FLAVOUR PHYSICS AT LHC

Centro de Ciencias de Benasque Pedro Pacual
2017, May 21 - May 27

run II

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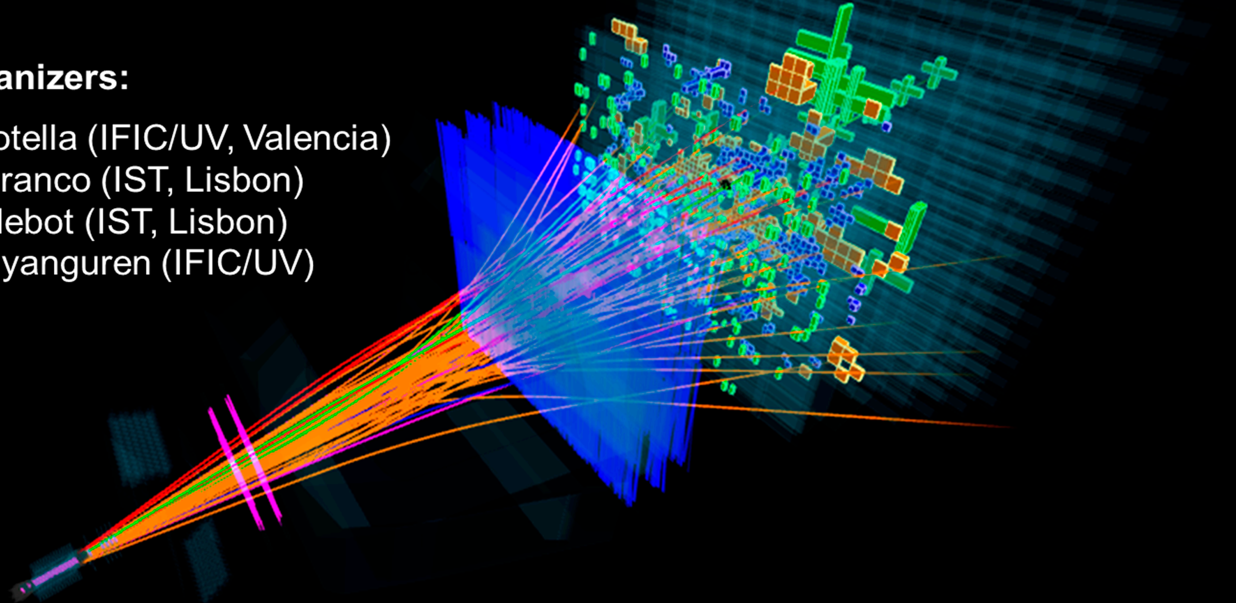

Radiative b-hadron decays

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on behalf of the LHCb collaboration
Laboratoire de Physique de Clermont
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CNRS/IN2P3

When penguins start flying

Nuclear Physics B131 (1977) 285–307

THE PHENOMENOLOGY OF THE NEXT LEFT-HANDED QUARKS

J. ELLIS, M.K. GAILLARD *, D.V. NANOPOULOS ** and S. RUDAZ ***
CERN, Geneva

Received 14 July 1977

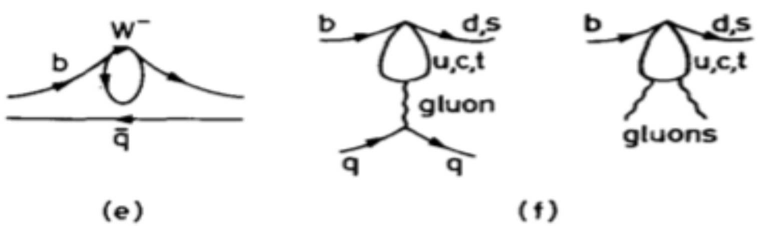


Fig. 2. Quark diagrams contributing to B decay in the free quark model [(a)–(d)], and in the presence of strong interactions [(e) and (f)].

We now turn to the "penguin" diagrams of figs. 2e and 2f. In the free-field approximation the penguin diagrams do not contribute because they reduce to a non-diagonal mass renormalization. Furthermore, if $m_W^2 >> m_q^2$ for all quarks, they do not contribute in the leading log approximation for strong interaction corrections because of the generalized GIM mechanism. However, we believe [17] that they play an important role in the matrix element enhancement for strange particle decay, where soft gluon exchange should be understood in the generic penguin diagram of fig. 2e. For charm decay, there is no contribution to the dominant $\Delta S = \Delta Q$ transitions because the relevant operator is exotic in flavour, but *a priori* there may be a contribution to bottom decay; however, we expect a suppression of order $\alpha(m_b^2)/\alpha(\mu^2)$ relative to strange particle decay. The lowest order contributions are those of fig. 2f.

Evidence for Penguins

VOLUME 71, NUMBER 5 PHYSICAL REVIEW LETTERS 2 AUGUST 1993

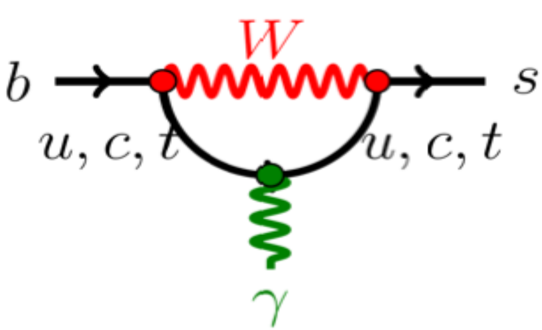
Evidence for Penguin-Diagram Decays: First Observation of $B \to K^*(892)\gamma$

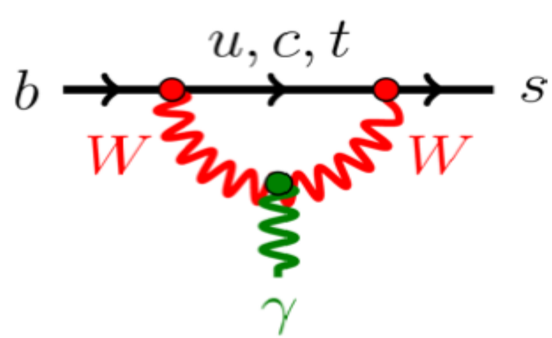
(CLEO Collaboration)

We have observed the decays $B^0 \to K^*(892)^0\gamma$ and $B^- \to K^*(892)^-\gamma$, which are evidence for the quark-level process $b \to s\gamma$. The average branching fraction is $(4.5 \pm 1.5 \pm 0.9) \times 10^{-5}$. This value is consistent with standard model predictions from electromagnetic penguin diagrams.

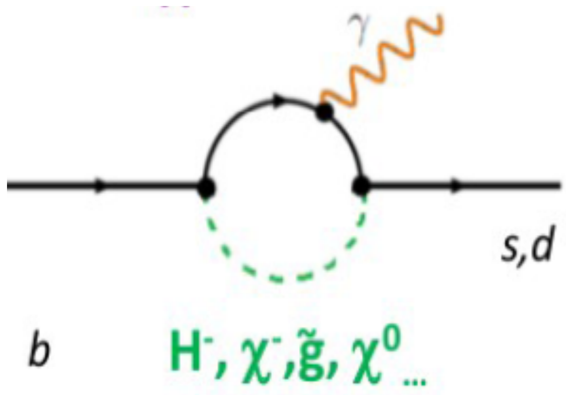
$b \to q\gamma$ radiative transition (q=s,d):

- FCNC electro-magnetic penguin





Radiative as a probe for NP



New physics affects the transition dynamics

BR, A_{CP},
Isospin asymmetry,
helicity structure

Phys. Rev. D 82, 073012, 2010

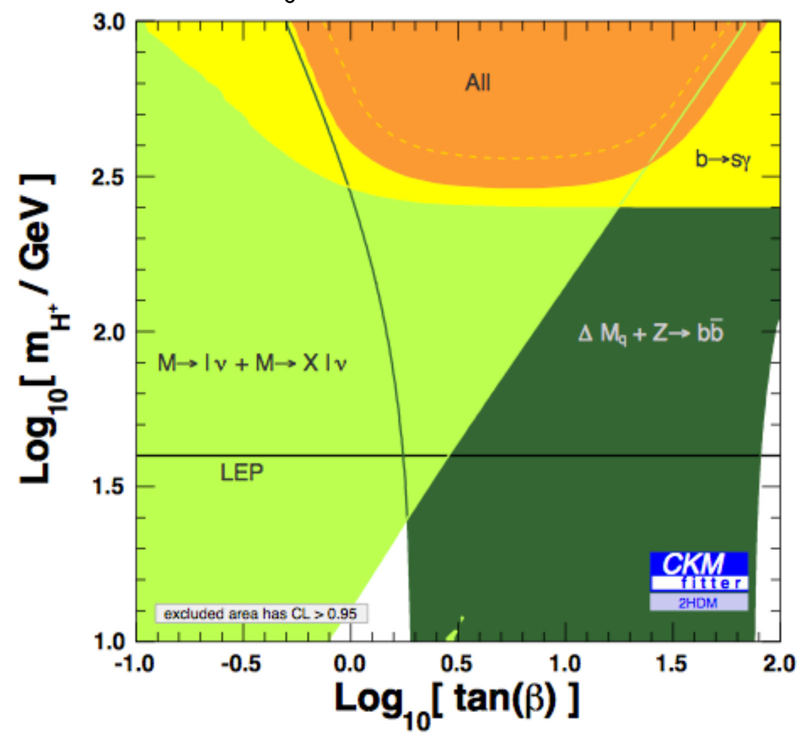


Figure 11: *Global constraints on 2HDM parameters m_{H^+} and $\tan\beta$ from all analysed observables. Each color corresponds to a different set of observables, as quoted in the Figure. The complementary area of the colored one is excluded at 95% CL. The horizontal black line indicates the 95% CL limit from direct searches at LEP [58]. The dotted line within the orange combined area delimits the corresponding 1σ confidence area. For the combination of leptonic and semileptonic constraints (light green area) we assumed that the p-value is best approximated by a 1 d.o.f. χ^2 distribution since 2HDM contributions essentially depend on the ratio $m_{H^+}/\tan(\beta)$.*

Radiative decays of B mesons

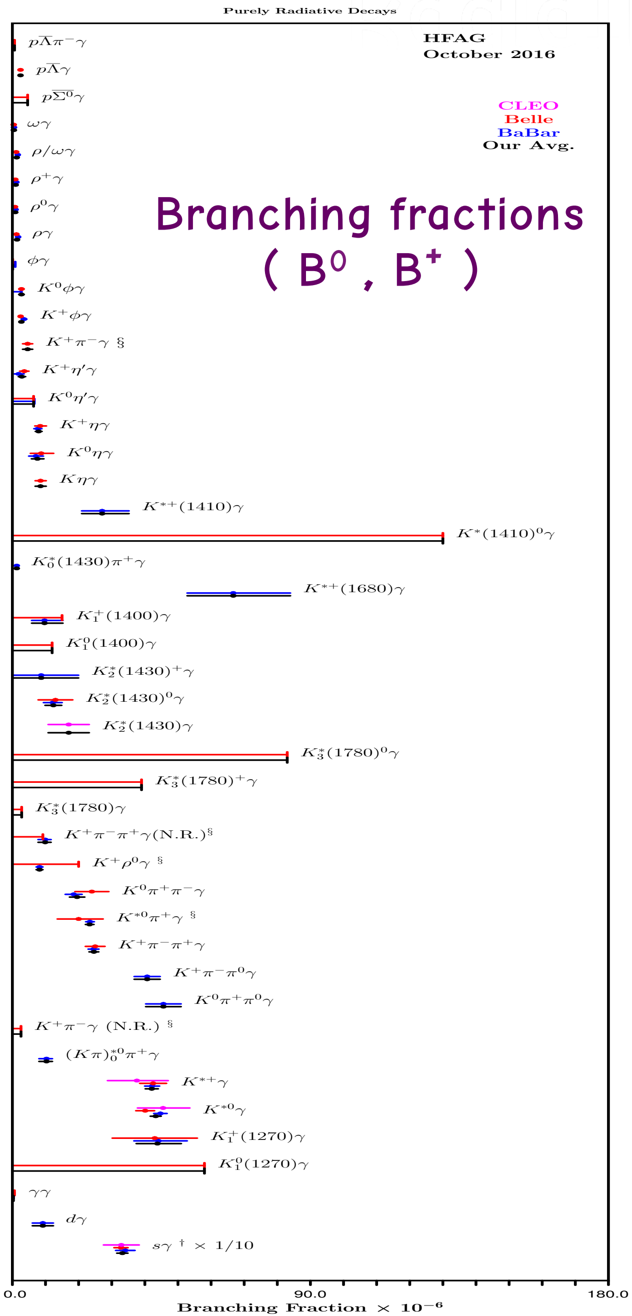
at the B-factory era

$BR(B_{d,u} \rightarrow V\gamma)$ ~ 40×10^{-6}

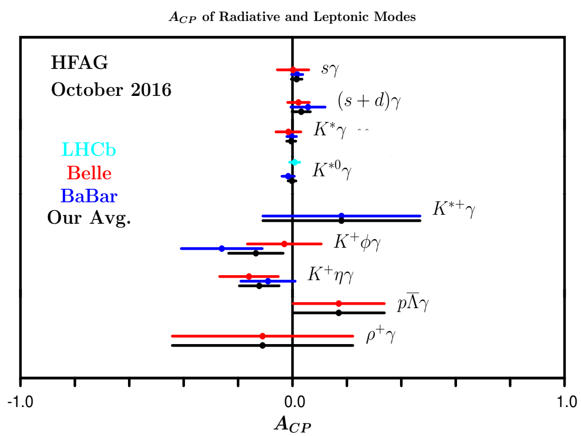
$BR(b \rightarrow s\gamma)_{E\gamma>1.6\ GeV}$ = $(352\pm15)\times10^{-6}$

$BR(b \rightarrow d\gamma)$ = $(9.2\pm3.0)\times10^{-6}$

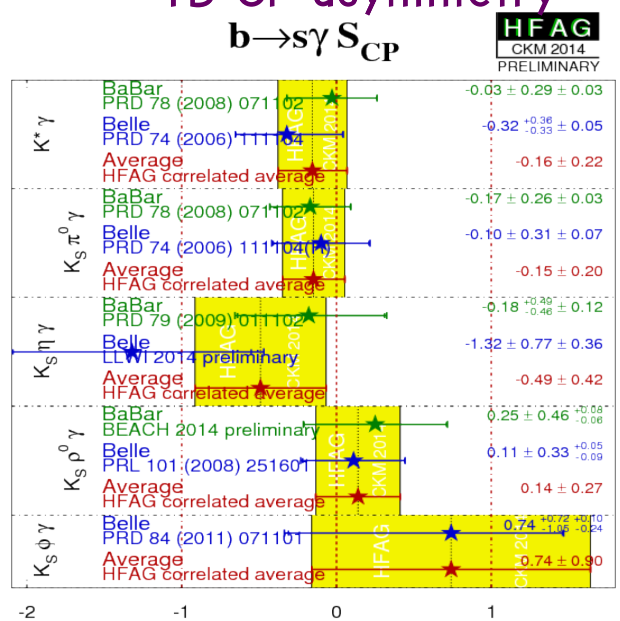
Branching fractions (B^0 , B^+)



Direct CP asymmetry



TD CP asymmetry



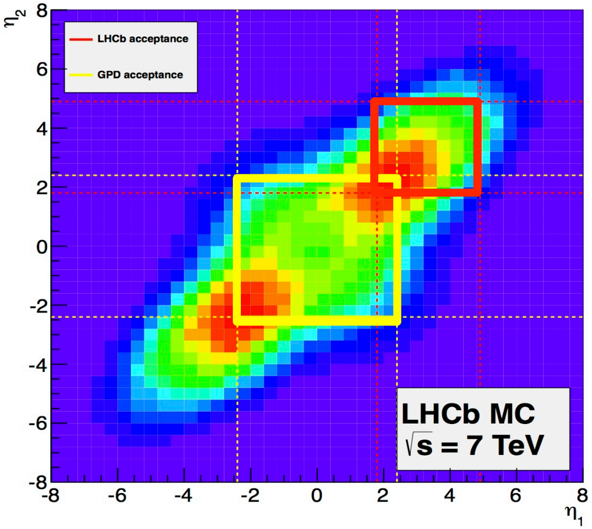
Isospin asymmetry

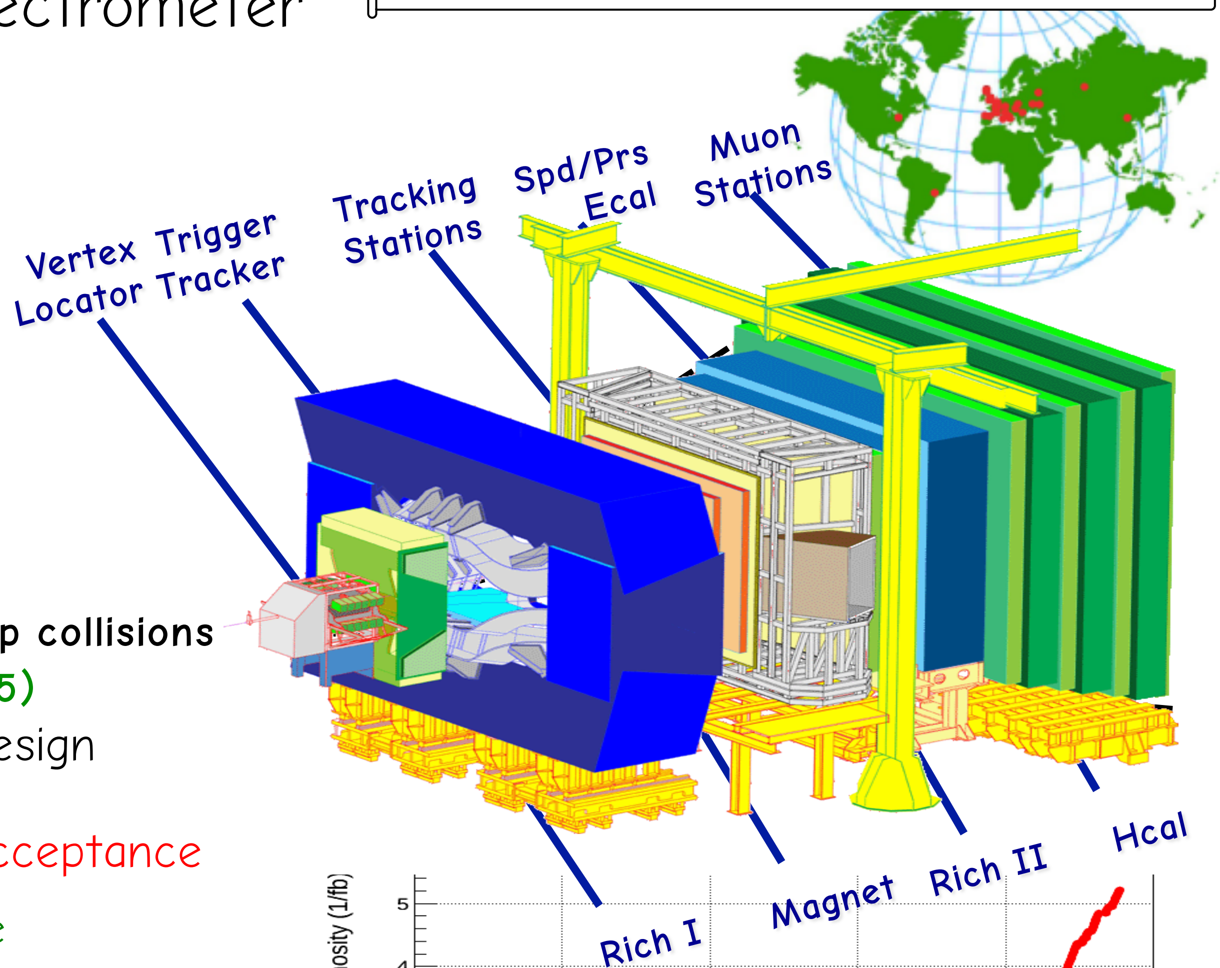
Parameter	PDG2014 Avg.	BABAR	Belle	LHCb	Our Avg.
$\Delta_{0-}(X_s\gamma)$	-0.01 ± 0.06	-0.01 ± 0.06 §			-0.01 ± 0.06
$\Delta_{0+}(K^*\gamma)$	0.052 ± 0.026	$0.066\pm0.021\pm0.022$	$0.012\pm0.044\pm0.026$		0.012 ± 0.051
$\Delta_{\rho\gamma}$	-0.46 ± 0.17	$-0.43^{+0.25}_{-0.22}\pm0.10$	$-0.48^{+0.21+0.08}_{-0.19-0.09}$		$-0.48^{+0.23}_{-0.21}$

The LHCb era

Single-arm forward spectrometer

LHCb detector performances, IJMP A. Vol.30, No 7 (2015) 1530022





- **RUN 1 (2010-2013): 7/8 TeV pp collisions**

Visible pp interaction/crossing: **O(1.5)**

factor 4 beyond the design

Integrated luminosity: **$3fb^{-1}$**

~2 $x10^{11}$ bb in LHCb acceptance

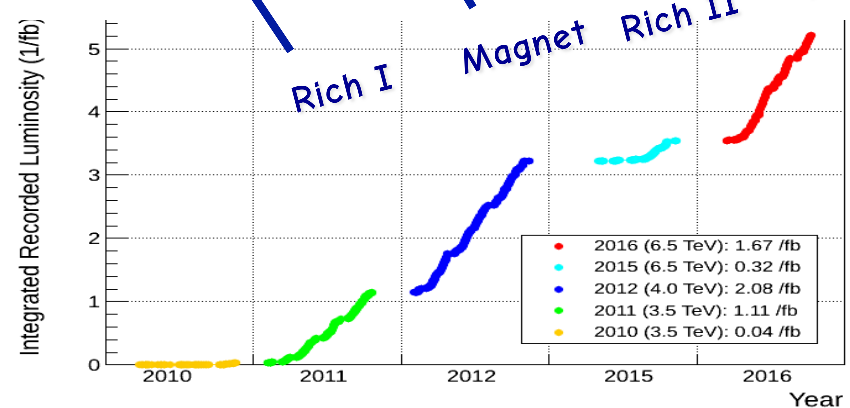
Radiative decay reconstruction rate

$B^0 \to K^{*0} \gamma$: ~ 7 events / pb^{-1}

$B_s \to \phi\gamma$: ~ 1 events / pb^{-1}

- **RUN 2 (2015-2018): 13 TeV pp collisions**

production rates increase by ~2

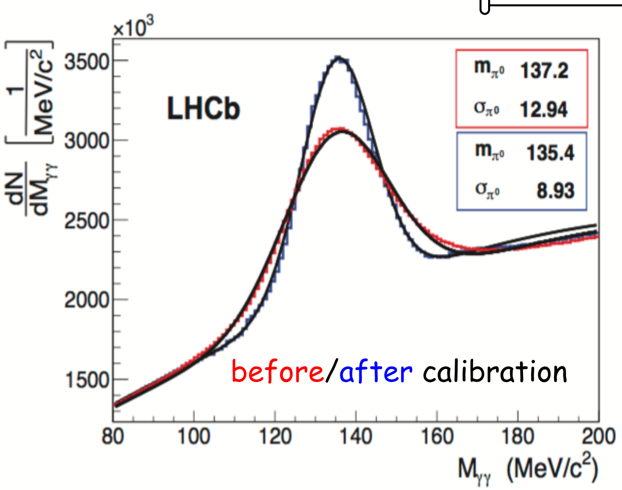


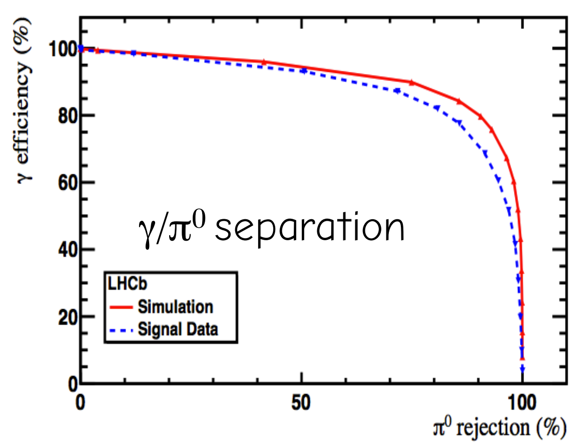
- Calorimetric photons: unconverted photons or conversion after magnet
  => from calorimeters deposit
- Di-electron photons: conversion before magnet
  => from tracking system

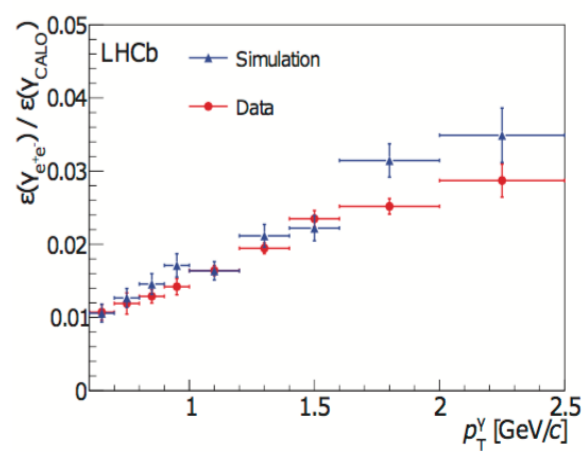
- Large calorimeter occupancy : large combinatorial background
  => neutralID to separate neutral EM showers from hadronic and electrons deposits

- Above p_T ~2.5 GeV/c π^0 likely produced a single Electromagnetic Calorimeter cluster
  ⇒ those π^0 represents an important background to high energy photons
  ⇒ γ/π^0 separation multivariate

« LHCb detector performances », IJMP A. Vol.30, No 7 (2015) 1530022





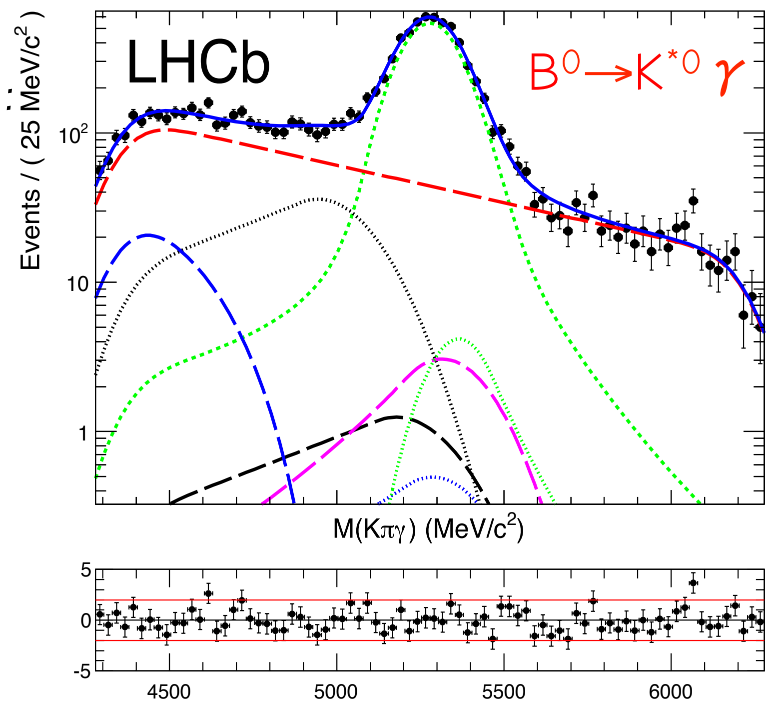


Radiative decay anatomy @ LHCb

Nuclear Physics B, 867, 1-18 (2013)

Due to trigger constraint and large combinatorics the radiative decays mostly rely on high pT photons :

L0 threshold in 2011(2012) : $E_T(\gamma) > 2.5\ (3.0)$ GeV
Typical trigger efficiency on radiative modes ~ 30-40%
For comparison : (di)muon channel ε_{trg}~80-90%



Mass resolution driven by calorimeter resolution :

$\sigma_M(B \to X\gamma) \sim 90$ MeV/c²
For comparaison : $\sigma_M(B \to hh) \sim 25$ MeV/c²
$\sigma_M(B \to J/\psi X) \leq 10$ MeV/c²

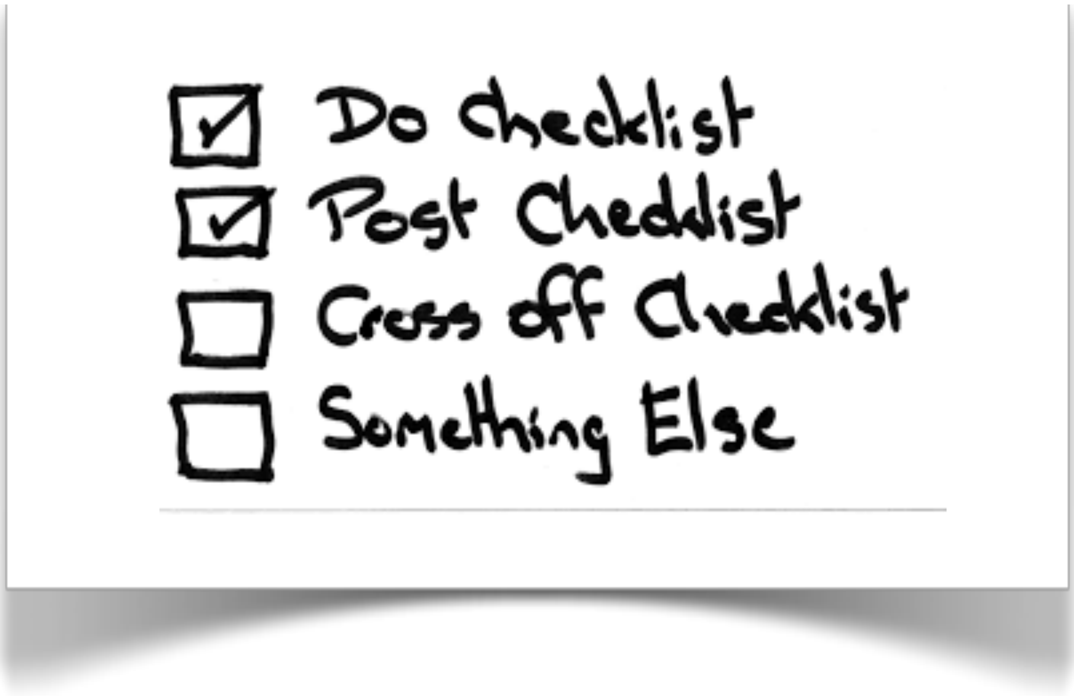
No constraint on vertexing from γ / large photon multiplicity / limited mass resolution :

Large combinatorial background
partially rec'ed and peaking backgrounds

- Generic background contamination :
  - Combinatorial background
  - Partially reconstructed $b \to s\gamma$ decays
  - Partially reconstructed $b \to c$ $(X+hh\pi^0)$
- Specific peaking backgrounds :
  - Charmless $B_{d,s} \to h^+h^-\pi^0$
  - Irreducible $b \to d\gamma$: $B_s \to K^{*0}\gamma$
  - b-baryons cross-feed $\Lambda_b \to \Lambda^*(K^-p)\gamma$

Tight selections are applied

Run 1 achievements

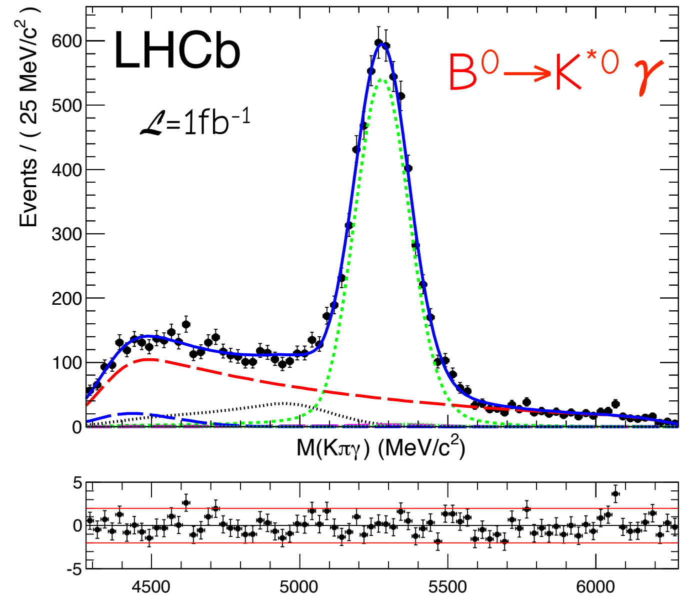


$B \to V\gamma$ measurements

$B_s \to \phi\gamma$ branching fraction

$BR(B^0 \to K^{*0}\gamma)$ =(43.3±1.5) x 10^{-6} [Belle, Babar, Cleo]

$BR(B_s \to \phi\gamma)$ =(57 $^{+21}_{-18}$) x 10^{-6} [Belle]

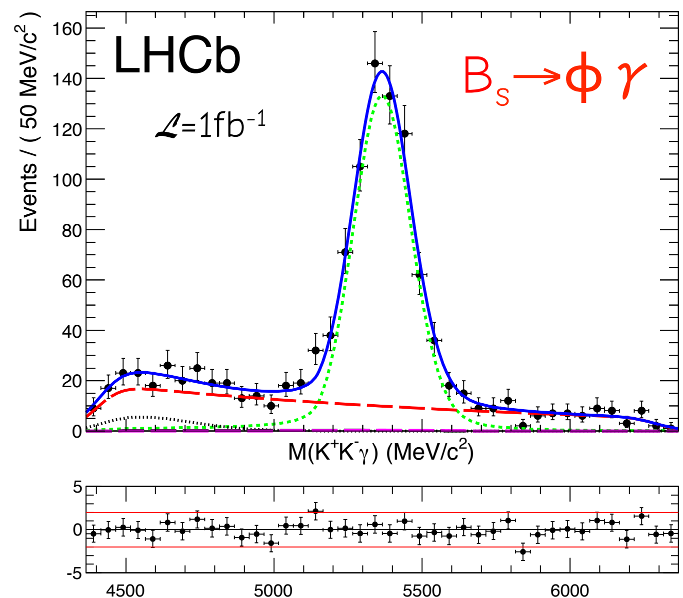


SM-predictions

large hadronic uncertainty mostly canceling in the ratio :

Ali, Pecjak, Greub, 2008

$BR(B^0 \to K^{*0}\gamma)/BR(B_s \to \phi\gamma)$ = 1.0 ± 0.2



LHCb result (1.0 fb^{-1} - 2011 data)

Nuclear Physics B, 867, 1-18 (2013)

$$\frac{\mathcal{B}(B^0 \to K^{*0}\gamma)}{\mathcal{B}(B^0_s \to \phi\gamma)} = 1.23 \pm 0.06\,(\text{stat.}) \pm 0.04\,(\text{syst.}) \pm 0.10\,(f_s/f_d)$$

$$\mathcal{B}(B^0_s \to \phi\gamma) = (3.5 \pm 0.4) \times 10^{-5}$$

$B_s \to \phi\gamma$ Branching Fraction

Phys. Rev. D 85 (2012) 032008

$$f_s / f_d = 0.267^{+0.021}_{-0.020}$$

- Systematic uncertainty dominated by f_s/f_d (±8%)

  from semi-leptonic $B_{u,d,s} \to D_{(s)} \mu \nu X$ and hadronic $B_{u,d,s,} \to D_{(s)} h$

- Background model (±2%)

  Contamination level and shape

- Reconstruction and selection (±2%)

  Trigger and selection efficiencies, Particle reconstruction & identification

Update with whole $3 fb^{-1}$ sample ongoing

both statistical and systematical uncertainty will improve

(more precise fs/fd, improved background model ...)

B→V γ measurements

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

SM-prediction :

Phys. Rev. D72 (2005) 014013

$$A_{CP} = -0.0061 \pm 0.0043$$

A_{CP} enhanced in NP scenarii

B-factory measurement

BABAR, Phys. Rev. Lett. 84, 5283–5287

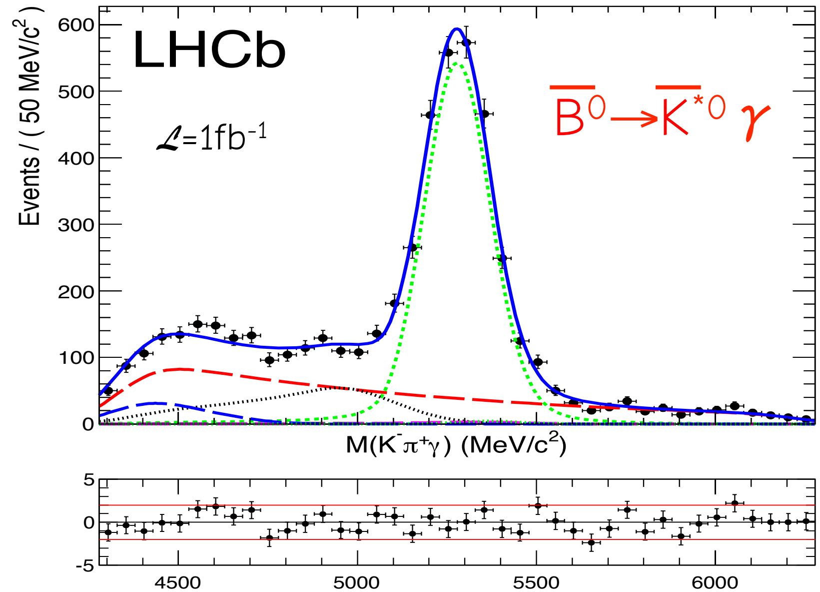
$$A_{CP} = -0.016 \pm 0.022 \pm 0.007$$

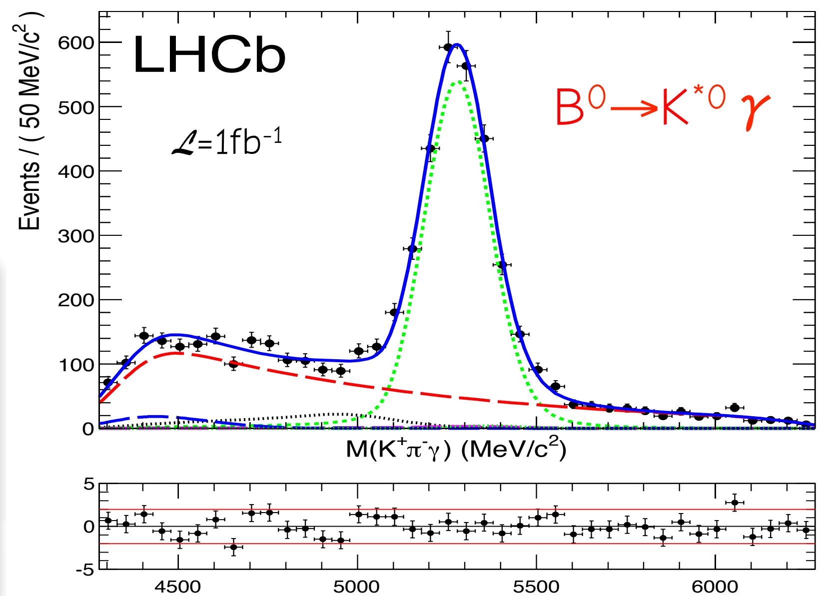
LHCb result (1.0 fb^{-1} - 2011 data) :

Nuclear Physics B, 867, 1-18 (2013)

$$N_{B^0} + N_{\bar{B}^0} = 5300 \pm 100$$

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





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

- $K^+\pi^-/K^-\pi^+$ detection asymmetry

  From charm $D^0 \to K\pi$ large control sample

$$A_D(K\pi) = \frac{\varepsilon(K^-\pi^+) - \varepsilon(K^+\pi^-)}{\varepsilon(K^-\pi^+) + \varepsilon(K^+\pi^-)} = (-1.0 \pm 0.2)\%$$

- B production asymmetry

  From large $B \to J/\psi K^*$ sample

$$A_P(B) = \frac{R(\bar{B}) - R(B)}{R(\bar{B}) + R(B)} = (1.0 \pm 1.3)\%$$

- Background model ΔA_{CP}=(-0.2±0.7)%

  Contamination level, shape & CP asymmetry in various background components
  Dominated by the unknown asymmetry from the misidentified $\Lambda_b \to (pK)\gamma$ contamination

- Detector non-uniformity ΔA_{CP}= (+0.1±0.2)%

  Possible detector bias strongly reduced by switching regularly the magnet polarity

Update with whole $3fb^{-1}$ sample ongoing

both statistical and systematical uncertainty will improve :
more precise detection and production asymmetry,
CP asymmetry from background in particular $\Lambda_b \to (pK)\gamma$

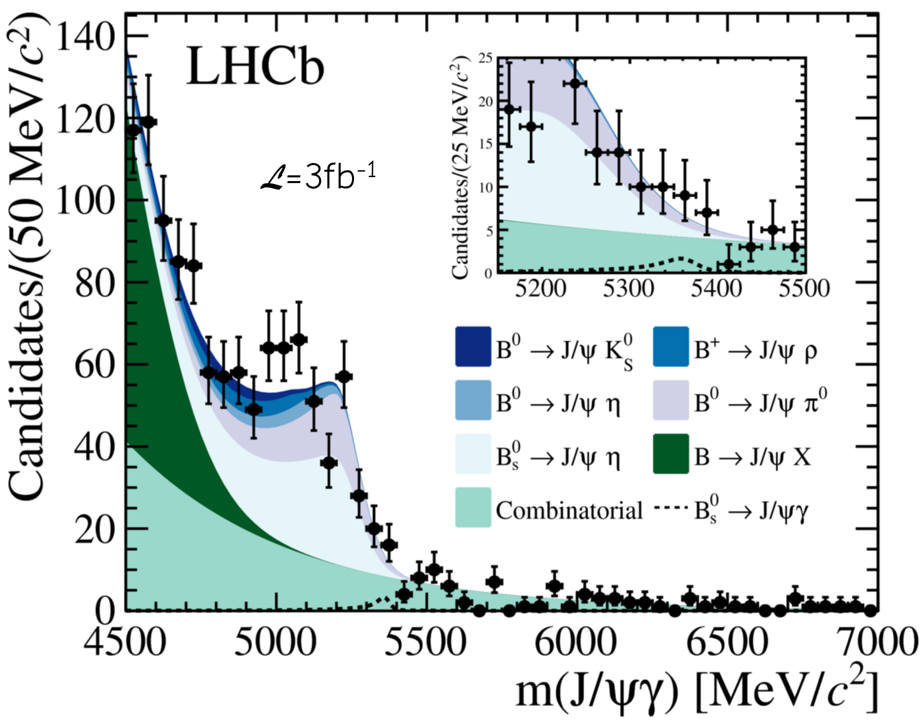
B→V γ measurements

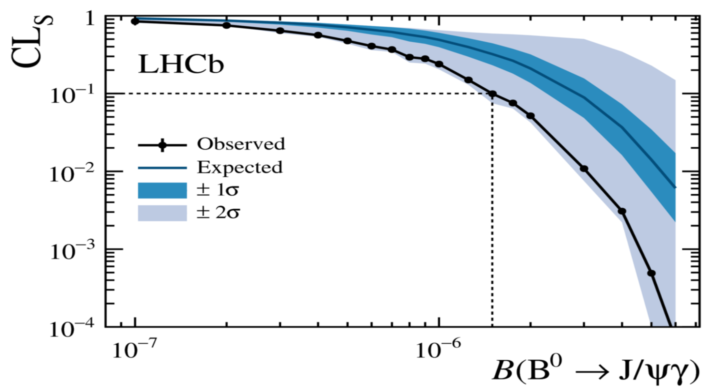
Search for $B^0 \to J/\Psi\gamma$ & $B_s \to J/\Psi\gamma$

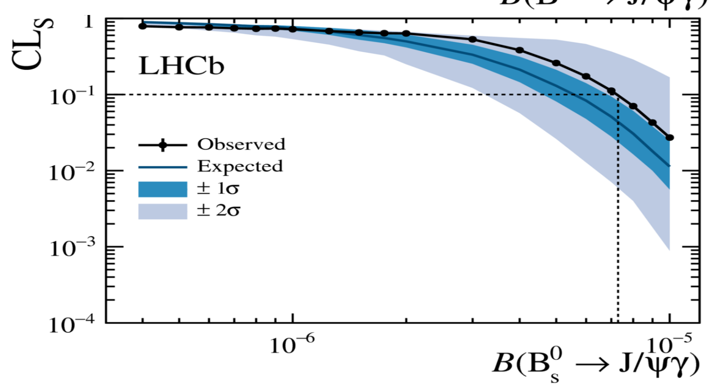
Not a radiative penguin transitions but share the same final-state problematics

Phys. Rev. D 92 (2015) 112002

$BR(B^0 \to J/\Psi\gamma) < 1.7 \times 10^{-6}$
$BR(B_s \to J/\Psi\gamma) < 7.4 \times 10^{-6}$ @ CL=90%

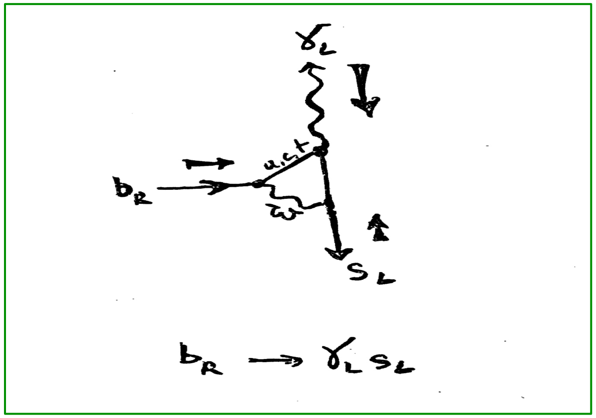


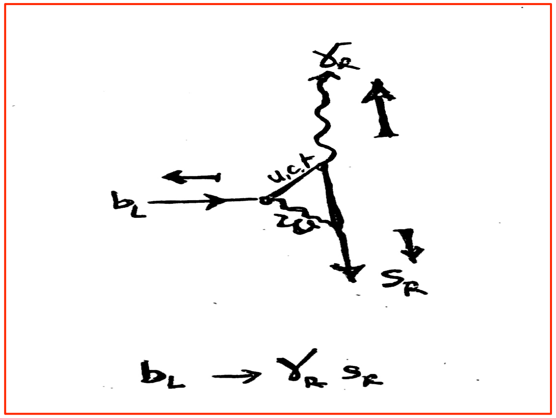




Photon polarisation

- Real photon (h=±1) implies the helicity flip on the quark lines
- SM : EW-penguin dominates the b→qγ transition
  - W-coupling to left-handed quarks => transition through helicity violation
  - Amplitude suppressed by m_q / m_W with m_q = the mass of the right-handed quark





- Leading (EM dipole) operator in the effective Hamiltonian approach :

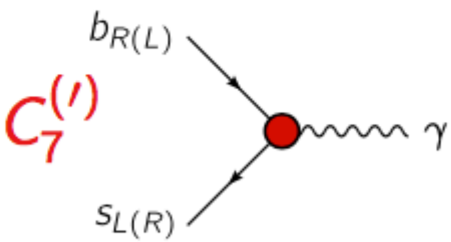
$$O_7 \propto m_b \bar{s} \sigma^{\mu\nu} F_{\mu\nu} (1+\gamma_5) b + m_s \bar{s} \sigma^{\mu\nu} F_{\mu\nu} (1-\gamma_5) b$$

$$\tan\psi = \left| A_R (b_L \to s_R \gamma_R) / A_L (b_R \to s_L \gamma_L) \right| \approx m_s / m_b$$

Photon polarisation

$$\mathcal{H}_{\text{eff}}^{\Delta F=1} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^{*} \sum (C_i \mathcal{O}_i + C_i' \mathcal{O}_i')$$

Wilson coefficient — Dimension-6 operator



mag. dipole operator

Naive approximation

$$\tan(\psi) \sim C'_7 / C_7$$

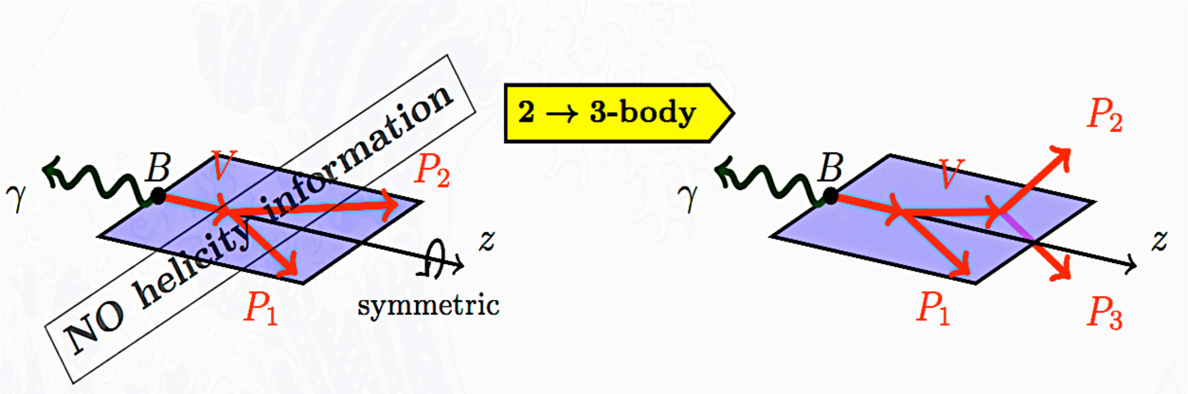
- other SM operator contributions (O_2, ...) : $A_R/A_L \sim O(5\%)$

Right-handed component could be enhanced in NP models

Photon polarisation

Experimentally, the photon polarization can be extracted from ...

- angular analysis of the recoil 3-body in the $B \to \gamma + (hhh)_{res.}$ decay mode



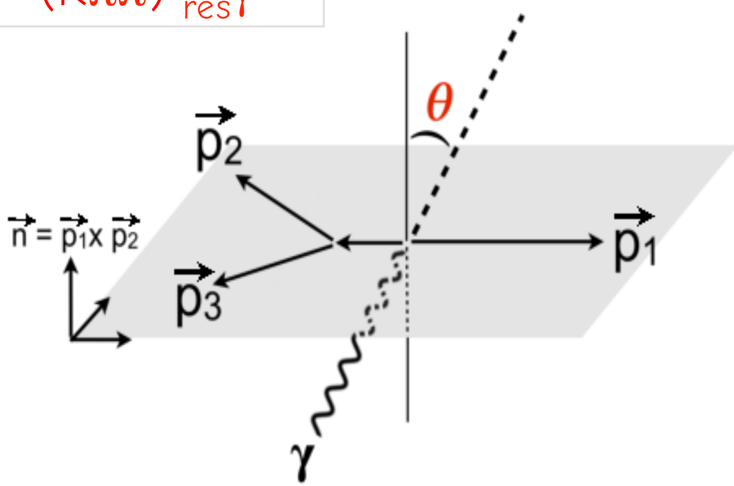
- time-dependent analysis of the $B \to \gamma\ \Phi_{CP}$ decay modes

- di-lepton angular analysis at low q^2 of the (virtual) photon decay in $B \to V e^+ e^-$

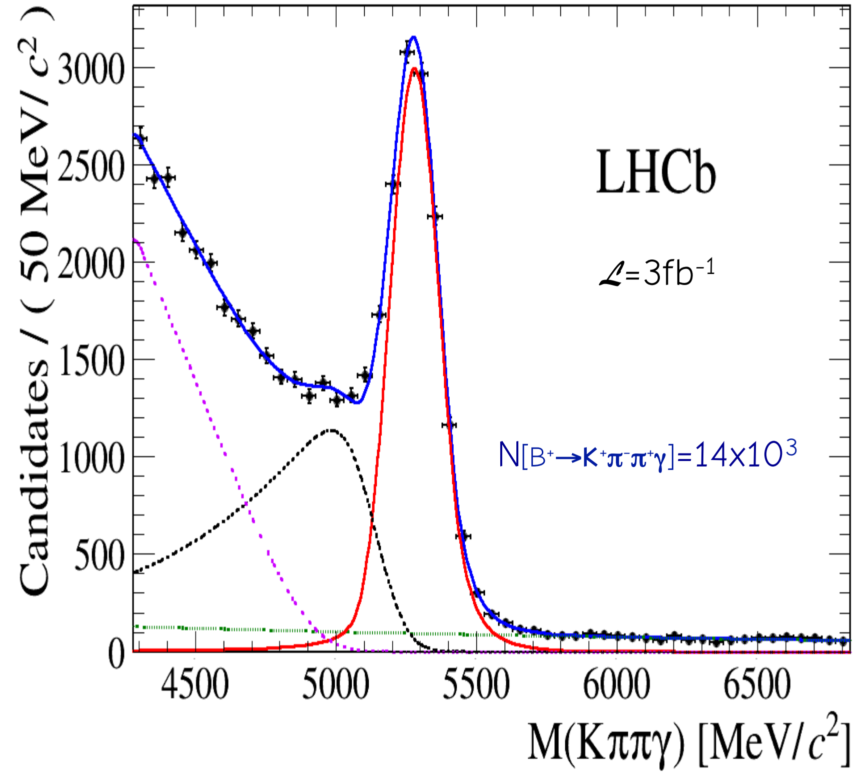
- angular analysis in the radiative transition of b-baryons

Helicity structure in $B \to (K\pi\pi)_{res}\gamma$

$B^+ \to (K\pi\pi)^+_{res}\gamma$



[Phys. Rev. Lett. 112, 161801 (2014)]



For a mixture of spin-parity $K_{res}(1^+,2^+,1^-)$:

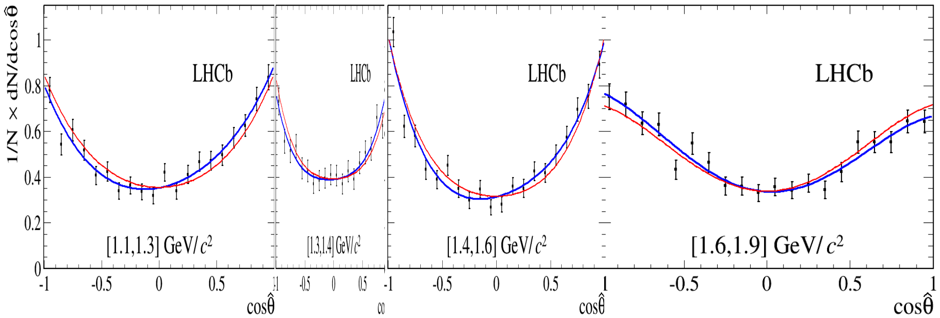
$$\frac{d\Gamma}{ds\, ds_{13}\, ds_{23}\, d\cos\theta} \propto$$

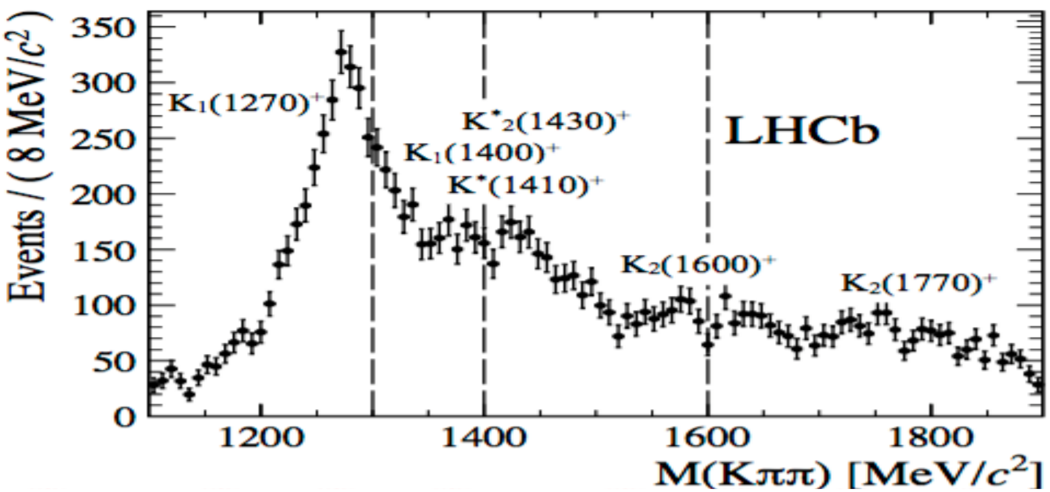
$$\sum_{i=0,2,4} a_i(s,s_{13},s_{23}) \cos^i\theta + \lambda_\gamma \sum_{j=1,3} a_j(s,s_{13},s_{23}) \cos^j\theta$$

Up-down photon asymmetry is proportional to the photon polarisation λ_γ

Helicity structure in $B \to (K\pi\pi)_{res}\gamma$

Angular analysis of photon direction wrt to $(K\pi\pi)_{res}$ decay plane in different mass bins





[Phys. Rev. Lett. 112, 161801 (2014)]

Photons from radiative decays are polarized @ 5.2σ significance

First direct observation of photon polarization in b→sγ transition

as a by-product:

LHCb-CONF-2013-009

$$\mathcal{A}_{CP} = -0.007 \pm 0.015\,(\text{stat})^{+0.012}_{-0.011}\,(\text{syst})$$

Measuring the λ_γ value from the up-down asymmetry require to separate the (Kππ) resonances & theoretical determination of the helicity amplitude

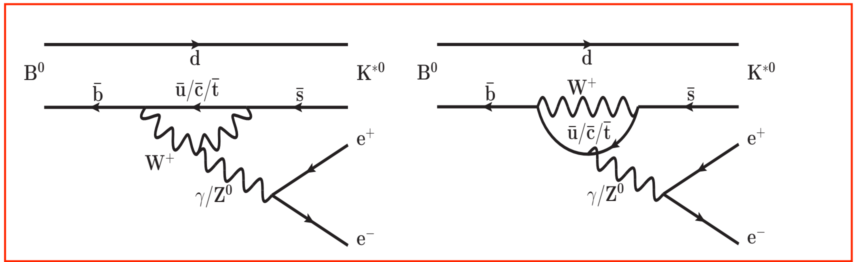
e.g. for a single 1+ resonance

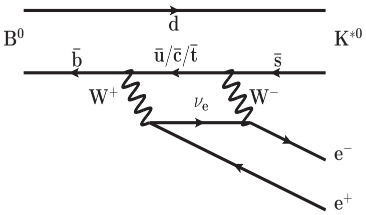
Phys. Rev. Lett. 88 (2002) 051802

$$\frac{d\Gamma(B \to K\pi\pi\gamma)}{ds\, ds_{13}\, ds_{23}\, d\cos\theta} \propto \frac{1}{2}|\vec{\mathcal{J}}|^2(1+\cos^2\theta) + \lambda_\gamma \cos\theta\, \mathrm{Im}[\vec{n}\cdot(\vec{\mathcal{J}}\times\vec{\mathcal{J}}^*)]$$

Virtual photon : $B^0 \to K^{*0} e^+ e^-$

$B^0 \to K^* e^+ e^-$ in the low q^2 region



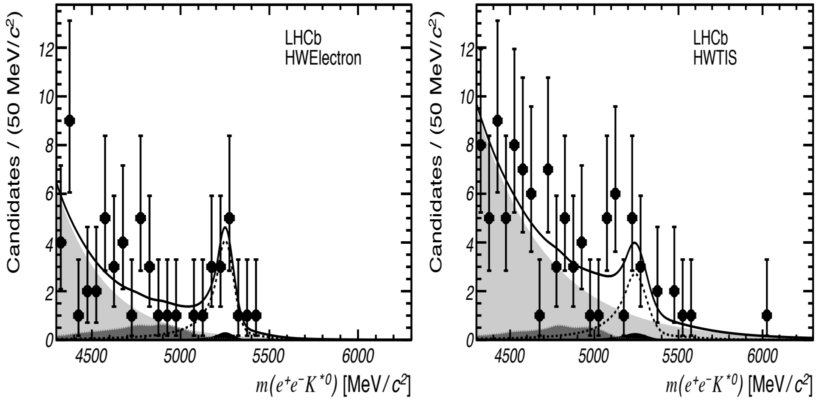


Branching fraction in q^2=[30 ; 1000] MeV/c^2

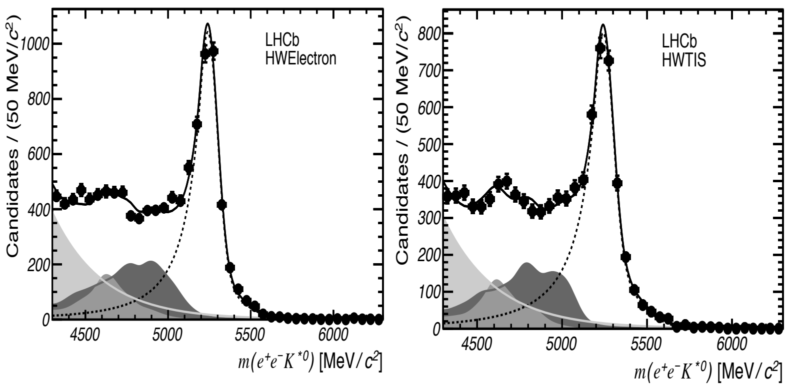
1.0 fb^{-1} - 2011 data :

J. High Energy Phys. 05 (2013) 159

$$\mathcal{B}(B^0 \to K^{*0} e^+ e^-)^{30-1000\,\mathrm{MeV}/c^2} = (3.1\,^{+0.9}_{-0.8}\,^{+0.2}_{-0.3} \pm 0.2) \times 10^{-7}$$



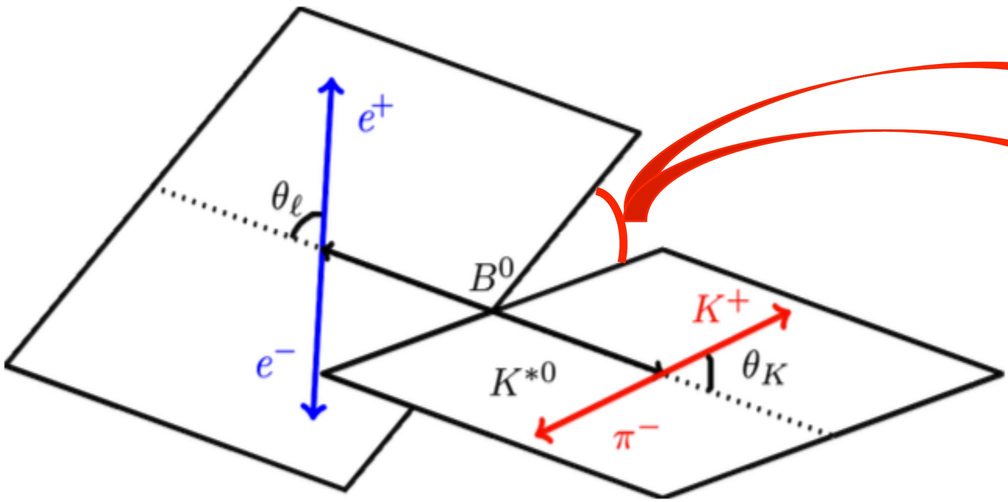
$B^0 \to K^* J/\psi(\to e^+e^-)$: control channel



Virtual photon : $B^0 \to K^{*0} e^+ e^-$

$B^0 \to K^* e^+ e^-$ angular analysis

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\tilde{\phi}} = \frac{9}{16\pi}\Big[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \left(\frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K - F_\mathrm{L}\cos^2\theta_K\right)\cos 2\theta_\ell + \frac{1}{2}(1-F_\mathrm{L})A_\mathrm{T}^{(2)}\sin^2\theta_K\sin^2\theta_\ell\cos 2\tilde{\phi} + (1-F_\mathrm{L})A_\mathrm{T}^\mathrm{Re}\sin^2\theta_K\cos\theta_\ell + \frac{1}{2}(1-F_\mathrm{L})A_\mathrm{T}^\mathrm{Im}\sin^2\theta_K\sin^2\theta_\ell\sin 2\tilde{\phi}\Big]. \quad (1)$$



angular analysis : $\cos\theta_l$, $\cos\theta_K$, $\tilde{\phi}$

Sensitive to the photon polarisation

$$F_\mathrm{L} = \frac{|A_0|^2}{|A_0|^2+|A_{||}|^2+|A_\perp|^2}$$

$$A_\mathrm{T}^{(2)} = \frac{|A_\perp|^2-|A_{||}|^2}{|A_\perp|^2+|A_{||}|^2}$$

$$A_\mathrm{T}^\mathrm{Re} = \frac{2\mathcal{R}e(A_{||L}A^*_{\perp L}+A_{||R}A^*_{\perp R})}{|A_{||}|^2+|A_\perp|^2}$$

$$A_\mathrm{T}^\mathrm{Im} = \frac{2\mathcal{I}m(A_{||L}A^*_{\perp L}+A_{||R}A^*_{\perp R})}{|A_{||}|^2+|A_\perp|^2},$$

Approximation:

$$\lim_{q^2\to 0} A_\mathrm{T}^{(2)} = \frac{2\mathcal{R}e(C_7C_7')}{|C_7|^2+|C_7'|^2}$$

$$\lim_{q^2\to 0} A_\mathrm{T}^\mathrm{Im} = \frac{2\mathcal{I}m(C_7C_7')}{|C_7|^2+|C_7'|^2}$$

Virtual photon : $B^0 \to K^{*0} e^+ e^-$

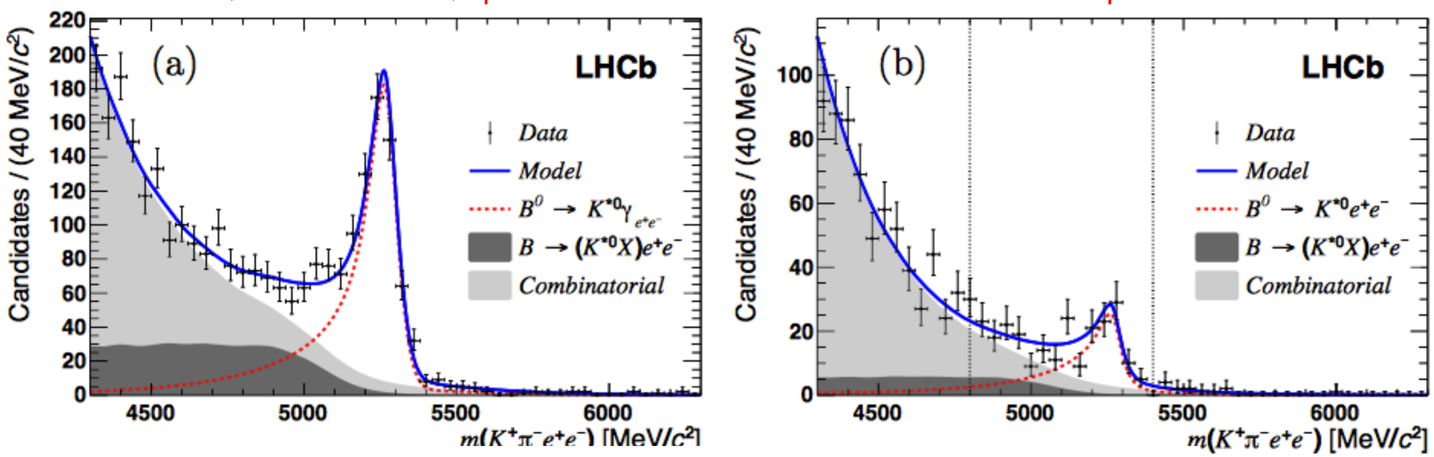
Full angular analysis in [20; 1120]MeV/c²

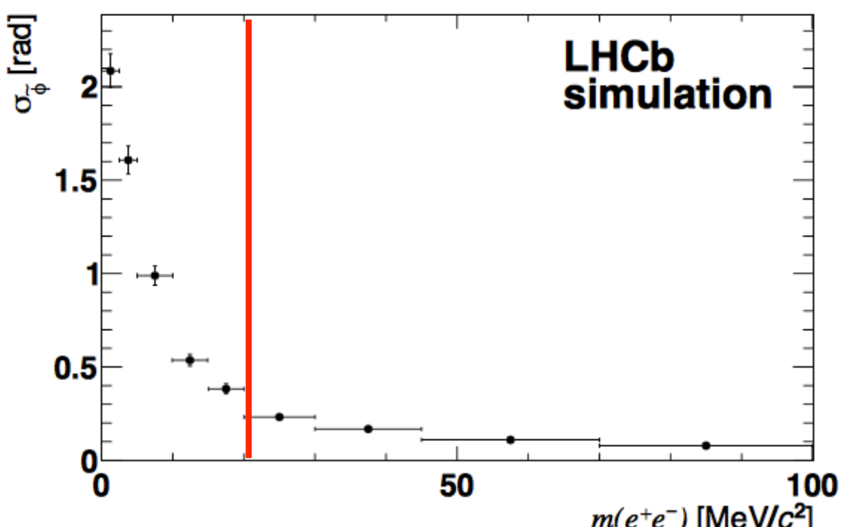
3.0 fb⁻¹ – 2011+2012 data :

J. High Energy Phys. 04(2015) 064

Real (converted) photons

virtual photons





Virtual photon : $B^0 \to K^{*0} e^+ e^-$

Full angular analysis in [20; 1120]MeV/c^2

3.0 fb^{-1} – 2011+2012 data :

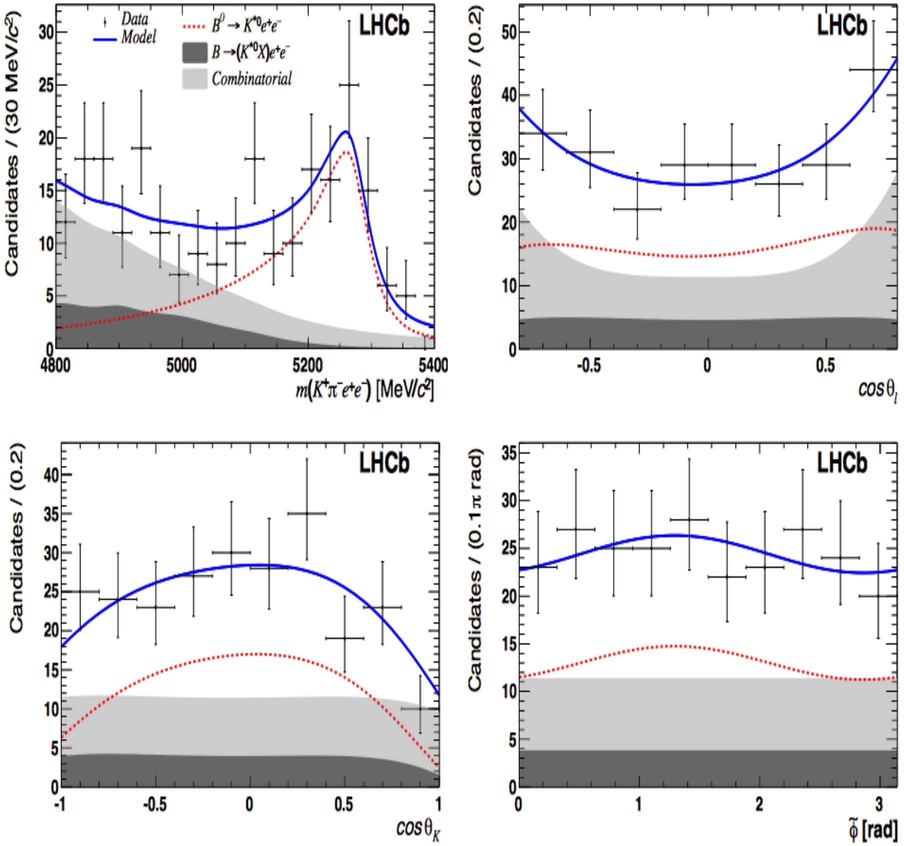
J. High Energy Phys. 04(2015) 064

$$F_L = 0.16 \pm 0.06 \pm 0.03$$

$$A_T^{(2)} = -0.23 \pm 0.23 \pm 0.05$$

$$A_T^{Im} = +0.14 \pm 0.22 \pm 0.05$$

$$A_T^{Re} = +0.10 \pm 0.18 \pm 0.05,$$



Time-dependent decay rate

Direct access via the time-dependent decay rate of $B \rightarrow \Phi^{CP}\gamma$

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

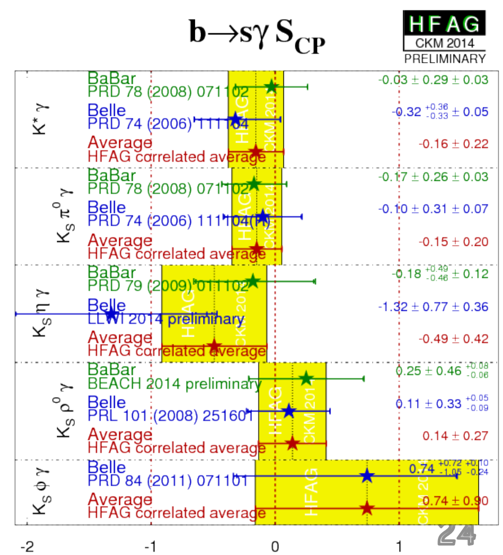
untagged / *tagged analysis required*

$$\mathcal{S}_{CP} \sim \sin 2\psi \sin\phi_{(s)}$$
$$\mathcal{A}_\Delta \sim \sin 2\psi \cos\phi_{(s)}$$
$$\tan\psi = \left|\frac{\mathcal{A}_R}{\mathcal{A}_L}\right|$$

$\phi_{(s)}$ is the mixing-decay weak phase

$B_s \rightarrow \phi\gamma$	: ϕ_s (SM)~$2\beta_s - 2\beta_s$	~ 0
$B_d \rightarrow K^{*0}\gamma$	: ϕ_d (SM)~$2\beta - 2\beta_s$	~ 2β
$B_d \rightarrow \rho^0\gamma$	: ϕ_d (SM)~$2\beta - 2\beta$	~ 0

- **B^0 decays :** sensitive to the polarisation through the TD asymmetry term S_{CP}
  Out of LHCb reach for the dominant decay mode $B^0 \rightarrow K^{*0}(\rightarrow K_s\pi^0)\gamma$
  No sensitivity to A_Δ ($\Delta\Gamma_d \sim 0$)



- **B_s decays** : sensitive through the mixing term A_Δ
  - $\Delta\Gamma_s / \Gamma_s \sim 10\%$
  - untagged analysis

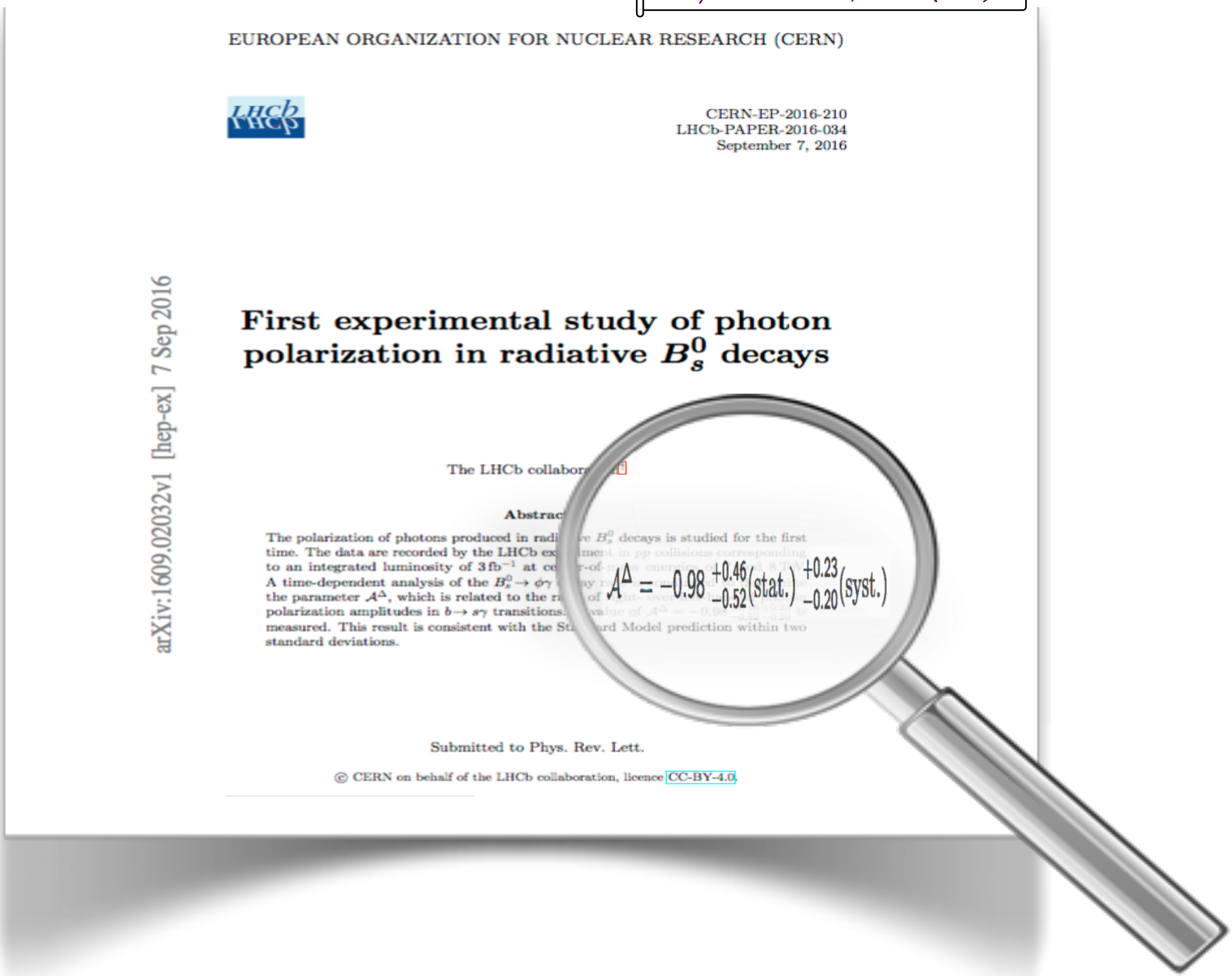
Muheim et al., PLB664(08)17

SM: $A_\Delta = 0.047 \pm 0.025 \pm 0.015$

Left-Right Symmetric model: $\mathcal{A}^\Delta_{LRSM} \sim 0.7$

Time-dependent decay rate

Phys. Rev. Lett. 118, 021801 (2017)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2016-210
LHCb-PAPER-2016-034
September 7, 2016

arXiv:1609.02032v1 [hep-ex] 7 Sep 2016

First experimental study of photon polarization in radiative B_s^0 decays

The LHCb collaboration

Abstract

The polarization of photons produced in radiative B_s^0 decays is studied for the first time. The data are recorded by the LHCb experiment in pp collisions corresponding to an integrated luminosity of $3\,\mathrm{fb}^{-1}$ at centre-of-mass energies ... A time-dependent analysis of the $B_s^0 \to \phi\gamma$ decay ... the parameter $\mathcal{A}^{\Delta}$, which is related to the ratio ... polarization amplitudes in $b \to s\gamma$ transitions. ... measured. This result is consistent with the Standard Model prediction within two standard deviations.

$$A^{\Delta} = -0.98\,^{+0.46}_{-0.52}(\text{stat.})\,^{+0.23}_{-0.20}(\text{syst.})$$

Submitted to Phys. Rev. Lett.

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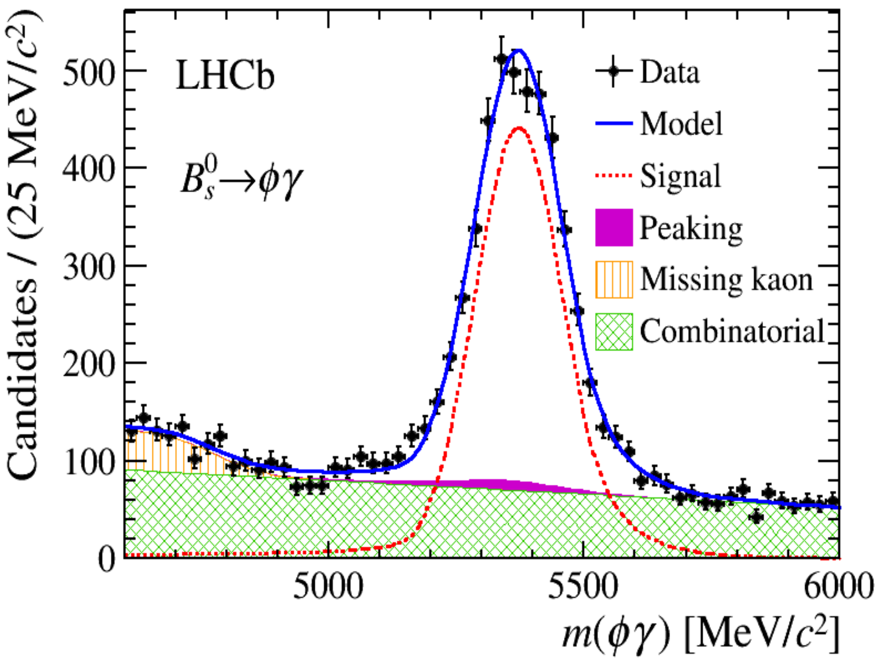
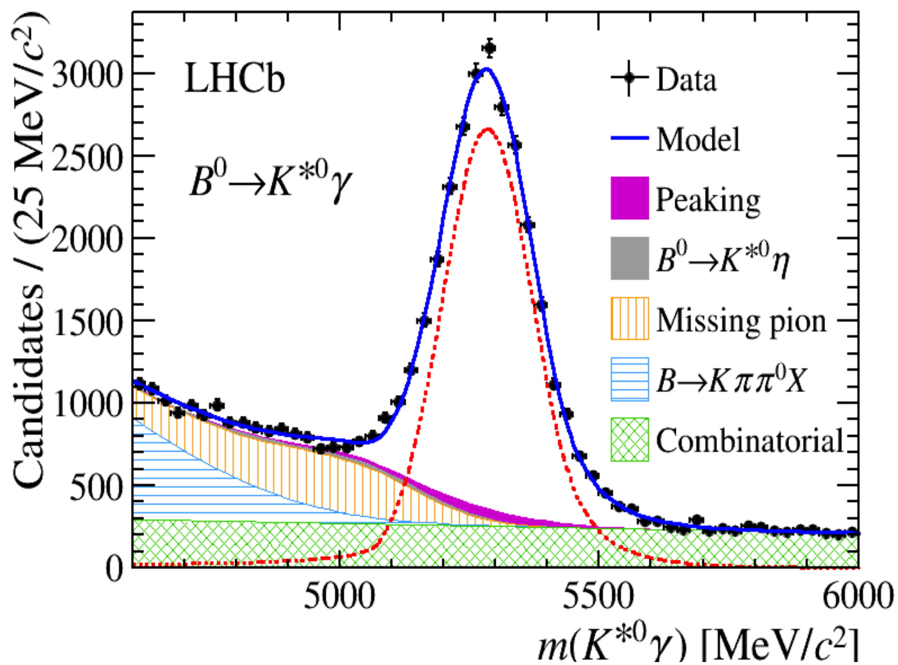
$B_s \to \phi\gamma$ signal extraction

Phys. Rev. Lett. 118, 021801 (2017)





Signal	dashed red line	N events	4214 ± 90
		μ (MeV/c^2)	5371.88 ± 1.89
		σ (MeV/c^2)	86.31 ± 1.97

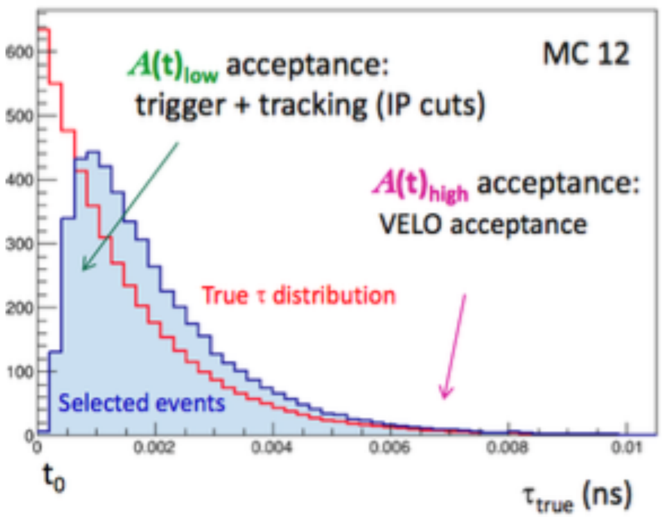
Signal	dashed red line	N events	25760 ± 301
		μ (MeV/c^2)	5284.07 ± 0.85
		σ (MeV/c^2)	87.83 ± 0.95

$B_s \to \phi\gamma$ propertime analysis

- **Propertime PDF**:

$$\mathcal{P}(t) = [\text{Physics} \times \text{Acceptance}] \otimes \text{Resolution}$$

- **Acceptance** $A(t)_{\text{low}} \times A(t)_{\text{high}}$: trigger, tracking, reconstruction and selection requirements



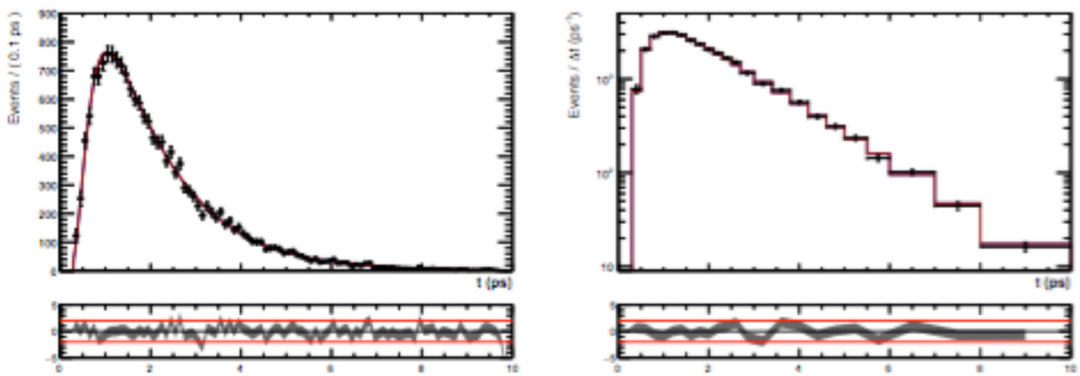
- Parameterization of the acceptance using function $A(t)$:

$$A(t) = \underbrace{\frac{[a(t-t_0)]^n}{1+[a(t-t_0)]^n}}_{A(t)_{\text{low}}} \times \underbrace{e^{-\delta\Gamma t}}_{A(t)_{\text{high}}}$$

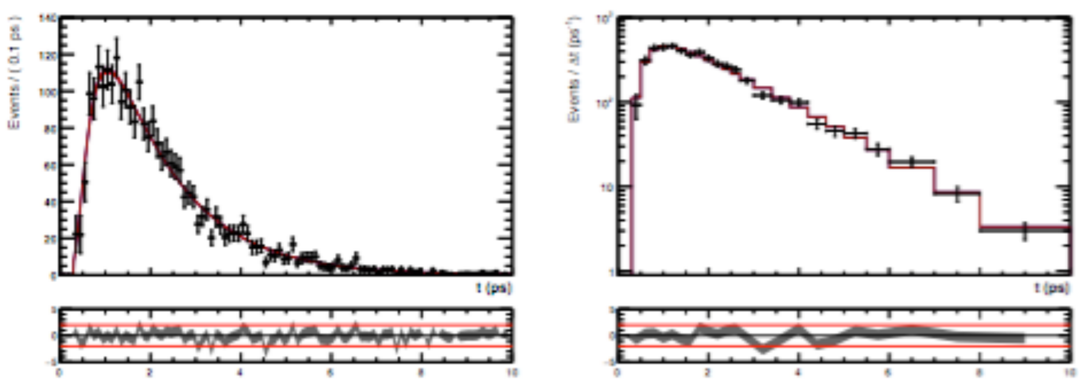
- Key in the photon polarization measurement;
- Need to be precisely determined/controlled.

Propertime fit

Background-subtracted samples



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



(b) $B^0_s \to \phi\gamma$

Phys. Rev. Lett. 118, 021801 (2017)

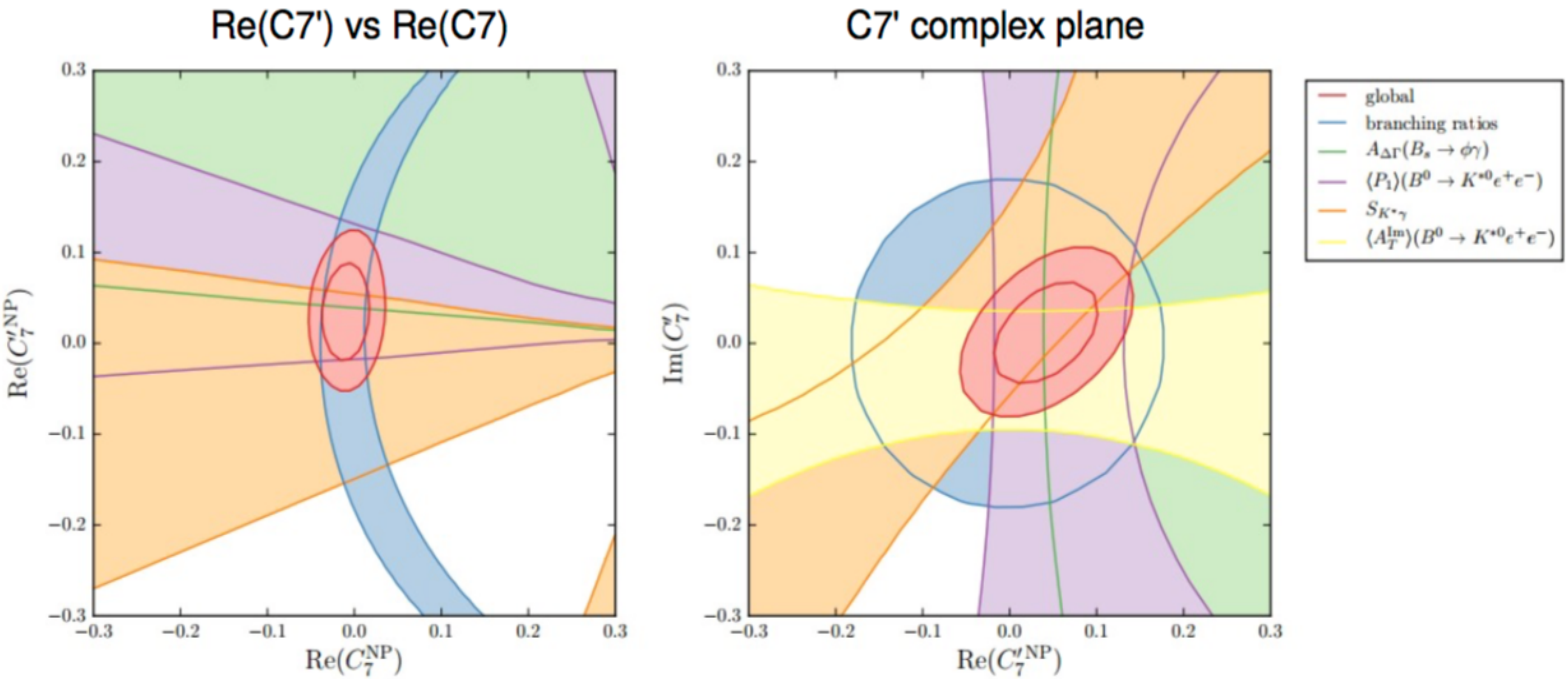
Parameter	Fitted value
Acceptance from MC	
a	1.870 ± 0.041 ps^{-1}
n	2.23 ± 0.10
$t_0(B^0 \to K^{*0}\gamma)$	184 ± 14 fs
$\Delta t_0(B^0_s \to \phi\gamma)$	-11.7 ± 3.4 fs
$\delta\Gamma(B^0 \to K^{*0}\gamma)$	39.5 ± 3.6 ns^{-1}
$\Delta\delta\Gamma(B^0_s \to \phi\gamma)$	-2.3 ± 3.5 ns^{-1}
Data-MC difference	
$\Delta t_0(B^0 \to K^{*0}\gamma\,\mathrm{Data})$	15.0 ± 5.1 fs
$\Delta\delta\Gamma(B^0 \to K^{*0}\gamma\,\mathrm{Data})$	5.1 ± 6.0 ns^{-1}

Parameter	Average
$\Delta\Gamma_s$	0.083 ± 0.006 ps^{-1}
Γ_s	0.6643 ± 0.0020 ps^{-1}
Γ_d	0.6579 ± 0.0017 ps^{-1}
$\rho(\Gamma_s, \Delta\Gamma_s)$	-0.239

$$\mathcal{A}^{\Delta} = -0.98\ ^{+0.46}_{-0.52}(\mathrm{stat.})\ ^{+0.23}_{-0.20}(\mathrm{syst.})$$

C7 constraints from radiative measurements

Paul, A. & Straub, D.M. J. High Energ. Phys. (2017) 2017: 27



Prospective

Prospective

- 2015-2018 run2 : statistics increases by > 4
  - 2015-2016 : $B_{d,s} \to V\gamma$ yield already a factor 2 above run1

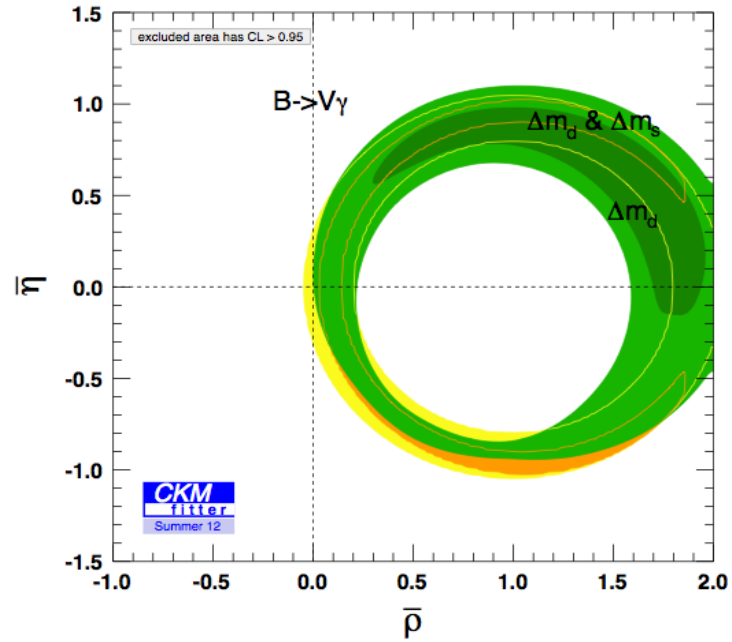
- improve previous measurements, mostly statistically limited
  - $B_{d,s} \to Vector(h^+h^-)\gamma$, $B_u \to (h^+h^-h^+)\gamma$

- explore rarer or yet unobserved modes
  - orbitaly excited final states, e.g Tensor($\to h^+h^-)\gamma$
  - decay w/ more neutrals in the final states, e.g $B^0 \to (h^+h^-h^0)\gamma$ with $h^0 = K_S$ or π^0
  - baryons decays
  - …

- V_{td} suppressed penguin : $b \to d\gamma$

BR & A_{CP} of exclusive $b \to (d + s)\gamma$ modes provide a direct constraint on UT

$B^0 \to \rho^0/\omega\,\gamma$, $B^+ \to a_1^+\gamma$



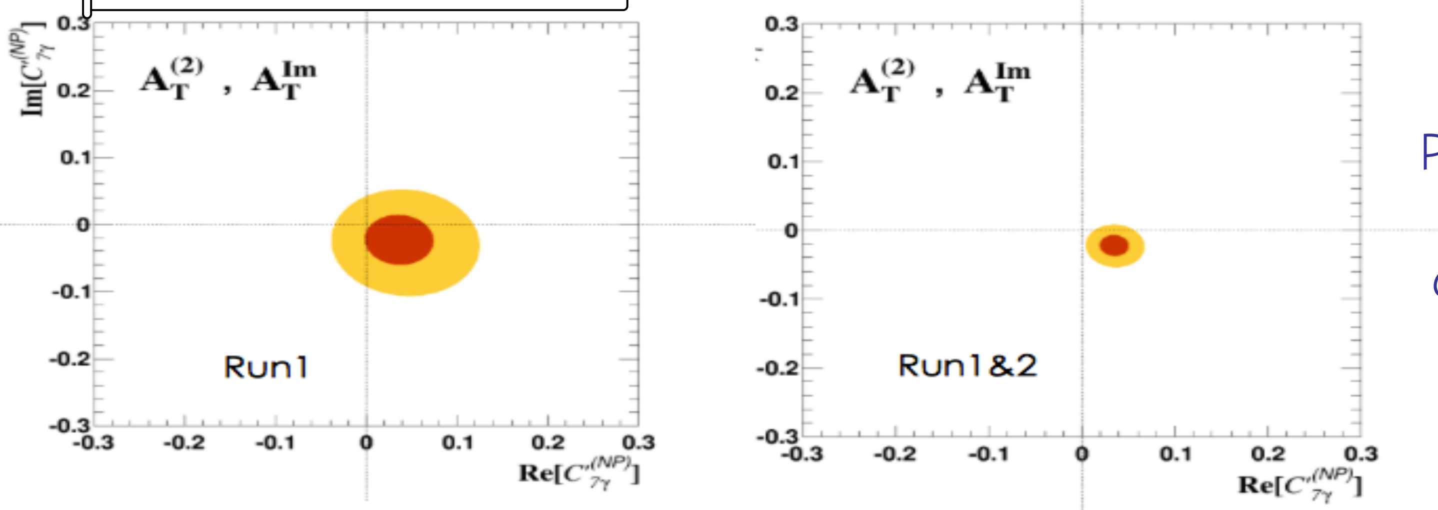
Separate $b \to d\gamma$ transition $B_s \to K^*\gamma$ from $b \to s\gamma$ in B^0 using converted photons

Prospective

- Photon polarisation : reach < 10 % resolution
  - Statistics (& systematics) improvement for existing measurements
  - Enhanced sensitivity with tagged analysis of the $B_s \to \phi\gamma$ TD decay rate
  - Amplitude analysis in $B^+ \to (K\pi\pi)^+_{res}\gamma$ decay
  - Explore new modes, e.g. S_{CP} $B^0 \to (K_S\pi\pi)\gamma$

$$\text{scenario } II\text{: } C_{7\gamma}^{(NP)} = 0,\ C_{7\gamma}^{\prime(NP)} \in \mathbb{C}$$

M. Borsato, thèse de doctorat, LAL, 2015



Prospective from $B^0 \to K^*ee$ angular analysis

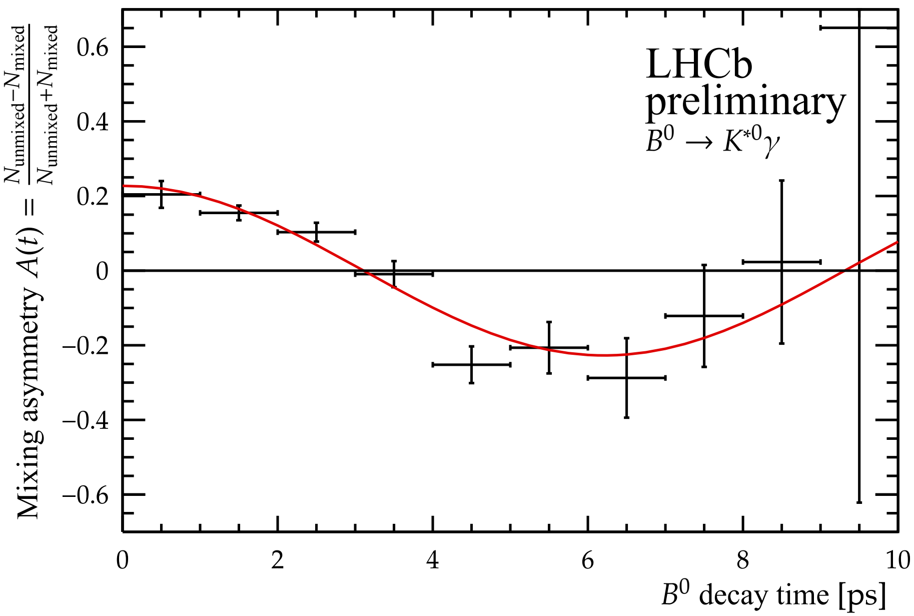
Prospective

- Photon polarisation (cont')

Enhanced sensitivity in neutral B decays from tagged analysis giving access to time-dependent asymmetry S_{CP}

For illustration :

LHCb tagging performance applied for the first time on a radiative decay



Prospective

Because of trigger constraints and the hadronic environment, some radiative channels are out of reach for LHCb

- What LHCb can do (or has already done) :
  - $(h^+h^-)\gamma$ channels from $b \to s\gamma$ transition of neutral b-hadrons : B^0, B_s, Λ_b
  - $(h^+h^-h^+)\gamma$ channel from charged b-hadrons
  - Same using converted photons $\gamma \to ee$
  - Same for suppressed $b \to d\gamma$ transitions when accumulating statistics

- What LHCb could probably do :
  - $(h^+h^-\pi^0)\gamma$, $(h^+h^-K_s)\gamma$: e.g $B^0 \to K_S\rho^0\gamma$, $B^0 \to \omega\gamma$, $B_s \to \phi(\to \pi\pi\pi^0)\gamma$
  - $B^+ \to K^{*+}(K_s\pi^+)\gamma$: e.g isospin asymmetry in $K^*\gamma$
  - $\Lambda_b \to \Lambda_{1115}\gamma$: challenging

- What LHCb can't do
  - $B^+ \to K^{*+}(K^+\pi^0)\gamma$ and a fortiori $B^+ \to \rho^+(\pi^+\pi^0)\gamma$
  - $B^0 \to K^{*0}(K_s\pi^0)\gamma$
  - inclusive $b \to X_s\gamma$ BR

Conclusions

LHCb provides an unique laboratory for precise measurements in many radiative decays

- world-largest radiative samples in several final-states
- access to photon polarisation in many ways

Great harvest of result with 2011-2012 Run 1

... so far consistent with SM expectation

Many updated or new results with run2 data