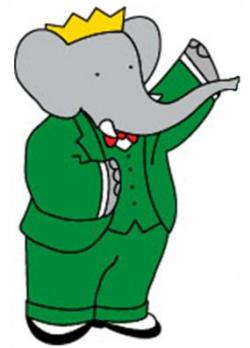


Rare decays and CP violation at B Factories



Yuuji Unno
Hanyang university
(On behalf of the Belle and BABAR collaborations)

March 1-7, 2009, La Thuile, Italy



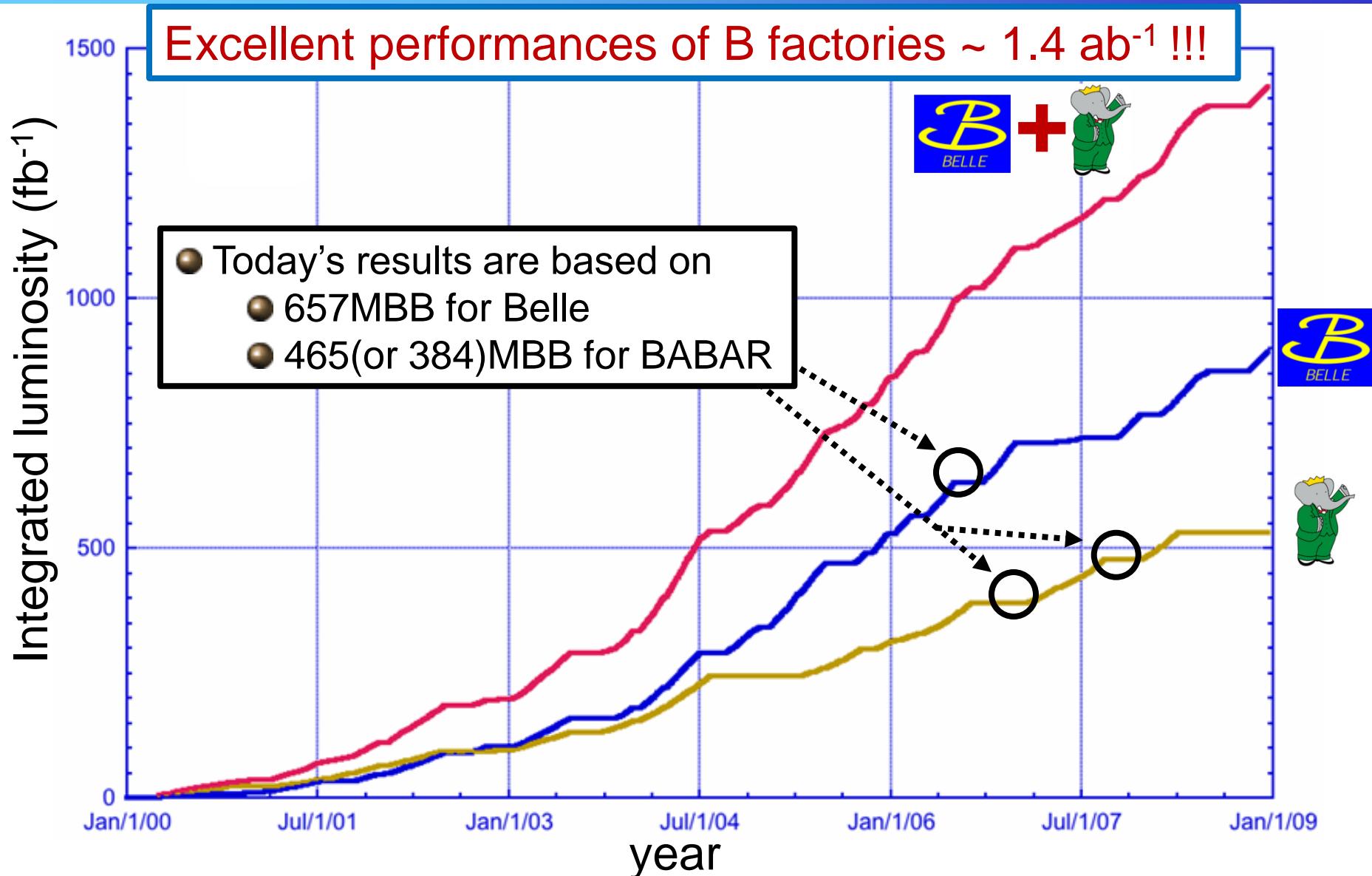
Contents

A part of recent results are shown from

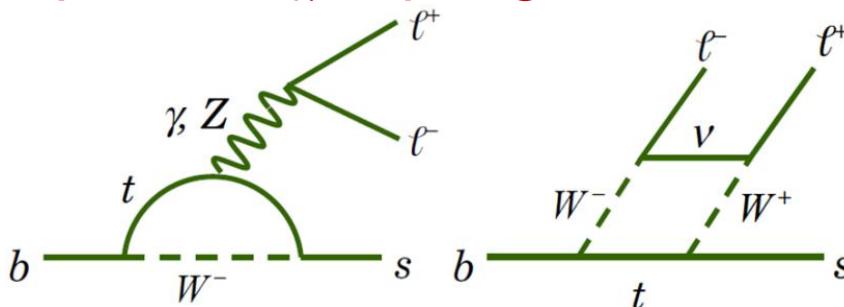


- Data set
- Wilson coefficient from $B \rightarrow K^{(*)} ll$
- Polarization puzzle in $B \rightarrow VV$ (& PV & VT)
 - $B^0 \rightarrow \rho^0 K^{*0}$
 - $B^+ \rightarrow K^{*0} \bar{K}^{*-}$
 - $B^+ \rightarrow \bar{K}^{*0} K^+$
 - $B \rightarrow \omega K^*, \omega \rho$
- Summary

Data set



- $b \rightarrow s$ FCNC process (γ/Z penguin and box diagrams)



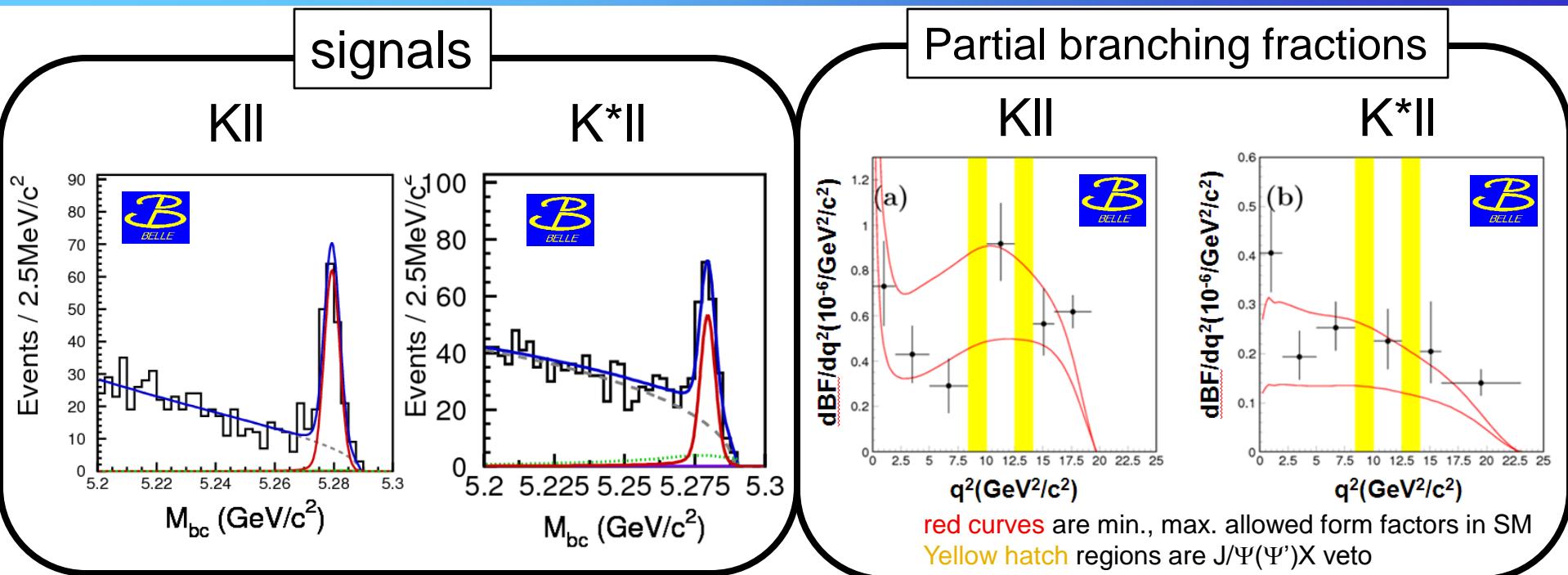
- The amplitude is a function of $s = q^2/m_b^2$

$$\frac{d\Gamma(b \rightarrow s \ell^+ \ell^-)}{d\hat{s}} \propto \left[(1 + 2\hat{s}) (|C_9^{\text{eff}}|^2 + |C_{10}^{\text{eff}}|^2) + 4 \left(1 + \frac{\hat{s}}{2}\right) |C_7^{\text{eff}}|^2 + 12 \text{Re} (C_7^{\text{eff}} C_9^{\text{eff}}) \right] + \text{corr.}$$

- Sensitive to C_9 , C_{10} and $\text{sign}(C_7)$, ($|C_7|$ from $b \rightarrow s \gamma$)
- New physics may contribute at the same order as the SM.
 - \rightarrow may change Wilson coefficients dramatically: $C_i = C_i^{\text{SM}} + C_i^{\text{NP}}$
- Many observables: Br , A_{CP} , A_l , A_{FB} ...
 - NP hints / models can be examined from various perspectives

$B \rightarrow K^{(*)} l^+ l^-$ (Branching fraction)

 657 $M B\bar{B}$
 384 $M B\bar{B}$



preliminary



Belle($\times 10^{-7}$)

BABAR($\times 10^{-7}$)

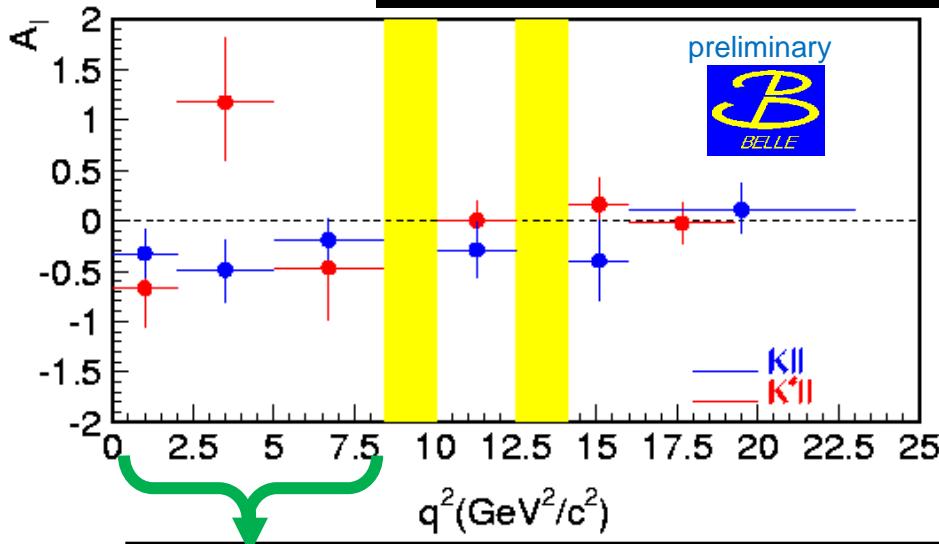


KII	$4.80^{+0.5}_{-0.4} \pm 0.3$	$3.9 \pm 0.7 \pm 0.2$
$K^* II$	$10.7^{+1.1}_{-1.0} \pm 0.9$	$11.1 \pm 1.9 \pm 0.7$

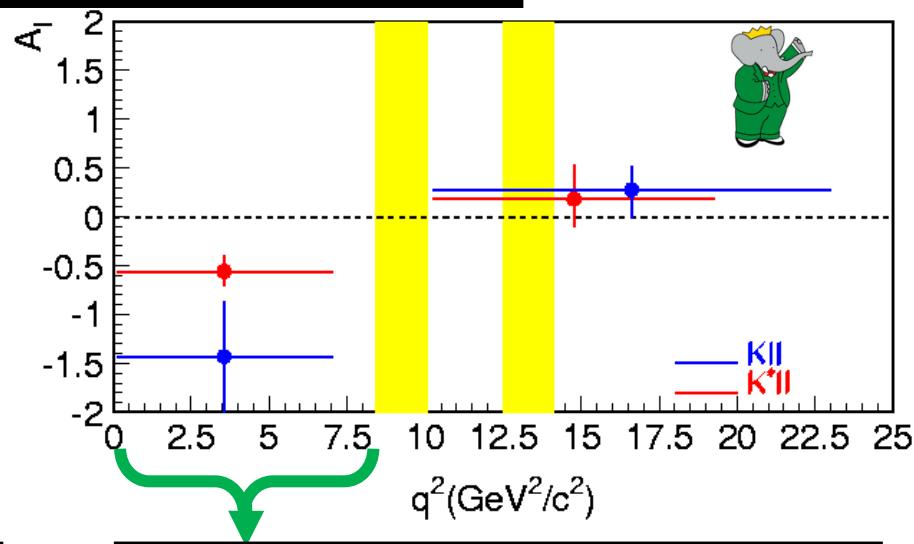
Belle and BABAR results are consistent

$B \rightarrow K^{(*)} l^+ l^-$ (Isospin asymmetry)

$$A_I \equiv \frac{(\tau_{B^+}/\tau_{B^0}) \times B(B^0 \rightarrow K^{(*)0} ll) - B(B^\pm \rightarrow K^{(*)\pm} ll)}{(\tau_{B^+}/\tau_{B^0}) \times B(B^0 \rightarrow K^{(*)0} ll) + B(B^\pm \rightarrow K^{(*)\pm} ll)}$$



$K^{*0} ll = -0.31^{+0.17}_{-0.14} \pm 0.05$ with $\sigma = 1.75$
 $K^0 ll = -0.29^{+0.16}_{-0.16} \pm 0.03$ with $\sigma = 1.40$
 $K^{(*)0} ll = -0.30^{+0.12}_{-0.11} \pm 0.04$ with $\sigma = 2.24$



$K^{*0} ll = -1.43^{+0.56}_{-0.85} \pm 0.05$ with 2.7σ
 $K^0 ll = -0.56^{+0.17}_{-0.15} \pm 0.03$ with 3.2σ
 $K^{(*)0} ll = -0.64^{+0.15}_{-0.14} \pm 0.03$ with 3.9σ

- Large negative A_I in the low q^2 region in BABAR, which is not expected in SM.
- No significant A_I in Belle data, but consistent with BABAR. Need more statistics.

$B \rightarrow K^{(*)} l^+ l^-$ (Lepton flavor ratio / CP asymmetry)

- Lepton flavor ratio : $R_{K^{(*)}} = B(K^{(*)}\mu^+\mu^-)/B(K^{(*)}e^+e^-)$

- In SM, $R(K^*) \sim 0.75$, $R(K) \sim 1.0$ are expected
- $R_{K^{(*)}}$ is sensitive to neutral SUSY Higgs if $\tan\beta$ is large

Mode	Belle 	BABAR 
$K ll$	$1.03 \pm 0.19 \pm 0.06$	$0.96^{+0.44}_{-0.34} \pm 0.05$
$K^* ll$	$0.83 \pm 0.17 \pm 0.05$	$1.37^{+0.53}_{-0.40} \pm 0.09$

- CP asymmetry : $A_{CP} = (N_{\bar{B}} - N_B)/(N_{\bar{B}} + N_B)$

- In SM, small A_{CP} is expected

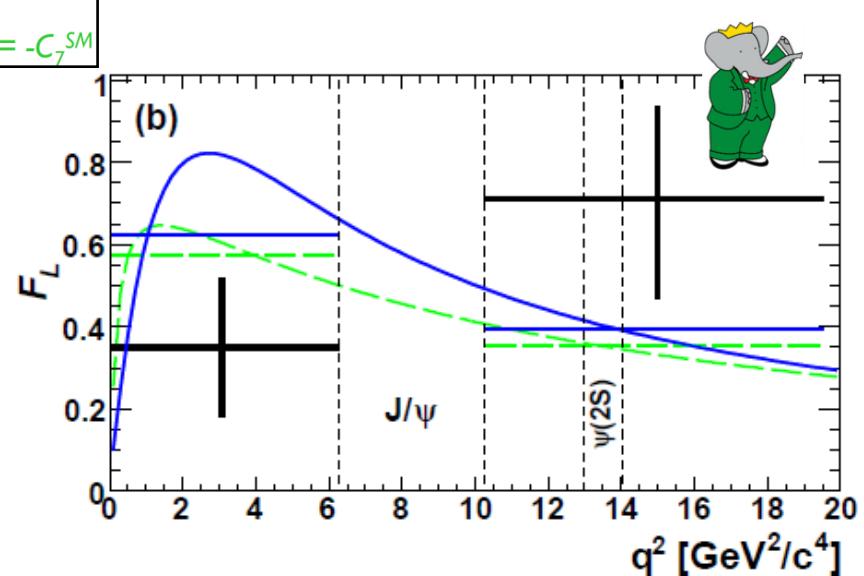
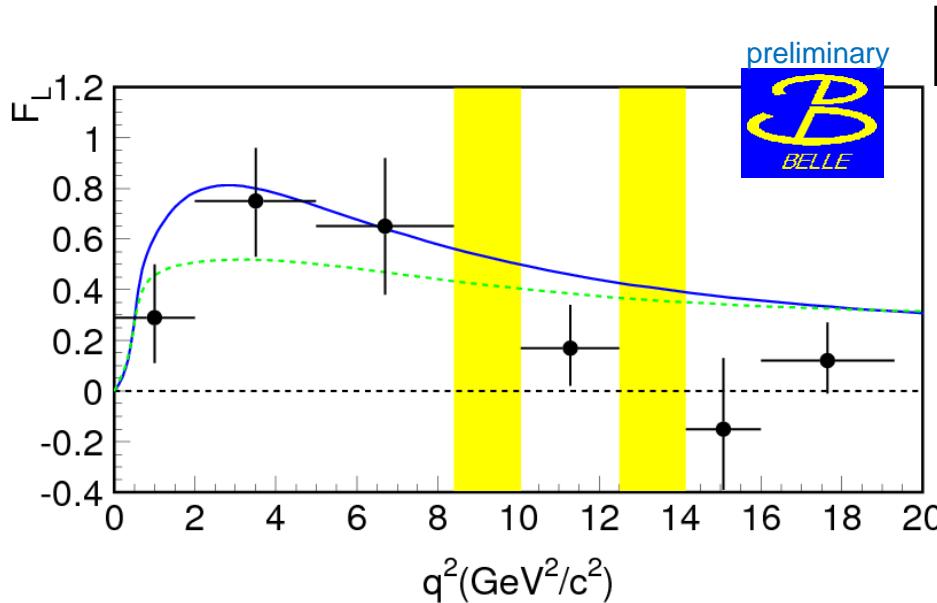
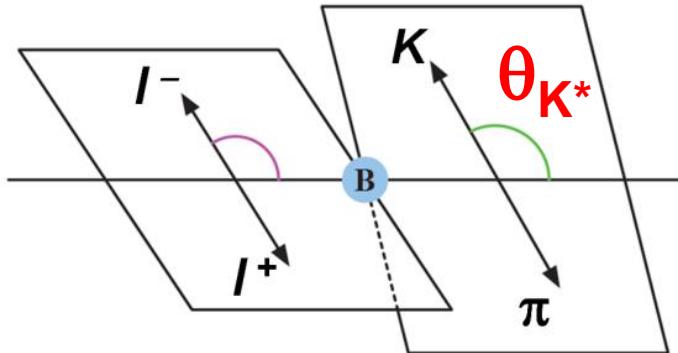
Mode	A_{CP}	preliminary 
$K ll$	$+0.04 \pm 0.10 \pm 0.02$	
$K^* ll$	$-0.10 \pm 0.10 \pm 0.01$	

Mode	combined q^2
$K^+ \ell^+ \ell^-$	$-0.18^{+0.18}_{-0.18} \pm 0.01$
$K^{*0} \ell^+ \ell^-$	$0.02^{+0.20}_{-0.20} \pm 0.02$
$K^{*+} \ell^+ \ell^-$	$0.01^{+0.26}_{-0.24} \pm 0.02$
$K^* \ell^+ \ell^-$	$0.01^{+0.16}_{-0.15} \pm 0.01$

$B \rightarrow K^{(*)} l^+ l^-$ (K^* longitudinal polarization)

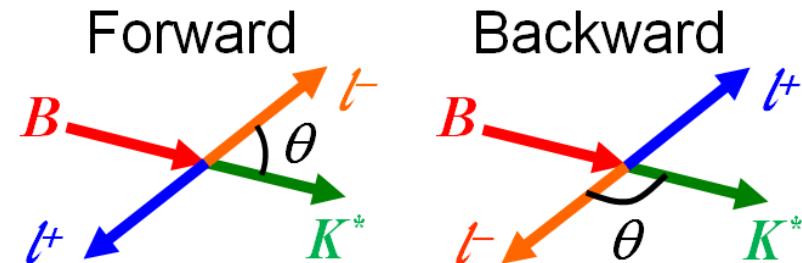
- Longitudinal K^* polarization F_L by fitting to $\cos \theta_{K^*}$
- Important for model independent A_{FB}

$$\frac{d\Gamma}{d \cos \theta_{K^*}} = \frac{3}{2} F_L \cos^2 \theta_{K^*} + \frac{3}{4} (1 - F_L) (1 - \cos^2 \theta_{K^*})$$

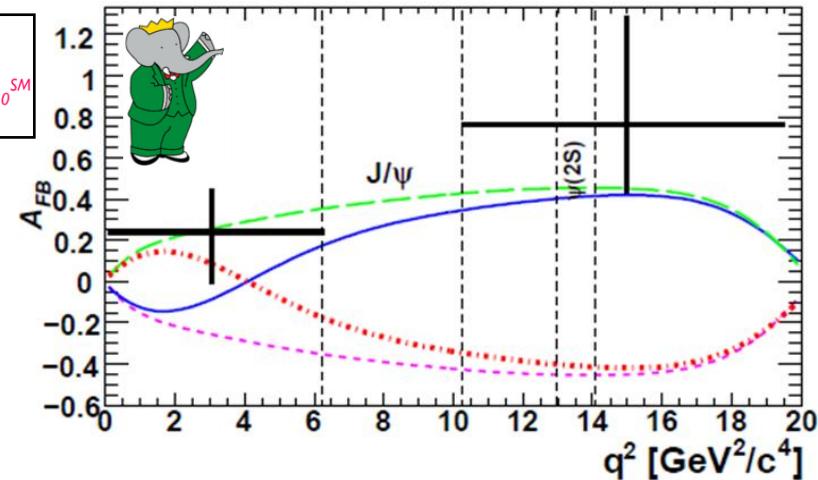
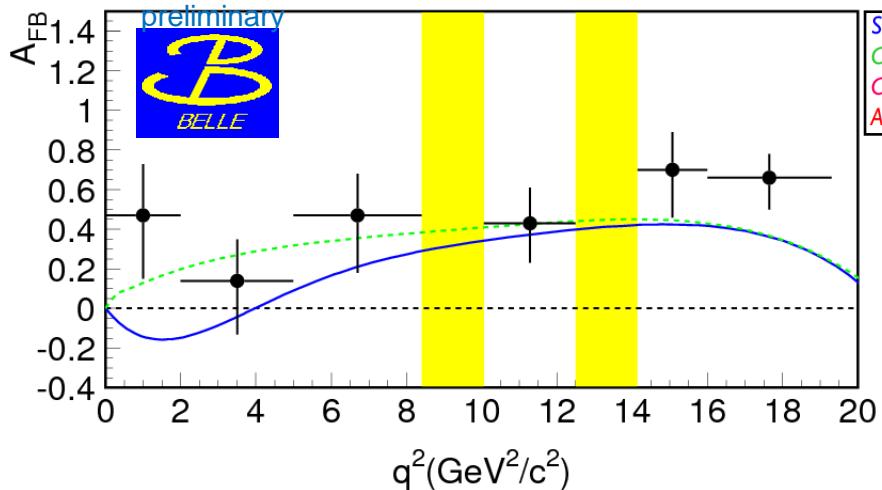


$B \rightarrow K^{(*)} l^+ l^-$ (lepton forward-backward asymmetry)

- A_{FB} due to an interference between γ and Z contributions
- C_9, C_{10} can be accessed from A_{FB}
- A_{FB} by fitting to $\cos \theta_{Bl}$



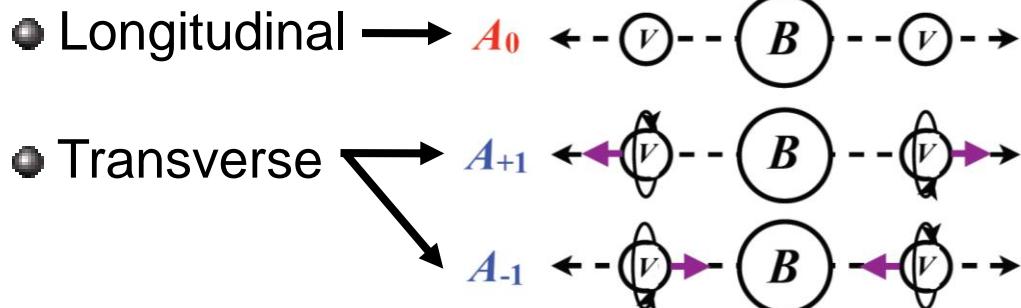
$$\frac{d\Gamma}{d \cos \theta_{Bl}} = \frac{3}{4} F_L (1 - \cos^2 \theta_{Bl}) + \frac{3}{8} (1 - F_L) (1 + \cos^2 \theta_{Bl}) + A_{FB} \cos \theta_{Bl}$$



Looks like wrong sign C_7 is found ???

$B \rightarrow VV$

- In $B \rightarrow VV$, three polarization states contribute:



- The amplitudes in SM are expected to be:

$$A_0 : A_+ : A_- = 1 : \frac{m_V}{m_B} : \frac{m_V^2}{m_B^2}$$

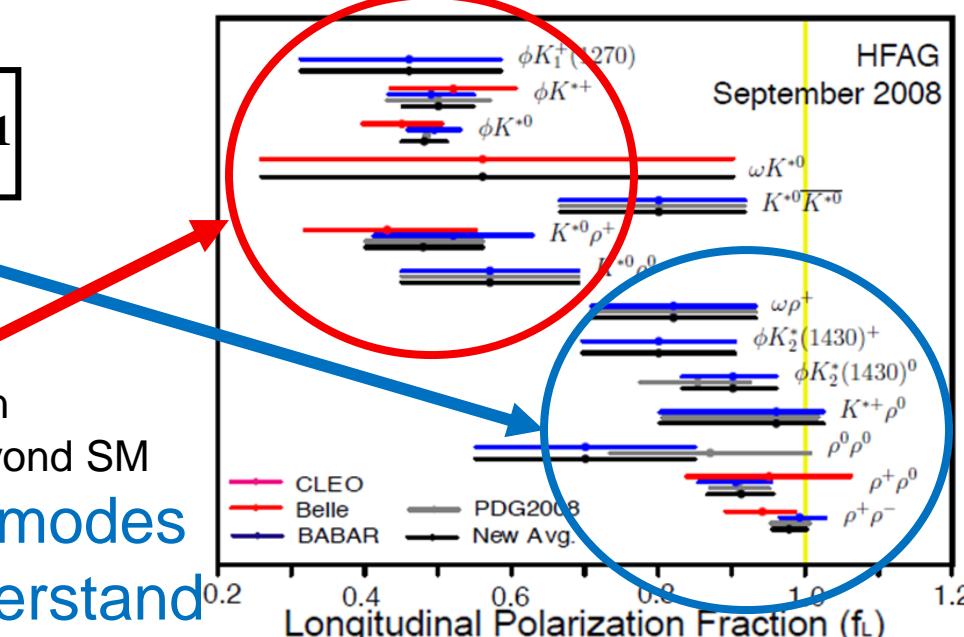
$$f_L = \frac{\Gamma_L}{\Gamma} = \frac{|A_0|^2}{|A_0|^2 + |A_+|^2 + |A_-|^2} \sim 1 - \frac{m_V^2}{m_B^2} \sim 1$$

$f_L \sim 1.0$ for tree dominant

$f_L \sim 0.5$ for penguin dominant

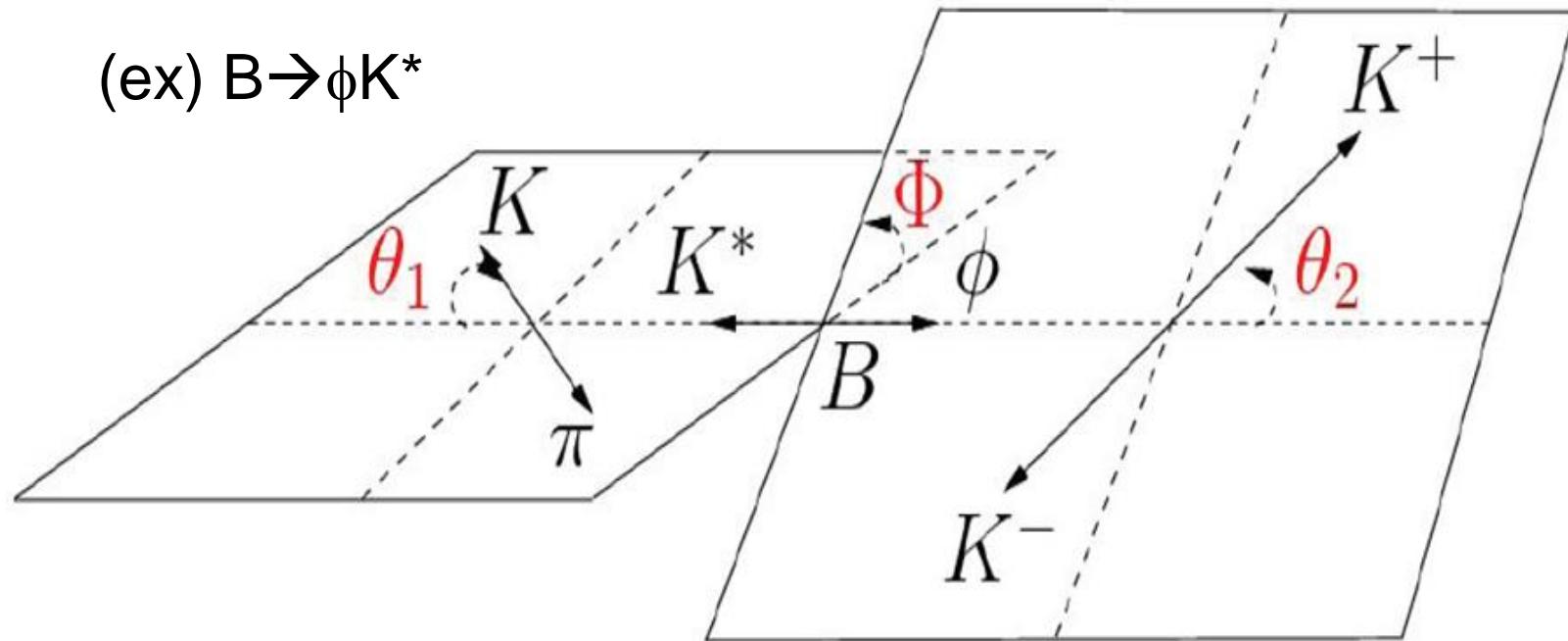
- Many theoretical attempts to explain within SM (P annihilation or rescattering) and beyond SM

- Br and f_L of ϕK^* SU(3) related modes are important for improved understand



$B \rightarrow VV$ (angular analysis)

(ex) $B \rightarrow \phi K^*$

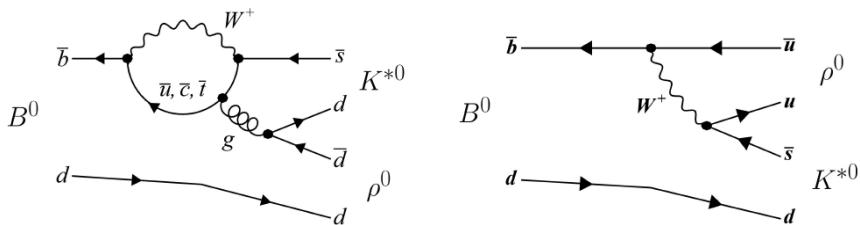


Decay rate can be formulated:

$$\frac{1}{\Gamma} \frac{d^2\Gamma}{d \cos \theta_1 d \cos \theta_2} = \frac{9}{4} \left(f_L \underbrace{\cos^2 \theta_1 \cos^2 \theta_2}_{\text{Longitudinal}} + \frac{1}{4} (1 - f_L) \underbrace{\sin^2 \theta_1 \sin^2 \theta_2}_{\text{Transverse}} \right)$$

f_L can be obtained by fitting to $\cos \theta_1$ and $\cos \theta_2$

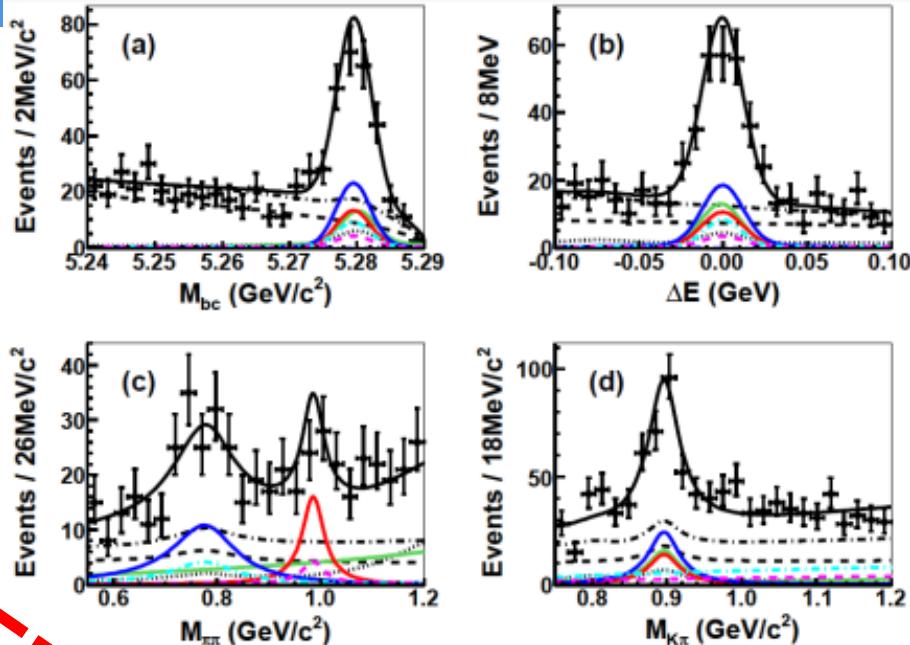
- $\rho^0 K^{*0}$ is through P and C



- First observation by BABAR

(232MBB : PRL 97,201801(2006))

- $\text{Br}(\rho^0 K^{*0}) = (5.6 \pm 0.9 \pm 1.3) \times 10^{-6} (5.3\sigma)$
- $f_L(\rho^0 K^{*0}) = 0.57 \pm 0.09 \pm 0.08$
- $\text{Br}(f^0 K^{*0}) = (2.6 \pm 0.6 \pm 0.9) \times 10^{-6} (5.0\sigma)$



Mode	Y (events)	ε (%)	\mathcal{S} (σ)	\mathcal{B} (10^{-6})	\mathcal{B}_{UL} (10^{-6})
$\rho^0 K^{*0}$	$77.6^{+28.6}_{-27.9}$	5.73	2.7	$2.1^{+0.8+0.9}_{-0.7-0.5}$	< 3.4
$f_0(980) K^{*0}$	$51.2^{+20.4}_{-19.3}$	5.56	2.5	$1.4^{+0.6+0.6}_{-0.5-0.4}$	< 2.2
$\rho^0 K^+ \pi^-$	$207.8^{+39.8}_{-39.2}$	11.15	5.0	$2.8 \pm 0.5 \pm 0.5$	-
$f_0(980) K^+ \pi^-$	$106.9^{+31.6}_{-29.9}$	11.43	3.5	$1.4 \pm 0.4^{+0.3}_{-0.4}$	-
$\pi^+ \pi^- K^{*0}$	$200.7^{+46.7}_{-44.9}$	6.74	4.5	$4.5^{+1.1+0.9}_{-1.0-1.6}$	-
$\pi^+ \pi^- K^+ \pi^-$	$-5.4^{+54.9}_{-44.9}$	6.84	0.0	$-0.1^{+1.2+1.4}_{-1.1-0.8}$	< 2.1

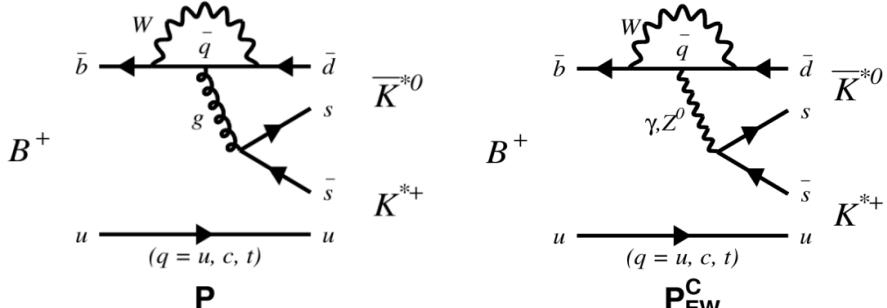
Excess but no evidence...

Difference between Belle and BABAR is less than 2σ , so this would be statistical fluctuation

← **First observations
for three body decays**



- $b \rightarrow d$ gluonic & electroweak penguin



- $b \rightarrow d$ penguin $K^{*0}K^{*0}$ by BABAR

- $\text{Br} = (1.28^{+0.35}_{-0.30} \pm 0.11) \times 10^{-6}$

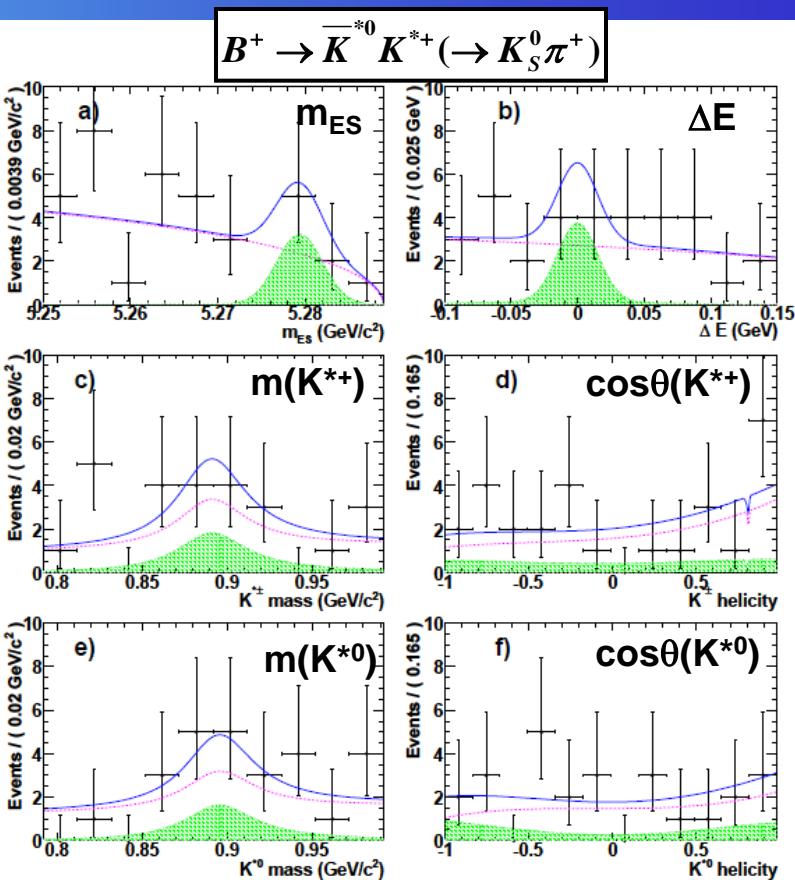
- $f_L = 0.80^{+0.10}_{-0.12} \pm 0.06$

- $\text{Br}(\bar{K}^{*0}K^{*+})$ is expected to be $\sim \text{Br}(K^{*0}\bar{K}^{*0})$

Final State	$K^- \pi^+ K_S^0 \pi^+$	$K^- \pi^+ K^+ \pi^0$
f_L	$0.72^{+0.23}_{-0.36} \pm 0.03$	$0.79^{+0.22}_{-0.36} \pm 0.03$
$\mathcal{B} (\times 10^{-6})$	$0.85^{+0.61}_{-0.44} \pm 0.11$	$1.80^{+1.01}_{-0.85} \pm 0.16$
\mathcal{B} Significance $S (\sigma)$	2.28	2.18

Combined Results:

f_L	$0.75^{+0.16}_{-0.26} \pm 0.03$
$\mathcal{B} (\times 10^{-6})$	$1.2 \pm 0.5 \pm 0.1$
\mathcal{B} Significance $S (\sigma)$	3.7
$\mathcal{B}_{UL} (\times 10^{-6})$	2.0



First evidence!

- $\text{Br}(\bar{K}^{*0}K^{*+}) \sim \text{Br}(K^{*0}\bar{K}^{*0})$
- $f_L(\bar{K}^{*0}K^{*+}) \sim f_L(K^{*0}\bar{K}^{*0}) \sim f_L(\rho\rho)$

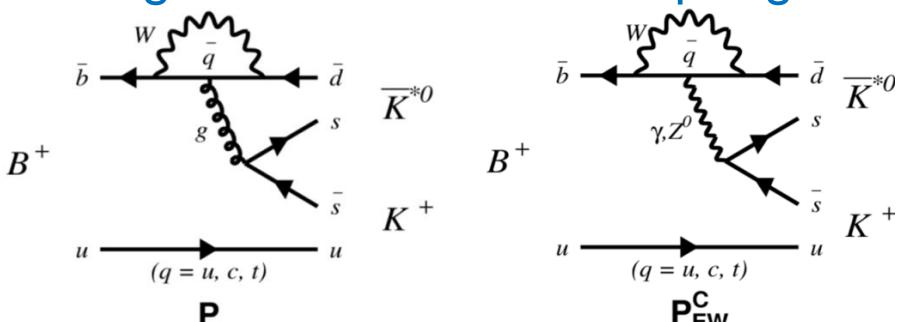
$B^+ \rightarrow \bar{K}^{*0} K^+$



657MB \bar{B}

Preliminary

• $b \rightarrow d$ gluonic & electroweak penguin

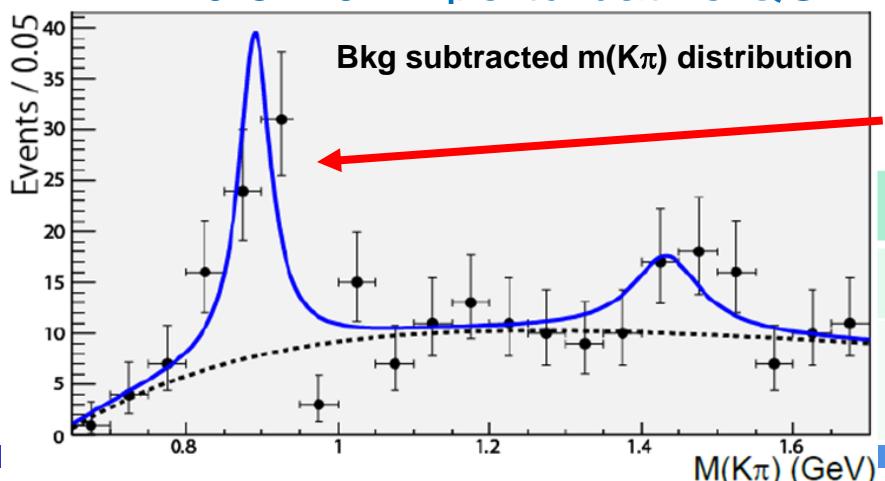


• Upper limits:

- CLEO : $\text{Br} < 5.3 \times 10^{-6}$ (with 10MBB)
- BABAR : $\text{Br} < 1.1 \times 10^{-6}$ (with 232MBB)

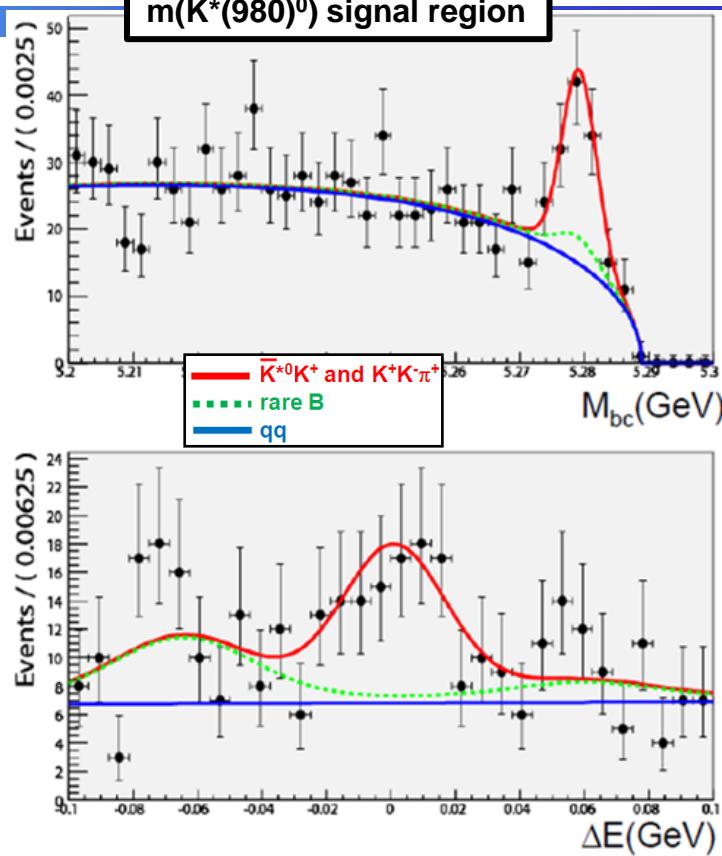
• Theoretical predictions

- $\sim 0.5 \times 10^{-6}$: flavor SU(3) symmetry
- $\sim 0.3 \times 10^{-6}$: perturbative QCD factorization



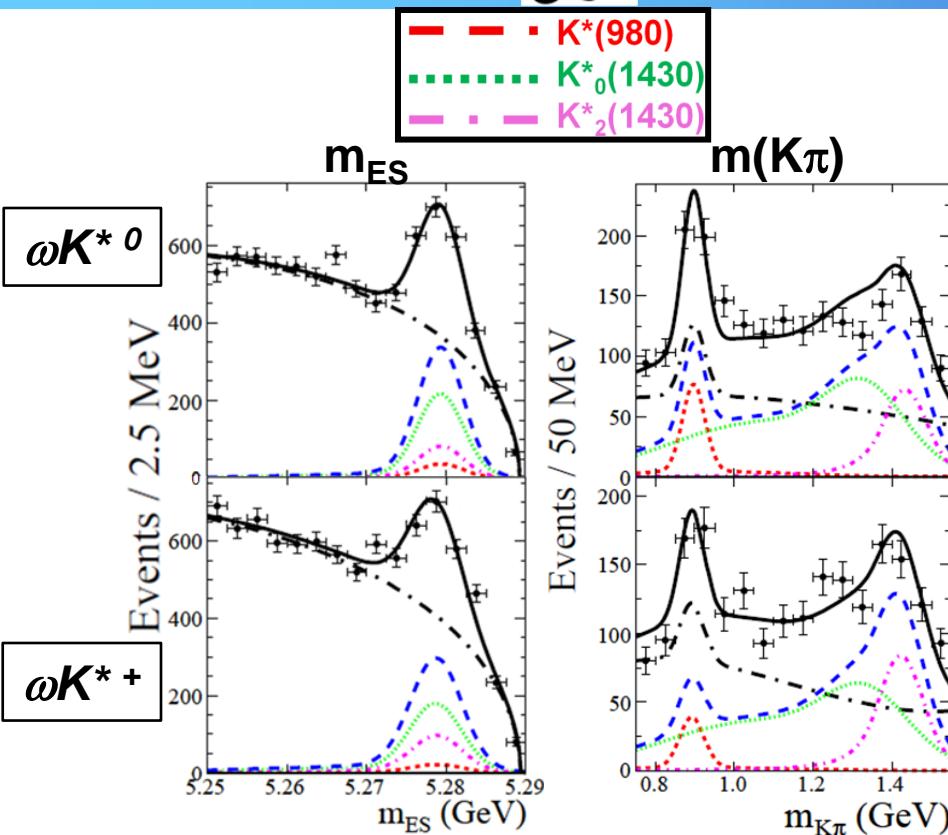
4 March, 2009

Y.Unno



First evidence of $B^+ \rightarrow \bar{K}^*(890)^0 K^+$

Mode	Yield	$\text{Br}(\times 10^{-6})$	σ
$\bar{K}^*(890)^0 K^+$	47.7 ± 11.1	$0.68 \pm 0.16 \pm 0.10$	4.4
$\bar{K}^*_2(1430)^0 K^+$	23.4 ± 12.1	$0.63 \pm 0.33 \pm 0.12$ < 1.10	1.5

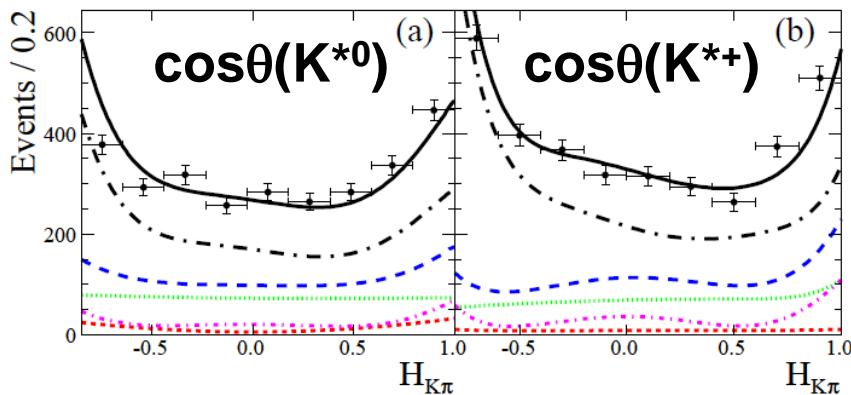


- $\omega K^*(980)^0$ first evidence by Belle

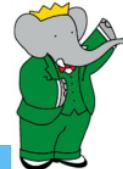
- (657MBB : PRL 101, 231801)
- $Br = (1.8 \pm 0.7 \pm 0.3) \times 10^{-6}$
- $f_L = 0.56 \pm 0.29^{+0.18}_{-0.08}$

- BABAR also found $\omega K^*(980)^0$

- Br, f_L are consistent with Belle
- $\omega K^*(980)^+$ excess is also seen



Mode	$Br(x10^{-6})$ (U.L.)	$S(\sigma)$	f_L	A_{CP}
$\omega K^*(980)^0$	$2.2 \pm 0.6 \pm 0.2$	4.1	$0.72 \pm 0.14 \pm 0.02$	$0.45 \pm 0.25 \pm 0.02$
$\omega K^*(980)^+$	$2.4 \pm 1.0 \pm 0.2 (< 7.4)$	2.5	$0.41 \pm 0.18 \pm 0.05$	$0.29 \pm 0.35 \pm 0.02$



SV, VT decays : $\omega K_0^*(1430)^{0/+}$, $\omega K_2^*(1430)^{0/+}$ are observed!

Mode	Br(x10 ⁻⁶) (U.L.)	S(σ)	f _L	A _{CP}
$\omega K_0^*(1430)^0$	$18.4 \pm 1.8 \pm 1.7$	9.8	---	$-0.07 \pm 0.09 \pm 0.02$
$\omega K_0^*(1430)^+$	$27.5 \pm 3.0 \pm 2.6$	9.2	---	$-0.10 \pm 0.09 \pm 0.02$
$\omega K_2^*(1430)^0$	$10.1 \pm 2.0 \pm 1.1$	5.0	$0.45 \pm 0.12 \pm 0.02$	$-0.37 \pm 0.17 \pm 0.02$
$\omega K_2^*(1430)^+$	$21.5 \pm 3.6 \pm 2.4$	6.1	$0.56 \pm 0.10 \pm 0.04$	$+0.14 \pm 0.15 \pm 0.02$
$\omega \rho^+$	$15.9 \pm 1.6 \pm 1.4$	9.8	$0.90 \pm 0.05 \pm 0.03$	$-0.20 \pm 0.09 \pm 0.02$
$\omega \rho^0$	$0.8 \pm 0.5 \pm 0.2 (< 1.6)$	1.6	---	---
ωf_0	$1.0 \pm 0.3 \pm 0.1 (< 1.5)$	4.5	---	---

What is happening in SU(3)
related VV and VT modes???

(BABAR) $B \rightarrow VT$ modes $f_L \sim 1$

Mode	f _L
$B \rightarrow \phi K_2^*(1430)^0$	$0.85^{+0.06}_{-0.07} \pm 0.04$
$B \rightarrow \phi K_2^*(1430)^+$	$0.80^{+0.09}_{-0.10} \pm 0.03$

$$\boxed{f_L(\phi K^*) \sim 0.5} = \boxed{f_L(\omega K^*) \sim 0.5 (?)}$$

↗ puzzle? ↘

$$\boxed{f_L(\phi K_2^*) \sim 1.0} \neq \boxed{f_L(\omega K_2^*) \sim 0.5}$$

Summary

- **K(^{*})II have been updated**
 - Intriguing results were found:
 - Large negative A_L in low q^2
 - Wrong sign C_7 appears to be favored(?!)
- **Many fresh results for $B \rightarrow VV$ polarization puzzle**
 - Many new observations
 - Additional polarization puzzle(!?) in VV , VT modes
- Super B factory is needed for more precise measurement
- More updates at summer 09 conferences!!!