Constraint on CKM angle ϕ_2 from B decays

PANIC05
Particles and Nuclei International Conference
Oct. 24-28, 2005, Santa Fe, NM, USA

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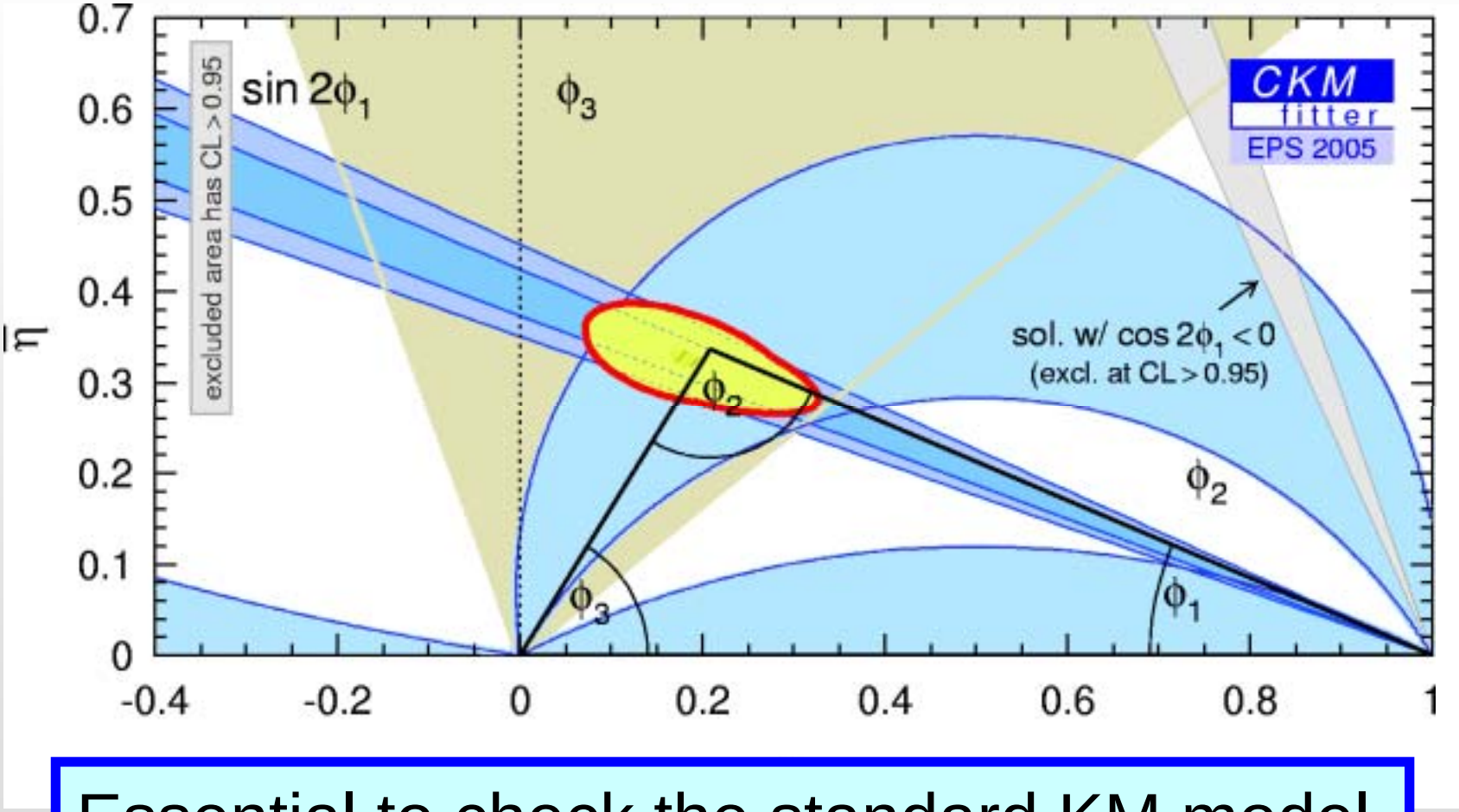
on behalf of Belle collaboration

So, why ϕ_2 ?

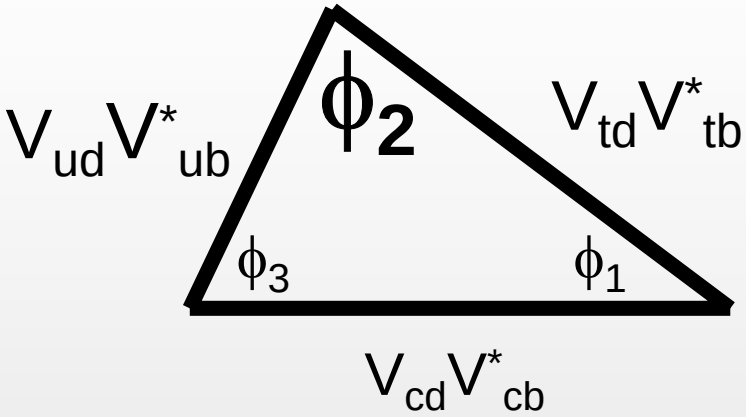


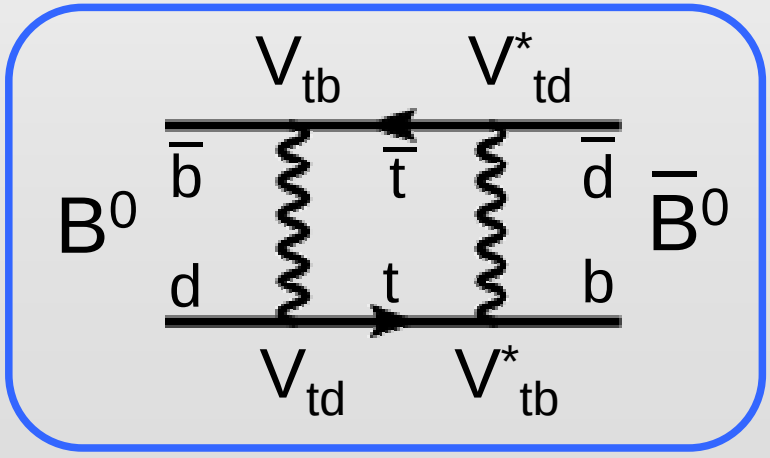
Essential to check the standard KM model.

Contents

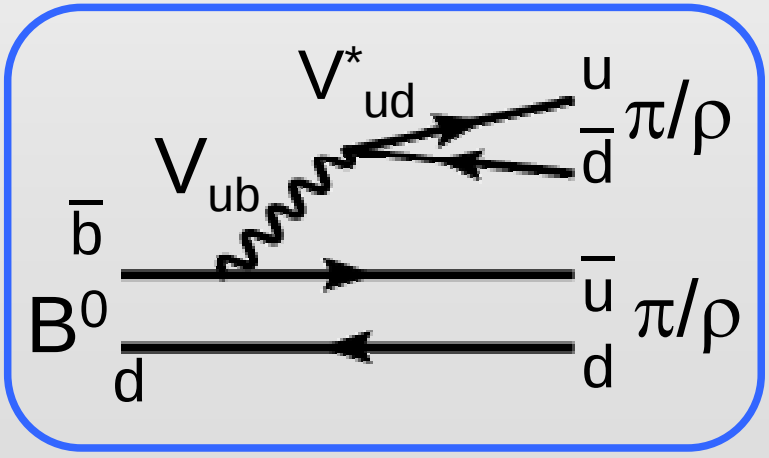
- Principle
- CP violation measurement
  - Event selection
  - CPV measurement of $B^0 \rightarrow \pi^+\pi^-$
  - CPV measurement of $B^0 \rightarrow \rho^+\rho^-$
    - Polarization
    - Time dependent fit
- Constraint on ϕ_2
  - Penguin pollution
  - Isospin analysis

CKM triangle and ϕ_2



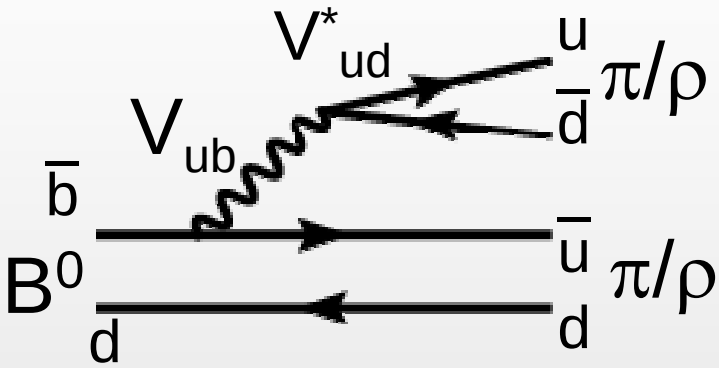


Mixing diagram



Decay diagram (tree)

CKM triangle and ϕ_2

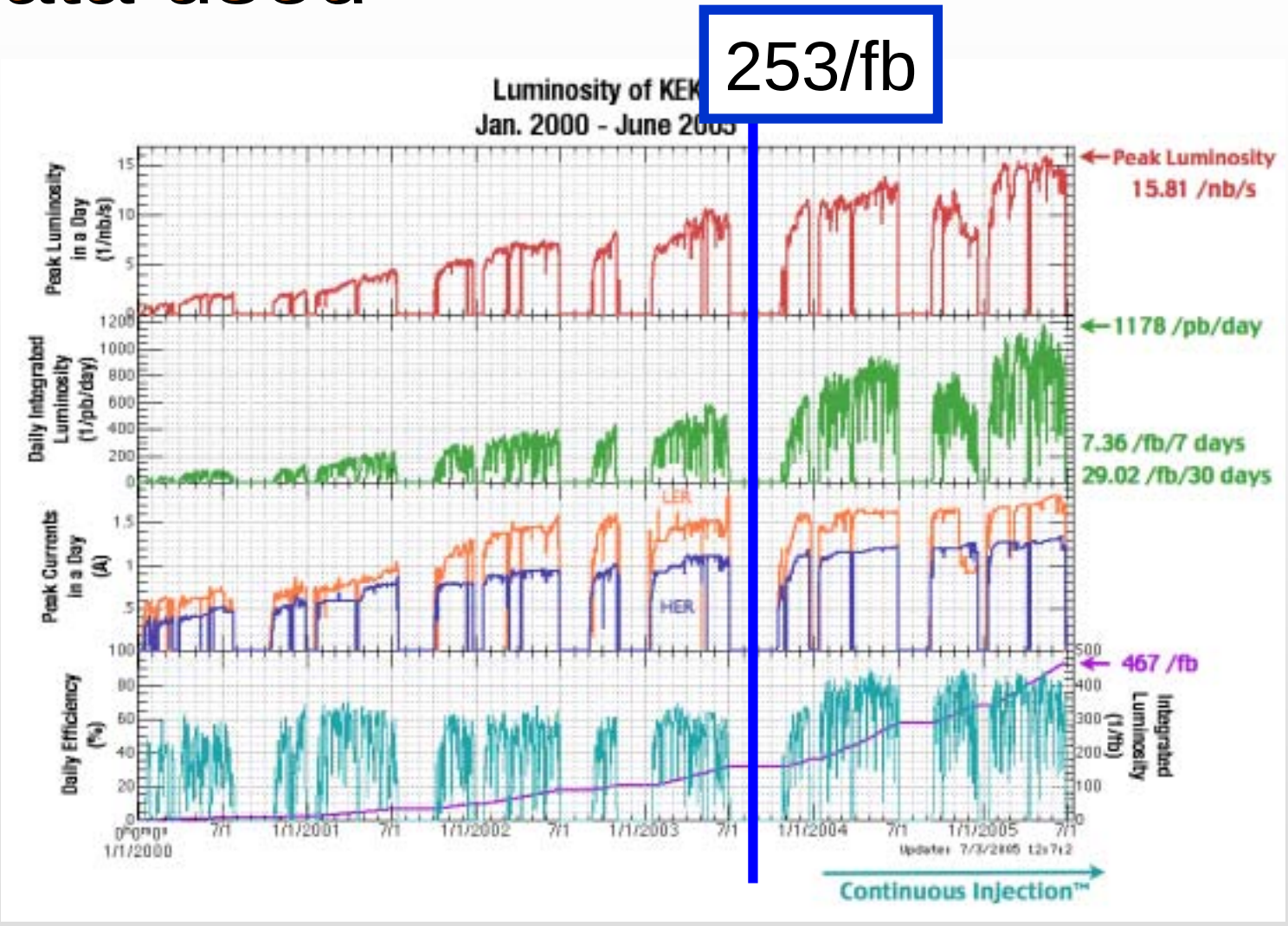


$$B^0 \rightarrow \pi^+\pi^-$$

$$B^0 \rightarrow \rho^+\rho^-$$

CP violation measurement

Data used



253/fb (275M $B\bar{B}$) until 2004 summer is used.

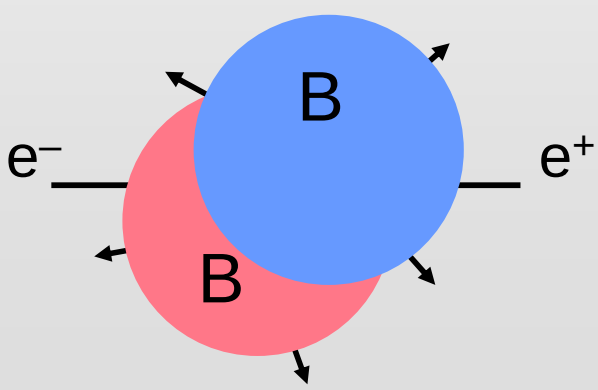
Event selection

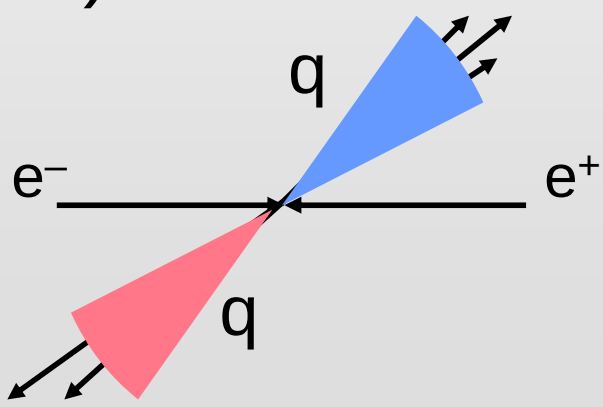
- Event reconstruction
  - π^0, ρ reconstruction ($\rho\rho$)

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^{*\,2}}$$

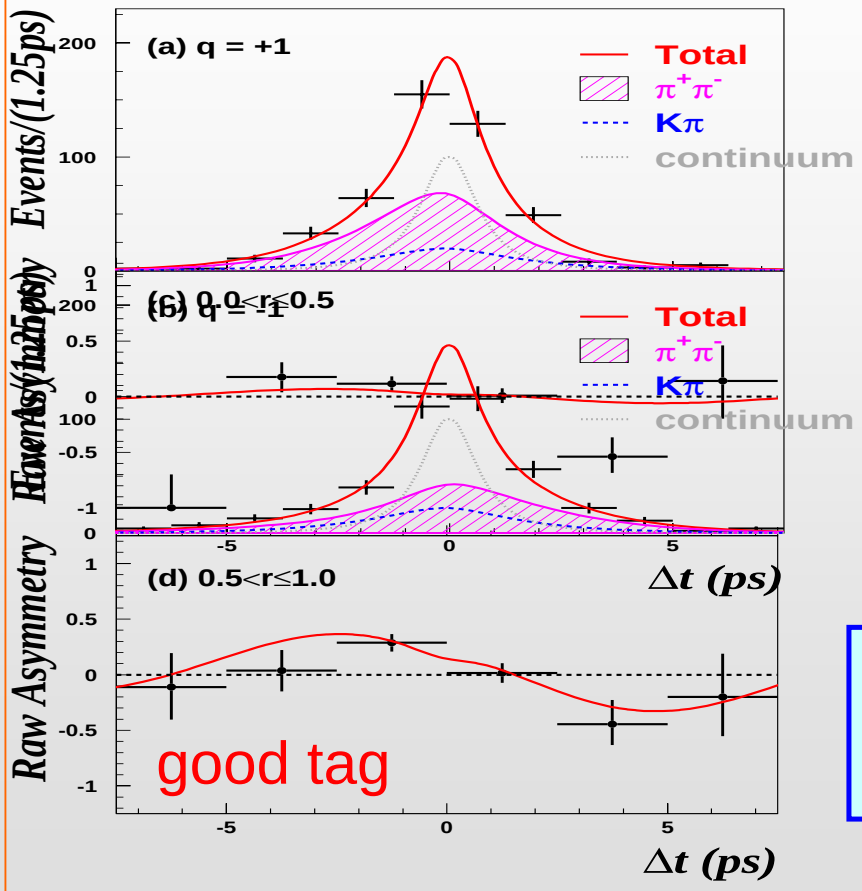
$$\Delta E = E_B^* - E_{beam}$$

- PID (K/π separation)
- Continuum suppression (modified SFW, flavor tagging information)

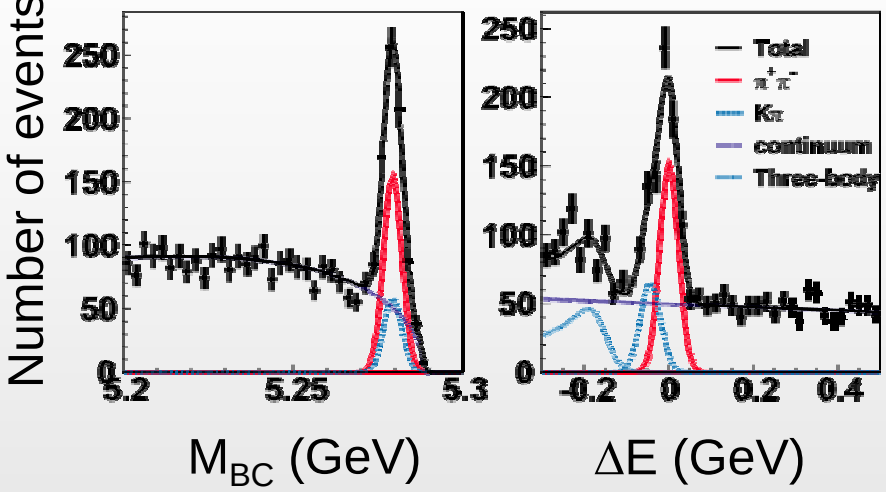




CPV measurement of $B^0 \rightarrow \pi^+\pi^-$



High Quality region



$$A_{\pi\pi} = +0.56 \pm 0.12 \pm 0.06$$
$$S_{\pi\pi} = -0.67 \pm 0.16 \pm 0.06$$

4σ evidence of Direct CPV!

Will be published as PRL 95, 101801

CPV measurement of $B^0 \to \rho^+\rho^-$

Differences from $B^0 \to \pi^+\pi^-$

- Good point
  - Small branching fraction of $B^0 \to \rho^0\rho^0$ (<1/20) compared with $B^0 \to \rho^+\rho^-$ and $B^+ \to \rho^+\rho^0$.

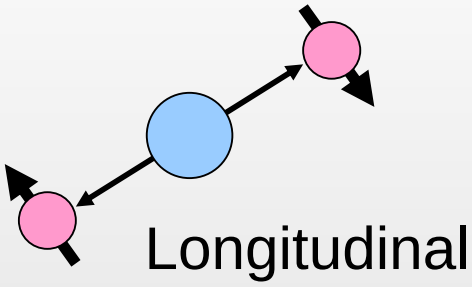
    →small penguin pollution
- Bad (difficult) points
  - Decay product contains two π^0

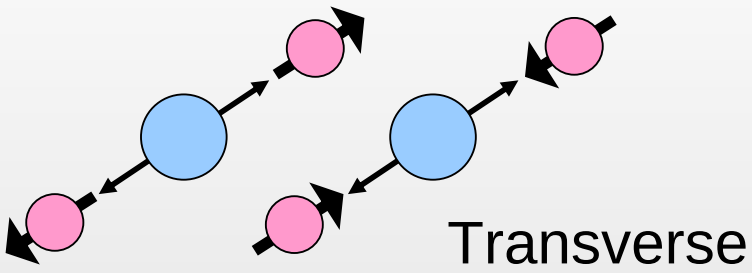
    →lower efficiency, larger BG
  - Consists of three polarization states

    →polarization measurement is essential

Polarization

- $B^0 \rightarrow \rho^+\rho^-$ has 3 polarization states with different CP eigenvalues

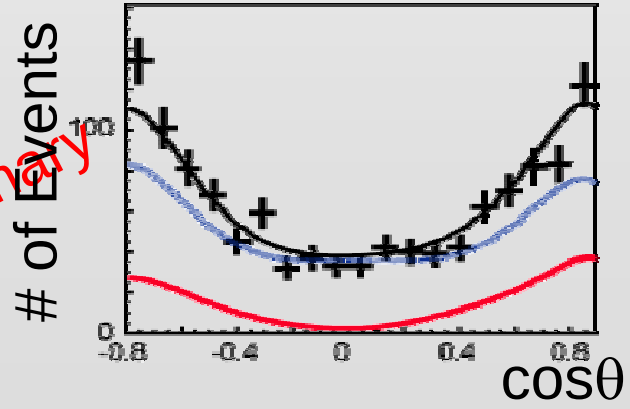




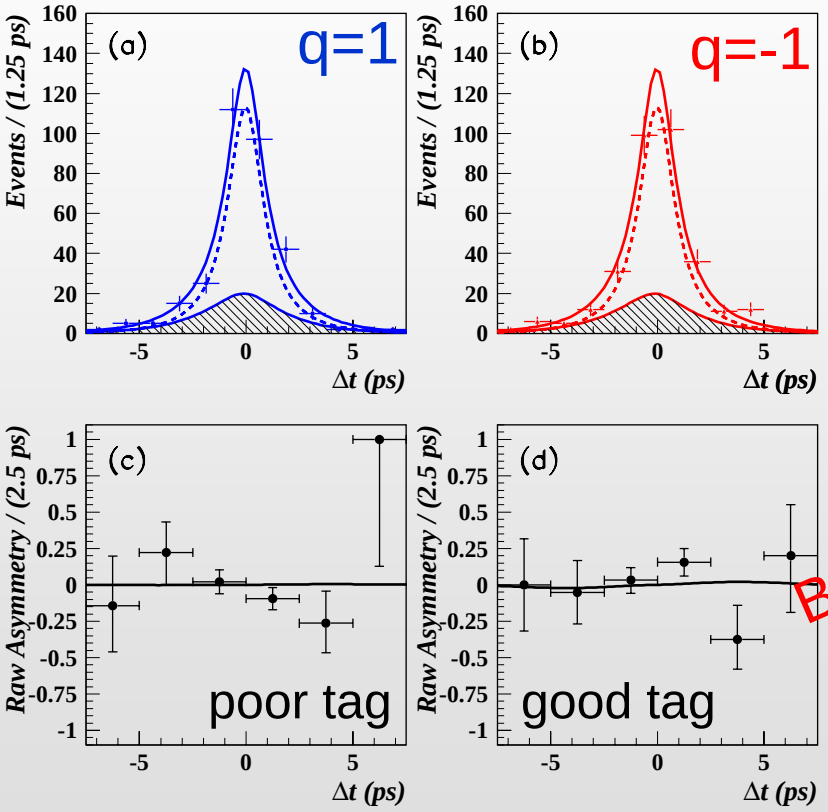
- Fortunately, longitudinal polarization is dominant.

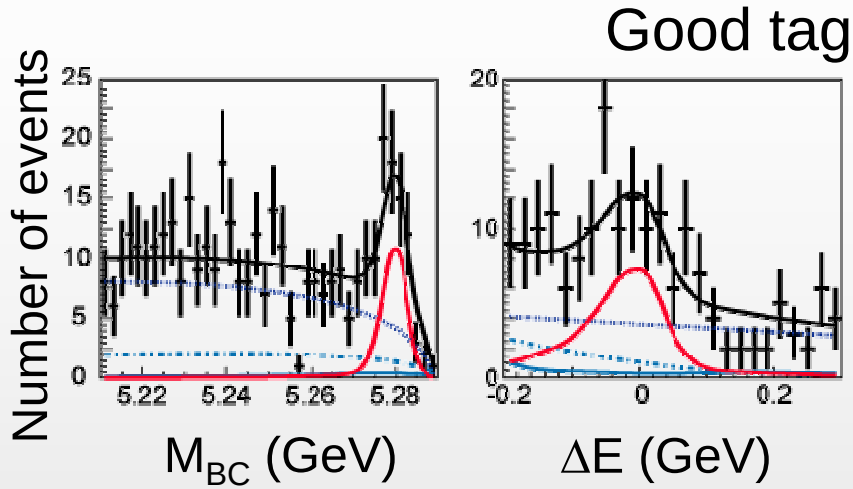
$$f_L = 0.951 \begin{matrix} +0.033 & +0.029 \\ -0.039 & -0.031 \end{matrix}$$

Belle preliminary



Time dependent fit





Belle preliminary

$$A^{L}_{\rho\rho} = 0.00 \pm 0.30 \; {}^{+0.10}_{-0.09}$$

$$S^{L}_{\rho\rho} = 0.09 \pm 0.42 \pm 0.08$$

No CP violation ⇒ $2\phi_2^{eff} \sim 180$ (deg.)

Comparison with BaBar

Belle 275M BB

$$A_{\pi\pi} = +0.56 \pm 0.12 \pm 0.06$$
$$S_{\pi\pi} = -0.67 \pm 0.16 \pm 0.06$$

$$A^{L}_{\rho\rho} = 0.00 \pm 0.30 \,{}^{+0.10}_{-0.09}$$
$$S^{L}_{\rho\rho} = 0.09 \pm 0.42 \pm 0.08$$

BaBar 227M BB

$$A_{\pi\pi} = +0.09 \pm 0.15 \pm 0.04$$
$$S_{\pi\pi} = -0.30 \pm 0.17 \pm 0.03$$

232M BB

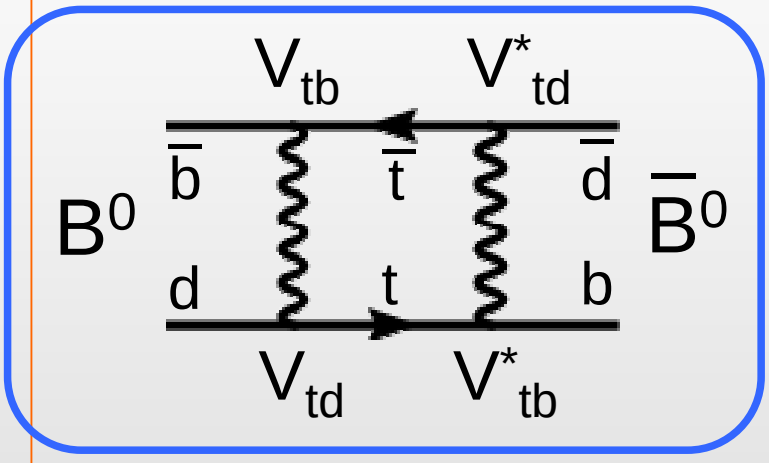
$$A^{L}_{\rho\rho} = -0.33 \pm 0.24 \,{}^{+0.08}_{-0.14}$$
$$S^{L}_{\rho\rho} = -0.03 \pm 0.18 \pm 0.09$$

Difference from Belle is 2.3σ

Results are consistent with each other.

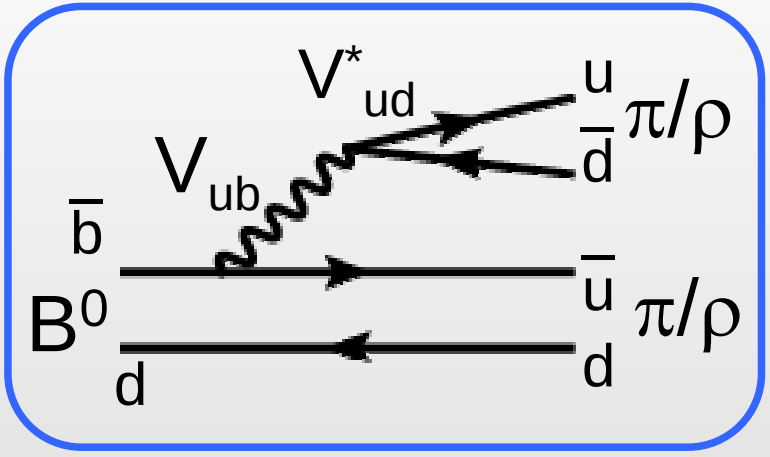
Constraint on ϕ_2

Penguin pollution



Mixing diagram

+



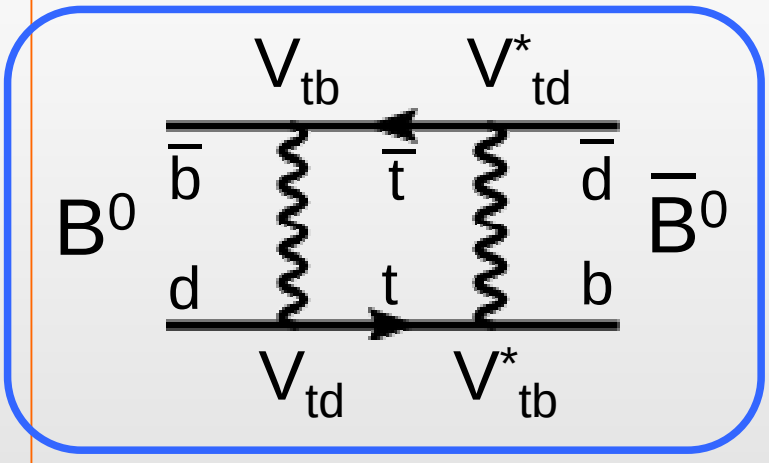
Tree diagram

ϕ_2

$$S = \sin(2\phi_2)$$

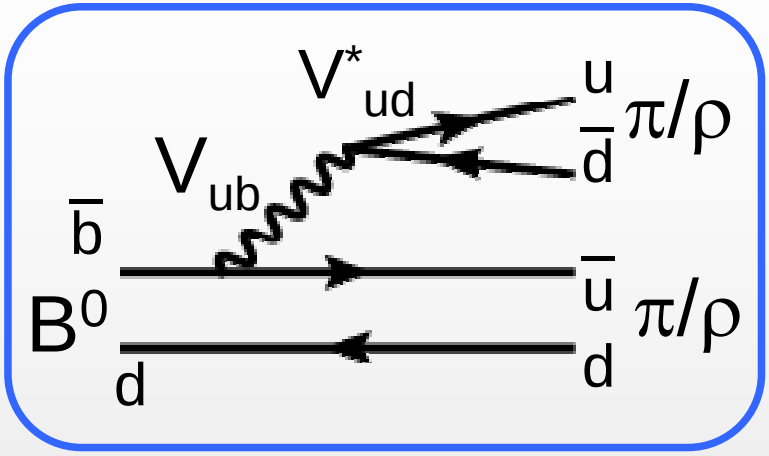
$$A = 0$$

Penguin pollution



Mixing diagram

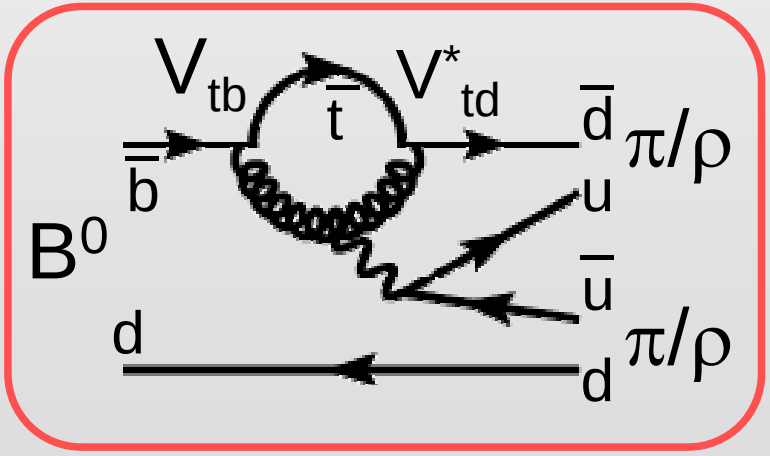
+



Tree diagram

ϕ_2

+



Penguin diagram

0

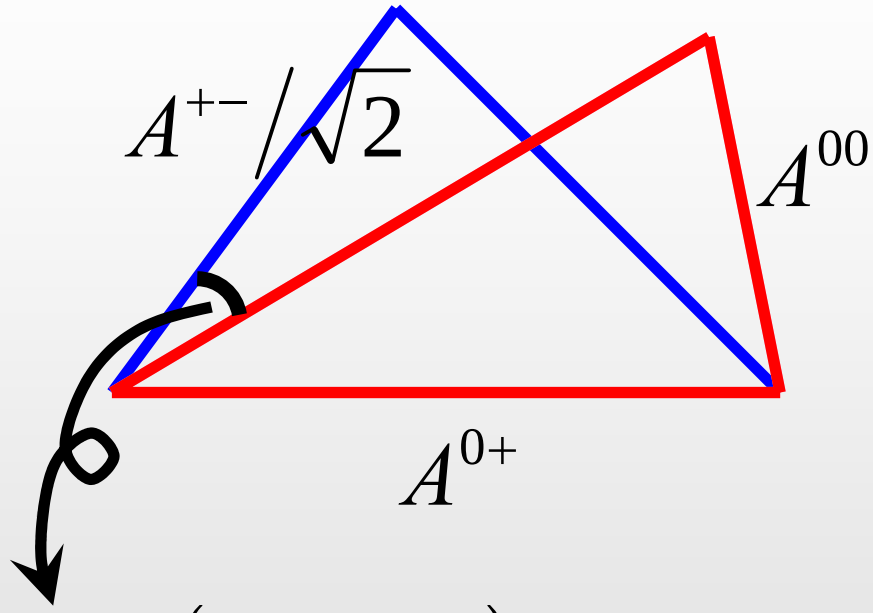
$$S = \sqrt{1 - A^2}\,\sin(2\phi_2^{\text{eff}})$$

$$2\phi_2^{\text{eff}} = 2\phi_2 + \kappa$$

Isospin analysis (how to get κ)

$$A^{+-} = A(B^0 \to \pi^+\pi^-)$$
$$A^{+0} = A(B^+ \to \pi^+\pi^0)$$
$$A^{00} = A(B^0 \to \pi^0\pi^0)$$

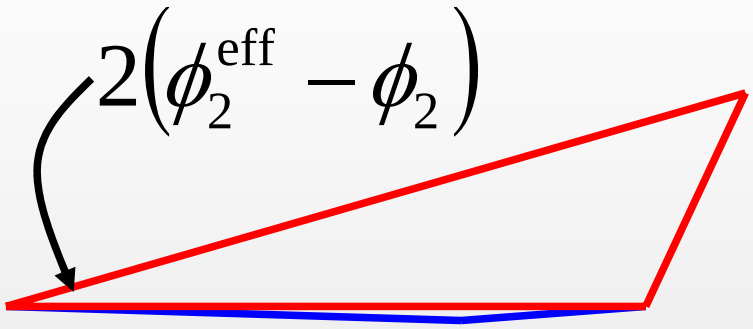
$$A^{+-}/\sqrt{2} + A^{00} = A^{0+}$$

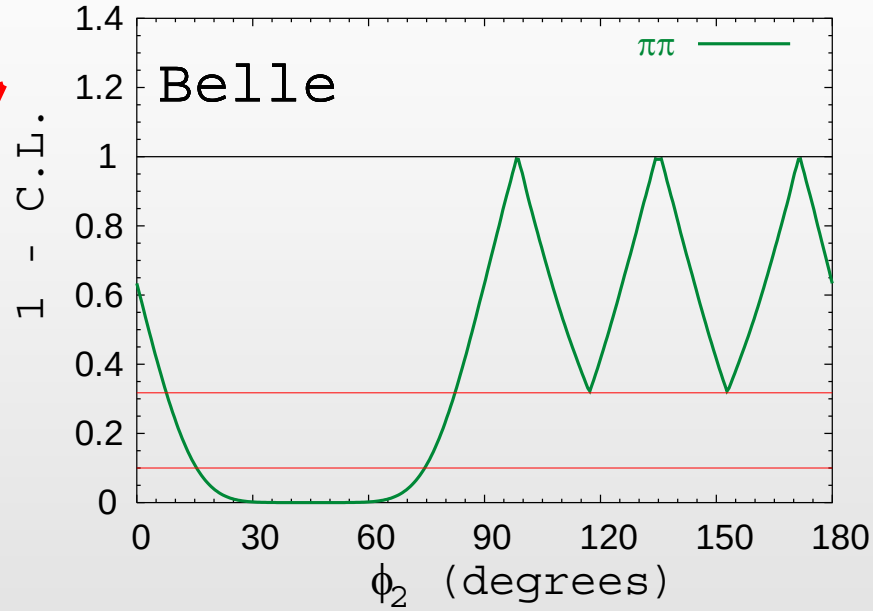


$$\kappa = 2\left(\phi_2^{\text{eff}} - \phi_2\right)$$

- BF and asymmetries: World average (HFAG)
- A_{hh} and S_{hh}: Belle measurement above.

Situation of B→ππ





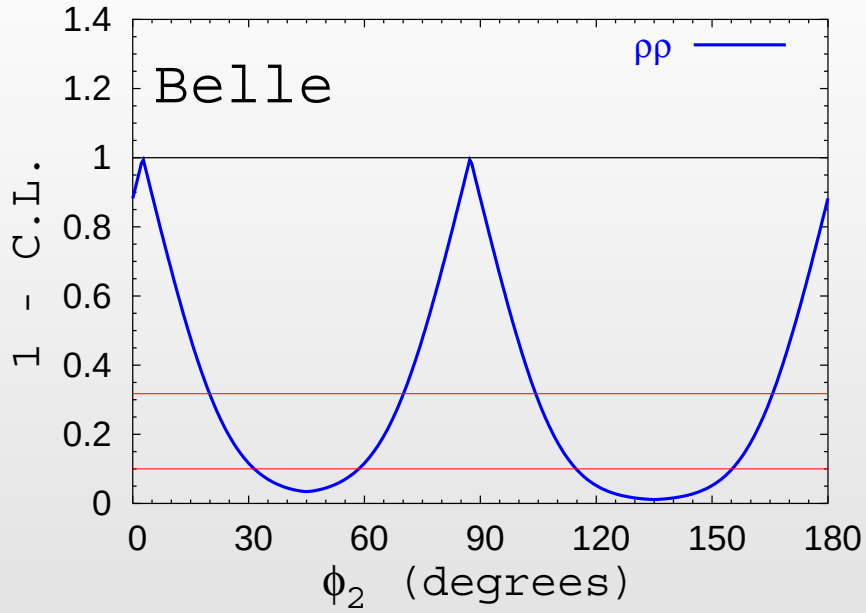
Due to the large $A_{\pi\pi}$, one of the triangles are squeezed.

$$0 < \phi_2 < 8^\circ, 82 < \phi_2 < 180^\circ \quad \text{at } 1\sigma$$

$$0 < \phi_2 < 15^\circ, 75 < \phi_2 < 180^\circ \quad \text{at } 90\% \text{ C.L.}$$

Situation of B→ρρ

$$2\left(\phi_2^{\text{eff}} - \phi_2\right)$$



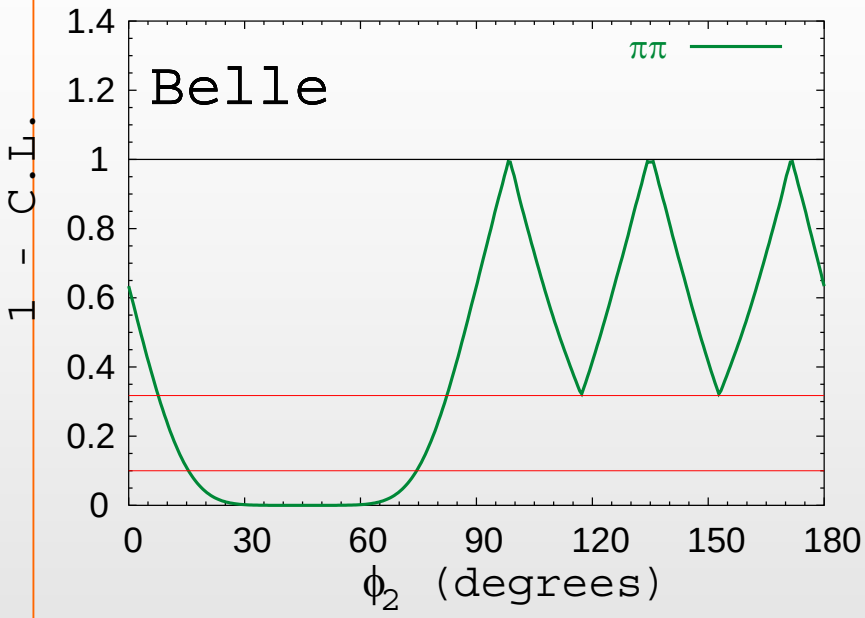
Due to the small Br of $B^0 \to \rho^0\rho^0$, both of two triangles are squeezed.

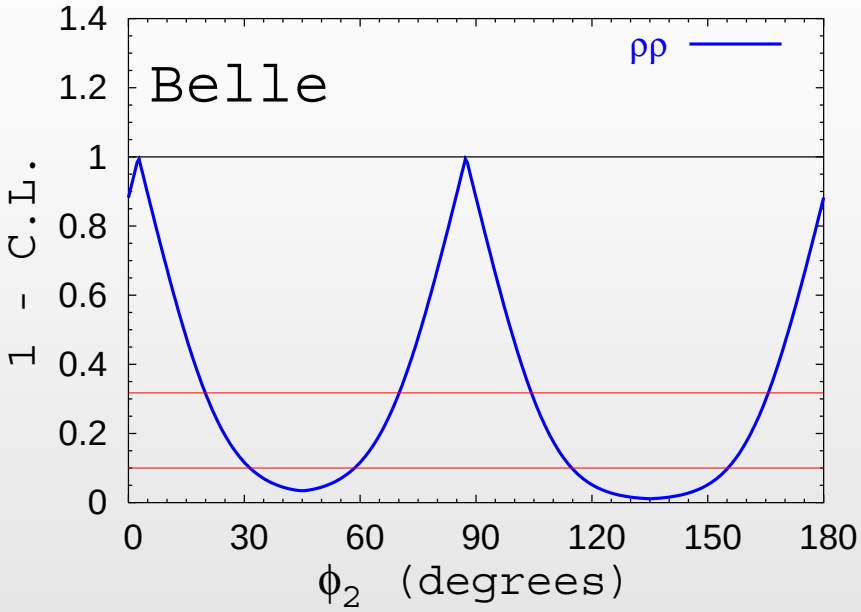
Good determination of ϕ_2
(with only two mirror solutions)

$$\phi_2 = 87 \pm 17^\circ \quad \text{at } 1\sigma$$

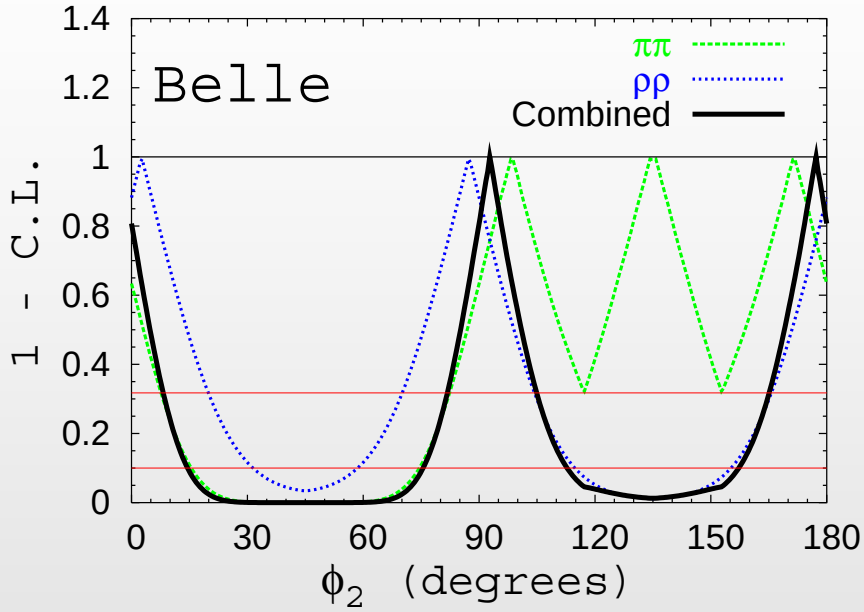
$$59 < \phi_2 < 115^\circ \text{ at } 90\% \text{ C.L.}$$

Combined result from Belle





Combined result from Belle

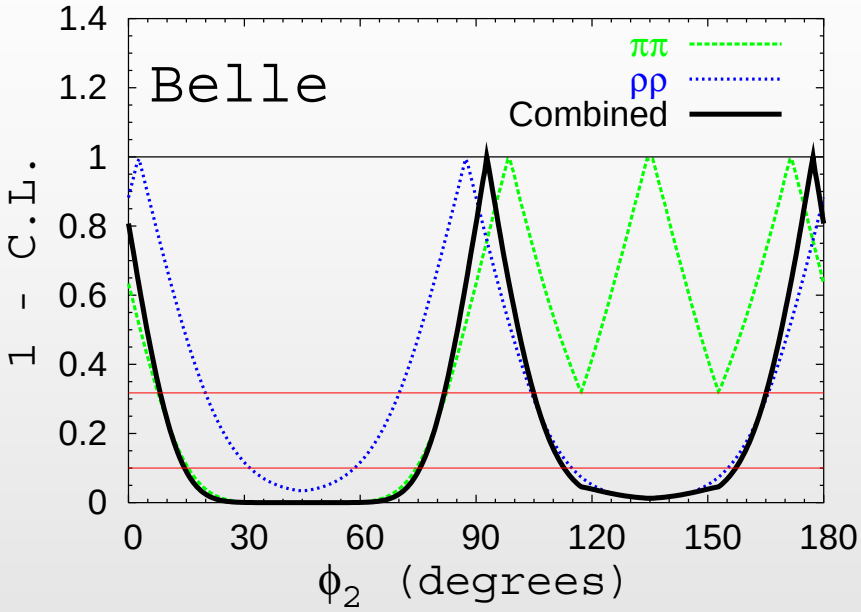


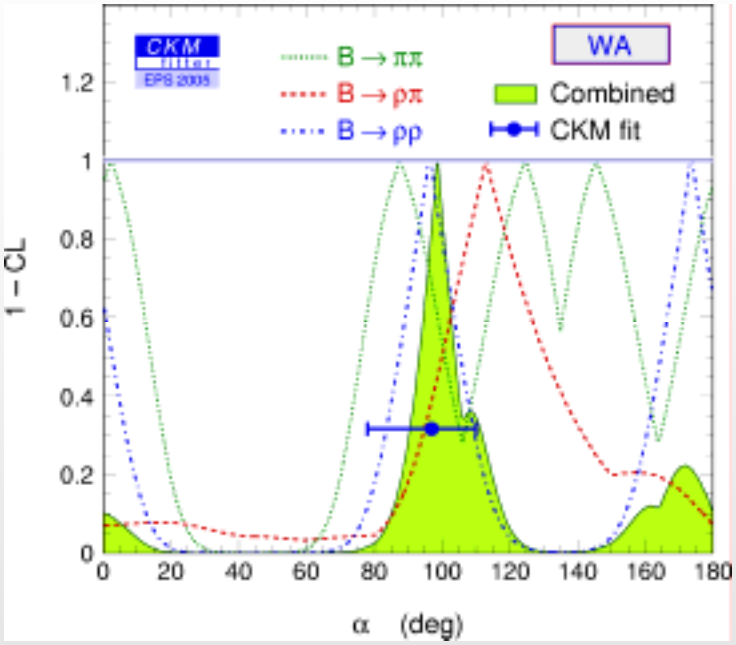
Belle

$$\phi_2 = 93^{+12^\circ}_{-11} \quad \text{at } 1\sigma$$

$$75 < \phi_2 < 113^\circ \quad \text{at 90\% C.L.}$$

Combined result from Belle





Belle

$$\phi_2 = 93^{+12^\circ}_{-11} \quad \text{at } 1\sigma$$

$$75 < \phi_2 < 113^\circ \quad \text{at 90\% C.L.}$$

ϕ_2 W.A. $\phi_2 = 98.6^{+12.6^\circ}_{-8.1}$

CKM (indirect) $\phi_2 = 97^{+13^\circ}_{-19}$

All W.A. $\phi_2 = 98.1^{+6.3^\circ}_{-7.0}$

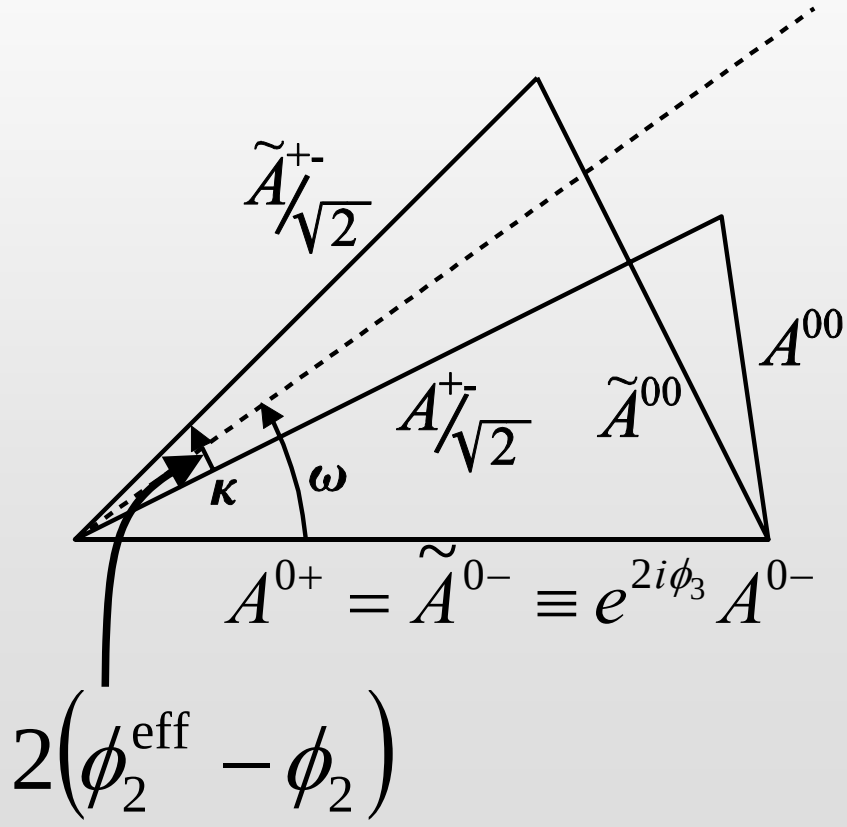
Summary

- This summer, we released new CPV measurement of $B \rightarrow \rho\rho$.
- Combining $B \rightarrow \pi\pi$ and $B \rightarrow \rho\rho$, we constrain $\phi_2 = 93^{+12}_{-11}{}^{\circ}$ for 1σ.
- The value from direct measurements is consistent with that from indirect measurements.

Isospin analysis

- With the amplitudes and asymmetries of three charged modes, ϕ_2^{eff}-ϕ_2 can be measured.
- Branching fraction and asymmetries: World average (HFAG)
- A_{hh} and S_{hh}: Belle measurement above.

$$A^{+-} = A(B^0 \to h^+h^-)$$
$$A^{+0} = A(B^+ \to h^+h^0)$$
$$A^{00} = A(B^0 \to h^0h^0)$$



- chi2 of isospin analysis.
  - $\pi\pi$: 0.35
  - $\rho\rho$: 0.60
  - combined: 1.15