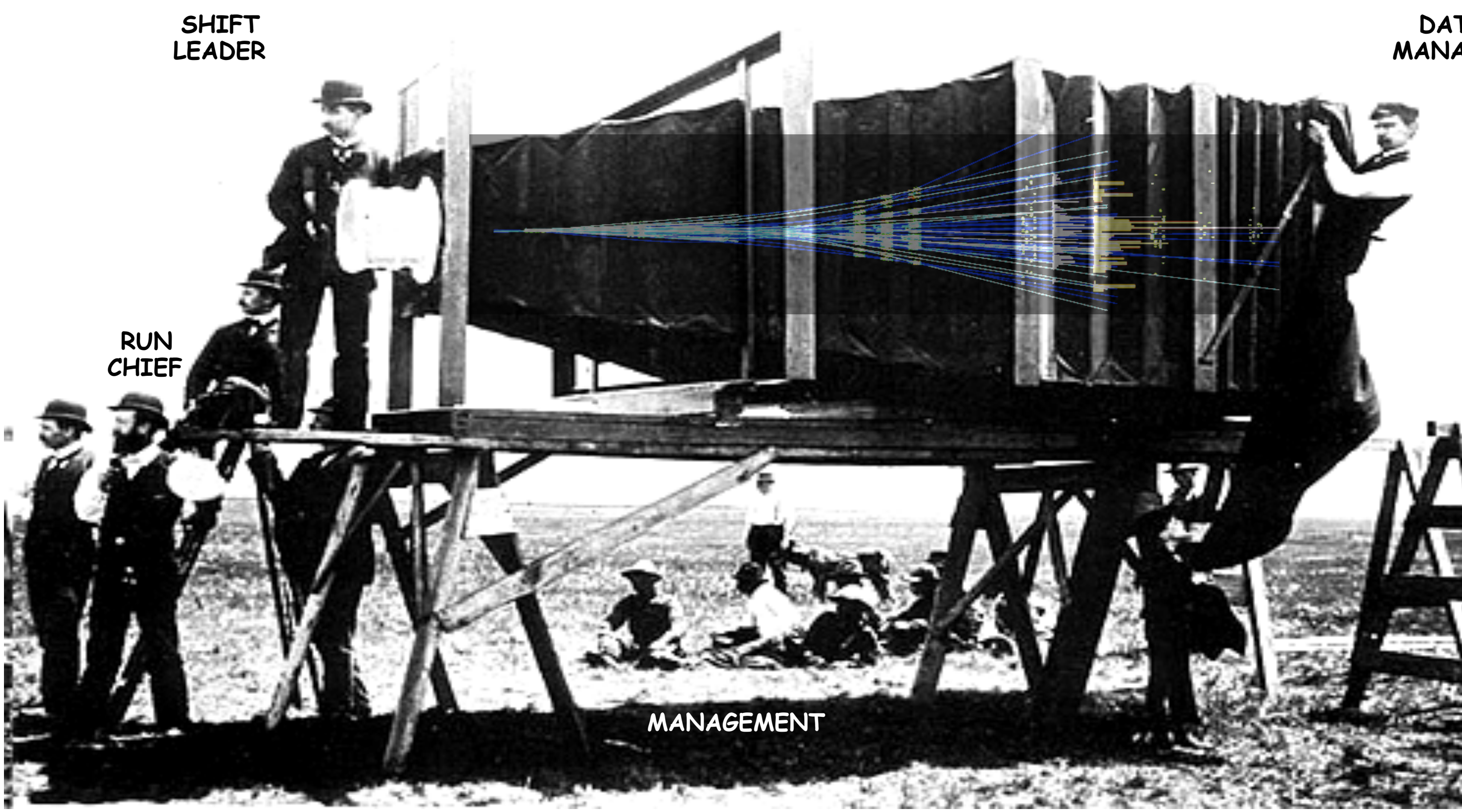
LHC France 2013
Rencontres françaises sur la physique des hautes énergies au LHC

Radiative B decays at LHCb
Status & prospective

2-6 Avril 2013, Annecy



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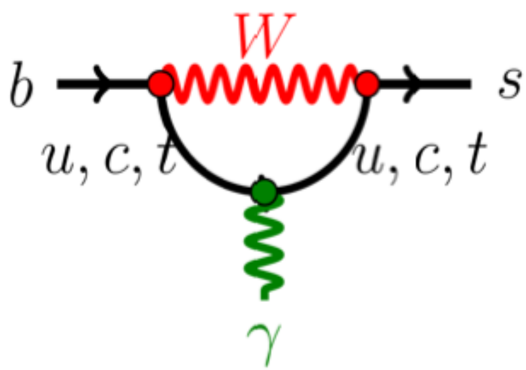
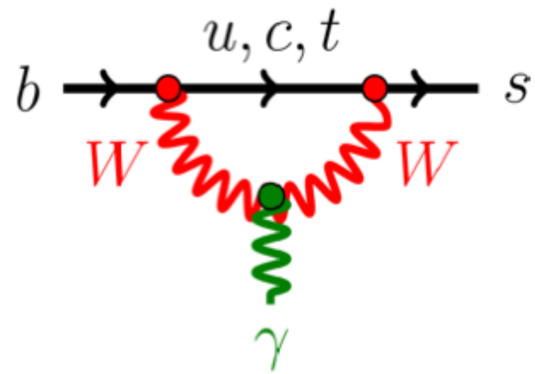
b→qγ transitions

- Radiative b→qγ (q=d,s) transition : FCNC electro-magnetic penguin



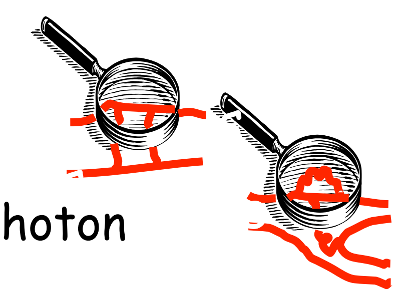


Leading (em dipole) operator in effective Hamiltonian :

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

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

New physics affect the transition dynamics



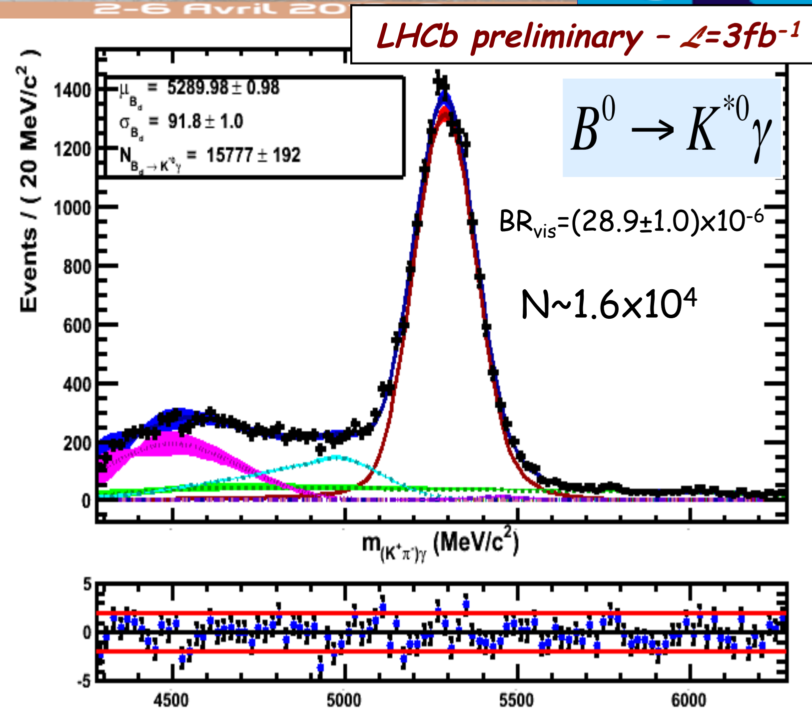
BR, A_{CP}, Isospin asymmetry, helicity structure of the photon

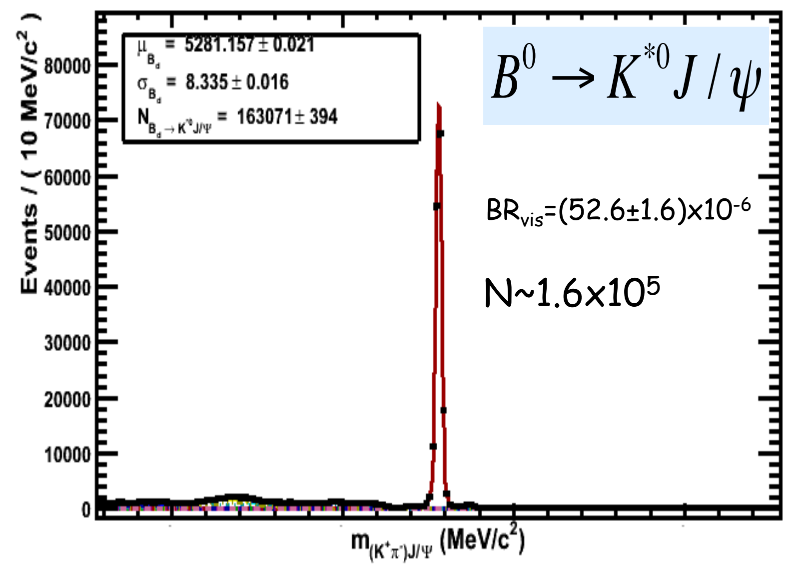
Radiative decays at LHCb

Experimental issues with radiative @ LHCb

- Due to trigger rate constraint versus large photon-induced combinatorial, the radiative decays in LHCb mostly rely on high pT photons :
  - L0 threshold in 2011(2012) : $E_T(\gamma)$ > 2.5-3.0 GeV
  - Typical L0+HLT efficiency on rad. ~ 30-40%
  - For comparaison : (di)muon channel ε_{trg}~80-90%
- Mass resolution driven by calorimeter resolution :
  - $\sigma_M(B\to X\gamma)$ ~ 90 MeV/c²
  - For comparaison :
    - $\sigma_M(B\to hh)$ ~ 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

→ Tight selections have to be applied





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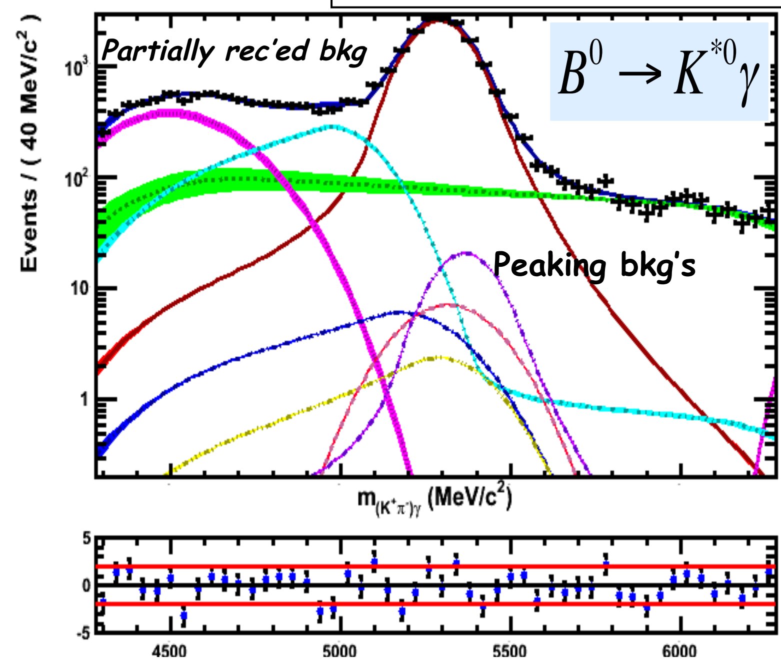
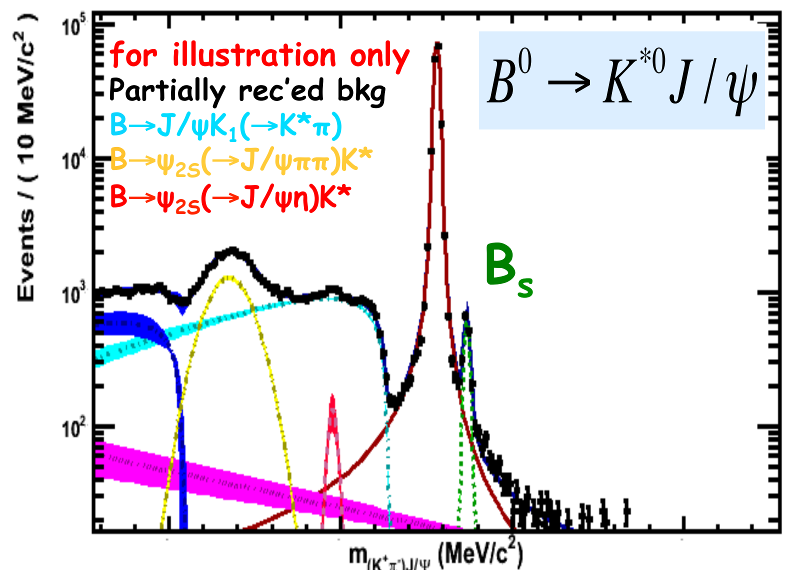
LHCb preliminary – $\mathcal{L}$=3fb⁻¹





Radiative decays : published analysis

$B_{(s)} \rightarrow V\gamma$ relative branching ratio

LHCb – $\mathcal{L}$=1fb^{-1} –

$B_s \rightarrow \phi(K^+K^-)\gamma$ / $B^0 \rightarrow K^{*0}(K^+\pi^-)\gamma$

- Branching fractions :

[HFAG, 2012]

$BR(B^0 \rightarrow K^{*0}\gamma) = (4.33 \pm 0.15) \times 10^{-5}$
$BR(B_s \rightarrow \phi\gamma) = (5.7^{+2.1}_{-1.8}) \times 10^{-5}$

- SM-predictions have large hadronic uncertainty mostly canceling in the ratio :

[Ali, Pecjak, Greub, 2008]

$R = BR(K^{*0}\gamma)/BR(\phi\gamma) = 1.0 \pm 0.2$

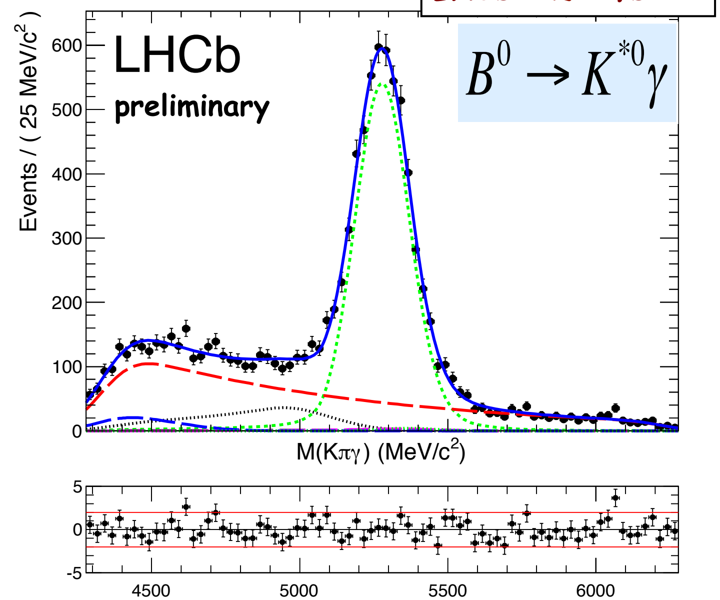
- LHCb result (1.0 fb^{-1} - 2011 data only)

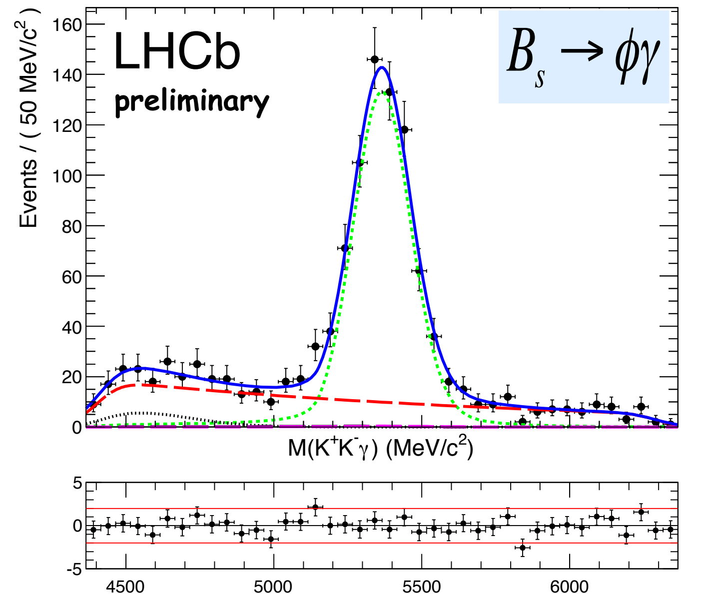
[Nuclear Physics B, 867, 1-18 (2013)]

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

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

Preliminary results on 0.37 fb^{-1} published in Phys. Rev. D 85, 112013 (2012)





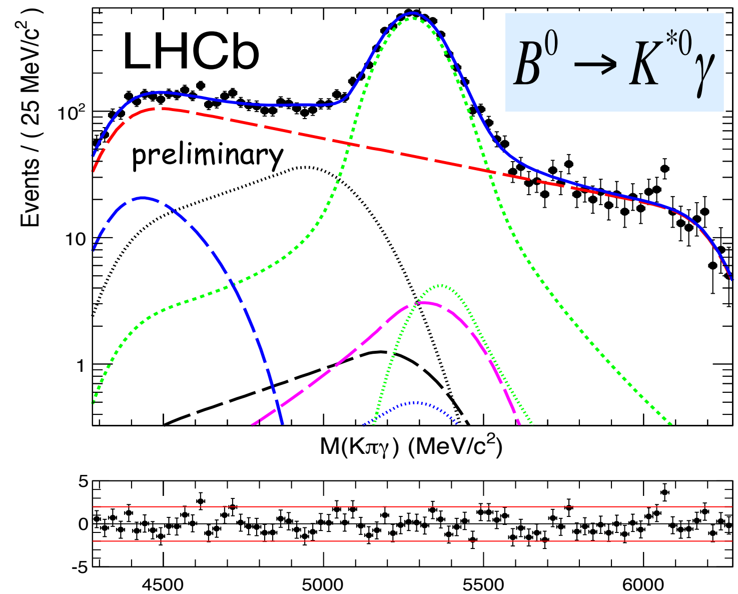
$B \to V\gamma$ branching fractions: backgrounds

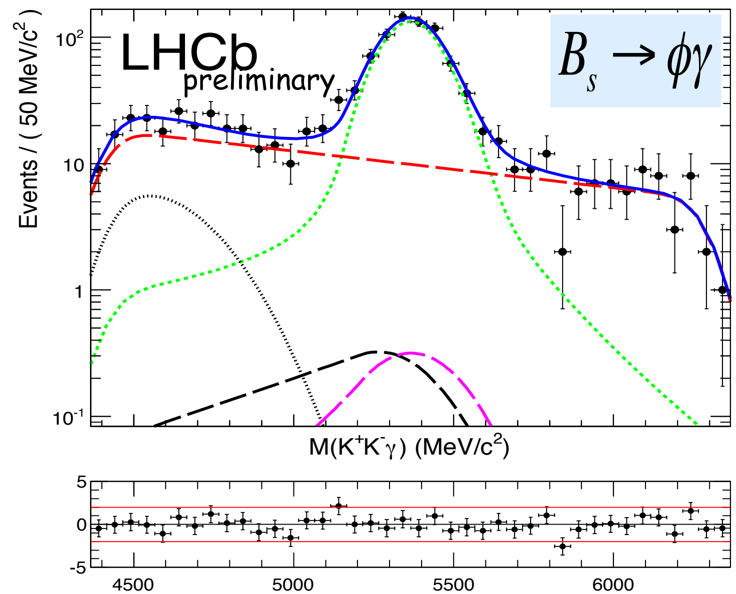
- Generic background contamination :
  - Combinatorial background
  - Partially reconstructed $b \to s\gamma$ decays
  - Partially reconstructed $b \to c$ $(X+hh\pi^0)$

- Specific peaking backgrounds :
  - b-baryons $\Lambda_b \to \Lambda^*(K^- p)\gamma$
  - Charmless $B_{d,s} \to h^+h^-\pi^0$
  - Irreducible $b \to d\gamma$: $B_s \to K^{*0}\gamma$

- No trivial side-bands shape
  - Threshold effect due to different mass resolution in trigger and offline analysis

	Branching fraction $(\times 10^6)$	Relative contamination to $B^0 \to K^{*0}\gamma$	Relative contamination to $B_s^0 \to \phi\gamma$
$\Lambda_b^0 \to \Lambda^*\gamma$	unknown	$(1.0 \pm 0.3)\%$	$(0.4 \pm 0.3)\%$
$B_s^0 \to K^{*0}\gamma$	1.26 ± 0.31 (theo. [20])	$(0.8 \pm 0.2)\%$	$\mathcal{O}(10^{-4})$
$B^0 \to K^+\pi^-\pi^0$	$35.9^{+2.8}_{-2.4}$ (exp. [4])	$(0.5 \pm 0.1)\%$	$\mathcal{O}(10^{-4})$
$B_s^0 \to K^+\pi^-\pi^0$	unknown	$(0.2 \pm 0.2)\%$	$\mathcal{O}(10^{-4})$
$B_s^0 \to K^+K^-\pi^0$	unknown	$\mathcal{O}(10^{-4})$	$(0.5 \pm 0.5)\%$
$B^+ \to K^{*0}\pi^+\gamma$	20^{+7}_{-6} (exp. [4])	$(3.3 \pm 1.1)\%$	$< 6 \times 10^{-4}$
$B^0 \to K^+\pi^-\pi^0\gamma$	41 ± 4 (exp. [4])	$(4.5 \pm 1.7)\%$	$\mathcal{O}(10^{-4})$
$B^+ \to \phi K^+\gamma$	3.5 ± 0.6 (exp. [4])	3×10^{-4}	$(1.8 \pm 0.3)\%$
$B \to K^{*0}(\phi)\pi^0 X$	$\mathcal{O}(10\%)$ [4]	few%	few%





$B \to V\gamma$ branching fractions: systematics

[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

	systematical uncertainty
$r_{acc.}$	0.4%
$r_{reco\&sel.}$	1.2%
r_{PID}	1.2%
$r_{trigger}$	0.8%
Subtotal $\frac{\epsilon_{B^0_s \to \phi\gamma}}{\epsilon_{B^0 \to K^{*0}\gamma}}$	2.0%
$\frac{\mathcal{B}(\phi \to K^+K^-)}{\mathcal{B}(K^{*0} \to K^+\pi^-)}$	1.0%
Background modelling	$^{+2.0}_{-1.8}\%$
Total	3%

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

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

SM-prediction :

[Phys. Rev. D72 (2005) 014013]

A_{CP} = -0.0061 ± 0.0043

A_{CP} enhanced in NP scenarii

Previous best measurement :

[BABAR, Phys. Rev. Lett. 84, 5283-5287]

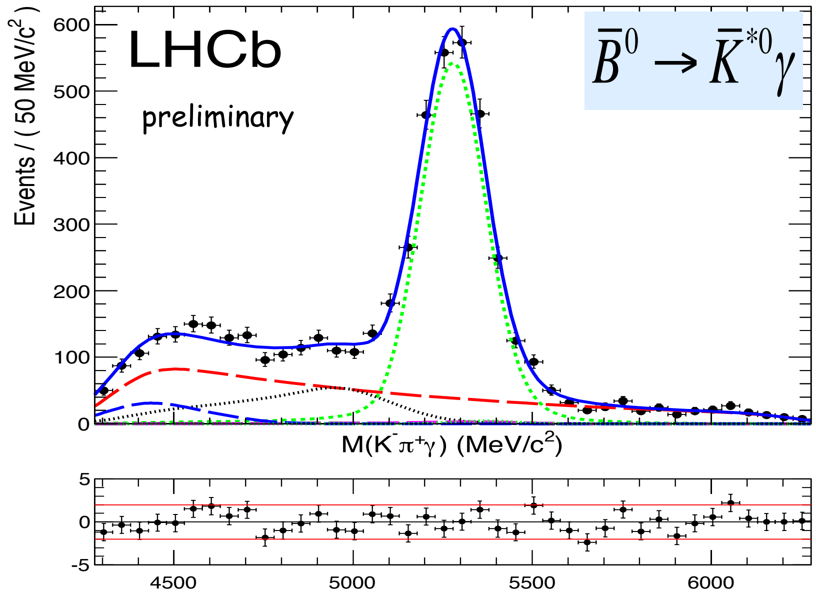
A_{CP} = -0.016 ± 0.022 ± 0.007

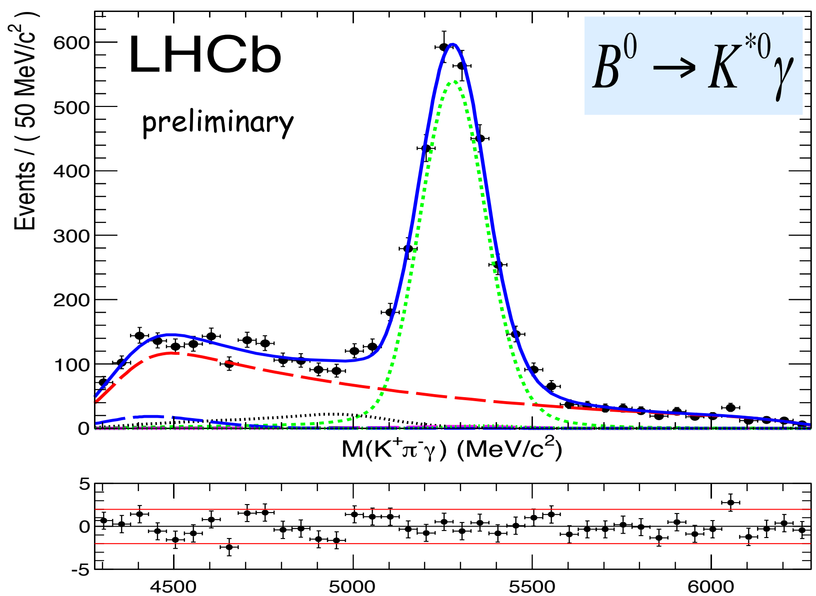
- LHCb result (1.0 fb^{-1}) :

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

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

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





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

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

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

  Contamination level, shape & CP asymmetry in various background components

- Detector non-uniformity

  Possible detector bias strongly reduced by switching regularly the magnet polarity

		correction (%)	uncertainty (%)
Detection	: $-\mathcal{A}_{\mathrm{D}}(K\pi)$	$+1.0$	± 0.2
B^0 production	: $-\kappa\mathcal{A}_{\mathrm{P}}(B^0)$	-0.4	± 0.5
Background model	: $\Delta\mathcal{A}_{bkg}$	-0.2	± 0.7
Magnet polarity	: $\Delta\mathcal{A}_{\mathcal{M}}$	$+0.1$	± 0.2
Total		$+0.5$	± 0.9

Radiative decays : prospects

- published results based on $1fb^{-1}$ from 2011 data so far
  - $b \to s\gamma$ in neutral $B_{(s)} \to V\gamma$: $br(B_d \to K^{*0}\gamma)/br(B_s \to \phi\gamma)$ & $A_{CP}(B_d \to K^{*0}\gamma)$
  - $b \to s\gamma^*(e^+e^-)$ at low q^2 : $BR(B_d \to K^{*0}ee)_{30<Mee<1000}$
    - First step toward $\gamma^*(\to ee)$ polarisation study

- Results demonstrate the LHCb ability to perform 'calorimetric' physics
  - exciting prospects for new observations and CP violation studies in modes with photons (and neutral pions)

- LHCb collected additional $\sim 2fb^{-1}$ in 2012 : new radiative decays under prospects
  - $b \to s\gamma$ in charged modes : $B^+ \to (K^+h^-h^+)\gamma$
    - direct A_{CP} in $B^+ \to K^{*0}\pi^+\gamma$, $B^+ \to \phi K^+\gamma$
    - photon polarisation from $B^+ \to K_1^+\gamma$ analysis
  - $b \to s\gamma$ in baryons decays : $\Lambda_b \to \Lambda^*(\to pK)\gamma$
    - Branching Ratio measurement
  - suppressed $b \to d\gamma$: $B^0 \to \rho^0(\to \pi\pi)\gamma$, $B^+ \to a_1^+ (\to \pi^+\pi^-\pi^+)\gamma$
    - Branching Ratio measurement
    - A_{CP} in $B^+ \to (\pi^+\pi^-\pi^+)\gamma$
  - $B_s \to \phi(\to K^+K^-)\gamma$
    - Effective $B_s \to \phi\gamma$ lifetime
    - Photon polarization from time-dependent decay rate

Radiative decays : helicity structure

- Investigating the photon helicity structure in $B^0 \to f^{CP}\gamma$
  - 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

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

$$A_s^{\Delta} \approx \sin(2\psi)$$

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

- $B_s \to \Phi(K^+K^-)\gamma$ is a promising channel for the extraction of $\sin(2\Psi)$
- First step will be an untagged effective lifetime measurement

$$\Gamma_{B_s}(t) \propto |A|^2 e^{-\Gamma_s t}\left[\cosh(\Delta\Gamma_s t/2) - \mathcal{A}^{\Delta}\sinh(\Delta\Gamma_s t/2)\right] = |A|^2 e^{-\Gamma_{B_s \to \phi\gamma} t}$$

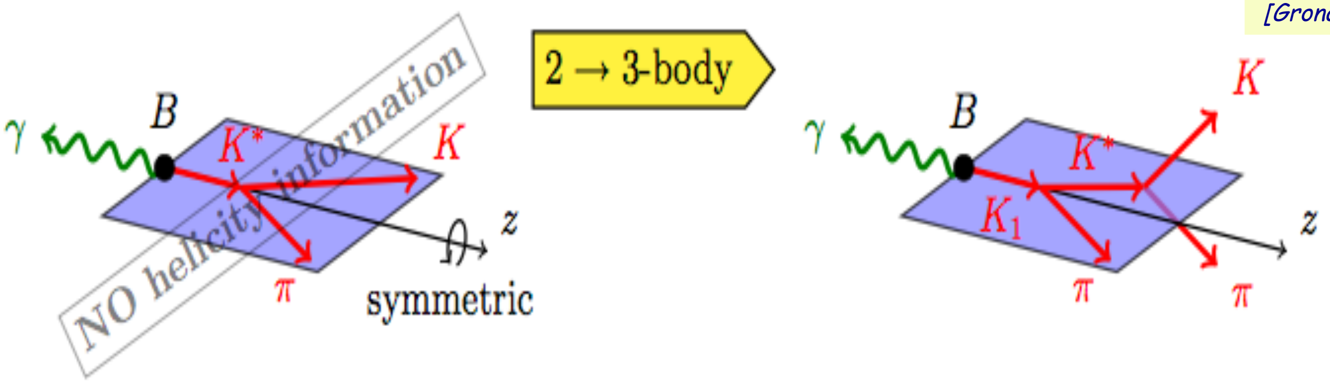
$$\tau_f = \frac{\int_0^{\infty} t\langle\Gamma(B_s(t) \to f)\rangle dt}{\int_0^{\infty}\langle\Gamma(B_s(t) \to f)\rangle dt} = \frac{\tau_{B_s}}{1-y_s^2}\left[\frac{1+2\mathcal{A}^{\Delta}y_s + y_s^2}{1+\mathcal{A}^{\Delta}y_s}\right]$$

Main issue is the extraction of the proper-time acceptance and bias

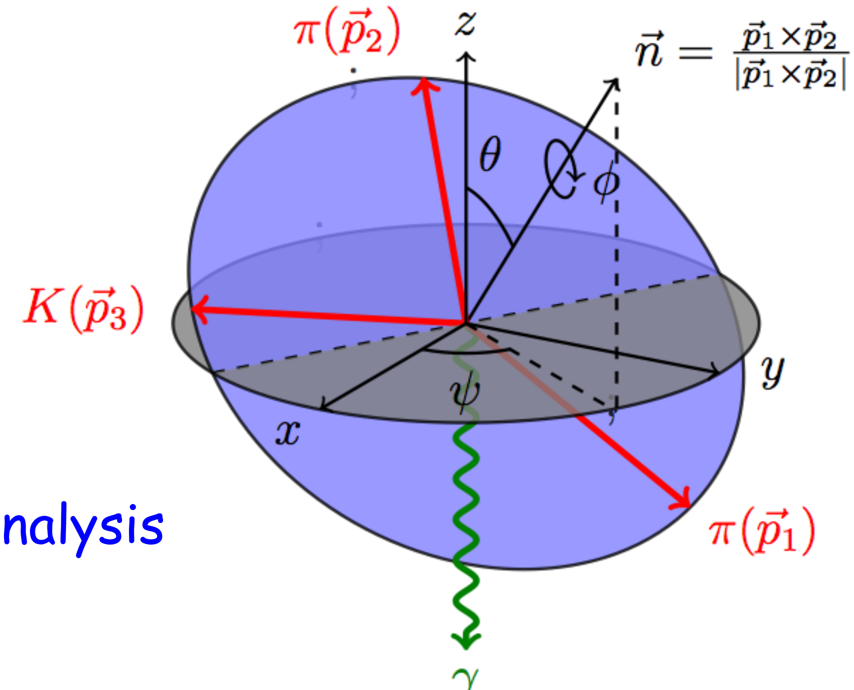
Radiative decays : helicity structure

- Investigating the photon helicity structure in $B^+ \to K^+_{res}(h_1h_2h_3)\gamma$ decay

[E. Kou hep-ex/1011.6593]
[Gronau et al., hep-ph/0107254 (2002)]



$$\frac{d\Gamma}{ds_{13}ds_{23}d\cos\Theta} = F(J_\mu(s_{13,}s_{23}),\lambda_\gamma,\cos\Theta)$$



- *Angular analysis*
- Helicity amplitudes J_μ from Dalitz analysis

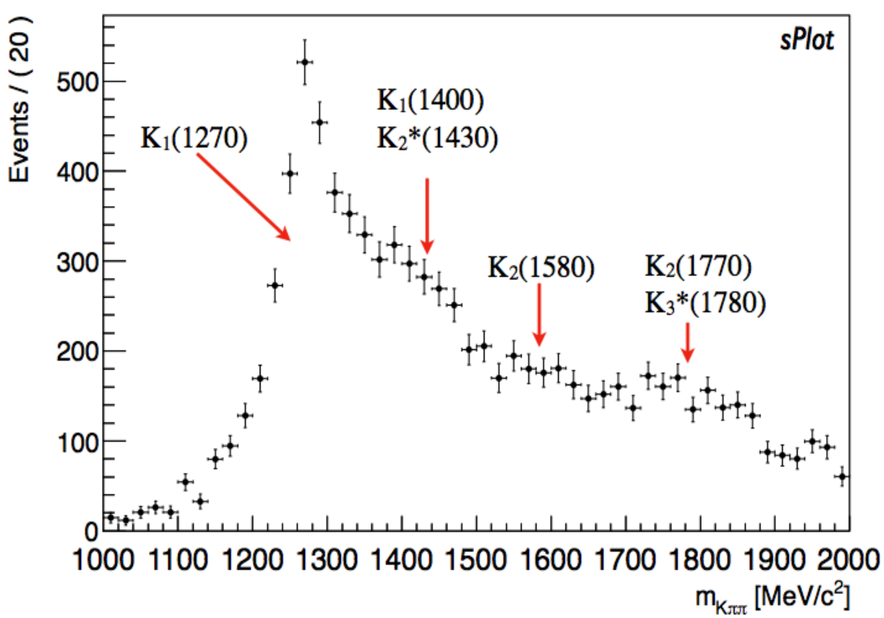
Radiative decays : helicity structure

- Investigating the photon helicity structure in $B^+ \to K^+_{res}(h_1h_2h_3)\gamma$ decay (con't)

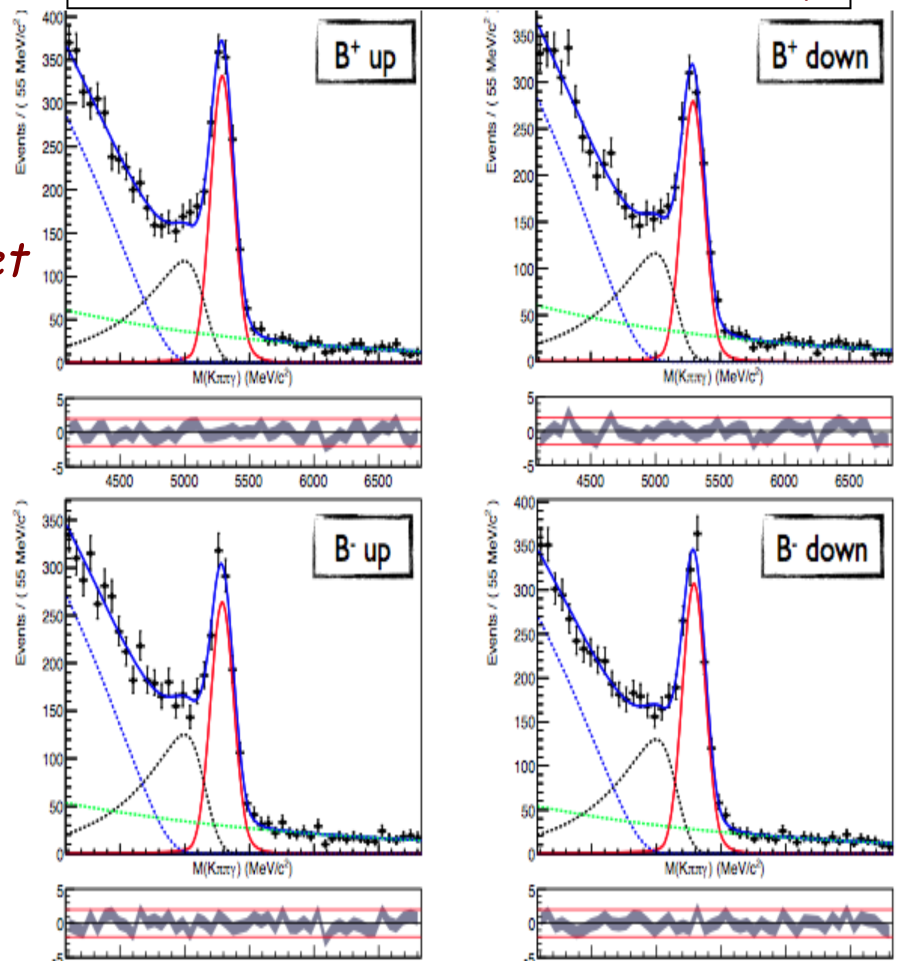
Up-down asymmetry :

$$\mathcal{A} = \frac{\int_0^{\pi/2} \frac{d\Gamma}{d\cos\tilde{\theta}} d\cos\tilde{\theta} - \int_{\pi/2}^{\pi} \frac{d\Gamma}{d\cos\tilde{\theta}} d\cos\tilde{\theta}}{\int_0^{\pi} \frac{d\Gamma}{d\cos\tilde{\theta}} d\cos\tilde{\theta}}$$

Main issue is to isolate single resonance
Integrated asymmetry difficult to interpret



LHCb unofficial– $\mathcal{L}$=2fb^{-1} – for illustration only



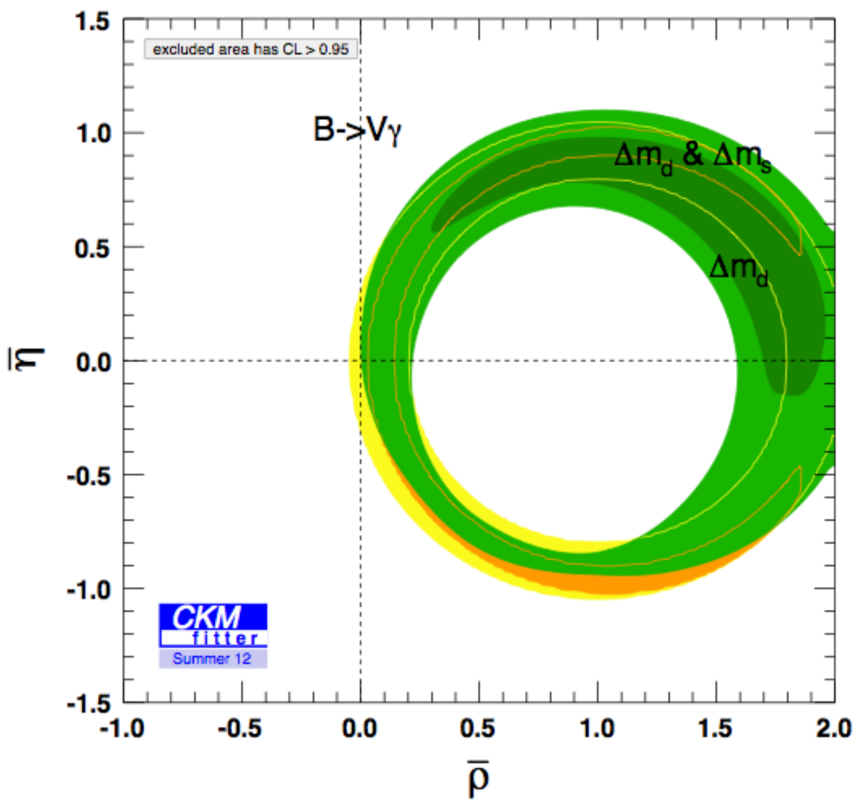
LHCb prospects : b→dγ

V_{td} suppressed penguin

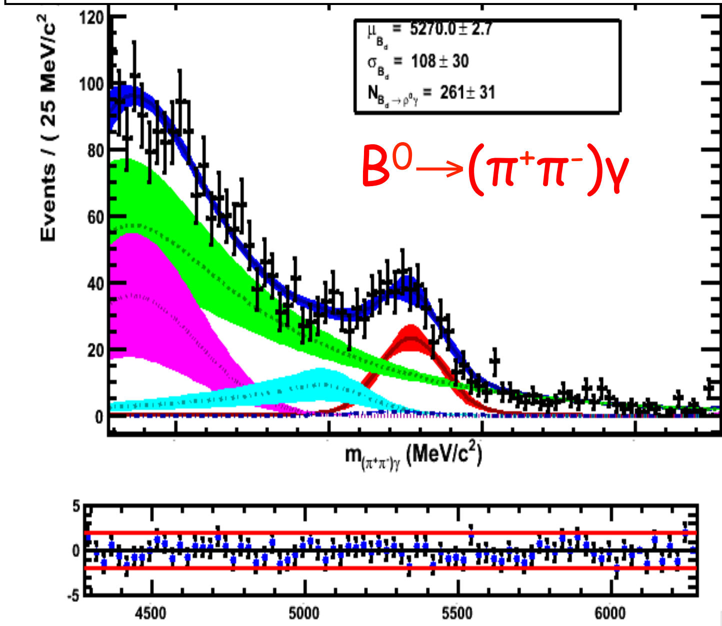
[HFAG, 2012]

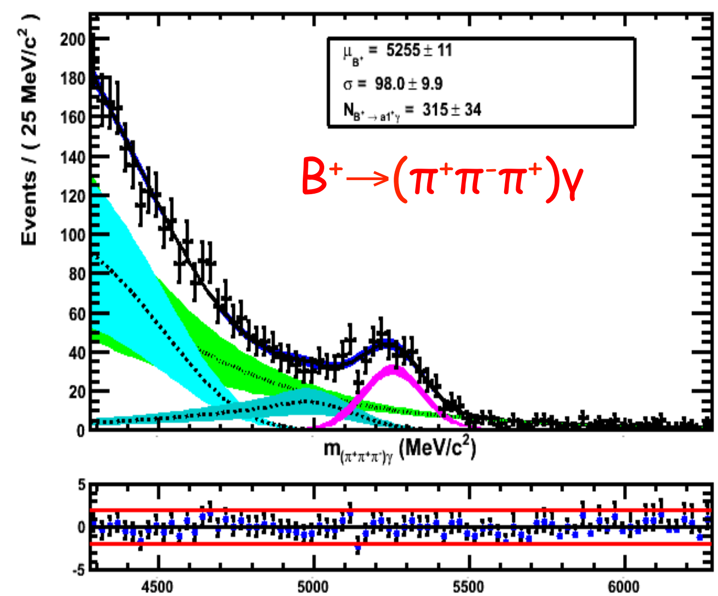
$$BR(B^0 \to \rho^0\gamma) = (8.6 \pm 1.5) \times 10^{-7}$$

Branching ratio & asymmetry of exclusive b→(d,s)γ modes provide a direct constraint on UT



LHCb unofficial – ℒ=3fb⁻¹ – for illustration only

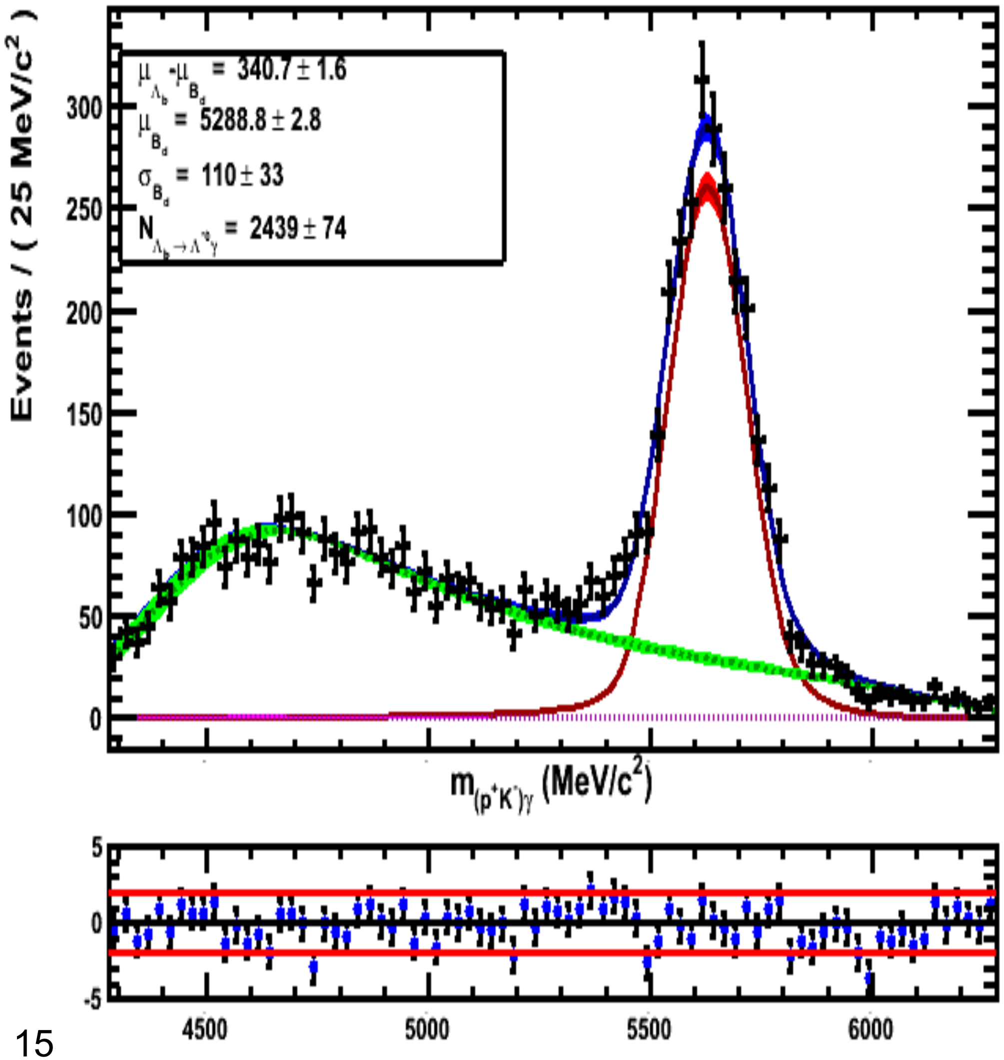


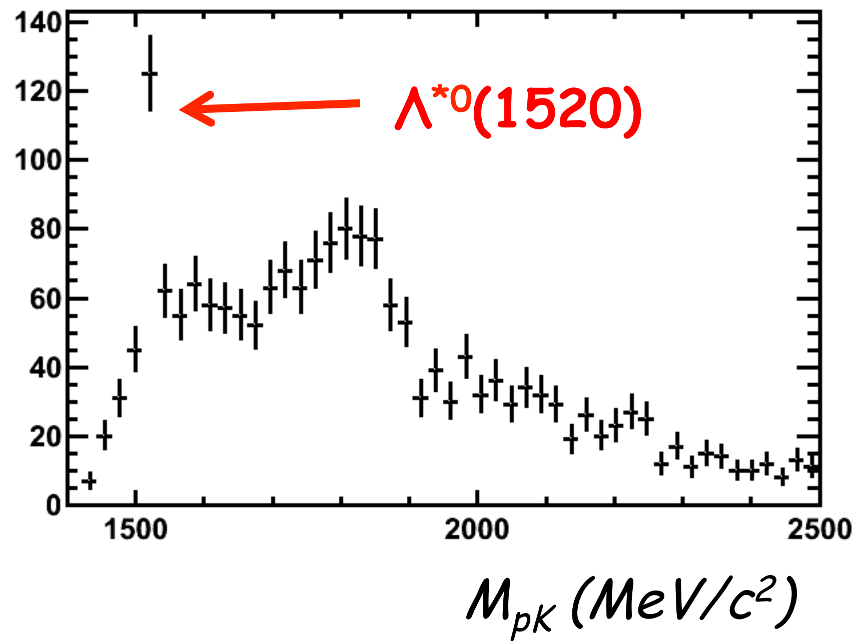


Baryonic decay : $\Lambda_b \to \gamma\Lambda^*(pK)$

First observation

LHCb unofficial– $\mathcal{L}$=3fb^{-1} – for illustration only





Summary

World best measurements in radiative Vγ decays …

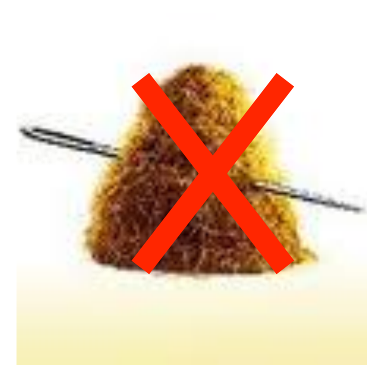
[Nuclear Physics B, 867, 1-18 (2013)]

$$\frac{B(B_d \to K^{*0}\gamma)}{B(B_s \to \Phi\gamma)} = 1.31 \pm 0.07(stat) \pm 0.04(syst) \pm 0.10(f_d / f_s)$$

$$B(B_s \to \Phi\gamma) = (3.3 \pm 0.3) \cdot 10^{-5}$$

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

… consistent with SM expectation



Other radiative B decays and photon polarization being investigated with 2012 data