SuperIso

Calculation of flavor physics observables

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CERN, 17 March 2009

Outline

What for?

SuperIso is a public C program

- dedicated to the flavor physics observable calculations
- aimed to provide to everyone the possibility to do the calculations in different models
- based on the most precise calculations publicly available in the literature

F. Mahmoudi, arXiv:0808.3144

Models

Standard Model

Two Higgs Doublet Model (Type II)

MSSM (with Minimal Flavor Violation)

automatic interfaces with Softsusy and Isajet available for

- CMSSM
- NUHM
- AMSB
- GMSB

NMSSM

automatic interface with NMSSMTools available for

- CNMSSM
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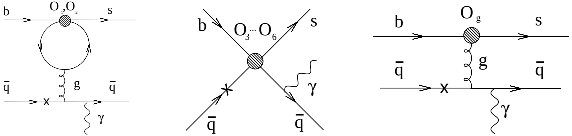
Observables

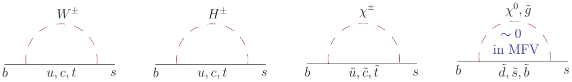
1) Penguin mediated observables

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

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



Contributing loops:



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

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

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

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

Inclusive branching ratio of $B \to X_s\gamma$ at NNLO

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

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

$$\begin{aligned} P(E_0) &= P^{(0)}(\mu_b) + \alpha_s(\mu_b)\left[P_1^{(1)}(\mu_b) + P_2^{(1)}(E_0,\mu_b)\right] \\ &+ \alpha_s^2(\mu_b)\left[P_1^{(2)}(\mu_b) + P_2^{(2)}(E_0,\mu_b) + P_3^{(2)}(E_0,\mu_b)\right] + \mathcal{O}\left(\alpha_s^3(\mu_b)\right) \end{aligned}$$

$$\left\{ \begin{aligned} P^{(0)}(\mu_b) &= \left(C_7^{(0)\rm eff}(\mu_b)\right)^2 \\ P_1^{(1)}(\mu_b) &= 2C_7^{(0)\rm eff}(\mu_b) C_7^{(1)\rm eff}(\mu_b) \\ P_1^{(2)}(\mu_b) &= \left(C_7^{(1)\rm eff}(\mu_b)\right)^2 + 2C_7^{(0)\rm eff}(\mu_b) C_7^{(2)\rm eff}(\mu_b) \end{aligned} \right.$$

Misiak and Steinhauser, Nucl. Phys. B764 (2007)

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

Observables

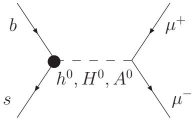
2) Neutral Higgs mediated observable

- branching ratio of $B_s \to \mu^+\mu^-$

Branching ratio of $B_s \to \mu^+\mu^-$

$$\mathcal{B}(B_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{64\pi^3} f_{B_s}^2 \tau_{B_s} M_{B_s}^3 |V_{tb}V_{ts}^*|^2 \sqrt{1-\frac{4m_\mu^2}{M_{B_s}^2}}$$

$$\times \left\{ \left(1-\frac{4m_\mu^2}{M_{B_s}^2}\right) M_{B_s}^2 |C_S|^2 + \left| C_P M_{B_s} - 2\, C_A \frac{m_\mu}{M_{B_s}} \right|^2 \right\}$$



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:

$$\mathcal{B}(B_s \to \mu^+\mu^-)_{MSSM} \sim \frac{m_b^2 m_\mu^2 \tan^6\beta}{M_A^4}$$

Observables

3) 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 $D_s \to \tau\nu/\mu\nu$

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

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

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

$$\epsilon_0 = -\frac{2\alpha_s}{3\pi} \frac{\mu}{m_{\tilde g}} H_2\left(\frac{m_{\tilde Q}^2}{m_{\tilde g}^2}, \frac{m_{\tilde D}^2}{m_{\tilde g}^2}\right)$$

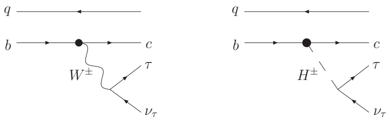
⚠ Large uncertainty from V_{ub}

Also implemented in SuperIso:

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

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

Another tree level process:



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

$w = v_B \cdot v_D$ 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

Implemented in SuperIso: $\mathcal{B}(B^- \to D^0\tau^-\nu)$ and $\dfrac{\mathcal{B}(B^- \to D^0\tau^-\nu)}{\mathcal{B}(B^- \to D^0e^-\nu)}$

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

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

Two observables are implemented in SuperIso:

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

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

⚠ Large uncertainty from f_K/f_π

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

Observables

4) Other observables

- collider mass limits
- muon anomalous magnetic moment $(g-2)_\mu$
- dark matter relic density

What's new?

- version 2.4 with $D_s \to \ell\nu$ observables recently released
- updated user manual (61 pages)

NMSSM

- all formulae have been extended to the NMSSM
- interfaced with NMSSMTools
- tested within the CNMSSM scenario
- beta version available on demand

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What's new?

Relic density

with Alexandre Arbey

- all coannihilation diagrams included
- squared amplitudes computed with FormCalc
- interfaced with FeynHiggs
- inclusion of cosmological scenarios beyond the standard model
- public version to be released very soon

What's next?

New observables

- forward-backward asymmetry in $B \to K^* \ell^+ \ell^-$
- $B^0_{(s,d)} - \bar{B}^0_{(s,d)}$ mixings: $\Delta M_{B_{s,d}}$

New models

- General 2HDM with O. Stål (see next talk)
- Non Minimal Flavor violation
- CP violation
- R parity violation?

Relic density

- many ideas: new models, new features, ...

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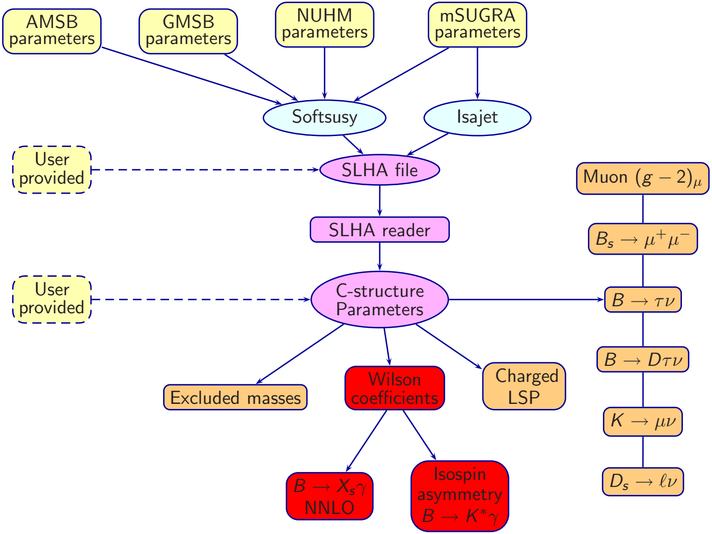
How does it work?



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http://superiso.in2p3.fr

SuperIso

By Farvah Nazila Mahmoudi

Calculation of flavor physics observables in supersymmetry

SuperIso is a program for calculation of flavor physics observables in the minimal supersymmetric extension of the Standard Model (MSSM). SuperIso, in addition to the isospin asymmetry of B -> K* gamma, which was the main purpose of the first version, incorporates other flavor observables such as the branching ratio of B -> Xs gamma at NNLO, the branching ratio of Bs -> mu+ mu-, the branching ratio of B -> tau nu, the branching ratio of B -> D tau nu and the branching ratio of K -> mu nu. It also computes the muon anomalous magnetic moment (g-2).

For the isospin asymmetry, the program calculates the NLO supersymmetric contributions using the effective Hamiltonian approach and within the QCD factorization method. Isospin asymmetry is a particularly useful observable to constrain supersymmetric parameter spaces.

SuperIso uses a SUSY Les Houches Accord file (SLHA1 or SLHA2) as input, which can be either generated automatically by the program via a call to SOFTSUSY or ISAJET, or provided by the user.

SuperIso is able to perform the calculations automatically in different supersymmetry breaking scenarios, such as mSUGRA, NUHM, AMSB and GMSB.

If you use SuperIso v2.x to publish a paper, please cite:

F. Mahmoudi, arXiv:0710.2067 [hep-ph], Comput. Phys. Commun. 178 (2008) 745
And
F. Mahmoudi, arXiv:0808.3144 [hep-ph], available in Comput. Phys. Commun.

Manual

NEW The latest version of the manual can be found here (05/03/2009).

For more information:

- F. Mahmoudi, arXiv:0710.3791 [hep-ph], JHEP12 (2007), 026
- M.R. Ahmady and F. Mahmoudi, hep-ph/0608212, Phys. Rev. D75 (2007), 015007
- A. Arbey and F. Mahmoudi, arXiv:0803.0741 [hep-ph], Phys. Lett. B 669 (2008), 46
- D. Eriksson, F. Mahmoudi and O. Stål, arXiv:0808.3551 [hep-ph], JHEP11 (2008), 035
- A.G. Akeroyd and F. Mahmoudi, arXiv:0902.2393 [hep-ph]

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NEW **SuperIso v2.4**

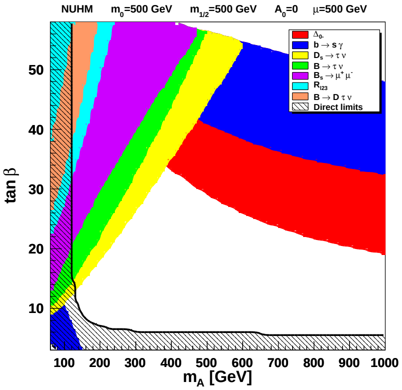
Version 2.4 (15 February 2009)

Example

```
superiso_v2.4 : bash
File Edit View Scrollback Bookmarks Settings Help
nazila@andromeda:~/superiso_v2.4$ ./msugra.x 500 500 0 50
SLHA file generated by SOFTSUSY
delta0=1.000e-01
BR_bsgamma=2.211e-04
BR_Btaunu=6.774e-05
Rtaunu=6.148e-01
BR_Kmunu/BR_pimunu=6.431e-01
Rl23=9.982e-01
BR_BDtaunu=6.333e-03
BR_BDtaunu/BR_BDenu=2.664e-01
BR_Bsmumu=3.558e-08
BR_Dstaunu=4.796e-02
BR_Dsmunu=4.952e-03
a_muon=1.994e-09
charged_LSP=0
excluded_mass=0
superiso_v2.4 : bash
```

Results

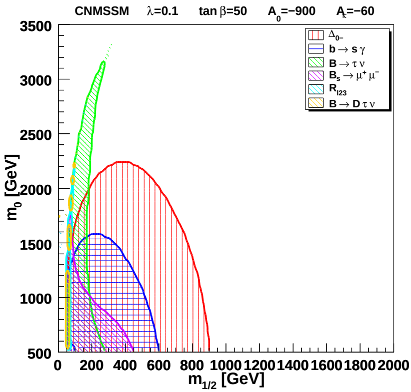
NUHM



A. Akeroyd & F. Mahmoudi, arXiv:0902.2393

Results

CNMSSM



F. Mahmoudi, preliminary results

Conclusion

Have fun using SuperIso!

Any feedback is most welcome!

Backup

Observable	Combined experimental value	95% C.L. Bound
$\mathrm{BR}(B \to X_s\gamma)$	$(3.52 \pm 0.23 \pm 0.09) \times 10^{-4}$	$2.15 \times 10^{-4} \leq \mathrm{BR}(b \to s\gamma) \leq 4.89 \times 10^{-4}$
$\Delta_0(B \to K^*\gamma)$	$(3.1 \pm 2.3) \times 10^{-2}$	$-1.7 \times 10^{-2} < \Delta_0 < 8.9 \times 10^{-2}$
$\mathrm{BR}(B_u \to \tau\nu_\tau)$ $R_{\tau\nu_\tau}$	$(1.41 \pm 0.43) \times 10^{-4}$ 1.28 ± 0.38	$0.39 \times 10^{-4} < \mathrm{BR}(B_u \to \tau\nu_\tau) < 2.42 \times 10^{-4}$ $0.52 < R_{\tau\nu_\tau} < 2.04$
$\mathrm{BR}(B \to D^0\tau\nu_\tau)$ $\xi_{D\ell\nu}$	$(8.6 \pm 2.4 \pm 1.1 \pm 0.6) \times 10^{-3}$ $0.416 \pm 0.117 \pm 0.052$	$2.9 \times 10^{-3} < \mathrm{BR}(B \to D^0\tau\nu_\tau) < 14.2 \times 10^{-3}$ $0.151 < \xi_{D\ell\nu} < 0.681$
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$< 5.8 \times 10^{-8}$	$\mathrm{BR}(B_s \to \mu^+\mu^-) < 6.6 \times 10^{-8}$
$\frac{\mathrm{BR}(K \to \mu\nu)}{\mathrm{BR}(\pi \to \mu\nu)}$ $R_{\ell 23}$	0.6358 ± 0.0011 1.004 ± 0.007	$0.6257 < \frac{\mathrm{BR}(K \to \mu\nu)}{\mathrm{BR}(\pi \to \mu\nu)} < 0.6459$ $0.990 < R_{\ell 23} < 1.018$
$\mathrm{BR}(D_s \to \tau\nu_\tau)$ $\mathrm{BR}(D_s \to \mu\nu_\mu)$	$(5.7 \pm 0.4) \times 10^{-2}$ $5.8 \pm 0.4 \times 10^{-3}$	$4.8 \times 10^{-2} < \mathrm{BR}(D_s \to \tau\nu_\tau) < 6.6 \times 10^{-2}$ $4.9 \times 10^{-3} < \mathrm{BR}(D_s \to \mu\nu_\mu) < 6.7 \times 10^{-3}$
δa_μ	$(2.95 \pm 0.88) \times 10^{-9}$	$1.15 \times 10^{-9} < \delta a_\mu < 4.75 \times 10^{-9}$