Muon Reconstruction and the Search for Leptoquarks at the LHC

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Leptoquarks are particles which could explain the symmetry between quarks and leptons revealed in the Standard Model. A leptoquark could decay into a quark and a lepton simultaneously. Earlier experiments yielded a lower mass limit of $M_{LQ} > 251$ GeV [1]; therefore a leptoquark decay in principle can lead to leptons with a high transverse momentum (p_T). Hence – and due to a low production cross-section – the search for leptoquarks heavily depends on the reconstruction of the high-p_T leptons. This study focuses on leptoquarks decaying into muons and uses the powerful muon spectrometer of the ATLAS detector. This spectrometer has a diameter of more than 20 meters within a toroidal magnetic field and is optimised for the track reconstruction and measurement of high-energetic muons. The track of the muon is not only reconstructed in the muon system in the outermost part of the ATLAS detector, but also in the central detector system, which leads to three options for track reconstruction: the standalone reconstruction either in the inner or the outer detector or a combination of both. For the combination of the tracks from the inner detector and the outer detector two different algorithms are used and compared. The first one (MuID) matches tracks based on the χ^2 from the difference between the track parameters and their summed covariance from the inner tracker and the muon system. For the combination a full refit to the measurements from the inner tracker and the muon system is done. The second reconstruction algorithm (STACO) uses a similar technique for matching the track in the inner detector as well as in the muon system. Then the two measurements are combined using their covariance matrices.

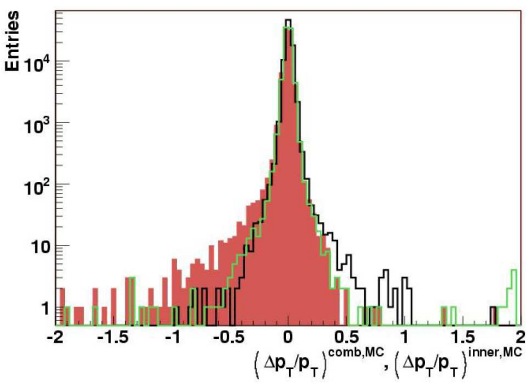

Fig. 1: The black curve shows the relative difference between p_T^{comb} and p_T^{MC}, while the red (MuID) and green (STACO) curves show the results of the presented selection. Note the reduced number of entries in the region > 0 for the red and the green curves compared to the black curve.

The relative weight of the inner detector versus the muon system for the reconstructed momentum depends on the measured transverse momentum. For lower p_Ts the combination is dominated by the information from the inner detector. For high-p_T muons the effects of multiple scattering and energy loss in the calorimeter get less important and due to the large dimensions the momentum determination from the muon system is more precise. In general the best results are obtained for a combination of both standalone reconstruction algorithms. However for a small fraction of events the muon system drastically overestimates the reconstructed momentum. Due to the high Z^0 cross-section even a small fraction of these muons can affect the background for a leptoquark search. The aim of this study is to reduce this fraction without discarding events [2].

The basic idea is to find a set of selection criteria in order to classify the muons and to select the best reconstruction algorithm for each class. As first criterion the χ^2/DoF of the combined track has been considered. Large χ^2/DoF indicate that the measurements in the muon system and the inner tracker differ by amounts larger than the expected error. Investigations have shown that for $\chi^2/\text{DoF} \geq 1.5$ the inner detector standalone reconstruction gives the best results. Even for small χ^2/DoF the difference of the muon system and the inner tracker might be large if one of the two has large uncertainties. The inner tracker is used in regions where it is well measured, while for regions with poor resolution of the inner tracker the combination is used. The latter is the case for $|\eta| > 2$. For $|\eta| < 2$ the quantity α, defined as

$$\alpha = \frac{p_T^{\text{comb}} - p_T^{\text{muon}}}{p_T^{\text{inner}} - p_T^{\text{muon}}}$$

is used to classify the events. For small α the combined reconstruction is dominated by the muon spectrometer standalone reconstruction. This indicates a large expected uncertainty of the inner track reconstruction. Hence for $\chi^2/\text{DoF} < 1.5$ and $|\eta| < 2$ in the case of $\alpha < 0.2$ the combination is preferred. A combined optimisation of the introduced selection criteria yields the following selection for the reconstructed muons:

$$\begin{array}{llll}
\chi^2/\text{DoF} & \geq 1.5 & & \Rightarrow p_T^{inner} \\
\chi^2/\text{DoF} & < 1.5 \;\wedge\; |\eta| \geq 2 & & \Rightarrow p_T^{comb} \\
\chi^2/\text{DoF} & < 1.5 \;\wedge\; |\eta| < 2 & \wedge\; |\alpha| \geq 0.2 & \Rightarrow p_T^{inner} \\
\chi^2/\text{DoF} & < 1.5 \;\wedge\; |\eta| < 2 & \wedge\; |\alpha| < 0.2 & \Rightarrow p_T^{comb}
\end{array}$$

In figure 1 one sees, that this selection reduces the number of muons with overestimated p_T ($\Delta p_T > 0$) substantially – without reducing the statistics. The accuracy of the reconstruction is improved and the rate of misidentified events drops.

References

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[2] B. Ruckert, diploma thesis, LMU München, 2006
[3] G. Krobath *et al.*, this report, p. 36