Physics Driver: Tracker and Vertex Detector for a Muon Collider

Time Frame: Long (2030)

Physics Justification: A Muon Collider is a possible path to a high-energy lepton collider at the Energy Frontier. Alternative technologies with e+e- colliders, such as CLIC, ILC or a circular machine all suffer from significant limitations for energies in the TeV range. The ILC increases in length in a way that quickly becomes unaffordable. CLIC consumes more than 500 MW at 3 TeV, and circular machines are limited by bremsstrahlung to a few hundred GeV. A Muon Collider scales differently, and can provide a 6 TeV lepton collider that could still fit on the Fermilab site. LHC measurements appear to exclude low energy supersymmetry and a high energy Muon Collider may be necessary to explore new physics discovered at LHC.

In addition to it's high energy scaling the Muon Collider can operate as an s-channel Higgs factory. It should be possible to provide a Muon Beam with a energy spread comparable to the 4.2 MeV Higgs width. This machine can provide a direct measurement of the Higgs width and a measurement of the Higgs mass ten times more precise than e+e- colliders.

Technical Requirements: The Muon Collider is limited not by bremsstrahlung, but by muon decays. These decays create a background environment that provides the primary challenge for detectors. Detector operation requires careful shielding design, including a tungsten cone that projects at a 10 degree angle from the interaction point. The overall radiation level is comparable to LHC, but is dominated by low energy neutrons and photons and is more uniform over the detector. The region around the beam crossing has limited shielding and the inner radius of the vertex detector must be greater than 6 cm.

MARS studies have shown that these backgrounds are typically very soft and out of time with respect to particles from the beam crossing. Detectors with time resolution of 1 ns can reduce background levels in the tracker by three orders of magnitude.

Technical Capabilities: For both the tracker and vertex detector requirements include low mass, low power, radiation hardness, and nanosecond level time time resolution. Time resolution is required to reject beam muon decay background. Pixel size in the tracker should be about 1 mm x 100 microns to insure low occupancy in the high background environment. Pixel size for the vertex detector should be 20 microns x 20 microns to provide precise vertexing and b and c tagging. Designs have been developed in 65 nm technology that achieve this time resolution with acceptable power dissipation.

Key R&D Directions: Nanosecond time resolution, sensor radiation hardness, low mass, and low power electronics. Possible technologies are 3D integrated sensors and electronics, CMOS active pixel, silicon-on-insulator, and hybrid devices. Of these, 3D technology holds the most promise, since it can utilize radiation hard CMOS combined with radiation hard sensors with active edges. 3D electronics also provides the ability to integrate complex electronics in a very small area by building up the CMOS functionality vertically.