Electroweak scale physics & exotic searches at LHCb

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The LHCb experiment has a broad and varied physics programme, extending far beyond its core set of flavour physics measurements. This contribution summarises recent electroweak scale measurements and searches for exotic states in the dimuon final state.

1 Introduction

The LHCb detector is a single-arm forward spectrometer covering the pseudorapidity range 2–5 that is principally designed for the study of $b$- and $c$-hadrons, but which is well-suited to a wide variety of electroweak scale measurements and exotic searches that are highly complementary to other experiments at the LHC and elsewhere. Several features of the detector that are crucial for the core flavour physics programme, such as excellent vertex and momentum resolution, and a powerful trigger system, contribute to excellent jet tagging performance and sensitivity to low mass exotic states. LHCb operates at a substantially lower instantaneous luminosity than the general purpose detectors at the LHC, ATLAS and CMS, which results in a clean, low pile-up environment in which to search for physics beyond the Standard Model (SM).

2 Searches for exotic dimuon resonances

The excellent mass resolution and muon identification performance of the detector over a wide range of momenta make searches for exotic dimuon resonances an attractive prospect in LHCb data. Two results are presented in this section, one covering a wide mass range and another focused on the region in the immediate vicinity of the $\Upsilon$ resonances.

2.1 Dark photons

Several theories of physics beyond the SM propose new particles that could explain the nature of dark matter. Such theories typically include additional particles and dark boson-mediated forces, with a massive dark photon $A'$ being a popular feature. These dark photons typically do not couple directly to charged SM particles, but they can gain a weak coupling to the SM electromagnetic current via kinetic mixing. The strength of this coupling is suppressed by a factor $\varepsilon$ with respect to the SM photon. There is, therefore, a 2D parameter space to be probed.

The LHCb measurement presented here uses the dimuon final state and is based on a dataset corresponding to an integrated luminosity of $L = 1.6 \text{fb}^{-1}$ recorded at $\sqrt{s} = 13 \text{ TeV}$ during 2016. The flexible nature of the LHCb software trigger allows the full rate of prompt, i.e. consistent with originating at the primary $pp$ interaction vertex, dimuon candidates to be recorded for analysis, from the dimuon mass threshold up to the $Z^0$. The prompt-like dimuon spectrum is shown in Fig. 1. Backgrounds due to semileptonic decays of heavy-flavour hadrons,
and misidentified hadrons, are determined using fits to $\chi^2$-like variables relating to the dimuon vertex quality. Background due to off-shell photon decays $\gamma^* \rightarrow \mu^+\mu^-$ is irreducible and used to normalise the dark photon search in a data-driven manner. The various well-known quarkonia peaks labelled in Fig. 1 are excluded from the prompt-like search, which extends up to 70 GeV/$c^2$.

A search is performed for displaced dimuon vertices in the mass range [214, 350] MeV/$c^2$, in this case the background composition is somewhat different. At radii of more than 5 mm and low mass the background is dominated by real photon conversions in the vertex locator material. Such conversions are vetoed using a new method based on a large dataset of secondary hadronic interaction vertices\(^3\). At smaller radii the background is dominated by heavy flavour decays.

No significant excess is found, and the limits set are shown in Fig. 2. The prompt-like search sets world-best limits in the mass region [10.7, 70] GeV/$c^2$, while the displaced search probes a world-first region of parameter space. Future updates to these searches are expected to take advantage of the novel all-software trigger in the LHCb experiment upgrade for Run 3 of the LHC, and to extend to lower values of $m(A')$ by exploiting the dielectron channel\(^4,5\).

### 2.2 Search in vicinity of the $\Upsilon$ resonances

A dedicated search for dimuon resonances in the vicinity of the $\Upsilon(nS)$ resonances has also been performed, probing closer to, and in between, these peaks than the dark photon search\(^6\). The mass region that is probed in this analysis is illustrated in Fig. 3. No significant excess is seen,
but the first limits are set in the mass range [8.7, 11.5] GeV/c². Limits are set assuming that the produced resonance is either a scalar or a vector boson.

3 \( \bar{t}t \) production

Top quark physics forms an important part of the electroweak scale physics programme at LHCb, and is an excellent example of an area of study where the forward acceptance of the LHCb detector has several advantages with respect to the central region instrumented by ATLAS and CMS. For example, top quark cross-sections can provide important constraints on the large-x gluon PDF, with the forward kinematic region being particularly sensitive. The forward region also provides a greater fraction of events with quark-initiated production than central detectors, enhancing the size of \( \bar{t}t \) asymmetries visible at LHCb.

Carrying out such measurements at LHCb presents several challenges relating to the small acceptance, low luminosity and lack of missing energy measurement. Despite these challenges, \( t \bar{t} \) and \( \bar{t}t \) production\(^7,8\) have previously been observed at LHCb using data recorded at \( \sqrt{s} = 7 \) TeV and 8 TeV.

The step to \( \sqrt{s} = 13 \) TeV for Run 2 of the LHC has increased the LHCb-visible cross sections for top quark processes by an order of magnitude, bringing new channels into statistical reach. The new result presented here is a measurement of \( \bar{t}t \) production at \( \sqrt{s} = 13 \) TeV using the \( e\mu b \) final state\(^9\) and an integrated luminosity of \( L = 2 \) fb\(^{-1} \). This is a very pure final state, as the second lepton suppresses \( W + b \bar{b} \) production and the opposite-flavour leptons suppress \( Z^0 + b \bar{b} \). The signal purity is illustrated in Fig. 4, and the fiducial cross section is calculated as

\[
\sigma_{\bar{t}t} = \frac{N - N_{\text{bkg}}}{L \cdot \epsilon} \cdot F_{\text{res}} = 126 \pm 19 \text{ (stat)} \pm 16 \text{ (syst)} \pm 5 \text{ (lumi)} \text{ fb}^{-1}. \quad (1)
\]

Figure 5 compares this result, and an extrapolation to the full cross section, with SM predictions at next-to-leading order. The measured cross sections are compatible with these predictions.

4 \( Z^0 \to b \bar{b} \)

The final measurement discussed in these proceedings is the first observation of \( Z^0 \to b \bar{b} \) production in the forward region\(^10\). This measurement is an important validation of the LHCb jet reconstruction and \( b \)-tagging performance. Two \( b \)-tagged jets are reconstructed, with a third balancing jet also reconstructed to help control the QCD background and define signal and
control regions using a multivariate technique. The background-subtracted signal distribution is shown in Fig. 6. The signal is observed with a statistical significance of 6σ and the measured cross section is found to be compatible with SM predictions at next-to-leading order.

5 Conclusions

LHCb has a broad and exciting programme of electroweak and exotic measurements, which are typically still statistically limited and will benefit significantly from further Run 2 updates and, crucially, from the LHCb upgrade ahead of Run 3 of the LHC.

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