CP Violation

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I) Why CP violation is highly

- Currently observed CP violation in the kaon de
  accommodated within the Standard Model.
  BUT, it cannot exclude that CP violation is **par**
  entirely due to **new physics**.
- Since CP violation is due to an “interference”,
  to a small effect.
- Cosmology (baryon genesis) suggests that an **ad**
  source of CP violation other than the Standard
  needed.

A promising place to look for new

II) CP violation in the Kaon sy

Observed CP violation in the kaon sys

CP

1) Re $\eta_{2\pi}$

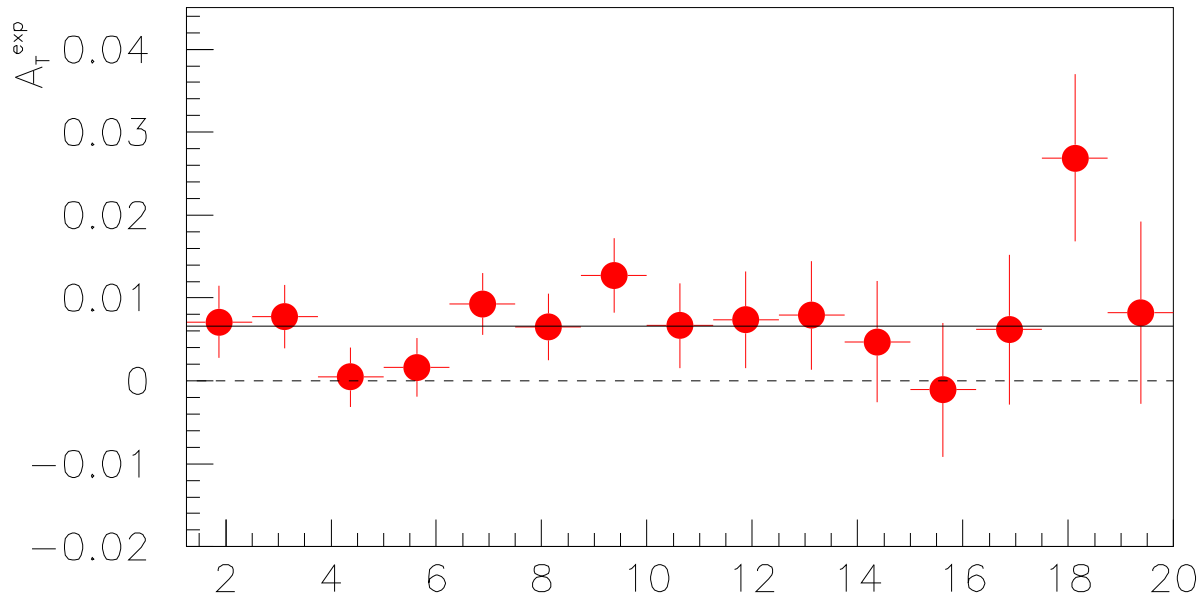
$$K^0_{t=0} \rightarrow \overline{K}^0_{t=t_1} \neq \overline{K}^0_{t=0} \rightarrow K^0_{t=t_1}$$

~~CP~~ and ~~T~~

so called CP violation in K^0- $\overline{K}^0$ osc

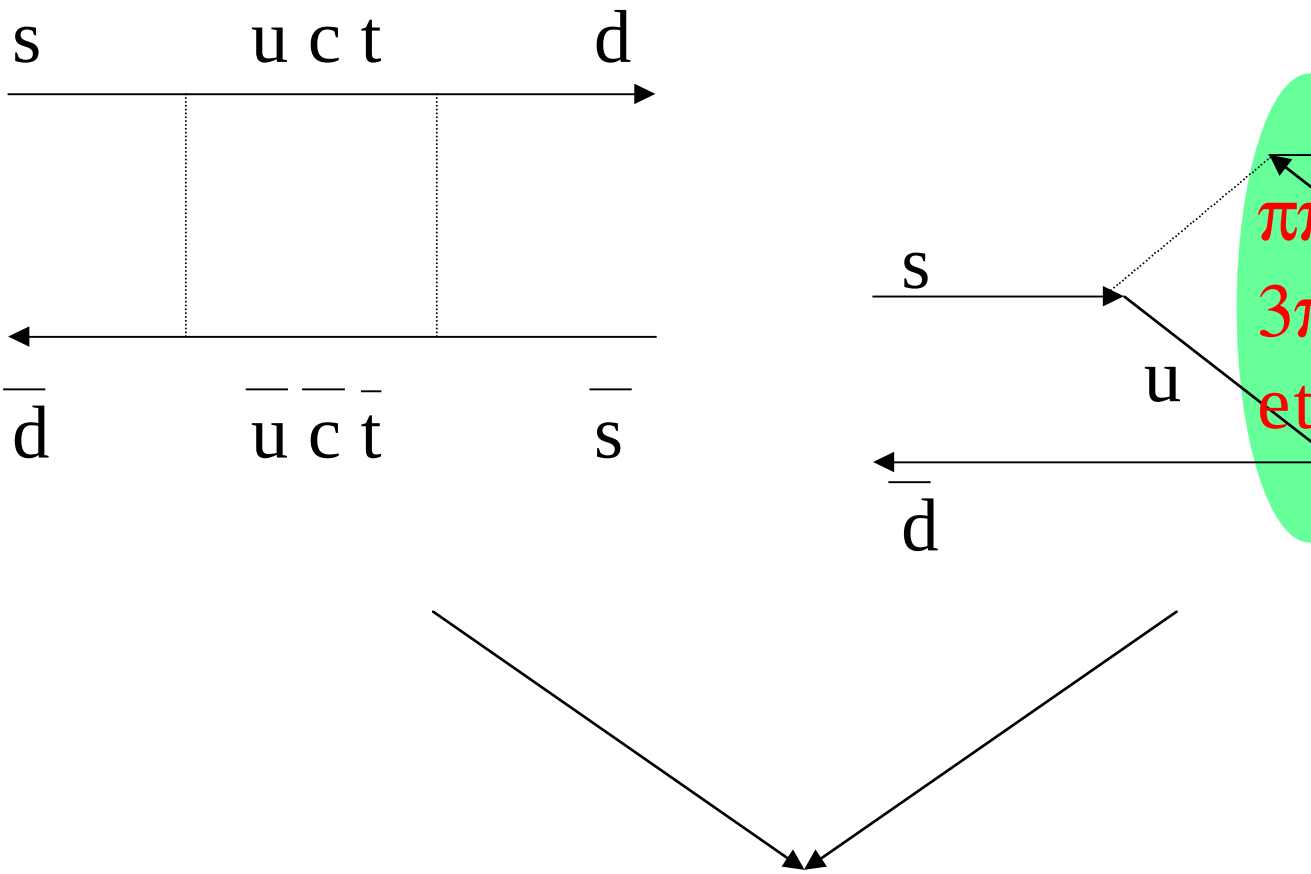
$$A_T(t) = \frac{\overline{K}^0_{t=0} \to K^0(t) - K^0_{t=0} \to \overline{K}^0(t}{\overline{K}^0_{t=0} \to K^0(t) + K^0_{t=0} \to \overline{K}^0(t}$$

CPLEAR 1998



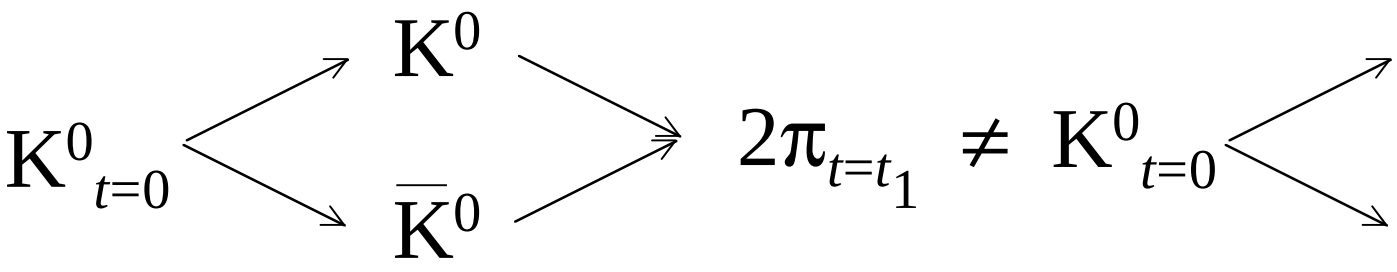
$(6.6 \pm$

$\sim 4\mathrm{Re}($

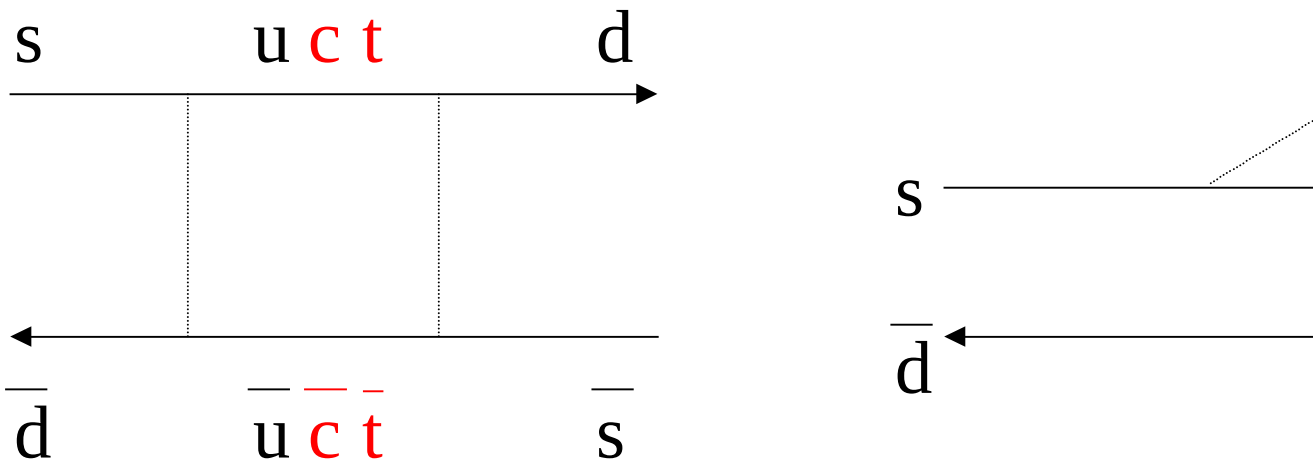


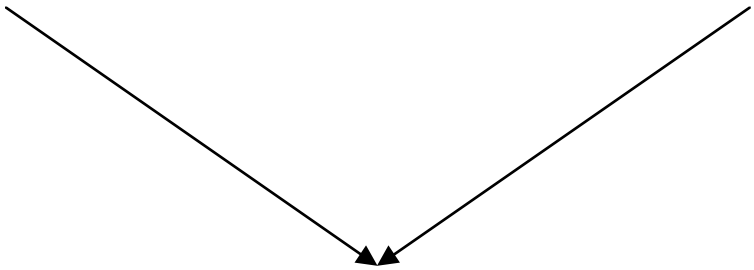
interference = $\not{CP}$

2) Im $\eta_{2\pi}$



So called CP violation in
the interplay between oscillations





interference = $\not{CP}$

3) Current experimental results are

$$\eta_{+-} = \eta_{00}$$

$$\arg \eta_{+-} = \tan^{-1} \Delta m/2\Delta\Gamma \approx$$

$$(\Delta m = m_L - m_S,\ \Delta\Gamma = \Gamma_S -$$

{ NA31,CPLEAR (CERN)
{ E731, E773 (FNAL)

This is compatible with

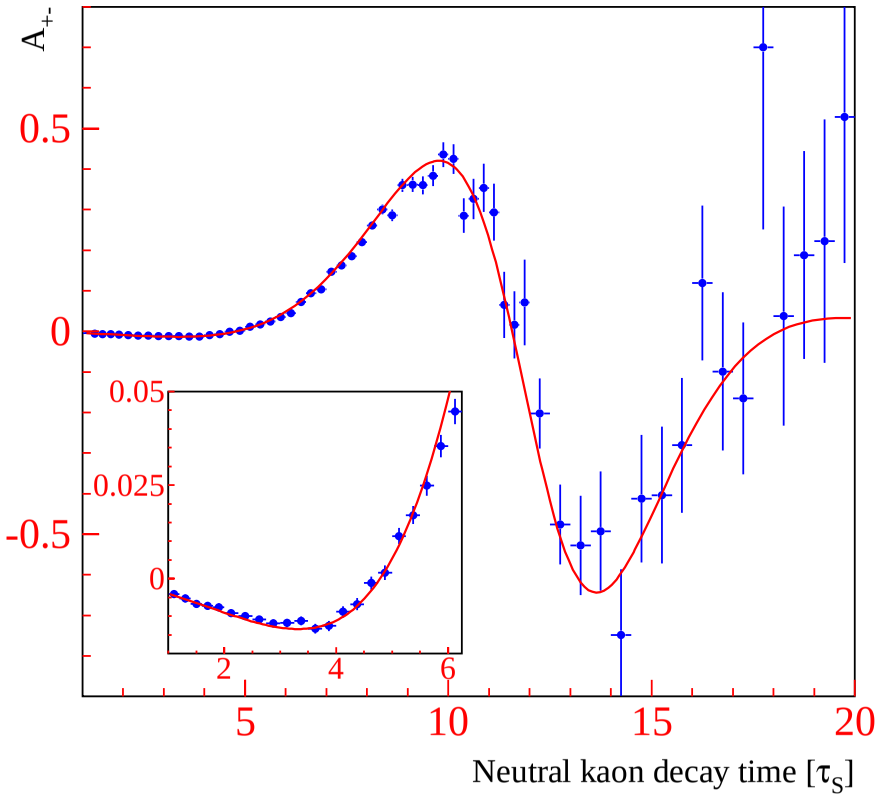
Standard Model

but also with

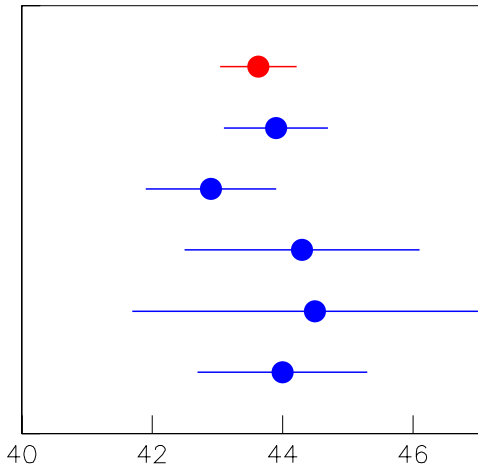
Superweak Model

CPLEAR

$$\frac{\overline{K}^0 \to \pi^+\pi^-(t) - K^0 \to \pi^+\pi^-(t)}{\overline{K}^0 \to \pi^+\pi^-(t) - K^0 \to \pi^+\pi^-(t)}$$



ϕ_{+-} =



4) Experimental attempt to exclude the Sup

1) To show

$|\eta_{+-}| \neq |\eta_{00}|$

so called $\mathrm{Re}(\varepsilon'/\varepsilon) \neq 0$

or CP violation in de

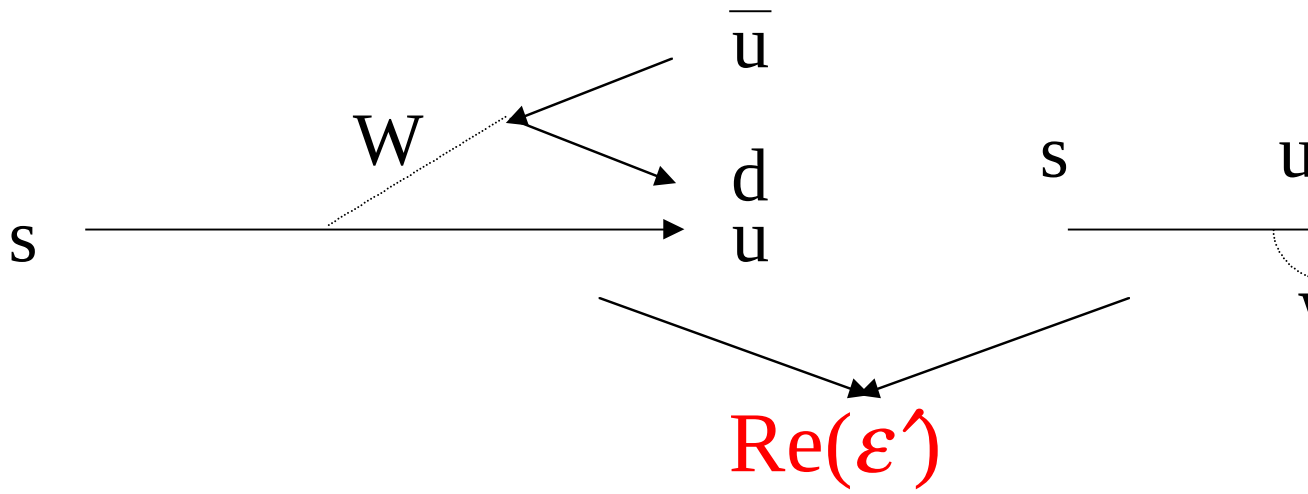
due to penguins

NA48 (CERN), KTeV(FNAL)

2) To show

$\mathrm{Br}(K_L \rightarrow \pi^0 \nu\bar{\nu}) \approx 10^{-11}$

Being discussed at FNAL and B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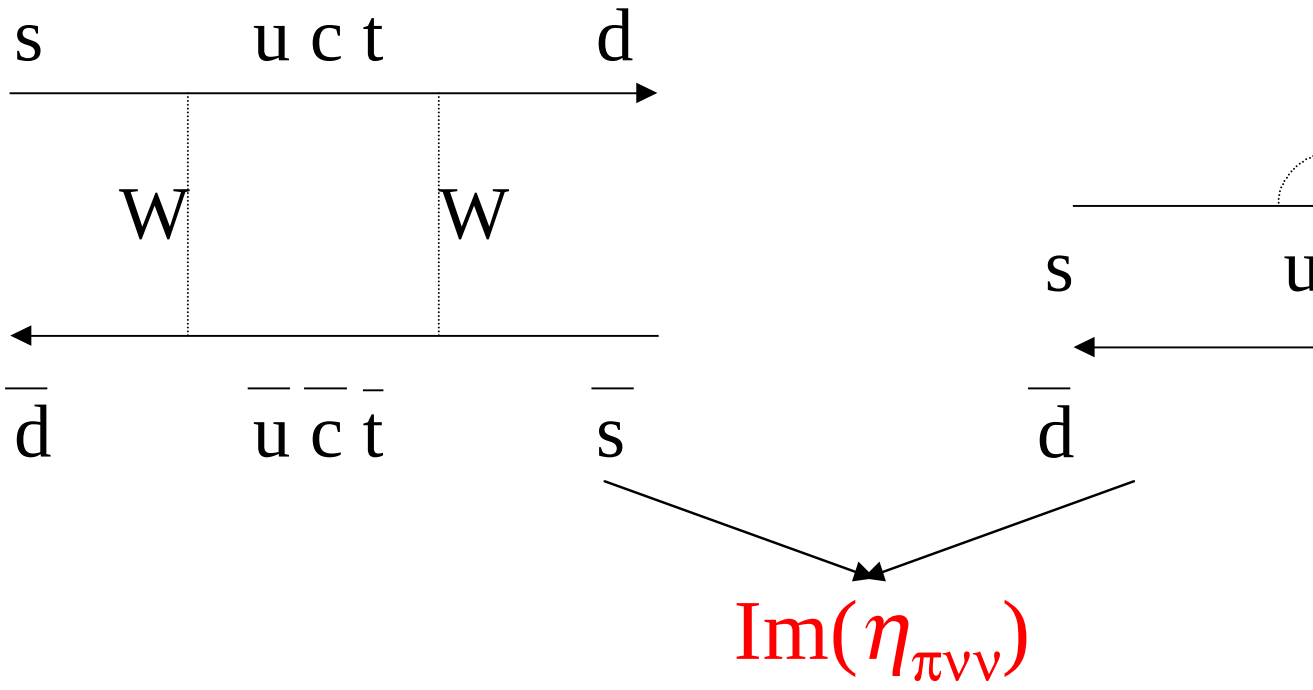
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Im(η_πνν)

Standard model predictions are uncertain f

hadronic effects: long range inte

penguins etc.

$Br(K_L \to \pi^0 \nu\bar{\nu})$ is experimentally really ha

Another place to look for CP violatio

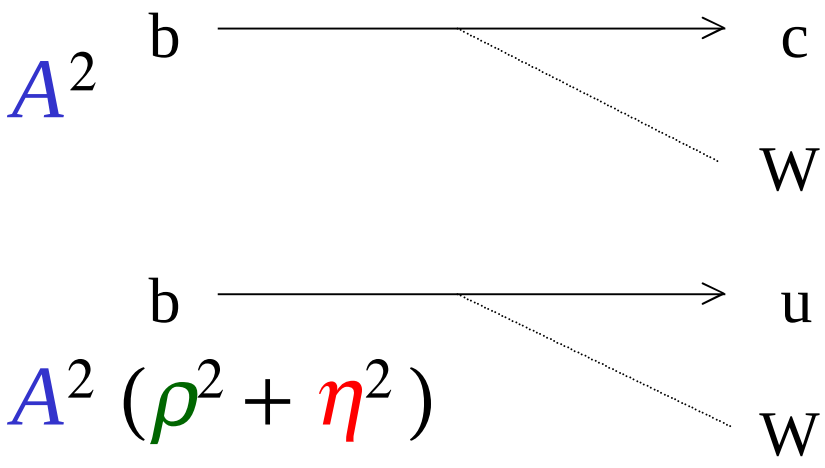
III) CP Violation and B-meson

If there is nothing else but the standard m

$\lvert V_{cb}\rvert$, $\lvert V_{ub}\rvert$	B-meson decays
Δm_d	B_d-$\bar{B}_d$ oscillations

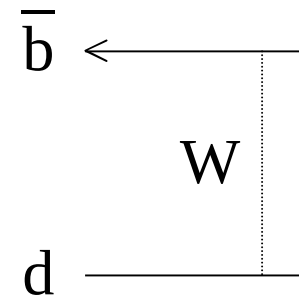
will fix all the Wolfenstein's parameters

A, ρ and η (λ is well known)



A^2

$A^2\,(\rho^2+\eta^2)$



$A^2\,[(1-\rho$

CKM matrix relevant for B Physic

(CP violation is all due to $\eta \neq 0$)

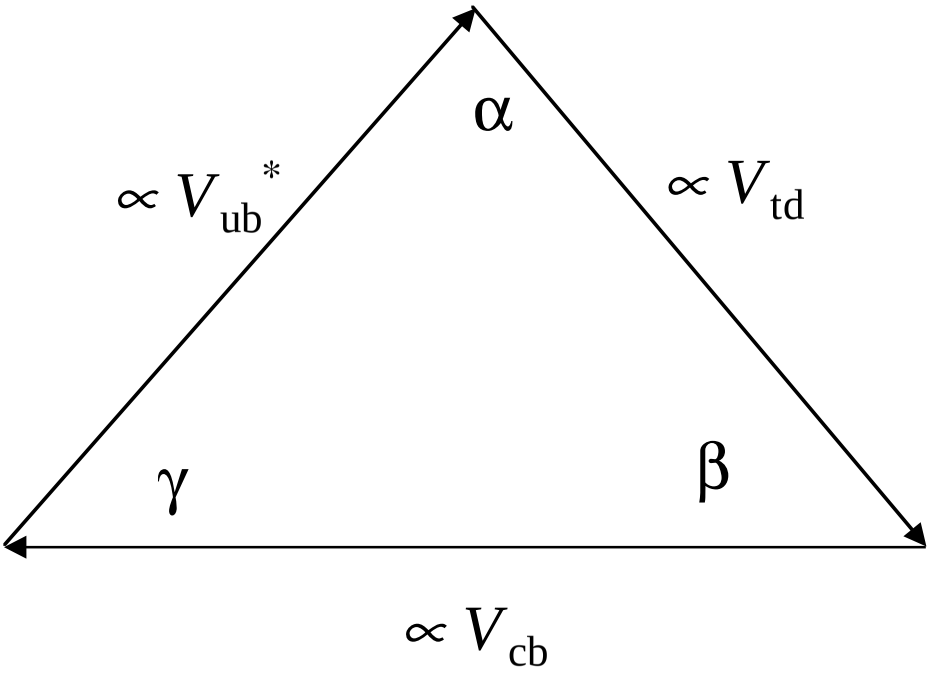
$$V_{\mathrm{CKM}} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3 (\rho - \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3 (1 - \rho - i\,\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

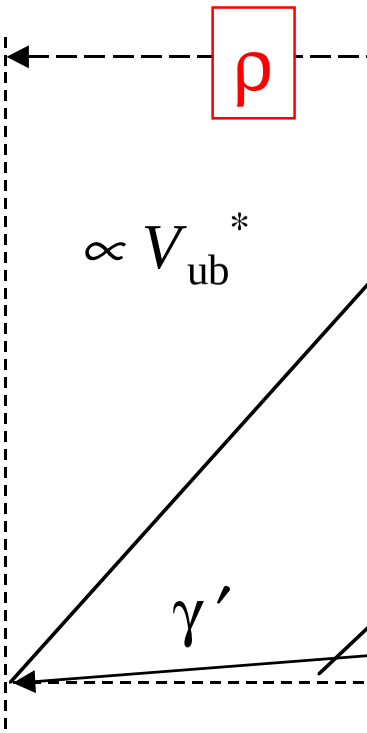
$$+ \begin{pmatrix} 0 & 0 \\ -iA^2\eta\lambda^5 & 0 \\ (\rho + i\eta)\lambda^5/2 & (1/2 - \rho)A\lambda^4 - i \end{pmatrix}$$

CKM Unitarity Trian

$$V_{td}V_{tb}^{*} + V_{cd}V_{cb}^{*} + V_{ud}V_{ub}^{*} = 0$$

$$V_{td}V_{ud}^{*} + V_{ts}$$

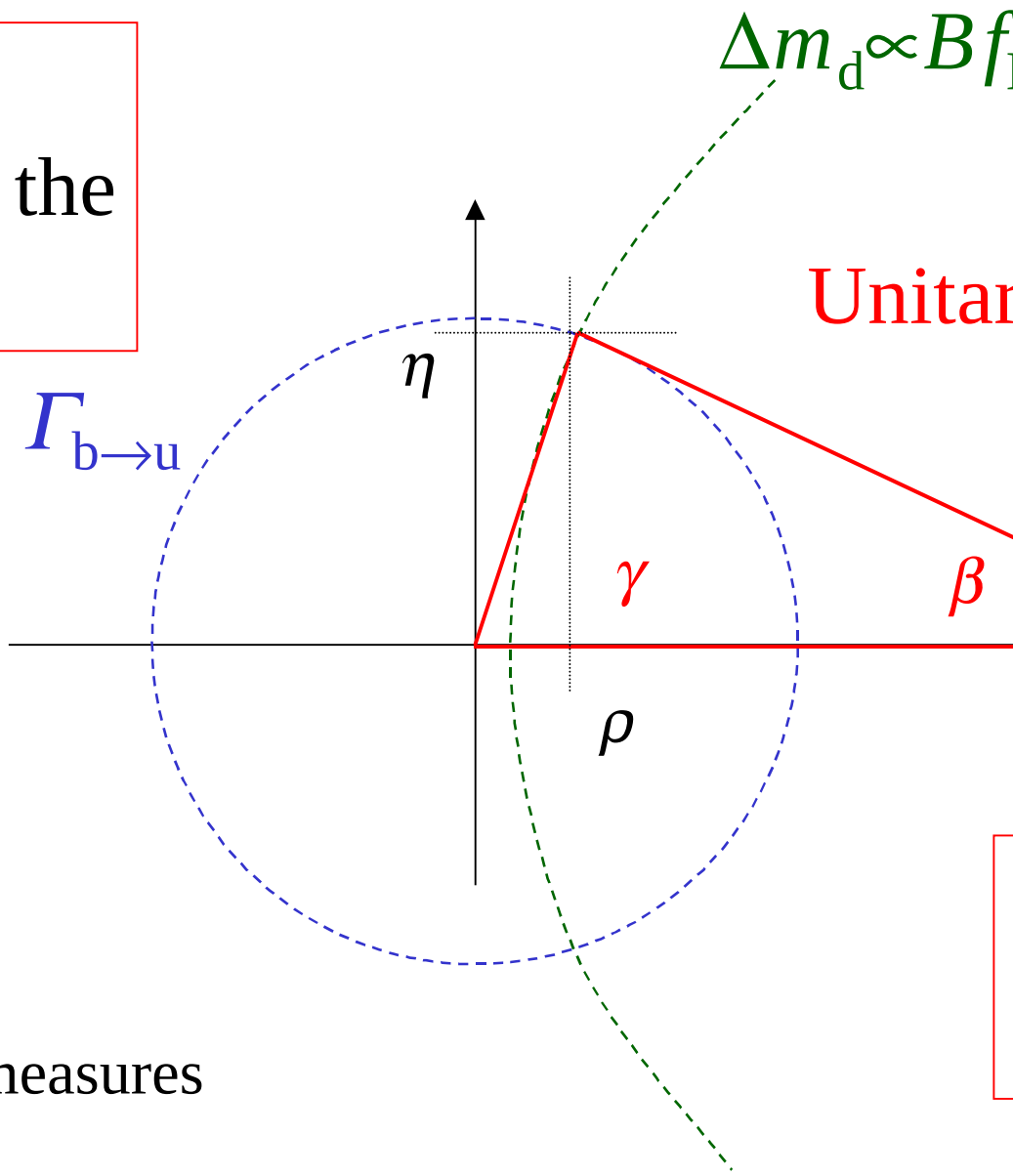




arg V_{cb} = 0, arg V_{ub} = – γ, arg V_{td} = – β, arg

From the neutral kaon system $\eta > 0$

β and γ are defined by the sides



NB:
Br($K^{\pm} \to \pi^{\pm} \nu\bar{\nu}$) measures also $|V_{td}|$

CP violation in

$B_d \to J/\psi\, K_S$ v.s. $\bar{B}_d \to J/\psi\, K_S$

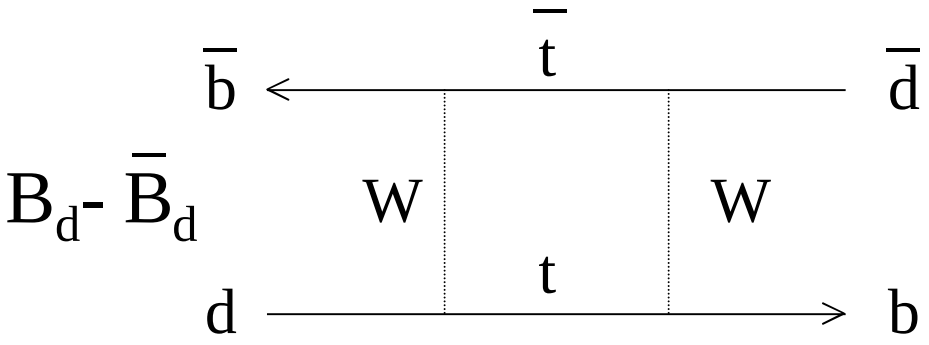
measures the phase of V_{td}, i.e. β

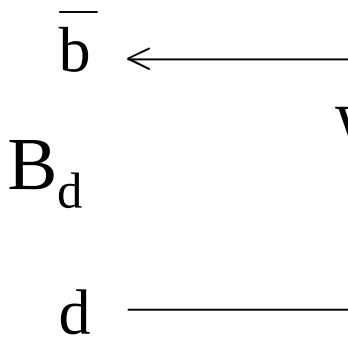
B_d

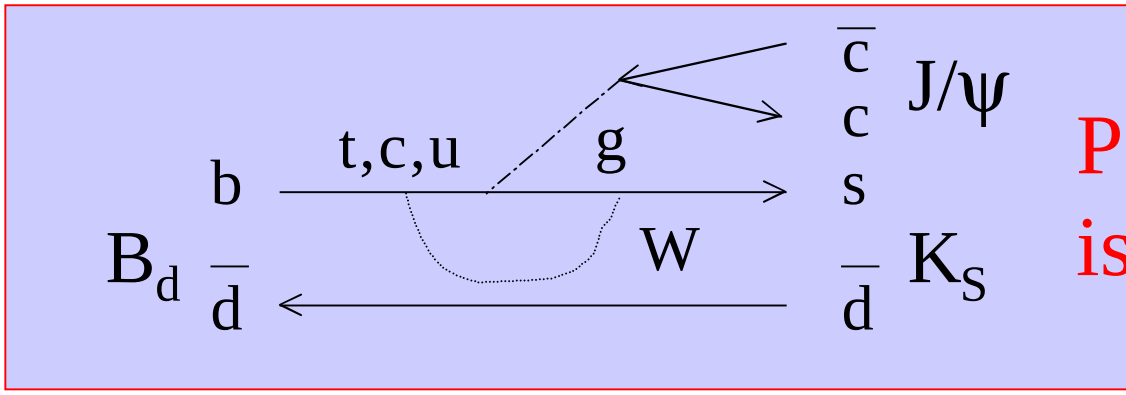
compare two β measurements = con

$H_{B\text{-}\bar{B}} \propto (V_{tb}^{*}\, V_{td})^2 \propto e^{2i\beta}$

$A_{B \to J/\psi Ks} \propto$







P

is

By 2005, CLEO, BaBar, BELLE, CDF, D
and HERA-B will have

-accurate $|V_{ub}|$, $|V_{cb}|$ and

-β from CP violation in $B_d \rightarrow J/\psi\, K_S$ wi

(Expected range in the Standard Model:

Possibilities are

a) There will be already a sign of new ph

-precision measurements in different c

in order to pin down the details of ne

b) Measurements look "consistent" with

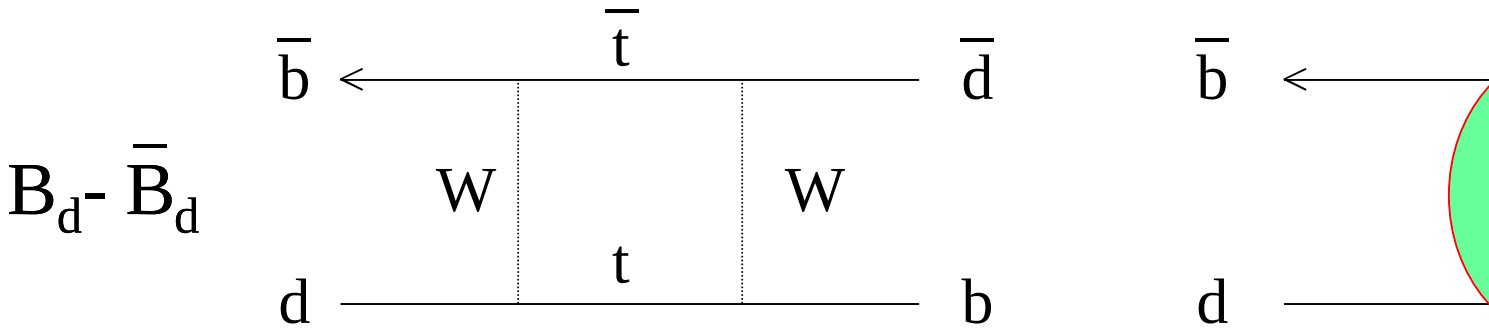
model.

-what could happen?

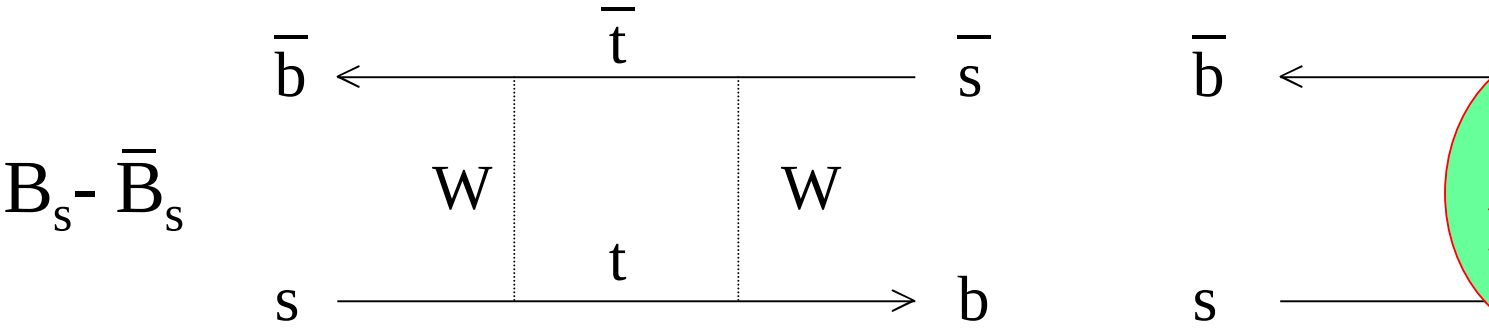
Let's make the following "interesting

A model for new physics

$$H_{B\text{-}\bar{B}} \propto [\{(1-\rho)^2+\eta^2\}+ r^2_{db}]\, e^{2}$$

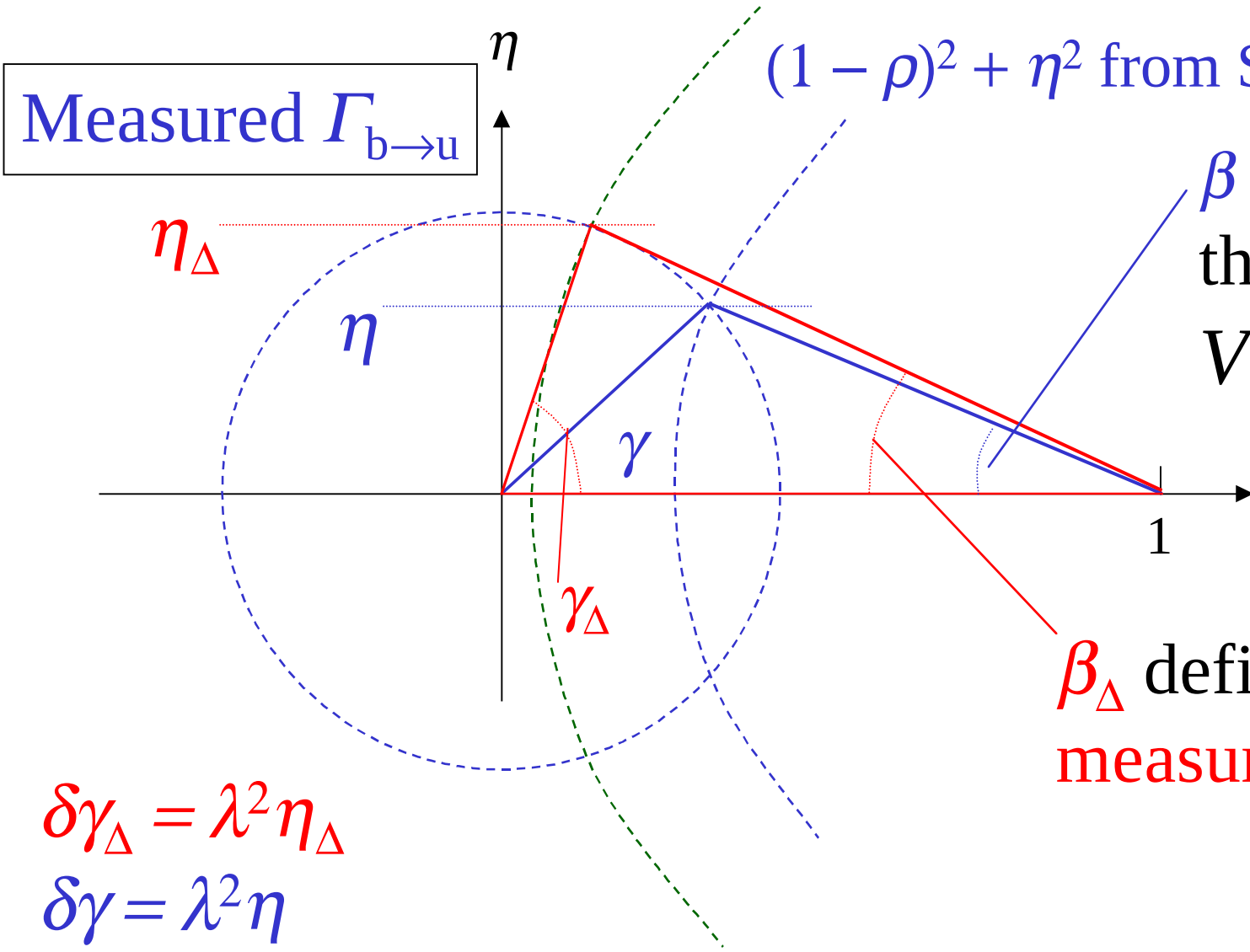


$$H_{B\text{-}\bar{B}} \propto [\ \lambda^{-2}+ r^2_{sb}\ ]\, e^{-2i(\delta\gamma+}$$



Measured $\Delta m(B_d) \rightarrow (1-\rho)$

Measured $\Gamma_{b\rightarrow u}$



$(1-\rho)^2 + \eta^2$ from S

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β_Δ defi

measu

$\delta\gamma_\Delta = \lambda^2\eta_\Delta$

$\delta\gamma = \lambda^2\eta$

CP violation in

$$B_d \to J/\psi\, K_S \text{ v.s. } \bar{B}_d \to J/\psi\, K_S$$

B_d-$\bar{B}_d \propto e^{2i(\beta + \phi_{db})}$ $B_d \to J/\psi\, K_S \propto V_{cb}^* V$

measures $\beta_{J/\psi K} = \beta + \phi_{db}$

If the model is such that numerically $\phi_{db} \approx \beta$

"$\beta_{J/\psi K} = \beta_\Delta$"

CP measurement and triangle measure

each other.

→ Look consistent with the Stan

BABAR and BELLE may have difficulty t

CP violation in $B_d \to \pi^+ \pi^-$

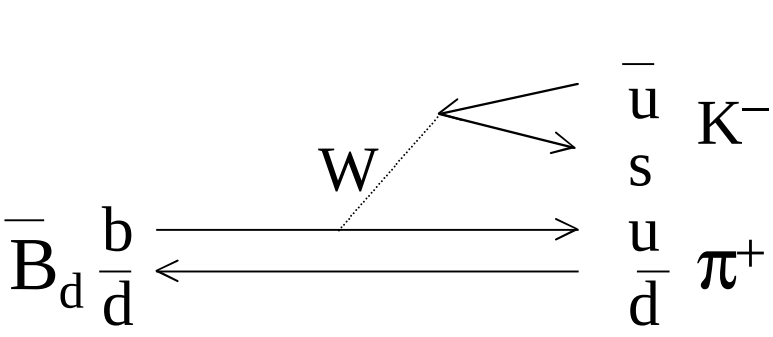
-experimental problem

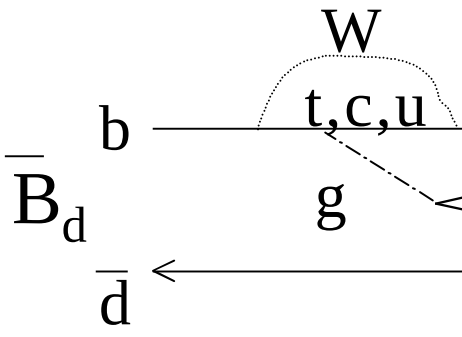
small branching fraction < 8×

-theoretical problem

large penguin contribution

CLEO: $Br(\pi^+\pi^-) < Br(K^+\pi^-) \approx 1.4 \times 10^{-5} \to$ p

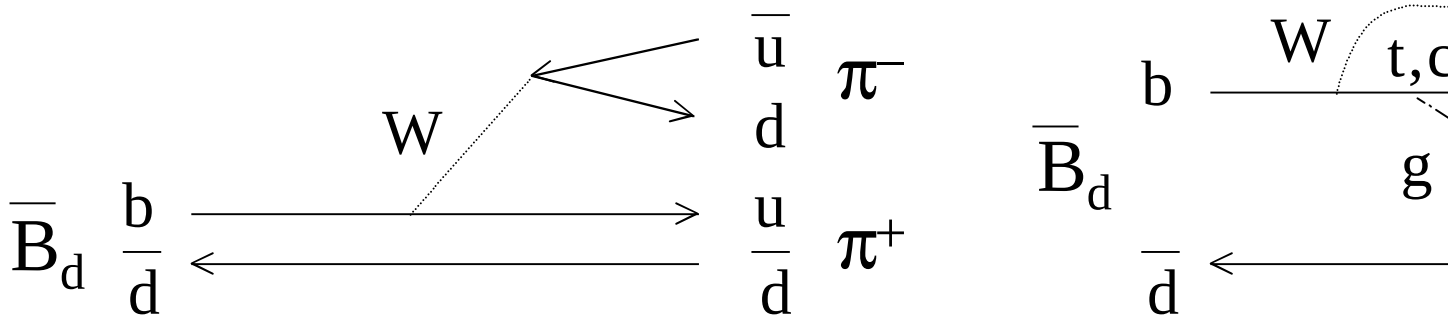




$\Gamma_T \propto (V_{us}^* V_{ub})^2 \propto \lambda^8$ $\Gamma_P \propto [P(m_t^2) \times V_{ts}^* V$

Top penguin dominates in $B_d \to K\pi$

$\Gamma_T \propto (V_{ud}^* V_{ub})^2 \propto \lambda^6$ $\Gamma_P \propto [P(m_t^2) \times V_{td}^* V$



$\mathrm{Br}(\pi^+\pi^-) < \mathrm{Br}(K^+\pi^-) \rightarrow$ penguin is large; $P(m_t$

$V_{ud}^* V_{ub} \propto e^{-i\gamma}$

$V_{td}^* V_{tb} [P(m_t^2)-$
$+ V_{ud}^* V_{ub} [P(m$
$\propto [P(m_t^2) - P(m_c$
$+[P(m_u^2) - P$

Problem: tree and penguin have differ

CP violation in $B_d \to \pi^+\pi^-$ is not really possibl

CDF and D0: no particle ID, HERA-B: not eno

$B_d \to \pi^+\pi^-$ can be used only if we know p

A way out:

measure Br($\pi^+\pi^0$) and Br($\pi^0\pi^0$) → **not enou**

CP violation in $B_d \to \rho^+\pi^-$, $\rho^-\pi^+$, $\rho^0\pi^0$

-experimental problem

decay time dependent Dalitz plot a

→ not enough statistics

-theoretical problem

assume $\pi^+\pi^-\pi^0$ to be always $\rho\pi$

CDF, D0 and HERA-B may be able to me

If $\Delta m(\mathrm{B_s})/\Gamma_\mathrm{b} < 20$. Does this help? Not rea

$$\frac{\Delta m(\mathrm{B_d})}{\Delta m(\mathrm{B_s})} = \frac{A^2\lambda^4\left[(1-\rho)^2+\eta^2\right]+r}{A^2\lambda^2+r(\mathrm{sb})}$$

-It helps to reduce hadronic uncertainties:

$f_\mathrm{B}{}^2B$ (~20% error, lattice calculation

$f_\mathrm{B}{}^2B(\mathrm{B_d})/f_\mathrm{B}{}^2B(\mathrm{B_s})$ is much better kno

-It is interesting if $\Delta m(\mathrm{B_s})$ is really large; n

But it is out of their sensitivities.

How can LHC attack the problem?

1) Improve $\beta_{J/\psi K}$ measurement.

ATLAS, CMS: $\sigma \sim 0.02$/year

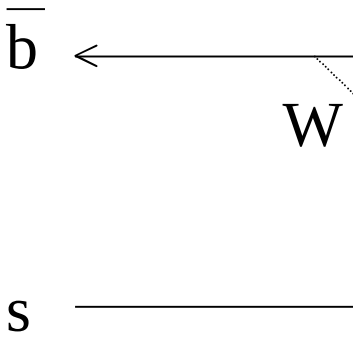
LHCb: $\sigma \sim 0.01$/year

2) Measure other angles using B_s

CP violation in $B_s \to J/\psi\phi$ measures $\delta\gamma$

$$B_s - \bar{B}_s \propto e^{-2i(\delta\gamma + \phi_{sb})}$$

$B_s \to J/\psi\ \phi \propto$



Penguin effect is negligible

If the model is such that numerically $\phi_{sb} \approx$

"$\delta\gamma_{J/\psi\phi} = \delta\gamma_{\Delta}$"

It will still look consistent.

$J/\psi\,\phi$ is a easy final state to reconstru

if the decay time resolution is g

ATLAS, CMS: $\sigma \sim 0.03$/year

LHCb:$\sigma \sim 0.01$/year

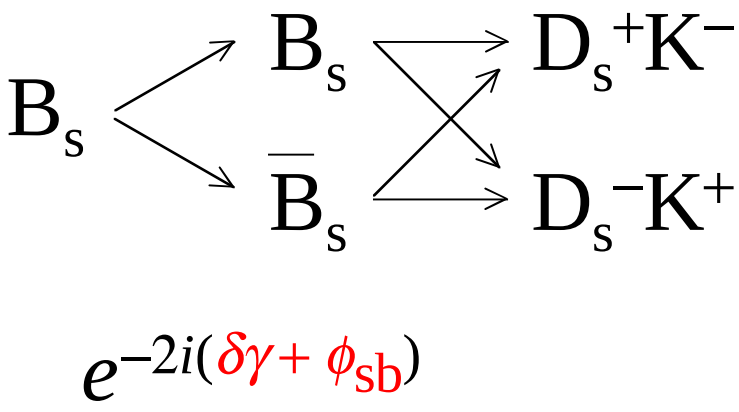
*additional complication: $J/\psi\,\phi$ { CP / CP

-angular momentum configuration has to

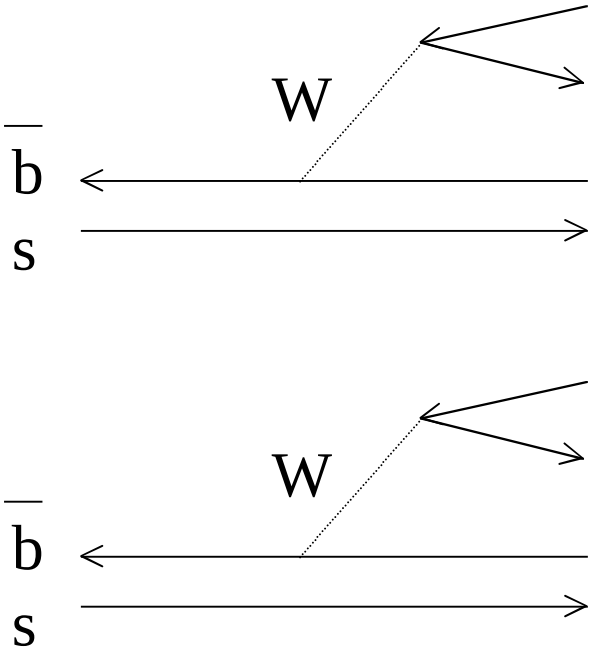
We need to do much more!

CP violation in

$B_s \to D_s^+K^-, D_s^-K^+$ $\quad \bar{B}_s \to D$



$e^{-2i(\delta\gamma + \phi_{sb})}$



+ c.c.

measures $\gamma_{DsK} = \gamma - 2\delta\gamma - 2\phi_{sb} \equiv \gamma$

There is no more freedom left to

$\gamma_{DsK} = \gamma_{\Delta} - 2\delta\gamma_{\Delta}$

No hadronic uncertainty

Measured γ_{DsK} disagrees with what one
the triangle relation $\Rightarrow$ New Physics

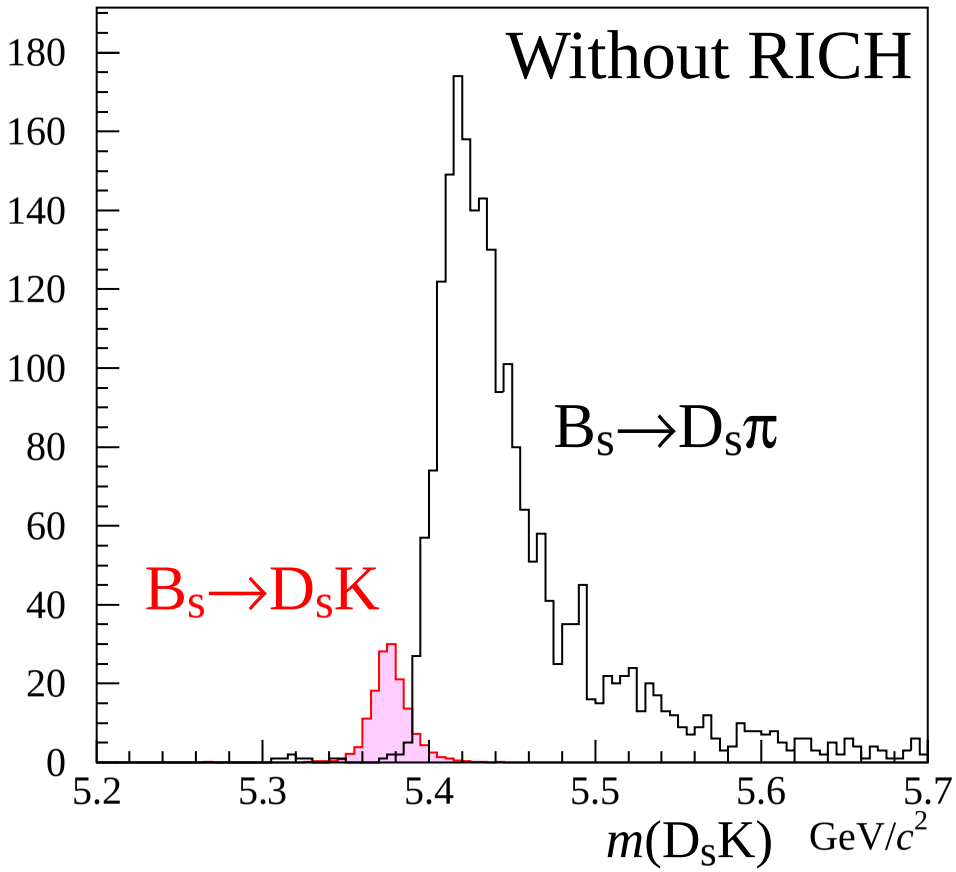
What are experimentally needed?

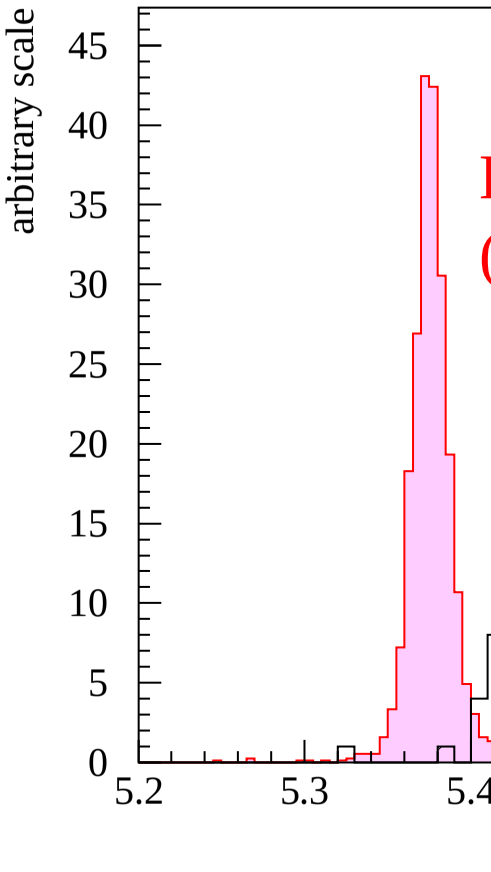
- decay time resolution
- K/π separation

$B_s \to D_sK$

Major background: $B_s \to D_s\pi$ (No CP v

Importance of particle identification and m





3) Further CP violation studies with B_d wh

very high statistics (difficult for BaBar

$B_d \to D^0 K^{*0}$, $\overline{D}^0 K^{*0}$, $D_{1,2} K^{*0}$

$\overline{B}_d \to D^0 \overline{K}^{*0}$, $\overline{D}^0 \overline{K}^{*0}$, $D_{1,2} \overline{K}^{*0}$

measure γ.

$B_d \to D^{*+}\pi^-$, $D^{*-}\pi^+$ $\overline{B}_d \to D^*$

measure $2\beta + \phi_{db} + \gamma$; $\neq 2\beta_\Delta + \gamma_\Delta$ i.

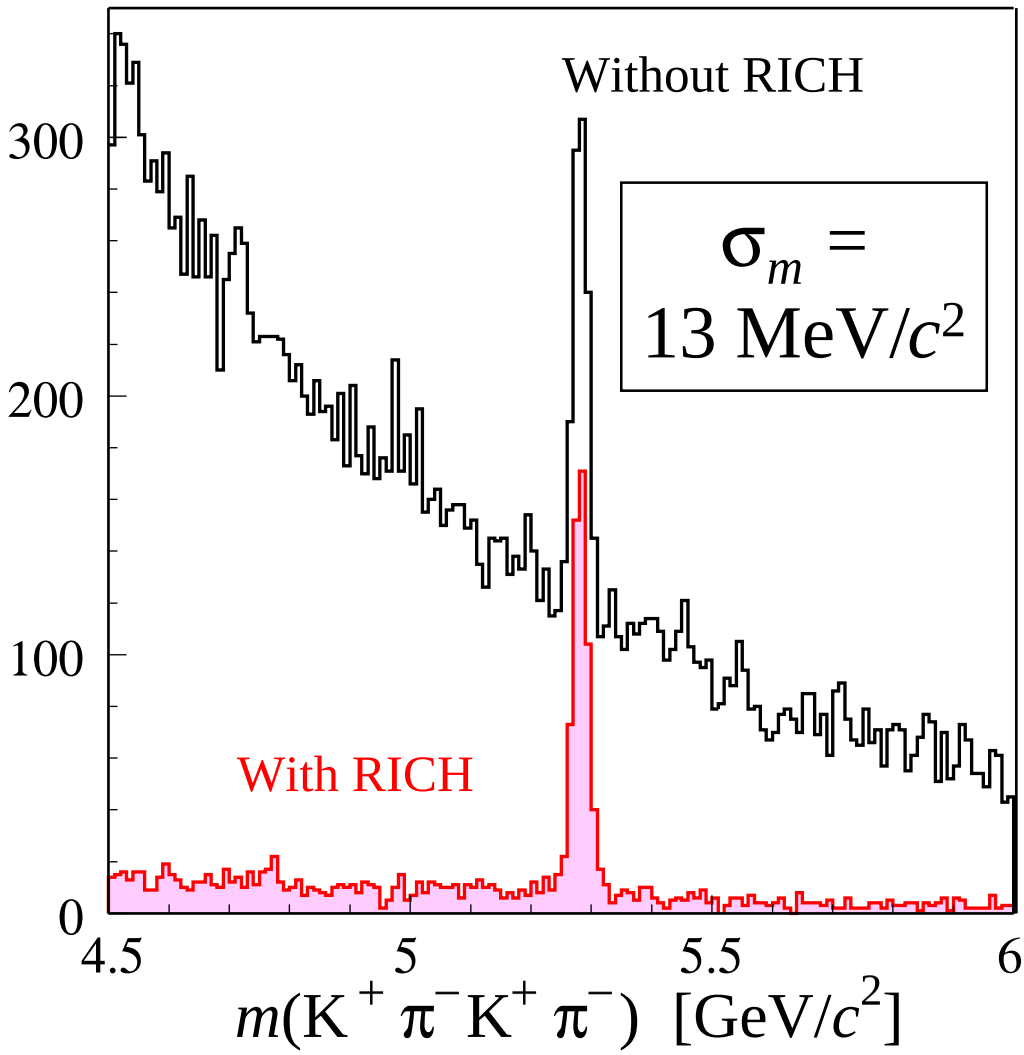
No hadronic uncertainties.

Experiment requires: K/π sepa

hadron tr

Very small visible branching fractions
(10^{-7}~10^{-8})

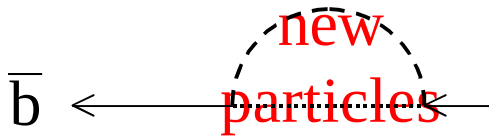
Importance of particle identification



More generally new physics can app

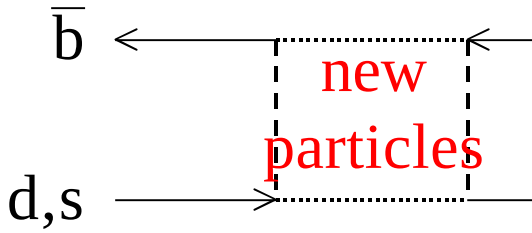
$\Delta b = 1$ process

through penguin

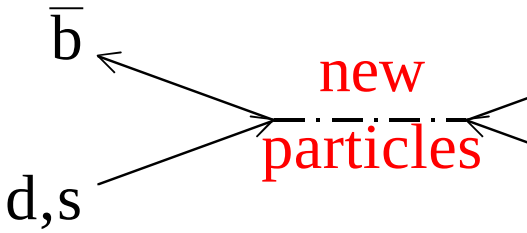


$\Delta b = 2$ process

through box



through tree



CP violation must be studied in

- B_d decays via Oscillations ⊗ b→c+W and b
- B_s decays via Oscillations ⊗ b→c+W and b
- $B_{d,s,u}$ decays via penguins
- $B_{d,s}$ decays via box

Experimental conditions are

- Small branching fractions → many $B_{d,s,u}$'s
- Rapid B_s oscillations → decay time resoluti
- Including multi-body hadronic final states –

→ ***LHCb*** **experiment**

An example of shopping list:	LHCb
$B_d \to J/\psi K_S$	✓
$B_s \to J/\psi \phi$	✓
$B_s \to D_S K$	✓
$B_d \to DK^*$	✓
$B_d \to D^*\pi$	✓
$B_d \to \pi\pi$	✓
$B_d \to K\pi$ ($\not{CP}$ in gluonic penguin)	✓
$B_d \to \rho\pi$ (BaBar 160 events, LHCb 670 events)	✓
$B_s \to K^*\gamma$ ($\not{CP}$ in radiative penguin)	✓
$B_s \to K^* l^+ l^-$ ($\not{CP}$ in radiative penguin)	✓
B_s oscillations, x_s up to	75
$B_s \to \mu^+\mu^-$	✓

V) Conclusions

1) New results on CP violation in the neut
will be available soon (~2000) and may
the Superweak model is not valid.

2) B-meson system will provide a rich fiel
violation studies.

3) BaBar, Belle, CDF, D0 and HERA-B w
violation in $B \rightarrow J/\psi K_S$ (>2000) if CP vi
largely due to the standard model.

4) In order to look for new physics, a dedi
experiment at LHC, i.e. *LHCb* is neede