Radiative B-decays at LHCb

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Outline

- Radiative decays, observables (asymmetries, polarization,…)
  - $b \to s\gamma$:
    - $B \to K^{*0}\gamma$, $B_s \to \phi\gamma$
    - $\Lambda_b \to \Lambda^0\gamma$, $\Lambda_b \to \Lambda(X)\gamma$
  - $b \to d\gamma$
- Event selection at LHCb
  - Annual Event yields
  - Background estimates
- Summary

Radiative penguin decays

- Loop-induced decays are the perfect place to search for New Physics hints
- In SM model loops are suppressed
  - GIM cancellation
  - “rare decays”
- Heavy particles are suppressed in trees
  - could appear in the loops
- New particles in loops:
  - Enhancements in decay rates: even the minor absolute enhancement could result in large relative enhancement
  - New phases
  - New asymmetries
  - … ?
- Ideal laboratory for New Physics search
  - But also some QCD tests

Radiative penguin decays

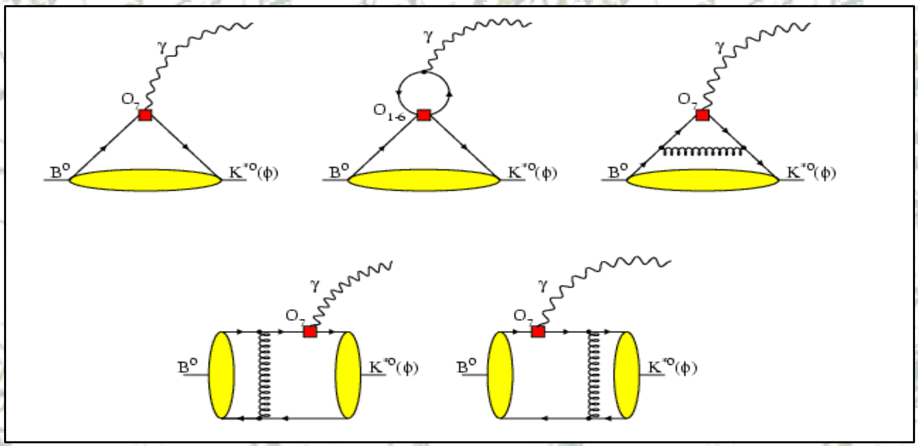
- No so rare decays
  - PDG

    $\mathrm{Br}(B\to K^{*0}\gamma) = (4.3\pm0.4)\mathrm{x}10^{-5}$

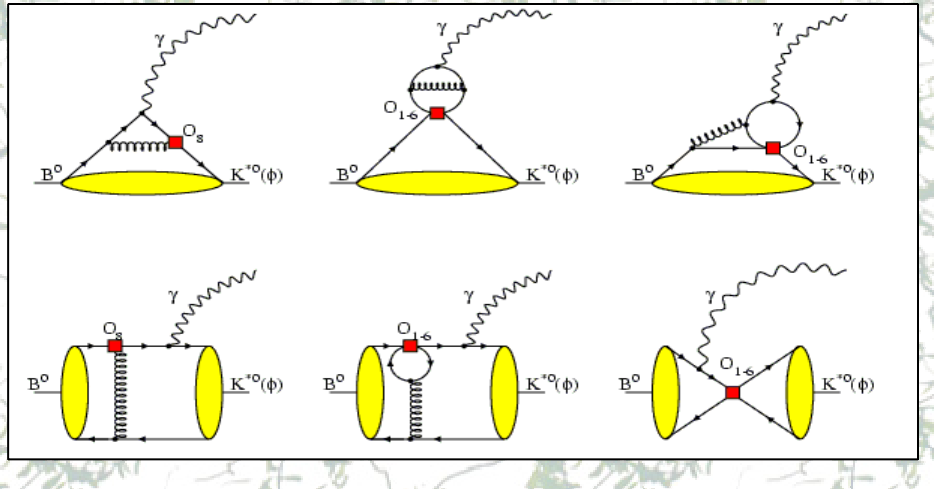
    $\mathrm{Br}(B^{-}\to K^{*-}\gamma) = (3.8\pm0.5)\mathrm{x}10^{-5}$
- 1-amplitude dominance
- strong phase appears at order of α_s or $1/m_b$

  →"Direct" asymmetries are small (0.6%) for $b\to s\gamma$ &
  a bit larger(-16%) for $b\to d\gamma$

$$\mathcal{A}^{\mathrm{dir}}_{B^0\to K^{*0}\gamma} = \frac{\Gamma_{B^0\to K^{*0}\gamma} - \Gamma_{\bar{B}^0\to \bar{K}^{*0}\gamma}}{\Gamma_{B^0\to K^{*0}\gamma} + \Gamma_{\bar{B}^0\to \bar{K}^{*0}\gamma}}$$



Suppressed by : α_s , $1/m_b$ or $|V_{CKM}|$

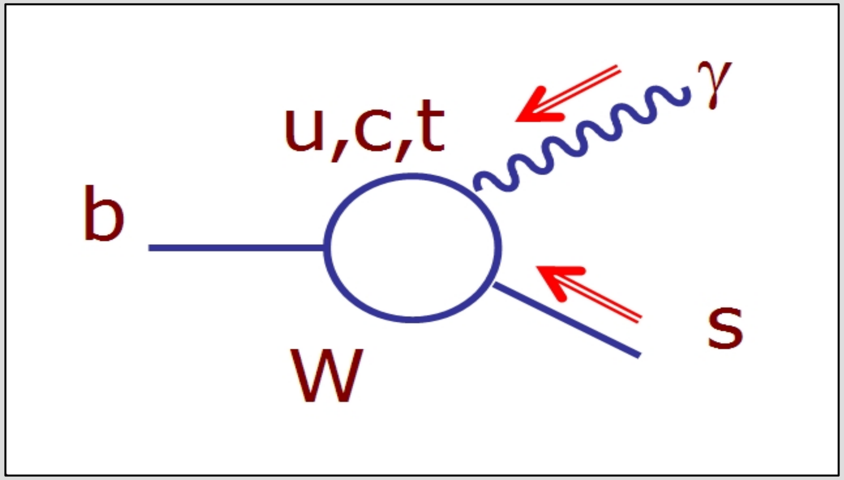


$b\to s(d)\gamma$: *CP*-asymmetries

- $B_s \to \phi\gamma$:
  - not *CP*-eigenstate!
  - V-A: γ is left-handed
    - "Wrong polarization": $\sim m_s(m_d)/m_b$
- Both A^{mix} and A^{dir} are small
  - Mix: product of small ϕ_s and small fraction of γ_R
  - Better sensitivity for relatively small Δms
    - space resolution for $\phi\to K^+K^-$ vertex ↔ B_s proper time resolution

$$\mathcal{A}_{B^0_{(s)}\to f_{\mathcal{CP}\gamma}}(t) = \frac{\Gamma_{B^0_{(s)}\to f_{\mathcal{CP}\gamma}}(t) - \Gamma_{\bar{B}^0_{(s)}\to f_{\mathcal{CP}\gamma}}(t)}{\Gamma_{B^0_{(s)}\to f_{\mathcal{CP}\gamma}}(t) + \Gamma_{\bar{B}^0_{(s)}\to f_{\mathcal{CP}\gamma}}(t)} \approx \boxed{\mathcal{A}^{dir}_{B^0_{(s)}\to f_{\mathcal{CP}\gamma}}} \cos\Delta m_{(s)}t + \boxed{\mathcal{A}^{mix}_{B^0_{(s)}\to f_{\mathcal{CP}\gamma}}} \sin\Delta m_{(s)}t$$

Photon Polarisation



- Naive:
- Left-handed photon (to conserve the angular momentum)
  - right handed components of the order of m_s/m_b

- true only for 2 body decays
- cannot be applied to $b \to s\gamma$ + gluons
  - other operators could contribute
  - explicit calculations for $B \to K^*\gamma$, $B \to \rho\gamma$
  - right handed components may be up to 10÷15%

Grinstein, Grossman, Ligeti, Pirjol, PRD 71, 011504 (2005)

How to measure γ-polarization?

"Photon-side"

- measure the polarization
  - virtual photon ($b \to s l^+ l^-$)

Melikov, Nikitin, Simula, PLB 442, 381 (1998)

  - real photon
    - conversion $\gamma \to e^+ e^-$

Grossman, Pirjol, JHEP06, 029 (2000)

Hadron side

- Exploit K^{**} ($K\pi\pi$) system

Gronau, Pirjol, PRD 66, 054008 (2002)

Gronau, Grossman, Pirjol, PRL 88, 051802 (2002)

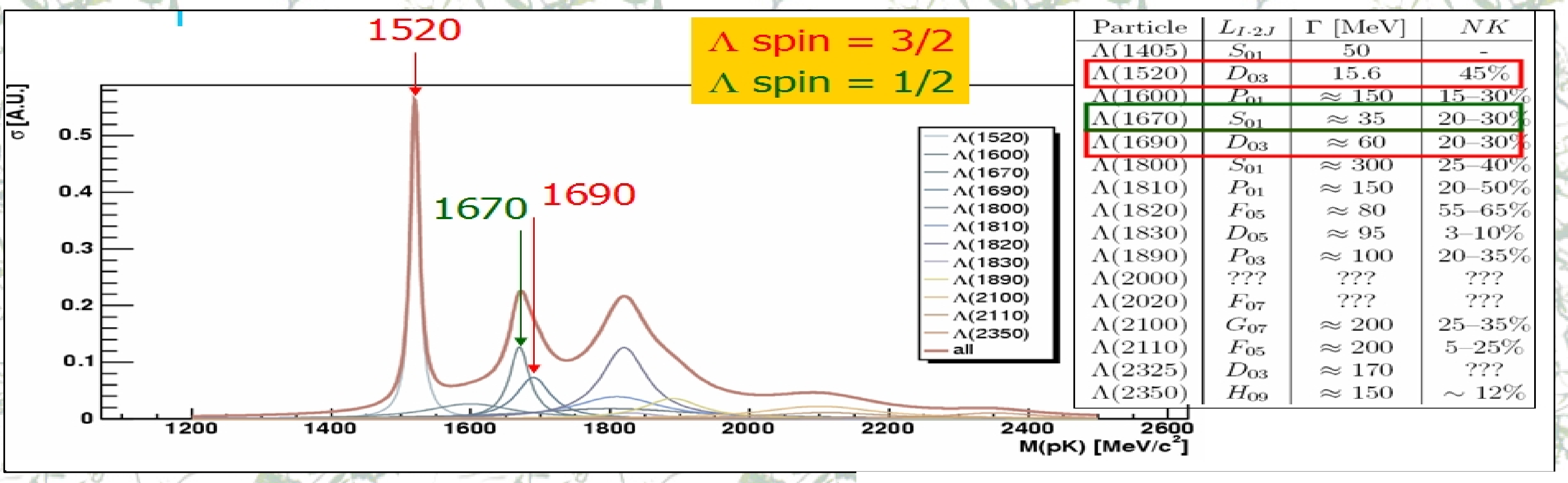
- Polarized b-baryon decays
  - exploit the angular correlations between initial and final state
  - Good to try at LHCb!

Mannel, Recksiegel, JPG: NPP 24, 979 (1998)

Hiller, Kagan, PRD 65, 074038 (2002)

$\Lambda_b \to \Lambda^0 \gamma$ $\Lambda_b \to \Lambda(X)\gamma$

- one can apply to higher resonances $\Lambda(X) \to pK$
  - spin 5/2 is useless (lack of observable BR ~ $10^{-5} \div 10^{-6}$
  - spin ½ need to be dseparated from 3/2
    - The measurement both photon and proton distributions are requred



Particle	$L_{I \cdot 2J}$	Γ [MeV]	NK
Λ(1405)	S_{01}	50	-
Λ(1520)	D_{03}	15.6	45%
Λ(1600)	P_{01}	≈ 150	15–30%
Λ(1670)	S_{01}	≈ 35	20–30%
Λ(1690)	D_{03}	≈ 60	20–30%
Λ(1800)	S_{01}	≈ 300	25–40%
Λ(1810)	P_{01}	≈ 150	20–50%
Λ(1820)	F_{05}	≈ 80	55–65%
Λ(1830)	D_{05}	≈ 95	3–10%
Λ(1890)	P_{03}	≈ 100	20–35%
Λ(2000)	???	???	???
Λ(2020)	F_{07}	???	???
Λ(2100)	G_{07}	≈ 200	25–35%
Λ(2110)	F_{05}	≈ 200	5–25%
Λ(2325)	D_{03}	≈ 170	???
Λ(2350)	H_{09}	≈ 150	~ 12%

Based on Hiller, Kagan, PRD 65, 074038 (2002)

γ polarization

- $\Lambda_b \rightarrow \Lambda^0 \gamma$

$$\frac{d\Gamma}{d\cos\theta_\gamma} \propto 1 - \alpha_\gamma P_B \cos\theta_\gamma$$

$$\frac{d\Gamma}{d\cos\theta_p} \propto 1 - \alpha_\gamma \alpha_p \cos\theta_p$$

Hiller, Kagan, PRD 65, 074038 (2002)

- $\Lambda_b \rightarrow \Lambda(½)\, \gamma$
  - Distribution for γ is the same
  - Distribution for proton is flat

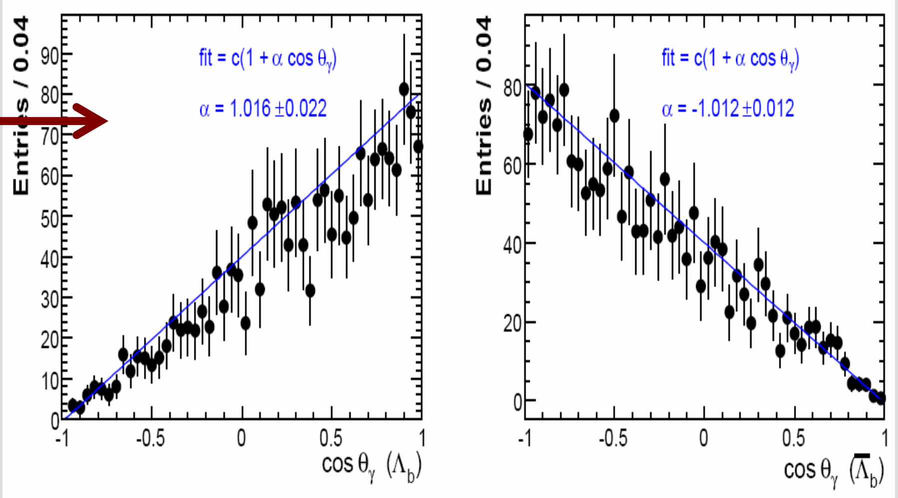
- $\Lambda_b \rightarrow \Lambda(3/2)\, \gamma$

$$\frac{d\Gamma}{d\cos\theta_\gamma} \propto 1 - \alpha_{\gamma,3/2} P_B \cos\theta_\gamma$$

$$\alpha_{\gamma,3/2} = \frac{1-\eta}{1+\eta}\,\alpha_{\gamma,}$$

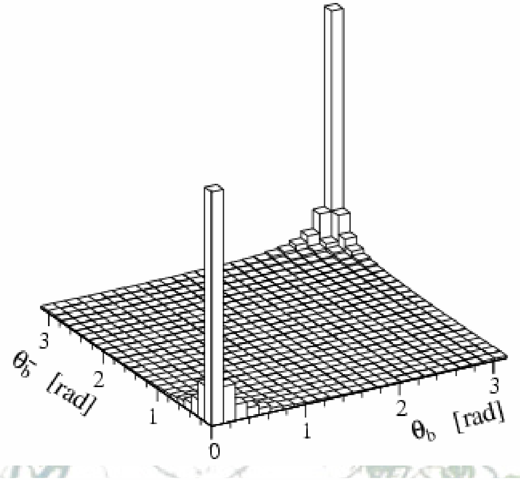
$$\frac{d\Gamma}{d\cos\theta_p} \propto 1 - \alpha_{p,3/2} \cos^2\theta_p$$

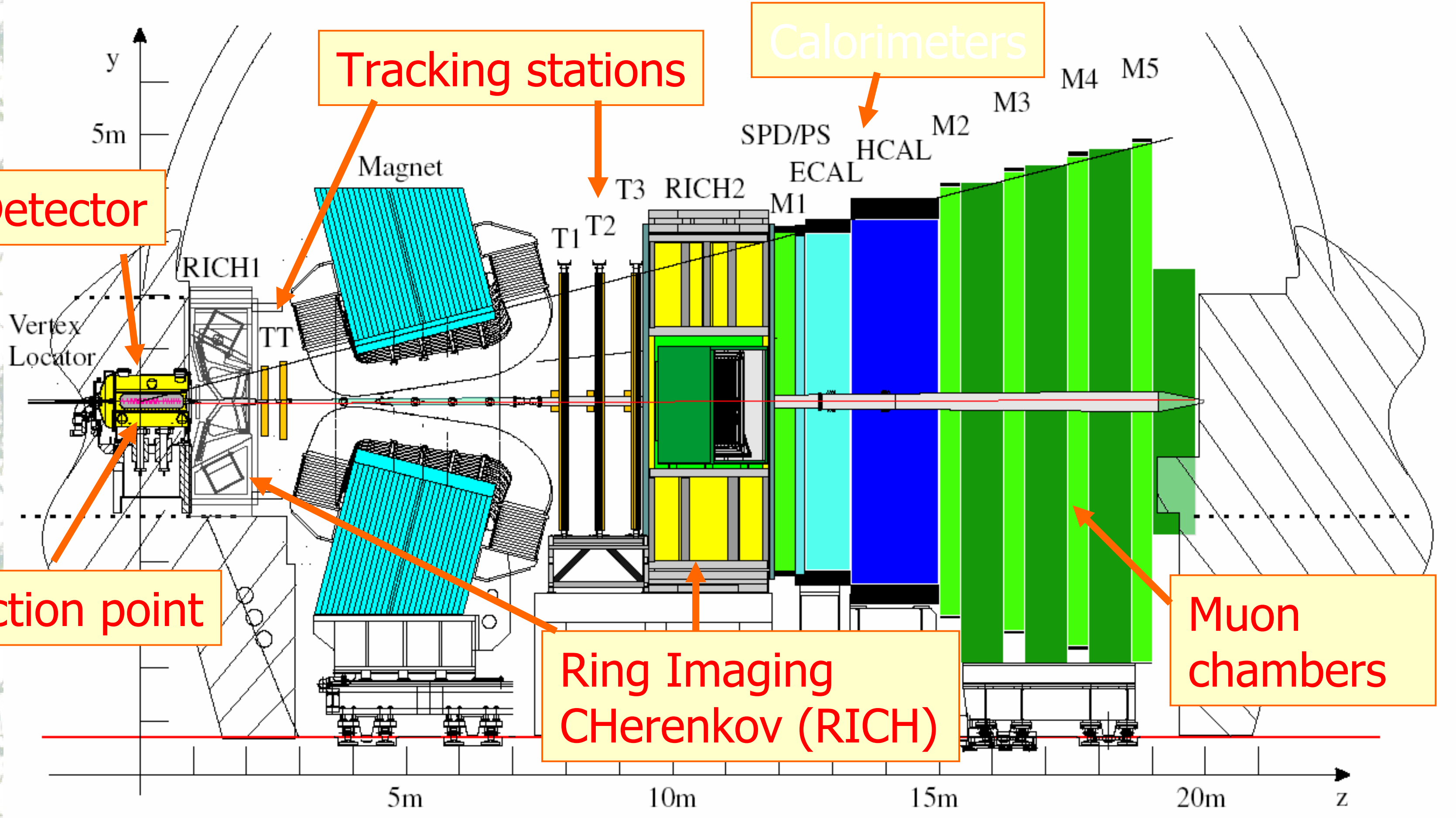
$$\alpha_{p,3/2} = \frac{\eta - 1}{\eta + \frac{1}{3}}$$



The LHCb experiment

- Single arm spectrometer
- b physics and rare decays
- $L = 2{\cdot}10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$





Tracking stations

Calorimeters

Vertex Detector

Interaction point

Ring Imaging CHerenkov (RICH)

Muon chambers

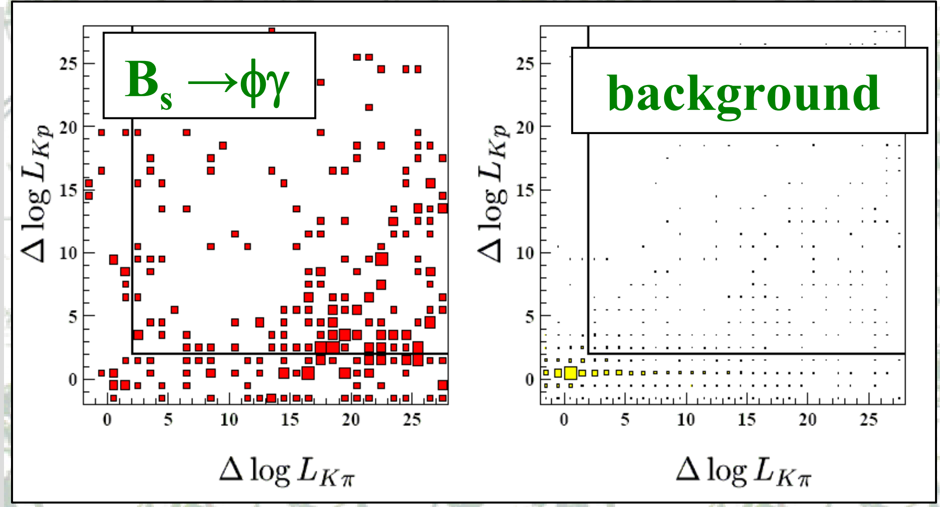
Analysis & Background suppression

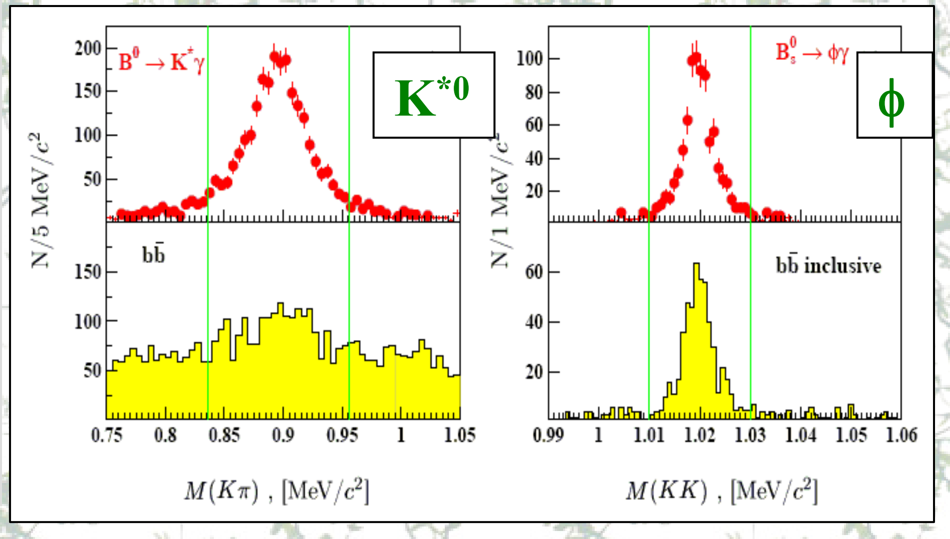
- Beauty particles:
  - $m_b \sim 5\ \mathrm{GeV}/c^2$
  - $\beta\gamma c\tau \sim O(1\mathrm{cm})$
- Particles from B-decays:
  - Large p_T
    - L0 (hardware) trigger:
      - leptons ($e^\pm, \mu^\pm, \mu\mu$),
      - photons
      - hadrons
  - Large impact parameters
    - (software) trigger
- Background:
  - $b\bar{b}$-production with at least one B within 400mrad cone

- High Level Trigger and Off-line background suppression continues to utilize these properties
- B-decay products do not point to reconstructed primary vertices
- Exclusively reconstructed B-candidate does point to primary vertex
- B-candidate is associated with primary vertex with minimal impact parameter (significance)

Selection of $B_d \to K^{*0}\gamma$ and $B_s \to \phi\gamma$

- Realistic simulation and recontruction!
- $\pi^\pm, K^\pm$:
  - charged tracks consistent with PID
  - Inconsistent with any PV
    - $\chi^2_{IP} > 16(4)$
- Two prong vertex
  - $\chi^2_{VX} < 49$
- K^{*0} :
  - $|\Delta M| < 60\ \mathrm{MeV}/c^2$
- ϕ :
  - $|\Delta M| < 10\ \mathrm{MeV}/c^2$
- γ :
  - clusters in Ecal not associated with any reconstructed track
  - $E_T > 2.8$ GeV
  - $2.2(2.0) < E_T^* < 2.7$ GeV





Selection of $B_d \to K^{*0}\gamma$ and $B_s \to \phi\gamma$ (II)

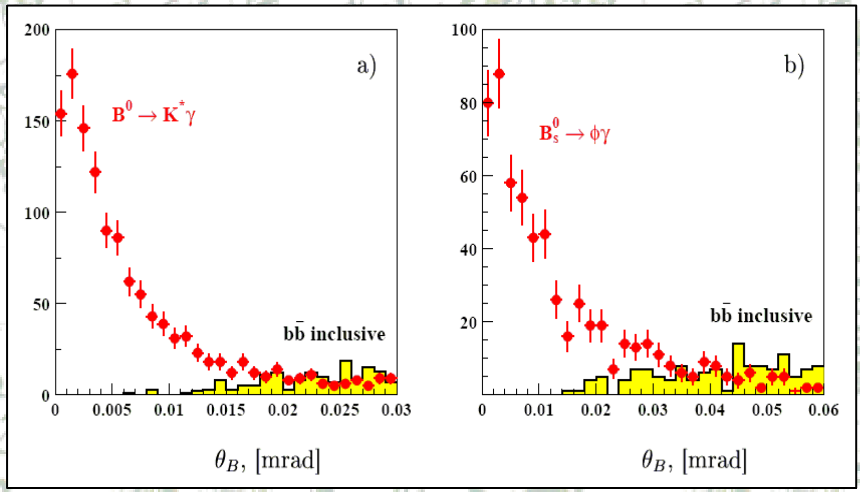
- **B :**
  - Angle between the momentum and the flight direction from production to decay vertex

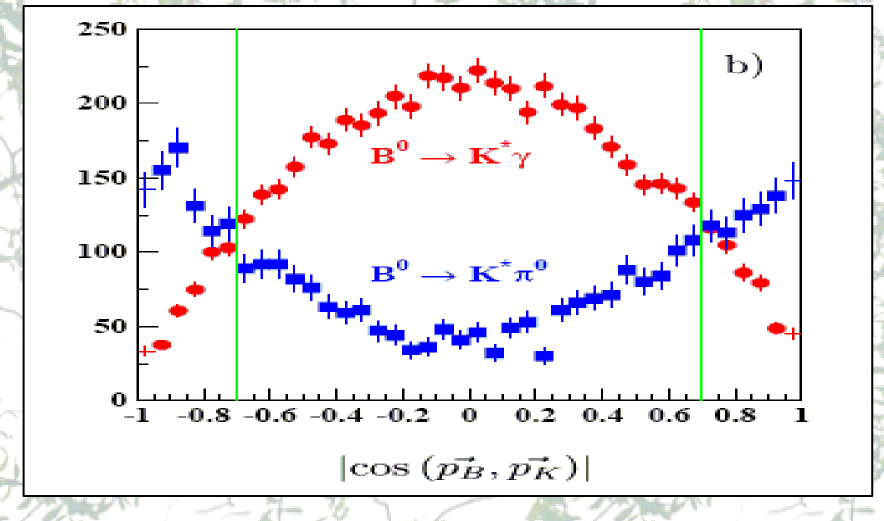
    $|\theta_B| < 6\ (15)$ mrad

- Correlated feeddown with merged π^0, wrongly reconstructed as single photon

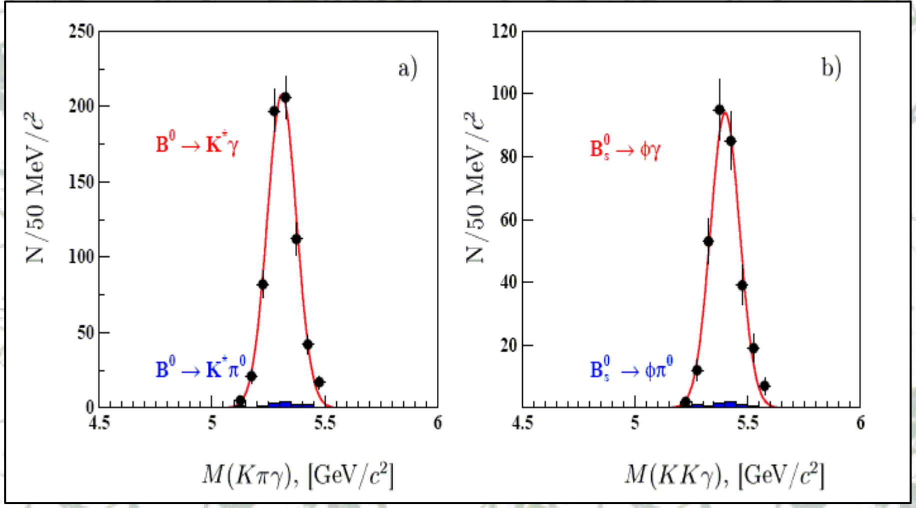
  $B \to K^{*0}\pi^0$, $B_s \to \phi\pi^0$

  - opposite $K^{*0}(\phi)$ polarization
    - $|\cos\theta| < 0.75$





$B_d \to K^{*0}\gamma$ $B_s \to \phi\gamma$ (III)



- B-mass window is defined as ±200 MeV/c^2
  - $\sigma(M_B) = 65$ MeV/c^2
- The correlated feeddown is well under the control

	$B_d \to K^{*0}\gamma$	$B_s \to \phi\gamma$
ε_{REC} [%]	4.5	4.3
$\varepsilon_{TRIG/REC}$ [%]	19	19
$\varepsilon_{SEL/TRIG}$ [%]	18	27
ε_{TOT} [%]	0.16	0.22

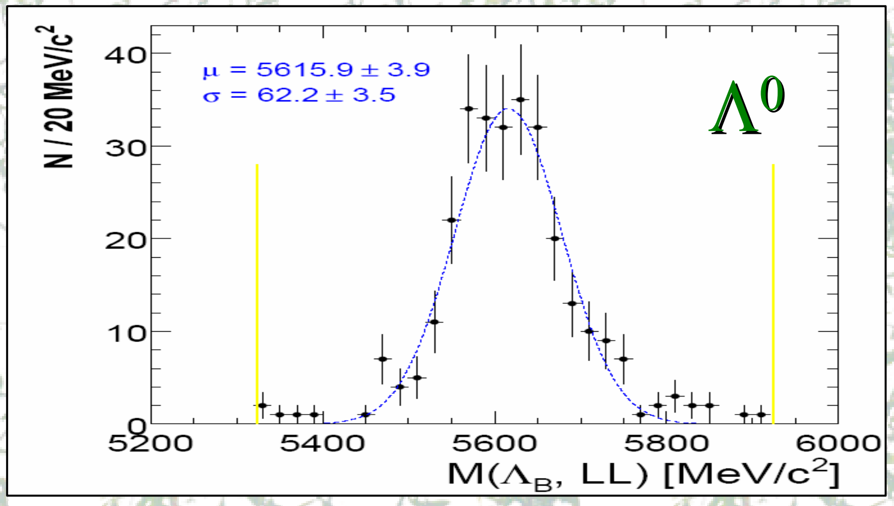
Annual yield (using 10^{12} $b\bar{b}$ events/10^7 second)

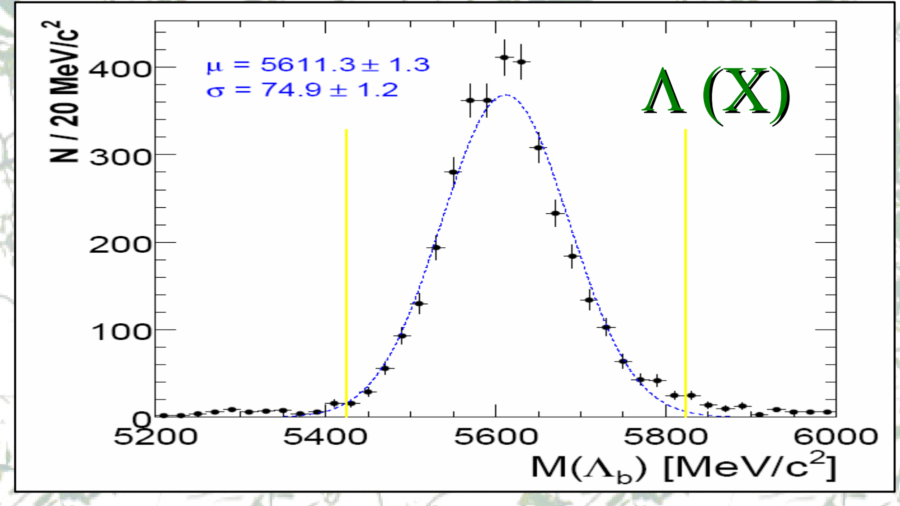
	$B_d \to K^{*0}\gamma$	$B_s \to \phi\gamma$
N/year	35k	9.3k

Selection of $\Lambda_b \to \Lambda^0\gamma$ $\Lambda_b \to \Lambda(X)\gamma$

- Basically on the same principles
  - Different for Λ^0, since Λ^0 decay vertex does not define Λ_b decay vertex
  - The special topology selection need to be used

$\Lambda_b \to \Lambda(1520)\gamma$	4200
$\Lambda_b \to \Lambda(1670)\gamma$	2200
$\Lambda_b \to \Lambda(1690)\gamma$	2200
$\Lambda_b \to \Lambda^0\gamma$	750





Background

Background estimation is limited by the size of available sample of $O(10^7)$ forward $b\bar{b}$ events and 3x10^7 minimum bias events

No background events are found in “wide” mass interval 4.5-6.0 GeV/c^2

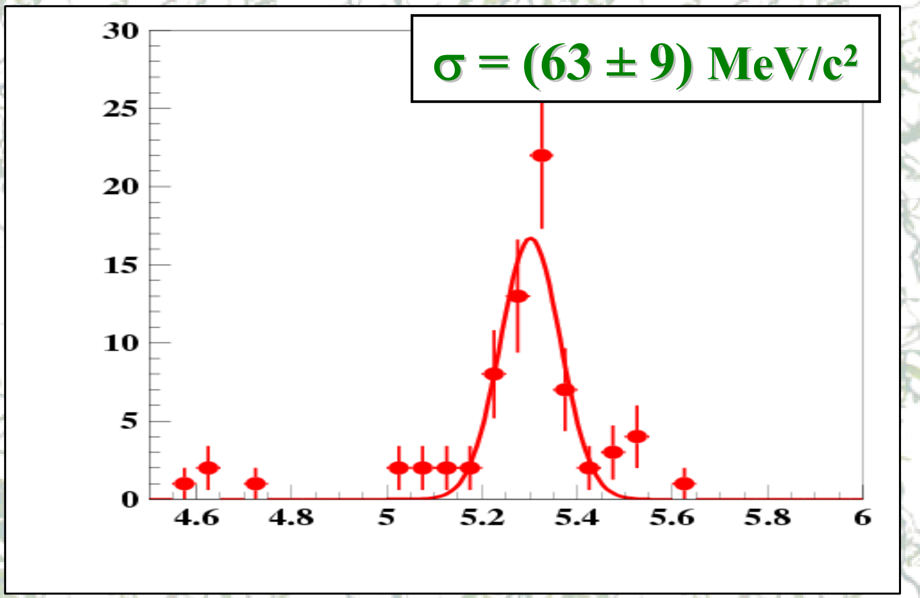
90%CL upper limits are set for the background from $b\bar{b}$-production

- We consider now forward $b\bar{b}$ production as a major source of background
  - large p_T, large impact parameters, secondary verticies, …
    - (This assumption need to be properly validated and proved)

	K*g	φγ	$\Lambda^0\gamma$	$\Lambda(X)\gamma$
B/S	<0.7	<2.4	<42	<10 <18

First look at $B_d \to \omega\gamma$

- $b \to d\gamma$ transition
- $|V_{td}/V_{ts}|$ can be extracted with moderate theoretical uncertanty
  - also for large Δm_s
  - Or formfactor calculations could be checked
- $Br(B \to K^*\gamma) / Br(B \to \omega\gamma) \sim 65$
- reconstruction efficiency is low:
  - π^0 need to be reconstructed
- Background condition is difficult
  - 3 neutral particles in final state



$\sigma = (63 \pm 9)$ MeV/c²

ε_{TOT} [%]	N/year
0.012	40
B / S < 3.5 @ 90 % CL	
Br $(B^0 \to \omega\ \gamma) = 0.5 \times 10^{-6}$	

Next steps

- Look at $B \to \rho^0\gamma$ events
  - expected to be better than $B \to \omega\gamma$ but not so nice as $B \to K^{*0}\gamma$
- Exploit the decays $B \to (K\pi\pi)\gamma$ to study the photon polarisation
- Probe the sensitivity for $A_{dir}(B_s \to \phi\gamma)$ and $A_{mix}(B_s \to \phi\gamma)$
  - Now we know that Δm_s is not very large
- …
- Study for systematic effects and uncertanties

Summary

- LHCb has a good physics potential for study of radiative B-decays

	N/year	B/S @90%CL
$B_d \to K^{*0}\gamma$	35k	<0.7
$B_s \to \phi\gamma$	9.3k	<2.4
$B_d \to \omega\gamma$	40	<3.5
$\Lambda_b \to \Lambda^0 \gamma$	750	<42
$\Lambda_b \to \Lambda(1520)\gamma$	4.2k	<10
$\Lambda_b \to \Lambda(1670)\gamma$	2.2k	<18
$\Lambda_b \to \Lambda(1690)\gamma$	2.2k	<18

The *statistical* error on $A_{dir}(B \to K^{*0}\gamma)$ is well below 1%

The *statistical* error on V_{td}/V_{ts} from $B \to K^{*0}\gamma$ and $B \to \omega\gamma$ of about $O(0.1\sqrt{(1+B/S)/N})$

15% sensitivity to γ_R after 5 years