Impact on calorimeters design, due to ILC staging at 250 GeV centre of mass

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Abstract

The staging of the ILC accelerator project to run at 250 GeV centre-of-mass energy, impacts directly the calorimeters design. The paper describes some of the consequences and draws the overall picture of the design in view of this impact.

Part of this work was carried out in the framework of the ILD detector concept group
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1 Physics program at 250 GeV e+e- collider

The physics program foreseen at an e+e- collider running at 250 GeV (ILC-250) is clearly centered on the detailed study of the Higgs boson. The tagging of the bosons Z, W and Higgs is realized through the mass of the decay products, even for Higgs, identified by the recoil mass of the Z. Since the large majority of the decays proceed through multi-jets (quarks or gluons) for all these 3 bosons, the best use of the luminosity of the accelerator is realised by the tagging of boson(s) through the multi-jet mass difference between their masses. At this centre of mass energy, the jets are dominantly at low energy, below 100 GeV, with a Jacobian peak around 50 GeV, like it can be seen in figure 1, obtained using WHIZARD events generator. For such energy distributions, the reconstruction technique called Particle Flow Algorithm (PFA) [1] is well suited to obtain the best possible performance on the jet energy resolution (JER), impacting directly the di-jets mass resolution of the bosons decays.

![Jet energy distribution for different final states at 250 GeV.](image)

Figure 1. Jet energy distribution for different final states at 250 GeV.

This can be illustrated by the event display shown by M. Ruan, using the ARBOR program (PFA reconstruction program).
Figure 2. Event display of an event $e^+e^- \rightarrow ZH$ at $\sqrt{s}=250$ GeV, with $Z$ and $H$ decaying to jets [2].

In addition, it can be noted that the study of CP violation in the Higgs sector, using ZH events, with $H \rightarrow \tau^+\tau^-$ pairs, needs a good purity and efficiency to disentangle the different tau decay channels. It can be obtained with an electromagnetic calorimeter (ECAL) with a large longitudinal segmentation (29 layers used in the simulation) and with small pixel sizes, typically 1 cm$^2$ or below. Table 1 gives the performances using a photon(s) reconstruction program adapted to the tau final state [3]. These performances are illustrated on figure 2 by the “jet” mass of the tau, where $\tau^\pm \rightarrow \pi^\pm \nu$, $\tau^\pm \rightarrow \rho^\pm \nu$ and $\tau^\pm \rightarrow A_1 \rightarrow \pi^\pm 4\gamma$, can be well separated.

Figure 3. Reconstructed “jet” mass distribution for the one-prong tau decays in ZH events at 250 GeV, with full GEANT4 simulation.

<table>
<thead>
<tr>
<th>Rec/Sim</th>
<th>$\tau \rightarrow \pi \nu$</th>
<th>$\tau \rightarrow \rho \nu$</th>
<th>$\tau \rightarrow a_1 \nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau \rightarrow \pi \nu$</td>
<td>90.2</td>
<td>1.7</td>
<td>8.1</td>
</tr>
<tr>
<td>$\tau \rightarrow \rho \nu$</td>
<td>1.7</td>
<td>87.3</td>
<td>7.4</td>
</tr>
<tr>
<td>$\tau \rightarrow a_1 \nu$</td>
<td>0.6</td>
<td>7.4</td>
<td>92.0</td>
</tr>
</tbody>
</table>

Table 1. Efficiency and cross contamination in one-prong tau decay channels for ZH events at $\sqrt{s}=250$ GeV. Values in %. Results of simulation for 30 silicon readout layers, 4 Tesla field and an internal radius of ECAL of 1.84m [4].
2 Impact on calorimeter design

2.1 Global geometry

Starting from the introduction, what is the impact on calorimeter? The first questions are related to the overall geometry. From a study based on full Geant4 simulation, figure 4 shows the JER as a function of the jet energy, for different internal radius of the ECAL. As shown in figure 1, we have only to consider jet energy below 150 GeV, and more probably around 50 GeV. We can conclude that for a radius at 1.4 meter, there is a loss of about 10% on JER when compared to a radius of 1.84 meter, but for a very important cost reduction (about 35%) on the ECAL, but also on HCAL, coil and return yoke. A full study on simulation has been made [5] and shows that JER, for these jet energies, is better for a large number of silicon layers. This effect comes from the better single photon energy resolution which plays a major role for these jet energies and this B-Field, even if the impact from B field, at least from 3 to 4 Tesla, is relatively modest. In fact, more globally, for B-field larger than 3 Tesla, and modest jets energies, typically below 100 GeV, the single particle resolution dominates the confusion term, coming from mixing between showers. It comes from the fact that, for this specific case and PFA reconstruction, the confusion term is relatively small because the bending increases the distance between charged particles trajectory and neutral ones, and therefore between their respective showers.

Regarding cost reduction, decreasing the number of layers would downgrade the single particle energy resolution. It is therefore not a solution favored for the ILC-250. as discussed above. However, it could be possible to mitigate the impact by increasing the active material of the layers. i.e. using silicon diodes about 700 $\mu$m thick, instead of 330$\mu$m, specially because producers seem to start processing on thicker wafers.

![Figure 4. Impact on the JER for different jet energies of different internal radii of the ECAL [5]](image)

2.2 Active layers

For a total number of channels at the level of 100M, there are obvious additional constraints related to the stability, to the overall calibration, to the noise. In addition, in order to reduce the overall
detector cost, it is important to have the possibility to play with parameters strongly correlated for what concerns the overall performances. It is the case for example of the internal radius of the ECAL and the individual pixel size. Eventually, due to large cost for the ECAL, there is an additional constraint which is to keep the same detector for a possible phase 2 of ILC running at $\sqrt{s}=500$ GeV. In this case, the linearity is also important and still a good S/N ratio, even for a larger signal dynamics. To summarise:

- small pixels size, allowing reduction of internal radius of the ECAL
- a good S/N at MIP level for a modest thickness (in fact, as thin as possible)
- a good linearity for large dynamics of the signal, from MIP to 250 GeV electron (for the phase 2 of ILC)

Silicon PIN diodes are one of the obvious possible choice for the active medium of the layers, since it fulfills all the requirements. The only evident drawback is the cost, and it is therefore important to work on the overall cost optimisation of the detector. One example is the reduction of cost of the silicon where one of the possibilities is to use degraded matrices, since there is no problem to work with up to 10% of dead wafers [1]. It could be noted that silicon can afford any type of pixel sizes, including 9 mm$^2$, which is well suited for glue connection and for passive cooling of the internal part of the detector.

### 3 Conclusion

The impacts of the staging at 250 GeV for the ILC project, for what concerns the electromagnetic calorimeter have been explored. The possibility to reduce overall cost of the detector using parameters like internal radius, B-field, or the number of active layers has been studied. Taking into account constraints and requirements, in particular a very good S/N silicon for such a number of channels, PIN diodes seems to be an obvious choice. However, the overall cost of the ECAL necessitates to perform continuous studies to reduce this cost. For example, this choice of silicon PIN diodes allows small pixels size which is very attractive for an important cost reduction by the decrease of the internal radius of ECAL, while keeping needed PFA performances.

### References


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