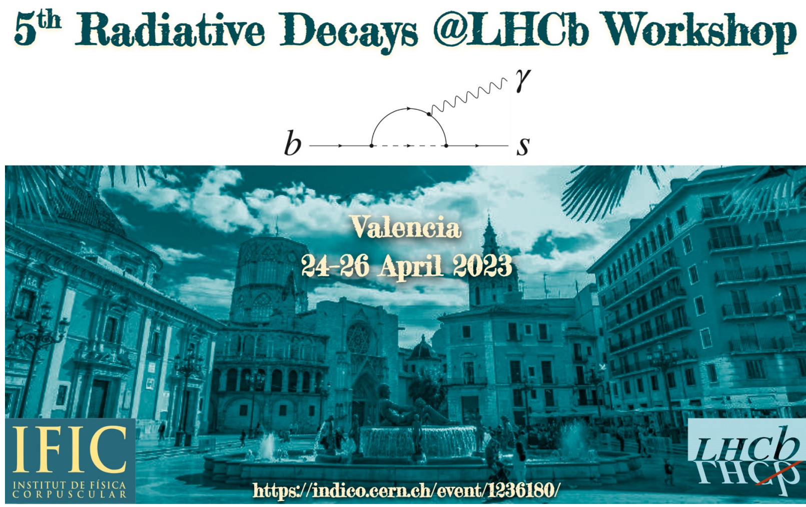
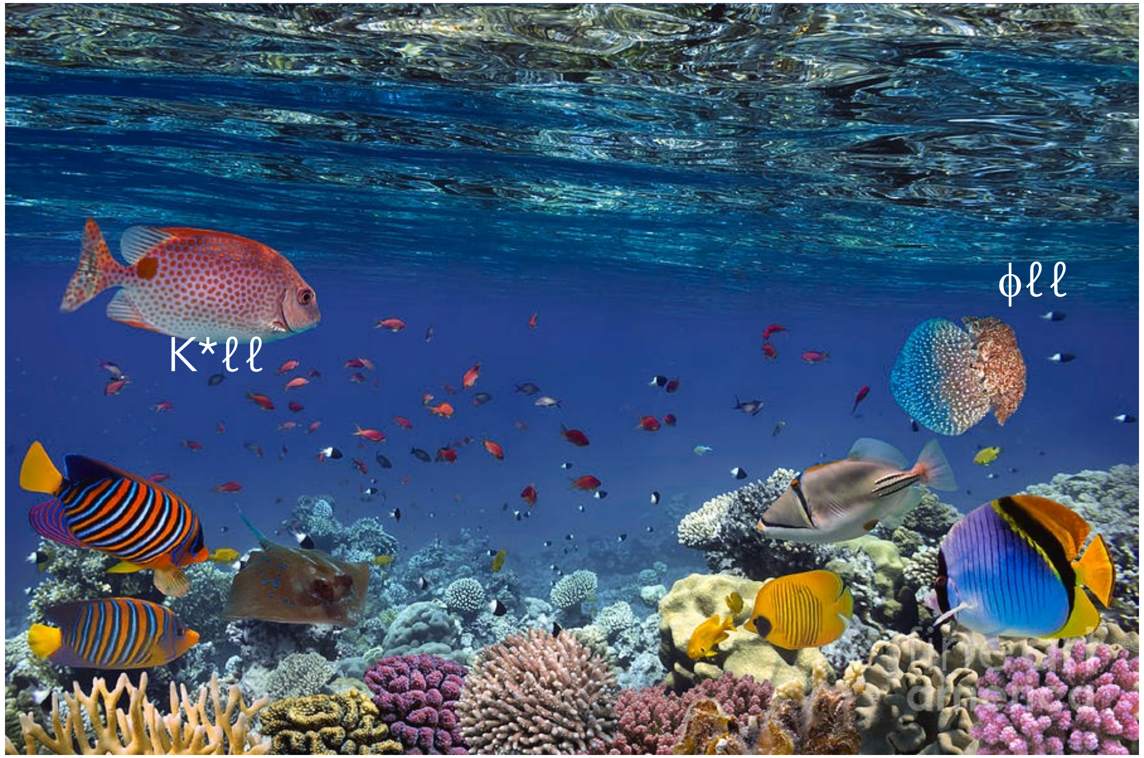
Interplay between b→s γ and b→see transitions

Marie-Hélène Schune

- b→sℓℓ transitions
- current constraints on the photon polarization
- Something else ?

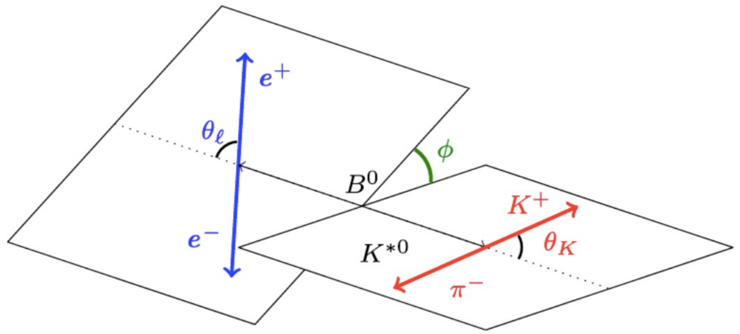


b→sℓℓ transitions



Motivation: Measurement of photon polarisation in b→s γ transition

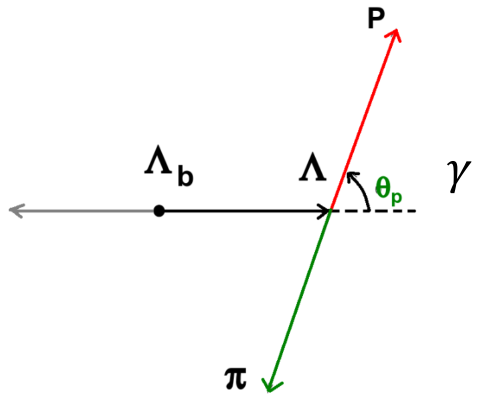
- Mixing-induced CP asymmetries in $B^0 \to K^{*0}$ ($\to K^0 \pi^0$) γ and $B_s \to \Phi\gamma$
  - Challenging final state and/or time dependent measurement with tagging
- $B \to K^*$ ($\to K^+ \pi^-$) γ or $B_s \to \Phi\gamma$ untagged & time-integrated : information not accessible
  ⇒ use virtual photons: access to the polarisation via the angle ϕ



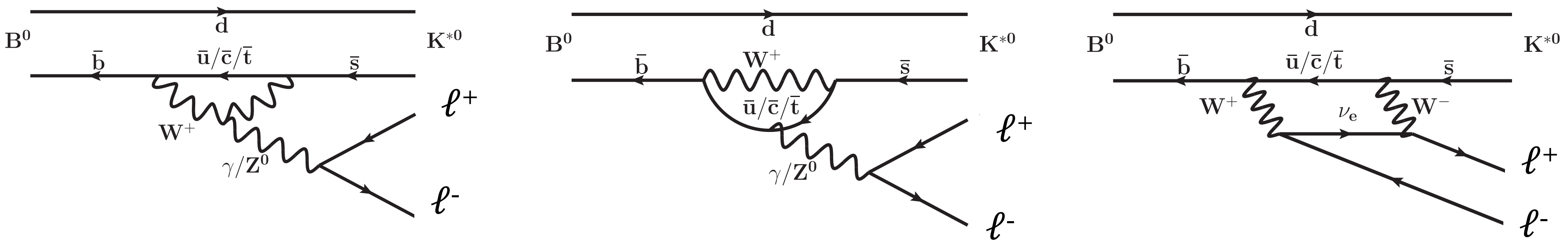
- $B \to K^{**}$ ($\to K\pi\pi$) γ : challenging experimentally & theoretically
- Unique case of the $\Lambda_b \to \Lambda\gamma$ decay + Λ weak decay

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

$\alpha_\Lambda = 0.754 \pm 0.004$ [BESIII]



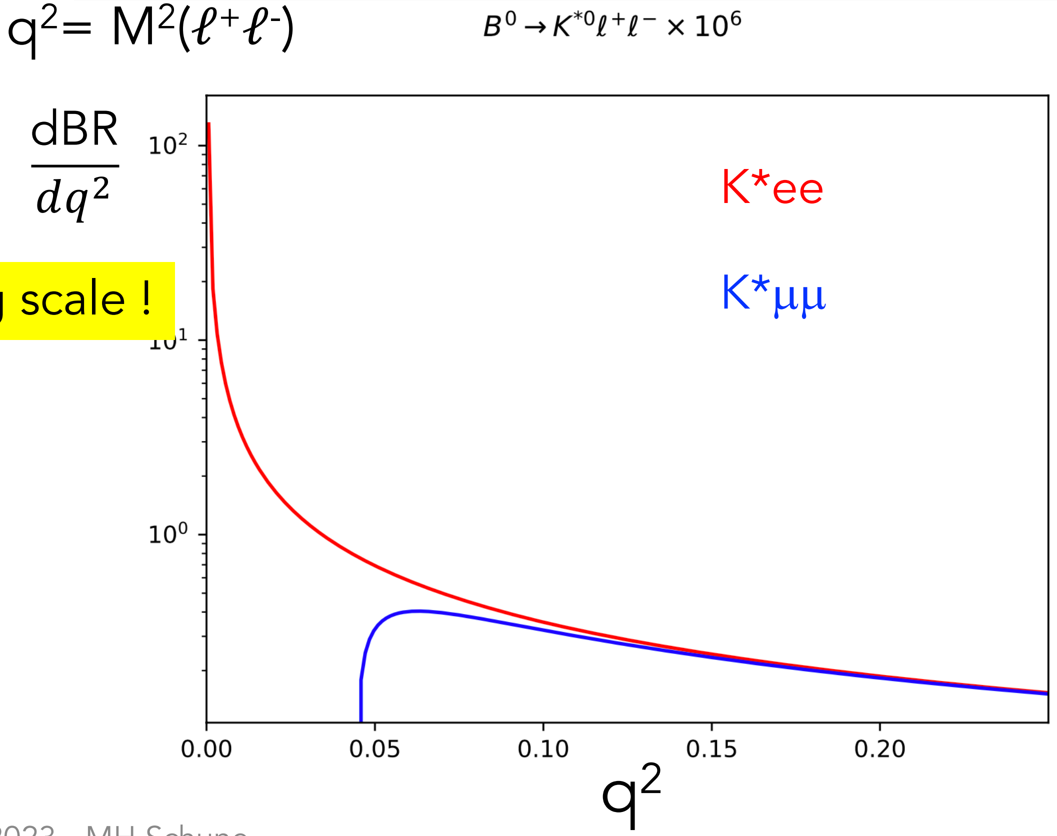
B→Vℓℓ



Relative importance of the different diagrams varies with $q^2 = M^2(\ell^+\ell^-)$

Focus on the interplay with B →Vγ
⇒ virtual photon: go for q^2 as low as possible :
⇒ use electrons

log scale !



$B^0 \to K^{*0}(\to K^+\pi^-)\ell\ell$

m_e is neglected

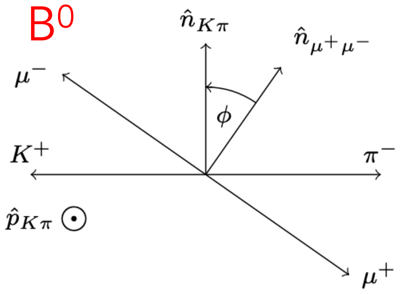
$$\cos\theta_\ell = \left(\hat{p}^{(\mu^+\mu^-)}_{\mu^+}\right)\cdot\left(\hat{p}^{(B^0)}_{\mu^+\mu^-}\right) = \left(\hat{p}^{(\mu^+\mu^-)}_{\mu^+}\right)\cdot\left(-\hat{p}^{(\mu^+\mu^-)}_{B^0}\right)$$

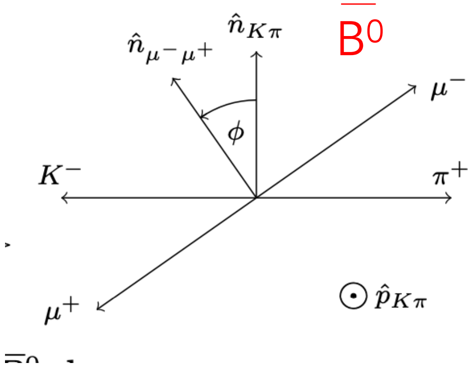
$$\cos\theta_K = \left(\hat{p}^{(K^{*0})}_{K^+}\right)\cdot\left(\hat{p}^{(B^0)}_{K^{*0}}\right) = \left(\hat{p}^{(K^{*0})}_{K^+}\right)\cdot\left(-\hat{p}^{(K^{*0})}_{B^0}\right)$$

+ ϕ folding to simplify the expression : keeps only cos(2ϕ) & sin(2ϕ)
no loss of sensitivity on the photon polarization

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} = \frac{9}{16\pi}\Big[F_\mathrm{L}\cos^2\theta_K + \frac{3}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K) - F_\mathrm{L}\cos^2\theta_K(2\cos^2\theta_\ell - 1) + \frac{1}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K)(2\cos^2\theta_\ell-1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}A_\mathrm{FB}(1-\cos^2\theta_K)\cos\theta_\ell + A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big].$$

μ^- for the $\overline{B}^0$





$$S_i = (I_i + \bar{I}_i)\Big/\left(\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} + \frac{\mathrm{d}\bar{\Gamma}}{\mathrm{d}q^2}\right) \text{ and}$$

$$A_i = (I_i - \bar{I}_i)\Big/\left(\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} + \frac{\mathrm{d}\bar{\Gamma}}{\mathrm{d}q^2}\right).$$

See eg https://arxiv.org/abs/1304.6325

$B_s \to \phi(\to K^+K^-)\ell\ell$

+ ϕ folding to simplify the expression : keeps only cos(2ϕ) & sin(2ϕ)
no loss of sensitivity on the photon polarization

$$\cos\theta_K = \frac{\vec{p}^{\,\mathrm{KK}}_{\mathrm{K}^-} \cdot \vec{p}^{\,\mathrm{KK}}_{B^0_s}}{|\vec{p}^{\,\mathrm{KK}}_{\mathrm{K}^-}||\vec{p}^{\,\mathrm{KK}}_{B^0_s}|}.$$

$$\cos\theta_l = \frac{\vec{p}^{\,\mu\mu}_{\mu^-} \cdot \vec{p}^{\,\mu\mu}_{B^0_s}}{|\vec{p}^{\,\mu\mu}_{\mu^-}||\vec{p}^{\,\mu\mu}_{B^0_s}|},$$

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} = \frac{9}{16\pi}\Big[F_\mathrm{L}\cos^2\theta_K + \frac{3}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K) - F_\mathrm{L}\cos^2\theta_K(2\cos^2\theta_\ell - 1) + \frac{1}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}A^{\mathrm{CP}}_{\mathrm{FB}}(1-\cos^2\theta_K)\cos\theta_\ell + A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big].$$

$$\cos\phi = \vec{n}^{\,B^0_s}_{\mathrm{K}^-\mathrm{K}^+} \cdot \vec{n}^{\,B^0_s}_{\mu^-\mu^+} \quad \text{and} \quad \sin\phi = \left(\vec{n}^{\,B^0_s}_{K^-K^+} \times \vec{n}^{\,B^0_s}_{\mu^-\mu^+}\right) \cdot \frac{\vec{p}^{\,B^0_s}_{\mathrm{KK}}}{|\vec{p}^{\,B^0_s}_{\mathrm{KK}}|}.$$

$$S_i = (I_i + \bar{I}_i) \Big/ \left(\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} + \frac{\mathrm{d}\bar{\Gamma}}{\mathrm{d}q^2}\right) \quad \text{and}$$

$$A_i = (I_i - \bar{I}_i) \Big/ \left(\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} + \frac{\mathrm{d}\bar{\Gamma}}{\mathrm{d}q^2}\right).$$

See eg arXiv:2210.11995

With a proper definition for the angles (for $K^{*0}ll$ decay) in both cases one measures

$$\frac{9}{16\pi}\Big[F_L \cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) \; - $$
$$F_L \cos^2\theta_K (2\cos^2\theta_\ell - 1) \; + $$
$$\frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) \; + $$
$$S_3 (1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} \; + $$
$$\frac{4}{3} A_{FB}^{CP} (1-\cos^2\theta_K)\cos\theta_\ell \; + $$
$$A_9 (1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi} \Big] .$$

'Optimised' observables

$$S_3 = \frac{1}{2}(1-F_L)\,A_T^{(2)}$$
$$S_6 = (1-F_L)\,A_T^{Re}$$
$$A_9 = \frac{1}{2}(1-F_L)\,A_T^{Im}$$

something written as $A_T^{Im,CP}$

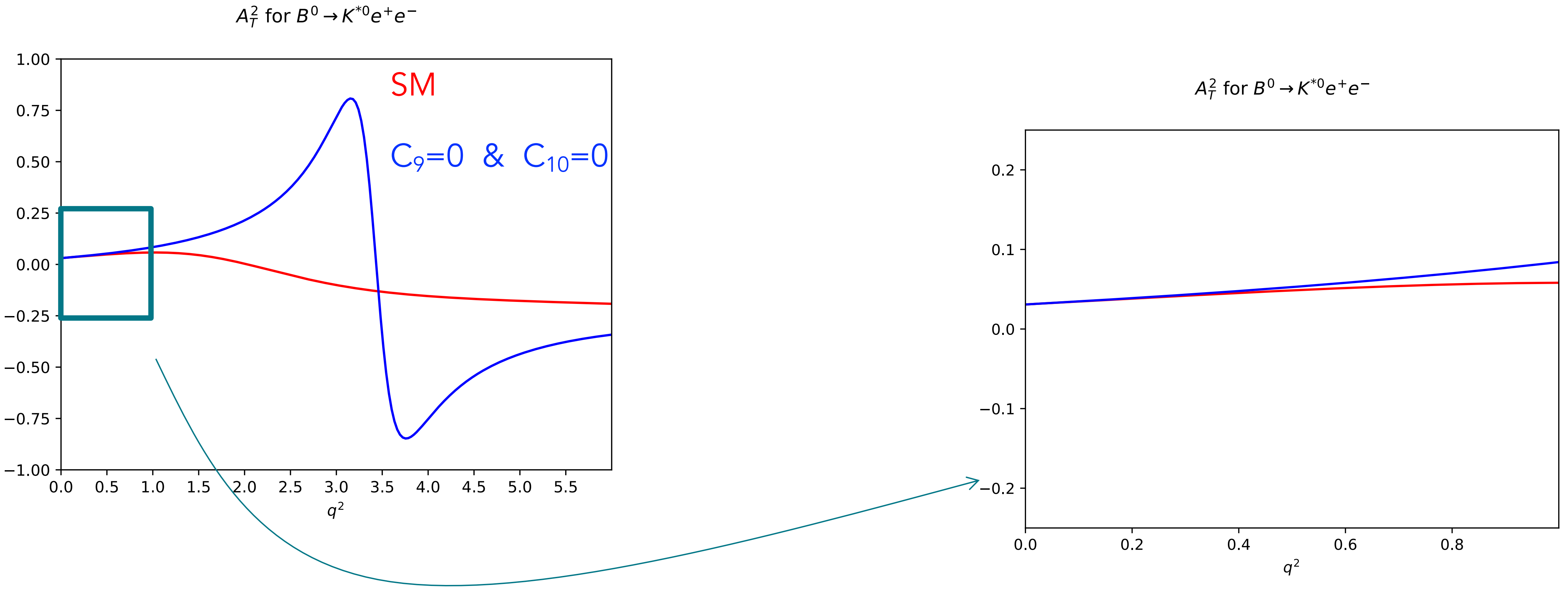
$$A_T^{(2)} = \frac{|A_\perp^L|^2 + |A_\perp^R|^2 - |A_{||}^L|^2 - |A_{||}^R|^2 + (A \leftrightarrow \bar{A})}{|A_\perp^L|^2 + |A_\perp^R|^2 + |A_{||}^L|^2 + |A_{||}^R|^2 + (A \leftrightarrow \bar{A})}$$

$$A_T^{(Im);CP} = -\frac{2\,\mathrm{Im}\big[(A_{||}^L A_\perp^{L*} + A_{||}^R A_\perp^{R*}) - (A \leftrightarrow \bar{A})\big]}{|A_\perp^L|^2 + |A_\perp^R|^2 + |A_{||}^L|^2 + |A_{||}^R|^2 + (A \leftrightarrow \bar{A})}$$

$$A_{\perp L,R} = \sqrt{2} N m_B (1-\hat{s}) \left[(C_9^{\rm eff} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}} (C_7^{\rm eff} + C_7^{\rm eff\prime}) \right] \xi_\perp(E_{K^*}),$$

$$A_{\parallel L,R} = -\sqrt{2} N m_B (1-\hat{s}) \left[(C_9^{\rm eff} \mp C_{10}) + \frac{2\hat{m}_b}{\hat{s}} (C_7^{\rm eff} - C_7^{\rm eff\prime}) \right] \xi_\perp(E_{K^*})$$

Dominating in the very-low q^2 region



$$S_3 = \frac{1}{2}(1 - F_{\rm L})\,{\rm A}_{\rm T}^{(2)}$$

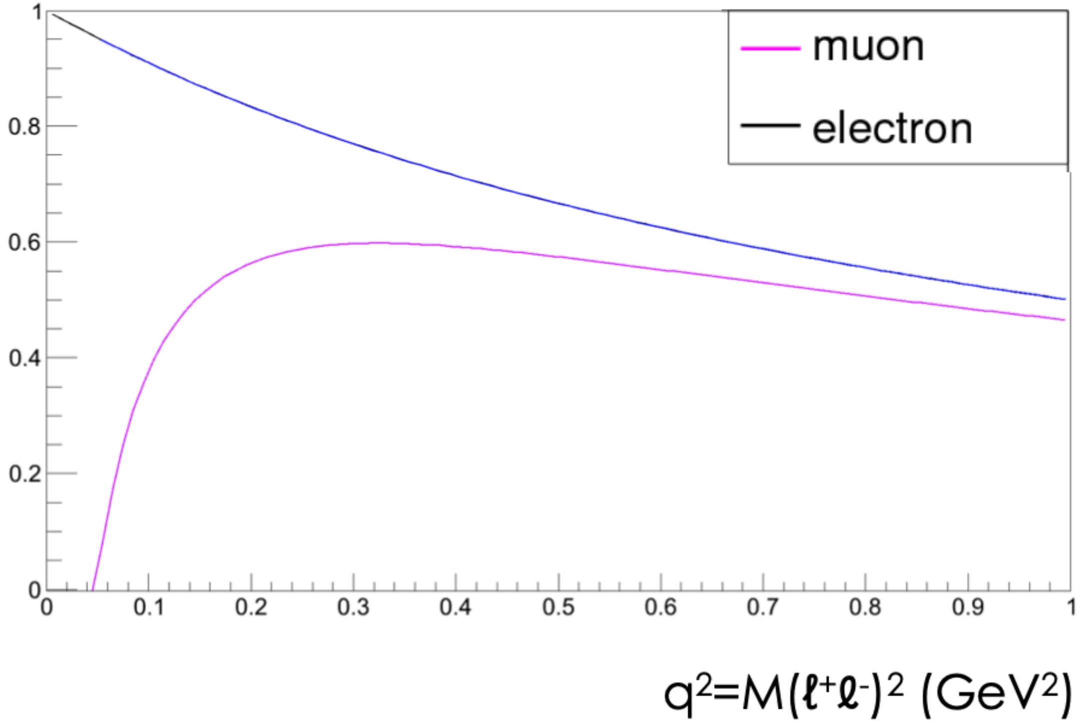
$$A_9 = \frac{1}{2}(1 - F_{\rm L})\,{\rm A}_{\rm T}^{\rm Im}$$

Beyond the yields, the precision on AT2 and ATIm is driven by $(1\text{-}F_L)$

$$(1 - F_L)$$

$$(1 - F_L)\frac{1 - x}{1 + \frac{x}{2}}$$

$$x = \frac{4m_\ell^2}{q^2}$$



Given the experimental challenges, going above 0.5 GeV^2 with the electrons channel is not meaningful.

In the very low-q^2 the amplitudes are dominated by the C_7 and C'_7 contributions
F_L is the longitudinal polarisation ⇒ small as the quasi-real photon is transversely polarised

Approximate expressions (C'^2_7 is neglected)

K*ee

$$A_T^{(2)}(q^2 \to 0) = \frac{2Re(C_7 C_7'^*)}{|C_7|^2}$$

$$A_T^{(Im)}(q^2 \to 0) = \frac{-2Im(C_7 C_7'^*)}{|C_7|^2}$$

ϕ*ee

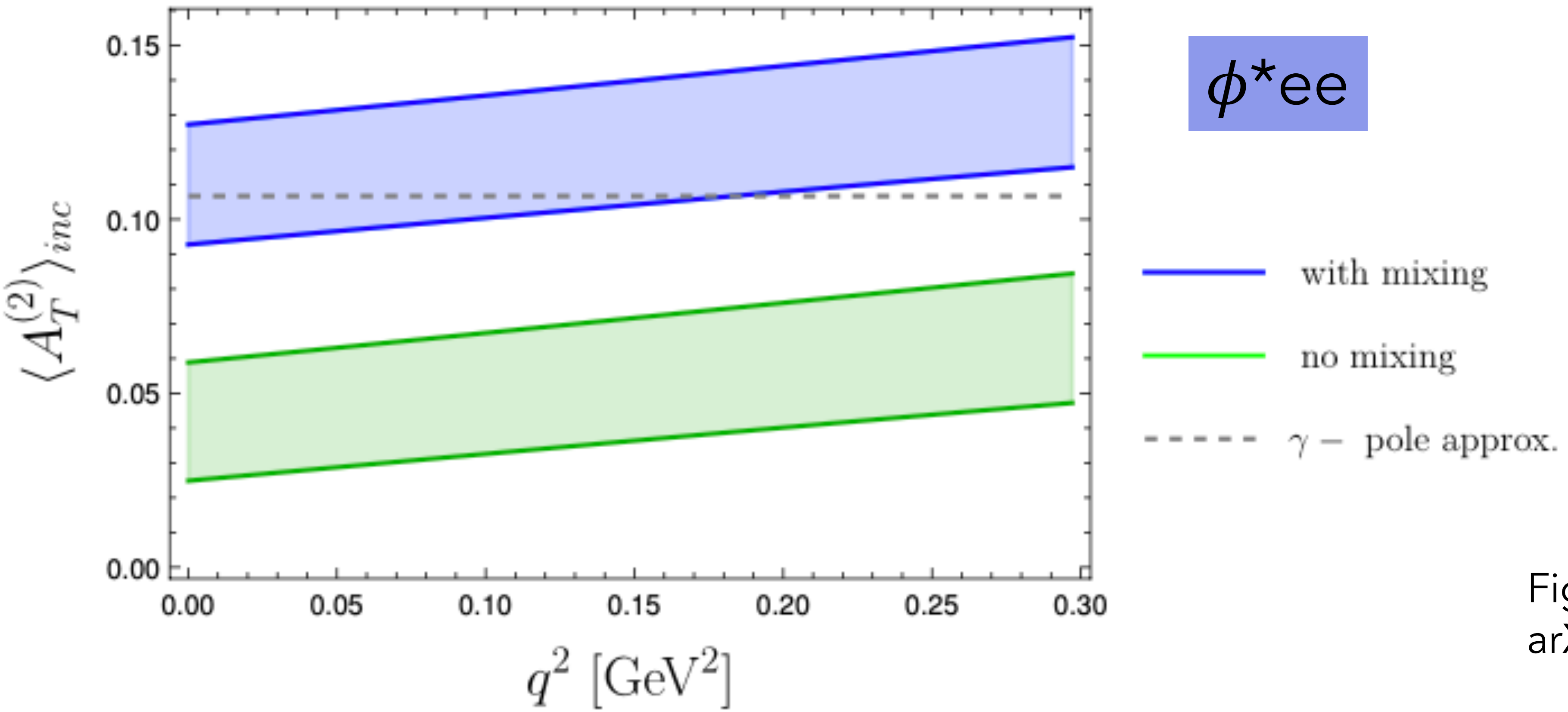
$$A_T^{(2)}(q^2 \to 0) = \frac{2\left[Re(C_7 C_7'^*) + \frac{y}{2}(Re(C_7)^2 - Im(C_7)^2)\right]}{|C_7|^2}$$

$$A_T^{(Im)}(q^2 \to 0) = \frac{2[-Im(C_7 C_7'^*) - y Re(C_7) Im(C_7)]}{|C_7|^2}$$

$$y \equiv \Delta\Gamma_s/(2\Gamma_s)$$
$$y = 0.0675 \pm 0.004$$

Comparing $A_T^{(2)}(K^* ee)$ and $A_T^{(2)}(\varphi^* ee)$ (same for $A_T^{(Im)}$) : constraint on C_7

Example of the effect of the photon pole approximation and the impact of mixing



ϕ*ee

K*ee

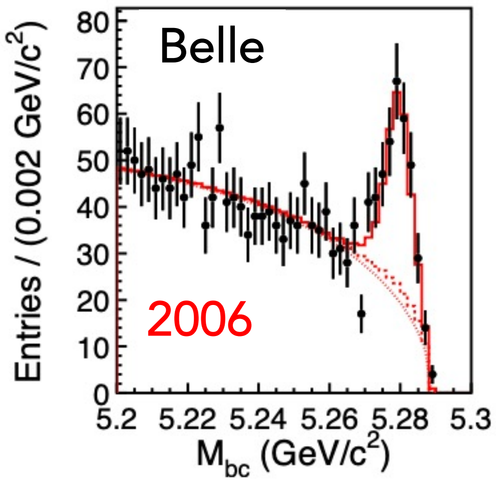
Figure from arXiv:2210.11995

Current constraints on the photon polarization: traditional recipes

Current available measurements

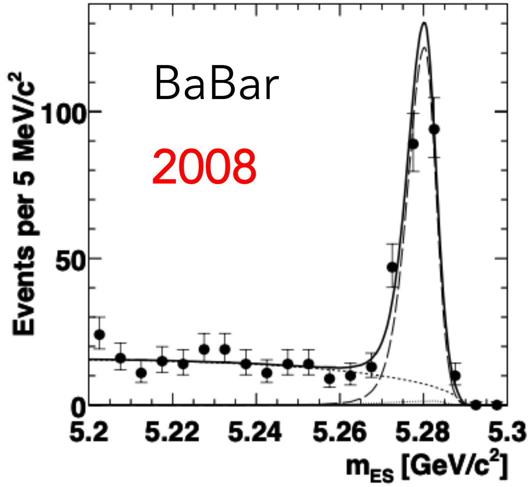
S ~ 110 (K*0 region)

Phys.Rev.D74:111104,2006



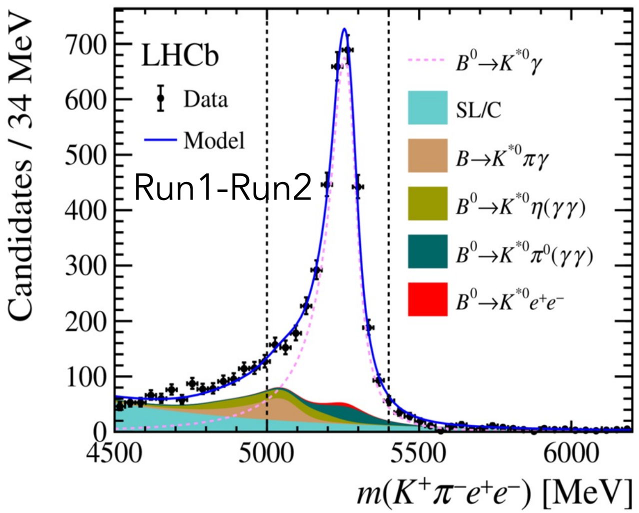
S~ 130 (K*0 region)

Phys.Rev.D78:071102,2008



2014 updated in 2020

S~ 450

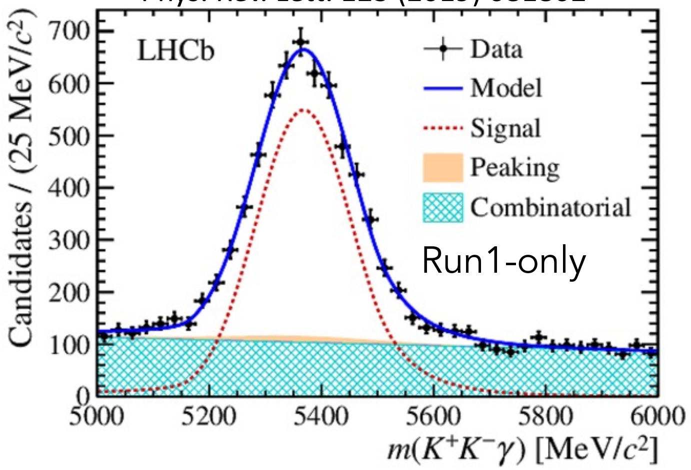


2016 updated in 2019

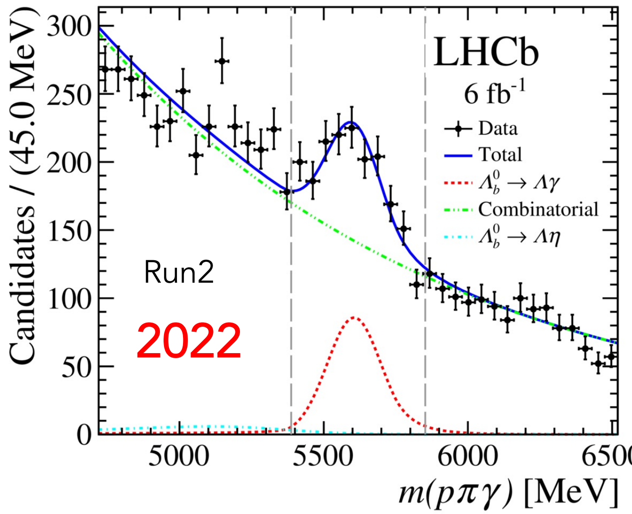
S~ 5100

⇔ ~ 250 fully tagged events

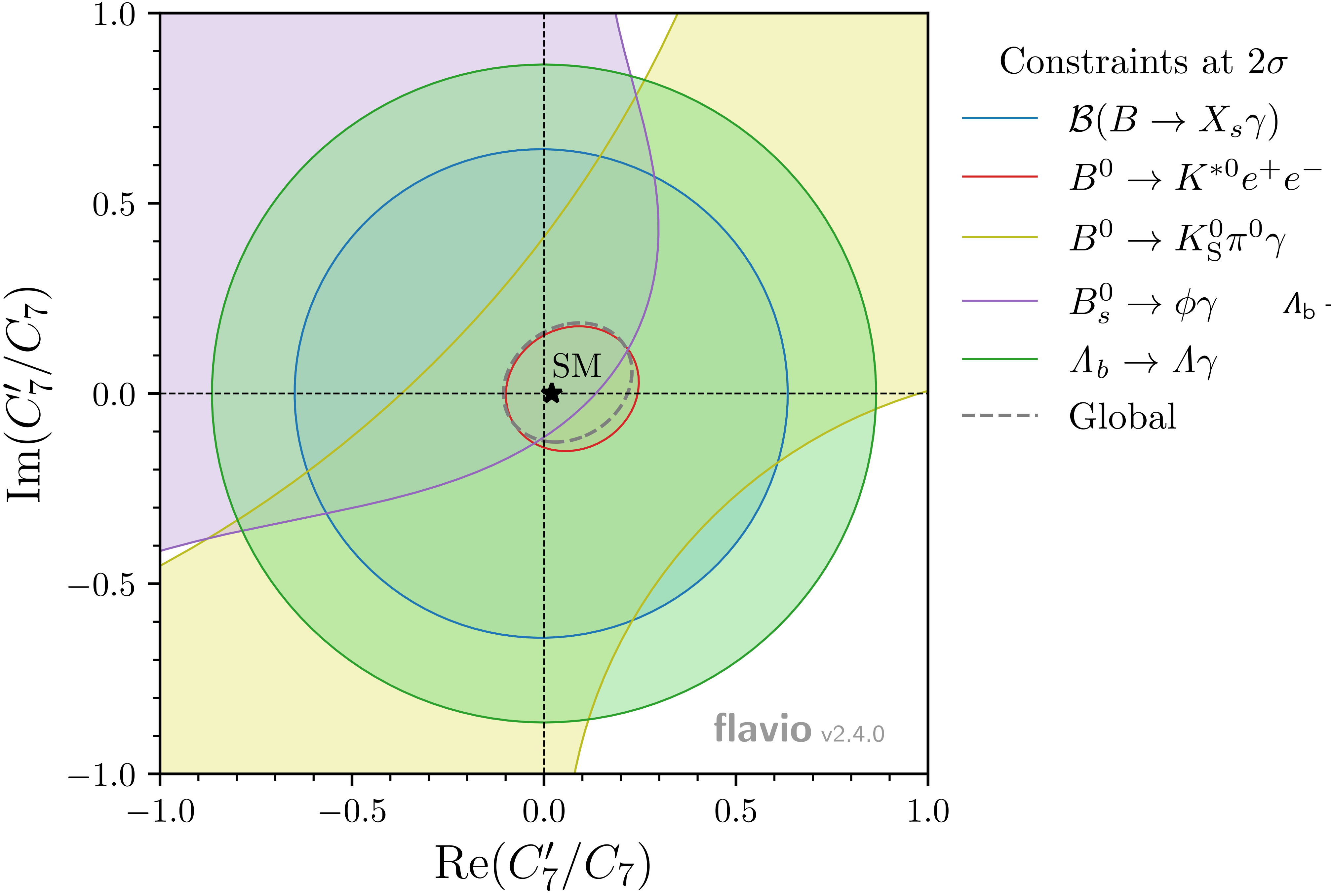
Phys. Rev. Lett. 123 (2019) 081802



Phys. Rev. D105 (2022) L051104



S~ 450



$\Lambda_b \to \Lambda\gamma : \alpha_\gamma \sim \frac{1-\left|\frac{C_7'}{C_7}\right|^2}{1-\left|\frac{C_7'}{C_7}\right|^2}$

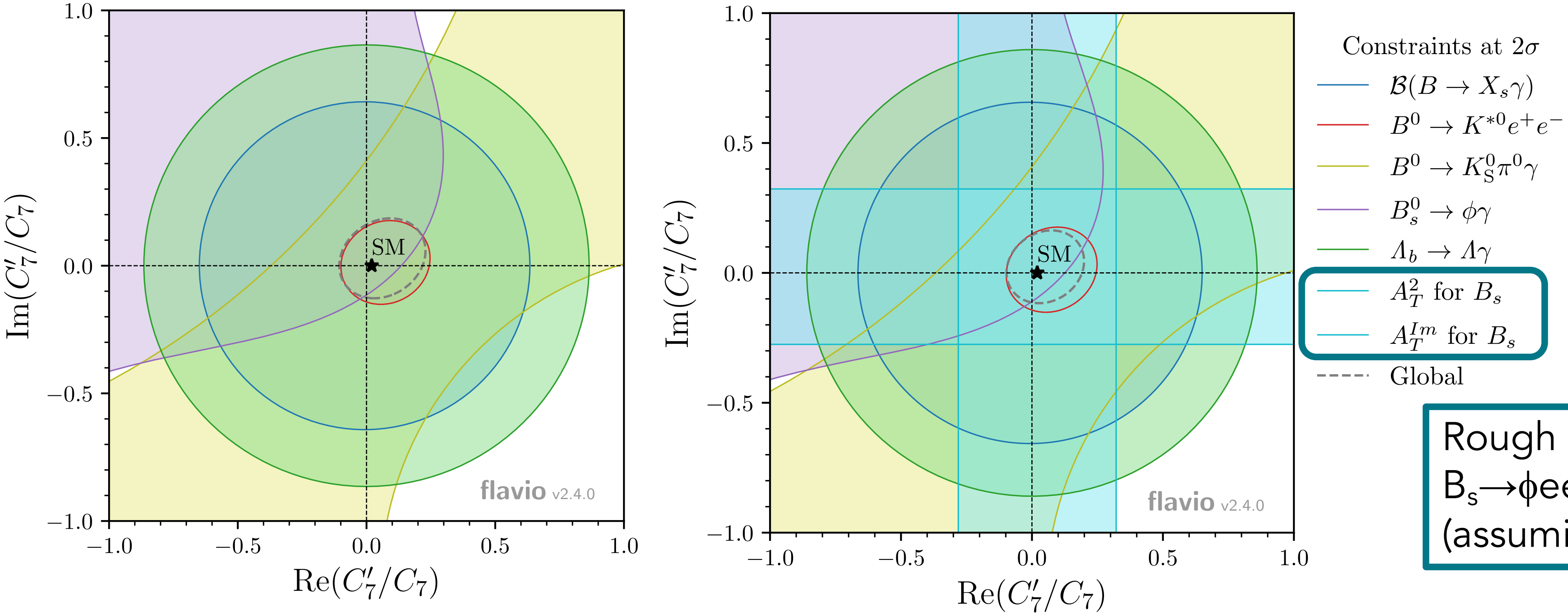
Something else ?

Some informal thinking ….

What could we still do in LHCb using Run1 & Run2 ?

On top of updating of the tagged time dependent analysis $B_s \to \Phi\gamma$

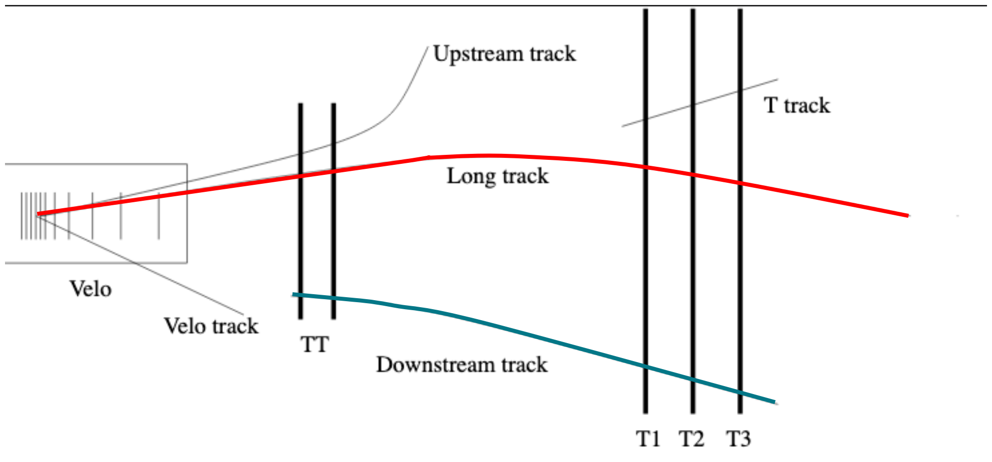
- $B_s \to \phi ee$:
  - limited sample size (compared to K*ee).
  - cleaner due to the hadronic resonance characteristic



Rough expected impact of $B_s \to \phi ee$ using Run1 + Run2 data (assuming SM values)

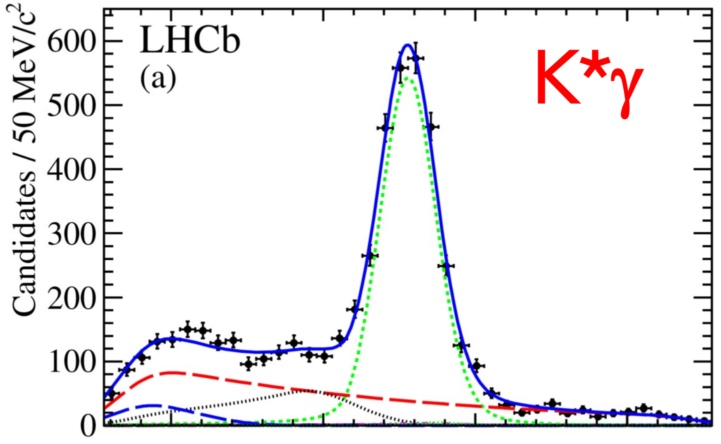
and what about converted photons ?

In LHCb ~ 4% of the photons are converting such as they can be reconstructed as LL track pairs

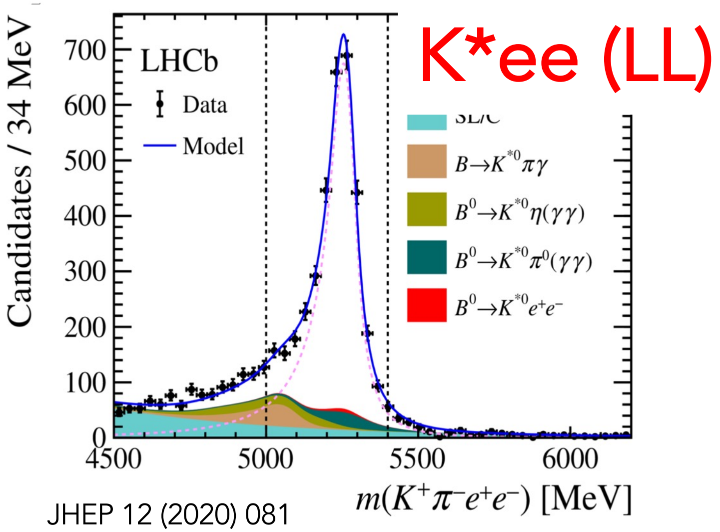


High quality tracks with excellent properties measurements (but bremsstrahlung …)

Phys. Rev. D85 (2012) 112013



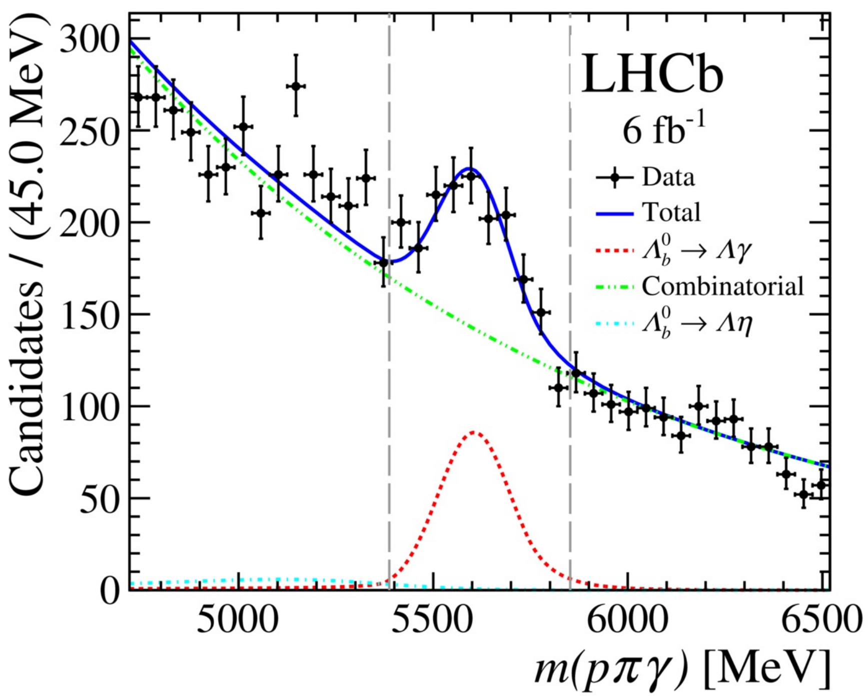
Roughly 30% more DD than LL (and cleaner?)



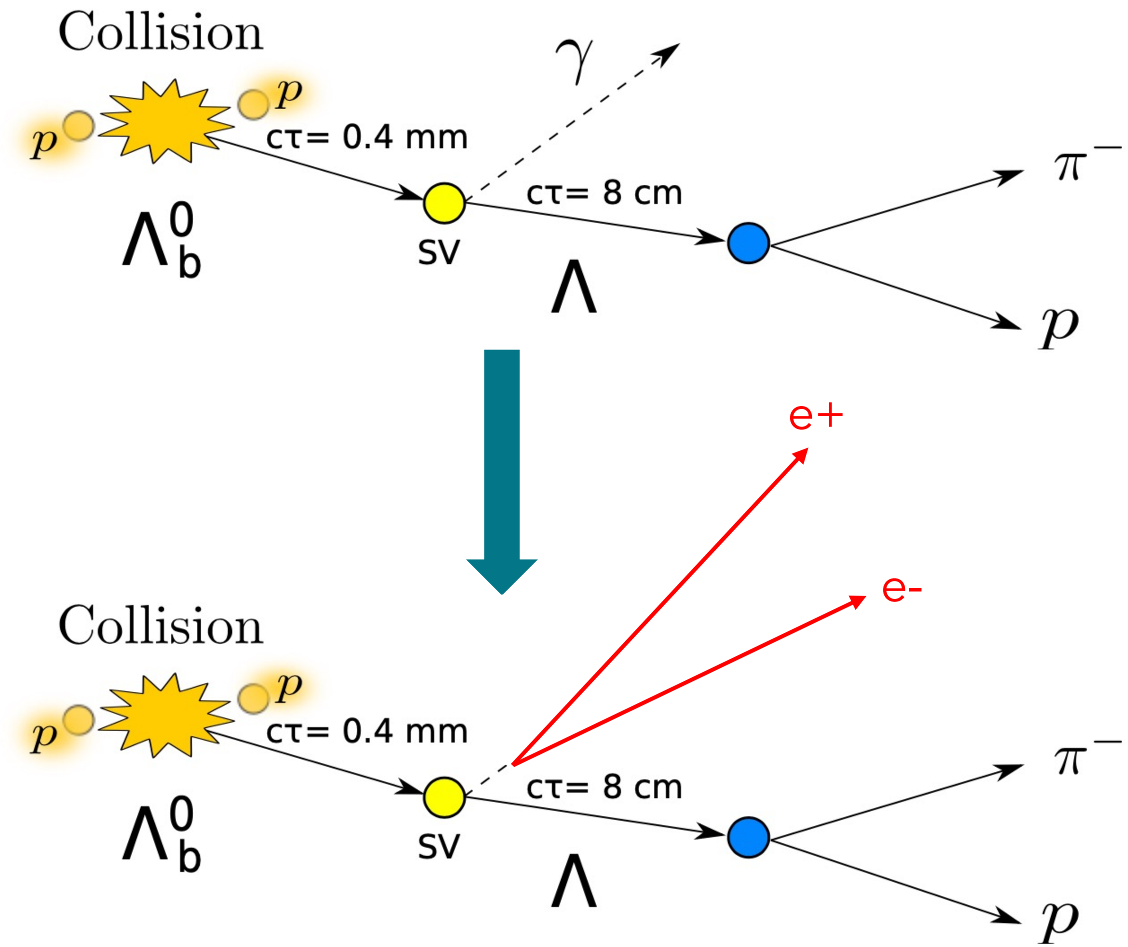
JHEP 12 (2020) 081

Could be interesting with a large integrated luminosity … and when vertexing would help !

Phys. Rev. D105 (2022) L051104



From PhD thesis of Luis Miguel Garcia Martin (2020)



Easier triggering
Lower background level accessible ?

Converted photons and photon polarization measurement

Weizacker-Williams approximation

In the cm of the ee pair :

$$d\sigma = \left(\frac{\beta r_0^2}{2x^2}\right)\{(1-\beta^2\cos^2\theta)^{-1} - \frac{1}{2} + 2\beta^2(1-\beta^2)(1-\beta^2\cos^2\theta)^{-2}\sin^2\theta\cos^2\phi\}\sin\theta d\theta d\phi.$$

x : photon energy in units of m_e — θ_ℓ — e velocity

G. C. Wick, Phys. Rev. 81 (Feb, 1951) 467- 468.

$$M(ee) = \frac{2m_e}{\sqrt{1-\beta^2}}$$

Work done with J. Lefrancois in the context of Martino Borsato PhD (2015)

The polarization is visible through the ϕ distribution

$$d\sigma = \left(\frac{\beta r_0^2}{2x^2}\right)\{(1-\beta^2\cos^2\theta)^{-1} - \frac{1}{2} + \cancel{2\beta^2(1-\beta^2)(1-\beta^2\cos^2\theta)^{-2}\sin^2\theta\cos^2\phi}\}\sin\theta d\theta d\phi.$$

$\beta \to 1$

'large' M(ee)

In short : sensitivity at very low M(ee) (< 5 – 10 MeV) where we cannot measure ϕ …

JHEP

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Probing the photon polarization in $B \to K^*\gamma$ with conversion

Fady Bishara[a,b] and Dean J. Robinson[c,d]

$$B \to (K^* \to K^+\pi^-)(\gamma \overset{\text{BH}}{\to} e^+e^-)$$

$$re^{i(\phi+\delta)} \equiv \frac{\mathcal{A}(B \to K^*\gamma_L)}{\mathcal{A}(B \to K^*\gamma_R)}$$

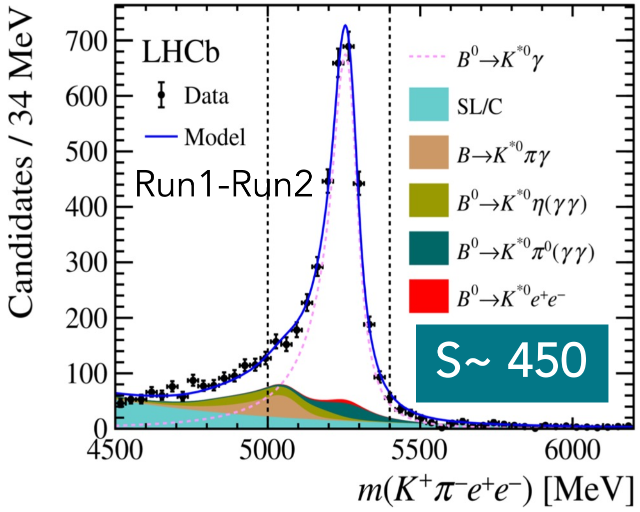
Impact of the various measurements

Decay mode	Sensitivity to r = C'_7/C_7	Experimental considerations
$B^0 \to K^{*0} (\to K^0 \pi^0) \gamma$	r	B-Factories only. Challenging. Low stat.
$B_s \to \Phi\gamma$	r	LHCb only. Acceptance control . Effective tagging efficiency (~ 5%)
$B^0 \to K^{*0}ee$ very low-q2	r. The lower-q2, the cleaner	B-factories & LHCb. 3D angular fit.
$B_s \to \Phi ee$ very low-q2	r . The lower-q2, the cleaner	LHCb only. 3D angular fit. Clean but statistics ~ K*ee/4
$\Lambda_b \to \Lambda\gamma$	r^2	LHCb only. 1D angular fit. Trigger challenges
$B \to K^{**} (\to K\pi\pi) \gamma$	r^2 but theoretical uncertainties ?	B factories & LHCb. Large sample (14k events in Run1) challenging
$B^0 \to K^{*0} \gamma_{conv}(\to ee)$	r. Theoretically possible ?	Would require a dedicated exp (!)

Conclusion

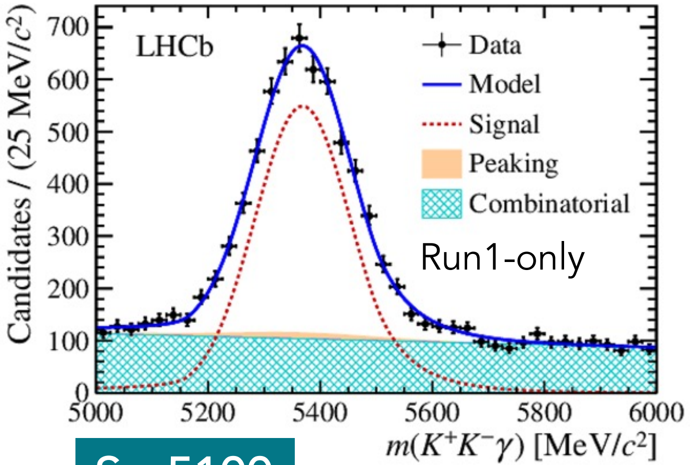
- The interplay is indeed present !
- Not a single way to access the photon polarization in $b \to s\gamma$ transitions.
- Use of converted photons instead of “normal” photons
  - large integrated luminosity
  - background so large that vertexing is mandatory
- Need Run3 to start exploring the (challenging) domain of $b \to d\gamma$ transitions via $b \to dee$ transitions in the very-low q^2 region.

STAY TUNED



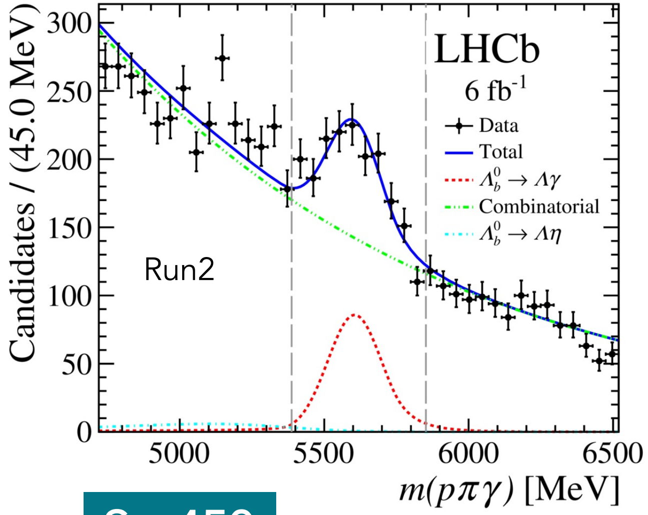
S~ 450

Phys. Rev. Lett. 123 (2019) 081802



S~ 5100

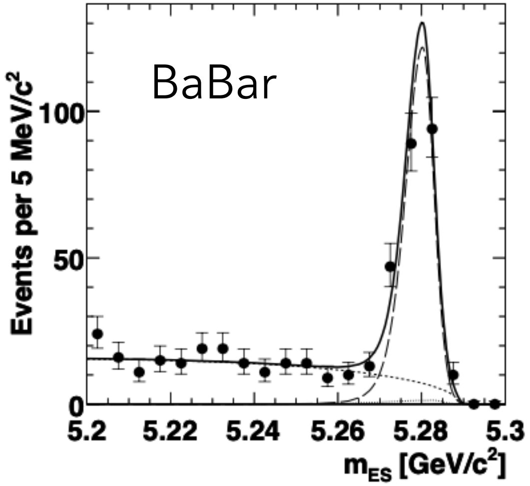
Phys. Rev. D105 (2022) L051104



S~ 450

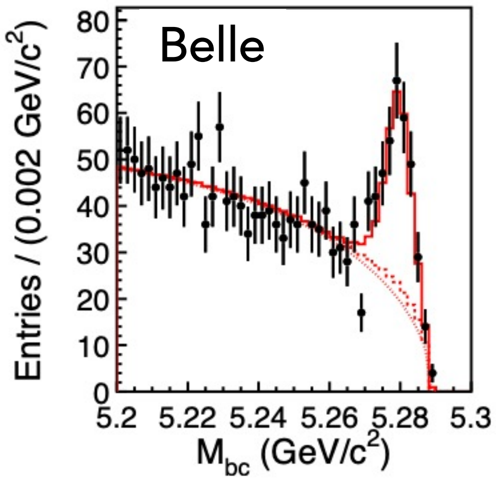
S~ 130 (K*0 region)

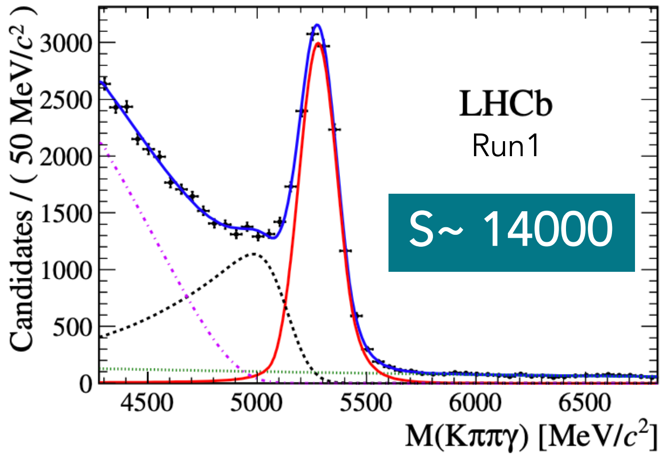
Phys.Rev.D78:071102,2008



S ~ 110 (K*0 region)

Phys.Rev.D74:111104,2006





S~ 14000