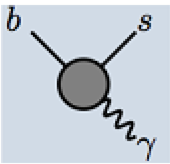

Radiative decays at LHCb

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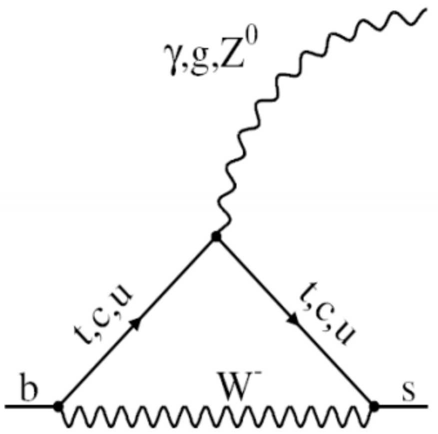
17 April 2012

Implications of LHCb measurements and future prospects

$b \to q\gamma$

- Radiative $b \to (d, s)\gamma$, one-loop penguin transition, sensitive to NP.



NP may introduce sizeable effects on the dynamics of the transitions, through contributions of new particles inside the loops

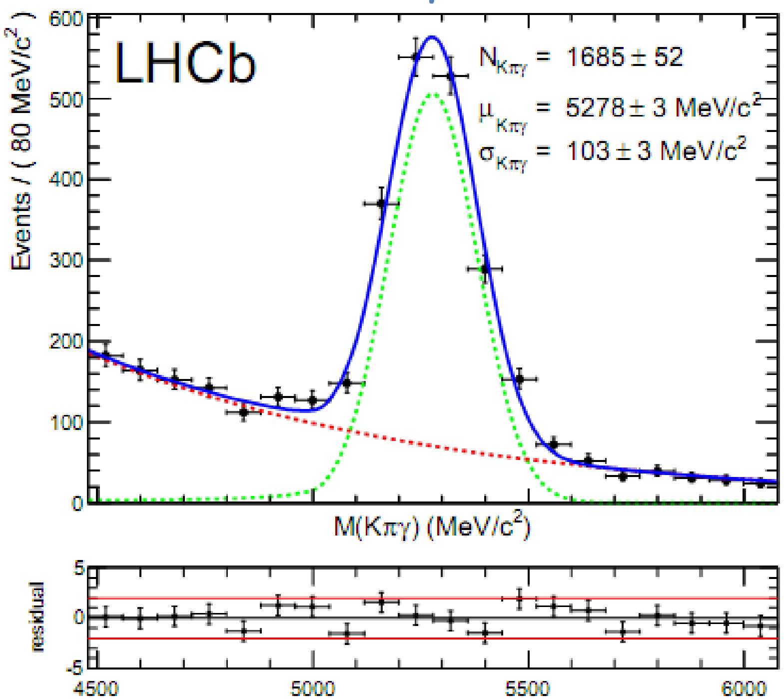
- Theoretically clean FCNC transition & experimentally accessible.
- Many observables: branching fractions (BR), CP asymmetries (A_{CP}), isospin asymmetry, helicity structure of the photon.

Radiative decays $B \to V\gamma$

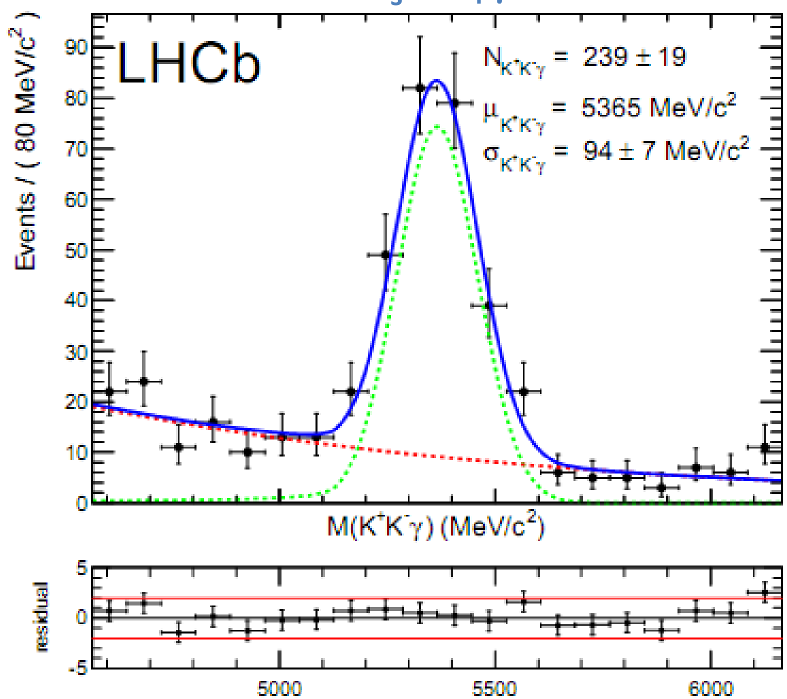
- $B^0 \to K^{*0}\gamma$ and $B_s^0 \to \phi\gamma$
- Resolution ~100 MeV/c^2 dominated by ECAL resolution

0.37 fb^{-1} of 2011 data

$B^0 \to K^{*0}\gamma$



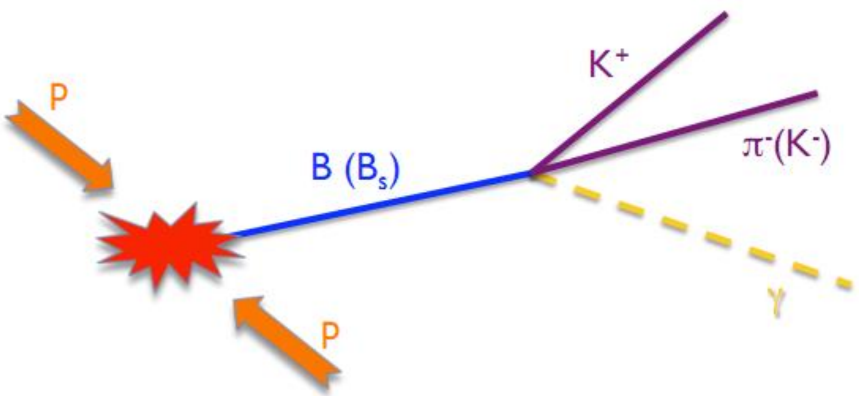
$B_s^0 \to \phi\gamma$



LHCb-PAPER-2011-042, submitted to Phys. Rev. D

Selection

- Similar selection for both decays to ensure cancellation of systematics.
  - Build K* or ϕ meson from two opposite charge tracks
    - p_T>500 MeV, not from PV, PID requirements, vertex quality, mass cut
  - Select high E_T photon
    - E_T>2.6 GeV, CL cut, π^0 rejection
  - Combine the meson with the photon to build the B candidate
    - p_T>3 GeV, from PV, helicity, isolation



Branching fractions

- Previous results:

[Ali, Pecjak, Greub, Eur. Phys, J. C55 (2008)] [HFAG, 2010]

	Theory ($\times 10^{-5}$)	Experiment ($\times 10^{-5}$)
$B^0 \to K^{*0}\gamma$	4.3±1.4	4.33±0.15
$B_s^0 \to \phi\gamma$	4.3±1.4	$5.7^{+2.1}_{-1.8}$

- SM prediction for the ratio:

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.0 \pm 0.2$$; 0.7±0.3 experimentally

- **LHCb result ($0.37\ \mathrm{fb}^{-1}$):** **LHCb-PAPER-2011-042**, submitted to Phys. Rev. D

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B_s^0 \to \phi\gamma)} = 1.12 \pm 0.08(\mathrm{stat})^{+0.06}_{-0.04}(\mathrm{syst})\ ^{+0.09}_{-0.08}(f_s/f_d)$$

Using $\mathcal{B}(B^0 \to K^{*0}\gamma) = (4.33 \pm 0.15) \times 10^{-5}$

⇒ $\mathcal{B}(B_s^0 \to \phi\gamma) = (3.9 \pm 0.5) \times 10^{-5}$ **World best measurements**

The ratio of branching fractions in more detail:

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

From unbinned fit to data

From PDG

From LHCb measurement (arXiv:hep-ex/1111.2357v1)

Ratio of efficiencies:

$$\frac{\epsilon_{B_s^0\to\phi\gamma}}{\epsilon_{B^0\to K^{*0}\gamma}} = r_{\text{acc}} \times r_{\text{reco\&sel}} \times r_{\text{PID}} \times r_{\text{trigger}}$$

From simulation

$$r_{\text{acc}} = 1.094 \pm 0.004\,(\text{stat})$$
$$r_{\text{reco\&sel}} = 0.949 \pm 0.006\,(\text{stat})$$
$$r_{\text{trigger}} = 1.057 \pm 0.008\,(\text{stat})$$

From data (D* calibration sample) $r_{\text{PID}} = 0.787 \pm 0.010\,(\text{stat})$

Systematic uncertainties

Source	σ/ratio
Acceptance (r_{acc})	± 0.3 %
Selection ($r_{reco\&sel}$)	± 1.4 %
PID efficiencies (r_{PID})	± 2.7 %
Trigger ratio ($r_{trigger}$)	± 0.8 %
B mass window	± 0.9 %
* Background	$\left(^{+4.5}_{-2.0}\right)$ %
Visible fraction of vector mesons	± 1.0 %
Uncertainty on the ratio of yields	$\left(^{+5.4}_{-3.3}\right)$ %
f_s/f_d	$\left(^{+7.9}_{-7.5}\right)$ %

* Different background contamination is accounted for in yield extraction (details in slide 17)

A_{CP} ($B^0 \to K^{*0}\gamma$)

- Direct CP asymmetry in $B^0 \to K^{*0}\gamma$

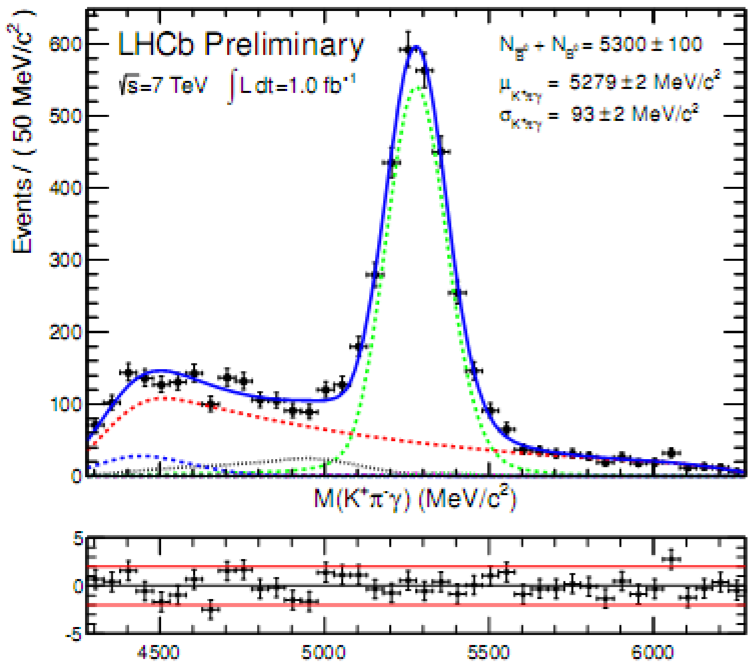
1.0 fb^{-1} of 2011 data

Larger yields than in B factories!!

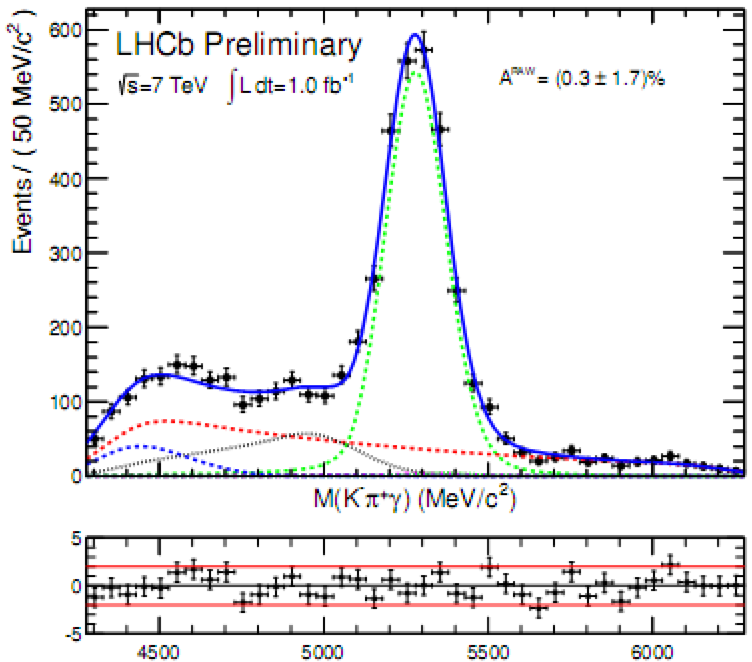
($B_s^0 \to \phi\gamma$, N=690±40)

N = 5300 ± 100

$B^0 \to K^{*0}\gamma$



$\bar{B}^0 \to \bar{K}^{*0}\gamma$



LHCb-CONF-2012-004

- Previous results:

	Theory [Keum, Matsumori, Sanda, PRD 72 (2005)]	Experiment [BaBar, PRL 103 (2009)]
$A_{CP}(B^0 \to K^{*0}\gamma)$	-0.006 ± 0.004	$-0.016 \pm 0.022 \pm 0.007$

- **Preliminary LHCb result (1 fb^{-1}):** **LHCb-CONF-2012-004**

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = \mathcal{A}^{\mathrm{RAW}}(B^0 \to K^{*0}\gamma) - \mathcal{A}_{\mathrm{D}}(K\pi) - \kappa\mathcal{A}_{\mathrm{P}}(B^0)$$

$\mathcal{A}_{\mathrm{P}}(B^0)$: Production asymmetry

$\mathcal{A}_{\mathrm{D}}(K\pi)$: Detection asymmetry

$$\boxed{\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = 0.008 \pm 0.017(\mathrm{stat}) \pm 0.009(\mathrm{syst})}$$

Most precise measurement

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = \mathcal{A}^{\rm RAW}(B^0 \to K^{*0}\gamma) - \mathcal{A}_{\rm D}(K\pi) - \kappa\,\mathcal{A}_{\rm P}(B^0)$$

$$\mathcal{A}^{\rm RAW} = \frac{N_{\overline{B}^0 \to \overline{K}^{*0}\gamma} - N_{B^0 \to K^{*0}\gamma}}{N_{\overline{B}^0 \to \overline{K}^{*0}\gamma} + N_{B^0 \to K^{*0}\gamma}} = 0.003 \pm 0.017(\mathrm{stat})$$

Detection asymmetry using control samples of charm decays

$$\mathcal{A}_{\rm D}(K\pi) = \frac{\epsilon(K^-\pi^+) - \epsilon(K^+\pi^-)}{\epsilon(K^-\pi^+) + \epsilon(K^+\pi^-)} = -0.010 \pm 0.002$$

LHCb-CONF-2011-011

B production asymmetry estimated using a large sample of $B^0 \to J/\psi K^{*0}$ decays

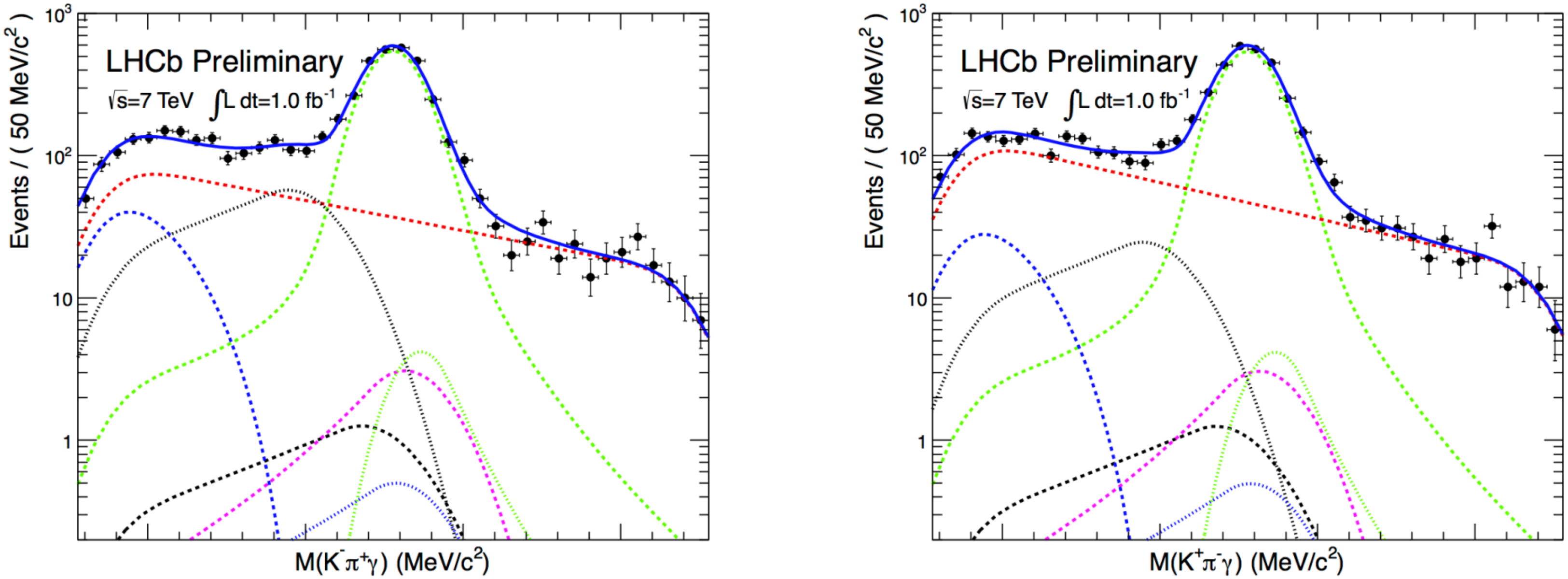
$$\mathcal{A}_{\rm P}(B^0) = \frac{R(\overline{B}^0) - R(B^0)}{R(\overline{B}^0) + R(B^0)} = 0.010 \pm 0.013$$

LHCb-CONF-2011-011

Reduction factor due to B^0 oscillation estimated in $B^0 \to K^{*0}\gamma$ data

$$\kappa = \frac{\int \cos(\Delta m_d t) e^{-\Gamma_d t} \epsilon(t) dt}{\int \cosh(\frac{\Delta\Gamma_d t}{2}) e^{-\Gamma_d t} \epsilon(t) dt} = 0.41 \pm 0.04$$

Background contributions



- Partially reconstructed $B \to Vh\gamma$ decays
- b-baryons $\Lambda_b \to \Lambda^*(K^-p)\gamma$
- Irreducible bkg, $B_s \to K^{*0}\gamma$
- Charmless $B \to K^{*0}\pi^0$

$B^{+,0} \to K^{*0}\pi^{+,0}\gamma$

$B \to K^{*0}\pi^0 X$

$\Lambda_b \to \Lambda^*\gamma$

$B_s^0 \to \bar{K}^{*0}\gamma$

$B^0 \to K^+\pi^-\pi^0$

$B_s^0 \to K^-\pi^+\pi^0$

Side-bands shape shows a threshold effect due to different trigger and offline mass resolutions

		Branching fraction ($\times 10^6$)		Contamination relative to $B^0 \to K^{*0}\gamma$ yield
Radiative	$\Lambda_b^0 \to \Lambda^*\gamma$	unknown		$(1.0 \pm 0.3)\%$
	$B_s^0 \to \bar{K}^{*0}\gamma$	1.26 ± 0.31	(theo. [16])	$(0.8 \pm 0.2)\%$
Charmless with π^0	$B^0 \to K^+\pi^-\pi^0$	$35.9^{+2.8}_{-2.4}$	(exp. [17])	$(0.5 \pm 0.1)\%$
	$B_s^0 \to K^-\pi^+\pi^0$	unknown		$(0.2 \pm 0.2)\%$
Partially reconstructed decays	$B^+ \to K^{*0}\pi^+\gamma$	20^{+7}_{-6}	(exp. [17])	$(3.3 \pm 1.1)\%$
	$B^0 \to K^+\pi^-\pi^0\gamma$	41 ± 4	(exp. [17])	$\mathcal{O}(5\%)$
	$B \to K^{*0}\pi^0 X$	$\mathcal{O}(10\%)$ [17]		$\mathcal{O}(1\%)$

Corrections and systematics

		correction	uncertainty
* Background model	: $\Delta\mathcal{A}_{bkg}$	-0.002	± 0.007
Detection	: $-\mathcal{A}_{\rm D}(K\pi)$	$+0.010$	± 0.002
Magnet polarity	: $\Delta\mathcal{A}_{\mathcal{M}}$	$+0.001$	± 0.002
B^0 production	: $-\kappa\mathcal{A}_{\rm P}(B^0)$	-0.004	± 0.005
Total		$+0.005$	± 0.009

* Bkg model systematic from varying amplitude and shape within uncertainties.
A_{CP}(bkg) = 0, varied between [-1, 1] except $A_{CP}(B^0 \to K^{*0}\pi^0)$ =-0.15±0.12 (Exp.)

Summary and Prospects

Results

Most precise measurements to date. In agreement with SM predictions

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B^0_s \to \phi\gamma)} = 1.12 \pm 0.08(\mathrm{stat})^{+0.06}_{-0.04}(\mathrm{syst})\ ^{+0.09}_{-0.08}(f_s/f_d)$$

$$\mathcal{B}(B^0_s \to \phi\gamma) = (3.9 \pm 0.5) \times 10^{-5}$$

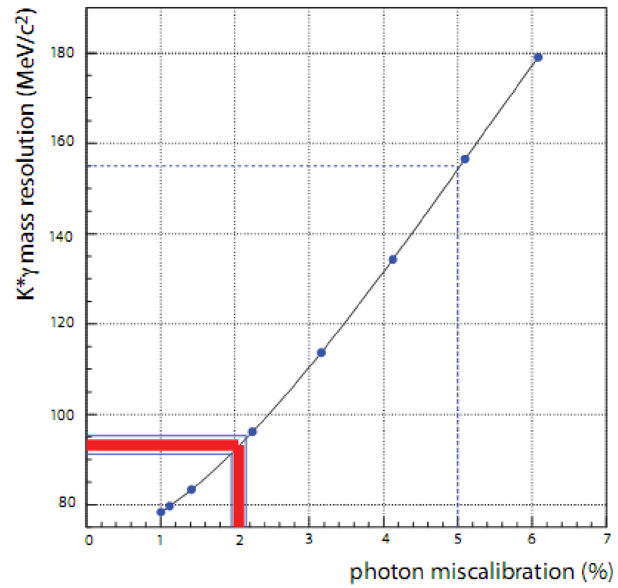
$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = 0.008 \pm 0.017(\mathrm{stat}) \pm 0.009(\mathrm{syst})$$

Prospects

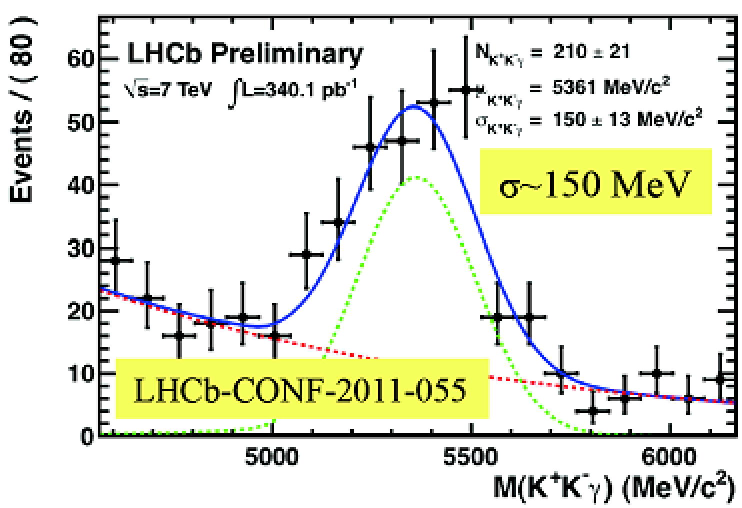
- CP asymmetry of charged $B \to VP\gamma$ modes: $B^+ \to K^{*0}\pi^+\gamma$, $B^+ \to \phi K^+\gamma$ - already observed in 2011 data
- b-Baryons: $\Lambda_b \to \Lambda\gamma$; $\Lambda_b \to \Lambda^*(K^-p)\gamma$ already observed in 2011 data
- $b \to d\gamma$ as $B^0 \to \omega\gamma$ and $B^0 \to \rho^0\gamma$; $B \to VV\gamma$ and neutral $B \to VP\gamma$ modes as $B \to V\pi^0\gamma$ and $B \to VK_s\gamma$ (?)
- Photon polarisation through time-dependent decay rate of $B_s^0 \to \phi\gamma$ and possibly through angular analysis of radiative decays of polarised Λ_b baryons
- Isospin asymmetry in $B \to K^*\gamma$

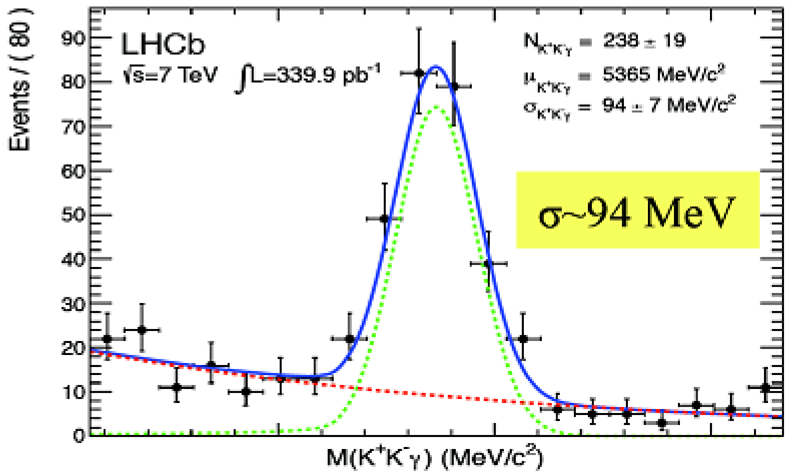
BACKUP

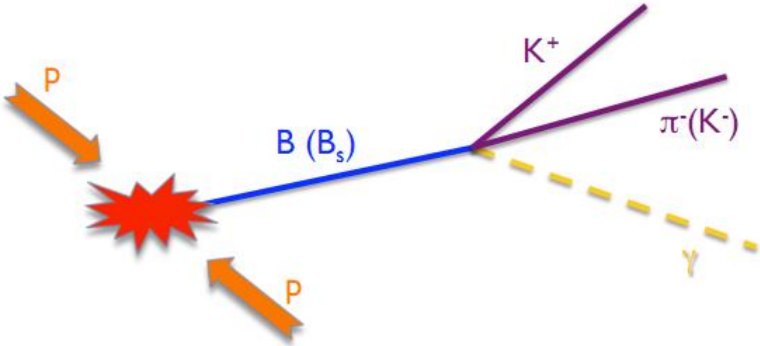
B mass resolution dominated by the photon calibration



Before/after Calorimeter calibration







Selection

		$B \to K^*\gamma$	$B_s \to \phi\gamma$
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

Similar selection for both decays to ensure cancellation of systematics

Background contributions account for in the ratio of BR

	$B^0 \to K^{*0}\gamma$		$B_s^0 \to \phi\gamma$		Ratio	
Contribution	Corr.	Error	Corr.	Error	Corr.	Error
$B_d \to K^+\pi^-\pi^0$	-1.3%	$\pm 0.4\%$	—	$\mathcal{O}(10^{-4})$	-1.3%	$\pm 0.4\%$
$B_s \to K^+\pi^-\pi^0$	-0.5%	$\pm 0.5\%$	—	$\mathcal{O}(10^{-4})$	-0.5%	$\pm 0.5\%$
$B_s \to K^+K^-\pi^0$	—	$\mathcal{O}(10^{-4})$	-1.3%	$\pm 1.3\%$	$+1.3\%$	$\pm 1.3\%$
$\Lambda_b \to \Lambda^*\gamma$	-0.7%	$\pm 0.2\%$	-0.3%	$\pm 0.2\%$	-0.4%	$\pm 0.3\%$
$B_s \to K^{*0}\gamma$	-0.8%	$\pm 0.4\%$	—	—	-0.8%	$\pm 0.4\%$
Partially reconstructed B	$+0.04\%$	$(^{+3.1}_{-0.2})\%$	$+4.5\%$	$(^{+1.3}_{-2.9})\%$	-4.5%	$(^{+4.2}_{-1.3})\%$
$\phi\gamma/K^{*0}\gamma$ cross-feed	-0.4%	$\pm 0.2\%$	—	$\mathcal{O}(10^{-4})$	-0.4%	$\pm 0.2\%$
Multiple candidates	-0.5%	$\pm 0.2\%$	-0.3%	$\pm 0.2\%$	-0.2%	$\pm 0.3\%$
Total	-4.2%	$(^{+3.2}_{-0.9})\%$	$+2.6\%$	$(^{+1.9}_{-3.2})\%$	-6.8%	$(^{+4.5}_{-2.0})\%$

Photon polarisation with $B_s^0 \to \phi\gamma$

$$\lambda_\gamma = \frac{|\mathcal{A}_R|^2 - |\mathcal{A}_L|^2}{|\mathcal{A}_R|^2 + |\mathcal{A}_L|^2}$$

Right-handed photon in $b \to q\gamma$ is suppressed by (m_q/m_b) within SM
Time-dependent decay rate is sensitive to photon helicity

$$\Gamma_{B^0_{(s)} \to \Phi^{CP}\gamma}(t) = |A|^2 e^{-\Gamma_{(s)}t}\left(\cosh\frac{\Delta\Gamma_{(s)}t}{2} - \mathcal{A}^\Delta \sinh\frac{\Delta\Gamma_{(s)}t}{2} + \mathcal{C}\cos\Delta m_{(s)}t - \mathcal{S}\sin\Delta m_{(s)}t\right)$$

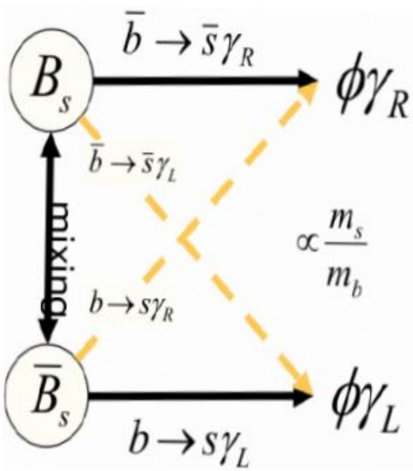
$$\mathcal{A}^\Delta \approx \sin(2\psi)\cdot\cos(2\beta_s) \qquad \mathcal{S} \approx \sin(2\psi)\cdot\sin(2\beta_s)$$

$$\tan\Psi = \left|\frac{A(B_q \to f^{CP}\gamma_R)}{A(B_q \to f^{CP}\gamma_L)}\right|$$

$$\mathcal{A}^\Delta \approx \sin(2\psi) \approx 0.1 \text{ in SM}$$

$$\lambda_\gamma = \cos 2\psi$$

Reliable theoretical prediction at NNLO → probe for NP in loop



$\sin(2\psi) = 0.28 \pm 0.44$, measured in B factories using $B^0 \to K^{*0}(K_s^0\pi^0)\gamma$

Extract $\sin(2\psi)$ with $B_s^0 \to \phi\gamma$, requires >= 2 fb^{-1}

LHCb sensitivity

	5 fb^{-1}	50 fb^{-1}	Theor
S ($B_s \to \phi\gamma$)	0.07	0.02	<0.01
$A^{\Delta\Gamma}$($B_s \to \phi\gamma$)	0.14	0.03	0.02

$B^+ \to \phi K^+ \gamma$

$\mathcal{B}(B^+ \to \phi K^+ \gamma) = (3.5 \pm 0.6) \cdot 10^{-6}$ Exp.
$A_{CP} = -0.26 \pm 0.14 \pm 0.05$ (BaBar)

$b \to d\gamma$

A_{CP} SM prediction of O(10%), but more difficult to access experimentally.
$\mathcal{B}(B \to \rho\gamma) = (1.30 \pm 0.19) \cdot 10^{-6}$ Theor., $(1.39 \pm 0.22) \cdot 10^{-6}$ Exp.
$|V_{td}|/|V_{ts}|$ using $B^0 \to \omega\gamma$ and $B^0 \to \rho\gamma$ (vs $K^*\gamma$)

Isospin asymmetry

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

Sensitive to MSSM effects at large $\tan\beta$ values.
Constraints on the mSUGRA parameter space.

Theor.

$$\Delta_{0-}(B^0 \to K^{*0}\gamma)_{\text{Kagan}} = (+8.0^{+2.1}_{-3.2})\% \times 0.3/T_1^{B\to K^*}$$

$(T_1^{B\to K^*}$ estimates go from 0.23 ± 0.06 to $0.38 \pm 0.06)$

$$\Delta_{0+}(B^0 \to K^{*0}\gamma)_{\text{Matsumori}} = +(2.7 \pm 0.8)\%$$

Exp.

$$\Delta_{0+}(B^0 \to K^{*0}\gamma)_{\text{Belle}} = +(1.2 \pm 4.4 \pm 2.6)\%$$

$$\Delta_{0-}(B^0 \to K^{*0}\gamma)_{\text{BaBaR}} = +(6.6 \pm 2.1 \pm 2.2)\%$$