Physics at Belle

Y.Sakai (KEK)

Goal of B-factory

Step1

Discovery of CPV in B decay ← **2001 summer !**

Step2

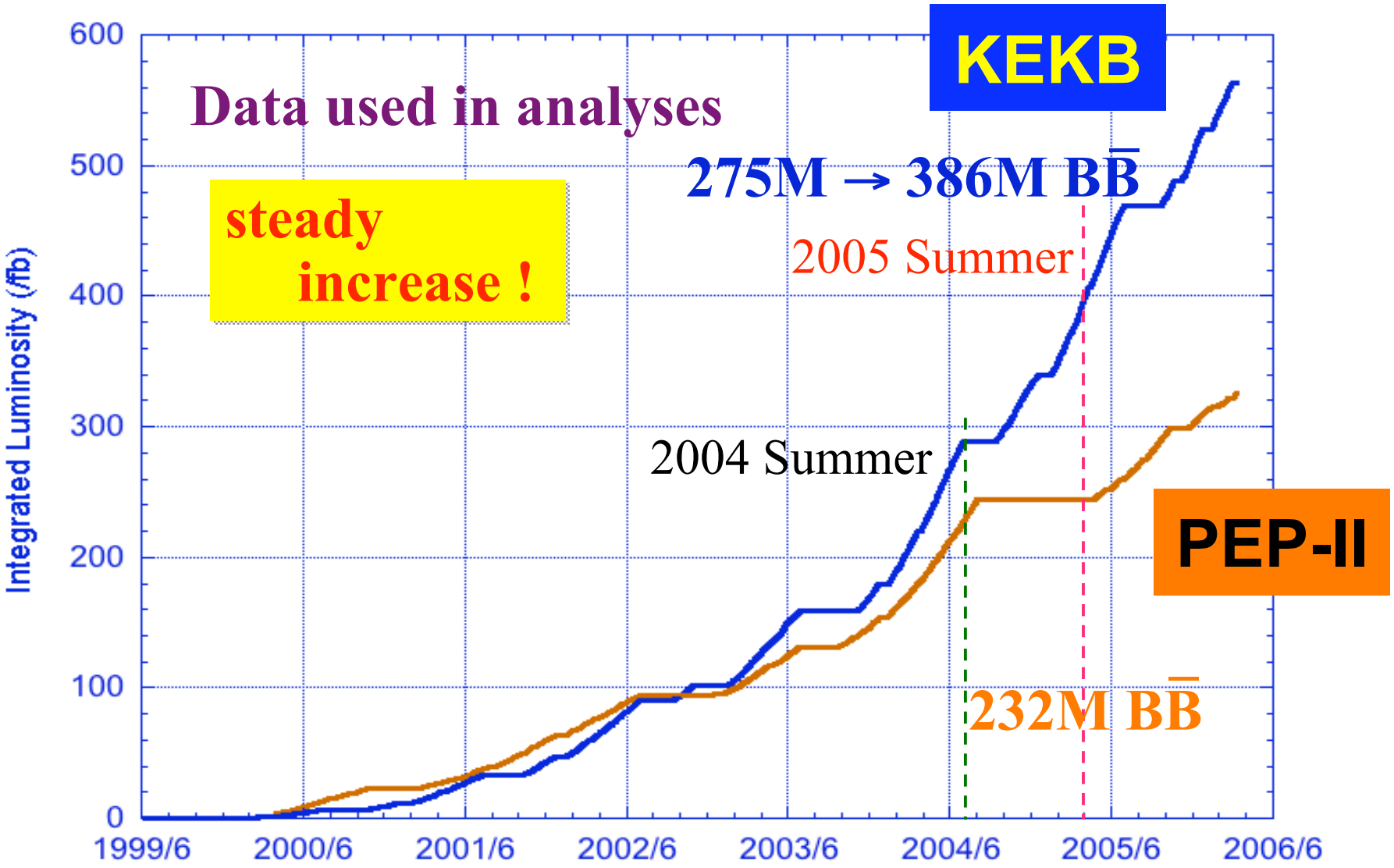
Precise test of KM(CPV) and SM

Step3

Search/Evidence for New Physics ← Now

B decays → QCD/Lattice, New Resonances
Also, excellent τ/charm factory

Integrated Luminosity



Physics Results in past year

71+2 abstracts submitted to LP05/EPS05

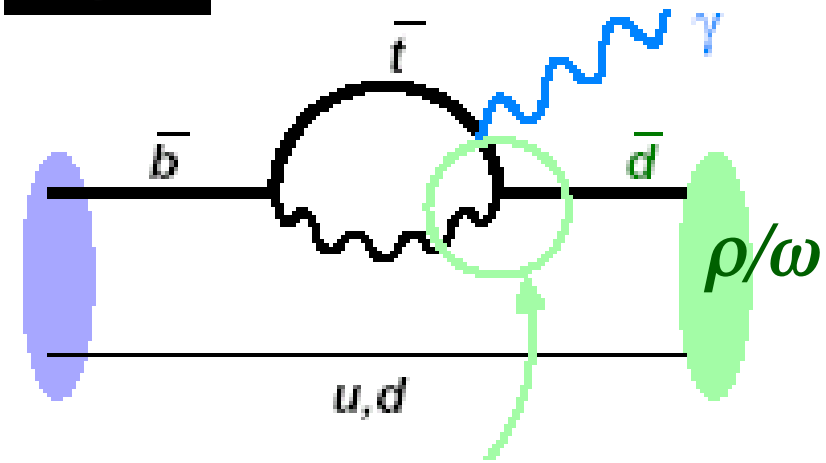
⇒ 43 papers submitted to journals

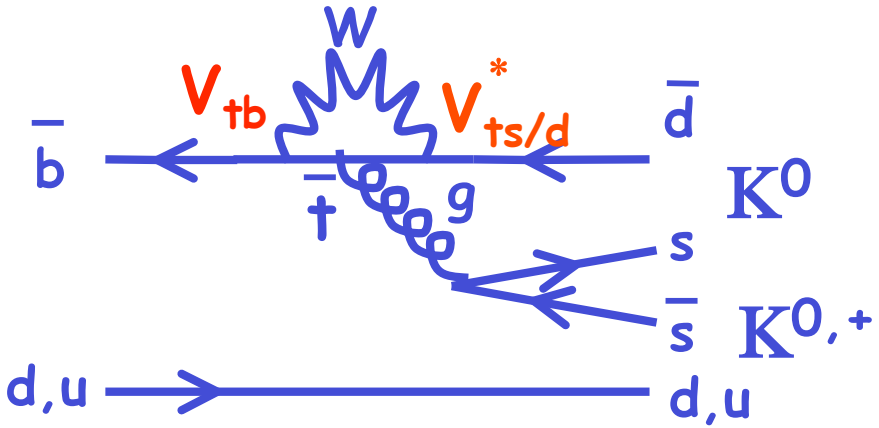
- $b \rightarrow d$ Penguin
- CP Violation ($\phi_{1,2,3}$, NP)
- New Resonances
- Y(5S), Y(3S) runs

$b \to d$ Penguins

Loops → Sensitive to New Physics

$(b \to s)$ x $|V_{td}/V_{ts}|^2$





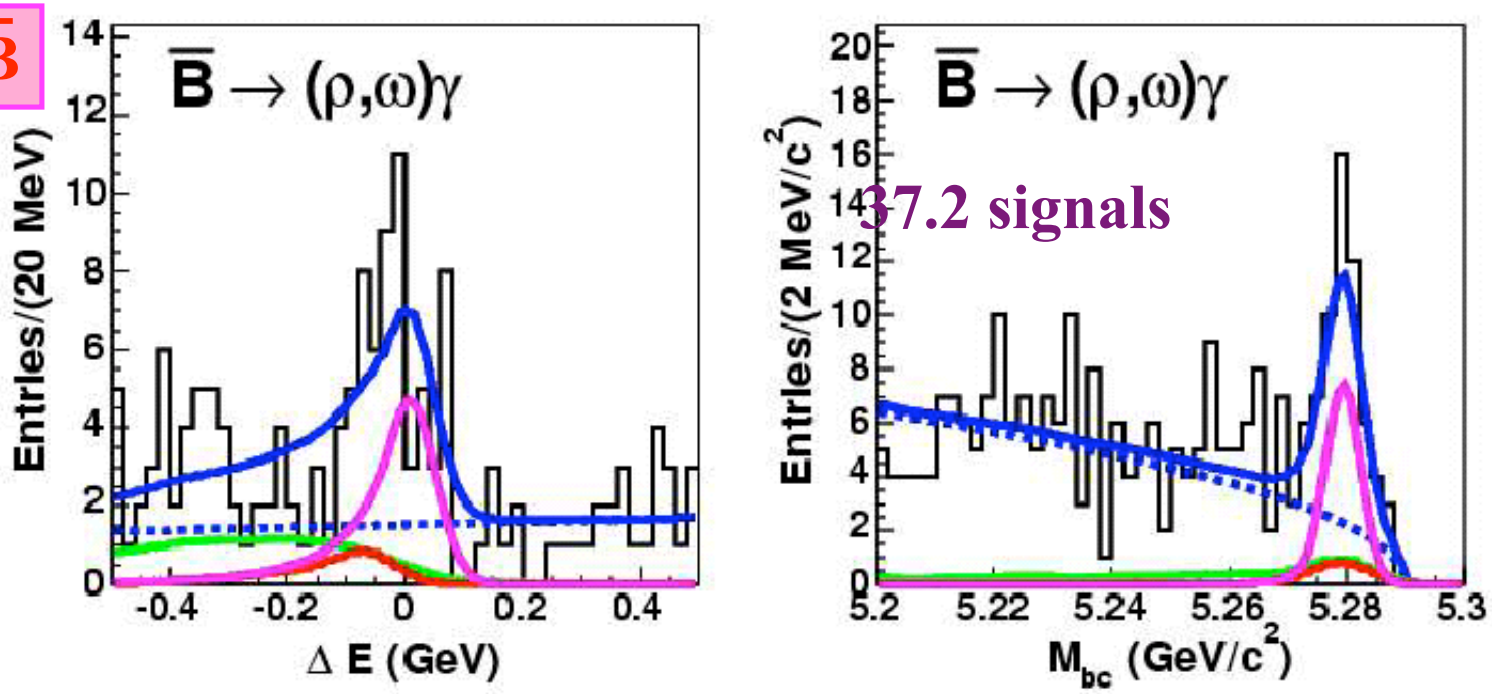
b → dγ penguin

b → dg penguin

$b \to d\gamma$

[hepex/0506079]
submitted to PRL

386M $B\bar{B}$



First observation (5.5σ) !

Simultaneous fit to 3 modes:

$$\Gamma(B\to(\rho,\omega)\gamma) = \Gamma(B^+\to\rho^+\gamma) = 2\Gamma(B^0\to\rho^0\gamma) = 2\Gamma(B^0\to\omega\gamma)$$

$$B(B\to(\rho,\omega)\gamma) = 1.34\ ^{+0.34}_{-0.31}\,(\text{stat})\ ^{+0.14}_{-0.10}\,(\text{sys}) \times 10^{-6}$$

Consistent with SM ($1\sim2 \times 10^{-6}$) ➡ Constraint to $|V_{td}|$

Constraint on $|V_{td}/V_{ts}|$

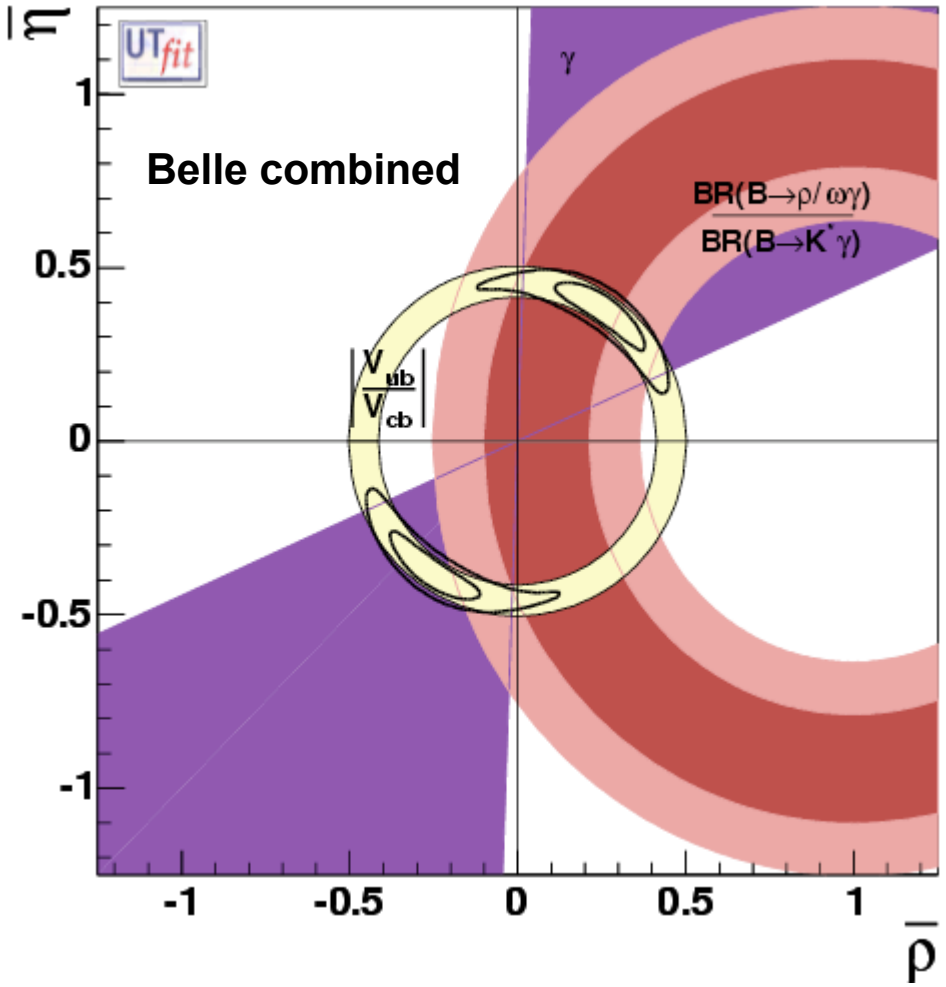
$$\frac{\overline{\mathcal{B}}[B \to (\rho/\omega)\gamma]}{\mathcal{B}(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/M_B^2}{1 - m_{K^*}^2/M_B^2}\right)^3 \zeta^2[1 + \Delta R]$$

$= 0.032 \pm 0.008 \pm \begin{matrix} 0.003 \\ 0.002 \end{matrix}$

Form factor ratio $\zeta = 0.85 \pm 0.10$

SU(3)-breaking effect $\Delta R = 0.1 \pm 0.1$

$0.143 < |V_{td}/V_{ts}| < 0.260$ (95%CL)

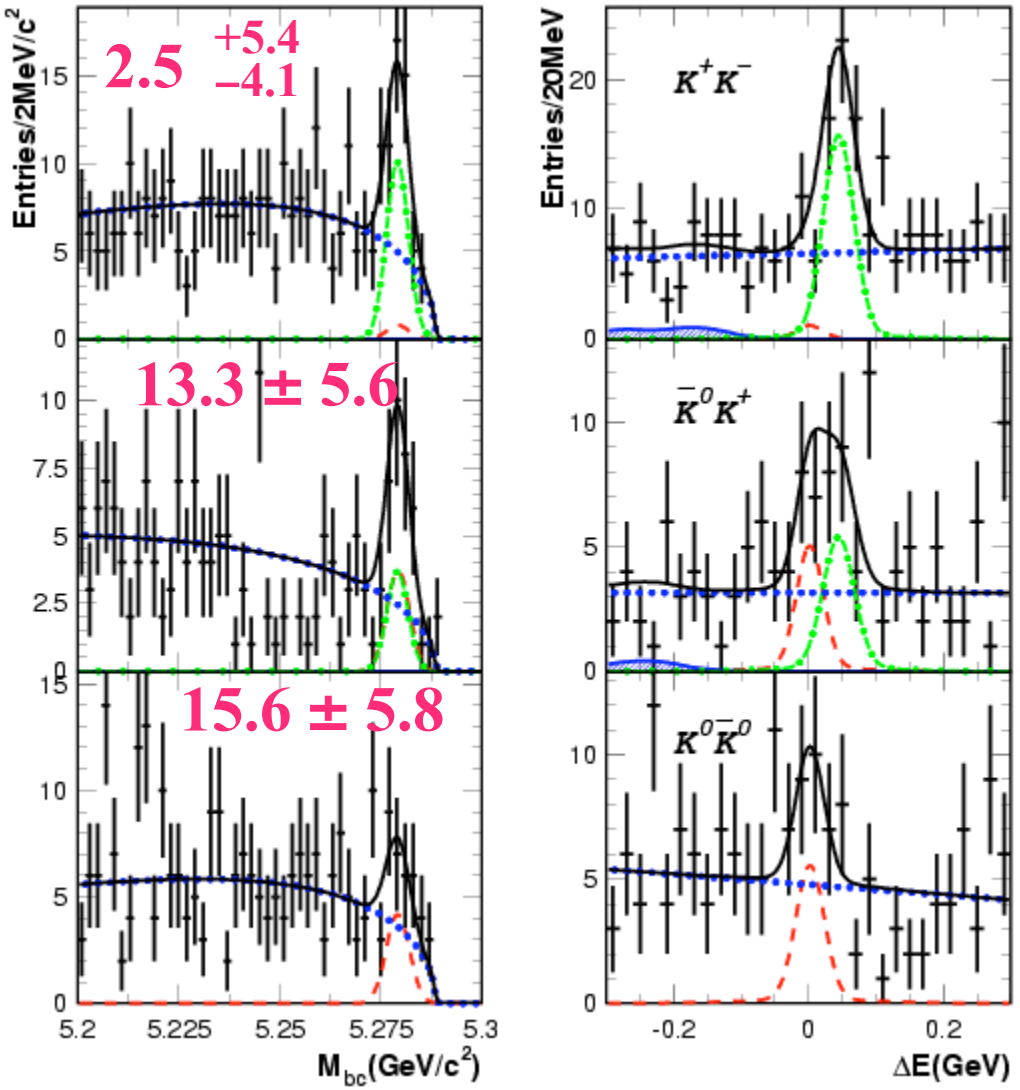


$B \to KK$

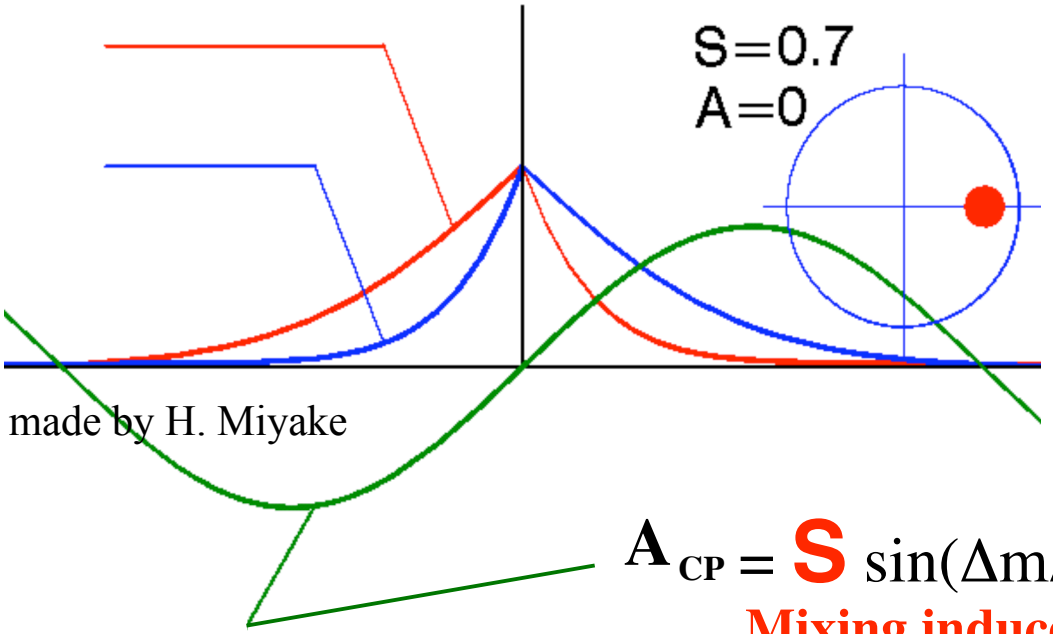
275M $B\bar{B}$

Mode	$\mathcal{B}(10^{-6})$	Sig.
K^+K^-	< 0.37	0.5
$\overline{K}^0K^+$	$1.0 \pm 0.4 \pm 0.1$	3.0
$K^0\overline{K}^0$	$0.8 \pm 0.3 \pm 0.1$	3.5

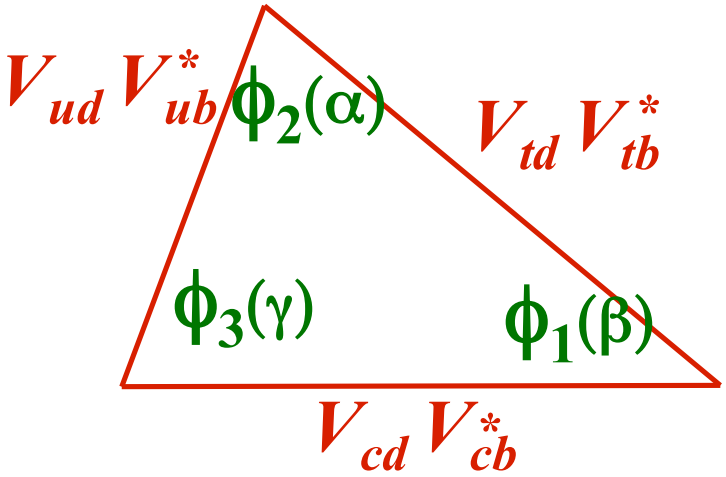
[PRL 95, 231801(05)]



CPV Measurements

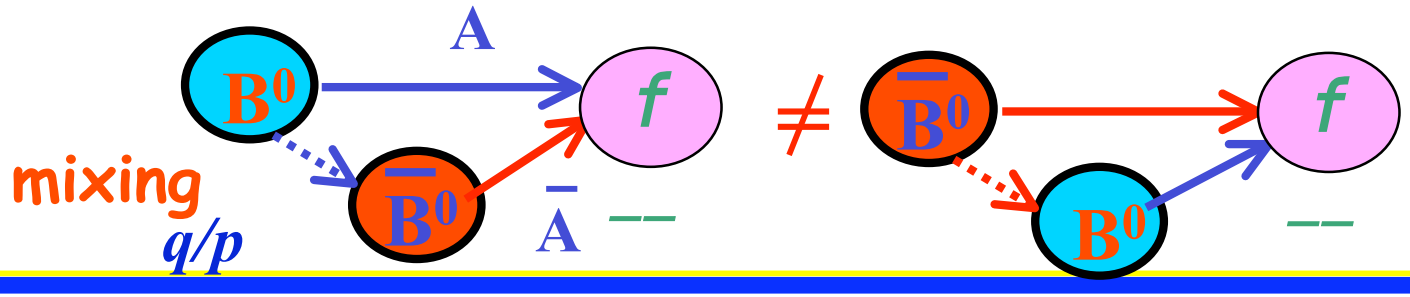


made by H. Miyake

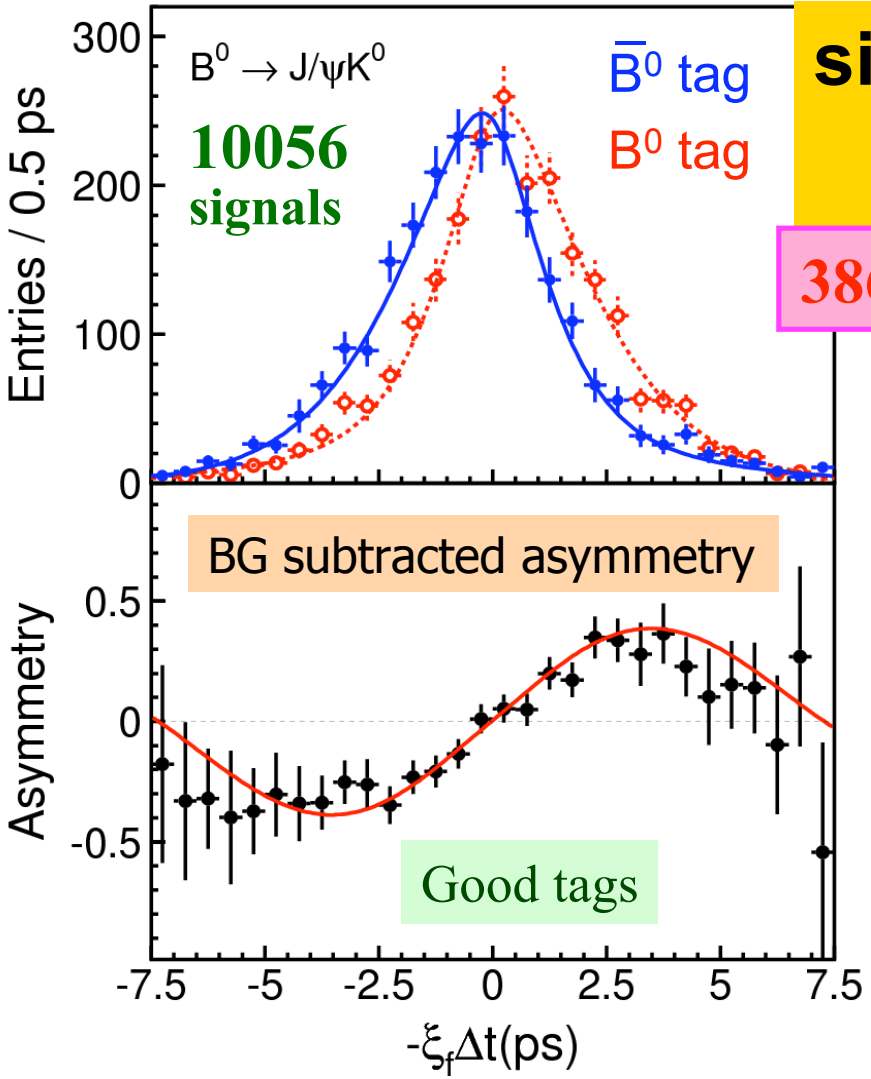


$$A_{CP} = S \sin(\Delta m \Delta t) + A \cos(\Delta m \Delta t)$$

Mixing induced CPV Direct CPV



$sin2\phi_1 : B^0 \rightarrow J/\psi\, K^0_{S,L}$



$sin2\phi_1$= 0.652 ±0.039 ±0.020

A = 0.010 ±0.026 ±0.036

(stat) (sys)

386M $B\bar{B}$

Belle preliminary

BaBar measurement

$sin2\phi_1$= 0.722 ± 0.040 ± 0.023

(227 M $B\bar{B}$ pairs)

WA: $sin2\phi_1$= 0.69 ±0.03

< 5% accuracy !

consistent w/ SM expectation

$\phi_2 : B^0 \to \rho^+\rho^-$ CPV

Similar to $\pi^+\pi^-$, but more complicated …

***B* → *VV*: not CP eigenstate** in general

$\rho^+ \to \pi^+\pi^0$: wide resonance

Two lucky cards !

- $f_L \sim 100\% \to CP \approx +1$
- $B(\rho^0\rho^0) \ll B(\rho^+\rho^-), B(\rho^+\rho^0)$ (HFAG 2005 End)

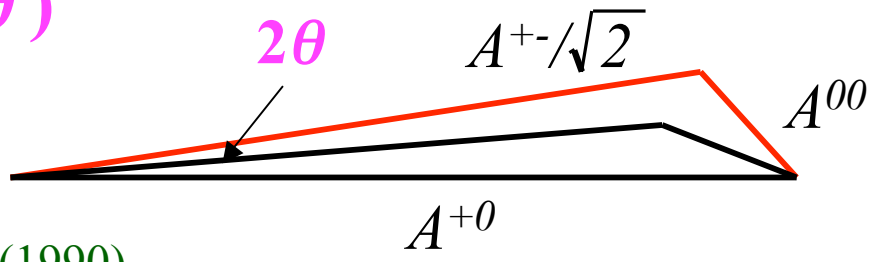
  < 1.1 $\quad 26 \pm 4$ $\quad 26 \pm 6$ $\quad \times 10^{-6}$

⇒ **small Penguin effect (θ)**

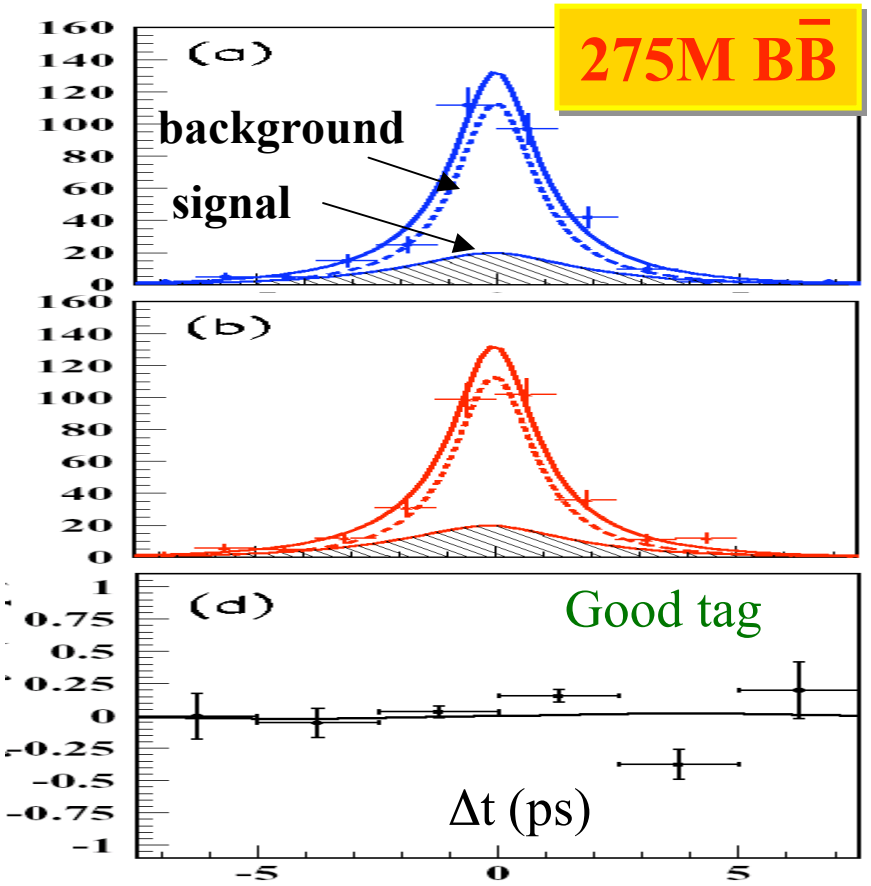
$$S_{\pi\pi} = \sqrt{1 - A_{\pi\pi}^2}\,\sin(2\phi_2 + 2\theta)$$

M. Gronau and D. London, PRL 65, 3381 (1990)

Isospin relation



$B^0 \to \rho^+\rho^-$ Result



275M $B\bar{B}$

232M $B\bar{B}$

$f_L = 0.978 \pm 0.014 \pm {}^{0.020}_{0.028}$

$S = -0.33 \pm 0.24 \pm {}^{0.08}_{0.14}$

$A = 0.03 \pm 0.18 \pm 0.09$

[PRL 95,041805(05)]

$S = +0.09 \pm 0.42 \pm 0.08$

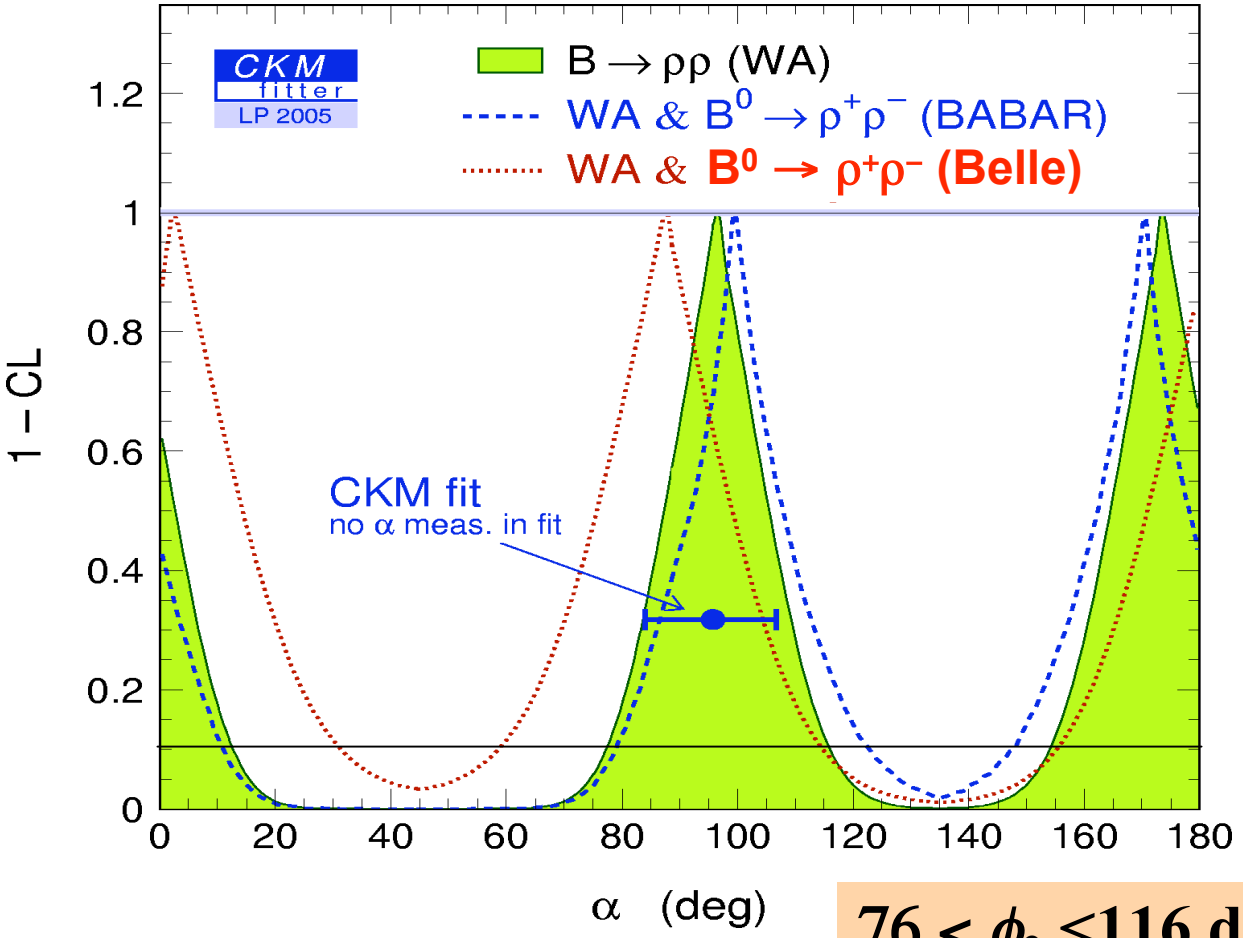
$A = 0.00 \pm 0.30 \pm {}^{0.10}_{0.09}$

$f_L = 0.951 \pm {}^{0.033}_{0.039} \pm {}^{0.029}_{0.031}$

[hep-ex/0507039, submitted to PRL]

$\rho^+\rho^-$ Isospin analysis

$\rho^+\rho^-$: most precise ϕ_2 determination to date !



add new Belle $\rho^+\rho^-$: **B, S, A**

Note:

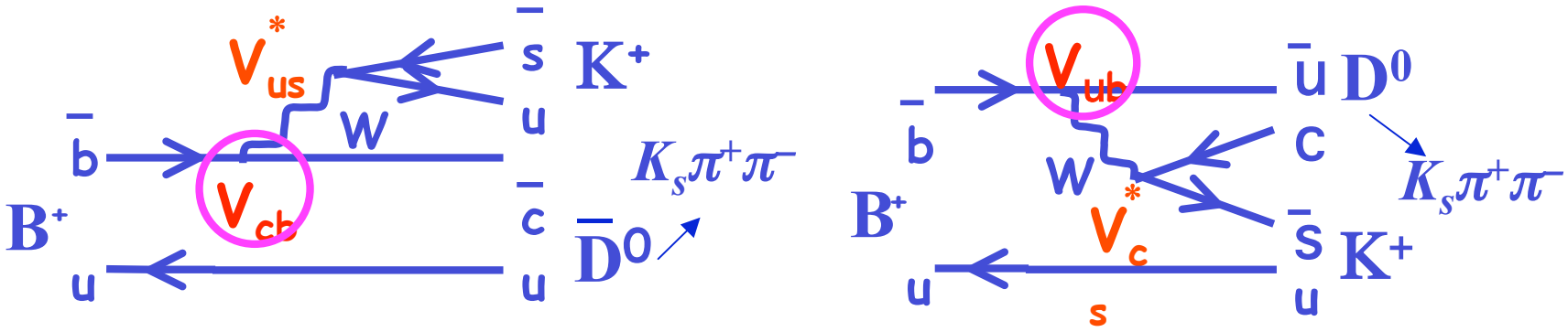
Isospin triangle does not close

- experimental error ?
- EW penguins (1-2°) effect (CKM Fitter/Gronau & Zupan)
- Possible I=1 amplitudes

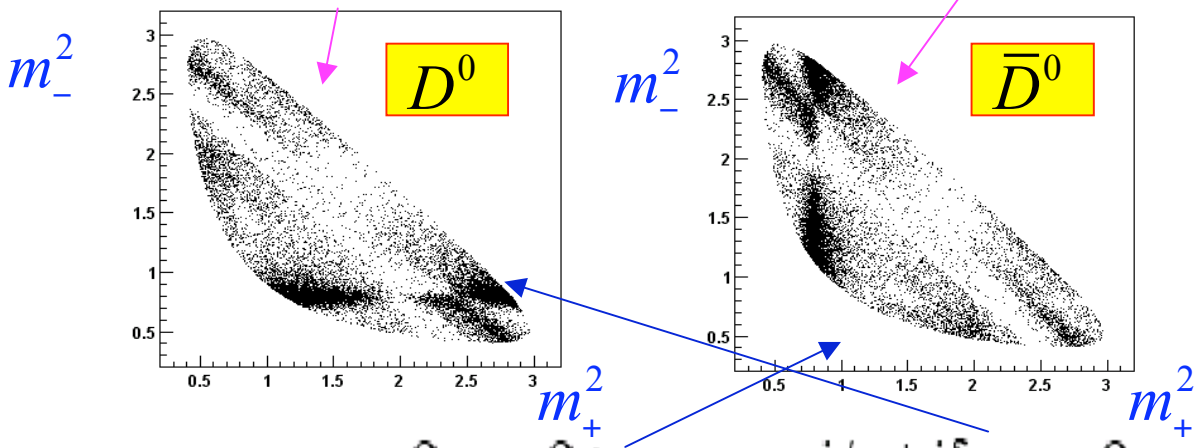
$\phi_2 = 96 \pm 13$ deg.

$76 < \phi_2 < 116$ deg. @90% CL

$\phi_3 : B \to D[K_s\pi^+\pi^-]K$ Dalitz



B^+: $M_+ = f(m_+^2, m_-^2) + re^{i\phi_3+i\delta} f(m_-^2, m_+^2)$



obtain from tagged D^0 ($D^{*+} \to D^0\pi^+$) sample

B^-: $M_- = f(m_-^2, m_+^2) + re^{-i\phi_3+i\delta} f(m_+^2, m_-^2)$ $\quad r = \frac{|A_2|}{|A_1|}$

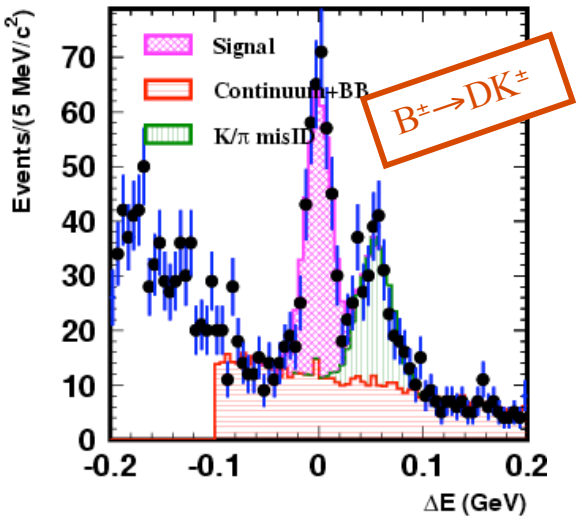
CPV: Asymmetry in Dalitz dist.: $m_+ = m(K_s\pi^+)$, $m_- = m(K_s\pi^-)$

$B \to D^{(*)}[K_s\pi^+\pi^-]K^{(*)}$ Signals

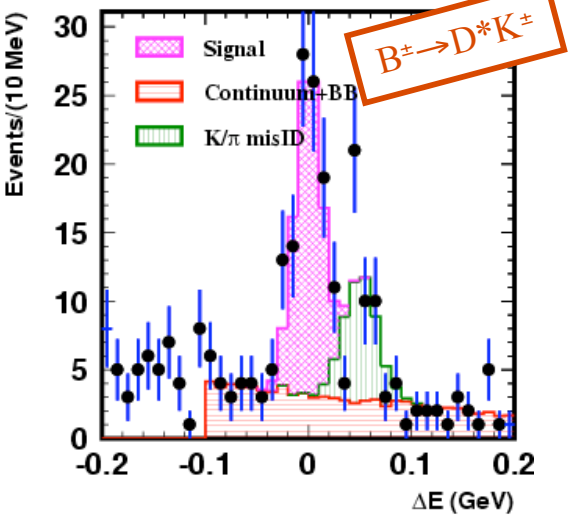
386M $B\bar{B}$

New at Winter Conf.

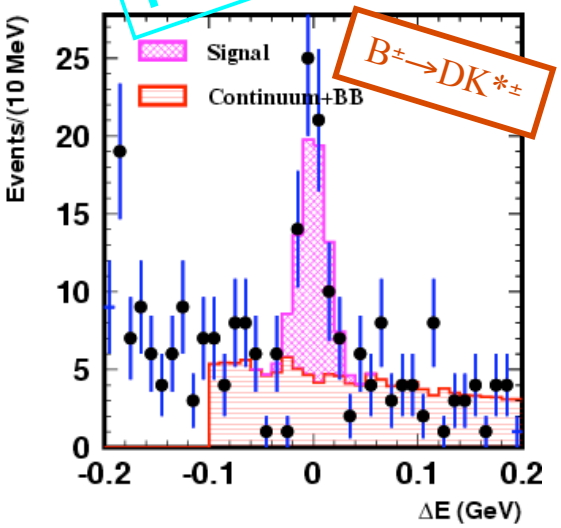
Preliminary



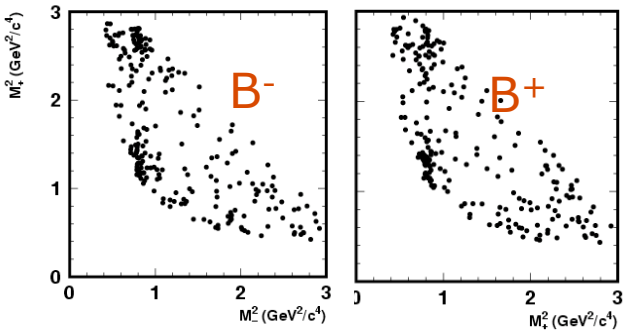
331±17 events

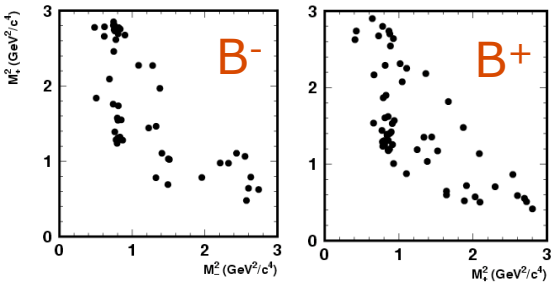


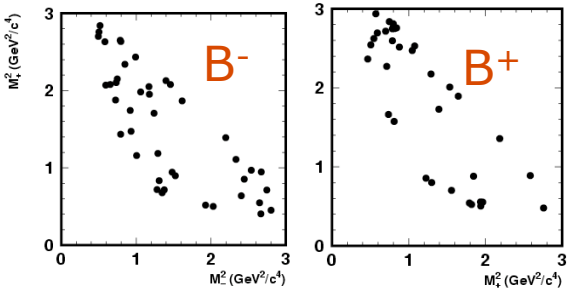
81±8 events



54±8 events

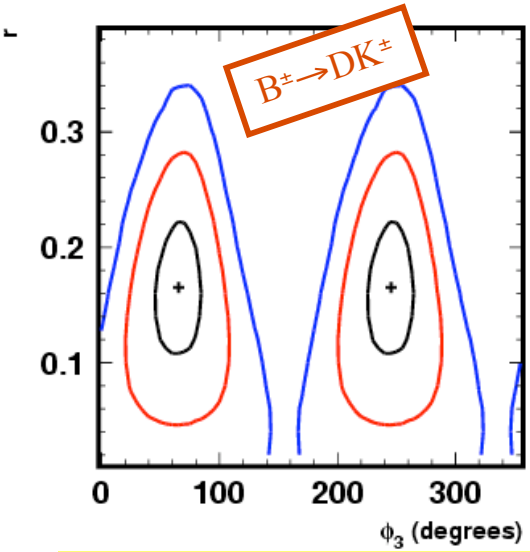




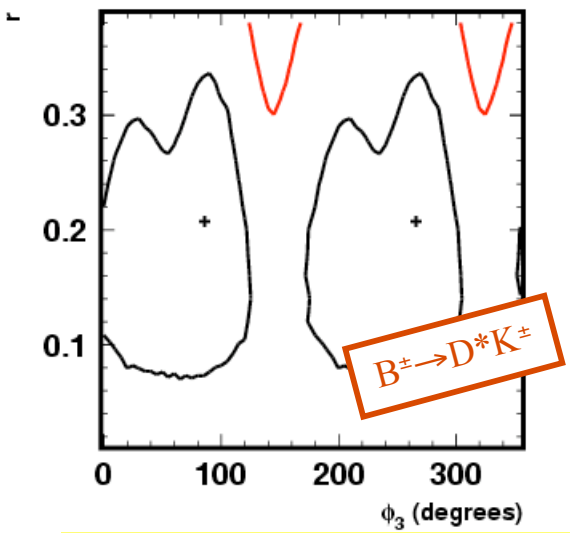


ϕ_3 : Fit Results

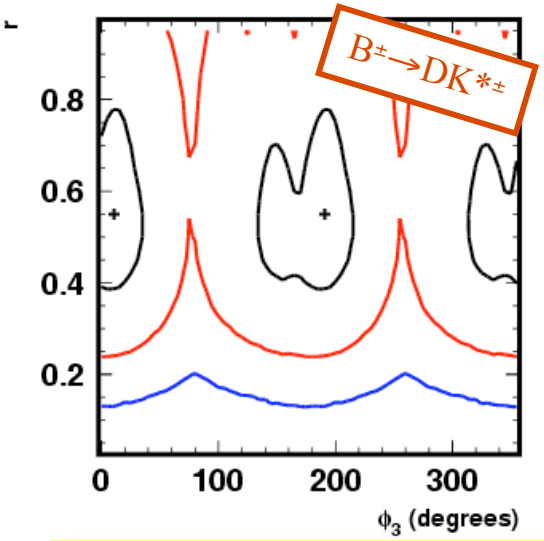
386M $B\bar{B}$



$\phi_3 = 66^{+19}_{-20}$ °(stat)



$\phi_3 = 86^{+37}_{-93}$ °(stat)



$\phi_3 = 11^{+23}_{-57}$ °(stat)

3 modes combined: $\phi_3 = 53^{\circ}\,^{+15}_{-18}$ (stat) ±3 (syst) ±9 (model)

Preliminary

$8^{\circ} < \phi_3 < 111^{\circ}$ (2σ interval)

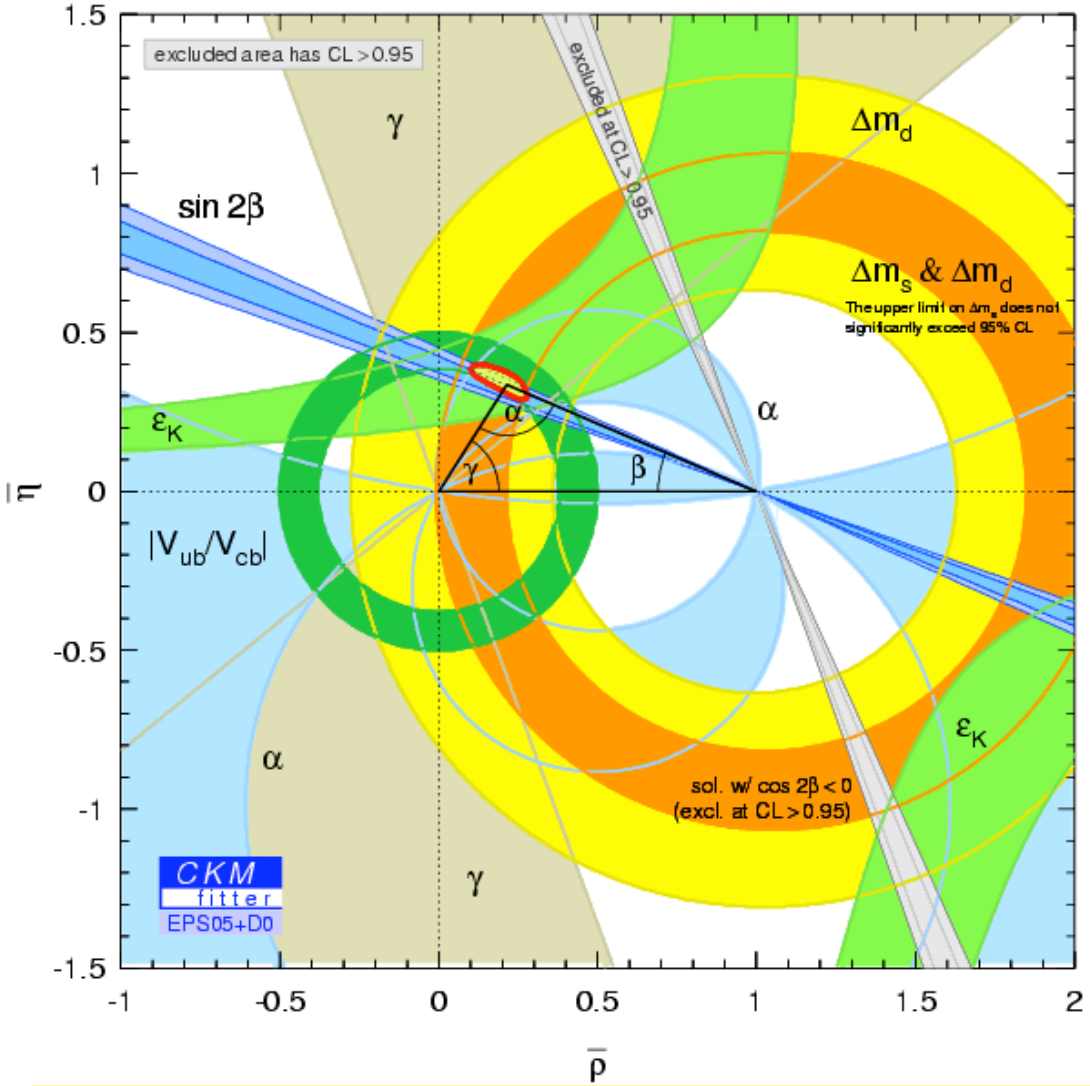
CPV significance: 78%

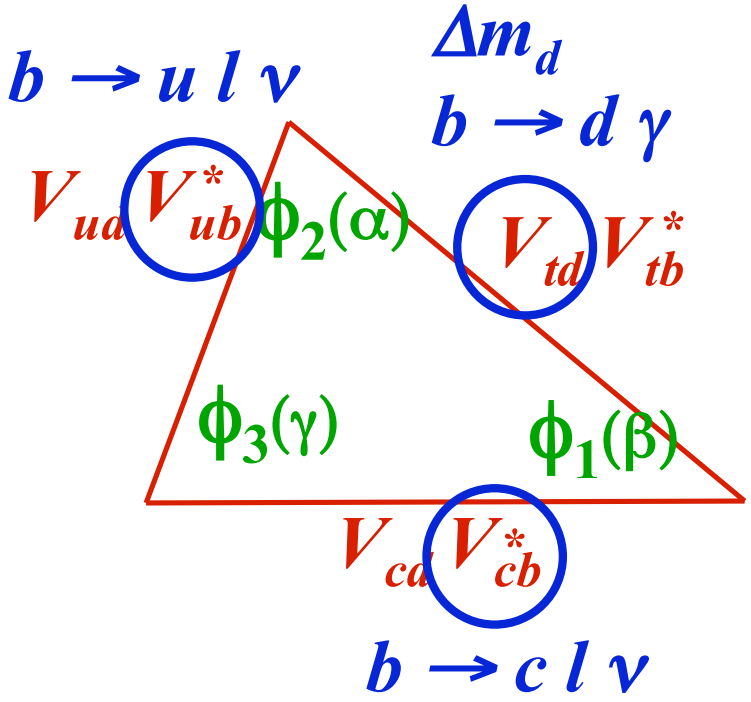
$r_{DK} = 0.159^{+0.054}_{-0.050} \pm 0.012(\text{syst}) \pm 0.049(\text{model})$

$r_{D^*K} = 0.175^{+0.108}_{-0.099} \pm 0.013(\text{syst}) \pm 0.049(\text{model})$

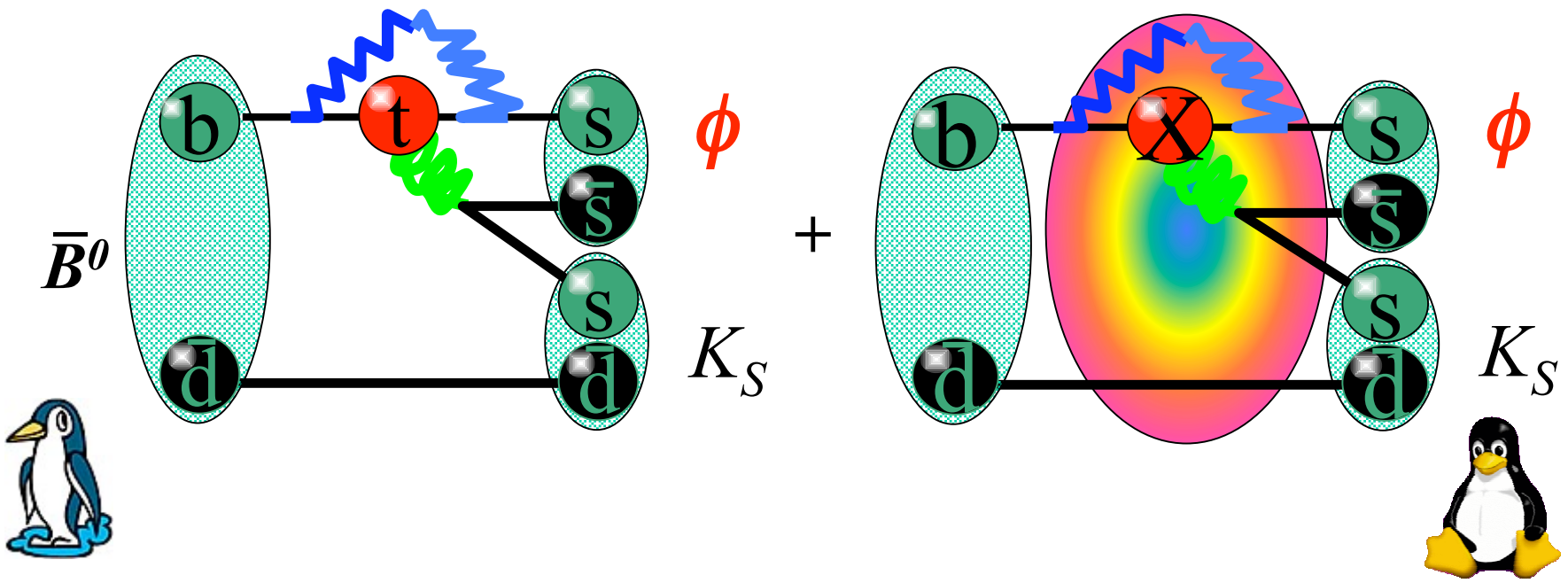
$r_{DK^*} = 0.564^{+0.216}_{-0.155} \pm 0.041(\text{syst}) \pm 0.084(\text{model})$

CKM UT summary





New physics Search : $b \to s\bar{q}q$



SM: b→s Penguin
phase = $(c\bar{c})$ K^0

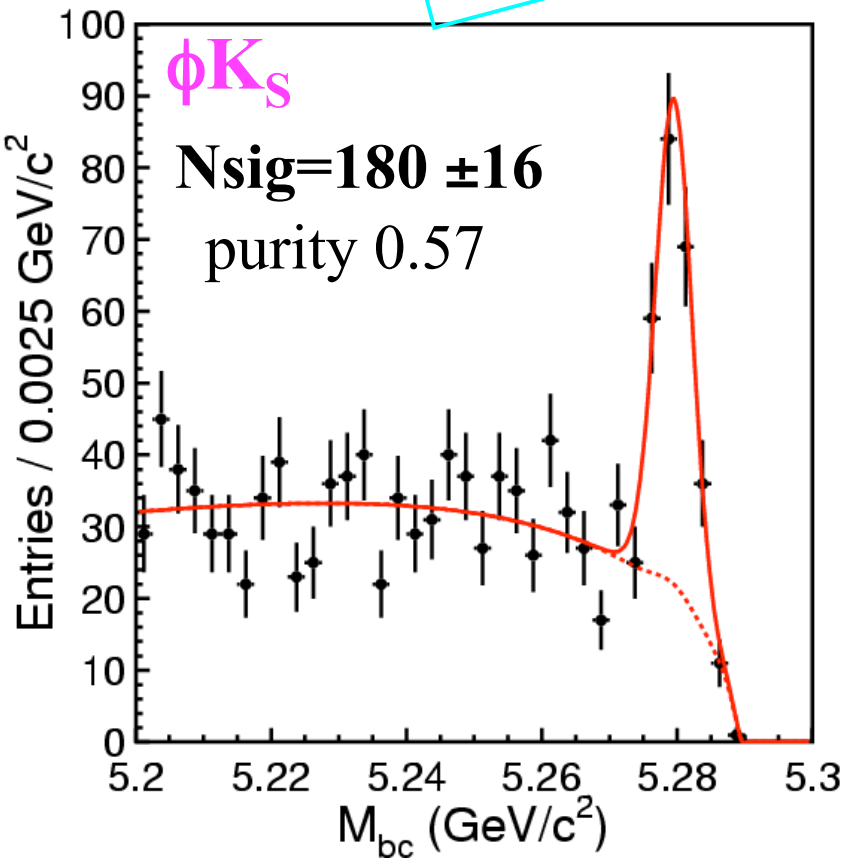
+ New Physics with New Phase
$S_{bs} \neq S_{bc}$, A can $\neq 0$

"b → $c\bar{c}s$: sin2ϕ_1" (SM reference) ⇒ deviation

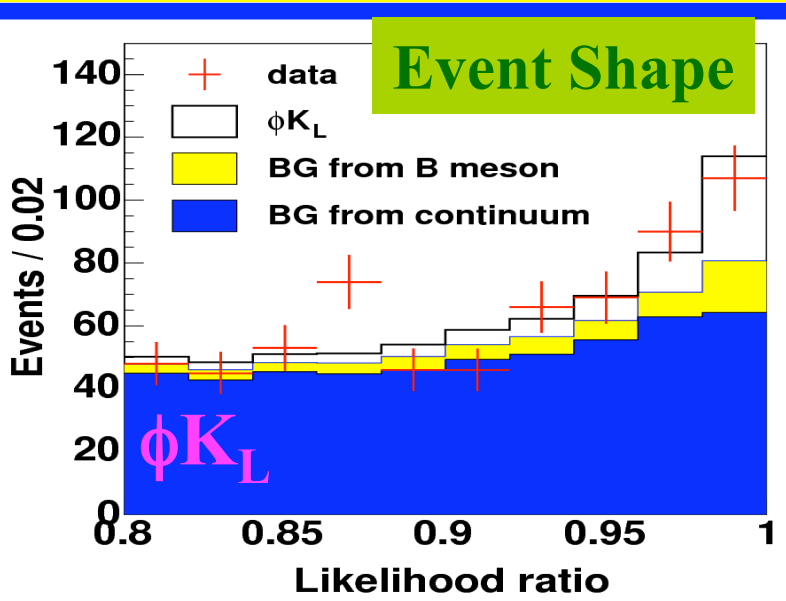
$B^0 \to \phi K^0$

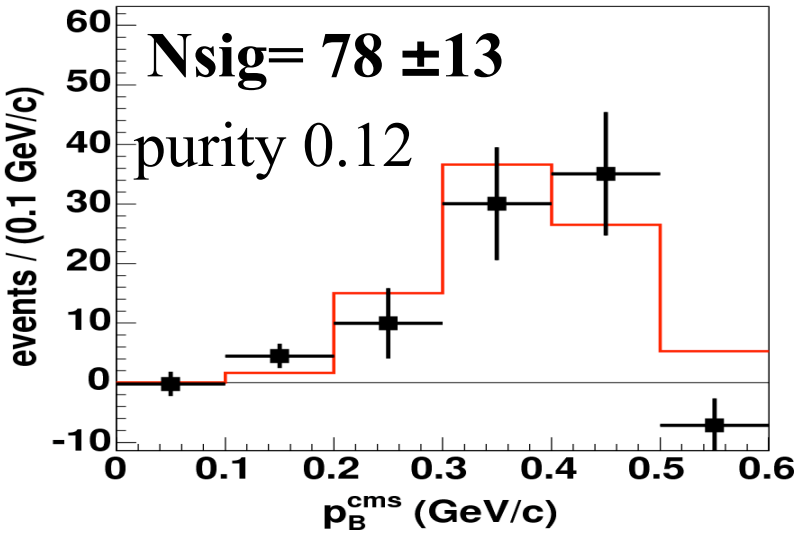
386M $B\bar{B}$

Preliminary

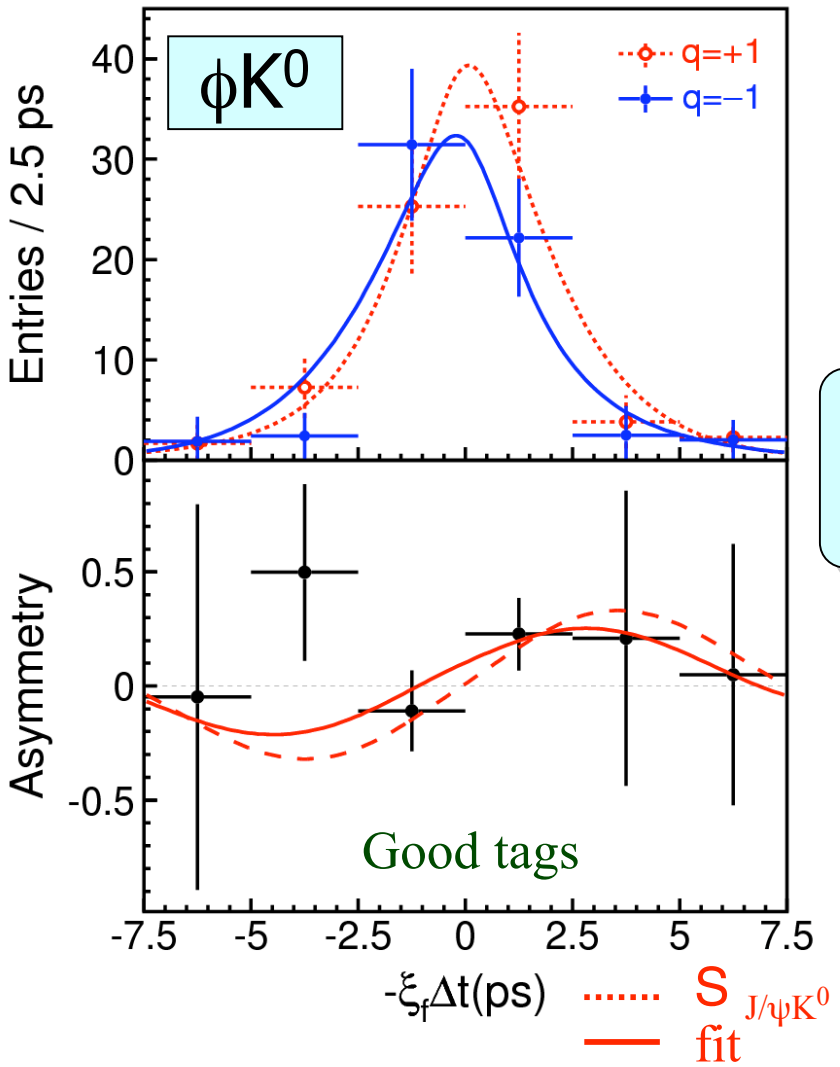


Event Shape





$B^0 \to \phi K^0$: result



BG subtracted asymmetry

386M $B\bar{B}$

"sin2ϕ_1"=+0.44 ±0.27 ±0.05

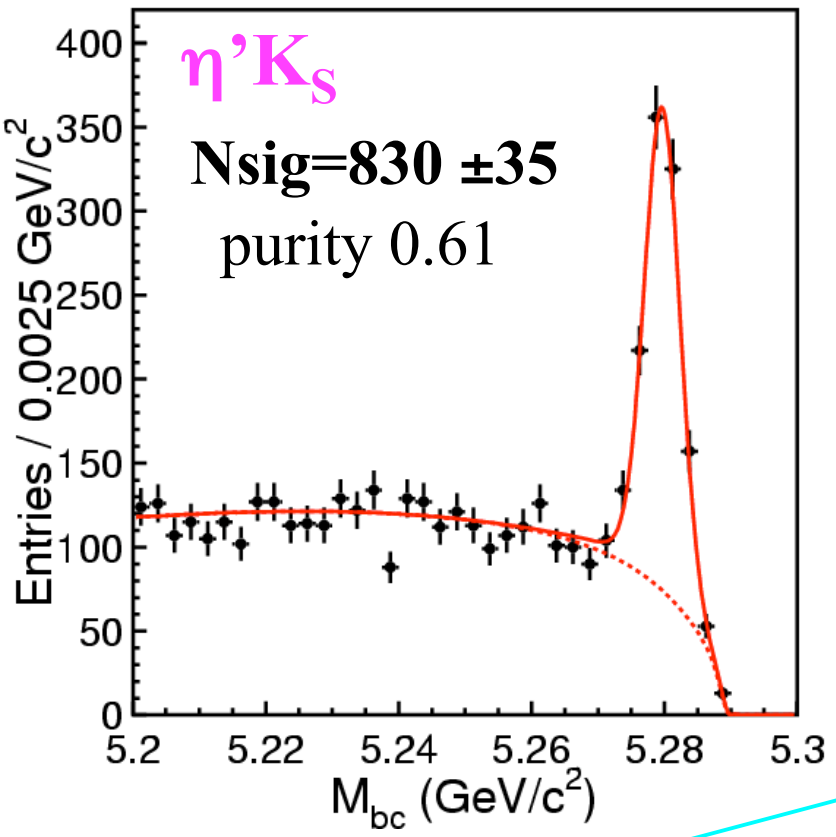
A =+0.14 ±0.17 ±0.07

Preliminary

$B^0 \to \eta' K^0$

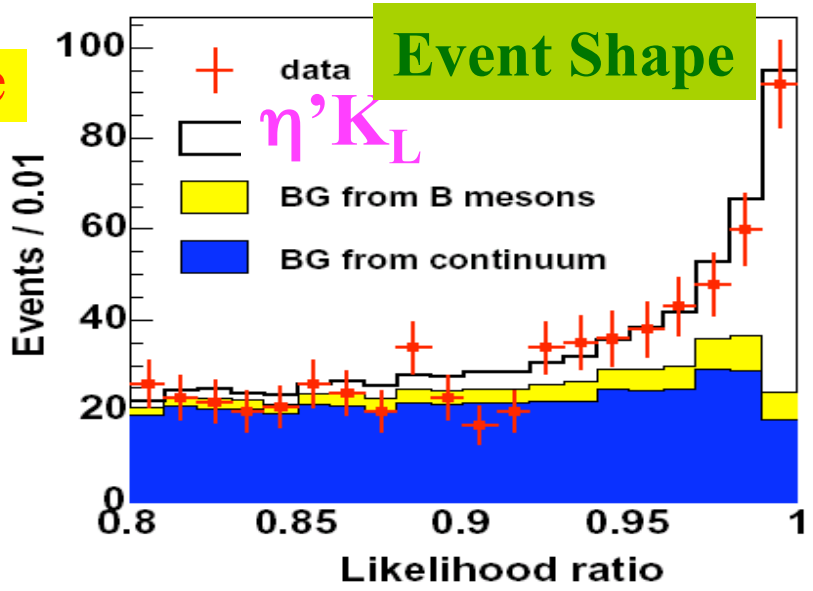
386M $B\bar{B}$

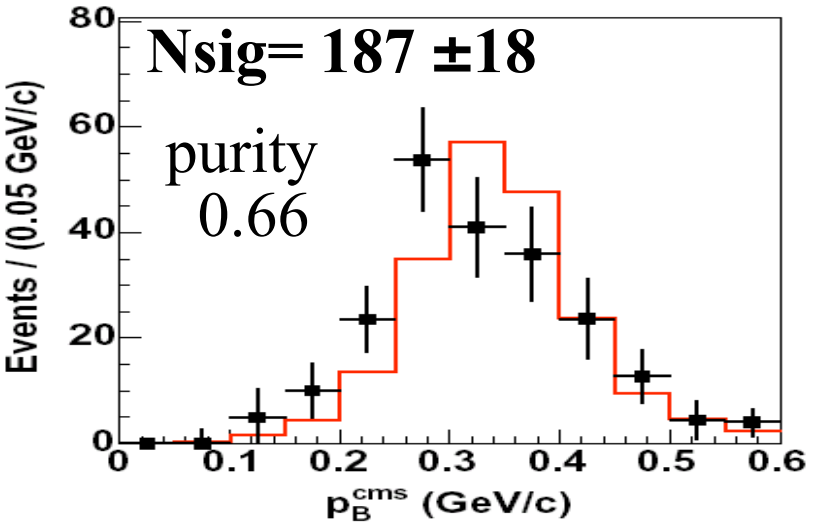
highest statistics mode



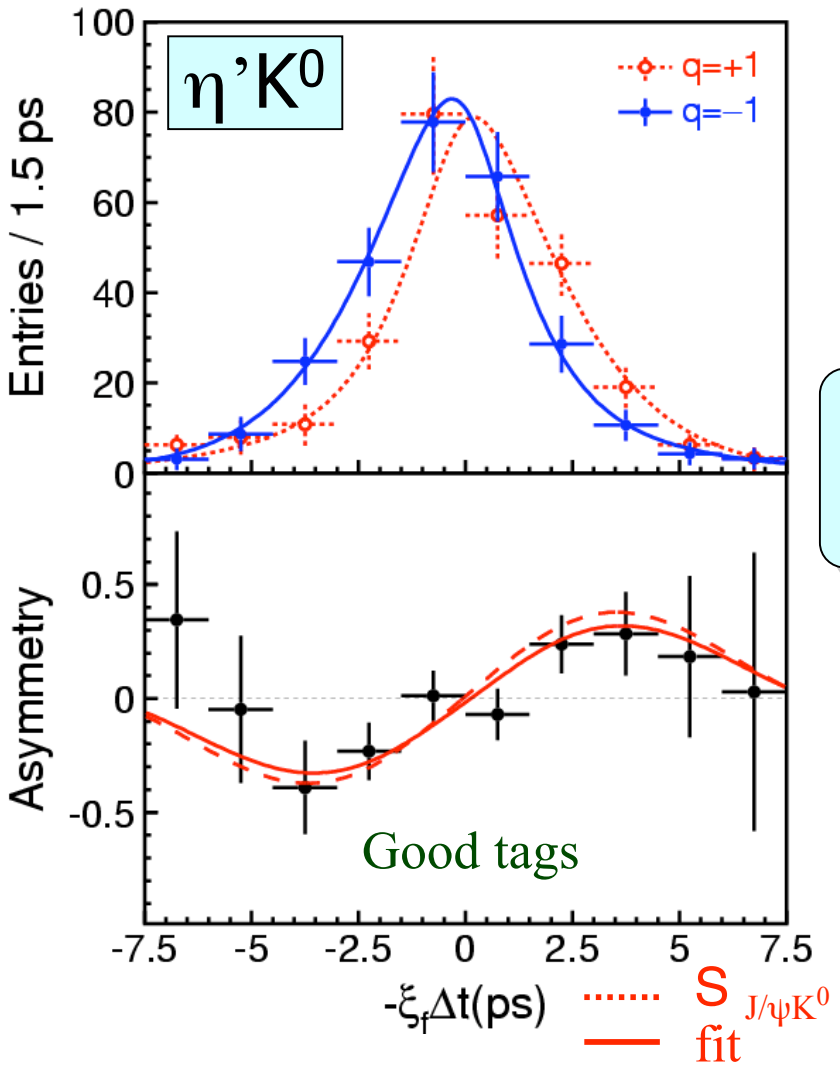
Preliminary

Event Shape





$B^0 \to \eta' K^0$: result



BG subtracted asymmetry

386M $B\bar{B}$

"$\sin 2\phi_1$" $= +0.62 \pm 0.12 \pm 0.04$

$A = +0.04 \pm 0.08 \pm 0.06$

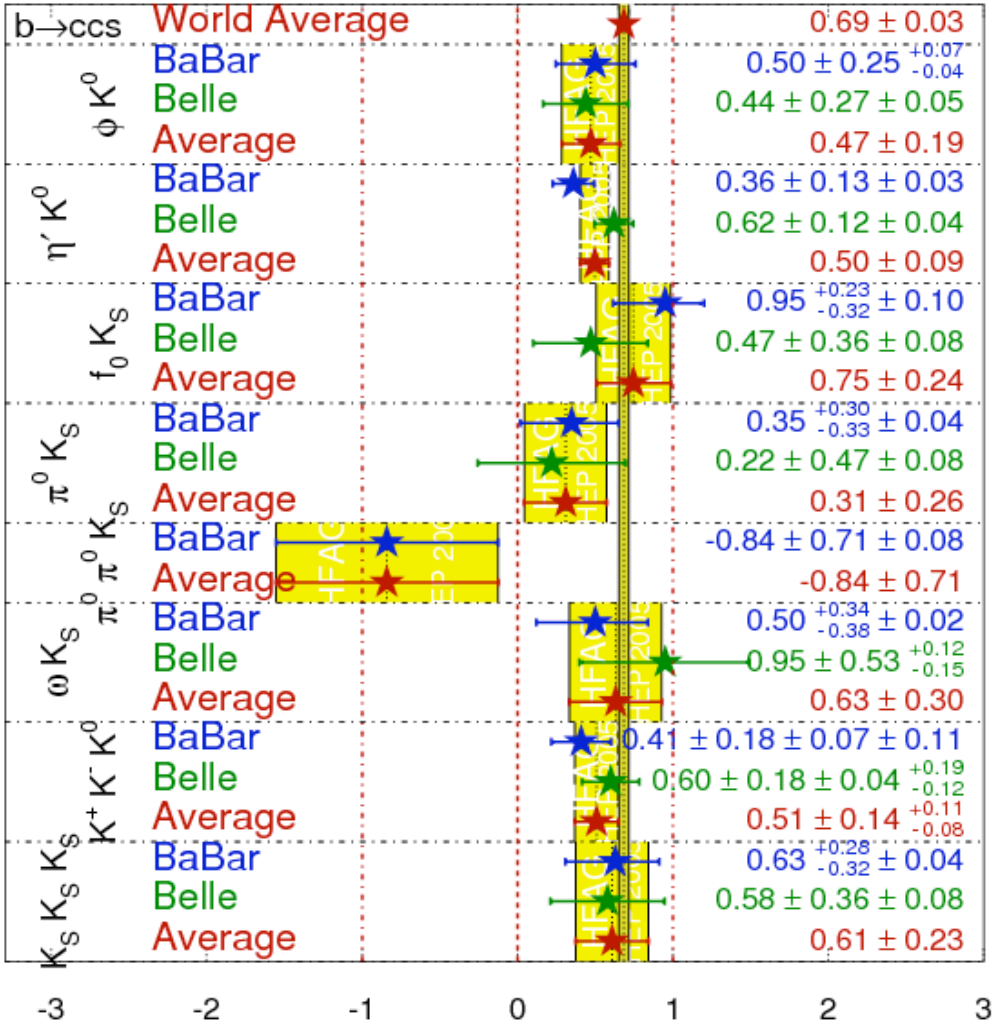
First CPV established ! (~5σ) for $b \to s\bar{q}q$ Penguin mode

Preliminary

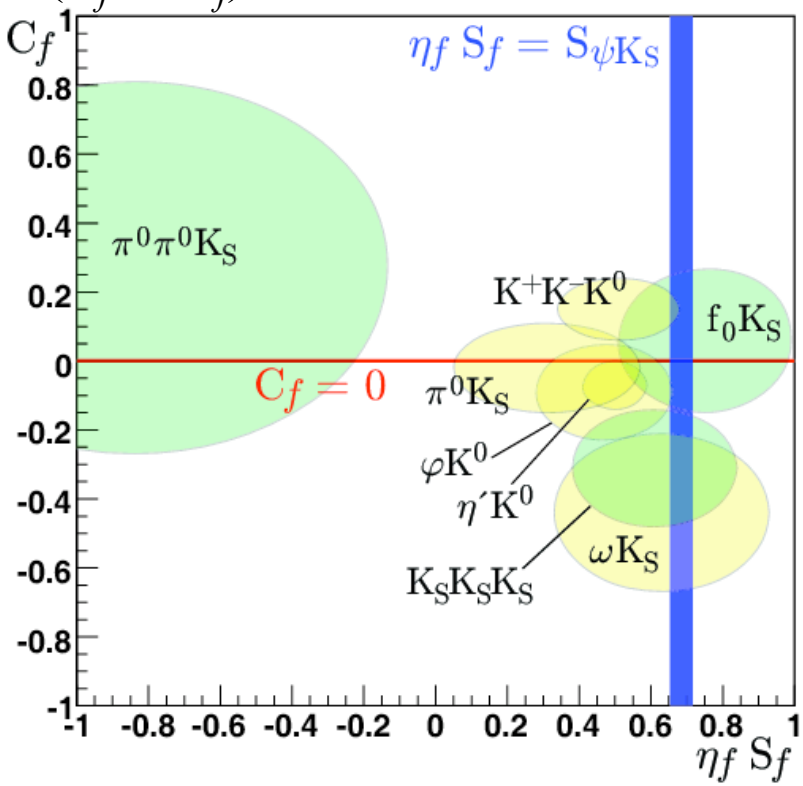
Summary: $b \to s\bar{q}q$ CPV

$\sin(2\beta^{eff})/\sin(2\phi_1^{eff})$

HFAG
HEP 2005
PRELIMINARY

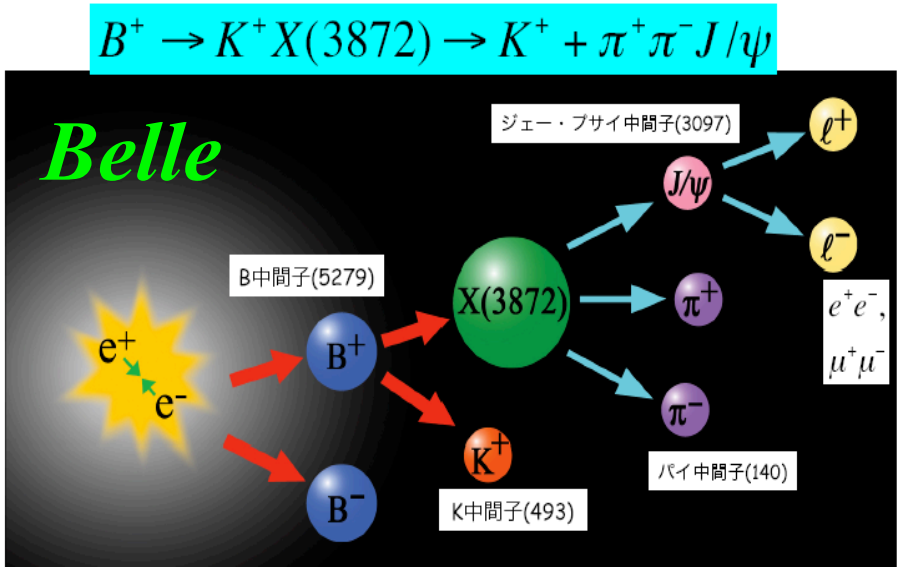


$(C_f = -A_f)$

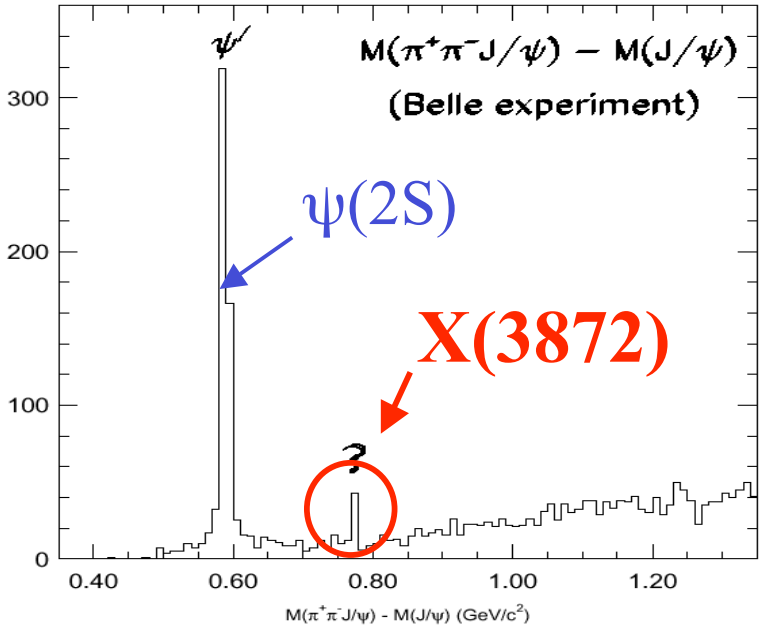


Naïve average
$\sin 2\phi_1^{eff} = 0.5 \pm 0.09$
(2.6σ from $\sin 2\phi_1$)

New Resonances



[PRL 91, 262001(2003)]



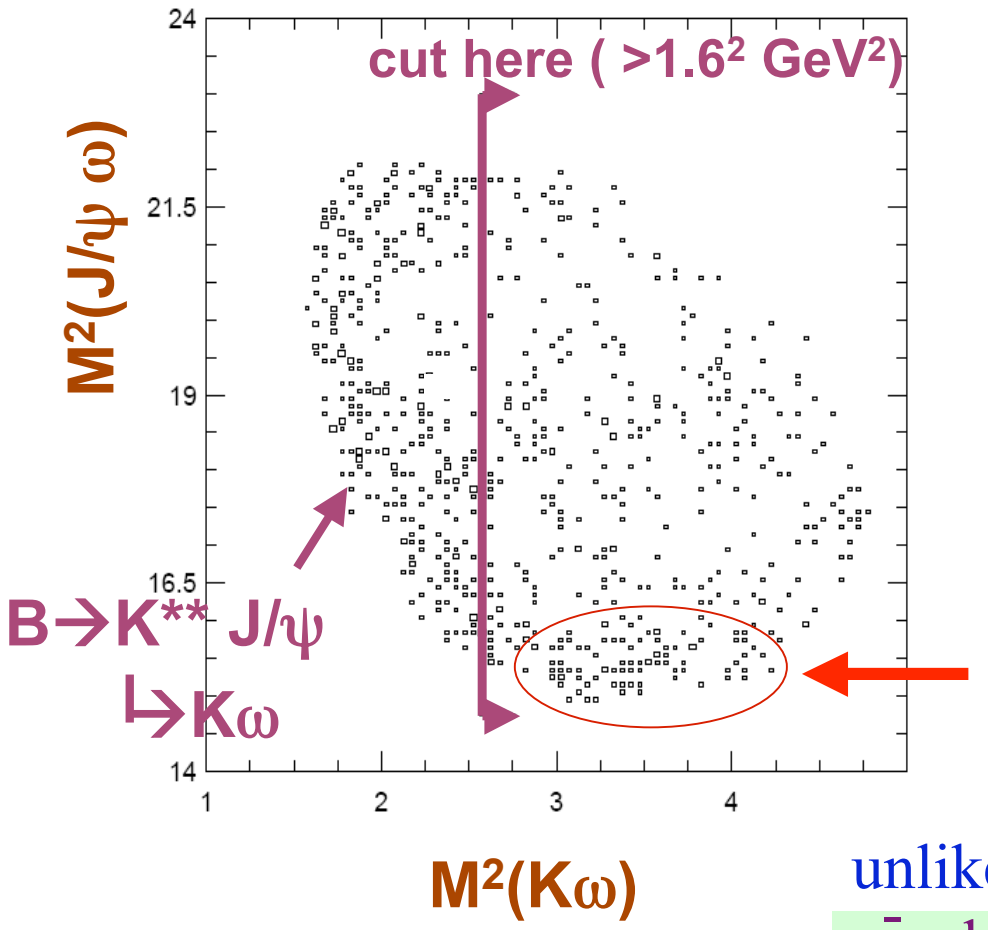
BaBar : $D_{sJ}(2317/2457)$ [PRL 90, 242001(2003)]

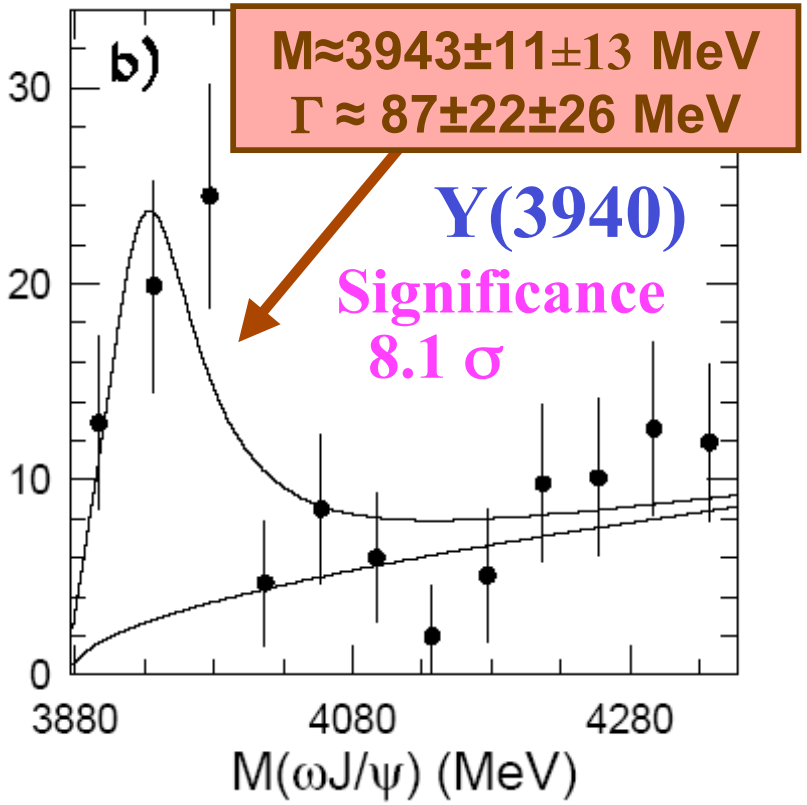
New resonances "X,Y, Z(3940)"

Y(3940)

275M $B\bar{B}$

$B \to J/\psi\,(\pi^+\pi^-\pi^0)K$ [PRL 94,182002(2005)]





unlikely normal ($c\bar{c}$) state

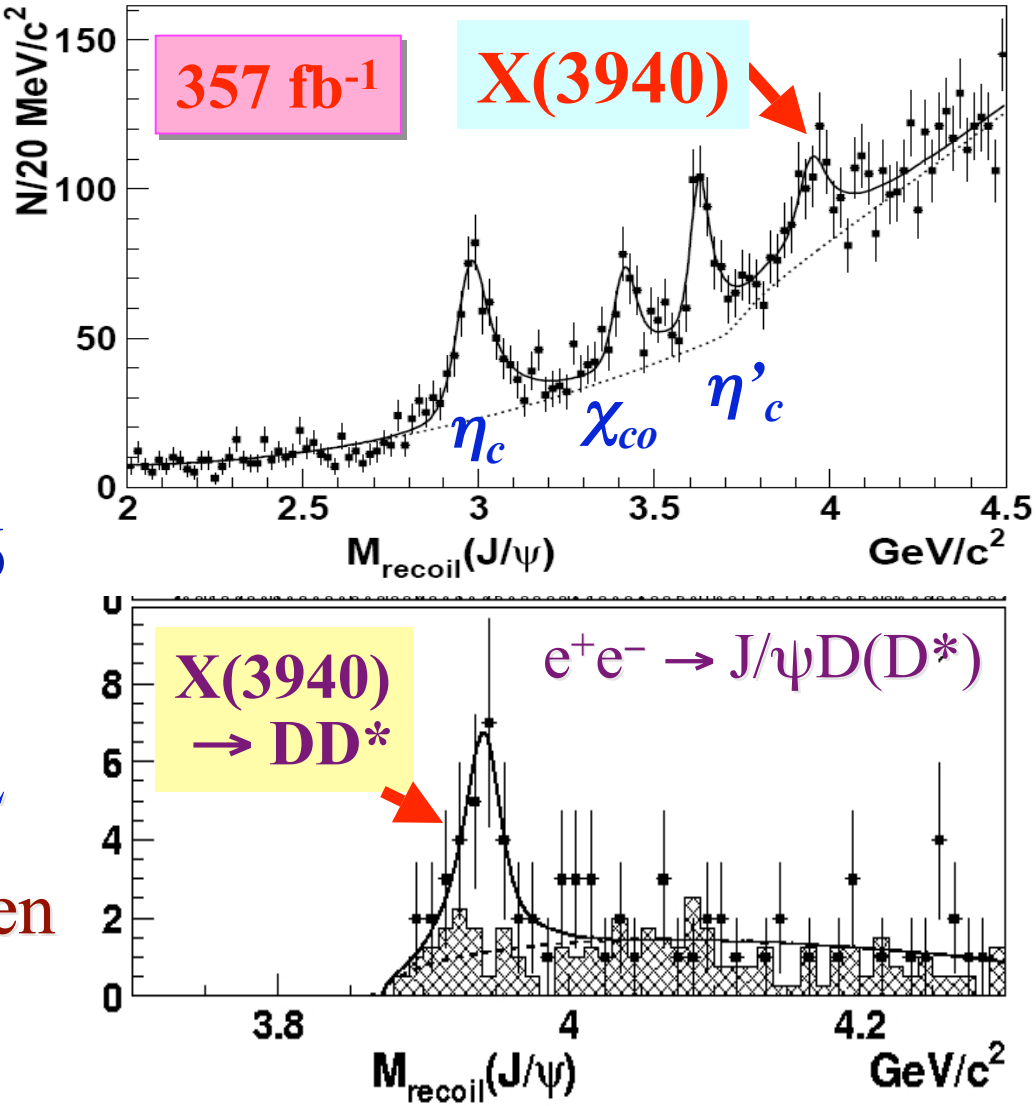
$c\bar{c}$-gluon hybrid ? [D.Horn, PRD17,898(78)]

X3940

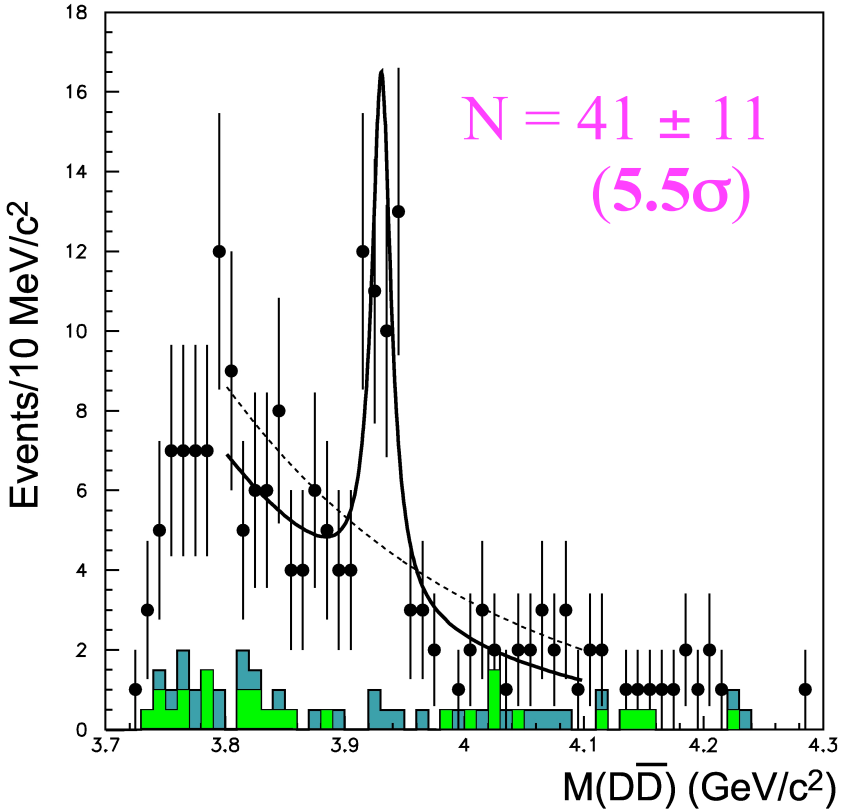
[hepex/0507019]
submitted to PRL

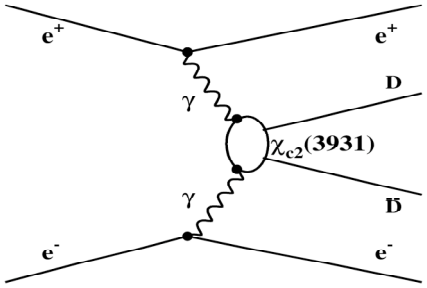
$e^+e^- \to J/\psi\,(cc)_{res}$

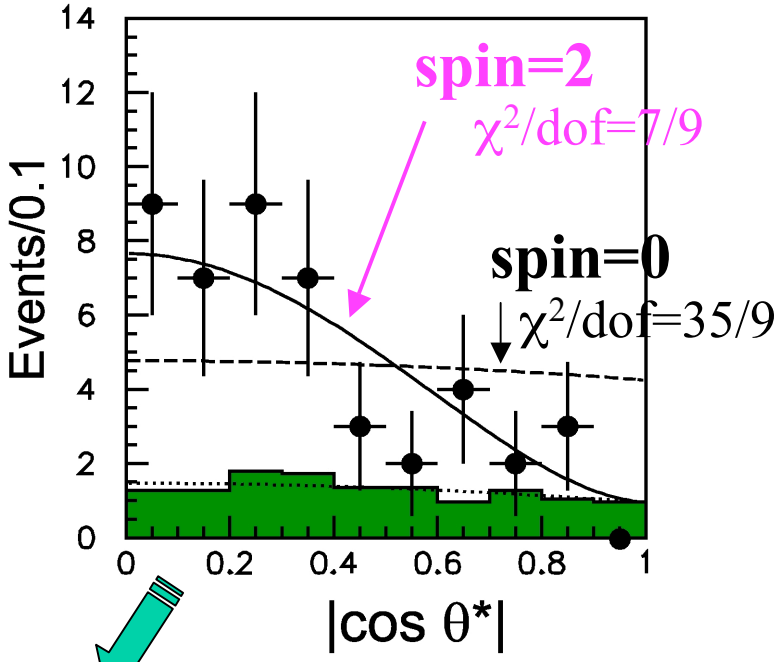
- Significant peak at
  N=266±63 (5.0σ)
- **X(3940) → DD*** seen
  in $e^+e^- \to J/\psi D(D^*)$
  M=3.943±0.006 ±0.006 GeV/c^2
  n =24.5±6.9 (5.0σ)
  $\Gamma < 52$ MeV/c^2 @90%CL
- X(3940) → J/ψω: not seen
  in $e^+e^- \to J/\psi\omega(J/\psi)$



Z(3940): $\gamma\gamma \to D\bar{D}$







$\Gamma = 20 \pm 8 \pm 3$ MeV

$M = 3.931 \pm 0.004 \pm 0.002$ GeV/c^2

Heliciy dist. → χ'_{c2} (2^3P_2)

[PRL 98,082003(06)]

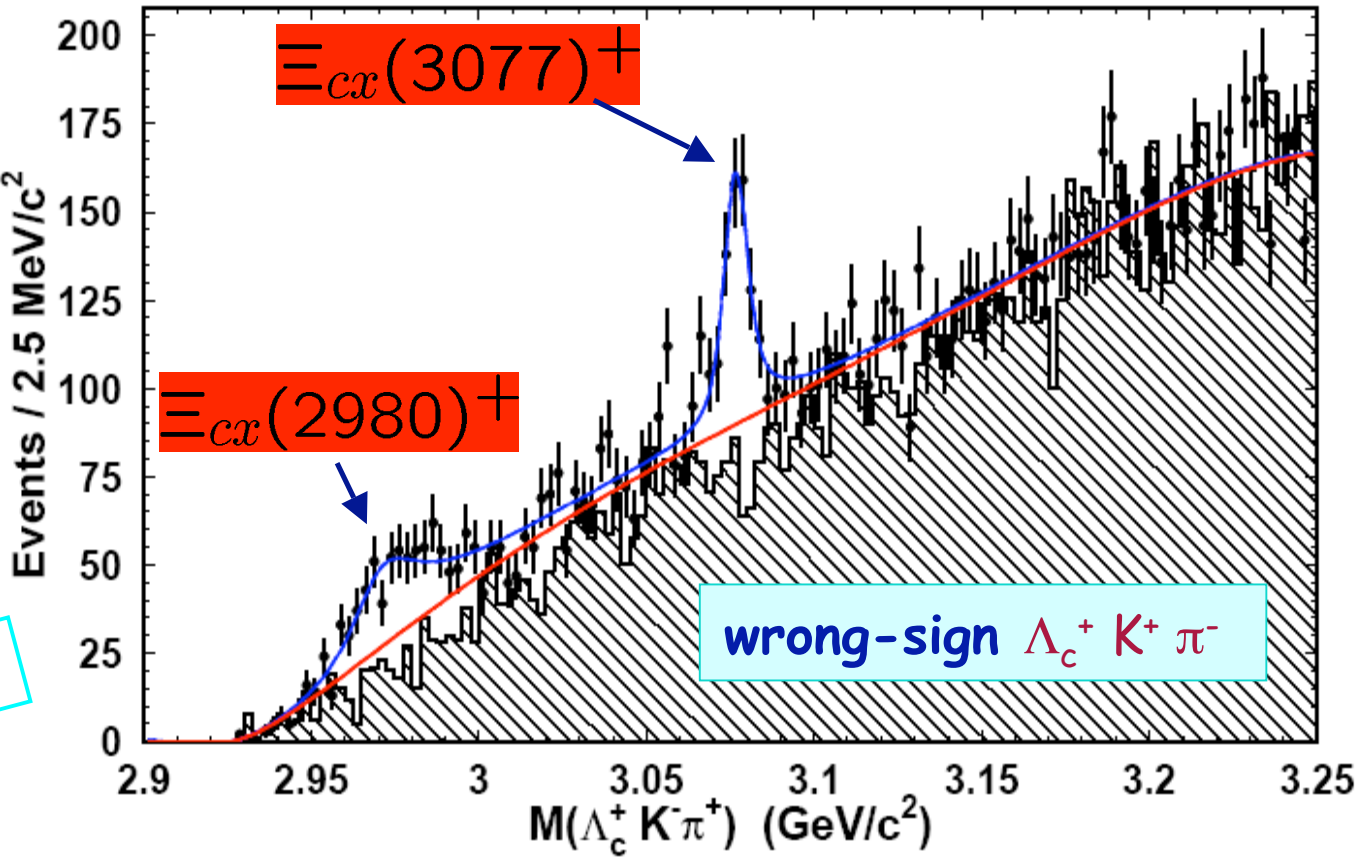
Two New Charmed Baryons

462 fb^{-1}

$\Lambda_c^+ K^- \pi^+$

New at Winter Conf.

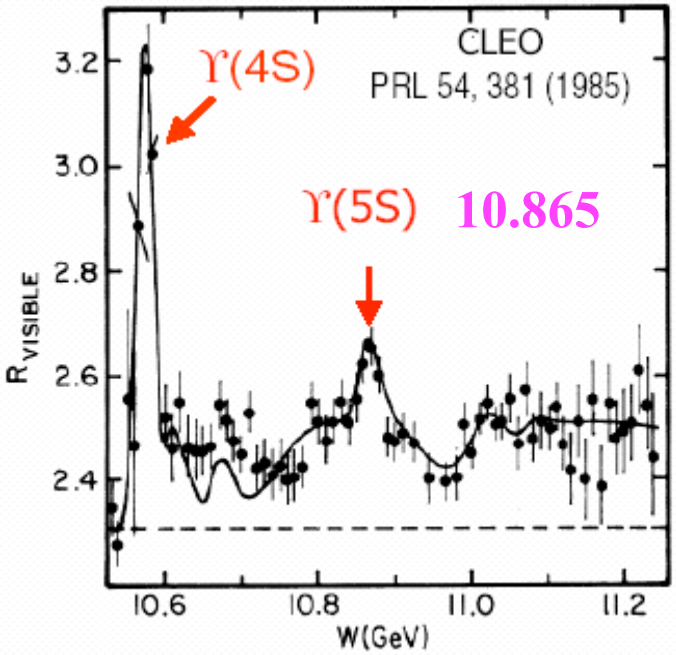
Preliminary



New State	Mass, (MeV/c^2)	Width, (MeV/c^2)	Yield, (events)	Significance, (σ)
$\Xi_{cx}(2980)^+$	$2978.5 \pm 2.1 \pm 2.0$	$43.5 \pm 7.5 \pm 7.0$	405.3 ± 50.7	6.3
$\Xi_{cx}(3077)^+$	$3076.7 \pm 0.9 \pm 0.5$	$6.2 \pm 1.2 \pm 0.8$	326.0 ± 39.6	9.7

Y(5S) Run

$\Upsilon(5S) \rightarrow B_sB_s,\ B_s^*B_s,\ B_s^*B_s^*$
$BB,\ B^*B,\ B^*B^*,\ BB\pi(\pi)$



- **Engineer run: 21-Jun-2005, 3 days**
  - **Integ. Lum: 1.86 /fb (World largest)**
  - **[cf. CLEO: 0.42/fb]**
  - **Acc./Detector: ~same as Y(4S)**

$N_{bb}(5S) =$ 561,000 ± 3,000 ± 29,000 events

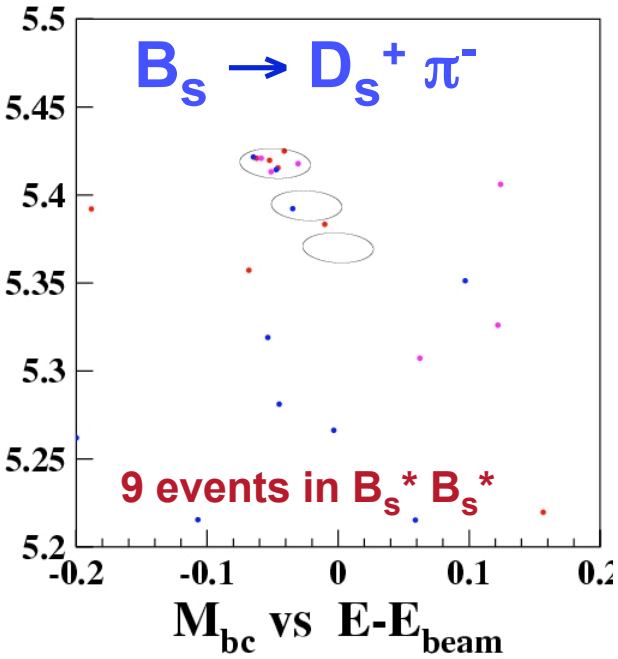
$N_{bb}(5S) / fb^{-1} = 302{,}000 \pm 15{,}000$

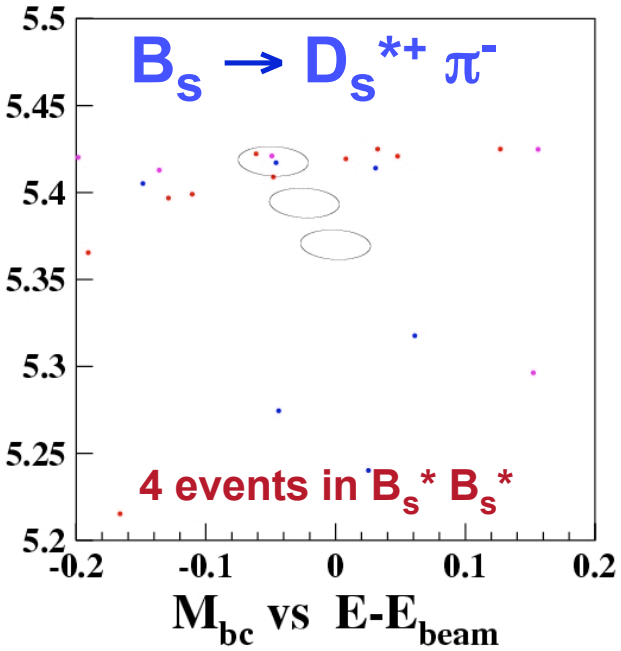
Preliminary

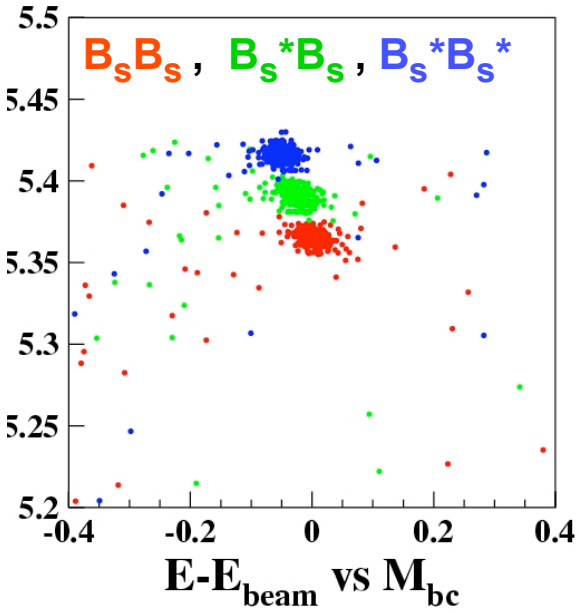
$f_s = N(B_s^{(*)}B_s^{(*)})/N_{bb} = (16.4 \pm 1.4 \pm 4.1)\%$ (inclusive D_s yield)

[CLEO: $(16.0 \pm 2.6 \pm 5.8)\%$]

Exclusive B_s Decays



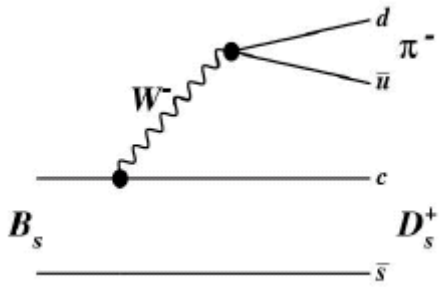




$D_s^+ \to \phi \pi^+$, $D_s^+ \to K^{*0} K^+$, $D_s^+ \to K_S K^+$

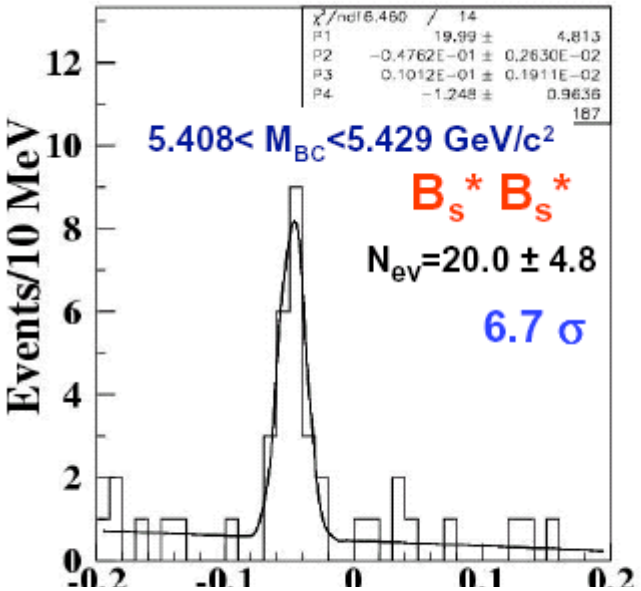
Preliminary

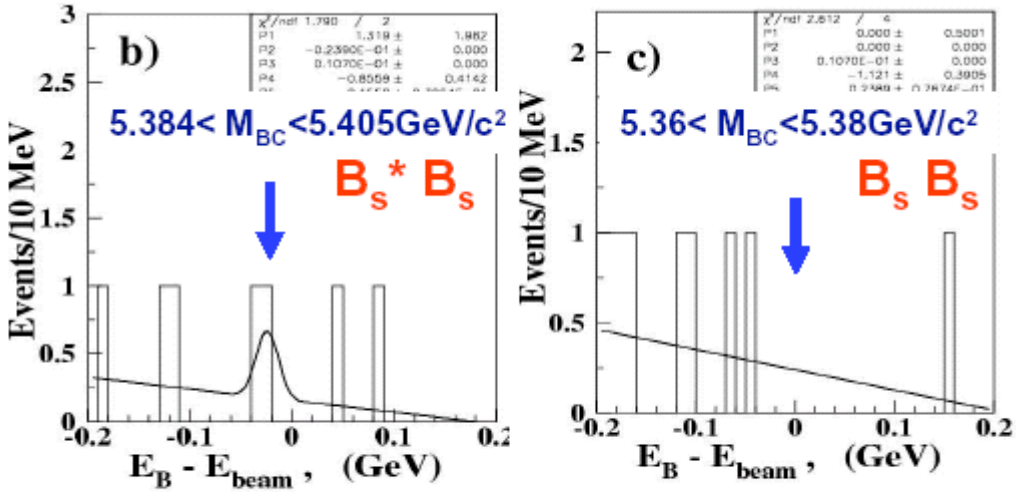
$Bf(B_s \to D_s^+ \pi^-) = (0.65 \pm 0.21 \pm 0.19)\%$



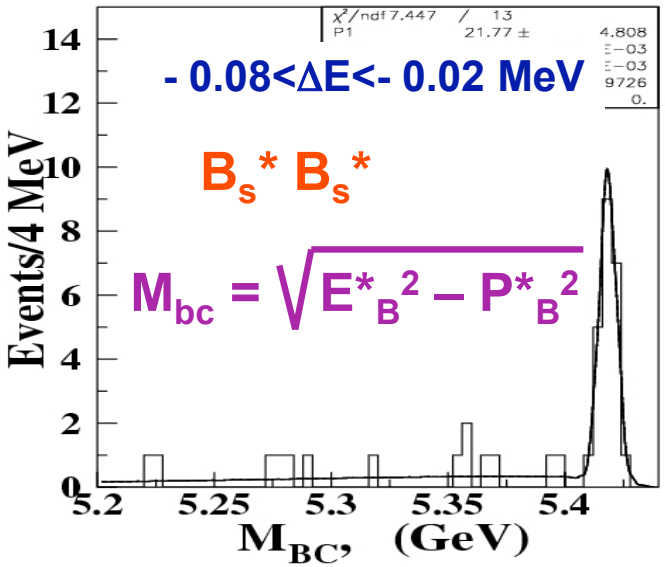
- $B_s \to D_s^{(*)+} \rho^-$, $B_s \to J/\psi \phi/\eta$ signals also seen

Sum of all exclusive decays





N_{ev}= 1.3 ± 2.0 ev. => small signal



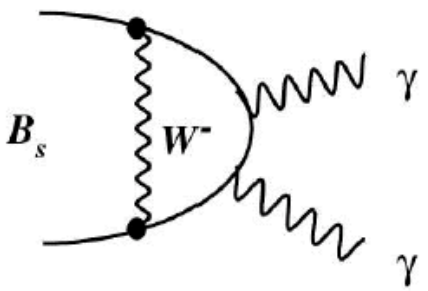
$B_s^* B_s^*$ fraction =(94 ± 9)%

Preliminary

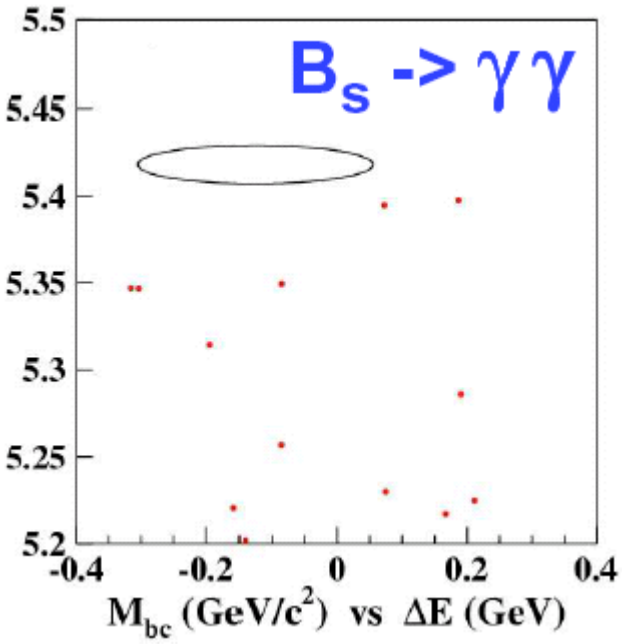
$M(B_s^*) = 5418 \pm 1 \pm$ (acc. err) MeV/c²

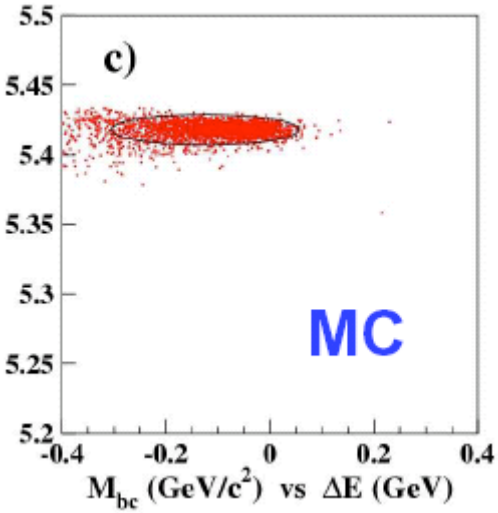
Photon momentum is neglected => does not change B_s^* mass position, only smearing.

Search for $B_s \to \gamma\gamma$



unique mode at B-factory





In SM: $Bf(B_s \to \gamma\gamma) = (0.5\text{-}1.0) \times 10^{-6}$

BSM can increase *Bf* up to two orders

Preliminary

90% *CL* UL with 1.86 fb^{-1} : $Bf(B_s \to \gamma\gamma) < 0.56 \times 10^{-4}$.

PDG limit : $Bf(B_s \to \gamma\gamma) < 1.48 \times 10^{-4}$

More analyses on going

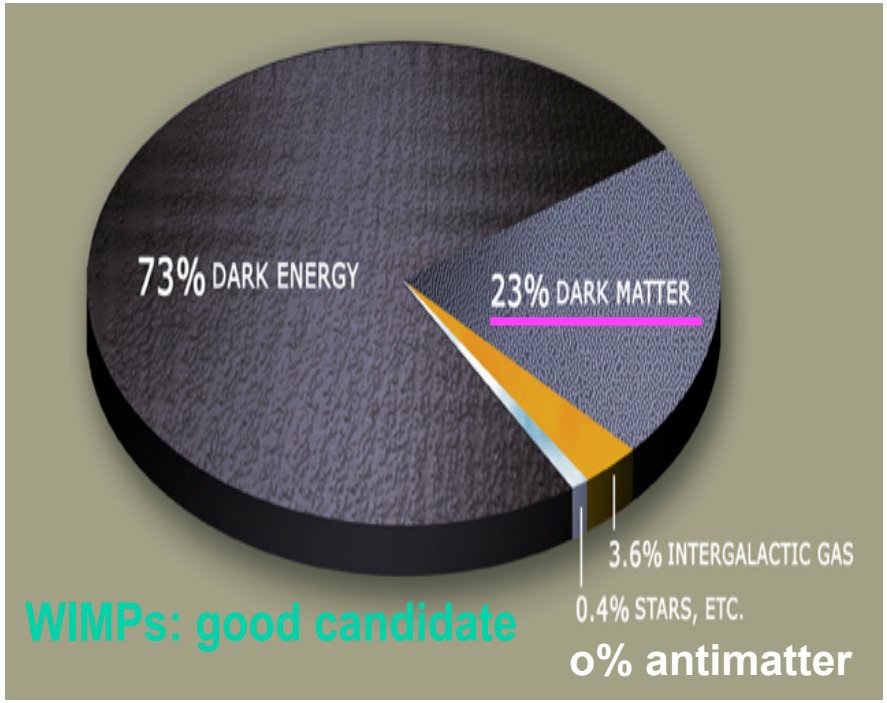
Y(3S) Run

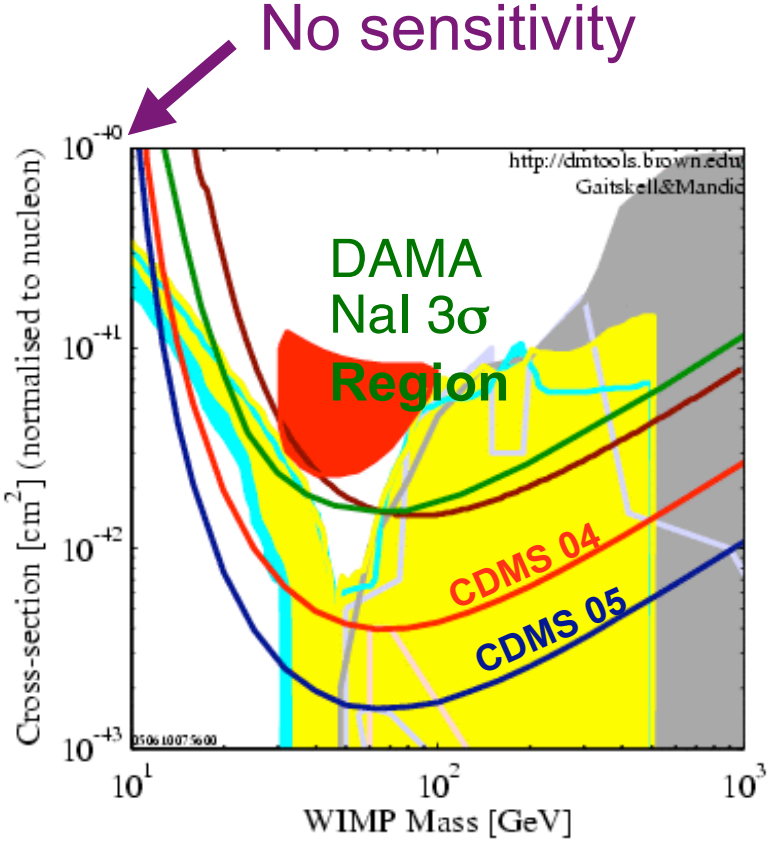
Dark Matter search:

[B.McElrath, PRD72, 103508 (05)]

B(Y(1S) → DM(invisible)) ~ 0.0041 (m_{DM}<4.73GeV/c^2)

$\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$



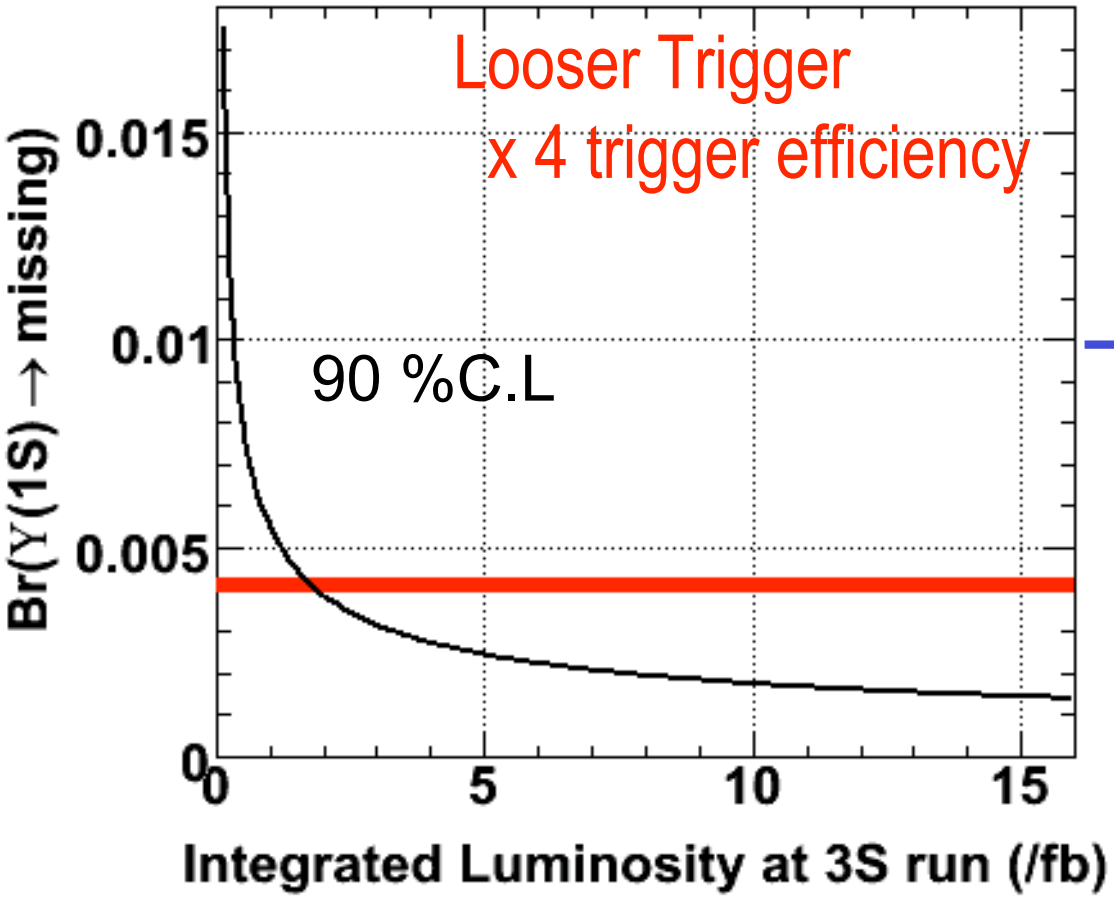


Search Sensitivity

Y(4S): $\sigma(e^+e^- \rightarrow Y(3S)\gamma_{ISR}) \sim 0.02$ nb

Y(3S): $\sigma(e^+e^- \rightarrow Y(3S)) \sim 3$ nb

S/N ratio x150



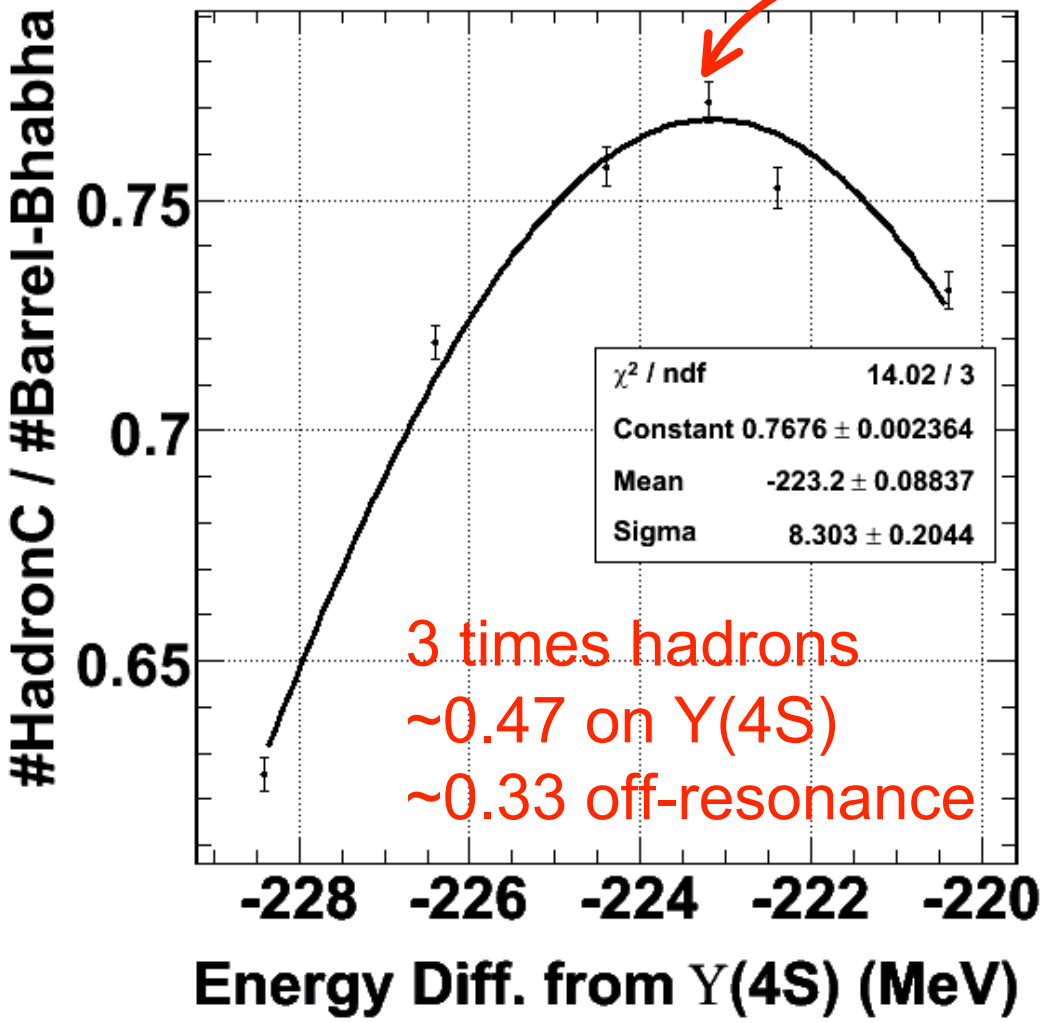
Y(4S) run
460 /fb

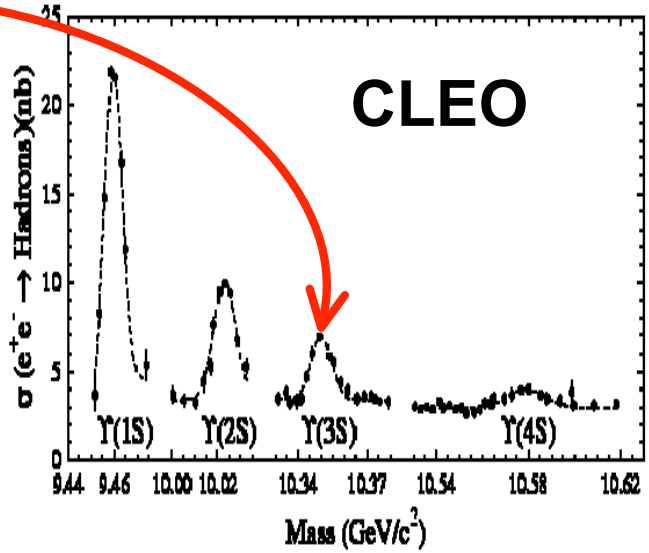
Theory prediction

**) Syst. error is not considered*

Engineering run

(25-Feb-2006, 4.5 days)





Energy scan ~ 4hours
We set E(4S)-223.6 MeV
~ 3 /fb on 3S resonance
~0.25 /fb on 30MeV below 3S

Analysis on going…

Summary

2004 summer → 2005 summer: **275M → 386M $B\bar{B}$**

Excellent KEKB performance: now **~550M $B\bar{B}$!**

⇒ Significant New/improved results !

- New ***b → d* penguin** established ! ***B→ ρ/ωγ, $K\bar{K}$***
- CKM UT/SM test & NP search: progresses
- More New resonances observed !
- Y(5S), Y(3S) engineering runs: successfully done

: (lot more… not shown here)

We (Belle) are looking forward to having higher/more luminosity and New excitements !

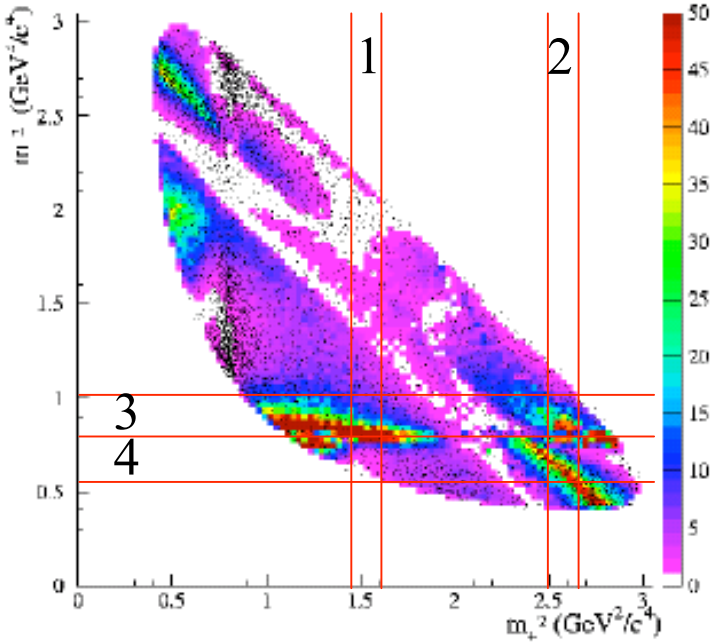
CPV in Dalitz plane

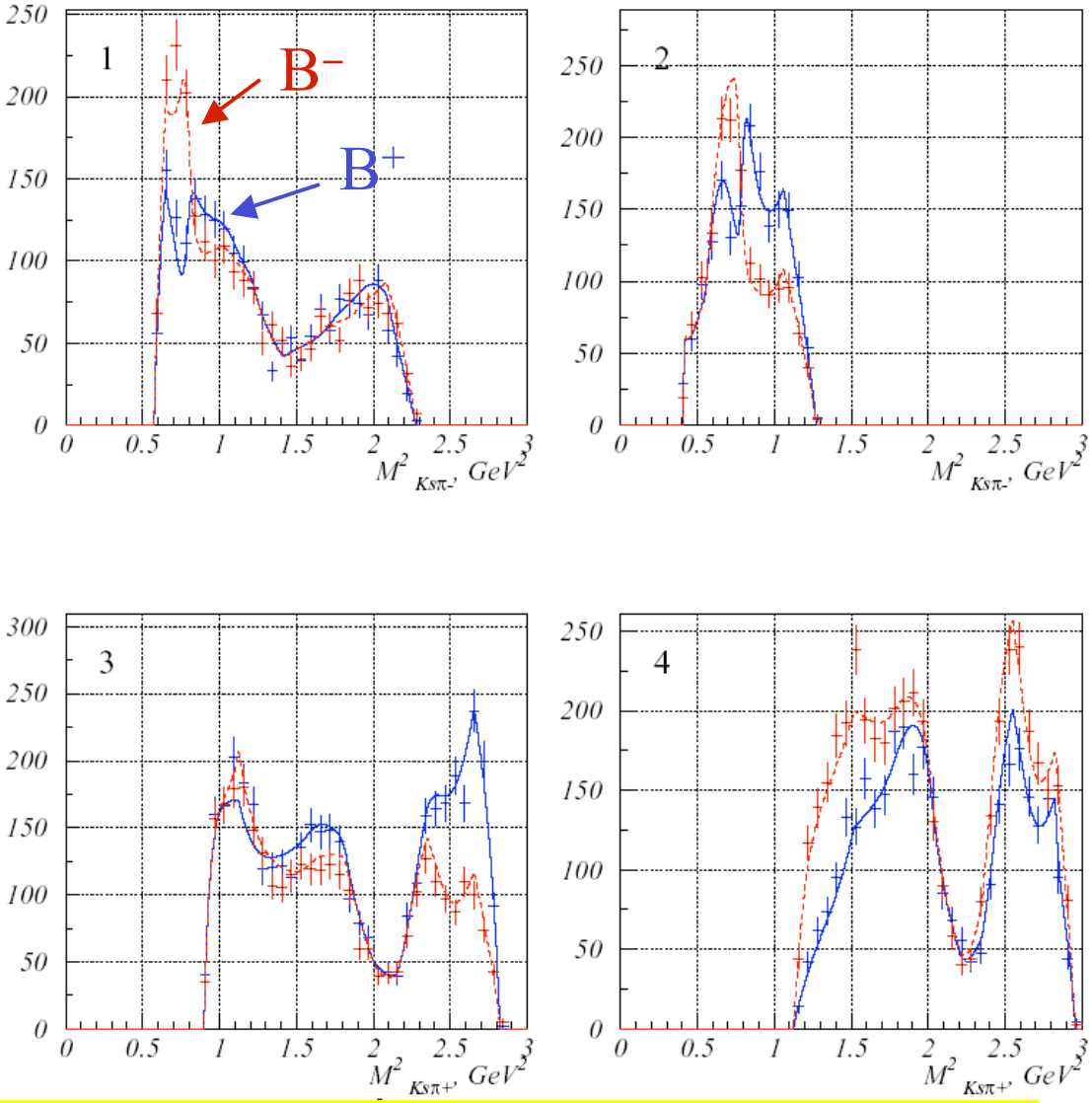
MC simulation

$\phi_3 = 70$ deg.

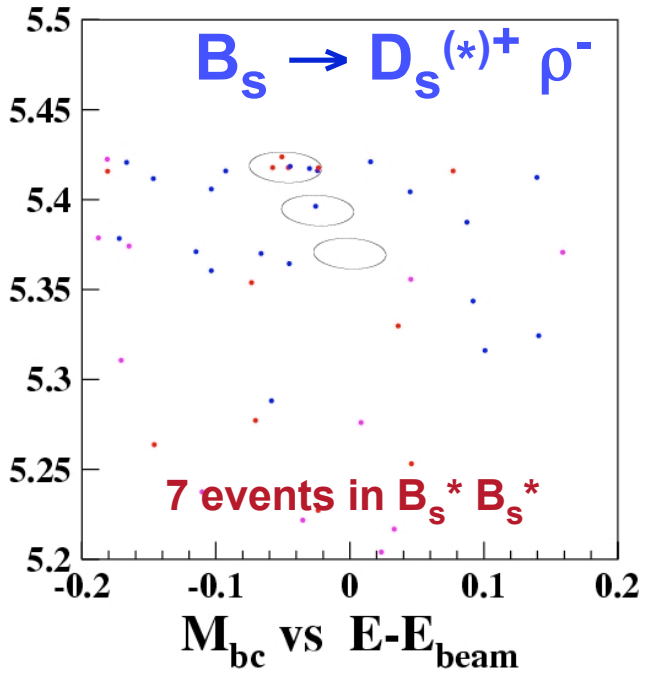
$\delta = 0$, $r = 0.125$

Sensitivity to ϕ_3

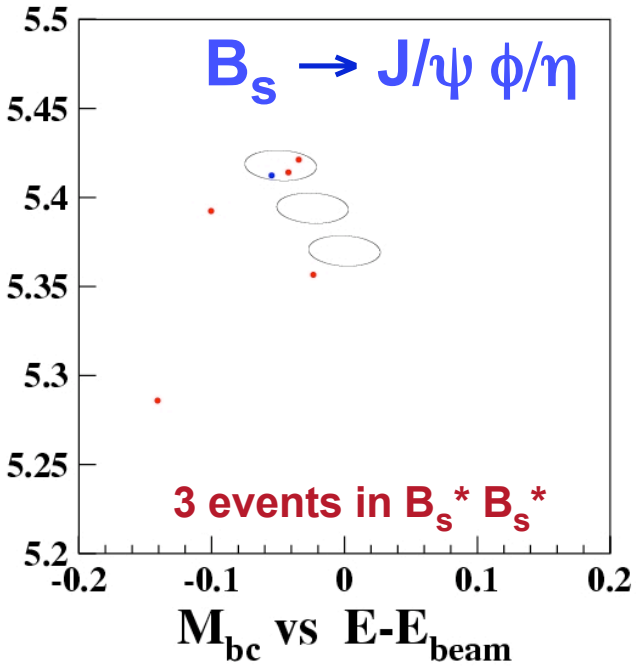




Exclusive B_s Decays (2)

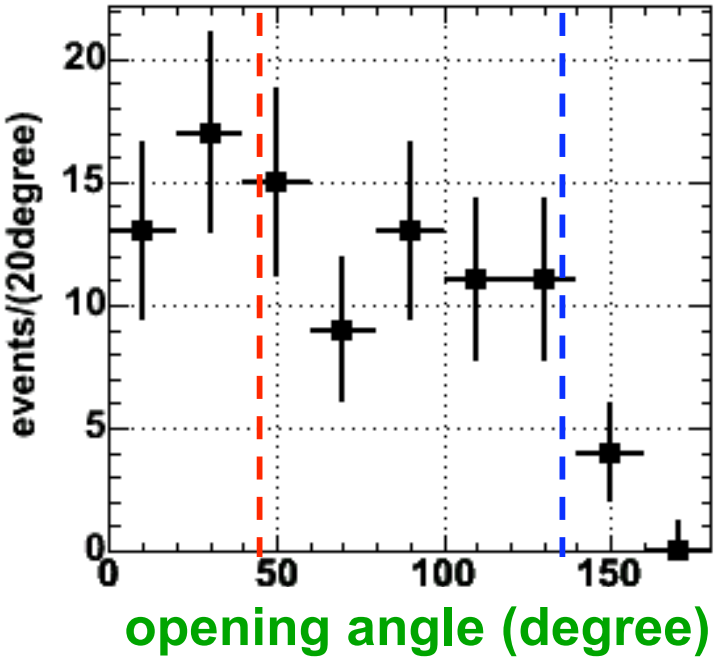


$D_s^+ \to \phi \pi^+$, $D_s^+ \to K^{*0} K^+$, $D_s^+ \to K_s K^+$

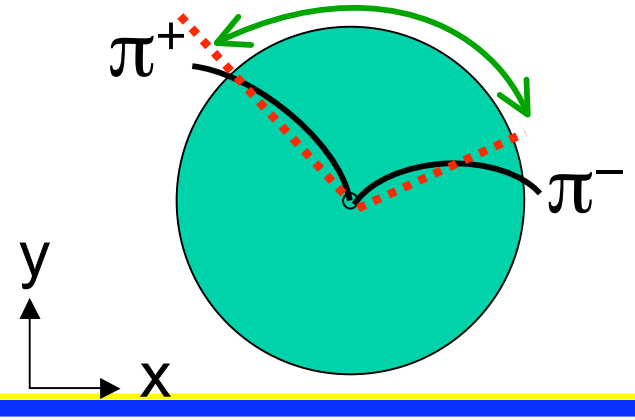


$B_s \to J/\psi \phi$, $B_s \to J/\psi \eta(\gamma\gamma)$

Trigger Efficiency



Control sample data
$\Upsilon(3S) \rightarrow \Upsilon(1S)\pi^+\pi^-$
$\Upsilon(1S) \rightarrow \mu^+\mu^-$
Eff. depends on opening angle



4 times efficiency gain is expected
- loose opening angle cut
  135 → 45 degree
- loose pt cut
  pt>350 MeV for both tracks
  → for one (or both) track