Flavour Physics (II)

Sixth CERN-Fermilab Hadron Collider Physics Summer School

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Plan of the lecture today

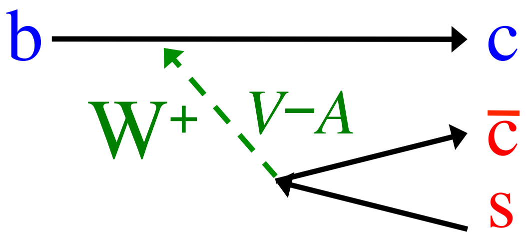
- More on Weak Decays
- Current Status of V_{CKM}

More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

quark decay

$b \rightarrow c + W^-(\rightarrow \bar{c}s)$



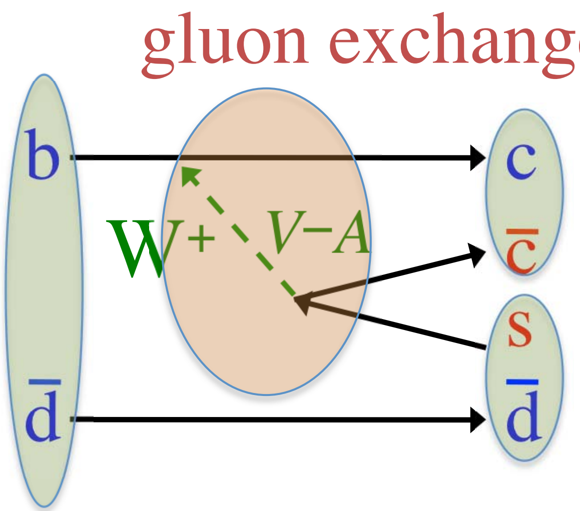
More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

quark decay to hadron decay

$B \to J/\psi K_S$

starts from a b-$\bar{d}$ bound state



quarks have to form hadrons

More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

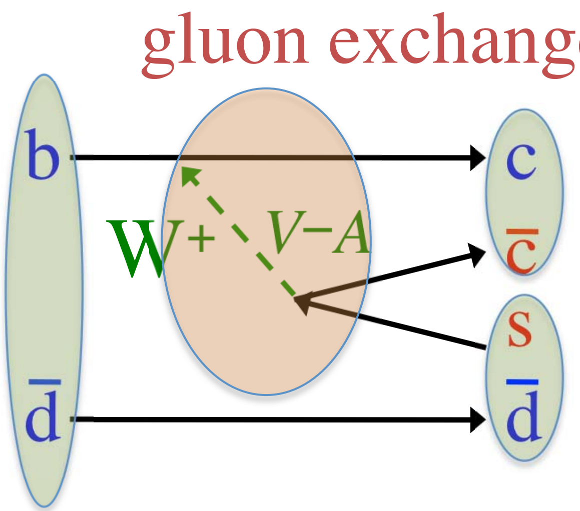
Theoretical tool to describe the decay amplitude for M→F

$$A(M \to F) = \left\langle F \middle| H^{\text{weak decay}}_{\text{effective}} \middle| M \right\rangle = \frac{G_F}{\sqrt{2}} \sum_i \xi^i_{\text{CKM}} C_i(\mu) \langle F | Q_i(\mu) | M \rangle$$

Q_i: quark operators

B→J/ψK_S

starts from a b-$\bar{d}$ bound state



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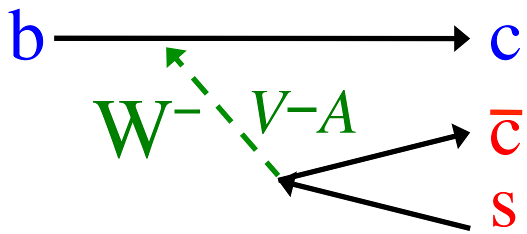
More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

lowest order weak interactions ($\Delta F = 1$)



No QCD

More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

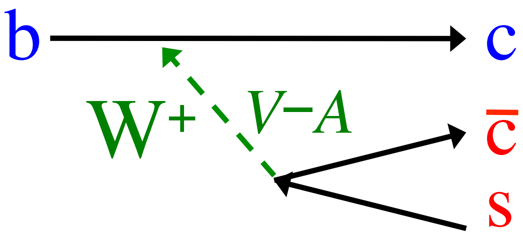
lowest order weak interactions ($\Delta F = 1$)

$$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$$

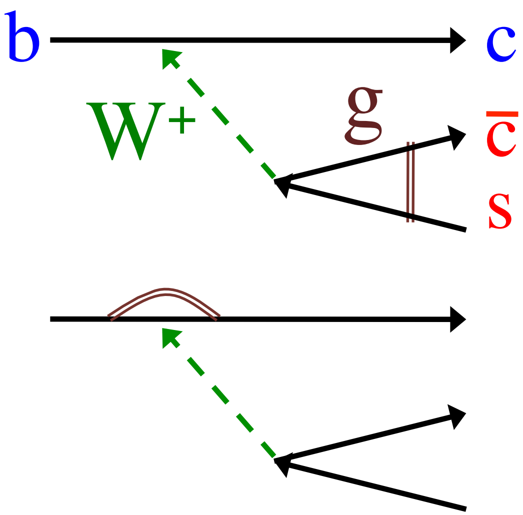
More on Weak Decays

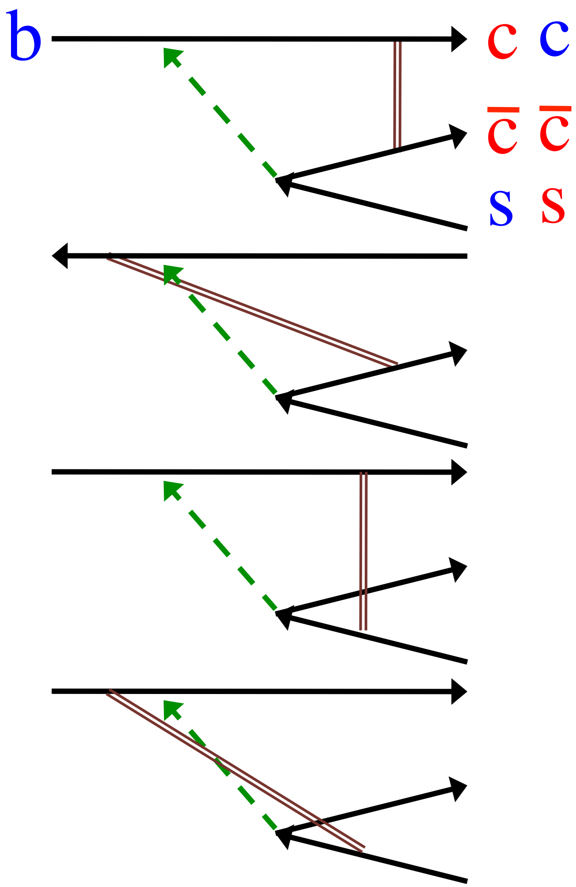
decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

lowest order weak interactions ($\Delta F = 1$)



Switching on QCD





More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

lowest order weak interactions ($\Delta F = 1$)

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

No-QCD tree diagram

+ one gluon
tree diagrams with two different colour structures

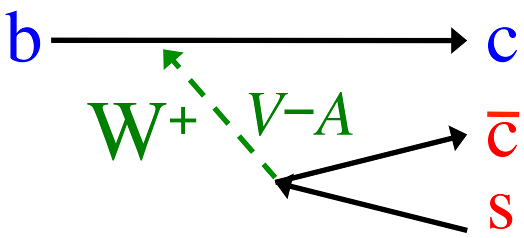
$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

$(\bar{c}_j b_i)_{V-A} (\bar{s}_i c_j)_{V-A}$

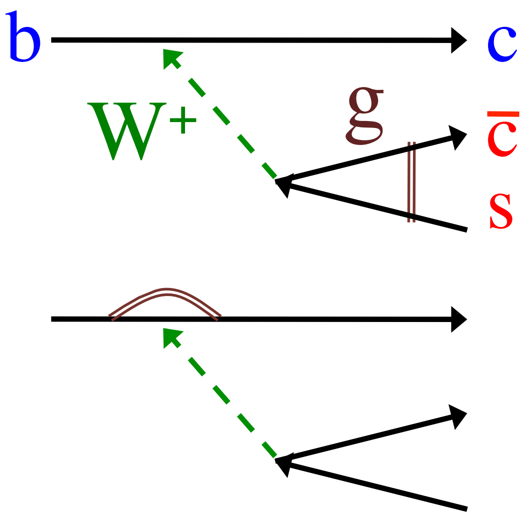
More on Weak Decays

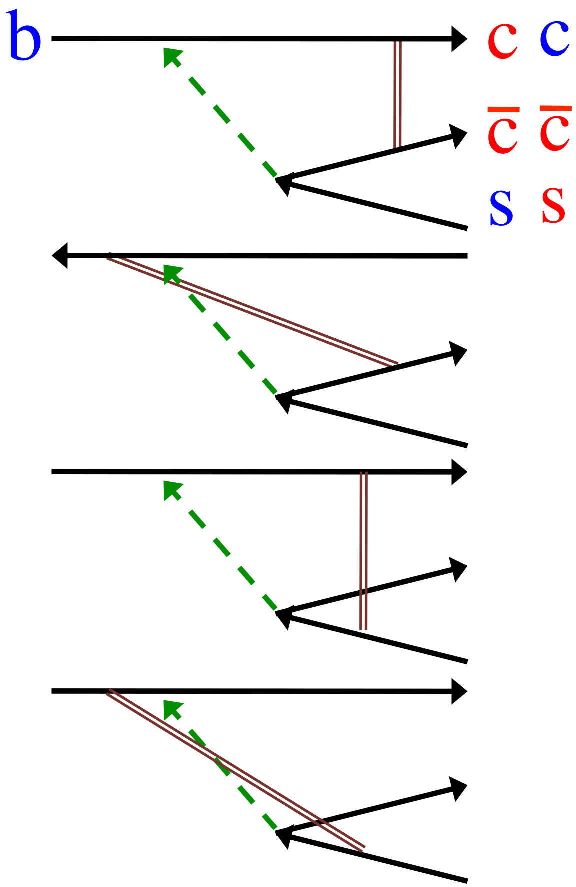
decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

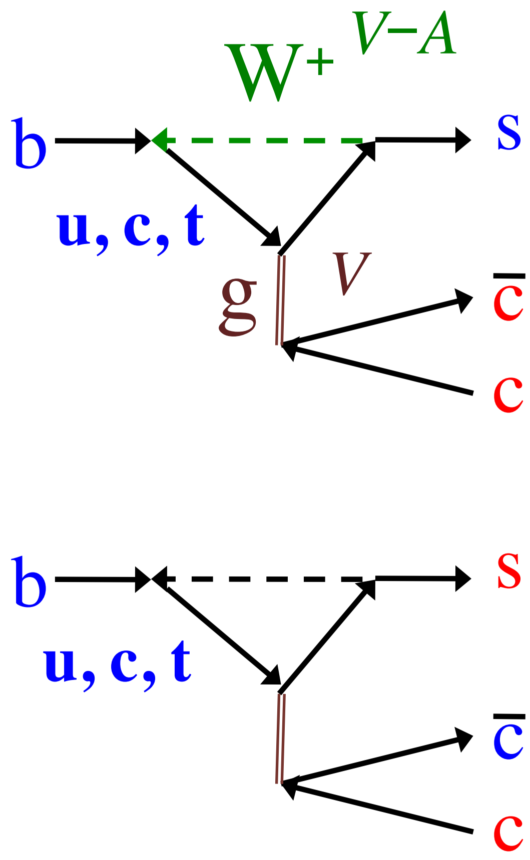
lowest order weak interactions ($\Delta F = 1$)



Switching on QCD







gluon penguins

More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

lowest order weak interactions ($\Delta F = 1$)

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

No QCD tree diagram

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

$(\bar{c}_j b_i)_{V-A} (\bar{s}_i c_j)_{V-A}$

\+ one gluon
tree diagrams with two
different colour structures

$(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_V$

\+ gluon penguins with two
different colour structure
gluon = V

$(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_V$

More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

lowest order weak interactions ($\Delta F = 1$)

$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$ $(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$

No QCD tree diagram

$(\bar{c}_j b_i)_{V-A} (\bar{s}_i c_j)_{V-A}$

+ one gluon
tree diagrams with two
different colour structures $(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V-A}$

+ gluon penguins with two $(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V+A}$
different colour structure
gluon = V
→ split to $(V-A) + (V+A)$ $(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_{V-A}$
(needed for the Q^2 evolution) $(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_{V+A}$

More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

lowest order weak interactions ($\Delta F = 1$)

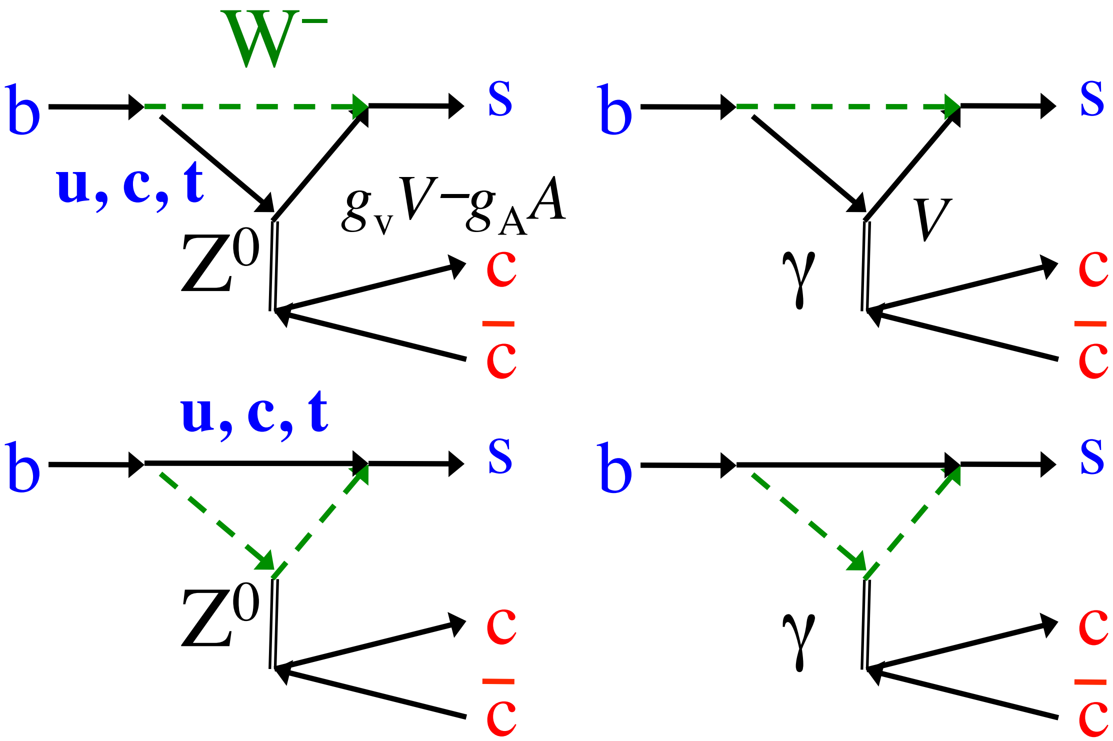
		operators
$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$	$(\bar{c}_i b_i)_{V-A} (\bar{s}_j c_j)_{V-A}$	Q_2
No QCD tree diagram	$(\bar{c}_j b_i)_{V-A} (\bar{s}_i c_j)_{V-A}$	Q_1
+ one gluon tree diagrams with two different colour structures	$(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V-A}$	Q_3
+ gluon penguins with two different colour structure	$(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V+A}$	Q_5
gluon = V → split to $(V-A) + (V+A)$	$(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_{V-A}$	Q_4
(needed for the Q^2 evolution)	$(\bar{s}_j b_i)_{V-A} (\bar{c}_i c_j)_{V+A}$	Q_6

More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

the second order electroweak interactions ($\Delta F = 1$)

electroweak penguins



$q_j(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V-A}$ Q_7

$q_j'(\bar{s}_i b_i)_{V-A} (\bar{c}_j c_j)_{V+A}$ Q_9

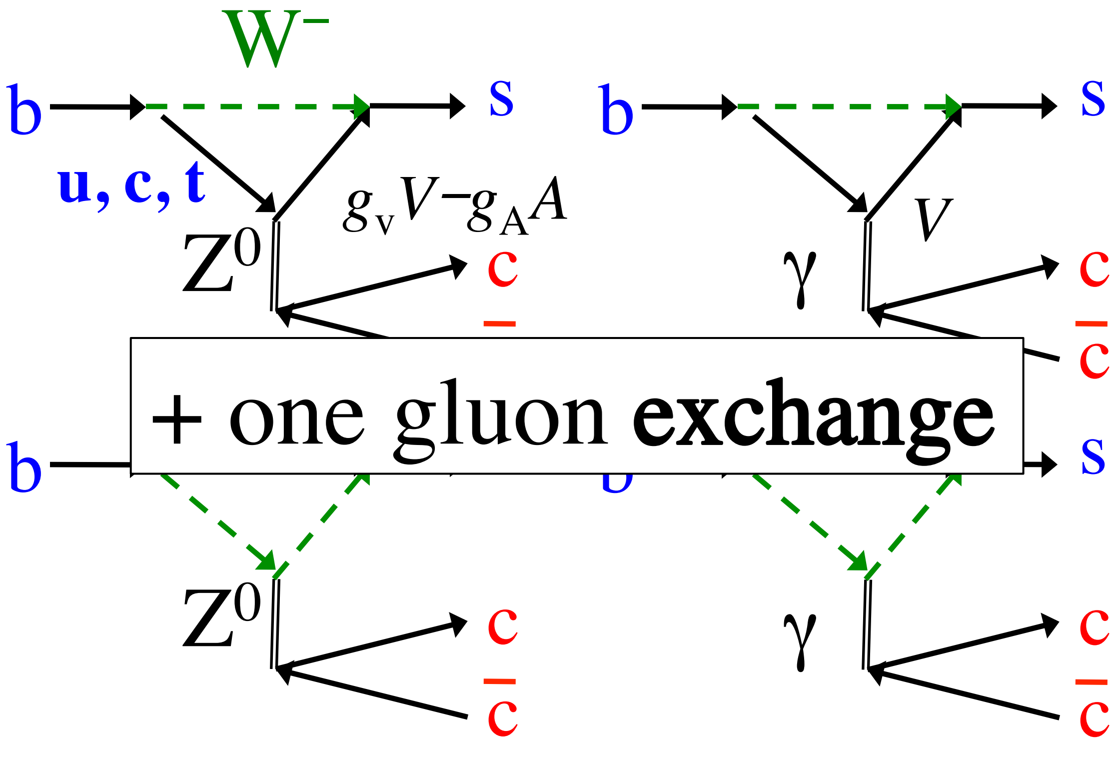
q_j and q_j' are appropriate electroweak coupling constants

More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

the second order electroweak interactions ($\Delta F = 1$)

electroweak penguins + QCD



$q_j(\bar{s}_i b_i)_{V-A}\,(\bar{c}_j c_j)_{V-A}$ $\quad Q_7$

$q_j'(\bar{s}_i b_i)_{V-A}\,(\bar{c}_j c_j)_{V+A}$ $\quad Q_9$

$q_j(\bar{s}_i b_i)_{V-A}\,(\bar{c}_j c_j)_{V-A}$ $\quad Q_8$

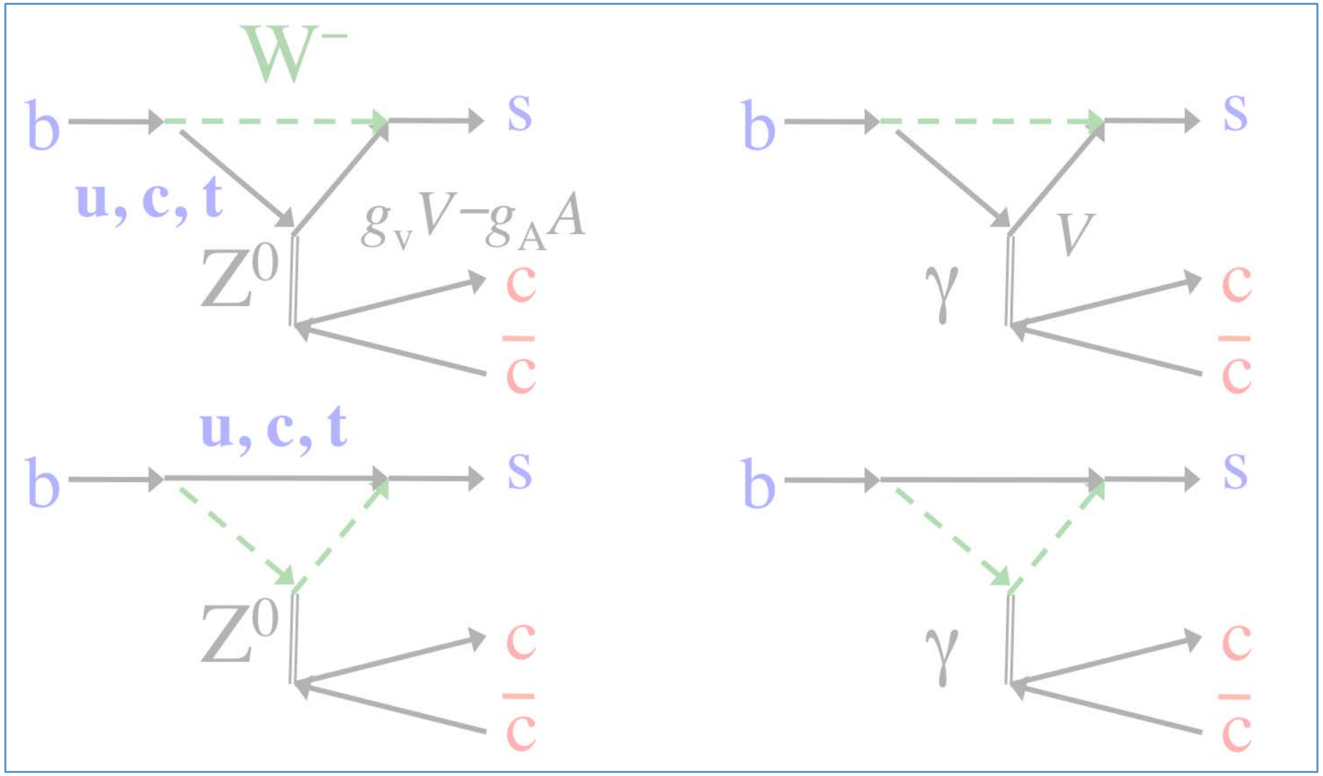
$q_j'(\bar{s}_i b_i)_{V-A}\,(\bar{c}_j c_j)_{V+A}$ $\quad Q_{10}$

q_j and q_j' are appropriate electroweak coupling constants

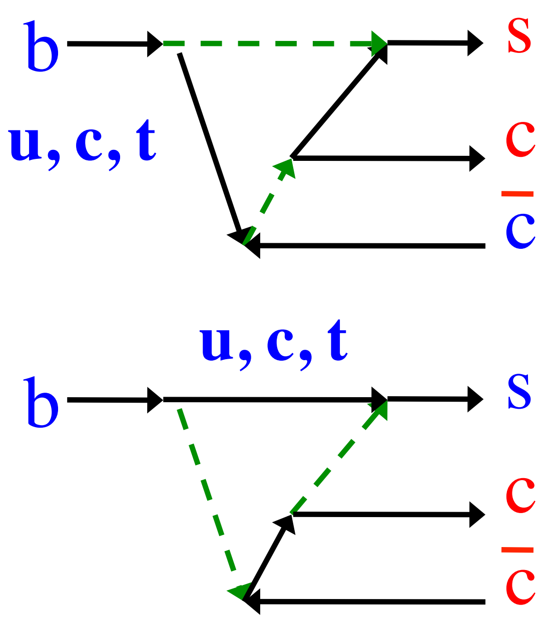
More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

also the second order electroweak interactions, $\Delta F = 2$



Box diagrams



More on Weak Decays

decay ($\Delta F = 1$) and oscillation amplitudes ($\Delta F = 2$)

Theoretical tool to describe the decay amplitude for M→F

$$A(M \to F) = \left\langle F \middle| H^{\text{weak decay}}_{\text{effective}} \middle| M \right\rangle = \frac{G_F}{\sqrt{2}} \sum_i \xi^i_{\text{CKM}} C_i(\mu) \langle F | Q_i(\mu) | M \rangle$$

G_F: Fermi constant,

$Q_i(\mu)$: Local four-fermion operators evaluated at energy scale μ
calculable in perturbation

$C_i(\mu)$: Coupling constants for $Q_i(\mu)$ at energy scale μ
i.e. Wilson coefficient, calculable in perturbation

$\langle F|Q_i(\mu)|M\rangle$: Hadronic matrix element
long distance effect

ξ_i^{CKM}: Combination of the CKM elements
the ultimate interest for Flavour Physics
extraction of the CKM matrix, search for new physics

More on Weak Decays

decay (ΔF = 1) and oscillation amplitudes (ΔF = 2)

Theoretical tool to describe the decay amplitude for M→F

$$A(M \to F) = \left\langle F \middle| H^{\text{weak decay}}_{\text{effective}} \middle| M \right\rangle = \frac{G_F}{\sqrt{2}} \sum_i \xi^i_{\text{CKM}} C_i(\mu) \langle F | Q_i(\mu) | M \rangle$$

- Comparing the full and effective theory at $\mu = m_W$
  → $C_i(\mu = m_W)$

- Scale C_i down to $\mu \approx$ 1 GeV (K), m_c (D), m_b (B)

$$C_i(\mu) = U_{ij}(\mu,\ \mu = m_W) C_j(\mu = m_W)$$

U_{ij} not diagonal ⇒ mixing of the operators in the evolution

- Evaluate $<F|Q_i(\mu)|M>$ (hadronic matrix element)
  with non perturbative methods at μ
  lattice, HQET, QCD sum rule, etc.
  major source of uncertainties

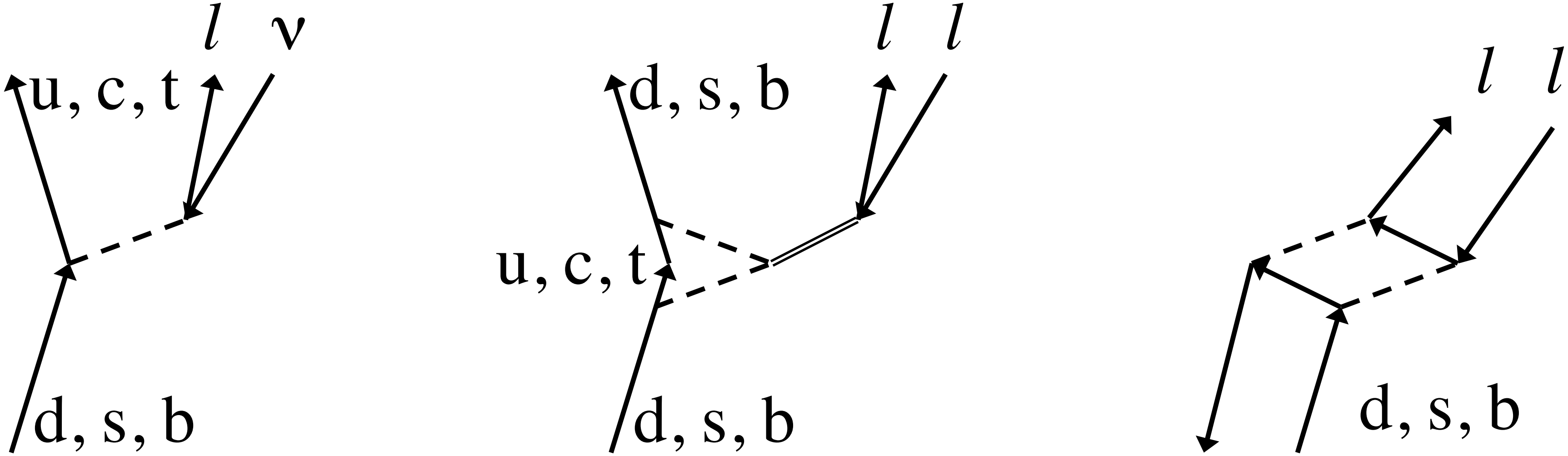
Current Status of V_{CKM}

Can be extract from decay widths generated by the tree, penguin, and box processes

examples of semileptonic and leptonic decays

$$V_{\mathrm{UD}}\begin{cases} \mathrm{U} = \mathrm{u},\ \mathrm{c},\ \mathrm{t} \\ \mathrm{D} = \mathrm{d},\ \mathrm{s},\ \mathrm{b} \end{cases}$$

$\Gamma \propto |V_{\mathrm{UD}}|$ $\qquad\qquad \propto |\sum_{\mathrm{U}} V_{\mathrm{UD}} V_{\mathrm{UD'}}^{*} f(m_{\mathrm{U}})|$



Current Status of V_{CKM}

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

First 2×2 sub-matrix: four $|V_{ij}|$ are measured by nucleus, pion, kaon and charm hadron decays

It is "almost" unitary with one single parameter

$\lambda\ (\equiv \sin\theta_{\mathrm{Cabibbo}}) = |V_{\mathrm{us}}| = 0.2246 \pm 0.0012$ (PDG 2010)

$$V_{\mathrm{CKM}} \approx \begin{pmatrix} 1 & \lambda & V_{\mathrm{ub}} \\ -\lambda & 1 & V_{\mathrm{cb}} \\ V_{\mathrm{td}} & V_{\mathrm{ts}} & V_{\mathrm{tb}} \end{pmatrix}$$

Current Status of V_{CKM}

$$V_{CKM} \approx \begin{pmatrix} 1 & \lambda & V_{ub} \\ -\lambda & 1 & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$|V_{cb}|$ and $|V_{ub}|$ measured by semileptonic B_u and B_d decays

$$|V_{cb}| = \begin{cases} (41.5 \pm 0.7) \times 10^{-3} \text{ inclusive decays} \\ (38.7 \pm 1.1) \times 10^{-3} \text{ exclusive decays} \end{cases}$$

-errors limited theoretically-

2.1σ discrepancy (PDG 2010)

$$|V_{ub}| = \begin{cases} (4.27 \pm 0.38) \times 10^{-3} \text{ inclusive decays} \\ (3.38 \pm 0.36) \times 10^{-3} \text{ exclusive decays} \end{cases}$$

-errors very limited theoretically-

1.7σ discrepancy (PDG 2010)

exclusives systematically smaller than exclusives…?

Current Status of V_{CKM}

$$V_{CKM} \approx \begin{pmatrix} 1 & \lambda & V_{ub} \\ -\lambda & 1 & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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Current Status of $V_{\rm CKM}$

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$|V_{cb}|$ and $|V_{ub}|$ measured by semileptonic B_u and B_d decays

arg $V_{cb} = 0$ by a phase convention

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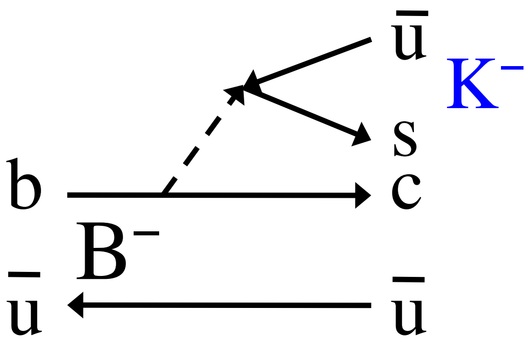
arg V_{ub} by CP violation in B→DK

Current Status of V_{CKM}

arg V_{ub} so called angle "γ"

two decay diagrams producing identical final states



$V_{cb}V_{us}{}^{*}$

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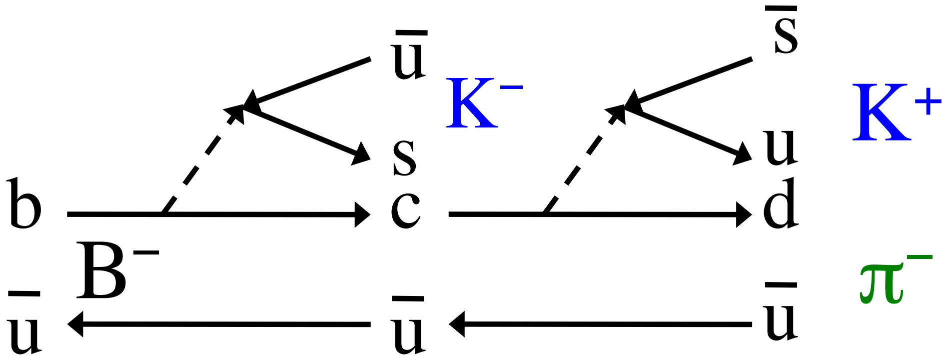

$V_{cb}V_{us}{}^{*}V_{cd}{}^{*}V_{us}$

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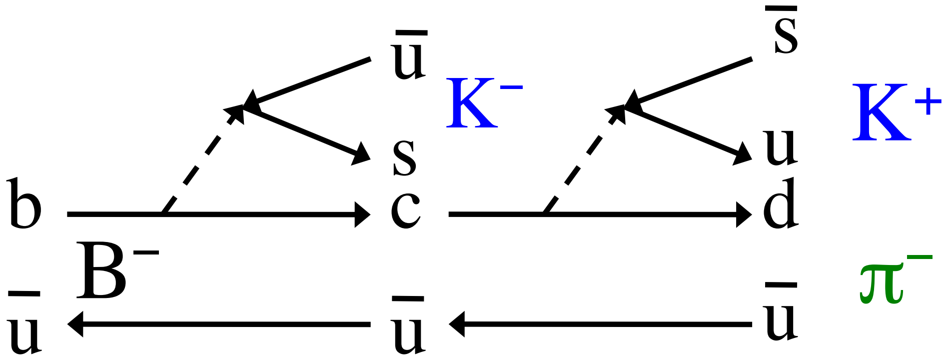

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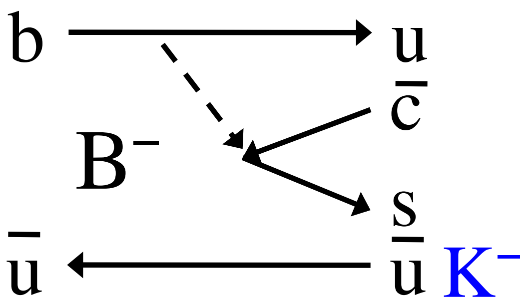

$V_{ub}V_{cs}{}^{*}$

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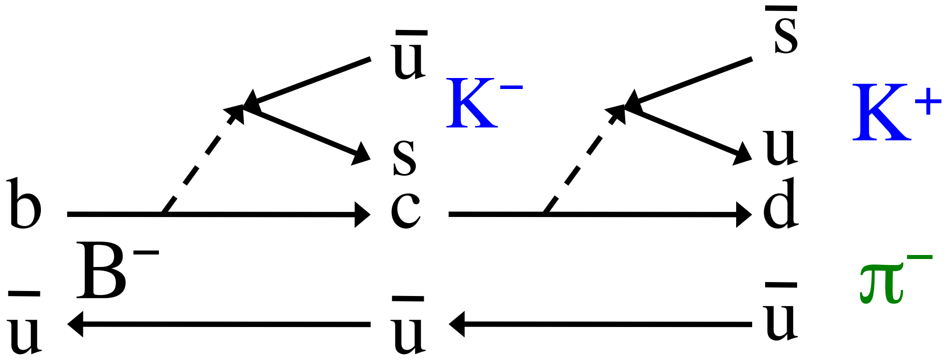
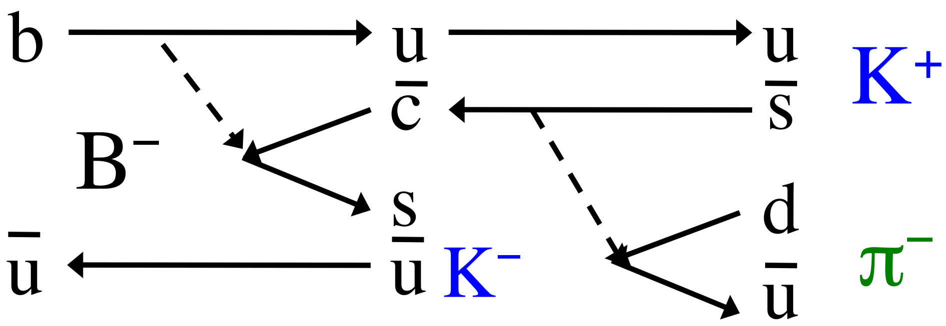


$V_{cb}V_{us}{}^{*}V_{cd}{}^{*}V_{us}$



$V_{ub}V_{cs}{}^{*}V_{ud}{}^{*}V_{cs}$

Current Status of V_{CKM}

arg V_{ub} so called angle "γ"

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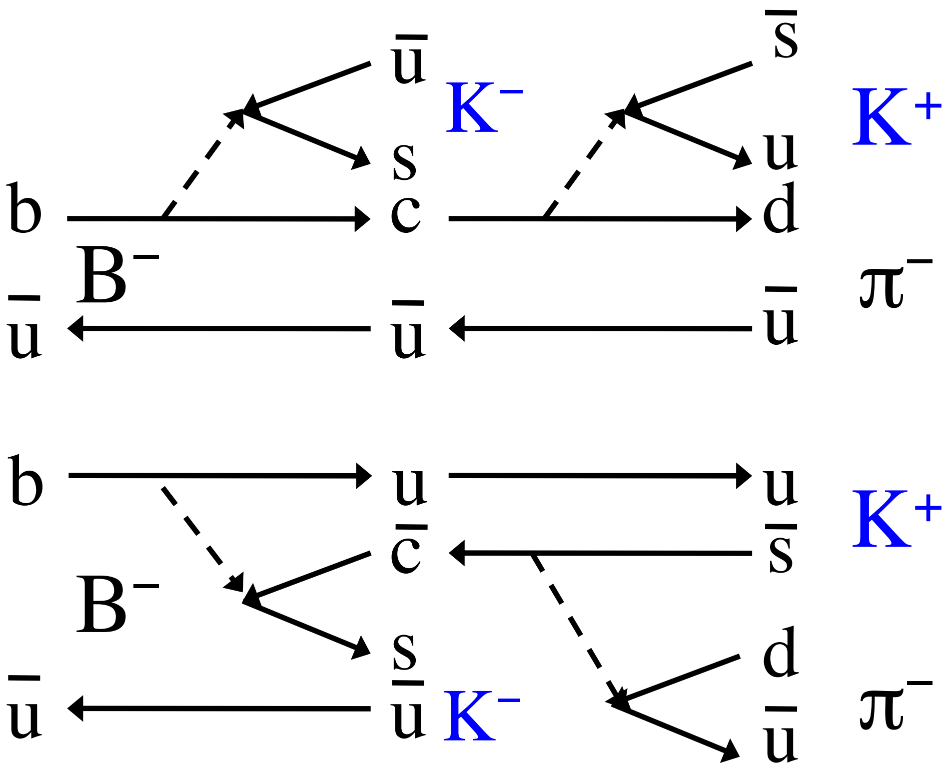


$V_{cb}V_{us}{}^*V_{cd}{}^*V_{us}$

$V_{ub}V_{cs}{}^*V_{ud}{}^*V_{cs}$

interfere

→ CPV

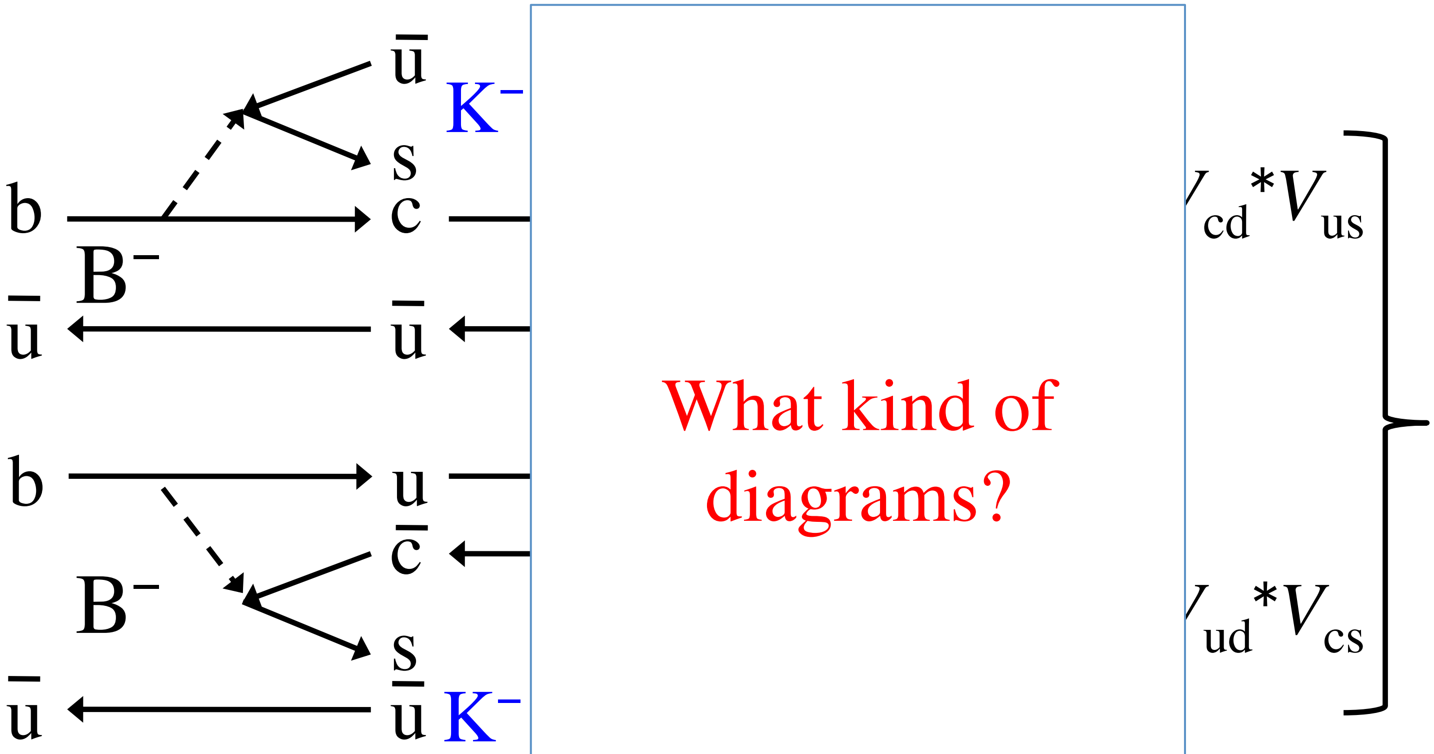
$F(\arg V_{ub})$

$$Br\,(B^-\rightarrow[K^+\pi^-]_{D\text{-mass}}\,K^-) \neq Br\,(B^+\rightarrow[K^-\pi^+]_{D\text{-mass}}\,K^+)$$

Current Status of V_{CKM}

arg V_{ub} so called angle "γ"

two decay diagrams producing identical final states



interfere

→ CPV

$F(\arg V_{ub})$

Br ($B^-\rightarrow[K^+\pi^-$ … $[K^-\pi^+]_{D\text{-mass}}\ K^+$)

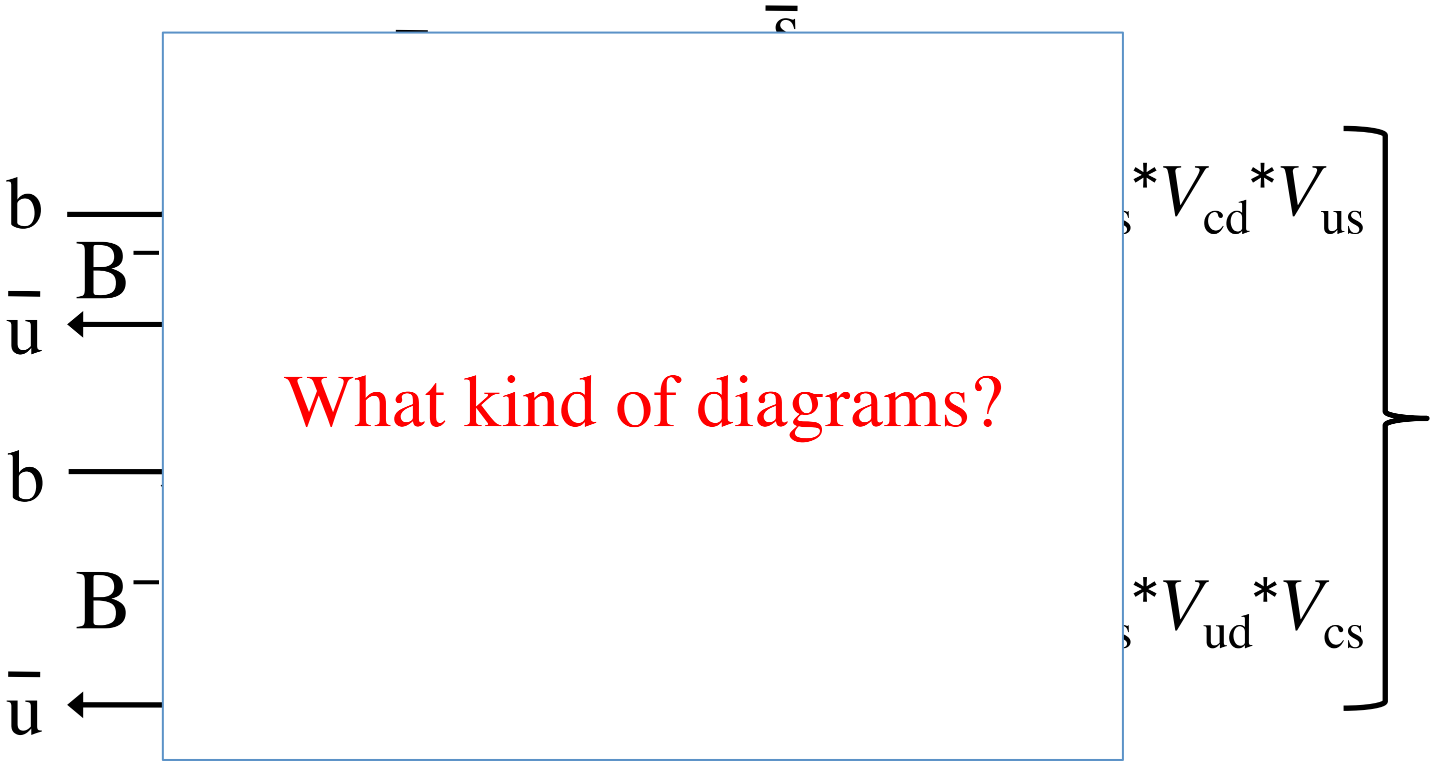
and also

Br ($B^-\rightarrow[K^-\pi^+]_{D\text{-mass}}\ K^-$) ≠ Br ($B^+\rightarrow[K^+\pi^-]_{D\text{-mass}}\ K^+$)

Current Status of V_{CKM}

arg V_{ub} so called angle "γ"

two decay diagrams producing identical final states



interfere

→ CPV

$F(\arg V_{ub})$

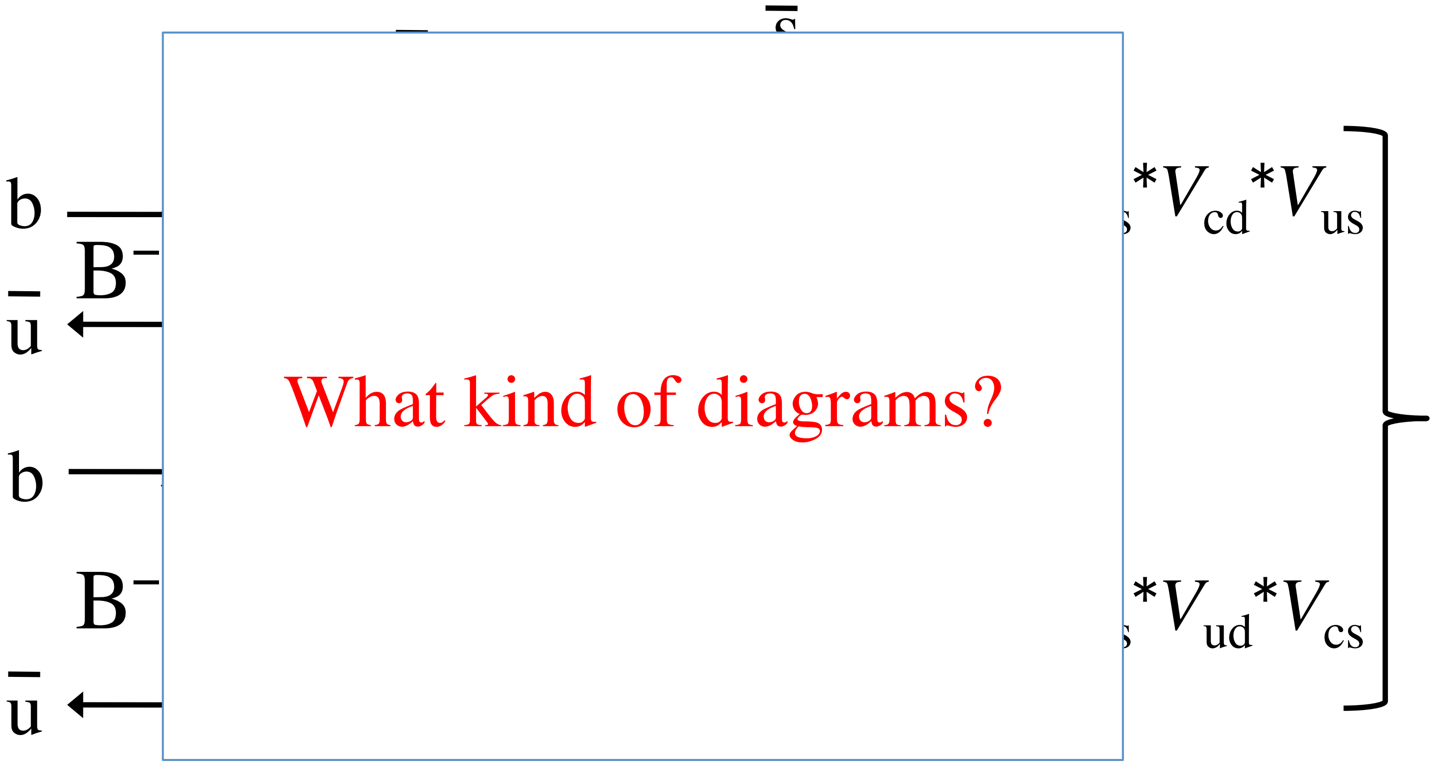
$\mathrm{Br}\ (B^- \to [K^+K^-]_{D\text{-mass}}\ K^-) \neq \mathrm{Br}\ (B^+ \to [K^+K^-]_{D\text{-mass}}\ K^+)$

$\mathrm{Br}\ (B^- \to [\pi^+\pi^-]_{D\text{-mass}}\ K^-) \neq \mathrm{Br}\ (B^+ \to [\pi^+\pi^-]_{D\text{-mass}}\ K^+)$

Current Status of V_{CKM}

arg V_{ub} so called angle “γ”

two decay diagrams producing identical final states



interfere

→ CPV

$F(\arg V_{ub})$

$\mathrm{Br}\,(B^- \rightarrow [K_S\pi^+\pi^-]_{D\text{-mass}}\, K^-) \neq \mathrm{Br}\,(B^+ \rightarrow [K_S\pi^+\pi^-]_{D\text{-mass}}\, K^+)$

Current Status of V_{CKM}

arg V_{ub} so called angle "γ"

two decay diagrams producing identical final states

Current average = $(73^{+22}_{-25})^\circ$ (PDG 2010)

Current Status of V_{CKM}

arg V_{ub} so called angle "γ"

two decay diagrams producing identical final states

Current average = $(73\,^{+22}_{-25})^\circ$ (PDG 2010)

-Determined by the "tree" level amplitude interference between V_{cb} and V_{ub} no "New Physics" effect

-So far measured only by the e^+e^- B factory experiments: BABAR and BELLE

-In future, hadron machine will over take this…

Current Status of V_{CKM}

$$V_{CKM} \approx \begin{pmatrix} 1 & \lambda & V_{ub} \\ -\lambda & 1 & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$|V_{cb}|$ and $|V_{ub}|$ measured by semileptonic B_u and B_d decays

arg $V_{cb} = 0$ by a phase convention

arg V_{ub} by CP violation in $B \rightarrow DK$

$V_{tb} \approx 1$ if we assume V_{CKM} to be unitary

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arg V_{ub} by CP violation in $B \rightarrow DK$

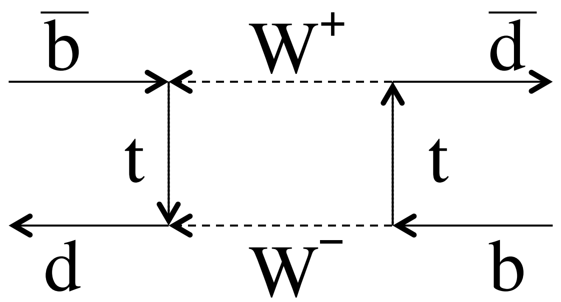
$V_{tb} \approx 1$ if we assume V_{CKM} to be unitary

$|V_{td}|\times|V_{tb}|$ by B^0-B^0 oscillation frequency (Δm_d)

$|V_{ts}|\times|V_{tb}|$ by $B_s{}^0$-$B_s{}^0$ oscillation frequency (Δm_s)

Current Status of V_{CKM}

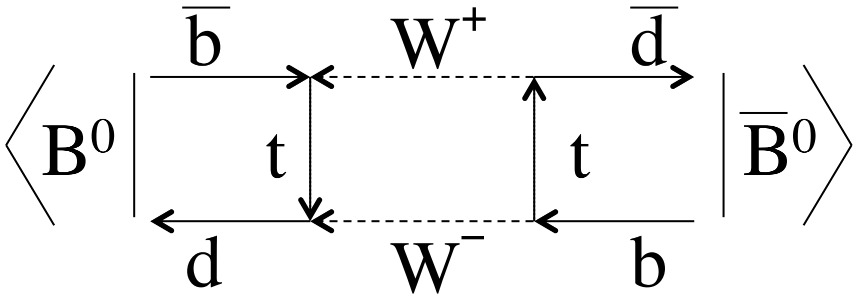
B-$\overline{\mathrm{B}}$ oscillation: dispersive part of the box diagram: M_{12}



$$\Delta m = 2|M_{12}| \propto |V_{td}|^2\,|V_{tb}|^2$$
$$= (0.507 \pm 0.005)\ \mathrm{ps}^{-1} \quad \text{(PDG 2010)}$$

Current Status of V_{CKM}

B-$\overline{\text{B}}$ oscillation: dispersive part of the box diagram: M_{12}

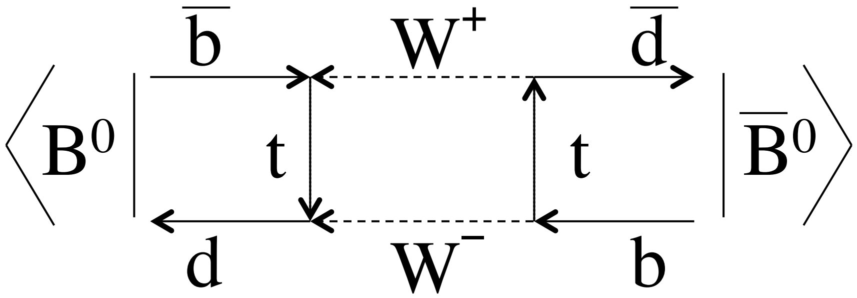


$$\Delta m = 2|M_{12}| \propto \text{B}_d f_d^{\,2} |V_{td}|^2\, |V_{tb}|^2$$
$$= (0.507 \pm 0.005)\ \text{ps}^{-1}$$ (PDG 2010)

B$f^{\,2}$: hadronic matrix elements

Current Status of V_{CKM}

B-$\overline{\mathrm{B}}$ oscillation: dispersive part of the box diagram: M_{12}



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$$\arg = M_{12} = \arg\,(V_{\mathrm{td}}{}^* V_{\mathrm{tb}})^2 + \pi$$

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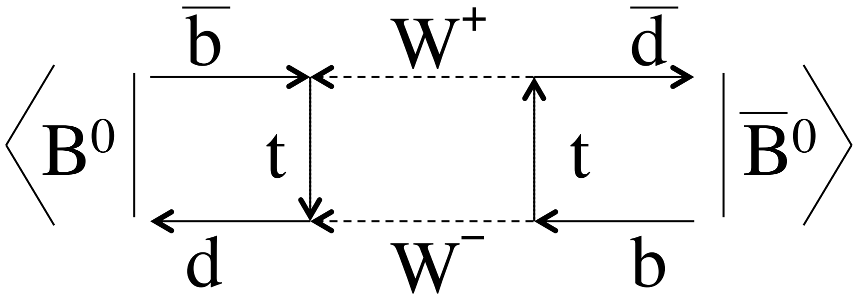
Current Status of V_{CKM}

B-$\overline{\text{B}}$ oscillation: dispersive part of the box diagram: M_{12}



$$\Delta m = 2|M_{12}| \propto B_d f_d^{\,2} |V_{td}|^2\ |V_{tb}|^2$$
$$= (0.507 \pm 0.005)\ \text{ps}^{-1} \quad \text{(PDG 2010)}$$
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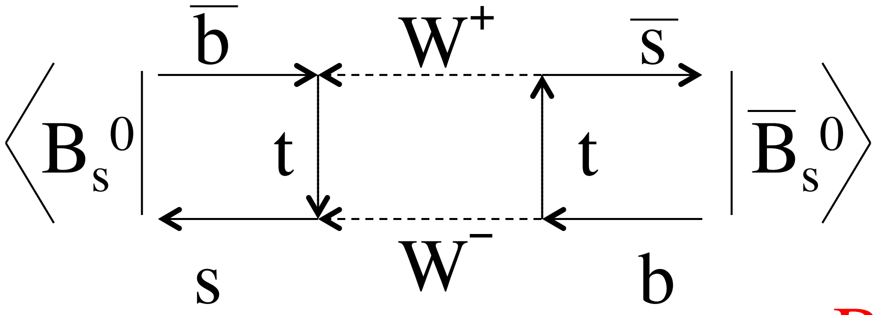
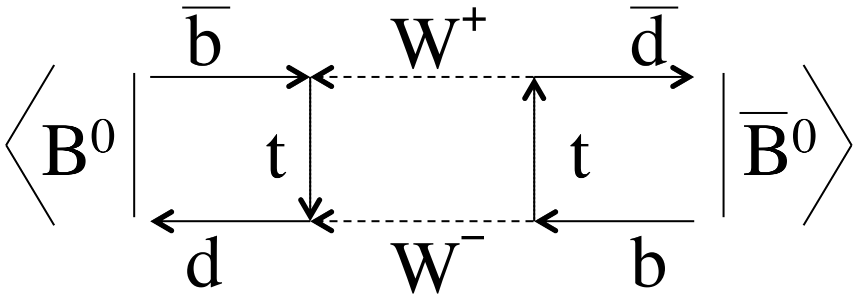


$$\Delta m_s = 2|M_{12}| \propto B_s f_s^{\,2} |V_{ts}|^2\ |V_{tb}|^2$$
$$= (17.77 \pm 0.12)\ \text{ps}^{-1} \quad \text{(PDG 2010)}$$
$$\arg M_{12} = \arg\ (V_{ts}{}^{*}V_{tb})^2 + \pi$$

$Bf^{\,2}$: hadronic matrix elements

Current Status of V_{CKM}

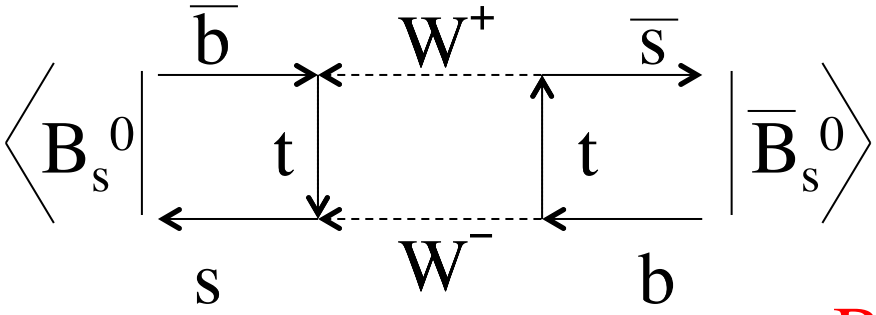
B-$\overline{\mathrm{B}}$ oscillation: dispersive part of the box diagram: M_{12}



$\Delta m = 2|M_{12}| \propto \mathrm{B_d} f_\mathrm{d}^{\,2} |V_{\mathrm{td}}|^2\ |V_{\mathrm{tb}}|^2$

$= (0.507 \pm 0.005)\ \mathrm{ps}^{-1}$ (PDG 2010)

$\arg = M_{12} = \arg\,(V_{\mathrm{td}}{}^* V_{\mathrm{tb}})^2 + \pi$



$\Delta m_\mathrm{s} = 2|M_{12}| \propto \mathrm{B_s} f_\mathrm{s}^{\,2} |V_{\mathrm{ts}}|^2\ |V_{\mathrm{tb}}|^2$

$= (17.77 \pm 0.12)\ \mathrm{ps}^{-1}$ (PDG 2010)

$\arg M_{12} = \arg\,(V_{\mathrm{ts}}{}^* V_{\mathrm{tb}})^2 + \pi$

$\mathrm{B}f^{\,2}$: hadronic matrix elements

$|V_{\mathrm{td}}| = (8.4 \pm 0.6)\times 10^{-3}$

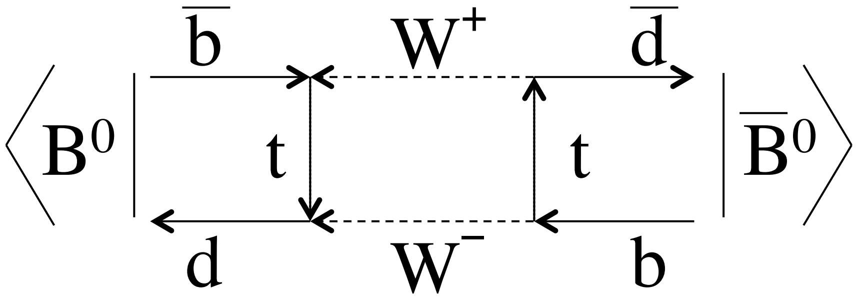
$|V_{\mathrm{ts}}| = (38.7 \pm 2.1)\times 10^{-3}$

} errors are totally theoretical: $\mathrm{B}f^{\,2}$

(PDG 2010)

Current Status of V_{CKM}

B-$\overline{\text{B}}$ oscillation: dispersive part of the box diagram: M_{12}



$\Delta m = 2|M_{12}| \propto B_d f_d^{\,2} |V_{td}|^2\, |V_{tb}|^2$

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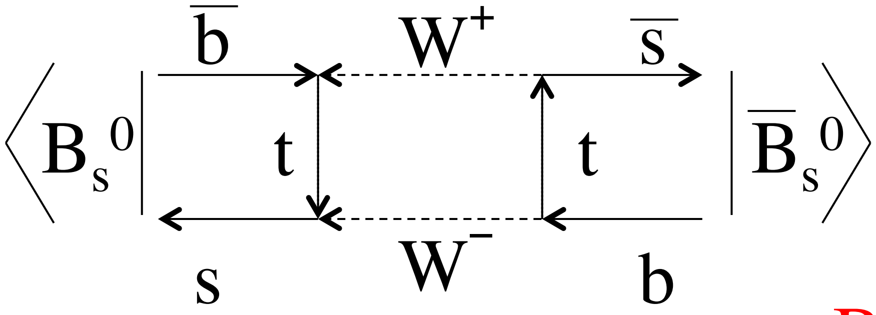

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$\arg M_{12} = \arg\,(V_{ts}^* V_{tb})^2 + \pi$

$Bf^{\,2}$: hadronic matrix elements

$|V_{td}| = (8.4 \pm 0.6)\times 10^{-3}$

$|V_{ts}| = (38.7 \pm 2.1)\times 10^{-3}$

} errors are totally theoretical: $Bf^{\,2}$

(PDG 2010)

$|V_{td}/V_{ts}| = 0.211 \pm 0.001 \pm 0.005$ $(B_d f_d^{\,2})/(B_s f_s^{\,2})$: smaller error

(PDG 2010) Δm_s measured only at the hadron machines

Current Status of V_{CKM}

$$V_{\mathrm{CKM}} \approx \begin{pmatrix} 1 & \lambda & V_{ub} \\ -\lambda & 1 & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$|V_{cb}|$ and $|V_{ub}|$ measured by semileptonic B_u and B_d decays

$\arg V_{cb} = 0$ by a phase convention

$\arg V_{ub}$ by CP violation in $B \to DK$

$V_{tb} \approx 1$ if we assume V_{CKM} to be unitary

$|V_{td}| \times |V_{tb}|$ by B^0-B^0 oscillation frequency (Δm_d)

$|V_{ts}| \times |V_{tb}|$ by B_s^0-B_s^0 oscillation frequency (Δm_s)

Current Status of V_{CKM}

$$V_{\mathrm{CKM}} \approx \begin{pmatrix} 1 & \lambda & V_{ub} \\ -\lambda & 1 & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

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$|V_{ts}| \times |V_{tb}|$ by $B_s{}^0$-$B_s{}^0$ oscillation frequency (Δm_s)

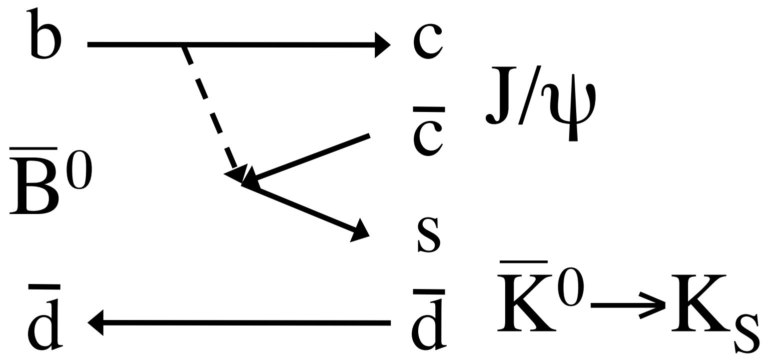
$\arg V_{td}$ by CP violation in $B_d \to J/\psi K_S$

$\arg V_{ts}$ by CP violation in $B_s \to J/\psi\phi$

Current Status of V_{CKM}

$\overline{B}^0 \longrightarrow \overline{B}^0$ $\quad b \rightarrow c+\bar{c}s$: $V_{cb}V_{cs}^* \propto e^{\iota 0}$

$\searrow J/\psi\, K_S$

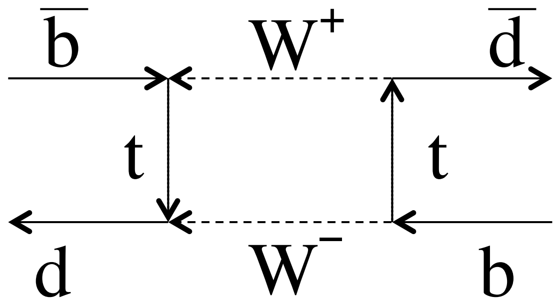


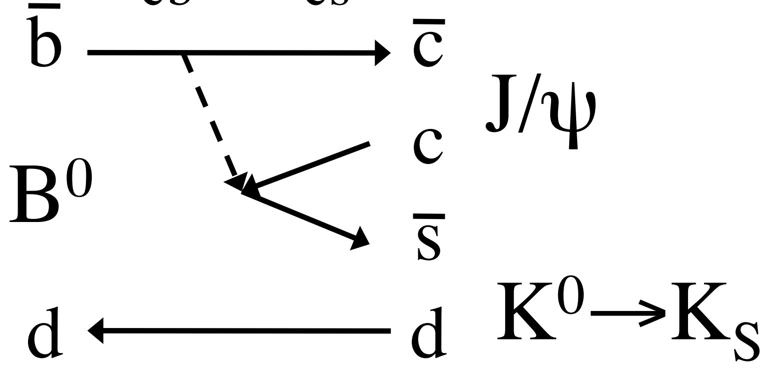
Current Status of V_{CKM}

$\overline{\mathrm{B}}^0$ → B^0 → $\mathrm{J}/\psi\,\mathrm{K_S}$

$M_{12} \propto -e^{2i\arg V_{td}}$

$\bar{\mathrm{b}} \rightarrow \bar{\mathrm{c}}+\mathrm{c}\bar{\mathrm{s}}$: $V_{cb}{}^* V_{cs} \propto e^{\iota 0}$





Current Status of V_{CKM}

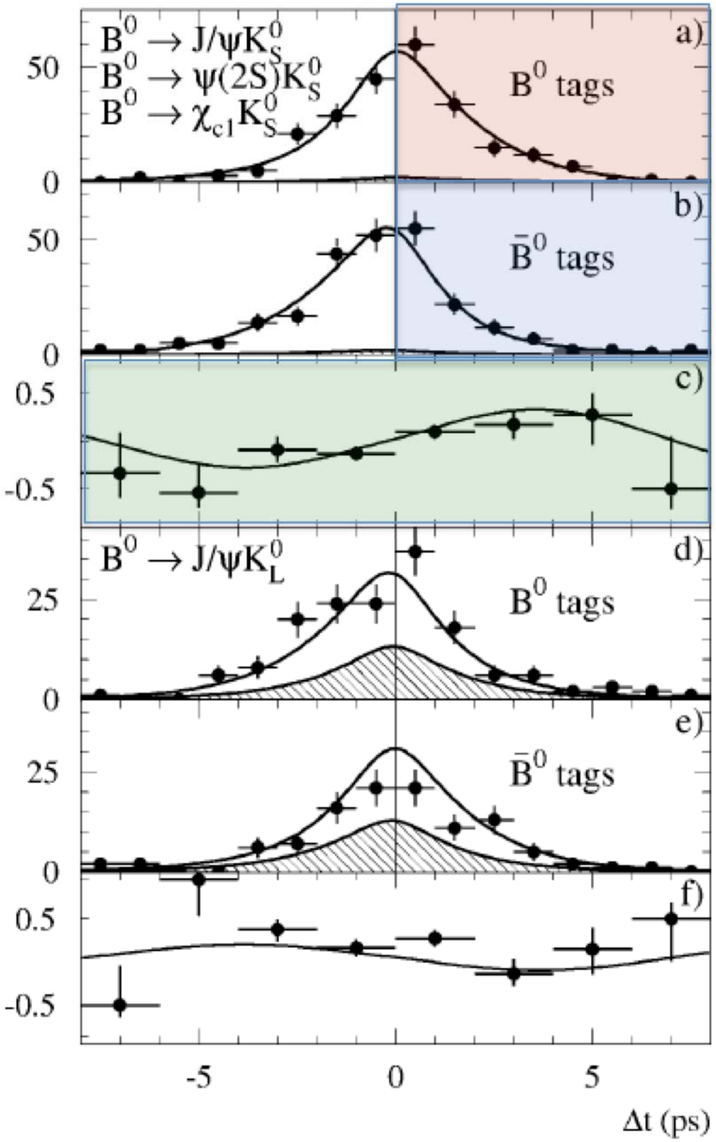
$\bar{\mathrm{B}}^0 \longrightarrow \bar{\mathrm{B}}^0$ $\mathrm{b} \rightarrow \mathrm{c}+\bar{\mathrm{c}}\mathrm{s}$: $V_{\mathrm{cb}} V_{\mathrm{cs}}{}^* \propto e^{\iota 0}$

$\bar{\mathrm{B}}^0 \longrightarrow \mathrm{B}^0$ $\bar{\mathrm{B}}^0, \mathrm{B}^0 \longrightarrow \mathrm{J}/\psi\, \mathrm{K_S}$

$M_{12} \propto -e^{2i\arg \mathrm{V_{td}}}$ B^0 $\bar{\mathrm{b}} \rightarrow \bar{\mathrm{c}}+\mathrm{c}\bar{\mathrm{s}}$: $V_{\mathrm{cb}}{}^* V_{\mathrm{cs}} \propto e^{\iota 0}$

two processes interfere → CPV ∝ sin $2\arg V_{\mathrm{td}}$

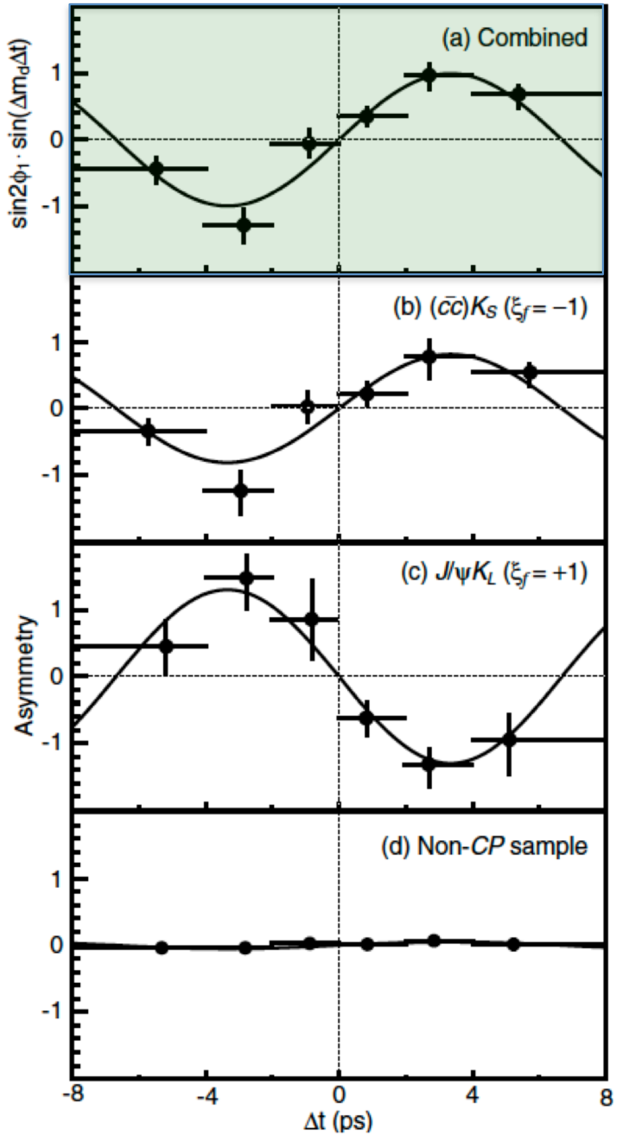
Current Status of V_{CKM}



$\overline{B}^0_{t=0} \rightarrow J/\psi K_S(t)$

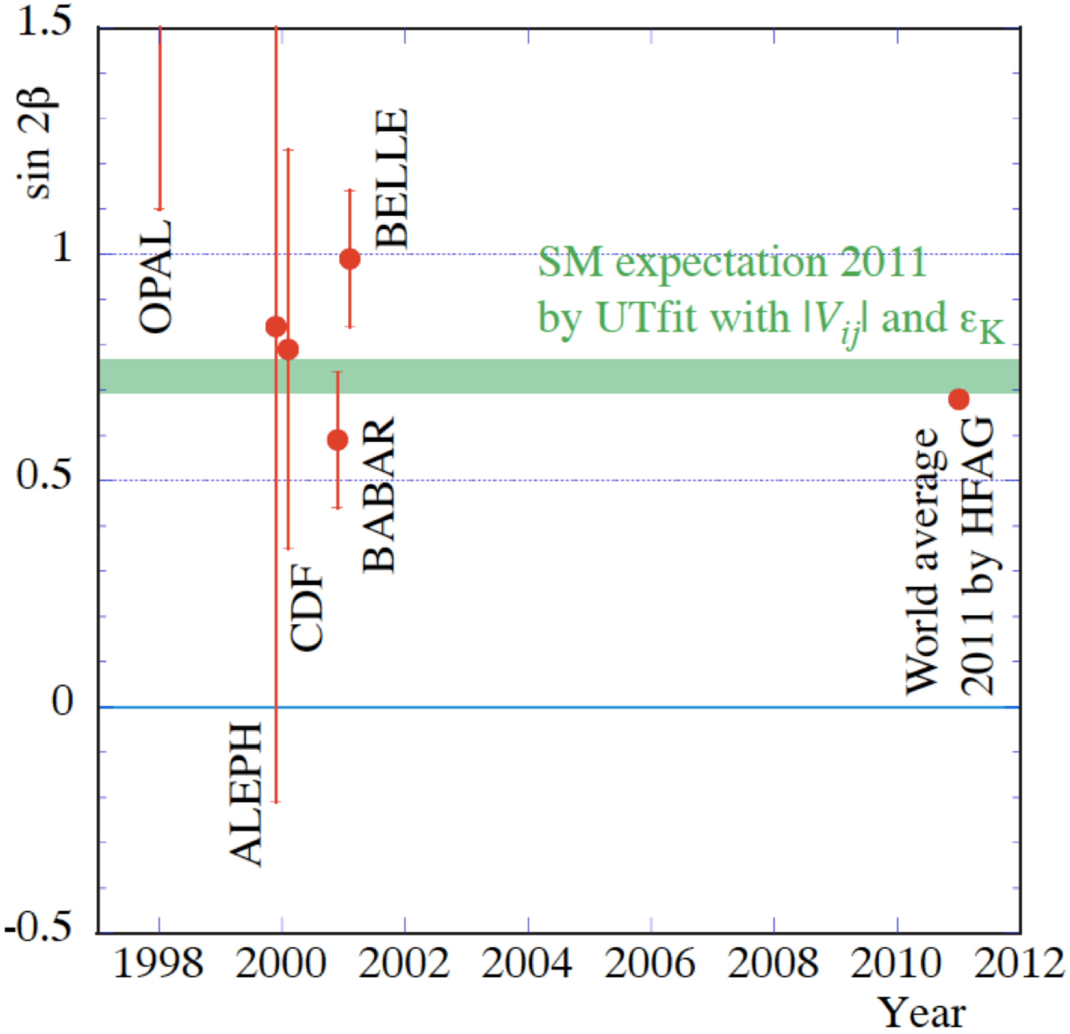
$B^0_{t=0} \rightarrow J/\psi K_S(t)$

Time dependent CP asymmetries



BABAR: Phys. Rev. Lett. 87, 091801 (2001) BELLE: Phys. Rev. Lett. 87, 091802 (2001)

Current Status of V_{CKM}



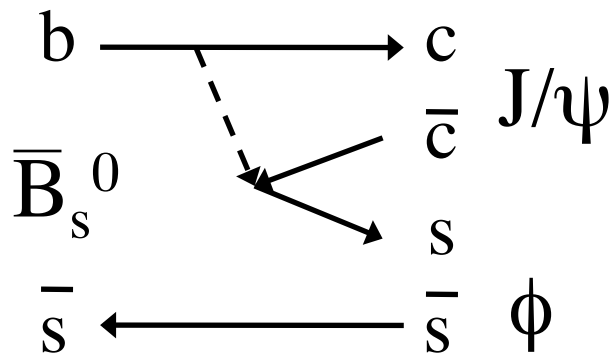
two processes interfere → CPV ∝ sin $2\arg V_{td}$

0.673 ± 0.023

Current Status of V_{CKM}

$\overline{\mathrm{B}}_s^0 \longrightarrow \overline{\mathrm{B}}_s^0$ $\quad \mathrm{b} \rightarrow \mathrm{c} + \bar{\mathrm{c}}\mathrm{s}$: $V_{cb}V_{cs}{}^* \propto e^{\iota 0}$

$\searrow \mathrm{J}/\psi\phi$

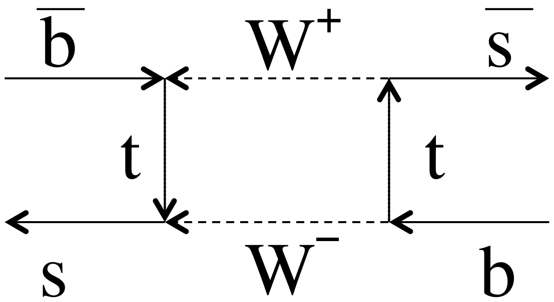


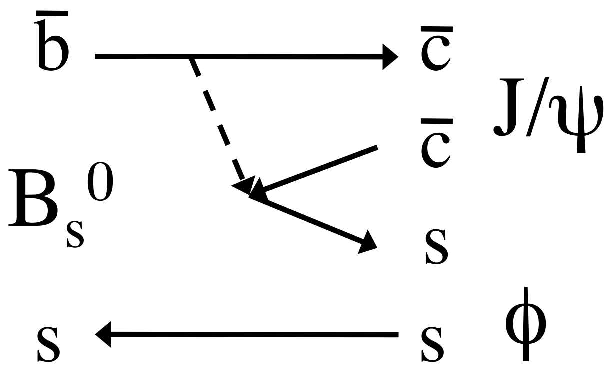
Current Status of V_{CKM}

$\overline{B}_s^0 \rightarrow B_s^0 \rightarrow J/\psi K_S$ or $J/\psi\phi$

$M_{12} \propto -e^{2i\arg V_{td}}$ or $-e^{2i\arg V_{ts}}$

$\bar{b} \rightarrow \bar{c} + c\bar{s}$: $V_{cb}{}^{*} V_{cs} \propto e^{i0}$





Current Status of V_{CKM}

$\bar{B}_s^0 \longrightarrow \bar{B}_s^0$ $\quad \mathrm{b} \to \mathrm{c}+\bar{\mathrm{c}}\mathrm{s}$: $V_{cb}V_{cs}^* \propto e^{\iota 0}$

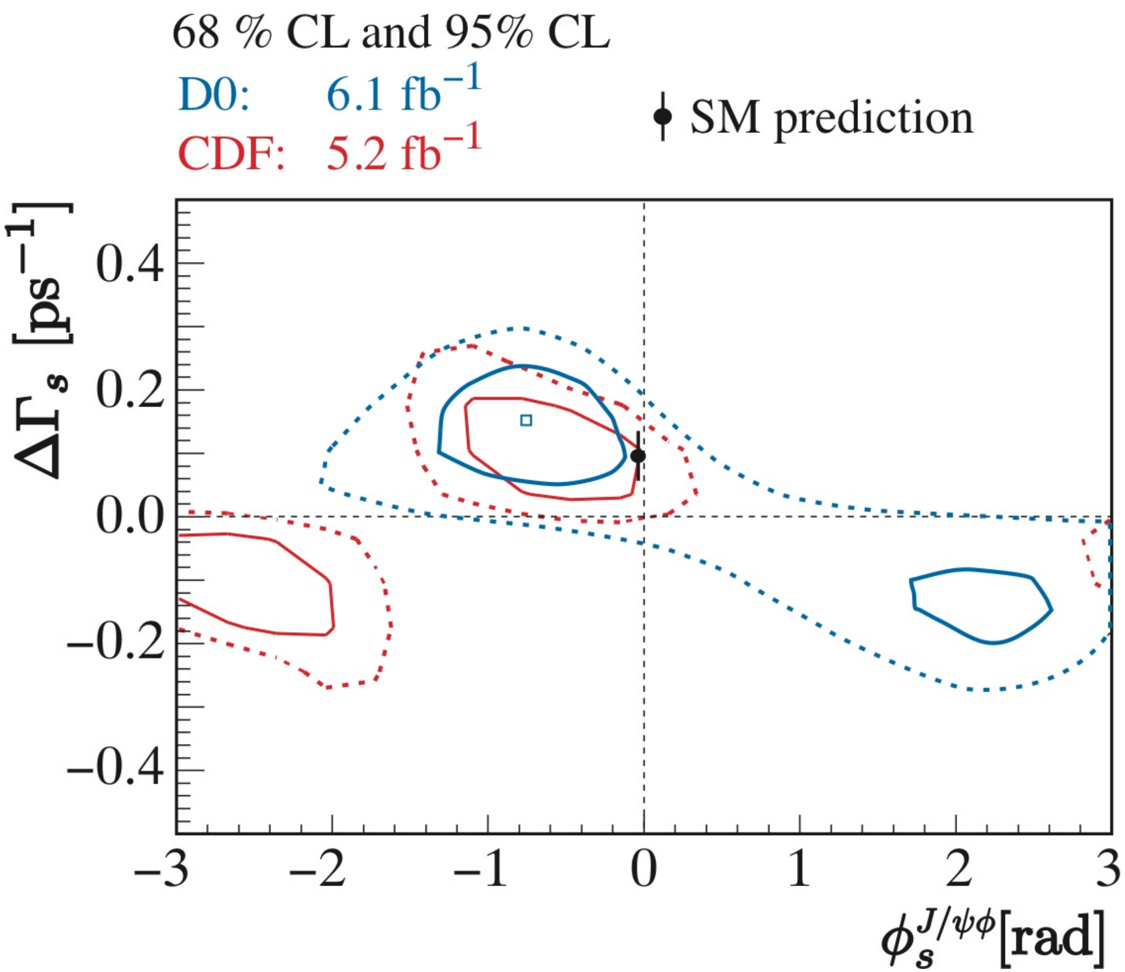
$\bar{B}_s^0 \to$ J/ψφ, $\quad B_s^0 \to$ J/ψφ

$M_{12} \propto -e^{2i\arg V_{ts}}$ $\quad \bar{B}_s^0 \to B_s^0$ $\quad \bar{\mathrm{b}} \to \bar{\mathrm{c}}+\mathrm{c}\bar{\mathrm{s}}$: $V_{cb}^* V_{cs} \propto e^{\iota 0}$

two processes interfere → CPV ∝ sin $2\arg V_{ts}$

not yet well measured

Current Status of V_{CKM}



two processes interfere → CPV ∝ sin $2\arg V_{\mathrm{ts}}$

not yet well measured

Current Status of V_{CKM}

$$\approx \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda - iA^2\lambda^5\eta & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\hat{\rho}-i\hat{\eta}) & -A\lambda^2 - iA\lambda^4\eta & 1 \end{pmatrix}$$

$$\hat{\rho} = \rho\left(1-\frac{\lambda^2}{2}\right)$$

$$\hat{\eta} = \eta\left(1-\frac{\lambda^2}{2}\right)$$

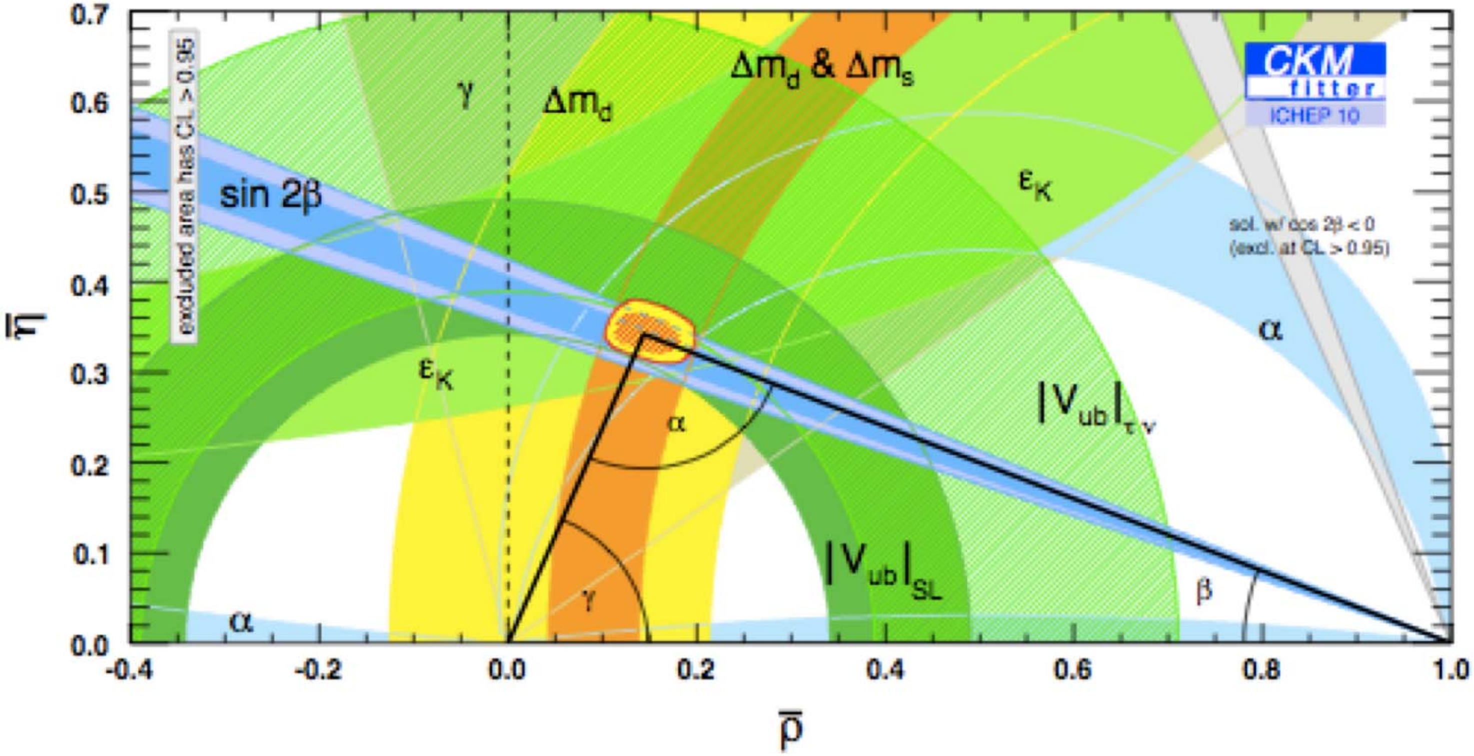
A from $|V_{cb}|$, ρ and η from

- $|V_{ub}|$ and arg V_{ub}
- $|V_{tb}|$ and arg V_{tb}
- $|V_{ub}|$ and $|V_{tb}|$
- $|V_{td}|$ and arg V_{ub}

many solutions i.e. consistency can be checked

Current Status of V_{CKM}

- All input from B factories, except ε_K and Δm_s



- BABAR and PEP-II completed in 2008
  Belle and KEKB completed in 2010
  with a total of ~1.2 ab^{-1} data, i.e. ~1.3×10^9 $B\bar{B}$!
  →Looking forward to seeing many key results with
  full statistics data in the coming conferences.