Measurement of $B^+ \rightarrow K^+ \tau^+ \tau^-$, $B \rightarrow K^* l^+ l^-$ and $B \rightarrow K \pi^+ \pi^- \gamma$ decays at BaBar

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LNF INFN, Frascati, Italy

on behalf of the BaBar collaboration

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26th May 2016
Outline

- Branching fraction of $B^+ \rightarrow K^+\tau^+\tau^-$
  
- Angular analysis of $B \rightarrow K^*l^+l^-$ ($l=e,\mu$)
  
- Time dependent analysis of $B^0 \rightarrow K_s\pi^+\pi^-\gamma$
  
- Study of $K^+\pi^+\pi^-$ system in $B^+ \rightarrow K^+\pi^+\pi^-\gamma$
  
- Summary

PRD 93, 052013 (2016)

PRD 93, 052015 (2016)

Full dataset
471x10^6 BB pairs
B⁺ → K⁺τ⁺τ⁻: overview

- Heavy τ mass impose upper limit on kaon momentum (~1.5 GeV/c) → no long distance contribution
- Hadronic B̅ tag reconstruction B̅ tag → DX, D=D(±)0, D(±), D s ± or J/ψ, X=combination of up to 5 π and/or K's

- Three different final states considered here:
  - Electron: τ⁺ → e⁺ νₑ νₜ, τ⁻ → e⁻ νₑ νₜ
  - Muon: τ⁺ → μ⁺ νₘ νₜ, τ⁻ → μ⁻ νₘ νₜ
  - Mixed: τ⁺ → e⁺ νₑ νₜ, τ⁻ → μ⁻ νₘ νₜ (+ CC)
- Cut and count analysis
\[ B^+ \rightarrow K^+\tau^+\tau^- : \text{signal selection} \]

- \( m_{ES} > 5.27 \text{ GeV/c}^2, |\Delta E| < 0.12 \text{ GeV} \) and \( E_{\text{sig, miss}} > 0 \)
- Exactly 3 tracks + PID
- Vetoes: J/ψ on \( m_{ll} \), \( D^0 \) on \( m_{lK} \), \( \pi^0 \) on any \( \gamma \) pair
- Main background: \( B_{\text{sig}} \rightarrow D^{(*)}l\bar{\nu}_l \) (peak.) + contr. from uds & mis-reco \( B_{\text{tag}} \) (comb.)
- Background suppression using MLP NN with 7 input variables
- Final cut on MLP chosen in order to get best value on the 90% CL UL

\[
m_{ES} = \sqrt{E_{beam}^2 - \vec{p}_{B_{\text{tag}}}^2}
\]

\[
\Delta E = E_{beam} - E_{B_{\text{tag}}}
\]
**B^+ → K^+\tau^+\tau^-**: results

<table>
<thead>
<tr>
<th>Mode</th>
<th>( \epsilon_{\text{sig}} )</th>
<th>( N_{\text{bkg}} )</th>
<th>( N_{\text{obs}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>1.11±0.12</td>
<td>49.4±5.3</td>
<td>45±6.7</td>
</tr>
<tr>
<td>Muon</td>
<td>1.29±0.21</td>
<td>45.8±5.1</td>
<td>39±6.2</td>
</tr>
<tr>
<td>Electron-Muon</td>
<td>2.05±0.26</td>
<td>59.2±6.2</td>
<td>92±9.6</td>
</tr>
<tr>
<td>Combined</td>
<td>4.77±0.42</td>
<td>154.4±9.6</td>
<td>176±13.2</td>
</tr>
</tbody>
</table>

Systematics:

- **Theoretical Uncertainty**: 3%
- **B_{tag} Yield**: 1.2%, 1.6%
- **Particle Identification**: ~5%
- **\( \pi^0 \) Veto**: 3%
- **MLP Cut**: 2.6%

Re-weighting reduced di-tau mass distribution according to lattice QCD vs Light Cone Sum Rule model

Varying bkg contributions with toy MC

From MC-data comparison using control samples

**Resulting branching fraction:**

\[
B(B^+ \rightarrow K^+\tau^+\tau^-) = (1.31^{+0.66}_{-0.61} \text{(stat.)} + 0.35^{+0.25}_{-0.25} \text{(sys.)}) \times 10^{-3}
\]

Upper limit at the 90% confidence level: 2.25 \times 10^{-3}

**BABAR preliminary**
**B → K* l^+ l^-: observables**

- Effective Hamiltonian factorizes short-distance from long-distance effects

\[
H_{\text{Eff}} \propto \sum_{i=1}^{10} C_i O_i
\]

- Three short-distance Wilson coefficients
  - \( C_7^{\text{eff}} \) from photon penguin (b→sγ) \( \sim 0.33 \)
  - \( C_9^{\text{eff}} \) (\( C_10^{\text{eff}} \)) from vector (axial-vector) parts of the Z, W box

- Decay rate can be parametrized by \( \phi, \theta_K \) and \( \theta_l \)

- Integrating out \( \phi \), and \( \theta_K \) or \( \theta_l \) alternately:

\[
\frac{1}{\Gamma(q^2)} \frac{d\Gamma}{d(\cos \theta_K)} = \frac{3}{2} F_L(q^2) \cos^2 \theta_K + \frac{3}{4} (1 - F_L(q^2)) (1 - \cos^2 \theta_K)
\]

\[
\frac{1}{\Gamma(q^2)} \frac{d\Gamma}{d(\cos \theta_l)} = \frac{3}{4} F_L(q^2) (1 - \cos^2 \theta_l) + \frac{3}{8} (1 - F_L(q^2)) (1 + \cos^2 \theta_l) + A_{FB}(q^2) \cos \theta_l.
\]

\( F_L \): K* longitudinal polarization

\( A_{FB} \): lepton forward-backward asymmetry
B → K*ℓ⁺ℓ⁻: final states

Reconstructed final states:

Mode 1 - B⁺ → K⁺μ⁺μ⁻ (K⁺ → K_S π⁺)
Mode 2 - B⁰ → K⁰μ⁺μ⁻ (K⁰ → K⁺ π⁻)
Mode 3 - B⁺ → K⁺e⁺e⁻ (K⁺ → K⁺ π⁰)
Mode 4 - B⁺ → K⁺e⁺e⁻ (K⁺ → K_S π⁺)
Mode 5 - B⁰ → K⁰e⁺e⁻ (K⁰ → K⁺ π⁻)

Signal modes:

B → K⁺ℓ⁺ℓ⁻ Modes: 1+2+3+4+5
B⁰ → K⁰ℓ⁺ℓ⁻ Modes: 2+5
B⁺ → K⁺⁺ℓ⁺ℓ⁻ Modes: 1+3+4

<table>
<thead>
<tr>
<th>q² bin</th>
<th>q² min (GeV²/c⁴)</th>
<th>q² max (GeV²/c⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>q₁</td>
<td>0.10</td>
<td>2.00</td>
</tr>
<tr>
<td>q₂</td>
<td>2.00</td>
<td>4.30</td>
</tr>
<tr>
<td>q₃</td>
<td>4.30</td>
<td>8.12</td>
</tr>
<tr>
<td>q₄</td>
<td>10.11</td>
<td>12.89</td>
</tr>
<tr>
<td>q₅</td>
<td>14.21</td>
<td>(m_B − m_{K*})²</td>
</tr>
<tr>
<td>q₀</td>
<td>1.00</td>
<td>6.00</td>
</tr>
</tbody>
</table>
$B \rightarrow K^* l^+ l^-$: signal selection

- $e$, $\mu$, $K$, $\pi$ particle ID, $p_1 > 0.3$ GeV/c
- $0.7 < M_{K\pi} < 1.1$ GeV/$c^2$, $0.115 < M(\pi^0) < 0.155$ GeV/$c^2$
- Bagged decision trees (BDTs) used to construct LH ratio $L_R$ used in fitting, along with $m_{ES}$, $M_{K\pi}$
- Separate BDTs for low (<$J/\psi$) and high $q^2$ regions
- $J/\psi$, $\psi(2S)$ regions vetoed, use as control samples

- $F_L$ and $A_{FB}$ are extracted from a simultaneous fit across $K^*$ final states in 3 steps:
  - 1st fit: $m_{ES} > 5.20$, $M_{K\pi}$, $L_R$ for every mode separately; fix results for fits 2,3
  - 2nd fit: $m_{ES} > 5.27$ dataset, fit $\cos(\theta_K)$, extract $F_L$, fix results for fit 3
  - 3rd fit: fit $\cos(\theta_\ell)$, extract $A_{FB}$
Several classes of events: truth-matched signal, cross-feed signal, physics backgrounds, combinatoric background, hadronic mis-id backgrounds ($\mu\mu$ states only)

$B^0 \rightarrow K^+ \pi^- e^+ e^-$

$B^0 \rightarrow K^+ \pi^- \mu^+ \mu^-$

**Signal yield:**

<table>
<thead>
<tr>
<th>Mode</th>
<th>$q_0^2$</th>
<th>$q_1^2$</th>
<th>$q_2^2$</th>
<th>$q_3^2$</th>
<th>$q_4^2$</th>
<th>$q_5^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B \rightarrow K^*\ell^+\ell^-$</td>
<td>40.8 ± 8.4</td>
<td>31.7 ± 7.1</td>
<td>11.9 ± 5.5</td>
<td>21.3 ± 8.5</td>
<td>31.9 ± 9.2</td>
<td>33.2 ± 7.8</td>
</tr>
<tr>
<td>$B^+ \rightarrow K^{*+}\ell^+\ell^-$</td>
<td>17.7 ± 5.2</td>
<td>8.7 ± 4.1</td>
<td>3.8 ± 4.0</td>
<td>7.7 ± 5.6</td>
<td>9.0 ± 4.8</td>
<td>9.4 ± 4.2</td>
</tr>
<tr>
<td>$B^0 \rightarrow K^{*0}\ell^+\ell^-$</td>
<td>23.1 ± 6.6</td>
<td>22.9 ± 5.8</td>
<td>8.1 ± 3.8</td>
<td>13.7 ± 6.4</td>
<td>22.8 ± 7.8</td>
<td>23.8 ± 6.6</td>
</tr>
</tbody>
</table>

**Comb. Charm. Crossfeed Total**
10 < q_0^2 < 6.0 \text{ GeV}^2/c^4

Systematic contributions:

- purely statistical uncertainties in the parameters obtained from the initial 3-d m_{ES}, m_{K\pi} fit which are used in the angular fits
- $F_L$ statistical uncertainty, which is propagated into the $A_{FB}$ fit
- modeling of the random combinatorial background pdfs
- signal angular efficiencies
- Several other sources studied → negligible

$B^+ \rightarrow K^+ \pi^+ e^+ e^-$
$B^+ \rightarrow K^+ \pi^+ \mu^+ \mu^-$ —— Signal
$B^+ \rightarrow K^+ \pi^0 e^+ e^-$
B → K* l⁺ l⁻: results

Broad agreement with other measurements
**B→Kπ⁺π⁻γ: overview**

- In SM: left-handed quarks, right-handed antiquarks → left handed photon
- New Physics, if present in the loop may enhance right-handed photons

**SM** ⇒ $b \rightarrow s \gamma_L$ or $\bar{b} \rightarrow \bar{s} \gamma_R$ ⇒
CP asymmetry parameters ≈ 0

**NP** ⇒ $b \rightarrow s \gamma_{L,R}$ or $\bar{b} \rightarrow \bar{s} \gamma_{R,L}$ ⇒
CP asymmetry parameters ≠ 0

\[
A_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0(\Delta t) \rightarrow f_{CP}\gamma) - \Gamma(B^0(\Delta t) \rightarrow f_{CP}\gamma)}{\Gamma(\bar{B}^0(\Delta t) \rightarrow f_{CP}\gamma) + \Gamma(B^0(\Delta t) \rightarrow f_{CP}\gamma)}
\]

\[
= S_{f_{CP}} \sin (\Delta m_d \Delta t) - C_{f_{CP}} \cos (\Delta m_d \Delta t)
\]

Goal: measurement of $S_f$ in $B\rightarrow K_s \rho^0 \gamma$ decays

<table>
<thead>
<tr>
<th>Observables</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_{f_{CP}}$</td>
</tr>
<tr>
<td>SM $m_s/m_b \approx 0.02$</td>
</tr>
</tbody>
</table>
**B→Kπ⁺π⁻γ: overview**

- **Problem:** irreducible background from B → K⁺πγ (non CP-eigenstates)

  - **Signal**
    - B⁰ → Kˢρ⁰(→π⁻π⁺)γ:
    - B⁰ → K⁺(→Kˢπ⁺)π⁻γ:
  
  - **Bkg**
    - B⁰ → K⁺π⁺π⁻γ:

- **S_{Kργ}** is diluted by:
  \[
  D_{K^{0}ργ} = \frac{S_{K^{0}π^+π^-γ}}{S_{K^{0}ργ}} = \frac{\int \left( \left| A_{ρK^{0}_S} \right|^2 - \left| A_{K^{*-π}} \right|^2 - \left| A_{(Kπ)_0^{*-π-}} \right|^2 + 2\Re \left( A_{ρK^{0}_S} A_{K^{*-π}} \right) + 2\Re \left( A_{ρK^{0}_S} A_{(Kπ)_0^{*-π-}} \right) \right) \, dm^2}{\int \left( \left| A_{ρK^{0}_S} \right|^2 + \left| A_{K^{*-π}} \right|^2 + \left| A_{(Kπ)_0^{*-π-}} \right|^2 + 2\Re \left( A_{ρK^{0}_S} A_{K^{*-π}} \right) + 2\Re \left( A_{ρK^{0}_S} A_{(Kπ)_0^{*-π-}} \right) \right) \, dm^2}
  \]

- **Need amplitude analysis to calculate dilution factor**

- **We use B⁺→K⁺π⁺π⁻γ to determine D_{Kργ} because of the higher signal yield assuming isospin symmetry**

- **K⁺π⁺π⁻γ final state is produced by resonances that decay via intermediate K⁺⁰(892)π⁺ or K⁺ρ⁰ states → determine 3-body resonance content of m_{Kππ}**

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**B⁺→K⁺π⁺π⁻γ analysis**

- Unbinned maximum likelihood fit to $m_{ES}$, $\Delta E$ and Fisher discriminant to extract $B⁺→K⁺π⁺π⁻γ$ signal yield

  *Fisher, Annals Eugen. 7, 179 (1936)*

- Extract signal $m_{K\pi\pi}$, $m_{K\pi}$ & $m_{\pi\pi}$ spectra using sPlot technique

  *Pivk et al., NIM A555, 356 (2005)*

- Fit model: $m_{K\pi\pi}$ distribution as a coherent sum of 5 resonances [$K_1(1270)^+$, $K_1(1400)^+$, $K^*(1410)^+$, $K^*(1680)^+$, $K^*_2(1430)^+$] by relativistic B-W line shapes

- We measure a branching fraction of $B(B⁺→K⁺π⁺π⁻γ) = (24.5±0.9±1.2)×10^{-6}$

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**BaBar**

<table>
<thead>
<tr>
<th>Mode</th>
<th>$B(B⁺→\text{Mode}) \times B(K_{\text{res}}→K⁺π⁺π⁻) \times 10^{-6}$</th>
<th>Previous world average [17] ($\times10^{-6}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B⁺→K⁺π⁺π⁻γ$</td>
<td>24.5 ± 0.9 ± 1.2</td>
<td>27.6 ± 2.2</td>
</tr>
<tr>
<td>$K_1(1270)^+\gamma$</td>
<td>14.5$^{+2.1+1.2}_{-1.4-1.2}$</td>
<td>43 ± 13</td>
</tr>
<tr>
<td>$K_1(1400)^+\gamma$</td>
<td>4.1$^{+1.9+1.2}_{-1.2-1.0}$</td>
<td>&lt; 15 at 90% CL</td>
</tr>
<tr>
<td>$K^*(1410)^+\gamma$</td>
<td>11.0$^{+2.2+2.1}_{-2.0-1.1}$</td>
<td>n/a</td>
</tr>
<tr>
<td>$K^*_2(1430)^+\gamma$</td>
<td>1.2$^{+1.0+1.2}_{-0.7-1.5}$</td>
<td>14 ± 4</td>
</tr>
<tr>
<td>$K^*(1680)^+\gamma$</td>
<td>15.9$^{+2.2+3.2}_{-1.9-2.4}$</td>
<td>&lt; 1900 at 90% CL</td>
</tr>
</tbody>
</table>

*PRD 93, 052013 (2016)*
Kπ analysis in $B \rightarrow K\pi\pi\gamma$

- We extract fit fractions and branching fractions from ML fit to $m_{K\pi}$ sPlot
- For $(K\pi)_R$, we include $K^*_0(892)$ (P-wave) and $0^+$ (S-wave) components, for $(\pi\pi)_R$ we include $\rho^0(770)$ (P-wave)
- We include also $K\pi$ and $\pi\pi$ P- and S-wave interference terms respectively
- Model $K^*_0(892)$ by relativistic BW, $\rho^0(770)$ by Gounaris-Sakurai line shape and $0^+$ by LASS (R + NR) parameterization
- We measure dilution factor for $0.6 < m_{\pi\pi} < 0.9$, $m_{K\pi} < 0.845$, $m_{K\pi} > 0.945$ and $m_{K\pi\pi} < 1.8$ GeV/c$^2$

$$\mathcal{D}_{K^0_S}(\rho \gamma) = -0.78^{+0.19}_{-0.17}$$

- This is the first observation of $(K\pi)^*0_0 \pi^+ \gamma$ NR-contribution

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\mathcal{B}(B^+ \rightarrow \text{Mode}) \times 10^{-6}$</th>
<th>$\mathcal{B}(B \rightarrow h\pi) \times 10^{-6}$</th>
<th>$\mathcal{B}(B^+ \rightarrow \text{Mode}) \times 10^{-6}$</th>
<th>Previous world average [17] $(\times10^{-6})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^*(892)^0_0 \pi^+ \gamma$</td>
<td>15.6 ± 0.6 ± 0.5</td>
<td>23.4 ± 0.9$^{+0.8}_{-0.7}$</td>
<td>20$^{+7}_{-6}$</td>
<td></td>
</tr>
<tr>
<td>$K^+ \rho(770)^0_0 \gamma$</td>
<td>8.1 ± 0.4$^{+0.8}_{-0.7}$</td>
<td>8.2 ± 0.4 ± 0.8 ± 0.02</td>
<td>&lt; 20 at 90% CL</td>
<td></td>
</tr>
<tr>
<td>$(K\pi)^*0_0 \pi^+ \gamma$</td>
<td>10.3$^{+0.7}_{-0.8}$</td>
<td>10.5$^{+1.5}_{-2.0}$</td>
<td>...</td>
<td>n/a</td>
</tr>
<tr>
<td>$(K\pi)^0_0 \pi^+ \gamma$ (NR)</td>
<td>...</td>
<td>9.9 ± 0.7$^{+1.5}_{-1.9}$</td>
<td>&lt; 9.2 at 90% CL</td>
<td></td>
</tr>
<tr>
<td>$K^+_0(1430)^0_0 \pi^+ \gamma$</td>
<td>0.82 ± 0.06$^{+0.13}_{-0.16}$</td>
<td>1.32$^{+0.09}_{-0.10}$</td>
<td>0.20 ± 0.26 ± 0.14</td>
<td>n/a</td>
</tr>
</tbody>
</table>

PRD 93, 052013 (2016)
B^0 \rightarrow K_s \pi^+ \pi^- \gamma: results

PRD 93, 052013 (2016)

- Selection of B^0 \rightarrow K_s \pi^+ \pi^- \gamma events is identical to that of the B^+ \rightarrow K^+ \pi^+ \pi^- \gamma mode
  \[ |m_{\pi\pi} - m_{Ks}| < 11 \text{ MeV}/c^2 \]

- We perform an unbinned extended ML fit to extract B^0 \rightarrow K_s \pi^+ \pi^- \gamma event yield along with time-dependent CP asymmetry parameters \( S_{K\pi\pi\gamma} \) and \( C_{K\pi\pi\gamma} \)

- We find: \( N_{\text{sig}} = 243 \pm 24^{+21}_{-17} \)

signal candidates, resulting in

\[
B(B^0 \rightarrow K^0 \pi^+ \pi^- \gamma) = (20.5 \pm 2.0^{+2.6}_{-2.2}) \times 10^{-6}
\]

\[
S_{K^0\pi+\pi-\gamma} = 0.14 \pm 0.25 \pm 0.03.
\]

\[
C_{K^0\pi+\pi-\gamma} = -0.39 \pm 0.20^{+0.03}_{-0.02}.
\]

and using previously calculated \( D_{K\rho\gamma} \)

\[
S_{K^0\rho\gamma} = -0.18 \pm 0.32^{+0.06}_{-0.05}
\]

in agreement with SM
Summary

- Babar continues to produce exciting physics results

- First search for $B^+ \rightarrow K^+ \tau^+ \tau^-$, no significant signal is observed and an upper limit at 90% CL is set

- First results for the angular analysis of $B^+ \rightarrow K^{*+} l^+ l^-$

- Inclusive analysis of $B \rightarrow K^* l^+ l^-$ broad agreement with SM and other experimental results, some tension with SM in low energy bins

- We have measured the time dependent asymmetry parameter $S_{K\rho\gamma}$ and found it to be in agreement with SM and previous measurements

- We have studied the decay $B^+ \rightarrow K^+ \pi^+ \pi^- \gamma$ and we have measured the intermediate resonant amplitudes and their branching fractions, many of which for the first time (or world best)
Additional Slides
The BaBar experiment

- BaBar at PEP-II asymmetric e⁺-e⁻ collider at Stanford Linear Accelerator Center
- Operated (mainly) at Y(4S) CM energy
- ≈500 fb⁻¹ of e⁺-e⁻ collisions recorded from 1999 to 2008

- Tracking: 40 layer drift chamber + 5 layer silicon vertex detector
- PID: π/K separation using dE/dx and quartz Ring Imaging Cherenkov Detector
- CsI(Tl) calorimeter for γ and e
- 1.5 T superconducting solenoid
- Muon detectors in the field flux return
B → K(*)l⁺l⁻: motivation

- Search for new physics (NP) in intensity frontier → new “virtual” particles in loops
- B → K(*)l⁺l⁻: flavor changing neutral current (FCNC) process, lowest order contribution from photon, Z penguins and W box in SM → theoretically clean
- New physics can enter at same order as SM → unambiguous

- Complementary to searches for pure leptonic decays (e.g. Bₛ → μ⁺μ⁻) and lepton universality (e.g. B(B→D*μν)/B(B→D*e τ ν))
- Significant deviations reported by various experiments

LHCb: JHEP 02 (2016) 104
$B^+ \rightarrow K^+\tau^+\tau^-$: excess in $e\mu$ mode

- 2.9σ excess in event yield observed in the mixed mode

**Muon Mode** *BABAR preliminary*

**Electron-Muon mode** *BABAR preliminary*
**B → K* l^+ l^-**: numerical angular results

<table>
<thead>
<tr>
<th></th>
<th>( B^+ \to K^{*+} l^+ l^- )</th>
<th>( B^0 \to K^{*0} l^+ l^- )</th>
<th>( B \to K^* l^+ l^- )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( q_0 )</td>
<td>( q_1 )</td>
<td>( q_2 )</td>
</tr>
<tr>
<td></td>
<td>(+0.05^{+0.09+0.02}_{-0.10-0.10})</td>
<td>(-0.02^{+0.18+0.09}_{-0.13-0.14})</td>
<td>(-0.24^{+0.27+0.18}_{-0.39-0.10})</td>
</tr>
<tr>
<td></td>
<td>(+0.43^{+0.12+0.02}_{-0.13-0.02})</td>
<td>(+0.34^{+0.15+0.15}_{-0.10-0.02})</td>
<td>(+0.18^{+0.16+0.02}_{-0.12-0.10})</td>
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<tr>
<td></td>
<td>(+0.15^{+0.14+0.05}_{-0.13-0.08})</td>
<td>(+0.48^{+0.14+0.05}_{-0.16-0.05})</td>
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<td></td>
<td>(+0.05^{+0.27+0.16}_{-0.16-0.15})</td>
<td>(+0.45^{+0.16+0.06}_{-0.14-0.06})</td>
<td>(+0.34^{+0.15+0.07}_{-0.10-0.10})</td>
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<tr>
<td></td>
<td>(+0.72^{+0.20+0.10}_{-0.31-0.21})</td>
<td>(+0.48^{+0.12+0.02}_{-0.12-0.11})</td>
<td>(+0.53^{+0.10+0.07}_{-0.12-0.14})</td>
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</tbody>
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<th>( F_L )</th>
<th>( A_{FB} )</th>
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<td></td>
<td>( q_0 )</td>
<td>( q_1 )</td>
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<tr>
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<td>(+0.32^{+0.18+0.08}_{-0.18-0.05})</td>
<td>(+0.44^{+0.20+0.13}_{-0.22-0.16})</td>
</tr>
<tr>
<td></td>
<td>(+0.06^{+0.15+0.06}_{-0.18-0.05})</td>
<td>(-0.12^{+0.23+0.10}_{-0.21-0.21})</td>
</tr>
<tr>
<td></td>
<td>(+0.21^{+0.10+0.07}_{-0.15-0.09})</td>
<td>(+0.44^{+0.15+0.14}_{-0.18-0.11})</td>
</tr>
<tr>
<td></td>
<td>(+0.40^{+0.12+0.17}_{-0.33-0.24})</td>
<td>(+0.42^{+0.11+0.14}_{-0.17-0.13})</td>
</tr>
</tbody>
</table>
B → K*1^+1^-: $A_{FB}$ & $F_L$

$1.0 < q_0^2 < 6.0$ GeV

(a) $F_L$

(b) $A_{FB}$
$\mathcal{B} \rightarrow \mathcal{K}^{*1+1-}: A_{\text{FB}} \& F_L @ \text{LHCb}$

**$F_L$**

- **LHCb**
- **SM from ABSZ**

**$A_{\text{FB}}$**

- **LHCb**
- **SM from ABSZ**
$B \rightarrow K^{*1+1-}: P_2$

$P_2 = \left( \frac{2}{3} \right) \frac{A_{FB}}{1 - F_L} \rightarrow \text{reduced theory uncertainty}$
B → K*1+1−: fit model

- **Truth-matched signal pdfs:**
  - Gaussian $m_{ES}$, relativistic Breit-Wigner $M_{K\pi}$ both from J/psi data
  - LH ratio and angular efficiency functions from signal MC

- **Crossfeed signal pdfs:**
  - $m_{ES}$, $M_{K\pi}$, LH ratio and angular shapes from MC, normalization relative to fit signal yield

- **Physics backgrounds:**
  - $m_{ES}$, $M_{K\pi}$, LH ratio fixed shapes and normalizations from MC
  - Several sources, all trivial except charmonium

- **Random combinatoric background:**
  - $m_{ES}$ Argus, floated slope, fixed single-valued endpoint
  - $M_{K\pi}$ taken from LFV events selected identically to ee/mm samples
  - LH ratio from generic MC
  - Angular shapes from $m_{ES}$ sideband and LFV events

- **Hadronic mis-id backgrounds (di-muon final states only)**
  - Fixed $m_{ES}$, $M_{K\pi}$, LH ratio and angular shapes plus