V_{ub} and the Case for New Physics in the B Sector

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Introduction

- LHC is a discovery machine, not a precision tool
- Many properties of new particles (if discovered) cannot be measured at LHC
- Need for facilities offering highest precision: high-luminosity experiments at low energies (B, K, neutrinos, g-2, EDMs, $0\nu\beta\beta$ decay, ...)
- Complementarity with energy frontier!
  → talk by M. Carena

Introduction

- At present, best indications for New Physics come from low-energy precision experiments
  - Muon anomalous magnetic moment
  - B physics (several intriguing effects):
    - $\sin 2\beta$: tree vs. penguin (2.6σ)
    - $\sin 2\beta$ vs. UT fit (2.9σ)

Introduction

- Other small effects: → talks by P. Ball, P. Gambino
  - B_s-$\overline{B}_s$ mixing phase 2σ off SM value
    [Lenz, Nierste, hep-ph/0612167]
  - NNLO prediction for $B \to X_s\gamma$ is 1.4σ lower than world-average experimental result
    [Misiak et al., hep-ph/0609232; Becher, MN, hep-ph/0610067]

$$\mathrm{Br}(\bar{B} \to X_s\gamma) = (2.98\,^{+0.13}_{-0.17\,\mathrm{pert}} \pm 0.16_{\mathrm{hadr}} \pm 0.11_{\mathrm{pars}} \pm 0.09_{m_c}) \cdot 10^{-4}$$

Combined theory error: ±9%

cf.: $B_{exp}(E_\gamma > 1.6\ \mathrm{GeV}) = (3.55 \pm 0.24 \pm 0.09 \pm 0.03) \cdot 10$

- Re-opens possibility for sizable NP contributions!

Introduction

- We probably won't establish New Physics in any of these channels prior to LHC data
- But after an LHC (or Tevatron) discovery, we would reinterpret the effects in terms of measurements of new flavor parameters
- If effects are real, low-energy experiments (LHC*b*, Super-B, K) will contribute greatly to comprehensive exploration of TeV scale

Introduction

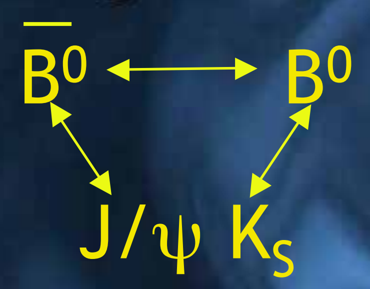
- *Important*: scenarios with O(0.1) New Physics contributions to amplitudes still possible (not necessarily MFV)
- Indeed, favored by present data!

Two intriguing puzzles

Hints for New Physics in rare B decays and/or B-$\bar{B}$ mixing

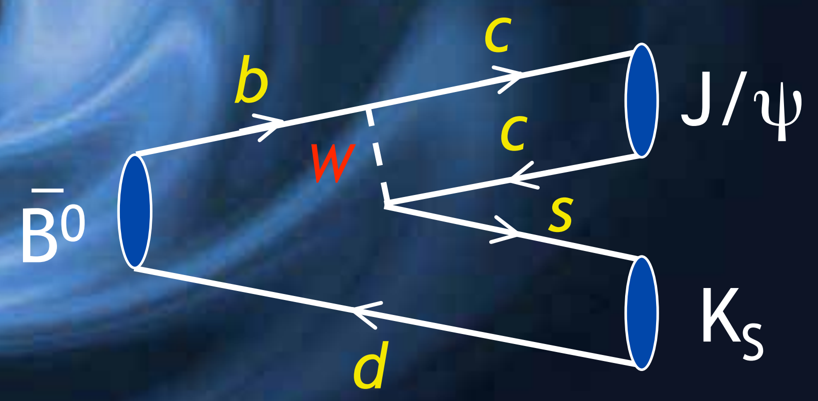
CP asymmetry in $B \to J/\psi K_S$

- Interference of mixing and decay:



- Time-dependent CP asymmetry measures $\sin 2\beta$

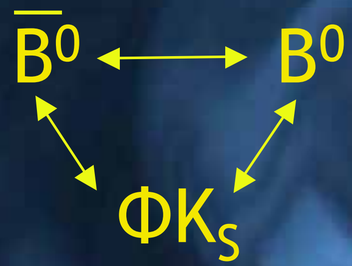
- Decay amplitude real to excellent approximation:



$S(J/\psi\ K_S) = \sin 2\beta = 0.675 \pm 0.026$ (WA)

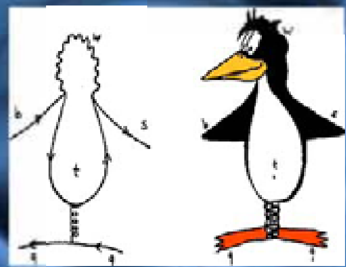
CP asymmetries in $B \to \Phi K_S, \eta' K_S$

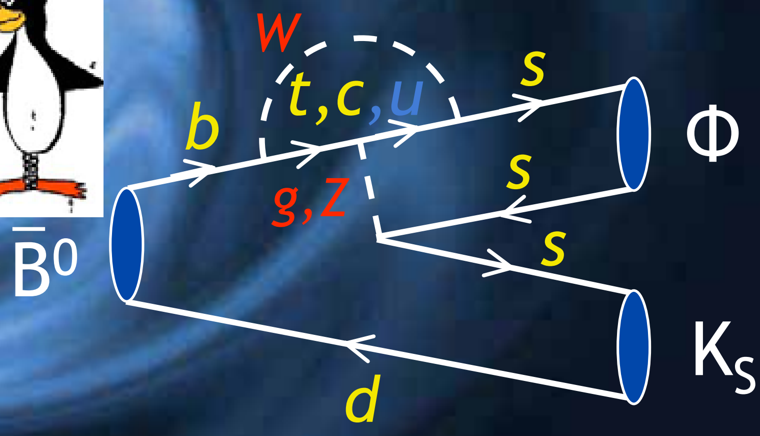
- Interference of mixing and decay:



- Phase structure identical to golden decay $B \to J/\psi\, K_S$
- Theor. prediction:

- Penguin graph real to excellent approx.:



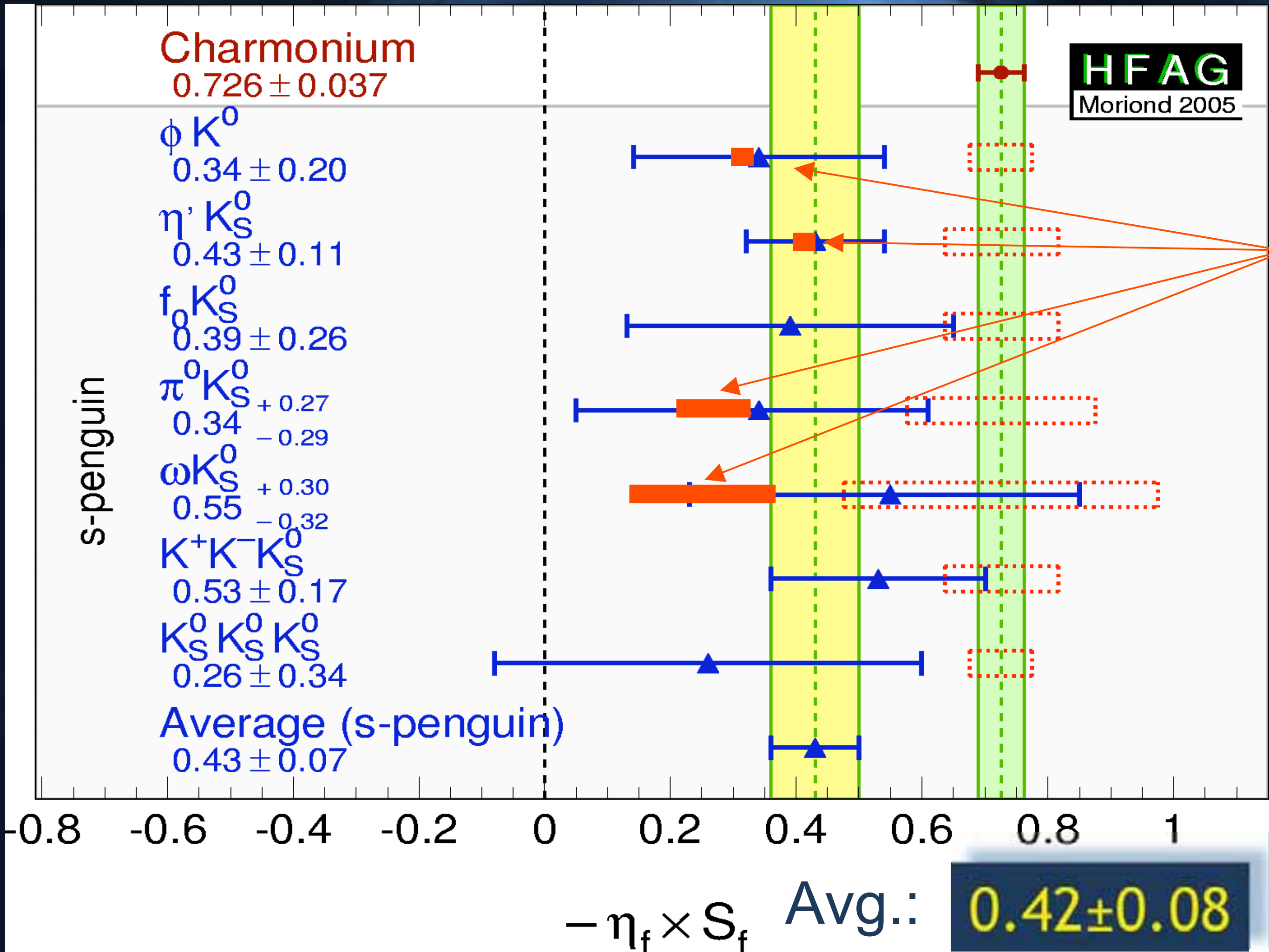


[Grossman, Worah (1996)]

$$S(\Phi K_S) - S(J/\psi\, K_S) = 0.02 \pm 0.01$$

Similar for $\eta' K_s$: 0.01 ± 0.01 [Beneke, MN (2003)]

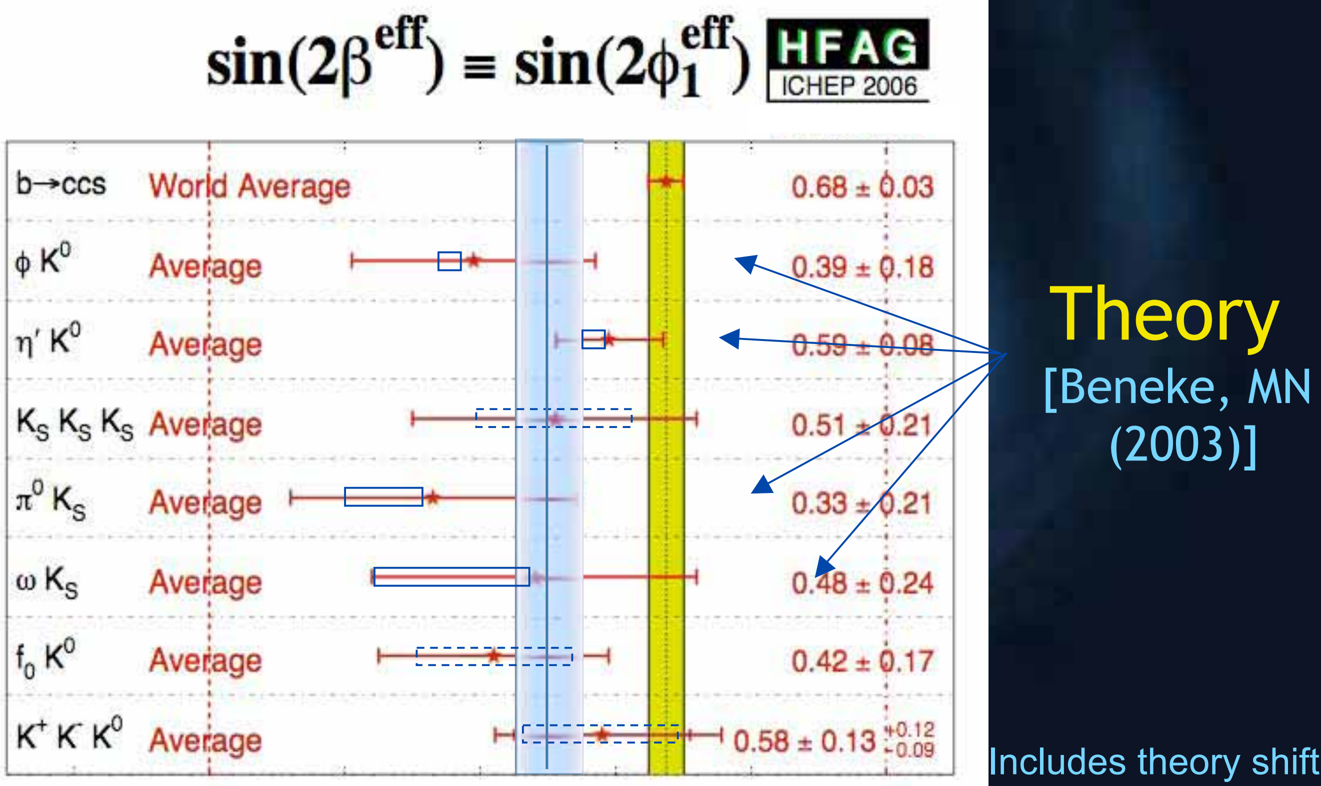
2005: 7 reasons for excitement



Theory
[Beneke, MN (2003)]

Deviation of 3.8σ!

Current situation (2006)



Avg.: 0.50 ± 0.06

Includes theory shifts and uncertainties; naïve HFAG avg.: 0.52 ± 0.05

Deviation of 2.6σ

Current situation (2006)

- New Physics explanation would invoke non-standard penguin contributions, preferably in electroweak sector (effect insensitive to New Physics in mixing)

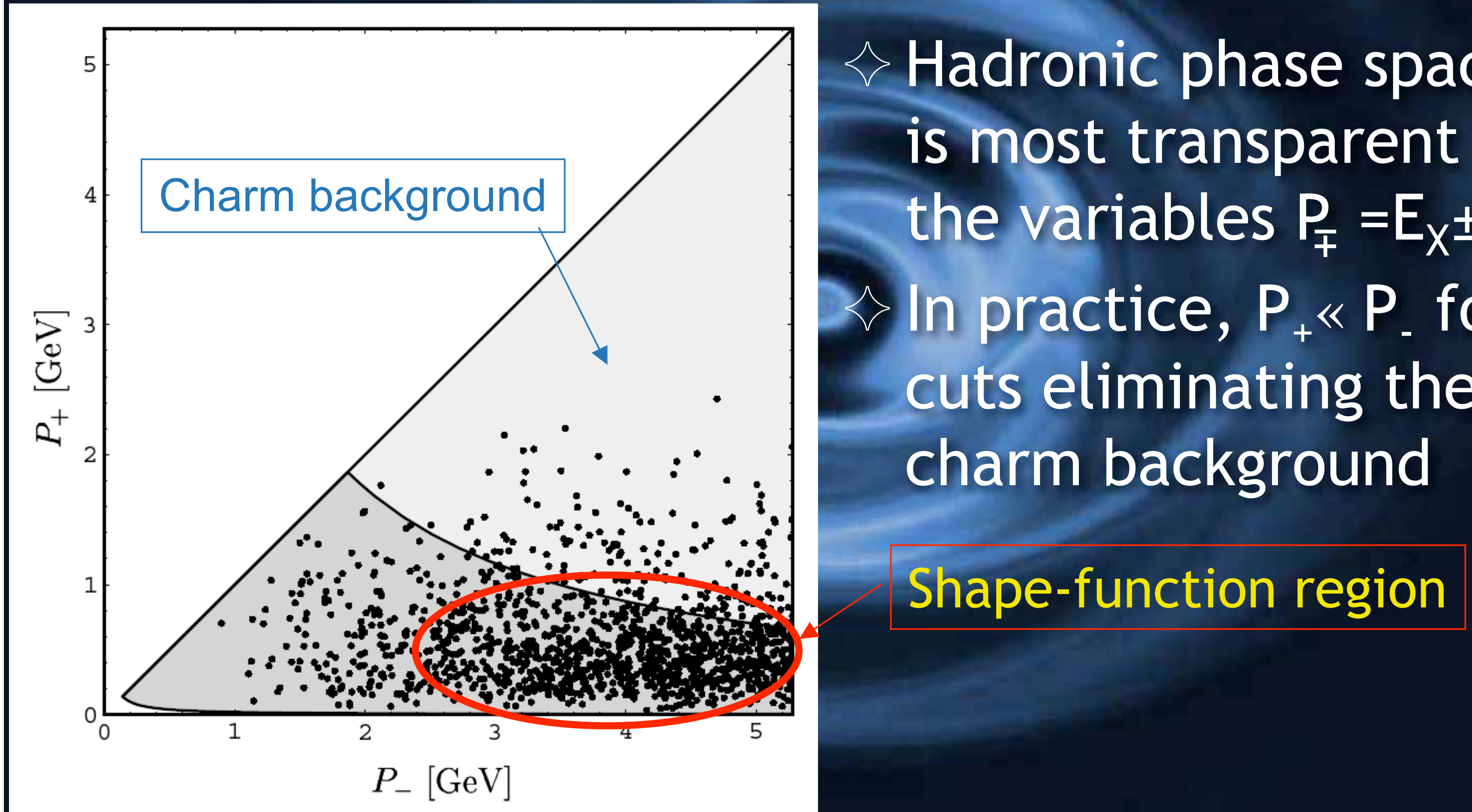
Current situation (2006)

- New Physics explanation would invoke non-standard penguin contributions, preferably in electroweak sector (effect insensitive to New Physics in mixing)
- If we believe this is a statistical fluctuation, then all determinations can be averaged to give $\sin 2\beta = 0.647 \pm 0.024$
- This value is significantly smaller than SM expectation!

Precision determinations of $|V_{ub}|$

Breaking the 10% barrier

Inclusive semileptonic decays



- Hadronic phase space is most transparent in the variables $P_{\mp} = E_X \pm P_X$
- In practice, $P_+ \ll P_-$ for cuts eliminating the charm background

Inclusive B→light decays

- Factorization formula:

$$d\Gamma(B \to \text{light}) = H\, J \otimes S$$

Hard and jet functions (perturbative)

Shape function = PDF (nonperturbative)

- Large logs resummed using RGEs
- Shape function universal (process-independent)

Strategy

- Extract shape function from $B \to X_s\gamma$ photon spectrum, then predict arbitrary distributions in $B \to X_u l\nu$ decay

[Bosch, Lange, MN, Paz (2004); Lange, MN, Paz: hep-ph/0504071]

- Functional form constrained by model-independent moment relations
  - Knowledge of m_b and μ_π^2 helps
- Variant: construct "shape-function independent relations" between spectra (equivalent)

[MN (1993); Leibovich, Low, Rothstein (2000); Lange, MN, Paz: hep-ph/0508178]

Predictions for various cuts

	m_b [GeV]	4.50	4.55	4.60	4.65	4.70	Theory Error
$M_X \leq M_D$ Eff = 84%	a Functional Form	9.5 1.4%	8.8 1.1%	8.2 0.8%	7.7 0.5%	7.3 0.4%	7%
$M_X \leq 1.7\,\mathrm{GeV}$ Eff = 75%	a Functional Form	12.5 2.9%	11.5 2.6%	10.5 2.2%	9.7 1.9%	8.9 1.6%	7%
$M_X \leq 1.7\,\mathrm{GeV}$ $q^2 \geq 8\,\mathrm{GeV}^2$ 35%	a Functional Form	10.3 2.0%	9.8 1.7%	9.3 1.5%	9.0 1.4%	8.7 1.4%	10%
$q^2 \geq (M_B - M_D)^2$ Eff = 18%	a Functional Form	11.4 5.0%	11.1 4.4%	10.9 4.0%	10.8 3.6%	10.6 3.2%	15%
$P_+ \leq M_D^2/M_B$ Eff = 65%	a Functional Form	16.7 5.3%	15.0 4.8%	13.6 4.4%	12.2 4.0%	11.1 3.6%	7%
$E_l \geq 2.2\,\mathrm{GeV}$ Eff = 11%	a Functional Form	22.6 16.2%	21.0 13.1%	19.7 11.0%	18.5 9.3%	17.4 7.9%	19%

Rate $\Gamma \sim (m_b)^a$

Results for various cuts

	nominal f_u	$\lvert V_{ub}\rvert \times 10^3$
*CLEO [79] $E_e > 2.1$ GeV	0.19	$4.02 \pm 0.47 \pm 0.35$
*BABAR [82] E_e, s_h^{max}	0.19	$4.06 \pm 0.27 \pm 0.36$
*BABAR [81] $E_e > 2.0$ GeV	0.26	$4.23 \pm 0.27 \pm 0.31$
*BELLE [80] $E_e > 1.9$ GeV	0.34	$4.82 \pm 0.45 \pm 0.31$
*BABAR [86] M_X/q^2	0.34	$4.76 \pm 0.34 \pm 0.32$
*BELLE [87] M_X/q^2	0.34	$4.38 \pm 0.46 \pm 0.30$
BELLE [85] M_X/q^2	0.34	$4.68 \pm 0.37 \pm 0.32$
BELLE [85] $P_+ < 0.66$ GeV	0.57	$4.14 \pm 0.35 \pm 0.29$
*BELLE [85] $M_X < 1.7$ GeV	0.66	$4.08 \pm 0.27 \pm 0.25$
Average of *		$4.38 \pm 0.19 \pm 0.27$
$\chi^2 = 5.9/6$, CL=0.43		Status 2005

Most recent HFAG update: $|V_{ub}| = (4.52 \pm 0.19 \pm 0.27) \cdot 10^{-3}$

Shape-function free relations

✧ Example for $P_+ = E_X - P_X$ spectrum:

$$\Gamma_u(\Delta) = \underbrace{\int_0^\Delta dP_+ \frac{d\Gamma_u}{dP_+}}_{\text{exp. input}} = |V_{ub}|^2 \int_0^\Delta dP_+ \underbrace{W(\Delta, P_+)}_{\text{theory}} \underbrace{\frac{1}{\Gamma_s(E_*)} \frac{d\Gamma_s}{dP_+}}_{\text{exp. input}}$$

- ✧ Weight function perturbatively calculable
- ✧ Small hadronic uncertainties enter at order $1/m_b$ [Lange, MN, Paz: hep-ph/0508178]

BaBar analysis (Feb. 2007): $|V_{ub}| = (4.40 \pm 0.30 \pm 0.41_{th} \pm 0.23) \cdot 10^{-3}$ consistent

Combined result

- Theory error on $|V_{ub}|$ is 5-10% for several different cuts (10% now conservative - seemed unrealistic only a few years ago)
- Average of different extractions gives $|V_{ub}|$ with a *total* error of 6%:

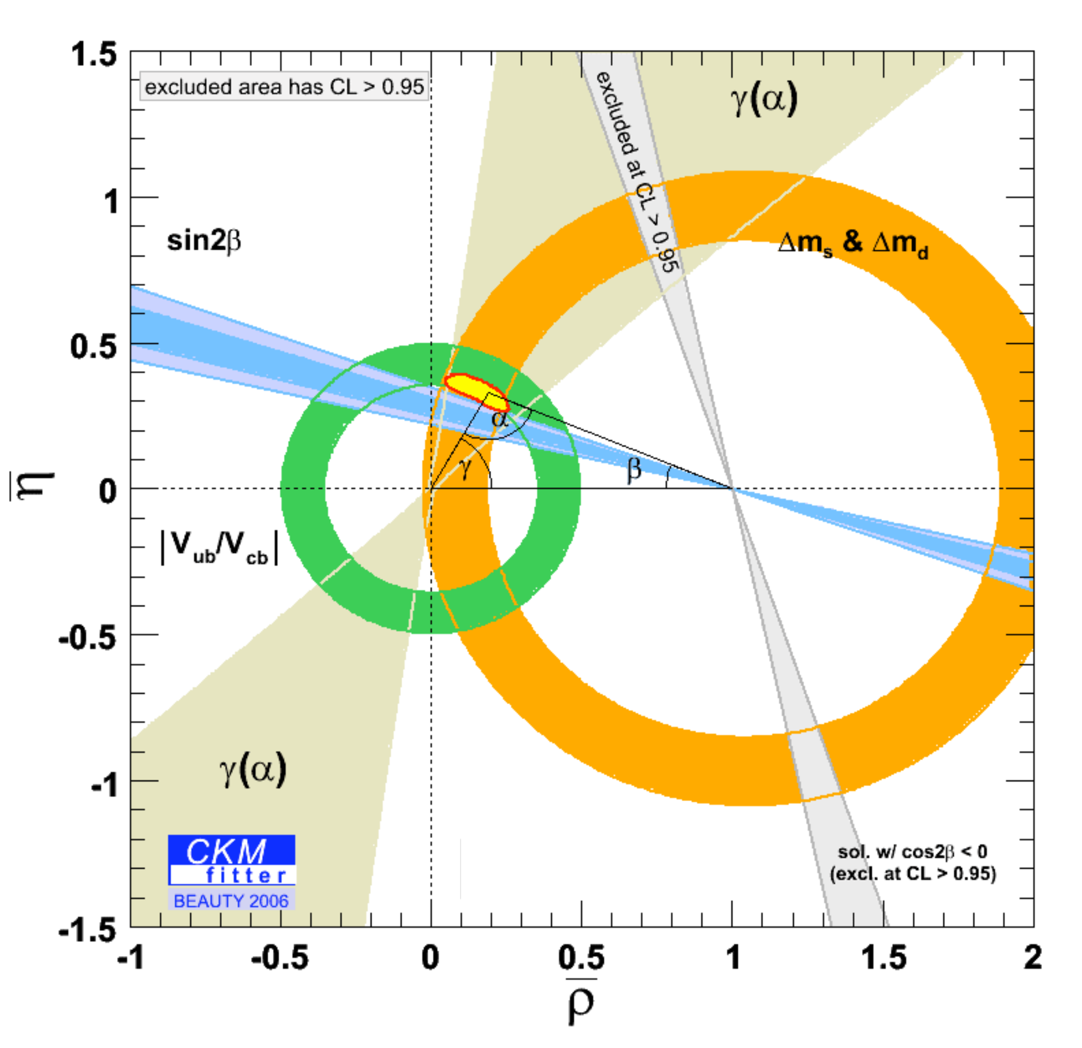
$$|V_{ub}| = (4.49 \pm 0.28)\cdot 10^{-3}$$

- Needed to match the precision of sin2β

Exclusive $B \to \pi l \nu$ + most recent lattice date (HPQCD '06): $(3.97^{+0.63}_{-0.47})\cdot 10^{-3}$

Impact of precise $|V_{ub}|$

- Combined average $\sin 2\beta = 0.647 \pm 0.024$ below "tree" value $\sin 2\beta = 0.794 \pm 0.045$ deduced from $|V_{ub}|$ and $|V_{td}|$
- Deviation 2.9σ (!)
- Increased precision in $|V_{ub}|$ and recent measurement of B_s-$\bar{B}_s$ mixing (D0, CDF) crucial



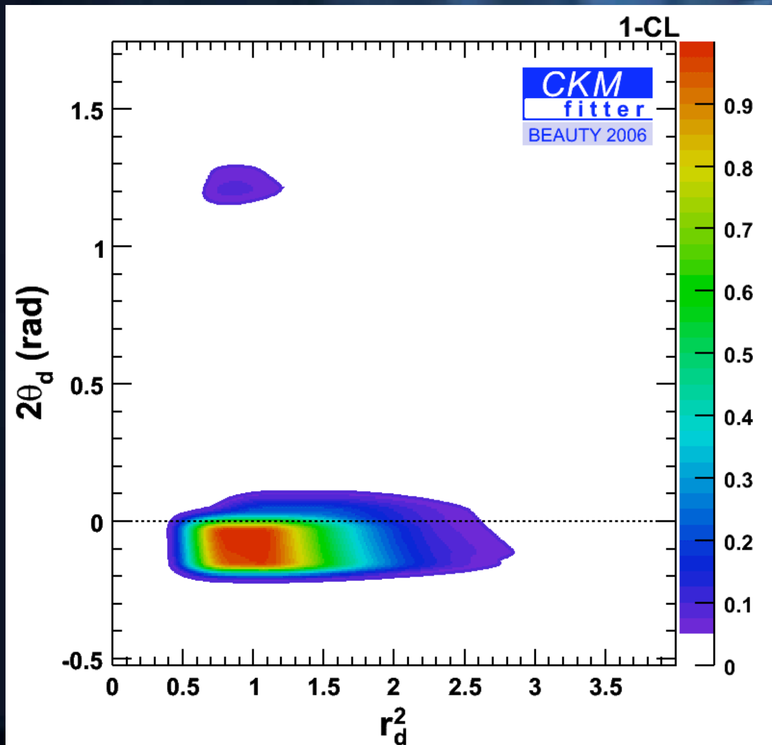
New Physics in B_d-$\bar{B}_d$ mixing?

- Most plausible explanation of the effect
- Possible and even natural in extensions of SM with new particles near TeV scale (e.g. SUSY, new Z’ bosons, extra dimensions …)
- Requires O(0.1-0.2) New Physics contribution to mixing amplitude

New Physics in B_d-$\bar{B}_d$ mixing?

- General parametrization:

$$\Delta m_d = \Delta m_d^{SM} * r_d^2 \, e^{i2\theta_d}$$



- New Physics contributions up to 50% of SM allowed
- Best fit prefers new, CP-violating phase $\theta_d \neq 0$
- After discovery of new particles at LHC → allowed parameter space for new flavor parameters

Why do I believe these effects might be real?

New Physics?

- It is not easy to affect rare B-decay processes, since by far dominant part of QCD penguin comes from mixing with SM 4-quark operators
- New Physics contributions can be sizeable for dipole operators, electroweak penguins, $\Delta F=2$ operators
- $\Delta F=2$ operators and electroweak (Z) penguin receive largest GIM violations (terms $\sim m_t^2$)

New Physics?

- Physical processes sensitive to these coefficients are B-$\bar{B}$ mixing (B_d and B_s) and rare, penguin-dominated B decays
- Indeed, this is where we see deviations from the Standard Model (experimental situation stable since several years)

Summary

- If present effects are real, future flavor physics experiments will help to determine or place constraints on flavor parameters of some new particles (e.g., quark-squark-gluino couplings in SUSY, KK fermions, …)
- Much like B-factories did for b- and t-quarks (V_{cb}, V_{ub}, V_{ts}, V_{td}, β, γ)

Summary

- Otherwise, absence of new sources of flavor-violation at TeV scale would teach us important lessons about nature of EWSB, and perhaps SUSY breaking
- Super flavor factories would play a similar role as LEP did for the understanding of EWSB
- It would impose severe constraints on model building for the post-LHC era