University of Zurich^UZH

Physics Institute

Electroweak penguin decays to leptons at LHCb

Flavour Physics Conference Quy Nhon July 28, 2014

Marco Tresch on behalf of the LHCb collaboration

Indirect search for NP

- Flavour changing neutral current (FCNC) transitions are heavily suppressed in the SM, only decays through loop diagrams are allowed (e.g. penguin decays).
- Ideal probe for indirect searches for New Physics (NP)!
  - Effective Hamiltonian for $b \to s$ transitions

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_{i=1\ldots10,S,P} (C_i O_i + C_i' O_i') + h.c.$$

  - NP can either
    - modify Wilson coefficients $C^{(\prime)}$
    - or add new operators $\sum_j C_j^{NP} O_j^{NP}$

  and change the decay rates, angular distributions, branching fractions, etc

- **Focus on the recent results from LHCb on $b \to s$ transitions**

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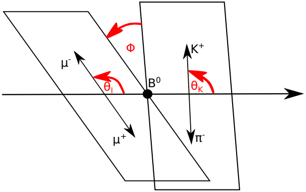
- **Focus on the recent results from LHCb on $b \to s$ transitions**

$B^0 \to K^{*0}\mu^+\mu^-$

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} = \frac{9}{32\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_\mathrm{K} + F_\mathrm{L}\cos^2\theta_\mathrm{K} + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_\mathrm{K}\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_\mathrm{K}\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_\mathrm{K}\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_\mathrm{K}\sin\theta_\ell\cos\phi$$
$$+ S_6\sin^2\theta_\mathrm{K}\cos\theta_\ell + S_7\sin 2\theta_\mathrm{K}\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_\mathrm{K}\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_\mathrm{K}\sin^2\theta_\ell\sin 2\phi\Big]$$

- Neglect lepton masses, average B^0 and $\bar{B}^0$
- Angular terms can be measured in bins of q^2
- Theory uncertainties are dominated by the $B^0 \to K^{*0}$ form-factors
- Analysed in two steps (JHEP08(2013)131) and (PhysRevLett.111.191801) with different foldings to reduce the number of coefficients



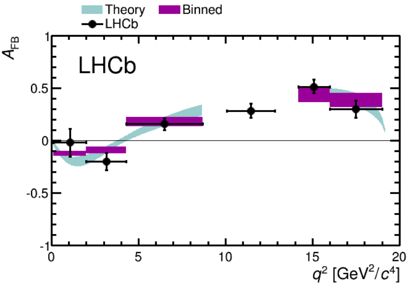
$B^0 \to K^{*0}\mu^+\mu^-$, Analysis Strategy

JHEP08(2013)131
with 1 fb^{-1}

1. loose cut based selection followed by a multivariate selection to select a clean sample
2. specific backrounds are then rejected using mass and particle identification criteria ($B^0 \to J/\psi\, K^{*0}$ and $B^0 \to \psi(2S)K^{*0}$).

   Remaining sources of background:
   - $B^0 \to J/\psi\, K^{*0}$ misidentified $(0.3 \pm 0.1)\%$
   - $B^0_s \to \phi\mu^+\mu^-$ $(1.2 \pm 0.5)\%$
   - $\bar{B}^0_s \to K^{*0}\mu^+\mu^-$ $(1.0 \pm 1.0)\%$
3. acceptance correction is applied to minimize the bias on the angular distribution
4. the angular observables are extracted with a multidimensional maximum likelihood fit

- $A_{\rm FB} = (4/3\ S_6)$, $A_{\rm FB}\ (q_0^2) = 0$

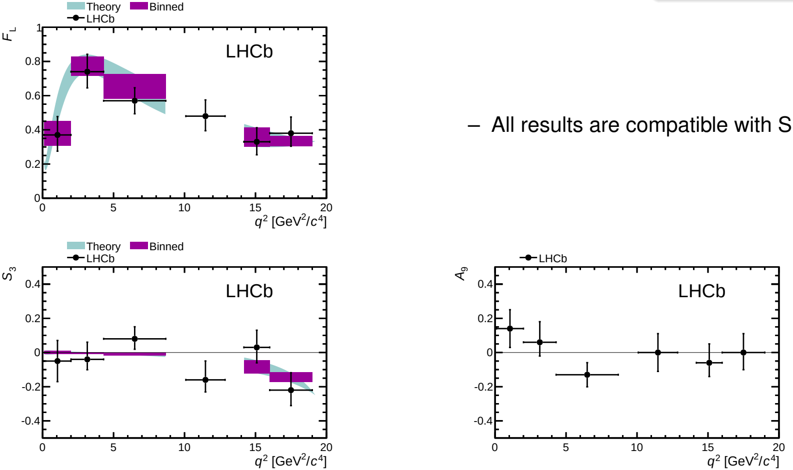


- $q_0^2 = 4.9 \pm 0.9\ \mathrm{GeV}^2/c^4$, consistent with SM $3.9 - 4.4\,\mathrm{GeV}^2/c^4$

Theory prediction:
(Bobeth et al. JHEP 07 (2011) 067 and references therein)

JHEP08(2013)131
with 1 fb^{-1}

$B^0 \to K^{*0}\mu^+\mu^-$, Observables



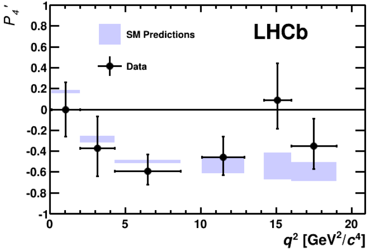
- All results are compatible with SM

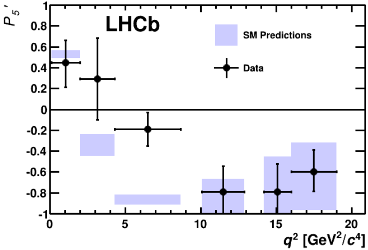
$B^0 \to K^{*0}\mu^+\mu^-$, form-factor independent observables

PhysRevLett.111.191801
with 1 fb^{-1}

- Change of basis, form-factor cancels at leading order

$$P'_{i=4,5,6,8} = \frac{S_{j=4,5,7,8}}{\sqrt{F_L(1-F_L)}}$$





- P'_5 shows a local deviation of 3.7σ in one q^2 bin ($4.30 - 8.68\,\mathrm{GeV}^2/c^4$), as discussed by M. Patel.

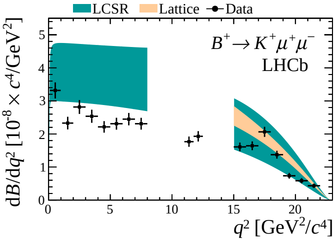
Theory prediction: (Decotes-Genon et al. JHEP 05 (2013) 137)

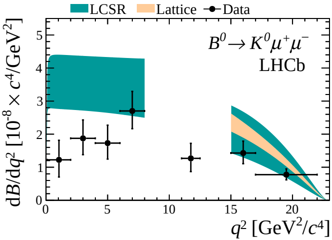
JHEP 06 (2014) 133

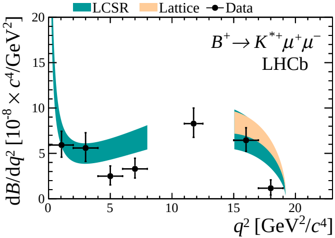
with 3 fb^{-1}

$B \rightarrow K^{(*)}\mu^+\mu^-$ branching fraction

- measured: $B^+ \rightarrow K^+\mu^+\mu^-$, $B^0 \rightarrow K^0\mu^+\mu^-$ and $B^+ \rightarrow K^{*+}\mu^+\mu^-$
- normalised to $B \rightarrow J/\psi\, K^{(*)}$
- measured branching fraction are below the SM predictions (see talk of M. Wingate)







$B \to K\mu^+\mu^-$ angular analysis

JHEP 05 (2014) 082

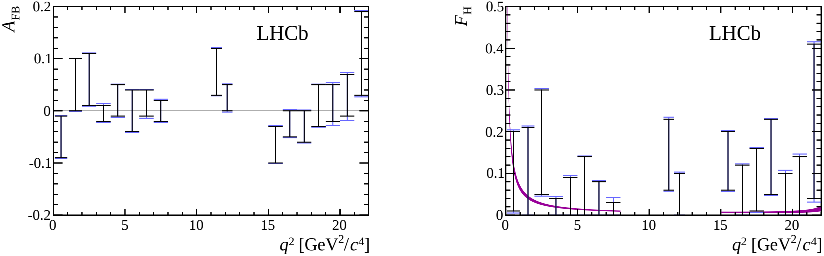
with 3 fb^{-1}

- Angular distribution for $B^+ \to K^+\mu^+\mu^-$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}(1 - F_H)(1 - \cos^2\theta_\ell) + \frac{1}{2}F_H + A_{\mathrm{FB}}\cos\theta_\ell$$

Both parameters are roughly zero in SM

- A_{FB} forward backward asymmetry
- F_H fractional contribution to decay width from (pseudo)-scalar or tensor amplitudes



- Similar for $B^0 \to K^0_{\mathrm{S}}\mu^+\mu^-$

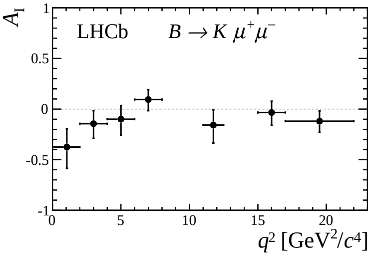
$B \to K^{(*)}\mu^+\mu^-$ isospin asymmetry

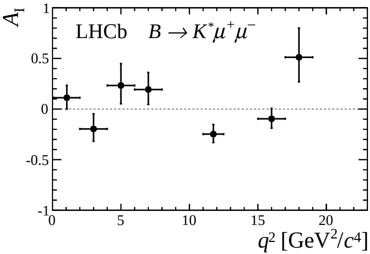
JHEP 06 (2014) 133
with 3 fb^{-1}

- Isopsin asymmetry:

$$A_I = \frac{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

- A_I predicted to be zero in SM





LHCB-PAPER-2014-024
with 3 fb^{-1}

Lepton universality test using $B^+ \to K^+\ell^+\ell^-$

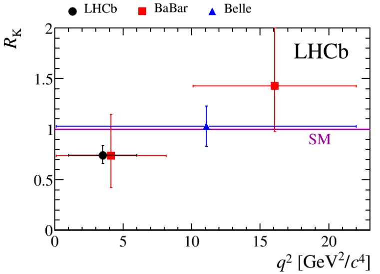
Defined as:

$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)} = 1 \pm \mathcal{O}(10^{-3}) \text{ in SM}$$

- to cancel systematics forming double ratios with $B^+ \to J/\psi K^+$ (assuming lepton universality for $J/\psi \to \ell^+\ell^-$)

$B^0 \to K^+e^+e^-$ challenging:

- Recover loss of Bremsstrahlung by adding ECAL cluster energy ($E_T > 75\,\mathrm{MeV}$)
- Signal shape depends heavily on number of Bremsstrahlungsphotons, p_{T} and occupancy of the event → split analysis in three trigger categories
- $B^0 \to K^{*0}e^+e^-$ largest contribution to part. background
- About 5 × less signal than in $B^+ \to K^+\mu^+\mu^-$



- $R_K = 0.745^{+0.090}_{-0.074}\,(\mathrm{stat}) \pm 0.036\,(\mathrm{syst})$

$B \to K^{(*)}\mu^+\mu^-$ *CP* asymmetries

NEW! with 3 fb^{-1}
preliminary
LHCb-PAPER-2014-032

- *CP* asymmetry:

$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-) - \Gamma(B \to K^{(*)}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-) + \Gamma(B \to K^{(*)}\mu^+\mu^-)}$$

- A_{CP} predicted for $B^+ \to K^+\mu^+\mu^-$ and $B^0 \to K^{*0}\mu^+\mu^-$ to be of $\mathcal{O}\,(10^{-3})$
- Measure A_{RAW} instead of A_{CP} directly

$$A_{RAW}(B \to K^{(*)}\mu^+\mu^-) = A_{CP}(B \to K^{(*)}\mu^+\mu^-) + A_D + A_P$$

- Assuming the A_D and A_P are identical between $B \to K^{(*)}\mu^+\mu^-$ and $B \to J/\psi\, K^{(*)}$, and use $A_{CP}(B \to J/\psi\, K^{(*)}) = 0$:

$$A_{CP}(B \to K^{(*)}\mu^+\mu^-) = A_{RAW}(B \to K^{(*)}\mu^+\mu^-) - A_{RAW}(B \to J/\psi\, K^{(*)}) - A_{CP}(B \to J/\psi\, K^{(*)})$$

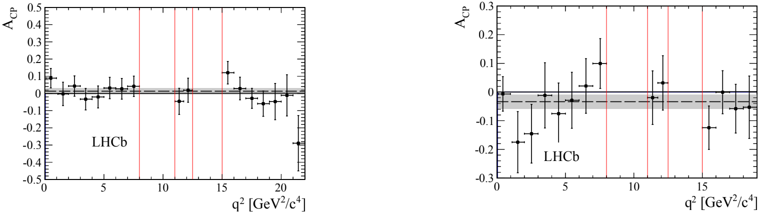
NEW! with 3 fb^{-1}
preliminary
LHCb-PAPER-2014-032

$B \to K^{(*)}\mu^+\mu^-$ *CP* asymmetries

- *CP* asymmetry:

$$A_{CP} = \frac{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-) - \Gamma(B \to K^{(*)}\mu^+\mu^-)}{\Gamma(\bar{B} \to \bar{K}^{(*)}\mu^+\mu^-) + \Gamma(B \to K^{(*)}\mu^+\mu^-)}$$

- A_{CP} predicted for $B^+ \to K^+\mu^+\mu^-$ to be zero and for $B^0 \to K^{*0}\mu^+\mu^-$ to be $\mathcal{O}\,(10^{-3})$



- weighted average of the q^2 bins:

$$A_{CP}(B^0 \to K^{*0}\mu^+\mu^-) = -0.035 \pm 0.024\,(\mathrm{stat}) \pm 0.003\,(\mathrm{syst})$$

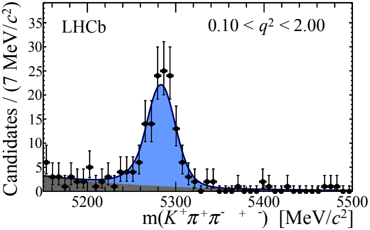
$$A_{CP}(B^+ \to K^+\mu^+\mu^-) = -0.012 \pm 0.017\,(\mathrm{stat}) \pm 0.001\,(\mathrm{syst})$$

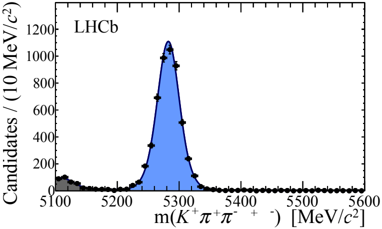
NEW! with 3 fb^{-1}
preliminary
LHCb-PAPER-2014-030

$B^+ \to K^+\pi^+\pi^-\mu^+\mu^-$ observation

- $B^+ \to K^+\pi^+\pi^-\mu^+\mu^-$ first observation measured in bins of q^2
- $B^+ \to \psi(2S)K^+$ as normalisation mode with:

$\mathcal{B}\,(B^+ \to \psi(2S)(\to J/\psi\,(\to \mu^+\mu^-)\pi^+\pi^-)K^+) = (1.26 \pm 0.05) \times 10^{-5}$



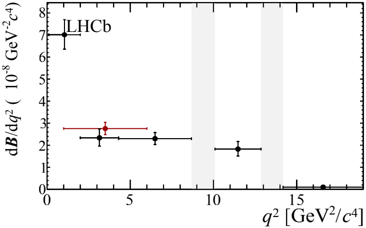


NEW! with 3 fb^{-1}
preliminary
LHCb-PAPER-2014-030

$B^+ \to K^+\pi^+\pi^-\mu^+\mu^-$ observation

- $B^+ \to K^+\pi^+\pi^-\mu^+\mu^-$ first observation measured in bins of q^2
- $B^+ \to \psi(2S)K^+$ as normalisation mode

q^2 bin $[\mathrm{GeV}^2/c^4]$	$\frac{d\mathcal{B}}{dq^2}$ $[\times 10^{-8}\ \mathrm{GeV}^{-2}c^4]$
[0.10, 2.00]	$7.01\,^{+0.69}_{-0.65} \pm 0.47$
[2.00, 4.30]	$2.34\,^{+0.41}_{-0.38} \pm 0.15$
[4.30, 8.68]	$2.30\,^{+0.28}_{-0.26} \pm 0.20$
[10.09, 12.86]	$1.83\,^{+0.34}_{-0.32} \pm 0.17$
[14.18, 19.00]	$0.10\,^{+0.08}_{-0.06} \pm 0.01$
[1.00, 6.00]	$2.75\,^{+0.29}_{-0.28} \pm 0.16$



$$\mathcal{B}(B^+ \to K^+\pi^+\pi^-\mu^+\mu^-) = \left(4.36^{+0.29}_{-0.27}\,(\mathrm{stat}) \pm 0.21\,(\mathrm{syst}) \pm 0.18(\mathrm{norm})\right) \times 10^{-7}$$

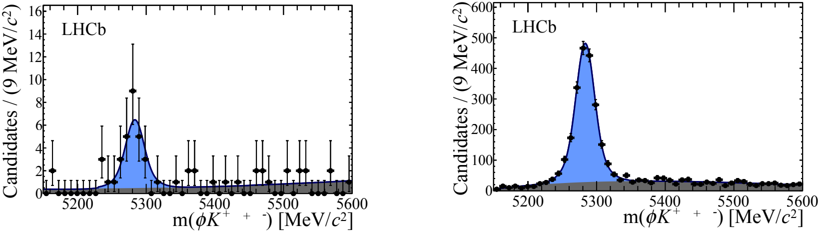
$$\frac{\mathcal{B}(B^+ \to K^+\pi^+\pi^-\mu^+\mu^-)}{\mathcal{B}(B^+ \to \psi(2S)K^+)} = (6.95^{+0.46}_{-0.43}\,(\mathrm{stat}) \pm 0.34\,(\mathrm{syst})) \times 10^{-4}$$

NEW! with 3 fb^{-1}
preliminary
LHCb-PAPER-2014-030

$B^+ \to \phi K^+ \mu^+ \mu^-$ observation

- $B^+ \to \phi K^+ \mu^+ \mu^-$ first observation
- $B^+ \to \phi J/\psi\, K^+$ as normalisation mode

$\mathcal{B}\,(B^+ \to J/\psi\,(\to \mu^+\mu^-)\phi K^+) = (3.08 \pm 1.01) \times 10^{-6}$



$$\mathcal{B}(B^+ \to \phi K^+ \mu^+ \mu^-) = \left(0.82^{+0.19}_{-0.17}\,(\text{stat})^{+0.10}_{-0.04}\,(\text{syst}) \pm 0.27(\text{norm})\right) \times 10^{-7}$$

$$\frac{\mathcal{B}(B^+ \to \phi K^+ \mu^+ \mu^-)}{\mathcal{B}(B^+ \to \phi J/\psi\, K^+)} = (1.58^{+0.36}_{-0.32}\,(\text{stat}) \pm^{+0.19}_{-0.07}\,(\text{syst})) \times 10^{-3}$$

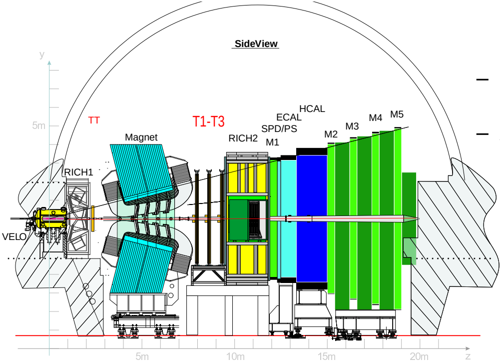
Summary

- Electroweak penguin decays are ideal laboratory to look for NP
- There is a great variety of electroweak penguin decays measured at LHCb

- Measured differential branching fractions tend to be lower then the SM prediction (see talk of M. Wingate)
- The tension in one of the angular observables of $B^0 \to K^{*0}\mu^+\mu^-$ (P_5') is under discussion

Backup

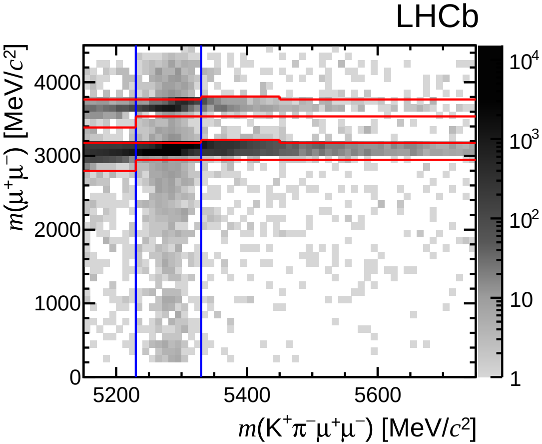
LHCb detector



- $\mathcal{L}_{int} = 1\ \text{fb}^{-1}$ at 7 TeV and 2 fb^{-1} at 8 TeV
- Acceptance $2 < \eta < 5$, with excellent vertexing, tracking and PID
  - $\sigma_{PV,x/y} \approx 10\mu m$, $\sigma_{PV,z} \approx 60\mu m$
  - $\Delta p/p$: 0.4% at 5 GeV/c, to 0.6% at 100 GeV/c
  - e ID efficiency: 90 %
  - K ID efficiency: 95 %
  - μ ID efficiency: 97 %

$B^0 \to K^{*0}\mu^+\mu^-$: Rejection cuts

JHEP08(2013)131
with 1 fb^{-1}



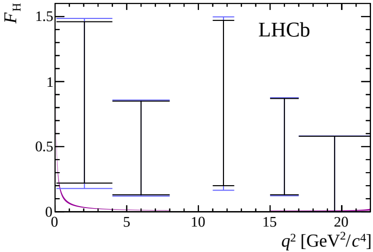
JHEP 05 (2014) 082
with 3 fb^{-1}

$B \to K\mu^+\mu^-$ angular analysis

- Angular distribution for $B^0 \to K^0_S\mu^+\mu^-$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d|\cos\theta_\ell|} = \frac{3}{2}(1 - F_H)(1 - |\cos\theta_\ell|^2) + F_H$$

As B^0 and $\bar{B}^0$ can decay to K^0_S, the flavour of the B meson is not determined by the decay products $\to \theta_\ell$ is always defined with respect to μ^+



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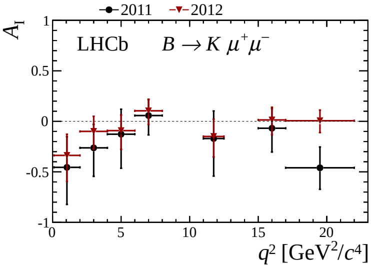
with 3 fb^{-1}

$B \to K^{(*)}\mu^+\mu^-$ isospin asymmetry

- Isopsin asymmetry:

$$A_I = \frac{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) - \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}{\Gamma(B^0 \to K^{(*)0}\mu^+\mu^-) + \Gamma(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

- A_I predicted to be zero in SM



Difference:

- additional data of 2 fb^{-1}
- previously assumed equal amounts of B^+ and B^0 are produced at $\Upsilon(4S)$. Now assume isospin asymmetry for $B \to J/\psi\, K^{(*)}$
- reanalysis of 2011 data with an updated selection

Lepton universality test using $B^+ \to K^+\ell^+\ell^-$

LHCB-PAPER-2014-024 with 3 fb^{-1}