. New Physics in the B Sector

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Pheno07 Meeting, Madison, 7th of May 2007

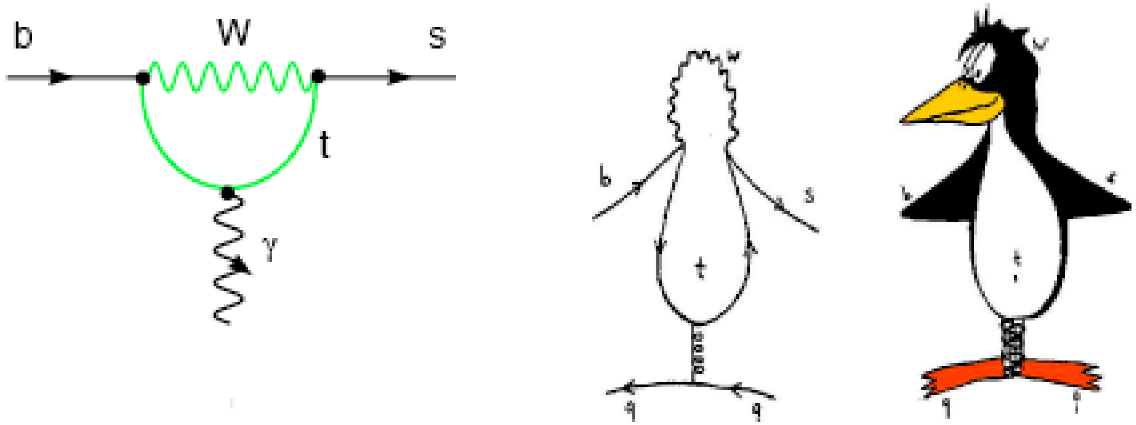
Plan of the Talk

- Flavour problem, minimal flavour violation
- Interplay of collider and flavour physics
- Various opportunities

(apologies for all omissions....)

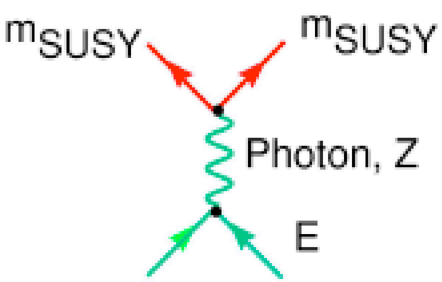
Indirect exploration of higher scales via flavour observables

- Flavour changing neutral current processes like $b \to s\gamma$ or $b \to s\ell^+\ell^-$ directly probe the SM at the one-loop level.

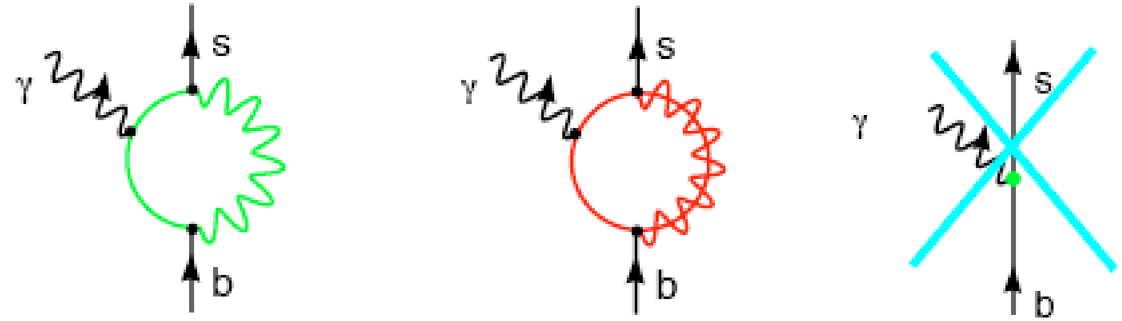


- Indirect search strategy for new degrees of freedom beyond the SM

Direct:



Indirect:



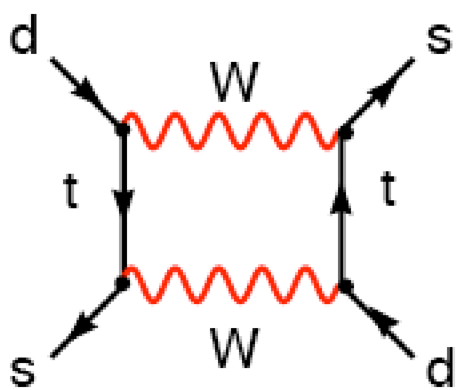
- High sensitivity for 'New Physics' ($\leftrightarrow$ electroweak precision data, 10% $\leftrightarrow$ 0.1%)

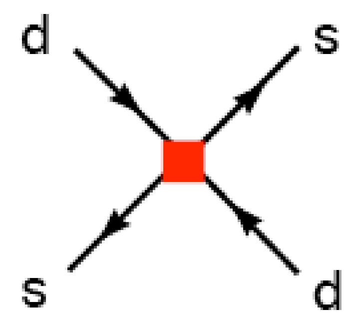
- Immense potential for synergy and complementarity between collider and flavour physics within the search for new physics

Flavour problem or how do FCNCs hide?

$$\mathcal{L} = \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs} + \sum_i \frac{c_i^{New}}{\Lambda_{\mathrm{NP}}} \mathcal{O}_i^{(5)} + \ldots$$

- SM as effective theory valid up to cut-off scale Λ_{NP}
- $K^0 - \bar{K}^0$-mixing $\mathcal{O}^6 = (\bar{s}\, d)^2$: $c^{SM}/M_W^2 \times (\bar{s}\, d)^2 + c^{New}/\Lambda^2 \times (\bar{s}\, d)^2 \Rightarrow \Lambda_{\mathrm{NP}} > 100\,\mathrm{TeV}$





- Natural stabilisation of Higgs boson mass (hierarchy problem) $\Rightarrow \Lambda_{\mathrm{NP}} \leq 1\mathrm{TeV}$
  (i.e. supersymmetry, little Higgs, extra dimensions)
- In addition: EW precision data $\leftrightarrow$ little hierarchy problem $\Rightarrow \Lambda_{\mathrm{NP}} \sim 3 - 10\mathrm{TeV}$

Possible New Physics at the TeV scale has to have a very non-generic flavour structure

This fundamental flavour problem has to be solved by any new physics scenario.

Rare decays and CP violating observables exclusively allow to analyse it.

Example: Supersymmetry

- In the MSSM too many contributions to flavour violation
  - CKM-induced contributions from H^+, χ^+ exchanges (quark mixing)
  - flavour mixing in the sfermion mass matrix (disalignment)

$\Rightarrow$ Supersymmetric flavour problem

- In the MSSM too many (44) phases: stringent bounds on phases by flavour-diagonal CP violating observables (EDM)

$\Rightarrow$ Supersymmetric CP problem

- $b \to s\gamma$ is sensitive to the mechanism of SUSY breaking, because in the limit of exact supersymmetry:

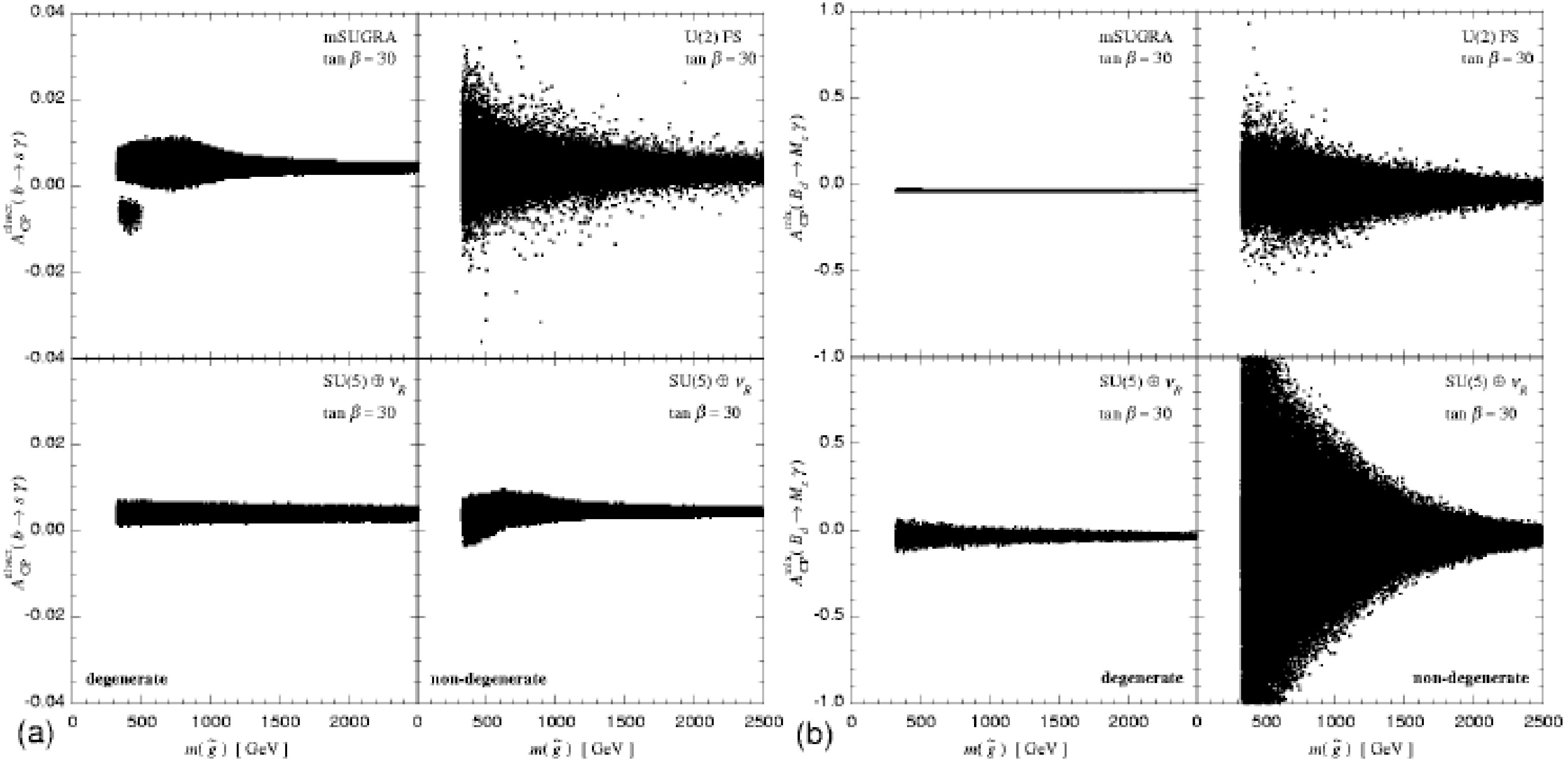
$$BR(b \to s\gamma) = 0\,!$$

Dynamics of flavour $\leftrightarrow$ Mechanism of SUSY breaking

$\Rightarrow$ Discrimination between various SUSY-breaking mechanism

Discrimination between various SUSY-breaking mechanism via flavour observables

Goto et al



Direct CP asymmtry in $b \to s\gamma$ Mixing-induced CP asymmtry $B_d \to M_s\gamma$

as functions of the gluino mass

Sensitivities (Super-B): $\Delta = \pm 0.004$ $\Delta = \pm 0.02$ (theoretically limited)

The indirect information will be most valuable when the general nature of new physics will be identified in the direct search (LHC), specifically when the mass scale of the new physics will be fixed.

Model-independent analysis: New flavour structures in $b \to s$ transitions ?

Data from K and B_d physics show that new sources of flavour violation in $s \to d$ and $b \to d$ are strongly constrained, the possibility of large new contributions to $b \to s$ still remains open.

Hints from model building

Susy-GUTs relate the large mixing angle in the neutrino sector to large mixing in the right-handed b-s sector.

Moroi, Harnik et al.

Possible direct correlations between B and collider physics

- Squark decays:

$$\tilde{u}_i \to u_j \tilde{\chi}_k^0 \, , \, d_j \tilde{\chi}_l^+ \qquad \tilde{d}_i \to d_j \tilde{\chi}_k^0 \, , \, u_j \tilde{\chi}_l^-$$

  with $i = 1, .., 6$, $j = 1, 2, 3$, $k = 1, .., 4$ and $l = 1, 2$.

- These decays are governed by the same mixing matrices as the contributions to flavour violating low-energy observables.

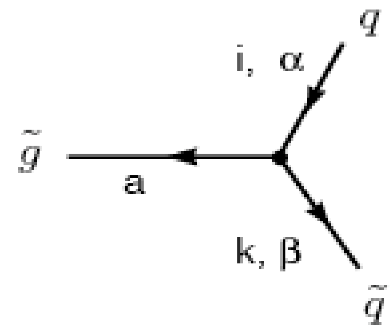
  Squarks can have large flavourviolating decay modes, compatible with present data from flavour physics. Hurth, Porod

- Flavour-tagging at LHC difficult:
  makes life at LHC potentially more interesting and more difficult, extra information from ILC or flavour factories needed.

Documented in the LHC Flavour Workshop - Yellow Report

More details on correlations via squark mixing:

- In the unconstrained MSSM (too many ?) new contributions to flavour violation
  - CKM induced contributions from H^+, χ^+ exchanges
  - flavour mixing in the sfermion mass matrix
- Gluino-quark-squark coupling: $-ig_s T^a_{\beta\alpha}(\Gamma^{ki}_{QL} P_L - \Gamma^{ki}_{QR} P_R)$



- Possible disalignment of quarks and squarks

Strategy

- take SPS1a as starting point:

  $M_0 = 100$ GeV, $M_{1/2} = 250$ GeV
  $A_0 = -100$ GeV, $\tan\beta = 10$, $\mu > 0$
  $\Rightarrow$
  $M_2 = 192$ GeV, $\mu = 351$ GeV
  $m_{H^+} = 403$ GeV $m_{\tilde{g}} = 594$ GeV, $m_{\tilde{t}_1} = 400$ GeV
  $m_{\tilde{t}_2} = 590$ GeV, $m_{\tilde{q}_R} \simeq 550$ GeV, $m_{\tilde{q}_L} \simeq 570$ GeV

  (SPheno 2.0)

- vary flavour-nondiagonal parameters
  (off-diagonal squark mass entries)

$\Rightarrow$ Typical results:

Branching ratios (in %) of u-type squarks

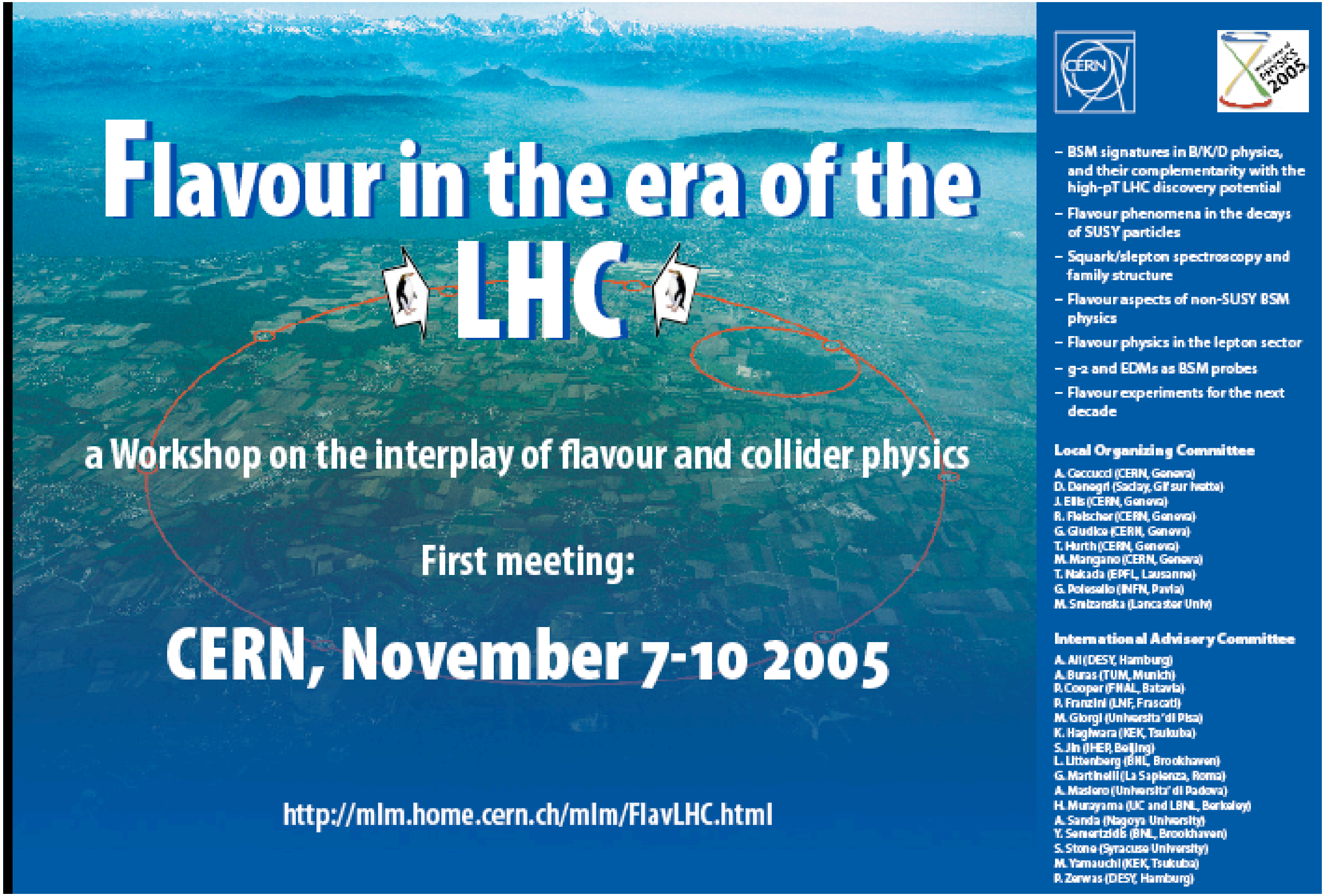
	$\tilde{\chi}_1^0 c$	$\tilde{\chi}_1^0 t$	$\tilde{\chi}_2^0 c$	$\tilde{\chi}_2^0 t$	$\tilde{\chi}_3^0 c$	$\tilde{\chi}_3^0 t$	$\tilde{\chi}_4^0 c$	$\tilde{\chi}_4^0 t$	$\tilde{\chi}_1^+ s$	$\tilde{\chi}_1^+ b$	$\tilde{\chi}_2^+ s$	$\tilde{\chi}_2^+ b$
$\tilde{u}_1$	4.7	18	5.2	9.6	6×10^{-3}	0	0.02	0	11.3	46.4	2×10^{-3}	4.7
$\tilde{u}_2$	·19.6	1.1	0.4	17.5	2×10^{-2}	0	6×10^{-2}	0	0.5	57.5	3×10^{-3}	2.9
$\tilde{u}_3$	7.3	3.7	20	1.4	6×10^{-2}	0	0.6	0	40.3	3.1	1	18.5
$\tilde{u}_6$	5.7	0.4	11.1	5.3	4×10^{-2}	5.7	0.6	13.2	22.9	13.1	0.6	8.0

Branching ratios (in %) of d-type squarks

	$\tilde{\chi}_1^0 s$	$\tilde{\chi}_1^0 b$	$\tilde{\chi}_2^0 s$	$\tilde{\chi}_2^0 b$	$\tilde{\chi}_3^0 s$	$\tilde{\chi}_3^0 b$	$\tilde{\chi}_4^0 s$	$\tilde{\chi}_4^0 b$	$\tilde{\chi}_1^- b$	$\tilde{\chi}_1^- t$	$\tilde{\chi}_2^- b$	$\tilde{\chi}_2^- t$	$\tilde{u}_1 W^-$
$\tilde{d}_1$	1.2	5.7	8.4	30.6	2×10^{-2}	1.5	0.2	0.9	16.6	34.1	0.6	0	0
$\tilde{d}_2$	·17.4	5.8	5.1	15.7	7×10^{-2}	7.4	0.3	09.2	9.7	19.7	0.7	0	8.8
$\tilde{d}_4$	14.7	21.7	11.3	2.2	5×10^{-2}	10.6	0.5	8.4	22.1	3.6	1.2	0	3.4
$\tilde{d}_6$	1.7	0.5	20.5	6.9	0.1	0.9	1.2	1.3	40.3	10.2	3.4	11.1	1.8

⇒ CERN workshop on the interplay of flavour and collider physics

Fleischer, Hurth, Mangano see http://mlm.home.cern.ch/mlm/FlavLHC.html



5 meetings between 11/2005 and 3/2007, Yellow Report to appear

Minimal Flavour Violation hypothesis

All flavour- and CP-violating interactions be linked to the known Yukawa couplings

RG-invariant definition based on a symmetry principle:
(Yukawa couplings are introduced as background values of fields transforming under the flavour group $SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}$) d'Ambrosio et al.

MFV predictions to be tested:

- usual CKM relations between $[b \to s] \leftrightarrow [b \to d] \leftrightarrow [s \to d]$ transitions:
  -we need high-precision $b \to s$, but also $s \to d$ measurements
  -$\mathcal{B}(\bar{B} \to X_d\gamma) \leftrightarrow \mathcal{B}(\bar{B} \to X_s\gamma)$, $\mathcal{B}(\bar{B} \to X_s\nu\bar{\nu}) \leftrightarrow \mathcal{B}(K \to \pi^+\nu\bar{\nu})$

- CKM phase only source of CP violation:
  -phase measurements in $B \to \phi K_s$ or $\Delta M_{B_{(s/d)}}$ are not sensitive to new physics
  -RG-invariant extension allowing for flavour-blind phases Hurth,Lunghi,Porod

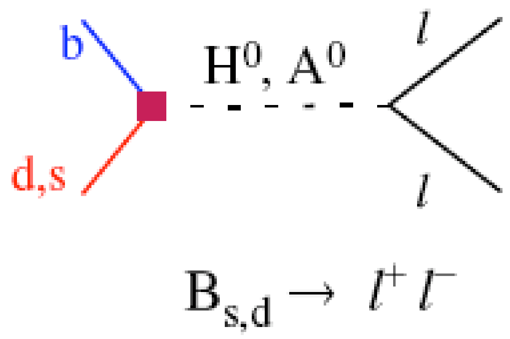
Real MFV bounds are important: measurements beyond those unambiguously indicate new flavour structures.

Simplified (so-called constraint) version of MFV: 'the relevant operators in effective Hamiltonians for weak decays are the same as in the SM.'
This scenario does not represent a consistent low-energy limit of the MSSM
Yukawa-type off-diagonal entries in squark mass matrix are important
see Altmannshofer et al.,hep-ph/0703200

The MFV hypothesis is far from being verified.

It also allows for specific $\tan\beta$ effects when additional Higgs doublets added, in particular in helicity-suppressed observable $B \to \mu\mu$

Order-of-magnitude enhancements possible $B \to \mu\mu$ even without new flavour structures: $A_{\rm SM} \sim m_\mu/m_b \Leftrightarrow A_{H^0,A^0} \sim \tan^3\beta$



Search for large tan β within MFV in SUSY Isidori, Paradisi,hep-ph/0605012

$B(B^{\pm} \to \tau^{\pm}\nu)^{SM} = (1.59 \pm 0.40)\ 10^{-4}$

$B(B^{\pm} \to \tau^{\pm}\nu)^{exp} = (0.88^{+0.68+0.11}_{-0.67\ -0.11})10^{-4}$ [Babar]

$B(B^{\pm} \to \tau^{\pm}\nu)^{exp} = (1.79^{+0.56+0.39}_{-0.49\ -0.46})10^{-4}$ [Belle]

MFV large-tanβ expectations:

~(10-50)% suppression

$\Delta M_{B_s}{}^{SM} = 21.5 \pm 2.6\ ps^{-1}$ [UTfit – pre CDF measurement]

$\Delta M_{B_s}{}^{exp} = 17.77 \pm 0.10 \pm 0.07\ ps^{-1}$ [CDF]

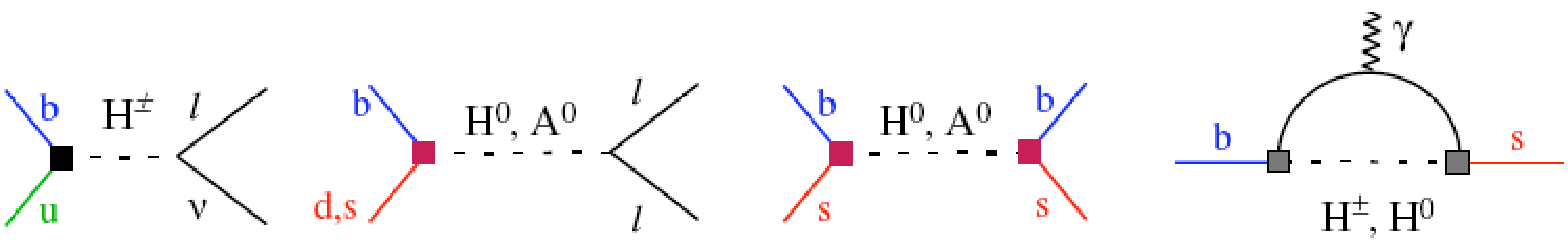
~(0-20)% suppression

$B(B_s \to \mu\mu)^{exp} / B(B_s \to \mu\mu)^{SM} < 23$ (90% CL) [CDF]

up to 100 × enhancement

$B(B \to X_s\gamma)^{exp} / B(B \to X_s\gamma)^{SM} = 1.13 \pm 0.12$ [Misiak et al. '06]

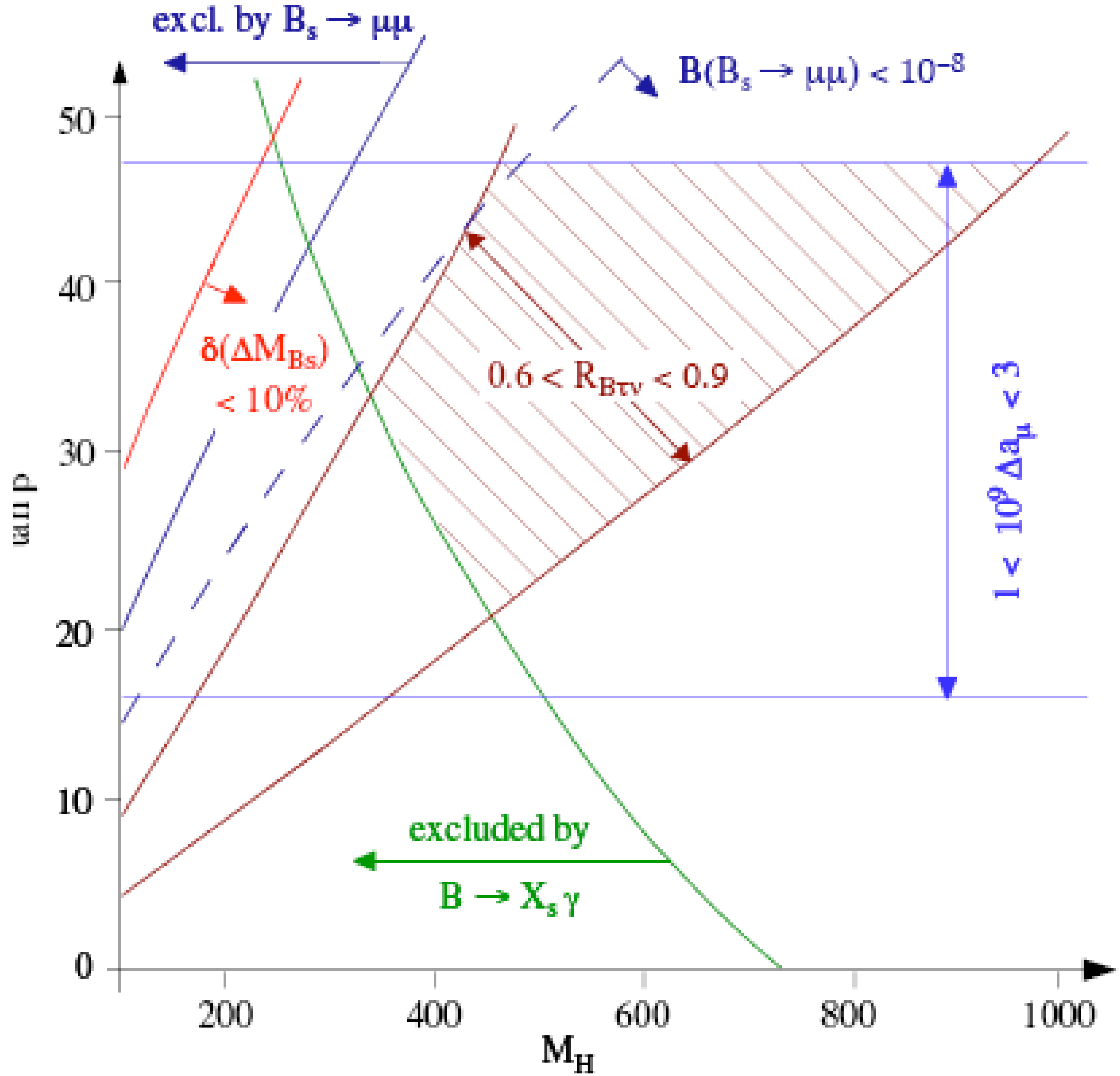
~(0-50)% enhancement



Courtesy of Gino Isidori

Search for large $\tan\beta$ within MFV in SUSY Isidori, Paradisi,hep-ph/0605012

B-physics observables and $(g-2)_\mu$ in the $M_{H^\pm}$–$\tan\beta$ plane:



Crosscheck of benchmark points

with all B-physics bounds,

all SUSY collider searches,

Higgs sector constraints,

EW precision data

$M_{\tilde{q}} = 1, M_{\tilde{l}} = 0.5, M_2 = 0.3, M_1 = 0.2, \mu = 0.5, A_U = -1.0$ TeV $\quad R_{B\tau\nu} := \frac{BR^{\text{SUSY}}(B_u \to \tau\nu)}{BR^{\text{SM}}(B_u \to \tau\nu)}$

Low-energy (LE) and Electroweak (EW) Constraints

Work started at the LHC Flavour workshop (collaboration from Experimentalist & Theorist)

S.Heinemeyer, G.I., P.Paradisi [TH],
O. Buchmuller, R. Cavanaugh,... [EXP]
work documented in the Yellow Report

A first start: Combine LE and EW calculations in one common code.
New Physics Parameter Space: MSSM

"Master Layer"
steers communication between the individual calculations / codes

"FeynHiggs"
http://www.feynhiggs.de/
calculation of the masses and mixing angles of the Higgs sector of the (real or complex) MSSM
&
EW observables in MSSM

"Flavour Observables"
Phys.Lett.B639:499-507,2006

Isidori & Paradisi
Calculation of B physics observables In MSSm (&MFV)

"other observables"
e.g. cosmology constraints

NOT yet included but on to-do-list

Courtesy of Oliver Buchmüller

Example: MSSM Parameter Fit

$$\chi^2 = \sum_i^{N_{const.}} \frac{(Const._i - Pred._i(MSSM))^2}{\Delta Const.^2 + \Delta Pred.^2}$$

Const. = Experimental Constraint value

Pred.(MSSM) = Predicted value for a given MSSM parameter set

2009 reference (pessimistic) scenario:

Observable	Constraint	theo. error
$R_{\mathrm{BR}_{b\to s\gamma}}$	1.127 ± 0.1	0.1
$R_{\Delta M_s}$	0.8 ± 0.2	0.1
$\mathrm{BR}_{b\to\mu\mu}$	$(3.5 \pm 0.35) \times 10^{-8}$	2×10^{-9}
$R_{\mathrm{BR}_{b\to\tau\nu}}$	0.8 ± 0.2	0.1
Δa_μ	$(27.6 \pm 8.4) \times 10^{-10}$	2.0×10^{-10}
M_W^{SUSY}	80.392 ± 0.020 GeV	0.020 GeV
$\sin^2\theta_W^{\mathrm{SUSY}}$	0.23153 ± 0.00016	0.00016
M_h^{light}(SUSY)	> 114.4 GeV	3.0 GeV

MSSM Parameter in the Fit

- $\tan\beta$ - ratio of vacuum expectation values
- M_A - mass of the CP odd Higgs boson
- A - tri-linear Higgs-stop coupling, all tri-linear couplings are set equal
- μ - Higgs mixing parameter
- M_{squark} - squark soft SUSY-breaking parameter; $M_{squark}=2M_{slepton}$

Assumptions (varied to evaluate systematic):
M_2=200 GeV, M_3=300 GeV, $M_1=1/2M_2$
$M_{gluino}=M_{squark}$
$M_{1,2,3}$ - Soft Susy breaking parameters in the gaugino sector

S.Heinemeyer, G.I., P.Paradisi [TH],
O. Buchmuller, R. Cavanaugh,... [EXP]
work documented in the Yellow Report

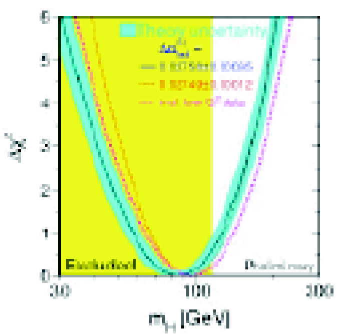
χ^2 Scan in the Mass of the Lightest Higgs h

Scan MSSM parameter space as function of M_h:

Determine for a given M_h the MSSM parameter set that minimizes the χ^2.

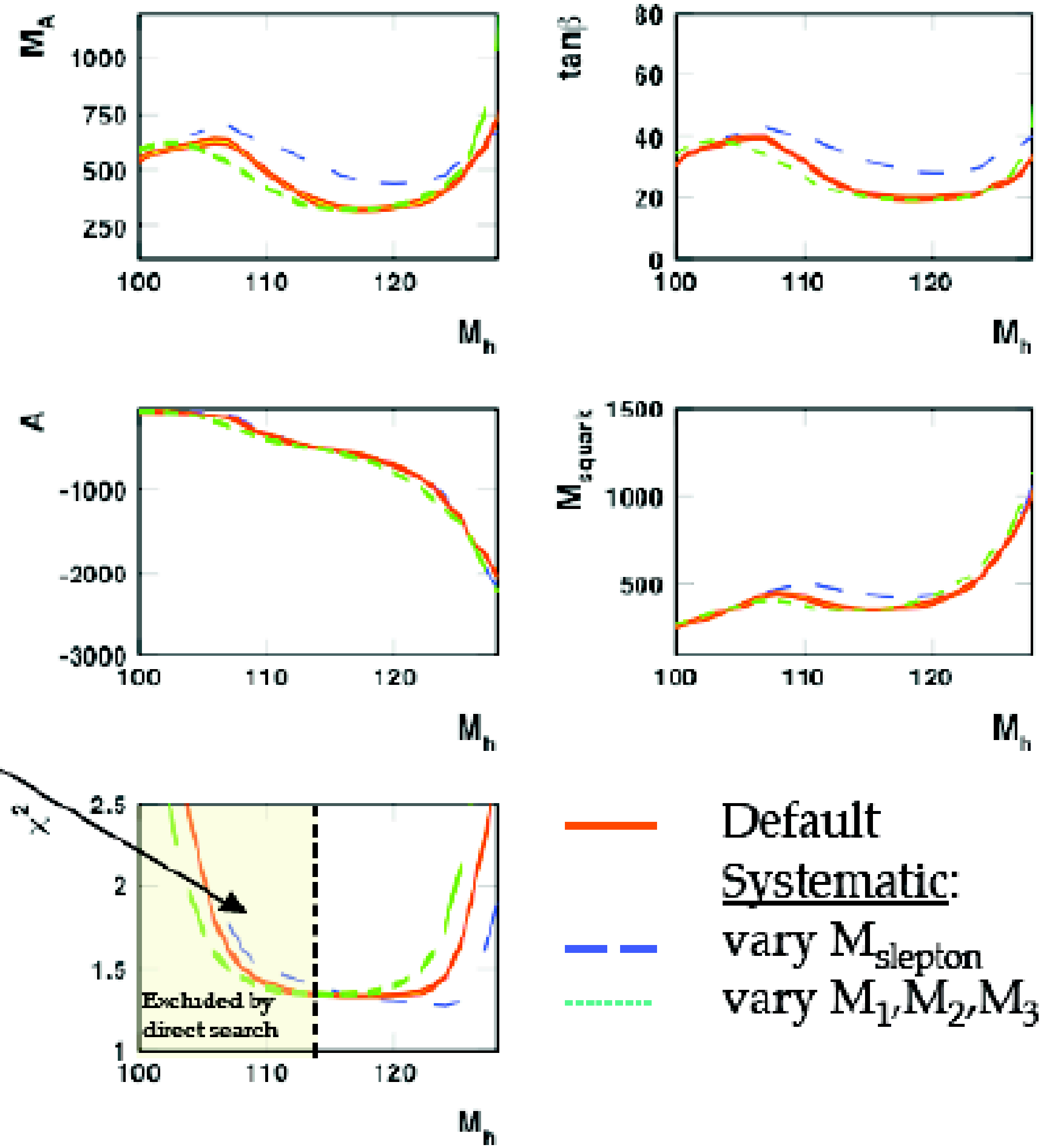
χ^2 minimum of the scan is between M_h~110 GeV and M_h~125 GeV.

Comparison: SM Fit



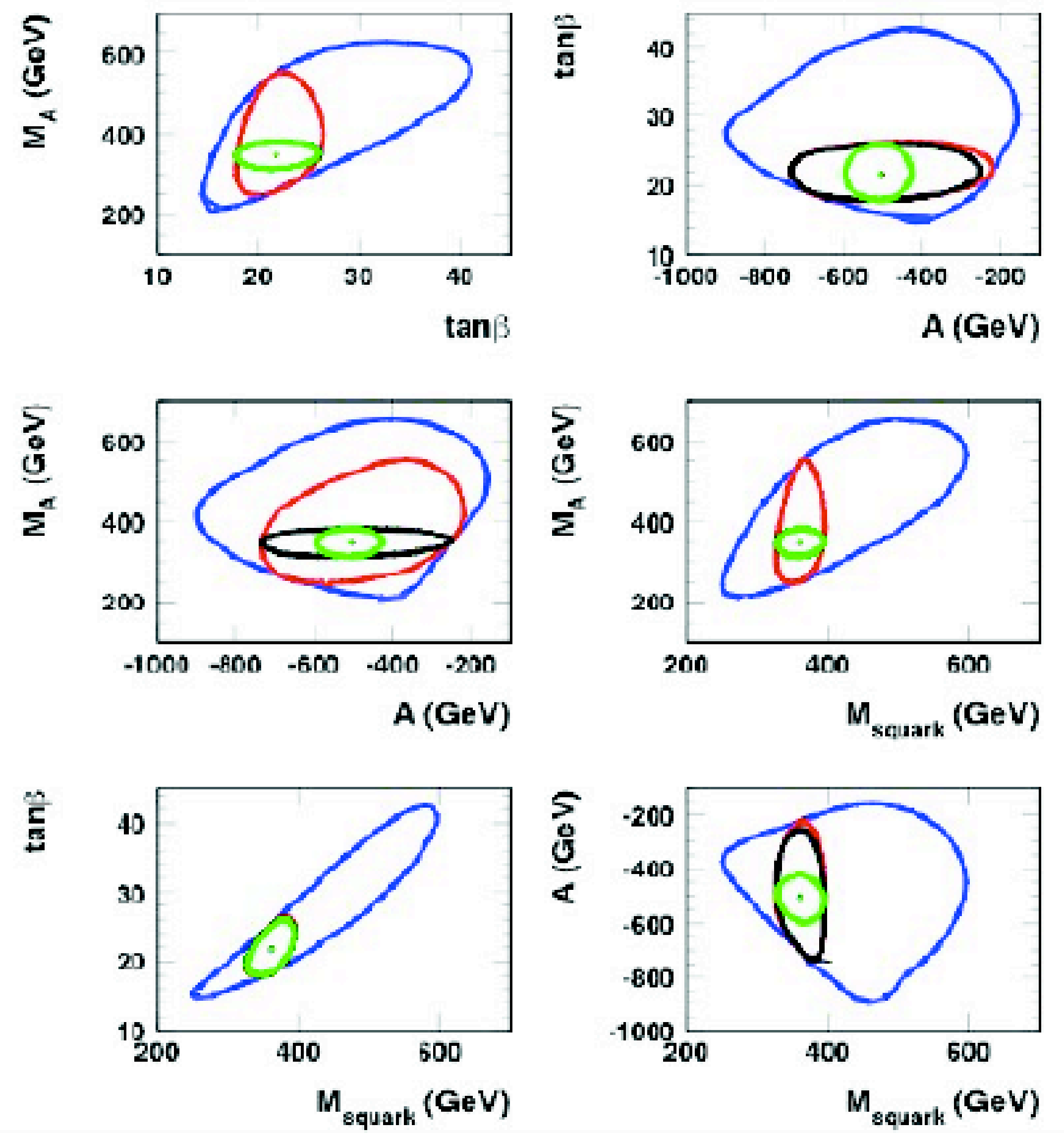
This nicely *illustrates* the potential of external constraints to restrict the allowed MSSM parameter space

2009 scenario



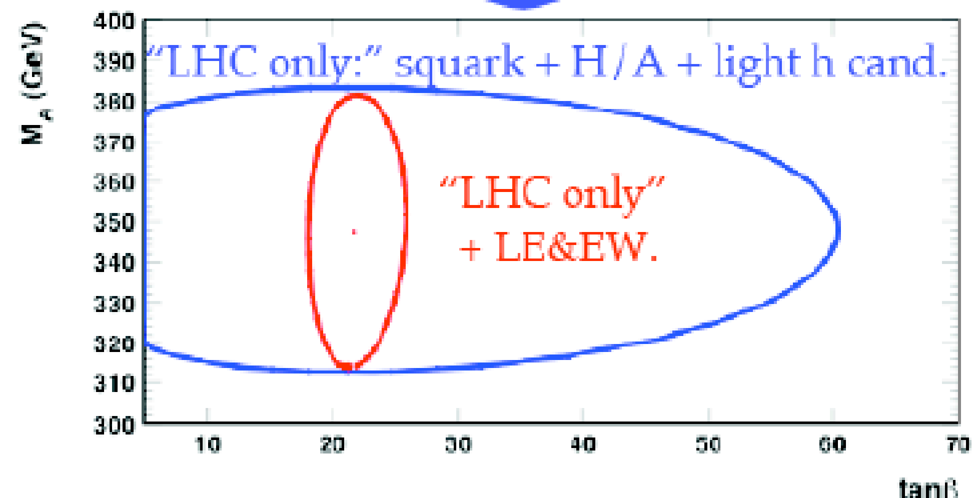
Documented in LHC Flavour Workshop - Yellow Report

Interpretation & Consistency



LE&EW: low-energy (LE) and EW constraints
LE&EW + squark candidate
LE&EW + squark cand. + H/A cand.
LE&EW + squark + H/A + light h cand.

Including LW&EW constraints facilitates the determination of fundamental MSSM parameters



Example: Almost no information on tanβ without external constraints. Note that a direct measurement of tanβ is very difficult at the LHC

Illustrative Example

Some recent work on the interplay of collider and flavour physics:

- Interplay between $H \to b\bar{s}$ and $b \to s\gamma$
  Hahn,Hollik,Illana,Penaranda,hep-ph/0512315
- Production and FCNC decay of supersymmetric Higgs bosons into heavy quarks
  Bejar,Guasch,Sola,hep-ph/0508043
- Challenges for MSSM Higgs searches at Hadron Colliders
  Carena,Menon,Wagner,hep-ph/07041143
- Many other studies in the Yellow Report

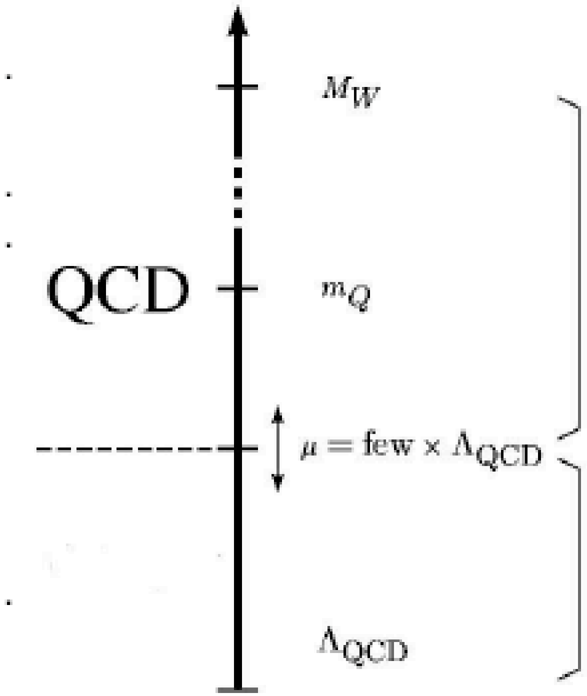
Follow-up workshop:

Working Group on the Interplay Between Collider and Flavour Physics

The working group addresses the complementarity and synergy between the LHC and the flavour factories within the new physics search. New collaborations on this topic were triggered by the two recent CERN workshop series Flavour in the Era of the LHC and CP Studies and Non–Standard Higgs Physics at the border line of collider and flavour physics and experiment and theory. This follow–up working group wants to provide a continuous framework for such collaborations and trigger new research work in this direction. Regular meetings at CERN (well–connected by VRVS) are planned in the near future.

Forthcoming event: Flavour day in Les Houches 16. June

https://twiki.cern.ch/twiki/bin/view/Main/ColliderAndFlavour



Strong interaction in B decays

short-distance physics
perturbative

long-distance physics
nonperturbative

Operator product expansion: Factorization of short- and long-distance physics

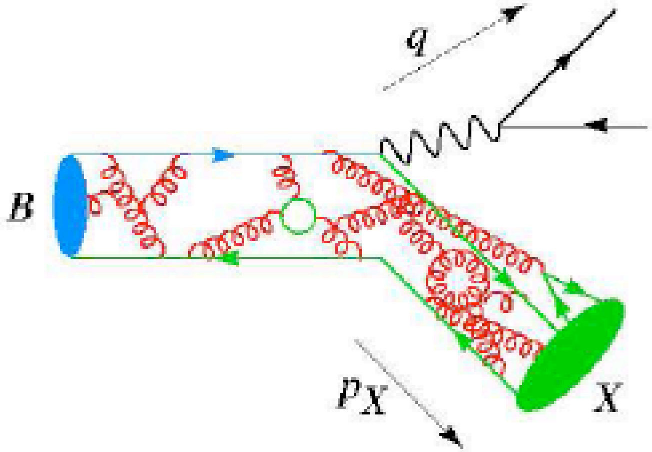
- $\mu^2 \approx M_W^2$: C_i: effective couplings, $< \mathcal{O}_i >$: matrix elements

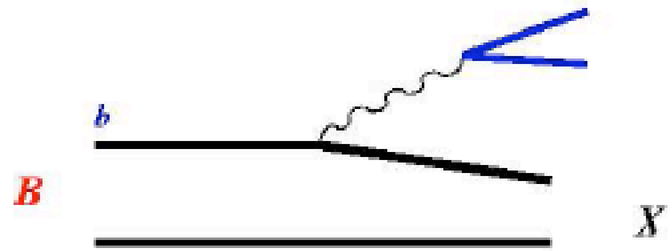
$$H_{eff} = -\frac{4G_F}{\sqrt{2}} \sum C_i(\mu, M_{heavy})\ \mathcal{O}_i(\mu)$$

- $\Lambda_{QCD} << m_Q = m_b$: $1/m_b$ expansion allows for separation of effects
  $\mu^2 \approx m_b^2,\ m_b\Lambda_{QCD}$ $\Rightarrow$ effective theories (HQET, SCET)

- $\mu^2 \approx \Lambda_{QCD}^2$: long-distance hadronic parameters (lattice-QCD , U-spin symmetry, QCD sum rules, chiral perturbation theory, ...)

- $\mu^2 \approx M_{New}^2 >> M_W^2$: 'new physics' effects: $C_i^{SM}(M_W) + C_i^{New}(M_W)$





Crucial problem: Separation of new physics effects and hadronic uncertainties!

Focus on theoretically clean observables is mandatory

Three strategies:

- focus on inclusive modes: operator product expansion (OPE)

$$\Gamma(\bar{B} \to X_s\gamma) \stackrel{m_b\to\infty}{\longrightarrow} \Gamma(b \to X_s^{parton}\gamma)\,, \quad \Delta^{nonpert.} \sim \Lambda^2_{QCD}/m_b^2$$

  No linear term Λ_{QCD}/m_b (perturbatively calculable contribution dominant)

  In general restricted to e^+e^- machines

- focus on ratios of exclusive modes like asymmetries
  (hadronic uncertainties partially cancel out)

  General strategy followed at LHCb

- focus on specific decays like $K \to \pi\nu\bar{\nu}$
  (hadronic matrix elements known from experiment)

Strategy I: Focus on inclusive modes $\bar{B} \to X_s \gamma$ or $\bar{B} \to X_s \ell^+ \ell^-$

- Perturbative QCD corrections are dominant and lead to large logarithms
  $\alpha_s(M_W) Log(m_b^2 / M_W^2)$ → resummation of Logs necessary:

LL	Leading Logs	$G_F \, (\alpha_s \, Log\,)^N$	$N = 0, 1, 2, \ldots$
NLL	Next-to-leading Logs	$G_F \, \alpha_s \, (\alpha_s \, Log\,)^N$	
NNLL	Next-to-next-to-leading Logs	$G_F \, \alpha_s^2 \, (\alpha_s \, Log\,)^N$	

- Previous NLL prediction Hurth,Lunghi,Porod,hep-ph/0312260

  $$\mathcal{B}(\bar{B} \to X_s \gamma) \times 10^4 |_{E_\gamma > 1.6 GeV} = (3.61 \; {}^{+0.24}_{-0.40} \Big|_{m_c/m_b} \pm 0.02_{\text{CKM}} \pm 0.25_{\text{param}} \pm 0.15_{\text{scale}})$$

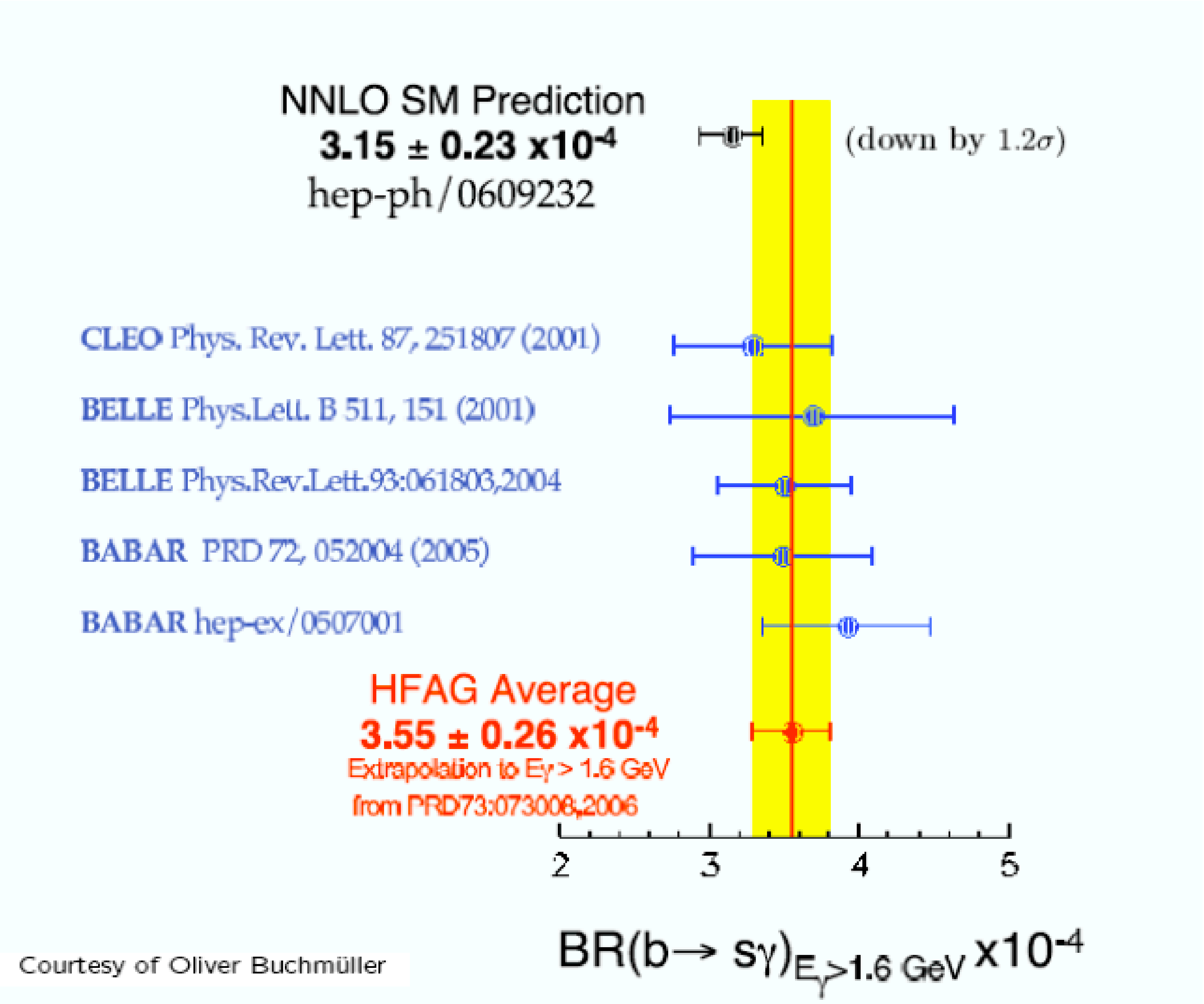
  First NNLL prediction of $\bar{B} \to X_s \gamma$ Misiak (spokesperson) et al.,hep-ph/0609232

  $$\mathcal{B}(\bar{B} \to X_s \gamma) \times 10^4 |_{E_\gamma > 1.6 GeV} = (3.17 \pm 0.23)$$

  Experimental world average HFAG

  $$\mathcal{B}(\bar{B} \to X_s \gamma) \times 10^4 |_{E_\gamma > 1.6 GeV} = (3.55 \; {}^{+0.09}_{-0.10} \Big|_{syst} \pm 0.24_{\text{stat}} \pm 0.03_{\text{shape,dgamma}})$$

- Also in beyond-the-SM scenarios NLL calculations exist: $C_i^{SM}(M_W) + C_i^{New}(M_W)$
  NLL analysis in MFV-supersymmetry Degrassi,Gambino,Slavich, hep-ph/0601135
  NLL in general supersymmetry (uMSSM) Greub,Hurth,Steinhauser, work in progress



NNLO SM Prediction
3.15 ± 0.23 x10-4
hep-ph/0609232
(down by 1.2σ)
CLEO Phys. Rev. Lett. 87, 251807 (2001)
BELLE Phys.Lett. B 511, 151 (2001)
BELLE Phys.Rev.Lett.93:061803,2004
BABAR PRD 72, 052004 (2005)
BABAR hep-ex/0507001
HFAG Average
3.55 ± 0.26 x10-4
Extrapolation to Eγ > 1.6 GeV
from PRD73:073008,2006
2
3
4
5
BR(b→ sγ)Eγ>1.6 GeV x10-4
Courtesy of Oliver Buchmüller

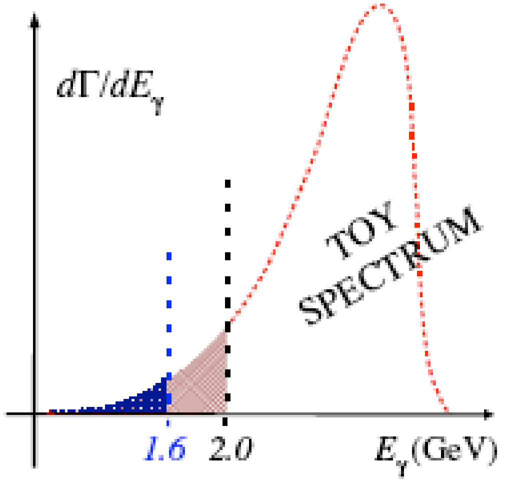
- Nonperturbative corrections $\Lambda^2/m_{b,c}^2$ to $\Gamma(\bar{B} \to X_s\gamma)$ are well under control

- However: Estimation of power corrections of $O(\alpha_s\Lambda/mb)$ should be improved:
  Largest uncertainty (5%) in our new NNLL prediction (see also Lee et al)

- Further uncertainties: parametric (3%), higher-order (3%), mc-interpolation (3%)

- Additional sensitivities to nonperturbative physics
  due to necessary cuts in the photon energy spectrum
  to suppress the $B\bar{B}$ background:

  Shape function methods or multi-scale SCET analysis
  $\Rightarrow$ Additional theoretical uncertainties
  Neubert,Mannel;Bigi et al.; Becher,Neubert



- General folklore: With $E_\gamma \leq 1.9 GeV$ local OPE of the rate is valid again.

- But: Becher,Neubert, hep-ph/0610067
  A low cut around $1.8 GeV$ might not guarantee that a theoretical description in terms of a local OPE is sufficient because of the sensitivity to the scale $\Delta = m_b - 2E_\gamma$.

  – Multiscale OPE with three short-distance scales m_b, $\sqrt{m_b\Delta}$ and Δ needed to connect the shape function and the local OPE region.

  – Using SCET, effects at the 3%-level found not by power corrections Λ_{QCD}/Δ, but by perturbative ones

  – $\mathcal{B}(\bar{B} \to X_s\gamma) \times 10^4|_{E_\gamma > 1.6 GeV} = (2.98 \pm 0.26)$

Analogously: $\bar{B} \to X_s \ell^+ \ell^-$

- NNLL prediction of $\bar{B} \to X_s \ell^+ \ell^-$: dilepton mass spectrum
  Ghinculov, Hurth, Isidori, Yao

$$\mathcal{B}(\bar{B} \to X_s \ell^+ \ell^-)_{Cut:\ q^2 \in [1GeV^2, 6GeV^2]} = (1.63 \pm 0.20) \times 10^{-6}$$

$$\mathcal{B}(\bar{B} \to X_s l^+ l^-)_{Cut:\ q^2 > 14.4GeV^2} = (4.04 \pm 0.78) \times 10^{-7}$$

  NNLL QCD for low q^2: central value: -14%, perturbative error: $13\% \to 6.5\%$

- NNLL prediction of $\bar{B} \to X_s \ell^+ \ell^-$: forward-backward-asymmetry (FBA)
  Ghinculov, Hurth, Isidori, Yao

$$A_{\text{FB}} \equiv \frac{1}{\Gamma_{semilep}} \left(\int_0^1 d(\cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta} - \int_{-1}^0 d(\cos\theta) \frac{d^2\Gamma}{dq^2 d\cos\theta} \right)$$

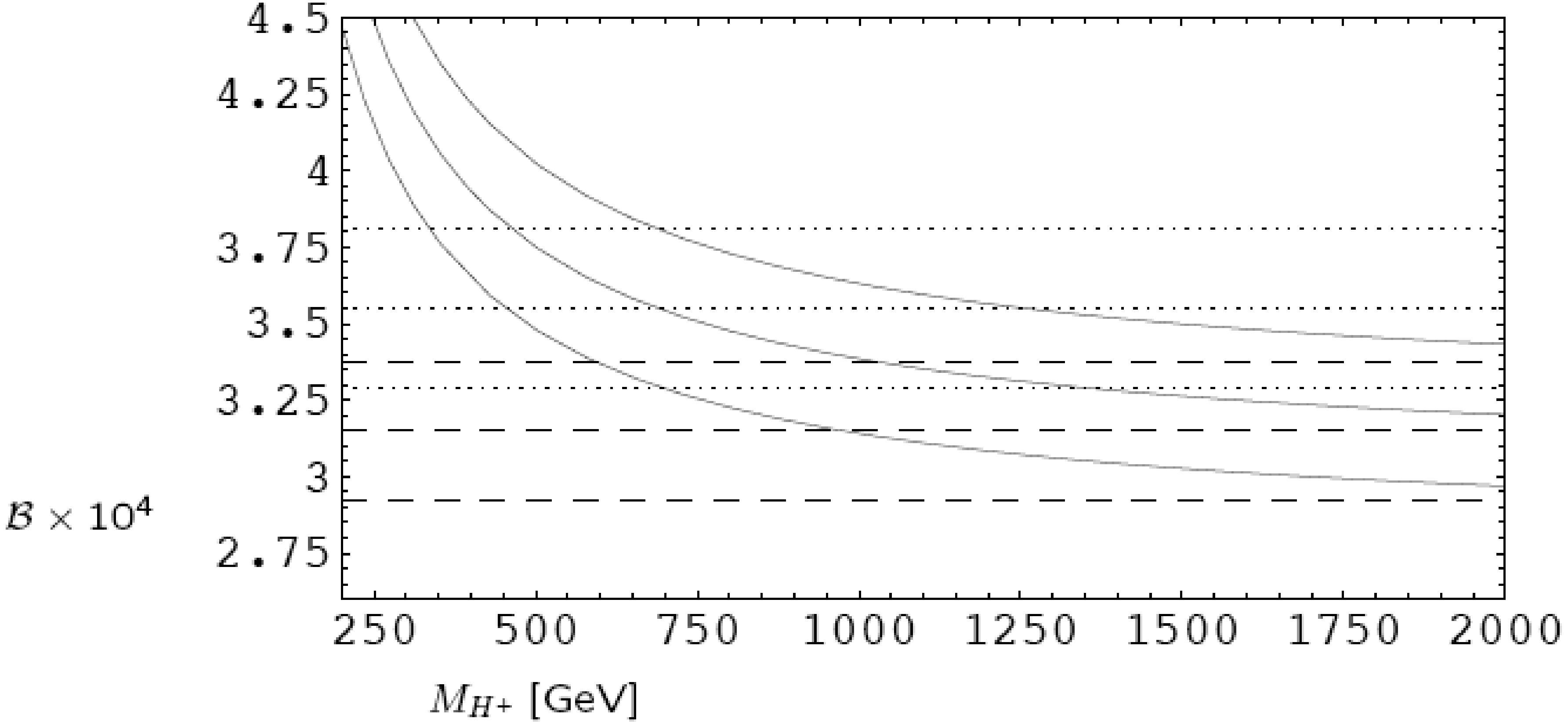
$$A_{FB}(q_0^2) = 0 \quad q_0^2 = (3.90 \pm 0.25) GeV^2$$

- Update with electromagnetic corrections for dilepton mass spectrum and FBA including the high-q^2 region Huber, Hurth, Lunghi, work in progress

- Again additional subtleties $\Rightarrow$ additional uncertainties
  - Breakdown of OPE in Λ_{QCD}/m_b in the high-q^2 endpoint
  - Hadronic invariant-mass cut is imposed in order to eliminate the background like $b \to c\,(\to s e^+ \nu) e^- \bar{\nu} = b \to s e^+ e^-$ + missing energy

Stringent bounds on new-physics models

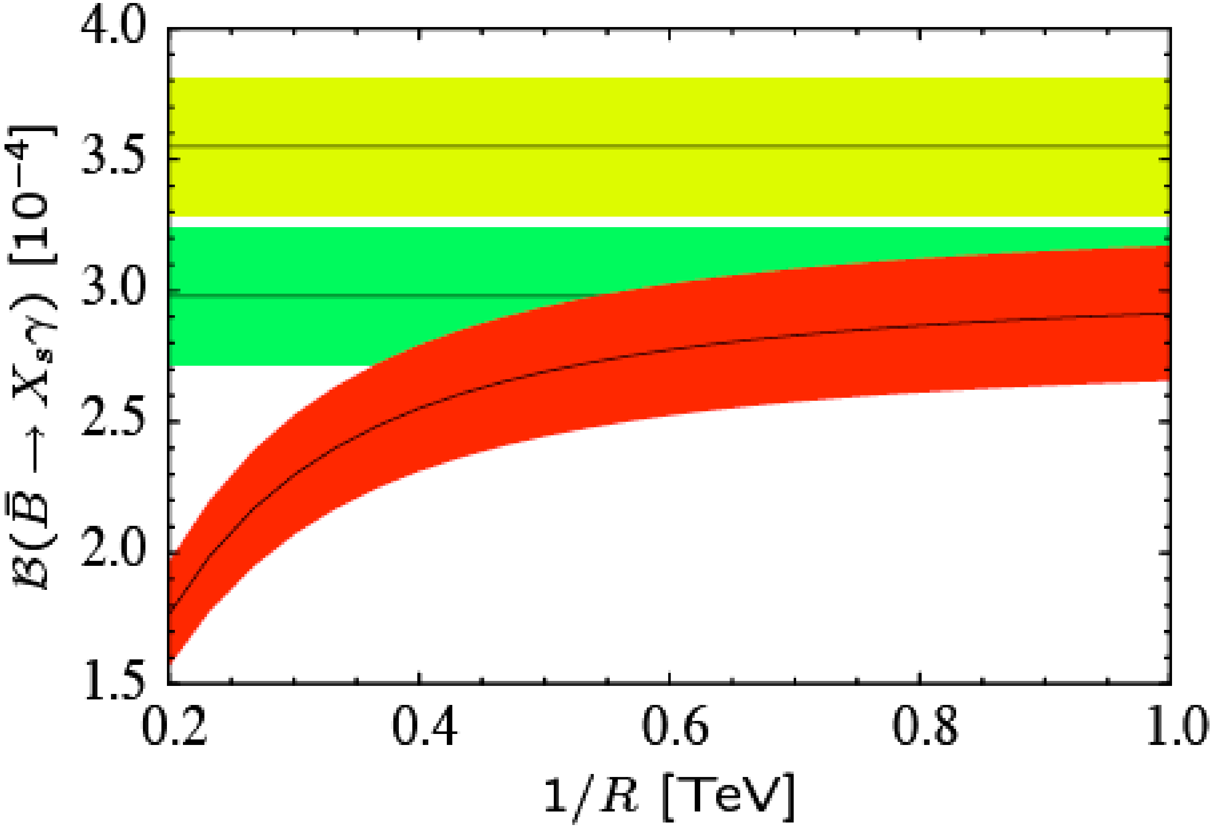
Example: Two-Higgs-Doublet Model-II at $\tan\beta = 2$: $\Rightarrow$ $M_{H^+} \succ 295$GeV at 95%CL



$\mathcal{B}(\bar{B} \to X_s\gamma)$ as a function of the charged Higgs boson mass (solid line)
Experiment/SM Theory, central values with 1σ bounds (dotted/dashed)

Misiak et al., hep-ph/0612231

Example: Bound on minimal universal extra dimensions $\Rightarrow 1/R \succ 600\text{GeV at } 95\%\text{CL}$



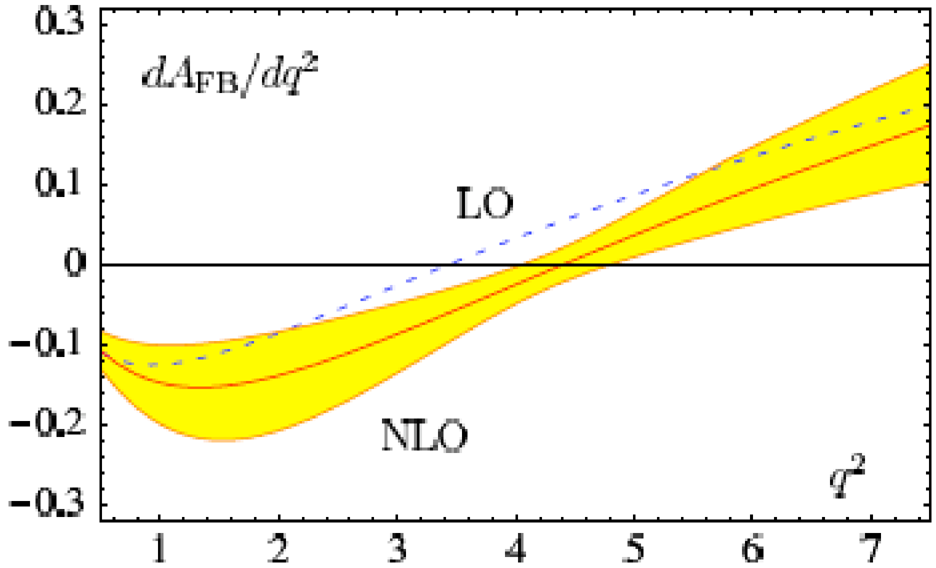
Red: LO-UED, Green: SM Theory, Yellow: Experiment

By far best bound !

Haisch,Weiler,hep-ph/0703064

Note: Flavour non-universal boundary terms arise radiatively.

Strategy II: Focus on ratios of exclusive modes like FBA in $B \to K^* \ell^+ \ell^-$



- At LO the zero depends on the short-distance Wilson coefficients only because the formfactor dependence cancels out:

$$q_0^2 = q_0^2(C_7, C_9), \quad q_0^2 = (3.4 + 0.6 - 0.5) GeV^2 \quad \text{(LO)}$$

- NLO contribution calculated within QCD factorization approach leads to a large shift: Beneke, Feldmann, Seidel, hep-ph/0412400

$$q_0^2 = (4.39 + 0.38 - 0.35) GeV^2 \quad \text{(NLO)}$$

- Note: Issue of power corrections $(1/m_b)$

Other examples: $\leftrightarrow$ $B_d \to \rho \ell^+ \ell^-$ or $B_s \to \Phi \ell^+ \ell^-$ $\leftrightarrow$ $B_s \to K^* \ell^+ \ell^-$ $[b \to s] \leftrightarrow [b \to d]$

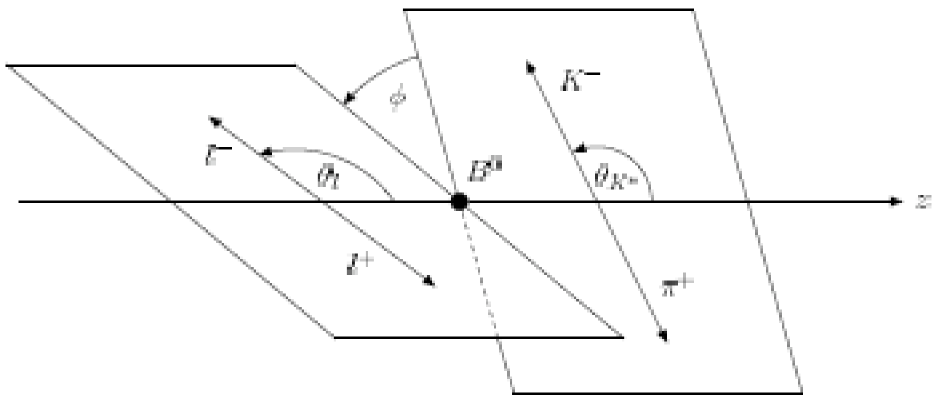
Transversity amplitudes in $B \to K^* \ell^+ \ell^-$ very sensitive probe for right-handed current

Further opportunity: Transversity amplitudes in $B \to K^* \ell^+ \ell^-$

Assuming the K^* to be on the mass shell, the decay $B^0 \to K^{*0}(\to K^- \pi^+)\ell^+\ell^-$ described by the lepton-pair invariant mass, s, and the three angles θ_l, θ_{K^*}, ϕ.

$$\frac{d^4\Gamma}{ds\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} \sum_{i=1}^{9} I_i(s, \theta_{K^*}) f_i(\theta_l, \phi),$$

I_i depend on the four K^* spin amplitudes A_i, f_i corresponding angular distributions



- In the heavy quark and large energy limit (at leading order in $1/m_b$ and α_s) the 7 $B \to K^*$ formfactors reduce to two universal ones in that limit!

- In specific transverse asymmetries those formfactors cancel out again and at leading order they depend on short-distance information only:

$$A_\perp^{(1)}(s) = \frac{-2\,\mathrm{Re}(A_\parallel A_\perp^*)}{|A_\perp|^2 + |A_\parallel|^2}, \quad A_\perp^{(2)}(s) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}.$$

- Including next-to-leading corrections and integrating over the low dimuon mass region $2m_\mu \leq M_{\mu^+\mu^-} \leq 2.5\,\text{GeV}$:

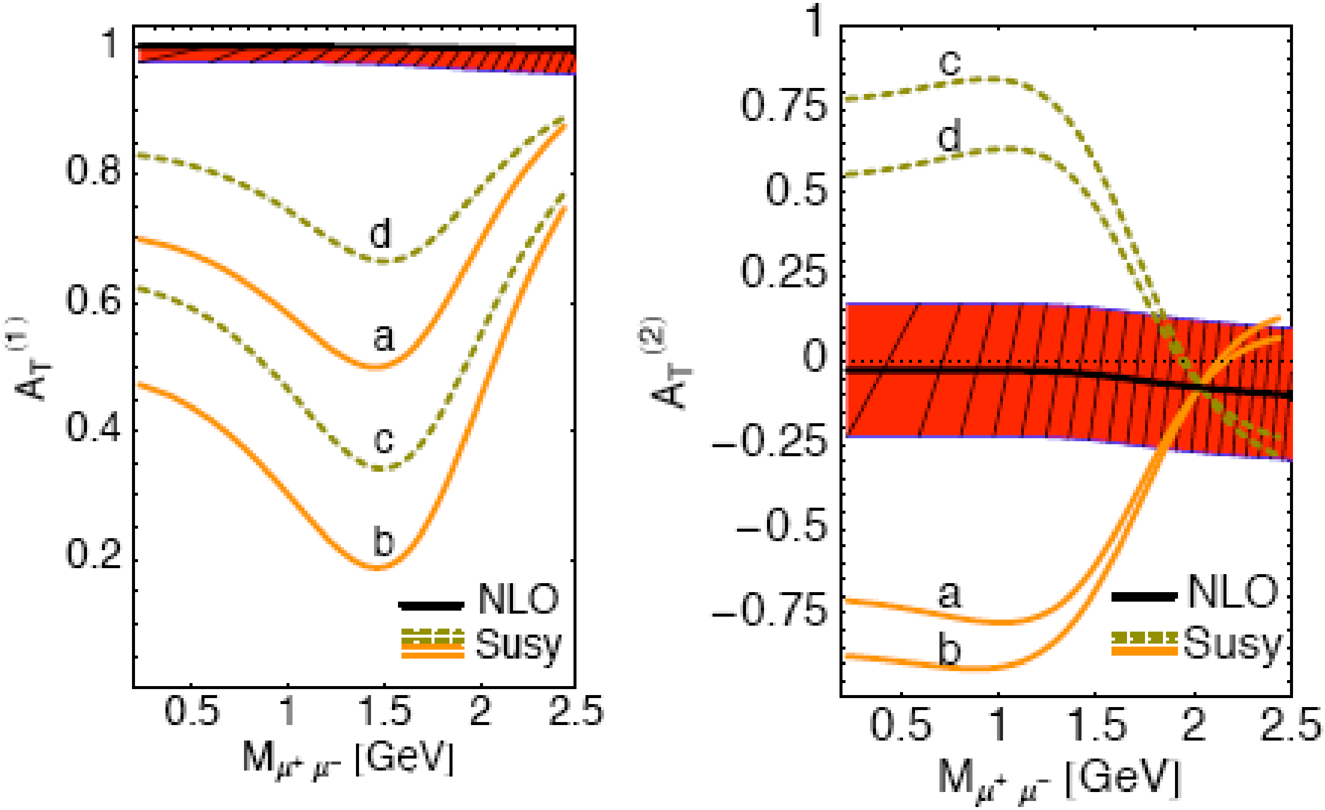
  $\mathcal{A}_T^{(1)} = 0.9986 \pm 0.0002, \quad \mathcal{A}_T^{(2)} = -0.043 \pm 0.003$

  Krüger,Matias,hep-ph/0502060 (underestimation of the error?)

- Sensitivity studies at LHCb work in progress

  The measurement of $A_\perp^{(1)}(s)$ is possible only via the measurement of all spin amplitudes while $A_\perp^{(2)}(s)$ looks more promising!

- A theoretically clean way to analyse the chiral structure of the $b \to s$ current
  Matias,Lunghi,hep-ph/0612166



Curves a-d Susy scenarios beyond MFV

Strategy IIII: Hadronic matrix elements known from experiment

Example: $K^+ \to \pi^+ \nu\bar{\nu}$

- BNL–E787/E949: three events 3/2004 !

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = \left(1.47\ ^{+\,1.3}_{-\,0.9}\right) \times 10^{-10}$$

- Present SM theory (in future error below 5% possible) Buras et al..

$$BR(K^+ \to \pi^+ \nu\bar{\nu})_{\rm SM} = (0.80 \pm 0.11) \times 10^{-10} \ .$$

What makes the neutrino modes $K \to \pi\nu\bar{\nu}$ so attractive?

- leading hadronic matrix element is known from K_{l3} decays: $< \pi \,|\, (\bar{s}d)_{V-A} \,|\, K >$
- amplitude dominated by short-distance due to quadratic GIM: $A^q \sim m_q^2 V_{qs} V_{qd}$

Neutrino modes as theoretically clean as inclusive B decays !

$\Rightarrow$ highly sensitive probe for degrees of freedom at higher scales

Main motivation: we need theoreticallly clean $s \to d$ transitions in order to test the main consequence of the MFV scenario:

usual CKM relations between $[b \to s] \leftrightarrow [b \to d] \leftrightarrow [s \to d]$ transitions

Proposed experiment at CERN, NA48/3: 'decay in flight'

80 $K^+ \to \pi^+ \nu \bar{\nu}$ events in about two years of data taking

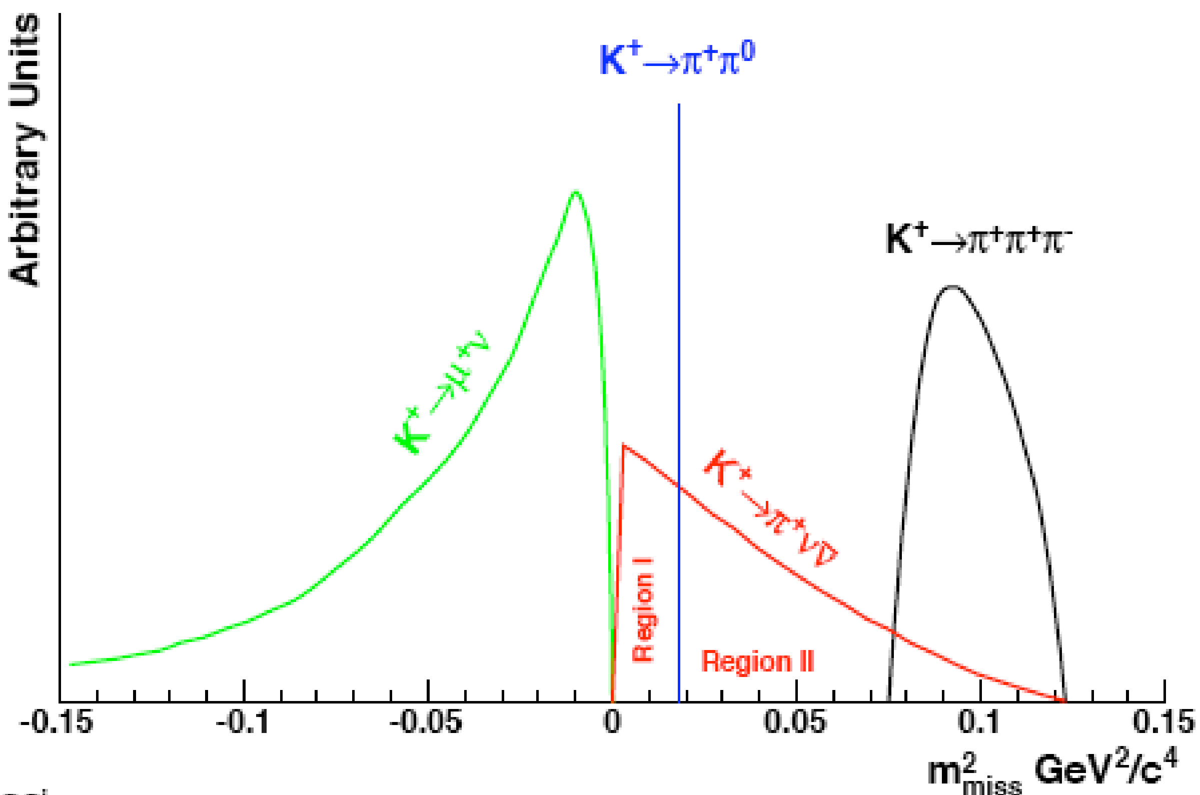
(4×10^{12} kaon decays/SPS year, 10% acceptance, SM)

Background rejection: kinematical rejection,photon vetoing and PID ($\mu \leftrightarrow \pi$)

Main Background $K^+ \to \pi^+ \pi^0$

γ veto much easier because of high energy kaon beam;

$P_K = 75 GeV/c$, with $P_{\pi^+} < 35 GeV/c$ we have $P_{\pi^0} > 40 GeV/c$



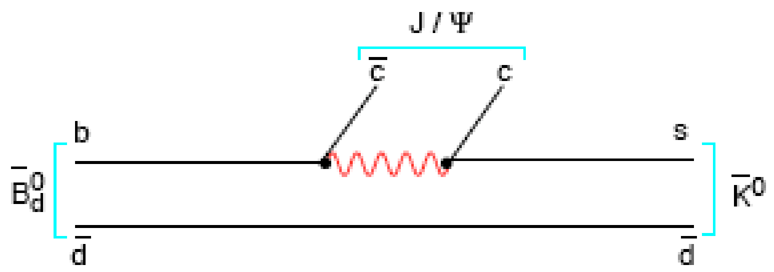
courtesy of A.Ceccucci

Addendum: Many more opportunities

- opportunity at LHC: $B_{s/d} \to \mu\mu$ Babu,Kolda
  - helicity suppression in the SM: $A_{SM} \sim m_\mu/m_b$
  - hadronic matrix element simple (f_B lattice calculations)
  - order-of-magnitude enhancements possible in multi-Higgs models even without new flavour structures: $A_{H^0,A^0} \sim tan^3\beta$
- angular distribution and transversity amplitudes in $B \to K^*\mu\mu$ and $B_s \to \Phi\mu\mu$ Melikhov,Nikitin,Simula; Kim,Kim,Lü; Krüger et al.; Krüger,Matias
- CP averaged isospin asymmetry $B^0 \to K^{*0}\mu^+\mu^-$ versus $B^\pm \to K^{*\pm}\mu^+\mu^-$ Feldmann,Matias
- $b \to se^+e^-$ versus $b \to s\mu^+\mu^-$ inclusive/exclusive Hiller
- CP violation in $B_d \to K^*\gamma$ and in $B_s \to \Phi\gamma$
- $B \to \rho\gamma$ / $B \to K^*\gamma$
- $B \to (D, D^*, X_c)\tau\nu$
- $B \to \tau\nu$, $B \to \mu\nu$
- $b \to s\nu\bar{\nu}$, $B \to K\nu\bar{\nu}$
-

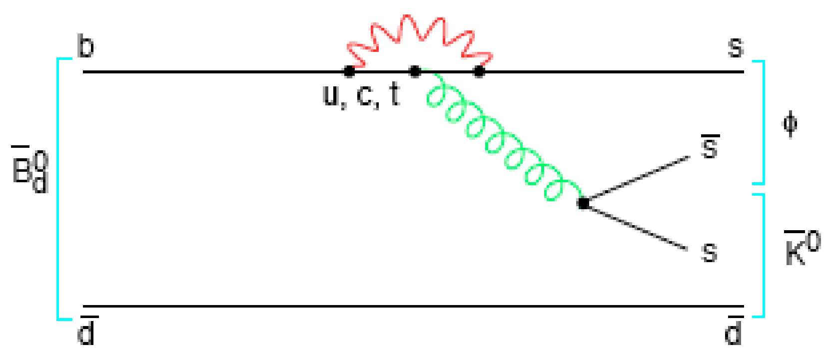
New physics in CP-violating observables ?

- SM is very predictive only one CP-violating parameter. (Kobayashi-Maskawa 1972 !)
- Baryon asymmetry: one needs more sources of CP violation, but not necessarily relevant at low energies
- KM mechanism has passed successfully its first precision test in tree process:



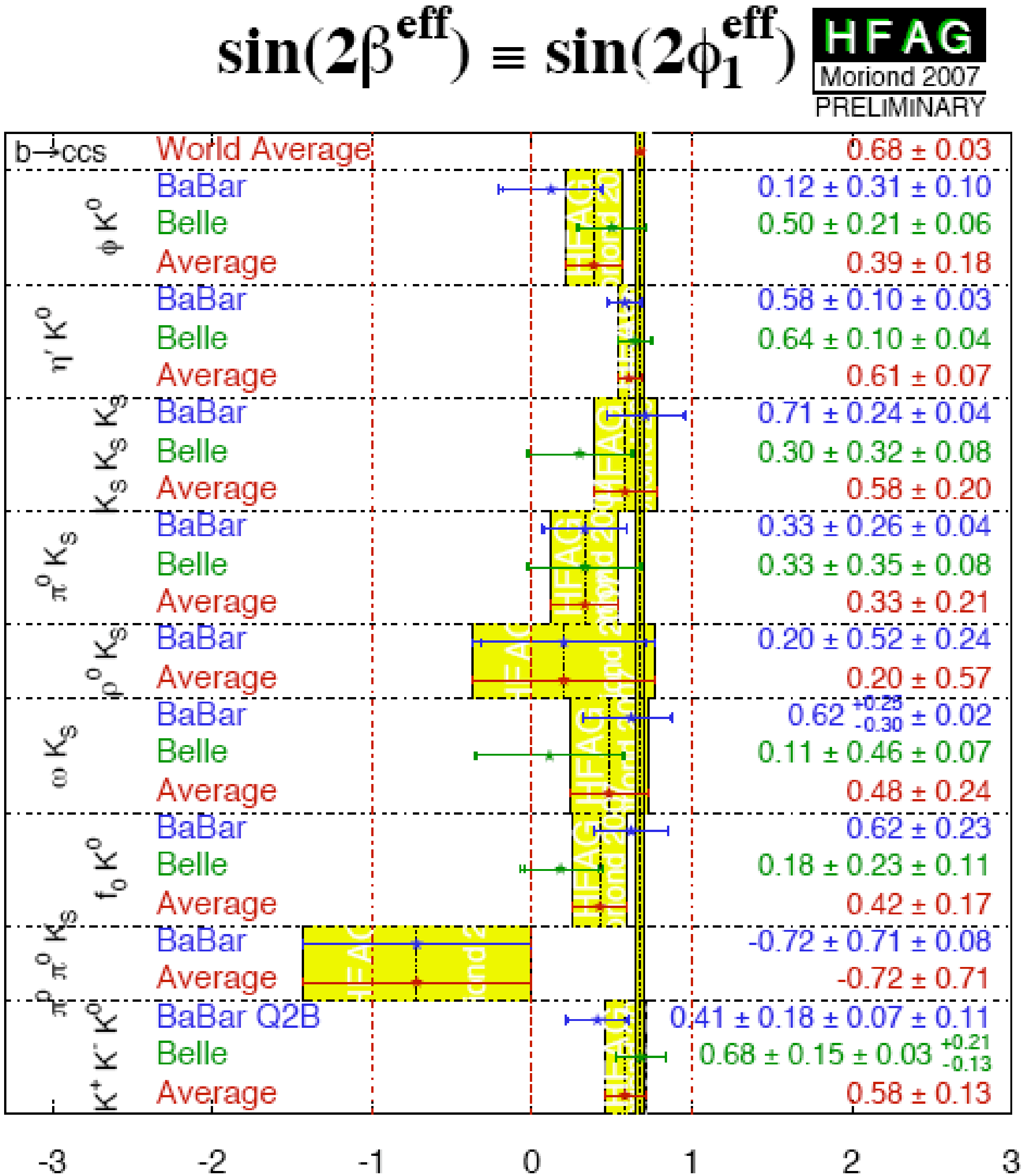
$$\sin(2\beta)(J/\psi K_S) = 0.67 \pm 0.03 \quad \leftrightarrow \quad \sin(2\beta)(\text{CKM fit}) = 0.75 + 0.06 - 0.04$$

- Test in $A_{CP}(B_d \to \Phi K_S)$ is still open Penguin



Not conclusive yet, various $b \to s\bar{s}s$ modes have different hadronic uncertainties

Estimation of possible deviations within SM important for detection of new physics



$\Delta\mathcal{S}_f \equiv -\eta_f \mathcal{S}_f - \mathcal{S}_{J/\psi K_s}$:

experimental central values for $\Delta\mathcal{S}_f$ are almost all negative,

while theoretical predictions based on short-distance calculations, QCDF, pQCD, SCET, are small and positive.

Good (theoretically clean) modes:

$\eta' K_S$, ΦK_S, $K_S K_S K_S$

- Mixing-induced CP asymmetries in $b \to s\gamma$ transitions
  - General folklore: within the SM are small, $O(m_s/m_b)$

$$\mathcal{O}_{7L} \equiv \frac{e}{16\pi^2} m_b \, \bar{s}\sigma_{\mu\nu} P_R \, b F^{\mu\nu} \quad \mathcal{O}_{7R} \equiv \frac{e}{16\pi^2} m_{s/d} \, \bar{s}\sigma_{\mu\nu} P_L \, b F^{\mu\nu} \; .$$

Mainly: $\bar{B} \to X_s \gamma_L$ and $B \to X_s \gamma_R$ $\Rightarrow$ almost no interference in the SM

  - But: within the inclusive case the assumption of a two-body decay is made, the argument does not apply to $b \to s\gamma gluon$

    Corrections of order $O(\alpha_s)$, mainly due operator $\mathcal{O}_2$ $\Rightarrow \Gamma_{22}^{\mathrm{brems}}/\Gamma_0 \sim 0.025$

    $\Rightarrow$ 11% right-handed contamination

    Grinstein,Grossman,Ligeti,Pirjol, hep-ph/0412019

  - QCD sum rule estimate of the time-dependent CP asymmetry in $B^0 \to K^{*0}\gamma$ including long-distance contributions due to soft-gluon emission from quark loops versus dimensional estimate of the nonlocal SCET operator series:

    Ball,Zwicky,hep-ph/0609037 $\leftrightarrow$ Grinstein,Pirjol,hep-ph/0510104

$$S = -0.022 \pm 0.015^{+0}_{-0.01}, \; S^{sgluon} = -0.005 \pm 0.01 \leftrightarrow |S^{sgluon}| \approx 0.06$$

Note: Expansion parameter is Λ_{QCD}/Q where Q is the kinetic energy of the hadronic part. There is no contribution at leading order. Therefore, the effect is expected to be larger for larger invariant hadronic mass, thus, the K^* mode has to have the smallest effect, below the ‘average’ 10%

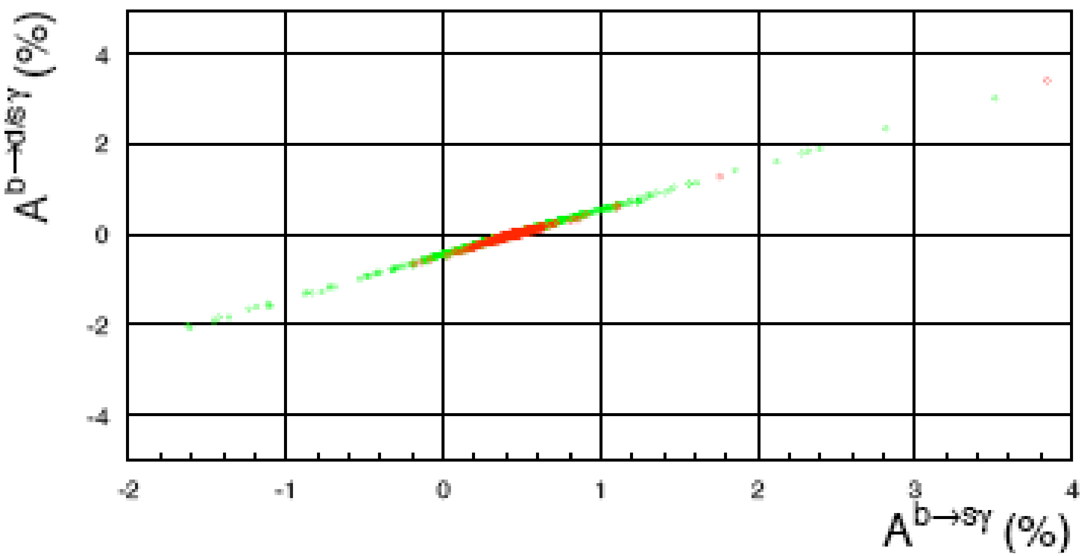
Experiment: $S = -0.28 \pm 0.26$

- Untagged direct CP asymmetries in $b \to s/d$ transitions

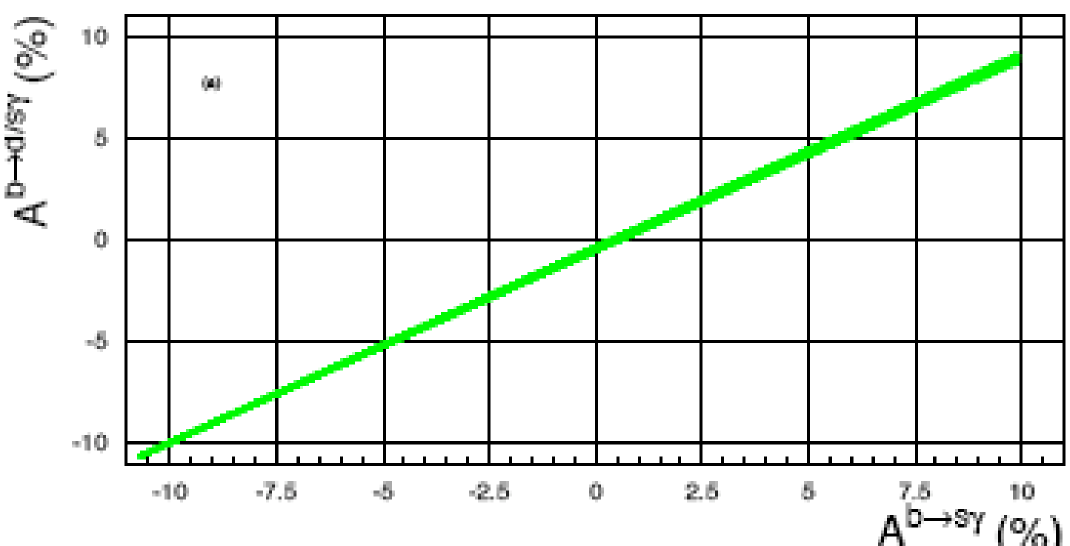
KM mechanism CKM unitarity + U spin symmetry of matrix elements $d \leftrightarrow s$:

$$|\Delta BR_{CP}(B \to X_s\gamma) + \Delta BR_{CP}(B \to X_d\gamma)| \sim 1 \cdot 10^{-9} \approx 0$$

Clean test, whether new CP phases are active or not
Hurth,Mannel,hep-ph/0109041; Hurth,Lunghi,Porod,hep-ph/0312260
Experiment: (Super-) B-factories ±3% (±0.3%) precision possible



MFV with (flavourblind) phases



Model-independent analysis C_7^s;

Is there a puzzle in hadronic $b \to s$ transitions ?

$B \to K\pi$ modes well-known for being sensitive to new electroweak penguins
Fleischer,Mannel; Grossman,Neubert,Kagan

Present data on CP averaged branching ratios:

$$R = \frac{\tau_{B^+}}{\tau_{B^0}} \frac{\text{BR}[B_d^0 \to \pi^- K^+] + \text{BR}[\bar{B}_d^0 \to \pi^+ K^-]}{\text{BR}[B_d^+ \to \pi^+ K^0] + \text{BR}[B_d^- \to \pi^- \bar{K}^0]} = 0.92 \pm 0.05$$

$$R_n = \frac{1}{2} \frac{\text{BR}[B_d^0 \to \pi^- K^+] + \text{BR}[\bar{B}_d^0 \to \pi^+ K^-]}{\text{BR}[B_d^0 \to \pi^0 K^0] + \text{BR}[\bar{B}_d^0 \to \pi^0 \bar{K}^0]} = 1.00 \pm 0.07$$

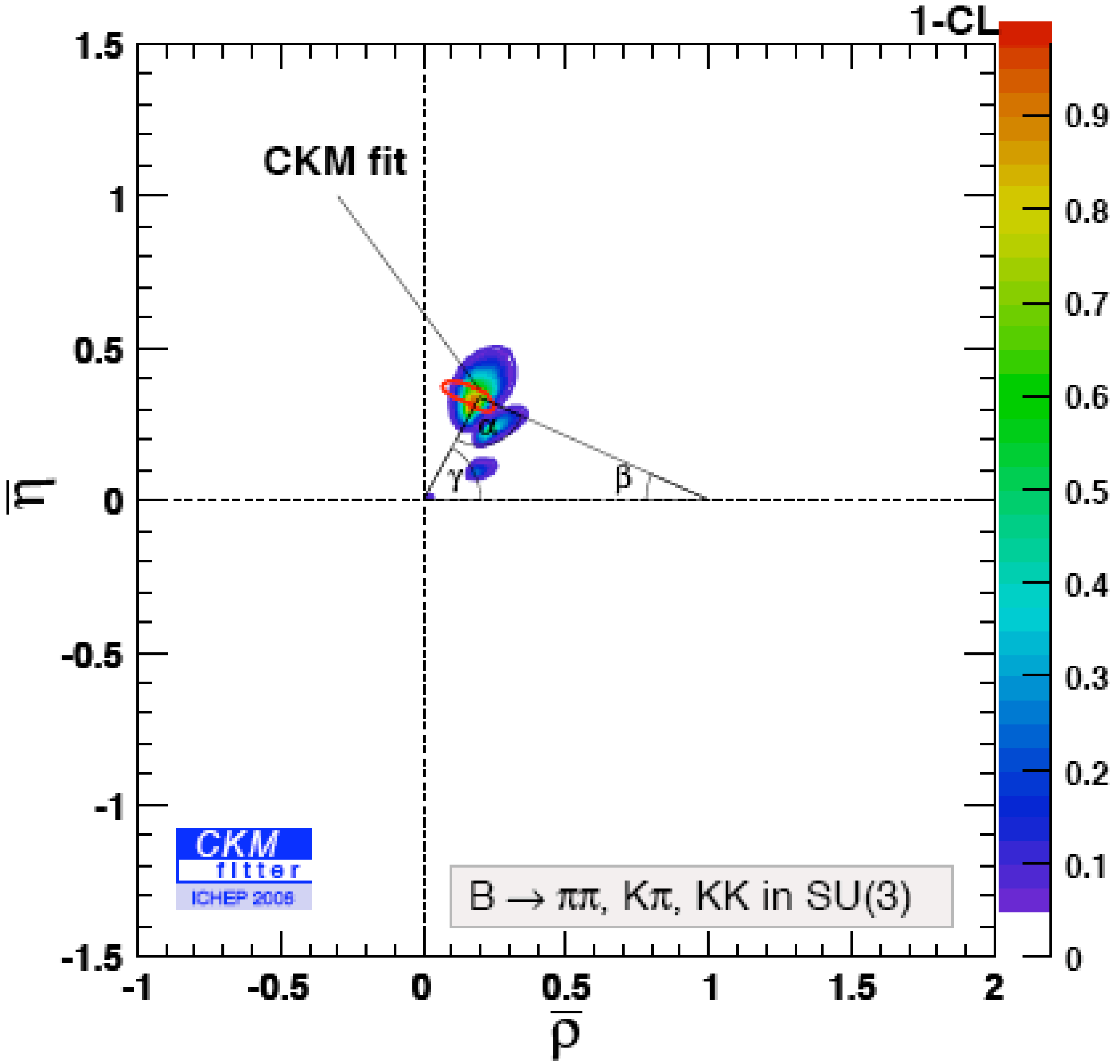
$$R_c = 2 \frac{\text{BR}[B_d^+ \to \pi^0 K^+] + \text{BR}[B_d^- \to \pi^0 K^-]}{\text{BR}[B_d^+ \to \pi^+ K^0] + \text{BR}[B_d^- \to \pi^- \bar{K}^0]} = 1.10 \pm 0.07$$

- pre-ICHEP06 data:
  $R = 0.84 \pm 0.06$, $R_n = 0.82 \pm 0.08$, $R_c = 1.00 \pm 0.09$
- pre-ICHEP04 data:
  $R = 0.91 \pm 0.07$, $R_n = 0.76 \pm 0.10$, $R_c = 1.17 \pm 0.12$
- Approach based on QCD factorization (BBNS)
  $R = 0.91^{+0.13}_{-0.11}$, $R_n = 1.16^{+0.22}_{-0.19}$, $R_c = 1.15^{+0.19}_{-0.17}$
- SM-Fit to $\pi\pi + SU(3)_F$ Buras et al.,hep-ph/0512032
  $R = 0.96 \pm 0.02$, $R_n = 1.12 \pm 0.05$, $R_c = 1.15 \pm 0.05$
  (errors reflect only exp. uncertainties of $B \to \pi\pi$; certain annihilation/exchange tops. neglected)

Additional uncertainties:

- large nonfactorizable contributions allow for large $SU(3)_F$ breaking, especially isospin-violating effects Feldmann, Hurth, hep-ph/0408188
- radiative corrections to decays with charged particles in the final states have now been taken into account properly in the experimental analysis as proposed in Baracchini, Isidori, hep-ph/0508071

New, more complete $SU(3)$ analysis CKM fitter group, see also hep-ph/0606083
(no contributions neglected, using all available modes, fact. $SU(3)_F$ break.only)



constraint in the $(\bar{\rho}, \bar{\eta})$ plane:

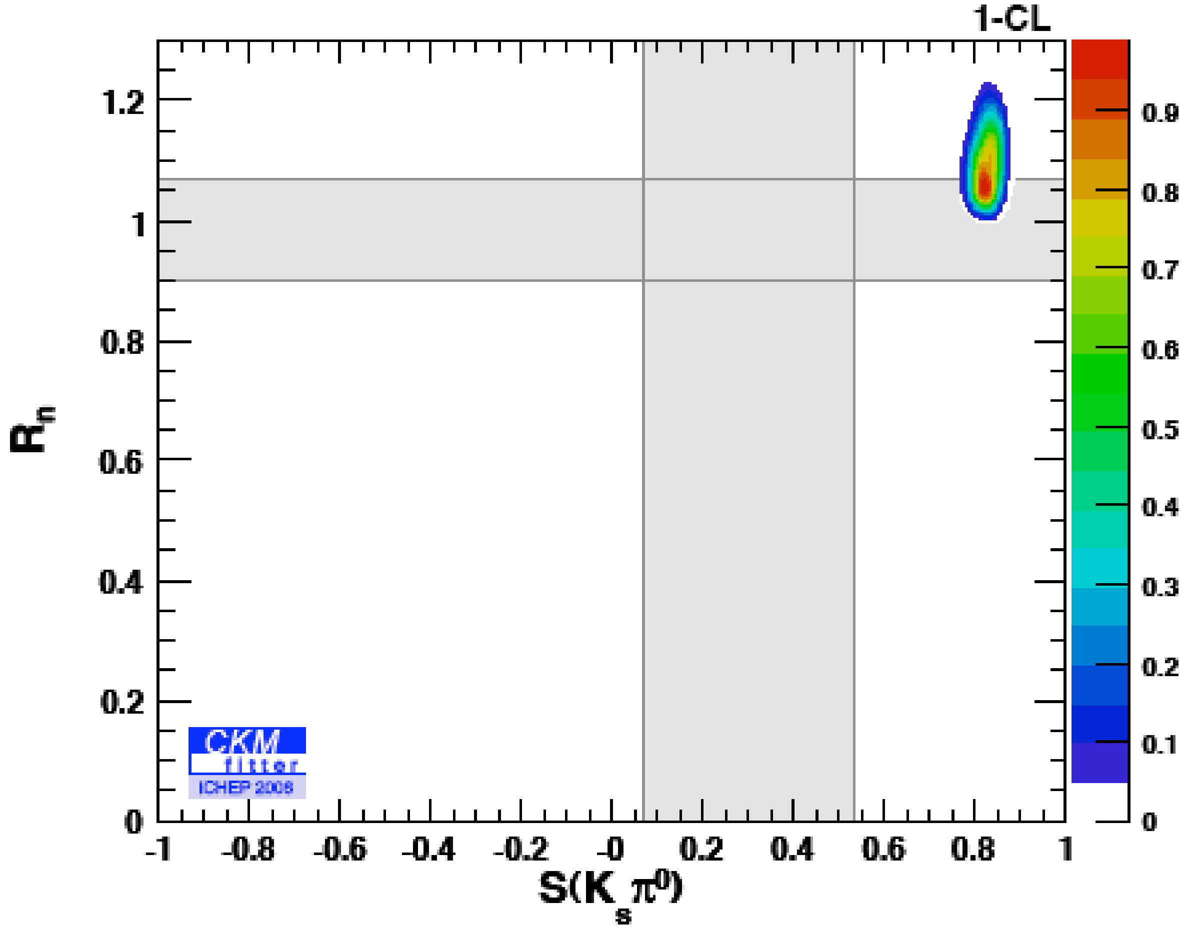
pValue of the SM analysis is of order $30 - 40\%$

(compatibilty of the data with the $SU(3)$ + SM hypothesis is very good)

Not always χ^2_{min} the best measure of the compatibility of the data with the theory

Main contributions to the χ^2 are $BR(K^+\pi^-), BR(K_s\pi^0), S(K_s\pi^0)$

Comparison of the output of the indirect fit with the direct measurements:



CKM fitter group

Input:

$\bar{\rho}, \bar{\eta}$ from the CKM fit and

all available modes besides

$BR(K^+\pi^-), BR(K_s\pi^0), S(K_s\pi^0)$

.

colored area $\leftrightarrow$ 2σ contour

direct measurements 1σ band

Future will tell us: We will have up to 38 measured observables depending on the same 13+2 theoretical parameters (study of $SU(3)$ break. and new physics possible)

Final remarks on the indirect search for new physics:

- If there is new physics within the LHC reach, then there is a flavour problem.
- To detect subtle patterns and to distinguish between the various new physics scenarios, measurements of complex kinematical distributions are necessary (CP, FBA, isospin and polarization asymmetries).
- Focus on theoretically clean observables mandatory.
- Fighting QCD effects in rare B decays:
  - Impact of NNLL (NLL) QCD calculations in inclusive modes are crucial!
  - In exclusive modes the issue of $1/m_b$ corrections to QCD factorization has to be improved. New theoretical tools are necessary.
- Interplay of collider and flavour physics:
  The indirect information will be most valuable when the general nature of new physics will be identified in the direct search (LHC), specifically when the mass scale of the new physics will be fixed.

Community is proposing SuperB Flavour factories

- Babar will end in 2008, but Belle is proposing a major upgrade (Super-KEK)

  Letter of Intent for KEK Super B Factory (KEK Report 2004-4)

  Part of the 'Japanese HEP master plan'

- Several studies on the physics case of a SuperB factory:

  Physics at a Super B Factory
  hep-ex/0406071, updated version will appear soon

  The Discovery Potential of a Super B Factory
  SLAC-R-709, hep-ph/0503261

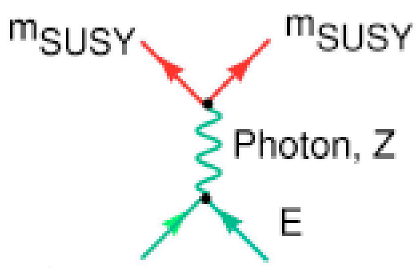
- Recent proposal: A High-luminosity Flavour Factory

  Conceptional Design Report (CDR) available at http://www.pi.infn.it/SuperB

  Different design partially based on ILC

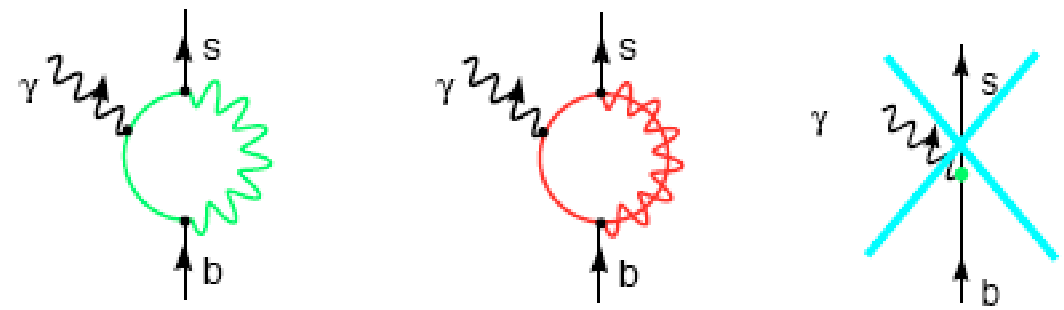
Analysis of new physics via

1) energy frontier gauge sector, EWSB



LHC,superLHC,ILC,CLIC,...

2) luminosity frontier flavour sector



Experiments on neutrinos, charged leptons, quarks (sLHCb, upgraded B factories, kaons)

We have to keep both options open!

Flavour problem, origin of neutrino masses, new sources of CP violation, $g-2$, EDM, lepton flavour violation, relation of flavour structure in the lepton and quark sectors, tau decays

Experimental evidence beyond SM:
Dark Matter
Neutrino masses
Baryon asymmetry of the Universe