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Kinematics and Particle Identification at Very High Energy Colliders

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At collider machines operating at energies much above the electroweak scale, all Standard Model particles will appear essentially massless, including the nominally heavy ones. The kinematic consequences of this can make the signals for the Standard Model, and for other models, very different from the signals at the LHC or other colliders of the past. These differences are explained and some of the common signals are revisited in the context of very high energy colliders.

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1. Introduction

The distinction in the collider signatures of massive Standard Model (SM) particles like $W^{\pm}, Z, H$ bosons and t quark is possible at the current colliders operating at the energies of electroweak scale using the kinematic properties. However, when new physics scenarios beyond the Standard Model are considered, detection of, e.g. heavier $Z^{'}, W^{'}$ in the mass range of a few TeVs requires colliders operating at energies much above the electroweak scale. There have been proposals for the construction of future very high energy lepton(upto 3 TeV) and hadron colliders (30 – 100 TeV)[1, 2]. At such very high energy colliders, *all* the SM particles will be practically massless and their decay products will be highly collimated due to a heavy boost. As a result, there will be different kinematics of the decay products, and the particle detection strategies from the current colliders may not work well. Hence, to detect the SM particles at very high energy colliders, one may need to drastically revise the particle detection and identification strategies applied at the current colliders.

2. Toy model at a lepton collider

In order to understand how the boost effect works on the final state particles, we initially consider a toy model interaction in which we have two particles in the initial state and two pairs of particles in the final state, arising from decay of a heavy particle pair. We gradually increase the boost for the interaction and calculate the total number of detected final state particles. We further assume that these final-state particles are coloured and each will notionally give rise to a 'hadronic jet'. As shown in Fig.1 (Left), as the boost increases, the angular separation between the final state jets reduces. Hence four jets in the final state at lower boost merge and we see two jets in the final state for a very high boost. In Fig.1 (Right), we calculate the jet multiplicity for increasing boost value. We see that as the boost increases, there is reduction in the number of events with large jet multiplicity.

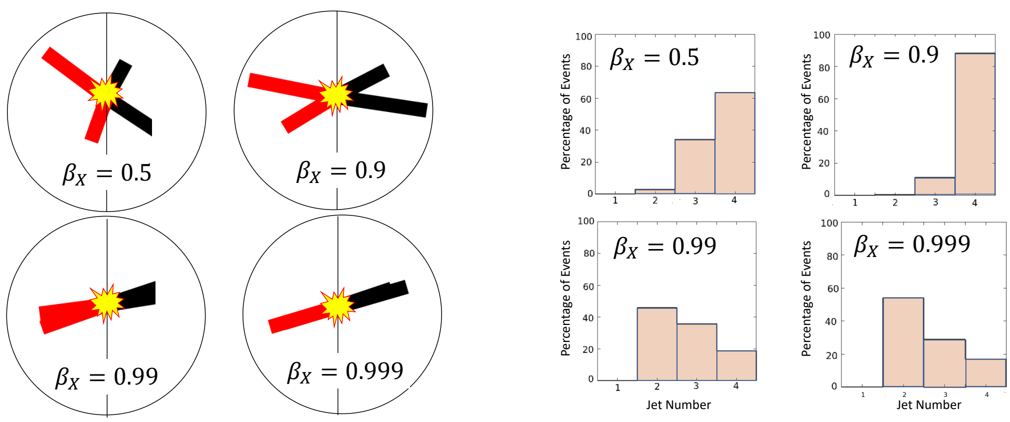

Figure 1: (Left) Difference in angular separation, (Right) Jet count for different values of boost factor β.

3. *WW* production at lepton collider

In order to check the reduction in the efficiency for signal at very high energy collider, we consider a standard process of WW production at lepton collider. We make a more realistic simulation, using the software packages MadGraph[3] and DELPHES[4], of the process $e^+e^- \to W^+W^-$ at parton level. The Ws are set to decay into muons and muon-neutrinos. The background for this process is muon pair production at the lepton collider. We choose two values of beam energies as 100 GeV and 1 TeV for the signal and background events generation. We calculate the following kinematic variables -

$$\delta\phi_{i,j} = \cos^{-1}\left[\frac{p_{x,i}\cdot p_{x,j} + p_{y,i}\cdot p_{y,j}}{\sqrt{p_{x,i}^2 + p_{y,i}^2}\ \sqrt{p_{x,i}^2 + p_{y,i}^2}}\right] \tag{1}$$

$$\delta \mathrm{R}i, j = \sqrt{(\eta_i - \eta_j)^2 + (\delta\phi_{i,j})^2} \tag{2}$$

where $\delta\phi_{i,j}$ is the difference in the azimuthal angle of the two leptons decaying from the Ws given by (1). We calculate the $\delta\phi_{i,j}$ in the transverse plane of the leptons. $\delta\mathrm{R}_{i,j}$ is the angular separation between two muons arising from the W decays given by (2).

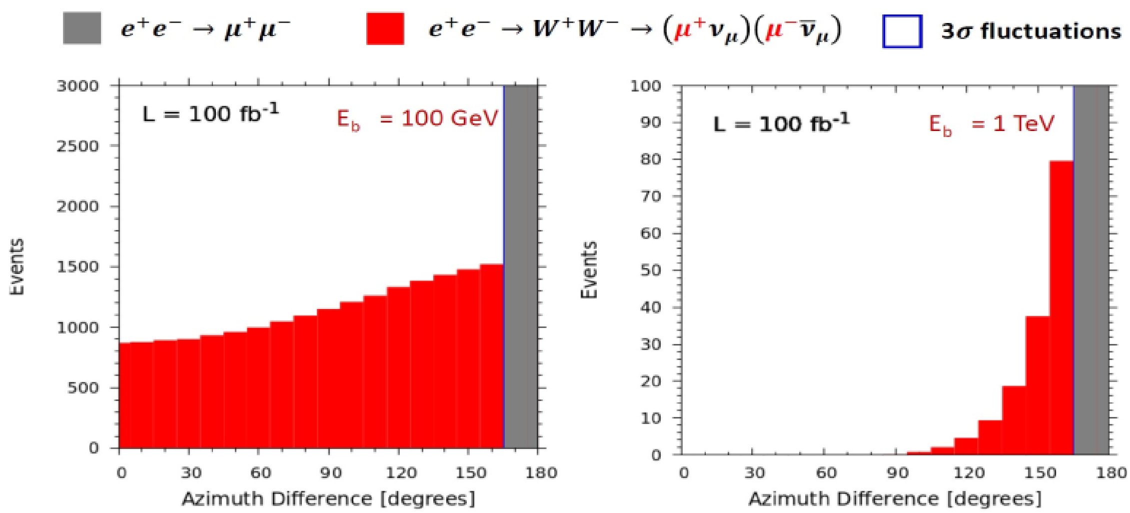

Figure 2

We plot $\delta\phi_{i,j}$ for signal as well as background as shown in Fig. 2 for luminosity of 100 fb^{-1}. We see that beam energy of 100GeV, there is a less overlap between the signal (red) and the background (grey). However, for beam energy of 1TeV, fewer events for signal are seen as compared to background. This shows that at very high energies, the distinction between the signal and background is difficult due to the large overlap.

Fig. 3 shows comparative analysis for different beam energies for the variable $\delta\mathrm{R}_{i,j}$. We can see that at lower beam energy, the signal and background are clearly distinguishable. However, as the beam energy increases, there is a large overlap between the signal and the background, indicating the loss in the signal due to heavy background.

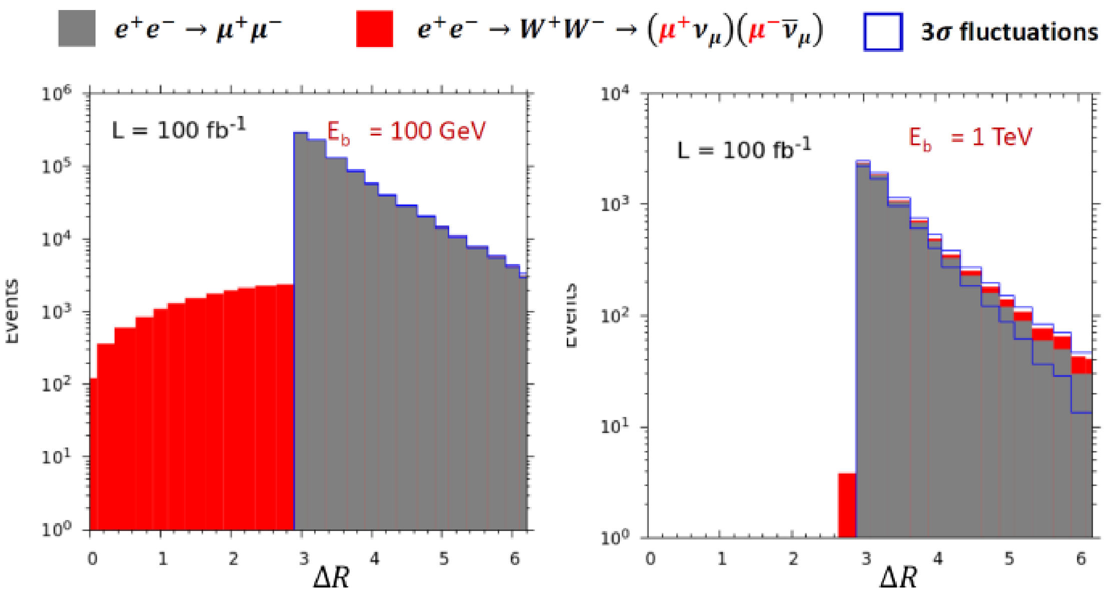

Figure 3

4. Conclusion

In this study, we see that when the beam energy is increased at the collider, the distinction between the signal and the background becomes difficult. This is due to the high collimation of final state particles in the interaction making them difficult to distinguish. We have presented the kinematics and particle identification scenario at very high energy lepton collider by choosing the two longitudinal boost invariant variables, namely $d\phi_{i,j}$ and $\delta R_{i,j}$

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