Search for the rare decays $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0 \to \mu^+\mu^-\mu^+\mu^-$ at LHCb

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Overview

- A search is made for the decays $B_s^0 \to \mu^+\mu^-\mu^+\mu^-$ and $B^0 \to \mu^+\mu^-\mu^+\mu^-$ using 1.0 fb^{-1} of integrated luminosity collected with the LHCb detector in 2011
- One signal candidate is observed in the B_d channel, and no signal candidates are observed in the B_s channel
- Consistent with the expected backgrounds
- 95% CL branching fractions are set at $\mathcal{B}(\mathbf{B_s^0 \to \mu^+\mu^-\mu^+\mu^-}) < \mathbf{1.3 \times 10^{-8}}$ and $\mathcal{B}(\mathbf{B^0 \to \mu^+\mu^-\mu^+\mu^-}) < \mathbf{5.4 \times 10^{-9}}$

Motivation

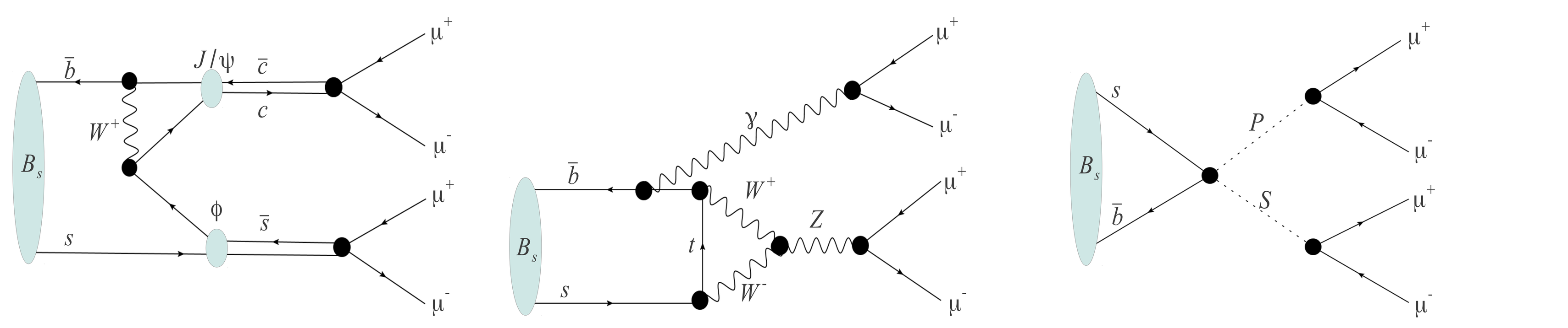

Figure: Feynmann diagrams showing the $B_s \to 4\mu$ transition for the Standard Model resonant $J/\psi\phi$(left) and non-resonant (centre) modes. The supersymmetric mode is shown on the right.

- $B \to 4\mu$ is a flavour changing neutral current decay that is sensitive to new physics
- Standard Model decay modes:
  - Resonant mode: $B_s \to (J/\psi \to \mu\mu)(\phi \to \mu\mu)$, $\mathcal{B} = (2.3 \pm 0.9) \times 10^{-8}$
  - Non-resonant mode: $B_s \to 4\mu$, predicted $\mathcal{B} < 10^{-10}$, new physics can enhance $\mathcal{B}$
- Supersymmetric mode: $B_s \to (P \to \mu\mu)(S \to \mu\mu)$[1]
  - S : scalar sGoldstino, P: pseudoscalar sGoldstino

The LHCb Detector

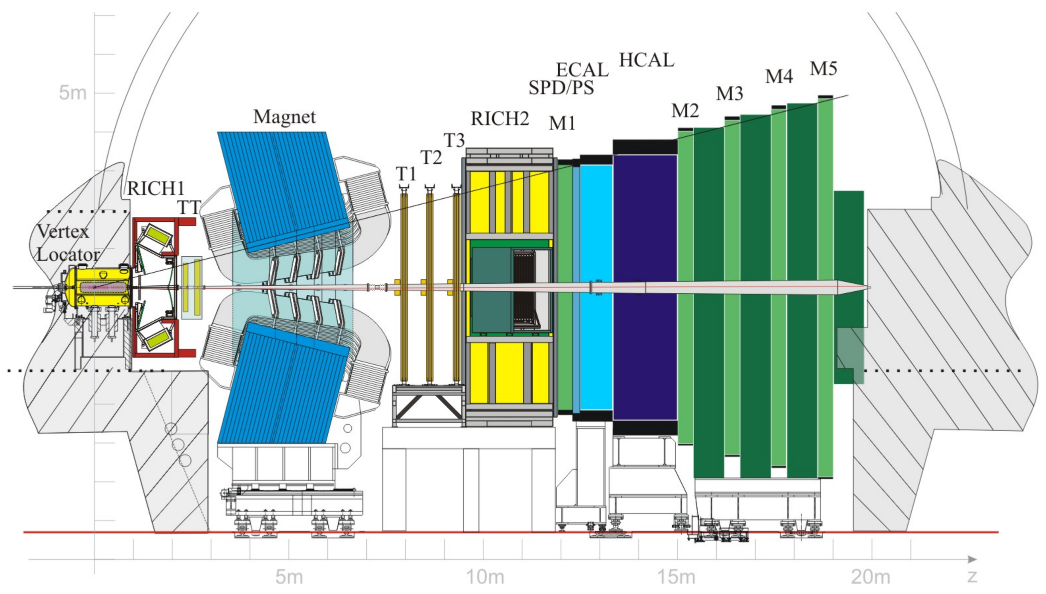

Figure: Cross-section of the LHCb detector

- Ring imaging cherenkov detectors (RICH1,2) give $> 90\%$ $K - \pi$ seperation in $2 - 100$ GeV momentum range
- Muon chambers provide $\sim 99\%$ muon identification efficiency
- Tracker provides B_d mass resolution of 17 MeV for $B_d \to J/\psi K^*$ channel

Results

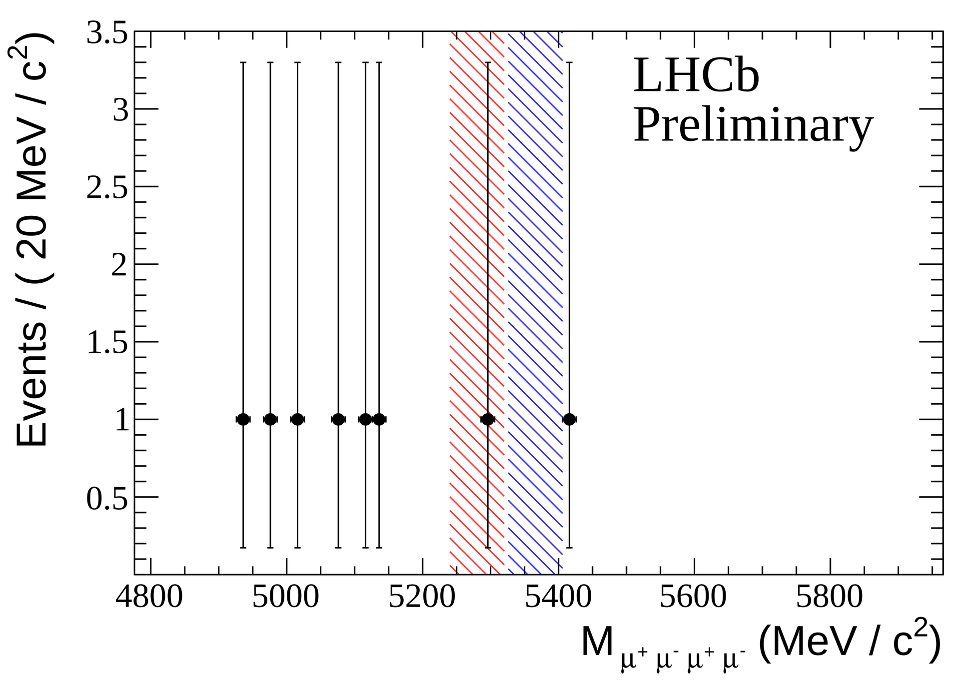

Figure: The unblinded non-resonant $M_{4\mu}$ invariant mass plot, the blue (red) region indicates the B_s (B_d) signal window.

- After unblinding, observe 1 event in B_d window, zero in B_s window
  - Consistent with background expectation
- Use CL_s method to set 95 % CL limits on the branching fraction

$\to$ $\mathcal{B}(\mathbf{B_s^0 \to \mu^+\mu^-\mu^+\mu^-}) < \mathbf{1.28 \times 10^{-8}}$

$\to$ $\mathcal{B}(\mathbf{B^0 \to \mu^+\mu^-\mu^+\mu^-}) < \mathbf{5.36 \times 10^{-9}}$

[1]S. Demidov and D. Gorbunov, Flavor violating processes with sgoldstino pair produc- tion, arXiv:1112.5230
[2]The LHCb Collaboration, R. Aaij et al., Measurement of b hadron production fractions in 7 TeV pp collisions, arXiv:1111.2357.

Selection

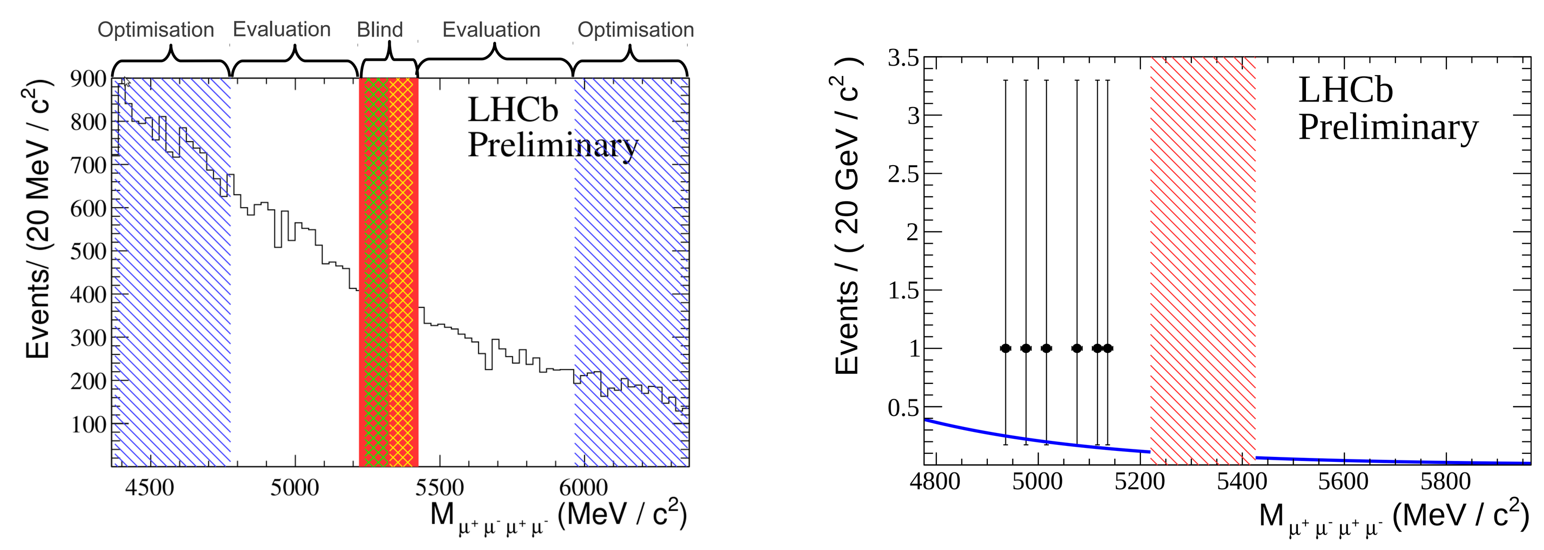

Figure: Left: Non-resonant $M_{4\mu}$ distribution before selection, the coloured regions indicate: the optimisation sideband (blue); the evaluation sideband (white); the blinded region (red); the B_s signal window (yellow); the B_d signal window (green).
Center: Non-resonant $M_{4\mu}$ distribution after selection, the red region indicates the blind region.
Right: Resonant $M_{4\mu}$ invariant mass plot after selection, the blue region indicates the B_s signal window.

- Used $B_s \to J/\psi\phi \to 4\mu$ mode as a signal proxy
  - Mass windows applied around J/ψ and ϕ masses
  - These are vetoed for the non-resonant $B \to 4\mu$ mode
- Cuts were tuned to maximise $S/\sqrt{S+B}$
  - S (signal) = number of events in $B_s \to J/\psi\phi$ window
  - B (background) = number of events in the optimisation sideband
- Evaluation sideband used to make unbiased evaluation of the background
- Cuts were applied on:
  - The quality of the B decay vertex
  - The difference in the log-likelihood of the muons being assigned a muon or kaon hypothesis against a pion hypothesis
  - The consistency of the B to originate from the primary vertex
  - The consistency of the final state particles to originate from a secondary vertex
- After selection, 6 background events observed in evaluation sideband
  - Fit background with exponential PDF $\to$ expect $0.30^{+0.22}_{-0.20}$ ($0.38^{+0.23}_{-0.17}$) events in the $B_s(B_d)$ signal window

Normalisation

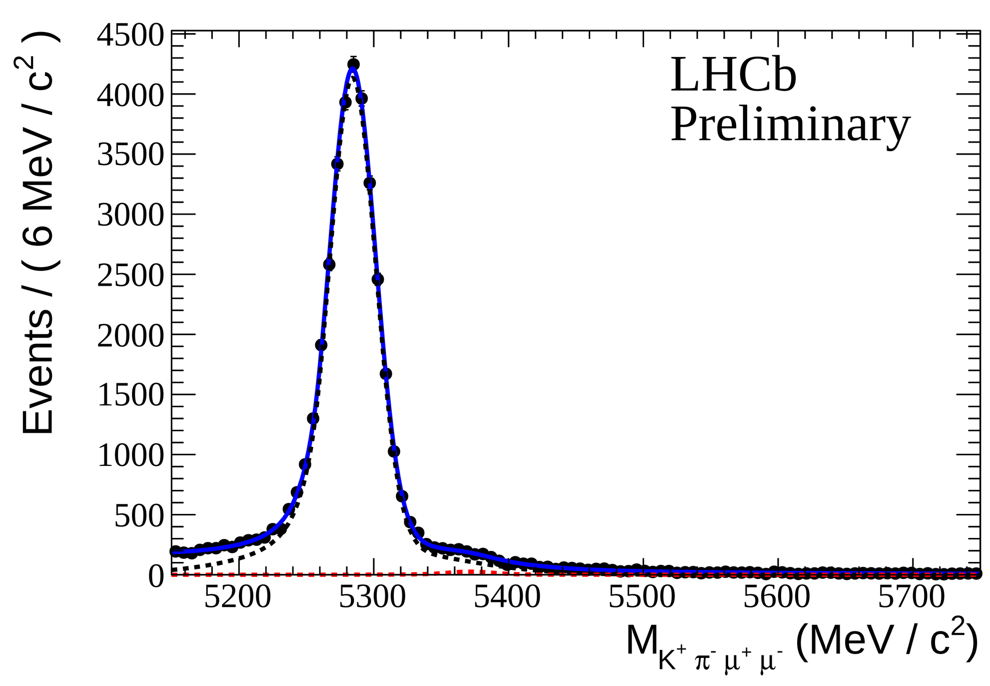

Figure: The invariant mass distribution of $B_d \to J/\psi K^*$ events after selection. PDFs for the B^0 and B_s^0 signal distributions are shown in black and red respectively.

- Use $B_d^0 \to J/\psi(\to \mu^+\mu^-)K^{*0}(\to K^+\pi^-)$ as a normalisation channel to convert the $B \to 4\mu$ yield into a branching fraction
  - Has a similar topology to $B \to 4\mu$, high statistics and a well measured $\mathcal{B}$
  - Same kinematic cuts applied to control and signal channels

$$\mathcal{B}(B_{s(d)} \to 4\mu) = \overbrace{\frac{\mathcal{B}(B_d \to K^* J/\psi)}{N_{B_d \to K^* J/\psi}}}^{(1)} \times \overbrace{\frac{\epsilon_{B_d \to K^* J/\psi}}{\epsilon_{B_{s(d)} \to 4\mu}}}^{(2)} \times \overbrace{\frac{F_d}{F_s}}^{(3)} \times \overbrace{N_{B_{s(d)} \to 4\mu}}^{(4)}$$

(1) $N_{B_d \to K^* J/\psi}$: Control channel yield, extracted from fit to mass plot
  - Fit model: double gaussian+radiative tail PDF's around B_s and B_d masses, exponential background
  - $B_d \to K^* J/\psi$ yield $= 35476 \pm 286$ events

(2) The relative efficiency of reconstructing control over signal channel events, taken from MC

(3) Production fraction of B_d over B_s in the LHCb acceptance (not used for $B_d \to 4\mu$ mode)
  - Measured value $= 3.7 \pm 0.3$[2]

(4) The signal yield, taken by counting events in the $B_{s(d)}$ signal window