Mixed sneutrino dark matter in light of recent experimental results

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based on arXiv:1205.soon
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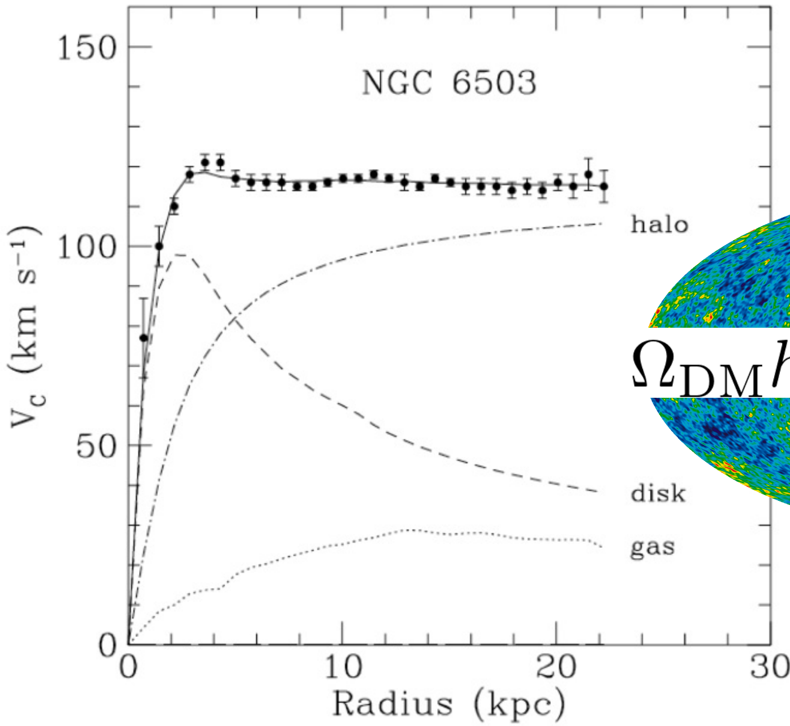
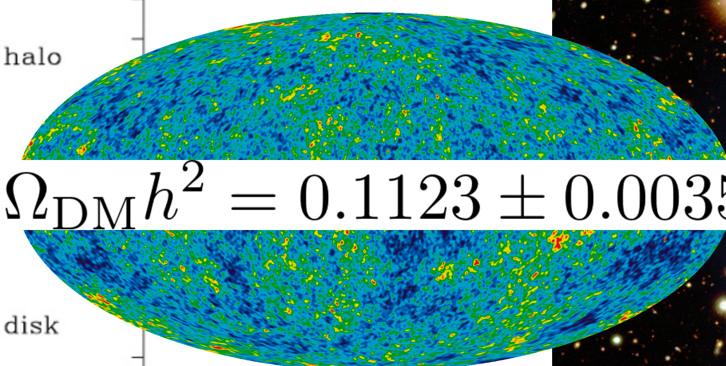
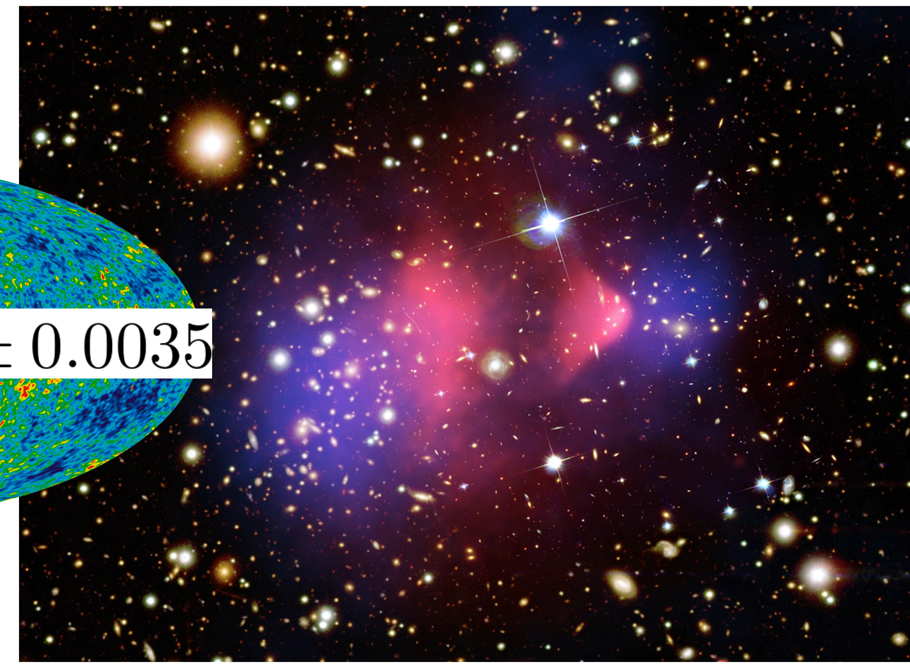
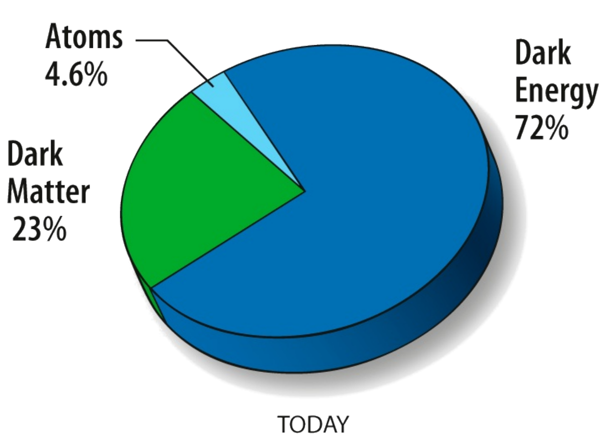
Dark matter evidences





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





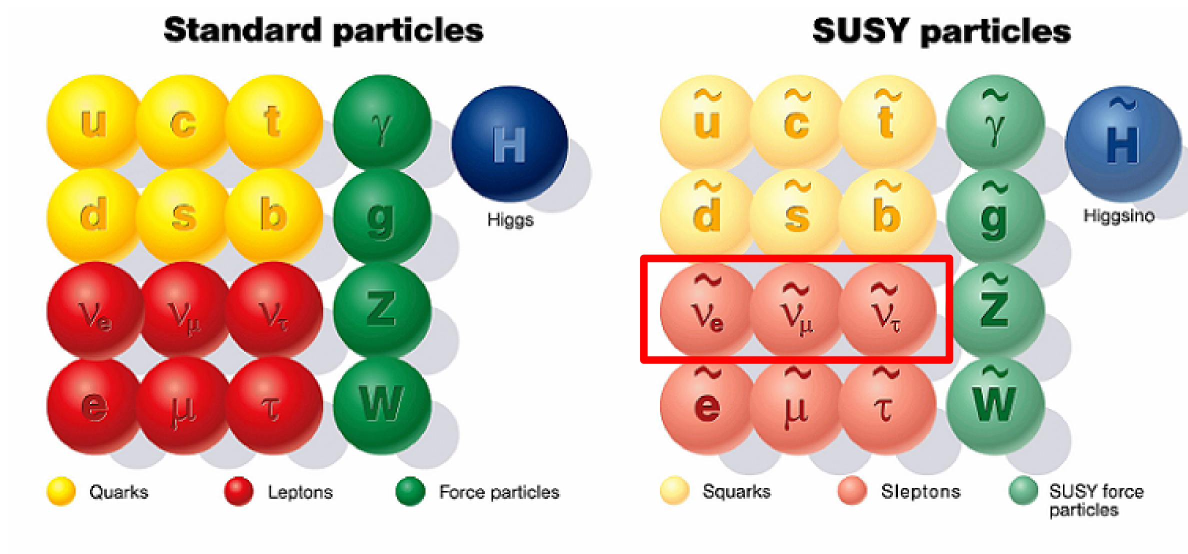
should be made of ~stable, electrically neutral and possibly weakly interacting particles

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

Supersymmetry and mixed sneutrinos

Framework: MSSM (with Dirac neutrinos)

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



Supersymmetry and mixed sneutrinos

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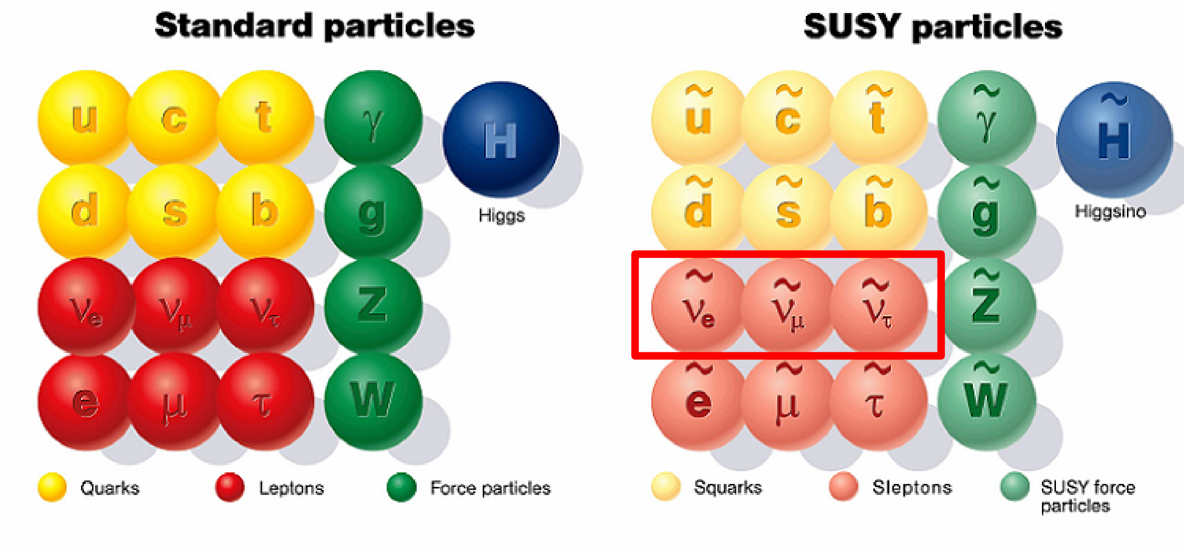


$$m^2_{\tilde{\nu}} = \begin{pmatrix} m^2_{\tilde{L}} + \frac{1}{2}m^2_Z\cos 2\beta & \frac{1}{\sqrt{2}}A_{\tilde{\nu}}\, v\sin\beta \\ \frac{1}{\sqrt{2}}A_{\tilde{\nu}}\, v\sin\beta & m^2_{\tilde{N}} \end{pmatrix}$$

with $A_{\tilde{\nu}} \sim \mathcal{O}(100\ \text{GeV})$ instead of $A_{\tilde{\nu}} \propto y_\nu \approx 0$

$\Rightarrow (\tilde{\nu}_1, \tilde{\nu}_2, \sin\theta_{\tilde{\nu}})$

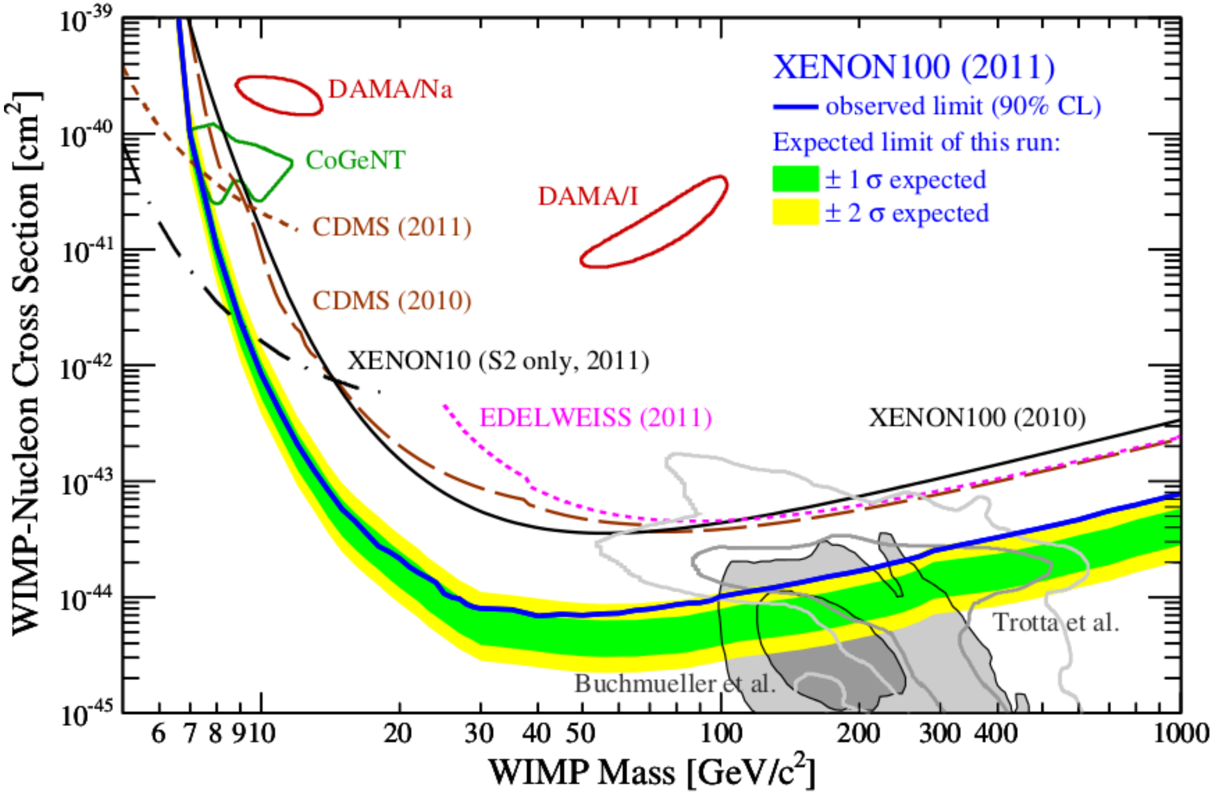
$\tilde{\nu}_1 \rightarrow$ LSP and dark matter candidate

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

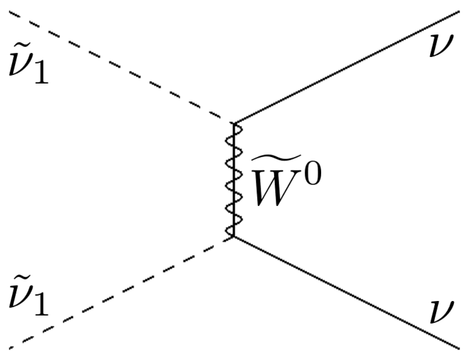
Light and heavy sneutrino dark matter

Two very different cases:

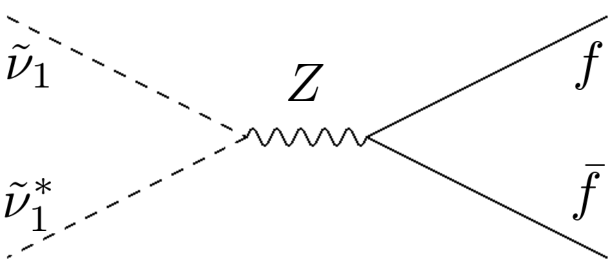
- light sneutrino ($m_{\tilde{\nu}_1} < m_Z/2$) → $\Gamma(Z \to \text{invisible})?$, $\Gamma(h^0 \to \text{invisible})?$
- heavy sneutrino ($m_{\tilde{\nu}_1} > m_Z/2$)



Main annihilation channels

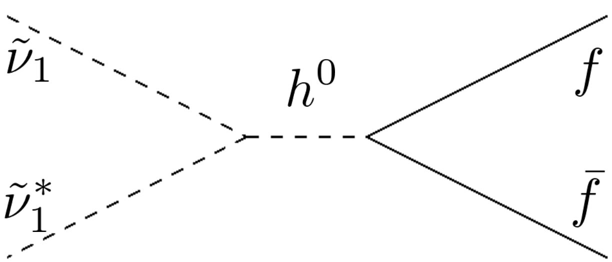


$\propto \sin^4\theta_{\tilde{\nu}}$ (also $\tilde{\nu}_1^*\tilde{\nu}_1^* \xrightarrow{\widetilde{W}^0} \nu^*\nu^*$)



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

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



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

MCMC scan

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	μ	$[-3000, 3000]$ 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 λ_i	Experimental result Λ_i	Likelihood function $L(\Lambda_i\|\lambda_i)$
1	m_u/m_d	0.553 ± 0.043	Gaussian
2	m_s/m_d	18.9 ± 0.8	Gaussian
3	$\sigma_{\pi N}$	44 ± 5 MeV	Gaussian
4	σ_s	21 ± 7 MeV	Gaussian
5	$\rho_{\rm DM}$	0.34 ± 0.09 GeV/cm^3	Gaussian
6	v_0	236 ± 8 km/s	Gaussian
7	$v_{\rm esc}$	550 ± 35 km/s	Gaussian
8	m_t	173.3 ± 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 ± 0.0007	Gaussian

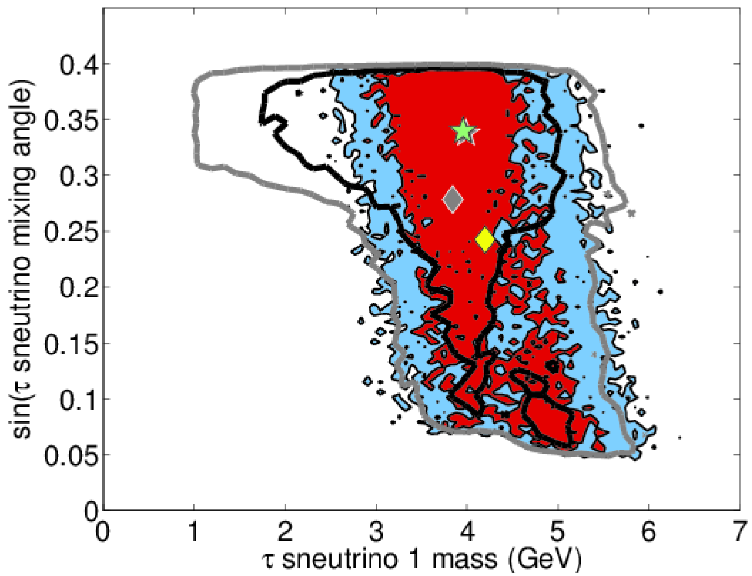
Astrophysical parameters from [arXiv:1005.0579].
Recent lattice QCD values for σ_s and $\sigma_{\pi N}$ from [arXiv:1202.6407].

MCMC scan

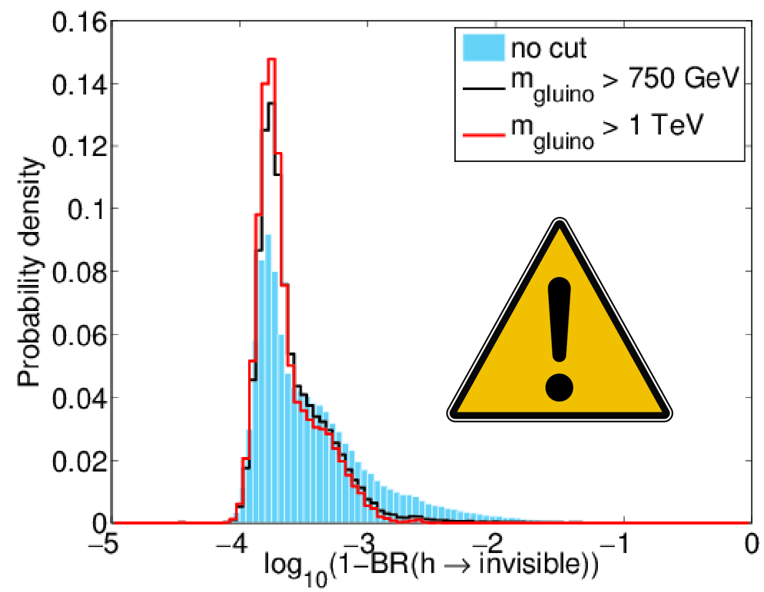
i	Observable μ_i	Experimental result D_i	Likelihood function $L(D_i\|\mu_i)$
1	$\Delta\Gamma_Z$	< 2 MeV (95% C.L.)	$\mathbf{F}(\mu_1, 2\text{ MeV})$
2	$\Omega_{\rm DM}h^2$	0.1123 ± 0.0118	Gaussian
3	Δa_μ	$(26.1 \pm 12.8) \times 10^{-10}$	Gaussian
4	$m_{\tilde{g}}$	> 750, 1000 GeV or none	not included (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	$\sigma_{\rm SI}$	$(m_{\rm DM}, \sigma_{\rm SI})$ constrained by XENON10, XENON100, CDMS and CoGeNT	$L_9 = e^{-\chi^2_{\rm DD}/2}$
10	$\mathcal{B}(b \to s\gamma)$	$(3.55 \pm 0.34) \times 10^{-4}$	Gaussian
11	$\mathcal{B}(B_s \to \mu^+\mu^-)$	$< 1.26 \times 10^{-8}$ (95% C.L.)	$\mathbf{F}(\mu_{11}, 1.26 \times 10^{-8})$

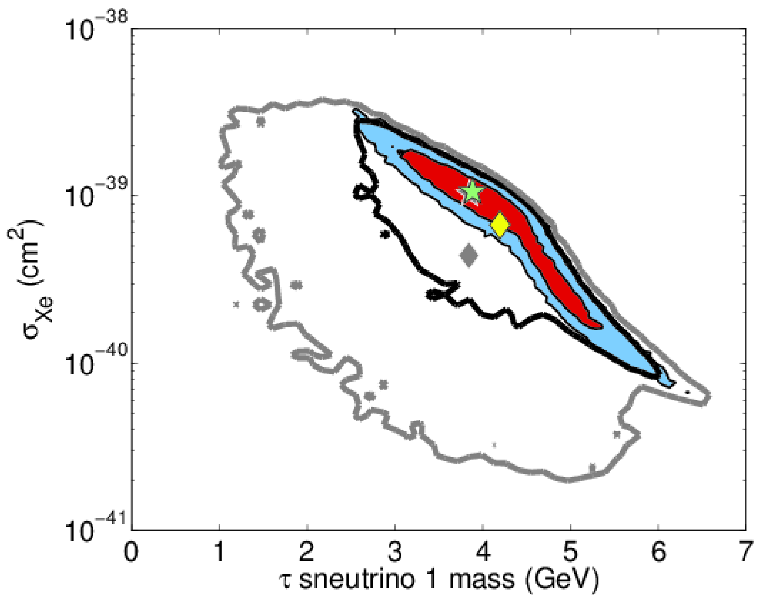
- We use `micrOMEGAs`, `SuSpect`, `HDECAY` and `HiggsBounds`
- We consider a posteriori the latest LHCb result: $\mathcal{B}(B_s \to \mu^+\mu^-) < 0.45 \times 10^{-8}$
- **F**: smoothed step function (emulates the 95% C.L. limits)

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



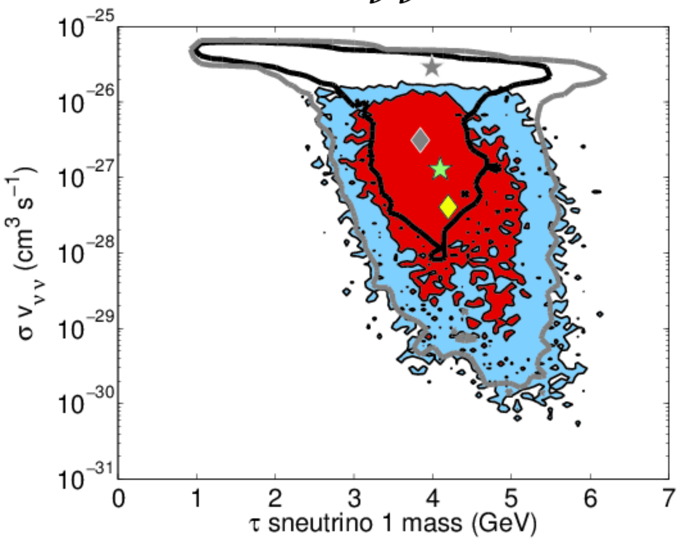


- the remaining points are very close to the direct detection limit

- 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)

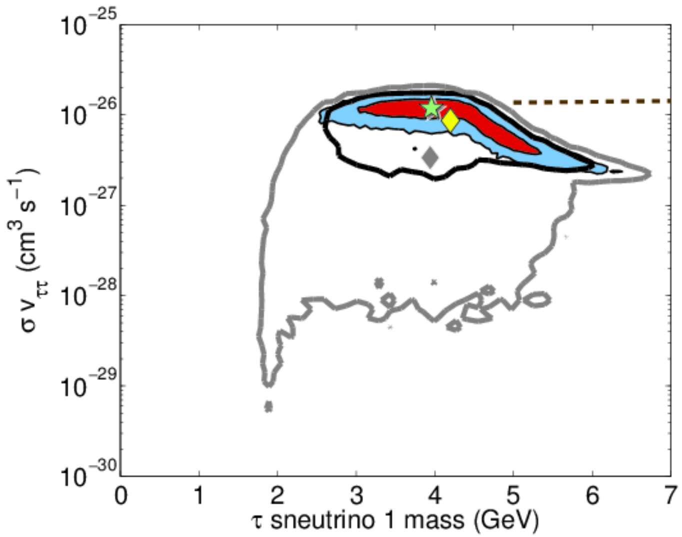
Light sneutrino results
indirect detction – Fermi-LAT limits on γ-rays

$\sigma v_{\nu\nu^*}$



suppression of the wino mediated annihilation

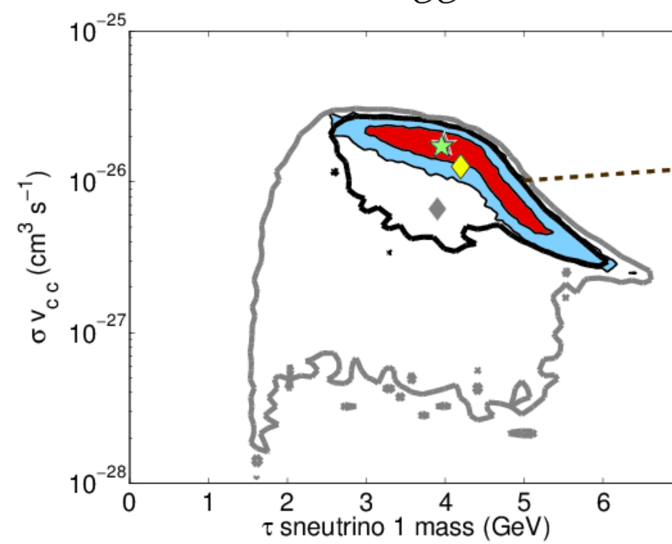
$\sigma v_{\tau^+\tau^-}$



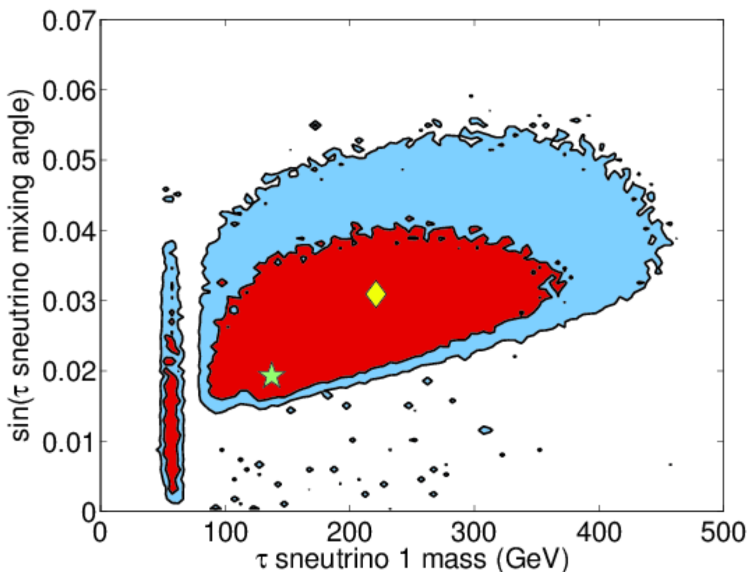
- latest Fermi limits: [1108.3546]
- our analysis could be refined
- Fermi results below 5 GeV are welcome!

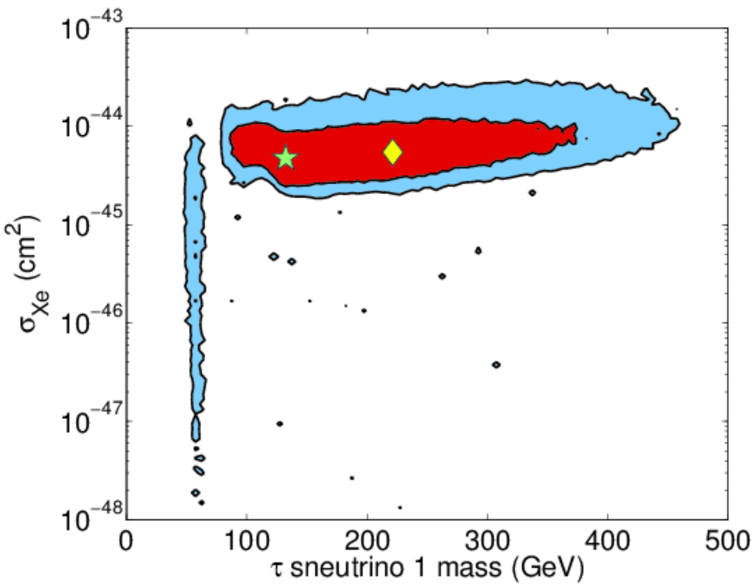
Fermi limit on $c\bar{c}$ does not exist – we show the $b\bar{b}$ one

$\sigma v_{c\bar{c}}$

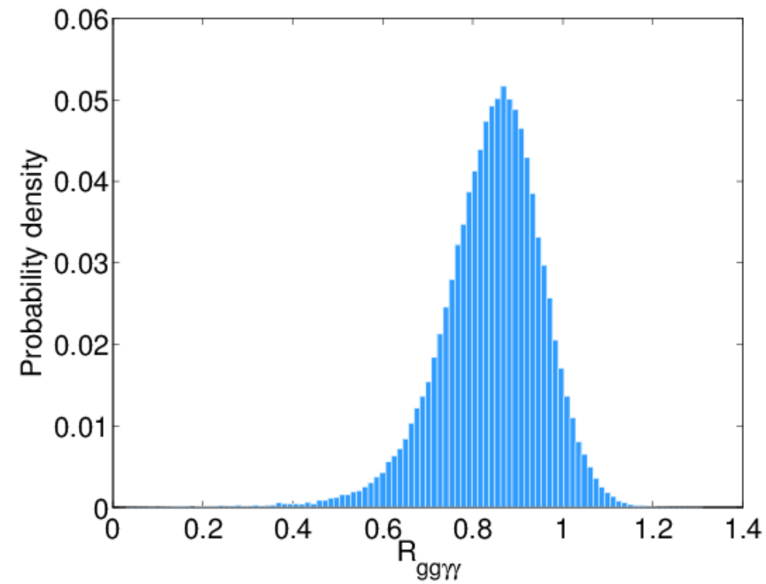


Heavy sneutrino results



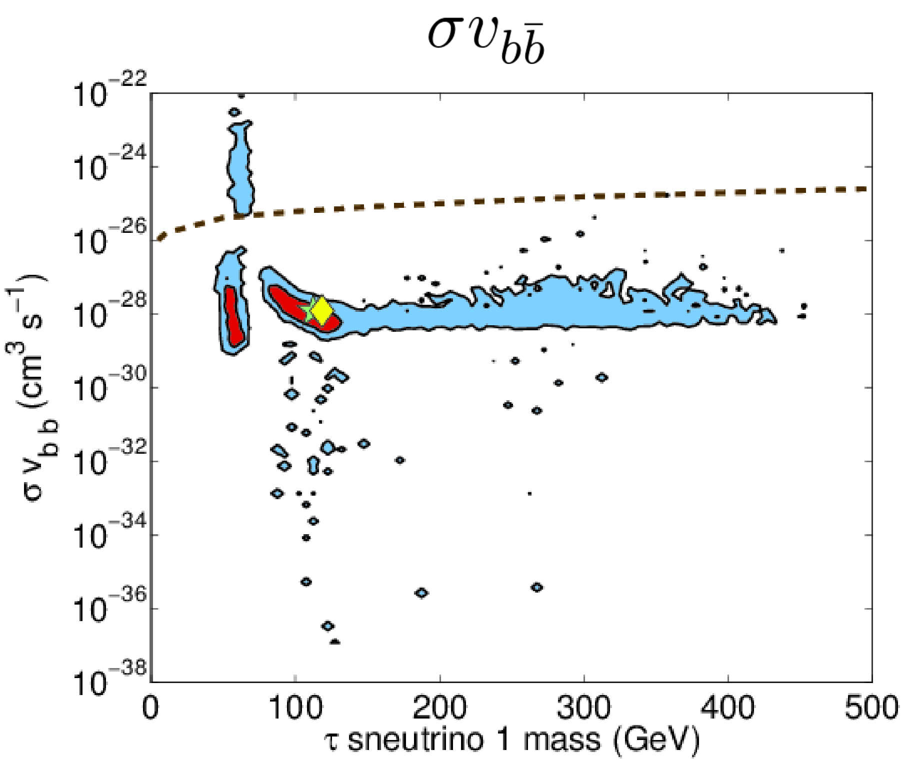


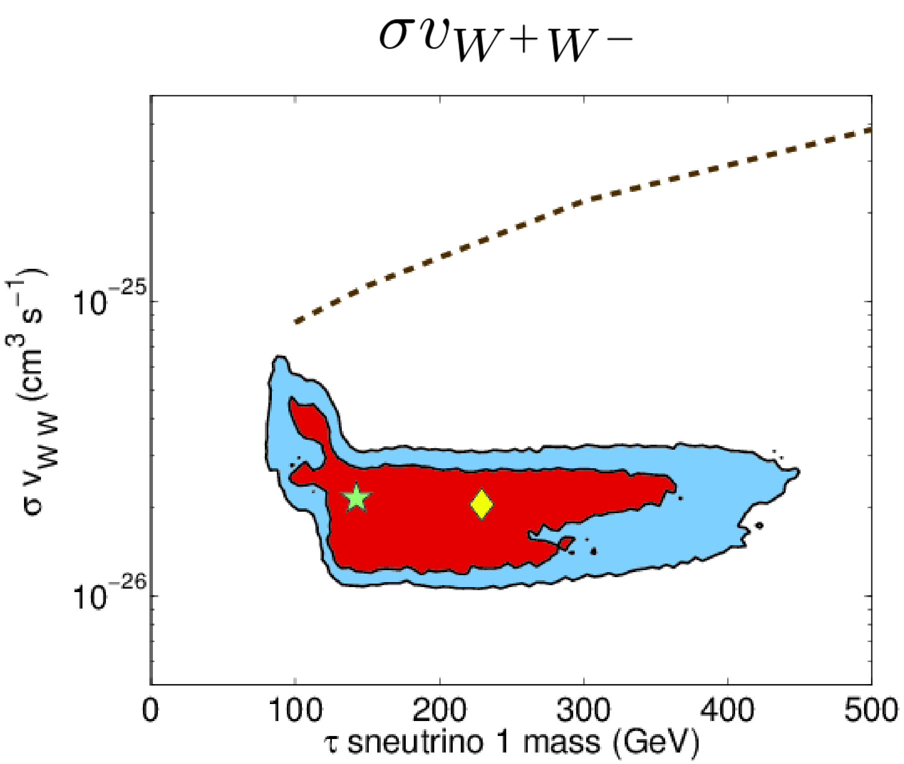
- we need a very low mixing angle to pass the XENON100 limit
- we have gluino mass > 1 TeV: current LHC bounds do not apply
- Higgs resonance for sneutrinos around 60 GeV
- the main region could soon be excluded by direct detection



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

Heavy sneutrino results indirect detction – Fermi-LAT limits on γ-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
$\mathcal{B}(\tilde{\chi}_1^0 \longrightarrow \tilde{\nu}_1 \nu) > 0.9$	95%	100%
$\mathcal{B}(\tilde{\chi}_2^0 \longrightarrow \tilde{\nu}_1 \nu) > 0.9$	78%	46%
$\mathcal{B}(\tilde{\chi}_1^\pm \longrightarrow \tilde{\nu}_{1e} e^\pm)$ $+\mathcal{B}(\tilde{\chi}_1^\pm \longrightarrow \tilde{\nu}_{1\mu} \mu^\pm) > 0.5$	8%	51%
$\mathcal{B}(\tilde{\chi}_1^\pm \longrightarrow \tilde{\nu}_{1\tau} \tau^\pm) > 0.5$	74%	7%

- 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

References

- Light mixed sneutrinos as thermal dark matter
  G. Belanger, M. Kakizaki, E.K. Park, S. Kraml, A. Pukhov
  JCAP 1011 (2010) 017
  arXiv:1008.0580
- Light Sneutrino Dark Matter at the LHC
  Genevieve Belanger, Sabine Kraml, Andre Lessa
  JHEP 1107 (2011) 083
  arXiv:1105.4878
- Small neutrino masses from supersymmetry breaking
  Nima Arkani-Hamed, Lawrence J. Hall, Hitoshi Murayama, David Tucker-Smith, Neal Weiner
  Phys.Rev. D64 (2001) 115011
  hep-ph/0006312
- Low scale seesaw mechanisms for light neutrinos
  Francesca Borzumati, Yasunori Nomura
  Phys.Rev. D64 (2001) 053005
  hep-ph/0007018

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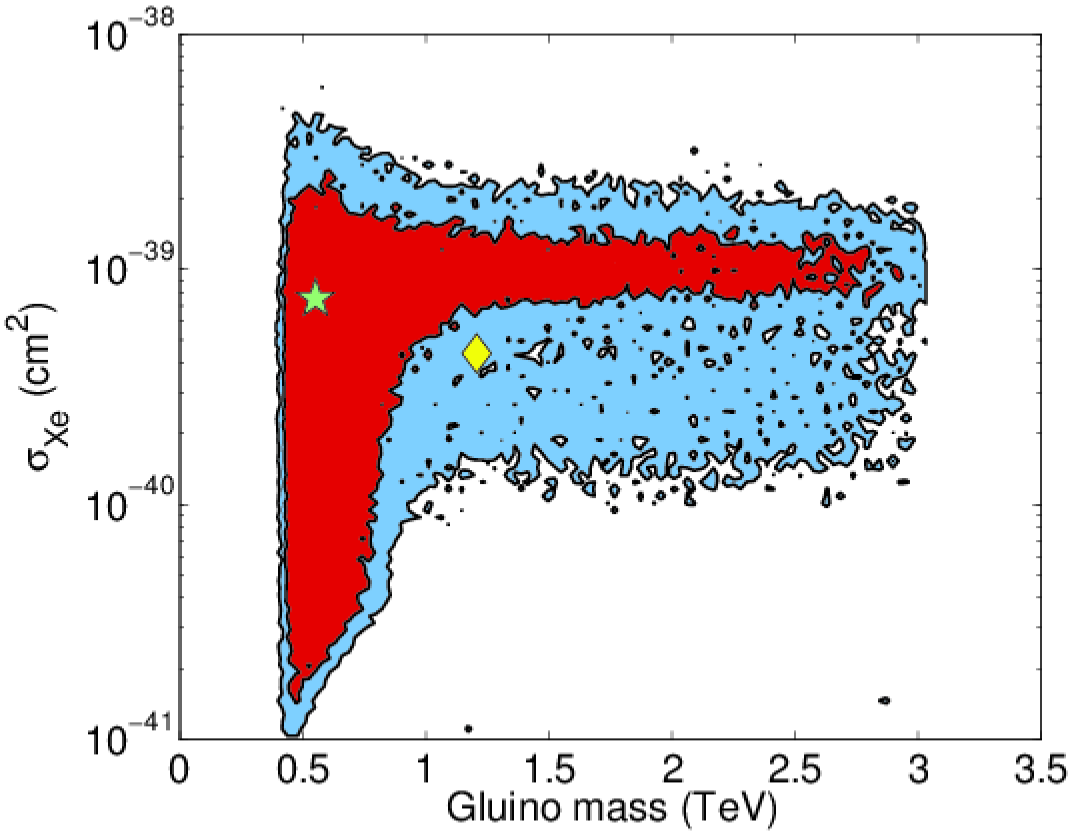

10^{-38}
10^{-39}
10^{-40}
10^{-41}
σ_{Xe} (cm^2)
0
0.5
1
1.5
2
2.5
3
3.5
Gluino mass (TeV)