Overview of the American Detector Models

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The American study groups have been investigating two different detector models for a future linear collider. These two models, representing complementary approaches, are chosen to reveal the requirements for a linear collider detector, and to illuminate the trade-offs in optimizing a specific design. One model, L, has a large tracking volume and a solenoidal magnetic field of 3 Tesla, while the other model, S, is characterized by its compact tracking volume, large solenodial magnetic field of 6 Tesla, and a highly segmented electromagnetic calorimeter based on silicon-tungsten.

1 Introduction

The American study groups have defined two detectors for study, which represent quite different approaches. Any choice for a detector must compromise competing contraints. Tracking optimization prefers a large tracking volume, while some electromagnetic calorimeter techniques constrain the tracking volume to a less than optimal size. This is the case for a crystal calorimeter, or a silicon-tungston calorimeter.[1] The American groups are investigating the physics perfomance of two such choices, without prejudice, to understand the performance trade-offs, and to consider the feasibility and identify research and development directions.[2]

The two models selected for study are described briefly in this paper. Model L, the large detector, is driven by the desire to provide a large tracking volume, to optimize tracking precision. This leads to a large radius calorimeter and limits the magnetic field strength to about 3 Tesla. Model S, the small detector, is driven by the desire to provide the largest feasible solenoidal magnetic field, to contain electron-positron pairs at the interaction point, which themselves limited the inner radius of the vertex detector.[3] Engineering a large field limits the radius of the coil, leading to a small tracking volume and a small radius calorimeter. This then allows agressive calorimeter options, such as the highly segmented silicon-tungsten electromagnetic calorimeter.

Table 1 summarizes the technology choices of the two models, and Figures 1 and 2 illustrate their layouts. In the following we briefly describe the parameters of each subsystem. See other contributions to this conference for details.

2 Vertex Detection

Both detectors assume a 5 barrel CCD vertex detector based on the concepts pioneered by SLD. [4] These detectors, with $(20\ \mu\mathrm{m})^3$ pixels, have better than 5 μm point resolution. Model S, with the 6 Tesla magnetic field, allows the inner layer of the vertex detector to be located just 1.2 cm from the interaction point. The five layers reside 1.2, 2.4, 3.6, 4.8, and 6.0 cm from the interaction point.

Table 1: Technology choices of the two models.

	Model S	Model L
Vertex Detector	CCDs	CCDs
Tracking	silicon drift (barrel)	TPC
EM calorimeter	silicon-tungsten	lead-scintillator
Hadronic calorimeter	copper-scintillator	lead-scintillator
Muons	gas detectors	RPCs
Magnetic Field	6 Tesla, coil between EM & Had cal	3 Tesla, coil outside Had cal

Model L provides a smaller magnetic field (3 Tesla) and the intensity of the electron positron pairs near the interaction point requires that the radius of the inner barrel of the vertex detector is 2.5 cm radius. The five layers of the Model L vertex detector are 2.5, 4.4, 6.3, 8.1, and 10. cm radius. The feasibility of this much CCD coverage is an open question.

The vertex detector performance for impact parameter is estimated to be

$$\text{Model S}: \ \sigma_b = (3\mu\text{m} \oplus 10\mu\text{m}/\text{p}\sin^{3/2}\theta)$$

$$\text{Model L}: \ \sigma_b = (3.5\mu\text{m} \oplus 25\mu\text{m}/\text{p}\sin^{3/2}\theta)$$

The vertex detectors of both models provide stand-alone tracking, independent of the tracking system.

3 Tracking

Model L is designed with tracking optimization in mind. The large radius of this system yields an optimal resolution. A TPC tracker is assumed for this model, with 144 measurement points. Model S, with its smaller tracking volume, requires the higher point precision provided by a silicon tracking system, but consequently has compromised low momentum resolution from the larger amount of material within the tracking volume. Three double layers of silicon drift detectors are assumed.

The tracking performance for each model is:

$$\text{Model S}: \ \sigma_{\text{p}}/\text{p} = (6 \times 10^{-5}\text{p} \oplus 0.0022)$$

$$\text{Model L}: \ \sigma_{\text{p}}/\text{p} = (5 \times 10^{-5}\text{p} \oplus 0.00065)$$

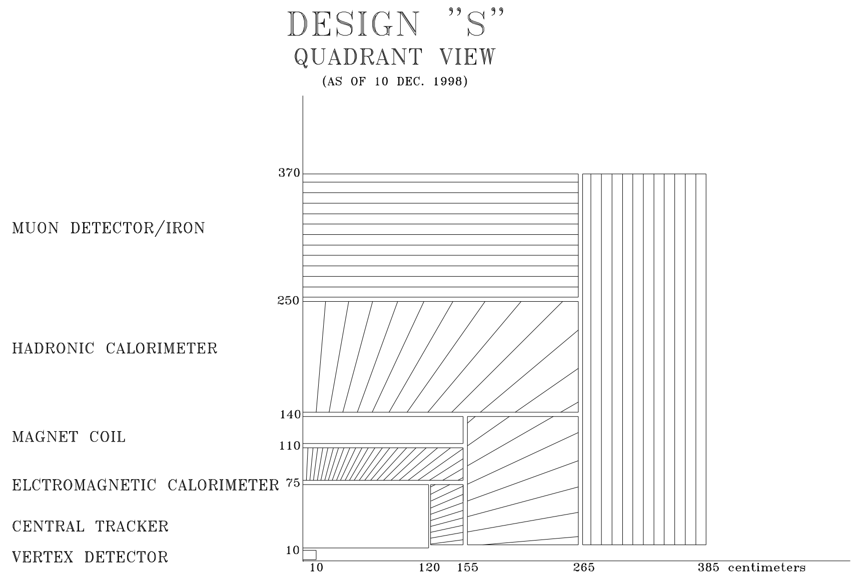

Figure 1: Quadrant view of Model S detector.

The high momentum performance is similar, but at lower momenta the multiple scattering in Model S leads to significant loss of resolution.

Model S has 5 layers of silicon strips to provide forward tracking; Model L assumes no special forward tracking.

4 Calorimeter

Model S provides a highly granular "tracking calorimeter" based on the silicon-tungsten concept studied at Snowmass 96. [1] The electromagnetic calorimeter is 29 radiation lengths of $1.5 \times 1.5\ cm^2$ pads detectors, and could contain as many as 100 readout layers. 50 are assumed in the model. This is backed up by a copper-scintillator electromagnetic calorimeter with $40 \times 40\ mrad^2$ transverse segmentation, and 76 cm of depth. The magnet coil separates the EM and hadronic calorimeters. The depth of the combined calorimeters is 6.1 interaction lengths. The assumed resolutions are:

$$\mathrm{Model\ S:}\ \sigma_{\mathrm{EM}}/\mathrm{E} = (12\%\sqrt{\mathrm{E}} \oplus 1\%)$$

$$\mathrm{Model\ S:}\ \sigma_{\mathrm{Had}}/\mathrm{E} = (50\%\sqrt{\mathrm{E}} \oplus 2\%)$$

Model L employs lead-scintillator for both electromagnetic and hadronic calorimetry. The EM calorimeter has $40 \times 40\ mrad^2$ transverse segmentation, and the Hadronic section has $80 \times 80\ mrad^2$ transverse segmentation. The magnet coil resides just outside the hadronic calorimeter. The depth of the combined calorimeters is 6.6 interaction lengths. The assumed resolutions are:

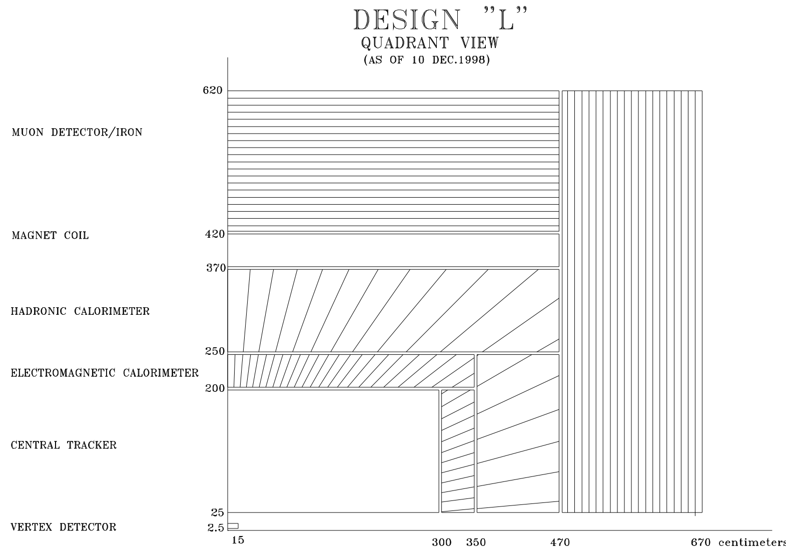

Figure 2: Quadrant view of Model L detector.

$$\text{Model L}: \ \sigma_{\rm EM}/{\rm E} = (15\%\sqrt{\rm E} \oplus 1\%)$$

$$\text{Model L}: \ \sigma_{\rm Had}/{\rm E} = (40\%\sqrt{\rm E} \oplus 2\%)$$

5 Muon Detectors and Magnetic Coil

The Model S muon detection system is based on gas chambers located in ten layers, separated by 10 cm of iron, with 1 cm precision at all ten depths in $r - \theta$ and at two depths in z. The Model L muon detection system is based on RPCs located in 24 layers, separated by 5 cm of iron, with 1 cm precision at all 24 depths in $r - \theta$ and at four depths in z.

The solenoidal magnetic field is provide by a superconducting coil located between the EM and hadronic calorimeters for Model S and outside the hadronic calorimeter for Model L. The Model S coil is about 0.5 interaction lengths thick and generates a field of 6 Tesla, while the model L coil is about one interaction length thick and generates a field of 3 Tesla.

6 Other Comments on Designs

Silicon-tungsten is used for small angle coverage to provide luminosity monitoring. The overall hermiticity of both models is in excess of 99%. A dedicated particle ID subsystem is not included in either of the present designs.

7 Examples of Trade-offs Under Investigation

Studies are underway to investigate the trade-offs between the different detector choices. Some of these are presented at Sitges in other papers.

The importance of the inner radius of the vertex detector needs to be quantified by physics. Likewise, the vertex detector layer thickness needs to be motivated by physics. SLD ladders are 0.4% of a radiation length thick, and it may be possible to reduced the ladder thickness to $\sim 10^{-3}X_0$. How important is this?

An example issue for the tracking system is the impact of the resolution for low momentum tracks. How does the efficiency for detecting two photon events depend on these parameters. Or how is the flavor tagging dependent on tracking parameters?

The energy flow jet reconstruction technique needs to be studied in detail, so that detector requirements can be more clearly defined. How small can the radius of the electromagnetic calorimeter be, while still permitting neutral/charged particle separation? A study of W/Z separation could quantify this. Another important capability could be measuring non-point gamma rays, such as those from neutralino decays: $\tilde{\chi}^0 \to \tilde{g}\gamma$.

8 Conclusion

The American study groups are studying two un-like detectors to explore the trade-offs in performance. Detailed studies of the physics capabilities of Models L and S should guide us to improved choices in the future.

Acknowledgments

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References

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