CP Violation in Meson Decays

Workshop on Heavy Quark Physics at the Upgraded Hera Collider
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Why do theorists like CP violation?

1. At last, the study of CPV is experiment-driven.

2. CP is a symmetry of the strong interactions*
   $\Longrightarrow$ Various CP asymmetries can be cleanly interpreted.

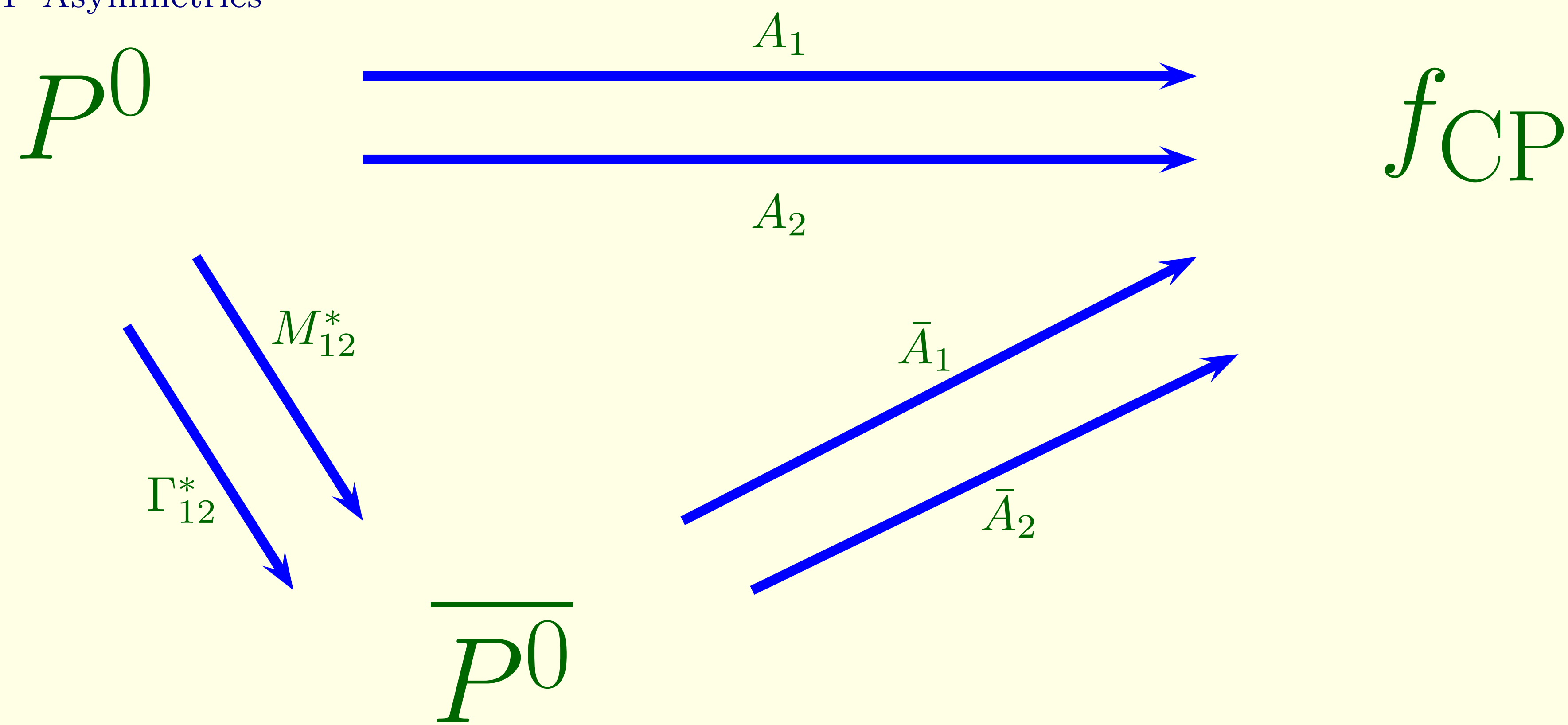
3. Almost any model of new physics gives new sources of CPV;
   In particular, CPV probes the mechanism of DSB.

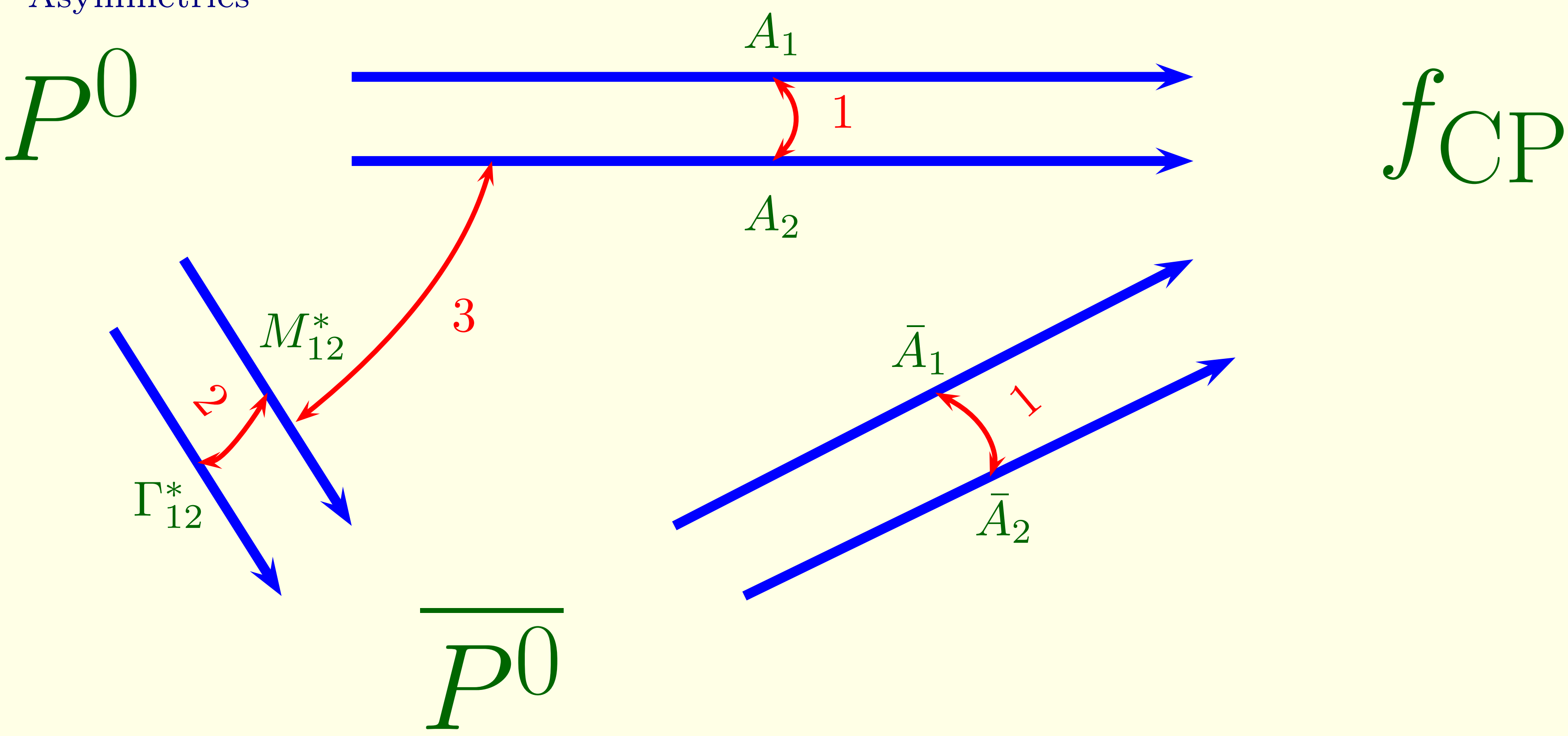
4. Baryogenesis implies that there must exist sources of CPV
   beyond the KM phase.

$*$ $\theta_{\rm QCD}$ is irrelevant in meson decays

Plan of Talk

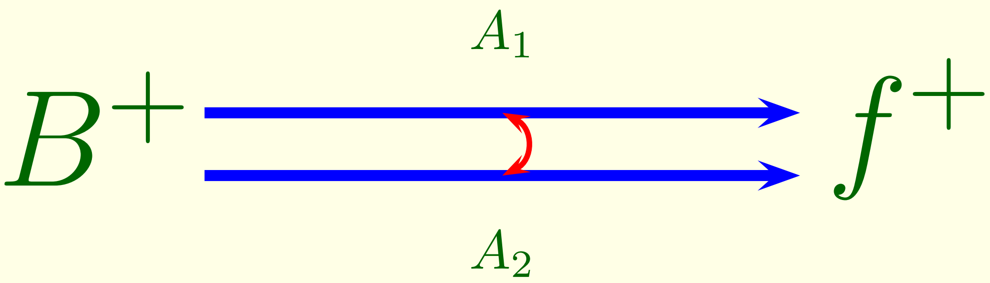
1. CP violation in meson decays
   (a) In decay: $|\bar{A}/A| \neq 1$
   (b) In mixing: $|q/p| \neq 1$
   (c) In interference of decays with and without mixing: $\mathcal{I}m\lambda \neq 0$
2. Results and Basic Implications
   (a) $s \to u\bar{u}d$: $K \to \pi\pi$
   (b) $c \to s\bar{s}u$: $D \to KK$
   (c) $b \to c\bar{c}s$: $B \to \psi K$
   (d) $b \to s\bar{s}s$: $B \to \phi K,\ \eta' K,\ KKK$
3. Conclusions


P^0
A_1
A_2
$f_{\rm CP}$
M_{12}^*
Γ_{12}^*
$\bar{A}_1$
$\bar{A}_2$
$\overline{P^0}$



1. In decay: $|\bar{A}/A| \neq 1$ $\left[\frac{\bar{A}}{A} = \frac{\bar{A}_1+\bar{A}_2}{A_1+A_2}\right]$
2. In mixing: $|q/p| \neq 1$ $\left[\left(\frac{q}{p}\right)^2 = \frac{2M_{12}^*-i\Gamma_{12}^*}{2M_{12}-i\Gamma_{12}}\right]$
3. In interference: $\mathcal{I}m\lambda \neq 0$ $\left[\lambda = \frac{q}{p}\frac{\bar{A}}{A}\right]$

CP asymmetry in charged B decay



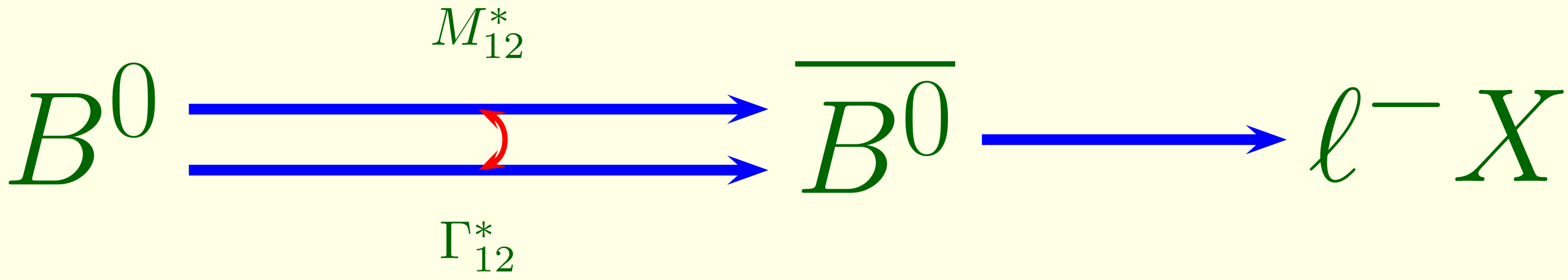
$$\mathcal{A}_{f^\mp} \equiv \frac{\Gamma(B^- \to f^-) - \Gamma(B^+ \to f^+)}{\Gamma(B^- \to f^-) + \Gamma(B^+ \to f^+)} = \frac{|\bar{A}_f/A_f|^2 - 1}{|\bar{A}_f/A_f|^2 + 1}$$

- CP violation in decay:

$$\left|\frac{\bar{A}_f}{A_f}\right| \neq 1 \quad \left[\frac{\bar{A}_f}{A_f} = \frac{\bar{A}_1 + \bar{A}_2}{A_1 + A_2}\right]$$

- Requires $\delta_2 - \delta_1$, $|A_2/A_1| \Longrightarrow$ Hadronic uncertainties

CP asymmetry in semileptonic neutral B decay

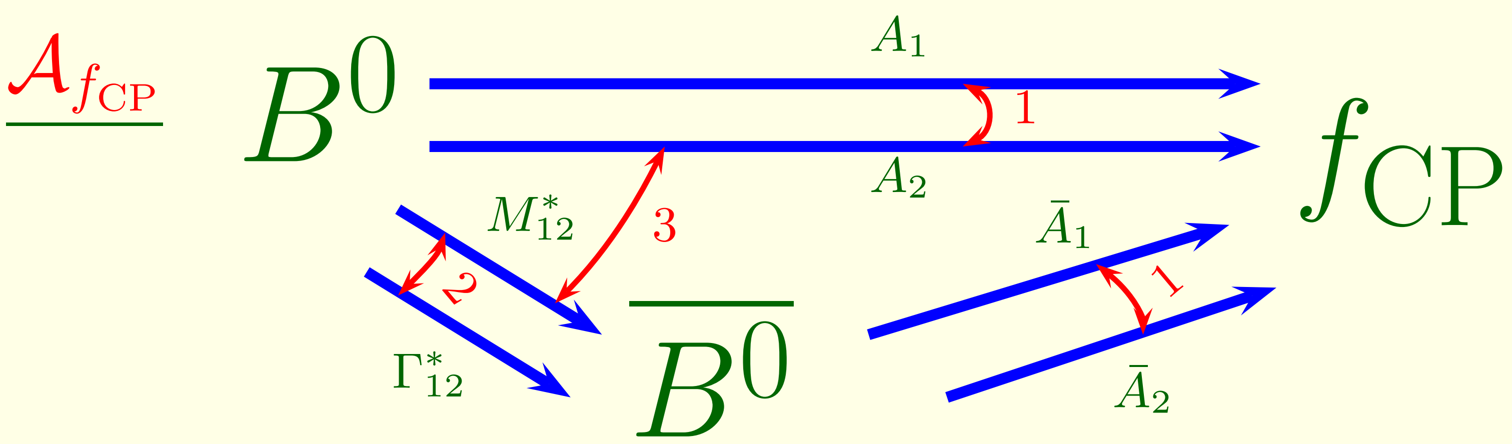


$$\mathcal{A}_{\rm SL} \equiv \frac{\Gamma(\bar{B}^0_{\rm phys}(t) \to \ell^+ X) - \Gamma(B^0_{\rm phys}(t) \to \ell^- X)}{\Gamma(\bar{B}^0_{\rm phys}(t) \to \ell^+ X) + \Gamma(B^0_{\rm phys}(t) \to \ell^- X)} = \frac{1 - |q/p|^4}{1 + |q/p|^4}$$

- CP violation in mixing:

$$\left|\frac{q}{p}\right| \neq 1 \qquad \left[\frac{q}{p} = -\frac{2M_{12}^* - i\Gamma_{12}^*}{\Delta m_B - \frac{i}{2}\Delta\Gamma_B}\right]$$

- Requires $\Gamma_{12} \Longrightarrow$ Hadronic uncertainties



- CP asymmetry in neutral B decay into final CP eigenstates:

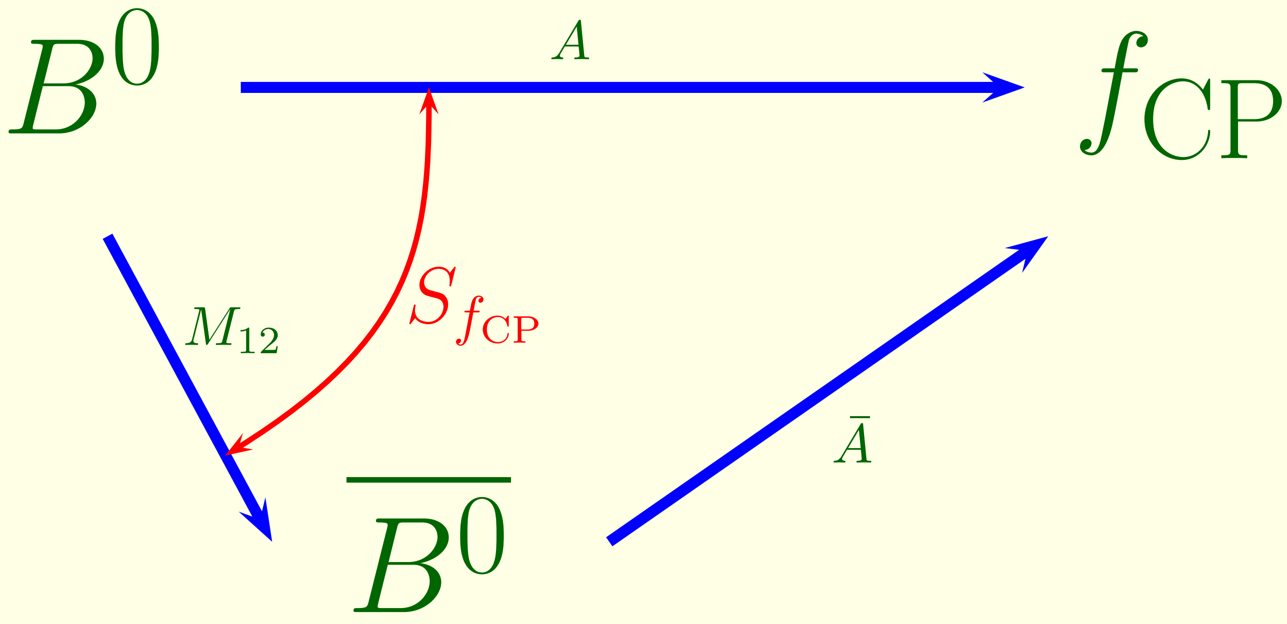
$$\mathcal{A}_{f_{CP}}(t) \equiv \frac{\Gamma(\bar{B}^0_{\rm phys}(t) \to f_{CP}) - \Gamma(B^0_{\rm phys}(t) \to f_{CP})}{\Gamma(\bar{B}^0_{\rm phys}(t) \to f_{CP}) + \Gamma(B^0_{\rm phys}(t) \to f_{CP})}$$

$$= -C_{f_{CP}} \cos(\Delta m_B\ t) + S_{f_{CP}} \sin(\Delta m_B\ t)$$

$$C_{f_{CP}} = -\mathcal{A}_{f_{CP}} = \frac{1-|\lambda_{f_{CP}}|^2}{1+|\lambda_{f_{CP}}|^2}, \quad S_{f_{CP}} = \frac{2\mathcal{I}m\lambda_{f_{CP}}}{1+|\lambda_{f_{CP}}|^2}.$$

- CP violation in interference of decays with and without mixing:
  $\mathcal{I}m\lambda \neq 0 \qquad \left[\lambda = \frac{q}{p}\frac{\bar{A}}{A}\right]$

The case theorists love



1. Decay dominated by a single CPV phase: $|\bar{A}/A| = 1$
2. CPV in mixing negligible: $|q/p| = 1$
3. The only remaining effect is

$$\boxed{S_{f_{\rm CP}} = \mathcal{I}m\lambda_{f_{\rm CP}} = \pm\sin[\arg(M_{12}^*) + \arg(\bar{A}_{f_{\rm CP}}) - \arg(A_{f_{\rm CP}})]}$$

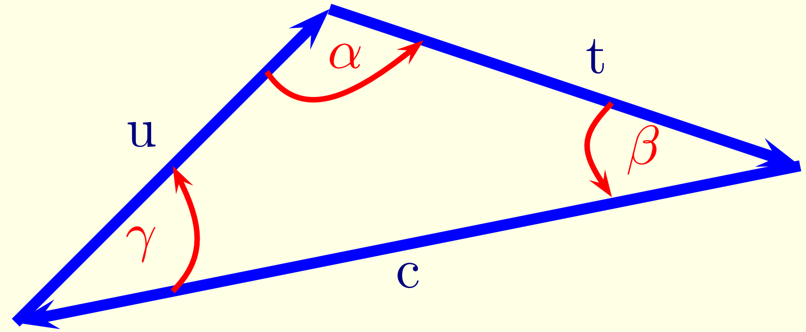
Direct vs. Indirect CPV

- Indirect CPV
  - Can be accounted for by a phase in M_{12} only
  - $|q/p| \neq 1$ and/or a single $S_f \neq 0$
  - Superwak models: only indirect CPV
- Direct CPV
  - cannot be accounted for by a phase in M_{12} only
  - $|\bar{A}/A| \neq 1$ and/or $S_{f_1} \neq S_{f_2}$
  - SM: possibly large direct CPV

In case that you never saw a UT before...

- A geometrical presentation of $\boxed{V_{ub}^* V_{ud} + V_{tb}^* V_{td} + V_{cd}^* V_{cb} = 0}$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



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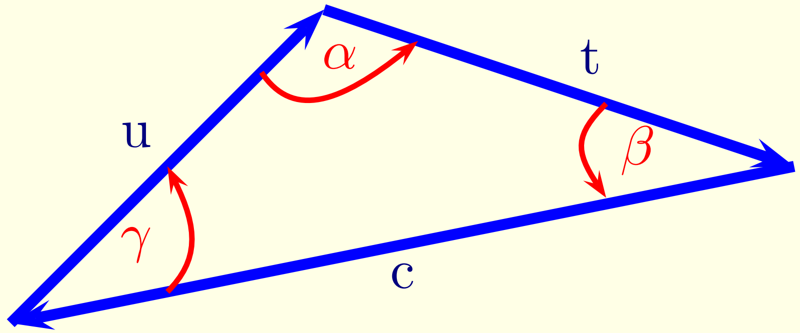
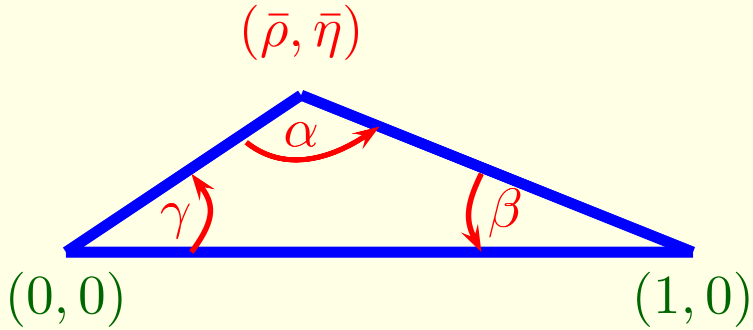


- Rescale and rotate: $\boxed{A\lambda^3\left[(\rho + i\eta) + (1 - \rho - i\eta) + (-1)\right] = 0}$

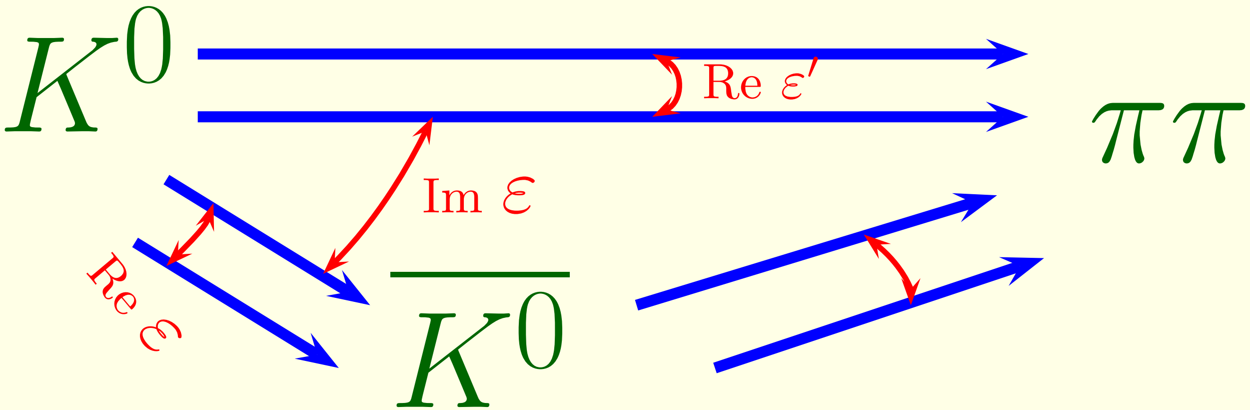
$$V = \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$



Wolfenstein (83); Buras *et al.* (94)

$\alpha \equiv \phi_2; \quad \beta \equiv \phi_1; \quad \gamma \equiv \phi_3$

$K \to \pi\pi$



$$|\varepsilon| = (2.27 \pm 0.01) \times 10^{-3} \quad \left(\varepsilon = \frac{1-\lambda_0}{1+\lambda_0}\right)$$

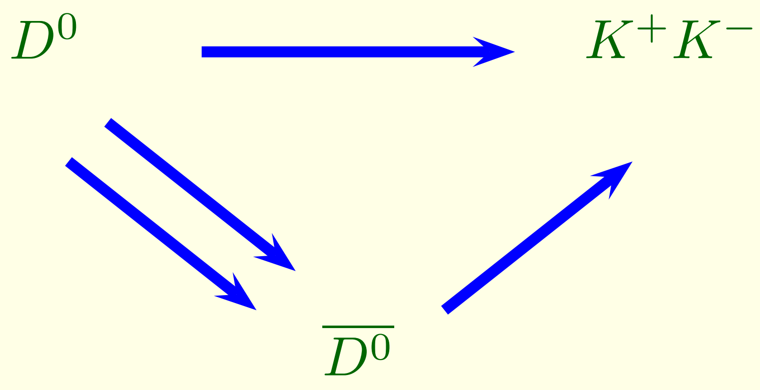
Christenson, Cronin, Fitch, Turlay (64)

$$\mathcal{R}e\ \varepsilon'/\varepsilon = (1.66 \pm 0.16) \times 10^{-3} \quad \left(\varepsilon' = \frac{1}{6}(\lambda_{00} - \lambda_{+-})\right)$$

NA31 (88), KTeV (01), NA48 (02): $(1.47 \pm 0.22) \times 10^{-3}$

Lessons from ε'/ε

- Direct CP violation has been observed.
- The superweak scenario is excluded.
  Wolfenstein (64)
- The result is consistent with the SM predictions.
- Large hadronic uncertainties $\Longrightarrow$ no useful CKM constraint.
- New physics (*e.g.* Supersymmetry) may contribute significantly.
  e.g. Masiero and Murayama (99)



- Define ($y_{\rm CP} \to y$ in the CP limit)

$$y_{\rm CP} \equiv \frac{\hat{\Gamma}(D\to K^+K^-)}{\hat{\Gamma}(D^0\to\pi^+K^-)} - 1$$

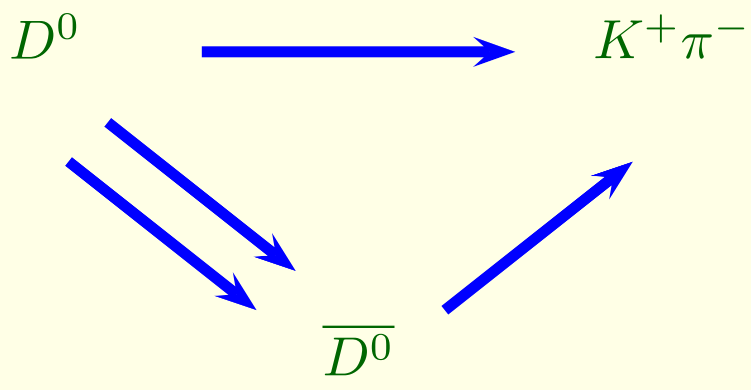
- Assume no direct CP violation:

$$y_{\rm CP} = y\cos\phi - x(|q/p| - 1)\sin\phi \qquad (\phi - \pi \equiv \arg\lambda)$$

Bergmann *et al.* (00)

- Experiments (FOCUS, E791, CLEO, BELLE, BABAR):

$$\boxed{y_{\rm CP} = (1.0 \pm 0.7) \times 10^{-2}}$$



- $K^+\pi^- \neq$ CP e.s. $\Longrightarrow$ analysis complicated by strong phases:

$$x' \equiv x\cos\delta + y\sin\delta, \quad y' \equiv y\cos\delta - x\sin\delta$$

- Assume no direct CP violation:

$$\Gamma(D^0(t) \to K^+\pi^-) \propto R + \sqrt{R}|q/p|(y'c_\phi - x's_\phi)\Gamma t + |q/p|^2(y^2+x^2)(\Gamma t)^2/4$$
$$\Gamma(\overline{D^0}(t) \to K^-\pi^+) \propto R + \sqrt{R}|p/q|(y'c_\phi + x's_\phi)\Gamma t + |p/q|^2(y^2+x^2)(\Gamma t)^2/4$$

- Experiment (CLEO):

$$R = (4.8 \pm 1.3) \times 10^{-3}, \quad y' = -0.025^{+0.014}_{-0.016}, \quad x' = 0.000 \pm 0.015$$
$$|q/p|^2 - 1 = 0.23^{+0.63}_{-0.80}, \quad \sin\phi = 0.0 \pm 0.6$$

Lessons from $D \to KK, K\pi$

- No signal of mixing yet:

	CPV (NP)	CPC (SM)
$y = \frac{\Delta\Gamma}{2\Gamma}$	< 0.046	< 0.022
$x = \frac{\Delta m}{\Gamma}$	< 0.063	< 0.050

- $y = \mathcal{O}(0.01)$ is possible within the SM (phase space effects).

Falk, Grossman, Ligeti, Petrov (02)

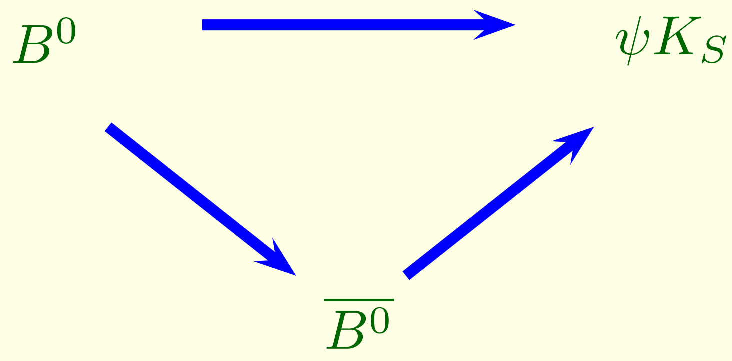
- CP violation is important in two ways:

1. CPV would be the only unambiguous signal of NP.
2. CPV has to be taken into account when constraining NP:

	$\phi \neq 0,\ \delta \neq 0$ (NP)	$\phi = 0,\ \delta = 0$ (PDG)
$\frac{\lvert M_{12}\rvert}{10^{-11}\ MeV}$	< 5.4	< 2.3

Raz (02)

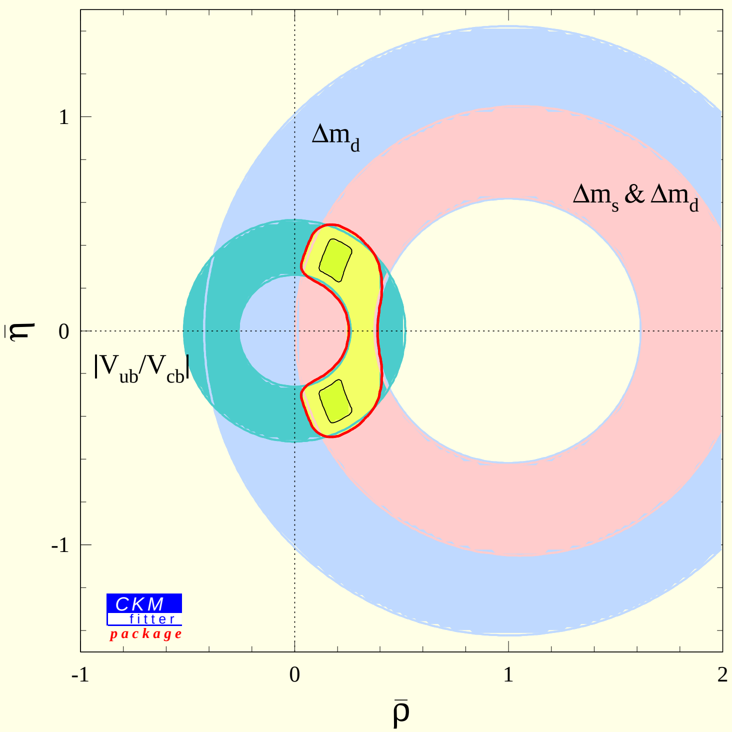
Carter and Sanda (80)
Bigi and Sanda (81)



- Within SM, dominated by a single phase $\Longrightarrow$ $\boxed{C_{\psi K_S} = 0}$
  (Subleading phase CKM- and loop-suppressed)
- Within SM, $M_{12}^* \propto (V_{tb}^* V_{td})^2$, $A \propto V_{cb}^* V_{cd}$ $\Longrightarrow$ $\boxed{S_{\psi K_S} = \sin 2\beta}$
- With NP, still $S_{\psi K_S} \simeq \sin[\arg(M_{12}^*) - 2\arg(V_{cb}^* V_{cd})]$ and $C_{\psi K_S} \simeq 0$, but $S_{\psi K_S} \neq \sin 2\beta$ is possible.
- BABAR and BELLE measure

mode	CP	$S_{\psi K_S}$	$C_{\psi K_S}$
ψK_S	$-$	$+0.74 \pm 0.05$	0.02 ± 0.04

Unitarity Triangles

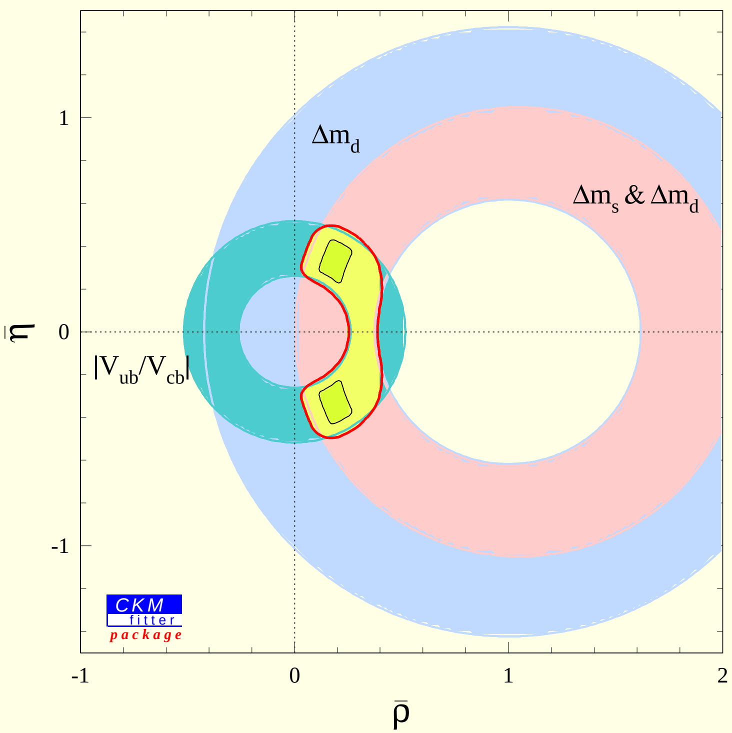


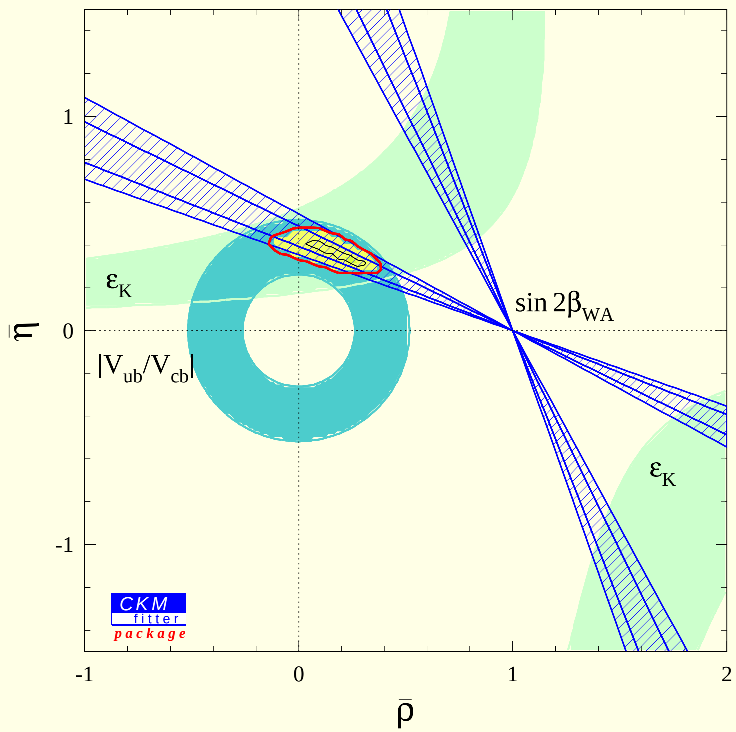
Tree level + CPC observables

$$\Delta m_B, \quad \Delta m_{B_s}$$

Using CKMFitter package (Höcker *et al.*, Eur. Phys. J. C21, 225 (01))

Unitarity Triangles





Tree level + CPC observables

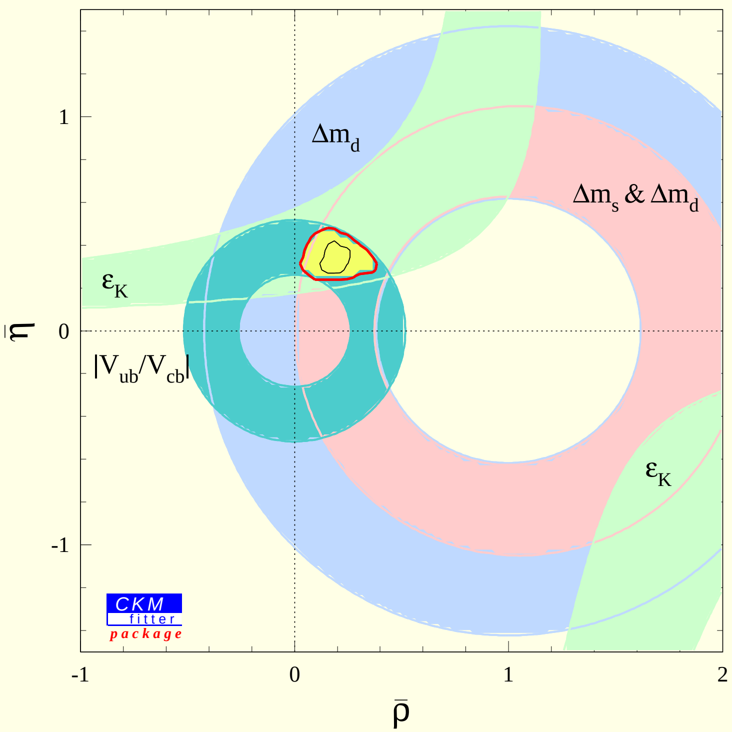
$\Delta m_B, \quad \Delta m_{B_s}$

Tree level + CPV observables

$\varepsilon, \quad S_{\psi K_S}$

Using CKMFitter package (Höcker *et al.*, Eur. Phys. J. C21, 225 (01))

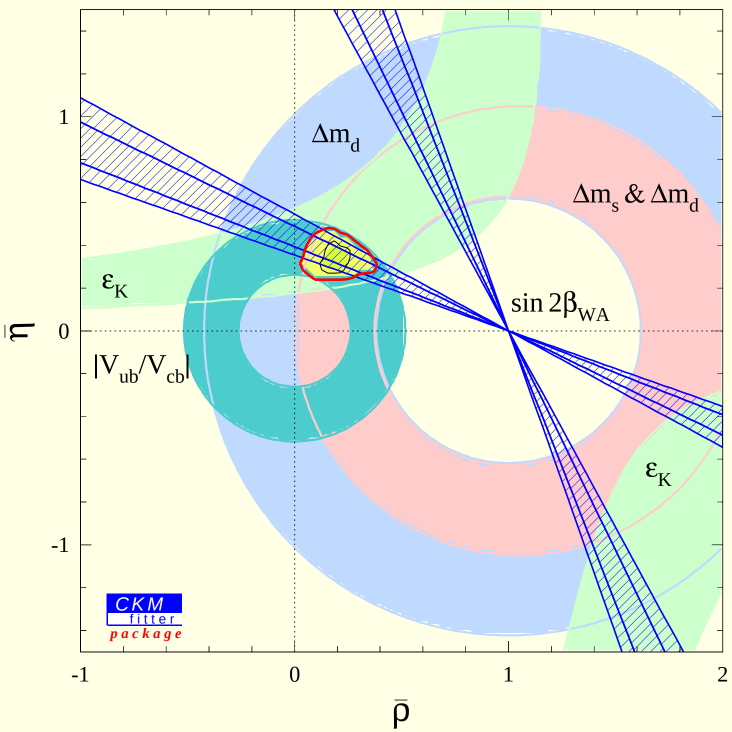
Unitarity Triangles



Without $S_{\psi K}$

$\Delta m_B, \;\; \Delta m_{B_s}, \;\; \varepsilon$

Unitarity Triangles



Without $S_{\psi K}$

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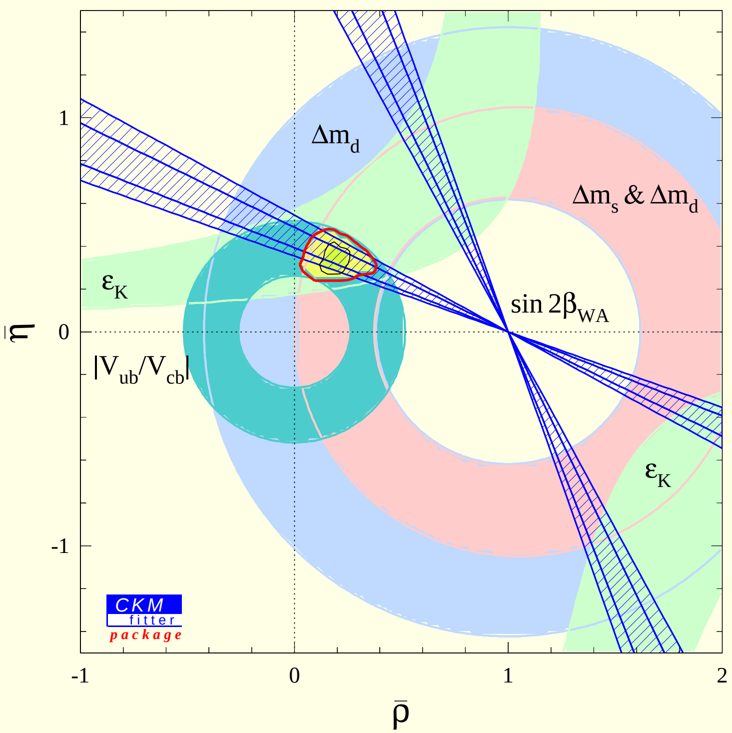
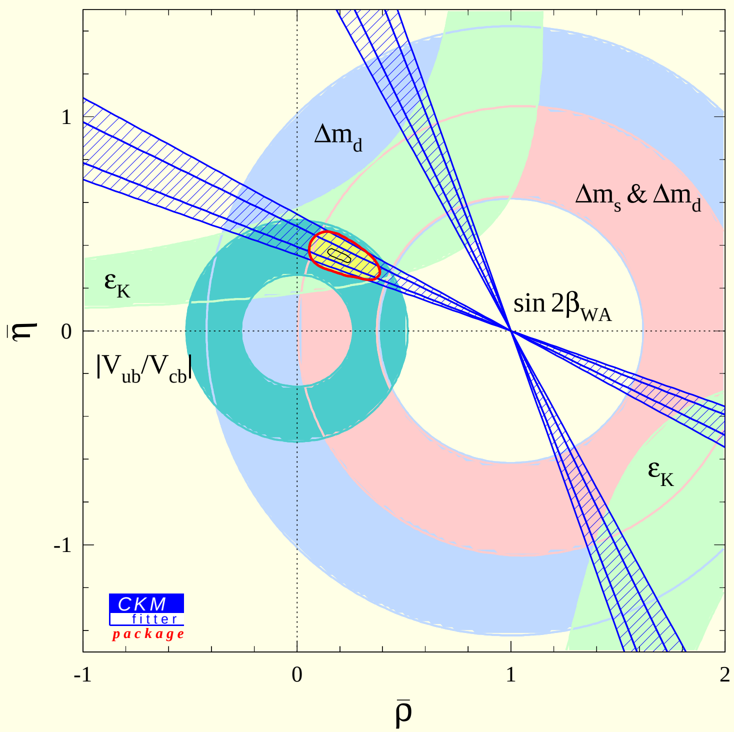
Unitarity Triangles





Without $S_{\psi K}$

$\Delta m_B, \ \Delta m_{B_s}, \ \varepsilon$

With $S_{\psi K}$

$\Delta m_B, \ \Delta m_{B_s}, \ \varepsilon, \ S_{\psi K_S}$

Lessons from $\mathcal{A}_{\rm CP}(B \to \psi K_S)$

- CPV in B decays has been observed.
- The Kobayashi-Maskawa mechanism of CPV has successfully passed its first precision test.
- Approximate CP (in the sense that all CPV phases are small) is excluded.
- A significant constraint on the CKM parameters $(\bar{\rho}, \bar{\eta})$:

$$\boxed{\mathcal{I}m\lambda_{\psi K_S} = \sin 2\beta = \frac{2\bar{\eta}(1-\bar{\rho})}{\bar{\eta}^2+(1-\bar{\rho})^2} = 0.736 \pm 0.048}$$

- New, CPV physics that contributes $> 20\%$ to $B^0 - \overline{B^0}$ mixing is disfavored.

The KM mechanism

- The KM mechanism successfully passed its first precision test

  Very likely, the KM mechanism is the dominant source of CP violation in flavor changing processes

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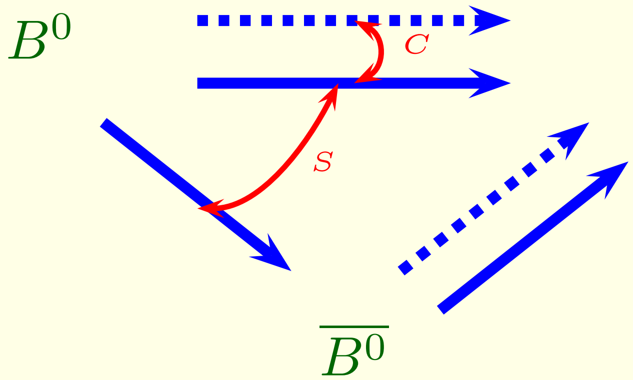
> Very likely, the KM mechanism is the dominant source of CP violation in flavor changing processes

- 'Very likely': The consistency could be accidental
  $\Longrightarrow$ More measurements of CPV are crucial.
- 'Dominant': There is still room for NP at the $\mathcal{O}(20\%)$ level
  $\Longrightarrow$ A challenge for theorists.
- 'FC processes': FD CPV can still be dominated by NP
  $\Longrightarrow$ Search for EDMs.



$\phi K_S, \eta' K_S, KKK$

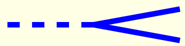
- Within SM, dominated by a single phase $\Longrightarrow$ $C \approx 0$
  (Subleading phase CKM-suppressed)
- Within SM, $A \propto V_{cb}^* V_{cd}$ $\Longrightarrow$ $S \approx S_{\psi K_S} (\approx +0.74)$
- With NP, $S \neq S_{\psi K_S}$, $S_{f_1} \neq S_{f_2}$ and $C \neq 0$ are possible.

mode	CP	$-\eta_{\rm CP} S$	C
ϕK_S	$-$	$-0.14 \pm 0.33 (0.69)^{\dagger}$	-0.04 ± 0.26
$\eta' K_S$	$-$	$+0.27 \pm 0.21$	$+0.04 \pm 0.13$
$K^+K^-K_S$	$+^*$	$+0.51 \pm 0.26^{+0.18}_{-0.00}$	$+0.17 \pm 0.16$

† Babar: $+0.45 \pm 0.43 \pm 0.07$; Belle: $-0.96 \pm 0.50 \pm 0.10$

* Isospin analysis is used to argue CP = + dominance.

Supersymmetry for Phenomenologists

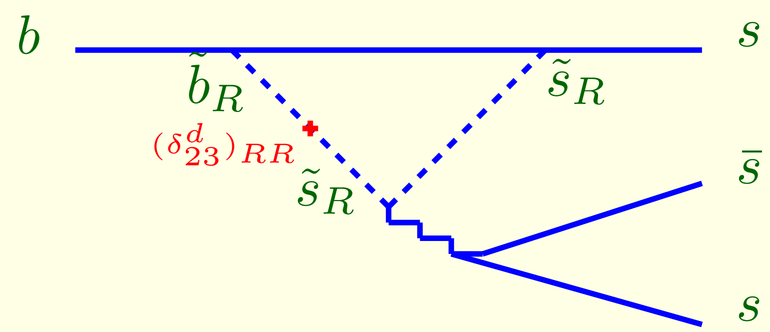
		FV	CPV
	Y	$+$	$+$
	μ	$-$	$+$
	A	$+$	$+$
	$m_{\tilde{g}}$	$-$	$+$
	$m^2_{\tilde{f}}$	$+$	$+$
	B	$-$	$+$

80 real + 44 imaginary parameters

CP Violation in Supersymmetry

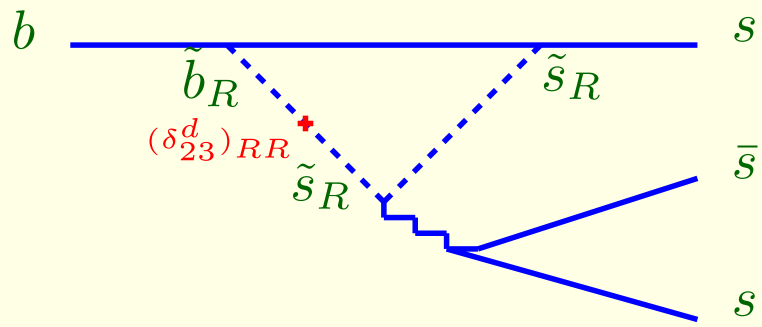
- K physics: $\frac{\mathcal{I}m M_{12}^{\rm SUSY}}{\mathcal{I}m M_{12}^{\rm exp}} \sim 10^8 \left(\frac{100\ GeV}{\tilde{m}}\right)^2 \left(\frac{\Delta\tilde{m}_{12}^2}{\tilde{m}^2}\right)^4 \mathcal{I}m\left[(K_{12}^d)^2\right]$
  - Heavy squarks: $\tilde{m} \gg 100\ GeV$;
  - Universality: $\Delta\tilde{m}_{21}^2 \ll \tilde{m}^2$;
  - Alignment: $|K_{12}^d| \ll 1$;
  - (Approximate CP: $\sin\phi \ll 1$)
- B physics: $S_{\psi K_S}^{\rm exp} \simeq S_{\psi K_S}^{\rm SM}$
  - consistent with exact universality,
  - constrains U(2) and U(1) models, disfavors heavy squarks.
- D physics: $x, y \lesssim 0.05$
  - probes alignment.
- EDMs: $\frac{d_N^{\rm SUSY}}{6.3\times10^{-26}\ e\ {\rm cm}} \sim 300 \left(\frac{100\ GeV}{\tilde{m}}\right)^2 \sin\phi_{A,B}$
  - can distinguish MFV ($\lesssim 10^{-31}$) from SUSY CPV ($\gtrsim 10^{-28}$).

SUSY contributions to $B \to \phi K_S$



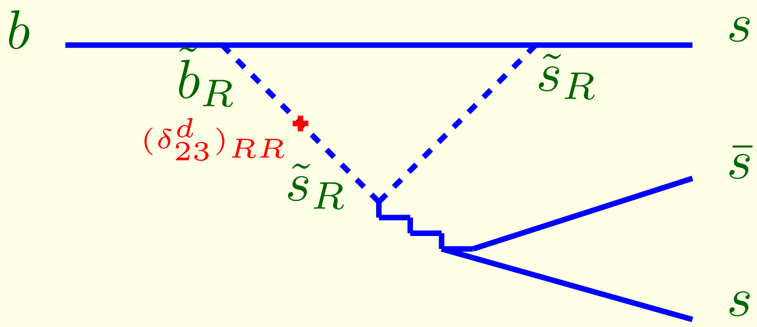
- Could there be large effects in $B \to \phi K_S$ and not in $B \to \psi K_S$?

SUSY contributions to $B \to \phi K_S$



- Could there be large effects in $B \to \phi K_S$ and not in $B \to \psi K_S$?
  - Yes: $\delta^d_{23} \leftrightarrow \delta^d_{13}$
- Could there be large effects in $B \to \phi K_S$ and not in $B \to X_s\gamma$?

SUSY contributions to $B \to \phi K_S$



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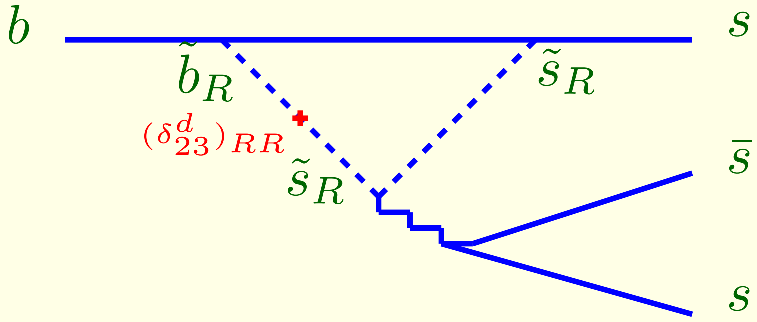
- Could there be large effects in $B \to \phi K_S$ and not in $B \to X_s\gamma$?
  - Yes: $\delta^d_{RR} \leftrightarrow \delta^d_{LR}$
- Are there well-motivated models with $(\delta^d_{23})_{RR} = \mathcal{O}(1)$?

SUSY contributions to $B \to \phi K_S$



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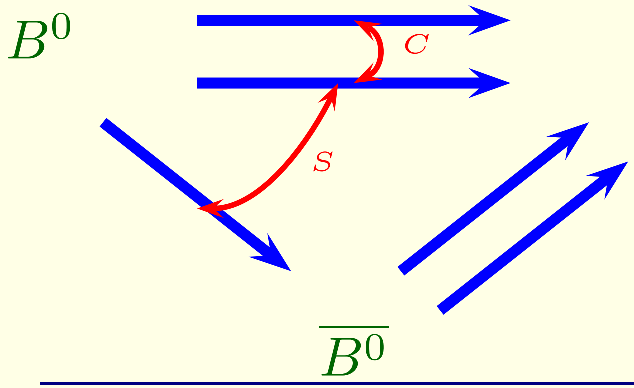
  - Yes: $\delta^d_{RR} \leftrightarrow \delta^d_{LR}$
- Are there well-motivated models with $(\delta^d_{23})_{RR} = \mathcal{O}(1)$?
  - U(1) flavor symmetry: $(\delta^d_{23})_{RR} \sim (m_s/m_b)/|V_{cb}|$
  - SO(10) GUTs: $(\delta^d_{23})_{RR} \sim \theta^\ell_{23}$



$\phi K_S, \eta' K_S, KKK, \pi K, DD, \psi\pi, \pi\pi$

$f_{\rm CP}$	$b \to q\bar{q}q'$	SM	$-\eta_{\rm CP} S = \pm \frac{2\mathcal{I}m\lambda}{1+\lvert\lambda\rvert^2}$	$C = \frac{1-\lvert\lambda\rvert^2}{1+\lvert\lambda\rvert^2}$
ψK_S	$b \to c\bar{c}s$	$\sin 2\beta$	$+0.74 \pm 0.05$	$+0.02 \pm 0.04$
ϕK_S	$b \to s\bar{s}s$	$\sin 2\beta$	-0.14 ± 0.69	-0.04 ± 0.26
$\eta' K_S$	$b \to s\bar{s}s$	$\sin 2\beta$	$+0.27 \pm 0.21$	$+0.04 \pm 0.13$
$K^+K^-K_S$	$b \to s\bar{s}s$	$\sin 2\beta$	$+0.51 \pm 0.26$	$+0.17 \pm 0.16$
$\pi^0 K_S$	$b \to u\bar{u}s$	$\sin 2\beta$	$+0.48 \pm 0.40$	$+0.40 \pm 0.30$
$D^{*+}D^{*-}$	$b \to c\bar{c}d$	$\sin 2\beta_{\rm eff}$	-0.05 ± 0.31	$+0.25 \pm 0.19$
$\psi\pi$	$b \to c\bar{c}d$	$\sin 2\beta_{\rm eff}$	$+0.43 \pm 0.38$	$+0.13 \pm 0.24$
$\pi\pi$	$b \to u\bar{u}d$	$\sin 2\alpha_{\rm eff}$	$+0.58 \pm 0.50$	-0.38 ± 0.16

Lessons from $\mathcal{A}_{\rm CP}(B \to f_{\rm CP})$

- CPV has not yet been observed in B decays other than $B \to \psi K$.

  (A 2.4σ effect in $C_{\pi\pi}$.)

- Direct CPV has not yet been observed in B decays.

  (2.5σ effect in $S_{DD} \leftrightarrow S_{\psi K}$.)

- No evidence of new physics.

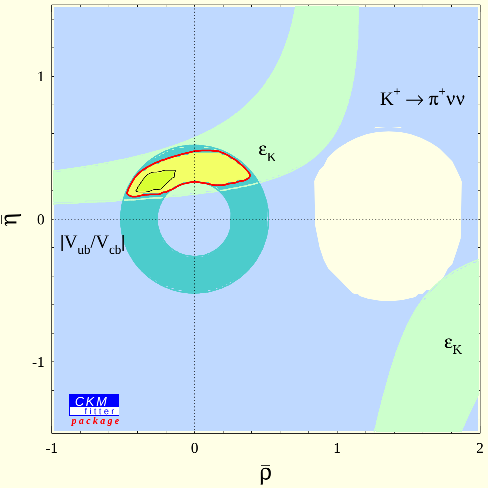
  (A 2.2σ effect in $S_{\eta' K} \leftrightarrow S_{\psi K}$.) Grossman, Isidori, Worah (98)

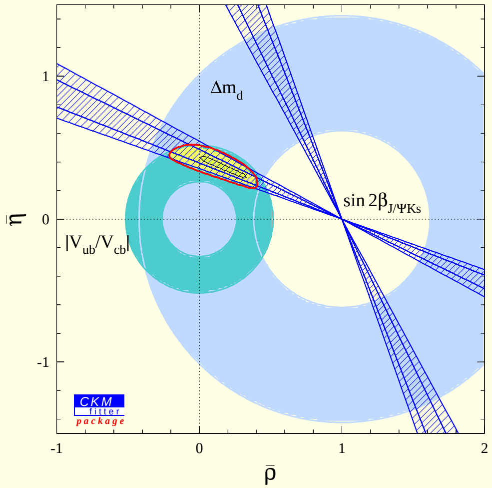
- The measurements of BR and CP asymmetries in $B \to \pi\pi$ decays are at a stage where restrictions on the CKM parameters and on hadronic parameters begin to emerge. Model independent constraints are still mild.

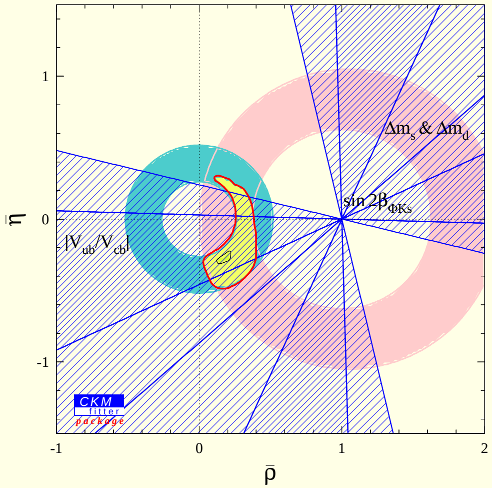
  $$\sin 2\alpha_{\rm eff} \equiv \frac{\mathcal{I}m\lambda_{\pi\pi}}{|\lambda_{\pi\pi}|}:\ \sin^2(\alpha_{\rm eff}-\alpha) \leq \mathcal{B}^{00}/\mathcal{B}^{+0} \leq 0.61$$

  Grossman and Quinn (98); Charles (99); Gronau, London, Sinha, Sinha (01)

Unitarity Triangles



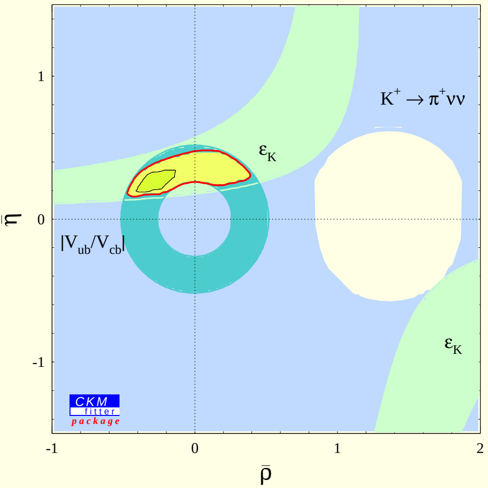




$s \to d$ | $b \to d$ | $b \to s$

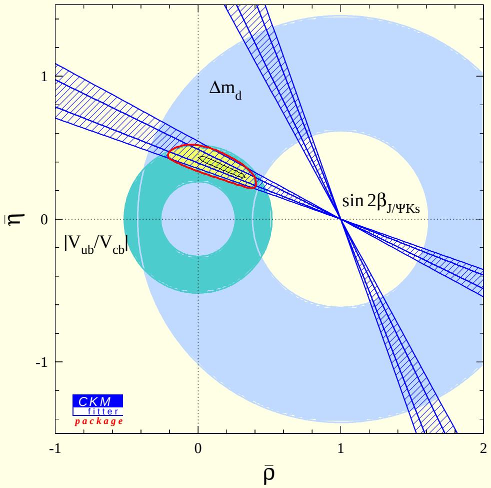
$\varepsilon,\ \ \mathcal{B}(K^+ \to \pi^+ \nu \bar\nu)$ | $\Delta m_{B_d},\ \ S_{\psi K_S}$ | $\Delta m_{B_s},\ \ S_{\phi K_S}$

Unitarity Triangles



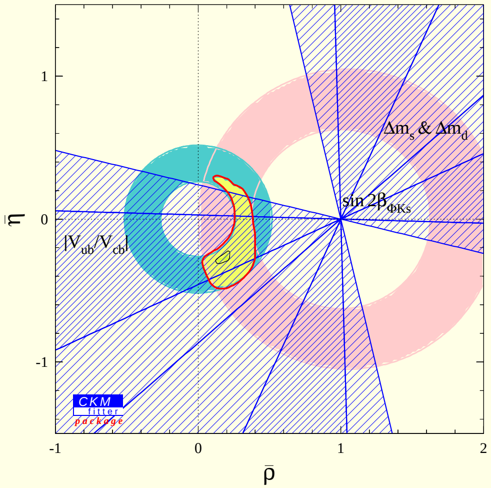
$s \to d$

$\varepsilon, \quad \mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$



$b \to d$

$\Delta m_{B_d}, \quad S_{\psi K_S}$



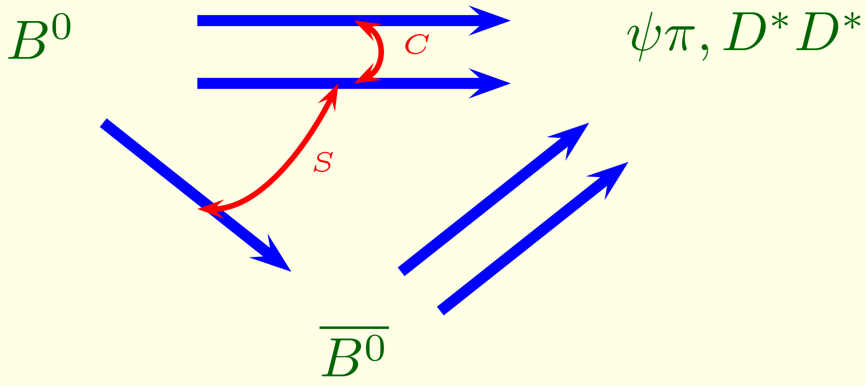
$b \to s$

$\Delta m_{B_s}, \quad S_{\phi K_S}$

There is still a lot to be learnt from future measurements

New Physics

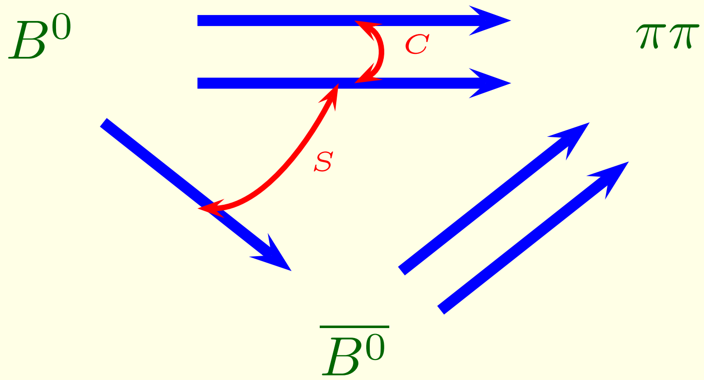
- We are leaving the era of hoping for NP alternatives to CKM. (Superweak models and approximate CP - excluded.)
- We are entering the era of seeking for NP corrections to CKM.
- It is still possible that the corrections are large in Δm_{B_s}, in CP asymmetries in B_s decays, and in $\mathcal{I}m\lambda_{(\bar{s}s)K_S}$.



- Penguins are not CKM suppressed and carry a different phase:
  $\Longrightarrow$ $\boxed{C \neq 0}$ is possible
- $A_{\rm tree} \propto V_{cb}^* V_{cd}$ and $A_{\rm peng} \propto V_{tb}^* V_{td}$
  $\Longrightarrow$ $\boxed{S = S_{\psi K_S} + \mathcal{O}(A_{\rm peng}/A_{\rm tree})}$.

mode	CP	$-\eta_{\rm CP} S$	C
$\psi\pi$	$+$	$+0.43 \pm 0.38$	$+0.13 \pm 0.24$
$D^{*+}D^{*-}$	$+^*$	-0.05 ± 0.31	$+0.25 \pm 0.19$

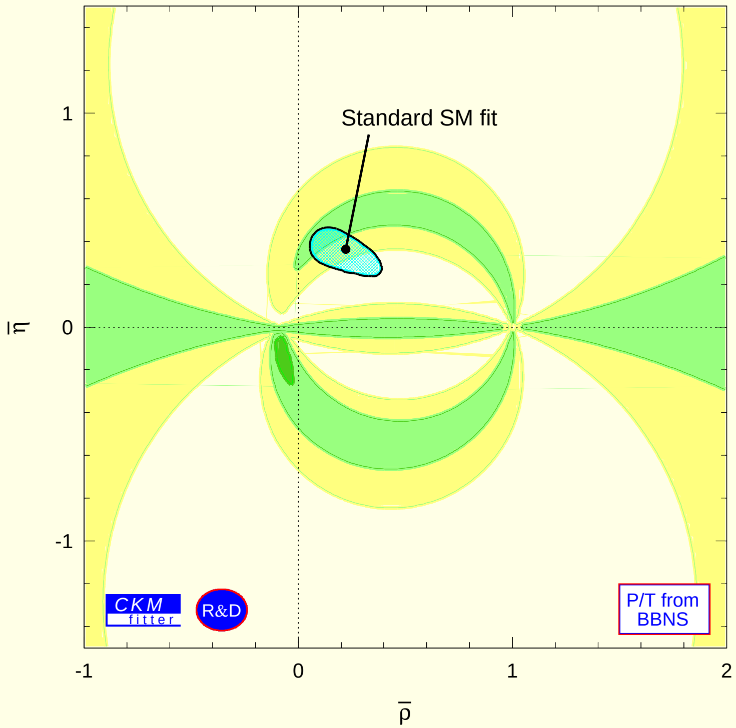
*Angular analysis is used to separate CP = + from CP = −.



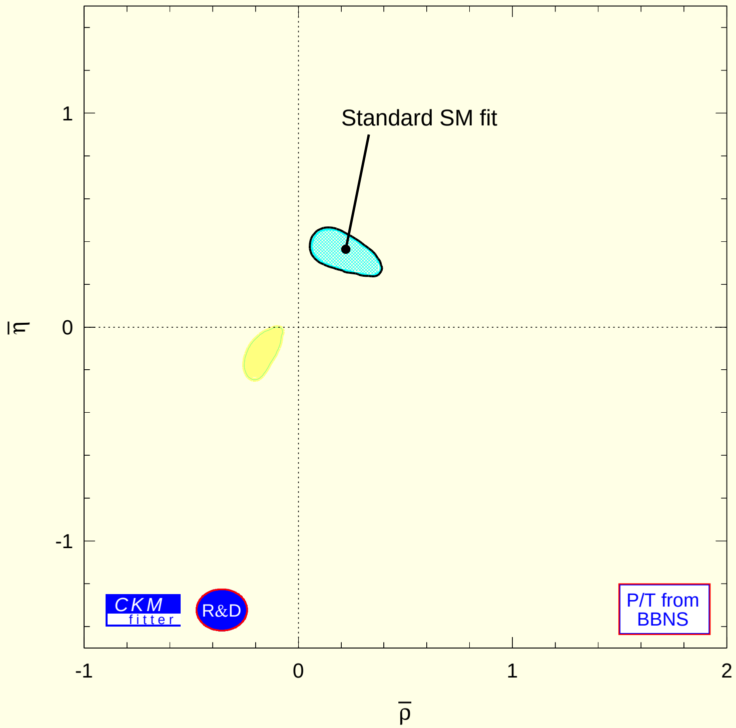
- Penguins are not CKM suppressed and carry a different phase $\Longrightarrow$ $C_{\pi\pi} \neq 0$ is possible (a test of BBNS $\leftrightarrow$ KLS).
- $A_{\text{tree}} \propto V_{ub}^* V_{ud} \Longrightarrow \boxed{S_{\pi\pi} = \sin 2\alpha + \mathcal{O}(A_{\text{peng}}/A_{\text{tree}})}$.
- $S_{\pi\pi} \neq S_{\psi K}$ is expected (Direct CPV).

Expt.	S	C
BABAR	$-0.40 \pm 0.22 \pm 0.03$	$-0.19 \pm 0.19 \pm 0.05$
BELLE	$-1.23 \pm 0.41^{+0.08}_{-0.07}$	$-0.77 \pm 0.27 \pm 0.08$
WA	$-0.58 \pm 0.20(0.50)$	-0.38 ± 0.16

α from $C_{\pi\pi}$ and $S_{\pi\pi}$



BABAR data

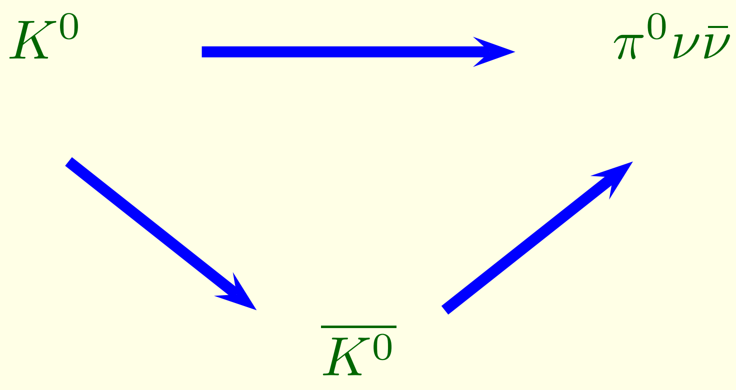


BELLE data

Experimental input: $C_{\pi\pi}$, $S_{\pi\pi}$

Theoretical input: $|P/T|$ from BBNS

Littenberg (89)



- CP violation in mixing and in decay are negligible.
- Hadronic uncertainties are negligible.
- A huge experimental challenge.

- The charged (CPC) mode has been measured by E787:

$$\boxed{\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu}) = (1.57^{+1.75}_{-0.82}) \times 10^{-10}}$$

Lessons from $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$

- Consistent with the SM:

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})_{\rm SM} = (0.72 \pm 0.21) \times 10^{-10}$$

Buchalla and Buras (99)

- There is still (much!) room for new physics.

D'Ambrosio and Isidori (01)

- Provides a model-independent upper bound on the K_L-decay:

$$\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) < 1.7 \times 10^{-9}$$

Grossman and Nir (97)

A more precise measurement would be extremely interesting both as a CKM constraint and as a probe of new physics