CERN - European Organization for Nuclear Research

Draft Version 3.2

Summer Student Report on Study of Differential Luminosity Spectrum Reconstruction using Bhabha Event at 350 GeV

Sicheng Wang* †

Supervisor: A. Sailer*

* *CERN, Switzerland,* † *HKUST, Hong Kong*

August 9, 2013

Abstract

For future linear colliders, it is essential to have a good knowledge at the differential luminosity spectrum for many center of mass energy related measurements. Following the methods developed previously for the reconstruction of the basic luminosity spectrum using Bhabha events, the framework is tested the case of 350 GeV. Starting from simulation between colliding beams, a simulated luminosity spectrum was generated and fitted with the model constructed. The model, with reconstruction method using Bhabha events is working well in the case of 350 GeV. The effective Bhabha cross section is calculated, and the detector resolution is estimated.

1 Introduction

For the future collider CLIC that would reach much higher colliding energy, we need a more powerful detector to accommodate for the higher luminosity. Generally, before the construction of the future detector, we always want to know how well the detector would be able to perform, and how well physics processes can be reconstructed.

On this specific study, we want to develop a method that can be later applied for obtaining the Differential Luminosity Spectrum in the case with nominal center of mass energy at 350 GeV. The Differential Luminosity Spectrum characterizes the effective colliding energy at the interaction point between the particles from the two beams, which is essential for many center of mass energy related measurements.

This report follows the method introduced and developed by S. Poss and A. Sailer [1] at 3 TeV and apply it to the case of 350 GeV.

2 Approach to the problem

The Luminosity spectrum has to be reconstructed from a process measurable in the detector.

With the equation:

$$N(\sqrt{s}) = \mathscr{L}(\sqrt{s}) \times \sigma(\sqrt{s}) \tag{1}$$

where $\sqrt{s}$ is the center-of-mass energy, N is the number of events on a specific process, $\mathscr{L}$ is the luminosity and σ is the cross section of the process.From the distribution $N(\sqrt{s})$ measured in the detector, the luminosity spectrum L can be reconstructed if the cross section sigma is known.

2.1 Bhabha Scattering

The Bhabha scattering, which has already been widely used in luminosity measurement around the lepton colliders, is an ideal candidate for our luminosity spectrum measurement. With a well known cross section:

$$\frac{\mathrm{d}\sigma_{\mathrm{Bhabha}}}{\mathrm{d}\theta} = \frac{2\pi\alpha^2}{s}\frac{\sin\theta}{\sin^4(\theta/2)} \tag{2}$$

and a dominant role in electron and positron production, we should be able to reconstruct the original luminosity spectrum with high precision through the Bhabha events.

2.2 Simulation

To start with, we need a spectrum that can be used to develop the reconstruction method, and also to test the precision of the reconstruction. To achieve that, we need a simulation for the future collider that can give us the center-of-mass energy for each particle collision at the interaction point.

As proposed by S. Poss and A. Sailer, 3 major effect of Beam Energy Spread, Beamstrahlung, Initial State Radiation (ISR) and Final State Radiation (FSR) should be taken into consideration.

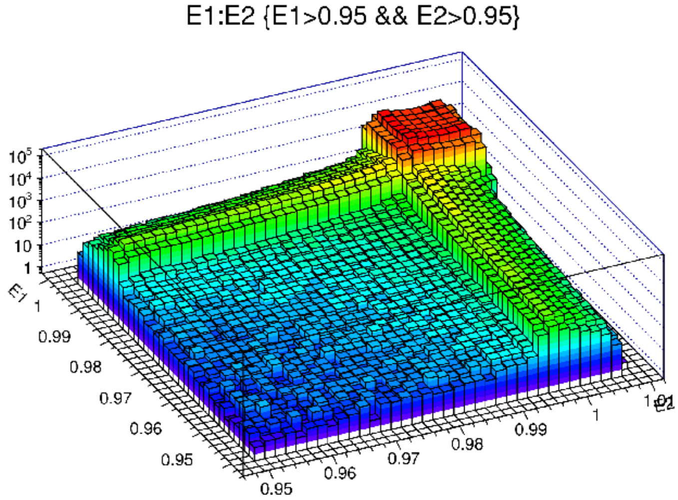


Figure 1: The Luminosity Spectrum at the interaction point

3 The Luminosity Spectrum and Contributing Factors

3.1 Luminosity Spectrum

The program GUINEAPIG is used to simulate the particle-particle interactions between the two beams and hence their center-of-mass energy. Taking the Beam Energy Spread and Beamstrahlung into account, we can plot the histogram base on energy spread of the electron and positron at the interaction point after the simulation, which gives the Differential Luminosity Spectrum as shown in Figure 1.

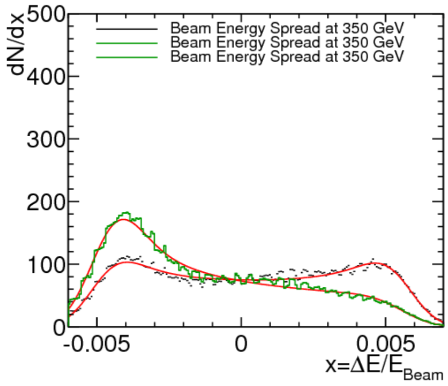
From Figure 1 we can see that the whole Luminosity Spectrum is complex in shape and cannot be described by a single simple function. To make a closer study, we want to separate the luminosity Spectrum into the smaller special regions that characterizes different effects and may be modeled separately with some basic functions. It's easy to see that the spectrum itself has some sharp divisions on its regions, and we can label the red region as Peak, the 2 green regions as to Arms and the blue part as Body.

3.2 Beam Energy Spread

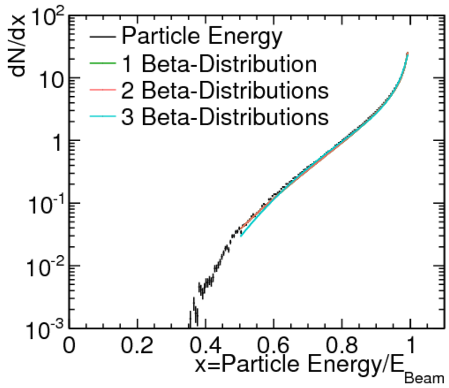
The distribution of the spectrum at the Peak region is mainly caused by the beam energy spread. In Figure 2a we only look at the Beam Energy Spread range ($\pm 0.5\%$) from one of the beam and plot the normalized spectrum separately for the Peak and Arm regions. Both part can be well fitted by the beta distribution convoluted with a Gaussian distribution.

3.3 Beamstrahlung

The spectrum in the rest region is mainly caused by the Beamstrahlung effect. We fit to this larger energy range spread with linear combination of beta distributions as in Figure 2b.



(a)



(b)

Figure 2: (a) The fit to the Luminosity Spectrum with Peak and Arm part (b) The fit to the Beamstrahlung effect to the Luminosity Spectrum

When applying a cut in the energy range ($E/E_{\text{nom}} > 0.5$), which excludes a small contribution to the spectrum out of the study and does little harm to the whole precision at its integration. We can see that the 1 beta-distribution would fit as good as the 3 beta-distribution, and this would largely simplify the model for it. The fit with 3 beta distribution is better than the 1 beta-distribution, but 1 can do as good when applying the cut.

4 Fitting

The separated part has been proved to follow the beta distribution well just as in the case of 3 TeV. Naturally we are motivated to follow the fitting method developed at the 3 TeV case.

4.1 The Model

$$\begin{aligned}
\mathscr{L}(x_1,x_2) = p_{\text{Peak}} \quad & \delta(1-x_1)\otimes\text{BES}(x_1;[p]^1_{\text{Peak}}) && \delta(1-x_2)\otimes\text{BES}(x_2;[p]^2_{\text{Peak}}) \\
+\, p_{\text{Arm1}} \quad & \delta(1-x_1)\otimes\text{BES}(x_1;[p]^1_{\text{Arm1}}) && \text{BB}(x_2;[p]^2_{\text{Arm1}},\beta^1_{\text{limit}}) \\
+\, p_{\text{Arm2}} \quad & \text{BB}(x_1;[p]^1_{\text{Arm2}},\beta^1_{\text{limit}}) && \delta(1-x_2)\otimes\text{BES}(x_2;[p]^2_{\text{Arm2}}) \\
+\, p_{\text{Body}} \quad & \text{BG}(x_1;[p]^1_{\text{Body}},\beta^2_{\text{limit}}) && \text{BG}(x_2;[p]^2_{\text{Body}},\beta^2_{\text{limit}}),
\end{aligned} \tag{3}$$

Where $\text{BES}(x)$ is used to describe the Beam Energy Spread, which mainly effect at the peak region. And $\text{BB}(x)$ is the BESx convoluted with a beta distribution, describing the Arm region, and finally $\text{BG}(x)$ for beta convolution with Gauss describing the Body.

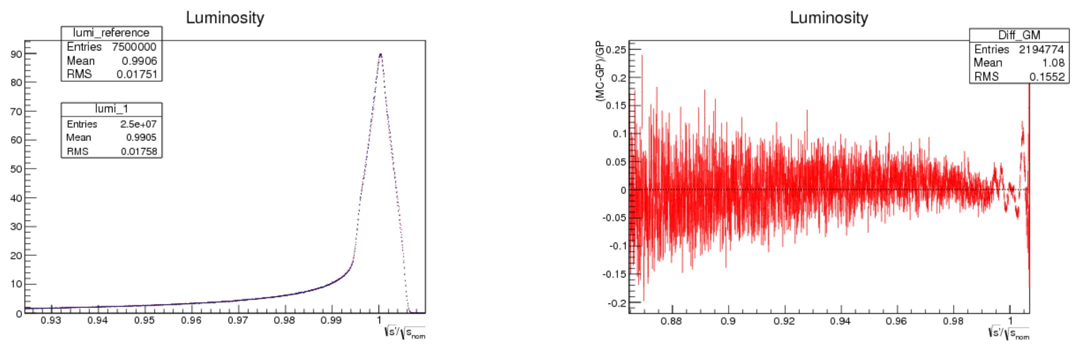
4.2 The Re-Weighting Fit

We use Reweighting Fit to fit the Luminosity Spectrum with the model. The Reweighting technique is applied to transform the existing MC events from following the origin parameter set to become MC events following the new parameter set. It has the advantage of computationally efficient because the numerical convolutions do not have to be calculated.

The initial parameters are set from the previous separate fit to obtain a closer initial distribution to the data.

4.3 Fit Result

Instead of comparing the fit result with the 2D Luminosity Spectrum, it would be much easier to compare with the center-of-mass energy spectrum as shown in Figure 3a, which becomes a 1D histogram.



(a) (b)

Figure 3: (a) The 1D Fit to the Luminosity Spectrum (b) The difference between the fit result and the origin spectrum

From this comparison we can see the mathematical model can well describe the Luminosity Spectrum simulated by the GUINEAPIG. To have a closer look at the difference we also plot Figure 3b, from which we can find the difference is around 5% at the peak (which takes most of the events). There's some fluctuation around the nominal value which requires a deeper study.

5 Bhabha Scattering

5.1 Effective Cross Section

To estimate the number of events expected from the Bhabha scattering, the effective cross section has to be known.

The effective cross section can be calculated by weighting the cross section with the normalized luminosity spectrum.

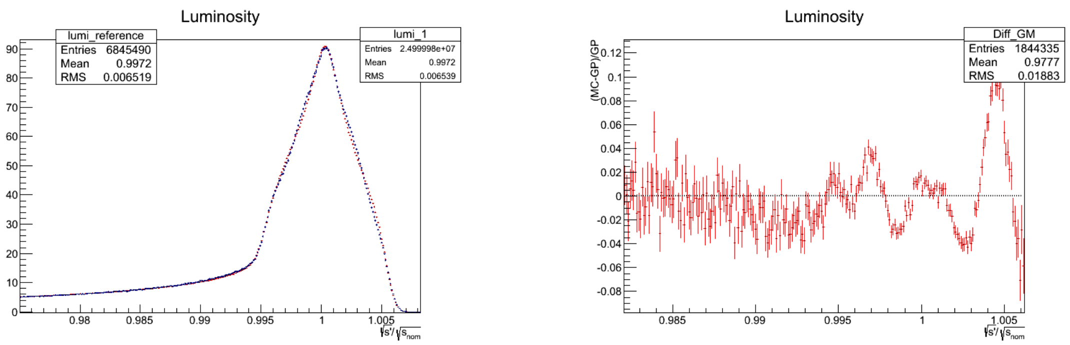
$$\sigma_{\text{eff}}(\sqrt{s_{\text{nom}}}) = \int \mathscr{L}(\sqrt{s'}) \cdot \sigma(\sqrt{s'}) \mathrm{d}\sqrt{s'} \tag{4}$$

For this specific study, when $\sqrt{s_{\text{nom}}} = 350$ GeV, the effective Bhabha cross section is calculated to be 0.62 nb, with electron and positron above a polar angle of 7 degrees. With an integrated luminosity $L_{\text{int}} \approx 10\text{fb}^{-1}$ which is also used for the measuring points in the $t\bar{t}$ threshold scan, $N_{\text{Bhabha}} = L_{\text{int}} \times \sigma_{\text{eff}} \approx 6.2 \times 10^{6}$ events are to be obtained. With instantaneous luminosity $L \approx 2 \times 10^{34}\text{s}^{-1}\text{cm}^{-2}$, it would take about 6 days to achieve.

5.2 Fit after Bhabha Scattering

The previous methods demonstrated that the model works well with the original Differential Luminosity Spectrum. For the next step we include the Bhabha scattering simulation into our consideration to get closer to the real measurement.

We use the simulation program BHWIDE to simulate Bhabha events for the original GUINEAPIG output events and the Model Monte Carlo events separately. And then compare the fit with the luminosity spectra after the simulation of Bhabha events to test if the model can still well to describe the luminosity spectrum. And the fit result as in Figure 4a is still working very well, with discrepancy at the peak between model and data in Figure 4b limited in about 5% of error. At this study the fluctuation around the nominal value may come from the defect in the input file for GUINEAPIG. The significance of this result can be interpreted in precision measurement analysis for other specific physics process.



(a)

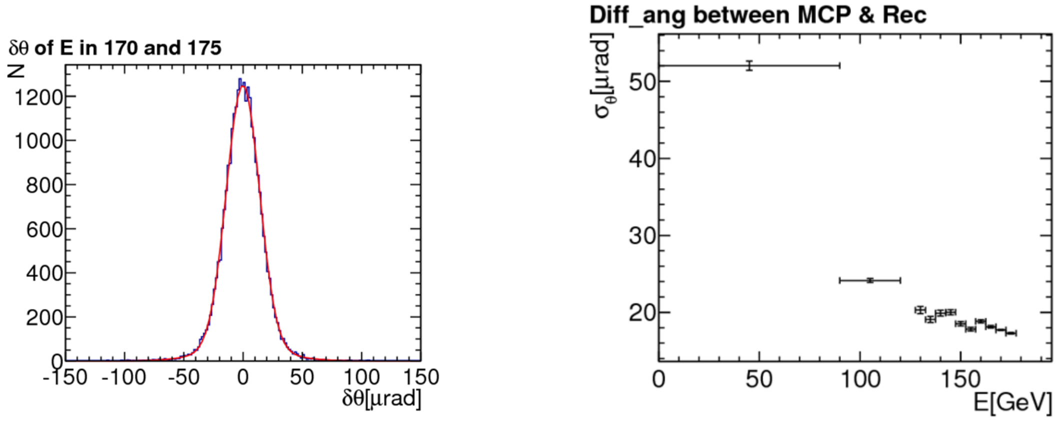
(b)

Figure 4: (a) Fit result after the Bhabha events generation (b) The difference between the fit result and the origin spectrum after the Bhabha events generation

Width of the Peak region is calculated to about $3.42 \times 10^{-3} \pm 2 \times 10^{-6}$. The difference between the widths of the GP data and the model is at the same level of the the uncertainty which can be neglect.

6 Detector Resolution Estimation

From the above simulations and fits, the model has been proved to be working well in describing the spectrum. The last step for the reconstruction of the spectrum would be adding the detec-



(a) (b)

Figure 5: (a) Angular difference distribution for the reconstruction simulation of the detector (b) Angular resolution for the reconstruction simulation of the detector

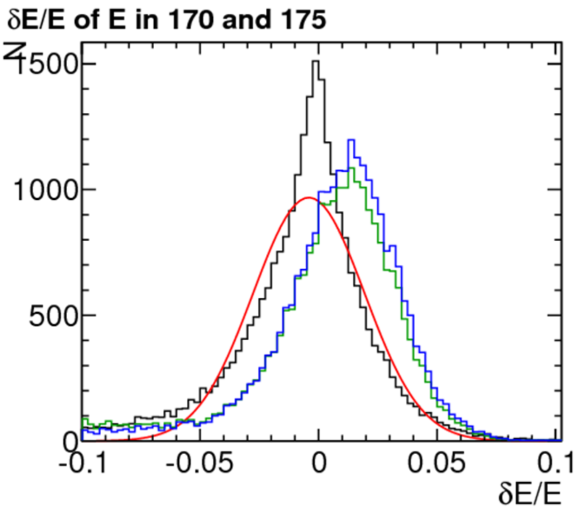
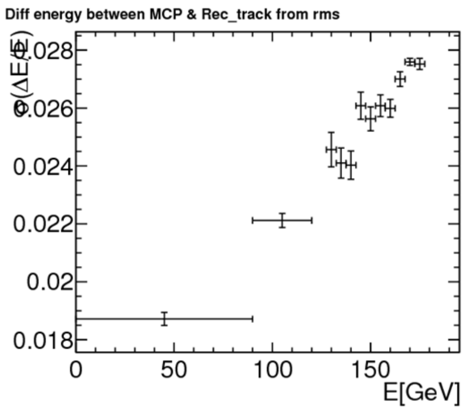


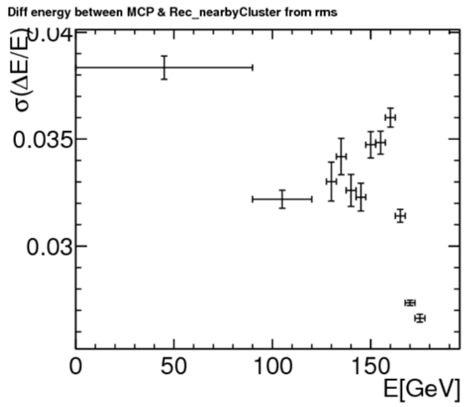
Figure 6: Energy difference for the reconstruction simulation of the detector. With Black reconstructed from the track, Green from the cluster and Blue from including the nearby clusters (within 2 cm)

tor resolution. We want to know how large the impact that the detector resolution has on the Luminosity Spectrum reconstruction, with the foreseen detector concept.

The detector resolutions are estimated with fully simulated and reconstructed events. The simulation and reconstruction was done in the Mokka and Marlin frameworks. We compare the reconstructed particles and the input MC particles of the Bhabha events via their momenta and



(a)



(b)

Figure 7: (a) Angular difference distribution for the reconstruction simulation of the detector (b) Angular resolution for the reconstruction simulation of the detector

energies. The results are shown in the Figures 5a – 7b.

Figure 5a shows the distribution of the angular difference between the reconstructed charged particle and the MC electron or positron. The distribution can be well fitted with a double Gauss distribution. While Figure 5b shows the angular resolution at different energy. The resolution is calculated from the RMS of the difference distribution in varying energy range. From the plot we can also conclude that the angular resolution reaches about 20 μrad at 350 GeV.

Figure 6 shows the distribution of the energy difference with reconstructed energy from different source. The double Gauss fit was apply to the track energy reconstruction, which does not work very well in this case. Figure 7a is also plotting the RMS from the distribution of difference for different energy with the particle energy reconstructed from the track and Figure 7b is using reconstruction energy from the nearby clusters. Between this two graphs we may conclude that the energy resolution for reconstruction from the track is better than the reconstruction from the calorimeter clusters. At the 175 GeV the resolutions are about the same. At smaller energies track momentum reconstruction has a better resolution.

7 Summary and Conclusion for the Project

The project was the application of the method developed for the Differential Luminosity Spectrum Measurement at 350 GeV CLIC. During the project period, I have modified the code for the fitting programs to make it accommodate to this lower energy case, made a macro to calculate the effective cross section and made the detector resolution estimation. Though the luminosity spectrum did have some difference compared with the case in 3 TeV, the methods developed can be well applied to the case of 350 GeV. With the existing data, the next step should be fitting with the estimated detector resolution smearing effect to test if the reconstruction would still work well.

8 Acknowledgements

I am very grateful to André Sailer for helping me with everything, including but not limited to explaining the concept and terms about his paper, providing code for the fitting programs and many helpful instructions; Samir Arfaoui for useful advice on this project. My thanks goes to all the PH-LCD group members for the accompany of this wonderful eight weeks.

References

[1] S. Poss, A. Sailer, *Differential Luminosity Measurement using Bhabha Events*, LCD-Note-2013-008, CERN, 2013