Direct and indirect detection of sneutrino dark matter

Chiara Arina

SUSY 2015
August 23 - 29
Lake Tahoe, California

- CA, M.E. Cabrera, S. Kraml, S. Kulkarni and U. Laa, JHEP 1505 (2015)
- CA, S. Kulkarni and J. Silk, arXiv: 1506.08202 [astro-ph.HE]

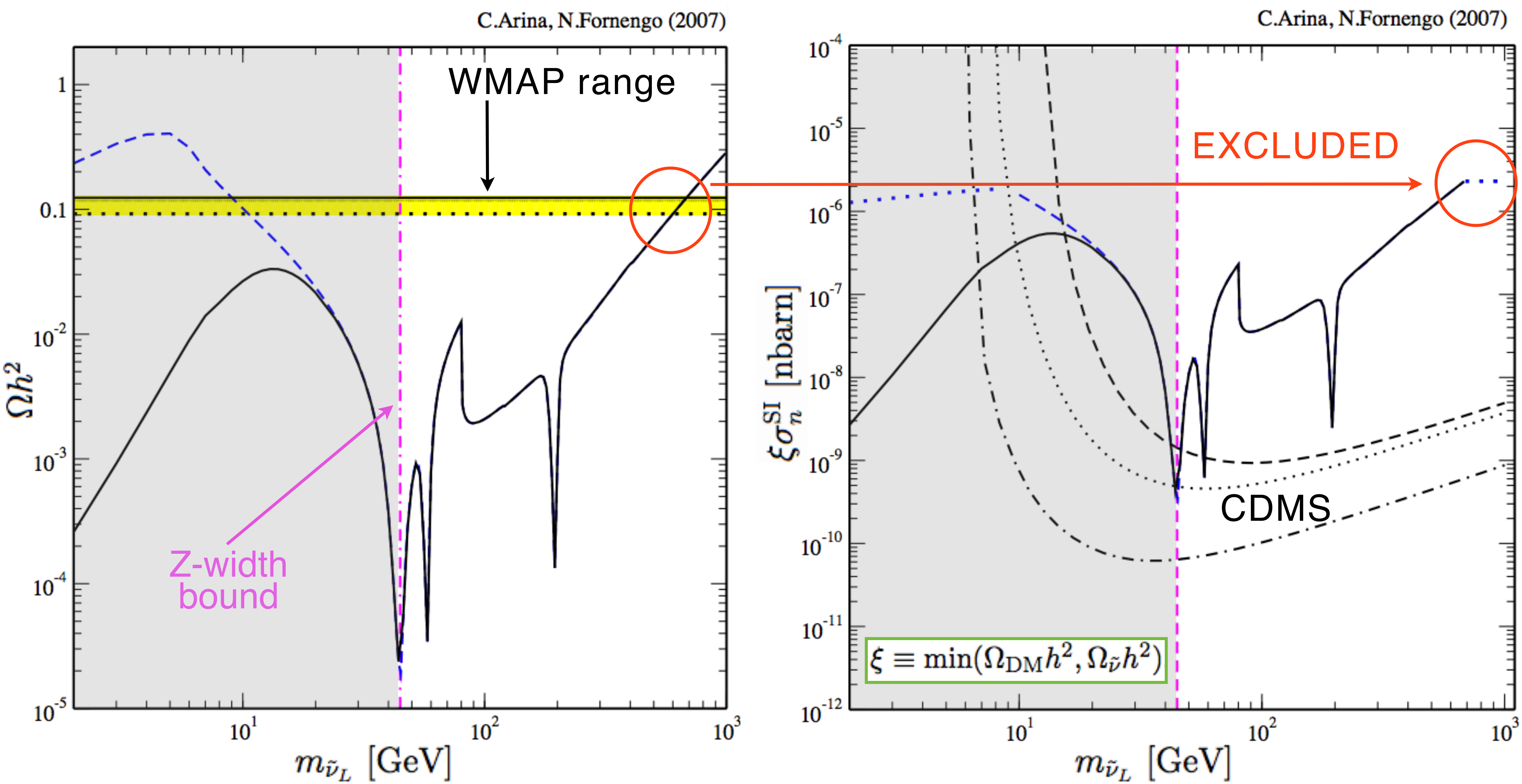
Credit: The Marenostrum Numerical Cosmology Project

Outline

- Why sneutrino as Dark Matter (DM) candidate?
- Model parameter space compatible with DM constraints
- Indirect detection of sneutrino DM: neutrino line feature
    - Estimate in a simplified model
    - Results for the MSSM+RN sample
- Conclusions

Sneutrino can not be DM in the MSSM

Sneutrino is the superpartner of the left-handed (LH) neutrino: is a $SU(2)_L$ doublet
(Y=1 ⟶ couples to the Z boson)



MSSM + Right-handed Neutrinos (MSSM+RN)

Inclusion of neutrino mass terms modify scalar sector as well:

$$W = \epsilon_{ij}(\mu \hat{H}_i^u \hat{H}_j^d - Y_l \hat{H}_i^d \hat{L}_j \hat{R} + Y_\nu \hat{H}_i^u \hat{L}_j \hat{N})$$

$$V_{\rm soft} = M_L^2 \, \tilde{L}_i^* \tilde{L}_i + M_N^2 \, \tilde{N}^* \tilde{N} - [\epsilon_{ij}(\Lambda_l H_i^d \tilde{L}_j \tilde{R} + \Lambda_\nu H_i^u \tilde{L}_j \tilde{N}) + {\rm h.c.}]$$

Dirac masses for neutrinos: $m_D = v_u Y_\nu$

Sneutrino left and right components mix:

$$\begin{cases} \tilde{\nu}_{\tau_1} = -\sin\theta_{\tilde{\nu}} \; \tilde{\nu}_L + \cos\theta_{\tilde{\nu}} \; \tilde{N} \\ \tilde{\nu}_{\tau_2} = +\cos\theta_{\tilde{\nu}} \; \tilde{\nu}_L + \sin\theta_{\tilde{\nu}} \; \tilde{N} \end{cases}$$

$$\mathcal{M}_{LR}^2 = \begin{pmatrix} m_L^2 + \frac{1}{2} m_Z^2 \cos(2\beta) + m_D^2 & \frac{v}{\sqrt{2}} A_{\tilde{\nu}} \sin\beta - \mu m_D {\rm cotg}\beta \\ \frac{v}{\sqrt{2}} A_{\tilde{\nu}} \sin\beta - \mu m_D {\rm cotg}\beta & m_N^2 + m_D^2 \end{pmatrix}$$

Sneutrino LSP models address two issues at once: DM and neutrino masses

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LSP

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MSSM+RN model parameters

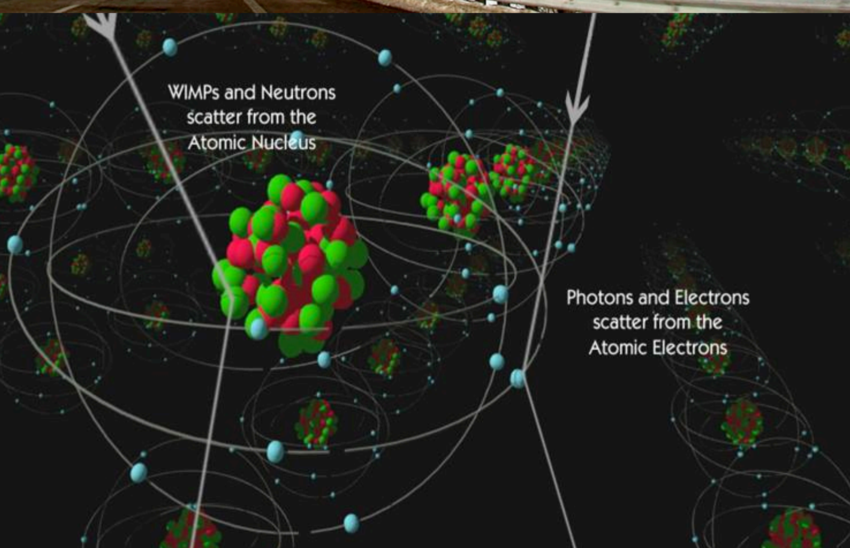
$$M_1, M_2, M_3, m_L, m_R, m_N, m_Q, m_H, A_l, A_{\tilde{\nu}}, A_q, \tan\beta, \text{sgn}\mu$$

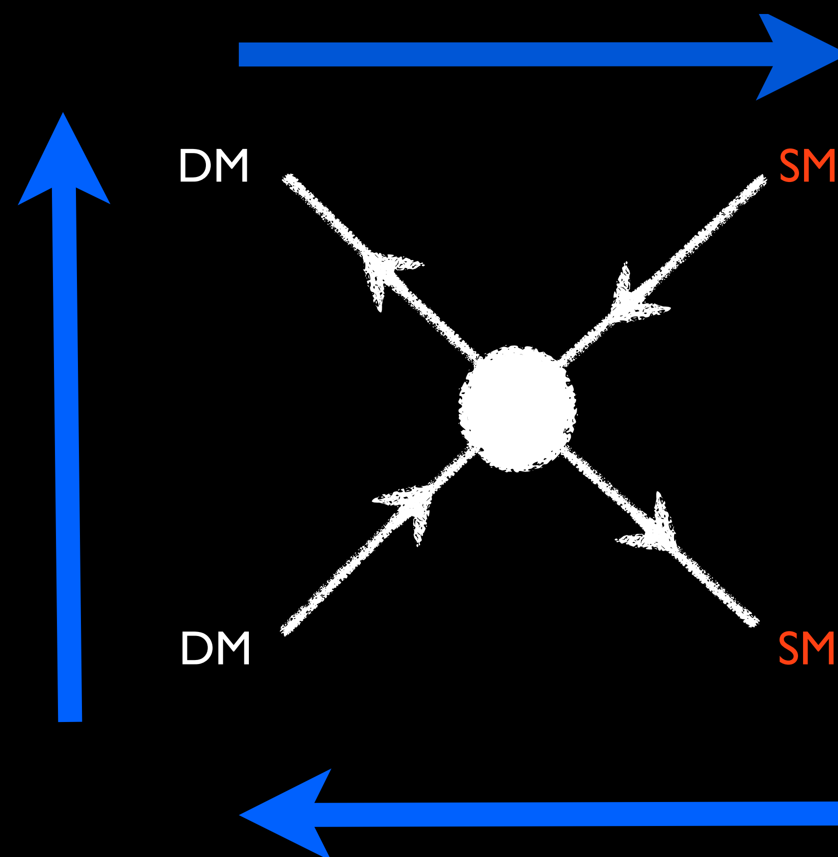
Nested sampling (several chains) with both log and flat priors on the free parameters

	Observable	Value/Constraint
Measurements (Gaussian likelihood function)	m_h	125.85 ± 0.4 GeV (exp) ± 4 GeV (theo)
	$\text{BR}(B \to X_s\gamma) \times 10^4$	$3.55 \pm 0.24 \pm 0.09$ (exp)
	$\text{BR}(B_s \to \mu^+\mu^-) \times 10^9$	$3.2^{+1.4}_{-1.2}$ (stat) $^{+0.5}_{-0.3}$ (sys)
Limits (Step likelihood function)	$\Delta\Gamma_Z^{\text{invisible}}$	< 2 MeV (95% CL)
	$\text{BR}(h \to \text{invisible})$	$< 20\%$ (95% CL)
	$m_{\tilde{\tau}_1^-}$	> 85 GeV (95% CL)
	$m_{\tilde{\chi}_1^+}, m_{\tilde{e},\tilde{\mu}}$	> 101 GeV (95% CL)
	$m_{\tilde{g}}$	> 308 GeV (95% CL)

+ DM constraints

DM constraints for sneutrino in MSSM+RN





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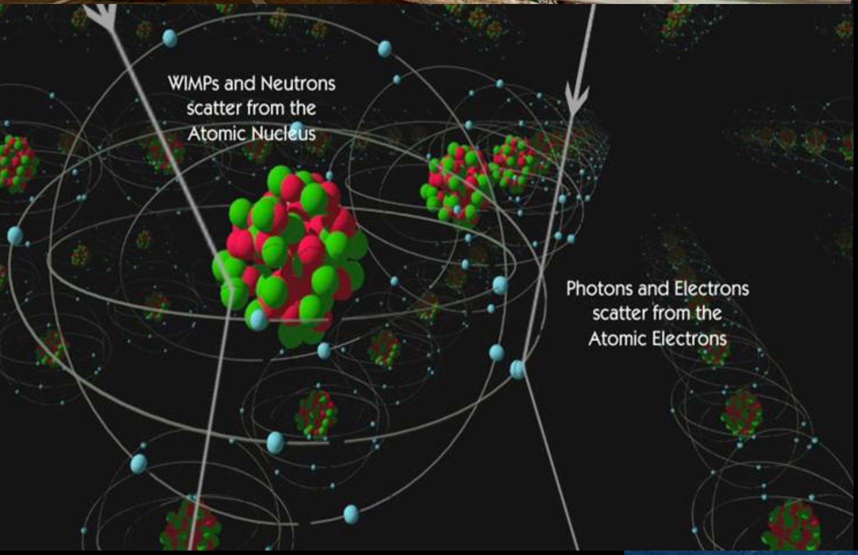
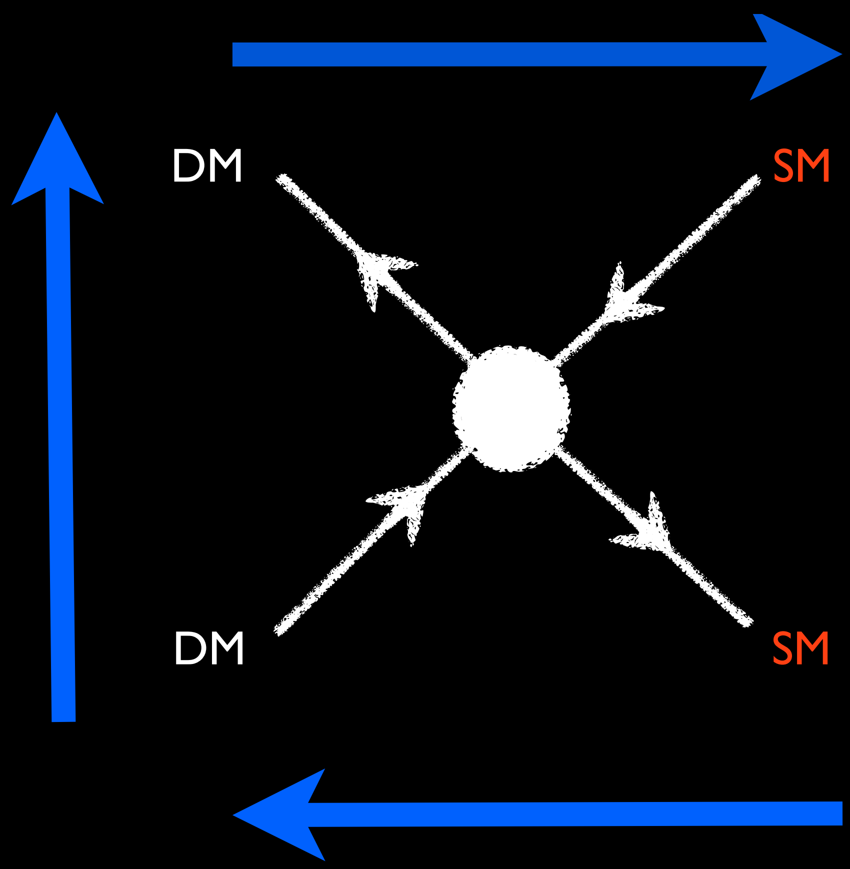
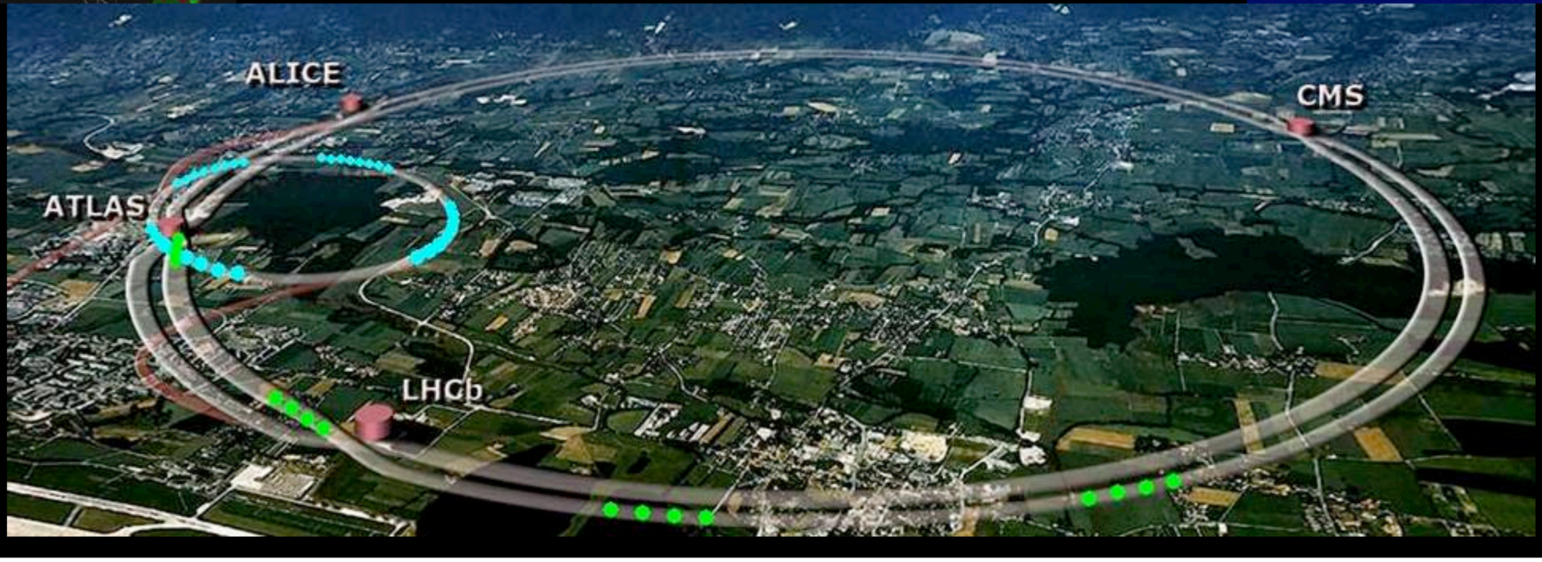


Freeze-out early Universe





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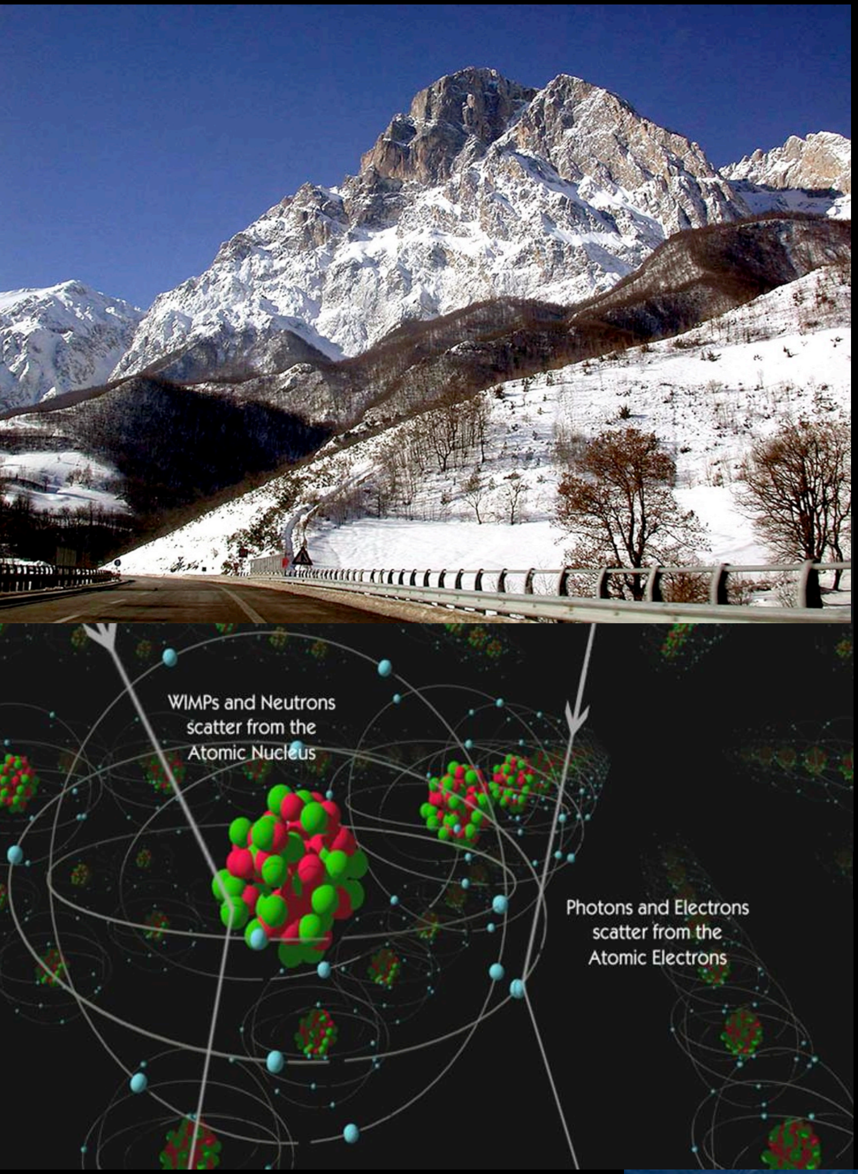

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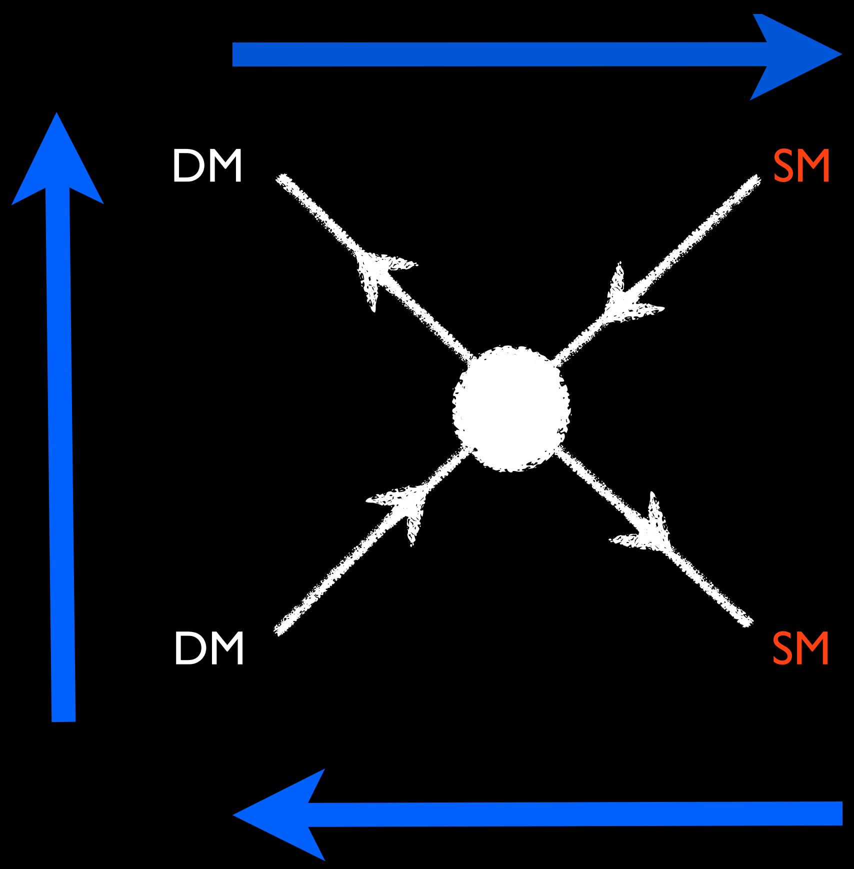

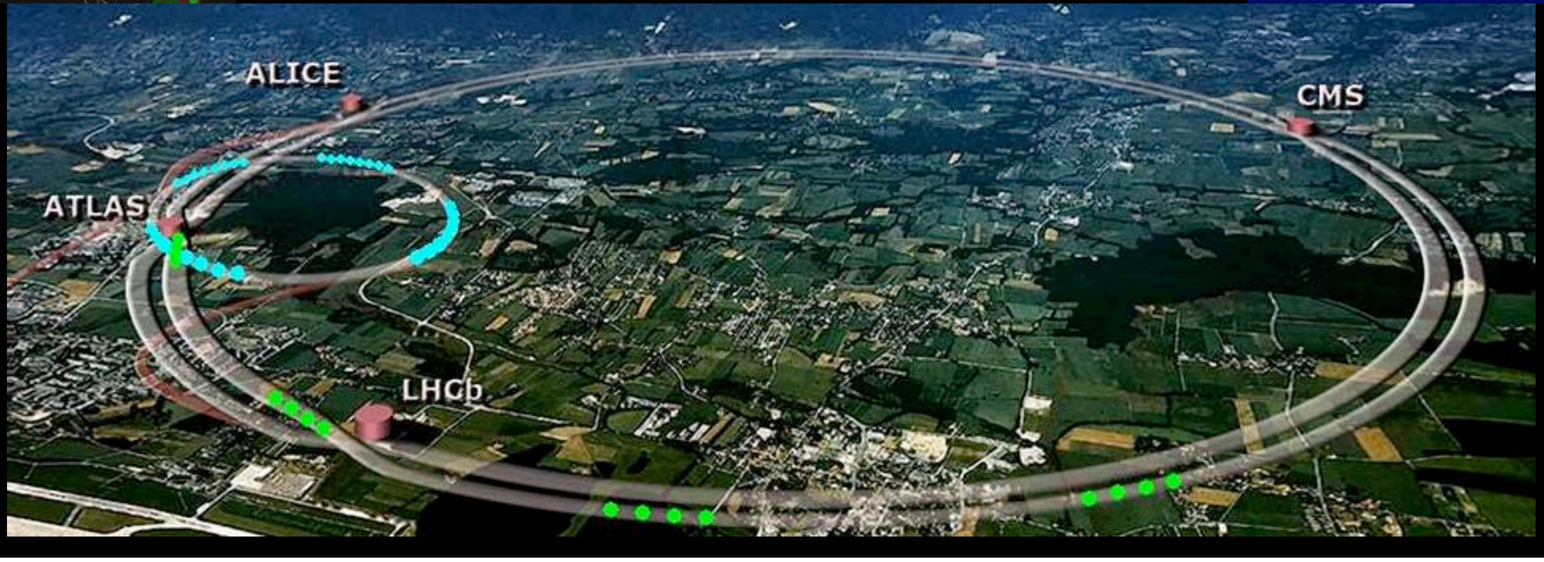

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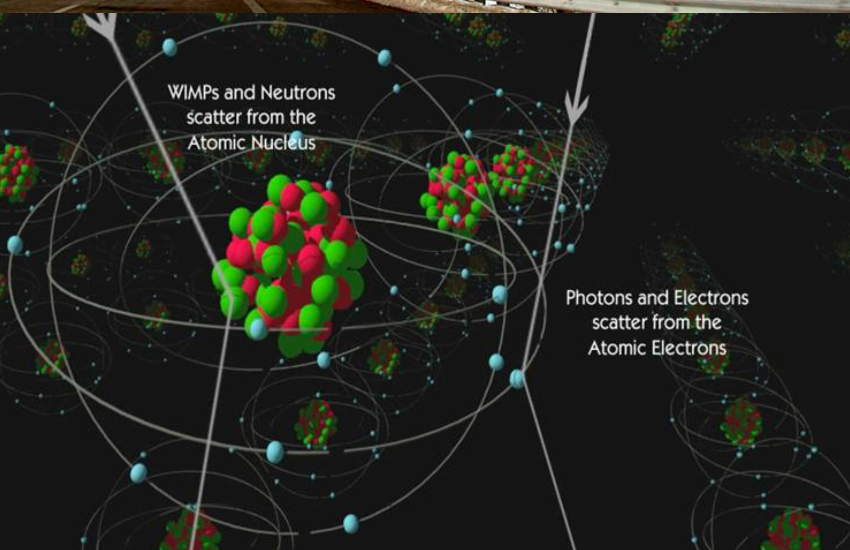

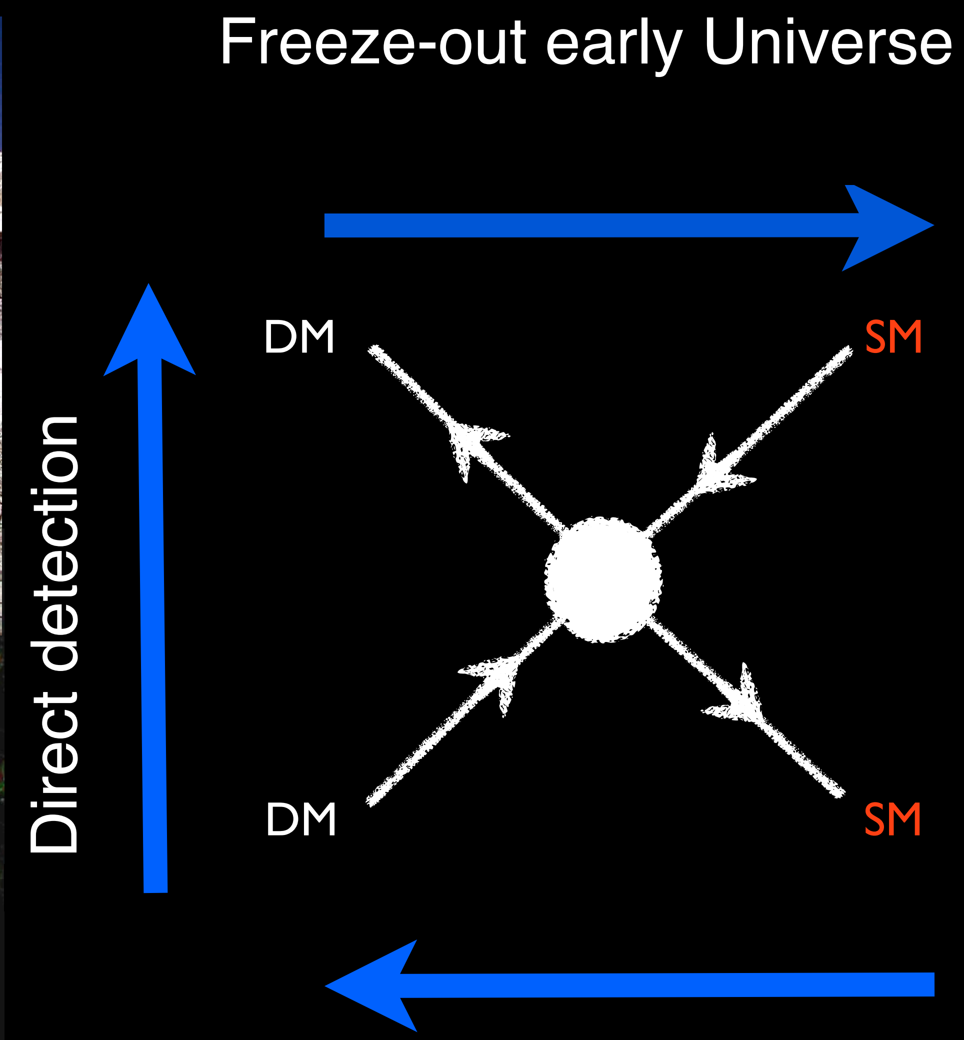

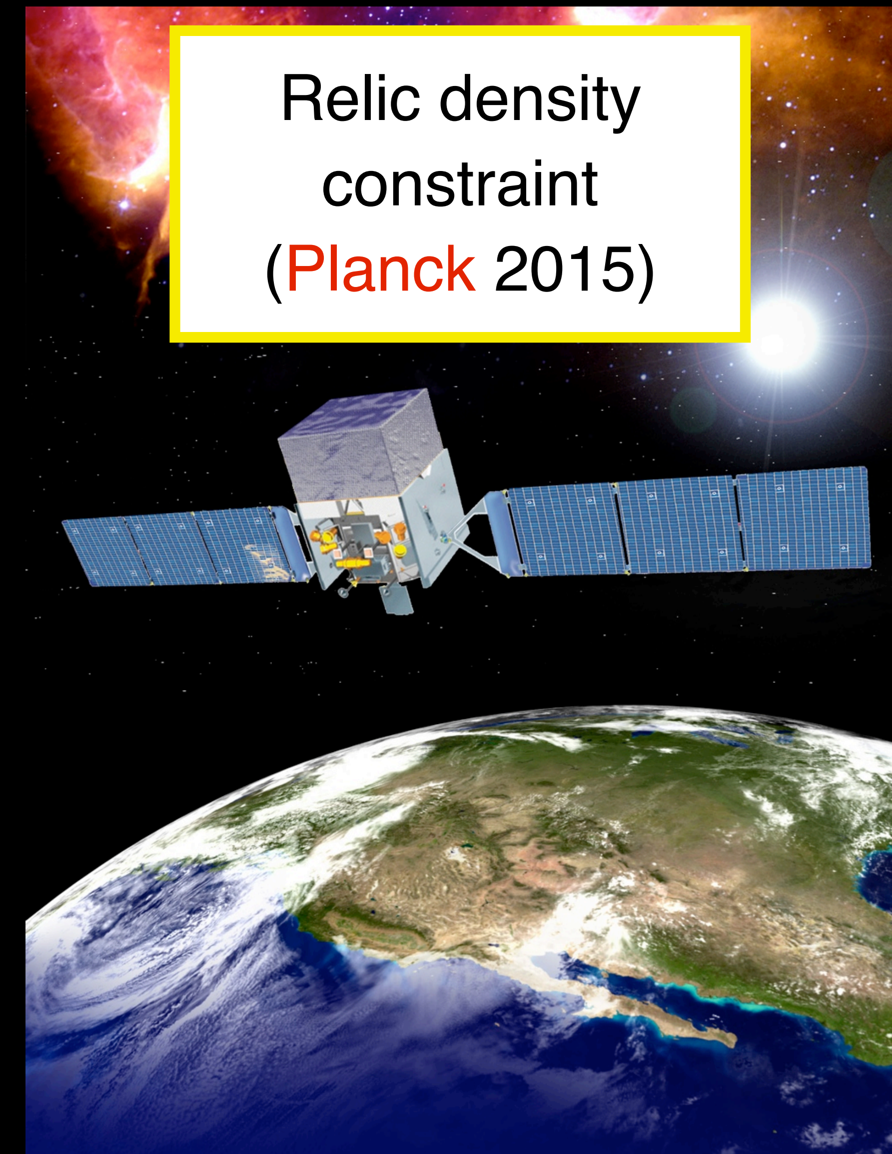

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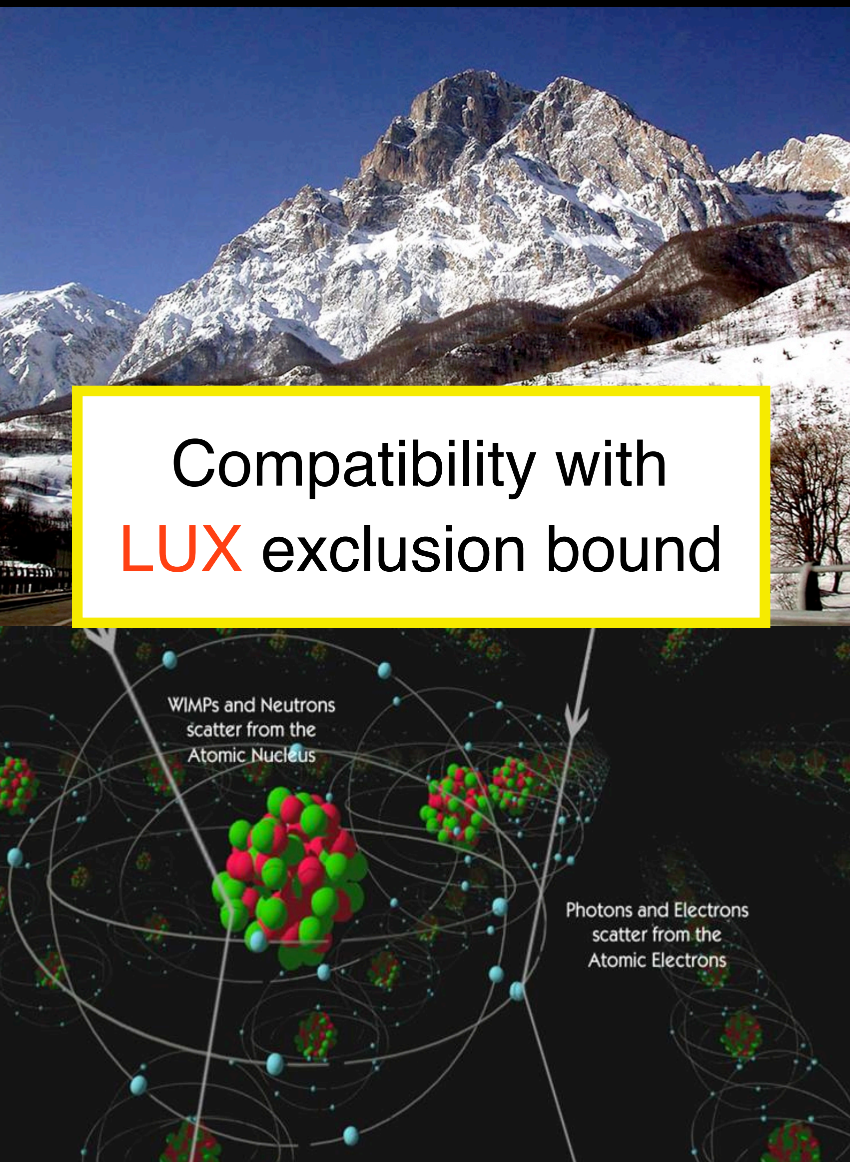

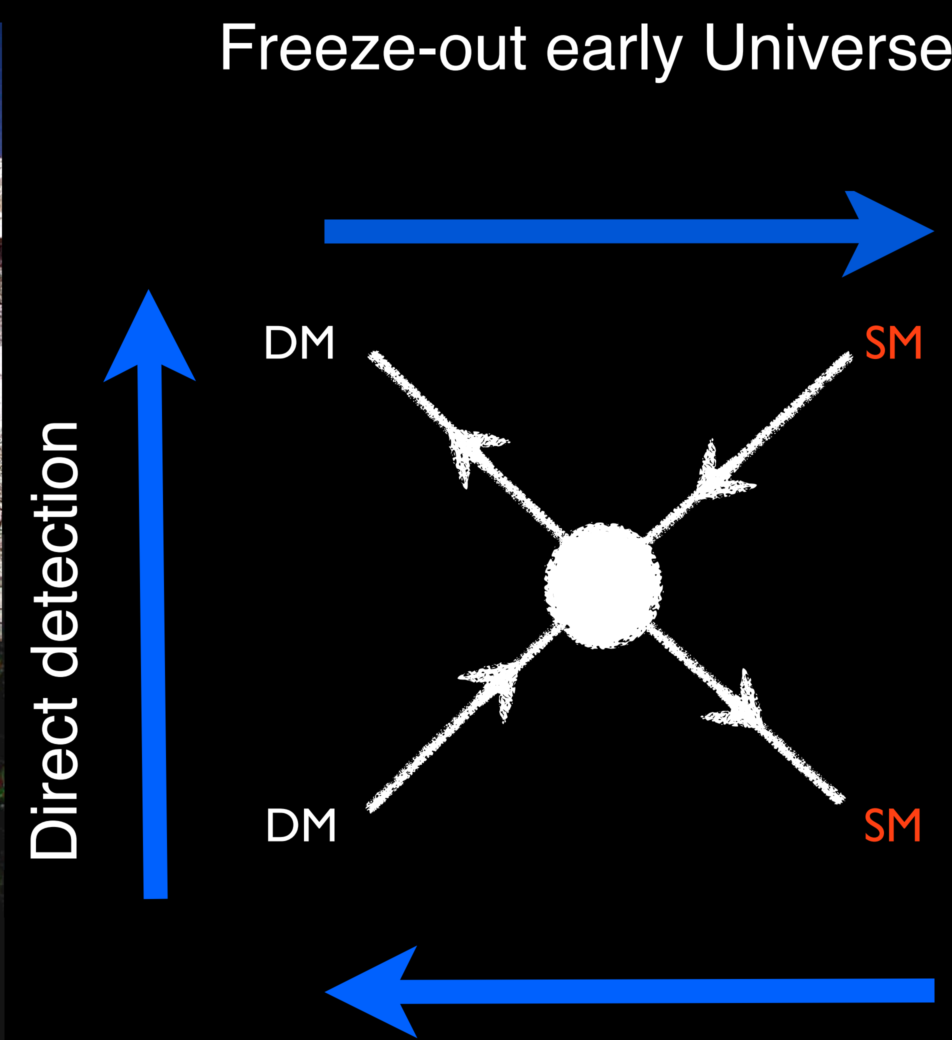

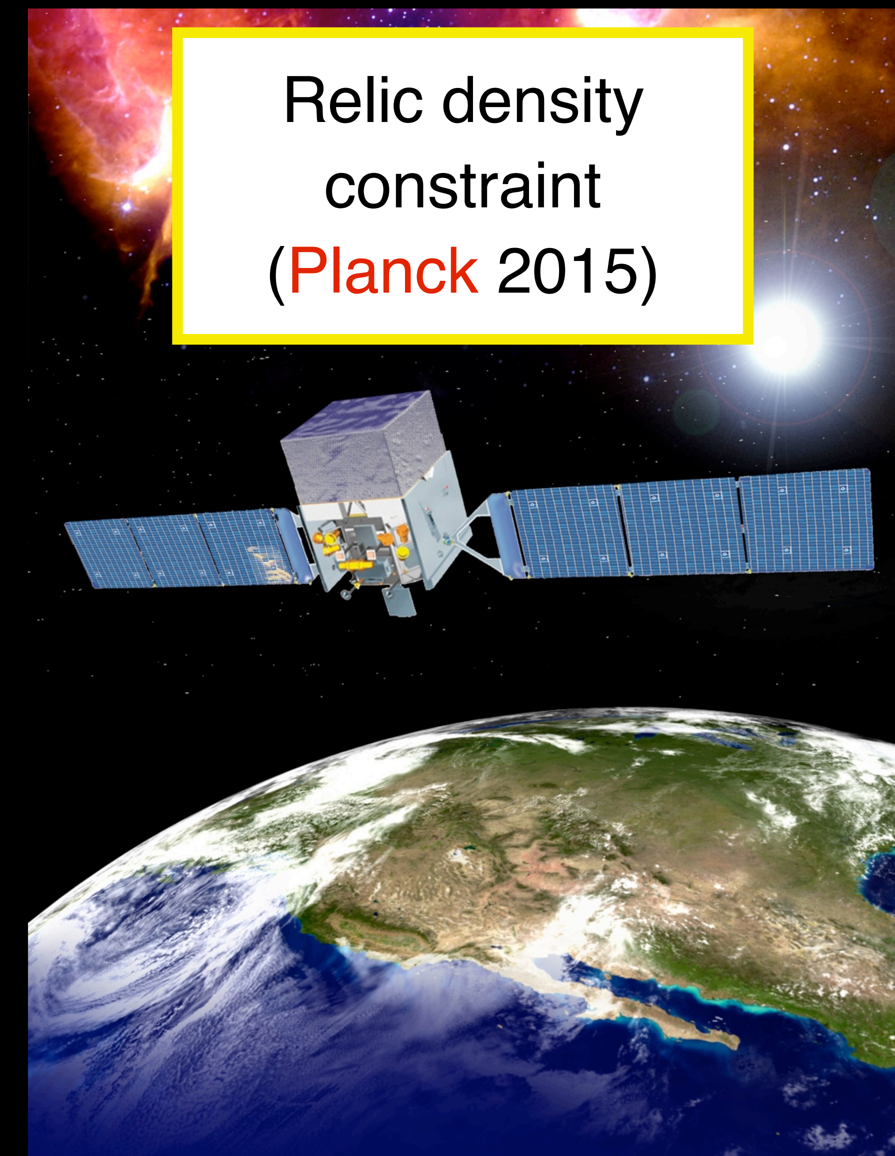

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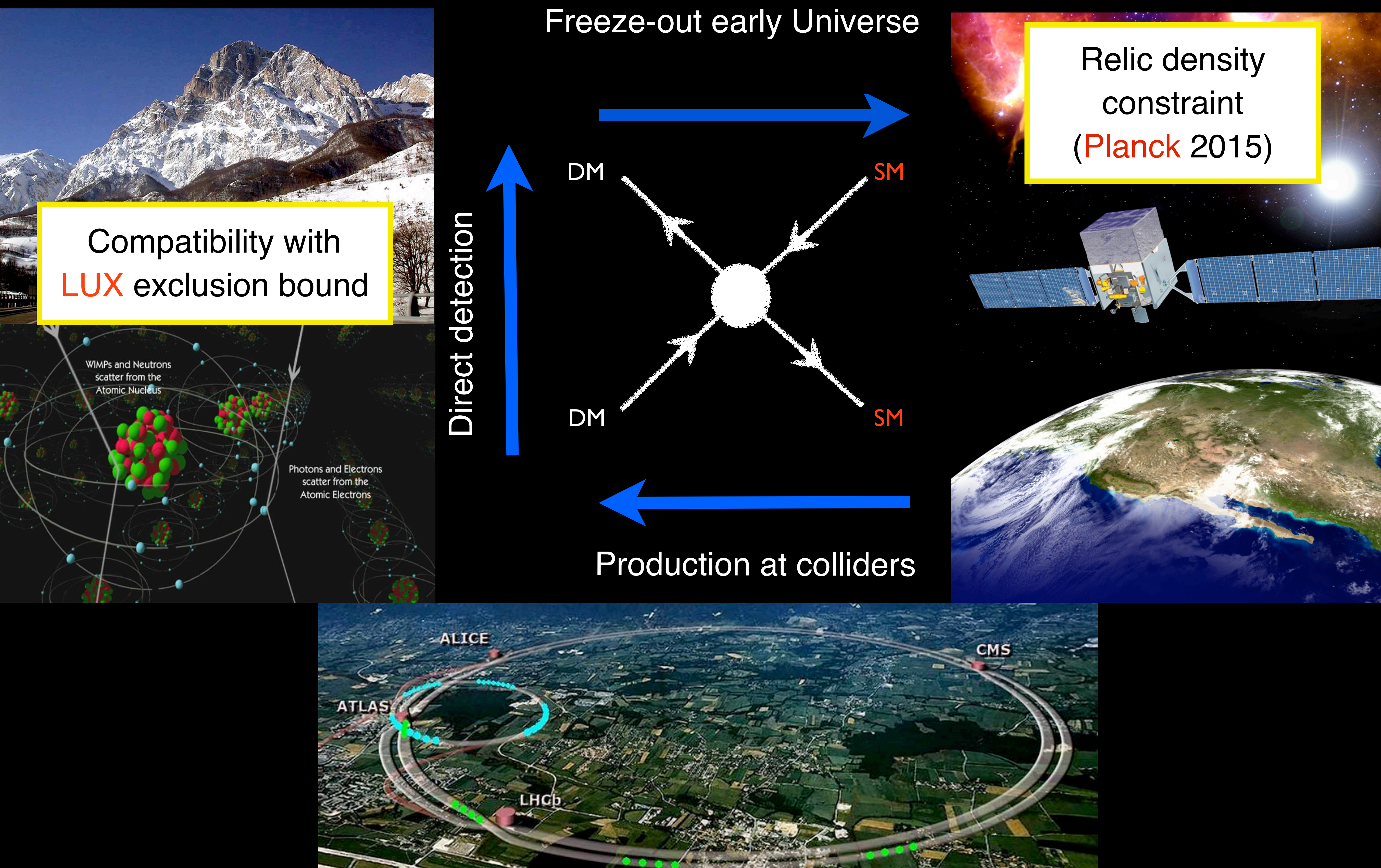

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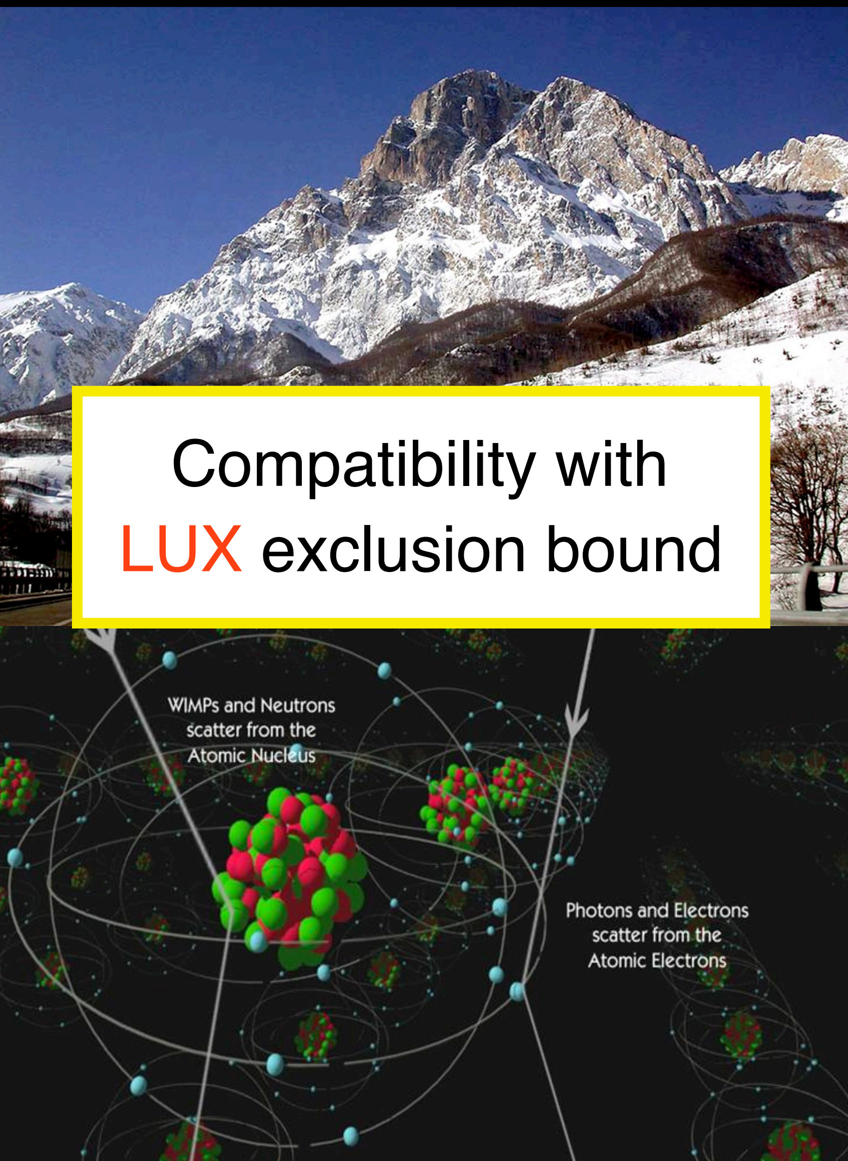
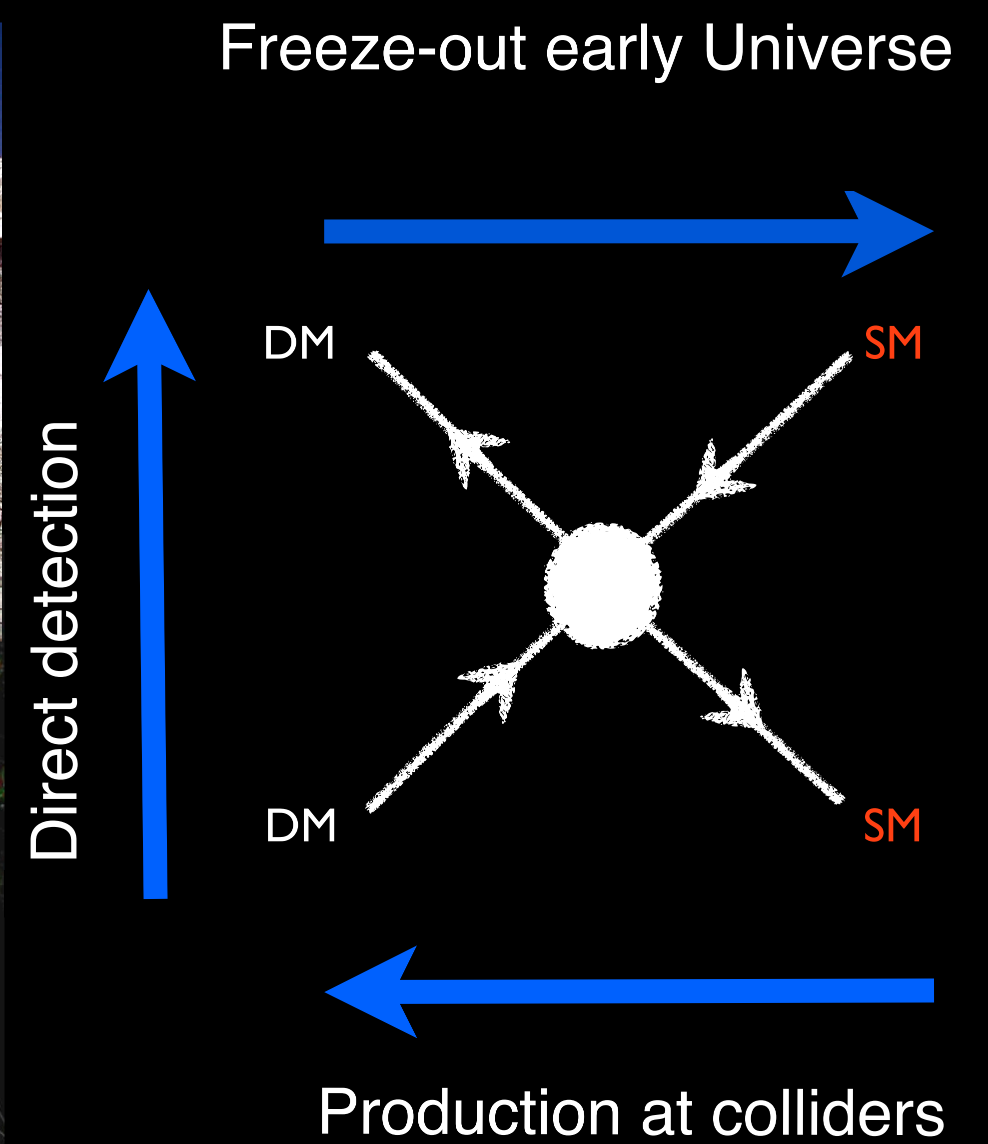
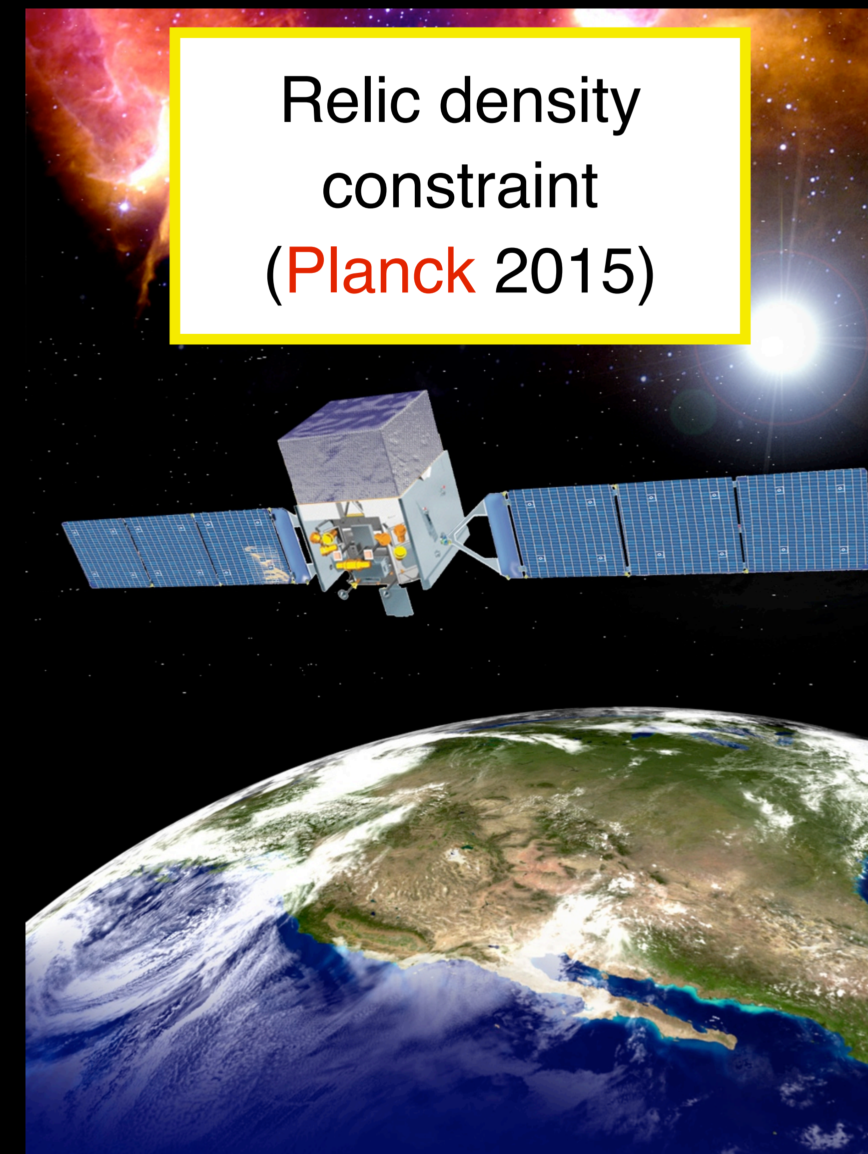
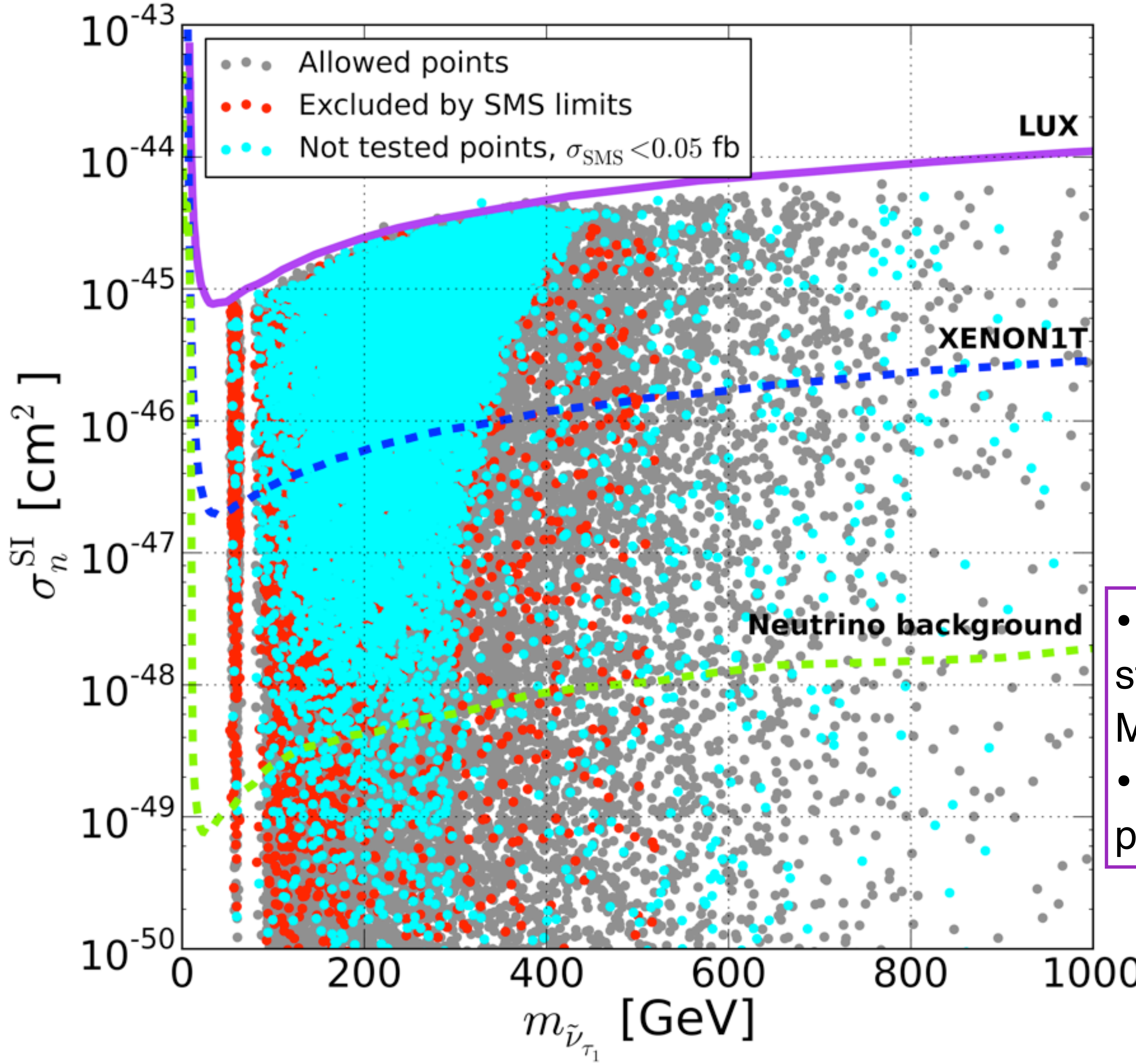






MSSM+RN: viable DM parameter space



- LUX exclusion bound: strongest constraint for the MSSM+RN
- It dictates how much LH part can survive (Z coupling)

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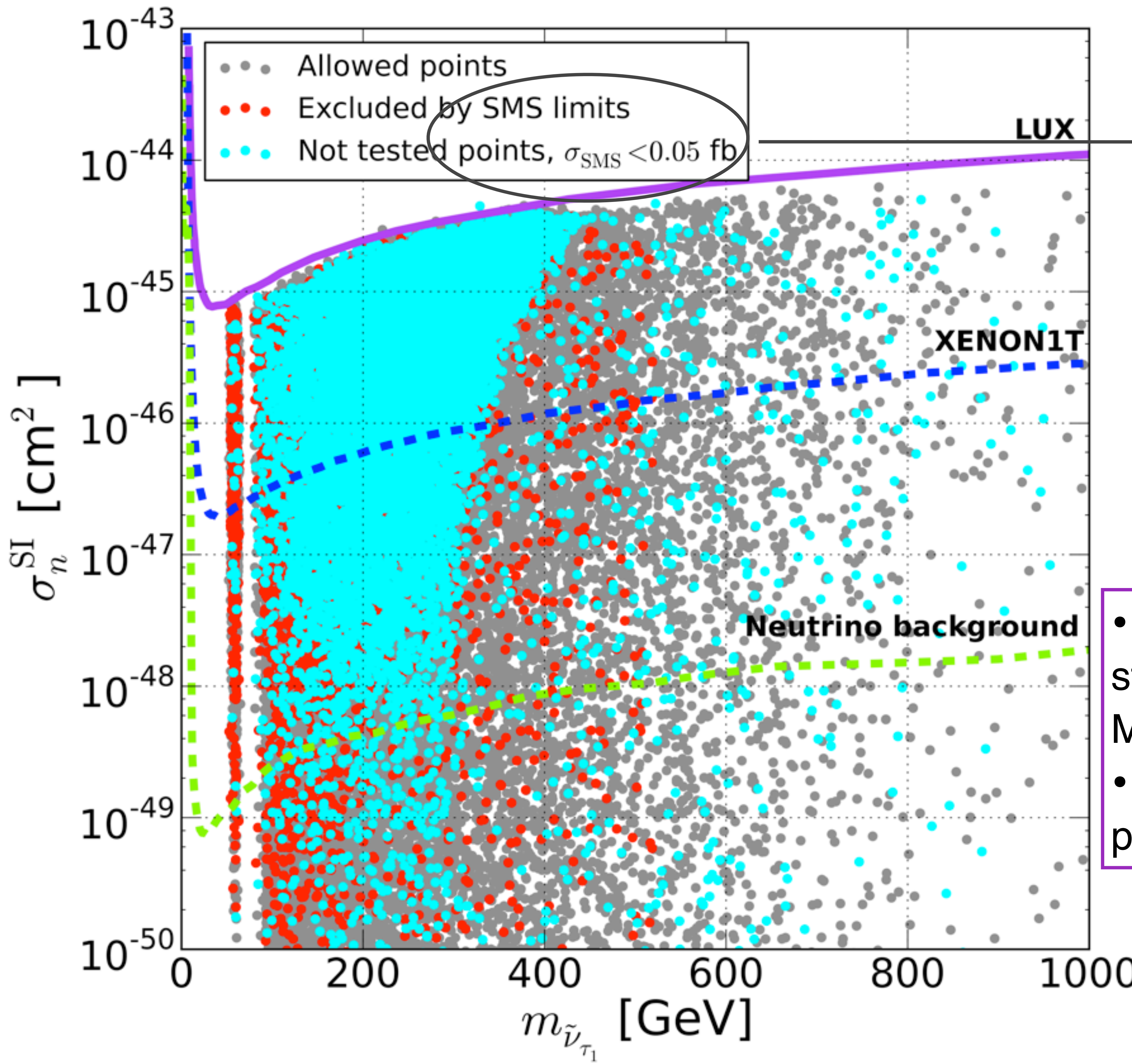
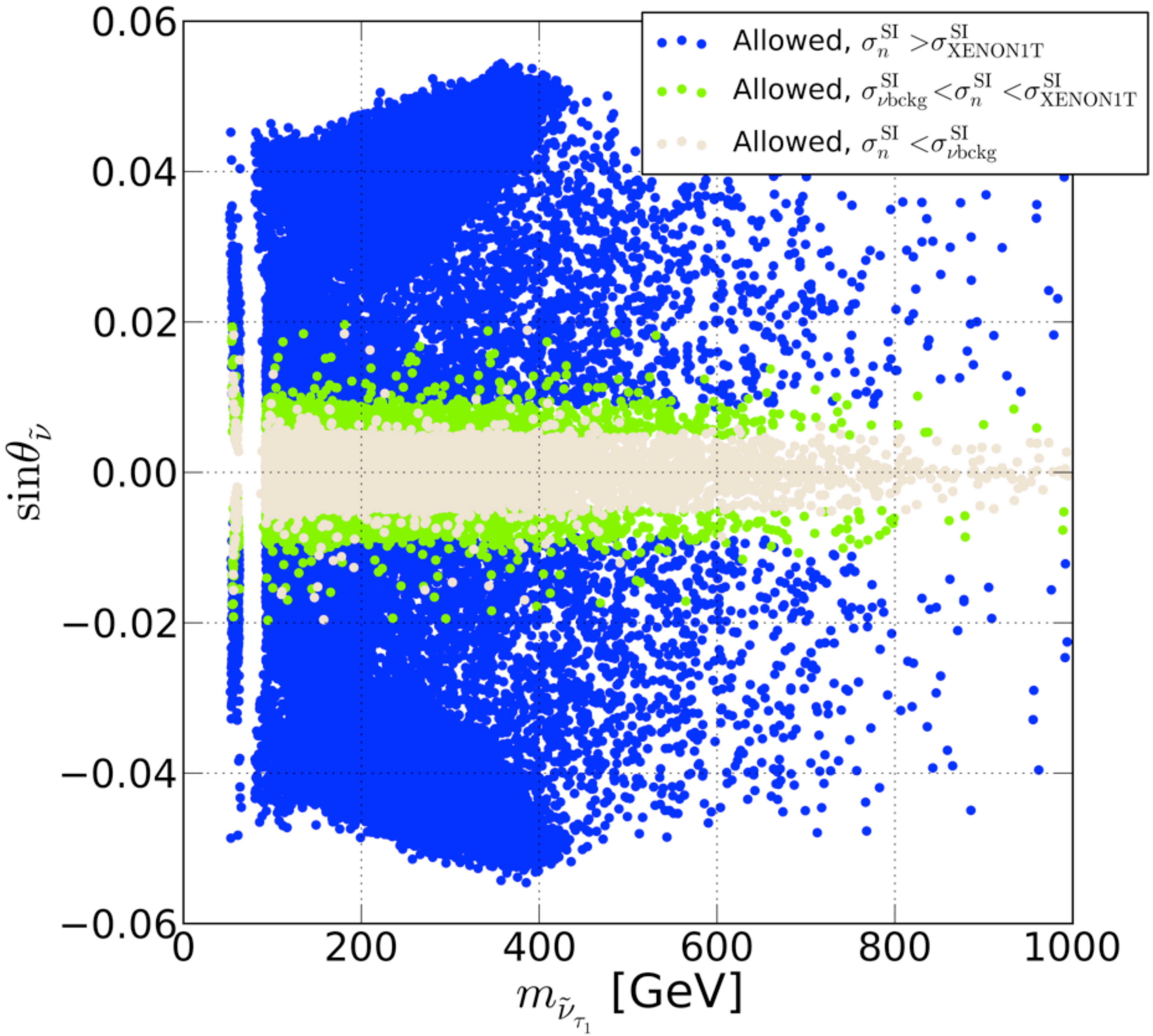


LHC run-I constraints from simplified models using SModelS package

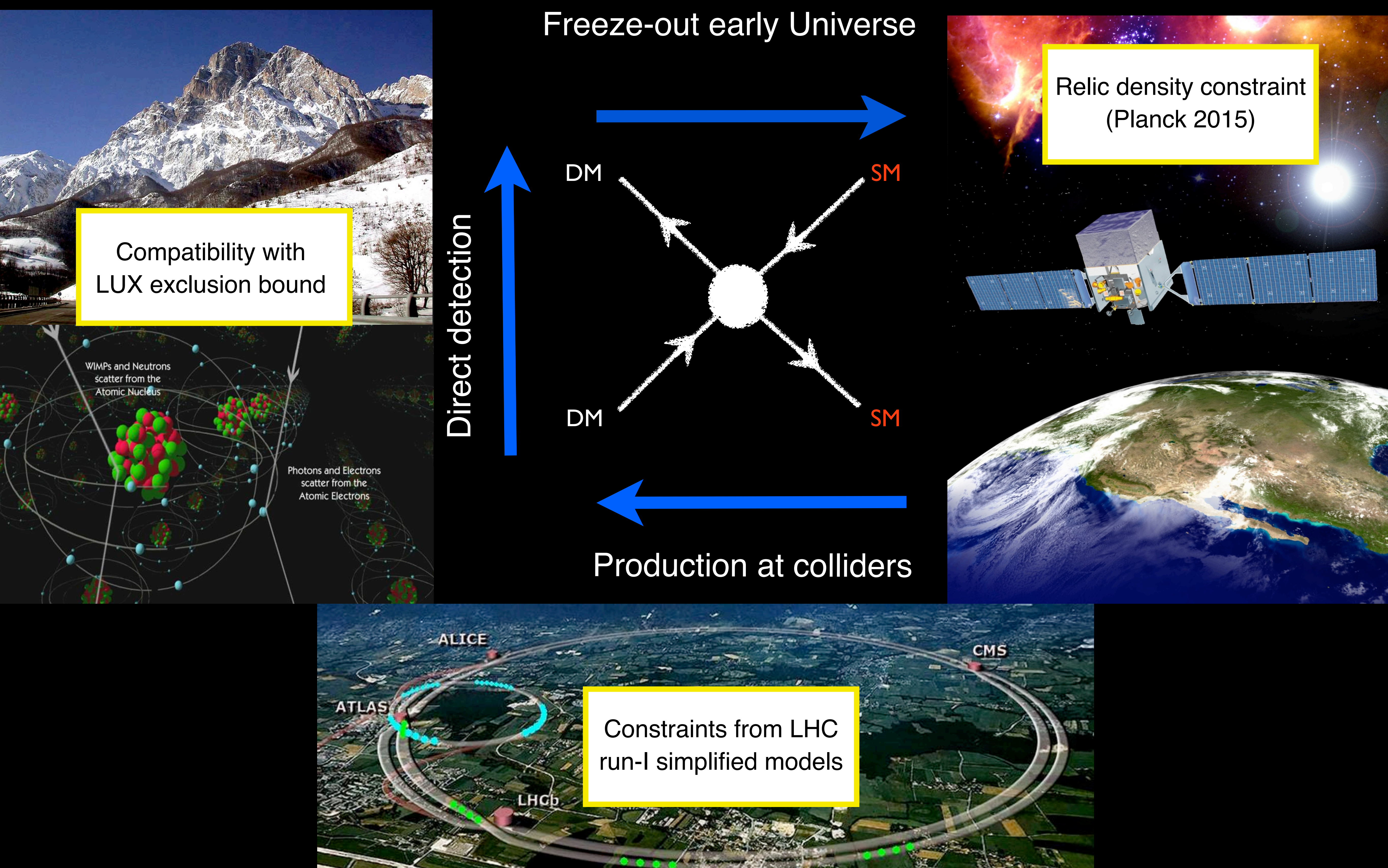
See talk by U. Laa, August 27th

- LUX exclusion bound: strongest constraint for the MSSM+RN
- It dictates how much LH part can survive (Z coupling)

Mixed sneutrino DM is almost sterile



Signature for sneutrino DM



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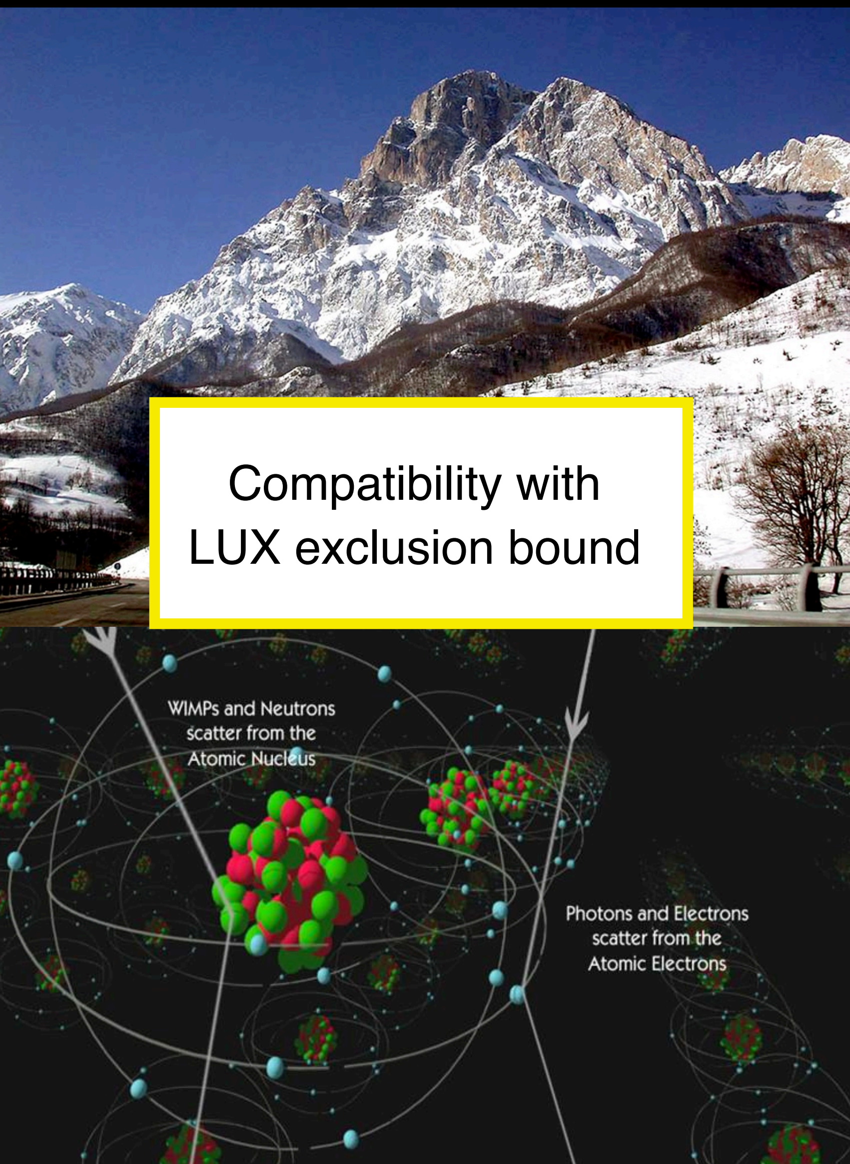

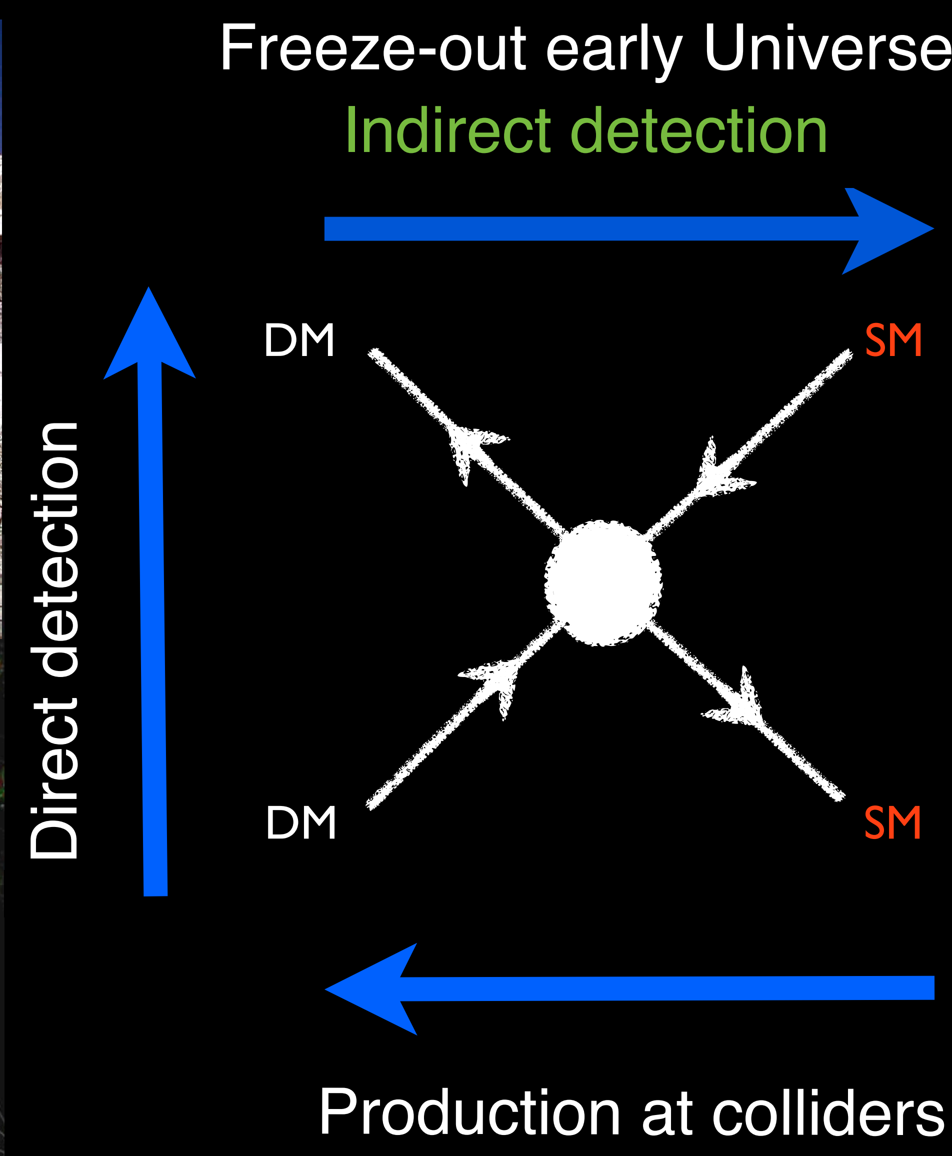

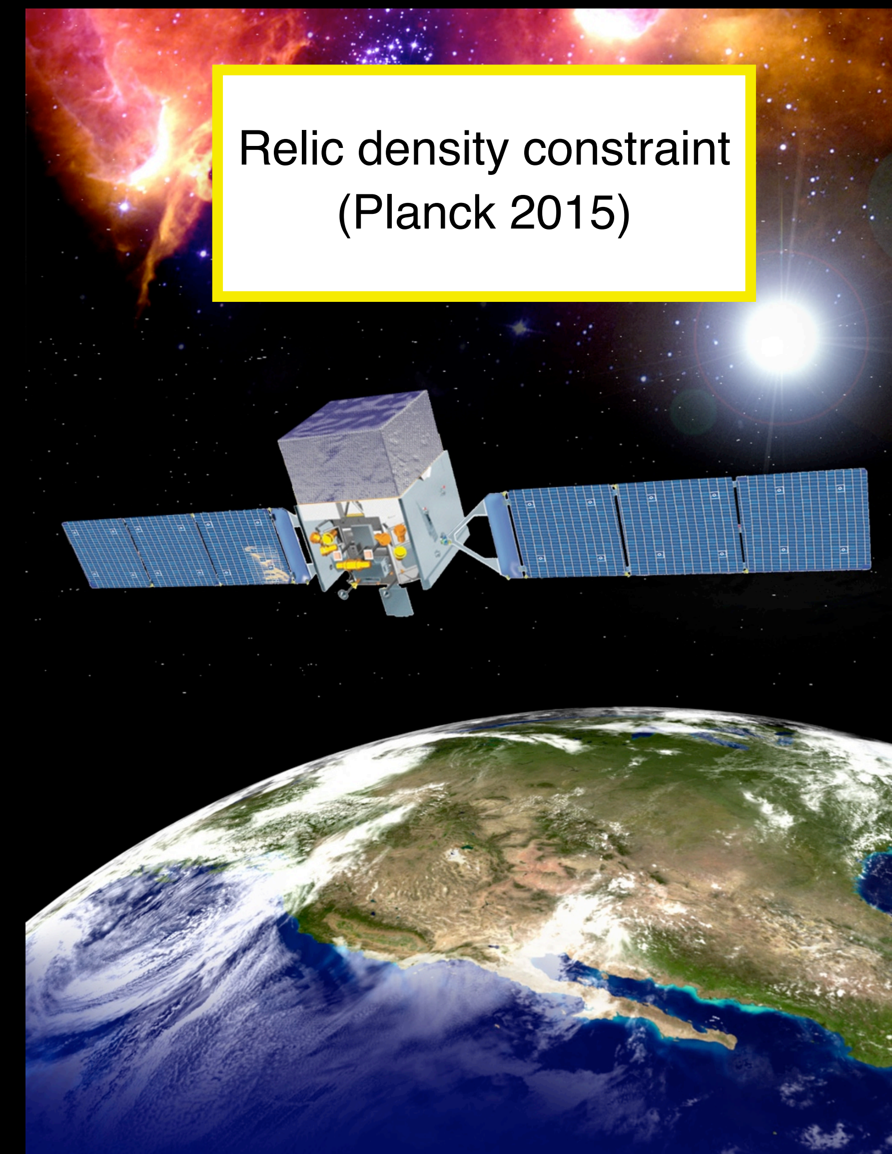

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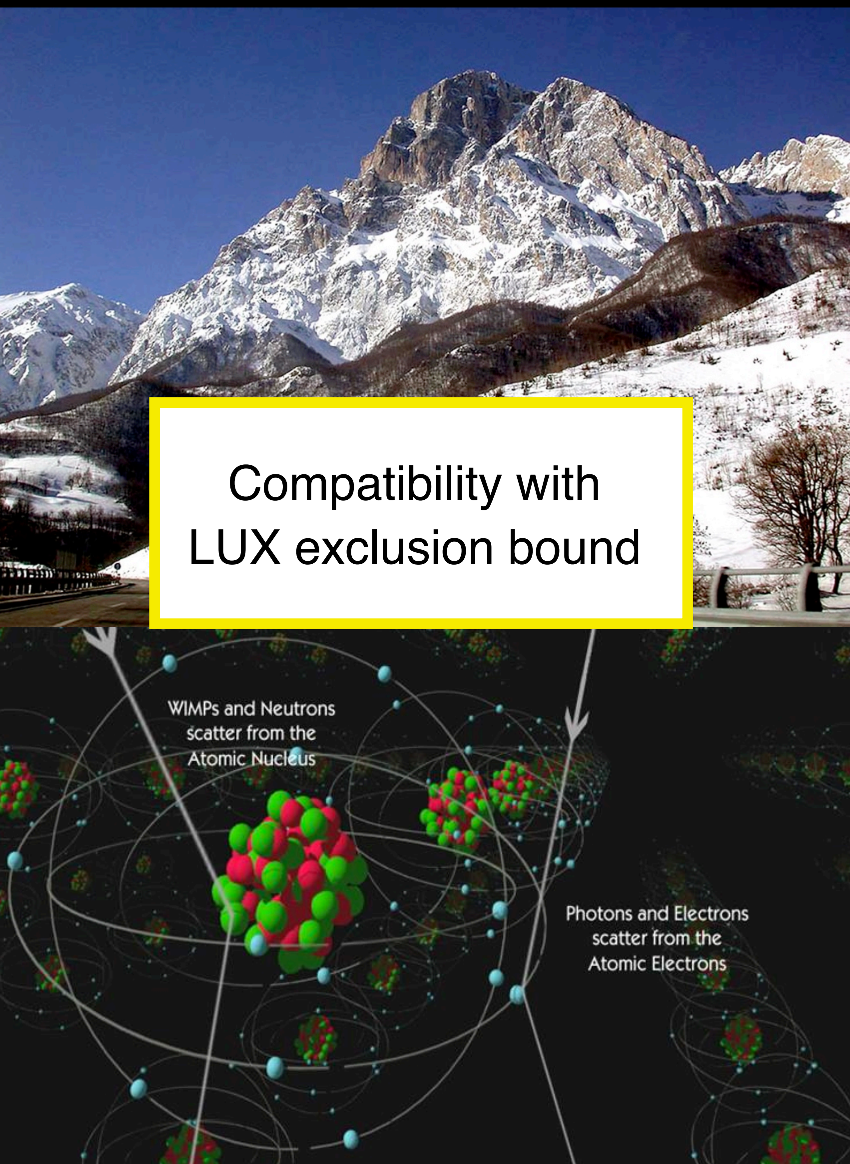

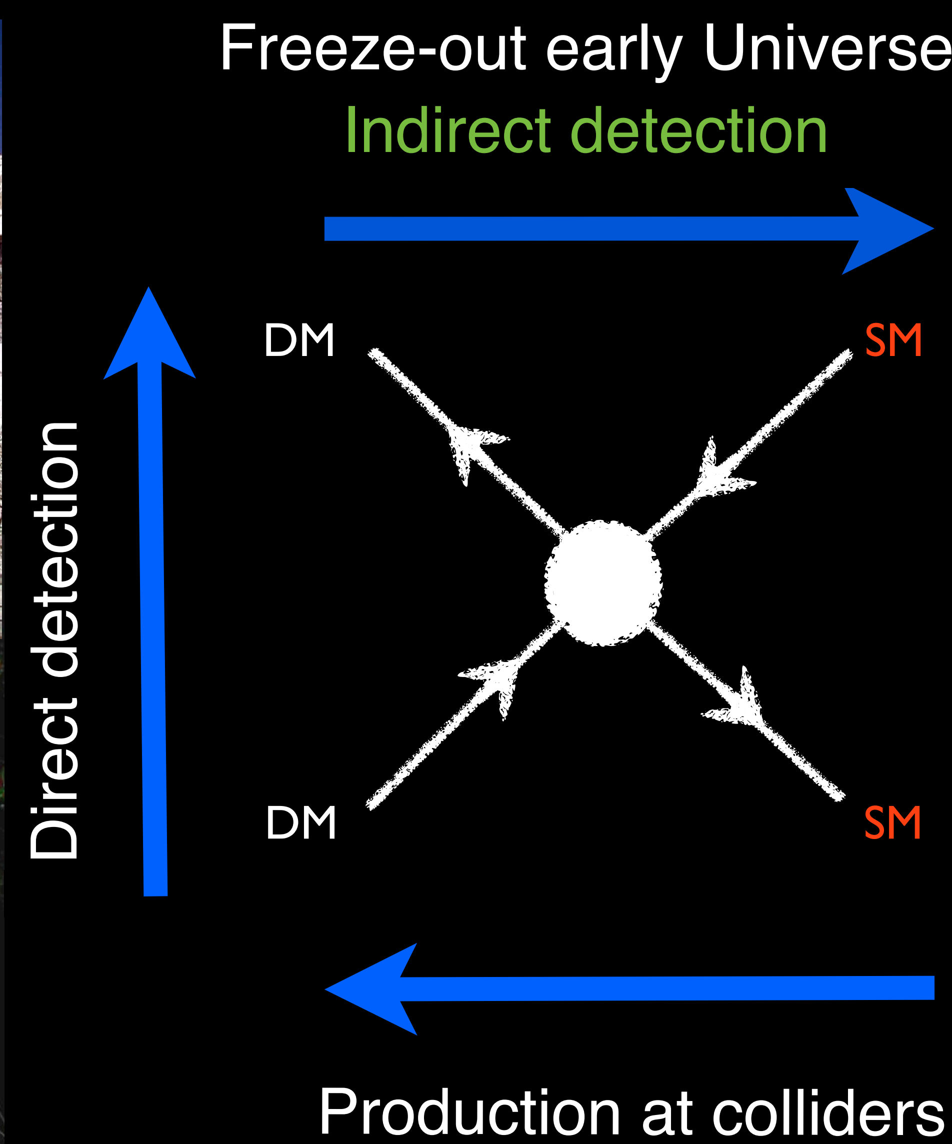

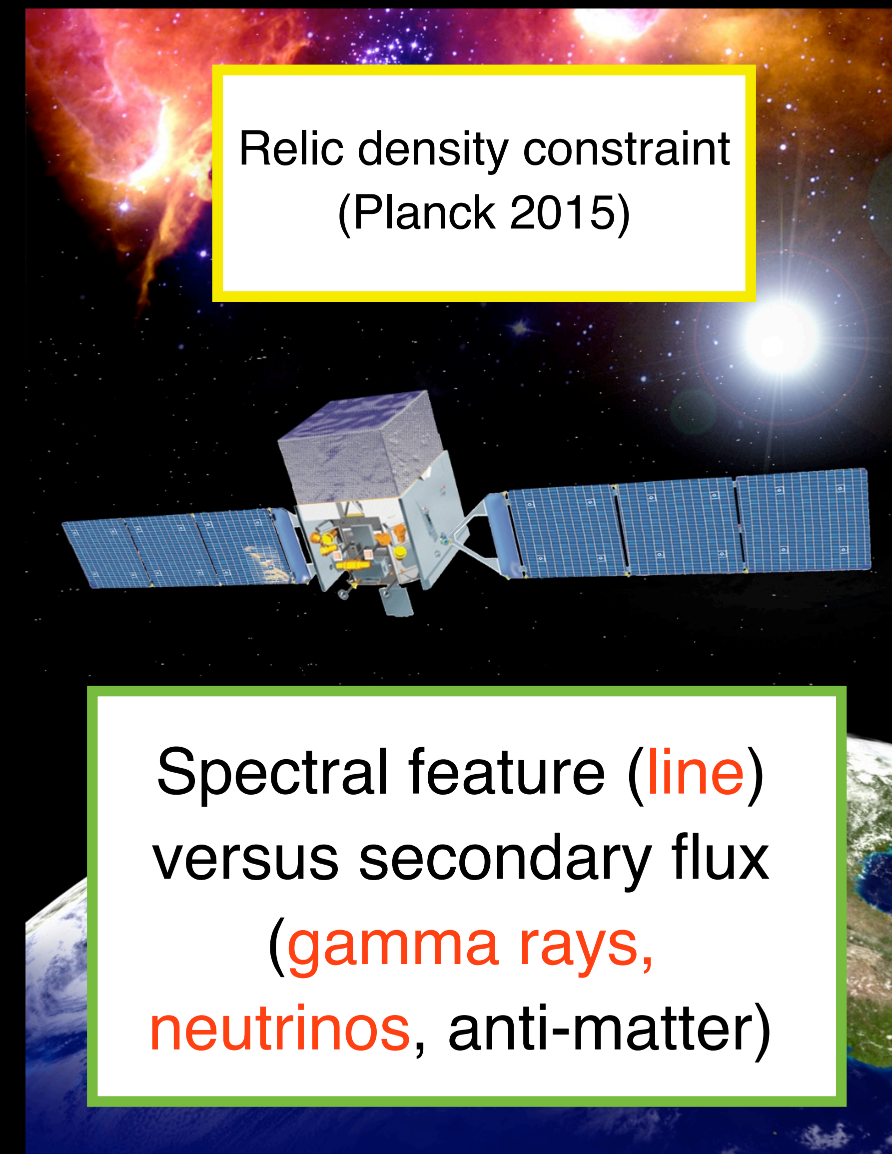

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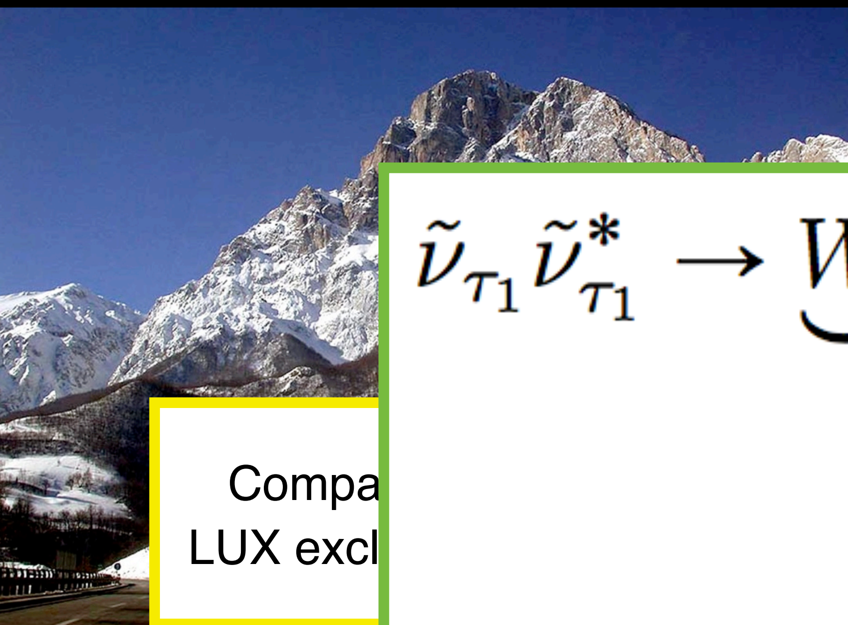
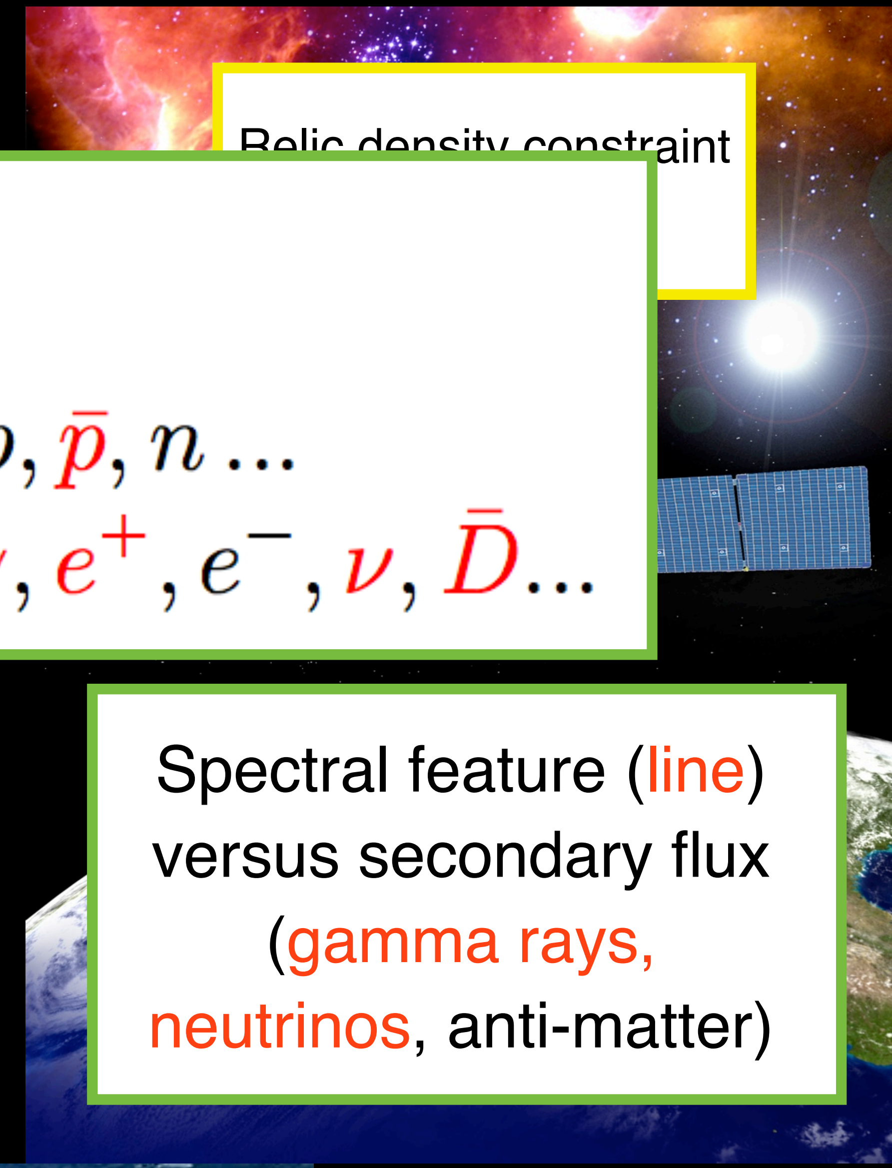


Freeze-out early Universe

Indirect detection



Relic density constraint

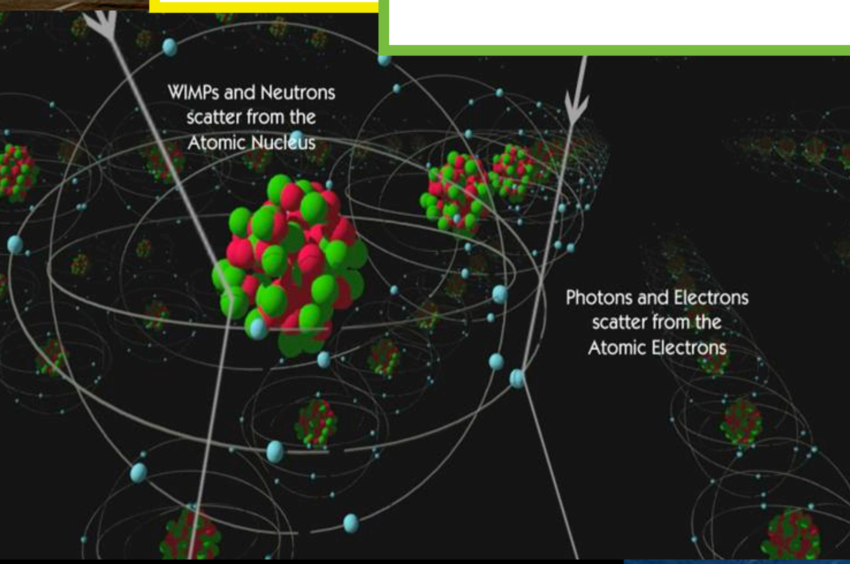
$$\tilde{\nu}_{\tau_1}\tilde{\nu}^*_{\tau_1} \to \underbrace{W^+W^-, ZZ, hh, t\bar{t}, \ldots}$$

$$\hookrightarrow \tau^\pm, \pi^0, \pi^\pm, p, \bar{p}, n \ldots$$

$$\hookrightarrow \gamma, e^+, e^-, \nu, \bar{D} \ldots$$

Compa

LUX excl



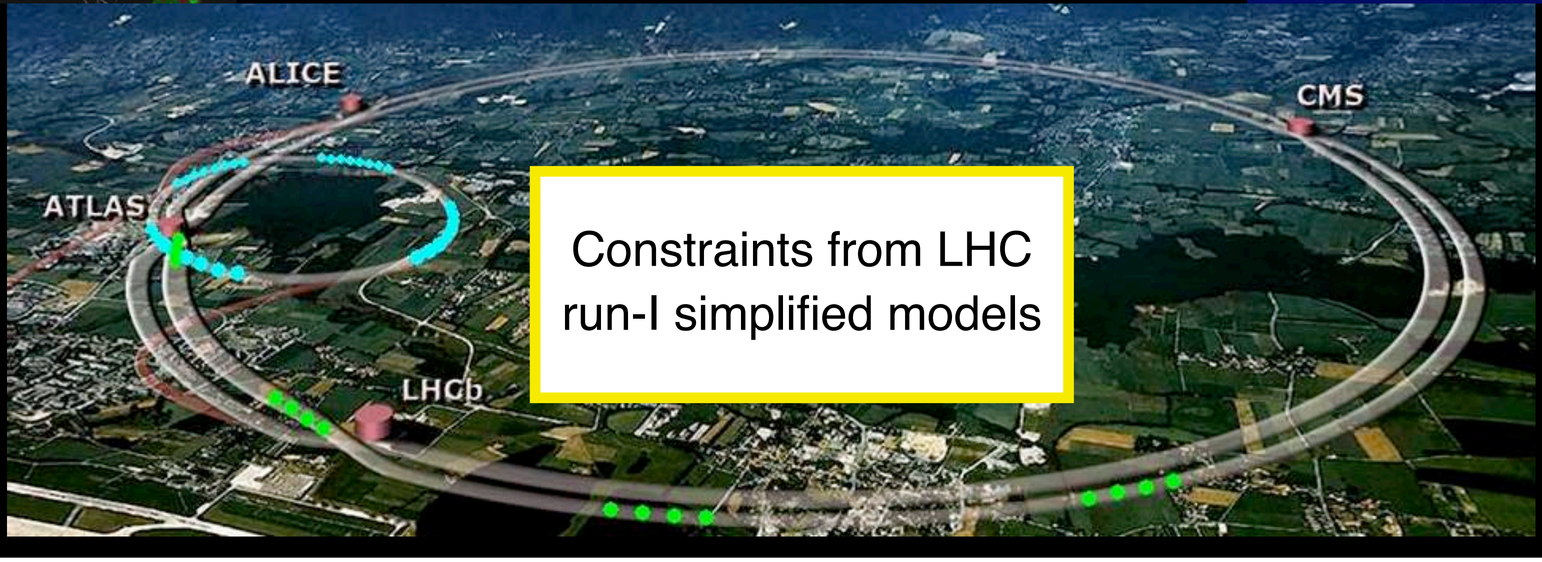
Direct

DM

SM

Spectral feature (line) versus secondary flux (gamma rays, neutrinos, anti-matter)

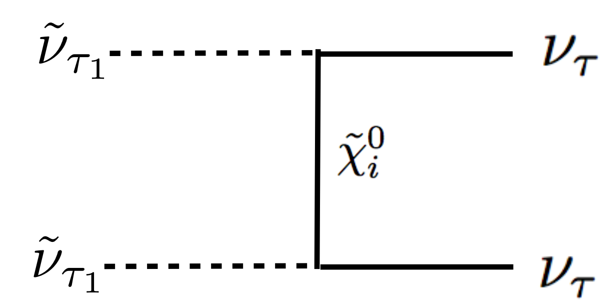
Production at colliders

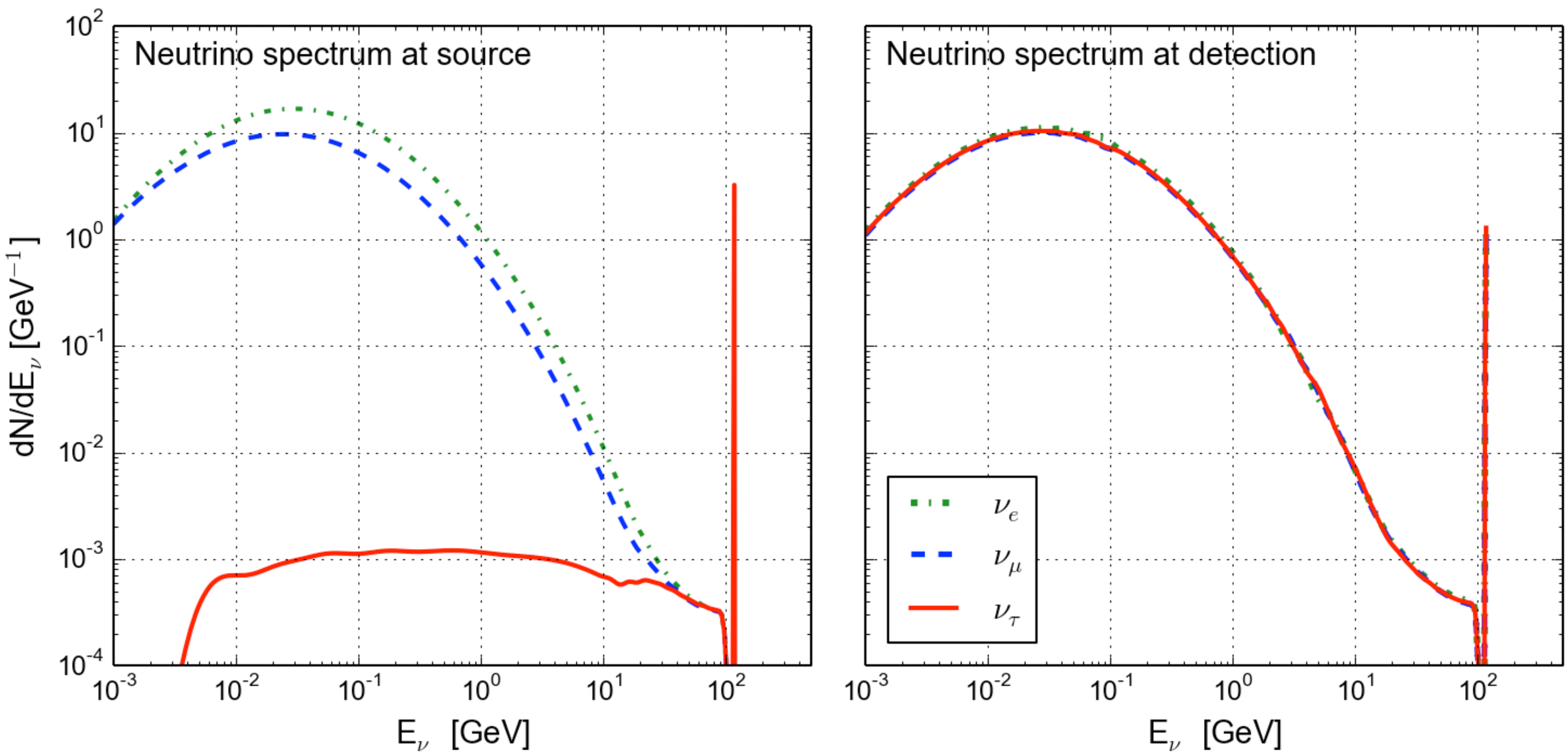


Constraints from LHC run-I simplified models

The monochromatic neutrino line

- The LSP and DM is a sneutrino tau
- t-channel exchange of neutralino gives rise to neutrino tau sharp line with $E_{nu} = m_{DM}$





Line versus secondary flux

$$\langle \sigma v \rangle_{\nu_\tau \nu_\tau} = \frac{C_{P_L}^2 + C_{P_R}^2}{8\pi} \frac{m_{\tilde{\chi}_1^0}^2}{(m_{\tilde{\chi}_1^0}^2 + m_{\tilde{\nu}_1}^2)^2}$$

$$C_{P_R} \propto \sin\theta_{\tilde{\nu}_\tau} Y_\nu N_{14} \sim 0$$
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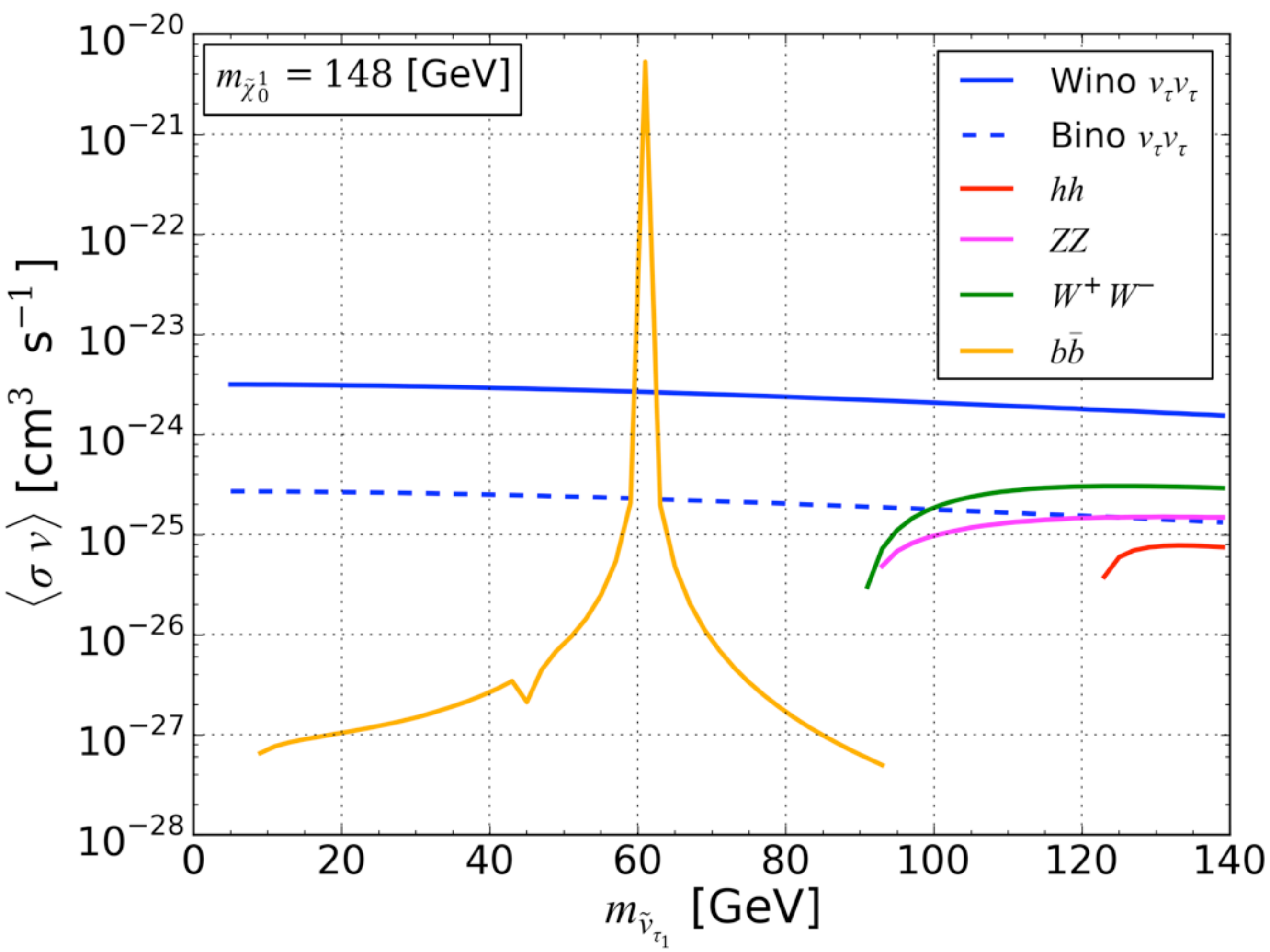

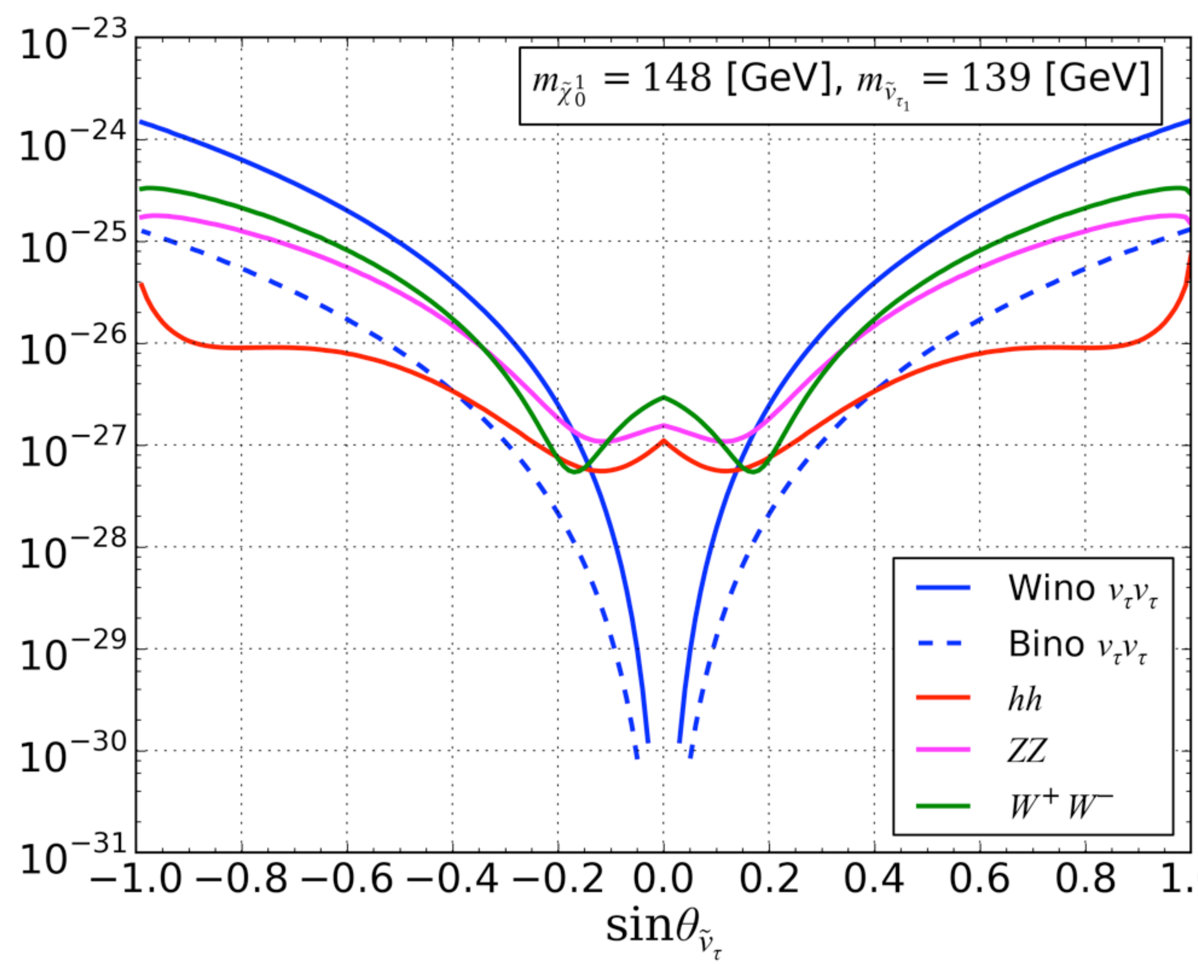

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- Dirac masses have negligible neutrino Yukawa: suppression of the signal

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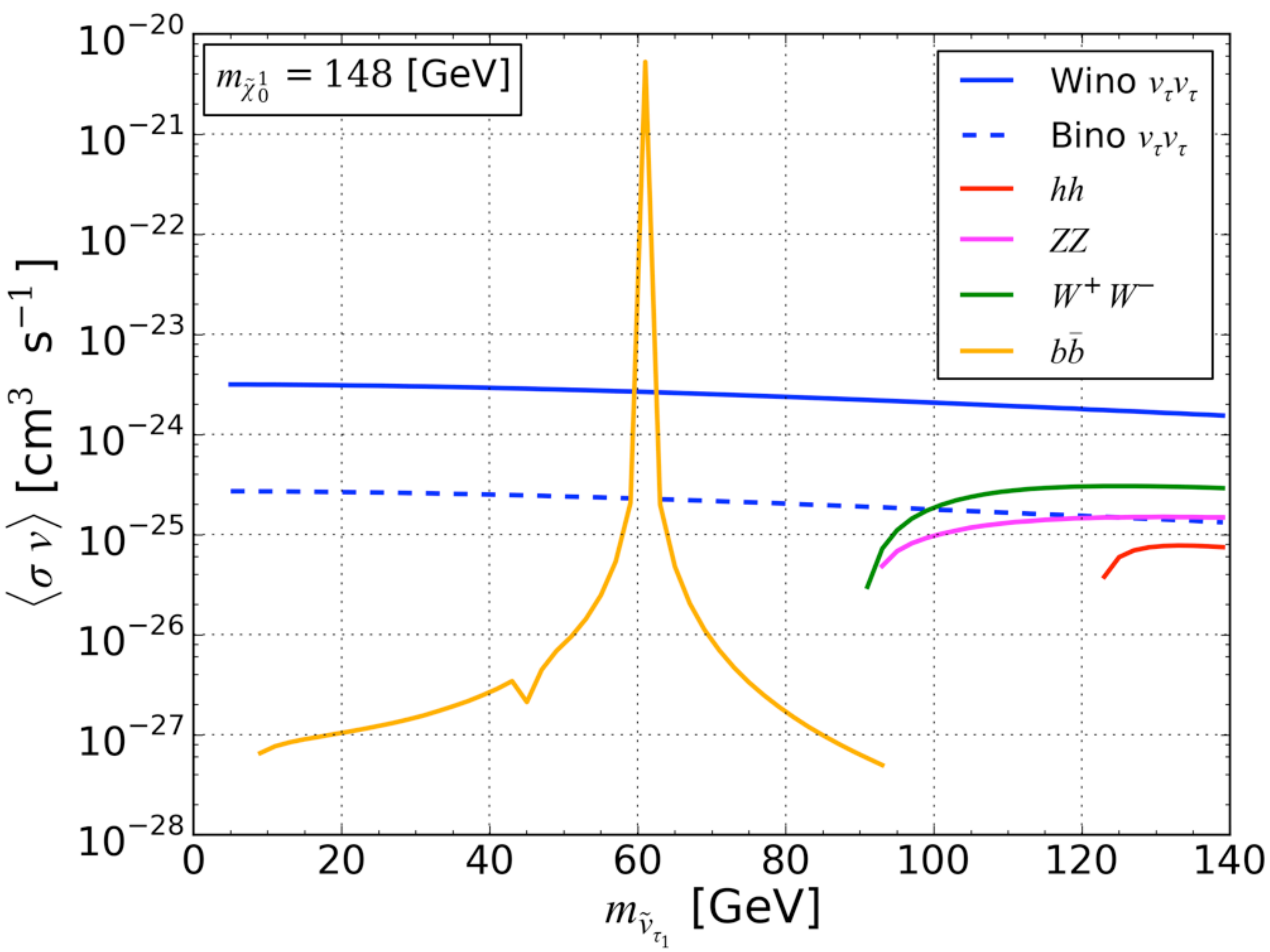

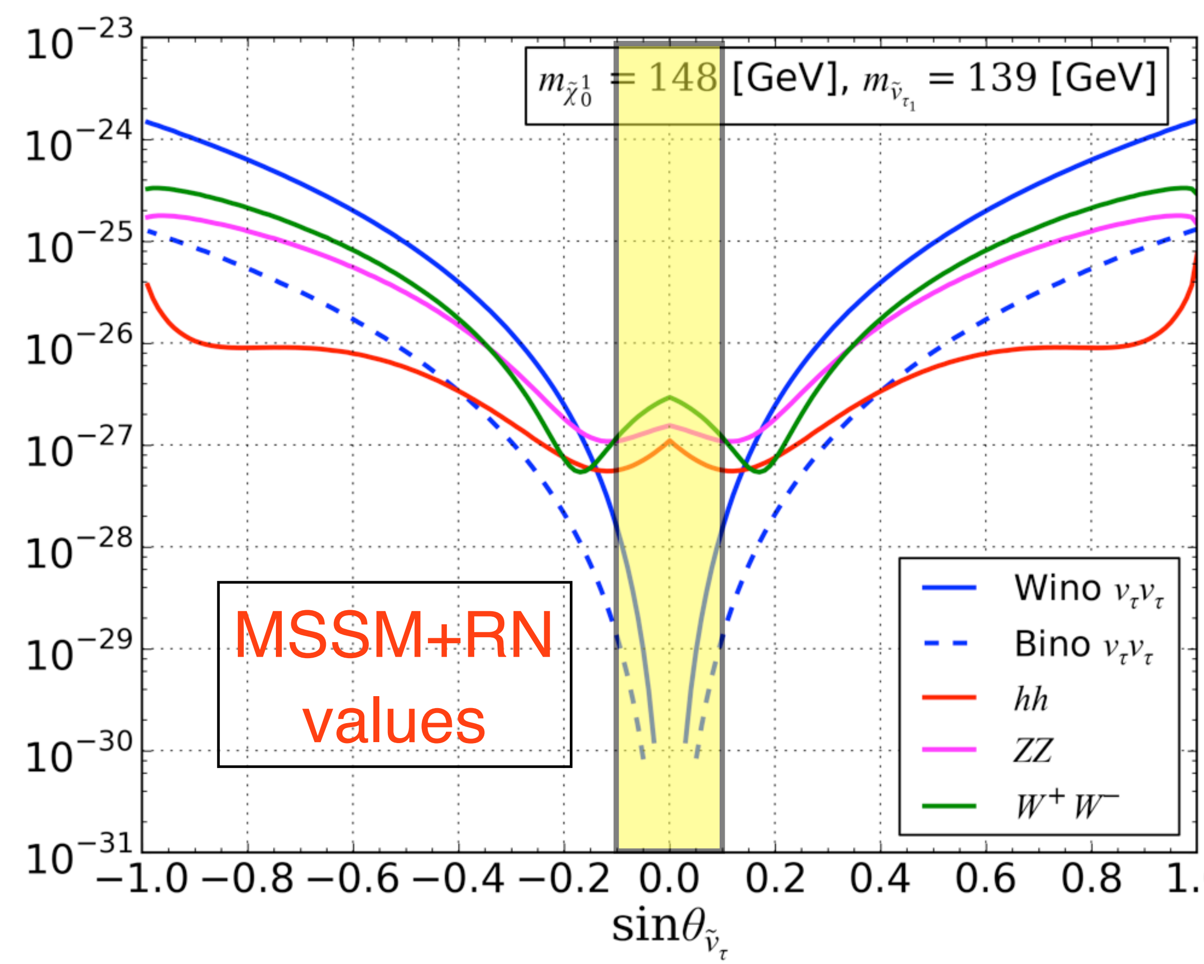

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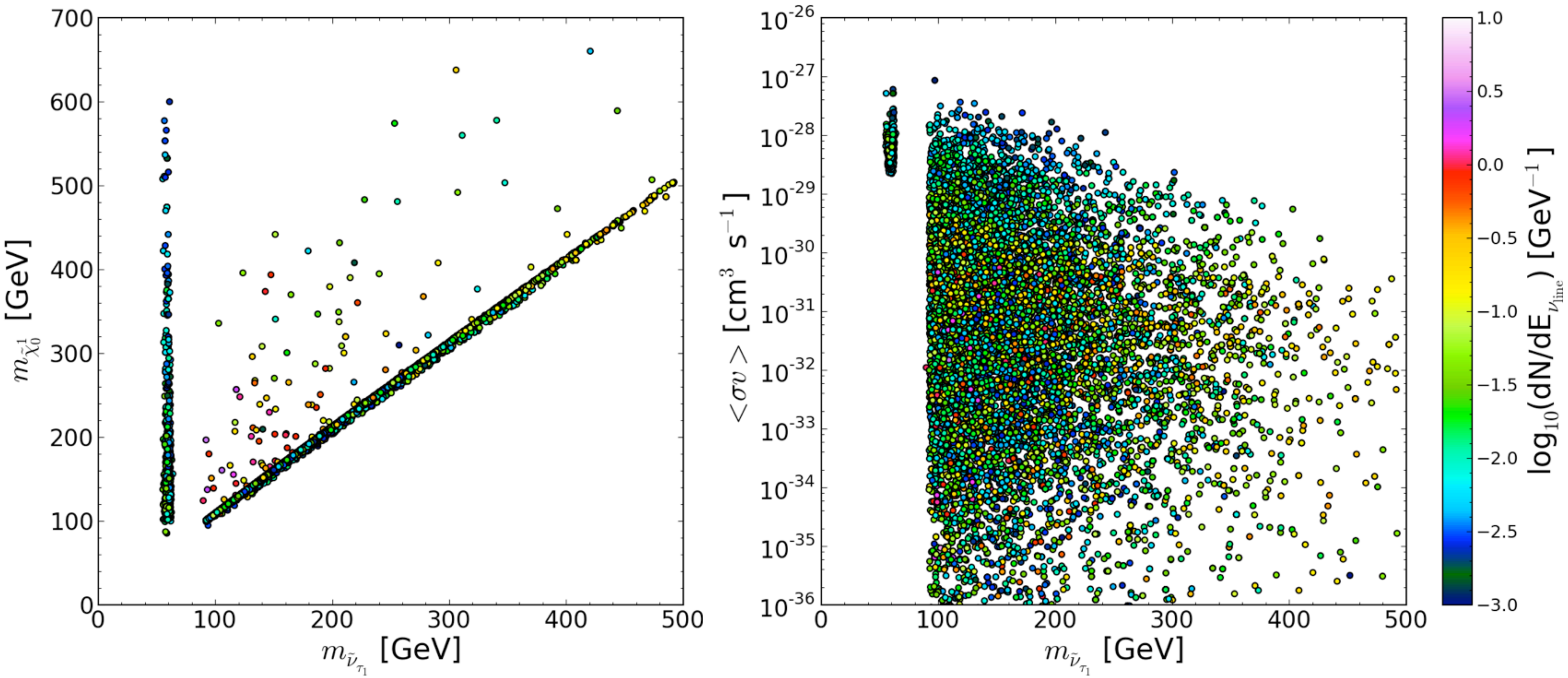
MSSM+RN



- The largest enhancements are for large neutralino-sneutrino mass splitting
- Sneutrino-neutralino tends to be degenerated because of relic density constraint
- Sigma v today small because relic density fixed by cohannihilation of neutralino-chargino and then communicated to sneutrino sector

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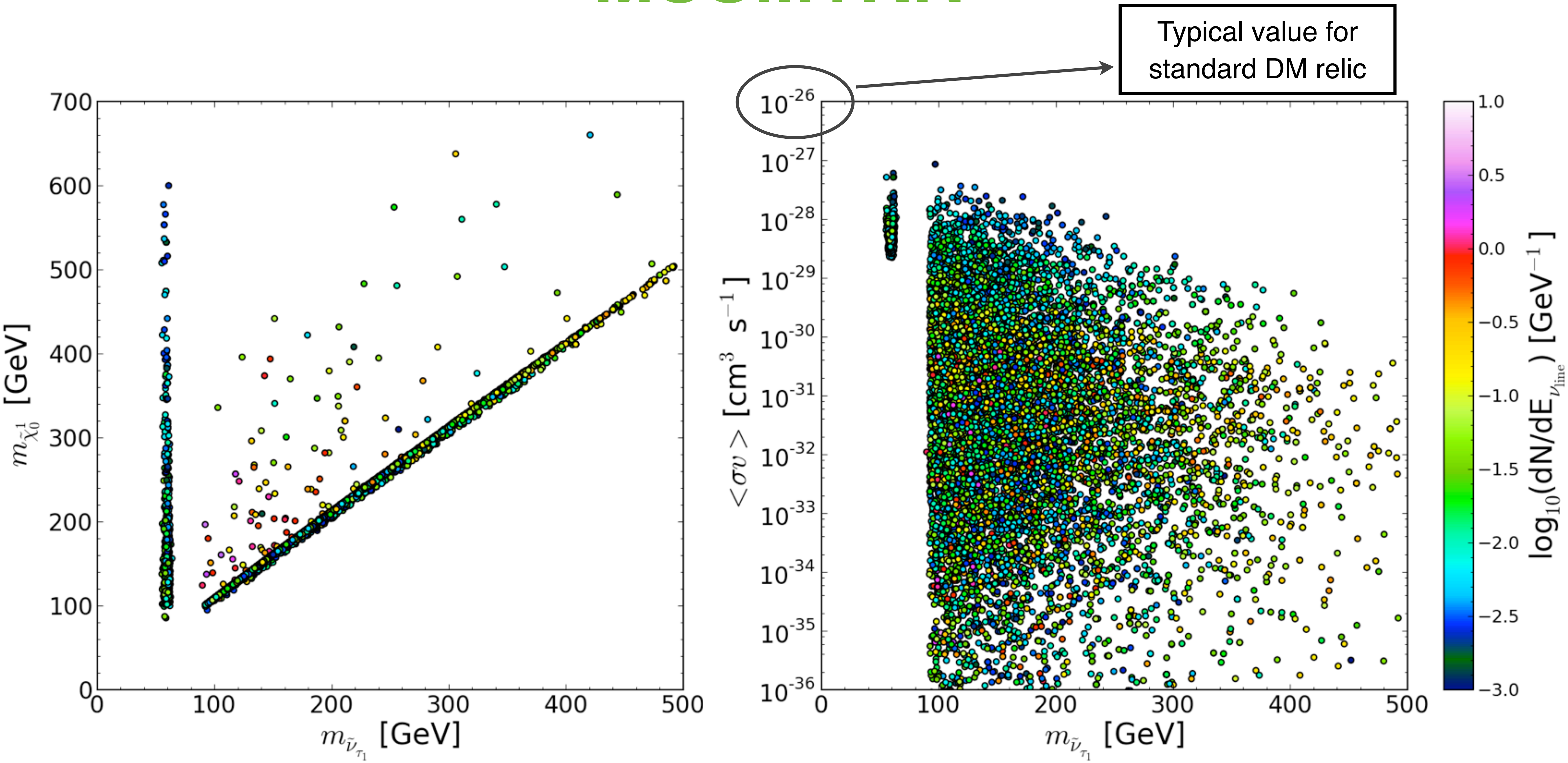

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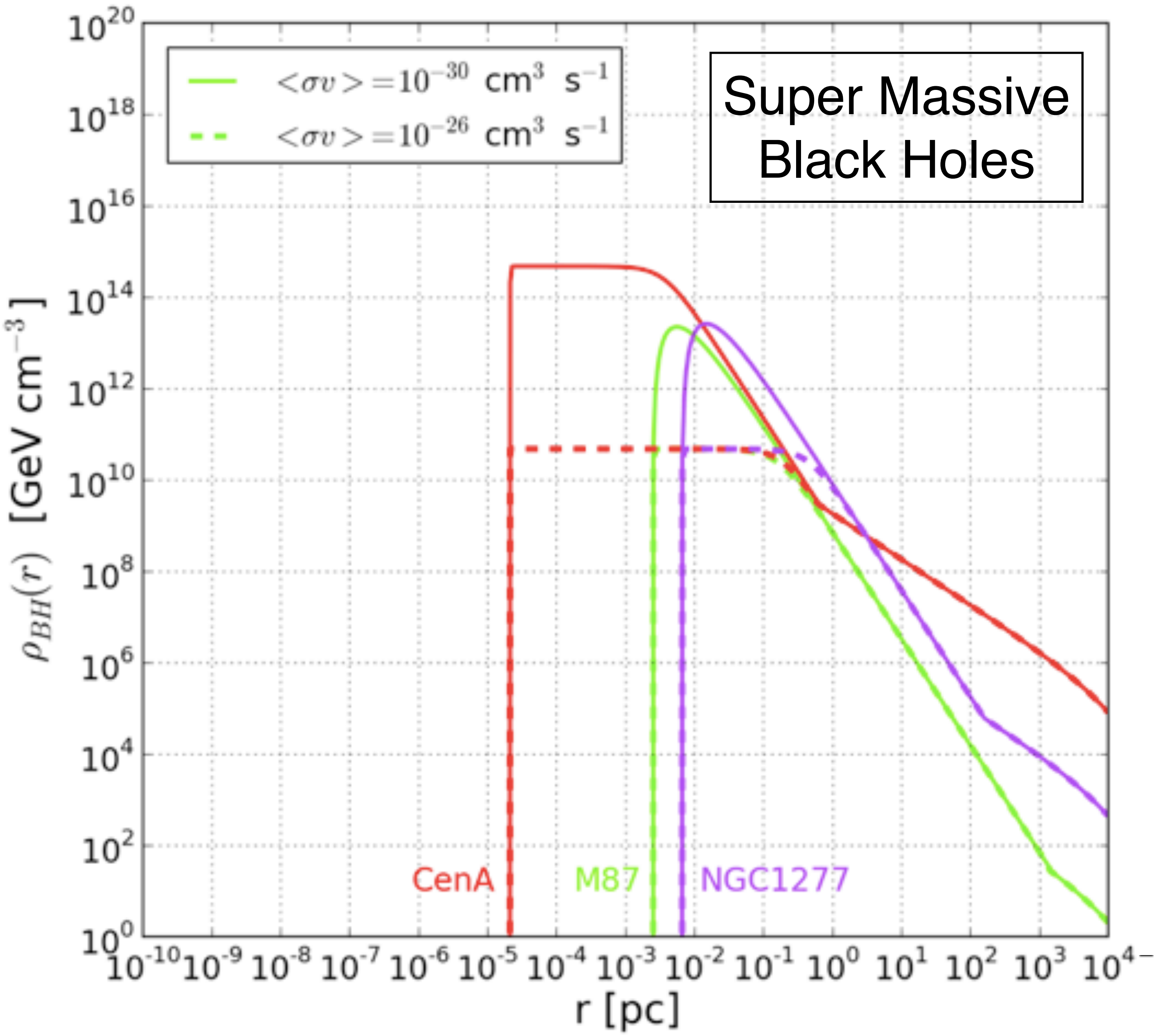
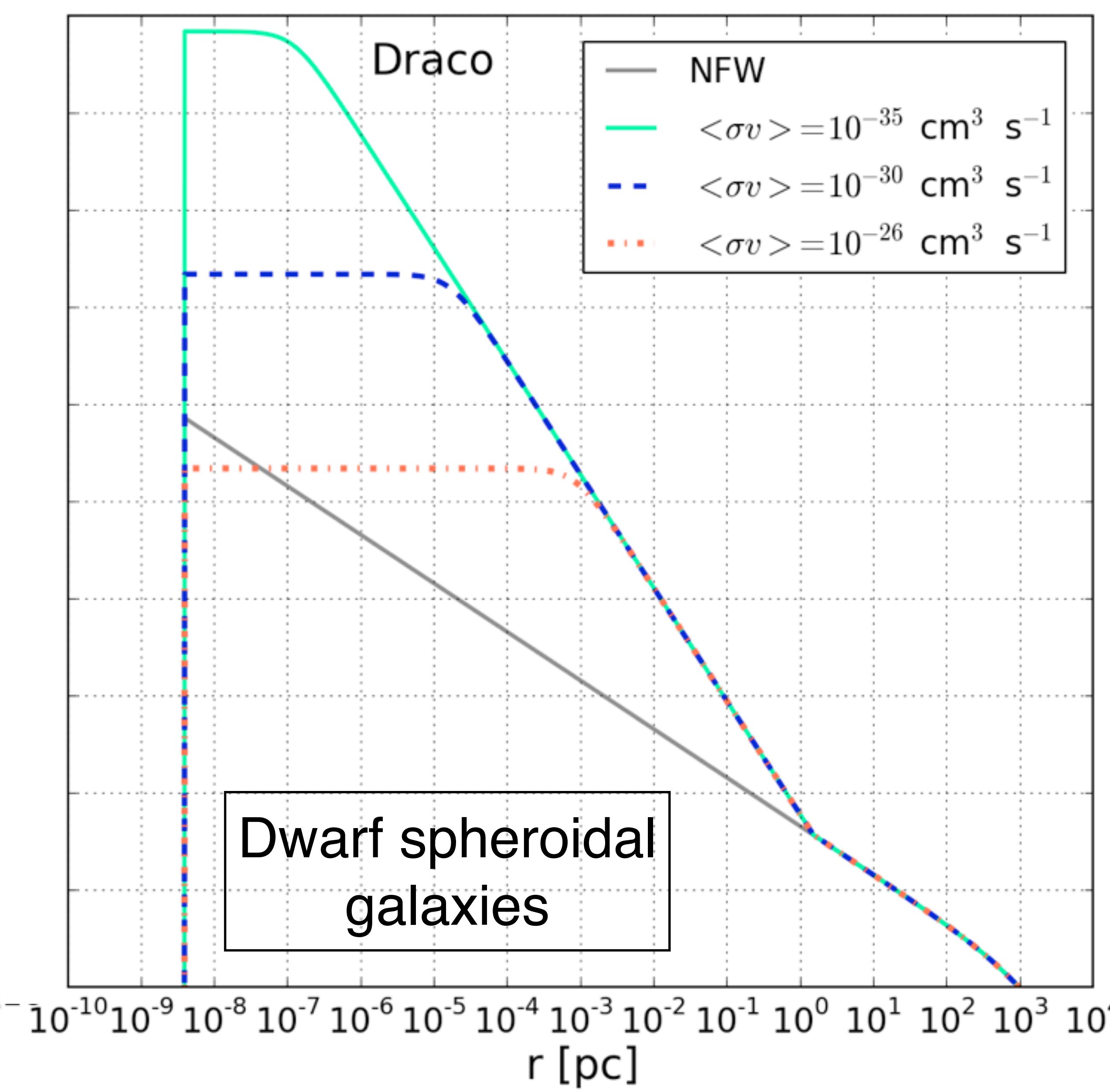
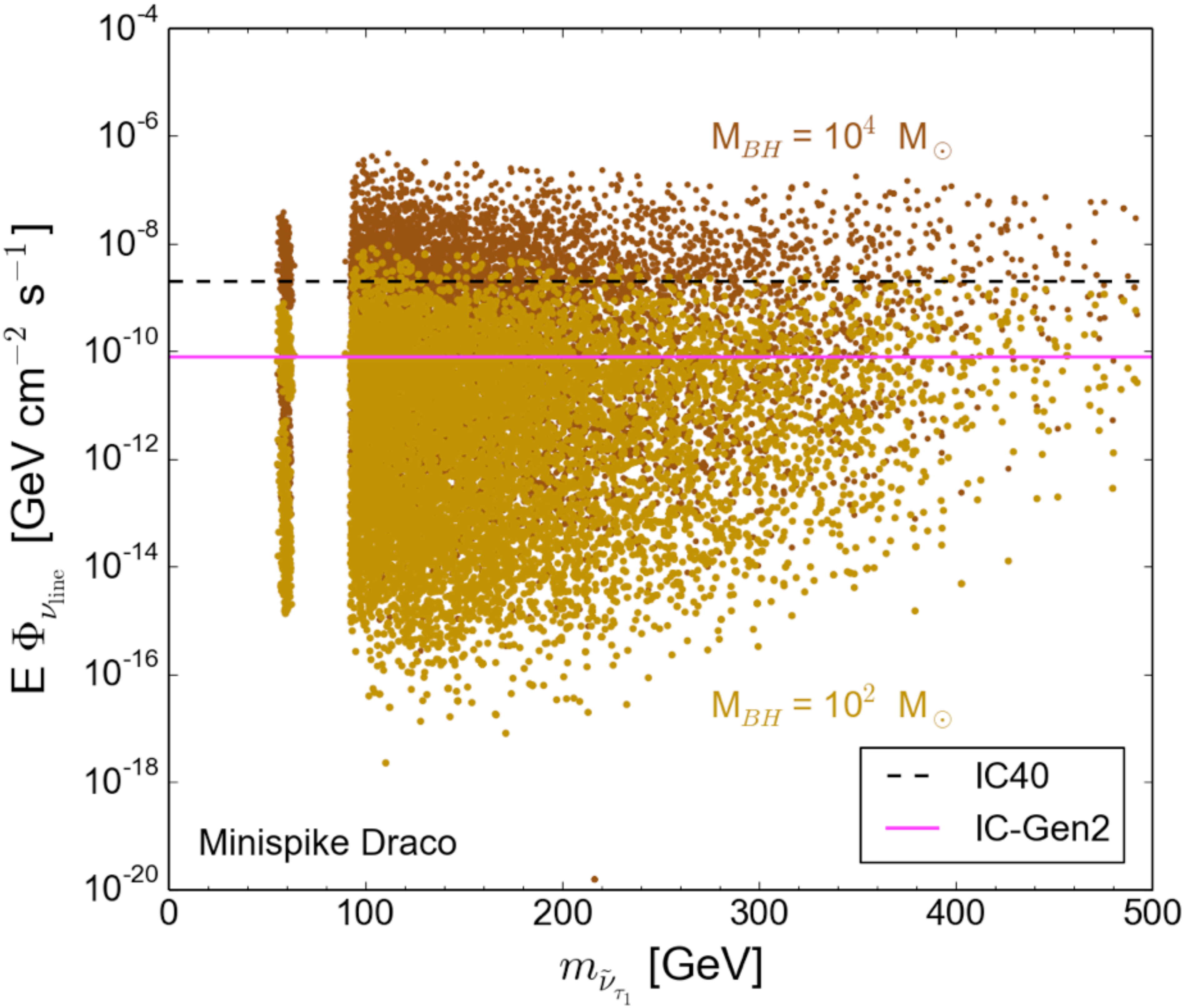
Astrophysics: how to boost the signal

- Due to the smallness of sigmav the monochromatic line is not detectable by present astrophysical probes
- When black holes (BHs) form, DM density MIGHT increase to form a DM spike





Expected neutrino flux from Draco dSPh



- Idealistic neutrino telescope set up
- Point source sensitivity for TeV nus extrapolated down to GeV energies

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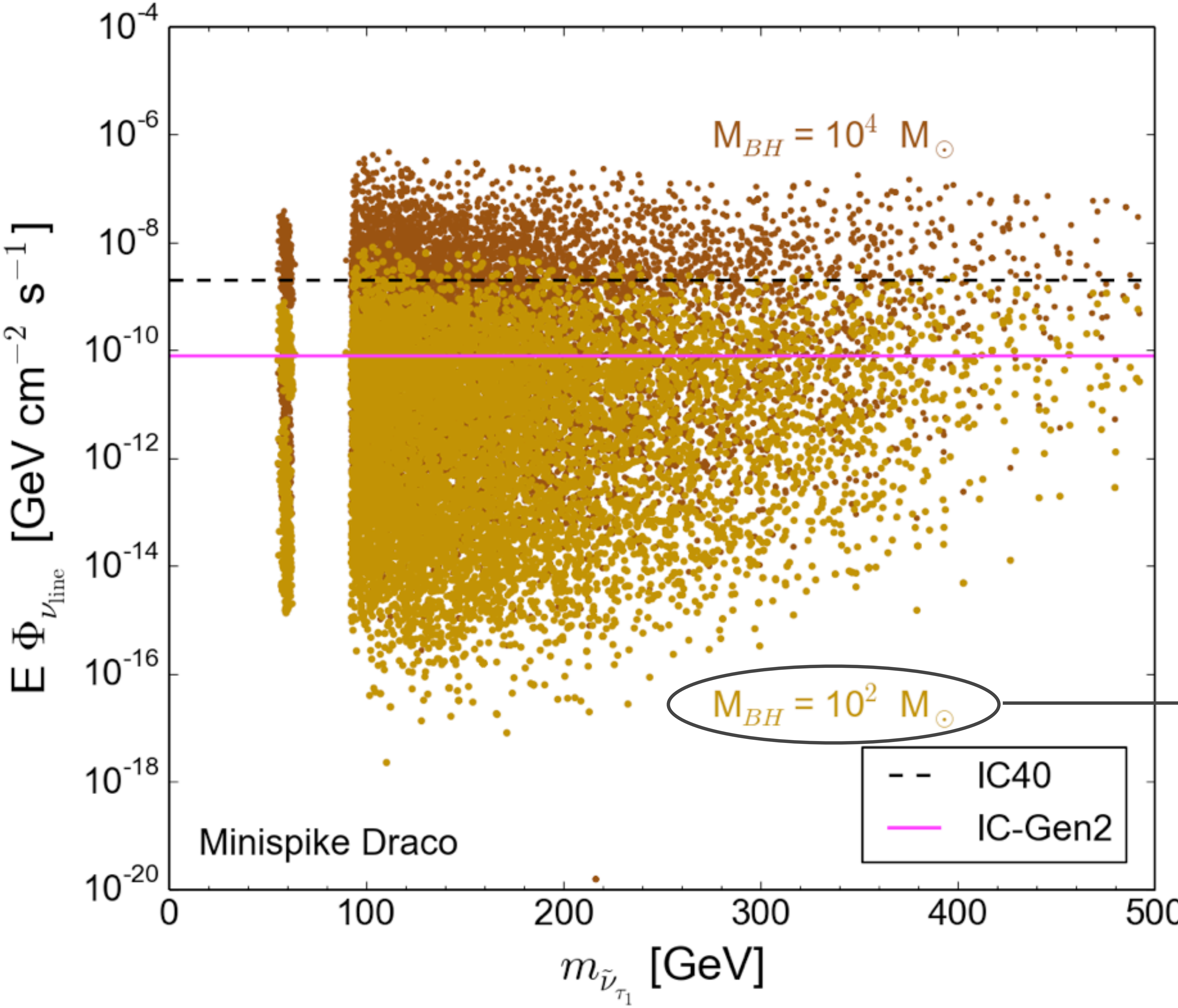

- Idealistic neutrino telescope set up
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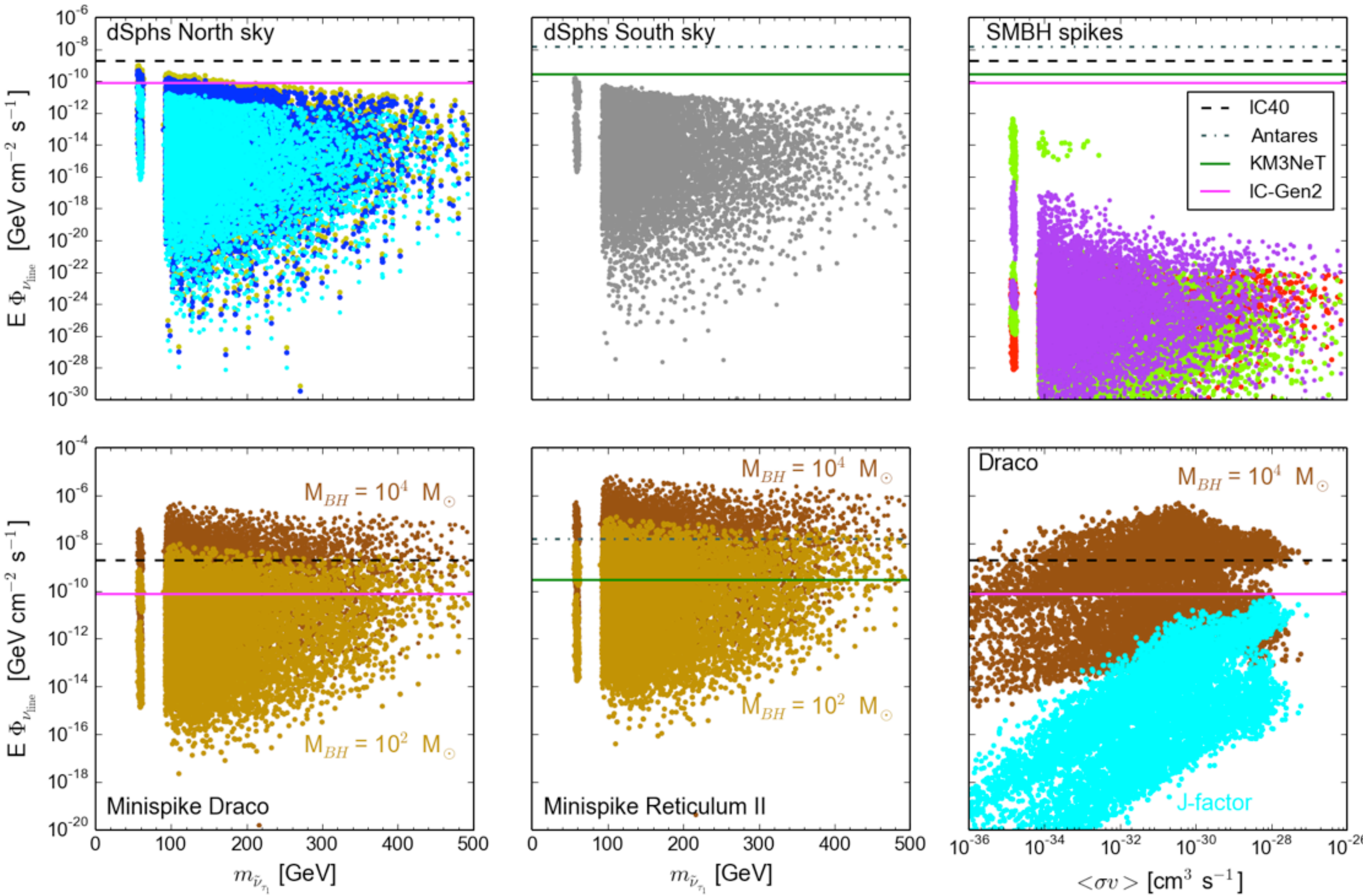
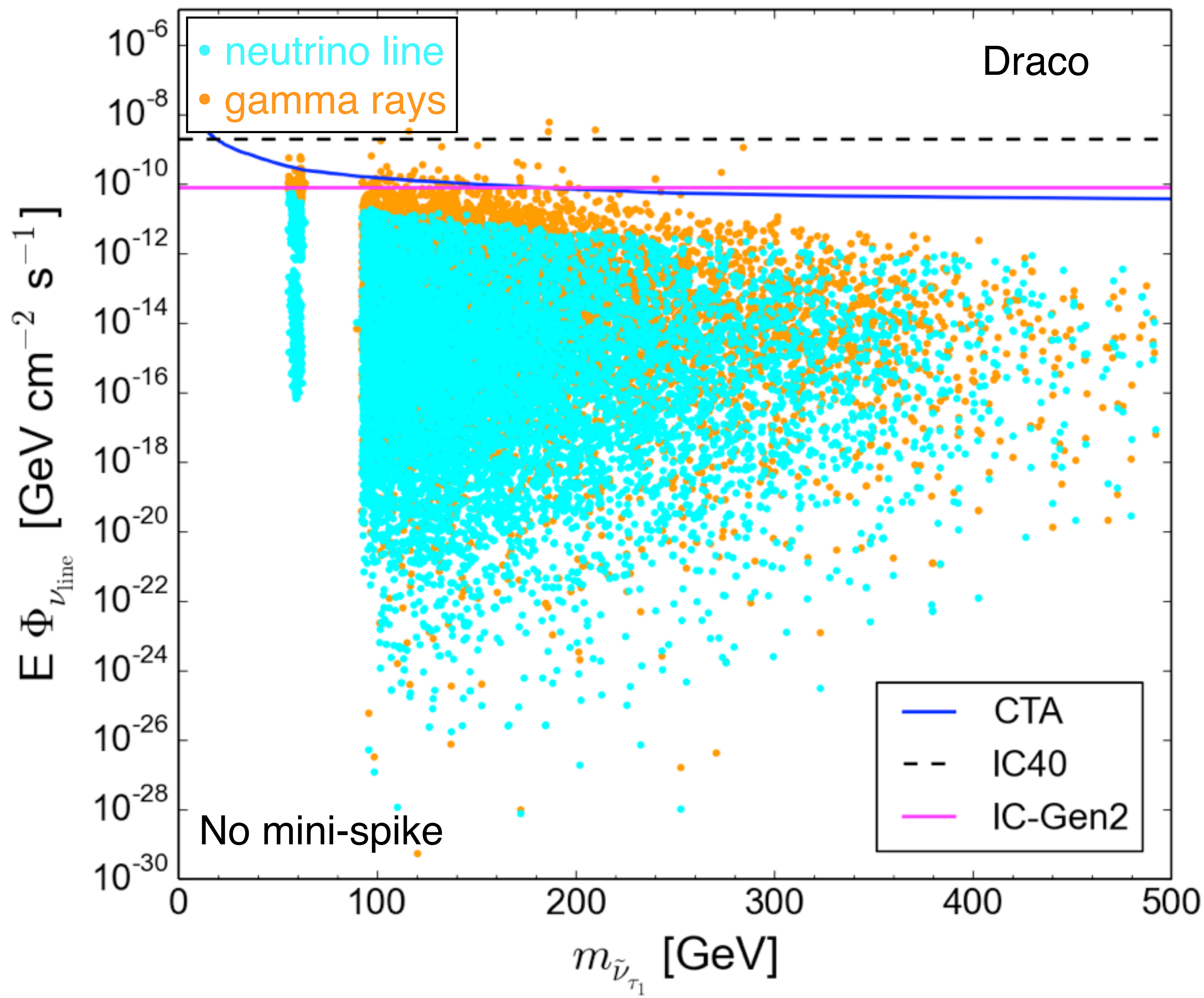
Typical expected BH mass for Draco-like system (from simulation)

Expected neutrino flux



Complementarity with gamma-ray searches

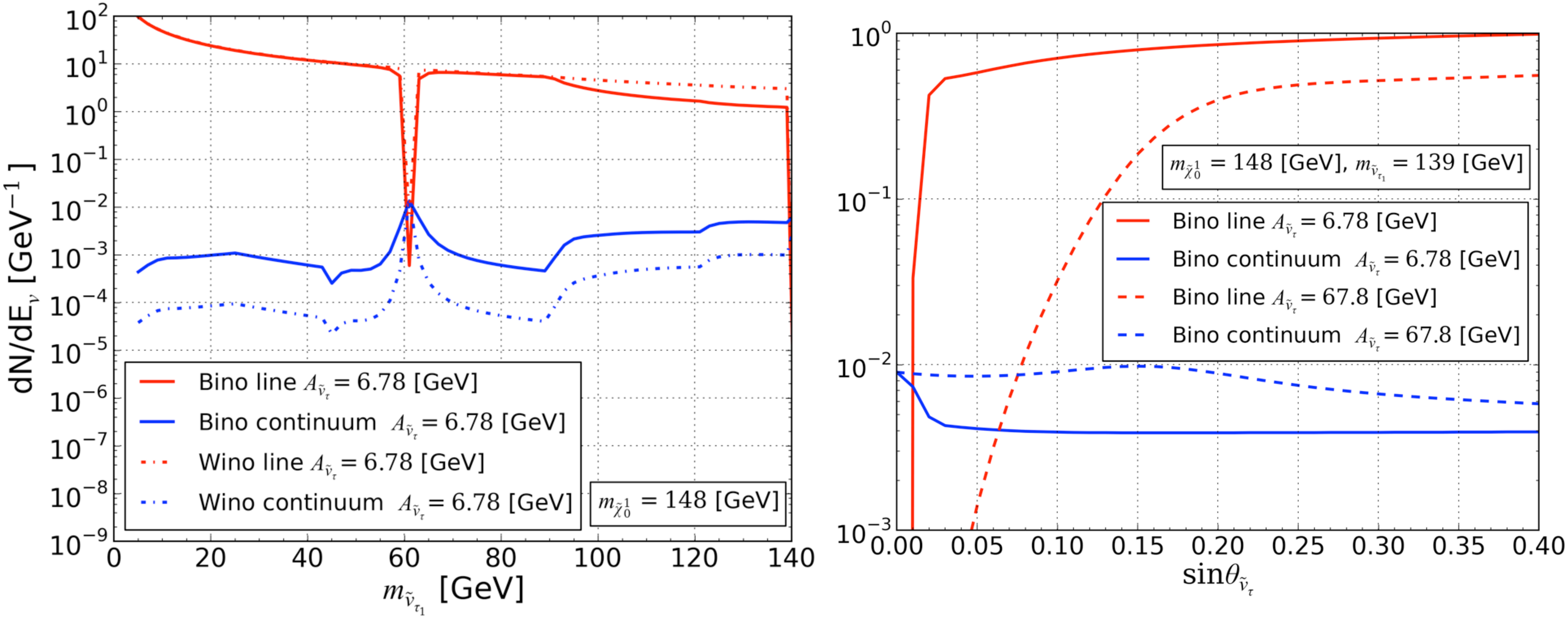


Conclusions

- Sneutrino as DM is a well motivated scenario: it relates with the generation of neutrino masses
- A large portion of the MSSM+RN parameter space is compatible with the LUX exclusion bound
- Complementary between LHC and direct detection searches
- Indirect searches: monochromatic neutrino linesare a striking signature for sneutrino DM (suppressed for neutralino DM)
- Dwarf spheroidal galaxies are the optimal targets for this signal

Back up slides

Dependence on the A term



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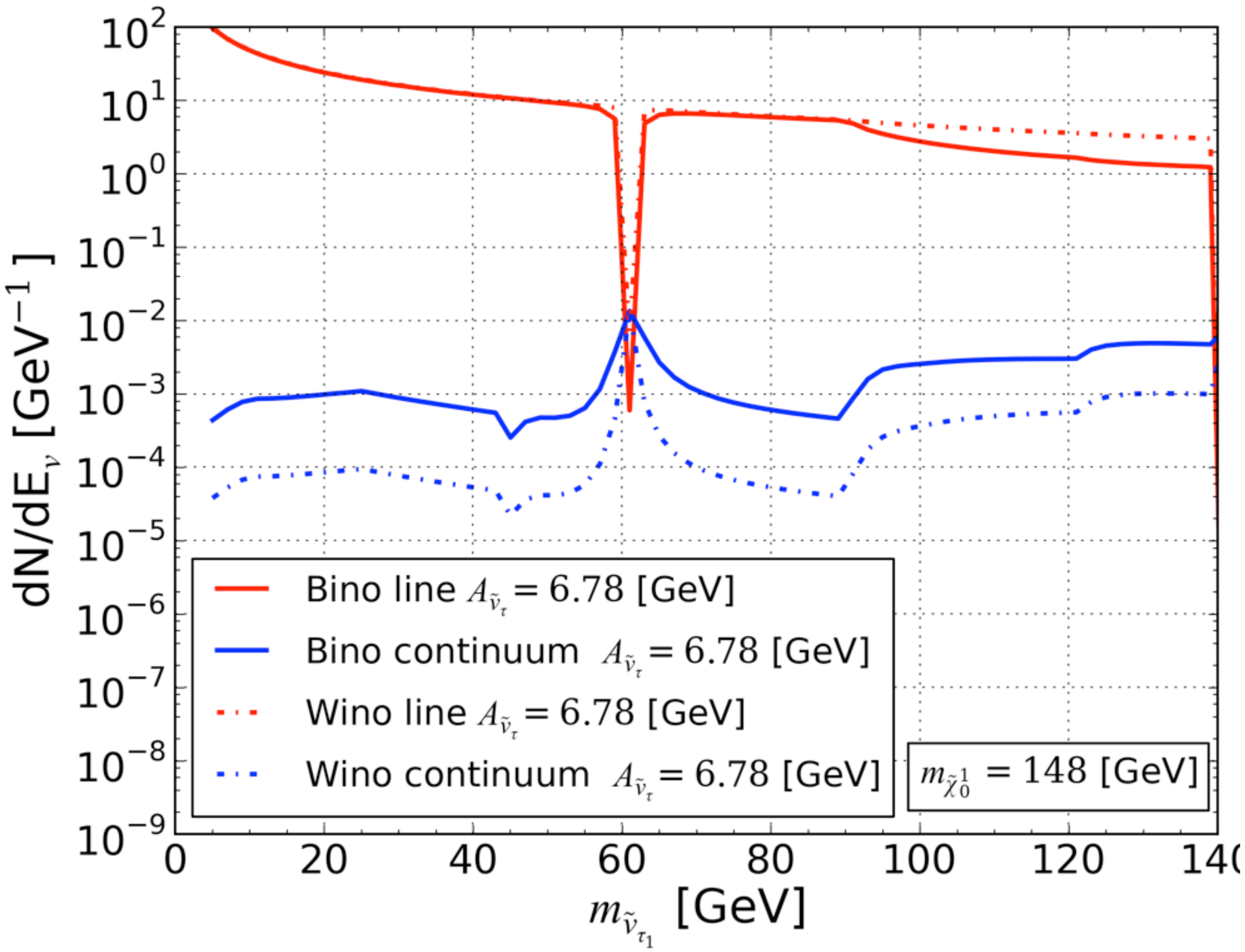
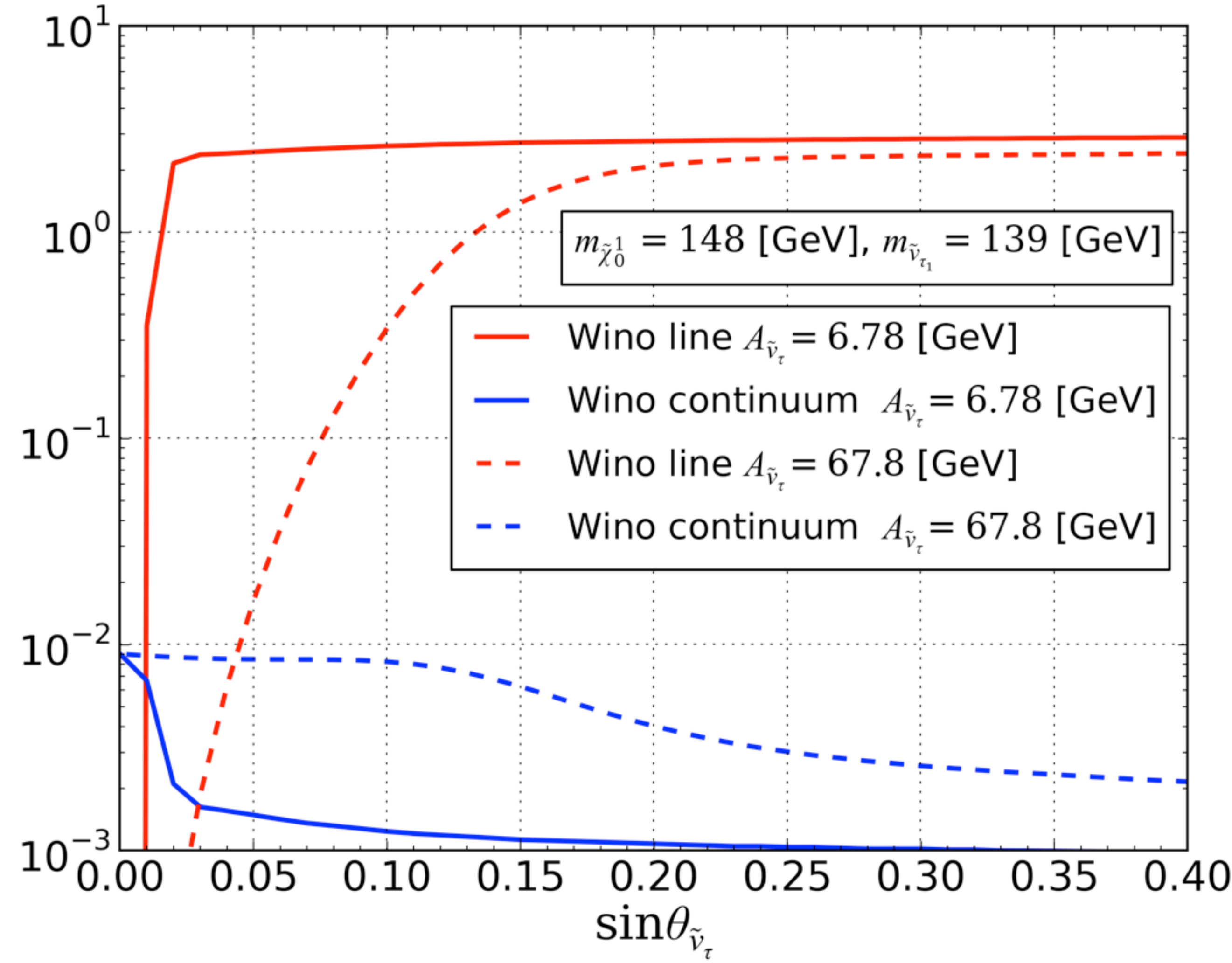
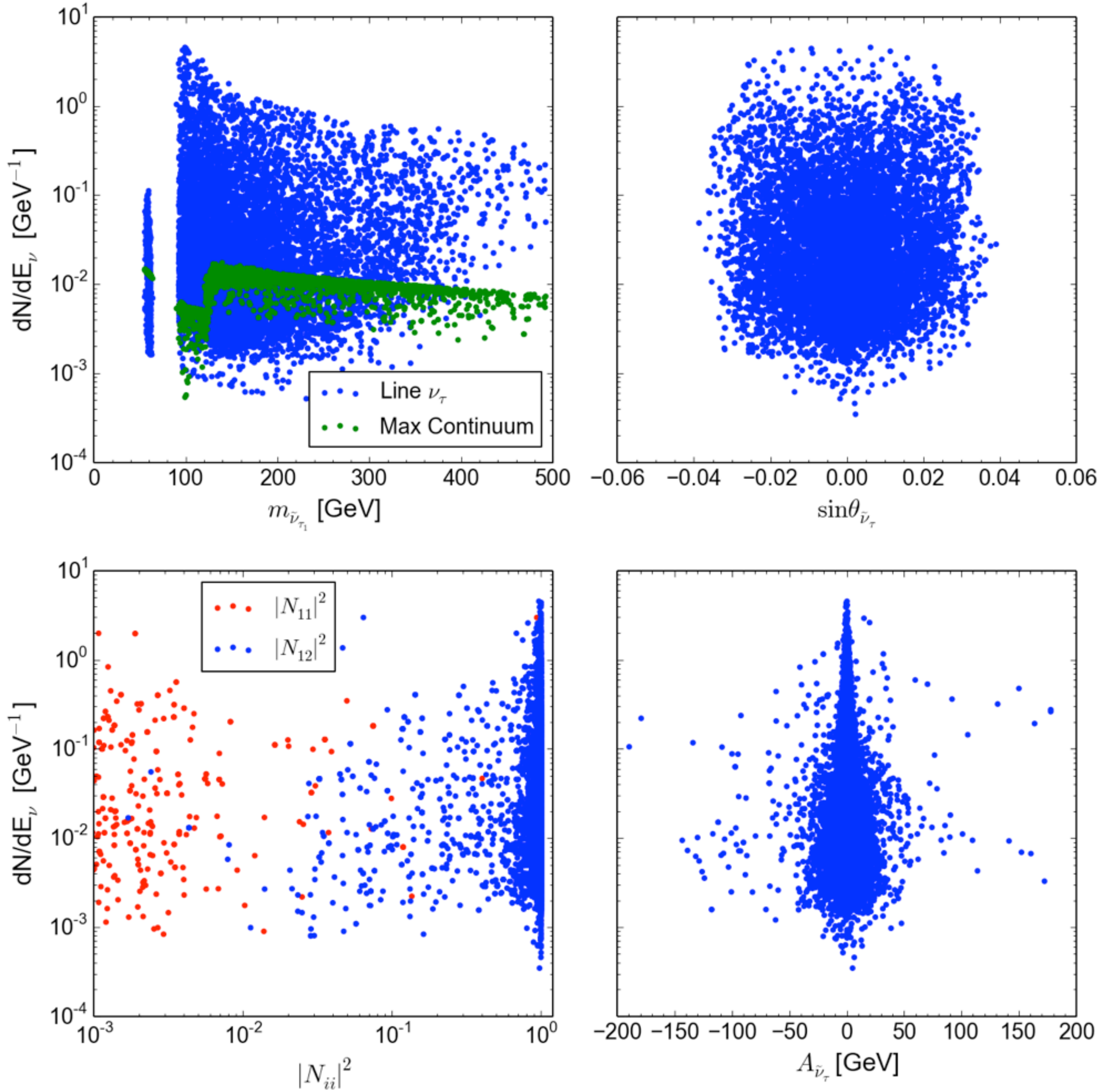




MSSM + RN parameter space



DM spike and plateau sensitivity

$$\rho_{\rm BH}(r) = \begin{cases} 0 & r < 4R_{\rm S} \\ \frac{\rho_{\rm sp}(r)\rho_{\rm pl}}{\rho_{\rm sp}(r)+\rho_{\rm pl}} & 4R_{\rm S} \leq r < R_{\rm sp} \\ \rho_0 \left(\frac{r}{r_0}\right)^{-\gamma} \left(1+\frac{r}{r_0}\right)^{-2} & r \geq R_{\rm sp}, \end{cases}$$

$$\Phi_{\rm Astro} = N_{\rm esc} \frac{1}{D^2} \int_{4R_{\rm S}}^{\infty} {\rm d}r\, r^2\, \rho_{\rm BH}^2(r)$$

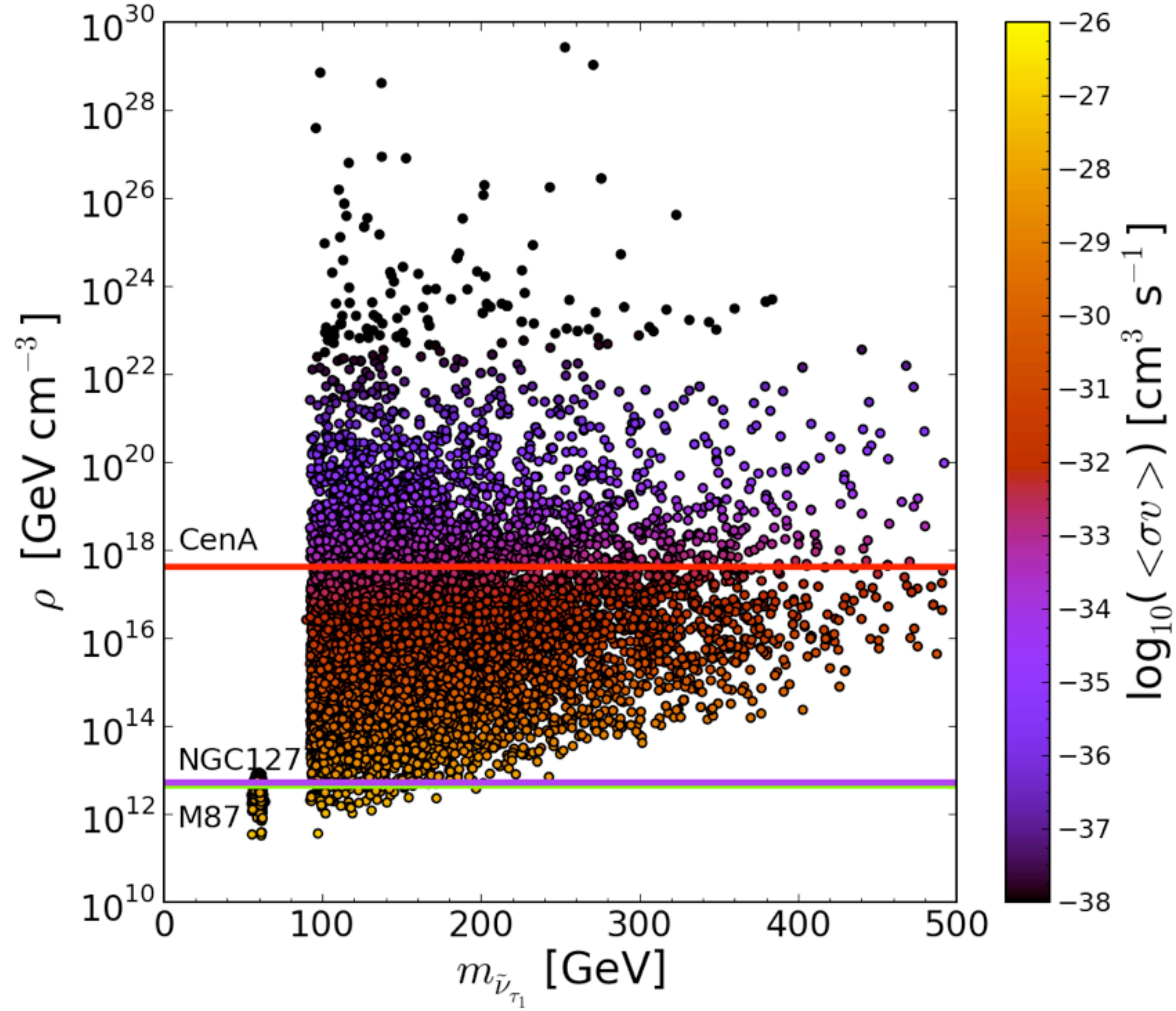
$$\rho_{\rm pl} = \frac{m_{\tilde{\nu}}}{\langle \sigma v \rangle t_{\rm BH}}$$

$$\rho_{\rm sp}(r) = \rho_{\rm R}\, g_\gamma(r) \left(\frac{R_{\rm sp}}{r}\right)^{\gamma_{\rm sp}}$$

$$\rho_{\rm R} = \rho_0 \left(\frac{R_{\rm sp}}{r_0}\right)^{-\gamma},$$

$$g_\gamma(r) \approx \left(1 - \frac{4R_{\rm S}}{r}\right)^3,$$

$$R_{\rm sp} = \alpha_\gamma r_0 \left(\frac{M_{\rm BH}}{\rho_0 r_0^3}\right)^{\frac{1}{3-\gamma}}$$



dSph J factors

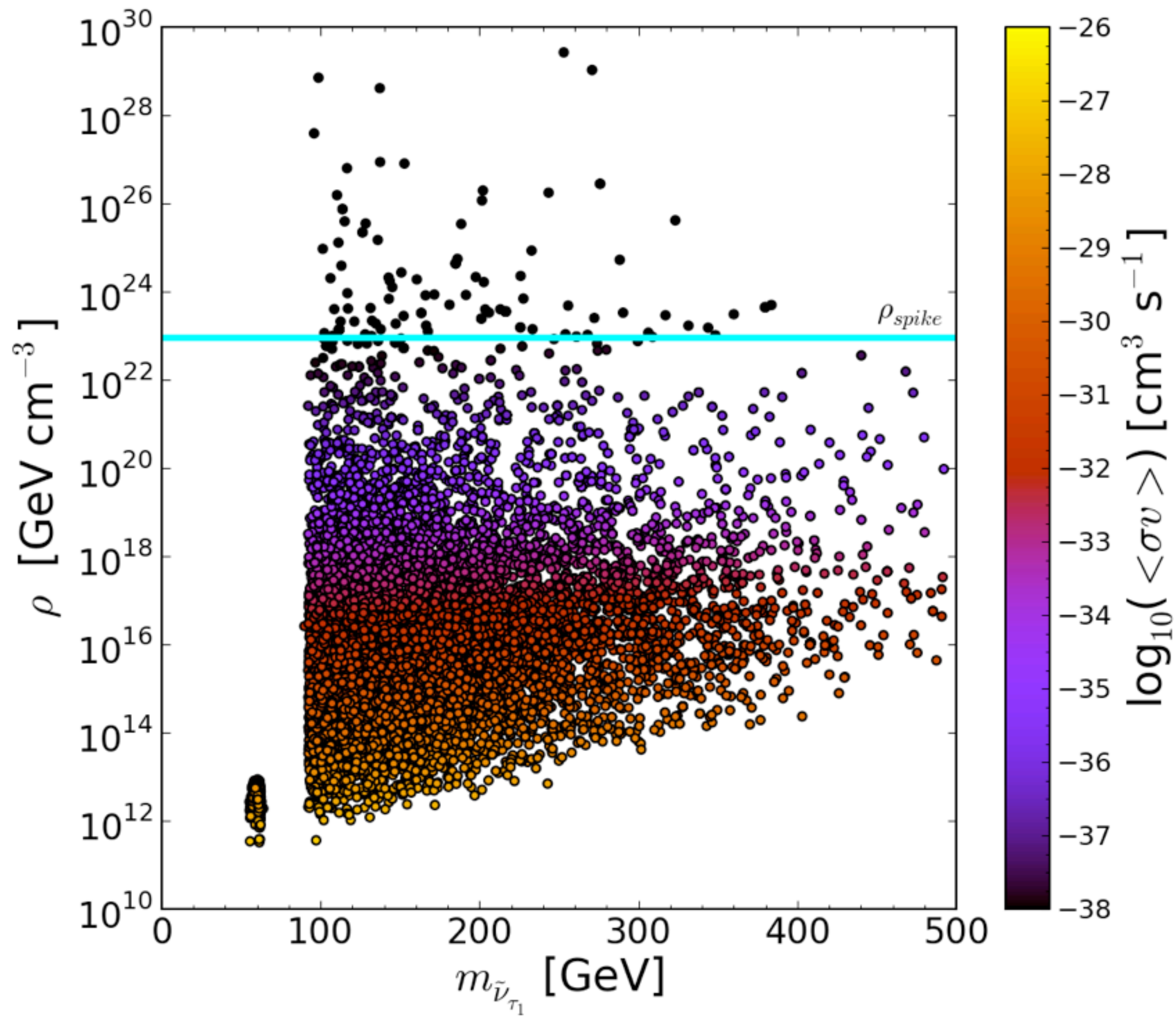
$$\frac{d\Phi_\nu}{dE} = \frac{1}{8\pi}\,\xi^2\,\frac{\langle\sigma v\rangle}{m^2_{\tilde{\nu}_{\tau_1}}}\,\frac{dN_\nu}{dE}\,\Phi_{\rm Astro}$$

$$\frac{dN_\nu}{dE} = \begin{cases} \mathcal{B}^\tau_\nu\,\frac{dN_{\nu_{\rm line}}}{dE}\,\delta(E - m_{\tilde{\nu}}) \\ \sum_k \mathcal{B}^k_\nu\,\frac{dN_{\nu_k}}{dE} \end{cases}$$

$$\Phi_{\rm Astro} \equiv J(\Delta\Omega) = \int_{\Delta\Omega} d\Omega' \int_{los} \rho^2_{\rm dwarf}(r(s,\theta))\,ds$$

dSph	D [kpc]	$J(1^\circ)$ [GeV^2 cm^{-5}]
Northern sky		
Draco	80	2.11×10^{19}
Ursa Minor	66	1.24×10^{19}
Sextans	86	8.09×10^{17}
Leo I	250	8.87×10^{17}
Leo II	205	1.37×10^{18}
Northern sky (ultra faint)		
Segue I	23	2.06×10^{17}
Ursa Major II	30	1.87×10^{20}
Segue II	35	1.72×10^{19}
Willman I	38	4.75×10^{19}
Coma	44	8.32×10^{19}
Boötes I	66	6.07×10^{18}
Ursa major I	97	6.79×10^{18}
Hercules	132	1.99×10^{18}
Canis Venatici II	160	4.13×10^{17}
Canis Venatici I	218	4.50×10^{18}
Leo V	180	1.88×10^{16}
LeoT	407	4.80×10^{17}
Southern sky		
Carina	101	1.05×10^{18}
Fornax	138	7.07×10^{17}
Sculptor	79	4.30×10^{18}
Southern sky (ultra faint)		
Leo IV	160	2.14×10^{16}
Reticulum II	30	5.88×10^{20}

DM spike and plateau sensitivity



DM spike parameters

Minispike in dSphs:

	dSph	r_0 [kpc]	ρ_0 [GeV cm^{-3}]	R_{sp} [pc]	ρ_R [GeV cm^{-3}]
$M_{BH} = 10^4(10^2)M_\odot$	Draco	2.09	0.99	1.5 (0.15)	$1.3 \times 10^3(1.3 \times 10^4)$
$R_S = 9.57 \times 10^{-9}(\times 10^{-12})$ pc	Reticulum II	4.28	2.81	0.63 (0.063)	$1.9 \times 10^4(1.9 \times 10^5)$

Spike in super massive black holes:

SMBH	M_{BH} [$M_\odot$]	R_S [pc]	D [Mpc]	ρ_0 [GeV cm^{-3}]	Φ_{Astro} [GeV^2 cm^{-5}]	Declination
M87	6.4×10^9	6.1×10^{-4}	16.4	2.3	3.5×10^{11}	+12°
CenA	5.5×10^7	5.3×10^{-6}	3	9×10^5	4.3×10^{20}	-43°
NGC1277	1.7×10^{10}	1.6×10^{-3}	20	495	2.5×10^{12}	+41°

$t_{BH} = 10^{10}$ years,

Dark Matter and Neutrino sectors in the MSSM can be related

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  - Dirac masses (G. Belanger et al 2010, B. Dumont et al 2012, CA and M.E. Cabrera 2014, CA et al 2015, ...)
  - Seesaw type I, II, III (high scale) (H. Haber et al 1997, N. Arkani-Hamed et al 2000, D. Hooper et al 2005, CA and N. Fornengo 2007, ...)
  - Inverse seesaw, linear seesaw (low scale) (CA et al 2008, H. An et al 2012, V. De Romeri and M. Hirsch 2012, S. Banerjee et all 2013, ...)
- Modification of the MSSM scalar sector as well
- Mixed sneutrino is again a viable DM candidate
- Sneutrino as DM addresses two issues at once

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