PROCEEDINGS OF SCIENCE

Search for b-associated Z' in the dimuon final state at CMS

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After finding the Higgs boson, hints at new physics at the LHC are scarce. An exception are the B-anomalies found by LHCb in R_{K} and R_{K^*} measurements, combining to a 4 sigma deviation from the SM. A possible explanation of this excess might be a new heavy neutral gauge boson Z$'$ with flavour-conserving couplings to second and third generation leptons, as well as third generation quarks, in addition to a flavour-violating b-s coupling. These proceedings cover search strategies and challenges for such a hypothetical particle in the dimuon channel at CMS.

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1. Introduction

Hints at physics beyond the standard model of particle physics are scarce. After the discovery of a Higgs boson that so far is consistent with a single standard model (SM) particle without anomalous couplings, only the neutrino sector that cannot be probed directly at the LHC has clear signs of beyond the standard model (BSM) physics. An exception to this void of BSM evidence are anomalies in the heavy flavour sector as probed by Belle or LHCb. These might point the way towards physics models which can be probed at the Large Hadron Collider (LHC) general purpose experiments.
These proceedings will cover the model of a new heavy neutral gauge boson Z' with non-universal couplings that introduce a flavour-changing neutral current (FCNC), the phenomenology of such a model including how to peruse associated bottom jets to distinguish this model from SM backgrounds, as well as current search exclusions and the expected power of a specialized search for such a model.

2. B-flavour anomalies with lepton universality violation

In particular, these proceedings will cover the deviations from the SM expectation in the variables $R_K = \left(\frac{\mathscr{N}_{K^+\mu^+\mu^-}}{\mathscr{N}_{K^+e^+e^-}}\right)\left(\frac{\mathscr{N}_{J/\psi(e^+e^-)K^+}}{\mathscr{N}_{J/\psi(\mu^+\mu^-)K^+}}\right) \times \left(\frac{\varepsilon_{K^+e^+e^-}}{\varepsilon_{K^+\mu^+\mu^-}}\right)\left(\frac{\varepsilon_{J/\psi(\mu^+\mu^-)K^+}}{\varepsilon_{J/\psi(e^+e^-)K^+}}\right)$ and
$R_{K^{*0}} = \frac{\mathscr{B}(B^0 \to K^{*0}\mu^+\mu-)}{\mathscr{B}(B^0 \to K^{*0}J/\psi(\to\mu^+\mu^-))} \Big/ \frac{\mathscr{B}(B^0 \to K^{*0}e^+e^-)}{\mathscr{B}(B^0 \to K^{*0}J/\psi(\to e^+e^-))}$. SM diagrams are due to the lack of FCNCs only possible in higher order diagrams, as shown in Fig. 1 and 2 for the case of R_K.

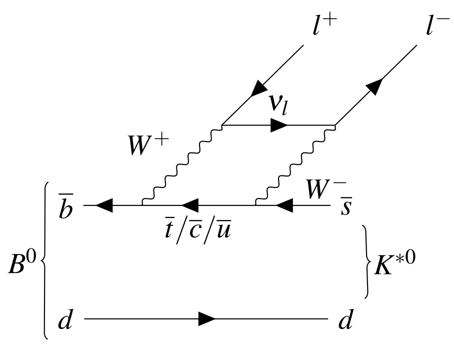

Figure 1: Box diagram

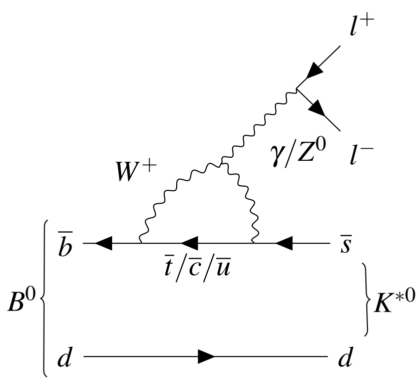

Figure 2: Penguin diagram

LHCb reports excesses in both R_{K} [1] and R_{K^*} [2] that reach a level of about 4σ in combination [3]. One possible explanation of this excess could be a new heavy gauge boson Z' introducing an FCNC.

3. A new heavy gauge boson Z' with non-universal couplings and flavour violation?

The minimal amount of couplings to explain the B anomalies as currently presented necessitate a coupling to muons g_μ, a flavour-preserving coupling to bottom quarks g_b, and a flavour-violating coupling between bottom and strange quarks $g_b\delta_{bs}$ [4].

Stringent limits on low mass Z' from LEP assume SM-like couplings to first and second generation quarks and first generation leptons while concurrent searches focus on similar assumptions. Instead requiring only third generation flavour-conserving couplings severely weakens current limits, still fits the requirements for an explanation of the B anomalies, and raises some decidedly non-SM like qualities of many events containing such Z'.

3.1 Associated bottom-jet multiplicity

The main distinguishing feature of this kind of Z' model is the number of associated bottom jets that can be tagged and used to distinguish signal from SM backgrounds. The bottom parton distribution function (PDF) contribution being small increases the relative contribution of gluon splittings to the production cross section of this kind of Z' model. While direct production (Fig. 3) is still dominant, b-associated production modes as shown in Fig. 4 and 5 are abundant.

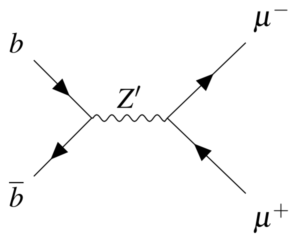

Figure 3: direct production

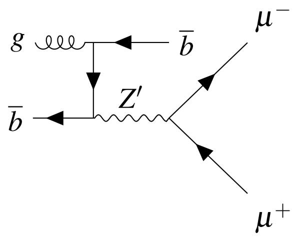

Figure 4: one associated bottom jet production

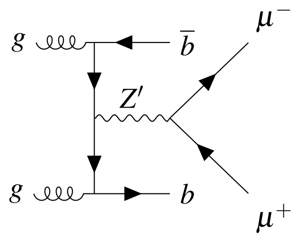

Figure 5: two associated bottom jets production

For a medium b-tag requirement and $p_T(\text{jet}) \geq 30\,\text{GeV}$, the rate of [0/1/2] associated b-tagged jets is [80.1%/18.5%/1.5%] for a 200 GeV Z' and [71.8%/25.1%/3.0%] for a 500 GeV Z'. These associated bottom jets are both central and soft, so lowering the requirement on transverse momentum even further increases acceptance significantly, e. g. [74.0%/23.8%/2.1%] for a 200 GeV Z' and a requirement of $p_T(b) \geq 20\,\text{GeV}$.

3.2 Phenomenological differences to standard model backgrounds

The associated bottom jets can be used to make stringent selection requirements that distinguish this kind of specialized analysis from an inclusive dilepton analysis. Requiring at least two jets, at least one of them passing a medium bottom tag requirement, and two opposite sign muons as a preselection, the following three additional requirements can be used, as shown in [4].
Fig. 6 demonstrates the effect of requiring the maximum mass out of the most similar in mass pair of top mass hypotheses (jet-muon pair masses) to be greater than 170 GeV.
In this signal model, there is no missing transverse energy from any sources but mismeasurements. To make a requirement on $E_{\mathrm{T}}^{\mathrm{miss}}$ invariant in as wide a range of possible Z' masses as viable, the missing transverse energy is normalized to the dimuon mass and required to be less than 0.2 to reduce $t\bar{t}$ contamination, as shown in Fig. 7.
The final requirement is the scalar sum of the leading two jet momenta H_{T} minus the scalar sum of the leading two lepton momenta L_{T} (Fig. 8). For SM-like events, this difference is more likely to be in favour of larger hadronic momenta, unlike the soft central bottom jets originating from gluon

splitting in the signal model.
All plots in Fig. 9 are shown after preselection on Delphes level only with a CMS [5] detector card and obtained from the authors of [4].

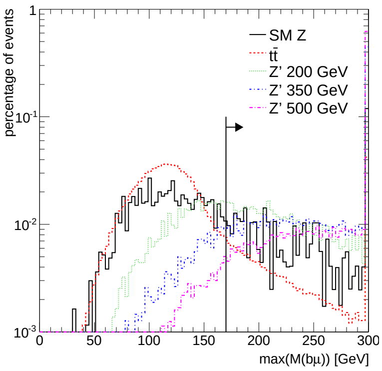

Figure 6

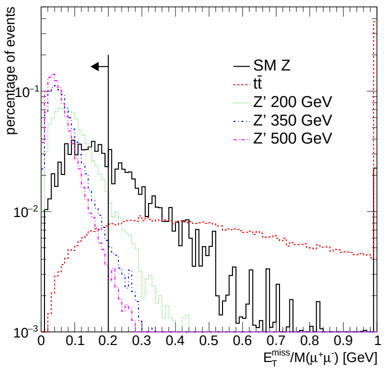

Figure 7

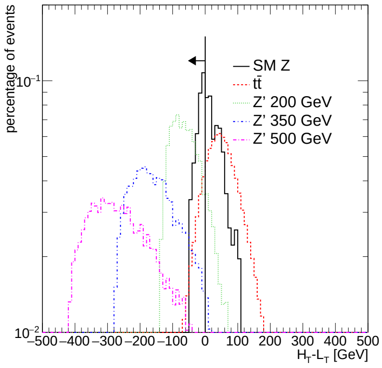

Figure 8

Figure 9: From left to right: Larger mass of the most similar pair of bottom-muon pair masses, missing transverse energy normalized to dimuon mass, sum of scalar leading two jet momenta minus sum of scalar leading two lepton momenta. Selection requirements are indicated by a black bar with an arrow denoting the direction of passing events. Obtained from the authors of [4].

4. Search prospects

Currently, only inclusive analyses are conducted, and only the dimuon channel is sensitive to this kind of Z' model. Reinterpreting the current CMS limits of [6] and comparing them to Delphes simulations, [4] claims the current exclusion limits in Fig. 10 to be as denoted in green, and the future prospects of a specialized search at different integrated luminosities to be as denoted in red.

As shown, current inclusive limits are equal or better, especially at large flavour-violating values where the cross section increases at the same time as the relative amount of associated bottom jets decreases in favour of direct production via the strange pdf or associated strange jets, for a 350 GeV Z' hypothesis. Improvements can still be reached by going to lower masses closer to the SM Z peak where DY background suppression by additional selection requirements can significantly improve exclusion power, as can be seen for the 200 GeV Z' hypothesis.
A specialized search for b-associated Z' is therefore beneficial and, including some improvements as including a single associated bottom search bin.

References

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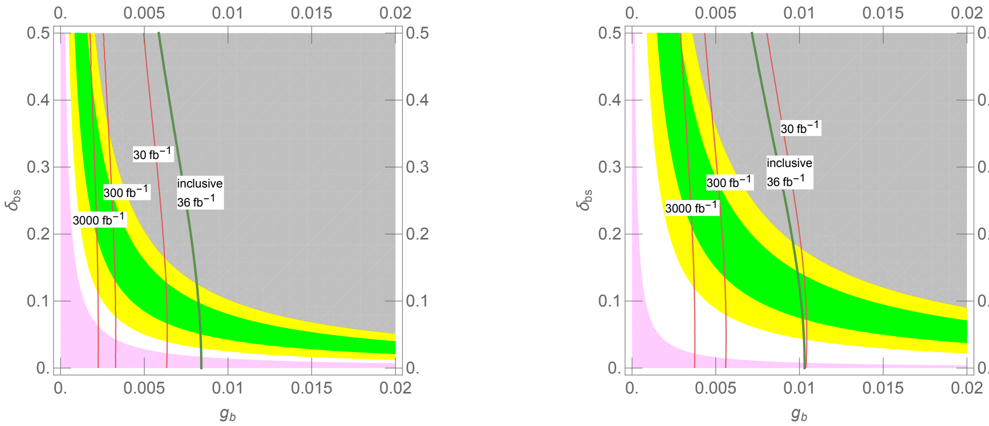

Figure 10: From left to right: Exclusion limit reinterpretation of [6] and projection for a 200 GeV and a 350 GeV mass Z' respectively as presented in [4]. The grey-shaded region is excluded as the effect would be too large to explain the current B anomalies. The pink region is excluded by neutrino trident limits on g_μ.
The green line indicates the reinterpretation of current CMS inclusive dimuon limits while the red lines denote the prospective power of a specialized search for b-associated Z' at different integrated luminosities.

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