

Proposal of a new tracking-based technique for the measurement of the top-quark mass.

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Abstract. We propose a new tracking-only method to measure the top quark mass. The analysis makes use of the $t \rightarrow Wb \rightarrow l\nu b$ decay chain and we use the invariant mass of the lepton and reconstructed secondary vertex - from the B-hadron decay. The method is tested by fitting pseudo-experiments generated from simulation using probability distributions for signal and background. The stability and expected uncertainties are evaluated. First results indicate that the errors are expected to be small but future development of the method is essential before applying it on data samples.

1. Introduction

1.1. Theory

The main goal of this project is to measure the mass of top quark. Almost every top quark decays into a W boson and a B-quark. Once the B-quark is produced, it forms hadrons. This process is called *hadronization*. Typically B-hadron has a relatively long life time and since the collisions occur at very high energies, a B-hadron propagates a certain distance before it decays. By looking at the tracks that come from a displaced vertex, one can reconstruct the secondary vertex corresponding to the point of B-hadron decay, Figure 1. Our method is based on this principle. We will be using the invariant mass of the lepton and the reconstructed secondary vertex - the tracks that come from the point of B-hadron decay.

1.2. Advantages

All existing measurements have precision limits at least in one of the following: jet energy calibration (standard methods), top quark production kinematics modeling (e.g. L_{xy} method[1]), limited number of usable samples (e.g. J/ψ method[2][3]). The proposed method relies mainly on a reconstructed secondary vertex from its tracks independently of jet energy. We use a proper Lorentz invariant quantity that does not depend on the top quark production, i.e. the invariant mass of a lepton and a secondary vertex. Finally, it is expected to have competitive statistical precision.

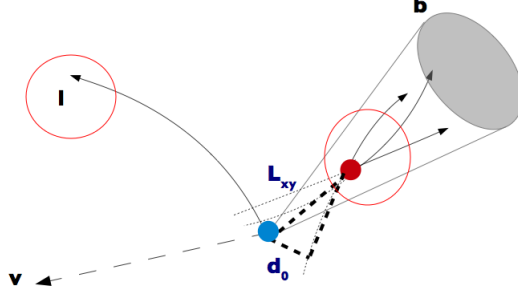


Figure 1. Final state products of a $t \rightarrow Wb$ decay with $W \rightarrow l\nu$. Tracks are represented by arrows and the circles mark the primary (blue) and secondary (red) vertices. The transverse decay length L_{xy} and the transverse impact parameter distance d_0 which characterize the secondary vertex are indicated by dashed lines. In the described method we are using the invariant mass of a lepton and a secondary vertex, indicated by red circles

2. Method

2.1. Event selection

The requirements are summarized as follows: at least one lepton and one reconstructed secondary vertex. Therefore we cannot use hadronic channel, but semileptonic and dileptonic channels are both possible. We have been using the cleanest $t\bar{t}$ decay channel, i.e. the $e\mu$ channel (Figure 2). Although there is almost no background, the main challenge is to select the correct lepton - secondary vertex combination. One possible solution: plot the invariant mass of the combination that has the smallest angle (ΔR) between a lepton and a secondary vertex,

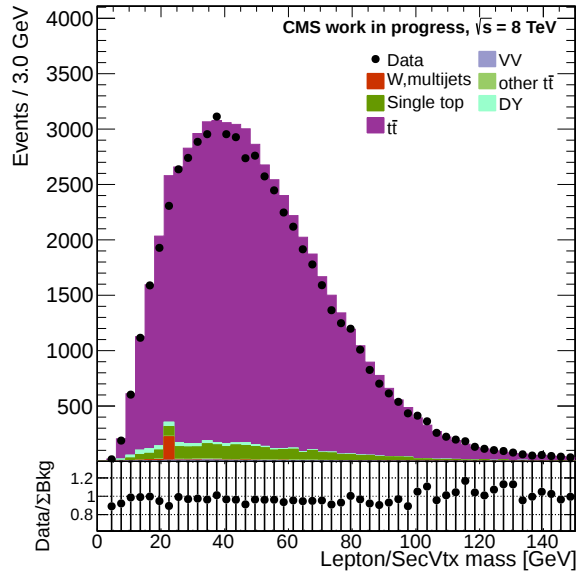


Figure 2. Secondary vertex-lepton system. Invariant mass is reconstructed in the $e\mu$ channel, $N_{t\bar{t}}/N_{total} \approx 94\%$. In addition, in the proposed method we are only looking at final products of B-hadron decay, therefore the T-quark production mechanism is irrelevant meaning single top and other $t\bar{t}$ events can also be treated as signal events which lead to even higher ratio $N_{t\bar{t}}/N_{total}$.

i.e. calculate ΔR value of all possible combinations $\rightarrow$ find the smallest value and save the corresponding combination $\rightarrow$ compute invariant mass of this combination $\rightarrow$ if more than 1 secondary vertex is reconstructed, compute invariant mass of the opposite combination. This gives $N_{corr.match}/N_{total} \approx 62.6\%$. Using the secondary vertex-lepton system with minimum mass (i.e. min mass) was the second approach in order to distinguish between correct and wrong match. The algorithm is the following: calculate invariant mass of the leading lepton and all given secondary vertices $\rightarrow$ take the smallest value. This results in $N_{correct}/N_{total} \approx 63.6\%$. The drawback of this method is that it requires at least 2 reconstructed secondary vertices, therefore we get less statistics ($N_{total} \approx 110'000$ per top mass samples) comparing with ΔR selection ($N_{total} \approx 360'000$ per top mass samples).

2.2. Analysis strategy

Using the MC samples we analyze invariant mass distribution of correct and wrong match separately for both selection methods. The distributions are shown in Figure 3 and Figure 4 correspondingly.

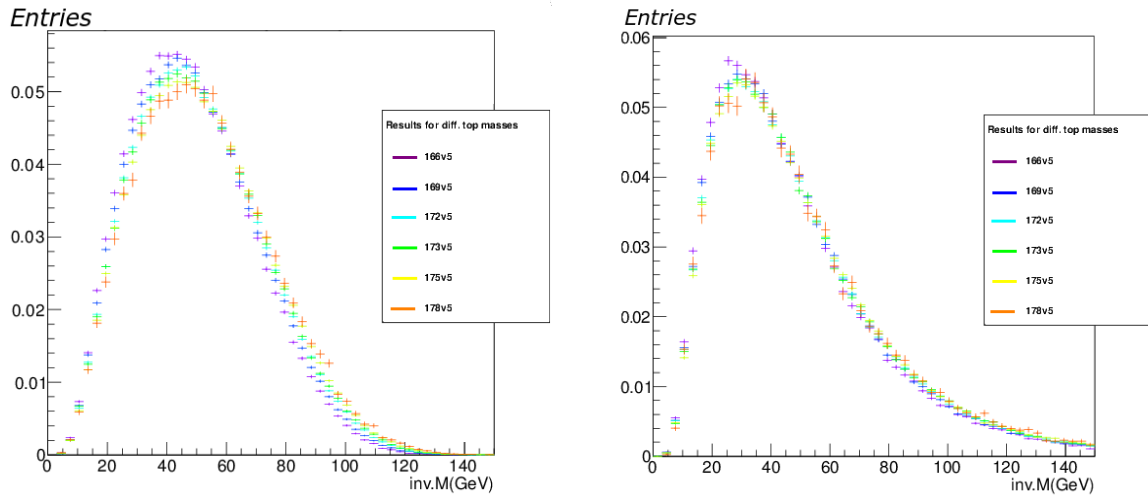


Figure 3. Invariant mass (normalized by area) of a correct combination (left) and wrong combination (right) of a lepton and a secondary vertex after ΔR selection for 6 different MC T-quark mass samples.

It can be seen from these histograms that the parameters that describe the probability distribution function for correct combinations are sensitive to the top quark mass while wrong combinations are not. In order to combine this information in a probability distribution function describing how the variable of interest is expected to evolve as a function of the top quark we have chosen to fit the simulated distributions using analytical functions. We have found that using an asymmetric Gaussian ($\mu_{mean}, \sigma_L, \sigma_R$) + generalised Gamma function (β, γ, μ), which describe separately the contribution from correct and wrong combinations, is expected to describe fairly well the simulation (Figure 5).

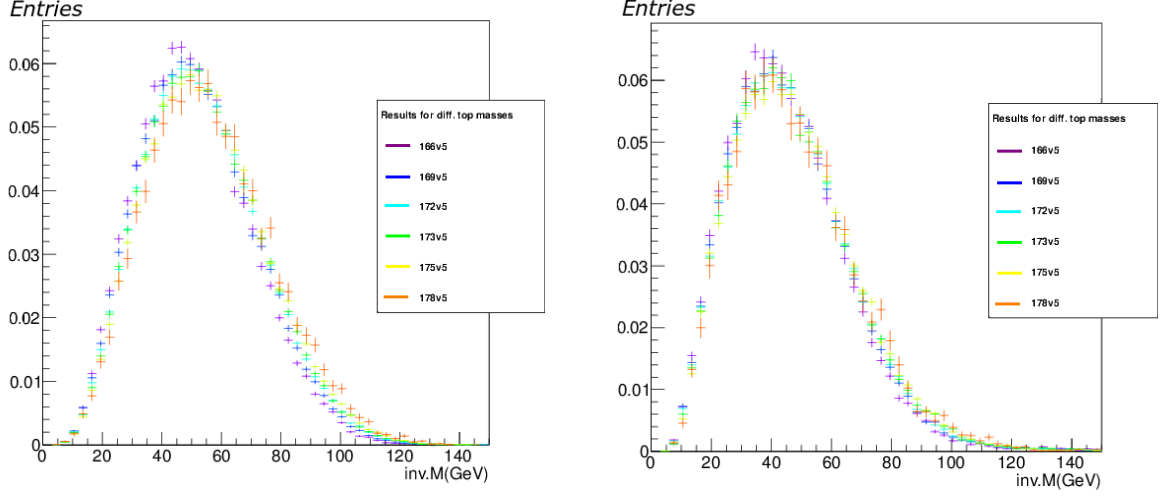


Figure 4. Invariant mass (normalized by area) of a correct combination (left) and wrong combination (right) of a lepton and a secondary vertex after min mass selection for 6 different MC T-quark mass samples.

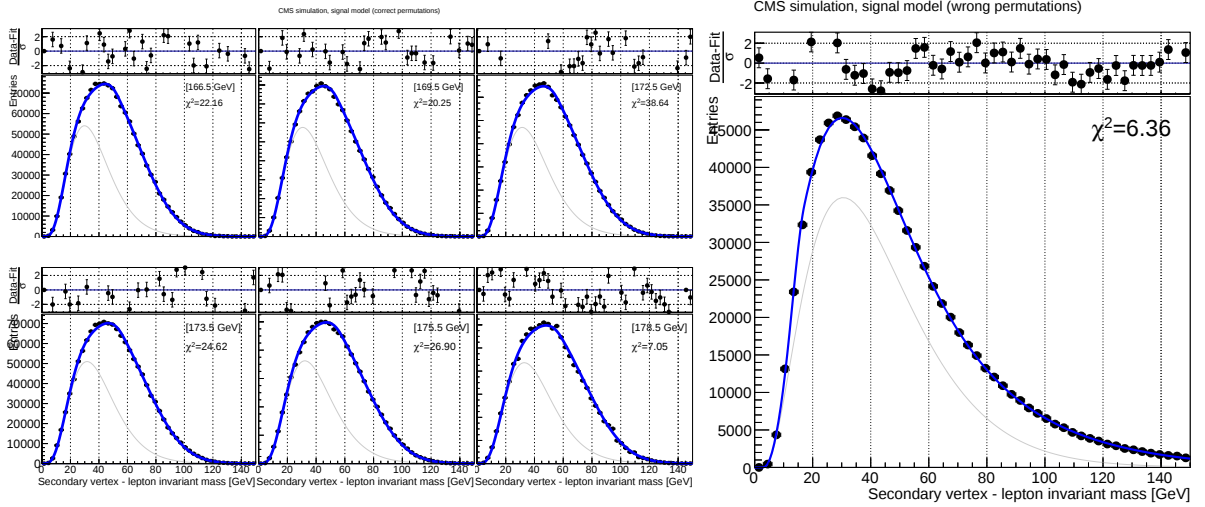


Figure 5. Template fits. We parameterize the correct match fit (left) as a function of top mass by assuming that all fit parameters are linearly dependant on top mass, whereas the wrong match template fit (right) is not sensitive to top mass, therefore, we do one average fit for all 6 MC samples.

2.3. Pseudo-experiments

We use pseudo-experiments in order to evaluate the statistical properties of the fit: bias and statistical uncertainty. The average value of the top quark mass fit m_{fit} is compared with the true value in Figure 6. We observe that some of the mass points used in pseudo-experiments have larger bias which indicates that the phenomenological analytical function to describe the expectations can be improved. However, in general it is close to 0. In the same figure we show the expected result obtained after varying the QCD scale in the simulation and the top quark p_T according to its uncertainty.

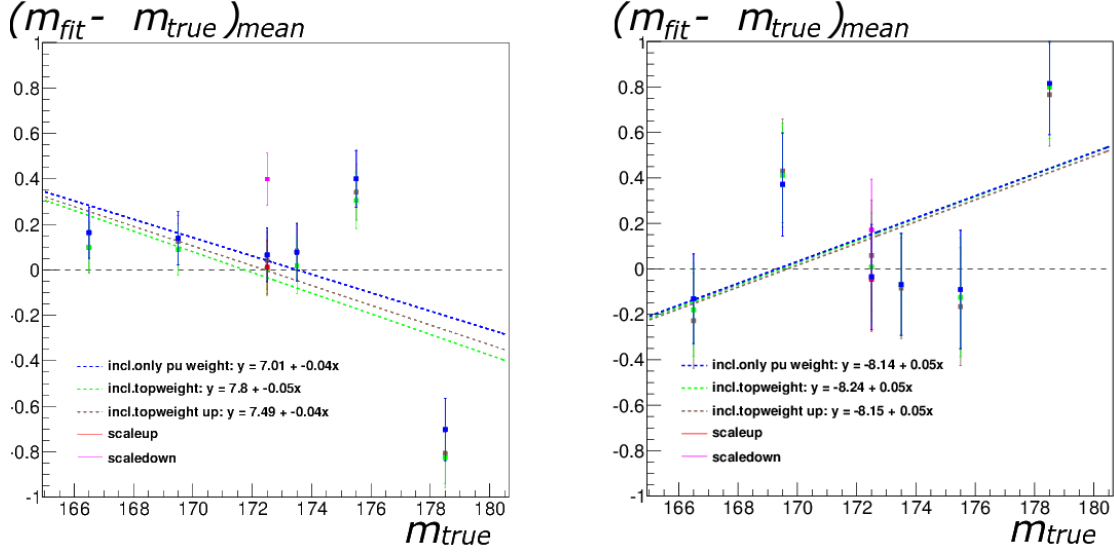


Figure 6. Mean measured top-quark mass from pseudo-experiments (using MC samples with different m_{true} value) by applying ΔR (left) and min mass selection (right). The linear fits are indicated by colored dashed lines, whereas the black dashed line corresponds to the expected fit in ideal scenario.

3. Results and discussions

From Figure 6 the expected uncertainties ($e\mu$ channel) are:

- $\sigma_{stat} < 0.4 GeV$ for ΔR selection, $\sigma_{stat} < 0.8 GeV$ for min mass selection,
- $\sigma_{syst} \sim small$,
- $\sigma_{pT} < 0.2 GeV$ for ΔR and min mass.

4. Conclusions

A new method has been implemented for extracting top quark mass by using tracking-only technique. The method needs further development but the obtained results already look very promising. From Figure 6 the expected uncertainties ($e\mu$ channel) are: $\sigma_{stat} < 0.4 GeV$, $\sigma_{pT} < 0.2 GeV$ and σ_{syst} is expected to be also small. It is a very remarkable improvement in uncertainty (especially in σ_{pT}) comparing with the result from L_{xy} method [1], where the final result for all channels combined was published to be: $m_t = 173.5 \pm 1.5_{stat} \pm 1.3_{syst} \pm 2.6_{pT} GeV$. The proposed method mainly relies on analyzing B-decay products and reconstructing the secondary vertex, therefore, it is still important to estimate uncertainty in systematics of B-decay modeling and secondary vertex reconstruction performance (detectors and software). Splitting up the measurement as a function of track multiplicity has the potential to control uncertainty related to the B-modeling and the performance of the secondary vertex algorithm. Further improvements are also possible in correct/wrong match combination selection or by using an ideogram technique to take all into account.

References

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