PROCEEDINGS OF SCIENCE

Kinematic Fitting for ParticleFlow Detectors at Future Higgs Factories

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In many analyses in Higgs, top and electroweak physics, the kinematic reconstruction of the final state is improved by constrained fits. This is a particularly powerful tool at e^+e^- colliders, where the initial state four-momentum is known and can be employed to constrain the final state. A crucial ingredient to kinematic fitting is an accurate estimate of the measurement uncertainties, in particular for composed objects like jets. This contribution will show how the particle flow concept, which is a design-driver for most detectors proposed for future Higgs factories, can — in addition to an excellent jet energy measurement — provide detailed estimates of the covariance matrices for each individual particle-flow object (PFO) and each individual jet. Combined with information about leptons and secondary vertices in the jets, the kinematic fit enables to correct b- and c-jets for missing momentum from neutrinos from semi-leptonic heavy quark decays. The impact on the reconstruction of invariant di-jet masses and the resulting improvement in ZH vs ZZ separation will be presented, using the full simulation of the ILD detector concept.

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1. Introduction

The Higgs boson decay modes to heavy b and c quarks are crucial for the Higgs physics studies. Undetectable neutrinos due to semi-leptonic decays (SLD) in the jets originating from heavy b and c quarks degrade the reconstruction of b- and c-jets [1, fig. 8.3d]. A kinematic fitting is a mathematical approach that can be used to retrieve the jet energy resolution beyond the detector resolution [2]. A key input to the kinematic fit is the measurement uncertainties. The ILD detector, as an example of highly-granular ParticleFlow optimized detector concept, is based on the reconstruction of individual particles and provides an unprecedented knowledge about the jet-level uncertainties [1]. A very simple approximation of the energy of a missing neutrino in addition to parametrisation of the jet energy error improves the di-jets invariant mass in $e^+e^- \to ZHH$ events at $\sqrt{s}$ = 500 GeV with $H \to b\bar{b}$, shown in figure 1 [3]. Despite the improvements in the Higgs

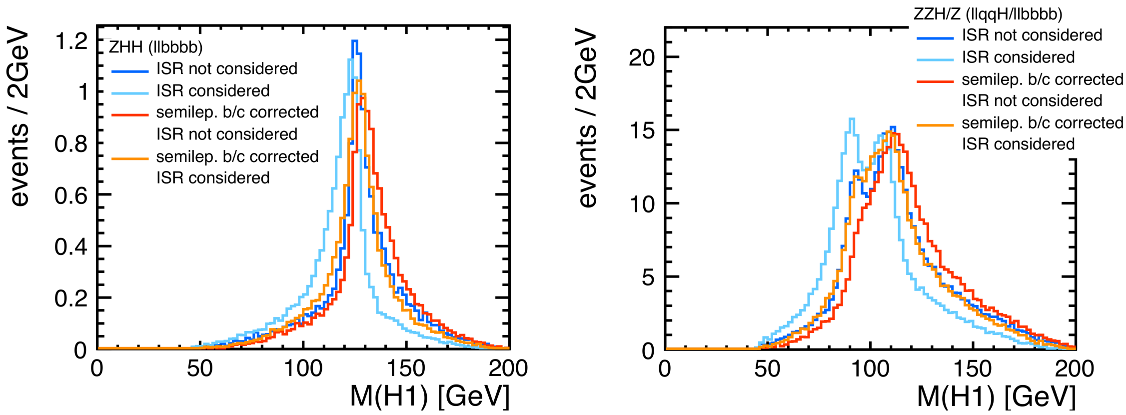

Figure 1: Higgs mass reconstruction in the presence of ISR photon and semi-leptonic decays. (a): the signal peak gets sharper by considering ISR photon and correction of semi-leptonic decays. (b): the background peak is pulled towards the signal.

mass reconstruction, the method applied in [3] does not have a satisfying outcome in the presence of ZZH/Z background. Thus a proper neutrino correction and a better jet error parametrisation are needed to avoid the issue that merges signal-background peaks. This new jet error parametrisation is evaluated using the $ZH/ZZ \to \mu\bar{\mu}b\bar{b}$ samples in presence of ISR photon and $\gamma\gamma \to$ low p_T hadrons (only for ZZ events) at $\sqrt{s}$=250 GeV.

2. Kinematic fitting

It can be shown that the energy and the momentum of the missing neutrino can be obtained using the kinematics of the semi-leptonic decay [4]. In this method, the semi-leptonic decays are found by tagging charged leptons within b- or c-jets. The energy and momentum of the neutrino is then obtained by a sign ambiguity if the four-momentum of visible decay products of the semi-leptonic decay, mass and flight direction of the parent hadron are known. The sign ambiguity is resolved by kinematic fitting technique [2]. The constraints could be energy and momentum conservation and/or invariant masses of known particles. A precise knowledge of the uncertainties of the measurements is a key point in using the kinematic fitting technique. The ParticleFlow

Algorithm used for event reconstruction in the ILD detector concept [1], provides full details of the measurement uncertainties for each PFO. Each of the ILD sub-detectors has their own spatial and energy resolution that affect the measurement error of particle reconstruction. For complicated cases like jets, the initial covariance matrix (σ_{det}) is formed by the summation of covariance matrices of all particles that belong to the jet (red histogram in figure 2a). Since the subdetector

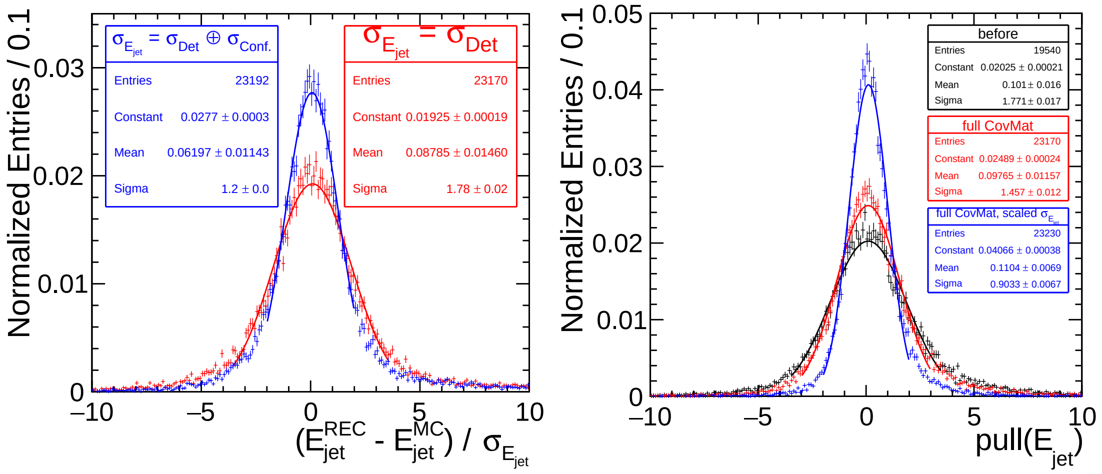

Figure 2: (a): jet energy modeling is improved by adding uncertainty due to particle confusion (σ_{conf}). (b): the new jet error parametrisation improves the kinematic fit performance (better pull(E_{jet}))

resolutions contributing to the calculated uncertainties for the neutral and charged PFOs are not the same, any confusion between hits created by charged and neutral PFOs will induce another error to the jet covariance matrix. Parametrisation of the uncertainty due to confusion (σ_{conf}) has been done for different jet energies using the fraction of the jet energy carried by each type of PFOs (blue histogram in figure 2a) [5, 6]. In presence of semi-leptonic decays, additional uncertainty will be added by neutrino correction (σ_ν) [6]. The impact of detector resolution for each PFO type and also the confusion in the particle flow has been studied in detail [4, 6]. The covariance matrix of the jet is then fed to kinematic fit as the uncertainty of the jet energy and angles measurement. This new jet error parametrisation improves the fit performance with a much better pull distribution of the jet energy (red histogram in figure 2b) which receives further improvement (blue histogram in figure 2b) by scaling up the jet energy error by a factor of 1.2 (derived from the width of the blue histogram in figure 2b).

3. Z/H mass reconstruction

The new jet error parametrisation and neutrino correction are applied on the introduced $ZH/ZZ \to \mu\bar{\mu}b\bar{b}$ samples. The blue and black histograms in figure 3 show the mass recovery by pure neutrino correction for both Higgs boson (solid histograms) and Z boson (dashed histograms). In the case of pure neutrino correction, the kinematic fit is performed to decide between solutions and resolves the sign ambiguity, but the pre-fit jet four-momenta are used for the invariant mass of di-jet. The cyan histograms in figure 3 show events without a neutrino correction and with only a pure kinematic fitting, receive a huge improvement in the di-jet invariant mass reconstruction which highly profits from the new jet error parametrization described in section 2.

In the end, a kinematic fit combined with neutrino correction results in not only the improvement in the peak position and resolution of the invariant mass for both Higgs and Z bosons, but also gives better H/Z mass separation. The latter would be important for any Higgs studies where event selection is done based on di-jet masses. It can be noted that the impact of the neutrino correction seems much smaller for $Z \rightarrow b\bar{b}$ than for $H \rightarrow b\bar{b}$. This is suspected to be related to the effect of the detector resolution (in addition to other sources of uncertainties) for the $H \rightarrow b\bar{b}$ distributions while the $Z \rightarrow b\bar{b}$ peak is dominated by the natural width of the Z boson and can not be narrower despite improvements in the jet reconstruction.

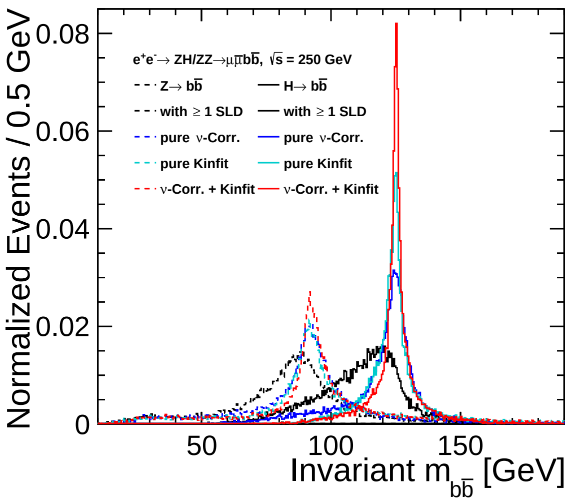

Figure 3: Applying kinematic fit and neutrino correction improves Higgs/Z mass separation.

4. Conclusions

The separation of the ZZ background and the ZH signal is very important for the Higgs self-coupling analysis since these processes have the same final state particles. The efficiency of ZHH vs ZZH/ZZZ separation is highly dependent on the reconstruction of heavy-flavor jets. A conceptual approach for correction to semi-leptonic decays is based on the detailed reconstruction of the decay kinematics. The combination of the neutrino correction and a kinematic fit improves the invariant mass of the boson assigned to each di-jet. Propagation of errors from PFO to the jet-level, in addition to contributing other relevant source of uncertainties, gives a precise knowledge about the measurement errors. Using the true information for neutrino correction proves the principle and if the neutrino correction based on reconstruction-level information is failed, a pure kinematic fit tremendously improves the invariant mass resolution of $b\bar{b}$ di-jets. The improvement achieved by the neutrino correction based on reconstruction-level information is expected to be between the red and cyan histograms in figure 3.

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