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Muon identification and pion rejection in the 4th concept

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Abstract. We describe a completely new way to reconstruct and identify muons with high efficiency and very high pion rejection in the 4th concept detector. The dual-solenoid magnetic field allows the reconstruction and precision momentum measurement of muons down to a few GeV (just the energy loss in the 10-$\lambda_{\rm int}$ calorimeter and the coil) and the dual-readout calorimeter provides a new, unique and powerful separation of muons from pions. We use test beam data for the calorimeter and calculations for the magnetic fields.

Keywords. International linear collider; dual solenoids; muon detector.

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1. Introduction

Traditional muon detectors in large collider experiments consist of a meter or two of iron absorber interrupted with charged particle detectors for measuring the trajectory of the penetrating particle, and the identification of a particle as a muon depends essentially on its penetrating probability, that is, the number of interaction lengths traversed without an interaction. In these systems, the muon iron absorber doubles as the magnetic flux return and also, therefore, as a muon momentum spectrometer. However, the Coulomb multiple scattering of a muon in iron and the saturation limit of $B = 1.8$ T fundamentally limits the momentum resolution to 10%, or worse, at which the random bending due to multiple scattering equals the magnetic bending.

The ATLAS detector at the LHC has avoided this limit with air-core toroids both around the cylindrical detector providing a largely azimuthal field, and separate toroids to cover the end cap regions of the detector.

2. Two essential features

Momentum resolution for background pion rejection. On the 4th concept we also avoid this momentum resolution limit but with a very different magnetic field geometry [1,2]. The dual solenoid augmented with a 'wall of coils' results in the magnetic

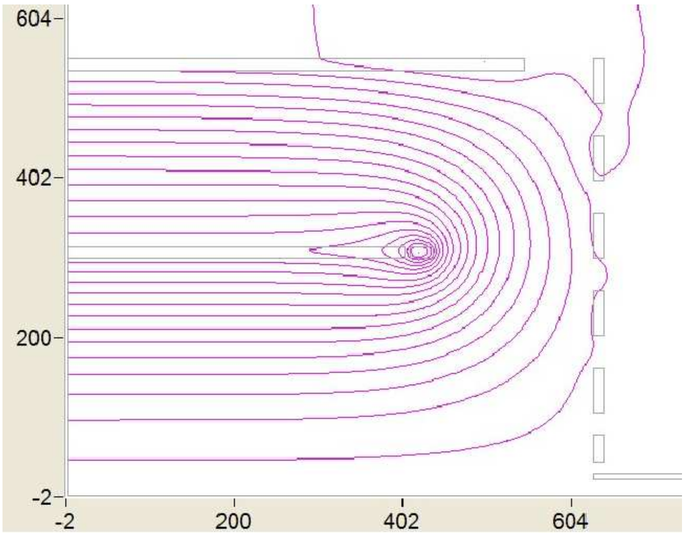

Figure 1. The magnetic field of the 4th concept showing the dual solenoids and the circular coils closing off the end cap regions by redirecting the magnetic field into the return annulus.

field shown in figure 1. These solenoids are large but manageable; the end coils are rather modest. In parallel with this design, we are studying the possibility of high-T_c superconductors such as MgB_2 for these solenoids.

The bending line integral of this field along the trajectory of a muon from the origin is shown in the 4th concept paper in these Proceedings and is typically 3 T·m over most of the solid angle and still larger than 0.5 T·m out to $\cos\theta \approx 0.95$. This resolution allows a strict energy balance between the TPC momentum, the energy deposit in the calorimeter and the momentum measured in this muon spectrometer. In addition, this configuration has momentum acceptance [3] down to approximately 2 GeV, and over a large fraction of the solid angle.

Dual-readout muon tagging and identification. The separate Cerenkov and scintillation fiber readouts yield separate measurements of the ionization and radiative energy losses in the calorimeter medium because the Cerenkov light from a muon at the Cerenkov angle is outside the numerical aperture of the fiber. Hence, the Cerenkov fibers measure only the radiative component, whereas the scintillation fibers measure both the radiative and ionization components. The difference $(S - C)$ is just the ionization part, which has a mean of 1.2 GeV for a muon in the DREAM module, independent of the degree of radiation inside the calorimeter. This difference $(S-C)$ is shown for muons and pions at 20 and 200 GeV in figure 2 plotted against $(S+C)/2$, the approximate total energy deposit in the calorimeter. Clearly, muons are very well separated from pions even at low energies [4]. We do not have data below 20 GeV.

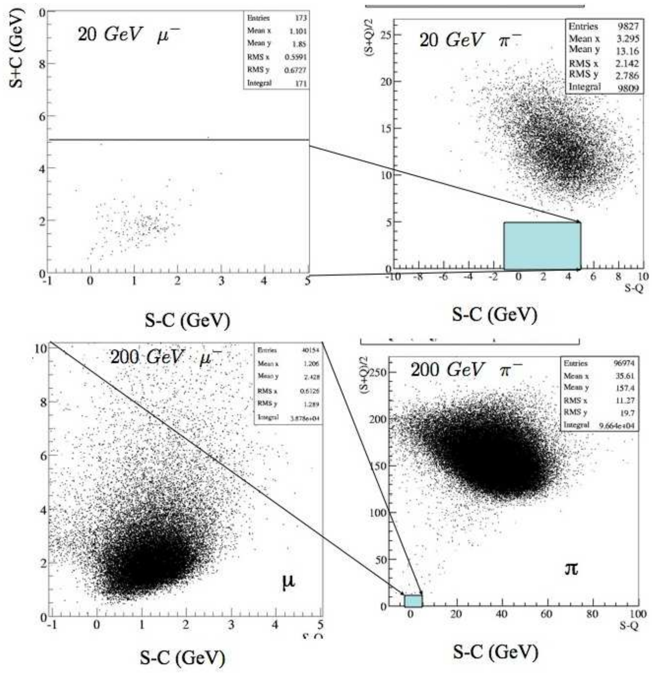

Figure 2. $(S - C)$ vs. $(S + C)/2$ for both pions and muons at 20 GeV (top frames) and 200 GeV (bottom frames). For isolated muons, the rejection of pion is 10^3–10^4.

3. Summary

We find this magnetic field configuration interesting and beneficial in several respects, for muon reconstruction and identification as shown in this note, but also for the critically important MDI issues we find that [5] an iron-free muon system allows great flexibility in the beam line design, including the capability to make the magnetic field on and near the beam whatever we want it to be, in addition to engineering and installation advantages. Finally, we note that an iron-free perimeter allows add-ons to a physics experiment (although rarely done), but a new machine and detector in new territory should remain as flexible as possible.

References

[1] Alexander Mikhailichenko has described a similar iron-free magnetic field system in his internal notes ‘Do detectors need a yoke’, Cornell LNS, CBN 01-20, 6 October 2001; and, ‘Detectors for linear collider’, Cornell LNS, 8 March 2002. A very recent note is ‘Few comments on the status of detectors for ILC’, A Mikhailichenko, CLNS 06/1951, 15 January 2006, in which the issue of an iron-free magnetic system is again discussed, along with comments on crossing angles and possible asymmetric beam energies

[2] Paul Colas has also thought of this idea but rejected it on the grounds that the outer solenoid is large, which is correct
[3] Gene Fisk, Fermilab, Helpful comments on muon systems, and the realization that one-half the muons from B physics are below a few GeV/c in momentum
[4] Heejong Kim, Sehwook Lee, J Hauptman, S Popescu, A Penzo and N Akchurin, *Muon identification and pion rejection in 4th concept*, 4th Note Muon-2006-2, 10 Jan. 2006 (www.4thconcept.org)
[5] Alexander Mikhailichenko, John Hauptman, Sehwook Lee, Nural Akchurin and Sorina Popescu, *4th concept answers to MDI questions*, 11 February 2006, at http://www.4thconcept.org