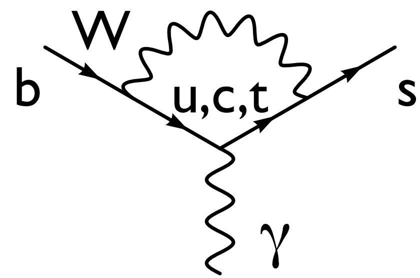
Experimental results in radiative B decays

towards a measurement of $b \to s\gamma$ photon polarization in LHCb

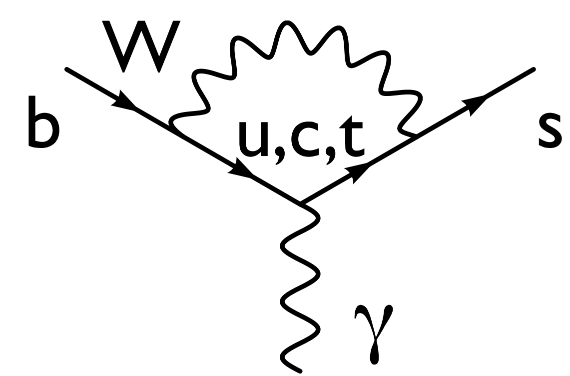


Martino Borsato
On behalf of the LHCb collaboration

Implications of LHCb measurements and future prospects
CERN 15-17 October 2014

Introduction

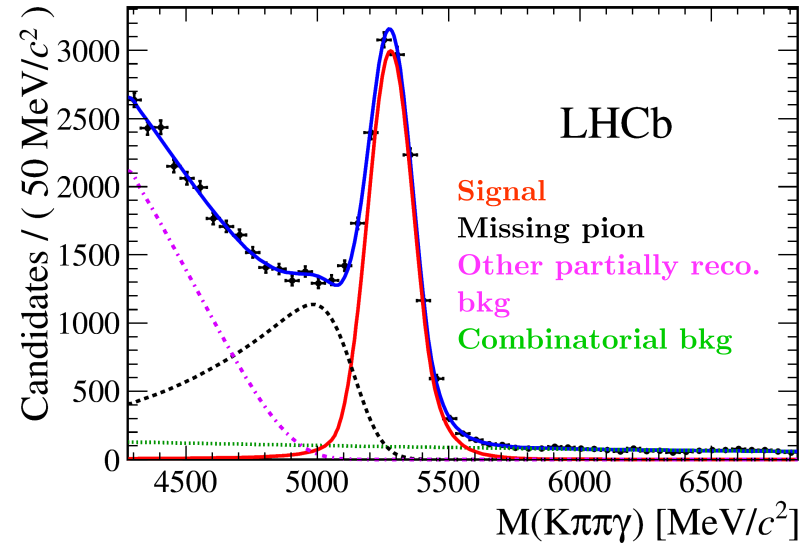
- $b \to s\gamma$ transitions amongst most sensitive to NP in LHCb
- FCNC $\to$ NP may enter in the electroweak penguin loop
- Gamma polarization is left handed in SM up to $\mathcal{O}(m_s/m_b)$
  $\to$ NP may change the chirality inside the loop
- LHCb has lot of potential:
  - Up-down asymmetry in $B^{\pm} \to K^{\pm}\pi^{\mp}\pi^{\pm}\gamma$
  - Transverse asymmetries in $B^0 \to K^*\ell^+\ell^-$
    (in particular e^+e^- at very low q^2)
  - Time dependent analysis of $B_s^0 \to \phi\gamma$
  - more ...

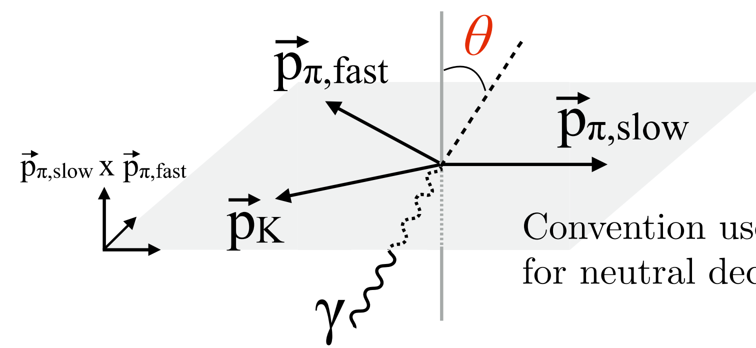


$\mathbf{B}^{\pm} \to \mathbf{K}^{\pm}\pi^{\mp}\pi^{\pm}\gamma$

PRL 112, 161801 (2014)

- **Published** analysis with $3\,\mathrm{fb}^{-1}$
- $\sim$14k signal events in $[1.1, 1.9]\,\mathrm{GeV}/c^2$ $K\pi\pi$ mass region $\to$ largest sample to date
- Many $K_{\mathrm{res}}^{(i)}$ will contribute and interfere $\to$ inclusive measurement in 4 $m(K\pi\pi)$ bins
- Photon polarization is the same for all $K_{\mathrm{res}}^{(i)}$ $\lambda_\gamma^{(i)} = \frac{|\mathcal{C}_7'|^2 - |\mathcal{C}_7|^2}{|\mathcal{C}_7'|^2 - |\mathcal{C}_7|^2} = \lambda_\gamma$ [PRD 66 054008]
- Measure the up down asymmetry $\mathcal{A}_{UD} = C\lambda_\gamma$ where C is the integral over the Dalitz plot $\to$ need input from theory to interpret $\mathcal{A}_{UD}$

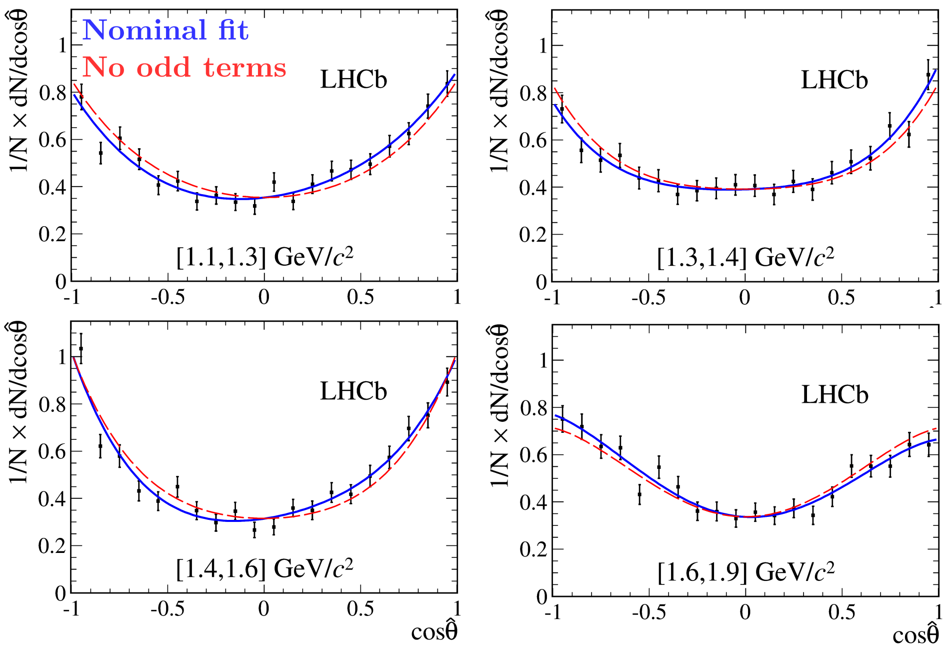


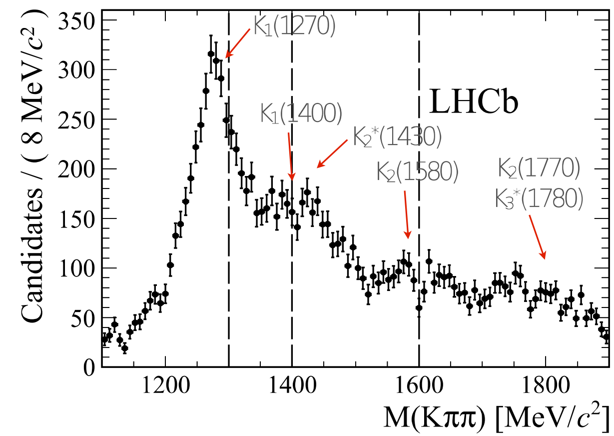


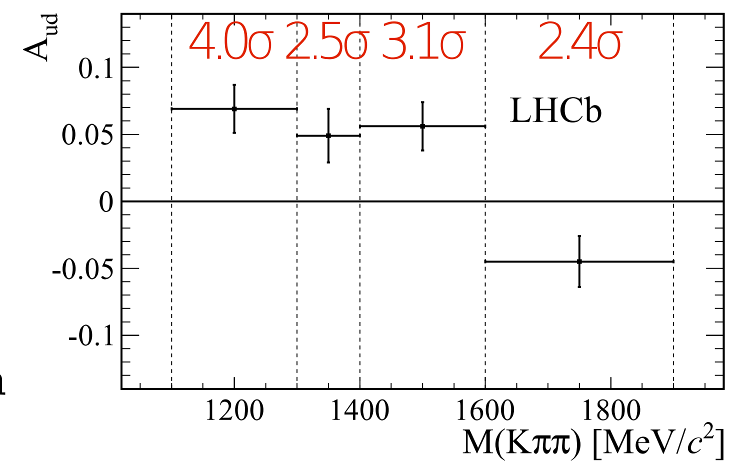
Convention used for neutral decays

$\mathbf{B}^{\pm} \to \mathbf{K}^{\pm}\pi^{\mp}\pi^{\pm}\gamma$

- Extract angular distributions in 4 bins of $m(K\pi\pi)$ through a χ^2 fit to 4th order polynomials





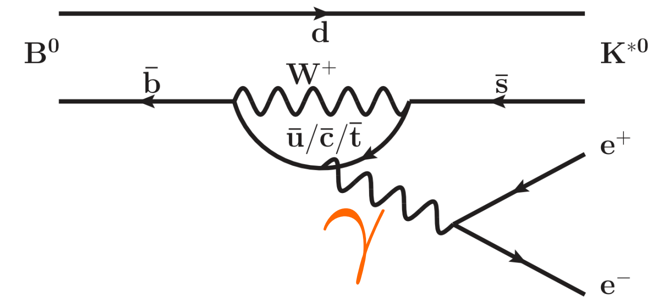


$\Rightarrow$ combined significance with respect to no-polarization scenario is 5.2σ

$\Rightarrow$ **first measurement of non-zero photon polarization in $b \to s\gamma$ tranistions**

Angular analysis of $B^0 \to K^{*0} e^+ e^-$

- Exploit electron channel to go very low in q^2 $\to$ analysis in q^2 bin $[0.0004, 1]\,\mathrm{GeV}^2$
- photon pole contribution dominating $\to$ very sensitive to photon polarization through an angular analysis



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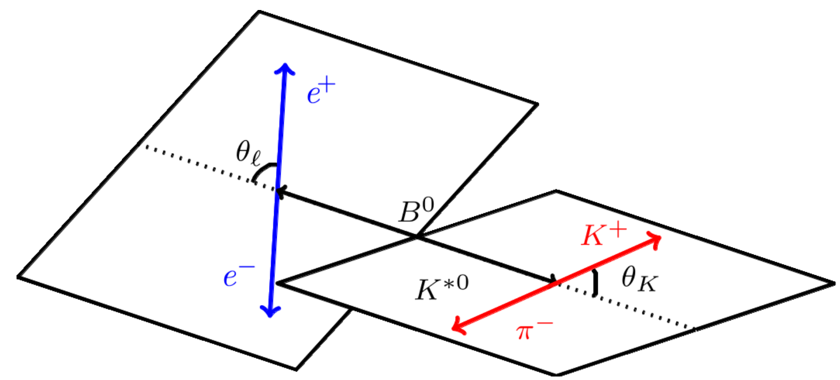
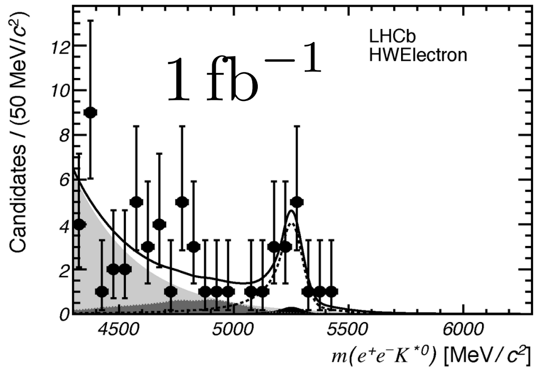
- measure $\mathrm{A}_{\mathrm{T}}^{(2)}$ and $\mathrm{A}_{\mathrm{T}}^{\mathrm{Im}}$ (also F_{L} and $\mathrm{A}_{\mathrm{T}}^{\mathrm{Re}}$)
- polarization information is in the ϕ angle which is experimentally very hard to bias



Angular analysis of $B^0 \to K^{*0} e^+ e^-$

- Branching ratio paper with $1\,\mathrm{fb}^{-1}$ JHEP1305(2014)159
  between 30 and 1000 MeV/c^2 ($\sim$ 30 events)
  $\mathcal{B}(B^0 \to e^+e^- K^{*0}) = (3.1\ ^{+0.9}_{-0.8}\ ^{+0.2}_{-0.3} \pm 0.2) \times 10^{-7}$

- Angular analysis with $3\,\mathrm{fb}^{-1}$ in **well advanced stage**
  - $m(e^+e^-)$ down to $20\,\mathrm{MeV}/c^2$
  - Better efficiency through MVA and isolation
  - Angular acceptance and background distributions modelled using MC and data from proxies $B^0 \to K^{*0}\gamma$ and $B^0 \to J/\psi\,(e^+e^-)K^{*0}$
  - Fit $m(K^*e^+e^-)$ and three angles $\cos\theta_l$, $\cos\theta_K$ and $\tilde{\phi}$ $\to$ extract 4 physical observables F_{L}, $\mathrm{A_T^{Re}}$, $\mathrm{A_T^{(2)}}$, $\mathrm{A_T^{Im}}$ (use ϕ folding to simplify the angular expression)
  - Efficiency is not flat in q^2
    $\Rightarrow$ provide $< q^2 >$ value as input to theory



3 fb^{-1} Sensitivity from toy-MC

	F_{L}	$\mathrm{A_T^{Re}}$	$\mathrm{A_T^{(2)}}$	$\mathrm{A_T^{Im}}$
σ^{stat}	0.07	0.17	0.25	0.25
σ^{syst}	0.03	0.05	0.05	0.05

- **Sensitivity to photon polarization**
- Complementarity to $B^0 \to K^{*0}\mu\mu$
- prospects: error dominated by statistics
  $\Rightarrow$ **good times ahead!**

Time dependent $B_s^0 \to \phi\gamma$

- The time dependent analysis with $3\,\text{fb}^{-1}$ is in **well advanced stage**

- The large $\Delta\Gamma_s$ allows to be sensitive to photon-polarization through an untagged analysis

$$\Gamma(t) = |A|^2 e^{-\Gamma_s t}\left(\cosh\frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_s t}{2}\right)$$

- SM value of $\mathcal{A}^{\Delta} = 0.047 \pm 0.025 \pm 0.015_{\alpha_S}$

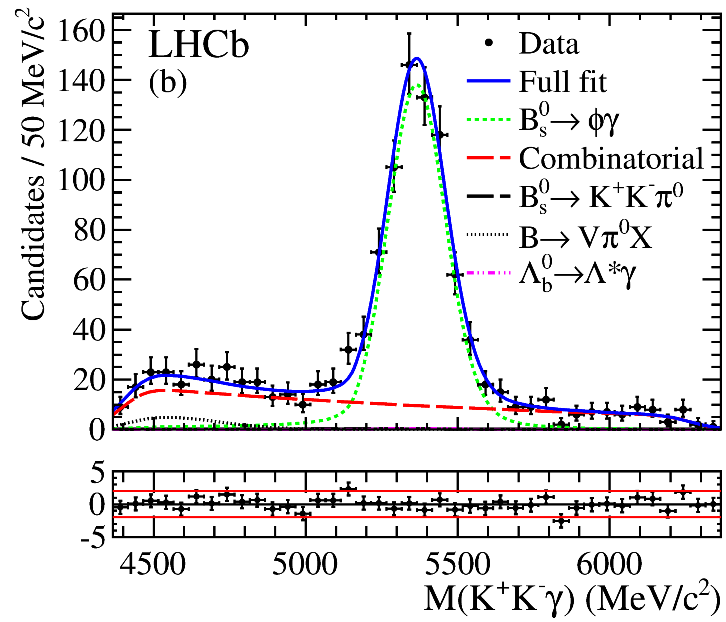
[Muheim, Xie, Zwicky, PLB664(08)174]

- expect a sensitivity of ~ 0.3 on $\mathcal{A}^{\Delta}$ with current statistics

- Statistically limited $\to$ good!

BR measured with $1\,\text{fb}^{-1}$

Nucl.Physics B 2013



Conclusions and prospects

- $b \to s\gamma$ polarization is being explored by LHCb
  - first observation of non-zero polarization in $B \to K\pi\pi\gamma$
  - need strong theoretical input to interpret result in terms of λ_γ measurement (investigating also full amplitude analysis)
  - $B^0 \to e^+e^-K^{*0}$ angular analysis being utlimated, $\sigma(\mathrm{A}_{\mathrm{T}}^{(2)}) \simeq 0.25$
  - time dependent $B_s^0 \to \phi\gamma$ well advanced, $\sigma(\mathcal{A}^{\Delta}) \simeq 0.3$
- – significant signal seen on $B \to VV\gamma$, $B^+ \to \phi K^+\gamma$

- Expect to gain a factor 2 on statistical errors with Run2 data
- Much more precision will be available with LHCb upgrade (2020)

BACKUP

Angular analysis of $B^0 \to K^{*0} e^+ e^-$

Folding: $\tilde{\phi} = \phi + \pi$ if $\phi < 0$ (and $\tilde{\phi} = \phi$ otherwise) $\rightarrow$ removes $J_{4,5,7,8}$

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2} \frac{\mathrm{d}^4(\Gamma+\bar{\Gamma})}{\mathrm{d}q^2\ \mathrm{d}\cos\theta_\ell\ \mathrm{d}\cos\theta_K\ \mathrm{d}} = \frac{9}{16\pi}\Bigg[\frac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \left(\frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K - F_\mathrm{L}\cos^2\theta_K\right)\cos(2\theta_\ell) + \frac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\sin^2\theta_\ell \boxed{\cos 2\phi\ \mathrm{A}_\mathrm{T}^{(2)}} + (1-F_\mathrm{L})\sin^2\theta_K \boxed{\cos\theta_l\ \mathrm{A}_\mathrm{T}^{\mathrm{Re}}} + \frac{1}{2}(1-F_\mathrm{L})\sin^2\theta_K\sin^2\theta_\ell \boxed{\sin 2\phi\ \mathrm{A}_\mathrm{T}^{\mathrm{Im}}}\Bigg]$$

$$\mathrm{A}_\mathrm{T}^{(2)} = P_1$$
$$\mathrm{A}_\mathrm{T}^{\mathrm{Im}} = -2P_3^{\mathrm{CP}}$$
$$\mathrm{A}_\mathrm{T}^{\mathrm{Re}} = 2P_2$$

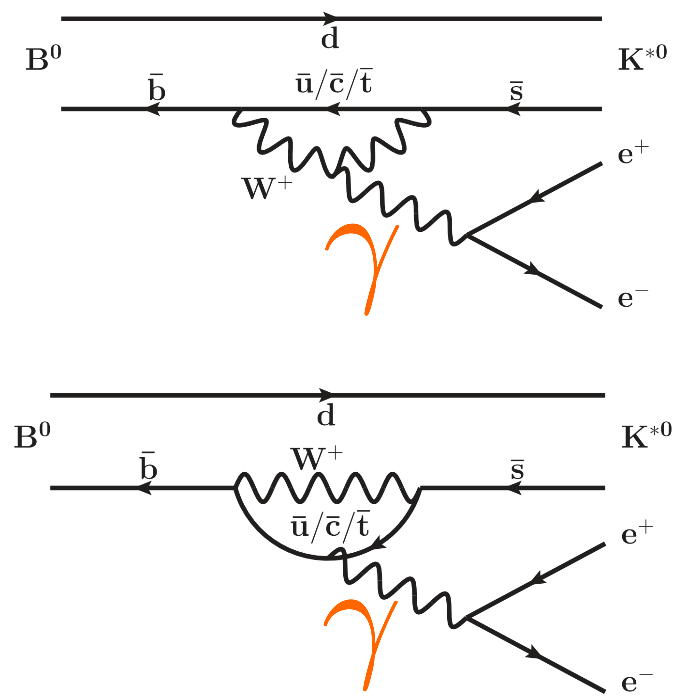
Angular analysis of $B^0 \to K^{*0} e^+ e^-$

- A_R/A_L to the 10% level (if it is small and real) $\Rightarrow \ \sigma(\frac{A_R}{A_L}) \sim \frac{\sigma(\mathrm{A}_\mathrm{T}^{(2)})}{2} \sim 0.12$

- $\lim_{q^2\to 0} \mathrm{A}_\mathrm{T}^{(2)} = \frac{2\mathcal{R}e(C_7^{\mathrm{eff}} C_7'^{\,\mathrm{eff}*})}{|C_7^{\mathrm{eff}}|^2 + |C_7'^{\,\mathrm{eff}}|^2}$
  $\lim_{q^2\to 0} \mathrm{A}_\mathrm{T}^{\mathrm{Im}} = \frac{2\mathcal{I}m(C_7^{\mathrm{eff}} C_7'^{\,\mathrm{eff}*})}{|C_7^{\mathrm{eff}}|^2 + |C_7'^{\,\mathrm{eff}}|^2}$

- loss of sensitivity on $\mathrm{A}_\mathrm{T}^{(2)}$ as a function of q^2 with $\frac{1-4m_\ell^2/q^2}{1+2m_\ell^2/q^2}$

- but above $1\,\mathrm{GeV}^2$ the μ mode has same sensitivity and higher yield in LHCb



Time dependent $B_s^0 \to \phi\gamma$

[Muheim, Xie, Zwicky, PLB664(08)174]

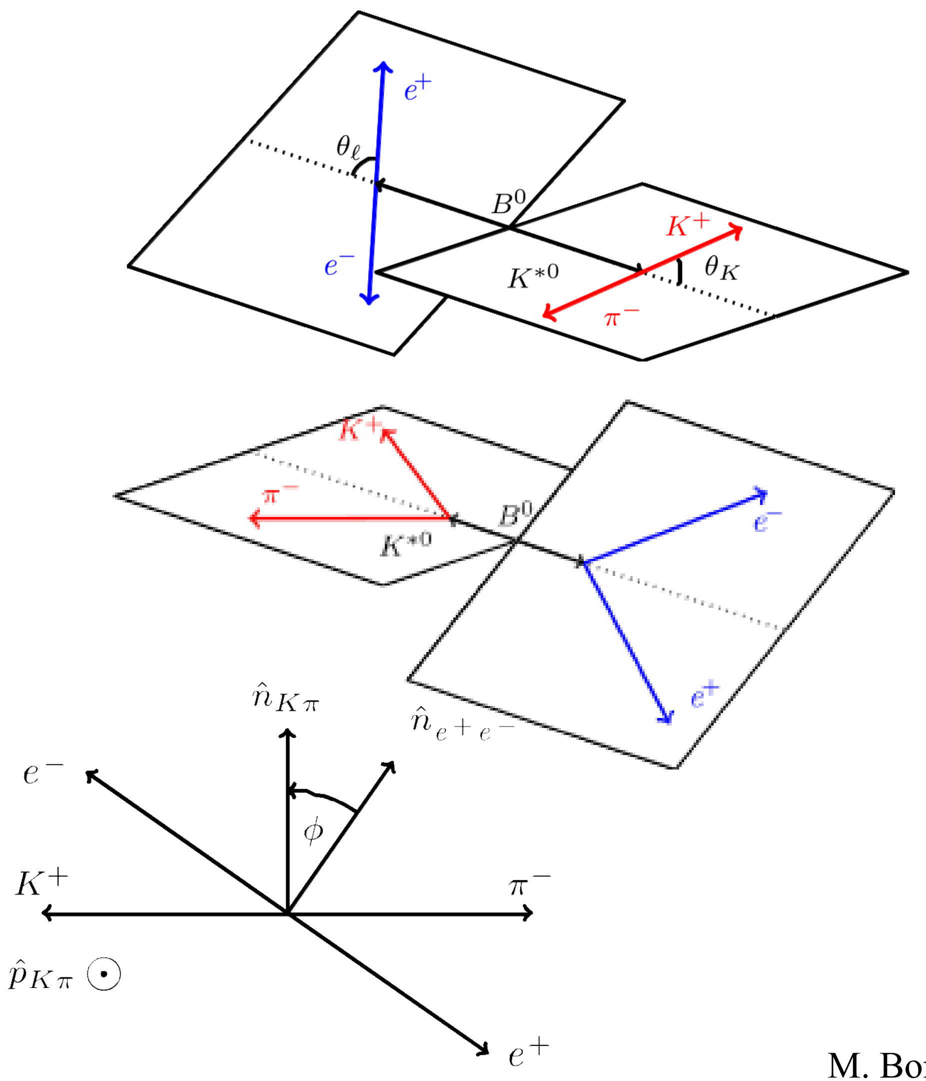
- The large $\Delta\Gamma_s$ allows to be sensitive to photon-polarization through an untagged analysis

$$\Gamma(t) = |A|^2 e^{-\Gamma_s t}\left(\cosh\frac{\Delta\Gamma_s t}{2} - \mathcal{A}^{\Delta}\sinh\frac{\Delta\Gamma_s t}{2}\right)$$

$$\mathcal{A}^{\Delta} = \frac{2\mathcal{R}e\left[\frac{q}{p}\left(\bar{\mathcal{A}}_L\mathcal{A}_L^* + \bar{\mathcal{A}}_R\mathcal{A}_R^*\right)\right]}{|\mathcal{A}_L|^2 + |\bar{\mathcal{A}}_L|^2 + |\mathcal{A}_R|^2 + |\bar{\mathcal{A}}_R|^2}$$

- SM value of $\mathcal{A}^{\Delta} = 0.047 \pm 0.025 \pm 0.015_{\alpha_S}$

3 Angles



- θ_l is defined as the angle btw the dir of the e^+ (e^-) in the dielectron rest frame and the direction of the dielectron in the B^0 ($\overline{B}^0$) rest frame

- θ_K is defined as the angle btw the dir of the K in the K^{*0} ($\overline{K}^{*0}$) rest frame and the direction of the K^{*0} ($\overline{K}^{*0}$) in the B^0 ($\overline{B}^0$) rest frame

- Φ is defined as the angle btw the plane containing the e^+ and e^- and the plane containing the K and the π.
  The definition does not change under a CP transformation (CP-symmetric observables)