Rare decays at LHCb

Siim Tolk (NIKHEF, Amsterdam) on behalf of the LHCb Collaboration

Bormio 2014
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Other talks from LHCb:

Monday (11:00)
LHCb overview (Ulrich Uwer)

Thursday (18:40)
CP violation at LHCb (Antonio Romero Vidal)

Bormio 2014
Flavour Changing Neutral Currents in meson decays:

- $c \rightarrow u$
- $s \rightarrow d$
- $b \rightarrow d$
- $b \rightarrow s$

All studied @ LHCb! Covered today
• Tree level diagrams forbidden in SM (GIM suppression)
• Main contributors: “W box” and “electroweak penguin”:

- Sensitive to new particles with masses \( \sim O(100 \text{ TeV}) \)
Standard Model
LHCb

• An event recorded by LHCb
An event recorded by LHCb

- Excellent precision:
  - Momentum resolution: $\frac{\Delta p}{p} \sim 0.4\%$ at 5 GeV/c to $0.6\%$ at 100 GeV/c
  - Impact parameter resolution: $20\,\mu m$ for high-pT tracks
  - Invariant mass resolution
  - Particle identification: $\sim 97\%$ for $1-3\% \pi \rightarrow \mu$ mis-id probability

- Very efficient trigger:
  - $\sim 90\%$ for dimuon channels
  - $\sim 30\%$ for multi-body hadronic final states
Rare decays: 3 groups

Radiative

$B_{u}^{\pm} \rightarrow (K_{res}^{*\pm})\gamma$

Semi-leptonic

$B_{d}^{0} \rightarrow K^{*}\mu^{+}\mu^{-}$

Leptonic

$B_{s,d}^{0} \rightarrow \mu^{+}\mu^{-}$
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• Many observables:

- $A_{CP}, A_{UD}, d(BR)/dE_{\gamma}$
- $A_{CP}, F_{L}, d(BR)/dq^{2}$
- $BR(B_{s,d}^{0} \rightarrow \mu^{+}\mu^{-})$

• Constraining many NP sensitive Wilson coefficients:

- $C_{7}^{(i)}, C_{8}^{(i)}$
- $C_{7}^{(i)}, C_{9}^{(i)}, C_{10}^{(i)}$
- $C_{10}^{(i)}, C_{S}^{(i)}, C_{P}^{(i)}$
Rare decays: 3 groups

Electroweak penguin

- **Radiative**
  \[ B_{u}^{\pm} \rightarrow (K_{res}^{*\pm})^{\gamma} \]
- **Semi-leptonic**
  \[ B_{d}^{0} \rightarrow K^{*} \mu^{+} \mu^{-} \]
- **Leptonic**
  \[ B_{s,d}^{0} \rightarrow \mu^{+} \mu^{-} \]
The decay $B_{s,d}^0 \rightarrow \mu^+\mu^-$

LHCb: “First evidence for Bs to mumu!”

[PRl 110, 021801 (2013)]

$\sim 10,000 \times$
The decay $B_{s,d}^0 \rightarrow \mu^+ \mu^-$

- FCNC and helicity suppressed

- Purely leptonic final state

- The SM prediction (Buras et al. [arXiv:1303.3820])

$BR(B_d \rightarrow \mu^+ \mu^-) = (1.07 \pm 0.10) \times 10^{-10}$

$BR(B_s \rightarrow \mu^+ \mu^-) = (3.25 \pm 0.17) \times 10^{-9}$
The decay $B_{s,d}^0 \rightarrow \mu^+ \mu^-$

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- The SM prediction (Buras et al. [arXiv:1303.3820])

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$$BR(B_s \rightarrow \mu^+ \mu^-) = (3.25 \pm 0.17) \times 10^{-9}$$

$$\times \frac{1 + A_{\mu \mu}^{\Delta \Gamma_s} \cdot \Delta \Gamma_s / 2 \Gamma_s}{1 - (\Delta \Gamma_s / 2 \Gamma_s)^2} = (3.56 \pm 0.18) \times 10^{-9}$$

Correction due to $\Delta \Gamma_s$

(De Bruyn et al. [PRD 86, 014027 (2012)])

- Theory error budget

![Error Budget Pie Chart]
The decay $B_{s,d}^0 \rightarrow \mu^+ \mu^-$

Analysis

Data sample

- 3fb$^{-1}$ integrated luminosity
- Reconstruction improved
- Dimuon mass signal region blinded

1) Identify signal like events
   - A loose muon pair selection
   - Separate combinatorial background with an (re-optimised) BDT
     - Based on the geometry and kinematics
     - Shape calibrated on the data

[doi:10.1103/PhysRevLett.111.101805]
[arXiv:1307.5024]
The decay $B_{s,d}^0 \rightarrow \mu^+ \mu^-$

Analysis

2) Extract the signal yield

- Mass PDF
  - Signal resolution taken from data
  - Partial reconstruction and mis-ID

\[ B_{(s)}^0 \rightarrow h^+ h'^- \quad B_S^0 \rightarrow K^- \mu^+ \nu_\mu \]
\[ \Lambda_b \rightarrow p\mu^- \nu_\mu \quad B^0 \rightarrow \pi^- \mu^+ \nu_\mu \]
\[ B_{(s)}^{0,+} \rightarrow \pi^{0,+} \mu^+ \nu_\mu \]
\[ B_c^+ \rightarrow J/\psi (\mu\mu) \mu^+ \nu_\mu \]

- Simultaneous mass fit in 8 BDT bins

[doi:10.1103/PhysRevLett.111.101805]
[arXiv:1307.5024]
The decay $B_{s,d}^0 \rightarrow \mu^+\mu^-$

**Analysis**

3) Normalize to **channels** with known BR's

\[ \text{BR} = \frac{N_{B_{s,d}^0}^{\mu^+\mu^-}}{N_{\text{cal}}} = \alpha(s) \times \frac{f_{cal}}{f_{d(s)}} \]

\[ \alpha(s) = \frac{\epsilon_{\text{cal}} \times \epsilon_{\text{TRIG}} \times \frac{f_{cal}}{f_{d(s)}}}{\epsilon_{\text{sig}} \times \epsilon_{\text{RE}} \times \epsilon_{\text{SEL}}} \]

[f_s/f_d uncertainty reduced from 7.8% to 5.8%]
The decay $B_{s,d}^0 \rightarrow \mu^+ \mu^-$

Results

LHCb results (3fb$^{-1}$):

$$BR(B_s \rightarrow \mu^+ \mu^-) = (2.9^{+1.1}_{-1.0}(\text{stat.})^{+0.3}_{-0.1}(\text{syst})) \times 10^{-9}$$
$$BR(B_d \rightarrow \mu^+ \mu^-) = (3.7^{+2.4}_{-2.1}(\text{stat.})^{+0.6}_{-0.4}(\text{syst})) \times 10^{-10}$$

CMS results (25fb$^{-1}$):

$$BR(B_s^0 \rightarrow \mu^+ \mu^-) = 3.0^{+1.0}_{-0.9} \times 10^{-9}$$
$$BR(B_d^0 \rightarrow \mu^+ \mu^-) = 3.5^{+2.1}_{-1.8} \times 10^{-10}$$

[doi:10.1103/PhysRevLett.111.101805]
[arXiv:1307.5024]

LHCb results (3fb$^{-1}$):

CMS results (25fb$^{-1}$):

[doi: 10.1103/PhysRevLett.111.101804]
[arXiv:1307.5025]
The decay $B_{s,d}^0 \rightarrow \mu^+ \mu^-$

Results

6) Combination: First observation!

$BR(B_s \rightarrow \mu^+ \mu^-) = (2.9 \pm 0.7) \times 10^{-9}$

$>5\sigma$

$BR(B_d \rightarrow \mu^+ \mu^-) = (3.6 \pm 1.6) \times 10^{-10}$

$<3\sigma$

Measured branching ratios are compatible with the SM expectations.
The decay $B_{s,d}^0 \rightarrow \mu^+\mu^-$

Implications

Before the LHC results

After the LHC results

Cartoon of plot from [D.Straub arXiv:1205.6094]

Cartoon of plot from [D.Straub arXiv:1205.6094]
Rare decays: 3 groups

Radiative

\[ B^\pm_u \rightarrow (K^{*\pm}_{res})\gamma \]

Semi-leptonic

\[ B^0_d \rightarrow K^* \mu^+ \mu^- \]

Leptonic

\[ B^0_{s,d} \rightarrow \mu^+ \mu^- \]
The decay $B_u^{\pm} \rightarrow (K_{res}^{*\pm}) \gamma \rightarrow K^{\pm} \pi^{\mp} \pi^{\pm}$

Motivation

- Measured inclusive $BR(B^{\pm} \rightarrow K^{\pm} \pi^{\mp} \pi^{\pm} \gamma)$ agrees well with the SM
The decay $B_u^\pm \rightarrow (K_{res}^*)^\pm \gamma \rightarrow K^\pm \pi^\mp \pi^\pm$

Motivation

- **New Physics** models can affect the angular variables:

In SM, photon is dominantly *left-handed*:

$$m_s/m_b \sim 0.02$$

NP models (LRSM, MSSM) can have a significant *right-handed component*!
The decay $B^\pm_u \rightarrow (K^{*\pm}_{res})\gamma \rightarrow K^\pm \pi^\mp \pi^\pm$

- Measure the **up-down asymmetry**
  

$$A_{ud} \equiv \frac{\int_0^1 d\cos \theta \frac{d\Gamma}{d\cos \theta} - \int_{-1}^0 d\cos \theta \frac{d\Gamma}{d\cos \theta}}{\int_{-1}^1 d\cos \theta \frac{d\Gamma}{d\cos \theta}}$$

The plane of $K^- \pi^+ \pi^-$
The decay $B^\pm_u \rightarrow (K^*_\text{res})^\gamma \rightarrow K^\pm \pi^\mp \pi^\mp$

**Observables**

- Measure the **up-down asymmetry**
  

  $$A_{\text{ud}} \equiv \frac{\int_0^1 \text{d} \cos \theta \frac{d \Gamma}{d \cos \theta} - \int_{-1}^0 \text{d} \cos \theta \frac{d \Gamma}{d \cos \theta}}{\int_{-1}^1 \text{d} \cos \theta \frac{d \Gamma}{d \cos \theta}}$$

- Directly proportional to **photon polarisation** for a single resonance:

  $$\lambda_\gamma \equiv \frac{|c_R|^2 - |c_L|^2}{|c_R|^2 + |c_L|^2}$$

- Not possible to translate from $A_{\text{UD}}$ to photon polarisation (for inclusive measurement)
The decay $B_u^\pm \rightarrow (K^*_{res})^\gamma \rightarrow K^{\pm} \pi^\mp \pi^\pm$

Analysis strategy

- Data sample: 2fb$^{-1}$ of 2012 data
- Mixture of cuts and multivariate techniques
- 2 Bins of $K_{res}$ mass

Background subtracted

[LHCb-CONF-2013-009]
The decay $B_u^{\pm} \rightarrow (K_{res}^{*\pm}) \gamma \rightarrow K^{\pm} \pi^{\mp} \pi^{\pm}$

Analysis strategy

- Data sample: 2fb$^{-1}$ of 2012 data
- Mixture of cuts and multivariate techniques
- 2 Bins of $K_{res}$ mass

Background subtracted

Signal
- combinatorial bkg
- missing pion
- partially reco.

[LHCb-CONF-2013-009]
The decay \( B_u^\pm \rightarrow (K_{res}^\ast)^\gamma \rightarrow K^\pm \pi^\mp \pi^\pm \)

Results

- The up-down asymmetry:
  \[ A_{UD}^\pm = \frac{U^\pm - D^\pm}{U^\pm + D^\pm} \]

\[
\begin{align*}
  A^+ &= -0.084 \pm 0.026 \text{ (stat)} \, ^{+0.004}_{-0.003} \text{ (syst)}, \\
  A^- &= -0.086 \pm 0.025 \text{ (stat)} \pm 0.002 \text{ (syst)}. \\
\end{align*}
\]

\[ A_{ud} = -0.085 \pm 0.019 \text{ (stat)} \pm 0.003 \text{ (syst)} \quad 4.6\sigma! \]

- Photons are polarised (strong evidence!)
- Parity violated.
The decay \( B_u^{\pm} \rightarrow (K_{res}^{*\pm})\gamma \rightarrow K^{\pm}\pi^{\mp}\pi^{\pm} \)

**Results**

- The **CP asymmetry**: \( A_{CP} = A_{CP}^{\text{raw}} - A_P - A_D + \Delta A_{CP}^{\text{raw}} \)
The decay \[ B_u^\pm \rightarrow (K_{res}^\ast\pm)\gamma \rightarrow K^\pm \pi^\mp \pi^\pm \]

**Results**

- **The CP asymmetry:**
  \[ A_{CP} = A_{CP}^{raw} - A_P - A_D + \Delta A_{CP}^{raw} \]

<table>
<thead>
<tr>
<th>Contribution</th>
<th>Value</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_{CP}^{raw} )</td>
<td>-0.022</td>
<td>0.015</td>
</tr>
<tr>
<td>( A_D ) and ( A_P )</td>
<td>0.013</td>
<td>0.008</td>
</tr>
<tr>
<td>( \Delta A_{CP}^{raw} )</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>Simulation parameters</td>
<td>0.000</td>
<td>±0.001</td>
</tr>
<tr>
<td>Fit model</td>
<td>0.000</td>
<td>0.002</td>
</tr>
</tbody>
</table>

\[ A_{CP} = -0.007 \pm 0.015 \text{ (stat)} \pm 0.008 \text{ (syst)} \]

[ LHCB-CONF-2013-009 ]
Summary

Summary

Radiative

\[ B_{u}^{\pm} \rightarrow (K_{res}^{*\pm})\gamma \]

2 fb\(^{-1}\) analysed

- Non-zero \( A_{UD} \), with 4.6\( \sigma \)!
- No \( A_{CP} \) seen.

Semi-leptonic

\[ B_{d}^{0} \rightarrow K^{*} \mu^{+}\mu^{-} \]

1 fb\(^{-1}\) analysed

- \( P_{S} \)'s discrepancy of 3.7\( \sigma \)!
- Other observables agree to SM

Leptonic

\[ B_{s,d}^{0} \rightarrow \mu^{+}\mu^{-} \]

3 fb\(^{-1}\) analysed

- Observation in \( B_{s} \) channel (\( >5\sigma \)!
- \( B_{d} \) channel (\( <3\sigma \)

Looking forward for the upgrade!
Summary

• Only a few B decays covered here, but many recent results:

**Very rare decays**
- $B_{(s)} \rightarrow \mu \mu$ [3fb$^{-1}$/arXiv:1307.5024]
- $D \rightarrow \mu \mu$ [0.9fb$^{-1}$/arXiv:1305.5050]
- $K_s \rightarrow \mu \mu$ [1fb$^{-1}$/arXiv:1209.4029]
- $B \rightarrow 4\mu$ [1fb$^{-1}$/arXiv:1303.1092]
- $B^+ \rightarrow \pi^+ \mu \mu$ [1fb$^{-1}$/arXiv:1210.2645]

**Angular an isospin analysis**
- $B \rightarrow K^* \mu \mu$ [1fb$^{-1}$/arXiv:1308.1707, 1fb$^{-1}$/arXiv:1304.6325]
- $\Lambda_b \rightarrow \Lambda \mu \mu$ [1fb$^{-1}$/arXiv:1306.2577]
- $B_s \rightarrow \phi \mu \mu$ [1fb$^{-1}$/arXiv:1305.2168]
- $B \rightarrow K(\ast) \mu \mu$ [1fb$^{-1}$/arXiv:1205.3422]
- $\psi (4160)$ [3fb$^{-1}$/arXiv:1307.7595]

**CP Asymmetries**
- $B \rightarrow K^* \mu \mu$ [1fb$^{-1}$/arXiv:1210.4492]
- $B^+ \rightarrow K^+ \mu \mu$ [1fb$^{-1}$/arXiv:1308.1340]

**No SM processes**
- $B^+ \rightarrow X \mu^+ \mu^-$ [0.41fb$^{-1}$/arXiv:1201.5600]
- $B_{(s)} \rightarrow \mu e$ [1fb$^{-1}$/arXiv:1307.4889]
- $\tau \rightarrow 3\mu$, $\tau \rightarrow \mu \mu$ [1fb$^{-1}$/arXiv:1304.4518]

**Radiative decays**
- $B \rightarrow K^* \gamma$, $B_s \rightarrow \phi \gamma$ [1fb$^{-1}$/arXiv:1202.6267]
Extras
Rare decays: 3 groups

- **Radiative**
  \[ B_{u}^{\pm} \rightarrow (K_{res}^{*\pm})\gamma \]
  - Electron or muon decay

- **Semi-leptonic**
  \[ B_{d}^{0} \rightarrow K^{*} \mu^{+}\mu^{-} \]
  - Leptons and pions

- **Leptonic**
  \[ B_{s,d}^{0} \rightarrow \mu^{+}\mu^{-} \]
  - Only leptons

Electroweak penguin

Diagram arrows:
- **Red** for electrons
- **Green** for muons
- **Blue** for leptons
The decay $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

Motivation

- **New Physics** can alter

  a) Branching ratio

  $BR(B_d^0 \rightarrow K^{*0} \mu^+ \mu^-) \approx O(10^{-6})$ from B factories, CDF.
  In agreement with SM.

  b) Differential branching ratio: $d(BR)/dq^2$ (q - dimuon mass)

  c) Angular distributions:

  - 3 helicity angles $(\theta_L, \phi, \theta_K)$
The decay $B^0_d \rightarrow K^{*0} \mu^+ \mu^-$

Differential branching ratio

Good agreement with SM!

Theory predictions from Bobeth et al. [JHEP 1107:067 (2011)]

- Normalization of event yields to $B^0 \rightarrow J/\psi K^{*0}$
  $\Rightarrow$ largest systematic uncertainty

- Uncertainties on hadronic parameters limit sensitivity

LHCb

Good agreement with SM!
The decay \( B_d^0 \rightarrow K^{*0} \mu^+ \mu^- \)

**Motivation**

- **Angular distributions** \((\theta_L, \phi, \theta_K)\)

  - Differential angular distribution can be written in terms of \(F_L\) and \(S_i\):
The decay $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

Motivation

- Angular distributions $(\theta_L, \phi, \theta_K)$

  o) Differential angular distribution can be written in terms of $F_L$ and $S_i$:

$$\frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{d\cos \theta_L d\cos \theta_K d\phi dq^2} = \frac{3}{32\pi} \left[ \frac{3}{4} (1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K + \frac{1}{4} (1 - F_L) \sin^2 \theta_K \cos 2\theta_L - F_L \cos^2 \theta_K \cos 2\theta_L + S_3 \sin^2 \theta_K \sin^2 \theta_L \cos 2\phi + S_4 \sin 2\theta_K \sin 2\theta_L \cos \phi + S_5 \sin 2\theta_K \sin \theta_L \cos \phi + S_6 \sin^2 \theta_K \cos \theta_L + S_7 \sin 2\theta_K \sin \theta_L \sin \phi + S_8 \sin 2\theta_K \sin 2\theta_L \sin \phi + S_9 \sin^2 \theta_K \sin^2 \theta_L \sin 2\phi \right],$$

- Message:
  - Yield and angular distributions in $q^2$, give us $F_L$ and $S_i$
  - $F_L$ and $S_i$ are functions of Wilson coefficients and form factors

[S. Descotes-Genon, T. Hurth, J. Matias, J. Virto, JHEP 05 (2013) 137]
[arXiv:1303.5794]
The decay $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

Angular observables

• **Message:**
  - Yield and angular distributions, give us $F_L$ and $S_i$
  - $F_L$ and $S_i$ are functions of Wilson coefficients and form factors

• There are **combinations** of $F_L$ and $S_i$ with **reduced form factor uncertainties**:
  
  $$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1 - F_L)}}$$

• **First** measurement ever!

• **Complementary** to the existing measurements

[S. Descotes-Genon, T. Hurth, J. Matias, J. Virto, JHEP 05 (2013) 137]
[arXiv:1303.5794]
The decay $B^0_d \rightarrow K^{*0} \mu^+ \mu^-$

Angular observables **IMPROVED FOLDING!**

- $P_{4,6,8}'$ in agreement with SM
- **BUT:** $P'_5$ shows $3.7\sigma$ local discrepancy!

- Integrated over the region $1.0 < q^2 < 6.0$ GeV$^2$/c$^4$, the observed discrepancy is $2.5\sigma$

---

**References:**

[JHEP 1308 (2013) 131]
[10.1103/PhysRevLett.111.191801]
The decay \( B_d^0 \rightarrow K^{*0} \mu^+ \mu^- \)

Angular observables \( P'_5 \)!

- Theory explains?

Wilson coefficient: \( C_9^{NP} < 0 \)!

\( Z' \) gauge boson?

2.3 Beyond Standard Model

We have proposed a simple \( Z' \) model [14] with couplings to left-handed quarks (with same phase as \( V_{tb} V_{ts}^* \) to avoid large contributions to \( \phi_3 \)) with flavour-changing couplings to down-type quarks and equal left and right handed couplings to charged leptons of order 0.1. The scale of the \( M_Z' \) is around 1-2 TeV to get \( C_9^{NP} = -1.5 \). An interesting implementation of our pattern for Wilson
New Observable: $\mathcal{B}(B_s^0 \to \mu^+\mu^-)/\mathcal{B}(B^0 \to \mu^+\mu^-)$

Sensitivity to New Physics

- Precise prediction in SM, MFV, and U(2)$^3$ flavour sym. [Buras, 2003]:

$$\frac{\mathcal{B}(B^0 \to \ell^+\ell^-)}{\mathcal{B}(B_s^0 \to \ell^+\ell^-)} = \frac{\tau_{B^0}}{\tau_{B_s^0}} \frac{m_{B^0}}{m_{B_s^0}} \frac{F_{B^0}}{F_{B_s^0}} \left| \frac{V_{td}}{V_{ts}} \right|^2$$

- Cannot be deduced by simply taking the ratio of:

$\mathcal{B}(B_s^0 \to \mu^+\mu^-) \underset{\text{LHCb}}{=} (2.9^{+1.1}_{-1.0}) \times 10^{-9}$

$\mathcal{B}(B^0 \to \mu^+\mu^-) \underset{\text{LHCb}}{=} (3.7^{+2.5}_{-2.1}) \times 10^{-10}$

as these two measurements are correlated!

- Ratio will be provided by LHCb.
Implications of the very rare decay results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Would point to</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{BR}(B_s \rightarrow \mu \mu) \neq \text{SM}$</td>
<td>Big enhancement from NP in the scalar sector, SUSY at high $\tan \beta$</td>
</tr>
<tr>
<td></td>
<td>$\text{BR}(B_s \rightarrow \mu \mu) \neq \text{SM}$</td>
</tr>
<tr>
<td></td>
<td>SUSY, ED’s, LHT, TC2</td>
</tr>
<tr>
<td>$\text{BR}(B_s \rightarrow \mu \mu) \approx \text{SM}$</td>
<td>Anything ($\Rightarrow$ rule out regions of parameter space that predict sizable departures w.r.t. SM)</td>
</tr>
<tr>
<td>$\text{BR}(B_{sL} \rightarrow \mu \mu) \lesssim 10^{-10}$</td>
<td>NP in the scalar sector, but full MSSM ruled out. NMSSM (Higgs singlet) good candidate</td>
</tr>
<tr>
<td>$\text{BR}(B_s \rightarrow \mu \mu) / \text{BR}(B_d \rightarrow \mu \mu) \neq \text{SM}$</td>
<td>CMFV ruled out. New FCNC fully independent of CMK matrix (RPV-SUSY, ED’s, etc ...)</td>
</tr>
</tbody>
</table>
Rare decays in the theory

• The effective Hamiltonian (for $b \rightarrow s$)

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C_i' O_i') + h.c.$$

Wilson coefficients
(SHORT-scale effects)

Operators
(LONG-scale effects)

The operators $O_i$ that are most sensitive to NP effects are

$$O_7 = \frac{m_b}{e} (\bar{s} \sigma_{\mu\nu} P_R b) F^{\mu\nu},$$

$$O_9 = (\bar{s} \gamma_{\mu} P_L b)(\bar{\ell} \gamma^\mu \ell),$$

$$O_5 = m_b (\bar{s} P_R b)(\bar{\ell} \ell),$$

$$O_8 = \frac{g m_b}{e^2} (\bar{s} \sigma_{\mu\nu} T^a P_R b) G^{\mu\nu a},$$

$$O_{10} = (\bar{s} \gamma_{\mu} P_L b)(\bar{\ell} \gamma^\mu \gamma_5 \ell),$$

$$O_P = m_b (\bar{s} P_R b)(\bar{\ell} \gamma_5 \ell),$$
The decay $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

Analysis strategy

- Dataset: 2011 (1fb$^{-1}$)
- Select candidates in $K^*(\rightarrow K\pi)$ invariant mass range
- Reject dimuon resonances:
  - BDT against combinatorial bkg.
    - Topological info and PID
    - Trained with $B^0 \rightarrow K^*J/\Psi$ data for signal
    - Trained with sideband data for bkg.
    - Designed to be flat in angular acceptance
- Verify the analysis on $B^0 \rightarrow K^*J/\Psi$

[JHEP 1308 (2013) 131]
[10.1103/PhysRevLett.111.191801]
The decay $B^0_d \rightarrow K^{*0} \mu^+ \mu^-$

Analysis strategy

- Analysis done in 6 bins in $q^2$ from $0.1 < q^2 < 19 \text{ GeV}^2/c^4$
  - With 883 signal candidates (1fb$^{-1}$)

- Peaking backgrounds reduced to negligible level!

[JHEP 1308 (2013) 131] [10.1103/PhysRevLett.111.191801]
The decay $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

Angular observables

$A_{FB} = \frac{4}{3} S_6$

In the SM, $A_{FB}$ changes sign as function of $q^2$. The zero crossing-point is free of hadronic uncertainties:

→ First measurement of the zero-crossing point in $A_{FB}$: $q_0^2 = 4.9 \pm 0.9 \text{ GeV}^2/c^4$

Good agreement with SM!