

Forward tracking detectors

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Abstract. Forward tracking is an essential part of a detector at the international linear collider (ILC). The requirements for forward tracking are explained and the proposed solutions in the detector concepts are shown.

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1. Introduction

At the ILC many of the most important physics reactions are central, so that the forward region, which is suppressed by the $\cos\theta$ phase space factor often is a bit neglected. However, many processes at the ILC are peaked in the forward region like Bhabha scattering or W -pair production [1]. Fermion pair production has its highest sensitivity to the forward–backward asymmetry or to the difference between effects from a Z' and from extra dimensions also in this region. In addition, the momentum of leptons from W -decays usually is high due to W -polarisation effects. A good momentum resolution in the forward region is thus essential to measure the charge and suppress the W -background in the fermion-pair analyses.

Another argument for a good forward coverage comes from the high jet multiplicity of some reactions at the ILC. There are processes with 6 jets, like $t\bar{t}$, 6–10 jets like ZHH or 8–10 jets like $t\bar{t}H$ and the chance that one jet is in the forward region is relatively high. For example, figure 1 (left) [2] shows the polar angle of the most forward jet from $t\bar{t}H$. It can be seen that full particle flow coverage down to the lowest possible angles is needed.

Apart from the events with a physics interest many calibration events also are peaked forward. The acolinearity of e^+e^- pairs from Bhabha scattering turns out to be the ideal tool to measure the luminosity spectrum at ILC [3]. The differential cross-section for small polar angles is distributed as $d\sigma/d\theta \propto 1/\theta^3$ so that very good forward coverage is needed to obtain sufficient statistics. The centre-of-mass energy of the e^+e^- system, $\sqrt{s'}$, can be reconstructed from the polar angle alone assuming that only one photon is radiated. The aim is to measure the beamstrahlung ($\mathcal{O}(10^{-2})$) simultaneously with the beam energy spread ($\mathcal{O}(10^{-3})$). The error on

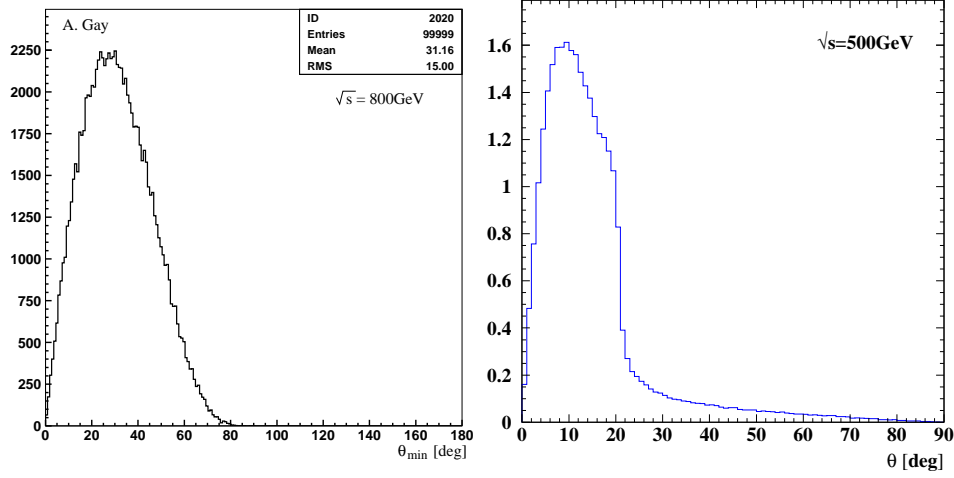


Figure 1. Left: lowest jet polar angle in $t\bar{t}H$ events [2]. Right: minimum lepton angle in radiative return events.

$\sqrt{s'}$ from the angular reconstruction method is $\Delta\sqrt{s'}/\sqrt{s'} \approx \Delta\theta/\sin\theta$ so that one needs $\Delta\theta < 10^{-4}$ in the forward region. Electrons radiate strongly in material and cylinders, like the TPC field cage are crossed under a very shallow angle so that it is important to assure a good momentum resolution in special forward detectors close to the interaction point (IP).

Another important calibration process is the radiative return to Z ($e^+e^- \rightarrow Z\gamma \rightarrow \ell^+\ell^-\gamma$). With this process the beam energy can be determined to a precision of $1.5 \cdot 10^{-4}$ using polar angles only ($\sqrt{s} = 350 \text{ GeV}$, $\mathcal{L} = 100 \text{ fb}^{-1}$) [4]. In the Z rest frame the lepton polar angle distribution is almost flat. However, due to the large boost in the lab system at least one lepton is again forward peaked (figure 1 right) so that here also excellent forward coverage is essential.

2. General considerations

In general, the momentum resolution of a detector scales as $\frac{\Delta p}{p} \propto \frac{p_t}{R^2}$ where the details depend on the exact detector set-up. R denotes the radius of the detector and p_t the transverse momentum. Usually a particle physics detector has a cylindrical shape with the transition from the barrel region, where tracks leave the detector through the outer cylindrical surface to the forward region, where the tracks leave through the endplate at a given angle θ_0 . In the barrel region one has $p_t = p \sin\theta$ and $R = \text{const.}$ so that $\frac{\Delta p}{p} \propto p \sin\theta$. On the contrary, in the forward region $R = l \tan\theta$ with l being the length of the detector, so that $\frac{\Delta p}{p} \propto p \sin\theta / \tan^2\theta \approx p / \tan\theta$. The momentum resolution thus deteriorates going to small polar angles.

As sketched in figure 2, in principle, there are two possible solutions to build detectors in the forward region. One possibility is to stay with the cylindrical lay-out. In this case, however, the detectors get very long and the z resolution

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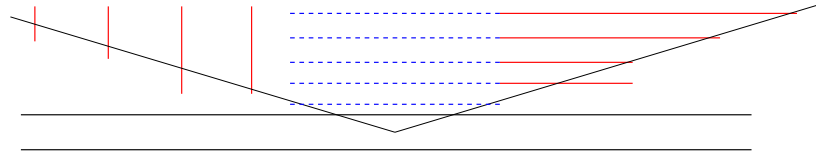


Figure 2. Possible lay-out of forward detectors close to the IP.

deteriorated with smaller angles. Another possibility is to use disks instead. In this case less material is needed and also the z resolution can be better. However, somewhere the forward tracks have to cross the material from the barrel support and cables which may be a problem for the vertex resolution.

To obtain optimal angular and momentum resolution a forward tracking system in general needs two components. A set of precise detectors close to the interaction point (IP) provides a precise measurement of the polar angle and an accurate start point for the momentum measurement. These detectors can measure the tracks before they have crossed a large amount of material. To optimise the tracking resolution, another precise space point is needed at maximum distance from the IP. This can be provided by a special detector in front of the calorimeter endplate, and also by the measurement of the central tracker. Intermediate detectors may be needed to improve the resolution and to extrapolate the track from the inner detectors to the endplate.

3. Background in the forward region

The background from e^+e^- pairs originating from the beam-beam interaction rises towards smaller polar angles [5]. There is thus a danger of many hits in the forward detectors close to the beam pipe. An additional problem arises for large crossing angles. The centre of the outgoing beam pipe is at a larger radius than the innermost forward detectors so that backscattered charged particles that follow the magnetic field direction hit the forward detectors in their sensitive area. The problem is even worse if the solenoidal field for the incoming beam is compensated by a detector integrated dipole (DID). In this case the background from the outgoing beam pipe is even guided to larger radii.

Figure 3 shows the background for different planes of the detector shown in figure 6. One can see that the direct hits as well as the backscattered background is relevant. It should be noted that the backscattered component has an about 5 m longer flight path to the detector than particles directly from the IP so that this component can be rejected if the detectors have a time resolution in the 5 ns range. Figure 4 shows the time distribution vs. the azimuthal angle ϕ for the innermost FTD disk of the LDC [6] for 20 mrad crossing angle with the DID. The gain of a good time resolution is clearly visible. Especially the large background cluster coming from backscattering near the exit hole can be suppressed.

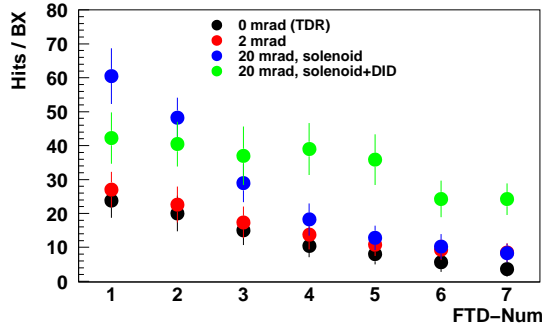


Figure 3. Background in the forward tracking disks for different assumptions on the crossing angle and the DID.

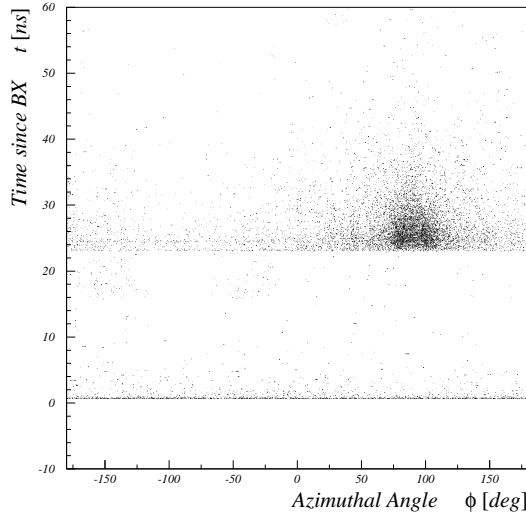


Figure 4. Arrival time vs. ϕ for background hits in the first FTD disk of the LDC.

4. Possible technologies

In the forward part not too close to the beam pipe a wide range of technologies can be used and there are no real restrictions. In the region close to the beam pipe on one hand a high precision and on the other hand a high background tolerance is required so that solid state detectors are the optimal choice. Silicon strip detectors have the advantage of being precise, fast and relatively cheap. However, they are sensitive to background and to the high track density in jets close to the IP.

Contrary to that pixel devices are much less sensitive to background and the track density, but they are significantly more expensive. Two types of pixel sensors are under consideration. The pixel technologies that are used for the vertex detector [7] are very precise and thin. However they are slow, integrating over about 100 bunch crossings increasing their background sensitivity by this factor. Another option is

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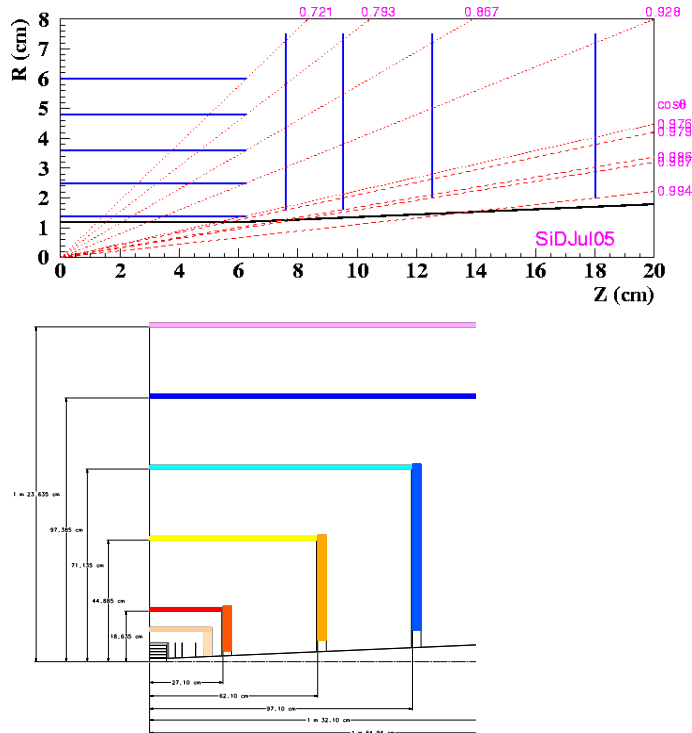


Figure 5. Forward tracking in the SID. The upper plot shows the vertex detector and the lower plot the full tracking system.

the use of hybrid pixels as they are used at the LHC, e.g. in ATLAS [8]. These devices can be very fast but have only a medium precision ($\sim (50 \times 400 \mu\text{m}^2)/\sqrt{12}$). In addition, they are relatively thick. The ATLAS pixel detector has a thickness of $2\%X_0$ per layer. However, most of that is due to cooling and could be reduced with power cycling at the ILC.

5. Implementation of forward tracking in the concepts

At present there are two different implementations of forward tracking in the detector concepts. SID [9] (see figure 5) uses four pixel planes in the vertex detector with the same technology as the barrel. At larger distances from the IP forward tracking is completed by five disks of back-to-back silicon strips.

LDC [10] (see figure 6) and GLD [11] have similar concepts where details are still to be defined. In both concepts the main tracker is a TPC that can do stand-alone tracking down to about 10° and sees a few points down to around 5° . The vertex detector consists of cylindrical layers only to minimise the material. At small polar angles the tracking is improved by several disks where the ones closer to the IP are fast pixels, while the outer ones are strips to reduce the costs and the material in the detector. In the LDC concept at present also a tracking detector behind the

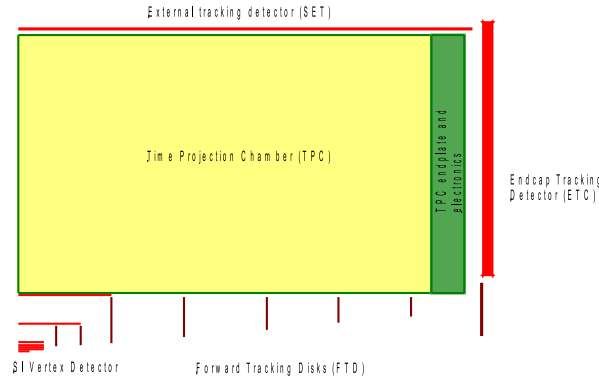


Figure 6. Tracking in the LDC detector concept.

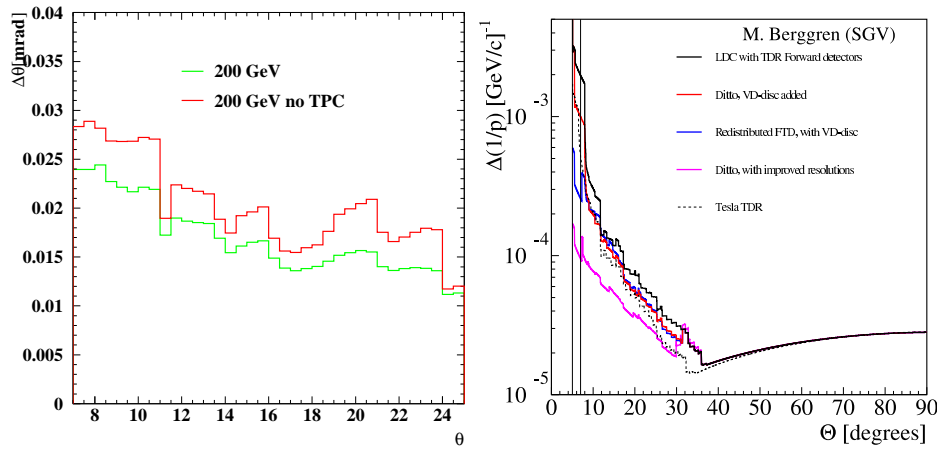


Figure 7. Angular (left) and momentum (right) resolutions of the forward tracking in LDC.

TPC is foreseen where as possible technologies silicon, MSGCs and straw tubes have been studied. The detector may however not be needed if for the TPC a resolution around $50 \mu\text{m}$ close to the endplate can be reached.

An important challenge for the forward detectors are systematic uncertainties. For the calibration processes absolute angular measurements are needed. A systematic shift in the aspect ratio R/L of the detector shifts the measured beam energy in the radiative return analysis. In order to match the statistical error of the method, the aspect ratio has to be known to $\Delta(R/L) = \Delta \tan \theta = 10^{-4}$. This is probably only possible if the detector is built on a robust mechanical support that can be precisely surveyed before installation.

With the proposed systems all concepts can reach the necessary performance. As an example, figure 7 shows the angular and momentum resolutions in the case of LDC.

6. Conclusions

Forward tracking in ILC detectors is needed for physics and for some important calibration processes. The required technologies are in principle under control but a careful optimisation is needed. A partially conflicting set of parameters like material, resolution, background tolerance and price have to be optimised where one has to take into account that the material does not only influence the resolution for the interesting processes but can also compromise the particle flow resolution because of hadronic interactions in the detector material. The optimum may also depend on the choice of the crossing angle and the DID. To start the optimisation procedure a full pattern recognition program for the forward detectors as well as a particle flow reconstruction is needed.

In order to get a forward tracking that fulfils the needs, it has to be implemented in the design of the detectors from the beginning. Past experience shows that this part was often underestimated and upgrades at a later stage could not deliver the required performance because the needed space was already taken by other parts of the detector.

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