Radiative decays at LHCb

Luis Miguel Garcia Martin

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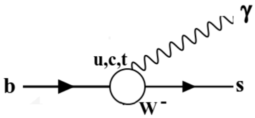
LHCb

Introduction: Theoretical motivation

The $b \to s\gamma$ process is forbidden at tree level in the Standard Model (SM).
Indirect searches grant access to larger energy scales than direct ones.
At LO in SM only O_7 and O'_7 contribute



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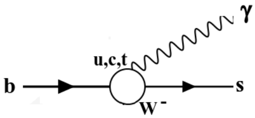

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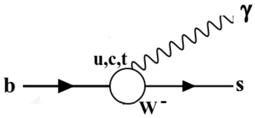
Wilson coefficient can be constrained through measurement of:

- Branching ratio: $\mathcal{B}_{\text{rad}} \propto |C_7|^2 + |C'_7|^2$
- Photon polarization: $\alpha_\gamma^{LO} = \frac{1-|\frac{C'_7}{C_7}|^2}{1+|\frac{C'_7}{C_7}|^2}$
- CP asymmetry: $A_{CP} \propto Im \frac{C_7 C'_7}{|C_7|^2+|C'_7|^2}$

Photons in such transitions are mainly **left-handed in the SM** since the W boson couples to left-handed quarks.



$$\mathcal{H}_{eff} = -4\frac{G_F}{\sqrt{2}} V_{ts}^* V_{tb} (\underbrace{C_7 O_7}_{\text{left}} + \underbrace{C_7' O_7'}_{\text{right}}) \quad C_7' O_7' \sim 0$$

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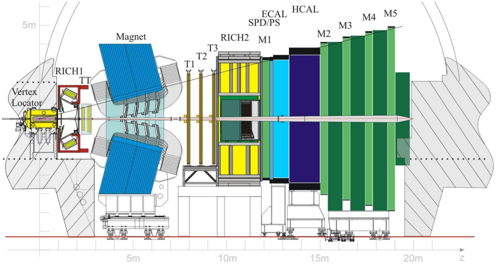
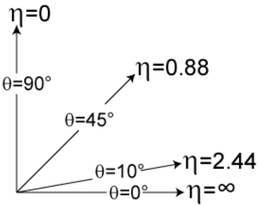
- CP asymmetry: $A_{CP} \propto Im \frac{C_7 C_7'}{|C_7|^2+|C_7'|^2}$ (~ 0)

LHCb detector

- One of the four detector at LHC
- LHCb is a single-arm ($2 < \eta < 5$) spectrometer
  - Optimised for beauty and charm decays
- Runs at lower luminosity
  - Optimised for precision measurements



$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$



θ: Angle between **p** and positive beam axis.

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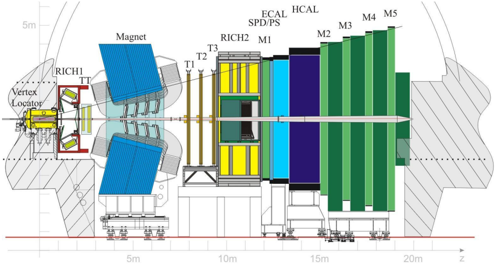

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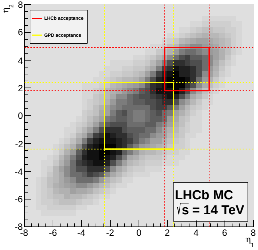

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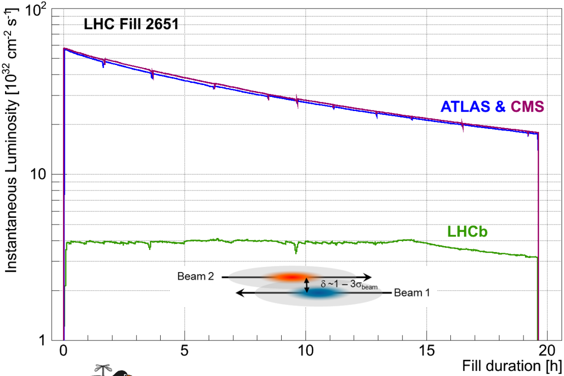
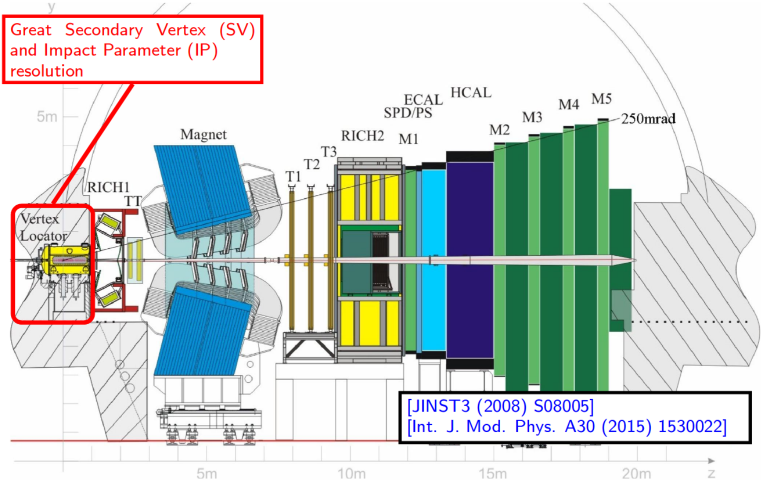
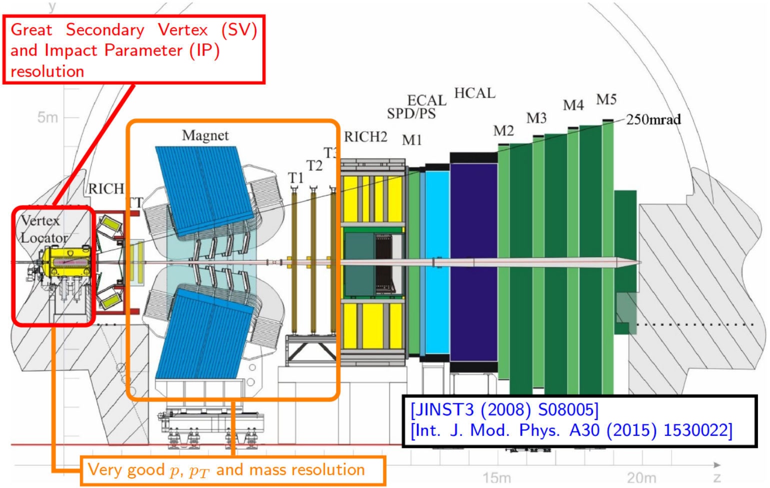


LHCb detector



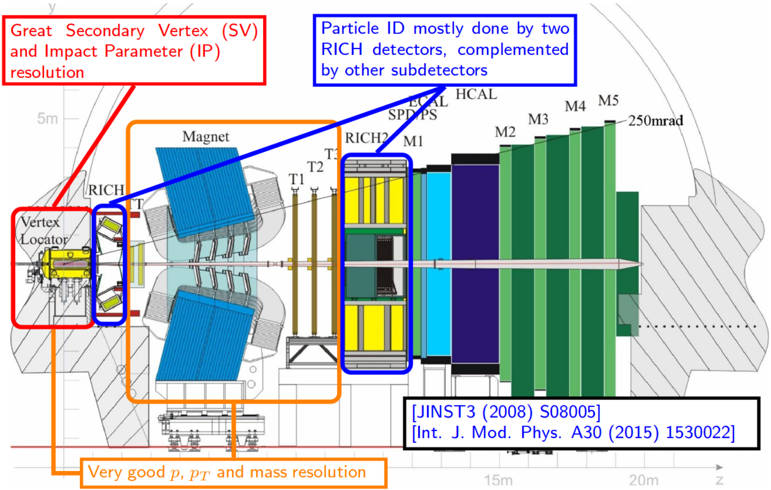
ΔIP $= (16{+}29/p_T\ [\text{GeV}])\ \mu$m

LHCb detector



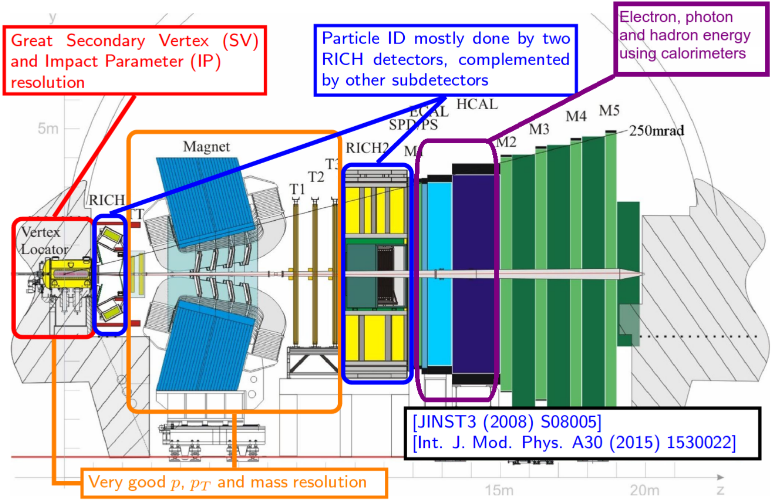
$\Delta p/p = 0.5 - 1.0\%$

LHCb detector



Kaon ID $\sim$ 95% for $\sim$ 5% $\pi \to K$ mis-id probability

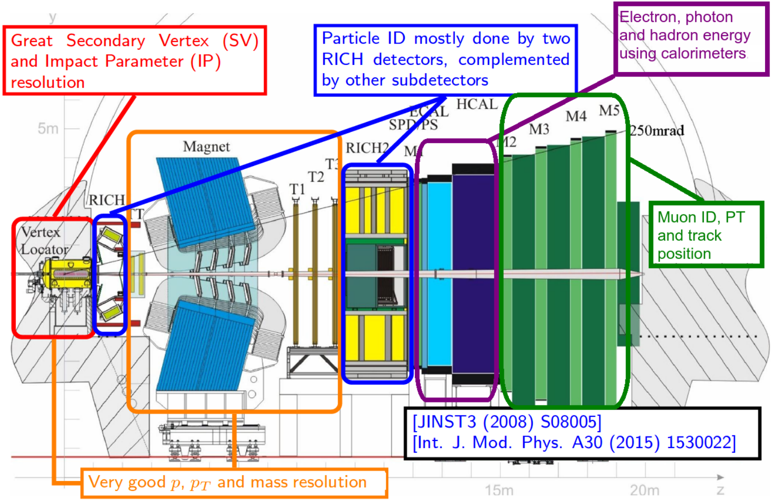
LHCb detector



Electron ID $\sim 90\%$ for $\sim 5\%$ $e \rightarrow h$ mis-id probability

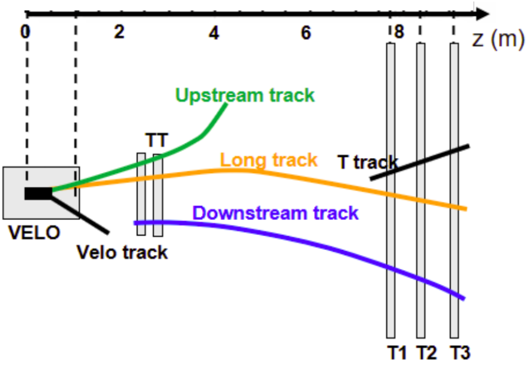
$\Delta E/E_{\mathrm{ECAL}} = 1\% + 10.0\%/\sqrt{E[\mathrm{GeV}]}$

LHCb detector



Muon ID $\sim$ 97% for $\sim$ 1-3% $\pi \to \mu$ mis-id probability

LHCb detector



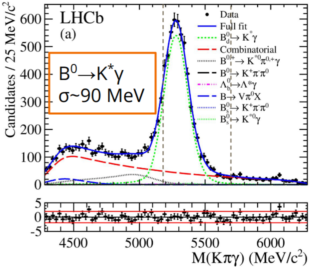
Long tracks

- Hits at least in VELO and T stations
- Used in majority of analyses

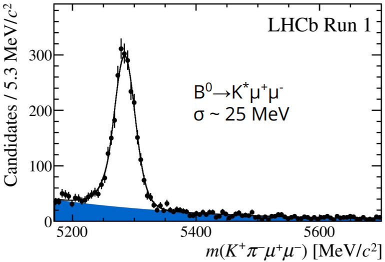
Downstream tracks

- Hits in TT and T stations (not in VELO)
- Decay products of long-lived particles

Introduction: Experimental challenges



[Nucl.Phys.B867(2013)1]



[PRL125(2020)011802]

Challenges for analysis involving neutrals (γ and π^0):

- Photon direction not reconstructed:
  - Mass resolution dominated by photon momentum
  - Large background ($\sim 10\,\gamma$/events, merge $\pi^0 \to \gamma\gamma$)
- Rare decays $\implies$ low signal yield $\left(\mathcal{B} \sim O(10^{-5})\right)$

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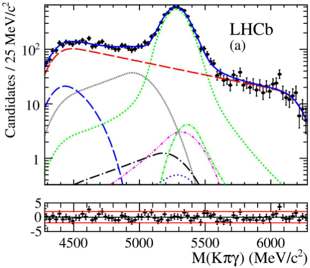

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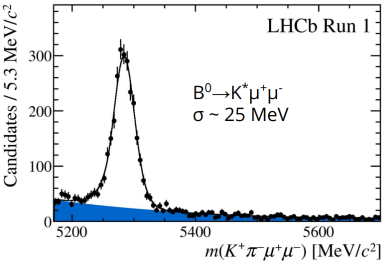

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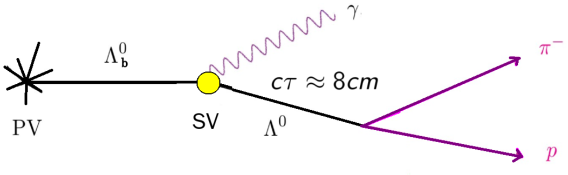

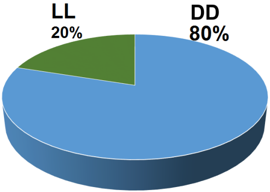

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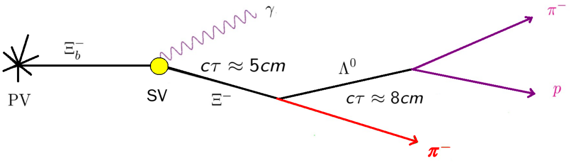
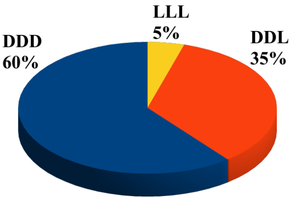
- Decays involving long-lived particles (K_S, Λ^0, Ξ^-)
  - Decay after the VELO
    - Worse IP/vertex position resolution
    - Hlt1 (trigger) only selects Long tracks





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  - Decay after the VELO
    - Worse IP/vertex position resolution
    - Hlt1 (trigger) only selects Long tracks
  - SV position cannot determined reconstructed

Time-dependent analysis of $B_s \to \phi\gamma$ decay

Time-dependent decay rates of $B_s \to \phi\gamma$ and $\overline{B_s} \to \phi\gamma$ grant access to photon polarization:

$$\Gamma_{B_s \to \phi\gamma}(t) \propto e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \mathcal{A}^{\Delta}_{\phi\gamma} \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C_{\phi\gamma} \cos\left(\Delta m_s t\right) - S_{\phi\gamma} \sin\left(\Delta m_s t\right)\right]$$

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- $\mathcal{A}^{\Delta}_{\phi\gamma}$ and $S_{\phi\gamma}$ are sensitive to photon polarization
- $C_{\phi\gamma}$ is related to direct CP violation
- SM prediction close to zero for $\mathcal{A}^{\Delta}_{\phi\gamma}$, $C_{\phi\gamma}$ and $S_{\phi\gamma}$
- $\mathcal{A}^{\Delta}$ only accessible for B_s decays :
  - $\Delta\Gamma_s \sim 0.081 \pm 0.011$
  - $\Delta\Gamma_d \sim 0$

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*Untag: No separation between B_s and $\overline{B_s}$

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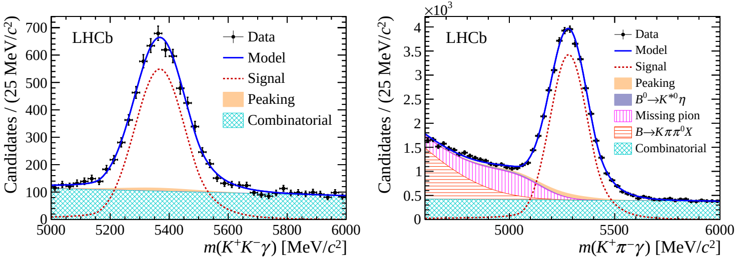
- **New:** $S_{\phi\gamma}$ and $C_{\phi\gamma}$ measurement using tagging [PRL123(2019)081802]

*Tagging: Separation between B_s and $\overline{B_s}$ [JINST11(2016)P05010]

- Mass fit of $B_s \to \phi\gamma$ (signal) and $B \to K^*\gamma$ (control) decays
- Using Run 1 data at LHCb [PRL123(2019)081802]
- Background subtracted with sPlot technique, fitting the B mass

Signal: $B_s \to \phi\gamma$

Control: $B \to K^*\gamma$

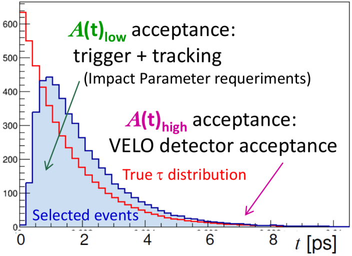


5300 signal yield

32000 signal yield

Time-dependent analysis of $B_s \to \phi\gamma$

- Mass fit of $B_s \to \phi\gamma$ (signal) and $B \to K^*\gamma$ (control) decays
- Using Run 1 data at LHCb [PRL123(2019)081802]
- Background subtracted with sPlot technique, fitting the B mass
- Decay time measured from B momentum and flight distance
- Need to control the proper time acceptance

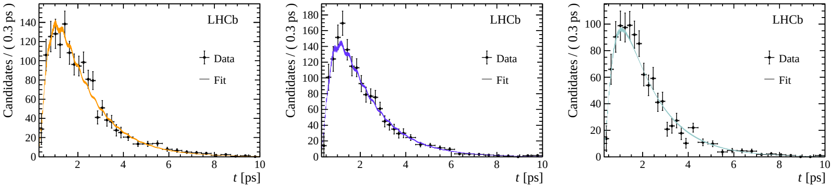


$$\mathcal{A}(t) = \frac{at^n}{1+at^n} \times (1+\beta t)$$

Analysis strategy:

- Simultaneous unbinned ML fit to $B_s \to \phi\gamma$ (signal) and $B \to K^*\gamma$ (control) channels
- Mis-tag probability and resolution evaluated per event

Tag: B_s — Tag: $\overline{B_s}$ — Untag

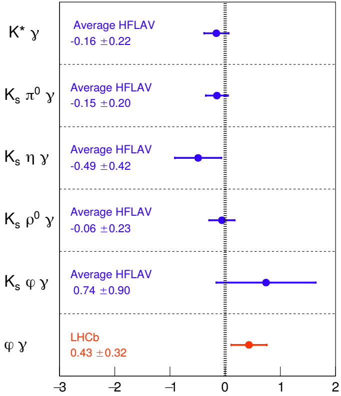


$$S_{\phi\gamma} = 0.43 \pm 0.30 \pm 0.11,$$
$$C_{\phi\gamma} = 0.11 \pm 0.29 \pm 0.11,$$
$$\mathcal{A}^{\Delta}_{\phi\gamma} = -0.67\,^{+0.37}_{-0.41} \pm 0.17$$

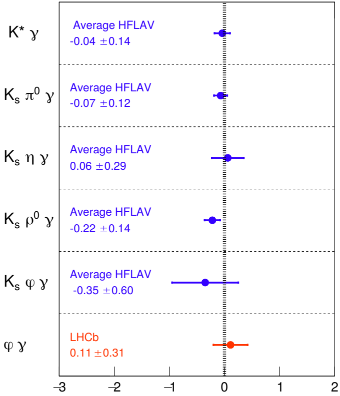
- Compatible with SM at 1.3, 0.3, 1.7 σ
- First measurement of S and C in the $B_s \to \phi\gamma$ decay [PRL123(2019)081802]

S_{CP} and C_{CP} in $b \to s\gamma$ transitions

S_{CP}



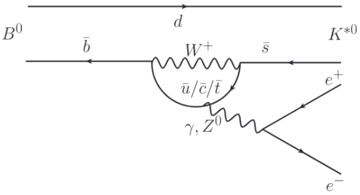
C_{CP}

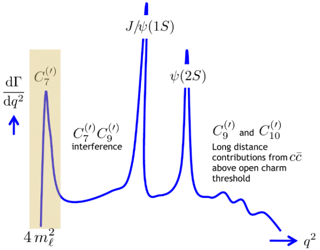


- Measurement competitive with other results from *b*-factories

$B \to K^* ee$ angular analysis

Decay dominated by $b \to s\gamma$ at very-low $q^2 = m^2_{ee}$ pole



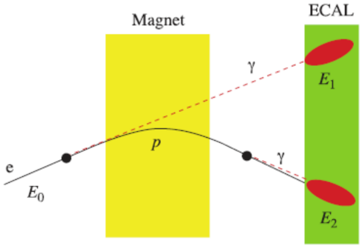


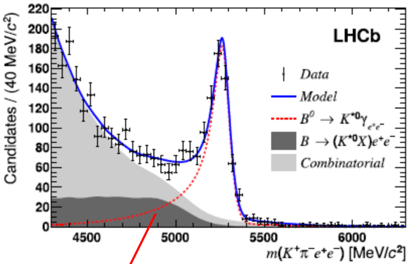
- Virtual γ decaying in an observable $\ell^+\ell^-$ pair
- Previous analysis with Run 1 data *[JHEP04(2015)064]*
- Recent update including Run 1 + Run 2 data [JHEP12(2020)081]
- All final state particles are charged $(K^+\pi^-e^+e^-)$

$B \to K^* ee$ angular analysis

Electrons loose energy by radiation (bremsstrahlung)

- difficult to reconstruct
- need bremsstrahlung recovery





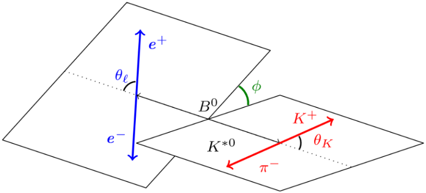
→ adding neutral clusters from the ECAL , with E_T > 75MeV

Long radiative tail in the B mass distribution: controlled from $B \to K^*\gamma$ events ($\gamma \to e^- e^+$, with bremsstrahlung emission)

$B \to K^* ee$ angular analysis

Angular distribution:

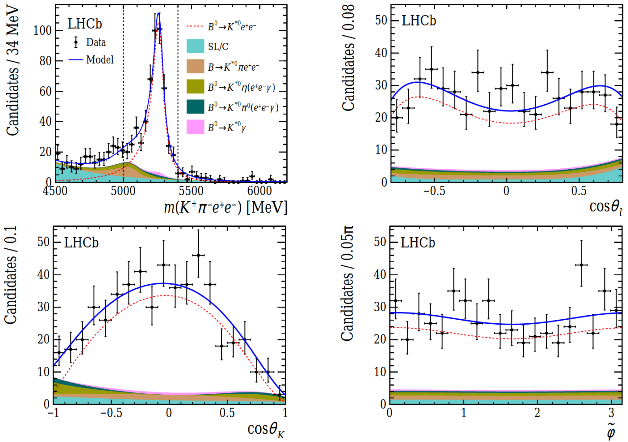
$$\frac{d(\Gamma+\bar{\Gamma})}{d\cos\theta_L \, d\cos\theta_K \, d\tilde{\phi}} = \frac{9}{16\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_L - F_L\cos^2\theta_K\cos 2\theta_L + \frac{1}{2}(1-F_L)A_T^{(2)}\sin^2\theta_K\sin^2\theta_L\cos 2\tilde{\phi} + (1-F_L)A_T^{Re}\sin^2\theta_K\cos\theta_L + \frac{1}{2}(1-F_L)A_T^{Im}\sin^2\theta_K\sin^2\theta_L\sin 2\tilde{\phi} \Big]$$



- Angular distribution with three angles: $\cos\theta_K, \cos\theta_L, \phi$
- Angular observables granting access to the photon polarization:
  - $A_T^{(2)}(q^2 \to 0) = \frac{2Re(C_7 C_7'^*)}{|C_7|^2+|C_7'|^2}$
  - $A_T^{Im}(q^2 \to 0) = \frac{2Im(C_7 C_7'^*)}{|C_7|^2+|C_7'|^2}$

$B \to K^*ee$ angular analysis

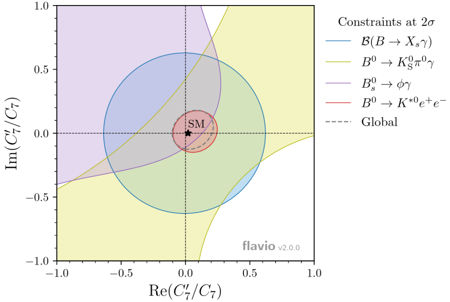
Fit to the B mass and angles (in reduced mass region)

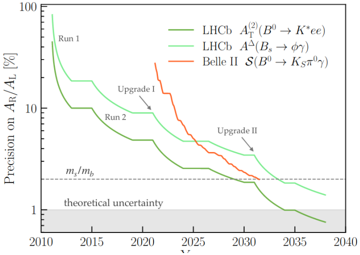


[JHEP12(2020)081]

$B \to K^* ee$ angular analysis : Constraint to C_7'

- This analysis set strong constraints in the C_7 - C_7' plane
- Still statistically limited
- precision will improve with Upgrade



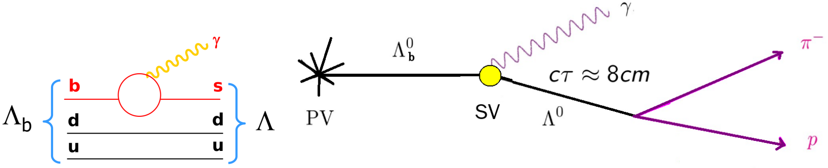


[JHEP12(2020)081]

Baryon decays

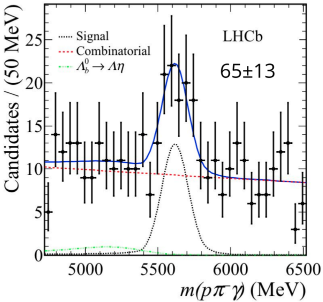
Radiative b-baryon decays:

- Non-zero spin grants access to more observables
- Two spectator quarks $\Longrightarrow$ different form factors
- Photon polarization has never been measured!!
- *b*-baryons only at accesible *pp* colliders (LHC)



First observation: $\Lambda_b^0 \to \Lambda\gamma$

First observation of a radiative *b*-baryon decay using 2016 data ($\mathcal{L} = 1.67\ \text{fb}^{-1}$) [PRL123(2019)031801]:



$$\mathcal{B}(\Lambda_b^0 \to \Lambda\gamma) = (7.1 \pm 1.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$

- Observed with 5.6σ significance
- Open door to photon polarization measurement

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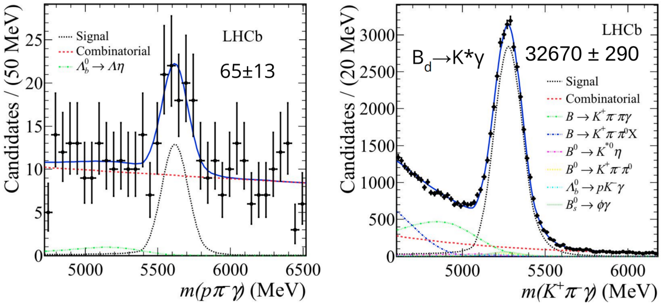

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- Observed with 5.6σ significance
- Open door to photon polarization measurement

Angular distribution: $\Lambda_b \to \Lambda\gamma$

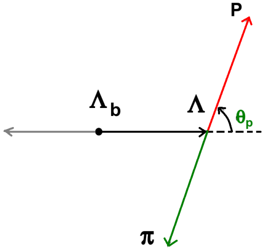
Angular distribution for Λ_b decay:

$$\Gamma_{\Lambda_b}(\theta_\gamma, \theta_p) = 1 - \alpha_\Lambda P_{\Lambda_b} \cos\theta_p \cos\theta_\gamma - \boldsymbol{\alpha_\gamma}\left(\alpha_\Lambda \cos\theta_p - P_{\Lambda_b}\cos\theta_\gamma\right)$$

Integrating in helicity angles:

$$\Gamma_{\Lambda_b}(\theta_\gamma) = \frac{1}{4}\left(1 - \boldsymbol{\alpha_\gamma} P_{\Lambda_b}\cos\theta_\gamma\right)$$

$$\Gamma_{\Lambda_b}(\theta_p) = \frac{1}{4}\left(1 - \boldsymbol{\alpha_\gamma}\alpha_\Lambda\cos\theta_p\right)$$



The decay parameters are:

- $P_{\Lambda_b} = 0.00 \pm 0.06(stat) \pm 0.06(sys)$ [PhysRevD.97(2018)072010]
- $\alpha_\Lambda = 0.732 \pm 0.010$ [PDG 2020]

Angular distribution: $\Lambda_b \to \Lambda\gamma$

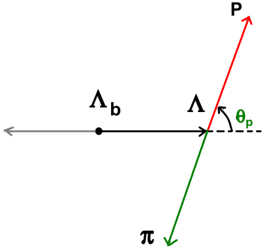
Angular distribution for Λ_b decay:

$$\cancel{\Gamma_{\Lambda_b}(\theta_\gamma, \theta_p)}^{\Gamma_{\Lambda_b}(\theta_p)} = 1 - \alpha_\Lambda \cancel{P_{\Lambda_b}}^{\sim 0} \cos\theta_p \cos\theta_\gamma - \boldsymbol{\alpha_\gamma}\left(\alpha_\Lambda \cos\theta_p - \cancel{P_{\Lambda_b}}^{\sim 0} \cos\theta_\gamma\right)$$

Integrating in helicity angles:

$$\cancel{\Gamma_{\Lambda_b}(\theta_\gamma)}^{\sim 1} = \frac{1}{4}\left(1 - \boldsymbol{\alpha_\gamma} \cancel{P_{\Lambda_b}}^{\sim 0} \cos\theta_\gamma\right)$$

$$\Gamma_{\Lambda_b}(\theta_p) = \frac{1}{4}\left(1 - \boldsymbol{\alpha_\gamma} \alpha_\Lambda \cos\theta_p\right)$$



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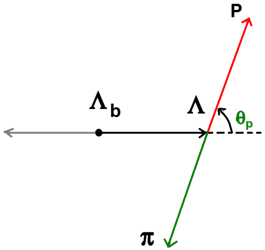
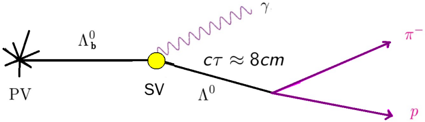


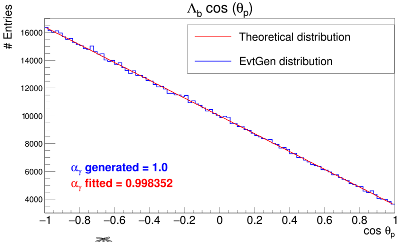
Angular distribution for Λ_b decay:

$$\Gamma_{\Lambda_b} = \frac{1}{4}\left(1 - \alpha_\gamma \alpha_\Lambda \cos\theta_p\right)$$

The value of the Λ decay parameter is:

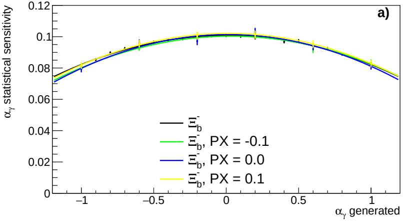
- $\alpha_\Lambda = 0.732 \pm 0.010$ [PDG 2020]

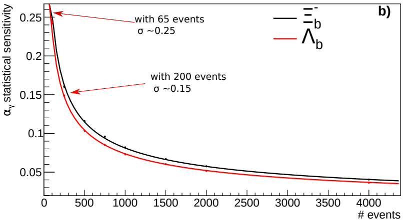




Statistical sensitivity to photon polarization

Sensitivity to the photon polarization (α_γ) [EPJC(2019)79:634]:

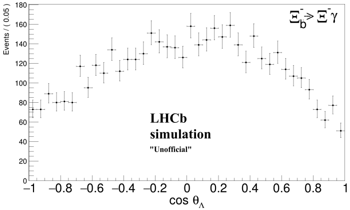


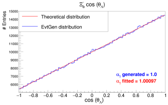


- Measuring P_{H_b} as well does not reduce the sensitivity to α_γ
  - For a large data sample
- Similar α_γ sensitivity using Λ_b and Ξ_b^- systems
- Only considering the theoretical angular polarization:
  - $\sigma_\alpha \sim 0.25$ with $\Lambda_b^0 \to \Lambda\gamma$ 2016 data sample (65 events)
  - $\sigma_\alpha \sim 0.15$ with $\Lambda_b^0 \to \Lambda\gamma$ Run2 data sample (assuming 200 events)

Sensitivity studies

$$\Gamma(\theta_\Lambda, \theta_p; \boldsymbol{\alpha_\gamma}) = \Big(Signal(\theta_\Lambda, \theta_p; \boldsymbol{\alpha_\gamma}) \times A(\theta_\Lambda, \theta_p) \Big) * Res(\theta_\Lambda, \theta_p) + \frac{S}{B} \left(BKG(\theta_\Lambda, \theta_p) \right)$$





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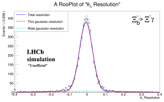

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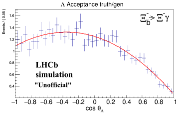

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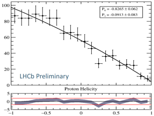


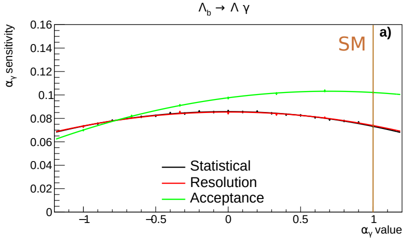
Angular. dist. | Resolution | Acceptance | Background

Sensitivity studies

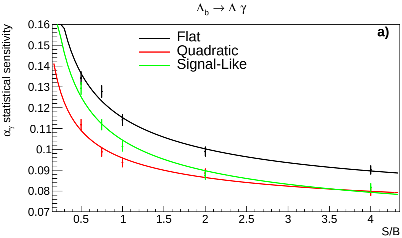
Independently testing the effects:

- Statistical: Shape of theoretical angular distribution
- Resolution: Effect of the detector
- Acceptance: Effect of the selection
- Studying the effect of the background:
  - with different angular background shapes
  - for several signal over background ratios

Acceptance/Resolution



Background



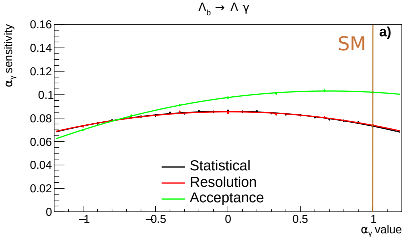
Tested for 1k events [EPJC(2019)79:634]

Sensitivity studies

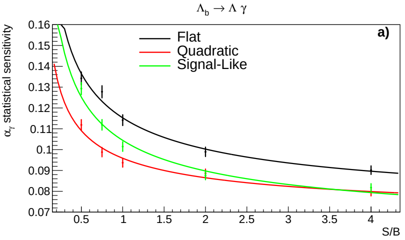
Independently testing the effects:

- Statistical: Shape of theoretical angular distribution
- Resolution: Effect of the detector (negligible effect)
- Acceptance: Effect of the selection (asymmetric with α_γ)
- Studying the effect of the background:
  - with different angular background shapes
  - for several signal over background ratios

Acceptance/Resolution



Background



Tested for 1k events [EPJC(2019)79:634]

Fit strategy: $\Lambda_b \to \Lambda\gamma$

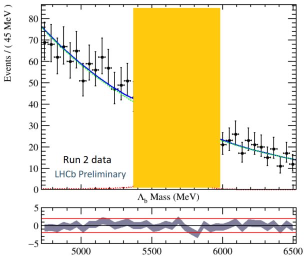
The photon polarization will be extracted using the PDF:

$$\Gamma(\theta_p;\boldsymbol{\alpha}_\gamma) = \frac{S}{S+B}\Big(Signal(\theta_p;\boldsymbol{\alpha}_\gamma)\times A(\theta_p)\Big) + \frac{B}{S+B}\big(BKG(\theta_p)\big)$$

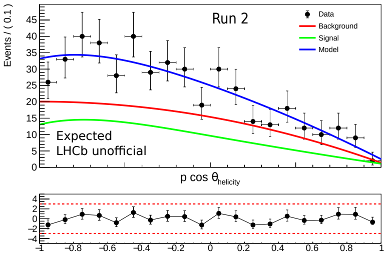
- Using Run 2 data in Λ_b^0 mass$_{PDG} \pm 2.5\sigma$
- **Signal:** $\frac{1}{4}\Big(1-\boldsymbol{\alpha}_\gamma\alpha_\Lambda\cos\theta_p\Big)$
- **Resolution:** Negligible effect
- **Acceptance:** Extracted from MC, controlled from data $(\Lambda_b \to \Lambda J/\psi)$
- **Background:** Extracted from data mass side-bands
- **Signal fraction** is Gaussian constrained
- Sensitivity to α_γ studied in [EPJC(2019)79:634]
- **Expected** σ_γ(stat.) ~ 0.32 (WIP)

$\Lambda_b^0 \to \Lambda\gamma$ analysis with Run 2 data

(Blinded) $\Lambda_b^0 \to \Lambda\gamma$ mass



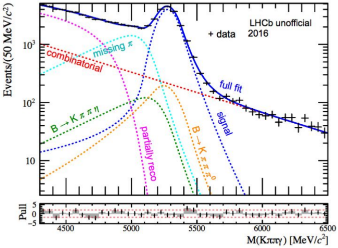
(Toy) $\Lambda_b^0 \to \Lambda\gamma$ ang dist

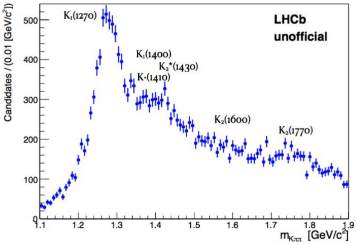


- Reconstruction and selection strategy defined using Run 2
- Background sources (other than combinatorial) found negligible
- Angular fit procedure established
  - Fitting signal and background, and including acceptance effects
- Systematics evaluated and found to be below 0.15
- Results (still blinded) will be delivered very soon!

$B \to K^+\pi^+\pi^-\gamma$ amplitude analysis

- First analysis observing a non-zero photon polarization at LHCb [PRL112(2014)161801]
- Inteference with reasonance grant access to the photon polarization [EPJC79(2019)622]
- Using amplitude analysis to provide a direct measurement
- Expecting an statistical uncertainty of 0.014 [EPJC79(2019)622]

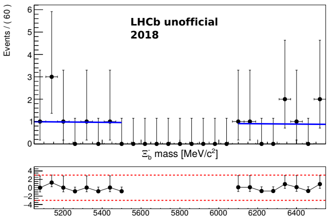


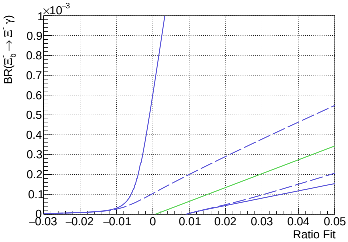


Search for $\Xi_b^- \to \Xi^- \gamma$

First search of the $\Xi_b^- \to \Xi^- \gamma$ decay

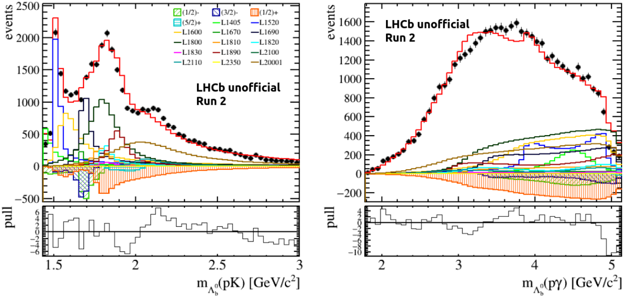
- No previous limit:
  - $\mathcal{B}(\Xi_b^- \to \Xi^- \gamma)_{\text{theo}} = (3.03 \pm 0.10) \times 10^{-4}$ [PRD83('11)054007]
  - $\mathcal{B}(\Xi_b^- \to \Xi^- \gamma)_{\text{theo}} = (1.23 \pm 0.64) \times 10^{-5}$ [arXiv:2008.06624]
- Only 5% events accessible (HLT1)
- Use of $\Xi_b^- \to \Xi^- J/\psi$ for normalization removes dependence with f_{Ξ_b}
- Still blinded
- Expected to set an upper limit of $\mathcal{O}(10^{-4})$





$\Lambda_b^0 \to (\Lambda^* \to pK^-)\gamma$ amplitude analysis

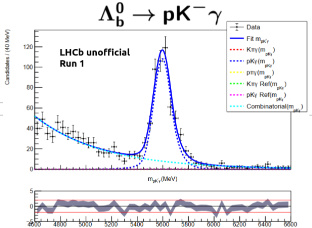
- **Goal:** Gain knowledge on the pK spectrum
  - Aid in the interpretation of the LFU measurement (R_{pK})
  - Pentaquarks: Set an upper limit on $\mathcal{B}(P_c \to p\gamma)$
    - $P_c \to pJ/\psi$ was observed in $\Lambda_b^0 \to pK^- J/\psi$ [PRL115(2015)072001]
- 2D fit in m_{pK} and $m_{p\gamma}$
- Isobar model with parameters from PDG when available



Other radiative decays

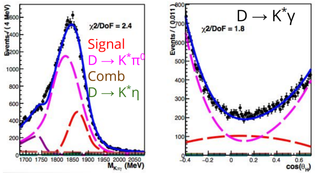
Search for $\Lambda_b \to p\pi\gamma$

- $b \to d\gamma$ transition:
  - More suppressed
  - Larger CPV
- No previous limit
- $pK\gamma$ and $K\pi\gamma$ contaminations controlled by simultaneous fit



Radiative charm decays: $D \to K^*\gamma, \phi\gamma, \rho\gamma$

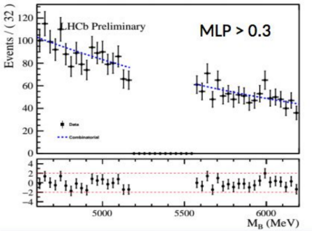
- $c \to u\gamma$ transition
- $\mathcal{B} \sim 10^{-4} - 10^{-5}$
- Cleaner NP probes (A_{CP}, γ pol.) [JHEP08(2017)091]
- More background
  - Softer γ
  - $\mathcal{B}(D \to V^0\pi^0) >> \mathcal{B}(V^0\gamma)$



Non-hadronic radiative decays

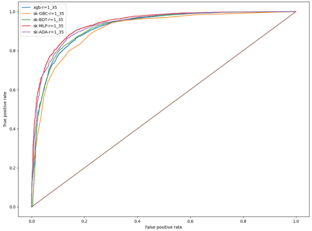
Search for $B_s \to \mu\mu\gamma$ with Run 2 data

- Sensitive to C_7, C_9 and C_{10}
- $\mathcal{B}_{\text{SM}} \sim 10^{-9} - 10^{-10}$
- BaBar limit $\mathcal{B} < 10^{-7}$



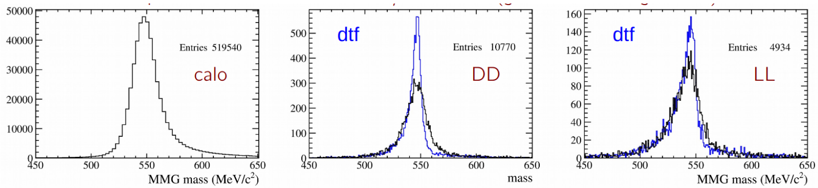
Search for $\gamma\gamma$ final states (B_s and ALPs)

- Light ALPs not reachable for ATLAS/CMS
- $\mathcal{B}_{\text{SM}} \sim 10^{-7}$
- Belle limit $\mathcal{B} < 3 \times 10^{-6}$
- Challenging topology



When photons convert before the magnet ($\gamma \to e^+e^-$):

- e^+e^- tracks can be reconstructed $\implies$ resolution 3 times better
  - Allow to access $|V_{td}/V_{ts}|$ suppressed modes like $B_s \to K^*\gamma$
- Its rate is 20 times lower than for calo photons



For Run 3:

- Converted photon analyses feasible with more luminosity
- Improvements in electron tracking for Upgrade

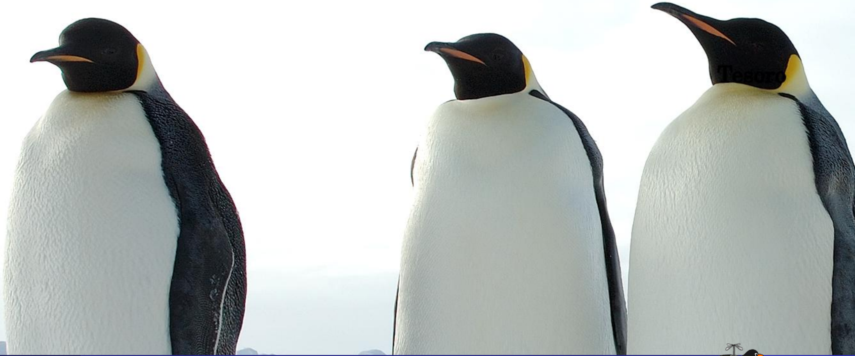
Conclusions

- The **photon polarization** is being measured at LHCb using several channels and different observables
- Important constraints to the Wilson coefficient $C_7^{(\prime)}$
- Nice competition ahead with Belle II

Preparations for Run 3:

- Developing fast downstream tracking algorithms fitting Hlt1 time-budget
  - Can increase statistics in b-baryon analysis **up to 20 times**
- Including BDT methods to Hlt2 lines:
  - Better sgl/bkg separation
  - Add downstream to channels with huge bkg

Thanks for your attention



Ratio of branching ratios

The branching ratio can be extracted from the signal yield:

$$N = 2 \times \mathcal{L} \times \sigma_{b\bar{b}} \times f_{\Xi_b} \times \mathcal{B}_{\Xi_b^- \to \Xi^- \gamma} \times \mathcal{B}_{\text{sub-decays}} \times \epsilon_{sel}$$

The $\mathcal{B}$ is extracted as a ratio of $\mathcal{B}$ using dimuonic channels

- Same hadronic decay chain

$$\frac{N(\Xi_b^- \to \Xi^- \gamma)}{N(\Xi_b^- \to \Xi^- J/\psi)} = \frac{\mathcal{B}(\Xi_b^- \to \Xi^- \gamma)}{\mathcal{B}(\Xi_b^- \to \Xi^- J/\psi)} \times \frac{1}{\mathcal{B}(J/\psi \to \mu^+ \mu^-)} \times \frac{\epsilon_{sel}(\Xi_b^- \to \Xi^- \gamma)}{\epsilon_{sel}(\Xi_b^- \to \Xi^- J/\psi)}$$

where:

- $\epsilon_{sel} = \epsilon_{acc} \times \epsilon_{reco+strip} \times \epsilon_{trigger} \times \epsilon_{Presel} \times \epsilon_{PID} \times \epsilon_{BDT} \times \epsilon_{IsPhoton}$

Why $\Xi_b^- \to \Xi^- J/\psi$ as normalization channel

$$\mathcal{B}(\Xi_b^- \to \Xi^- J/\psi) = (5.0 \pm 2.4) \times 10^{-4}$$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi) = (3.29 \pm 1.11) \times 10^{-4}$$

$$\mathcal{B}(\Lambda_b^0 \to pK^- J/\psi) = (3.2 \pm 0.6) \times 10^{-4}$$

$$\frac{f_{\Xi_b}}{f_{\Lambda_b}} = (8.2 \pm 2.6) \times 10^{-4}$$

$$\mathcal{B}(\Xi_b^- \to \Xi^- \gamma) \propto \mathcal{B}(\Xi_b^- \to \Xi^- J/\psi) \implies \sigma = 48\%$$

$$\mathcal{B}(\Xi_b^- \to \Xi^- \gamma) \propto \frac{1}{f_{\Xi_b}/f_{\Lambda_b}} \mathcal{B}(\Lambda_b^0 \to \Lambda\gamma) \implies \sigma = 46\%$$

$$\mathcal{B}(\Xi_b^- \to \Xi^- \gamma) \propto \frac{1}{f_{\Xi_b}/f_{\Lambda_b}} \mathcal{B}(\Lambda_b^0 \to pK^- J/\psi) \implies \sigma = 37\%$$

- When $\mathcal{B}(\Lambda_b^0 \to \Lambda J/\psi)$ is measured by LHCb $\sigma = 37\%$
- When $\mathcal{B}(\Xi_b^- \to \Xi^- J/\psi)$ is measured by LHCb, no f_{H_b} dependency and $\sigma = 20\%$

Expected yields: $\Xi_b^- \to \Xi^- \gamma$

$$N = 2 \times \mathcal{L} \times \sigma_{b\bar{b}} \times f_{\Xi_b} \times \mathcal{B}_{\Xi_b^- \to \Xi^- \gamma} \times \mathcal{B}_{\text{sub-decays}} \times \epsilon_{sel}$$

Variable	Value	
$\int \mathcal{L}$ [fb^{-1}]	2.19	
$\sigma_{b\bar{b}}$ [μb]	~ 600	
f_{Ξ_b} [%]	0.021 ± 0.007	
$\mathcal{B}(\Xi_b^- \to \Xi^- \gamma)$	$(1.1 \pm 0.3) \times 10^{-5}$	$(3.03 \pm 0.10) \times 10^{-4}$
$\mathcal{B}(\Xi^- \to \Lambda^0 \pi^-)$ [%]	99.887 ± 0.035	
$\mathcal{B}(\Lambda^0 \to p\pi)$ [%]	63.9 ± 0.5	
ϵ_{sel}	$(4.3 \pm 0.2) \times 10^{-6}$	
Expected yield	0.8 ± 0.4	22 ± 7

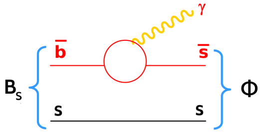
Assumming:

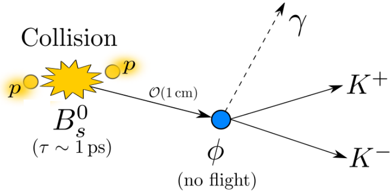
- $\mathcal{B}(\Xi_b^- \to \Xi^- \gamma) = \frac{3}{2}\mathcal{B}(\Lambda_b^0 \to \Lambda\gamma)$ (as for dimuonic channels)
- Theoretical prediction

Introduction: Meson decays

Radiative b-meson decays:

- Can oscillate
- SV can be determined from resonances decays
- Quite studied (lot of experience)
- Large production
- Accessible at B-factories

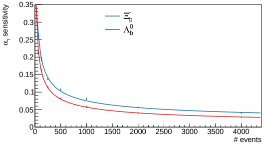




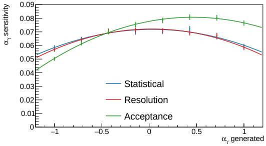
Sensitivity to photon polarization

Sensitivity to the photon polarization in the $\Lambda_b \to \Lambda\gamma$ decay using angular distribution [EPJC(2019)79:634]:

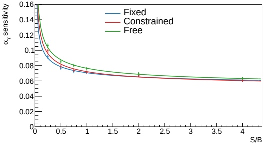
Statistical



Resolution + Acceptance



Background



- Statistical uncertainty: Goes as $1/\sqrt{N}$ with number of events
- Resolution: Effect neglible
- Acceptance: Asymmetric in α_γ
- Background: Important dilution

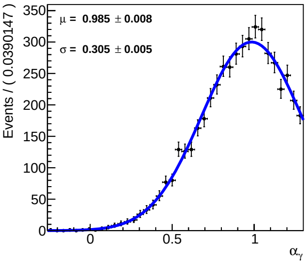
Simultaneous Mass fit: Validation

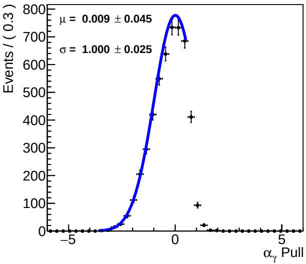
Mass fit validated throught MC Study:

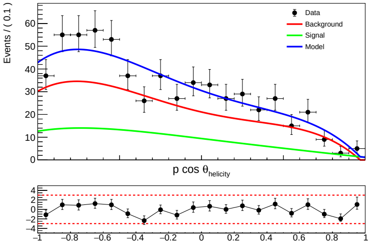
- 1000 pseudo-experiments
- Testing $\mathcal{B}(\Xi_b^- \to \Xi^- \gamma)$ hypotheses in range $(10^{-5}, 10^{-3})$
- Measurement significance using Wilk's theorem

$\mathcal{B}(\Xi_b^- \to \Xi^- \gamma)$	Evidence Prob [%] ($\sigma \geq 3$)	Observation Prob [%] ($\sigma \geq 5$)
1×10^{-3}	100.0	100.0
5×10^{-4}	100.0	98.0
3.3×10^{-4}	96.7	57.1
1×10^{-4}	26.2	0.8
5×10^{-5}	5.5	0.0
1.1×10^{-5}	0.9	0.0

MC-Toys result (S=197, B=412): α_γ







Amplitud Model

Helicity formalism + isobar lineshape in m_{pK}

Amplitude for a defined set of helicities in $\Lambda_b \to \Lambda^*(\to pK)\gamma$

$$D^{J_{\Lambda_b}}_{(\lambda_\Lambda-\lambda_\gamma)M_{\Lambda_b}}(\varphi_\Lambda \theta_\Lambda - \varphi_\Lambda)\, D^{J_\Lambda}_{\lambda_p \lambda_\Lambda}(\varphi_p \theta_p - \varphi_p)$$

$$\times \sum_{L=|J_{\Lambda_b}-S|}^{|J_{\Lambda_b}+S|} \sum_{S=|J_\Lambda - J_\gamma|}^{|J_\Lambda + J_\gamma|} \left[C_1 C_2 C_3 \, h_{LS} \left(\frac{p}{M_{\Lambda_b}}\right)^L \left(\frac{q}{M_\Lambda}\right)^l B_L(p) B_l(q) X(m_{pK}) \right]$$

Wigner D: $\Lambda_b \to \Lambda^* \gamma$
Wigner D: $\Lambda^* \to pK$
Clebsch-Gordans
fit parameter
orb. ang. mom. barriers
Blatt-Weisskopf form factors
lineshape

To obtain full decay rate

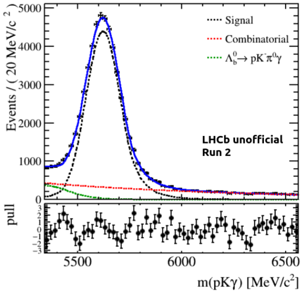
Coherently sum possible Λ^* helicities and Λ^* resonances
Incoherently sum possible proton, photon, and Λ_b helicities

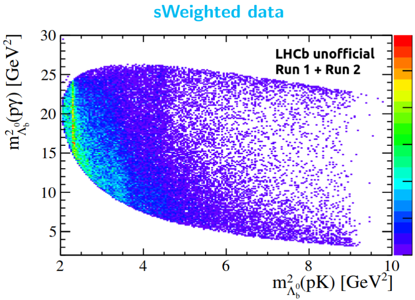
To check for pentaquarks in $m_{p\gamma}$

Need for second decay chain amplitude
Non-trivial relation between the decay planes of $\Lambda_b \to \Lambda^*(\to pK)\gamma$ and $\Lambda_b \to P_c(\to p\gamma)K$

Mass fit and Dalitz plot

- Signal: Bifurcated Crystal Ball
- Background:
  - Combinatorial: Exponential
  - Partially reconstructed: Argus convoluted with signal shape
- Tails parameters fixed in MC





Introduction: Experimental status

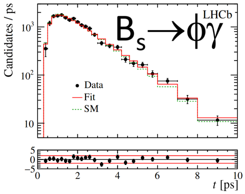
Photon polarization has only been measured using radiative *b*-meson decays:

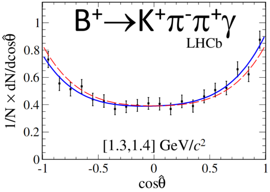
Proper time distribution:

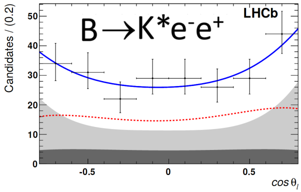
- $B - \overline{B}$ interference:
  $B_s \to \phi\gamma$,
  [PRL118('17)109901]

Angular distribution:

- $B^+ \to K^-\pi^+\pi^+\gamma$,
  [PRL 112('14)161801]
- $B \to K^* e^+ e^-$ at low q^2,
  [JHEP04('15)064]







Angular distribution: $\Xi_b^- \to \Xi^- \gamma$

Angular distribution for unpolarized Ξ_b^- decay (integrating on azimuthal angles):

$$\Gamma_{\Xi_b}(\theta_\Lambda, \theta_p) = \frac{1}{4}\left(1 - \boldsymbol{\alpha}_\gamma \alpha_\Xi \cos\theta_\Lambda + \alpha_\Lambda \cos\theta_p \left(\alpha_\Xi - \boldsymbol{\alpha}_\gamma \cos\theta_\Lambda\right)\right)$$

The values of the decay parameters are:

- $\alpha_\Xi = -0.401 \pm 0.010$ *[PDG 2020]*
- $\alpha_\Lambda = 0.732 \pm 0.010$ *[PDG 2020]*

Advantages of Ξ_b^- over Λ_b

- Extra decay $\Longrightarrow$ richer angular distribution
- Charged particle: Ξ^-