
# New results from charmless B decays at BaBar

Matt Graham
SLAC
on behalf of the BaBar Collaboration
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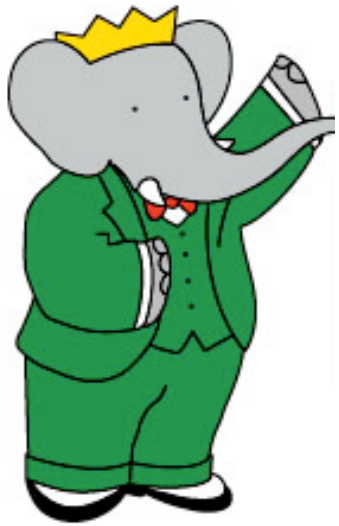
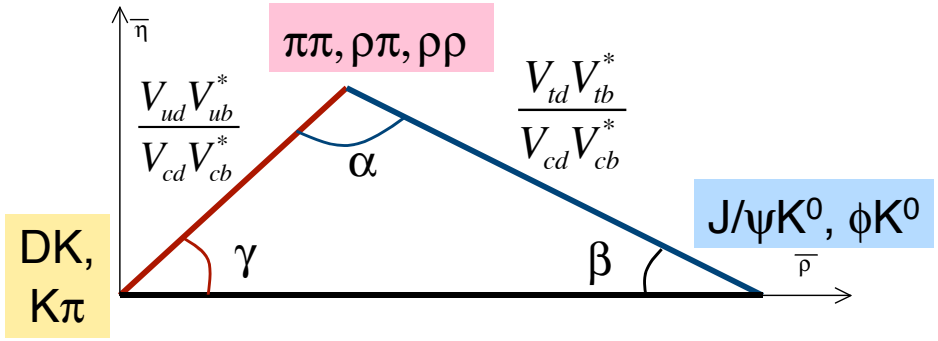
Aspen Winter Conference



# Charmless B-decays in one slide...

Charmless hadronic decays are key for meeting two of the primary goals of B-Factories:

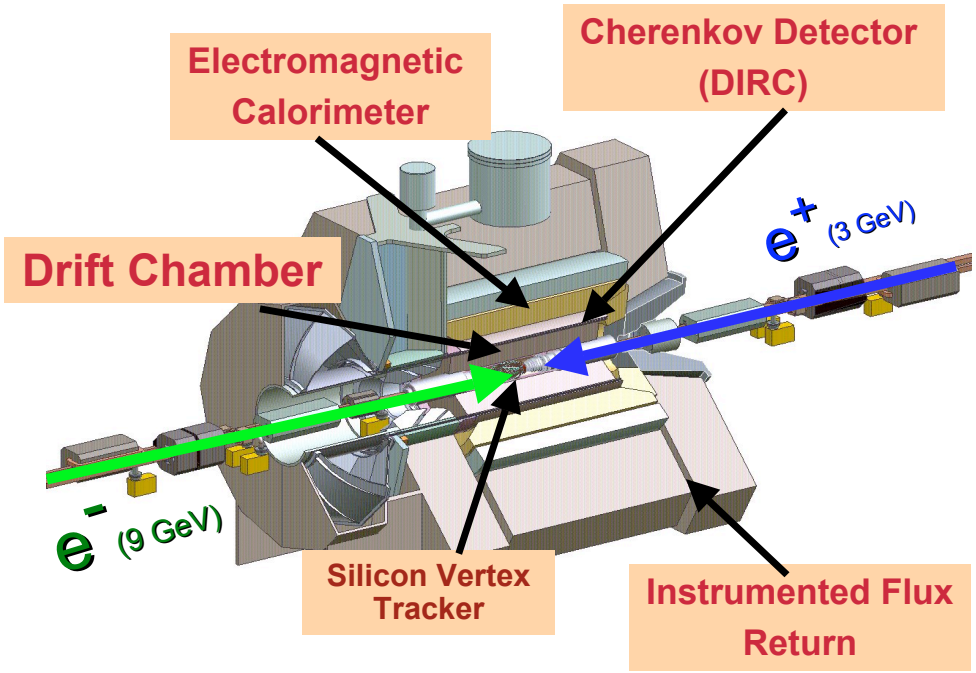
- measure the UT→test the KM picture of CPV




  - α: $B^+ \to \rho^+\rho^0$, $B^+ \to \pi^+\pi^-\pi^+$

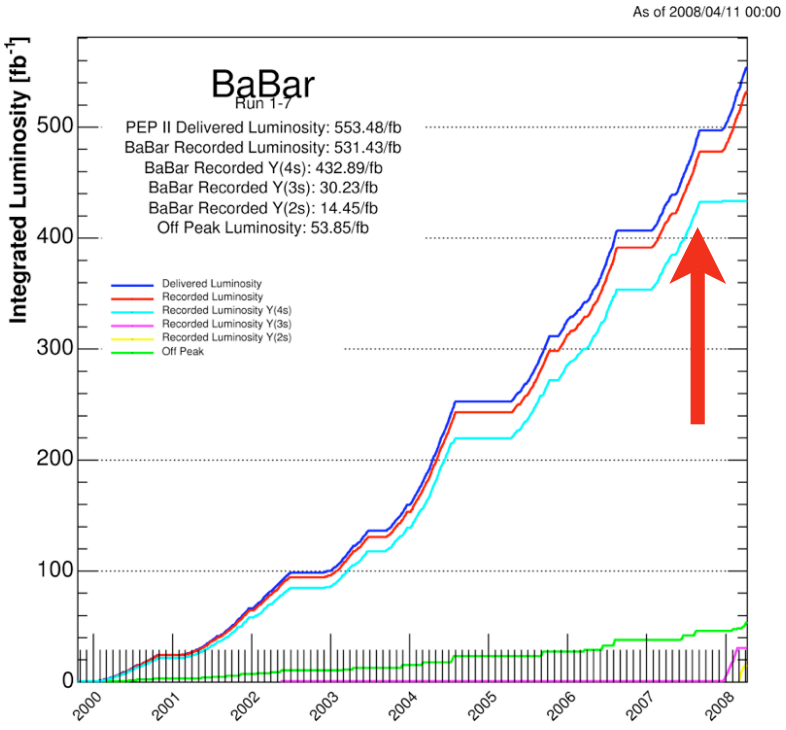
- search for hints of new physics in penguin decays
  - the B→VV polarization puzzle: $B \to \omega V$, $B^+ \to \rho^+\rho^0$, $B^+ \to K^{*0}K^{*+}$
  - b→d penguins: $B^+ \to K_S K_S \pi^+$, $B^+ \to K^{*0}K^{*+}$

# The BaBar detector and status



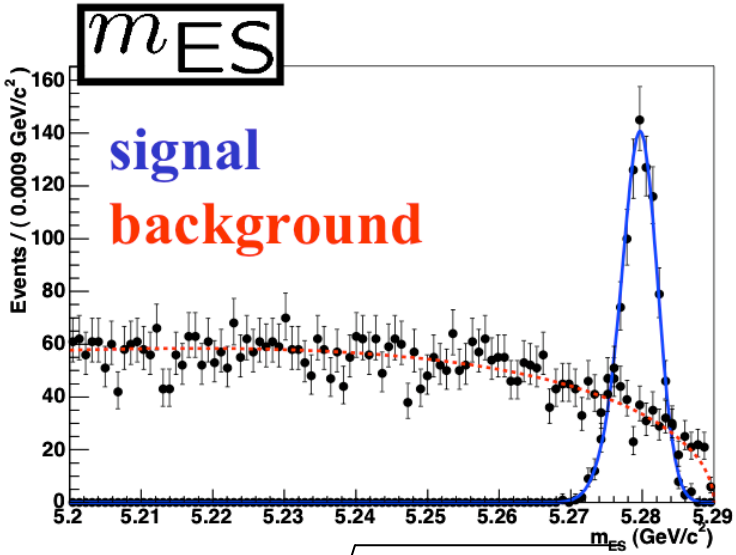

ran from 1999→2008

465M $B\bar{B}$ pairs collected

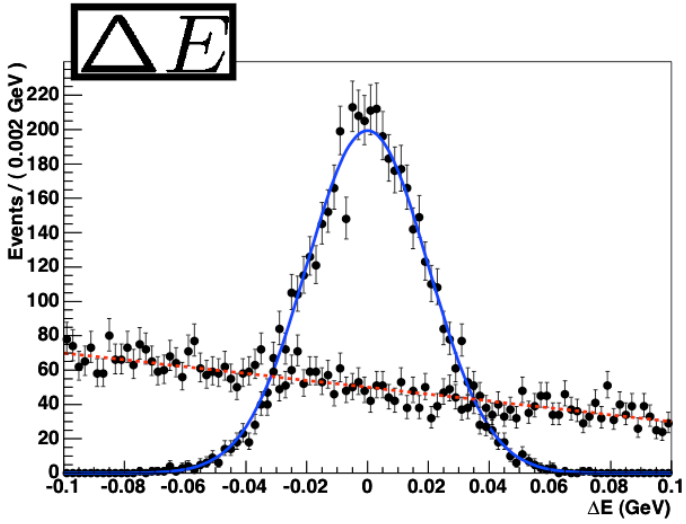



all results are shown here for first time; all use full dataset

# A typical B-decay analysis




$$m_{ES} = \sqrt{E^{*2}_{beam} - p^{*2}_{B}}$$




$$\Delta E = (E^{*}_{B} - E^{*}_{beam})$$

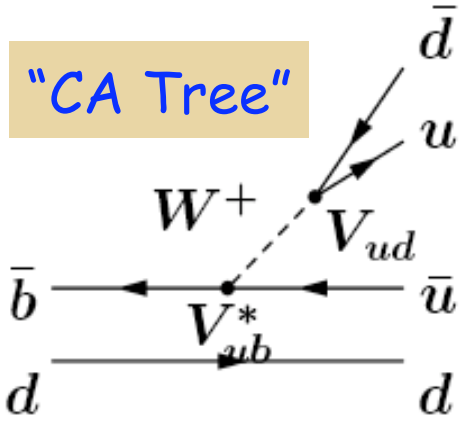
- Use $m_{ES}$ and $\Delta E$ to discriminate signal events from the large $q\bar{q}$ background and B-backgrounds
- additionally, use event-shape variables...typically combine in an MVA (e.g. Fisher discriminant or neural network)

→ these variables go into ML fit

# Extracting α from b→uūd

…at the quark level, same for ππ, ρρ, ρπ, etc; just a b→uud transition.

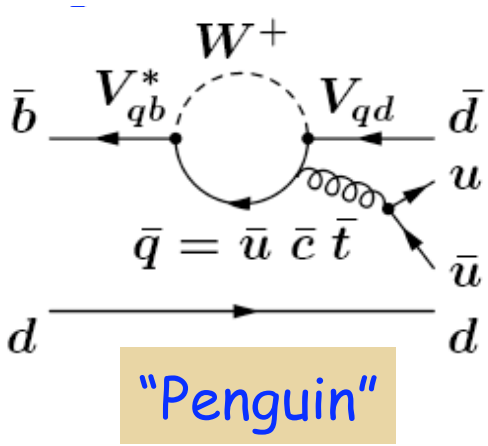
$$A \cong V_{ud}V_{ub}^{*}\left(T^{u}+P^{u}-P^{c}\right)+V_{td}V_{tb}^{*}\left(P^{t}-P^{c}\right)$$
$$= V_{ud}V_{ub}^{*}\;T+V_{td}V_{tb}^{*}\;P \cong R_{u}e^{+i\gamma}\;T+R_{t}e^{-i\beta}\;P$$




**Time dependent asymmetry:**

$$a(t)=\frac{\Gamma\left(\bar{B}^{0}_{phys}(t)\to f_{CP}\right)-\Gamma\left(B^{0}_{phys}(t)\to f_{CP}\right)}{\Gamma\left(\bar{B}^{0}_{phys}(t)\to f_{CP}\right)+\Gamma\left(B^{0}_{phys}(t)\to f_{CP}\right)}$$
$$\propto \sqrt{1-C^{2}}\,\sin\left(2\alpha_{\text{eff}}\right)\sin\left(\Delta m\cdot t\right)$$

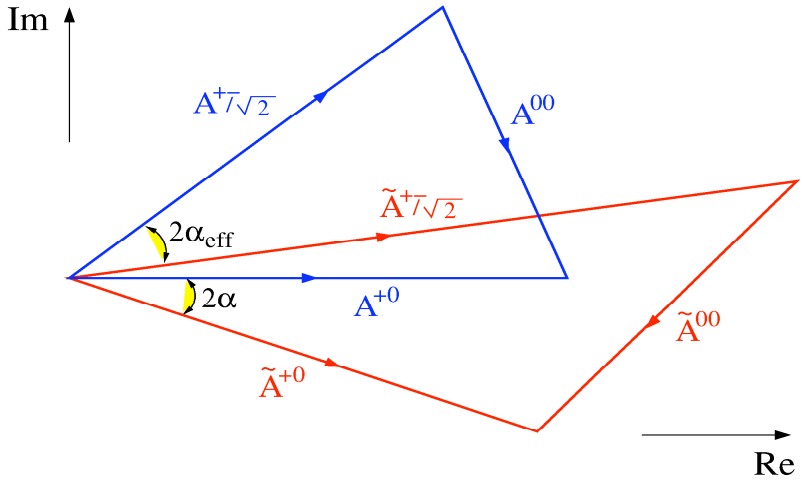
…if no penguins, $\alpha=\alpha_{\text{eff}}$



# Isospin analysis: α from ρρ

In general, we don't know the penguin amplitude of the $B \to \rho^+\rho^-$ decay so we can only get $\alpha_{eff}$

…but, assuming isospin, we can get to α!




**Amplitudes under SU(2) symmetry:**

$$A^{+-}/\sqrt{2} = Te^{i\gamma} + Pe^{-i\beta}$$
$$A^{00} = T_C e^{i\gamma} - Pe^{-i\beta}$$
$$A^{+0} = (T_C + T)e^{i\gamma}$$

…need to measure all observables for $\rho^+\rho^-$, $\rho^+\rho^0$, and $\rho^0\rho^0$

There are geometric ambiguities from this method, arising from how the triangles are oriented

# B→ρρ polarization

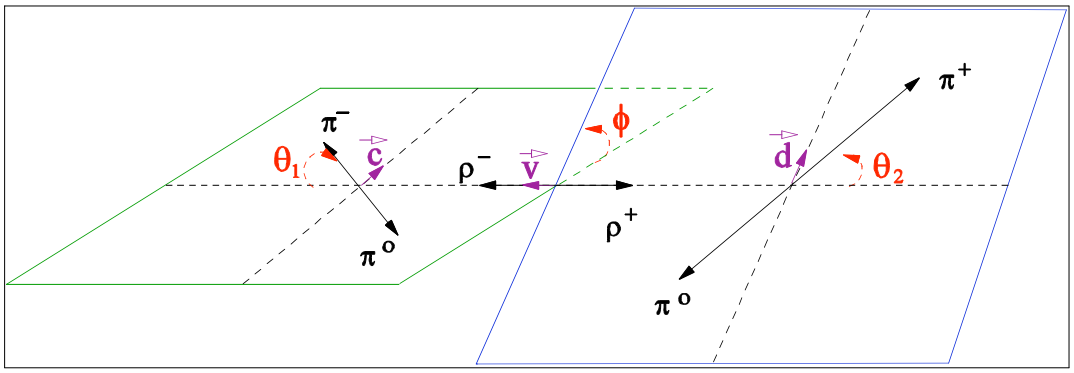
*a priori*, B→ρρ is not a definite CP eigenstate

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

Tranverse CP=?

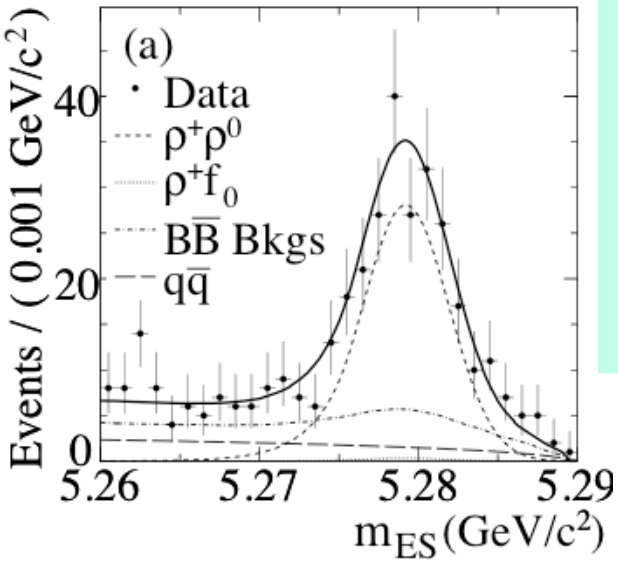
Longitudinal CP=+

Fortunately nature gives us $f_L$~1.0




integrated over φ

# $B^+ \to \rho^+\rho^0$: fit results

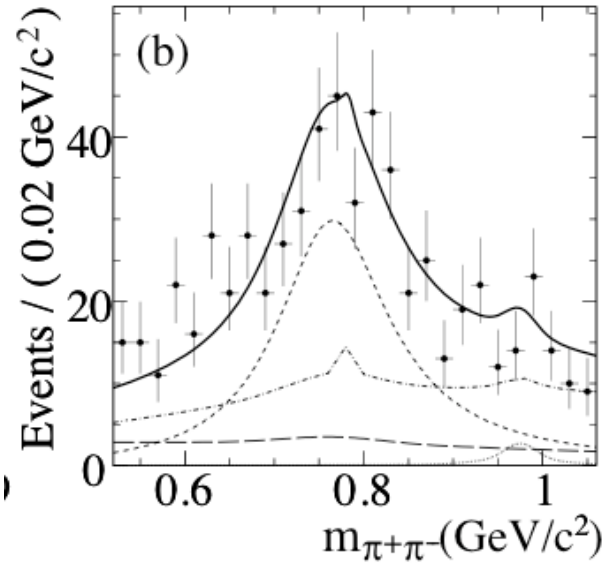



$N(B^0 \to \rho^+\rho^0) = 1122 \pm 63$

$BF(B^0 \to \rho^+\rho^0) = (23.7 \pm 1.4 \pm 1.4) \times 10^{-6}$

$A_{cp} = -0.054 \pm 0.055 \pm 0.010$

$f_L = 0.950 \pm 0.015 \pm 0.006$




hep-ex/0901.3522; submitted to PRL

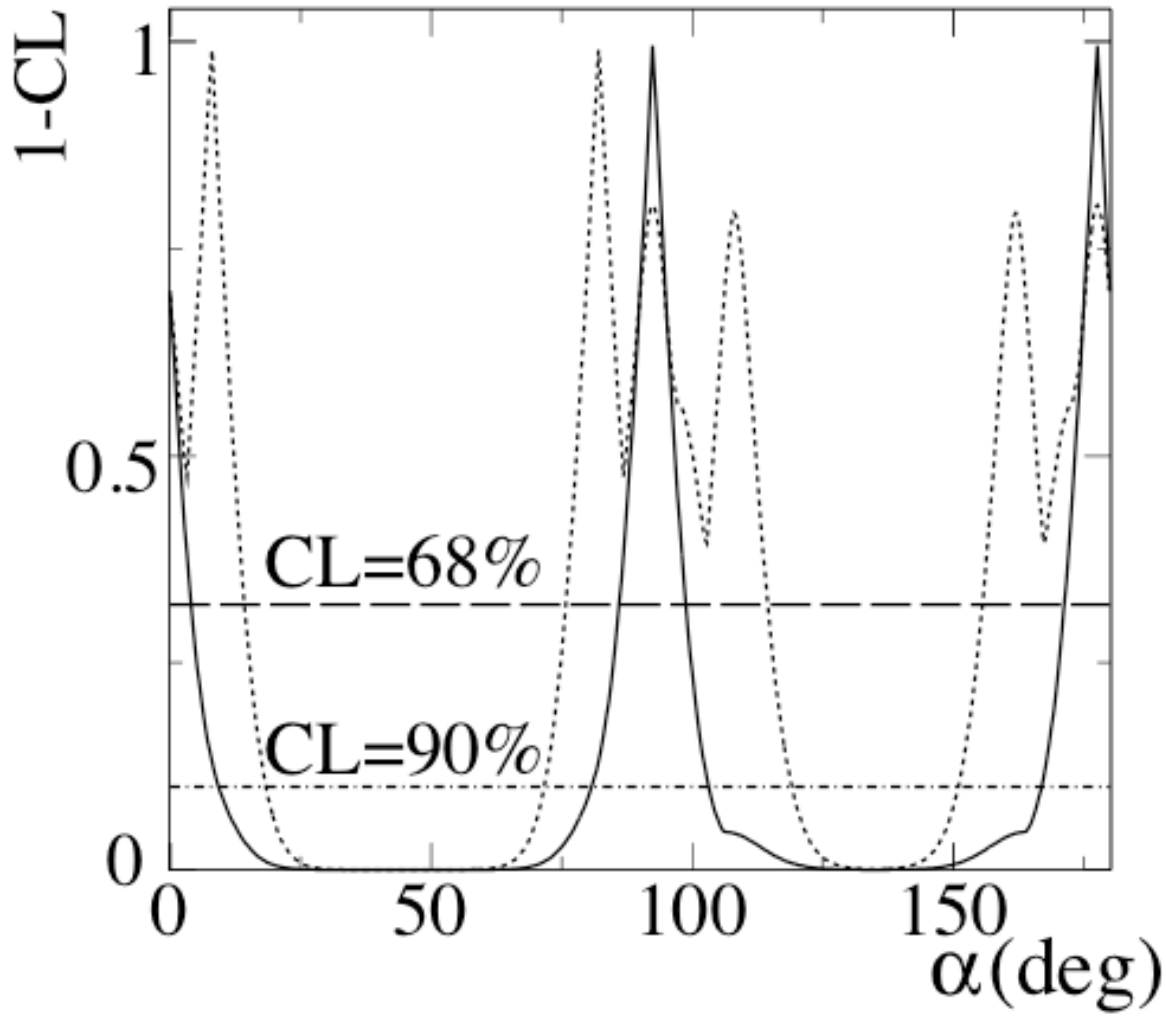
# $B^0 \to \rho^+\rho^0$: $\alpha$ results

dashed: old $\rho^+\rho^0$

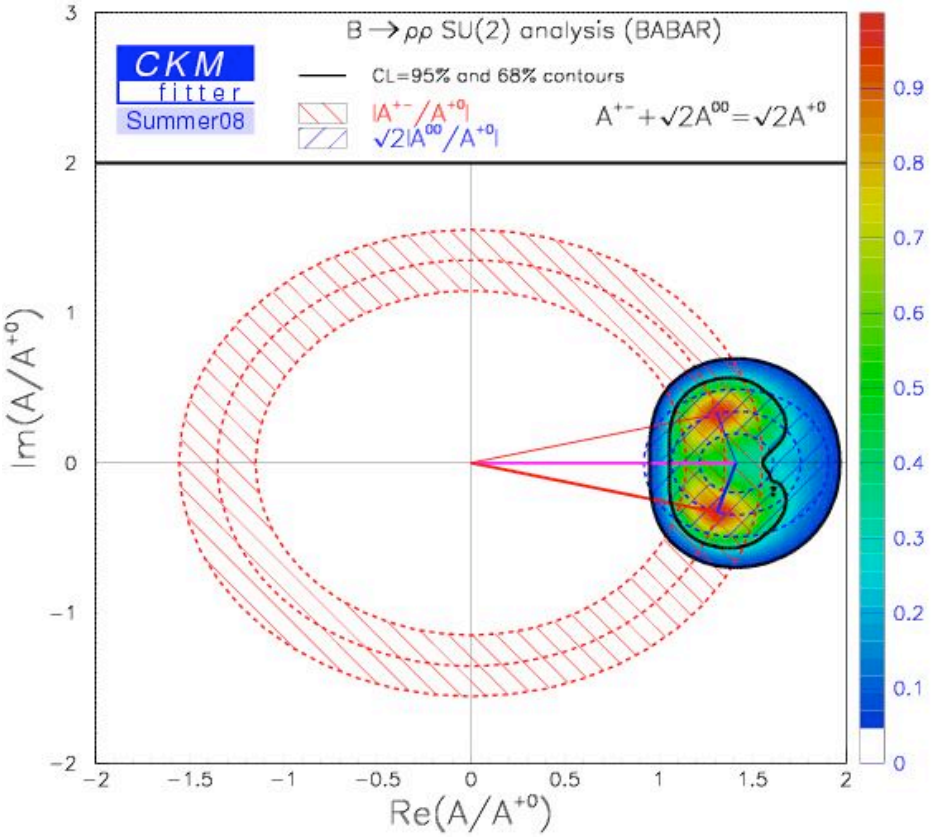
$B(\rho^+\rho^0)=(16\pm3)\times10^{-6}$ with 240 $B\bar{B}$ pairs

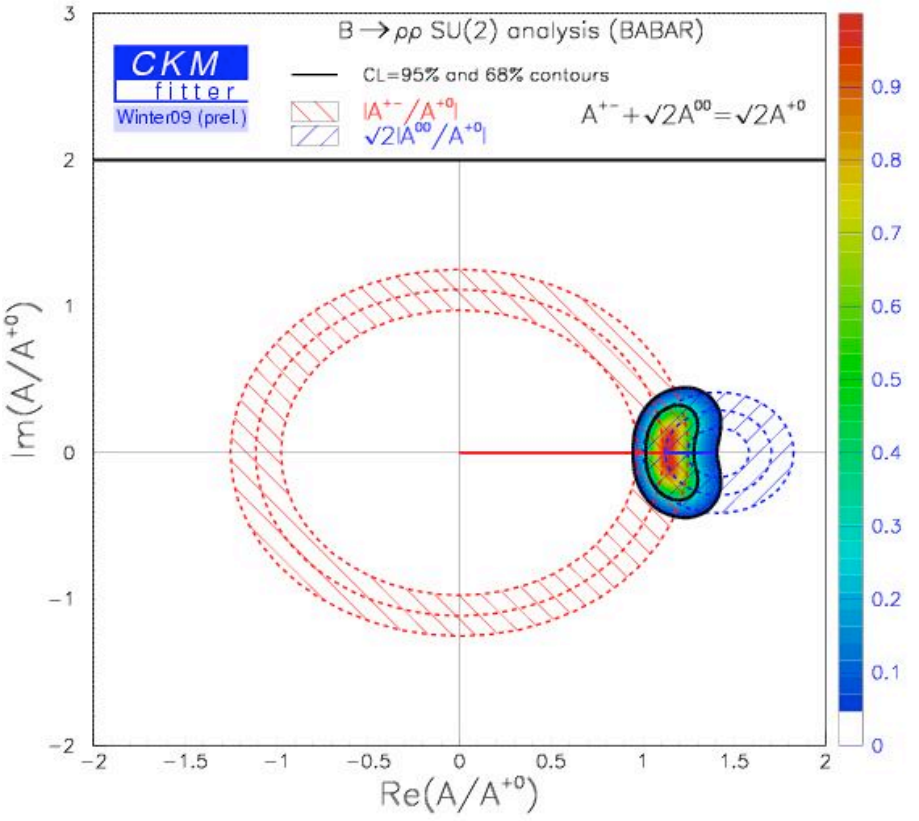
solid: new $\rho^+\rho^0$

$$\alpha = (92.4^{+6.0}_{-6.5})^o$$



# How did this improve so much?



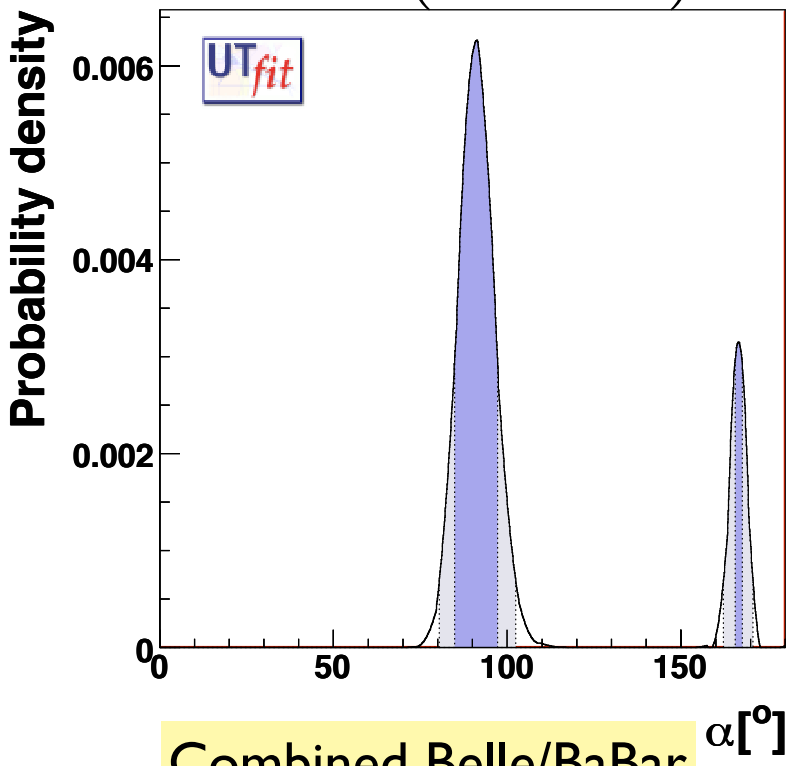




- triangle flattens out: two distinct solutions → single solution
  - similar picture for $\bar{A}$

# Current combined results for α

UTfit: Bayesian

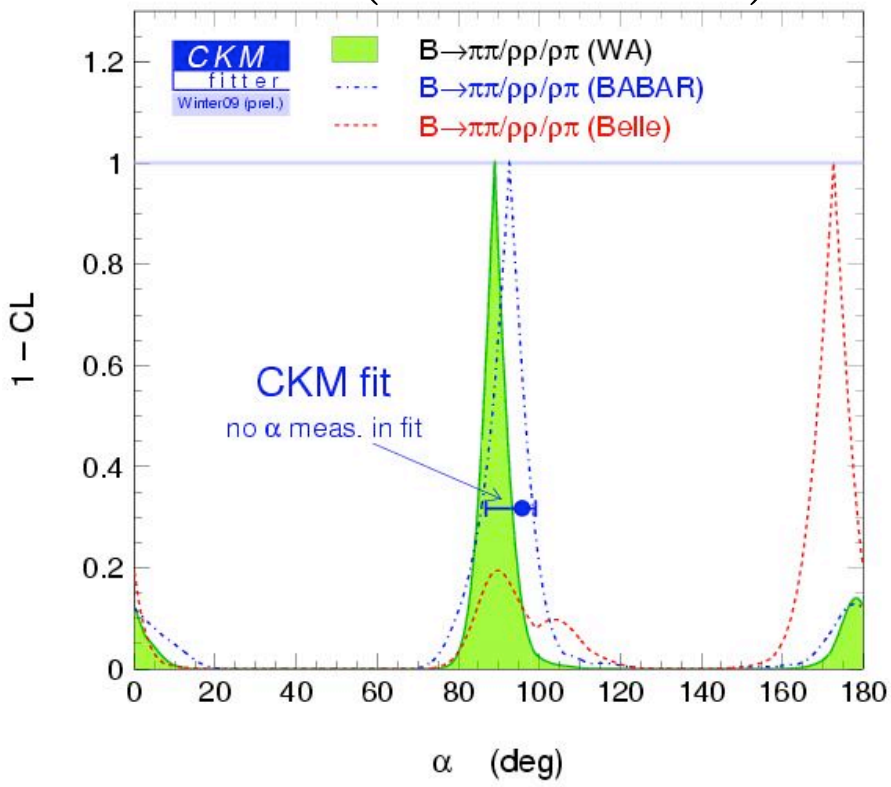
$\alpha = (90 \pm 5)^o$




Combined Belle/BaBar for ππ/ρπ/ρρ

CKM fitter: frequentist

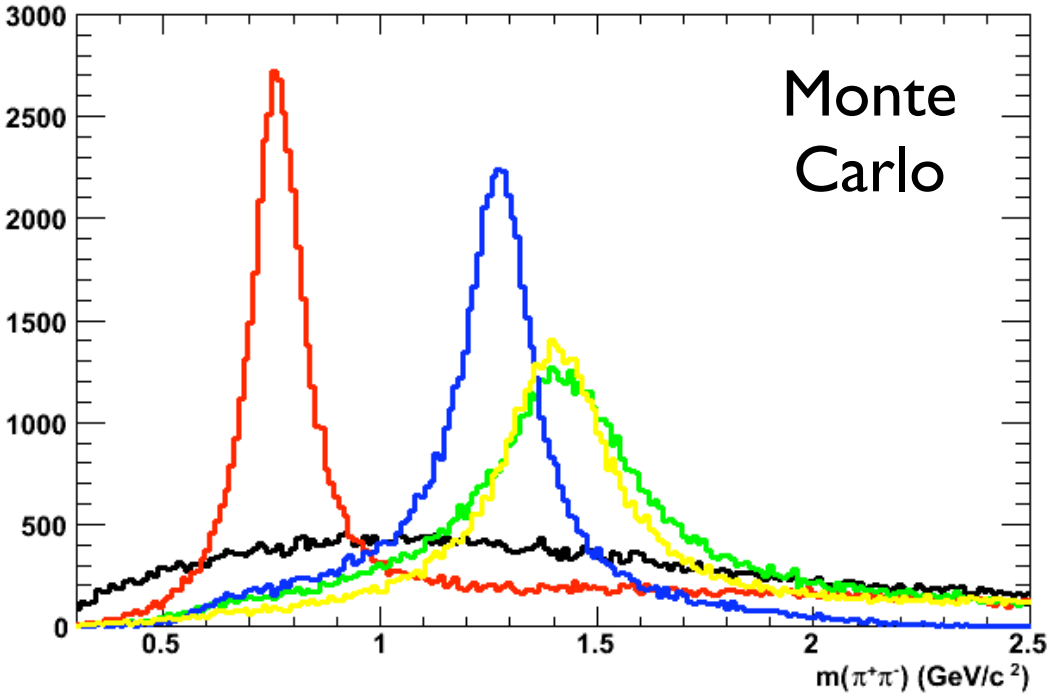
$\alpha = (89.0 \pm 4.3)^o$



# Dalitz plot analysis of $B^+ \to \pi^+\pi^-\pi^+$

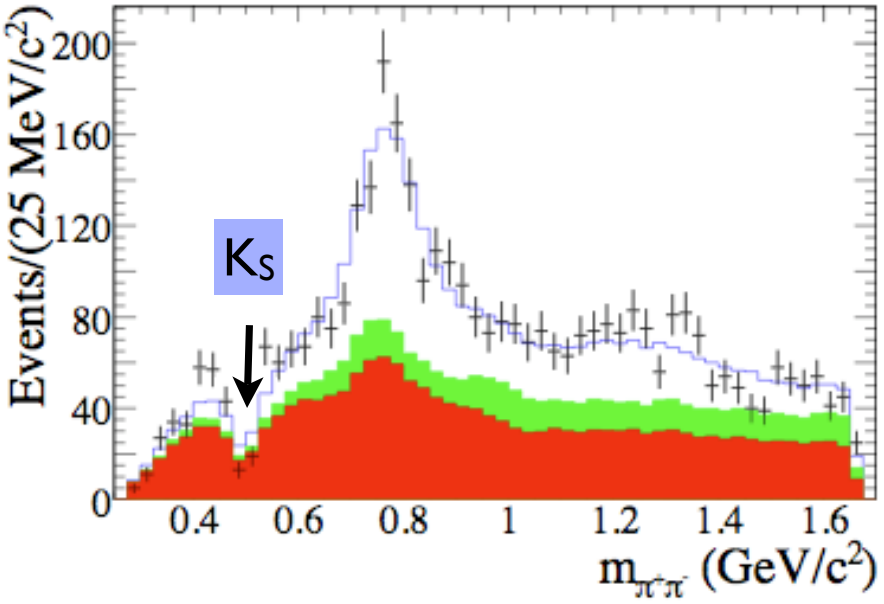
ingredients:

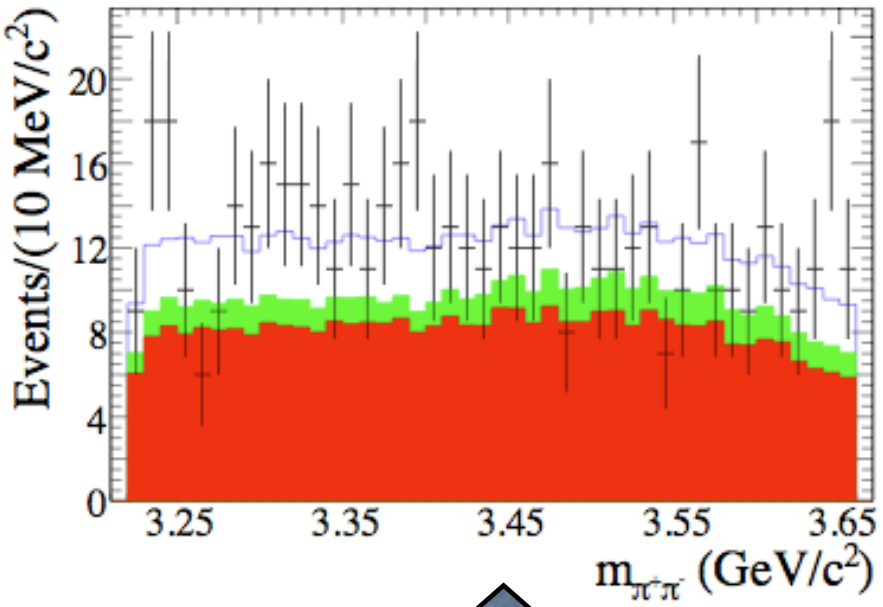
$\rho^0(770)\pi^+$
$\rho^0(1450)\pi^+$
$f_2(1270)\pi^+$
$f_0(1370)\pi^+$
nonresonant




- useful for i) what is needed for "$\rho^0$" spectrum in $\pi^+\pi^-\pi^0$ DP analysis; ii) additional constraint on $\rho\pi$ amplitudes when extracting $\alpha$
- the $f_0(1370)$ needed for a good fit: $M=1400\pm40$ MeV; $\Gamma=300\pm80$ MeV
- "non-resonant" is taken to be exponential in $m(\pi^+\pi^-)$

# $B^+ \to \pi^+\pi^-\pi^+$: fit projections



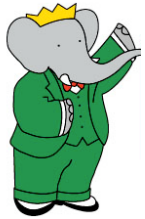




$N(\pi^+\pi^-\pi^+) = 1219 \pm 50 \pm 75 \pm 29$

No evidence for $\chi_{c0}$ or $\chi_{c2}$

hep-ex/0902.2051; submitted to PRD (today)


# $B^+ \to \pi^+\pi^-\pi^+$: fit results

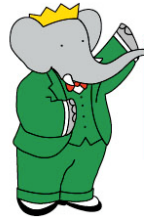


Total $\pi^+\pi^-\pi^+$ BF=$(15.2\pm0.6\pm1.2\pm0.4)\times10^{-6}$

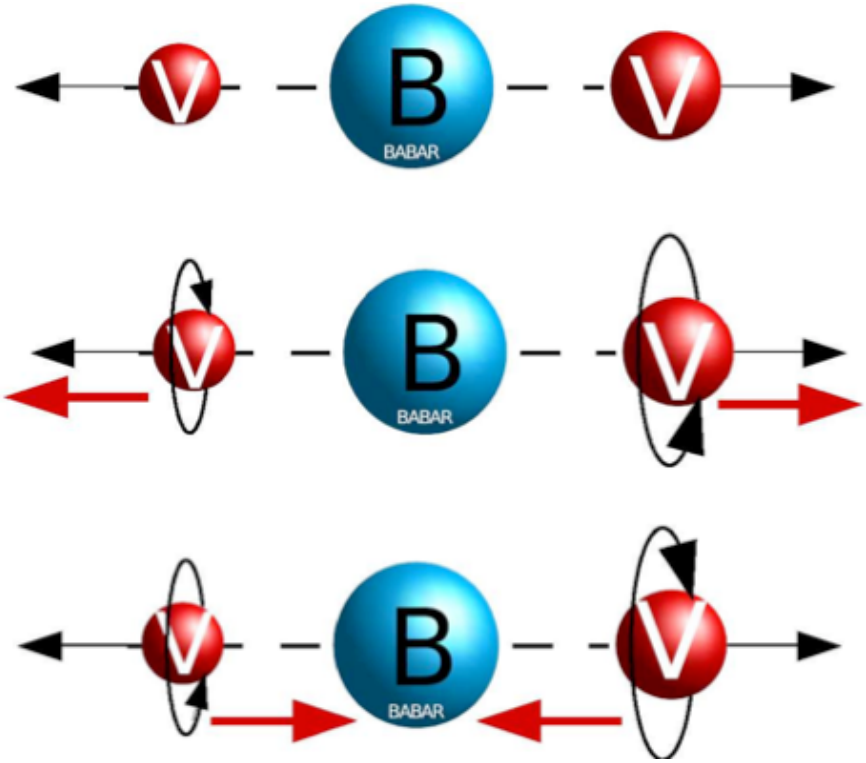
| mode | BF($\times10^{-6}$) | $A_{CP}$ (%) |
|---|---|---|
| $\rho(770)\pi$ | $8.1\pm0.7\pm1.2^{+0.4}_{-1.1}$ | $18\pm7\pm5^{+2}_{-14}$ |
| $\rho(1450)\pi$ | $1.4\pm0.4\pm0.4^{+0.3}_{-0.7}$ | $-6\pm28\pm20^{+12}_{-35}$ |
| $f_2(1270)\pi$ | $0.9\pm0.2\pm0.1^{+0.3}_{-0.1}$ | $41\pm25\pm13^{+12}_{-8}$ |
| $f_X(1370)\pi$*** | $2.9\pm0.5\pm0.5^{+0.7}_{-0.5}$ | $72\pm15\pm14^{+7}_{-8}$ |
| nonresonant | $5.3\pm0.7\pm0.6^{+1.1}_{-0.5}$ | $-14\pm14\pm7^{+17}_{-3}$ |
| $f_0(980)\pi$ | <1.5 @ 90% CL | |
| $\chi_{c0}\pi$ | <15 @ 90% CL | $\chi_{c0}\to\pi\pi$ factored out |
| $\chi_{c2}\pi$ | <20 @ 90% CL | $\chi_{c2}\to\pi\pi$ factored out |

***second solution 5 units of NLL worse has different amplitude for $f_X(1370)\pi$...we quote UL < $4\times10^{-6}$ @ 90% CL

# Polarization of B→VV decays



•from simple arguments (helicity conservation, left-handed quarks):



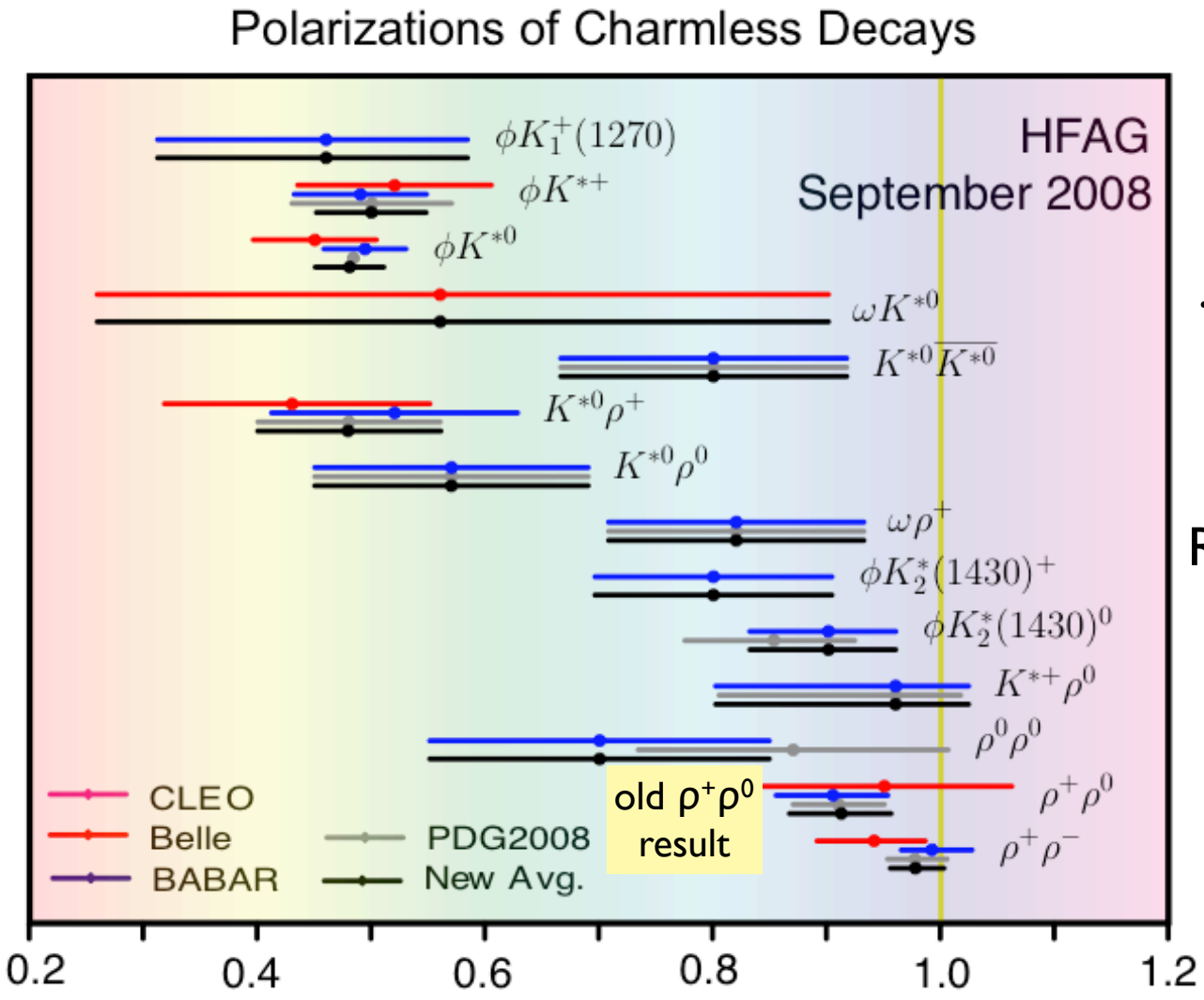

$A_{00} \sim 1$ } Longitudinal

$A_{++} \sim m_V/m_B$

$A_{--} \sim (m_V/m_B)^2$ } Transverse

→ naively expect B→VV to be >90% longitudinal

# The polarization "puzzle"

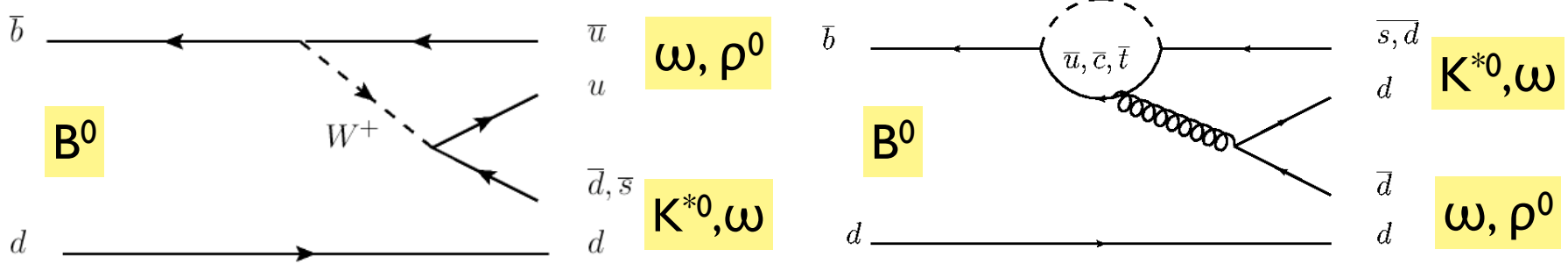



For the ρρ states, we do see large $f_L$ ...not so for φK* states!

A number of possible (SM) explanations. Recent NLO calculations of the penguin seem to describe this pattern pretty well...

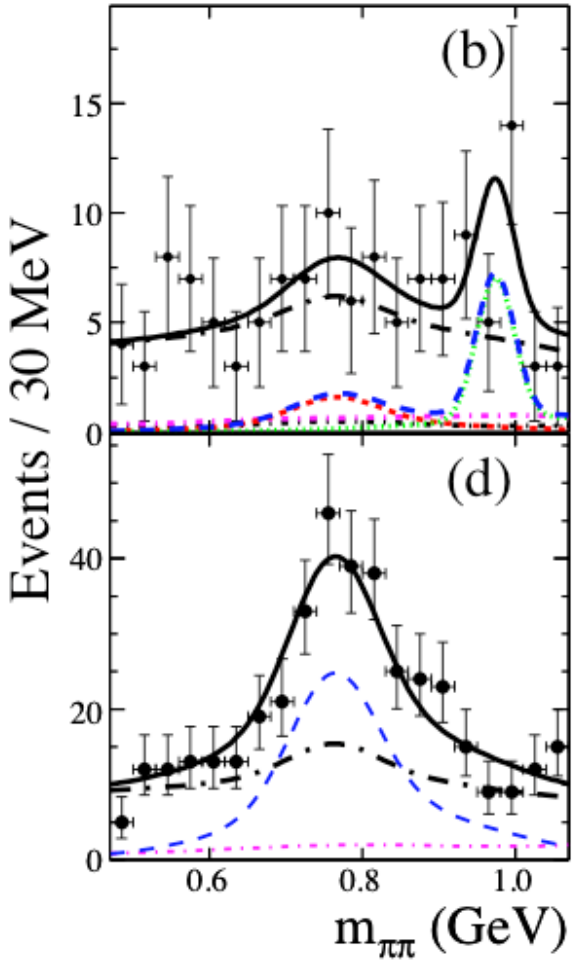
Nucl.Phys.B, 744:64, 2007
PRD,78,094001, 2008

# B→ωX



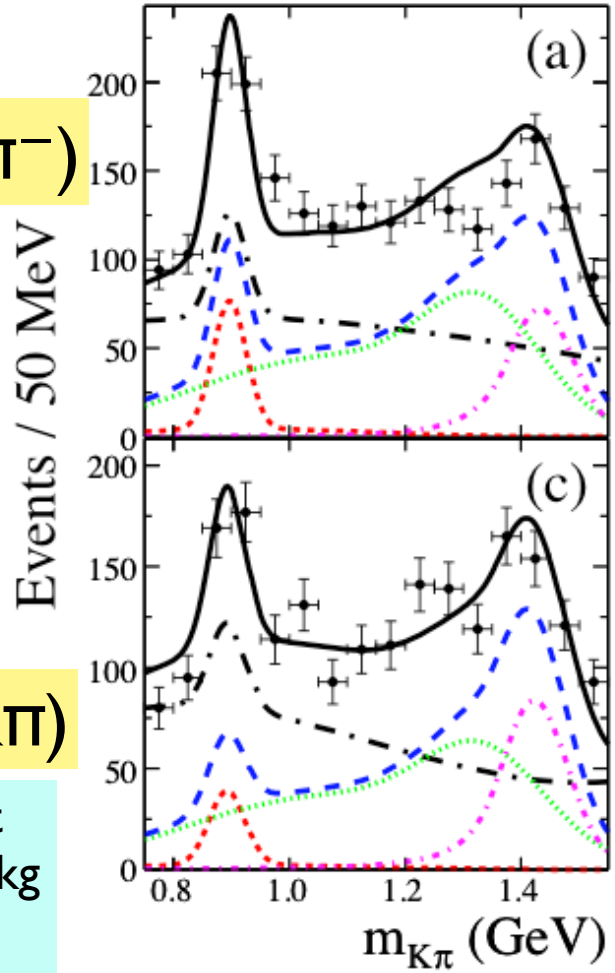

- many modes included in this analysis
  - tree dominated VV: B→ωρ
  - tree/penguin mix VV: B→ωK*(892)
  - also include related decay modes:
    - B→ω(ππ): $f_0(980)$
    - B→ω(Kπ): $K_2(1430)$, Kπ S-wave
  - nine channels in total

# B→ωX: mX fit projections




m(π+π-)

m(π+π0)



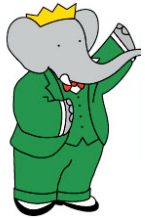

m(K+π−)

m(Kπ)

solid black: total fit
dashed black: total bkg
magenta: b→c bkg
blue: total signal

hep-ex/0901.3703; accepted by PRD-RC

# $B \to \omega X$: fit results

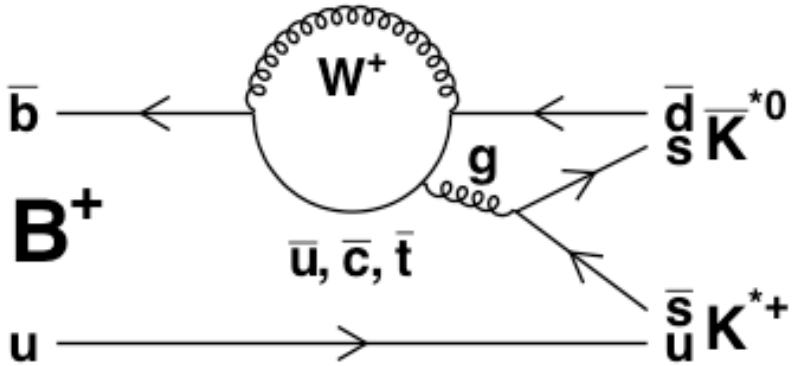


First observation

| mode | BF($\times 10^{-6}$) | Signif. | $A_{cp}$ | $f_L$ |
|---|---|---|---|---|
| $\omega\rho^0$ | 0.8±0.5±0.2 | 1.9 | ---------- | ---------- |
| $\omega f_0$ | 1.0±0.3±0.1 | 4.5 | ---------- | ---------- |
| $\omega\rho^+$ | 15.9±1.6±1.4 | 9.8 | −0.20±0.09±0.02 | 0.90±0.05±0.03 |
| $\omega K^{*0}$ | 2.2±0.6±0.2 | 4.1 | 0.45±0.25±0.02 | 0.72±0.25±0.02 |
| $\omega K^{*+}$ | 2.4±1.0±0.2 | 2.5 | 0.29±0.35±0.02 | 0.41±0.18±0.05 |
| $\omega(K\pi)_0^{*0}$ | 18.4±1.8±1.7 | 9.8 | −0.07±0.25±0.02 | ---------- |
| $\omega(K\pi)_0^{*+}$ | 27.5±3.0±2.6 | 9.2 | −0.10±0.09±0.02 | ---------- |
| $\omega K_2^{*0}$ | 10.1±2.0±1.1 | 5.0 | −0.37±0.17±0.02 | 0.45±0.12±0.02 |
| $\omega K_2^{*+}$ | 21.5±3.6±2.4 | 6.1 | 0.14±0.15±0.02 | 0.56±0.10±0.04 |

Five newly observed modes!
The $f_L$ pattern is as expected

# $B^+ \to \overline{K}^{*0} K^{*+}$




decay is dominated by b→d penguin diagram

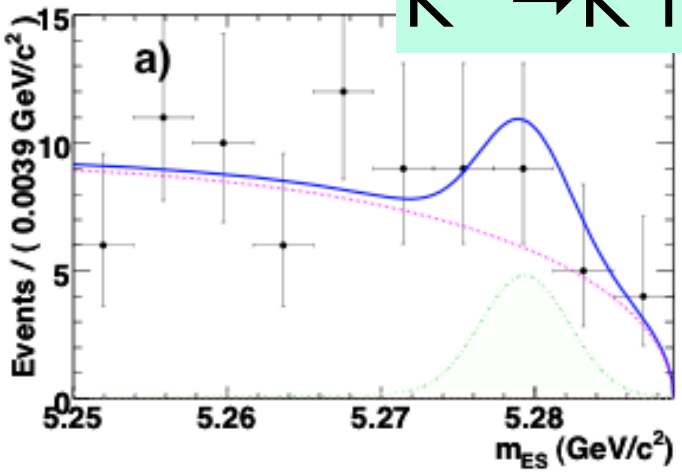
- related decay mode B0→$\overline{K}^{*0}K^{*0}$ observed:

$$\mathcal{B}(B^0 \to K^{*0}\overline{K}^{*0}) = (1.3 \pm 0.3) \times 10^{-6}$$
$$f_L(B^0 \to K^{*0}\overline{K}^{*0}) = 0.80 \pm 0.13$$

- analysis is performed for both $K^{*+} \to K^+\pi^0$ and $K^{*+} \to K_s\pi^+$

# $B^+ \to \overline{K}^{*0} K^{*+}$ Results

$K^{*+} \to K^+ \pi^0$

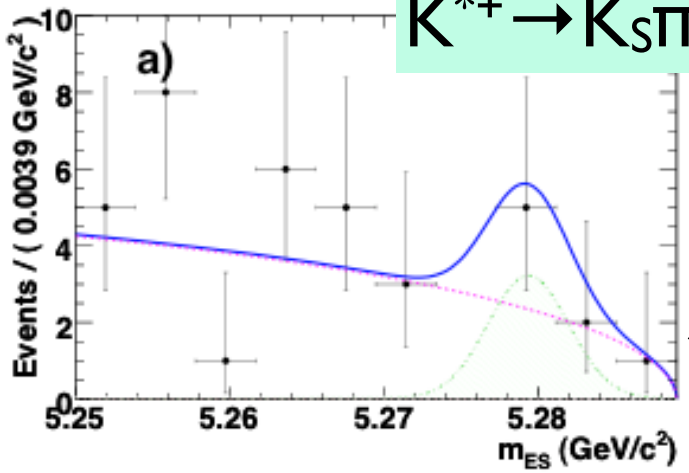



$$N\left[B^+ \to K^{*0}(\to K^+\pi^-)K^{*+}(\to K^+\pi^0)\right] = 13.9^{+7.6}_{-6.4}$$

$$\mathcal{B} = (1.2 \pm 0.5 \pm 0.1) \times 10^{-6}$$
$$f_L = 0.75^{+0.16}_{-0.26} \pm 0.03$$

**3.7σ significance**

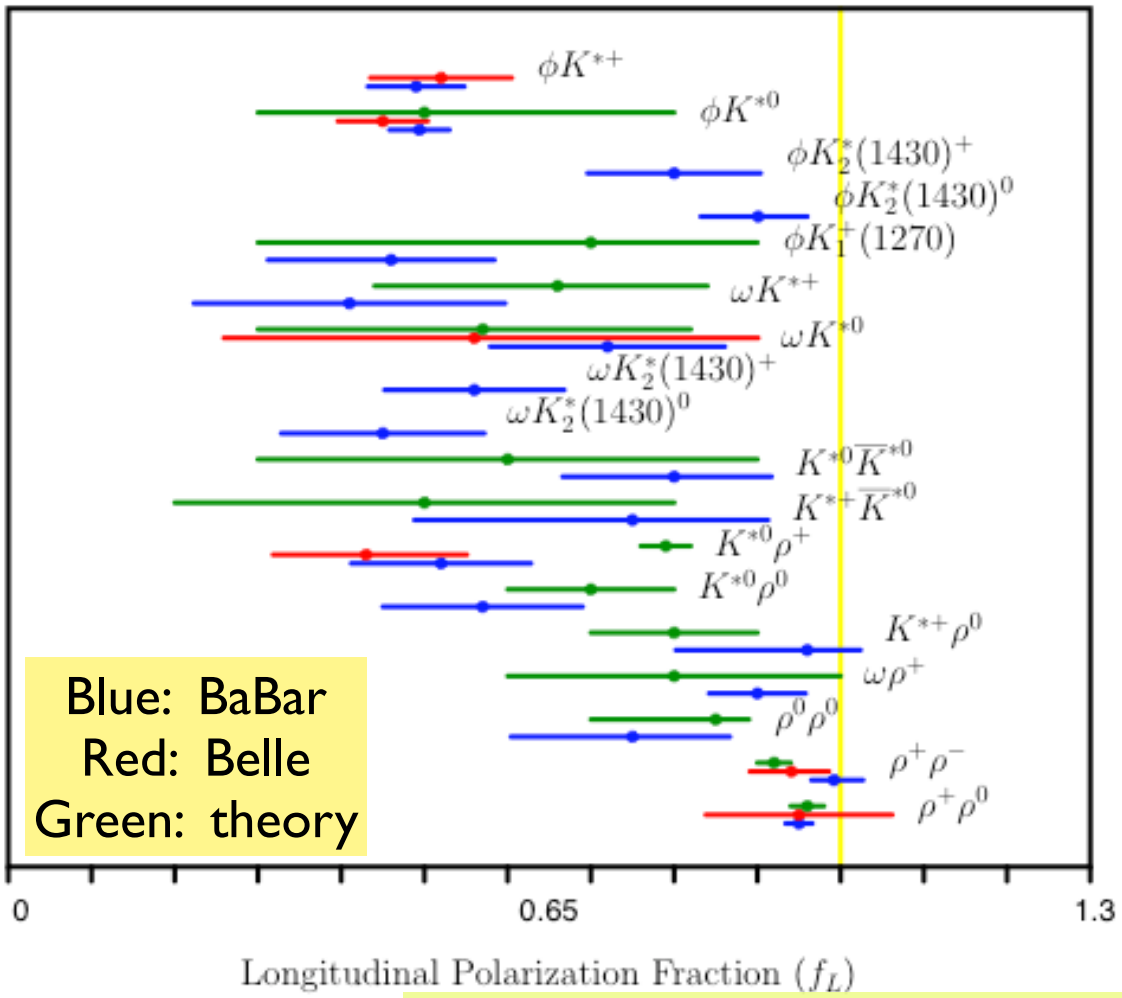
$K^{*+} \to K_S \pi^+$




$$N\left[B^+ \to K^{*0}(\to K^+\pi^-)K^{*+}(\to K_s\pi^+)\right] = 6.9^{+4.5}_{-3.5}$$

hep-ex/0901.1223; submitted to PRD-RC

# VV Polarization as of today



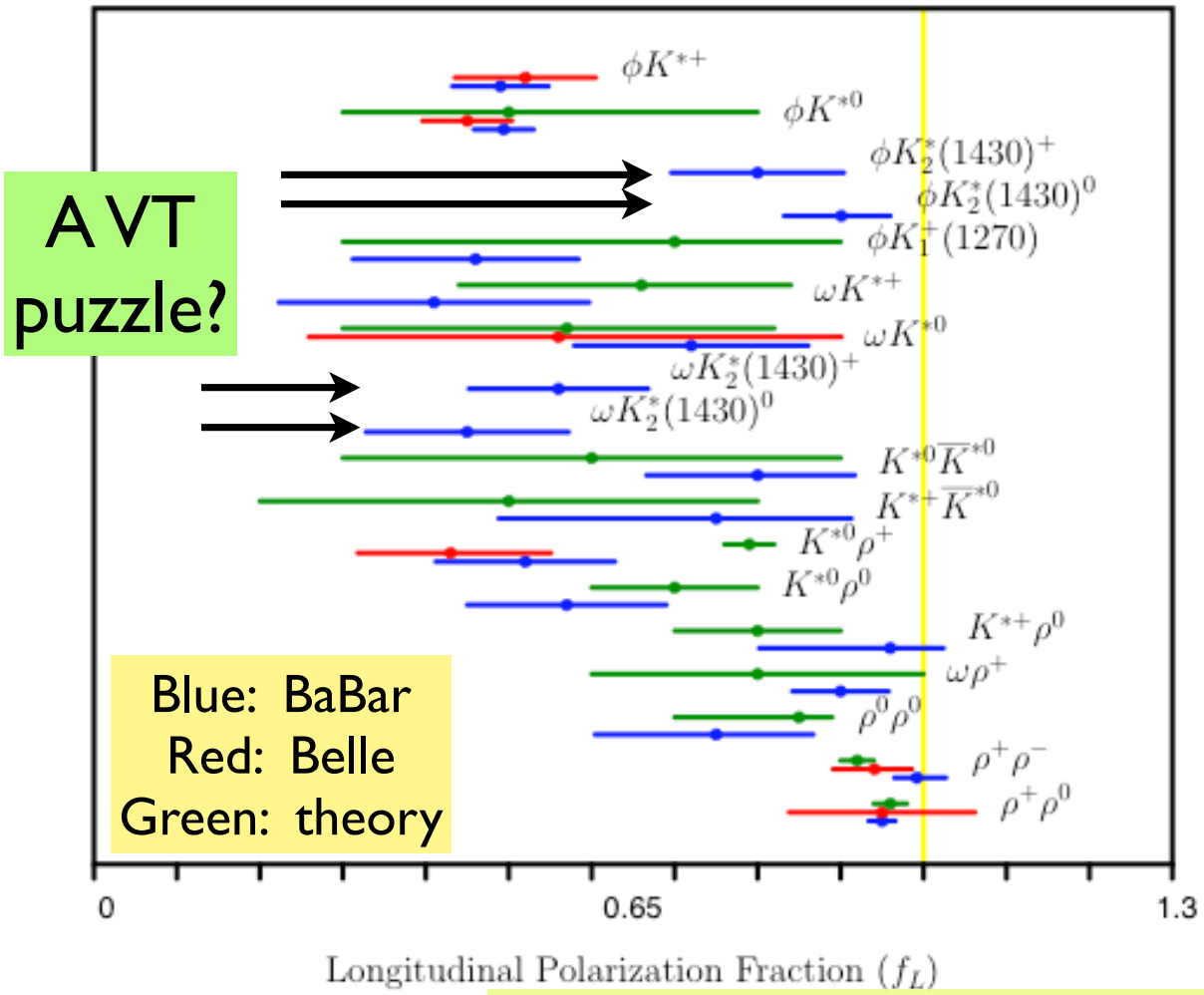

Blue: BaBar
Red: Belle
Green: theory

Penguin dominated

Tree dominated

Cheng & Smith, hep-ph/0901.4396

# VV Polarization as of today




AVT puzzle?

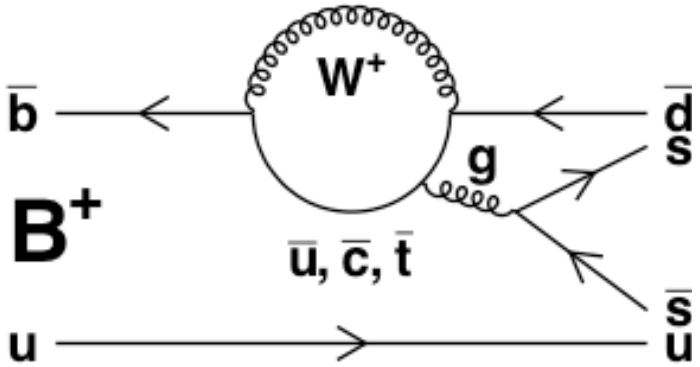
Blue: BaBar
Red: Belle
Green: theory

Penguin dominated

Tree dominated

Cheng & Smith, hep-ph/0901.4396

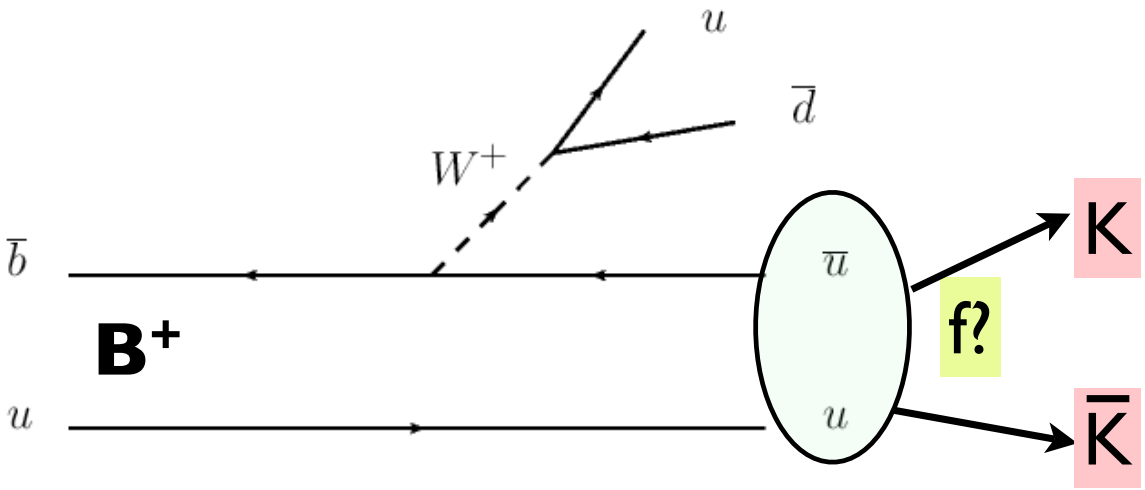
# $B^+ \to K\bar{K}\pi^+$




$\bar{K}^{*0}/K_S$

$K^+/K^{*+}$

at first glance, should be a b→d penguin dominated decay with intermediate states like $K^*K$

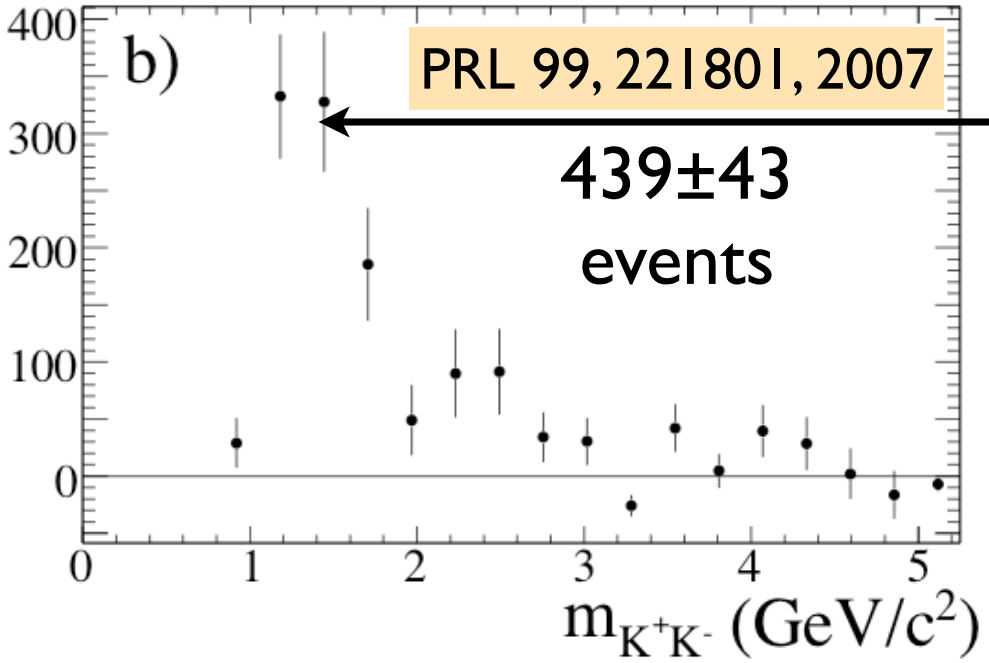



Other diagrams are allowed though...

# $B^+ \to K^+K^-\pi^+$

Surprisingly large rate seen in $B^+ \to K^+K^-\pi^+$; no evidence for $\varphi\pi^+$

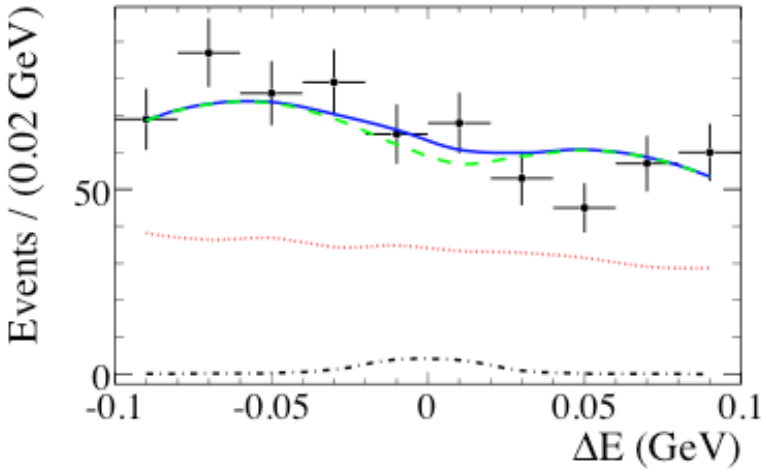
$$\mathcal{B}(B^+ \to K^+K^-\pi^+) = (5.0 \pm 0.5 \pm 0.5) \times 10^{-6}$$

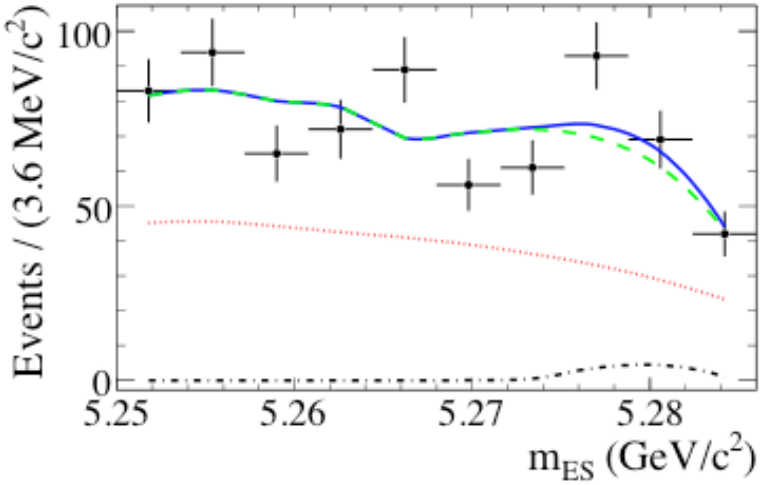



~ 1/2 of the events seen at low $K^+K^-$ mass; structure at ~1.5GeV?
Similar broad structures seen in $K^+K^-K^+/K^+K^-K_S$ and $\pi^+\pi^-K^+/\pi^+\pi^-K_S$

What about $K_SK_S\pi^+$?

# $B^+ \to K_S K_S \pi^+$: fit results




$N(K_S K_S \pi^+) = 15 \pm 15$

$BF(K_S K_S \pi^+) = (2.5 \pm 2.4 \pm 0.9) \times 10^{-7}$

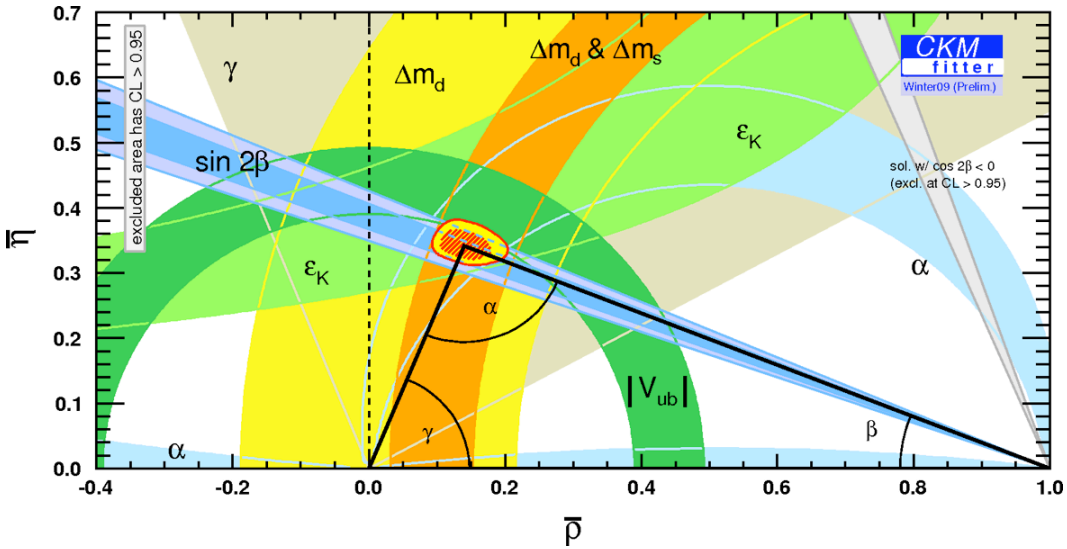
$BF(K_S K_S \pi^+) < 5.1 \times 10^{-7}$ @90% CL

If $f_X$ is a "regular", even spin resonance: expect ~75 events → odd spin? exotic?

hep-ex/0811.1979; accepted by PRD-RC

# Summary

- The B-factories have been (mostly!) hugely successful




- measured $\bar{\rho}$ and $\bar{\eta}$ to ~0.02 (including new α!)
- over 100 charmless modes measured → BF ~ $10^{-6}$
- hundreds of other measurements (D-mixing! $\eta_B$!)

- Where we have failed: no unambiguous signs of new physics!

**Bring on the LHC!**