Title
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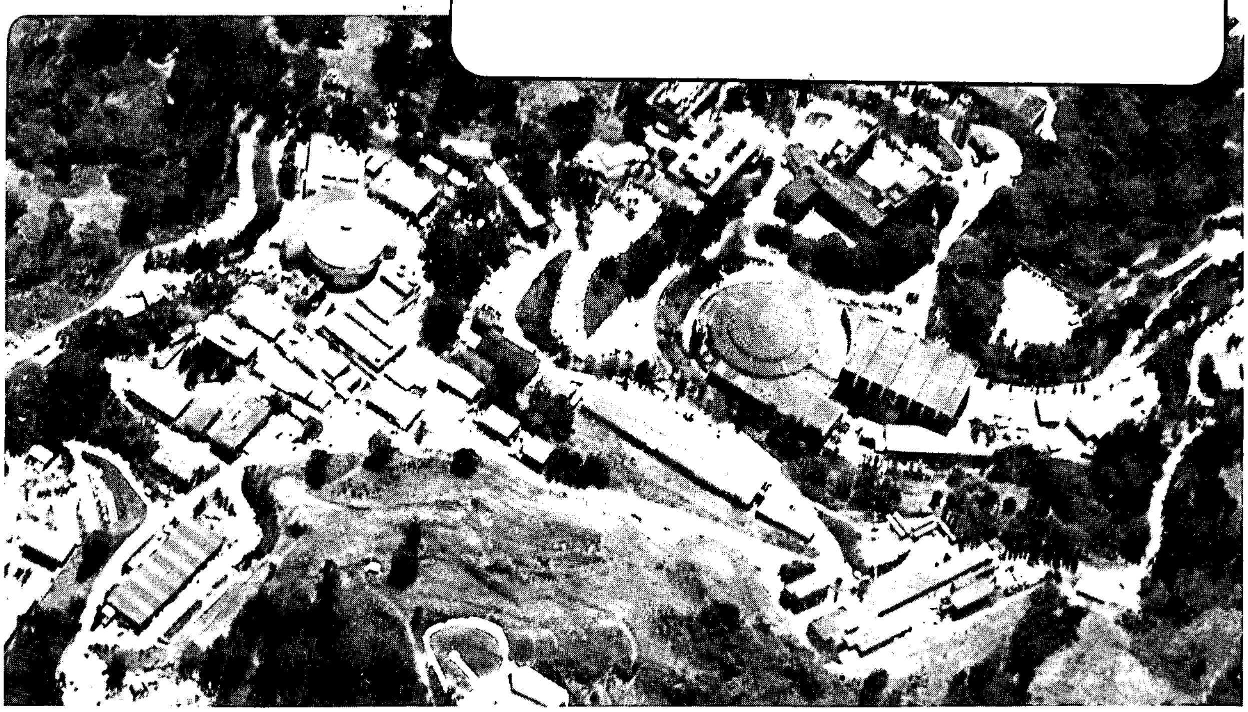

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HIGH P_T DETECTORS FOR THE SSC*

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1. INTRODUCTION

I shall summarize here some of the work done at the recent Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider held at Berkeley, July 7 to 17, 1987. The Workshop organization is shown on Table I. The major goal was to develop an understanding of what complement of detectors would provide the capability for a well-balanced physics program at the SSC. Unlike earlier studies which had emphasized individual components such as tracking, calorimetry, etc. the intention was to focus on complete detectors. In view of the limited space and my own involvement with the high-P_T detectors, I confine my discussion here to them, but remind the reader that they represent but one part of the Berkeley Workshop output [1]. These remarks are considerably briefer than the high-P_T detector summary by Cashmore et al. [1] to which the reader is referred for more details.

2. DETECTOR REQUIREMENTS FROM PARAMETRIZATION GROUPS

The physics topics considered by the parametrization subgroups are shown in Table I. A rough summary of the resulting detector requirements for high P_T physics is given in Table II. It should be noted that a detector just satisfying those requirements will not necessarily be capable of solving all the high-P_T problems listed in Table I. Indeed some areas (such as non-standard Higgs or even intermediate-mass Higgs) look very difficult with even the most idealized of detectors. However, with the listed capabilities, one should be able to attack fruitfully several of the most urgent physics issues and to recognize the occurrence of a variety of new or unexpected phenomena. I should also point out that the parametrization efforts have concentrated on defining signals

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and backgrounds for each of the physics topics separately and asking for the capabilities needed to separate an adequately strong signal from background. The inverse but more realistic problem of unambiguously associating a particular signal with a specific physics phenomenon has had much less attention except in those cases, such as heavy Higgs or heavy Z's, where clear mass peaks may be expected. This is only to say that much work remains. Below, we provide some further detail in connection with the specific entries in Table II.

Luminosity

Practically all the high-P_T experiments seem to require a luminosity capability of at least 10^{33} cm^{-2} s^{-1} to cover an adequate range of discovery parameters.

Vertex Detection and Tracking

Vertex detection does not play an important role in defining signals for most of the high-P_T areas considered, with the exception of the very difficult intermediate-mass Higgs. It may however be valuable in removing backgrounds, such as leptons from b- and c-quark decays. Charged-particle tracking is mostly needed for lepton identification and sign determination of electrons. The leptons of interest here are mostly isolated ones, and tracking within a jet core is generally not required.

Electron and Muon Identification

A lepton-identification rapidity range of ± 3 seems, for the processes considered, to provide an adequate efficiency. In almost all cases, the leptons of interest are "isolated" in that there is very little additional energy within a rapidity neighborhood of order 0.1 - 0.2. For such leptons at relatively high P_T, the hadron background is relatively small and the required rejection is therefore a modest 10^{-2}. There was a general sense among the detector designers, however, that this estimate was optimistic and that a rejection factor of at least 10^{-3} was a more appropriate design goal. For the purpose of accurate missing-transverse-energy measurement, the capability of detecting and measuring muons out to rapidities of order ± 5 is desirable.

Calorimetry

Calorimetry and lepton identification are at the heart of much of the high-P_T physics. Rapidity coverage of $\pm$5-6 is needed to handle missing E_T down to a level of 100 GeV. The proposed transverse segmentation is the same as discussed at Snowmass-86 [2] and seems to be a reasonable match to event structure, shower sizes and economic reality. The importance of equality in the ratio of electron to hadron response, e/h=1 within a few percent, is a technical detector issue rather than a physics parameter. However the pioneering work of Wigmans [3] has demonstrated its impact on the physics capabilities of calorimeters. In particular this requirement must be satisfied to provide: (i) linear response as a function of energy, (ii) energy dependence of the fractional resolution as $E^{-1/2}$ up to the highest energies and (iii) the absence of non-Gaussian tails in the energy resolution. For all the physics issues whose study requires measurement of hadron jets or missing transverse energy, these requirements must be fulfilled.

3. THE PROPOSED DETECTORS

I refer the interested reader to the reports in the Berkeley Workshop Proceedings for detailed descriptions of the high-P_T detectors and confine myself here to showing some figures and making a few descriptive remarks.

3.1 Large Solenoid Detector [4]

This device, shown schematically in Fig. 1, grows out of the large detectors discussed in Snowmass-84 [5] and Snowmass-86 [2]. There are however important differences motivated by the rapidity range requirement on lepton identification and the desire to maintain e/h = 1 in the calorimetry even in the presence of a relatively thick coil. Thus tracking extends only to a radius of 1.6 m, and all calorimetry is located inside a 4-m radius, 16-m long, 2T solenoid. The iron return is used for muon identification and measurement in the central region, and there are toroids only in the forward regions. Candidate technologies for the calorimetry include uranium/liquid-argon (U/LA), lead or uranium warm-liquid, lead/scintillating-fibers (Pb/SciFi) and uranium/silicon (U/Si).

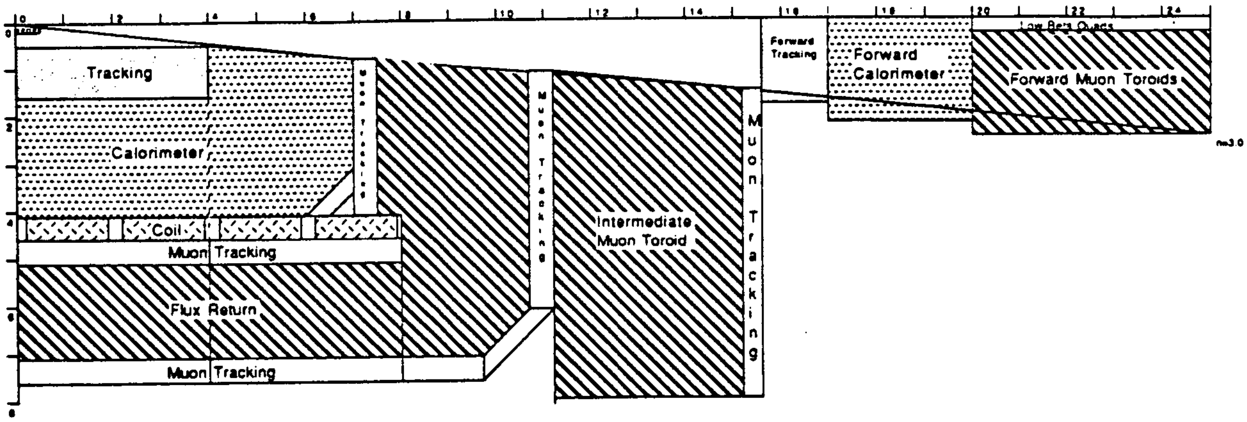

Fig. 1. The Large Solenoid Detector

3.2 Compact Solenoid Detectors [6]

A better name for these detectors would be "high-technology" solenoid detectors. Two varieties were proposed. The solid-state ball (SSB), shown in Fig. 2, consists of a 2-m radius 4T solenoid, inside of which are silicon-strip tracking devices out to a radius of about 50 cm, followed by U/Si electromagnetic and fine hadronic calorimeters to a depth of 5-6λ. On the outside of the coil are iron hadron tail-catchers to complete the calorimetry.

The second high-tech detector, with the name SMART for "Strong Magnet and Revolutionary Technology" is shown in Fig. 3. It emphasizes scintillating-fiber technology with a tracking system consisting of just two bundles of 30 μm diameter fibers at radii of 50 and 60 cm followed by a Pb/SciFi electromagnetic calorimeter and a 6T 1-m radius solenoid coil. On the outside of the coil is the full Pb/SciFi hadronic calorimeter, and the muon toroids.

There are numerous ingenious features in both these detectors, which I have no space to describe here, and the reader is referred to the original reports for details.

3.3 Non-Magnetic Detector [7]

This device shown in Fig. 4 emphasizes the role of high precision calorimetry. There ae also tracking and transition-radiation detectors

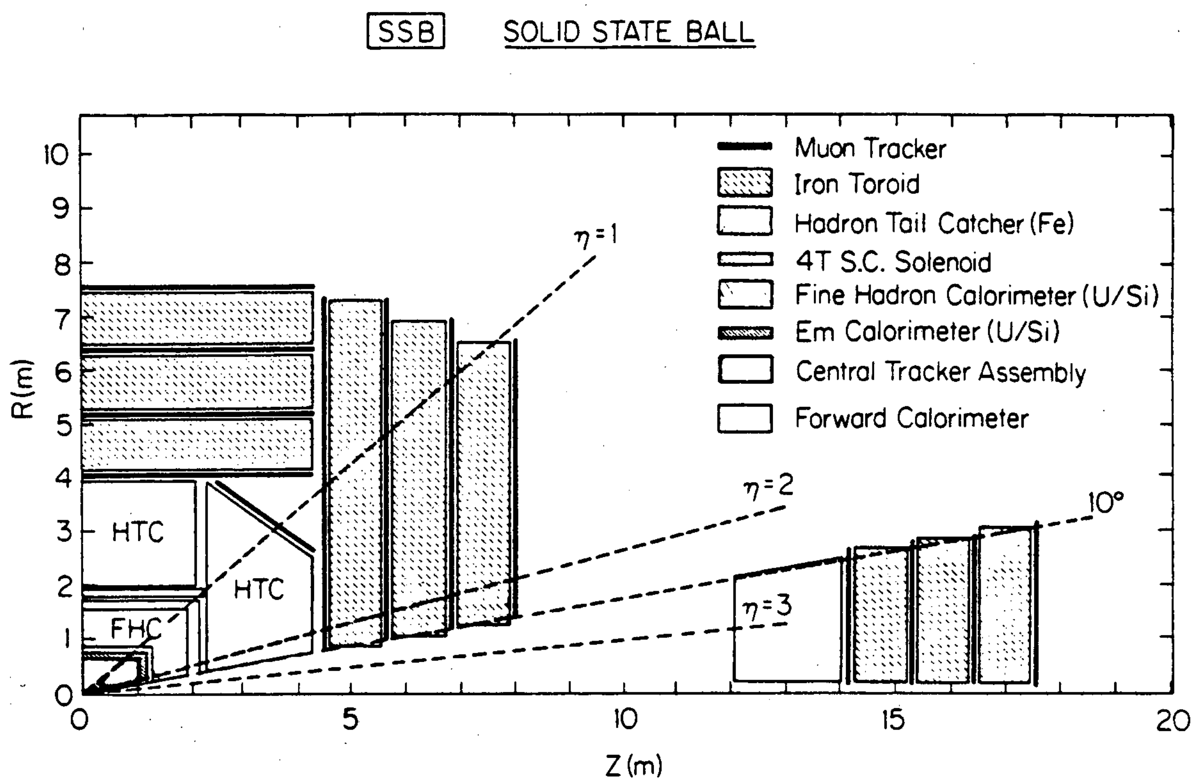

Fig. 2. The SSB Compact Detector

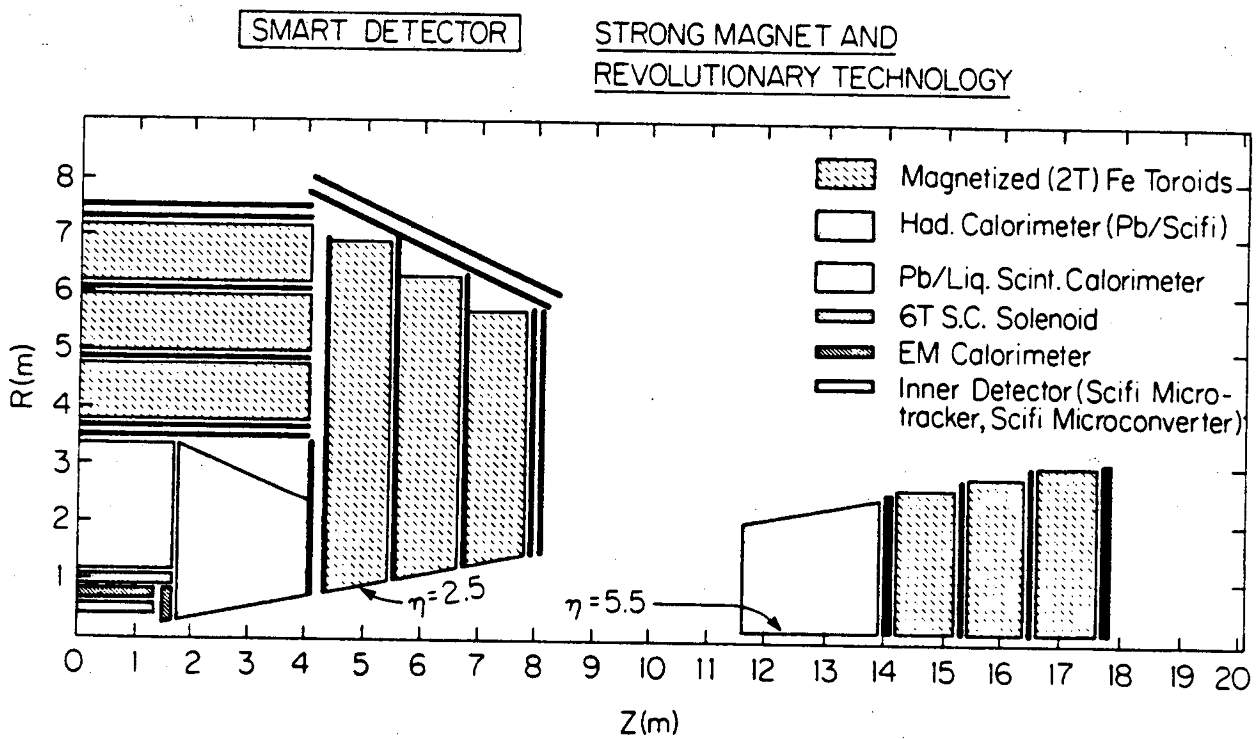

Fig. 3. The SMART Compact Detector

(TRD) to enhance electron identification. The possibility of introducing a coil to provide a modest magnetic field is left open. As in the large solenoid detector, several calorimeter technologies are considered possible candidates.

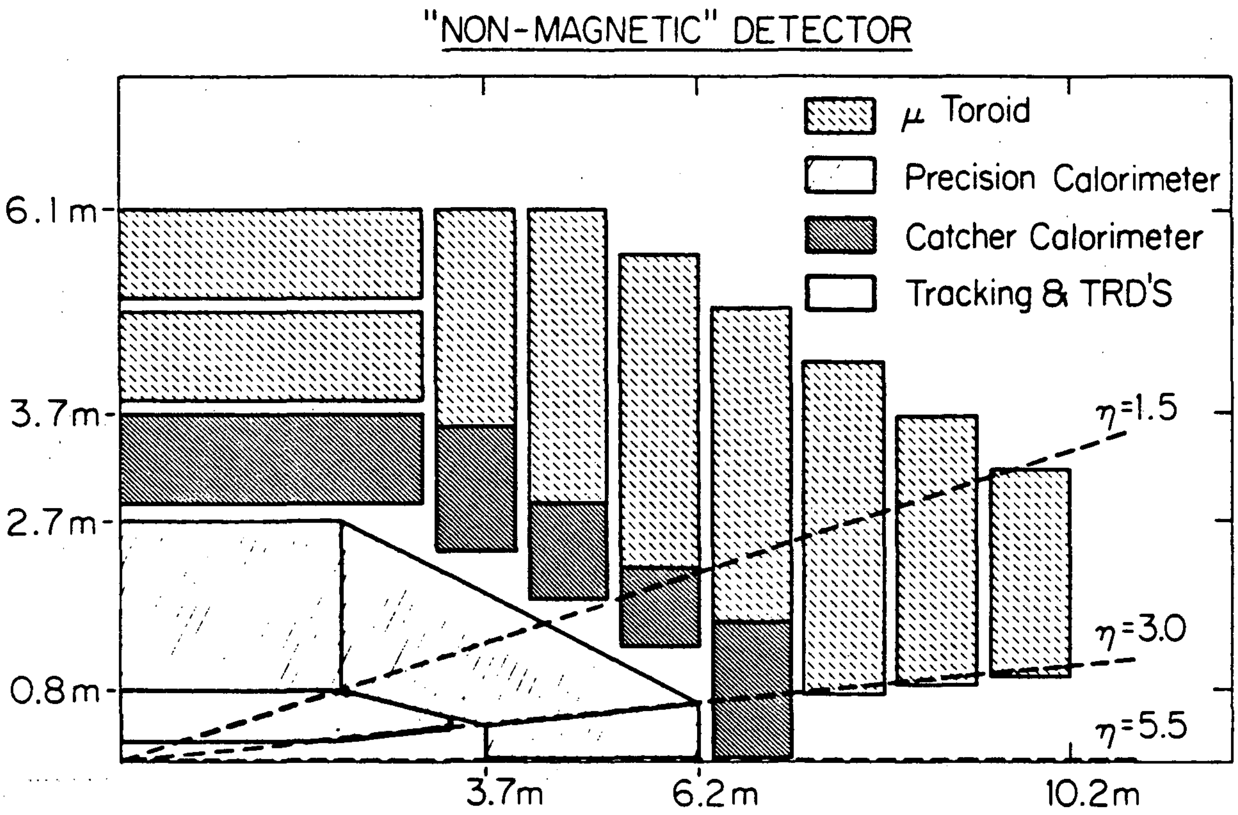

Fig. 4. The Non-Magnetic Detector

3.4 Dipole Detector [8]

Some consideration was given at the Workshop to the properties of dipole detectors, but that direction seemed to elicit only limited interest. The reader is referred to the Berkeley Proceedings for details.

3.5 Muon Detectors

Consideration was given to two different detectors emphasizing muon detection. One, shown in Fig. 5, is unique among proposed SSC detectors in that no calorimetry is used [9]. An absorber placed near the beam line removes the hadronic and electromagnetic components, and muons are measured in a central magnetic tracking system and in iron toroids. This detector design, though limited in its total capabilities, may be able to handle luminosities higher than 10^{33} cm^{-2} s^{-1}.

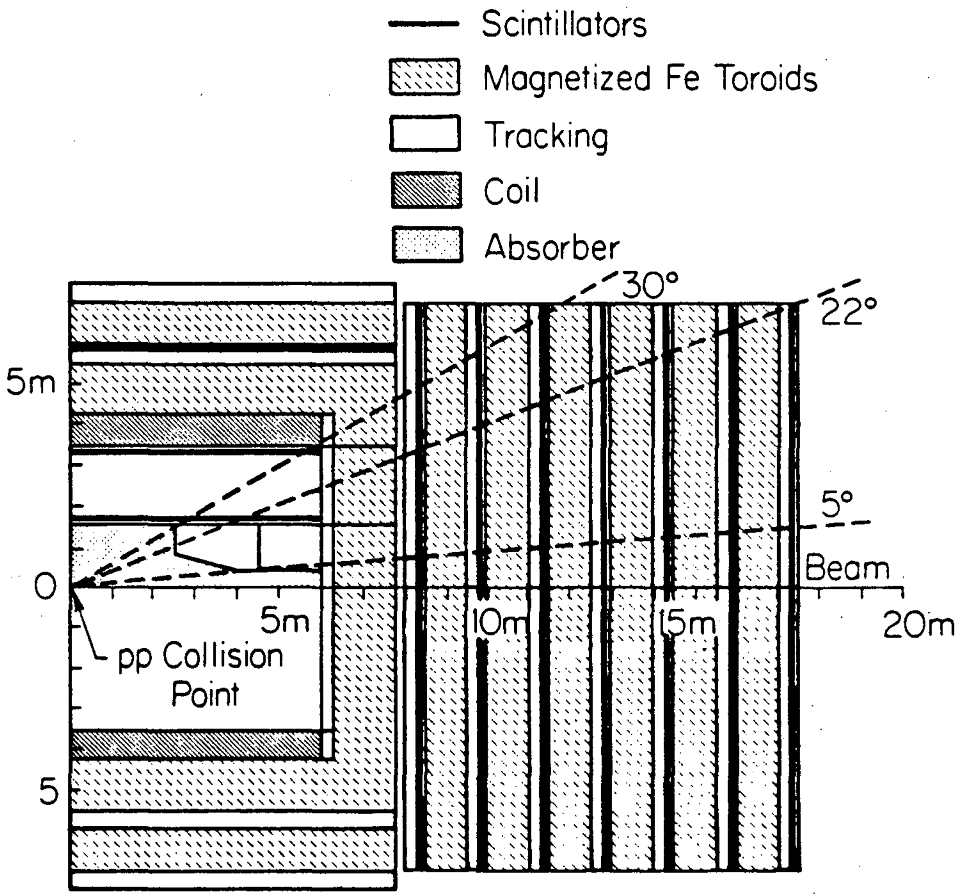

Fig. 5. The Muon Detector

The second muon detector [10], named L3+1, is similar in conception to the L3 detector at LEP. It is shown in Fig. 6, and provides measurement precision of $\pm 2\%$ for 500 GeV muons at $|\cos \theta| \leqslant 0.8$, and $\pm 14\%$ out to much more forward angles. Calorimetry consisting of liquid xenon scintillator for the electromagnetic part and U/warm-liquid for the hadronic part is proposed.

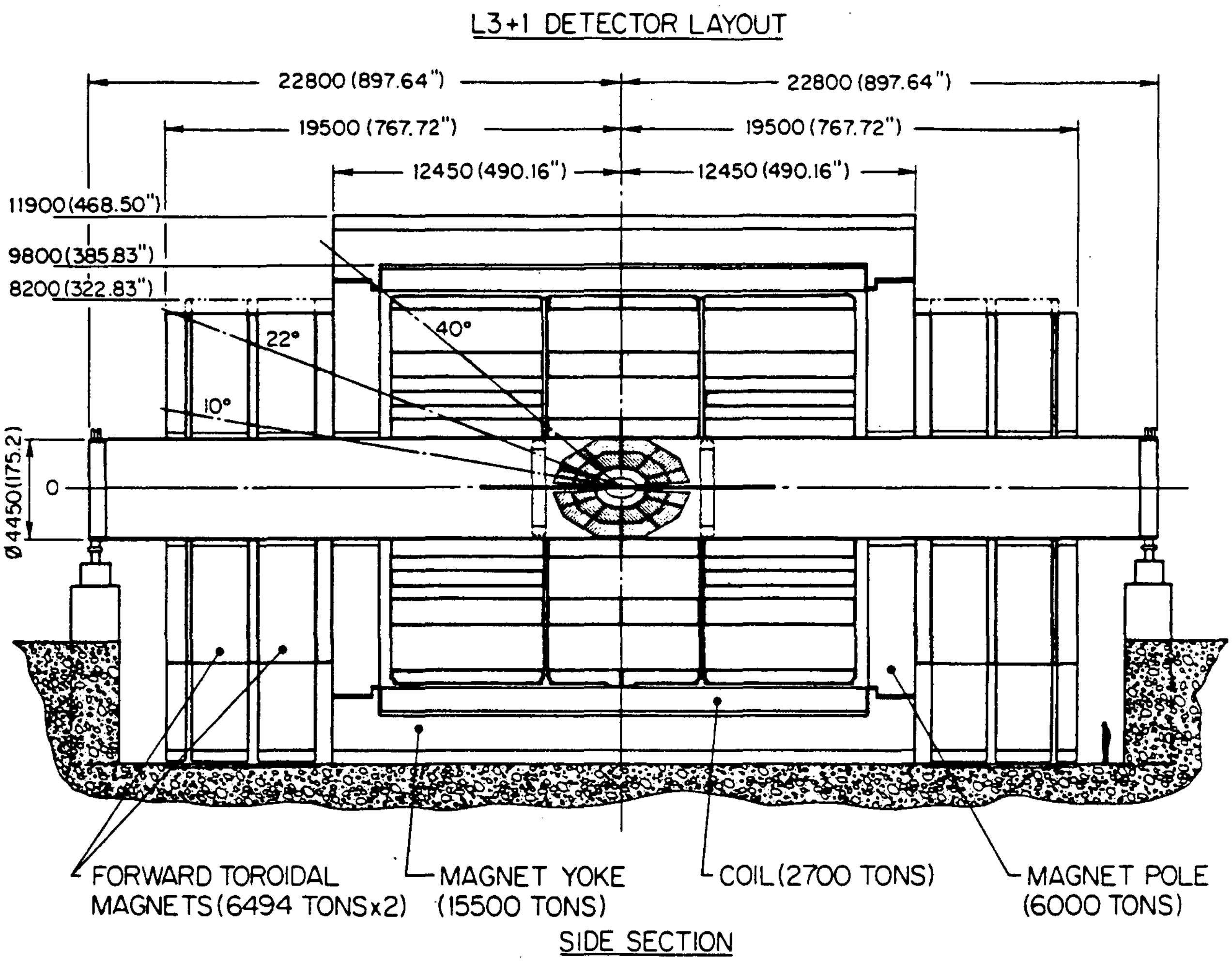

Fig. 6. The L3+1 Detector

4. COMMENTS ON PROPOSED DETECTORS

These comments are principally based on the summary of Cashmore et al. at the Berkeley Workshop [1]. We consider the various subareas of the detectors.

Calorimetry

There was not enough time at the Workshop to carry out designs of calorimeters in sufficient detail to say something useful about achievable hermeticity. For example, only a detailed design would show whether the absence of a solenoid coil allows sufficient improvement in the quality of calorimetry to justify the loss of magnetic tracking information. It does appear that the important $e/h = 1$ criterion has been somewhat neglected in the compact and L3+1 calorimeter designs.

The technologies of particular promise for calorimetry at the SSC appear to be U/LA, Pb/SciFi, U or Pb/warm-liquid, and U/Si. There are major open R&D issues for all these technologies, especially for the latter three.

Charged Particle Tracking

Technologies proposed for tracking include drift or straw chambers, large scale silicon strip devices, and scintillating plastic fibers of very small diameter. In addition, silicon pixel systems with sparse readout were proposed for vertex detectors.

The drift/straw chamber technology is the more established. However its feasibility at $L = 10^{33}$ cm^{-2} s^{-1} with about ten superposed events per trigger has yet to be proved. Such devices are unlikely to track particles efficiently in the cores of jets for jet energies above 100 GeV.

The silicon or fiber tracking detectors provide the advantages of more rapid response, more compactness, and the potential to reconstruct tracks within jet cores for jet energies up to 500 GeV or perhaps even higher. However costs may be prohibitive, and problems of radiation hardness of detector and electronics must be addressed.

Again all technologies require substantial R&D.

Lepton Measurement

Calorimetry alone can probably provide electron ID with hadron rejection of 10^{-2}-10^{-3}. Good longitudinal segmentation and a small Moliere radius are desirable to achieve this goal. With magnetic charged-particle tracking to provide E/P plus the calorimetry, the achievable rejection should be at least 10^{-3}. With the TRD's (non-magnetic detector) or a micro-converter (compact detector) total rejection should reach 10^{-4}. As mentioned in Table II, the high P_T physics studies seem to demand rejection at only the 10^{-2} level, but the higher levels seem desirable for general-purpose detectors.

Muon capabilities appear to be comparable in all the proposed detectors (with momentum precision at the 10-20% level at 1 TeV) except for the L3+1 detector with its 4% error at 1 TeV over a limited rapidity range.

Solenoid Magnets

All the superconducting magnet designs exhibited some level of optimism. The large solenoid detector with its 2T, 4 m radius lumped coil carries about an order of magnitude more energy than the LEP magnets. The compact solenoids with 4T or 6T fields, if built by presently known technology, would be so thick as to degrade seriously the calorimetric performance. Clearly R&D is also needed here.

One final comment may be useful. Many of the physics areas involve the detection of several leptons within a single event. There is thus a great advantage to having both electron and muon identification capability within a single detector. A muon detector capable of 10^{34} cm^{-2} s^{-1} operation has a rate advantage of only 2.5 over an electron/muon detector with 10^{33} cm^{-2} s^{-1} capability.

5. SOME GENERAL CONCLUSIONS ON HIGH P_T DETECTORS

The particular advantages of the large solenoid, compact solenoid or non-magnetic detectors did not clearly emerge from the limited effort at the Workshop. Indeed, the real trade-offs will only appear with detailed optimization. In principle the high-tech compact detectors hold out the possibility of improved capabilities, but there will have to be major R&D breakthroughs before one can confidently embark on the design of such detectors. Clearly the perspectives of what can be achieved and how best to achieve it will change as the R&D efforts progress, and as detailed design work gives more realism to the detector concepts. It is clear that improved detector simulation tools will play an important role in optimizing designs.

Table I
WORKSHOP ORGANIZATION

WORKING GROUP (1) -- HIGH P_T

Parametrization Subgroups
- Heavy Higgs
- Non-Standard Higgs
- Intermediate Mass Higgs
- New Quarks and Leptons
- Supersymmetry
- New W or Z
- Jets and Compositeness

Detector Configuration Subgroups
- Large Solenoid
- Compact Solenoid
- Non-Magnetic
- Dipole
- Muon Spectrometers

WORKING GROUP (2) -- INTERMEDIATE P_T

Parametrization Subgroups
- B Physics
- Forward W, Z, and T

Detector Configuration Subgroups
- B Physics Spectrometer
- Forward Spectrometers
- Jet Spectrometers

WORKING GROUP (3) -- LOW P_T

WORKING GROUP (4) -- EXOTICS

Table II
PARAMETERS FOR HIGH PT PHYSICS

Luminosity
$\geq 10^{33}$ cm^{-2} s^{-1}

Vertex Detection
Not crucial for most studies (except intermediate Higgs and background removal)

Charged Particle Tracking
As needed for lepton ID ($|y| \leq 3$)
Electron sign determination up to 1 TeV in some cases
No requirement to track within jets (possible exception may be jet compositeness studies)

Electron ID
Essential over $|y| \leq 3$
Hadron rejection better than 10^{-2}

Muon ID
Same as electron ID
For missing E_T, may need to measure muon energies up to $|y| < 5$-6

Calorimetry
Hermeticity within $|y| < 5$-6
Transverse Segmentation
0.03 x 0.03 (EM), 0.06 x 0.06 (HAD)
Longitudinal Segmentation as needed for electron ID
Resolution ~ $0.15/E^{1/2}$ (EM), $0.5/E^{1/2}$ (HAD)
e/h = 1 within a few %

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