V workshop italiano sulla fisica p-p ad LHC

Perugia, 30 Gennaio - 2 Febbraio

B-Physics: Theoretical Predictions in the LHC Era

- Theoretical Approach and Tools
- State of the art of the theoretical predictions

Cecilia Tarantino
University of Rome and INFN Roma Tre

Flavour Physics:

- precision tests of the Standard Model (SM) → Unitarity Triangle (uncert. ~few%)
- search for New Physics (NP) → Interplay with Direct Searches [see Paride's discussion]

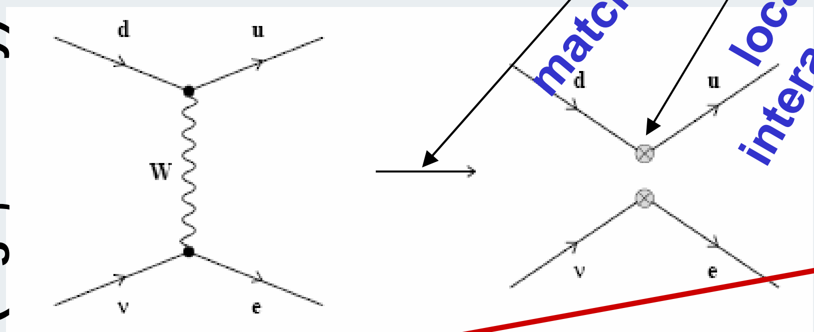
Theoretical Approach to Weak Decays of Hadrons (occurring well below the electroweak scale)
(including the effects of strong interactions)

$$H_{eff} = \frac{G_F}{\sqrt{2}} V_i^{CKM} C_i(\mu) Q_i(\mu)$$

matching

local interactions

(e.g. β-decay)



$C_i(\mu)$: **Wilson coefficients** (short-distance)

$Q_i(\mu)$: **local operators** (long-distance)

- perturbative QCD corrections [up to NNLO (e.g. $b \to s\gamma$, $b \to s\, l^+ l^-$) +Renormalization Group to resum large $\ln^n (M_W/\mu)$]
- affected by NP

- non-perturbative QCD contributions [main source of theoretical uncertainty]

Beyond the SM

$$H_{eff}^{NP} = \frac{G_F}{\sqrt{2}} \bullet [V_i^{CKM} \left(C_i^{NEW}(\mu) Q_i(\mu) + C_i^{MFV}(\mu) Q_i^{MFV}(\mu) \right)$$ within MFV

$$+ V_i^{non\text{-}MFV} C_i^{non\text{-}MFV}(\mu) Q_i^{non\text{-}MFV}(\mu)]$$ beyond MFV

Minimal Flavour Violation (MFV): supported by the great success of the SM in Flavour Physics!

the SM Yukawa couplings are the only *building-blocks* of flavour violation

[G.D´Ambrosio et al., hep-ph/0207036], [A.J. Buras et al., hep-ph/0007085]

Beyond MFV:

New sources of flavour violation ($V_i^{non\text{-}MFV}$) can appear

New operators (Q_i^{MFV}, $Q_i^{non\text{-}MFV}$) can appear but their (long-distance) matrix elements are not affected by NP

Some Appealing NP Models

MFV

MSSM with MFV

(boson-fermion symmetry,minimal spectrum (sparticles,2 Higgs doublets,$\tan\beta = v_u/v_d$), R-parity)

Appelquist-Cheng-Dobrescu (ACD) Model

(1 universal extra-dimension → SM particles propagate in 5 dimensions, in 4 dimensions Kaluza-Klein modes appear , KK—Parity conservation, only one additional free parameter: 1/R)

Beyond MFV

MSSM with a general Flavour Structure

27 new Flavour Changing couplings along the squark lines)

Littlest Higgs with T-Parity (LHT)

(Higgs= Goldstone boson of a spontaneously broken global symmetry $SU(5) \xrightarrow{f} SO(5)$, heavy partners ($W_H$, Z_H, A_H, T, Φ)
+ a discrete symmetry (T-Parity)→ heavy particles forbidden at tree-level
(to soften ew precision constraints: $f > 500$GeV)
new mirror fermions with new flavour interactions)

Theorist's Golden Modes

Suppression within the SM ⇒ **Sensitivity to NP**

- **FCNCs forbidden at tree-level in the SM**
  (radiative and rare decays: $b \to (s,d)\,\gamma$, $b \to (s,d)\, l^+ l^-$, $b \to s\nu\bar{\nu}$, $B_{d,s} \to l^+ l^-$,...)

- **CKM-, helicity-suppression**
  (semileptonic CP-asymmetry: A^s_{SL}...,t-dep. CP-asymmetries: $A_{CP}(B \to K^*\gamma)$,...)

Small hadronic uncertaintes ⇒ **Theoretically clean**

- **At most one hadron in the final state**
  (leptonic and semileptonic decays: $B_{d,s} \to l^+ l^-$, $b \to (s,d)\, l^+ l^-$, $b \to s\nu\bar{\nu}$,...)
- **Smearing of bound-effects in the final state**
  (Inclusive quantities: lifetimes, ΔM_q, $\Delta\Gamma_q/\Gamma_q$, A^q_{SL}, ϕ_s,...)
- **Suppression/cancellation of some hadronic uncertainties**
  (clean dominant contributions, peculiar ratios/correlations: $A_{CP}(B \to J_\psi K_S)$, $\Delta M_s/\Delta M_d$,...)

Hadronic Matrix Elements: Theoretical Tools

$\langle Q_i \rangle$: long-distance ⇒ Non-perturbative methods

Lattice QCD: True theory (QCD) simulated on a finite and discrete space-time.
Physical results require continuum and infinite volume limits, and extrapolations to the physical masses.
Recent simulations are unquenched (N_f=2, 2+1).
Typical uncertainties are of O(10-15%)

Significant improvements are expected thanks to increasing computational power, improved algorithms and theoretical approaches
→larger volumes, finer lattices, lower masses,…

Sum Rules: based on correlation function analyses and dispersion relations, require phenomenological inputs and model-dependent ansatz.

Useful predictions, mainly for quantities not calculated yet on the Lattice.
Uncertainties difficult to be estimated.

Effective Theories
- ChPT (light hadrons),
- HQET (heavy-light hadrons),
- NRQCD (heavy-heavy hadrons),
- SCET (heavy to light decays)

+

Factorization
approximation for non-leptonic or exclusive matrix elements
$\langle M_1 M_2|Q_i|B\rangle \sim \langle M_1|J_i^a|B\rangle\langle M_2|J_i^b|0\rangle$+corr. in Λ_{QCD}/m_b, α_s
(pert. kernels, non-pert. distr. amplit. and form factors)

Perturbative QCD (PQCD)
to separate hard perturbative components from non-perturbative ones enclosed in hadron wave functions (from exp.)

B-Physics

Advantages

$m_b >> \Lambda_{QCD}$ ⇒ $\alpha_s(m_b) \sim 10^{-1}$

Heavy Quark Symmetry (HQS):
soft gluons do not resolve spin and flavour on scales $\sim 1/m_b \rightarrow$ invariance of strong interactions under heavy spin-flavour $SU(2N_h)$

Heavy Quark Effective Theory (HQET):
describes an heavy quark almost on-shell through an expansion in $p/m_b \sim \Lambda_{QCD}/m_b$

Heavy Quark Expansion (HQE):
Operator product expansion of physical quantities in series of Λ_{QCD}/m_b to separate short- and long-distance effects

Soft Collinear Effective Theory (SCET):
describes heavy to light hadron decays, including both soft and collinear gluon modes

Interest (at the LHC)

Angles of the UT

- α: $B \rightarrow \pi\pi$, $B \rightarrow \rho\rho$, $B \rightarrow \rho\pi$
- β: $B \rightarrow J_\psi K_S$, …
- γ: $B \rightarrow DK$, $B \rightarrow DK^*$, $B \rightarrow D^*K$

B_s-$\overline{B}_s$ Mixing

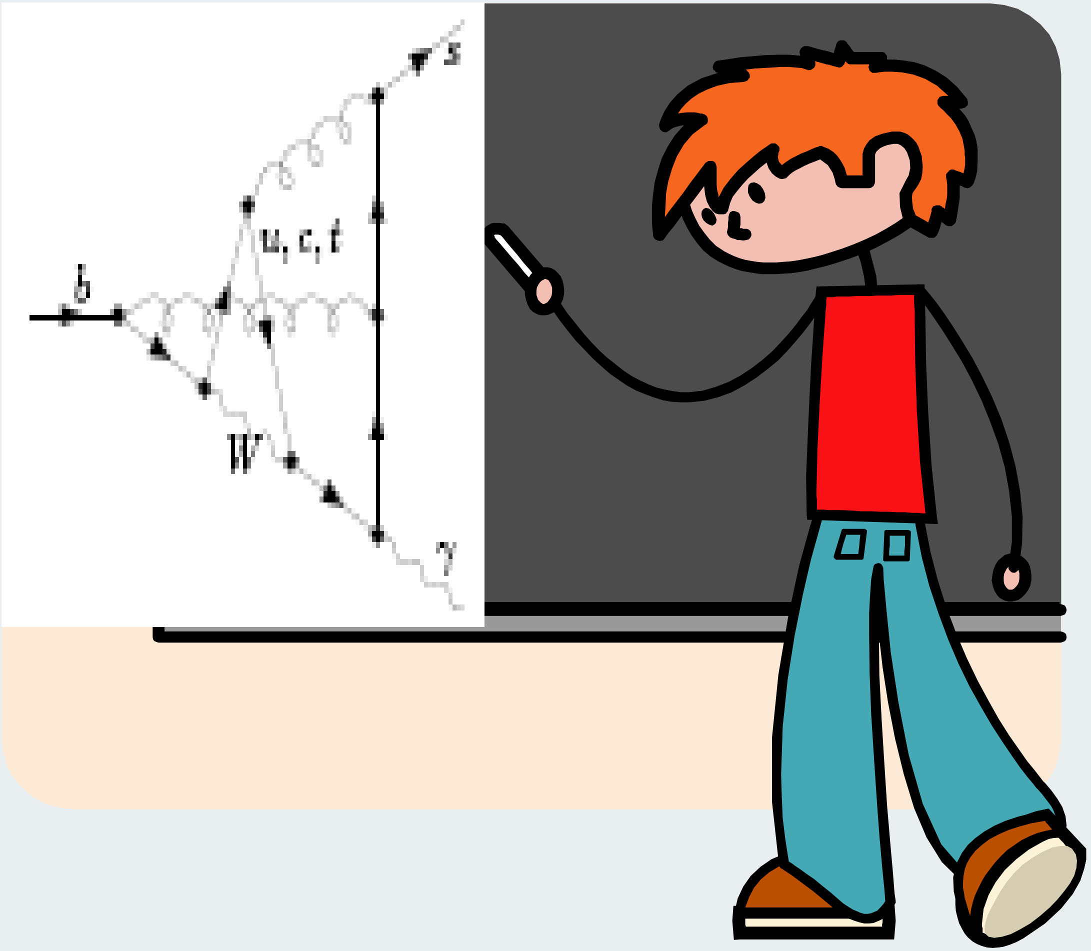
- $\Delta\Gamma_s/\Gamma_s$, A^s_{SL}, ϕ_s
- ΔM_s, lifetimes

rapid oscillations can be studied at LHC thanks to large boost!

Radiative and rare decays

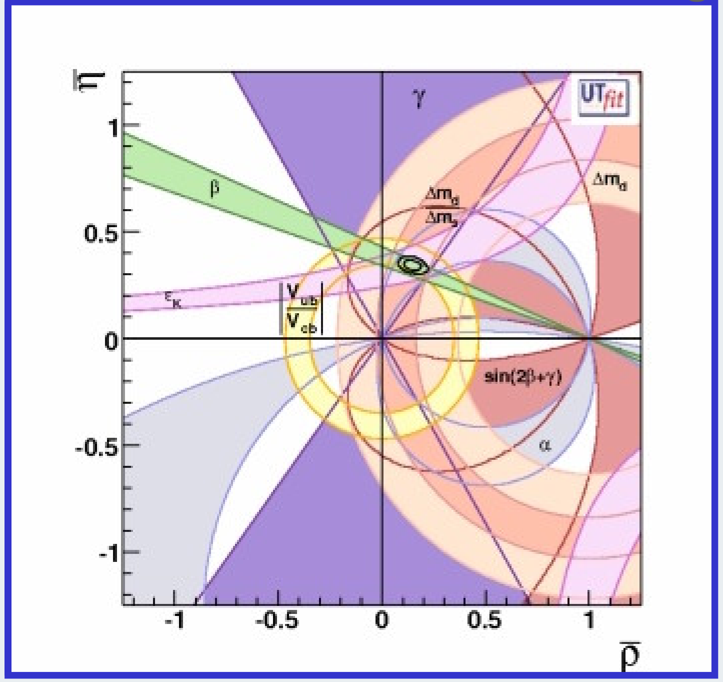
- $b \rightarrow (s,d)\,\gamma$ (incl. and excl.)
- $B_{d,s} \rightarrow l^+l^-$
- $b \rightarrow (s,d)\, l^+l^-$ (incl. and excl.)

State of the art of the theoretical predictions in B-Physics



Angles of the Unitarity Triangle

www.utfit.org



- Great success of the SM
- High level of precision (~few %)
- Agreement among side and angle measurements

All 3 angles can be determined from B decays

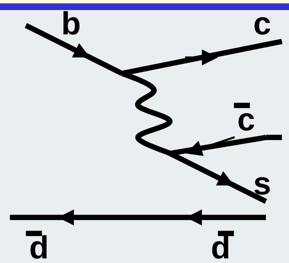
Improving the (NP-free) determinations of CKM elements
is a key ingredient
to improve the SM predictions in processes sensitive to NP

β (ϕ_1)

$V_{td}=|V_{td}|e^{-i\beta}$

Golden mode: $B\to J_\psi K_S$

Dominated by one tree-level amplitude $b\to c\bar{c}s$ ⇒ **Simple expression for the t-dep. CP-asymmetry $A_{CP}(t)= -\sin 2\beta \sin(\Delta M_d t)$**



Main theoretical uncertainty from the hadronic matrix elements of the CKM-suppressed $b\to u\bar{u}s$ contribution (irreducile theory error ~1%)

- **Similar semplification in other $b\to c\bar{c}s$ channels:** $\Psi(2S)K_S$, $\chi_{c1} K_S$, $\eta_c K_S$, $J_\psi K_L$, $J_\psi K^*$, $B_s\to\Psi\phi$
- **Alternative determinations (sensitive to NP) from the charmless $b\to s$ one-loop (penguin) amplitude:** $B\to \eta' K_{S,L}$, $B\to\phi K_S$
- **$\cos 2\beta$ from a time-dep. analysis of $B\to J_\psi K^*$, $B\to D\pi^0$** ($\cos 2\beta>0$ solving the $\beta \leftrightarrow(\pi/2-\beta)$ ambiguity)

$(\sin 2\beta)_{HFAG}=0.681\pm0.025$

in slight tension with the result from the UT analysis

$(\sin 2\beta)_{UTfit}=0.744\pm0.039$

from all other INFOS

⇔

model-dependence in the non-pert. threshold region

due to the high value

$|V_{ub}^{incl}|=43.1(3.9)\cdot10^{-4}$

$\vee$ [HFAG, 200

$|V_{ub}^{excl}|=34.0(4.0)\cdot10^{-4}$

Recently

[U.Aglietti et al., 0711.0860]:

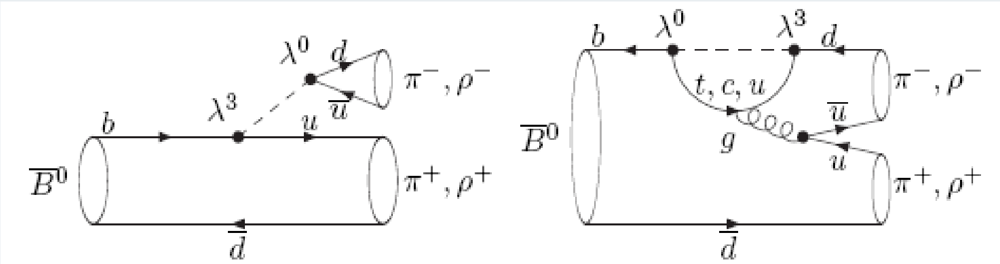
$|V_{ub}^{incl}|=36.9(1.3)(3.1)\cdot10^{-4}$

from a different modelling of the threshold region

$\alpha\ (\phi_2)$

$$\alpha = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right]$$

from charmless decays: B→ππ, B→ρρ, B→ρπ
(↔tree-level transition $b \to u\bar{u}d$ carrying V_{ub})



The penguin contribution, introducing different CKM factors, complicate the extraction of α: tree-penguin disentanglement is required

⇓

Analysis of a large set of observables:
Br's, $A_{CP}(t)$ both in neutral and charged B decays

B→ππ: isospin analysis [M.Gronau, D.London,1990] **+ info from $Br(B_s \to K^+K^-)$** [M.Bona et al (UTfit),hep-ph/0701204]

B→ρρ: advantage of the suppression of $Br(B \to \rho^0\rho^0)$ and of the related uncertainty

B→ρπ: advantage of $\rho^+\pi^-$ and $\rho^-\pi^+$ reachable by both B^0 and $\overline{B}^0$, no model-dependance for the strong phase

[A.E.Snyder, H.R.Quinn,1993]

M.Bona et al. [UTfit coll.], hep-ph/0501199

$(\alpha)_{dir.} = (91 \pm 8)°$

Main theoretical uncertainty from isospin violations mainly in ew penguins and FSI (irreducile theory error few%)

in perfect agreement with the result from the UT analysis

$(\alpha)_{UTfit} = (91 \pm 6)°$

from all other INFOS

Similar results from a frequentist approach

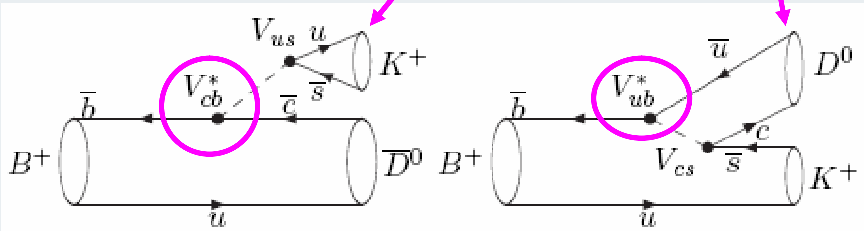
the unphysical $\alpha \approx 0$ region is ruled out by simple arguments on the hadronic matrix elements!
M.Bona et al. [UTfit coll.], hep-ph/0701204

γ (ϕ_3)

$V_{ub}=|V_{ub}|e^{-i\gamma}$

Determination of γ from B→DK decays: [I.I.Y.Bigi, A.I.Sanda, 1988, A.B.Carter, A.I. Sanda, 1988]

- $B^+ \to DK^+$ can produce both D^0 and $\overline{D}^0$, via $\overline{b}\to\overline{c}u\overline{s}$ and $\overline{b}\to\overline{u}c\overline{s}$
- D^0 and $\overline{D}^0$ can decay to a common final state
- The two amplitudes interfere with a relative phase $\delta_B \pm \gamma$, for $B^+(B^-)$



Main contributions from (theoretically clean) tree-level diagrams

Remaining theoretical uncertainty from simplifying D-$\overline{D}$ mixing neglection (irreducile theory error 0.1%)

Various methods consider different final states:

- CP-eigenstates (Gronau,London,Wyler [GLW]) ($\pi^+\pi^-$, K^+K^-, $K_S\pi^0$, $K_S\phi$, $K_S\omega$,…)
- doubly Cabibbo suppressed D modes (Atwood,Dunietz,Soni [ADS]) ($K^+\pi^-$, $K^+\rho^-$,$K^*\pi^-$,…)
- three-body D decaying modes (Dalitz plot analysis) ($K_S\pi^+\pi^-$ provides the best estimate at present)

[A.Giri, hep-ph/0303187]

The best strategy is a combined analysis taking into account many D and D* modes

M.Bona et al. [UTfit coll.], hep-ph/0501199

$(\gamma)_{dir.}=(88 \pm 16)°$

compatible with the result from the UT analysis

$(\gamma)_{UTfit}=(65.1 \pm 6.5)°$

from all other INFOS

Similar results from a frequentist approach [CKMfitter]

B_q-$\bar{B}_q$ Mixing

$$\hat{H} = \hat{M} - \frac{i}{2}\hat{\Gamma}$$

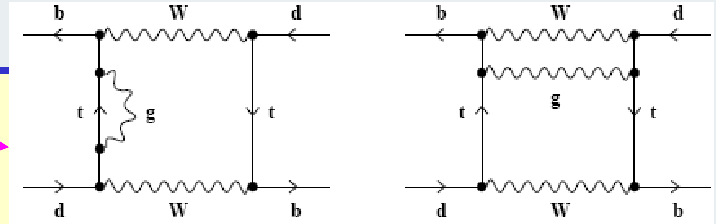
oscillation $\qquad\qquad$ **decay**

$$\hat{M} = \begin{pmatrix} M_{11} & M_{12} \\ M_{12}^{*} & M_{11} \end{pmatrix} \qquad \hat{\Gamma} = \begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^{*} & \Gamma_{11} \end{pmatrix}$$

Eigenstates:

$$\left|B_q^{L,H}\right\rangle = \frac{1}{\sqrt{1+\left|(q/p)_q\right|^2}}\left(\left|B_q^0\right\rangle \pm (q/p)_q \left|\bar{B}_q^0\right\rangle\right)$$

- Oscillation ↔ box-diagrams
- Wilson coeff. at NLO in QCD [A.J.Buras et al., 1990]
- Matrix elements from Lattice QCD (f_{Bq} and B_{Bq} with uncert. <15%) [see M.Della Morte, Lattice07 Proceedings]

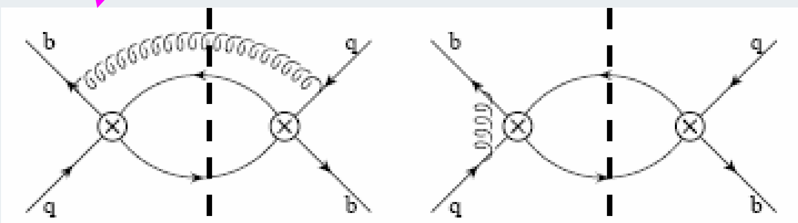


$$\Delta M_q = M_{B_H^q} - M_{B_L^q} = 2\left|M_{12}^q\right|$$

- Decay ↔ cut diagrams
- Wilson coeff. at NLO in QCD and $O(\Lambda_{QCD}/m_b)$ in the HQE
- Matrix elements from Lattice QCD
- +VSA for some subleading operators (main source of theoretical uncertainty)

[see C.T., hep-ph/0702235]

$$\Gamma_{B_q} = \Gamma_{11}^q$$ ΔB=0 transition



$$\Delta\Gamma_q = \Gamma_{B_L^q} - \Gamma_{B_H^q} = -2\left|M_{12}^q\right| \mathrm{Re}\left(\frac{\Gamma_{12}^q}{M_{12}^q}\right)$$

$$A_{SL}^q = -2\left(\left|\frac{q}{p}\right|_q - 1\right) = \mathrm{Im}\left(\frac{\Gamma_{12}^q}{M_{12}^q}\right)$$

ΔB=2 transition

Lifetime Ratios

Theoretical predictions:

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.06 \pm 0.02, \quad \frac{\tau(B_s)}{\tau(B_d)} = 1.00 \pm 0.01, \quad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.88 \pm 0.05$$

[E.Franco, V.Lubicz, F.Mescia, C.T. hep-ph/0310241, C.T. hep-ph/0702235]

Experimental averages:

$$\frac{\tau(B^+)}{\tau(B_d)} = 1.071 \pm 0.009, \quad \frac{\tau(B_s)}{\tau(B_d)} = 0.939 \pm 0.021, \quad \frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.921 \pm 0.036$$

[HFAG, 2007]

Larger than the 2006 average due to the new CDF measurement (3.2 σ above the previous average)

Width Differences and Semileptonic CP-Asymmetries

Theoretical predictions:

$$\frac{\Delta\Gamma_d}{\Gamma_d} = (3.6 \pm 1.0) \cdot 10^{-3}, \quad \frac{\Delta\Gamma_s}{\Gamma_s} = (11 \pm 4) \cdot 10^{-2}$$

[M.Ciuchini, E.Franco, V.Lubicz, F.Mescia, C.T. hep-ph/0308029, M.Beneke et al. hep-ph/0307344, A.Lenz, U.Nierste hep-ph/0612167, C.T. hep-ph/0702235]

Experimental averages:

$$\frac{\Delta\Gamma_d}{\Gamma_d} = (9 \pm 37) \cdot 10^{-3}, \quad \frac{\Delta\Gamma_s}{\Gamma_s} = \left(12.1^{+8.3}_{-9.0}\right) \cdot 10^{-2}$$

[HFAG, 2007]

- Quite large uncertainties (due to large NLO and $O(\Lambda_{QCD}/m_b)$ contributions that induce strong cancellations)
- Average of results in two operator bases (significant differences reflect relevant $O(\alpha_s^2)$ and $O(\alpha_s \Lambda_{QCD}/m_b)$ corrections)

Theoretical predictions:

$$A^d_{SL} = -(6.4 \pm 1.6) \cdot 10^{-4}, \quad A^s_{SL} = (2.7 \pm 0.6) \cdot 10^{-5}$$

[M.Ciuchini, E.Franco, V.Lubicz, F.Mescia, C.T. hep-ph/0308029, M.Beneke et al. hep-ph/0307344, A.Lenz, U.Nierste hep-ph/0612167, C.T. hep-ph/0702235]

Experimental averages:

$$A^d_{SL} = -(5 \pm 56) \cdot 10^{-4}, \quad A^s_{SL} = -(300 \pm 1010) \cdot 10^{-5}$$

[HFAG, 2007]

Mass Difference

Theoretical prediction:

Main source of th. unc.
$f_{Bs}\sqrt{B_{Bs}}$=262(35)MeV (Lattice)
[S.Hashimoto hep-ph/0411126]

In agreement with the precise exp. determination
$f_{Bs}\sqrt{B_{Bs}}$=257(6)MeV (UTA within SM)
[M.Bona et al. (UTfit), hep-ph/0606167]

$$(\Delta M_s)^{SM}_{dir} = (17.8 \pm 4.8) \cdot ps^{-1}$$

[M.Blanke, A.Buras, D.Guadagnoli, C.T. hep-ph/0604057]

$$(\Delta M_s)^{UTfit} = (17.5 \pm 2.1) \cdot ps^{-1}$$

[UTfit, www.utfit.org]

Experimental measurement:

$$(\Delta M_s)^{exp.} = (17.77 \pm 0.10 \pm 0.07) \cdot ps^{-1}$$

[CDF hep-ex/0609040]

Sensitivity to NP

Γ_{12}^{q} describes decay (to SM particles only) ⇒ Insensitive to NP

M_{12}^{q} describes oscillation through box-diagrams ⇒ Sensitive to NP ⇒ $M_{12}^{q} = \left(M_{12}^{q}\right)_{SM} C_{B_q} e^{2i\varphi_{B_q}}$

($2i\varphi_{B_q}$ → beyond MFV)

$$\frac{\Delta\Gamma_q}{\Gamma_q} = -\left(\frac{\Delta M_q}{\Gamma_q}\right)^{exp}\left[\mathrm{Re}\left(\frac{\Gamma_{12}^{q}}{M_{12}^{q}}\right)^{SM}\frac{\cos 2\varphi_{B_q}}{C_{B_q}} - \mathrm{Im}\left(\frac{\Gamma_{12}^{q}}{M_{12}^{q}}\right)^{SM}\frac{\sin 2\varphi_{B_q}}{C_{B_q}}\right]$$

$$A_{SL}^{q} = \left[\mathrm{Im}\left(\frac{\Gamma_{12}^{q}}{M_{12}^{q}}\right)^{SM}\frac{\cos 2\varphi_{B_q}}{C_{B_q}} - \mathrm{Re}\left(\frac{\Gamma_{12}^{q}}{M_{12}^{q}}\right)^{SM}\frac{\sin 2\varphi_{B_q}}{C_{B_q}}\right]$$

In B_s: Re>>Im ⇒ Even a small $\varphi_{B_s} \equiv \phi_s/2$ can be seen in A_{SL}^{s}

ϕ_s appears in a clean way in the t-dep. CP-asymmetry:

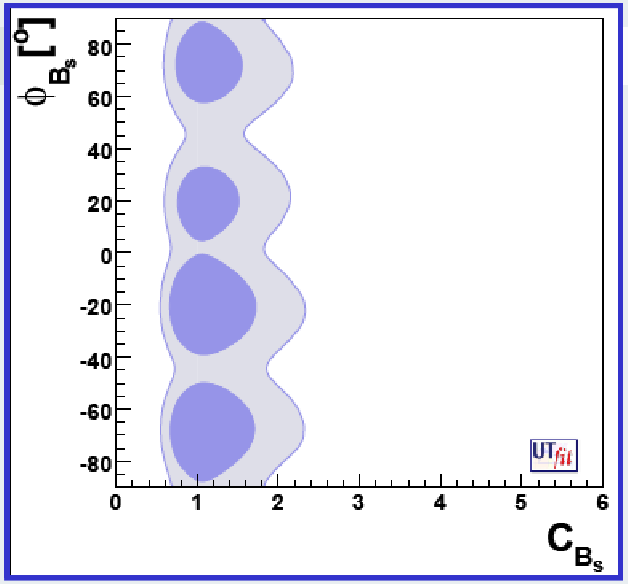
$$A_{CP}(B_s \to J_\psi \phi) \cong \frac{-\eta_f \sin\phi_s \sin(\Delta M_s t)}{\cosh\left(\Delta\Gamma_s \frac{t}{2}\right) - \eta_f \cos\phi_s \sinh\left(\Delta\Gamma_s \frac{t}{2}\right)}$$

β_s=-1°≈0

⇒ Observing a large $A_{CP}(B_s \to J_\psi\, \phi)$ at LHC would be a clear signal of NP, beyond MFV

From a NP (model-indep.) analysis
[M.Bona et al. (UTfit), 0707.0636, hep.ph/0605213]

Contrary to B_d and K systems, a large NP phase φ_{Bs} is still possible

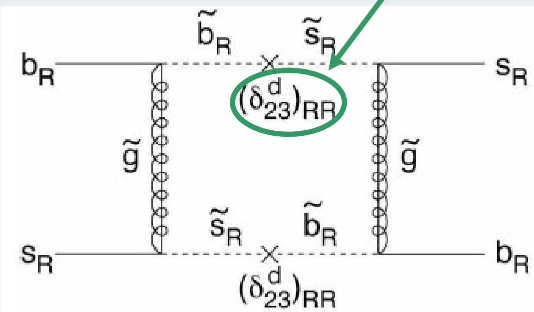


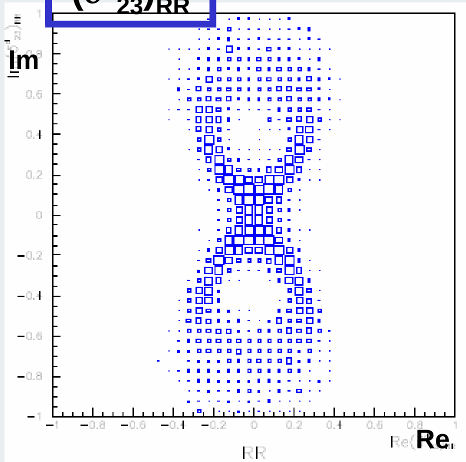
In specific NP models beyond MFV:

MSSM

[M.Ciuchini, L.Silvestrini hep-ph/0603114, M.Ciuchini et al., in preparation]

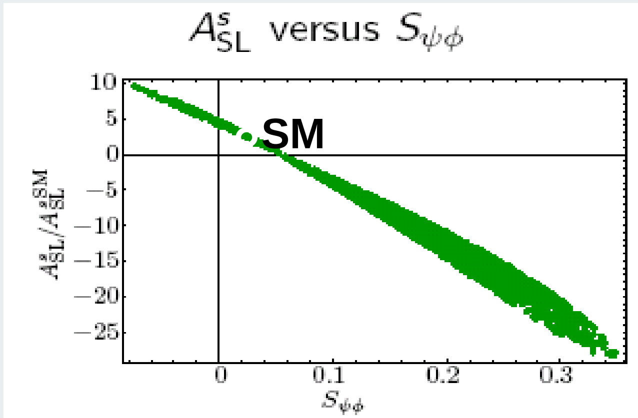
- Constraints on the δ's (non-diagonal entries of sfermion mass matrices)
- ΔM_s constraints mainly $(\delta^d_{23})_{RR}$ (| | <$7 \cdot 10^{-1}$, with tanβ=3)





Littlest Higgs model with T-Parity

$$S_{\psi\phi} = \sin(2|\beta_s| - 2\varphi_{B_s})$$



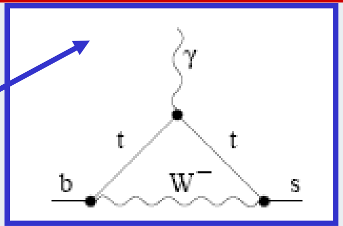
- A^s_{SL} can be enhanced by 10-20
- $S_{\psi\phi}$ can be as high as +0.3

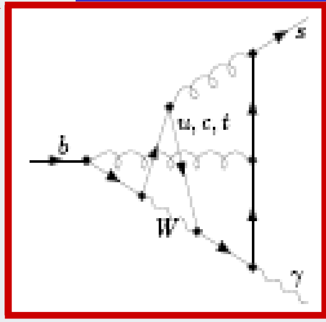
[Blanke,Buras,Poschenrieder,CT,Uhlig,Weiler, hep-ph/0605214]

Radiative and Rare Decays

$b \to s\gamma$ (inclusive)

- highly sensitive to NP (loop FCNC)
- theoretically well under control
- with a small experimental error





$$Br(B \to X_s\gamma)^{exp}_{E_\gamma > 1.6GeV} = (3.55 \pm 0.24)\cdot 10^{-4}$$

[HFAG, 2007]

NNLO QCD correct. to Wilson coefficients
+ RG resummation of large logs $\ln(M_W^2/m_b^2)$
[M.Misiak et al., hep-ph/0609232]

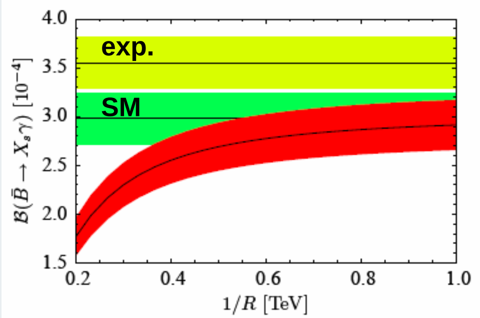
$$Br(B \to X_s\gamma)^{SM}_{E_\gamma > 1.6GeV} = (3.15 \pm 0.23)\cdot 10^{-4}$$

Main theoretical uncertainty:
unknown $O(\alpha_s \Lambda_{QCD}/m_b)$ non-pert.
effects in 4-quark operators

A small positive NP effect is still allowed ⇒ Significant constraint on NP models

1 Universal Extra Dimension

$Br(B \to X_s \gamma)$ now represents the strongest constraint:
1/R > 600GeV
[U.Haisch, A.Weiler, hep-ph/0703064]



mSUGRA (MSSM with MFV)

$b \to s\gamma$ indicates for the light Higgs mass $m_h \approx 110$GeV compatible with the LEP limit
[O.Buchmuller et al. 0707.3447]

MSSM beyond MFV

Strong constraint on the non-diagonal entry $(\delta^d_{23})_{LR}$ ($<5\cdot 10^{-3}$)
[M.Ciuchini, L.Silvestrini hep-ph/0603114, M.Ciuchini et al., in preparation]

Littlest Higgs model with T-Parity

Small (~4%) effects are possible
[M.Blanke et al., hep-ph/0605214]

b→sγ (exclusive)

$$\langle V\gamma|Q_i|B\rangle = \left[T_1^{B\to V}(0)\,T_i^I + \int_0^1 d\xi\, du\, T_i^{II}(\xi,u)\,\phi_B(\xi)\,\phi_{2;V}^{\perp}(v)\right]\cdot\epsilon$$

Theoretical predictions require QCD factorization:

- pert. hard scattering kernels
- non-pert. form factors
- non-pert. light cone distribution amplitudes

from Lattice QCD [D.Becirevic et al., hep-ph/0611295]

from quark models and

from QCD sum rules on the light cone [P.Ball et al., hep.ph/0612081]

Br(B→K*γ) is theoretically cleaner than Br(B→ργ), where $O(\Lambda_{QCD}/m_b)$ corrections turn out to be relevant

$|V_{td}|/|V_{ts}|$ can be extracted from their BR ratios

[P.Ball, R.Zwicky, hep-ph/0603232]

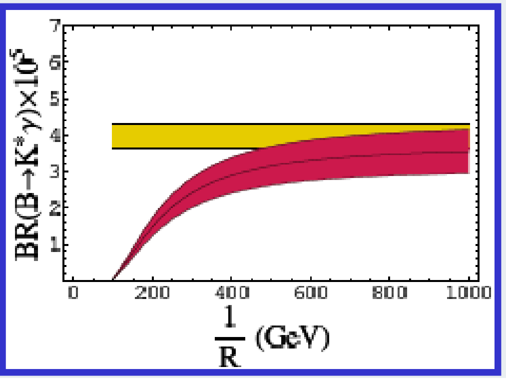
Interesting exclusive observables are the t-dep. CP-asymmetries $A_{CP}(B\to V\gamma)$:

- they are (helicity) suppressed within the SM ~O(1%)
- their observation would be a clear signal of NP

In 1 Universal Extra Dimensions

B→K*γ represents a stringent constraint

[P.Colangelo et al., hep-ph/0604029, hep-ph/0610044]



(with form factors from light-cone QCD sum rules)

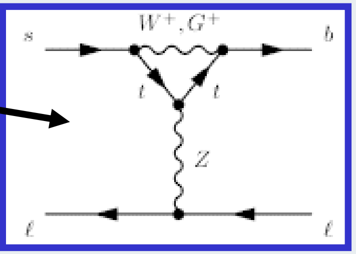
$B_q \to l^+ l^-$

The $\mu^+\mu^-$ modes are experimentally the best:
- e^+e^- is m_e^2/m_μ^2 suppressed
- $\tau^+\tau^-$ has at least other two missing ν from decaying τ's

Upper bounds have been recently obtained

$Br(B_d \to \mu^+\mu^-) < 1.8 \cdot 10^{-8}$ (95% C.L)
$Br(B_s \to \mu^+\mu^-) < 5.8 \cdot 10^{-8}$ [CDF, 0712.1708]

- Highly sensitive to NP (loop FCNC: Z-penguin dominated)
- Theoretically clean (purely leptonic)



$$Q_A = (\bar{b}_L \gamma^\mu q_L)\ (\bar{l} \gamma^\mu \gamma^5 l)$$

Wilson coeff. at NLO in QCD
[Misiak, J.Urban hep-ph/9901278, G.Buchalla, A.J.Buras hep-ph/9901288]

$Br(B_d \to \mu^+\mu^-)^{SM} = (1.03 \pm 0.09) 10^{-10}$
$Br(B_s \to \mu^+\mu^-)^{SM} = (3.35 \pm 0.32) 10^{-9}$

[M.Blanke, A.J.Buras, D.Guadagnoli, C.T., hep-ph/0604057]

There is still a lot of room for NP

Within the SM or MFV without new operators, there are clean correlations (with ΔM_q and between B_d and B_s systems):

$$Br(B_q \to \mu^+\mu^-) = C \frac{\tau(B_q)}{\hat{B}_{B_q}} \frac{Y^2(x_t)}{S(x_t)} \Delta M_q$$

$$\frac{Br(B_s \to \mu^+\mu^-)}{Br(B_d \to \mu^+\mu^-)} = \frac{\hat{B}_{B_d}}{\hat{B}_{B_s}} \frac{\tau(B_s)}{\tau(B_d)} \frac{\Delta M_s}{\Delta M_d} = 32.4 \pm 1.9$$

[M.Blanke, A.J.Buras, D.Guadagnoli, C.T., hep-ph/0604057]

A deviation would signal NP with new operators and/or new sources of flavour violation

MSSM with large $\tan\beta$

New (Higgs-generated) scalar and pseudoscalar operators yield $Br \propto \tan^6\beta$
$\to B_q \to l^+ l^-$ is a smoking gun for Higgs effects in MSSM

[K.S.Babu, C.F.Kolda, hep-ph/9909476, G.Isidori, A.Retico, hep-ph/0110121, A.J.Buras et al., hep-ph/0210145, hep-ph/0207241, hep-ph/0107048, G.Isidori, P.Paradisi, hep-ph/0605012]

$b \to (s,d)\, l^+ l^-$

- Highly sensitive to NP (loop FCNC)
- Main SM contribution from em dipole operator (Q_7^{γ}), and ew penguin operators (Q^9, Q^{10})

Close to the charm threshold (long-distance) $c\bar{c}$ resonances appear

Two approaches can be used:
- appropriate exp. cuts are introduced
- models (for resonances) + disp. relations

[A.Ali et al., hep-ph/9910221]

In certain phase-space regions some incl. and excl. observables have hadronic uncert. under control

Inclusive: $B \to X_s\, l^+ l^-$

- Wilson coefficients at NNLO in QCD
  [C.Bobeth et al., hep-ph/0312090, M.Gorban, U. Haisch, hep-ph/0411071]
- HQE at $O(\Lambda^2_{QCD}/m_c^2)$, $O(\Lambda^2_{QCD}/m_b^2)$, $O(\Lambda^3_{QCD}/m_b^3)$
- QED corrections
- bremmstrahlung effects

[see the WG2 CERN-report 0801.1833]

[T.Huber at al., hep-ph/0512066]

$$Br(\bar{B} \to X_s \mu^+\mu^-)^{SM} = (1.59 \pm 0.11)10^{-6}$$
$$Br(\bar{B} \to X_s e^+e^-)^{SM} = (1.64 \pm 0.11)10^{-6}$$

$1\,GeV^2 < m^2_{ll} < 6\,GeV^2$

Sensitive to the interference of the Wilson coefficients C_7 and C_9

The forward-backward asymmetry (A_{FB}) is sensitive to C_7C_{10} and C_9C_{10}

Exclusive: $B \to K^* l^+ l^-$

The most interesting observables are:

- $d\Gamma^2 / (dq^2\, d\cos\theta_l)$ → extraction of C_9/C_7 and C_{10}/C_7 [Belle, hep-ex/0603018]
  (q^2: l^+l^- Invariant mass; θ_l: l^+B angle)
  sensitive to NP in $C_{9,10}$ and eventual NP (chirally flipped) $C'_{9,10}$

Theoretical study in terms of trasversity amplitudes [K.J.M.Lee et al., hep-ph/0612156], based on QCD factorization + SCET [A.Ali et al., hep-ph/0601034] and HQET [B.Grinstein and D.Pirjol, hep-ph/0404250] (main source of uncertainty: Λ_{QCD}/m_b corrections)

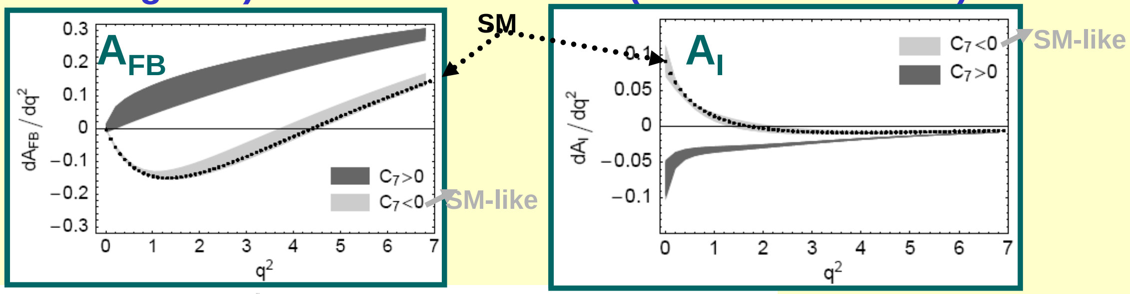
- A_{FB} and its zero q_0^2: main source of uncertainty → hadronic inputs from QCD sum rules [M.Beneke et al., hep-ph/0106067] or exp. results on $B \to K^*\gamma$ [A.Ali et al., hep-ph/0601034]

Significant deviations from the SM in the MSSM [A.Ali et al.,hep-ph/9910221,T.Feldmann,J.Matias,hep-ph/0212158]

A_I (isospin asymmetry between neutral and charged B): Small within the SM (=0 in factorization)

[T.Feldmann and J.Matias, hep-ph/0212158]

MSSM with MFV



- **Muon to electron ratio:** $R_H \equiv \int_{q_1}^{q_2} dq^2 \frac{d\Gamma(B \to H\mu^+\mu^-)}{dq^2} \Big/ \int_{q_1}^{q_2} dq^2 \frac{d\Gamma(B \to He^+e^-)}{dq^2}, \quad H = \{ K^* \}$

=0.991±0.002 within the SM, ~13% NP effects are possible [G.Hiller and F.Krüger, hep-ph/0310219]

[model indep.(combined $R_H \leftrightarrow B_s \to \mu^+\mu^-$,...)analysis within MFV,neglecting RightHanded contributions, assuming $C_{S,P} \propto m_l$ (as due to $\tan\beta$ enhanced Higgs couplings in the MSSM)]

Other exclusive channels:

$B \to K\, l^+l^-$, (A_{FB}=0 in the SM, a deviation would be a smoking gun of NP with scalar and pseudoscalar operators) [M.Beneke et al., hep-ph/0106067]

$B_s \to \phi\, l^+l^-$, $B_s \to \eta'\, l^+l^-$ (larger hadronic uncertainties in meson wave functions)

$\Lambda_b \to \Lambda^0\, l^+l^-$ (theoretically more complicated)

Conclusions

- There is plenty of interesting B-observables sensitive to NP and accessible at LHC

- A combined analysis, including clean correlations, plays an important role to identify a SM breakdown and its sources

- The NP flavour structure can only be determined with improved measurements in the flavour sector

see Paride's discussion of:
- Interplay with Direct Searches
- Lepton flavour violation
- …