New constraints on supersymmetric models from $b \longrightarrow s\gamma$

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Outline

Introduction

New physics appears as a necessity:

- cosmological problems: dark matter, dark energy
- hierarchy problem in the Standard Model
- unification of interactions
- ...

Many realistic theoretical models beyond the SM!

- Need for constraints!

Let's take Supersymmetry as an example.

SUSY Constraints

The most used constraints:

- Collider limits
- Electroweak precision tests
- The anomalous magnetic moment of the muon $(g-2)_\mu$

$$\Delta a_\mu \equiv a_\mu^{SUSY} \equiv a_\mu^{exp} - a_\mu^{SM} = (29.5 \pm 8.8) \times 10^{-10}$$

- B Physics
- Cosmological constraints, in particular from WMAP and the relic density

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B Physics

A good strategy to find the information on SUSY particles would be

- to look at where the SM contributions are vanishingly small,
- to study processes for which QCD corrections are known with high accuracy
- and branching ratios can be measured precisely.

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$\Rightarrow$ Rare B decays are IDEAL CHOICES for that!

Constraints from B Physics

- $b \longrightarrow s\gamma$ transition: very sensitive to new physics
  - forbidden at the tree level in SM and can only be induced via loop diagrams,
  - SM contributions are vanishingly small,
- branching ratios have been extensively used to constrain SUSY parameter space
- Study another observable: isospin asymmetry
  - already measured by BELLE and BABAR
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Effective Hamiltonian

The calculation of $b \to s\gamma$ observables begins with introducing an effective Hamiltonian:

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{8} C_i(\mu) O_i(\mu)$$

$$\left\{\begin{array}{ll} O_1 = (\bar{s}_L \gamma_\mu T^a c_L)(\bar{c}_L \gamma^\mu T^a b_L) & O_2 = (\bar{s}_L \gamma_\mu c_L)(\bar{c}_L \gamma^\mu b_L) \\ O_3 = (\bar{s}_L \gamma_\mu b_L) \sum_q (\bar{q}\gamma^\mu q) & O_4 = (\bar{s}_L \gamma_\mu T^a b_L) \sum_q (\bar{q}\gamma^\mu T^a q) \\ O_5 = (\bar{s}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} b_L) \sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} q) & \\ O_6 = (\bar{s}_L \gamma_{\mu_1}\gamma_{\mu_2}\gamma_{\mu_3} T^a b_L) \sum_q (\bar{q}\gamma^{\mu_1}\gamma^{\mu_2}\gamma^{\mu_3} T^a q) & \\ O_7 = \frac{e}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu} & O_8 = \frac{g}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} T^a b_R) G^a_{\mu\nu} \end{array}\right.$$

Wilson Coefficients

Two main steps:

- Calculating $C_i^{eff}(\mu)$ at scale $\mu \sim M_W$ by requiring matching between the effective and full theories

$$C_i^{eff}(\mu) = C_i^{(0)eff}(\mu) + \frac{\alpha_s(\mu)}{4\pi} C_i^{(1)eff}(\mu) + \cdots$$

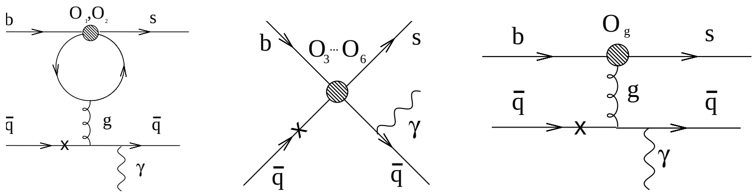
- Evolving the $C_i^{eff}(\mu)$ to scale $\mu \sim m_b$ using the RGE:

$$\mu \frac{d}{d\mu} C_i^{eff}(\mu) = C_j^{eff}(\mu) \gamma_{ji}^{eff}(\mu)$$

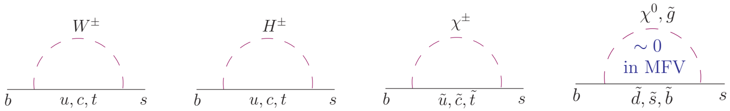
driven by the anomalous dimension matrix $\hat{\gamma}^{eff}(\mu)$:

$$\hat{\gamma}^{eff}(\mu) = \frac{\alpha_s(\mu)}{4\pi} \hat{\gamma}^{(0)eff} + \frac{\alpha_s^2(\mu)}{(4\pi)^2} \hat{\gamma}^{(1)eff} + \cdots$$

$b \longrightarrow s\gamma$ transitions



Contributing loops:



Inclusive Branching ratio

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

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

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

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

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

Inclusive Branching ratio

- Theoretical values for the SM:

NLO (Gambino & Misiak '02): $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.60 \pm 0.30) \times 10^{-4}$
NNLO (Misiak & Steihauser '07): $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.15 \pm 0.23) \times 10^{-4}$
or (Becher & Neubert '07): $\mathcal{B}[\bar{B} \to X_s\gamma] = (2.98 \pm 0.26) \times 10^{-4}$
or (Gambino & Giordano '08): $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.30 \pm 0.24) \times 10^{-4}$

- Experimental values:

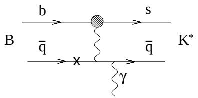
PDG 2002: $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.30 \pm 0.40) \times 10^{-4}$
HFAG 2008: $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.52 \pm 0.25) \times 10^{-4}$

Big changes in both the theoretical and experimental values!

$$\boxed{\text{Allowed Region: } 2.15 \times 10^{-4} < \mathcal{B}[\bar{B} \to X_s\gamma] < 4.89 \times 10^{-4}}$$

Isospin Asymmetry

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



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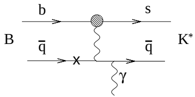

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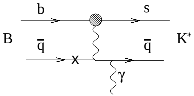

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$$b_q = \frac{12\pi^2 f_B\, Q_q}{m_b\, T_1^{B\to K^*} a_7^c}\left(\frac{f_{K^*}^{\perp}}{m_b} K_1 + \frac{f_{K^*} m_{K^*}}{6\lambda_B m_B} K_2\right)$$

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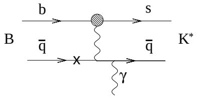

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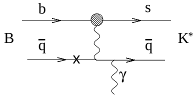

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In the Standard Model: $\Delta_{0-} \simeq 8\%$

Kagan and Neubert, Phys. Lett. B539, 227 (2002)
Bosch and Buchalla, Nucl. Phys. B621, 459 (2002)
Ali and Parkhomenko, Eur. Phys. J. C23, 89 (2002)

Experimental data

BABAR

$$\Delta_{0-} = +0.029 \pm 0.019(stat) \pm 0.016(syst) \pm 0.018(R^{+/0})$$

Aubert et al. (BABAR Collaboration) arXiv:0808.1915

BELLE

$$\Delta_{0+} = +0.012 \pm 0.044(stat) \pm 0.026(syst)$$

Nakao et al. (BELLE Collaboration) Phys. Rev. D69 (2004)

$$\boxed{\text{Allowed Region: } -0.017 < \Delta_{0-} < 0.089}$$

SuperIso v2.5

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:0710.2067, Comput. Phys. Commun. 178 (2008)

F. Mahmoudi, arXiv:0808.3144, Comput. Phys. Commun. (2009)

Implemented Observables

1) Penguin mediated observables

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

2) Neutral Higgs mediated observable

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

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

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Implemented Observables

4) Other observables

- collider direct limits
- muon anomalous magnetic moment $(g-2)_\mu$
- dark matter relic density (**SuperIso Relic**, with A. Arbey)

Implemented models

Standard Model

General Two Higgs Doublet Model

- Type I, Type II, Type III and Type IV

MSSM (with Minimal Flavor Violation)

automatic interfaces with Softsusy and Isajet available for:

- CMSSM, NUHM, AMSB and GMSB

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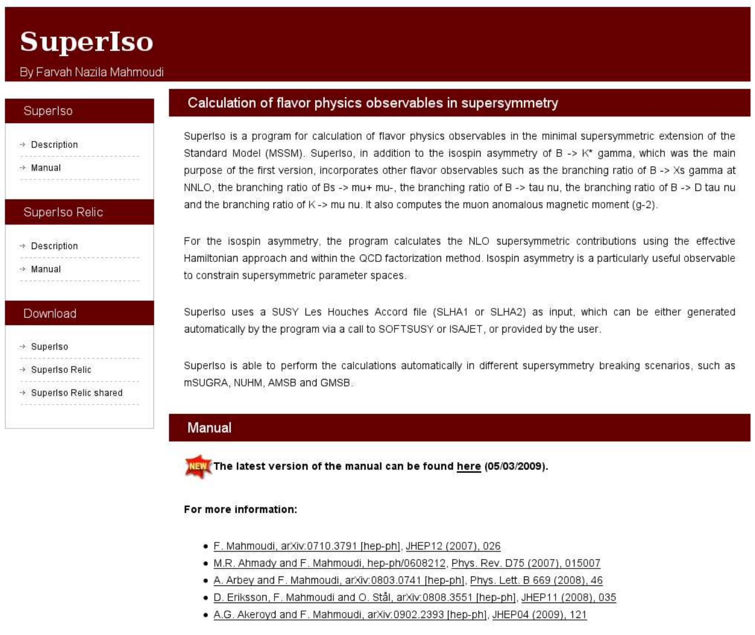
Download

http://superiso.in2p3.fr



SuperIso

By Farvah Nazila Mahmoudi

SuperIso
- Description
- Manual

SuperIso Relic
- Description
- Manual

Download
- SuperIso
- SuperIso Relic
- SuperIso Relic shared

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.

Manual

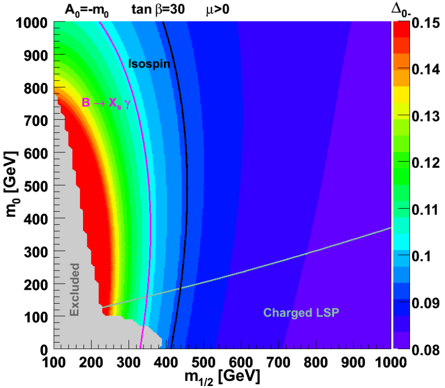
NEW **The latest version of the manual can be found here (05/03/2009).**

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], JHEP04 (2009), 121

Results

mSUGRA



M. Ahmady & F. Mahmoudi, Phys. Rev. D75 (2007)

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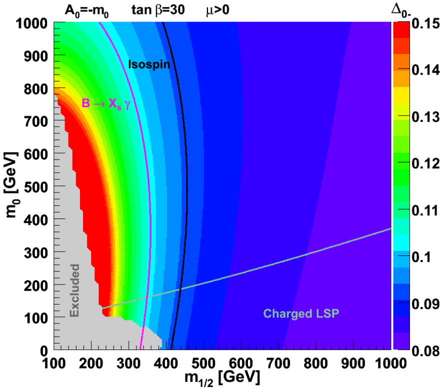
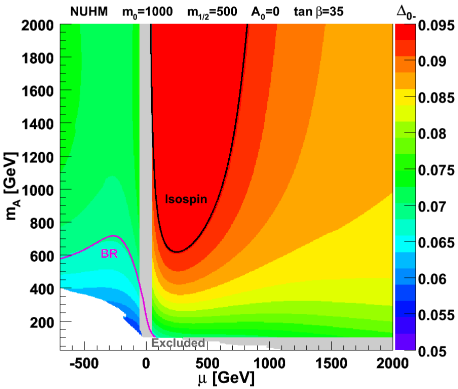


M. Ahmady & F. Mahmoudi, Phys. Rev. D75 (2007)

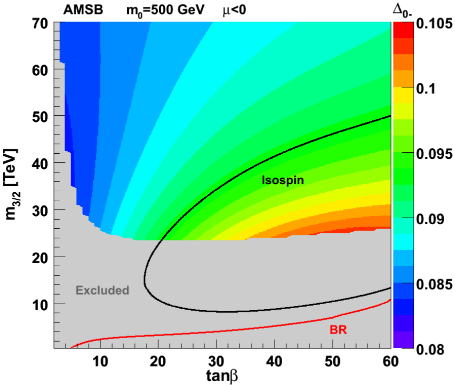
NUHM



F. Mahmoudi, JHEP 0712, 026 (2007)

Results

AMSB



F. Mahmoudi, JHEP 0712, 026 (2007)

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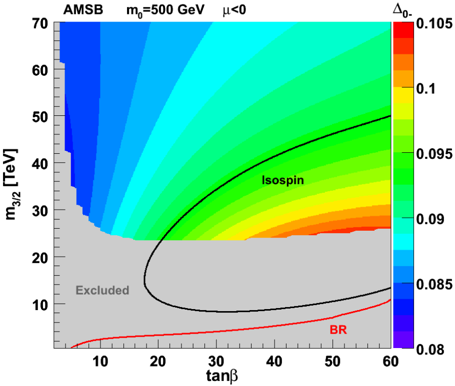
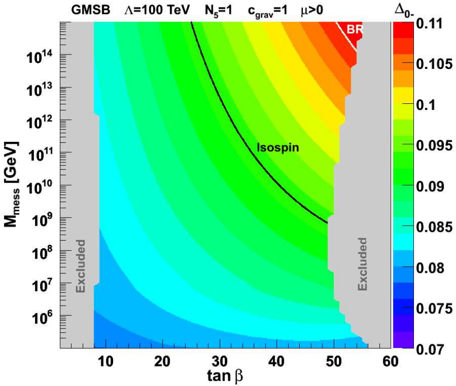


GMSB



F. Mahmoudi, JHEP 0712, 026 (2007)

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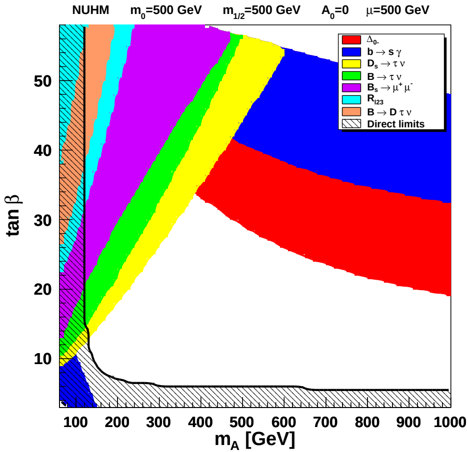

A. Akeroyd & F. Mahmoudi, JHEP 0904, 121 (2009)

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
- $b \longrightarrow s\gamma$ transitions and in particular isospin asymmetry provide valuable information

Perspectives

New observables:

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

New Models:

- Non Minimal Flavor violation
- CP violation

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- $b \longrightarrow s\gamma$ transitions and in particular isospin asymmetry provide valuable information

Perspectives

New observables:

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

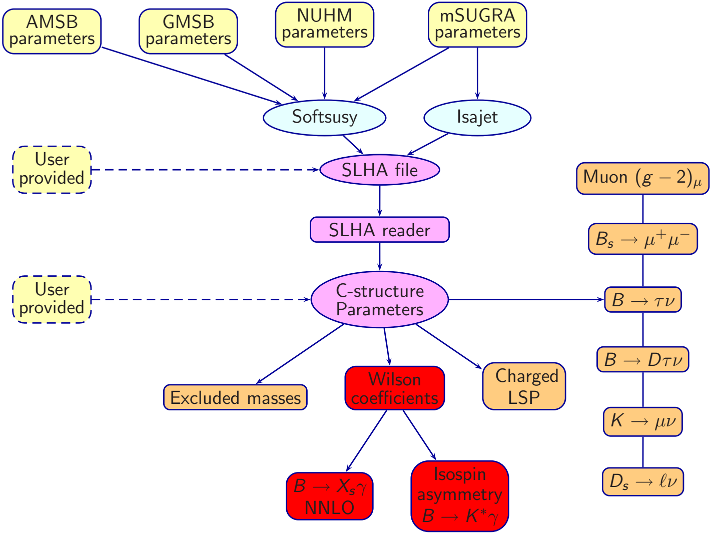
New Models:

- Non Minimal Flavor violation
- CP violation

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

SuperIso


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