A W-Si electromagnetic calorimeter for Higgs physics at a linear collider

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Abstract.
Since the Sitges linear collider workshop it has become common belief that a linear collider detector has for first priority to ensure proper measurement of many jet events, hence to provide a good energy flow, as is termed now the reconstruction of such events. This may mean a specific detector design. In this paper it is shown that some simple ideas on the mechanical structure and the read out for a silicon tungsten sandwich electromagnetic calorimeter may bring a solution.

INTRODUCTION

It is the general creed that the main physics motivation of a Linear Collider is the full study of the Higgs boson. In the standard model or its supersymmetric extensions it is clear that most of the final states contain many jets. The necessity to measure the momentum and mass of colourless systems of two jets is primordial. That means being able of properly identifying and measuring its components. This process is commonly understood under the name of "energy flow". To accomplish such a task, it is clear that as little as possible energy should escape detection and that the energies should be well measured avoiding in particular any double counting. Our goal in the present talk is to analyse the underlying problems and to show that few simple ideas can provide promising elements of solution. This is a solution retained for the ECFA-DESY Technical Design Report.

THE CONSTRAINTS

The first basic point is to make a hermetic detector, a way to say that the energy produced in the reaction is fully contained for what can be contained. This clearly means that the detector has to extend to very low angles, as low as the machine background tolerates. This means also that the elements of detection, tracker and calorimeter do not suffer from cracks where particles could escape. Less trivially this requires also that there is no dead material on the way to absorb an undefined fraction of energy. At a linear collider the machine background impact is minimised by the use of strong magnetic fields, 4 T are considered for TESLA. This implies a rather thick coil and has lead to situate the full calorimeter inside the coil.

An energy flow in a multijet environment, together with the importance to identify well leptons to sign the presence of neutrinos in quark decays, speaks for a good separation between particles. This means a high tridimensional granularity which requires a high density calorimeter. An interesting consequence of a very high 3d granularity is that it allows to drop the projectivity of the calorimeter cells. It is important to notice that the sampling, the layer structure, is dictated by the E-resolution, not really by the granularity in depth.

THE DESIGN

All these considerations led naturally to choose a high density pictorial calorimeter totally inside the coil, with enough interaction lengths. The solution we propose is a calorimeter in two parts, an electromagnetic part is a sandwich of tungsten as radiator and silicon diodes for detector, the hadronic part would be a sandwich of stainless steel, may be with some denser material, and a detector with tiny cells but read out purely digitally, a cell is fired or not. We will focus here on the electromagnetic part.

The layer structure is currently the following but will be largely optimised. There are 40 layers, 30 with a tungsten thickness of 1.4 mm making 12 radiation lengths, 10 4.2 mm thick making 12 more. This, together with the silicon detectors ends up into a calorimeter 21 cm thick for 24 radiation lengths. As the calorimeter surrounds a TPC and starts at a radius of 1.7 m this makes a good area of silicon, about 3000 m^2. Dense, this needs very small cells, about 1x1 cm^2, hence very numerous, about 30 millions, as many as seconds in a year. The price of the silicon, large, is due to the surface, not to the cell number, and the surface is linked to the radius and to the number of layers, itself purely related to the resolution in energy.

The mechanical structure

Renouncing to the projectivity pays off immediately for the mechanical design since the boundaries do not need anymore to follow a projective pattern. It eases the crack problem and the technical choices, in particular in the end caps. The figure 1 shows on the left the barrel structure. The eight modules are arranged in an unusual way. The detecting layers end up on one side just between the electromagnetic and the hadronic parts. This is the place where we install the front end electronics, which is then completely behind the electromagnetic, for more details see figure 2. The cracks, tiny, are far from projective. On the right of the figure 1 is a schema of the end caps. They are divided in four modules and the boundaries, parallel to the beam axis are not projective.

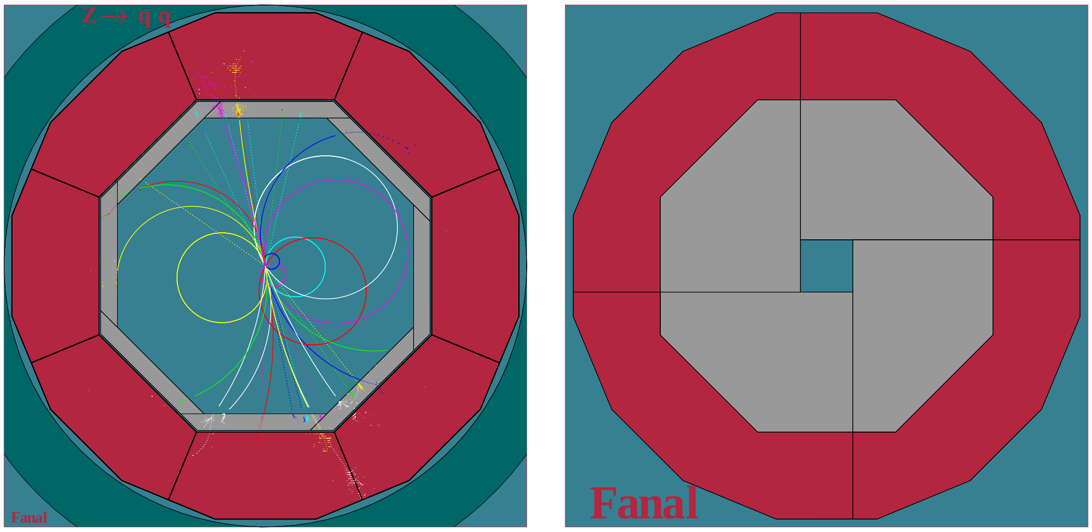

FIGURE 1. View of the barrel structure on the left and of an end-cap on the right, the electromagnetic calorimeter is in grey and the hadronic in bordeaux.

Another source of cracks comes from the spaces needed to hold the modules together. Here a very trivial solution is considered, instead of large holes a lot of small ones, with respect to the shower size, are used. The radiator is made out of tungsten slabs 9 cm wide. In the odd layers the slabs are aligned with the beam, in the even ones they are perpendicular. These last ones are used to support the silicon detecting layers making detector slabs. To build the mechanical structure, the tungsten slabs from the odd layers and steel kernels playing the role of the detector slabs are wrapped in an epoxy-carbon fibre composit and the module is cured. The kernels are taken out leaving slots, called alveoli, in the structure. The detector slabs can then be slit in. The composit walls are few tenth of a millimeter wide. This can be seen in the figure 3.

The figure 4 shows the structure of a detector slab and the way the signals are extracted. On each face of the tungsten slab silicon wafers are glued, a thin layer of G10 with metallized holes makes the connection between the wafer and the flat cable. The flat cable under study has four layers, each one being made of gold plated tungsten wires 50 micron diameter at a spacing of 300. At the end of the module in the tiny pace reserved for it, the wires are bonded to a board helding the front-end chips.

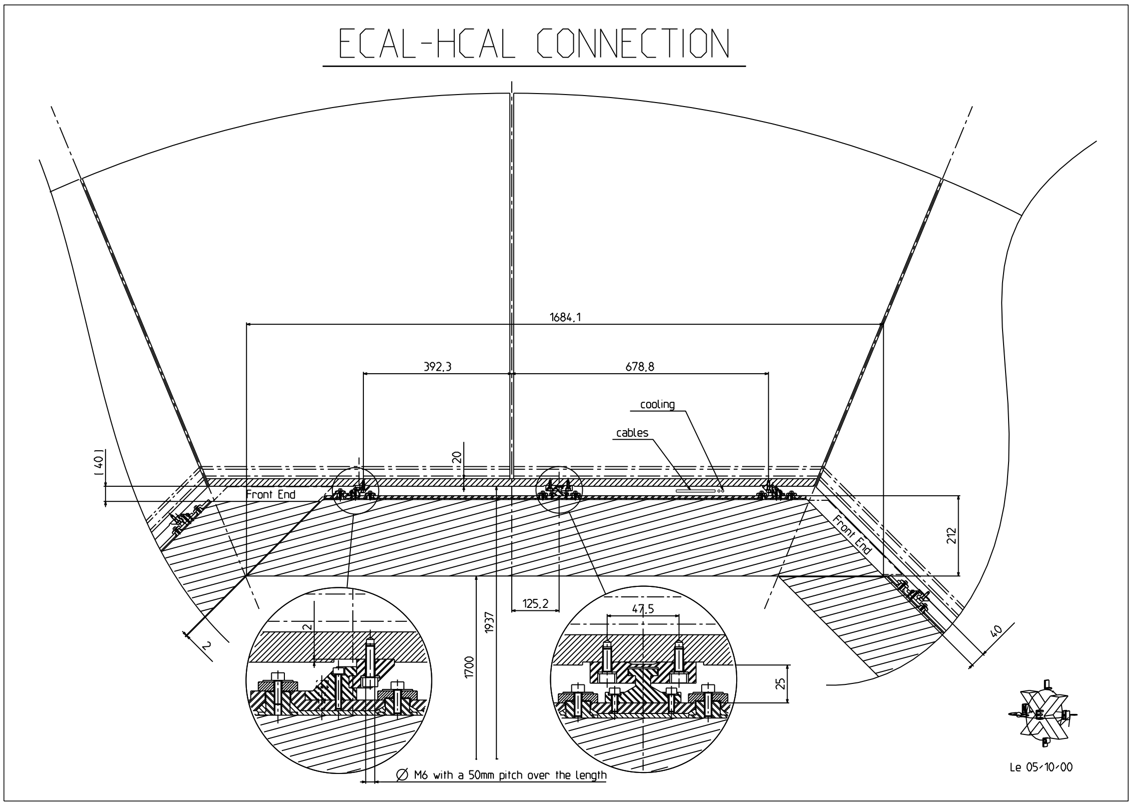

FIGURE 2. Detail of the calorimeter structure showing the way the electromagnetic part is supported by the hadronic and the location of the front-end electronics.

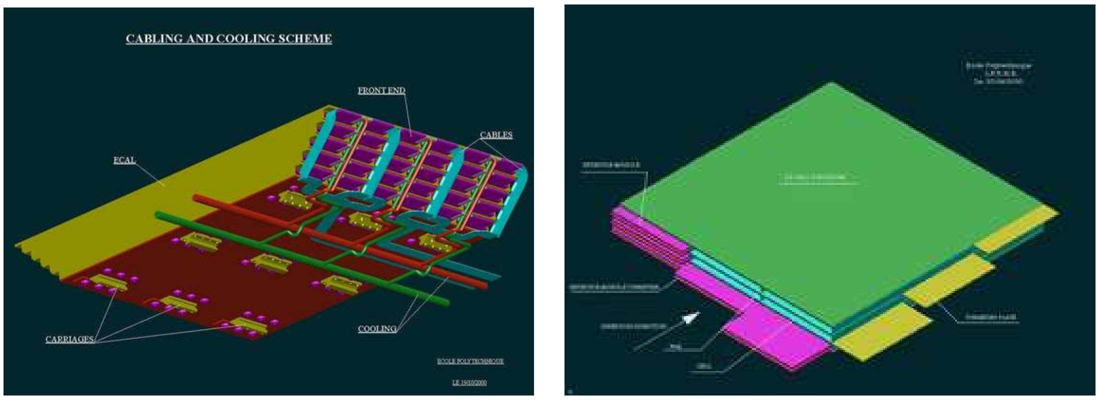

FIGURE 3. On the left an artist view of a module with its cables and cooling, for simplicity four layers only are represented instead of 40, on the right the mechanical structure is shown with the structural tungsten slabs on the right and the detector slabs on the left.

Electronics and read out

The front-end electronics is characterized by a large number of channels with rather low occupancy. It is mandatory to be able to see the minimum ionizing particles with good efficiency out of the noise and to measure the maximum deposit of a 500 GeV electron in a cell. This means a dynamics of 15 bits. But the precision needed can be obtained easily with 2 gains and 10 bits each. In TESLA the time between crossings, greater than 150 ns, is long enough to get the incoherent noise at the level of a tenth of a m.i.p. A possible problem is the coherent noise; the cables should be well shielded but the noise on the chips is still under study.

The functions of the front-end are, to amplify with two gains, to provide a threshold at about two third of a m.i.p. which gives a 97% efficiency, to stamp the bunch number and the spatial address, possibly in an analogic way, to store enough hits not to have any dead time. A chip should handle about 150 channels.

A set of 40 detector slabs can be read out (through a token ring for example) and digitised in few ms by one ADC leading to less than 1000 ADC's plus some storage for a full train to be shipped to the data acquisition.

A GLIMPSE AT THE HADRONIC PART

This concerns the digital solution for the hadronic calorimeter. It is made of a stainless steel with possibly some heavier material to reduce the interaction length. The detector will provide signals in small cells, about 1 cm^2 in a digital way. Possible solutions are resistive plate chambers, Geiger cells or streamer tubes read by shift register. If the occupancy happens to be too large, a proportionnal chamber, à la ALEPH, but read digitally with a preamplifier in the shift register chip is possible. The resolution obtained that way compares well with an analog measurement

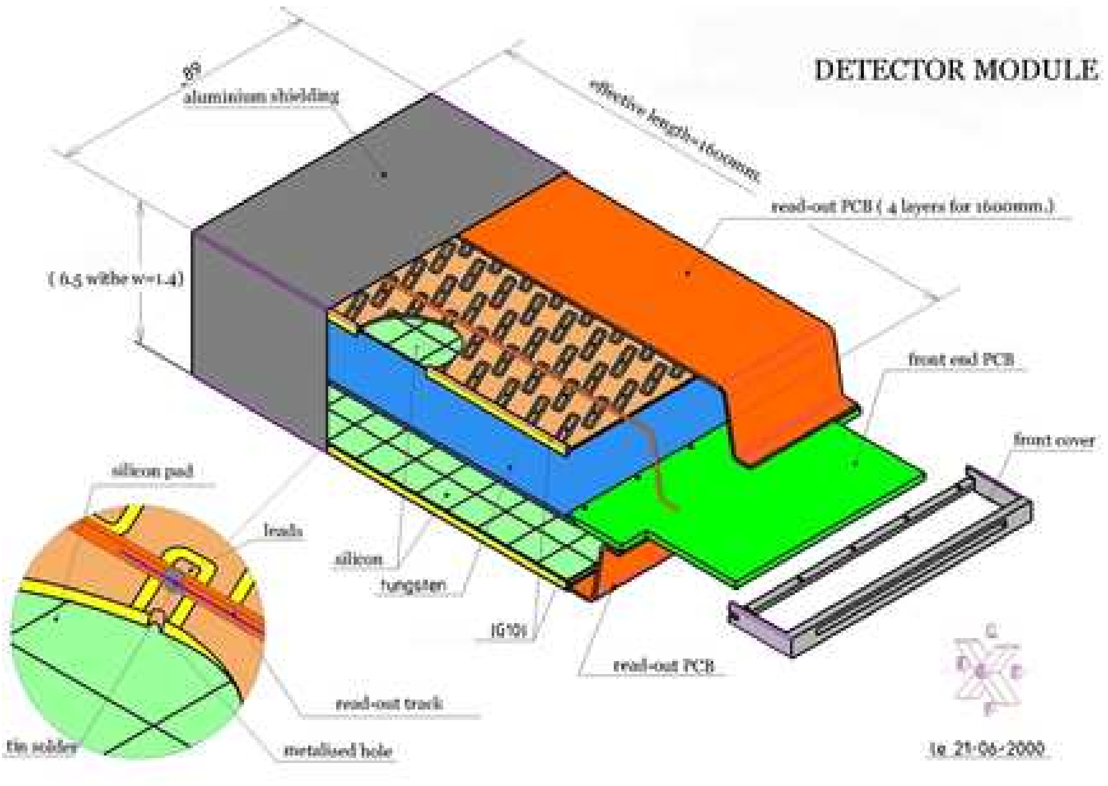

FIGURE 4. This figure is a schematic of the connections between the silicon pads and the front-end electronics.

as has been seen in simulation and from data collected in ALEPH. There is no need to say that the pattern is beautiful, figure 5.

THE PERFORMANCES

The detector design has been studied on the basis of a Geant4 study, see the talk by Paulo Mora de Freitas, and the performances are estimated from that simulation, they are detailed in Pascal Gay's talk and we refer to him for the performances on neutral hadrons. Concerning the performances on photons, the efficiencies and rate of generation of fake photons are shown on figures 6. The energy resolution does not follow a $1/\sqrt{E}$ law due to the presence of two stacks with different tungsten thicknesses. At low energy the stochastic term is about 0.10 when at high energy it grows to 0.14. This stack structure has the consequence that the resolution is essentially flat in angle. The position resolution is $1\mathrm{mm}/\sqrt{\mathrm{EGeV}} + 0.4\mathrm{mm}$ and the angular resolution of the shower itself is $60\mathrm{mrad}/\sqrt{\mathrm{EGeV}}$.

For jets with no neutral hadrons the visible energy resolution is $0.17/\sqrt{E}$ which shows that the contribution due to the photon energy collection is of the same order as the intrinsic resolution, itself direcly related to the sampling. When hadrons are present 0.17 grows to slightly less than 0.40 which is about two times better than achieved by ALEPH. This is illustrated by figure 7. This means that this resolution is, as expected, totally dominated by the hadron calorimetry. This is where the work on pattern and resolution has to go.

The identification of isolated electrons or muons above 2 GeV has an inefficiency of 2 per mille with a contamination at a few per mille, work is going on for leptons in jets.

CONCLUSION

We have now a quite precise design for an electromagnetic calorimeter dedicated to Higgs physics. It seems technically feasible with some delicate areas. The detector and the way to get the signals out is being prototyped, the front-end electronics integration is challenging, a chip should be tested in 2001, the industrialization of the silicon processing has to be worked out to reduce the price.

All the design has to be optimised, in particular for the layer structure. The software to exploit the capabilities of such a device is a very interesting challenge and should bring a much better understanding.

Finally the price, 135 MEuros as of today, is totally dominated by the silicon area. Two factors will make it change, the price of silicon itself and the effective area after optimising the layer structure. It should not be surprising to gain a factor 2 to 3.

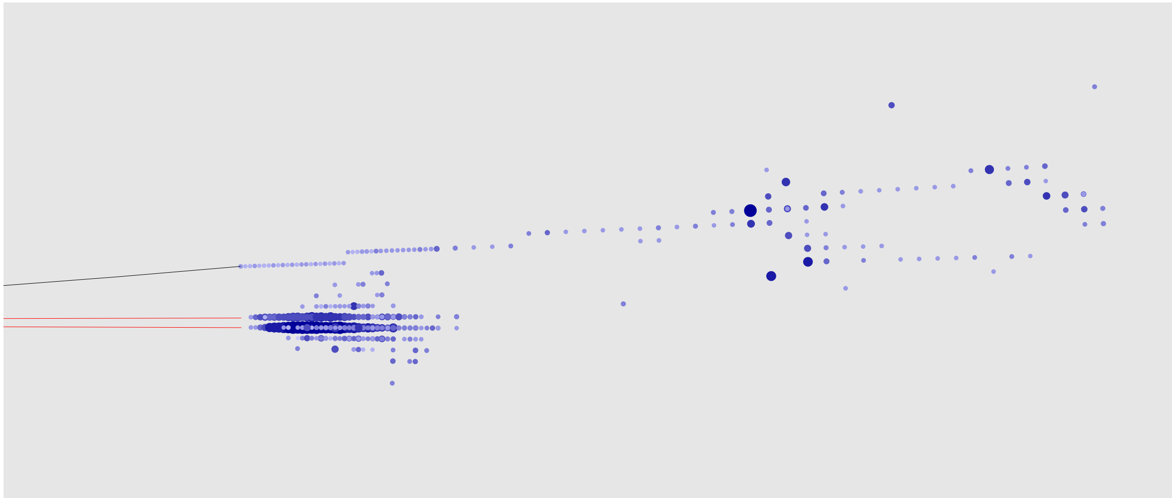

FIGURE 5. Example of a 300 GeV τ decaying into a ρ. The trajectory of the π is in black and of the two photons in red.

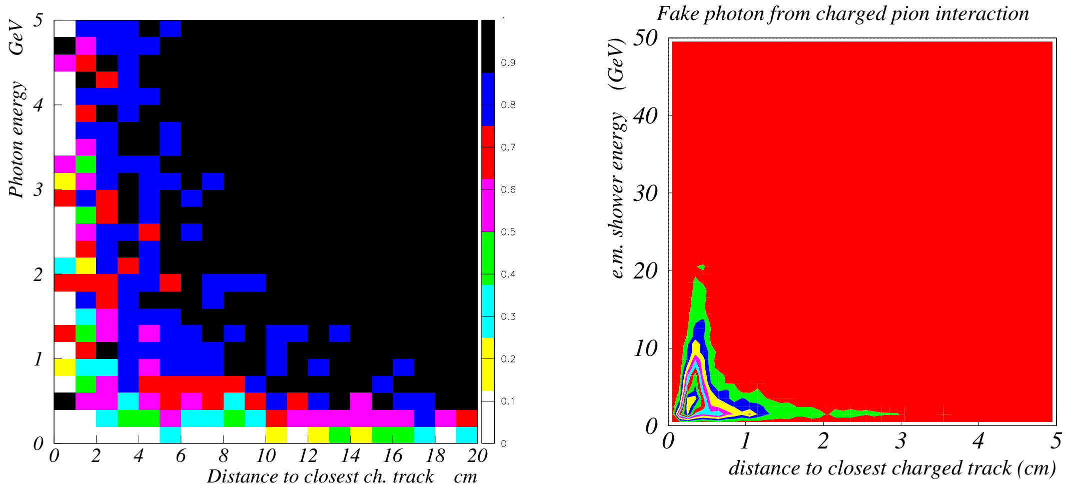

FIGURE 6. On the left is shown the efficiency to find a photon, on the right the probability to interpret a debris of a hadronic shower as a photon.

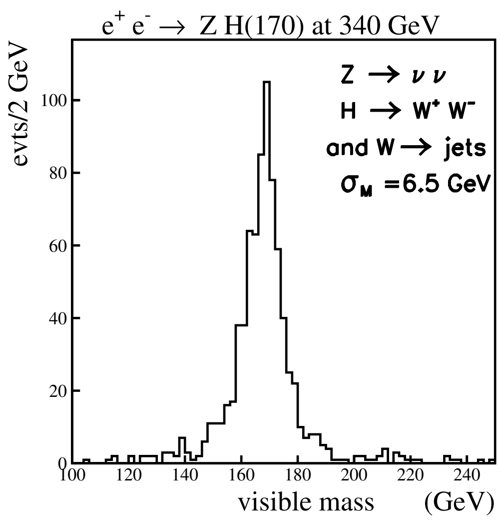

FIGURE 7. Reconstructed mass of a 170 GeV Higgs decaying into two W's.