Branching fraction measurement of $B_s^0 \to \phi\mu^+\mu^-$ and search for $B_s^0 \to f_2'(1525)\mu^+\mu^-$

FSP Meeting in Rostock

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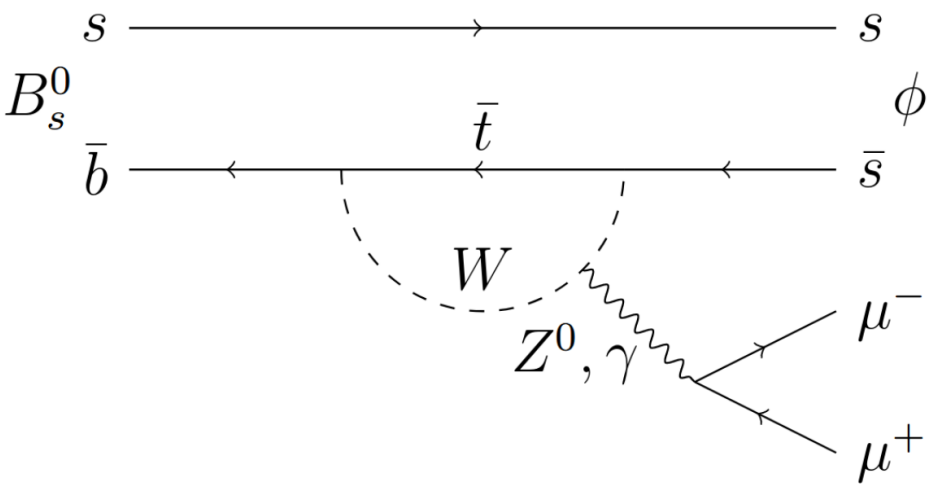
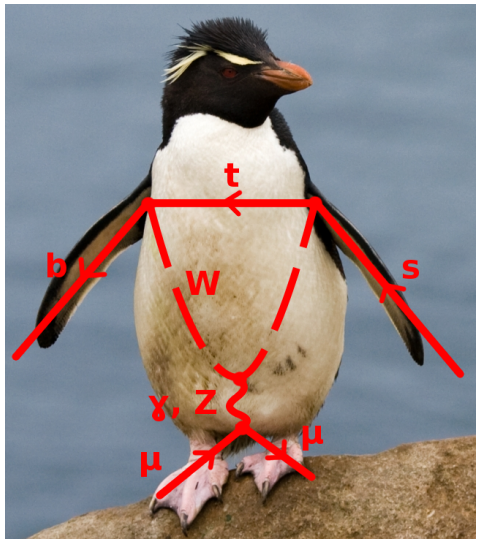
Probing for New Physics with $B_s^0 \to \phi(\to K^+K^-)\mu^+\mu^-$



Southern rockhopper penguin

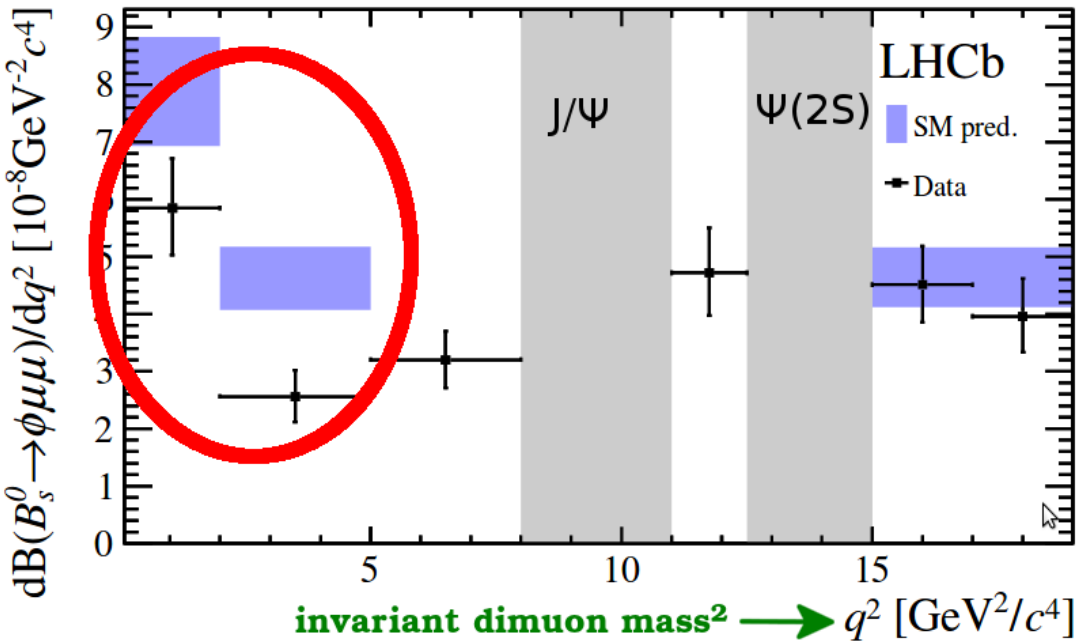


- $b \to s\mu^+\mu^-$: Flavour Changing Neutral Current
- Only occurs via higher order diagrams - highly suppressed in the SM
- Sensitive to possible New Physics contributions

Run 1 Analysis of $B_s^0 \to \phi\mu^+\mu^-$

- Run 1 analysis in JHEP 09 (2015) 179
  ("Angular analysis and differential branching fraction of the decay $B_s^0 \to \phi\mu^+\mu^-$")

JHEP 09 (2015) 179

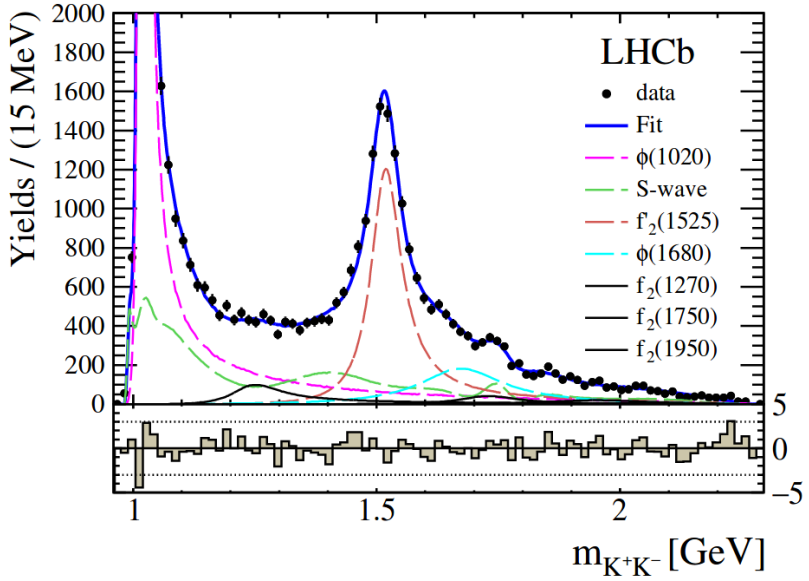


- Result: Branching fraction around $3\,\sigma$ lower compared to Standard Model expectation at low q^2
- Goal: Update analysis using Run 2 data

$B_s^0 \to f_2'(1525)(\to K^+K^-)\mu^+\mu^-$

- Similar to $B_s^0 \to \phi\mu^+\mu^-$ mode: $B_s^0 \to f_2'(1525)\mu^+\mu^-$
- $\mathcal{B}(B_s^0 \to J/\psi\, f_2'(1525))$ already measured [PRL 108 (2012) 151801]
- Rare mode $B_s^0 \to f_2'(1525)\mu^+\mu^-$ should also be observable!
- Bonus: Would be the first FCNC decay with spin-2 particle

[JHEP 08 (2017) 037]



General idea:
Keep analysis as close to $B_s^0 \to \phi\mu^+\mu^-$ as possible
Expect more background pollution due to larger width...

Branching Fraction Analysis Strategy

Measurement strategy ($X = \phi(1020)$, $f_2'(1525)$):

$$\frac{d\mathcal{B}(B_s^0 \to X\mu^+\mu^-)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)dq^2} = \frac{\mathcal{B}(J/\psi \to \mu^+\mu^-)}{q^2_{\text{max}} - q^2_{\text{min}}} \cdot \frac{N_{X\mu^+\mu^-}}{N_{J/\psi\phi}} \cdot \frac{\epsilon_{\text{tot}}^{J/\psi\phi}}{\epsilon_{\text{tot}}^{X\mu^+\mu^-}}$$

- Control channel with $q^2 \in [8, 11]\,\text{GeV}^2/c^4$
- Event selection (incl. MVA) to reduce backgrounds
- Fits for event yields
- Efficiencies from corrected simulations

Binning:

- Align $B_s^0 \to \phi\mu^+\mu^-$ binning to $B^0 \to K^{*0}\mu^+\mu^-$ analysis
- Plan $B_s^0 \to f_2'(1525)\mu^+\mu^-$ observation using one bin

Datasets and selection - $B_s^0 \to \phi\mu^+\mu^-$ analysis

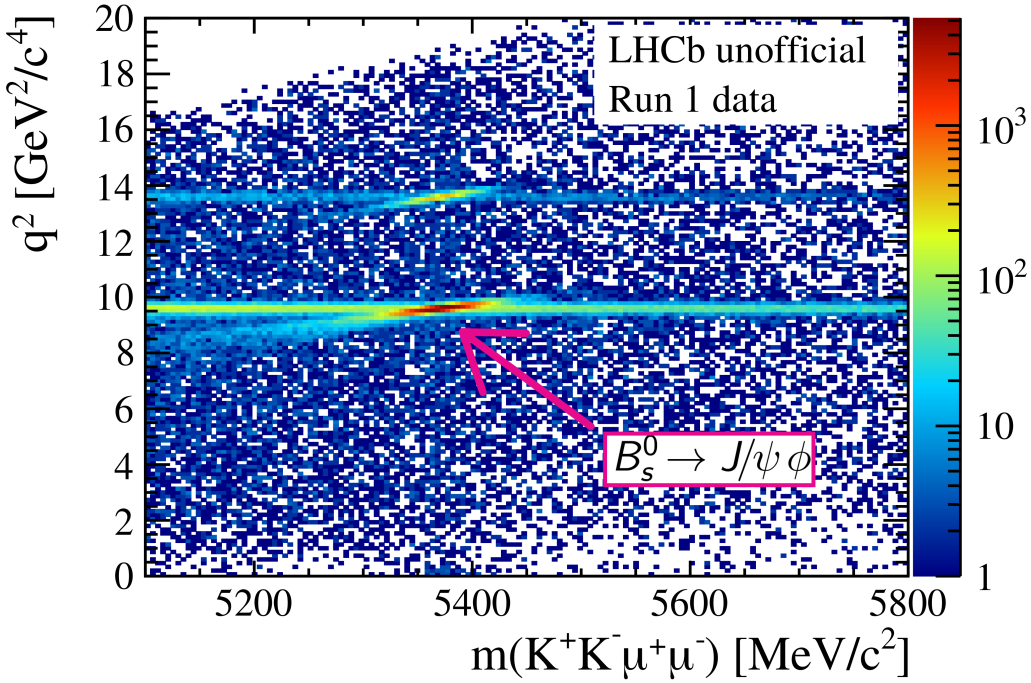
Datasets:

- 3/fb Run 1 (2011/12)
- 1.67/fb 2016 - still blinded!
- 0.33/fb 2015 - still blinded!

Selection:

- B_s^0 meson from pp-collision
- flight distance of B_s^0
- kaons, muons well identified
- $|m_{K^+K^-} - m_\phi| < 12.\,\mathrm{MeV}/c^2$

$B_s^0 \to \phi\mu^+\mu^-$ selection applied:



⇒ **BDT against comb. background**

Datasets and selection - $B_s^0 \to \phi\mu^+\mu^-$ analysis

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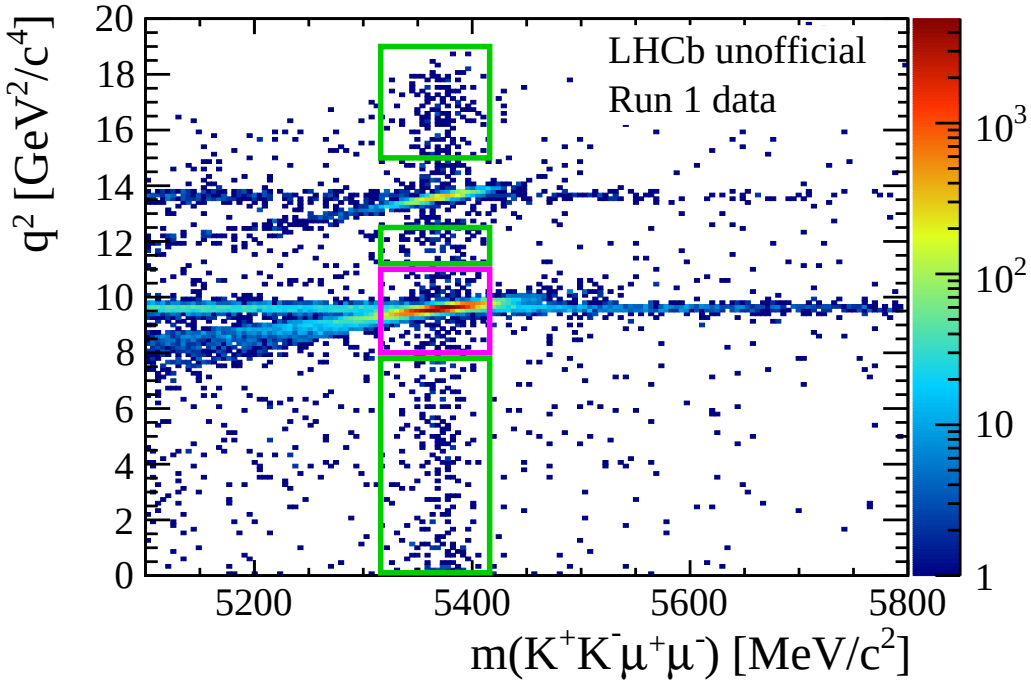
- kaons, muons well identified
- $|m_{K^+K^-} - m_\phi| < 12.\,\mathrm{MeV}/c^2$

BDT:

- trained on data:
  $B_s^0 \to J/\psi\,\phi$ (sig. proxy), upper mass band (bkg. proxy)
- variables:
  topology, daughter PID

$B_s^0 \to \phi\mu^+\mu^-$ **selection+BDT applied:**



⇒ **Signal clearly visible**

Datasets and selection - $B_s^0 \to f_2'(1525)\mu^+\mu^-$ analysis

Datasets:

- 3/fb Run 1 (2011/12)
- 1.67/fb 2016 - still blinded!
- 0.33/fb 2015 - still blinded!

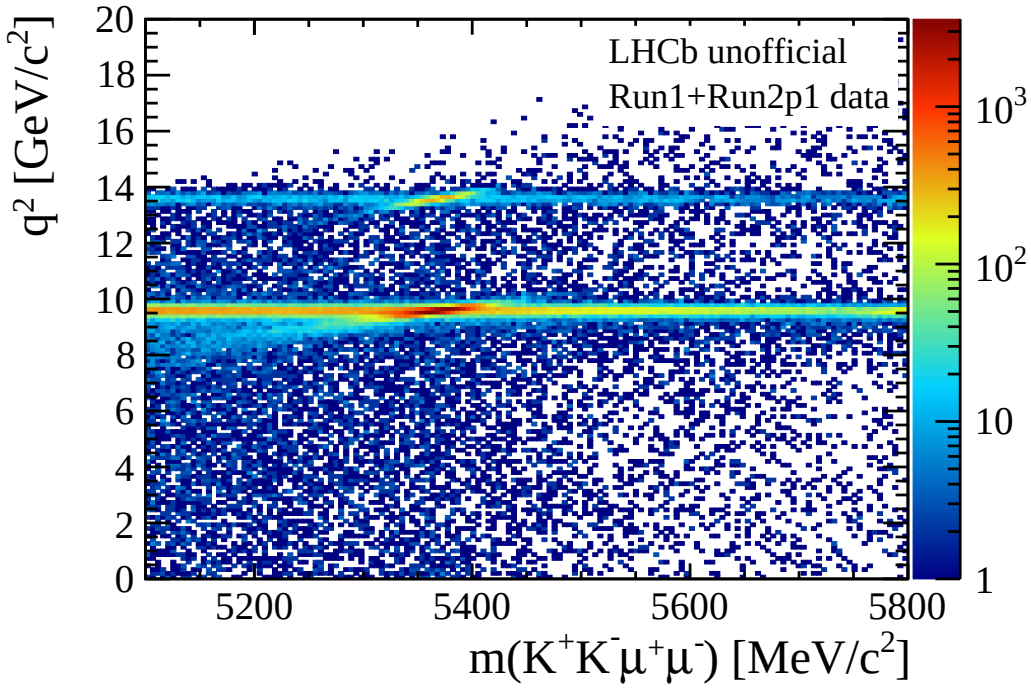
Selection:

- B_s^0 meson from pp-collision
- flight distance of B_s^0
- kaons, muons well identified
- $|m_{K^+K^-} - m_{f_2'}| < 225.\,\mathrm{MeV}/c^2$
- tighter requirement on kaon PID

BDT:

- trained on data:
  $B_s^0 \to J/\psi\,\phi$ (sig. proxy), upper mass band (bkg. proxy)
- variables:
  topology, daughter PID

$B_s^0 \to f_2'(1525)\mu^+\mu^-$ selection + BDT ($B_s^0 \to \phi\mu^+\mu^-$ WP) applied:



separate BDT optimization, tighter cut on BDT

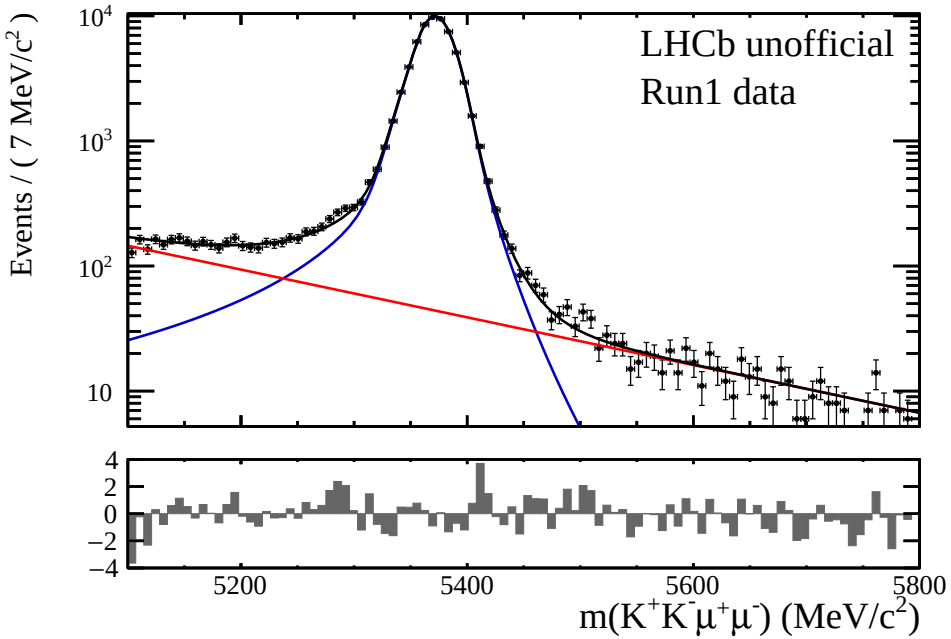
$B_s^0 \to J/\psi\,\phi$ and $B_s^0 \to \phi\mu^+\mu^-$ yields

Mass model:

DCB for signal (tail params + rel. fraction fixed from simulation),
exponential for combinatorial background

Control mode:

$B_s^0 \to J/\psi\,\phi$, $8.0 < q^2 < 11.0\,\mathrm{GeV}/c^2$

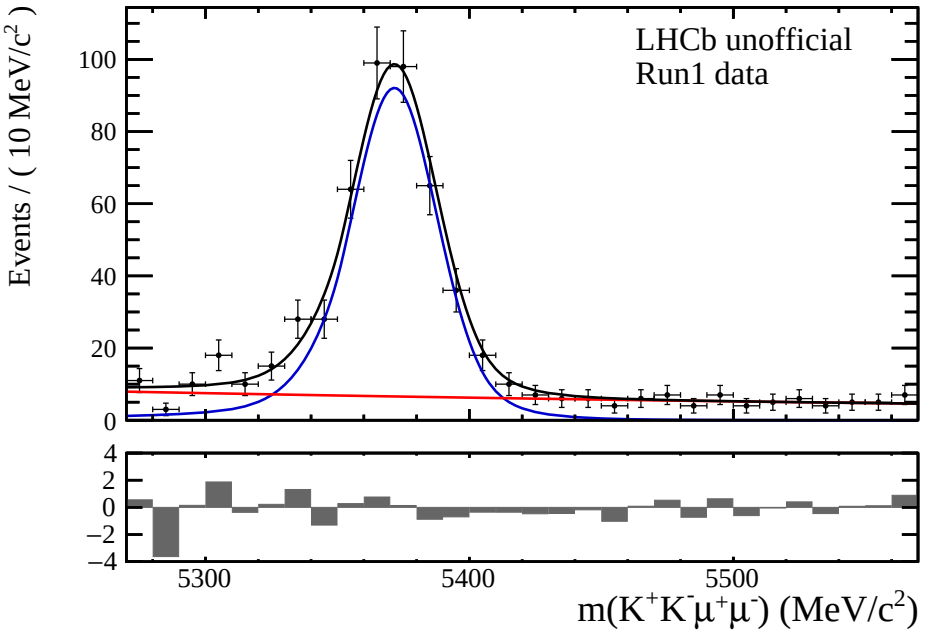


$N_{\text{Run 1}} = 64729 \pm 262$

$N_{\text{Run 2p1}} = 72874 \pm 278$

Rare mode:

$B_s^0 \to \phi\mu^+\mu^-$, $q^2 \notin [8, 11], [12.5, 15.0]\,\mathrm{GeV}/c^2$



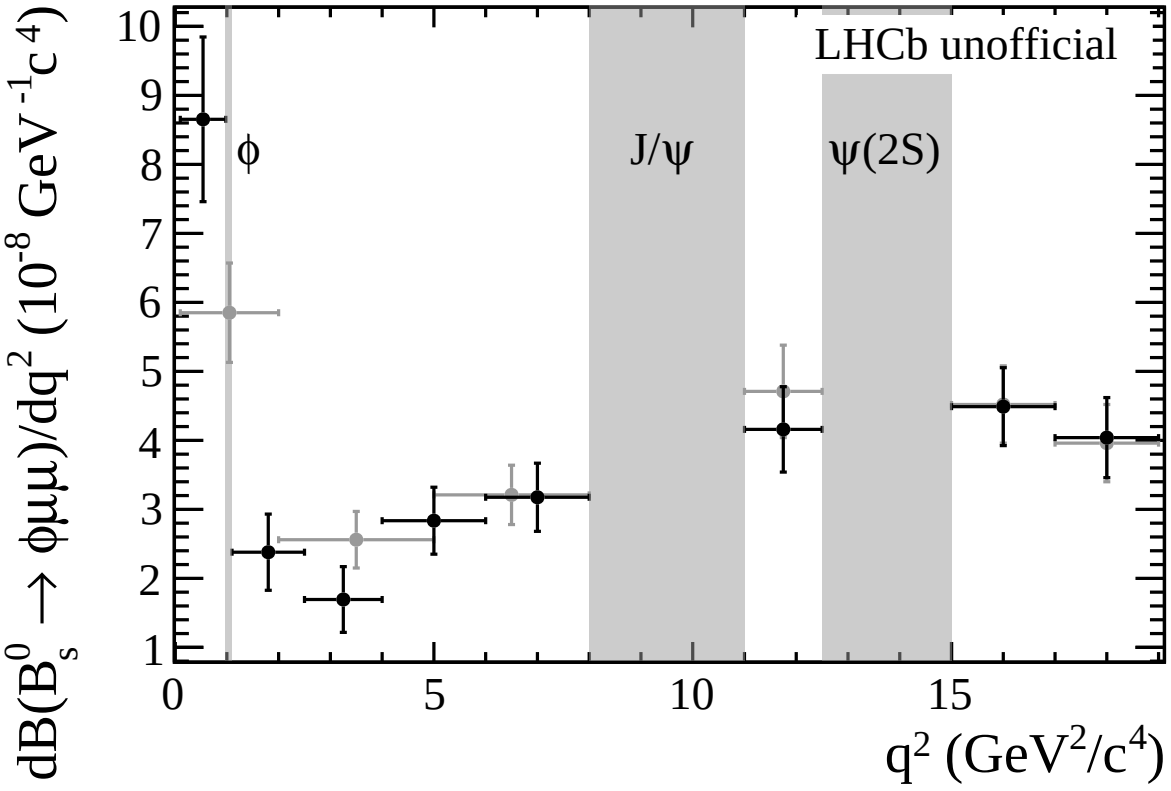
$N_{\text{Run 1}} = 413 \pm 24$

$N_{\text{Run 2p1}} = 470 \pm 70$ (expectation)

$B_s^0 \to \phi\mu^+\mu^-$ branching fraction Run 1

Efficiencies: Taken from corrected simulation of $B_s^0 \to \phi\mu^+\mu^-$ and $B_s^0 \to J/\psi\,\phi$

Branching fraction:
Comparison of published Run 1 to this work's result. **Note:** Statistical errors only



Good agreement with Run 1 result

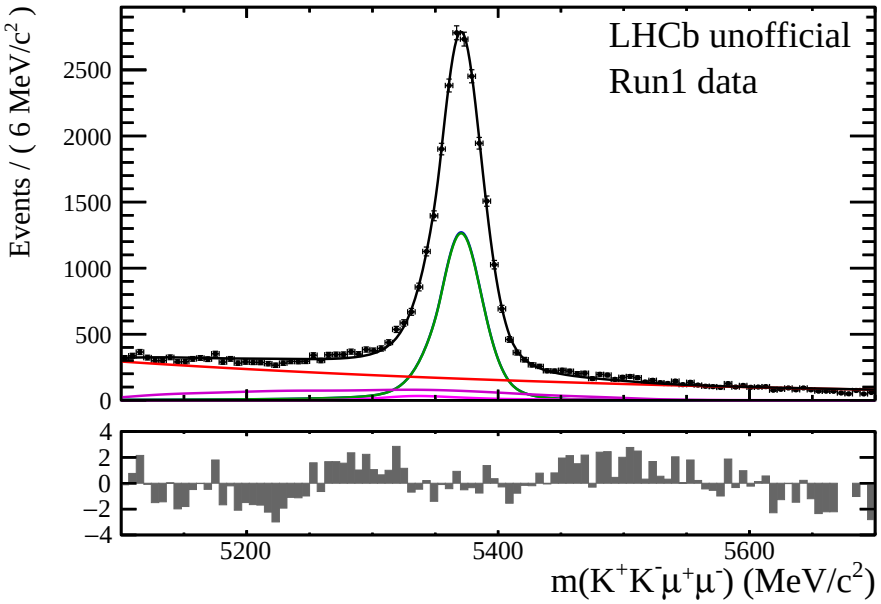
$B_s^0 \to J/\psi\, f_2'(1525)$ and $B_s^0 \to f_2'(1525)\mu^+\mu^-$ fit model

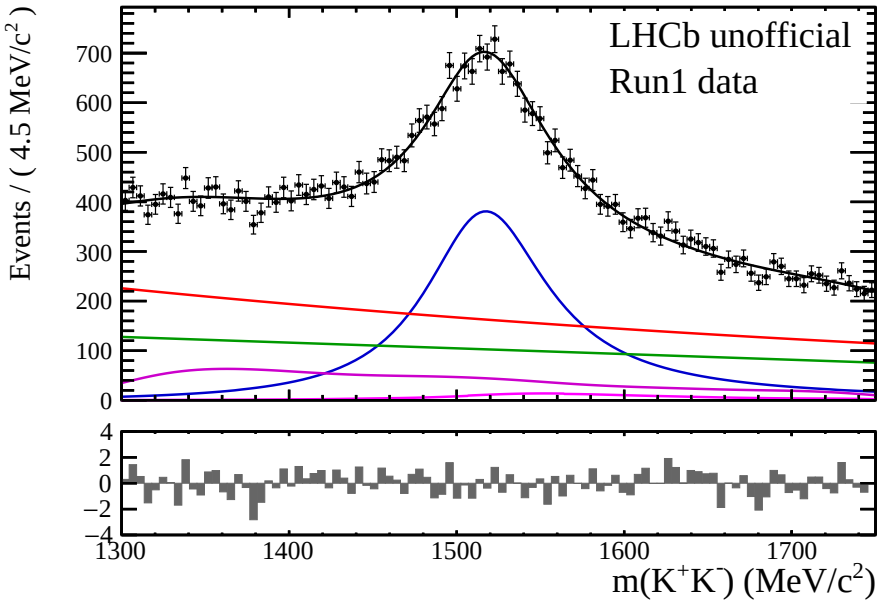
Plan for observation: Use full q^2 range

Fit model:

$$\underbrace{\mathrm{DCB}(m_{B_s^0}) \cdot \mathrm{BW}(m_{KK})}_{\text{signal}} + \underbrace{\mathrm{DCB}(m_{B_s^0}) \cdot \mathrm{lin.}(m_{KK})}_{\text{S-wave}} + \underbrace{\exp(m_{B_s^0}) \cdot \exp(m_{KK})}_{\text{comb. bkg.}} + \underbrace{f(m_{B_s^0}, m_{KK})}_{B^0, \Lambda_b^0}$$

Charmonium mode: $B_s^0 \to J/\psi\, f_2'(1525)$





$N_{\text{Run 1}} = 10251 \pm 311$

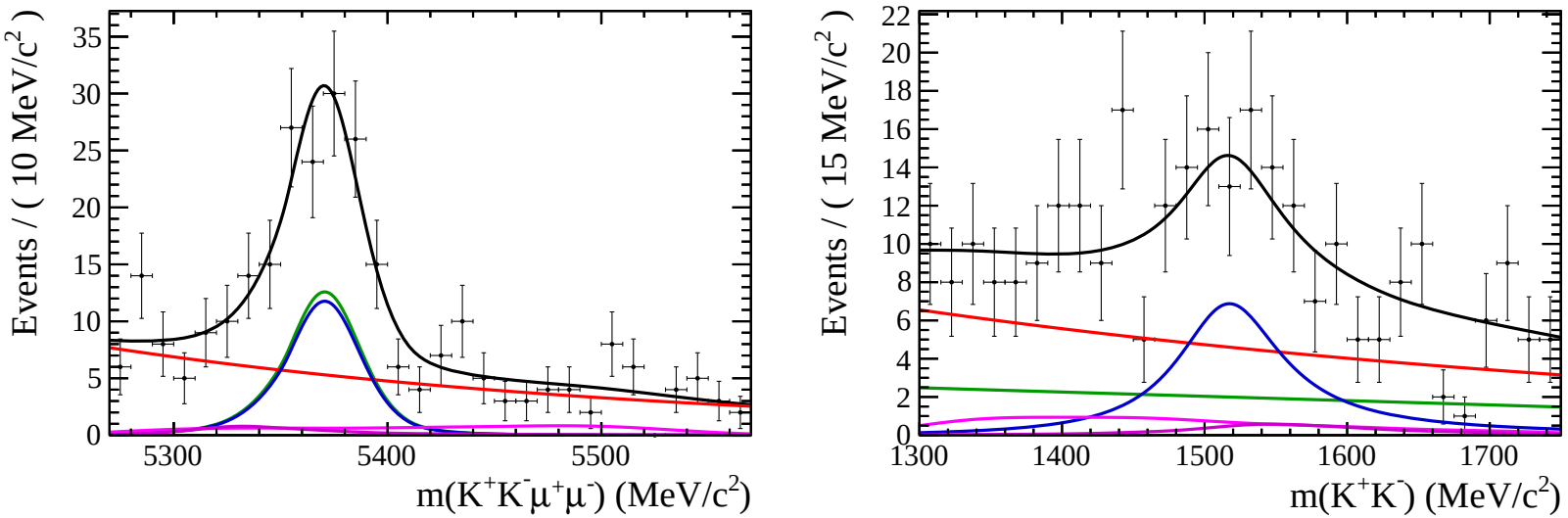
$N_{\text{Run 2p1}} = 11764 \pm 329$

Rare mode $B_s^0 \to f_2'(1525)\mu^+\mu^-$ exp. sensitivity

Expected yields: $N_{\text{Run 1}} = 50 \pm 12$ and $N_{\text{Run 2p1}} = 57 \pm 13$

Expected sensitivity:
Generate using $B_s^0 \to J/\psi\, f_2'(1525)$ model with yields extrapolated to rare mode.

Example for such toy (Run 1):



Using Wilk's theorem:

5.2σ in Run 1 + Run 2p1

(considering only statistical uncertainties so far)

Summary and Outlook

Run 1 branching fraction analysis of $B_s^0 \to \phi\mu^+\mu^-$: around 3σ deviation from expectation

Status of analysis:

- Performed analysis on Run 1 following previous $B_s^0 \to \phi\mu^+\mu^-$ analysis ✓
- Reproduced Run 1 $B_s^0 \to \phi\mu^+\mu^-$ branching fraction result ✓
- Added blind Run 2p1 data ✓
- First sensitivity estimates for $B_s^0 \to f_2'(1525)\mu^+\mu^-$ observation ✓
- Finished large fraction of studies of systematics (◆)

Outlook:

- Update of $B_s^0 \to \phi\mu^+\mu^-$ angular analysis (by M. Materok) ◆
- Currently considering adding 2017/2018 data ◆