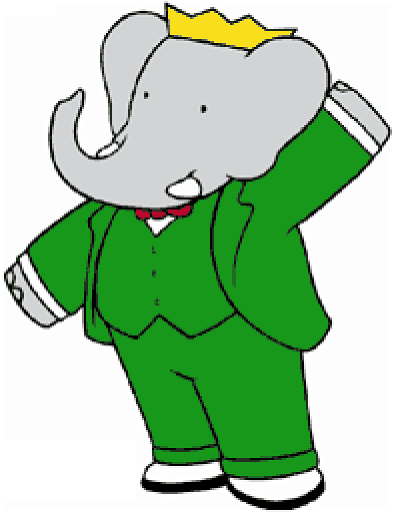


Studies of the rare decays $B \to K^{*} l^{+} l^{-}$ and $B \to K\pi^{+}\pi^{-}\gamma$ and search for $B^{+} \to K^{+}\tau^{+}\tau^{-}$ with the *BABAR* detector

Tim Gershon

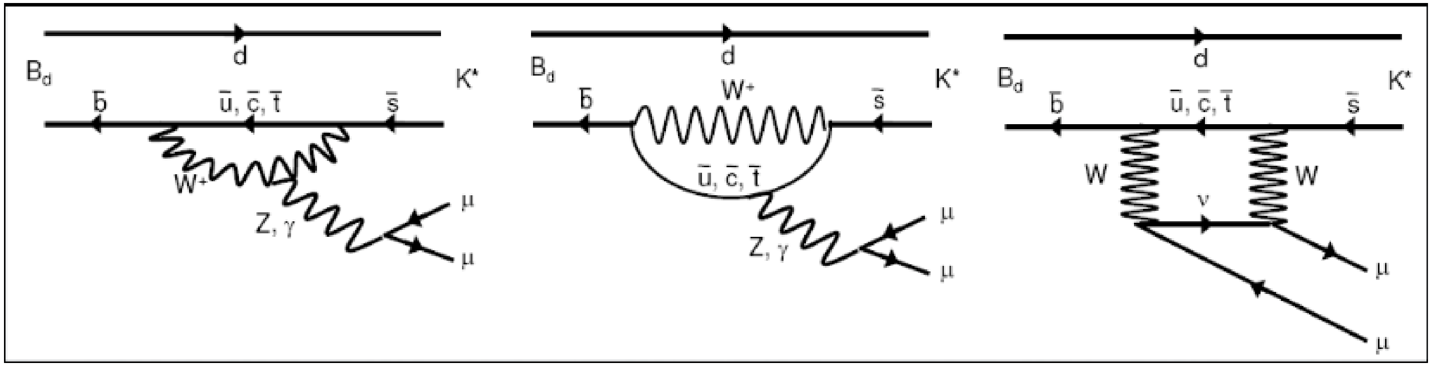
University of Warwick

On behalf of the *BABAR* collaboration

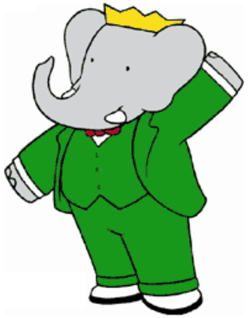
6th August 2016

Outline

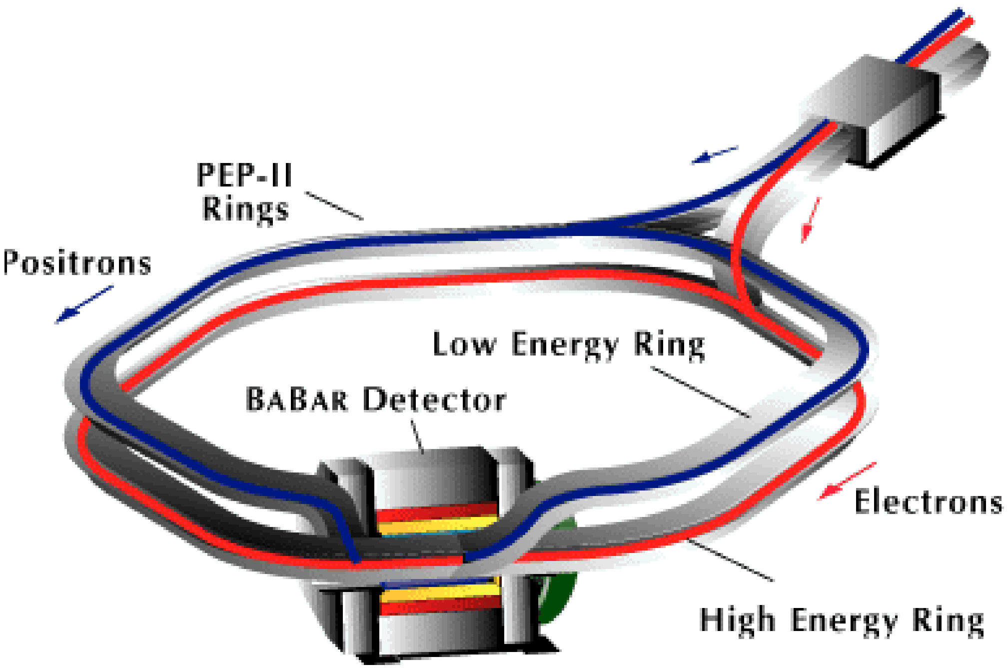
- Flavour-changing neutral current *B* decays are sensitive to physics beyond the Standard Model
- Various observables can be constructed to test the SM: rates, asymmetries (kinematic, isospin, *CP*)
  - Results can be used to constrain Wilson coefficients
- BaBar collaboration has published many such measurements, but still has a few up its sleeve. Recent results include
  - $B \to K^{*}l^{+}l^{-}$: angular asymmetries PRD 93 (2016) 052015
  - $B \to K\pi^{+}\pi^{-}\gamma$: photon polarisation PRD 93 (2016) 052013
  - $B^{+} \to K^{+}\tau^{+}\tau^{-}$: search for rare decay arXiv:1605.09637

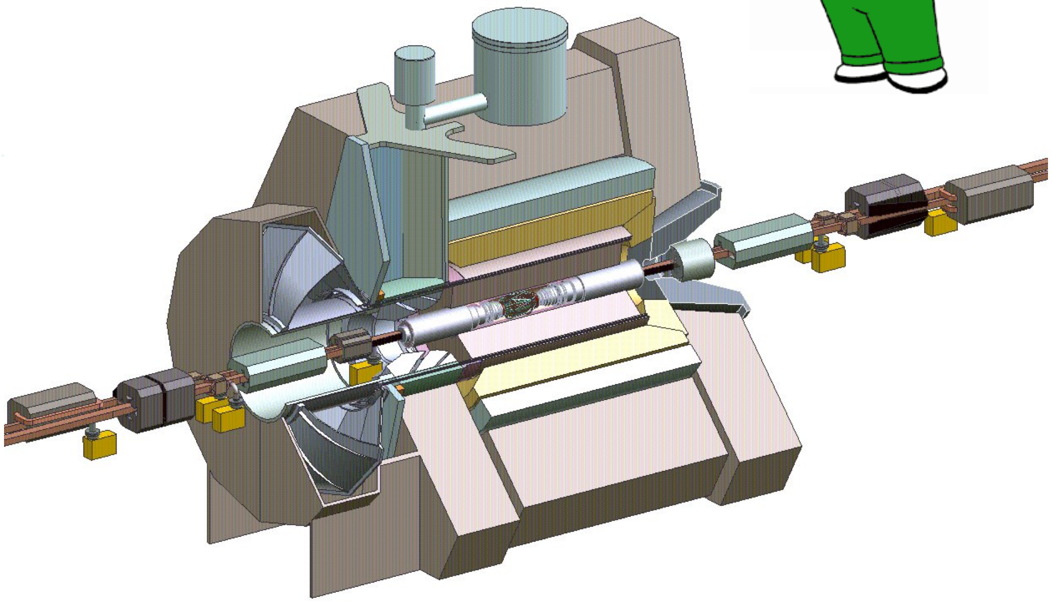


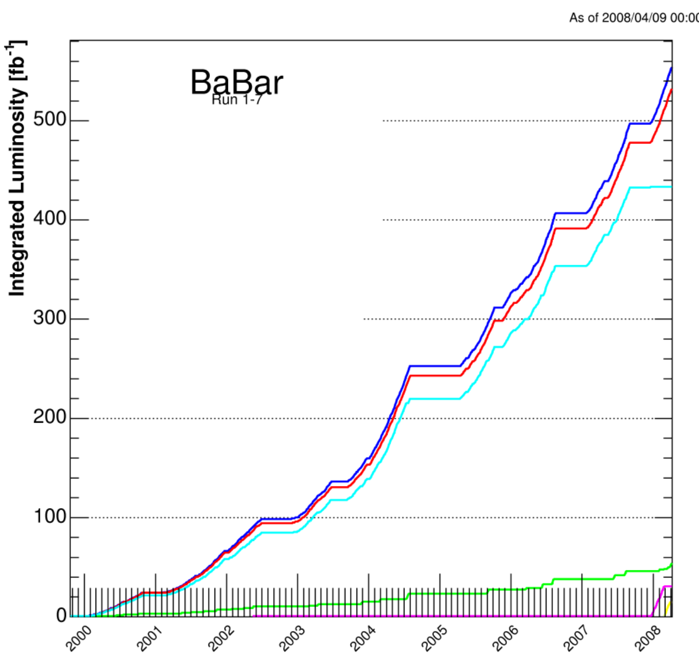
PEPII & BaBar



9.0 GeV e^- on 3.1 GeV e^+







424/fb on Υ(4S)

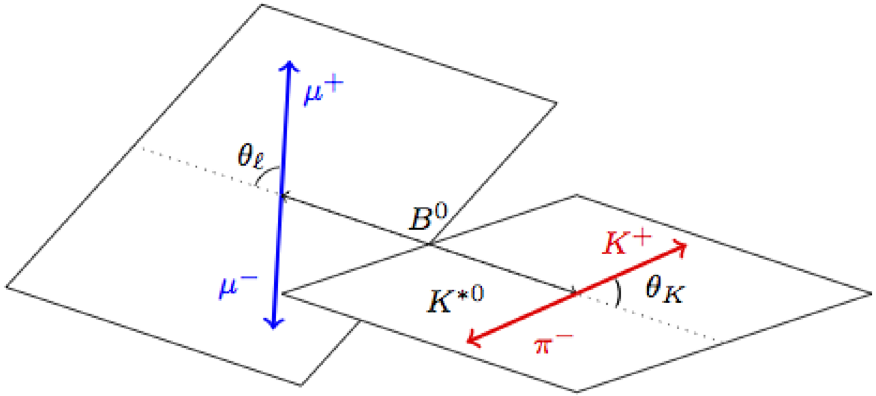
471 M $B\bar{B}$ pairs

PRD 93 (2016) 052015

Angular analysis of $B\to K^*l^+l^-$

Possible hints of BSM effects seen in previous analyses (e.g. LHCb JHEP 02 (2016) 104)

Determine longitudinal polarisation F_L and forward-backward asymmetry A_{FB} from $\cos\theta_K$ and $\cos\theta_l$ distributions



$$\frac{1}{\Gamma(q^2)}\frac{\mathrm{d}\Gamma}{\mathrm{d}(\cos\theta_K)} = \frac{3}{2}F_L(q^2)\cos^2\theta_K + \frac{3}{4}(1-F_L(q^2))(1-\cos^2\theta_K)\,.$$

$$\frac{1}{\Gamma(q^2)}\frac{\mathrm{d}\Gamma}{\mathrm{d}(\cos\theta_\ell)} = \frac{3}{4}F_L(q^2)(1-\cos^2\theta_l) + \frac{3}{8}(1-F_L(q^2))(1+\cos^2\theta_l) + \mathcal{A}_{FB}(q^2)\cos\theta_l\,.$$

Measurements in 5 bins of $q^2 = m(l^+l^-)^2$, with several B^+ & B^0 decays combined

First angular analysis of $B^+\to K^{*+}l^+l^-$

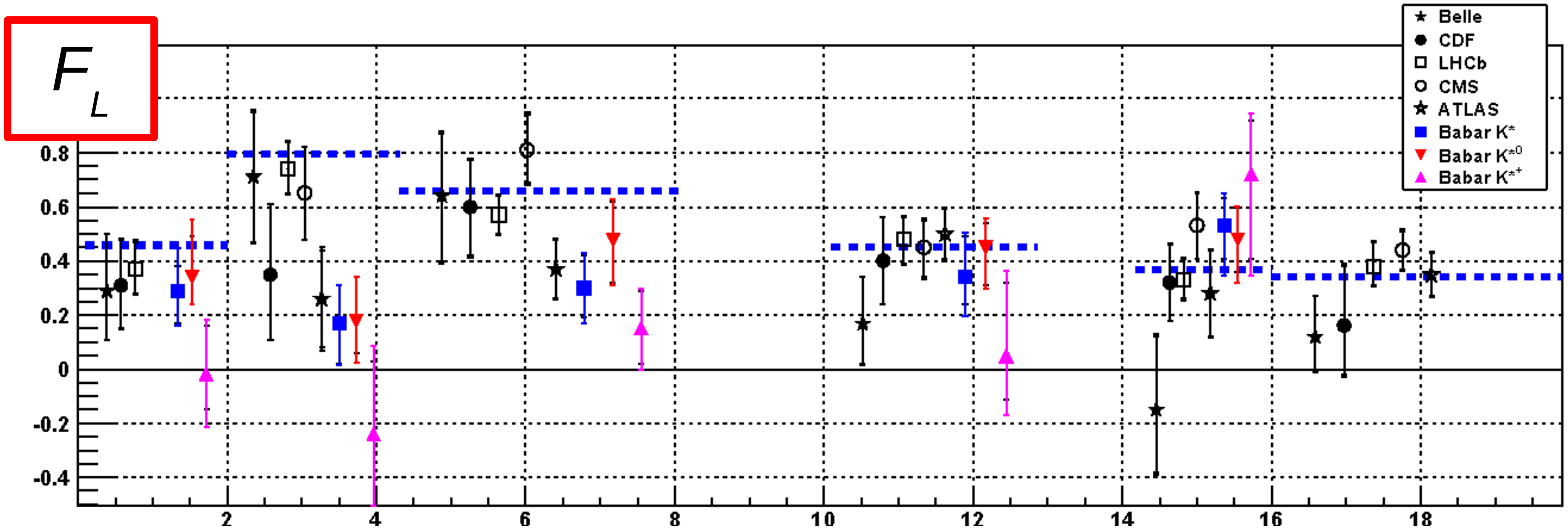
$B^+\to K^{*+}(\to K^+\pi^0)e^+e^-$ $B^+\to K^{*+}(\to K^0_S\pi^+)\mu^+\mu^-$

$B^+\to K^{*+}(\to K^0_S\pi^+)e^+e^-$ $B^0\to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$

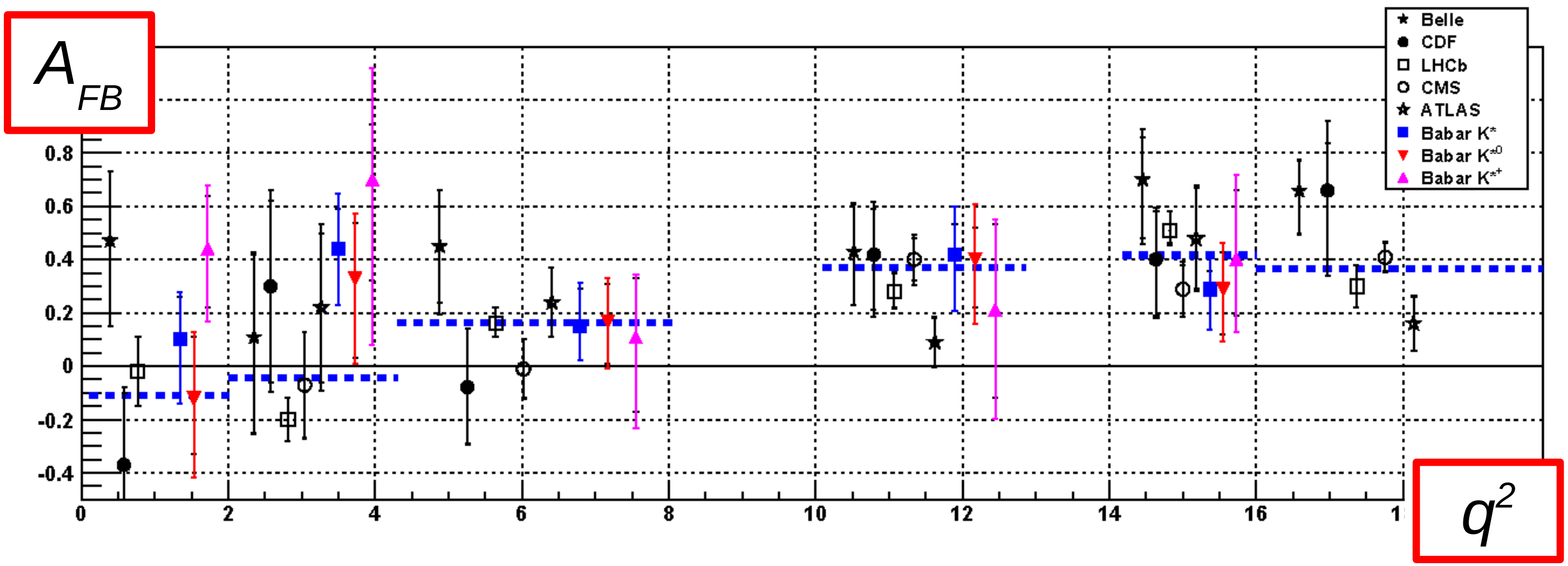
$B^0\to K^{*0}(\to K^+\pi^-)e^+e^-$

PRD 93 (2016) 052015

Angular analysis of $B \to K^* l^+ l^-$



SM predictions with ~ ± 10% uncertainties



Latest LHCb results not included

PRD 93 (2016) 052013

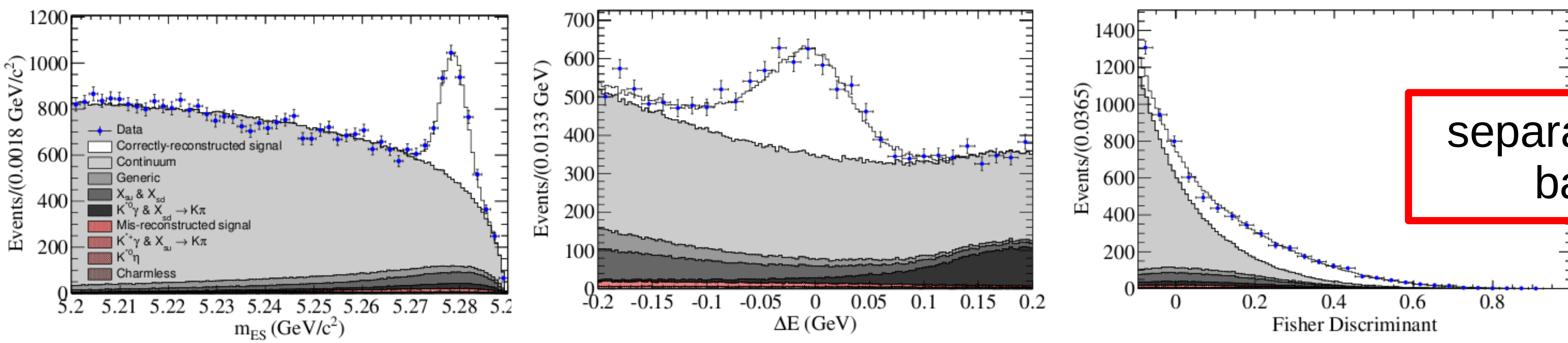
Photon polarisation in $B \to K\pi\pi\gamma$

- Photon polarisation in $b \to s\gamma$ transitions excellent probe for physics beyond SM in form of new right-handed currents
- Powerful method from time-dependent asymmetries of B^0 (also B_s^0) decays
  - if photon 100% polarised (~ as in SM), B and $\overline{B}$ give different final states → no interference: S = 0
  - if less polarised, interference term appears: S ~ sin(2ψ) sin(Φ)
    - ψ ~ polarisation; Φ ~ *CP* violation (PRL 79 (1997) 185, PRD71 (2005) 076003)
- Problem to accumulate enough statistics for a sensitive measurement
  - results from both BaBar and Belle on $B^0 \to (K_S\pi^0)_{K^*}\gamma$
  - desirable to add more final states, e.g. $B^0 \to K_S\rho^0\gamma$

Photon polarisation in $B \to K\pi\pi\gamma$

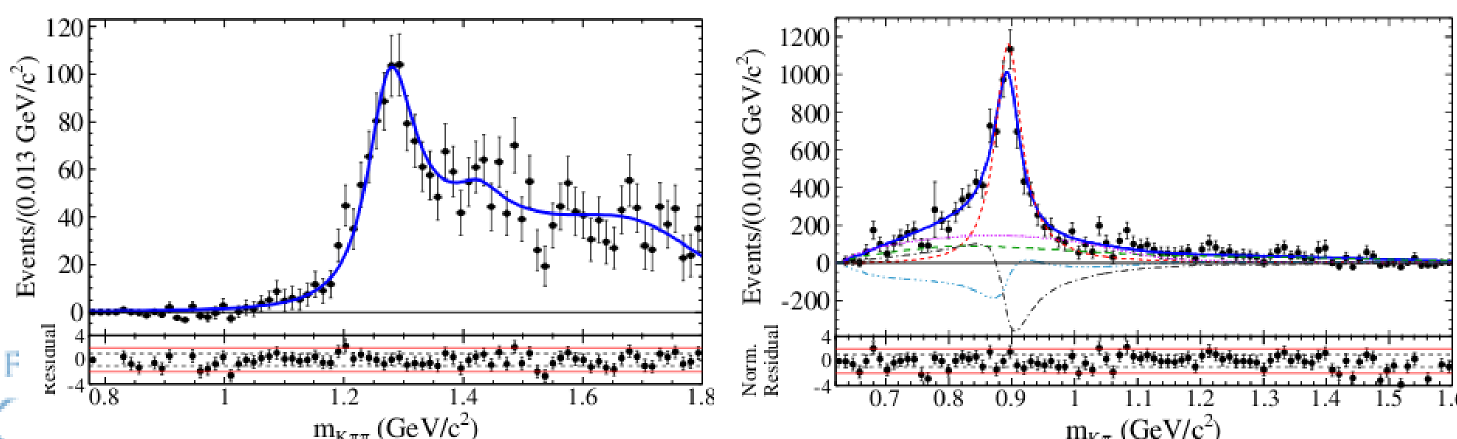
- Due to width of ρ meson, necessary to determine dilution factor
  - account for contributions from flavour-specific $B \to K^*\pi\gamma$ amplitude
  - $D_{K\rho\gamma} = S_{K\rho\gamma}/S_{K\pi\pi\gamma} = -0.78\,^{+0.19}_{-0.17}$ (obtained from $B^+ \to K^+\pi^+\pi^-\gamma$ decays)

Hebinger, Kou and Yu, LAL-15-75



separate signal from background

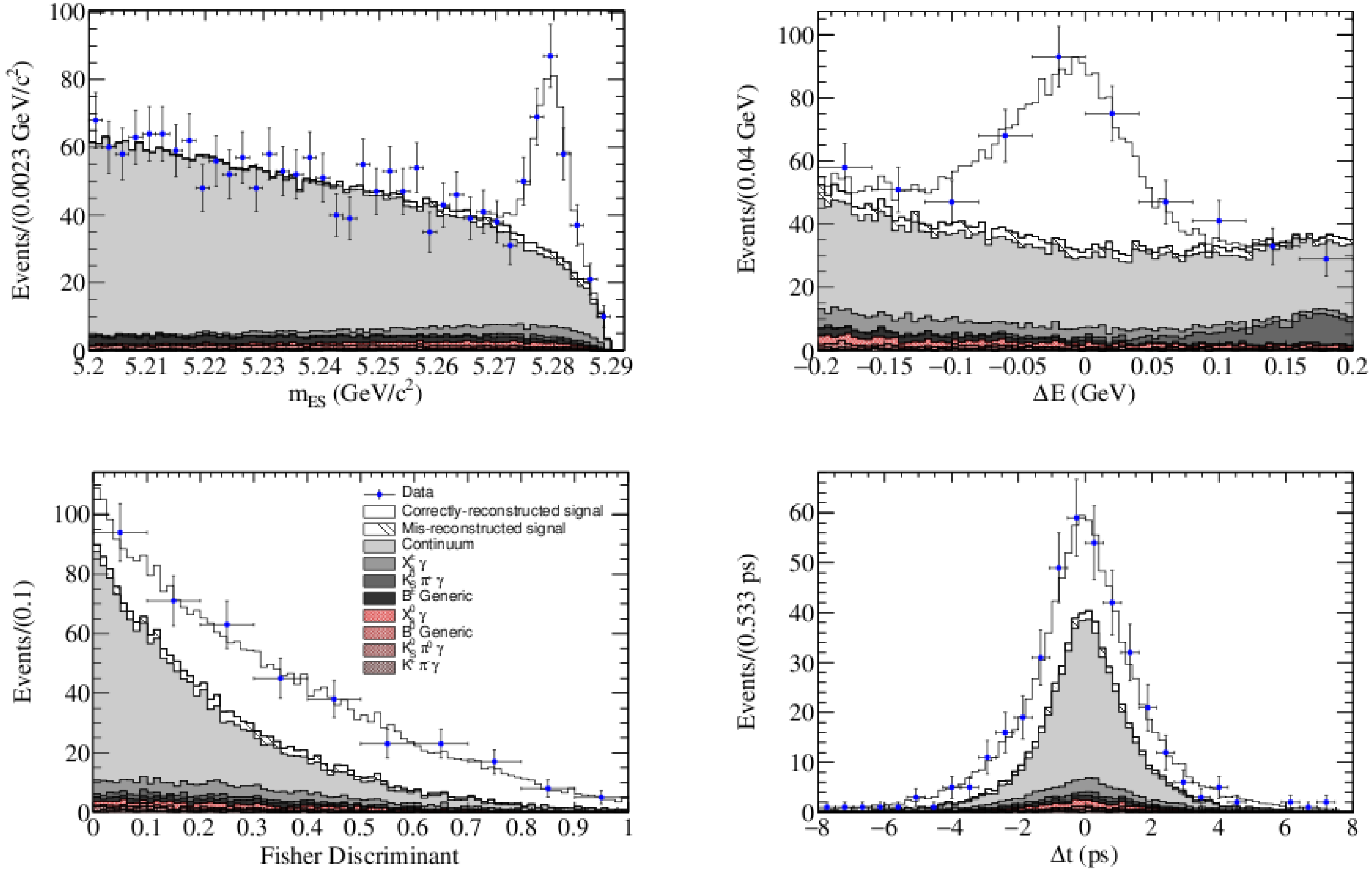
determine D from amplitude analysis fitting $m(K\pi\pi)$ and $m(K\pi)$



PRD 93 (2016) 052013

Photon polarisation in $B \to K\pi\pi\gamma$

Fit to $B^0 \to K_S \pi^+\pi^-\gamma$ sample



$$\mathcal{S}_{K^0_S\pi^+\pi^-\gamma} = \quad 0.14 \pm 0.25 \pm 0.03,$$
$$\mathcal{C}_{K^0_S\pi^+\pi^-\gamma} = -0.39 \pm 0.20^{+0.03}_{-0.02}.$$

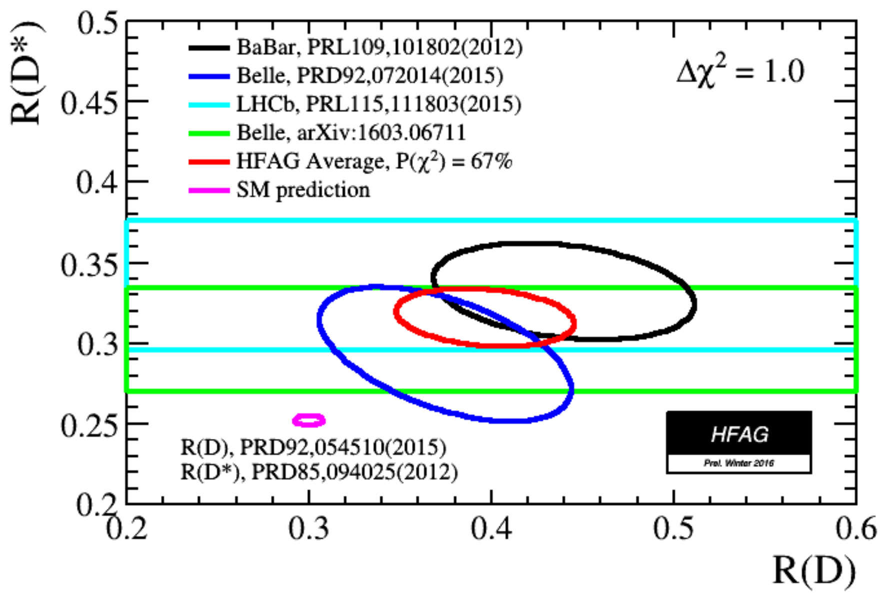
$\rightarrow$

$$\mathcal{S}_{K^0_S\rho\gamma} = -0.18 \pm 0.32^{+0.06}_{-0.05}.$$

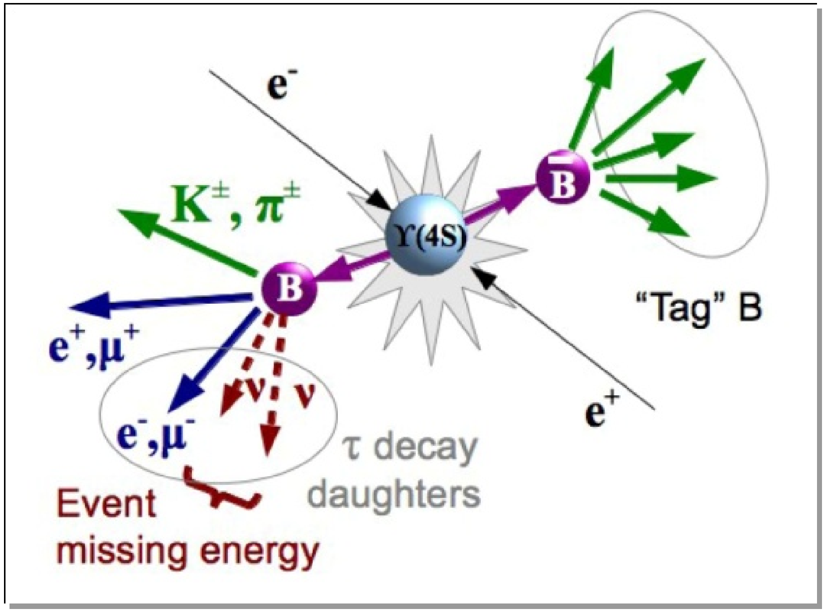
arXiv:1605.09637

Search for $B^+ \to K^+\tau^+\tau^-$

- Hints of lepton universality violation in both $B^+ \to K^+l^+l^-$ and $B \to D^{(*)}\tau^+\nu$ decays

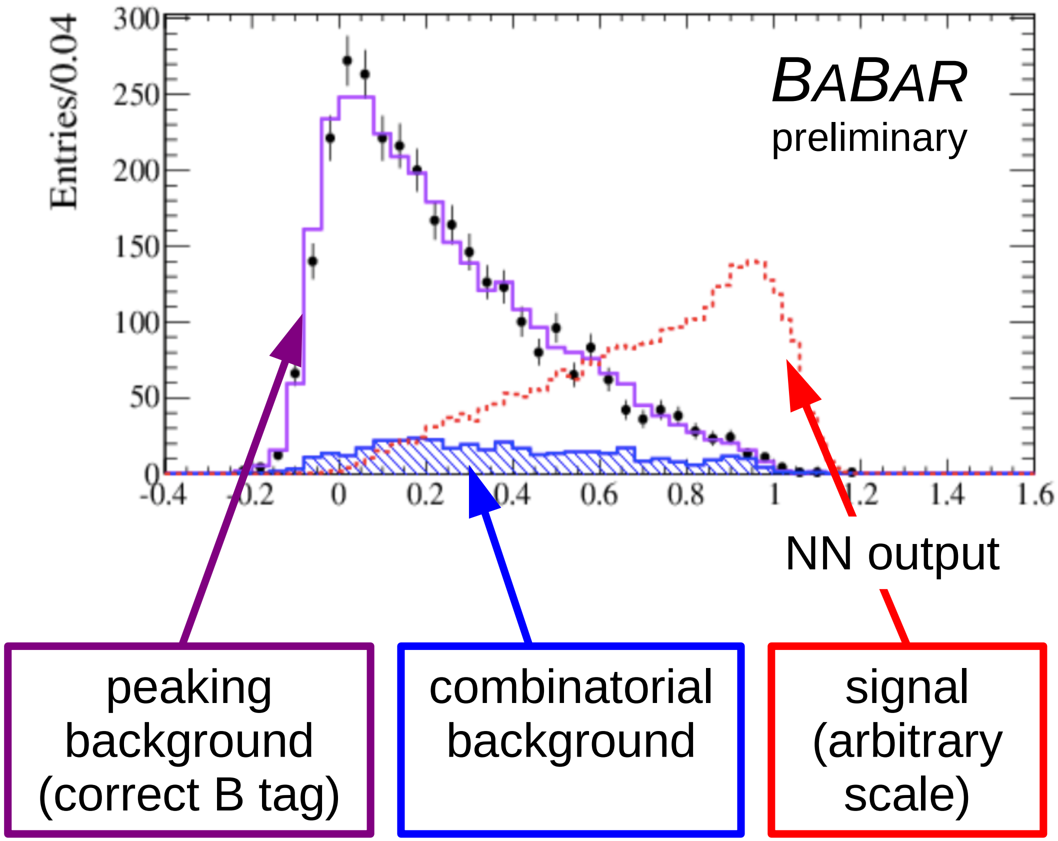


- Obvious interest to look for $B^+ \to K^+\tau^+\tau^-$ but extremely challenging
  - requires full event reconstruction
  - "tag" B in modes with charm(onium) + <6 extra K/π tracks



arXiv:1605.09637

Search for $B^+ \to K^+\tau^+\tau^-$



- Combine discriminating variables into neural network to optimally separate signal from background
- Apply cut and compare observed number of candidates with expectation from background
- No excess → set upper limit

$$B(B^+ \to K^+\tau^+\tau^-) = (1.31^{+0.66+0.35}_{-0.61-0.25}) \times 10^{-3}$$

$$B(B^+ \to K^+\tau^+\tau^-) < 2.25 \times 10^{-3} \text{(90\% CL UL)}$$

First upper limit on this important mode

Sensitivity far from SM expectation of BF ~ 10^{-7} but probes phase space of some models

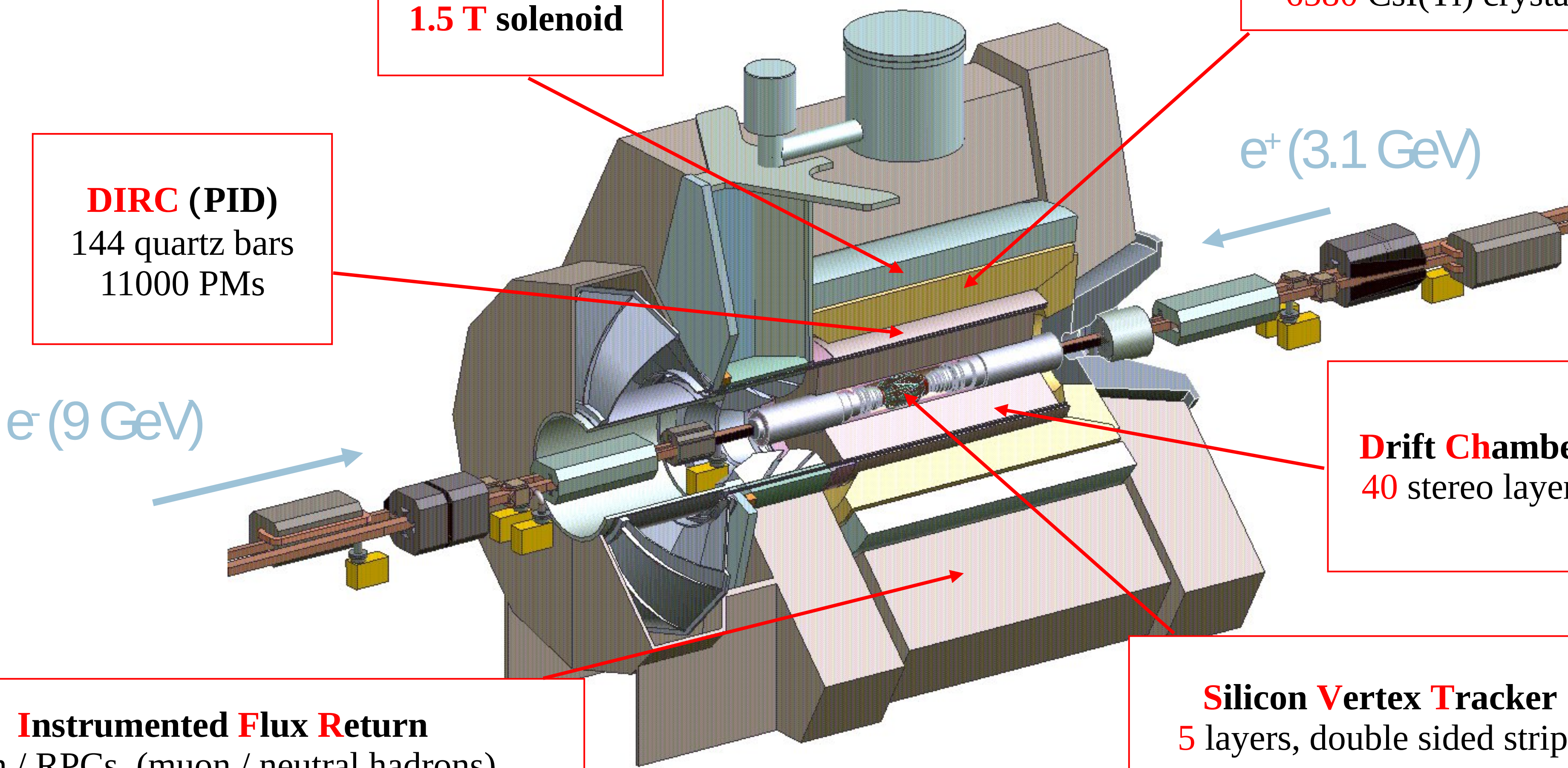
Summary

- BaBar continues to produce important results searching for new physics in FCNCs
  - $B \to K^*l^+l^-$: angular asymmetries PRD 93 (2016) 052015
  - $B \to K\pi^+\pi^-\gamma$: photon polarisation PRD 93 (2016) 052013
  - $B^+ \to K^+\tau^+\tau^-$: search for rare decay arXiv:1605.09637
    - many first and world's best measurements
    - several novel approaches investigated

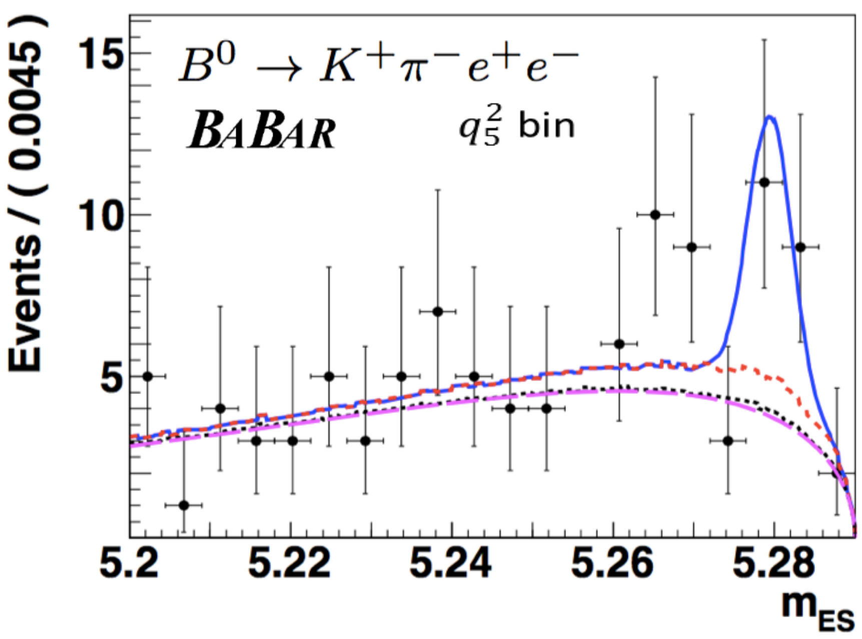
- All results statistically limited & consistent with SM
  - expect that this work will be pursued by future experiments

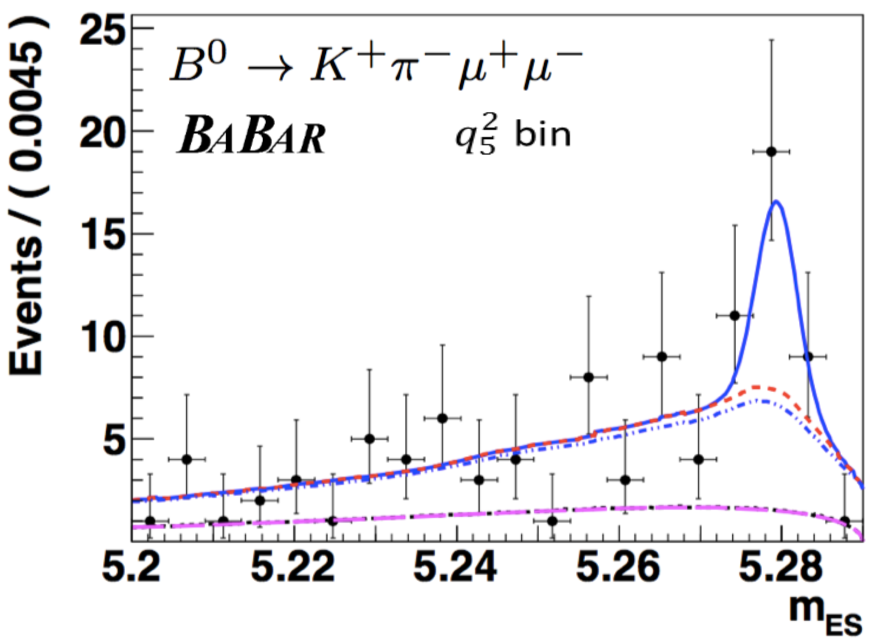

BACKUP

BaBar Detector



Example $B \to K^* l^+ l^-$ fits $(14.21\ \mathrm{GeV}^2 < q^2)$





Example $B \to K^* l^+ l^-$ fits $(1 < q^2 < 6\ \mathrm{GeV}^2)$

$K^+\pi^0 e^+ e^-$

$K^+\pi^0 \mu^+ \mu^-$

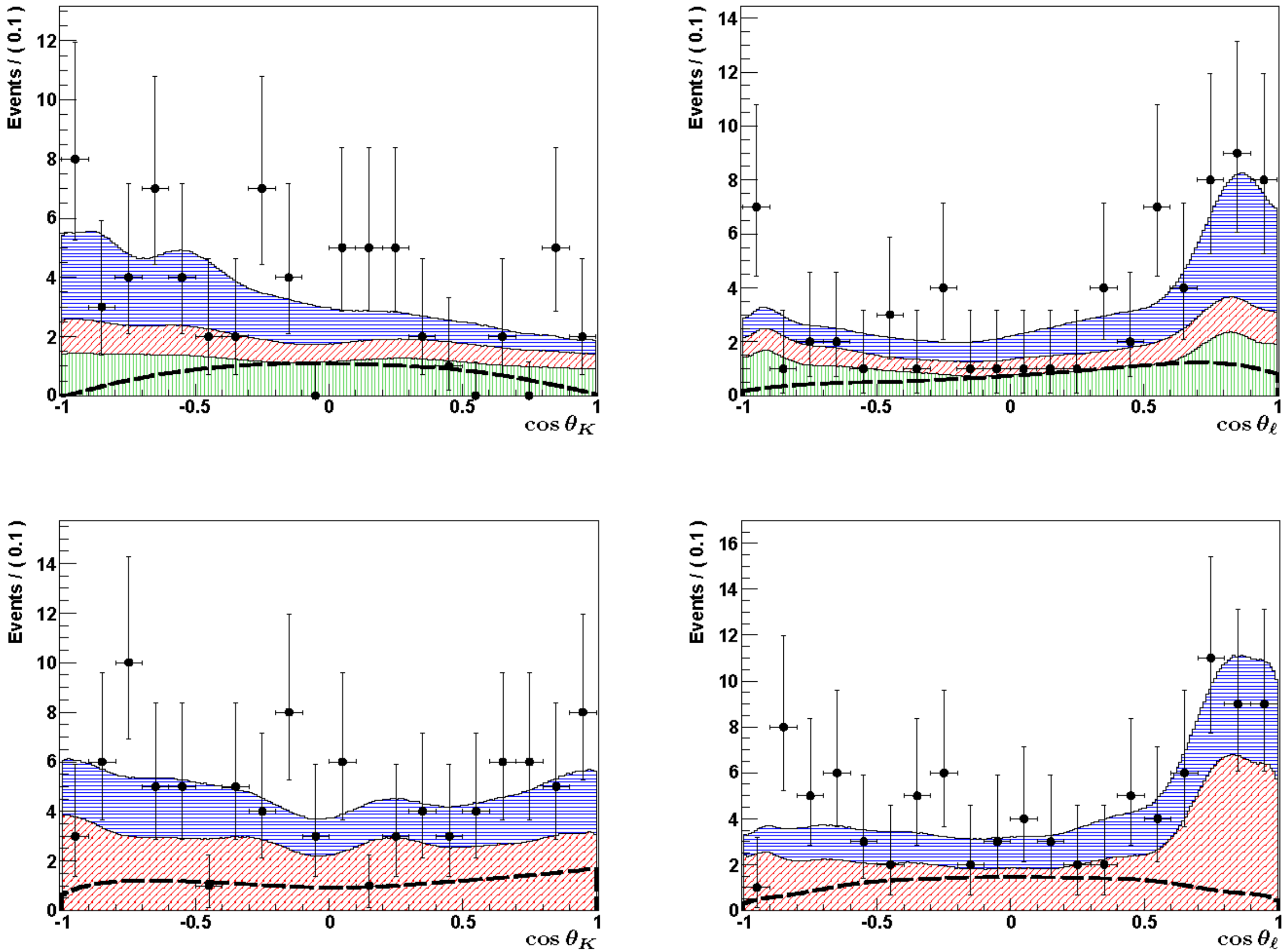
$K^0_s\pi^0 \mu^+ \mu^-$

Signal

$K^+\pi^- e^+ e^-$

$K^+\pi^- \mu^+ \mu^-$

Signal



$\cos\theta_K$ $\cos\theta_l$

PRD 93 (2016) 052013

Photon polarisation in $B \to K\pi\pi\gamma$

$$\mathcal{D}_{K_S^0\rho\gamma} \equiv \frac{\mathcal{S}_{K_S^0\pi^+\pi^-\gamma}}{\mathcal{S}_{K_S^0\rho\gamma}} = \frac{\int \left[\left|A_{\rho K_S^0}\right|^2 - \left|A_{K^{*+}\pi^-}\right|^2 - \left|A_{(K\pi)_0^{*+}\pi^-}\right|^2 + 2\Re\left(A^*_{\rho K_S^0} A_{K^{*+}\pi^-}\right) + 2\Re\left(A^*_{\rho K_S^0} A_{(K\pi)_0^{*+}\pi^-}\right)\right] dm^2}{\int \left[\left|A_{\rho K_S^0}\right|^2 + \left|A_{K^{*+}\pi^-}\right|^2 + \left|A_{(K\pi)_0^{*+}\pi^-}\right|^2 + 2\Re\left(A^*_{\rho K_S^0} A_{K^{*+}\pi^-}\right) + 2\Re\left(A^*_{\rho K_S^0} A_{(K\pi)_0^{*+}\pi^-}\right)\right] dm^2} \quad (1)$$

Mode	$\mathcal{B}(B^+ \to \text{Mode})\times$ $\mathcal{B}(K_{\text{res}} \to K^+\pi^+\pi^-) \times 10^{-6}$	$\mathcal{B}(B^+ \to \text{Mode}) \times 10^{-6}$	Previous world average [18] $(\times 10^{-6})$
$B^+ \to K^+\pi^+\pi^-\gamma$	$\cdots$	$24.5 \pm 0.9 \pm 1.2$	27.6 ± 2.2
$K_1(1270)^+\gamma$	$14.5^{+2.1+1.2}_{-1.4-1.2}$	$44.1^{+6.3+3.6}_{-4.4-3.6} \pm 4.6$	43 ± 13
$K_1(1400)^+\gamma$	$4.1^{+1.9+1.2}_{-1.2-1.0}$	$9.7^{+4.6+2.8}_{-2.9-2.3} \pm 0.6$	< 15 at 90% CL
$K^*(1410)^+\gamma$	$11.0^{+2.2+2.1}_{-2.0-1.1}$	$27.1^{+5.4+5.2}_{-4.8-2.6} \pm 2.7$	n/a
$K_2^*(1430)^+\gamma$	$1.2^{+1.0+1.2}_{-0.7-1.5}$	$8.7^{+7.0+8.7}_{-5.3-10.4} \pm 0.4$	14 ± 4
$K^*(1680)^+\gamma$	$15.9^{+2.2+3.2}_{-1.9-2.4}$	$66.7^{+9.3+13.3}_{-7.8-10.0} \pm 5.4$	< 1900 at 90% CL

Mode	$\mathcal{B}(B^+ \to \text{Mode})\times$ $\mathcal{B}(R \to h\pi) \times 10^{-6}$	$\mathcal{B}(B^+ \to \text{Mode}) \times 10^{-6}$	Previous world average [18] $(\times 10^{-6})$
$K^*(892)^0\pi^+\gamma$	$15.6 \pm 0.6 \pm 0.5$	$23.4 \pm 0.9^{+0.8}_{-0.7}$	20^{+7}_{-6}
$K^+\rho(770)^0\gamma$	$8.1 \pm 0.4^{+0.8}_{-0.7}$	$8.2 \pm 0.4 \pm 0.8 \pm 0.02$	< 20 at 90% CL
$(K\pi)_0^{*0}\pi^+\gamma$	$10.3^{+0.7+1.5}_{-0.8-2.0}$	$\cdots$	n/a
$(K\pi)_0^0\pi^+\gamma$ (NR)	$\cdots$	$9.9 \pm 0.7^{+1.5}_{-1.9}$	< 9.2 at 90% CL
$K_0^*(1430)^0\pi^+\gamma$	$0.82 \pm 0.06^{+0.12}_{-0.16}$	$1.32^{+0.09+0.20}_{-0.10-0.26} \pm 0.14$	n/a