Dalitz-plot analyses of three-body charmless decays and search for CPV in $b$-baryon decays

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On behalf of the LHCb collaboration  
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Outline

- Motivations

- The LHCb detector at LHC

- Results on charmless decays from LHCb Run I analysis
  - Update of $B_{d,s} \rightarrow K_S h^+ h'^-$ branching fractions. [JHEP. (2017) 2017: 27]
  - Amplitude analysis of $B_d \rightarrow K_S \pi^+ \pi^-$ decays and first observation of CP asymmetry in $B^0 \rightarrow K^* (892)^+ \pi^-$. [PRL. 120, 261801 (2018)]
  - Search for CP violation using tripleproduct asymmetries in $\Lambda_b \rightarrow p K^- \pi^+$, $\Lambda_b \rightarrow p K^- K^+$ and $\Xi_b \rightarrow p K^- K^+ \pi^+$ decays. [arxiv:1805.03941]
  - Search for CP violation in $\Lambda_b \rightarrow p \pi^-$ and $\Lambda_b \rightarrow p K^-$ decays. [LHCB-PAPER-2018-025-002]

- Conclusion and prospects
**Introduction**

- Charmless $b$-hadron decays proceed through various processes.

- BSM particles can contribute inside of loops or instead of $W^+$.

- Three-body decays allow access to *phases* between quasi two-body decays (Q2B) using
  - angular analyses;
  - Dalitz-plot analyses.
  - No trigonometric ambiguity!

- CP violation in baryons has only recently been observed
Current status of charmless $b$-decays

- Many channels not yet observed
  - Suppressed decays (BR < $10^{-5}$)
  - Includes decays of $B_s$, $\Lambda_b$, $b$-baryons etc. → not accessible by $B$ factories.

- Final-state particles: protons, kaons, pions, and sometimes photons from $\pi^0$ decays.
  - Decays involving $\pi^0$ are more difficult, but lots of effort in that area.

- For most decays, programme in two steps:
  1. Observe modes for the first time and extract branching fractions.
  2. Perform angular, Dalitz-plot analyses to access physics observables, e.g. phases, CPV observables.
The LHCb detector

Tracking
$\Delta p/p = 0.5-1\%$

PID
95% $K_{\text{eff}}$
For 5% $\pi \to K$ misID

Calorimetry
ECAL resolution:
1 % + 10 %/ $\sqrt{E[\text{GeV}]}$

LHCb performance paper
arXiv:1412.6352
Results on charmless decays from LHCb Run I analysis (3fb$^{-1}$)
Update of $B_{d,s} \rightarrow K_S h^+ h'^-$ branching fractions

$B_{d,s} \rightarrow K_S h^+ h'^-$, with $h, h' = \pi, K \rightarrow 8$ decays.

- **Green**: observed;
- **Red**: not observed;
- **Black**: favoured decay (see below).

### Previous LHCb analysis (1fb$^{-1}$)

- Observed $B_s \rightarrow K_S \pi^+ \pi^-$.
- Confirmed $B_d \rightarrow K_S K^\pm \pi^\pm$.
- Observed $B_s \rightarrow K_S K^\pm \pi^\pm$.

### Goals of the LHCb analysis using 3fb$^{-1}$:
- Update measurement of branching fractions;
- Search for $B_s \rightarrow K_S K^+ K^-$;
- Prepare Dalitz-plot analyses of all modes.

### Dataset divided into:
- 4 final states;
- 2 $K_S$ reconstruction categories (Long-Long, Downstream-Downstream);
- 3 data-taking periods.

$\rightarrow$ 24 invariant-mass distributions
Update of $B_{d,s} \rightarrow K_S h^+ h'^-$ branching fractions

- Shapes taken from Monte-Carlo, except for combinatorial background.
- $B_d$ and $B_s$ masses and widths fit in data.
- Fast Monte-Carlo developed for partially reconstructed backgrounds modeling.
- Gaussian constraints on misidentified signals and partially reconstructed backgrounds yields.
Update of $B_{d,s} \to K_S h^+ h^\prime -$ branching fractions

\[ \frac{\mathcal{B}(B_{d,s}^0 \to K_S^0 h^+ h^\prime -)}{\mathcal{B}(B^0 \to K_S^0 \pi^+ \pi^-)} = \frac{f_{d,s} N_{\text{corr}}^{B_{d,s}^0 \to K_S^0 h^+ h^\prime -}}{N_{\text{corr}}^{B^0 \to K_S^0 \pi^+ \pi^-}}. \]

\[ N_{\text{corr}}^{B_{d,s}^0 \to K_S^0 h^+ h^\prime -} = \varepsilon_{\text{tot}} N_{B_{d,s}^0 \to K_S^0 h^+ h^\prime -}. \]

B_{s} \to K_S K^+ K^-: 2.5\sigma significance.

\[ \frac{\mathcal{B}(B_{s}^0 \to K_S^0 K^+ K^-)}{\mathcal{B}(B^0 \to K_S^0 \pi^+ \pi^-)} \in [0.008 - 0.051] \text{ at 90\% C.L.} \]

Compatible with previous measurements

Dalitz-plot analyses underway.
Amplitude analysis of $B^0 \to K_S \pi^+ \pi^-$

- Possibly related to the “$K\pi$” puzzle (difference between $A_{\text{CP}}$ in $B \to K^- \pi^+$ and $B \to K^- \pi^0$).
- Current statistics do not allow to use flavour tagging (power $\sim 5\%$ in LHCb).
- Analysis is time-integrated $\to$ amplitude is an incoherent sum of $B$ and $\bar{B}$.
- Presence of flavour-specific resonances $\to$ possible to measure direct CP asymmetries:

$$\mathcal{P}(s_+, s_-) = \frac{|\mathcal{A}(s_+, s_-)|^2 + |\bar{\mathcal{A}}(s_+, s_-)|^2}{\int_{\mathcal{D}} (|\mathcal{A}(s_+, s_-)|^2 + |\bar{\mathcal{A}}(s_+, s_-)|^2) \, ds_+ ds_-} \quad \mathcal{A} = \sum_{j=1}^{N} c_j F_j(s_+, s_-), \quad \bar{\mathcal{A}} = \sum_{j=1}^{N} \bar{c}_j \bar{F}_j(s_+, s_-),$$

- Baseline model inspired by previous BaBar and Belle analyses, educated by add/remove algorithm.

$$A_{\text{CP}} = A_{\text{raw}} - A_{\Delta}$$

$$A_{\text{raw}} = \frac{|\bar{c}_j|^2 - |c_j|^2}{|\bar{c}_j|^2 + |c_j|^2}, \quad A_{\Delta} = A_P(B^0) + A_D(\pi)$$

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Parameters</th>
<th>Lineshape</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K^*(892)^-$</td>
<td>$m_0 = 891.66 \pm 0.26$</td>
<td>RBW</td>
</tr>
<tr>
<td></td>
<td>$\Gamma_0 = 50.8 \pm 0.9$</td>
<td></td>
</tr>
<tr>
<td>$(K\pi)_0^-$</td>
<td>$\Re e(\lambda_0) = 0.204 \pm 0.103$</td>
<td>EFKLM [1]</td>
</tr>
<tr>
<td></td>
<td>$\Im m(\lambda_0) = 0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Re e(\lambda_1) = 1$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\Im m(\lambda_1) = 0$</td>
<td></td>
</tr>
<tr>
<td>$K^*_S(1430)^-$</td>
<td>$m_0 = 1425.6 \pm 1.5$</td>
<td>RBW</td>
</tr>
<tr>
<td></td>
<td>$\Gamma_0 = 98.5 \pm 2.7$</td>
<td></td>
</tr>
<tr>
<td>$K^*(1680)^-$</td>
<td>$m_0 = 1717 \pm 27$</td>
<td>Flatté [2]</td>
</tr>
<tr>
<td></td>
<td>$\Gamma_0 = 332 \pm 110$</td>
<td></td>
</tr>
<tr>
<td>$f_0(500)$</td>
<td>$m_0 = 513 \pm 32$</td>
<td>RBW</td>
</tr>
<tr>
<td></td>
<td>$\Gamma_0 = 335 \pm 67$</td>
<td></td>
</tr>
<tr>
<td>$\rho(770)^0$</td>
<td>$m_0 = 775.26 \pm 0.25$</td>
<td>GS [3]</td>
</tr>
<tr>
<td></td>
<td>$\Gamma_0 = 149.8 \pm 0.8$</td>
<td></td>
</tr>
<tr>
<td>$f_0(980)$</td>
<td>$m_0 = 965 \pm 10$</td>
<td>Flatté</td>
</tr>
<tr>
<td></td>
<td>$g_x = 0.165 \pm 0.025 \text{ GeV}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$g_K = 0.695 \pm 0.119 \text{ GeV}$</td>
<td></td>
</tr>
<tr>
<td>$f_0(1500)$</td>
<td>$m_0 = 1505 \pm 6$</td>
<td>RBW</td>
</tr>
<tr>
<td></td>
<td>$\Gamma_0 = 109 \pm 7$</td>
<td></td>
</tr>
<tr>
<td>$\chi_{\alpha\beta}$</td>
<td>$m_0 = 3414.75 \pm 0.31$</td>
<td>RBW</td>
</tr>
<tr>
<td></td>
<td>$\Gamma_0 = 10.5 \pm 0.6$</td>
<td></td>
</tr>
</tbody>
</table>

Direct CP violation is already apparent in the $m^2(K_S\pi^+)$ and $m^2(K_S\pi^-)$ projections.

Resonant structure is modelled and fit fractions extracted.

Critical role of the $(K\pi)$ S-wave $\to$ EFFKLM modelisation.

### Statistical, Systematic, Model

<table>
<thead>
<tr>
<th>$F(K^*(892)^-\pi^+)$</th>
<th>$9.43 \pm 0.40 \pm 0.33 \pm 0.34%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F((K\pi)_0^+\pi^+)$</td>
<td>$32.7 \pm 1.4 \pm 1.5 \pm 1.1%$</td>
</tr>
<tr>
<td>$F(K^*_2(1430)^-\pi^+)$</td>
<td>$2.45 \pm 0.16 \pm 0.14 \pm 0.12%$</td>
</tr>
<tr>
<td>$F(K^*(1680)^-\pi^+)$</td>
<td>$7.34 \pm 0.30 \pm 0.31 \pm 0.06%$</td>
</tr>
<tr>
<td>$F(f_0(980)K_S^0)$</td>
<td>$18.6 \pm 0.8 \pm 0.7 \pm 1.2%$</td>
</tr>
<tr>
<td>$F(\rho(770)^0K_S^0)$</td>
<td>$3.8 \pm 1.1 \pm 0.7 \pm 0.4%$</td>
</tr>
<tr>
<td>$F(f_0(500)K_S^0)$</td>
<td>$0.32 \pm 0.40 \pm 0.19 \pm 0.23%$</td>
</tr>
<tr>
<td>$F(f_0(1500)K_S^0)$</td>
<td>$2.60 \pm 0.54 \pm 1.28 \pm 0.60%$</td>
</tr>
<tr>
<td>$F(\chi_c(0)K_S^0)$</td>
<td>$2.23 \pm 0.40 \pm 0.22 \pm 0.13%$</td>
</tr>
<tr>
<td>$F(K_S^0\pi^+\pi^-)_{NR}$</td>
<td>$24.3 \pm 1.3 \pm 3.7 \pm 4.5%$</td>
</tr>
</tbody>
</table>

$A_{CP}(K^*(892)^-\pi^+) = -0.308 \pm 0.060 \pm 0.011 \pm 0.012,$

$A_{CP}((K\pi)^+\pi^+) = -0.032 \pm 0.047 \pm 0.016 \pm 0.027,$

$A_{CP}(K^*_2(1430)^-\pi^+) = -0.29 \pm 0.22 \pm 0.09 \pm 0.03,$

$A_{CP}(K^*(1680)^-\pi^+) = -0.07 \pm 0.13 \pm 0.02 \pm 0.03,$

$A_{CP}(f_0(980)K_S^0) = 0.28 \pm 0.27 \pm 0.05 \pm 0.14,$

6σ significant CP violation.

Compatible with current measurements, with similar precision.

[Dominated by a $b → usū$ tree and a $b → suū$ penguin. Relative weak phase dominated by the angle $γ$.]

First evidence for CP violation in baryons in the $Λ_b → pπ^-π^+π^-$ decay mode. [Nature Physics 13, 391-396 (2017)]

CP-violation effects could be enhanced by the rich resonant structure of these decays.

Triple products in the final states defined as $C_\hat{T} = \vec{p}_p \cdot (\vec{p}_{h_1} \times \vec{p}_{h_2})$ ($h_1$ is the $K^-$ (with the largest momentum if need to disambiguate), and $h_2$ the positively charged pion or kaon).

The motion-reversal operator $T$ reverses the spins and momenta of particles. Used to define asymmetries that are (largely) insensitive to production and detection asymmetries:

\[
\begin{align*}
A_\hat{T} &= \frac{N(C_\hat{T} > 0) - N(C_\hat{T} < 0)}{N(C_\hat{T} > 0) + N(C_\hat{T} < 0)}, \\
\bar{A}_\hat{T} &= \frac{\bar{N}(-C_\hat{T} > 0) - \bar{N}(-C_\hat{T} < 0)}{\bar{N}(-C_\hat{T} > 0) + \bar{N}(-C_\hat{T} < 0)}, \\
A^{\hat{T}-\text{odd}}_P &= \frac{1}{2} (A_\hat{T} + \bar{A}_\hat{T}), \\
A^{\hat{T}-\text{odd}}_{CP} &= \frac{1}{2} (A_\hat{T} - \bar{A}_\hat{T}),
\end{align*}
\]

Complementary with “usual” $A_{CP}$ observable ($ϕ'$: weak phase, $δ'$: strong phase):

$A_\hat{T} \propto \sin(δ' + ϕ')$

$\bar{A}_\hat{T} \propto \sin(δ' - ϕ')$

$A^{\hat{T}-\text{odd}}_P \propto \sin φ' \cos δ'$

$A^{\hat{T}-\text{odd}}_{CP} \propto \sin φ' \sin δ'$

$A_{CP} = \frac{N(Λ^0_b, Ξ^0_b → f) - N(Λ^0_b, Ξ^0_b → \bar{f})}{N(Λ^0_b, Ξ^0_b → f) + N(Λ^0_b, Ξ^0_b → \bar{f})} \propto \sin φ \sin δ$
Search for CP violation using triple-product asymmetries in $\Lambda_b \rightarrow pK^-K^+K^-$, $pK^-\pi^+\pi^-$ and $\Xi_b \rightarrow pK^-K^+\pi^+$ decays

[arxiv:1805.03941]

- Selection fully optimised on data.
- Numbers of events extracted from fits.
- First observation of $\Lambda_b \rightarrow pK^- (\chi_{c0}(1P) \rightarrow K^+K^-)$ and $\Lambda_b \rightarrow pK^- (\chi_{c0}(1P) \rightarrow \pi^+\pi^-)$ decays.
- Phase-space integrated asymmetries:

<table>
<thead>
<tr>
<th></th>
<th>$A^0_b \rightarrow pK^-\pi^+\pi^-$</th>
<th>$A^0_b \rightarrow pK^-K^+K^-$</th>
<th>$\Xi^0_b \rightarrow pK^-K^+\pi^+$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_P A^{\text{odd}}$ (%)</td>
<td>$-0.60 \pm 0.84 \pm 0.31$</td>
<td>$-1.56 \pm 1.51 \pm 0.32$</td>
<td>$-3.04 \pm 5.19 \pm 0.36$</td>
</tr>
<tr>
<td>$a_{CP} A^{\text{odd}}$ (%)</td>
<td>$-0.81 \pm 0.84 \pm 0.31$</td>
<td>$1.12 \pm 1.51 \pm 0.32$</td>
<td>$-3.58 \pm 5.19 \pm 0.36$</td>
</tr>
</tbody>
</table>

- Consistent with no P or CP violation.
- Phase space divided in bins.

No CP violation observed, either integrated or in regions of phase space

Uncertainties are dominated by statistics
Search for CP violation in $\Lambda_b \rightarrow p\pi^-$ and $\Lambda_b \rightarrow pK^-$ decays


Previous result by CDF compatible with 0, with a 8-9% uncertainty [Phys. Rev. Lett. 113 (2014) 242001].

Analysis strategy: measure raw CP asymmetries

$$A_{\text{raw}}(pK^-) = \frac{N(\Lambda_b^0 \rightarrow pK^-) - N(\bar{\Lambda}_b^0 \rightarrow \bar{p}K^+)}{N(\Lambda_b^0 \rightarrow pK^-) + N(\bar{\Lambda}_b^0 \rightarrow \bar{p}K^+)} ,$$

$$A_{\text{raw}}(p\pi^-) = \frac{N(\Lambda_b^0 \rightarrow p\pi^-) - N(\bar{\Lambda}_b^0 \rightarrow \bar{p}\pi^+)}{N(\Lambda_b^0 \rightarrow p\pi^-) + N(\bar{\Lambda}_b^0 \rightarrow \bar{p}\pi^+)} ,$$

and relate them to CP asymmetries through

$$A_{CP}(pK^-) = A_{\text{raw}}(pK^-) - A_D(p) - A_D(K^-)$$
$$\quad - A_{\text{PID}}(pK^-) - A_P(\Lambda_b^0) - A_{\text{trigger}}(pK^-) ,$$

$$A_{CP}(p\pi^-) = A_{\text{raw}}(p\pi^-) - A_D(p) - A_D(\pi^-)$$
$$\quad - A_{\text{PID}}(p\pi^-) - A_P(\Lambda_b^0) - A_{\text{trigger}}(p\pi^-) ,$$
Search for CP violation in \( \Lambda_b \to p\pi^- \) and \( \Lambda_b \to pK^- \) decays

- Large possible contamination from \( B^0_{(s)} \to K^+\pi^-\pi^+ \), \( \pi^+\pi^- \) and \( K^+K^- \) (crossfeeds).

- Yields are extracted from simultaneous extended maximum likelihood fits to invariant-mass distributions in the \( pK^+/- \) and \( p\pi^+/- \) for the signal, and \( K^+\pi^-\pi^+ \), \( \pi^+\pi^- \) and \( K^+K^- \).

- Crossfeed yields fixed to values in the fit to corresponding final-state hypothesis, multiplied by an efficiency ratio.

**Signals.** Double Gaussian convolved with power law (radiative losses).

**Crossfeeds.** Yields are extracted from fits to corresponding final state, multiplied by efficiency ratio.

**Partially reconstructed backgrounds** (three-body decays of which a particle is not reconstructed). Modelled with an ARGUS convolved with the same two Gaussian as in the signal.

**Combinatorial backgrounds** (random association of unrelated tracks). Modelled with exponential functions.
Search for CP violation in $\Lambda_b \rightarrow p\pi^-$ and $\Lambda_b \rightarrow pK^-$ decays

[LHCB-PAPER-2018-025-002]

- K detection asymmetry: from $D^+ \rightarrow K^-\pi^+\pi^+$ and $D^+ \rightarrow K^0\pi^+$ (as in JHEP 07 (2014) 041).
- $\pi$ detection asymmetry: from $D^{*+} \rightarrow \pi^+D^0(\rightarrow K^-\pi^+\pi^-\pi^+)$ (as in Phys. Lett. B713 (2012) 186).
- Proton detection asymmetry: simulated events folded with momentum distributions.
- PID asymmetries: reference samples + Monte-Carlo.
- Trigger asymmetries: from $B^0 \rightarrow K^-\pi^+$ samples, studying the charge asymmetry for hardware and software decisions.

<table>
<thead>
<tr>
<th>Systematic uncertainty</th>
<th>$A_{CP}^{pK^-}$ [%]</th>
<th>$A_{CP}^{p\pi^-}$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaon or pion detection asymmetry</td>
<td>0.23</td>
<td>0.11</td>
</tr>
<tr>
<td>Proton detection asymmetry</td>
<td>0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>PID asymmetry</td>
<td>0.74</td>
<td>0.73</td>
</tr>
<tr>
<td>$A_b^0$ production asymmetry</td>
<td>1.40</td>
<td>1.40</td>
</tr>
<tr>
<td>Trigger asymmetry</td>
<td>0.53</td>
<td>0.55</td>
</tr>
<tr>
<td>Signal model</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Background model</td>
<td>0.23</td>
<td>0.47</td>
</tr>
<tr>
<td>PID efficiencies</td>
<td>0.57</td>
<td>0.74</td>
</tr>
<tr>
<td>Total</td>
<td>1.91</td>
<td>2.00</td>
</tr>
</tbody>
</table>

$A_{CP}^{pK^-} = -0.020 \pm 0.013 \pm 0.019$,  
$A_{CP}^{p\pi^-} = -0.035 \pm 0.017 \pm 0.020$,  
$\Delta A_{CP} = 0.014 \pm 0.021 \pm 0.013$,  

No CPV observed, with greatly improved precision.
Conclusion and prospects
Conclusion and prospects

- All presented results use only data from Run I of the LHC → 3fb⁻¹ at centre-of-mass energy of 7 and 8 TeV.

- Run 2 aims at adding 5 fb⁻¹ at 13 TeV → more than four times as much data as in Run I.

- All presented analyses are (mostly) dominated by statistical uncertainties.

- Upgrade of all subsystems planned after 2018.

Conclusion and prospects

- New channels observed → physics programme of (three-body) charmless decays is expanding.

- Wealth of different channels:
  - Initial hadron: baryon, $B^0$, $B_s$, $B_c^+$
  - Final state: baryonic, V0 particle...

- Work on amplitude analyses already ongoing.
  - Allows to measure many more $Q_2B$ branching fractions.
  - Allows to access more physics observables.

"Phase transition" in charmless analyses at LHCb from first observations to fully fledged amplitude analyses already started.
THANK YOU!
Backup: amplitude model

- EFKLLM has no cutoff compared to LASS

\[
\mathcal{R}(m_{K\pi}) = \frac{m_{K\pi}}{p(m_{K\pi}) \cot \delta_B - ip(m_{K\pi})} + e^{2i\delta_B} \frac{m_0^2 \Gamma_0 / p(m_0)}{(m_0^2 - m_{K\pi}^2 - i m_0 \frac{p(m)}{m_{K\pi} \Gamma_0})}
\]

where \( \cot \delta_B = \frac{1}{a p(m) + \frac{1}{2} r p(m)} \).

- Reduced K-matrix has been considered but not retained due to weak experimental constraints. F0(500) has been kept in the model

\[
\mathcal{R}_f(m) = F(m) \left( \frac{c_0}{m^2} + c_1 \right)
\]

\[
\mathcal{R}(m) = \frac{K(m)}{1 - i \rho(m) K(m)} \sqrt{\frac{p(m)}{m} \frac{p(m)}{M}}
\]

with

\[
K(m) = K_{\text{res}}(m) + K_{\text{non-res}} = \frac{m_0 \Gamma(m)}{(m_0^2 - m^2) \rho(m)} + \kappa
\]
Experimental bias on CP is taken from Lb2Lcpi, where 0 ACP is expected.

- P has to have the same as CP.

- Stat fully uncorrelated between bins, syst fully correlated.

<table>
<thead>
<tr>
<th>Contribution</th>
<th>( \Lambda_b^0 \to pK^-\pi^+\pi^- ) (%)</th>
<th>( \Lambda_b^0 \to pK^-K^+K^- ) (%)</th>
<th>( \Xi_b^0 \to pK^-K^-\pi^+ ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental bias</td>
<td>±0.31 (±0.60)</td>
<td>±0.31 (±0.60)</td>
<td>±0.31</td>
</tr>
<tr>
<td>( C_T ) resolution</td>
<td>±0.01</td>
<td>±0.05</td>
<td>±0.02</td>
</tr>
<tr>
<td>Fit model</td>
<td>±0.03</td>
<td>±0.08</td>
<td>±0.19</td>
</tr>
<tr>
<td>Total</td>
<td>±0.31 (±0.60)</td>
<td>±0.32 (±0.61)</td>
<td>±0.36</td>
</tr>
</tbody>
</table>

(a) Tree diagram \( \propto V_{ub} \sim \lambda^3 \)

(b) Penguin diagram \( \propto \sum_{x=u,c,t} V_{bx}V_{xd} \sim \lambda^3 \)