Flavor data constraints on supersymmetry

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Motivations

Searches for New Physics

- direct detection of new physics particles
- nature of Dark Matter
- indirect evidence for new physics

Indirect constraints

- search for new physics effects
- guideline for other searches
- check consistencies with direct observations

Indirect Constraints

Flavor observables

1. Penguin mediated observables
2. Neutral Higgs mediated observables
3. Charged Higgs mediated observables

Other observables

1. Direct search limits
2. Anomalous magnetic moment of muon $a_\mu = (g-2)/2$
3. Relic density

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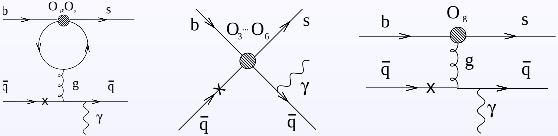
I) Penguin mediated observables

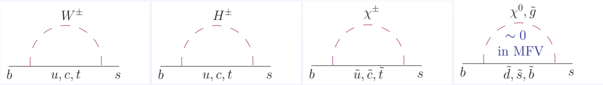
- inclusive branching ratio of $B \to X_s\gamma$
- isospin asymmetry of $B \to K^*\gamma$

I) Penguin mediated observables

Isospin asymmetry of $B \to K^*\gamma$ at NLO



Contributing loops:



$$\Delta_{0-} \equiv \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) - \Gamma(B^- \to K^{*-}\gamma)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\gamma) + \Gamma(B^- \to K^{*-}\gamma)}$$

$$\Delta_{0-} = \mathrm{Re}(b_d - b_u)\ ,\ b_q = \frac{12\pi^2 f_B\, Q_q}{m_b\, T_1^{B\to K^*} a_7^c}\left(\frac{f_{K^*}^\perp}{m_b} K_1 + \frac{f_{K^*} m_{K^*}}{6\lambda_B m_B} K_2\right)$$

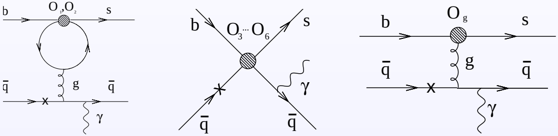
$$a_7^c = C_7 + \frac{\alpha_s(\mu) C_F}{4\pi}\Big(C_1(\mu) G_1(s_p) + C_8(\mu) G_8\Big) + \frac{\alpha_s(\mu_h) C_F}{4\pi}\Big(C_1(\mu_h) H_1(s_p) + C_8(\mu_h) H_8\Big)$$

In the Standard Model: $\Delta_{0-} \simeq 8\%$

Kagan and Neubert, Phys. Lett. B539, 227 (2002)

I) Penguin mediated observables

Isospin asymmetry of $B \to K^* \gamma$ at NLO



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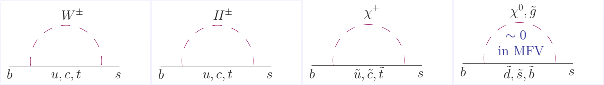

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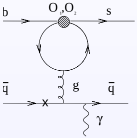

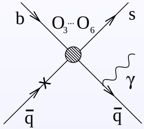

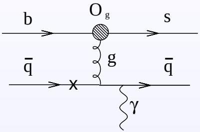

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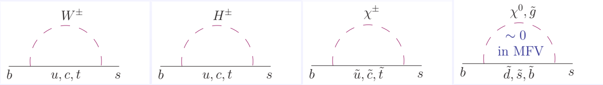

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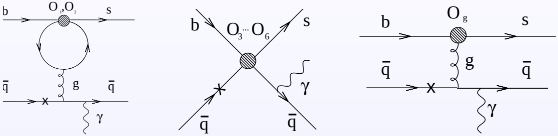

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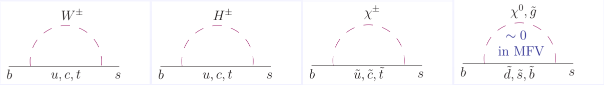

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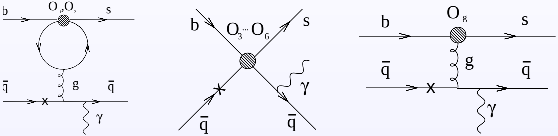

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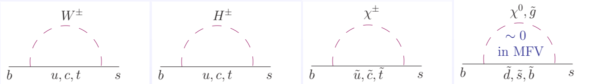

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$$\mathcal{B}(\bar{B} \to X_s\gamma)_{E_\gamma > E_0} = \mathcal{B}(\bar{B} \to X_c e\bar{\nu})_{\rm exp} \left|\frac{V_{ts}^* V_{tb}}{V_{cb}}\right|^2 \frac{6\alpha_{\rm em}}{\pi C} [P(E_0) + N(E_0)]$$

$$\text{with } C = \left|\frac{V_{ub}}{V_{cb}}\right|^2 \frac{\Gamma[\bar{B} \to X_c e\bar{\nu}]}{\Gamma[\bar{B} \to X_u e\bar{\nu}]}$$

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SM prediction: $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.15 \pm 0.23) \times 10^{-4}$

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II) Neutral Higgs mediated observable

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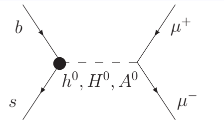

Upper limit: $\mathcal{B}(B_s \to \mu^+\mu^-) < 5.8 \times 10^{-8}$ at 95% C.L.

SM predicted value: $\mathcal{B}(B_s \to \mu^+\mu^-)_{SM} \sim 3 \times 10^{-9}$

Interesting in the high $\tan\beta$ regime, where the SUSY contributions can lead to an O(100) enhancement over the SM:

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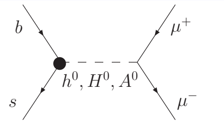

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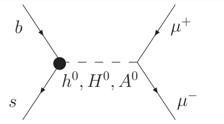

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Flavor observables

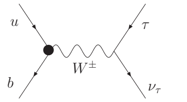
III) Charged Higgs mediated observables

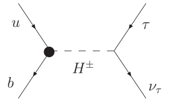
- branching ratio of $B \to \tau\nu$
- branching ratio of $B \to D\tau\nu$
- branching ratio of $K \to \mu\nu$
- branching ratios of $D_s \to \tau\nu/\mu\nu$

III) Charged Higgs mediated observables

Branching ratio of $B \to \tau\nu$

Tree level process, mediated by W^+ and H^+, higher order corrections from sparticles





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$$\epsilon_0 = -\frac{2\alpha_s}{3\pi} \frac{\mu}{m_{\tilde{g}}} H_2\left(\frac{m_Q^2}{m_{\tilde{g}}{}^2}, \frac{m_D^2}{m_{\tilde{g}}{}^2}\right), \quad H_2(x,y) = \frac{x \ln x}{(1-x)(x-y)} + \frac{y \ln y}{(1-y)(y-x)}$$

⚠ Large uncertainty from V_{ub}

Also used:

$$R_{\tau\nu_\tau}^{\mathrm{MSSM}} = \frac{\mathrm{BR}(B_u \to \tau\nu_\tau)_{\mathrm{MSSM}}}{\mathrm{BR}(B_u \to \tau\nu_\tau)_{\mathrm{SM}}} = \left[1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta}\right]^2$$

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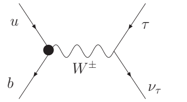
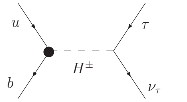
Branching ratio of $B \to \tau\nu$

Tree level process, mediated by W^+ and H^+, higher order corrections from sparticles





$$\mathcal{B}(B \to \tau\nu) = \frac{G_F^2 |V_{ub}|^2}{8\pi} m_\tau^2 f_B^2 m_B \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left|1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta}\right|^2$$

$$\epsilon_0 = -\frac{2\alpha_s}{3\pi} \frac{\mu}{m_{\tilde g}} H_2\left(\frac{m_{\tilde Q}^2}{{m_{\tilde g}}^2}, \frac{m_{\tilde D}^2}{{m_{\tilde g}}^2}\right) \; , \quad H_2(x,y) = \frac{x \ln x}{(1-x)(x-y)} + \frac{y \ln y}{(1-y)(y-x)}$$

⚠ Large uncertainty from V_{ub}

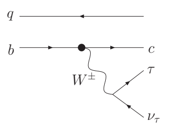
Also used:

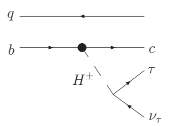
$$R_{\tau\nu_\tau}^{\rm MSSM} = \frac{{\rm BR}(B_u \to \tau\nu_\tau)_{\rm MSSM}}{{\rm BR}(B_u \to \tau\nu_\tau)_{\rm SM}} = \left[1 - \left(\frac{m_B^2}{m_{H^+}^2}\right) \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta}\right]^2$$

III) Charged Higgs mediated observables

Branching ratio of $B \to D\tau\nu$

Another tree level process:





$$\frac{d\Gamma(B \to D\ell\overline{\nu})}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} \rho_V(w) \left[1 - \frac{m_\ell^2}{m_B^2} \left|1 - \frac{t(w)}{(m_b - m_c)} \frac{m_b}{m_{H^+}^2} \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta}\right|^2 \rho_S(w)\right]$$

$w = v_B \cdot v_D$ $\quad$ ρ_V and ρ_S: vector and scalar Dalitz density contributions

- Depends on V_{cb}, which is known to better precision than V_{ub}
- Larger branching fraction than $B \to \tau\nu$
- Experimentally challenging due to the presence of neutrinos in the final state

Branching ratios: $\mathcal{B}(B^- \to D^0\tau^-\nu)$ and $\dfrac{\mathcal{B}(B^- \to D^0\tau^-\nu)}{\mathcal{B}(B^- \to D^0 e^-\nu)}$

III) Charged Higgs mediated observables

Branching ratio of $B \to D\tau\nu$

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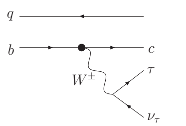

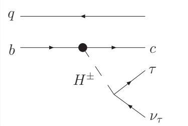

$$\frac{d\Gamma(B\to D\ell\overline{\nu})}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3}\rho_V(w)\left[1-\frac{m_\ell^2}{m_B^2}\left|1-\frac{t(w)}{(m_b-m_c)}\frac{m_b}{m_{H^+}^2}\frac{\tan^2\beta}{1+\epsilon_0\tan\beta}\right|^2\rho_S(w)\right]$$

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III) Charged Higgs mediated observables

Branching ratio of $B \to D\tau\nu$

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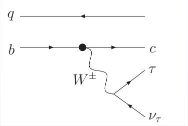

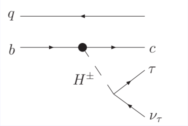

$$\frac{d\Gamma(B \to D\ell\overline{\nu})}{dw} = \frac{G_F^2 |V_{cb}|^2 m_B^5}{192\pi^3} \rho_V(w) \left[1 - \frac{m_\ell^2}{m_B^2} \left|1 - \frac{t(w)}{(m_b - m_c)} \frac{m_b}{m_{H^+}^2} \frac{\tan^2\beta}{1 + \epsilon_0 \tan\beta}\right|^2 \rho_S(w)\right]$$

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III) Charged Higgs mediated observables

Branching ratio of $K \to \mu\nu$

Tree level process similar to $B \to \tau\nu$

Two observables can be considered:

$$\frac{\Gamma(K \to \mu\nu)}{\Gamma(\pi \to \mu\nu)} = \left|\frac{V_{us}}{V_{ud}}\right|^2 \frac{f_K^2 m_K}{f_\pi^2 m_\pi} \left(\frac{1 - m_\ell^2/m_K^2}{1 - m_\ell^2/m_\pi^2}\right)^2 \times \left(1 - \frac{m_{K^+}^2}{M_{H^+}^2}\left(1 - \frac{m_d}{m_s}\right)\frac{\tan^2\beta}{1+\epsilon_0 \tan\beta}\right)^2 (1+\delta_{\rm em})$$

$$R_{\ell 23} = \left|\frac{V_{us}(K_{\ell 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{us}(0^+ \to 0^+)}{V_{ud}(\pi_{\ell 2})}\right| = \left|1 - \frac{m_{K^+}^2}{M_{H^+}^2}\left(1 - \frac{m_d}{m_s}\right)\frac{\tan^2\beta}{1+\epsilon_0\tan\beta}\right|$$

III) Charged Higgs mediated observables

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III) Charged Higgs mediated observables

Branching ratio of $D_s \to \ell\nu$

Tree level process similar to $B \to \tau\nu$

$$\mathcal{B}(D_s \to \ell\nu) = \frac{G_F^2}{8\pi} |V_{cs}|^2 f_{D_s}^2 m_\ell^2 M_{D_s} \tau_{D_s} \left(1 - \frac{m_\ell^2}{M_{D_s}^2}\right)^2 \times \left[1 + \left(\frac{1}{m_c + m_s}\right)\left(\frac{M_{D_s}}{m_{H^+}}\right)^2 \left(m_c - \frac{m_s \tan^2\beta}{1 + \epsilon_0 \tan\beta}\right)\right]^2 \text{ for } \ell = \mu, \tau$$

- Competitive with and complementary to analogous observables
- Dependence on only one lattice QCD quantity
- Interesting if lattice calculations eventually prefer $f_{D_s} < 250$ MeV
- Promising experimental situation (BES-III)

⚠ Sensitive to f_{D_s} and m_s/m_c

SuperIso

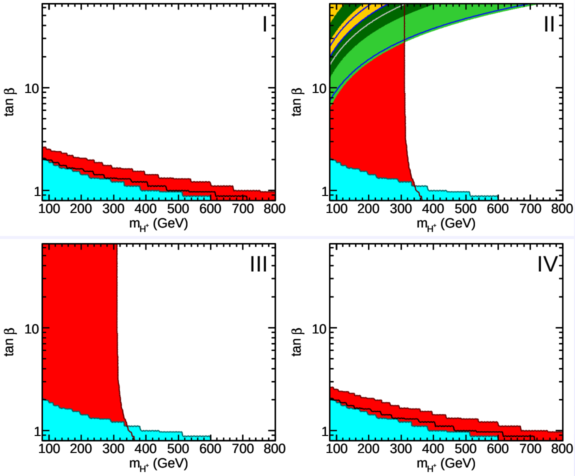
SuperIso is a public C program

- dedicated to the flavor physics observable calculations
- implemented models: SM, THDM, MSSM and NMSSM with MFV
- interfaced to spectrum calculators (2HDMC, SOFTSUSY, ISAJET, SUSPECT, SPHENO, NMSSMTOOLS)
- SuperIso Relic: extension to the relic density calculation, featuring alternative cosmological scenarios

F. Mahmoudi, Comput. Phys. Commun. 178 (2008) 745
F. Mahmoudi, Comput. Phys. Commun. 180 (2009) 1579
F. Mahmoudi, Comput. Phys. Commun. 180 (2009) 1718
A. Arbey & F. Mahmoudi, Comput. Phys. Commun. 181 (2010) 1277

THDM

THDM (Types I–IV)

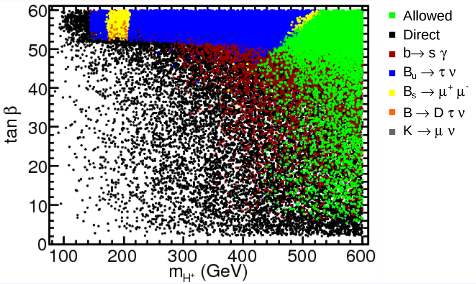


Red: $b \to s\gamma$
Cyan: ΔM_{B_d}
Blue: $B_u \to \tau\nu_\tau$
Yellow: $B \to D\ell\nu_\ell$
Gray: $K \to \mu\nu_\mu$
Green: $D_s \to \tau\nu_\tau$
Dark green: $D_s \to \mu\nu_\mu$

F. Mahmoudi & O. Stål, Phys. Rev. D81, 035016 (2010)

MSSM

mSUGRA

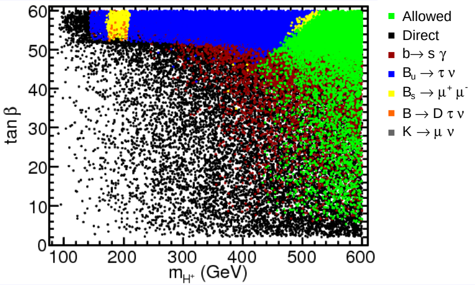


$$m_{H^+} \gtrsim 400 \text{ GeV}$$

D. Eriksson, F. Mahmoudi & O. Stål, JHEP 0811 (2008)

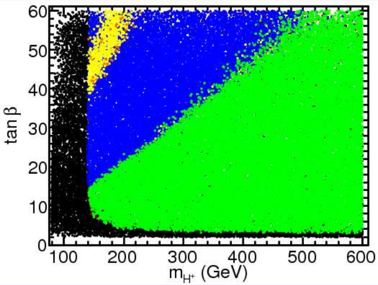
MSSM

mSUGRA



$m_{H^+} \gtrsim 400$ GeV

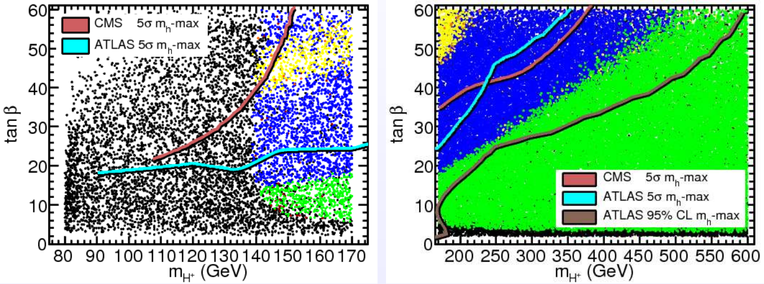
NUHM



$m_{H^+} \gtrsim 135$ GeV

D. Eriksson, F. Mahmoudi & O. Stål, JHEP 0811 (2008)

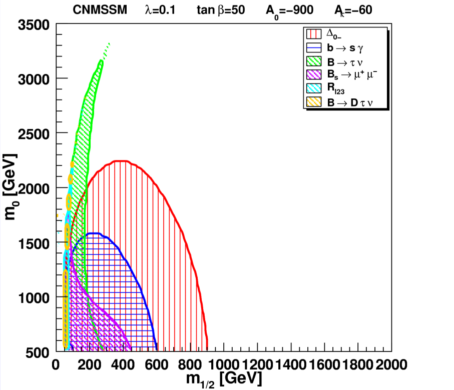
MSSM



D. Eriksson, F. Mahmoudi & O. Stål, JHEP 0811 (2008)

NMSSM

CNMSSM



F. Mahmoudi, preliminary results

Conclusion

- Indirect constraints and in particular flavor physics are essential to restrict new physics parameters
- That will become even more interesting when combined with LHC data
- This kind of analysis should be generalized to more new physics scenarios

Ongoing Developments

- Extension to NMFV
- Implementation of other observables

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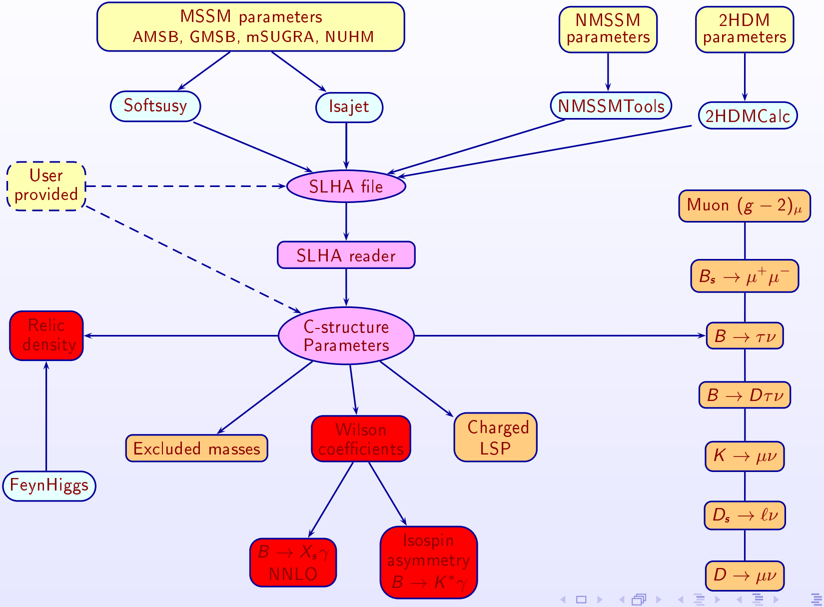
Backup

THDM types I–IV

- Type I: one Higgs doublet provides masses to all quarks (up and down type quarks) ($\sim$ SM)
- Type II: one Higgs doublet provides masses for up type quarks and the other for down-type quarks ($\sim$ MSSM)
- Type III,IV: different doublets provide masses for down type quarks and charged leptons

Type	λ_U	λ_D	λ_L
I	$\cot\beta$	$\cot\beta$	$\cot\beta$
II	$\cot\beta$	$-\tan\beta$	$-\tan\beta$
III	$\cot\beta$	$-\tan\beta$	$\cot\beta$
IV	$\cot\beta$	$\cot\beta$	$-\tan\beta$

SuperIso


MSSM parameters
AMSB, GMSB, mSUGRA, NUHM
NMSSM parameters
2HDM parameters
Softsusy
Isajet
NMSSMTools
2HDMCalc
User provided
SLHA file
SLHA reader
Muon $(g-2)_\mu$
$B_s \to \mu^+\mu^-$
C-structure Parameters
Relic density
$B \to \tau\nu$
$B \to D\tau\nu$
Excluded masses
Wilson coefficients
Charged LSP
$K \to \mu\nu$
FeynHiggs
$D_s \to \ell\nu$
$B \to X_s\gamma$ NNLO
Isospin asymmetry $B \to K^*\gamma$
$D \to \mu\nu$