The Physics of Beauty (& Charm[& τ]) at the LHC and in the Era of the LHC

Ikaros Bigi, Notre Dame du Lac

7/'06

Jagiellonian University = ~ Founding & Elite Member of Academia

At turn of the Millenium a phase transition or `quantum jump' in knowledge -- though not in understanding -- has occurred:

❶ SM's Paradigm of Large $\not{CP}$ in B Decays has been validated

➥ CKM dynamics promoted from an ansatz to a tested theory

❷ ν oscillations established (& solar model validated)

❸ emergence of `Dark Energy' -- who ordered that?

Even item ❶ -- a great, unqualified & novel success -- does not invalidate arguments in favour of the SM being incomplete already at the ~ TeV scale

LHC's justification:

Reveal dynamics driving electroweak phase transition

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Reveal dynamics driving electroweak phase transition

S. Beckett: "Ever tried? Ever failed?
No matter.
Try again. Fail again. Fail better.

Our foremost & central goal:
Make LHC succeed greatly -- even beyond our expectations
(& prove Beckett wrong)
[We know we will not fail forever -- I am confident we will succeed soon.]

My message:

☞ must study impact of that NP on flavour dynamics

➥ LHCb program intrinsically connected to core mission of LHC

i.e.,

integrate comprehensive flavour studies into this mission

✎ including dedicated studies of charm and τ decays

➼ not primarily to enlighten us about flavour/family puzzle

✍ though it could happen

➼ not to uncover the New CP Paradigm driving baryogenesis

✍ though it can quite possibly happen

➼ primarily instrumentalize CP … studies to interprete the footprints of New Physics to be revealed at high p_t studies at the LHC

☞ a neccesity -- not a luxury!

☞ a Super-Flavour Factory a most desirable component

Outline

I The SM's Paradigm of Large ~~CP~~ in B Decays -- a Triple Triumph

II Calibrating & Validating Theoretical Tools

III On Future Lessons in B Decays

IV The Dark Horses -- Charm and τ Leptons

V Summary & Outlook --The Need for a Super-Flavour Factory

I The SM's Paradigm of Large $\cancel{CP}$ in B Decays -- a Triple Triumph

3 central & predicted consequences of CKM theory

❶ Large $\cancel{CP}$ in B decays with no plausible deniability

2×10^{-3} in K^0-$\bar{K}^0$ system $\longrightarrow$ $\leq$ few$\times$100(!)$\times10^{-3}$ in B^0-$\bar{B}^0$ system

Act 1: $B \to \psi K_S$

Act 2: $B \to \pi^+ \pi^-$

Act 3: $B \to K^+ \pi^-$

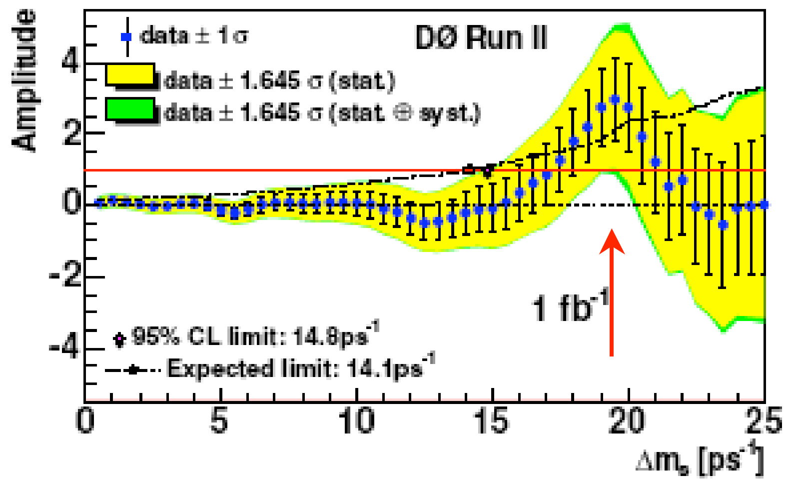
Act 4(?): $B^\pm \to K^\pm (\pi^+ \pi^-)_\rho$

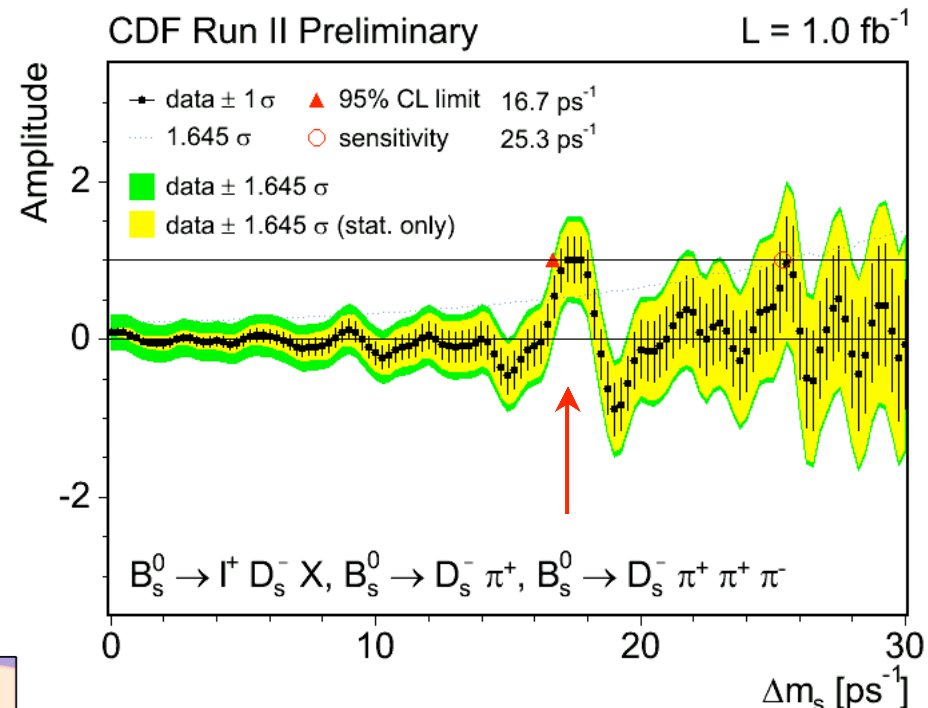
❷ large direct $\cancel{CP}$: see Acts 2,3 & 4(?)

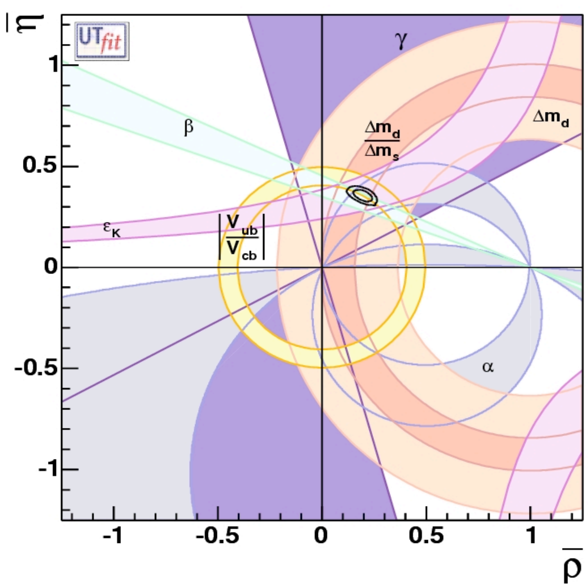
❸ CP insensitive observables --$|V(ub)|$,$|\Delta M_d/\Delta M_s|$-- imply $\cancel{CP}$ in qualitative as well as quantitative agreement with the data!

have all been validated!

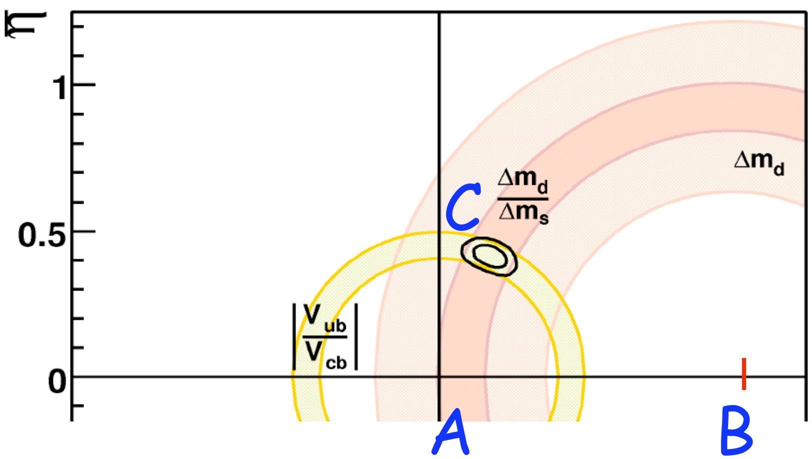
ad ❸ : B_s - $\bar{B}_s$ oscillations

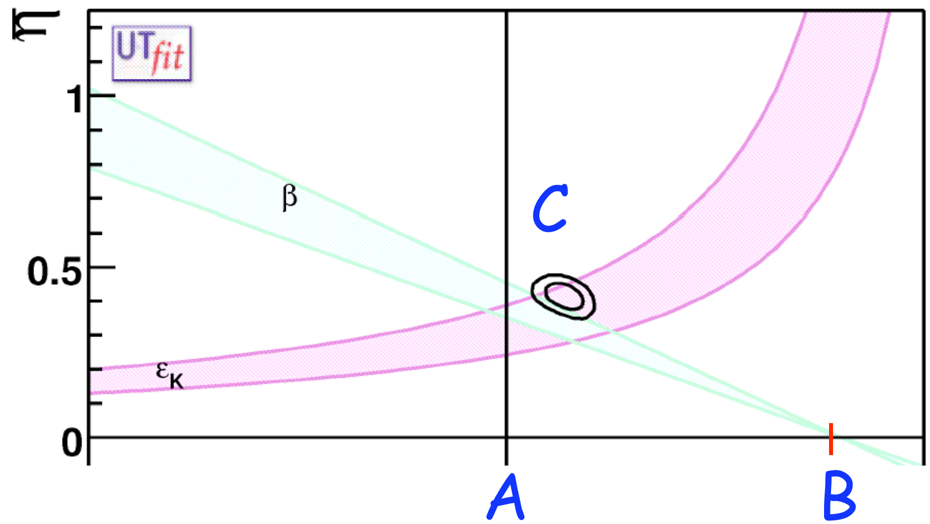






If true, another triumph for CKM theory:
CP insensitive observables ($V(ub), \Delta M_s$) imply ~~CP~~!





nevertheless -- B_s transitions able or even likely to exhibit manifestations of New Physics (see later)!

since summer '01:

- CKM paradigm has become a *tested* theory!
- \`demystification of $\cancel{CP}$':

  if dynamics can support $\cancel{CP}$, it can be large!

  i.e., observable phases can be large!

➡ \`demystification' completed

  if find $\cancel{CP}$ anywhere in lepton sector

there are domains with large $\cancel{CP}$ in $K^{neut} \to \pi\pi$ & in $K_L \to \pi^+\pi^- e^+ e^-$

$K_{neutral}$ vs. $B_{neutral}$

but: Mass ES ~ CP ES | Mass ES ≠ CP ES

Theorem: $M^{neut}(t) \to f_{CP} = Ke^{-\Gamma t}$, unless $\cancel{CP}$

$K^{neut} \to \pi\pi \sim Ke^{-\Gamma t}$ but $B_d \to \pi\pi \neq Ke^{-\Gamma t}$

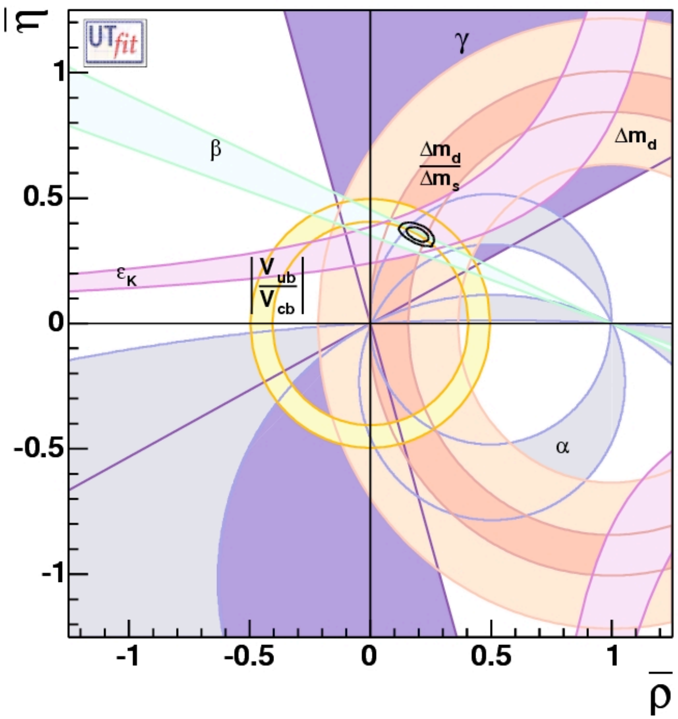
➡ statement \`$\cancel{CP}$ in B decays is much larger than in K decays'

is an empirically verified fact

$B \to \psi K_S$

- Summer 2005

$\sin 2\phi_1|_{WA} = 0.685 \pm 0.032$ vs. $\sin 2\phi_1|_{CKM} = 0.725 \pm 0.065$



Paradigm of large $\not{C}P$ in B decays
established in qualit. & quantit. agreement with CKM theory
in 3 (4?) quite distinct B_d channels

- commensurate with $\not{T}$ and with
- large direct $\not{C}P$ in 2 (3?) modes

`battle for supremacy' has been decided

goal no longer to find alternatives to CKM --

`monopoly'? Baryogenesis: no!

goal to identify corrections to CKM!

SM has scored novel successes with CKM dynamics that have to be viewed as amazing due to its very peculiar structure --

successes of its scalar, not its gauge sector!

❶ expect confidently LHC will find New Physics at TeV scale

❷ \`merely' establishing existence of New Physics not enough -- goal must be to identify its salient characteristics

SUSY an organizing principle, not a theory!

❸ TeV scale dynamics likely to have some impact on B decays

❹ discovery potential in B [D & τ] decays essential to figuring out the New Physics -- not a luxury!

☞ must add high accuracy to high sensitivity in studies of flavour dynamics

➻ goal can be achieved combining robust theory with detailed & comprehensive data

II Calibrating & Validating Theoretical Tools

Theory faces two types of challenges:

✍ Generic TeV scale New Physics scenarios should already have manifested themselves in FlChNC --
i.e, we are missing an important message about flavor dynamics
➥ \`New Flavour Problem'
i.e., \`hypothesis-generating' rather than \`hypothesis-probing'
Classification:
Minimal Flavour Violation, Non-Minimal Flavour Violation

✍ Need to bring nonperturbative QCD dynamics under quantitative theoretical control
☞ will focus on this challenge

2.1 Heavy Quark Theory

One of the most active fields of QCD

✍ the goal: to treat nonperturbative dynamics quantitatively

☺ the hope: $m_b \gg \Lambda_{QCD}$

➻ Heavy Quark Symmetry + Heavy Quark Expans. in $1/m_b$

i.e., combine global symmetry with dynamical treatement

Novel symbiosis between different theoretical technologies for heavy flavour nonperturbative dynamics -- in particular between HQE and LQCD

$$\text{observables} = \Sigma_i\, c_i(CKM, m_Q, \alpha_S)\, \underbrace{\langle H_Q | O_i | H_Q \rangle}_{\text{LQCD}}$$

HQE

HQP

LQCD

- ➻ duality ≠ additional ad-hoc assumption
- ➻ duality violation in $\Gamma_{SL}(B)$ < 0.5 %!

IB & N.Uraltsev, Int.J.Mod.Phys.A16(01)5201

$$M_B = m_b + \overline{\Lambda} + \frac{\mu_\pi^2 - \mu_G^2}{2m_b} + \frac{\mu_3^2}{m_b^2} + \ldots$$

yet $\boxed{\overline{\Lambda} \text{ does not affect the width!}}$

local colour gauge symmetry of QCD essential

Exact cancellation of the bound state effects with the final state interaction

- leading nonperturb. contrib. ~ $O(1/m_Q^2)$:

  ~ $O(5\ \%)$ for Q = b

not true for exclusive modes!

weight of nonpert. effects greatly reduced in beauty decays

➥ perturb. contributions numerically important

☞ with `smart' pert. treatment Γ_{parton} often good estimate

(2.1.1) Lifetimes of Beauty Hadrons

Status '05

	$1/m_b$ predict.	comment	data
$\tau(B^-)/\tau(B_d)$	$1+0.05(f_B/0.2\text{GeV})^2$ '92 1.06 ±0.02 '98-'03	PI in $\tau(B^-)$ fact. at low scale ~ 1 GeV	1.076 ± 0.008 ☺
$<\tau(B_s)>/\tau(B_d)$	1 ± $\mathcal{O}(0.01)$ '94		0.920 ± 0.030 😐
$\tau(\Lambda_b)/\tau(B_d)$	~0.9 - 1.0 '93 0.88 - 0.97 '98	quark model ME	0.806 ± 0.047 😐
$\tau(B_c)$	~ 0.5 psec '94	largest lifetime difference! no $1/m_Q$ crucial	0.45±0.12 psec ☺
$\Delta\Gamma(B_s)/\Gamma(B_s)$	$0.18(f_B/0.2\text{GeV})^2$ '87 0.12±0.04 '04	less reliable than $\Delta M(B_s)$	0.65±0.3 CDF 0.23±0.17 D0

'93/'94: $\tau(\Lambda_b)/\ \tau(B_d) \sim 0.9 - 1.0$ ibiBlokShifUraltVainsh

'94ff: $\tau(\Lambda_b)/\ \tau(B_d) \sim 0.806 \pm 0.047$

'98: $\tau(\Lambda_b)/\ \tau(B_d) \sim 0.94^{+0.03}_{-0.06}$ [0.88 - 0.97] Uralt

'04: $\cancel{\tau(\Lambda_b)/\ \tau(B_d) \sim 0.86 \pm 0.05}$ GOP

'05: $\tau(\Lambda_b)/\ \tau(B_d) \sim 0.87 \pm 0.17 \pm 0.03$ D0

$\tau(\Lambda_b)/\ \tau(B_d) \sim 0.944 \pm 0.086$ CDF

'06: $\tau(\Lambda_b)/\ \tau(B_d) \sim 1.037 \pm 0.058$ CDF

- still desirable to measure $\tau(\Xi^0_b)$ & $\tau(\Xi^-_b)$

'93/'94: $\tau(B_s)/\ \tau(B_d) = 1 \pm \mathcal{O}(1\ \%)$ ibiUralt

'05: $\bar{\tau}(B_s)/\ \tau(B_d) = 0.957 \pm 0.027$

(2.1.2) Applications to SL & rad. B Decays

Can we answer the ~ % level accuracy challenge?

Status '05

Inclusive $B \to l\nu X_c$ & $B \to \gamma X_s$ yield:

$m_b^{kin}(1\ \mathrm{GeV}) = (4.59 \pm 0.04)\ \mathrm{GeV}$ ⇐ 1.0 %

$m_c^{kin}(1\ \mathrm{GeV}) = (1.14 \pm 0.06)\ \mathrm{GeV}$ ⇐ 5.0 %

$|V(cb)| = (41.96 \pm 0.67) \times 10^{-3}$ ⇐ 1.6 %

vs.

$|V(us)|_{KTeV} = 0.2252 \pm 0.0022$ ⇐ 1.1 %

Buchmueller-Flaecher, hep-ph/0507253

need

- robust theoretical framework:
  - ✔ $1/m_Q$ expansions, Sum Rules, LQCD
- comprehensive & detailed data
  - ✔ SL B decays, lepton spectra, moments…

Quark masses

complication in weak decays:

$\Gamma(H_Q) \propto m_Q^{5}(\mu)$ [$z_3(m,\mu,\alpha_S)+ \ldots$]

- `pole' mass cannot be used -- renormalon ambiguity
- $\overline{MS}$ mass
  - appropriate when relevant scale $\mu > m_Q$, e.g.: $Z, H \to b\,\bar{b}$
  - inadequate for decays where $\mu < m_Q$

  fine as a reference point
- `kinetic' mass most appropriate

$$dm_Q(\mu)/d\mu = - 16\alpha_S(\mu)/3\pi - 4\alpha_S(\mu)/3\pi(\mu/m_Q) + \ldots$$

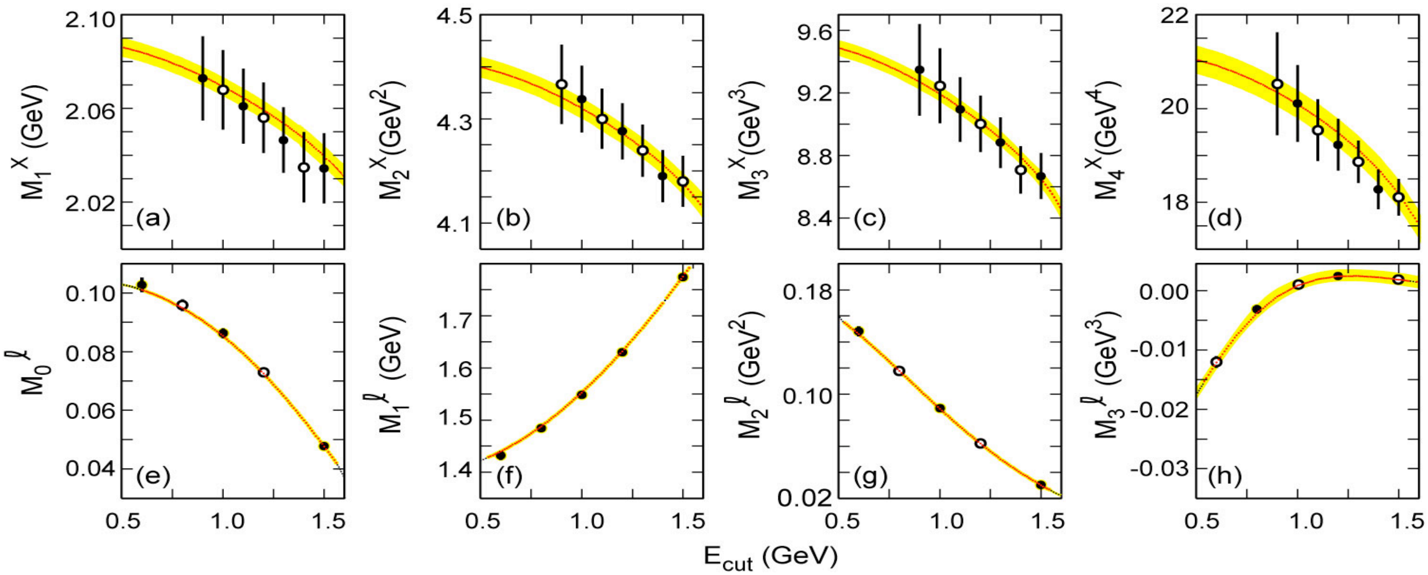
i.e., linear scale dependence in IR

- 1S mass inferior to kinetic mass

yet PDG `par ordre du mufti' declared it will list m(1S), but not $m_{kinetic}$.

Can somebody explain the scientific reason behind it?

On the dangers of restrictive experimental cuts

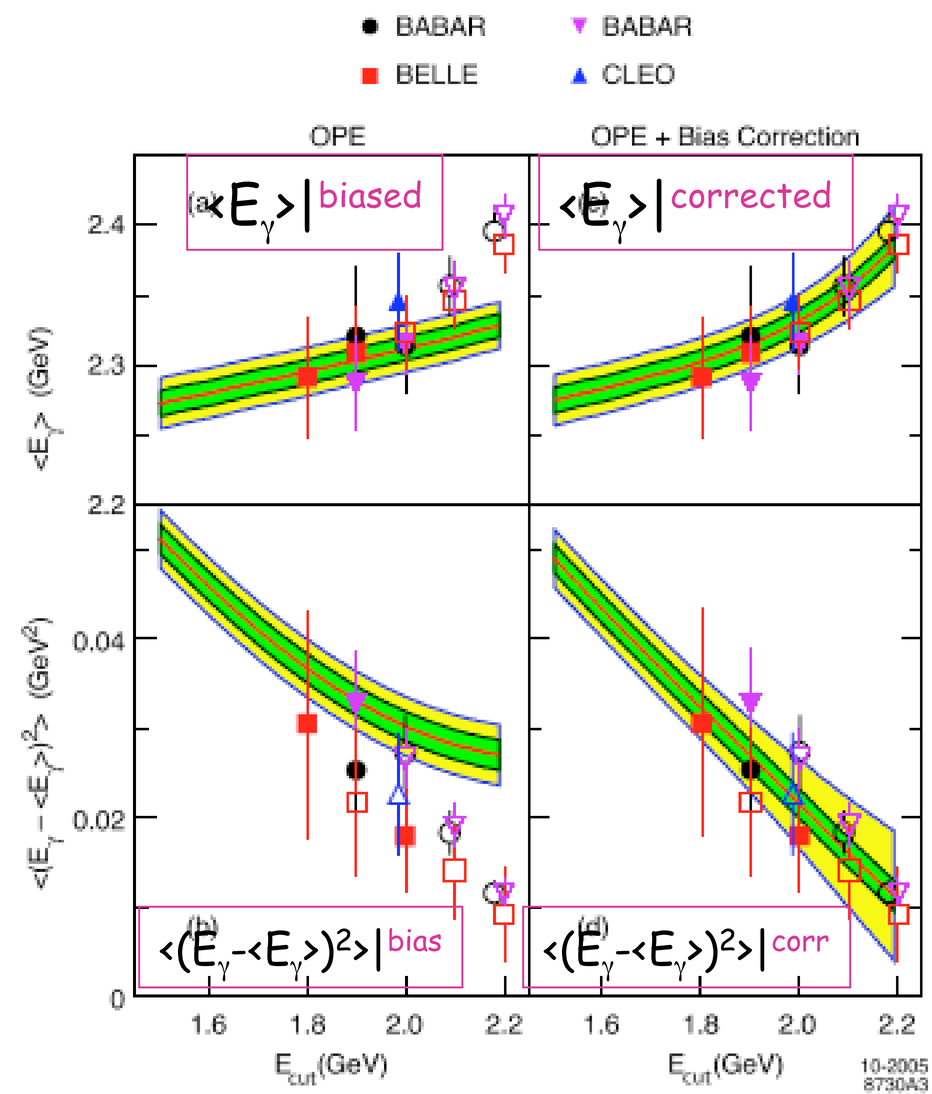


$B \to l\nu X_c$ moments from BABAR

http://www.geocities.com/Hollywood/Theater/9876/askdad1.html

$B \to \gamma X_s$ moments

Buchmueller-Flaecher, hep-ph/0507253



our predictions as evaluated by O. Buchmueller using HQP from BABAR's global fit to $B \to l\nu X_c$;
green band errors due to uncertainties in HQP
yellow band overall error

2.1.3 Lessons for $B \to l\nu X_u$

no need to `re-invent the wheel' -- for $B \to l\nu X_u$ use the same values of the HQP as determined in $B \to l\nu X_c$

- in principle $\Gamma(B \to l\nu X_u)$ under better theoretical control than $\Gamma(B \to l\nu X_c)$

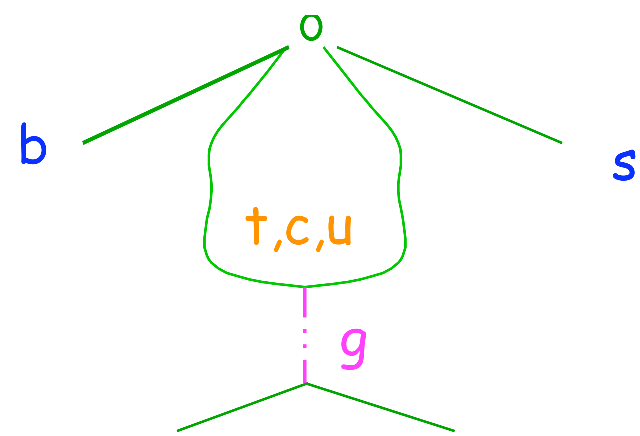
Lepton energy endpoint spectrum ?

- ☹ model dependent!
- 😐 can get heavy quark distribution function from $B \to \gamma X$
  - 😐 but only to leading order in $1/m_b$
- 😐 endpoint spectrum different for SL B_u and B_d decays (WA)

Hadronic recoil mass spectrum !

➥ |V(ub)| within 10 % likely, 5 % possible

(2.1.4) $\Gamma(B \to \gamma X_s)$



natural hunting ground for SUSY --
yet to extract width from data, need prediction for spectrum

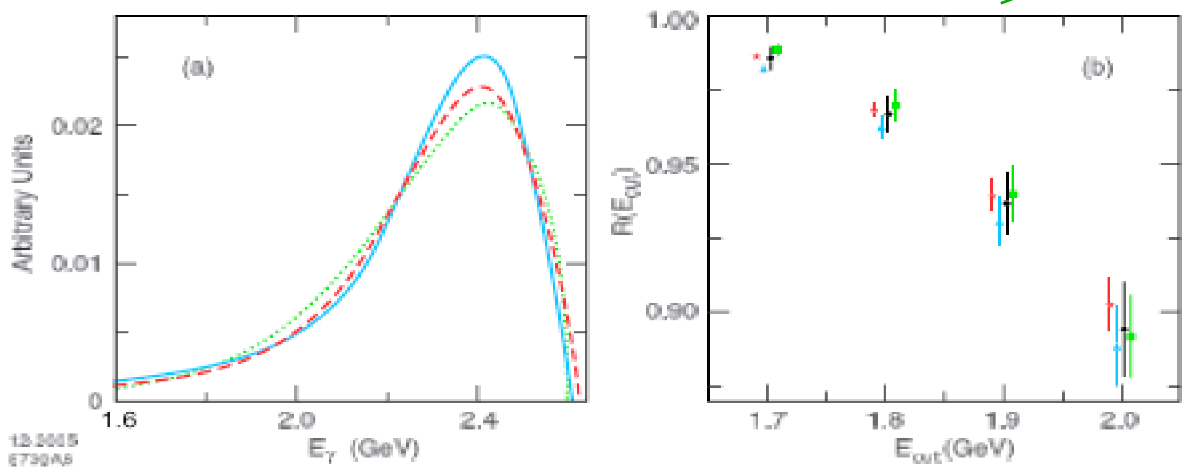


FIG. 6: Figure (a) shows the photon energy spectra corresponding to the fitted heavy quark distribution parameters in the kinetic scheme (dashed red), Shape Function scheme (solid blue) and Kagan-Neubert scheme (dotted green). Figure (b) shows the corresponding extrapolation factors $R(E_{cut})$ for varying E_{cut} for the kinetic scheme (red stars), Shape Function scheme (blue triangles) and Kagan-Neubert scheme (green squares) together with our average (black circles).

➥ main uncertainty in prediction is normalization

$$BR(B \to \gamma X_s)_{SM}^{E>1.6\ GeV} = (3.33 \pm 0.33) \times 10^{-4}$$

$$BR(B \to \gamma X_s)_{WA}^{E>1.6\ GeV} = (3.50 \pm 0.24) \times 10^{-4}$$

2.2 Charm as Bridge

Issue at stake: *not* QCD as theory of the strong forces,
but our ability to perform calculations

`charm: a bridge between bona fide heavy & light flavours'

light | heavy | super-heavy

u,d s | c | b | t

χpert th $\longrightarrow$ $\longleftarrow$ HQE

$\longrightarrow$ LQCD $\longleftarrow$

with challenges provided by CLEO-c now & BESIII data soon

III On Future Lessons in B Decays

Based on CKM's previous successes -- cannot count on massive manifestations of New Physics in flavour dynamics

➥ must combine high accuracy with high sensitivity in studies of flavour dynamics

3.1 On the Powers of the Dalitz Plot -- Case Studies

- Hard to bring hadronization under quantitative control --
- yet should view it as an essential even if quirky ally
- we can deal with by treating rich & complex data judiciously with Dalitz studies etc.

Dalitz plot studies a powerful high sensitivity tool rather than pre-historic remnant used only by people too old to learn C++.

3.1.1 Case I: ϕ_3 from $\cancel{CP}$ in $B^\pm \to D^{neut}K^\pm$

$$\begin{tikzcd} & D^0K^- \arrow[dr] & \\ B^- \arrow[ur] \arrow[dr, "\phi_3"'] & & f_{common} \\ & \overline{D}^0K^- \arrow[ur] & \end{tikzcd} \quad \text{vs.} \quad \begin{tikzcd} & D^0K^+ \arrow[dr] & \\ B^+ \arrow[ur, "-\phi_3"] \arrow[dr] & & f_{common} \\ & \overline{D}^0K^+ \arrow[ur] & \end{tikzcd}$$

original idea: $f_{common} = h_1h_2$ -- $K_S\pi^0, K^+K^-, \pi^+\pi^-, K^+\pi^-, K^-\pi^+$

drawback: small BR's

new idea implemented by BELLE:

use $f_{common} = K_S\pi^+\pi^-$ coupled with Dalitz plot analysis

requires a lot of investment & effort -- yet pays handsome profit in cross checks $\Longrightarrow$ confidence!

A. Poluektov *et al.* (Belle Collaboration), hep-ex/0406067, to appear in PRD.

Using $B^\pm \to DK^\pm$ and $B^\pm \to D^*K^\pm$ ($D^* \to D\pi^0$)

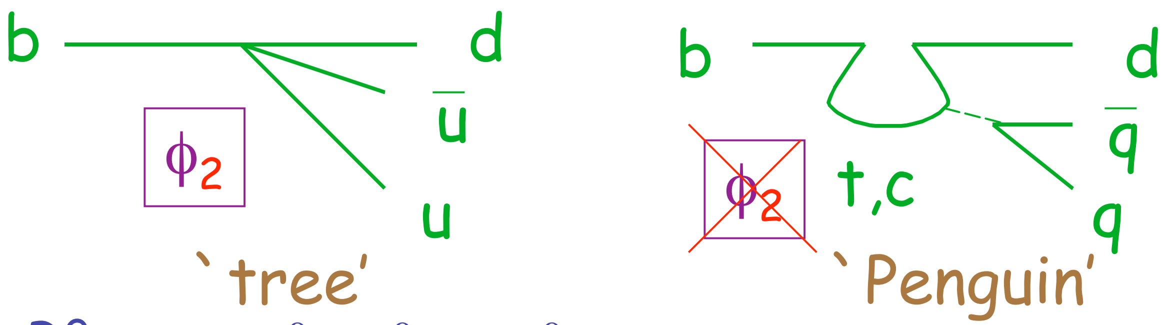
$$\phi_3 = 77^\circ \,{}^{+17^\circ}_{-19^\circ}(\mathrm{stat}) \pm 13^\circ(\mathrm{syst}) \pm 11^\circ(\mathrm{model})$$

uncertainties can be defended intrinsically

➥ a method with a great future!

3.1.2 Case II: ϕ_2 from $\not{C}P$ in $B_d \to$ pions

2 operators contribute:



➬ $B^{0,\pm} \to \pi^{+,0}\pi^{-,0}, \pi^{\pm}\pi^{0}$

challenging experimentally, yet reliable theoretically

➬ $B^{0,\pm} \to \rho^{+,0}\pi^{-,0}, \rho^{\pm}\pi^{0}, \pi^{+,0}\rho^{-,0}, \pi^{\pm}\rho^{0}$

less challenging experimentally, yet reliable theoretically??

$B \to \pi\pi\pi$: $\rho\pi$ vs. $\sigma\pi$ vs. ?? (U. Meissner, S. Gardner)

➬ $B^{0,\pm} \to \rho^{+,0}\rho^{-,0}, \rho^{\pm}\rho^{0}$

even better experimentally, yet even worse theoretically

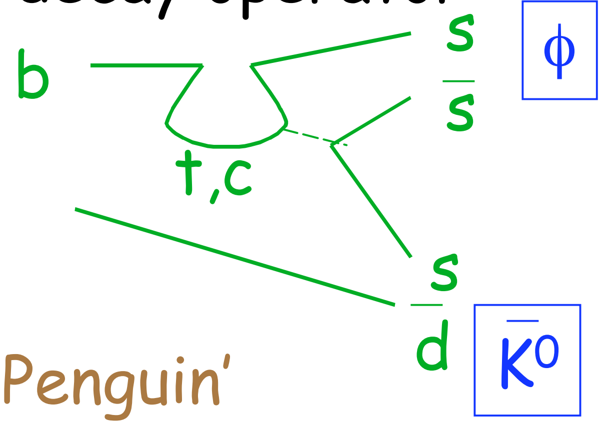
$B \to \pi\pi\pi\pi$: $\rho\rho$ vs. $\sigma\rho$ vs. $\sigma\sigma$ vs. $\rho\pi\pi$ vs. $\sigma\pi\pi$ vs. ...

➥ need expertise from low-energy hadronization

(chiral dynamics, Dalitz plot)

3.1.3 Case III: ϕ_1 from $\cancel{C}P$ in $B_d \to$ 3 kaons

1 decay operator:



'Penguin'

excellent for searching for NP

- pure loop effect in SM
- single $\Delta B=1$ operator
- reliable SM prediction

$\sin 2\phi_1 (B_d \to \psi K_S) \approx \sin 2\phi_1 (B_d \to \phi K_S)$

- ϕ a narrow resonance

$\sin 2\phi_1 = 0.685 \pm 0.032$ from $B_d \to \psi K_S$

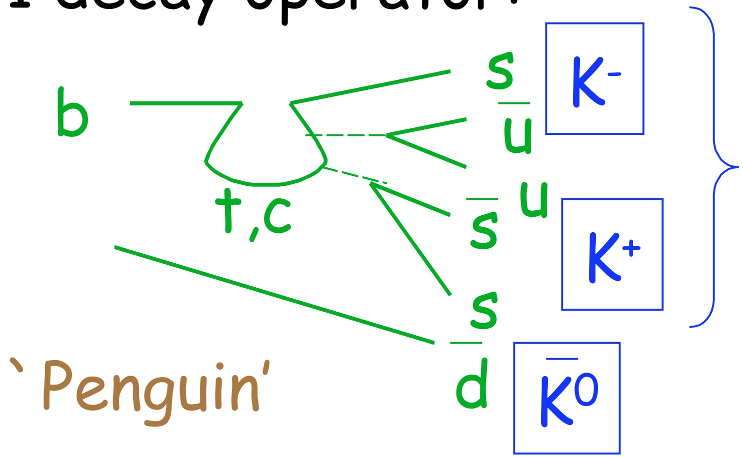
[hep-ex/0408072]

"$\sin 2\phi_1$" $= +0.50 \pm 0.25 \,{}^{+0.07}_{-0.04}$
A $= 0.00 \pm 0.23 \pm 0.05$

BELLE

"$\sin 2\phi_1$" $= +0.44 \pm 0.27 \pm 0.05$
A $= -0.14 \pm 0.17 \pm 0.07$

1 decay operator:



$\phi, f_0(980)$, ...

$\cancel{CP}(B_d \to \phi K_S)$ = - $\cancel{CP}(B_d \to$ `f_0'$(980) K_S)$

i.e., a smallish `pollution' by `f_0'K_S

reduces $\cancel{CP}$ observed in ϕK_S

➥ need to perform full time-dep. Dalitz plot analysis for

- $B_d \to K^+ K^- K_S$,
- $B_d \to K_S K_S K_S$
- $B^+ \to K^+ K^- K^+$,
- $B^+ \to K^+ K_S K_S$

S. Bianco's Razor:

measure $\cancel{CP}$ in $B_d \to [K^+ K^-]_M K_S$ as function of cut on M

3.2 Other Rare B Decays

$B \to \tau\nu D$

search for charged Higgs contrib. in large tan β scenario in $\Gamma(B \to \tau \nu D) / \Gamma(B \to \mu \nu D)$ (Miki, Miura & Tanaka)

Yet

☹ hadronic form factors drop out only for $m_{b,c} \to \infty$

☺ BPS approx. (Uraltsev) allows to calc. to all orders in $1/m_Q$

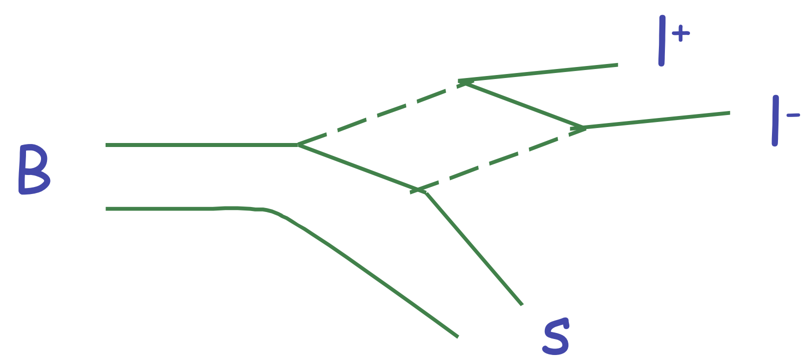
if validated in extracting V(cb) from $B \to \tau\nu D$

➥ sensitive probe for non-minimal Higgs dynamics due to novel theoretical tool

$B \to \tau\nu X_c$

Can calculate width to ≤ 5% -- measure it to within ? %?

$B \to l^+ l^- X_s$



$BR(B \to l^+ l^- X)$
- $= (6.2 \pm 1.1 \pm 1.5) \times 10^{-6}$ BELLE/BaBar
- $= (4.2 \pm 0.7) \times 10^{-6}$ SM

$B \to \nu\nu X_q$

$BR(B \to \nu \nu K)$
- $\leq 7.0 \times 10^{-5}$ BaBar
- $= (3.8^{+1.2}_{-0.6}) \times 10^{-6}$ SM (BuHiIs)

$BR(B \to \nu \nu X)$
- $\leq 7.7 \times 10^{-4}$ ALEPH
- $= 3.5 \times 10^{-5}$ SM $\gg BR(B \to l^+ l^- X)$

➾ dynamical info in general different from $B \to l^+ l^- X$

3.3 ~~CP~~ in B_s Decays -- an Independent Chapter in Nature's Book

`Think outside the box!' -- several SM relations unlikely to hold beyond minimal extensions of SM

B_u/B_d and B_s 2 different chapters in

Nature's Book on Fundamental Dynamics!

$\Delta\Gamma_s$	theoret. predict. based on quark box diagram	data
$\Delta\Gamma(B_s)/\Gamma(B_s)$	$0.18(f_B/0.2\,GeV)^2$ '87	0.65 ± 0.3 CDF
	0.12 ± 0.04 '04	0.23 ± 0.17 D0

my heart wishes $\Delta\Gamma(B_s)/\Gamma(B_s) \sim 0.5$

yet my head tells me $\Delta\Gamma(B_s)/\Gamma(B_s) > 0.25$ very unlikely

$\Delta\Gamma_s$: $B_s \to c\,\bar{c}\,s\,\bar{s} \to \bar{B}_s$

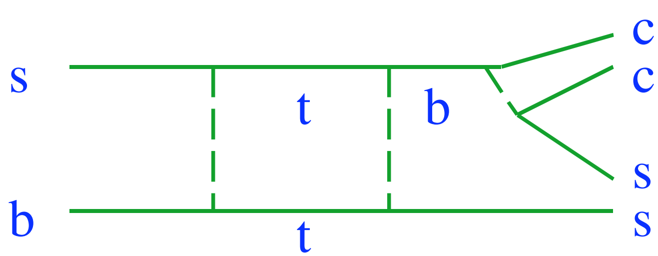
- enhance $\Delta\Gamma_s$
  - enhance Γ_s

$\Delta\Gamma(B_s)/\Gamma(B_s) > 0.25$ inconsistent with $\langle\tau(B_s)\rangle/\tau(B_d) = 1 \pm \sim 0.01\text{-}0.02$

☞ quark box diagram less reliable for $\Delta\Gamma(B)$ than for $\Delta M(B)$

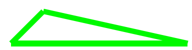
chance for massive impact of NP:

- $B_s \to \mu^+\mu^-$ in some SUSY scenarios $(tg\beta)^6$!
- $\cancel{CP}$ in $B_s \to \psi\ \phi/\eta$ in CKM ~ 2 %



quarks of 2nd and 3rd family only!

several × 10 % possible with NP



bs triangle: $V^*_{us}V_{ub} + V^*_{cs}V_{cb} + V^*_{ts}V_{tb} = \delta_{bs} = 0$

- $\cancel{CP}$ in $B_s \to \phi\ \phi$ much more than a repetition of $B_d \to \phi\ K_S$ -- 3 partial waves!
- $B_s \to l^+X$ vs. $B_s \to l^-X$ in CKM < 10^{-4}, yet could be enhanced by ~ 100!

Capabilities of HadColl

- $B_s \to \mu^+\mu^-$ everybody!
- $B_s \to \tau^+\tau^-$ anybody?
- ΔM_s if not found by CDF/D0 probably DONE now
- $\cancel{CP}$ in $B_s \to \psi\phi/\eta$ to probe for NP in $\Delta B=2$

  need good flavour tagging & tracking
- $\cancel{CP}$ in $B_s \to D_s K$ to probe for NP in $\Delta B=2\&1$

  need good flavour tagging, tracking & particle id
- $\cancel{CP}$ in $B_s \to l^{ws} X$ to probe for NP in $\Delta B=2$

  need good flavour tagging & lepton id
- rates, spectra & asymm. in $B_{u,d} \to l^+ l^- K/K^*$, $l^+ l^- \pi/\rho$

  need efficient trigger, good flavour tagging & particle id
- rates, spectra & asymm. in $B_s \to l^+ l^- \phi$, $l^+ l^- K^*$

  need efficient trigger, good flavour tagging, tracking & particle id

IV The Dark Horses -- Charm and τ Leptons

4.1 ~~CP~~ in Charm Decays

S. Bianco et al., `A Cicerone for the Physics of Charm', hep-ex/0309021, La Rivista d. N. C.

`I know she invented fire -- but what has she done recently?

only up-type quark allowing full range of probes for New Phys.

- top quarks do not hadronize
- up quarks: no π^0-π^0 oscillations possible

CP asymmetries basically ruled out by CPT

basic contention:
charm transitions are a unique portal for obtaining a novel access to the flavour problem with the experimental situation being a priori favourable (apart from absence of Cabibbo suppression)!

only now are entering realistic domain for New Physics

CP Violation

- ☺ baryon # of Universe implies/requires NP in ~~CP~~ dynamics
- ☺ within SM:
  - ☞ highly diluted weak phase in 1x Cabibbo supp. Modes
    $V(cs) = 1 \ldots + i\lambda^4$
  - ☞ no weak phase in Cab. favoured & 2 x Cab. supp. modes
    (except for $D^\pm \to K_S h^\pm$)
- ☺ CP asymmetry linear in NP amplitude

✍ B factories can contribute

☞ challenge to LHCb: can you?
$D^{*+} \to D^0(t) \to K^+\pi^-$ vs. $D^{*-} \to \overline{D}^0(t) \to K^-\pi^+$

An example for a T odd distribution

$K_L \to \pi^+\pi^- e^+ e^-$

ϕ = angle between $\pi^+\pi^-$ & e^+e^- planes

forward-backward asymmetry in ϕ: A= 14 % driven by ϵ=0.002

$D \to K \bar{K} \pi^+\pi^-$

ϕ= angle between $\pi^+\pi^-$ & $K \bar{K}$ planes

$d\Gamma/d\phi \, (D \to K \bar{K} \pi^+\pi^-) = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \cos\phi \sin\phi$

$d\Gamma/d\phi \, (\bar{D} \to K \bar{K} \pi^+\pi^-) = \bar{\Gamma}_1 \cos^2\phi + \bar{\Gamma}_2 \sin^2\phi + \bar{\Gamma}_3 \cos\phi \sin\phi$

- Γ_3 drops out after integrating over ϕ
  - Γ_1 vs. $\bar{\Gamma}_1$ & Γ_2 vs. $\bar{\Gamma}_2$: $\cancel{CP}$ in partial widths
- T odd moments $\Gamma_3, \bar{\Gamma}_3 \neq 0$ can be faked by FSI
  yet $\Gamma_3 \neq \Gamma_3$ $\Longrightarrow$ CP!

☞ question to LHCb: can you do that?

4.2 $\cancel{CP}$ & LFV in τ Decays -- the Next Hero Candidates

$\boxed{\Gamma_{CP} \sim A^*_{SM}\, A_{NP}}$

Compelling impetus to search for $\cancel{CP}$ in leptodynamics

- to complete `demystification' of $\cancel{CP}$
- baryogenesis due to primary leptogenesis (?)

ν oscillations	Electron EDM	$\cancel{CP}$ in τ Decays

most promising channels: $\tau \to \nu K \pi$

- most sensitive to Higgs dynamics
- CP asymmetries possible also in final state distributions rather than integrated rates
- unique opportunity for $e^+e^- \to \tau^+\tau^-$ pair produced with spins aligned:

LFV

SM forbidden τ decays

$\Gamma_{LFV} \sim |A_{NP}|^2$

$\tau \to \mu/e\,\gamma$ only in e+e-

$\tau \to 3\,l$ competition from LHC with 10^{12} τ/year?

- if New Physics in $b \to sss \approx$ SM Physics in $b \to sss$ ad-hoc
  if New Physics in $b \to sss \approx$ New Physics in $\tau \to \mu\mu\mu$ ad-hoc
  then $BR(\tau \to \mu\mu\mu) \sim 10^{-8}$
- most NP models: $\Gamma(\tau \to \mu/e\,\gamma) > \Gamma(\tau \to 3\,l)$
  - but not all
  - often $\Gamma(\tau \to 3l)$ within factor 10 of $\Gamma(\tau \to \mu/e\,\gamma)$

V Summary & Outlook --The Need for a Super-Flavour Factory

- Validation of the *SM Paradigm of Large ~~CP~~* in B decays in the last 5 years
  - CKM describes at least the lion's share of observed ~~CP~~
- B_s decays represent an independent chapter in Nature's book on fundamental dynamics
- Apparently another qualitative success of CKM: $\Delta M(B_s)$
  - ☹ a certain feeling of `deja vue all over again' for theorists
  - ☺ yet good news for dedicated experimentalists
    - even with $\Delta M(B_s) \sim \Delta M(B_s)|_{SM}$ observable ~~CP~~ in $B_s \to \psi\,\phi/\eta$ can greatly exceed SM prediction of 2%
    - relatively low value of $\Delta M(B_s)$ should allow CMS & Atlas to participate in `the hunt'
    - likewise for $B_s \to l^+ l^- \phi$

- Large discovery potential for New Physics in both charm as well as τ decays
  - τ decays
    - LFV: $\tau \to l\,\gamma$, $\tau \to 3l$
    - $\cancel{CP}$: leptogenesis
  - charm decays: only up-type quark allowing full search
    - only $\cancel{CP}$ can yield unambiguous signal
  - only now entering realistic search domains
  - can LHCb take up the charm challenge?
  - can Atlas/CMS take up $\tau \to 3l$ challenge?

The Big Picture

❶ What drives the electroweak phase transition?
Identifying the *cpNP* driving it has to be our primary goal.

❷ This *cpNP* can affect flavour transitions significantly

☞ studies of flavour transitions likely to elucidate salient features of the *cpNP*

➥ Heavy flavour decays provide probe for New Physics that is complementary to the TEVATRON, LHC & Linear Collider

i.e., CP studies are instrumentalized

❸ A dedicated program of studying heavy flavour decays essential -- not a luxury

☞ precision measurements essential in B decays

✍ precise data drive (some) theorists to accuracy

❹ "Know so much, yet understand so little!"

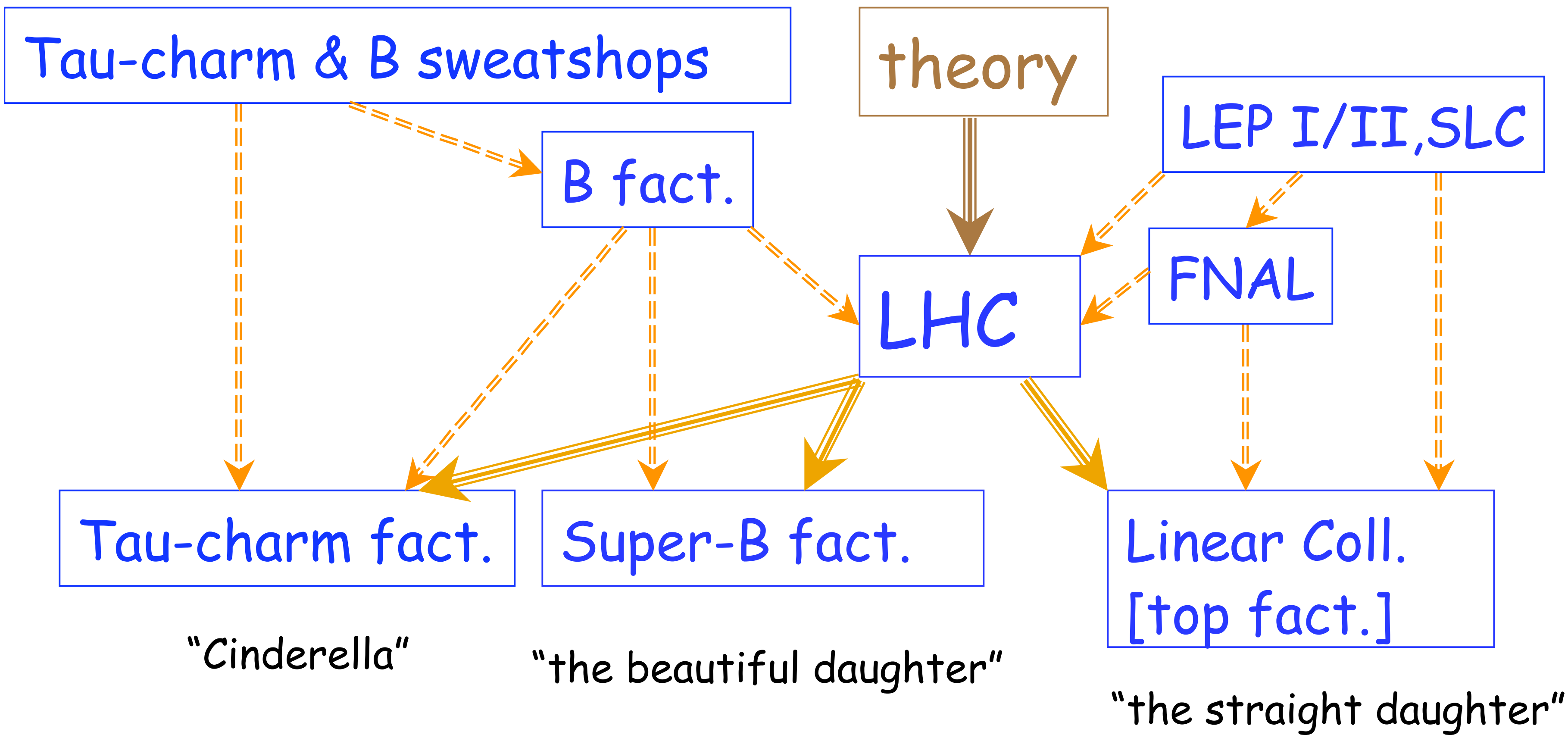
The SM's success in describing flavour transitions not matched by an understanding of the origin of flavour.

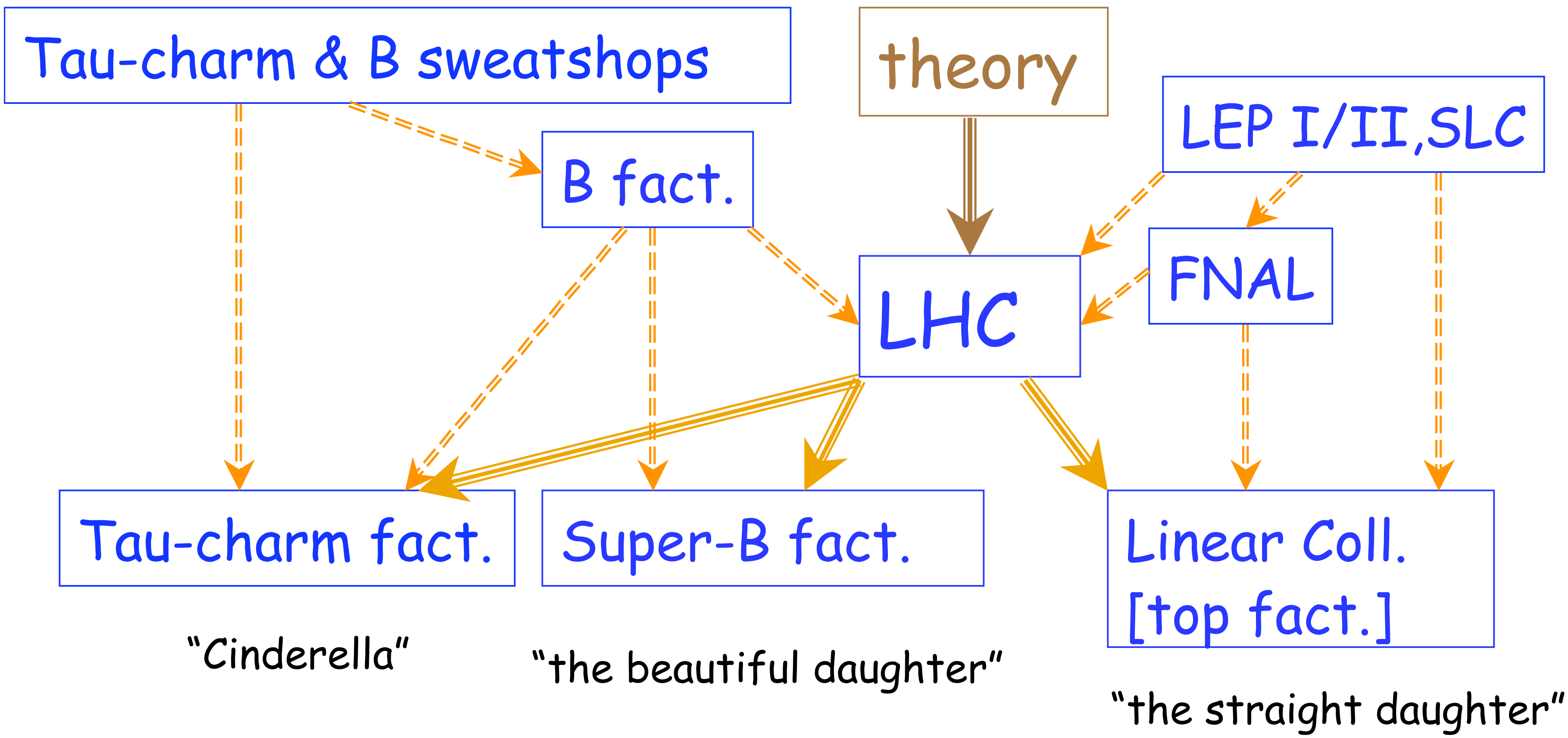
☞ heavy flavour studies

- are of fundamental importance;
- its lessons cannot be obtained any other way;
- cannot become obsolete;
- sweep out dynamical scales up to ~ 100 TeV & beyond

❺ Super-B factory = e^+e^- collid. near Y(4S) with L~ 10^{36} cm^{-2} s^{-1} appears peerlessly able to provide required data base

LHC high p_t program -- largely `hypothesis-probing' research
B studies -- significantly `hypothesis-probing' research
Charm & τ studies -- mostly `hypothesis-generating' research


Tau-charm & B sweatshops
theory
LEP I/II,SLC
B fact.
LHC
FNAL
Tau-charm fact.
Super-B fact.
Linear Coll.
[top fact.]
"Cinderella"
"the beautiful daughter"
"the straight daughter"



beginning of an exciting adventure ...

and we are most privileged to participate!

Backup slides

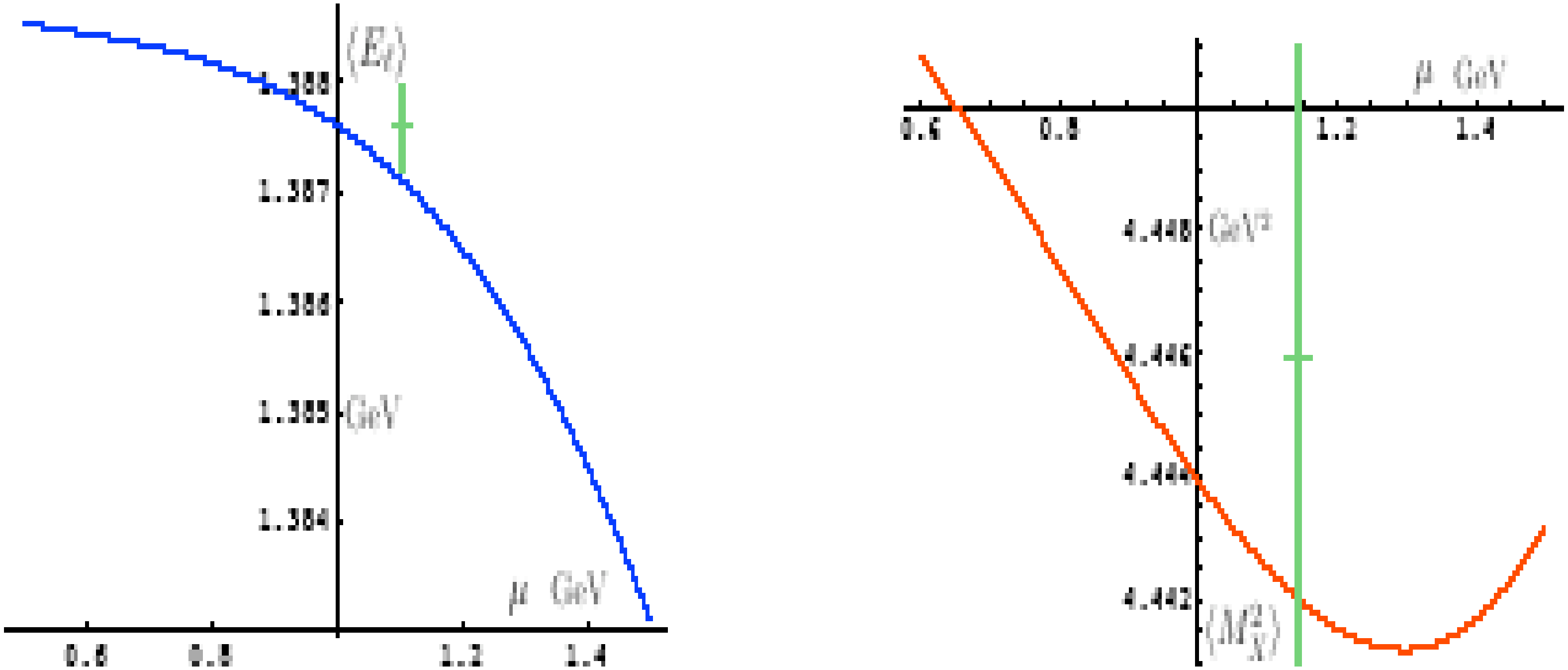


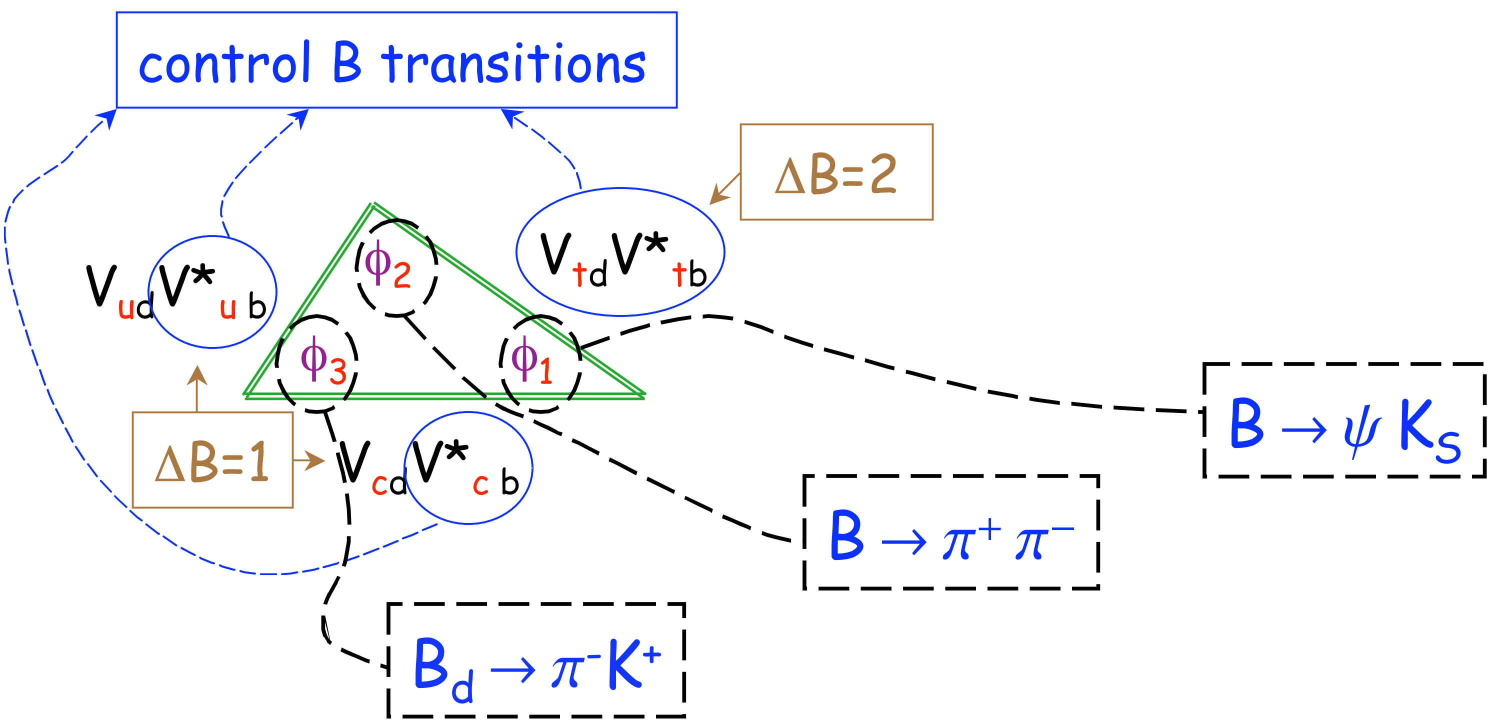
Figure 5: Dependence of $\langle E_\ell \rangle$ (left) and of $\langle M_X^2 \rangle$ (right) on the separation scale μ. The green vertical bars show the change in the moments when m_b is varied by $\pm 1\,\mathrm{MeV}$

Uraltsev

$V_{CKM} V_{CKM}^{*} = 1$ ⟹ 6 unitarity triangles

single $SU(2)_L$

$\tau_B \sim 1$ psec ⟹ `the' CKM triangle with 3 naturally large angles

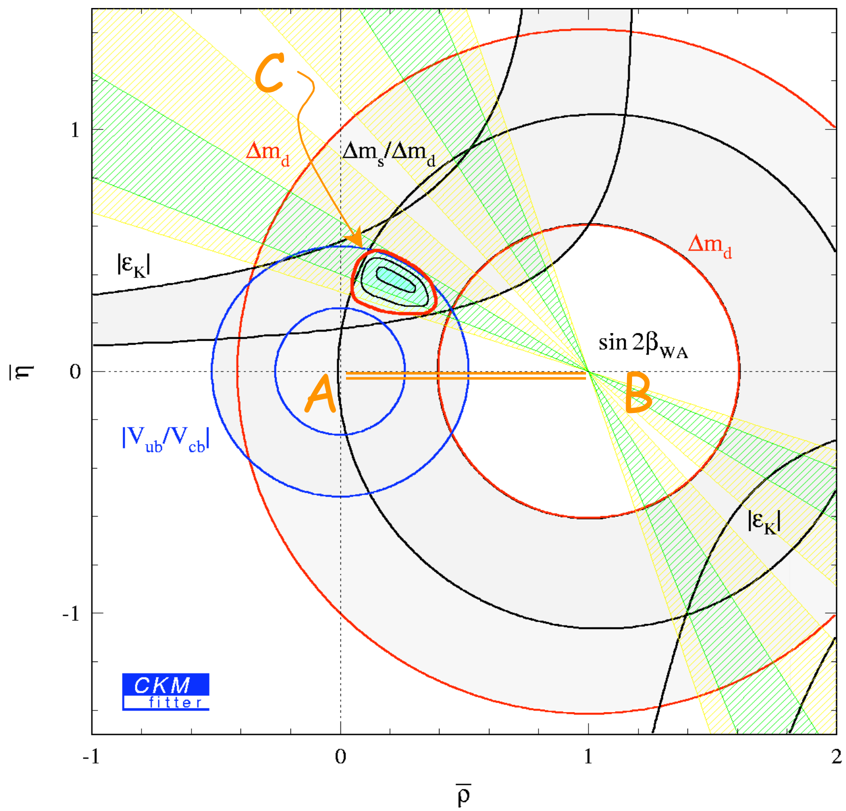


Yes, indeed …

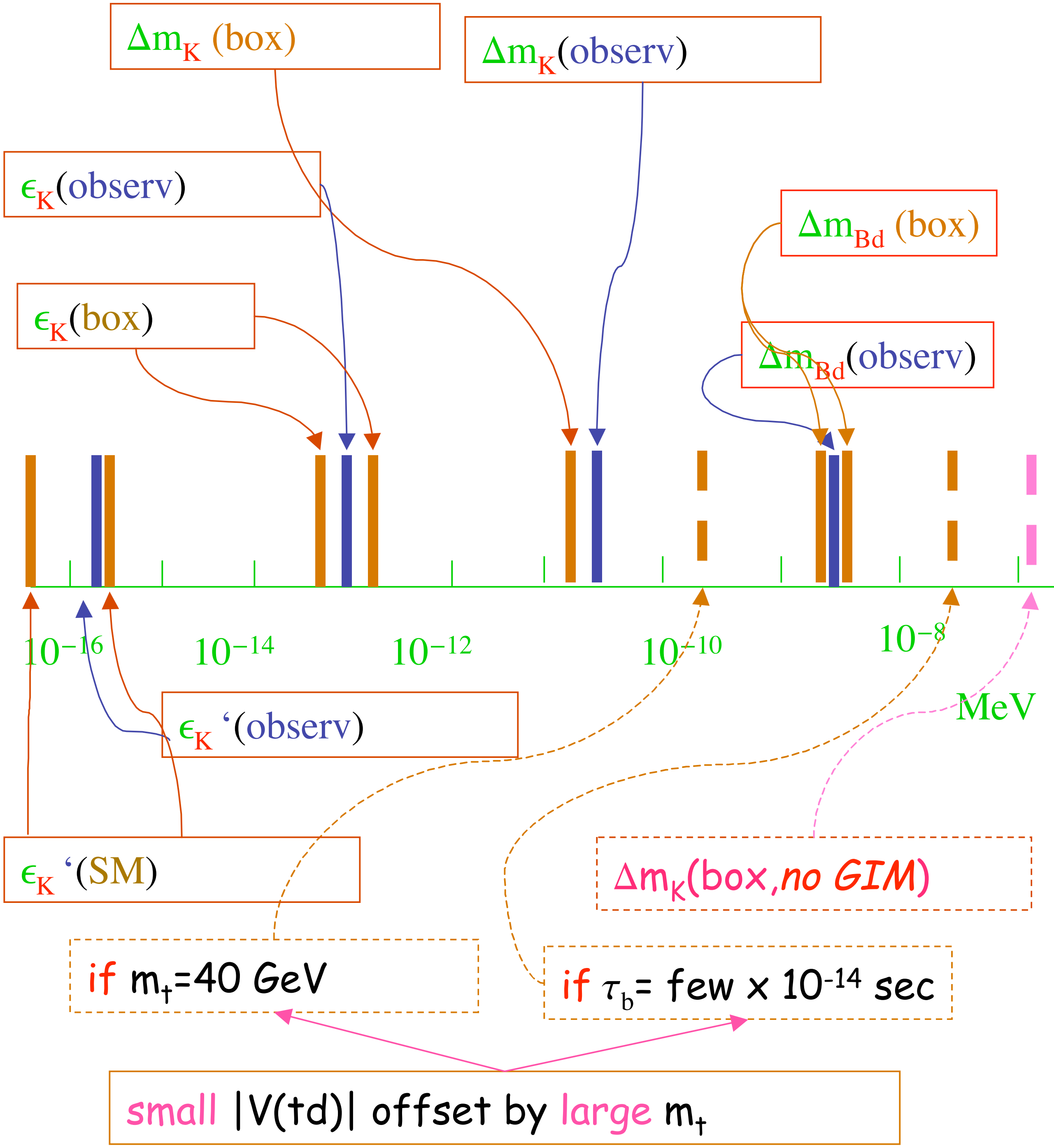
large fraction of Δm_K, ϵ_K, Δm_B — could be due to New Physics
most of ϵ_K'

or equivalently

data constraints translate into `broad' bands in unitarity triangle plots



yet such a statement misses the real point!



can be reproduced with

$|V(us)| \sim 0.22, |V(ts)| \sim 0.04$

$|V(td)| \sim 0.004$

$m_u \sim 5$ MeV, $m_c \sim 1.2$ GeV

$m_t \approx 180$ GeV, $m_d \sim 10$ MeV

$m_s \sim 0.15$ GeV, $m_b \approx 4.6$ GeV

observables spanning several orders of magnitude accommodated with

parameter choices that a priori would seem frivolous!

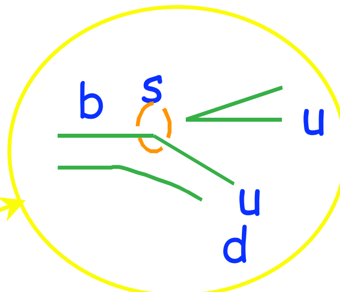
There could easily have been inconsistencies!

Act 3: More on Direct ~~CP~~

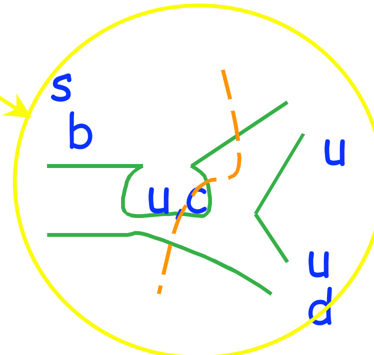
$B_d \to \pi^- K^+$

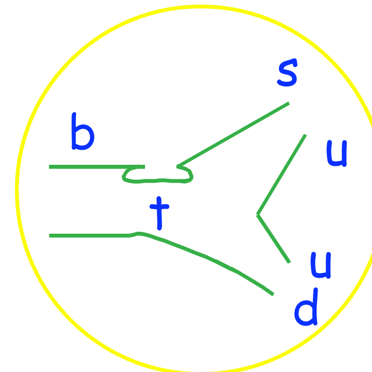
BSS

local operator
with weak phase



nonlocal operator
with strong phase





local operator not
needed, but there

BKSU

1987: $BR(B_d \to \pi^- K^+) \sim 10^{-5}$, $A_{CP} = -0.10$

2004

BABAR

hep-ex/0408057, submitted to PRL

$$A_{CP} = -0.133 \pm 0.030 \pm 0.009$$

4.2σ

Belle

Confirmation at ICHEP04

Signal (274M $B\bar{B}$ pairs): 2140 ± 53

$$A_{CP} = -0.101 \pm 0.025 \pm 0.005$$

3.9σ

Average $$A_{CP} = -0.114 \pm 0.020$$

1.2 Establishing CKM as a Theory: $\cancel{CP}$ in B Decays

Nature has been extremely kind to us in creating this

`Paradigm of large $\cancel{CP}$ in B decays'

with `no plausible deniability!'

by arranging for

(i) huge top quark mass

(ii) `long' B lifetime

$$\left.\begin{array}{l}\text{(i) huge top quark mass}\\ \text{(ii) `long' B lifetime}\end{array}\right\} \quad \Delta M(B_d)/\Gamma(B_d) \sim 1$$

and making it observable by arranging for

(iii) $\Upsilon(4S)$ being above $B\bar{B}$, yet below BB^* threshold

(iv) charm initiating the development of μvertex detectors

Pythagoras:"There is no royal way to mathematics!"

Nor is there to fundamental insights into nature's inner working.

Need data that are

- detailed &
- accurate &
- comprehensive &
- can be interpreted with commensurate reliability

e.g.:

high statistics studies of charm decays (Dalitz plots etc.) are essential to saturate discovery potential in B decays