Flavour Identification at the Future Linear Collider

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High performance flavour tagging of jets containing heavy flavours is crucial for the studies planned for the future high energy e^+e^- Linear Collider (LC).
Pixel detectors have proven to provide very powerfull flavour identification, for this reason the Linear Collider Flavour Identification (LCFI) collaboration has decided to concentrate its R&D work for the future LC on a Charged Coupled Device (CCD) pixel vertex detector, and study the flavour tagging performance of the design to optimize it. In this work we first evaluate the basic tracking perfomance. We then estimate the flavour tagging performance of the present detector layout, using a neural network approach. We conclude by studying the energy dependence of the perfomance.

1. Introduction

The tagging of jets containing heavy flavours is crucial for the studies planned for the future high energy Linear Collider (LC). One of the main goals will be to study in detail the Higgs boson and its branching ratios to different quarks. LEP and SLD have shown that high b tagging performances can be achieved, and that they are an essential element in precision measurements and new particle searches. At the next LC, with a more ambitious programme in the Higgs sector, charm tagging also becomes important. This poses more stringent requirements on the vertex detector, because of the kinematics of charm decays. The studies described here (see also [1]) show that the current design for the CCD detector, proposed by the LCFI collaboration, should certainly fulfill the requirements of the LC physics program, and provide very high quality physics results in this new energy regime.

2. Detector and simulation tools

The studies described in this paper are done with the generation package JETSET7.4 and with the detector simulation and track reconstruction package for TESLA, BRAHMS 2.01 [2]. The tracking detectors used are:

- a CCD vertex detector, 5 layers, starting at 1.5 cm from the beam line, and with a point resolution of 3.5 μm.
- a Time Projection chamber, extending radially from 32 to 170 cm, with a half length in z of 273 cm, and providing 118 points with a resoluton in r-ϕ of 160 μm and in z of 1 mm.
- a Silicon Inner Tracker, two cylinders of radii 16 and 30 cm, and half length in z up to 66 cm.
- a Forward Tracker (pixel/strips) at positions in z from 20 to 130 cm, and exteding radially between 15 and 30 cm.
- a magnetic field of 40 KGauss (4 Tesla)

The software used for jet reconstruction, vertex finding and fitting, and neural network tagging is carefully described in [3], and that work is now updated here.

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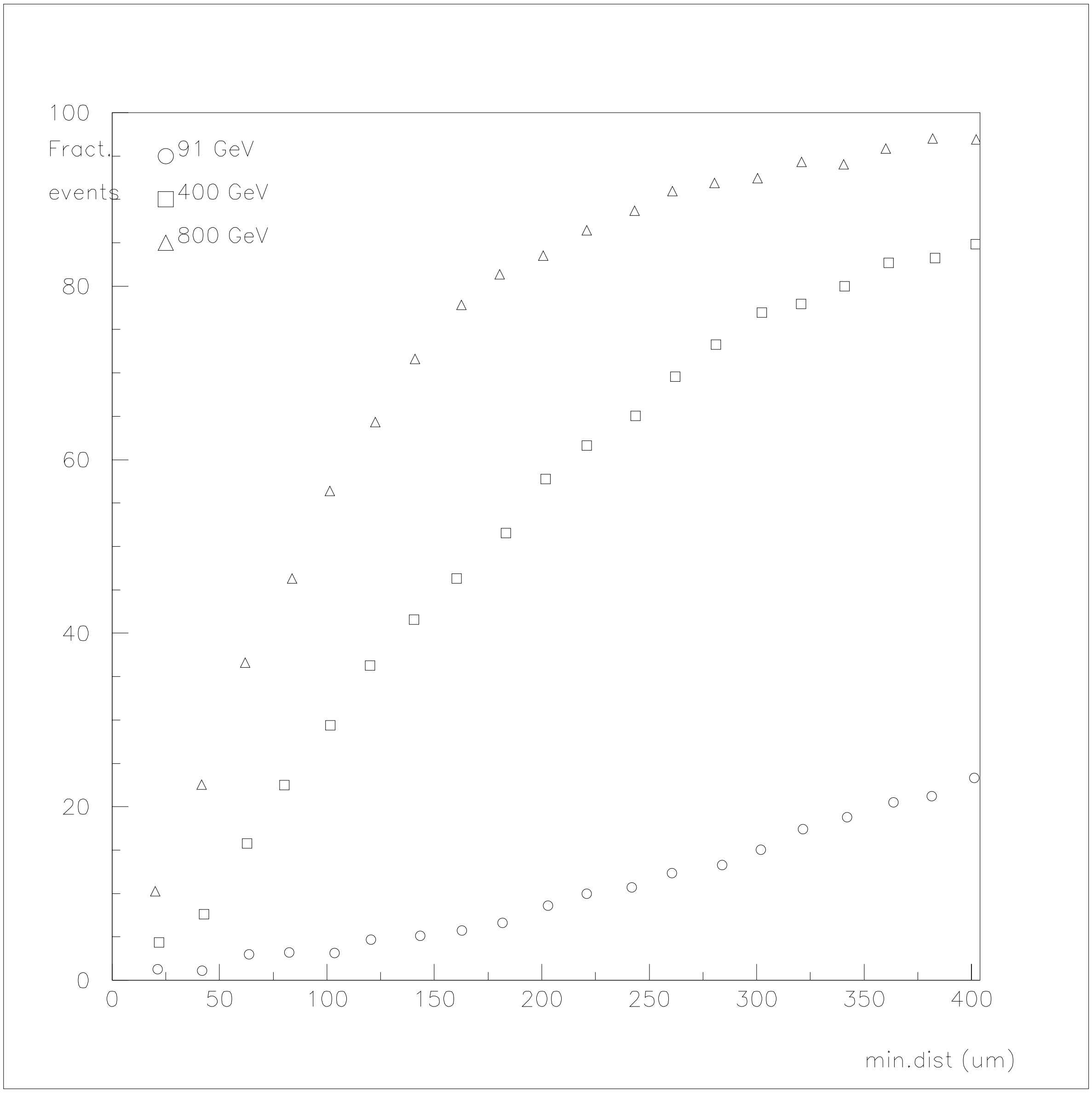

Figure 1: For a given value of minimal distance (in micrometers), the fraction of events having a minimal distance for pairs on layer 1 smaller than that is plotted

2.1. Pixel size of the vertex detector

The CCD detector design used in this study, and subject of the R&D work of the LCFI collaboration, has a pixel size of $20 \times 20 \mu m^2$. A detector with larger pixel sizes, while maybe preferable for readout speed reasons, gives a worse performance in the reconstruction of tracks in jets (and hence in flavour identification) because of the larger probability for 2 tracks to leave signal in the same pixel (or cluster of pixels). The performance gets obviously worse when the cms energy of the process increases. This can be understood when looking at Figure 1, where the fraction of events having a minimal distance for track pairs on layer 1 smaller than some value, is plotted versus that value. At 91 GeV, in $e^+e^- \to q\bar{q}$ events, in layer 1, passing from a 20×20 to a $100 \times 100 \mu m^2$ pixel size, the percentage of events with at least 1 track leaving signal in the detector overlapping with some other(s) track(s) passes from 1% to 10%.

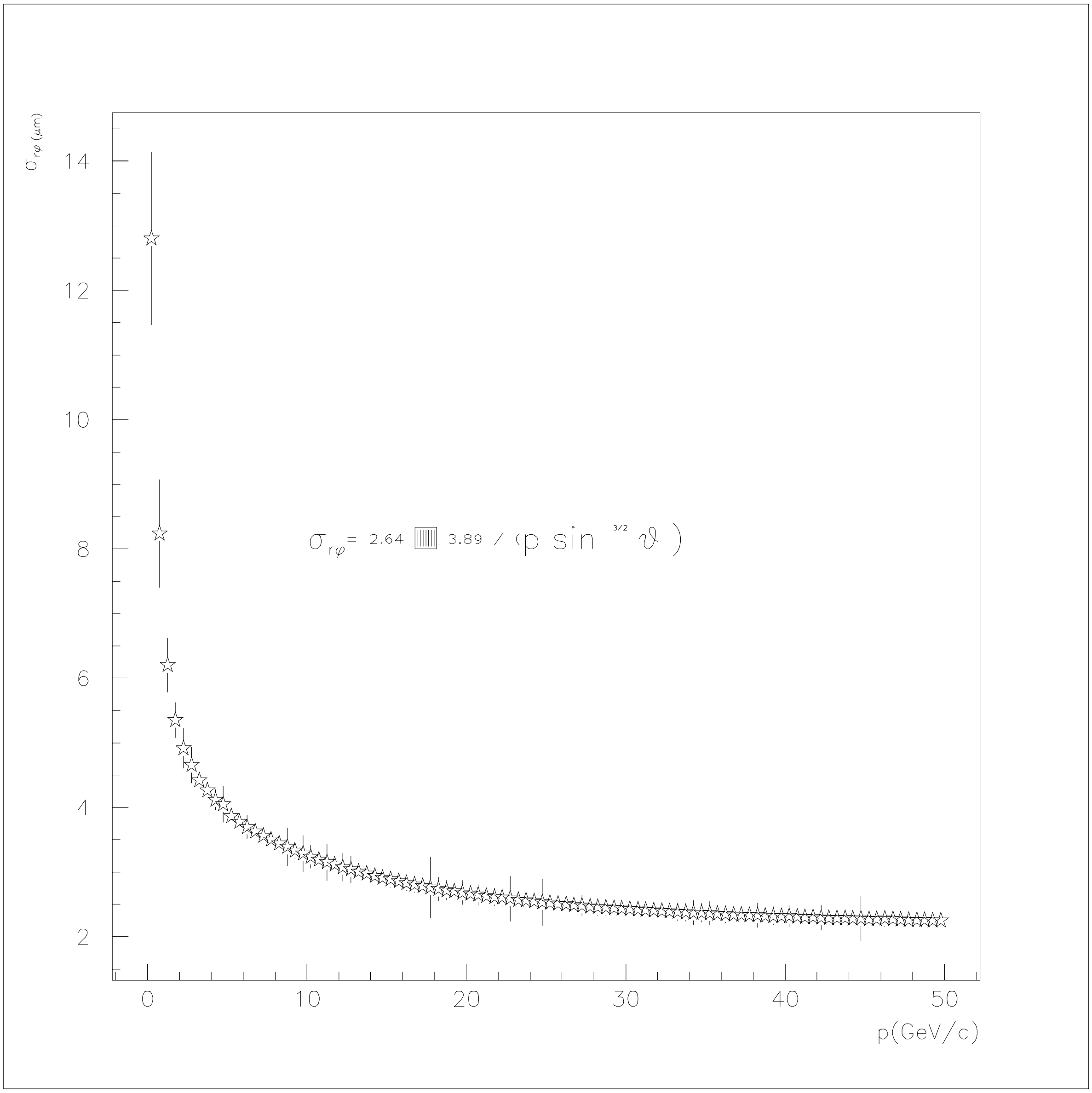

Figure 2: Distribution of impact parameter resolution versus momentum, for single pions generated at 90° with respect to the beam axis

3. Impact parameter resolution

The first, simple measurement of the performance of a vertex detector (combined with the information from the outer tracking system), is the resolution of the distance of closest approach of a track to a point (e.g. the nominal interaction point). Figure 2 shows the results obtained from full track fits for the resolution in r-ϕ plane, which goes like:

$$\sigma_{r-\phi} = \sqrt{a_\phi^2 + (b_\phi / p \ sin^{3/2}\theta)^2}$$

where a_ϕ depends on the point resolution of the detector, and b_ϕ represents the resolution degradation due to multiple scattering. The value for a_ϕ is 2.86 μm, and for b_ϕ is 3.89 μm. These performances are much improved with respect to the SLD CCD detector, where the same constants took values of 14 μm and 33 μm respectively.

4. Heavy flavour tagging

4.1. Neural network tagging

Tagging of a jet flavour is done using a NN algorithm. This algorithm is combining informations from 3 different algorithms. A joint impact parameter probability tag, used already in Lep experiments to discriminate u, d, s from b and c flavours by means of the impact parameter of tracks in the $r - \phi$ and r–z planes. Zvtop, a vertex finder algorithm used in SLD, providing tagging informations like the number of secondary vertices and the reconstructed vertex mass and transverse momentum from all secondary vertices found in a jet. A "1-prong" tag, to be used for jets where no secondary vertices are found, using information about the maximal impact parameter in a jet in the $r - \phi$ and r–z plane. B and c flavours are expected to provide an asymmetric distribution, light flavours a symmetric one. 1-prong decays of B and D hadrons are lost by zvtop, and this last tag helps recovering them. This is especially important for charm hadrons, a good fraction of which is 1-prong. Interestingly enough, light flavours jets give too a slightly asymmetric distribution (see also [3]). This has been investigated, and seems to be due to tracks coming from decays of light flavour baryons (like Σ) and of b and c hadrons coming from gluon splitting processes, both indeed having asymmetric impact parameter distributions.

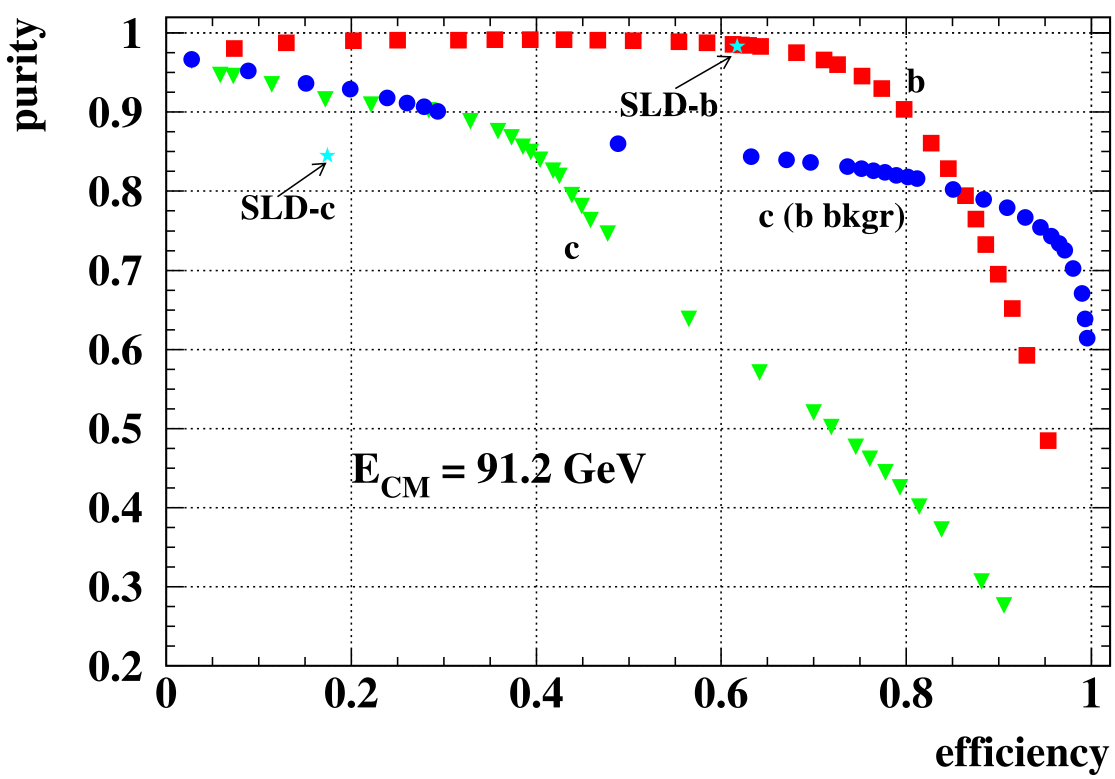

Figure 3: Purity versus efficiency for jets of beauty and charm flavour, generated in Z^0 events at 91.2 GeV in the c.m.s.

4.2. Performance at 91 GeV

Figure 3 shows the simulated detector performance for heavy flavour tagging in $Z^0 \to q\bar{q}$ events. Plots b and c show the performance of a neural net analysis for beauty and charm tagging respectively [1]. For comparison, the best b and c tagging results currently achieved are shown, from the SLD experiment [4]. The gain in b tagging efficiency at TESLA is modest, whereas there is an improvement by a large factor (2 to 4) in charm tagging efficiency with high purity; this will provide a powerful new tool for physics. The third plot (labelled *c(b bkgr)*) shows the spectacular performance for charm tagging in an environment with mainly b background, relevant for example to the measurement of Higgs branching ratios.

The performance here shown depends on the physics process considered , and on the energy at which it is happening. A change in process or energy will clearly need a retraining of the network and will in general lead to a different performance.

4.3. Dependence of performance with energy

It is important to study the dependence of the performance on jet energy, since the TeV-scale collider will include events with much higher energy jets. A previous study [1] done on monojets of different flavours sent through the detector at various energies, has shown good stability of the tagging algorithm with increasing energy, which is very encouraging. Recently we have also studied the performance of our flavour identification procedure on $e^+e^- \to q\bar{q}$ events at 500 GeV cms energy. In both cases the neural network was appositely retrained.

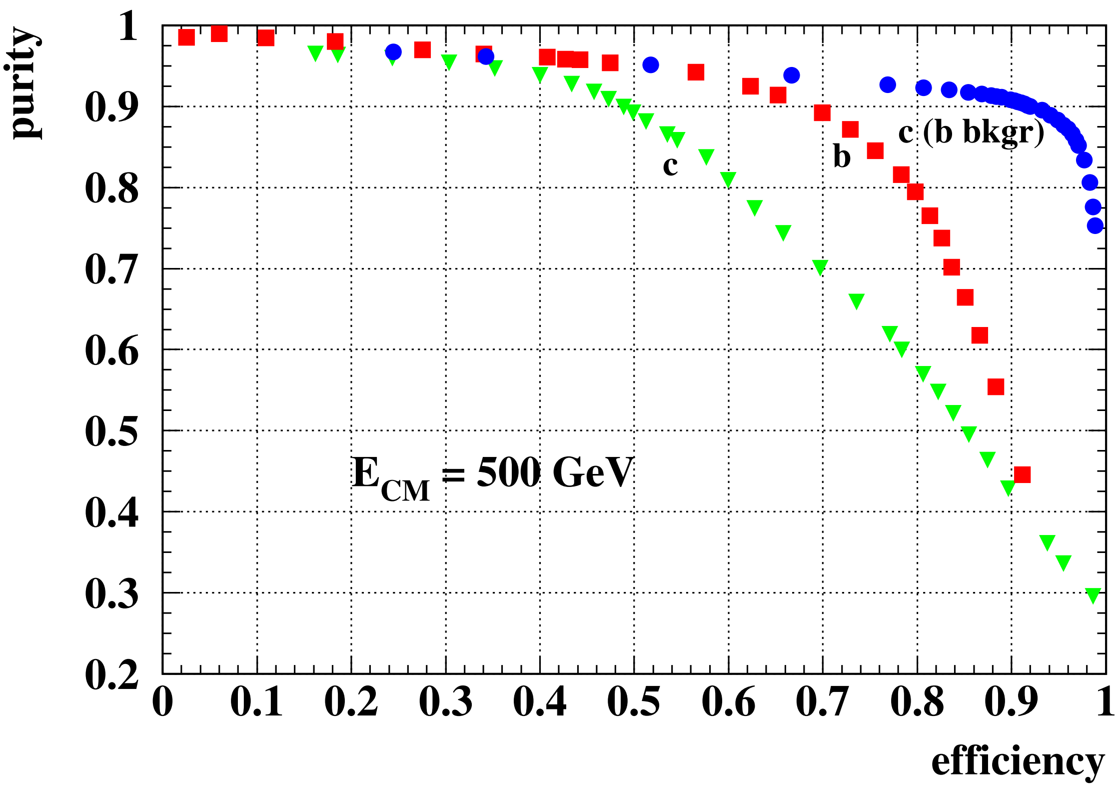

Figure 4: Purity versus efficiency for jets of beauty and charm flavour, generated in $e^+e^- \to q\bar{q}$ events at 500 GeV in the c.m.s. energy

The results for 500 GeV are shown in Figure 4. One can see that, in comparison with the 91 GeV case, c tagging (with only b background and with u, d, s background too) improves nicely, with purities falling below 80% at 55% efficiency or higher. The b tagging performance is instead slightly worse. We have investigated the reasons for the difference in b tagging performance, and for now we seem to trace it down to the following points: first of all gluon splitting becomes a more important fraction of light flavour events at 500 GeV, secondly the criteria used for track attachment to vertices in zvtop (needed for the calculation of the reconstructed mass and transverse momentum of the jet) need to be retuned for 500 GeV, and finally K_s^0 contribution seems to spoil more the track attachment procedure in zvtop at 500 GeV than at 91 GeV. This study started only recently, and more needs to be understood in the performance of tagging at high energy. Though the performance at 500 GeV is very good, one message seems to come out clear: it needs not to be as high as at 91 GeV, mainly because of the different characteristics of the physics process at higher energy.

5. Conclusion

These studies have demonstrated that a vertex detector compatible with the conditions at the future TeV-scale linear collider (TESLA as an example) will provide a powerfull tool for physics. The performance at 91 GeV far exceeds that of the LEP/SLD vertex detectors, particularly in the area of charm tagging. This performance is preserved as the jet energy is increased. With further study, it is expected that the performance in high energy events will be similar.

References

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