Is Super-B Sufficiently Superb ? -- On a Physics Menu for a Super-B Factory

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2 questions

(A) $\exists$ sufficiently strong justification for dedicated heavy flavour program?

(B) If so -- does one really need a Super-B factory as part of such a program?

answer to question (A) straightforward:

- fermion masses, family structure, CKM parameters } central mysteries / strongly suspected NP
  ssNP at ~ ??? TeV
- Baryogenesis?

- Heavy flavour studies
  - are of fundamental importance,
  - their lessons cannot be obtained any other way and
  - they cannot become obsolete.

They will remain crucial in our efforts to reveal

Nature's Grand Design

irrespective of high p_T studies at FNAL, LHC & LC!

answer to question (B) much less straightforward

Outline

- (I) Sizing up the Enemy
- (II) Defining Goals of the Campaign
- (III) Strategies of Attack
  - (3.1) Frontal/Brute Force Attack
  - (3.2) Obvious Attacks
  - (3.3) Attacking Supply Lines
  - (3.4) Flanking Attacks
- (IV) Lessons

(I) Sizing up the Enemy

Remember AC Milano leading FC Liverpool 3:0 at halftime
with gorgeous play -- yet the pesky Brits,
while still being outplayed, refused to concede.

That is the story as well with the SM:

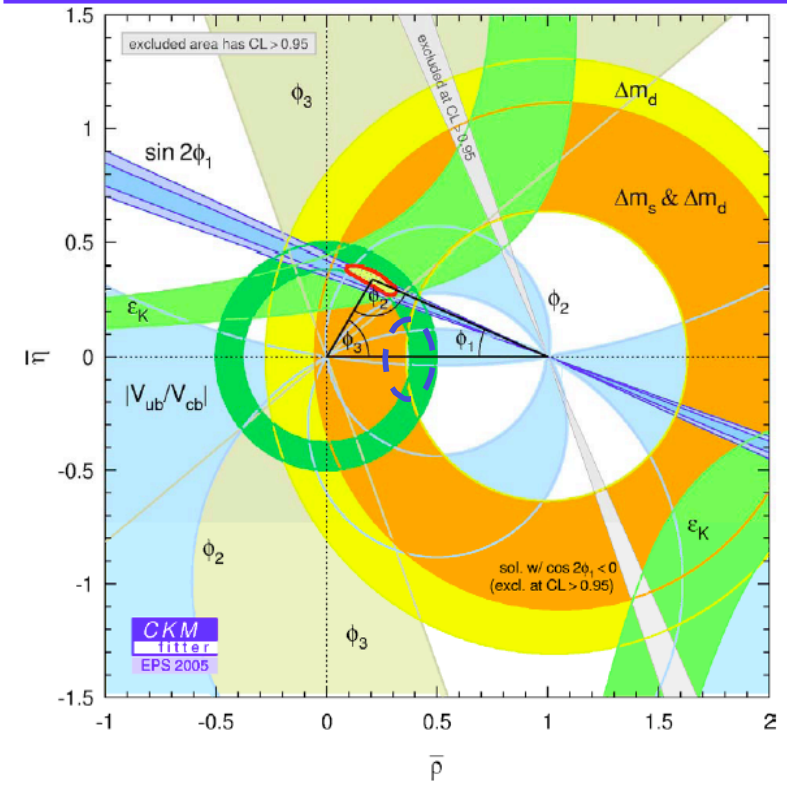
Every self-respecting HEP type has designed extensions of
the SM that are greatly superior to it --

now we have to overcome the stubborness of the SM to yield!

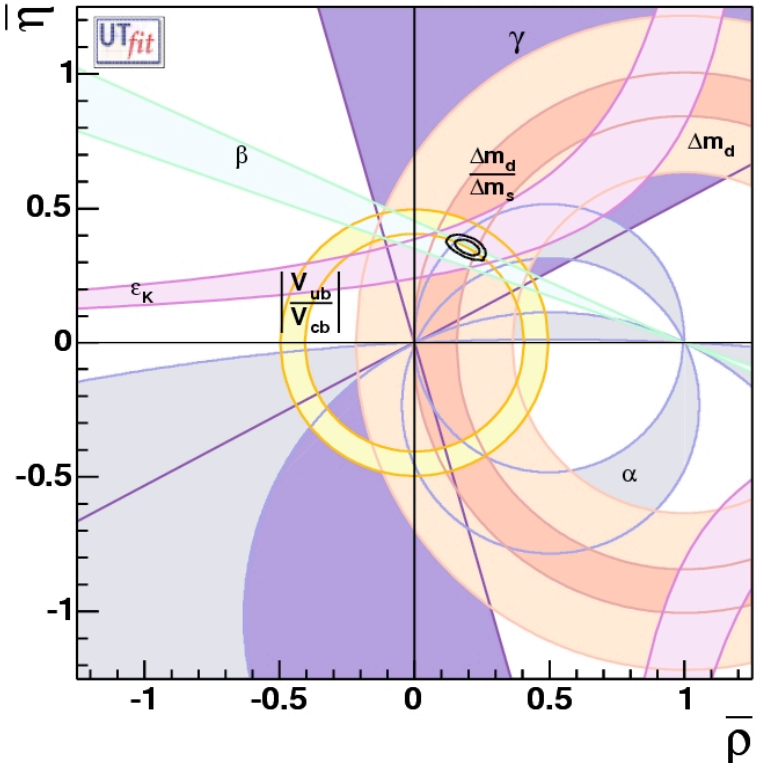
Latest point in case:

B_s - $\bar{B}_s$ oscillations!

New CKM Triangle



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



3 basic tenets

- none of the novel successes of the SM weaken the case for New Physics -- presumably around the TeV scale

- to learn the salient features of this New Physics we must study its impact on heavy flavour transitions -- even if there is none observable

  ☞ CP studies `instrumentalized' to analyze this New Physics

- we cannot count on numerically massive impact of this New Physics

  ➥ need precision experimentally & theoretically

I am an enthusiastic supporter of a Super-B factory -- even if it is not near Rome or near Venice or near Pisa

(II) Defining Goals of the Campaign

- finding manifestations of TeV scale NP not enough --
  must aim for identifying its salient features
  - ☞ remember: SUSY an organizing principle - not a theory
    source & type of SUSY breaking quite obscure
    if *cpNP* = SUSY, then very atypical SUSY
  - ☞ info from heavy flavour studies complementary
    (not just additive) to that from LC studies

- Super-B = Superflavour Factory!
  τ & charm
  include their requirements from the start
- resist temptation to fight last war!

justification for B factory	≠	justification for Super-B factory

2nd generation	3rd generation
∃ killer application ~~CP~~ in: $B_d \to \psi K_S$, $\pi\pi$ $B^{\pm} \to D^{neut} K^{\pm}$ predicted with no plausible deniability when only $\epsilon_K \neq 0$ known (semi)quantit. exploration of heavy flavour dynamics as `virgin territory'	precision tool: higher stat. ⇒ more accuracy ⇒ more decays ⇒ new territory with no unequivocal killer application heavily mined gold mine
☞ promoted KM paradigm ansatz → tested theory	competing against larger than expected success of B fact.

you cannot overdesign Super-B

Sanda's Challenge of L ~ 10^{43} `tongue-in-cheek',

yet not frivolous

- Super-B has to & can be justified by comprehensive program:

  1st priority B

  2nd priority τ

  3rd priority charm

(III) Strategies of Attack

(3.1) Frontal/Brute Force Attack

LHC

(3.2) Obvious Attacks

~~CP~~ in $B_d \to \pi\pi, \pi\pi\pi, \phi K_S \ldots \eta K_S \ldots$

time dependent Dalitz plot studies the tool of the future

"there is no royal way to fundamental physics"

can experimental sensitivity be exploited theoretically?

(3.3) Attacking Supply Lines

Prediction only as good as numerical input

➥ need accurate values for |V(ub)|, |V(td)|, i.e. ± few %

V(ub)

popular opinion:

exclusive SL B decays

$B \to l\,\nu\,D^*$

$B \to l\,\nu\,\rho$

} + { `in the lattice we trust' } |V(cb)|, |V(ub)|

yet Lenin: "Trust is good -- control is better!"

- inclusive SL B decays

partially integrat. had. recoil mass spectrum

$\int dM_X d\sigma/dM_X\,(B \to l\,\nu\,X)$ with $M_{X,max} < M_D$

relevant HQP m_b, μ_π^2, μ_G^2, ρ_D^3 already known from
energy and mass moments of $B \to l\nu X_c$ (need better $M_{2,3,4}^X$!)
$\Delta V(ub)/V(ub) \sim 5$ % appears quite feasible

least reliable part theoretically: low q^2 (q=lepton momentum)

- cut low q^2 Bauer et al.
  - ☺ can be done
  - ☹ lose constraints due to Sum Rules
  - ☹ retain < 50 % of rate -- duality viol.?
  - 😐 need dependence on q^2 statistics of Super-B

- infer from recoil mass spectrum in $B \to \gamma X$ Uraltsev,IBI
  - ☹ need photon spectrum below 2 GeV --

    say 1.8 GeV < E_γ < 2 GeV

can one do that at Super-B?

V(cb)

$B \to l\,\nu\,D$: 2 % conceivably achievable

novel tool (Uraltsev):

- BPS limit for $\mu_\pi^2 = \mu_G^2$
- expansions in $(\mu_\pi^2 - \mu_G^2)/\,\mu_\pi^2$ & in $1/m_Q$

can be validated

- ☞ compare V(cb) from $B \to l\nu D$ with $V(cb)|_{incl}$
- ☞ can calculate $f_-(q^2)$, which can be measured in $B \to \tau\,\nu\,D$ -- presumably beyond B factories

if validation successful

➥ search for NP in $B \to \tau\,\nu\,D$ (s. later)

Interpretation of accurate data?

~~CP~~ in $B \to 3\pi, 4\pi,$ 3K, ...

different partial waves contribute with different signs to CP asymmetry even for given weak parameters:

$A_{CP}(B^0 \to f) = \eta_f \sin 2\phi \ldots \sin\Delta m t$, $CP|f\rangle = \eta_f |f\rangle$

- $B \to 3\pi$ ϕ_3/α & search for New Physics

$3\pi = \rho\pi + \sigma\pi + \ldots$ even close to the ρ bands

$\sigma\pi$ - chiral dynamics: not described by Breit-Wigner curve

memento: `wrong' amplitudes contribute linearly to asymmetry -- & possibly with opposite sign!

☞ need multi-neutral channels for clarification

not feasible at hadronic colliders

(3.4) Flanking Attacks

search for a CP asymmetry in $B \to \gamma X_{s,d}$

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

- larger # of effective operators
- more observables: spectra of leptons, their forward-backward & CP asymmetries

☞ with the statistics of Super-B can (start to) mine this wealth of potential information on New Physics

➥ much wider window to
  - find New Physics &
  - diagnose its features

$B \to \nu\nu X$

$BR(B \to \nu\nu K)$

$\leq 7.0 \times 10^{-5}$ 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 >> $BR(B \to l^+l^- X)$

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

can a Super-B detector be sufficiently hermetic?

$B \to \tau\nu\, D/\tau\nu\, X_c$

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 formalism (Uraltsev) allows to calculate 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

Novel Territory: $e^+e^- \to B_s B_s$

- validate V(cb), V(ub) [V(td)]
- validate NP signals from $B \to \gamma X$, $l^+l^- X$
- search for $\Delta\Gamma$ driven ~~CP~~

τ Decays

- if baryogenesis driven by leptogenesis, want to find leptonic ~~CP~~:

  better chance in τ decays since

  - more complex final states
  - τ can be polarized -- even without polarized beams

$$e^+e^- \to \underbrace{\tau^+\tau^-}_{\text{EPR!}}$$

- rare decays

  $\tau \to \mu\gamma,\ e\gamma$

  $\tau \to 3\mu,\ 3e,\ \mu ee,\ \ldots$

  tests of lepton universality

$\tau \to \mu\,\mu^+\mu^-$ $\quad\leftrightarrow\quad$ $b \to s\,\bar{s}\,s$ $\quad$ $B \to \phi K_S$!

Charm Decays

- ☺ FlChNC dynamics could be much stronger in up-type quarks
- ☺ only charm allows full range of probes for New Phys. there

- present absence of any New Physics hint not telling
  - ☺ only now entering realistic search territory
  - ☺ … and a long way to go!

- ☞ ~~CP~~ with and without D^0 oscillations most reliable probe for NP

(IV) Lessons

The program at the B factories has *primarily* been of the
`hypothesis *driven*' variety
-- and a most successful one at that!

Yet at a Super-B factory (with τ & charm) we *primarily* have to do
`hypothesis *generating*' research
and search for the
`New ~~CP~~ Paradigm'

You cannot overdesign it!

A Super-B factory is also a

- Super-Tau as well as
- Super-Charm factory

of truly unique capabilities

3rd family down-type quark

3rd family down-type lepton

2nd family up-type quark

NB:

Studies of CP, oscillations & rare decays instrumentalized to probe & analyze TeV scale New Physics

❶ μvertex driven by demands from charm & τ studies

❷ high quality data:

low background

hermetic detector

$B \to \tau\tau, \tau\nu, \tau\nu X$

$B \to \nu\nu X$, $B \to \gamma X_d$ vs. γX_s

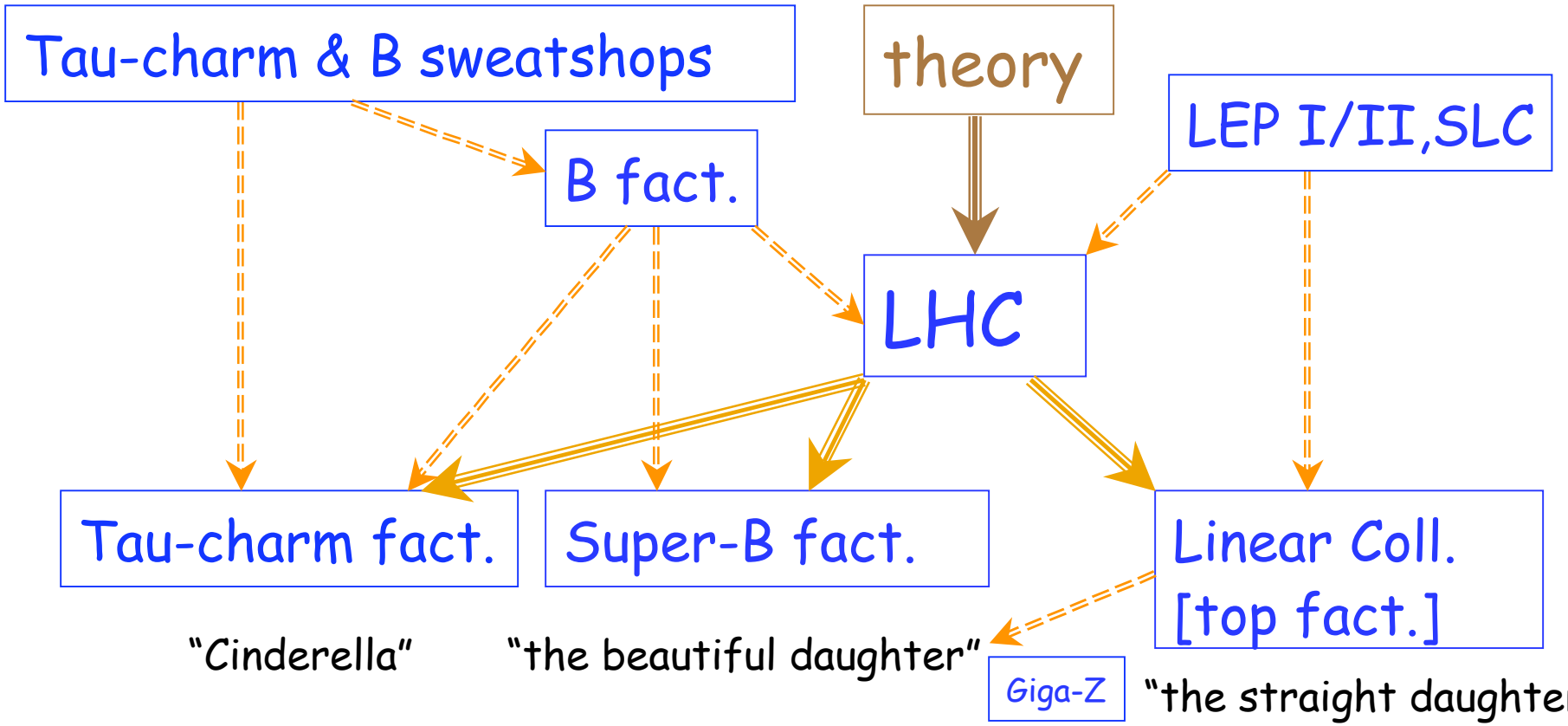
$\tau \to \nu e\nu/\mu\nu, \nu K\pi$

❸ `flexibility' most desirable

$\Upsilon(5S) \to B_s \bar{B}_s$ [$\psi''(3770) \to D \bar{D}$]

❹ polarized e^- beam?

Mainly for CP studies of τ decays



it is a new paradigm centered on precision in addition to high sensitivity -- many questions raised and problems suggested; answers require nontrivial work --

yet positive decision must be based on a vision!

There are still huge treasures to be found in heavy flavour studies --

but it will not be another `California Gold Rush'

`All roads lead to Rome'

Personally I wish this one does as well