CP Violation and B Physics at the LHC

Robert Fleischer

CERN, Department of Physics, Theory Division

HEP-MAD 07, Antananarivo, 10–15 September 2007

- Setting the Stage

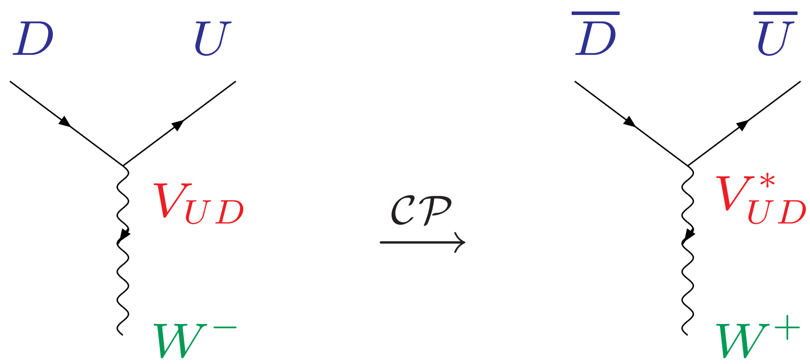
- Key Targets of the B Physics Programme at the LHC

- Conclusions and Outlook

Setting the Stage

- Standard Model (SM):

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



Detailed review: R.F., *J. Phys.* **G32** (2006) R71 [hep-ph/0512253]

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 $\gtrsim$ 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, ...

  $\oplus$ 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 ...
- ν 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:
    * attractive 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* $\longrightarrow$ "hadronic" uncertainties
- There are various flavour probes: K, D decays …
- The B-meson system is a *particularly promising* probe: $\longrightarrow$ 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

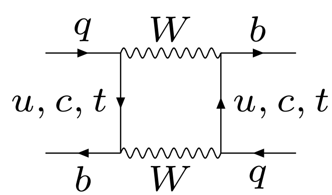
- Charged B mesons:

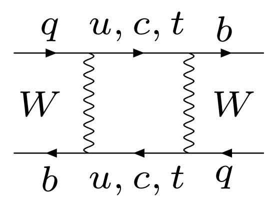
$$B^+ \sim u\,\bar{b} \qquad B^- \sim \bar{u}\,b$$
$$B_c^+ \sim c\,\bar{b} \qquad B_c^- \sim \bar{c}\,b$$

- Neutral B mesons:

$$B_d^0 \sim d\,\bar{b} \qquad \bar{B}_d^0 \sim \bar{d}\,b$$
$$B_s^0 \sim s\,\bar{b} \qquad \bar{B}_s^0 \sim \bar{s}\,b$$

  – B_q^0–$\bar{B}_q^0$ mixing:





$$\Rightarrow \quad \boxed{|B_q(t)\rangle = a(t)|B_q^0\rangle + b(t)|\bar{B}_q^0\rangle \;:}$$

  * Schrödinger equation $\Rightarrow$ mass eigenstates:

$$\boxed{\Delta M_q \equiv M_{\rm H}^{(q)} - M_{\rm L}^{(q)}, \quad \Delta\Gamma_q \equiv \Gamma_{\rm H}^{(q)} - \Gamma_{\rm L}^{(q)}}$$

  * Decay rates: $\Gamma(\overset{(-)}{B_q^0}(t) \to \overset{(-)}{f})$:

$$\cos(\Delta M_q t) \;\&\; \sin(\Delta M_q t) \;\longrightarrow$$ oscillations!

Where to Study B-Meson Decays?

- B factories: asymmetric e^+e^- colliders @ $\Upsilon(4S) \to B_d^0 \bar{B}_d^0,\ B_u^+ B_u^-$
  - PEP-II with the *Babar* experiment (SLAC);
  - KEK-B with the *Belle* experiment (KEK):

    $\to$ { 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: $\to$ produce also B_s mesons,[1] as well as B_c, Λ_b, ...
  - Tevatron: CDF and D0 have reported first $B_{(s)}$-decay results ...
  - ... to be continued at the LHC $\gtrsim$ summer 2008:

ATLAS & CMS (can also address some B physics)

$\oplus$ *dedicated* B-decay experiment: LHCb

(interest from Madagascar: talk by F. Andrianala)

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

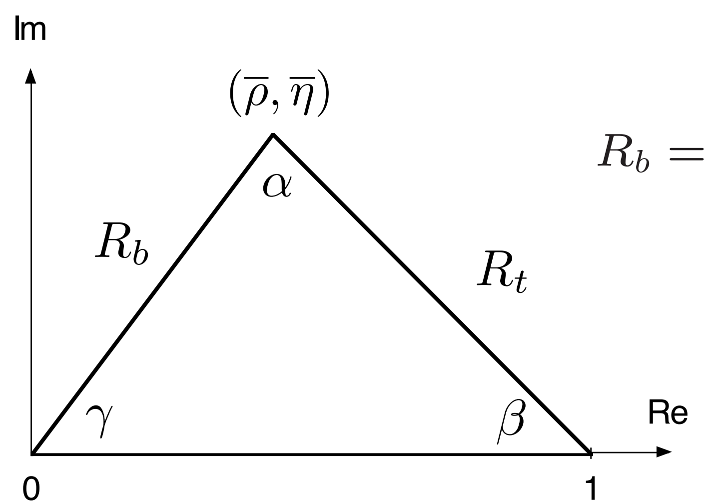
Central Target: Unitarity Triangle (UT)

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

$$\hat{V}_{\text{CKM}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\,\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\,\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

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

- Unitarity of the CKM matrix: $\hat{V}^\dagger_{\text{CKM}} \cdot \hat{V}_{\text{CKM}} = \hat{1} = \hat{V}_{\text{CKM}} \cdot \hat{V}^\dagger_{\text{CKM}}$ $\Rightarrow$



$$R_b = \left(1-\frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right|$$

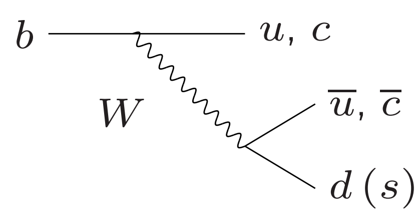
$$R_t = \frac{1}{\lambda}\left|\frac{V_{td}}{V_{cb}}\right|$$

$$\overline{\rho} \equiv (1-\lambda^2/2)\rho, \quad \overline{\eta} \equiv (1-\lambda^2/2)\eta$$

$\longrightarrow$ NLO corrections [Buras *et al.* (1994)]

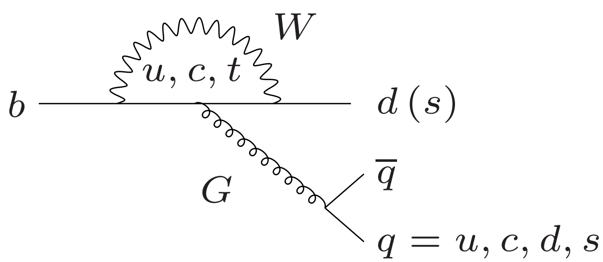
Key Processes for CP Violation: Non-Leptonic B Decays

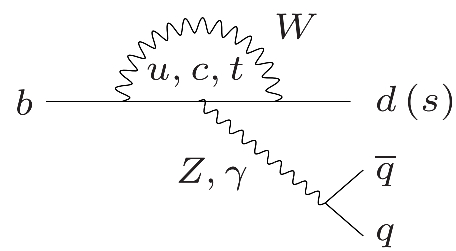
- Tree diagrams:

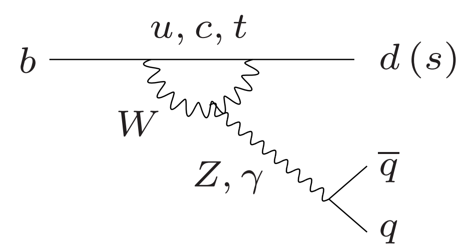


- Penguin diagrams:

  ◇ QCD penguins: ◇ Electroweak (EW) penguins:







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

$$A(B \to f) \sim \sum_k \underbrace{C_k(\mu)}_{\text{pert. QCD}} \times \underbrace{\langle f|Q_k(\mu)|B\rangle}_{\text{“unknown”}}$$

[QCD Factorization (QCDF), PQCD, Soft Collinear Effective Theory (SCET), ...]

... but calculation of $\langle f|Q_k(\mu)|B\rangle$ can be circumvented:

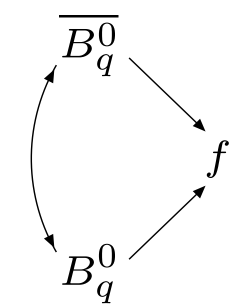
- Amplitude relations allow us in fortunate cases to eliminate the hadronic matrix elements ($\to$ typically strategies to determine the UT angle γ):

  - *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 $SU(3)_{\mathrm{F}}$:

$$B \to \pi\pi,\; B \to \pi K,\; B_{(s)} \to KK.$$

- Decays of neutral B_d and B_s mesons:



Interference effects through B^0_q–$\overline{B^0_q}$ mixing:

  - Lead to "mixing-induced" CP violation $\mathcal{A}_{\mathrm{CP}}^{\mathrm{mix}}$!

  - If one CKM amplitude dominates:

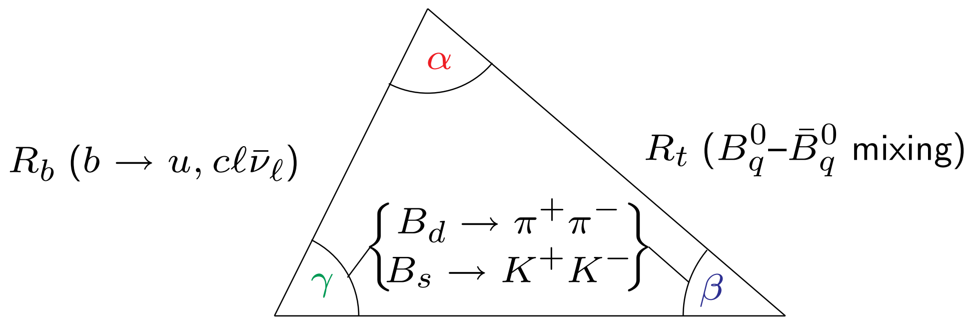
$$\Rightarrow \textit{hadronic matrix elements cancel!}$$

  $*$ Example: $\boxed{B^0_d \to J/\psi\, K_{\mathrm{S}} \;\Rightarrow\; \sin 2\beta}$ [Bigi, Carter & Sanda ('80–'81)]

A Brief Roadmap of Quark-Flavour Physics

- CP-B studies through various processes and strategies:

$B \to \pi\pi$ (isospin), $B \to \rho\pi$, $B \to \rho\rho$



$B \to \pi K$ (penguins)

$B_d \to \psi K_S\ (B_s \to \psi\phi :\ \phi_s \approx 0)$

$B_d \to \phi K_S$ (pure penguin)

$$\left.\begin{matrix} B_u^\pm \to K^\pm D \\ B_d \to K^{*0} D \\ B_c^\pm \to D_s^\pm D \end{matrix}\right\} \text{only trees}$$

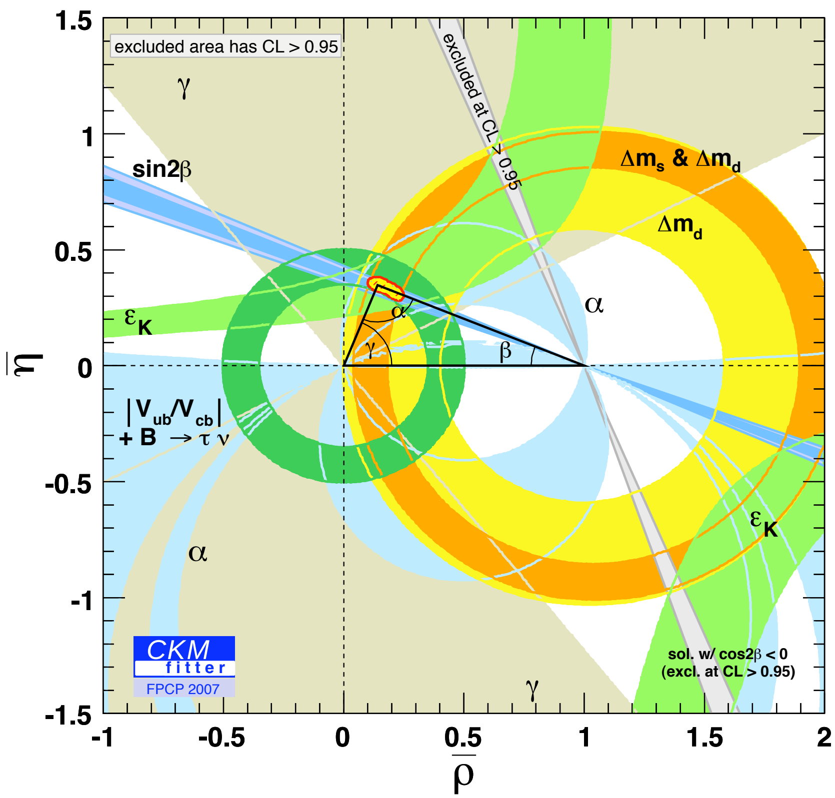
$$\left.\begin{matrix} B_d \to D^{(*)\pm}\pi^\mp :\ \gamma + 2\beta \\ B_s \to D_s^\pm K^\mp :\ \gamma + \phi_s \end{matrix}\right\} \text{only trees}$$

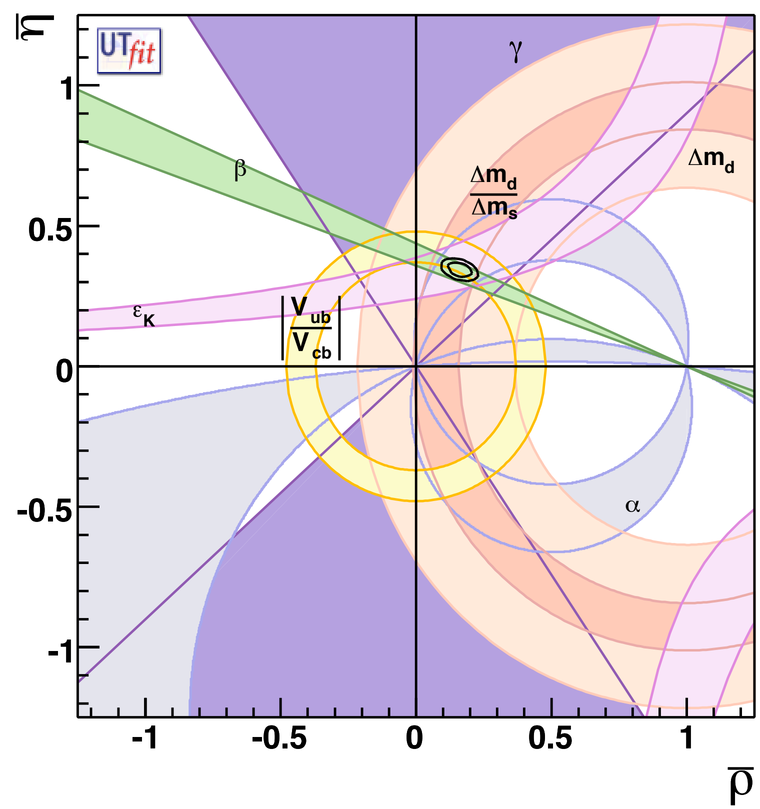
- Moreover "rare" decays: $B \to X_s\gamma$, $B_{d,s} \to \mu^+\mu^-$, $K \to \pi\nu\bar{\nu}$, ...
  - Originate from loop processes in the SM.
  - Interesting correlations with CP-B studies.

New Physics $\Rightarrow$ Discrepancies

Current Status of the Unitarity Triangle

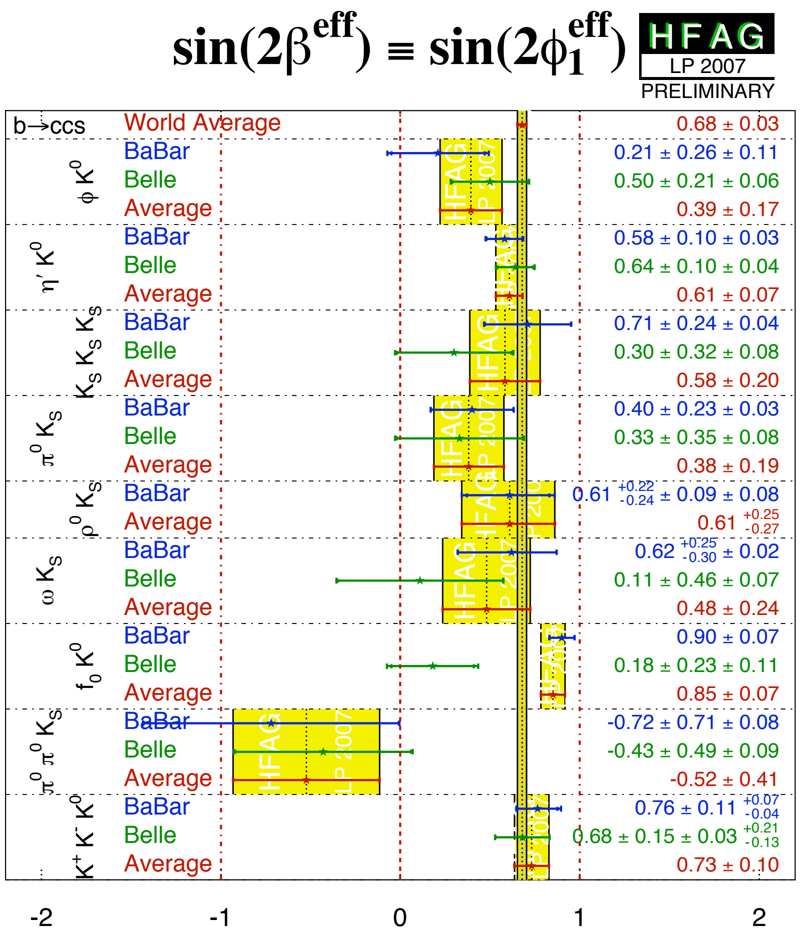
- Two competing groups: $\longrightarrow$ many plots & correlations ...
  - *CKMfitter* Collaboration `[http://ckmfitter.in2p3.fr/]`;
  - *UTfit* Collaboration `[http://www.utfit.org]`:

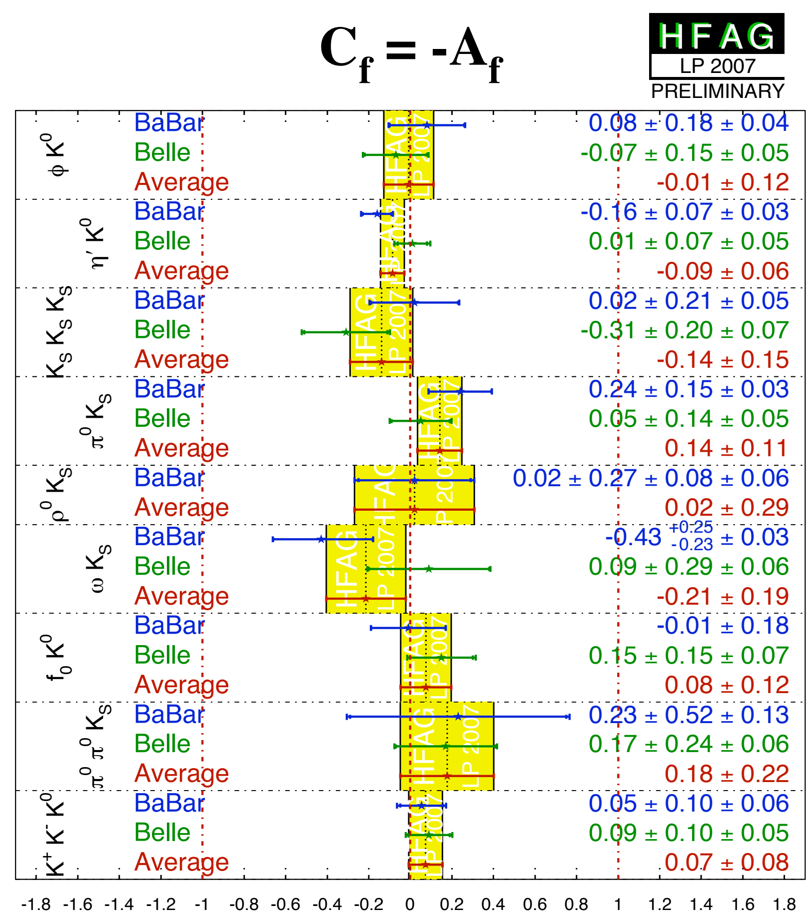




$\Rightarrow$ impressive global agreement with KM, but some "tension" ...

Moreover: A Puzzling Pattern ...





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

- LHCb: $\rightarrow$ look forward to data for $B_s \rightarrow \phi\phi$ ...

Key Targets of the

B Physics Programme

at the LHC

$\longrightarrow$ 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: $\Delta M_s \stackrel{\rm SM}{=} \mathcal{O}(20\,\text{ps}^{-1}) \gg \Delta M_d \stackrel{\rm exp}{=} 0.5\,\text{ps}^{-1}$

  $\Rightarrow$ challenging to resolve them experimentally!

- The width difference $\Delta\Gamma_s/\Gamma_s$ is expected to be of $\mathcal{O}(10\%)$ [$\tau_{B_s} \sim 1.5$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:

$$\langle\Gamma(B_s(t) \to f)\rangle \equiv \Gamma(B_s^0(t) \to f) + \Gamma(\overline{B_s^0}(t) \to f)$$

  * 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:

$$\boxed{\phi_s \stackrel{\rm SM}{=} -2\lambda^2\eta \approx -2^\circ}$$

$\Rightarrow$ 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 ΔM_s were available from the LEP (CERN) experiments and SLD (SLAC)!
  - Finally, the value of ΔM_s could be pinned down:
    * D0: $\Rightarrow$ two-sided bound $17\,\mathrm{ps}^{-1} < \Delta M_s < 21\,\mathrm{ps}^{-1}$ (90% C.L.)

      $\Rightarrow$ 2.5 σ @ $\Delta M_s = 19\,\mathrm{ps}^{-1}$; 2007: $\boxed{\Delta M_s = (18.56 \pm 0.87)\,\mathrm{ps}^{-1}}$
    * CDF: $\boxed{\Delta M_s = [17.77 \pm 0.10(\mathrm{stat}) \pm 0.07(\mathrm{syst})]\ \mathrm{ps}^{-1}}$ $\gtrsim 5\sigma$

- Most recent lattice prediction: [HPQCD collaboration, hep-lat/0610104]

$$\boxed{\Delta M_s^{\mathrm{SM}} = 20.3(3.0)(0.8)\,\mathrm{ps}^{-1}}$$

- But there is still a lot of space for NP in B_s^0–$\bar{B}_s^0$ mixing left: $\boxed{\rightarrow}$

[Details: P. Ball & R.F. (2006); ...]

Golden Process to Search

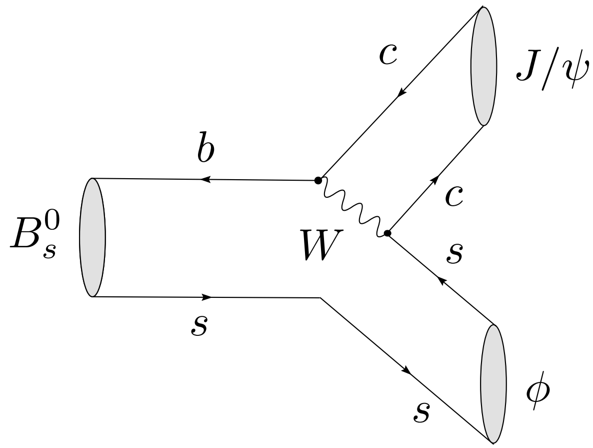
for NP in B_s^0–$\bar{B}_s^0$ Mixing:

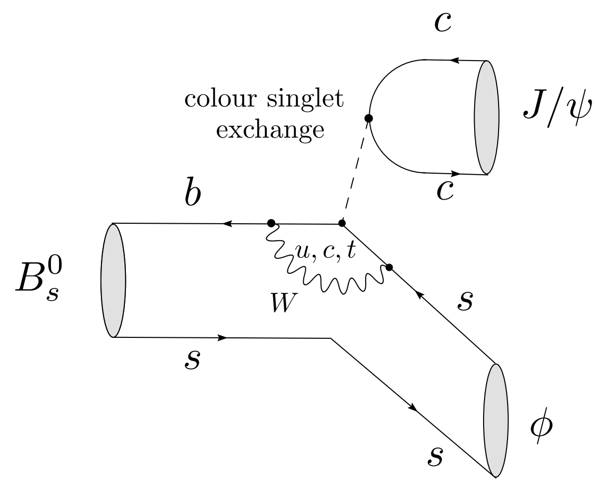
$$\boxed{B_s^0 \to J/\psi\phi}$$

$\longrightarrow$ B_s^0 counterpart of $B_d^0 \to J/\psi K_{\rm S}$ ...

[Dighe, Dunietz & R.F. (1999); Dunietz, R.F. & Nierste (2001)]

Let's have a closer look ...





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

⇒ hadronic matrix elements cancel in mixing-induced observables!

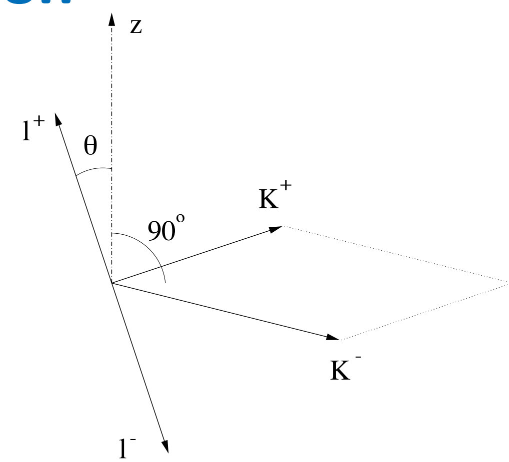
- There is an important difference with respect to $B_d^0 \to J/\psi K_S$:

The final state is an admixture of different CP eigenstates!

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

⇒ the different CP eigenstates can be disentangled ...

Simple Case: One-Angle Distribution



$$\frac{d\Gamma(t)}{d\cos\Theta} \propto \underbrace{[P_+(t)]}_{\text{CP even}} \frac{3}{8}(1+\cos^2\Theta) + \underbrace{[P_-(t)]}_{\text{CP odd}} \frac{3}{4}\sin^2\Theta$$

- *Untagged* data samples: $\longrightarrow$ untagged rates ...

$$P_\pm(t) + \overline{P}_\pm(t) \propto \left[(1 \pm \cos\phi_s)e^{-\Gamma_{\rm L}t} + (1 \mp \cos\phi_s)e^{-\Gamma_{\rm H}t}\right]$$

- *Tagged* data samples: $\longrightarrow$ CP asymmetries ...

$$\frac{P_\pm(t) - \overline{P}_\pm(t)}{P_\pm(t) + \overline{P}_\pm(t)} = \pm \frac{2\sin(\Delta M_s t)\sin\phi_s}{(1 \pm \cos\phi_s)e^{+\Delta\Gamma_s t/2} + (1 \mp \cos\phi_s)e^{-\Delta\Gamma_s t/2}}$$

$$\boxed{B^0_s\text{–}\bar{B}^0_s \text{ mixing phase } \phi_s = (-2\lambda^2\eta)_{\rm SM} + \phi_s^{\rm NP} \approx \phi_s^{\rm NP}} \quad \Rightarrow$$

- 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 $B_s \to J/\psi\phi$ distribution:

$$\Rightarrow \boxed{\phi_s = -0.79 \pm 0.56\,(\text{stat.}) \pm 0.01\,(\text{syst.}) = -(45 \pm 32 \pm 0.6)^\circ}$$

  - Imposing also constraints form certain semileptonic B decays:

$$\Rightarrow \boxed{\phi_s = -0.56^{+0.44}_{-0.41} = -\left(32^{+25}_{-23}\right)^\circ}$$

$\Rightarrow$ still not stringently constrained, but very accessible @ LHC ...

- Experimental reach at the LHC:
  - LHCb: $\sigma_{\rm stat}(\sin\phi_s) \approx 0.031$ (1 year, i.e. 2 fb^{-1}) $[0.013$ (5 years)];
  - ATLAS & CMS: expect uncertainties of $\mathcal{O}(0.1)$ (1 year, i.e. 10 fb^{-1}).

Further Benchmark Decays

for the

LHCb Experiment

$\longrightarrow$ very rich physics programme ...

[See also the experimental talk by A. Pellegrino]

Two Major Lines of Research

1. Precision measurements of γ:

   - Tree strategies, with expected sensitivities after 1 year of taking data:
     - $B_s^0 \to D_s^\mp K^\pm$: $\sigma_\gamma \sim 14^\circ$
     - $B_d^0 \to D^0 K^*$: $\sigma_\gamma \sim 8^\circ$
     - $B^\pm \to D^0 K^\pm$: $\sigma_\gamma \sim 5^\circ$
   - Decays with penguin contributions:
     - $B_s^0 \to K^+K^-$ and $B_d^0 \to \pi^+\pi^-$: $\sigma_\gamma \sim 5^\circ$
     - $B_s^0 \to D_s^+ D_s^-$ and $B_d^0 \to D_d^+ D_d^-$

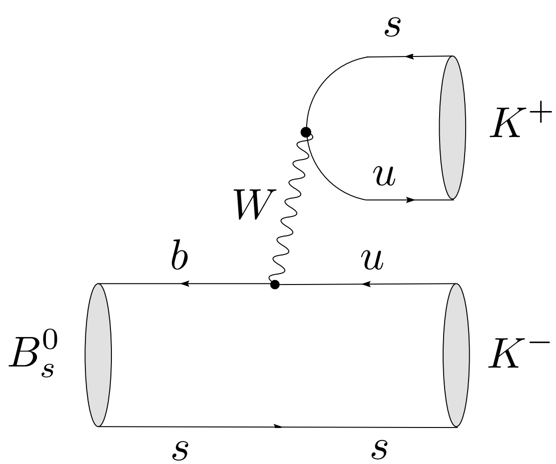
2. Analyses of rare decays which are absent at the SM tree level:

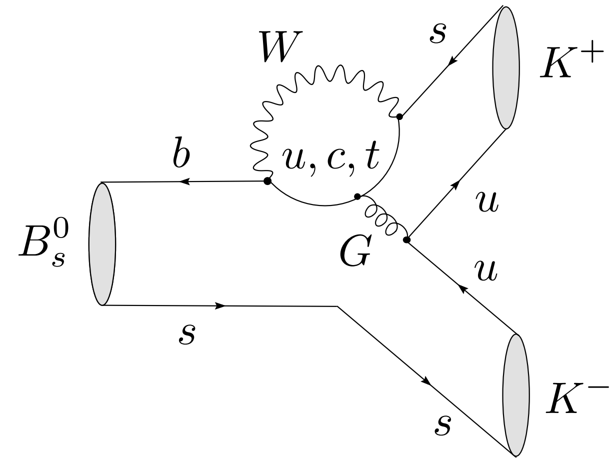
   - $B_s^0 \to \mu^+\mu^-$, $B_d^0 \to \mu^+\mu^-$
   - $B_d^0 \to K^{*0}\mu^+\mu^-$, $B_s^0 \to \phi\mu^+\mu^-$; ...

$\to$ let's have a closer look at some decays ...

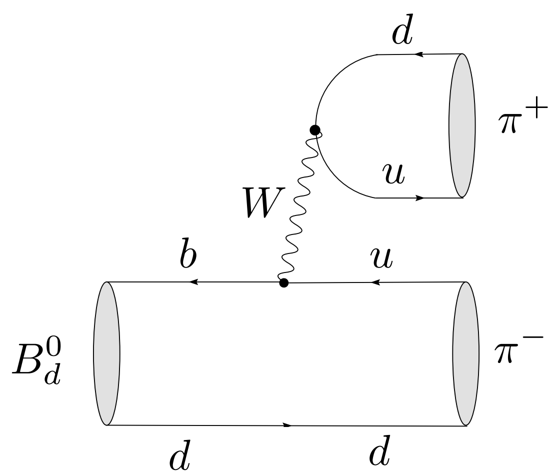
The $B_s \to K^+K^-$, $B_d \to \pi^+\pi^-$ System

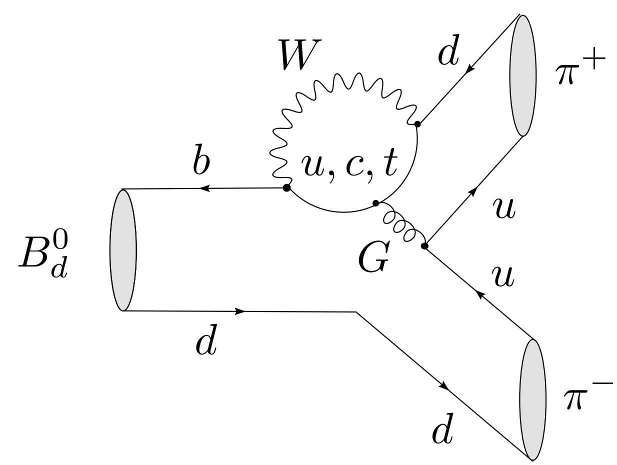
- $B_s^0 \to K^+K^-$:





- $B_d^0 \to \pi^+\pi^-$:





$$\Rightarrow \quad \boxed{s \leftrightarrow d}$$

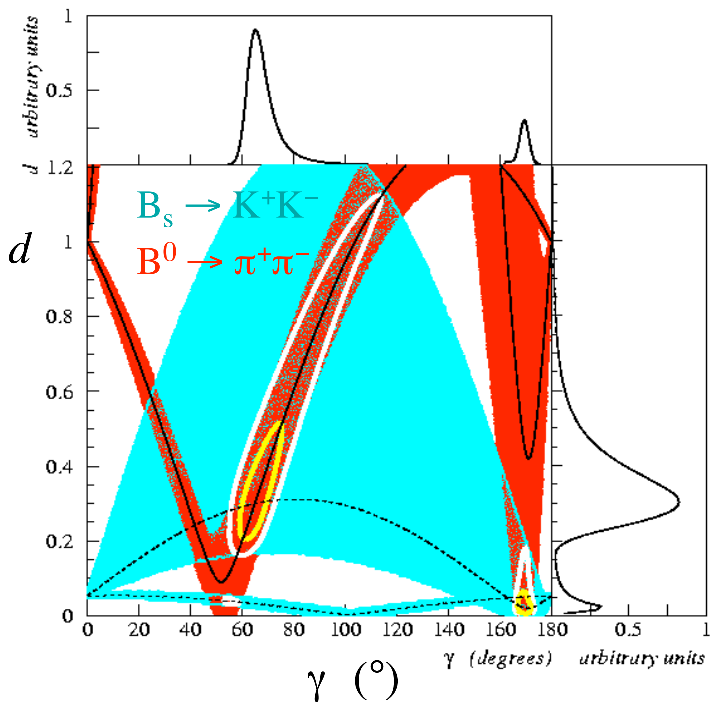
- The decays $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$ are related to each other through the interchange of all down and strange quarks:[3]

U-spin symmetry $\Rightarrow$

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

[R.F. (1999); current picture: arXiv:0705.1121 [hep-ph] (EPJC, in press)]

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



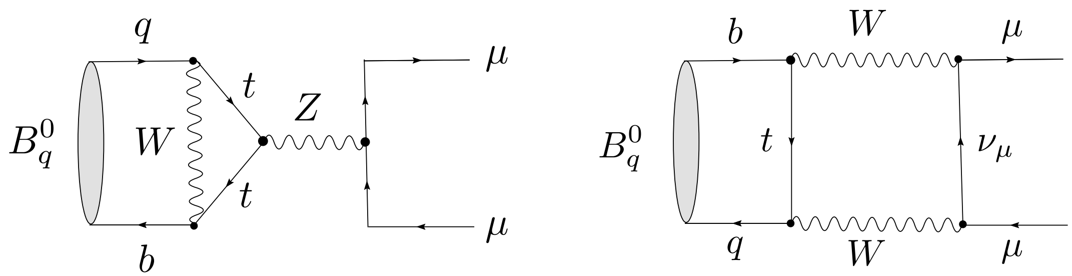
$\to$ experimental accuracy for γ of a few degrees!

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

[3] U spin: $SU(2)$ subgroup of the $SU(3)_{\rm F}$ flavour-symmetry group of QCD.

The Rare Decays $B_q \to \mu^+\mu^-$ $(q \in \{d, s\})$

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



- Corresponding low-energy effective Hamiltonian: [Buchalla & Buras (1993)]

$$\mathcal{H}_{\rm eff} = -\frac{G_{\rm F}}{\sqrt{2}}\left[\frac{\alpha}{2\pi \sin^2\Theta_{\rm W}}\right] V_{tb}^* V_{tq} \eta_Y Y_0(x_t)(\bar{b}q)_{\rm V-A}(\bar{\mu}\mu)_{\rm V-A}$$

  - α: QED coupling; $\Theta_{\rm W}$: Weinberg angle.
  - η_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: $\to$ very simple situation:
  - Only the matrix element $\langle 0|(\bar{b}q)_{\rm V-A}|B_q^0\rangle$ is required: f_{B_q}

$\Rightarrow$ **belong to the cleanest rare B decays!**

- Most recent SM predictions: [Blanke, Buras, Guadagnoli, Tarantino ('06)]

  $\rightarrow$ use the data for the ΔM_q to reduce the hadronic uncertainties:

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

- Most recent experimental upper bounds from the Tevatron:
  - CDF collaboration @ 95% C.L.: [CDF Public Note 8956 (2007)]

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

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

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

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

- However, NP may significantly enhance $\text{BR}(B_s \to \mu^+\mu^-)$:
  - In SUSY secenarios: 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 $B_d^0 \to K^{*0}\mu^+\mu^-$

- Key observable for NP searches: Forward–Backward Asymmetry

$$A_{\rm FB}(\hat{s}) = \frac{1}{{\rm d}\Gamma/{\rm d}\hat{s}}\left[\int_0^1 {\rm d}(\cos\theta)\frac{{\rm d}^2\Gamma}{{\rm d}\hat{s}\,{\rm d}(\cos\theta)} - \int_{-1}^0 {\rm d}(\cos\theta)\frac{{\rm d}^2\Gamma}{{\rm d}\hat{s}\,{\rm d}(\cos\theta)}\right]$$

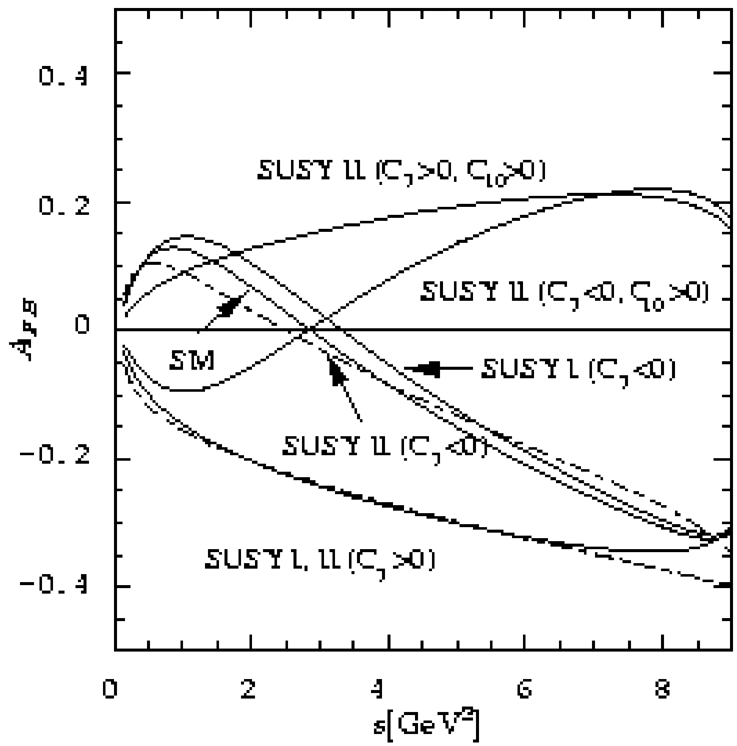
  - θ is the angle between the B_d^0 momentum and that of the μ^+ in the dilepton centre-of-mass system,
  - and $\hat{s} = s/M_B^2$, with $s = (p_{\mu^+} + p_{\mu^-})^2$.

- Particularly interesting:

$$\boxed{A_{\rm FB}(\hat{s}_0)|_{\rm SM} = 0}$$ [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:

    $\longrightarrow$ may yield $A_{\rm FB}(\hat{s})$ of opposite sign or without a zero point $\longrightarrow$



[A. Ali *et al.*, *Phys. Rev.* **D61** (2000) 074024]

- Sensitivity at the LHC:
  - LHCb: ~ 4400 decays/year, yielding $\Delta\hat{s}_0 = 0.06$ after one year.
  - ATLAS will collect about 1000 $B^0 \to K^{*0}\mu^+\mu^-$ 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 $\int A_{\rm FB}$ 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: $\longrightarrow$ first signals of NP??

- New perspectives for B-decay studies @ LHC $\gtrsim$ 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 γ: $\longrightarrow$ key ingredients for NP searches!
  - Powerful studies of rare decays: $B_{s,d} \to \mu^+\mu^-$, ...

$\longrightarrow$ 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 ...

$\oplus$ complementary and further studies at ILC/CLIC

- Synergy with the flavour sector:[4]

$B \quad \oplus \quad K$, D, 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: