Perspectives of B radiative penguin decays

Vicente J Rives Molina

Vicente.Rives@cern.ch

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Outline

- Theoretical introduction
- Brief summary of studied decay channels
- Ongoing work
- Future prospects

Theory reminder

The quarks mass eigenstates are not the same than the flavour eigenstates. This leads to the possibility of the mixing of quarks. This mixing is described by the CKM matrix.

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

The off-diagonal terms allow transitions between the different quark generations.

The CKM matrix is unitary: $\sum V_{ij} V_{ik}^{*} = \delta_{jk}$

The SM has three mixing angles and one CPV phase. Easy to see when doing parametrization.

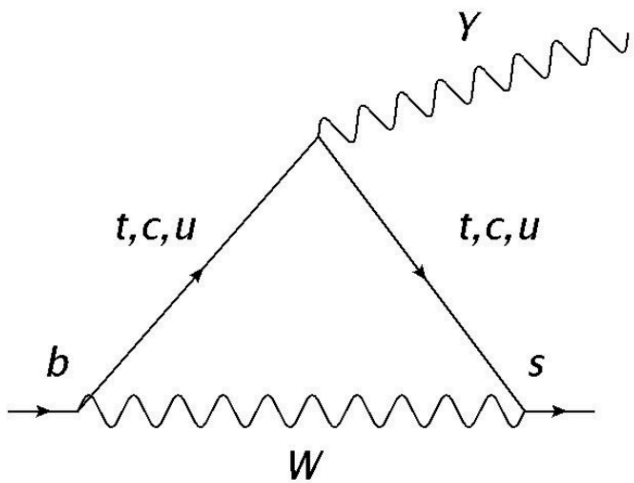
Radiative decays measurements give access to the CKM elements:

- $b \rightarrow d\gamma$ gives access to V_{td}
- $b \rightarrow s\gamma$ gives access to V_{ts}

LHCb tries to over-constrain the measurement of the different CKM matrix elements to find inconsistencies → New Physics

Radiative decays

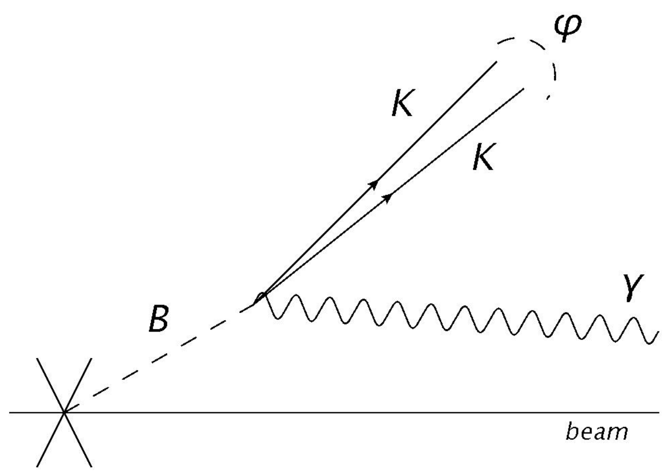
- FCNC are forbidden in the SM at tree level
- Large mass of the *top* quark weakens the GIM suppression
- Sensitive to contribution of NP particles
- Many observables:
    - Branching Ratios
    - Photon polarization through angular analysis and CP observables
    - Time dependent CP asymmetry
    - Isospin asymmetry
- The photon polarization has never been measured. All photons to be left-handed in the SM



Published studies

$B \to V\gamma$: Branching Ratios

- Two channels studied in detail: $B \to K^{*}\gamma$ and $B_s \to \phi\gamma$
  - Already studied in previous experiments: BaBar, Belle, CLEO
  - Large uncertainty for $B_s \to \phi\gamma$:
    - Theory: $BR(B_s \to \phi\gamma) = (4.3 \pm 1.4)10^{-5}$ [Phys. Rev. D, 75 (2007)]
    - Experiment: $BR(B_s \to \phi\gamma) = (5.7^{+2.1}_{-1.8})10^{-5}$ [Phys. Rev. Lett. 103 (2009) 211802]
- B mass resolution (~ 90 MeV) dominated by the ECal resolution
- Selection requires:
  - Large photon transverse momentum
  - Large impact parameter for the product particles
  - B meson isolation
  - Vertices quality



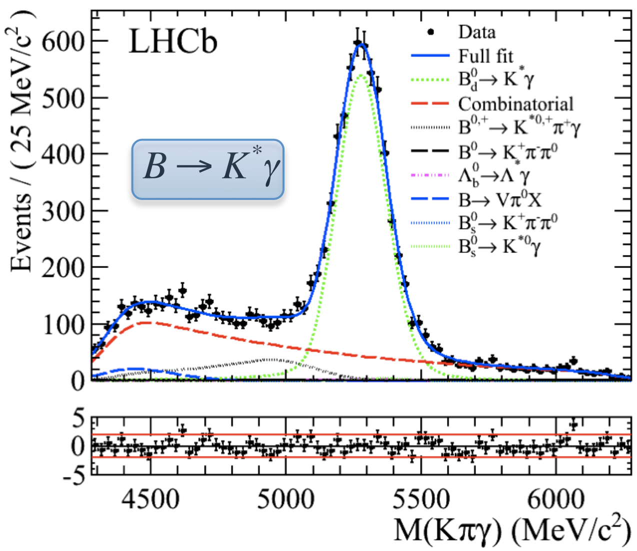
$B \to V\gamma$: Branching Ratios

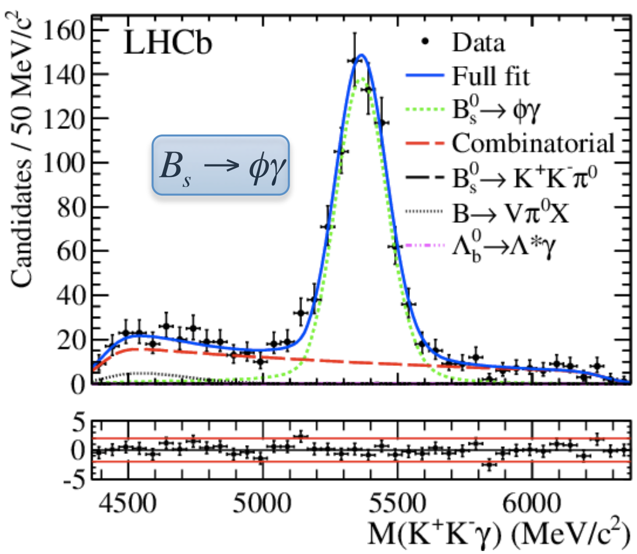
- Measurement of the Branching Ratios ratio:
  - Use of similar selections to reduce systematics

$$N = L\sigma_{\bar{b}b} 2 f_i BR(channel)\varepsilon$$

$$R = \frac{BR(B^0 \to K^{*0}\gamma)}{BR(B_s \to \phi\gamma)} = \frac{N_{sig}^{B^0 \to K^{*0}\gamma}}{N_{sig}^{B_s \to \phi\gamma}} \frac{BR(\phi \to K^+K^-)}{BR(K^* \to K^+\pi^-)} \frac{f_s}{f_d} \frac{\varepsilon_{B_s \to \phi\gamma}}{\varepsilon_{B^0 \to K^*\gamma}}$$

- From PDG (green)
- From LHCb measurement [arXiv:hep-ex/1111.2357] (purple)
- From fit to data (blue)
- From simulation and data (red)





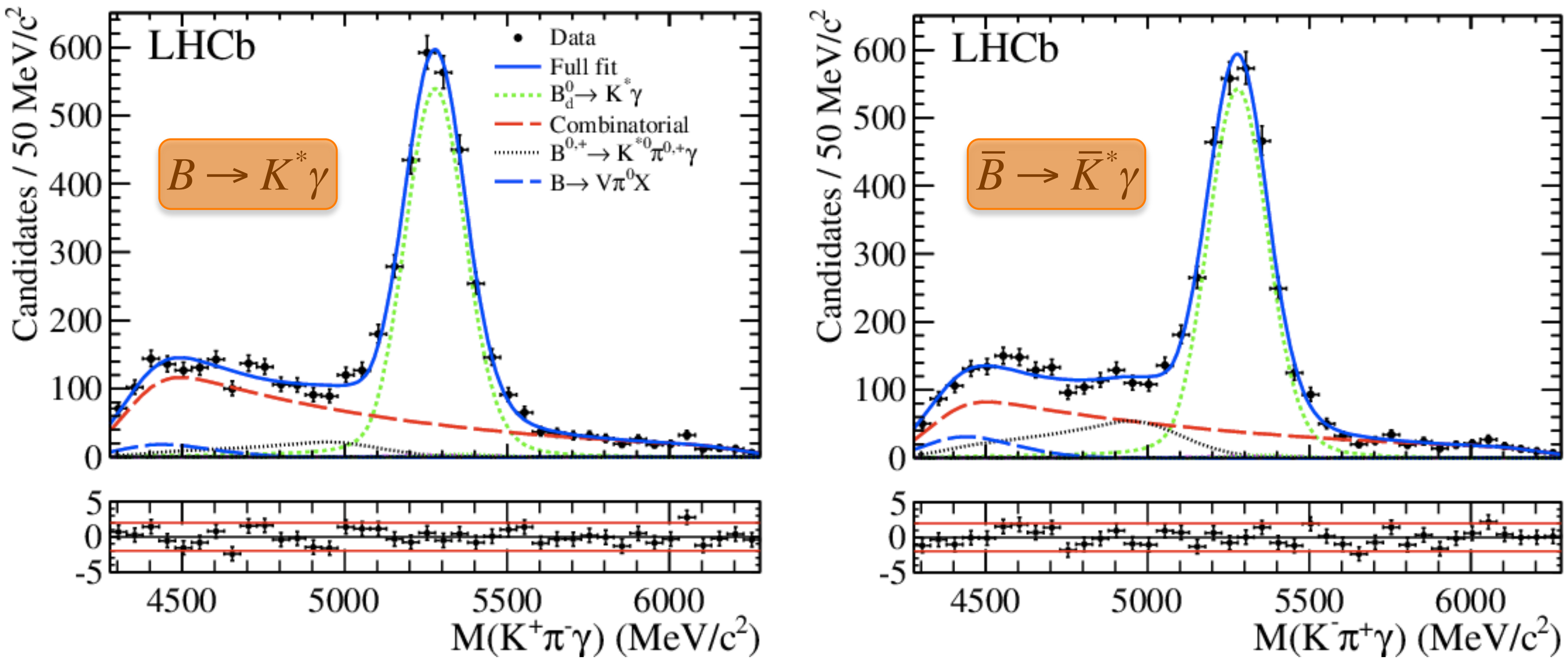
$B \to V\gamma$: Branching Ratios

- Results published:
  - Nuclear Physics B 867 (2013)
- World best measurement with $1fb^{-1}$ from 2011 data:
  - $R = \frac{BR(B_d \to K^* \gamma)}{BR(B_s \to \phi\gamma)} = 1.23 \pm 0.06(stat) \pm 0.04(syst) \pm 0.10(f_d / f_s)$
- This and PDG data:
  - $BR(B_s \to \phi\gamma) = (3.5 \pm 0.4)10^{-5}$
- Agreement with SM predictions:
  - $BR(B_s \to \phi\gamma) = (4.3 \pm 1.4)10^{-5}$ [Phys. Rev. D, 75 (2007)]
  - $R = 1.0 \pm 0.2$ [Eur. Phys. J. C55 (2008) 577]

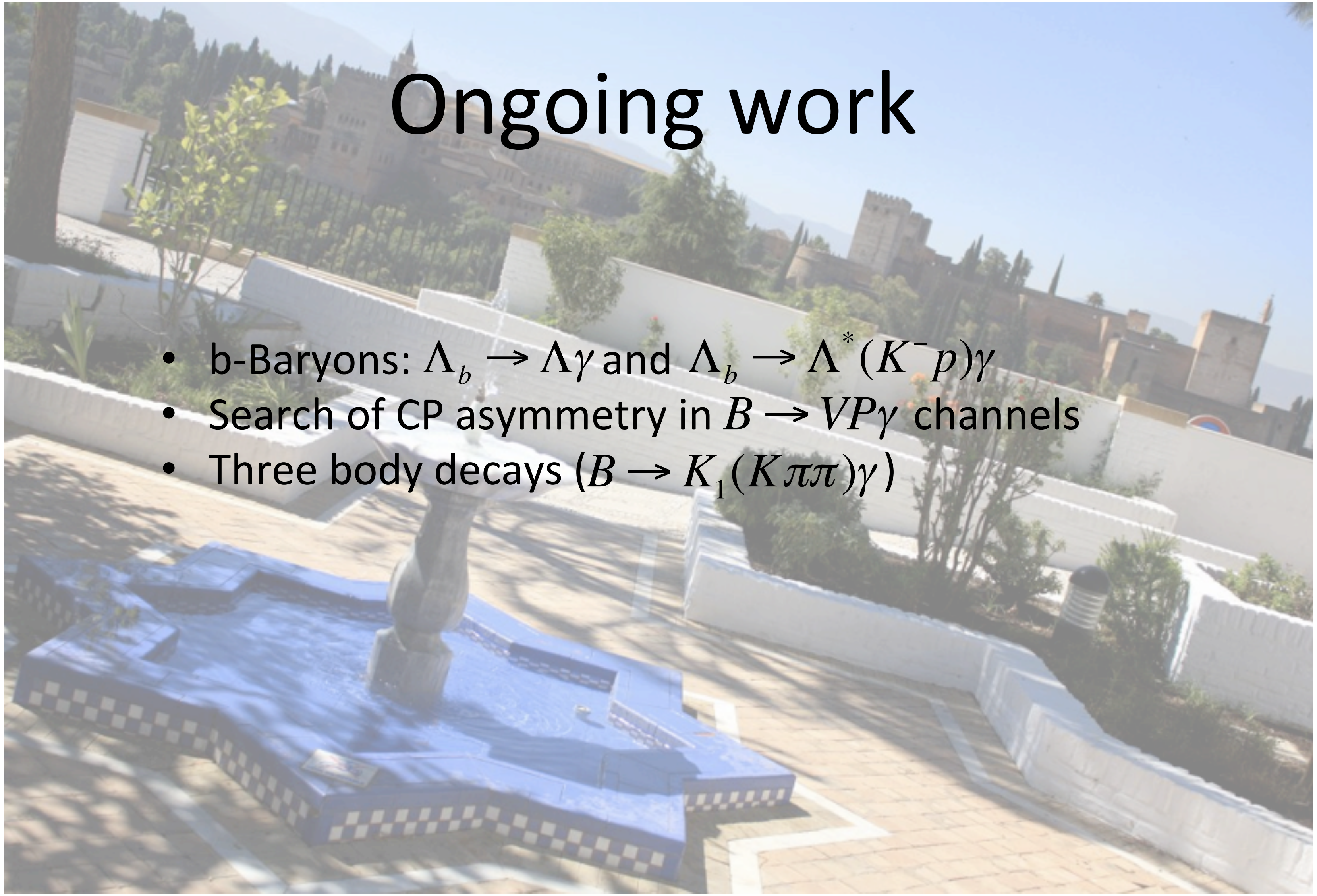
$B \to V\gamma$: CP asymmetry

Direct CP asymmetry in the $B \to K^{*}\gamma$ channel
SM prediction: A_{CP} = (-0.61 ± 0.43) %   [Phys. Rev. D72 (2005) 014013]
LHCb measurement:

A_{CP} = (0.8 ± 1.7(stat) ± 0.9(syst)) %   [Nuclear Physics, Section B 867 (2013)]



See Ricardo's presentation for a more detailed description



Ongoing work

- b-Baryons: $\Lambda_b \to \Lambda\gamma$ and $\Lambda_b \to \Lambda^*(K^- p)\gamma$
- Search of CP asymmetry in $B \to VP\gamma$ channels
- Three body decays ($B \to K_1(K\pi\pi)\gamma$)

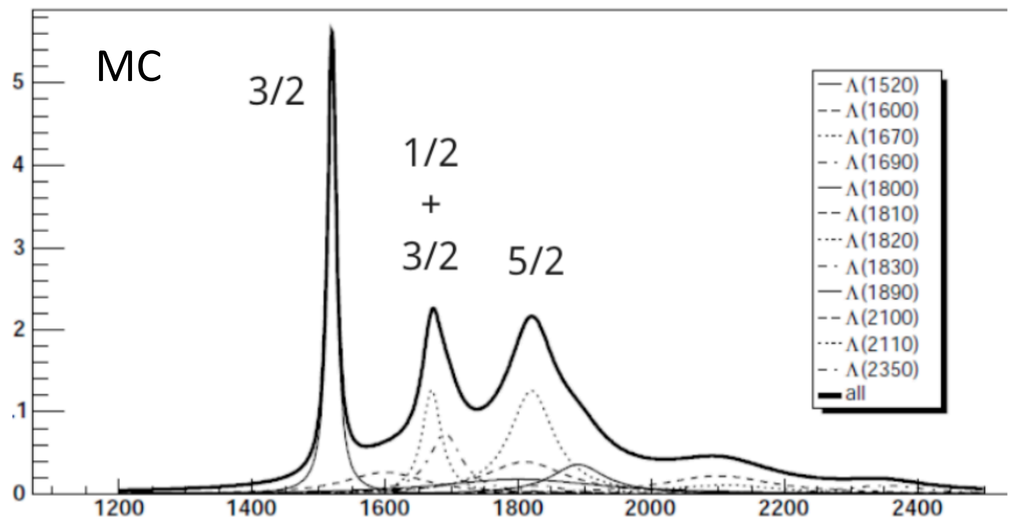
$\Lambda_b \to \Lambda^*(X)\gamma$

The photon polarization for these decays are dependent on the spin of Λ*
Λ*(1520) is well established:

- J=3/2 so may not be sensitive to photon polarization
- Contamination from poorly known Λ*(1600)

Λ*(1670) and Λ*(1690) not well known

Very early stages. Analysis at the moment possible but limited to the Λ*(1520) region



$B \to K_1(K\pi\pi)\gamma$

Useful for the measurement of the photon polarization through the up/down asymmetry [Gronau, Grossman, Pirjol, Ryd hep-ph/0107254].

$$A = \frac{\int_0^{\pi/2} d|M|^2\, d\theta - \int_{\pi/2}^{\pi} d|M|^2\, d\theta}{\int_0^{\pi} d|M|^2\, d\theta}$$

where θ is the angle between the photon momentum and the perpendicular to the K_1 decay plane.

The polarization information is in the angular distribution and in the Dalitz distribution [Kou, Le Yaouanc, Tayduganov, PRD83(2011)].

$B \to K_1(1270)\gamma$ observed by Belle [Phys. Rev. Lett. 94 (2005) 111802]

$$\omega(s_{13}, s_{23}, \cos\theta) = \frac{2\,\mathrm{Im}(\hat{n}\cdot(\vec{J}\times\vec{J}^*))\cos\theta}{|\vec{J}|^2\,(1+\cos^2\theta)} \qquad \lambda = \frac{<\omega>}{<\omega^2>}$$

Dalitz information

Angular distribution information

$B \to VP\gamma$

Still first steps of the analysis

Use of selections of the $B \to V\gamma$ channels but bearing in mind that:

- There are more tracks → more info available
- Less combinatorial background

Goals:

- Measurement of the direct CP asymmetry
- Photon polarization measurement (very long term)

$B \rightarrow \phi K \gamma$

First decay of the $B \rightarrow VP\gamma$ studied:

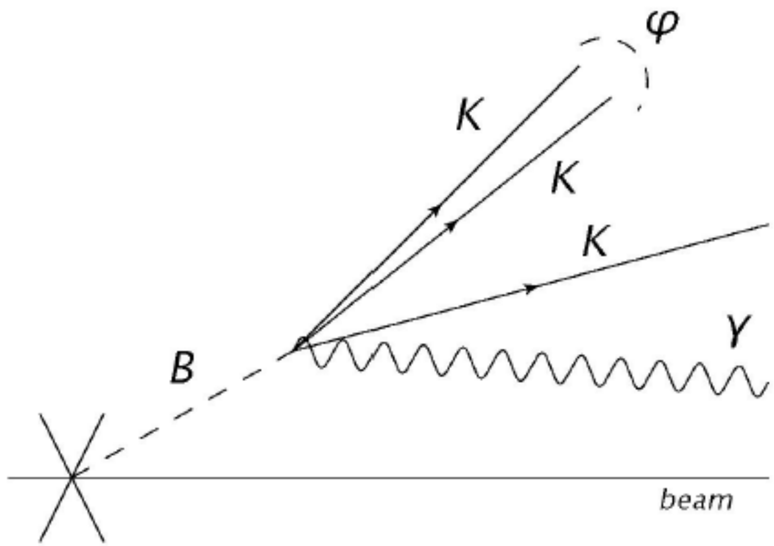
- $BR(B \rightarrow \phi K \gamma) = (3.5 \pm 0.6 \pm 0.4)10^{-6}$ [PRD-RC 75, 051102 (2007)]

Already studied by BaBar:

- A_{CP} = -0.26 ± 0.14 ± 0.05 [PRD-RC 75, 051102 (2007)]

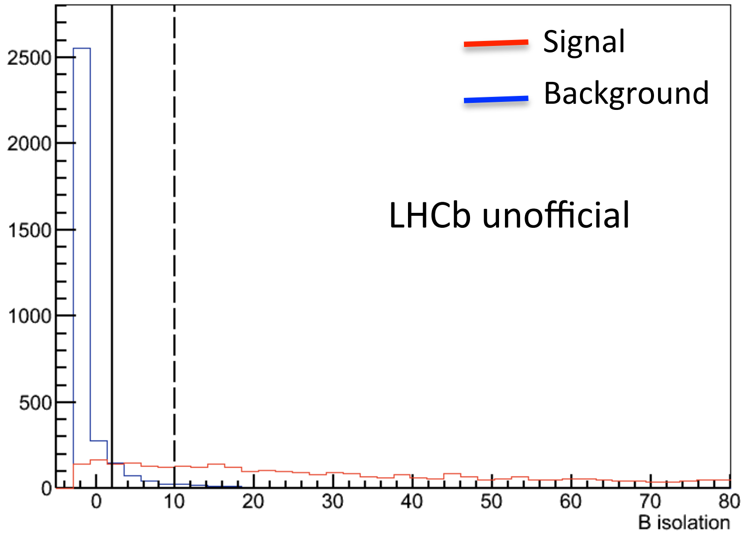
Selection puts constraints in:

- Vertex of the B
- Impact parameters of the charged particles
- Transverse momentum of the final products



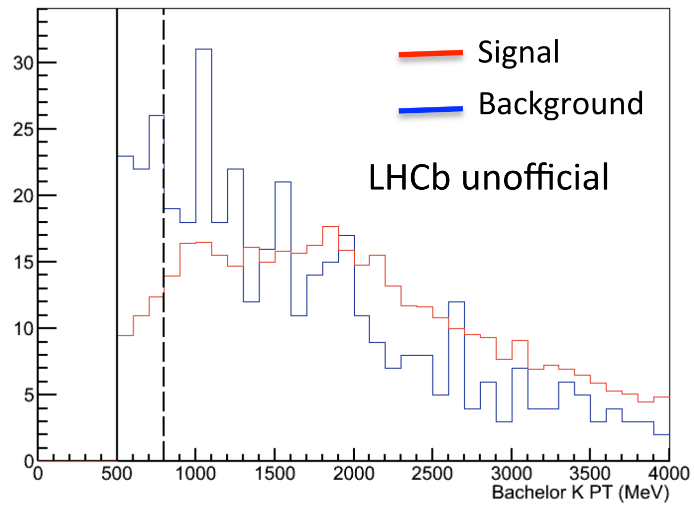
$B \to \phi K \gamma$

- The selection is based on that for the $B_s \to \phi\gamma$ channel.
- New decay products lead to an optimization of the offline selection for some variables.



Some cuts may be loosened and some may be tightened.

Found new kinematic cuts to improve S/B.



Future prospects

$b \to d\gamma$

- The SM predicts an A_{CP} of 10%
- Difficult to access experimentally
- Branching ratios:
  - Theory: $BR(B \to \rho\gamma) = (4.9 \pm 1.8)10^{-7}$ [arXiv:hep-ex/0209346]
  - Experimental: $BR(B \to \rho\gamma) = (8.6 \pm 1.5)10^{-7}$ [PDG]
- Access to $|V_{td}|/|V_{ts}|$ using $B \to \omega\gamma$ and $B \to \rho\gamma$ vs. $B \to K^{*}\gamma$

Isospin Asymmetry

- For well-known channels as the $B \to K^{*}\gamma$

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

Photon helicity structure in radiative decays

- Right-handed photons in $b \to q\gamma$ is suppressed by m_q/m_b in the SM

$$\tan\psi = \left| \frac{A(\bar{B}_q \to f^{CP}\gamma_R)}{A(\bar{B}_q \to f^{CP}\gamma_L)} \right|$$ is a sensitive parameter for NP search

- Time-dependent decay rate is sensitive to photon helicity

$$\Gamma(B_q \to f^{CP}\gamma) = |A|^2 e^{-\Gamma_q \tau}[\cosh(\Delta\Gamma_q \tau / 2) + A_q^{\Delta} \sinh(\Delta\Gamma_q \tau / 2) \pm C_q \cos(\Delta m_q \tau) \mp S_q \sin(\Delta m_q \tau)]$$

If q=s, $A^{\Delta}_s \approx \sin(2\psi)$

Conclusions

- Radiative decays is a good place to test the Standard Model
- Measurements so far compatible with the Standard Model
- Ongoing work still at its first steps
- New decay channels and new observables in the to-do list
- Suggestions for new analysis welcome!


Thank you for your attention!

Back-up

THEORY

Direct CPV:

- in SM:
  - <= 1% for $b \rightarrow s\gamma$
  - < 16% for $b \rightarrow d\gamma$
- other models:
  - up to 40%

PhiGamma & KstGamma

		$B \to K^* \gamma$	$B_s \to \phi\gamma$
Track IP χ^2		> 25	> 25
$p_{T,track}$	(MeV)	> 500	> 500
K PID_K		> 5	> 5
K $PID_K - PID_p$		> 2	> 2
π PID_K		< 0	-
meson ΔM_{PDG}	(MeV)	< 50	< 9
meson vertex χ^2		< 9	< 9
γ E_T	(MeV)	> 2600	> 2600
γ CL		> 0.25	> 0.25
π/γ separation		> 0.5	> 0.5
$p_{T,B}$	(MeV)	> 3000	> 3000
B IP χ^2		< 9	< 9
B helicity		< 0.8	< 0.8
B isolation $\Delta\chi^2$		> 0.5	> 0.5

B2 PhiKGamma selection

Old selection

		Stripping cut	Selection cut
B meson	Impact parameter chi2	15	9
	Vertex quality chi2	-	9
	Pointing angle (rad)	0.02	0.02
	Isolation	-	2
	Flight distance chi2	64	100
	Transverse momentum (MeV)	-	3000
photon	Likelihood vs. pi0	-	0.5
	Transverse momentum (MeV)	2500	2600
	Likelihood vs. electrons	0.25	0.25
phi	Vertex quality chi2	15	9
	Deviation from the nominal mass (MeV)	15	9
tracks	Minimum impact parameter chi2	16	25
	Likelihood vs. pions	-	0
	Likelihood vs. protons	-	-2
	Transverse momentum (MeV)	300	500

New selection

		New selection cut
B meson	Impact parameter chi2	6
	Vertex quality chi2	9
	Pointing angle (rad)	0.014
	Isolation	10
	Flight distance chi2	100
	Transverse momentum (MeV)	3000
photon	Likelihood vs. pi0	0.5
	Transverse momentum (MeV)	2600
	Likelihood vs. electrons	0.25
phi	Vertex quality chi2	6
	Deviation from the nominal mass (MeV)	9
tracks	Minimum impact parameter chi2	25 (75 for bachelor)
	Likelihood vs. pions	0
	Likelihood vs. protons	-2
	Transverse momentum (MeV)	500 (800 for bachelor)
Kinematics	$M(\phi K_b)$ (MeV)	2500