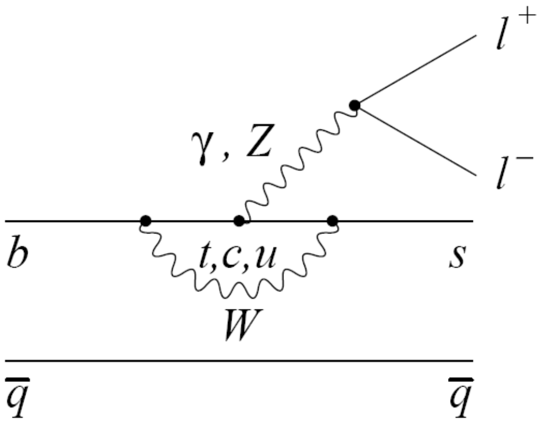
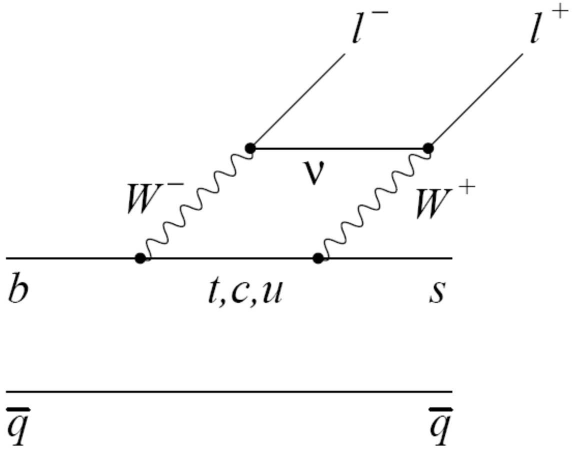
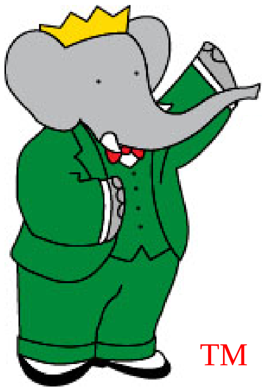
Working Group 2: Recent Experimental Progress in $b \to sll$ and Plans for Report





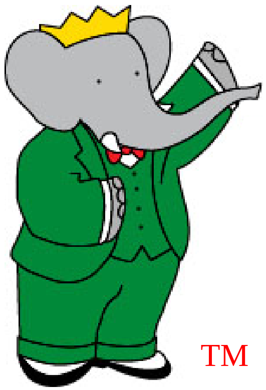


Jeffrey Berryhill (UC Santa Barbara)

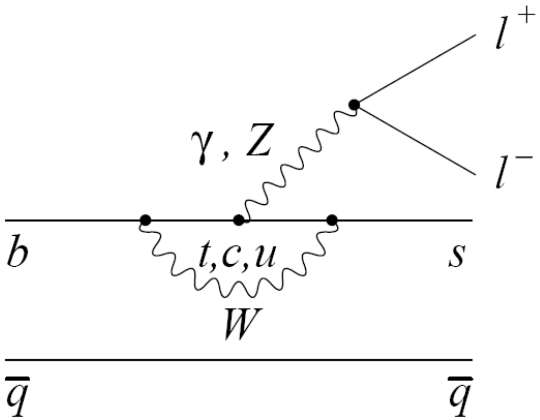
for the BaBar Collaboration

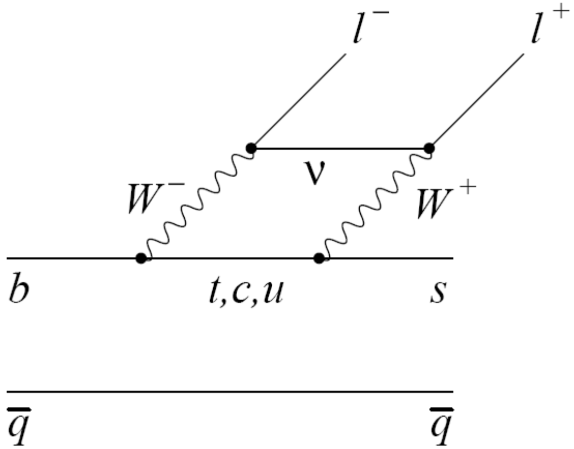
May 15, 2006

Recent K*ll Results from BaBar

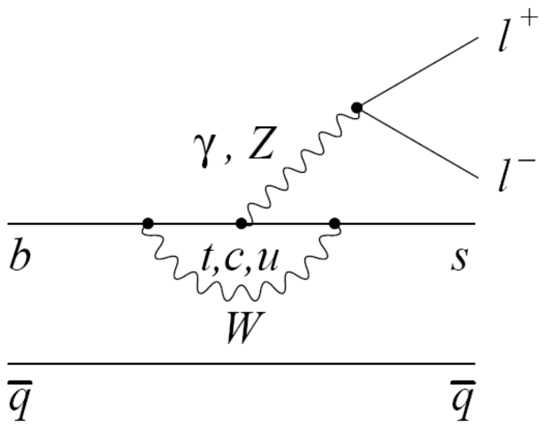


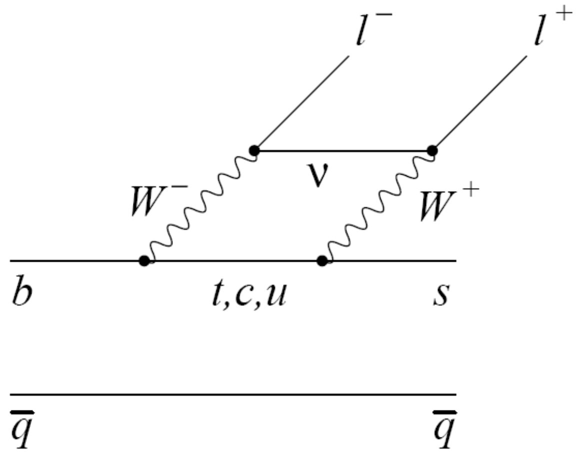
TM





B →K *ll* and B →K* *ll*

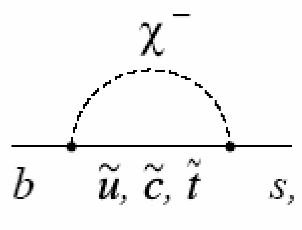




Photon penguin (C7)
Vector EW (C9)
Axial-vector EW (C10)

Exclusive decays from three b→ s*ll* penguin diagrams

New physics possible for each diagram, and also new operators (scalar penguins, right-handed currents)



Three-body kinematic distributions and decay rates to measure all three (complex) penguin amplitudes

Rare process with BF ~ 10^{-6}

Decay Rates Well-Measured; Next step: distributions and asymmetries

B →K *ll* and B →K* *ll* at BaBar

Latest published result, 208 fb^{-1}, hep-ex/0604007, PRD 73 092001 (2006)

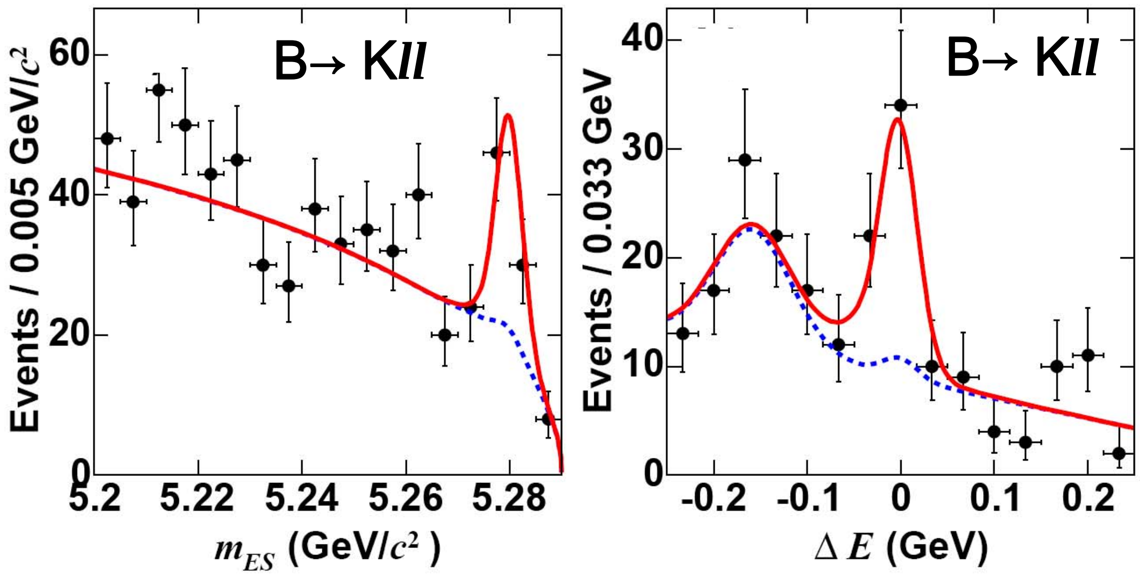
Full B decay reconstruction to charged tracks: K^+ll, $K_S ll$, $K^{*0}ll$, $K^{*+}ll$, l = e or μ

Strict particle ID requirements

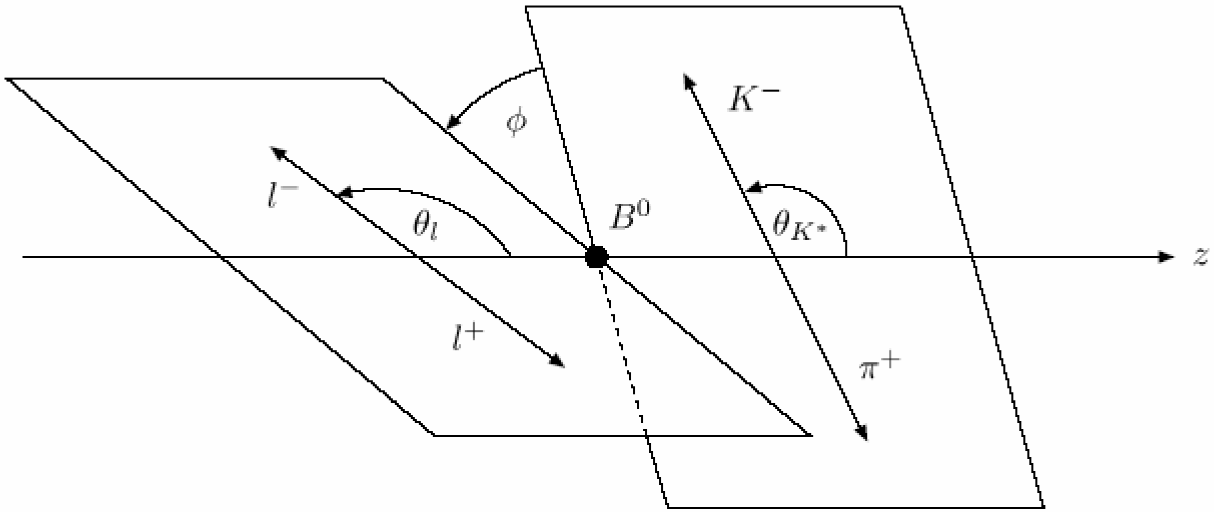
Veto "peaking" backgrounds of B decays similar to signal

Construct multivariate discriminants to suppress "combinatorial" backgrounds

Signal yield extraction via multi-dimensional unbinned maximum likelihood fit



General angular distribution of $B \to K^*ll$



3 angles

Lepton angle θ_l

Kaon angle θ_K

Decay plane angle ϕ

$$d^4\Gamma = \frac{9}{32\pi} I(s, \theta_l, \theta_{K^*}, \phi) ds\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi,$$

with the physical region of phase space

See for example
Kruger&Matias hep-ph/0502060
Ali&Safir hep-ph/0205254

$$4m_l^2 \leqslant s \leqslant (m_B - m_{K^*})^2, \quad -1 \leqslant \cos\theta_l \leqslant 1, \quad -1 \leqslant \cos\theta_{K^*} \leqslant 1, \quad 0 \leqslant \phi \leqslant 2\pi,$$

and

$$I = \boxed{I_1 + I_2 \cos 2\theta_l} + I_3 \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_l \cos\phi + I_5 \sin\theta_l \cos\phi + \boxed{I_6 \cos\theta_l}$$
$$+ I_7 \sin\theta_l \sin\phi + I_8 \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_l \sin 2\phi.$$

Integrating out ϕ leaves 3 terms

Angular distribution of $B \to K^*ll$

Transversity amplitude ($A_\parallel$, $A_\perp$, A_0) dependence of I1,I2,I6

$$I_1 = \left\{\frac{3}{4}[|A_{\perp L}|^2 + |A_{\parallel L}|^2 + (L \to R)]\left(1 - \frac{4m_l^2}{3s}\right) + \frac{4m_l^2}{s}\mathrm{Re}(A_{\perp L}A_{\perp R}^* + A_{\parallel L}A_{\parallel R}^*)\right\}\sin^2\theta_{K^*}$$
$$+ \left\{(|A_{0L}|^2 + |A_{0R}|^2) + \frac{4m_l^2}{s}[|A_t|^2 + 2\mathrm{Re}(A_{0L}A_{0R}^*)]\right\}\cos^2\theta_{K^*}, \quad \text{(A.6a)}$$

$$I_2 = \left(1 - \frac{4m_l^2}{s}\right)\left[\frac{1}{4}(|A_{\perp L}|^2 + |A_{\parallel L}|^2)\sin^2\theta_{K^*} - |A_{0L}|^2\cos^2\theta_{K^*} + (L \to R)\right], \quad \text{(A.6b)}$$

$$I_6 = 2\left(1 - \frac{4m_l^2}{s}\right)^{1/2}\left[\mathrm{Re}(A_{\parallel L}A_{\perp L}^*)\sin^2\theta_{K^*} - (L \to R)\right],$$

Neglecting terms of order m_l^2/s, simple dependence of the general angular distribution on transversity (or helicity) amplitudes

Angular parameterizations

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_K} = \frac{3}{2}F_0\cos^2\theta_K + \frac{3}{4}F_T\sin^2\theta_K$$

Integrate out θ_l OR

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}F_0\sin^2\theta_\ell + \frac{3}{8}F_T(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$

Integrate out θ_K OR

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta_\ell d\cos\theta_K} = \frac{9}{8}F_0\cos^2\theta_K\sin^2\theta_\ell + \frac{9}{32}F_T\sin^2\theta_K(1+\cos^2\theta_\ell) + \frac{3}{4}A_{FB}\sin^2\theta_K\cos\theta_\ell$$

Measure correlated dist.

$$F_0 = \frac{|A_0|^2}{|A_0|^2+|A_\perp|^2+|A_\parallel|^2}$$

$$F_T = \frac{|A_\perp|^2+|A_\parallel|^2}{|A_0|^2+|A_\perp|^2+|A_\parallel|^2}$$

$$A_{FB} = \frac{3}{2}\frac{\mathrm{Re}(A_{\parallel L}A^*_{\perp L}) - \mathrm{Re}(A_{\parallel R}A^*_{\perp R})}{|A_0|^2+|A_\perp|^2+|A_\parallel|^2}$$

NB including $\cos\theta_K$ does not increase number of fit parameters!

Transversity Amplitudes vs. Wilson Coefficients

$$A_{\perp L,R} = N\sqrt{2}\lambda^{1/2}\left[(C_9^{\rm eff} \mp C_{10})\frac{V(s)}{m_B + m_{K^*}} + \frac{2m_b}{s}(C_7^{\rm eff} + C_7^{\rm eff\prime})T_1(s)\right],$$

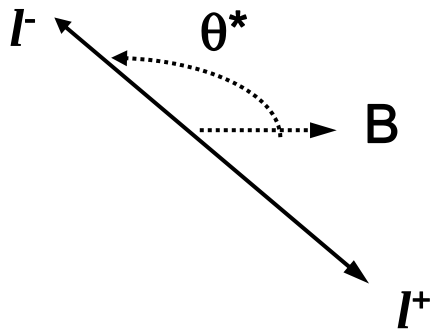
$$A_{\parallel L,R} = -N\sqrt{2}(m_B^2 - m_{K^*}^2)\left[(C_9^{\rm eff} \mp C_{10})\frac{A_1(s)}{m_B - m_{K^*}} + \frac{2m_b}{s}(C_7^{\rm eff} - C_7^{\rm eff\prime})T_2(s)\right],$$

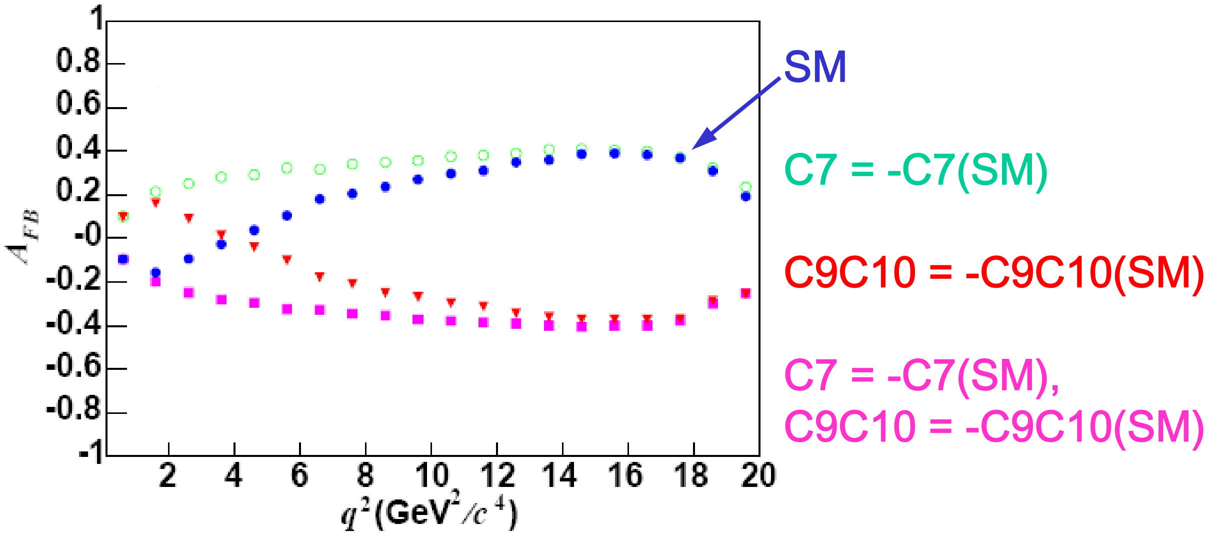
$$A_{0L,R} = -\frac{N}{2m_{K^*}\sqrt{s}}\Bigg[(C_9^{\rm eff} \mp C_{10})\left\{(m_B^2 - m_{K^*}^2 - s)(m_B + m_{K^*})A_1(s) - \lambda\frac{A_2(s)}{m_B + m_{K^*}}\right\}$$
$$+ 2m_b(C_7^{\rm eff} - C_7^{\rm eff\prime})\left\{(m_B^2 + 3m_{K^*}^2 - s)T_2(s) - \frac{\lambda}{m_B^2 - m_{K^*}^2}T_3(s)\right\}\Bigg],$$

Lepton asymmetry comes from differing transverse AL, AR

Includes (non-SM) right-handed current contribution C7’
(can be extended to C9’ and C10’ also)

$B \to K^* ll$ Lepton Angular Asymmetry





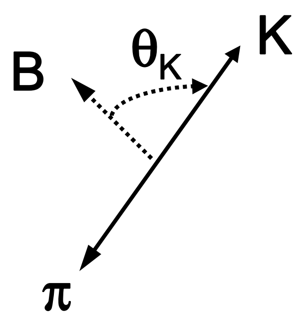
Cos θ* lepton- angle in dilepton rest frame. Forward-backward asymmetric!

due to axial vector penguin (C10) amplitude

Asymmetry A_{FB} vs. dilepton mass q^2 gives C10 evolution

relative to symmetric C9 and C7

Cos θ_K kaon angle in K* rest frame. Gives K* polarization



B →K *ll* Angular Distribution

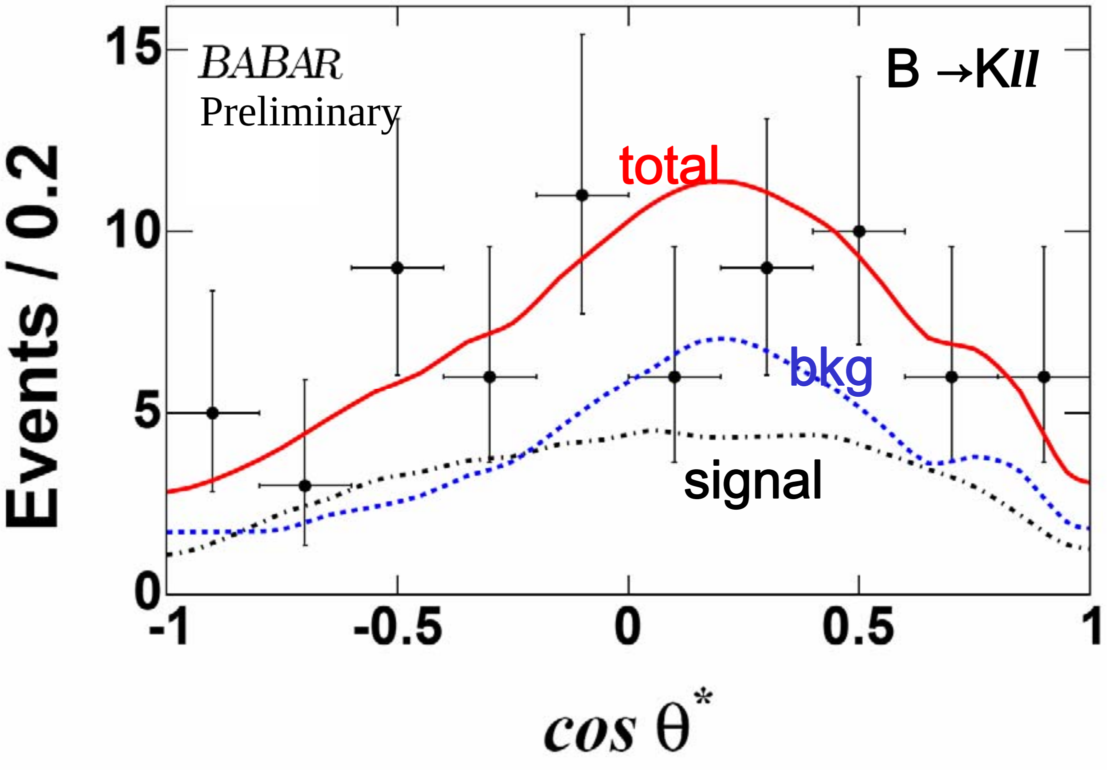
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{4}(1-F_S)(1-\cos^2\theta^*) + \frac{1}{2}F_S + A_{FB}\cos\theta^*$$

A_{FB} is non-zero only for non-zero scalar penguin contribution F_S

$$A_{FB}(B^+ \to K^+\ell^+\ell^-) = 0.15^{+0.21}_{-0.23} \pm 0.08$$

Consistent with SM expectation $F_S = A_{FB} = 0$

$$F_S(B^+ \to K^+\ell^+\ell^-) = 0.81^{+0.58}_{-0.61} \pm 0.46$$

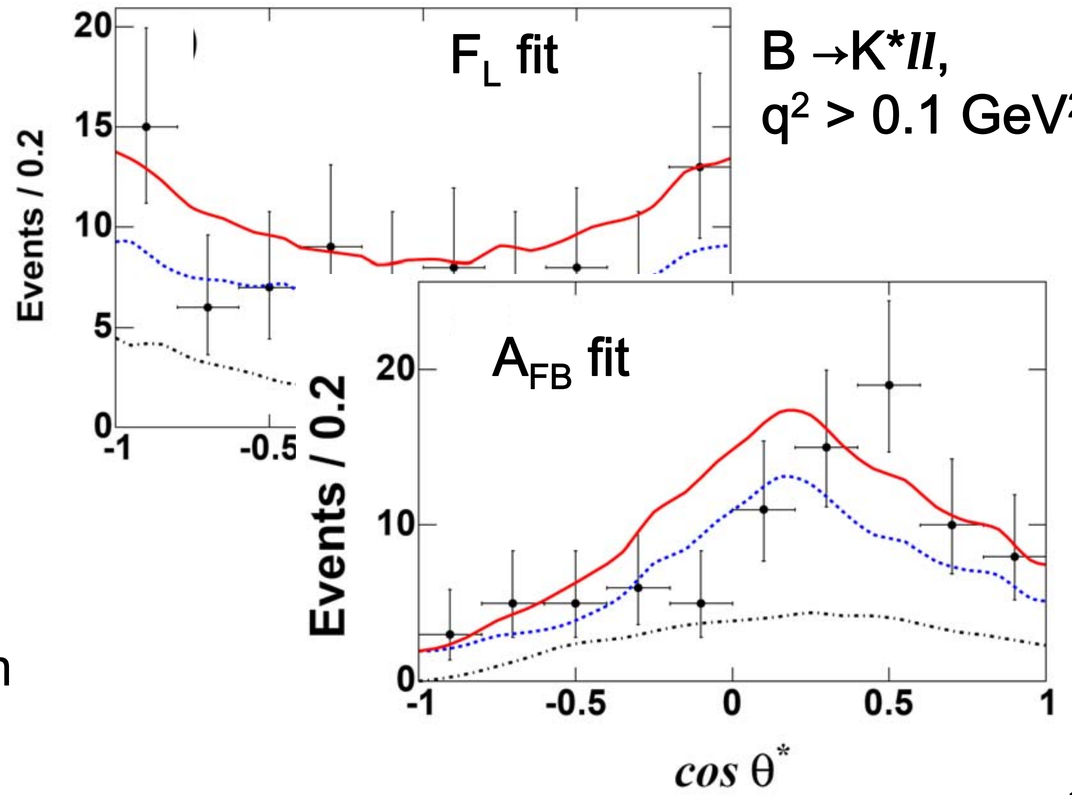


$B \to K^* \ell\ell$ Angular Distribution

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

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{4}F_L(1-\cos^2\theta^*) + \frac{3}{8}(1-F_L)(1+\cos^2\theta^*) + A_{FB}\cos\theta^*$$

- Fit F_L in q^2 bins with 4d (m_{ES}, ΔE, $m(K\pi)$, $\cos\theta_K$)
- Fix F_L, fit A_{FB} in q^2 bins with 4d (m_{ES}, ΔE, $m(K\pi)$, $\cos\theta^*$)



$B \to K^*\ell\ell$,
$q^2 > 0.1$ GeV^2

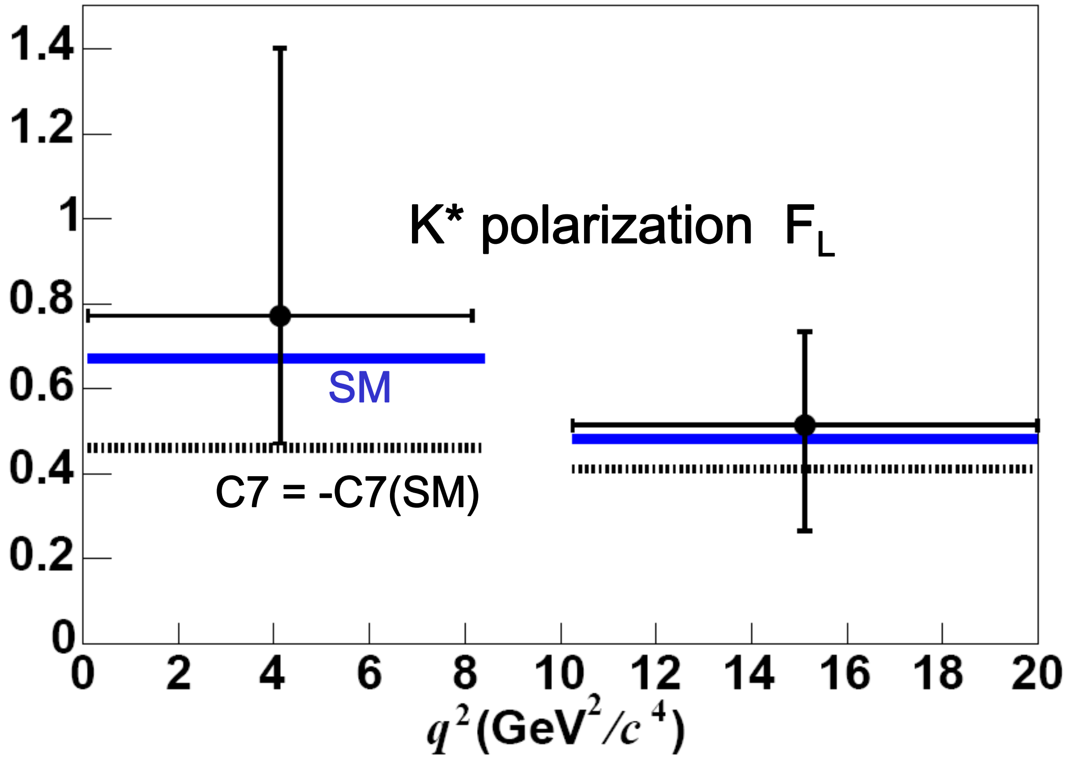
All procedures validated by J/ψ K(*) control samples

Background shape modeled from m_{ES},ΔE sidebands

B →K* *ll* Angular Distribution

K* polarization consistent with Standard Model

Possible to exclude
C7 = -C7(SM) with 1 ab^{-1}



$B \to K^* ll$ Angular Distribution

Low q^2 lower limit excludes SM at 98% CL (2.05σ)

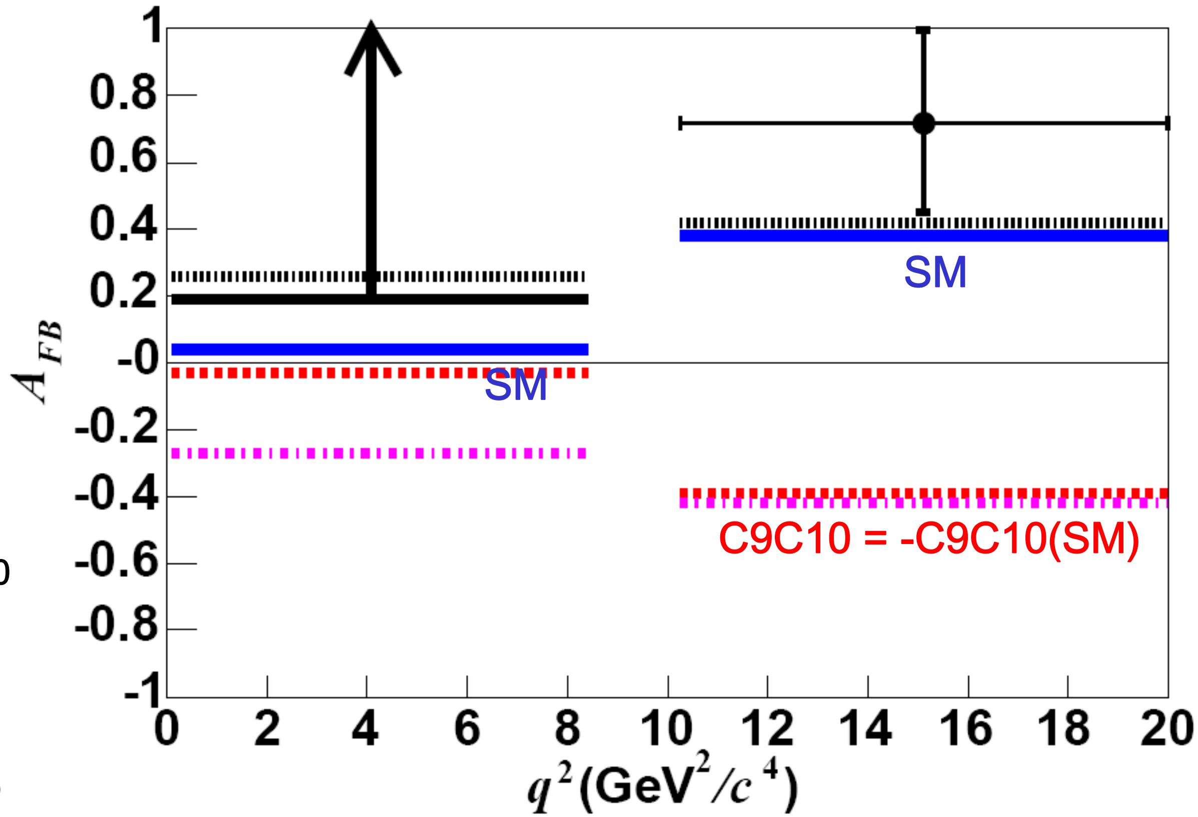
$$A_{FB} > 0.19\ (95\%\mathrm{CL})$$

$$A_{FB}(SM) = 0.03$$

At high q^2, wrong-sign C_9C_{10} is excluded at >3σ

$$A_{FB} = 0.72^{+0.28}_{-0.26} \pm 0.08$$

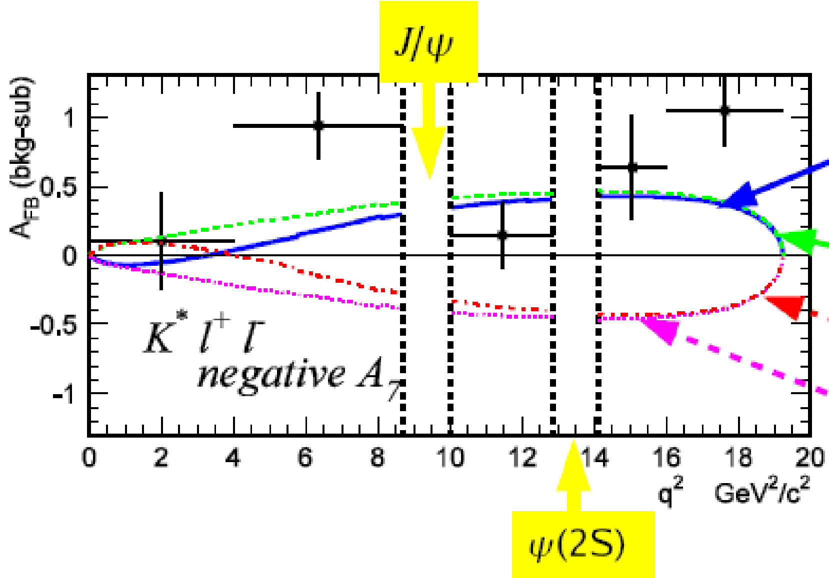
$$A_{FB}(SM) = 0.38$$



SM and alternate predictions from NNLO OPE + LCSR form factors,
Ali et al. Phys. Rev. D 66 034002 (2002)
Ball and Zwicky Phys. Rev. D 71 014029 (2005)

Belle K*ll Results

Fit results hep-ex/0603018 submitted to PRL

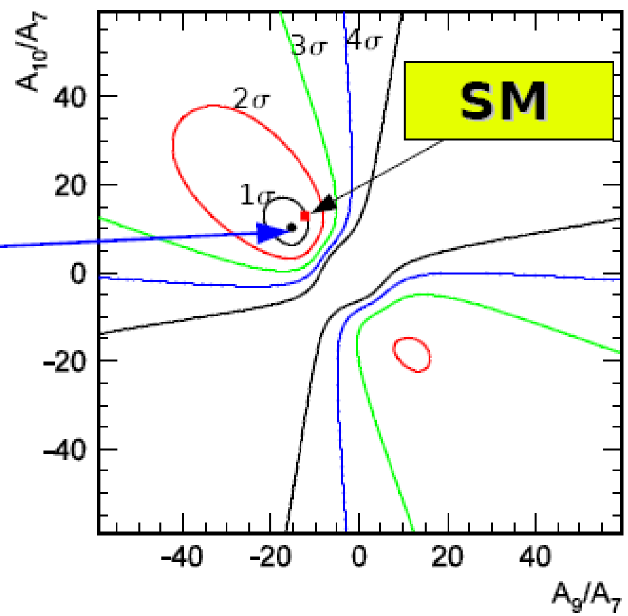


fix $A_7 = -0.330$; $A_{FB} > 0$ at 3.4σ

$A_{FB}^{\text{bkg-sub}}(B \to K^* \ell\ell) = 0.56 \pm 0.13$ (stat.)

A_7A_{10} sign flipped — slightly worse fit, but OK

Both A_7A_{10} and A_9A_{10} signs flipped
A_9A_{10} sign flipped
} excluded!



Wilson coefficients:

$A_9/A_7 = -15.3^{+3.4}_{-4.8} \pm 1.1$

$A_{10}/A_7 = 10.3^{+5.2}_{-3.5} \pm 1.8$ (A_7^{SM})

$-1401 < A_9 A_{10} / A_7^2 < -26.4$ (any A_7)

SM: $A_9/A_7 = -12.3,$
$A_{10}/A_7 = 12.8.$

BaBar vs. Belle Results

BaBar and Belle measure consistent values for global K*ll and Kll AFB

BaBar

$$A_{FB}(B \to K^*\ell^+\ell^-) > 0.55$$

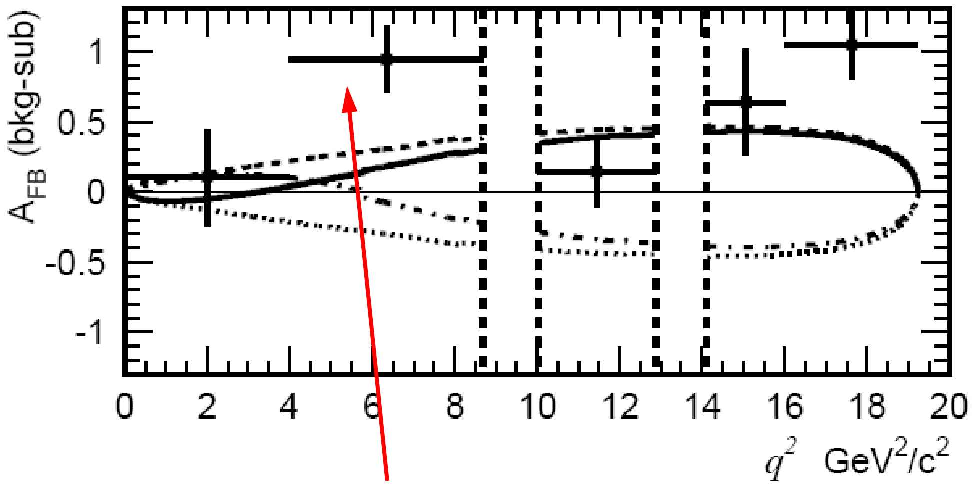
$$A_{FB}(B^+ \to K^+\ell^+\ell^-) = 0.15^{+0.21}_{-0.23} \pm 0.08$$

Belle

$$\tilde{A}_{\rm FB}(B \to K^*\ell^+\ell^-) = 0.50 \pm 0.15 \pm 0.02,$$

$$\tilde{A}_{\rm FB}(B^+ \to K^+\ell^+\ell^-) = 0.10 \pm 0.14 \pm 0.01,$$

Also consistent conclusions for K*ll AFB vs. Q^2



Large positive asymmetry at high Q^2

BUT large positive asymmetry at low Q^2 too!

What is going on here?

BaBar vs. Belle Observables

BaBar
AFB and F0 in two separate fits of lepton angle and kaon angle
In two bins of dilepton mass + fit to sum over all dilepton mass

Belle
A9 and A10 from global fit to lepton angle and dilepton mass
AFB computed for sum over all dilepton mass

BaBar method
includes more angular information
model independent and form factor independent
analgous to $B \to VV$ analyses, readily interpreted by experimental community

Belle method
exploits global constraints of allowed standard model operators
readily interpreted by phenomenological/model-builder community

FUTURE MEASUREMENTS NEED BOTH INTERPRETATIONS!

Another angular observable

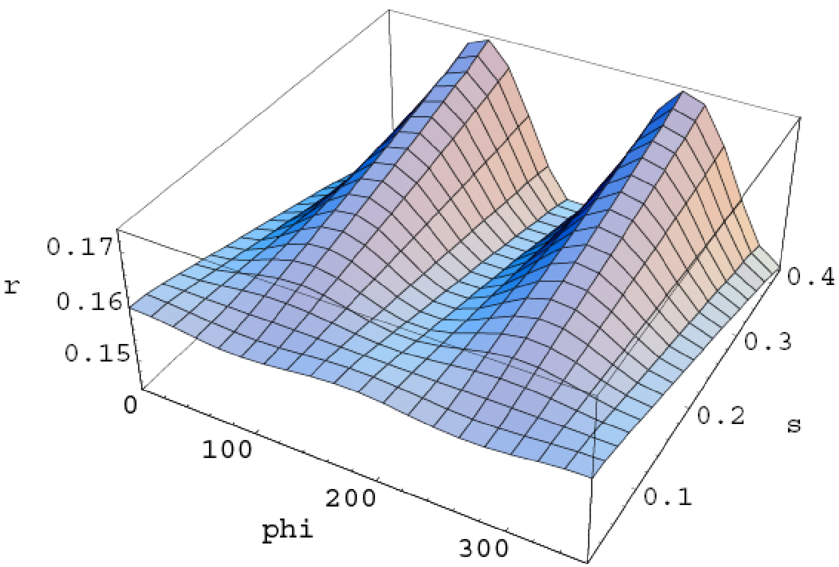
Decay plane angle ϕ distribution has simple form if other angles integrated out:

$$r(\phi, \hat{s}) \equiv \left[\frac{dBr}{dl^2 d\phi}\right] / \left[\frac{dBr}{dl^2}\right] = \frac{1}{2\pi}\left\{1 - \frac{\cos 2\phi Re(H^R_{+1}H^{R*}_{-1} + H^L_{+1}H^{L*}_{-1}) - \sin 2\phi Im(H^R_{+1}H^{R*}_{-1} + H^L_{+1}H^{L*}_{-1})}{|H^R_0|^2 + |H^R_{+1}|^2 + |H^R_{-1}|^2 + |H^L_0|^2 + |H^L_{+1}|^2 + |H^L_{-1}|^2}\right\}$$

Kim/Kim/Lu/Morozumi hep-ph/0001151
Phys.Rev.D62:034013,2000

Sin 2ϕ term vanishes in SM
Cos 2ϕ is small for small Q^2

Non-flat behavior could indicate right-handed currents



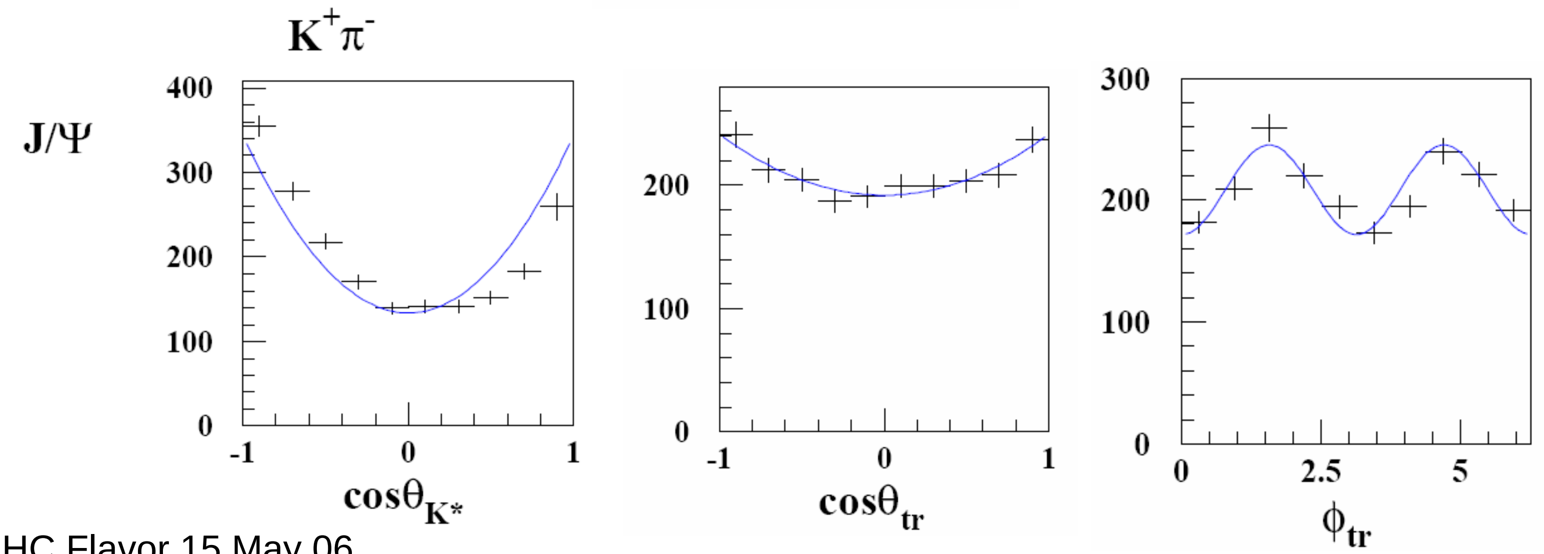
Fully Correlated Angular Analysis: J/ψ K*

With thousands of K*ll events expected in LHCb/Superb era, full 4d angular analysis should be statistically feasible, as is already done in B →VV

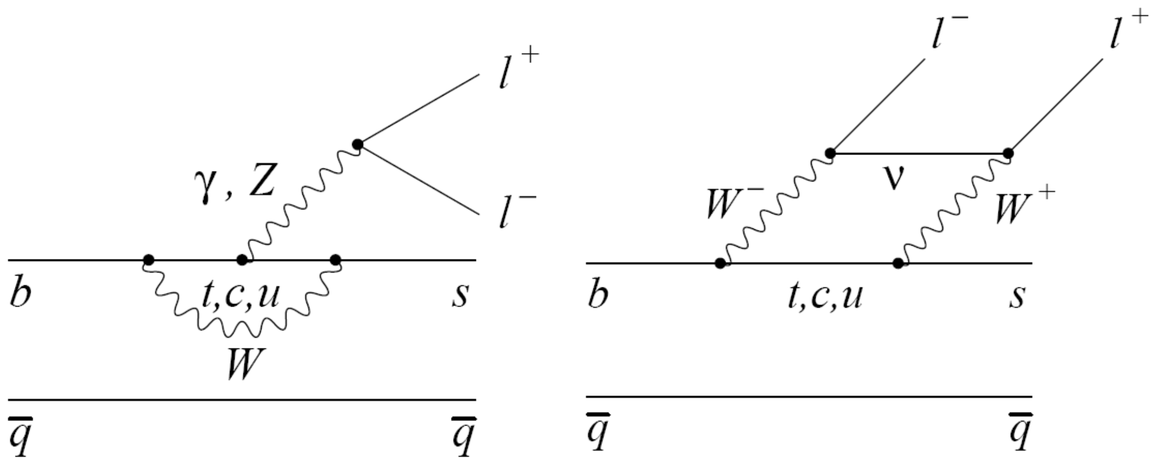
Amplitude	*Angular dependence*
$\|A_0\|^2$	$2\cos^2\theta_{K^*}\left[1-\sin^2\theta_{tr}\cos^2\phi_{tr}\right]$
$\|A_\parallel\|^2$	$\sin^2\theta_{K^*}\left[1-\sin^2\theta_{tr}\sin^2\phi_{tr}\right]$
$\|A_\perp\|^2$	$\sin^2\theta_{K^*}\sin^2\theta_{tr}$
$\Im m(A_\parallel^* A_\perp)$	$\sin^2\theta_{K^*}\sin 2\theta_{tr}\sin\phi_{tr}$
$\Re e(A_\parallel A_0^*)$	$-\frac{1}{\sqrt{2}}\sin 2\theta_{K^*}\sin^2\theta_{tr}\sin 2\phi_{tr}$
$\Im m(A_\perp A_0^*)$	$\frac{1}{\sqrt{2}}\sin 2\theta_{K^*}\sin 2\theta_{tr}\cos\phi_{tr}$

(integrated) transversity amplitudes can be extracted with several % precision

Studies of phases, CP/T violation



WG2 Report Task/Wish List for Experimenters



WG2 Report Task/Wish List

K*ll angular analysis prospects for Superb and LHCb

Extrapolate Babar observables in (more finely) binned Q^2 fits to 10, 50 ab^{-1}

Extrapolate Belle Wilson Coefficient global fits to 10, 50 ab^{-1}

LHCb estimates with more recently computed MC
what is the most realistic S/B?

Perhaps test one or more of the other untried observables (ϕ, triple product asymmetries, CP/T asymmetries, general amplitudes)?

Kll measurements

Same tasks for AFB, RK, FS observables

CMS/ATLAS: at the very least, projections of reconstructed K $\mu\mu$

WG2 Report Task/Wish List

sll sum-of-exclusive prospects

Superb studies of expected precision for $d\Gamma/dQ^2$ and its impact on Wilson coefficient constraints

Feasibility of extending BaBar/Belle results to higher Mx to reduce shape function effects.

AFB expected precision and possible decay model systematics

Other sll/dll decays

$B \to \pi ll$, ρll
Angular analysis of $\Lambda b \to \Lambda$ ll
Bs $\to \phi$ ll
B$\to$ K + npi ll

Is there UNIQUE information on EW penguins to be gained here beyond K*ll et al.?

WG2 Report Task/Wish List

Some questions/tasks for theorists

What is the unique role, if any, in whatever new physics model, of $b \to sll$ in light of expected precision for $b \to s\gamma$, $Bs \to \mu\mu$, and Bs mixing

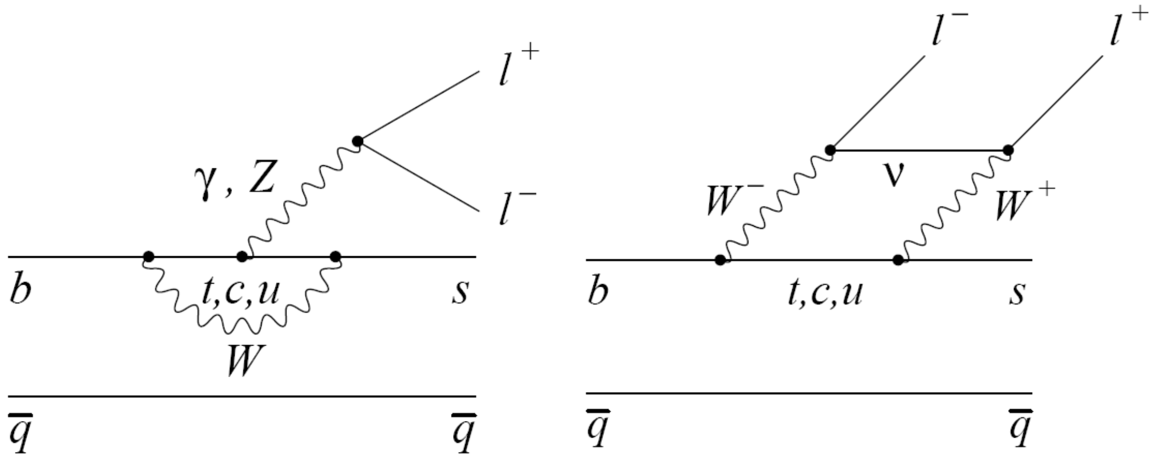
Is it possible to estimate contemporary theoretical uncertainties for FORM FACTOR RATIOS?

What is possible irreducible contamination to K*ll observables from $J/\psi K^*$ and $K\pi ll$?

Implement new MX models for $b \to sll$ in EvtGen or other common generator?

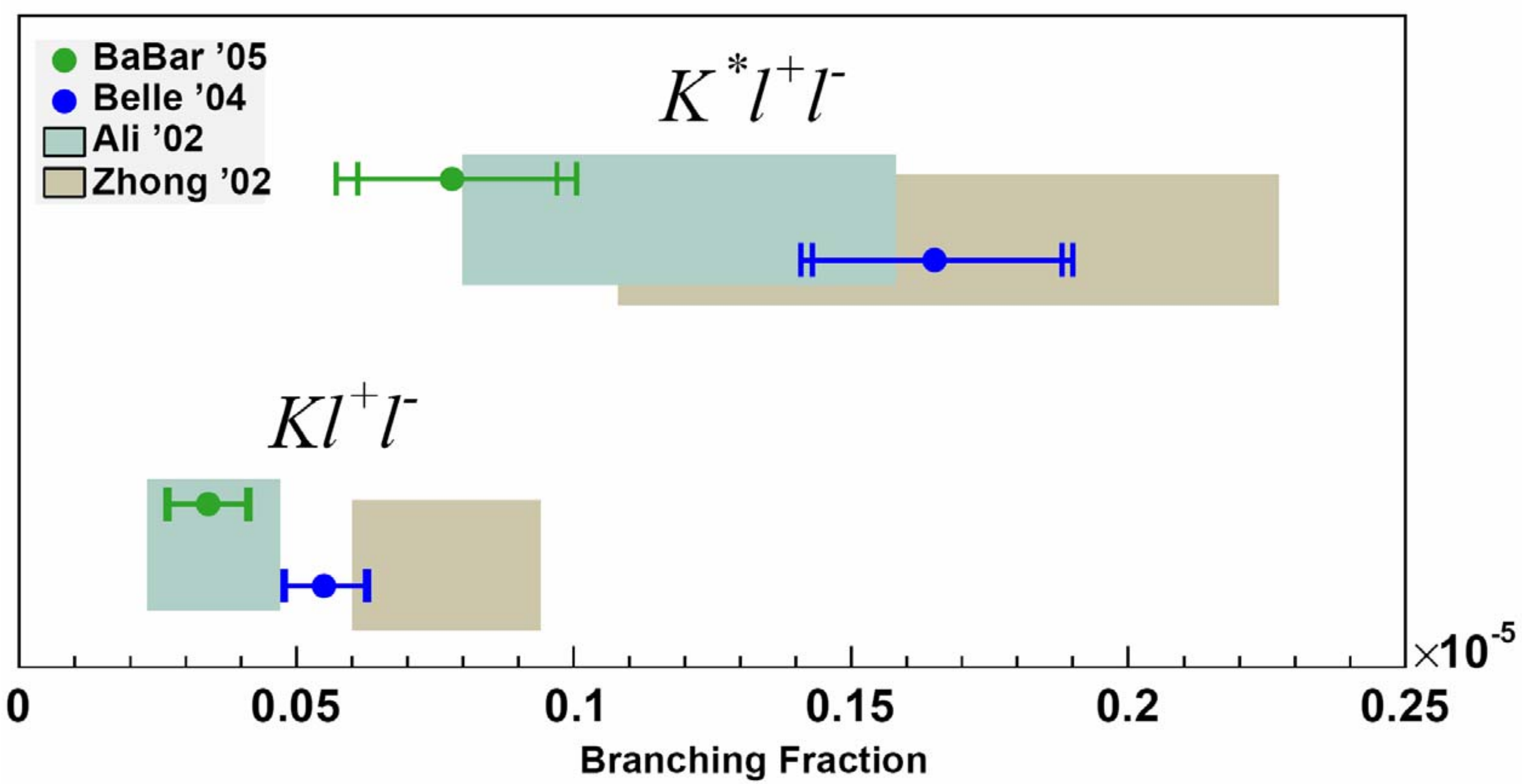
Explanation in simple terms of how angular observables relate to various Wilson coefficients?

Backup Slides



B →K *ll* and B →K* *ll*

BaBar and Belle branching fractions agree with SM predictions
Experimental uncertainty already better than theory
Difference between BaBar and Belle becoming significant?

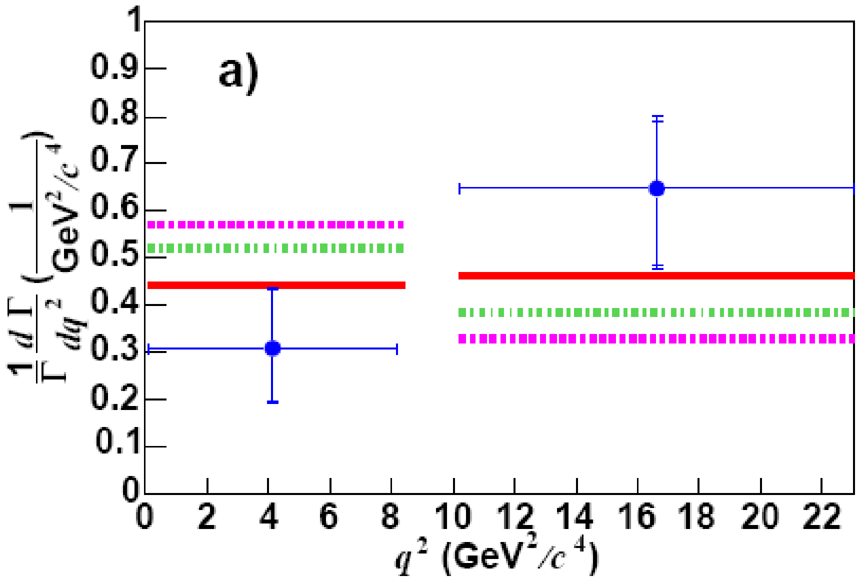


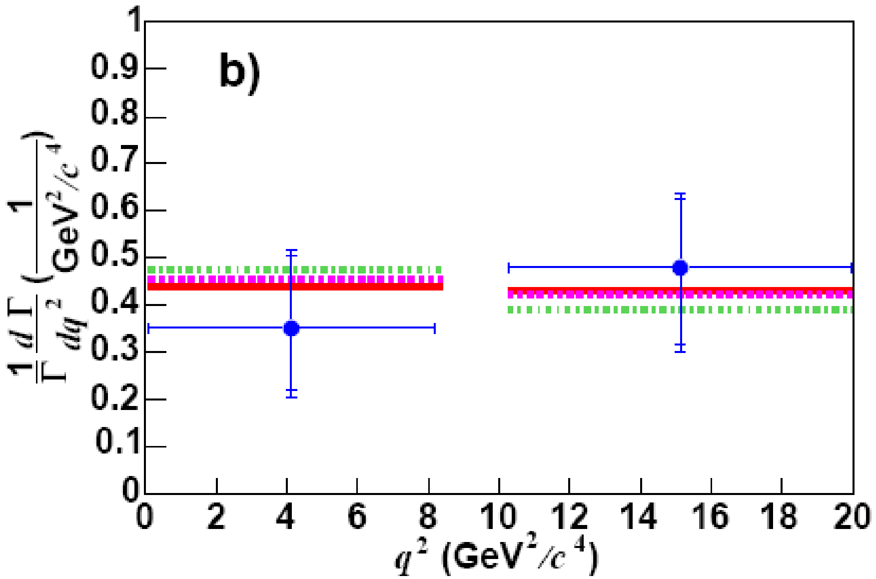
Also A_{CP} consistent with 0 at 25% level, e/μ ratio consistent with unity

$q^2(\mathrm{GeV}^2/c^4)$	$\mathcal{B}(10^{-6})$	$B \to K^*\ell^+\ell^-$ F_L	A_{FB}
$0.1 - 8.41$	$0.27^{+0.12}_{-0.10} \pm 0.05$	$0.77^{+0.63}_{-0.30} \pm 0.07$	> 0.19 (95%CL)
> 10.24	$0.37^{+0.13}_{-0.11} \pm 0.05$	$0.51^{+0.22}_{-0.25} \pm 0.08$	$0.72^{+0.28}_{-0.26} \pm 0.08$
> 0.1	$0.73^{+0.20}_{-0.18} \pm 0.11$	$0.63^{+0.18}_{-0.19} \pm 0.05$	> 0.55 (95%CL)

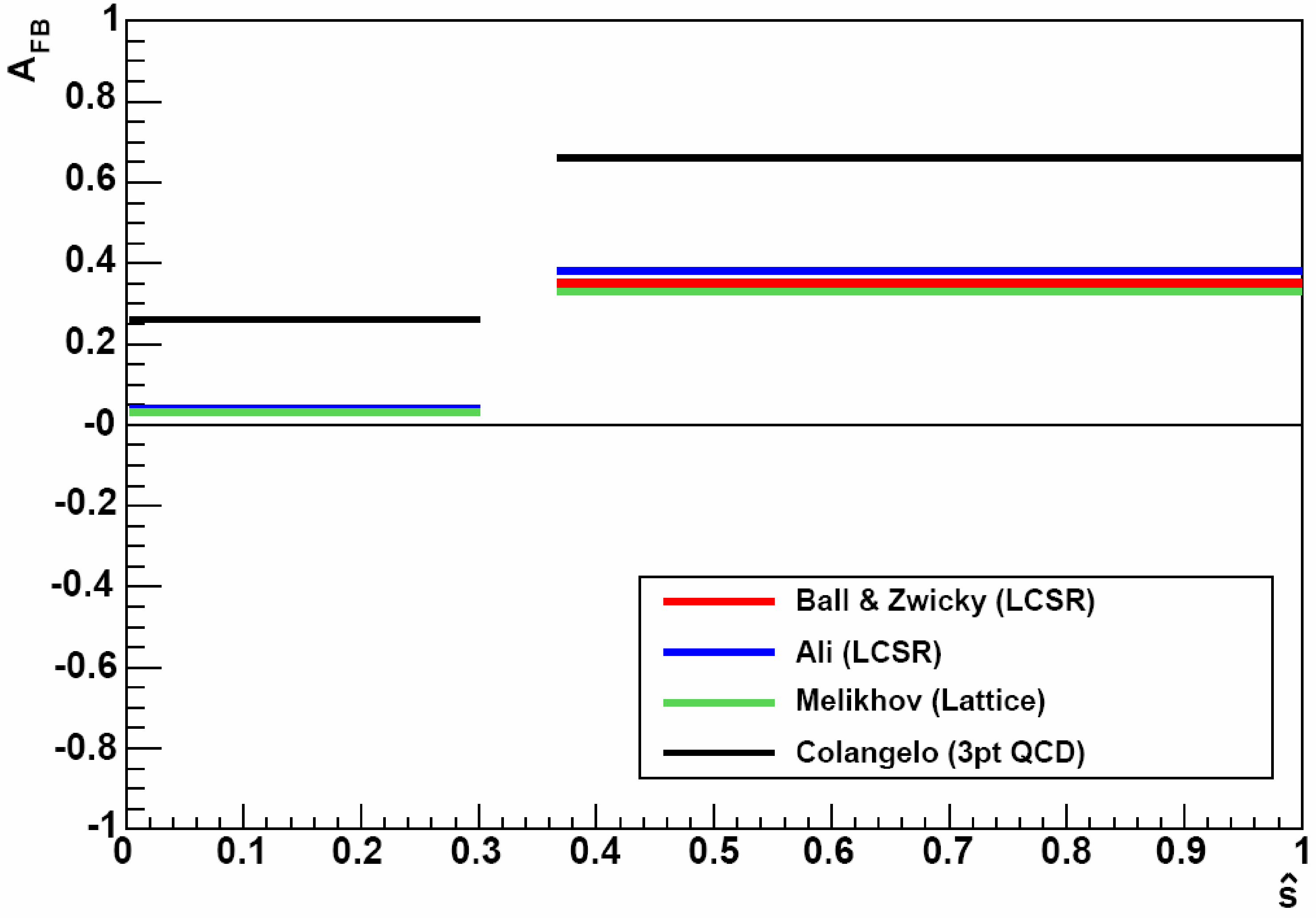
$q^2(\mathrm{GeV}^2/c^4)$	$\mathcal{B}(10^{-6})$	$B \to K\ell^+\ell^-$ F_S	A_{FB}
$0.1 - 8.41$	$0.10^{+0.04}_{-0.04} \pm 0.01$	0	$-0.49^{+0.51}_{-0.99} \pm 0.18$
> 10.24	$0.22^{+0.05}_{-0.05} \pm 0.02$	0	$0.26^{+0.23}_{-0.24} \pm 0.03$
> 0.1	$0.34^{+0.07}_{-0.07} \pm 0.02$	$0.81^{+0.58}_{-0.61} \pm 0.46$	$0.15^{+0.21}_{-0.23} \pm 0.08$

Partial branching fractions vs. dilepton mass consistent with SM + form factors





Form Factor Model Dependence: AFB



Colangelo strongly disagrees with LCSR and Lattice (T3 form factor)