Status of SuperIso and SuperIso Relic

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Outline

1. Code description
   - SuperIso
   - SuperIso Relic
2. Results
3. News
4. Conclusion

Description

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. 178 (2008) 745, arXiv:0710.2067

Models

Standard Model

General Two Higgs Doublet Model

automatic interface with 2HDMC for

- General 2HDM and Types I, II, III, IV
  → See J. Rathsman's talk on Friday

MSSM (with Minimal Flavour Violation)

automatic interfaces with Softsusy and Isajet available for

- CMSSM, NUHM, AMSB, GMSB

NMSSM

automatic interface with NMSSMTools available for

- CNMSSM, NNUHM, NGMSB

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Observables

Observables

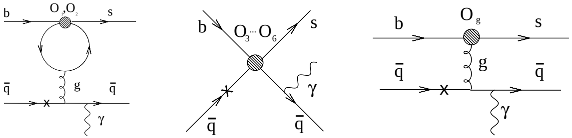
1. Penguin mediated observables
2. Neutral Higgs mediated observables
3. Charged Higgs mediated observables
4. Other observables

Observables

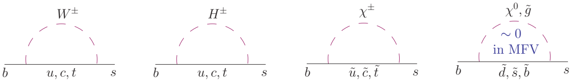
1) Penguin mediated observables

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

Observables

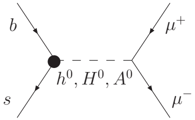
2) Neutral Higgs mediated observable

- 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: $\mathcal{B}(B_s \to \mu^+\mu^-) < 4.3 \times 10^{-8}$ at 95% C.L. (CDF 2009)

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

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

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

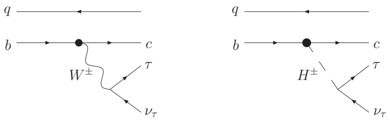
⚠ Large uncertainty from V_{ub}

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:



$$\frac{d\Gamma(B \to D\ell\overline{\nu})}{dw} =$$

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

$w = v_B \cdot v_D$ $\quad$ 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

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 $\rightarrow$ SuperIso Relic

SuperIso Relic

Description

In collaboration with Alexandre Arbey

- Automatized computation of flavour observables and relic density in SUSY
- Flexible particle physics model implementation (CMSSM, NUHM, AMSB, ...)
- Flexible cosmological model implementation (dark energy, reheating, ...)
- Publicly available on http://superiso.in2p3.fr/relic

A. Arbey and F. Mahmoudi, Comput. Phys. Commun. 181 (2010) 1277, arXiv:0906.0369

SuperIso Relic

Structure of the code

- Generation of a SLHA file with Isajet or Softsusy
- Initialization of the variables using the SLHA file
- Generation of additional Higgs sector variables with FeynHiggs
- Calculation of W_{eff}
- Calculation of $\langle \sigma_{eff} v \rangle$
- Solving of the Boltzmann equation
- Computation of the other SuperIso observables

SuperIso Relic

Diagram generation

- Analytical calculation of the amplitudes with Mathematica / FeynArts / FormCalc / FORM
- Implementation of the FormCalc squared amplitudes in SuperIso
- Use of LoopTools (if needed) to compute loop amplitudes
- Possibility to use FeynArts model file generators (FeynRules, LanHEP, ...)
- All coannihilation diagrams included

SuperIso Relic

Alternative cosmological models

- Different QCD equations of state for radiation
- Modification of the expansion of the early Universe with an effective dark density

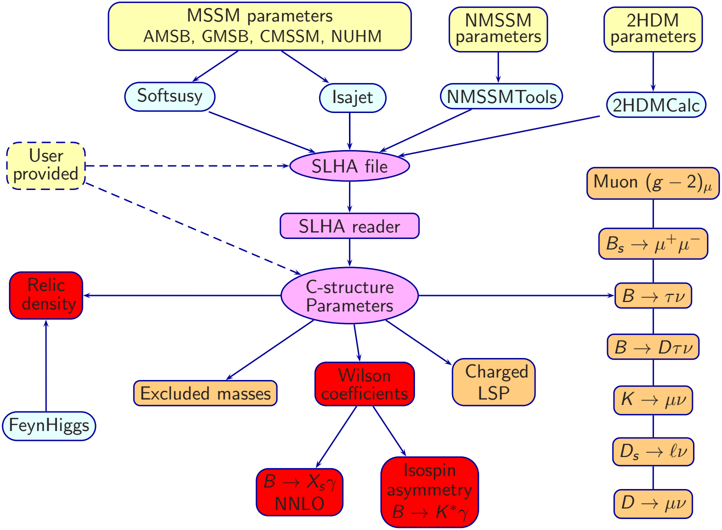
$$\rho_D(T) = \rho_D^0 \, T^{n_\rho}$$

- Modification of the thermal properties of the Universe with an effective dark entropy

$$s_D(T) = s_D^0 \, T^{n_s}$$

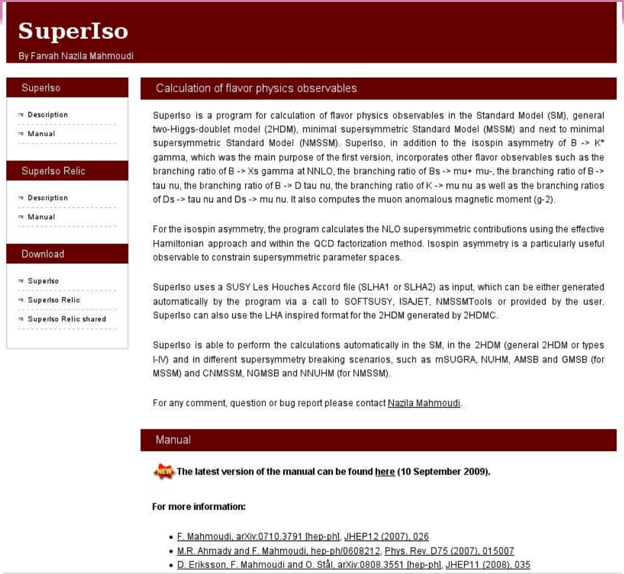
- Includes a Big-Bang Nucleosynthesis code to check cosmological scenarios

How does it work?



Download

http://superiso.in2p3.fr



SuperIso

By Farvah Nazila Mahmoudi

SuperIso
- Description
- Manual

SuperIso Relic
- Description
- Manual

Download
- SuperIso
- SuperIso Relic
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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

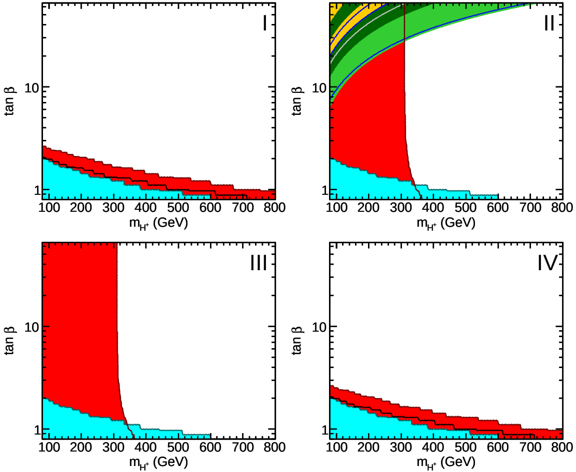
NEW **The latest version of the manual can be found here (10 September 2009).**

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: $K \to \mu\nu_\mu$

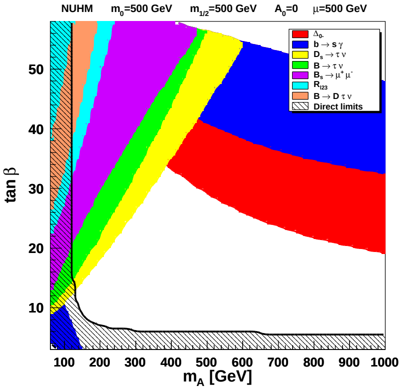
Green: $D_s \to \tau\nu_\tau$

Dark green: $D_s \to \mu\nu_\mu$

F. Mahmoudi and O. Stål, Phys. Rev. D81 (2010) 035016, arXiv:0907.1791

Results

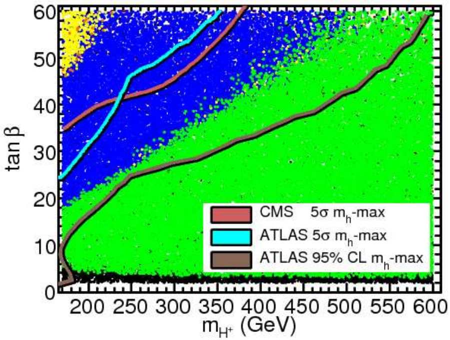
NUHM



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

Results

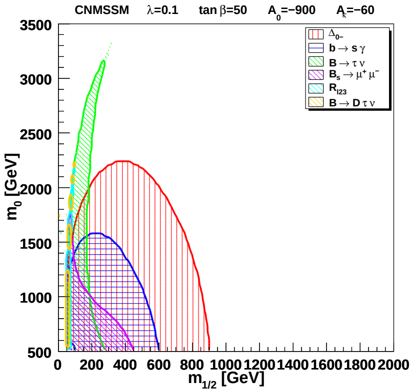
NUHM



D. Eriksson, F. Mahmoudi and O. Stål, JHEP 0811 (2008) 035, arXiv:0808.3551

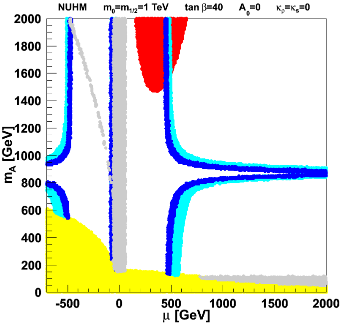
Results

CNMSSM



Results

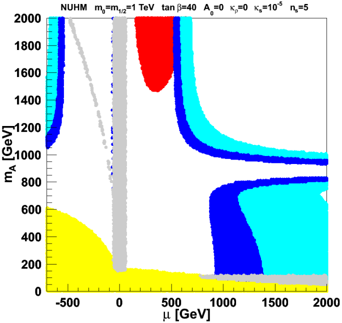
standard cosmology | modified expansion rate

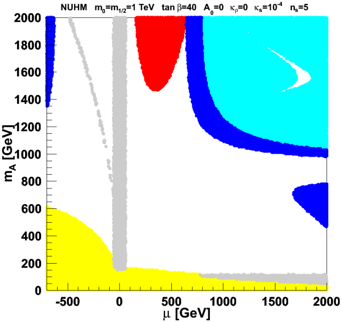


A. Arbey & F. Mahmoudi, Phys. Lett. B669 (2008), 46, arXiv:0906.0368
A. Arbey & F. Mahmoudi, JHEP 1005 (2010), 051, arXiv:0906.0368

Results

modified entropy content

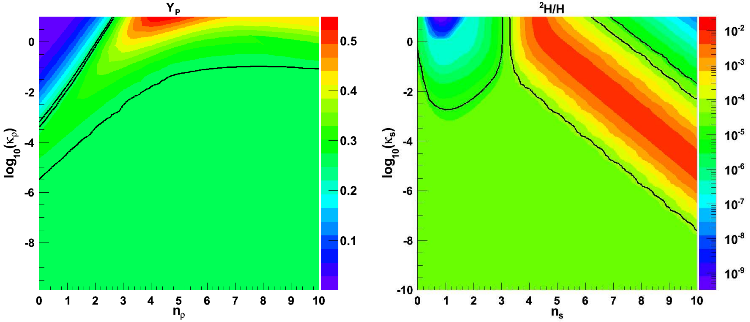




A. Arbey & F. Mahmoudi, JHEP 1005 (2010), 051, arXiv:0906.0368

Results

BBN constraints on the energy and entropy contents



A. Arbey & F. Mahmoudi, JHEP 1005 (2010), 051, arXiv:0906.0368

Next release

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

- Mixed-moduli AMSB
- Hypercharged AMSB

New interfaces

- SPheno
- Suspect
- HiggsBounds and Hdecay

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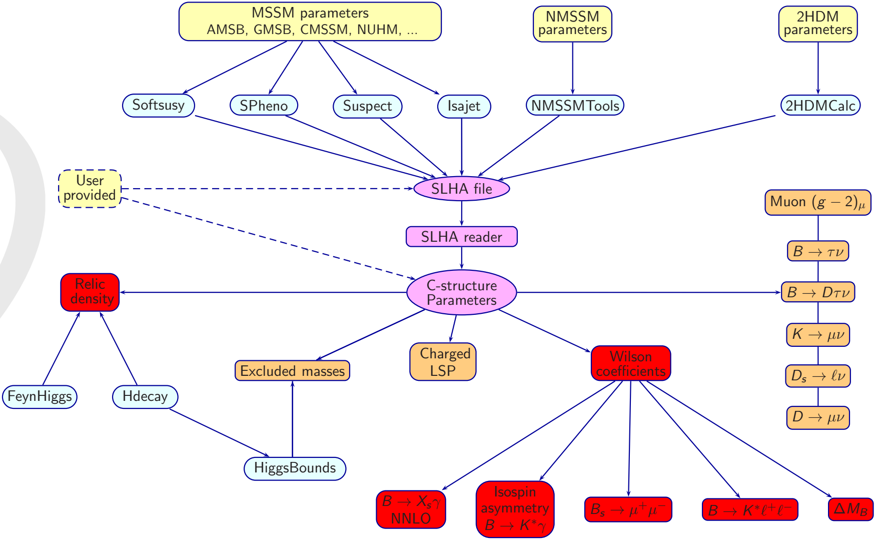
Next release

Relic density

- improved performance
- automatic configuration scripts
- all-in-one version (static and shared versions unified in one package)
- choice of the Higgs width calculator (Hdecay or FeynHiggs)
- different parametrizations of the cosmological entropy content
- addition of a Big-Bang nucleosynthesis code to check the viability of the implemented cosmological models

Next release



Future developments

New models

- Flavour Les Houches Accord (FLHA) output
- Non Minimal Flavour violation
- CP violation
- R parity violation?

Relic density

- many ideas: new cosmological models, new features, NMSSM, NLO, ...

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FLHA

The Flavour Les Houches Accord format

Standard format for flavour related quantities, providing:

- A model independent parametrization
- A standalone flavour output in the FLHA format
- Based on the existing SLHA structure
- A clear and well-defined structure for interfacing computational tools of "New Physics" models with low energy flavour calculations
- That will allow different programs to talk and to be interfaced, and users to have a clear and well defined result that can eventually be used for different purposes

FLHA

Flavour Les Houches Accord

- Based on the same considerations as SLHA
- Not only for Supersymmetry
- Consistent structure and definitions
- Flavour quantities are defined in blocks
- FLHA can contain SLHA blocks
- FLHA block names start with "F" to avoid confusion
- FLHA will not modify SLHA blocks
- Avoiding ambiguities, no double blocks,...

FLHA

- Involved people:
  A. Arbey, A. Bharucha, T. Goto, T. Hahn, U. Haisch, S. Heinemeyer, S. Kraml, F. Mahmoudi, M. Muhlleitner, J. Reuter, P. Skands, P. Slavich
- More information on the Wiki page:
  http://www.lpthe.jussieu.fr/LesHouches09Wiki/index.php/Flavour_Les_Houches_Accord
- Les Houches write-up: arXiv:1003.1643

Conclusion

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- SuperIso program provides the possibility to calculate many flavour observables in different models
- Indirect constraints from flavour observables are essential to restrict new physics parameters
- That will become even more interesting when combined with LHC data
- Relic density is strongly dependent on the cosmological assumptions

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

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Backup

Backup: General THDM

Charged Higgs boson couplings to fermions:

$$H^+ D\bar{U}: \qquad \frac{ig}{2\sqrt{2}m_W} V_{UD} \left[\lambda^U m_U \left(1-\gamma^5\right) - \lambda^D m_D \left(1+\gamma^5\right) \right]$$

$$H^+ \ell^- \bar{\nu}_\ell: \qquad -\frac{ig}{2\sqrt{2}m_W} \lambda^\ell m_\ell \left(1+\gamma^5\right)$$

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	$\cot\beta$	$\cot\beta$	$-\tan\beta$