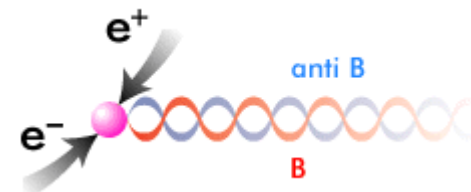


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Measurement of Angular Asymmetries in $B \rightarrow K^{(*)} \ell^+ \ell^-$ at BaBar

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(For the rest of the analysis group)

University of Bergen

The 20th Nordic Particle Physics Meeting

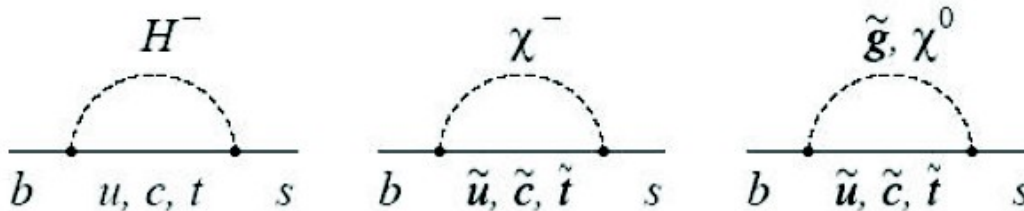
Spåtind, Norway

Jan 3, 2008



Motivation

- $B \rightarrow X_s \ell \ell$ decays are flavor-changing neutral current (FCNC) transitions
- In the SM, these transitions are forbidden at tree level
- Rare decay rates of $O(10^{-6})$
- Wilson coefficients $C_7^{eff}, C_9^{eff}, C_{10}$ represent different short-distance contributions and are sensitive to New Physics
- Possibly New Physics diagrams:

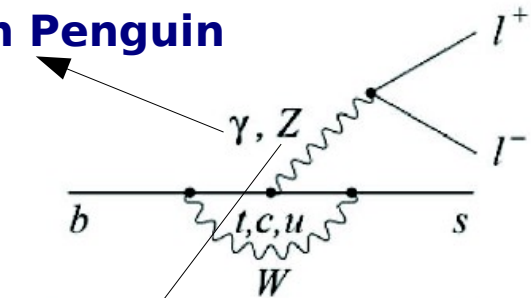


- Study on exclusive modes $B \rightarrow K \ell \ell$ and $B \rightarrow K^* \ell \ell$

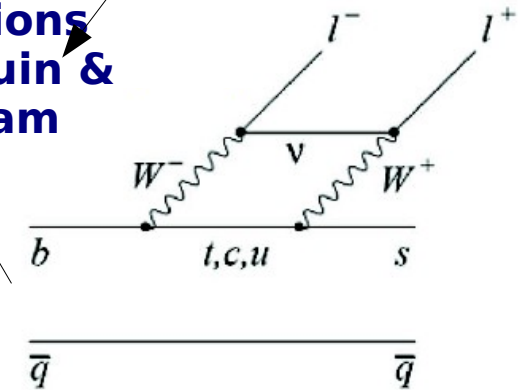
Operator Product Expansion of B decay Hamilton:

$$H_{eff} \propto \sum C_i O_i$$

C_7 : Photon Penguin

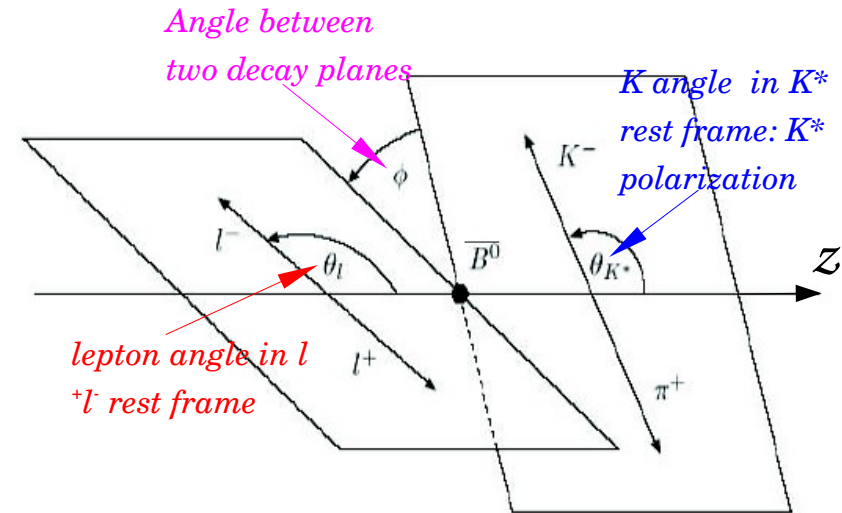


C_9, C_{10} : Linear Combinations of Z penguin & box diagram

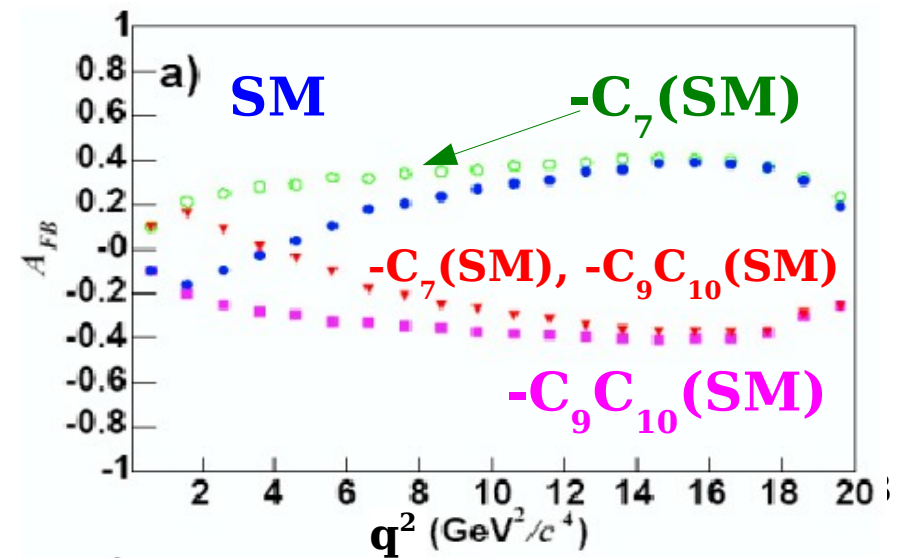
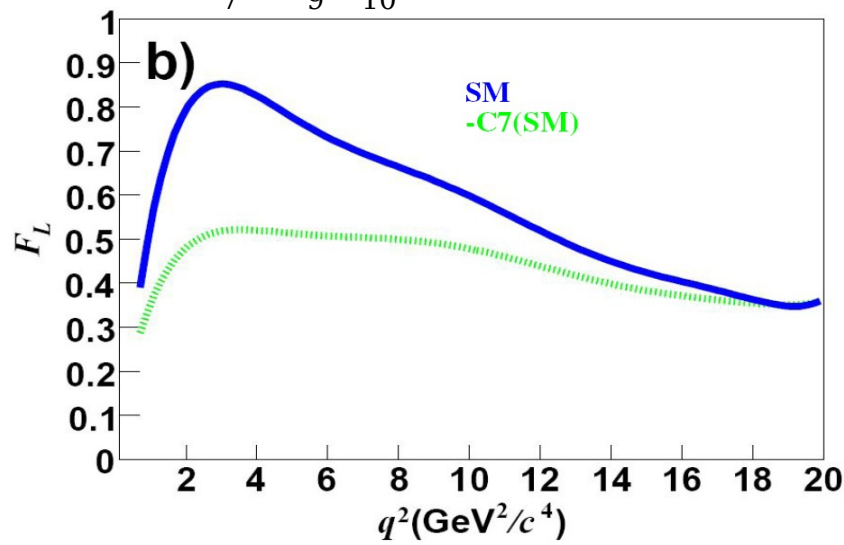


Measurements of $B \rightarrow K^{(*)} \ell \ell$

- Angular asymmetries in the $B \rightarrow K^* \ell^+ \ell^-$ decay:
 - Fraction of Longitudinal Polarization $F_L(\mathbf{q}^2)$ of K^* ($q^2 = m_{\ell^+ \ell^-}^2$)
 - Forward-Backward Asymmetry $A_{FB}(\mathbf{q}^2)$ of $\ell^+ \ell^-$
 - Both well predicted in SM and can be altered dramatically by non-SM physics due to their sensitivity to the signs of C_7, C_9, C_{10}

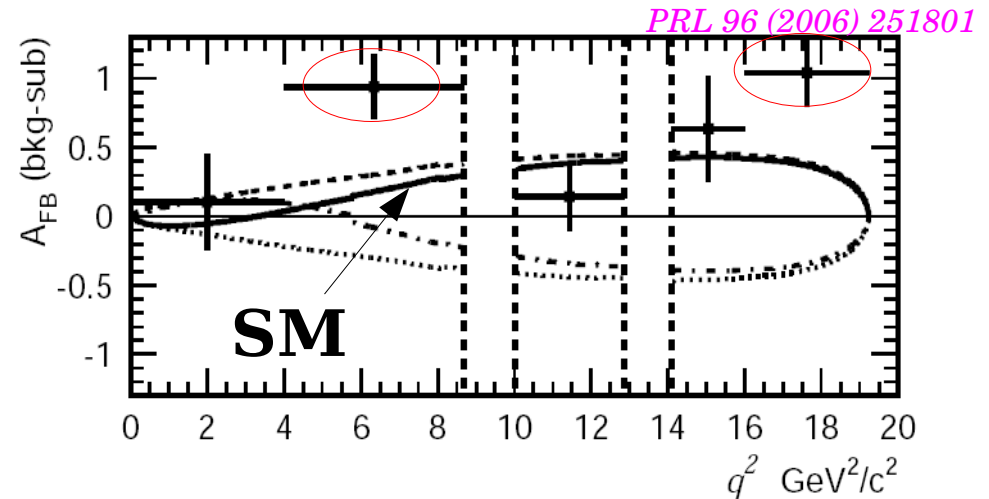
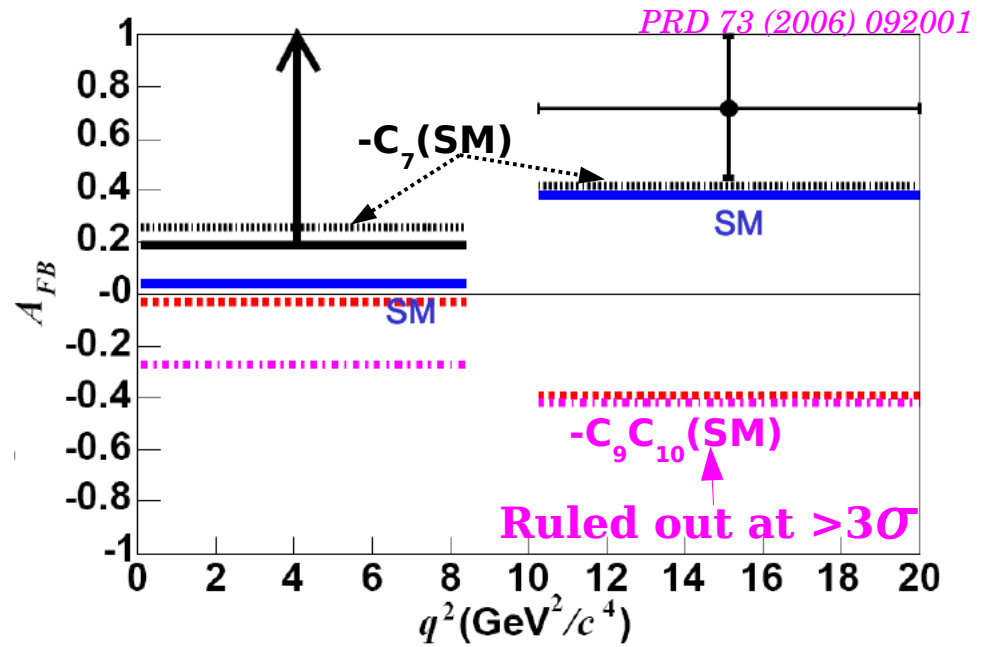


B decay planes, A_{FB} & F_L can be extracted from fits to lepton & K angular distributions



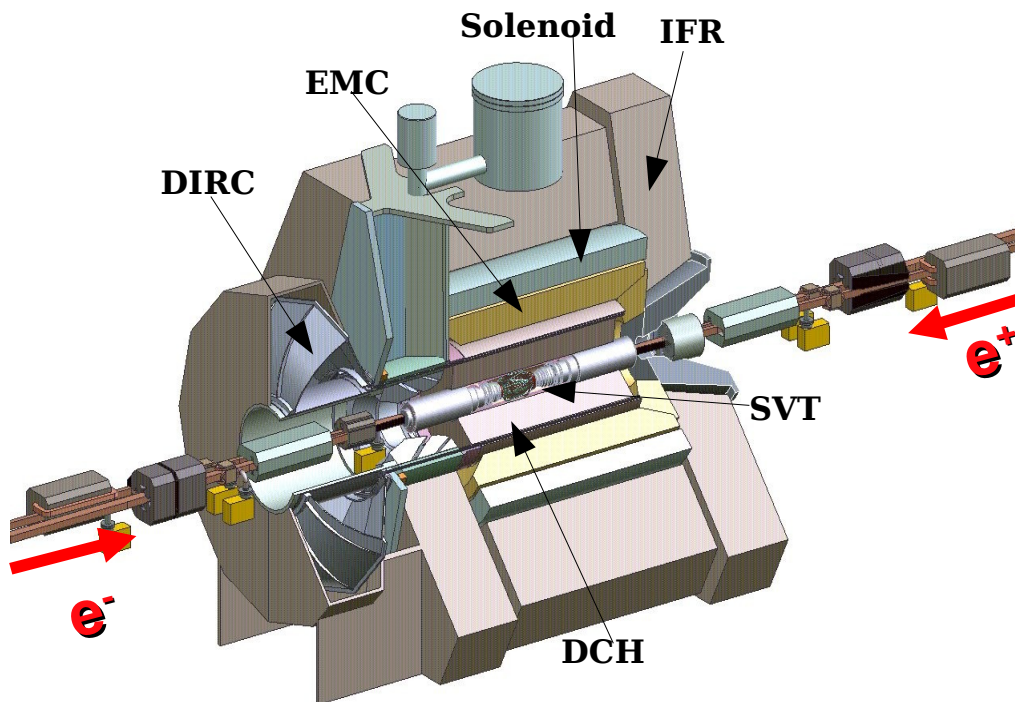
Previous A_{FB} Measurements

- The previous BaBar 210fb^{-1} measurement of A_{FB}
 - In the low q^2 region, SM is excluded at 98% CL (2.05σ)
- Belle collaboration presented consistent A_{FB} results
 - Large positive asymmetries

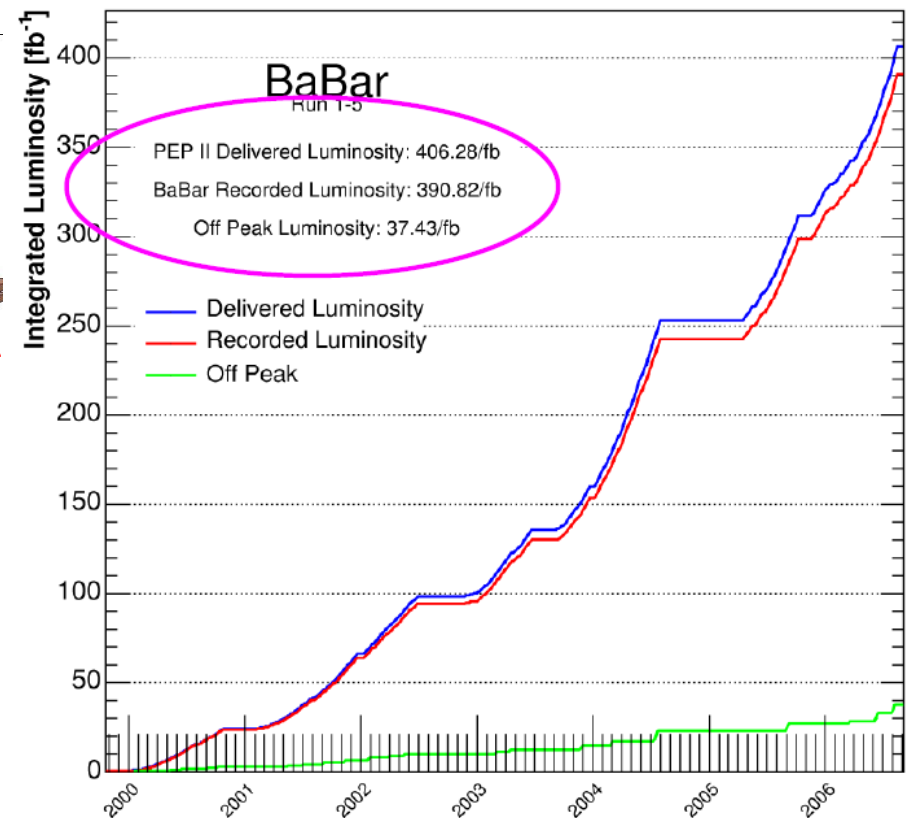


Experimental Details

- The experimental data is collected with the BaBar detector at the PEP-II asymmetric e^+e^- collider located at the Stanford Linear Accelerator Center
- The Run1-5 dataset comprises $\sim 384\text{M } B\bar{B}$ pairs, corresponding to an integrated luminosity of 350 fb^{-1} collected on the $\Upsilon(4S)$ resonance



Layout of the BaBar Detector

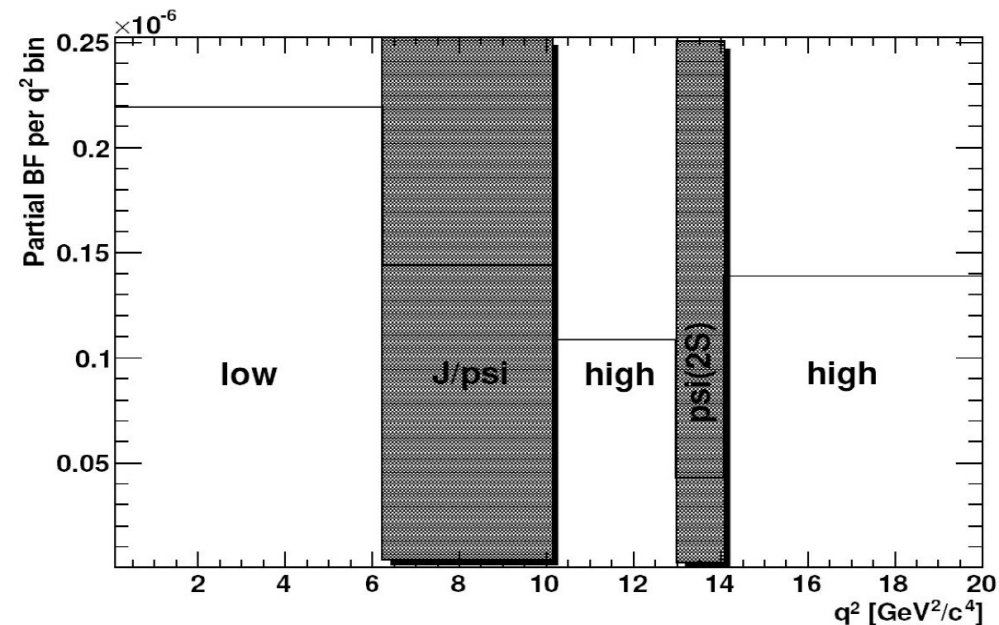
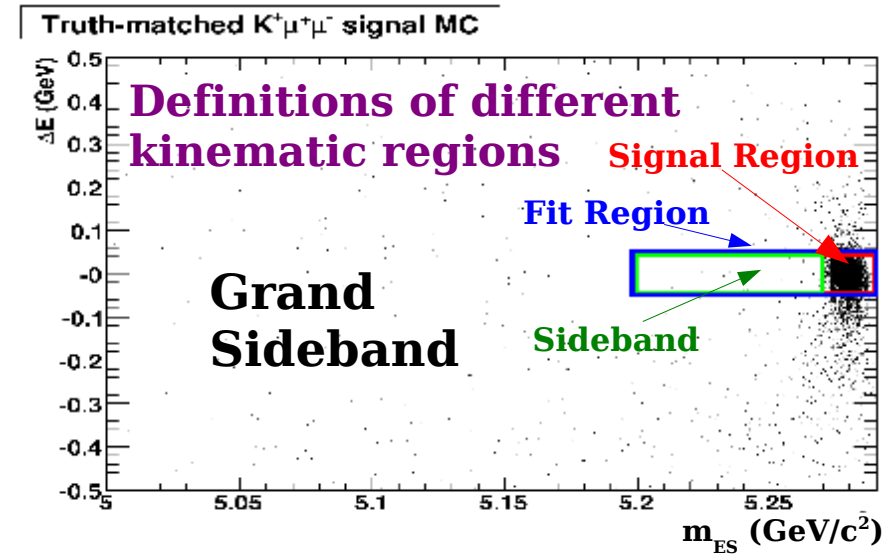


Analysis Outline

- Reconstruct $B \rightarrow K^* \ell \ell$ decay in 6 final states (modes)
 - $K^* = (K_s \pi^+ / K^+ \pi^0 / K^+ \pi^-)$, $\ell \ell = (e^+ e^- / \mu^+ \mu^-)$
- Train multivariate Neural Networks (NNs) mode by mode to suppress combinatorial backgrounds
- Veto charmonium decays ($B \rightarrow (c \bar{c}) K^*$) by cutting out corresponding di-lepton mass regions
- Estimate peaking backgrounds of various origins
- Measure both F_L & A_{FB} in bins of q^2 with unbinned Maximum Likelihood fits
- Use charmonium decays and $B^+ \rightarrow K^+ \ell^+ \ell^-$ as cross-checks in the expectation of null results of A_{FB}

Event Selection

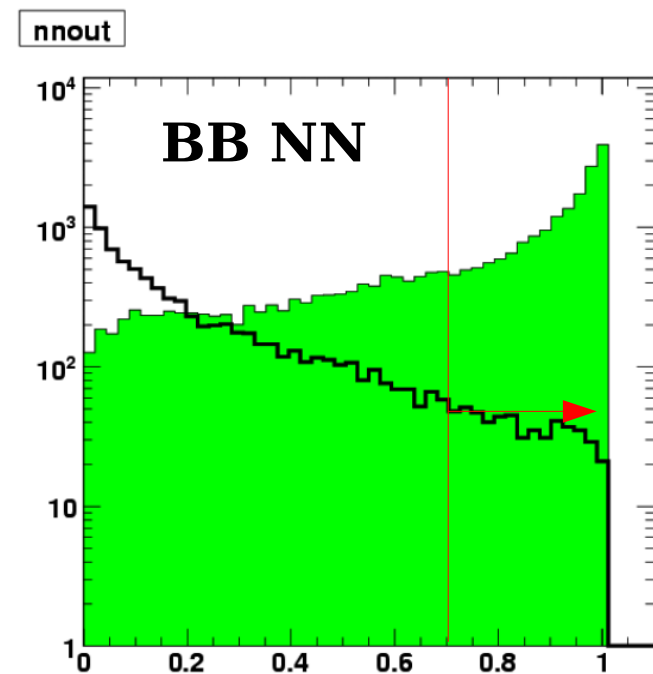
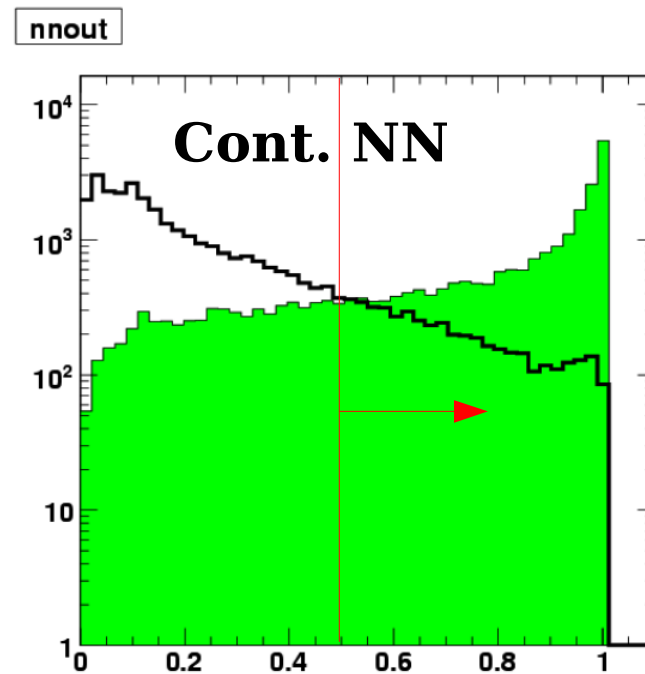
- Kinematic quantities:
 - $m_{ES} = \sqrt{E_{\text{beam}}^{*2} - p_B^{*2}}$, $\Delta E = E_B^* - E_{\text{beam}}^*$
 - $0.82\text{GeV}/c^2 < m_{K\pi} < 0.97\text{GeV}/c^2$ for K^* selection
- Tight selection on particle identification to suppress fake signal contributions
- Define 2 disjoint q^2 regions (low/high), separated by J/ψ resonance



Neutral Networks

- In each of two q^2 bins of each reconstruction mode:
 - Two independent NNs are trained respectively to suppress backgrounds from continuum and $B\bar{B}$ events using signal MC samples and corresponding simulated backgrounds
 - A set of 13 input variables for NNs
 - NN cuts are optimized to maximize $n_{\text{sig}} / \sqrt{n_{\text{sig}} + n_{\text{bkg}}}$, n_{sig} and n_{bkg} have all been normalized to the luminosity

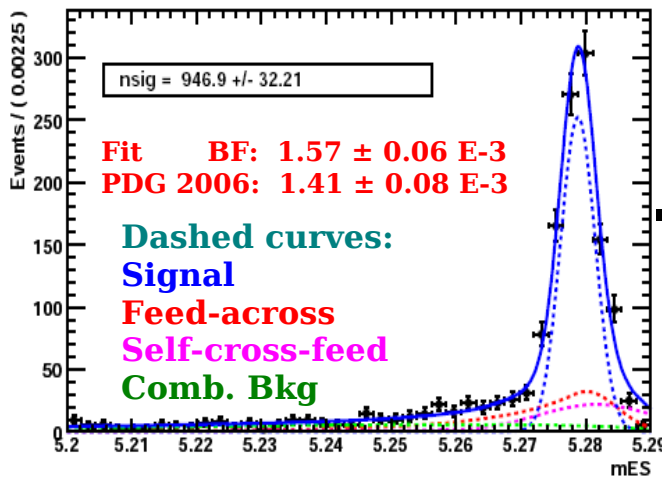
$B^+ \rightarrow K^+ \pi^0 e^+ e^-$
mode, low q^2
Signal (Green)
Bkg. (Black)



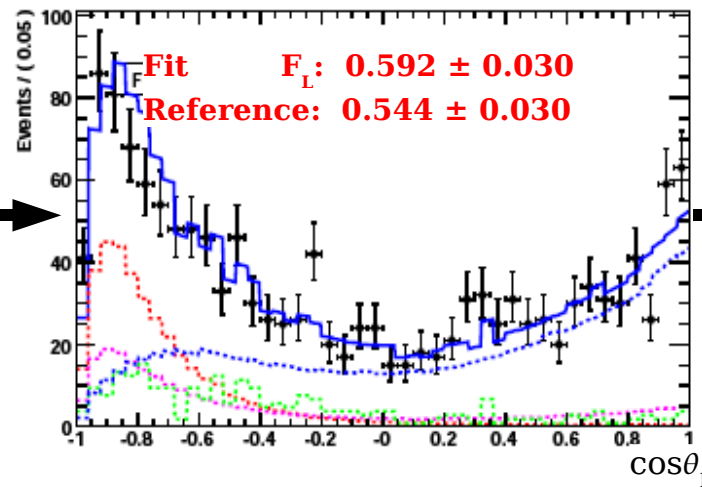
Optimized cuts are marked with red lines

Fit Strategy

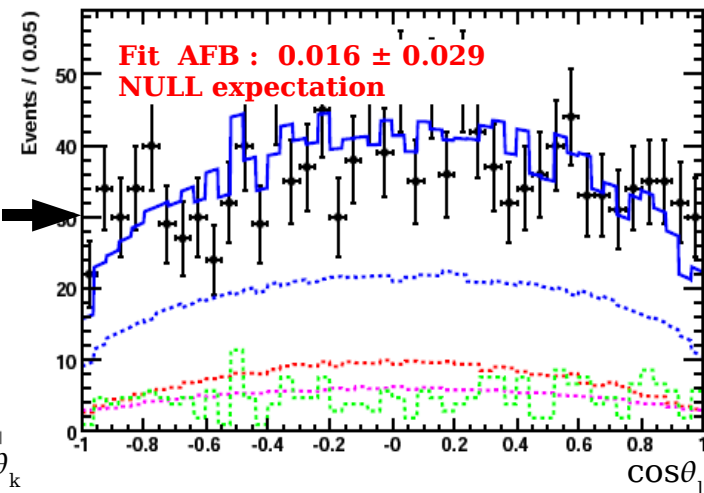
- Combined fits for 6 K^*l decay modes in each q^2 bin
- Hierarchical fits in m_{ES} , $\cos\theta_k$, $\cos\theta_l$:
 - **Fit 1:** Fit m_{ES} distribution to extract the signal & background yields
 - **Fit 2:** Fix signal & background yields and fit $\cos\theta_k$ spectrum to extract F_L
 - **Fit 3:** Fix all the rest variables and fit $\cos\theta_l$ spectrum to extract A_{FB}
- Validation using $B \rightarrow J/\psi K^*$ data samples:



J/ψ m_{ES} fit, $B^+ \rightarrow K^+\pi^0 e^+ e^-$



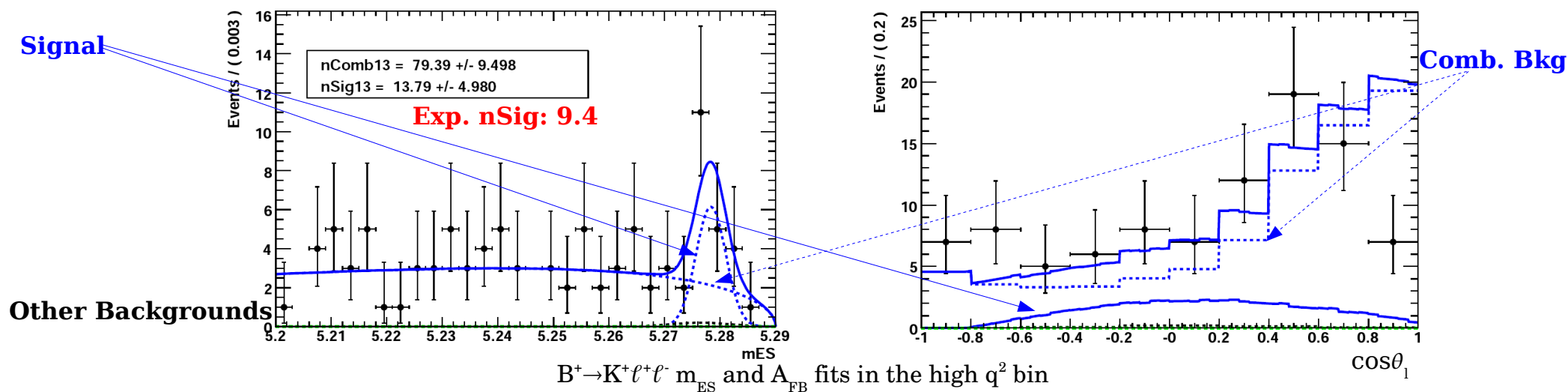
J/ψ F_L fit, $B^+ \rightarrow K^+\pi^0 e^+ e^-$



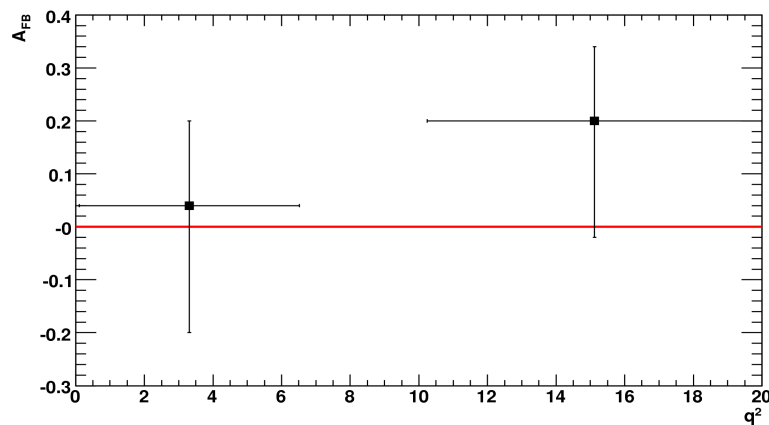
J/ψ A_{FB} fit, $B^+ \rightarrow K^+\pi^0 e^+ e^-$

Unblinded Analysis

- Proceed for $B \rightarrow K^* \ell \ell$ fits after we make sure that for $B^+ \rightarrow K^+ \ell \ell$ decay
 - Signal yields from m_{ES} fits and A_{FB} fit results from each s bins reasonably match our expectations



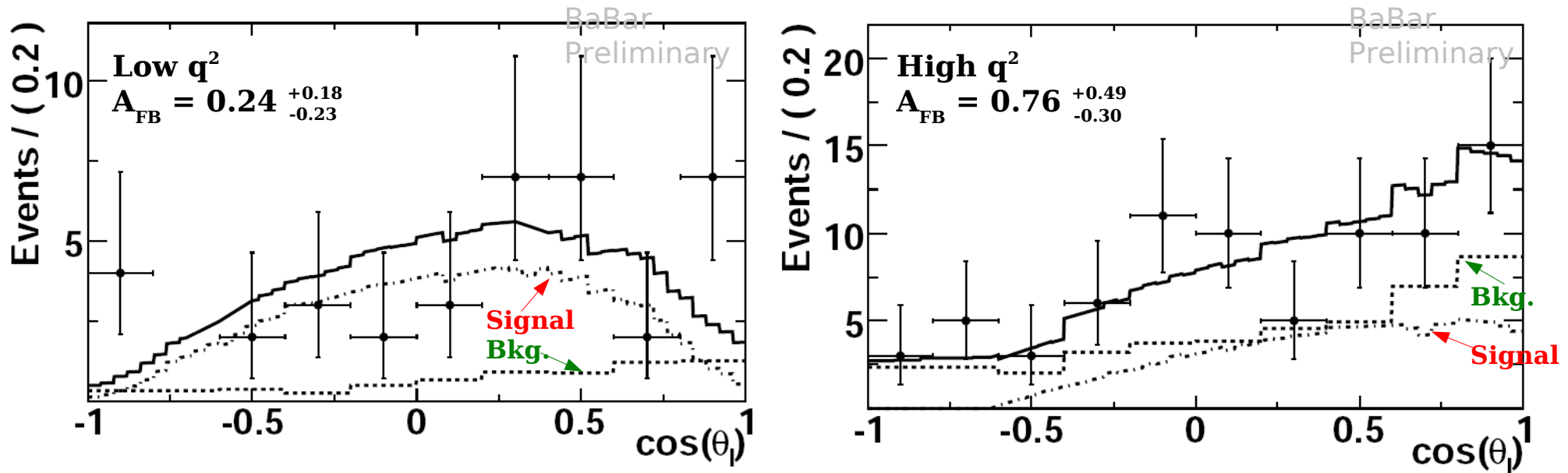
B \rightarrow K $\ell\ell$ A_{FB} Results



$B^+ \rightarrow K^+ \ell^+ \ell^-$ A_{FB} results.

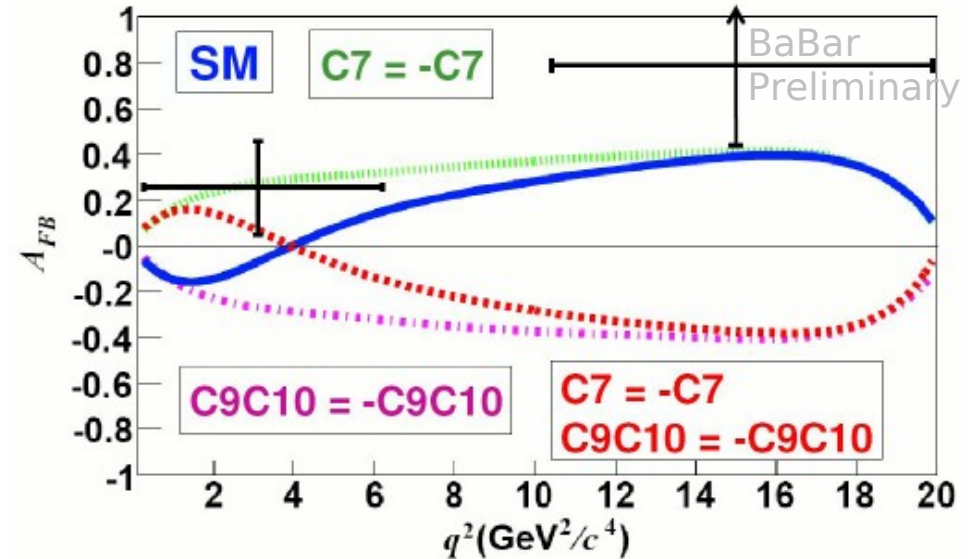
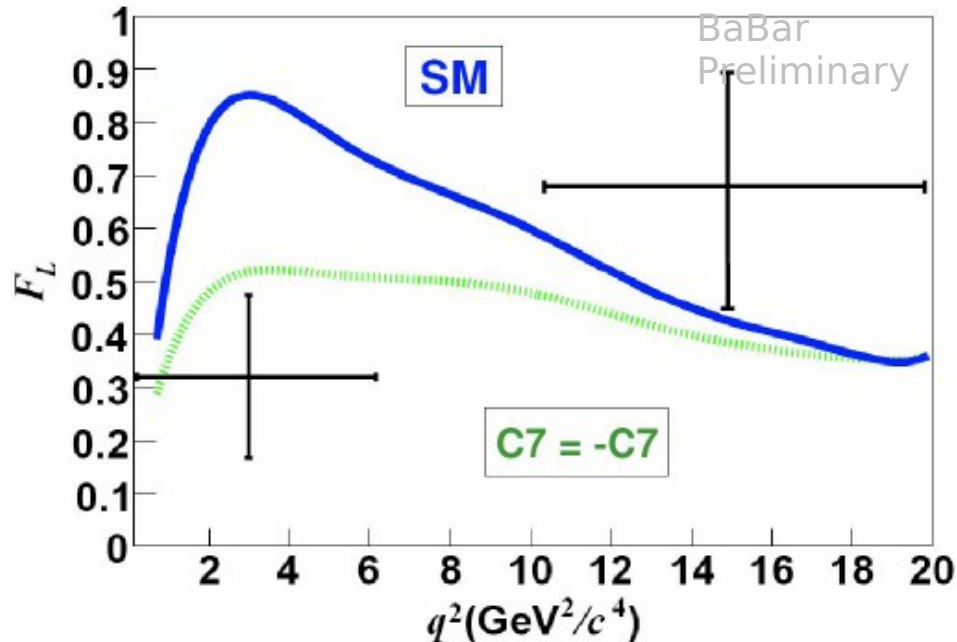
Both consistent with null expectation (within 1σ), now move on for $K^* \ell \ell$ fits

Final K^*l Fits



- Systematic errors for F_L & A_{FB} are considered:
 - Errors from various sources are summed up in quadrature
 - Quite small comparing to fit errors
 - ~ 0.06 for all cases

Interpretation of the Results



- Flipped C_7 sign model seem to be favored by both F_L and A_{FB} results
- In high q^2 , flipped C_9C_{10} sign model is excluded at $\sim 3\sigma$ by the A_{FB} result
- Consistent with previous measurements

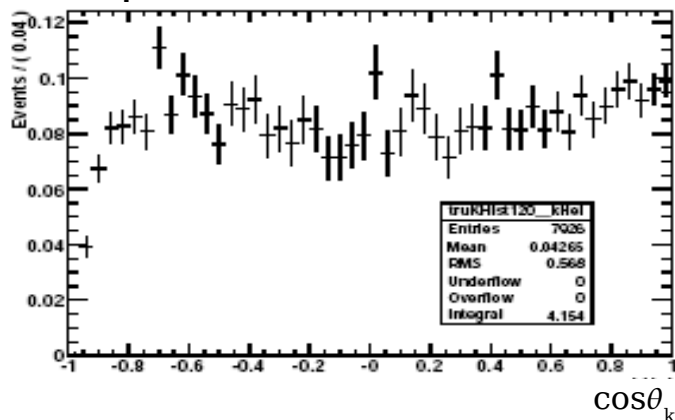
Outlook

- Following activities on our agenda:
 - Complete the measurements of $B \rightarrow K^{(*)} \ell \ell$ rate asymmetries based on BF results
 - Proceed to study the following decay modes with the same analysis techniques to approximate inclusive $B \rightarrow X_s \ell \ell$ decay:
 - $B \rightarrow K \pi \pi \ell \ell$, $B \rightarrow K \pi \pi \pi \ell \ell$, $B \rightarrow K \pi \pi \pi \pi \ell \ell$ (with up to one π^0)
 - Expect $B \rightarrow X_s \ell \ell$ measurement results by summer 2008

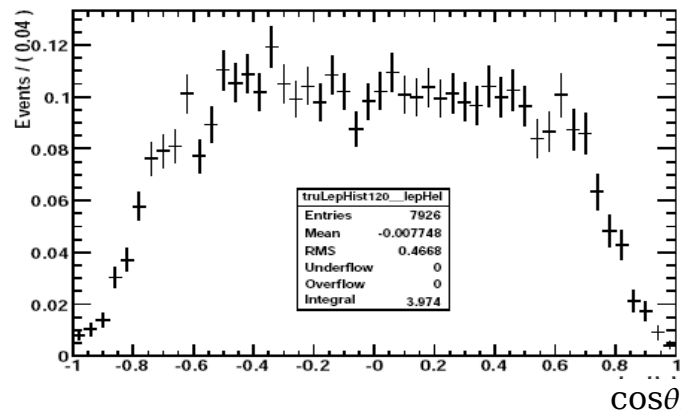
Backup Slides

Signal PDFs

- Signal m_{ES} :
 - Gaussian shape parametrized from the fit to $B \rightarrow J/\psi K^{(*)}$ data sample in each mode
- Signal $\cos\theta_k$:
 - $$\frac{1}{\Gamma} \frac{d\Gamma_{B \rightarrow K^* \ell^+ \ell^-}}{d\cos\theta_K} = \frac{3}{2} F_L \cos^2 \theta_K + \frac{3}{4} (1 - F_L) (1 - \cos^2 \theta_K)$$
- Signal $\cos\theta_l$:
 - $$\frac{1}{\Gamma} \frac{d\Gamma(B \rightarrow K^* \ell^+ \ell^-)}{d\cos\theta_\ell} = \frac{3}{4} F_L (1 - \cos^2 \theta_\ell) + \frac{3}{8} (1 - F_L) (1 + \cos^2 \theta_\ell) + A_{FB} \cos\theta_\ell$$
- To make the true angular distributions, these functions are multiplied with corresponding efficiency functions $\varepsilon(\cos\theta_k)$ and $\varepsilon(\cos\theta_l)$, which are step functions obtained from signal MC simulations



$B^0 \rightarrow K^+ \pi^- e^+ e^-$ efficiency as a function of $\cos\theta_K$ in low- s bin

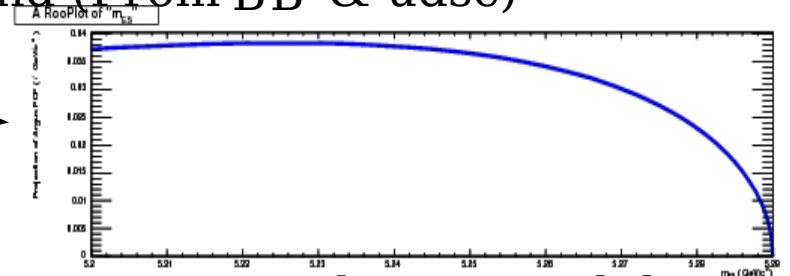


$B^0 \rightarrow K^+ \pi^- e^+ e^-$ efficiency as a function of $\cos\theta_\ell$ in low- s bin

Background PDFs

- Random Combinatorial Background (From $B\bar{B}$ & $udsc$)

- m_{ES} : Argus shape



- $\cos\theta_k$ & $\cos\theta_l$: Step functions parametrized using real data in Sideband region

- Feed-across between different decay modes

- Typically caused by the swap between a π^0 and π^\pm

- a Crystal Ball PDF to characterize smeared m_{ES} peaking shape

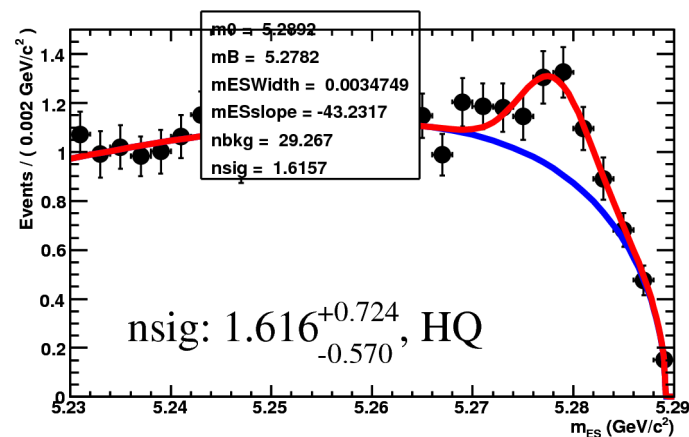
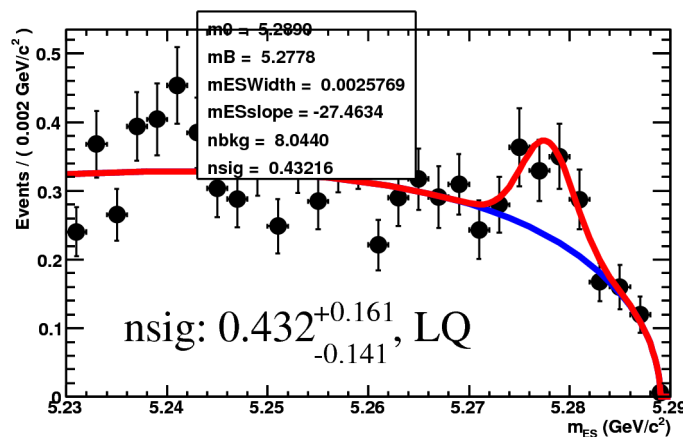
- Fit to the normalized histogram from signal MC events decide the shape parameters of the PDF and ratio to the signal yield

- $\cos\theta_k$ & $\cos\theta_l$: Histogram PDFs from signal MC

- Similar procedure for Self-crossfeed events

Background PDFs (Cont.)

- Peaking backgrounds
 - Charmonium leakage from our veto
 - PDFs Estimated from normalized MC events
 - Hadronic decays (via π/μ mis-ID)
 - Determined from muon ID removed data samples
 - The data is then weighted via PID efficiency tables
 - Yields & mES PDF shapes determined from Argus + Gaussian binned fits to weighted samples
 - PDFs of $\cos\theta_k$ & $\cos\theta_l$ determined from comb. background subtracted data samples in the signal region



$K^{(*)}ll$ BF Measurements

- The following measurements are being undertaken in parallel:
 - Finalizing the partial and full branching fraction measurements
 - Various rate asymmetries for $K^{(*)}ll$ in all q^2 & different q^2 bins:
 - Direct CP Asymmetries:
 - $$A_{CP}(s) \equiv \frac{\Gamma(\bar{B} \rightarrow \bar{K}^{(*)} \ell^+ \ell^-) - \Gamma(B \rightarrow K^{(*)} \ell^+ \ell^-)}{\Gamma(\bar{B} \rightarrow \bar{K}^{(*)} \ell^+ \ell^-) + \Gamma(B \rightarrow K^{(*)} \ell^+ \ell^-)}$$
 - Lepton Flavor Asymmetries, SUSY Higgs search:
 - $$R_K(s) = \mathcal{B}(B \rightarrow K \mu^+ \mu^-) / \mathcal{B}(B \rightarrow K e^+ e^-)$$
 - $$R_{K^*}(s) = \mathcal{B}(B \rightarrow K^* \mu^+ \mu^-) / \mathcal{B}(B \rightarrow K^* e^+ e^-)$$
 - Isospin Asymmetries:
 - $$\frac{dA_I}{ds} \equiv \frac{d\Gamma(B^0 \rightarrow (K/K^*)^0 \ell^+ \ell^-) / ds - d\Gamma(B^\pm \rightarrow (K/K^*)^\pm \ell^+ \ell^-) / ds}{d\Gamma(B^0 \rightarrow (K/K^*)^0 \ell^+ \ell^-) / ds + d\Gamma(B^\pm \rightarrow (K/K^*)^\pm \ell^+ \ell^-) / ds}$$
- These analyses will be finished in a couple of weeks
 - Fit model fully validated by charmonium samples & toy MC study
 - Need permission for unblinded study on real data

