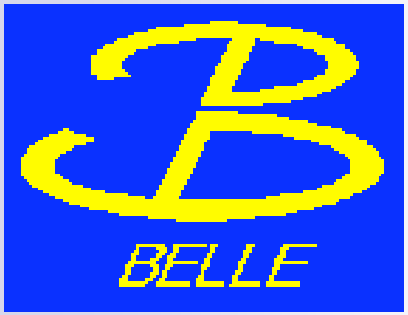
Experimental Status of sin2β Measured from b→s Penguin Decays



TM & © Nelvana

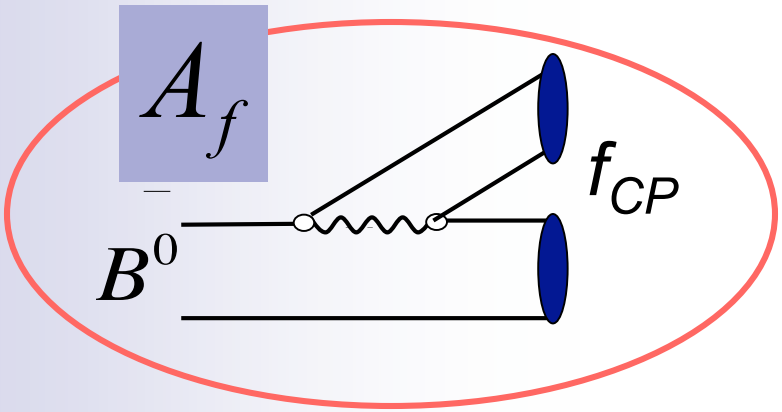
Mathew Graham

SLAC

FPCP06: Vancouver

April 9, 2006

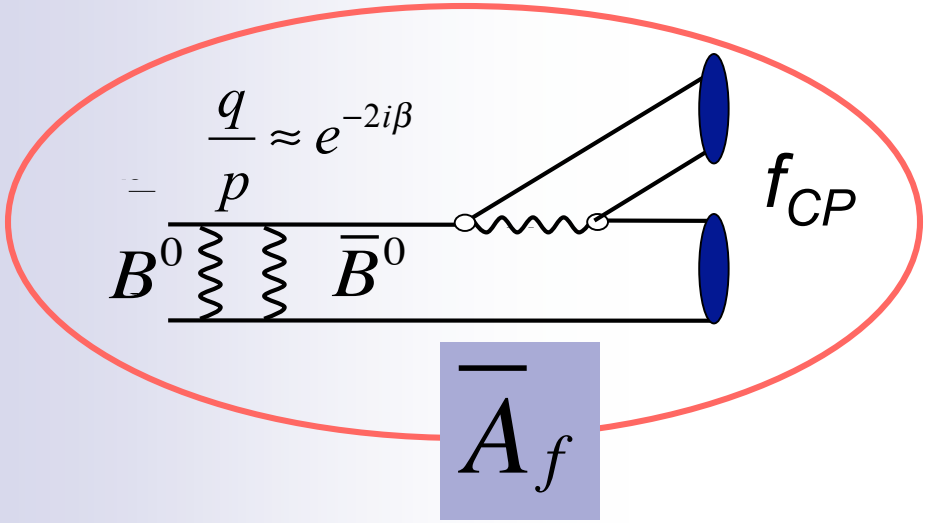
Time-Dependent CP-Violation



$$A_{CP}(\Delta t) = \frac{\Gamma\left(\overline{B} \to f\right) - \Gamma\left(B \to f\right)}{\Gamma\left(\overline{B} \to f\right) + \Gamma\left(B \to f\right)}$$

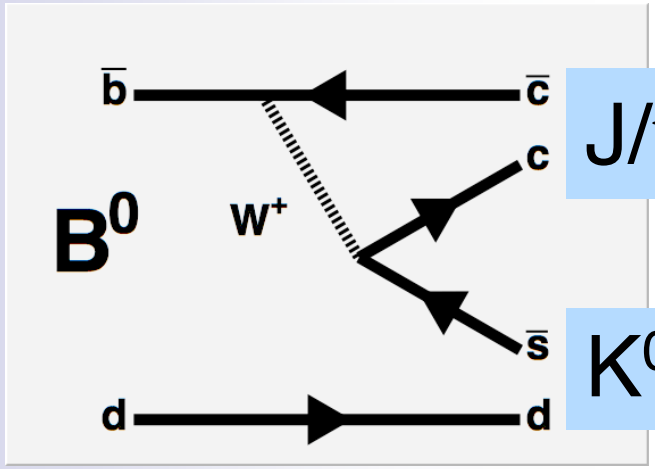
$$= \frac{2\,\mathrm{Im}\,\lambda}{1+|\lambda|^2}\sin\Delta m_d \Delta t - \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos\Delta m_d \Delta t$$

"S" "C"



$$\lambda = \eta_f \left(\frac{q}{p}\right)\left(\frac{\overline{A}_f}{A_f}\right)$$

Measuring sin2β with charmless B-decays



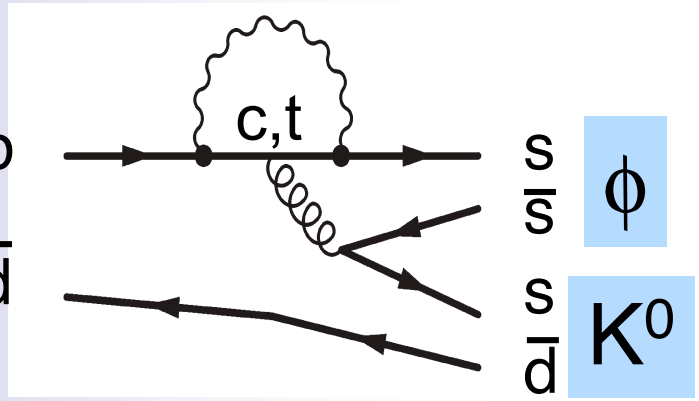
J/ψ

K0

B0→J/ψK0

BR~ 10-3

sin2β=0.69±0.03



ϕ

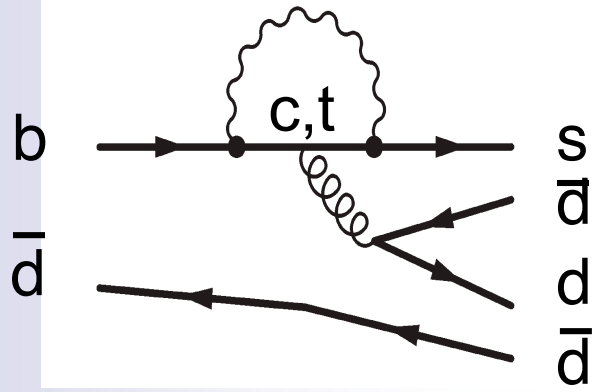
K0

B0→ϕK0

BR~ 10-5

Sources of Standard Model pollution

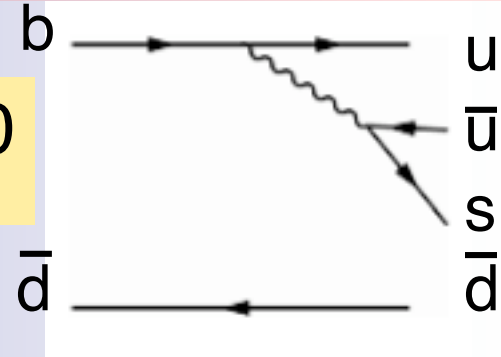
There are many modes that dominantly decay via $b \to s(q\bar{q})$…but not all modes were created equal



K^0

$\omega, \pi^0, \rho^0, \eta'(?), f_0(?)\ldots$

This is ok; still gives $\sin 2\beta$ in SM.

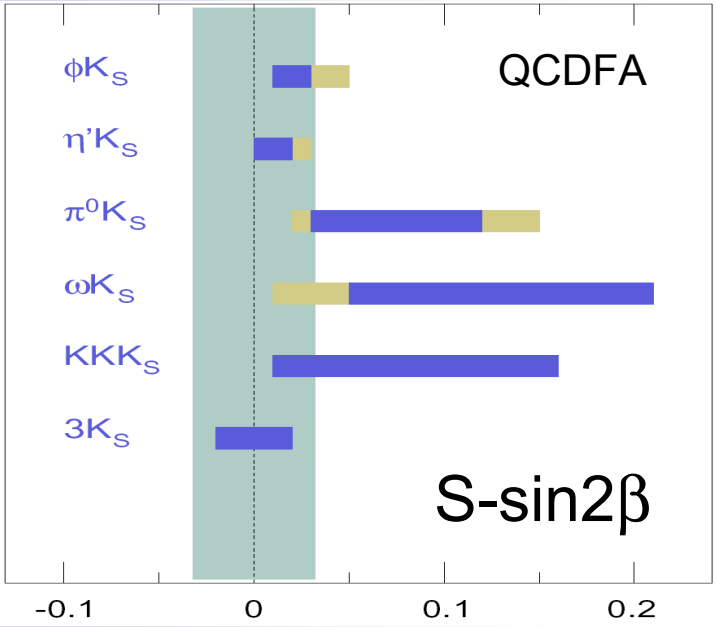


$\omega, \pi^0, \rho^0, \eta'(?), f_0(?)\ldots$

K^0

CKM and color suppressed.. but will lead to slight deviation.

Expected deviations from sin2β



2-body: [Beneke; PL B620, 143 (2005)]
3-body: [Cheng,Chua,Soni; PRD72, 094003 (2005)]

There are various estimates for the deviation from sin2β due to SM pollution…most of them expect a ***larger*** value!

Measuring the rates of related modes help to pin down the magnitude of these deviations

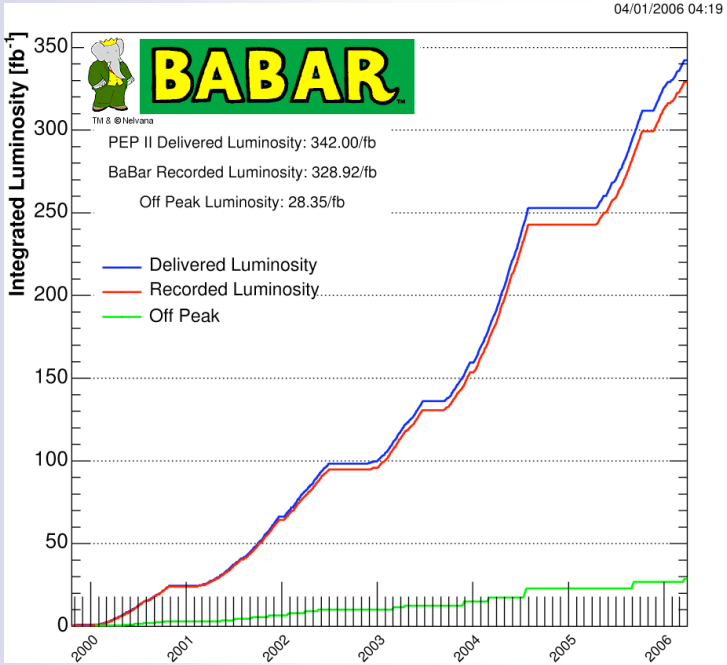
Status of the B-Factories

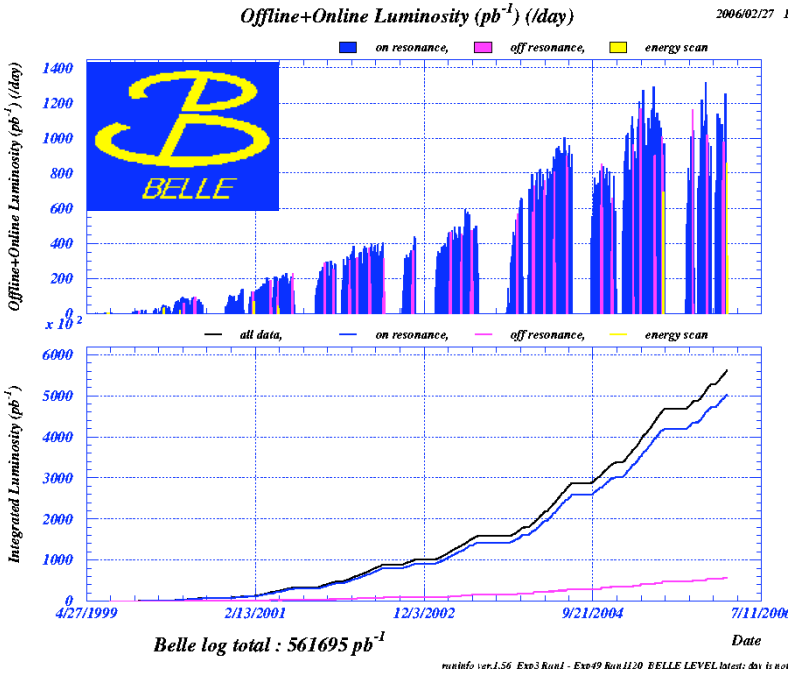
Belle : 500 fb^{-1}; current results based on 357 fb^{-1}

(almost) all results from hep-ex/0507037 and are preliminary

BaBar: 330 fb^{-1}; current results based on 210 fb^{-1}

results come from variety of publications

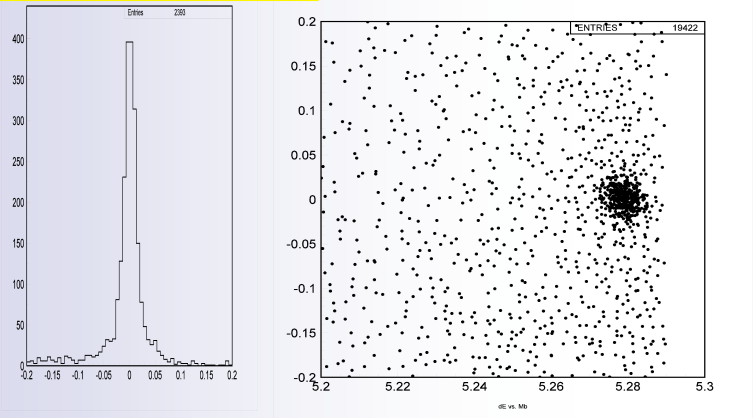




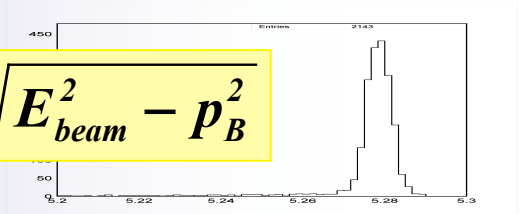
Detecting a signal…in general

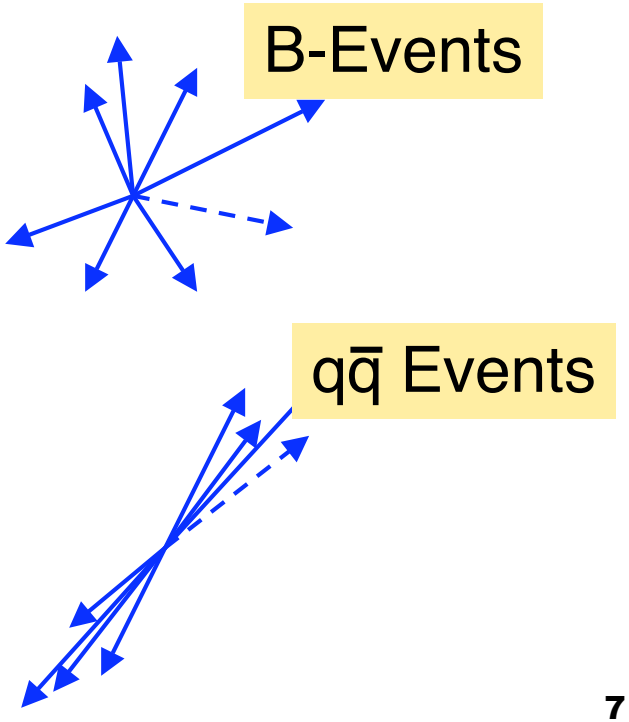
- largest source of background comes from qq interactions
  - use ΔE, m_{ES}, and event shape to discriminate signal from background
  - in case of quasi-2 body modes (ϕK^0, $\eta' K^0$, etc) can also use invariant mass and helicity information

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

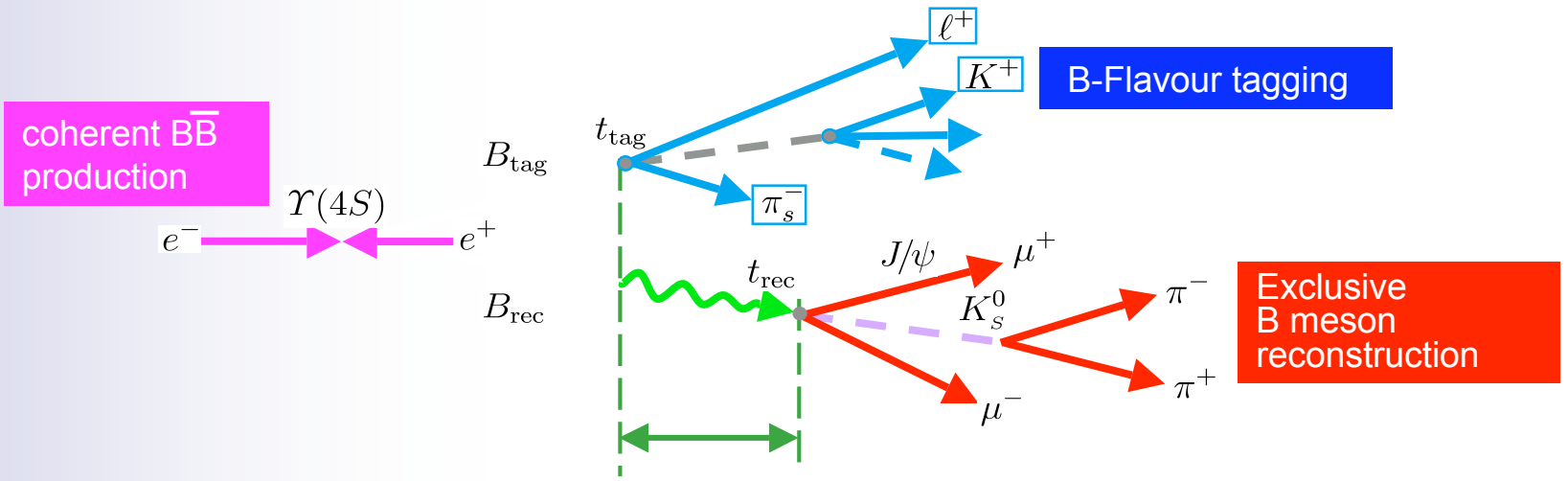


$$M_{ES} = \sqrt{E_{beam}^2 - p_B^2}$$





Tagging the B and measuring Δt



The Δt resolution function obtained from high stat. B$\rightarrow$DX

Events tagged using the charge of the leptons, kaons, pions

Effective tagging efficiency (including mistag-rate) ~30%

The "golden" mode: ϕK^0

- Considered the "golden mode" because it's almost pure $b \to s\bar{s}s$
- Use both ϕK_s and ϕK_L

BaBar:

$N(\phi K_s) = 114 \pm 12$

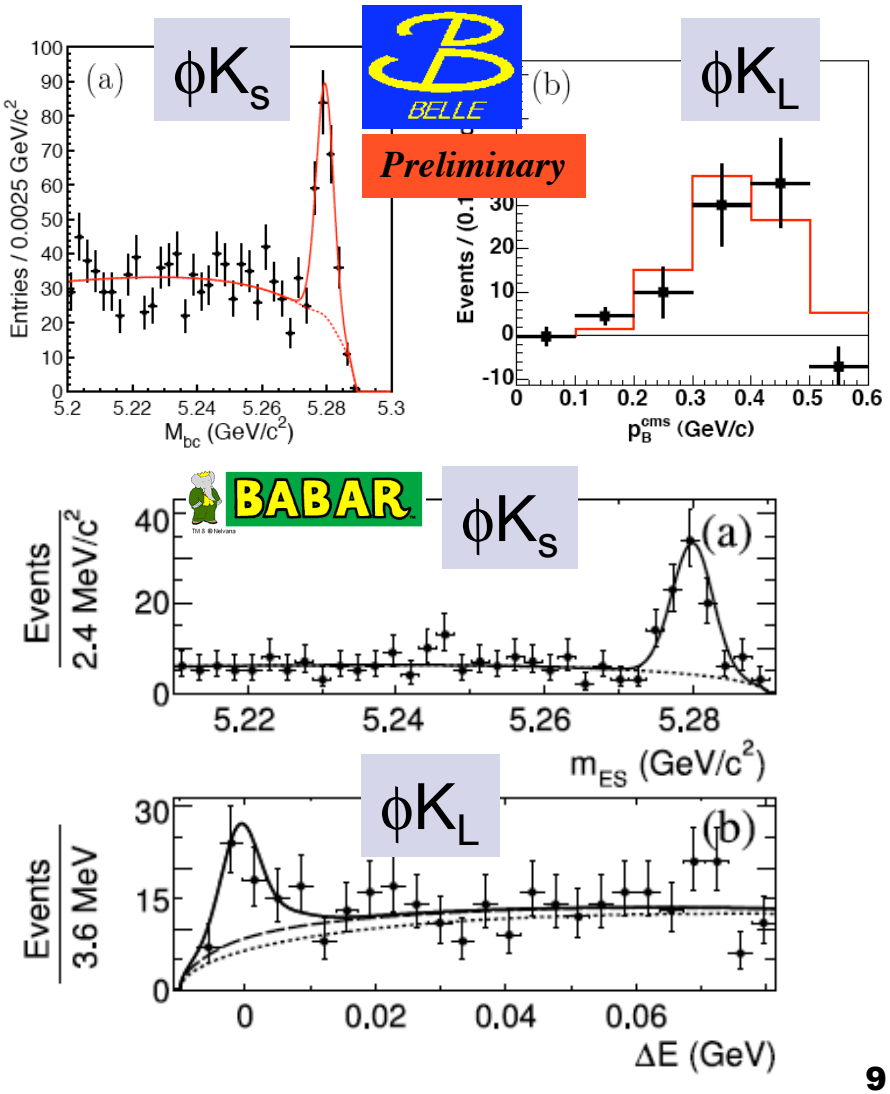
$N(\phi K_L) = 98 \pm 18$

Belle:

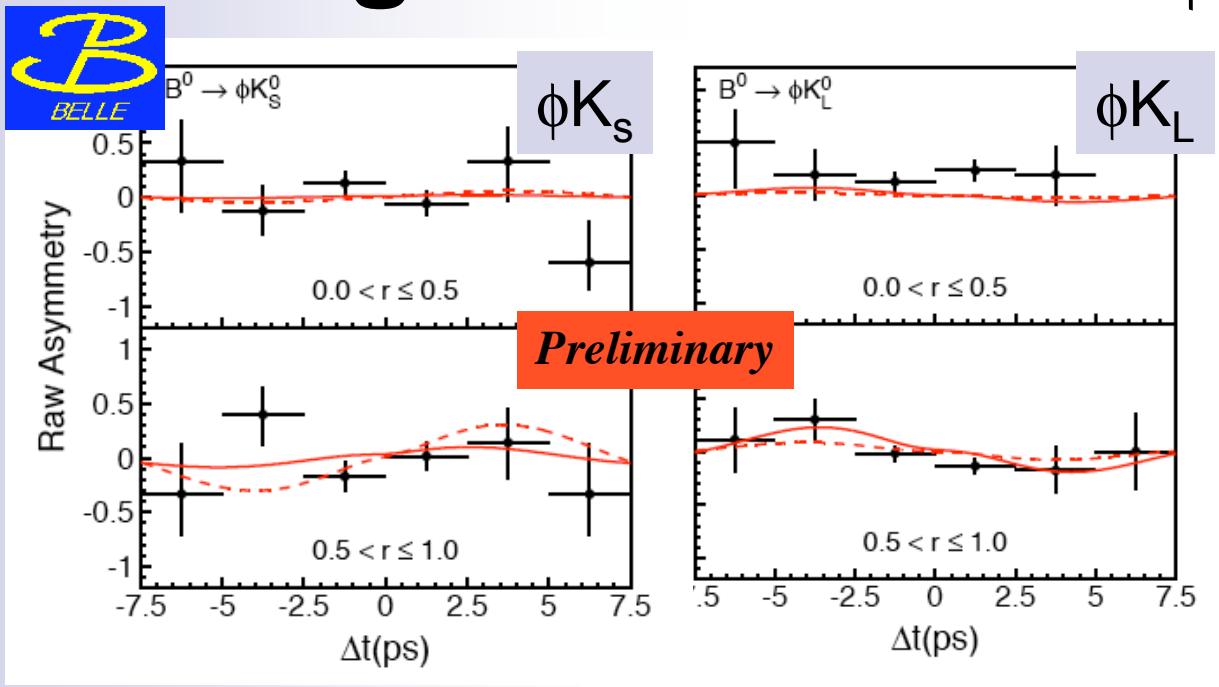
$N(\phi K_s) = 180 \pm 16$

$N(\phi K_L) = 78 \pm 13$

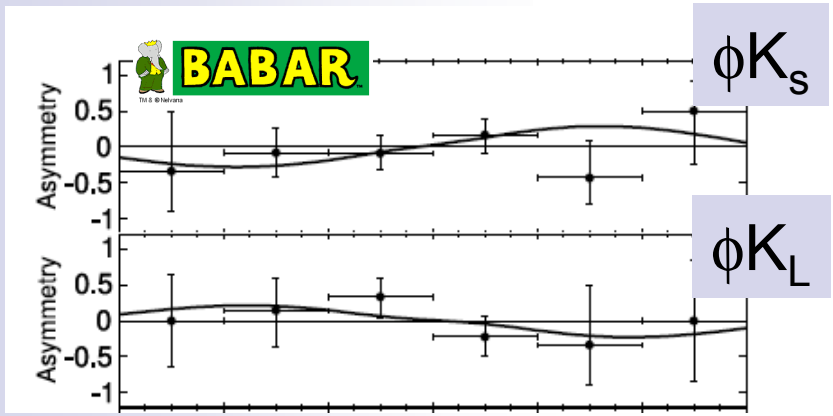
- No energy measurement for the K_L…constrain m_{ES} to m_B



The "golden" mode: ϕK^0



BaBar:
sin2β=0.50±0.25±0.06
C=0.00±0.23±0.05
Belle:
sin2β=0.44±0.27±0.05
C=-0.14±0.17±0.07



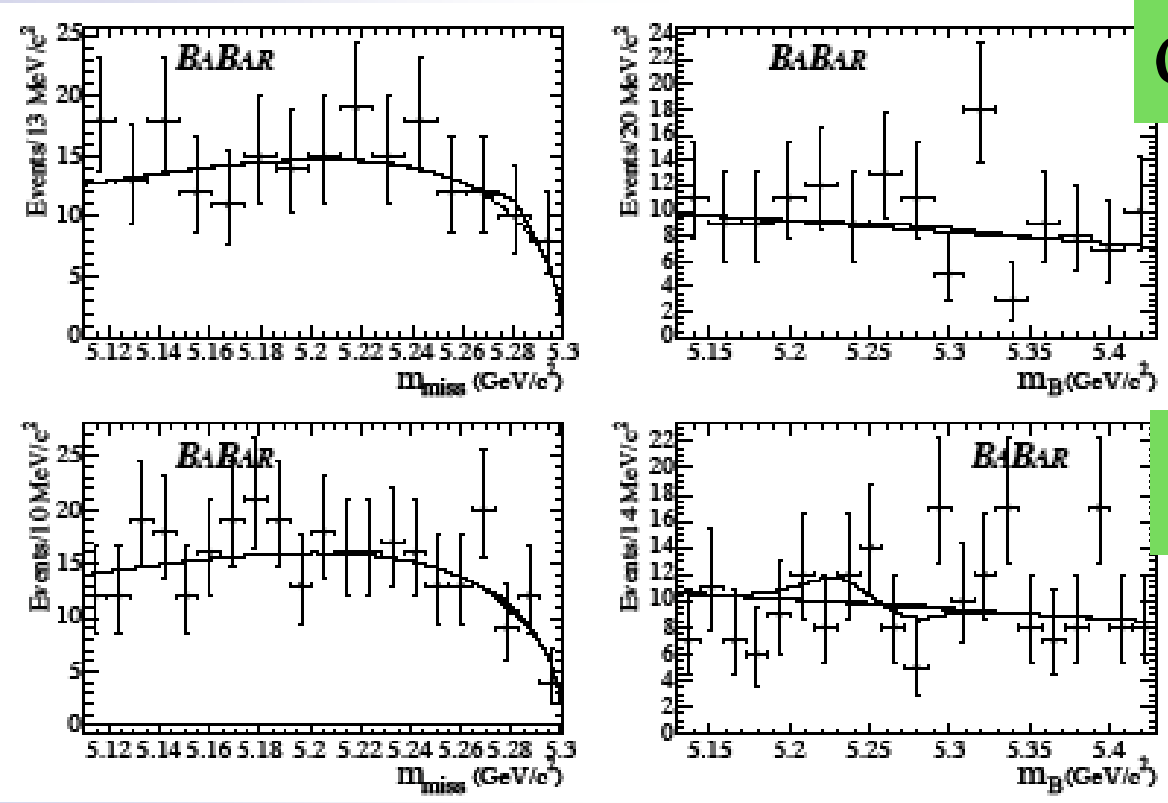
- fit both the Ks and KL samples to a common S/C
- good agreement between experiments!

NEW for '06

BABAR

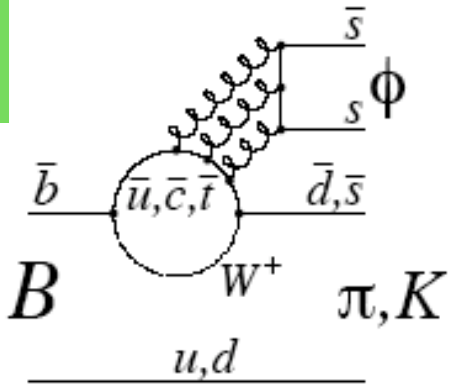
TM & © Nelvana

SM pollution to ϕK^0: $\phi\pi$



$\phi\pi^0$

$\phi\pi^+$



BaBar:

$N(\phi\pi^0) = 4.0 \pm 3.5$

$N(\phi\pi^+) = -1.5 \pm 5.9$

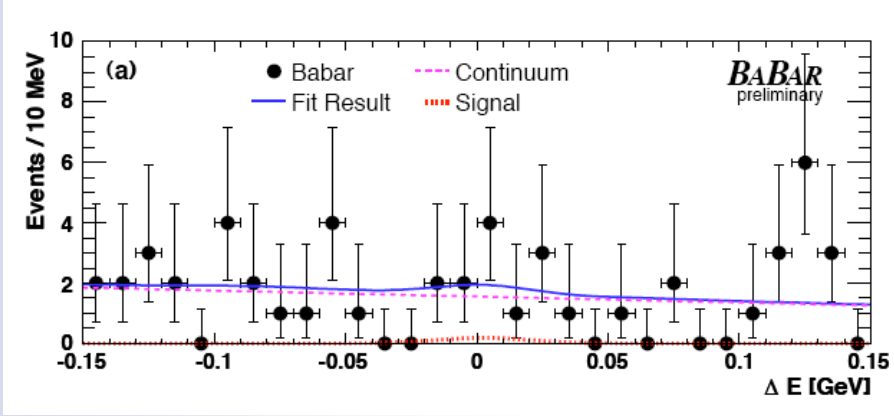
$BR(\phi\pi^0) < 2.8 \times 10^{-6}$

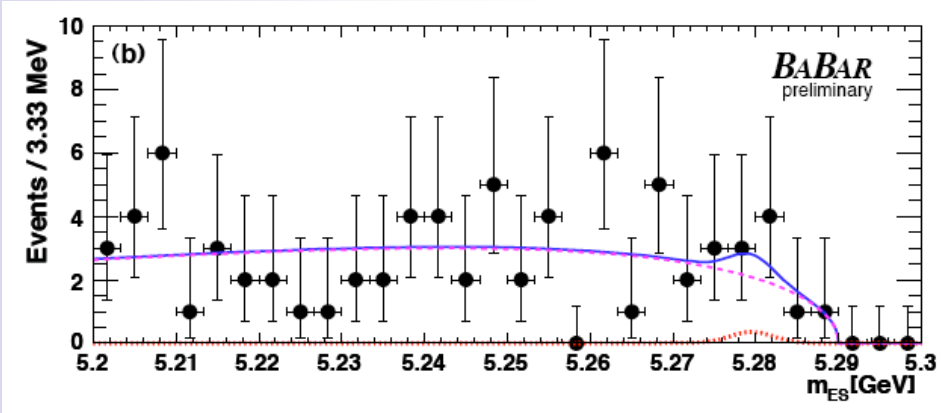
$BR(\phi\pi^+) < 2.4 \times 10^{-6}$

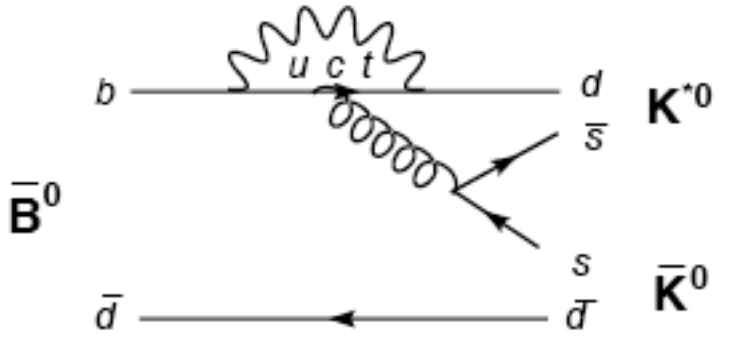
Preliminary

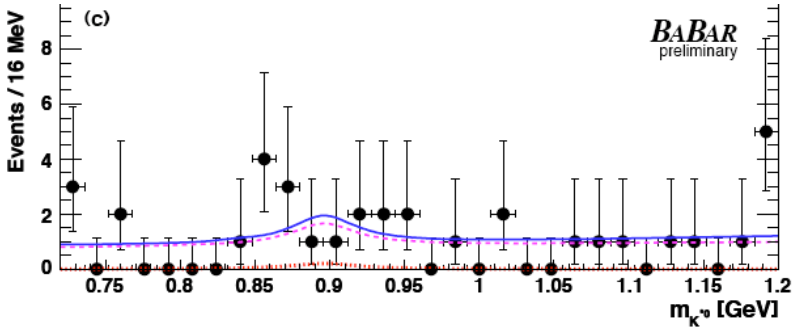
NEW for '06

SM pollution to ϕK^0: $K^{*0}K_s$









BaBar:

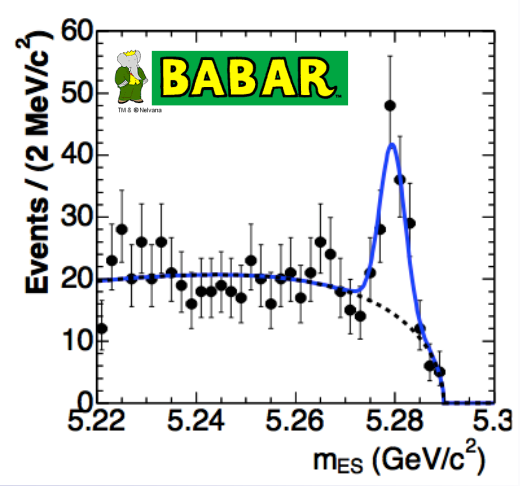
$N(K^{*0}K_s) = 1.0 \pm 4.3$

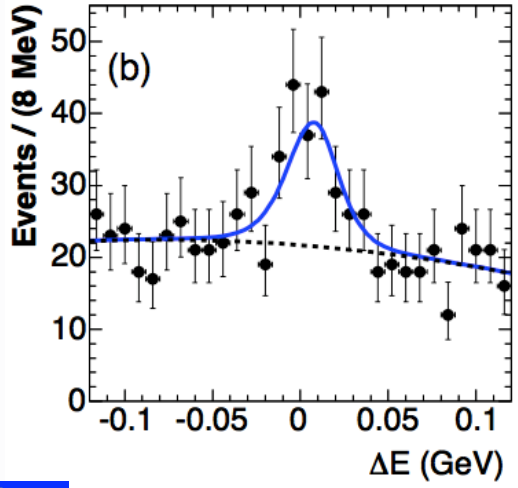
$BR(K^{*0}\overline{K}^0 + C.C.) < 1.9 \times 10^{-6}$

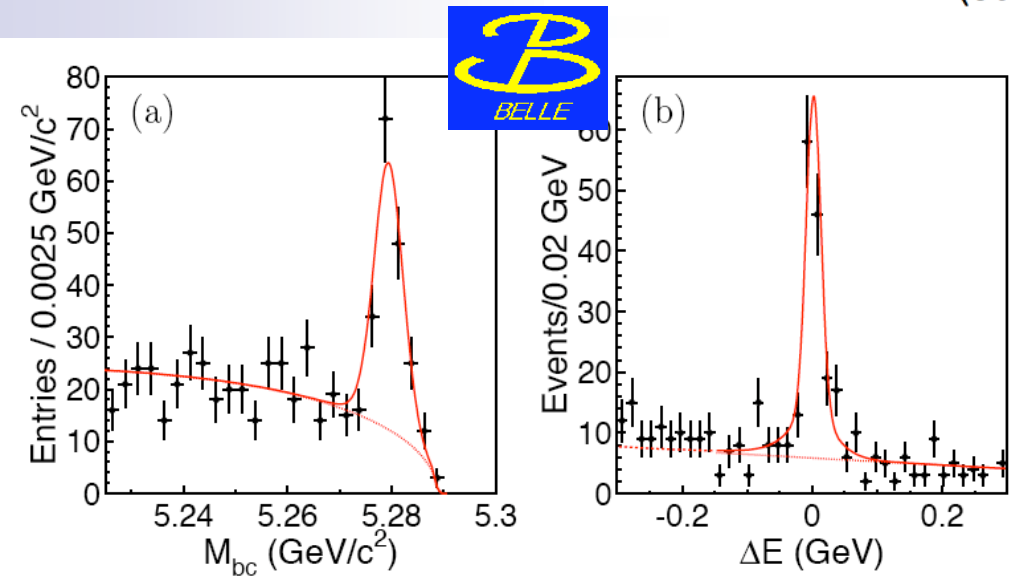
Preliminary

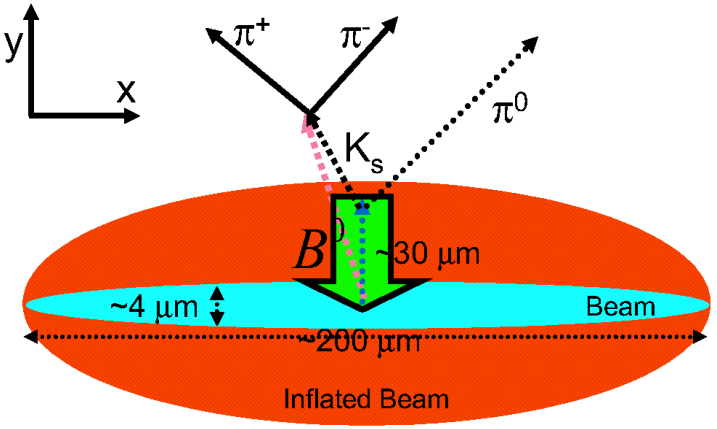
$K_sK_sK_s$

Preliminary





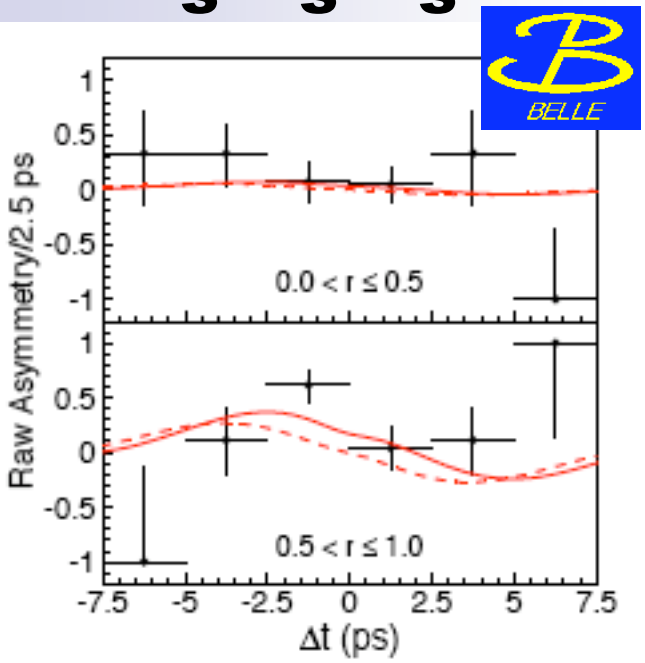


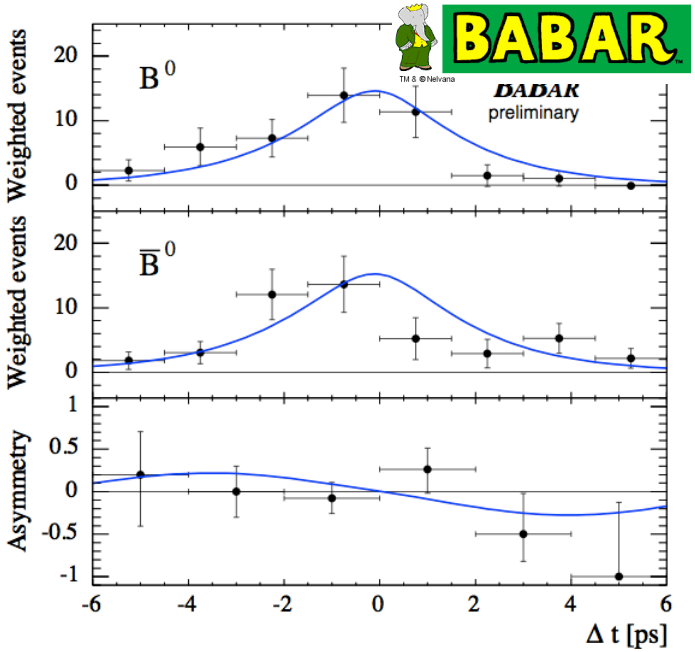


- The K_s fly…utilize the beam spot constraint in order to determine the vertex…
- Allow (at most) one K_s to decay to $\pi^0\pi^0$

BaBar:
$N(3K_s)= 129 \pm 13$
Belle:
$N(3K_s)=105 \pm 12$

$K_sK_sK_s$ time-dependent results





- one of the cleanest modes w/r to SM pollution
- also quite clean experimentally because of the $3K_s$'s

Preliminary

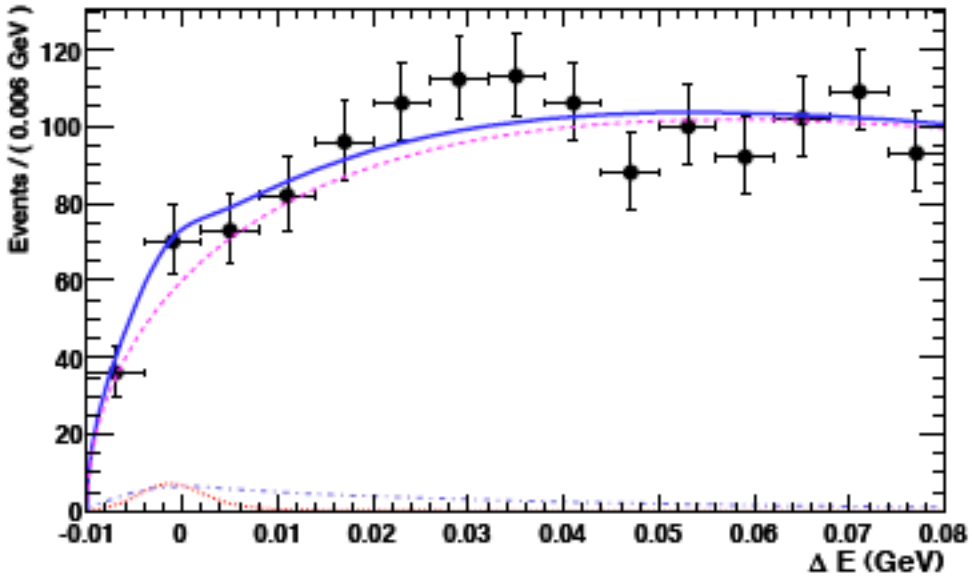
BaBar:
$\sin 2\beta = 0.63 \pm 0.30 \pm 0.04$
$C = -0.10 \pm 0.25 \pm 0.05$
Belle:
$\sin 2\beta = 0.58 \pm 0.36 \pm 0.08$
$C = -0.50 \pm 0.23 \pm 0.06$

NEW for '06

$K_sK_sK_L$

Excluding ϕK_s

Preliminary



Like KsKsKs, this is a very clean mode w/r to SM pollution…the K_L makes it more difficult experimentally

BaBar:

$N(K_sK_sK_L) = 23.0 \pm 23 \pm 6$

----Assuming phase space

$BR(K_sK_sK_L) < 6.4 \times 10^{-6}$

----No Assumptions

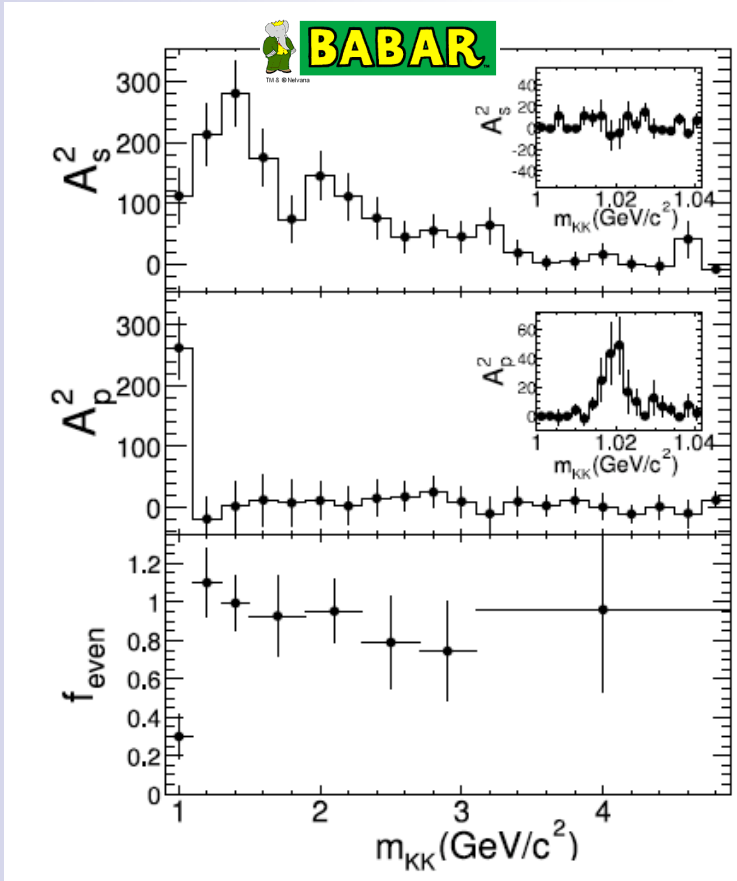
$BR(K_sK_sK_L) < 14 \times 10^{-6}$

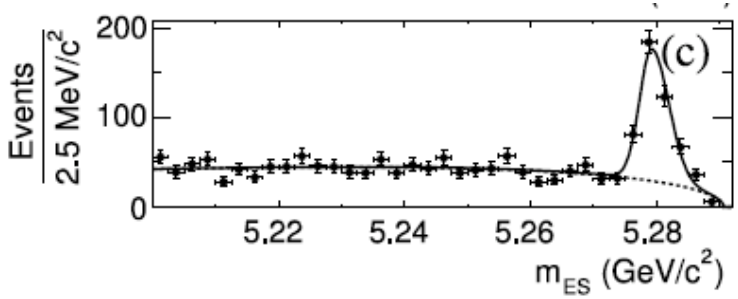
The prediction** for this mode is $BR \sim 6 \times 10^{-6}$

**Cheng,Chua,Soni; PRD72, 094003 (2005)

$K^+K^-K^0$ CP content

Excluding ϕK_s





- $K^+K^-K^0$ compliments ϕK^0 nicely with higher statistics…two problems
  - not in a definite CP eigenstate
  - tree contribution to NR component
- Fortunately, this decay is almost entirely CP-even (for K_s-mode)

BaBar:

$N(K^+K^-K_s)=452 \pm 28$

$f_{even}=0.89 \pm 0.08 \pm 0.06$ (moments)

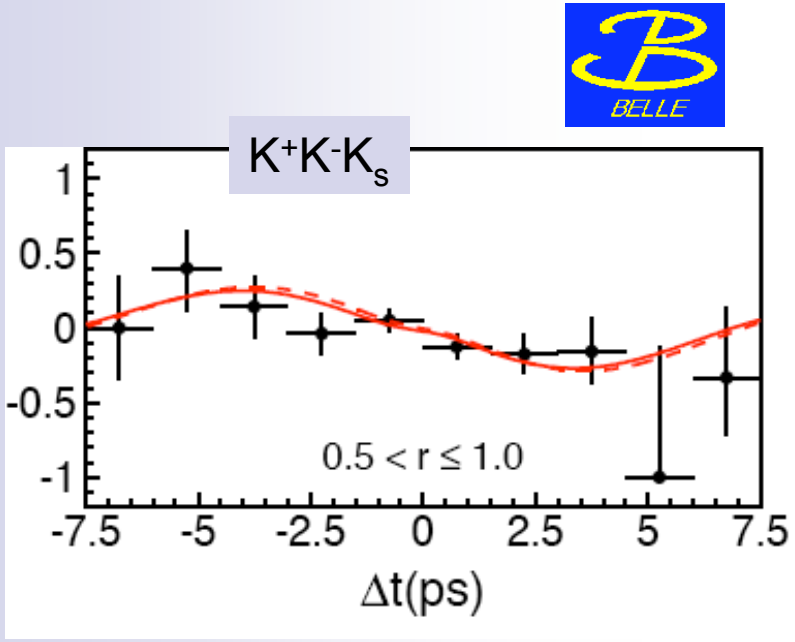
Belle:

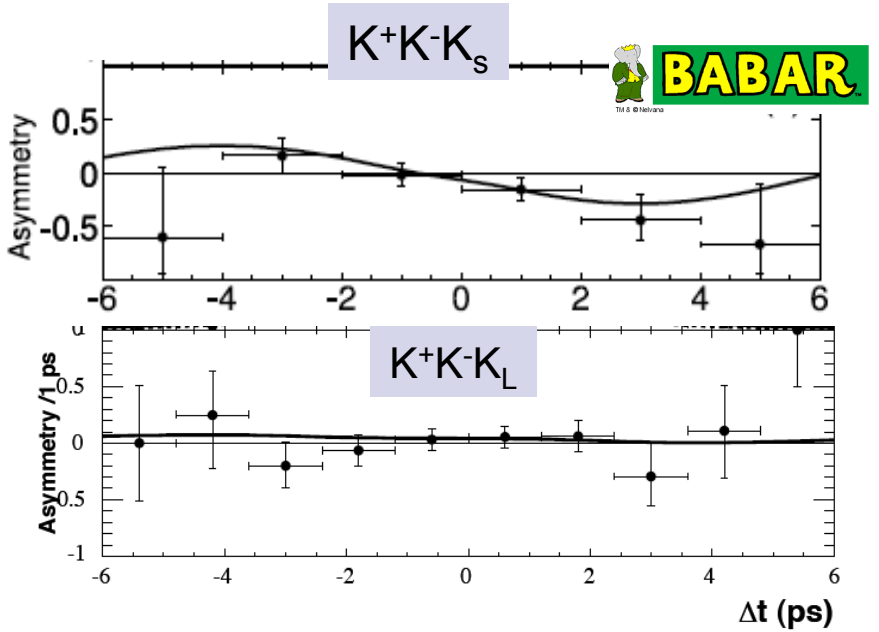
$N(K^+K^-K_s)=536 \pm 29$

$f_{even}=0.93 \pm 0.09 \pm 0.05$ (SU2)

Excluding ϕK_s

$K^+K^-K^0$ time-dependent results



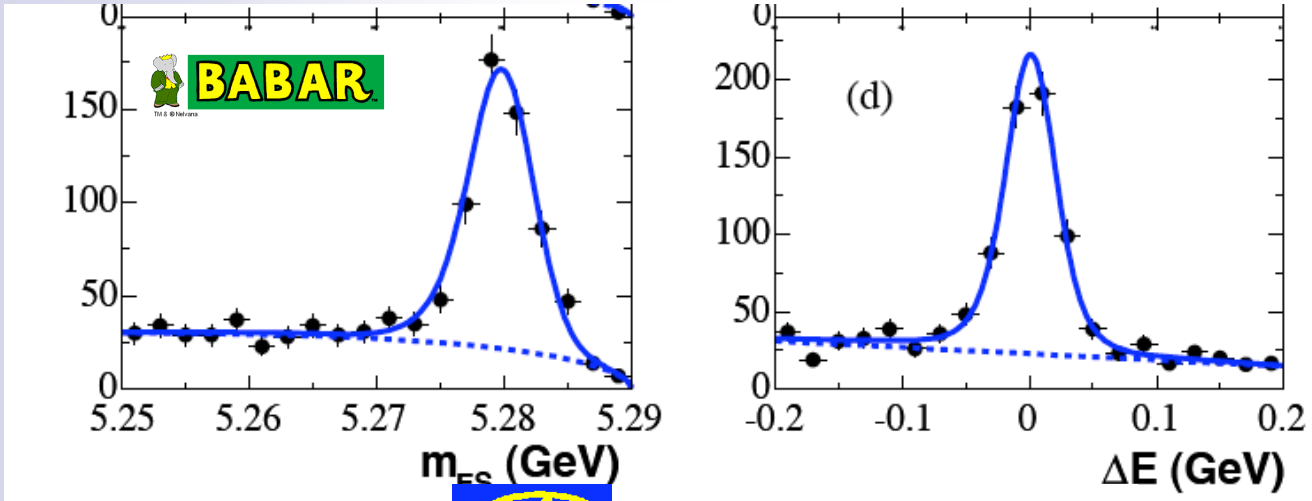


BaBar:
sin2β=0.41±0.18±0.07±0.11(CP)
C=0.23±0.13
Belle:
sin2β=0.60±0.18±0.04±0.16(CP)
C=0.06±0.11±0.07

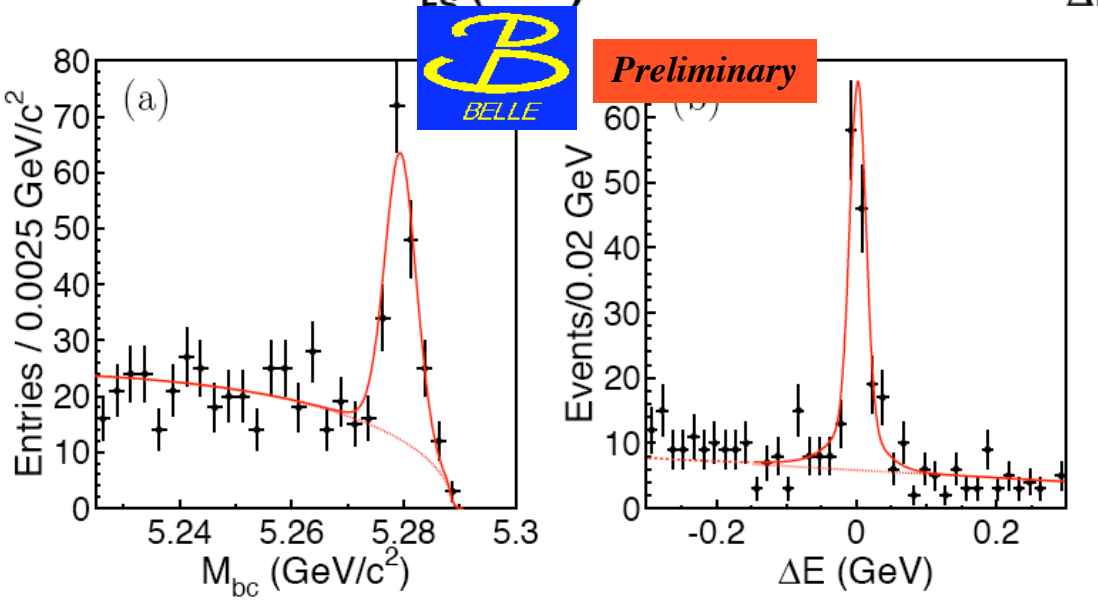
The BaBar result includes
777 ± 80 $K^+K^-K_L$
events(preliminary)

Preliminary

η'K⁰: the second "golden" mode?



- very high statistics
- most models predict small SM pollution



BaBar:

$N(\eta' K_s)=804 \pm 40$

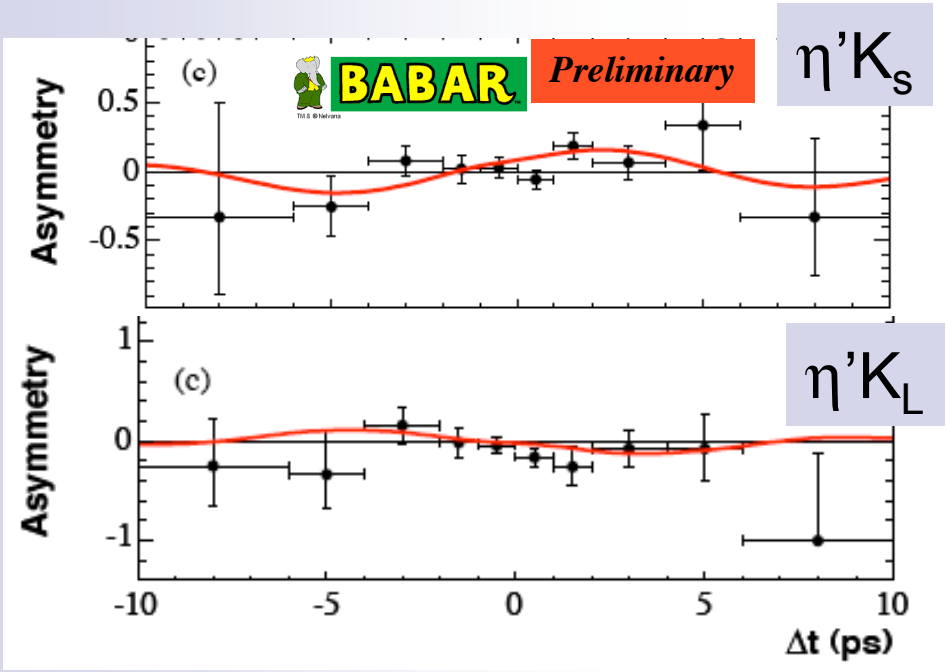
$N(\eta' K_L)=440 \pm 53$

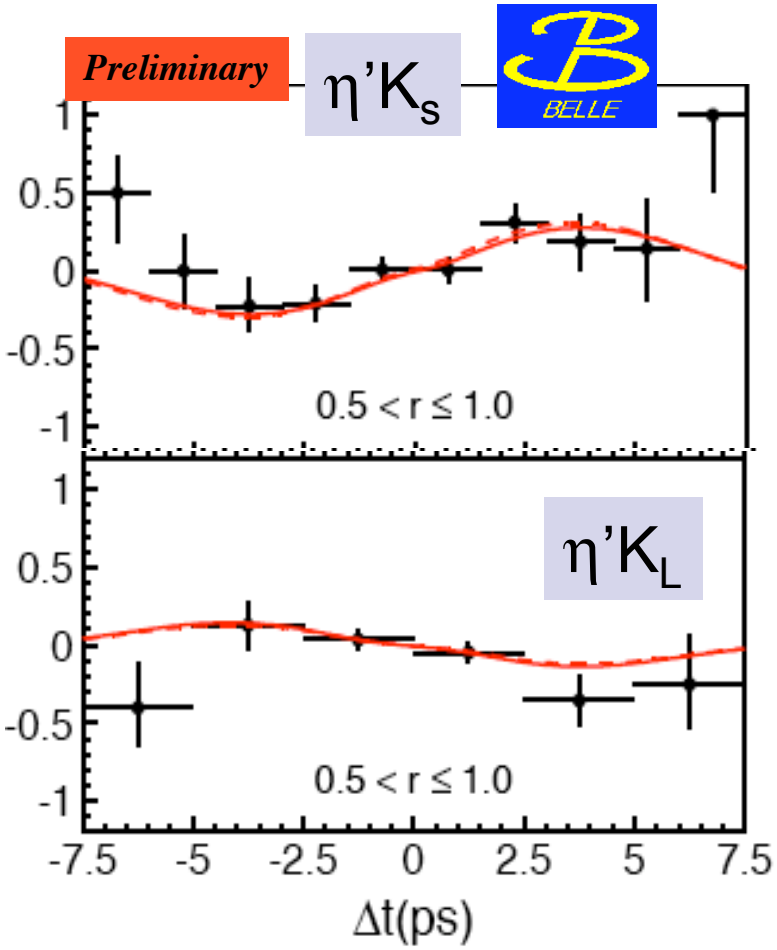
Belle:

$N(\eta' K_s)=830 \pm 35$

$N(\eta' K_L)=187 \pm 18$

η'K⁰ time-dependent results





BaBar:

sin2β=0.36±0.13±0.03

C=-0.16±0.09±0.02

Belle:

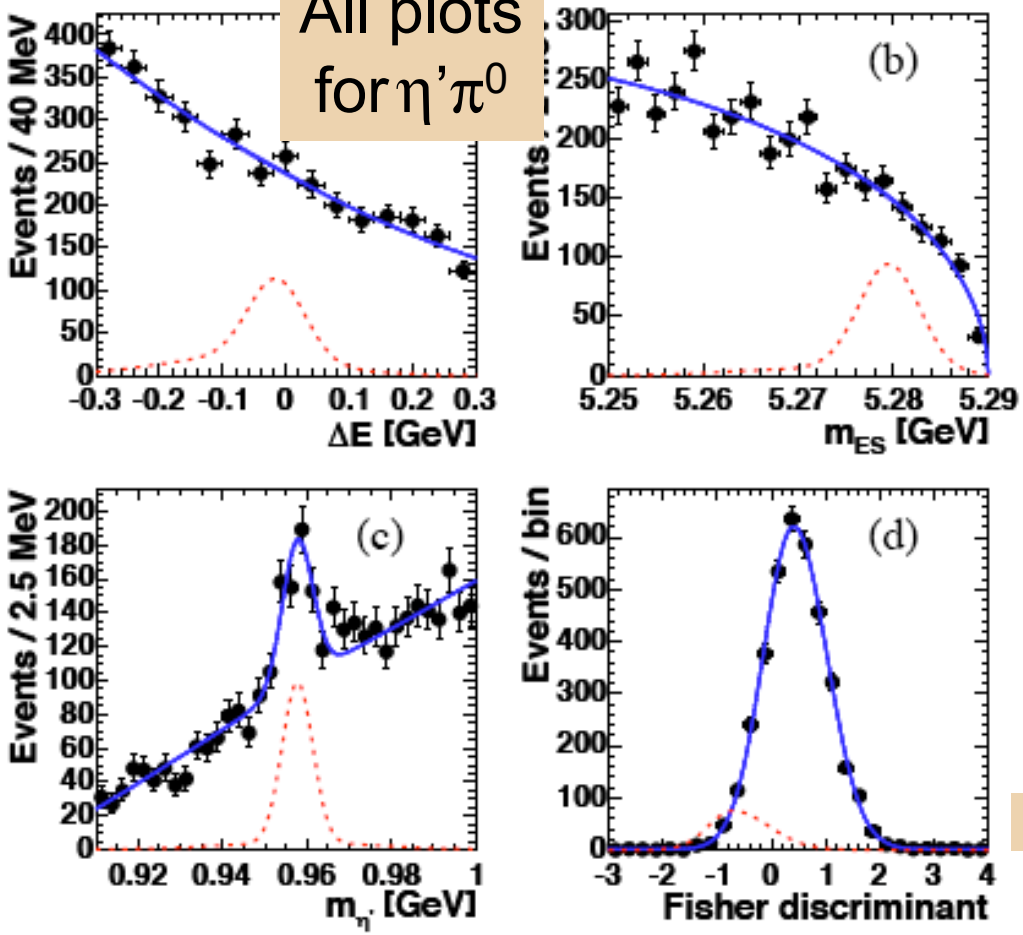
sin2β=0.62±0.12±0.04

C=-0.04±0.08±0.06

NEW for '06

$\eta'K^0$ SM pollution: $\eta'\pi^0, \eta\pi^0, \eta'\eta$

All plots for $\eta'\pi^0$



- These 3 modes help constrain the tree and color-singlet penguin contributions to $\eta'K^0$
- Expectations for the BRs are ~0.2-2 x 10^{-6}

BaBar:

$BR(\eta'\pi^0) < 2.1 \times 10^{-6}$

$BR(\eta\pi^0) < 1.3 \times 10^{-6}$

$BR(\eta'\eta) < 1.7 \times 10^{-6}$

Belle:

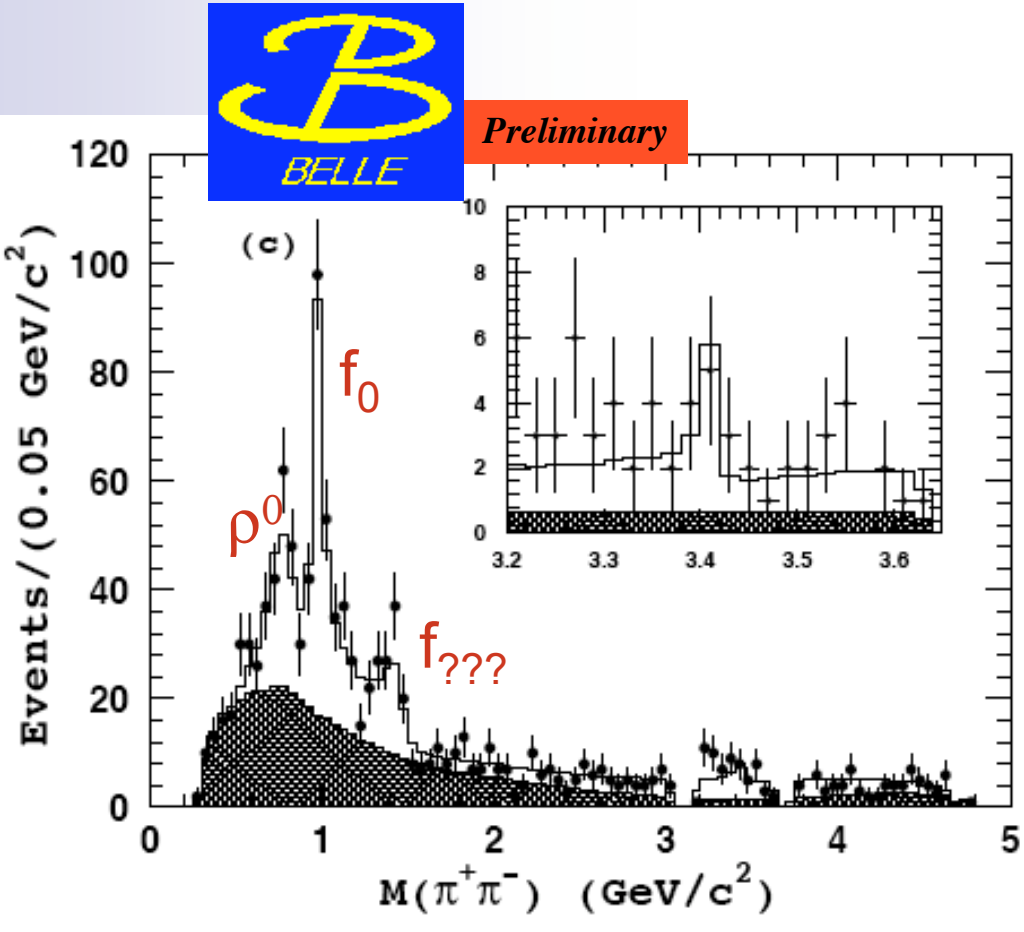
new! $BR(\eta'\pi^0) = (2.8 \pm 1.0 \pm 0.3) \times 10^{-6}$

$BR(\eta\pi^0) < 2.3 \times 10^{-6}$

BaBar result accepted by PRD-RC; hep-ex/0603013

See talk by J. Smith for more details on $\eta'\pi^0$

sin2β_{eff} from $B^0 \to \pi^+\pi^- K_s$ final states



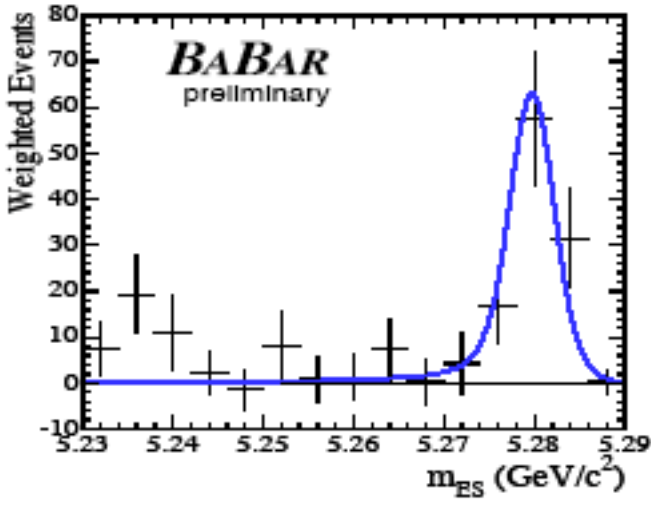
- quite a few CP events in this decay including $\rho^0 K_s$ and $f_0 K_s$
- also a higher (f?) resonance ~1500 MeV
- there is a possible tree diagram which contaminates the sin2β measurement
- time-dep CP has been measured for $f_0 K_s$ and (now) $\rho^0 K_s$

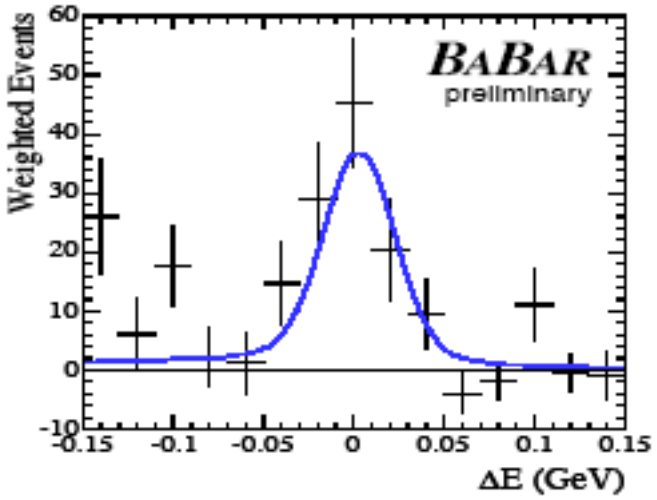
Last summer, Belle presented a (time and tag independent) DP analysis of this mode…this approach will be important in the future!

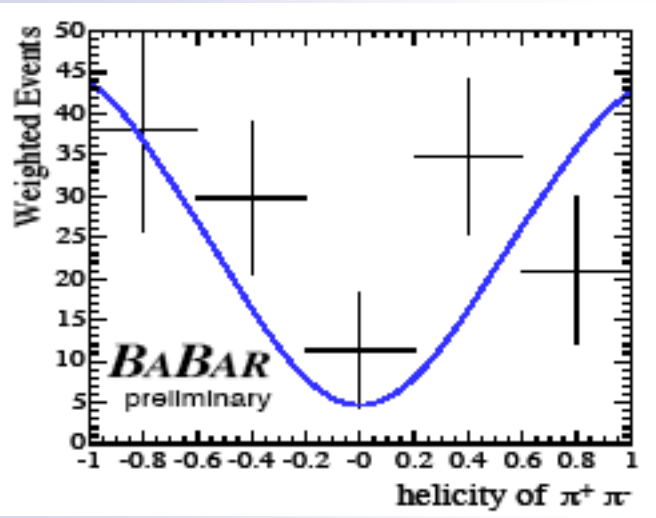
NEW for '06

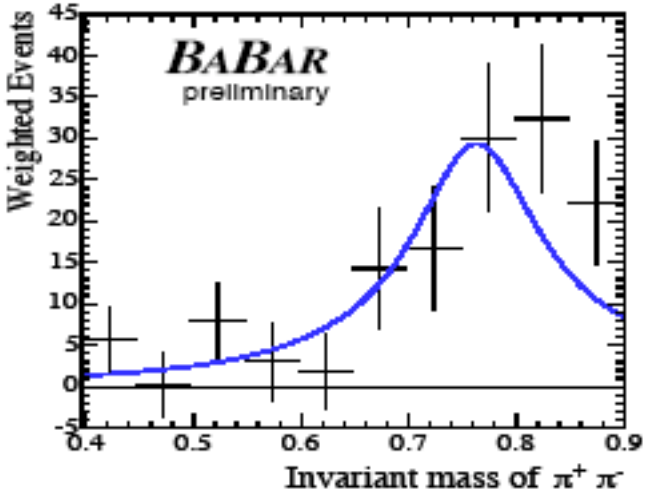
ρKs: a new mode

Preliminary









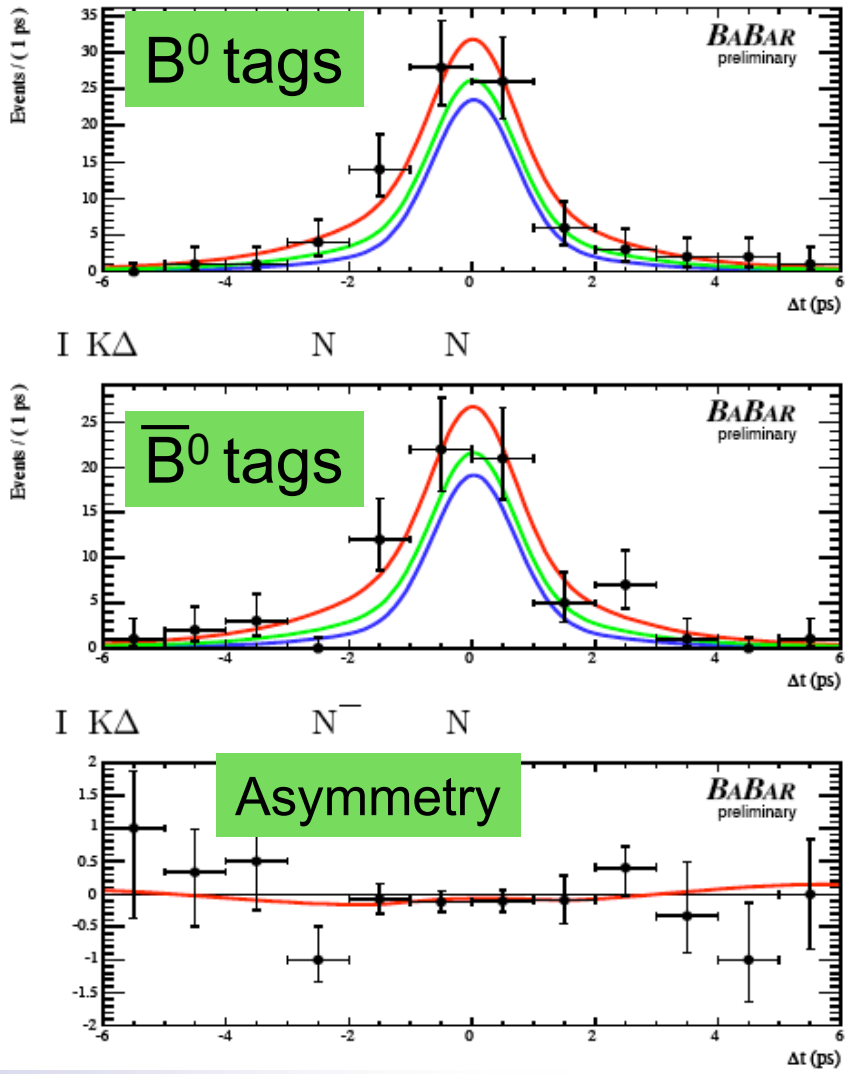
BaBar:
$N(\rho K_s) = 111 \pm 19$

Complications
- high bkg
- ρ is broad
- CP-even "under" the ρ?

NEW for '06

ρKs results

Preliminary



BaBar:
sin2β=0.17±0.52±0.26
C=0.64±0.41±0.25

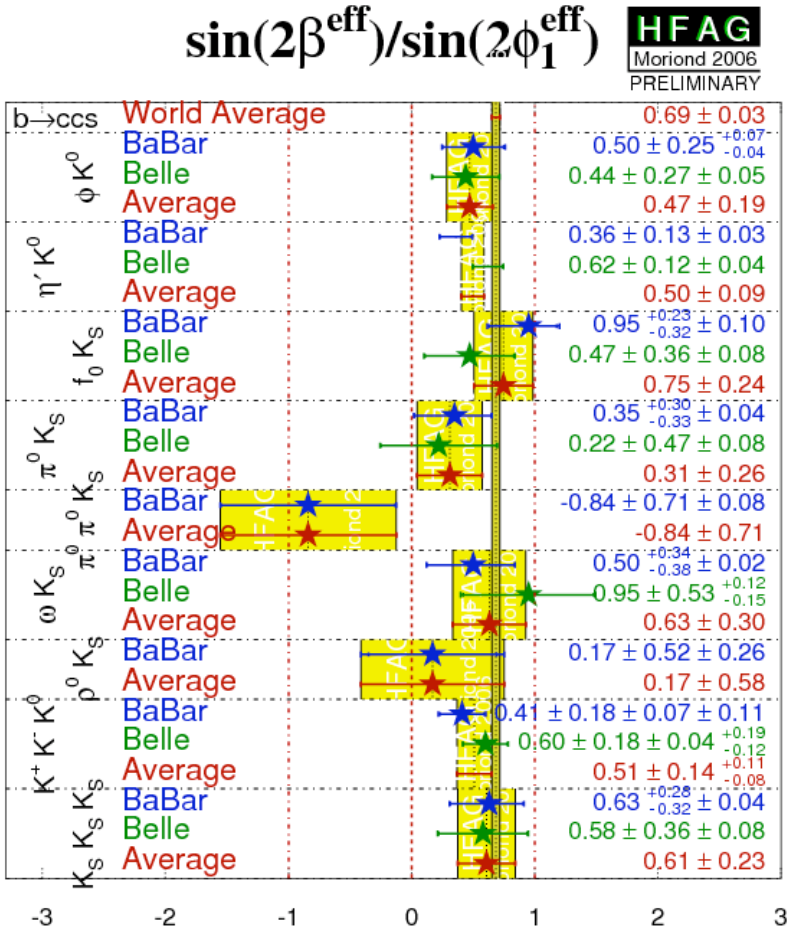
- A large source of error comes from the possible CP-even under the rho (including interference effects)
  - still statistically limited

“other” modes…

….which I don’t have time to go into detail about.

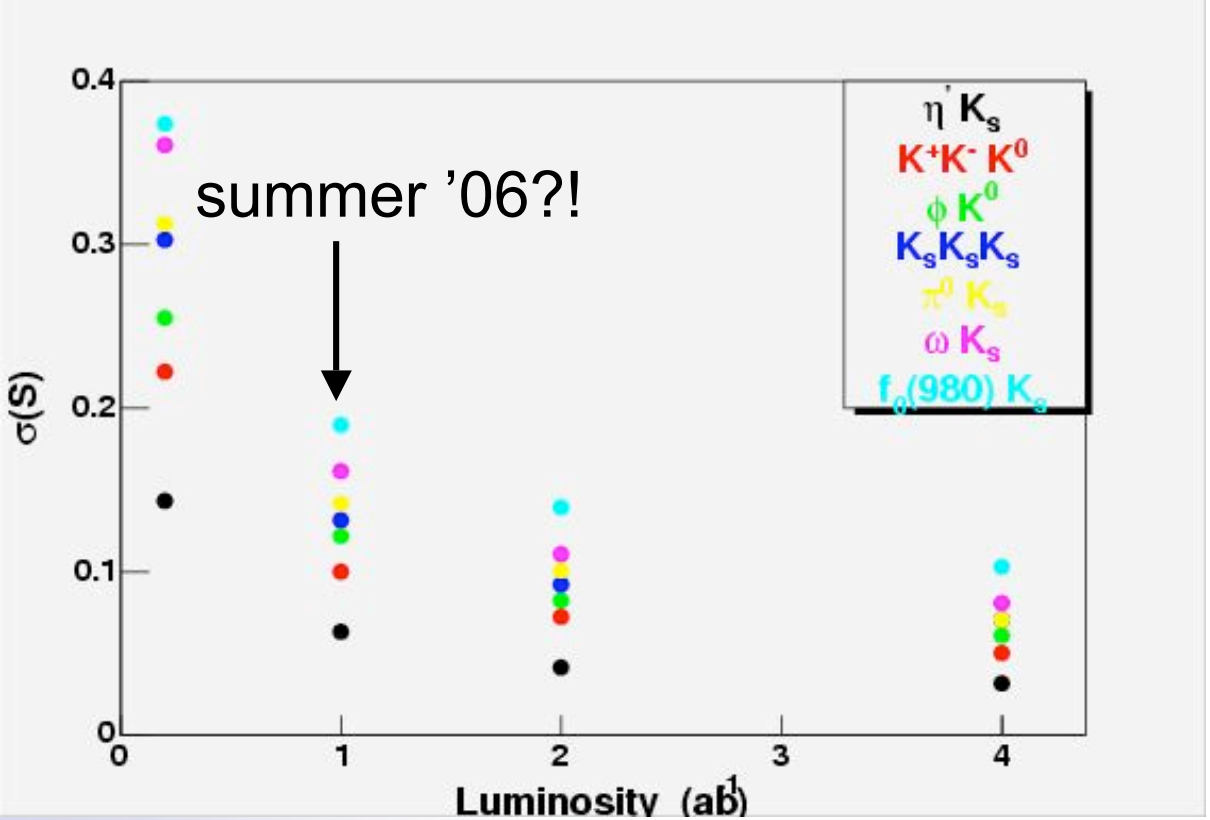
Mode	$\langle \sin 2\beta_{eff} \rangle$	Comments
$B^0 \to \pi^0 K_s$	0.31±0.26	Novel vertexing technique…SM pollution well understood?
$B^0 \to f_0 K_s$	0.75±0.24	possible tree contribution; what’s an “f_0”?
$B^0 \to \omega K_s$	0.63±0.30	tree contribution gives possibly large SM pollution
$B^0 \to \pi^0 \pi^0 K_s$	-0.84±0.72	Low stat…BaBar only

Current status



- Taken on averge, there decent agreement with the SM expectation…
- However, (almost) all measurements are ***lower*** than sin2β from $J/\psi K^0$
  - most models predict SM pollution to ***increase*** $\sin 2\beta_{eff}$

The future of sin2β_{eff}



…looks good!

- The error on η'Ks alone should get down to <5%!
- will remain statistics limited for foreseeable future