WWU MÜNSTER

IceCube constraints on the scotogenic model

DESY theory workshop

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Based on: T. de Boer et al. (2021-08). "Indirect detection constraints on the scotogenic dark matter model". In: *JCAP* 2021.08, p. 038. arXiv: 2105.04899 [hep-ph]

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DESY.

Scotogenic model

- Originally proposed by Ernest Ma (*scotos*: Greek for darkness)
- Dark matter generates neutrino masses
- Two viable dark matter candidates (fermion singlet & scalar doublet)

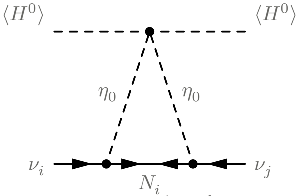


Figure: Neutrino loop in the scotogenic model

Field	Generation	Spin	$U(1)_Y \times SU(2)_L \times SU(3)_c$	$\mathbb{Z}_2$
η	1	0	$(\frac{1}{2}, 2, 1)$	-1
N	3	$\frac{1}{2}$	$(0, 1, 1)$	-1
SM particles	—	—	—	$+1$

Part of the Lagrangian

$$\mathcal{L} \supset y_{i\alpha}(\eta^\dagger l_\alpha)N_i + \text{h.c.}$$
$$- \lambda_3(H^\dagger H)(\eta^\dagger \eta)$$
$$- \lambda_4(H^\dagger \eta)(\eta^\dagger H)$$
$$- \frac{\lambda_5}{2}\left[(H^\dagger \eta)^2 + (\eta^\dagger H)^2\right]$$

After EWSB:

$$\eta^0 = \frac{1}{\sqrt{2}}(\eta_R + i\eta_I)$$

$$m_R^2 = m_\eta^2 + (\lambda_3 + \lambda_4 + \lambda_5)\langle H^0\rangle^2$$
$$m_I^2 = m_\eta^2 + (\lambda_3 + \lambda_4 - \lambda_5)\langle H^0\rangle^2$$

Neutrino loop can be evaluated

$$(M_\nu)_{\alpha\beta} \approx 2\lambda_5\langle H^0\rangle \sum_{i=1}^{3} \frac{y_{i\alpha}y_{i\beta}m_{N_i}}{32\pi^2(m_{R,I}^2 - m_{N_i}^2)} \times \times \left[1 + \frac{m_{N_i}^2}{m_{R,I}^2 - m_{N_i}^2}\ln\left(\frac{m_{N_i}^2}{m_{R,I}^2}\right)\right]$$

Inelastic scattering

- Majorana Neutrino masses violate Lepton number

  $\Rightarrow$ λ_5 naturally small ('t Hooft)

  $\Rightarrow$ Mass splitting $\delta = |m_R - m_I| \approx \lambda_5 \frac{\langle H^0 \rangle^2}{2m_{R,I}}$ small

- Scalar DM scattering off nuclei

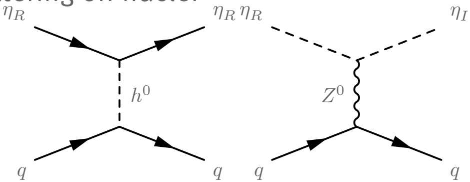


Figure: Scattering diagrams for scalar DM.

Why IceCube?

- Gravitation pulls DM towards sun

  $\Rightarrow$ Higher relative velocity as for direct detection on earth
- DM scatters off nuclei in the sun
  - Inelastic scattering possible if $\delta < \frac{\mu v^2}{2}$
- DM looses kinetic energy and is captured

  $\Rightarrow$ DM overdensity
- Annihilation into neutrinos
- Detect at IceCube

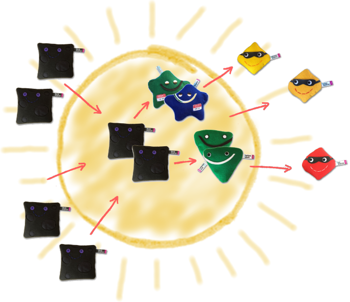
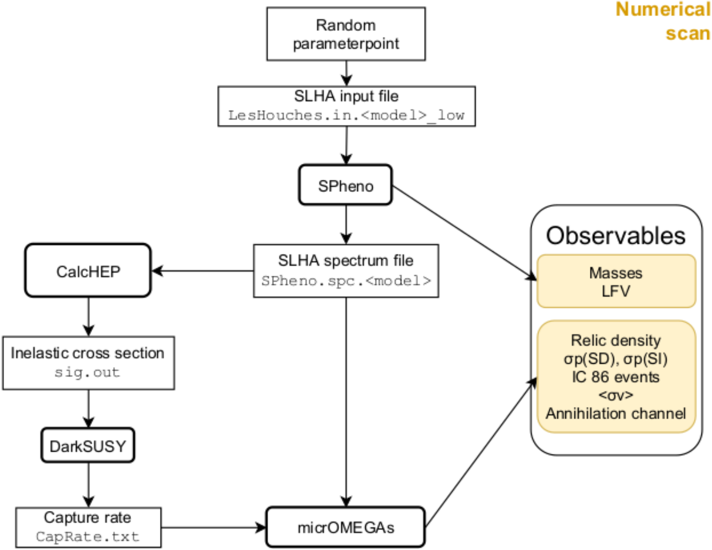


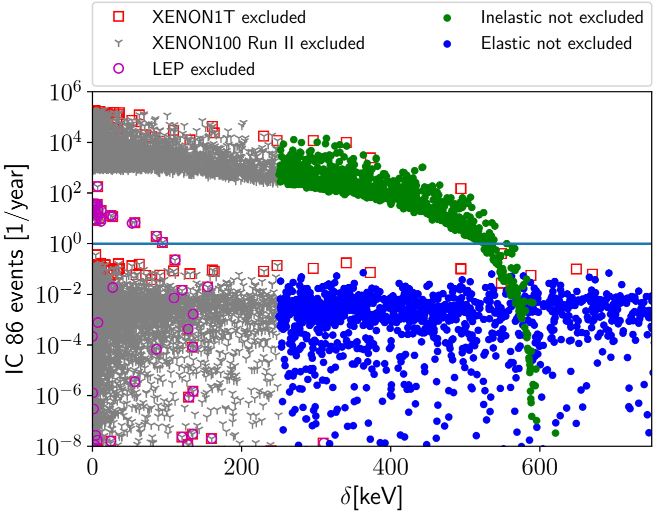
Figure: Figure from R. Busse & `www.particlezoo.net`

Numerical scan



Constraints

- KATRIN limits on neutrino mass
- Neutrino osciallation parameter (mixing angles...)
- Relic density: $\Omega h^2 = 0.12 \pm 0.02$
- XENON1T limits on elastic scattering
- XENON100 limits on inelastic scattering
- LEP limit on charged scalars ($m_{\eta^+} > 98$ GeV)
- Invisible Z^0 decays ($m_{\mathrm{DM}} > m_{Z^0}/2$)


XENON1T excluded
XENON100 Run II excluded
LEP excluded
Inelastic not excluded
Elastic not excluded
IC 86 events [1/year]
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
0
200
400
600
δ[keV]

Conclusion

- Scotogenic model
  - Scalar doublet and fermion singlet dark matter
  - Neutrino masses at one loop
- Inelastic scattering occurs naturally
- Scattering in the sun (higher relative velocity $\rightarrow$ more sensitive to inelastic scattering)
- Dark matter annihilates $\Rightarrow$ Neutrinos
- IceCube can exclude mass splitting up to $\delta \approx 500$ keV
- $\lambda_5 \gtrsim 1.6 \cdot 10^{-5} \cdot m_{\mathrm{DM}}/\mathrm{TeV}$

Thank you for your attention

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Any Questions?

Backup slides

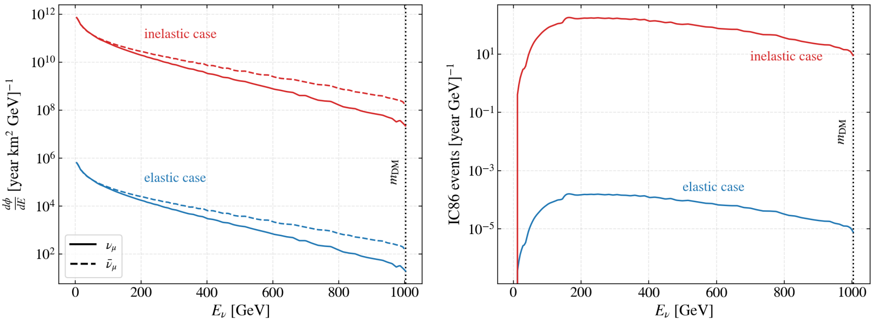

Figure: Neutrino flux (left) and IceCube event rate.

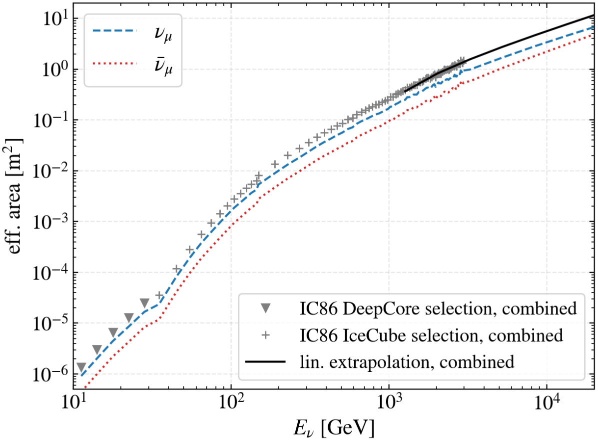

Figure: IceCube effective area.