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Exotic searches in LHCb

Veerle A. M. Heijne[*] [†]
Affiliation: Nikhef
E-mail: vheijne@nikhef.nl

The LHCb experiment has performed a multitude of exotic searches that are either unique, or complementary to the b-factories and the general purpose detectors at the LHC. A selection of results from exotic searches in LHCb are summarised, including the search for Majorana neutrinos, lepton and flavour violating τ decays, Higgs decay to τ leptons, and Higgs decay to long-lived exotic particles.

The 15th International Conference on B-Physics at Frontier Machines at the University of Edinburgh, 14 -18 July, 2014
University of Edinburgh, UK

[*]Speaker.
[†]On behalf of the LHCb collaboration

PoS(Beauty2014)039

The LHCb experiment is a single arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$. It has performed a multitude of exotic searches that are either unique, or complementary to the b-factories and the general purpose detectors at the LHC. The advantages of LHCb over other experiments are its low trigger thresholds and flexible software trigger, its particle identification and excellent displaced vertex reconstruction. Searches for Majorana neutrinos, lepton and baryon flavour violating τ decays, Higgs decay to τ leptons and Higgs decay to long-lived exotic particles are summarised in the following paragraphs. Updates of these searches with the 2011 and 2012 data are underway, with increased luminosity and improved analysis techniques.

1. Majorana neutrinos

The observation of neutrino oscillations implies that neutrinos are massive and that lepton flavour conservation is violated. The relatively low neutrino masses could be explained by adding Majorana mass terms to the Standard Model that introduce new right-handed neutrinos at a high energy scale. The existence of these Majorana neutrinos can be experimentally tested via lepton-number violating processes. The decay $B^- \to \pi^+\mu^-\mu^-$ is the most sensitive B meson decay in the neutrino mass range up to 5 GeV [1]. Prior limits on this decay were set by CLEO [2], Babar [3] and LHCb [4].

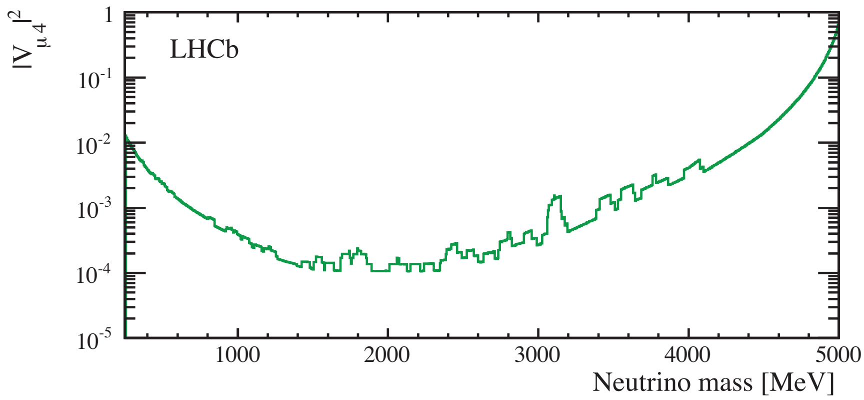

Figure 1: Upper limit on $|V_{\mu 4}|^2$ at 95% CL, as a function of m_N [5].

An update of the LHCb analysis with 1 fb^{-1} of data collected at $\sqrt{s} = 7$ TeV and 2 fb^{-1} at 8 TeV measures this decay for neutrinos with a lifetime up to 1 ns [5]. Events are triggered on a muon or di-muon with $p_T > 1.64$ GeV at the hardware level, and on a vertex with a muon and displaced tracks at the software level. Two different selections are used, one for short-lived (< 1 ps) and one for long-lived (< 1 ns) neutrinos, that exploit the separation of the $(\pi\mu)$ neutrino decay vertex from the B^-. The efficiency of the selection is dependent on the neutrino mass and lifetime. The background consists of a peaking B^- to charmonium and a flat combinatoric background. The background is subtracted using the normalisation channel $B^- \to J/\psi(\mu^+\mu^-)K^-$. After selection, no candidates are observed in the signal window around the B^- mass. First, a model-independent upper limit is set as a function of neutrino mass, for various lifetimes. For a lifetime of $\tau_N = 1$ ps, the analysis results in an upper limit of $\mathscr{B}(B^- \to \pi^+\mu^-\mu^-) < 4.0 \times 10^{-9}$ at 95% CL, which is the best limit to date. Second, this is translated into a model-dependent limit on the coupling of a single fourth-generation Majorana neutrino to muons, $|V_{\mu 4}|^2$, which is extracted using the formalism in Ref. [1]. Figure 1 shows the resulting limit on $|V_{\mu 4}|^2$ as a function of the neutrino mass.

2. LFV and BNV in τ decays

The observation of neutrino oscilations means that lepton flavour violation is expected at low rate ($\mathscr{B} < 10^{-40}$) [6]. However, the rate may be enhanced by new physics. LHCb performed a search for the lepton and baryon number violating decays $\tau^- \to \mu^-\mu^-\mu^+$ (LFV), $\tau^- \to \bar{p}\mu^-\mu^+$ (LFV, BNV) and $\tau^- \to p\mu^-\mu^-$ (LFV, BNV) on a data set of 1 fb^{-1} collected in 2011 at $\sqrt{s} =$ 7 TeV [7]. The calibration channel for the analysis is $D_s^- \to \phi(\mu^+\mu^-)\pi^-$, and the separation between signal and background is made using a likelihood for the decay topology, particle identification and τ mass. The number of observed events in the signal mass window is compatible with the background expectation, as illustrated in Fig. 2. The resulting limit on the lepton flavour violating decay is $\mathscr{B}(\tau^- \to \mu^-\mu^-\mu^+) < 8.0\ (9.8) \times 10^{-8}$ at 90% (95%) CL, which is the first result at a hadron collider. Additional upper limits are set on the decays to protons and muons: $\mathscr{B}(\tau^- \to \bar{p}\mu^-\mu^+) < 3.3\ (4.3) \times 10^{-7}$ and $\mathscr{B}(\tau^- \to p\mu^-\mu^-) < 4.4\ (5.7) \times 10^{-7}$. The result for the decay to three muons has in the meantime been updated with the full data set to $\mathscr{B}(\tau^- \to \mu^-\mu^-\mu^+) < 4.6\ (5.6) \times 10^{-8}$ [8].

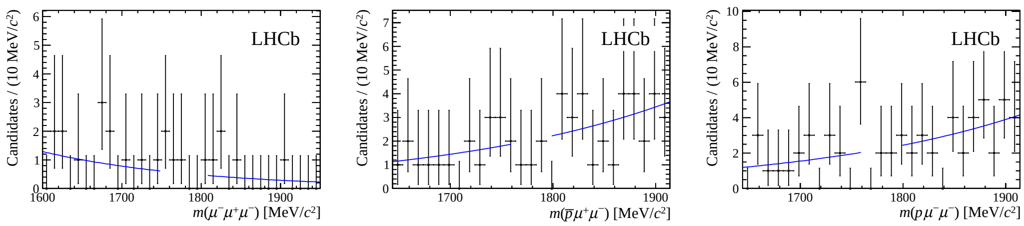

Figure 2: Invariant mass distributions and fits to the mass sidebands in data for candidates in the merged likelihood bins that contain the highest signal probabilities. Left: $\mu^-\mu^-\mu^+$ candidates, middle: $\bar{p}\mu^-\mu^+$ candidates, and right: $p\mu^-\mu^-$ candidates [7].

3. Higgs decay to $\tau\tau$

As an extension of the $Z \to \tau\tau$ cross-section measurement [9], LHCb presented a search for a neutral Higgs decaying to $\tau\tau$ using 1 fb^{-1} of data collected in 2011 [10]. The two τ leptons in turn decay to either one of the final states $\mu\mu$, μe, μh and eh. The background consists of $Z \to \tau\tau$, hadronic processes (QCD), electroweak where one τ decay product comes from a W or Z boson and the other comes from the underlying event, $t\bar{t}$, WW and $Z \to ll$. The mass distributions of the background, data and superimposed signal are shown in Fig. 3. The model-independent upper limit on the Standard Model Higgs to $\tau\tau$ decay ranges between 8.6 and 0.7 pb for m_H between 90 and 250 GeV, as shown on the left of Fig. 4. In order to compare to other results, the model-dependent limit as a function of $\tan\beta$ is shown on the right, giving $\tan\beta$ in the MSSM between 34 and 70 for m_H between 90 and 140 GeV.

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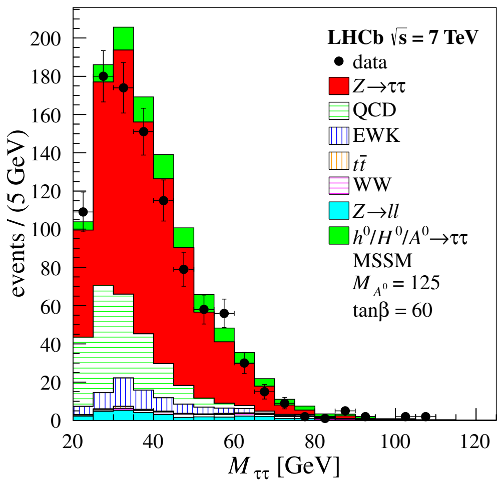

Figure 3: Invariant mass distributions for $H \to \tau\tau$ candidates. The $Z \to \tau\tau$ background (solid red) is normalised to the theoretical expectation. The QCD (horizontal green), electroweak (vertical blue), and Z (solid cyan) backgrounds are estimated from data. The $t\bar{t}$ (vertical orange) and WW (horizontal magenta) backgrounds are estimated from simulation and generally not visible. The contribution that would be expected from an MSSM signal for $M_{A^0} = 125$ GeV and $\tan\beta = 60$ is shown in solid green [10].

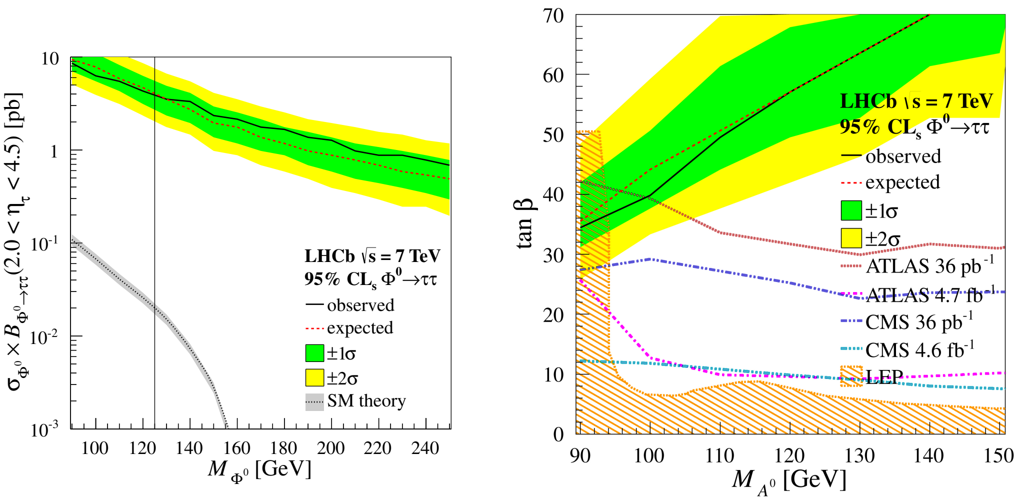

Figure 4: Left: model-independent limit on the cross-section times branching fraction for a Higgs boson decaying to two tau leptons at 95% CL, as a function of M_{Φ^0}. The background-only expected limit (dashed red) and $\pm 1\sigma$ (green) and $\pm 2\sigma$ (yellow) bands are compared with the observed limit (solid black) and the expected SM theory (dotted black) with uncertainty (grey). Right: model-dependent 95% CL limit on $\tan\beta$ for a MSSM model as a function of M_{A^0}, compared to ATLAS, CMS and LEP results. From [10].

4. Long-lived heavy exotic particles

A range of new-physics models, such as Hidden Valley [11] or mSUGRA with R-parity violation [12] predict the existence of exotic heavy long-lived particles. A search for a Higgs decaying through a neutralino to Standard Model particles was performed in LHCb with 39 pb^{-1} of 2010 data at $\sqrt{s} = 7$ TeV [13]. Events are triggered with a software trigger requiring at least two displaced vertices. Offline, the vertices are required to have at least six tracks and a mass above 6 GeV. The selected candidate pairs are consistent with pure $b\bar{b}$ background, as shown in Fig. 5. After requiring a minimal opening angle $\Delta\phi$ between the two candidates, no events survive. The resulting upper limit for neutralinos with a mass of 48 GeV and 10 ps lifetime, produced from a Higgs with a mass of 114 GeV, is $\mathscr{B}(h^0 \to \chi_1^0\chi_1^0) < 32$ pb at 95% CL. LHCb can set limits for similar models in a region of low lifetime and low mass that has so far been inaccessible to ATLAS and CMS.

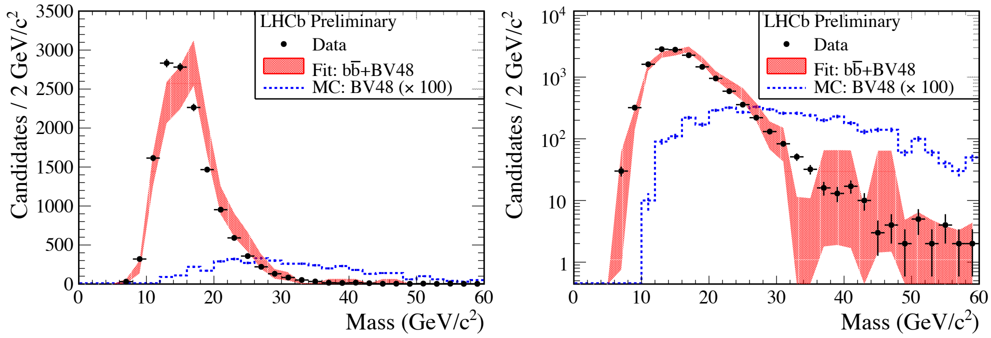

Figure 5: Invariant mass distribution of the Higgs-like candidates in data before the $\Delta\phi$ selection (black points). The result of a likelihood fit to the data using the background $b\bar{b}$ simulated events is shown in red, with the band reflecting the statistical precision of the model. The blue-dotted line indicates the simulated signal component multiplied by 100 [13].

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