Measurement of the Differential Branching Fraction and Forward-Backward Asymmetry for $B \rightarrow K^{(*)} l^+ l^-$

1/12 論文購読

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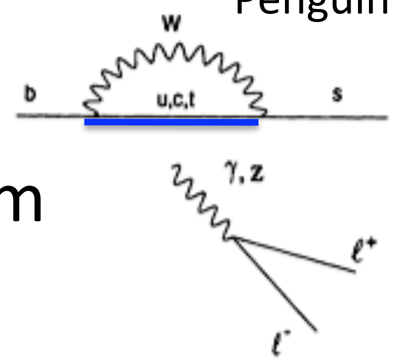
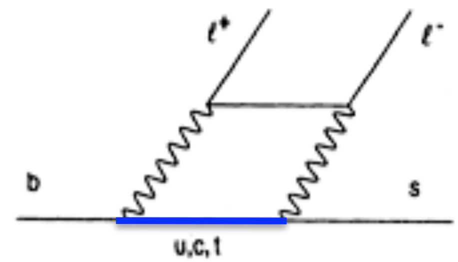
Motivation

Penguin





Box

- $b \rightarrow s\, l^+ l^-$
  - Z/γ penguin diagram
  - $W^+ W^-$ box diagram
- In various extended models some expectations differ from SM's
  - A_{FB} : Lepton forward-backward asymmetry
  - $B(B \rightarrow K^*ll)$: Differential branching fraction

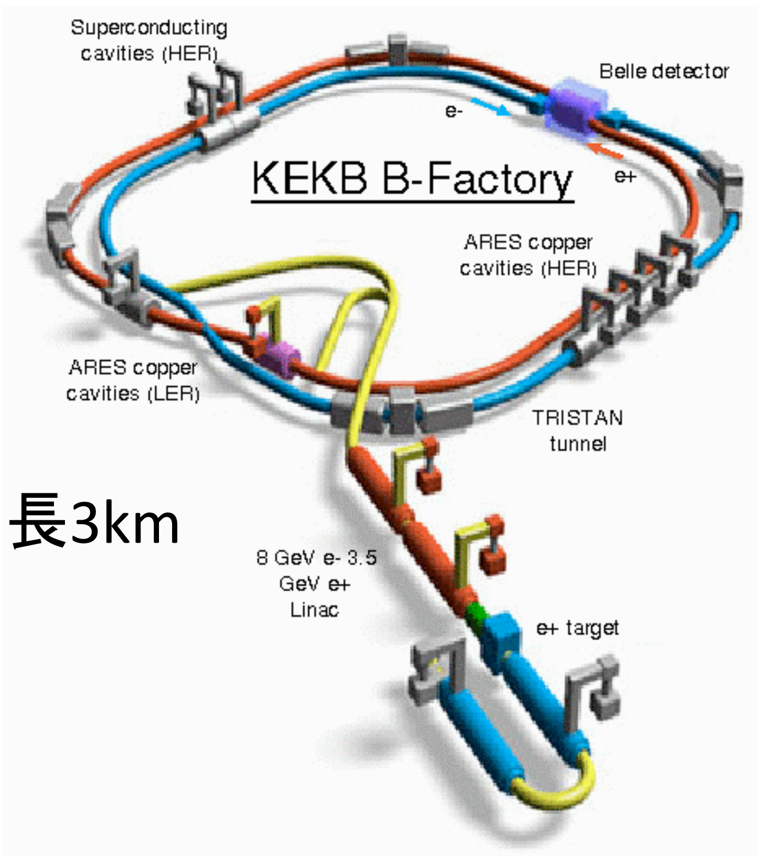
- Searching for the beyond SM clue

Belle実験

KEKB加速器：電子(e^-)8.0GeV、陽電子(e^+)3.5GeV

重心エネルギー10.6GeVの非対称衝突型加速器

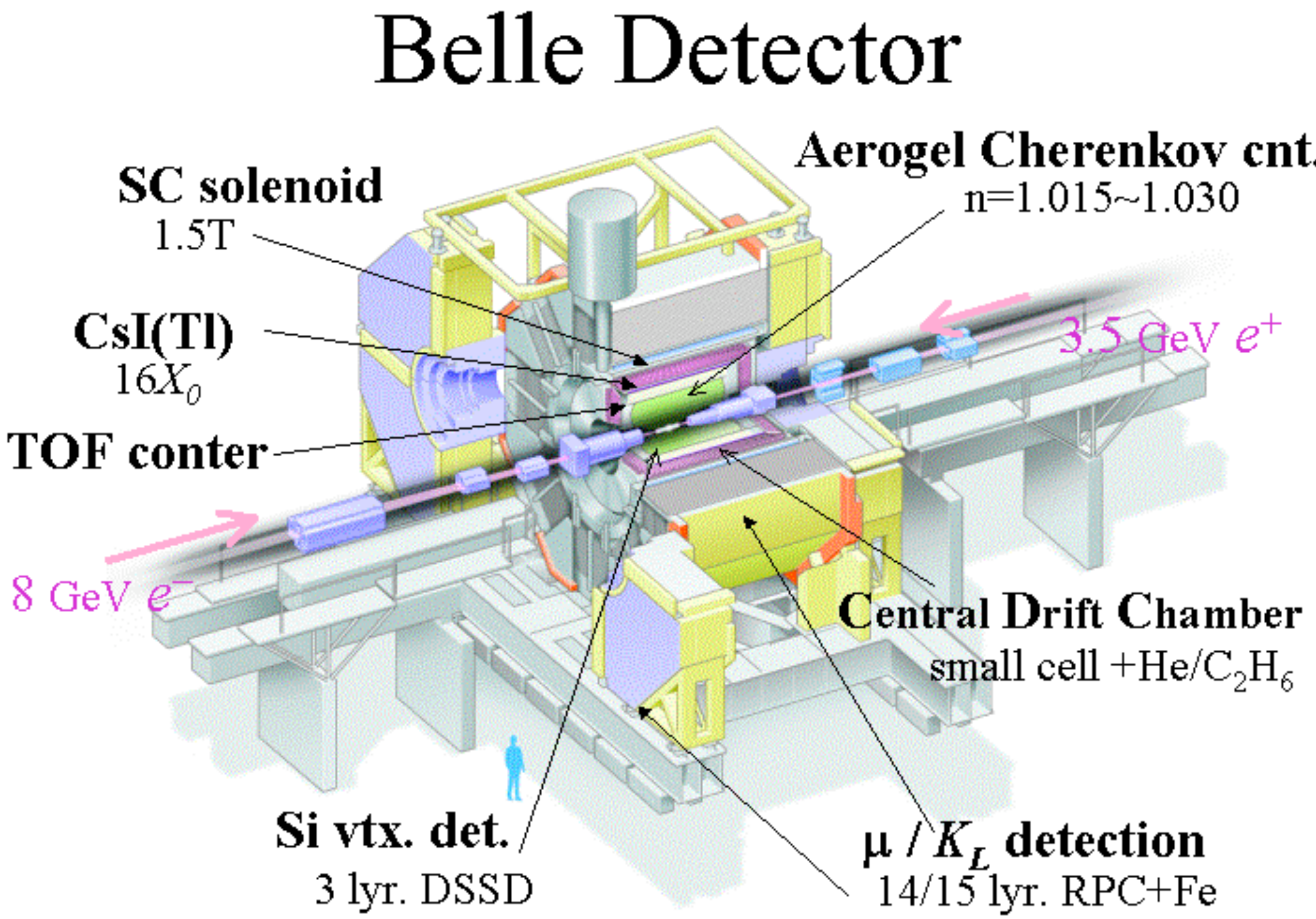
(10.6GeV = B中間子一対がしきい値で生成)



e^-e^+衝突器として世界一のルミノシティ

周長3km

B中間子の崩壊はBelle検出器でとらえる



Belle検出器はいくつかのサブ検出器からなる

Measurement

- q^2 ($= M_{ll}^2$) : dilepton invariant mass
  - Differential branching fraction
  - F_L : K* longitudinal polarization fraction
  - A_{FB} : lepton forward-backward asymmetry
  - A_I : Isospin asymmetry

Sample Data

- 605 fb^{-1} @Belle
  = 657 * 10^6 BB pairs
- $B \to K^{(*)} l^+ l^-$
  - $K^{(*)} \to K^+ \pi^-$, $Ks^0 \pi^+$, $K^+ \pi^0$, K^+, Ks^0
  - $l^+ l^- = \mu^+ \mu^-$ or $e^+ e^-$

Selection criteria

- All charged track are associated with the IP (other than $Ks^0 \rightarrow \pi^+\pi^-$)
- Particle ID
  - K : efficiency > 85 %, remove π > 92 %
  - π : efficiency > 89 %, remove K > 91 %
  - μ : retain 93.4 ± 2.0 %, remove 98.8 ± 0.2 % π
  - e : retain 92.3 ± 1.7 %, remove 99.7 ± 0.1 % π
    - $e^{\pm}$ is contained neutral clusters (20 ~ 500 MeV) within 50 mrad. ← Bremsstrahlung γ

Reconstruction (Ks^0, π^0)

- Pairs of opposite charged tracks are $Ks^0 \rightarrow \pi^+\pi^-$ candidates (483 ~ 513 MeV)
- Ks^0 vertex direction and distance from IP
- $\pi^0 \rightarrow \gamma\gamma$ candidates are required $m_{\pi 0}$, minimum γ energy, γ energy asymmetry, π^0 momentum.

Reconstruction (B)

$$M_{\rm bc} \equiv \sqrt{E_{\rm beam}^2 - p_B^2}$$
$$\Delta E \equiv E_B - E_{\rm beam}$$

- B candidate
  - 5.20 GeV < M_{bc}
  - -35 < ΔE < 35 MeV ($l = \mu$)
  - -55 < ΔE < 35 MeV ($l = e$)
  - K* : $M_{K\pi}$ < 1.2 GeV

- Signal region
  - 5.27 < M_{bc} < 5.29 GeV
  - K* : $|M_{K\pi} - m_{K^*}|$ < 80 MeV

Background

- Continuum ($e^+e^- \to qq$)
  - using the some variables and likelihood ratio
- Semileptonic B decay
  - Fisher discriminant (with 16 Fox-Wolfram moment), M_{miss}, $\cos\theta_B$, lepton separation are conbined to form likelihood ratio R
- Combinatorial
  - q^2, B-flavor tagging information

Background

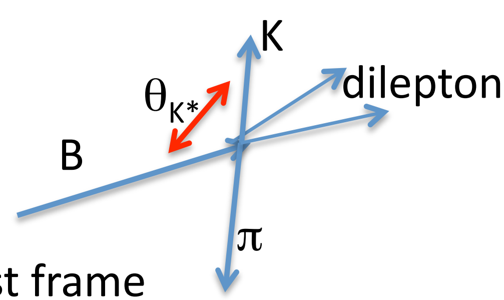
- $B \to J/\psi X$, $\psi' X$ have a peak in signal region.
  - rejecting some q^2 region
    - $8.68 < q^2 < 10.09$, $12.86 < q^2 < 14.18$ GeV ($\mu\mu$)
    - $8.11 < q^2 < 10.03$, $12.15 < q^2 < 14.11$ GeV (ee)
  - consider $\mu-\pi$ misidentification
    - $-0.10 < M_{\pi\mu} - m_{J/\psi(\psi')} < 0.08$ GeV
- Rejecting $B \to D X$
  - $|M_{K\mu(K\pi\mu)} - m_D| < 0.02$ GeV μ is assigned m_π
- Removing γ conversion and $\pi^0 \to \gamma ee$
  - $M_{ee} < 0.14$ GeV
- Multiple B candidate
  - select smallest $|\Delta E|$

- To determine the signal yields, an extended unbinned maximum likelihood fit to M_{bc} (and $M_{K\pi}$) is performed.
- likelihood function
  - signal
  - combinatorial
  - $B \to J/\psi(\psi') X$, $K^{(*)} \pi \pi$

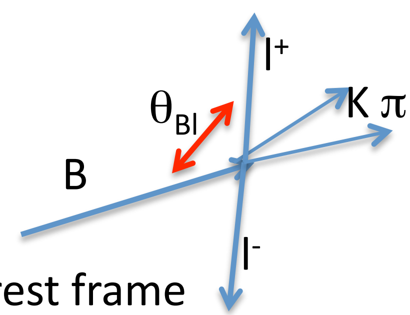
- F_L and A_{FB} are extracted from fits to $\cos\theta_{K*}$ and $\cos\theta_{Bl}$.
- The signal PDFs for fit to $\cos\theta_{K*}$ and $\cos\theta_{Bl}$
  - $\cos\theta_{K*}$: $[\frac{3}{2}F_L\cos^2\theta_{K^*} + \frac{3}{4}(1-F_L)(1-\cos^2\theta_{K^*})]\epsilon(\cos\theta_{K^*})$
  - $\cos\theta_{Bl}$: $[\frac{3}{4}F_L(1-\cos^2\theta_{B\ell}) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_{B\ell}) + A_{FB}\cos\theta_{B\ell}]\epsilon(\cos\theta_{B\ell})$

dilepton polarization function
correspond to the production K*'s with
longitudinal and transverse polarization

forward-backward asymmetry



K* rest frame

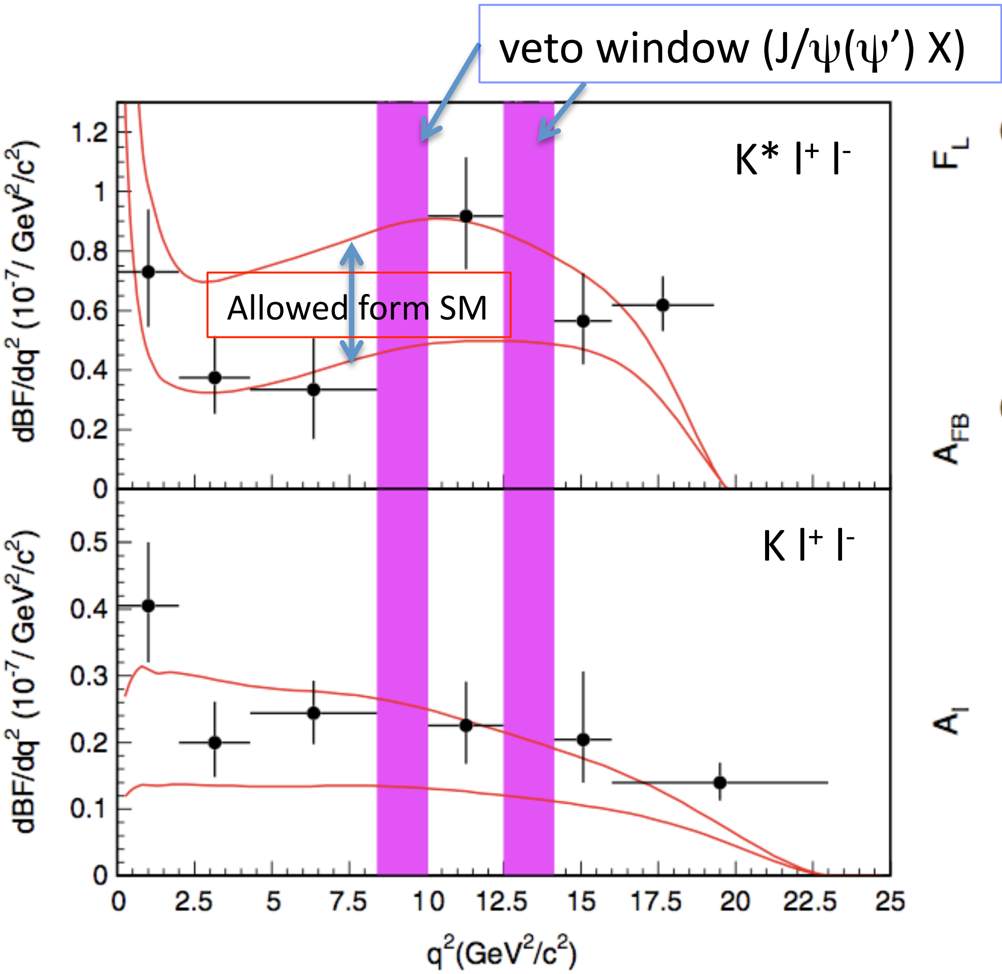


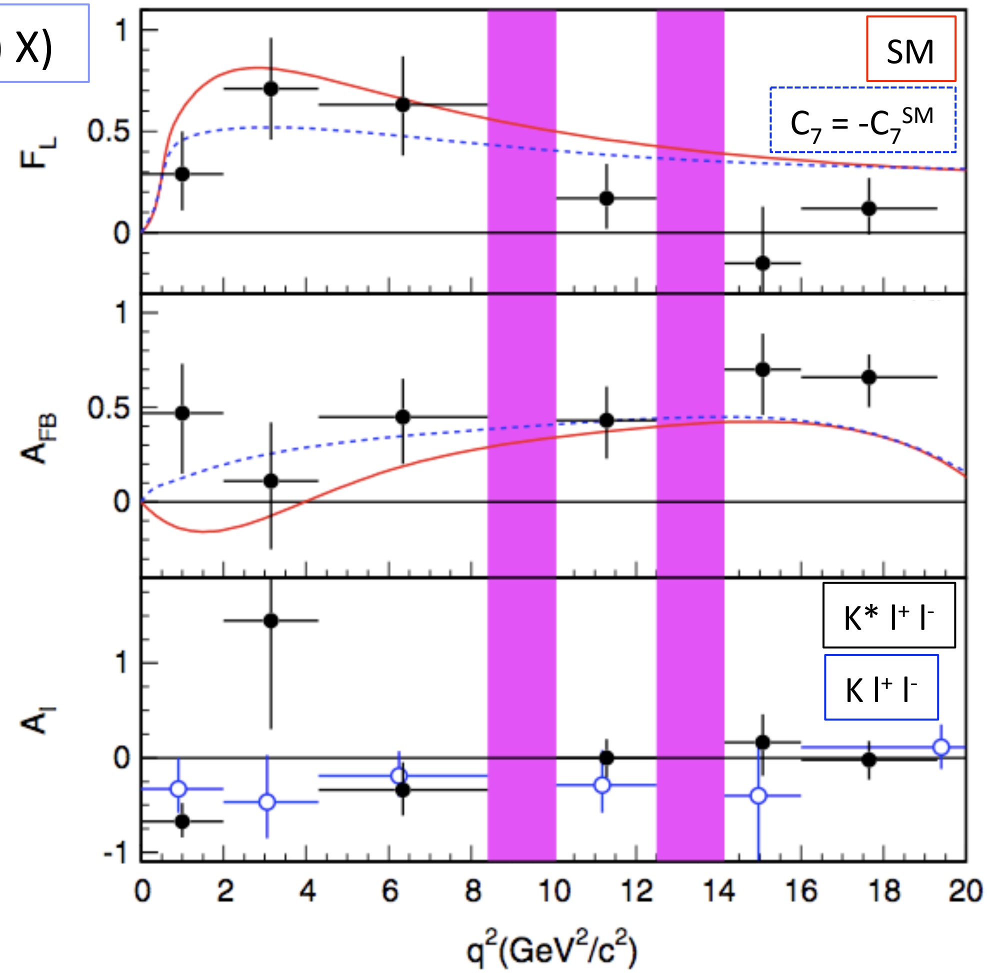
dilepton rest frame

q^2 (GeV^2/c^2)	N_s	$\mathcal{B}(10^{-7})$	F_L	A_{FB}	A_I
			$B \to K^* \ell^+ \ell^-$		
0.00–2.00	$27.4^{+7.4}_{-6.6}$	$1.46^{+0.40}_{-0.35} \pm 0.11$	$0.29^{+0.21}_{-0.18} \pm 0.02$	$0.47^{+0.26}_{-0.32} \pm 0.03$	$-0.67^{+0.18}_{-0.16} \pm 0.05$
2.00–4.30	$16.8^{+6.1}_{-5.3}$	$0.86^{+0.31}_{-0.27} \pm 0.07$	$0.71^{+0.24}_{-0.24} \pm 0.05$	$0.11^{+0.31}_{-0.36} \pm 0.07$	$1.45^{+1.04}_{-1.15} \pm 0.10$
4.30–8.68	$27.9^{+9.5}_{-8.5}$	$1.37^{+0.47}_{-0.42} \pm 0.39$	$0.64^{+0.23}_{-0.24} \pm 0.07$	$0.45^{+0.15}_{-0.21} \pm 0.15$	$-0.34^{+0.29}_{-0.27} \pm 0.14$
10.09–12.86	$54.0^{+10.5}_{-9.6}$	$2.24^{+0.44}_{-0.40} \pm 0.19$	$0.17^{+0.17}_{-0.15} \pm 0.03$	$0.43^{+0.18}_{-0.20} \pm 0.03$	$0.00^{+0.20}_{-0.21} \pm 0.09$
14.18–16.00	$36.2^{+9.9}_{-8.8}$	$1.05^{+0.29}_{-0.26} \pm 0.08$	$-0.15^{+0.27}_{-0.23} \pm 0.07$	$0.70^{+0.16}_{-0.22} \pm 0.10$	$0.16^{+0.30}_{-0.35} \pm 0.09$
>16.00	$84.4^{+11.0}_{-9.9}$	$2.04^{+0.27}_{-0.24} \pm 0.16$	$0.12^{+0.15}_{-0.13} \pm 0.02$	$0.66^{+0.11}_{-0.16} \pm 0.04$	$-0.02^{+0.20}_{-0.21} \pm 0.09$
1.00–6.00	$29.42^{+8.9}_{-8.0}$	$1.49^{+0.45}_{-0.40} \pm 0.12$	$0.67^{+0.23}_{-0.23} \pm 0.05$	$0.26^{+0.27}_{-0.30} \pm 0.07$	$0.33^{+0.37}_{-0.43} \pm 0.08$
			$B \to K \ell^+ \ell^-$		
0.00–2.00	$27.0^{+6.0}_{-5.4}$	$0.81^{+0.18}_{-0.16} \pm 0.05$	···	$0.06^{+0.32}_{-0.35} \pm 0.02$	$-0.33^{+0.33}_{-0.25} \pm 0.08$
2.00–4.30	$17.6^{+5.5}_{-4.8}$	$0.46^{+0.14}_{-0.12} \pm 0.03$	···	$-0.43^{+0.38}_{-0.40} \pm 0.09$	$-0.47^{+0.50}_{-0.38} \pm 0.07$
4.30–8.68	$39.1^{+7.5}_{-6.9}$	$1.00^{+0.19}_{-0.18} \pm 0.06$	···	$-0.20^{+0.12}_{-0.14} \pm 0.03$	$-0.19^{+0.25}_{-0.21} \pm 0.08$
10.09–12.86	$22.0^{+6.2}_{-5.5}$	$0.55^{+0.16}_{-0.14} \pm 0.03$	···	$-0.21^{+0.17}_{-0.15} \pm 0.06$	$-0.29^{+0.37}_{-0.29} \pm 0.08$
14.18–16.00	$15.6^{+4.9}_{-4.3}$	$0.38^{+0.19}_{-0.12} \pm 0.02$	···	$0.04^{+0.32}_{-0.26} \pm 0.05$	$-0.40^{+0.61}_{-0.69} \pm 0.07$
>16.00	$40.3^{+8.2}_{-7.5}$	$0.98^{+0.20}_{-0.18} \pm 0.06$	···	$0.02^{+0.11}_{-0.08} \pm 0.02$	$0.11^{+0.24}_{-0.21} \pm 0.08$
1.00–6.00	$52.0^{+8.7}_{-8.0}$	$1.36^{+0.23}_{-0.21} \pm 0.08$	···	$-0.04^{+0.13}_{-0.16} \pm 0.05$	$-0.41^{+0.25}_{-0.20} \pm 0.07$

- The SM lepton flavor ratio of the full q^2 is
  - $R^{SM}_{K^*}$ = 0.75 (B → K*ll)
  - R^{SM}_{K} = 1 (B → Kll)

$$R_{K^{(*)}} \equiv \frac{\mathcal{B}(B \to K^{(*)} \mu^+ \mu^-)}{\mathcal{B}(B \to K^{(*)} e^+ e^-)}$$





- Fit result

C7 : Wilson coefficients
which are evaluated perturbatively
at the electroweak scale.

- Total branching fractions

$$\mathcal{B}(B \to K^* \ell^+ \ell^-) = (10.7^{+1.1}_{-1.0} \pm 0.9) \times 10^{-7},$$
$$\mathcal{B}(B \to K \ell^+ \ell^-) = (4.8^{+0.5}_{-0.4} \pm 0.3) \times 10^{-7},$$

- CP asymmetries

$$A_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\bar{B} \to \bar{K}^{(*)} l^+ l^-) - \mathcal{B}(B \to K^{(*)} l^+ l^-)}{\mathcal{B}(\bar{B} \to \bar{K}^{(*)} l^+ l^-) + \mathcal{B}(B \to K^{(*)} l^+ l^-)} \equiv (N_b - N_{\bar{b}})/(N_b + N_{\bar{b}})$$

  – $N_{b(\bar{b})}$: $\bar{B}$ (B) yeild

$$A_{CP}(K^* \ell^+ \ell^-) = -0.10 \pm 0.10 \pm 0.01$$
$$A_{CP}(K^+ \ell^+ \ell^-) = 0.04 \pm 0.10 \pm 0.02.$$

- Lepton flavor ratio $R_{K^{(*)}} \equiv \frac{\mathcal{B}(B \to K^{(*)} \mu^+ \mu^-)}{\mathcal{B}(B \to K^{(*)} e^+ e^-)}$

  – sensitive to Higgs emission

$$R_{K^*} = 0.83 \pm 0.17 \pm 0.08$$
$$R_K = 1.03 \pm 0.19 \pm 0.06$$

$R^{SM}_{K^*} = 0.75$
$R^{SM}_{K} = 1$

- Isospin asymmetry

$$A_I \equiv \frac{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(K^{(*)0}\ell^+\ell^-) - \mathcal{B}(K^{(*)\pm}\ell^+\ell^-)}{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(K^{(*)0}\ell^+\ell^-) + \mathcal{B}(K^{(*)\pm}\ell^+\ell^-)}$$

  - τ_{B+}/τ_{B0} = 1.071 : lifetime ratio

$$A_I(B \to K^*\ell^+\ell^-) = -0.29^{+0.16}_{-0.16} \pm 0.09 \qquad \sigma = 1.37$$

$$A_I(B \to K\ell^+\ell^-) = -0.31^{+0.17}_{-0.14} \pm 0.08 \qquad \sigma = 1.75$$

$$A_I(B \to K^{(*)}\ell^+\ell^-) = -0.30^{+0.12}_{-0.11} \pm 0.08 \qquad \sigma = 2.22$$

  - $\sigma \equiv \sqrt{-2\ln(\mathcal{L}_0/\mathcal{L}_{\max})}$: significance from a null asymmetry
    - L_0 : likelihood with $A_I = 0$
    - L_{max} : maximum likelihood

- No significant A_I is found at $q^2 < 8.68$ GeV

Summary

- Consistent with the SM prediction
  - Differential branching fraction
  - Lepton flavor ratio
  - K* polarization
- No significant CP asymmetry is found.
- The isospin asymmetry does not deviate significantly from the null value.
- The $A_{FB}(q^2)$ spectrum for $B \rightarrow K^*ll$ decays tende to be shifted toward the positive seide from the SM expectation.
- The cumulative difference between the SM prediction and measured points is found to be 2.7 σ.

Back up

- Previous result
  - @Belle 2003/12 152*10[6]BB

$$\mathcal{B}(B \to K^* \ell^+ \ell^-) = (11.5^{+2.6}_{-2.4} \pm 0.8 \pm 0.2) \times 10^{-7},$$

$$\mathcal{B}(B \to K \ell^+ \ell^-) = (4.8^{+1.0}_{-0.9} \pm 0.3 \pm 0.1) \times 10^{-7},$$

  - @BABAR 2006 229*10[6]BB

$$\mathcal{B}(B \to K^* \ell^+ \ell^-) = (0.78^{+0.19}_{-0.17} \pm 0.11) \times 10^{-6}$$

$$\mathcal{B}(B \to K \ell^+ \ell^-) = (0.34 \pm 0.07 \pm 0.02) \times 10^{-6}$$

$$F_L(B \to K^* \ell^+ \ell^-)_{(q^2 > 0.1\ \mathrm{GeV}^2/c^4)} = 0.63^{+0.18}_{-0.19} \pm 0.05$$

$$A_{\mathrm{FB}}(B^+ \to K^+ \ell^+ \ell^-)_{(q^2 > 0.1\ \mathrm{GeV}^2/c^4)} = 0.15^{+0.21}_{-0.23} \pm 0.08$$

$$A_{CP}(B \to K^* \ell^+ \ell^-) = +0.03 \pm 0.23 \pm 0.03$$

$$A_{CP}(B^+ \to K^+ \ell^+ \ell^-) = -0.07 \pm 0.22 \pm 0.02$$

$$R_{K^*} = 0.91 \pm 0.45 \pm 0.06$$

$$R_K = 1.06 \pm 0.48 \pm 0.08$$

$$A_I^{K^{(*)}} = -0.64^{+0.15}_{-0.14} \pm 0.03 \qquad 3.9\sigma$$