CP-Violating Asymmetries in $b \to s$ penguins

$B^0 \to K^0_S K^0_S K^0_S$, $B^0 \to \pi^0 \pi^0 K^0_S$

Lei Zhang

On Behalf of the *BABAR* Collaboration

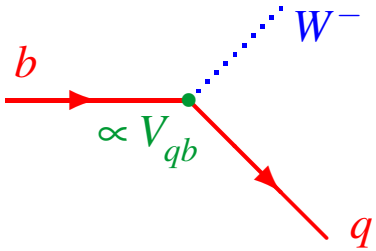
Joint Meeting Of Pacific Region Particle Physics Communities

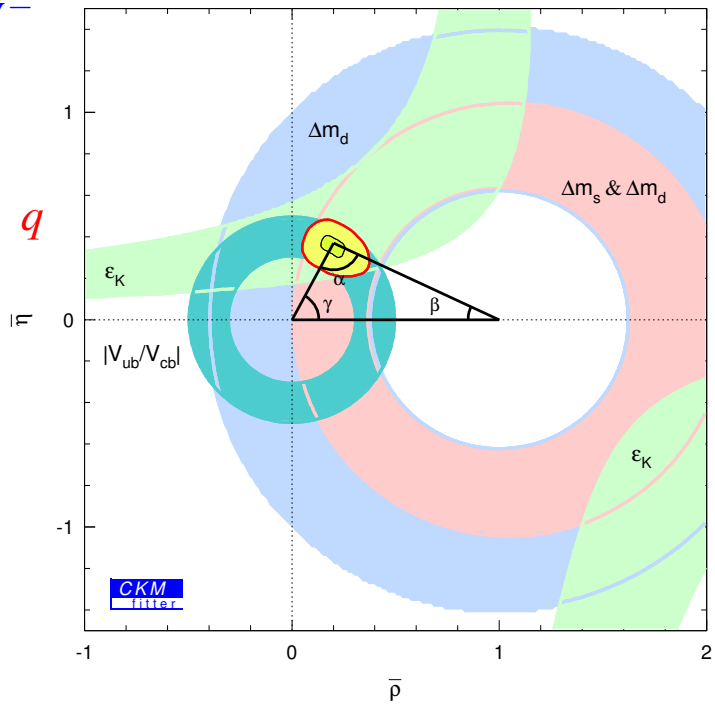
Oct 29–Nov 3 2006, Honolulu, Hawaii

CKM Matrix and *CP* Violation

- Quark mixing (CKM matrix)

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \overbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}^{V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$





- Unitarity of CKM matrix $\Longrightarrow$
  $V_{id}V_{is}^* = 0$, $V_{is}V_{ib}^* = 0$, and

$$\boxed{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$$

$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

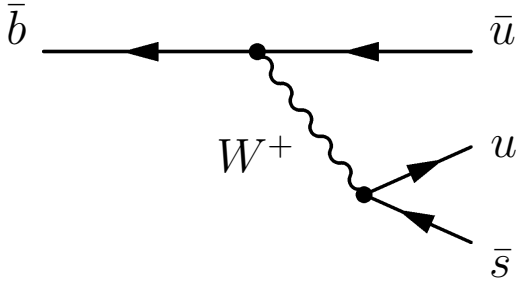
$(\lambda = 0.22,\ A = 0.8,\quad \rho,\ \eta)$

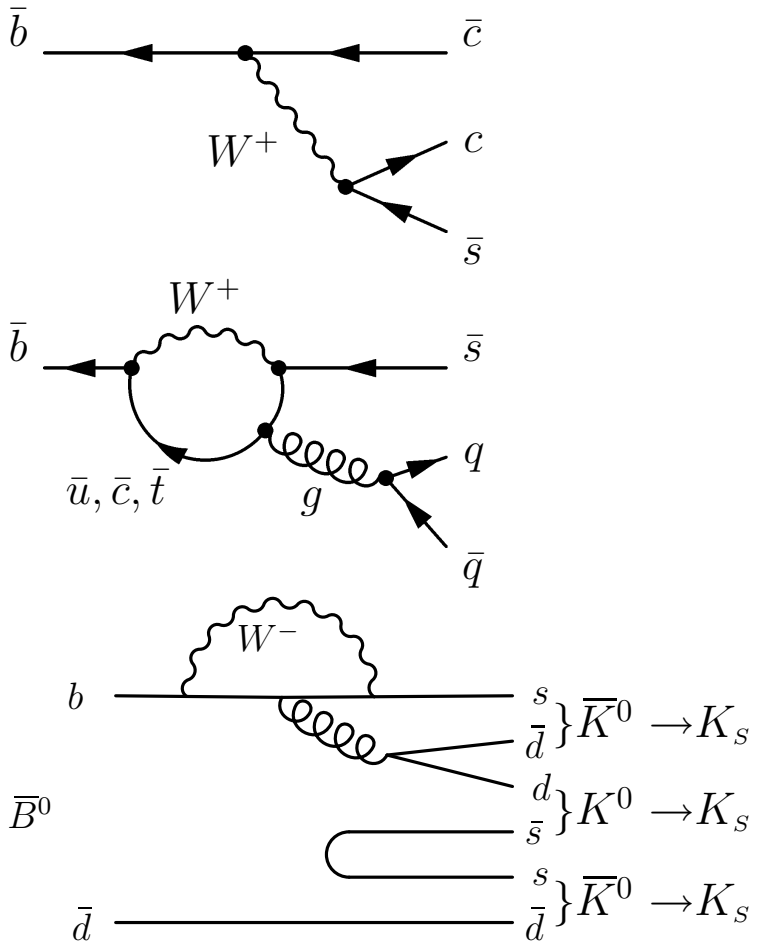
- *CPV* from interference:
  $B^0 \to f_{CP}$, $B^0 \to \bar{B}^0 \to f_{CP}$

$$\boxed{A_{f_{CP}}(\Delta t) = C_{f_{CP}} \cos(\Delta m_d \Delta t) - S_{f_{CP}} \sin(\Delta m_d \Delta t)}$$

CPV in $b \to s$ Penguin

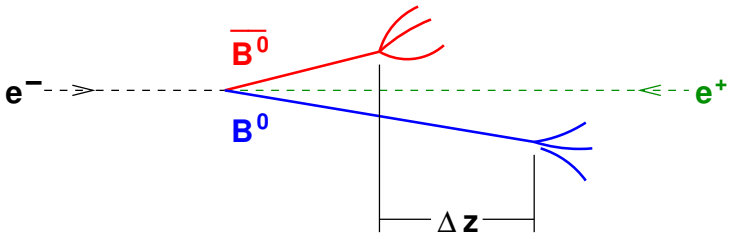
- $b \to c$ tree to extract sin2β
- $b \to s$ penguin diagram
  - sin2$\beta_{eff} \approx$ sin2β in SM
  - Uncertainties on ΔS due to SM pollution
  - Possible contributions from New Physics (NP)
- $B^0 \to K^0_S K^0_S K^0_S$, pure penguin channel, *CP*-even final state. ($B^0 \to P_0 P_0 P_0'$)
  - $C = 0$, $S = -$ sin2β in SM
- $B \to \pi^0\pi^0 K^0_S$, *CP*-even final state
  $b \to s$ penguin dominated
  tree contributions CKM and color suppressed



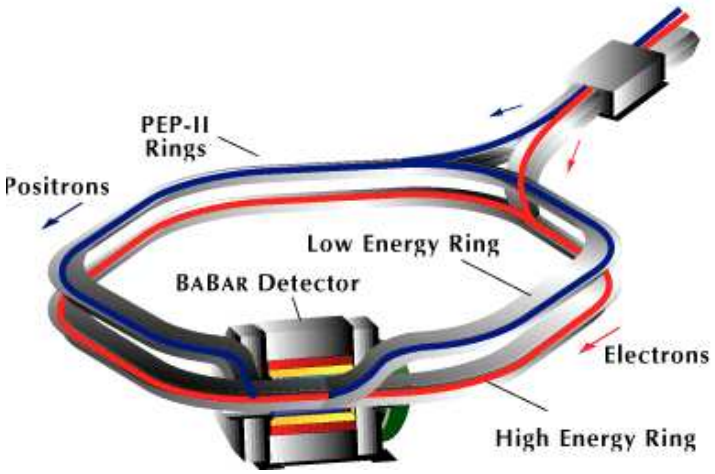


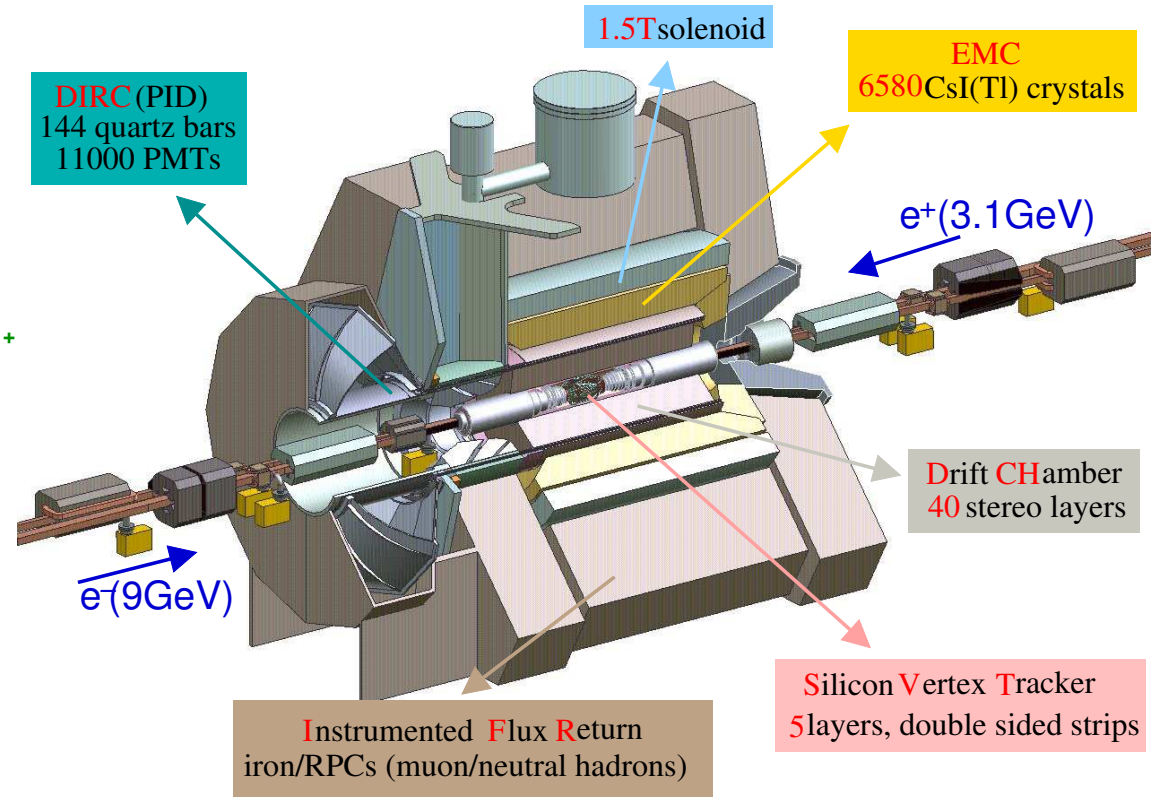
The PEP-II *B* Factory and *BABAR* Detector

- PEP-II asymmetric e^+e^- collider at SLAC
- 3.1 GeV e^+ / 9 GeV e^- $\Rightarrow$ $<\beta\gamma>=0.56$



- $\Delta t \approx \dfrac{\Delta z}{<\beta\gamma> c}$
- Peak luminosity $> 12 \times 10^{33} cm^{-2} s^{-1}$

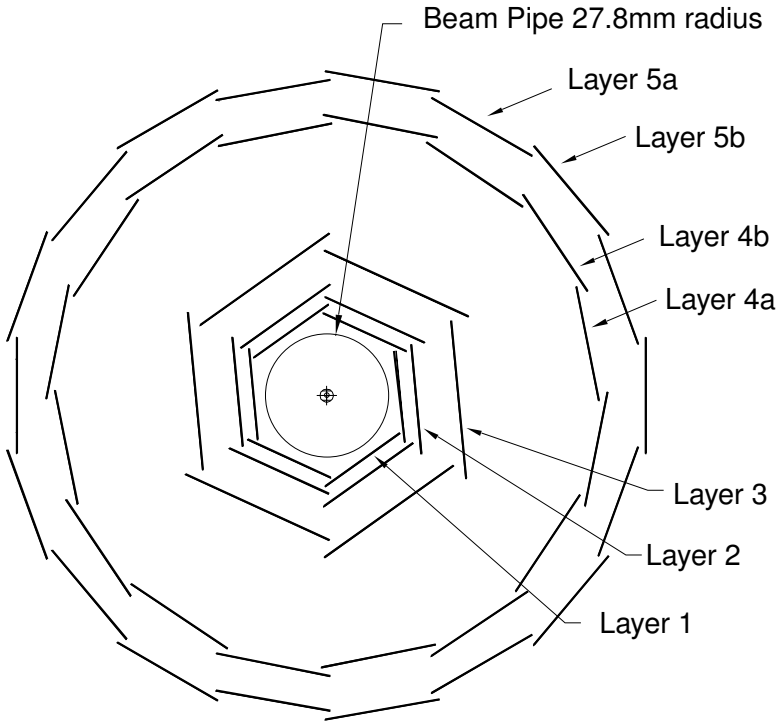




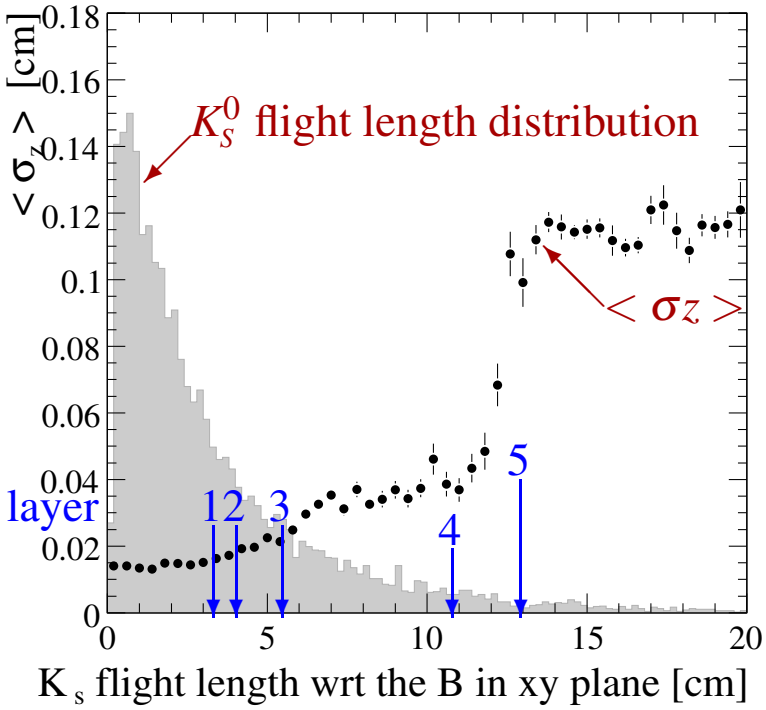
- Tracker: SVT+DCH
- Calorimeter: CsI(Tl) EMC
- PID: DIRC+dE/dx
- 374M $\Upsilon(4S) \to B\bar{B}$ recorded on *BABAR*

Vertex Reconstruction

- No charged tracks from B^0_{rec} vertex
  - Need excellent vertexing from K^0_S
  - $c\tau(K^0_S) \approx 27\,\text{mm}$
  - SVT is crucial
  - Must have first 3-layer hits
    radii of inner layers: 32, 40, and 54 mm

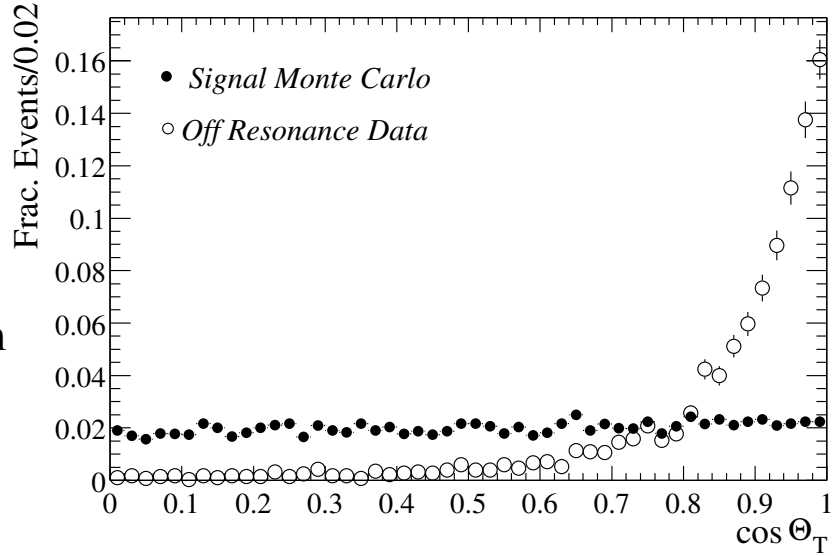


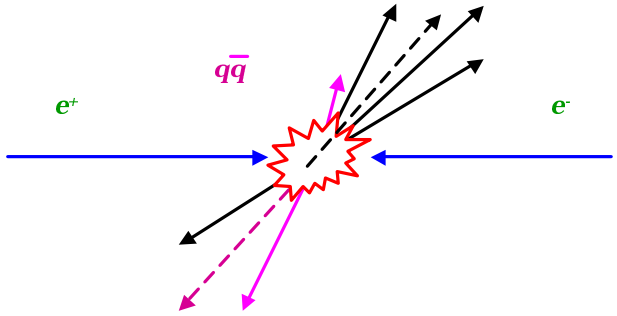
- Interaction Point (IP) constrained Vertexing
  - Take advantage of small beam size
    $\sigma_x \sim 200\,\mu\text{m}$, $\sigma_y \sim 4\,\mu\text{m}$
  - B^0 production vertex constrained to the beam-spot on $x-y$ plane
- Δt resolution is similar to other *BABAR* analyses

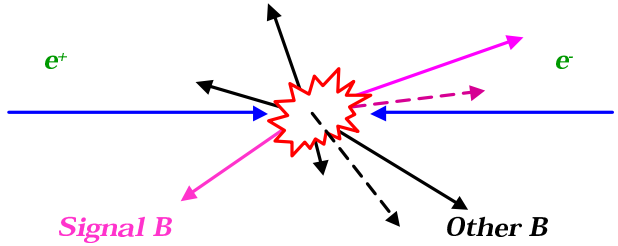


Event Reconstruction

- $\pi^0 \to \gamma\gamma$, $K^0_S \to \pi^+\pi^-$
- $B^0 \to 3K^0_S(\pi^+\pi^-)$, or $B^0 \to K^0_S K^0_S K^0_S$ with one $K^0_S \to \pi^0\pi^0$
- $B^0 \to \pi^0\pi^0 K^0_S$
- Main background from $e^+e^- \to q\bar{q}$, $q = u,d,s,c$ continuum
  - Event-shape variables to reject continuum
  - Include into Neural Net or Fisher variable





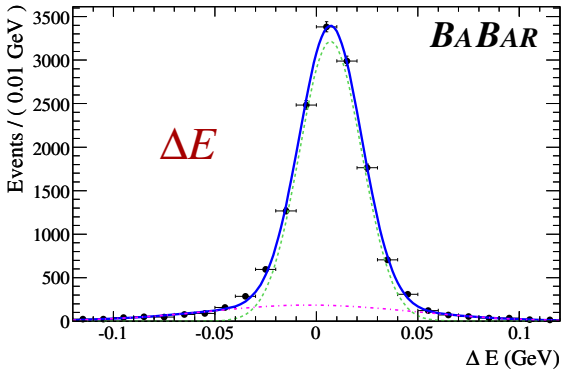


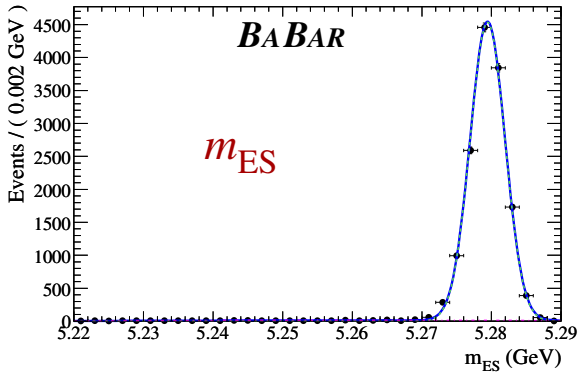
B Candidate Reconstruction

- B^0 decay kinematic variables:

  ΔE and $m_{\rm ES}$
  - $\Delta E = E^*_B - \sqrt{s}/2$,
  - $m_{\rm ES} = \sqrt{s/4 - (p^*_B)^2}$, or

  m_B and m_{miss}
  - $m_B = |q_{rec}|$
  - $m_{miss} = |q_{e^+e^-} - q_B|$

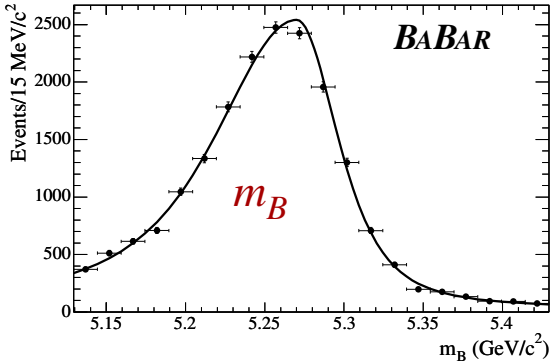


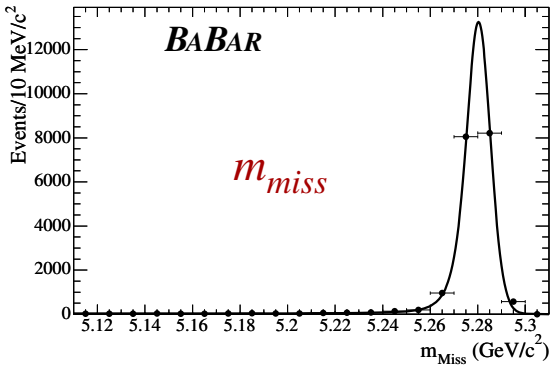


- Major *B* backgrounds:

  $B^0 \to K^0_S K^0_S K^0_S$
  - Vetoes on $B^0 \to \chi_{c0/c2}(K^0_S K^0_S)K^0_S$
  - Other *B* backgrounds negligible for $B^0 \to 3K^0_S(\pi^+\pi^-)$

  $B^0 \to \pi^0\pi^0 K^0_S$
  - Vetoes on $B^0 \to \chi_{c0}(\pi^0\pi^0)K^0_S$
  - Invariant mass cuts on $B^0 \to K^0_S\pi^0$ and $D^0 \to K^0_S\pi^0$
  - Helicity cuts to remove $B^0 \to K^{*0}\gamma$
  - Peaking and non-peaking *B* backgrounds included





B^0 Tagging

- Coherent production of $B^0\overline{B}^0$ from $\Upsilon(4S)$
- $B_{rec} \to f_{CP}$
- The other B, B_{tag}, partially reconstructed, to determine the flavor of B_{rec} at $\Delta t = 0$
- Categorize B_{tag} w.r.t. decay information and mis-tag rate
  - 7 mutually exclusive tagging categories:
    Lepton, KaonI, KaonII, Kaon-Pion, Pion, Other, NoTag
- Total effective tagging efficiency $Q \approx 30.5\%$

Analysis Techniques

- Extract signal yields, C, S from unbinned maximum-likelihood fit
- Likelihood function

$$\mathcal{L} = \frac{\exp(-\sum_j n_j)}{N!} \prod_{i=1}^{N} \left(\sum_j n_j \mathcal{P}_j(x_i; a_i) \right)$$

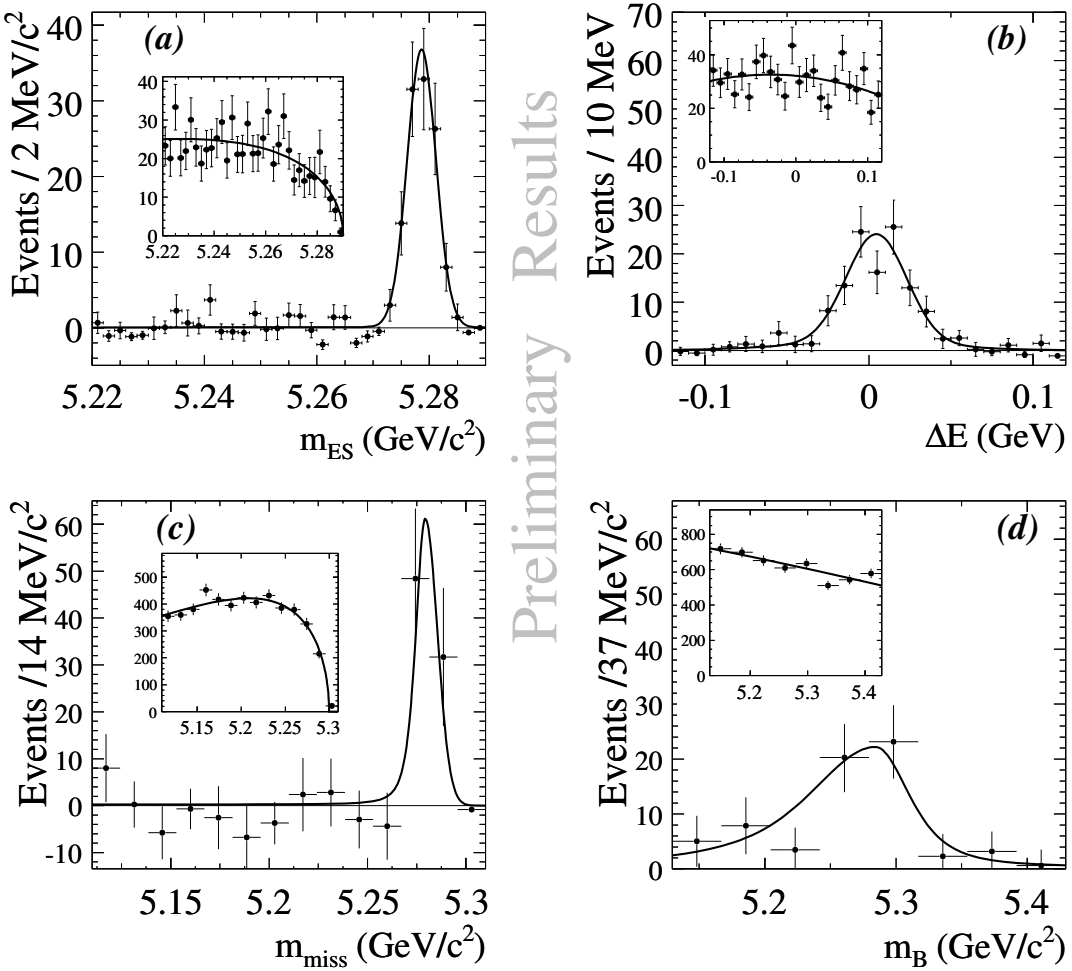
- In fit models, signal and continuum background included
  - B background included for $B^0 \to K^0_S K^0_S K^0_S$ with one $K^0_S \to \pi^0\pi^0$
  - Peaking B and non-peaking B background included for $B^0 \to \pi^0\pi^0 K^0_S$
- Continuum parameters float as many as we can
- Core parameters of ΔE and $m_{\rm ES}$ for $B^0 \to 3K^0_S(\pi^+\pi^-)$ floated
- Fit models validated with simulated studies
- Blind analysis until finalized

Yields for $B^0 \to K^0_S K^0_S K^0_S$

- **All results are preliminary**
- Based on 347M $B\bar{B}$ pairs
- Observables:
  - $(\pm)$: ΔE, $m_{\rm ES}$, $\mathcal{F}$, Δt, $\sigma(\Delta t)$, tagging
  - (00): m_{miss}, m_B, l_2/l_0, $m_{\pi^0\pi^0}$, Δt, $\sigma(\Delta t)$, tagging
- Yields:

	$B_{CP(+-)}$	$B_{CP(00)}$
N_S	116 ± 12	60 ± 12
$N_{q\bar{q}}$	670 ± 26	4482 ± 71
$N_{B\bar{B}}$	–	8 ± 25

- ${}_s\mathcal{P}lot$ (arxiv:physics/0402083)



C and S for $B^0 \to K^0_S K^0_S K^0_S$

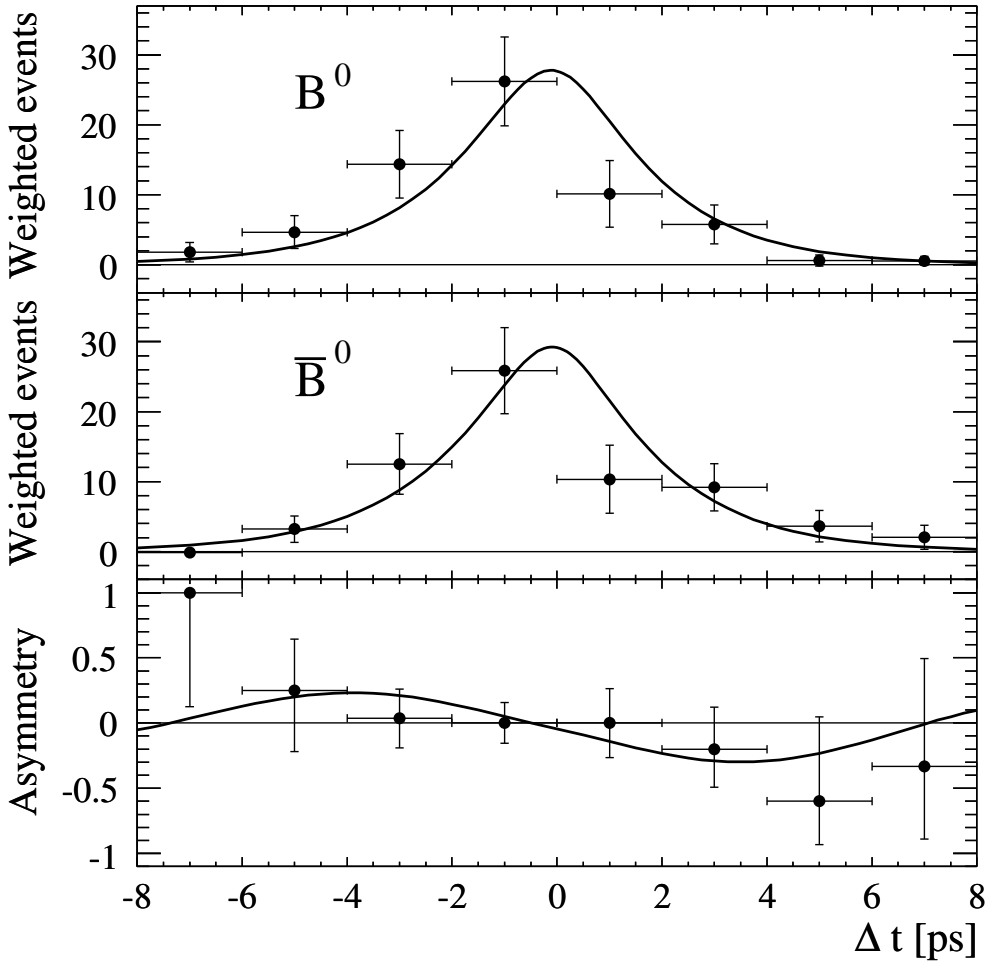
- Combined fit for C and S

	$B_{CP(+-)}$	$B_{CP(00)}$	Combined
S	$-1.04^{+0.26}_{-0.17}$	$0.37^{+0.52}_{-0.54}$	$-0.66 \pm 0.26 \pm 0.08$
C	$-0.31^{+0.25}_{-0.23}$	0.21 ± 0.38	$-0.14 \pm 0.22 \pm 0.05$

- Dominant systematic errors:
  - PDF shapes
  - Bkg composition
  - Δt resolution
  - Fit bias

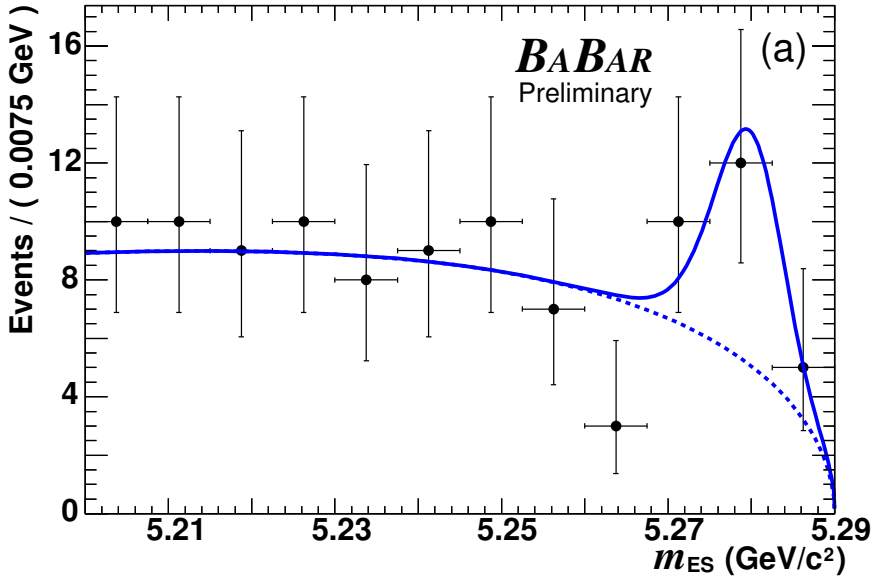
- ${}_s\mathcal{P}lot$:

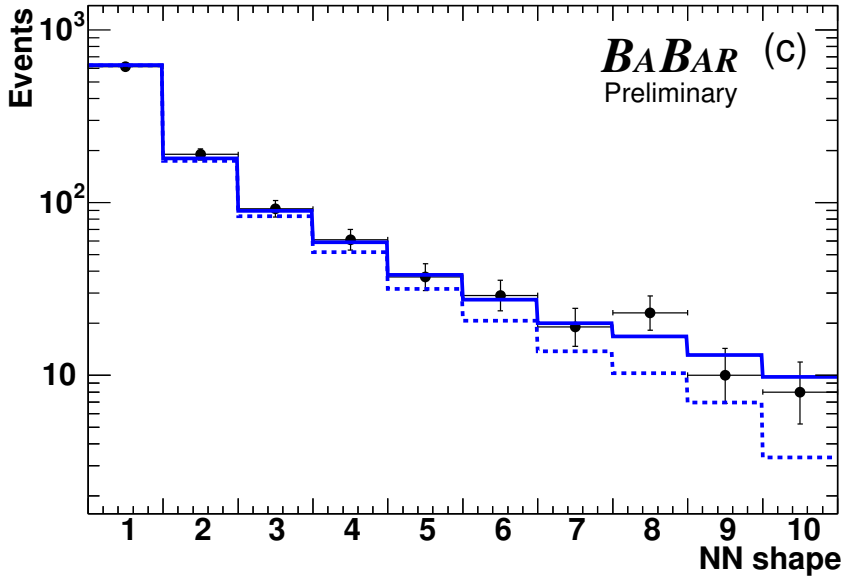
Preliminary Results



Yields for $B^0 \to \pi^0\pi^0 K^0_S$

- Based on 227M $B\bar{B}$ pairs
- Observables: $m_{\rm ES}$, $\Delta E/\sigma_{\Delta E}$, event-shape NN, Δt, $\sigma(\Delta t)$, tagging
- Yield components: signal, peaking and non-peaking B background, and continuum
- $N_{sig} = 117 \pm 27$ (Stat. Signf. 5.8σ)
- $m_{\rm ES}$ and NN projection plots (after signal LLR cuts):



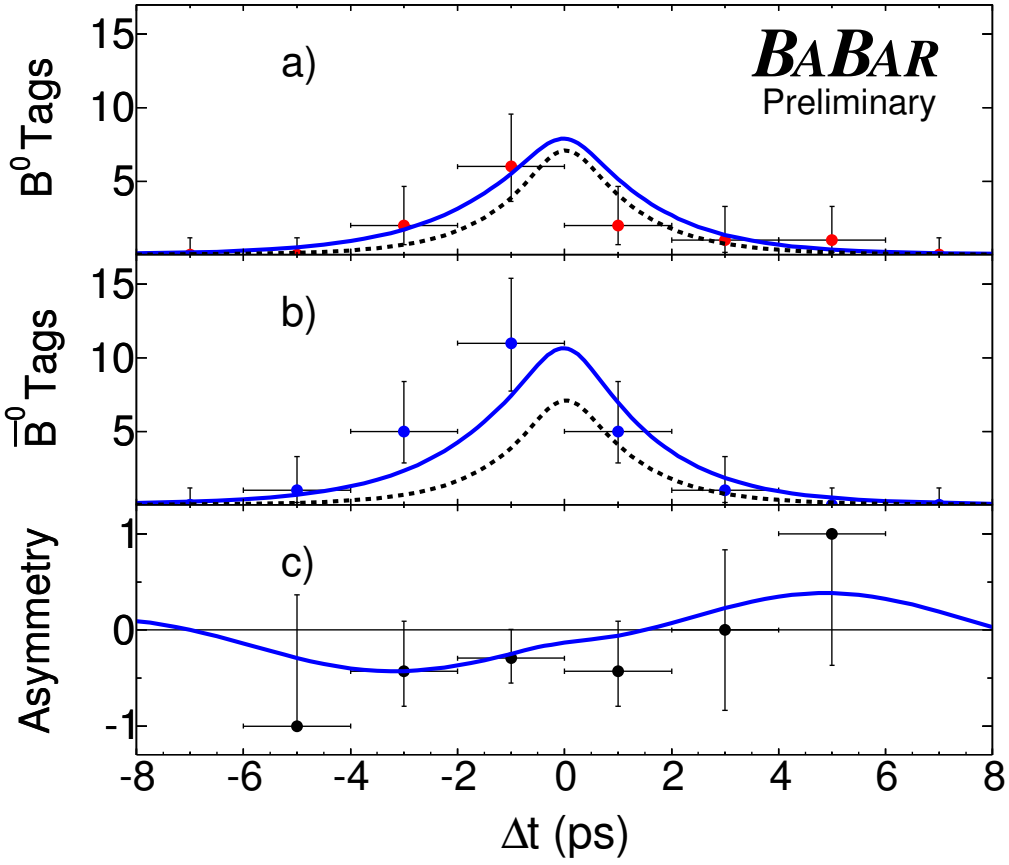


C and S for $B^0 \to \pi^0\pi^0 K^0_S$

- $S = 0.84 \pm 0.71 \pm 0.08$
- $C = 0.27 \pm 0.52 \pm 0.13$
- Fix $S = -\sin 2\beta = -0.725$ and $C = 0$, NLL increase 2.5

- Dominant systematic errors:
  - PDF shapes
  - Bkg composition
  - Δt resolution
  - Fit bias

- Δt projection plots (after signal LLR cuts):



Summary

- World Average $\sin 2\beta_{b\to ccs} = 0.68 \pm 0.03$
- $B^0 \to K^0_S K^0_S K^0_S$ *CPV* results consistent with SM

  $-S = 0.66 \pm 0.26 \pm 0.08$

- $B^0 \to \pi^0\pi^0 K^0_S$
  - First observation and *CP* measurement

    $-S = -0.84 \pm 0.71 \pm 0.08$

  - Need more data

$\sin(2\beta^{\rm eff}) \equiv \sin(2\phi_1^{\rm eff})$ HFAG ICHEP 2006 PRELIMINARY