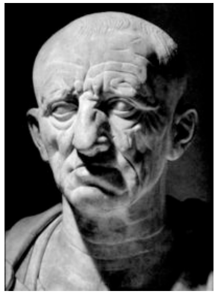


"Ceterum Censeo Fabricam Super Saporis Esse Faciendam"
"Moreover I Advise a Super-Flavour Factory has to be Built"

Ikaros Bigi (Notre Dame du Lac)

A short look back:

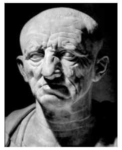
Before 1987

"… yes, yes, we know, Ikaros, but could you not talk about something relevant? …"

After the ARGUS' discovery

… the rest is history … *thank you, thank you, ARGUS!!*

(A.I. Sanda & ibi)



At the time of ARGUS' discovery B_d oscillations were predicted to proceed rather slowly.

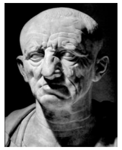
Why?

UA1 had reported discovery of top quarks with

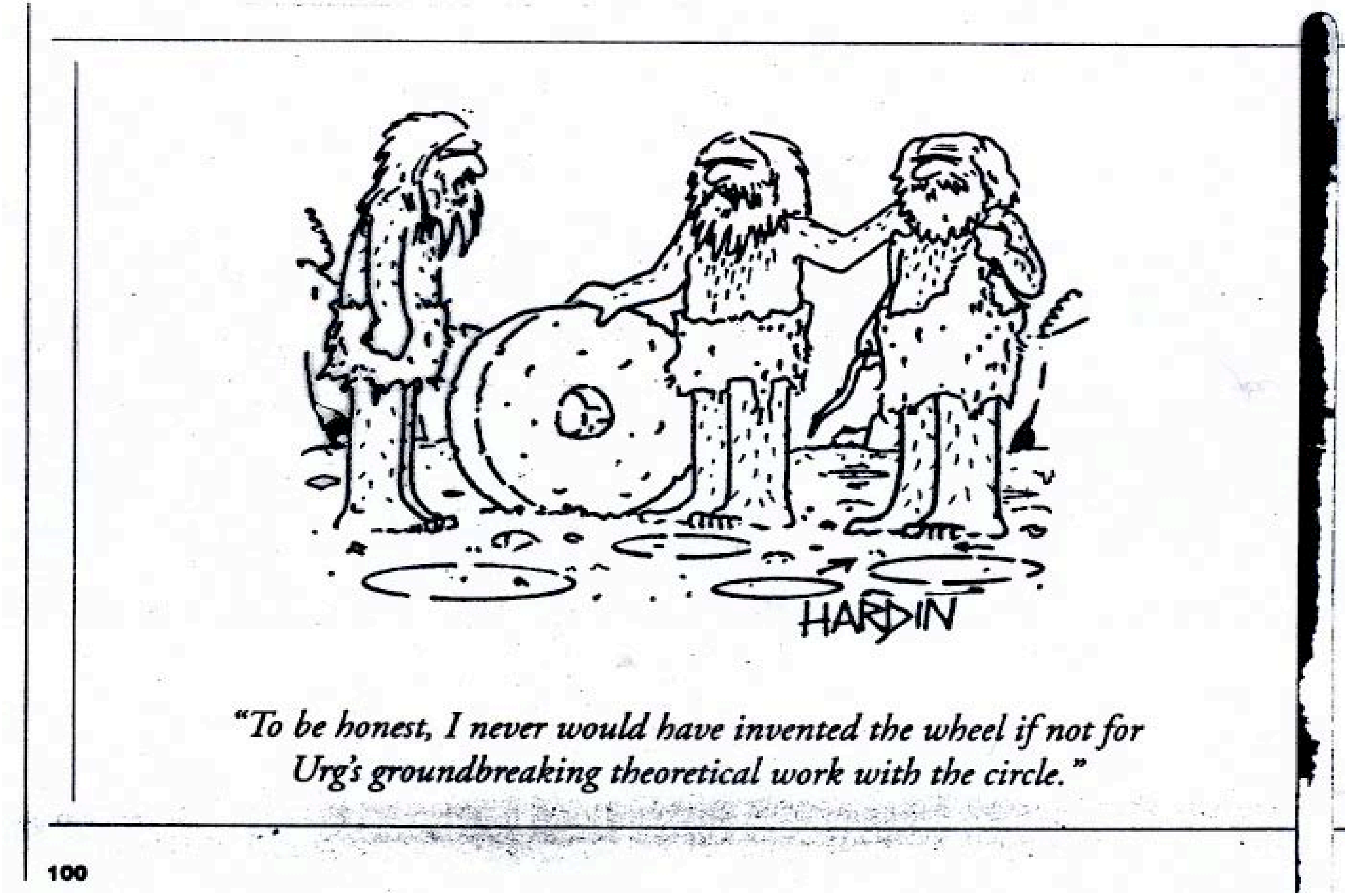
$m_t = 40 \pm 10$ GeV.

Peter Zerwas never believed it --

I should have listened to Peter -- the only time I did not!

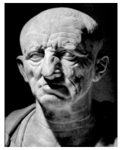


Theory versus Experiment



"To be honest, I never would have invented the wheel if not for Urg's groundbreaking theoretical work with the circle."

"To be honest, I never would have invented the wheel if not for Urg's groundbreaking theoretical work with the circle."



“Ceterum Censeo Fabricam Super Saporis Esse Faciendam”

Fundamental catholic tenet:

If it can be expressed in Latin, it must be true!

For the non-catholic pagans:

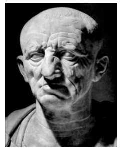
need (less august) arguments

The Menu

I The Role & Status of Flavour Physics

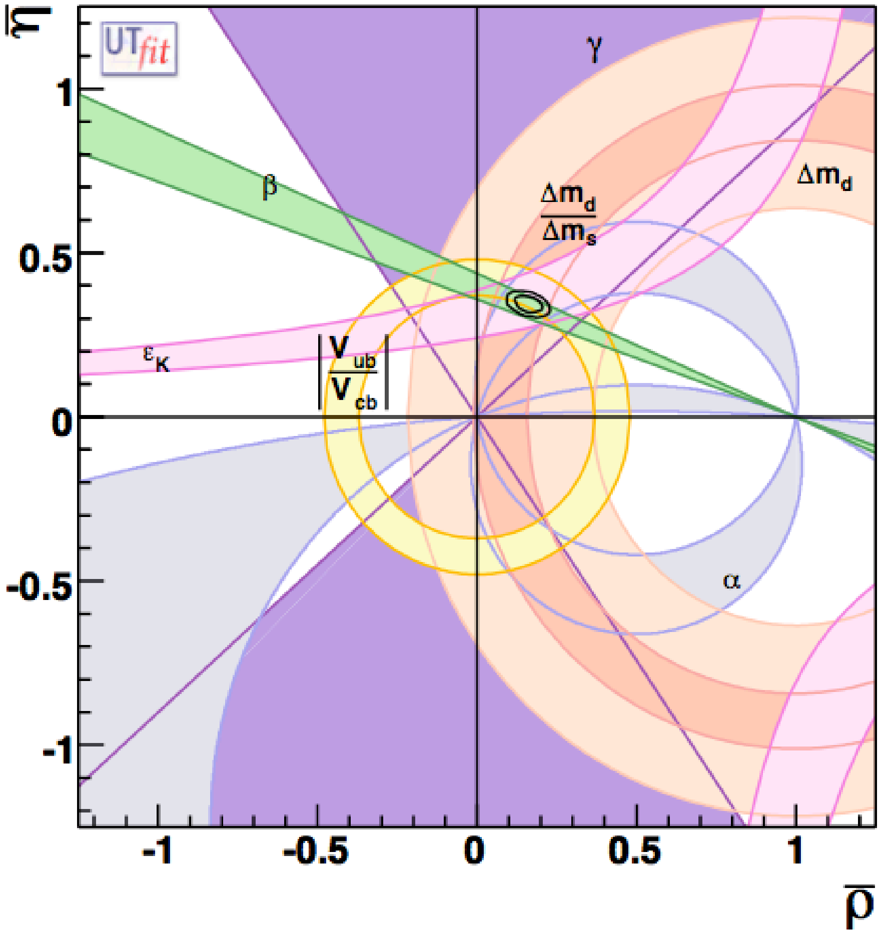
II On the Future: LHCb & Super-Flavour Factories

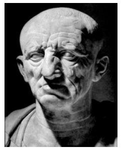
III Conclusions & Outlook



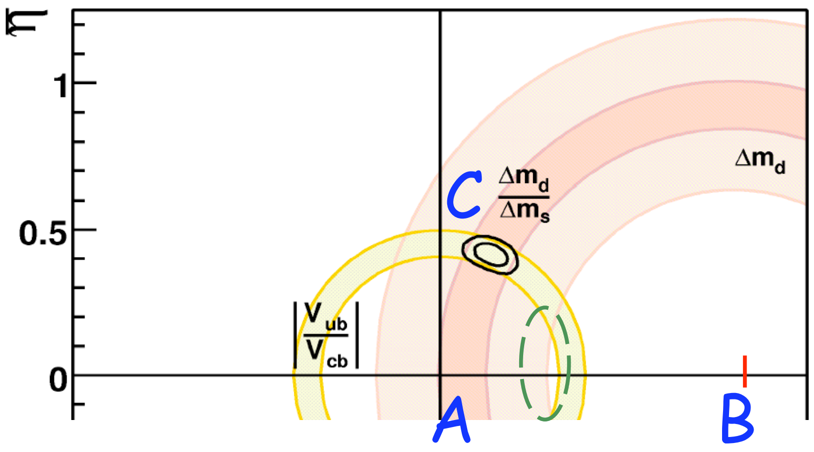
I The Role & Status of Flavour Physics

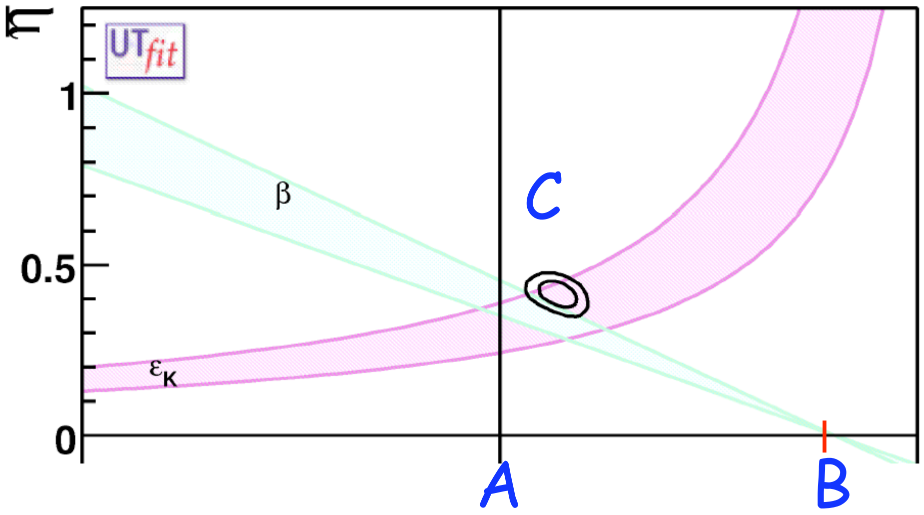
Study of
$\Delta S \neq 0$ instrumental in creation of SM
$\Delta C \neq 0$ central in its acceptance
$\Delta B \neq 0$ almost completed its validation





Impact of measurement of B_s - $\overline{B}_s$ oscillations

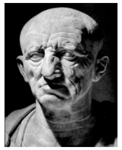




Another triumph for CKM theory:

CP insensitive observables (|V(ub)|,ΔM_s) imply ~~CP~~

qualitatively as well as quantitatively!



novel successes do not illuminate any of the mysterious features of the SM; if anything, they deepen the mysteries:

Explanatory deficits

(i) electroweak symmetry breaking

$SU(2)_L \times U(1) \rightarrow U(1)_{QED}$

(ii) family structure (charge quantiz.)

$Q_e = 3\ Q_d$

(iii) finite family replication

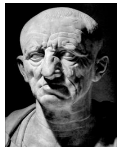
$Z^0 \rightarrow 3\ \nu\bar{\nu}$

illuminations/explanations

\`confidently predicted' NP at ~ 1 TeV = *cpNP*; e.g. SUSY

\`guaranteed' NP at $\mathcal{O}(10^{11})$ TeV = *gNP*; e.g. SO(10)

CKM pattern most unlikely accidental
➥ \`strongly suspected' NP at ??? scale = *ssNP*
e.g., ??? (M theory ??)



heavy flavour studies might provide insights into (iii) & (ii) -- they will be crucial for identifying the *cpNP*

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 impact on B,D & τ decays

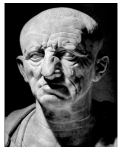
➥ discovery potential in B,D & τ decays essential to figuring out the New Physics -- not a luxury!

❹ We should have seen `generic SUSY'

➥ the one certain aspect of SUSY -- that it is broken -- is the least understood one, if SUSY is `nearby'

❺ Minimal Flavour Violation -- absolute or approximate?

➥ need comprehensive experimental program -- also to reduce theoret. uncertainties through cross checks



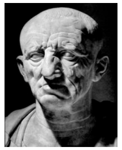
II On the Future: LHCb & Super-Flavour Factories

State of heavy flavour physics

(unlike "State of the Union" speech `reality based' rather than `~ challenged')

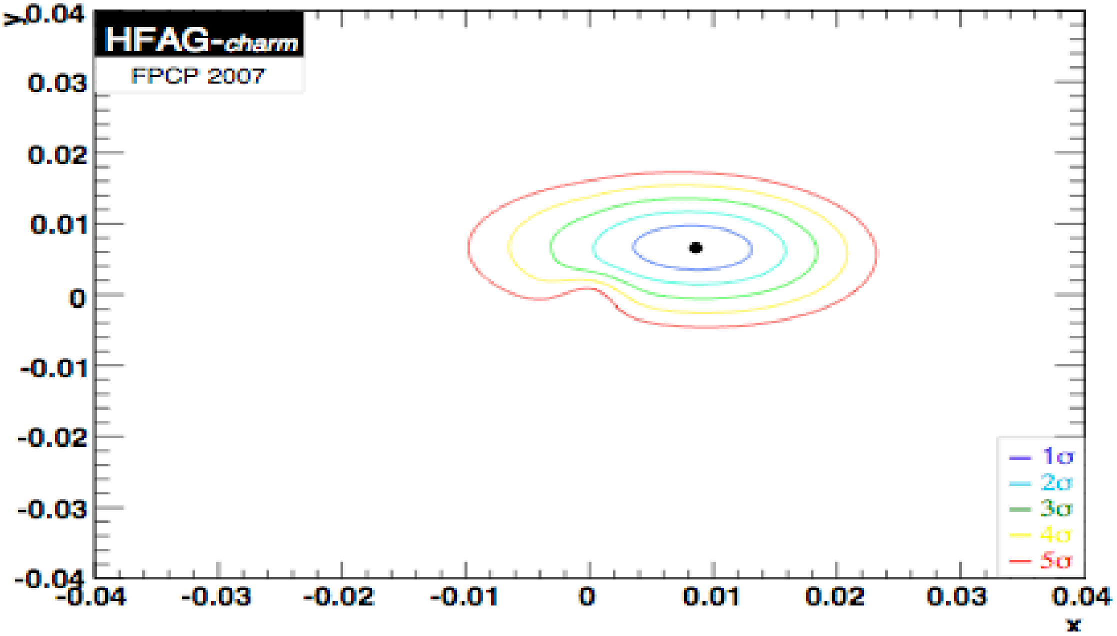
is strong:

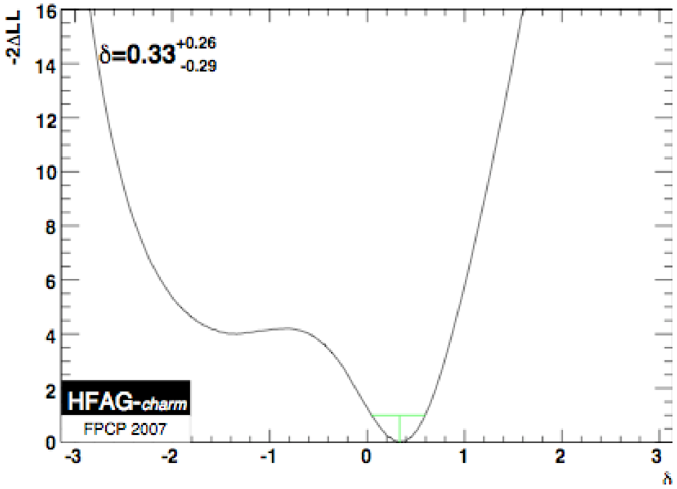
- Experiments at hadronic colliders have greatly exceeded expectations in B & D physics -- see B_s - $\bar{B}_s$ oscillations
- LHCb approved as `first hour' experim. (a credit to the Europ. HEP community)
  - LHCb will make seminal contributions in
    - in B decays -- most notably ~~CP~~ in $B_s(t) \to \psi\phi/\eta, \phi\phi$
    - & probably in D decays



(2.1) The Second Renaissance of Charm Physics

Strong experim. evidence for D^0- $\overline{D}^0$ oscillations

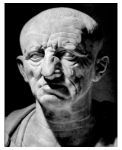




$$x_D = \frac{\Delta m_D}{\Gamma_D} \qquad y_D = \frac{\Delta\Gamma_D}{2\Gamma_D}$$

in this exercise $(x_D,y_D) \neq (0,0)$ emerges with 5 σ

$x_D = (0.87^{+0.30}_{-0.34})\%$, $y_D = (0.66^{+0.21}_{-0.20})\%$, $\delta = 0.33^{+0.26}_{-0.29}$



Interpretation?

☞ $x_D > 1\ \% \gg y_D$ could be interpreted as manifestation of New physics -- yet such a scenario has basically been ruled out

☞ data suggest: x_D, y_D can be in range ~ 0.5 - 1%

✍ could be due `merely' to SM dynamics --

- ✒ even then it would be a great discovery &
- ✒ it should be measured accurately

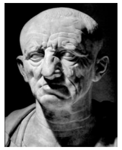
✍ yet might also contain large contributions from NP!

How to resolve this conundrum?

- ❍ theoretical breakthrough?
- ❍ ~~CP~~ violation!

will history repeat itself in a `centi-ARGUS' scenario?

☺ baryon # of Universe implies/requires NP in ~~CP~~ dynamics !



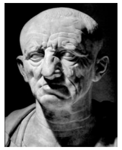
$D^0(t) \to K^+K^-, K_S\pi^+\pi^-, K^+\pi^-$ ($K^+K^-\pi^+\pi^-, K^+K^-\mu^+\mu^-$)

oscillations can generate time *dependent* CP asymmetries

❑ none seen so far down to the 1% (1%/$tg^2\,\theta_C$) level --

☞ they are ~ (x_D or y_D) (t/τ_D)sin ϕ_{weak};

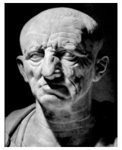
- ➼ with x_D , $y_D \leq 0.01$ a signal would not have been credible
- ➼ yet now it is getting interesting!



(2.2) The Case for a Super-Flavour Factory

I expect LHCb to be a highly successful experiment in heavy flavour physics -- yet it will not complete the program.

- Since we should expect at most moderate deviations from SM predictions, precision required on both the experimental and theoretical side in B decays:
  - need to study final states with (multi)neutrals
    e.g.: $B^0 \to \pi^+ \pi^- \pi^0$, $\pi^0\pi^0\pi^0$, $B^- \to \pi^-\pi^+\pi^-$, $\pi^-\pi^0\pi$
  - need to study $B_d(t) \to \phi K_S$, ηK_S with precision
  - want to measure *in*cl. rather than *ex*cl. rates
  - " " " $B \to \tau\nu D$, $\tau\nu X$ ($H^\pm$ exchange!)
  - ...
- comprehensive CP studies in D decays
- ~~CP~~ in τ decays and LFV τ decays

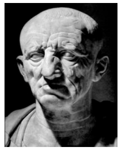


A Super-Flavour Factory -- L ~ 10^{36}cm^{-2} s^{-1} -- can take on these challenges.

Warning:

$$\left\{\begin{matrix}\text{justification}\\ \text{for B factory}\end{matrix}\right\} \neq \left\{\begin{matrix}\text{justification}\\ \text{for Super-B factory}\end{matrix}\right\}$$

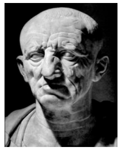
∃ killer application $\cancel{C}P$ in: $B_d \rightarrow \psi K_S$, $\pi\pi$ $B^\pm \rightarrow D^{neut} K^\pm$ predicted with no plausible deniability when only $\varepsilon_K \neq 0$ known (semi)quantit. exploration of heavy flavour dynamics as `virgin territory'	precision tool: higher stat. • more 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.



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’

Top priority of a Super-Flavour Factory:
B physics!



(2.2.1) 2nd Priority: ~~CP~~ Studies in Charm

Example A: The `Dark Horse'

SL: $D^0 \longrightarrow l^- \nu K^+$ vs. $D^0 \longrightarrow l^+ \nu K^-$

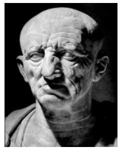
$a_{SL} \sim \mathrm{Min}[\Delta\Gamma/\Delta M, \Delta M/\Delta\Gamma] \sin\phi_{NP}$, $\quad \Delta\Gamma/\Delta M \sim O(1)$

- $a_{SL} \sim 0.1$ conceivable (even few x 0.1)

  -- i.e. relatively few wrong-sign leptons, yet with a large asymmetry!

vs.

- $a_{SL}(K_L) = 3.3 \times 10^{-3}$ with $\Delta\Gamma/\Delta M \sim O(1)$ & $\sin\phi_{CKM,eff} \ll 1$
- $a_{SL}(B_d) \sim 4 \times 10^{-4}$ with $\Delta\Gamma/\Delta M \sim O(\text{few} \times 10^{-3})$
- $a_{SL}(B_s) \sim 2 \times 10^{-5}$ with $\Delta\Gamma/\Delta M \sim O(\text{few} \times 10^{-3})$ & $\sin\phi_{CKM,eff} \sim O(\text{few} \times 10^{-2})$



Example B: Final state distributions,T-odd moments

So far all observed $\cancel{CP}$ in partial widths -- except for one:

$$\boxed{K_L \rightarrow \pi^+\pi^-e^+e^-}$$

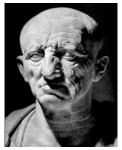
$$K_L \xrightarrow[\uparrow\ \text{suppressed}]{\cancel{CP}} \pi^+\pi^- \xrightarrow{E1} \pi^+\pi^-\gamma^* + K_L \xrightarrow[\uparrow\ \text{suppressed}]{CP,M1} \pi^+\pi^-\gamma^*$$

ϕ = angle between $\pi^+\pi^-$ & e^+e^- planes analyzes γ^* polarization

interference between $\cancel{CP}$ E1 & CP M1 amplitude

➥ Forw-Backw asymmetry A in ϕ (Sehgal et al.)

$$\left.\begin{array}{l} A = 14\ \%\ \text{driven by}\ \varepsilon=0.002 \\ \\ \text{price: BR} \sim 3 \times 10^{-7} \end{array}\right\}\ \text{trade BR for size of asymm.!}$$



close analogy

$D_L \to K^+ K^- \mu^+ \mu^-$

BR ~ $O(10^{-6})$

$$D_L \underset{\substack{\uparrow \\ \text{suppressed}}}{\xrightarrow{\cancel{CP}}} K^+K^- \xrightarrow{E1} K^+K^- \gamma^* + D_L \underset{\substack{\uparrow \\ \text{suppressed}}}{\xrightarrow{CP, M1}} K^+K^- \gamma^*$$

ϕ = angle between K^+K^- & $\mu^+ \mu^-$ planes analyzes γ^* polarization

interference between $\cancel{CP}$ E1 & CP M1 amplitude

➥ Forw-Backw asymmetry A in ϕ

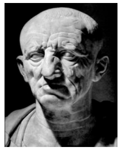
preliminary studies:

factor ~ 50 enhancement of $\cancel{CP}$ in $D_L \to K^+K^-$

example for a unique capability of Super-Fl. Fact.:

$$e^+ e^- \to \psi''(3770) \to D\bar{D} \to (K^+K^-)_D D_L$$

$$\quad \hookrightarrow K^+K^-\mu^+\mu^-$$



(2.2.3) 3rd Priority: τ Decays

Example C: LFV decays $\tau \to l\gamma$, $3l$

BR ~ 10^{-8} - 10^{-9} promising range [GUTs, scaling with $\mu \to e\gamma$]

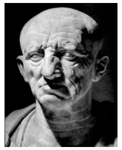
- no competition from LHC for $\tau \to l\gamma$
- maybe competition from LHC for $\tau \to 3l$

Example D: $\cancel{CP}$ in τ decays like $\tau \to K\pi\nu$

- next great challenge -- $\cancel{CP}$ in leptodynamics
  completing `de-mystification' of $\cancel{CP}$ [+ leptogenesis]
- no competition from LHC
- unique tool at a Super-Flavour Factory:
  beam polarization

CP odd ~ $|T^*_{SM}\, T_{NP}|$ vs. LFV ~ $|T_{NP}|^2$

i.e., 0.1 % $\cancel{CP}$ in $\tau \to \nu K\pi$ ~ 10^{-8} BR for $\tau \to \mu\gamma$

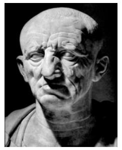


(2.3) Design Criteria for a Super-Flavour Factory

- You cannot overdesign a Super-Flavour Factory

  Sanda's dictum " L ~ 10^{43}" `tongue-in-cheek', not frivolous

  if you must `stage' it, do not compromise on final performance
- keep background as low as possible
- make detector as hermetic as possible
- keep flexibility to run on Υ(5S)
- obtain flexibility to run in charm threshold region with good luminosity
- make a strong effort to obtain polarized beams



III Conclusions & Outlook

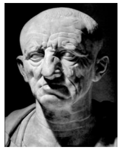
❑ We are at the beginning of a most exciting era that carries the realistic promise to reveal the origin of electroweak symmtry breaking

❑ The LHC will be the `work horse', yet heavy flavour studies

- are of fundamental importance;
- its lessons cannot be obtained any other way;
- cannot become obsolete.

comprehensive studies of flavour dynamics will remain crucial in our efforts to reveal Nature's Grand Design

❑ Studies of $\not{C}P$, oscillations & rare decays instrumentalized to probe & analyze TeV scale New Physics



3 scenarios for the next 5 - 8 years out

A -- the optimal one:

new physics observed at high p_t (FNAL/LHC)

➥ must study their impact on flavour dynamics

☺ some features -- mass scale etc. known !

B -- the intriguing one

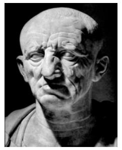
deviations from SM established in heavy flavour decays

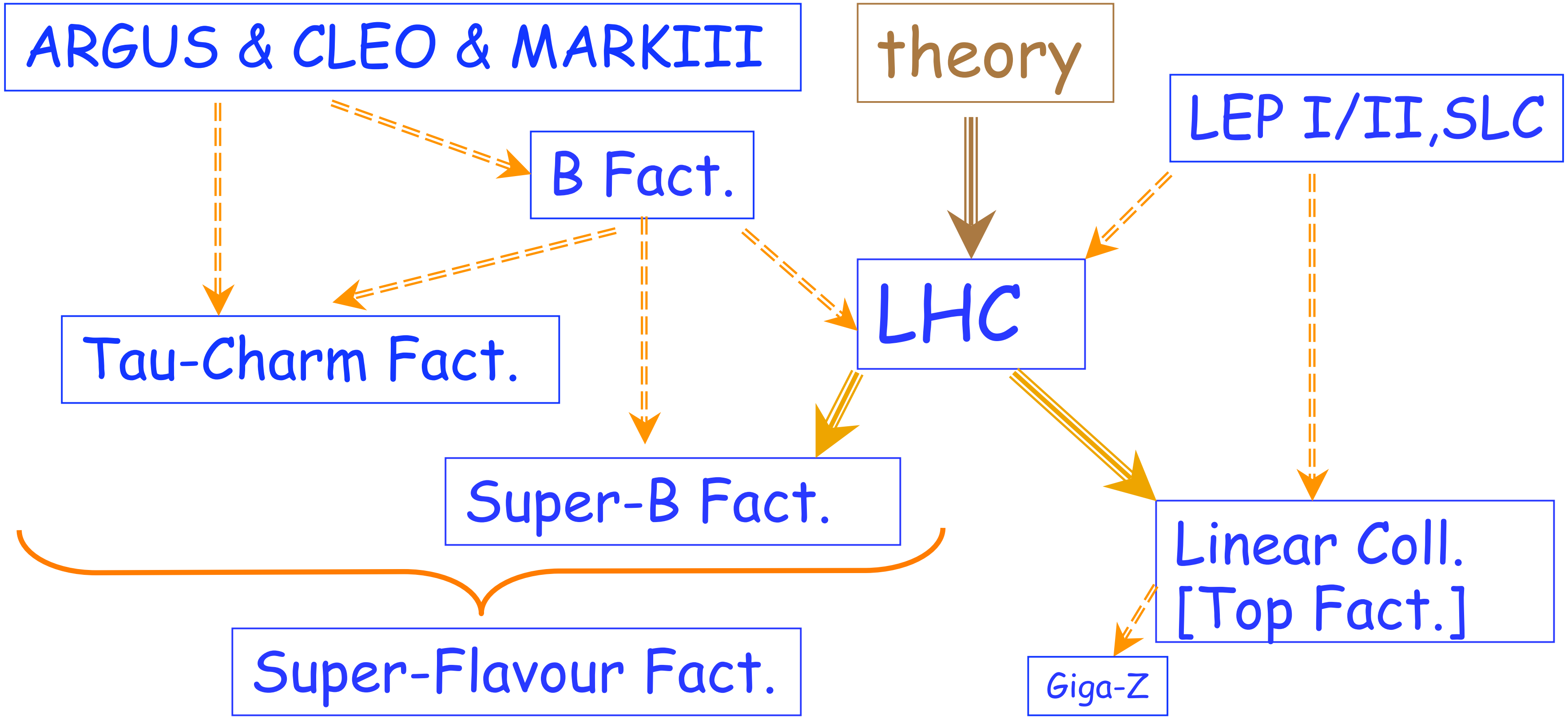
C -- the frustrating one

no deviation from SM prediction identified

My bet: scenario A with some elements of scenario B
[remember sensitivity in B probes can go to 10 - 100 TeV]

➾ none of these scenarios weakens the role of flavour studies being essential for coming to grips with nature's `Grand Design'





ARGUS & CLEO & MARKIII

theory

LEP I/II,SLC

B Fact.

LHC

Tau-Charm Fact.

Super-B Fact.

Linear Coll.
[Top Fact.]

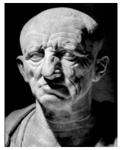
Super-Flavour Fact.

Giga-Z

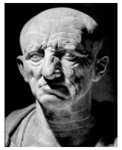
\`All roads lead to Rome'

I think that is not a bad endpoint

Continuation/beginning of an exciting adventure and we are most privileged to participate!



Backup slides



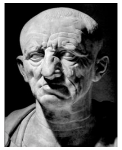
The generalized `Nakada Concern’:

While we have more promising avenues for exploring fundamental physics than ever,

While we have more technical abilities & tools than ever,

While we live in a world with immense political, social, environmental … problems and have to deal with governments with less interest in basic research to a degree that goes well beyond a justified pre-occupation with these problems --

How do we choose our priorities?



Be comprehensive (necessary, yet not necessarily sufficient):

A Super-B factory is also a	3rd family down-type quark
➬ Super-Tau as well as	3rd family down-type lepton
➬ Super-Charm factory	2nd family up-type quark
of truly unique capabilities