Study of the rare B_s^0 and B^0 decays into the $\pi^+\pi^-\mu^+\mu^-$ final state

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on behalf of the LHCb collaboration

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Motivation

- In the standard model (SM) $B_{(s)}^0 \to \pi^+\pi^-\mu^+\mu^-$ decays are governed by flavour changing neutral current $b \to d(s)$ transitions and are described by loop diagrams.
  - They are loop suppressed and can be sensitive to a possible non-SM effects.
- Similar to $B_{(s)}^0 \to J/\psi\pi^+\pi^-$, the $\pi^+\pi^-$ pairs are expected to be produced mainly from the $\rho(770)^0(f_0(980))$ resonance
- Current SM predictions for the $B_s^0 \to f_0(980)\mu^+\mu^-$ and $B^0 \to \rho(770)^0\mu^+\mu^-$ decays suffers from uncertainties in the calculation of hadronic matrix elements associated to the transitions.
- No experimental information exists to date.

$Br(B_s^0 \to f_0(980)\mu^+\mu^-)$	
$\left(5.21^{+3.23}_{-2.06}\right) \times 10^{-7}$	[PRD79,014013]
$\left(9.5^{+3.1}_{-2.6}\right) \times 10^{-8}$	[PRD81,074001]
$(1.67 \pm 0.61) \times 10^{-7}$	[PRD81,074001]
$(0.81 - 2.02) \times 10^{-8}$	[PRD80,016009]
$(0.63 - 3.37) \times 10^{-9}$	[PRD80,016009]
$Br(B^0 \to \rho(770)^0\mu^+\mu^-)$	
$\left(5.0^{+2.1}_{-2.6}\right) \times 10^{-8}$	[PRD56,5452]
$\left(8.6^{+3.4}_{-4.5}\right) \times 10^{-8}$	[PRD53,3672]

Table 1: Theoretical predictions for studied decays.

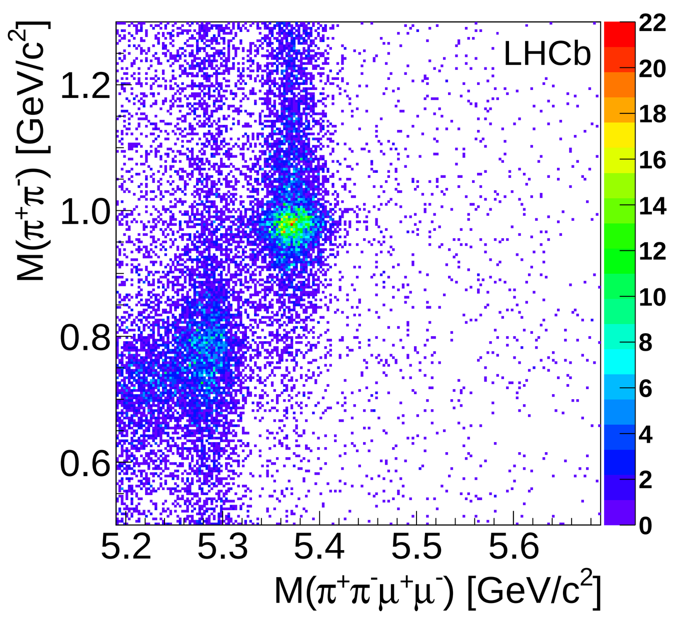

Figure 1: Distribution of the $\pi^+\pi^-$ mass versus the $\pi^+\pi^-\mu^+\mu^-$ mass. The accumulation of candidates around 5.37 GeV/c^2 represent $B_s^0 \to J/\psi\pi^+\pi^-$ decays; the candidates around 5.28 GeV/c^2 are $B^0 \to J/\psi\pi^+\pi^-$ decays, with an overlap of misidentified $B^0 \to J/\psi K\pi$ decays at lower masses

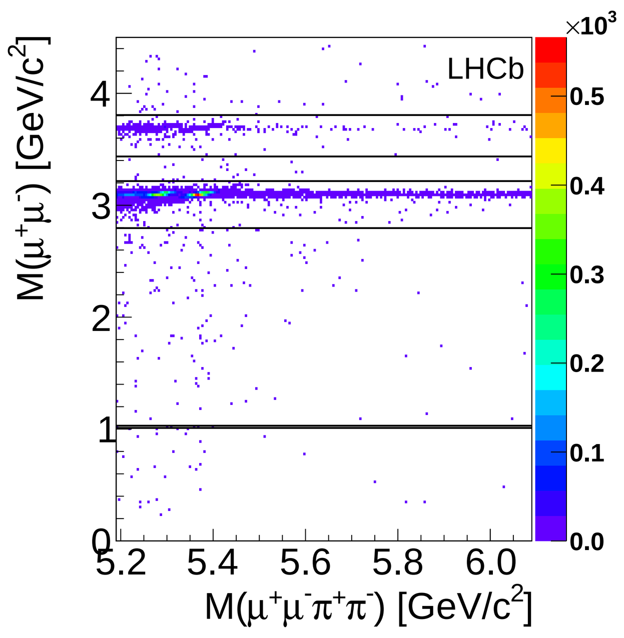

Figure 2: Distribution of the $\pi\pi\mu\mu$ mass versus the $\mu\mu$ mass. The regions of $\phi(1020)$, J/ψ and $\psi(2S)$ resiances are excluded in the singal sample. Candidates with the dimuon mass in the J/ψ region are used to form the control sample of $B_{(s)}^0 \to J/\psi\pi^+\pi^-$ decays.

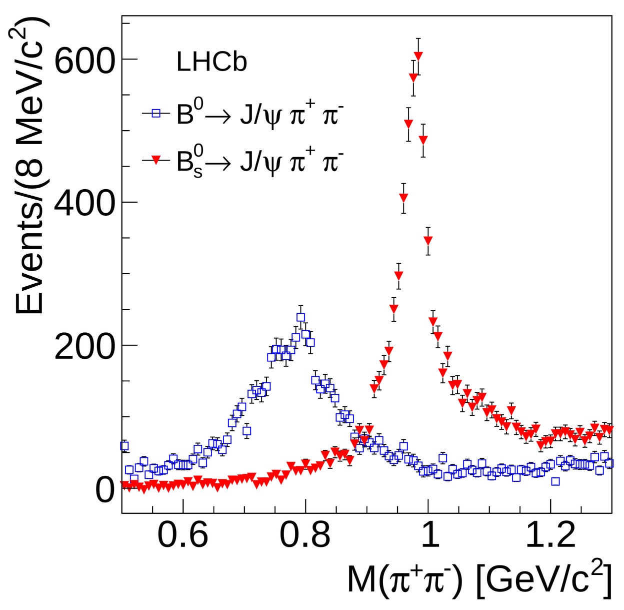

Figure 3: Background-subtracted dipion invariant mass distribution of $B_{(s)}^0 \to J/\psi\pi^+\pi^-$ decays in $[0.5, 1.3]\ \mathrm{GeV}/c^2$

Analysis strategy

We measure the branching fraction of $B_{(s)}^0 \to \pi^+\pi^-\mu^+\mu^-$ decays relative to that of the $B^0 \to J/\psi K^*(892)^0$ decay (normalisation channel):

$$\mathcal{R}_{d(s)} = \frac{Br(B_{(s)}^0 \to \pi\pi\mu\mu)}{Br(B^0 \to J/\psi K^*)} = \frac{N_{B_{(s)}^0 \to \pi\pi\mu\mu}}{N_{B^0 \to J/\psi K^*}} \times \frac{\epsilon_{B^0 \to J/\psi K^*}}{\epsilon_{B_{(s)}^0 \to \pi\pi\mu\mu}} \left(\times \frac{f_d}{f_s}\right)$$

- ϵ - selection efficiency, evaluated with simulations and control samples from data.
- $N_{B^0 \to J/\psi K^*}$ - number of observed events for the normalisation channel. Estimated from the fit of the $M_{K\pi\mu\mu}$ spectrum.
- $N_{B_{(s)}^0}$ - number of signal events. Estimated from the fit of the $M_{\pi\pi\mu\mu}$ spectrum.
- $J/\psi\pi\pi$ mass distribution was used to identify decays, which contribute to the $\pi\pi\mu\mu$ mass distribution.
- Use the full Run I sample collected by LHCb in 2011 ($\sqrt{s} = 7\,\mathrm{TeV}$) and 2012 ($\sqrt{s} = 8\,\mathrm{TeV}$).

Candidates selection

- Trigger on high p_T muons, and look for displaced vertexes
- Offline preselection:
  - require good quality tracks, cut on p_T and impact parameters, good quality secondary vertex produced by two muons and two pions candidates and separated from the pp interaction vertex.
  - Dipion mass in a range of $[0.5, 1.3]\ \mathrm{GeV}/c^2$ to include both $f_0(980)$ and $\rho(770)^0$ resonances (see figures 1,3)
- Multivariate selection to suppress combinatorial background, based on a BDT classificator
- PID selection combining information from RICH, calorimeters and muon stations:
  - require a good separation between the pion and kaon mass hypotheses for the two hadron tracks

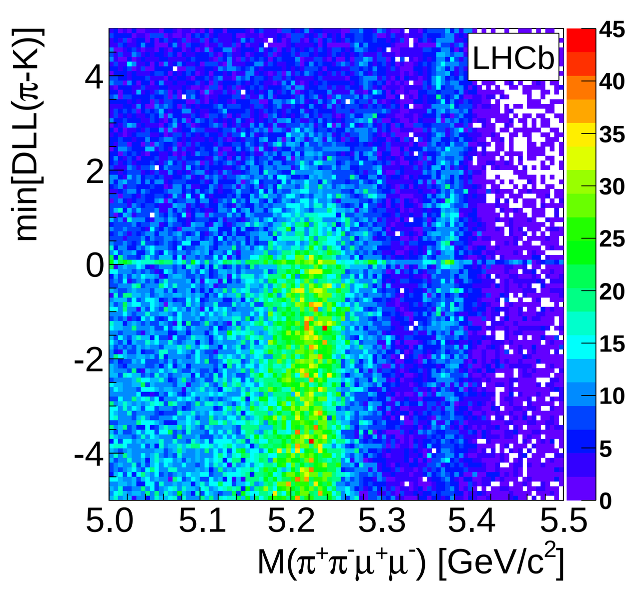

Figure 4: Distribution of DLL(π-K) versus the dipion mass. The DLL(π-K) is a PID variable used to distinguish pions from kaons. The accumulation of candidates in the region around 5.2 GeV/c^2 for DLL(π-K)< 1 is due to $B^0 \to J/\psi K^*(892)^0$, where the kaon is misidentified with a pion. The band around 5.37 GeV/c^2 is given by $B_s^0 \to J/\psi\pi^+\pi^-$; the band around 5.28 GeV/c^2 is due to $B^0 \to J/\psi\pi^+\pi^-$ decays candidates.

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Fit of $B_{(s)}^0 \to J/\psi\pi^+\pi^-$ and $B_{(s)}^0 \to J/\psi K\pi$ decay samples

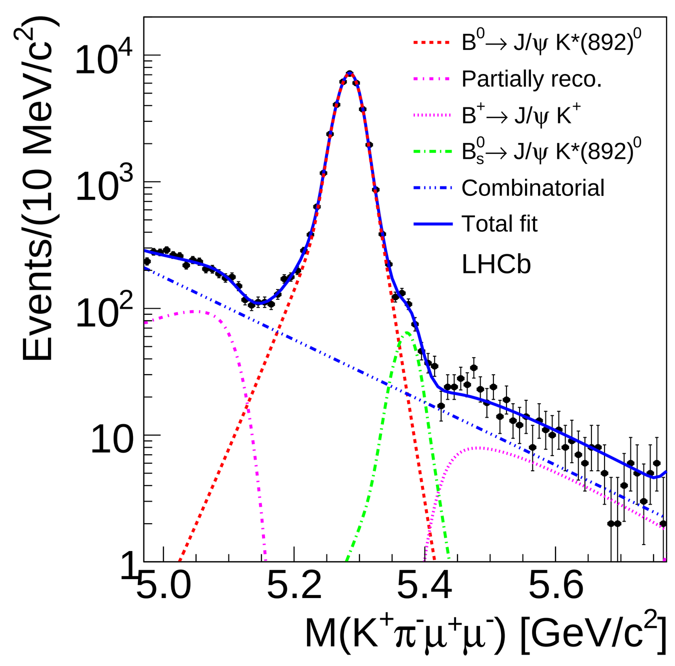

Figure 5: Fit of the $M_{K\pi\mu\mu}$ mass distribution of the normalisation decay $B^0 \to J/\psi K^*(892)^0$.

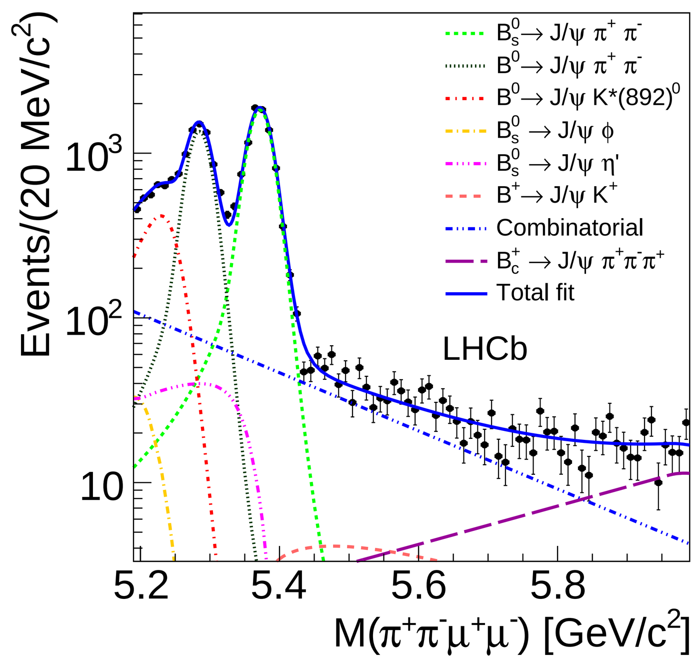

Figure 6: Fit of the $M_{\pi\pi\mu\mu}$ mass distribution of the control decays $B_{(s)}^0 \to J/\psi\pi^+\pi^-$.

Fit of signal decays sample

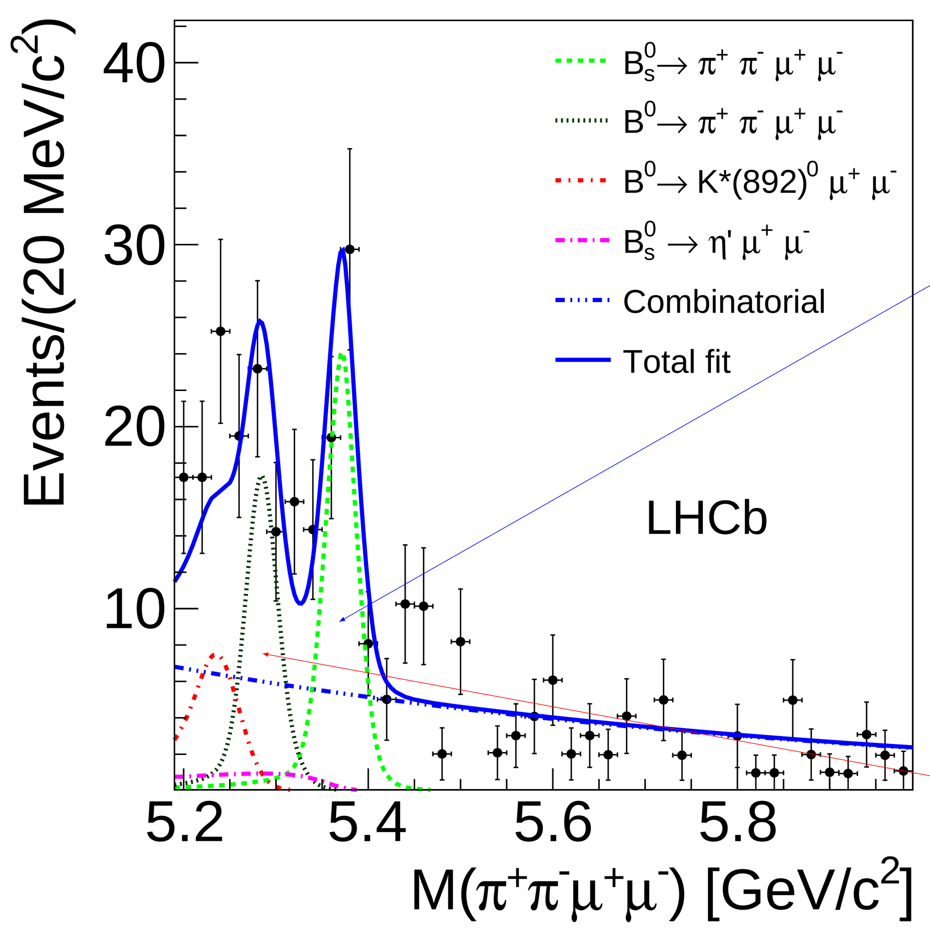

Figure 7: Fit of the $M_{\pi\pi\mu\mu}$ mass distribution of the $B_{(s)}^0 \to \pi^+\pi^-\mu^+\mu^-$ signal candidates

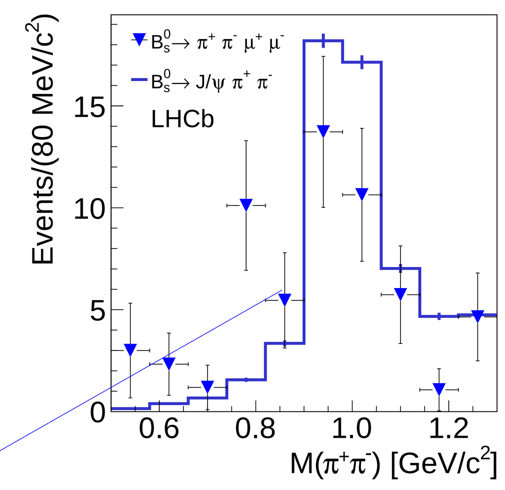

Figure 8: Background-subtracted $M_{\pi^+\pi^-}$ mass distribution of $B_s^0 \to \pi^+\pi^-\mu^+\mu^-$ decays (data points), compared with $B_s^0 \to J/\psi\pi^+\pi^-$ data (solid line)

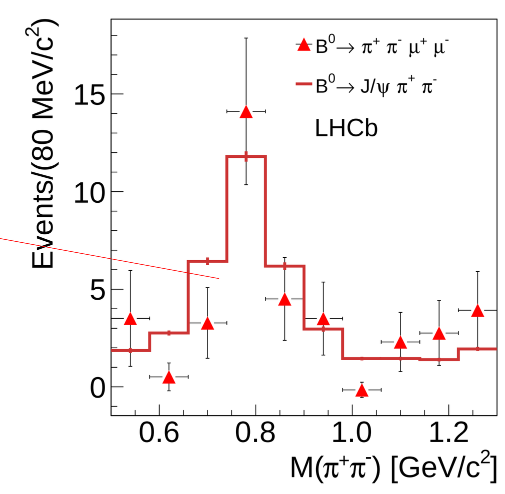

Figure 9: Background-subtracted $M_{\pi^+\pi^-}$ mass distribution of $B^0 \to \pi^+\pi^-\mu^+\mu^-$ decays (data points), compared with $B^0 \to J/\psi\pi^+\pi^-$ data (solid line)

Systematics

The total uncertainty is statistically dominated. For the B_s^0 decays, the largest contribution is due to the uncertainty on the ratio of the fragmentation probabilities of B_s^0 and B^0 mesons (f_s/f_d). Other relevant contributions to systematic uncertainties are given by the uncertainties on the efficiencies estimation, on the yield of the normalisation decay, and on the modelling of the combinatorial background and of the signal shape.

Source	$\sigma(\mathcal{R}_s)\ [10^{-3}]$	$\sigma(\mathcal{R}_d)\ [10^{-3}]$
Shape of misidentified decays	0.003	0.004
Partially reconstructed decays	0.003	0.004
Combinatorial background	0.029	0.014
Signal shapes	0.020	0.014
Efficiencies	0.061	0.013
Normalisation decay yields	0.055	0.014
f_s/f_d	0.093	–
Quadratic sum	0.130	0.028

Table 2: Summary of systematic uncertainties on $\mathcal{R}_s$ and $\mathcal{R}_d$.

Results: first observation and first evidence.

- The first observation of the rare decay $B_s^0 \to \pi^+\pi^-\mu^+\mu^-$ and the first evidence of the rare decay $B^0 \to \pi^+\pi^-\mu^+\mu^-$ are obtained.
- About 55 $B_s^0 \to \pi^+\pi^-\mu^+\mu^-$ decays and 40 $B^0 \to \pi^+\pi^-\mu^+\mu^-$ decays are found with significances of 7.3σ and 4.8σ, respectively.
- Branching fractions are measured to be:
  - $\mathcal{B}(B_s^0 \to \pi^+\pi^-\mu^+\mu^-) = (8.6 \pm 1.5\,(\mathrm{stat}) \pm 0.7\,(\mathrm{syst}) \pm 0.7\,(\mathrm{norm})) \times 10^{-8}$
  - $\mathcal{B}(B^0 \to \pi^+\pi^-\mu^+\mu^-) = (2.11 \pm 0.51\,(\mathrm{stat}) \pm 0.15\,(\mathrm{syst}) \pm 0.16\,(\mathrm{norm})) \times 10^{-8}$
- Assuming that the decays $f_0(980) \to \pi^+\pi^-$ and $\rho(770)^0 \to \pi^+\pi^-$ are the dominant processes in the $B_s^0 \to \pi^+\pi^-\mu^+\mu^-$ and $B^0 \to \pi^+\pi^-\mu^+\mu^-$ decays, respectively, and neglecting other contributions in the $M_{\pi^+\pi^-}$ spectru, the following values are obtained:
  - $\mathcal{B}(B_s^0 \to f_0(980)(\to \pi^+\pi^-)\mu^+\mu^-) = (8.3 \pm 1.7) \times 10^{-8}$
  - $\mathcal{B}(B^0 \to \rho(770)^0\mu^+\mu^-) = (1.98 \pm 0.53) \times 10^{-8}$