Impact of squark flavour violation on the neutralino relic density

Q. Le Boulc'h (LPSC Grenoble), Research Seminar - ITP Münster
Based on arXiv:1106.6229 with B. Herrmann (LAPTH Annecy) and M. Klasen (Münster)

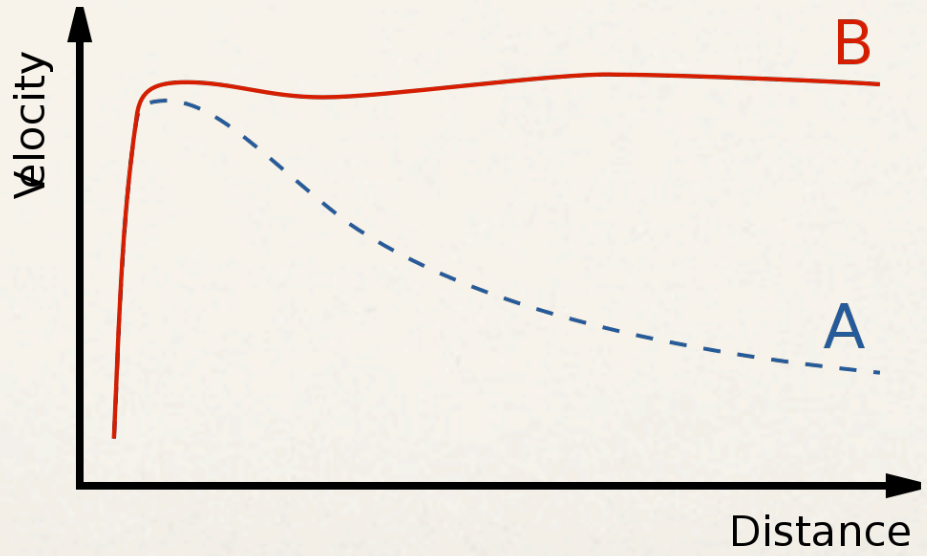
Impact of squark flavour violation on the neutralino relic density

- Neutralino dark matter: constraining the cMSSM
- Phenomenology of non minimal flavour violation
- Non minimal flavour violation and neutralino relic density: a numerical study
- Conclusion and Perspectives

Neutralino dark matter: constraining the cMSSM

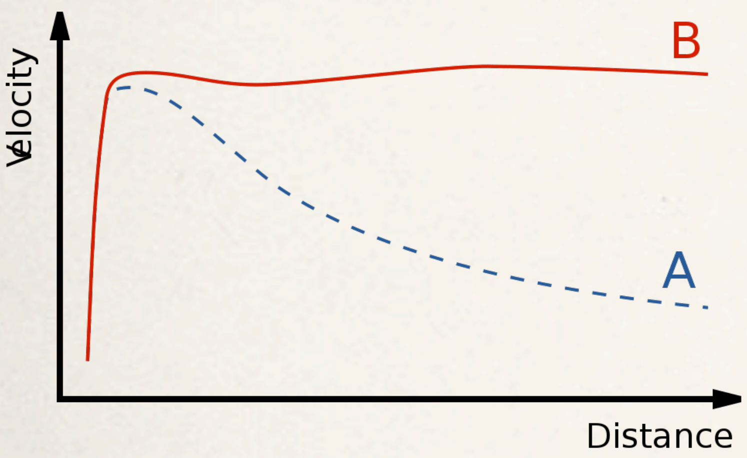
Dark matter evidences and the ΛCDM model

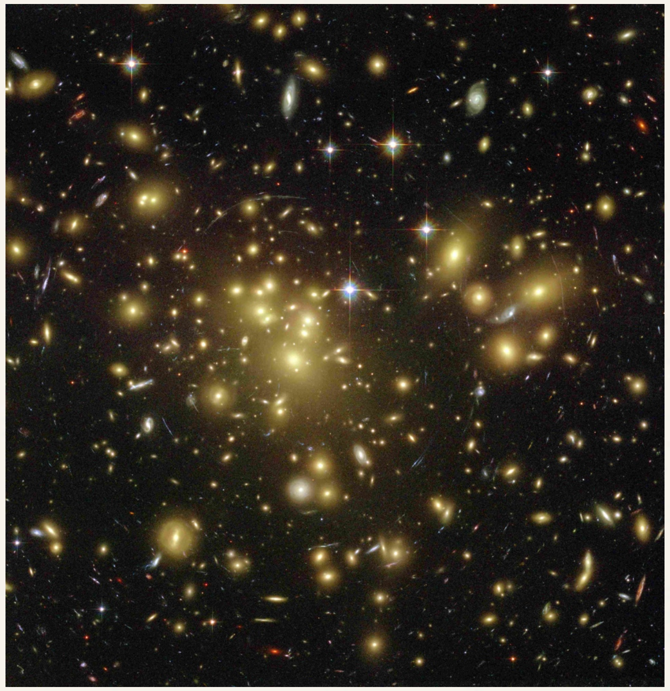
- F. Zwicky, 1933: application of the viriel theorem to the Coma galaxy cluster and observation of unseen mass
- V. Rubin, 1970's: observation of spiral galaxies rotation curves
  - Newtonian gravity is not universal, or...
  - ...most of the galactic mass is contained in a dark halo

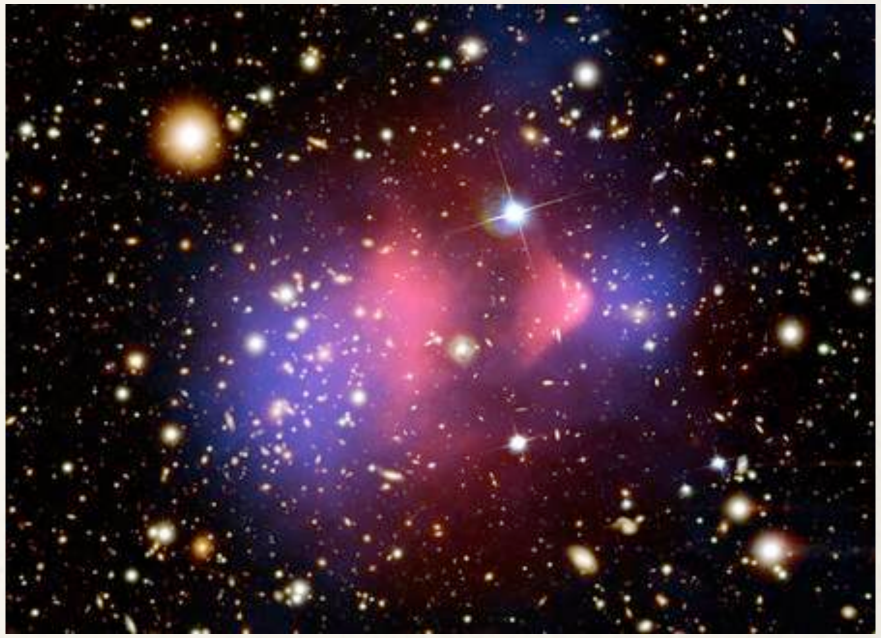


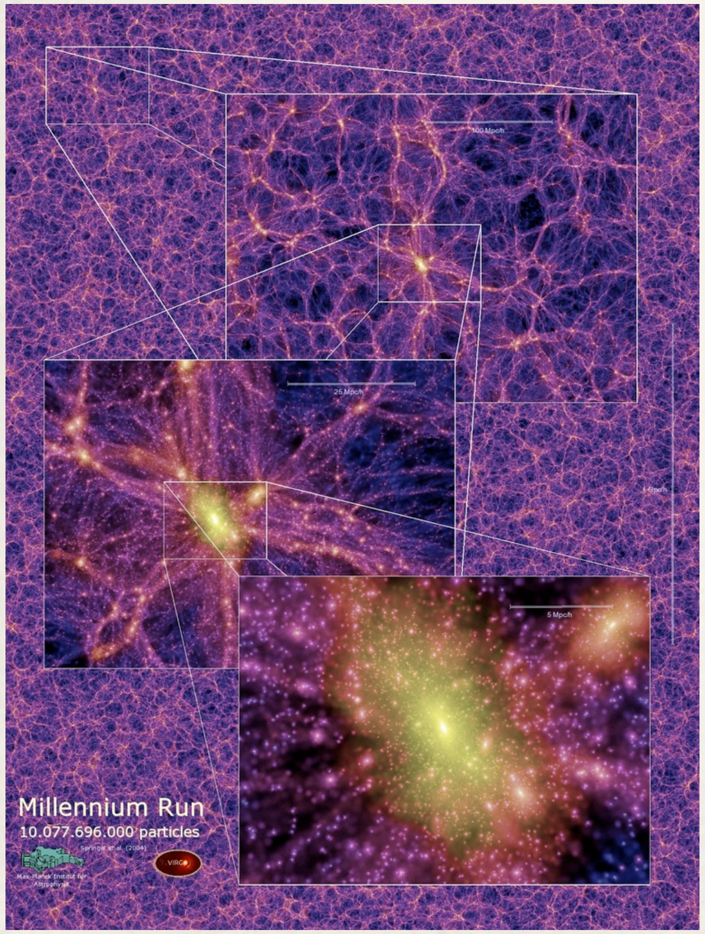
Rotation curve of a typical spiral galaxy: predicted (A) and observed (B)

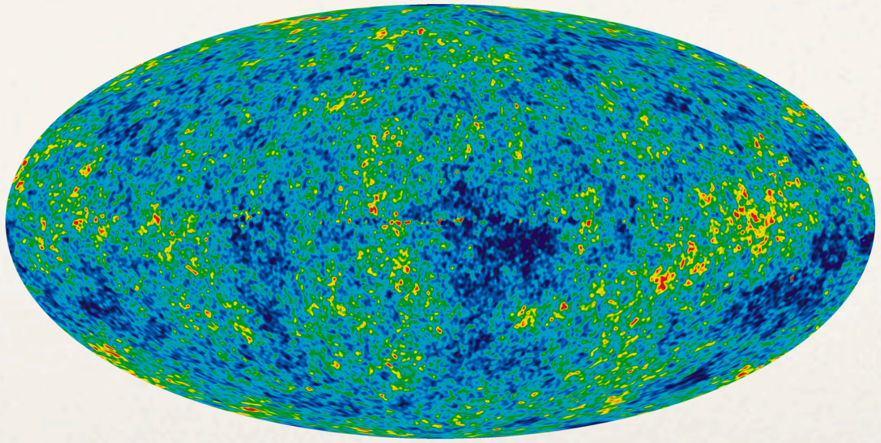
Dark matter evidences and the ΛCDM model

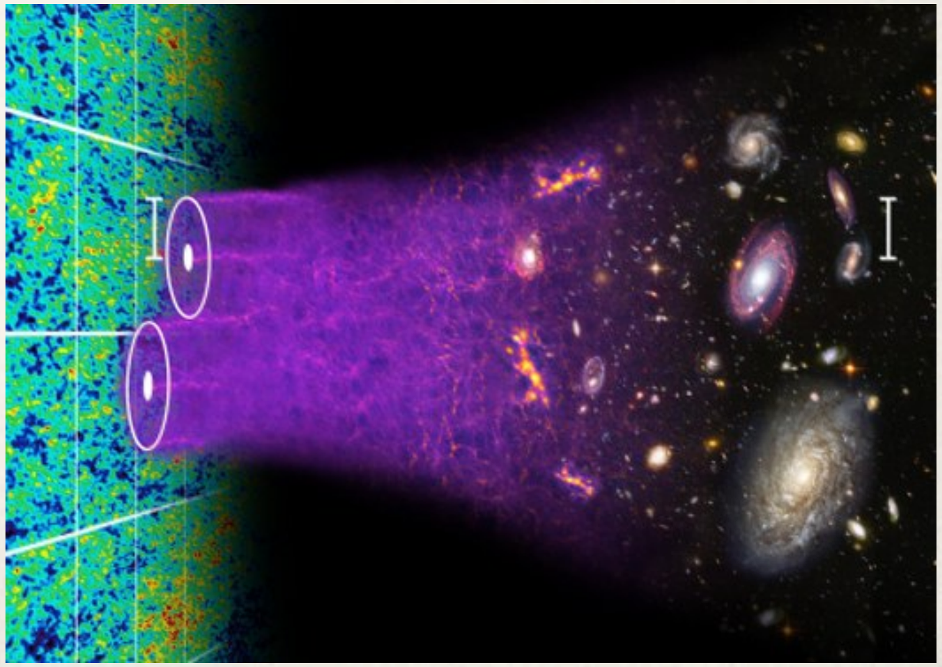




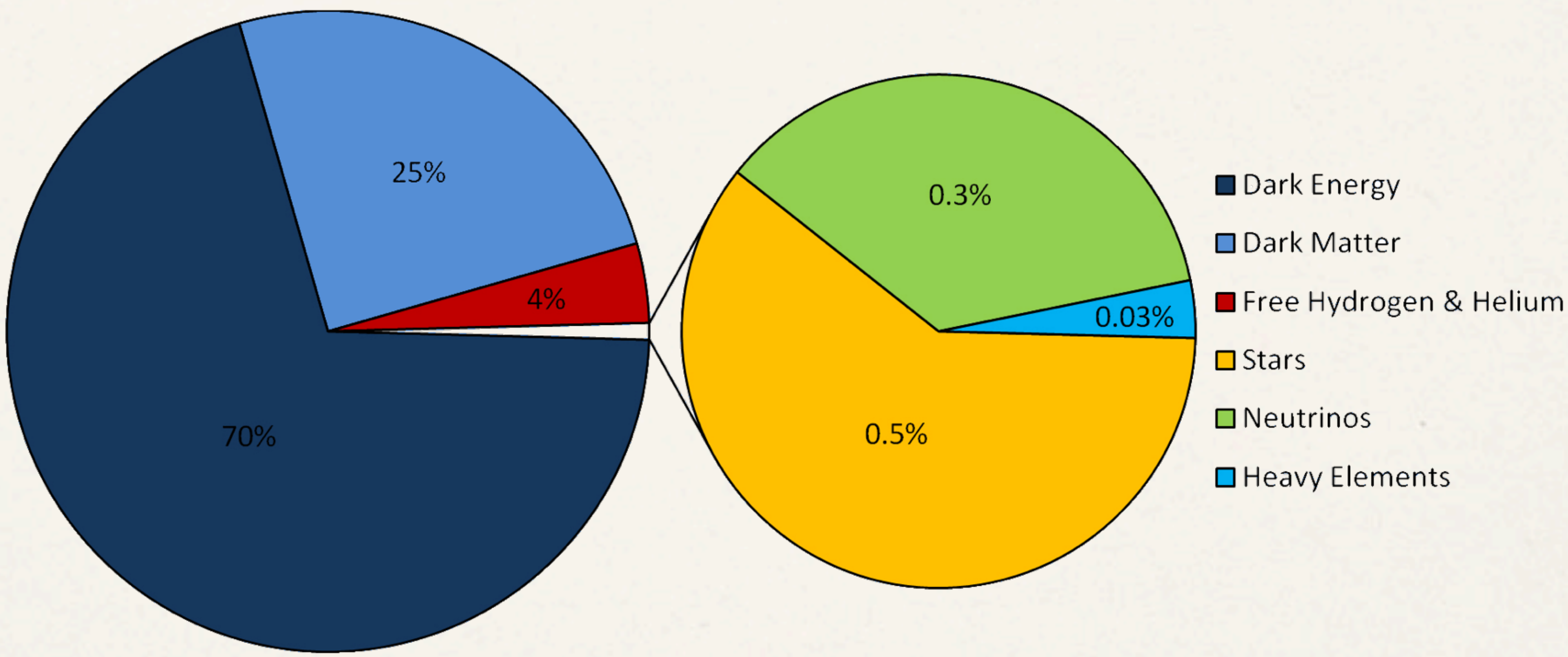




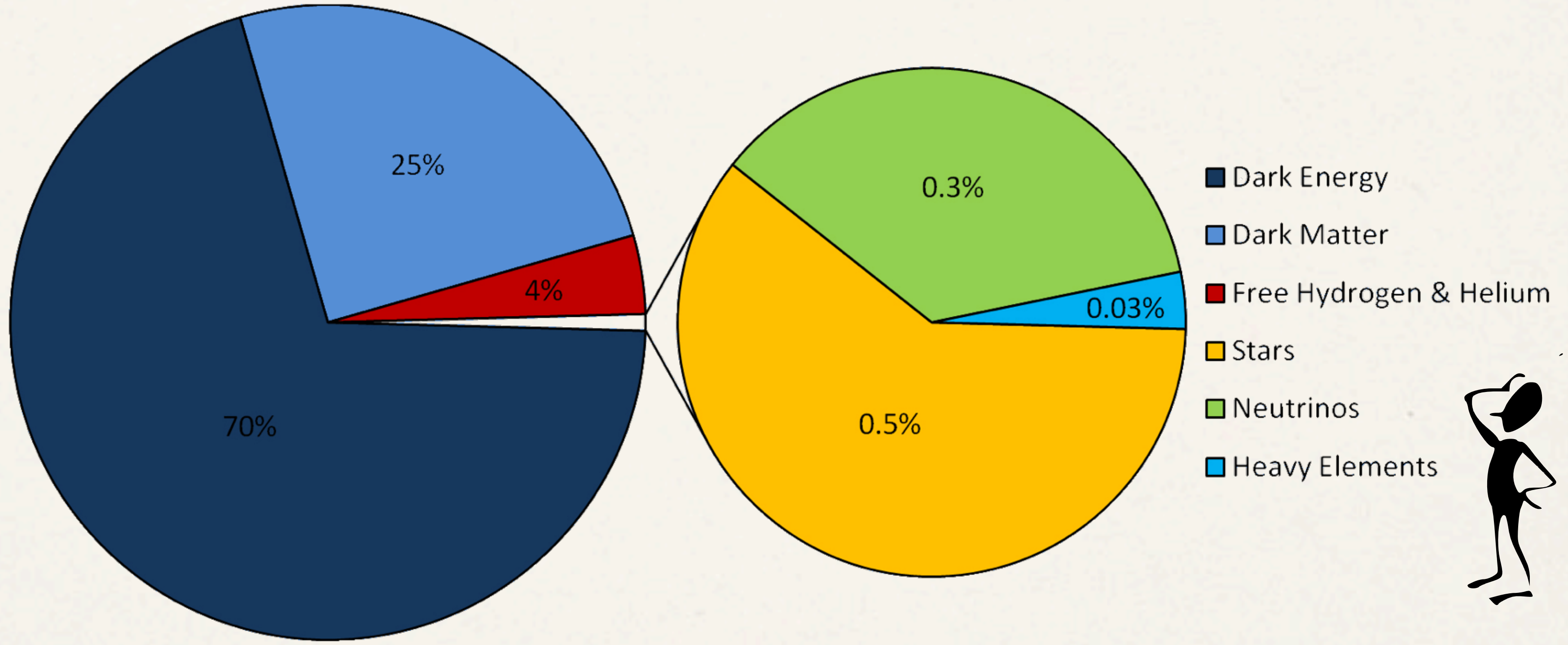




Dark matter evidences and the ΛCDM model



Dark matter evidences and the ΛCDM model



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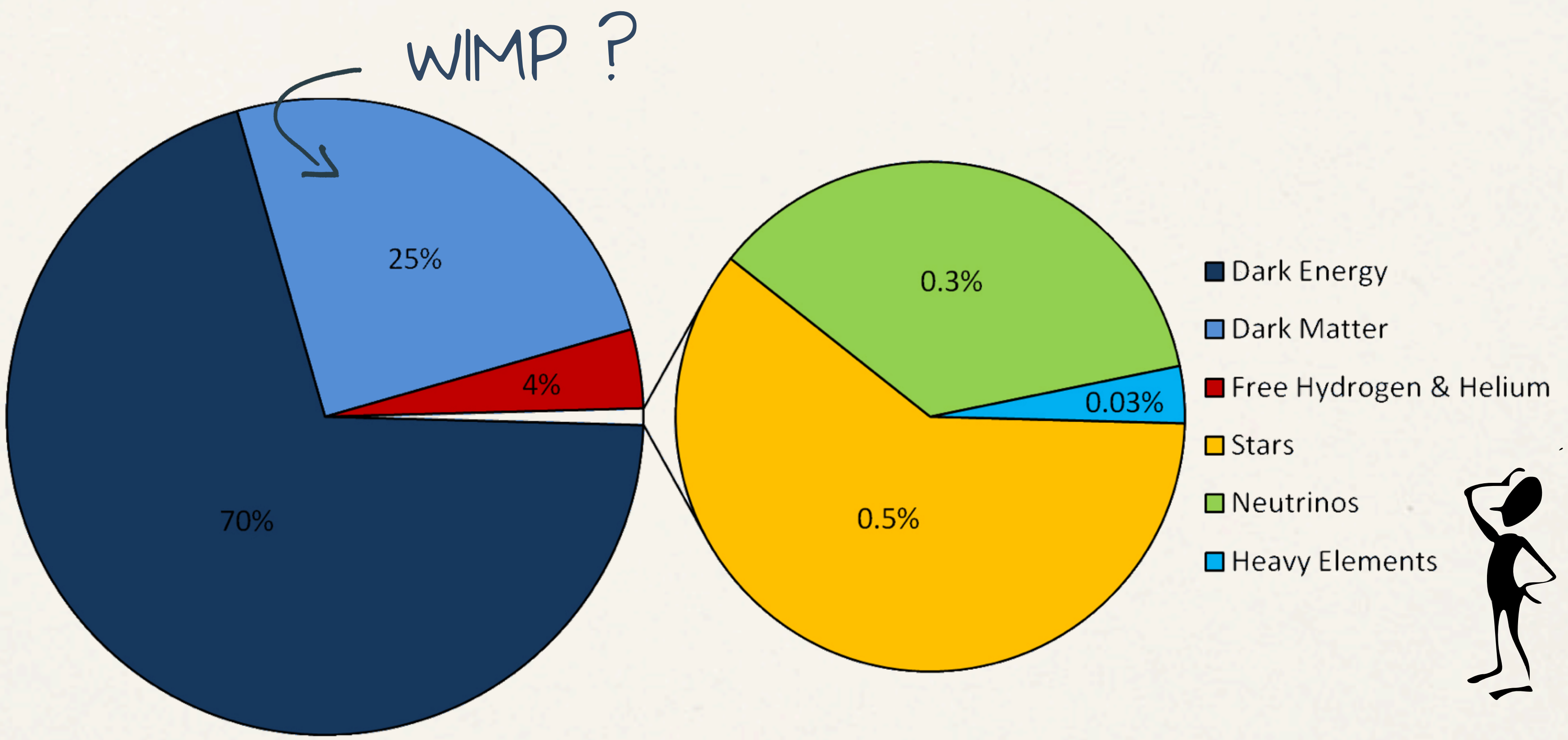

The neutralino: a supersymmetric WIMP

Supersymmetry (relates bosons and fermions)

Minimal field content

MSSM (~100 parameters)

Gravity mediated SUSY breaking
+ Universal soft breaking terms

cMSSM
(5 parameters at GUT scale)

m_0, $m_{1/2}$, A_0, $\tan\beta$, sign(μ)

The neutralino: a supersymmetric WIMP

m_0, $m_{1/2}$, A_0, $\tan\beta$, sign(μ)

RGE

Interaction eigenstates		Mass eigenstates	
Symbol	**Name**	**Symbol**	**Name**
$\tilde{q}_L$, $\tilde{q}_R$	left and right squark	$\tilde{q}_1$, $\tilde{q}_2$	squark 1 and 2
$\tilde{l}_L$, $\tilde{l}_R$	left and right slepton	$\tilde{l}_1$, $\tilde{l}_2$	slepton 1 and 2
$\tilde{\nu}$	sneutrino	$\tilde{\nu}$	sneutrino
$\tilde{g}$	gluino	$\tilde{g}$	gluino
$\tilde{W}^{\pm}$	charged winos		
$\tilde{H}_1^-$	higgsino $-$	$\tilde{\chi}^{\pm}_{1,2}$	charginos
$\tilde{H}_2^+$	higgsino $+$		
$\tilde{B}$	bino		
$\tilde{W}^3$	neutral wino	$\tilde{\chi}^0_{1,2,3,4}$	neutralinos
$\tilde{H}^0_{1,2}$	neutral higgsinos		

The neutralino: a supersymmetric WIMP

m_0, $m_{1/2}$, A_0, $\tan\beta$, sign(μ)

↓ RGE

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↳ WIMP !

The neutralino: a supersymmetric WIMP

The lightest neutralino is:

- **W**eakly **I**nteracting
- a **M**assive **P**article
- often the **L**ightest **S**upersymmetric **P**article (**stable** if R-parity is assumed)

→ It is a good dark matter candidate ! Its relic density can be:

- calculated for any cMSSM point
- compared with WMAP result: $\Omega_{\mathrm{CDM}} h^2 = 0.1126 \pm 0.0036$

Relic density: definition

« Relic: *an object surviving from an earlier time, esp. one of historical or sentimental interest.* »

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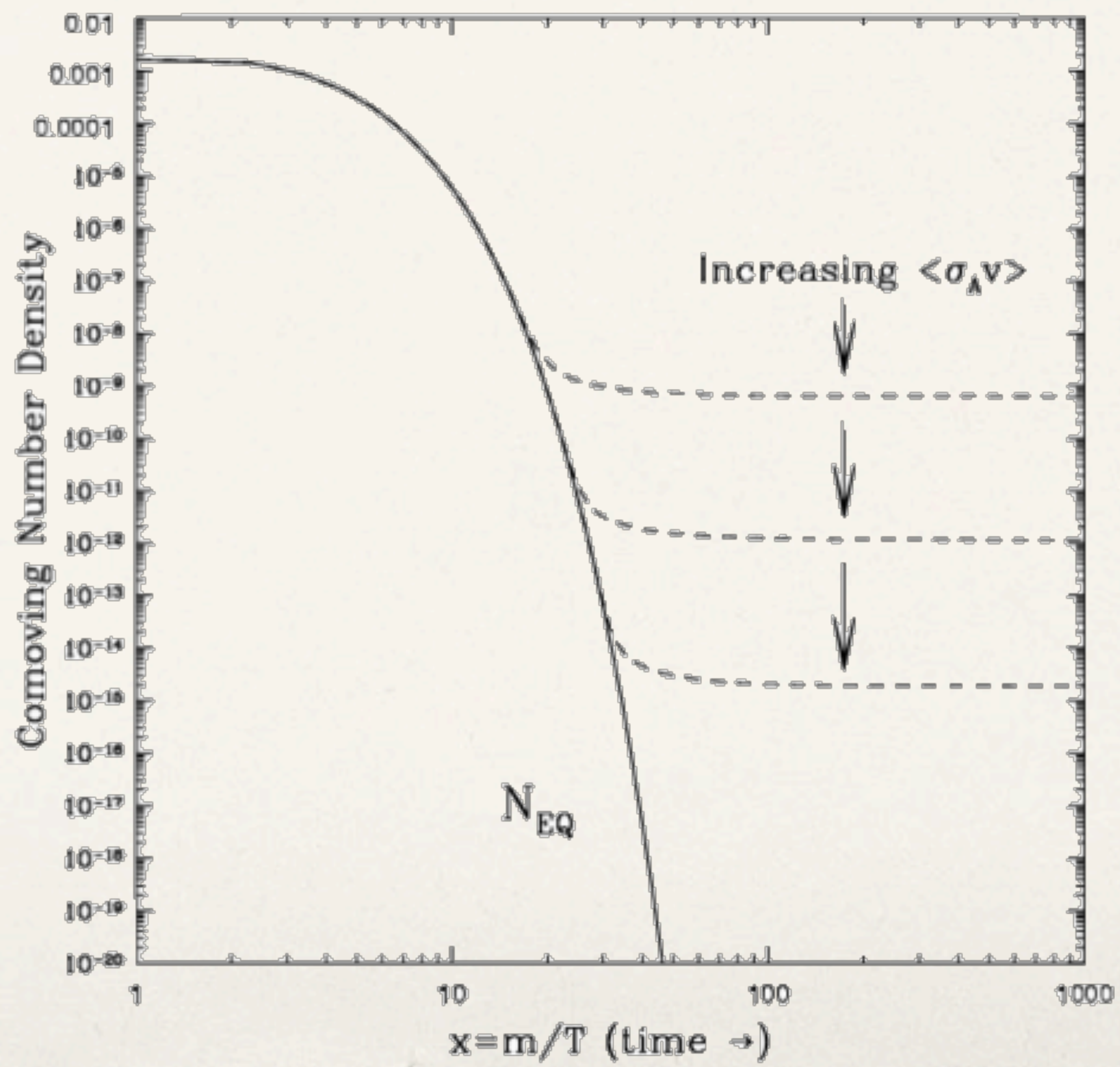
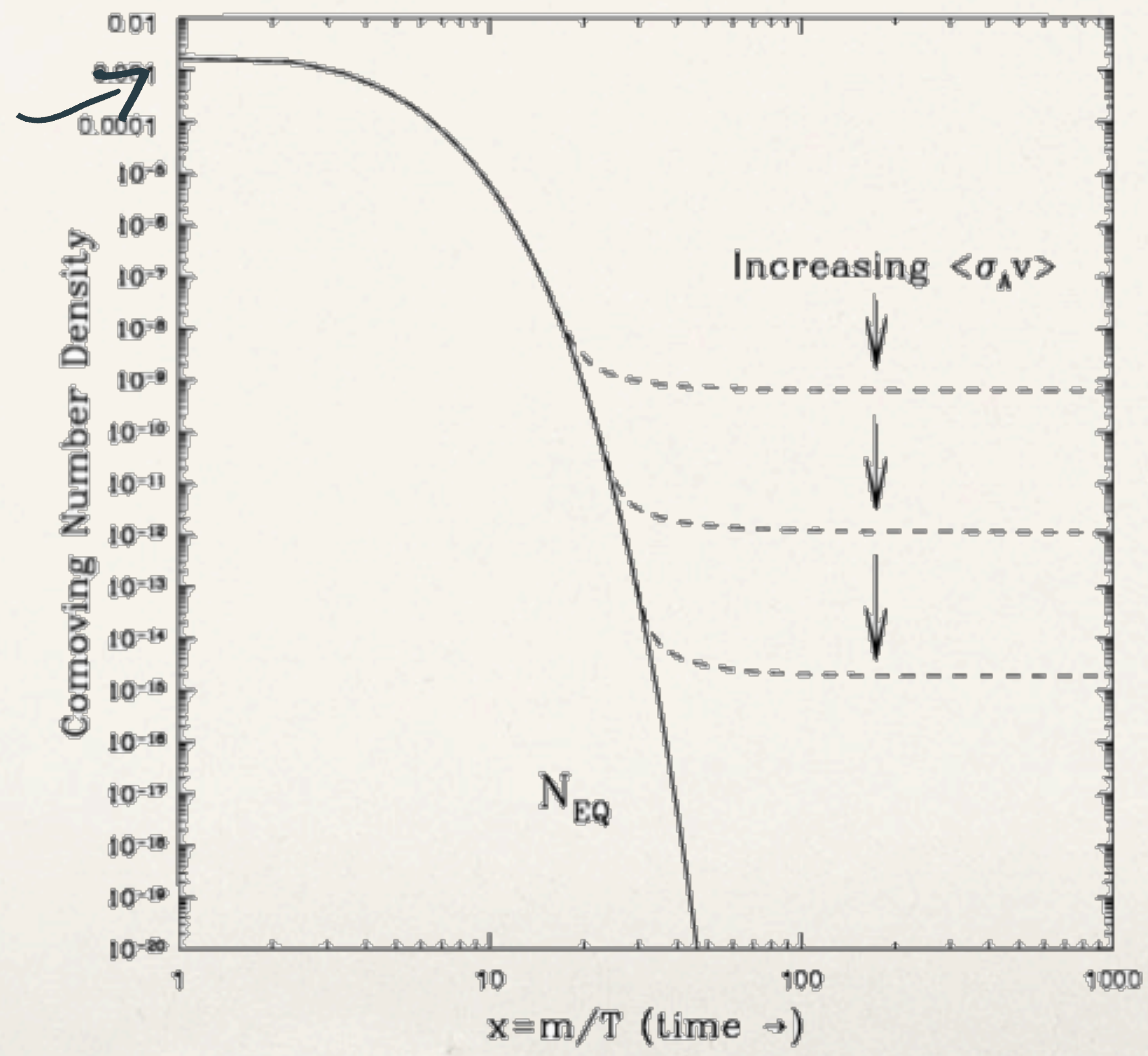


Relic density: definition

« Relic: *an object surviving from an earlier time, esp. one of historical or sentimental interest.* »

When temperature is high enough, equilibrium with SM particles



Relic density: definition

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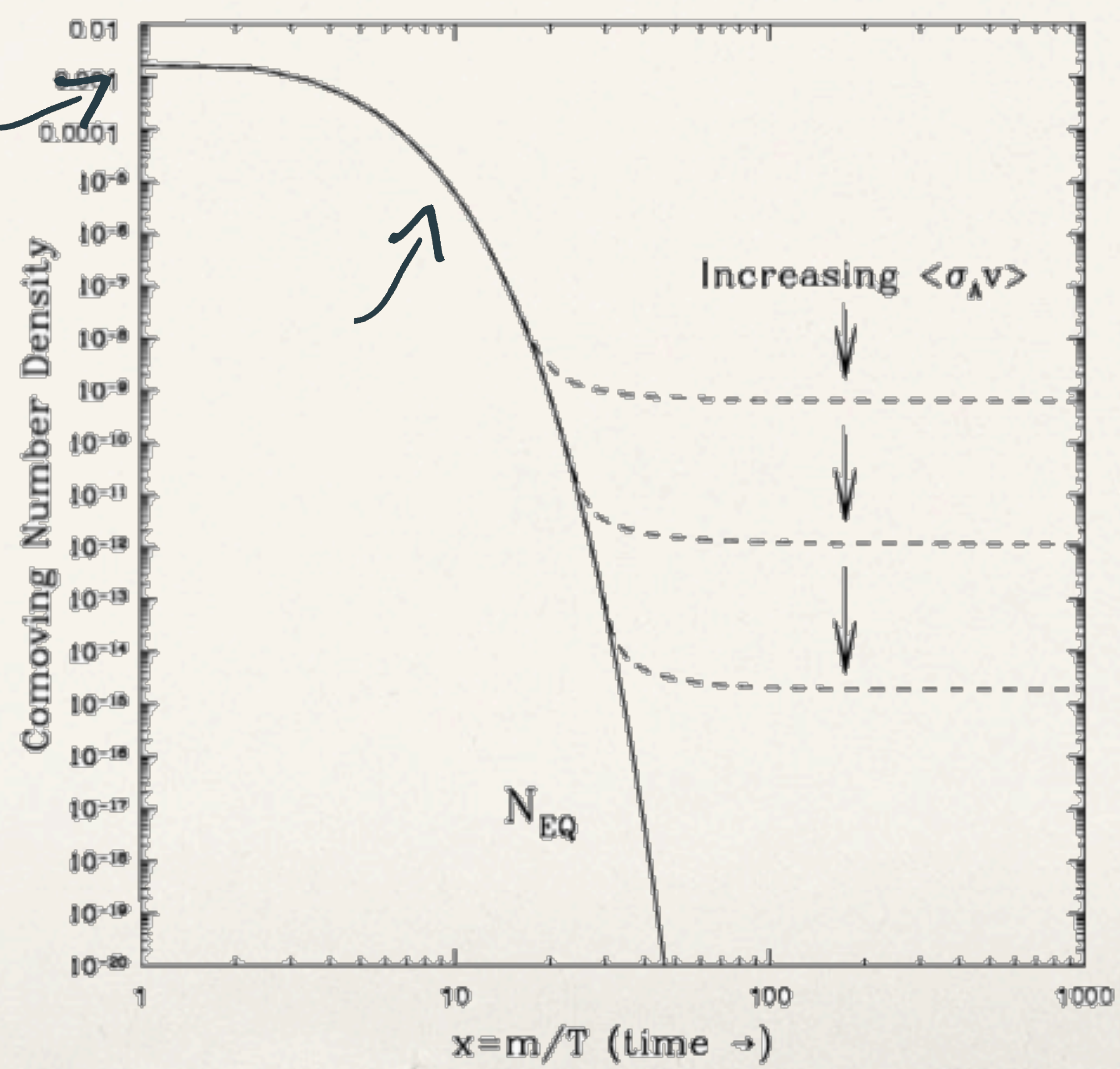
When temperature is high enough, equilibrium with SM particles

Universe expands: temperature drop, density decrease because of annihilation



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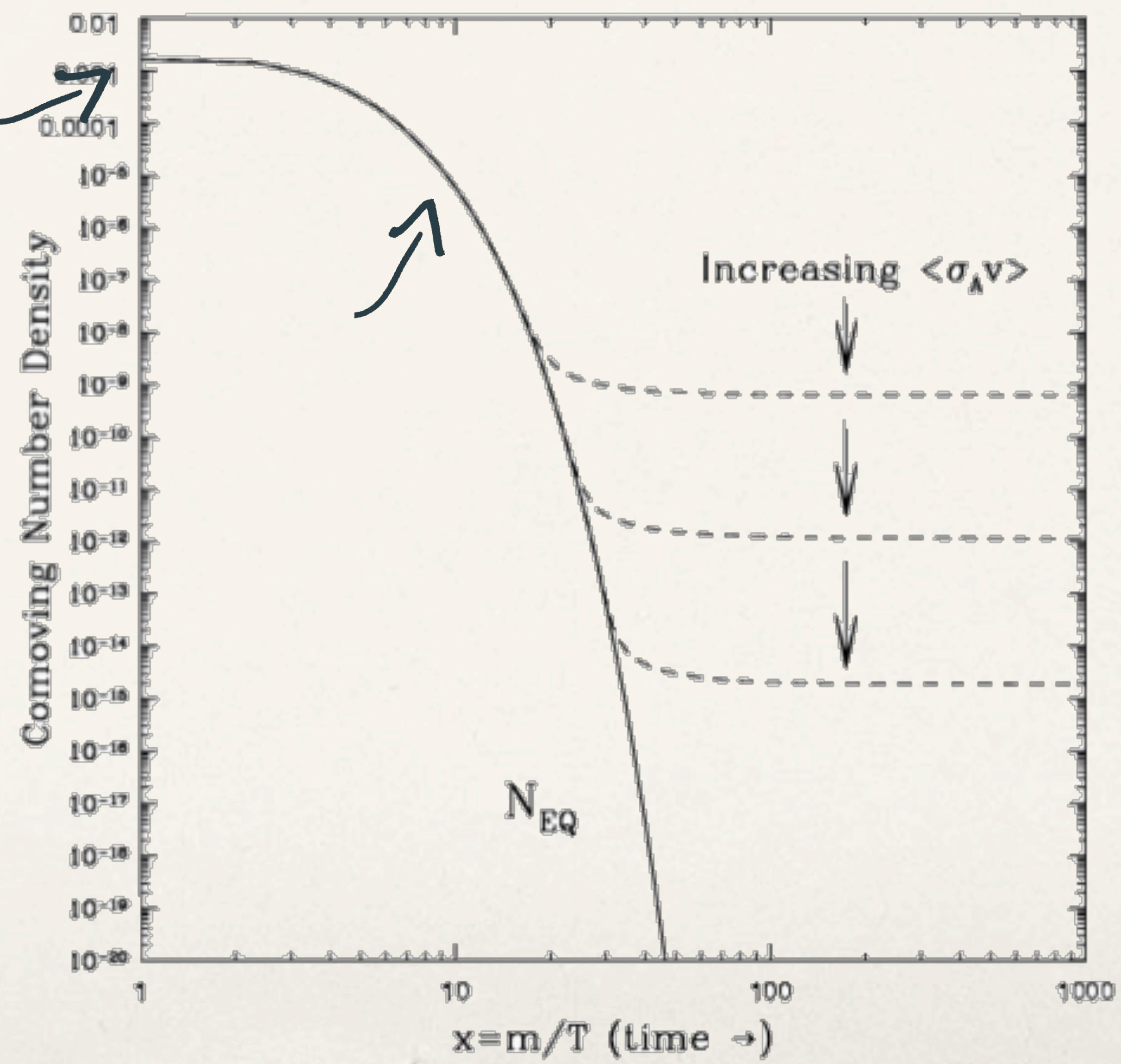


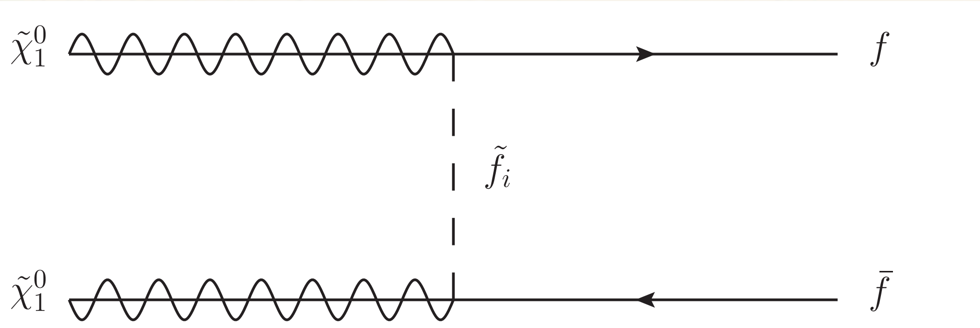
Annihilation rate lower than expansion rate: freezeout

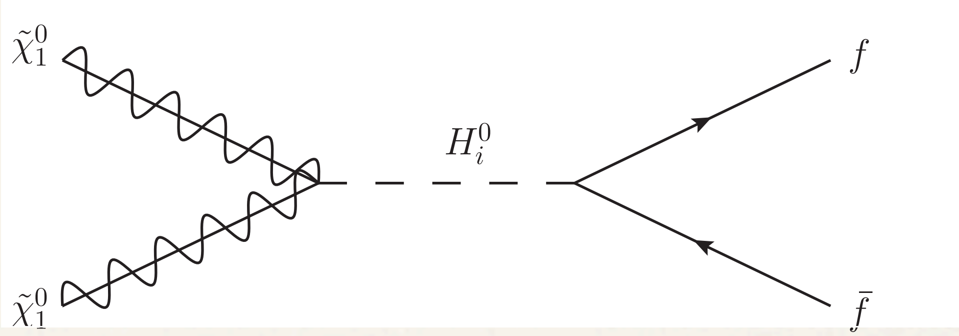
$$\Omega_c h^2 \sim \frac{1}{\langle \sigma_{\text{ann}} v \rangle}$$

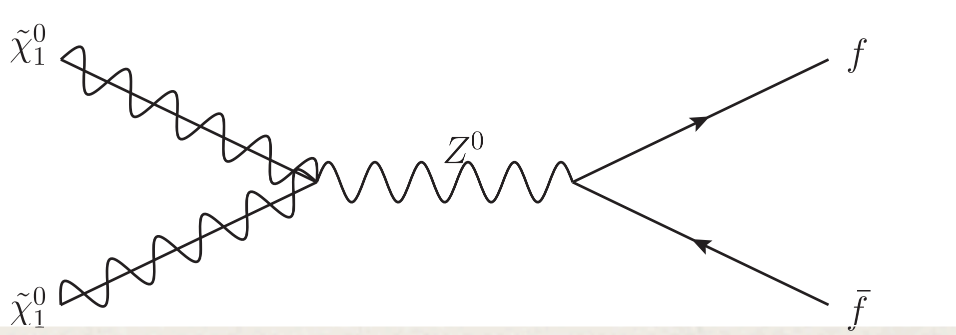
Universe expands: temperature drop, density decrease because of annihilation

Relic density: definition

Different annihilation processes contributes to the cross-section. Annihilation into fermions:

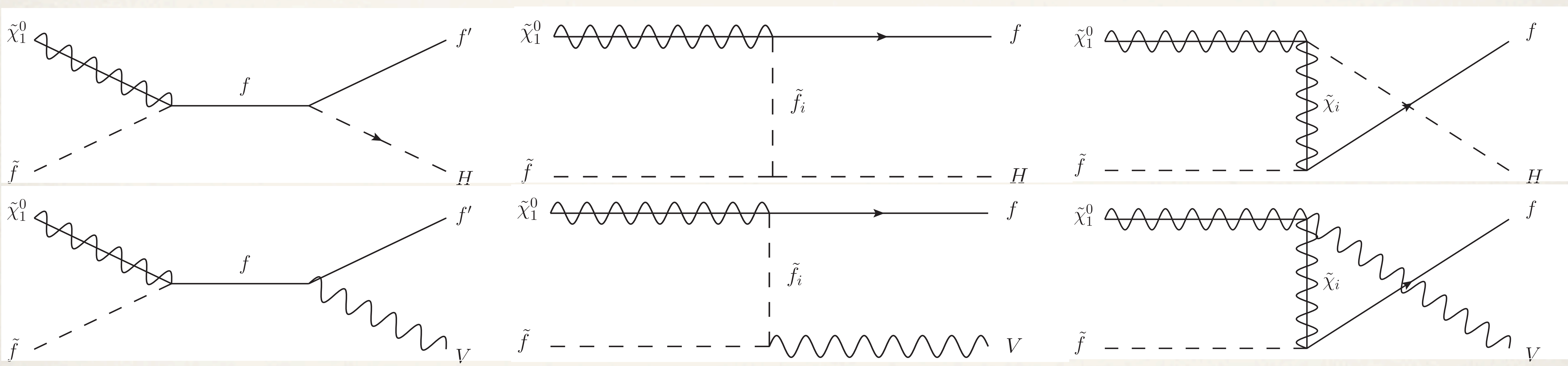






Relic density: definition

- But coannihilation with a sfermion also contributes:



- Significant contribution when $m_{\tilde{\chi}_1^0} \approx m_{\tilde{f}}$

- Possible with stau or stop in cMSSM

Relic density: calculation

Need to solve the Boltzmann equation:

$$\frac{\mathrm{d}n}{\mathrm{d}t} = -3Hn - \langle \sigma_{\mathrm{ann}} v \rangle \left(n^2 - n_{\mathrm{eq}}^2\right)$$

Relic density: calculation

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particle physics !

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particle physics !

Where the thermally averaged total cross-section is:

$$\langle \sigma_{\mathrm{ann}} v \rangle = \sum_{i,j=0}^{N} \langle \sigma_{ij} v_{ij} \rangle \frac{g_i g_j}{g_{\mathrm{eff}}^2} \left(\frac{m_i m_j}{m_0^2}\right)^{3/2} \exp\left\{ -\frac{(m_i + m_j - 2m_0)}{T} \right\}$$

Relic density: calculation

Need to solve the Boltzmann equation:

$$\frac{\mathrm{d}n}{\mathrm{d}t} = -3Hn - \langle \sigma_{\rm ann} v \rangle \left(n^2 - n_{\rm eq}^2\right)$$

particle physics !

Where the thermally averaged total cross-section is:

$$\langle \sigma_{\rm ann} v \rangle = \sum_{i,j=0}^{N} \langle \sigma_{ij} v_{ij} \rangle \frac{g_i g_j}{g_{\rm eff}^2} \left(\frac{m_i m_j}{m_0^2} \right)^{3/2} \exp\left\{ -\frac{(m_i + m_j - 2m_0)}{T} \right\}$$

(co)annihilation cross-sections

Relic density: calculation

To summarize the numerical calculation:

cMSSM parameters

↓ SPheno [W. Porod, arXiv:hep-ph/0301101]

Mass spectrum

↓ MicrOmegas [G. Belanger, F. Boudjema, A. Pukhov, A. Semenov, arXiv:hep-ph/1005.4133]

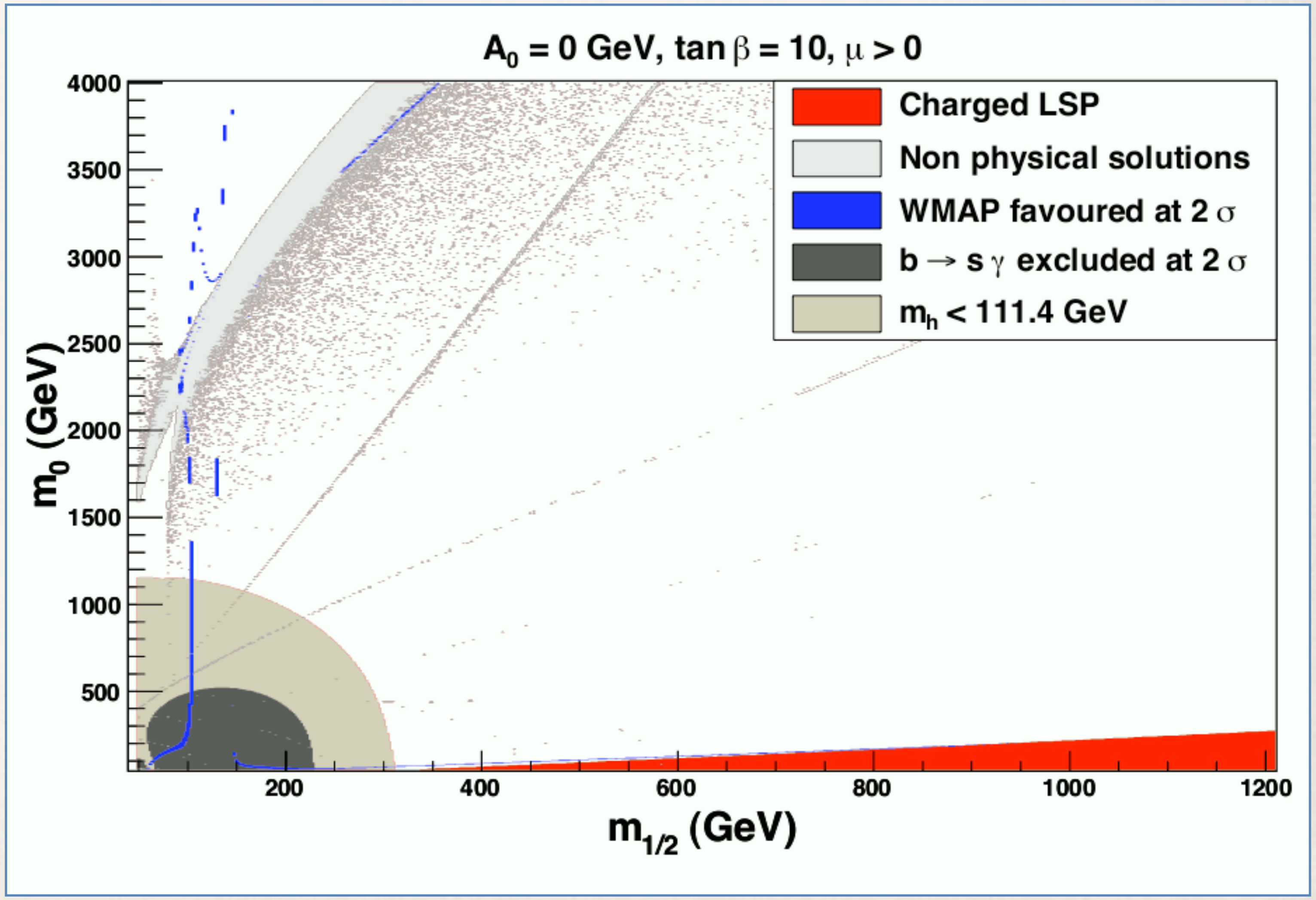
Relic density

Then apply the constraint $\Omega_{\mathrm{CDM}} h^2 = 0.1126 \pm 0.0036$

Relic density: phenomenology

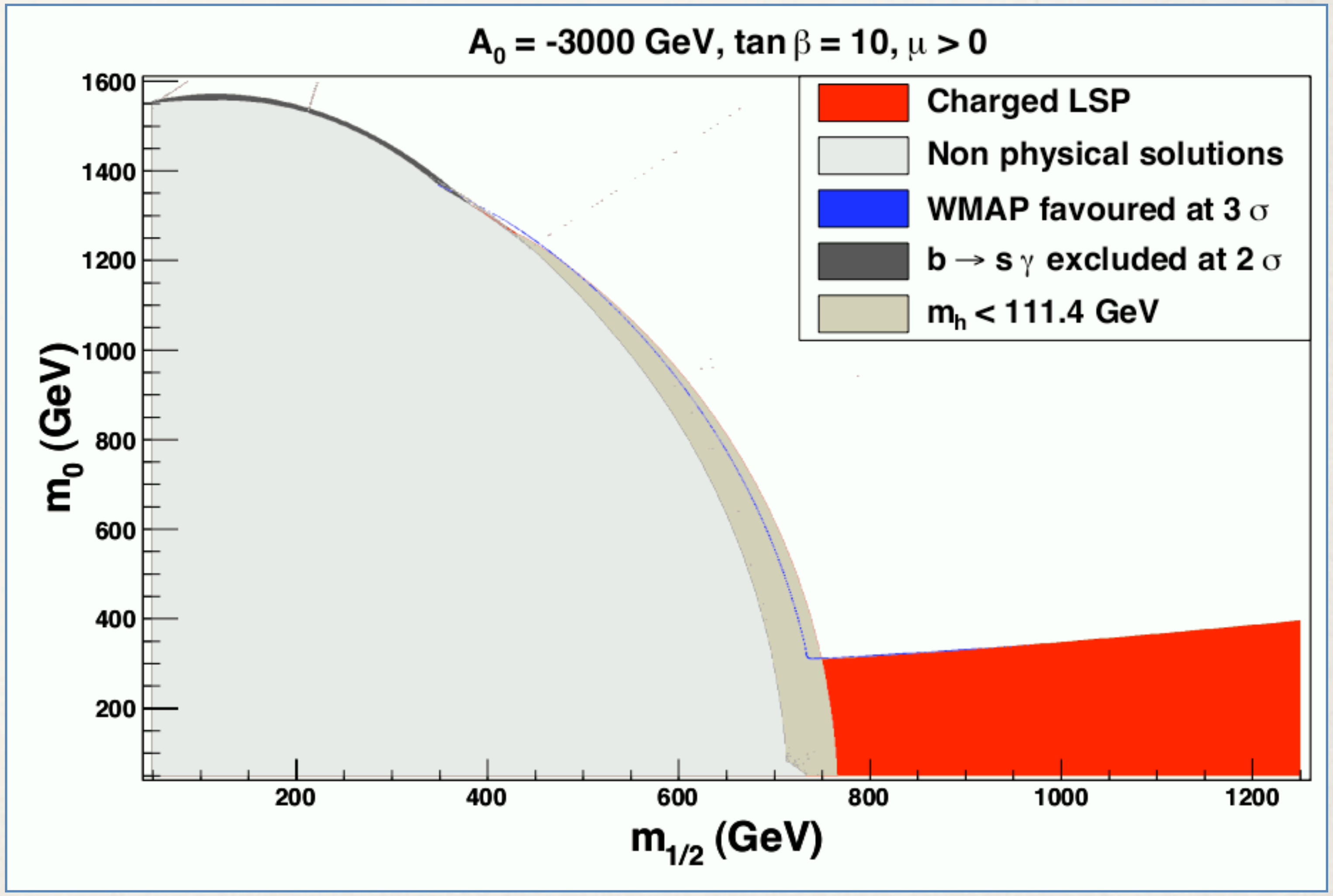
Depending on the masses and mixings, contributions to the total cross-section will be qualitatively and quantitatively different, leading to different allowed regions:

- Annihilation into W pairs via chargino exchange («focus point»)
- Annihilation into quark pairs (Z and higgs resonances)
- Coannihilation with stau (along the stau-LSP region)



Relic density: phenomenology

- Large trilinear coupling increase stops splitting: lightest stop can be very light (LSP, NLSP)
- Neutralino annihilation in top pairs via stop exchange
- Coannihilation neutralino-stop
- Coannihilation neutralino-stau



cMSSM: a (too) naive model?

Relic density in the framework of cMSSM is well known, let's add new ingredients and look for deviations from this standard picture!

Many possibilities to change the SUSY soft breaking terms:

- CP violation
- R-parity violation
- **Flavour violation**
- **Non universal soft breaking terms**

Phenomenology of non minimal flavour violation

Beyond minimal flavour violation

Flavour violation in the quark sector:

- In the Standard Model: Yukawa couplings (CKM matrix)
- In supersymmetry:
  - **MFV**: all flavour violating couplings related to the CKM matrix
  - **NMFV**: additional non diagonal entries in the soft breaking terms (*e.g. predicted by Grand Unification Theories*). These soft breaking terms enters in the squark mass matrices.

$$M^2_{\tilde{U}} = \begin{pmatrix} M^2_{\tilde{U}_1} & M^2_{\tilde{U}_{12}} & M^2_{\tilde{U}_{13}} \\ M^2_{\tilde{U}_{21}} & M^2_{\tilde{U}_2} & M^2_{\tilde{U}_{23}} \\ M^2_{\tilde{U}_{31}} & M^2_{\tilde{U}_{32}} & M^2_{\tilde{U}_3} \end{pmatrix}$$

Beyond minimal flavour violation

$$\mathcal{M}^2_{\tilde{u}} = \begin{pmatrix} \mathcal{M}^2_{\tilde{u},\mathrm{LL}} & \mathcal{M}^2_{\tilde{u},\mathrm{LR}} \\ \mathcal{M}^2_{\tilde{u},\mathrm{RL}} & \mathcal{M}^2_{\tilde{u},\mathrm{RR}} \end{pmatrix}$$

$$\begin{aligned} \mathcal{M}^2_{\tilde{u},\mathrm{RR}} &= \mathbf{M^2_{\tilde{U}}} + m_u^2 + e_u m_Z^2 \sin^2\theta_W \cos 2\beta, \\ \mathcal{M}^2_{\tilde{u},\mathrm{LL}} &= V_{\mathrm{CKM}} \mathbf{M^2_{\tilde{Q}}} V^\dagger_{\mathrm{CKM}} + m_u^2 + m_Z^2 \cos 2\beta (I_u - e_u \sin^2\theta_W), \\ \mathcal{M}^2_{\tilde{u},\mathrm{RL}} = \left(\mathcal{M}^2_{\tilde{u},\mathrm{LR}}\right)^\dagger &= \frac{v_u}{\sqrt{2}} \mathbf{T_U} - \mu^* m_u \cot\beta. \end{aligned}$$

- Soft breaking matrices considered as non diagonal
- Diagonalization of the mass matrix gives mass eigenstates:

$$\mathcal{R}_{\tilde{u}} \mathcal{M}^2_{\tilde{u}} \mathcal{R}^\dagger_{\tilde{u}} = \mathrm{diag}\left(m^2_{\tilde{u}_1}, \ldots, m^2_{\tilde{u}_6}\right)$$

- Off-diagonal elements will change the rotation matrices and the mass eigenvalues

Beyond minimal flavour violation

- Effective parametrization of these off-diagonal elements (given at low energy)
- Off-diagonal elements normalized with respect to the diagonal ones

  ⟶ dimensionless parametrization of flavour violating entries:

$$
\begin{aligned}
\delta_{ij}^{\rm LL} &= \left(\mathbf{M^2_{\tilde{Q}}}\right)_{ij} / \sqrt{\left(M^2_{\tilde{Q}}\right)_{ii} \left(M^2_{\tilde{Q}}\right)_{jj}}, \\
\delta_{ij}^{u,\rm RR} &= \left(\mathbf{M^2_{\tilde{U}}}\right)_{ij} / \sqrt{\left(M^2_{\tilde{U}}\right)_{ii}, \left(M^2_{\tilde{U}}\right)_{jj}}, \\
\delta_{ij}^{u,\rm RL} &= \frac{v_u}{\sqrt{2}} \left(\mathbf{T_U}\right)_{ij} / \sqrt{\left(M^2_{\tilde{Q}}\right)_{ii}, \left(M^2_{\tilde{U}}\right)_{jj}}, \\
\delta_{ij}^{u,\rm LR} &= \frac{v_u}{\sqrt{2}} \left(\mathbf{T_U}^\dagger\right)_{ij} / \sqrt{\left(M^2_{\tilde{U}}\right)_{ii}, \left(M^2_{\tilde{Q}}\right)_{jj}}.
\end{aligned}
$$

These parameters are experimentally constrained!

Experimental constraints on NMFV

- Mixing with the first generation strongly constrained by K and D meson mixing
- Possibility of large NP effects in second-third generations transitions...
- ...but down sector quite constrained by B mesons observables (rare decays, mixings)
- Up sector: left-left and left-right transitions also constrained

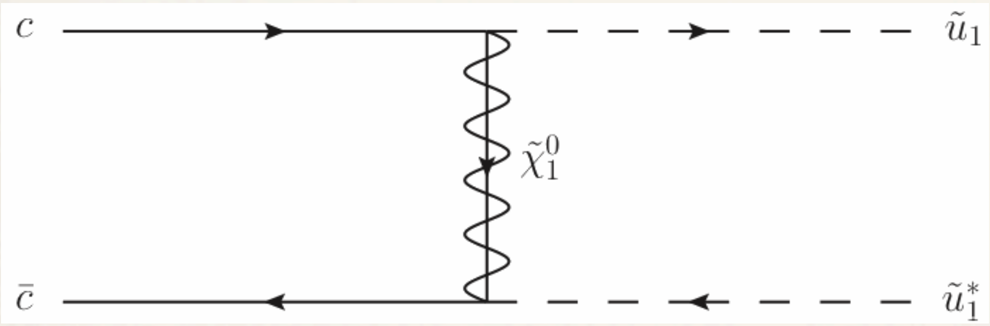
$\longrightarrow \delta_{23}^{u,\mathrm{RR}}$ less constrained flavour violating parameter!

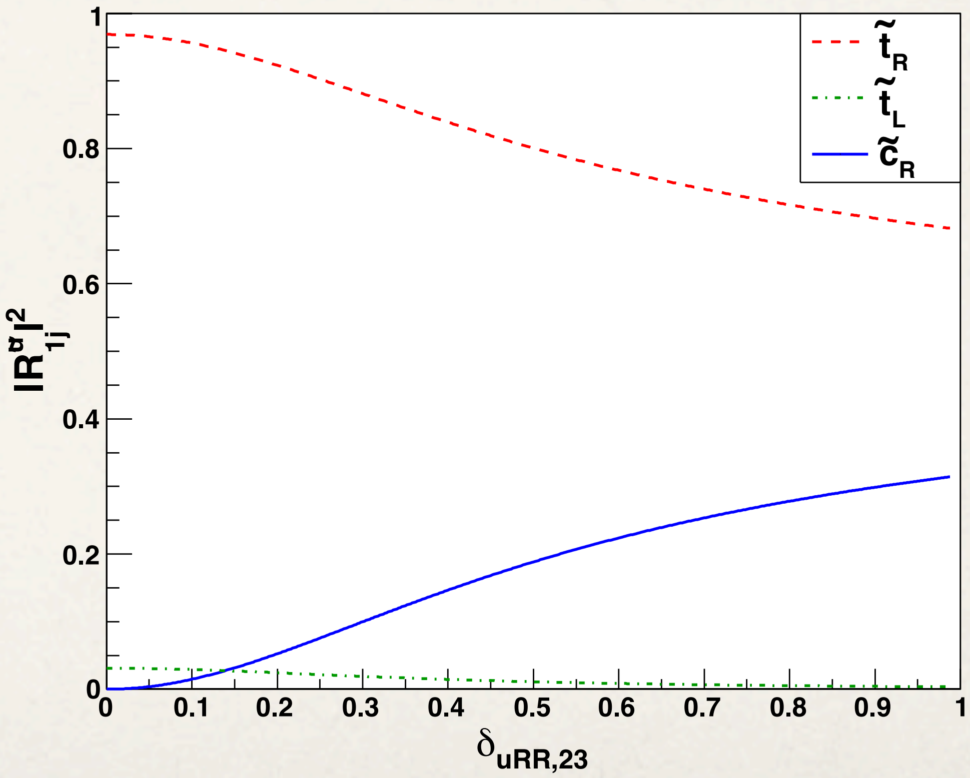
NMFV at collider: an example

- NMFV at collider is a vast topic. Let's choose $\delta_{23}^{u,\mathrm{RR}}$ as unique FV parameter and discuss consequences on the signature $p\ p \to \tilde{u}_1\ \tilde{u}_1 \to c\ t\ \tilde{\chi}_1^0\ \tilde{\chi}_1^0$
- This process is made of:
    - production of squarks from protons
    - decays of squarks into quarks and neutralinos
- Each step will be modified when including NMFV

NMFV at collider: an example

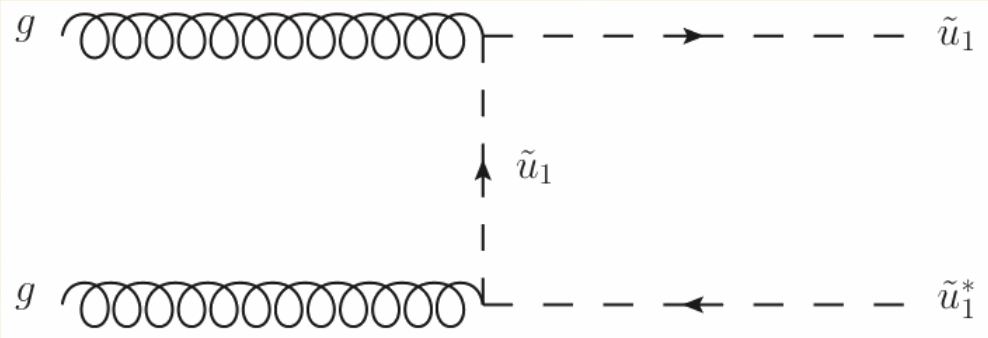
- Squark production is modified by NMFV:
    - Squark-quark couplings depends on the squark content. New T-channel contribution opens when the lightest squark has a charm component.



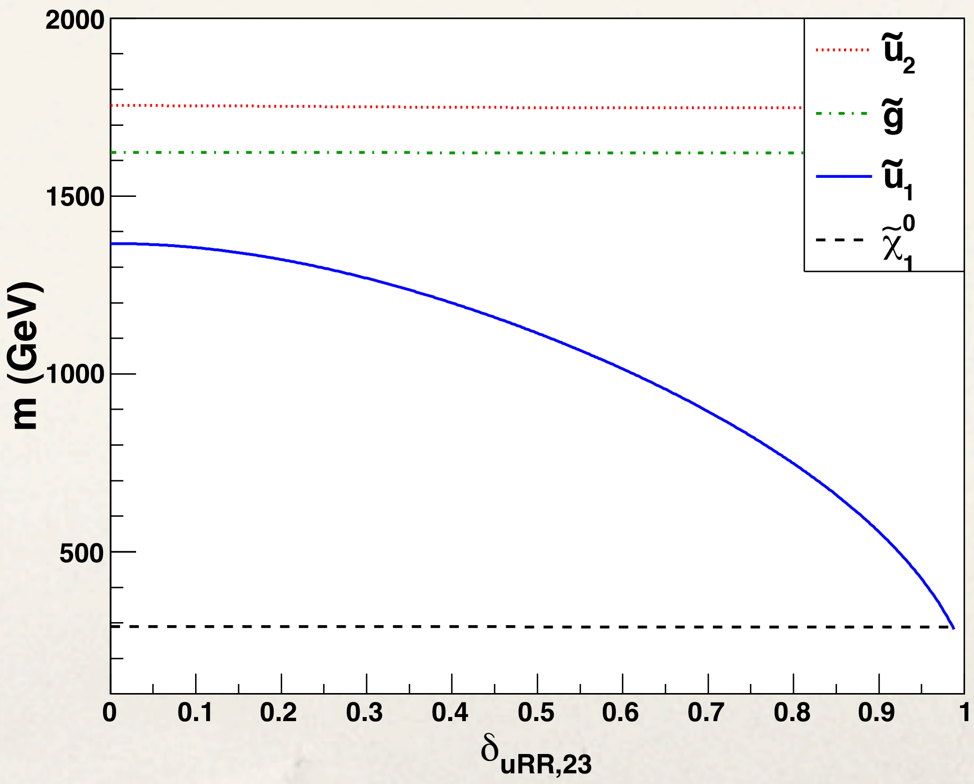


NMFV at collider: an example

- The lightest squark appears as internal in some T-channel processes:



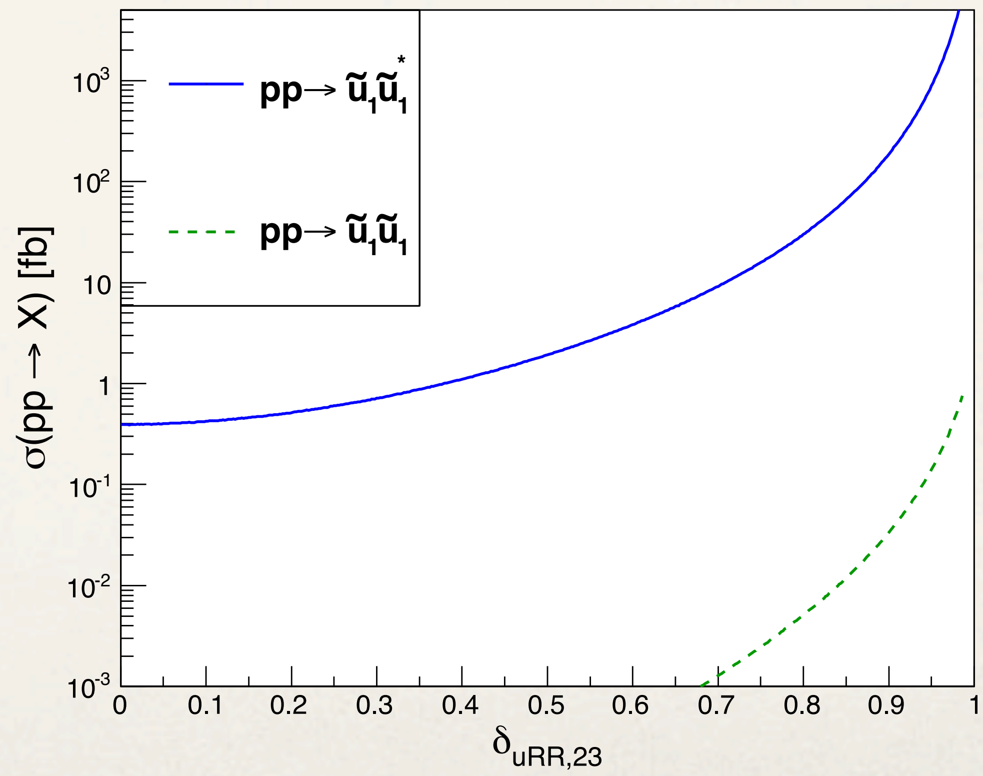
A lighter mass gives a larger contribution. Off diagonal elements in the mass matrix increases the splitting:



NMFV at collider: an example

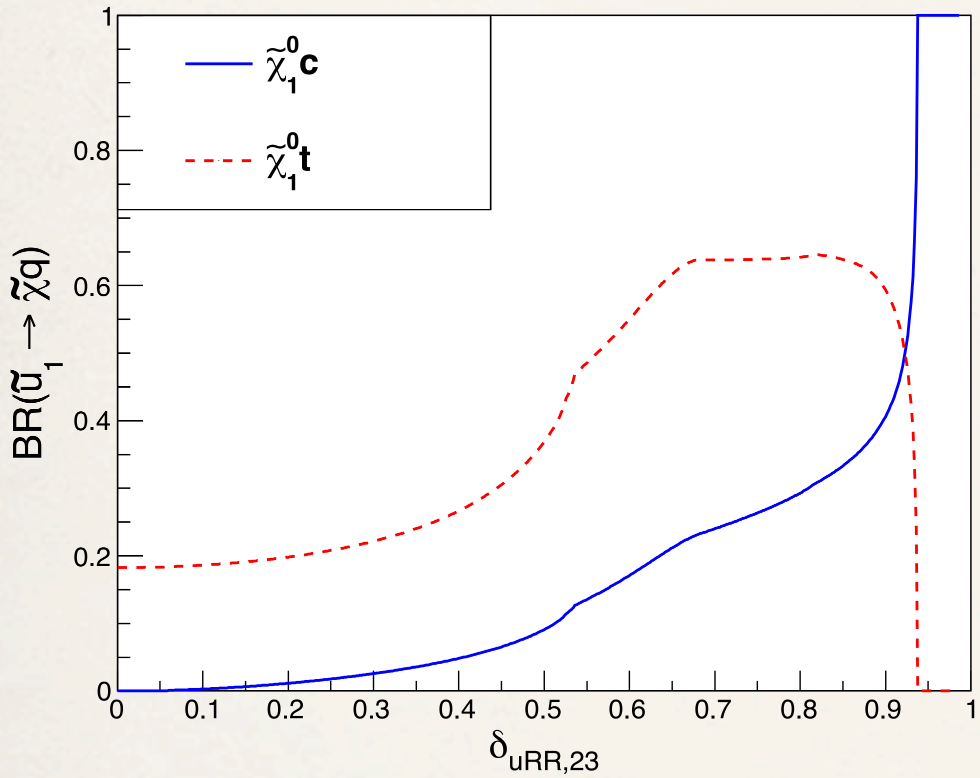
- Squarks appears as external state in all diagrams: lighter mass means larger available phase-space.

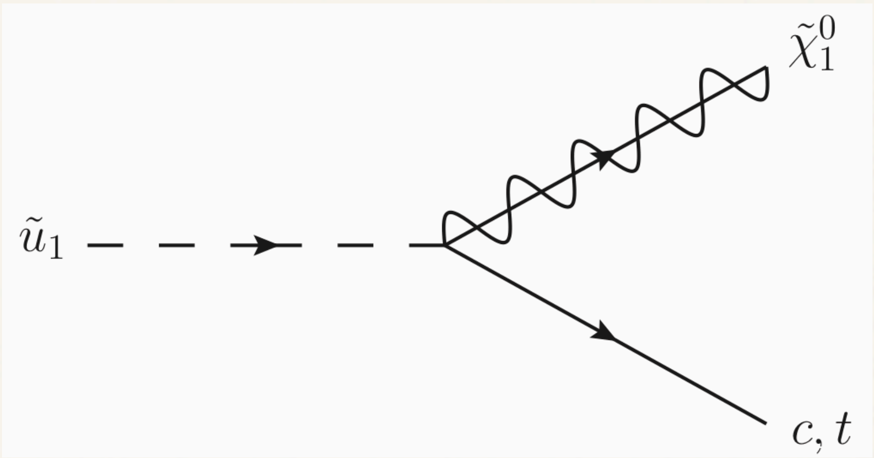
- All these effects modify the squark production cross-section:



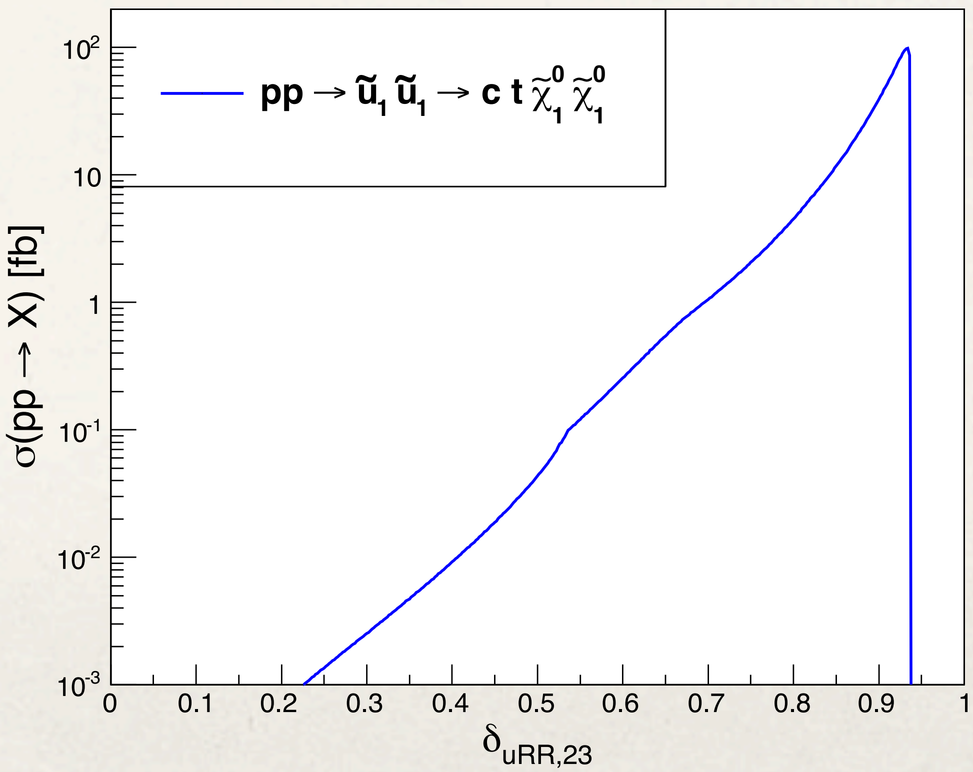
NMFV at collider: an example

- Squark decays is also modified by NMFV (mass and content of the squark):





- Consequence on the signal:



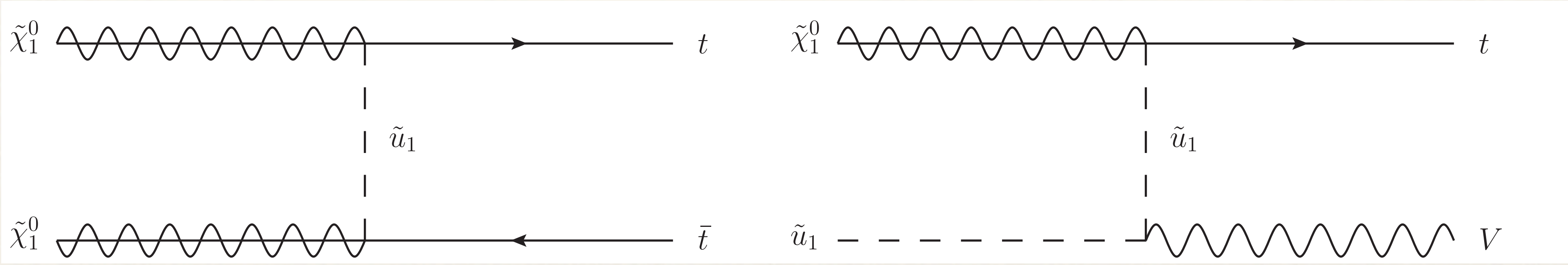
NMFV and relic density

- Relic density calculation implies neutralino annihilation and its coannihilation with sfermions (a squark here)

- These processes have some similarities with the squark production processes

⟶ similar effects will be observed:

  - Some diagrams has an internal squark. T-channel neutralino (co)annihilation is enhanced when squark becomes lighter:



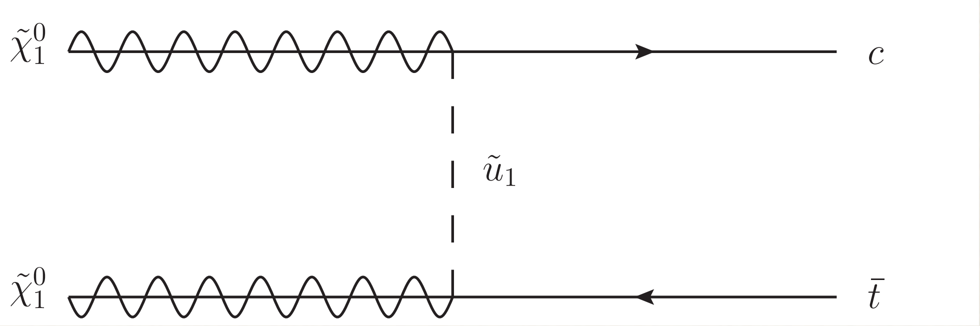
NMFV and relic density

- Some diagrams has a flavour violating neutralino-Squark-quark coupling. Resulting quarks flavour depends on the Squark content.

→ new external states will contributes and modify relic density

  - As rotation matrices are unitary, this effect is generally small
  - But for some particular spectrum configurations, this effect can be kinematically enhanced for T-channel annihilation !

→ important contribution of top-charm final state:



NMFV and relic density

- Coannihilation processes have an initial squark

→ Additional effect in coannihilation case ! Remember the exponential factor:

$$\langle \sigma_{\mathrm{ann}} v \rangle = \sum_{i,j=0}^{N} \langle \sigma_{ij} v_{ij} \rangle \frac{g_i g_j}{g_{\mathrm{eff}}^2} \left(\frac{m_i m_j}{m_0^2} \right)^{3/2} \exp \left\{ - \frac{(m_i + m_j - 2m_0)}{T} \right\}$$

- Annihilation: $m_i = m_j = m_0 \;\rightarrow\; 1$
- Coannihilation: $m_i = m0,\; m_j = m_{\tilde{u}_1} \;\rightarrow\; \exp \left\{ - \frac{(m_{\tilde{u}_1} - m_0)}{T} \right\}$

→ Coannihilation contribution depends exponentially on squark mass !

Non minimal flavour violation and relic density: a numerical study

Constraints

- WMAP relic density measurement: $\Omega_{\rm CDM} h^2 = 0.1126 \pm 0.0036$
- Direct limits on supersymmetric particle masses given in MFV scenarios. Just consider LEP-Tevatron exclusion limits:
  $m_{\tilde{\chi}_1^0} > 46$ GeV, $m_{\tilde{\chi}_1^\pm} > 94$ GeV, $m_{\tilde{t}_1} > 96$ GeV, $m_{\tilde{g}} > 308$ GeV
- Higgs mass limit with a 3 GeV uncertainty: $m_{h^0} > 111.4$ GeV
- Constraints on flavour mixing from precise measurements:

	Exp. value	Exp. error	Theor. uncertainty
$10^4 \times {\rm BR}(b \to s\gamma)$	3.55	± 0.26	± 0.23
$10^8 \times {\rm BR}(B_s \to \mu^+\mu^-)$	< 5.6		
ΔM_{B_s} [ps^{-1}]	17.77	± 0.12	± 3.3
$\Delta\rho$	< 0.0012		
$10^{11} \times \Delta a_\mu$	255	± 80	

Tools and numerical procedure

cMSSM parameters

SPheno

[W. Porod, arXiv:hep-ph/0301101]

Soft terms at 1 TeV. Introduce $\delta_{23}^{u,\mathrm{RR}}$

SPheno

Low energy spectrum

Low energy observables

SPheno

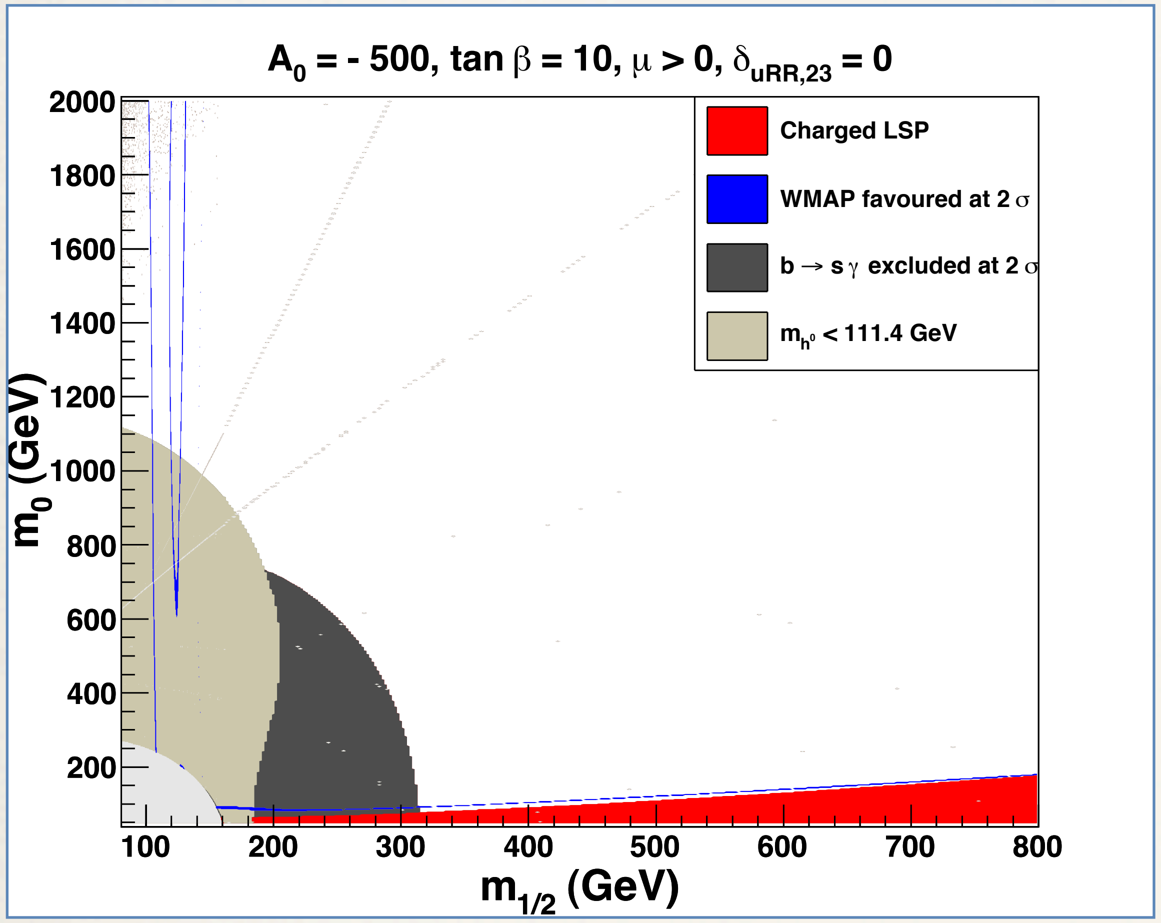
Relic density

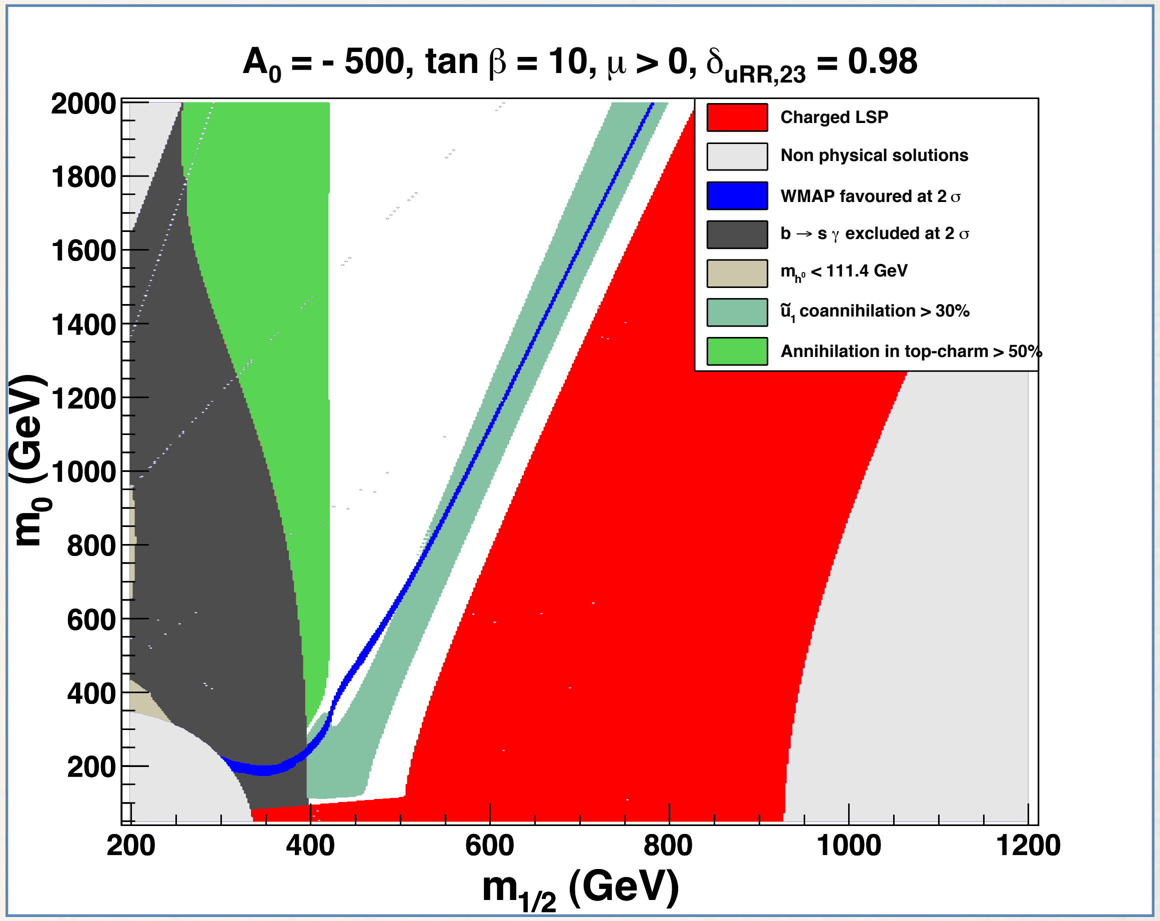
MicrOmegas

[G. Belanger, F. Boudjema, A. Pukhov, A. Semenov, arXiv:hep-ph/1005.4133]

Cross-sections calculation: CalcHEP
Generation of model files: SARAH

cMSSM: impact of NMFV on the (m0, m12) plane





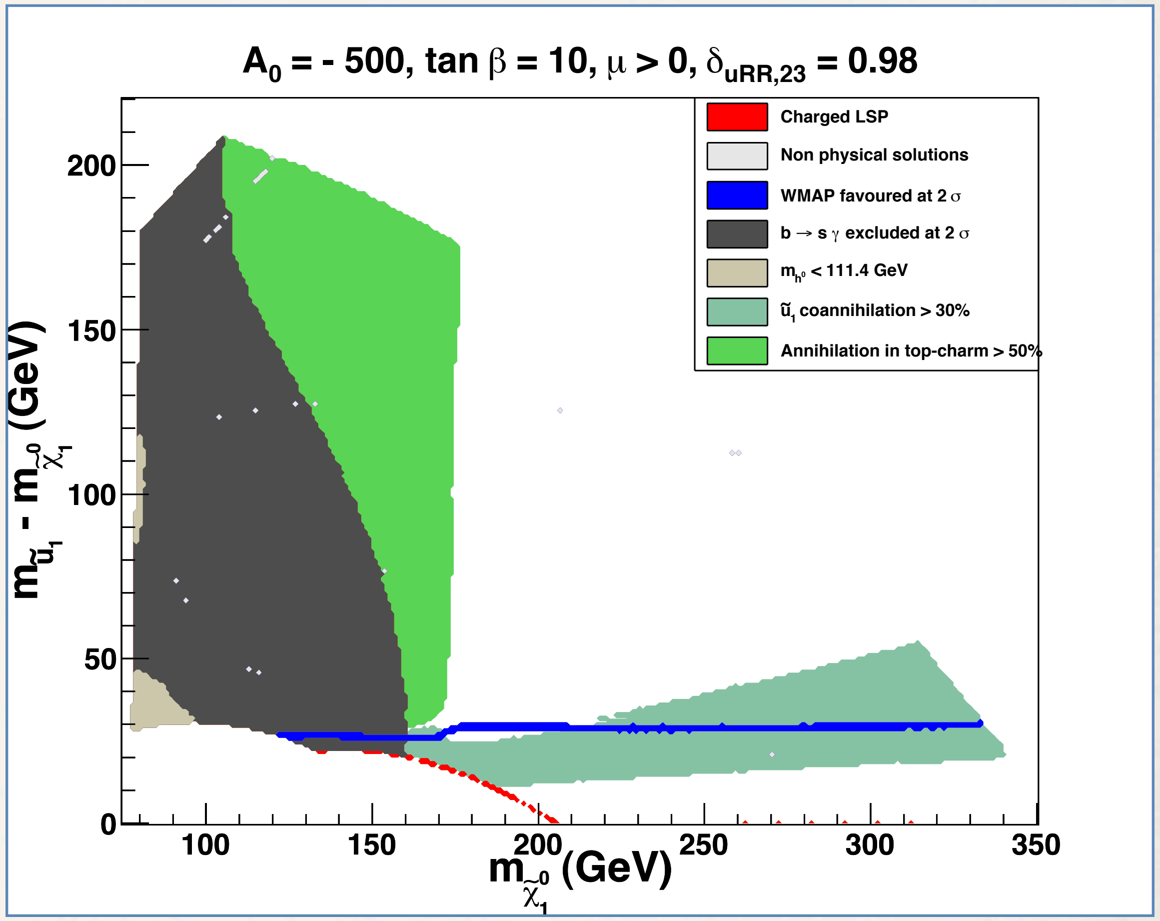
- Coannihilation contribution becomes significant:

$$\tilde{\chi}_1^0\ \tilde{u}_1 \to gt\ (30\%),\ \tilde{u}_1\tilde{u}_1 \to gg\ (25\%),\ \tilde{\chi}_1^0\ \tilde{u}_1 \to gc\ (15\%)$$

- In light mass region, neutralino mass forbids $\tilde{\chi}_1^0\ \tilde{\chi}_1^0 \to t\bar{t}$, but $\tilde{\chi}_1^0\ \tilde{\chi}_1^0 \to t\bar{c}$ allowed (and enhanced : light squark in the T channel + light c quark in final state)

cMSSM: impact of NMFV on the (m0, m12) plane

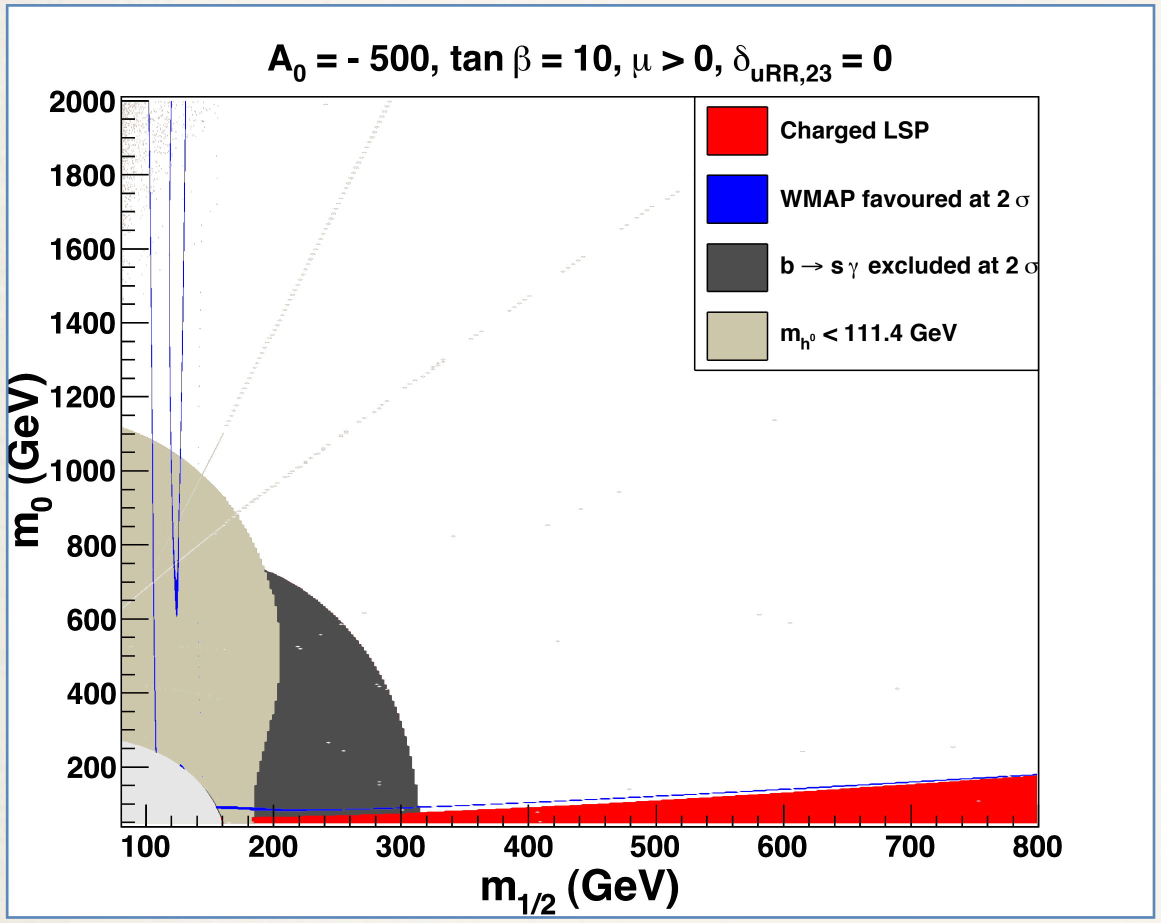
Looking at physical masses we can check that:

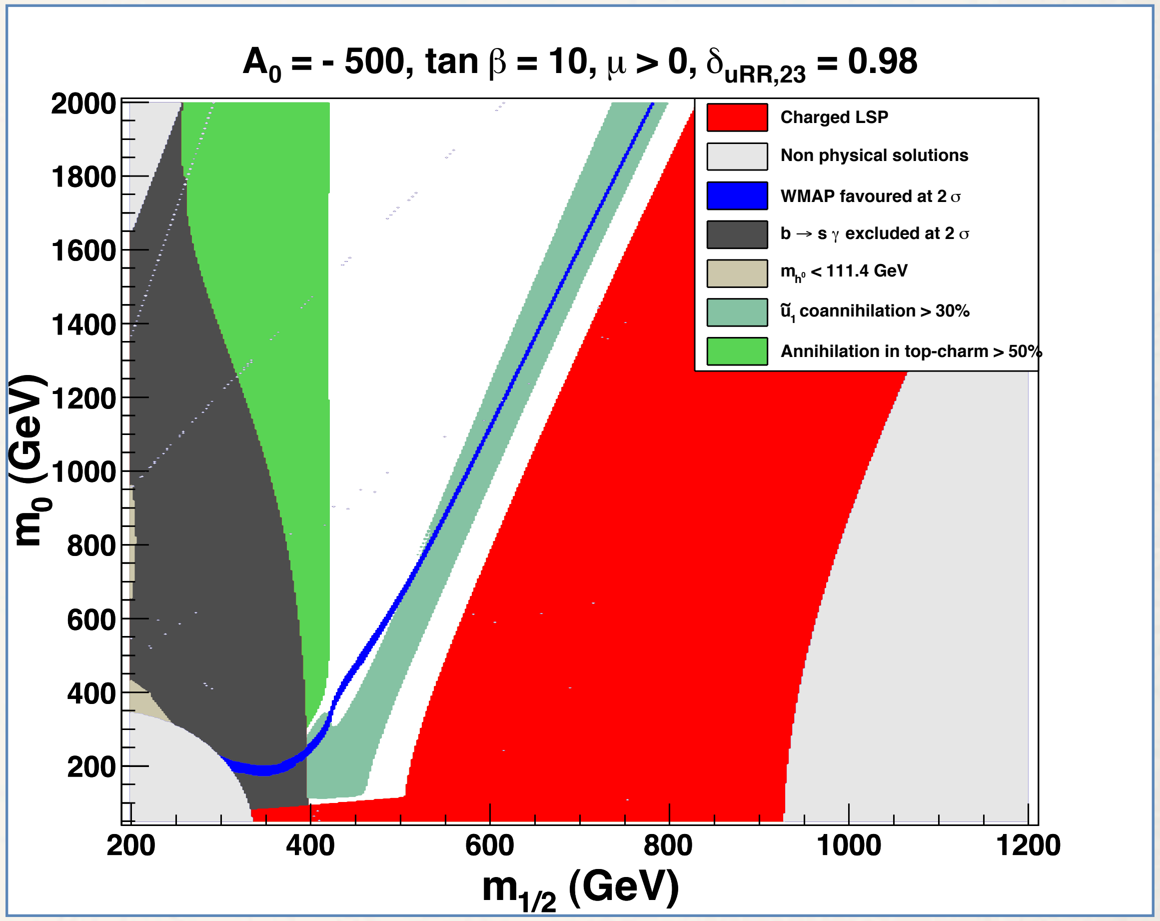


- Coannhilation contributes for close masses. The relic density is correct for a mass difference of 30 GeV

- When neutralino is heavier than the top, it can annihilate into top pairs, and top-charm final states becomes relatively less important

cMSSM: $b \to s\ \gamma$ exclusion in the (m0, m12) plane



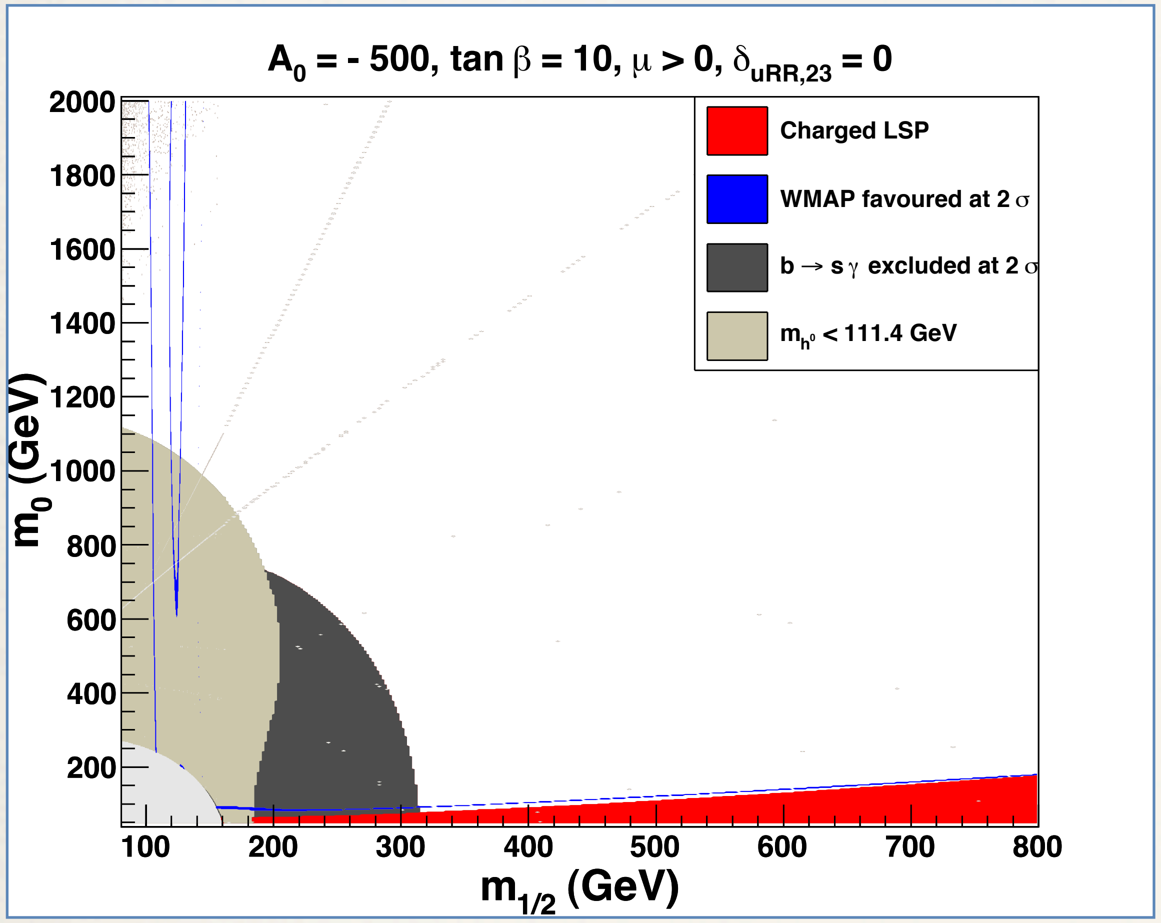


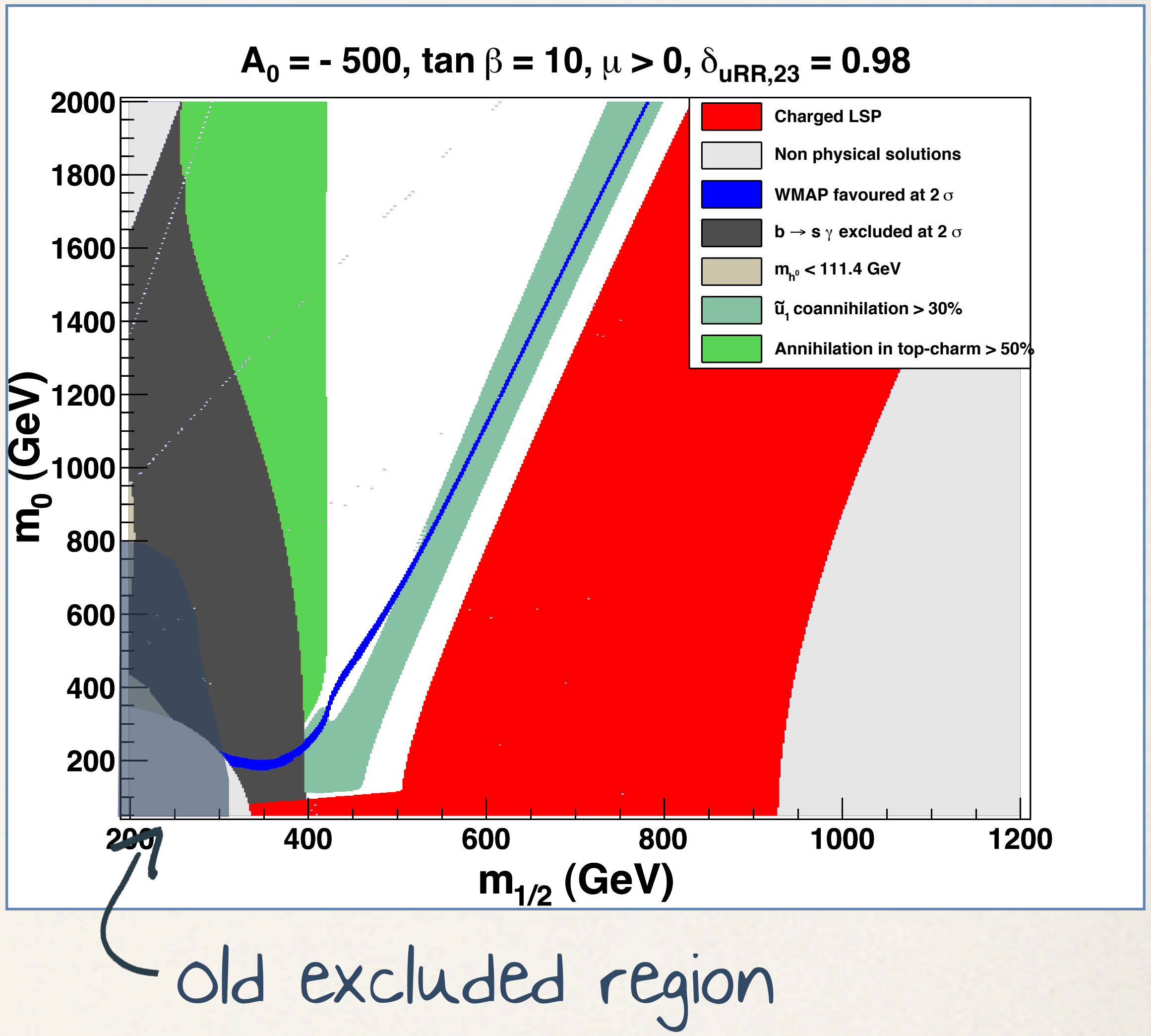
New excluded region much larger, but new allowed still safe!

Dependance of $b \to s\ \gamma$ on flavour violating terms in the right sector is not so important.

Mainly a mass effect: light stop gives important negative contribution from chargino

cMSSM: $b \to s\ \gamma$ exclusion in the (m0, m12) plane





New excluded region much larger, but new allowed still safe!

Dependance of $b \to s\ \gamma$ on flavour violating terms in the right sector is not so important.

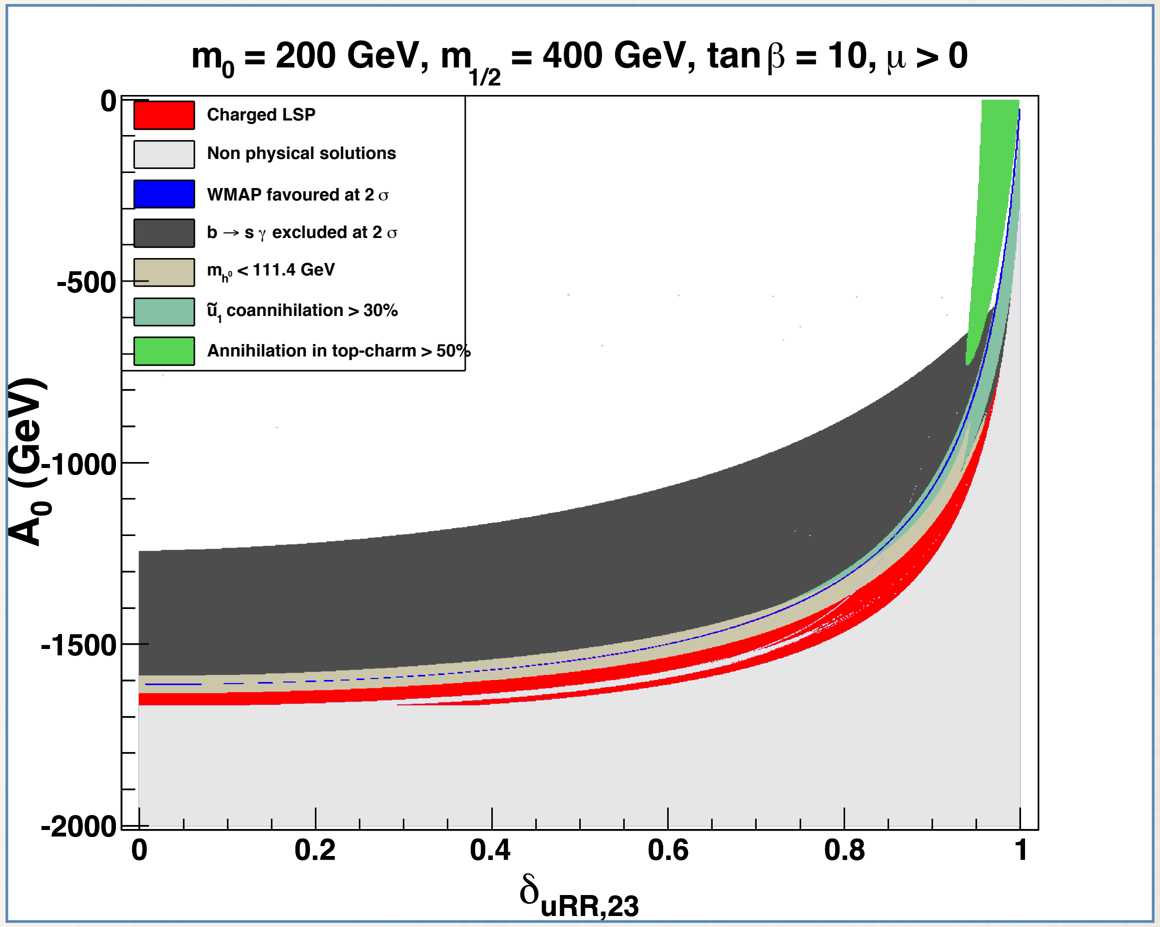
Mainly a mass effect: light stop gives important negative contribution from chargino

cMSSM: helicity and flavour mixings

- Helicity and flavour mixing has competitive effect on stop mass. Coannihilation needs a large mixing: A_0 or $\delta_{23}^{u,\mathrm{RR}}$ has to be large

- Flavour violating processes (as neutralino annihilation into top-charm quarks) depends only on flavour mixing. A large $\delta_{23}^{u,\mathrm{RR}}$ is needed

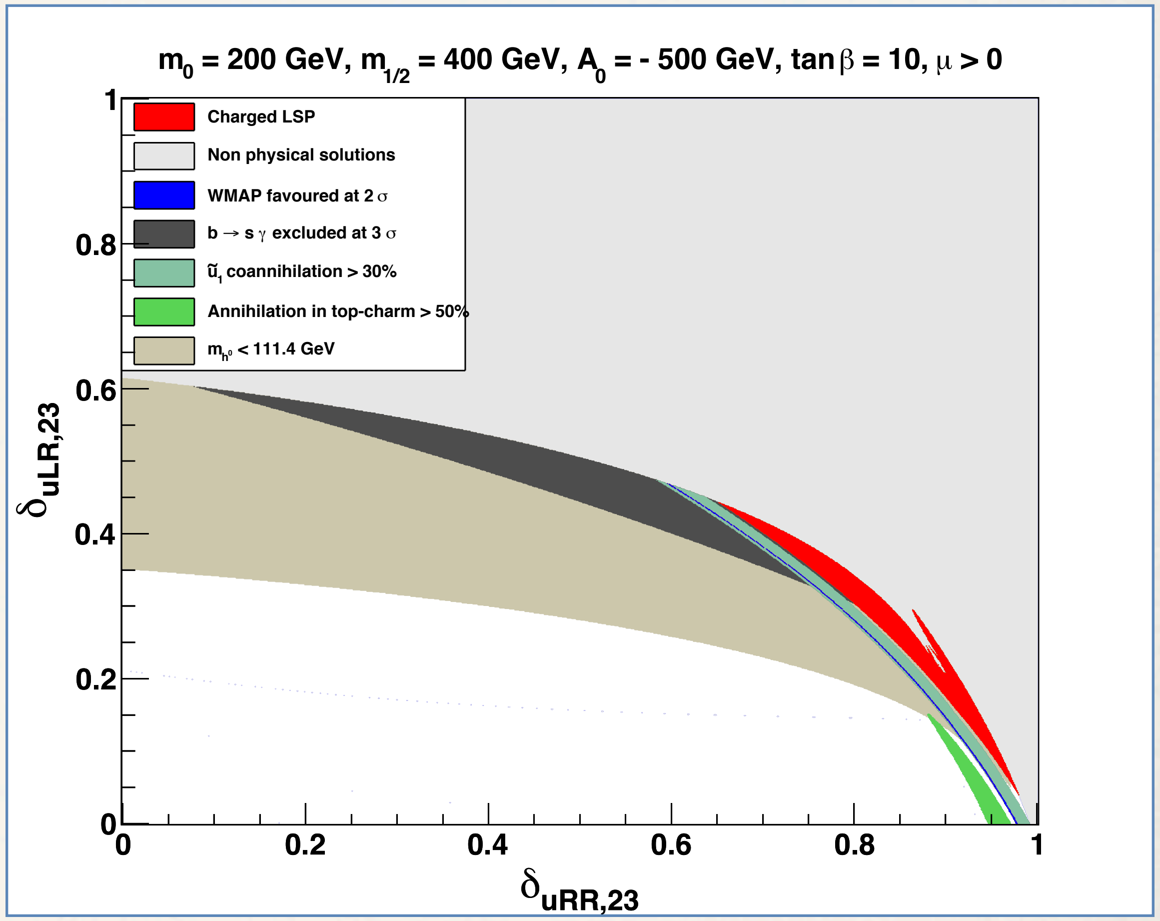
- $b \to s\ \gamma$ depends on the mass spectrum, not really on flavour violation in the RR sector: dependance on A_0 is larger than on $\delta_{23}^{u,\mathrm{RR}}$



→ Here the only allowed region is for low A_0 and large $\delta_{23}^{u,\mathrm{RR}}$

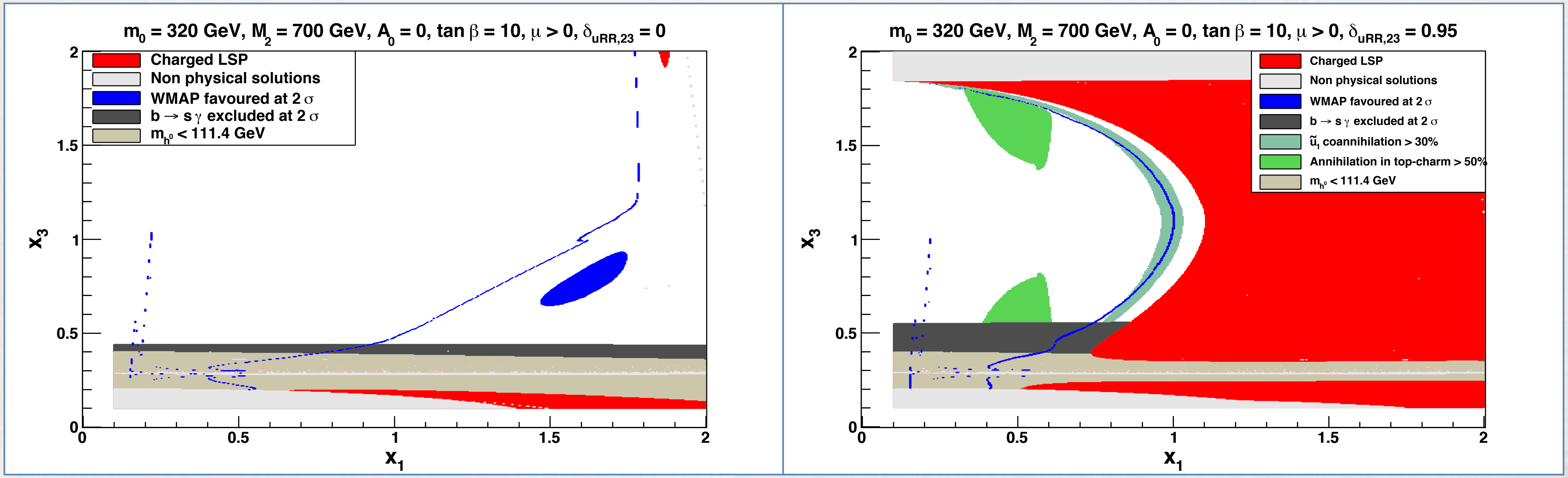
cMSSM: mixing with the left sector

- Here off-diagonal elements are added in the Right-Right and Left-Right sector.
- As expected, mixing with left sector strongly constrained by higgs mass and $b \to s\ \gamma$ (here at 3σ)



NMFV beyond cMSSM: NUGM

- Gauginos masses do not need to be Universal at the Unification scale
- Relaxing this condition gives Non Universal Gaugino Masses model: $M_1 \neq M_2 \neq M_3$
- Two additional independant parameters: $x_1 = M_1/M_2$ and $x_3 = M_3/M_2$
- Leads to interesting dark matter phenomenology. When adding NMFV we obtain:



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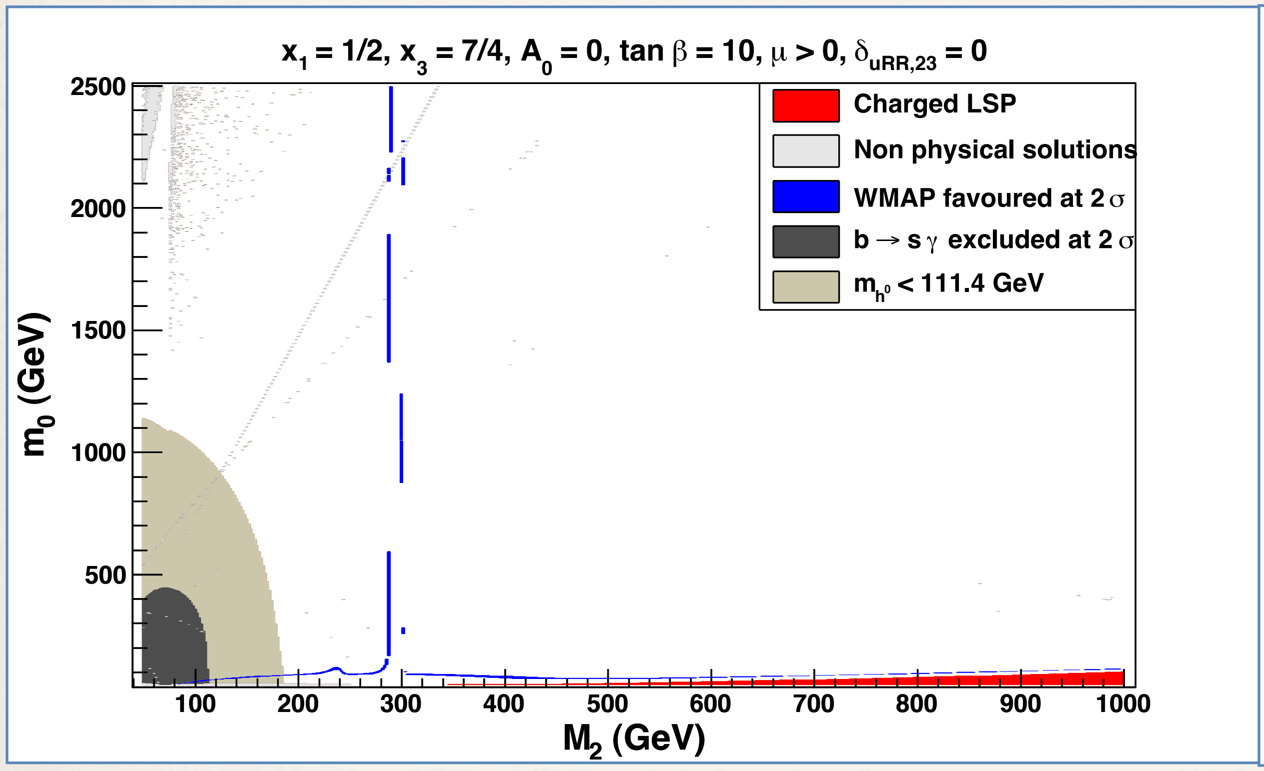
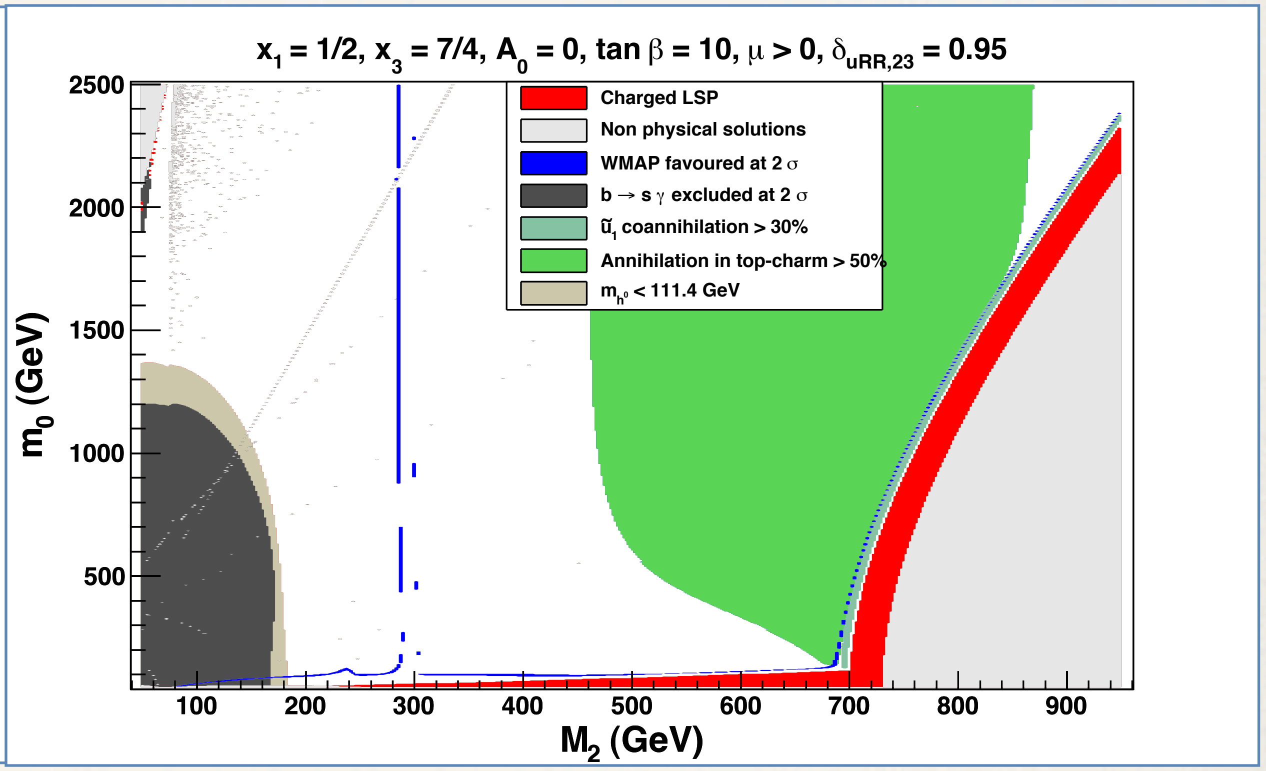


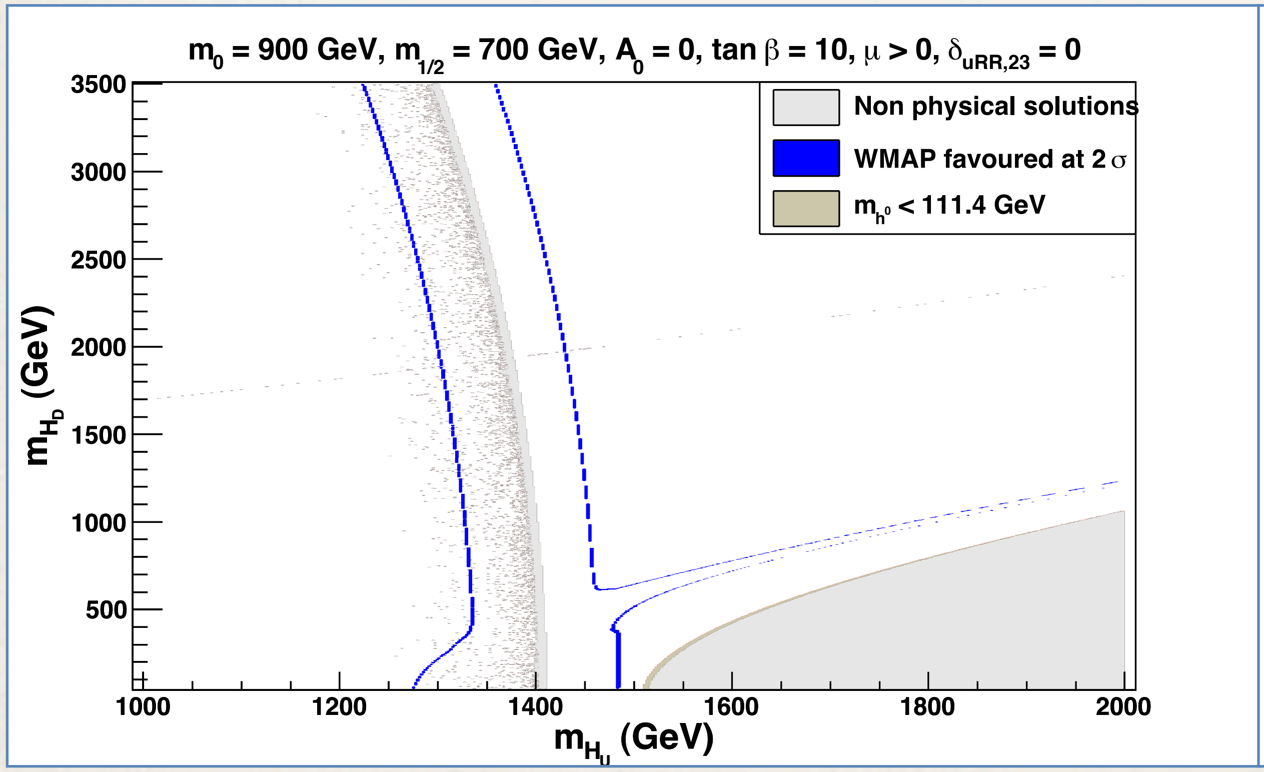


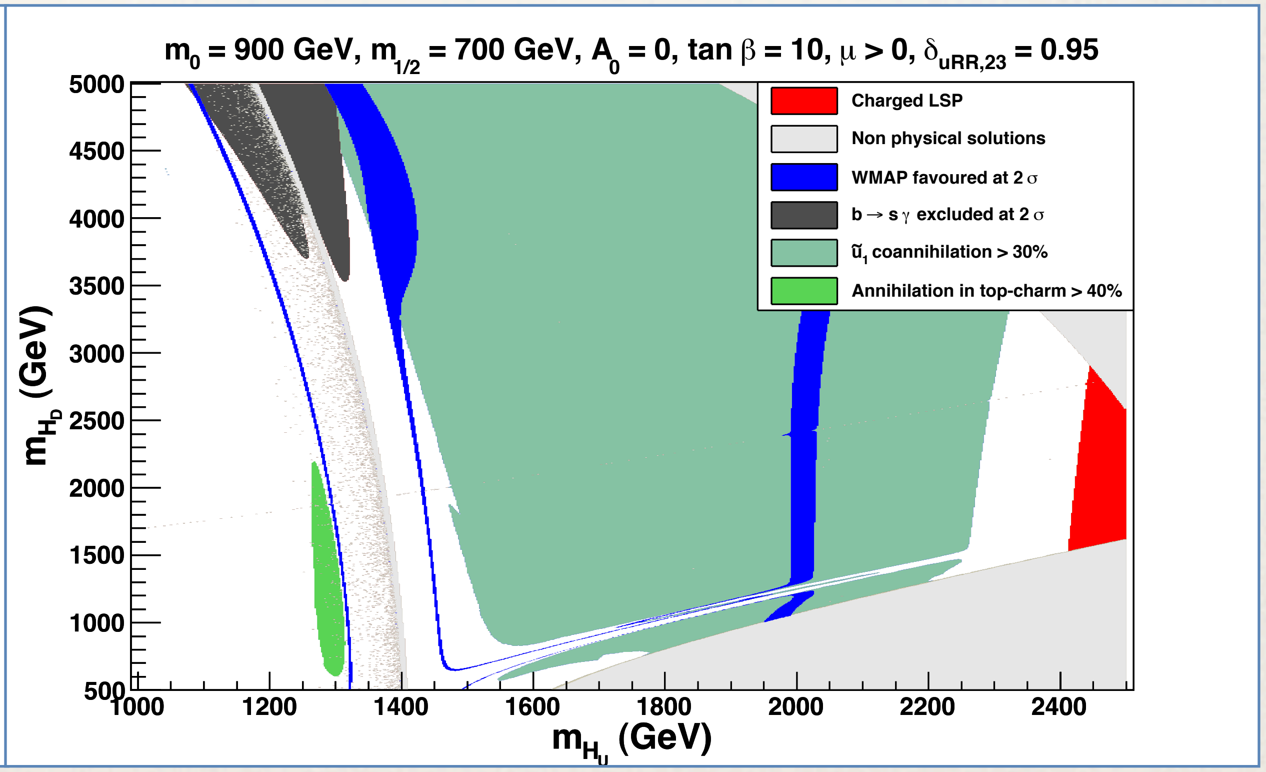
- Large x3 shift SUSY spectrum up, which reduce chargino contribution to $b \to s\ \gamma$

⟶ Coannihilation region clearly separated from $b \to s\ \gamma$ excluded region

NMFV beyond cMSSM: NUHM

- Similarly, Higgs masses do not need to be Universal at the Unification scale
- Relaxing this condition gives Non Universal Higgs Masses model: $m_{H_U} \neq m_{H_D} \neq m_0$
- Two additional independant parameters: m_{H_U} and m_{H_D}





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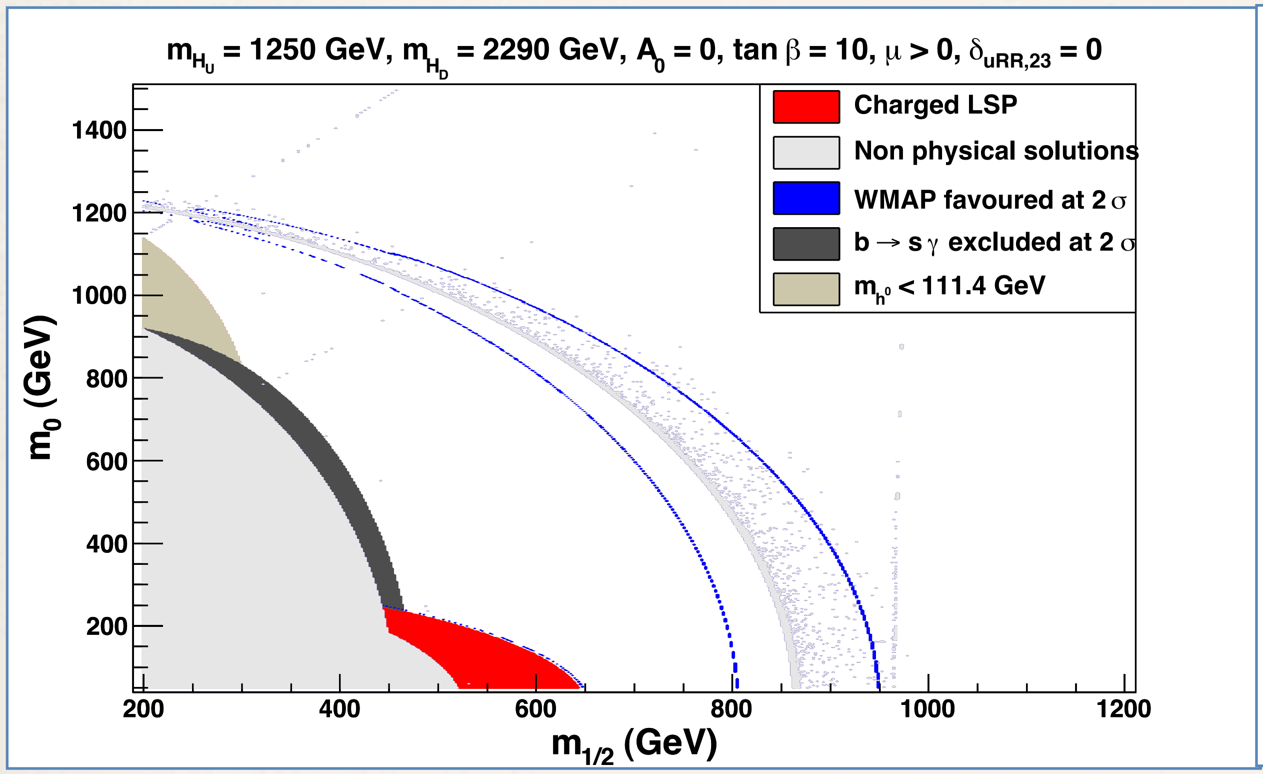
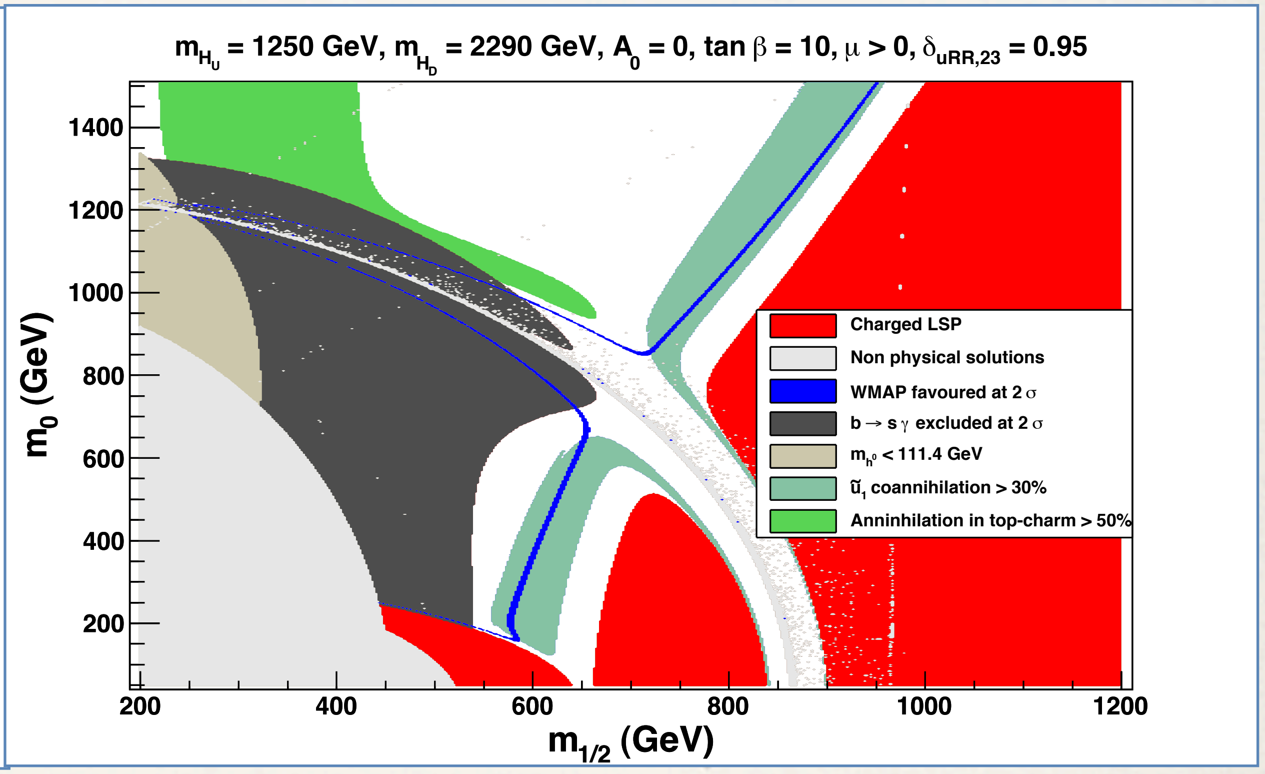




- As in CMSSM, new regions appears where relic density is correct
- Mainly thanks to coannihilation with the lightest squark
- $b \rightarrow s\ \gamma$ does not exclude these new regions

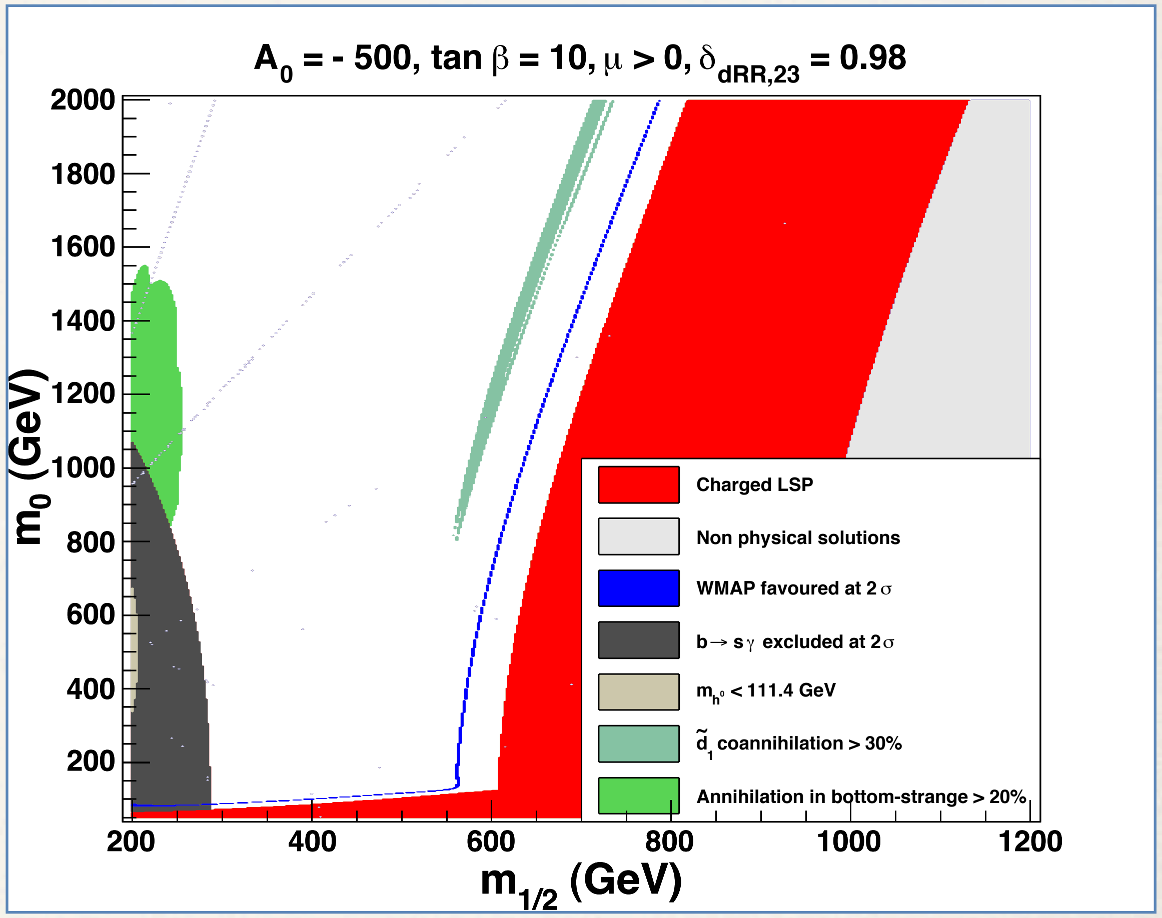
What about down (S)quarks?

Could we have similar effects in the down Squarks sector without being constrained by bsgamma ?

- Sbottom heavier than Stop in CMSSM
  - No coannihilation with sbottom (non universal sfermion masses needed)
  - Neutralino annihilation in b quarks mostly from flavour-conserving s channel (Z and light higgs poles). T channel with Sbottom exchange suppressed.
  - But as for Stops, a large $\delta_{23}^{d,\mathrm{RR}}$ can decrease Sbottom mass!
- Then $b \to s\,\gamma$ may be very constraining (gluino contributions). But gluino contribution is positive (chargino one is negative...)

What about down (S)quarks?

- We observe similar effects for down Squarks: here the relic density drop down thanks to neutralino-Sbottom coannihilation!
- Flavour violating channels ($\tilde{\chi}_1^0\ \tilde{d}_1 \to gs$) are also present
- Large contribution from $\tilde{d}_1 \tilde{d}_1^* \to gg$
- Annihilation in bottom-strange final states also present but with a low contribution



- $b \to s\ \gamma$ exclude low mass region where the Branching Ratio is too large because of gluino contribution.
- This excluded region is much smaller than for a large $\delta_{23}^{u,\mathrm{RR}}$

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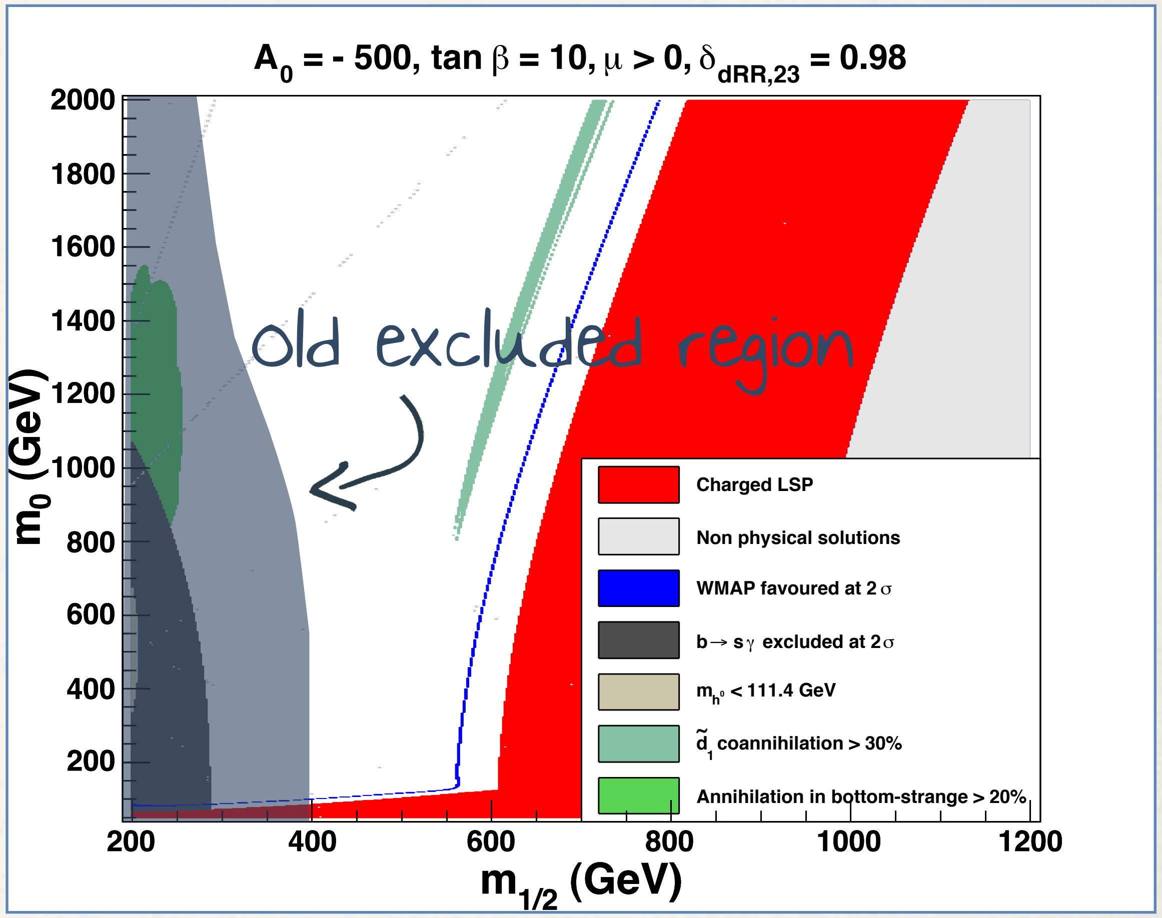

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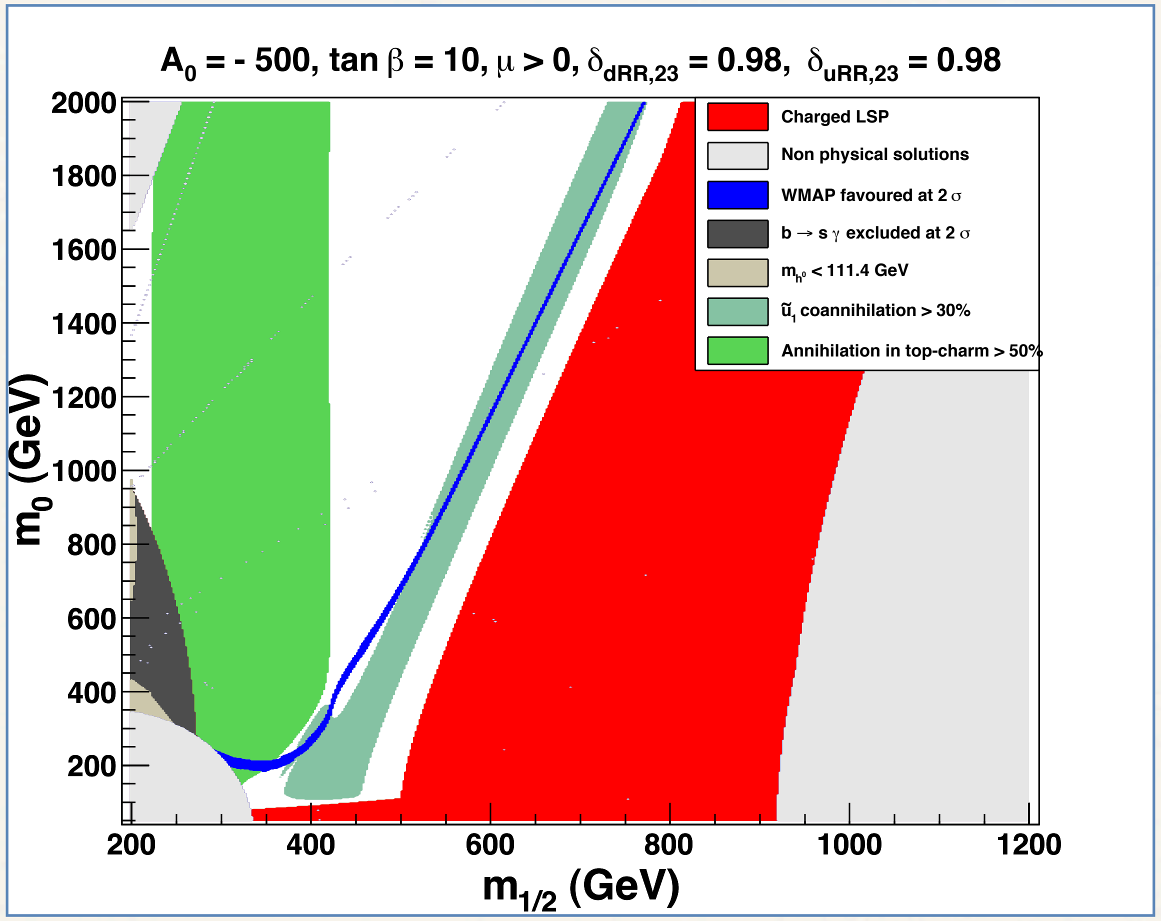


- When considering flavour violation in the up and down sector at the same time, relic density constraint is similar as if only $\delta_{23}^{u,\mathrm{RR}}$ was non zero (Stop lighter than Sbottom)

- However, $b \to s\ \gamma$ much less constraining ! (cancellations)

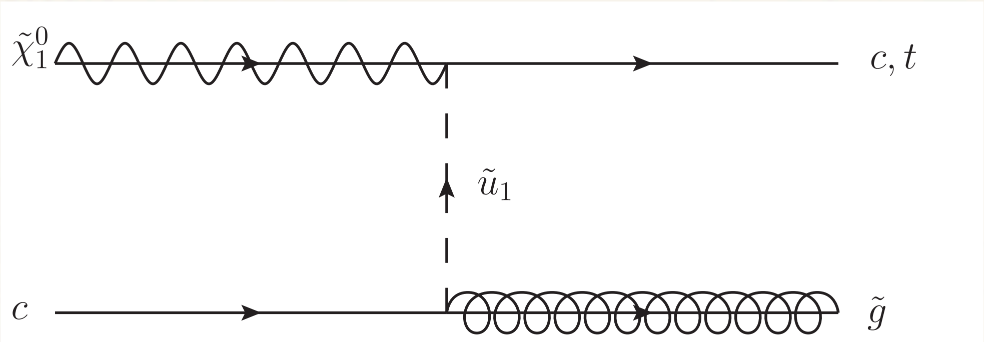
Conclusion and perspectives

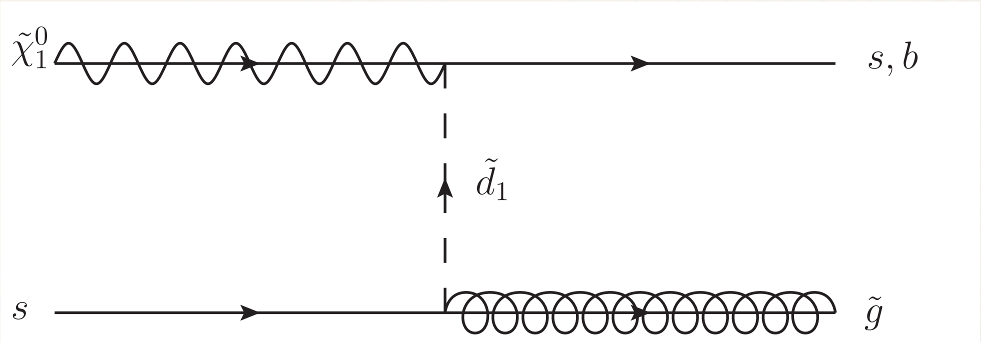
Conclusion

- A large $\delta_{23}^{u,\mathrm{RR}}$ can modify relic density via different effects:
  - modification of the squark content
  - modification of the squark mass
  - additional kinematical / thermodynamical effects
- In NMFV, the shape of relic density constraint in the parameter space can be significantly different compared to MFV
- New interesting regions can be compatible with flavour physics constraints
- Adding flavour violation in the down squark sector via a simple relation $\delta_{23}^{RR} = \delta_{23}^{u,\mathrm{RR}} = \delta_{23}^{d,\mathrm{RR}}$ gives even better results for $b \to s\ \gamma$
- Taking into account flavour violation only in the down squark sector gives sbottom coannihilation.

Perspectives: NMFV impact on dark matter detection?

- Direct detection:
    - Neutralino can scatter off charm content of the nucleon via lightest squark
    - Larger effect for strange content in case of flavour violation in down sector ?





→ Cross-section can be modified by NMFV

- Indirect detection:
    - Neutralino annihilation can be enhanced
    - Flavour violating final states (like top-charm) can modify photon spectrum

Thank you!

Backup slides

$b \to s\ \gamma$ cancellations: up and down (Squarks)

Some rough numbers about $b \to s\ \gamma$ Branching Ratio (let's forget the 10^{-4}):

- The measured BR is 3.55
- With the uncertainty considered here, the 2 sigma bounds are then 2.86 < BR < 4.24
- The (Higgsless) Standard Model BR is 3.15
- Here the MFV cMSSM contributions are from the Higgs (positive) and chargino (negative): the lower bound constrain our parameter space in the low masses region.
- A large $\delta_{23}^{u,\mathrm{RR}}$ increases the (absolute value of the) chargino contribution: same situation, but even more constrained.
- A large $\delta_{23}^{d,\mathrm{RR}}$ increases the gluino contribution: the upper bound constrain our parameter space.
- Large $\delta_{23}^{u,\mathrm{RR}}$ and $\delta_{23}^{d,\mathrm{RR}}$: same situation, but even less constraining.

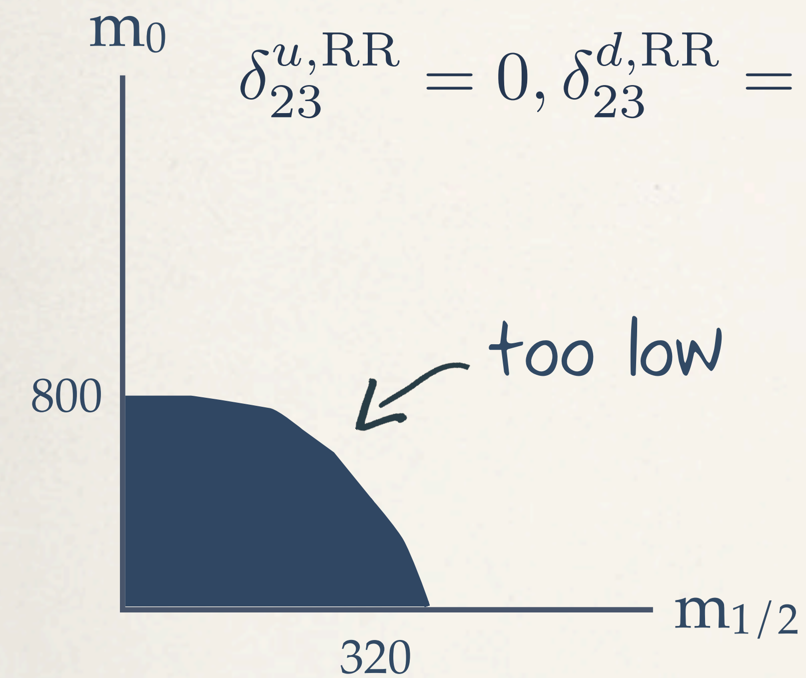
$b \to s\ \gamma$ cancellations: up and down (Squarks)

Some numbers for the point $(m_0, m_{1/2}) = (200,400)$

$\delta_{23}^{u,\mathrm{RR}}$	$\delta_{23}^{d,\mathrm{RR}}$	Charged Higgs	Chargino-Stop	Gluino-Sbottom	Total + SM
0	0	0.3	-0.4	0	3.05
0.98	0	0.3	-0.6	0	2.85
0	0.98	0.3	-0.4	0.3	3.35
0.98	0.98	0.3	-0.6	0.3	3.15

$b \to s\ \gamma$ cancellations: up and down (Squarks)

$\delta_{23}^{u,\mathrm{RR}} = 0, \delta_{23}^{d,\mathrm{RR}} = 0$



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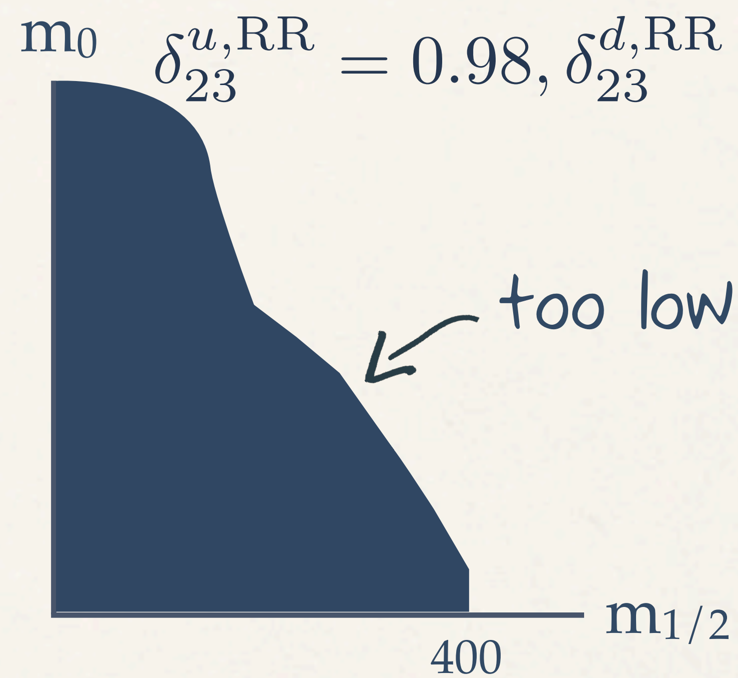

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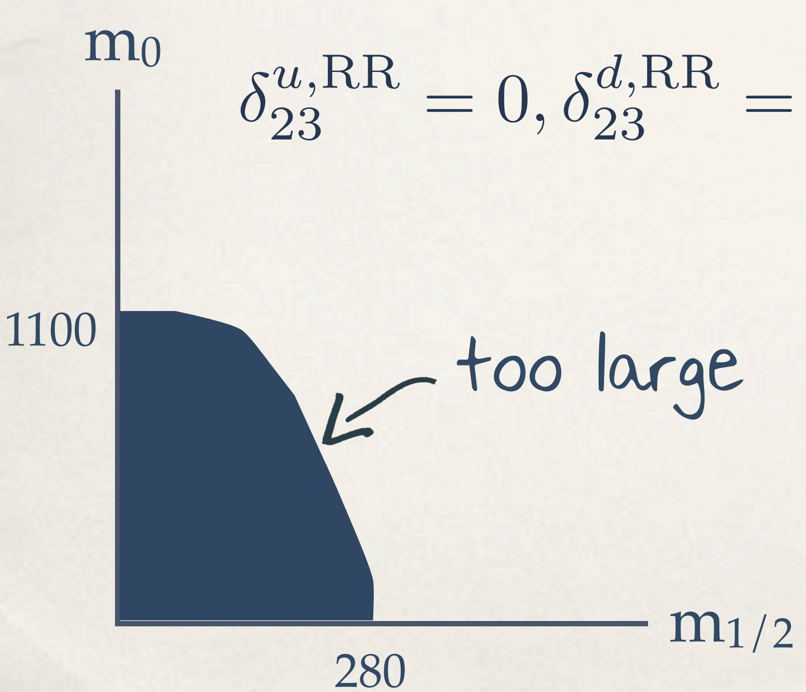
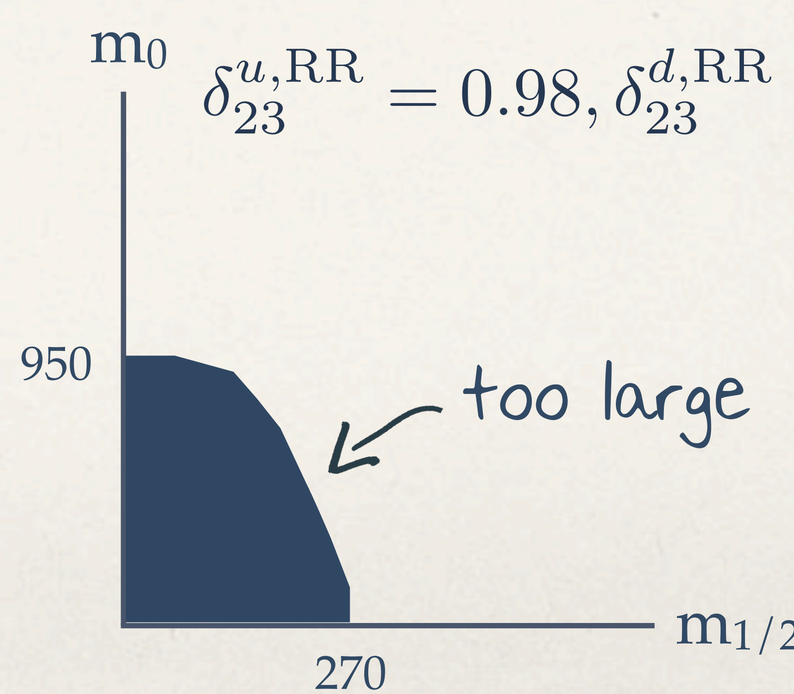


$\delta_{23}^{u,\mathrm{RR}} = 0.98, \delta_{23}^{d,\mathrm{RR}} = 0.98$



Relic density contributions