Search for New Physics in the $B \to K^{(*)}\ell^+\ell^-$ Decays at BaBar

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Outline

- Theoretical motivation
- Experimental details
- Rate-based studies for $B \to K^{(*)} \ell^+ \ell^-$
  - Total and partial branching fractions
  - CP asymmetries and lepton flavor ratios
  - Isospin asymmetries
- Angular studies for $B \to K^* \ell^+ \ell^-$
  - Kaon longitudinal polarization
  - Forward-backward asymmetry
- Summary

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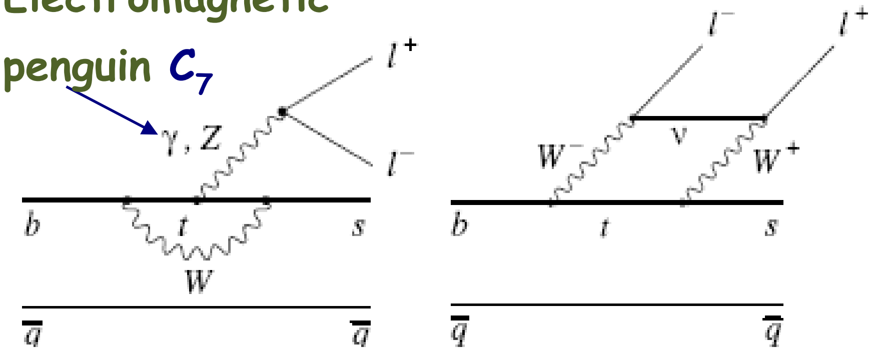
Motivation

- $b \to s \ell^+ \ell^-$ transitions are forbidden at tree level in the SM
- Rare decays with BF ~$\mathcal{O}(10^{-6})$
- Wilson coefficients C_7, C_9, C_{10} represent short-distance contributions
  - $|C_7| \approx 0.33$ constraint from $\mathcal{B}(B \to X_s \gamma)$
- New physics at electro-weak scale may produce sizable changes in Wilson coefficients
  - C_7, C_9, C_{10} can be probed through measuring rate-based and angular observables in $B \to K^{(*)} \ell^+ \ell^-$ decays

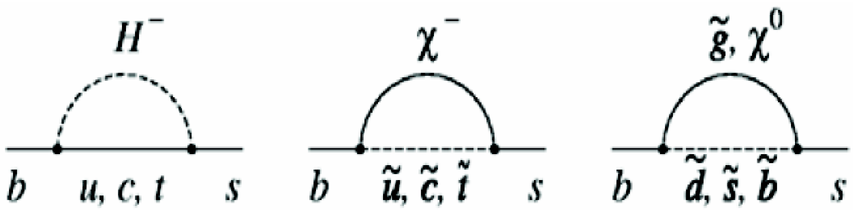
Standard Model diagrams

Electromagnetic penguin C_7



Linear combination of Z penguin and W box diagrams gives C_9, C_{10}

SUSY diagrams

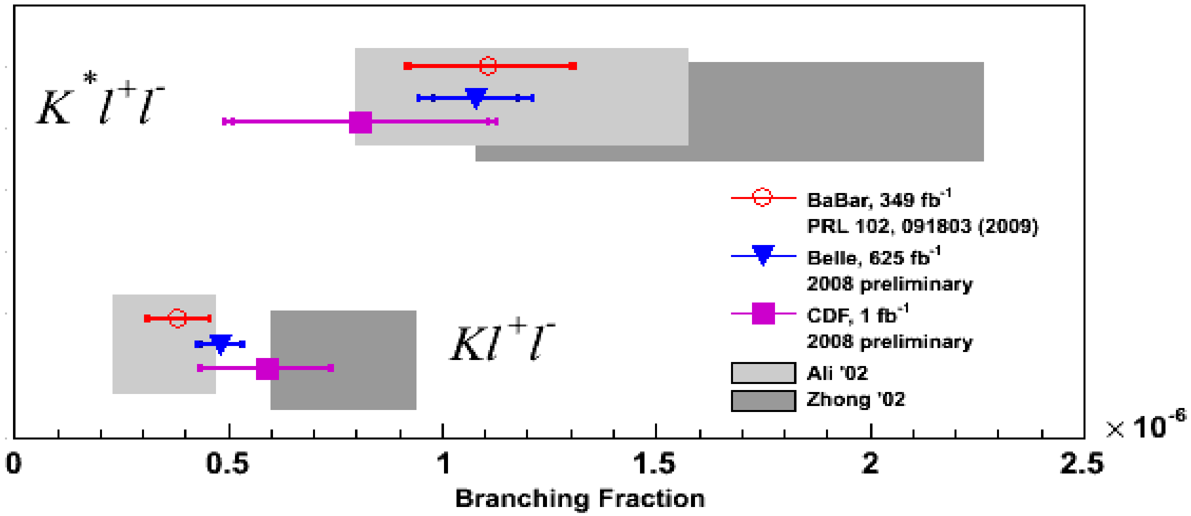


Analysis Strategy

- A sample of 384×10^6 $B\bar{B}$ events (349 fb^{-1}) collected with *BABAR* detector
- Fully reconstruct **10** exclusive final states for decays $B \to K^{(*)}\ell^+\ell^-$
  - $\ell^+\ell^-$: e^+e^-, $\mu^+\mu^-$
  - $K^{(*)}$: $K^\pm$, $K_s(\to\pi^+\pi^-)$, $K^\pm\pi^0$, $K_s(\to\pi^+\pi^-)\pi^\pm$, $K^+\pi^-$
- Define two $q^2(\equiv m_{\ell\ell}{}^2)$ bins: low and high, separated by J/ψ resonance
- Suppress random combinatorial backgrounds using artificial neural networks with event shape variables as inputs
- Backgrounds from pions mis-identified as muons are either vetoed (for $B\to D(\to K^{(*)}\pi)\pi$ events) or estimated from dedicated data samples (for $B\to K^{(*)}\pi\pi$ events)
- Define kinematic variables for signal discrimination
  - $$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}, \qquad \Delta E = E_B^* - E_{beam}^*$$
- Reject events with dilepton mass in the J/ψ and $\psi(2S)$ charmonium regions
  - Charmonium events are used to calibrate signal m_{ES} PDF shapes & validate the fit model
- 1D m_{ES} fits with optimized selections on ΔE and neural network outputs

B→K$^{(*)}$ll Branching Fractions

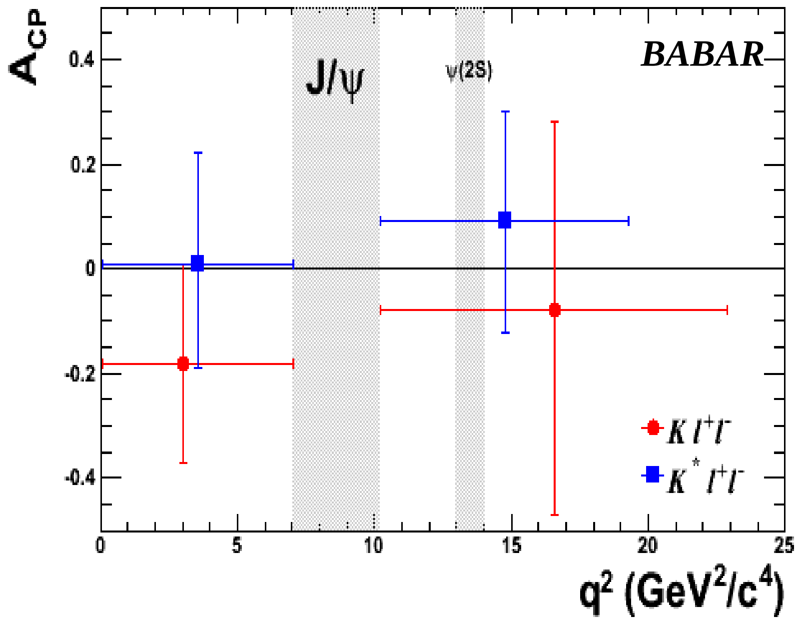
- The BaBar results for the B→K$^{(*)}$ll total branching fractions:
  - $\mathcal{B}(B\to K\ell^+\ell^-) = (3.94^{+0.73}_{-0.69}\pm 0.20)\times 10^{-7}$
  - $\mathcal{B}(B\to K^*\ell^+\ell^-) = (1.11^{+0.19}_{-0.18}\pm 0.07)\times 10^{-6}$
- The measured BFs agree well with the SM based Ali'02 predictions and Belle/CDF results



$B \to K^{(*)}ll$ CP Asymmetries

- The direct A_{CP} in $B \to K^{(*)}ll$ is expected to be very small of $\mathcal{O}(10^{-3})$ in the SM
- The BaBar A_{CP} results for all q^2:
  - $A_{cp}(B^{\pm} \to K^{\pm}\ell^{+}\ell^{-}) = -0.18^{+0.18}_{-0.18} \pm 0.01$
  - $A_{cp}(B \to K^{*}\ell^{+}\ell^{-}) = +0.01^{+0.16}_{-0.15} \pm 0.01$
  - Both are consistent with null SM expectation

$$A_{CP}^{K^{(*)}} \equiv \frac{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^{+}\ell^{-}) - \mathcal{B}(B \to K^{(*)}\ell^{+}\ell^{-})}{\mathcal{B}(\overline{B} \to \overline{K}^{(*)}\ell^{+}\ell^{-}) + \mathcal{B}(B \to K^{(*)}\ell^{+}\ell^{-})}$$

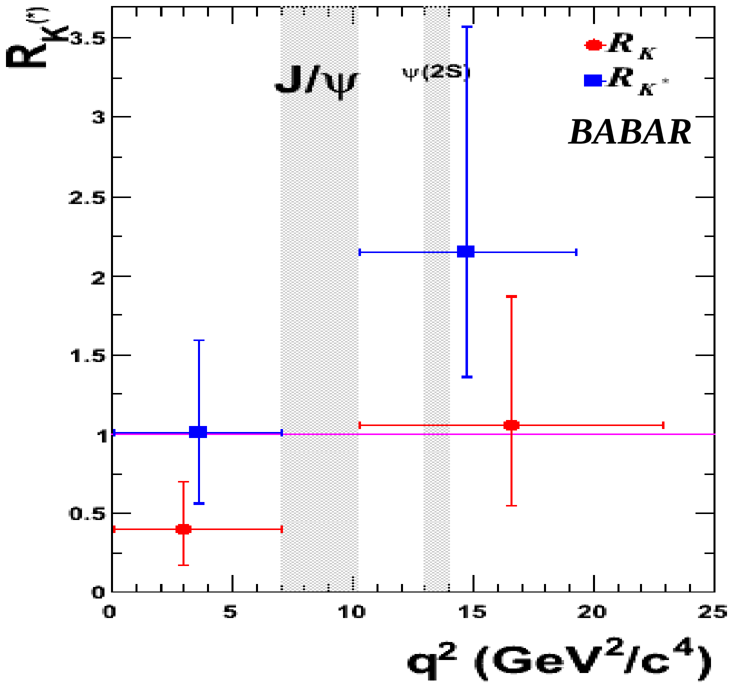


•The BaBar A_{CP} observations in the separate q^2 bins are also consistent with zero

B→K(*)ll Lepton Flavor Ratios

- In the SM, we expect $R_{K(*)} \approx 1$ for $q^2 > 0.1\ \mathrm{GeV}^2/c^4$
- $R_{K(*)}$ may get 10% enhancement from SUSY Higgs with large tanβ
- The BaBar $R_{K(*)}$ results:
  - $R_K = 0.96^{+0.44}_{-0.34} \pm 0.05,$
  - $R_{K^*} = 1.37^{+0.53}_{-0.40} \pm 0.09$
  - Both agree with SM expectations

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



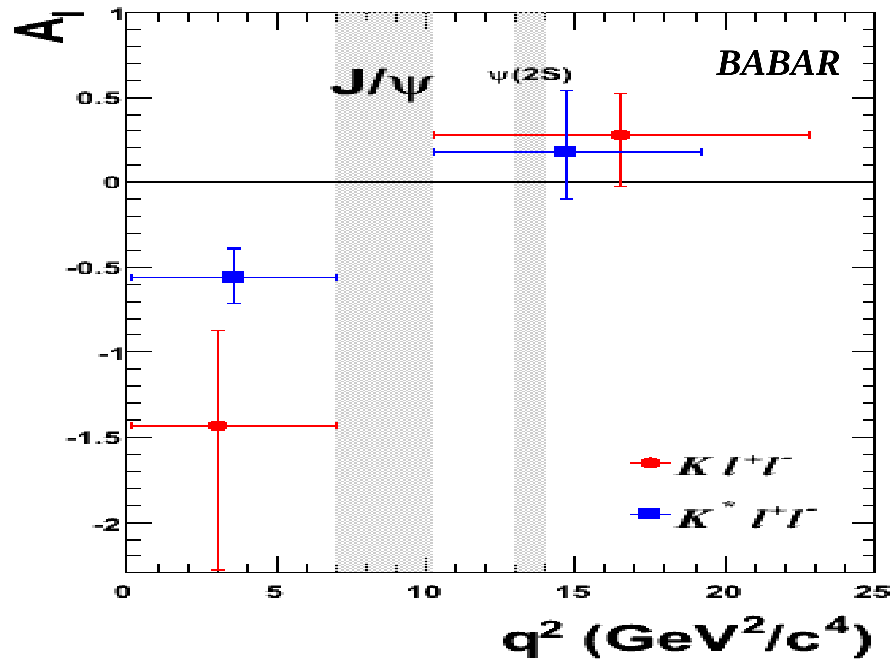
•The BaBar $R_{K(*)}$ observations in the separate q^2 bins are also consistent with unity

B→K$^{(*)}$ll Isospin Asymmetries

- In the SM, $A_I^{K(*)}$ is expected to be ~$\mathcal{O}(10^{-2})$
- The BaBar A_I results in the low q^2 show large deviation from zero:
  - $A_I^{Low}\left(Kl^+l^-\right) = -1.41^{+0.49}_{-0.69} \pm 0.04,$
  - $A_I^{Low}\left(K^*l^+l^-\right) = -0.56^{+0.17}_{-0.15} \pm 0.03$
- The results in both high q^2 and all q^2 are consistent with SM expectation of very small observation

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

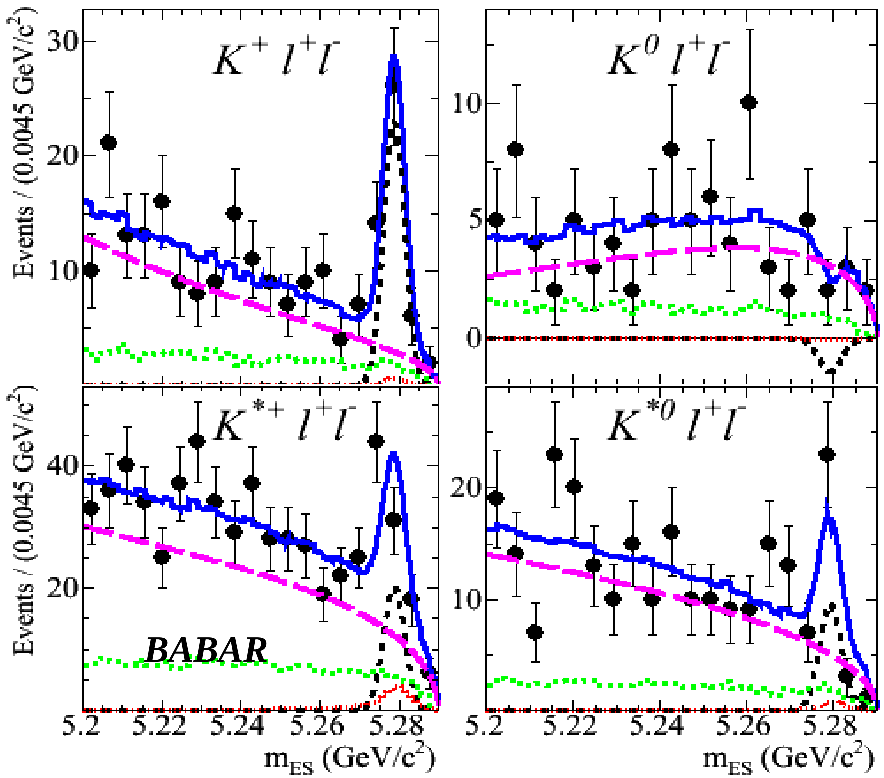
$$r = \tau_0/\tau_+ = 1/(1.07 \pm 0.01)$$

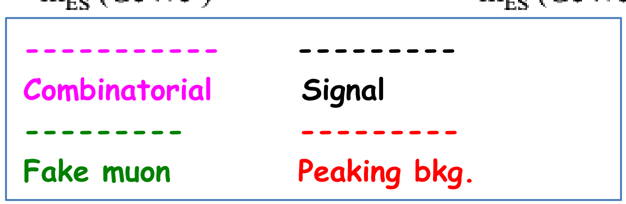


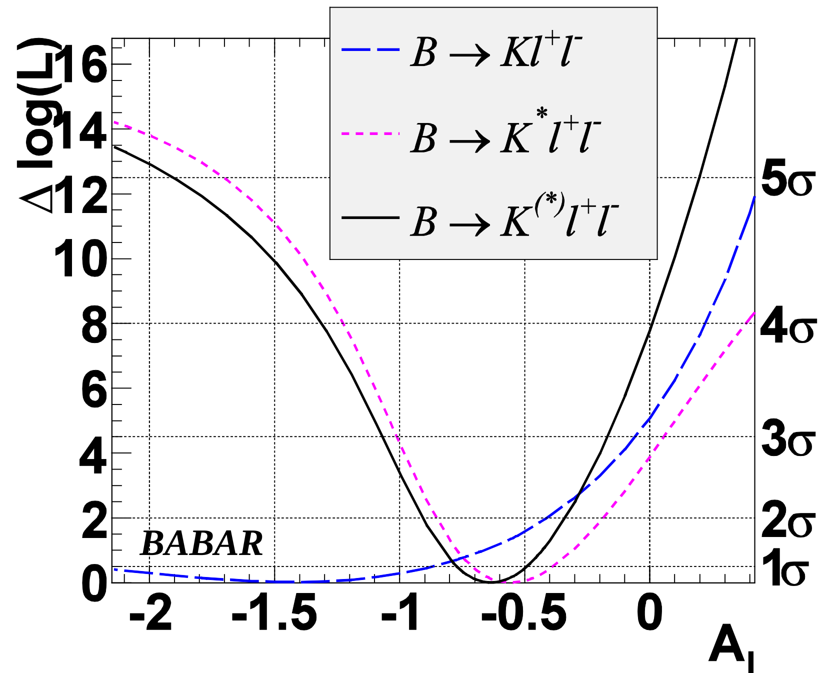
- BaBar results in all q^2:
  - $A_I^{All}(K\,l^+l^-) = -0.37^{+0.27}_{-0.34} \pm 0.04,$
  - $A_I^{All}(K^*\,l^+l^-) = -0.12^{+0.18}_{-0.16} \pm 0.04$

A_l in the Low q^2 Region

- m_{ES} fits in the low q^2:

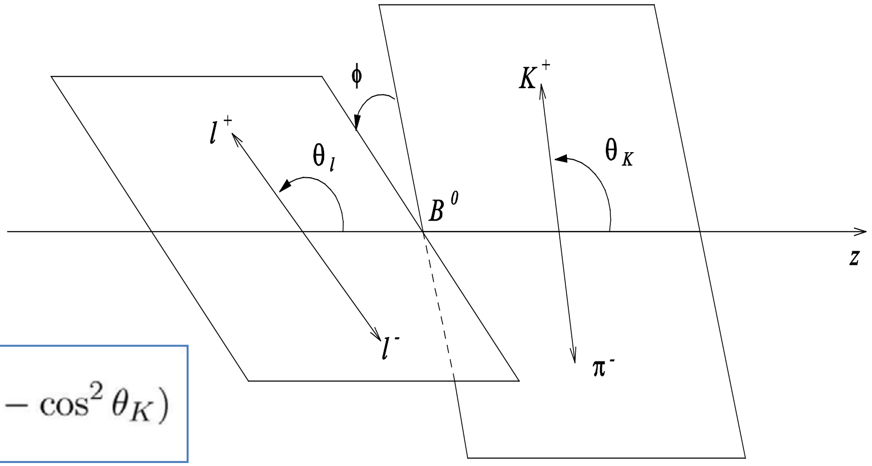






- The significance of A_l results from zero is estimated using a likelihood scan
  - The significance in Kll: **3.2σ**
  - The significance in K^*ll: **2.7σ**
  - For the combined Kll & K^*ll results, $A_l = 0$ is rejected with a significance of **3.9σ**

B→K*ll Angular Distributions

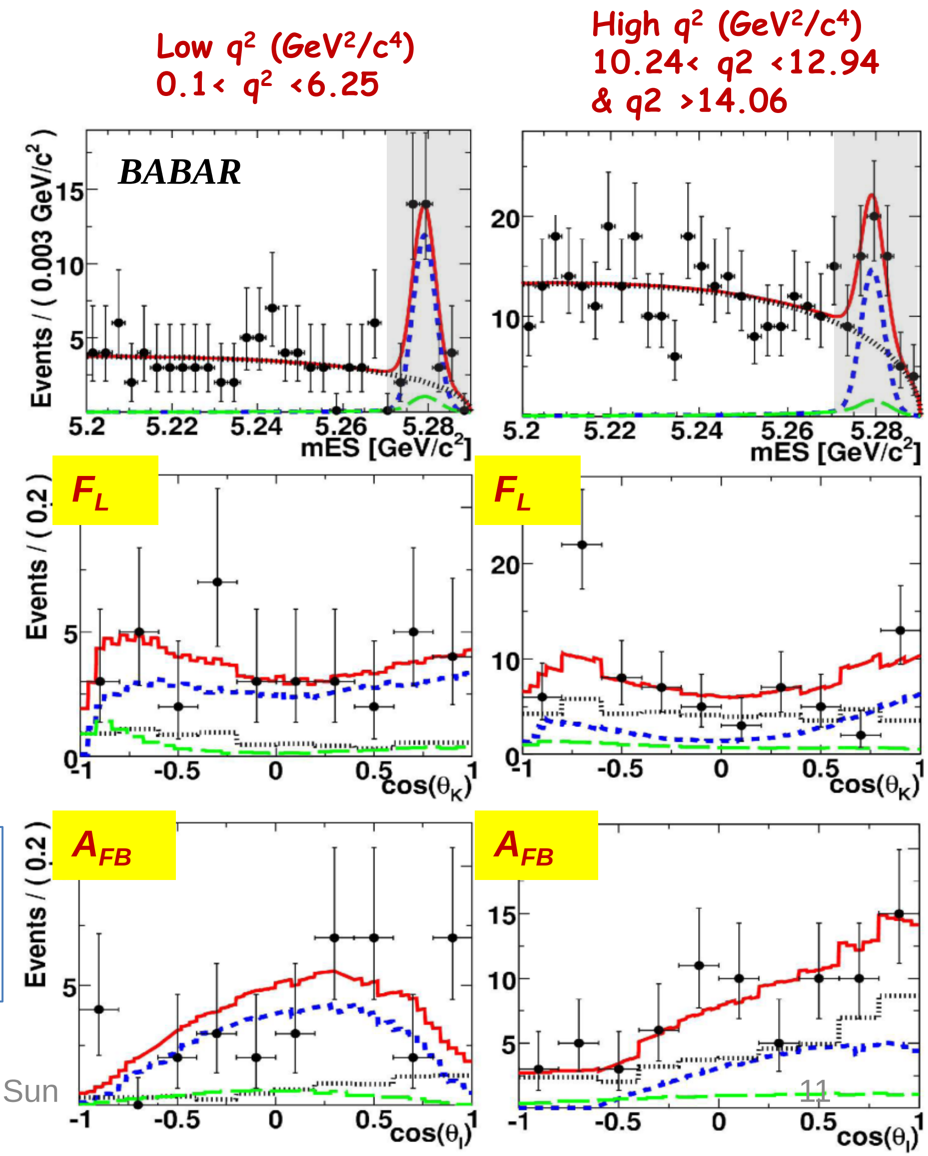


- Fraction of K* Longitudinal Polarization **$F_L(q^2)$**
  - Obtained from distribution of angle **θ_K** between the K and B in the K* rest frame
    - $$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_K} = \frac{3}{2}F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K)$$
- Lepton forward-backward asymmetry **$A_{FB}(q^2)$**
  - Obtained from distribution of angle **θ_ℓ** between the $\ell^+(\ell^-)$ and B($\overline{B}$) in the $\ell^+\ell^-$ rest frame
    - $$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_\ell} = \frac{3}{4}F_L(1-\cos^2\theta_\ell) + \frac{3}{8}(1-F_L)(1+\cos^2\theta_\ell) + A_{FB}\cos\theta_\ell$$
- Both **$F_L(q^2)$** and **$A_{FB}(q^2)$** are well predicted in the SM. New physics may change magnitude and q^2-dependence

$B \to K^{*}ll$ Angular Fits

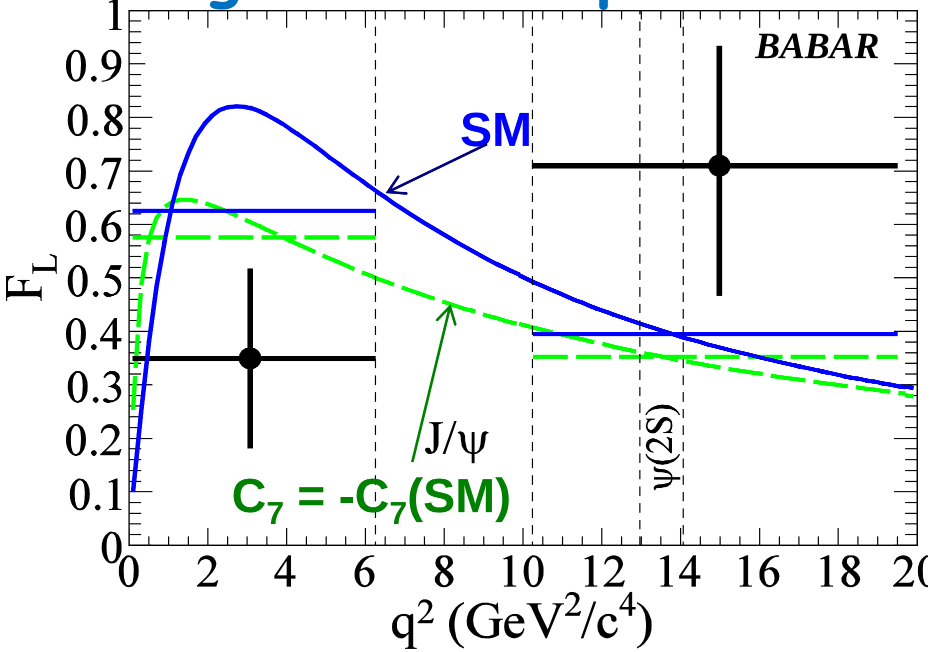
- Three-step fit procedure in the low and high q^2:
  - Fit 1: m_{ES} fit to extract signal & combinatorial background yields
  - Fit 2: With yields fixed, $\cos\theta_K$ fit in the m_{ES} > 5.27 GeV region to extract $\mathbf{F_L}$
  - Fit 3: With yields and F_L fixed, $\cos\theta_\ell$ fit in the m_{ES} > 5.27 GeV region to extract $\mathbf{A_{FB}}$

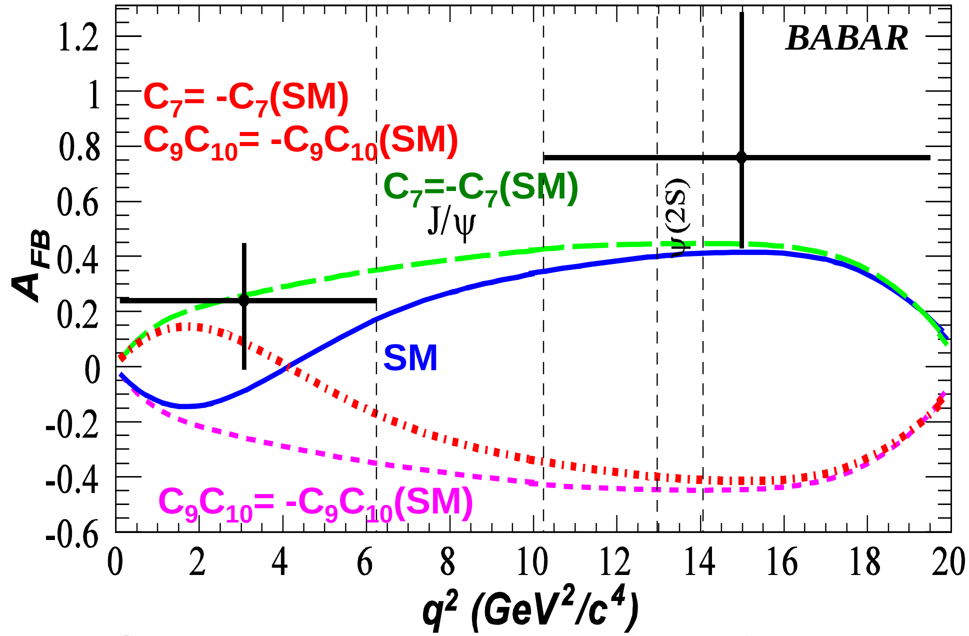
------ Signal
------ Peaking background
------ Combinatorial background

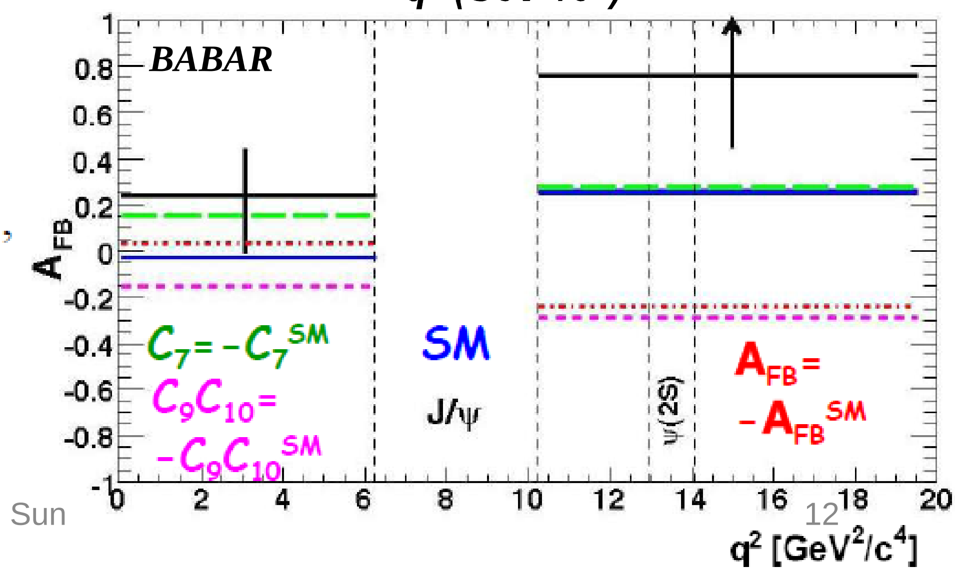


F_L/A_{FB} Results

Longitudinal K* polarization **Forward-backward Asymmetry**







- The BaBar results:
  - Low q^2: $F_L = 0.35 \pm 0.16 \pm 0.04,$

    $A_{FB} = 0.24^{+0.18}_{-0.23} \pm 0.05$
  - High q^2: $F_L = 0.71^{+0.20}_{-0.22} \pm 0.04,$

    $A_{FB} = 0.76^{+0.52}_{-0.32} \pm 0.07$

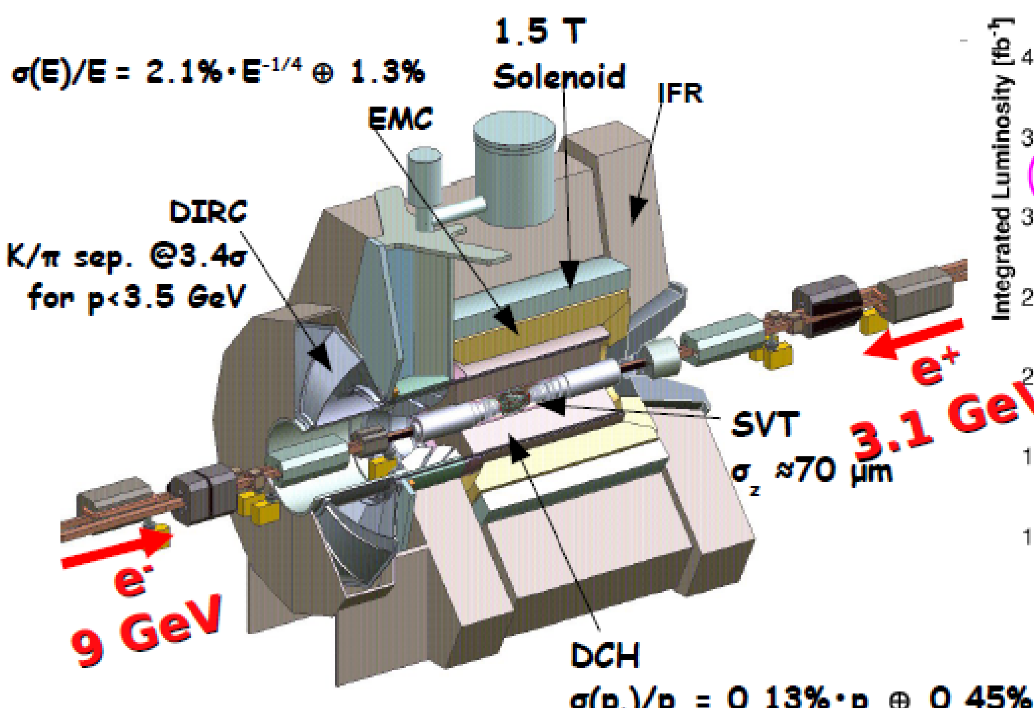
Summary

- The BF results for combined Kll and K*ll modes in all q^2 and low q^2 agree with SM predictions, though statistical errors are rather large
- No significant direct CP asymmetry is observed in $B \to K\ell^+\ell^-$ and $B \to K^*\ell^+\ell^-$ decays
- Lepton flavor ratios are consistent with lepton universality
- The isospin asymmetries for all q^2 and in the high q^2 for Kll and K*ll modes are consistent with null expectation
- The isospin asymmetries in low q^2 differ significantly from zero (~3.9σ for Kll and K*ll combined)
  - This is unexpected in the SM
- The A_{FB} and F_L results are consistent with SM, though the A_{FB} agreement in the high q^2 is not as good as in the low q^2
  - The flipped-sign C_9C_{10} scenario is disfavored

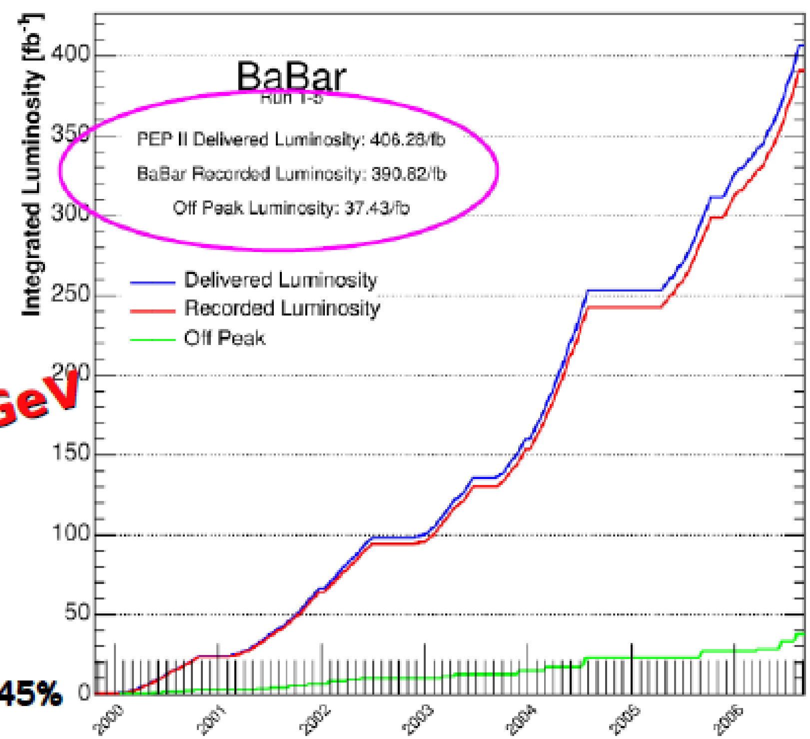
Backup Slides

BaBar Experiment

- The experimental data is collected with the BABAR detector at the PEPII asymmetric e^+e^- collider located at SLAC
- The Runs 1-5 dataset comprises ~**384**M BB pairs, corresponding to an integrated luminosity of **349** fb^{-1} collected on the $\Upsilon(4S)$ resonance

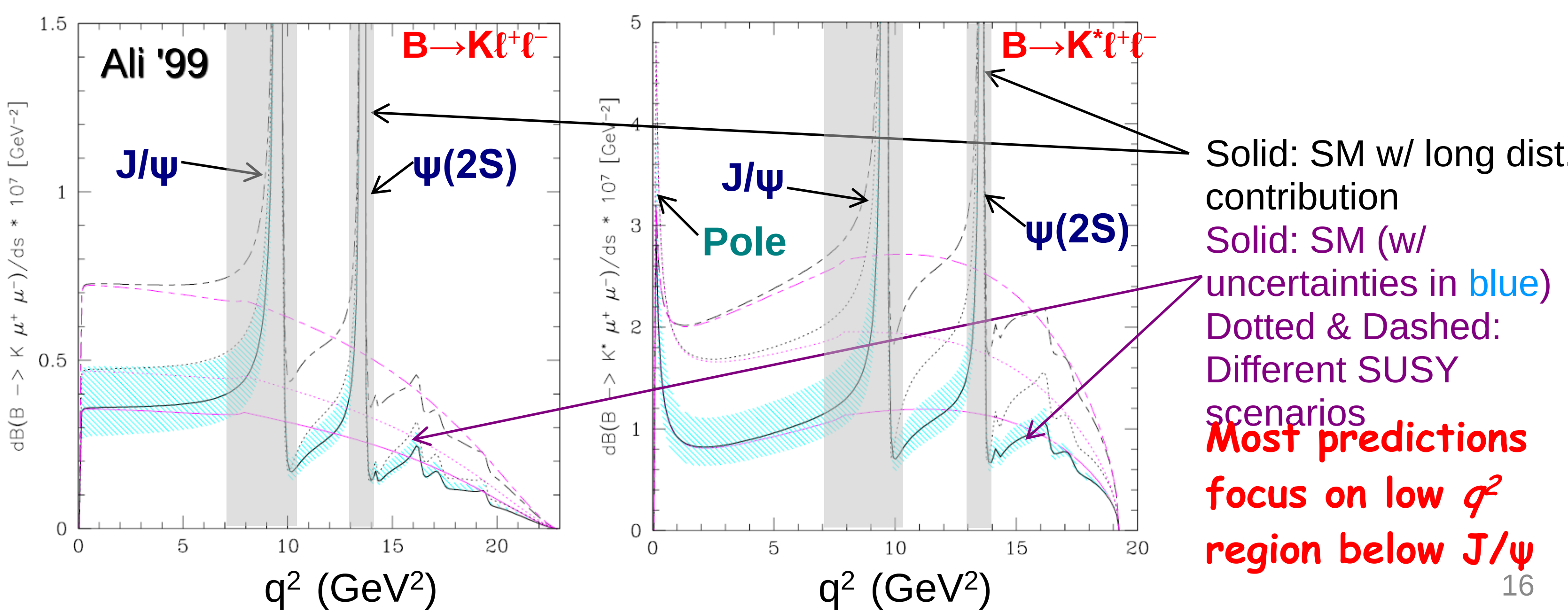


Layout of the BABAR Detector



$K^{(*)}ll$ Partial BF predictions

- The dilepton mass ($q^2 \equiv m_{ll}^2$) distributions are predicted in the SM, along with a few new physics scenarios
- Long-distance contribution from charmonium states lead to greatly enhanced rates in the resonance regions
  - Need to be vetoed in the analyses
  - Provide very important control samples with well measured observables



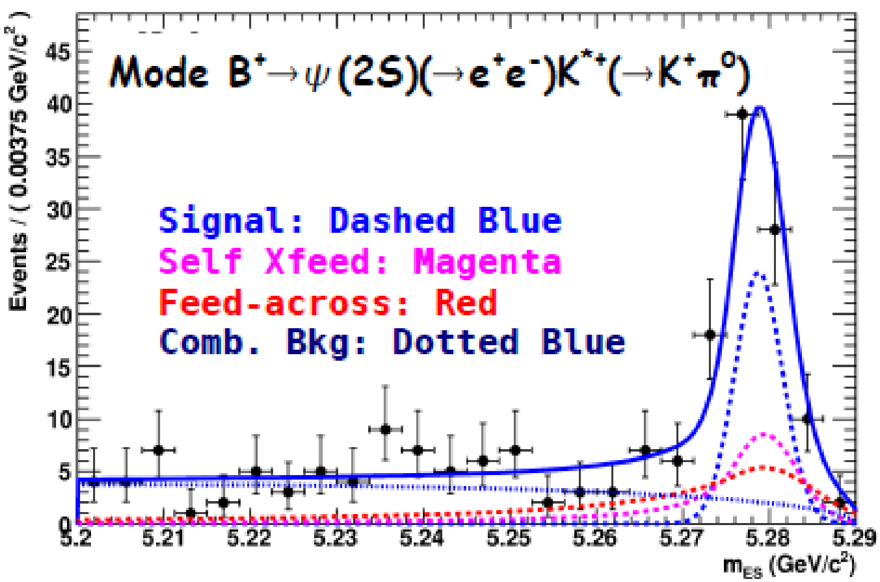
Fit Model

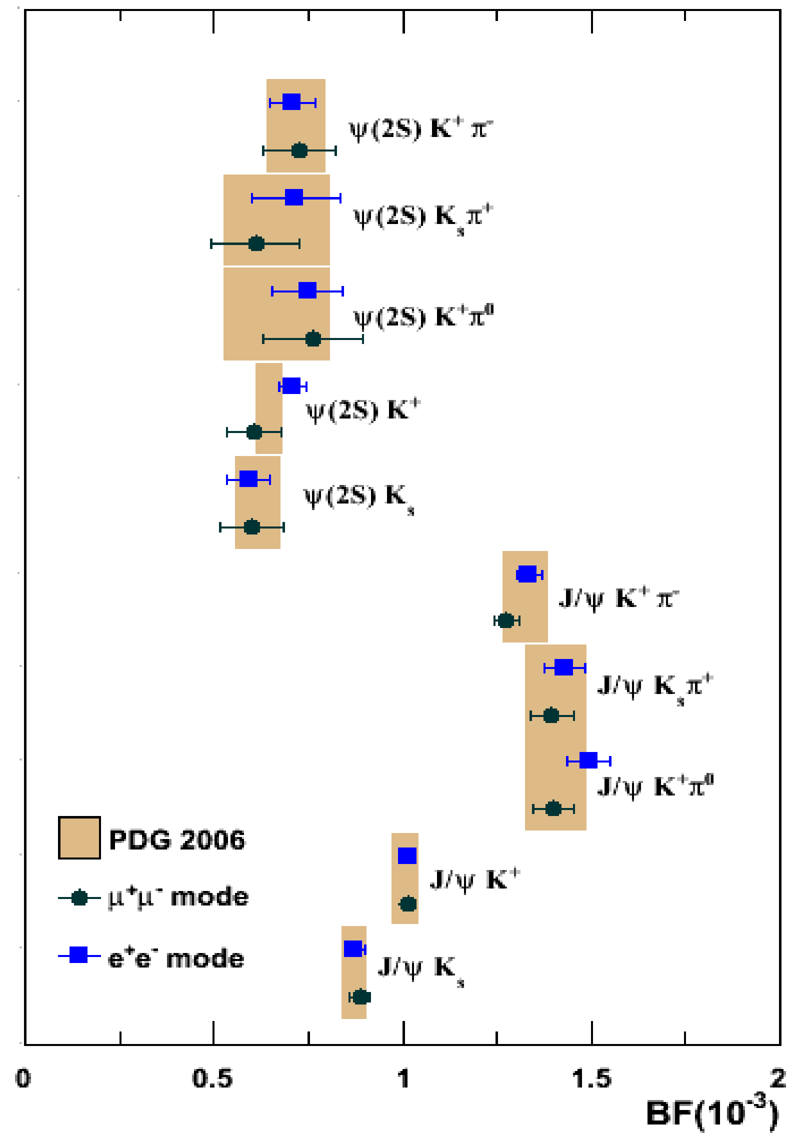
- Unbinned maximum likelihood m_{ES} fits with a sum of the following PDFs:
  - True signal: Gaussian, shape fixed from J/ψ fits, yield floated
  - Combinatorial: ARGUS, slope & yield floated, endpoint m0 fixed at 5.290 GeV/c2
  - Self-crossfeed & Feed-across: Revised Gaussian shape with smeared low side tail, shape & ratios fixed from fits to normalized signal MC samples Validated with charmonium samples
  - Charmonium leakage: Fixed signal-like shape, yield fixed from normalized MC samples
    - 9% of expected signals as the most extreme case
  - Hadronic (fake muon) events: Histogram PDFs with both normalization and shape fixed
  - Peaking bkgs (Photon conversions & Dalitz decays): Yield & shape parameters fixed from fits to normalized MC samples
    - Sum up to <1% of expected signal yields

Charmonium Validation

- We test our fit methodology using J/ψ and ψ(2s) samples reconstructed in all 10 decay channels

  - All the measurements agree well with world averages





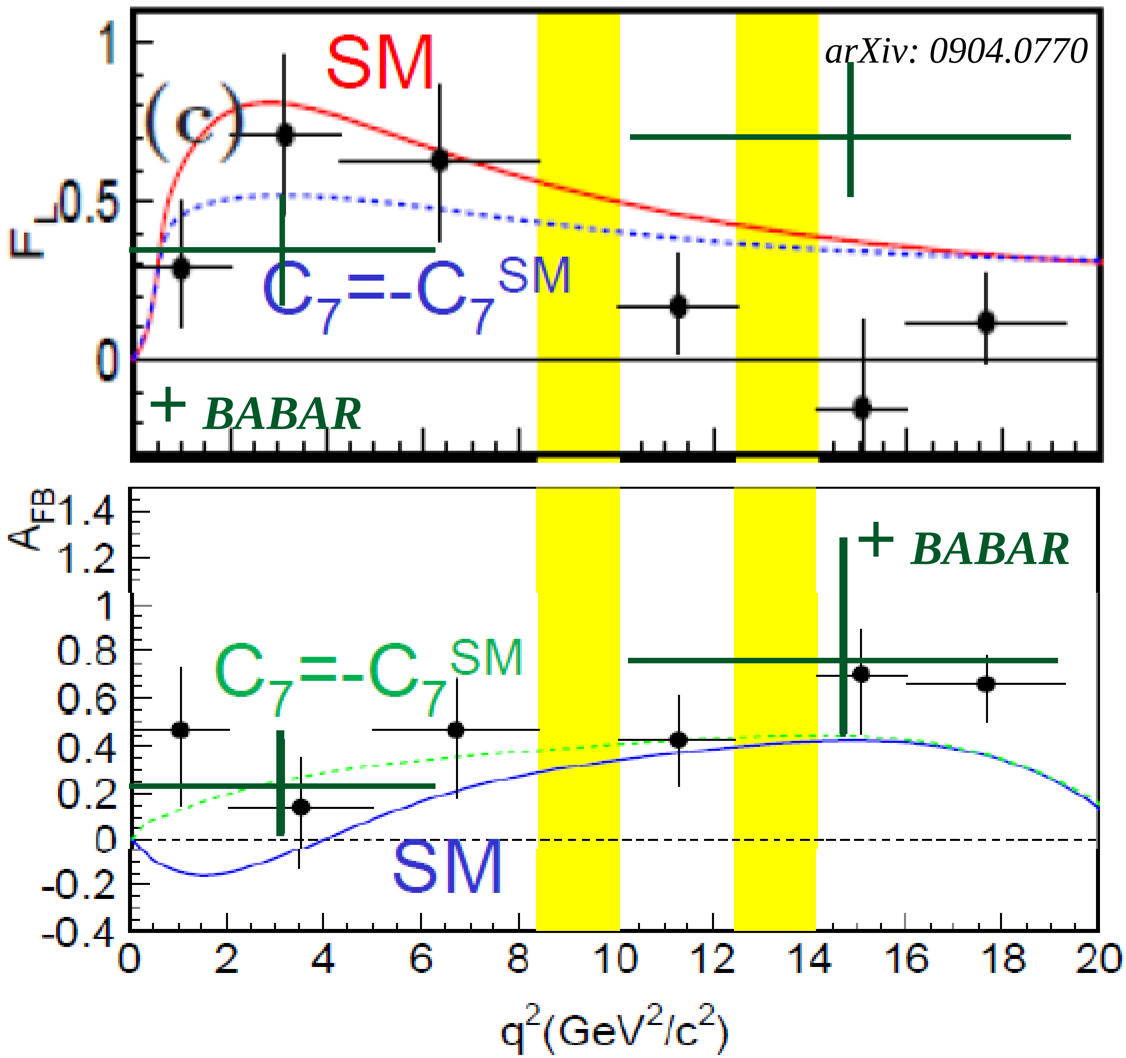
$K^{(*)}ll$ BFs By Mode & q^2 bin

- 90% condence level upper limits are provided for measurements with < 4σ statistical significance

Mode	combined q^2 (10^{-6})	90% UL	low q^2 (10^{-6})	90% UL	high q^2 (10^{-6})	90% UL
$K^0\mu^+\mu^-$	$0.49^{+0.29}_{-0.25} \pm 0.03$ (2.2σ)	0.99	$0.01^{+0.15}_{-0.13} \pm 0.01$ (0.0σ)	0.31	$0.25^{+0.16}_{-0.14} \pm 0.02$ (1.9σ)	0.53
$K^+\mu^+\mu^-$	$0.41^{+0.16}_{-0.15} \pm 0.02$ (3.0σ)	0.62	$0.123^{+0.082}_{-0.071} \pm 0.007$ (1.8σ)	0.25	$0.116^{+0.079}_{-0.072} \pm 0.010$ (1.7σ)	0.24
$K^0e^+e^-$	$0.08^{+0.15}_{-0.12} \pm 0.01$ (0.6σ)	0.36	$-0.049^{+0.061}_{-0.049} \pm 0.004$ (0.0σ)	0.10	$0.177^{+0.118}_{-0.091} \pm 0.011$ (2.3σ)	0.38
$K^+e^+e^-$	$0.51^{+0.12}_{-0.11} \pm 0.02$ (5.8σ)	–	$0.308^{+0.070}_{-0.062} \pm 0.013$ (6.7σ)	–	$0.125^{+0.062}_{-0.055} \pm 0.006$ (2.5σ)	0.21
$K^{*+}\mu^+\mu^-$	$1.46^{+0.79}_{-0.75} \pm 0.12$ (2.0σ)	2.55	$0.75^{+0.49}_{-0.45} \pm 0.07$ (1.7σ)	1.48	$0.78^{+0.43}_{-0.40} \pm 0.06$ (2.1σ)	1.36
$K^{*0}\mu^+\mu^-$	$1.35^{+0.40}_{-0.37} \pm 0.10$ (4.1σ)	–	$0.41^{+0.24}_{-0.21} \pm 0.04$ (2.2σ)	0.83	$0.62^{+0.21}_{-0.19} \pm 0.05$ (3.8σ)	0.97
$K^{*+}e^+e^-$	$1.38^{+0.47}_{-0.42} \pm 0.08$ (3.7σ)	1.97	$1.06^{+0.31}_{-0.28} \pm 0.07$ (4.7σ)	–	$0.19^{+0.23}_{-0.21} \pm 0.01$ (0.9σ)	0.53
$K^{*0}e^+e^-$	$0.86^{+0.26}_{-0.24} \pm 0.05$ (4.2σ)	–	$0.20^{+0.12}_{-0.11} \pm 0.01$ (2.1σ)	0.42	$0.35^{+0.15}_{-0.13} \pm 0.02$ (3.0σ)	0.60

From supplemental files for paper PRL 102, 091803 (2009)

Bell Angular Results



Belle results with 658 M BB pairs