News from SuperIso

Extension to general 2HDM and NMSSM

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GDR Terascale, Heidelberg, 16 October 2009

Outline

What for?

SuperIso is a public C program

- dedicated to the flavour 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, Comput. Phys. Commun. 180 (2009) 1579, arXiv:0808.3144

Models

Standard Model

General Two Higgs Doublet Model

automatic interface with 2HDMC for

- General 2HDM and Types I, II, III, IV

MSSM (with Minimal Flavour Violation)

automatic interfaces with Softsusy and Isajet available for

- CMSSM, NUHM, AMSB, GMSB

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- CNMSSM, NNUHM, NGMSB

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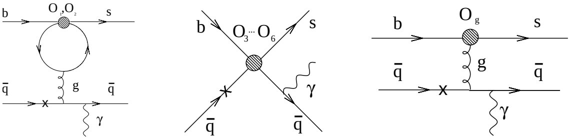
Observables

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

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

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

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

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

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

SM prediction: $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.07 \pm 0.23) \times 10^{-4}$

Observables

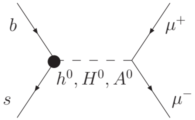
2) Neutral Higgs mediated observable

- 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. (CDF 2008)

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

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

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

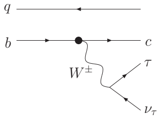
⚠ Large uncertainty from V_{ub}

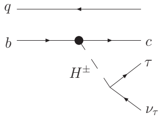
Also implemented in SuperIso:

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

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

Another tree level process:





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

$w = v_B \cdot v_D$ $\qquad$ 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 $\dfrac{\mathcal{B}(B^- \to D^0\tau^-\nu)}{\mathcal{B}(B^- \to D^0 e^-\nu)}$

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

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

Two observables are implemented in SuperIso:

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

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

⚠ 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 2.6: current MSSM and 2HDM version
  - improved $(g-2)$ calculation
  - extension to 2HDM
  - interface with 2HDMC
- version 3.0: current NMSSM version (including also MSSM and 2HDM)
  - extension to NMSSM
  - interface with NMSSMTools
- Updated user manual (80 pages)

What's new?

2HDM 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	$\cot\beta$	$\cot\beta$	$-\tan\beta$

What's new?

General 2HDM

- all Yukawa couplings have been extended to the General 2HDM
- interfaced with 2HDMC
- automatic calculations in Types I–IV
- possibility to work in more general 2HDM scenarios
- usage of a SLHA inspired format for the 2HDM inputs

What's new?

NMSSM

- all formulas have been extended to the NMSSM
- interfaced with NMSSMTools
- automatic calculations in the CNMSSM, NNUHM and NGMSB
- fully compliant with the NMSSM SLHA2 format

F. Mahmoudi, Comput. Phys. Commun. 180 (2009) 1718

What's new?

SuperIso Relic

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 and manual available on http://superiso.in2p3.fr/relic

A. Arbey and F. Mahmoudi, arXiv:0906.0369

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

- Non Minimal Flavour violation
- CP violation
- R parity violation?

Relic density

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

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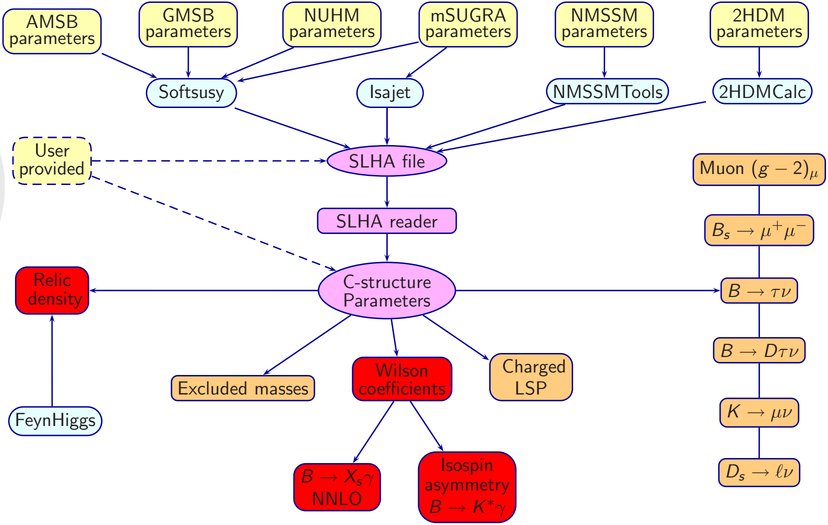
How does it work?



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SuperIso

By Farvah Nazila Mahmoudi

SuperIso
- Description
- Manual

SuperIso Relic
- Description
- Manual

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Calculation of flavor physics observables

SuperIso is a program for calculation of flavor physics observables in the Standard Model (SM), general two-Higgs-doublet model (2HDM), minimal supersymmetric Standard Model (MSSM) and next to minimal supersymmetric Standard Model (NMSSM). 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, the branching ratio of K -> mu nu as well as the branching ratios of Ds -> tau nu and Ds -> 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, ISAJET, NMSSMTools or provided by the user. SuperIso can also use the LHA inspired format for the 2HDM generated by 2HDMC.

SuperIso is able to perform the calculations automatically in the SM, in the 2HDM (general 2HDM or types I-IV) and in different supersymmetry breaking scenarios, such as mSUGRA, NUHM, AMSB and GMSB (for MSSM) and CNMSSM, NGMSB and NNUHM (for NMSSM).

For any comment, question or bug report please contact Nazila Mahmoudi.

Manual

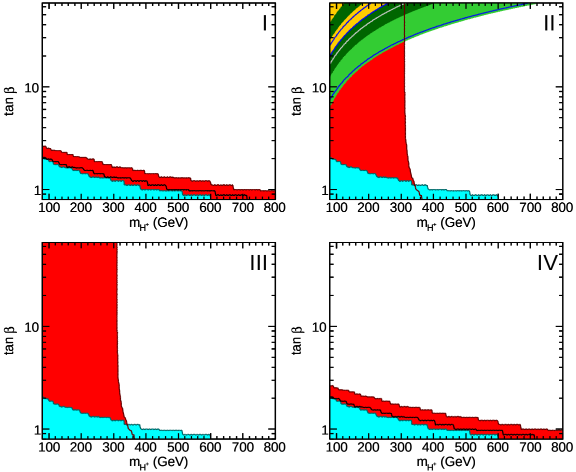
NEW **The latest version of the manual can be found here (10 September 2009).**

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
- D. Eriksson, F. Mahmoudi and O. Stål, arXiv:0808.3551 [hep-ph], JHEP11 (2008), 035

Results

2HDM (Types I–IV)

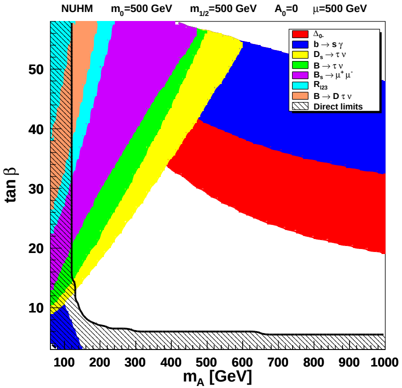


Red: $b \to s\gamma$
Cyan: ΔM_{B_d}
Blue: $B_u \to \tau\nu_\tau$
Yellow: $B \to D\ell\nu_\ell$
Gray: $K \to \mu\nu_\mu$
Green: $D_s \to \tau\nu_\tau$
Dark green: $D_s \to \mu\nu_\mu$

F. Mahmoudi and O. Stål, arXiv:0907.1791

Results

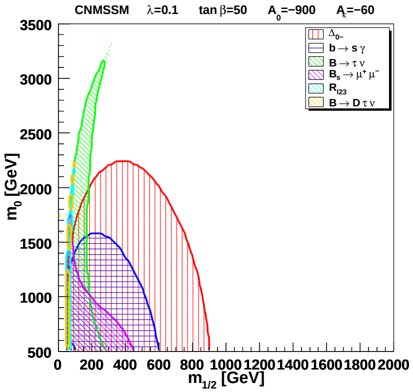
NUHM



A. Akeroyd & F. Mahmoudi, JHEP 0904 (2009), 121, arXiv:0902.2393

Results

CNMSSM



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- Indirect constraints from flavour observables are essential to restrict new physics parameters
- That will become even more interesting when combined with LHC data

The interplay between flavour and collider physics will hopefully be very rich in the next few years.

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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	$(2.95 \pm 0.88) \times 10^{-9}$	$1.15 \times 10^{-9} < \delta a_\mu < 4.75 \times 10^{-9}$