Prospects for future CP violation Experiment in the B-meson system

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-CP violation has been seen only in
the neutral kaon system.

-Experimental attempt in the B-meson system:

$B_d^0(t=0) \rightarrow J/\psi\, K_S(t)$ vs. $\overline{B}_d^0(t=0) \rightarrow J/\psi\, K_S(t)$

OPAL: $\sin 2\beta_{J/\psi\, K_S} = 3.2\ ^{+\,1.8}_{-\,2.0} \pm 0.5$

CDF: $\sin 2\beta_{J/\psi\, K_S} = 1.8 \pm 1.1 \pm 0.3$

where $$\frac{\Gamma_{B^0 \rightarrow J/\psi\, K_S}(t) - \Gamma_{\overline{B}^0 \rightarrow J/\psi\, K_S}(t)}{\Gamma_{B^0 \rightarrow J/\psi\, K_S}(t) + \Gamma_{\overline{B}^0 \rightarrow J/\psi\, K_S}(t)} = \sin 2\beta_{J/\psi K_S} \sin\ \Delta m_d t$$

The next steps are

1) To observe CP violation in B-meson decays

2) To test whether CP violation is largely generated by the Standard Model

If the standard model is the main source of CP violation,
CP violation in $B_d^0 \rightarrow J/\psi\, K_S$ will be discovered by

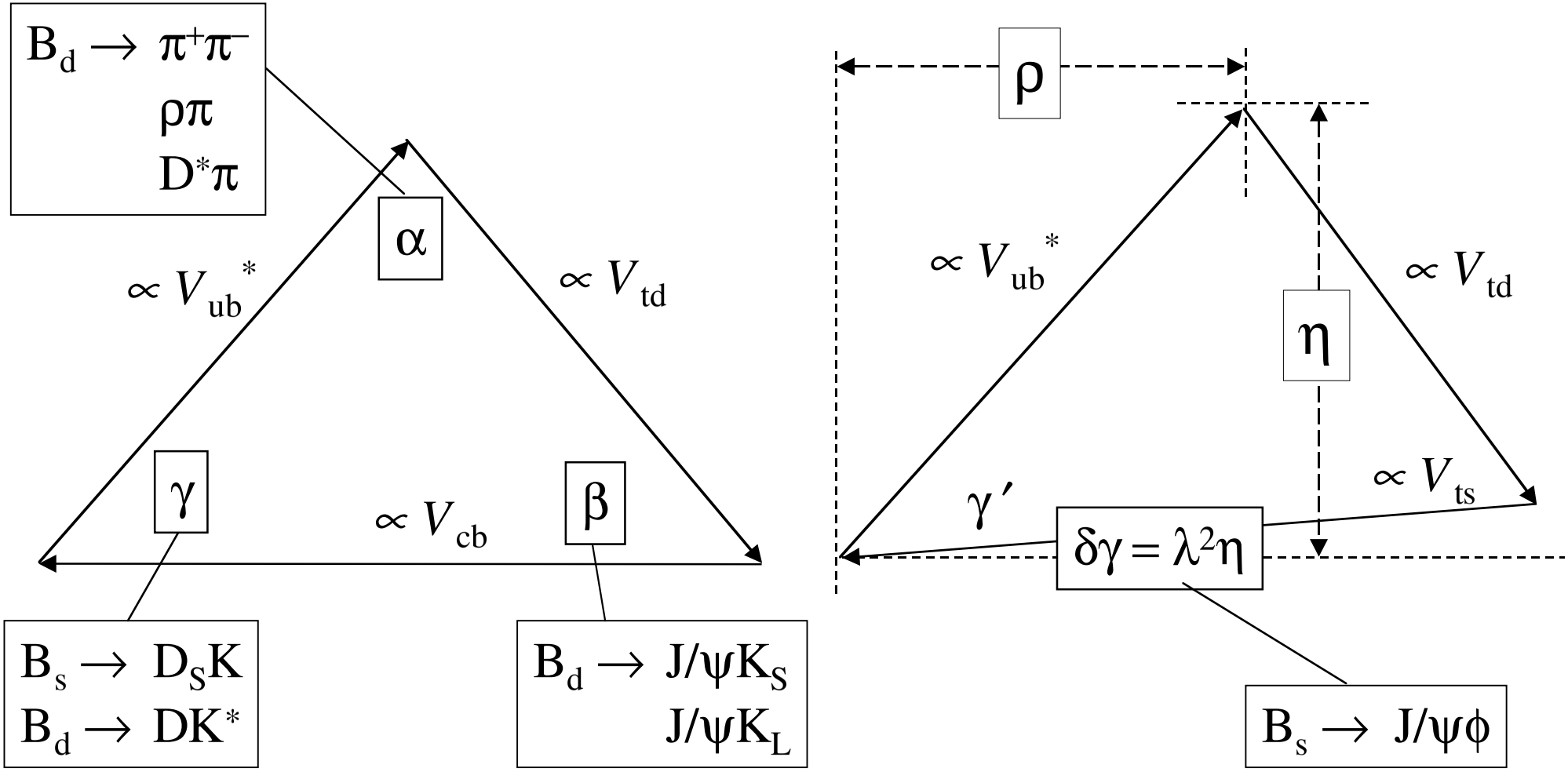
BaBar, BELLE
HERA-B
CDF, D0

} starting 1999~2000

Expected to be large: $0.3 < \sin 2\beta < 0.8$

CKM Unitarity Triangles

$$V_{td}\,V_{tb}^{*} + V_{cd}\,V_{cb}^{*} + V_{ud}\,V_{ub}^{*} = 0 \qquad V_{td}\,V_{ud}^{*} + V_{ts}\,V_{us}^{*} + V_{tb}\,V_{ub}^{*} = 0$$



(Theoretically clean channels)

"Golden" channels

β measurements:

$B_d \to J/\psi K_S$ + theoretically clean (little penguin)
+ experimentally easy

"γ" measurements:

$B_s \to D_s K$ + theoretically very clean (no penguin)
– need time development of B_s decays

$B_d \to DK^*$ + theoretically very clean (no penguin)
– very small visible branching fractions

"α" measurements:

$B_d \to D^*\pi$ + theoretically very clean (no penguin)
– very small asymmetry ($\sim 10^{-2}$)

"$\delta\gamma$" measurements:

$B_s \to J/\psi\phi$ + theoretically very clean (no penguin)
– need time development of B_s decays
– CP = +1/CP = –1 has to be measured

Penguin and "α" measurements

$B_d \to \pi^+\pi^-$

time dependent studies,

– penguin/tree must be known,

$B_d \to \pi^+\pi^-$, $\pi^0\pi^0$, $B_u \to \pi^+\pi^0$

isospin analysis using branching fractions

– small branching fractions ($\pi^0\pi^0$: ~10^{-6})

$B_d \to \rho^+\pi^-$, $\rho^0\pi^0$, $\rho^-\pi^+$

time dependent $\pi^+\pi^-\pi^0$ Dalitz plot studies

– small branching fractions ($\rho^0\pi^0$: ~10^{-6})

– possible contributions from non-resonance, re-scattering

etc.

	Experiment Now	In preparation (1998→2003)	R&D (2003 →?)
	sym. e^+e^-@Υ(4S) CLEO II	CLEO III	
$\sigma_{b\bar{b}}$	~1 nb		
L	4×10^{32}	1.7×10^{33}	3×10^{34}
$\sigma_{b\bar{b}}/\sigma_{hadronic}$	$\sim2\times10^{-1}$		
B-hadron	B_u, B_d		
Detector	central		
Trigger	all		
σ_t(B)	very modest		
Particle ID	e/μ/hadron limited π/K/p	e/μ/π/K/p	

few$\times10^7$ B's by ~2000: Rare decays, direct ~~CP~~ but not $J/\psi K_S$

Experiments in near future(~2000)			
	asym. e^+e^-	hadron	
	$\Upsilon(4S)$ BaBar/BELLE	p+metal@40GeV HERA-B	$p\bar{p}$@2TeV CDF/D0
$\sigma_{b\bar{b}}$	~1 nb	~760 nb	~60 μb
$B\bar{B}$/sec	3/10	38	6000
$\sigma_{b\bar{b}}/\sigma_{hadronic}$	$\sim 2\times 10^{-1}$	$\sim 10^{-6}$	$\sim 10^{-3}$
B-hadron	B_u, B_d	B_u,B_d,B_s,B_c	B_u,B_d,B_s,B_c
Detector	slightly forward	forward	central
Trigger	all	J/ψ	high p_t μ
σ_t	modest	good	good
Particle ID	e/μ/π/K/p	e/μ/π/K/p	e/μ/hadron

Around 2005, we will have all combined results of:

σ_β: ~ 0.02 [rad]

σ_α: depends on how well we understand strong interactions
penguin, re-scattering, SU(3), resonance etc.

x_s: depends on the value, measured if x_s<~20

$\sigma_{\delta\gamma}$: depends on x_s

Physics with "10^8" B's

α, γ, $\delta\gamma$, x_s would remain to be still open questions

For a significant improvement (>10^9 B's physics)
$\rightarrow$ new generation of experiments

Which is needed to discover New Physics.

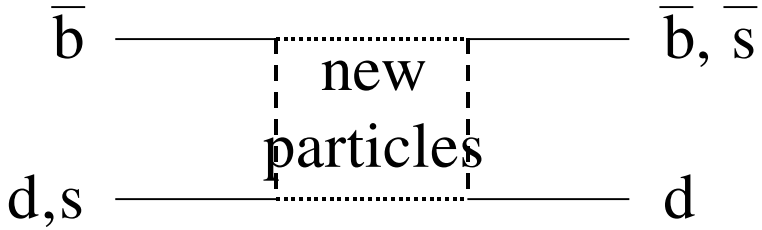
New physics can appear in

$\Delta b = 1$ process

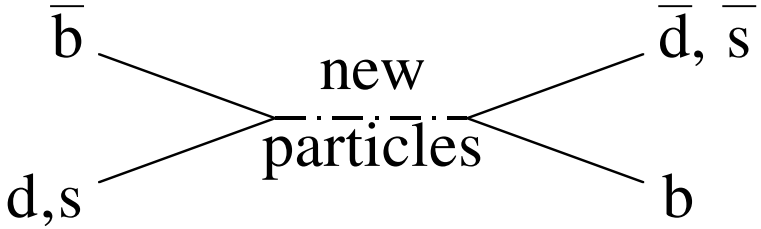
through penguin

$\Delta b = 2$ process

through box



through tree



CP violation must be studied in

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

Experimental conditions are

- Small branching fractions $\rightarrow$ many $B_{d,s,u}$'s
- Rapid B_s oscillations $\rightarrow$ decay time resolution
- Including multi-body hadronic final states $\rightarrow$ particle ID
  mass resolution

Experiments >~2005			
	pp@14TeV ATLAS/CMS* approved	pp@14TeV LHCb& recommended for approval	$p\bar{p}$@2TeV BTeV proposed
$\sigma_{b\bar{b}}$	~500 μb	~500 μb	~60 μb
$B\bar{B}$/sec	500k	100k	6-60k+
$\sigma_{b\bar{b}}/\sigma_{hadronic}$	$\sim 5\times10^{-3}$	$\sim 5\times10^{-3}$	$\sim 10^{-3}$
B-hadron	B_u, B_d, B_s, B_c	B_u, B_d, B_s, B_c	B_u, B_d, B_s, B_c
Detector	central	forward	double forward
Early trigger (reduction >100)	high p_t μ	medium p_t e/μ/h ⊗vertex	vertex
σ_t	good	very good	very good
Particle ID	e/μ/hadron	e/μ/π/K/p	e/μ/π/K/p

*$L=10^{33}$ for the first few years, &$L=2\times10^{32}$ for many years, +$L=1\text{-}10\times10^{32}$

>2005

New generation of experiments could give

σ_β: < 0.01

$\sigma_{\delta\gamma}$: < 0.01

x_s: up to x_s~40 (ATLAS/CMS), ~80 (LHCb/BTeV)

In addition, due to the particle identification capability and efficient trigger, dedicated experiments could give

σ_γ: < 0.1

σ_α: < 0.1

} **essential for discovering new physics**

using various decay modes.

Also:

$B_s \to K^* l^+ l^-$, $K^*\gamma$, $\mu^+\mu^-$, $B_d \to \phi K_S$, rare D and tau decays etc.

Conclusions

CP violation studies in B-meson decays have just started.
Exploratory works will be done by (<2005)

BaBar, BELLE: asymmetric e+e- machine at $\Upsilon(4S)$
CLEO III: symmetric e^+e^- machine at $\Upsilon(4S)$
HERA-B: fixed target experiment with the HERA proton beam
CDF, D0: general purpose central detector at Tevatron

Thorough work will be done by (>2005)

at LHC
ATLAS and CMS (approved general purpose experiments)
and
LHCb (recommended special purpose experiment)
at Tevatron
BTeV (proposed special purpose experiment)

We all hope to discover New Physics!