Radiative B decays at LHCb

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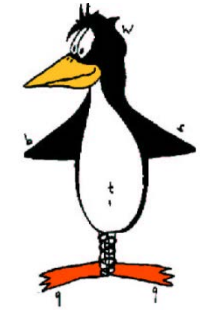
V CPAN days, Santiago de Compostela

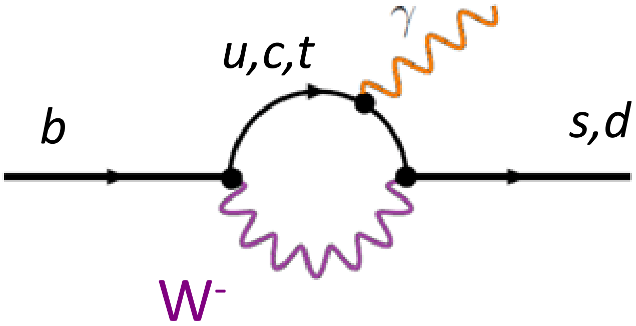
Outline

- Radiative B decays
- The LHCb experiment
- Physics results
- Prospects
- Summary and conclusions

Radiative B decays



- ***b→sγ*** transitions are one of the best examples of **Flavor Changing Neutral Currents (FCNCs)**, which are forbidden in the Standard Model (SM) at tree level
→ they go through loops (*penguins diagrams*)

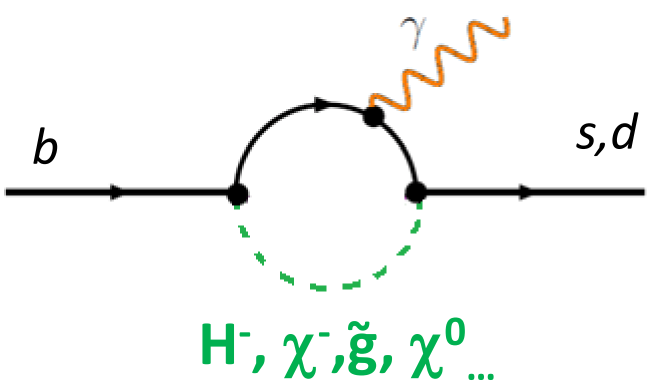


- SM rates (and other observables) can be calculated with high precision using effective theories

- Rare processes ($BR_{SM} \lesssim 10^{-5}$), but experimentally accessible by flavour experiments (**B- factories & LHCb**)
→ Experimental signature: high P_T photons

- Excellent probe for physics beyond the SM
→ sensitivity to **new heavy particles** in loops

  - Two-Higgs-doublet models (2HDMs)
  - Left-right symmetric models
  - Constrained MSSM
  - Models with new quark generations …



Radiative decays

Which kind of observables can be measured?

- Branching fractions:

Measurement of the $\mathcal{B}(B\to K^*\gamma)/\mathcal{B}(B_s\to\phi\gamma)$

[LHCb, Nuc. Phys. B 867 (2013) 1-18]

- CP Asymmetries:

Measurement of the $A_{CP}(B\to K^*\gamma)$

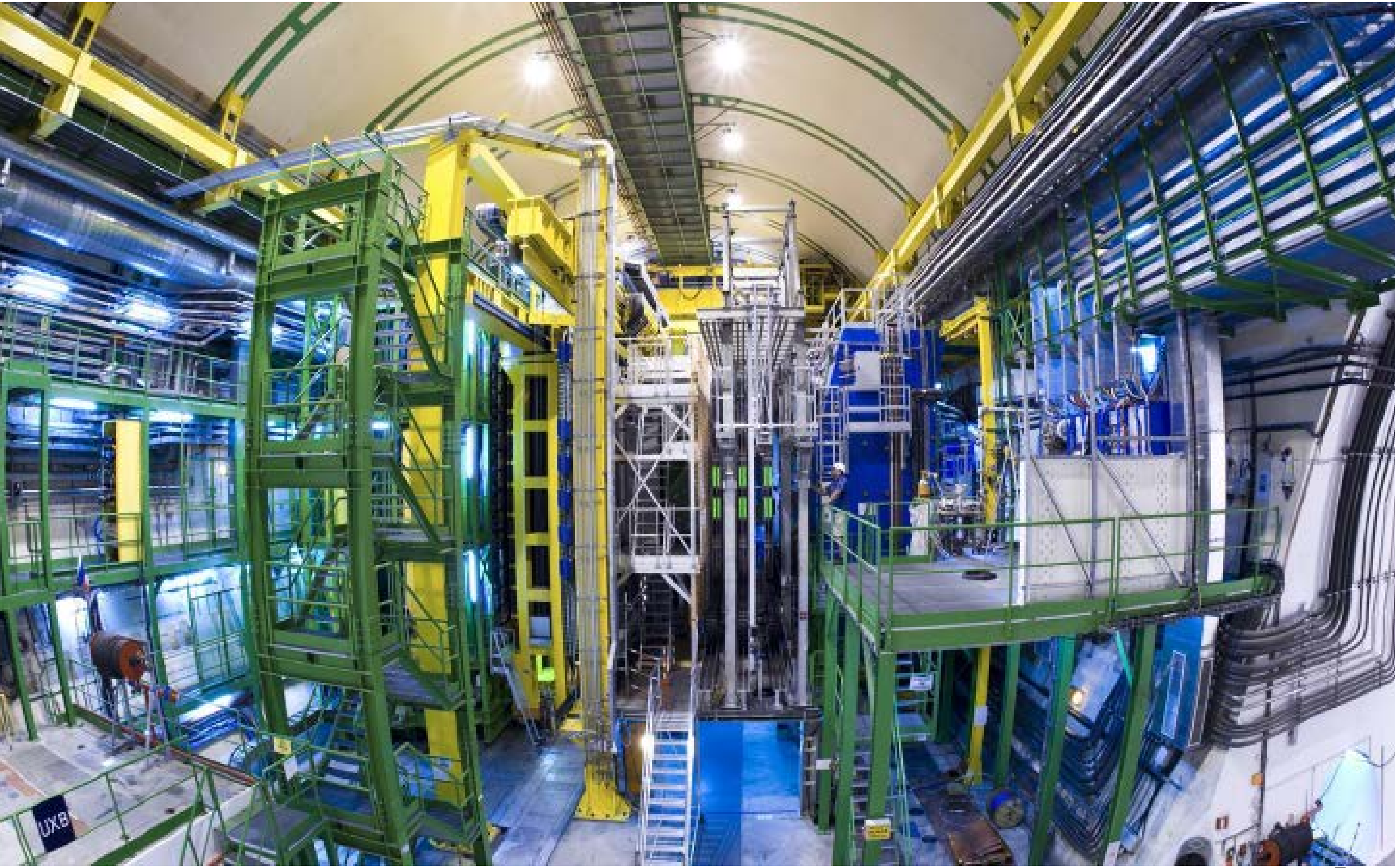
[LHCb, Nuc. Phys. B 867 (2013) 1-18]

CP and up-down asymmetries in $B\to(K\pi\pi)\gamma$

[LHCb-CONF-2013-009]

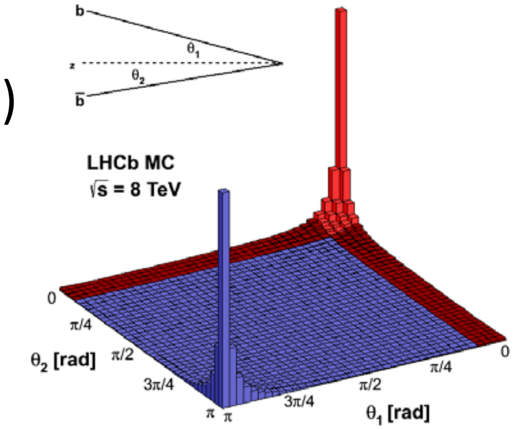
- Lifetimes, angular distributions… **… in progress**

The LHCb experiment



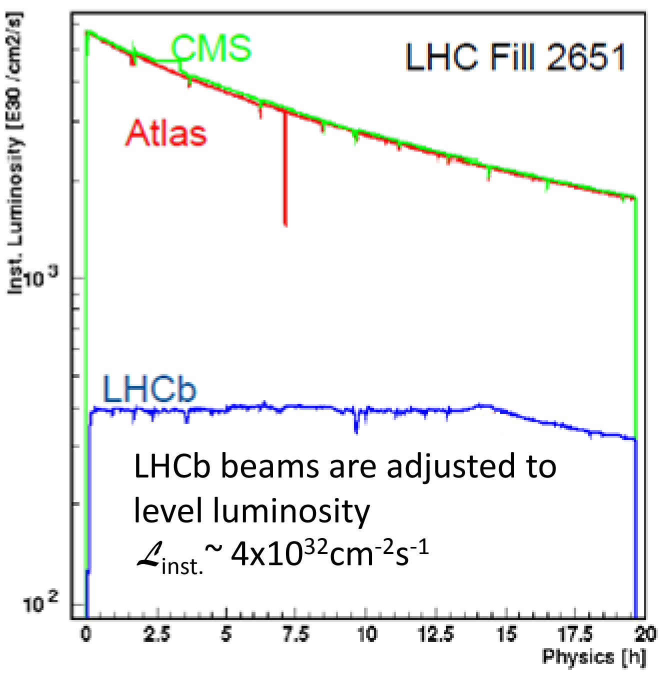
The LHCb experiment

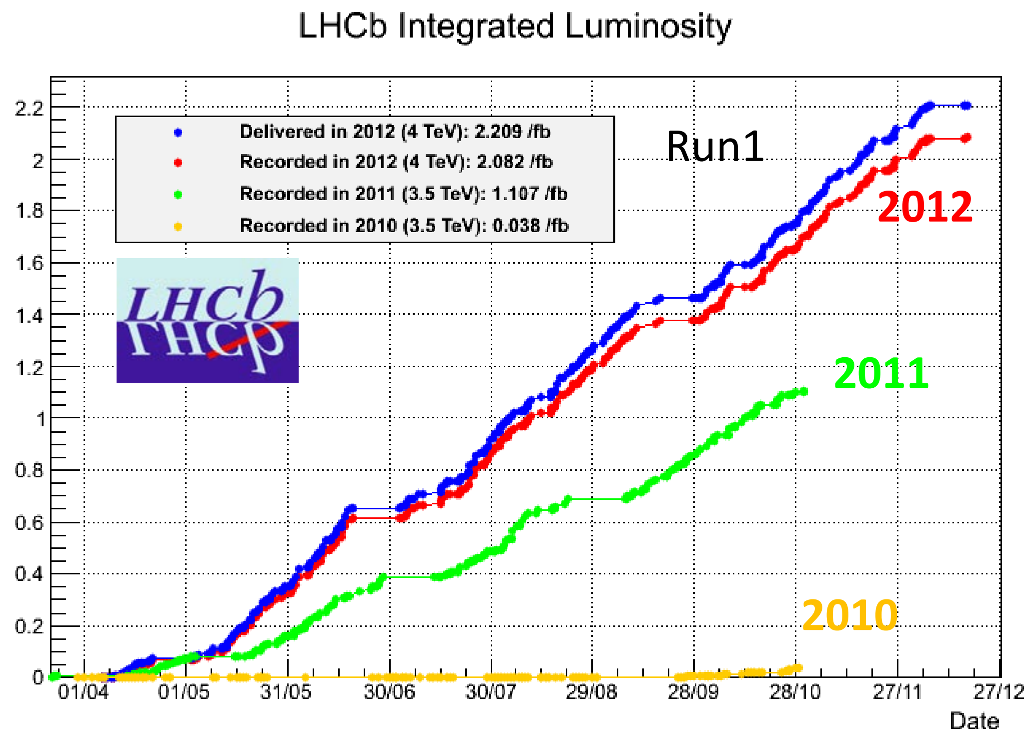
- LHC: Large $b\bar{b}$ cross section in pp colisions (gluon fusion) (~250 μb – 500 μb @ $\sqrt{s}$=7 – 14 TeV):



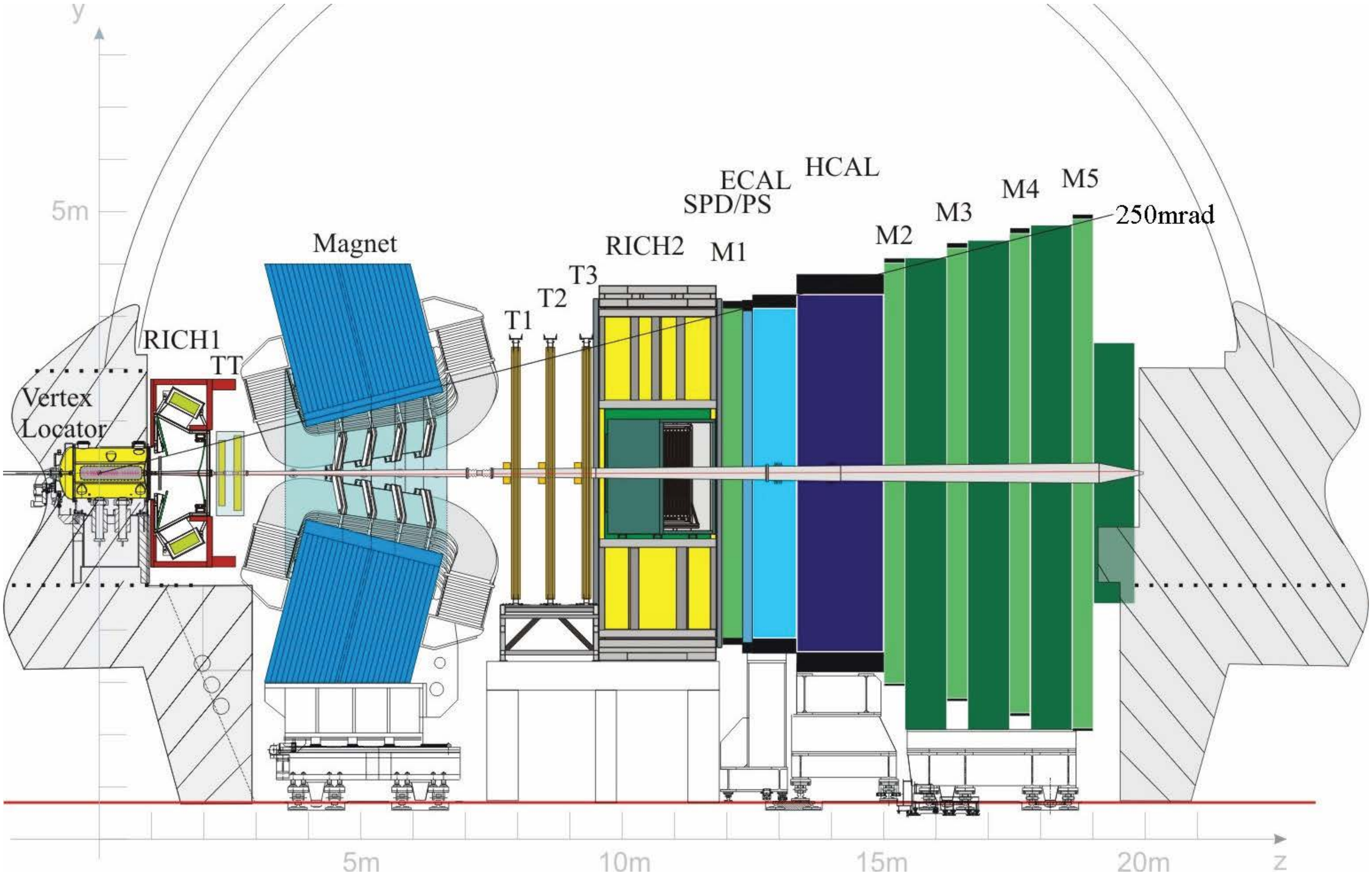
- LHCb: single-arm forward spectrometer (2 < η < 5): ~ 4% of the solid angle, ~30% of the *b* hadron production

- Very good performance: **3 fb^{-1}** accumulated in Run1



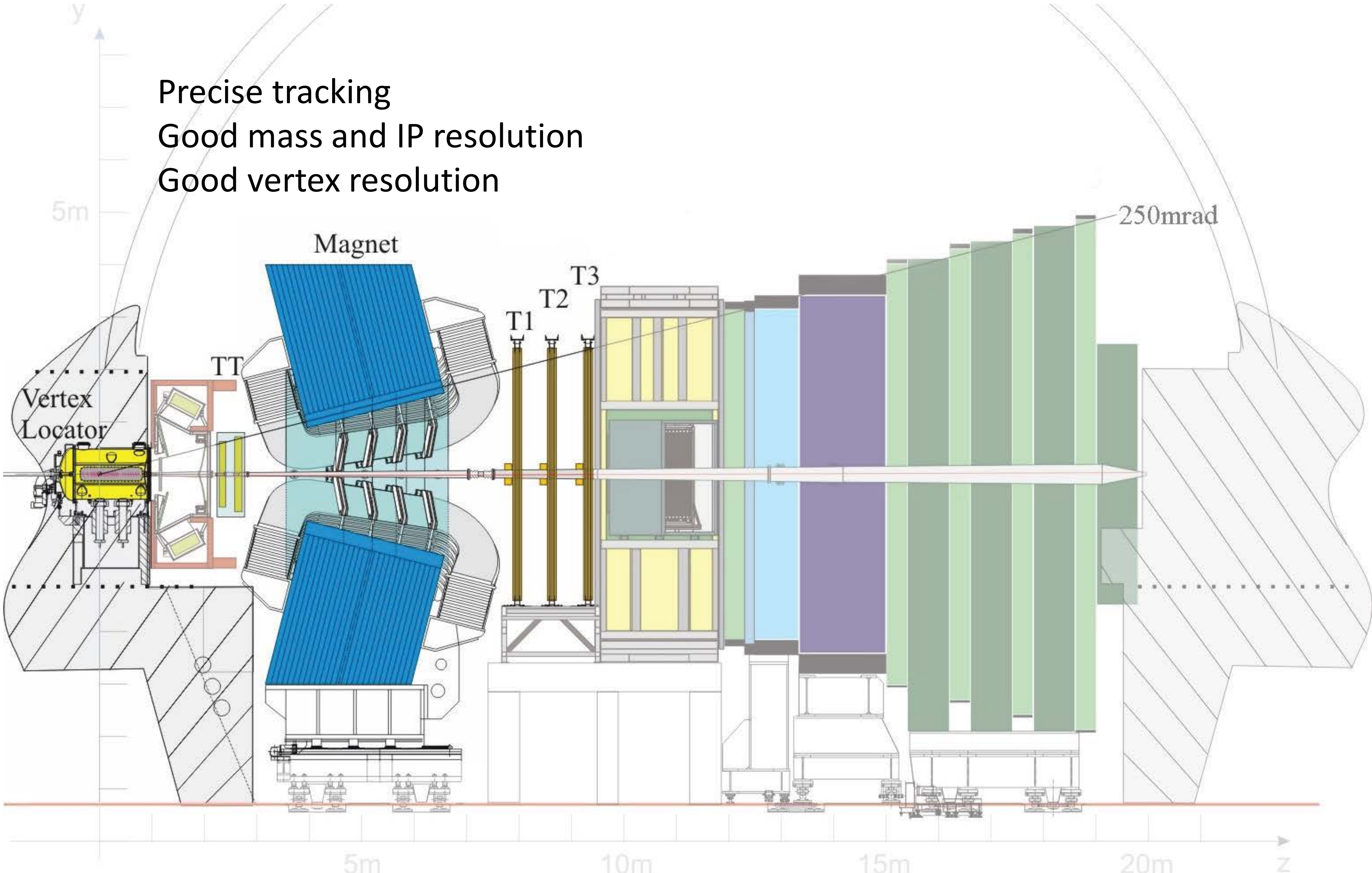


The LHCb experiment



The LHCb experiment

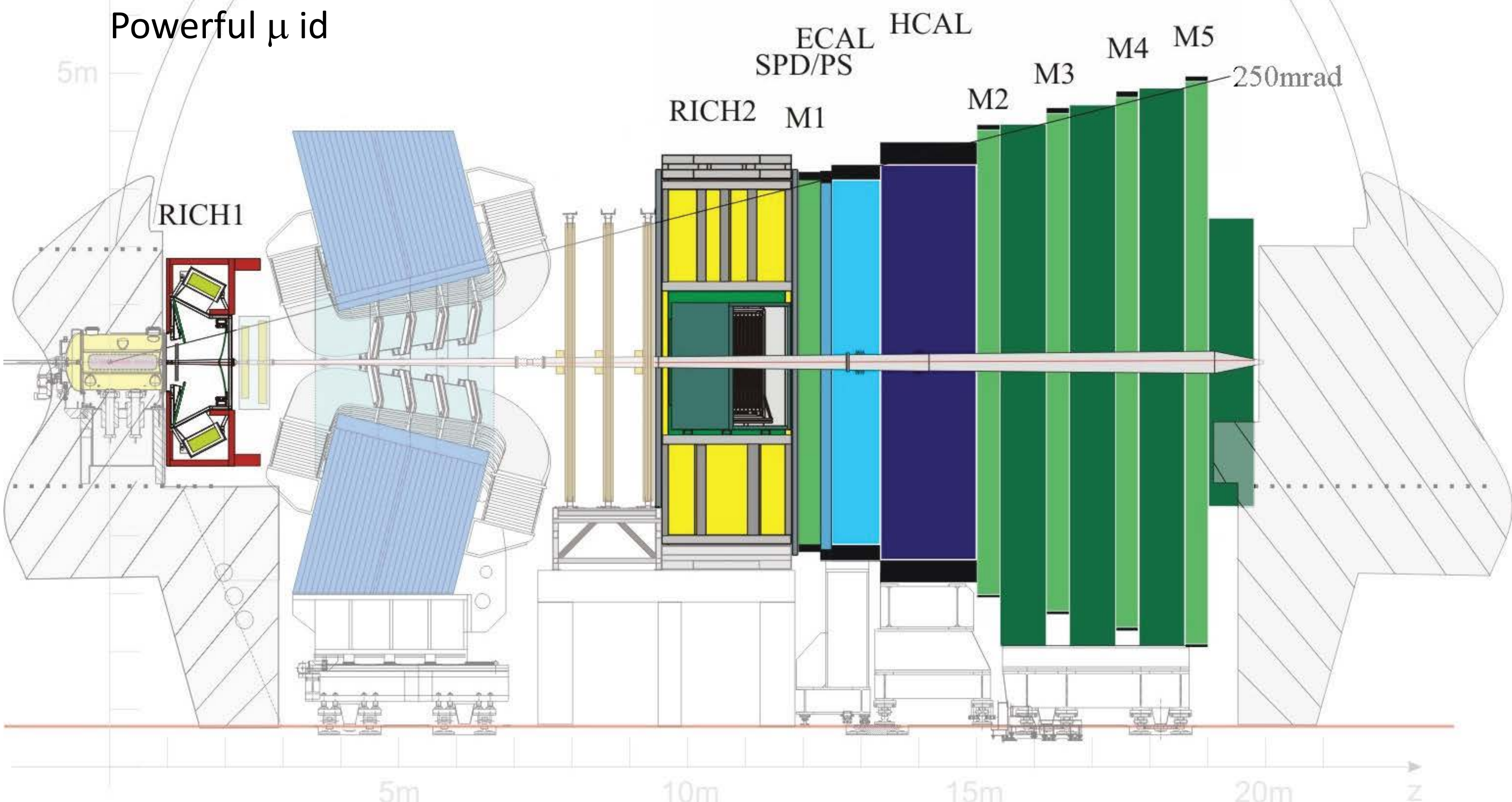
Precise tracking
Good mass and IP resolution
Good vertex resolution



The LHCb experiment

Excellent particle identication
π/K separation over 2-100 GeV
Powerful μ id

Calorimeter system
Trigger
Photon reconstruction



Predictions for $\mathcal{B}(B\to K^*\gamma)/\mathcal{B}(B_s\to\phi\gamma)$ and $A_{CP}(B\to K^*\gamma)$

Branching fractions and CP asymmetries in $b\to s\gamma$ decays are largely sensitivity to non-standard sources of flavor violation and CP violation

SM predictions (NNLO):

$$\mathcal{B}(B_s^0\to\phi\gamma) = (4.3\pm1.4)\times10^{-5}$$
$$\mathcal{B}(B^0\to K^{*0}\gamma) = (4.3\pm1.4)\times10^{-5}$$

(dominated by hadronic uncertainties)

- The ratio of branching fractions:

$$\frac{\mathcal{B}(B^0\to K^{*0}\gamma)}{\mathcal{B}(B_s^0\to\phi\gamma)} = 1.0\pm0.2$$

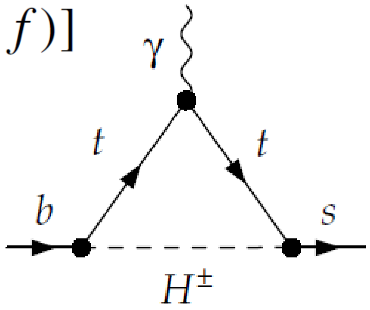
[A. Ali, B.D. Pecjak, C. Greub, EPJC55(08)577]

- and the CP asymmetry:

$$\mathcal{A}_{CP} = \frac{[\Gamma(\bar{B}^0\to\bar{f}) - \Gamma(B^0\to f)]}{[\Gamma(\bar{B}^0\to\bar{f}) + \Gamma(B^0\to f)]}$$

[M. Matsumori, A.I.Sanda, YY. Keum, PRD72(05)014013]

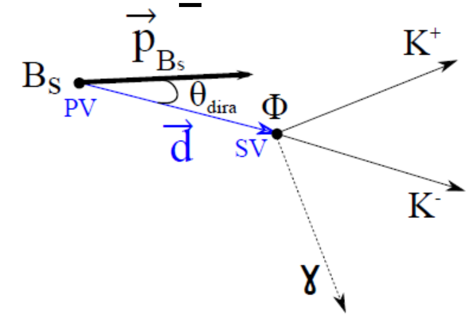
$$\mathcal{A}_{CP}^{SM}(B^0\to K^{*0}\gamma) = (-0.61\pm0.43)\%$$



▶ All these quantities can then be enlarged by **New Physics** contributions

Measurement of the $\mathcal{B}(B\to K^*\gamma)/\mathcal{B}(B_s\to\phi\gamma)$

[LHCb, Nuc. Phys. B 867 (2013) 1-18]



Signature: a high E_T photon + two opposite charged tracks detached from primary vertex (PV):

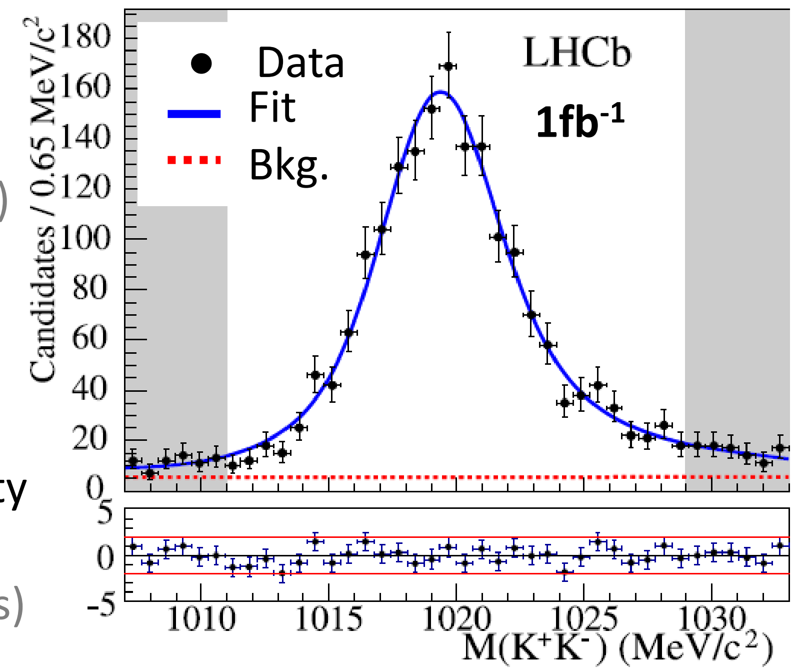
→ Reconstruct the **ϕ** or **K*** meson vertexing the two tracks (KK, Kπ) ($\sigma_{M\ \phi,K^*}$ ~ a few MeV)

→ Combine the reconstructed meson with a **photon** with E_T >2.6GeV (not compatible with being an e^-/π^0)

→ **$B_{(s)}$** meson compatible with PV, with high P_T ($\sigma_{MB,Bs}$ dominated by γ reconstruction (~100 MeV))

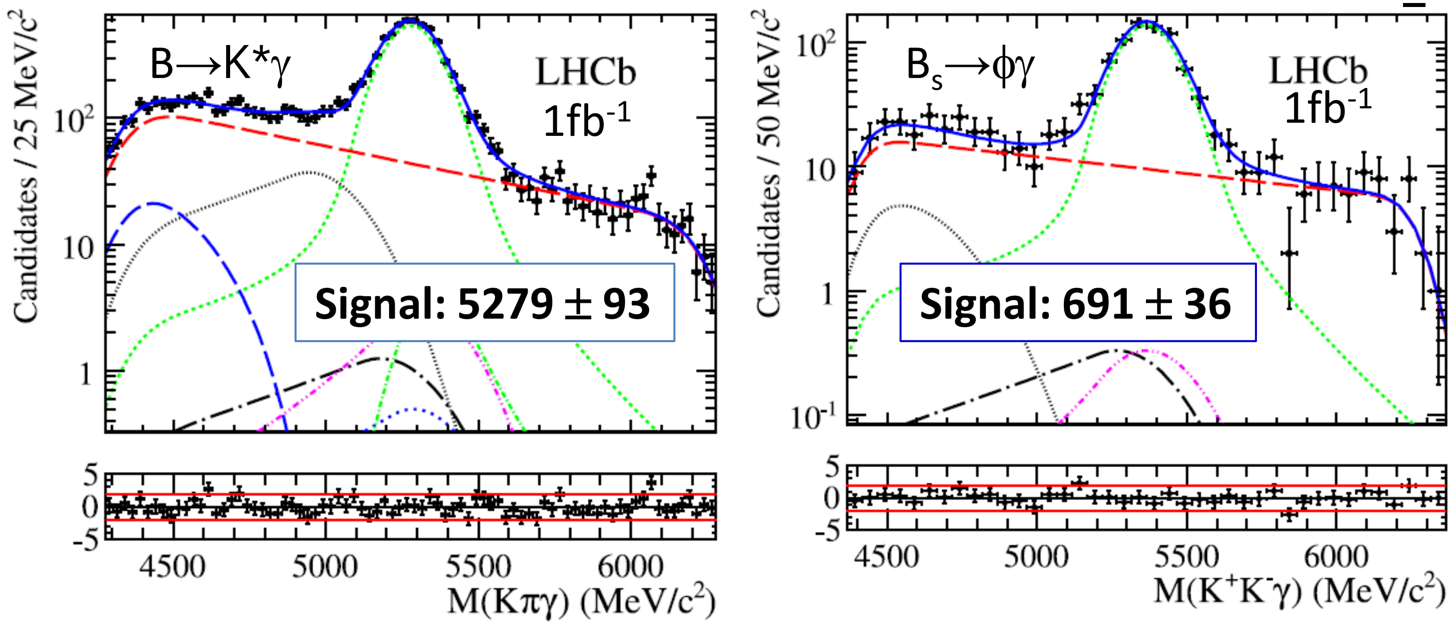
→ Background supression by isolation of PV, $B_{(s)}$ helicity (against π^0) and flight direction (Main bkg: combinat., partially reconstructed channels)

$\phi\to K^+K^-$ + γ candidates



→ Signal yields from an Extended Max. Likelihood to the B and B_s invariant mass

Measurement of the $\mathcal{B}(B\to K^*\gamma)/\mathcal{B}(B_s\to\phi\gamma)$



The ratio of BR's:

Fit values — PDG values — LHCb [PRD85(12)032008] — (selection, trigger, PID) **0.877 ± 0.017**

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

$$= 1.23 \pm 0.06\,(\text{stat.}) \pm 0.04\,(\text{syst.}) \pm 0.10\,(f_s/f_d)$$

Compatible with the SM

$\mathcal{B}(B\to K^*\gamma)$ from HFAG →

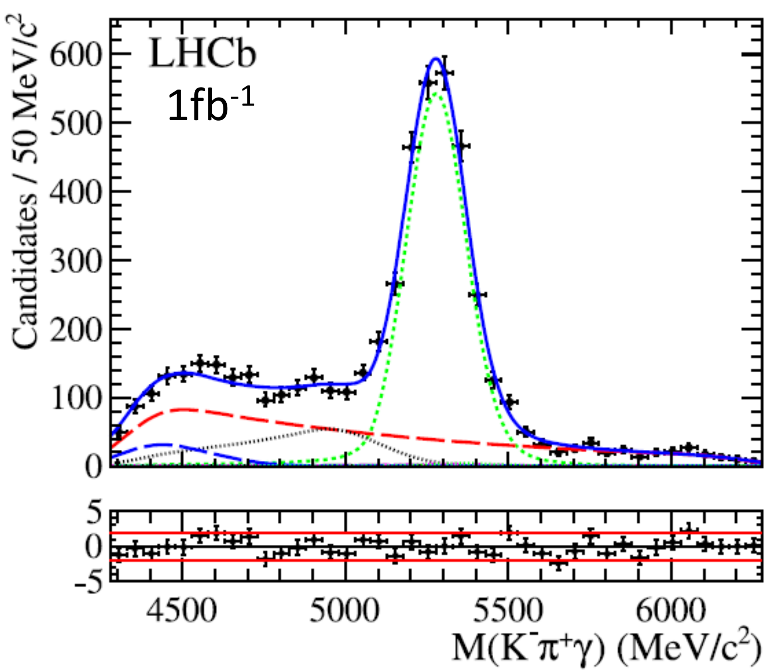
$$\mathcal{B}(B_s^0\to\phi\gamma) = (3.5\pm0.4)\times10^{-5}$$

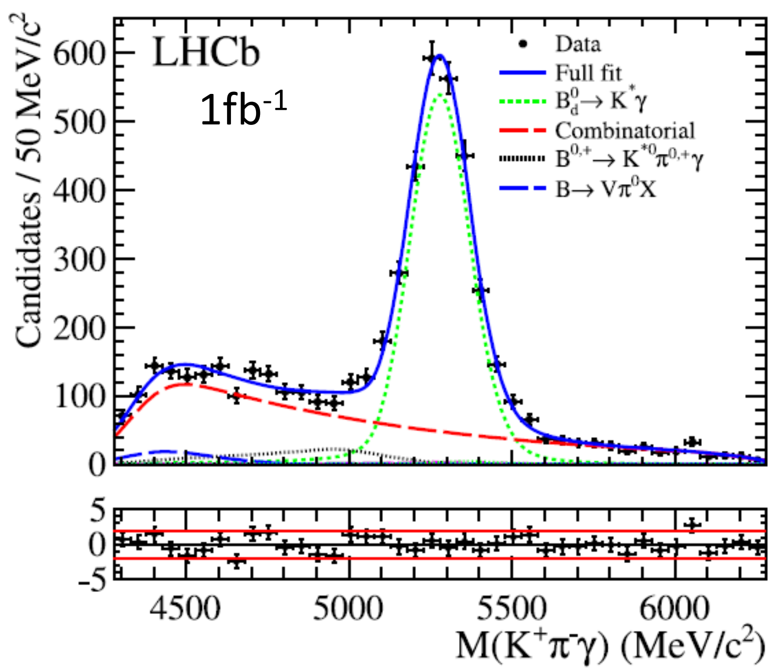
Compatible with BELLE, LHCb more accurate

Measurement of the $A_{CP}(B \to K^*\gamma)$

Using the same selection and reconstruction for the $B \to K^*\gamma$ decay channel
Now separate between flavours to measure the CP (raw) asymmetry:

$$\mathcal{A}_{\mathrm{RAW}} = \frac{N(K^-\pi^+\gamma) - N(K^+\pi^-\gamma)}{N(K^-\pi^+\gamma) + N(K^+\pi^-\gamma)} = (0.3 \pm 1.7)\%$$





Measurement of the $A_{CP}(B\to K^*\gamma)$

The raw asymmetry has to be corrected by production and detection asymmetries

$$\mathcal{A}_{\rm P}(B^0) = \frac{R(\bar{B}^0) - R(B^0)}{R(\bar{B}^0) + R(B^0)}$$

(from $B\to J/\psi\phi$)

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

(from charm control samples)

Correction to $A_{\rm RAW}$		Value [%]
Background model	$\Delta\mathcal{A}_{\rm bkg}$	-0.2 ± 0.7
Magnet polarity	$\Delta\mathcal{A}_{\rm M}$	$+0.1 \pm 0.2$
Detection	$-\mathcal{A}_{\rm D}(K\pi)$	$+1.0 \pm 0.2$
B^0 production	$-\kappa\mathcal{A}_{\rm P}(B^0)$	-0.4 ± 0.5
Total		$+0.5 \pm 0.9$

κ =dilution factor due to B^0 mixing

corrected

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = (0.8 \pm 1.7\ (\text{stat.}) \pm 0.9\ (\text{syst.}))\%$$

Most precise measurement up to date

Compatible with the SM

A_{CP} and $A_{UP\text{-}DOWN}$ in $B \rightarrow (K\pi\pi)\gamma$

[LHCb-CONF -2013-009]

In the SM, the photon from $b \rightarrow s\gamma$ decays is predicted to be left handed with the **photon polarization parameter λ_γ** :

$$\lambda_\gamma \equiv \frac{|c_R|^2 - |c_L|^2}{|c_R|^2 + |c_L|^2}$$

expected to be -1 ($\bar{B}$) or +1 (B) with corrections of 10%

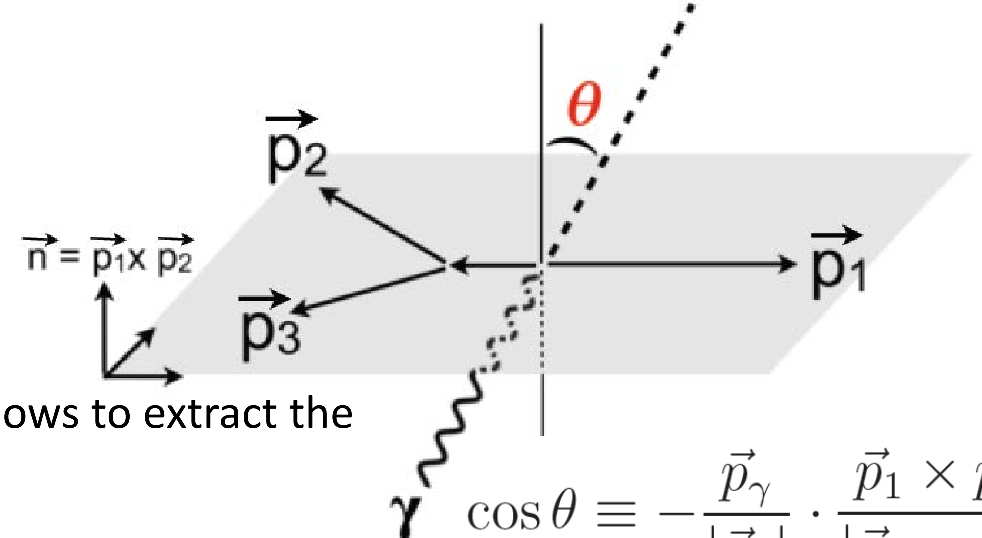
(C_R, C_L right and left amplitudes)

For a radiative $B \rightarrow K_{res}\gamma$, with the K_{res} a three body decay $K_{res} \rightarrow P_1P_2P_3$

$$\frac{d\Gamma(\overline{B} \to \overline{K}_{res}\gamma \to P_1P_2P_3\gamma)}{ds\, ds_{13}\, ds_{23}\, d\cos\theta}$$

$s_{ij}=(p_i+p_j)^2$; $s=(p_1+p_2+p_3)^2$

is the sum of the helicity amplitudes



$$\cos\theta \equiv -\frac{\vec{p}_\gamma}{|\vec{p}_\gamma|} \cdot \frac{\vec{p}_1 \times \vec{p}_2}{|\vec{p}_1 \times \vec{p}_2|}$$

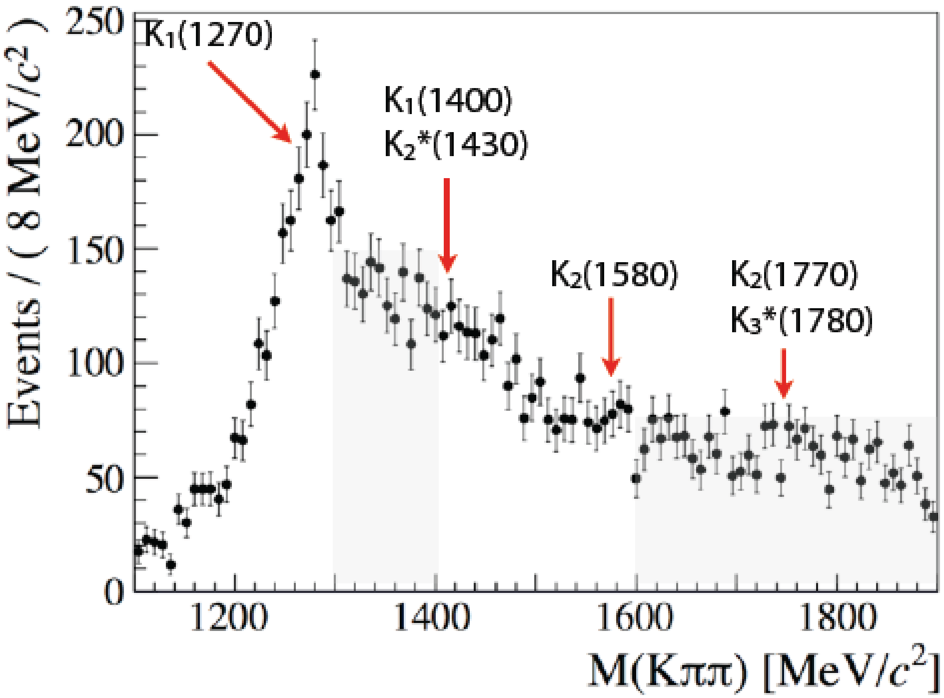
Up-down asymmetry $A_{UD} \propto \lambda_\gamma \rightarrow$ allows to extract the photon polarization information

[Kou et al, PRD83 (2011) 094007; Gronau et al, PRL88 (2002) 051802]

A_{CP} and $A_{UP\text{-}DOWN}$ in $B \to (K\pi\pi)\gamma$

- Reconstruction of a kaon resonance from three charged tracks: two pions of opposite sign and a kaon, plus a high E_T photon.

Individual resonances cannot be resolved without angular analysis, then:



Background substracted Kππ spectrum showing the expected resonant contributions

- Use the full mass range to measure A_{CP}

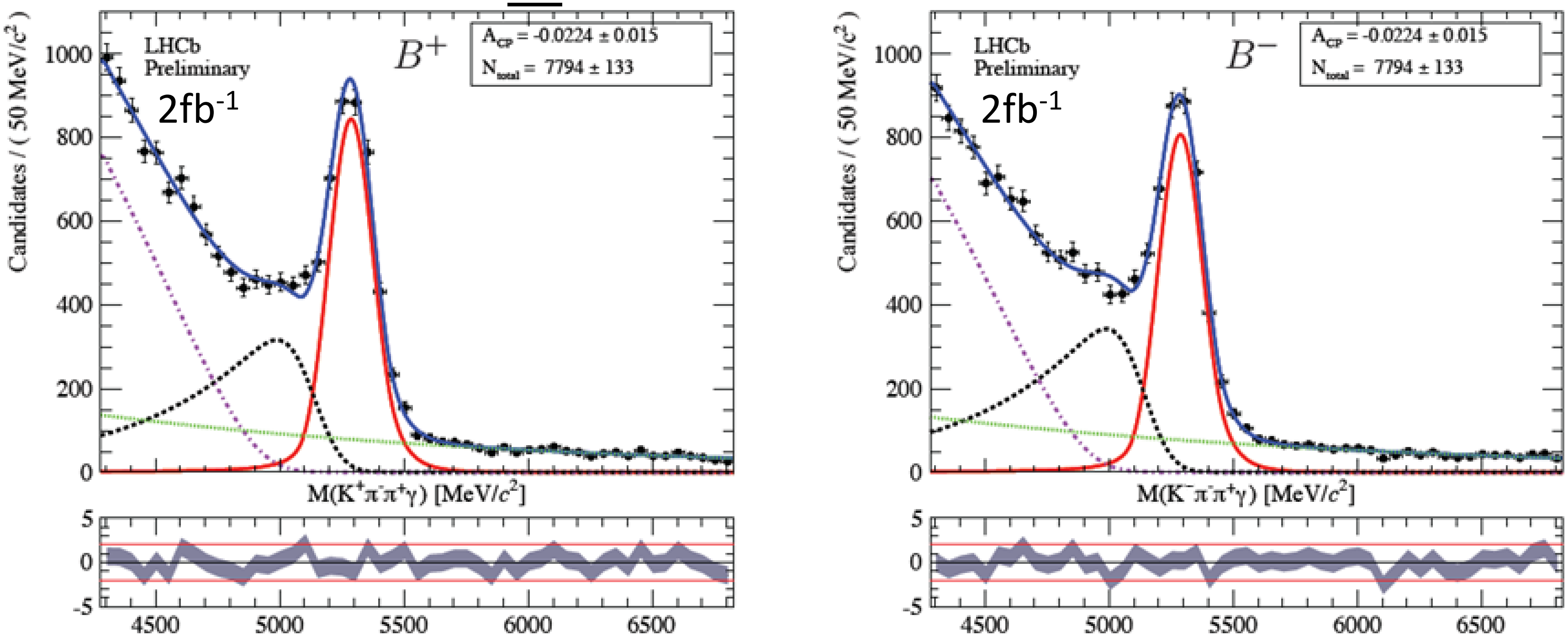
$$\mathcal{A}_{CP} = \frac{N(K^-\pi^+\pi^-\gamma) - N(K^+\pi^-\pi^+\gamma)}{N(K^-\pi^+\pi^-\gamma) + N(K^+\pi^-\pi^+\gamma)}$$

- Avoid the interference mass regions to measure A_{UD}

$$\mathcal{A}_{UD} = \frac{N(K\pi\pi\gamma)_{\cos\theta>0} - (K\pi\pi\gamma)_{\cos\theta<0}}{N(K\pi\pi\gamma)_{\cos\theta>0} + (K\pi\pi\gamma)_{\cos\theta<0}}$$

(since there are effects from several contributions, results are difficult to interprete in terms of photon polarization)

A_{CP} in $B \to (K\pi\pi)\gamma$



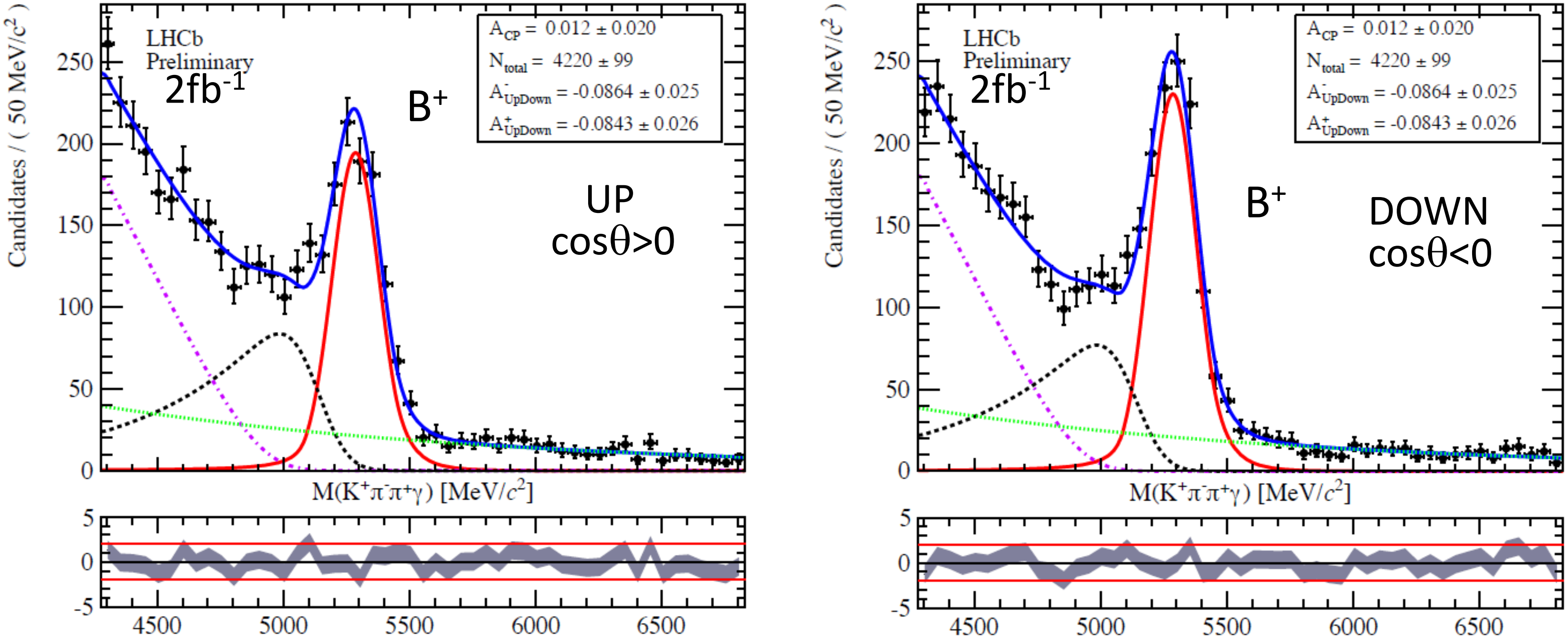
Corrections to raw A_{CP}:

$\mathcal{A}_{\rm D}$ and $\mathcal{A}_{\rm P}$	0.013 ± 0.008
$\Delta\mathcal{A}_{CP}^{\rm raw}$	0.002 ± 0.001
Fit model	0.000 ± 0.002

$$\mathcal{A}_{CP}^{\rm raw} = -0.022 \pm 0.015$$

$$\mathcal{A}_{CP} = -0.007 \pm 0.015\ ({\rm stat}) \pm 0.008\ ({\rm syst})$$

$A_{UP\text{-}DOWN}$ in $B \to (K\pi\pi)\gamma$



Contributions to the A_{UD} uncertainties very small (~1-3‰)

$$\mathcal{A}^{+} = -0.084 \pm 0.026\,(\mathrm{stat})\,^{+0.004}_{-0.003}\,(\mathrm{syst})$$

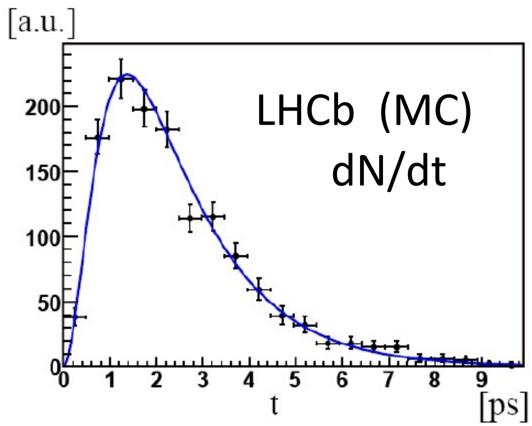
$$\mathcal{A}^{-} = -0.086 \pm 0.025\,(\mathrm{stat}) \pm 0.002\,(\mathrm{syst})$$

$$\mathcal{A}_{\mathrm{ud}} = -0.085 \pm 0.019\,(\mathrm{stat}) \pm 0.003\,(\mathrm{syst})$$

→ **Proportional to photon polarization (first evidence at 4.6σ)**

Prospects for radiative B decays

- Photon polarization in $B_s \to \phi\gamma$ decays (B_s effective lifetime)



(see P. Ruiz talk in the flavour session yesterday)

- BR's and CP asymmetries for several vector channels:
(update $B_s \to \phi\gamma$, $B \to K^*\gamma$, new $B \to \rho\gamma$, $\Lambda_b \to \Lambda\gamma$)

- More challenging channels: $B \to K^{*0}\pi^+\gamma$, $B \to K\phi\gamma$ …

Summary

- LHCb has performed very well in Run1: **$3fb^{-1}$**
- Radiative B decays are candles for Beyond SM Physics
- LHCb has the more accurate results on

$\rightarrow$ Measurement of the $\mathcal{B}(B\rightarrow K^*\gamma)/\mathcal{B}(B_s\rightarrow\phi\gamma)$

$\rightarrow$ Measurement of the $A_{CP}(B\rightarrow K^*\gamma)$

$\rightarrow$ A_{CP} and A_{UD} in $B\rightarrow(K\pi\pi)\gamma$

(still to be updated with the whole data sample)

- Willing more data + new theoretical inputs