Observation of photon polarization in $B^\pm \rightarrow K^\pm \pi^\mp \pi^\pm \gamma$ decays

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\textbf{Introduction}

The Standard Model (SM) predicts that the photon emitted in $b \rightarrow s\gamma$ transitions is predominantly left-handed. While the measured inclusive $b \rightarrow s\gamma$ rate agrees with the SM calculations, no direct evidence exists for a nonzero photon polarization $\lambda_\gamma$ in this type of decays. Several extensions of the SM, compatible with all current measurements, predict that the photon acquires a significant right-handed component.

$$A^\pm \rightarrow K^\pm \pi^\mp \pi^\pm \gamma$$

The up-down asymmetry $A_{ud}$ between the number of photons found in each side of the plane is expected to be proportional to the photon polarization $\lambda_\gamma$.

$$A_{wd} \propto \lambda_\gamma$$

The background-subtracted angular distribution of the photon direction with respect to the plane defined by the momenta of the three final-state hadrons in their centre-of-mass frame.

$$f(\cos \theta, \cos \phi, c_1, c_2, c_3, c_4) = \sum_{i=0}^{1} c_i L_i(\cos \theta)$$

\textbf{The LHCb detector}

The LHCb detector is a single-arm spectrometer designed for precision studies of $b$ and $c$ hadrons in the forward direction.

The detector has a large coverage in pseudorapidity ($2 < \eta < 5$), an excellent tracking resolution ($\Delta p/p < 0.35 - 0.55\%$) and very good PID performances.

\textbf{Event selection}

- Track $p > 2000$ MeV/c
- Max track $p_T > 1200$ MeV/c
- Min track $p_T > 500$ MeV/c
- Track $\chi^2 < 3$
- Track ghost probability < 0.4
- Kaon ID: $K\text{Prob}(K) > 0.2$
- Pion ID: $\pi\text{Prob}(\pi) > 0.2$
- $K\pi$ vertex isolation $\chi^2 > 2$
- $K\pi$ mass window $[100, 1900]$ MeV/c^2
- Photon $E_p > 3000$ MeV
- Photon confidence level > 0.25
- Photon and tracks $\Sigma p_T > 5000$ MeV/c
- Photon $\gamma$ separation > 0.6
- $K^\pm \pi^\mp$ mass $> 2000$ MeV/c^2
- $K^\pm \pi^\mp$ mass $> 1100$ MeV/c^2

Additionally, a BDT has been trained using the IP $\chi^2$ of both the B and the tracks, the B meson flight distance, the $K\pi$ vertex $\chi^2$ and the B pointing angle.

\textbf{Angular fit}

A background-subtracted angular distribution is obtained in each of the $K\pi\gamma$ mass regions simultaneously fitting the B-candidate mass spectra in bins of the sign-weighted photon direction angle $\theta$.

The obtained distribution is fit with a linear combination of Legendre polynomials $L_i$ normalized to unit area.

$$f(\cos \theta, c_0, c_1, c_2, c_3, c_4) = \sum_{i=0}^{4} c_i L_i(\cos \theta)$$

The up-down asymmetries are found from $A_{ud} = c_1 - c_2/4$

Combining the four independent results for $A_{ud}$, a 5.2$\sigma$ significance for the photon polarization to be different from zero is obtained.

\textbf{Conclusions}

The inclusive $B^\pm \rightarrow K^\pm \pi^\mp \gamma$ decay, with the $K\pi$ mass in the $[1100, 1900]$ MeV/c^2 range, has been studied in 3 fb$^{-1}$ of data collected by the LHCb detector at 7 and 8 TeV centre-of-mass energies.

From the study of the angular distribution of the photon, a parity-violating photon polarization different from zero at 5.2$\sigma$ significance level is observed in the $b \rightarrow s\gamma$ transition for the first time.

With further development of theoretical predictions, the results of this study may be used to extract a value for $\lambda_\gamma$. This would be the first measurement of such quantity, and could help constraining the effects of new physics in the $b \rightarrow s\gamma$ sector.

\textbf{Event selection}

<table>
<thead>
<tr>
<th>Track $p$</th>
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<td>&lt; 0.4</td>
<td>&gt; 0.2</td>
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<td>&gt; 2</td>
<td>[100, 1900] MeV/c^2</td>
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\textbf{Full statistics fit}

The fit on the 3 fb$^{-1}$ LHCb data sample is shown.

\textbf{Background}

The signal events are split in four regions of $K\pi$ mass, while the rest of the study is carried on independently, in order to separate the contributions from various resonances.