"Ceterum Censeo Fabricam Super Saporis Esse Faciendam" ("Moreover I Advise a Super-Flavour Factory has to be Built")¹

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Abstract

The discovery of $B_d - \overline{B}_d$ oscillations twenty years ago by the ARGUS collaboration marked a watershed event. It persuaded a significant part of the HEP community that the large time dependent **CP** asymmetries predicted for some B_d decays might be within the reach of specially designed experiments. This opened the successful era of the *B* factories, which has a great future still ahead. After sketching the status of heavy flavour physics I describe why we need to continue a comprehensive heavy flavour program not only for its intrinsic reasons – it is even mandated as an integral part of the LHC program. Notwithstanding the great success anticipated for the LHCb experiment I explain why a Super-Flavour Factory is an essential complement to the LHC program.

Contents

Act	I – On the Role and Status of Flavour Physics	3
Act	II: On the Future – LHCb and Super-Flavour Factories	6
2.1	The "Second Renaissance" of Charm Physics	6
2.2	The Case for a Super-Flavour Factory	8
	2.2.1 2nd Priority: CP Studies in Charm Transitions	9
	2.2.2 3rd Priority: τ Physics	10
2.3	Design Criteria for a Super-Flavour Factory	11
Con	clusions and Outlook	12
	Act 2.1 2.2 2.3 Cor	Act II: On the Future – LHCb and Super-Flavour Factories 2.1 The "Second Renaissance" of Charm Physics 2.2 The Case for a Super-Flavour Factory 2.2.1 2nd Priority: CP Studies in Charm Transitions 2.2.2 3rd Priority: τ Physics 2.3 Design Criteria for a Super-Flavour Factory Conclusions and Outlook

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Prologue

Earlier this afternoon we heard from Prof. Schopper how on his first visit here his request to be taken to DESY was misconstrued by the taxi driver. My experience this time was fundamentally different: when I told my taxi driver in Altona that I have to go to DESY, he immediately understood the nature of my destination. He perked up and said: "Oh, I am just reading a book on quantum chemistry – can we talk about it?" I take my experience as re-assuring evidence for a growing appreciation of scientific culture. Yet the reality-based among you – i.e. the experimentalists – will probably think: "Typical theorist!" For looking at me you will realize that I am much older now than Prof. Schopper was *then*: therefore I – unlike him – was above suspicion.

Allow me another brief look back. When I was invited before 1987 to give a talk and I suggested my topic – you can easily guess, what it was [2] – I heard the following reaction: "Yes, yes, we know, Ikaros ..., but could you not talk about something relevant?" After ARGUS' discovery of $B_d - \overline{B}_d$ oscillations twenty years ago [1], I never heard that again. Tony Sanda and I benefitted more from this discovery than most high energy physicists, and I can state an emphatic: "Thank you, thank you, ARGUS!"

At the time of ARGUS' discovery B_d oscillations had been expected to proceed rather slowly. The main reason for that prediction was that the UA1 experiment had reported strong evidence for having discovered top quarks with a mass of 40 ± 10 GeV. Almost all theorists accepted those findings. Peter Zerwas, however, did not, and he explained the reasons for his skepticism to me at the time. I should have listened to Peter – it is the only time I did not, and I have been kicking myself for it ever since!

Our knowledge of B meson dynamics has been expanded greatly over the last twenty years in a process accelerated by the success of the B factories. This development has been helped by theorists in a way nicely expressed by the cartoon of Fig.1, which I found last spring reading the In-flight journal of United Airlines: The chap in the middle, obviously an experimentalist, graciously – if with a slightly patronizing flavour – gives some credit to the theorist on his left by declaring: "To be honest, I never would have invented the wheel if not for Urg's groundbreaking theoretical work with the circle."

I have given the first title of my talk in Latin based on a fundamental Catholic tenet recently re-confirmed by the new church leadership: *If it can be expressed in Latin, it must be true.* Since Hamburg is not exactly a hotbed of Catholicism, I will use a less august language, while fully aware that the elegance and cogency of the argument will suffer from this drawback.

The talk will be organized as follows: In Act I I will sketch the role and status of studies of flavour dynamics; in Act II I will gaze into my crystal ball concerning the future of flavour physics as carried out for certain by LHCb and hopefully Super-Flavour Factories; in Act III I will present my conclusions before finishing with an Epilogue.



Figure 1: " To be honest, I never would have invented the wheel if not for Urg's groundbreaking theoretical work with the circle."

1 Act I – On the Role and Status of Flavour Physics

Allow me to go "medias in res" rather than beat around the bushes. While the detailed study of strangeness changing processes was instrumental for the creation of the Standard Model (SM), that of charm changing ones was central for its acceptance, and that of beauty changing ones has almost completed the SM's validation (with only the Higgs boson not having been discovered yet).

As explained in previous talks [3, 4], the unitarity of the 3×3 CKM matrix V_{CKM} implies among others the following relation among its (complex) elements:

$$V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0 , \qquad (1)$$

which can be represented as a triangle in the complex plane. It is usually referred to as 'the' CKM unitarity triangle. While the sides of the triangle reflect transition rates for K and B mesons (including pure quantum effects like oscillations), the angles determine **CP** asymmetries. Accordingly the area of the triangle is a measure for those asymmetries. Since re-scaling the triangle leaves the angles unchanged, one conveniently normalizes the base line to unit length. Our knowledge of flavour dynamics is sketched in a highly condensed form in Fig.2 by showing constraints from data – most importantly from ΔM_{B_d} , ΔM_{B_s} [5], $|V_{ub}/V_{cb}|$ [6] and the **CP** sensitive observables ϵ_K and ϕ_1 (a.k.a. β). The latter is the angle extracted from the time dependent **CP** asymmetry in $B_d \rightarrow \psi K_S$. These constraints are inferred from a very heterogeneous set of transitions occurring on vastly different time scales. Yet they do overlap in a smallish domain indicated by the two ellipses for the apex of the triangle – a highly non-trivial success for the SM!

Fig.2 containing all constraints is very busy and thus obscures some of the relevant findings. Let me illuminate this by a highly topical example, namely the profound impact resolving $B_s - \bar{B}_s$ oscillations has had. Look at the left plot in Fig.3. The triangle there is constructed from its three sides: the unit length baseline, and the other two sides as



Figure 2: The CKM Unitarity Triangle fit (courtesy CKM fitter collab.).

inferred from $|V_{ub}/V_{cb}|$ [6] and $\Delta M_{B_d}/\Delta M_{B_s}$ [5], respectively, with the widths of the bands denoting the uncertainties (mainly of a theoretical nature). The two bands overlap in a small domain, where the apex has to lie. The resulting triangle clearly has a non-zero area: from two **CP** insensitive observables – i.e., two quantities that can be non-zero, even when **CP** invariance holds – we can thus infer that the SM has to contain **CP** violation. Yet the situation is even more intriguing, as the right plot in Fig.3 shows: the amount of **CP** violation inferred from $|V_{ub}/V_{cb}|$ and $\Delta M_{B_d}/\Delta M_{B_s}$ is completely consistent with the observed **CP** asymmetries as expressed through ϵ_K and ϕ_1 (a.k.a. β)! This marks another triumph for KM theory: From the observed values of two **CP** insensitive observables one infers the size of **CP** asymmetries in even quantitative agreement with the data.

So why not declare victory and close (the heavy flavour) shop? There are two sets of reasons against it:

- 1. We have experimental evidence of mostly heavenly origin that the SM is incomplete: neutrino oscillations, dark matter and dark energy.
- 2. The novel successes the SM has scored since the turn of the millenium having the predictions of truly large **CP** asymmetries in B decays confirmed do not illuminate any of its mysterious features; if anything, they deepen the mysteries:
 - (a) Theoretical arguments centered on the 'gauge hierarchy problem' strongly suggest that the electroweak symmetry breaking is driven by something beyond the SM's $SU(2)_L \times U(1)$ gauge theory with that something entering around the TeV energy scale. Those arguments have been sufficiently persuasive as to motivate the construction of the LHC complex at CERN, and I will refer to



Figure 3: CKM unitarity triangle from |V(ub)/V(cb)| and $\Delta M_{B_d}/\Delta M_{B_s}$ on the left and compared to constraints from ϵ_K and $\sin 2\phi_1$ on the right (courtesy V. Sordini).

it as the "confidently predicted New Physics" (cpNP). A popular candidate is provided by SUSY.

- (b) We have no structural explanation for charge quantization and the leptonquark connection; i.e., why is the electric charge of the electron exactly three times that for d quarks? A natural resolution of this puzzle arises in Grand Unified Theories, which place quarks and leptons into the same multiplets. I will refer to it as the "guaranteed New Physics" (gNP) characterized by scales of the order of about 10^{14} GeV; an SO(10) gauge theory provides an attractive scenario.
- (c) It seems likely that family replication and the hierarchical pattern in the CKM parameters is created by some fundamental dynamics operating at some high scale. I will call it "strongly suspected New Physics" (*ssNP*). We do not know what that scale is, and expressing the hope that M theory will resolve this puzzle is a polite way of saying that we have hardly a clue about it.

Detailed and comprehensive heavy flavour studies might – just might – provide insights into the gNP and ssNP – i.e., items (b) and (c) above – although we cannot count on it. Yet they are likely to be essential for identifying the cpNP, item (a)!

Let me explain the last point in some detail:

- I am confident the LHC will reveal the presence of New Physics directly by the production of new quanta.
- Yet we should aim higher than 'merely' establishing the existence of such New Physics. The goal must be to identify its salient features. I am a big fan of SUSY, yet we should remember that SUSY per se is not a theory or even class of theories it is an organizing principle.

- TeV scale dynamics is likely to have some impact on B, D and τ decays. We need to probe the discovery potential in those processes in order to identify the New Physics. A dedicated heavy flavour program is not a luxury it is integral to the core mission of the LHC program.
- We should already have seen, say, the impact of a 'generic SUSY' [7] i.e., a version of SUSY picked at random out of the multitude of SUSY implementations. On the other hand past experience shows that Nature has not exhibited much taste for generic dynamics. Furthermore the one aspect of SUSY that is beyond dispute, namely that it is broken, is also the least understood one.
- The often heard term of 'minimal flavour violation' is a classification scheme [8], not a theory analogous to the case of the 'superweak model' of **CP** violation. We have to ask to which degree do dynamics implement such a scenario: does it represent a strict or more likely an approximate one?

To summarize: we need to continue a comprehensive program of experimental heavy flavour studies, not to shed light on the flavour mystery of the SM – although that might happen – but as a high sensitivity instrument for probing more fully the dynamics behind the electroweak phase transition. We have learnt (and some of us had actually predicted it several years ago [10]) that heavy flavour transitions typically will *not* be affected in a *numerically massive* fashion by the anticipated New Physics. Yet this should make us strive for higher sensitivity in our searches, not to abandon them.

2 Act II: On the Future – LHCb and Super-Flavour Factories

Looking at the next few years I am pleased to say that the state of heavy flavour studies is promising and strong. The contributions from the CDF and D0 experiments studying hadronic collisions have greatly exceeded expectations with respect to B physics. The latest example – and a spectacular one – was the measurement of $B_s - \bar{B}_s$ oscillations [5]. More than a decade ago LHCb with its focus on B physics was approved as an experiment to take data from day one of LHC's operation. The European HEP community deserves credit for this visionary decision. I am confident that LHCb will make truly seminal contributions in particular in the exploration of B_s decays – most notably the time dependent **CP** asymmetries in $B_s \rightarrow \psi \phi$, $\phi \phi$. Since B_d and B_s transitions a priori represent different chapters in Nature's book of dynamics, we better analyze both with high accuracy. There is no doubt in my mind that the HEP community will reap great benefits from the support it gives to LHCb.

2.1 The "Second Renaissance" of Charm Physics

The case for a continuing experimental program of heavy flavour physics has been strengthened considerably by the strong evidence presented by Belle and BaBar in the spring of 2007 [11, 12, 13]. Analogous to the B_d case $D^0 - \overline{D}^0$ oscillation rates can be expressed in terms of the calibrated mass and width differences between the two mass eigenstates: $x_D \equiv \Delta M_D / \overline{\Gamma}_D, y_D \equiv \Delta \Gamma_D / 2\overline{\Gamma}_D$. Averaging over all relevant data – an intriguing enterprise, yet one that is not without risk at present – one obtains [6]

$$x_D = (0.87^{+0.30}_{-0.34}) \cdot 10^{-2} , \quad y_D = (0.66^{+0.21}_{-0.20}) \cdot 10^{-2} , \quad (2)$$

which represents 5 σ evidence for $(x_D, y_D) \neq (0, 0)$.

If we had observed $x_D > 1\% \gg y_D$, we would have a strong prima facie case for New Physics – but such a scenario has been basically ruled out now. For the data point to $x_D \sim y_D \sim 0.5 - 1\%$.

- 1. Effects of that size could be due 'merely' to SM dynamics [14, 15]. Even then it would be a seminal discovery and should be measured accurately; for it can help to validate the observation of time dependent **CP** asymmetries as discussed below.
- 2. At the same time $D^0 \overline{D}^0$ oscillations can still receive sizable contributions from New Physics.

How can we resolve this conundrum?

- We might be just one theoretical breakthrough away from a more accurate SM prediction. Maybe.
- Rather than wait for that to happen, since it might take a while, the experimentalists might follow the Calvinist tradition of demonstrating heavenly favour by achieving earthly success. For they can search for **CP** violation in charm transitions. It is most appropriate to emphasize this option at this ARGUS-Fest. Will history repeat itself in the sense that the discovery of oscillations will prompt a program of **CP** studies? There are obvious challenges involved: We are dealing with a 'centi-ARGUS' scenario, since x_D is about a factor of hundred smaller than x_{B_d} . I think our experimental colleagues will learn to deal with that. Another difference is that KM theory does not predict sizable, let alone large effects in the charm system. I submit this is actually an advantage, since the ratio of signal to 'theoretical noise' (from SM contributions) might well be large. Furthermore we are not engaging in a 'wild goose chase' here, since baryogenesis requires New Physics with **CP** violation.

The decay channels being analyzed for oscillations $[16] - D^0 \rightarrow K^+ K^- / \pi^+ \pi^- / K_S \pi^+ \pi^-$ are also excellent targets for such searches. For oscillations can generate *time dependent* **CP** asymmetries there. No such effects have been seen so far – but the experimental sensitivity has only recently reached a domain, where one could hope for a signal [17, 18]. Consider

$$D^0 \to K^+ K^- \tag{3}$$

In qualitative analogy to $B_d \to \psi K_S$ the oscillation induced **CP** asymmetry is given by

$$\frac{\operatorname{rate}(D^0(t) \to K^+ K^-) - \operatorname{rate}(\overline{D}^0(t) \to K^+ K^-)}{\operatorname{rate}(D^0(t) \to K^+ K^-) + \operatorname{rate}(\overline{D}^0(t) \to K^+ K^-)} \sim x_D \ [\text{or } y_D] \cdot \frac{t}{\tau_D} \cdot \sin\phi_{\text{weak}} ; \qquad (4)$$

i.e., it is by and large bounded by the value of x_D [or y_D]. If those do not exceed the 1% level, nor can the asymmetry, and that is about the experimental sensitivity at present. Having seen a signal would hardly have been credible. Yet now it is getting interesting; for any improvement in experimental sensitivity might reveal an effect.

2.2 The Case for a Super-Flavour Factory

I count on LHCb to become a highly successful experiment in heavy flavour studies – benchmark transitions like $B_s \to \psi \phi$, $\phi \phi$ or $D^0 \to K^+ K^-$, $K^+ \pi^-$ are optimal for LHCb's consumption – yet it will *not* complete the program!

As indicated above we can typically expect at most moderate deviations from SM predictions. Precision is therefore required both on the experimental and the theoretical side. The latter requires 'flanking measures'; i.e., in order to calibrate our theoretical tools for interpreting decay rates, we want to analyze final states with (multi)neutral hadrons like $B^0 \to \pi^+ \pi^- \pi^0/3\pi^0$, $B^- \to \pi^- \pi^0 \pi^0$. We need to study $B_d \to \phi K_S$, $\eta^{(\prime)} K_S$ with precision, since those lessons are complementary rather than repetitive to those inferred from $B_s \to \phi \phi$. Inclusive reactions can be described more reliably than exclusive ones – a valuable asset when searching for smallish effects. We want to measure also semileptonic B decays – $B \to \tau \nu D/\tau \nu X$ – as a probe for the exchange of charged Higgs bosons with a mass in the several hundred GeV range. Comprehensive **CP** studies in charm transitions are mandated now more than ever before due to the strong evidence for $D^0 - \overline{D}^0$ oscillations. Last, but most certainly not least we have to search for both lepton flavour and **CP** violation in τ decays.

A Super-Flavour Factory – a low-energy e^+e^- machine with a luminosity of 10^{36} cm⁻² s^{-1} is needed to take on these challenges [20]. In this context let me express a warning: a Super-Flavour Factory requires a very different kind of justification than the original B factories at KEK and SLAC did. For those we had so-called 'killer applications' [2]; i.e., effects that *individually* would have an immediate and profound impact on the SM, if they were observed or ruled out. Those were the time dependent **CP** asymmetries in $B_d \rightarrow \psi K_S/\pi^+\pi^-$; for they were predicted – with no plausible deniability – to reach the several \times 10 % range; this was inferred from the only known ${\bf CP}$ violation in the early 1990's, namely $K_L \to \pi \pi$, which is characterized by $|\epsilon_K| \simeq 0.22\%$. Furthermore the domain of quantitative heavy flavour dynamics was still largely 'virgin' territory. The success of the B factories has greatly exceeded our expectations: they have promoted the KM paradigm from an ansatz to a *tested theory*. As far as **CP** violation in the decays of hadrons is concerned, we no longer look for alternatives to KM theory, only to corrections to it. However, the very success of the B factories has raised the bar for a Super-Flavour Factory. Rather than exploring unchartered territory, we want to revisit it, albeit with greatly enhanced sensitivity. It is like going back into a heavily mined gold mine.

To say it slightly differently. There are two types of research programs, namely 'hypothesis driven' and 'hypothesis generating' research. While the former tests an existing paradigm (and thus is favoured by funding agencies), the latter aims at developing a new paradigm. The program at the B factories belonged to the former variety – and repre-

sents a most successful one – yet a Super-Flavour Factory aims at the latter by searching mainly for the anticipated 'New \mathbf{CP} Paradigm'.

The top priority at a Super-Flavour Factory has to be assigned to studies of B physics, which still has a rich agenda as explained in the talks by Ligeti [3] and Golutvin [9]; for more details see Ref.[20]. I will not repeat their discussion here and instead sketch the agenda of two other areas accessible at a Super-Flavour Factory, namely charm and τ physics.

2.2.1 2nd Priority: CP Studies in Charm Transitions

I had mentioned before that the observed rate of $B_s - \overline{B}_s$ oscillations is consistent with the SM prediction within the latter's significant uncertainty. The potential New Physics hiding behind the uncertainty can be revealed in the time dependent **CP** asymmetry in $B_s \to \psi \phi$, since the latter is small in the SM for reasons germane to it [2].

The same strategy can and should be pursued in charm transitions. While the observed oscillation rate is not clearly inconsistent with the SM, the uncertainties are quite large. Yet decisive tests can be provided by **CP** studies in $D^0 \to K^+ K^- / \pi^+ \pi^- / K^+ \pi^- / K_S \pi^+ \pi^-$ as mentioned before, since the 'signal to theoretical noise' ratio is very likely higher in **CP** asymmetries than in pure oscillation phenomena. For the former are shaped to a higher degree by short-distance dynamics, over which we have better theoretical control than over the non-perturbative long-distance dynamics. Furthermore KM theory allows for only small asymmetries to arise in a rather restricted set of channels [16].

I want to add two examples of a bit unorthodox nature.

The 'Dark Horse': Semileptonic D^0 Decays

In analogy to the B_d case, the emergence of 'wrong-sign' leptons $-D^0 \rightarrow l^- \overline{\nu} K^+$ or $\overline{D}^0 \rightarrow l^+ \nu K^-$ – signals oscillations have taken place. We already know that unlike for B_d mesons it is a rare process for neutral charm mesons. Once we have accumulated such wrong-sign events, we can ask whether this rate is different for the meson and anti-meson transition:

$$a_{SL}(D^0) \equiv \frac{\Gamma(D^0 \to l^- \overline{\nu} K^+) - \Gamma(\overline{D}^0 \to l^+ \nu K^-)}{\Gamma(D^0 \to l^- \overline{\nu} K^+) + \Gamma(\overline{D}^0 \to l^+ \nu K^-)}$$
(5)

Such differences have been and are being searched for in the semileptonic decays of neutral K and B mesons. For K_L decays the expected rate has been found $-a_{SL}(K_L) \simeq 3.3 \cdot 10^{-3}$; the experimental upper bounds for neutral B mesons have not yet reached the SM predictions: $a_{SL}(B_d) \simeq 4 \cdot 10^{-4}$, $a_{SL}(B_s) \simeq 2 \cdot 10^{-5}$ [21]. We understand why these numbers are so tiny. For a_{SL} is given very roughly by

$$a_{SL} \sim \frac{\Delta\Gamma}{\Delta M} \cdot \sin\phi_{\text{weak}}$$
. (6)

While $\Delta\Gamma/\Delta M \simeq 1$ for kaons, we have $\sin\phi_{\text{weak}} \ll 1$ due to the third quark family being almost decoupled from the first two. For B_d it is the other way around: $\Delta\Gamma/\Delta M \ll 1$, yet $\sin\phi_{\text{weak}} \sim \mathcal{O}(0.1)$. For B_s mesons we have furthermore $\sin\phi_{\text{weak}} \ll 1$, since on the leading level only the second and third quark family contribute. A rough estimate yields $a_{SL}(D^0)|_{SM} \leq 10^{-3}$. Present data suggest $\Delta\Gamma/\Delta M$ to be about unity. With New Physics inducing a weak phase we could conceivably obtain a relatively large value: $a_{SL}(D^0) \sim \text{few} \times 10^{-2}$; i.e., while we know that semileptonic D^0 decays produce few wrong-sign leptons, they might exhibit a large **CP** asymmetry – in marked contrast to K_L , B_d and B_s mesons.

Final State Distributions, T odd Moments

So far all **CP** violation has been found in partial widths – except for one, the forwardbackward asymmetry in the orientation of the $\pi^+\pi^-$ and e^+e^- planes in $K_L \to \pi^+\pi^-e^+e^-$. It had been predicted [22] and subsequently found that the expectation value for this angular asymmetry is about 14% [19] – yet driven by $|\epsilon_K| \simeq 0.23\%$. How can that be? This puzzle is resolved, when one realizes that both amplitudes that generate the asymmetry through their interference – $K_L \xrightarrow{CPV} \pi^+\pi^- \xrightarrow{E1} \pi^+\pi^-\gamma^* \to \pi^+\pi^-e^+e^-$ and $K_L \xrightarrow{M1} \pi^+\pi^-\gamma^* \to \pi^+\pi^-e^+e^-$ – are greatly suppressed, albeit for different reasons: it is the **CP** violation in the first and the *M*1 feature in the second amplitude. Such a dramatic enhancement of the asymmetry does not come for free, of course: the price one pays is a tiny branching ratio of about $3 \cdot 10^{-7}$; i.e., one trades branching ratio for size of the asymmetry. This is a very desirable trade – if one has a copious production source.

There might be a close analogy in the charm complex, namely in the angular distribution of the K^+K^- relative to the $\mu^+\mu^-$ plane in

$$D_L \to K^+ K^- \mu^+ \mu^- \,, \tag{7}$$

where a **CP** violating E1 amplitude interferes with a **CP** conserving M1 amplitude to generate a forward-backward asymmetry. The latter could exhibit an enhancement of the underlying **CP** violation leading to $D_L \to K^+K^-$ by an order of magnitude depending on details of the strong dynamics. This radiative decay has not been observed yet; its branching ratio could be as 'large' as about 10^{-6} .

The reader might view this discussion as completely academic, since it requires a pure sample of long-lived neutral D mesons in qualitative analogy to K_L . Yet since the lifetime difference between D_L and D_S can hardly reach even the 1% level, 'patience' – waiting for the D_S component to decay away – is insufficient. Yet there is a unique capability of a Super-Flavour Factory that can be harnessed here through the use of EPR correlations [23] or 'entanglement'. Consider running at charm production threshold:

$$e^+e^- \to \psi''(3770) \to D_S D_L$$
 (8)

Once one of the neutral D mesons decays as $D \to K^+K^-$, we know unambiguously that the other meson has to be a D_L , as long as **CP** is conserved. We can then track its decays into the $K^+K^-\mu^+\mu^-$ final state.

2.2.2 3rd Priority: τ Physics

Lepton Flavour Violating Decays (LFV)

Finding a transition of the type $\tau \to l\gamma$ or $\tau \to 3l$ establishes the existence of New Physics, since lepton flavour is violated. The *B* factories have established upper bounds

of few×10⁻⁸. The range $10^{-8} - 10^{-10}$ is a very promising search domain rather than an ad hoc one. For several classes of New Physics scenarios – in particular of the GUT variety with their connections to $\mu \to e\gamma/3e$ – point to that range [20]. The radiative transition $\tau \to l\gamma$ seems to be clearly beyond the reach of LHC experiments; this might well turn out to be true for $\tau \to 3l$ as well. Yet a Super-Flavour factory can push into this domain and possible sweep it out.

CP Violation in τ Physics

The next great challenge in **CP** studies is to find **CP** violation in leptodynamics. The leading contenders are the electron EDM, **CP** asymmetries in neutrino oscillations and in semi-hadronic τ decays like $\tau \to K\pi(\pi)\nu$ [24, 25]. If found, it would 'de-mystify' **CP** violation as a phenomenon present both in the quark and lepton sectors. Maybe more importantly it would provide us with a potential benchmark for leptogenesis that can subsequently induce baryogenesis in our Universe. There will not be any competition from LHC experiments for probing **CP** symmetry in τ decays. At a Super-Flavour Factory one can also employ a unique and powerful tool, namely longitudinal beam polarization: it will lead to the production of polarized τ leptons, which provides another handle on **CP** invariance [26, 25].

For proper perspective one should note that while a LFV rate has to be *quadratic* in a New Physics amplitude, a **CP** asymmetry (in a SM mode) is linear only:

$$\mathbf{CP} \text{ odd } \sim |T_{\mathrm{SM}}^* T_{\mathrm{NP}}| \text{ vs. LFV } \sim |T_{\mathrm{NP}}|^2 .$$
 (9)

Observing a 10^{-3} [10^{-4}] **CP** asymmetry in $\tau \to K\pi\nu$ then corresponds very roughly to discovering $\tau \to \mu\gamma$ with a branching ratio of about 10^{-8} [10^{-10}].

2.3 Design Criteria for a Super-Flavour Factory

The preceding discussion leads to the following strategic goals when designing a Super-Flavour Factory:

• You cannot overdesign a Super-Flavour Factory. If what we know now about the size of the **CP** asymmetry in $B_d \rightarrow \psi K_S$ had been known when the *B* factories were proposed, a less ambitious target for the luminosity would most likely have been chosen. In retrospect both *B* factories had been over-designed – yet that is exactly what was a cornerstone of their spectacular success! What is true for a 'hypothesis driven' research program, is even more true for a 'hypothesis generating' one. Tony Sanda's dictum "We need a luminosity of 10^{43} cm⁻² s⁻¹" is certainly 'tongue-in-cheek', but not frivolous in that sense. If you must stage the construction, do *not* compromise on final performance. To be more down to earth: a data sample of 10 ab⁻¹ – an increase by an order of magnitude over the existing set – should be targeted as an intermediate step; in the end one should aim for at least 50 ab⁻¹.

• Keep the background as low as possible.

• Make the detector as *hermetic* as possible. This is essential when aiming for $B \rightarrow \nu \bar{\nu} K^{(*)} \dots, B \rightarrow \tau \nu D \dots, D_{(s)} \rightarrow \tau \nu$ modes.

• Keep the flexibility to eventually have quality runs on the $\Upsilon(5S)$ resonance, be it for calibrating *absolute* rates for B_s transitions or analyzing some of their features that could not be settled by LHCb.

• It might turn out to be even more important to be able to run in the charm threshold region with good luminosity to reduce systematic uncertainties when searching for tiny **CP** asymmetries in charm decays. For the background is lowest there; furthermore quantum correlations can be harnessed to obtain unique information [16]. I have mentioned just one example, namely the ability to prepare a 'beam' of D_L mesons.

• Make a reasonably strong effort to obtain at least one longitudinally polarized beam. This is an essential tool in probing **CP** invariance in the production and decay of τ leptons. It would also be valuable in dealing with the background when searching for LFV τ decays (and for some **CP** asymmetries in charm baryon decays).

3 Conclusions and Outlook

We are about to embark on a most exciting adventure: we stand at the beginning of an era that promises to reveal the dynamics behind electroweak symmetry breaking. The central stage for this adventure will be the LHC, where quanta signaling New Physics are expected to be produced. Since failure of the LHC program would have disastrous consequences for the future of fundamental physics, it just cannot be tolerated! Yet heavy flavour studies probing the family structure and **CP** symmetry in the K, D, B and τ sectors will be central players in the evolving drama.

- Such studies are and will remain of fundamental importance in our efforts of revealing 'Nature's Grand Design';
- their lessons cannot be obtained any other way;
- they cannot become obsolete.

At the same time comprehensive studies of \mathbf{CP} violation, oscillations and rare decays can be *instrumentalized* to analyze the anticipated TeV scale New Physics. I see three scenarios play out over the next several years:

- 1. The 'optimal' one: New Physics has been discovered in high p_{\perp} collisions at the LHC. Then we must determine its salient features, and this cannot be done without analyzing its impact on flavour dynamics even if there is none! With the mass scale of the New Physics revealed directly, lessons from heavy flavour rates can be interpreted with more quantitative rigour.
- 2. The 'intriguing' one: deviations from SM predictions have been established in heavy flavour decays.
- 3. The 'frustrating' one: no deviations from SM predictions have been identified anywhere.

I bet it will be the first scenario with some elements of the second one. We should not overlook that heavy flavour studies can realistically have sensitivities up to the about 10 - 100 TeV scale – well beyond the direct reach of the LHC. But in any case none of these scenarios weaken the essential role of flavour studies. For even the 'frustrating' scenario does not resolve any of the central mysteries of the SM.²

The LHCb experiment will be a worthy and successful standard bearer of heavy flavour physics, yet it will not complete the program. The era of the heavy flavour factories inaugurated by ARGUS' discovery twenty years ago has not run its profitable course yet – the best might actually still be ahead. A Super-Flavour Factory provides unique capabilities in searching for LFV and **CP** violation in τ decays, unmatched access to **CP** studies in charm transitions and measurements of *B* decays that are highly complementary to the LHCb program. The HEP community is fortunate to have a battle tested and enthusiastic 'army' to embark on a Super-Flavour Factory campaign and will benefit greatly from the results of the latter.

Epilogue

When we look back over the last thirty years – i.e. including the period leading up to ARGUS' discovery of $B_d - \overline{B}_d$ oscillations – we see several strands of developments: from the 'heavy flavour sweatshops' – ARGUS, CLEO and MARKIII – to the present B and tau-charm factories – Belle, BaBar, CLEO-c and BESIII – hopefully to a Super-Flavour Factory; accelerators pushing the high energy frontier – the SPS, Tevatron, LEP I/II and SLC – leading to the LHC and hopefully to the ILC; last (and presumably least for some of the readers) theory. These strands are not isolated from each other, but substantially intertwined. The generational challenge facing us is to understand the electroweak phase transition. This will be tackled in a dedicated way at the high energy frontier by the LHC experiments Atlas and CMS and at the high sensitivity frontier by LHCb. Yet they are unlikely to complete the task – we will need more precise and more comprehensive data. This is where the ILC, which is also a top factory, and a Super-Flavour Factory come in as essential parts of the adventure.

Let me allow a very personal look back as well: Fig.4 shows me giving a talk at the Heidelberg Heavy Quark Symposium in 1986. Fig.5 on the other hand might be closer to how some see me now. It actually shows the person whose most famous quote I adapted for the title.

It has been said: "All roads lead to Rome." Personally I think Rome is never a bad destination. When I said before we are at the beginning of an exciting journey into the unknown I was incorrect, as shown by celebrating ARGUS' seminal achievements: For it is actually the continuation of an age-long adventure, and we are most privileged to be able to participate in it.

 $^{^{2}}$ This is of course a purely scientific-intellectual argument – the political one would play out very differently.



Figure 4: Giving a talk in Heidelberg in 1986



Figure 5: Cato the Elder

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