A High Resolution Detector for $H^0 \to \gamma\gamma$

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1. Brief Description

SSC detectors represent a challenging departure, both in size and precision, from currently operating detectors. In this note we enumerate some of the benefits of using high magnetic fields both to simplify the detector and improve its resolution and sensitivity. We have chosen an arrangement optimized to search for the reaction $H^0 \to \gamma\gamma$. The arrangement also has the excellent momentum resolution for muons and electrons considered critical for the discovery of such processes as $H^0 \to Z^0 Z^{0*} \to \ell^+\ell^-\ell^+\ell^-$, $H^0 \to Z^0 Z^0 \to \ell^+\ell^-\ell^+\ell^-$, new and narrow vector bosons, and bound states of extra generational quarks. This detection scheme represents an improvement in the $H^0 \to \gamma\gamma$ mass resolution of at least a factor of 7 beyond the best currently proposed detectors. This is exceedingly valuable given the marginality of this signal. In addition, we have a significantly improved rejection of common $H^0 \to \gamma\gamma$ backgrounds. As indeed most experiments do not exceed their initial projections, this extra factor could insure the unambiguous discovery of this decay should it indeed occur. As no reasonably realistic detector can achieve excellent detection for all physics signatures we chose to give up on excellent hadron calorimetry. Hence one might cede the discovery of important but speculative processes such as supersymmetry to other detector systems.

For Higgs masses between 80 and 150 GeV/c^2 the Higgs decay into two photons is an excellent signature. To date, all attempts to search for this decay mode have centered on the use of electromagnetic calorimetery. This method has the unfortunate feature of having a constant resolution term dominating at high energy. We are proposing a different approach. We will convert the two photons close to the production point and measure the momenta of the electron pairs. This makes it necessary to have a large magnet with a large field.

As an initial ansatz we examine a detector shown in Fig. 1.1 consisting of a solenoidal magnet of a 3.5 meter inner radius and 17 meter length, capable of up to 10 Tesla excitation. The magnet will house a standard tracking system, a silicon vertex detector with a thin (about 1 R.L.) converter and an electromagnetic calorimeter. The surrounding iron flux return (5 meters thick) will serve to filter and identify muons of momenta as low as $P_t = 10 GeV/c$. Forward and backward dipole magnets can further enhance the acceptance and

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resolution of this system. The region of $|\eta| \geq 3.5$ has an open hole to minimize radiation dosage in the detector.

The relevant features of the detector can be listed as follows:

1. Mass resolution for the decay $H^0 \rightarrow \gamma\gamma$ of about 65 MeV/c^2 at a Higgs mass of 100 GeV/c^2.
2. Single particle momentum resolution of about 0.65% to 3% at P_t =500 GeV/c for the region $0 \leq |\eta| \leq 3.5$.
3. Vertex resolution of close to 10μm, allowing for event separation within a single crossing.
4. A robust and simple muon system for P_t exceeding 10 GeV/c.
5. Positive separation of photons from electrons and π^0.

As an illustration of the power of this detection scheme we will consider an example of the decay $H^0 \rightarrow \gamma\gamma$.

2. Performance for $H^0 \rightarrow \gamma\gamma$

The distribution of both decay photons for a 100 GeV/c^2 Higgs is shown in Fig. 2.1. As an example, we select an event with photon energies of 80 and 120 GeV/c^2 and an opening angle of $\theta = 49°$. The photons are allowed to convert in the vertex detector/Lead converter. The converter is sandwiched between two layers of silicon detectors, placed as close to the interaction point as possible. The momenta of the electron pairs is measured magnetically in the tracking system. The electron pairs are then detected in the electromagnetic calorimeter on the perimeter of the magnetic tracking system. In the event reconstruction, one can require that no charged tracks enter the vertex detector but that the correct number of charged tracks exit the vertex detector (after the converter). The conversion point can be measured to O(10) μm. The electron pairs for each photon can be extrapolated to the interaction point, which can be measured also to O(10) μm. It is then possible to require the two photons to have a common origin, and hence reconstruct the Higgs mass even in the presence of several secondary interactions. In addition, the electron pairs can be further identified by requiring an agreement between the magnetically measured momenta and the calorimeter measured energy. Timing information about the electron pairs can be provided (to the nsec level) by scintillation counters at the entrance to the calorimeter.

The arrangement shown can significantly reduce,or even completely eliminate, the possibility that a π^0 will simulate a photon. The standard isolation cuts to eliminate π^0 from jets are vulnerable to small variations in π^0 suppression efficiency. A small change in this efficiency (say from 0.9999 to 0.9989) will yield a significantly higher background. We require positive identification of the photons. In addition, the rejection of π^0 away from the jet is systematically achieved by:

1. Requiring the energy in the electromagnetic calorimeter for the $H^0 \rightarrow \gamma\gamma$ to match an equivalent charged track thus eliminating all non-converted overlapping π^0.
2. If an electron pair is found, then the vector sum of that pair's momenta must not point to a calorimeter cell with excess energy. This eliminates π^0 where

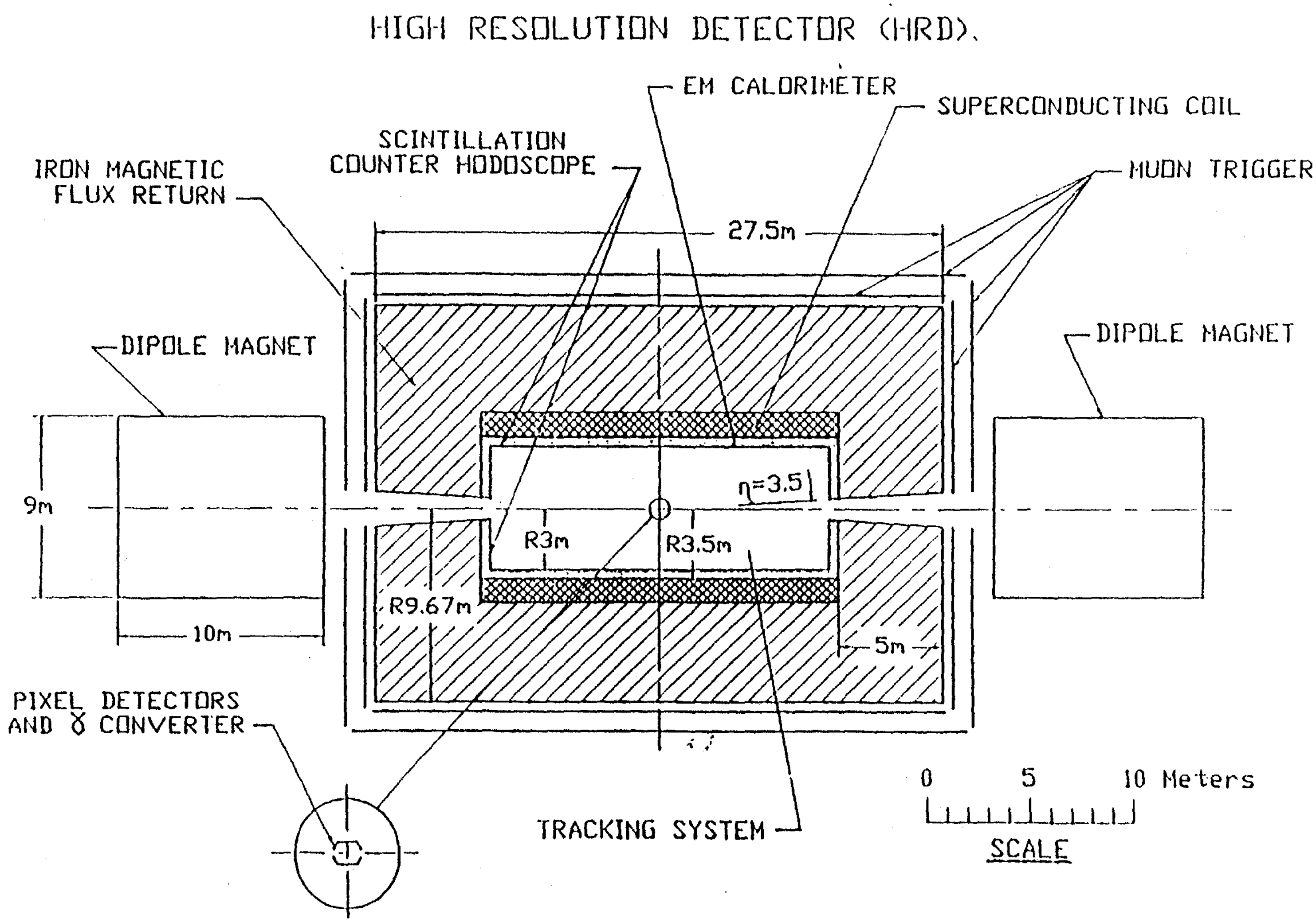

Figure 1.1: The HRD Detector

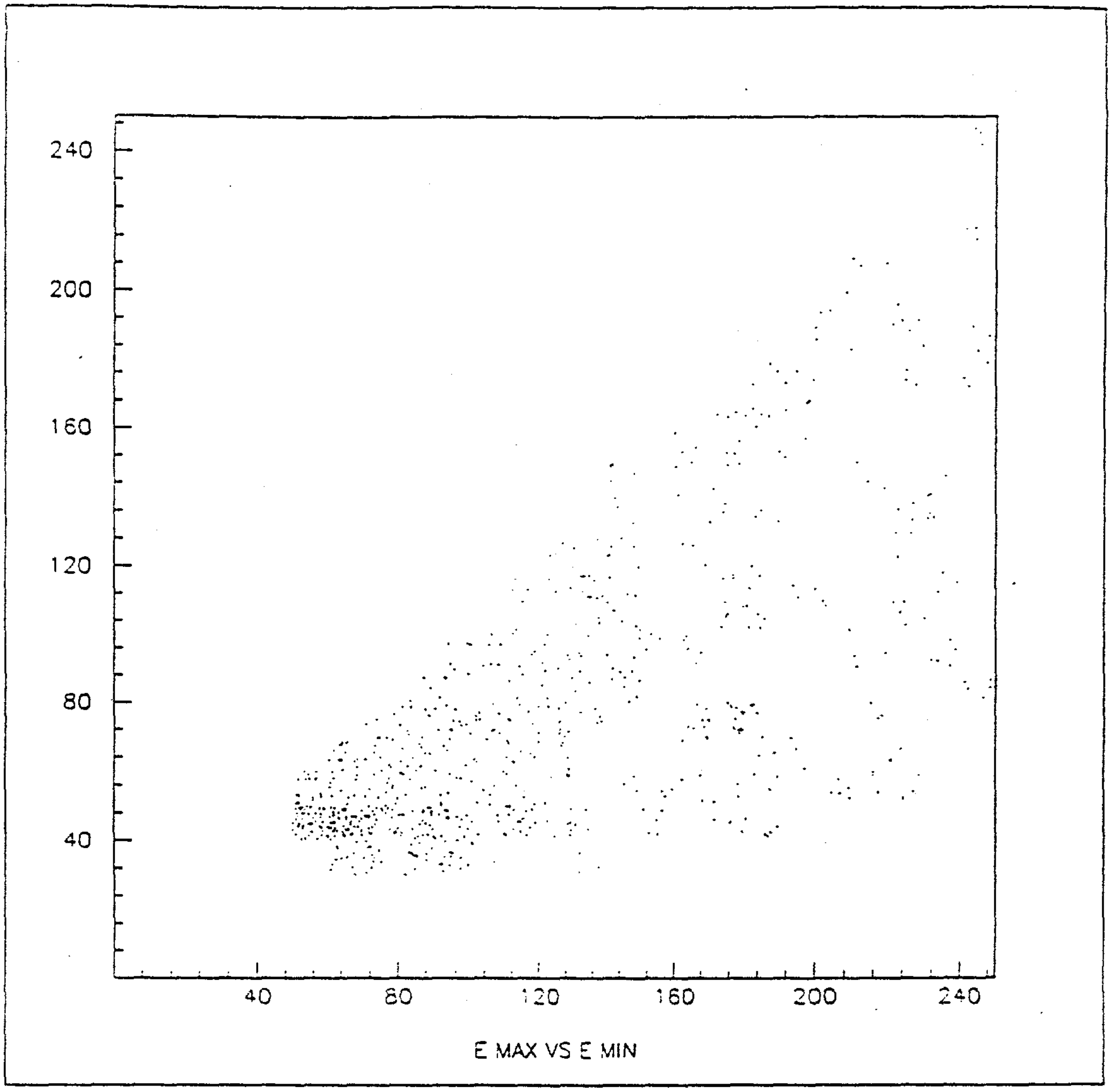

Figure 2.1: Distribution of the two photon energy from a 100 GeV Higgs decay

one photon converted in the radiator while the other converted in the electromagnetic calorimeter.

3. If an electron pair from the converter has a total momentum vector coinciding with that of an electron pair originating from the production point then the event is rejected. This eliminates π^0 where either photon underwent a Dalitz decay. At high energies a Dalitz decay will also be rejected by the requirement that a neutral particle enters the converter.

One is then left with the rare directly produced photons and the irreducible QCD background from $gg \rightarrow \gamma\gamma$ and $q\bar{q} \rightarrow \gamma\gamma$. Earlier studies have identified event topology cuts to enhance the Higgs signal relative to the background. After applying these cuts the *only* handle left is the two photon mass resolution, which we optimize by measuring the momenta of the converted pairs at the highest magnetic field of 10 Tesla.

The expression for the uncertainty of the mass (m) for a Higgs decaying into two photons of energies E_1 and E_2 and with an opening angle θ is given by Δm where

$$\frac{\Delta m}{m} = \sqrt{\left(\frac{\Delta E_1}{E_1}\right)^2 + \left(\frac{\Delta E_2}{E_2}\right)^2 + \left(\frac{\sin\theta\Delta\theta}{1-\cos\theta}\right)^2}$$

For the event mentioned above (E_1=80 GeV/c^2, E_2=120 GeV/c^2 and $\theta = 49°$) the following table shows the mass resolution for both HRD and L^*.

Quantity	HRD	L^*
$\left(\frac{\Delta E_1}{E_1}\right)^2_{80GeV}$	49×10^{-7}	4.16×10^{-5}
$\left(\frac{\Delta E_2}{E_2}\right)^2_{120GeV}$	11×10^{-7}	3.83×10^{-5}
$\Delta\theta$ per γ	3.3×10^{-5}	10^{-3}
$\left(\frac{\sin\theta\Delta\theta}{1-\cos\theta}\right)^2$	0.1×10^{-7}	0.96×10^{-5}
Δm	63 MeV/c^2	473 MeV/c^2

Again our arrangement represents a factor of 7 improvement over L^* in mass resolution, which will naturally reflect as a similar improvement in sensitivity.

The assumptions about HRD are as follows

1. The energy loss of the electron pair in the converter is negligible; otherwise an active converter might be considered.
2. The momentum resolution for each of the electron pair is 0.65% at 500 GeV/c.
3. The uncertainty of the direction of the photon is 100μm over the 3 meter tracking span.

The assumptions for L^* are derived from the L^* documents and are

1. The energy resolution of the electromagnetic calorimeter (BaF_2 crystals) is given by
$$\left(\frac{\Delta E}{E}\right) = \frac{1.3\%}{\sqrt{E}} + 0.5\%$$
2. The photons can be located within the 3 cm crystals to 1 mm.
3. The two photons are assumed to have originated at the vertex given by the other charged tracks.

It should be noted that the converter can be removed for experiments other than the $H^0 \rightarrow \gamma\gamma$ search.

3. Single Particle Resolution

The calculation of single particle resolution is straightforward and is reproduced in Fig. 3.1 as a function of η.

We have,for comparison, also drawn the resolution estimated by the SDC collaboration, and the resolution deduced from the detector drawings of the L^* collaboration (The latter chose to plot resolution vs $cos\theta$, thus sharply contracting the barrel-forward transition region).

Two points need to be made about our baseline resolution of 0.65% for a P_t=500 GeV/c shown in the graph.

1. We have not attempted to optimize the resolution in the forward direction by the common practice of increasing the number of forward tracking chambers. This is desirable and will naturally improve the resolution in the forward direction.
2. The resolution for particles with less than 10 GeV/c momentum is further improved because of the large bend radius and hence longer measurement arm.

It has been repeatedly pointed out that experiments with high lepton resolution have had a distinct advantage in the discovery of new physics. This should be no exception. In addition, for processes such as $H^0 \rightarrow Z^0 Z^{0*} \rightarrow \ell^+\ell^-\ell^+\ell^-$ the lepton resolution over a large acceptance region in both η and P_t is crucial for both discovery and background suppression.

4. The Superconducting Magnet

The superconducting magnet could be built either from Niobium-Titanium operating at a reduced temperature or from Niobium-Tin. Ralph Shutt has looked at a possible design of the coil and concluded that it can be built with a conservative safety margin with a coil thickness of one meter. A 5 meter thick iron cylinder is required for the magnetic flux return. We should note that with this arrangement Particles of $P_t \leq 4.5$ GeV/c will not exit the tracker thus reducing the rate at the face of the barrel calorimeter by at least a factor of 100.

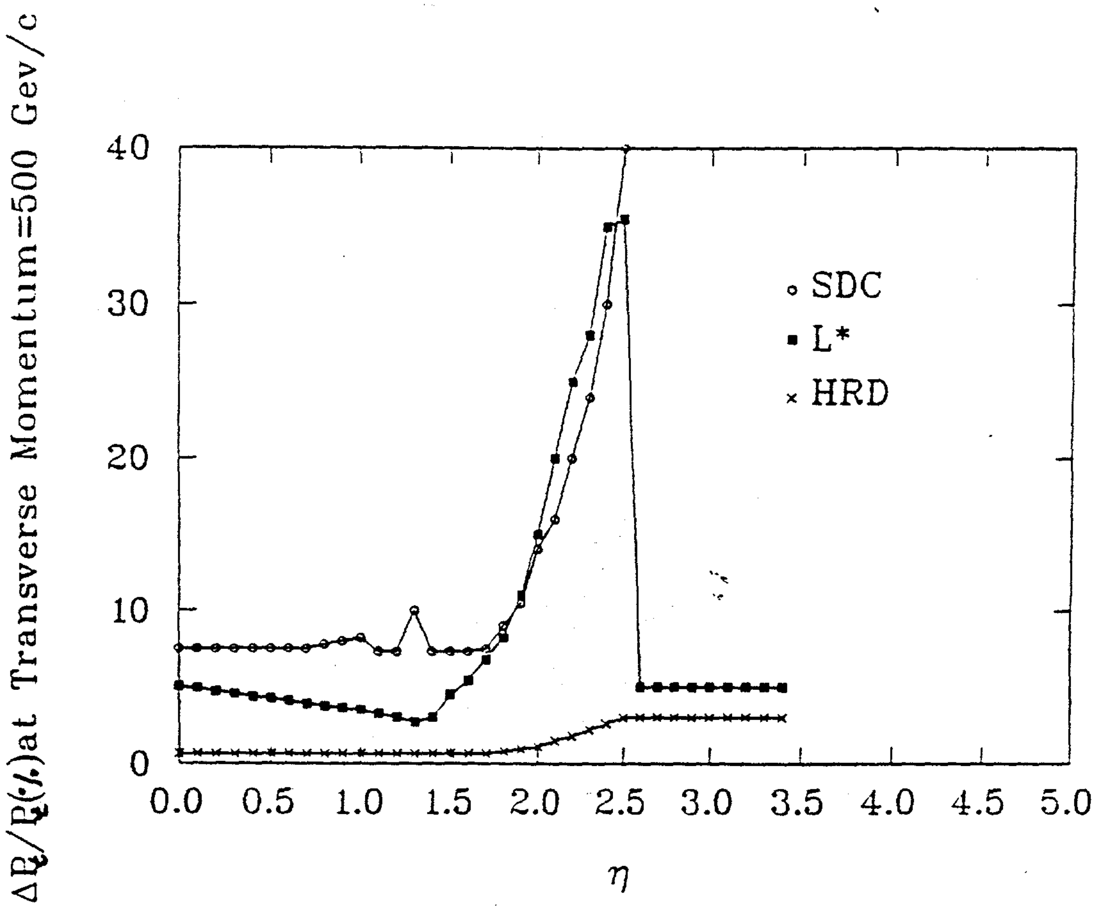

Figure 3.1: Momentum resolution of a particle with P_t=500 GeV/c as a function of η

5. Outstanding issues

An innovative concept will undoubtly require significant R&D before actual implementation. We list some of the possible issues

1. Operation of the Vertex detector/Converter. There is no current data on the operation of such devices in high magnetic fields. However no practical or fundamental issues prevent such operation.
2. Operation of tracking chambers in high magnetic fields. The most recent experience comes from the AMY detector which operated at 3 T. The tracking system suffered no significant resolution loss, although there are lessons to be learned from the collection time of ions near pockets of low fields. As the Lorenz angle does not change significantly from 3 to 10 T we expect to overcome any technical problems with a modest R&D program.
3. The ability to do hadron calorimetery. This detection scheme is not entirely helpless to detect hadronic jets. The charged component of the jets will be measured with great accuracy magnetically. The neutral electromagnetic component and some fraction of the neutral hadronic component will be measured in the electromagnetic calorimeter. We are studying the optimal longitudinal segmentation of the electromagnetic calorimeter to separate the two components. We are also studying the degradation in resolution should one simply use the known fractional jet energy contained in neutral hadrons to compensate the magnetic measurement. Clearly this will never yield a perfect calorimeter, but should enable us to use jet energy for event cuts and isolation.
4. The operation of the electromagnetic calorimeter in a high magnetic field. The most recent experience with gas calorimeters comes from the ALEPH experiment at CERN. We should note that we do not require very high resolution, only sufficient resolution to insure matching with the momentum measurement.

6. Conclusion

The method of using high magnetic fields to measure the decay $H^0 \rightarrow \gamma\gamma$, among many other interesting physics signatures, shows great promise. The improved lepton and single particle momentum resolution, as well as the robustness of the muon identification system are an additional incentive to explore this idea.