

# Mixed sneutrino dark matter in light of recent experimental results

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based on arXiv:1205.soon

in collaboration with:

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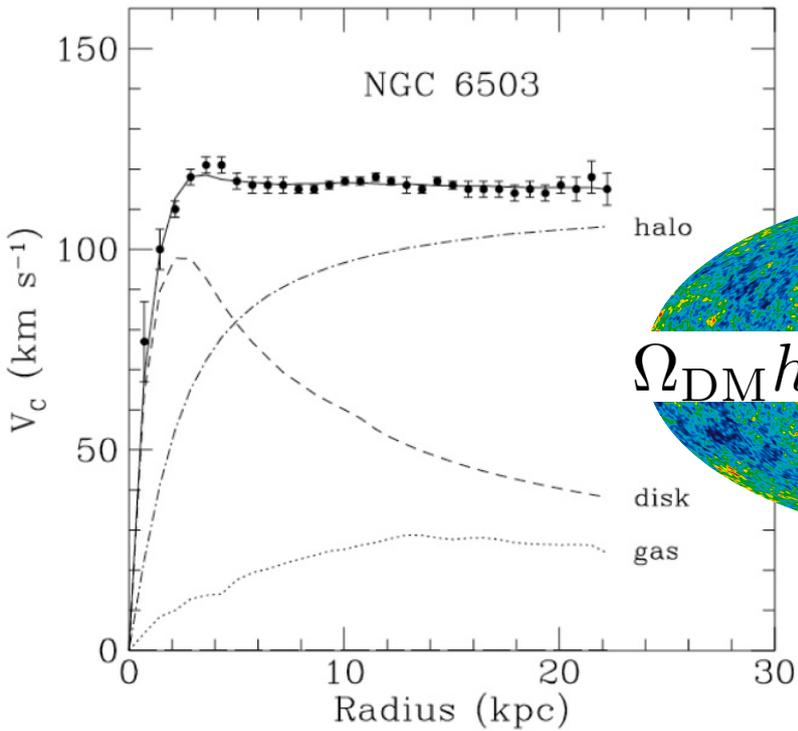
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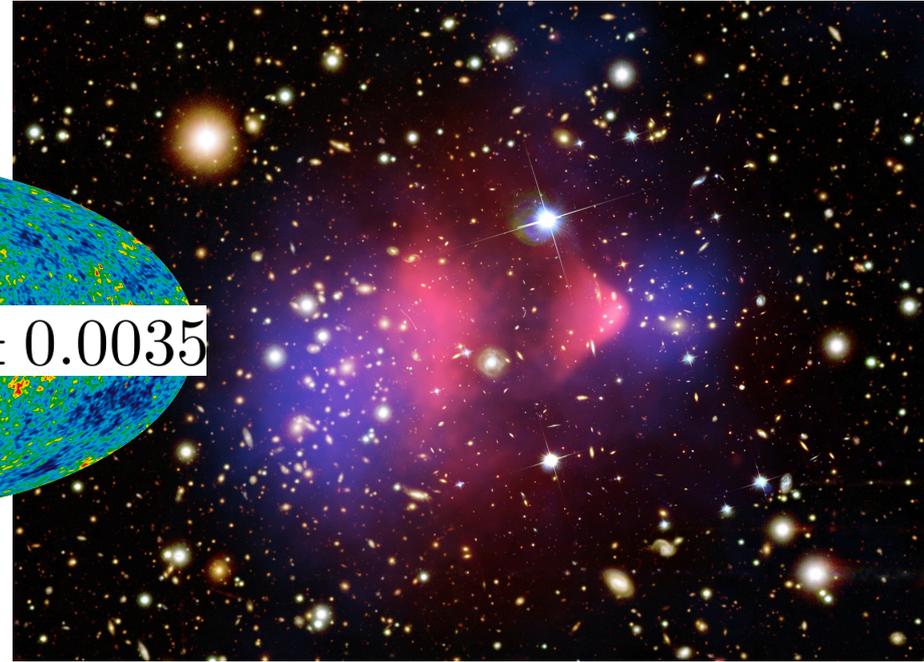
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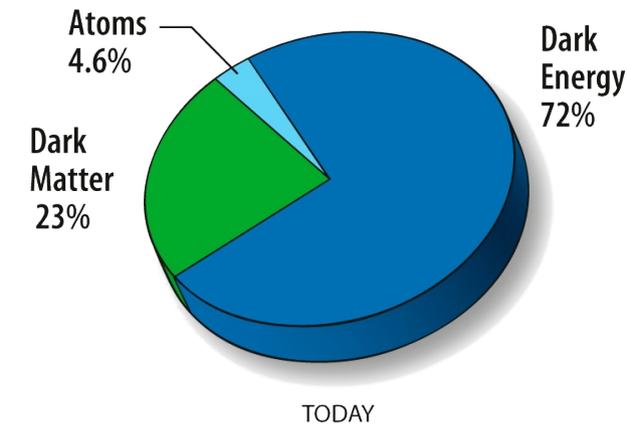
# Dark matter evidences



$$\Omega_{\text{DM}} h^2 = 0.1123 \pm 0.0035$$



should be made of ~stable, electrically neutral and possibly weakly interacting particles

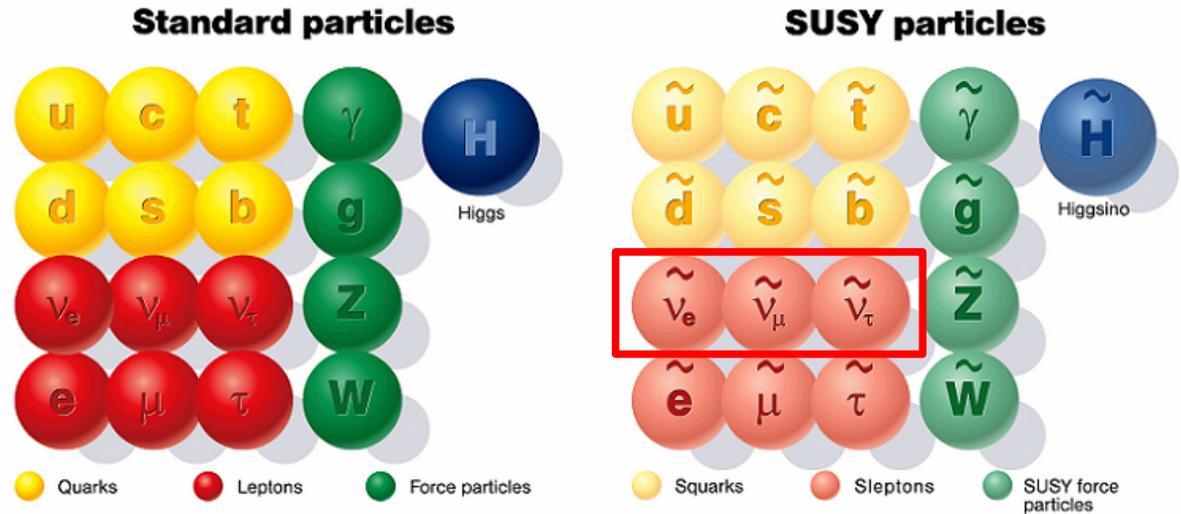


keyword	number of results on arXiv
"neutralino dark matter"	332
"sneutrino dark matter"	34

# Supersymmetry and mixed sneutrinos

Framework: MSSM  
(with Dirac neutrinos)

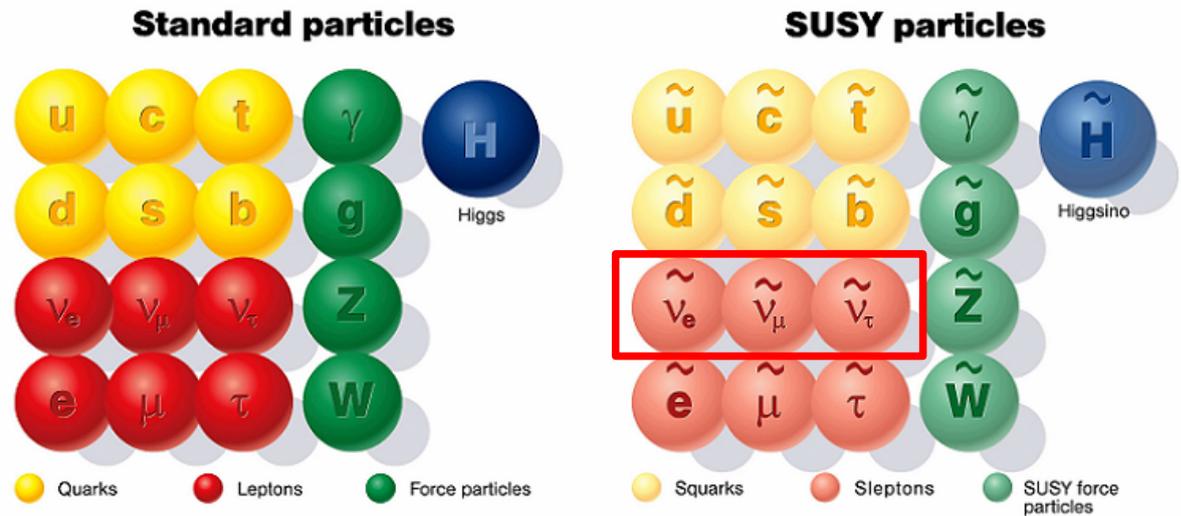
$$\begin{aligned} \Delta\mathcal{L}_{\text{soft}} &= m_{\tilde{N}_i}^2 |\tilde{N}_i|^2 \\ &+ A_{\tilde{\nu}_i} \tilde{L}_i \tilde{N}_i H_u \\ &+ \text{h.c.} \end{aligned}$$



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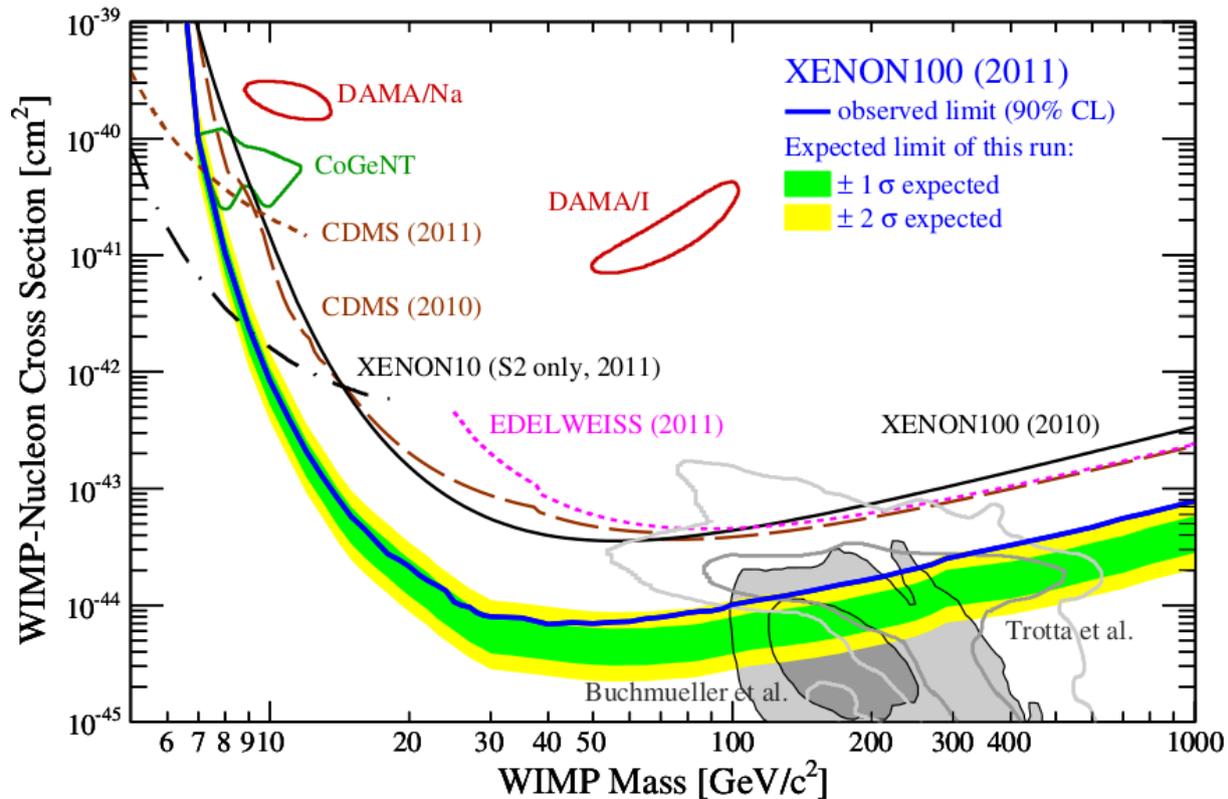
$$m_{\tilde{\nu}}^2 = \begin{pmatrix} m_{\tilde{L}}^2 + \frac{1}{2} m_Z^2 \cos 2\beta & \frac{1}{\sqrt{2}} A_{\tilde{\nu}} v \sin \beta \\ \frac{1}{\sqrt{2}} A_{\tilde{\nu}} v \sin \beta & m_{\tilde{N}}^2 \end{pmatrix} \quad \text{with } A_{\tilde{\nu}} \sim \mathcal{O}(100 \text{ GeV}) \text{ instead of } A_{\tilde{\nu}} \propto y_\nu \approx 0$$

$\Rightarrow (\tilde{\nu}_1, \tilde{\nu}_2, \sin \theta_{\tilde{\nu}})$        $\tilde{\nu}_1 \rightarrow$  LSP and dark matter candidate

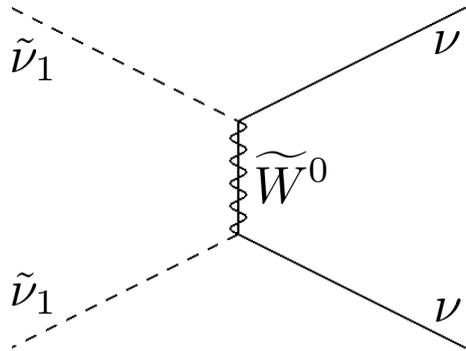
Dirac neutrinos and  $A_{\tilde{\nu}} \sim \mathcal{O}(100 \text{ GeV})$  is well motivated [hep-ph/0006312]  
[hep-ph/0007018]

# Light and heavy sneutrino dark matter

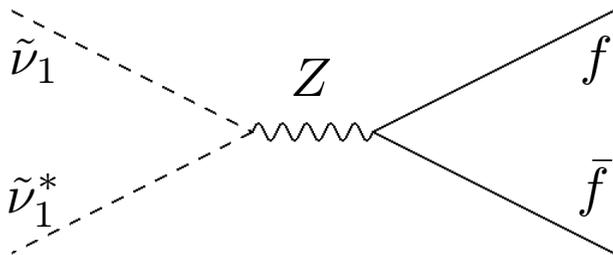
- Two very different cases:
- light sneutrino ( $m_{\tilde{\nu}_1} < m_Z/2$ )  $\rightarrow \Gamma(Z \rightarrow \text{invisible})?$
  - heavy sneutrino ( $m_{\tilde{\nu}_1} > m_Z/2$ )  $\rightarrow \Gamma(h^0 \rightarrow \text{invisible})?$



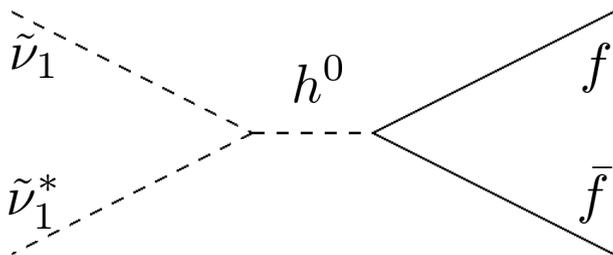
# Main annihilation channels



$$\propto \sin^4 \theta_{\tilde{\nu}} \quad (\text{also } \tilde{\nu}_1^* \tilde{\nu}_1^* \xrightarrow{\tilde{W}^0} \nu^* \nu^*)$$



$$\propto \sin^4 \theta_{\tilde{\nu}}$$



$$\propto (A_{\tilde{\nu}} \sin \theta_{\tilde{\nu}})^2$$

with heavy sneutrinos, we also have annihilations into a pair of W, Z, h

# MCMC scan

## Parameters and nuisance parameters

Bayesian inference using MCMC methods.  
We assume uniform (linear) priors on all the parameters.

$i$	Parameter $p_i$	Scan bounds
1	$m_{\tilde{\nu}_{\tau_1}}$	$[1, m_Z/2]$ GeV (light) or $[m_Z/2, 1000]$ GeV (heavy)
2	$m_{\tilde{\nu}_{\tau_2}}$	$[m_{\tilde{\nu}_{\tau_1}} + 1, 3000]$ GeV
3	$\sin(\theta_{\tilde{\nu}_\tau})$	$[0, 1]$
4	$m_{\tilde{\nu}_{e_1}} = m_{\tilde{\nu}_{\mu_1}}$	$[m_{\tilde{\nu}_{\tau_1}} + 1, m_Z/2]$ GeV (light) or close to $m_{\tilde{\nu}_{\tau_1}}$ (heavy)
5	$m_{\tilde{\nu}_{e_2}} = m_{\tilde{\nu}_{\mu_2}}$	$[m_{\tilde{\nu}_{e_1}} + 1, 3000]$ GeV (light) or close to $m_{\tilde{\nu}_{\tau_2}}$ (heavy)
6	$\sin(\theta_{\tilde{\nu}_e}) = \sin(\theta_{\tilde{\nu}_\mu})$	$[0, 1]$ (light) or close to $\sin(\theta_{\tilde{\nu}_\tau})$ (heavy)
7	$\tan \beta$	$[3, 65]$
8	$\mu$	$[-3000, 3000]$ GeV
9	$M_2 = 2M_1 = M_3/3$	$[30, 1000]$ GeV
10	$A_{\tilde{t}}$	$[-8000, 8000]$ GeV
11	$M_A$	$[30, 3000]$ GeV
12	$m_{\tilde{Q}_3} = m_{\tilde{U}_3} = m_{\tilde{D}_3}$	$[100, 3000]$ GeV

other squarks masses: 2 TeV

$i$	Nuisance parameter $\lambda_i$	Experimental result $\Lambda_i$	Likelihood function $L(\Lambda_i \lambda_i)$
1	$m_u/m_d$	$0.553 \pm 0.043$	Gaussian
2	$m_s/m_d$	$18.9 \pm 0.8$	Gaussian
3	$\sigma_{\pi N}$	$44 \pm 5$ MeV	Gaussian
4	$\sigma_s$	$21 \pm 7$ MeV	Gaussian
5	$\rho_{\text{DM}}$	$0.34 \pm 0.09$ GeV/cm <sup>3</sup>	Gaussian
6	$v_0$	$236 \pm 8$ km/s	Gaussian
7	$v_{\text{esc}}$	$550 \pm 35$ km/s	Gaussian
8	$m_t$	$173.3 \pm 1.1$ GeV	Gaussian
9	$m_b(m_b)$	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian
10	$\alpha_s(m_Z)$	$0.1184 \pm 0.0007$	Gaussian

Astrophysical parameters  
from [arXiv:1005.0579].

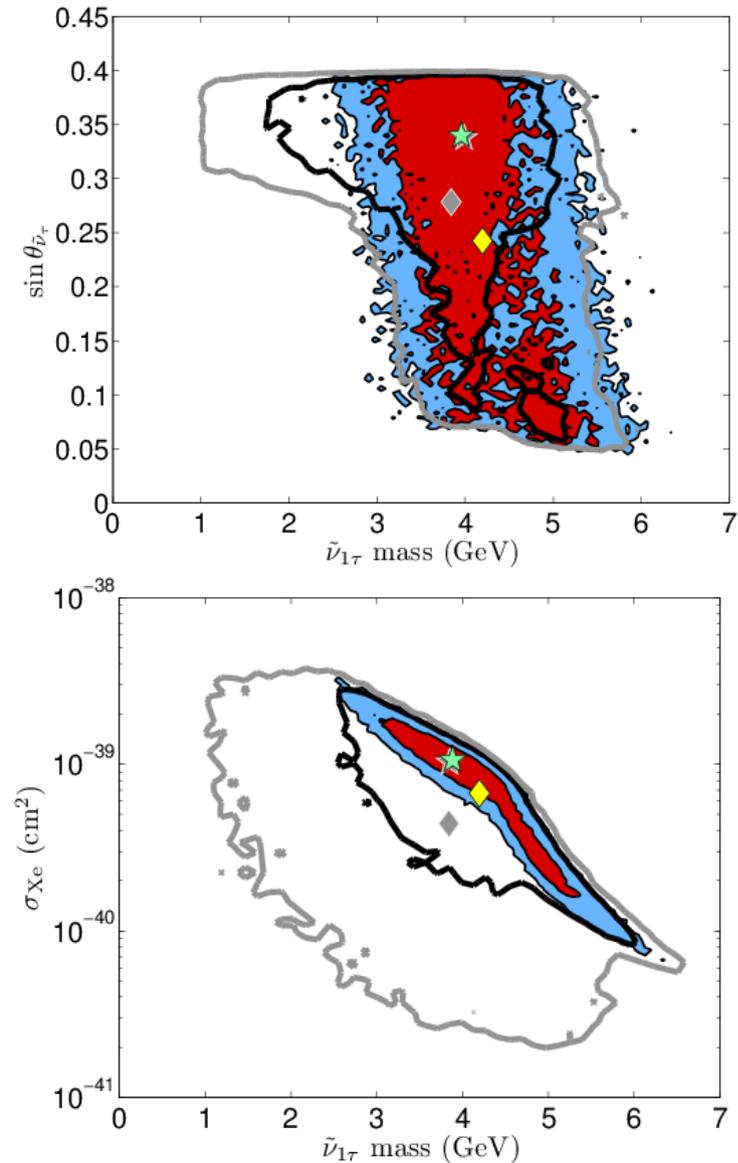
Recent lattice QCD values for  
 $\sigma_s$  and  $\sigma_{\pi N}$  from [arXiv:1202.6407].

# MCMC scan Observables

$i$	Observable $\mu_i$	Experimental result $D_i$	Likelihood function $L(D_i \mu_i)$
1	$\Delta\Gamma_Z$	$< 2$ MeV (95% C.L.)	$\mathbf{F}(\mu_1, 2 \text{ MeV})$
2	$\Omega_{\text{DM}}h^2$	$0.1123 \pm 0.0118$	Gaussian
3	$\Delta a_\mu$	$(26.1 \pm 12.8) \times 10^{-10}$	Gaussian
4	$m_{\tilde{g}}$	$> 750, 1000$ GeV or none	not included (a posteriori cut)
5	Higgs masses	from HiggsBounds 3.6.1beta	$L_5 = 1$ if allowed $L_5 = 10^{-9}$ if not
6	$m_{\tilde{\chi}_1^+}$	$> 100$ GeV	$L_6 = 1$ if allowed $L_6 = 10^{-9}$ if not
7	$m_{\tilde{e}_R} = m_{\tilde{\mu}_R}$	$> 100$ GeV	$L_7 = 1$ if allowed $L_7 = 10^{-9}$ if not
8	$m_{\tilde{\tau}_1}$	$> 85$ GeV	$L_8 = 1$ if allowed $L_8 = 10^{-9}$ if not
9	$\sigma_{\text{SI}}$	$(m_{\text{DM}}, \sigma_{\text{SI}})$ constrained by XENON10, XENON100, CDMS and CoGeNT	$L_9 = e^{-\chi_{\text{DD}}^2/2}$
10	$\mathcal{B}(b \rightarrow s\gamma)$	$(3.55 \pm 0.34) \times 10^{-4}$	Gaussian
11	$\mathcal{B}(B_s \rightarrow \mu^+\mu^-)$	$< 1.26 \times 10^{-8}$ (95% C.L.)	$\mathbf{F}(\mu_{11}, 1.26 \times 10^{-8})$

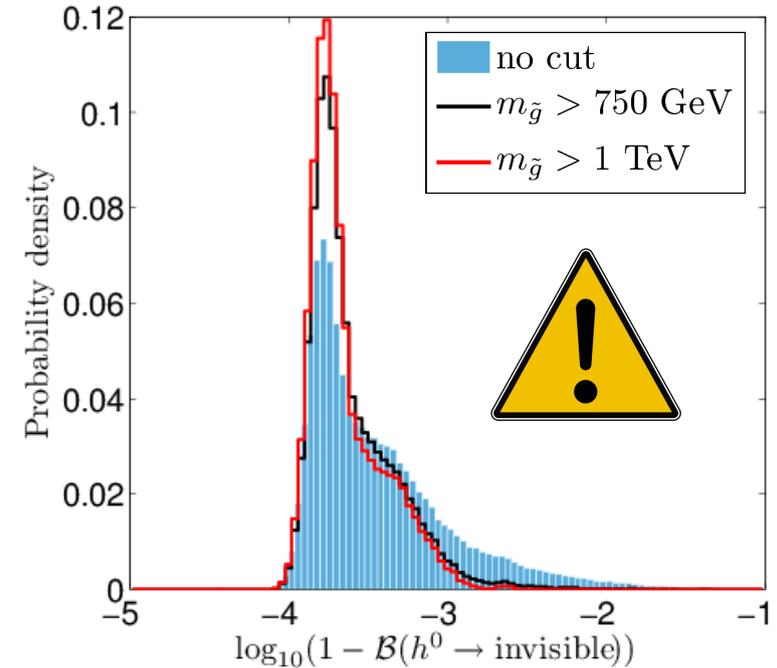
- We use micrOMEGAs, SuSpect, HDECAY and HiggsBounds
- We consider a posteriori the latest LHCb result:  
 $\mathcal{B}(B_s \rightarrow \mu^+\mu^-) < 0.45 \times 10^{-8}$
- **F**: smoothed step function (emulates the 95% C.L. limits)

# Light sneutrino results



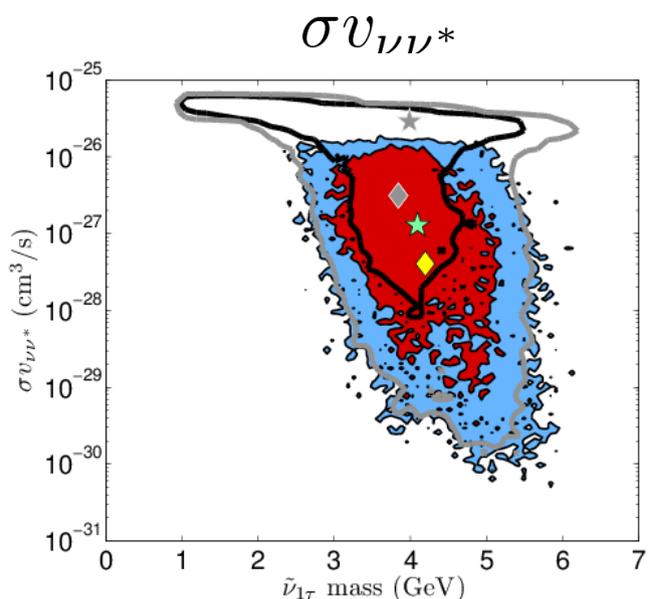
- gluino mass bounds from ATLAS and CMS rule out the (hard to probe with direct detection) low mass region → suppression of the wino mediated annihilation

- the remaining points are very close to the direct detection limit

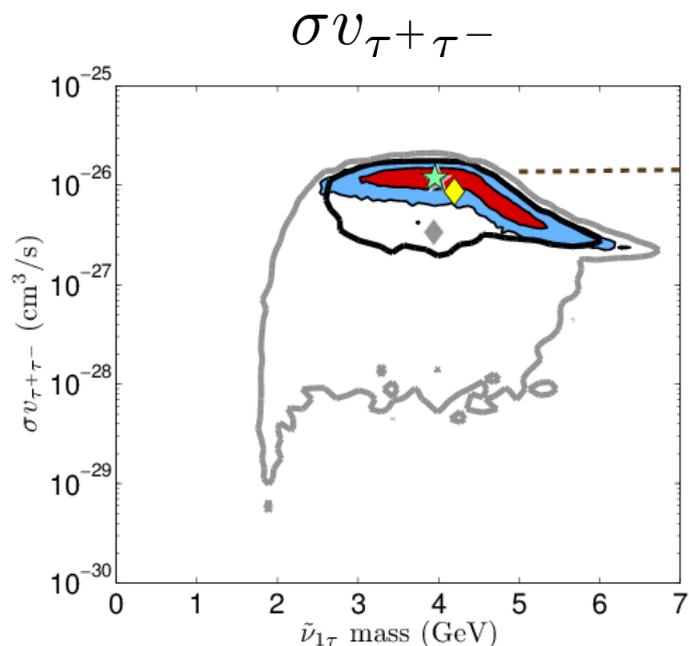


- If the excess around 125 GeV in Higgs searches is confirmed, it rules out a light mixed sneutrino dark matter. (similar result and interpretation if one sneutrino is light, the others heavy)

# Light sneutrino results indirect detection – Fermi-LAT limits on $\gamma$ -rays

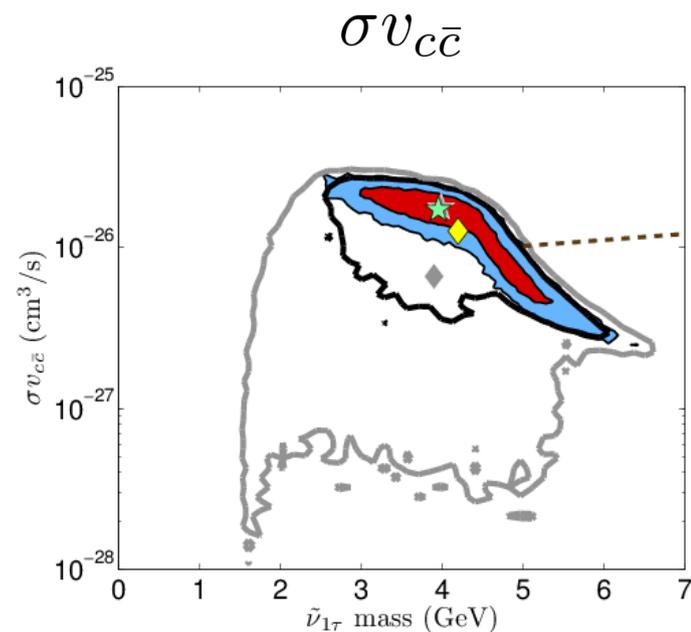


suppression of the wino mediated annihilation

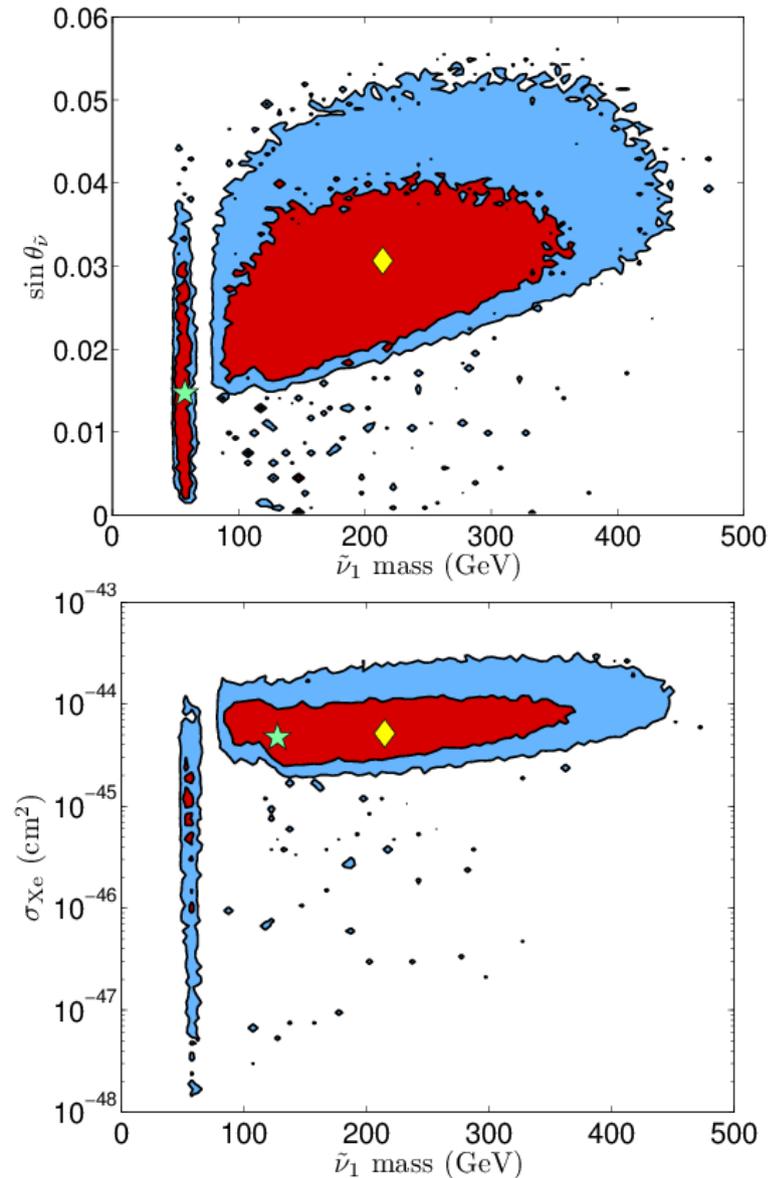


- latest Fermi limits: [1108.3546]
- our analysis could be refined
- Fermi results below 5 GeV are welcome!

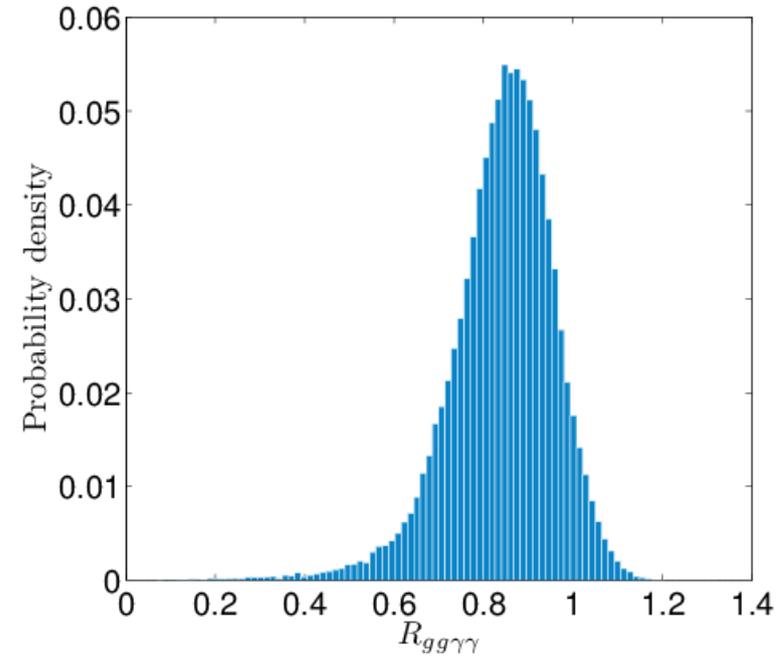
Fermi limit on  $c\bar{c}$  does not exist  
– we show the  $b\bar{b}$  one



# Heavy sneutrino results

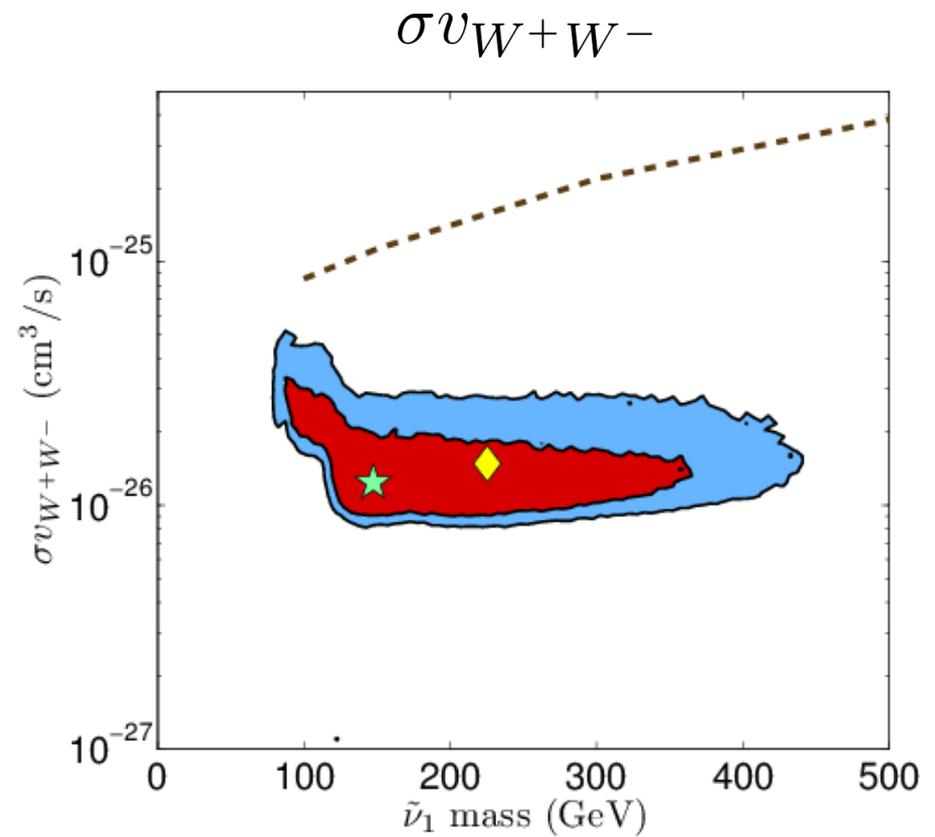
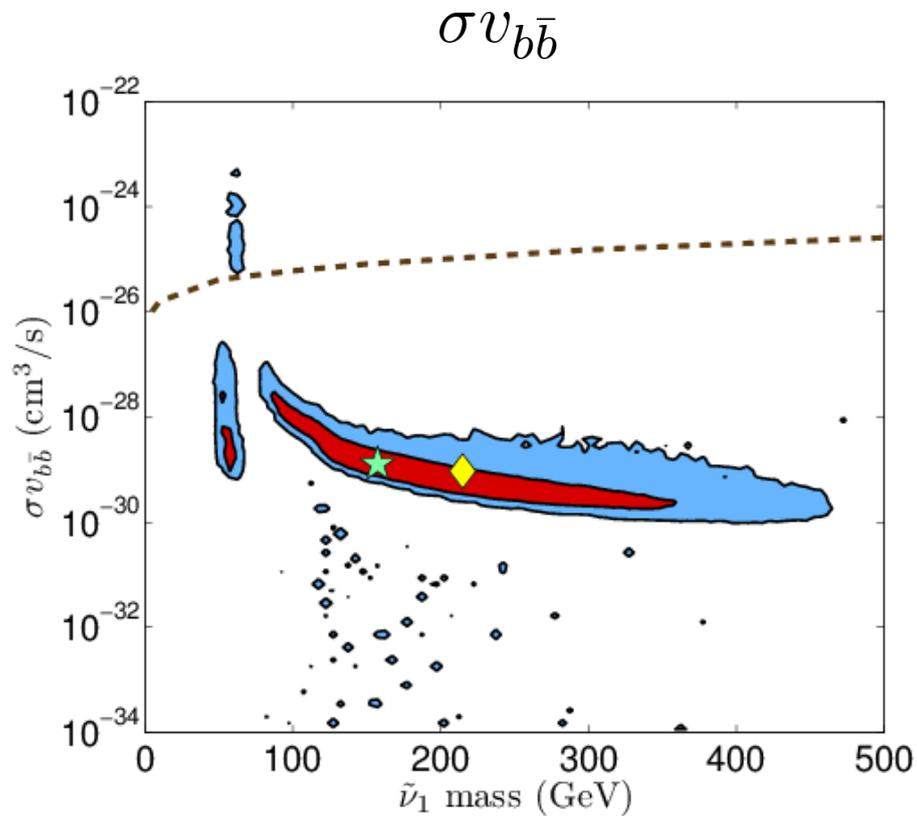


- we need a very low mixing angle to pass the XENON100 limit
- we have gluino mass  $> 1$  TeV: current LHC bounds do not apply
- Higgs resonance for sneutrinos around 60 GeV
- the main region could soon be excluded by direct detection



- pMSSM-like result
- the sneutrino sector and the higgs sector are decoupled

# Heavy sneutrino results indirect detection – Fermi-LAT limits on $\gamma$ -rays



# LHC phenomenology

Mixed sneutrino dark matter has a sizable effect on SUSY signatures at the LHC.

posterior probability of having	light sneutrino	heavy sneutrino
$\mathcal{B}(\tilde{\chi}_1^0 \longrightarrow \tilde{\nu}_1 \nu) > 0.9$	90%	99%
$\mathcal{B}(\tilde{\chi}_2^0 \longrightarrow \tilde{\nu}_1 \nu) > 0.9$	71%	44%
$\mathcal{B}(\tilde{\chi}_1^\pm \longrightarrow \tilde{\nu}_{1e} e^\pm)$ $+ \mathcal{B}(\tilde{\chi}_1^\pm \longrightarrow \tilde{\nu}_{1\mu} \mu^\pm) > 0.5$	12%	48%
$\mathcal{B}(\tilde{\chi}_1^\pm \longrightarrow \tilde{\nu}_{1\tau} \tau^\pm) > 0.5$	65%	10%

- dominant invisible decays for the two light neutralinos
- sizable lepton production from chargino decay
- LHC potential to resolve the light sneutrino DM scenario: [1105.4878]

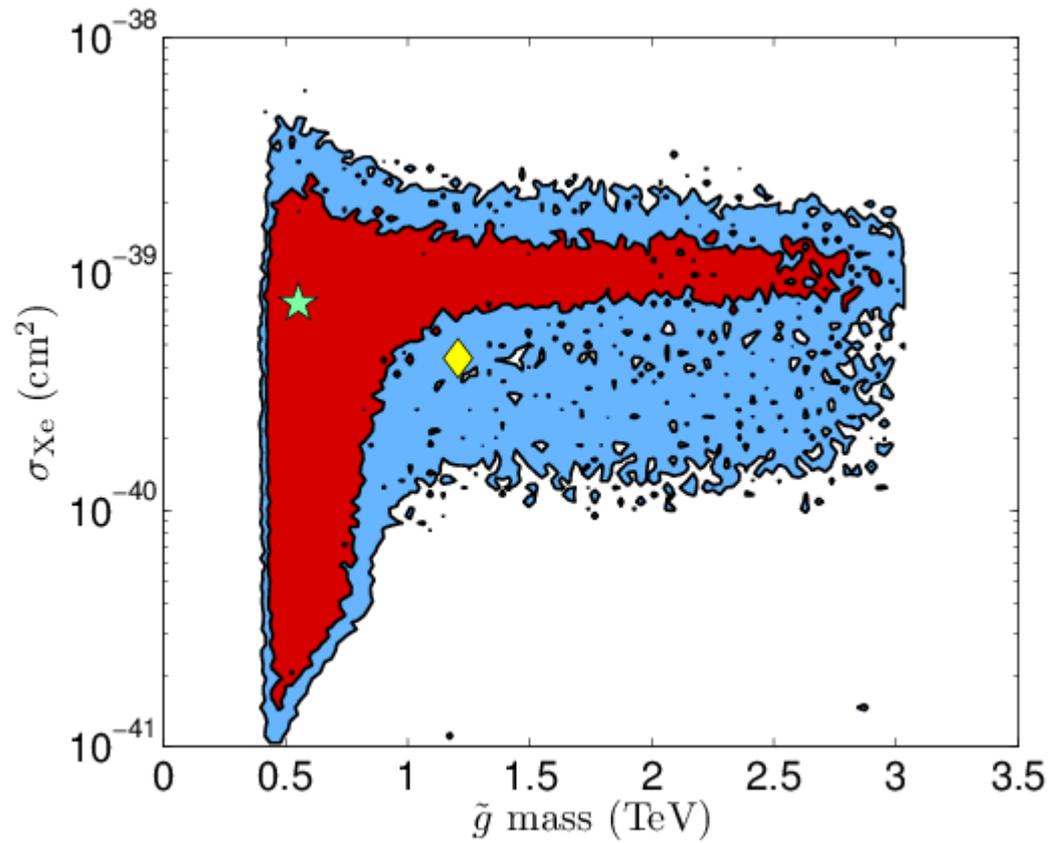
# Conclusion

- Mixed sneutrino dark matter is an interesting alternative to neutralino dark matter
- There is a lower limit on the scattering cross-section → direct detection limits are very constraining and could soon cover the whole parameter space
- Fermi-LAT results below 5 GeV are needed for light sneutrinos – for heavy sneutrinos, the limit is one or two orders of magnitude above
- Dramatic consequences on the Higgs boson if the sneutrino is light
- Gluino and squarks cascade decays are different from the CMSSM – the limit may be more stringent → requires a dedicated analysis

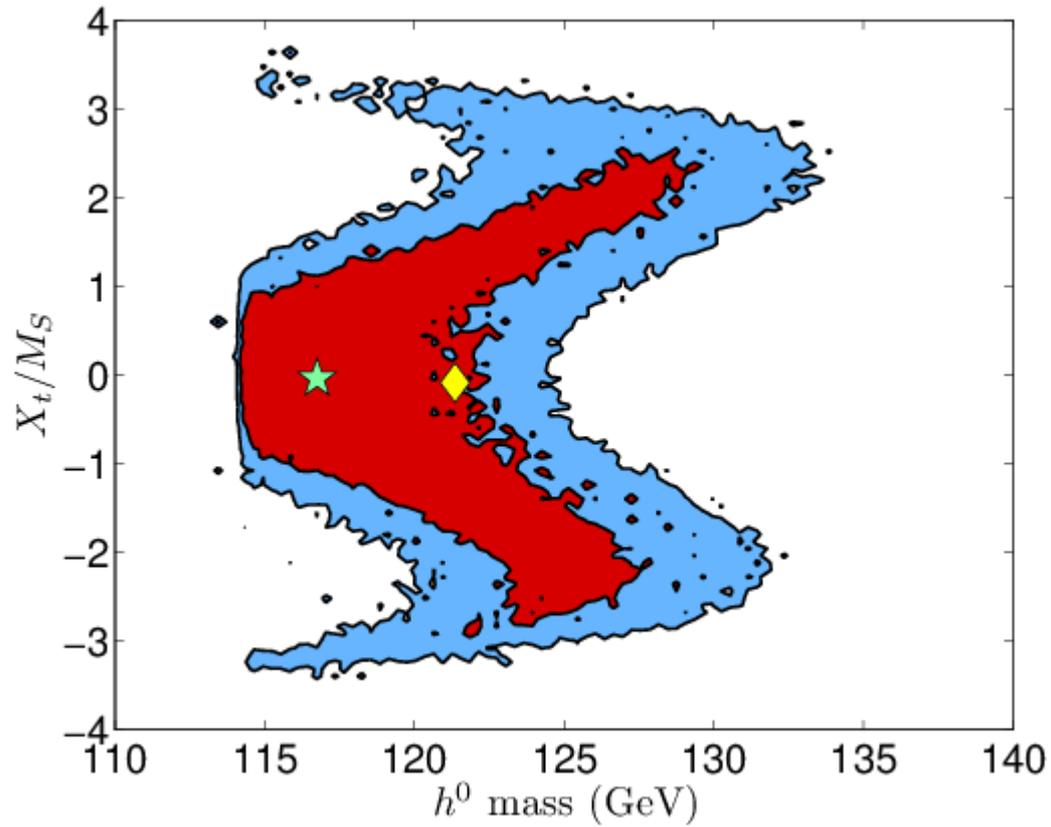
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