What can we hope to learn with half an attobarn^{-1}?

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BaBar, April 25, 2001

- Introduction
- What are we after?
  ... standard model / new physics?
  ... comments on hadronic uncertainties
- Testing CKM at the $\sim 10\%$ level
  ... quick look at V_{ub}, factorization
- Physics with $1/2\,$ab^{-1} (and more)
  ... a (subjective) best buy list
- Conclusions

Thanks to: A. Falk, Y. Grossman, Y. Nir, H. Quinn

Disclaimer: If your favorite decay mode is not mentioned, it doesn't mean that I think it's not important!

Dictionary: CPV $=CP$ violation

SM $=$ standard model

NP $=$ new physics

Introduction

Central questions about SM

1. Origin of electroweak symmetry breaking

   $SU(2)_L \times U(1)_Y \to U(1)_{\mathrm{EM}}$ gauge sym.

2. Origin of flavor symmetry breaking

   $U(3)_Q \times U(3)_u \times U(3)_d \to U(1)_B$ global sym.

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1. spontaneous breaking of a gauge symmetry

   $v \sim 250$ GeV vacuum condensate

   $W_L W_L \to W_L W_L$ breaks unitarity ∼TeV

   ... we know where to look

2. global symmetries broken by renormalizable interactions... we do not know what scale to look

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It would be nice if flavor symmetry breaking and electroweak symmetry breaking were connected...

– fermion masses depend on both

– flavor is a problem for many EWSB scenarios

Flavor symmetry breaking

The gauge sector of the SM is precisely tested
Additional links to short distance come from flavor

- Masses are generated by something hideous like

$$\mathcal{L} = \bar{Q}^i_L\, \Phi^{ij}_u\, u^j_R + \bar{Q}^i_L\, \Phi^{ij}_d\, d^j_R$$

where $i, j =$ generations. Φ^{ij}_a are $SU(2)$ doublets and have non-zero VEV's — but this is all we know
(elementary / composite? one / several fields?)

- In the SM:

$$\Phi^{ij}_d = \lambda^{ij}_d\, \phi\,, \qquad \Phi^{ij}_u = \lambda^{ij}_u\, (i\sigma_2\, \phi^*)\,,$$

and ϕ is the single Higgs field of EWSB

The Yukawa couplings $\lambda^{ij}_{u,d}$ determine the quark masses, mixing, and CP violation

Why is CPV interesting?

"CPV is a mystery"

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

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

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

But...

Why is CPV interesting?

CPV is one of the least tested aspects of the SM

Almost all extensions of the SM contain new sources of CPV

The observed baryon asymmetry requires new CPV (need not imply CPV in flavor changing processes)

$$\Downarrow$$

It is possible, likely, unavoidable
that the SM picture of CPV is incomplete

Are there new particles / interactions in the 100 GeV – 1 TeV region which couple to flavor?

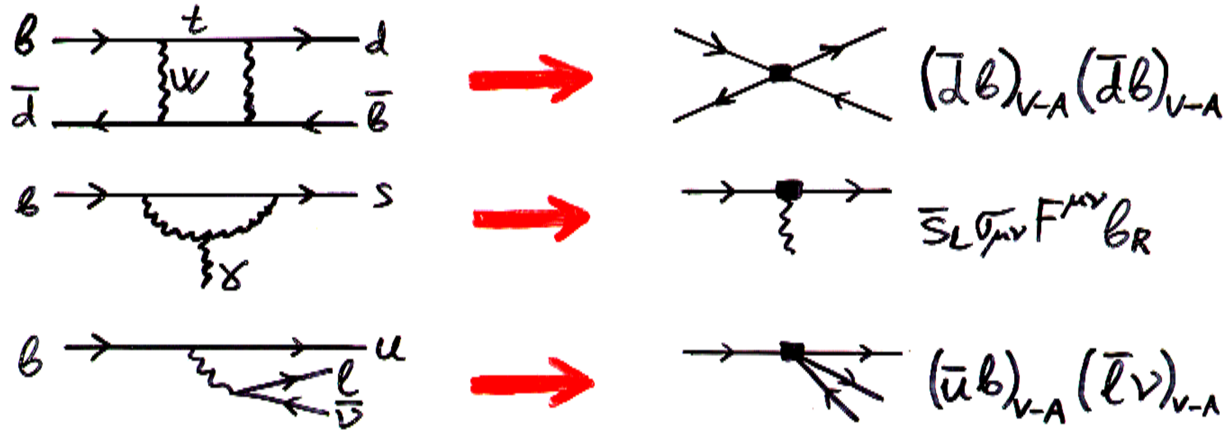
If $\Lambda \gg \Lambda_{\rm EW}$ then no observable deviation in B decays $\Rightarrow$ precision flavor measurements

If $\Lambda \sim \Lambda_{\rm EW}$ then dramatic effects are possible (but not guaranteed) $\Rightarrow$ detailed information on NP

Physics at $\sim 5\,$GeV

- All flavor changing processes are mediated by local operators which arise from integrating out heavy particles... dozens of operators:

$\sim$ weak scale $\qquad\qquad$ $\sim 5\,$GeV



- Are all flavor changing operators which occur at $\sim 5\,$GeV consistent with integrating out W, Z, t?

  At what level can we check?

$\Rightarrow$ *Right operators? Right coefficients?*

Unitarity triangle

- Charged current weak interactions:

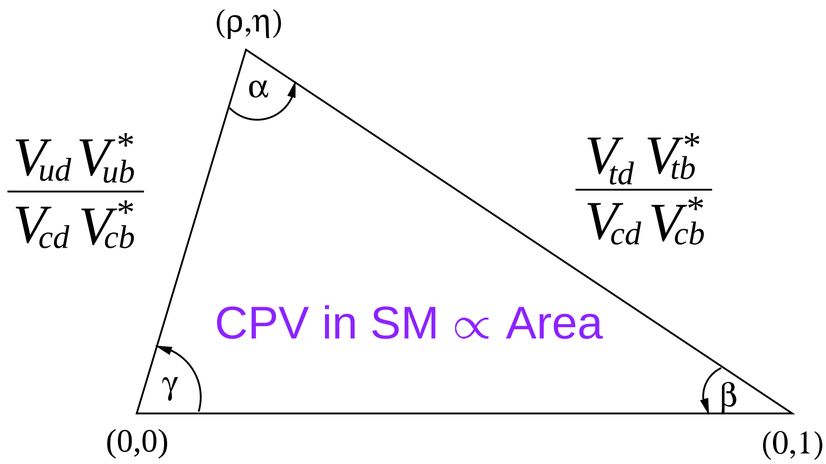
$$(u,\ c,\ t)\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}\begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

~ 1
$\sim \lambda$
$\sim \lambda^2$
$\sim \lambda^3$

$\Rightarrow$ $\mathbf{V}_{\rm CKM}$ is the only source of CPV in the SM

$\Rightarrow$ Elements depend on 4 real parameters in the SM (3 angles $+$ 1 CPV phase)

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



$$\alpha \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

$$\beta \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

$$\gamma \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

The angles and sides are directly measurable

Present status

- Observed CPV in K system is at the right level, but hadronic uncertainties preclude precision tests (ϵ') — CKM consistent at the $\sim 100\%$ level

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- At present we know (from $\sin 2\beta$, $|V_{ub}|$, ϵ_K) that CKM is consistent at the $\sim 30\%$ level

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

  Does the SM *fully* explain flavor physics?

- Heading towards $\sim 10\%$ sensitivity — possible ways:
  - Neubert: $\sin 2\beta$, $|V_{td}/V_{ts}|$, α or γ w/ factorization
  - Martinelli: already knows from Bayesian fit
  - Ligeti: $\sin 2\beta$, $|V_{td}/V_{ts}|$, $|V_{ub}/V_{cb}|$ w/ q^2 spectrum

  I guess this will take $\sim 250\,\text{fb}^{-1}$

- Interesting to improve measurements as long as sensitivity to New Physics increases — desired precision limited by control over hadronic uncertainties!

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: α, γ, $\pi - \beta - \gamma$, $2\beta + \gamma$... but this does not make any difference...

$\Rightarrow$ 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 and B_s mixing, decays. Then "α, β, γ" is only a language.

  E.g., two "would-be" γ measurements can be sensitive to totally different NP contributions

  Do all possible measurements which have clean interpretation; correlations narrow down type of NP

$\Rightarrow$ Independent measurements are searching for NP

How can NP enter?

Good tests: – Likely to be sensitive to NP
– Have small theory uncertainties
– Easy to measure ("easy"$\to$ possible)

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

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

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

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

The program

- Want to make many redundant measurements of observables which in the SM determine CKM elements, but sensitive to different short distance phys.

- Only very few observables are theoretically clean at the $1-2\%$ level:
  $B \to \psi K_S$, $B \to \pi\pi$ with isospin analysis,
  $B_s \to D_s K,\ K_L \to \pi^0 \nu\bar{\nu}$, ...
  and some observables which vanish in the SM

  Except for $\sin 2\beta$, all are extremely hard to measure

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- To overconstrain CKM in B decays, need one more piece of information besides β and $|V_{td}/V_{ts}|$

  It is not clear yet which of $\{\alpha,\ \gamma,\ |V_{ub}|\}$ will first be known with reliable and small ($\sim 10\%$) uncertainty

  For any of $\{\alpha,\ \gamma,\ |V_{ub}|\}$, there is a rich program of measurements which can validate / check the errors

Hadronic uncertainties

- My definition of "model independent":

  Quantity of interest $=$ (calculable prefactor)

  $$\times \left[1 + \sum_k (\text{small parameters})^k\right]$$

  In all cases [I know] there are uncertainties in the corrections $\sim$ (small parameter)^N, which cannot be estimated without some assumptions

  Some people argue whether the uncertainty is (small parameter)^N $\times\ 1,\ 1/3,$ or 3 — but this is silly and may only be decided by looking at the data...

- Consider, e.g., the determination of $|V_{cb}|$:

  $$\text{Excl.}\ |V_{cb}| = F(G_F, m_B, m_{D^*}) \times \left[1 + \frac{\Lambda^2_{\rm QCD}}{(2m_c)^2}\,(\mathcal{O}(1))\right]$$

  $$\text{Incl.}\ |V_{cb}| = F'(G_F, m_b, m_c) \times \left[1 + \frac{\Lambda^2_{\rm QCD}}{m_b^2}\,(\mathcal{O}(1))\right]$$

  Both are needed to have confidence that the error is as small as $\sim 5\%$!

Other examples

- To get $|V_{td}/V_{ts}|$ need from the lattice: $\frac{f_{B_s}^2 B_{B_s}}{f_{B_d}^2 B_{B_d}} \equiv \xi^2$

  $\xi = 1$ in $SU(3)$ limit — chiral logs give $\xi^2 \sim 1.3$
  Lattice: $\xi = 1.16(5)$, need unquenched calculation!

  tests: f_D, f_{D_s} (what about the B's?)

- To get $|V_{ub}/V_{cb}|$ need to determine m_b, test quark-hadron duality

  tests: $B \to X_s\gamma$ photon spectrum, $B \to X_c\ell\bar{\nu}$ lepton energy and hadronic invariant mass spectra

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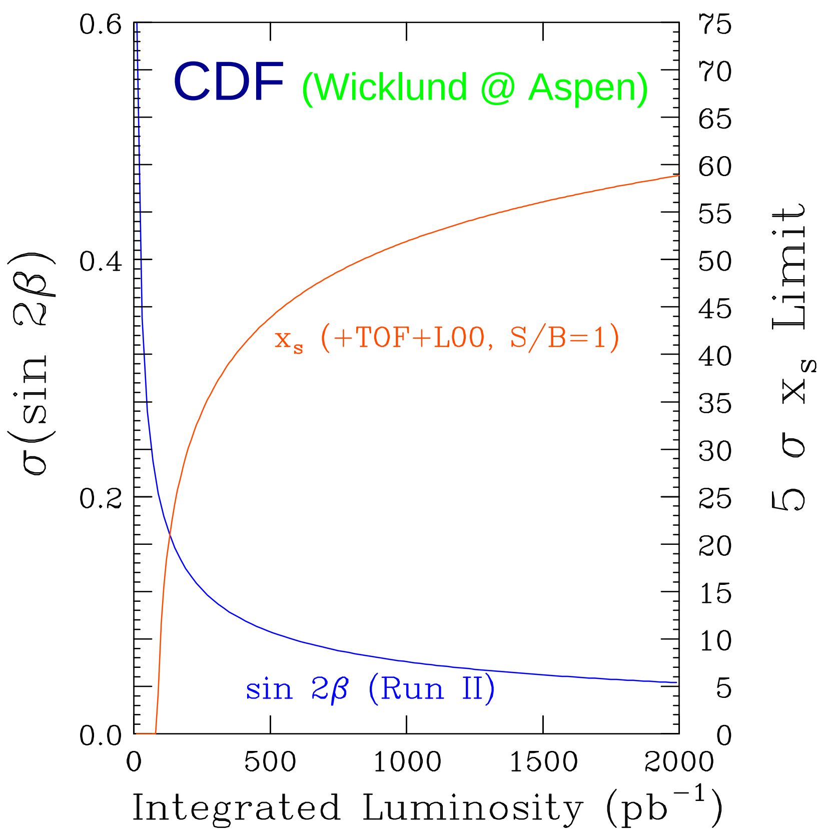
- To use factorization with confidence for α and/or γ need to test its accuracy / mechanism

  tests: Look at pattern of deviations from factorization in $B \to DX$, study many $B_{(s)}$ charmless decays

Last two items discussed later...

The competition (near) East

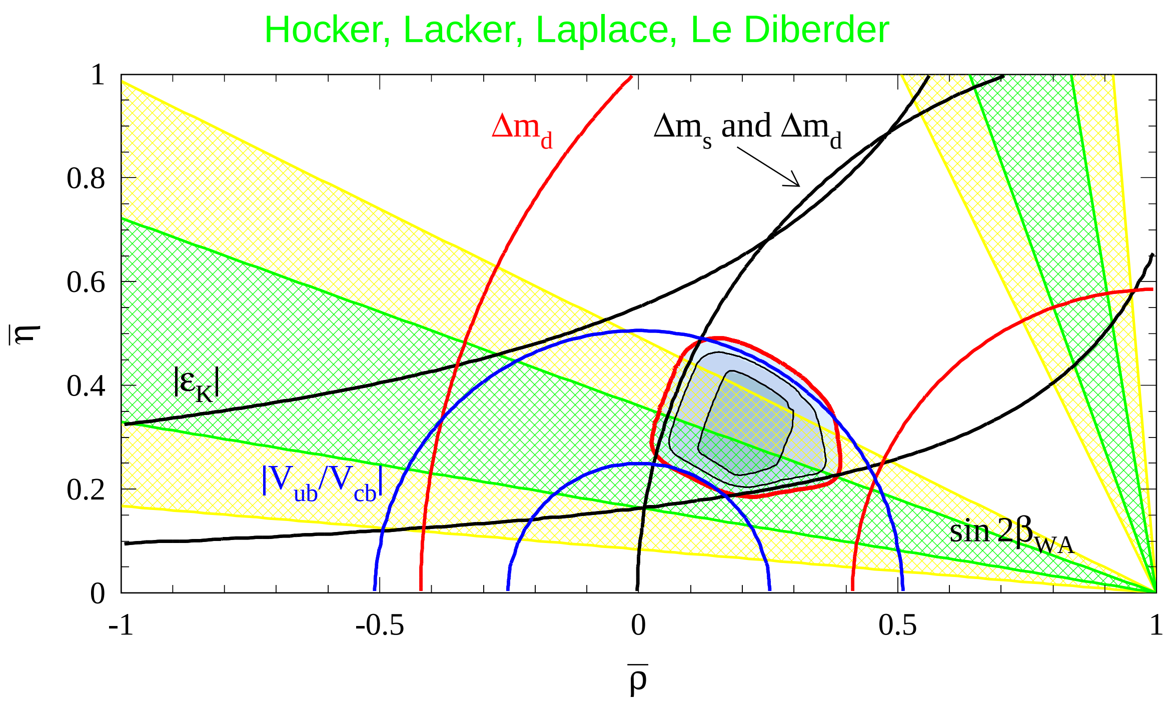


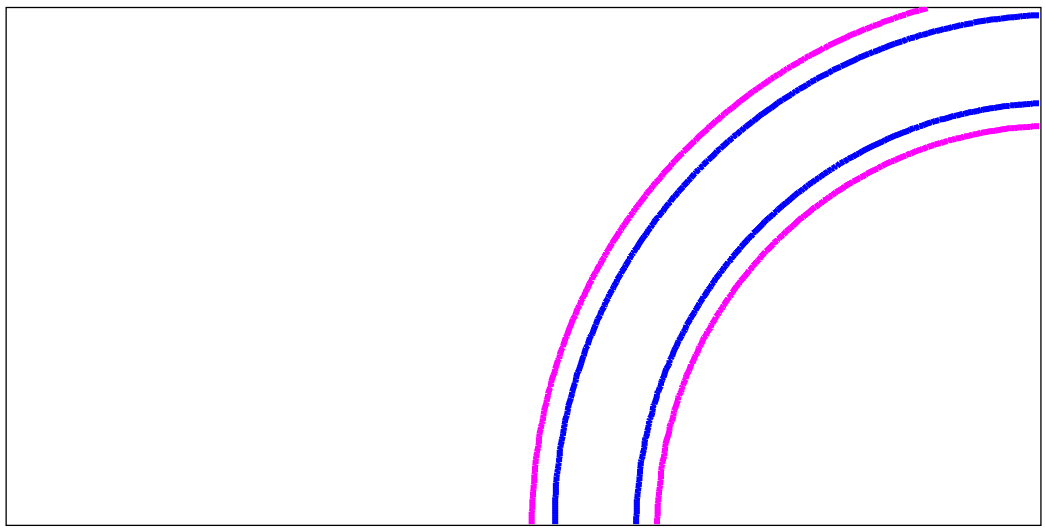
$\sin(2\beta)$ and x_s

in the large x_s limit, the (stat.) error at the time of 5σ observation is $\sigma(x_s) = 0.2/\sqrt{2} = 0.14$

- A_{CP} in $B_s \to \psi\phi$: B_s mixing phase sensitive to NP; If small [$\mathcal{O}(\lambda^2)$ in the SM] then it becomes a precision game and needs angular analysis
- $B \to K^{(*)}\ell^+\ell^-$: expect about ~ 50 events / fb^{-1}; Inclusives will be better at e^+e^-
- $B_s \to h^\pm h^\mp$: To test applicability of factorization for α/γ, many cross-checks possible in B_s decays

Impact on CKM fits





Using $\Delta m_s = 18\,\mathrm{ps}^{-1}$, and $10\%/5\%$ lattice error on ξ

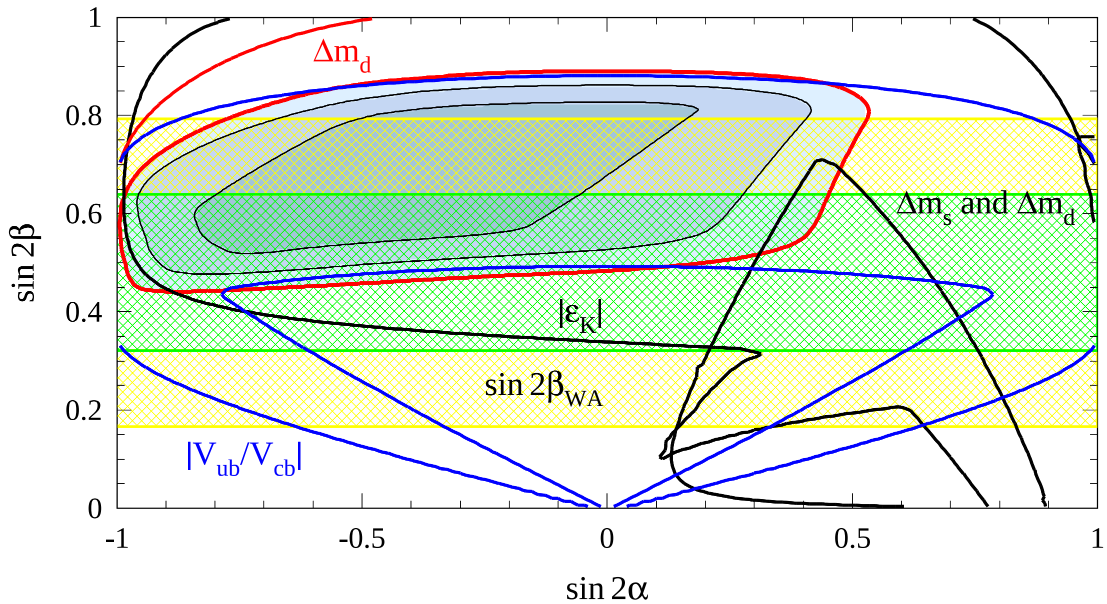
- Experimental error on $\Delta m_s/\Delta m_d$ could soon be $\lesssim 1\%$ — when can lattice (unquenched) get closer?

Testing CKM at the $\sim 10\%$ level

Few comments on $|V_{ub}|$, factorization

$\Downarrow$

Theory error dominates SM allowed range of $\sin 2\beta$:



$|V_{ub}|$ — Inclusive

- Exclusive $|V_{ub}|$ at $\lesssim 10\%$ level probably needs unquenched lattice QCD — won't discuss it here

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- OPE: expand decay rates in $\Lambda_{\rm QCD}/m_b$ and $\alpha_s(m_b)$

  Model independent results for "sufficiently inclusive" observables

$$d\Gamma = \begin{pmatrix} b \text{ quark} \\ \text{decay} \end{pmatrix} \times \left\{ 1 + \frac{0}{m_b} + \frac{f(\lambda_1, \lambda_2)}{m_b^2} + \alpha_s(\ldots) + \ldots \right\}$$

  Interesting quantities computed to order α_s, $\alpha_s^2\beta_0$, and $1/m^2$ ($1/m^3$ used to estimate uncertainties)

  - For these predictions to have small uncertainties need to know m_b — extract from $B \to X_s\gamma$ photon spectrum and/or $B \to X_c\ell\bar{\nu}$ spectra
  - In certain regions of phase space the OPE & pert. series do not converge (related)

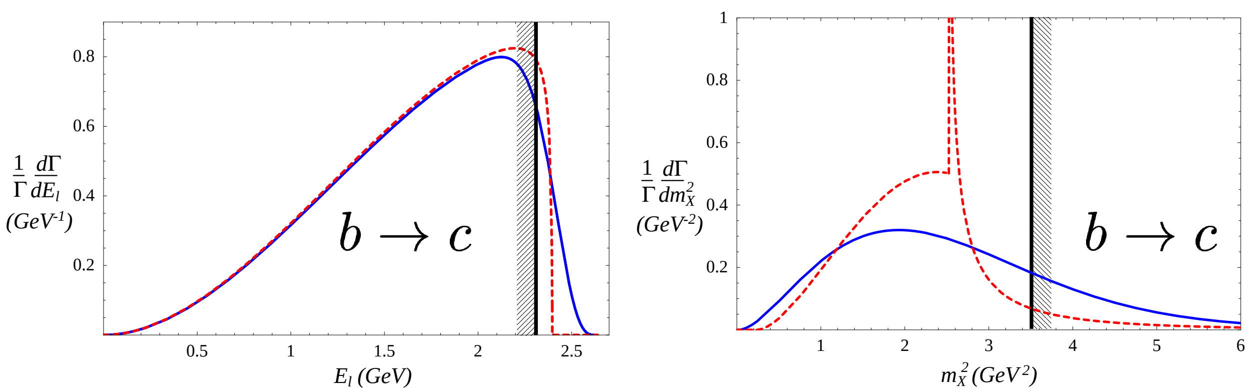
- Total rates are known at the $\lesssim 5\%$ level (duality...)
  V_{ub} is hard "only" due to the huge $b \to c$ background

$B \to X_u \ell \bar{\nu}$ spectra

- For the OPE to converge, need to allow final states with $m_X^2 \gg E_X \Lambda_{\rm QCD} \gg \Lambda_{\rm QCD}^2$ to contribute

  ...not the case in the $b \to u$ phase space regions:
  $E_\ell > (m_B^2 - m_D^2)/(2m_B)$ and $m_X < m_D$
  since $E_X < m_B$, $m_X < m_D$, and $\underline{m_B \Lambda_{\rm QCD} \sim m_D^2}$

$\Rightarrow$ In these E_ℓ and m_X regions, an infinite set of terms in the OPE are equally important and need to be resummed ("shape function" $\sim$ "Fermi motion")



— order α_s — including shape fn

- Extract shape function from $B \to X_s \gamma$ spectrum

Leibovich, Low, Rothstein

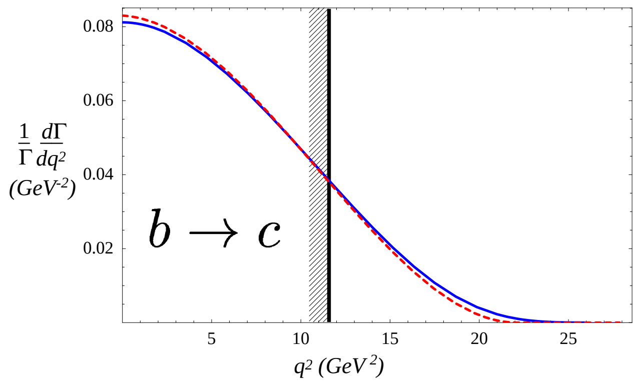
Still, unknown order $1/m_b$ corrections left over

$|V_{ub}|$: q^2 spectrum

- $q^2 > (m_B - m_D)^2$ cut implies both $m_X, E_X < m_D$!

  $\Rightarrow$ In the large q^2 region, first few terms in the OPE can be trusted

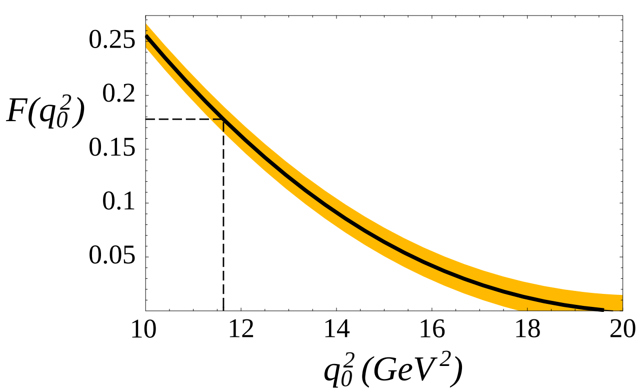
  Bauer, ZL, Luke

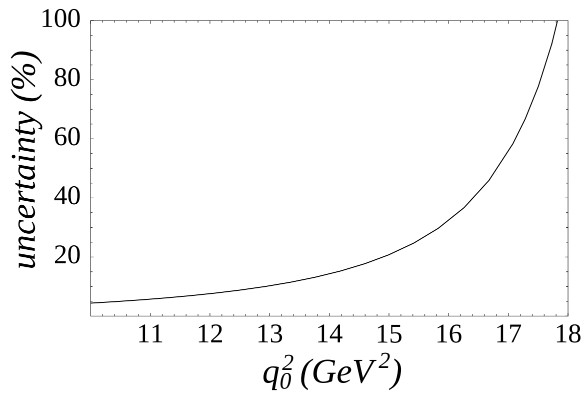


— order α_s
— including shape fn

Unknown corrections are of order $1/m^3$

Fraction of events with $q^2 > q_0^2$ (only $1/m_c^3$ error)





- Eventually, using $\mathrm{d}\Gamma/\mathrm{d}q^2\mathrm{d}m_X$, can get $30 - 40\%$ of events with small theoretical uncertainty

Factorization

- $B \to M_1 M_2$ — M_1 inherits the spectator

  Start from OPE; estimate matrix elements of four-quark operators using Fiertz rearrangements that group the quark fields into two that mediate $B \to M_1$ transition, and two that can describe vacuum $\to M_2$

- If M_1 is heavy ($D^{(*)}$) and M_2 is light (π, ρ) then "color transparency" provides a physical picture how factorization may work Bjorken; Politzer, Wise; Dugan, Grinstein

  This was shown to be consistent to 2-loops, i.e., infrared divergences precisely cancel the IR singularities in the perturbative expansion of the semileptonic form factor and the pion light-cone distribution

  Beneke, Buchalla, Neubert, Sachrajda

- If M_2 is heavy then color transparency does not justify factorization, except if M_2 is "small", e.g., J/ψ

- No OPE $\Rightarrow$ corrections of order Λ/m_b (?) unknown

Origin of factorization?

- Factorization has been observed to work at the $10 - 20\%$ level in $B \to D^{(*)}\pi$, $B \to D^{(*)}\rho$, etc.
  - could be flukes, specific to these final states...
  - the interesting level is just below this ($\sim 1/N_c^2$)

- The perturbative QCD argument for factorization relies on M_2 being a fast color singlet particle; the large-N_c argument is independent of this

  Does factorization become a worse approximation in a pattern consistent with the PQCD expectation?

- At the level of existing data, factorization also works in $B \to D_s^{(*)} D$ Luo, Rosner

  It would be fun to see if factorization is (much) worse in $B \to D_s^{(*)}\pi, D_s^{(*)}\rho$ than in $B \to D^{(*)}\pi, D^{(*)}\rho$?

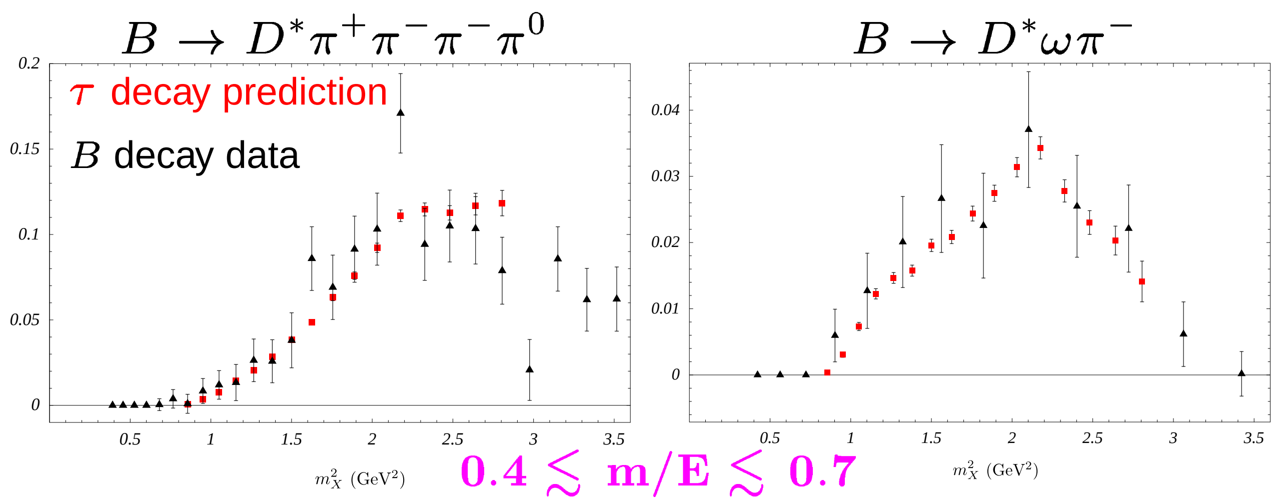
  (M_1 light, M_2 heavy — needs $B \to \pi, \rho$ form factors)

Factorization in $B \to D^{(*)} X$

- Do tests where the accuracy can be studied as a function of the kinematics, with fixed final states

ZL, Luke, Wise

Study $B \to D^* 4\pi$ (use CLEO's B and τ decay data)



$\mathbf{0.4 \lesssim m/E \lesssim 0.7}$

The "background" from the $(\bar{c}\, b)$ current creating some of the π's is probably tiny in $B \to D^* \omega \pi^-$

- If the primary reason for factorization is
  - large-N_c: accuracy should be independent of m_X
  - PQCD: may observe deviations that grow with m_X at the $\sim 10\%$ level — This would be evidence that PQCD is an important part of the success of factorization in $B \to D^* X$

Heavy $\to$ light

- BBNS neglect Sudakov suppression of π form factor

  Argue that higher Fock state contributions and final state interactions are power suppressed

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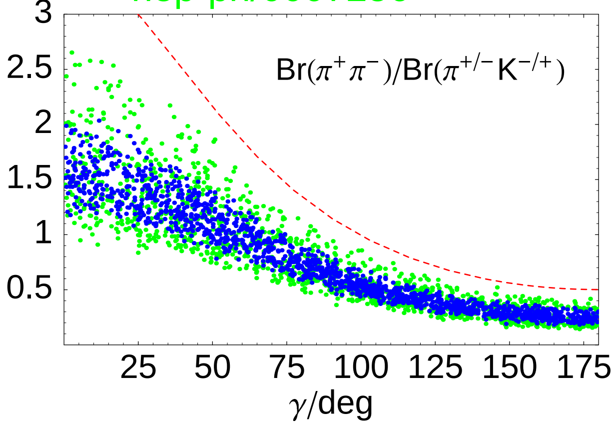
- "Subleading" effects can significantly alter results:

hep-ph/0007256



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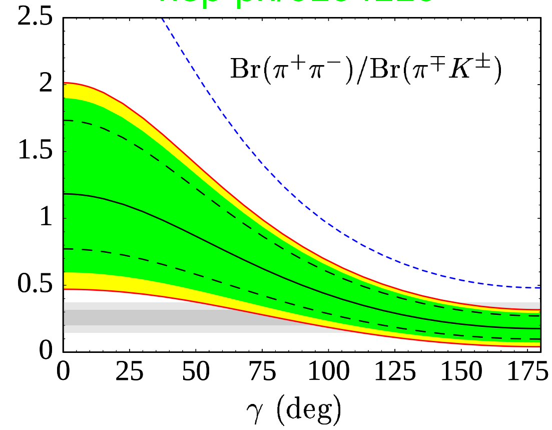


  – chirally enhanced terms $(2m_K^2/m_b m_s \sim 1)$
  – charming penguins (Martinelli et al.)
  – Perturbative QCD approach (Keum, Li, Sanda)
    $\to$ larger strong phases, annihilation and penguin contributions more important
  – Intrinsic charm (Brodsky)

It is unfortunately a lot harder to test the assumptions than to use the predictions... — careful!

Physics with $1/2\,\mathrm{ab}^{-1}$

(and more)

A (subjective) best buy list

- $B \to \phi K_S$: β from non-$(b \to c\bar{c}s)$ decay
- $B \to \rho\pi$: pursue Dalitz plot, and other "α" modes
- $B \to D^*\pi$: could provide $\sin(2\beta + \gamma)$ cleanly
- rare decays: $B \to X_s \ell^+ \ell^-$; $B \to K^{(*)} \ell^+ \ell^-$, in particular A_{FB} is clean probe of NP
- rare decays: $B \to X_s \gamma$ nail photon spectrum, down to as low E_γ as possible; $B \to K^* \gamma$ search for CPV
- $B \to DK$: try to get at "γ" another way
- $B \to \mu\bar{\nu}$: 1×10^{-6} limit with $300\,\text{fb}^{-1}$ (SM $\sim 3 \times 10^{-7}$)
  $B \to \ell\bar{\nu}\gamma$: is the theory uncertainty small?

Of course, one will want to improve $\sin 2\beta$, $|V_{ub}/V_{cb}|$, charmless branching ratios, search for direct CPV, $D - \bar{D}$ mixing, etc., as more data is accumulated

β from non-$(b \to c\bar{c}s)$ decay

$\sin 2\beta$ from $B \to \psi K_S$ is very clean theoretically (Have to be reconsidered at the ~ 0.01 level)

- In the SM both $\begin{cases} B \to \psi K_S & b \to c\bar{c}s \text{ tree} \\ B \to \phi K_S & b \to s\bar{s}s \text{ penguin} \end{cases}$

  measure $\sin 2\beta$ — NP can easily modify $b \to s\bar{s}s$ decay amplitude Grossman, Worah

  Important to measure same angle in several modes

The decay rate is:
$\mathcal{B}(B \to \phi K_S) = (8.1^{+3.1}_{-2.5}) \times 10^{-6}$ (BaBar)

Using Ba'book p.315, with $1/2\,\text{ab}^{-1}$: $\delta A_{CP} \sim 0.13$

Interesting to push until ~ 0.05 error

- Constrain rescattering ($b \to u\bar{u}s, s\bar{d}d \to s\bar{s}s$), by measuring $B^+ \to \phi\pi^+, K^*K^+$ Grossman, Isidori, Worah

“α” modes

- $B^0 \to \pi^+\pi^-$: Penguin / Tree is $20 - 50\%$

  Penguin only contributes to $\Delta I = 1/2$ amplitude $\Rightarrow$ To get clean information, need $B \to \pi^0\pi^0$ to isolate CP asymmetry in the clean $\Delta I = 3/2$ channel.

  Expect $\mathcal{B}(\pi^0\pi^0) \lesssim 10^{-6}$ — hard, if not impossible

  Not needed if P/T (incl. phase) can be computed...

  (claimed by Beneke, Buchalla, Neubert, Sachrajda)

- $B \to \rho\pi$: Isospin analysis is still possible (Dalitz plot), and $\pi^+\pi^-\pi^0$ final state has two charged tracks

$\mathcal{B} \times 10^5$	CLEO	BaBar
$\rho^0\pi^+$	1.0 ± 0.4	< 3.9
$\rho^\pm\pi^\mp$	2.8 ± 0.9	4.9 ± 1.4

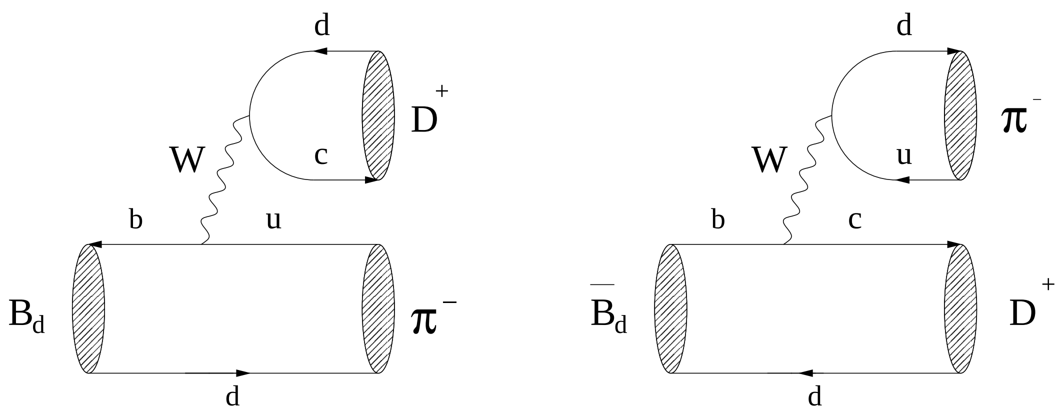
  ~ 1000 reconstructed events needed — Snyder, Quinn

  I was told that it’s yet unclear how well this can be done; $\lesssim 10^\circ$ error with $1/2\,\mathrm{ab}^{-1}$ may be possible

$B \to D^* \pi$

- Interference between $b\bar{d} \to c\bar{u}d\bar{d}$ and $\bar{b}d \to \bar{u}c\bar{d}d$

  Four time dependent rates, $B, \bar{B} \to D^{*\pm}\pi^{\mp}$, determine A_1/A_2 and $\sin(2\beta+\gamma)$ free of theory errors

  Problem: $A(\bar{b} \to \bar{u}c\bar{d})/A(b \to c\bar{u}d) \sim \lambda^2$

  Alternative: constrain A_1/A_2 using theory and/or data

  Belle study obtains 0.2 error from $1/2\,\mathrm{ab}^{-1}$ (BCP4)
  [Scaling Ba'book p.490 $\to \sim 3$ smaller (stat.) error]

  Even crude measurement could help with discrete ambiguities (different from 2β or $2\alpha = 2\pi - 2\beta - 2\gamma$)

- $B_s \to D_s^{\pm} K^{\mp}$: in analogy with the above, measures $\sin(\gamma - 2\beta_s)$ — and $A(\bar{b} \to \bar{u}c\bar{s})/A(b \to c\bar{u}s) \sim 1$

  A gold-plated mode for LHCB / BTeV

Rare decays

Inclusives: under better theoretical control for now

Exclusives: need form factors (not for CPV!). Useful relations between different form factors from HQS; ultimately want unquenched lattice calculations.

- $B \to X_s \gamma$ or $B \to K^* \gamma$:
  Best $m_{H^\pm}$ limits in 2HDM — in SUSY many param's
- $B \to X_{s,d}\, \ell^+ \ell^-$ or $B \to K^{(*)} \ell^+ \ell^-$: bsZ penguins, SUSY, right handed couplings, $|V_{ts}|$, $|V_{td}|$, etc.
- $B \to X_{s,d}\, \nu\bar{\nu}$ or $B \to K^{(*)} \nu\bar{\nu}$: (a dream...)
  Very clean — the B physics analog of $K \to \pi\nu\bar{\nu}$
- $B \to \ell\bar{\nu}$:
  Measures $f_B |V_{ub}|$, sensitive to charged Higgs, etc.
- Direct CPV, e.g., in $B \to K^* \gamma$; lepton number / lepton flavor violating modes; $B \to \ell^+ \ell^-$; etc.

$\Rightarrow$ Richness: sensitivity to NP — applications for $|V_{ij}|$

There may be lots of money to be made here...!

Heavy $\to$ light form factors

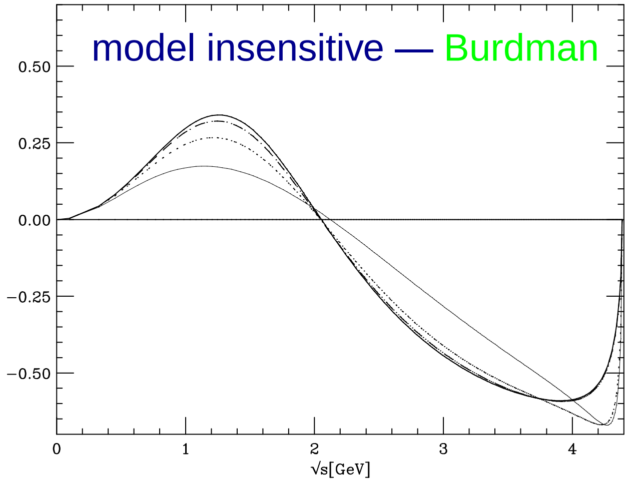
HQS relates form factors in large q^2 region ($B \to \rho\ell\bar{\nu}, B \to K^*\ell^+\ell^-, B \to K^*\gamma$, etc.)

- Recently: for $q^2 \ll m_B^2$, with some assumptions, all 7 vector meson form factors related to $\xi_\perp(E)$, $\xi_\|(E)$; and 3 pseudoscalar form factors related to $\xi_P(E)$

  Charles, Le Yaouanc, Oliver, Pene, Raynal

  – Computation of α_s corrections — Beneke, Feldman
  – Constraints from $B \to K^*\gamma$ — Burdman, Hiller

- Forward-backward asymmetry in $B \to K^*\ell^+\ell^-$



A_{FB} changes sign:

$$C_9^{\text{eff}}(s_0) = -\frac{2m_B m_b}{s_0} C_7^{\text{eff}} \times [1 + \mathcal{O}(\alpha_s) + \dots]$$

$\Rightarrow$ Clean measurement of C_9 (sensitive to NP)

Other "γ" modes

Direct CPV: $b \to u\bar{u}d,\ u\bar{c}d$ — requires strong phase, which must be extracted from the analysis

- $B^\pm \to (D^0, \bar{D}^0)K^\pm \to f_i K^\pm \qquad (i = 1, 2)$
  Triangle construction from rates $\Rightarrow \quad \sin(\gamma \pm \delta)$
  Total Br's $\sim 10^{-7}$ — statistics?
- $B \to K\pi$ — careful
  Combination of rates. Need some assumptions on rescattering effects, penguins, factorization, $SU(3)$
- $B_d \to \pi^+\pi^-$ vs. $B_s \to K^+K^-$ Fleischer
  My feeling: measure all possible $B_{d,s} \to \pi\pi$, $K\pi$, KK asymmetries and rates, we'll figure out something, build a case...

NP could enter γ determinations very differently

Summary

What luminosity is "enough"?

If NP is discovered then many couplings may only be measurable in B decays (recall: $|V_{ts}|$ and $|V_{td}|$ will be measured in B – not in top – decay)

If results consistent with SM, then program is interesting as long as sensitivity to NP can be improved

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Some outrageous (?) guesstimates:

- $1000\ B \to K^{(*)}\ell^+\ell^-$ events $\to \sim 4\,\mathrm{ab}^{-1}$
- $\delta A_{CP}(B \to \phi K_S) = 0.05 \ \to \sim 4\,\mathrm{ab}^{-1}$
- $\delta|V_{ub}| = 1-2\% \ \to \sim 10\,\mathrm{ab}^{-1}$ (Shipsey, BCP4)

Other good goals:

- $\sin(2\beta+\gamma)$ from 4 time dependent $B \to D^*\pi$ rates
- $B \to \mu\bar\nu, \tau\bar\nu$
- ... etc.

It seems there's enough physics to want more $\int$lumi

To be compared with LHCB / BTeV

Some remarks

- The program as a whole is a lot more interesting than any single measurement
- One theoretically clean measurement is worth ten dirty ones — but dirty ones help!
- We are not simply measuring (ρ, η), or (α, β, γ), or looking for CP violation in B decays
  ... we are trying to learn as much as possible about the physics of flavor
- When new phenomena are seen at the LHC or Tevtron Run-II, "low energy high energy physics" may be crucial to understand what the new phenomena are, and what it is not

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I could have given a very different talk on what NP can give large effects in B decays — but I feel that the real question is how small deviations from the SM we can unambiguously disentangle from hadronic uncertainties

This may have seemed a bit like a laundry list, but I could not say, e.g., that the $B \to \rho\pi$ Dalitz plot analysis is more / less important than $B \to K^{(*)}\ell^+\ell^-$

It's a very broad program with a lot of exciting and important physics... which analyses will be most fruitful depend on possible new physics, on experimental details, and other things no one knows yet...

Conclusions

- To overconstrain CKM, all possible clean measurements are very important (both CP violating and conserving), even if redundant in SM (correlations!)

- e^+e^- and hadronic B factories are complementary; first precise test of CKM, in my opinion, will be from

$$\sin 2\beta, \quad |V_{ub}/V_{cb}|, \quad |V_{td}/V_{ts}|$$

(both) (e^+e^-) (Tevatron)

- Studying CKM/CPV and hadronic physics is complementary; except for a few very clean cases, several measurements needed to minimize theoretical uncertainties — with more data we'll find new ways to get rid of nasty things hard to constrain otherwise

Vibrant theoretical and experimental program

Hope to find exciting and unexpected physics

good luck!