Status and future of flavor physics and CP violation

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NIKHEF, Feb. 14, 2003

- Introduction to flavor physics

  ... Why bother? What are we after?

- Status of CKM matrix

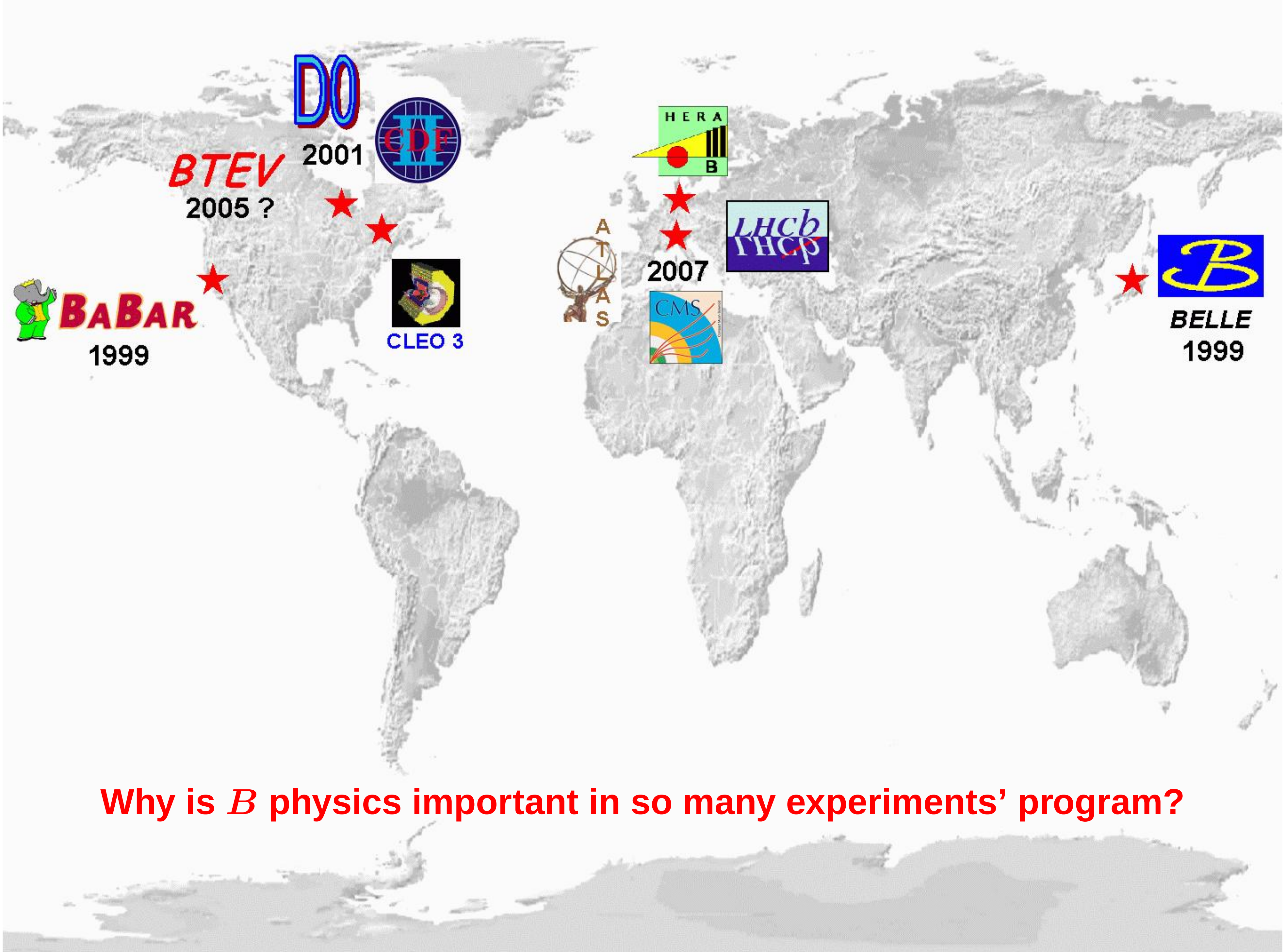
  ... Why are $\sin 2\beta$ and $B_{d,s}$ mixing clean?

- Future – what are the good tests?

  ... Some nice and clean measurements

  ... Bits of theory

- Conclusions



Why is B physics important in so many experiments' program?

Why is CPV interesting?

- Almost all extensions of the SM contain new sources of CP and flavor violation
- A major constraint for model building, may distinguish between NP models
- The observed baryon asymmetry of the Universe requires CPV beyond the SM (not necessarily in flavor changing processes)

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not true:

"CPV is a mystery"

... the SM with 3-generations "predicts" it

"CPV is one of the least understood parts of the SM"

... $\sin 2\beta$, ϵ_K, ϵ' are all in the right ballpark

Baryogenesis

$$\frac{\#\text{ baryons}}{\#\text{ photons}} \sim 10^{-9} \text{ now} \iff \frac{n_q - n_{\bar{q}}}{n_q + n_{\bar{q}}} \sim 10^{-9} \text{ at } t < 10^{-6}\,\text{sec } (T > 1\,\text{GeV})$$

- To produce such an asymmetry, need (Sakharov conditions)

1. baryon number violating interactions
2. C and CP violation
3. deviation from thermal equilibrium

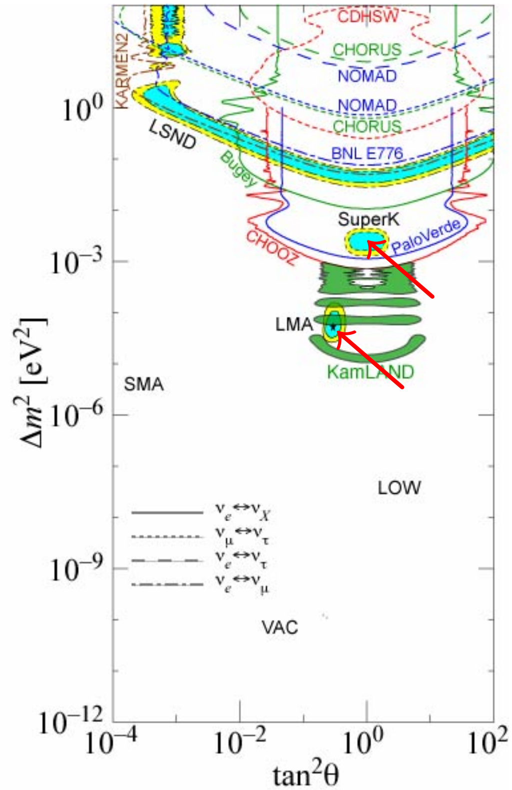
- SM contains 1–3, but

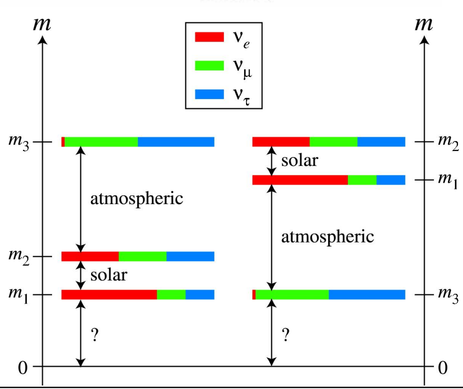
A. CP violation is too small

B. deviation from thermal equilibrium too small with just one Higgs doublet

NP models can solve A–B near the weak scale, and may have observable effects (possibly only in flavor diagonal processes, such as electric dipole moments)

Neutrinos and leptogenesis





Two large mixing angles observed — a real surprise!

Leptogenesis appears more and more plausible:

... generate $B - L$ by CPV decay of $\nu_{\rm heavy}$

... $\nu_{\rm heavy}$ lives long enough to decay when $T < m_{\nu_{\rm heavy}}$

Baryon asymmetry due to $B + L$ violating but $B - L$ conserving processes above electroweak phase transition

Relevant CPV parameters may or may not be related to CPV in light neutrino sector

Connection to $\sim$TeV scale is model dependent

Central questions about the SM

1. Origin of electroweak symmetry breaking:

   $SU(2)_L \times U(1)_Y \to U(1)_{\rm EM}$

   spontaneous breaking of a gauge symmetry by $v \sim 250\,$GeV VEV

   $W_L W_L \to W_L W_L$ breaks unitarity $\sim 1\,$TeV ... determines scale of Higgs / NP

2. Origin of flavor symmetry breaking:

   $U(3)_Q \times U(3)_u \times U(3)_d \to U(1)_{\rm Baryon}$ (for leptons don't even know yet!)

   Global symmetries (e.g, d_R, s_R, b_R identical if massless) broken by dimensionless Yukawa couplings ... we do not know the relevant scale

   There is no "standard" new physics scenario in flavor sector

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It would be nice if there was a connection — flavor physics depends on both

... Yukawa couplings determine quark masses, mixing, and CP violation

Central questions of flavor physics

1. Does the SM (only virtual quarks, W, and Z interacting through CKM matrix in tree and loop diagrams) explain all flavor changing interactions?
2. At what level and where could we see deviations?

Need: Experimental precision and Theoretical precision — cleanliness

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New physics most likely to modify:

– SM loop processes: mixing
rare decays

– CP violation

So we want to measure:

– mixing & rare decays

– CPV asymmetries

– compare tree and loop processes

- The point is not simply to measure CKM elements, but to overconstrain the SM by many "redundant" measurements; correlations may be crucial to narrow down NP

The track record

- Bits of history: $K\overline{K}$ mixing $\Rightarrow$ GIM & charm
  CP violation $\Rightarrow$ KM & three generations
  $B\overline{B}$ mixing $\Rightarrow$ heavy top

- Best sensitivity to some particles predicted in the MSSM comes from (crudely...)

experiment	energy scale	best sensitivity to
Tevatron	~ 2 TeV	squarks, gluinos
LEP	~ 200 GeV	sleptons, charginos
$B \to X_s\gamma$	~ 5 GeV	charged Higgs

If $\Lambda_{\rm NP} \gg \Lambda_{\rm EW}$: no observable effects in B decays $\Rightarrow$ precise SM measurements

If $\Lambda_{\rm NP} \sim \Lambda_{\rm EW}$: sizable effects possible $\Rightarrow$ could get detailed information on NP

The problem: strong interactions

- Can we learn about high energy physics from low energy hadronic processes?

Solutions: – Symmetries of QCD (exact or approximate)

– Certain processes are determined by short-distance physics

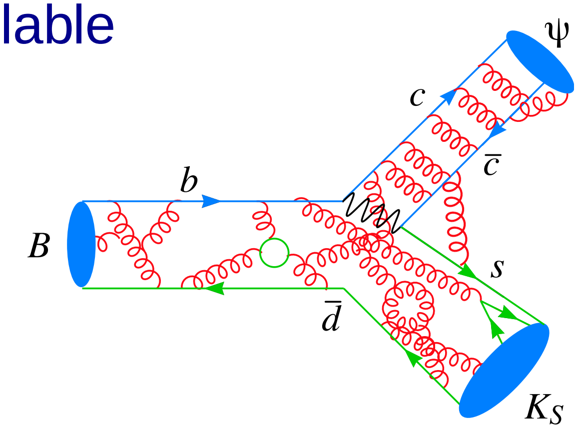
Sometimes possible to combine data and symmetries to eliminate hadronic mess

Example: $\sin(2\beta)$ from $B \to \psi K_S$ — amplitude not calculable

Solution: CP symmetry of QCD ($\theta_{\rm QCD}$ can be neglected)

Magnitude of the amplitude does not matter, as long as dominated by contributions with one weak phase

$$\langle \psi K_S | \mathcal{H} | B^0 \rangle = -\langle \psi K_S | \mathcal{H} | \overline{B}^0 \rangle \times [1 + \mathcal{O}(\alpha_s \lambda^2)]$$



- The key processes are those which can teach us about high energy physics without hadronic uncertainties

Status of CKM matrix

CKM matrix and the unitarity triangle

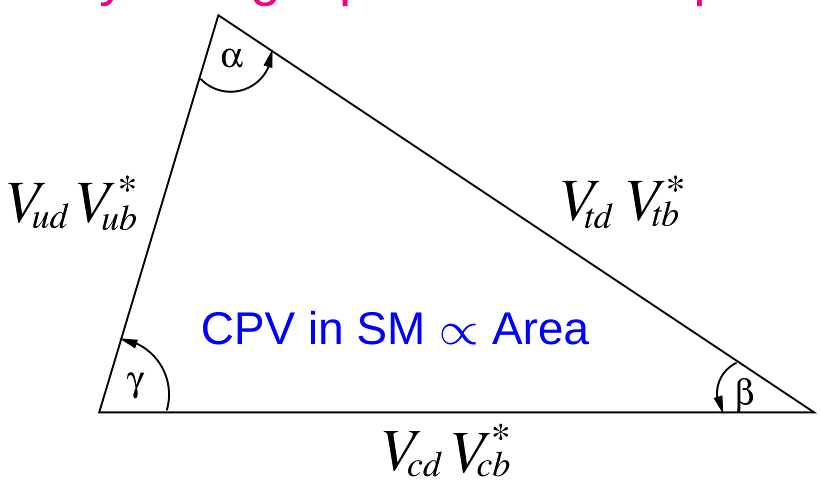
- Charged current weak interactions — CKM matrix:

$$(u,\ c,\ t)\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}\begin{pmatrix} d \\ s \\ b \end{pmatrix} \qquad \begin{matrix} \sim 1 \\ \sim \lambda \\ \sim \lambda^2 \\ \sim \lambda^3 \end{matrix} \qquad \lambda \sim 0.22$$

Elements depend on 4 real parameters (3 angles $+$ 1 CPV phase)

$\mathbf{V}_{\mathrm{CKM}}$ is the only source of CPV in the SM (except for possible θ_{QCD} term)

- The unitarity triangle provides a simple way to visualize the SM constraints



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

The angles and sides are directly measurable — want to overconstrain this picture

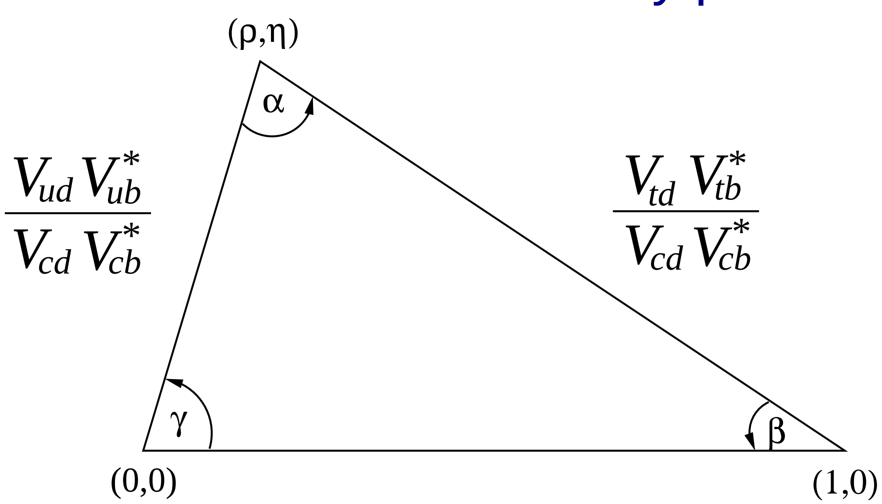
Wolfenstein parameterization

- It is convenient to exhibit the hierarchical structure by expanding in $\lambda = \sin\theta_C$

$$V = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

Present uncertainties: $\lambda \sim 1\%$, $A \sim 5\%$, $\eta/\rho \sim 7\%$, $\sqrt{\rho^2+\eta^2} \sim 20\%$,

- Constraints on CKM usually plotted on the $(\bar\rho, \bar\eta)$ plane



Main uncertainties of two sides:

V_{td} — $B_{d,s}$ mixing

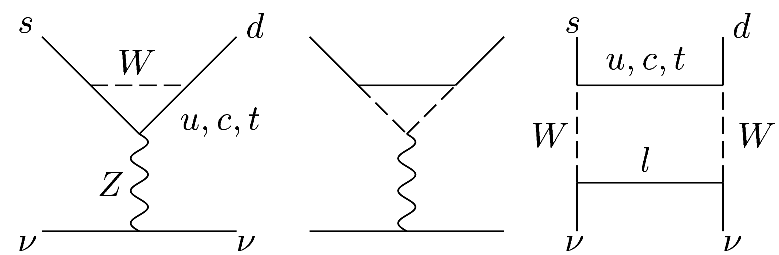
V_{ub} — semileptonic B decay

Why B physics?

- CPV in K system is at the right level (ϵ_K can be described with $\mathcal{O}(1)$ CKM phase); hadronic uncertainties preclude precision tests (ϵ'_K notoriously hard to calculate)

  Plan to measure $K \to \pi\nu\overline{\nu}$ — theoretically clean, but $\mathcal{B} \sim 10^{-10}(K^\pm),\ 10^{-11}(K_L)$

$$\mathcal{A} \propto \begin{cases} (\lambda^5\, m_t^2) + i(\lambda^5\, m_t^2) & t: \text{CKM suppressed} \\ (\lambda\, m_c^2) + i(\lambda^5\, m_c^2) & c: \text{GIM suppressed} \\ (\lambda\, \Lambda_{\rm QCD}^2) & u: \text{GIM suppressed} \end{cases}$$



- In D decays the SM predicts small CPV — both GIM and CKM suppressed

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- In the B meson system, large variety of interesting processes:
  - top quark loops neither GIM nor CKM suppressed (large mixing, rare decays)
  - large CP violating effects possible, some of which have clean interpretation
  - some of the hadronic physics understood model independently ($m_b \gg \Lambda_{\rm QCD}$)

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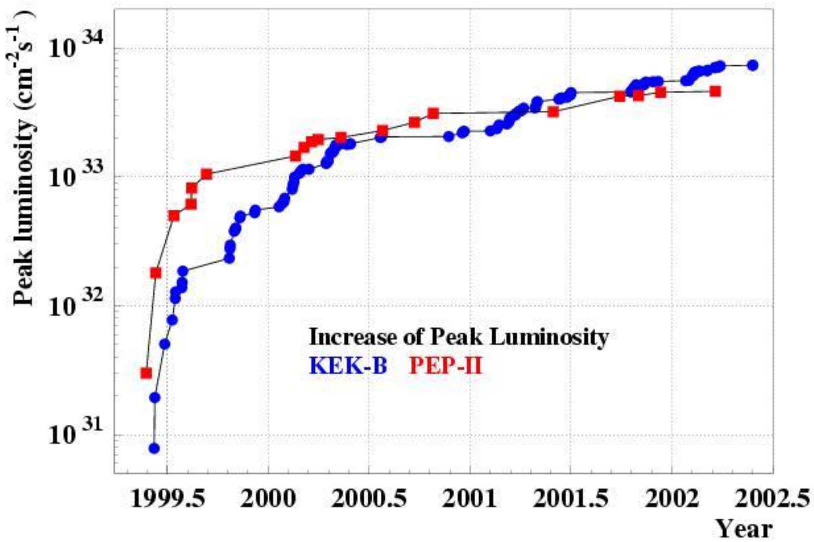
A new era: B factories

- Number of B meson pairs accessible to experimental studies:

Summer '99: ~ 10 million
Summer '00: ~ 30 million
Summer '01: ~ 90 million
Summer '02: ~ 200 million

} Beginning of exciting era



During this talk Babar (SLAC) and Belle (KEK) should produce $10 - 20$ k B meson pairs each

Next 4–5 years: $\gtrsim 10^9$ B decays will be studied

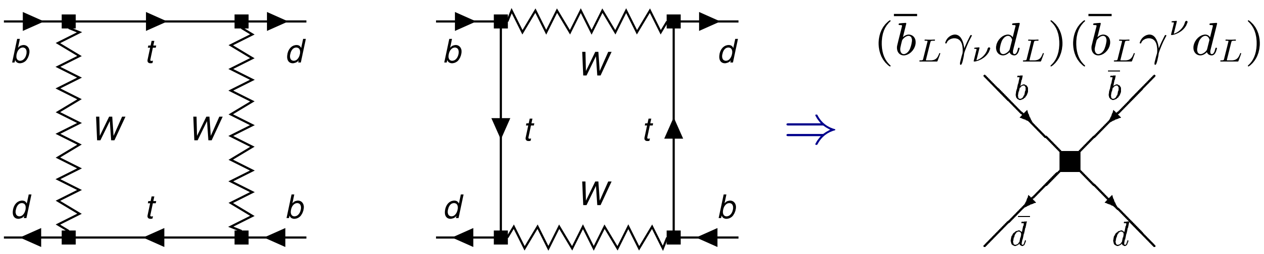
And it's after these that LHCB/BTeV and maybe a super-B-factory enter the stage

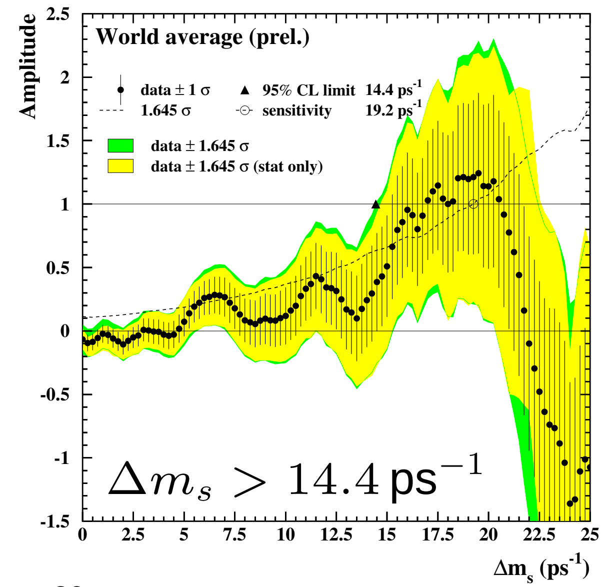
$B_{d,s}$ mixing and $\sin 2\beta$

$B_{d,s}$ mixing: $|V_{td}|$ and $|V_{ts}|$

Two mass eigenstates: $|B_{H,L}\rangle = p\,|\bar{b}\,d\rangle \mp q\,|b\,\bar{d}\rangle$

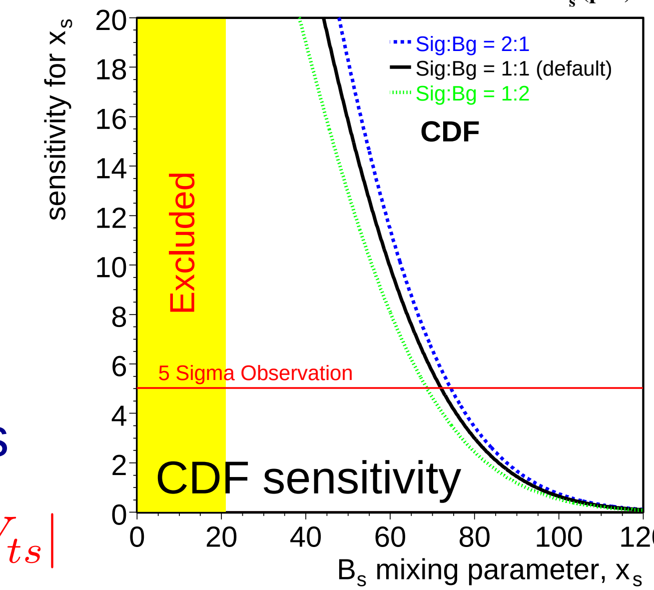
Mixing dominated by top quarks:





$$\Delta m_q = 2|M_{12}| = |V_{tb}V_{tq}^*|^2\, \underbrace{f_{B_q}^2 B_{B_q}} \times [\text{known factors}]$$

Nonperturbative matrix element



In $SU(3)$ symmetry limit: $\xi^2 \equiv f_{B_s}^2 B_{B_s} / f_{B_d}^2 B_{B_d} = 1$

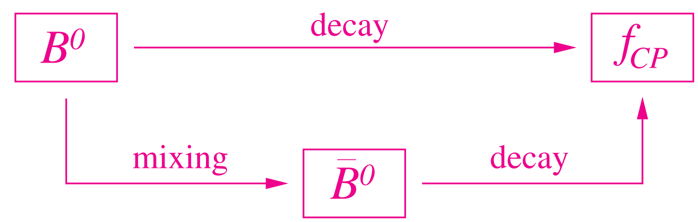
Lattice QCD: $\xi^2 \sim [1.15(6)]^2$ Chiral logs: ~ 1.3

Real uncertainty probably larger — light quark effects

This may soon be the main limitation to extract $|V_{td}/V_{ts}|$

CPV in interference between decay and mixing

- Especially interesting case if both B^0 and $\overline{B}^0$ can decay to same final state, e.g., $|f\rangle = |f_{CP}\rangle$:



$$\lambda_{f_{CP}} = \frac{q}{p}\frac{\overline{A}_{f_{CP}}}{A_{f_{CP}}} = \eta_{f_{CP}}\,\frac{q}{p}\frac{\overline{A}_{\overline{f}_{CP}}}{A_{f_{CP}}}$$

$$a_{f_{CP}} = \frac{\Gamma[\overline{B}^0(t)\to f] - \Gamma[B^0(t)\to f]}{\Gamma[\overline{B}^0(t)\to f] + \Gamma[B^0(t)\to f]} = \frac{2\,\mathrm{Im}\,\lambda_f}{1+|\lambda_f|^2}\sin(\Delta m\,t) - \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos(\Delta m\,t)$$

If $|\lambda_f| \neq 1$ then CP is violated in mixing and/or decay, or, for any $|\lambda_f|$ if

$$\mathrm{Im}\,\lambda_f \neq 0 \quad \Rightarrow \quad \text{CPV in interference}$$

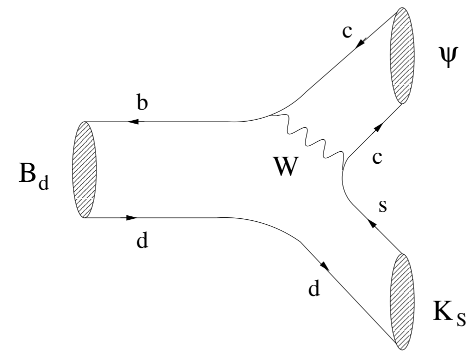
- If $|\lambda_f| = 1$ then CP asymmetry measures phase difference theoretically cleanly

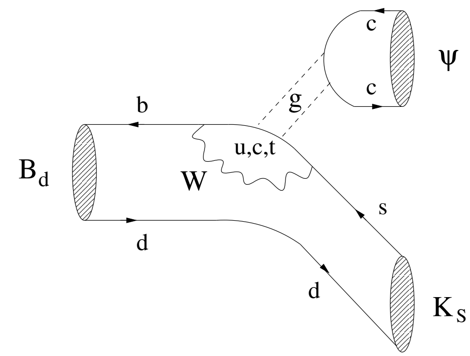
$$a_{f_{CP}} = \mathrm{Im}\,\lambda_f \sin(\Delta m\,t)$$

The question is whether amplitudes with one weak phase dominate a decay?
[If yes, then $|\lambda_f| \simeq 1$ is also satisfied, since in $B_{d,s}$ mixing $|q/p| - 1 < \mathcal{O}(10^{-2})$]

The cleanest case: $B \to \psi K_{S,L}$

- Several contributions, but one weak phase dominates:





"Tree" ($b \to c\bar{c}s$): $\overline{A}_T = \overset{[\lambda^2]}{V_{cb}V_{cs}^*}\, A_{c\bar{c}s}$

"Penguin": $\overline{A}_P = \overset{[\lambda^2]}{V_{tb}V_{ts}^*}\, P_t + \overset{[\lambda^2]}{V_{cb}V_{cs}^*}\, P_c + \overset{[\lambda^4]}{V_{ub}V_{us}^*}\, P_u$

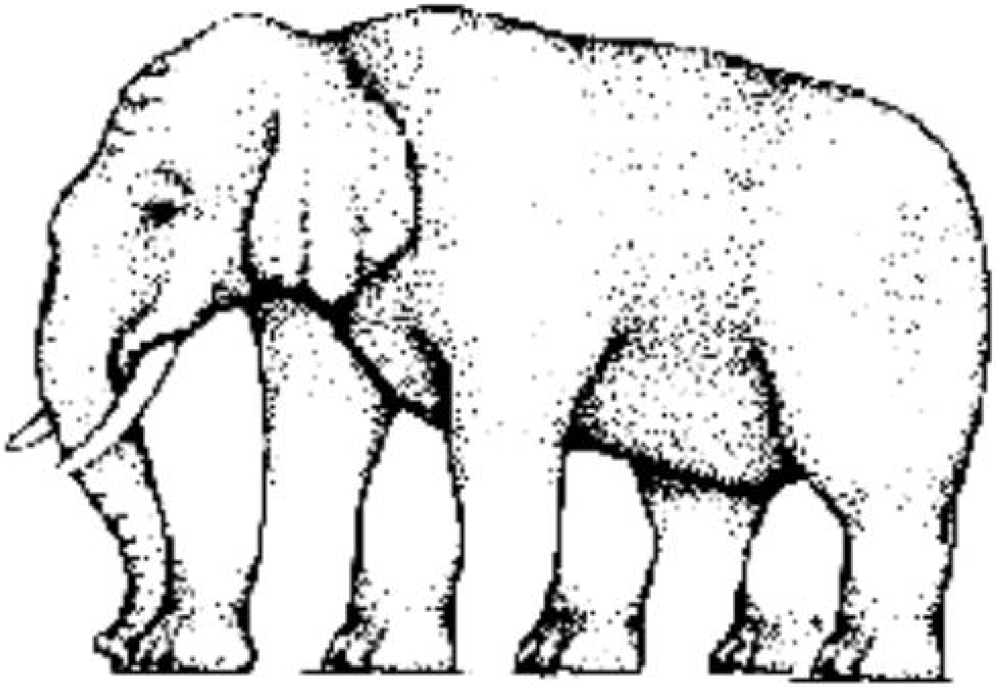
Rewrite $\overline{A}_P$ using $V_{tb}V_{ts}^* + V_{cb}V_{cs}^* + V_{ub}V_{us}^* = 0$

$$\overline{A}_{\psi K_S} = \underbrace{\overset{[\lambda^2]}{V_{cb}V_{cs}^*}}_{\text{"Tree" phase}} [A_{c\bar{c}s} + P_c - P_t] + \underbrace{\overset{[\lambda^4]}{V_{ub}V_{us}^*}}_{\text{suppressed by } \lambda^2} [P_u - P_t]$$

- $|\overline{A}/A| - 1 = \mathcal{O}[\lambda^2 \times (\text{loop})]$ $\Rightarrow$ theoretically very clean

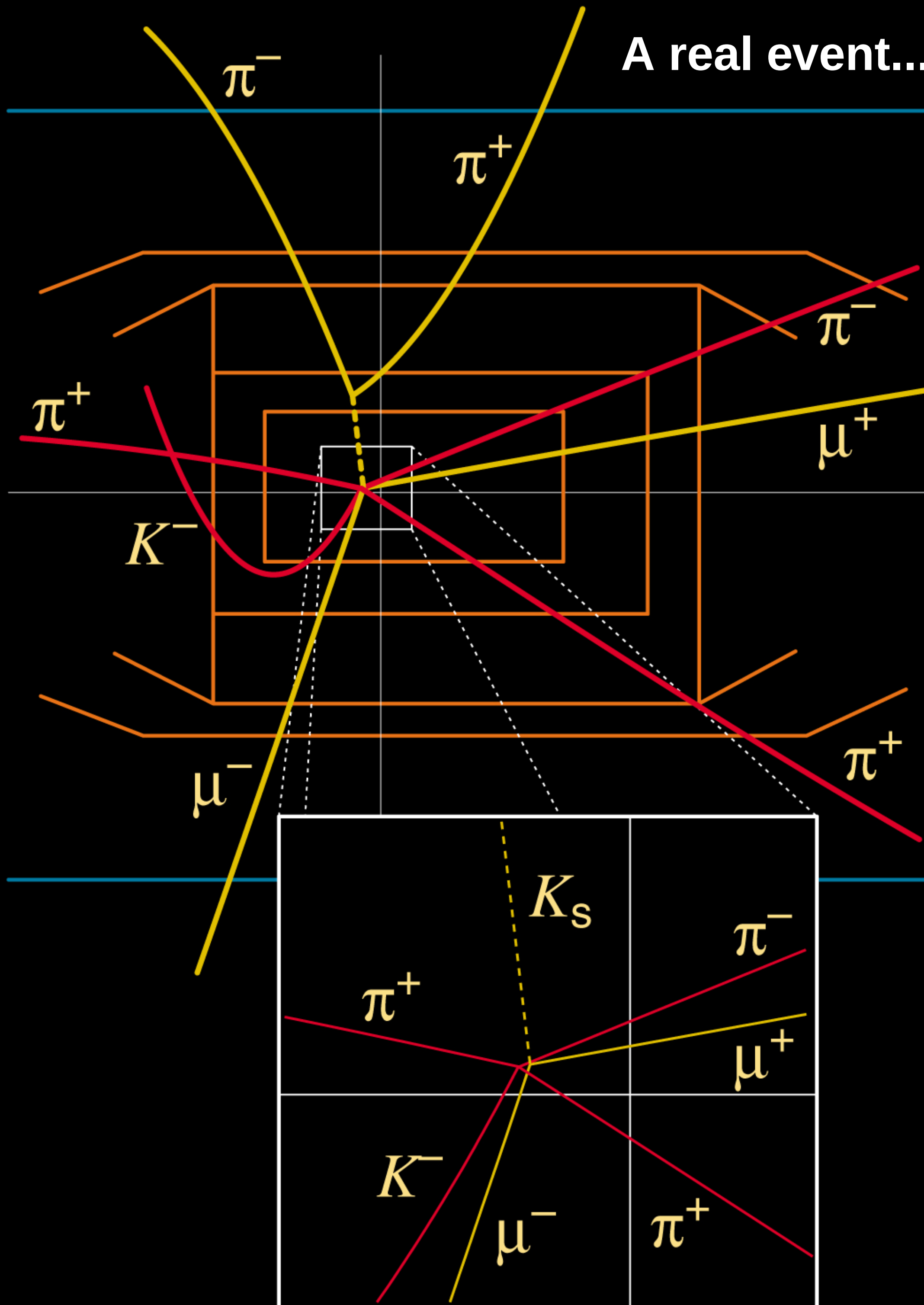
$$\lambda_{\psi K_{S,L}} = \mp \left(\frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*}\right) \left(\frac{V_{cb} V_{cs}^*}{V_{cb}^* V_{cs}}\right) \left(\frac{V_{cs} V_{cd}^*}{V_{cs}^* V_{cd}}\right) = \mp e^{-2i\beta} \quad \Rightarrow \quad \mathrm{Im}\lambda_{\psi K_{S,L}} = \pm \sin 2\beta$$

Even or odd...?



How many legs does this elephant have?

A real event...



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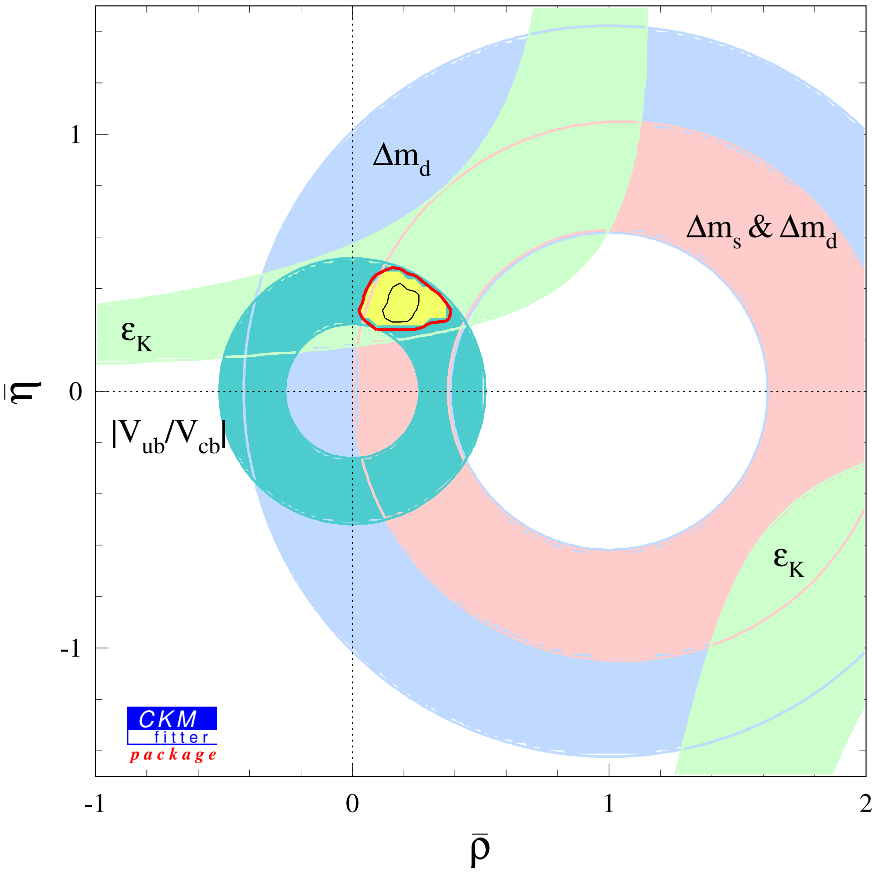
Present knowledge of $(\bar{\rho}, \bar{\eta})$

Standard model fit without $\sin 2\beta$



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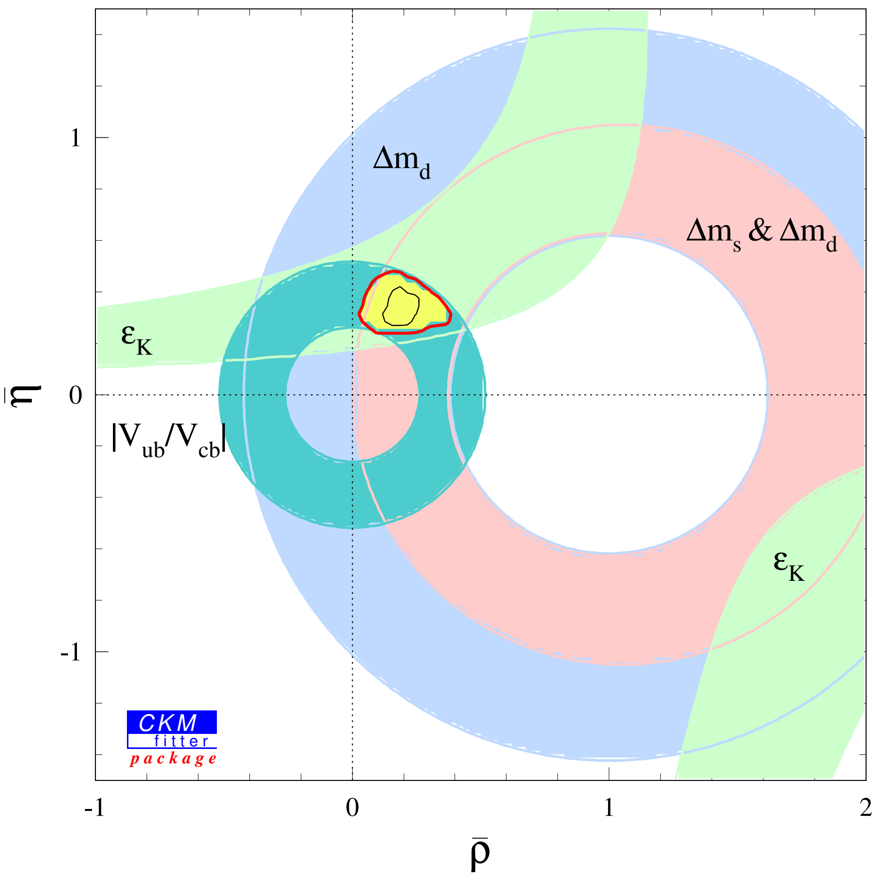
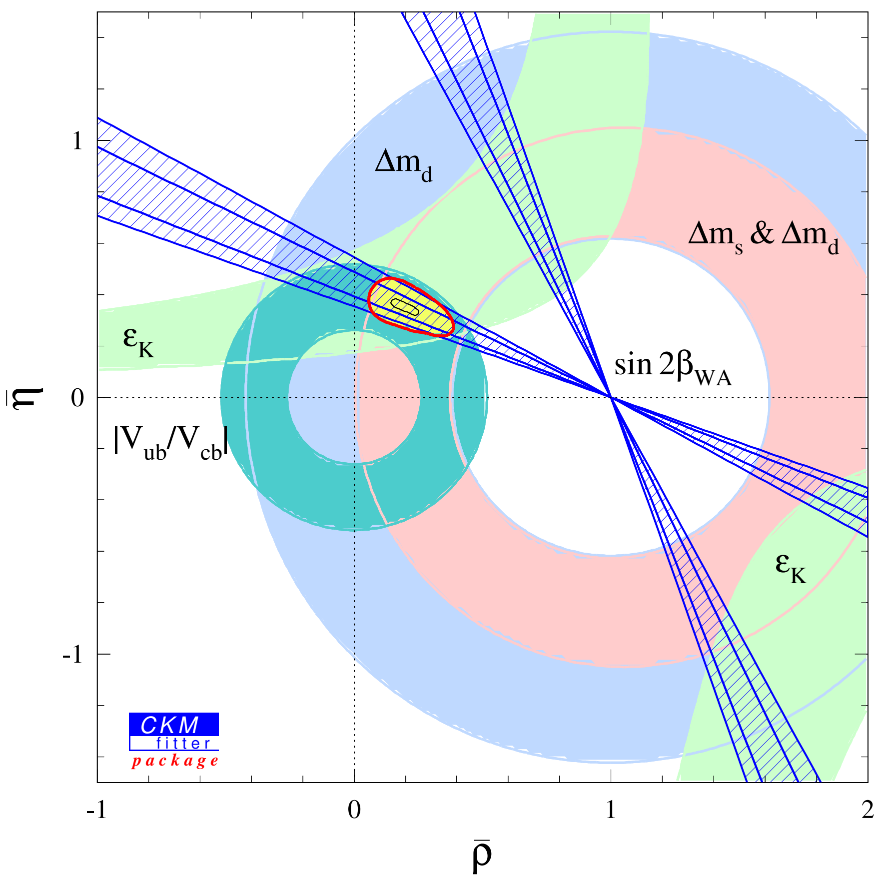


Full SM fit including $\sin 2\beta$



Summary — so far

- The CKM picture of CPV passed its first real test; $\sin 2\beta$ has become the best known ingredient of the unitarity triangle

  Paradigm change: look for corrections – rather than alternatives – to CKM picture

  Questions: Is the SM the *only* source of CPV?

  Does the SM *fully* explain flavor physics?

  Key measurements: ones that are theoretically clean and experimentally doable

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- Ability to test CKM at $\leq 10\%$ level depends on precision of 3rd, 4th, etc., most precise measurements besides $\sin 2\beta$ and $|V_{td}/V_{ts}|$

  Central themes: 1) Model independent determinations of $|V_{ub}|$

  2) Factorization in certain decays (may be important for α, γ)

  3) "Zero prediction" observables: $a_{CP}(B \to s\gamma)$, $a_{CP}(B_s \to \psi\phi)$

Future: what are the good tests?

What are we after?

- In SM: Only V_{ub} and V_{td} have large phases
  any large interference type CPV is a function of these

One is "easy" to measure, β , second can be called: $\alpha,\ \gamma,\ \beta+\gamma,\ 2\beta+\gamma$ ...
but this does not make any difference...

Independent measurements are cross-checks

- Beyond SM: NP is likely to enter where SM is suppressed:
  1) mixing; 2) decays which are loops in SM

Many phases can be large and different ($B_{d,s}$ mixing, decays) and "α, β, γ" is only a language; two "would-be" γ measurements can be sensitive to different NP

Independent measurements are searching for NP! Do all possible measurements which have clean interpretation; correlations narrow down type of NP

The goal is to find NP

Q: Big deal... Do all possible tests

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Q: Big deal... Do all possible tests

A: Some tests are better than others

Q: It's trivial... Check $\alpha + \beta + \gamma = \pi$

A: This is the wrong test

i) In most NP models $\alpha + \beta + \gamma = \pi$

ii) Even if $\alpha + \beta + \gamma \neq \pi$, probably an easier test will show NP first

iii) Takes very long time and hard to do

How can NP enter?

1. Two measurements which relate to the same quantity in the SM incompatible
2. B_s or D mixing incompatible with SM
3. Zero prediction observable found large, e.g.: $a_{CP}(B_s \to \psi\phi)$, $a_{CP}(B \to s\gamma)$
4. Angles inconsistent with the sides
5. Enhancement of rare decays (B, B_s, K, D)

All are easier than checking $\alpha + \beta + \gamma = \pi$ and more sensitive to NP

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All are easier than checking $\alpha + \beta + \gamma = \pi$ and more sensitive to NP

1.a NP cannot change things we "know", e.g.: $a_{\psi K_S} = -a_{\psi K_L}$

1.b NP unlikely to compete with "large" SM rates, e.g.: $a_{\psi K_S} = -a_{D^+D^-}$

1.c NP can easily alter SM loops, e.g.: $a_{\psi K_S} = a_{\phi K_S}$

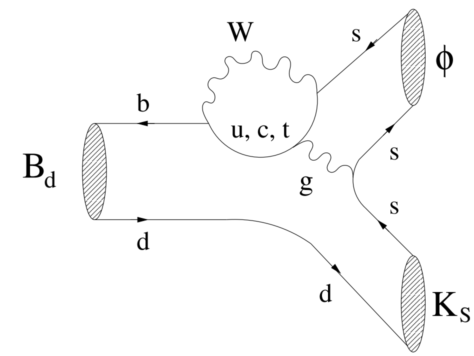
Goal: identify "type 1.c" cases

Some nice and clean measurements

$B \to \phi K_S$ — window to NP?

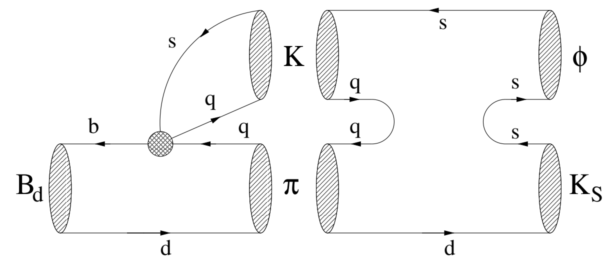
- "Naively" no tree contribution to $b \to s\bar{s}s$, use unitarity to write penguins:

"Penguin": $\overline{A}_P = \underbrace{\overset{[\lambda^2]}{V_{cb}V_{cs}^*}}_{\text{dominant contribution}} [P_c - P_t] + \underbrace{\overset{[\lambda^4]}{V_{ub}V_{us}^*}}_{\text{suppressed by } \lambda^2} [P_u - P_t]$



"Tree": $b \to u\overline{u}s$ followed by $u\overline{u} \to s\overline{s}$ rescattering

Constrain rescattering by measuring $B^+ \to \phi\pi^+, K^*K^+$



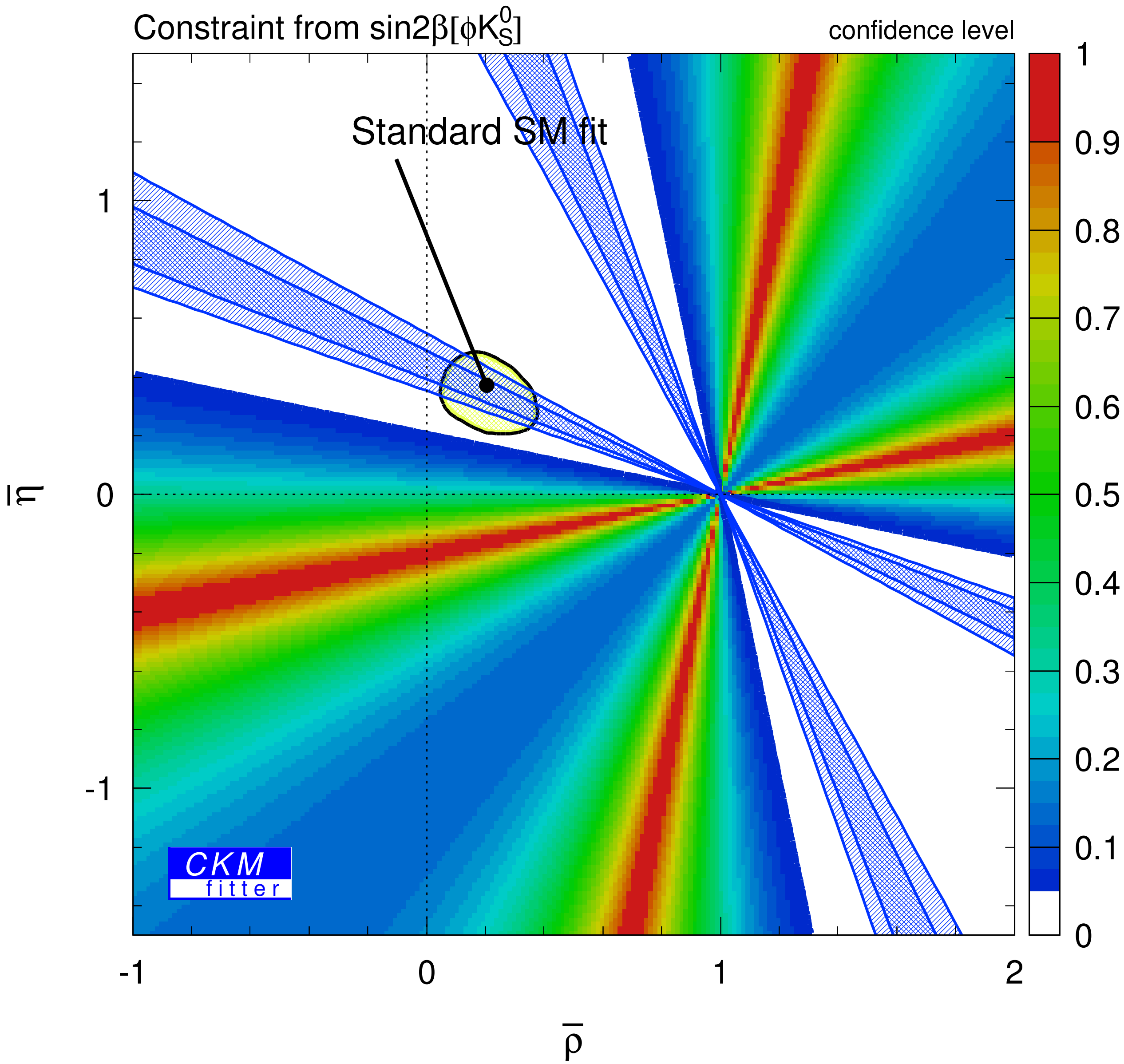
ψK_S: NP expected to enter $\lambda_{\psi K}$ mainly through q/p

ϕK_S: NP could enter $\lambda_{\phi K}$ through both q/p and $\overline{A}/A$

Expect $\sin 2\beta_{\phi K} = \sin 2\beta_{\psi K}$ to hold in the SM at $\sim 5\%$ level

- Measuring same angle in decays sensitive to different short distance physics may be the key to finding deviations from the SM!

$B \to \phi K_S$ — present status



$$S_{\psi K} = 0.734 \pm 0.054$$
$$C_{\psi K} = 0.026 \pm 0.020$$

$$S_{\phi K} = -0.39 \pm 0.41$$
$$C_{\phi K} = 0.56 \pm 0.43$$

S terms differ by: 2.7σ

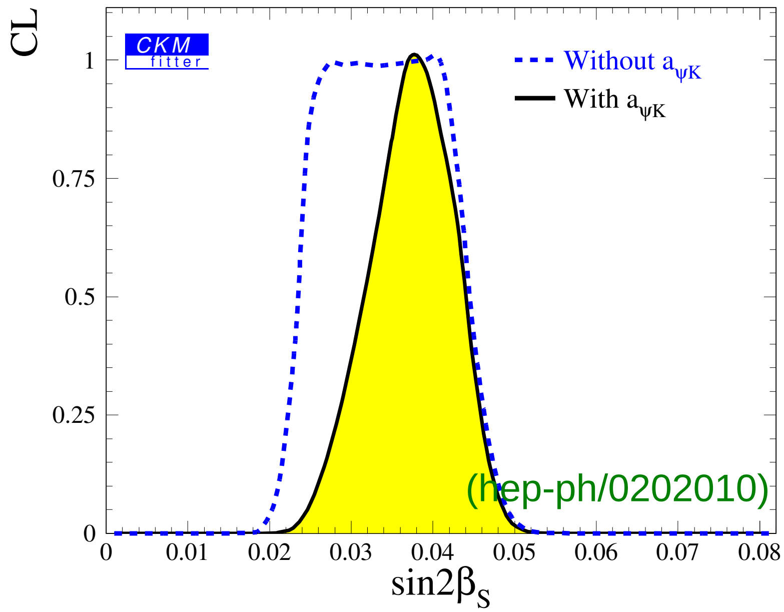
Need more data to tell...

(Smaller difference in $\eta' K_S$ and $K^+K^-K_S$ modes)

$B_s \to \psi\phi$ and $B_s \to \psi\eta^{(\prime)}$

- Analog of $B \to \psi K_S$ in B_s decay — determines the phase between B_s mixing and $b \to c\bar{c}s$ decay, β_s, as cleanly as the determination of β

  β_s is a small angle (of order λ^2) in one of the “squashed” unitarity triangles



- $\psi\phi$ is a VV final state, so the asymmetry is diluted by the CP-odd component

  $\psi\eta^{(\prime)}$, on the other hand, is pure CP-even

  $\Rightarrow$ A large asymmetry would be clear sign of NP

$B_s \to D_s^{\pm} K^{\mp}$ — when $|f\rangle \neq |f_{CP}\rangle$

- Interference of B_s and $\overline{B}_s$ decay; clean because single weak phase in each decay

Four amplitudes: $\overline{B}_s \overset{A_1}{\to} D_s^+ K^- \quad (b \to c\bar{u}s)\,, \qquad \overline{B}_s \overset{A_2}{\to} K^+ D_s^- \quad (b \to u\bar{c}s)$

$$B_s \overset{A_1}{\to} D_s^- K^+ \quad (\bar{b} \to \bar{c}u\bar{s})\,, \qquad B_s \overset{A_2}{\to} K^- D_s^+ \quad (\bar{b} \to \bar{u}c\bar{s})$$

$$\frac{\overline{A}_{D_s^+ K^-}}{A_{D_s^+ K^-}} = \frac{A_1}{A_2}\left(\frac{V_{cb}V_{us}^*}{V_{ub}^* V_{cs}}\right), \qquad \frac{\overline{A}_{D_s^- K^+}}{A_{D_s^- K^+}} = \frac{A_2}{A_1}\left(\frac{V_{ub}V_{cs}^*}{V_{cb}^* V_{us}}\right)$$

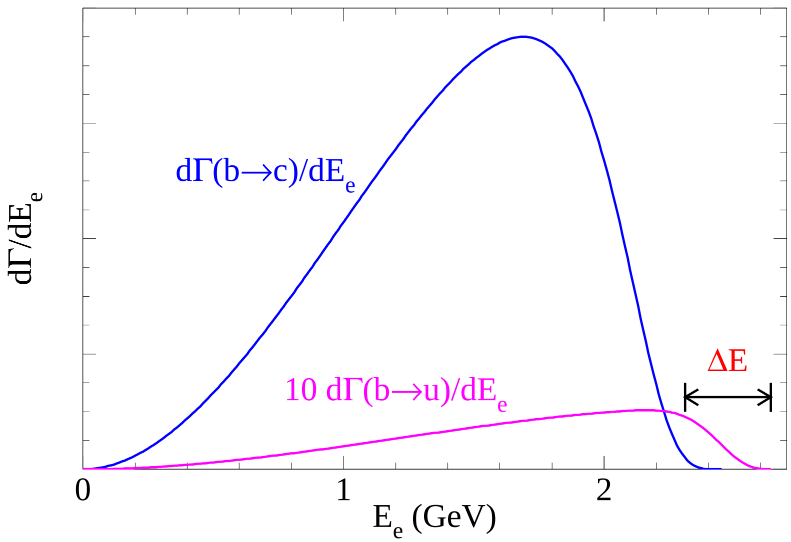
Magnitudes and relative strong phase of A_1 and A_2 drop out if four time dependent rates are measured $\Rightarrow$ no hadronic uncertainty:

$$\lambda_{D_s^+ K^-}\,\lambda_{D_s^- K^+} = \left(\frac{V_{tb}^* V_{ts}}{V_{tb} V_{ts}^*}\right)^2 \left(\frac{V_{cb}V_{us}^*}{V_{ub}^* V_{cs}}\right)\left(\frac{V_{ub}V_{cs}^*}{V_{cb}^* V_{us}}\right) = e^{-2i(\gamma - 2\beta_s - \beta_K)}$$

- Similarly, $B_d \to D^{(*)\pm}\pi^{\mp}$ determines $\gamma + 2\beta$: $\quad \lambda_{D^+\pi^-}\,\lambda_{D^-\pi^+} = e^{-2i(\gamma + 2\beta)}$

... ratio of amplitudes $\mathcal{O}(\lambda^2) \Rightarrow$ expected asymmetries are small

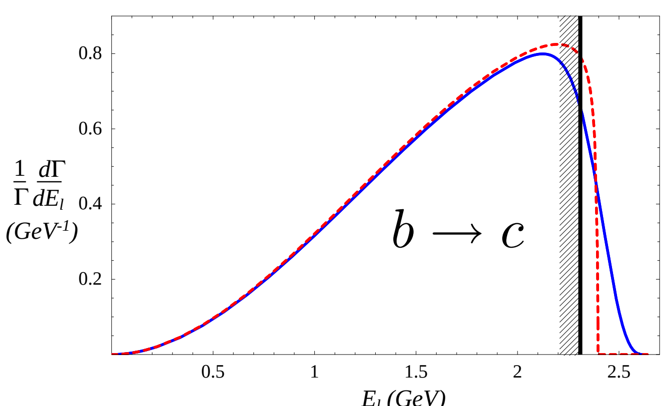
Theory also progresses, e.g., $|V_{ub}|$

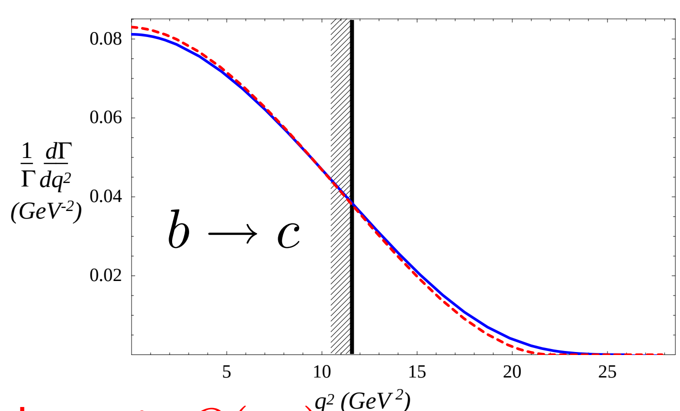


$|V_{ub}| \sim \frac{1}{10}|V_{cb}| \Rightarrow$ experimental cuts needed

... first measured from lepton endpoint

Purely nonperturbative effects shift endpoint from $m_b/2$ to $m_B/2$ — infinite series of terms in the OPE are equally important





— b quark decay to $O(\alpha_s)$

— incl. "Fermi-motion" (model)

In the $q^2 > (m_B - m_D)^2$ region the $b \to c$ background is kinematically forbidden, but first few terms in the OPE can still be trusted

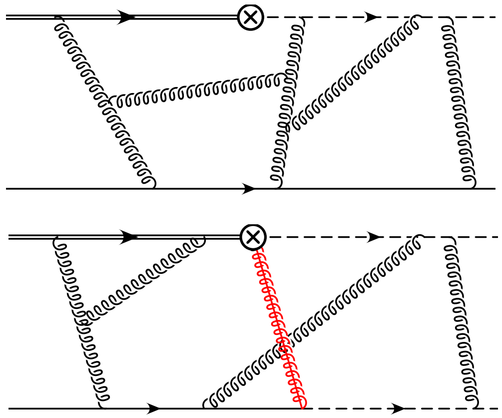
Soft-Collinear Effective Theory

- A new EFT to describe the interactions of energetic but low invariant mass particles with soft quanta [“the” connection between heavy quarks and jet physics?]
  ... Operator formulation instead of studying regions of Feynman diagrams
  ... New and simplified proofs of factorization theorems

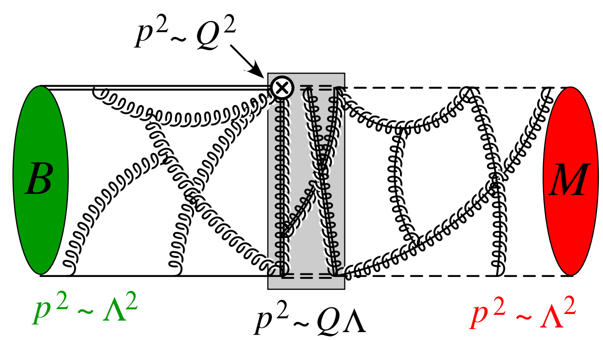
- E.g.: $B \to \pi \ell \bar{\nu}$ form factor: Issues: tails of wave fn’s, Sudakov suppression, etc.

“soft”

“hard”



$\Rightarrow$



Recently proven: $F(Q) = f^{\rm F}(Q) + f^{\rm NF}(Q)$ — two terms arise in SCET from matrix elements of distinct operators between the same states

Many important omissions

Model independent determination of $|V_{ub}|$ (“hardest” side of UT)

Rare decays — many observables, sensitive to different NP

α from $B \to \pi\pi$ isospin analysis

α from $B \to \rho\pi$ Dalitz plot analysis

γ from $B^{\pm} \to K^{\pm}\,(D^0, \overline{D}^0) \to K^{\pm}\,f_i$

⋮

etc.

Very broad program — independent measurements are searching for NP!

A (near future) best buy list

Many important results expected in the next couple of years:

- $|V_{td}/V_{ts}|$: Tevatron should nail this, hopefully very soon (lattice caveats?)
- β: reduce error in ϕK_S, $\eta' K_S$, and KKK modes
- β_s: is CPV in $B_s \to \psi\phi$ small?
- Rare decays: $B \to X_s\gamma$ near theory limited; q^2 distribution in $B \to X_s \ell^+\ell^-$ will be very interesting
- $|V_{ub}|$: reaching $\lesssim 10\%$ would be significant (need to better understand $|V_{cb}|$; could be a BABAR/BELLE measurement unmatched by LHCB/BTeV)
- α: how small is $B \to \pi^0\pi^0$? How big are other resonances in $\rho - \pi$ Dalitz plot?
- γ: clean modes hard — need to try all; test $SU(3)$ relations, factorization, etc.
- Search for null observables, $a_{CP}(b \to s\gamma)$, enhanced $B \to \ell^+\ell^-$, $B \to \ell\nu$, etc.

(apologies for omissions!)

Conclusions

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At last, the field is now experiment driven!

Extra slides

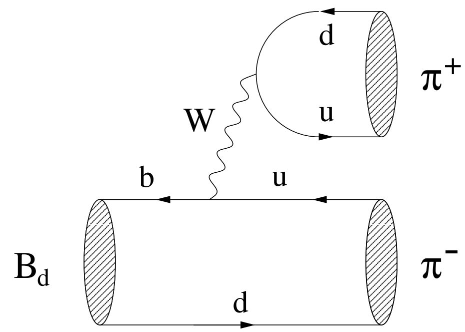
$B \to \pi\pi$ — the problem

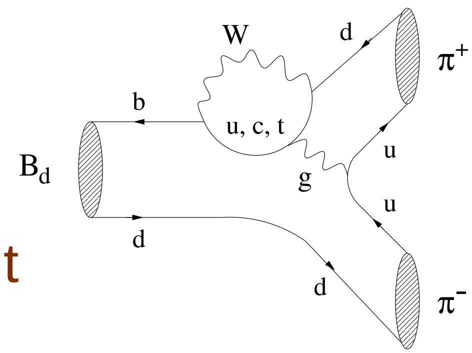
- There are tree and penguin amplitudes, just like for ψK_S

"Tree" ($b \to u\bar{u}d$): $\overline{A}_T = \overbrace{V_{ub}V_{ud}^*}^{[\lambda^3]} A_{u\bar{u}d}$

"Penguin": $\overline{A}_P = \overbrace{V_{tb}V_{td}^*}^{[\lambda^3]} P_t + \overbrace{V_{cb}V_{cd}^*}^{[\lambda^3]} P_c + \overbrace{V_{ub}V_{ud}^*}^{[\lambda^3]} P_u$

unitarity: $\overline{A}_{\pi^+\pi^-} = \underbrace{\overbrace{V_{ub}V_{ud}^*}^{[\lambda^3]}}_{\text{same as Tree phase}} [A_{u\bar{u}d} + P_u - P_t] + \underbrace{\overbrace{V_{cb}V_{cd}^*}^{[\lambda^3]}}_{\text{not suppressed}} [P_c - P_t]$





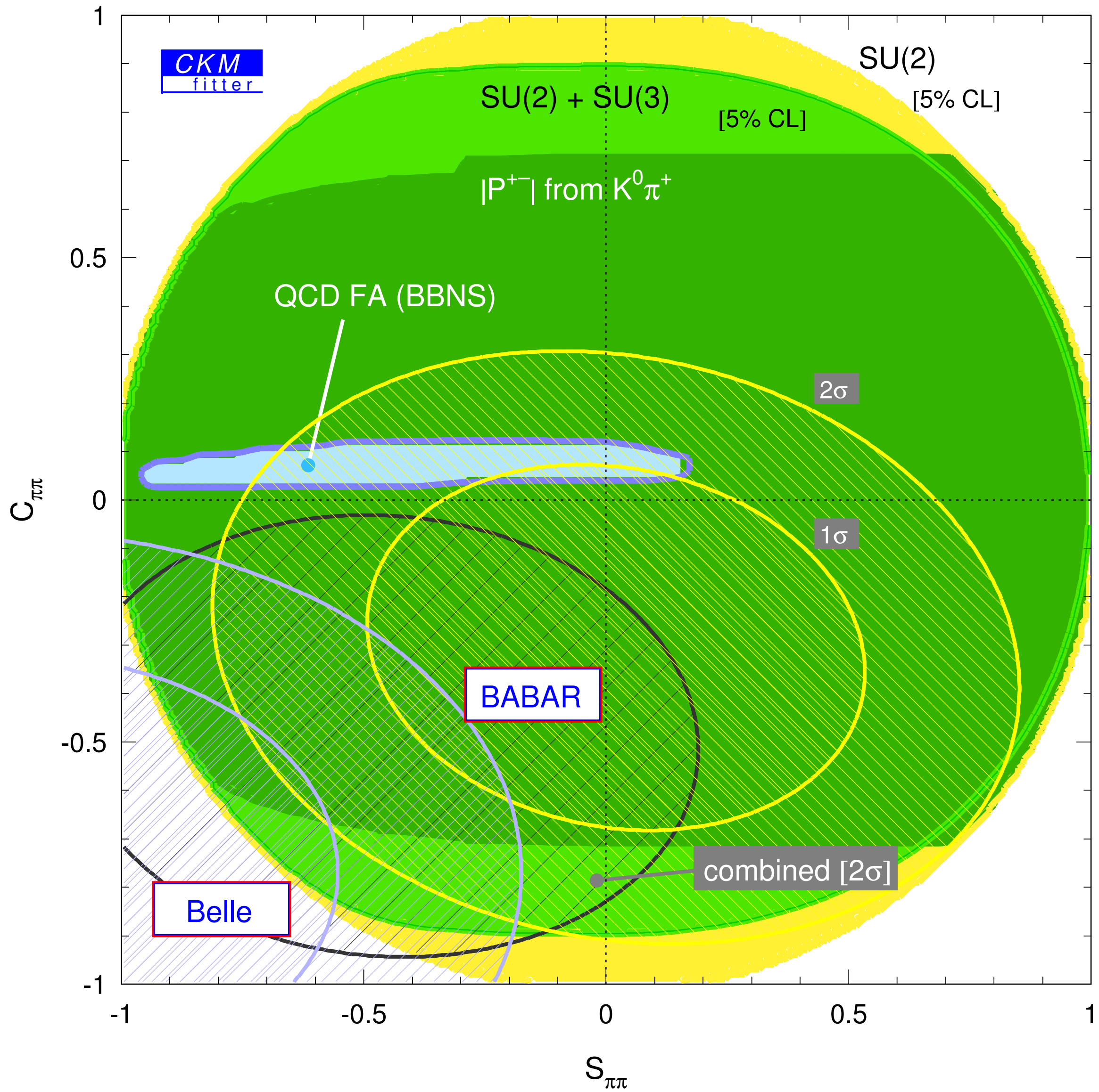
Two amplitudes with different weak- and possibly different strong phases; their values not known model independently

Define P and T by: $\overline{A}_{\pi^+\pi^-} = T(V_{ub}V_{ud}^*) + P(V_{cb}V_{cd}^*)$

Ratio of $K\pi$ and $\pi\pi$ rates: $|P/T| \sim 0.2 - 0.4$, i.e., $|P/T| \not\ll 1$

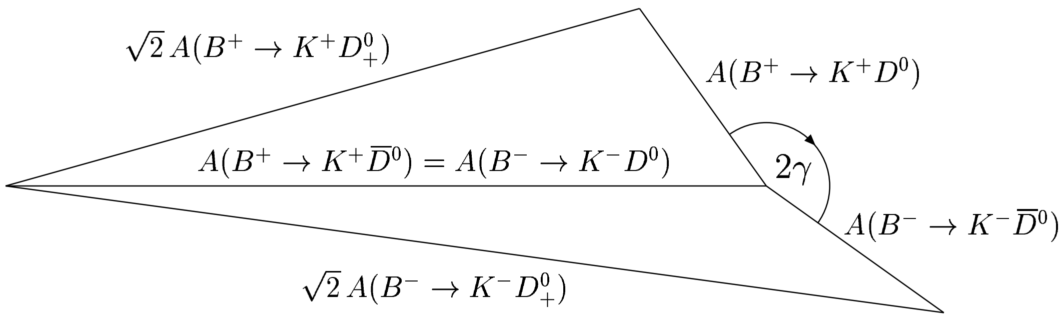
- Possible solutions: (1) eliminate P; or (2) attempt to calculate P

$B \to \pi\pi$ — present status



$B^\pm \to (D^0, \overline{D}^0) K^\pm \to f_i\, K^\pm$

- $B^\pm \to K^\pm D$: theoretically clean, experimentally very hard (Gronau-Wyler)



$$\frac{|A(B^+ \to K^+ D^0)|}{|A(B^+ \to K^+ \overline{D}^0|} \sim \frac{|V_{ub}|}{\lambda |V_{cb}|}\,\frac{1}{N_c}$$

- $B^\pm \to K^\pm (D^0, \overline{D}^0) \to K^\pm f_i \qquad (i = 1, 2,$ at least$)$ (Atwood, Dunietz, Soni)

  Use (and determine) final state interaction in D decay in the analysis

  Idea: $B^+ \to K^+ \overline{D}^0 \to K^+ f_i$ in doubly Cabibbo-suppressed $\overline{D}^0$ decay

  $B^+ \to K^+ D^0 \to K^+ f_i$ in Cabibbo-allowed D^0 decay (e.g.: $f_i = K^- \pi^+ / \rho^+$)

- It may be better to consider singly Cabibbo-suppressed D decays, $D \to K^\pm K^{*\mp}$
  Less sensitive to $D - \overline{D}$ mixing (Grossman, ZL, Soffer)