Supersymmetry and indirect constraints

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LPC Clermont-Ferrand

GDR Supersymétrie – LAL Orsay – December 3-4, 2008

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
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Where to look for?

SUSY models can be divided into two categories:

- R-parity conserving models
- R-parity violating models

R-parity conserving models can also be divided according to how SUSY breaks:

- mSUGRA $\{m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sign}(\mu)\}$
- NUHM {mSUGRA parameters + M_A and μ}
- AMSB $\{m_0,\ m_{3/2},\ \tan\beta,\ \mathrm{sign}(\mu)\}$
- GMSB $\{\Lambda,\ M_{\mathrm{mess}},\ N_5,\ c_{\mathrm{grav}},\ \tan\beta,\ \mathrm{sign}(\mu)\}$

In these models, SUSY effects always appear in loops

$\longrightarrow$ difficult to detect unless the SM process is absent or loop-mediated.

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SUSY Constraints

Observable	Constraint measure
$BR(B_s \to \mu\mu)$	0 ± 0
ΔM_{B_s}	0 ± 0
$\sin^2 \theta_{\text{eff}}$	0.007 ± 0
$BR(B \to \tau\nu)$	0.011 ± 0
M_W	0.051 ± 0.001
$BR(b \to s\gamma)$	0.188 ± 0.003
$\Delta_{0-}(b \to s\gamma)$	0.208 ± 0.006
$(g-2)_\mu$	0.390 ± 0.012
$\Omega_{DM}h^2$	0.443 ± 0.006
m_h	0.453 ± 0.053

Molding power of individual observables for a specific MSSM scenario with $\mu > 0$

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A public C–program for calculating different observables in supersymmetry

- Automatic calculation in mSUGRA, NUHM, AMSB and GMSB scenarios
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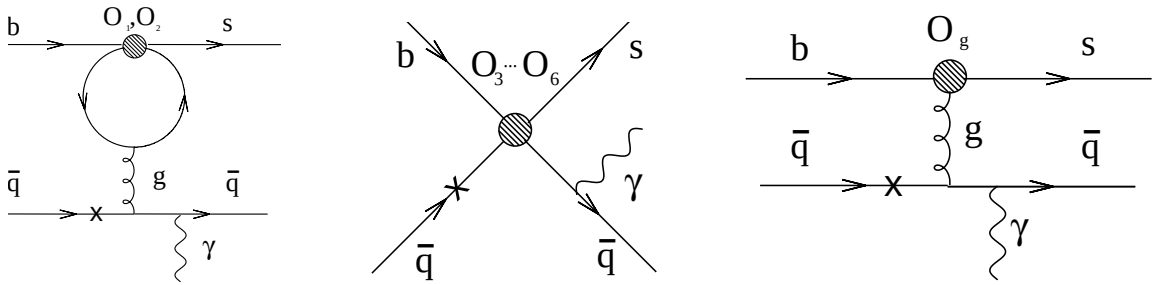

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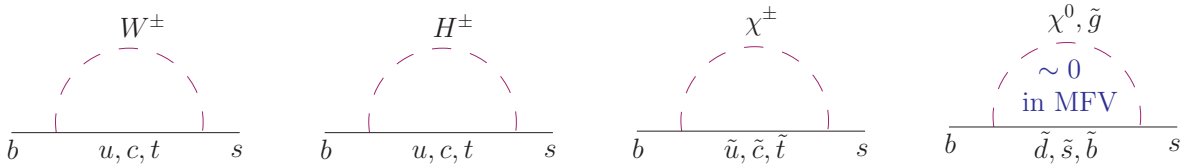

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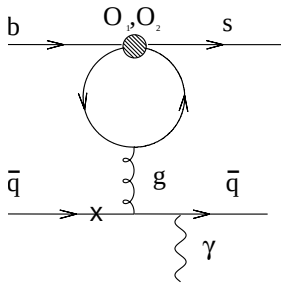

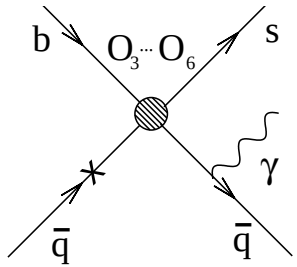

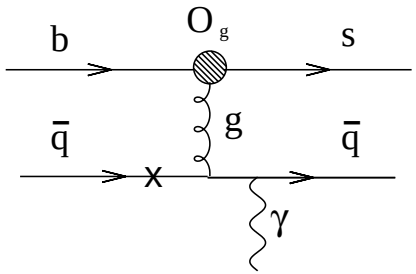

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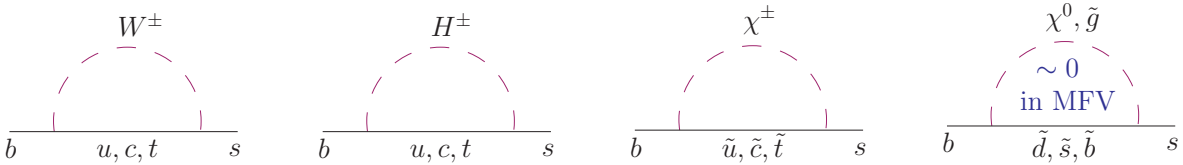

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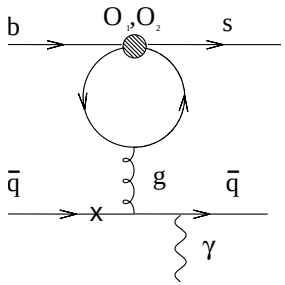

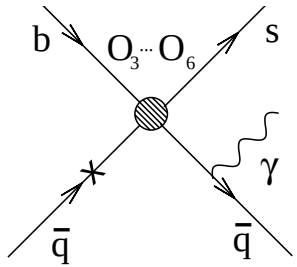

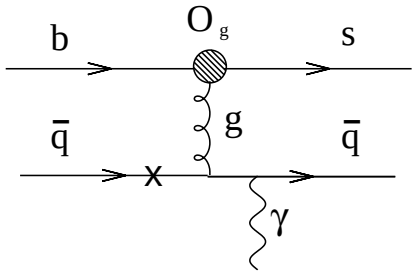

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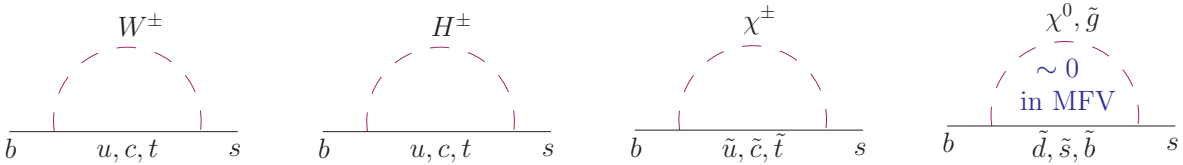

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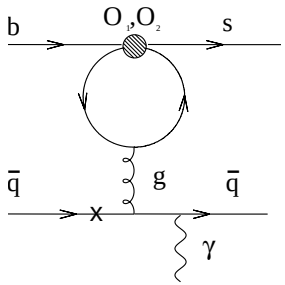

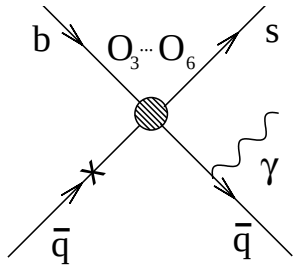

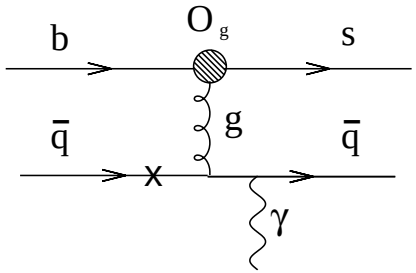

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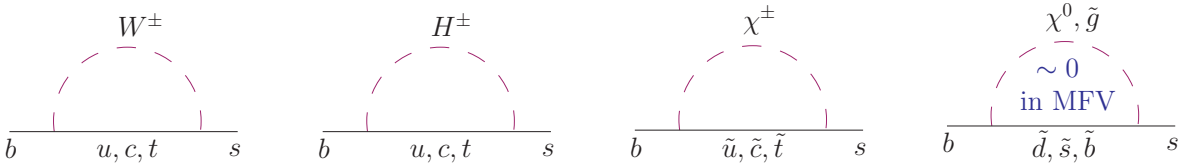

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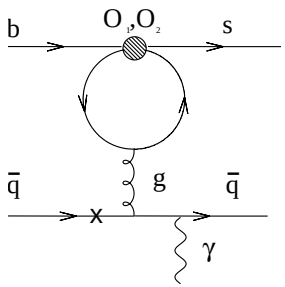

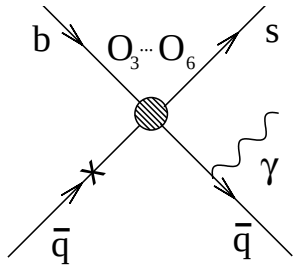

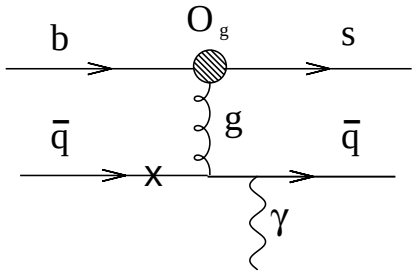

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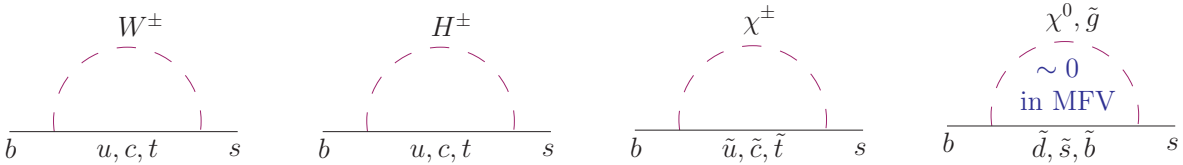

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$$\begin{aligned} P(E_0) &= P^{(0)}(\mu_b) + \alpha_s(\mu_b)\left[P_1^{(1)}(\mu_b) + P_2^{(1)}(E_0,\mu_b)\right] \\ &+ \alpha_s^2(\mu_b)\left[P_1^{(2)}(\mu_b) + P_2^{(2)}(E_0,\mu_b) + P_3^{(2)}(E_0,\mu_b)\right] + \mathcal{O}\left(\alpha_s^3(\mu_b)\right)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

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

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

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

SuperIso v2.3: implemented observables

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

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

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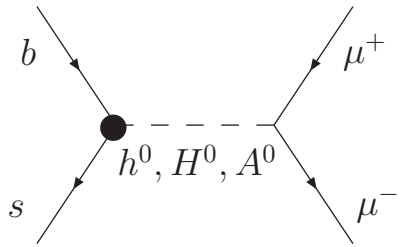
SM prediction: $\mathcal{B}[\bar{B} \to X_s\gamma] = (3.15 \pm 0.23) \times 10^{-4}$

SuperIso v2.3: implemented observables

3. 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:

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

SuperIso v2.3: implemented observables

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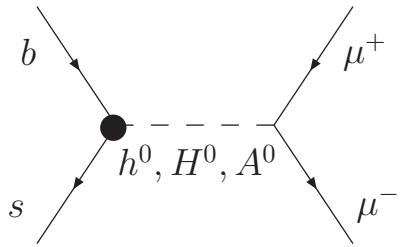

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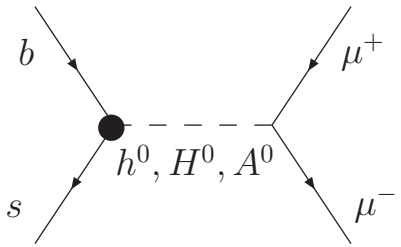

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SuperIso v2.3: implemented observables

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

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

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

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

⚠ Large uncertainty from V_{ub}

Also implemented in SuperIso:

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

SuperIso v2.3: implemented observables

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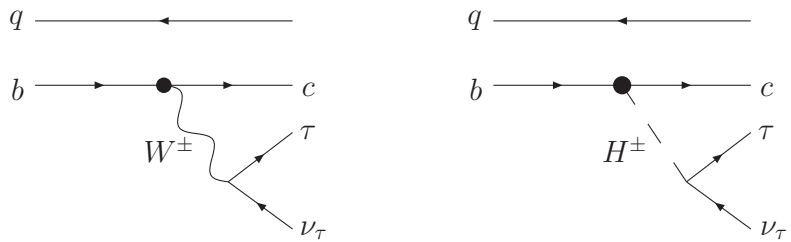
SuperIso v2.3: implemented observables

5. 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 $\frac{\mathcal{B}(B^- \to D^0\tau^-\nu)}{\mathcal{B}(B^- \to D^0 e^-\nu)}$

SuperIso v2.3: implemented observables

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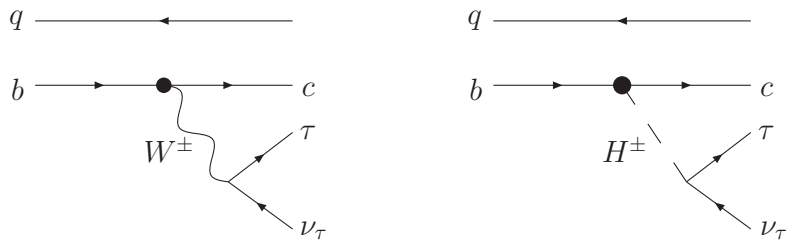

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SuperIso v2.3: implemented observables

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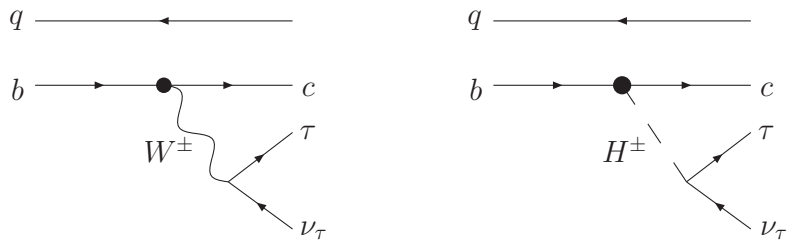

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SuperIso v2.3: implemented observables

6. 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

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SuperIso v2.3: implemented observables

7. Anomalous magnetic moment of muon $a_\mu = (g-2)/2$

Latest measurement on e^+e^- data: $a_\mu^{\rm exp} = (11\,659\,208.0 \pm 6.3) \times 10^{-10}$

Bennett *et al.*, Phys. Rev. D73 (2006)

SM prediction: $a_\mu^{\rm SM} = (11\,659\,178.5 \pm 6.1) \times 10^{-10}$

MSSM contributions:

$$\delta a_\mu^{\rm SUSY} = \delta a_\mu^{\chi^0} + \delta a_\mu^{\chi^\pm} + \delta a_{\mu,\,2\,\rm loop}^{\rm SUSY}$$

Deviation from the SM:

$$\delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (29.5 \pm 8.8) \times 10^{-10}$$

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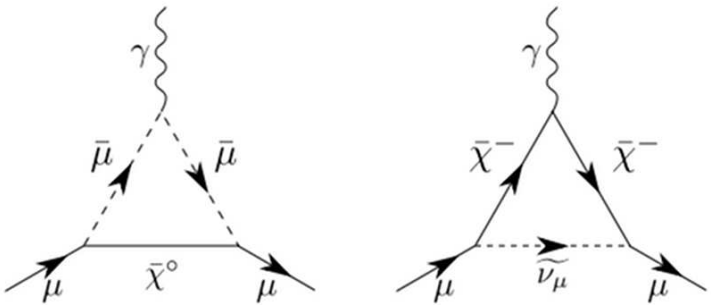

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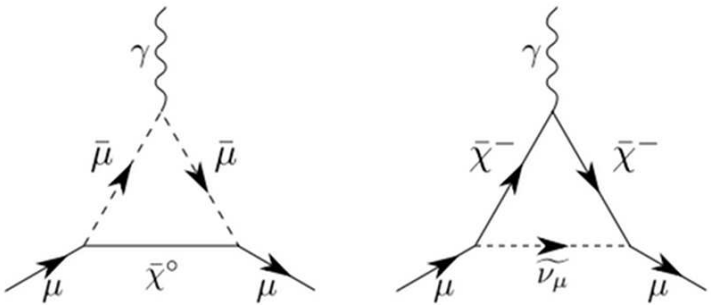

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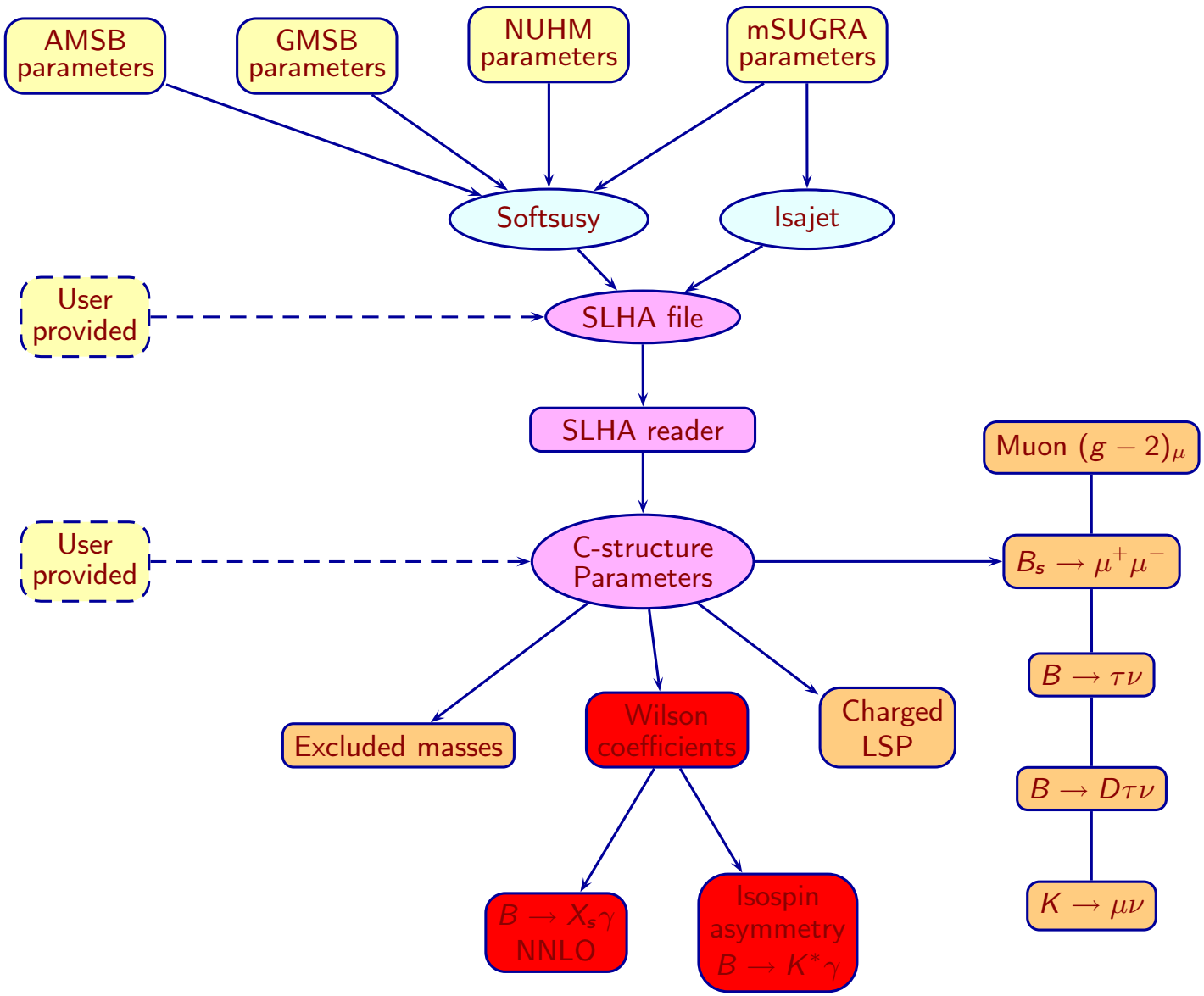
SuperIso v2.3



SuperIso v2.3

Can be downloaded from:

http://www3.tsl.uu.se/∼nazila/superiso/

Manual:

F. Mahmoudi, arXiv:0710.2067, Comput. Phys. Commun. 178, 745 (2008)

F. Mahmoudi, arXiv:0808.3144 [hep-ph]

For more information:

F. Mahmoudi, JHEP 0712, 026 (2007)

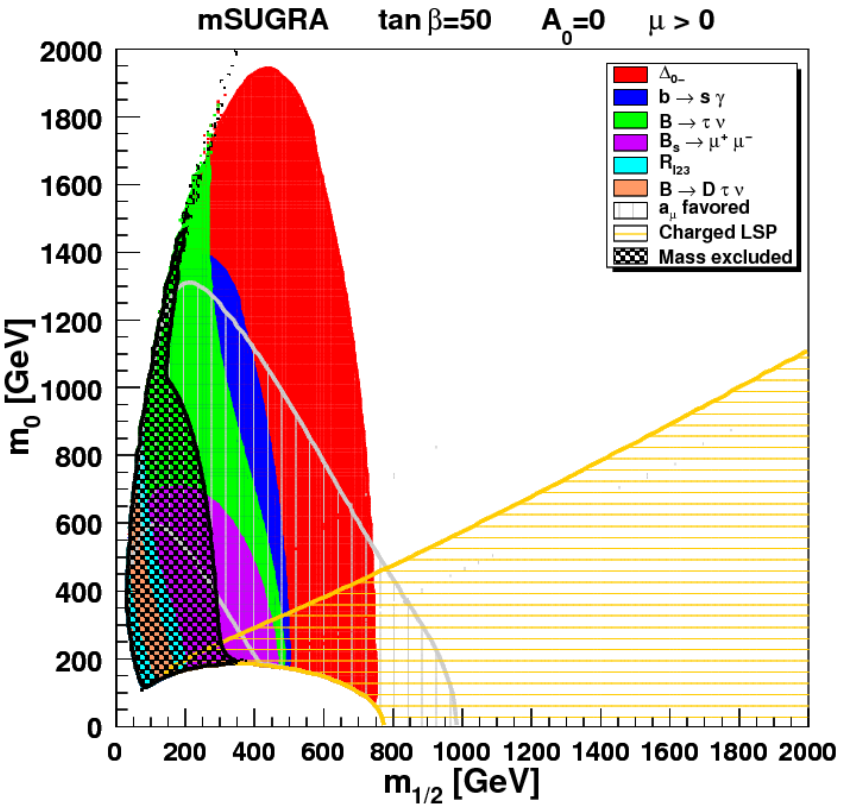
M. Ahmady & F. Mahmoudi, Phys. Rev. D75 (2007)

A. Arbey & F. Mahmoudi, Phys. Lett. B (2008)

D. Eriksson, F. Mahmoudi, O. Stål, JHEP 0811, 035 (2008)

Combined constraints in the MSSM

mSUGRA



F. Mahmoudi, arXiv:0808.3144

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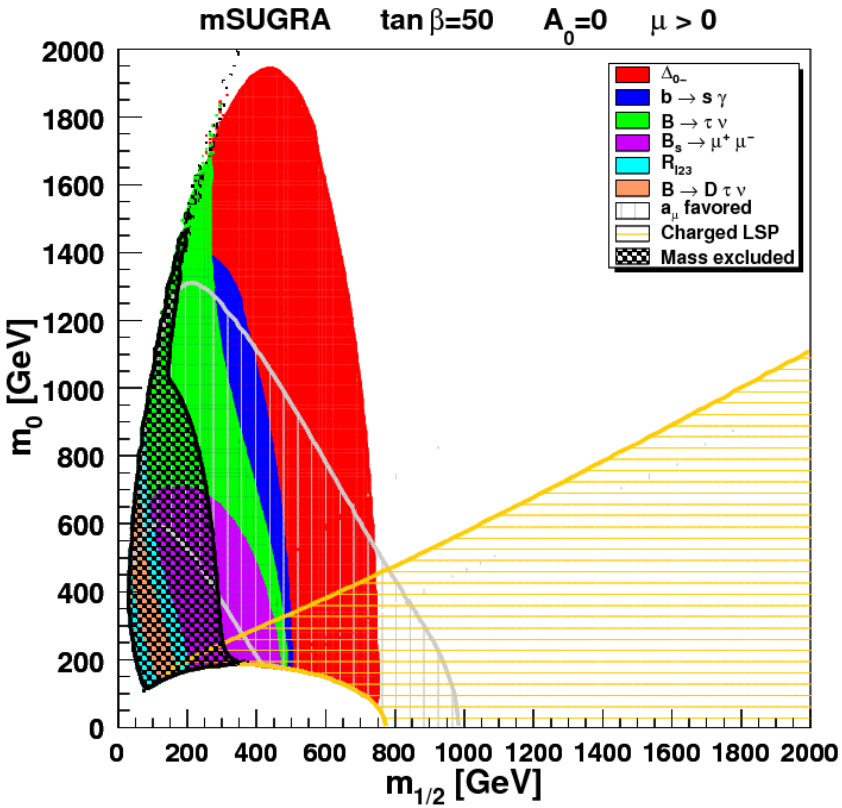
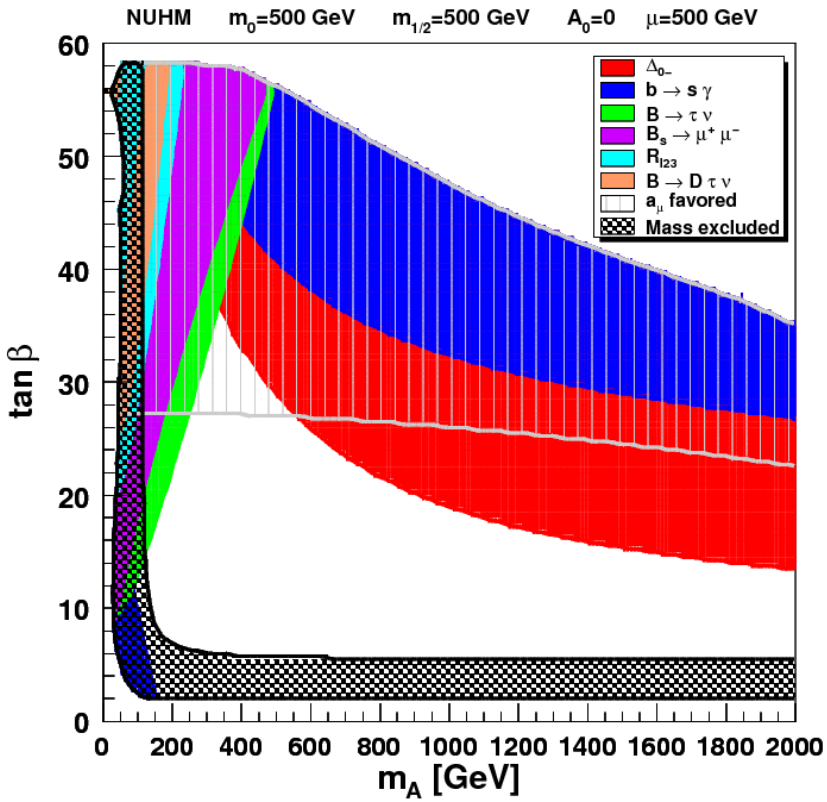


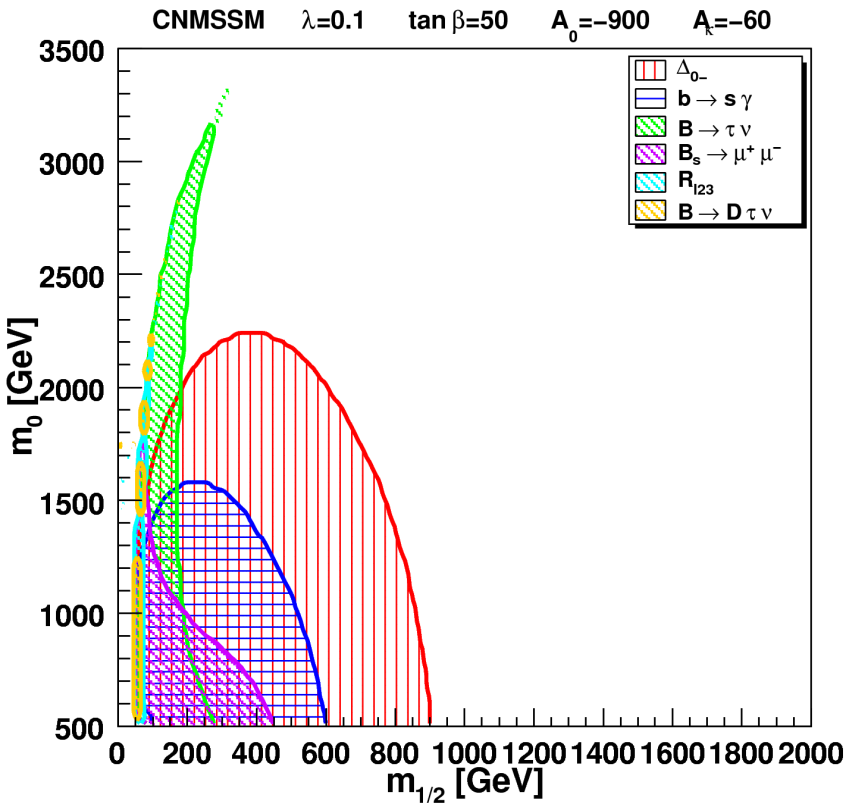
NUHM



F. Mahmoudi, arXiv:0808.3144

Combined constraints in the NMSSM

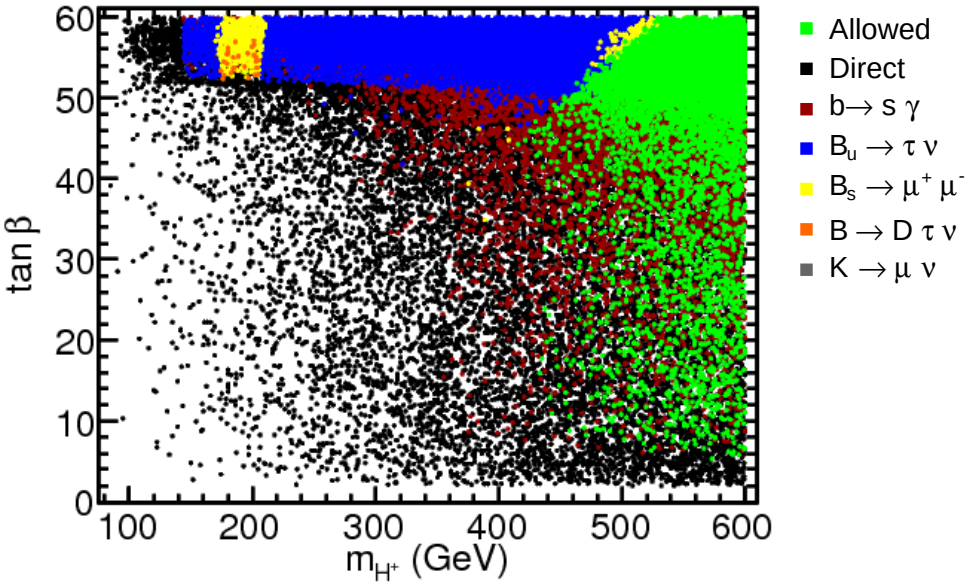
CNMSSM



F. Mahmoudi, preliminary results

Application to the charged Higgs

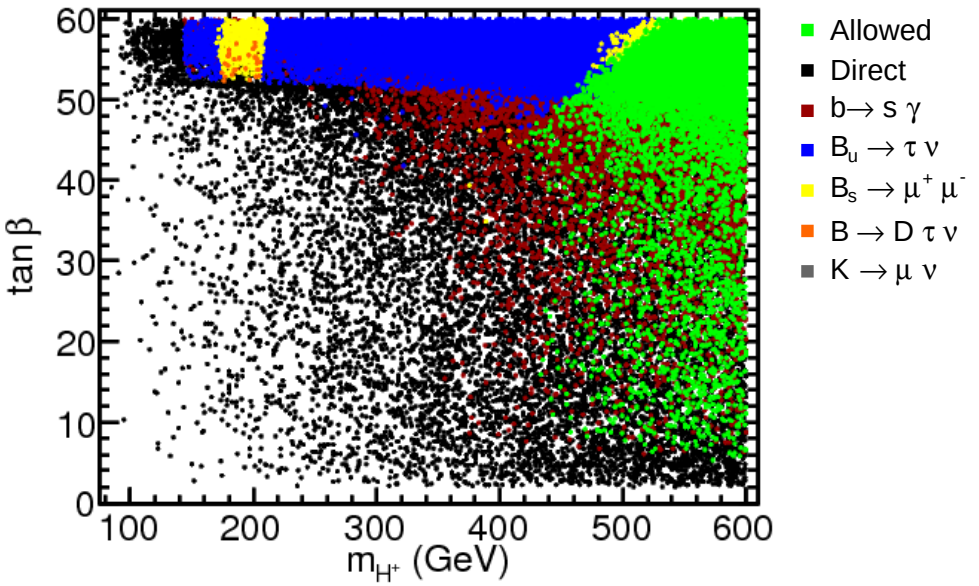
mSUGRA



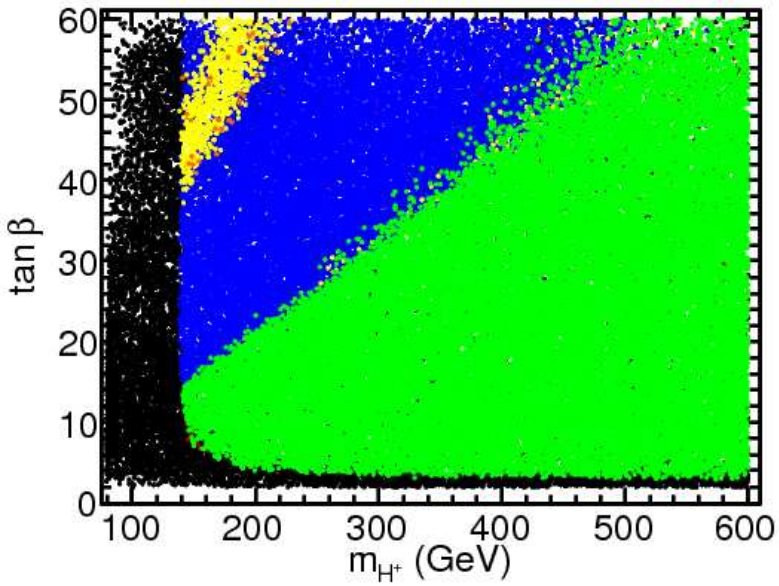
D. Eriksson, F. Mahmoudi, O. Stål, arXiv:0808.3551

Application to the charged Higgs

mSUGRA



NUHM



D. Eriksson, F. Mahmoudi, O. Stål, arXiv:0808.3551

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 NMSSM
- Implementation of the relic density calculation (with A. Arbey)
- Extension to NMFV
- Implementation of other observables ($\mathcal{B}(D_s \to \tau\nu)$, AFB, ...)

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