Accuracy of the forward luminosity calorimeter at TESLA

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The future linear collider TESLA (Tera-electronVolt Energy Superconducting Linear Accelerator) at DESY will collide electrons with positrons at an energy of 500 GeV - 1 TeV. This energy should be high enough to produce Higgs bosons and Supersymmetric (SUSY) particles if they exist. We need a luminosity $> 3.4 \times 10^{34} cm^{-2} s^{-1}$ to be able to detect these particles. In order to get the best results possible from TESLA we need an error in the luminosity measurement of approx. 10^{-4}. In this report I investige the various factors that effect this luminosity measurement and determine our scope within the error margins. These results could then be utilised in the design of the forward detector region

1 Introduction

TESLA will be a machine for precision measurements. It will compliment the LHC (Large Hadron Collider) at CERN which will be operational in 2007. It is hoped that LHC or TESLA will discover Higgs bosons and SUSY particles then TESLA will do precise measurements of the characteristics of these particles.

For optimum results TESLA will need
1.Very high luminosity.
2.Very good detectors.
3.Precise predictions, either from theory or from LHC data.

Small-angle Bhabha scattering is used to measure and monitor the luminosity in e^+e^- colliders, because of the relatively large cross-section [1], and it is possible to accurately calculate the cross-section from theory. The reasons for this are that it is possible to count the number of Bhabha events reasonably accurately and to distinguish these events from other processes. Bhabha scattering is the elastic scattering of electrons and positrons ($e^+e^- \longrightarrow e^+e^-$), a pure QED process. It was one of the first scattering processes calculated [2] [3].

I used and modified a FORTRAN code (written by Achim Stahl) to analyse the Bhabha processes using the BHLUMI Monte Carlo simulator and I displayed the data using PAW.

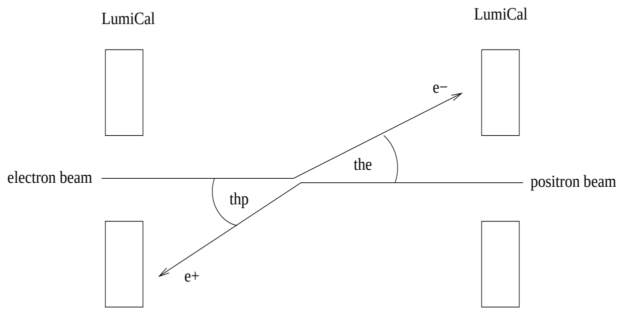

Fig. 1: *Schematic view of Bhabha scattering. The final trajectory of the e^+ and e^- is measured in the LumiCal's, and then the IP (interaction point) and the scattering angles can be determined. Note these scattering angles are very small in the order of < 100 milliradians.*
Note: the = scattering angle of electrons.
thp = scattering angle of positrons.

2 The Theory

Figs. 2 & 3 below show the Feynman diagrams for Bhabha scattering, the time-axis points to the right.

The cross-section and the luminosity are related by the formula

$$\dot{N} = \sigma \mathcal{L} \tag{1}$$

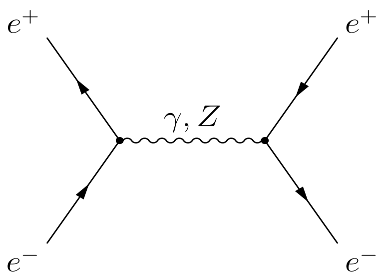

Fig. 2: *Feynman diagram of Bhabha scattering (s-channel process).*

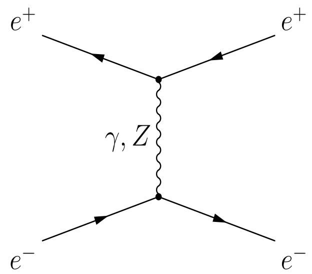

Fig. 3: *Feynman diagram of Bhabha scattering(t-channel process).*

where
$\dot{N}$ = rate of Bhabha events
σ = the cross-section for Bhabha scattering
$\mathcal{L}$ = Luminosity

Hence the Luminosity can be defined as the interaction rate per unit cross-section. Integrating (1) gives

$$N = \sigma \mathcal{L}_{integrated} \quad (2)$$

where
N is the total number of Bhabha events
σ is as above
$\mathcal{L}_{integrated}$ is the total integrated luminosity

The reason we need such a high luminosity at TESLA is that the cross-section for SUSY particle production is very small (in the order of a few fbn(femtobarn)), so from (1) we see if σ is very small $\mathcal{L}$ must be very large.

We need to apply some cuts to select the number of Bhabha events from total events. These cuts are explained in section 3. We then use the formula

$$\frac{N_{select}}{N_{total}} = \frac{\sigma_{effective}}{\sigma_0} \quad (3)$$

where
N_{select} = the number of Bhabha events
N_{total} = the total number of events
$\sigma_{effective}$ = cross-section for total angular acceptance 26.2 mrad - 80 mrad
σ_0 = cross-section for selected angular acceptance 30 mrad - 75 mrad, the angular range used to generate events with BHLUMI

The luminosity calorimeter (LumiCal) in the forward detector measures the rate of events $\dot{N}$. σ can be estimated from a Monte Carlo simulation and then we can find $\mathcal{L}$ by substituting into (1).

The error is proportional to $\sqrt{N}$ so we need 10^8 events to get our error below 10^{-4}. We expect to get 10^9 Bhabha events per year at TESLA [4] so this error margin is within experimental capabilities. The collision rate is 28 kiloHertz and the interaction rate is 10 Hertz, so roughly 1 in 3000 collisions is a Bhabha event.

3 The selection criteria

We only take events where the energy of the electron and positron are greater than 80% of the beam energy.

We take the angular acceptance to be 30 - 75 milliradians instead of the entire range 26.2 - 82 milliradians. This is because when a particle hits the edge only part of its energy is detected in LumiCal, the rest leaks out at the sides. This makes a precise measurement of the particle position and therefore the scattering angle impossible.

In a Bhabha event the final trajectories of the electron and the positron should be collinear (i.e. back to back), so we only take events where

$$cos(\theta_{accollineraty}) > 0.98^1 \quad (4)$$

These cuts allow us to distinguish bhabha events from other possible events,and hence to use equation (3).

4 Beam parameters

Errors in the following beam parameters could effect the number of events selected, hence increase the error in luminosity measurement.

[1] The angle of accollineraty is the angle between the positron momentum and minus the electron momentum. i.e. $cos(\theta_{accollineraty}) = \frac{-P \cdot E}{|P||E|}$

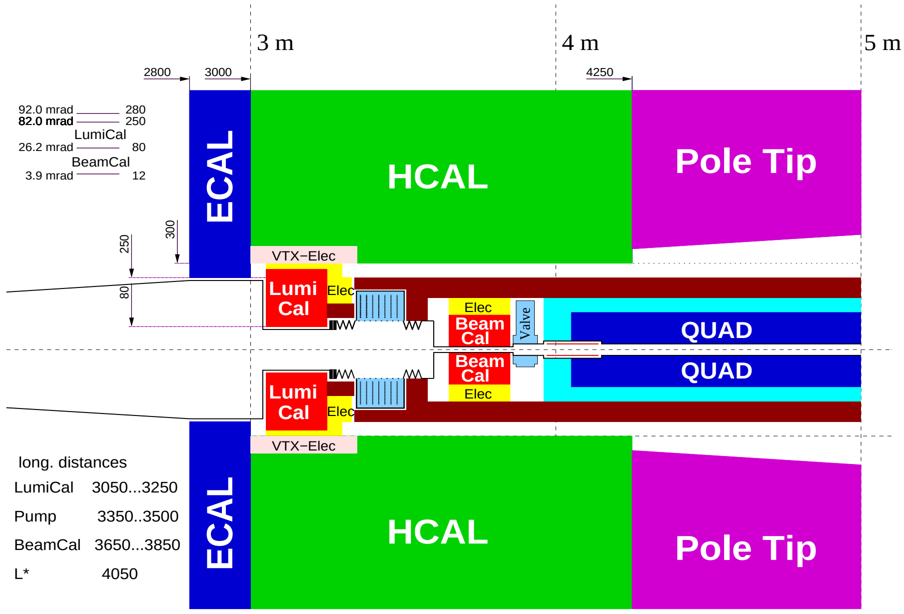

Fig. 4: *Schematic cross-section of the forward detector, an equal detector is placed the other side of the IP. Note the LumiCal which this report mostly concerns. This view is a cross-section in the y-z plane, in reality the LumiCal's are donought shaped.*

Parameter		*Explaination*
Radial resolution	=	Error in measurement of the exact point hit in the detector
Beam energy	=	Energy of the e^+ and e^- beams
Longitudinal misplacement	=	Error in the measurement of distance between interaction point (IP) and LumiCal
IP misplacement	=	Misplacement of IP from centre of the 2 LumiCal's
Offset in x	=	Offset of beam centrepoint in the x direction
Offset in y	=	Offset of beam centrepoint in the y direction
Error in diameter	=	Error in diameter measurement of LumiCal

Tab. 1: *Beam parameters*

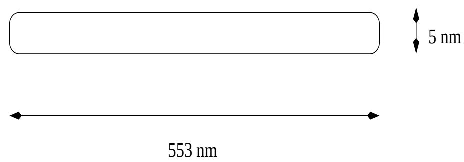

Fig. 5: *Beam dimensions in x-y plane (Bunch length is 300 μm)*

5 Results of investigations

The following plots show the dependence of N_{select}/N_{total} on the various beam parameters, using (3).

In the following plots the horizontal dashed lines represent our error margins of $< 10^{-4}$. Anything within the two lines is acceptable error, anything outside these lines means the error is too high and is hence unacceptable.

5.1 Resolution

We see from Fig. 6 that we need to have a resolution of < 3.6mm to be within our error margin. The error increases very rapidly after about 4mm, so anything above this means very big error.

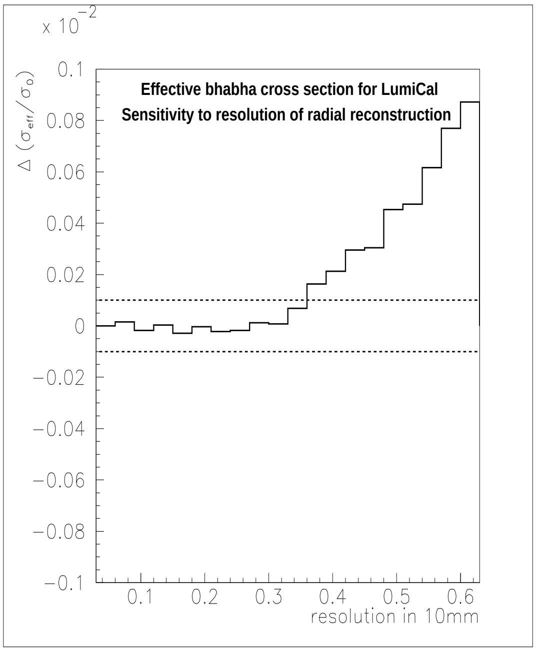

Fig. 6: *Resolution plot.*

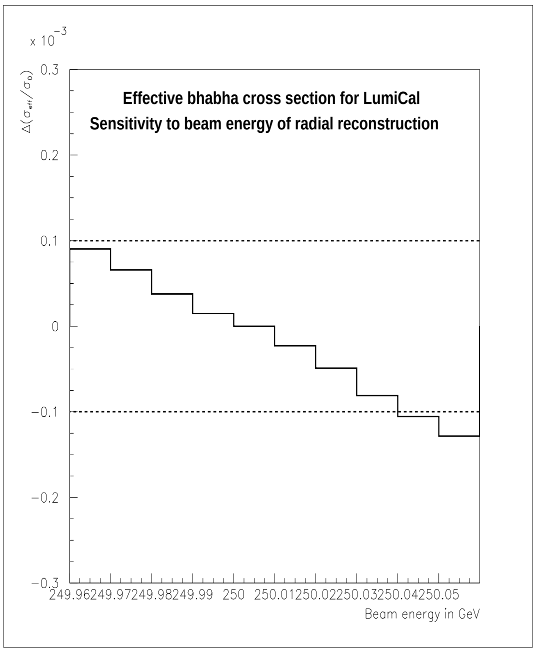

Fig. 7: *Beam energy plot.*

5.2 Beam energy

We see from Fig. 7 that we are extremely sensitive to error in beam energy. This is not such a big problem as it is possible to measure and monitor beam energy very accurately. The beam is sent through an S bend by magnets whose strengths are well known. Then the alignment of the out coming beam is measured and this is used to calculate the energy of the beam. From the plot we need to be accurate to within ± 40 MeV. This is well within experimental capabilities.

5.3 Longitudinal misplacement

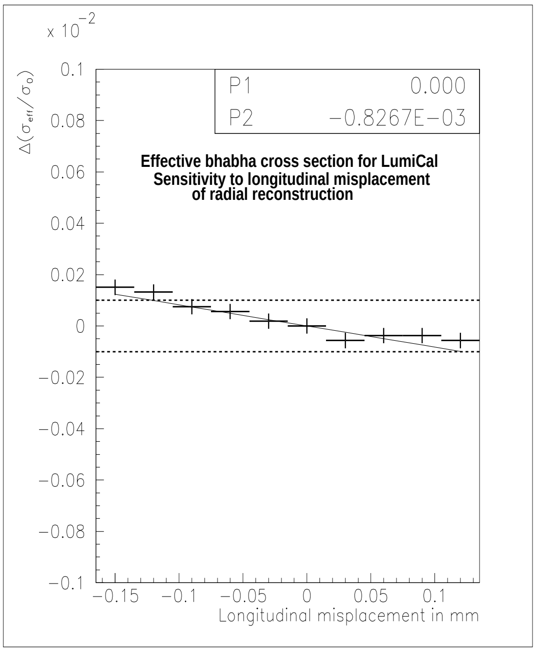

Fig. 8: *Longitudinal misplacement plot.*

The plot seems to be a linear relationship, so I fitted a straight line to it. We need to be accurate to within ± 0.12mm in the distance from IP to LumiCal which is 3050mm. Technically this is achievable.

5.4 IP misplacement

This is of course symmetrical as being further from 1 LumiCal means being closer to the other. So I just ploted positive values of IP misplacement. We see from Fig. 9 that we need to be accurate to within 0.17mm of the position of IP w.r.t. LumiCal's.

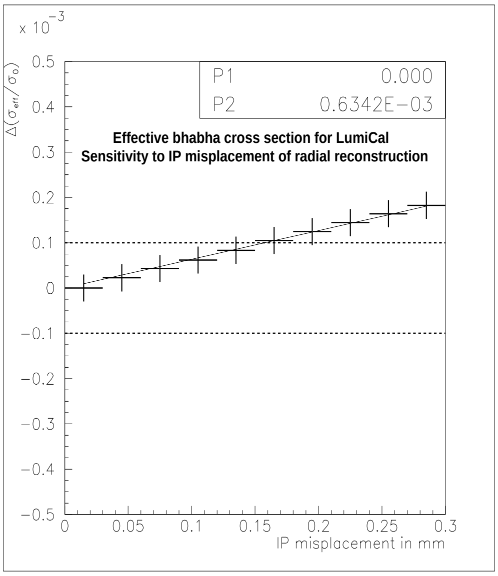

Fig. 9: *IP misplacement plot.*

We can calculate the position of the IP very accurately by recreating the paths from LumiCal, and when we account for so many events (10^9 per year) the IP is pinpointed, as shown in Fig. 10.

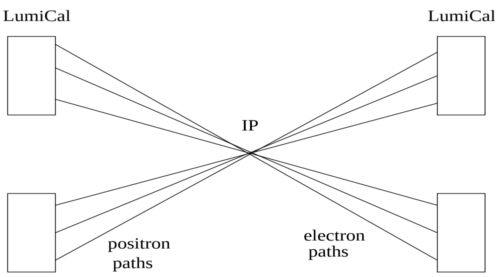

Fig. 10: *From the impact points of the electrons and positrons in the LumiCal's we can reconstruct their paths and hence determine the interaction point very accurately because of the high number of events.*

5.5 Beam offsets

We see from Figs. 11 & 12 that we are equally sensitive to beam offsets in x and y directions. This is as expected when we compare the beam dimensions to those of the LumiCal and distance from IP to LumiCal (order 10^9 higher). We need to be accurate to within 0.2 mm in the x and y directions of the position of the centre of the beam.[2]

[2] The beam being offset from the centre of LumiCal is identical to LumiCal being offset from the beam. Its just a question of where you observe the effect from.

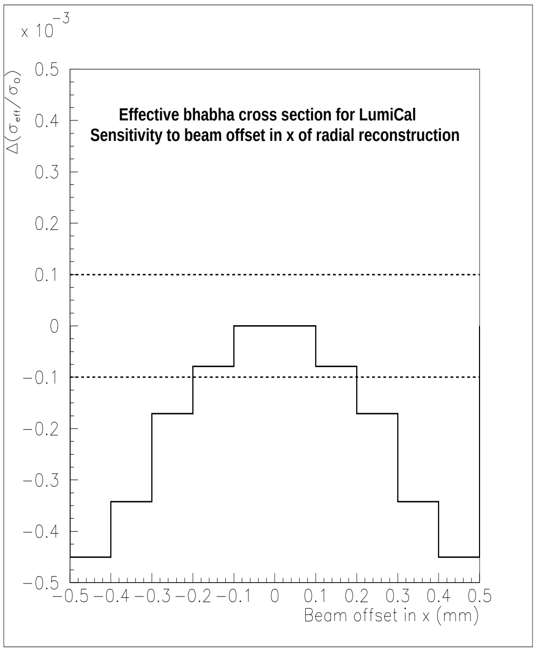

Fig. 11: *Beam offset in x plot.*

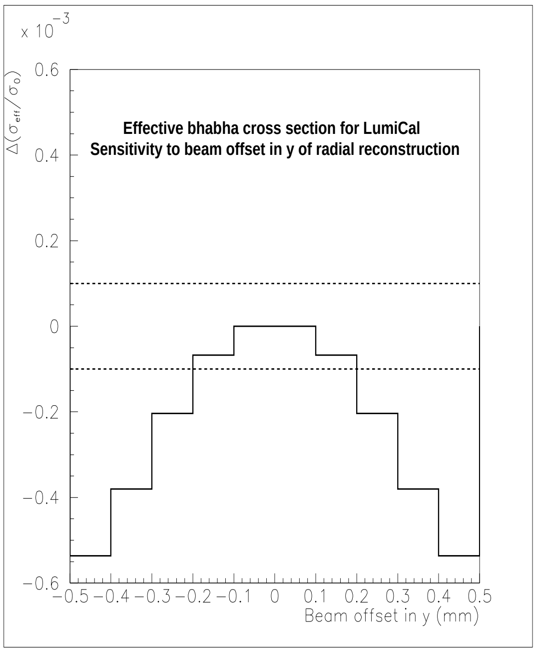

Fig. 12: *Beam offset in y plot.*

5.6 *Error in diameter* [3]

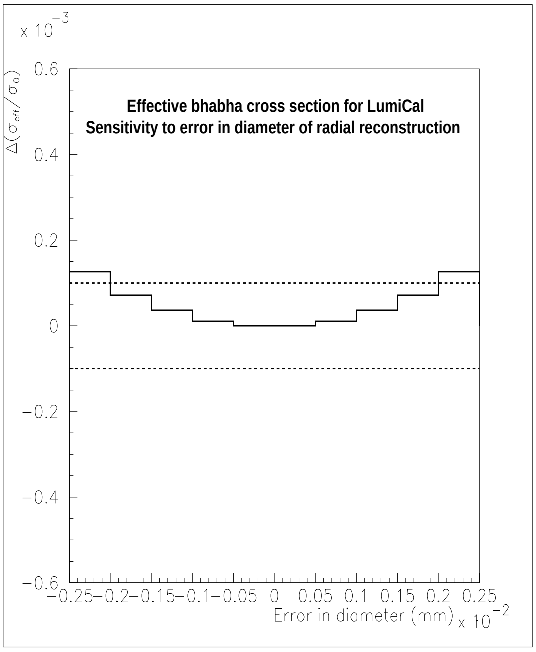

Fig. 13: *Error in diameter plot.*

We see from fig. 13 that we have to know the diameter of the LumiCal's to within $\pm 0.002mm$. This could be quite challenging as 2μm is very small compared to the diameter of 600mm.

This was previously noted as being a problem in the detector design, it was estimated that we would need an accuracy of $\pm 0.001mm$ and there was a question as to whether this was possible. Now we see that we can afford an error of twice what was estimated and the manufacturers say this is achievable.

[3] σ_{eff} is $\sigma_{effective}$ in all these plots

6 Conclusions

In order to get an error in the luminosity measurement of approx. 10^{-4} we need to know:

Variable	*to accuracy of*
Beam energy	< 40 MeV
Distance IP to LumiCal	< 0.12 mm
Diameter of LumiCal	< 0.002 mm

Tab. 2: *Conclusions 1*

and we need a

Resolution	of	< 3.6 mm
Beam offset in x	of	< 0.2 mm
Beam offset in y	of	< 0.2 mm
IP misplacement	of	< 0.17mm

Tab. 3: *Conclusions 2*

7 Outlook

I thought of a few other factors which might affect the luminosity measurement, but did not investigate them any further, the reasons for this will become clear.

1. Tilt of LumiCal perpendicular to the beam axis. This is axis independent so assume the axis is the x-axis through the centrepoint. Above the axis the angular acceptance will be increased and below the axis it will be decreased. This means that the first order effects will cancel each other out, we would need to check the second order effects. The assumption is that second order effects are very small.

2. The two LumiCal's being rotated w.r.t. each other. This would effect only the accollinearity cut. But they would have to be misaligned by a few degrees to make much difference, and this would be easily detected.

3. A crossing angle, an angle between the e^+ beam and the e^- beam (i.e. not a head on collision). This crossing angle is very easy to keep close to 0, and hence would not effect the luminosity measurement too much.[4]

If we needed to measure the luminosity even more accurately these effects would have to be investigated.

[4] Because TESLA uses superconducting magnets it is possible for the crossing angle to be 0 i.e. head on collisions. The other proposed linear colliders NLC in USA and JLC in Japan are normal conducting and hence must have a non-zero crossing angle.

8 Acknowledgements

I would like to thank my supervisor Achim Stahl for his great help and advice and for being so approachable and supportive. I would also like to thank Klaus Mönig, Ralph Dollan and Gunnar Klaemke for help with computer questions, and all the members of the TESLA group in Zeuthen for making this a very interesting and enjoyable experience.
I would especially like to compliment the DESY summer student program and organisers for running this great program.

References

[1] R Schwitters and K Strauch, *The physics of e^+e^- collisions*

[2] H. J. Bhabha, *The Scattering of Positrons by Electrons with Exchange on Dirac's Theory of the Positron*, Proc. Roy. Soc. **A154** (1936) 195.

[3] DESY Zeuthen Bhabha scattering home page. www-zeuthen.desy.de/theory/research/bhabha

[4] The OPAL collaboration, *Precision luminosity for Z^0 lineshape measurements with a Silicon-Tungsten calorimeter*, Eur. Phys. J. C