Measurement of the time-dependent CP asymmetry for $B \rightarrow \phi K^0$, $B \rightarrow K^+K^-K_s$ and $B \rightarrow f_0 K_s$

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Introduction(1)

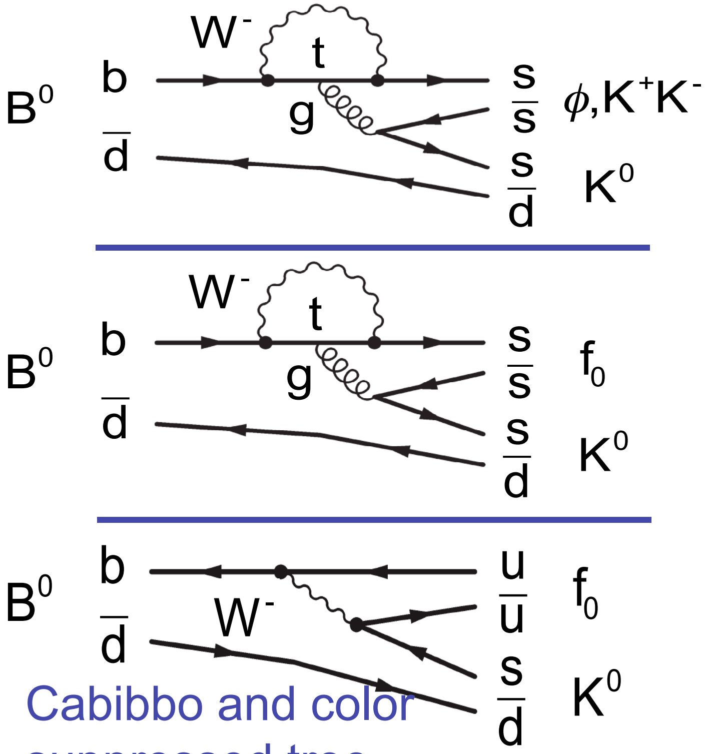
- $B^0 \rightarrow \phi K^0$, $B^0 \rightarrow K^+K^-K_s$, $B^0 \rightarrow f_0 K_s$: All are penguin-dominated b → sss decays- **Thought to be sensitive to new physics!**
- SM says: for these modes, can measure A_{fcp} to get sin(2β)

$$A_{f_{cp}} = \frac{\Gamma(B^0 \rightarrow f_{cp}) - \Gamma(\overline{B}^0 \rightarrow f_{cp})}{\Gamma(B^0 \rightarrow f_{cp}) + \Gamma(\overline{B}^0 \rightarrow f_{cp})}$$

$$= -S_{f_{cp}} \sin(\Delta m_d t) + C_{f_{cp}} \cos(\Delta m_d t)$$

$$S_{f_{cp}} \sim \eta_{cp} \times \sin(2\beta),\ C_{f_{cp}} \sim 0$$

$$\eta_{cp,\phi K^0} = 1, \eta_{cp,f_0 K_s} = -1, \eta_{cp,K^+K^-K_s} = ?$$



Cabibbo and color suppressed tree

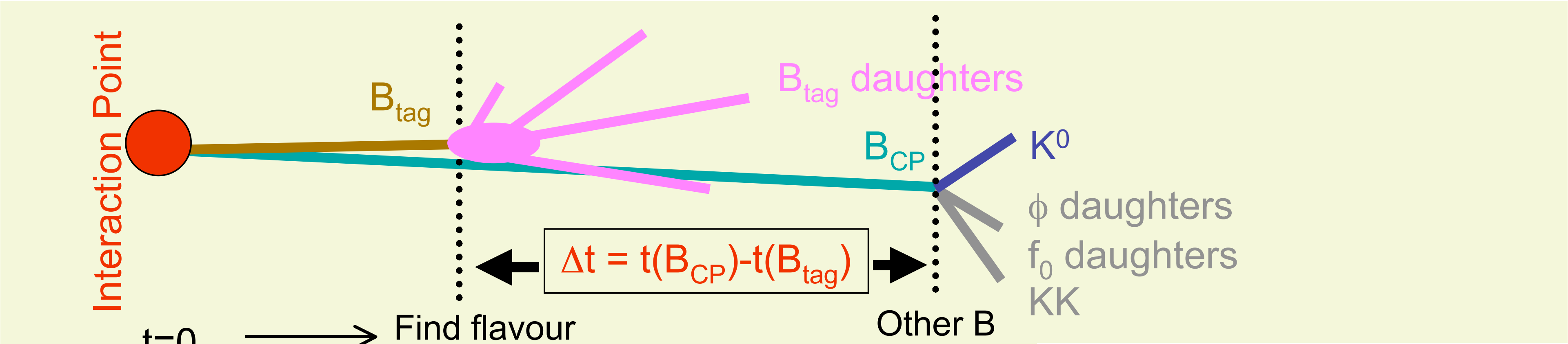
- **Can measure S and compare to sin(2β) from b → ccs modes**

Previous Results

	J/Ψ	**φ K⁰**	**K⁺K⁻K_s**	**f₀K_s**
sin(2β)	**0.741 ± 0.067 ± 0.034**	**$0.47 \pm 0.34\ ^{+0.08}_{-0.06}$**	**$0.57 \pm 0.26\ ^{+0.17}_{-0.04}$**	**$1.62\ ^{+0.51}_{-0.56} \pm 0.10$**
Reference	**BABAR,PRL 89,201802 (2002)**	**BABAR, hep-ex/0403026**	**BABAR, hep-ex/0406005**	**BABAR, hep-ex/0406040**

Introduction(2)

Time-Dependant Decay Rate: $$f_{\pm tag}(\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B}\left(1 \pm S\sin\left(\Delta m_d \Delta t\right) \mp C\cos\left(\Delta m_d \Delta t\right)\right)$$



$\Delta t = t(B_{CP}) - t(B_{tag})$

t=0
BB pair

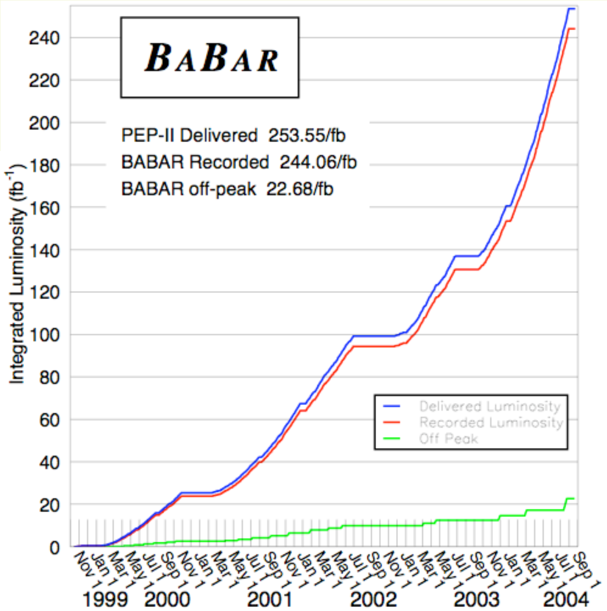
t

Find flavour
of one B:
B_{tag}

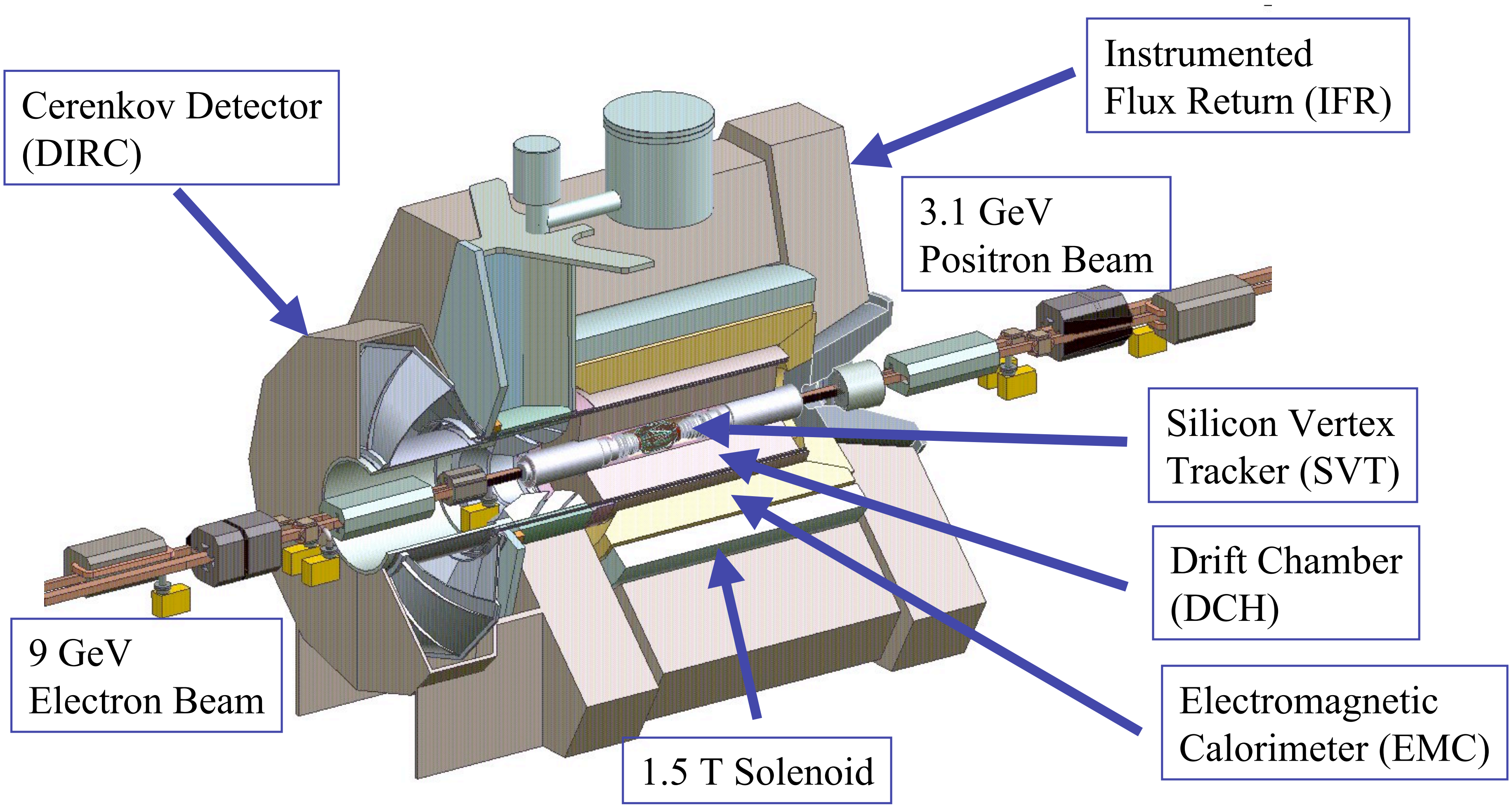
Other B
decays to
signal: B_{CP}

Luminosity

	Lumi (fb^{-1})	# BB Pairs
ϕK^0	205	227×10^6
$K^+K^-K_s$	205	227×10^6
f_0K_s	192	209×10^6



BaBar Detector



Cerenkov Detector (DIRC)

Instrumented Flux Return (IFR)

3.1 GeV Positron Beam

Silicon Vertex Tracker (SVT)

Drift Chamber (DCH)

Electromagnetic Calorimeter (EMC)

1.5 T Solenoid

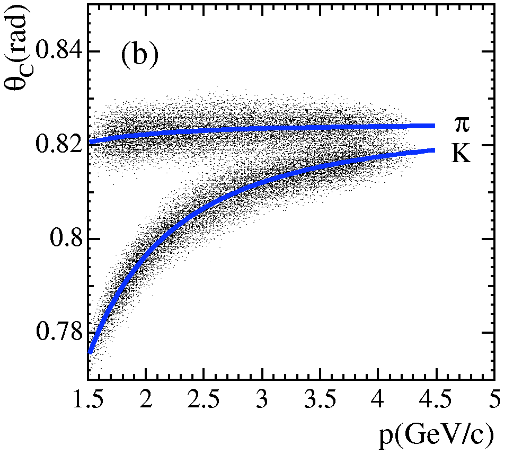
9 GeV Electron Beam

Common Analysis Techniques(1)

Final State Candidates/PID

- Look for final states $\phi \rightarrow K^+K^-$, $f_0 \rightarrow \pi^+\pi^-$, $K_s \rightarrow \pi^+\pi^-$, ie for candidates:

ϕK^0		$K^+K^-K_s$	f_0K_s
ϕK_s	ϕK_L		
$K^+K^-\pi^+\pi^-$	$K^+K^- K_L$	$K^+K^-\pi^+\pi^-$	$\pi^+\pi^-\pi^+\pi^-$



- Use DIRC particle ID to separate $\pi^\pm$ from $K^\pm$
  - 3 sigma difference at 3 GeV

Kinematic B-Candidate Variables

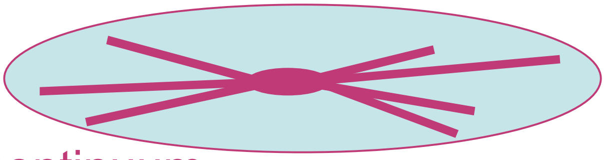
$$m_{ES} = \sqrt{\left(\frac{1}{2}s + \vec{p}_0 \bullet \vec{p}_B\right)^2 \Big/ E_0^2 - p_B^2} \qquad \Delta E = E_B^* - \frac{1}{2}\sqrt{s}$$

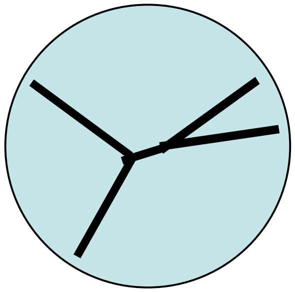
- Not for ϕK_L

Common Analysis Techniques(2)

Event-shape continuum-fighting variables

- In CM, qq is jetlike, signal is spherical- exploit this!
- Monomials, summed over particles not hypothesized to be from B_{CP}(ROE): $L_0 = \sum_i |\vec{p}_i|$ $L_2 = \sum_i |\vec{p}_i| \cos^2(\theta_i)$
  - where: p_i is momentum of ith ROE particle, θ_i is angle between p_i and *B*-candidate thrust axis
- Angles between *B*-candidate momentum/thrust and beam-axis
- Combine into MVA (Neural Net or Fisher Discriminant)





Sample Size and *Approximate* Expected Signal/Background

		Sample size	qq-background	B-background		Expected Yield	Signal Efficiency
				b→c	other		
ϕK_0	ϕK_S	4300	4200	<6		97	40%
	ϕK_L	8238	7960	125	55	97	20%
$K^+K^-K_s$		27368	26370	<530		460	26%
f_0K_s		12586	12100	220	105	160	39%

Common Analysis Techniques(3)

Extended Maximum Likelihood Fit

- MVA- use event shape Fisher Discriminant (Fish) or Neural Net (NN)
- Δt and tagging parameters taken from fit to fully reconstructed *B* decays to charm
- Events split into 4 types- correctly (COR) and misreconstructed (MRC) signal, *B* decays, and qq decay
- Float as many parameters as possible in fit to data

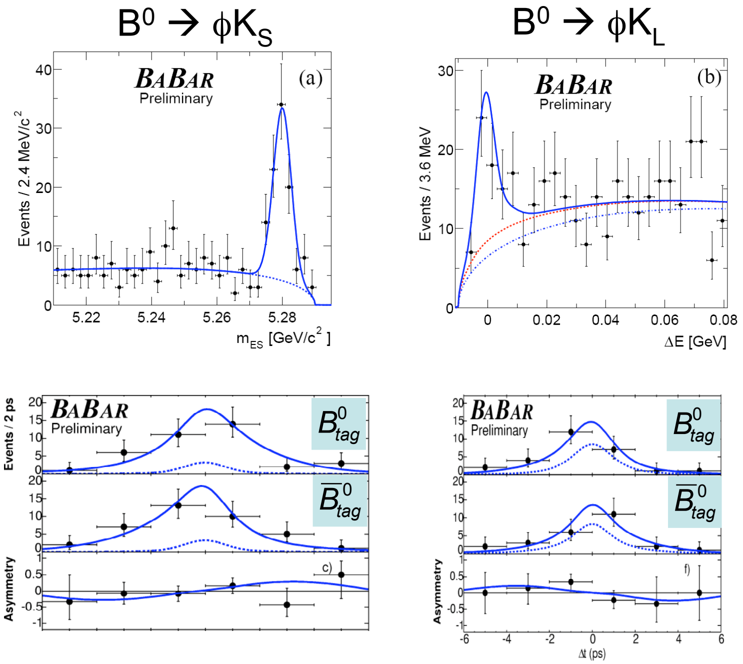
		Discriminating Variables						**Event-Types**			
								Signal		**B-back**	**qq-back**
		m_{ES}	**ΔE**	**MVA**	**m(KK)/ m($\pi\pi$)**	**|*cos*(θ_H)|**	**Δt**	**COR**	**MRC**		
ϕK_0	**ϕK_S**	√	√	**Fish**	√	√	√	√		**†**	√
	ϕK_L	**-**	√	**Fish**	√	√		√	√	√	√
$K^+K^-K_s$		√	√	**Fish**	**-**	**-**	√	√		√	√
f_0K_s		√	√	**NN**	√	√	√	√	√	√	√

- †: varied as a systematic, but set to 0 in nominal fit

$B^0 \rightarrow \phi K^0$(1)

- Combined fit to ϕK_S and ϕK_L
- Treatment of K_L: direction from calorimeter, assume nominal m(B^0) to find kinematics- no m_{ES}

$S_{\phi K0}$	**$+0.50 \pm 0.25$ (stat) $^{+0.07}_{-0.04}$ (syst)**
$C_{\phi K0}$	**0.00 ± 0.23 (stat) ± 0.05(syst)**
ϕK_S Yield	114 ± 12 (stat)
ϕK_L Yield	98 ± 18 (stat)



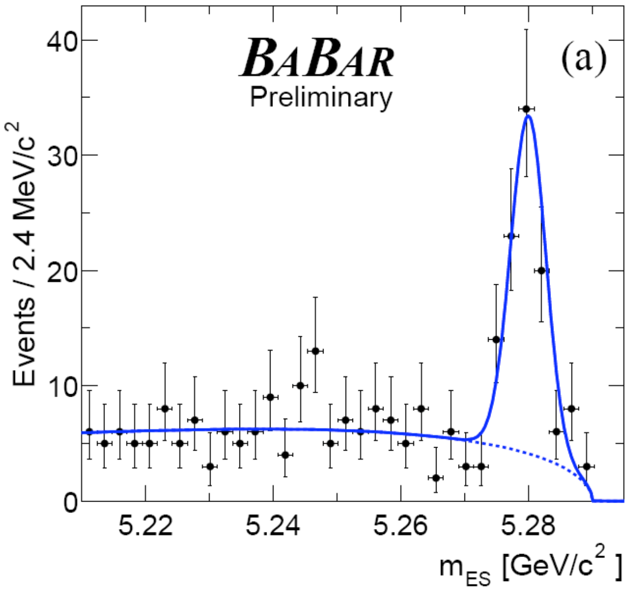
Sources of Dominant Systematic Error

- Opposite CP background (S – Wave contributions)
  - Used moment analysis method [S.U. Chung, Phys Rev. D 56, 7299 (1997)] to bound contribution to 6.6% at 95% C.L.
- PDF Model
- Tag-Side CP Violation

$B^0 \rightarrow \phi K^0$(2)- Bigger Plots

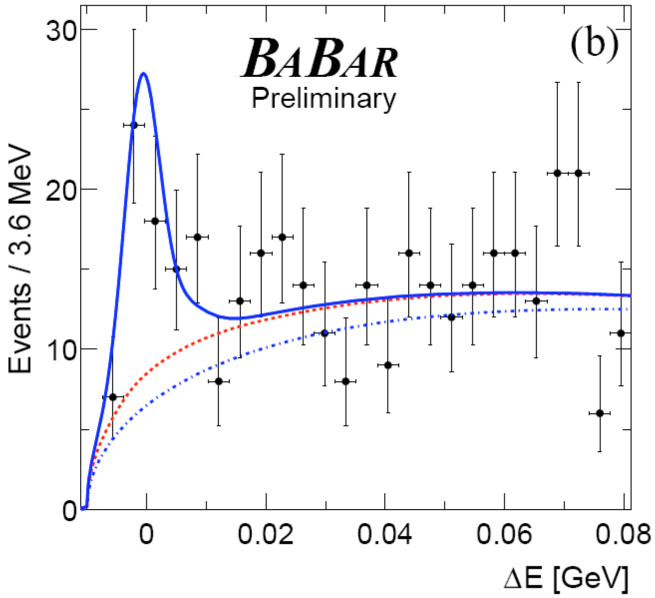
$B^0 \rightarrow \phi K_S$

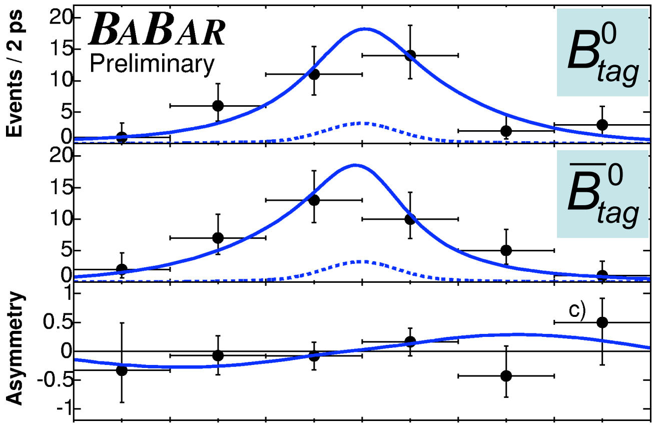
$B^0 \rightarrow \phi K_L$

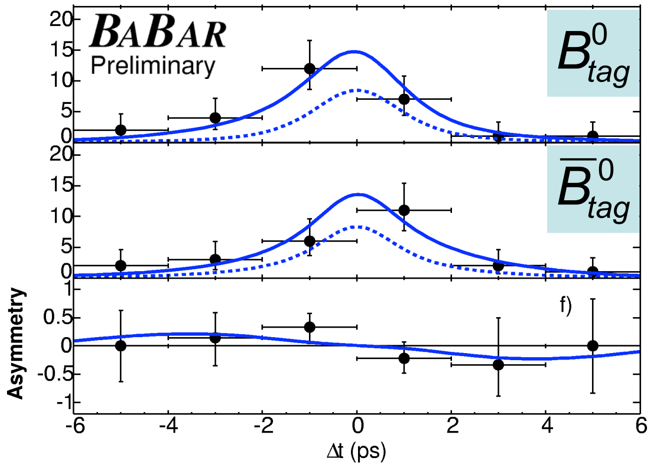


qq background ⋯⋯⋯⋯

B-background ▬▬▬



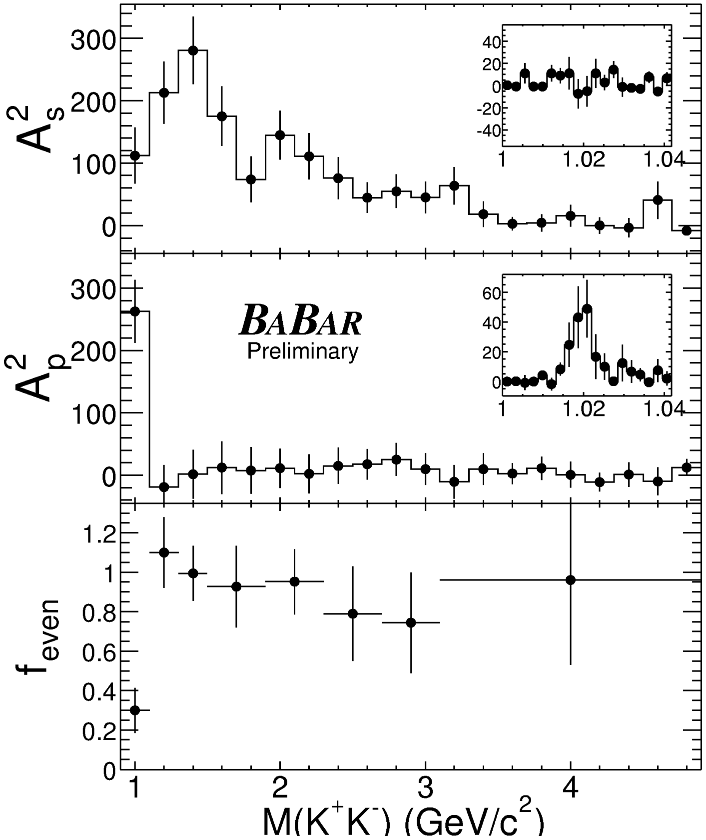




$B^0 \rightarrow K^+K^-K_s(1)$

- Exclude ϕK_s- much higher statistics than ϕK_s, but…

CP content unknown- must be determined experimentally!



- Write total amplitude A in terms of avg. moments <Pl> of Legendre polynomials **[G.Costa et al., Nucl. Phys. B 175, 402 (1980)]**, calculate from sum of background-corrected signal weights returned by ML fit ("sPlot" technique, **[Pivk-Le Diberder, physics/0402083]**)
  - $A^2 = \sum_l \langle P_l \rangle \times \cos(\theta_H)$
- Also write total amplitude A in terms of CP-even S wave and CP-odd P wave
  - $A = A_s\, P_0(\cos\theta_H) + e^{i\phi} A_p\, P_1(\cos\theta_H)$
- Then easy to show that:

$$A_s^2 = \sqrt{2}\langle P_0 \rangle - \sqrt{\frac{5}{2}}\langle P_2 \rangle \qquad A_p^2 = \sqrt{\frac{5}{2}}\langle P_2 \rangle$$

$$f_{even} = \frac{A_S^2}{A_S^2 + A_P^2} = 1 - \sqrt{\frac{5}{4}}\frac{\langle P_2 \rangle}{\langle P_0 \rangle}$$

$f_{even} = 0.89 \pm 0.08$ (stat) ± 0.06 (syst)

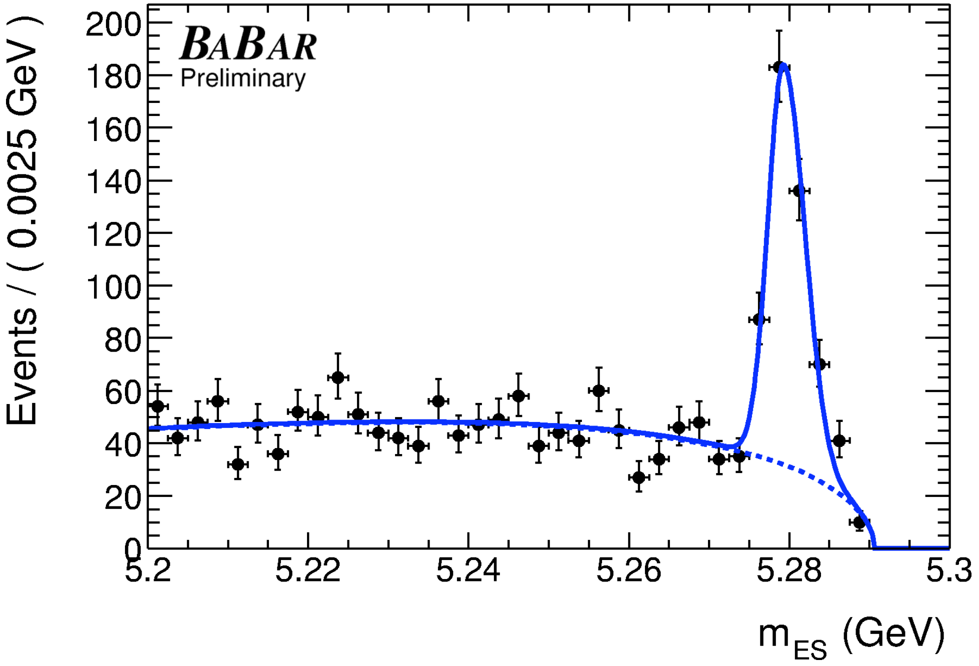
$B^0 \rightarrow K^+K^-K_s(2)$

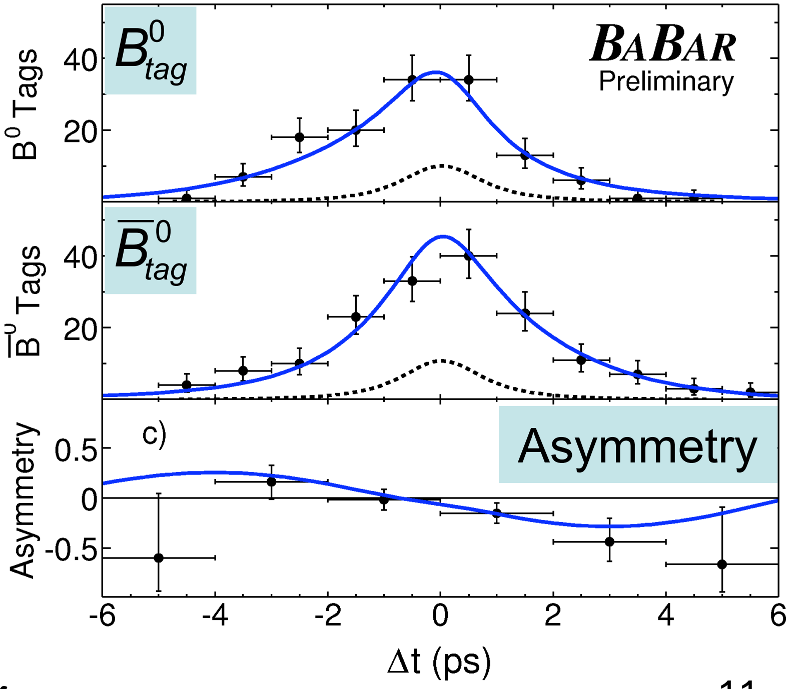
S_{K+K-Ks}	**-0.42 ± 0.17 (stat) ± 0.04 (syst)**
C_{K+K-Ks}	**0.10 ± 0.14 (stat) ± 0.06 (syst)**
f_{even}	**0.89 ± 0.08 (stat) ± 0.06 (syst)**
Yield	452 ± 28

Sources of Dominant Systematic Error

- Fit bias
- Tag-side CP violation

$$\sin(2\beta)\ \left(= -S_{K+K-Ks}/(2\ f_{even} - 1)\right) = 0.55 \pm 0.22\ (\text{stat}) \pm 0.04\ (\text{syst}) \pm 0.11\ (\text{cp})$$





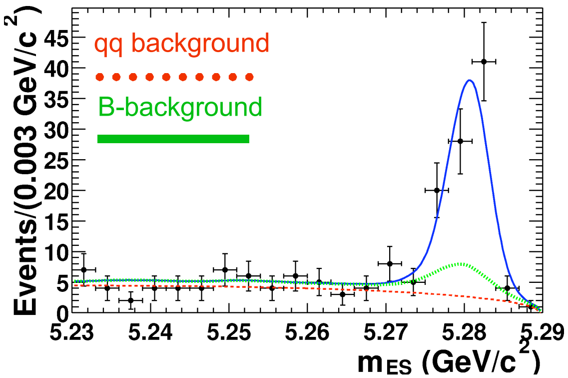
$B^0 \rightarrow f_0K_s(1)$

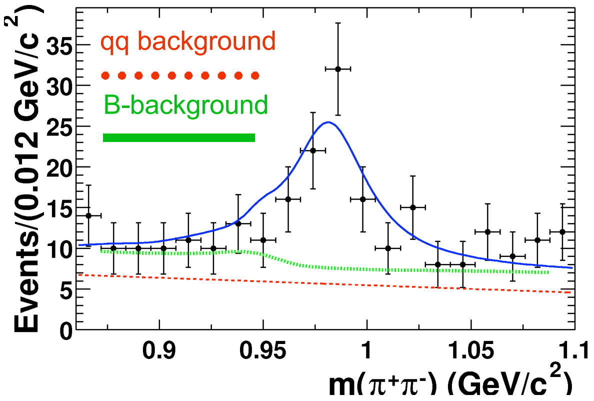
- *BR*($B^0 \rightarrow f_0(980)K_s$) ~ 6×10^{-6} [BABAR, hep-ex/0406040]
- Width ($f_0(980)$) ~ $45^{+12}_{-9} \pm 10$ MeV [BABAR, hep-ex/0406040]
- Requires thorough estimation of CP dilution due to interference in B0 → $\pi\pi K_s$ Dalitz plot

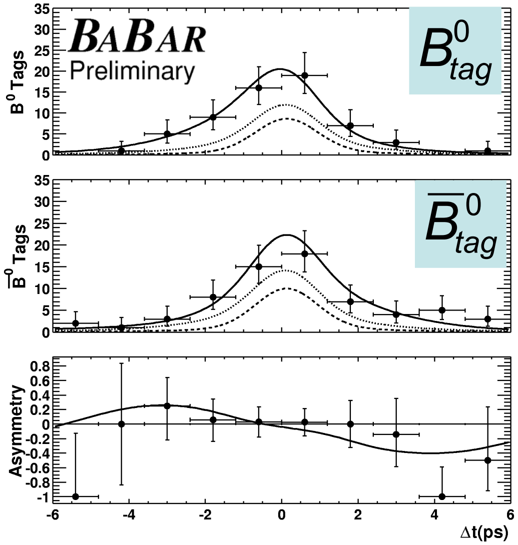
S_{f0Ks}	**$-0.95\ ^{+0.32}_{-0.23}$ (stat) ± 0.10 (syst)**
C_{f0Ks}	**-0.24 ± 0.31 (stat) ± 0.15 (syst)**
Yield	152 ± 19 (stat)

Sources of Dominant Systematic Error

- Fit bias
- Interference with other modes



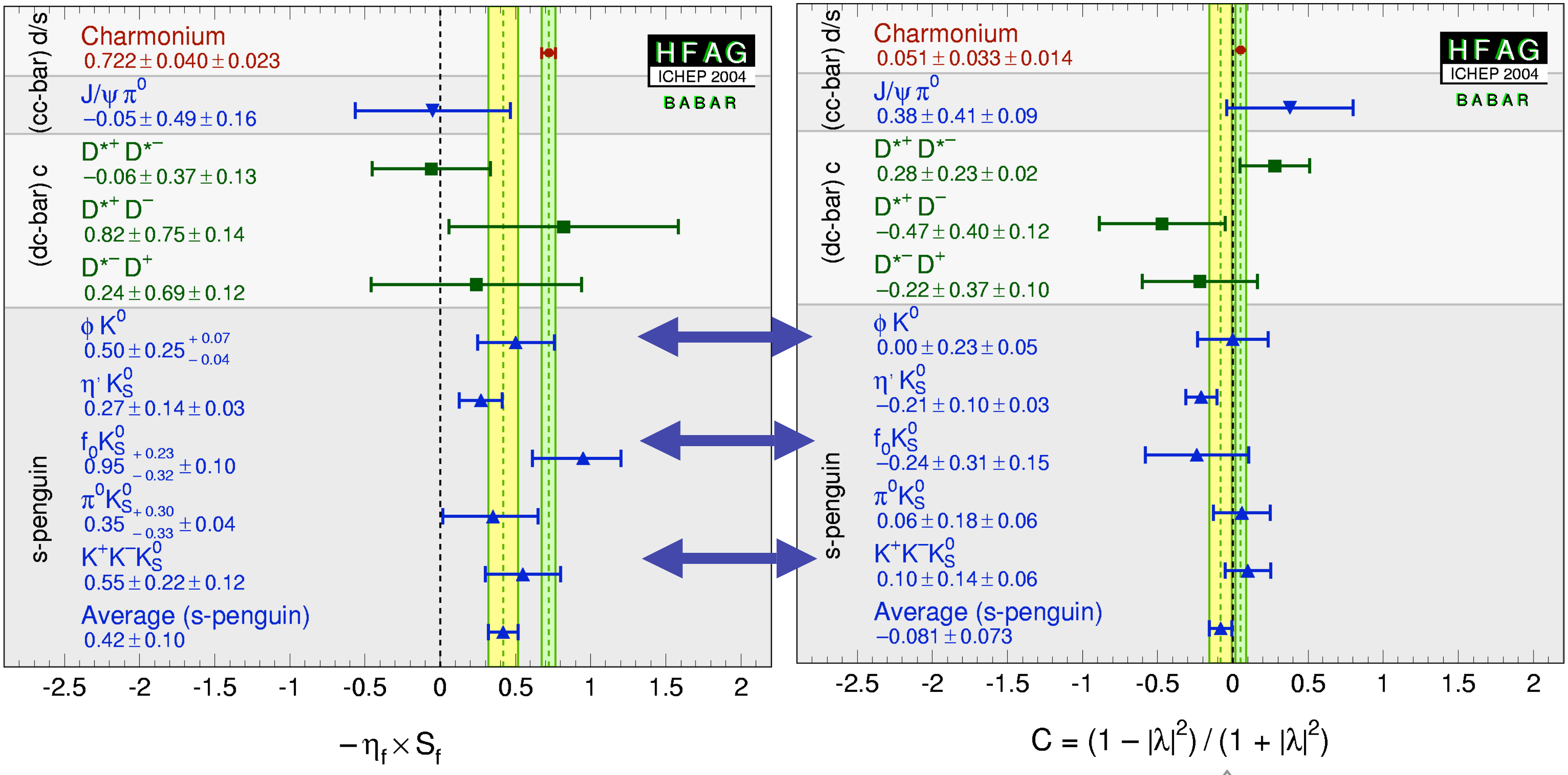




BaBar measurements of sin2B

For ϕK,KKK$_s$,f$_0$K$_s$: weighted avg sin(2β) = 0.62 ± 0.16

***s*-penguin average at 2.7σ from sin2β[cc] (BABAR only)**



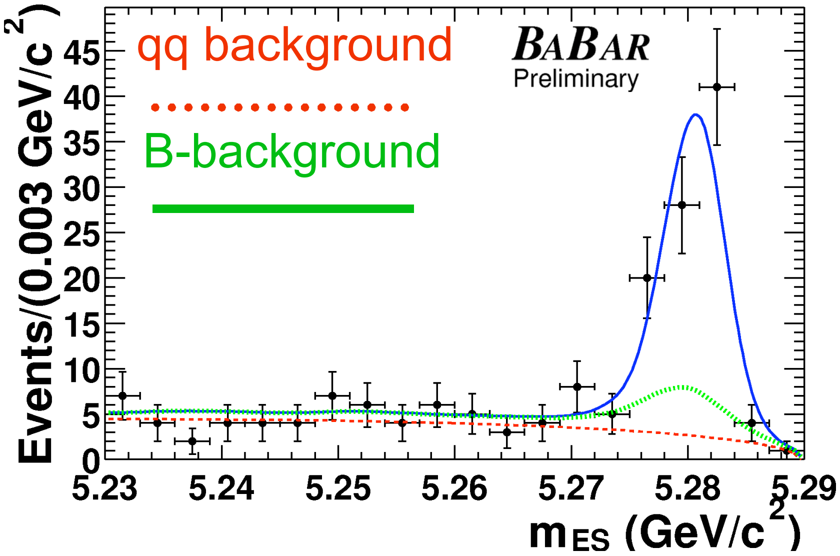
no indication for direct *CP* violation

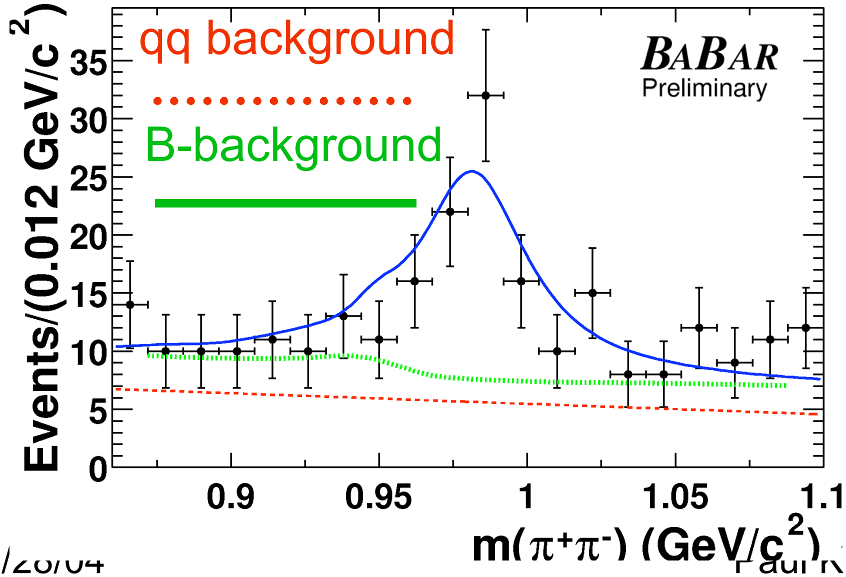
Conclusion

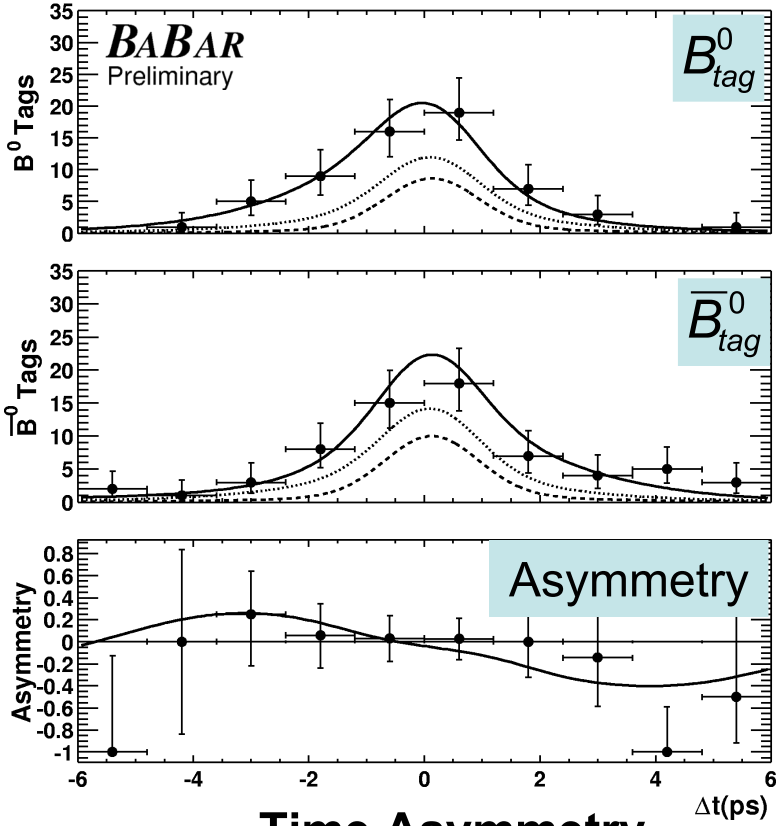
- BaBar has new $\sin(2\beta)$ results for penguin-dominated $b \rightarrow sss$ decays
- Not yet clear whether seeing new physics
- Errors dropping- beginning to obtain a precision measurement

	$\sin(2\beta)$- Preliminary
ϕK^0	**$+0.50 \pm 0.25$ (stat) $^{+0.07}_{-0.04}$ (syst)**
$K^+K^-K_s$	**$+0.55 \pm 0.22$ (stat) ± 0.04 (syst) ± 0.11 (cp)**
f_0K_s	**$+0.95\,^{+0.23}_{-0.32}$ (stat) ± 0.10 (syst)**

$B^0 \rightarrow f_0K_s$(2)- Bigger Plots







Time Asymmetry