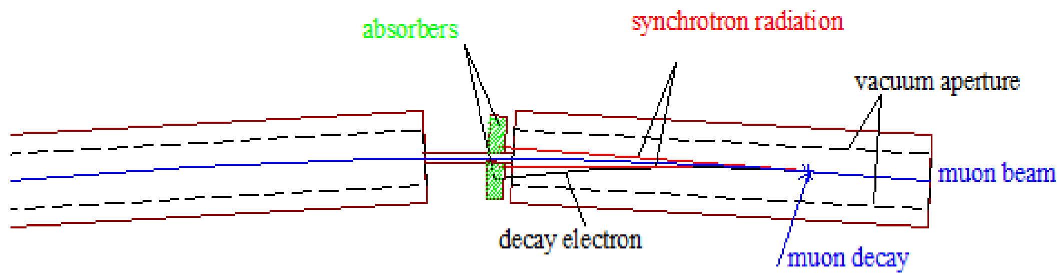
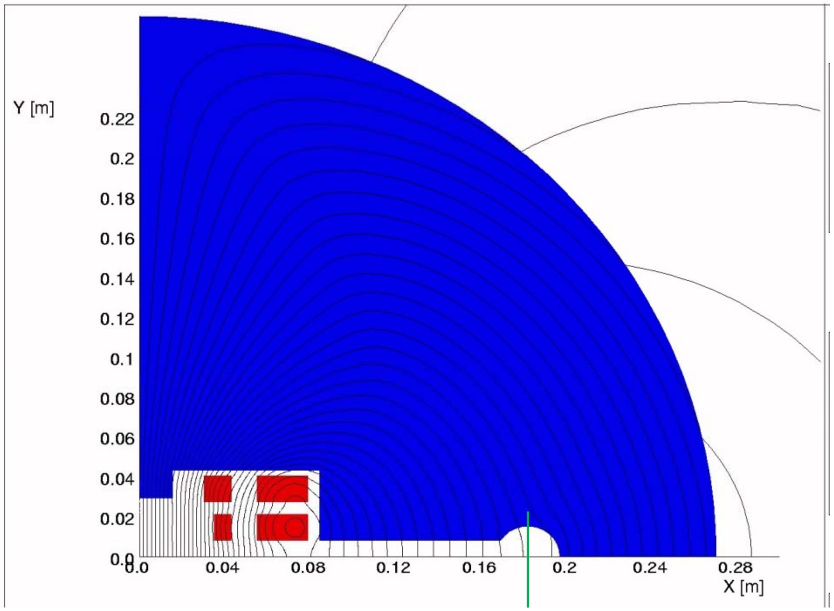
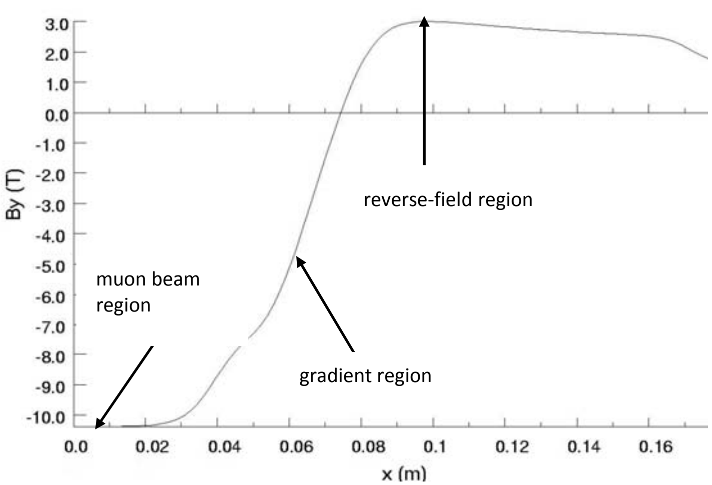
In this paper, we demonstrated several aspects of the dynamics of decay electrons and their synchrotron radiation that were not widely appreciated at that time:

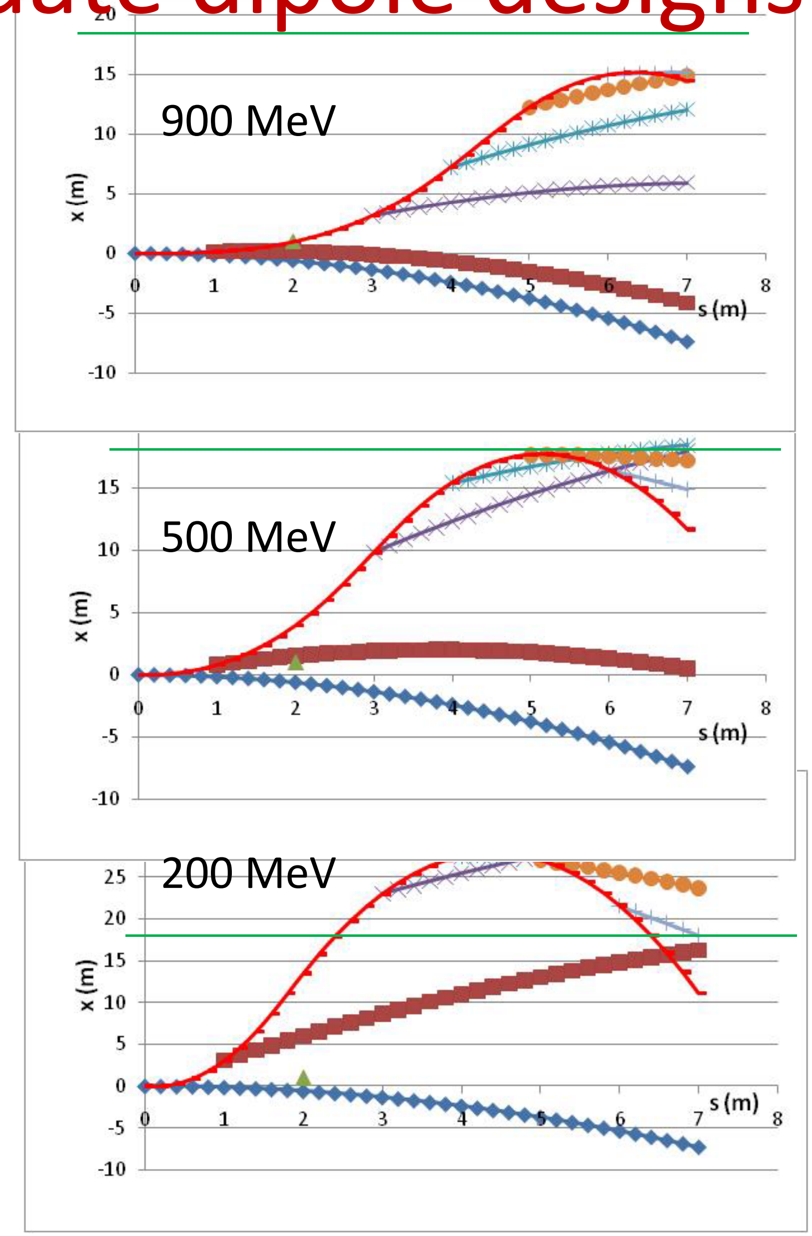
- Decay electrons describe betatron orbits with equilibrium @ location in coil region of dipole.
- Synchrotron light has critical energy >>GeV, so cannot be easily contained by simple tube in dipole.
- Midplane opening must extend far beyond coil if it is to channel decay particles to end of dipole.
- With such a deep cut, 'most' particles can be passed to room-temp absorber at end of dipole.



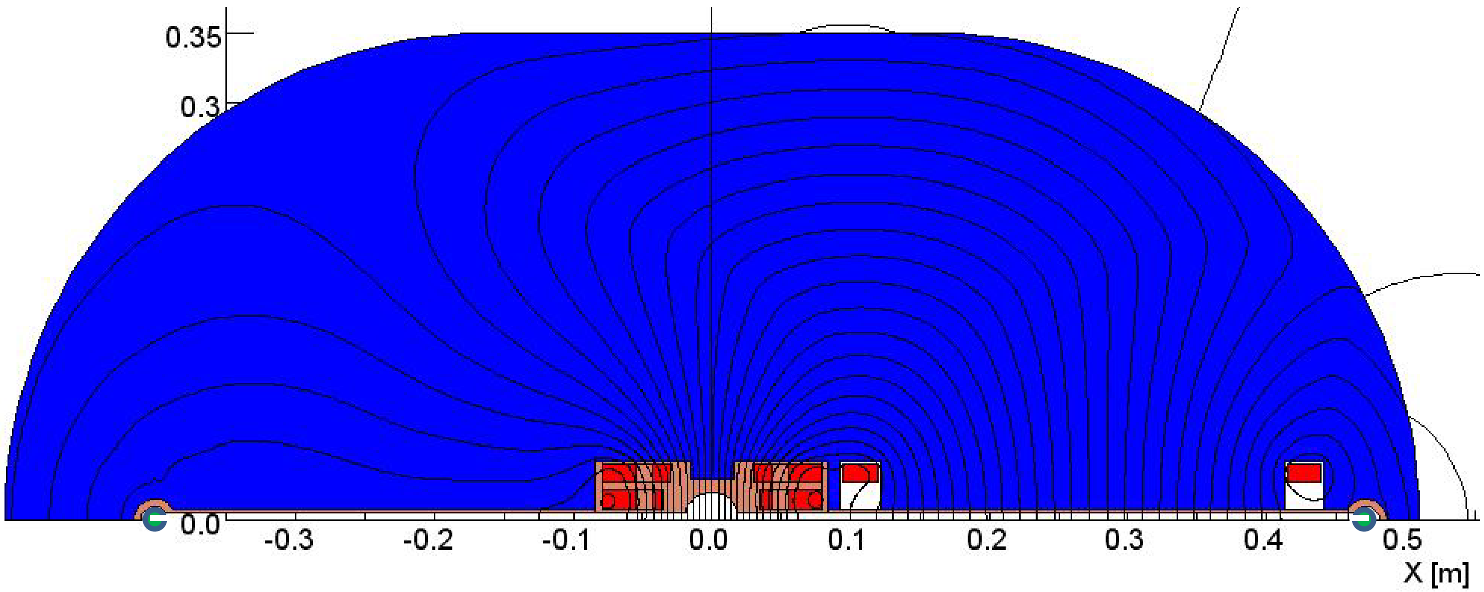
Track decay electrons and synchrotron light through candidate dipole designs

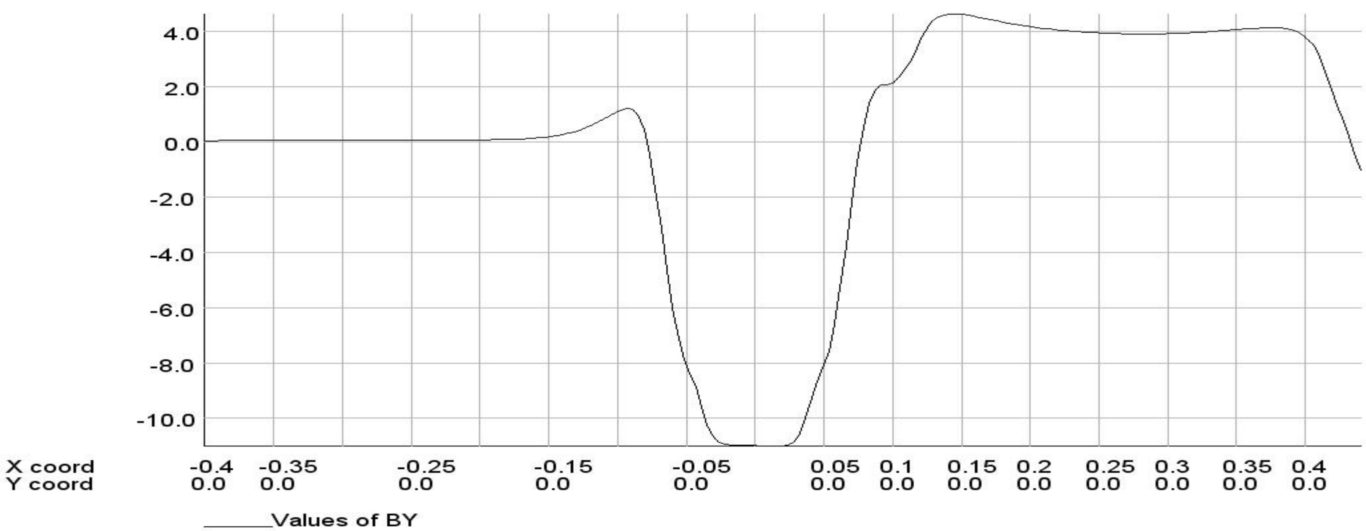




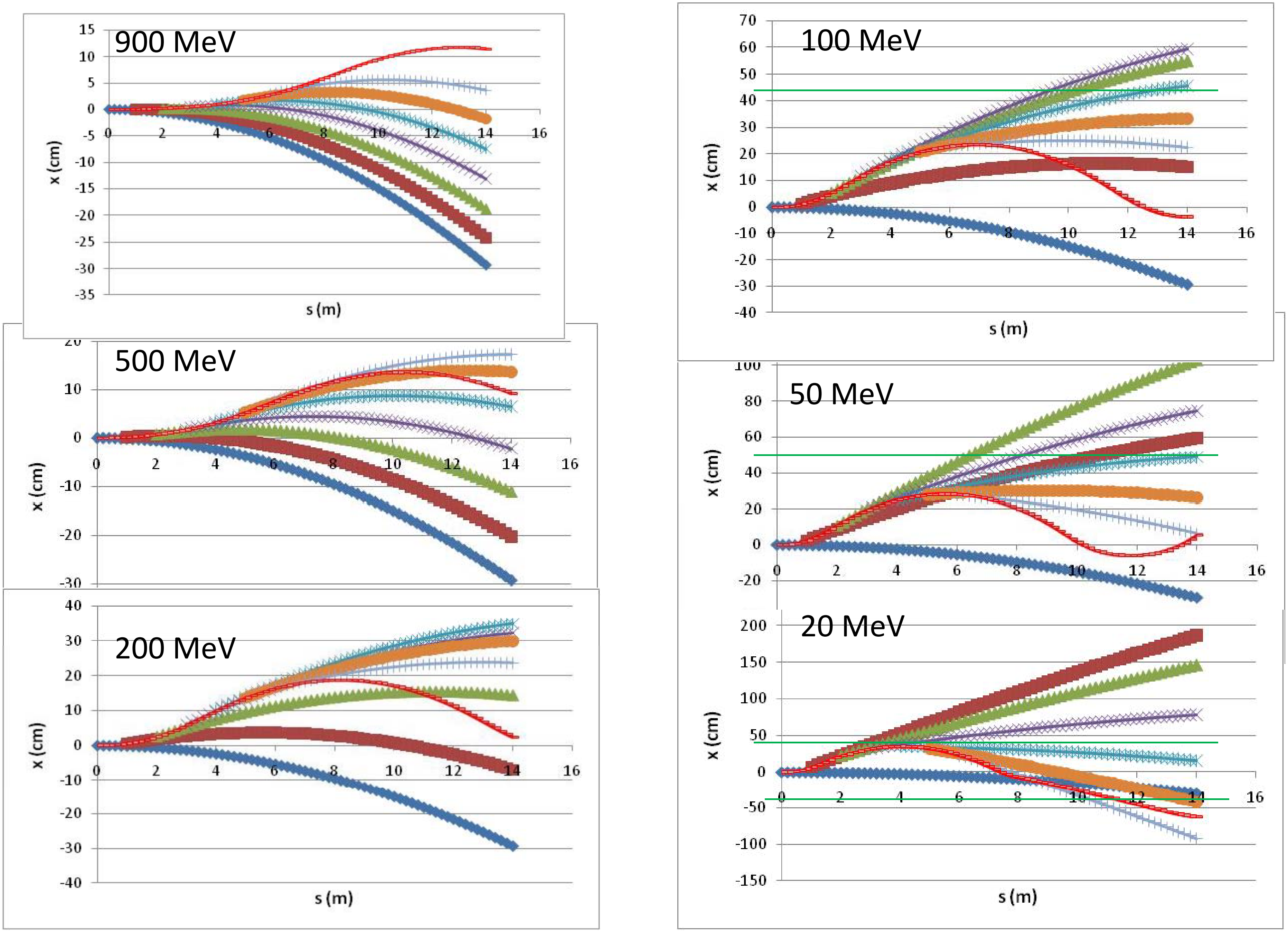


Need more horizontal aperture and more return flux to turn the electrons

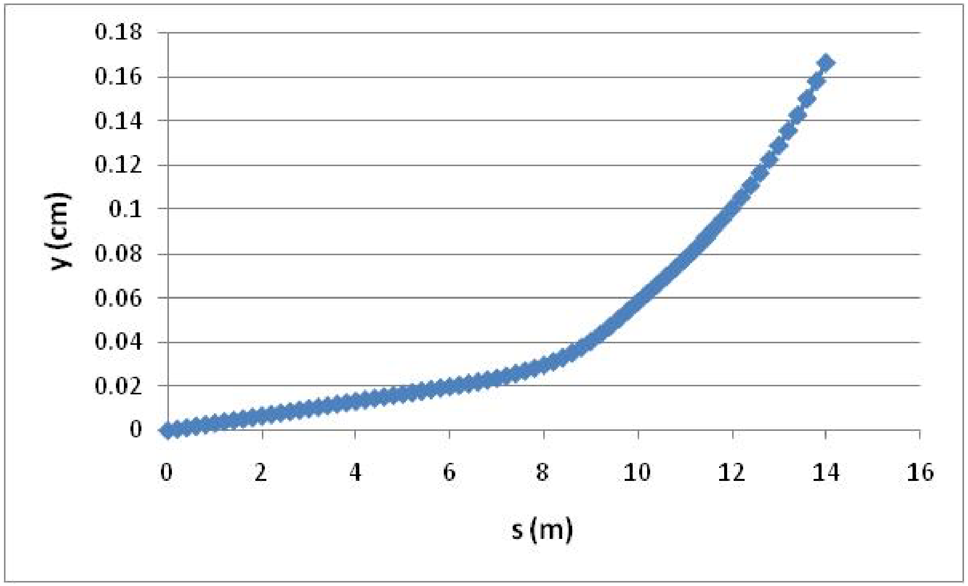


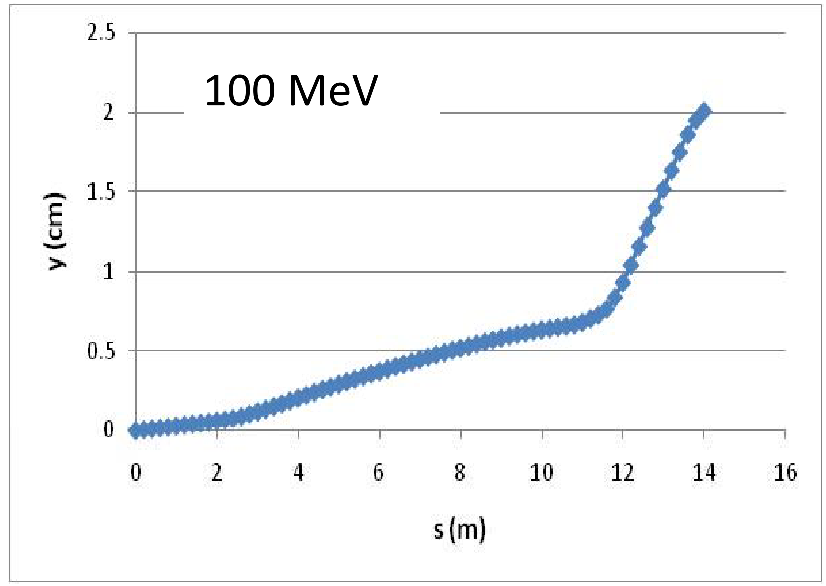


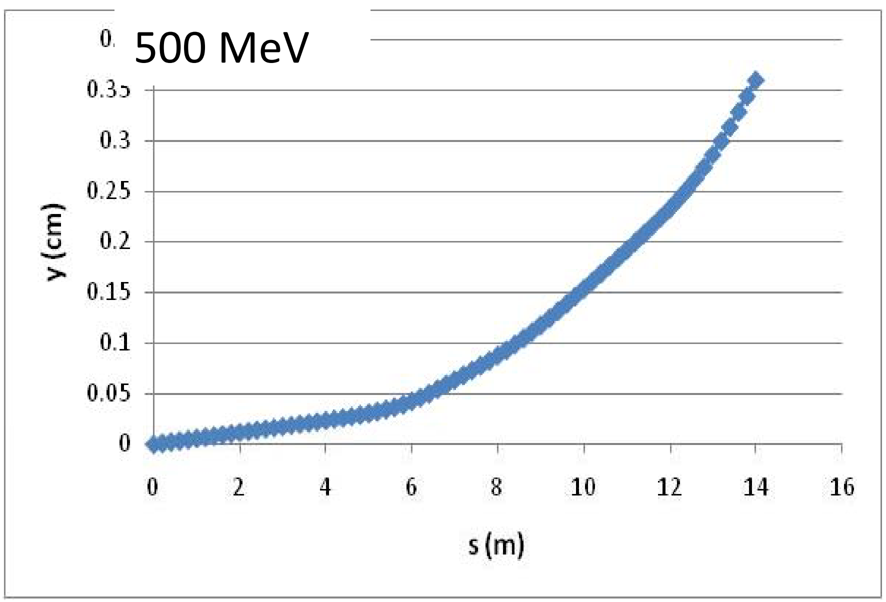
All electrons clear, low-energy photons can intercept on tubes

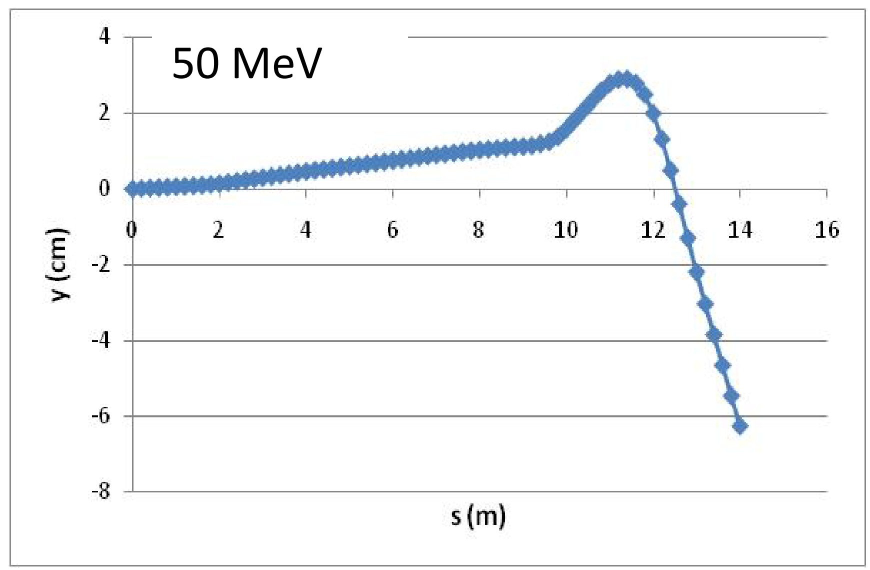


Check vertical trajectories with p_{ty} = 30 MeV/c

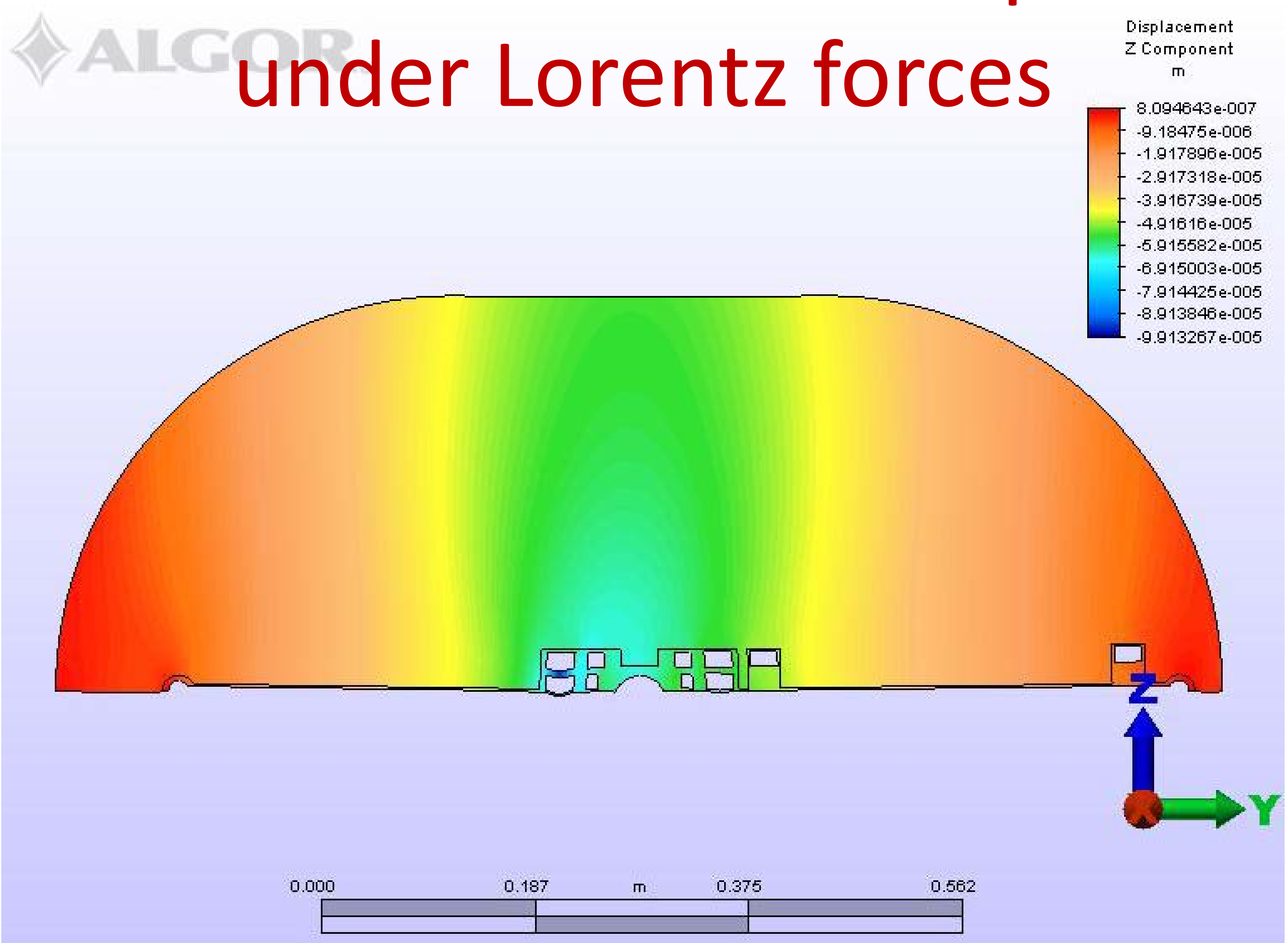






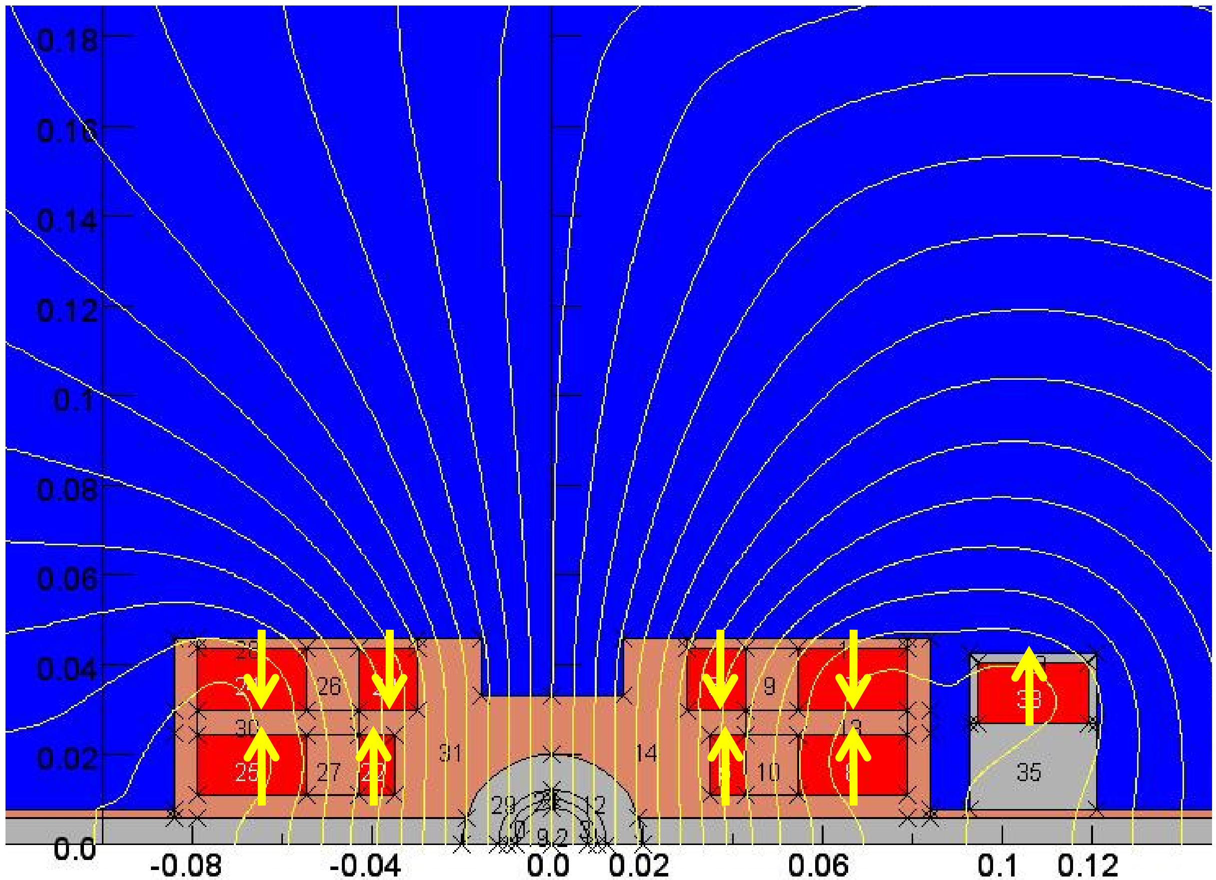


Deflection of OMAR dipole under Lorentz forces



Coil region deflects vertically by **0.1 mm** under full Lorentz load.
With appropriate design, it might be possible to live with this deflection.
Otherwise put more cold steel (!)

Inner set of windings are levitated, top/bottom windings supported by skyhook



Conclusions

- It is possible to design an open-midplane active-return (OMAR) dipole that transports ~all particles > 50 MeV out the end of the dipole without interacting.
- With an iris of ~±4 mm, ~all particles passing through the iris would clear the next dipole.
- No detailed analysis of magnetic field quality, iris impedances, mechanical stress/strain, heat deposition distribution, etc. have been done.
- If you like this concept and want it pursued, we need funding for a grad student and half postdoc.