$B \rightarrow K^{(*)} l^+ l^-$ from B-Factories and Tevatron

G. Eigen, University of Bergen (BABAR collaboration)

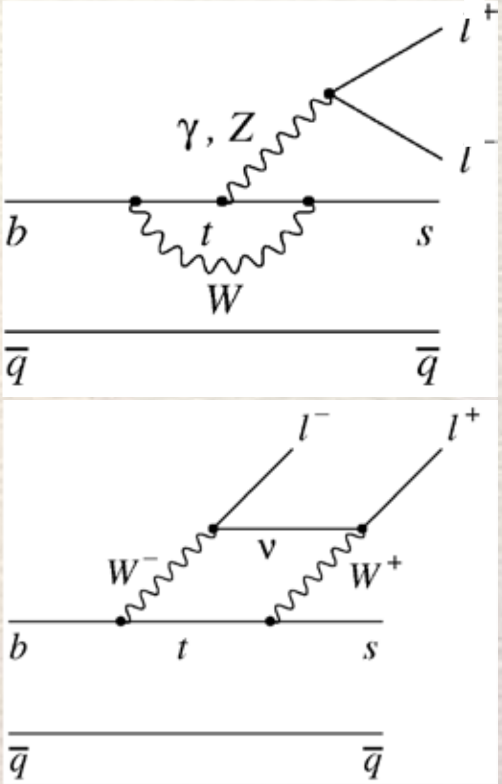
presenting results fromBABAR, Belle and CDF

CKM10, 07-09-2010

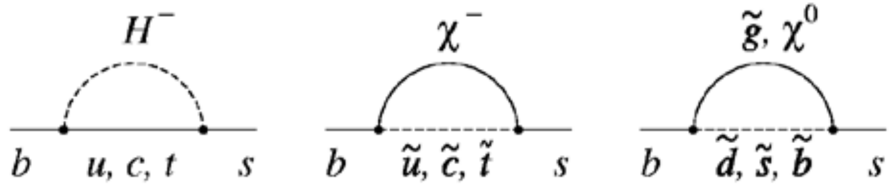
Topics in this Talk

- Studies of $B\to K\ell^+\ell^-$ and $B\to K^*\ell^+\ell^-$ rates and rate asymmetries from BABAR, Belle and CDF (new)
  - Branching fractions
  - Isospin asymmetries
  - CP asymmetries
  - Lepton flavor ratios
- Angular analyses of $B\to K\ell^+\ell^-$ and $B\to K^*\ell^+\ell^-$ from BABAR, Belle and CDF (new)
  - K^* longitudinal polarization
  - Lepton forward-backward asymmetries
- First search for $B\to K^*\tau^+\tau^-$ in BABAR

Rare Decays $B \to K^{(*)} \ell^+ \ell^-$



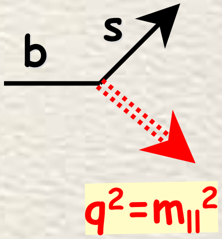
- $b \to s \ell \ell$ are flavor-changing neutral current (FCNC) processes, forbidden in SM at tree level
- Effective Hamiltonian factorizes short-distance from long-distance effects [$\mathcal{O}(\alpha_s)$]
- 3 effective Wilson coefficients contribute
  - C_7^{eff} from electromagnetic penguin diagram
    $|C_7^{eff}| \approx 0.33$ from $\mathcal{B}(B \to X_s \gamma)$
  - C_9^{eff} from vector part of weak diagrams
  - C_{10}^{eff} from axial-vector part of weak diagrams
- New Physics adds new loops with new particles ➔ modifies SM values values of C_7^{eff}, C_9^{eff}, C_{10}^{eff} and introduces new coefficients C_S and C_P
- Need to measure many observables to extract $|C_i|$ & phases



- Probe here New Physics at a scale of a few TeV

Isidori, Nir, Prerez
arXiv:1002.0900 (2010)

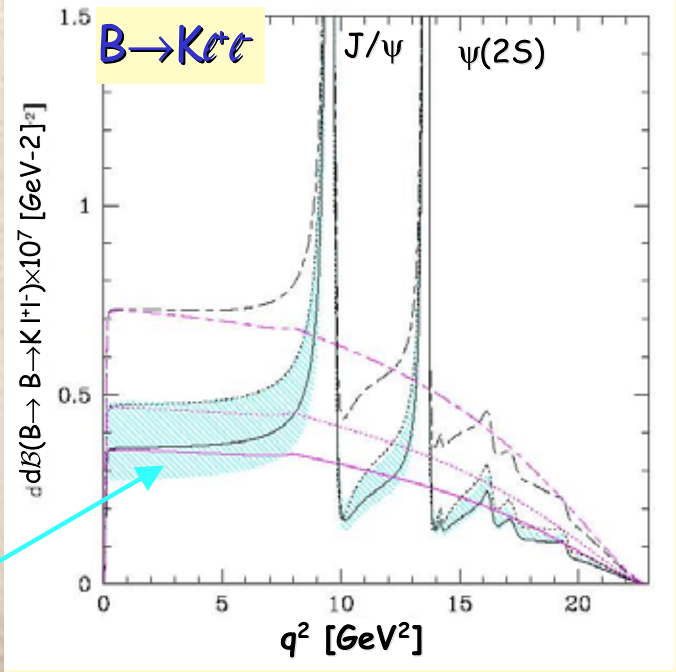
Characteristics of $B\to K^{(*)}\ell^+\ell^-$ Decays



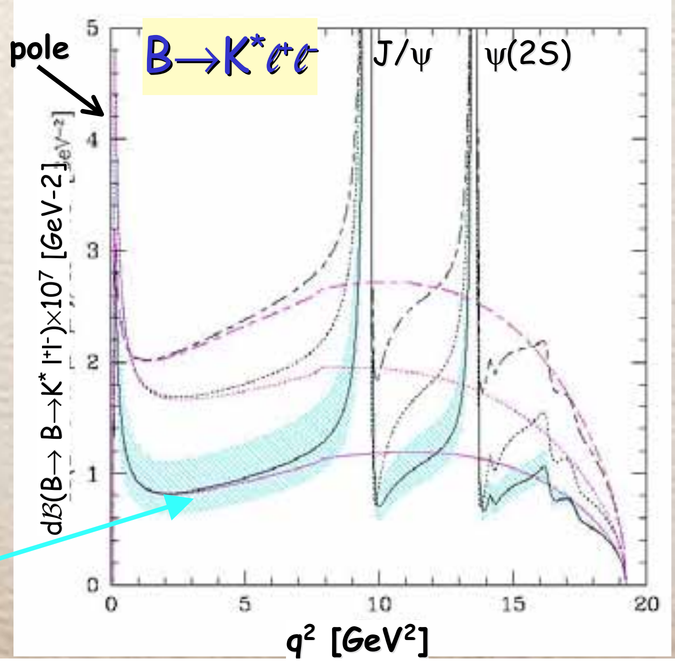
$q^2=m_{ll}^2$

- The overall shape of the $B\to K^{(*)}\ell^+\ell^-$ spectra is determined by the q^2 dependence of $C_9^{eff}(q^2)$
- At $q^2=0$, $B\to K^*\ell^+\ell^-$ exhibits a singularity (from $B\to K^*\gamma$), while $B\to K\ell^+\ell^-$ is finite at $q^2=0$
- J/ψ & $\psi(2S)$ modes interfere with $B\to(K,K^*)\ell^+\ell^-$ ➔ remove q^2 regions

Ali et al. PRD 61, 074024 (2000)



SM



SM

Analysis Methodologies for $B\to K^{(*)}\ell^+\ell^-$

- Both BABAR and Belle fully reconstruct 10 $B\to K^{(*)}\ell^+\ell^-$ final states
  - K, K^0_S, $K^\pm\pi^\mp$, $K^\pm\pi^0$ or $K^0_S\pi^\pm$ recoiling against e^+e^- or $\mu^+\mu^-$
  - Select $e^\pm$ with $p>0.3$ (0.4) GeV/c; $\mu^\pm$ with $p > 0.7$ GeV/c
  - Require good particle ID for e, μ, K, π; select $K^0_S\to\pi^+\pi^-$
- CDF reconstructs only $K^\pm\mu^+\mu^-$ and $K^\pm\pi^\mp\mu^+\mu^-$ final states
  - Select $\mu^\pm$ ($p_T>0.4$ GeV/c) K, π ($p_T>1.0$ GeV/c) & B ($p_T>4.0$ GeV/c)
  - Require good particle ID for μ, K, π; vertex fit of $\mu^+\mu^-$
- All experiments suppress combinatorial $B\bar{B}$ & $q\bar{q}$ backgrounds, where each lepton originates from semileptonic b, c decays
  - BABAR trains neural networks (NN) using event shape variables, vertexing, E_{miss}, & ℓ separation near IP optimized in each mode and each q^2-bin
  - Belle trains a Fisher discriminant using event shape variables, missing mass, B flavor tagging, & lepton separation in z near IP
  - CDF trains NNs using vertexing, pointing variables and ℓ separation

Analysis Methodologies for $B\rightarrow K^{(*)}\ell^+\ell^-$

- BABAR and Belle select candidates using the mass $m_{ES}=\sqrt{E^{*2}_{beam}-p^{*2}_{B}}$ & and the B energy $\Delta E = E^*_B - E^*_{beam}$
  - BABAR extracts the signal yield from 1d unbinned extended maximum log-likelihood fit in m_{ES}
  - Belle extracts the signal yield from 1d (2d) unbinned extended maximum log-likelihood fit in m_{ES} (and $m_{K\pi}$)
- CDF selects signal candidates from a unbinned maximum log-likelihood fit in the B invariant mass distribution
- All experiments reject events in J/ψ and $\psi(2S)$ mass regions
- All experiments reject background from $B\rightarrow DX$ by requiring that $K\mu$ and $K\pi\mu$ masses are not consistent with a D
- All experiments use charmonium control samples for various checks

$B \to K \ell^+\ell^-$ and $B \to K^* \ell^+\ell^-$ Signals

- All three experiments see significant signal yields
- CDF data sample:

  4.4 $\text{fb}^{-1} \to > 2\times10^{10}\, B\bar{B}$

  [for $p_T(B)$>6 GeV/c]

  $\mathcal{N}_{K\ell^+\ell^-} = 120 \pm 16$

  $\mathcal{N}_{K^*\ell^+\ell^-} = 101 \pm 12$

- BABAR data sample:

  349 $\text{fb}^{-1} \to 384$ M $B\bar{B}$

  TM & ©Ne

  $\mathcal{N}_{K\ell^+\ell^-} = 60 \pm 11$

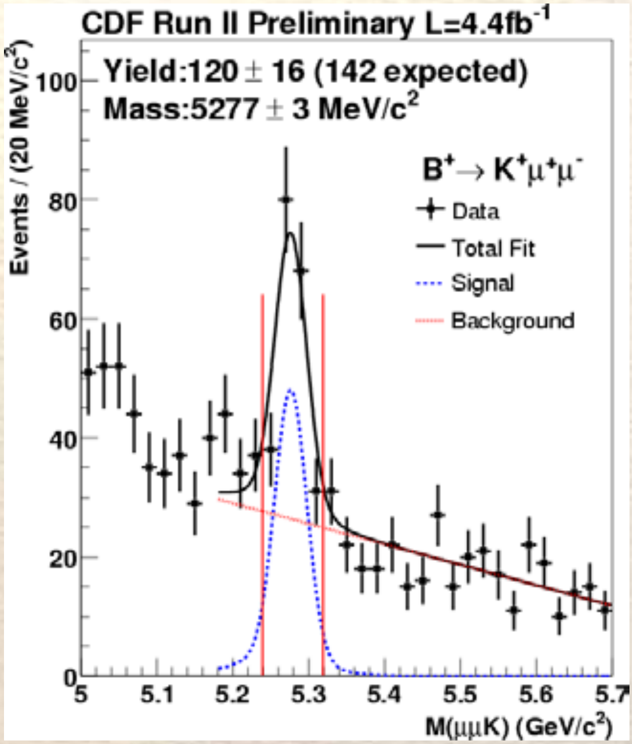
  $\mathcal{N}_{K^*\ell^+\ell^-} = 74 \pm 13$

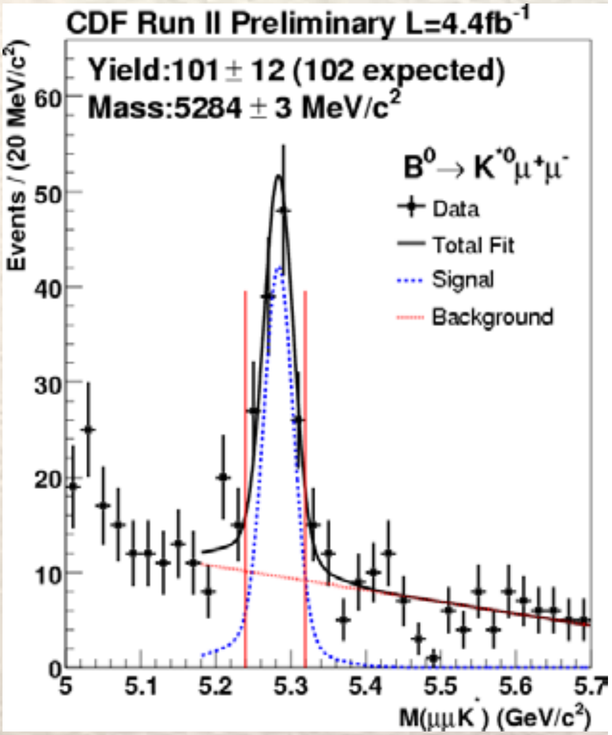
- Belle data sample:

  605 $\text{fb}^{-1} \to 656$ M $B\bar{B}$

  $\mathcal{N}_{K\ell^+\ell^-} = 161.6^{+22.6}_{-20.3}$

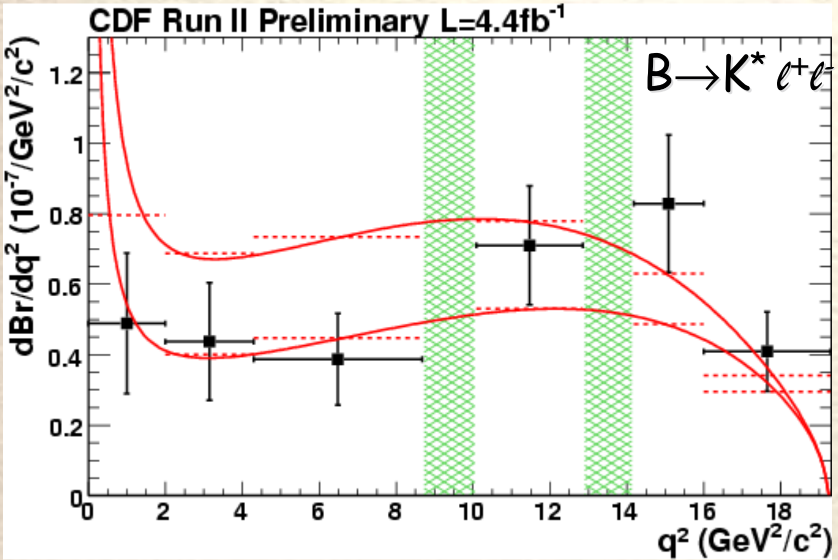
  $\mathcal{N}_{K^*\ell^+\ell^-} = 246.3^{+15.9}_{-14.3}$

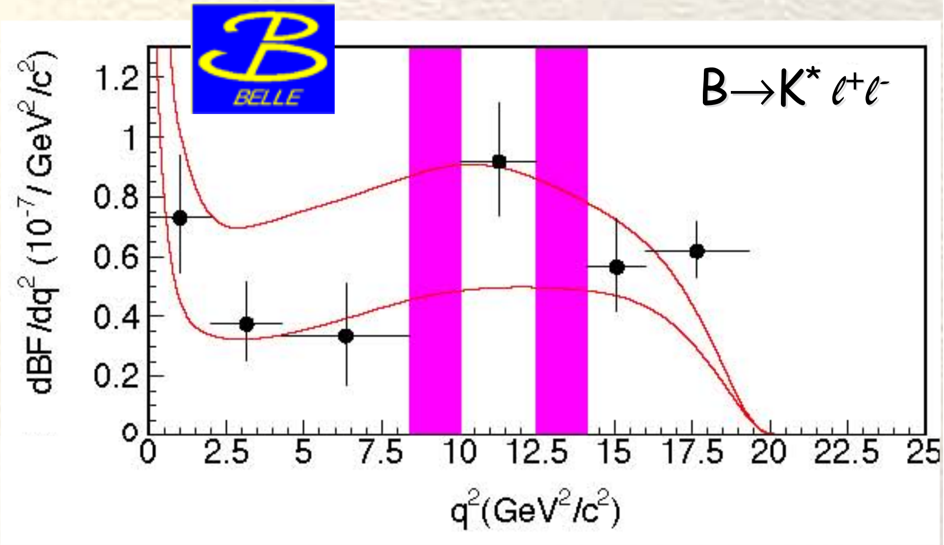


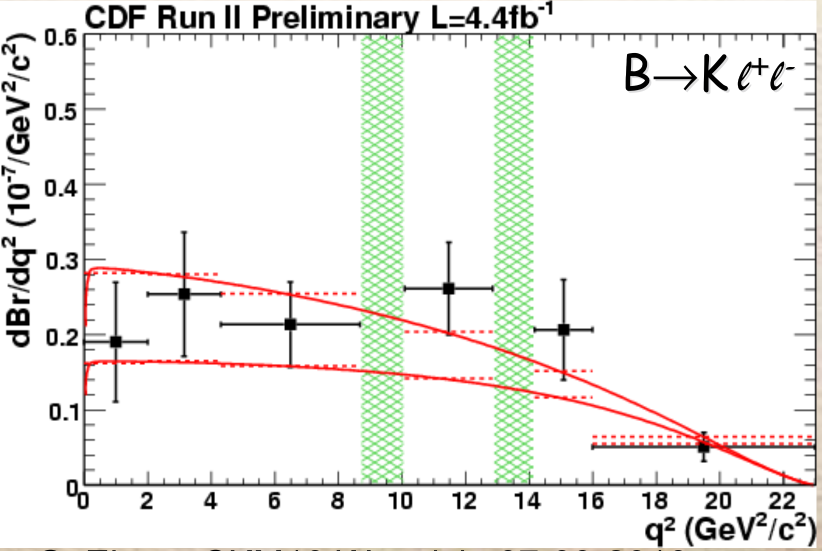


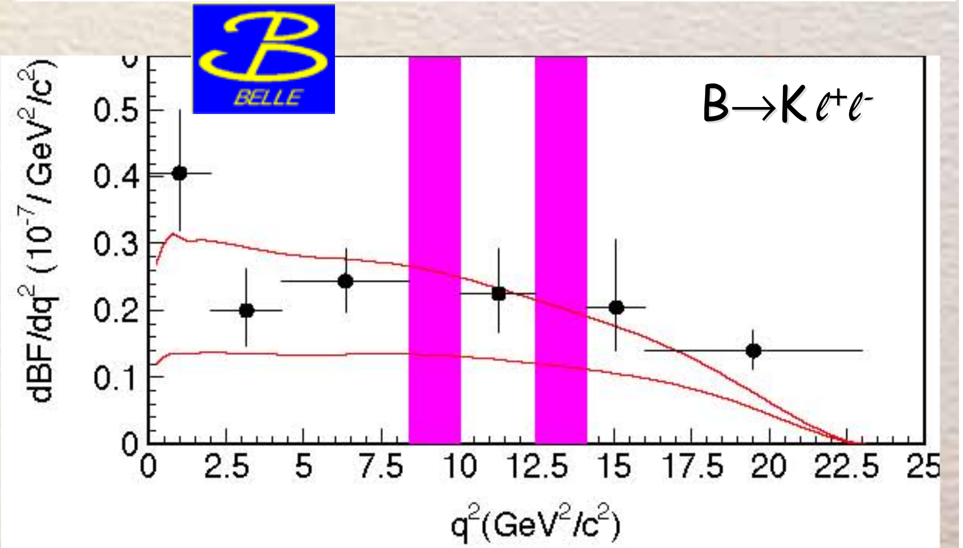
$B \to K^{(*)} \ell^+ \ell^-$ Partial Branching Fractions

- CDF and Belle measure $d\mathcal{B}/dq^2$ consistent with the SM







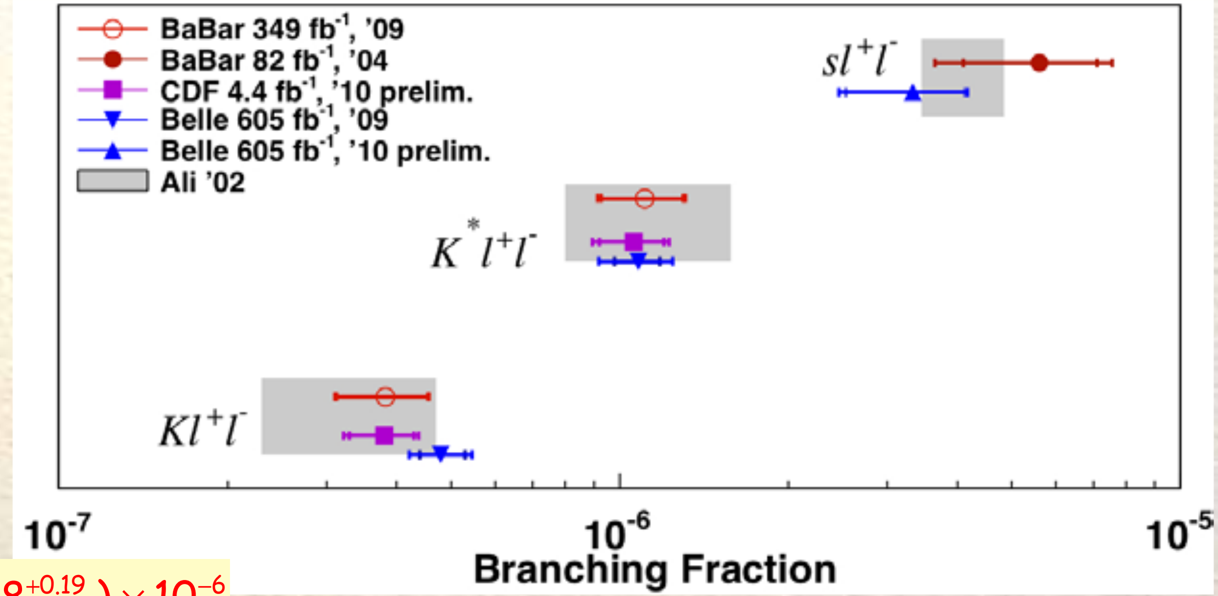


$B \to K^{(*)} \ell^+ \ell^-$ Branching Fractions

- Total branching fractions of all 3 experiments are consistent with each other and the SM

- Belle updated $B(B \to X_s \ell^+ \ell^-)$ using 605 fb^{-1}

new $\mathcal{B}(B \to X_s \ell^+ \ell^-) = (3.33 \pm 0.8^{+0.19}_{-0.24}) \times 10^{-6}$



Ali et al PRD 66, 034002 (2002)

BABAR: PRL 102, 091803 (2009)
PRL 93,081862 (2004)
CDF: Note 10047 (2010)
Belle: PRL 103, 171801 (2009)
C.C.Ciang, ICHEP(2010)

- BABAR: $\mathcal{B}(B \to K \ell^+ \ell^-) = (0.394^{+0.073}_{-0.069} \pm 0.02) \times 10^{-6}$ $\mathcal{B}(B \to K^* \ell^+ \ell^-) = (1.11^{+0.19}_{-0.18} \pm 0.07) \times 10^{-6}$

- Belle: $\mathcal{B}(B \to K \ell^+ \ell^-) = (0.48^{+0.05}_{-0.04} \pm 0.03) \times 10^{-6}$ $\mathcal{B}(B \to K^* \ell^+ \ell^-) = (1.07^{+0.11}_{-0.10} \pm 0.09) \times 10^{-6}$

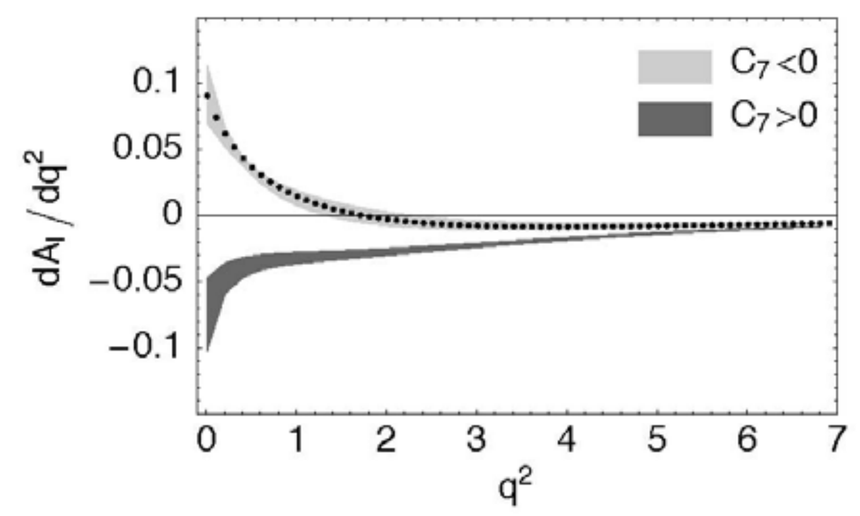
- new CDF: $\mathcal{B}(B^\pm \to K^\pm \mu^+ \mu^-) = (0.38^{+0.05}_{-0.05} \pm 0.03) \times 10^{-6}$ $\mathcal{B}(B^0 \to K^{*0} \mu^+ \mu^-) = (1.06^{+0.14}_{-0.14} \pm 0.09) \times 10^{-6}$

$B \to K^{(*)} \ell^+ \ell^-$ Isospin Asymmetry

- Since branching fractions are affected by large theory uncertainties, we focus on rate & angular asymmetries as many uncertainties cancel
- We start with the isospin asymmetry defined in different q^2 bins by

$$\mathcal{A}_I^{q^2-\mathrm{bin}} \equiv \frac{\mathcal{B}^{q^2-\mathrm{bin}}(B^0 \to K^{(*)0}\ell^+\ell^-) - \mathcal{B}^{q^2-\mathrm{bin}}(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}{\mathcal{B}^{q^2-\mathrm{bin}}(B^0 \to K^{(*)0}\ell^+\ell^-) + \mathcal{B}^{q^2-\mathrm{bin}}(B^\pm \to K^{(*)\pm}\ell^+\ell^-)}$$

- We scale the B^+ branching fractions by $\tau_{B^0}/\tau_{B^+} = 1/(1.071 \pm 0.09)$
- In the SM, $\mathcal{A}_I$ is expected to be small (<10% for most q^2)
- $\mathcal{A}_I$ shows a q^2-dependence in the low q^2 region
- For flipped C_7, $\mathcal{A}_I$ is negative at low q^2

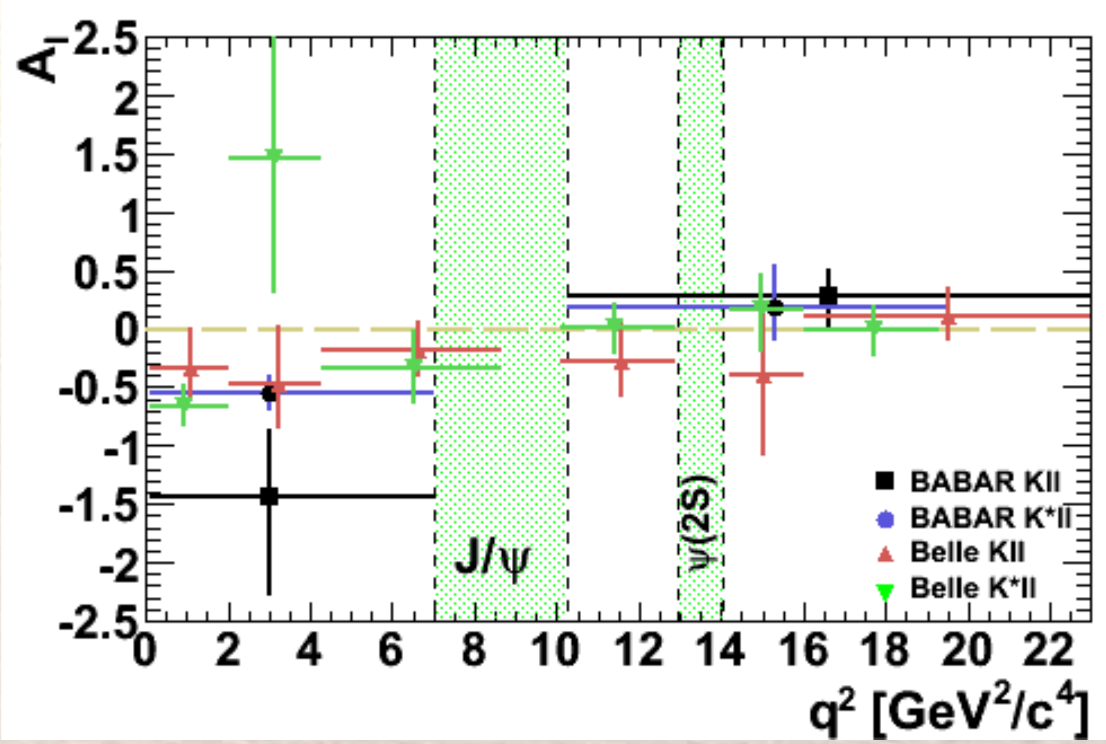


Feldmann & Matias JHEP 0301, 074 (2003)

$B \to K^{(*)} \ell^+ \ell^-$ Isospin Asymmetry

- $\mathcal{A}_I$ is consistent with zero for all q^2 and in the high-q^2 region
- In the low-q^2 region $\mathcal{A}_I$ shows a significant deviation from zero
- BABAR measures a significant $\mathcal{A}_I$ in the low q^2 region

  ➔ $K\ell^+\ell^-$ and $K^* \ell^+\ell^-$ modes modes differ from the SM prediction by 3.9σ
- Belle and BABAR results are consistent
- Belle is also consistent with SM prediction



BABAR: PRL 102, 091803 (2009)
Belle: PRL 103, 171801 (2009)

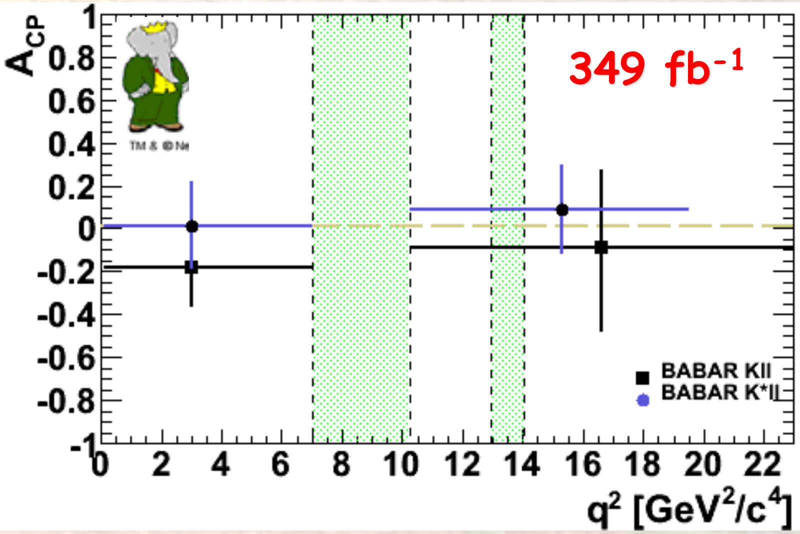
CP Asymmetry in $B \to K^{(*)} \ell^+ \ell^-$

- Define time-integrated CP asymmetry

$$\mathcal{A}_{CP} \equiv \frac{\mathcal{B}(\bar{B} \to \bar{K}^{(*)} \ell^+ \ell^-) - \mathcal{B}(B \to K^{(*)} \ell^+ \ell^-)}{\mathcal{B}(\bar{B} \to K^{(*)} \ell^+ \ell^-) + \mathcal{B}(B \to K^{(*)} \ell^+ \ell^-)}$$

- In the SM, $\mathcal{A}_{CP}$ is expected at <1% level

- BABAR performs a simultaneous fit for all $B^\pm \to K^\pm \ell^+ \ell^-$ and $B \to K^* \ell^+ \ell^-$ modes



-
$$\mathcal{A}_{CP}^{\text{all } q^2}(B^\pm \to K^\pm \ell^+ \ell^-) = -0.18^{+0.18}_{-0.18} \pm 0.01$$
$$\mathcal{A}_{CP}^{\text{all } q^2}(B \to K^* \ell^+ \ell^-) = -0.01^{+0.16}_{-0.15} \pm 0.01$$

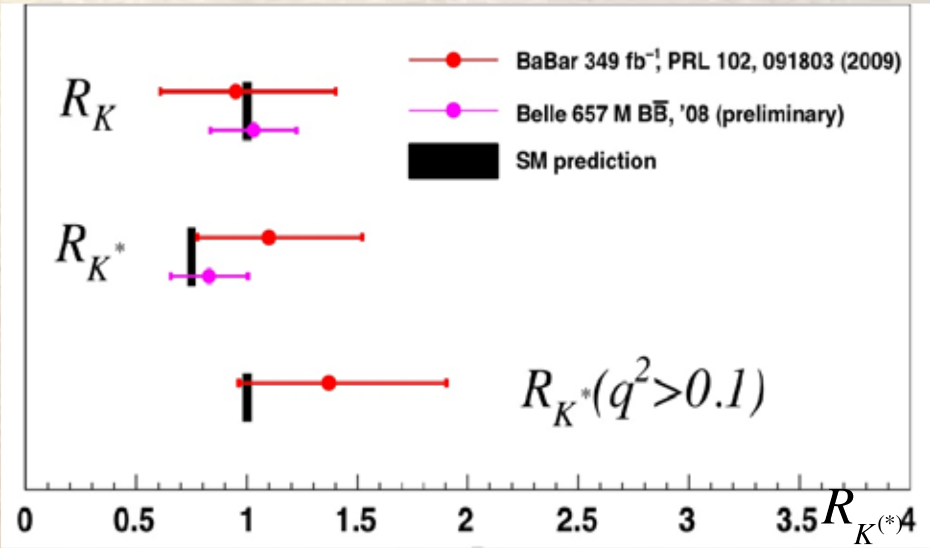
BABAR: PRL 102, 091803 (2009)
Belle: PRL 103, 171801 (2009)

-
$$\mathcal{A}_{CP}^{\text{all } q^2}(B^\pm \to K^\pm \ell^+ \ell^-) = 0.04 \pm 0.1 \pm 0.02$$
$$\mathcal{A}_{CP}^{\text{all } q^2}(B \to K^* \ell^+ \ell^-) = -0.10 \pm 0.1 \pm 0.01$$

- All measurements are consistent with zero, agreeing with the SM

$B \to K^{(*)} \ell^+\ell^-$ Lepton Flavor Ratios

- Define ratios $\mathcal{R}_K \equiv \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)}$ and $\mathcal{R}_{K^*} \equiv \frac{\mathcal{B}(B \to K^*\mu^+\mu^-)}{\mathcal{B}(B \to K^*e^+e^-)}$
- In the SM $\mathcal{R}_K$=1 and $\mathcal{R}_{K^*}$=0.75 ($\mathcal{R}_{K^*}$=1, if the $q^2 <$ 0.1 GeV region is removed)
- BABAR and Belle measure $R_{K(*)}$ values that are consistent with the SM prediction

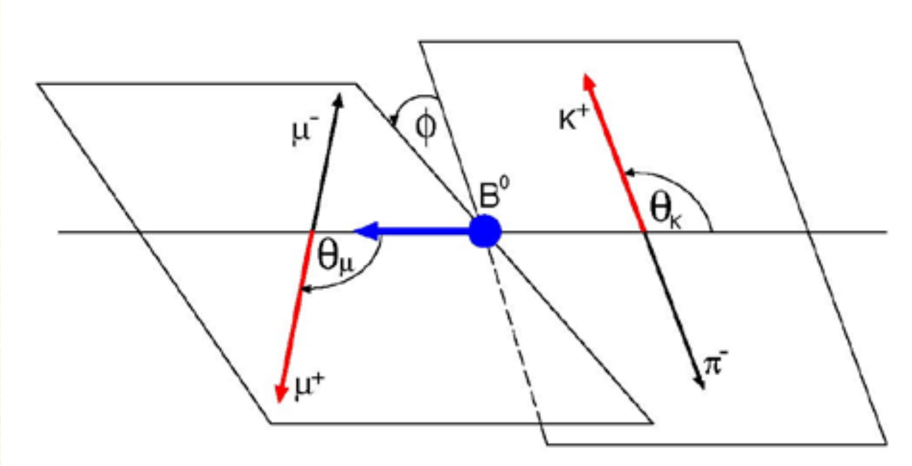


- $$\mathcal{R}_K = 0.96^{+0.44}_{-0.34} \pm 0.05$$
  $$\mathcal{R}_{K^*} = 1.10^{+0.42}_{-0.32} \pm 0.07$$
- $$\mathcal{R}_K = 1.03 \pm 0.19 \pm 0.06$$
  $$\mathcal{R}_{K^*} = 0.83 \pm 0.17 \pm 0.08$$

BABAR: PRL 102, 091803 (2009)
Belle: PRL 103, 171801 (2009)

Angular Distributions in B→K* $\ell^+\ell^-$

- The B→K* $\ell^+\ell^-$ angular distribution depends on three angles, θ_K, θ_ℓ, ϕ
- It involves 12 coefficients J_i that can be determined from a full angular fit as a function of q^2
- A large data sample is needed to perform this task (LHCb, or Super B-factory)



$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi} J\left(q^2,\theta_\ell,\theta_K,\phi\right)$$

Krüger et al.,PRD, 61114028 (2000)
Kim et al, PRD 62, 034013 (2000)

$$J\left(q^2,\theta_\ell,\theta_K,\phi\right) =$$
$$J_{1s}\sin^2\theta_K + J_{1c}\cos^2\theta_K + \left(J_{2s}\sin^2\theta_K + J_{2c}\cos^2\theta_K\right)\cos 2\theta_\ell + J_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+J_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + J_5\sin 2\theta_K\sin\theta_\ell\cos\phi + \left(J_{6s}\sin^2\theta_K + J_{6c}\cos^2\theta_K\right)\cos\theta_\ell$$
$$+J_7\sin 2\theta_K\sin\theta_\ell\sin\phi + J_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + J_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi$$

Angular Distributions in $B\to K^* \ell^+\ell^-$

- Since the present experiments have limited data samples, the 1d-angular projections have been studied which allow to extract the K^* longitudinal polarization and the lepton forward backward asymmetry in different q^2 regions

- K^* longitudinal polarization $\mathcal{F}_L$ is obtained from the distribution of angle θ_K between K & B in K^* rest frame

$$W(\cos\theta_K) = \tfrac{3}{2}\mathcal{F}_L \cos^2\theta_K + \tfrac{3}{4}(1-\mathcal{F}_L)\sin^2\theta_K$$

$\mathcal{F}_L \sim J_{1c} = -J_{2c}$

- Lepton forward-backward asymmetry $\mathcal{A}_{FB}$ is obtained from distribution of angle θ_ℓ between ℓ^+ (ℓ^-) & $B(\bar{B})$ in $\ell^+\ell^-$ rest frame

$$W(\cos\theta_\ell) = \tfrac{3}{4}\mathcal{F}_L \sin^2\theta_\ell + \tfrac{3}{8}(1-\mathcal{F}_L)(1+\cos^2\theta_\ell) + \mathcal{A}_{FB}\cos\theta_\ell$$

$\mathcal{A}_{FB} \sim J_6$

- Belle and CDF measured $\mathcal{F}_L$ and $\mathcal{A}_{FB}$ in 6 bins of q^2

- BABAR measure $\mathcal{F}_L$ and $\mathcal{A}_{FB}$ in 2 bins of q^2 (update with 6 bins is in progress)

Angular Distributions for $B \to K^{(*)} \ell^+ \ell^-$

- $\mathcal{A}_{FB}$ results from interplay between $C_9(q^2)C_{10}$ and $C_7 C_{10}/q^2$

$$\frac{d\mathcal{A}_{FB}}{dq^2} \propto -\left\{\mathrm{Re}\left[C_9^{eff}(q^2)C_{10}\right]VA_1 + \frac{m_b m_B}{q^2}\mathrm{Re}\left[C_7^{eff}C_{10}\right]\left[VT_2\left(1-\frac{m_{K^*}}{m_B}\right)+A_1T_1\left(1+\frac{m_{K^*}}{m_B}\right)\right]\right\}$$

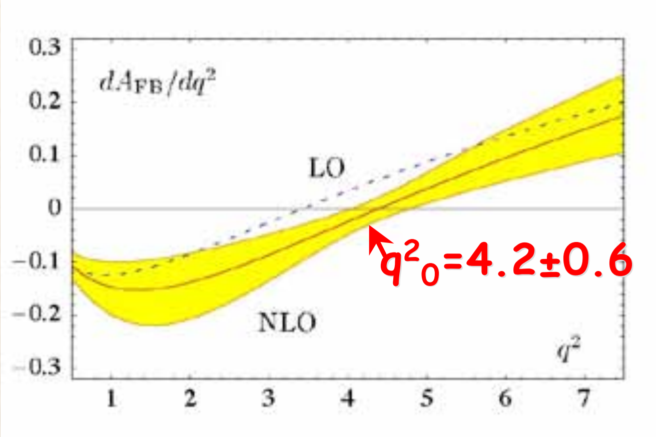
$K^* \ell^+ \ell^-$

form factors

- Recent SM calculations focus on low q^2-region

$K^* \ell^+ \ell^-$

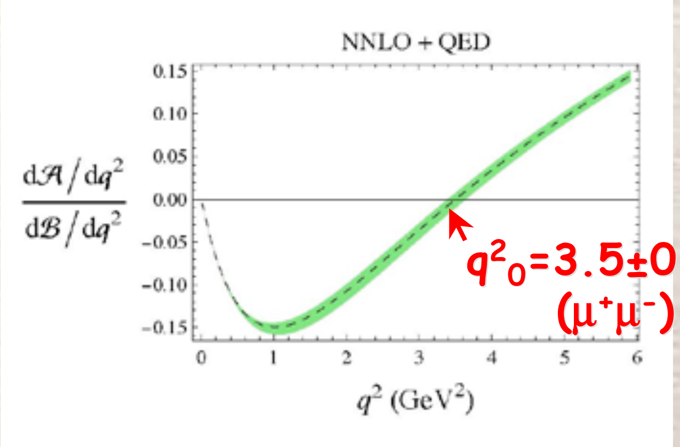
$\mathcal{O}(\alpha_s)$



$q^2_0=4.2\pm0.6$

$X_s \ell^+ \ell^-$

$\mathcal{O}(\alpha_s^2)$



$q^2_0=3.5\pm0.12$ $(\mu^+\mu^-)$

Feldmann & Matias JHEP 0301, 074 (2003)

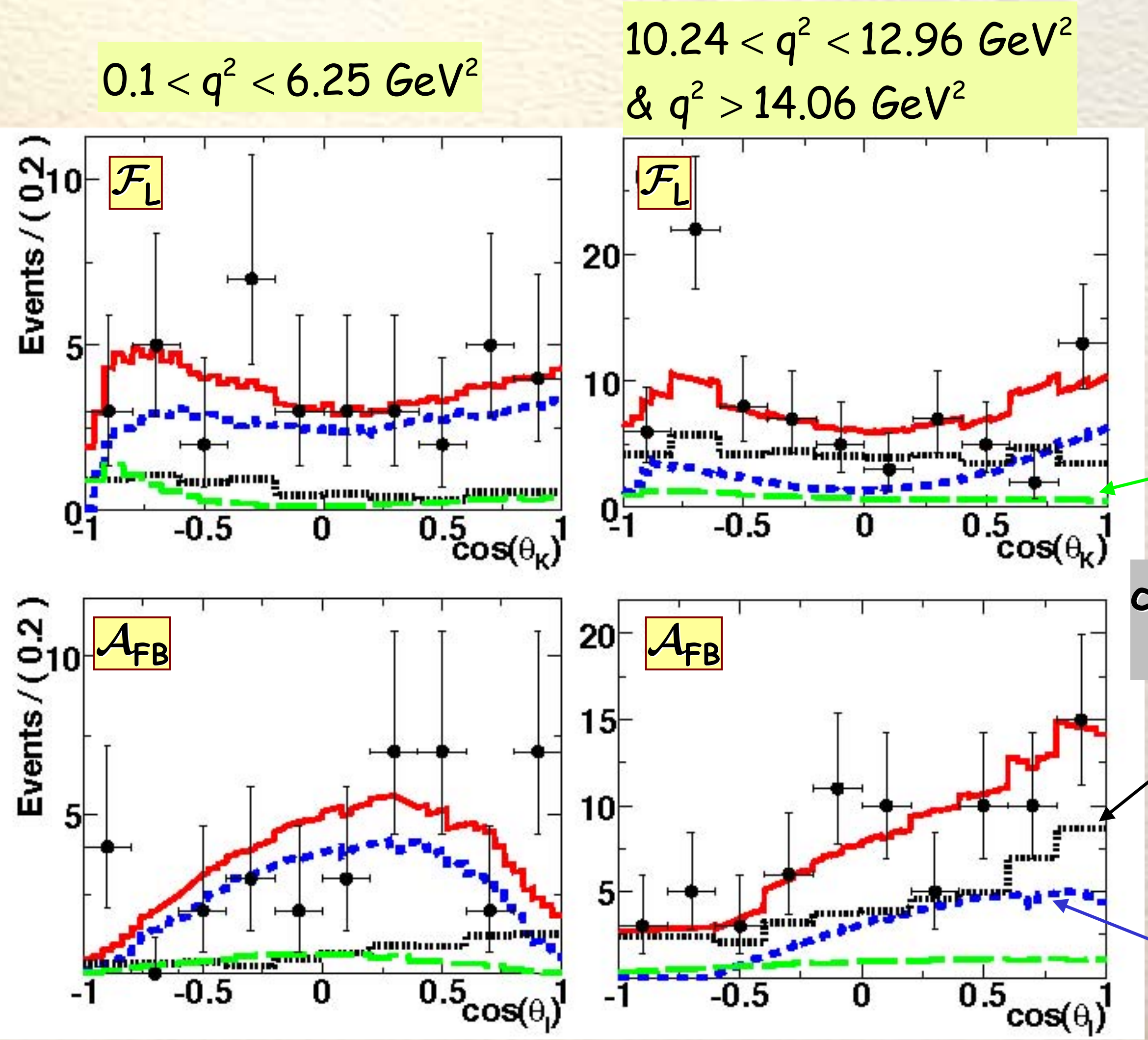
Huber, Hurth & Lunghi, Nucl.Phys B802, 40 (2008)

- In the SM, $\mathcal{A}_{FB}$ crosses zero around $q^2_0 = 3.5\text{-}4.5\ \mathrm{GeV}^2$

BABAR $B\to K^{*}\ell^{+}\ell^{-}$ Angular Distributions

- Fit data to signal distribution, combinatorial backgrounds and peaking backgrounds
- Extract yields from m_{ES} fit
- Extract $\mathcal{F}_L$ from fits to the $\cos\theta_K$ distribution
- Extract $\mathcal{A}_{FB}$ from fits to the $\cos\theta_\ell$ distribution

349 fb^{-1}



$0.1 < q^2 < 6.25\ \mathrm{GeV}^2$

$10.24 < q^2 < 12.96\ \mathrm{GeV}^2$
$\&\ q^2 > 14.06\ \mathrm{GeV}^2$

peaking background

combinatorial background

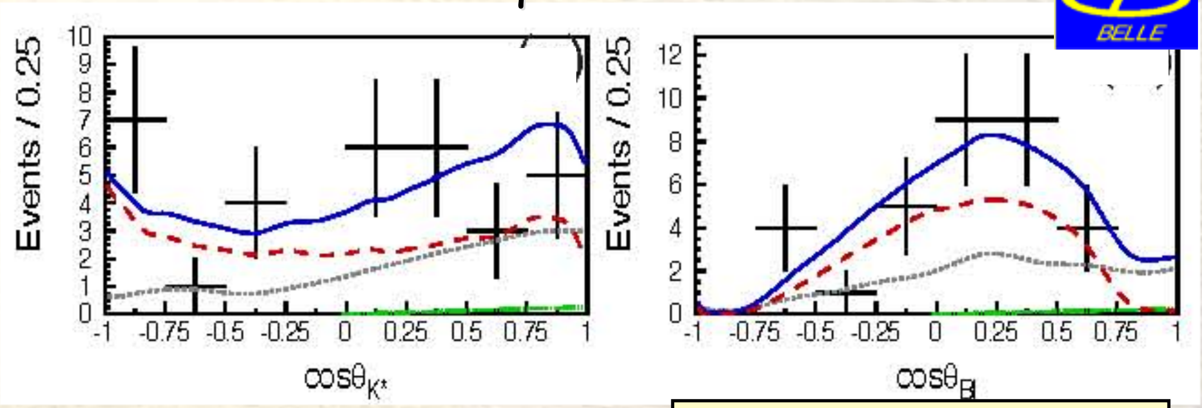
signal

BABAR: PRL 102, 091803 (2009)

Belle $B\rightarrow K^* \ell^+\ell^-$ Angular Distributions

- First extract $\mathcal{F}_L$ from fits to the $\cos\theta_K$ distribution
- Then extract $\mathcal{A}_{FB}$ from fits to the $\cos\theta_\ell$ distribution
- The shape of both angular distributions is different for low and high q^2 regions

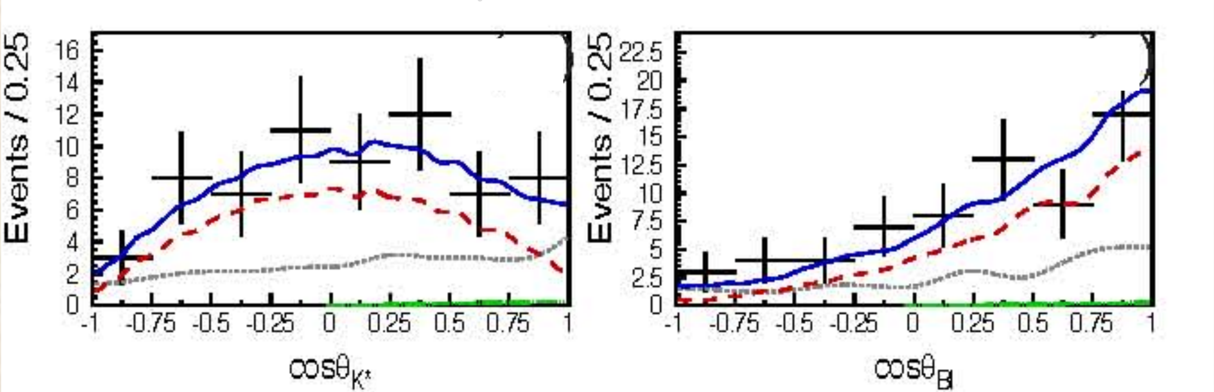
$0 < q^2 < 2\ \mathrm{GeV}^2/c^2$



$\mathcal{F}_L = 0.29^{+0.21}_{-0.18} \pm 0.02$

$\mathcal{A}^K_{FB} = 0.47^{+0.26}_{-0.32} \pm 0.03$

$q^2 > 16\ \mathrm{GeV}^2/c^2$



$\mathcal{F}_L = 0.12^{+0.15}_{-0.13} \pm 0.02$

$\mathcal{A}^K_{FB} = 0.66^{+0.11}_{-0.16} \pm 0.04$

— total fit

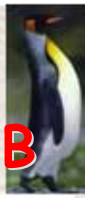
– – signal

- - - - combinatorial backg.

- - - - $J/\psi X, \psi(2S)X$ backg.

Belle: PRL 103, 171801 (2009)

Lepton Forward-Backward Asymmetry $\mathcal{A}_{FB}$



- BABAR, Belle and CDF measured $\mathcal{A}_{FB}$

BABAR: PRL 102, 091803 (2009)
CDF: Note 10047 (2010)
Belle: PRL 103, 171801 (2009)

- $(0.1<q^2<6.25\ \mathrm{GeV}^2/c^2)$

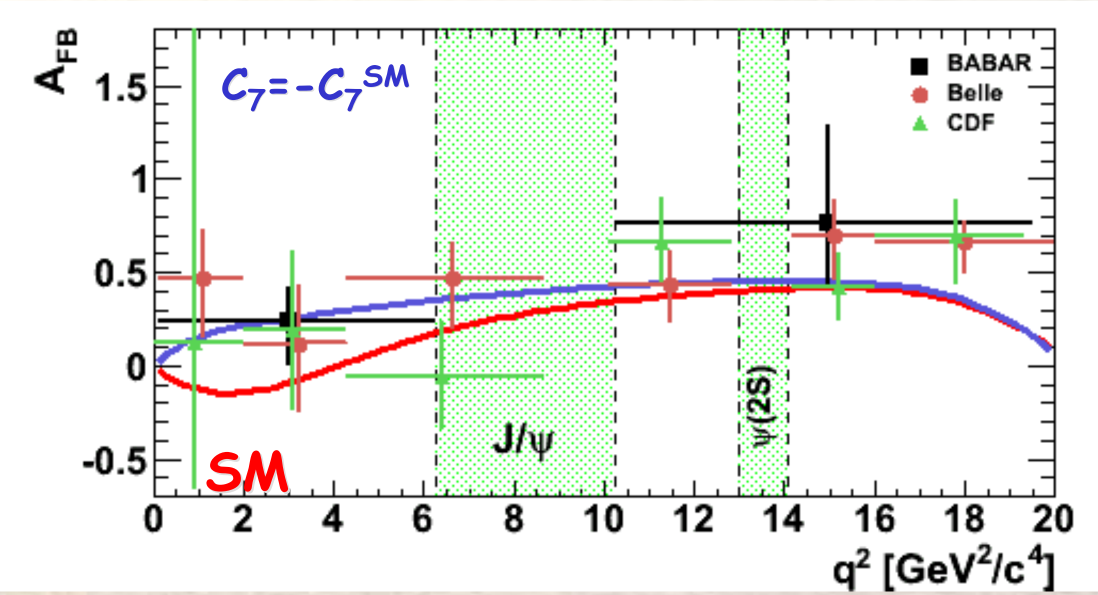
$$\mathcal{A}_{FB} = 0.24^{+0.18}_{-0.23} \pm 0.05$$

- $(1<q^2<6\,\mathrm{GeV}^2/c^2)$

$$\mathcal{A}_{FB} = 0.26^{+0.27}_{-0.30} \pm 0.07$$

- $(1<q^2<6\,\mathrm{GeV}^2/c^2)$

$$\mathcal{A}_{FB} = 0.43^{+0.36}_{-0.37} \pm 0.06$$



Ali et *al.* PRD 61, 074024 (2000)
Buchalla et *al.* PRD 63, 014015 (2000)
Ali et *al.* PRD 66, 034002 (2002)
Krüger et *al.* PRD 61, 114028 (2002)
Krüger & Matias PRD71, 094009 (2005)

- The measurements of the 3 experiments are in good agreement

- They are consistent with the SM prediction

$$\mathcal{A}_{FB}^{SM} = -0.05^{+0.03}_{-0.04} \quad (1 < q^2 < 6\ \mathrm{GeV}^2)$$

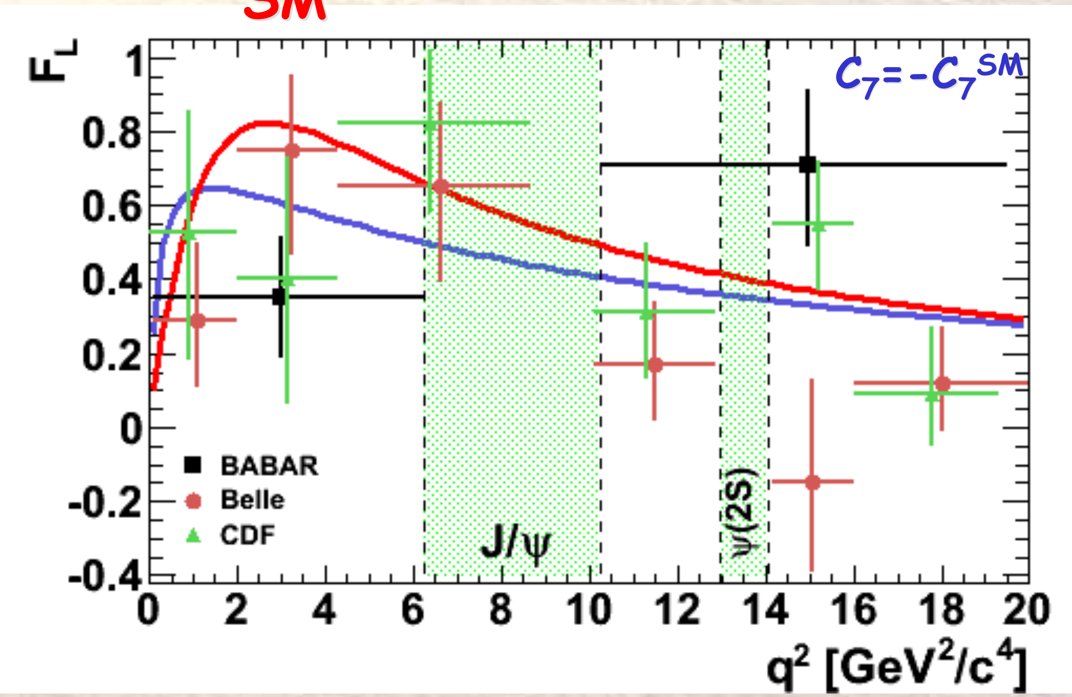
C. Bobeth *et al.* arXiv:1006.5013

K* Longitudinal Polarization $\mathcal{F}_L$

BABAR: PRL 102, 091803 (2009)
CDF: Note 10047 (2010)
Belle: PRL 103, 171801 (2009)

- BABAR, Belle and CDF measured $\mathcal{F}_L$
- $(0.1<q^2<6.25\ \mathrm{GeV}^2/c^2)$
  $\mathcal{F}_L = 0.35 \pm 0.16 \pm 0.04$
- $(1<q^2<6\mathrm{GeV}^2/c^2)$
  $\mathcal{F}_L = 0.67 \pm 0.23 \pm 0.04$
- $(1<q^2<6\mathrm{GeV}^2/c^2)$
  $\mathcal{F}_L = 0.50^{+0.27}_{-0.30} \pm 0.04$

SM



Krüger & Matias PRD71, 094009 (2005)

- The 3 measurements are consistent with each other
- They are also consistent with the SM prediction

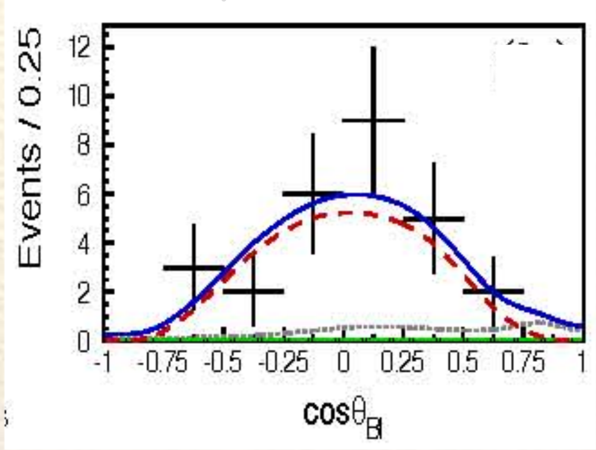
$$\boxed{\mathcal{F}_L^{SM} = 0.73^{+0.13}_{-0.23} \quad (1 < q^2 < 6\ \mathrm{GeV}^2)}$$

C. Bobeth *et al.* arXiv:1006.5013

Belle $B\rightarrow K\ell^+\ell$ Angular Distributions

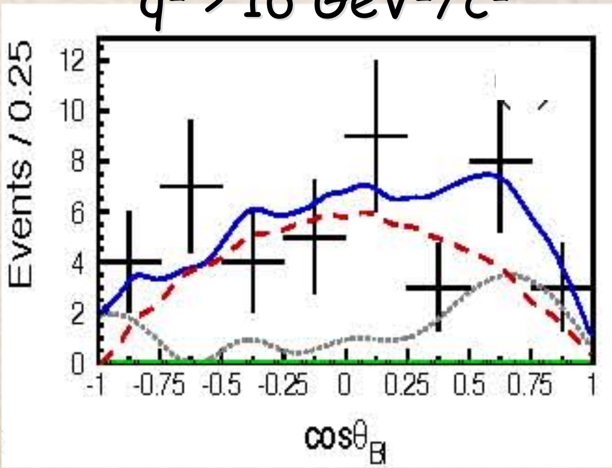
- Set $\mathcal{F}_L=1$ and fit $W(\theta_\ell)$ to extract $\mathcal{A}_{FB}$
- In the SM $\mathcal{A}_{\mathcal{FB}}=0$
- In MSSM scalar and pseudoscalar amplitudes arise that may interfere with the SM amplitudes and thus change $\mathcal{A}_{\mathcal{FB}}$ from the SM expectation
- In BABAR, Belle and CDF $\mathcal{A}_{\mathcal{FB}}$ is consistent with zero in all q^2 bins
- At LHCb and at Super B-factories $\mathcal{A}_{\mathcal{FB}}$ from $B\rightarrow K\ell^+\ell$ provides another test for New Physics

$0 < q^2 < 2$ GeV^2/c^2



$$\mathcal{A}^K_{FB}=0.06^{+0.32}_{-0.35}\pm 0.02$$

$q^2 > 16$ GeV^2/c^2



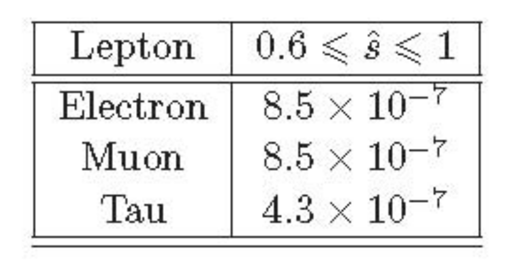
$$\mathcal{A}^K_{FB}=0.02^{+0.11}_{-0.08}\pm 0.02$$

—— total fit
– – signal
- - - - combinatorial backg.

Belle: PRL 103, 171801 (2009)

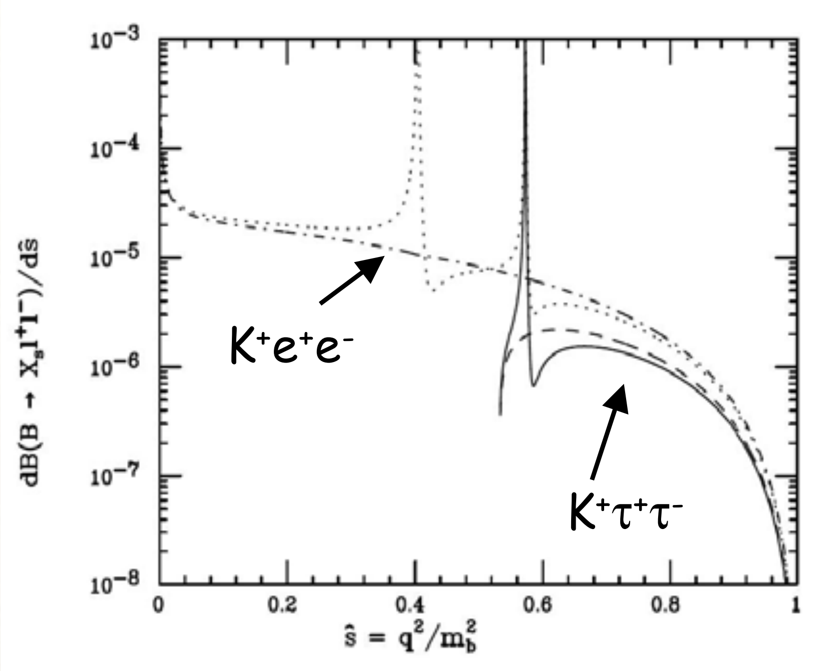
Search for $B^\pm \to K^\pm \tau^+ \tau^-$

- For $B \to X_s \tau^+\tau^-$ the SM rate similar to $B \to X_s\ \ell+\ell-$ ($\ell = e, \mu$) in the kinematic region accessible to all



Lepton	$0.6 \leqslant \hat{s} \leqslant 1$
Electron	8.5×10^{-7}
Muon	8.5×10^{-7}
Tau	4.3×10^{-7}

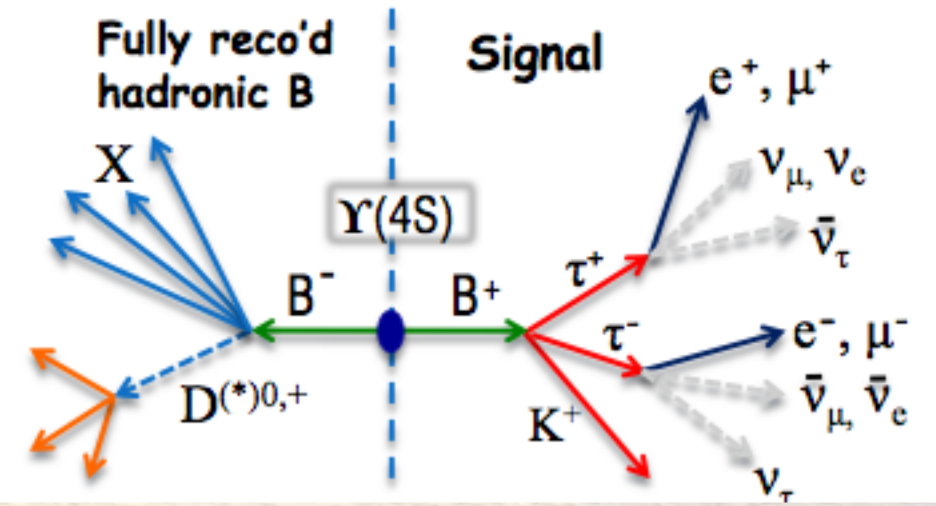
- $B^\pm \to K^\pm \tau^+\tau^-$ ~50% of total inclusive rate
- In NMSSM rate enhancements could be proportional to $(M_\tau^2/M_\mu^2) \sim 280$
- Since signal modes contain between 2-4 ν's, a different analysis strategy is needed to control backgrounds
- BABAR has performed first search for $B^\pm \to K^\pm \tau^+\tau^-$ using 423 fb^{-1}



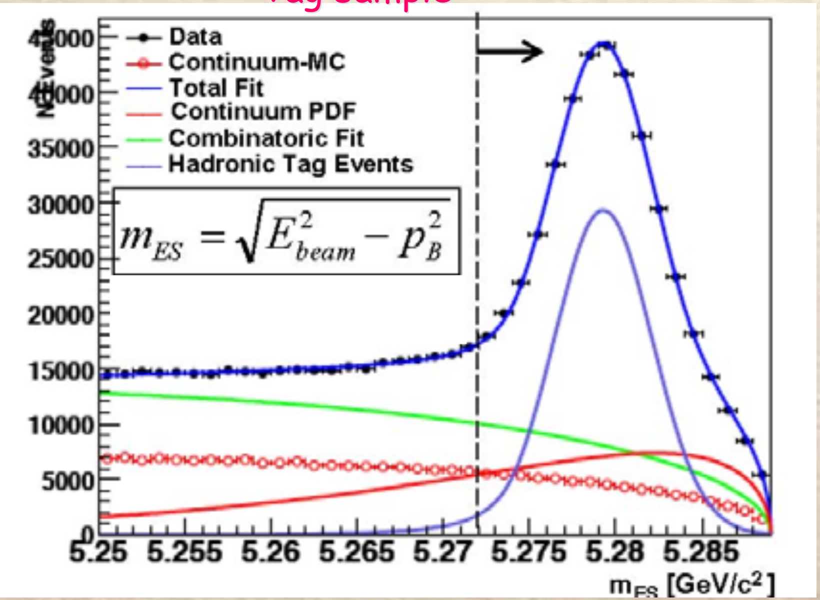
Hewett, PRD 53, 4964 (1996)

Analysis Strategy for $B^{\pm}\rightarrow K^{\pm}\tau^{+}\tau^{-}$

- BABAR reconstructs recoiling B in many hadronic final states $B^{-}\rightarrow D^{(*)0,+}X$, where X=up to total of six π^0, π^+, K_S, K^+
- Tag efficiency <~0.2%
- Use $\tau\rightarrow e\nu\bar{\nu}, \mu\nu\bar{\nu}, \pi\nu$ as signal modes

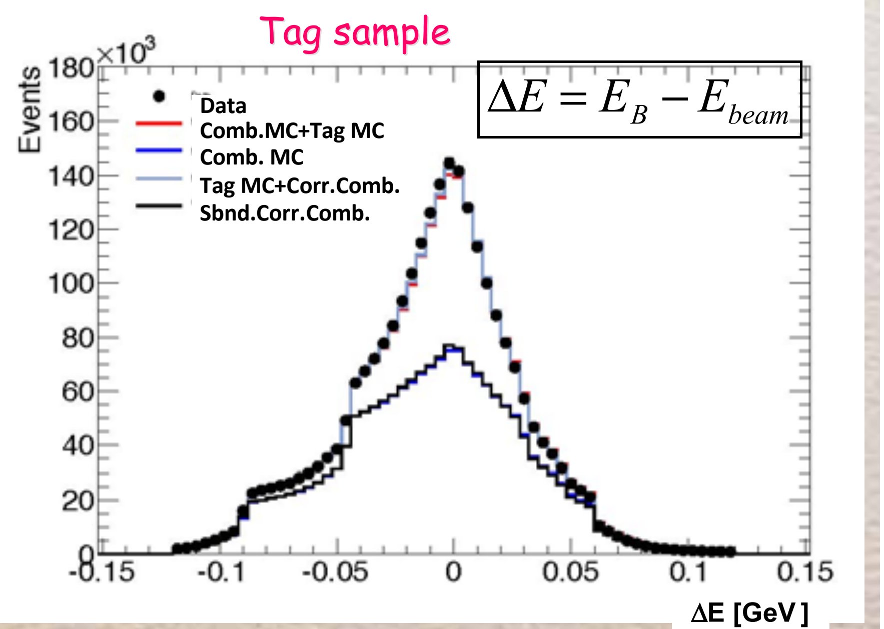


Tag sample



$$m_{ES} = \sqrt{E_{beam}^2 - p_B^2}$$

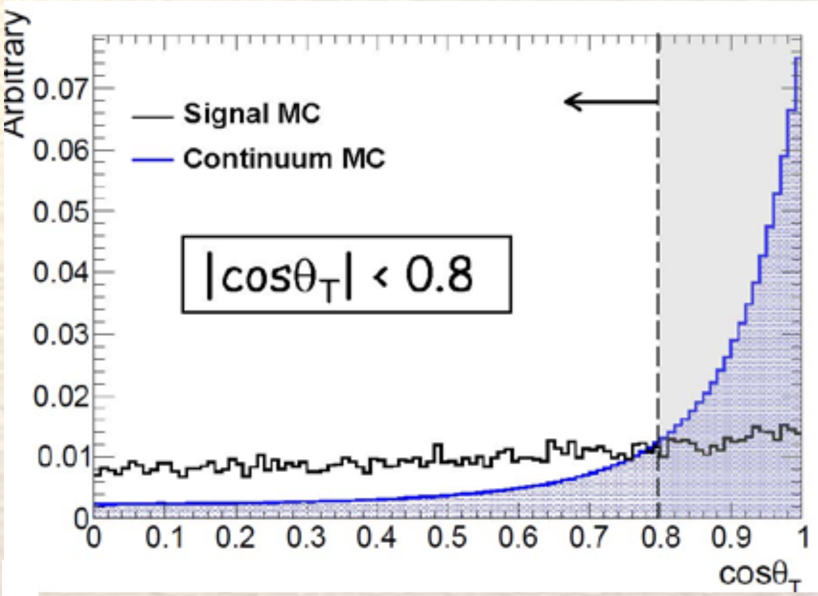
Tag sample



$$\Delta E = E_B - E_{beam}$$

Signal Selection for $B^{\pm} \to K^{\pm} \tau^{+} \tau^{-}$

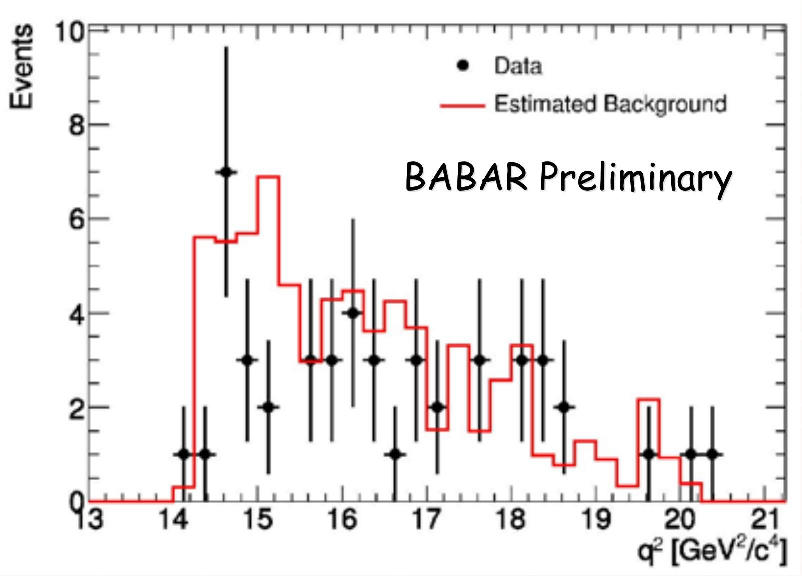
- Suppress continuum backgrounds by $|\cos\theta_T|<0.8$, (θ_T is opening angle between thrusts $T_{\text{tag B}}$ & $T_{\text{rest-of-the-event}}$

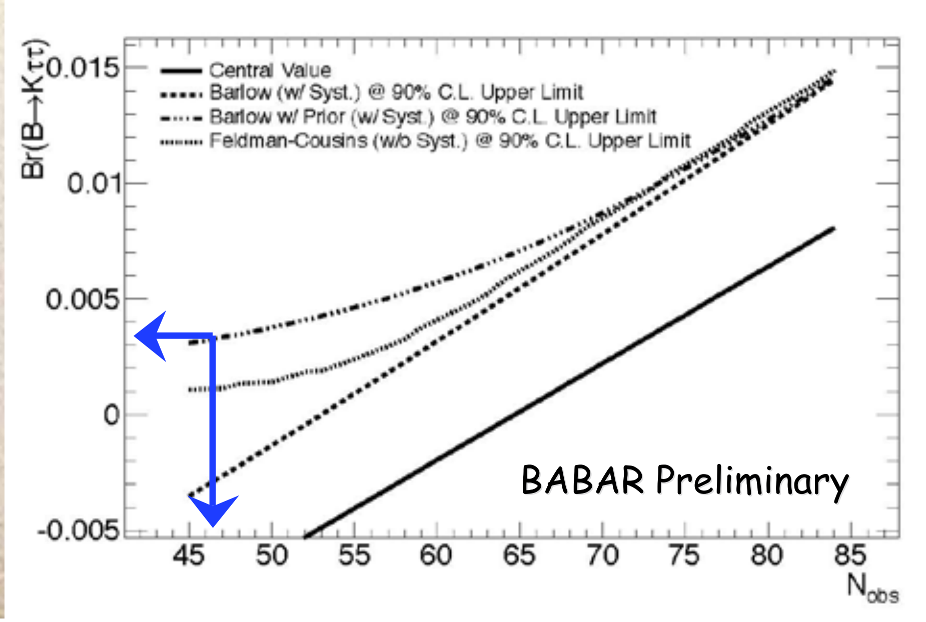


- Require 3 charged tracks only
  - 1 charged K with PID
    $0.44 < p < 1.4$ GeV/c, $Q_K{*}Q_{tag}=-1$
  - 1 e^+, μ^+, or π^+ & 1 e^-, μ^-, or π^- (PID)
    $p < 1.59$ GeV/c, $M_{pair} < 2.89$ GeV/c^2
  - $q^2 = (p_{\Upsilon(4S)}-p_{tag}-p_K)^2 > 14.23$ GeV^2
  - Missing energy: $1.39 < E_{miss} < 3.38$ GeV
  - Extra neutral energy in EM calorimeter: $E_{extra} < 0.74$ GeV
- Suppress largest remaining background from $B^+ \to D^0 X^+$ decays by combining signal $K^{\mp}$ with signal $\tau^{\pm}$ daughter (assigning a π mass hypothesis) and requiring: $M(K\pi) > 1.96$ GeV/c^2

Results for $B^\pm \to K^\pm \tau^+ \tau^-$

- BABAR observes 47 events (423 fb^{-1})
- Expected background is 64.7±7.3 events
- Systematic errors include B counting (1.1%), tag efficiency (3.2%), signal efficiency (14.8%), background estimate (5.1%) for PID of correct tags) and (14.8%) for data/MC statistics of incorrect tags
- Set branching fraction upper limit of $\mathcal{B}(B^+ \to K^+ \tau^+ \tau^-) < 3.3 \times 10^{-3}$ @90% CL
  ➔ nearly 4 orders of magnitude above the SM prediction





Conclusion

- BABAR and Belle have measured rate asymmetries in $B\to K(*)\ell^+\ell^-$
  - CP asymmetries agree with zero as expected in the SM
  - Lepton-flavor asymmetries are consistent with universality
  - For high q^2, isospin asymmetries are consistent with zero
  - For low q^2, BABAR sees an $\mathcal{A}_I$ different from zero (3.9σ)
  - Belle measurements are consistent both with BABAR and the SM
- BABAR, Belle & CDF measured $B\to K^{(*)}\ell^+\ell^-$ angular distributions in q^2 bins
  - $\mathcal{A}_{FB}$: for all q^2, well agreeing results are consistent with the SM
    For low q^2, non-zero $\mathcal{A}_{FB}$ values fit better to the flipped C_7-model
  - $\mathcal{F}_L$: for all q^2, data are consistent with each other and with the SM
- BABAR, Belle and CDF also have measured $B\to K^{(*)}\ell^+\ell^-$ partial and total branching fractions that agree with the SM (large uncertainties ~50%)
- BABAR performed the first search for $B^\pm\to K^\pm\tau^+\tau^-$ ➔ no signal is seen yielding an upper limit $\mathcal{B}(B^+\to K^+\tau^+\tau^-) < 3.3\times10^{-3}$ @90% CL
- Though all experiments will update results, significant progress will come from LHCb and Super B-factories ➔ the sensitivity to new observables (J_i) helps in revealing small discrepancies wrt the SM

Backup Slides

Transversity Amplitudes

- Left and right transversity amplitudes

$$A_\perp^{L,R} = +i\left\{(\mathcal{C}_9^{\text{eff}} \mp \mathcal{C}_{10}) + \kappa\frac{2\hat{m}_b}{\hat{s}}\,\mathcal{C}_7^{\text{eff}}\right\} f_\perp,$$

$$A_\parallel^{L,R} = -i\left\{(\mathcal{C}_9^{\text{eff}} \mp \mathcal{C}_{10}) + \kappa\frac{2\hat{m}_b}{\hat{s}}\,\mathcal{C}_7^{\text{eff}}\right\} f_\parallel,$$

$$A_0^{L,R} = -i\left\{\left(\mathcal{C}_9^{\text{eff}} \mp \mathcal{C}_{10}\right) + \kappa\frac{2\hat{m}_b}{\hat{s}}\,\mathcal{C}_7^{\text{eff}}\right\} f_0,$$

- Form factors

$$f_\perp = N m_B \frac{\sqrt{2\hat{\lambda}}}{1+\hat{m}_{K^*}} V,$$

$$f_\parallel = N m_B \sqrt{2}\,(1+\hat{m}_{K^*})\,A_1$$

$$f_0 = N m_B \frac{(1-\hat{s}-\hat{m}_{K^*}^2)(1+\hat{m}_{K^*})^2 A_1 - \hat{\lambda}\,A_2}{2\,\hat{m}_{K^*}(1+\hat{m}_{K^*})\sqrt{\hat{s}}},$$

- Normalization

$$N = \sqrt{\frac{G_F^2\,\alpha_e^2\,|\lambda_t|^2\,m_B\,\hat{s}\sqrt{\hat{\lambda}}}{3\cdot 2^{10}\,\pi^5}}.$$

- Old observables in terms of transversity amplitudes

$$\frac{d\Gamma}{dq^2} = 2\,\rho_1 \times (f_0^2 + f_\perp^2 + f_\parallel^2),$$

$$A_{\text{FB}} = 3\,\frac{\rho_2}{\rho_1} \times \frac{f_\perp f_\parallel}{(f_0^2 + f_\perp^2 + f_\parallel^2)},$$

$$F_{\text{L}} = \frac{f_0^2}{f_0^2 + f_\perp^2 + f_\parallel^2},$$

where

$$\rho_1 \equiv \left|\mathcal{C}_9^{\text{eff}} + \kappa\frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\text{eff}}\right|^2 + |\mathcal{C}_{10}|^2,$$

$$\rho_2 \equiv \text{Re}\left\{\left(\mathcal{C}_9^{\text{eff}} + \kappa\frac{2\hat{m}_b}{\hat{s}}\mathcal{C}_7^{\text{eff}}\right)\mathcal{C}_{10}^*\right\}.$$

C. Bobeth *et al.* arXiv:1006.5013

J_i in Terms of Transversity Amplitudes

$$J_1^s = \frac{3}{4}\left\{\frac{(2+\beta_l^2)}{4}\left[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L \to R)\right] + \frac{4m_l^2}{q^2}\mathrm{Re}\left(A_\perp^L A_\perp^{R^*} + A_\parallel^L A_\parallel^{R^*}\right)\right\},$$

$$J_1^c = \frac{3}{4}\left\{|A_0^L|^2 + |A_0^R|^2 + \frac{4m_l^2}{q^2}\left[|A_t|^2 + 2\mathrm{Re}(A_0^L A_0^{R^*})\right]\right\},$$

$$J_2^s = \frac{3\beta_l^2}{16}\left[|A_\perp^L|^2 + |A_\parallel^L|^2 + (L \to R)\right],$$

$$J_2^c = -\frac{3\beta_l^2}{4}\left[|A_0^L|^2 + (L \to R)\right],$$

$$J_3 = \frac{3}{8}\beta_l^2\left[|A_\perp^L|^2 - |A_\parallel^L|^2 + (L \to R)\right],$$

$$J_4 = \frac{3}{4\sqrt{2}}\beta_l^2\left[\mathrm{Re}(A_0^L A_\parallel^{L^*}) + (L \to R)\right],$$

$$J_5 = \frac{3\sqrt{2}}{4}\beta_l\left[\mathrm{Re}(A_0^L A_\perp^{L^*}) - (L \to R)\right],$$

$$J_6 = \frac{3}{2}\beta_l\left[\mathrm{Re}(A_\parallel^L A_\perp^{L^*}) - (L \to R)\right],$$

$$J_7 = \frac{3\sqrt{2}}{4}\beta_l\left[\mathrm{Im}(A_0^L A_\parallel^{L^*}) - (L \to R)\right],$$

$$J_8 = \frac{3}{4\sqrt{2}}\beta_l^2\left[\mathrm{Im}(A_0^L A_\perp^{L^*}) + (L \to R)\right],$$

$$J_9 = \frac{3}{4}\beta_l^2\left[\mathrm{Im}(A_\parallel^{L^*} A_\perp^L) + (L \to R)\right],$$

$$\beta_l = \sqrt{1 - \frac{4m_l^2}{q^2}}.$$

C. Bobeth *et al.* arXiv:1006.5013

Observables in terms of J_{is}

- Old observables

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} = 2J_1^s + J_1^c - \frac{2J_2^s + J_2^c}{3} = |A_0^L|^2 + |A_\perp^L|^2 + |A_\parallel^L|^2 + (L \leftrightarrow R),$$

$$A_{\mathrm{FB}} = \left[\int_0^1 - \int_{-1}^0\right] \mathrm{d}\cos\theta_l \, \frac{\mathrm{d}^2\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_l} \Bigg/ \frac{\mathrm{d}\Gamma}{\mathrm{d}q^2} = \frac{J_6}{\mathrm{d}\Gamma/\mathrm{d}q^2},$$

$$F_{\mathrm{L}} = \frac{|A_0^L|^2 + |A_0^R|^2}{\mathrm{d}\Gamma/\mathrm{d}q^2},$$

- Transversity observables (new)

$$A_T^{(2)} = \frac{|A_\perp^L|^2 + |A_\perp^R|^2 - |A_\parallel^L|^2 - |A_\parallel^R|^2}{|A_\perp^L|^2 + |A_\perp^R|^2 + |A_\parallel^L|^2 + |A_\parallel^R|^2} = \frac{1}{2}\frac{J_3}{J_2^s},$$

$$A_T^{(3)} = \frac{|A_0^L A_\parallel^{L*} + A_0^{R*} A_\parallel^R|}{\sqrt{(|A_0^L|^2 + |A_0^R|^2)(|A_\perp^L|^2 + |A_\perp^R|^2)}} = \sqrt{\frac{4J_4^2 + \beta_l^2 J_7^2}{-2J_2^c(2J_2^s + J_3)}},$$

$$A_T^{(4)} = \frac{|A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R|}{|A_0^{L*} A_\parallel^L + A_0^R A_\parallel^{R*}|} = \sqrt{\frac{\beta_l^2 J_5^2 + 4J_8^2}{4J_4^2 + \beta_l^2 J_7^2}},$$

$$H_T^{(1)} = \frac{\mathrm{Re}(A_0^L A_\parallel^{L*} + A_0^{R*} A_\parallel^R)}{\sqrt{(|A_0^L|^2 + |A_0^R|^2)(|A_\parallel^L|^2 + |A_\parallel^R|^2)}} = \frac{\sqrt{2}J_4}{\sqrt{-J_2^c(2J_2^s - J_3)}},$$

$$H_T^{(2)} = \frac{\mathrm{Re}(A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R)}{\sqrt{(|A_0^L|^2 + |A_0^R|^2)(|A_\perp^L|^2 + |A_\perp^R|^2)}} = \frac{\beta_l J_5}{\sqrt{-2J_2^c(2J_2^s + J_3)}},$$

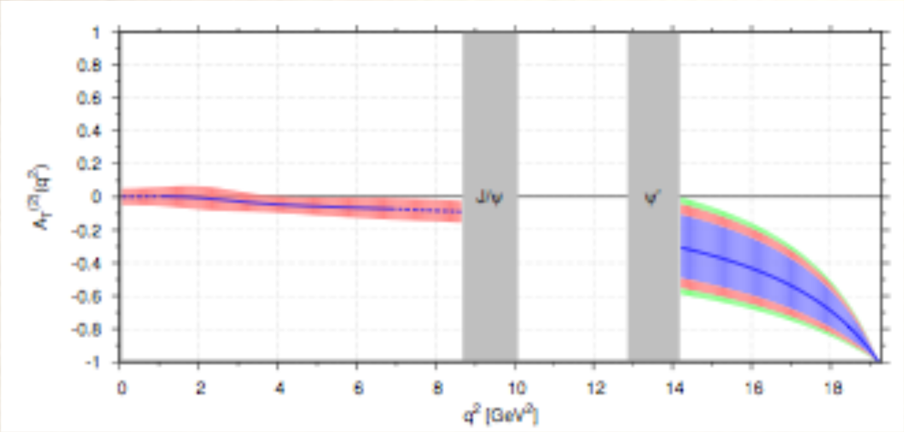
$$H_T^{(3)} = \frac{\mathrm{Re}(A_\parallel^L A_\perp^{L*} - A_\parallel^{R*} A_\perp^R)}{\sqrt{(|A_\parallel^L|^2 + |A_\parallel^R|^2)(|A_\perp^L|^2 + |A_\perp^R|^2)}} = \frac{\beta_l J_6}{2\sqrt{(2J_2^s)^2 - J_3^2}}.$$

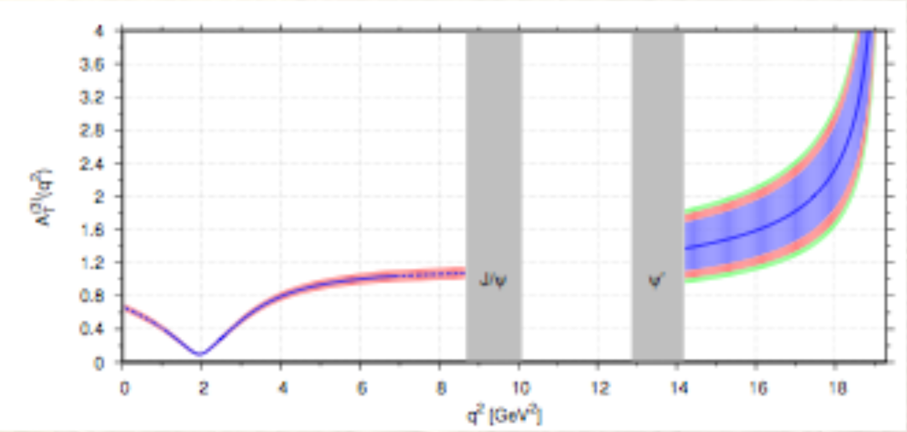
C. Bobeth *et al.* arXiv:1006.5013

Transverse Asymmetries

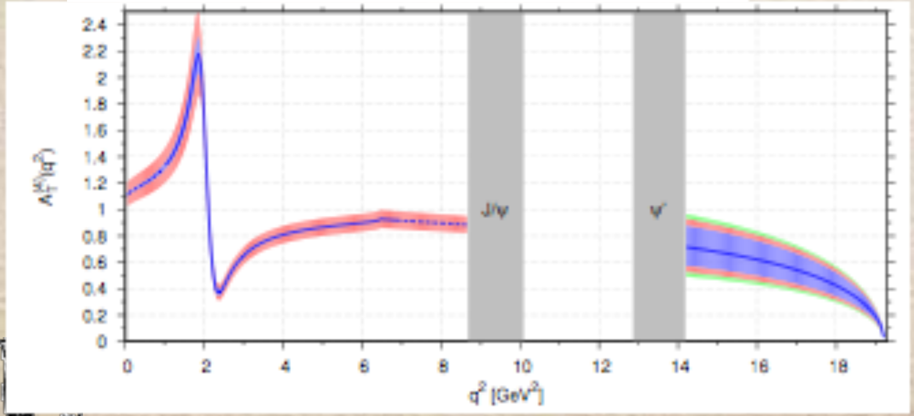
- $$A_T^{(2)} = \frac{|A_\perp^L|^2 + |A_\perp^R|^2 - |A_\parallel^L|^2 - |A_\parallel^R|^2}{|A_\perp^L|^2 + |A_\perp^R|^2 + |A_\parallel^L|^2 + |A_\parallel^R|^2} = \frac{1}{2}\frac{J_3}{J_2^s},$$

$$A_T^{(3)} = \frac{|A_0^L A_\parallel^{L*} + A_0^{R*} A_\parallel^R|}{\sqrt{\left(|A_0^L|^2 + |A_0^R|^2\right)\left(|A_\perp^L|^2 + |A_\perp^R|^2\right)}} = \sqrt{\frac{4J_4^2 + \beta_l^2 J_7^2}{-2J_2^c(2J_2^s + J_3)}},$$



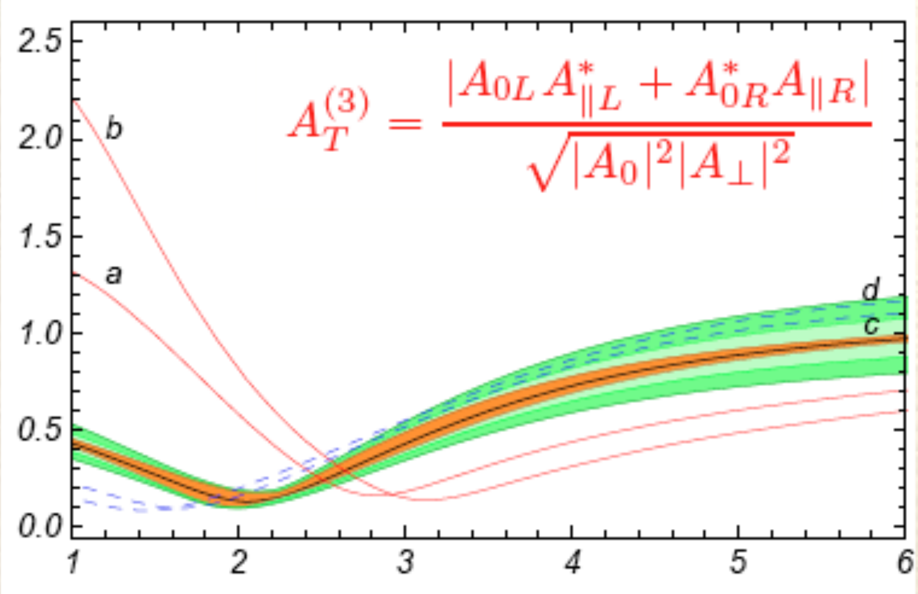


- $$A_T^{(4)} = \frac{|A_0^L A_\perp^{L*} - A_0^{R*} A_\perp^R|}{|A_0^{L*} A_\parallel^L + A_0^R A_\parallel^{R*}|} = \sqrt{\frac{\beta_l^2 J_5^2 + 4J_8^2}{4J_4^2 + \beta_l^2 J_7^2}},$$

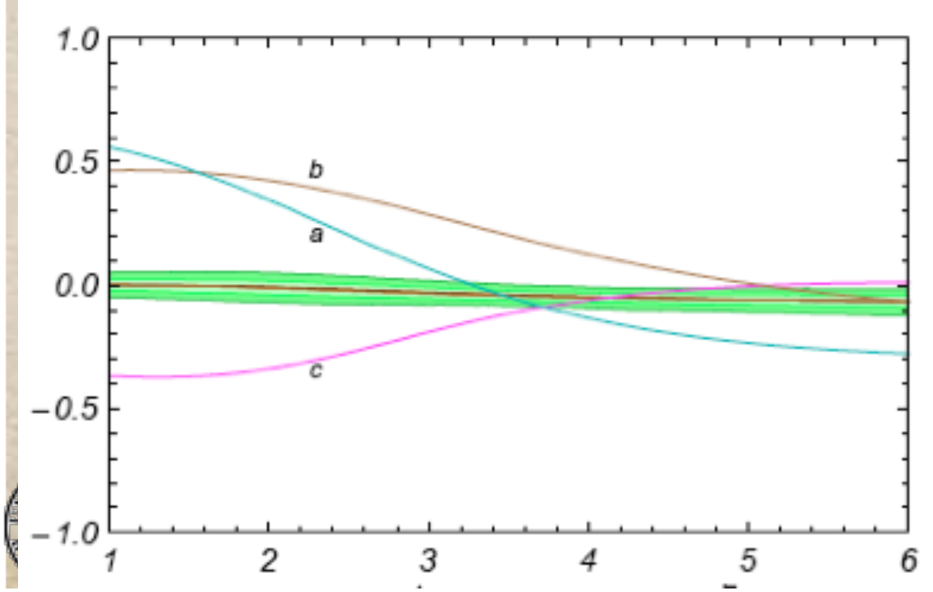


C. Bobeth *et al.* arXiv:1006.5013

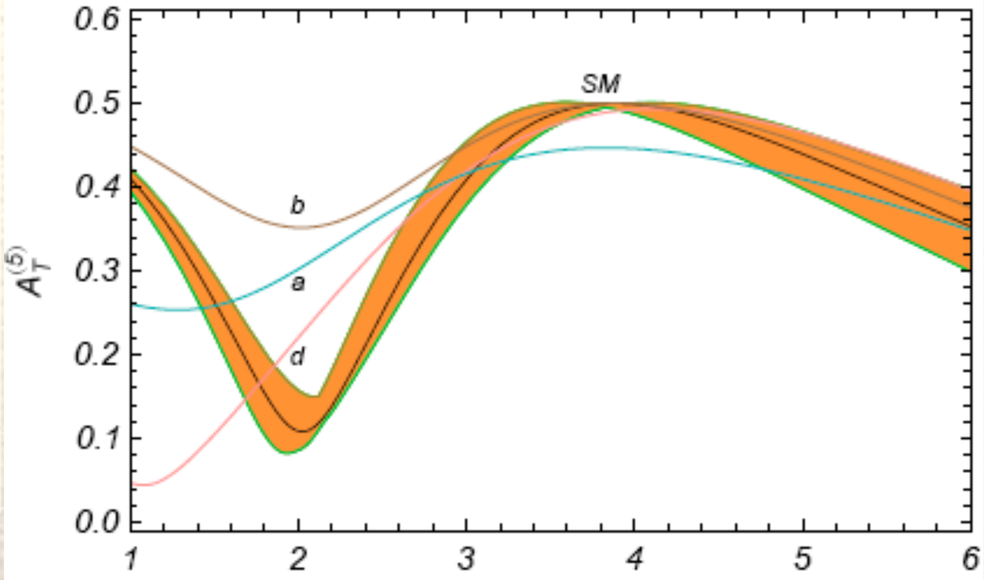
Transverse Asymmetries with New Physics



$$A_T^{(3)} = \frac{|A_{0L} A^*_{\|L} + A^*_{0R} A_{\|R}|}{\sqrt{|A_0|^2 |A_\perp|^2}}$$



$$A_T^{(5)}\Big|_{m_\ell=0} = \frac{\sqrt{16 J_1^{s\,2} - 9 J_6^{s\,2} - 36(J_3^2 + J_9^2)}}{8 J_1^s}$$



$$(a) \quad (\mathcal{C}_7^{\mathrm{NP}}, \mathcal{C}_7') = (0.26 e^{-i\frac{7\pi}{16}}, 0.2 e^{i\pi})$$

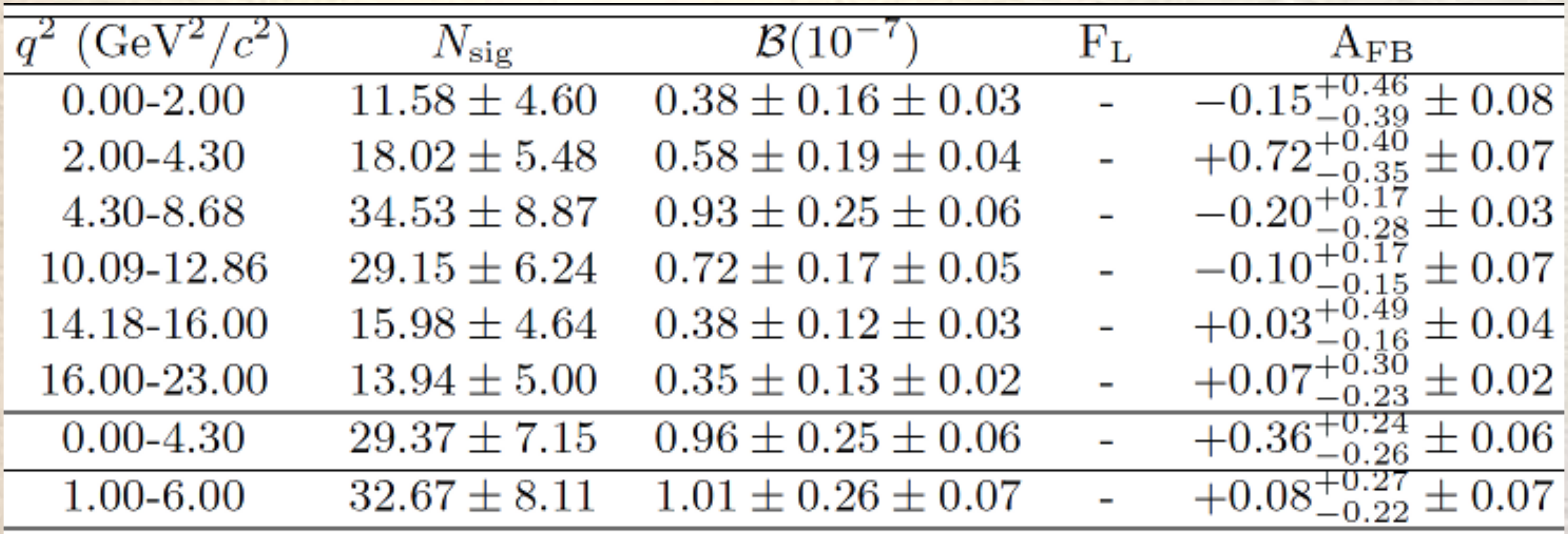
$$(b) \quad (0.07 e^{i\frac{3\pi}{5}}, 0.3 e^{i\frac{3\pi}{5}})$$

$$(d) \quad (0.18 e^{-i\frac{\pi}{2}}, 0)$$

CDF $B\to K^{(*)}\ell^+\ell^-$ Results

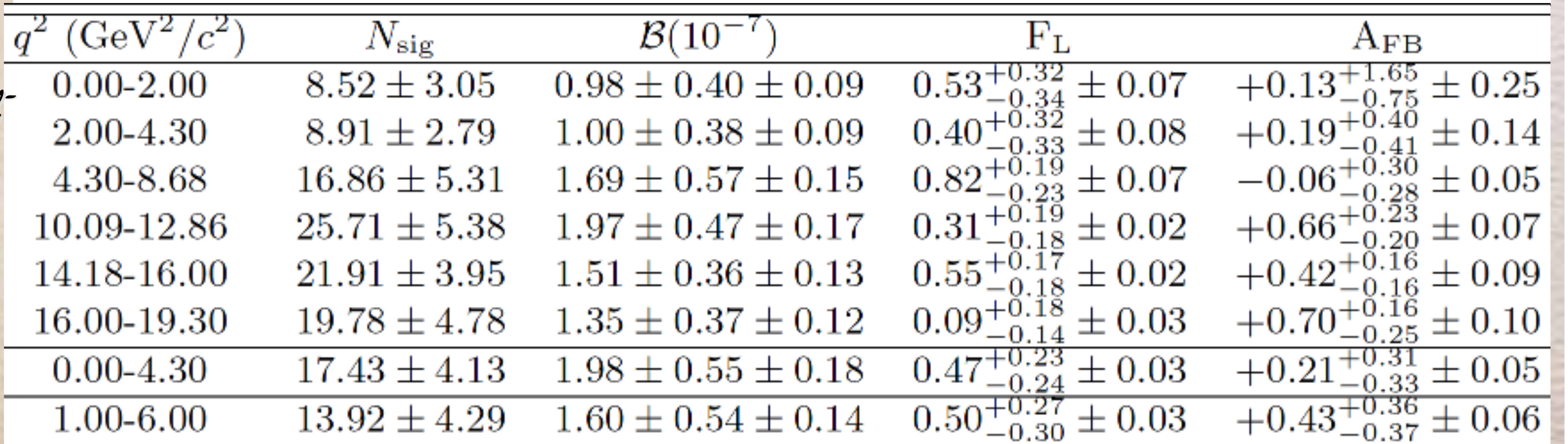
- Branching fractions, $\mathcal{F}_L$ and $\mathcal{A}_{FB}$ for $B\to K^{(*)}\ell^+\ell^-$ in bins of q^2

$K\ell^+\ell^-$



q^2 (GeV^2/c^2)	N_{sig}	$\mathcal{B}(10^{-7})$	F_L	A_{FB}
0.00-2.00	11.58 ± 4.60	$0.38 \pm 0.16 \pm 0.03$	-	$-0.15^{+0.46}_{-0.39} \pm 0.08$
2.00-4.30	18.02 ± 5.48	$0.58 \pm 0.19 \pm 0.04$	-	$+0.72^{+0.40}_{-0.35} \pm 0.07$
4.30-8.68	34.53 ± 8.87	$0.93 \pm 0.25 \pm 0.06$	-	$-0.20^{+0.17}_{-0.28} \pm 0.03$
10.09-12.86	29.15 ± 6.24	$0.72 \pm 0.17 \pm 0.05$	-	$-0.10^{+0.17}_{-0.15} \pm 0.07$
14.18-16.00	15.98 ± 4.64	$0.38 \pm 0.12 \pm 0.03$	-	$+0.03^{+0.49}_{-0.16} \pm 0.04$
16.00-23.00	13.94 ± 5.00	$0.35 \pm 0.13 \pm 0.02$	-	$+0.07^{+0.30}_{-0.23} \pm 0.02$
0.00-4.30	29.37 ± 7.15	$0.96 \pm 0.25 \pm 0.06$	-	$+0.36^{+0.24}_{-0.26} \pm 0.06$
1.00-6.00	32.67 ± 8.11	$1.01 \pm 0.26 \pm 0.07$	-	$+0.08^{+0.27}_{-0.22} \pm 0.07$

$K^*\ell^+\ell^-$

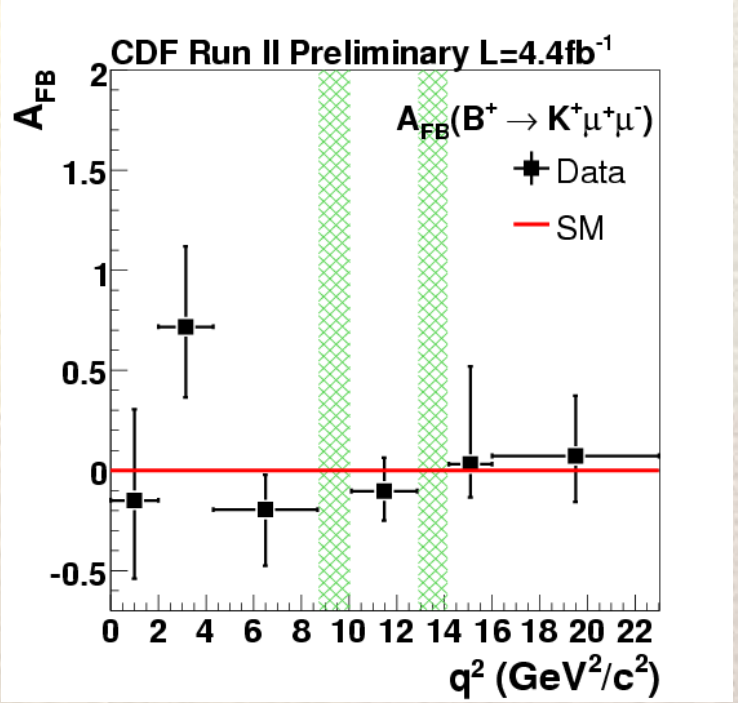


q^2 (GeV^2/c^2)	N_{sig}	$\mathcal{B}(10^{-7})$	F_L	A_{FB}
0.00-2.00	8.52 ± 3.05	$0.98 \pm 0.40 \pm 0.09$	$0.53^{+0.32}_{-0.34} \pm 0.07$	$+0.13^{+1.65}_{-0.75} \pm 0.25$
2.00-4.30	8.91 ± 2.79	$1.00 \pm 0.38 \pm 0.09$	$0.40^{+0.32}_{-0.33} \pm 0.08$	$+0.19^{+0.40}_{-0.41} \pm 0.14$
4.30-8.68	16.86 ± 5.31	$1.69 \pm 0.57 \pm 0.15$	$0.82^{+0.19}_{-0.23} \pm 0.07$	$-0.06^{+0.30}_{-0.28} \pm 0.05$
10.09-12.86	25.71 ± 5.38	$1.97 \pm 0.47 \pm 0.17$	$0.31^{+0.19}_{-0.18} \pm 0.02$	$+0.66^{+0.23}_{-0.20} \pm 0.07$
14.18-16.00	21.91 ± 3.95	$1.51 \pm 0.36 \pm 0.13$	$0.55^{+0.17}_{-0.18} \pm 0.02$	$+0.42^{+0.16}_{-0.16} \pm 0.09$
16.00-19.30	19.78 ± 4.78	$1.35 \pm 0.37 \pm 0.12$	$0.09^{+0.18}_{-0.14} \pm 0.03$	$+0.70^{+0.16}_{-0.25} \pm 0.10$
0.00-4.30	17.43 ± 4.13	$1.98 \pm 0.55 \pm 0.18$	$0.47^{+0.23}_{-0.24} \pm 0.03$	$+0.21^{+0.31}_{-0.33} \pm 0.05$
1.00-6.00	13.92 ± 4.29	$1.60 \pm 0.54 \pm 0.14$	$0.50^{+0.27}_{-0.30} \pm 0.03$	$+0.43^{+0.36}_{-0.37} \pm 0.06$

CDF: Note 10047 (2010)

CDF B→K$\ell^+\ell^-$ $\mathcal{A}_{FB}$ Results

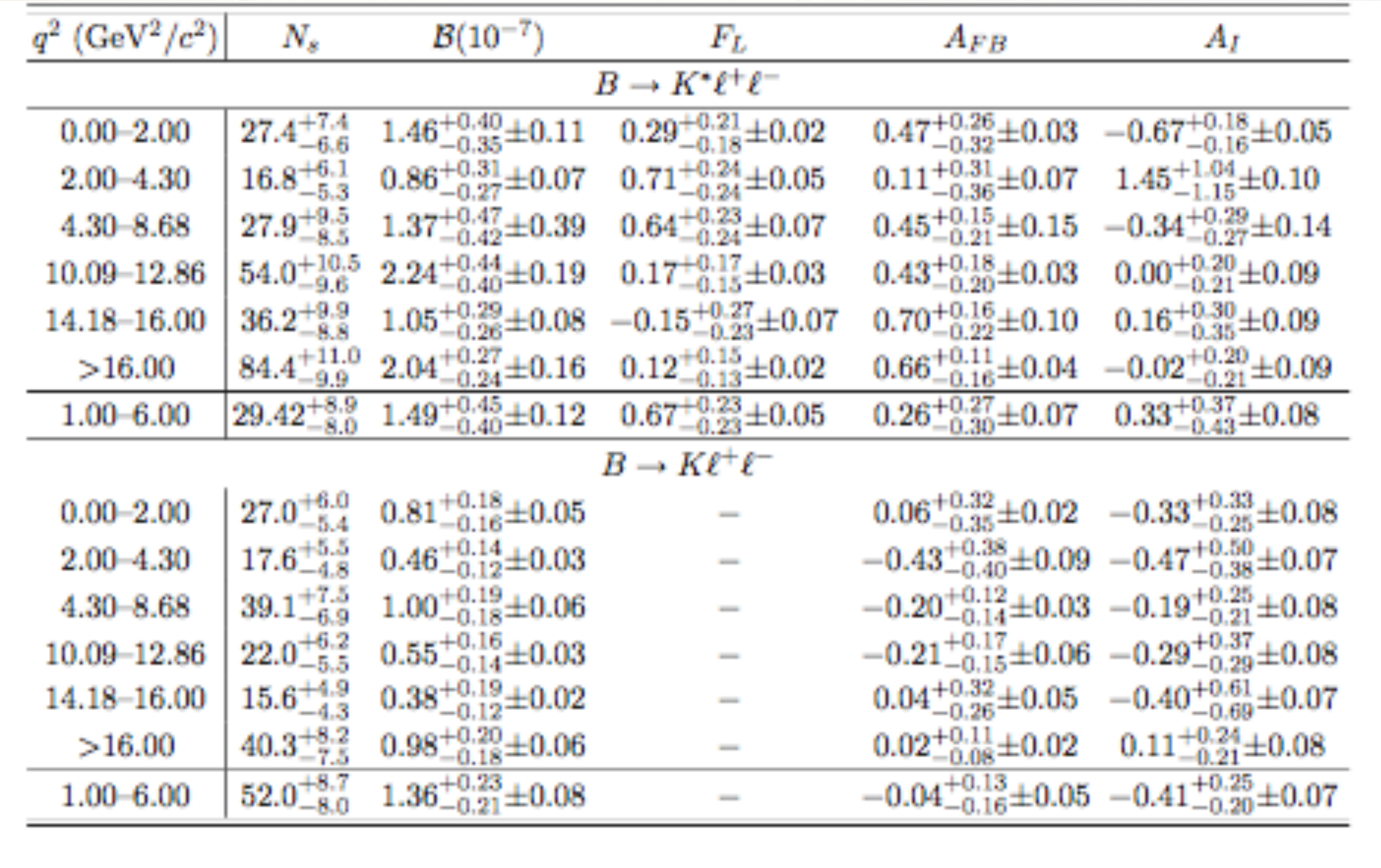
- CDF measured $\mathcal{A}_{FB}$ for B→K$\ell^+\ell^-$ in different bins of q^2



CDF: Note 10047 (2010)

Belle $B \to K^{(*)} \ell^+\ell^-$ Results

- Branching fractions, $\mathcal{F}_L$, $\mathcal{A}_{FB}$, and $\mathcal{A}_I$ for $B \to K^{(*)} \ell^+\ell^-$ in bins of q^2

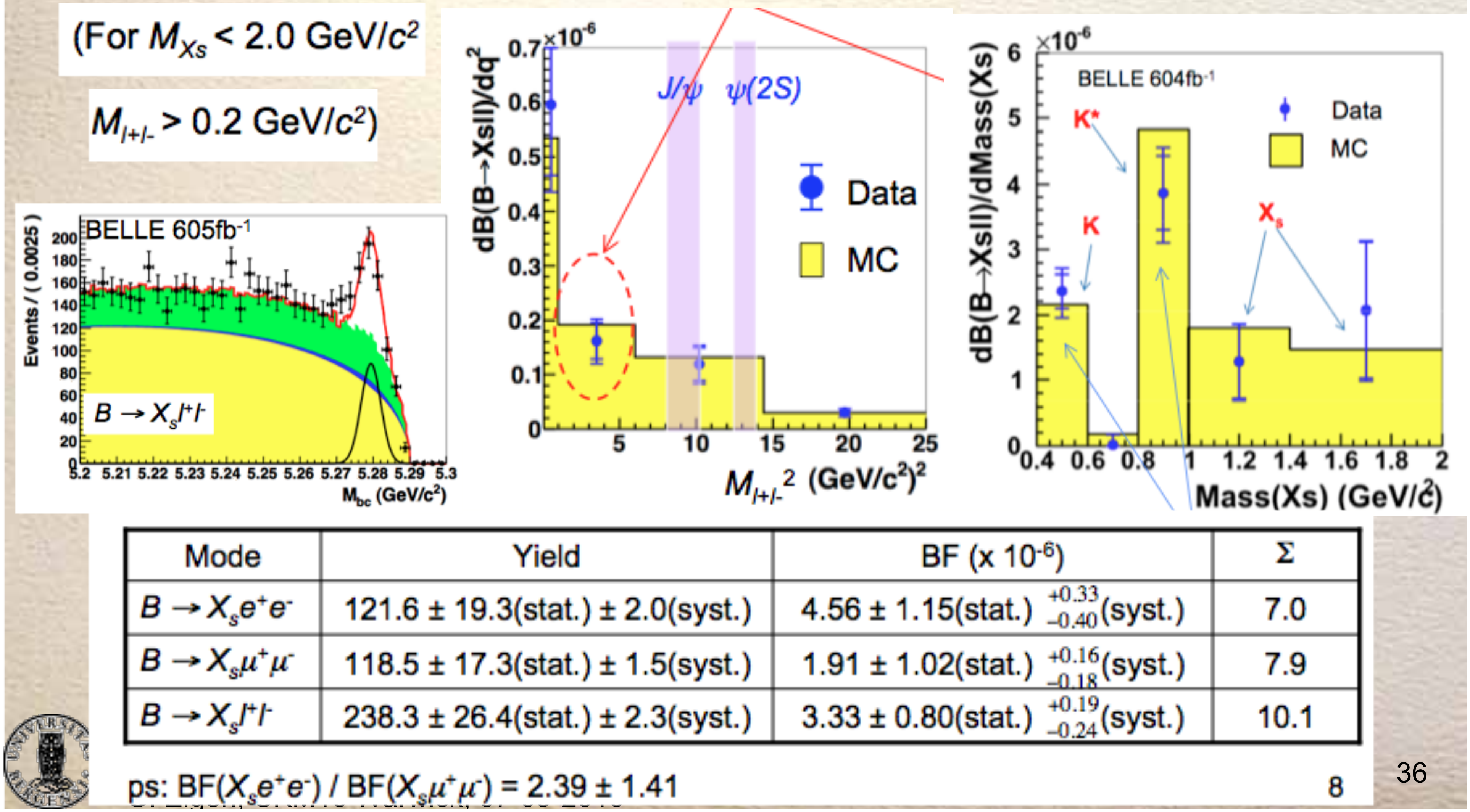


q^2 (GeV^2/c^2)	N_s	$\mathcal{B}(10^{-7})$	F_L	A_{FB}	A_I
			$B \to K^*\ell^+\ell^-$		
0.00–2.00	$27.4^{+7.4}_{-6.6}$	$1.46^{+0.40}_{-0.35}\pm0.11$	$0.29^{+0.21}_{-0.18}\pm0.02$	$0.47^{+0.26}_{-0.32}\pm0.03$	$-0.67^{+0.18}_{-0.16}\pm0.05$
2.00–4.30	$16.8^{+6.1}_{-5.3}$	$0.86^{+0.31}_{-0.27}\pm0.07$	$0.71^{+0.24}_{-0.24}\pm0.05$	$0.11^{+0.31}_{-0.36}\pm0.07$	$1.45^{+1.04}_{-1.15}\pm0.10$
4.30–8.68	$27.9^{+9.5}_{-8.5}$	$1.37^{+0.47}_{-0.42}\pm0.39$	$0.64^{+0.23}_{-0.24}\pm0.07$	$0.45^{+0.15}_{-0.21}\pm0.15$	$-0.34^{+0.29}_{-0.27}\pm0.14$
10.09–12.86	$54.0^{+10.5}_{-9.6}$	$2.24^{+0.44}_{-0.40}\pm0.19$	$0.17^{+0.17}_{-0.15}\pm0.03$	$0.43^{+0.18}_{-0.20}\pm0.03$	$0.00^{+0.20}_{-0.21}\pm0.09$
14.18–16.00	$36.2^{+9.9}_{-8.8}$	$1.05^{+0.29}_{-0.26}\pm0.08$	$-0.15^{+0.27}_{-0.23}\pm0.07$	$0.70^{+0.16}_{-0.22}\pm0.10$	$0.16^{+0.30}_{-0.35}\pm0.09$
>16.00	$84.4^{+11.0}_{-9.9}$	$2.04^{+0.27}_{-0.24}\pm0.16$	$0.12^{+0.15}_{-0.13}\pm0.02$	$0.66^{+0.11}_{-0.16}\pm0.04$	$-0.02^{+0.20}_{-0.21}\pm0.09$
1.00–6.00	$29.42^{+8.9}_{-8.0}$	$1.49^{+0.45}_{-0.40}\pm0.12$	$0.67^{+0.23}_{-0.23}\pm0.05$	$0.26^{+0.27}_{-0.30}\pm0.07$	$0.33^{+0.37}_{-0.43}\pm0.08$
			$B \to K\ell^+\ell^-$		
0.00–2.00	$27.0^{+6.0}_{-5.4}$	$0.81^{+0.18}_{-0.16}\pm0.05$	–	$0.06^{+0.32}_{-0.35}\pm0.02$	$-0.33^{+0.33}_{-0.25}\pm0.08$
2.00–4.30	$17.6^{+5.5}_{-4.8}$	$0.46^{+0.14}_{-0.12}\pm0.03$	–	$-0.43^{+0.38}_{-0.40}\pm0.09$	$-0.47^{+0.50}_{-0.38}\pm0.07$
4.30–8.68	$39.1^{+7.5}_{-6.9}$	$1.00^{+0.19}_{-0.18}\pm0.06$	–	$-0.20^{+0.12}_{-0.14}\pm0.03$	$-0.19^{+0.25}_{-0.21}\pm0.08$
10.09–12.86	$22.0^{+6.2}_{-5.5}$	$0.55^{+0.16}_{-0.14}\pm0.03$	–	$-0.21^{+0.17}_{-0.15}\pm0.06$	$-0.29^{+0.37}_{-0.29}\pm0.08$
14.18–16.00	$15.6^{+4.9}_{-4.3}$	$0.38^{+0.19}_{-0.12}\pm0.02$	–	$0.04^{+0.32}_{-0.26}\pm0.05$	$-0.40^{+0.61}_{-0.69}\pm0.07$
>16.00	$40.3^{+8.2}_{-7.5}$	$0.98^{+0.20}_{-0.18}\pm0.06$	–	$0.02^{+0.11}_{-0.08}\pm0.02$	$0.11^{+0.24}_{-0.21}\pm0.08$
1.00–6.00	$52.0^{+8.7}_{-8.0}$	$1.36^{+0.23}_{-0.21}\pm0.08$	–	$-0.04^{+0.13}_{-0.16}\pm0.05$	$-0.41^{+0.25}_{-0.20}\pm0.07$

Belle: PRL 103, 171801 (2009)

Belle $B \to X_s \ell^+\ell^-$ Results

- Belle reported on updated $B \to X_s \ell^+\ell^-$ branching fraction measurements



(For M_{Xs} < 2.0 GeV/c^2

M_{l+l-} > 0.2 GeV/c^2)

Mode	Yield	BF (x 10^{-6})	Σ
$B \to X_s e^+e^-$	121.6 ± 19.3(stat.) ± 2.0(syst.)	4.56 ± 1.15(stat.) $^{+0.33}_{-0.40}$(syst.)	7.0
$B \to X_s \mu^+\mu^-$	118.5 ± 17.3(stat.) ± 1.5(syst.)	1.91 ± 1.02(stat.) $^{+0.16}_{-0.18}$(syst.)	7.9
$B \to X_s l^+l^-$	238.3 ± 26.4(stat.) ± 2.3(syst.)	3.33 ± 0.80(stat.) $^{+0.19}_{-0.24}$(syst.)	10.1

ps: BF($X_s e^+e^-$) / BF($X_s \mu^+\mu^-$) = 2.39 ± 1.41