Constraints on Dark Matter Annihilation from the Rare $B_s \to \mu^+\mu^-$ Decay in the MSSM with NMFV

Christoph Borschensky, Guillaume Chalons, Florian Domingo, Ulrich Nierste | May 14, 2012

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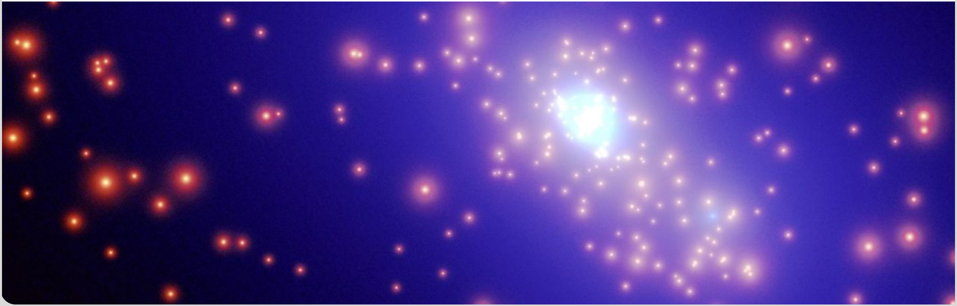

Outline

The CKM matrix (1)

- Yukawa term for up-type quarks:

$$\mathcal{L}_Y \supset -Y^u_{fi}\bar{Q}_{fL}\tilde{\Phi}u_{iR}$$

with

$$Q_{fL} = \begin{pmatrix} u_{fL} \\ d_{fL} \end{pmatrix}, \quad \tilde{\Phi} = i\sigma^2\Phi^*, \quad \Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

- Rotating the fields

$$Q_{fL} \to Q^{\text{phys.}}_{fL} = S^*_{jf} Q_{jL}$$
$$u_{iR} \to u^{\text{phys.}}_{iR} = U^*_{ki} u_{kR}$$

renders the Yukawa matrix diagonal in flavor space:

$$S^*_{jf} Y^u_{fi} U_{ik} = Y^{u(\text{diag.})}_j \delta_{jk}$$

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The CKM matrix (2)

- Yukawa term for down-type quarks:

$$\mathcal{L}_Y \supset -Y^d_{fi}\bar{Q}_{fL}\Phi d_{iR}$$

- Rotating the field

$$d_{iR} \rightarrow d^{\text{phys.}}_{iR} = D^*_{ki} d_{kR}$$

does not diagonalize Y^d_{fi}, since the rotation of Q_{fL} is already fixed:

$$S^*_{jf} Y^d_{fi} D_{ik} = \left(VY^{d(\text{diag.})}\right)_{jk}$$

with the so-called CKM matrix V containing off-diagonal entries.

⇒ Additionally rotate the down part of Q_{fL} with V to diagonalize down quark mass terms:

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Flavor violation

= Processes that change the flavor quantum number

- ***Charged currents (CC)***
  - Standard Model (SM): $W^{\pm}$ bosons
  - Two Higgs Doublet Model (THDM): charged Higgs bosons $H^{\pm}$
  - Minimal Supersymmetric Standard Model (MSSM): charginos $\tilde{\chi}_k^{\pm}$
- ***Flavor changing neutral currents (FCNC)***
  - SM: Z^0 penguins, $W^{\pm}$ boxes; **loop suppressed!**
  - THDM: new flavor changing couplings (non-holomorphic); **on tree level!**
  - MSSM: for a general flavor structure, squark mass matrices can induce flavor mixing on **tree level** as well
- ***Minimal flavor violation (MFV)*****:** Process proportional to a Yukawa matrix
- ***Non-minimal flavor violation (NMFV)*****:** General flavor structure (e.g. squark mass matrices in a general MSSM)

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- **Quadratic divergencies** of radiative corrections to the Higgs mass **are canceled**
- **Quartic Higgs self coupling** connected to gauge couplings, **not a new parameter** like in the SM
- **SM** just an **effective low energy theory**; requires **a more comprehensive theory** at higher energies
- Possibility for a **GUT**: unification of gauge couplings
- Possibility for a **dark matter** candidate (*R-parity*)
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MSSM fields & particles

Supermultiplet	$\mathrm{SU}(3)_C$	$\times$	$\mathrm{SU}(2)_L$	$\times$	$\mathrm{U}(1)_Y$	Particle content
$\hat{Q} \equiv \begin{pmatrix} \hat{u} \\ \hat{d} \end{pmatrix}$	3		2		$+\frac{1}{3}$	$\begin{pmatrix} u_L \\ d_L \end{pmatrix}, \begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix}$
$\hat{U}$	3		1		$+\frac{4}{3}$	$u_R, \tilde{u}_R$
$\hat{D}$	3		1		$-\frac{2}{3}$	$d_R, \tilde{d}_R$
$\hat{L} \equiv \begin{pmatrix} \hat{\nu} \\ \hat{e} \end{pmatrix}$	1		2		-1	$\begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \begin{pmatrix} \tilde{\nu}_L \\ \tilde{e}_L \end{pmatrix}$
$\hat{E}$	1		1		-2	$e_R, \tilde{e}_R$
$\hat{H}_d \equiv \begin{pmatrix} \hat{H}_d^0 \\ \hat{H}_d^- \end{pmatrix}$	1		2		-1	$\begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}, \begin{pmatrix} \tilde{H}_d^0 \\ \tilde{H}_d^- \end{pmatrix}$
$\hat{H}_u \equiv \begin{pmatrix} \hat{H}_u^+ \\ \hat{H}_u^0 \end{pmatrix}$	1		2		$+1$	$\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \begin{pmatrix} \tilde{H}_u^+ \\ \tilde{H}_u^0 \end{pmatrix}$

MSSM fields & particles

Fields	$\mathrm{SU}(3)_C$	$\times$	$\mathrm{SU}(2)_L$	$\times$	$\mathrm{U}(1)_Y$
$G^a_\mu,\ \tilde{g}^a$	8		1		0
$W^j_\mu,\ \lambda_j$	1		3		0
$B_\mu,\ \lambda_0$	1		1		0

A new symmetry? Let's break it!

- Reasons for supersymmetry breaking:
  - There are no particles with the same mass as the electron
  - Bosonic selectrons in atoms: fatal impact on chemistry

But why introduce it when it's broken?

- **Solution:** Only break mass symmetry, but keep coupling symmetry intact
- **I.e.** standard model and SUSY particles have different masses, but their fields transform under the same gauge symmetry with the same coupling strength

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Soft SUSY breaking

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- Parameterize SUSY breaking as additional terms in the Lagrangian:

$$
\begin{aligned}
-\mathcal{L}_{\text{soft}} = {} & \tilde{Q}^*_{iL}\left(M^2_{\tilde{q}}\right)_{ij}\tilde{Q}_{jL} + \tilde{u}^*_{iR}\left(M^2_{\tilde{u}}\right)_{ij}\tilde{u}_{jR} + \tilde{d}^*_{iR}\left(M^2_{\tilde{d}}\right)_{ij}\tilde{d}_{jR} \\
& + A^d_{ij} H_d \epsilon \tilde{Q}_{iL}\tilde{d}^*_{jR} + A^u_{ij} H_u \epsilon \tilde{Q}_{iL}\tilde{u}^*_{jR} + \text{h.c.} \\
& + A'^d_{ij} H^*_u \tilde{Q}_{iL}\tilde{d}^*_{jR} + A'^u_{ij} H^*_d \tilde{Q}_{iL}\tilde{u}^*_{jR} + \text{h.c.} \\
& + M^2_{H_d}|H_d|^2 + M^2_{H_u}|H_u|^2 + (B\mu H_d \epsilon H_u + \text{h.c.}) \\
& + \frac{1}{2}\left(M_1 \bar{\lambda}_0 P_L \lambda_0 + \text{h.c.}\right) + \frac{1}{2}\left(M_2 \sum_{i=1}^{3} \bar{\lambda}_i P_L \lambda_i + \text{h.c.}\right) \\
& + \frac{1}{2}\left(M_3 \bar{\tilde{g}}^a P_L \tilde{g}^a + \text{h.c.}\right)
\end{aligned}
$$

Higgs sector: THDM

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- Extension of the SM Higgs sector $\rightarrow$ one additional Higgs doublet:

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \qquad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$$

- Type II $\rightarrow$ each doublet couples to either up- or down-type quarks only
- Two vacuum expectation values (VEV) and their ratio $\tan\beta$:

$$\langle H_u \rangle = \begin{pmatrix} 0 \\ v_u \end{pmatrix}, \qquad \langle H_d \rangle = \begin{pmatrix} v_d \\ 0 \end{pmatrix}, \qquad \tan\beta \equiv \frac{v_u}{v_d}$$

- Yukawa terms:

$$\mathcal{L}_Y = -Y^u_{fi} \bar{Q}_{fL} \epsilon H_u^* u_{iR} + Y^d_{fi} \bar{Q}_{fL} \epsilon H_d^* d_{iR} + \text{h.c.}$$

  To get the fermion mass terms, replace $H_{u/d}$ by its VEV
- More physical fields than SM: h^0, H^0, A^0, $H^\pm$

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R-parity

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- Discrete symmetry that distinguishes standard model particles from SUSY particles:

$$R = (-1)^{3(B-L)+2s}$$

  - Quarks, leptons, Higgs and gauge bosons: $R = +1$
  - Squarks, sleptons, Higgsinos and gauginos: $R = -1$

- R-parity conservation in the MSSM has a lot of consequences:
  - R-parity violating terms are forbidden in the Lagrangian: no $(B-L)$-violation, no proton decay
  - Standard model particles only decay into pairs of SUSY particles: distinct signatures at collider data
  - There is a ***lightest supersymmetric particle (LSP)*** at the end of each decay chain of a SUSY particle
    $\rightarrow$ dark matter candidate!
    $\rightarrow$ seen as missing energy at colliders

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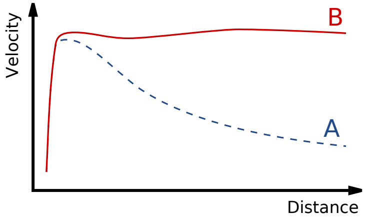
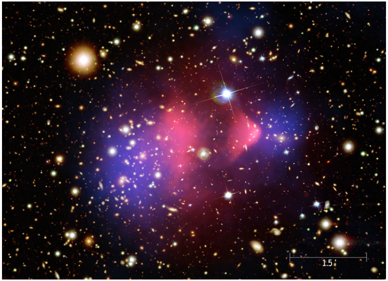
Constituents of the universe

		Value
Baryon density	Ω_b	0.044 ± 0.004
Dark matter density	Ω_χ	0.21 ± 0.02
Total matter density	Ω_{m}	0.26 ± 0.02
Dark energy density	Ω_Λ	0.74 ± 0.03
Photon density	Ω_γ	$(4.8 \pm 0.4) \cdot 10^{-5}$
Neutrino density	Ω_ν	$0.0009 < \Omega_\nu < 0.048$
Total energy density of the universe	Ω_{tot}	1.006 ± 0.006

Why dark?

- Rotation curves of galaxies indicate more than just the **luminous** matter
- Bullet Cluster
- Gravitational lensing
- Cosmic microwave background (CMB)





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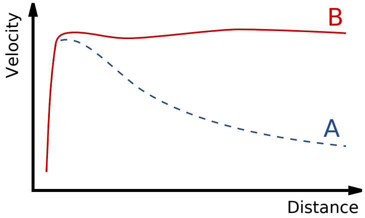

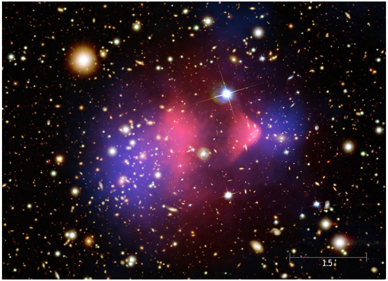

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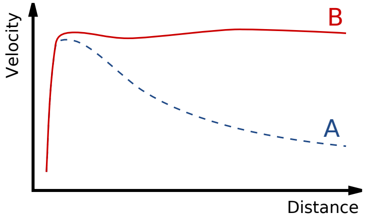

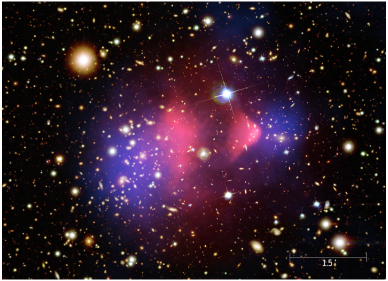

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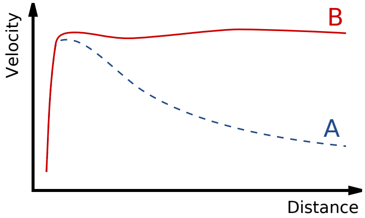
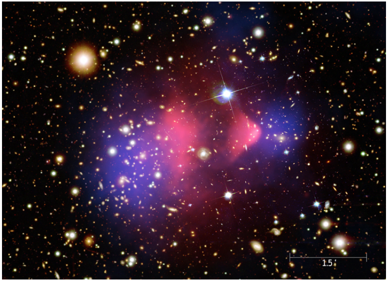
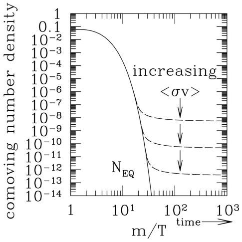




(source for pictures: Wikipedia)

Relic density

- Short history on dark matter (DM):
  1) After big bang, when universe is still hot, DM particles annihilate into *lighter* SM particles and vice versa; **equilibrium**
  2) Not enough thermal energy to produce DM particles, only process is **DM annihilation**
  3) DM **freezes out** when the expansion of the universe is fast enough
- Today's amount of dark matter strongly depends on annihilation mechanism



(source: http://ned.ipac.caltech.edu/)

- Relic density approximation for a radiation dominated universe:

$$\Omega_\chi h^2 \sim \frac{10^{-10}}{\langle \sigma v \rangle} \text{ GeV}^{-2}$$

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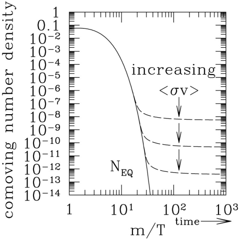

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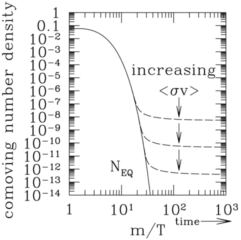

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Effective couplings (1)

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- Additional **holomorphic** and **non-holomorphic** couplings to tree level THDM couplings of type II
- With $\epsilon_{12} = 1$,

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix} = \begin{pmatrix} H^+ \cos\beta \\ v_u + \frac{1}{\sqrt{2}}\left(H^0 \sin\alpha + h^0 \cos\alpha + iA^0 \cos\beta\right) \end{pmatrix},$$

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→ Mass terms non-diagonal! Effective contributions render the couplings flavor-changing

→ Rotate the quark fields back into physical basis with a rotation in flavor space:

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- Perturbative diagonalization: U^{dL} and U^{dR} have small off-diagonal entries, can be expressed through effective couplings, e.g.

$$\tilde{E}'^{d}_{23} \approx E'^{d}_{23} - \frac{E'^{d}_{33}\left(E^{d}_{23} v_d + E'^{d}_{23} v_u\right)}{m_{d_3}}$$

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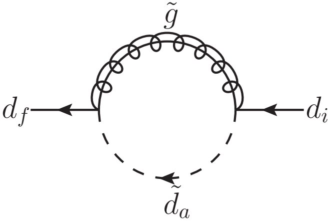
Chirally enhanced self energies



- Given as:
  $\Sigma^{d}_{fi} = \not{p}\left(\Sigma^{dLL}_{fi}(p^2)P_L + \Sigma^{dRR}_{fi}(p^2)P_R\right) + \Sigma^{dRL}_{fi}(p^2)P_L + \Sigma^{dLR}_{fi}(p^2)P_R$
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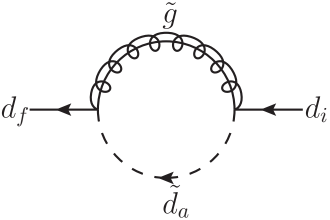
- In order to get the chirally enhanced parts, it is enough to evaluate the self energies at vanishing external momentum

Chirally enhanced self energies



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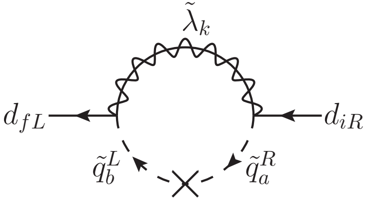
E.g.: gluino contribution

$$\Sigma_{fi}^{dLR,\tilde{g}} = \frac{2\alpha_s}{3\pi} m_{\tilde{g}} \sum_{a=1}^{6} W_{fa}^{\tilde{d}L} W_{ia}^{\tilde{d}R*} B_0(m_{\tilde{g}}^2, m_{\tilde{d}_a}^2)$$

- The mixing matrices W^d depend on the squark matrix elements, in the decoupling limit ($M_{\mathrm{SUSY}} \gg v$) to only one power of the matrix element



$\rightarrow$ Mass insertion in squark line with the corresponding flavor changing matrix element

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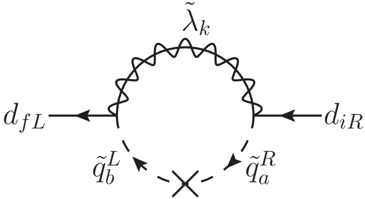

$\rightarrow$ Mass insertion in squark line with the corresponding flavor changing matrix element

Gluino contribution, decoupling limit

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- With

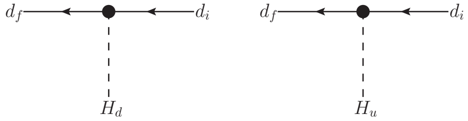
$$\mathcal{M}^2_{\tilde{d}} = \begin{pmatrix} \left(\mathcal{M}^{\tilde{d}}_{LL}\right)^2 & \Delta^{d,LR} \\ \Delta^{d,RL} & \left(\mathcal{M}^{\tilde{d}}_{RR}\right)^2 \end{pmatrix} :$$

$$\Sigma^{dLR,\tilde{g}}_{fi} \overset{(\text{dec.})}{=} \frac{2\alpha_s}{3\pi} m_{\tilde{g}} \sum_{a,b=1}^{3} \sum_{l,m=1}^{3} W^{\tilde{d}L}_{fa} W^{\tilde{d}L*}_{la} \Delta^{d,LR}_{lm} W^{\tilde{d}R}_{mb} W^{\tilde{d}R*}_{ib} \times C_0\left(m^2_{\tilde{g}}, m^2_{\tilde{d}^L_a}, m^2_{\tilde{d}^R_b}\right)$$

- The chirality-changing matrix element is given as

$$\Delta^{d,LR}_{ij} = v_d A^d_{ij} - v_u \mu Y^d_i \delta_{ij}$$

Effective couplings in the MSSM



- Replace E^d and E'^d with contributions from $\Sigma^{dLR,\tilde{g}}$:

$$E^d_{fi} = \frac{1}{v_d} \Sigma^{dLR}_{fi\ A}, \qquad E'^d_{fi} = \frac{1}{v_u} \Sigma^{dLR}_{fi\ \mu}$$

- Write down new effective coupling:

$$\Gamma^{H^0_k, LR}_{d_f d_i} = \frac{1}{v_d} \left[x^d_k m_{d_i} \delta_{fi} + y^d_k \tilde{\Sigma}^{dLR}_{fi\ \mu} \right] = \frac{1}{v_d} \left[x^d_k m_{d_i} \delta_{fi} + y^d_k \left(\Sigma^{dLR}_{fi\ \mu} - \frac{\Sigma^{dLR}_{ii\ \mu}}{m_{d_i}} \Sigma^{dLR}_{fi} \right) \right]$$

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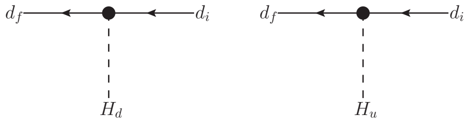

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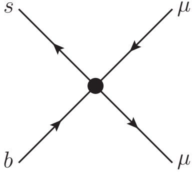
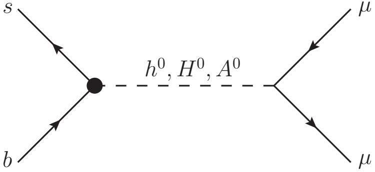
Wilson coefficients

- Effective coupling with the Wilson coefficients as the coupling strength:



- From leading contribution



the scalar and pseudoscalar Wilson coefficients can be calculated:

$$c_S = -c_P = -\frac{2\pi m_\mu \tan^2\beta}{\alpha m_b M_{A^0}^2 V_{ts}^* V_{tb}} \left(\Sigma_{23\;\mu}^{dLR} - \frac{\Sigma_{33\;\mu}^{dLR}}{m_b} \Sigma_{23}^{dLR} \right)$$

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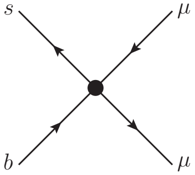

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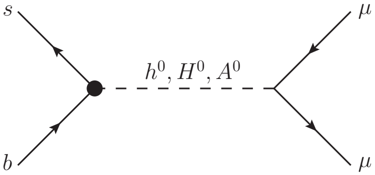

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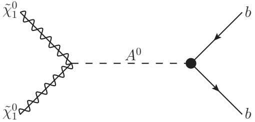
Input



- Relic density: $\Omega_\chi h^2 \propto 1/\langle \sigma v \rangle \propto M_{A^0}^4 / \tan^2\beta$
- Parameterization of the NMFV sources in $\Delta_{ij}^{d,LR}$:

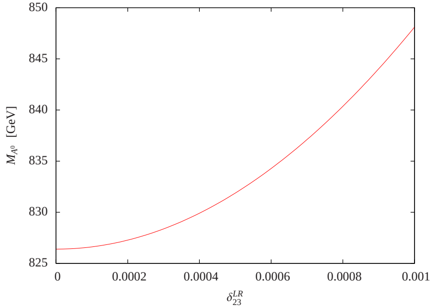
$$\delta_{ij}^{d,LR} = \frac{\Delta_{ij}^{d,LR}}{\sqrt{\left(\mathcal{M}_{LL}^{\tilde{d}}\right)_{ii}^2 \left(\mathcal{M}_{RR}^{\tilde{d}}\right)_{jj}^2}}$$

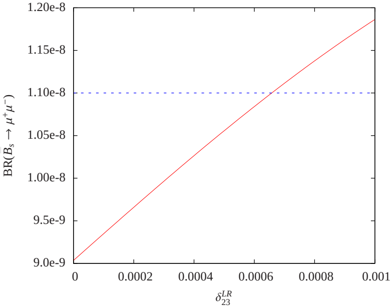
- High $\tan\beta = 50 \rightarrow$ Higgs funnel region

Input parameters

- Higgs mass for h^0: 115.5 GeV [ATLAS; arXiv:1202.1408]
- Top pole mass: 172.9 GeV [PDG '11]
- $\mathrm{BR}(\bar{B}_s \rightarrow \mu^+\mu^-) < 1.1 \times 10^{-8}$ [CMS; arXiv:1201.4257]
- Relic density: $0,0997 \leq \Omega_\chi h^2 \leq 0,1221$ [WMAP 7-year-data]

Dependence on $\delta_{23}^{d,LR}$ (1)

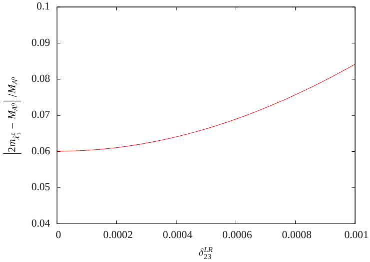


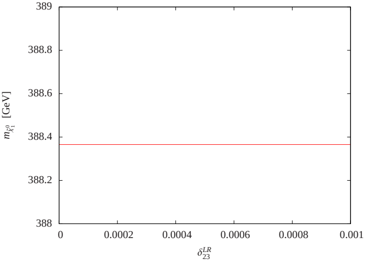


Input:

$m_0 = 780$ GeV, $m_{1/2} = 910$ GeV, $\tan\beta = 50$ GeV, $\mathrm{sign}(\mu) > 0$, $A_0 = 0$ GeV

Dependence on $\delta_{23}^{d,LR}$ (2)





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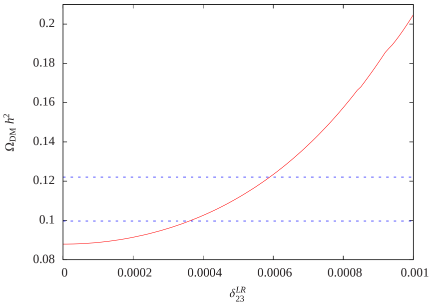
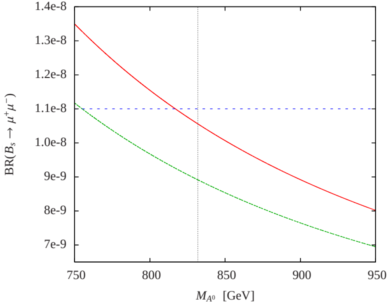
Dependence on $\delta_{23}^{d,LR}$ (3)





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$A_0 = 0$ **GeV**, $\tan\beta = 50$, **sign**$(\mu) > 0$

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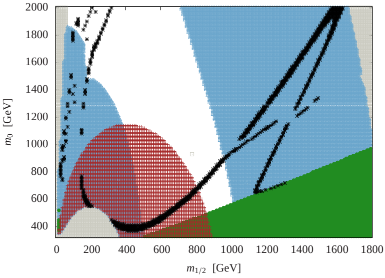
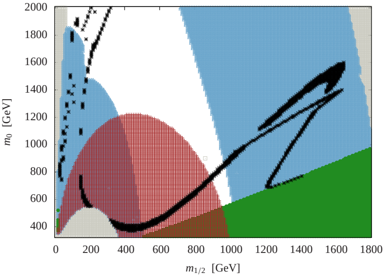
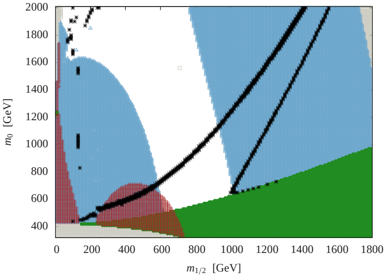


$\delta_{23}^{d,LR} = 0$



$\delta_{23}^{d,LR} = 0.0005$

$A_0 = 1000$ **GeV**, $\tan\beta = 50$, **sign**$(\mu) > 0$



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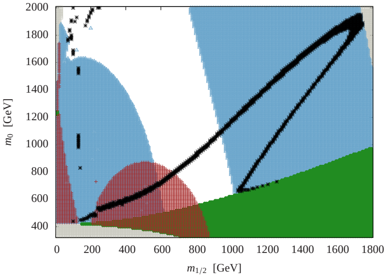

$\delta_{23}^{d,LR} = 0.0005$

$A_0 = -1000$ GeV, $\tan\beta = 50$, sign$(\mu) > 0$

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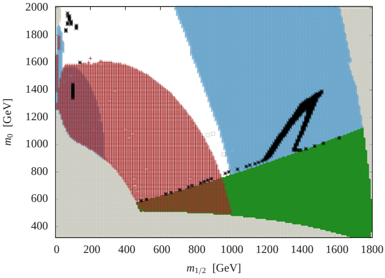

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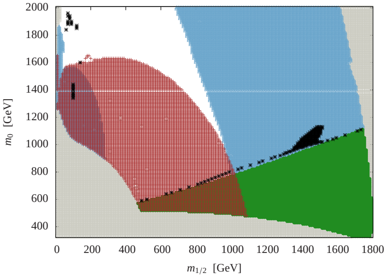

$\delta_{23}^{d,LR} = 0.0005$

Conclusion

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- M_{A^0} has strong dependence on $\delta_{23}^{d,LR}$
  $\rightarrow$ effect on relic density and branching ratio
  $\rightarrow$ correlation between the two
- Big excluded region due to Higgs mass
- $\bar{B}_s \rightarrow \mu^+\mu^-$ limits the little parameter space that is left for the funnel region
  $\rightarrow$ even less space available with high $\delta_{23}^{d,LR}$
- Most parameter space available in the Higgs funnel region for high positive A_0, fewest parameter space available for high negative A_0
- No visible change in the excluded region from Higgs mass for different $\delta_{23}^{d,LR}$
  $\rightarrow$ M_{h^0} does not depend on $\delta_{23}^{d,LR}$

Conclusion

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  $\rightarrow$ effect on relic density and branching ratio
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- Big excluded region due to Higgs mass
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Outlook

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- There is a need to include other rare processes such as $b \to s\gamma$ and $B_s - \bar{B}_s$ (more sensitive to $\delta_{23}^{d,LR}$?)
- Find an underlying theory to account for the size of $\delta_{23}^{d,LR}$
- Check A'^d and A'^u contributions as well

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Backup

Perturbative diagonalization (1)

$$U^{dL}=\begin{pmatrix} 1 & \frac{E^d_{12}v_d+E'^d_{12}v_u}{m_{d_2}} & \frac{E^d_{13}v_d+E'^d_{13}v_u}{m_{d_3}} \\ -\frac{E^{d*}_{12}v_d+E'^{d*}_{12}v_u}{m_{d_2}} & 1 & \frac{E^d_{23}v_d+E'^d_{23}v_u}{m_{d_3}} \\ -\frac{E^{d*}_{13}v_d+E'^{d*}_{13}v_u}{m_{d_3}} & -\frac{E^{d*}_{23}v_d+E'^{d*}_{23}v_u}{m_{d_3}} & 1 \end{pmatrix}$$

$$U^{dR}=\begin{pmatrix} 1 & \frac{E^{d*}_{21}v_d+E'^{d*}_{21}v_u}{m_{d_2}} & \frac{E^{d*}_{31}v_d+E'^{d*}_{31}v_u}{m_{d_3}} \\ -\frac{E^{d}_{21}v_d+E'^{d}_{21}v_u}{m_{d_2}} & 1 & \frac{E^{d*}_{32}v_d+E'^{d*}_{32}v_u}{m_{d_3}} \\ -\frac{E^{d}_{31}v_d+E'^{d}_{31}v_u}{m_{d_3}} & -\frac{E^{d}_{32}v_d+E'^{d}_{32}v_u}{m_{d_3}} & 1 \end{pmatrix}$$

Perturbative diagonalization (2)

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$$\tilde{E}'^{d}_{fi} = U^{dL*}_{kf} E'^{d}_{kl} U^{dR}_{li}$$

$$\approx E'^{d}_{fi} - \begin{pmatrix} 0 & \frac{E'^{d}_{22}\left(E^{d}_{12} v_d + E'^{d}_{12} v_u\right)}{m_{d_2}} & \frac{E'^{d}_{33}\left(E^{d}_{13} v_d + E'^{d}_{13} v_u\right)}{m_{d_3}} \\ \frac{E'^{d}_{22}\left(E^{d}_{21} v_d + E'^{d}_{21} v_u\right)}{m_{d_2}} & 0 & \frac{E'^{d}_{33}\left(E^{d}_{23} v_d + E'^{d}_{23} v_u\right)}{m_{d_3}} \\ \frac{E'^{d}_{33}\left(E^{d}_{31} v_d + E'^{d}_{31} v_u\right)}{m_{d_3}} & \frac{E'^{d}_{33}\left(E^{d}_{32} v_d + E'^{d}_{32} v_u\right)}{m_{d_3}} & 0 \end{pmatrix}_{fi} .$$

Neutralino, Chargino

$$\Sigma_{fi}^{dLR,\tilde{\chi}^\pm} = -\frac{Y_i^{d(0)}}{16\pi^2} \sum_{a=1}^{6} \sum_{k=1}^{2} \sum_{j,n=1}^{3} m_{\tilde{\chi}_k^\pm} \mathcal{U}_{k2} V_{nf}^* V_{ji} \Big[-g_2 \mathcal{V}_{k1} W_{na}^{\tilde{u}L} W_{ja}^{\tilde{u}L*} + Y_n^{u(0)} \mathcal{V}_{k2} W_{na}^{\tilde{u}R} W_{ja}^{\tilde{u}L*} \Big] \times B_0(m_{\tilde{\chi}_k^\pm}^2, m_{\tilde{u}_a}^2)$$

$$\Sigma_{fi}^{dLR,\tilde{\chi}^0} = -\frac{1}{16\pi^2} \sum_{a=1}^{6} \sum_{k=1}^{4} m_{\tilde{\chi}_k^0} \Bigg[g_2^2 \frac{t_w}{3} \left(\frac{1}{3} Z_{k1} t_w - Z_{k2} \right) Z_{k1} W_{fa}^{\tilde{d}L} W_{ia}^{\tilde{d}R*} + g_2 Y_f^{d(0)} t_w \frac{\sqrt{2}}{3} Z_{k1} Z_{k3} W_{fa}^{\tilde{d}R} W_{ia}^{\tilde{d}R*} + g_2 \frac{Y_i^{d(0)}}{\sqrt{2}} \left(\frac{1}{3} Z_{k1} t_w - Z_{k2} \right) Z_{k3} W_{fa}^{\tilde{d}L} W_{ia}^{\tilde{d}L*} + Y_f^{d(0)} Y_i^{d(0)} Z_{k3}^2 W_{fa}^{\tilde{d}R} W_{ia}^{\tilde{d}L*} \Bigg] B_0(m_{\tilde{\chi}_k^0}^2, m_{\tilde{d}_a}^2)$$

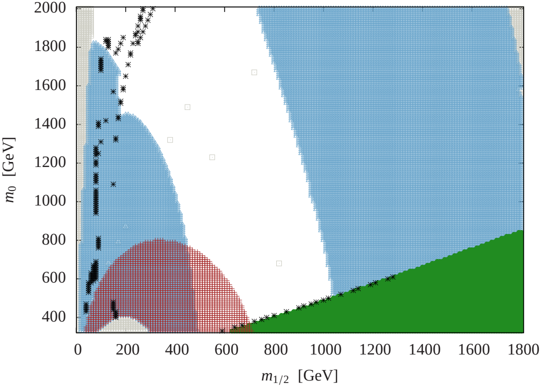
Branching ratio of $\bar{B}_s \to \mu^+\mu^-$

$$\mathrm{BR}(\bar{B}_s \to \mu^+\mu^-) = \frac{G_F^2 \alpha^2 M_{B_s} \tau_{B_s}}{16\pi^3} |V_{ts}^* V_{tb}|^2 \sqrt{1 - \frac{4m_\mu^2}{M_{B_s}^2}} \left\{ \left(1 - \frac{4m_\mu^2}{M_{B_s}^2}\right) |F_S|^2 + |F_P + 2m_\mu F_A|^2 \right\}$$

with the form factors

$$F_A = -\frac{i}{2} f_{B_s} c_A,$$
$$F_S = -\frac{i}{2} f_{B_s} M_{B_s}^2 m_b c_S,$$
$$F_P = -\frac{i}{2} f_{B_s} M_{B_s}^2 m_b c_P.$$

$A_0 = 0$ **GeV**, $\tan\beta = 45$, $\textbf{sign}(\mu) > 0$



$$\delta_{23}^{d,LR} = 0.0005$$