Rare decays searches

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On behalf of LHCb
Including also results from BES-III, CLAS, CMS, NA48/2, and NA62
Rare Decays

- Very rare decays
  - $B_s \to \mu\mu$, $B_d \to \mu\mu$
  - Rare charm decays
  - Rare strange decays

- Lepton universality tests
  - Tests on $B \to D^{(*)} l\nu$
  - Tests on $b \to s ll$ transitions

- Other results from $b \to s(d) ll$ transitions
  - Branching ratios
  - Angular analyses

- Not covered here: radiative decays

See also:
Federico Redi, Exotics session
31/8/2015 14:30 - 14:55
Giovanni Veneziano, HF Physics session
2/9/2015 11:36 - 11:54
Rare Decays

- Rare decays correspond to indirect searches for BSM Dynamics (i.e., new particles)
- Indirect approach has been very successful in the past
  - Neutral Currents (Z$^0$ inferred ten years before direct observation)
  - Kaon mixing (top-quark inferred 30 years before direct observation)
Rare Decays

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- Indirect approach has been very successful in the past
  - Neutral Currents  
    (Z$^0$ inferred ten years before direct observation)
  - Kaon mixing  
    (top-quark inferred 30 years before direct observation)

( you may also notice Earth’ radius was inferred indirectly 2.3k years before direct observation…)

~2.3 K years till the direct observation…
VERY RARE DECAYS
$B_{s(d)} \rightarrow \mu\mu$ (results)

Full Run-I dataset analysed, giving:

$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (2.9^{+1.1}_{-1.0}\text{(stat)}^{+0.3}_{-0.1}\text{(syst)}) \times 10^{-9}$,

$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) = (3.7^{+2.4}_{-2.1}\text{(stat)}^{+0.6}_{-0.4}\text{(syst)}) \times 10^{-10}$

Consistent with SM predictions:

$BR(B_s \rightarrow \mu\mu) = (3.66 \pm 0.23) \times 10^{-9}$  \hspace{1cm} $BR(B_d \rightarrow \mu\mu) = (1.06 \pm 0.09) \times 10^{-10}$ (time averaged)
**$B_{s(d)} \rightarrow \mu \mu$ (results)**

Full Run-I dataset analysed, giving:

$$
\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (2.9^{+1.1}_{-1.0}\text{(stat)} ^{+0.3}_{-0.1}\text{(syst)}) \times 10^{-9},
$$

$$
\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = (3.7^{+2.4}_{-2.1}\text{(stat)} ^{+0.6}_{-0.4}\text{(syst)}) \times 10^{-10}
$$

Combined with CMS (joint likelihood fit)


6.2$\sigma$ observation of $B_s \rightarrow \mu \mu$

3.0$\sigma$ evidence for $B_d \rightarrow \mu \mu$

$$
\mathcal{B}\mathcal{R}(B_s \rightarrow \mu^+ \mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9}
$$

$$
\mathcal{B}\mathcal{R}(B_d \rightarrow \mu^+ \mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10}
$$

Ratio $B_s/B_d$ BF’s agreement with SM at 2.3$\sigma$
Rare charm decays: $D^0 \to \gamma\gamma$ BES III

- Analyzed 2.9 fb-1
- BR normalized to $D^0 \to \pi^0\pi^0$, which is also a background source

$\mathcal{B}(D^0 \to \gamma\gamma) < 3.8 \times 10^{-6}$ (@ 90% CL)
Rare charm decays: $D^0 \rightarrow \mu\mu$

SM prediction: $\text{BR}(D^0 \rightarrow \mu\mu) < 1.6 \times 10^{-11}$
(Precision depends on knowledge of $\text{BR}(D^0 \rightarrow \gamma\gamma)$)

BSM physics (RPV, ED’s) can enhance it up to the $10^{-10}$ level

LHCb performed a search using 1 fb$^{-1}$

$\text{BR}(D^0 \rightarrow \mu\mu) < 6.2(7.6) \times 10^{-9}$ @ 90(95) % CL$_s$

Potential to reach more interesting region with LHCb upgrade
### Other rare charm decays @ LHCb

<table>
<thead>
<tr>
<th>Decay</th>
<th>Run -I</th>
<th>Run - II</th>
<th>Upgrade</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{(s)}^{+} \rightarrow \pi^{+} \mu^{+} \mu^{-}$</td>
<td>Few 10⁻⁸</td>
<td>Fewer 10⁻⁸</td>
<td>Few 10⁻⁹</td>
<td>1/3 Run-I arXiv:1304.6365, Phys. Lett. B 724 (2013) 203-212</td>
</tr>
<tr>
<td>$D_{(s)}^{+} \rightarrow \pi^{-} \mu^{+} \mu^{+}$</td>
<td>Few 10⁻⁸</td>
<td>Fewer 10⁻⁸</td>
<td>Few 10⁻⁹</td>
<td>1/3 Run-I arXiv:1304.6365, Phys. Lett. B 724 (2013) 203-212</td>
</tr>
<tr>
<td>$D_{s}^{+} \rightarrow K^{+} \mu^{+} \mu^{-}$</td>
<td>Few 10⁻⁷</td>
<td>Fewer 10⁻⁷</td>
<td>Few 10⁻⁸</td>
<td>Work ongoing</td>
</tr>
<tr>
<td>$D^{0} \rightarrow h^{+} h^{-} \mu^{+} \mu^{-}$</td>
<td>Few 10⁻⁷</td>
<td>Fewer 10⁻⁷</td>
<td>Few 10⁻⁸</td>
<td>Work ongoing</td>
</tr>
<tr>
<td>$\Lambda_{c}^{+} \rightarrow p \mu^{+} \mu^{-}$</td>
<td>Few 10⁻⁷</td>
<td>Fewer 10⁻⁷</td>
<td>Few 10⁻⁸</td>
<td>Work ongoing</td>
</tr>
<tr>
<td>$D^{0} \rightarrow \mu^{+} e^{-}$</td>
<td>Few 10⁻⁸</td>
<td>Fewer 10⁻⁸</td>
<td>Few 10⁻⁹</td>
<td>Work ongoing</td>
</tr>
<tr>
<td>$\sigma(A_{CP}D^{0} \rightarrow \phi \gamma)$</td>
<td>~10%</td>
<td>5%</td>
<td>?</td>
<td>Work ongoing</td>
</tr>
</tbody>
</table>
Rare strange decays: Recent results

NA48/2: Discovery of $K^\pm \rightarrow \pi^\pm \pi^0 e^+e^-$

$\text{BR}(K^\pm \rightarrow \pi^\pm \pi^0 e^+e^-) = (4.06\pm0.17) \times 10^{-6}$

(CLAS collaboration (Jefferson Lab):
Limits on $B$ and $L$ violation

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$B_{UL}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda \rightarrow K^+e^-$</td>
<td>$2 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\Lambda \rightarrow K^+\mu^-$</td>
<td>$3 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\Lambda \rightarrow K^-e^+$</td>
<td>$2 \times 10^{-6}$</td>
</tr>
<tr>
<td>$\Lambda \rightarrow K^-\mu^+$</td>
<td>$3 \times 10^{-6}$</td>
</tr>
<tr>
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</tr>
<tr>
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<td>$6 \times 10^{-7}$</td>
</tr>
<tr>
<td>$\Lambda \rightarrow \pi^-e^+$</td>
<td>$4 \times 10^{-7}$</td>
</tr>
<tr>
<td>$\Lambda \rightarrow \pi^-\mu^+$</td>
<td>$6 \times 10^{-7}$</td>
</tr>
<tr>
<td>$\Lambda \rightarrow \bar{p}\pi^+$</td>
<td>$9 \times 10^{-7}$</td>
</tr>
<tr>
<td>$\Lambda \rightarrow K_S^0\nu$</td>
<td>$2 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

(Preliminary)

arXiv:1508.01307 [hep-ex]

arXiv:1507.03859 [hep-ex]
Rare strange decays: $K_S \rightarrow \mu\mu$

- SM prediction: $BR(K_S \rightarrow \mu\mu) = (5.1\pm1.5)\times10^{-12}$

- $K_S \rightarrow \mu\mu$ sensitive to different physics than $K_L \rightarrow \mu\mu$ (see JHEP 0401 (2004) 009)

- LHCb performed a search using 1fb$^{-1}$:

$$BR(K_S \rightarrow \mu\mu) < 9(11)\times10^{-9} @90(95)\% \text{CL}_s$$

Potential to reach more interesting region with LHCb upgrade
Rare strange decays: prospects

**NA62**

- Started data taking end of June
- Measured detector performances within expectation
- Aims for 10% precision in \( \text{BR}(K^\pm \rightarrow \pi^\pm \nu\nu) \)

**KOTO** \( \text{BR}(K_L \rightarrow \pi^0 \nu\nu) \) also starting data taking

**LHCb**

- \( \Sigma \rightarrow p\mu\mu \): aim to confirm / reject Hyper CP anomaly
- Work ongoing in \( K_S \rightarrow \mu\mu \) update
- Several other kaon/hyperon decays being explored (\( K_S \rightarrow \pi^0 \mu\mu, K_S \rightarrow \pi\pi \mu\mu, K_S \rightarrow \mu\mu\mu\mu, \text{electron modes} \ldots \))
Lepton Universality in $B \to D(*) l \nu$

\[ R(D) = \frac{B(B^0 \to D^+ \tau^- \nu)}{B(B^0 \to D^+ \mu^- \nu)} \quad R(D^*) = \frac{B(B^0 \to D^{*+} \tau^- \nu)}{B(B^0 \to D^{*+} \mu^- \nu)} \]

- Some tension found in the past by Babar and Belle
- LHCb analyzed the full Run-I dataset, using $\tau \to \mu \nu \nu$
- Separate signal from background fitting $M_{\text{miss}}^2$, $q^2$, and $E_\mu$

R($D^*$) measured value in LHCb is $2.1 \sigma$ higher than SM prediction, strengthening the tension.

\[ \Delta \chi^2 = 1.0 \]

Average is $3.9\sigma$ away from SM

arXiv:1506.08614
Lepton Universality in $b \rightarrow s ll$ transitions

LHCb performed a lepton universality test in $B^+ \rightarrow K^+ \ell^+ \ell^-$ with full Run-I dataset

$$R_K = \frac{BF(B^+ \rightarrow K^+\mu^+\mu^-)}{BF(B^+ \rightarrow K^+e^+e^-)} = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.036(\text{syst})$$

Result in agreement within 2.6σ from SM prediction of $R_K = 1$
Result with $m_{ll}$ at the $J/\psi$ resonance consistent with 1

Work ongoing to test lepton universality in $K^*\ell^+\ell^-$ and $\Phi\ell^+\ell^-$ models
Other $b \to s(d) \ell^+\ell^-$ transitions
$B_d \rightarrow K^*(\rightarrow K\pi) \, \mu\mu$

- Full Run-I dataset analyzed.
- We select events using a BDT and special vetoes for specific backgrounds.
- Correct (in an event-by-event basis) for the effect of reconstruction/selection/trigger using simulation.
- Validated on data via control channels (mainly $B_d \rightarrow J/\psi(\mu\mu) \, K^*(K\pi)$).
- Fit yields and angular distributions for observables in bins of $q^2$ (dimuon invariant mass squared).
$B_d \rightarrow K^* (\rightarrow K\pi) \, \mu\mu$

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$B_d \to K^* (\to K\pi) \mu\mu$

$$\frac{1}{d\Gamma/dq^2 dq^2 d\cos\theta_\ell d\cos\theta_K} d\phi = \frac{9}{16\pi} \left[ F_L \cos^2\theta_K + \frac{3}{4} (1 - F_L) (1 - \cos^2\theta_K) - F_L \cos^2\theta_K (2 \cos^2\theta_\ell - 1) + \frac{1}{4} (1 - F_L) (1 - \cos^2\theta_K) (2 \cos^2\theta_\ell - 1) + S_3 (1 - \cos^2\theta_K) (1 - \cos^2\theta_\ell) \cos 2\phi + \frac{1}{2} A_{FB} (1 - \cos^2\theta_K) \cos\theta_\ell + A_9 (1 - \cos^2\theta_K) (1 - \cos^2\theta_\ell) \sin 2\phi \right]$$

Zero crossing point of $A_{FB}$

$q_{ZCP}^2 = 3.7^{+0.8}_{-1.1} \text{GeV}^2$ (Preliminary)

Consistent with SM:

JHEP 01 (2012) 107
PDF can also be parameterized to minimize form factors uncertainties

\[
\frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{d\cos\theta_L d\cos\theta_K d\phi d^2q} = \frac{9}{32\pi} \left[ \frac{3}{4} (1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K + \frac{1}{4} (1 - F_L) \sin^2 \theta_K \cos 2\theta_L \\
- F_L \cos^2 \theta_K \cos 2\theta_L + S_3 \sin^2 \theta_K \sin^2 \theta_L \cos 2\phi \\
+ S_4 \sin 2\theta_K \sin 2\theta_L \cos \phi + S_5 \sin 2\theta_K \sin \theta_L \cos \phi \\
+ S_6 \sin^2 \theta_K \cos \theta_L + S_7 \sin 2\theta_K \sin \theta_L \sin \phi \\
+ S_8 \sin 2\theta_K \sin 2\theta_L \sin \phi + S_9 \sin^2 \theta_K \sin^2 \theta_L \sin 2\phi \right],
\]

\[
P_i' = \frac{S_{ij=4,5,7,8}}{\sqrt{F_L (1 - F_L)}}
\]

Experimental precision will keep improving
Work ongoing in the theory community (SM/NP) to better understand the pattern
$B_s \rightarrow \Phi(\rightarrow KK) \mu\mu$

- Similar to $B_d \rightarrow K^*(\rightarrow K\pi) \mu\mu$ but changing spectator quark ($s \rightarrow d$)
- Full Run-I dataset analysed
$\Lambda_b \to \Lambda(\to p\pi) \mu\mu$

- Similar to $B_d \to K^*(\to K\pi) \mu\mu$ but in the baryonic mode
- There is also an additional observable: $A_{FB}^h$
- Full Run-I dataset analysed
**B^+ \rightarrow \pi^+\mu\mu**

- **b \rightarrow d\mu \mu** transition
- **Full Run-I data analysed to measure branching fraction and CP asymmetry**

Preliminary

\[ \mathcal{A}_{CP} \equiv \frac{\Gamma(B^- \rightarrow \pi^-\mu^+\mu^-) - \Gamma(B^+ \rightarrow \pi^+\mu^+\mu^-)}{\Gamma(B^- \rightarrow \pi^-\mu^+\mu^-) + \Gamma(B^+ \rightarrow \pi^+\mu^+\mu^-)} \]

\[ \mathcal{B}(B^{\pm} \rightarrow \pi^{\pm}\mu^+\mu^-) = (1.83 \pm 0.24 \pm 0.05) \times 10^{-8} \]

\[ \mathcal{A}_{CP}(B^{\pm} \rightarrow \pi^{\pm}\mu^+\mu^-) = -0.11 \pm 0.12 \pm 0.01 , \]

Preliminary
Angular analysis of $B_d \rightarrow K^* (\rightarrow K\pi) e^+ e^-$ at small $q^2$ values is sensitive to photon polarization, which is predominantly left-handed in the SM.

Measurement of $F_L$, $A_T^{(2)}$, $A_T^{(\text{Im})}$, $A_T^{(\text{Re})}$ in the $q^2$ region $[0.004, 1.0]$ GeV$^2$, using 124 signal candidates using full Run-I dataset.

$$A_T^{(2)}(q^2 \rightarrow 0) = \frac{2Re(C_7 C_7')}{|C_7|^2 + |C_7'|^2} \quad A_T^{\text{Im}}(q^2 \rightarrow 0) = \frac{2Im(C_7 C_7')}{|C_7|^2 + |C_7'|^2}$$

<table>
<thead>
<tr>
<th>Result</th>
<th>obs.</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_L$</td>
<td>+0.16±0.06±0.03</td>
<td></td>
</tr>
<tr>
<td>$A_T^{(2)}$</td>
<td>−0.23±0.23±0.05</td>
<td></td>
</tr>
<tr>
<td>$A_T^{\text{Re}}$</td>
<td>+0.10±0.18±0.05</td>
<td></td>
</tr>
<tr>
<td>$A_T^{\text{Im}}$</td>
<td>+0.14±0.22±0.05</td>
<td></td>
</tr>
</tbody>
</table>

Results consistent with SM, sensitivity to $C'_7$ comparable to time-dependent analysis of $B \rightarrow K_s \pi^0 \gamma$ by B factories (PRD 78 071102, PRD 74 111104)
Global model-independent fit of the Wilson coefficients using measurements from ATLAS, CMS, LHCb (Altmannshofer, Straub)

The fit prefers $C_{9}^{\text{NP}} \sim -1.1$

Could be due to a $Z'$ (Gauld et al., JHEP 1401 (2014) 069, Buras et al., JHEP 1402 (2014) 112, Altmannshofer et al. PRD 89 (2014) 095033,...) or not well understood hadronic effect.

For details see C. Bobeth’s talk yesterday
Conclusions

• $B_{s(d)} \rightarrow \mu\mu$ full Run-I dataset analysed, also combined with CMS Run-I data
  • $B_s \rightarrow \mu\mu$ significance is 6.2σ.
  • First evidence for $B_d \rightarrow \mu\mu$ (3.2σ). Ratio $B_d/B_s$ within SM at 2.3σ Level

• Results and prospects for rare charm and strange and decays presented

• $b \rightarrow s(d)\ell\ell$ transitions: several analyses using full Run-I data.
  • The overall picture shows some tension with SM in the Wilson coefficient $C_9$ (If not a fluctuation, then its either missing SM contributions or, if interpreted as NP then the likeliest is a $Z'$).

• Lepton universality tests on $B^+ \rightarrow K^+\ell^+\ell^-$ show 2.6σ agreement with SM.
Bone, you are hard...

... but I am patient...

source: google osso duro
The LHCb experiment

Forward spectrometer with very precise tracking and PID

- Decay time resolution
  40 fs ($B \rightarrow J/\psi KK$)
- Invariant mass resolution
  ~23 MeV ($B \rightarrow \mu \mu$)
- 95% ($K-\pi$) ID efficiency for 5% fake rate

Efficient and flexible trigger
$\varepsilon \sim 90\%$ $B \rightarrow \mu \mu$ decays

Recorded luminosity: 3 fb$^{-1}$

1 fb$^{-1}$ at 7 TeV (2011)
2 fb$^{-1}$ at 8 TeV (2012)

Also, took 13nb$^{-1}$ of pA data
Rare strange decays: prospects

- LHCb will keep being world leading on $K_S \rightarrow \mu \mu$

- **Most interesting region** ($\text{BR}(K_S \rightarrow \mu \mu) < 10^{-10}$) might be achievable with LHCb upgrade (**requires trigger developments**)

- Sensitivity to other decays under investigation:
  - $\Sigma \rightarrow \rho \mu \mu$: aim to confirm / reject Hyper CP anomaly
  - $K_S \rightarrow \pi^0 \mu \mu$: $K_L \rightarrow \pi^0 \mu \mu$ (sensitive to eg, ED) NP reach is limited by experimental uncertainty on $K_S \rightarrow \pi^0 \mu \mu$. We might have a chance to improve that (**requires trigger developments**)
  - Other possibilities under investigation: $K_S \rightarrow \pi \pi \mu \mu, K_S \rightarrow \mu \mu \mu \mu, \text{electron modes...}$
These decays are very suppressed in SM

$$\text{BR}(B_s \rightarrow \mu\mu) = (3.66 \pm 0.23) \times 10^{-9} \quad \text{BR}(B_d \rightarrow \mu\mu) = (1.06 \pm 0.09) \times 10^{-10}$$

... but can be modified by NP.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Would point to</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{BR}(B_s \rightarrow \mu\mu) &gt;&gt; \text{SM})</td>
<td>Big enhancement from NP in the scalar sector, SUSY at high (\tan\beta)</td>
</tr>
<tr>
<td>(\text{BR}(B_s \rightarrow \mu\mu) \neq \text{SM})</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 parameters space that predict sizable departures w.r.t SM)</td>
</tr>
<tr>
<td>(\text{BR}(B_s \rightarrow \mu\mu) &lt;&lt; \text{SM})</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 independent of CKM matrix (RPV-SUSY, ED’s, etc …)</td>
</tr>
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</table>
**\( \text{B}_{s(d)} \to \mu\mu \) (what does it imply?)**

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<td>( \text{BR}(\text{B}<em>{s} \to \mu\mu)/\text{BR}(\text{B}</em>{d} \to \mu\mu) \neq \text{SM} )</td>
<td>CMFV ruled out. New FCNC fully independent of CKM matrix (RPV-SUSY, ED’s, etc…).</td>
</tr>
</tbody>
</table>

... You expect some constraints at least in SUSY at high tan\( \beta \)
$B_{s(d)} \rightarrow \mu \mu$ (LHCb analysis strategy)

I) Selection cuts in order to reduce the amount of data to analyse.

II) Classification of $B_{s,d} \rightarrow \mu \mu$ events in a 2D space
   - Invariant mass of the $\mu \mu$ pair
   - Boosted Decision Tree (BDT) combining geometrical and kinematical information about the event.

III) Control channels ($B \rightarrow hh$, $B \rightarrow J/\psi K$, mass sideb.) to get signal and background expectations w/o relying on simulation

IV) Fit for signal strength : simultaneous fit of the mass spectrum in the different BDT regions
Rare strange decays: introduction

- Minimal Flavour Violation motivated by search of NP ~ TeV
- But if NP > few TeV, non-MFV scenarios become very interesting
- In such contest rare decays of strange particles are very important: $s \to d$ transitions have the strongest CKM suppression (i.e., strongest suppression of SM “background”)

\[
A = A_0 \left[ c_{SM} \frac{1}{M_W^2} + c_{NP} \frac{1}{\Lambda^2} \right]
\]

\[
\sim V_{ts} V_{td} \approx 10^{-4}
\]

From G. Isidori @ Rare’n’Strange
# Other very rare decays @ LHCb

(Update)

<table>
<thead>
<tr>
<th>Decay</th>
<th>Main BSM test</th>
<th>95% upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow \mu\mu\mu\mu$</td>
<td>Some SUSY scenarios</td>
<td>$&lt;1.6 \times 10^{-8}$ (PRL. 110, 211801)</td>
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<td>$B_d \rightarrow \mu\mu\mu\mu$</td>
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</tr>
<tr>
<td>$\tau \rightarrow \mu\mu\mu$</td>
<td>LFV (ex: LHT)</td>
<td>$&lt;5.6 \times 10^{-8}$ (arXiv:1409.8548)</td>
</tr>
<tr>
<td>$B_s \rightarrow e\mu$</td>
<td>RPV, Pati-Salam LQ…</td>
<td>$&lt;1.4 \times 10^{-8}$ (PRL. 111 141801)</td>
</tr>
<tr>
<td>$B_d \rightarrow e\mu$</td>
<td>RPV, Pati-Salam LQ…</td>
<td>$&lt;3.7 \times 10^{-9}$ (PRL. 111 141801)</td>
</tr>
<tr>
<td>$B \rightarrow X\mu^+\mu^+$</td>
<td>4th gen. Majoranas</td>
<td>See Phys. Rev. D 85, 112004</td>
</tr>
</tbody>
</table>

A good example of flavour physics accessing high energy scales.

$M_{LQ}(B_s^0 \rightarrow e^\pm\mu^{\mp}) > 106$ TeV/$c^2$

$M_{LQ}(B^0 \rightarrow e^\pm\mu^{\mp}) > 127$ TeV/$c^2$

(arXiV references in backup)
C. Bobeth, yesterday

\begin{table}
\centering
\begin{tabular}{|l|c|c|}
\hline
Ref. & $q^2 \in [2.5, 4]\;\text{GeV}^2$ & $q^2 \in [4, 6]\;\text{GeV}^2$ \\
\hline
LHCb (3/fb) & $-0.07^{+0.34}_{-0.36}$ & $-0.30 \pm 0.16$ \\
\hline
ABSZ (qua) & $-0.50 \pm 0.10$ & $-0.77 \pm 0.07$ \\
ABSZ (lin) & $-0.50 \pm 0.16$ & $-0.77 \pm 0.11$ \\
\hline
DHMV (qua) & $-0.49^{+0.14}_{-0.16}$ & $-0.79^{+0.10}_{-0.12}$ \\
DHMV (lin) & $-0.49^{+0.26}_{-0.30}$ & $-0.79^{+0.16}_{-0.21}$ \\
\hline
JMC (68\%) & $-0.28^{+0.14}_{-0.13}$ & $-0.71^{+0.11}_{-0.10}$ \\
JMC (max spread) & $-0.28^{+0.54}_{-0.42}$ & $-0.70^{+0.49}_{-0.31}$ \\
\hline
\end{tabular}
\caption{Comparison of different models for $q^2$ integration.}
\end{table}

ABSZ = $1411.3161 + 1503.05534$, \quad DHMV = $1407.8526 + 1503.03328$, \quad JMC = $1412.3183 +$ talk S. Jäger Portoroz ’15

LHCb = LHCb-CONF-2015-002
# Results on $b \rightarrow s ll$

(Update)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Luminosity</th>
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<tr>
<td>$\text{BR}(B^+ \rightarrow \pi^+\mu^+\mu^-)$</td>
<td>$1 \text{ fb}^{-1}$</td>
<td>JHEP 12 (2012) 125</td>
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<tr>
<td>$\text{BR}(B_d \rightarrow K^*e^+e^-)$</td>
<td>$1 \text{ fb}^{-1}$</td>
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<td>$B_d \rightarrow K^*\mu^+\mu^-$, angular analysis (I) ($A_{FB}, F_L, S_3 ...$)</td>
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<td>$B_s \rightarrow \Phi\mu^+\mu^-$, angular analysis</td>
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<td>$\text{BR}(\Lambda_b \rightarrow \Lambda\mu^+\mu^-)$</td>
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<td>PRL 111, 112003 (2013)</td>
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<td>$B_d \rightarrow K^*\mu^+\mu^-$, angular analysis (II) ($P'_i$)</td>
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<td>$B \rightarrow K(\ast)\mu^+\mu^-$, BR and Isospin Asymmetry</td>
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<td>$B \rightarrow Kl^+l^-$ Lepton universality</td>
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<td>$B \rightarrow K(\ast)\mu^+\mu^-$ CP asymmetries</td>
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<td>$\text{BR}(B^+ \rightarrow hhh\mu^+\mu^-)$</td>
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<td>JHEP 1410 (2014) 064</td>
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(arXiv references in backup)