Searches for long lived heavy particles at LHCb

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Abstract

Its forward acceptance and excellent vertex resolution allow LHCb to perform competitive searches for heavy particles beyond the Standard Model. A search for Hidden Valley particles with the LHCb detector using 35.8 pb^{-1} of data at $\sqrt{s} = 7$ TeV is reported and prospects for searches of the stau particle presented.

Keywords: New physics, Supersymmetry, Hidden Valley, LHCb

1. Introduction

Despite its experimental success, the Standard Model (SM) has its limitations. In particular, it cannot explain the observed matter-antimatter asymmetry and the inferred presence of dark matter and dark energy. Efforts to solve these issues have resulted in a large variety of new models. Many of them predict the existence of long-lived heavy particles (LLP) that decay into SM particles.

In the context of minimal supergravity (mSUGRA) with small R-Parity and baryon number violating couplings, the lightest neutralino $\tilde{\chi}_1^0$ is unstable and decays into three quarks [1]. Such processes are generically called BV in the following. The Hidden Valley (HV) model predicts the existence of a new non-abelian gauge group consisting of light particles with "Hidden Valley" charge, or v-particles, hidden at large energy scales [2]. The hidden region may be accessible at the LHC, through the decay of hidden particles into SM particles through heavy mediators. For instance, a SM-like Higgs boson may decay as $h^0 \rightarrow \pi_v \pi_v$, where π_v is a new v-particle that decays mostly to a $b\bar{b}$ pair, as shown in Figure 1.

Another example is the Minimal Gauge Mediated Supersymmetry Breaking (mGMSB) which proposes that its next-to-lightest supersymmetry particle, the stau $\tilde{\tau}$, is charged, massive and long-lived [3], allowing for direct searches.
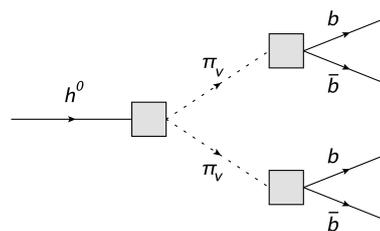

Figure 1: Diagrammatic scheme of the decay $h^0 \rightarrow \pi_v \pi_v \rightarrow b\bar{b}b\bar{b}$ in the Hidden Valley model.

2. The LHCb detector

LHCb [4] is one of the four main experiments at the LHC, placed at CERN. It is a single-arm forward spectrometer covering the pseudorapidity range $2 < \eta < 5$ consisting of a vertex locator, tracking system and magnetic field, ring imaging Cherenkov detectors, electromagnetic and hadronic calorimeters and muon system.

The vertex locator (VELO) is designed for the detection of primary and displaced secondary vertices (SV). Together with the flexible LHCb trigger, optimized to select events with displaced vertices, it provides an ideal scenario to search for long-lived particles.

Photon, electron and hadron candidates are identified by a calorimeter system consisting of scintillating-pad and preshower detectors, an electromagnetic calorimeter (ECAL) and a hadronic calorimeter (HCAL), with an ECAL resolution of $10\%/\sqrt{E[\text{GeV}]} \oplus 1\%$.

Different types of charged particles are distinguished using the information from two ring-imaging Cherenkov (RICH) detectors. RICH 1 covers the low and intermediate momentum region $2 - 40$ GeV/c while RICH 2 covers the high-momentum region $15 - 100$ GeV/c.

Muons are identified by a system composed of alternating layers of iron and multiwire proportional chambers. The overall muon identification efficiency is 97% with a $1 - 3\%$ pion mis-identification probability.

3. Search for Higgs-like bosons decaying into long-lived exotic particles

A search for a Higgs-like boson decaying into a pair of Hidden-Valley particles, π_v, or neutralinos, $\tilde{\chi}_1^0$, has been performed in the $b\bar{b}b\bar{b}$ final state using 35.8 pb^{-1} of LHCb data at $\sqrt{s} = 7$ TeV [5]. The approximate sensitivity range of this analysis covers long-lived particle lifetimes (τ_{LLP}) from 3 to 25 ps, masses (m_{LLP}) between 30 and 55 GeV/c^2, and parent Higgs masses (m_h) of 100 to 125 GeV/c^2. Two models, with different flavour structure, have been used for this analysis, the HV [2] and the BV [1] models.

All tracks with VELO information are used to reconstruct primary vertices (PV) and secondary or LLP vertices. A loose selection is applied using the features of the signal: each LLP candidate vertex is required to have at least four forward tracks, no backward tracks, an invariant mass reconstructed from the tracks greater than 3 GeV/c^2 (assuming the pion mass for each track) and a distance to the beam-line greater than 0.4 mm.

A total number of 58,552 events pass the above selection criteria. The invariant mass distribution of the candidates is shown in Figure 2 and is found to be compatible with $b\bar{b}$ events only.

To fully suppress this background, a tighter selection is applied. In the final selection at least six tracks and an invariant mass larger than 6 GeV/c^2 for each LLP are required. The LLP vertex position error is required to be $\sigma_r < 0.05$ mm and $\sigma_z < 0.24$ mm. These requirements are chosen to remove all the SM background, while optimizing the Higgs signal detection efficiency. The requirements for the both loose and tight selections are shown in table 1.

After the tight selection, no candidates are found and 95% CL upper limits are set for the production cross-section. Figure 3 shows the cross-section upper limit for $\tau_{LLP} = 10$ ps and for different values of m_{LLP} and m_h using the BV model.
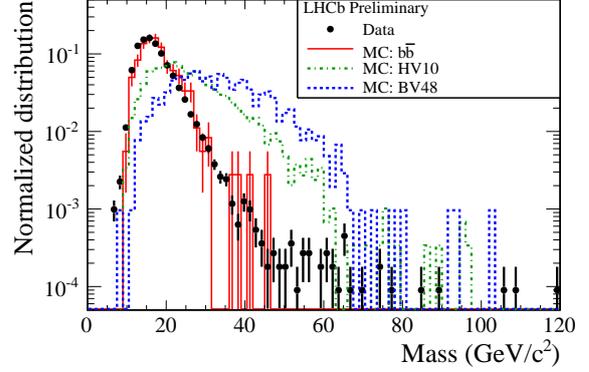
Figure 2: Invariant mass distribution of candidates after the loose selection. Black dots represent the data points, red solid line the MC distribution of $b\bar{b}$ events, blue dashed the MC distribution of events generated with the BV48 model and green dot-dashed the MC distribution of events generated with the HV10 model.

Table 1: Requirements of loose and tight selections.

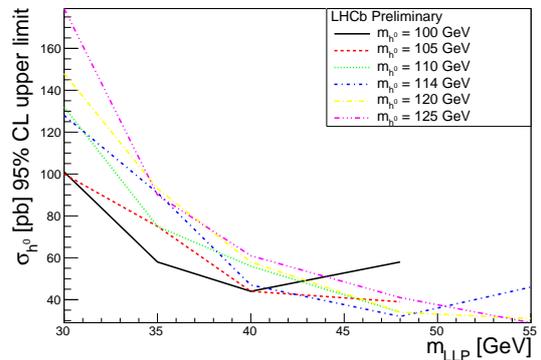| Variable	Loose	Tight	Units
n Tracks SV	≥ 4	≥ 6	
m_{LLP}	≥ 3	≥ 6	GeV/c^2
Beam-line d	> 0.4	> 0.4	mm
SV σ_r	-	< 0.05	mm
SV σ_z	-	< 0.24	mm

Figure 3: Production cross-section upper limits at 95% CL for $\tau_{LLP} = 10$ ps and for different values of m_{LLP} and m_h using the BV model.
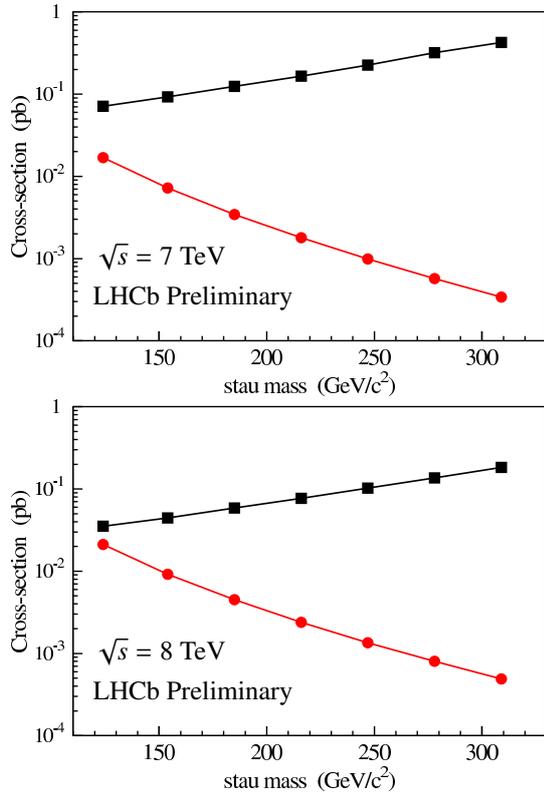
Figure 4: 95% CL upper limits on the cross-sections for stau pair production (black squares) and corresponding theoretical predictions (red dots) as a function of the stau mass for pp collisions at $\sqrt{s} = 7$ (top) and 8 (bottom) TeV.

4. Stau search prospects

A search for stau pairs with a stau mass ranging from 124 to 309 GeV/c^2 has been performed using the full LHCb dataset of 3 fb^{-1} recorded at $\sqrt{s} = 7$ and 8 TeV [6].

On one hand, staus are expected to behave like very massive muons in matter, releasing energy by ionization in the detector material. The triggering signal is therefore the detection of a muon candidate. On the other hand, several properties differentiate them from muons:

- High momentum muons can radiate in matter while this effect is very small for staus at LHC energies; hence, their energy deposition of staus in thick calorimeters (ECAL, HCAL) is small compared to the muons.

- The stau momentum thresholds to trigger the Cherenkov effect in the two RICH detectors are much higher than for muons.

- The difference in the masses of the staus and of the muons leads to a difference between the energies they leave by ionization and excitation of the silicon structure of the VELO.

Consequently, in the absence of a time-of-fight measurement in LHCb the identification of the staus relies on the amount of energy deposited in the VELO and calorimeters and on the threshold effect in the two RICH detectors, the later providing the main discrimination power. A neural network is used to classify candidates taking into account these properties.

No evidence has been observed for the production of such long-lived states and limits on the di-stau production cross-section have been set as a function of the stau mass as shown in Figure 3.

5. Conclusions

The search for long-lived particles at LHCb has been presented.

Decays of $h^0 \to \pi_v \pi_v (\tilde{\chi}_1^0 \tilde{\chi}_1^0) \to b\bar{b}b\bar{b}$ have been studied using 35.8 pb^{-1} of LHCb data at $\sqrt{s} = 7$ TeV. No signal has been found and upper limits have been set to the production cross-sections using the HV and BV models.

Stau pairs with a stau mass ranging from 124 to 309 GeV/c^2 have been searched directly in the muon chambers using the full LHCb dataset of 3 fb^{-1} recorded at $\sqrt{s} = 7$ and 8 TeV. The amount of energy deposited in the VELO and calorimeters, and the threshold effect in the two RICH detectors has been used to separate them from muons. No signal has been found and upper limits have been set to the production cross-section as a function of the stau mass.

References

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