Exclusive Rare B Decays
$(B \rightarrow V\gamma)$

Flavour and the Fourth Family

Albert Puig

Exclusive Radiative B Decays

Flavour and the Fourth Family

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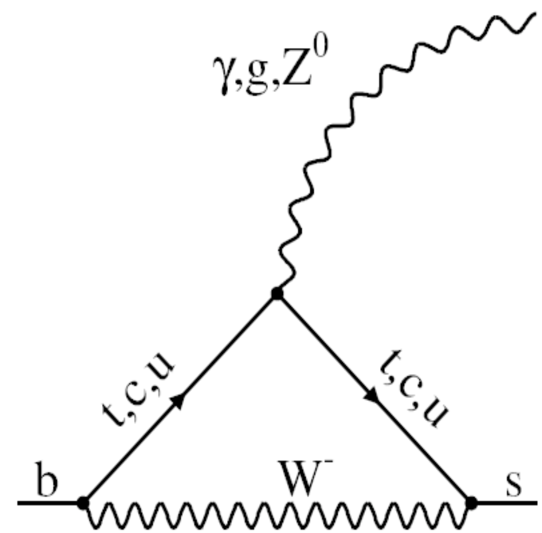
Outlook

- Theory, motivation of radiative B decays
- Current status
- Measurements with exclusive radiative B decays
- The LHCb contribution
- Prospects for the future

Penguin decays of B mesons

- In the SM, flavor-changing neutral currents (FCNC) are forbidden
- Effective FCNC are introduced by penguin (1-loop) diagrams.
  - Combinations of CKM matrix elements
  - Sensitive to new physics (NP)



- Because the b quark has no kinematically allowed CKM-favored decay, the importance of the penguin diagram is greater
  - Sensitivity to $|V_{td}|$ and $|V_{ts}|$

Effective theory of penguin decays

- Heavy degrees of freedom are integrated out to obtain an effective coupling for point-like interactions

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i(\mu) Q_i(\mu)$$

- Radiative decays are sensitive to the C_7 Wilson coefficient
  - New Physics (NP) is introduced by new heavy particles that modify the Wilson coefficients
    - SUSY, 4th generation, extra Higgs…

Inclusive vs Exclusive

- Inclusive B decays are theoretically clean because they are dominated by perturbatively calculable partonic contributions
  - Use of Heavy Mass Expansion (HME) in inverse powers of the *b* quark mass
- Exclusive radiative B decays are less clean
  - Use of QCD-improved factorization (QCDF) and soft collinear effective theory (SCET) methods
  - Larger nonperturbative QCD corrections than inclusive modes
    - Very difficult to calculate matrix elements from first principles

Inclusive vs Exclusive

	Theory $(\times 10^{-5})$	Experiment $(\times 10^{-5})$
$B \to X_s \gamma$	$1.38^{+0.14}_{-0.21}\vert_{\frac{m_c}{m_b}} \pm 0.15_{\mathrm{CKM}} \pm 0.09_{\mathrm{param}} \pm 0.05$	$0.72 \pm 0.27 \pm 0.23$
$B \to X_d \gamma$	31.5 ± 2.3	$35.2 \pm 2.3 \pm 0.9$
$B^0 \to K^{*0} \gamma$	4.3 ± 1.4	4.33 ± 0.15
$B_s \to \phi \gamma$	4.3 ± 1.4	$5.7^{+4.8}_{-1.5}{}^{+1.2}_{-1.1}$
$B \to \rho \gamma$	$0.130^{+0.018}_{-0.019}$	$0.139^{+0.022}_{-0.021}$

Facts about radiative decays

- Electromagnetic (radiative) penguins have a very distinct experimental signature: γ
- Quark-level FCNC processes cannot be directly measured because of hadronization.
- Inclusive decays are well-understood theoretically, but are harder experimentally
- Exclusive final states have less predictive power theoretically, but they are more accessible experimentally.
  - Useful observables beyond branching fractions, such as direct CP and isospin asymmetries, as well as photon polarization.

Isospin asymmetry

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

- Strong sensitivity to NP effects (see next slides)
- Theory predictions

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

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

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

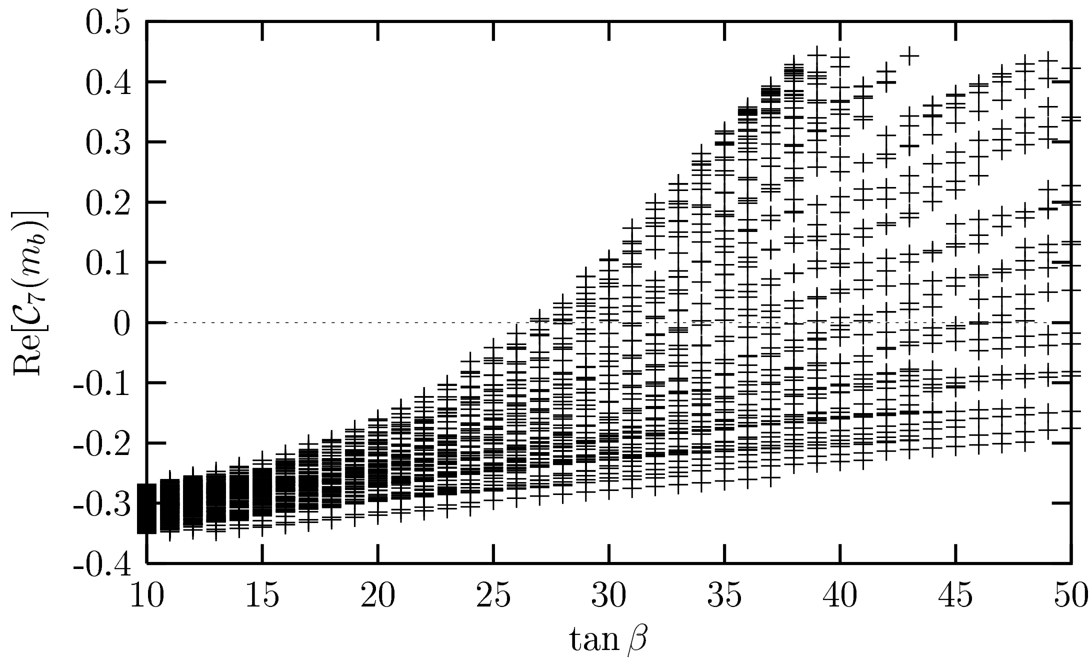
- Experimental status

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

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

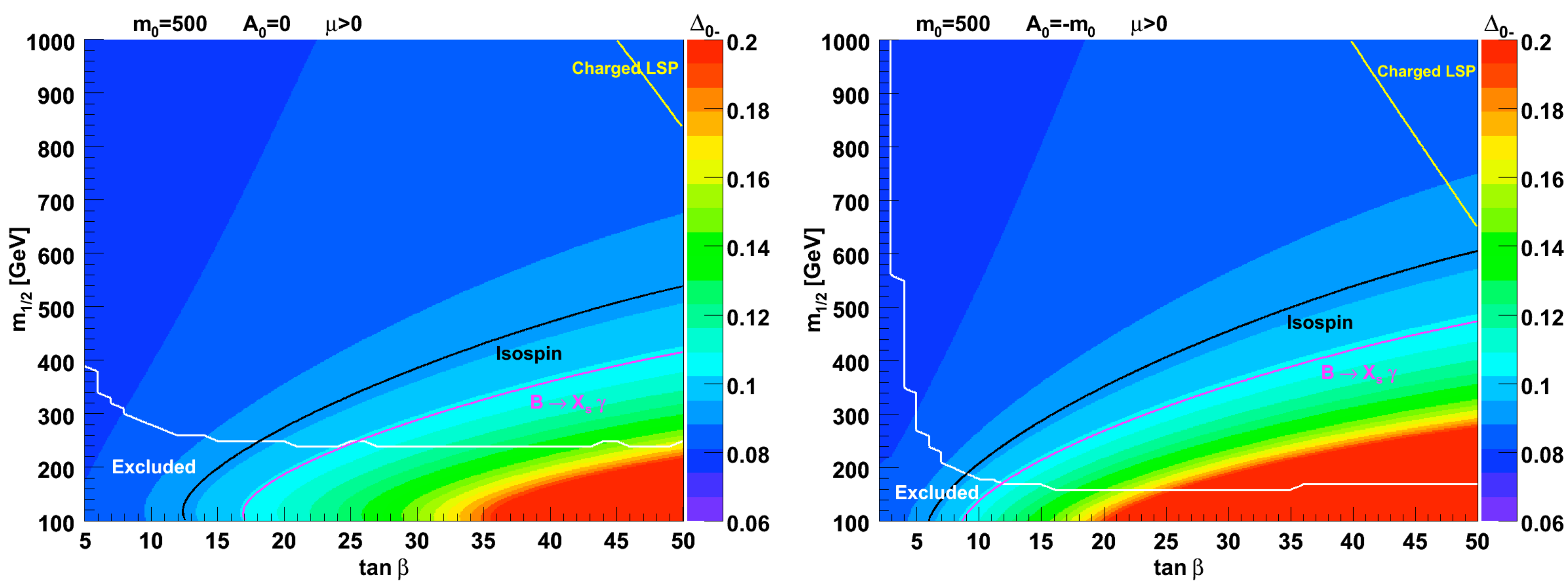
Isospin asymmetry and MSSM

- For low tanβ, Re(C_7) is negative as in the SM
- For large tanβ, Re(C_7) can take >0 and <0 values
  - Positive values, which flip the sign of Δ_{0-}, become more probable as tanβ increases



Isospin asymmetry and mSUGRA

- A precise measurement of the isospin asymmetry can help constrain the mSUGRA parameter space
  - Isospin asymmetry is more restrictive than inclusive $B \to X_s \gamma$



arxiv:hep-ph/0610144

Photon polarization

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

- Admixture of photons with the "wrong" polarization can be large in SM extensions
  - Left Right Symmetric Model (LSRM)
  - Unconstrained MSSM
  - Models with non-supersymmetric extra dimensions
- Measure as "null test", since photons are ~100% polarized in the SM

Time-dependent CP asymmetry

- Time evolution of $B \rightarrow \Phi^{CP}\gamma$

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

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

- Time-dependent CP asymmetry can be used to probe the photon polarization

Photon polarization through time-dependent CP-asymmetry

- In the SM

sum of $B_{(s)}$ mixing phase and CP-odd weak phases for right and left amplitudes

$$\mathcal{C} \approx 0$$

$$\mathcal{S} \approx \sin 2\psi \sin \varphi_{(s)}$$

$$\mathcal{A}^{\Delta} \approx \sin 2\psi \cos \varphi_{(s)}$$

$$\tan\psi \equiv \left| \frac{\mathcal{A}(\bar{B}_{(s)} \to \Phi^{CP}\gamma_R)}{\mathcal{A}(\bar{B}_{(s)} \to \Phi^{CP}\gamma_L)} \right| \longrightarrow \lambda_\gamma = \cos 2\psi$$

- Therefore, measurement of $\mathcal{S}$ and $\mathcal{A}^{\Delta}$ directly determines the fraction of "wrongly"-polarized photons

Photon polarization in the B^0 system

- $\Delta\Gamma$ is negligible, so terms proportional to $\mathcal{A}^\Delta$ vanish

$$\Gamma_{B^0\to\Phi^{CP}\gamma}(t) = |A|^2 e^{-\Gamma t}(1 + \mathcal{C}\cos\Delta m t - \mathcal{S}\sin\Delta m t)$$
$$\Gamma_{\bar{B}^0\to\Phi^{CP}\gamma}(t) = |A|^2 e^{-\Gamma t}(1 - \mathcal{C}\cos\Delta m t + \mathcal{S}\sin\Delta m t)$$

- Also one expects in the SM

CP-odd weak penguin phase

$$\varphi = \sin(2\beta - \phi_p)$$

- Therefore

$$\mathcal{S}_{B^0} = \sin 2\psi \sin 2\beta$$

Photon polarization in the B_s system

- $\Delta\Gamma$ is not negligible, and

$$\varphi_s = \sin(2\beta_s - \phi_p) \approx 0$$

so the term with S vanishes

$$\Gamma_{B_s^0 \to \Phi^{CP}\gamma}(t) = |A|^2 e^{-\Gamma_s t}(\cosh \frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta} \sinh \frac{\Delta\Gamma_s t}{2})$$

$$\Gamma_{\bar{B}_s^0 \to \Phi^{CP}\gamma}(t) = \Gamma_{B_s^0 \to \Phi^{CP}\gamma}(t)$$

- Therefore

$$\mathcal{A}^{\Delta}_{B_s^0} \approx \sin 2\psi$$

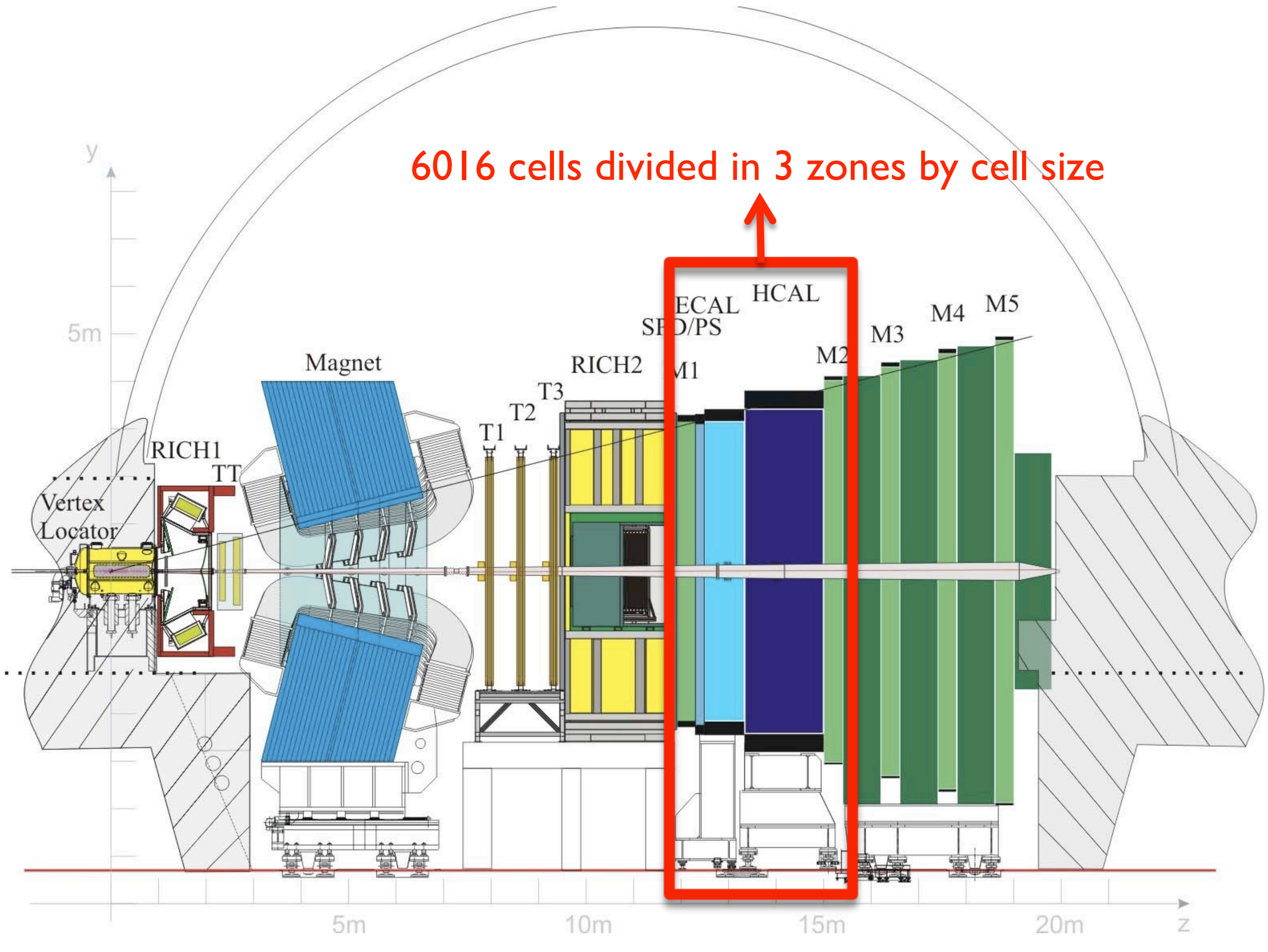
Direct CP asymmetry

- Uncertainties due to form factors cancel to a large extent
- In $B \to K^* \gamma$ CP asymmetry is suppressed by $m_{s,d}/m_b$
  - Theoretically, values of O(3%) with uncertainties ~1.5%
  - Experimental measures dominated by BaBaR

$$\mathcal{A}^0_{CP} = -(1.6 \pm 2.2 \pm 0.7)\%$$
$$\mathcal{A}^+_{CP} = (1.8 \pm 2.8 \pm 0.7)\%$$
$$\mathcal{A}^{\rm combined}_{CP} = -(0.3 \pm 1.7 \pm 0.7)\%$$

- In $B \to \rho\gamma$, one finds O(10%) predictions in the SM
  - Very challenging experimentally

What does LHCb have to offer?



Experimental challenges (in LHCb)

- Experimental signature of radiative decays is the γ
  - Resolution in the B mass peak is completely dominated by γ
  - Calorimeter calibration is essential
  - Difficult separation between γ/π^0
- High background level due to pp interactions
- In $b \to d\gamma$ decays, huge background from $b \to s\gamma$
  - Both BaBaR and Belle measurements were established in the later stages of the experiments

First LHCb measurement

- First measurement (LP11)

$$\frac{\mathcal{B}(B \to K^*\gamma)}{\mathcal{B}(B_s \to \phi\gamma)} = 1.52 \pm 0.15(\mathrm{stat}) \pm 0.10(\mathrm{syst}) \pm 0.12$$

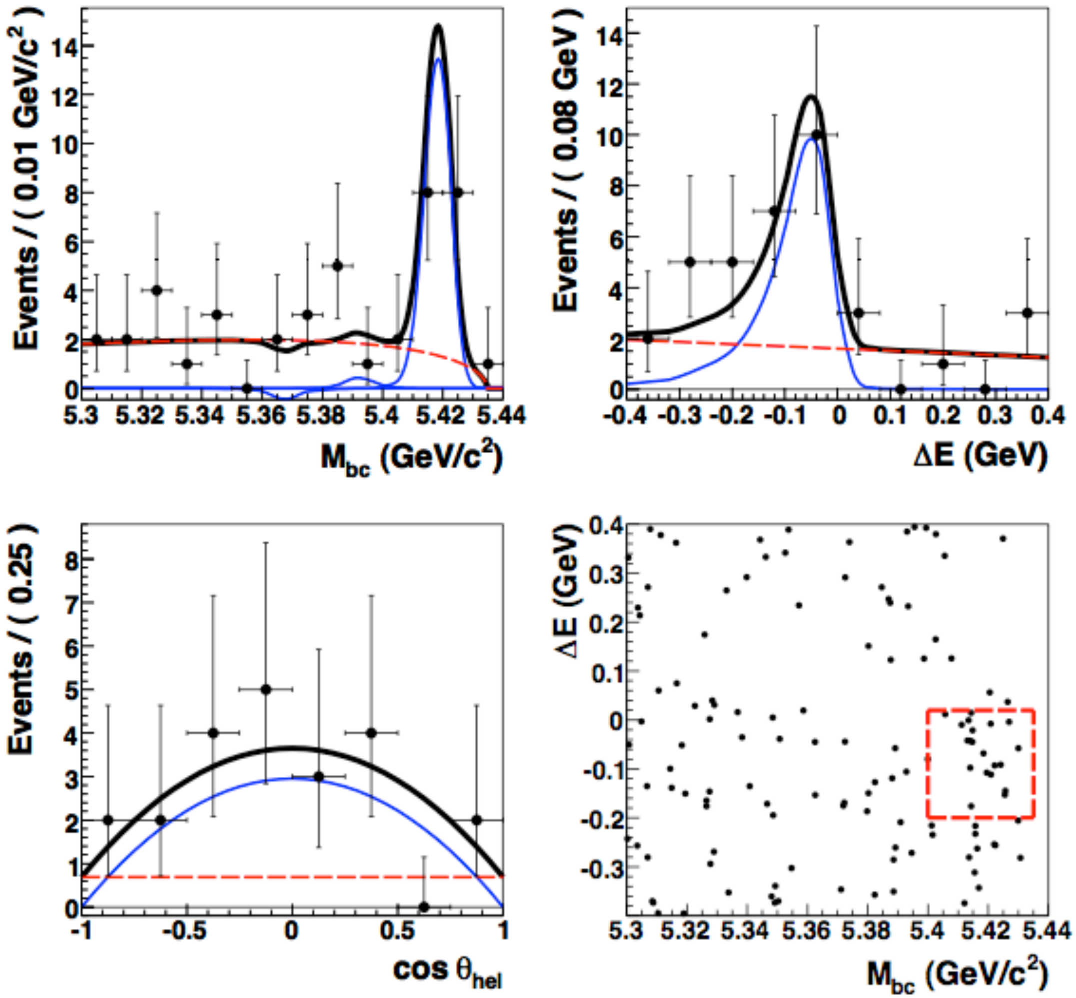
$$\mathcal{B}(B_s \to \phi\gamma) = (2.8 \pm 0.5) \times 10^{-5}$$

- Within 1.5σ from previous result from Belle but with lower uncertainty

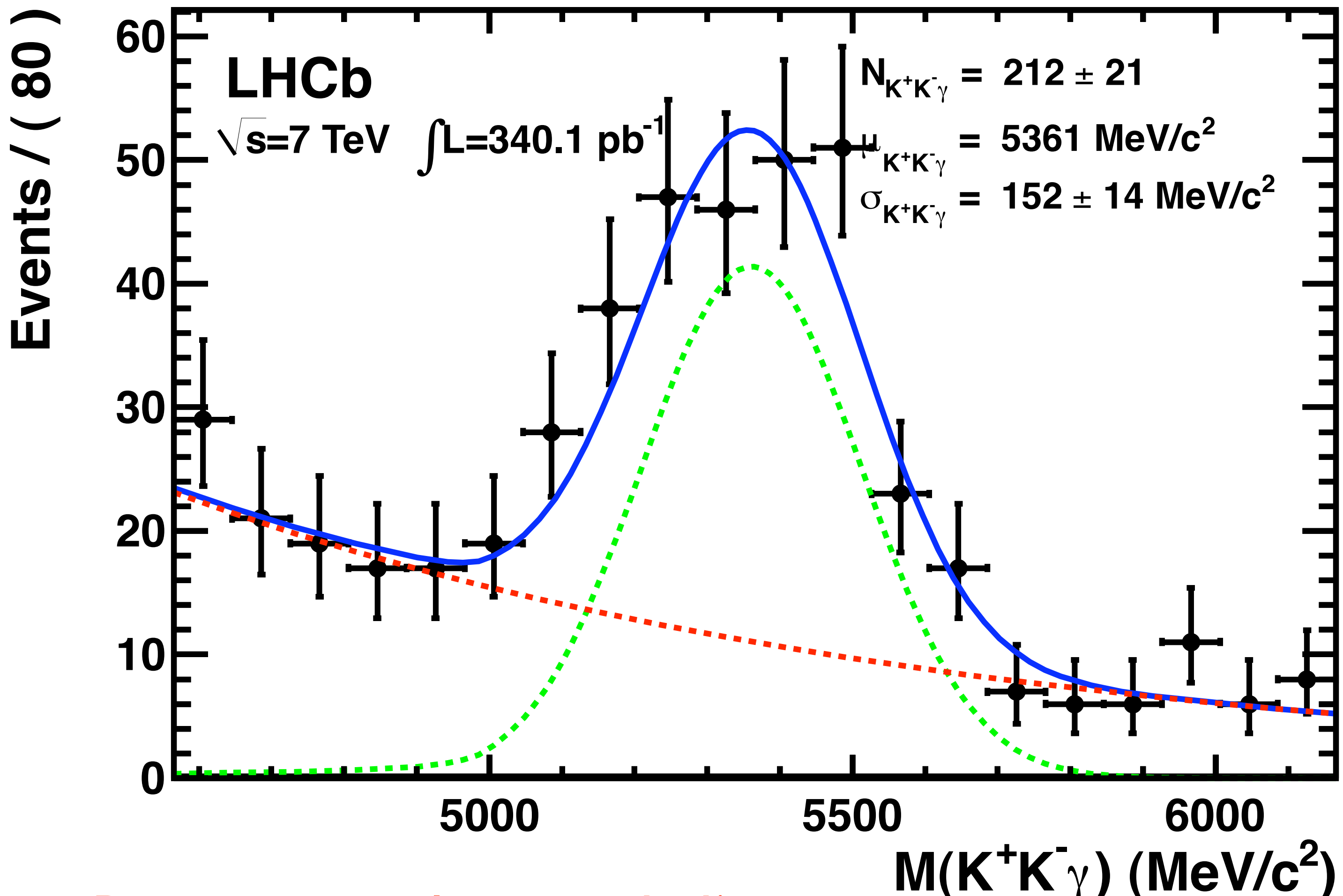
$$\mathcal{B}(B_s \to \phi\gamma) = (5.7^{+2.1}_{-1.8}) \times 10^{-5}$$

  - LHCb can do very good physics with $B_s \to \phi\gamma$

$B_s \to \phi\gamma$ in Belle



$B_s \to \phi\gamma$ in LHCb



Largest $B_s \to \phi\gamma$ sample recorded!

LHCb prospects

- Direct CP asymmetry in $B \rightarrow K^*\gamma$
  - Expected statistical precision at the level of ~2% with 1fb^{-1}
- Isospin asymmetry in $B \rightarrow K^*\gamma$
  - No studies so far, will start soon
- Photon polarization in $B_s \rightarrow \phi\gamma$
  - Not easily accessible until now, but with the B_s decay one can directly access "wrongly"-polarized fraction
  - Need to 2fb^{-1} to achieve a precision of ~0.2 in $\mathcal{A}^{\Delta}$

Conclusions

- Exclusive B radiative decays are sensitive probes to NP
- Experimentally easier than inclusive measures
- While BRs are difficult to predict theoretically, there is plenty of NP-sensitive observables
  - Isospin asymmetry
  - Photon polarization
  - CP asymmetries
- Radiative decays are starting to give results in LHCb
  - Many interesting prospects

Exciting times ahead!

Thank you