The photon polarisation in radiative B decays

Jeremy Hebinger

Laboratoire de l'Accélérateur Linéaire

May 9, 2016

Pheniccs Days
Introduction

- Radiative B meson decays
- How to extract the photon polarisation
- Experimental results
Why $b \rightarrow s \gamma$?

- Since this is a Flavour Changing Neutral Current (FCNC), this process only occurs through at loop level.

- May be sensitive to New Physics.

- We can test the standard model for such decays by confronting theoretical predictions against experimental measurements.
Which observable to use?

- **Exclusive decay rate**: \( \Gamma(B \to M\gamma) \)
  
  Experimentally accessible but difficulty to predict accurately.

- **Inclusive decay rate**: \( \Gamma(b \to X_u\gamma) \)
  
  Experimentally difficult but small theoretical uncertainties.

- **Photon Polarisation**:
  
  \[ \frac{\Gamma_R - \Gamma_L}{\Gamma_R + \Gamma_L} = \lambda_\gamma \]

  In accelerator experiment, the polarisation cannot be directly measured but the theoretical uncertainties are of the order of 10%.

- **CP asymmetry**:
  
  \[ \frac{\bar{\Gamma} - \Gamma}{\bar{\Gamma} + \Gamma} \]

  Experimentally difficult but small theoretical uncertainties.
Photon polarisation in the SM

- Decay rate:
  \[
  \bar{s} \Gamma(b \rightarrow s\gamma)_{\mu} b \propto \bar{s}\sigma_{\mu\nu} q^\nu \left( m_b \frac{1 + \gamma^5}{2} + m_s \frac{1 - \gamma^5}{2} \right) b
  \]

  - \( m_s \approx 95 \text{ MeV} \)
  - \( \frac{m_s}{m_b} \approx 0.02 \)
  - \( m_b \approx 4.18 \text{ GeV} \)

  According to the SM:
  The photon will be mostly left-handed for \( b \rightarrow s\gamma \) and right-handed for \( \bar{b} \rightarrow \bar{s}\gamma \).

  We expect \( \lambda_\gamma \approx -1 \)

- Charm loop contribution: 10%
Extracting the photon polarisation

We can relate the polarisation of the s quark and the photon:

How to measure the polarisation of the s quark:

We need an observable which changes sign under parity.

Angular analysis can provide such observables given that we have 2 amplitudes with a relative phase.

If the photon decays, we can as well measure the interferences of left and right handed amplitude:

Virtual photon contribution. \[ b \rightarrow s(e^+e^-) \]

Nuclear conversion to a lepton pair.
Extracting the photon polarisation

- Why and which 3-body decay?

\[ B^+ \to K_1^+ \gamma \to (K^+\pi^-\pi^+)\gamma \]

- The Kππ decay can be used as a reference plane

- We count how many times \( \Upsilon \) is going above and under this plane.

\[
|M(K_1 \to K\pi\pi)|^2 \propto |\vec{e}_{K_1} \cdot \vec{J}|^2
\]

\[
|M(K_{1R/L} \to K\pi\pi)|^2 \propto \frac{1}{4}(1 + \cos^2 \theta)(|J_x|^2 + |J_y|^2) \pm \cos \theta \text{Im}[J_x J_y^*]
\]

\[ A_{up-down} = \frac{\int_{-1}^{1} d\cos \theta \frac{d\Gamma}{d\cos \theta} - \int_{-1}^{0} d\cos \theta \frac{d\Gamma}{d\cos \theta}}{\int_{-1}^{1} d\cos \theta \frac{d\Gamma}{d\cos \theta}} = \lambda \gamma \frac{3}{2} \int d\sigma_{23} d\sigma_{13} \text{Im}[J_x J_y^*]
\]
Modeling the hadronic decay

Considering only $K_1(1270)$, we have 3 decay channels leading to $K\pi\pi$:

$$K^*\pi \quad \rho K \quad \kappa\pi$$

Large uncertainties originating from the kappa channel contribution and limited knowledge on the relative branching ratios of other kaonic resonances.

$$A_{\text{up-down}} = \lambda \gamma \frac{3}{2} \frac{\int ds_{23} ds_{13} \text{Im}[J_\gamma J_\gamma^*]}{\int ds_{23} ds_{13} (|J_\gamma|^2 + |J_\gamma|^2)}$$

My results:
Experimental results

\[ B^+ \rightarrow K^{+}\gamma \rightarrow (K^{+}\pi^{-}\pi^{+})\gamma \]

LHCb recently collected a sample of about 14000 events leading to measurements of the Up-Down asymmetry $4\sigma$ away from zero in the $K_1(1270)$ region.

Belle has smaller sample but we can expect results from Belle II in the future.
Conclusions

• We can test the SM with the $B \to K_1 \gamma$ decay.
• Experimental results show a $4 \sigma$ deviation from zero for the measurements of the Up- Down asymmetry.
• More work is needed on the modelisation of $K_1$ decay in order to extract the photon polarisation.
$B^+ \rightarrow K^+_1 \gamma \rightarrow K^+ \pi^+ \pi^-$
\( K_{1(1270)} \) and \( K_{1(1400)} \) are a mixture of \( 1^1P_1 \) and \( 1^3P_1 \) states

\[
\begin{align*}
|K_{1(1270)}\rangle &= |K_{1A}\rangle \sin \theta_{K_1} + |K_{1B}\rangle \cos \theta_{K_1} \\
|K_{1(1400)}\rangle &= |K_{1A}\rangle \cos \theta_{K_1} - |K_{1B}\rangle \sin \theta_{K_1}
\end{align*}
\]

\[
\begin{align*}
A_{K_{1(1270)} \to K^* \pi / \rho}^S &= S_{K^*/\rho}(\sqrt{2} \sin \theta_{K_1} + \cos \theta_{K_1}) \\
A_{K_{1(1270)} \to K^* \pi / \rho}^D &= D_{K^*/\rho}(- \sin \theta_{K_1} + \sqrt{2} \cos \theta_{K_1}) \\
A_{K_{1(1400)} \to K^* \pi / \rho}^S &= S_{K^*/\rho}(\sqrt{2} \cos \theta_{K_1} \pm \sin \theta_{K_1}) \\
A_{K_{1(1400)} \to K^* \pi / \rho}^D &= D_{K^*/\rho}(- \cos \theta_{K_1} \pm \sqrt{2} \sin \theta_{K_1})
\end{align*}
\]

\[
S^{(ABC)} = \gamma \sqrt{\frac{3}{2} \frac{2I_1^{(ABC)} - I_0^{(ABC)}}{18}}, \quad D^{(ABC)} = \gamma \sqrt{\frac{3}{2} \frac{I_1^{(ABC)} + I_0^{(ABC)}}{18}}
\]

In this model, \( \mathcal{J} \) can be computed in term of \( \gamma \) and \( \theta_{K_1} \)

\[
I_m^{(ABC)} = \frac{1}{8} \int d^3 \vec{k} \mathcal{Y}_1^m(\vec{k}_B - \vec{k}) \psi^{(A)}(\vec{k}_B + \vec{k}) \psi^{(B)}(-\vec{k}) \psi^{(C)}(\vec{k})
\]
Results s-depended with

\[
\Gamma_{K_1,\text{pol.}}(s) = \int_{s_{13},s_{23}} \frac{1}{128(2\pi)^3} \frac{1}{s^{3/2}} \left| M_{K_1,\text{pol.}} \right|^2 ds_{13} ds_{23}
\]

\[
\Gamma_{K_1(1270)} \approx 90 MeV
\]

\[
\Gamma_{K_1(1400)} \approx 174 MeV
\]