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

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Abstract: Abstract : The staging of the ILC accelerator project to run at 250 GeV center-of-mass, impacts directly on the calorimeters design. The papers describe some of the consequences and draw the overall picture of the design in view of this impact.

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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 (LC-250) is clearly centered on the detailed study of the Higgs boson. The tagging of the different bosons Z, W and Higgs is realized through the mass of the decay products. Since the large majority of the decays proceed through multi-jets (quarks or gluon) for all these 3 bosons, the tagging can be done only through the multi-jet mass difference between their respective masses. At this center of mass energy , the jets are essentially at low energy , below 100 GeV, with a Jacobian peak around 50 GeV, like it can be seen on figure 1, obtained through WHIZARD generation. 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.

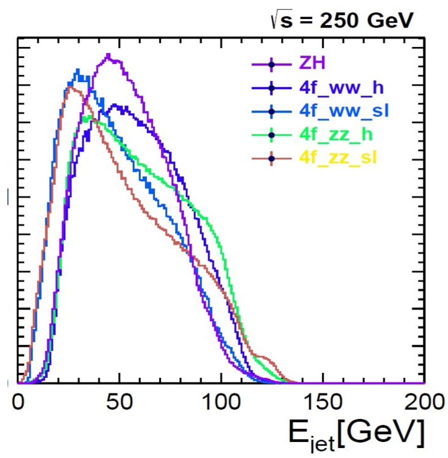

Figure 1. Jet energy distribution for different final state at 250 GeV.

This can be illustrated by the event display shown by M. Ruan, using the ARBOR program (PFA reconstruction program)

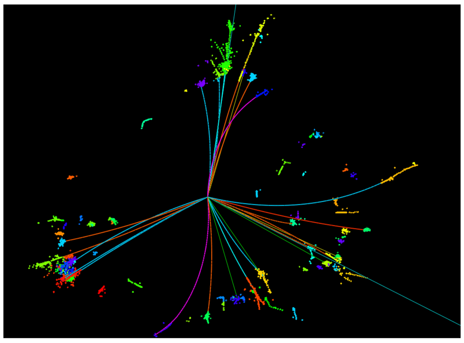

Figure 2. Event display of an event e+e- $\longrightarrow$ ZH at $\sqrt{s}$=250 GeV, with Z and H decaying to di-jet [2]

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 pixels size, typically 1 cm^2 or below. Table 1 gives the performances using a photon(s) reconstruction program adapted to the tau final state [3] . Theses performances can be illustrated on figure 2 by the "jet" mass of the tau, where $\tau^\pm \longrightarrow \pi^\pm\nu$, $\tau^\pm \longrightarrow \rho^\pm\nu$ and $\tau^\pm \longrightarrow \mathrm{A}_1 \longrightarrow \pi^\pm 4\gamma$, can be well separated.

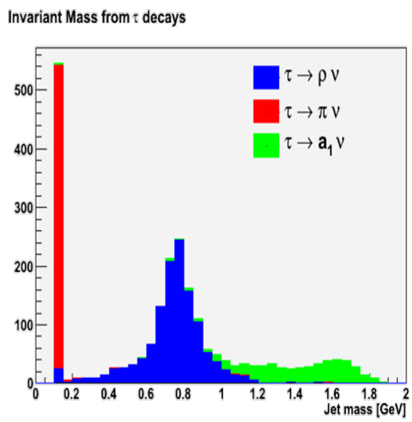

Figure 3. Reconstructed "jet" Mass distribution for the one prong tau decays in ZH events final state at 250 GeV, with full GEANT4 simulation.

Rec/Sim	$\tau \longrightarrow \pi\nu$	$\tau \longrightarrow \rho\nu$	$\tau \longrightarrow$ A1
$\tau \longrightarrow \pi\nu$	90.2	1.7	8.1
$\tau \longrightarrow \rho\nu$	1.7	87.3	7.4
$\tau \longrightarrow a1\nu$	0.6	7.4	92.0

Table 1. efficiency and cross contamination from other one prong tau decay channels for ZH events at $\sqrt{s}$=250 GeV . Value 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 discussed above, what is the impact on calorimeter ?. The first questions are the ones related to the overall geometry. From a study based on full Geant4 simulation, figure 4 shows the JER performances as a function of the jet energy , for different internal radius of the ECAL, as a function of the jets energy distributions. 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 it 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 binding increases the distance between charged particles and neutral ones, and therefore between their respective showers.

Speaking about cost reduction, decreasing the number of layers would downgrade the single particle energy resolution. It is therefore not a solution favored for the LC-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 thickness of about 700 μm , instead of 330μm , specially because producers seem to start processing work on thicker wafers.

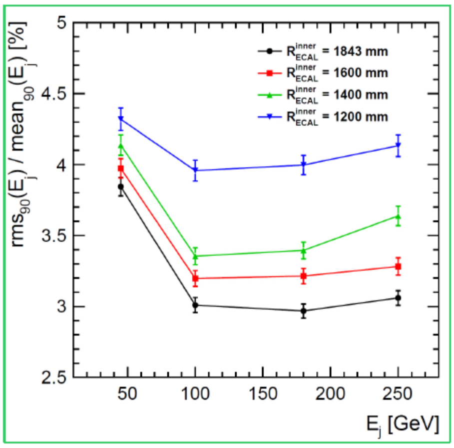

Figure 4. Impact on the JER for different jet energy and different internal radius of the ECAL [5]

2.2 Active layers

For a total number of channels at the level of 0(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 several 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, taking into account the fraction of the cost of the ECAL for the overall detector, 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 dynamics of signal. To summarize :

- 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, from MIP to 250 GeV electron (for the phase 2 of ILC)

Silicon PIN diodes is one of the obvious possible choice for the active medium of the layers, since it fulfills integrally the requirements . The only evident drawback is the cost, and it is therefore important to work on overall cost optimisation of the detector. one example is the reduction of cost of the silicon where one of the possibility is to use degraded matrices, since there is no problem to work with up to 10% of dead wafers [1]. A technical study has shown that silicon pixels size as small as 0.06 mm^2 continue to be well suited for glue connection and for passive cooling 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, particularly a very good S/N silicon for such a number of channels, PIN diodes seem an obvious choice. However, the overall cost of the ECAL leads to perform continuous studies to reduce this cost. For example, this choice of silicon PIN diodes allows small pixels size and it is very attractive for an important cost reduction by the decrease of the internal radius of ECAL, while keeping needed PFA performances.

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