# Some Comments on Cosine Theta Dipole Versus Open Structure Dipoles For the Storage Ring

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# What Defines the Design of the Storage Ring Dipole?

**There are three factors that determine the design of the storage ring dipole:**

1) **The power per unit dipole length deposited from muon decay is the key factor that determines the thickness of warm (room temperature) shielding that must protect the cold parts of the magnet from the muon beam.**

2) **The physical size of the muon beam plus all stay clear dimensions will strongly influence the design of the dipole. The physical size of the beam is a function of beam emittance and the beta values. Well-cooled muon beams will be smaller that not so well cooled muon beams for a given beta value and energy.**

3) **The energy of the beam affects how energy is deposited in the magnet. The electron divergence angle goes as one over gamma. On the other hand the particles produced by scattering will be spread more when the electron energy is high.**

# Shield Thickness

**The circulating muon beam power is the number of muons circulating around the ring per second times the muon beam energy times the unit charge per muon. When a muon decays, it decays to one electron and two neutrinos. The electron on average contains 35 percent of the energy of the muon. The beam power carried by the electrons is 35 percent of the muon beam power. All of the beam power that is deposited in the storage ring comes from the electrons or the synchrotron radiation produced by the electrons. None of the energy that is in the neutrinos is deposited in the magnets.**

**The average beam power per unit length of the ring is the electron beam power divided by the circumference of the ring. There is additional beam power deposited in the magnet at the ends of the straight sections. This must be taken care of.**

## *Shield Thickness Continued*

**In order to reduce the beam power deposited into the 4 K region of the magnets a shield is needed. The thickness of the shield is proportional to its interaction length. High-density high Z shields are preferred. If the shield is made from tungsten, the power into the 4 K due to decay products is reduced by one order of magnitude for every 2 centimeters of tungsten used. If lead is used, as a shield material instead of tungsten, the shield thickness must be increased a factor of 1.7.**

**Thus for the 2 TeV on TeV collider with an electron power per unit length of 2 kW per meter, the tungsten shield thickness was 65 mm. For the 50 GeV on 50 GeV collider with fewer circulating muons, the tungsten shield thickness was 40 mm. The neutrino factory tungsten shield thickness is about 30 mm. The shield thickness in the magnets at the ends of the long straight sections will have to larger.**

**Depending on the details of the design of the magnets it may be possible to dump much of the decay electron power into shields between the magnets.**

# Types of Dipole Magnets

**Cosine theta dipoles have been used for the Tevetron, and HERA. This type of dipole will be used for the LHC. This type of dipole is characterized by having a peak induction in the winding that is within a ten percent of the central induction. Cosine theta can be built as combined function magnet by including quadruple windings. These windings may be either normal or skew. In general, the cosine theta dipole is well suited to niobium titanium and for a given aperture uses the minimum amount of superconductor for a given good field region.**

**Window frame or Vobly type (modified window frame) can be built as short magnets with very sharp well-defined end effects. Vobly type magnets can have a pole width large compared to the gap. The field rise in the conductor is only a few percent. A combined function version of this magnet can be built with skew quadrupole built in. Common window frame magnets are efficient in their use of superconductor, but Vobly magnets are not as efficient.**

## *Types of Dipole Magnets Continued*

**Open magnets with no superconductor on the mid-plane use more superconductor for a given central induction in the magnet.  The field rise at the superconductor can be over fifty percent in this type of magnet.  As a result, an 8 T dipole must be made using niobium tin as a superconductor.  This type of magnet should be used only if the superconductor can be brought close to the beam region.  This means that the decay electrons and the synchrotron radiation due to the decay are caught by shields are the end of the magnet or shields that are on the mid-plane of the magnet some distance from the superconducting coils.**

**In all cases the cost of the superconducting dipole with a given central induction is directly proportional to the largest physical aperture (horizontal or vertical) to some power between one and two.  The cost of a superconducting dipole is proportional to the central induction to some power between one and two.  This means that the magnets for a high field ring will cost more than magnets for a low field ring of the same energy.**

# Magnet Selection Criteria

If the beam plus stay clear radius in all directions is larger than the thickness of the shield needed to protect the conductor on the mid-plane, the cosine theta magnet or the Vobly type magnet is favored. Under these circumstances, the cosine theta design will be less expensive to build. The Vobly design allows a skew quadrupole to be built in to the magnet. For an 8 T dipole, the cosine theta dipole can be made from niobium titanium cooled to 1.8 K. This is also true for the combined function Vobly type dipole as long as the conductor peak induction does not exceed 8.5 T.

When beam plus stay clear radius is smaller than the thickness of the shield material needed to protect the coil on the mid-plane, the open design with no coils on the mid-plane should be considered. When an open dipole has a central induction at the edge of the stay clear region, the field in the winding will be above 10 T. This means that niobium-tin is the conductor of choice despite its higher cost.