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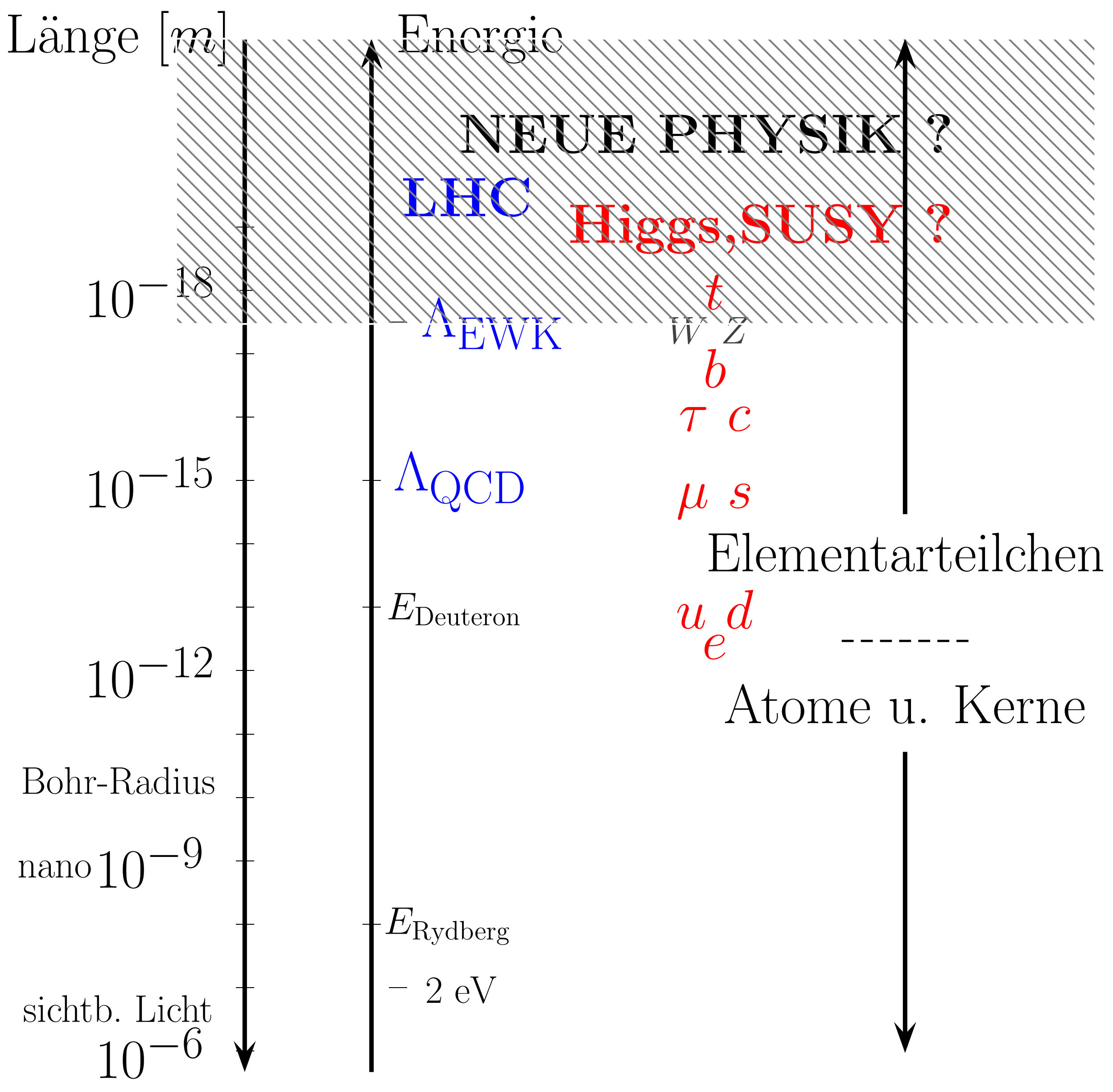
“Implications of current and future b-data for beyond-the-SM Physics”

CKM $\rightarrow$ see talk by H.Boos

QCD (SCET et al) $\rightarrow$ see talks by N.Offen, S.Jäger

SM=Standard Model, NP=New Physics, EWKSB=electroweak symmetry breaking, FCNC=Flavor changing neutral currents


Länge [m]
Energie
NEUE PHYSIK ?
LHC
Higgs,SUSY ?
10^{-18}
$\Lambda_{\rm EWK}$
t
W Z
b
τ c
10^{-15}
$\Lambda_{\rm QCD}$
μ s
Elementarteilchen
$E_{\rm Deuteron}$
u d
e

10^{-12}
Atome u. Kerne
Bohr-Radius
nano 10^{-9}
$E_{\rm Rydberg}$
2 eV
sichtb. Licht
10^{-6}

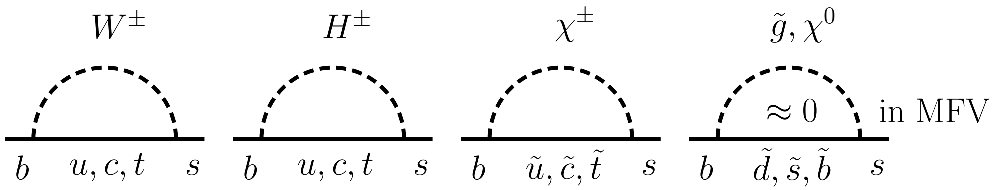
SM tests with indirect processes

indirect loop processes: $\Lambda \gtrsim m_W$ scale of New Physics

$$\mathcal{L}_{eff} = \sum_i c_i^{(n)} \frac{O_i^{(n)}}{\Lambda^n} \qquad c_i^{(n)} \leftrightarrow f(\underbrace{m_j, g_l, \ldots}_{colliders}; \underbrace{\varphi_{\rm CKM}, \varphi_m, \delta_n}_{flavorphysics})$$

no competition from large SM tree contributions

FCNC: sensitivity to SM, NP phases φ, flavor-breaking couplings δ



MFV $=$ no more flavor/CP violation than in SM, i.e. in Yukawas (CKM) $U(3)^5$ symmetry only broken by "Y" spurions; RG-invariant

Flavor breaking in SUSY

superpotential leads to CKM-like flavor-viol. (w. unbroken R-parity)

$$-\mathcal{L}_{soft} \supset \tilde{Q}^\dagger m_Q^2 \tilde{Q} + \tilde{U}^\dagger m_U^2 \tilde{U} + \tilde{D}^\dagger m_D^2 \tilde{D} + A_U \tilde{Q} H_U \tilde{U} + A_D \tilde{Q} H_D \tilde{D}$$

squark masses (A-terms) : 3×3 hermitean (complex) matrices

super-CKM basis: quarks$=$mass eigenstates, squarks not UNLESS

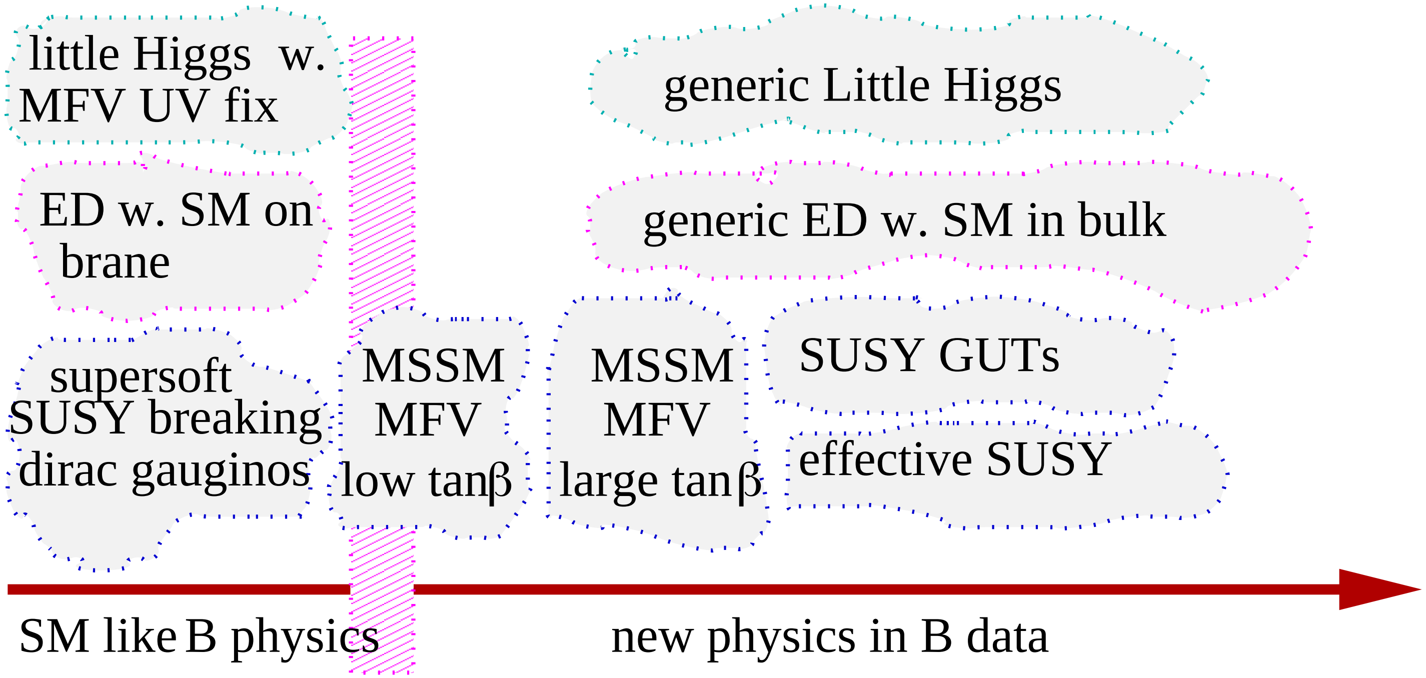
$$m^2_{Q,D,U} \propto 1 \text{ and } A_{U,D} \propto Y_{U,D} \qquad (1)$$

beyond (1) $\rightarrow$ large # of new sources of flavor/CP violation

(1) realized in GMSB, AMSB, CMSSM

beyond MFV terms in $b \rightarrow s$ motivated from GUTs from large $\nu_\mu - \nu_\tau$ oscillations $\rightarrow$ sizeable effects in $B_s - \bar{B}_s$-mixing hep-ph/0212180, 0212397 models of EWKSB with NP @ TeV

Fig from hep-ph/0207121



reach in indirect signals rare b, c, K, τ-decays, mixing, EDMs, g-2
depends on beyond the SM flavor/CP violation (minimal=CKM ?),
large parameters e.g. $\tan\beta$ and theor. and exp. uncertainties

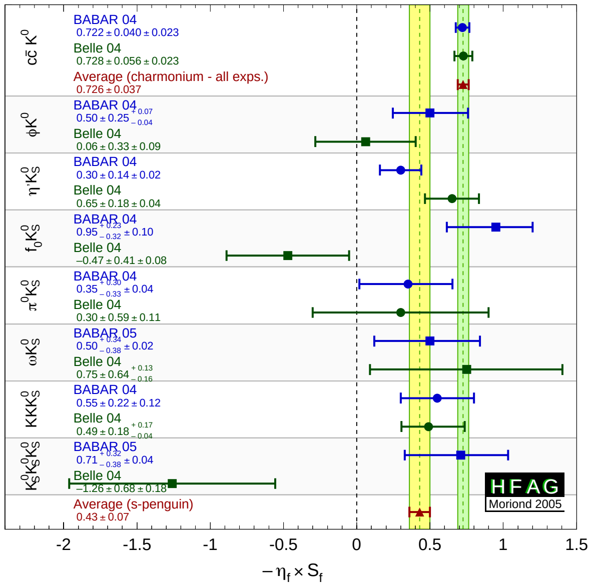
- Introduction: New Physics effects in b-physics $\checkmark$
- Searching for BSM phases in $b \to s$: "$\sin 2\beta$" measurements*
- Recent and future SM tests from $b \to s\gamma$, $b \to s\ell^+\ell^-$ processes
- Flavor violation in models beyond the minimal model
  - R-parity violating effects in double radiative decays
  - light A^0 in NMSSM at large $\tan\beta$
- Outlook

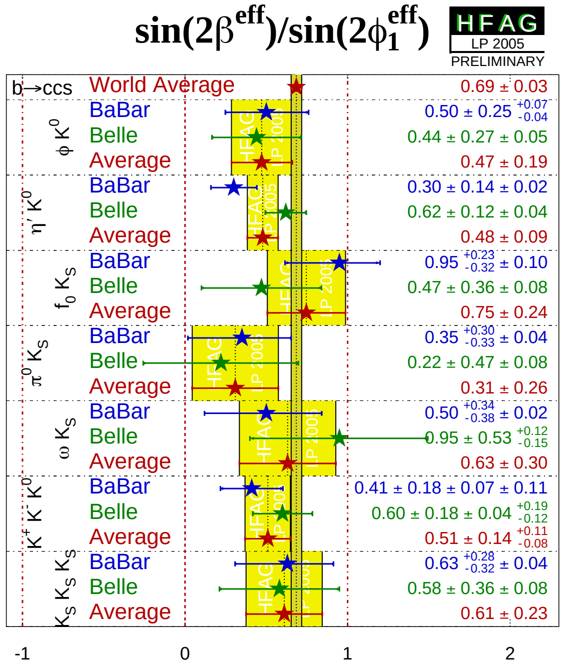
*in this talk β denotes the phase of $B\bar{B}$-mixing, i.e. $\beta_{\rm eff}$

Time-dependent CP asymmetries in $b \to s\bar{q}q$ decays

SM+MFV: $-\eta_{CP} \sin 2\beta(\underbrace{(\bar{s}s)K_S}_{FCNC}) = \sin 2\beta(\underbrace{(\bar{c}c)K_S}_{tree}) + |\underbrace{\frac{V_{ub}V_{us}^*}{V_{tb}V_{ts}^*}}_{\mathcal{O}(\lambda^2)}| \cdot \#$

SM background $\mathcal{O}(\lambda^2) \sim 0.04$, $\#$ non-universal, hadronic physics





since Moriond: $\sim 1\sigma$ shifts in $\bar{c}c$, Φ, larger ones in K_S^3, f_0; η' off by 2.3σ

better agreement between Belle and BaBar

SM background to ΔS

$\Delta S = -\eta_f S_f - \sin 2\beta$ hep-ph/0505075, 0503151 hep-ph/9708305, 0310020, 0303171, 0403287

f	$\Delta S_{SM}^{QCDF@NLO}$	$\Delta S_{SM}^{QCDF@LO}$	$\vert\Delta S_{SM}^{SU(3)+}\vert$	S_f LP'05	C_f LP'05
ΦK^0	$0.01\ldots0.03$	0.02	$\lesssim 0.3$	0.47 ± 0.19	-0.09 ± 0.14
$\eta' K^0$	$0\ldots0.02$	$-0.01\ldots0.02$	$\lesssim 0.15$	0.48 ± 0.09	-0.08 ± 0.07
$\pi^0 K_S$	$0.03\ldots0.12$	$0.03\ldots0.10$	$\lesssim 0.2$	0.31 ± 0.26	-0.02 ± 0.13
ωK_S	$0.05\ldots0.22$	$0.05\ldots0.25$	–	0.63 ± 0.30	-0.44 ± 0.23

LO captures central value and uncertainty of full NLO calc. of ΔS_f

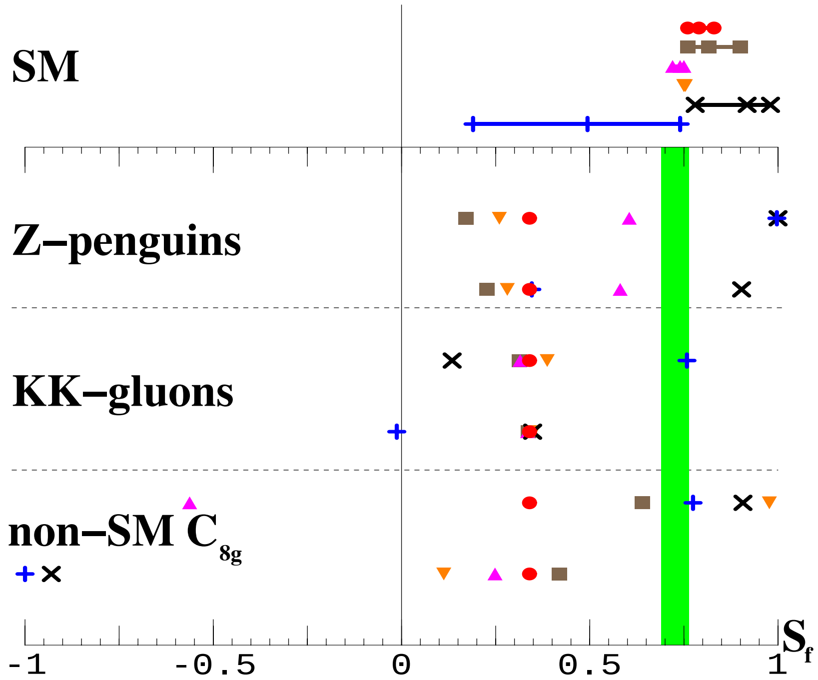
for all above modes: QCD factorization predicts $\Delta S_f > 0$, experimental shifts < 0; no significant $C_f \neq 0$

ultimately more precision needed; all exp. errors $\lesssim 0.1$ only by time of super-b-factory hep-ph/0503261

Pattern of NP in $b \to s$ Penguin modes

generic NP scenarios with one additional phase, use QCDF @ LO

hep-ph/0503151



input: $S_{\pi^0 K_S} = 0.34$ ● and maximal NP amplitude ok with other data

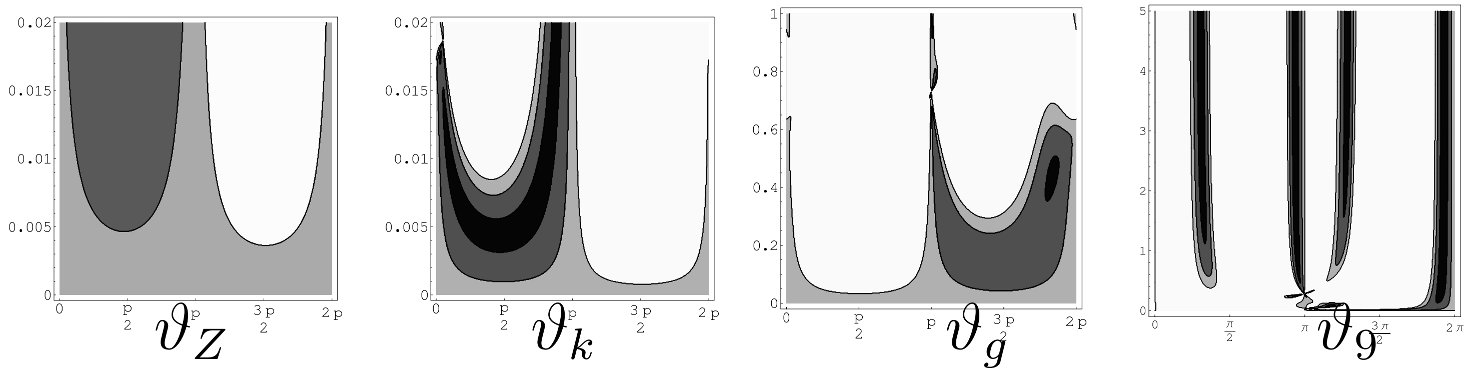
predict S_f for: ▼ $= \Phi$, ▲ $= \eta'$, ■ $= \eta$, $\times = \omega$, $+ = \rho$

goal: identify type of NP from characteristic SM departure

Fit generic NP scenarios to current data

$A = A_{SM} + A_{NP}$; $A_{NP} \propto \epsilon_i e^{i\vartheta_i}$; 3 NP scenarios sZb, KK, sbg hep-ph/0503151

χ^2-fit to $b \to s$ penguin data, LP‘05 update



black, dark grey, light grey regions: probability $>$ 0.32, 0.046, 0.0027

$A_{NP} >> A_{SM}$: 4-fold solution $\sin 2(\beta + \vartheta) \simeq 0.4$ (with $\cos 2\beta > 0$)

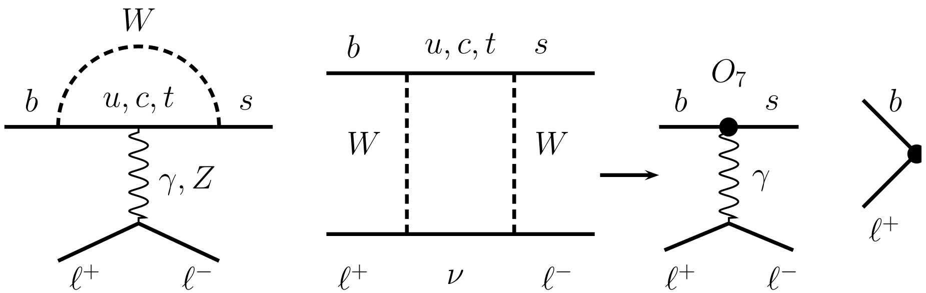
NP amplitudes can be larger if no phase $\vartheta = 0, \pi$

all 3 scenarios have solution, which is more favored than SM $(\epsilon_i = 0)$

Some (further) SM tests with b-physics

	experiment	SM	comments
$a_{CP}(b \to s\gamma)$	$0.4 \pm 3.6\,\%$	$0.42 \pm 0.17\,\%$ hep-ph/0312260	CPX in $bs\gamma, g$
$a_{CP}(b \to d/s\gamma)$	-0.110 ± 0.116 BaBar'05	10^{-9} hep-ph/0312260	test MFV
$S_{K_S \pi^0 \gamma}$	0.00 ± 0.28 Belle/BaBar'05	$-2m_s/m_b$	V+A FCNCs
$\mathcal{B}(B \to X_s g)$	$< 9\%$ CLEO'97	$5.0 \pm 1.0 \cdot 10^{-3}$	NP in bsg
$\mathcal{B}(B \to X_s \bar{\mu}\mu)$	$4.3 \pm 1.2 \cdot 10^{-6}$	$4.3 \pm 0.7 \cdot 10^{-6}$	q^2-spectra
$a_{CP}(B \to X_s \bar{\ell}\ell)$	-0.22 ± 0.26	-0.2 ± 0.2 % hep-ph/9812267	CPX
$A_{FB}^{CP}(B \to K^* \bar{\ell}\ell)$	–	$\lesssim 10^{-3}$ hep-ph/0006136	CPX in bsZ
R_K $\mu\mu$ vs. ee	1.06 ± 0.48 BaBar'05	$1 + \mathcal{O}(m_\mu^2/m_b^2)$ hep-ph/0310219	non-SM Higgs
$\mathcal{B}(B \to K \nu \bar{\nu})$	$< 3.6 \cdot 10^{-5}$ Belle'05	$3.8^{+1.2}_{-0.6} \cdot 10^{-6}$	$O(10)$ from SM
$\mathcal{B}(B_s \to \mu^+ \mu^-)$	$< 5.8 \cdot 10^{-7}$	$3.2 \pm 1.5 \cdot 10^{-9}$	$O(100)$ from SM
$\mathcal{B}(B_s \to \tau^+ \tau^-)$	$< \mathcal{O}(5\%)$	$7.2 \pm 1.1 \cdot 10^{-7}$	$O(10^5)$ from SM
Δm_s	$> 15/\mathrm{ps}$	$(15 - 22)/\mathrm{ps}$	hadron colliders

diagrams in SM



$$\mathcal{H}_{eff} = -4\frac{G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum C_i(\mu) O_i(\mu)$$

dipole operators $O_7 \propto \bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu}$ $\quad O_8 \propto \bar{s}_L \sigma_{\mu\nu} b_R G^{\mu\nu}$

4-Fermi operators $O_9 \propto (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \ell)$ $\quad O_{10} \propto (\bar{s}_L \gamma_\mu b_L)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$

NP in Wilson coefficients $C_i = C_i^{SM} + C_i^{NP}$ or new operators

model-independent analysis: Br‘s, $A_{CP}, A_{FB} = f(C_i) \to$ fit !

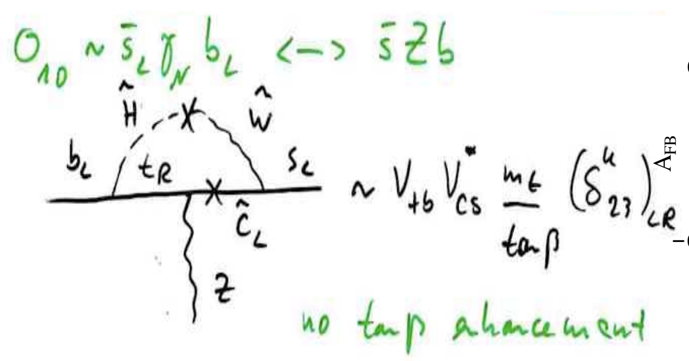
Impact of $b \to s\ell^+\ell^-$ beyond MFV, perspectives

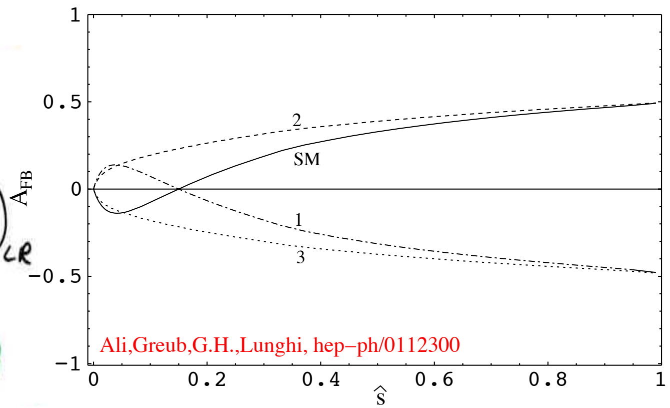
$\mathcal{B}(b \to s\ell^+\ell^-)$: best bound on $\bar{s}Zb$-penguin $\sim C_{10} \lesssim 2C_{10}^{\rm SM}$

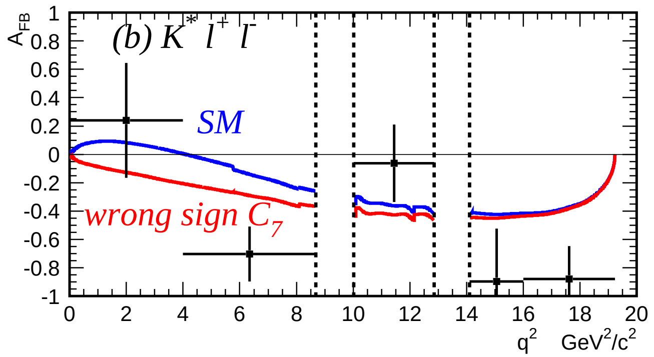
SUSY O(1) effects in C_{10} from δ_{23}^U possible (LR and LL) hep-ph/9906286,0006136

great NP sensitivity in q^2-spectra in $b \to s\ell^+\ell^-$; asy # forward - # backward ℓ^+ in dilepton CMS w.r.t. $\bar{B}$ needs tagging $A_{FB}^{SM} + \bar{A}_{FB}^{SM} \simeq 0$

$A_{FB}(\hat{s}) \sim {\rm Re}\left[C_{10}^*(C_7^{eff} + \beta(\hat{s})C_9^{eff})\right]$ also $B \to K^*\ell^+\ell^- \to$ Belle'04



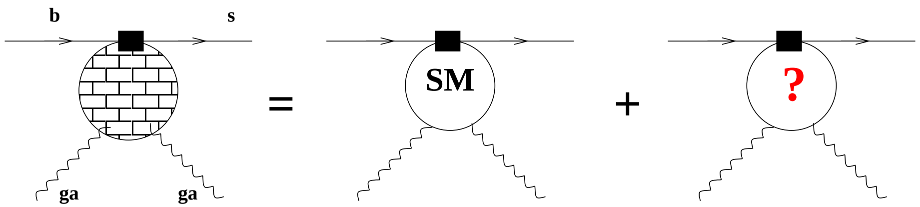




shape sensitive to signC_7; $A_{FB} \propto C_{10}$; flat possible

zero allows precision test $\hat{s}_{SM}^{NNLL} = 0.162 \pm 0.002(8)$ hep-ph/0208088,0209006

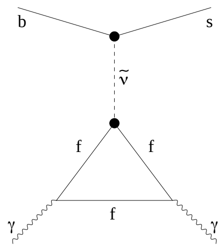
NP in $bs\gamma + \gamma$ tightly constrained by $\mathcal{B}(B \to X_s\gamma)$, but 1PI has room



impact of 4-Fermi's higher order in $b \to s\gamma$, lepton-loop down by α_{em}

$b \to s\tau^+\tau^-$ essentially unconstrained $\mathcal{B}(B_s \to \tau^+\tau^-) < 5\%$ hep-ph/0411344

R-parity viol.: biggest contribution from $\tilde{\nu}_\mu$ through $\lambda'_{232}\lambda_{233}$ hep-ph/0404152



RPV: $Br/Br_{SM}(B_s \to \gamma\gamma) \lesssim 16 \qquad Br/Br_{SM}(B \to X_s\gamma\gamma) \lesssim 5$

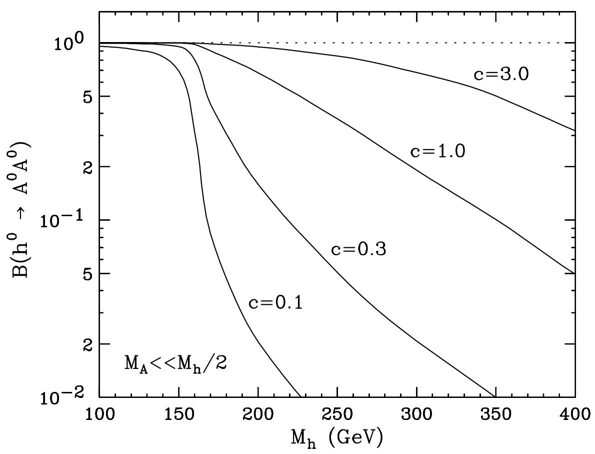
model-independently: $Br/Br_{SM}(B \to K\gamma\gamma) \lesssim O(10)$ hep-ph/0411344

$\mathcal{B}^{L3}(B_s \to \gamma\gamma) < 1.48 \cdot 10^{-4} \simeq 10^2 \cdot \mathcal{B}_{SM}(B_s \to \gamma\gamma)$

Light CP-odd A^0: implications for hadron colliders

direct searches: $h^0 \to A^0 A^0$ open if $2m_{A^0} < m_{h^0}$

can be VERY important for $\mathcal{O}(1)$ $h^0 A^0 A^0$-coupling c hep-ph/0005308



decay modes: $A^0 \to b\bar{b}, \tau\tau$, 3π or higher hadronic, $\mu\mu, ee, \gamma\gamma$

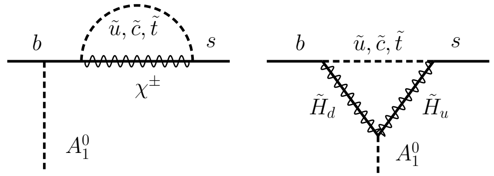
if A^0 very light and weakly coupled, it becomes missing energy

Υ-decays, beam dump, astro physics $m_{A^0} \gtrsim \mathcal{O}(100\text{MeV})$ ok

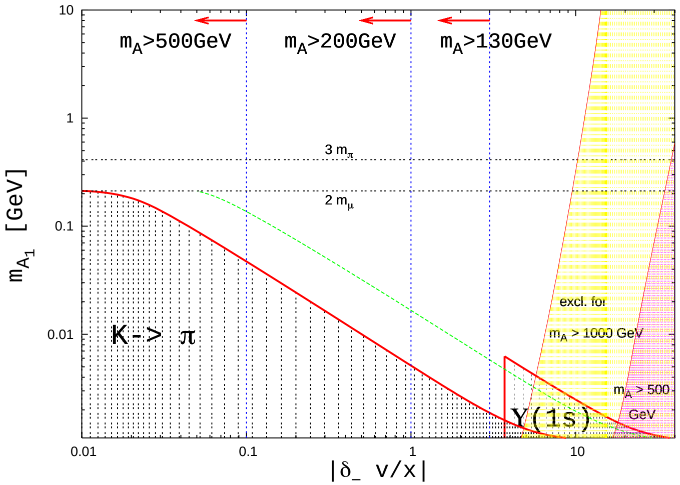
NMSSM constraints from indirect signals

$W = QY_uH_uU + QY_dH_dD + LY_eH_dE + \lambda H_dH_uN - \frac{1}{3}kN^3$ N:singlet

at large $\tan\beta$: naturally light A_1^0, rad. stable $\qquad b \to sA_1^0$ transitions



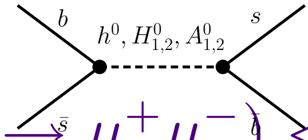
bounds from $B \to KA_1^0$, $K \to \pi A_1^0$, $\Upsilon(1s) \to \gamma A_1^0$ decays



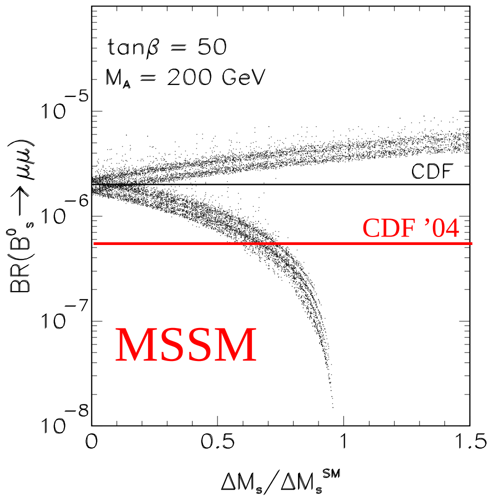
A_1^0 masses as low as $\mathcal{O}(10\text{MeV})$ viable hep-ph/0404220

Light CP-odd A^0: further tests from b-physics

- improve bounds from radiative Υ-decays or $B \to K +$ missing E
- for $m_{\psi'} < m_{A_1^0} \lesssim m_B$: search for A_1^0 in $b \to s\tau^+\tau^-$ processes
  sensitivity e.g. $\mathcal{B}(B \to X_s \tau^+\tau^-) \sim 10^{-3}$



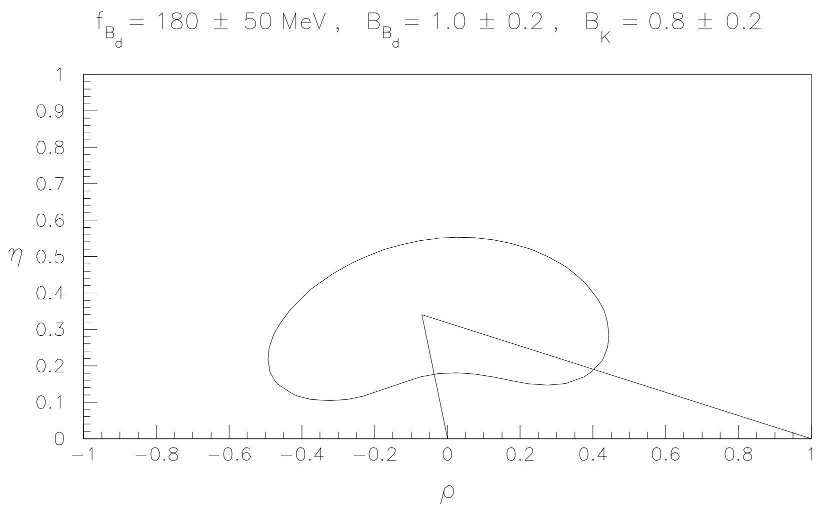
- $B_s - \bar{B}_s$ mixing and $B_s \to \mu^+\mu^-$ CDF: $\mathcal{B}(B_s \to \mu^+\mu^-) < 5.8 \cdot 10^{-7}$
  in MSSM correlated Fig adopted from hep-ph/0207241
  in NMSSM: SM-like Δm_s (A_1^0 contribution constrained by Δm_d),
  but not correlated with $\mathcal{B}(B_s \to \mu^+\mu^-)$ hep-ph/0404220



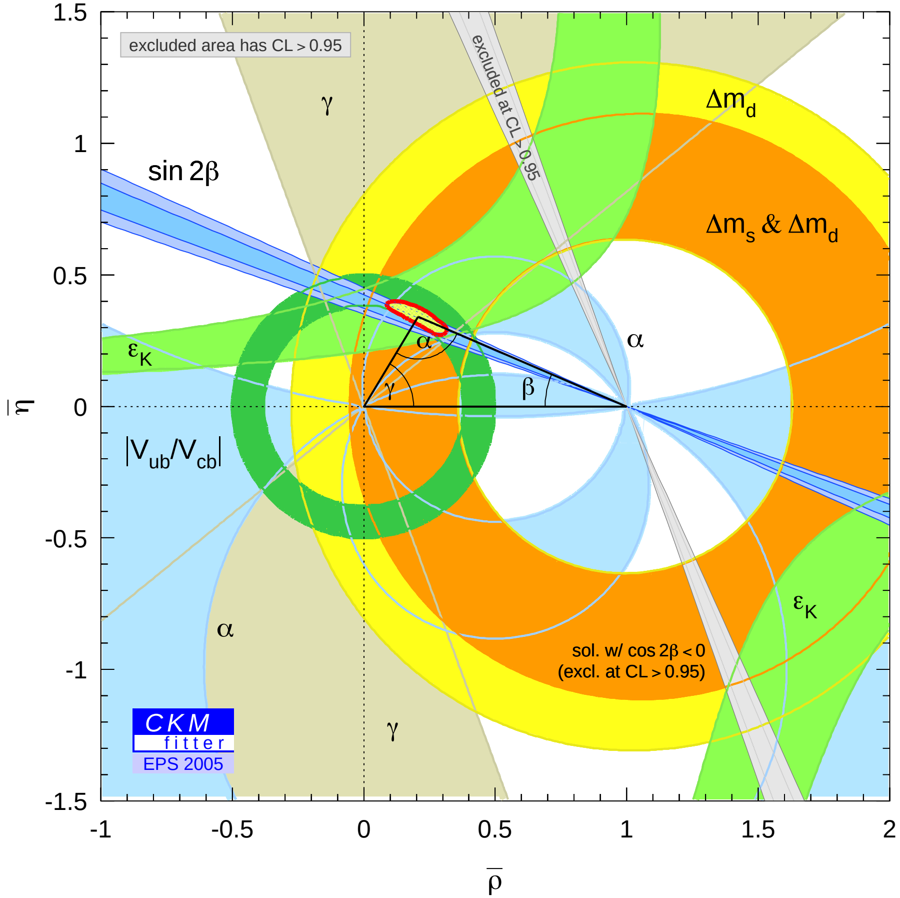
Summary

- indirect (loop) processes are <u>unique</u> probes of CP/flavor sector
- flavor experiments distinguish MFV vs. non-MFV; very different model-building; sensitivity to very high scales $\Lambda_{\not{S}USY} \gg \Lambda_{EWK}$
- goal: measure ALL (flavor diagonal $\rightarrow$ direct searches and flavor breaking $\rightarrow$ FCNC) couplings/parameters precisely
- CKM becomes input $\rightarrow$ $fits$

CKM anno 1995: ϵ_K, Δm_d, $|V_{ub}/V_{cb}|$, $|V_{cb}|$, λ hep-ph/9508272



summer 2005:



Summary

- so far agreement with SM/CKM, $\sin 2\beta$ moved closer to MFV
  some hints ($\eta' K^0$) $\rightarrow$ higher precision
- many FCNCs only weakly or just un-constrained ..Δm_s,$\tau^\pm$,..
- $b \rightarrow s\ell\ell$ modes under th and exp investigation Belle/BaBar
- $b \rightarrow d$ FCNCs beginning to be probed
- B_s-physics coming up (Tevatron) !
- study correlations & pattern rather than individual observables
- much more information on flavor physics from the LHC