Forward-backward asymmetry of semi-leptonic B decays in SM and new physics models

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based on work with Run-Hui Li, Wei Wang, Yu-Ming Wang

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PRD79,094024 (2009), PRD83,034034 (2011)

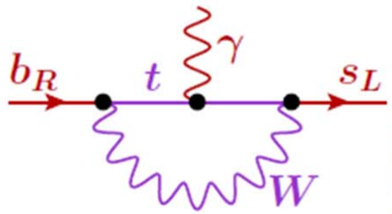
Outline

- Introduction
- B→ $K_1(K^*_0, K_2, K_3, K_4)$ l+ l- decays in SM

  Angular distributions

  Branching ratios, polarizations, FB asymmetry
- New physics contributions
- Summary

Introduction



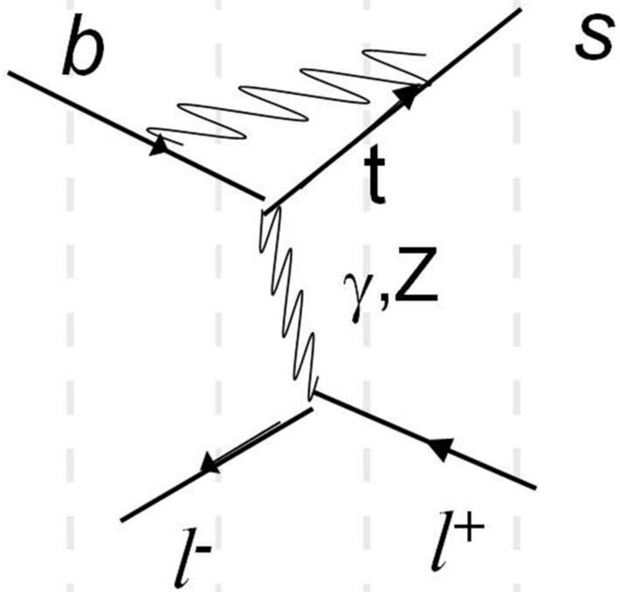
- Unlike $b \to s\gamma$ or $B \to K^*\gamma$, which have only limited physical observables
- $b \to s\, l^+l^-$, and especially $B \to K^*\, l^+l^-$, with a number of observables accessible (exp. also easier), provides a wealth of information of weak interactions, ranging from the forward-backward asymmetries, isospin asymmetries, and polarization fractions

Flavor changing Electroweak penguin operators

$$O_7 = \frac{em_b}{8\pi^2}\bar{s}\sigma^{\mu\nu}(1+\gamma_5)bF_{\mu\nu} + \frac{em_s}{8\pi^2}\bar{s}\sigma^{\mu\nu}(1-\gamma_5)bF_{\mu\nu}$$

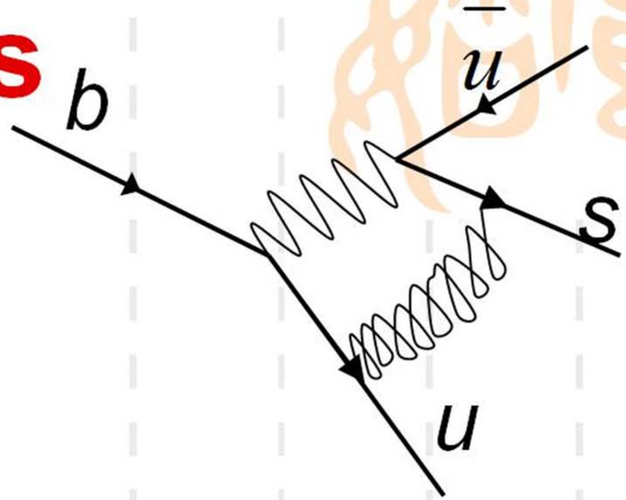
$$O_9 = \frac{\alpha_{em}}{2\pi}(\bar{l}\gamma_\mu l)(\bar{s}\gamma^\mu(1-\gamma_5)b),$$

$$O_{10} = \frac{\alpha_{em}}{2\pi}(\bar{l}\gamma_\mu\gamma_5 l)(\bar{s}\gamma^\mu(1-\gamma_5)b)$$



No tree level flavor changing neutral current in SM

With QCD corrections from the four quark operators

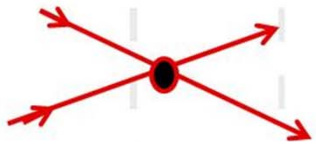


$$H_{eff} = \frac{G_F}{\sqrt{2}} V_{CKM} \sum_i C_i O_i$$

$$O_1 = \bar{u}\gamma^{\mu} Lu \cdot \bar{s}\gamma_{\mu} Lb \qquad O_2 = \bar{s}\gamma^{\mu} Lu \cdot \bar{u}\gamma_{\mu} Lb$$

$$O_3 = \bar{s}\gamma^{\mu} Lb \cdot \sum_q \bar{q}\gamma_{\mu} Lq \qquad O_4 = \bar{s}_{\alpha}\gamma^{\mu} Lb_{\beta} \cdot \sum_q \bar{q}_{\beta}\gamma_{\mu} Lq_{\alpha}$$

$$O_5 = \bar{s}\gamma^{\mu} Lb \cdot \sum_q \bar{q}\gamma_{\mu} Rq \qquad O_6 = \bar{s}_{\alpha}\gamma^{\mu} Lb_{\beta} \cdot \sum_q \bar{q}_{\beta}\gamma_{\mu} Rq_{\alpha}$$

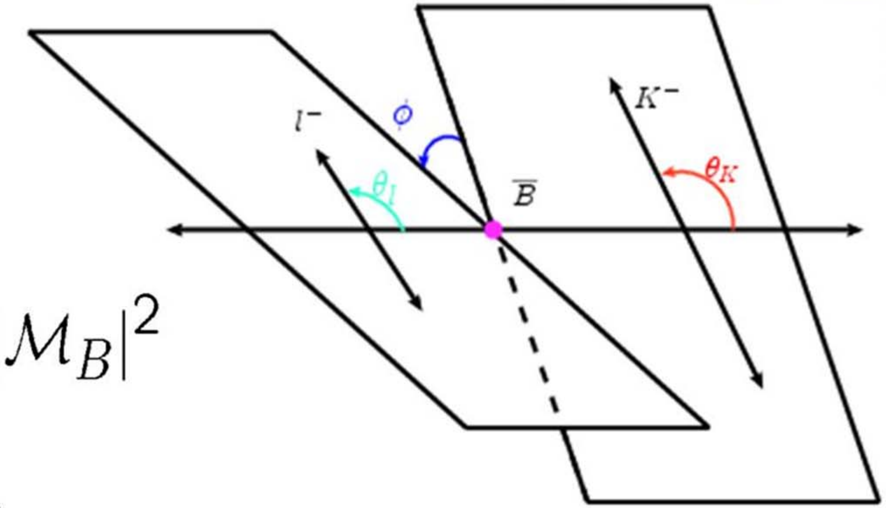


CD Lu

Branching ratios are proportional to form factors, have large uncertainties, but Angular distribution is not

Partial decay width

$$\frac{d^4\Gamma}{dq^2 d\cos\theta_K d\cos\theta_l d\phi} = \frac{3}{8}|\mathcal{M}_B|^2$$



$|\mathcal{M}_B|^2$ is decomposed into 11 terms

$$\begin{aligned}|\mathcal{M}_B|^2 = & [I_1^c C^2 + 2I_1^s S^2 + (I_2^c C^2 + 2I_2^s S^2)\cos(2\theta_l) \\ & +2I_3 S^2 \sin^2\theta_l \cos(2\phi) + 2\sqrt{2} I_4 CS \sin(2\theta_l)\cos\phi \\ & +2\sqrt{2} I_5 CS \sin(\theta_l)\cos\phi + 2I_6 S^2 \cos\theta_l \\ & +2\sqrt{2} I_7 CS \sin(\theta_l)\sin\phi + 2\sqrt{2} I_8 CS \sin(2\theta_l)\sin\phi \\ & +2I_9 S^2 \sin^2\theta_l \sin(2\phi)]\end{aligned}$$

Angular distribution

$$I_7 = \sqrt{2}\beta_l[\mathrm{Im}(A_{L0}A^*_{L||}) - \mathrm{Im}(A_{R0}A^*_{R||})]$$
$$I_8 = \frac{1}{\sqrt{2}}\beta_l^2[\mathrm{Im}(A_{L0}A^*_{L\perp}) + \mathrm{Im}(A_{R0}A^*_{R\perp})]$$
$$I_9 = \beta_l^2[\mathrm{Im}(A_{L||}A^*_{L\perp}) + \mathrm{Im}(A_{R||}A^*_{R\perp})]$$

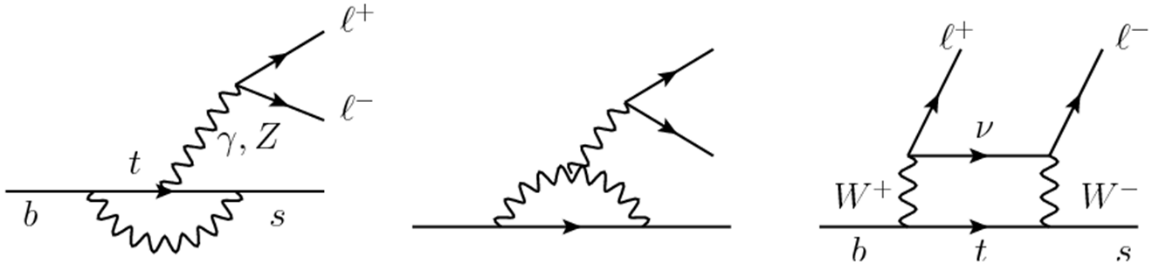
- $A_{Ri} = A_{Li}|_{C_{10}\to -C_{10}}$
- Up to one-loop matrix element and resonances taken out, only C_9^{eff} contributes an imaginary part.

Without higher order QCD corrections

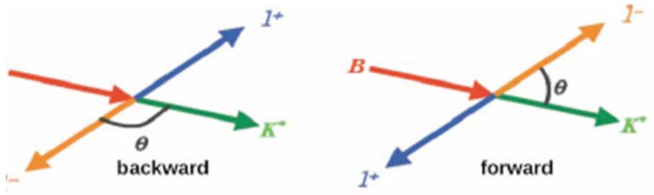
$I_7 = 0$, I_8 and I_9 is tiny

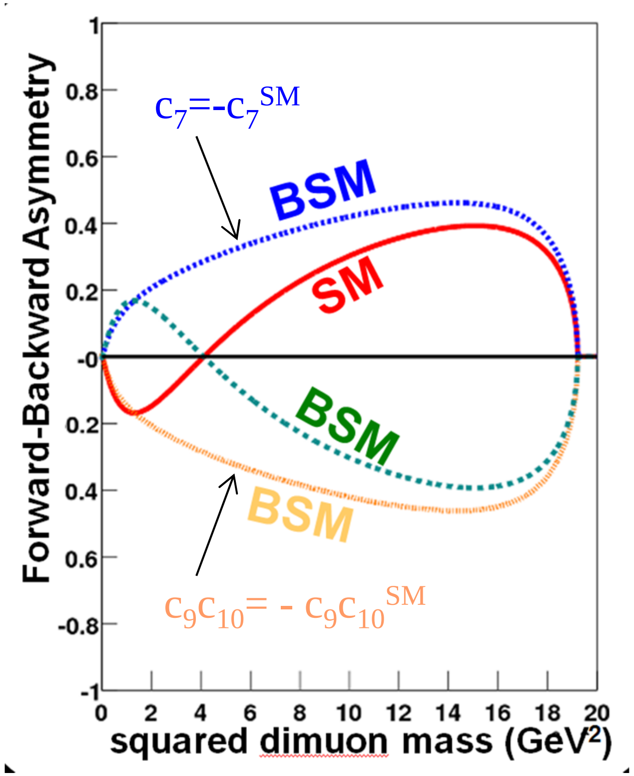
They could be chosen as the window to observe those effects that can change the behavior of the Wilson coefficients, such as NP effects.

Forward-backward asymmetry in $B \to K^* l^+ l^-$



$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

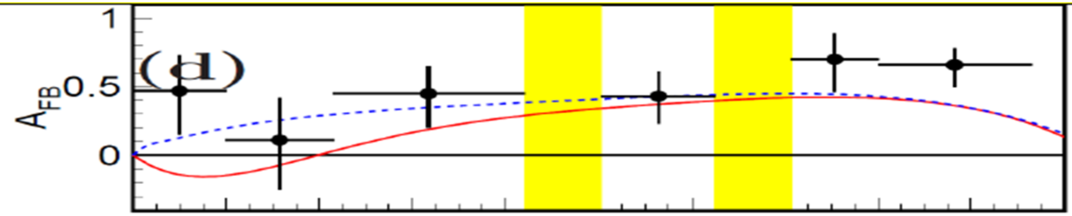




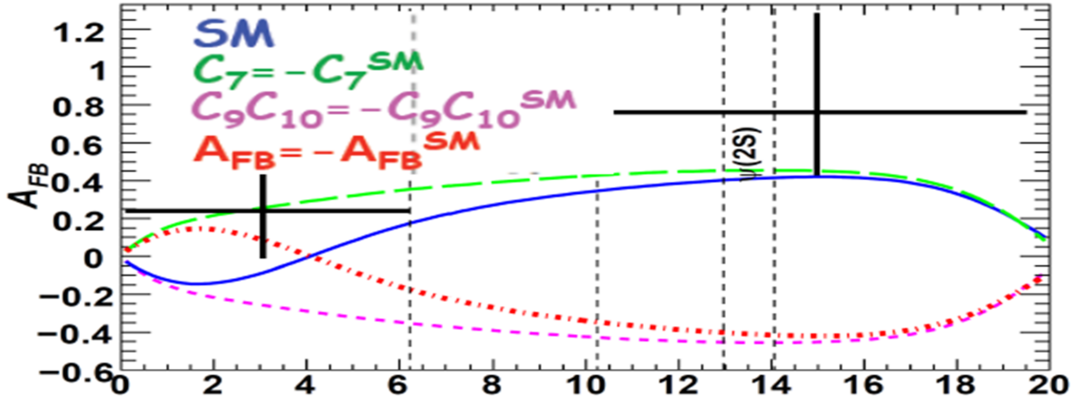
$A_{FB}(q^2) = -c^{eff}_{10}\, \xi(q^2)\, [\, Re c_9^{eff} F_1 + c_7^{eff} F_2 / q^2\,]$

SM: $c_7^{eff} \sim -0.304$, $c_{10}^{eff} \sim -4.103$,
$c_9^{eff} \sim 4.211 + Y(q^2)$

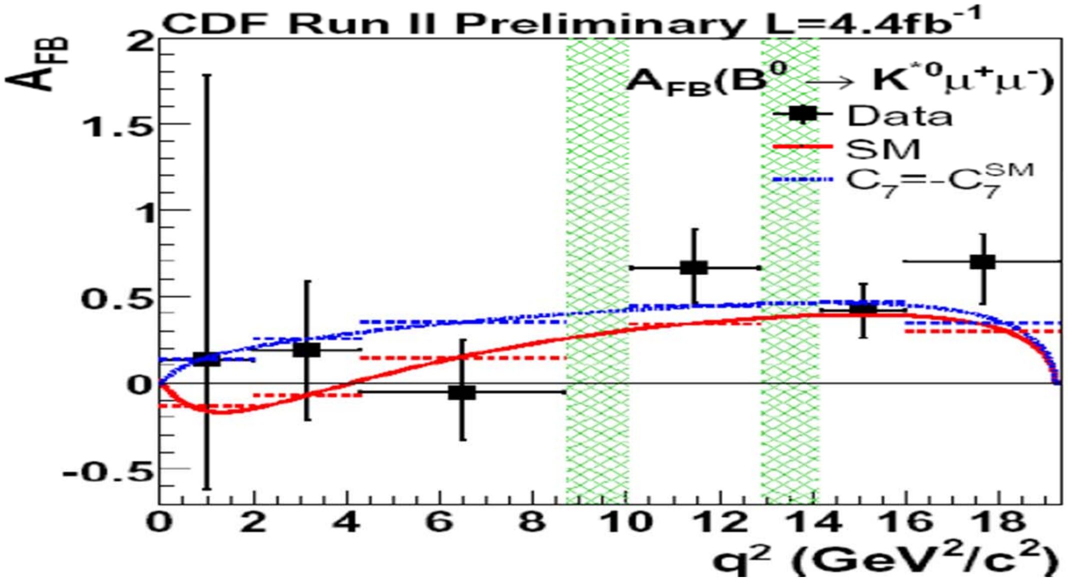
zero of A_{FB} occurs at $q^2 \sim 4.3$ GeV^2



250 events

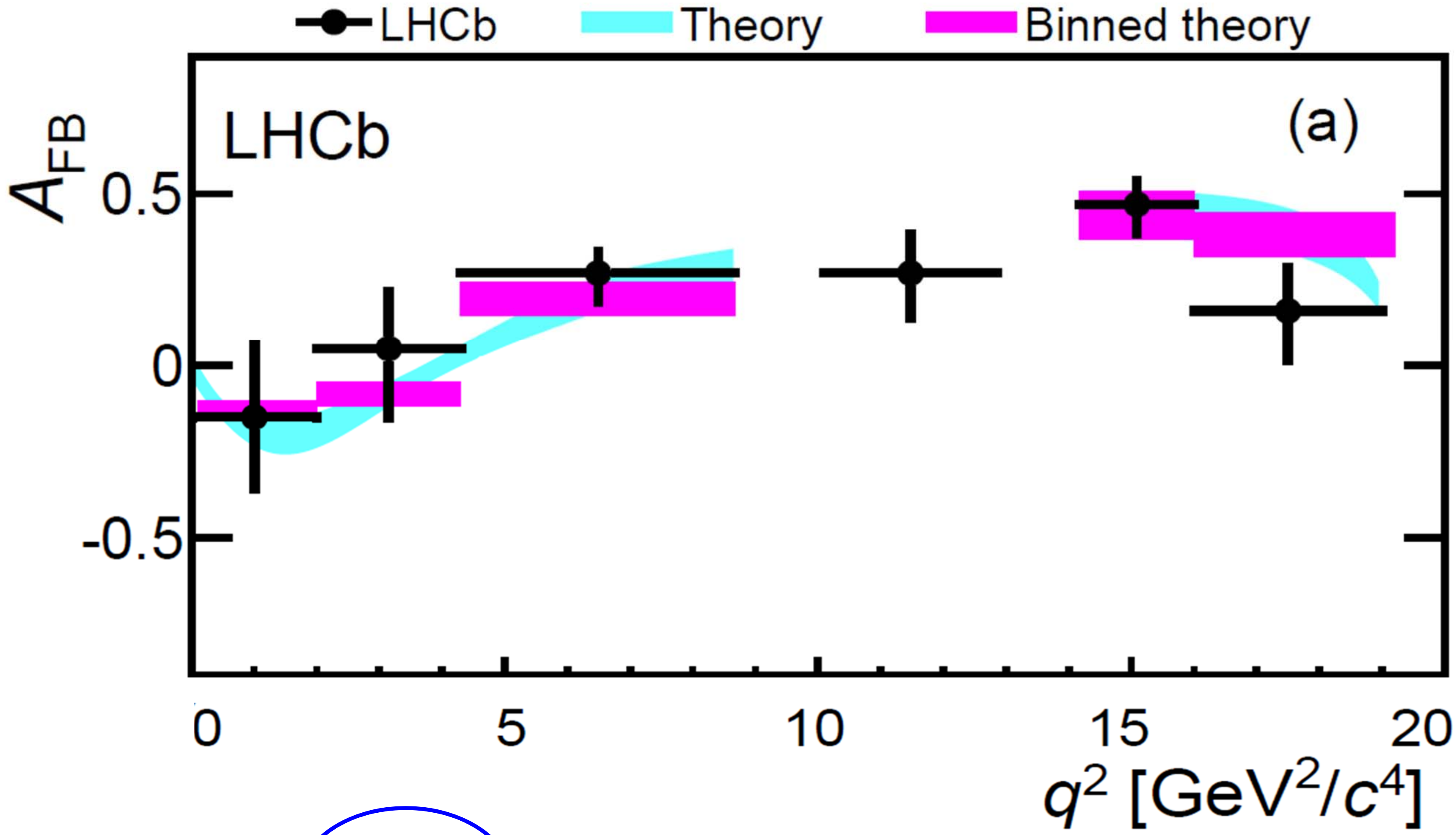


100 events



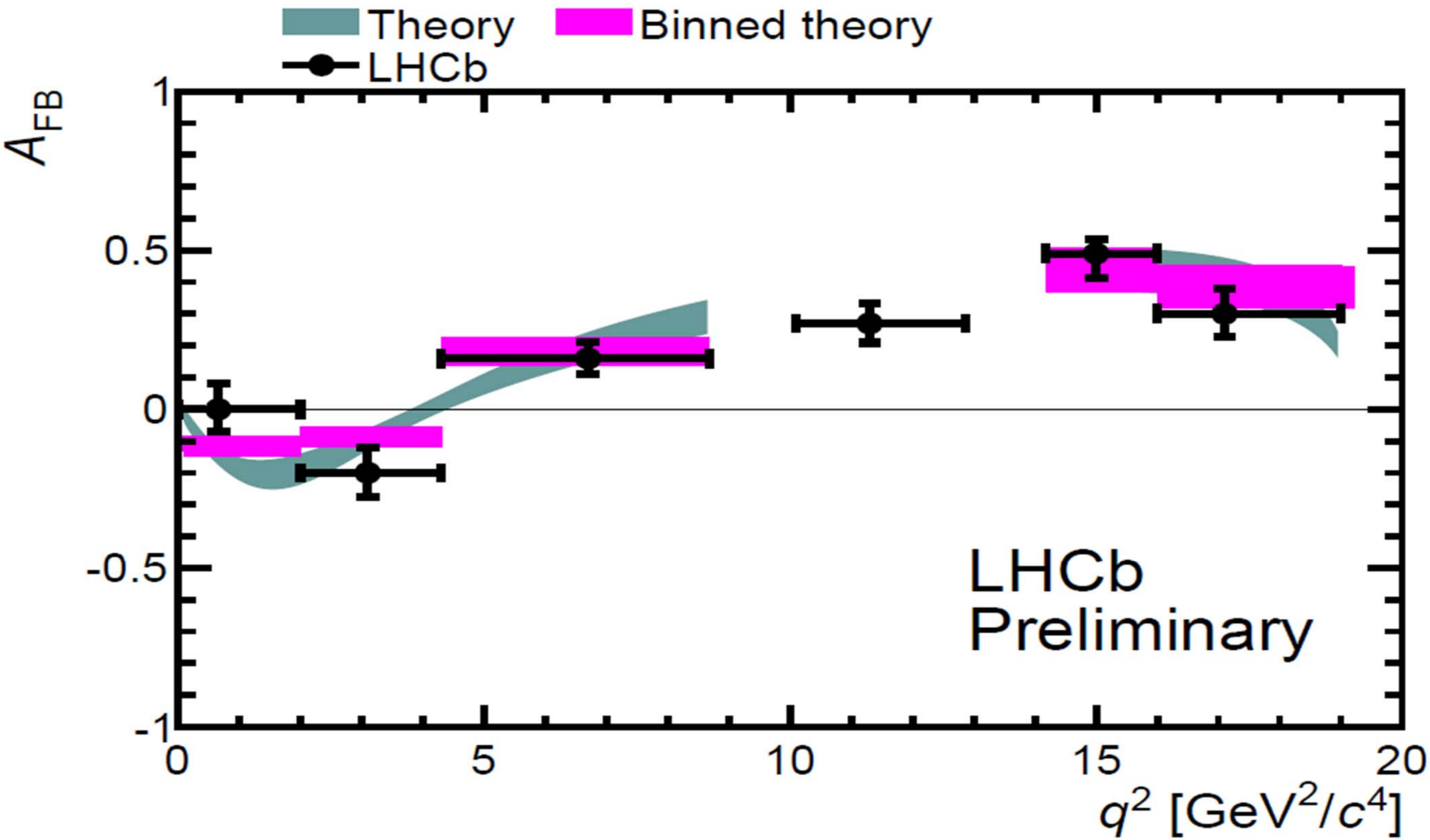
100 events

$B \to K^* \mu^+ \mu^-$: AFB



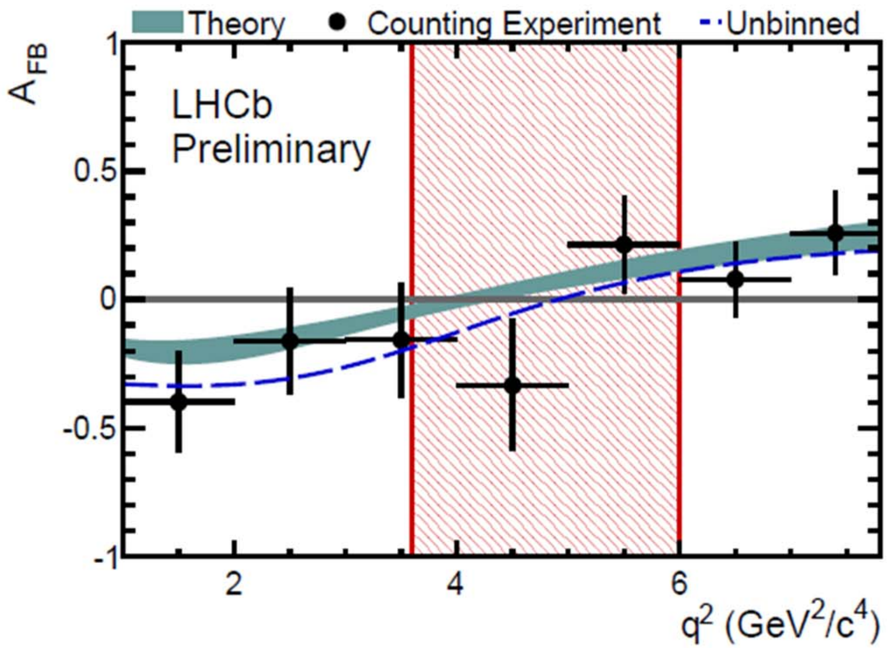
arXiv: 1112.3515

March 2012 at Moriond QCD



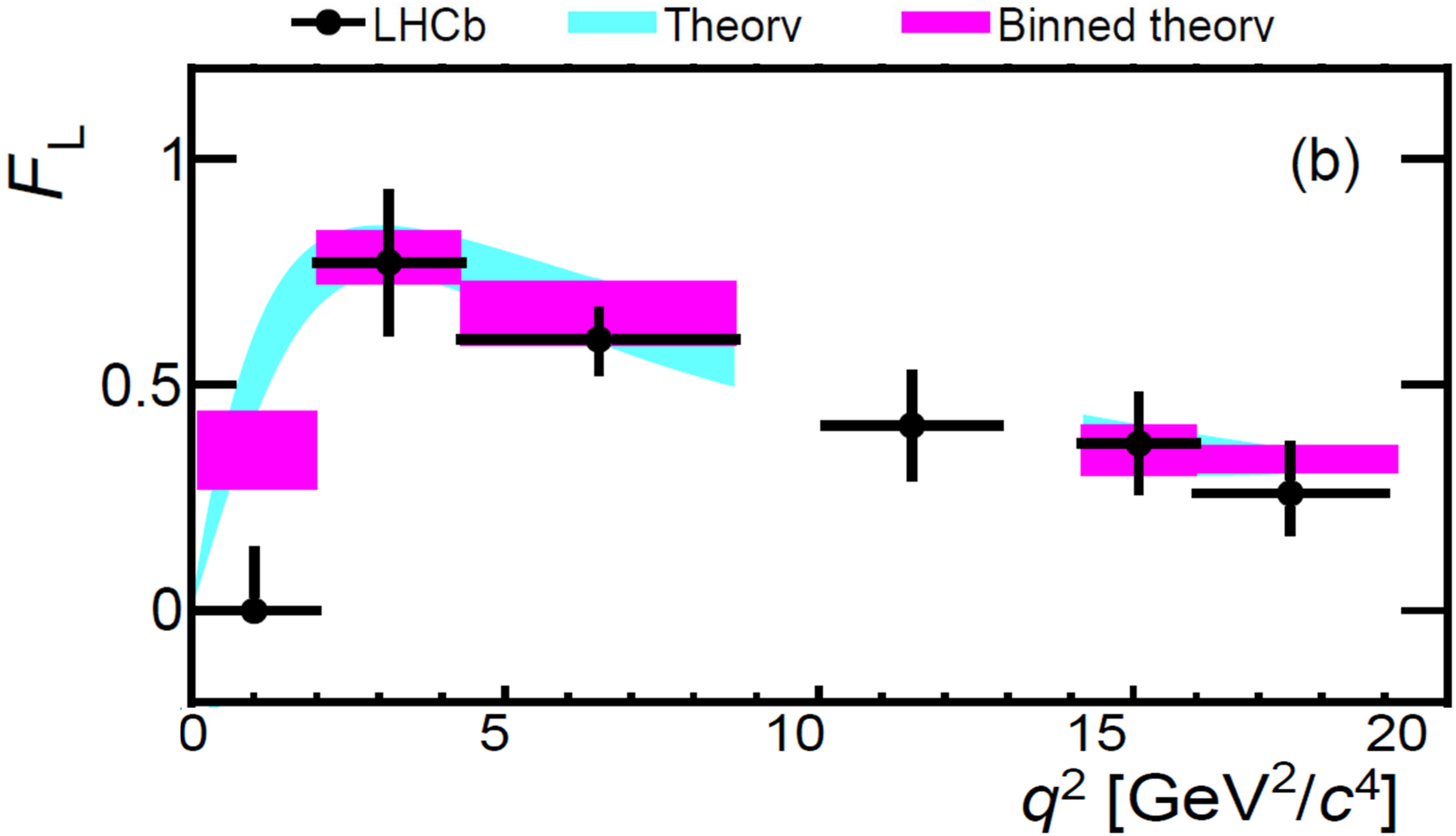
$B^0 \to K^{*0}\mu^+\mu^-$ A_{FB} zero-crossing point

- The SM predicts A_{FB} to change sign at a well defined point in q^2
- This zero-crossing point q_0^2 is largely free from form-factor uncertainties
- Extracted through a 2D fit to the foward- and backward-going m_{B^0} and q^2 distributions



- The worlds first measurement of q_0^2, at $q_0^2 = 4.9^{+1.1}_{-1.3}\ \mathrm{GeV}^2/c^4$ [preliminary]
- This is consistent with SM predictions which range from $4 - 4.3\ \mathrm{GeV}^2/c^4$ [1, 2, 3]

B→ K*$\mu^+ \mu^-$: polarization



arXiv: 1112.3515

Properties of resonances K^*_J

In addition to the lowest K*, can be best cross check

K_J^*	J^P	$n^{2S+1}L_J$	m (MeV)	Γ (MeV)	$\mathcal{B}(K_J^* \to K\pi)(\%)$
$K^*(1410)$	1^-	2^3S_1?	1414 ± 15	232 ± 21	6.6 ± 1.3
$K_0^*(1430)$	0^+	$1^3P_0, 2^3P_0$?	1425 ± 50	270 ± 80	93 ± 10
$K_2^*(1430)$	2^+	$^3P_2$	1432.4 ± 1.3	109 ± 5	49.9 ± 1.2
$K^*(1680)$	1^-	1^3D_1	1717 ± 27	322 ± 110	38.7 ± 2.5
$K_3^*(1780)$	3^-	1^3D_3	1776 ± 7	159 ± 21	18.8 ± 1.0
$K_4^*(2045)$	4^+	1^3F_4	2045 ± 9	198 ± 30	9.9 ± 1.2

About $K_2^*(1430)$ and $f_2'(1525)$

$\Gamma =$ 100MeV , 73 MeV

→ K π , → K K

l	s	J	$^{2s+1}L_J$	J^{PC}	Meson
$l=0$	$s=0$	$J=0$	$^1S_0$	0^{-+}	Pseudoscalar (P)
	$s=1$	$J=1$	$^3S_1$	1^{--}	Vector (V)
$l=1$	$s=0$	$J=1$	$^1P_1$	1^{+-}	Axial-vector $(A(^1P_1))$
	$s=1$	$J=0$	$^3P_0$	0^{++}	$K_0^*(1430)$
		$J=1$	$^3P_1$	1^{++}	$K_1(1270)$, $K_1(1400)$
		$J=2$	$^3P_2$	2^{++}	Tensor (T)

$$B \to K_2^* l^+ l^- (B_s \to f_2' l^+ l^-)$$

- 5 polarization states: Jz= -2, -1, 0, 1, 2
- 3 contribute to $\bar{B}^0 \to K_2^* l^+ l^-$, Jz=-1, 0, 1, because of angular momentum conservation
- Similar to K* mesons. $\bar{B}^0 \to K_2^* l^+ l^-$ formulism can be got by some substitution in $\bar{B}^0 \to K^* l^+ l^-$ formulism in pQCD approach.

Form factors needed for exclusive decays

- For a scalar meson K^*_0,
- Only three form factors involved

$$\langle K_0^*(P_2)|\bar{s}\gamma_\mu\gamma_5 b|\bar{B}(P_B)\rangle = -i\left\{\left[P_\mu - \frac{m_B^2 - m_{K_0^*}^2}{q^2}q_\mu\right]F_1(q^2) + \frac{m_B^2 - m_{K_0^*}^2}{q^2}q_\mu F_0(q^2)\right\}$$

$$\langle K_0^*(P_2)|\bar{s}\sigma_{\mu\nu}q^\nu\gamma_5 b|\bar{B}(P_B)\rangle = [(m_B^2 - m_{K_0^*}^2)q_\mu - q^2 P_\mu]\frac{F_T(q^2)}{m_B + m_{K_0^*}},$$

For (axial)vector or tensor, there are more complications

- **They are non-perturbative in nature , difficult to calculate with high precision**

$$\langle K_J^*(P_2,\epsilon)|\bar{s}\gamma^\mu b|\bar{B}(P_B)\rangle = -\frac{2V(q^2)}{m_B+m_{K_J^*}}\epsilon^{\mu\nu\rho\sigma}\epsilon^*_{J\nu}P_{B\rho}P_{2\sigma},$$

$$\langle K_J^*(P_2,\epsilon)|\bar{s}\gamma^\mu\gamma_5 b|\bar{B}(P_B)\rangle = 2im_{K_J^*}A_0(q^2)\frac{\epsilon_J^*\cdot q}{q^2}q^\mu + i(m_B+m_{K_J^*})A_1(q^2)\left[\epsilon^*_{J\mu} - \frac{\epsilon_J^*\cdot q}{q^2}q^\mu\right] - iA_2(q^2)\frac{\epsilon_J^*\cdot q}{m_B+m_{K_J^*}}\left[P^\mu - \frac{m_B^2-m_{K_J^*}^2}{q^2}q^\mu\right],$$

$$\langle K_J^*(P_2,\epsilon)|\bar{s}\sigma^{\mu\nu}q_\nu b|\bar{B}(P_B)\rangle = -2iT_1(q^2)\epsilon^{\mu\nu\rho\sigma}\epsilon^*_{J\nu}P_{B\rho}P_{2\sigma},$$

$$\langle K_J^*(P_2,\epsilon)|\bar{s}\sigma^{\mu\nu}\gamma_5 q_\nu b|\bar{B}(P_B)\rangle = T_2(q^2)[(m_B^2-m_{K_J^*}^2)\epsilon^*_{J\mu} - \epsilon_J^*\cdot qP^\mu] + T_3(q^2)\epsilon_J^*\cdot q\left[q^\mu - \frac{q^2}{m_B^2-m_{K_J^*}^2}P^\mu\right]$$

Form factors calculated in pQCD to leading order of $1/m_b$

F	$F(0)$	a	b
$V^{BK_2^*}$	$0.21^{+0.04+0.05}_{-0.04-0.03}$	$1.73^{+0.02+0.05}_{-0.02-0.03}$	$0.66^{+0.04+0.07}_{-0.05-0.01}$
$A_0^{BK_2^*}$	$0.18^{+0.04+0.04}_{-0.03-0.03}$	$1.70^{+0.00+0.05}_{-0.02-0.07}$	$0.64^{+0.00+0.04}_{-0.06-0.10}$
$A_1^{BK_2^*}$	$0.13^{+0.03+0.03}_{-0.02-0.02}$	$0.78^{+0.01+0.05}_{-0.01-0.04}$	$-0.11^{+0.02+0.04}_{-0.03-0.02}$
$A_2^{BK_2^*}$	$0.08^{+0.02+0.02}_{-0.02-0.01}$	...	...
$T_1^{BK_2^*}$	$0.17^{+0.04+0.04}_{-0.03-0.03}$	$1.73^{+0.00+0.05}_{-0.03-0.07}$	$0.69^{+0.00+0.05}_{-0.08-0.11}$
$T_2^{BK_2^*}$	$0.17^{+0.03+0.04}_{-0.03-0.03}$	$0.79^{+0.00+0.02}_{-0.04-0.09}$	$-0.06^{+0.00+0.00}_{-0.10-0.16}$
$T_3^{BK_2^*}$	$0.14^{+0.03+0.03}_{-0.03-0.02}$	$1.61^{+0.01+0.09}_{-0.00-0.04}$	$0.52^{+0.05+0.15}_{-0.01-0.01}$
$V^{B_sf_2'}$	$0.20^{+0.04+0.05}_{-0.03-0.03}$	$1.75^{+0.02+0.05}_{-0.00-0.03}$	$0.69^{+0.05+0.08}_{-0.01-0.01}$
$A_0^{B_sf_2'}$	$0.16^{+0.03+0.03}_{-0.02-0.02}$	$1.69^{+0.00+0.04}_{-0.01-0.03}$	$0.64^{+0.00+0.01}_{-0.04-0.02}$
$A_1^{B_sf_2'}$	$0.12^{+0.02+0.03}_{-0.02-0.02}$	$0.80^{+0.02+0.07}_{-0.00-0.03}$	$-0.11^{+0.05+0.09}_{-0.00-0.00}$
$A_2^{B_sf_2'}$	$0.09^{+0.02+0.02}_{-0.01-0.01}$	...	...
$T_1^{B_sf_2'}$	$0.16^{+0.03+0.04}_{-0.03-0.02}$	$1.75^{+0.01+0.05}_{-0.00-0.05}$	$0.71^{+0.03+0.06}_{-0.01-0.08}$
$T_2^{B_sf_2'}$	$0.16^{+0.03+0.04}_{-0.03-0.02}$	$0.82^{+0.00+0.04}_{-0.04-0.06}$	$-0.08^{+0.00+0.03}_{-0.09-0.08}$
$T_3^{B_sf_2'}$	$0.13^{+0.03+0.03}_{-0.02-0.02}$	$1.64^{+0.02+0.06}_{-0.00-0.06}$	$0.57^{+0.04+0.05}_{-0.01-0.09}$

W. Wang, PRD83,014008

And different models give quite different results

	ISGW2 [22]	CLFQM [22, 23]	LCSR [17]	LEET+BSW [10]	PQCD [7]
$V^{BK_2^*}$	0.38	0.29	0.16 ± 0.02	0.21 ± 0.03	$0.21^{+0.06}_{-0.05}$
$A_0^{BK_2^*}$	0.27	0.23	0.25 ± 0.04	0.15 ± 0.02	$0.18^{+0.05}_{-0.04}$
$A_1^{BK_2^*}$	0.24	0.22	0.14 ± 0.02	0.14 ± 0.02	$0.13^{+0.04}_{-0.03}$
$A_2^{BK_2^*}$	0.22	0.21	0.05 ± 0.02	0.14 ± 0.02	$0.08^{+0.03}_{-0.02}$
$T_1^{BK_2^*}$		0.28	0.14 ± 0.02	0.16 ± 0.02	$0.17^{+0.05}_{-0.04}$
$T_3^{BK_2^*}$		-0.25	$0.01^{+0.02}_{-0.01}$	0.10 ± 0.02	$0.14^{+0.05}_{-0.03}$

And different models give quite different results

	ISGW2 [22]	CLFQM [22, 23]	LCSR [17]	LEET+BSW [10]	PQCD [7]
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$T_1^{BK_2^*}$		0.28	0.14 ± 0.02	0.16 ± 0.02	$0.17^{+0.05}_{-0.04}$
$T_3^{BK_2^*}$		-0.25	$0.01^{+0.02}_{-0.01}$	0.10 ± 0.02	$0.14^{+0.05}_{-0.03}$

- The B→ K^*_J form factors are mostly resorts to the Lattice QCD simulations, which is quite limited at this stage.
- in the heavy quark limit and the large energy limit, interactions of the heavy and light systems can be expanded in small ratios Λ/E and Λ/m_B
- At the leading power, the large energy symmetry is obtained and such symmetry to a large extent simplifies the heavy-to-light transition
- This soft-collinear effective theory constrains the independent Lorentz structures
- reduces the seven independent hadronic form factors for each B→ K^*_J ($J\geq1$) type to two universal functions

B→ K*J (J≥1)

$$A_0^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} \equiv A_0^{K_J^*,\mathrm{eff}} \simeq \left(1-\frac{m_{K_J^*}^2}{m_B E}\right)\xi_\parallel^{K_J^*}(q^2)+\frac{m_{K_J^*}}{m_B}\xi_\perp^{K_J^*}(q^2),$$

$$A_1^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} \equiv A_1^{K_J^*,\mathrm{eff}} \simeq \frac{2E}{m_B+m_{K_J^*}}\xi_\perp^{K_J^*}(q^2),$$

$$A_2^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} \equiv A_2^{K_J^*,\mathrm{eff}} \simeq \left(1+\frac{m_{K_J^*}}{m_B}\right)\left[\xi_\perp^{K_J^*}(q^2)-\frac{m_{K_J^*}}{E}\xi_\parallel^{K_J^*}(q^2)\right]$$

$$V^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} \equiv V^{K_J^*,\mathrm{eff}} \simeq \left(1+\frac{m_{K_J^*}}{m_B}\right)\xi_\perp^{K_J^*}(q^2),$$

$$T_1^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} \equiv T_1^{K_J^*,\mathrm{eff}} \simeq \xi_\perp^{K_J^*}(q^2),$$

$$T_2^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} \equiv T_2^{K_J^*,\mathrm{eff}} \simeq \left(1-\frac{q^2}{m_B^2-m_{K_J^*}^2}\right)\xi_\perp^{K_J^*}(q^2),$$

$$T_3^{K_J^*}(q^2)\left(\frac{|\vec{p}_{K_J^*}|}{m_{K_J^*}}\right)^{J-1} \equiv T_3^{K_J^*,\mathrm{eff}} \simeq \xi_\perp^{K_J^*}(q^2)-\left(1-\frac{m_{K_J^*}^2}{m_B^2}\right)\frac{m_{K_J^*}}{E}\xi_\parallel^{K_J^*}(q^2).$$

For the case of B to scalar meson transition, in the large energy limit, the soft-collinear effective theory applies

- Three form factors reduce to only one

$$\frac{m_B}{m_B + m_{K_0^*}} F_T(q^2) = F_1(q^2) = \frac{m_B}{2E} F_0(q^2) = \xi^{K_0^*}(q^2)$$

In fact, if applying LO SCET, we need only these functions, by Hatanaka and Yang, Phys. Rev. D 79, 114008 (2009); Eur. Phys. J. C 67, 149 (2010)

TABLE III. $B \to K_J^*$ form factors taken from Ref. [10].

K_J^*	$\xi_\parallel$	$\xi_\perp$
$K^*(1410)$	0.22 ± 0.03	0.28 ± 0.04
$K_0^*(1430)$	0.22 ± 0.03	-
$K_2^*(1430)$	0.22 ± 0.03	0.28 ± 0.04
$K^*(1680)$	0.18 ± 0.03	0.24 ± 0.05
$K_3^*(1780)$	0.16 ± 0.03	0.23 ± 0.05
$K_4^*(2045)$	0.13 ± 0.03	0.19 ± 0.05

BRs, fL

With the recent pQCD results for $\bar{B}^0 \to K_2^*$ form factors

Branching ratios:

$$\mathcal{BR}(B \to K_2^* \mu^+ \mu^-) = (2.5^{+1.6}_{-1.1}) \times 10^{-7},$$
$$\mathcal{BR}(B \to K_2^* \tau^+ \tau^-) = (9.6^{+6.2}_{-4.5}) \times 10^{-10}.$$

Longitudinal Polarization fractions:

$$f_L \equiv \frac{\Gamma_0}{\Gamma} = \frac{\int dq^2 \frac{d\Gamma_0}{dq^2}}{\int dq^2 \frac{d\Gamma}{dq^2}}$$

$$f_L(B \to K_2^* \mu^+ \mu^-) = (66.6 \pm 0.4)\%,$$
$$f_L(B \to K_2^* \tau^+ \tau^-) = (57.2 \pm 0.7)\%$$

Estimate BRs from exp.

- Experimentally, we have

$$\mathcal{B}(\bar{B}^0 \to K_2^*\gamma) = (12.4 \pm 2.4) \times 10^{-6},$$

$$\mathcal{B}(\bar{B}^0 \to K^*\gamma) = (43.3 \pm 1.5) \times 10^{-6}.$$

$$B(\overline{B}^0 \to K^* l^+ l^-) = (1.09 \pm 0.12) \times 10^{-6}$$

- Assume $R = B(K_2^*)/B(K^*)$ is the same for radiative and semi-leptonic decays, we have

$$\mathcal{B}_{\exp}(B^0 \to K_2^{*0} l^+ l^-) = (3.1 \pm 0.7) \times 10^{-7}$$

Compare with KC Yang, **PRD79:114008,2009**

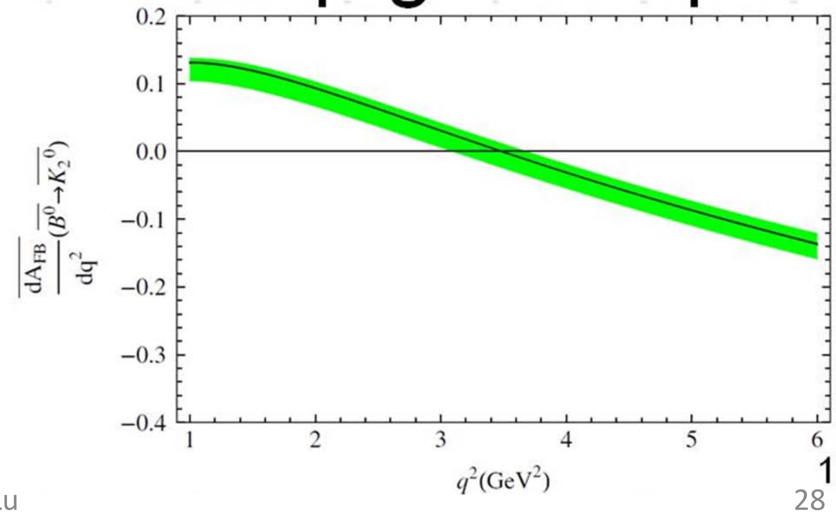
$$\mathcal{B}(B^0 \to K_2^{*0}(1430)\mu^+\mu^-) = (3.5^{+1.1+0.7}_{-1.0-0.6}) \times 10^{-7}$$

D. Forward-backward asymmetry

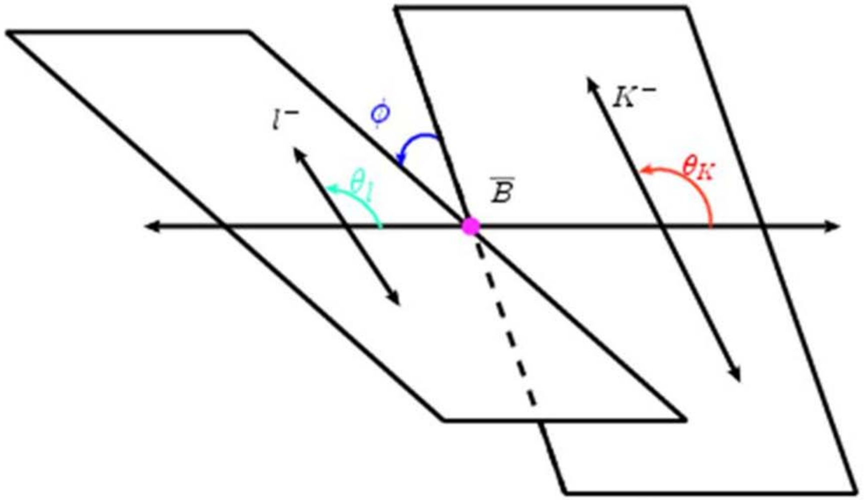
The differential forward-backward asymmetry of $\bar{B} \to \bar{K}_2^* l^+ l^-$ is defined by

$$\frac{dA_{\rm FB}}{dq^2} = \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_l \frac{d^2\Gamma}{dq^2 d\cos\theta_l} = \frac{3}{4} I_6$$

- The forward backward asymmetry varies from positive to negative as q^2 grows up
- The 0-cross point is sensitive to new physics



Forward and Backward Asymmetry



$$\frac{dA_{FB}}{dq^2} = \left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_l \frac{d^2\Gamma}{dq^2 d\cos\theta_l}$$

The zero-crossing point s_0 of FBAs is determined by the equation

$$C_9 A_1(s_0)V(s_0) + C_{7L}\frac{m_b(m_B+m_{K_2^*})}{s_0}A_1(s_0)T_1(s_0) + C_{7L}\frac{m_b(m_B-m_{K_2^*})}{s_0}T_2(s_0)V(s_0) = 0$$

$$s_0 = (3.1 \pm 0.1)\ \mathrm{GeV}^2,$$

Smaller uncertainty

Using the form factor relations derived from heavy quark symmetry and large energy limit, the 0-crosing point of forward-backward asymmetry simplify to

$$\mathrm{Re}[C_9] + 2\frac{m_b m_B}{s_0} C_{7L} \mathcal{R}^{K_J^*}(s_0) = 0.$$

with $$\mathcal{R}^{K_J^*}(q^2) \equiv \frac{m_B + m_{K_J^*}}{m_B} \frac{T_1^{K_J^*}(q^2)}{V^{K_J^*}(q^2)}$$ =1

And in model calculations:

$$\mathcal{R}^{K_2}_{\mathrm{PQCD}} \sim 1.03, \qquad \mathcal{R}^{K_2}_{\mathrm{LCSR}} \sim 1.11,$$

Similarly for $B_s \to f_2' \, l^+ l^-$

$$\mathcal{B}(B_s \to f_2' \mu^+ \mu^-) = (1.8^{+1.1}_{-0.7}) \times 10^{-7},$$

$$f_L(B_s \to f_2' \mu^+ \mu^-) = (63.2 \pm 0.7)\%,$$

$$s_0(B_s \to f_2' \mu^+ \mu^-) = (3.53 \pm 0.03)\ \mathrm{GeV}^2$$

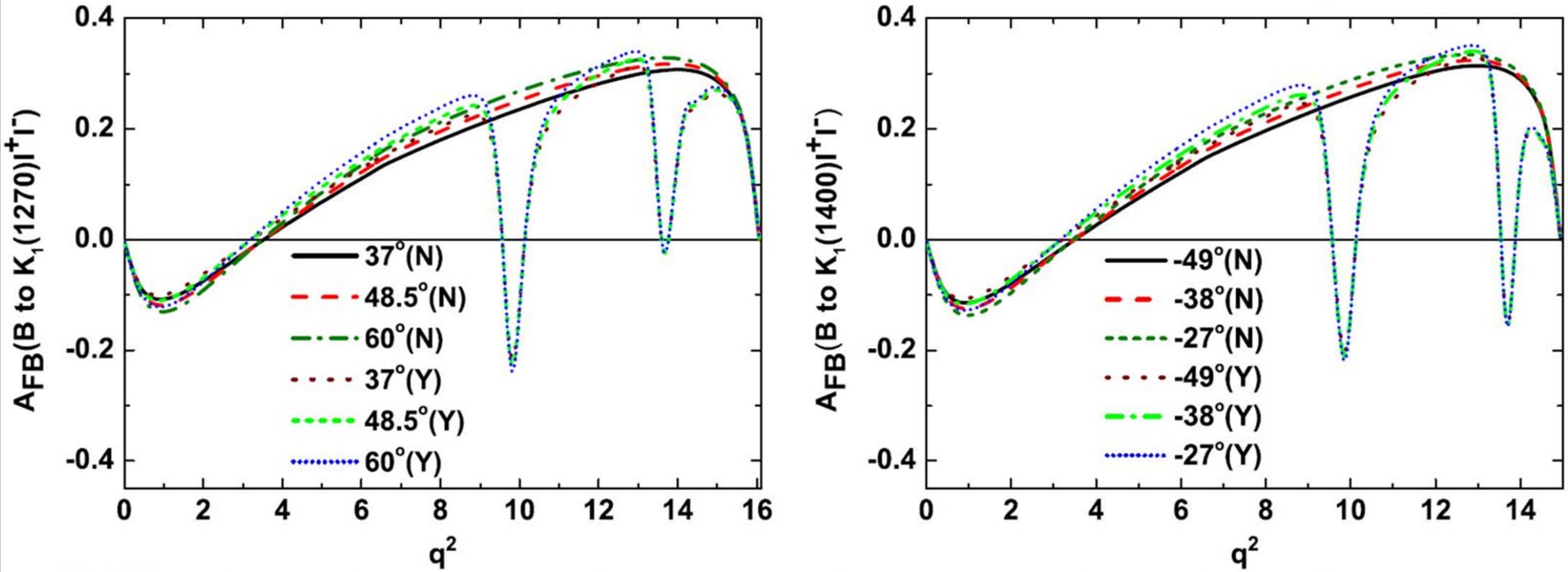
$$\mathcal{B}(B_s \to f_2' \tau^+ \tau^-) = (5.8^{+3.7}_{-2.1}) \times 10^{-10},$$

$$f_L(B_s \to f_2' \tau^+ \tau^-) = (53.9 \pm 0.4)\%.$$

Forward backward asymmetry

$$\frac{d A_{FB}}{dq^2}$$

In $B \to K_1\, l^+ l^-$ decays



- The 0-cross point is at q^2=3.55 GeV^2

NP scenario: Vector-like quark model (VQM)

Expanding SM including a $SU(2)_L$ singlet down type quark, Yukawa sector of SM is modified to

$$\mathcal{L}_Y = \bar{Q}_L Y_D H d_R + h_D \bar{Q}_L H D_R + m_D \bar{D}_L D_R + h.c.$$

This modification brings FCNC for the mass eigenstates at tree level.

The interaction for b-s-Z in VQM is

$$\mathcal{L}_{b\to s} = \frac{g c_L^s \lambda_{sb}}{\cos\theta_W} \bar{s}\gamma^\mu P_L b Z_\mu + h.c.,$$

free parameter

$$\lambda_{sb} = |\lambda_{sb}| \exp(i\theta_s)$$

with which the effective Hamiltonian for $b \to s l^+ l^-$ is given as

$$\mathcal{H}^Z_{b\to s l^+ l^-} = \frac{2G_F}{\sqrt{2}} \lambda_{sb} c_L^s (\bar{s}b)_{V-A} \left[c_L^\ell (\bar{\ell}\ell)_{V-A} + c_R^\ell (\bar{\ell}\ell)_{V+A} \right]$$

NP scenario: Vector-like quark model (VQM)

The VQM effects can be absorbed into the Wilson coefficients C_9 and C_{10}

$$C_9^{\mathrm{VLQ}} = C_9^{\mathrm{SM}} - \frac{4\pi}{\alpha_{\mathrm{em}}}\frac{\lambda_{sb}c_L^s(c_L^\ell + c_R^\ell)}{V_{ts}^* V_{tb}},$$

$$C_{10}^{\mathrm{VLQ}} = C_{10}^{\mathrm{SM}} + \frac{4\pi}{\alpha_{\mathrm{em}}}\frac{\lambda_{sb}c_L^s(c_L^\ell - c_R^\ell)}{V_{ts}^* V_{tb}}.$$

Lepton section in VQM is the same as in SM.

NP scenario: Family non-universal Z' model

Expand SM by simply including an additional U(1)' symmetry. The current is

$$J^{\mu}_{Z'} = g' \sum_i \bar{\psi}_i \gamma^{\mu} [\epsilon_i^{\psi_L} P_L + \epsilon_i^{\psi_R} P_R] \psi_i \,,$$

which couples to a family non-universal Z' boson.
After rotating to the mass eigen basis, FCNC appears at tree level in both LH and RH section.

Interaction for b-s-Z' is given as

$$\mathcal{L}^{Z'}_{\text{FCNC}} = -g'(B^L_{sb} \bar{s}_L \gamma_\mu b_L + B^R_{sb} \bar{s}_R \gamma_\mu b_R) Z'^{\mu} + \text{h.c.}$$

The effective Hamiltonian for $b \to s l^+ l^-$ is given as

$$\mathcal{H}^{Z'}_{\text{eff}} = \frac{8G_F}{\sqrt{2}} (\rho^L_{sb} \bar{s}_L \gamma_\mu b_L + \rho^R_{sb} \bar{s}_R \gamma_\mu b_R)(\rho^L_{ll} \bar{\ell}_L \gamma^\mu \ell_L + \rho^R_{ll} \bar{\ell}_R \gamma^\mu \ell_R)$$

NP scenario: Family non-universal Z' model

Different from VQM, the couplings in both the quark and lepton section are free parameters.

Too many free parameters. So we set $\rho_{sb}^R = 0$ in our analysis to reduce freedoms.

Z' also only affects C_9 and C_{10} phenomenally:

$$C_9^{Z'} = C_9 - \frac{4\pi}{\alpha_{em}} \frac{\rho_{sb}^L(\rho_{ll}^L + \rho_{ll}^R)}{V_{tb}V_{ts}^*}, \quad C_{10}^{Z'} = C_{10} + \frac{4\pi}{\alpha_{em}} \frac{\rho_{sb}^L(\rho_{ll}^L - \rho_{ll}^R)}{V_{tb}V_{ts}^*}$$

Constrain the model parameters by exp.

Data used for fitting

$b \to c l \bar{\nu}$	$b \to s l^+ l^-$	$\overline{B}^0 \to K^* l^+ l^-$
$(10.58 \pm 0.15) \times 10^{-2}$	$(3.66^{+0.76}_{-0.77}) \times 10^{-6}$	$(1.09^{+0.12}_{-0.11}) \times 10^{-6}$

$q^2(\mathrm{GeV}^2)$	$\mathcal{B}(10^{-7})$	F_L	$-A_{FB}$
$[0, 2]$	1.46 ± 0.41	0.29 ± 0.21	0.47 ± 0.32
$[2, 4.3]$	0.86 ± 0.32	0.71 ± 0.25	0.11 ± 0.37
$[4.3, 8.68]$	1.37 ± 0.61	0.64 ± 0.25	0.45 ± 0.26
$[10.09, 12.86]$	2.24 ± 0.48	0.17 ± 0.17	0.43 ± 0.20
$[14.18, 16]$	1.05 ± 0.30	-0.15 ± 0.28	0.70 ± 0.24
> 16	2.04 ± 0.31	0.12 ± 0.15	0.66 ± 0.16
$[1, 6]$	1.49 ± 0.47	0.67 ± 0.24	0.26 ± 0.31

Heavy Flavor Averaging Group, arXiv:1010.1589;
Particle Data Group, J. Phys. G 37,075021.

Definition of χ^2

$$\chi_i^2 = \frac{(B_i^{the} - B_i^{exp})^2}{(B_i^{err})^2}$$

Constrain the VQM parameters

$$\begin{aligned} \mathrm{Re}\lambda_{sb} &= (0.07 \pm 0.04) \times 10^{-3} \\ \mathrm{Im}\lambda_{sb} &= (0.09 \pm 0.23) \times 10^{-3} \end{aligned} \Rightarrow$$

$|\lambda_{sb}| < 0.3 \times 10^{-3}$

Phase less constrained

Constrains on the Wilson coefficients

with $\chi^2/d.o.f. = 2.4$

$$|\Delta C_9| = |C_9 - C_9^{SM}| < 0.2$$

$$|\Delta C_{10}| = |C_{10} - C_{10}^{SM}| < 2.8$$

Constrain the Z′ model parameters

Assume ΔC_9, ΔC_{10} as real

$$\Delta C_9 = 0.88 \pm 0.75, \quad \Delta C_{10} = 0.01 \pm 0.69$$

Both ΔC_9 and ΔC_{10} are complex numbers.

with $\chi^2/d.o.f. = 2.3$

$$\Delta C_9 = (-0.81 \pm 1.22) + (3.05 \pm 0.92)i$$
$$\Delta C_{10} = (1.00 \pm 1.28) + (-3.16 \pm 0.94)i$$

with $\chi^2/d.o.f. = 2.4$

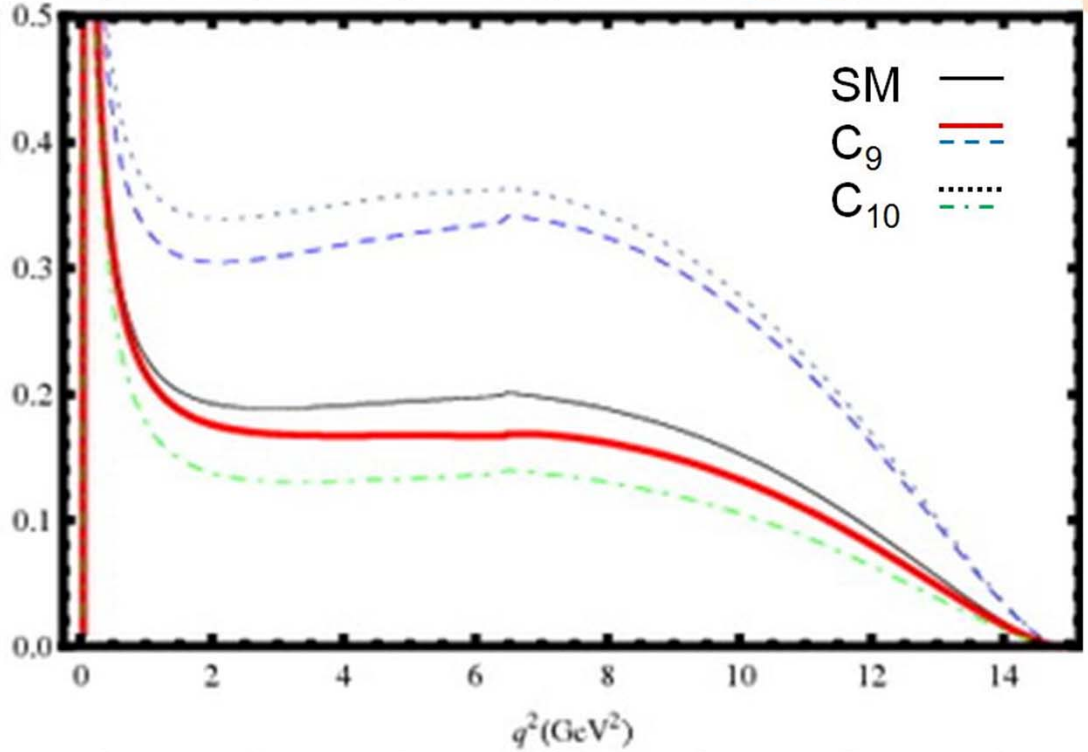
$\text{Im}[C_{10}]$ has little effect on χ^2

Combining the above results $|\Delta C_9| < 3, \quad |\Delta C_{10}| < 3$

New Physics effects in observables

In the NP effects, we choose $\Delta C_9 = 3e^{i\pi/4, i3\pi/4}$ and $\Delta C_{10} = 3e^{i\pi/4, i3\pi/4}$ as the reference points.

$\frac{dBr}{dq^2}$



Br (10^{-7}) may be enhanced, however, large uncertainties

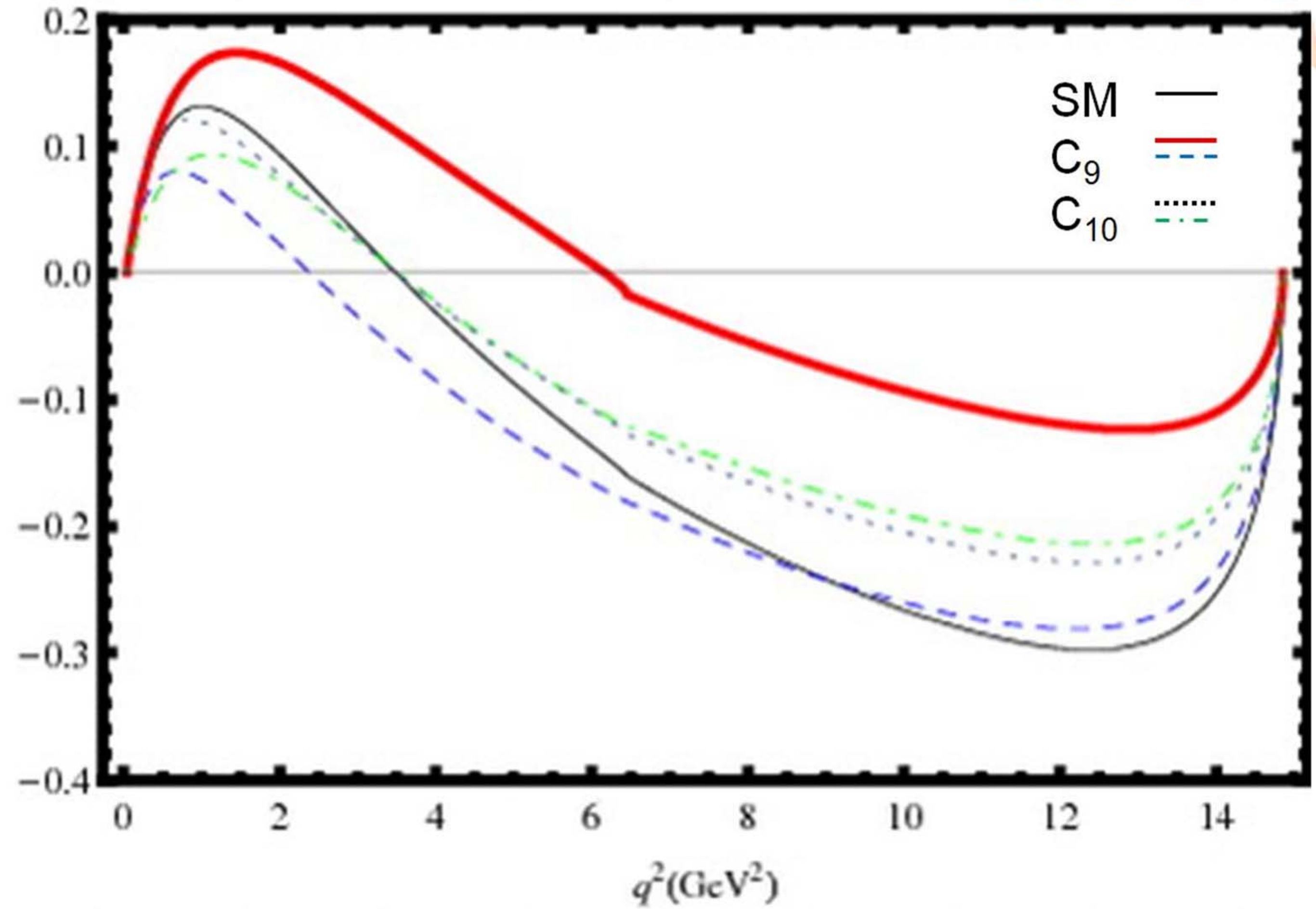
In this parameter space, $\mathcal{B}(B_s \to \mu^+\mu^-)$ is consistent with the recent measurement. $\mathcal{B}(B_s \to \mu^+\mu^-) < 5.1 \times 10^{-8}$

D0 collaboration, PLB 693,539.

New Physics effects in observable $\overline{\frac{dA_{FB}}{dq^2}}$

$B \to K^*_2\, l^+ l^-$

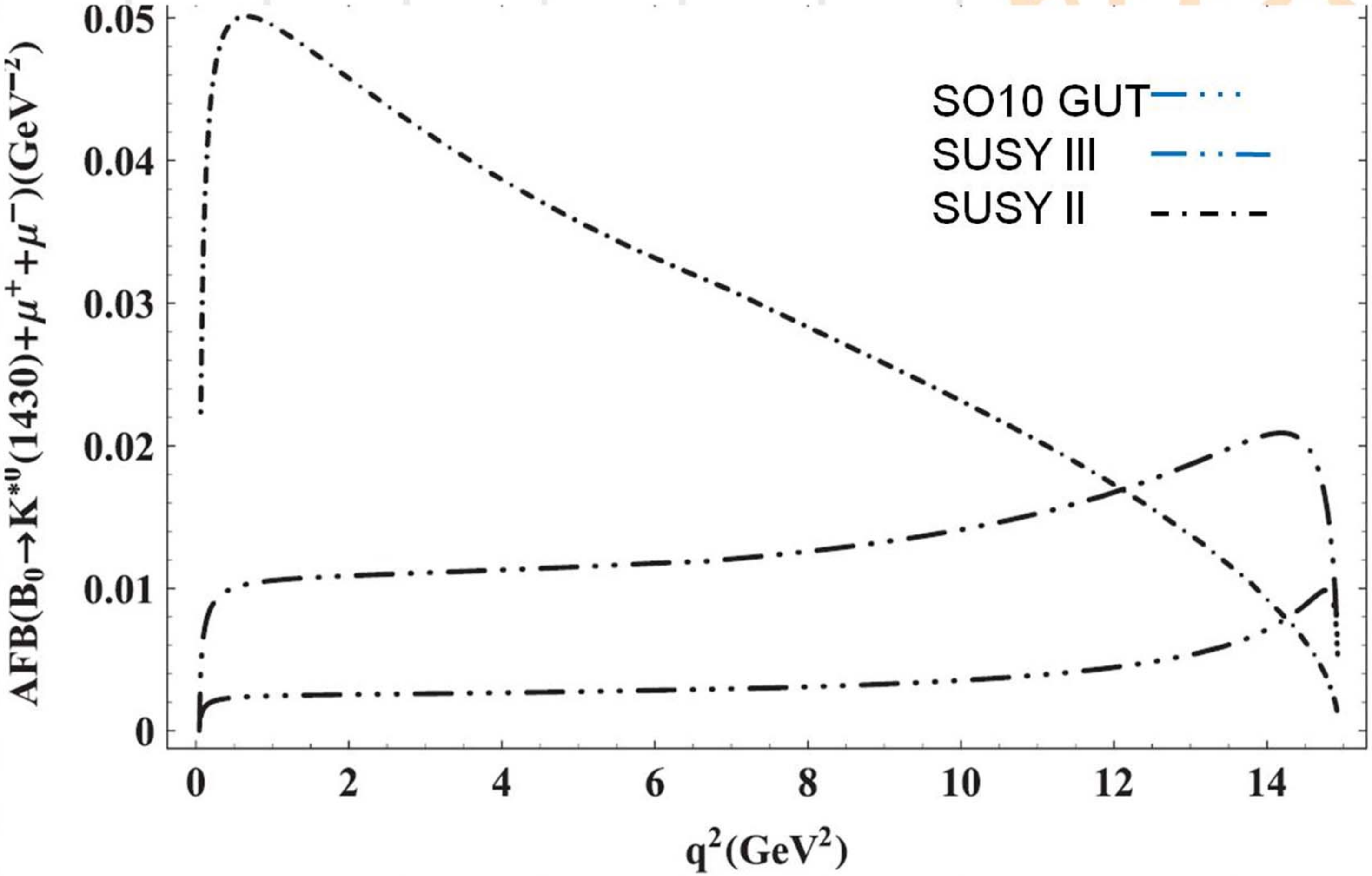
Zero-crossing point of AFB may be changed significantly in new physics model.



New Physics effects in observable $\overline{\frac{dA_{FB}}{dq^2}}$

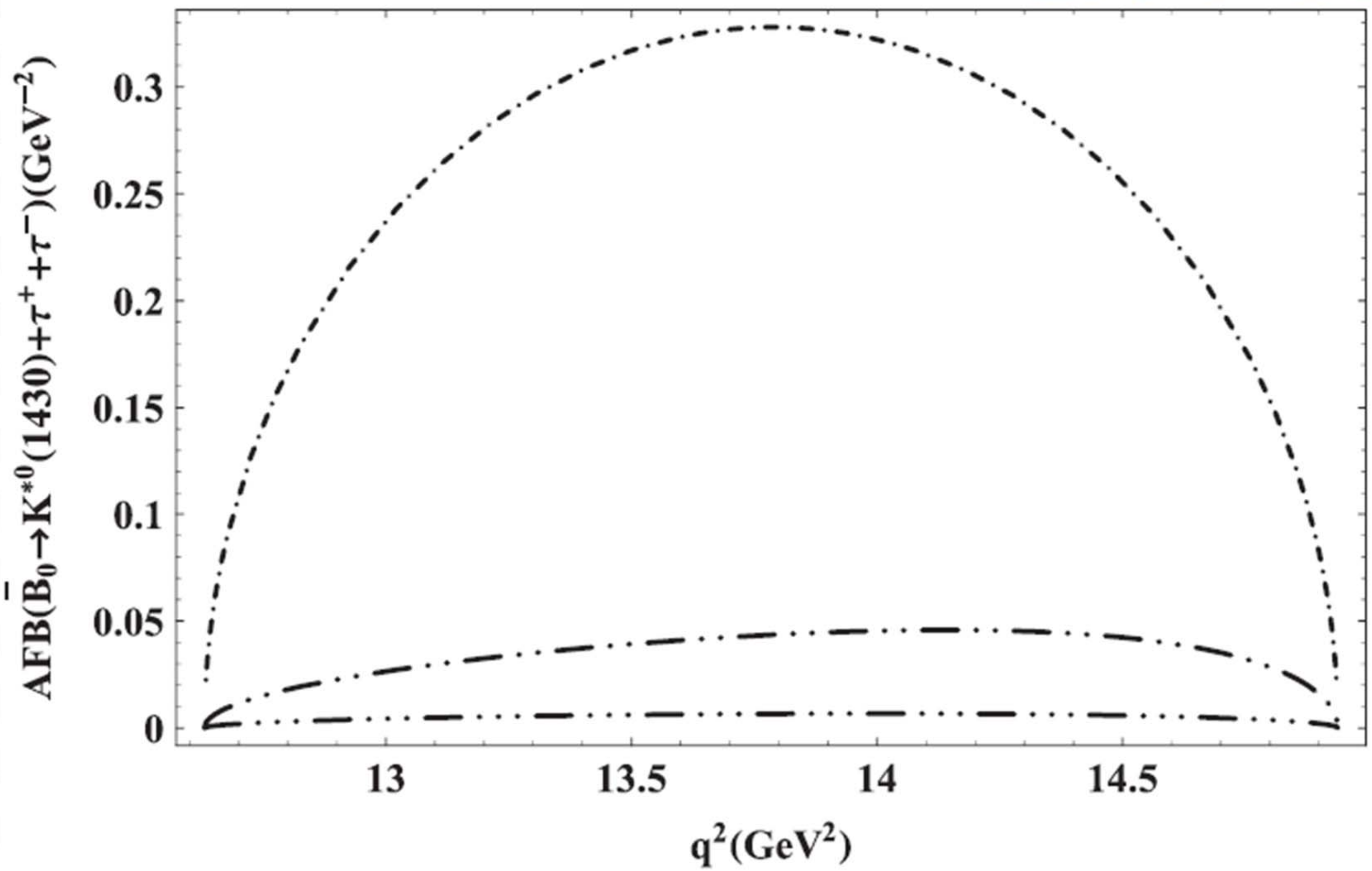
Of B→ K^*_0 l^+l^-

0 Asymmetry is expected in SM, changed significantly in new physics model



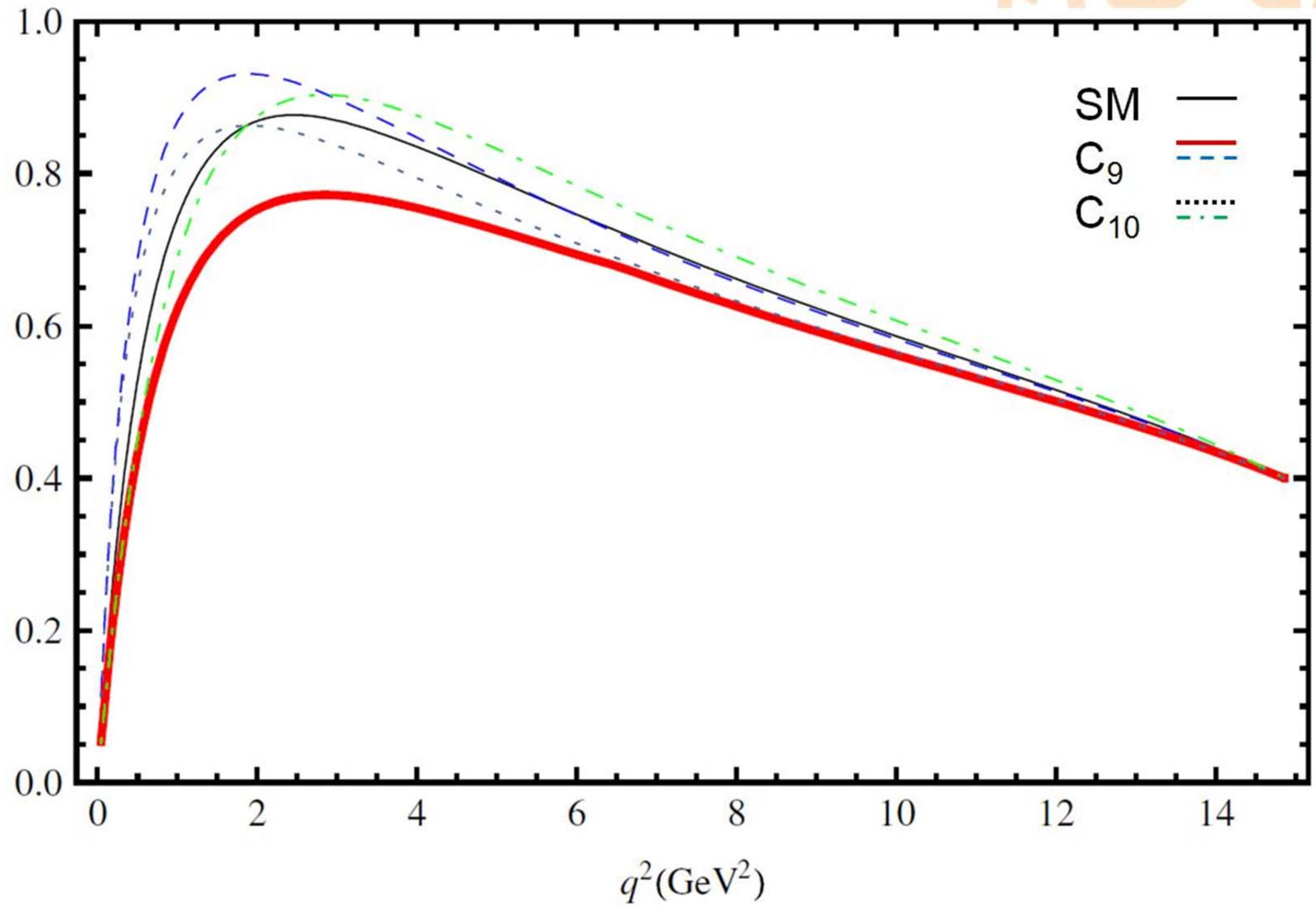
SUSY contributions to parameter $\frac{dA_{FB}}{dq^2}$ Of B → $K^*_0\ \tau^+\ \tau^-$

0 Asymmetry is expected in SM, changed significantly in new physics model



B→ K^*_2 l^+l^- Polarization fraction f_L

some changes of Polarization fraction f_L in new physics model.



Summary

- **B→ $K_1(K^*_0, K_2, K_3, K_4)$ l+ l- decays are investigated in SM with large branching ratios up to $10^{-6} \sim 10^{-7}$**

  polarizations, FB asymmetries are predicted with smaller theoretical uncertainties

- **Some New physics contributions are also studied with quite different behavior from SM**
- **These channels are cross checks in addition to the B→ K* l+ l- decay**

Thank you