CP Violation and $B$ Physics at the LHC

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- Setting the Stage
- Key Targets of the $B$ Physics Programme at the LHC
- Conclusions and Outlook
Setting the Stage

- Standard Model (SM):

  → Kobayashi–Maskawa (KM) mechanism of CP violation:

![Diagram showing CP violation](image)

Current Status of the SM: Tremendous Success

Impressive precision measurements @ LEP → but still ...

- Is the breaking of the electroweak symmetry and the generation of the particle masses in fact caused by the “minimal” Higgs mechanism, i.e. through the non-vanishing vacuum expectation value of a scalar field?
  → insights at the “Large Hadron Collider” (LHC) @ CERN ∼ 2008

- On the other hand, also a close connection between the Higgs sector and flavour physics through Yukawa interactions (→ Fermion masses):
  → rich quark-flavour phenomenology: flavour “factories”!

- The SM is – with the exception of a few “flavour puzzles” (?) – in good shape! However, the SM cannot be complete:
  → indications:
  - Neutrino oscillations (→ lepton-flavour phenomenology), dark matter, generation of the baryon asymmetry of the Universe, ...
  ⊕ fundamental theoretical questions (hierarchy problem, etc.)
Why Study Flavour Physics & CP Violation?

• **New Physics (NP):**  
  Typically new patterns in the flavour sector
  - SUSY scenarios;
  - left–right-symmetric models;
  - models with extra $Z'$ bosons;
  - scenarios with extra dimensions;
  - “little Higgs” scenarios ...

• **$\nu$ masses:**  
  Origin beyond the Standard Model (SM)!
  - CP violation in the neutrino sector?
  - Connection with quark-flavour physics?

• **Cosmology:**  
  Baryon asymmetry suggests new CP violation!
  - Could be associated with very high energy scales:
    * attractively mechanism: “leptogenesis”, involving new CP-violating sources in the decays of heavy Majorana neutrinos.
  - But could also be accessible in the laboratory ...
Challenging the Standard Model through Flavour Studies

Before searching for NP, we have to understand the SM picture!

- **The key problem:**
  
  ◊ *impact of strong interactions* $\rightarrow$ *“hadronic” uncertainties*

- There are various flavour probes: $K$, $D$ decays ...

- The $B$-meson system is a *particularly promising probe*: $\rightarrow$ our focus
  
  – Offers various strategies: simply speaking, there are *many* $B$ decays!
  
  – Search for clean SM relations that could be spoiled by NP ...
The Main Actors of this Talk: \( B \) Mesons

- **Charged \( B \) mesons:**
  \[
  B^+ \sim u \bar{b} \quad B^- \sim \bar{u} \, b \\
  B_c^+ \sim c \bar{b} \quad B_c^- \sim \bar{c} \, b
  \]

- **Neutral \( B \) mesons:**
  \[
  B_0^d \sim d \bar{b} \quad B_d^0 \sim \bar{d} \, b \\
  B_0^s \sim s \bar{b} \quad B_s^0 \sim \bar{s} \, b
  \]

- \( B_0^q - \bar{B}_0^q \) mixing:

\[
\begin{aligned}
  &|B_q(t)\rangle = a(t)|B_0^q\rangle + b(t)|\bar{B}_0^q\rangle : \\
  \Rightarrow \quad &|B_q(t)\rangle = a(t)|B_0^q\rangle + b(t)|\bar{B}_0^q\rangle : \\
  \end{aligned}
\]

- **Schrödinger equation** \( \Rightarrow \) **mass eigenstates:**

\[
\Delta M_q \equiv M_H^{(q)} - M_L^{(q)}, \quad \Delta \Gamma_q \equiv \Gamma_H^{(q)} - \Gamma_L^{(q)}
\]

- **Decay rates:**
  \[
  \Gamma(B_0^q(t) \to f) : \\
  \cos(\Delta M_q t) \& \sin(\Delta M_q t) \to \text{oscillations!}
  \]
Where to Study $B$-Meson Decays?

- **$B$ factories:** asymmetric $e^+e^-$ colliders @ $\Upsilon(4S) \rightarrow B_d^0\bar{B}_d^0, B_u^+B_u^-$
  - PEP-II with the *Babar* experiment (SLAC);
  - KEK-B with the *Belle* experiment (KEK):
    - could well establish CP violation in the $B$ system;
    - many interesting results with $\sum\mathcal{O}(10^9)\ B\bar{B}$ pairs ...
  - Discussion of a super-$B$ factory, with increase of luminosity by $\mathcal{O}(10^2)$.

- **Hadron colliders:** produce also $B_s$ mesons,\(^1\) as well as $B_c, \Lambda_b, ...$
  - Tevatron: CDF and D0 have reported first $B^{(s)}$-decay results ...
  - ... to be continued at the LHC $\sim$ summer 2008:
    - ATLAS & CMS (can also address some $B$ physics)
      - dedicated $B$-decay experiment: LHCb
        (interest from Madagascar: talk by F. Andrianala)

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\(^1\)Recently, data at $\Upsilon(5S)$ were taken by Belle, allowing also access to $B_s$ decays [hep-ex/0610003].
Central Target: Unitarity Triangle (UT)

- Application of the Wolfenstein parametrization: [Wolfenstein (1984)]

\[
\hat{V}_{\text{CKM}} = \left(\begin{array}{ccc}
1 - \frac{1}{2} \lambda^2 & \frac{\lambda}{2} & A \lambda^3 (\rho - i \eta) \\
-\lambda & 1 - \frac{1}{2} \lambda^2 & A \lambda^2 \\
A \lambda^3 (1 - \rho - i \eta) & -A \lambda^2 & 1 \end{array}\right) + \mathcal{O}(\lambda^4)
\]

\[\rightarrow \text{phenomenological expansion in } \lambda \equiv |V_{us}| = 0.22 \text{ [from } K \rightarrow \pi \ell \bar{\nu}_\ell]\]

- Unitarity of the CKM matrix:

\[
\hat{V}_{\text{CKM}}^\dagger \cdot \hat{V}_{\text{CKM}} = \hat{1} = \hat{V}_{\text{CKM}} \cdot \hat{V}_{\text{CKM}}^\dagger \Rightarrow
\]

\[
R_b = \left(1 - \frac{\lambda^2}{2}\right) \frac{1}{\lambda} \left|\frac{V_{ub}}{V_{cb}}\right| \\
R_t = \frac{1}{\lambda} \left|\frac{V_{td}}{V_{cb}}\right|
\]

\[\bar{\rho} \equiv (1 - \lambda^2/2) \rho, \quad \bar{\eta} \equiv (1 - \lambda^2/2) \eta \rightarrow \text{NLO corrections} \text{ [Buras et al. (1994)]}\]
Key Processes for CP Violation: Non-Leptonic $B$ Decays

- **Tree diagrams:**
  \[ b \rightarrow u, c \]
  \[ W \rightarrow \bar{u}, \bar{c} \]
  \[ W \rightarrow d (s) \]

- **Penguin diagrams:**
  - **QCD penguins:**
    \[ b \rightarrow u, c, t \]
    \[ W \rightarrow d (s) \]
    \[ G \rightarrow \bar{q} \]
    \[ q = u, c, d, s \]
  - **Electroweak (EW) penguins:**
    \[ b \rightarrow u, c, t \]
    \[ W \rightarrow d (s) \]
    \[ Z, \gamma \rightarrow \bar{q} \]
    \[ q \]

- **The calculation of the decay amplitudes is theoretically very challenging:**

\[
A(B \rightarrow f) \sim \sum_k C_k(\mu) \times \langle f | Q_k(\mu) | B \rangle
\]

[QCD Factorization (QCDF), PQCD, Soft Collinear Effective Theory (SCET), ...]
... but calculation of $\langle f | Q_k(\mu) | B \rangle$ can be circumvented:

- Amplitude relations allow us in fortunate cases to eliminate the hadronic matrix elements ($\to$ typically strategies to determine the UT angle $\gamma$):
  - **Exact relations:** class of pure “tree” decays (e.g. $B \to DK$).
  - **Approximate relations,** which follow from the flavour symmetries of strong interactions, i.e. $SU(2)$ isospin or $SU(3)_F$:
    \[ B \to \pi\pi, \ B \to \pi K, \ B_s \to KK. \]

- Decays of neutral $B_d$ and $B_s$ mesons:

  ![Diagram of $B_q^0$ and $\overline{B_q^0}$ mixing]

  - Lead to “mixing-induced” CP violation $\mathcal{A}_{\text{mix}}^{\text{CP}}$!
  - If one CKM amplitude dominates:
    \[ \Rightarrow \text{hadronic matrix elements cancel!} \]

* Example: $B_d^0 \to J/\psi K_S \Rightarrow \sin 2\beta$ [Bigi, Carter & Sanda (’80–’81)]
A Brief Roadmap of Quark-Flavour Physics

- CP-B studies through various processes and strategies:

\[ B \rightarrow \pi \pi \text{ (isospin)}, \quad B \rightarrow \rho \pi, \quad B \rightarrow \rho \rho \]

- Moreover “rare” decays: \( B \rightarrow X_s \gamma, \quad B_{d,s} \rightarrow \mu^+ \mu^-, \quad K \rightarrow \pi \nu \bar{\nu}, \ldots \)
  - Originate from loop processes in the SM.
  - Interesting correlations with CP-B studies.

\[ \text{New Physics} \quad \Rightarrow \quad \text{Discrepancies} \]
Current Status of the Unitarity Triangle

- Two competing groups: many plots & correlations ...
  - UTfit Collaboration [http://www.utfit.org];

⇒ impressive global agreement with KM, but some “tension” ...
Moreover: A Puzzling Pattern ...

\[
\sin(2\beta^{\text{eff}}) = \sin(2\phi_1^{\text{eff}})
\]

\[
C_f = -A_f
\]

[See the experimental talks about BaBar (C.M. Hawkes) & Belle (K. Trablesi)]

- **LHCb**: look forward to data for \( B_s \rightarrow \phi\phi \) ...
Key Targets of the $B$ Physics Programme at the LHC

→ high statistics and complementarity to the $B$ factories:

fully exploit the $B_s$-meson system!
General Features of the $B_s$ System

- **Rapid $B_s^0$–$\bar{B}_s^0$ oscillations:** $\Delta M_s^{\text{SM}} = \mathcal{O}(20 \text{ ps}^{-1}) \gg \Delta M_d^{\text{exp}} = 0.5 \text{ ps}^{-1}$

  $\Rightarrow$ challenging to resolve them experimentally!

- **The width difference $\Delta \Gamma_s/\Gamma_s$ is expected to be of $\mathcal{O}(10\%)$ [$\tau_{B_s} \sim 1.5\text{ps}$]:**
  - Experimental status: $B_s \to J/\psi \phi$ @ Tevatron $\Rightarrow$
    
    \[ \Delta \Gamma_s = \begin{cases} 
    (0.17 \pm 0.09 \pm 0.02) \text{ps}^{-1} & \text{[D0 ('07)}}
    
    (0.076^{+0.059}_{-0.063} \pm 0.006) \text{ps}^{-1} & \text{[CDF ('07)]}
    \end{cases} \]
  
  - May provide interesting CPV studies through “untagged” rates:
    
    \[ \langle \Gamma(B_s(t) \to f) \rangle \equiv \Gamma(B_s^0(t) \to f) + \Gamma(\bar{B}_s^0(t) \to f) \]

  * The rapidly oscillating $\Delta M_s t$ terms cancel!
  * Various “untagged” strategies were proposed.
    
    [Dunietz ('95); R.F. & Dunietz ('96); Dunietz, Dighe & R.F. ('99); ...]

- **The CP-violating phase of $B_s^0$–$\bar{B}_s^0$ mixing is tiny in the SM:**

  $\phi_s^{\text{SM}} = -2\lambda^2\eta \approx -2^\circ$ $\Rightarrow$ interesting for NP searches (see below)!
Hot News of 2006:

• **Signals for** $B_s^0 - \bar{B}_s^0$ **mixing at the Tevatron:**
  
  – For many years, only lower bounds on $\Delta M_s$ were available from the LEP (CERN) experiments and SLD (SLAC)!
  
  – Finally, the value of $\Delta M_s$ could be pinned down:
    
    * D0: $\Rightarrow$ two-sided bound $17 \, \text{ps}^{-1} < \Delta M_s < 21 \, \text{ps}^{-1}$ (90% C.L.)
      $\Rightarrow 2.5 \sigma$ @ $\Delta M_s = 19 \, \text{ps}^{-1}$; 2007: $\Delta M_s = (18.56 \pm 0.87) \, \text{ps}^{-1}$
    
    * CDF: $\Delta M_s = [17.77 \pm 0.10 \text{(stat)} \pm 0.07 \text{(syst)}] \, \text{ps}^{-1} \gtrsim 5\sigma$
  
• **Most recent lattice prediction:** [HPQCD collaboration, hep-lat/0610104]
  
  $\Delta M_s^{\text{SM}} = 20.3(3.0)(0.8) \, \text{ps}^{-1}$
  
• But there is still a lot of space for NP in $B_s^0 - \bar{B}_s^0$ mixing left:
  
  [Details: P. Ball & R.F. (2006); ...]
Golden Process to Search

for NP in $B^0_s - \bar{B}^0_s$ Mixing:

$B^0_s \rightarrow J/\psi\phi$

$\rightarrow B^0_s$ counterpart of $B^0_d \rightarrow J/\psi K_S$ ...

Let’s have a closer look ...

- Amplitude phase structure (robust under NP, as tree dominated):

  ⇒ hadronic matrix elements cancel in mixing-induced observables!

- There is an important difference with respect to $B_{d}^{0} \rightarrow J/\psi K_{S}$:

  The final state is an admixture of different CP eigenstates!

- Angular distribution of the $J/\psi[\rightarrow \ell^{+}\ell^{-}]\phi[\rightarrow K^{+}K^{-}]$ decay products:

  ⇒ the different CP eigenstates can be disentangled ...
Simple Case: One-Angle Distribution

\[
\frac{d\Gamma(t)}{d \cos \Theta} \propto \begin{cases} 
\left[P_+(t)\right] \frac{3}{8} (1 + \cos^2 \Theta) & \text{CP even} \\
\left[P_-(t)\right] \frac{3}{4} \sin^2 \Theta & \text{CP odd}
\end{cases}
\]

- **Untagged data samples:** → untagged rates ...

\[
P_\pm(t) + \bar{P}_\pm(t) \propto \left[(1 \pm \cos \phi_s) e^{-\Gamma_L t} + (1 \mp \cos \phi_s) e^{-\Gamma_H t}\right]
\]

- **Tagged data samples:** → CP asymmetries ...

\[
\frac{P_\pm(t) - \bar{P}_\pm(t)}{P_\pm(t) + \bar{P}_\pm(t)} = \pm \frac{2 \sin(\Delta M_{st} t) \sin \phi_s}{(1 \pm \cos \phi_s) e^{+\Delta \Gamma_{st}/2} + (1 \mp \cos \phi_s) e^{-\Delta \Gamma_{st}/2}}
\]

\[
B^0_s - \bar{B}^0_s \text{ mixing phase } \phi_s = (-2\lambda^2 \eta)_{\text{SM}} + \phi_s^{\text{NP}} \approx \phi_s^{\text{NP}} \Rightarrow
\]

- CP-violating NP effects would be indicated by the following features:\(^2\)
  
  – The untagged observables depend on two exponentials;
  
  – sizeable values of the CP-violating asymmetries.

\(^2\)Similar features hold also for the full three-angle distribution: more complicated, but no problem ...
News from the Tevatron & Reach at the LHC

- Very recent (preliminary) analysis by D0: [D0Conference note 5144 ('06)]
  - Untagged, time-dependent three-angle $B_s \rightarrow J/\psi \phi$ distribution:
    \[ \Rightarrow \phi_s = -0.79 \pm 0.56 \text{ (stat.)} \pm 0.01 \text{ (syst.)} = -(45 \pm 32 \pm 0.6)^\circ \]
  - Imposing also constraints form certain semileptonic $B$ decays:
    \[ \Rightarrow \phi_s = -0.56^{+0.44}_{-0.41} = -(32^{+25}_{-23})^\circ \]
    \[ \Rightarrow \text{still not stringently constrained, but very accessible @ LHC} \ldots \]

- Experimental reach at the LHC:
  - LHCb: $\sigma_{\text{stat}}(\sin \phi_s) \approx 0.031$ (1 year, i.e. $2 \text{ fb}^{-1}$) [0.013 (5 years)];
  - ATLAS & CMS: expect uncertainties of $\mathcal{O}(0.1)$ (1 year, i.e. $10 \text{ fb}^{-1}$).
Further Benchmark Decays for the LHCb Experiment → very rich physics programme ...

[See also the experimental talk by A. Pellegrino]
Two Major Lines of Research

1. **Precision measurements of $\gamma$:**

- **Tree strategies**, with expected sensitivities after 1 year of taking data:
  - $B^0_s \rightarrow D^+_s K^\pm$: $\sigma_\gamma \sim 14^\circ$
  - $B^0_d \rightarrow D^0 K^*$: $\sigma_\gamma \sim 8^\circ$
  - $B^\pm \rightarrow D^0 K^\pm$: $\sigma_\gamma \sim 5^\circ$

- **Decays with penguin contributions:**
  - $B^0_s \rightarrow K^+ K^-$ and $B^0_d \rightarrow \pi^+ \pi^-$: $\sigma_\gamma \sim 5^\circ$
  - $B^0_s \rightarrow D^+_s D^-_s$ and $B^0_d \rightarrow D^+_d D^-_d$

2. **Analyses of rare decays which are absent at the SM tree level:**

- $B^0_s \rightarrow \mu^+ \mu^-$, $B^0_d \rightarrow \mu^+ \mu^-$
- $B^0_d \rightarrow K^{*0} \mu^+ \mu^-$, $B^0_s \rightarrow \phi \mu^+ \mu^-$; ...

   → let’s have a closer look at some decays ...
The $B_s \rightarrow K^+K^-$, $B_d \rightarrow \pi^+\pi^-$ System

- $B^0_s \rightarrow K^+K^-$:
  
  - $B^0_s \rightarrow \pi^+\pi^-$:
    
  $\Rightarrow \quad s \leftrightarrow d$
- The decays $B_d \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$ are related to each other through the interchange of all down and strange quarks.\(^3\)

\[ U\text{-spin symmetry} \Rightarrow \]

- Determination of $\gamma$ and hadronic parameters $d(=d')$, $\theta$ and $\theta'$.  
- Internal consistency check of the $U$-spin symmetry: $\theta \overset{?}{=} \theta'$.


- Detailed studies show that this strategy is very promising for LHCb:

CERN-LHCb/2003-123 & 124; most recent: J. Nardulli @ CKM 2006, Nagoya, Dec. ’06

\(^3\)U spin: $SU(2)$ subgroup of the $SU(3)_F$ flavour-symmetry group of QCD.
The Rare Decays $B_q \rightarrow \mu^+\mu^- \ (q \in \{d, s\})$

- Originate from $Z$ penguins and box diagrams in the Standard Model:

  $B_q^0 \rightarrow WtZ$ $B_q^0 \rightarrow Wt\mu

- Corresponding low-energy effective Hamiltonian: \cite{Buchalla & Buras (1993)}

$$H_{\text{eff}} = -\frac{G_F}{\sqrt{2}} \left[ \frac{\alpha}{2\pi \sin^2 \Theta_W} \right] V_{tb}^* V_{tq} \eta_Y Y_0(x_t) (\bar{b}q)_{V-A} (\bar{\mu} \mu)_{V-A}$$

  - $\alpha$: QED coupling; $\Theta_W$: Weinberg angle.
  - $\eta_Y$: short-distance QCD corrections (calculated ...)
  - $Y_0(x_t \equiv m_t^2/M_W^2)$: Inami–Lim function, with top-quark dependence.

- Hadronic matrix element: very simple situation:
  - Only the matrix element $\langle 0 | (\bar{b}q)_{V-A} | B_q^0 \rangle$ is required: $f_{B_q}$

$$\Rightarrow \text{belong to the cleanest rare } B \text{ decays!}$$
• **Most recent SM predictions:** [Blanke, Buras, Guadagnoli, Tarantino ('06)]

  → use the data for the $\Delta M_q$ to reduce the hadronic uncertainties:

  $$
  \begin{align*}
  \text{BR}(B_s \to \mu^+\mu^-) &= (3.35 \pm 0.32) \times 10^{-9} \\
  \text{BR}(B_d \to \mu^+\mu^-) &= (1.03 \pm 0.09) \times 10^{-10}
  \end{align*}
  $$

• **Most recent experimental upper bounds from the Tevatron:**

  – CDF collaboration @ 95% C.L.: [CDF Public Note 8956 (2007)]

    $$
    \begin{align*}
    \text{BR}(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-8}, & \quad \text{BR}(B_d \to \mu^+\mu^-) < 1.8 \times 10^{-8}
    \end{align*}
    $$

  – D0 collaboration @ 90% C.L. (95% C.L.): [D0note 5344-CONF (2007)]

    $$
    \begin{align*}
    \text{BR}(B_s \to \mu^+\mu^-) < 7.5 (9.3) \times 10^{-8}
    \end{align*}
    $$

  \Rightarrow \text{still a long way to go (?) \rightarrow LHC (background under study)}

• **However, NP may significantly enhance BR}(B_s \to \mu^+\mu^-):**

  – In SUSY scenarios: $\text{BR} \sim (\tan \beta)^6 \rightarrow$ dramatic enhancement (!);
    [see, e.g., Foster *et al.* and Isidori & Paride ('06) for recent analyses]

  – NP with modified EW penguin sector: sizeable enhancement.
The Rare Decay $B_d^0 \rightarrow K^{*0} \mu^+ \mu^-$

- **Key observable for NP searches:**

\[ A_{FB}(\hat{s}) = \frac{1}{d\Gamma/d\hat{s}} \left[ \int_{0}^{1} d(\cos \theta) \frac{d^2\Gamma}{d\hat{s} d(\cos \theta)} - \int_{-1}^{0} d(\cos \theta) \frac{d^2\Gamma}{d\hat{s} d(\cos \theta)} \right] \]

- $\theta$ is the angle between the $B_d^0$ momentum and that of the $\mu^+$ in the dilepton centre-of-mass system,
- and $\hat{s} = s/M_B^2$, with $s = (p_{\mu^+} + p_{\mu^-})^2$.

- **Particularly interesting:**

\[ A_{FB}(\hat{s}_0)|_{SM} = 0 \]  
[Burdman ('98); Ali et al. ('00); ...]

- The value of $\hat{s}_0$ is very robust with respect to hadronic uncertainties!
- SUSY extensions of the SM:
  \[ \rightarrow \text{may yield } A_{FB}(\hat{s}) \text{ of opposite sign or without a zero point} \]
Fig. 54: Dimuon-mass spectrum of $B \to K^* \mu^+ \mu^-$ in the SM and two SUSY models

Fig. 55: Forward-backward asymmetry of $B \to D_s \mu^+ \mu^-$, showing $\Delta A_{FB}$ ratios like (8.25).

The ATLAS collaboration has studied the decays $B_0 \to \rho^0 \mu^+ \mu^-$, $B_0 \to K^0 \mu^+ \mu^-$ and $B_s \to \phi \mu^+ \mu^-$. ATLAS will collect about 1000 decay events/year, yielding $\Delta \hat{s}_0 = 0.06$ after one year.

- **Sensitivity at the LHC:**
  - LHCb: $\sim 4400$ decays/year, yielding $\Delta \hat{s}_0 = 0.06$ after one year.
  - ATLAS will collect about 1000 $B^0 \to K^* \mu^+ \mu^-$ decays per year.

- **Other $b \to s \mu^+ \mu^-$ decays under study:** $\Lambda_b \to \Lambda \mu^+ \mu^-$, $B_s^0 \to \phi \mu^+ \mu^-$...

- **Current $B$-factory data:** inclusive $b \to s \ell^+ \ell^-$ BRs and the integrated asymmetries $\int A_{FB}$ in accordance with SM, but still large uncertainties.
Conclusions and Outlook (I)

- Tremendous progress in $B$ physics during the recent years:
  - Fruitful interplay between theory and experiment
  - $e^+e^-$ $B$ factories: have already produced $\sum \mathcal{O}(10^9)$ $B\bar{B}$ pairs;
  - Tevatron: has recently succeeded in observing $B_s^0-\bar{B}_s^0$ mixing.

- Status in September 2007:
  - The data agree globally with the Kobayashi–Maskawa picture!
  - But we have also hints for discrepancies: $\rightarrow$ first signals of NP??

- New perspectives for $B$-decay studies @ LHC $\gg$ summer 2008:
  - Large statistics and full exploitation of the $B_s$ physics potential, thereby complementing the physics programme of the $e^+e^-$ $B$ factories.
  - Precision determinations of $\gamma$: $\rightarrow$ key ingredients for NP searches!
  - Powerful studies of rare decays: $B_{s,d} \rightarrow \mu^+\mu^-$, ...

  $\rightarrow$ much more stringent CKM consistency tests!
Conclusions and Outlook (II)

Flavour physics & CP violation in direct context with LHC

• Main goals of the ATLAS and CMS experiments:
  – Exploration of the mechanism of EW symmetry breaking: Higgs!?
  – Production and observation of new particles ...
  – Then back to questions of dark matter, baryon asymmetry ...

  ⊕ complementary and further studies at ILC/CLIC

• Synergy with the flavour sector:\(^4\)

  \[ B \oplus K, D, \text{top physics \& lepton/neutrino sector} \]

  – If discovery of new particles, which kind of new physics?
  – Insights into the corresponding new flavour structures and possible new sources of CP violation through studies of flavour processes.
  – Sensitivity on very high energy scales of new physics through precision measurements, also if NP particles cannot be produced at the LHC ...

\(^4\)Topic of CERN Workshop: http://flavlhc.web.cern.ch/flavlhc/
New Activity @ CERN-TH:

Flavour as a Window to New Physics at the LHC
5 May - 13 June 2008

Organizers: Robert Fleischer, Thomas Mannel, Yosef Nir (e-mail)

Scientific Case

Tremendous progress has been achieved in recent years in the understanding of the physics of flavour and of CP violation. This progress was made possible through the interplay between the data from the e+e- B factories and from the Tevatron and intensive theoretical work. The results have given evidence that the Cabibbo-Kobayashi-Maskawa matrix is the source of flavour violation and, in particular, that the Kobayashi-Maskawa phase is the dominant source of CP violation. Yet, a number of results is not quite consistent with the Standard-Model expectations, implying either a statistical fluctuation, or an incomplete understanding of the hadronic aspects or, more intriguingly, intervention of New Physics. Some other aspects of flavour physics and of CP violation could not yet be investigated.

This scientific adventure will soon be continued at the LHC. At this new collider, B-decay studies are the domain of LHCb, which will allow us to enter a new territory in the exploration of CP violation through the full exploitation of