

Probing the Sun for BSM Physics Using RHESSI

Presenter: R. Andrew Gustafson¹

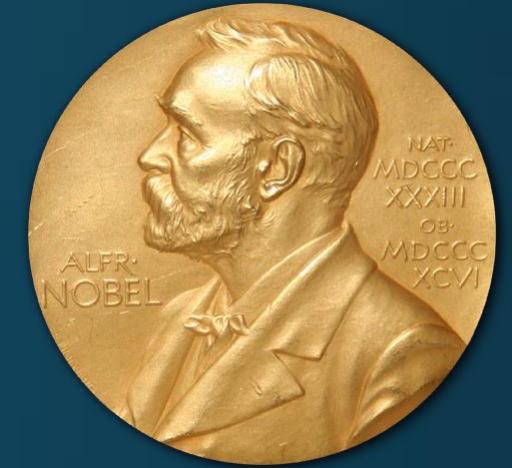
Co-Authors: Ryan Plestid^{2,3,4}, Ian Shoemaker¹



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2. Department of Physics and Astronomy, University of Kentucky
3. Theoretical Physics Department, Fermilab
4. Walter Burke Institute of Theoretical Physics, Caltech

Where is Physics Beyond the Standard Model (BSM)?

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It does not interact with Standard Model (SM) physics in an appreciable way.

BSM physics could be

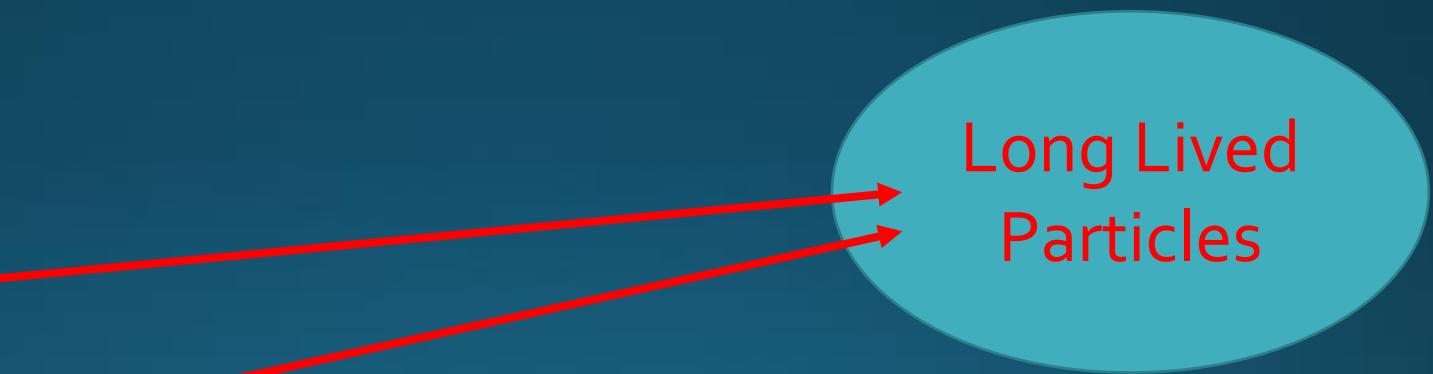
- 1) Rare
- 2) Weak coupling w/ SM
- 3) Too heavy to probe

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BSM physics could be

- 1) Rare
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Long Lived Particles

Outline

- Long-Lived Particles Overview
- RHESSI
- Models Considered
- Future Improvements

What are Long-Lived Particles (LLPs)?

- Unstable
- Travel macroscopic distances before decaying
- Produced on-shell (real)

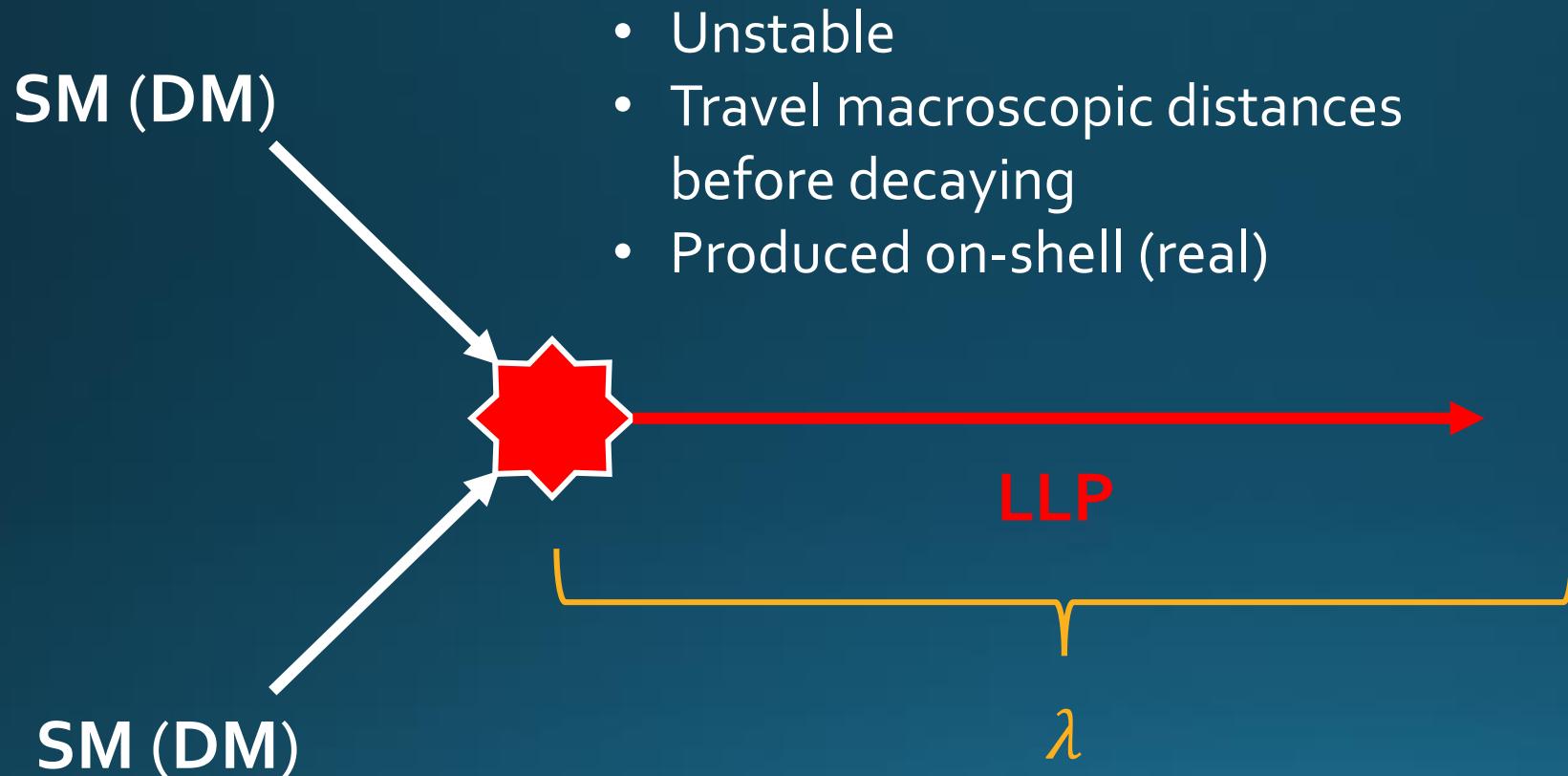
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SM (DM)

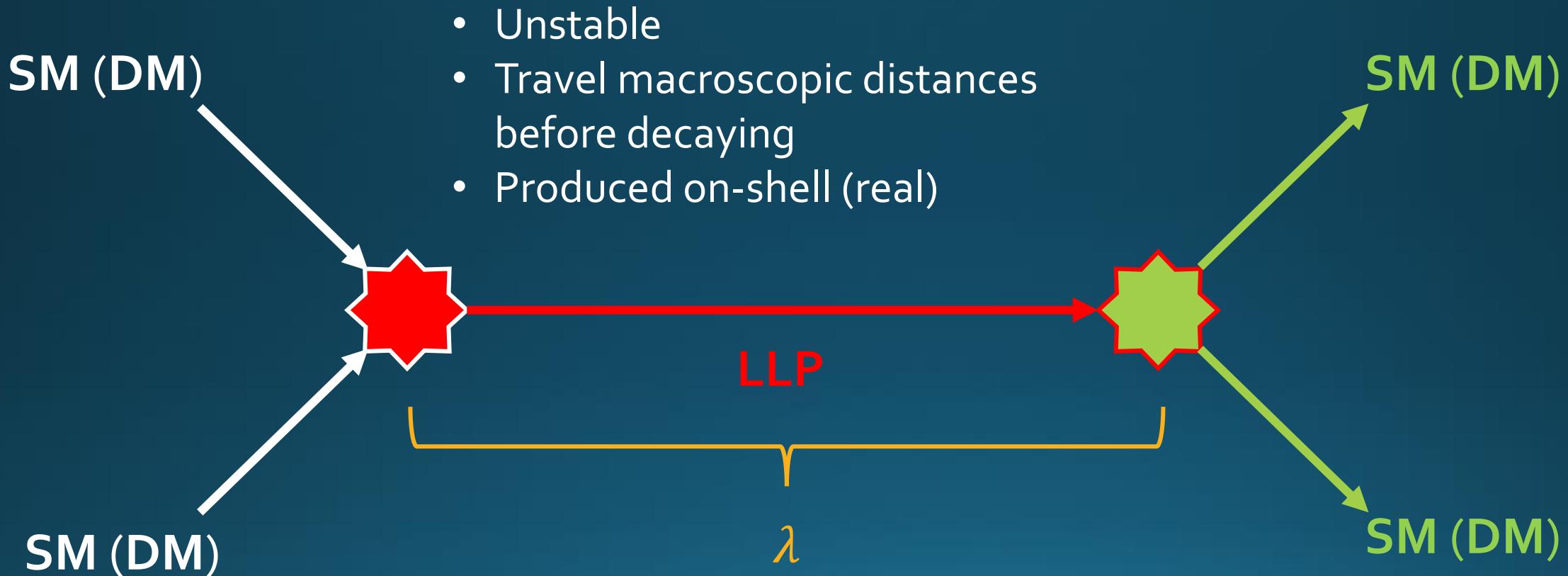
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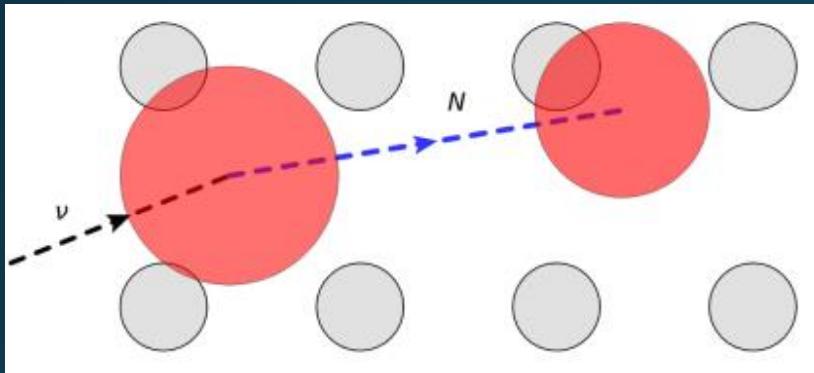
What are Long-Lived Particles (LLPs)?



Where to Search for LLPs

Large Volume Detectors

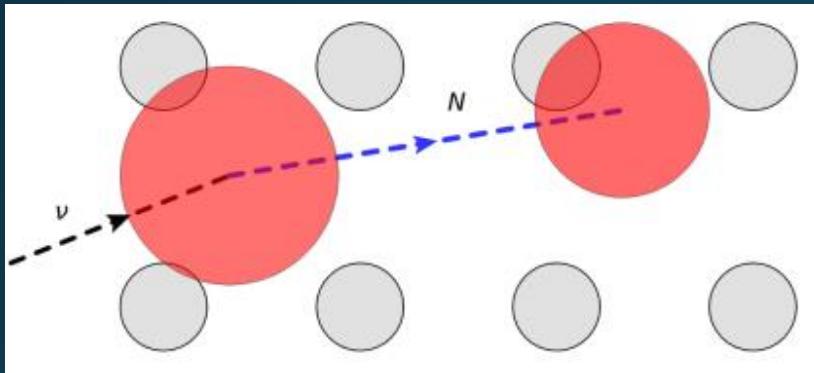
$$\lambda < L_{det}$$



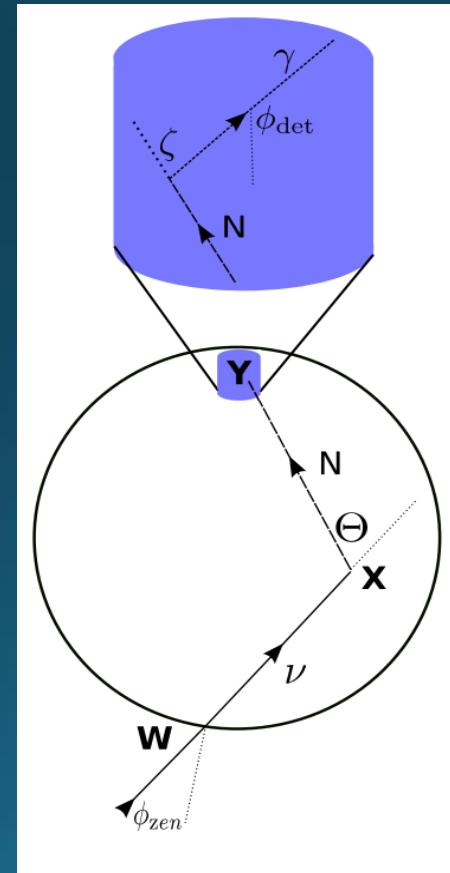
[1]Coloma, P., Machado, P. A., Martinez-Soler,
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Where to Search for LLPs

Large Volume Detectors
 $\lambda < L_{det}$



Earth
 $L_{det} \ll \lambda \ll R_\oplus$

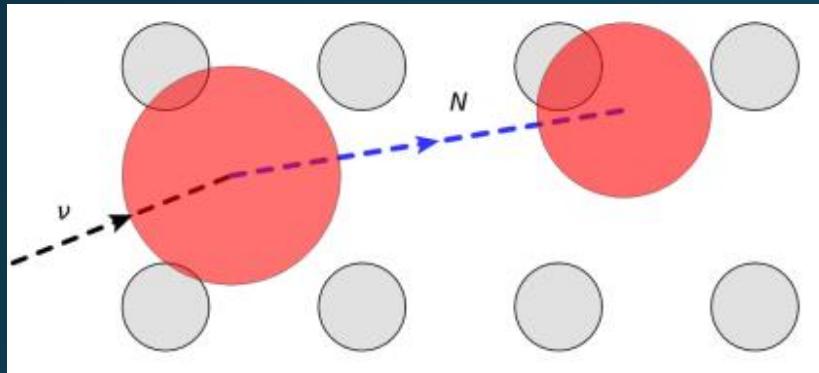


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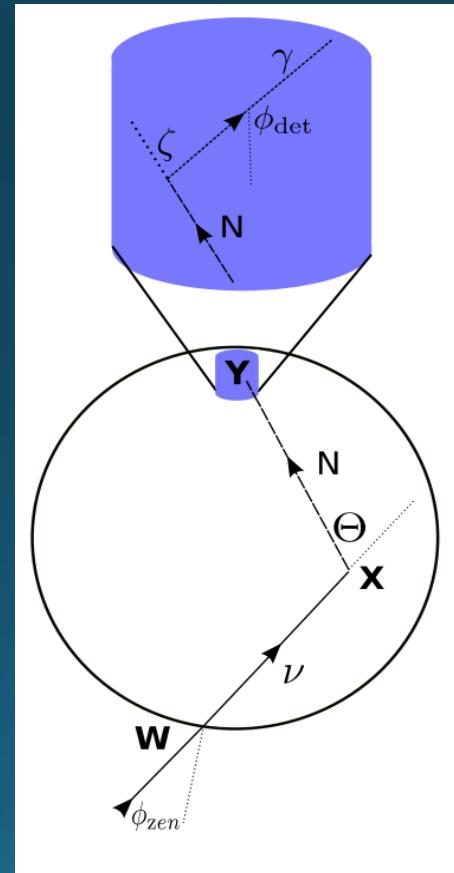
[2] Gustafson, R. A., Plestid, R., & Shoemaker, I. M. (2022)

Where to Search for LLPs

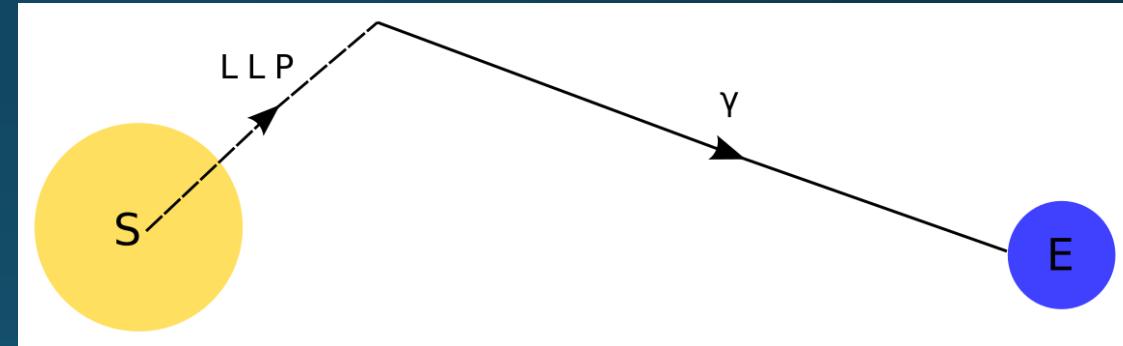
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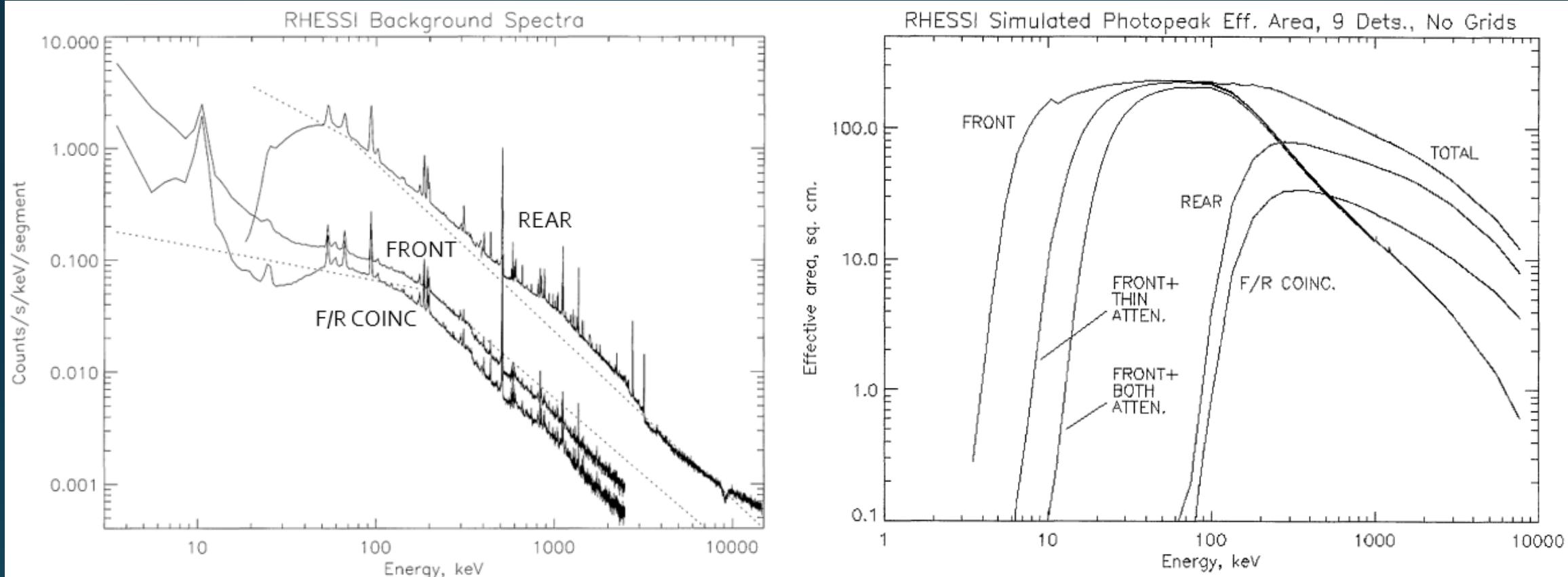
Sun
 $R_\odot \ll \lambda \ll d_\odot$



[1] Coloma, P., Machado, P. A., Martinez-Soler, I., & Shoemaker, I. M. (2017).

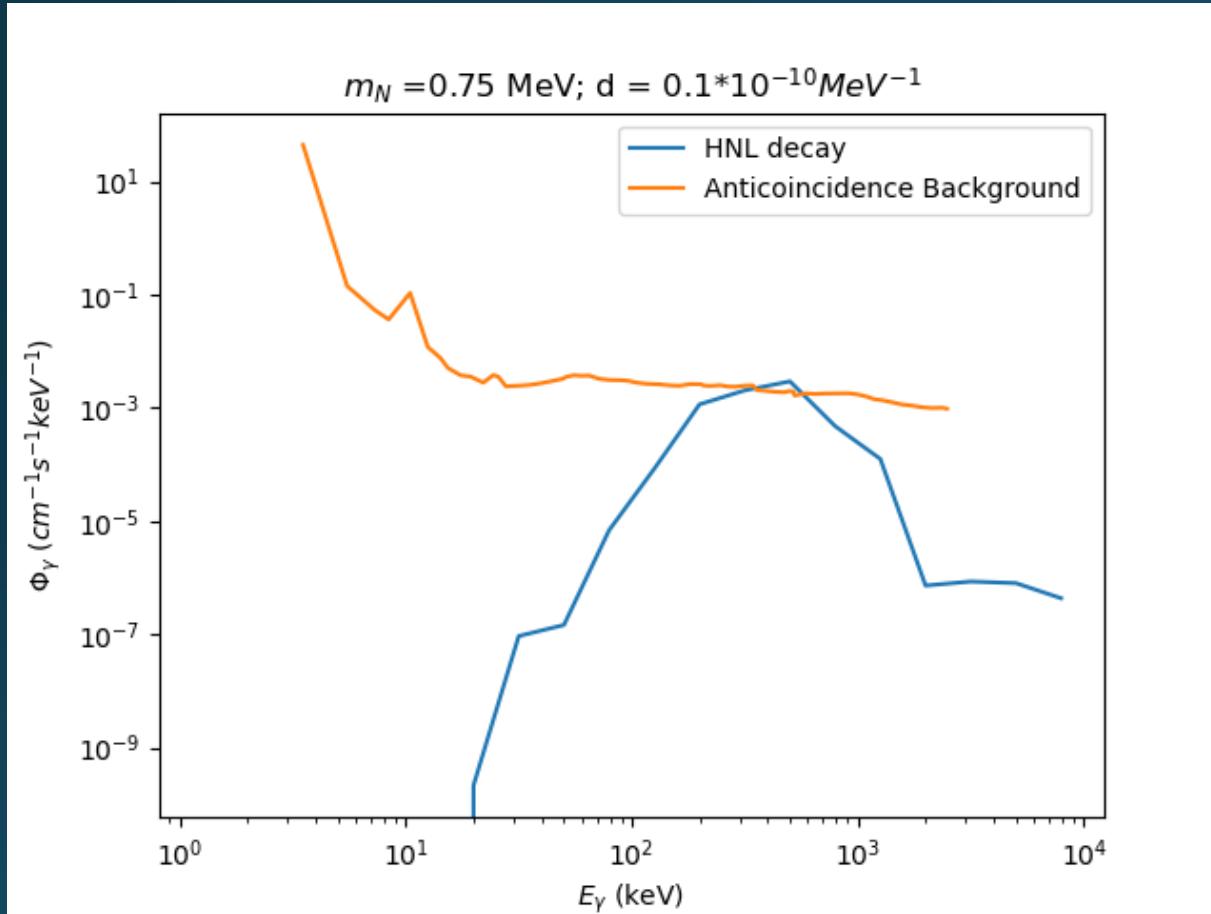
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RHESSI- Reuven Ramaty High-Energy Solar Spectroscopic Imager



[3] Smith, D. M., Lin, R. P., Turin, P., Curtis, D. W., Primbsch, J. H., Campbell, R. D., ... & Schwartz, R. (2003).

RHESSI (cont)

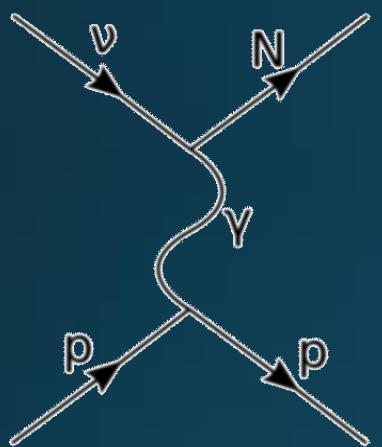


To obtain the background flux, we multiply a smoothed background count by the effective area.

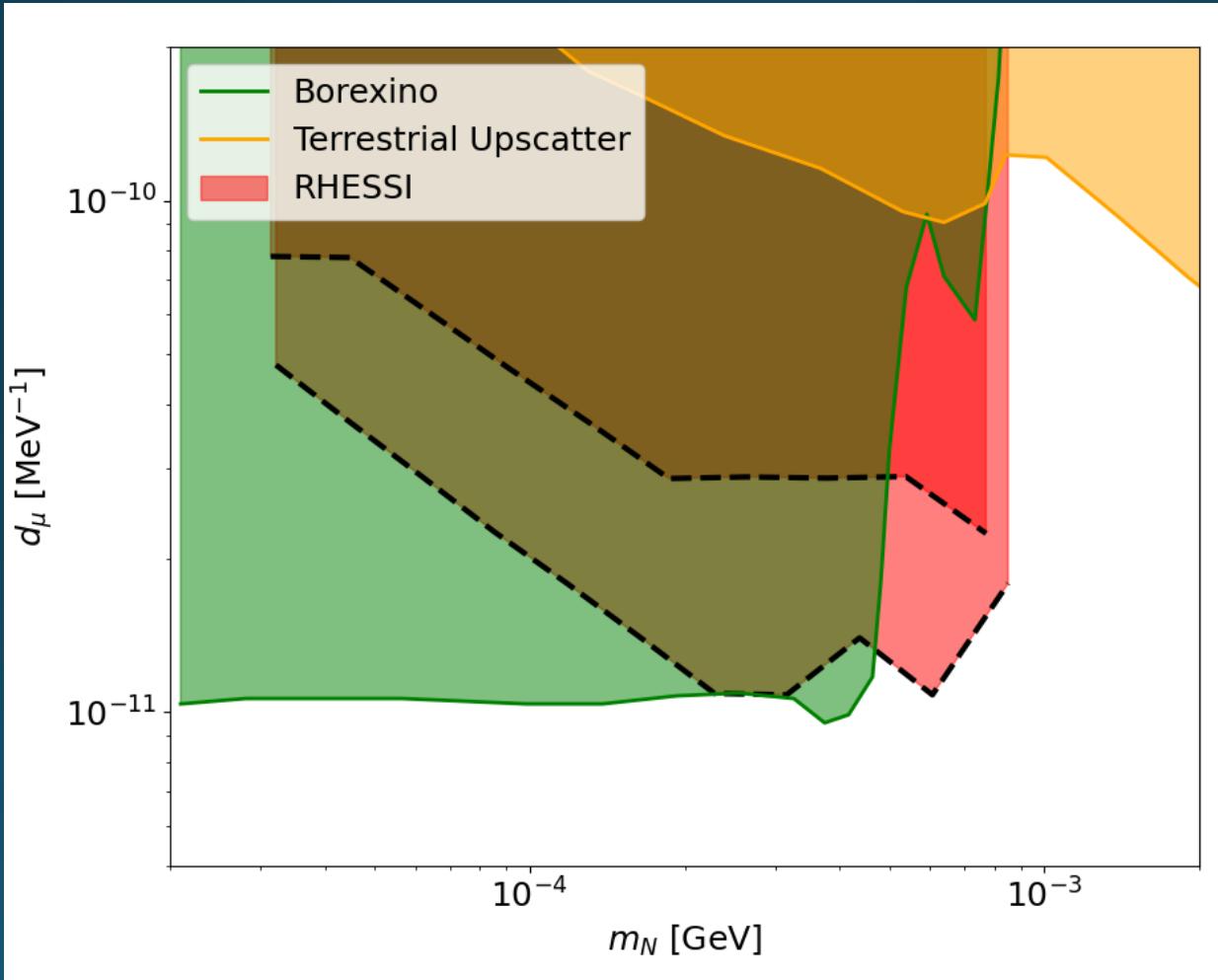
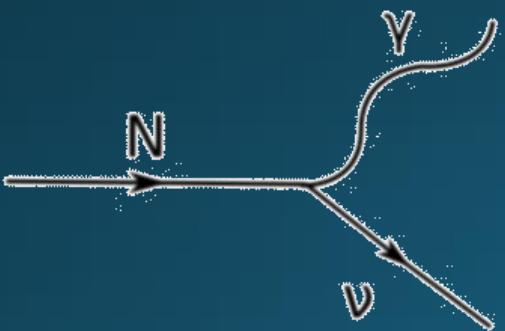
Note: A more formal analysis would work the other way; taking the flux and transforming it into a RHESSI count.

Transition Dipole Model

Production



Decay



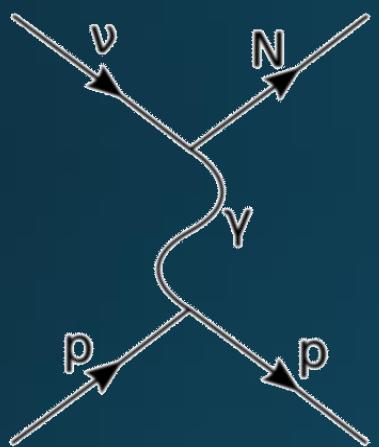
Parameters:

d (Transition dipole strength)
 m_N (HNL Mass)

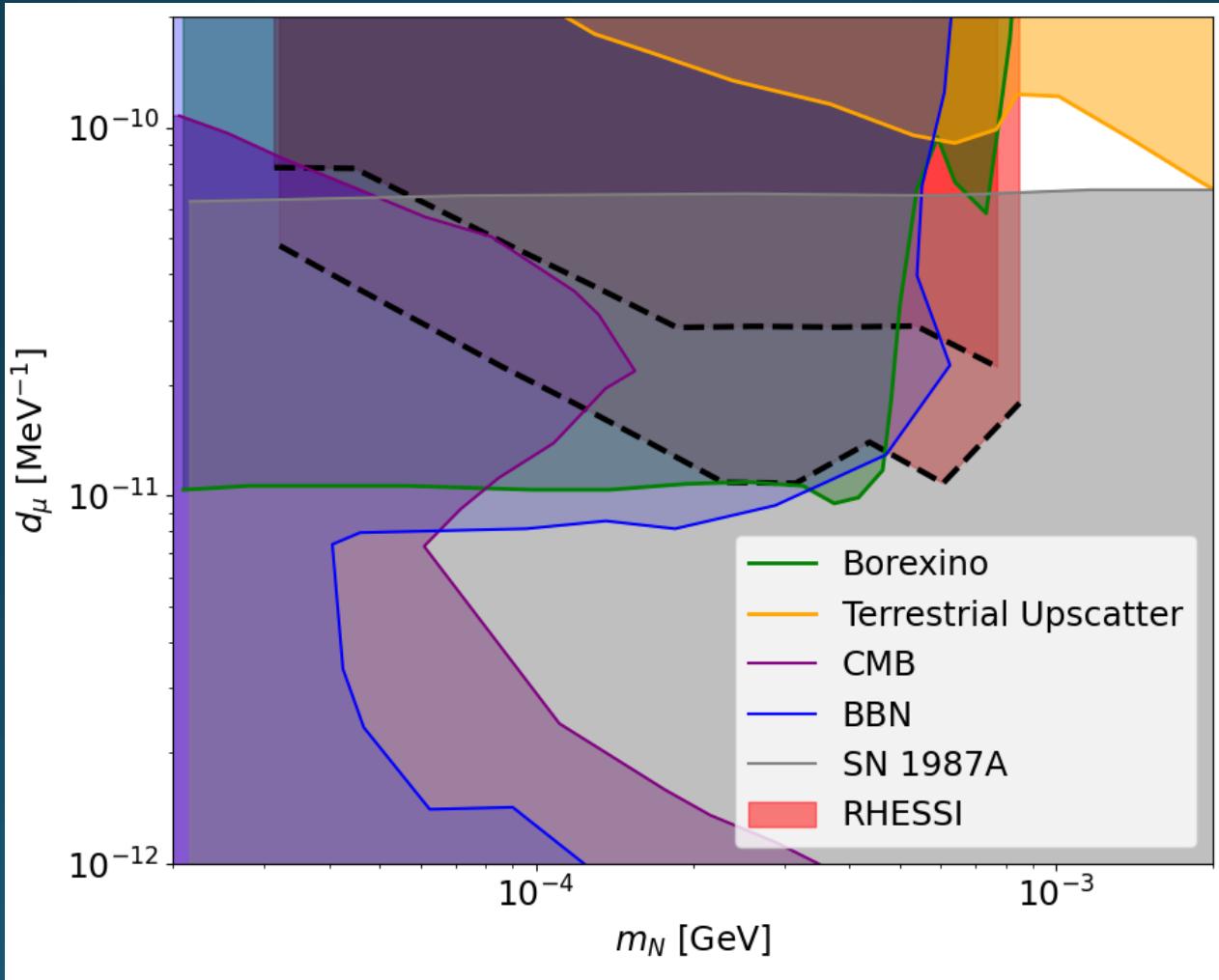
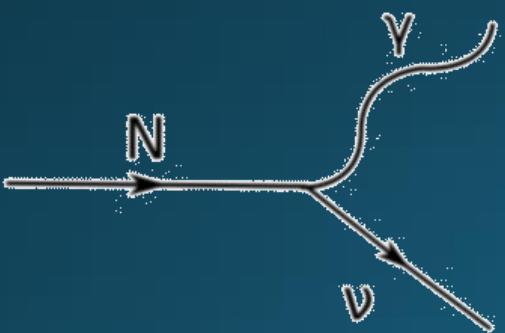
CMB+BBN- [4] Magill, G., Plestid, R., Pospelov, M., & Tsai, Y. D. (2018).
Borexino + 1987A – [5] Brdar, V., Greijo, A., Kopp, J., & Opferkuch, T. (2021).
Borexino – [6] "Comprehensive measurement of pp-chain solar neutrinos." *Nature* 562, no. 7728 (2018): 505-510.
Terrestrial Upscattering – [7] Plestid, R. (2021).

Transition Dipole Model

Production



Decay

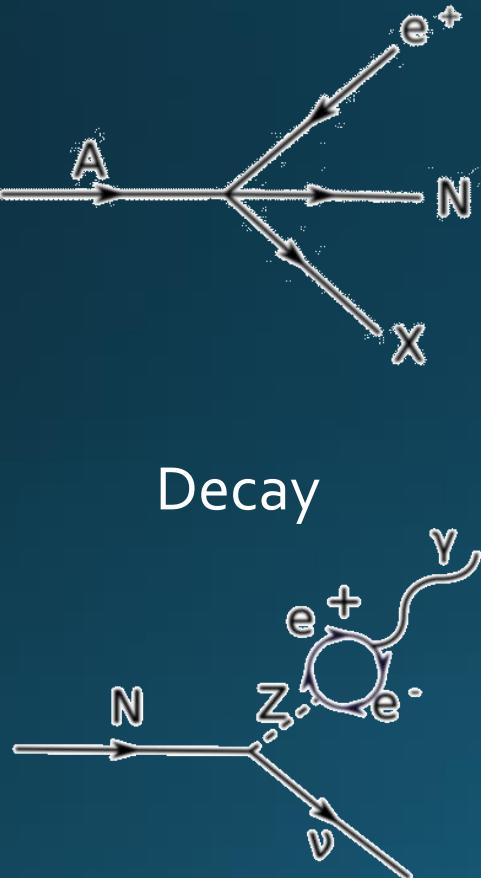


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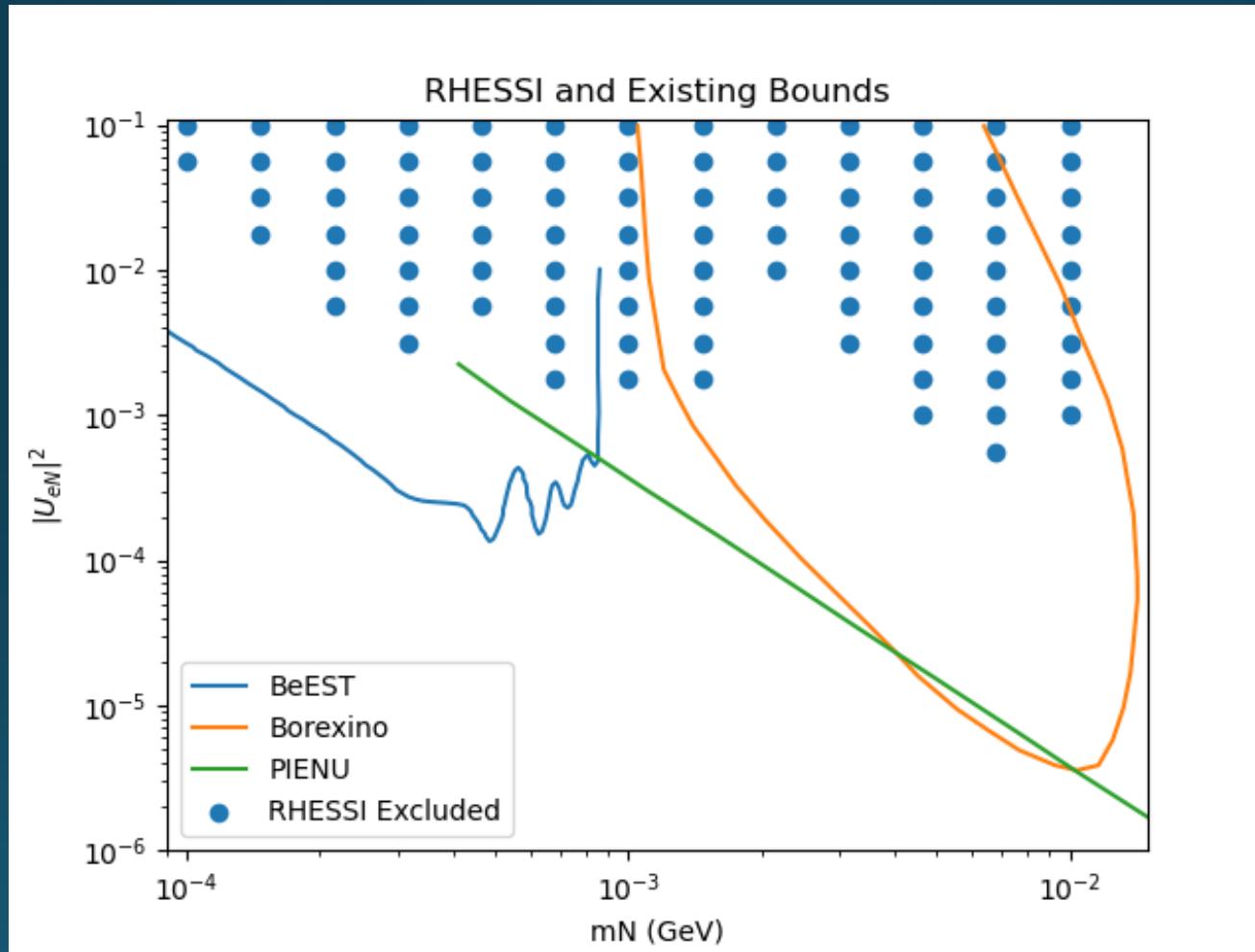
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Mass Mixing Model

Production



Decay



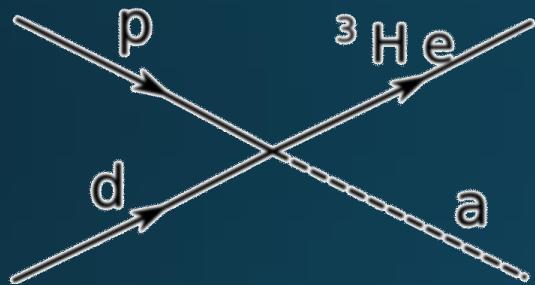
Parameters:

U_{eN} (HNL-electron neutrino coupling)
 m_N (HNL mass)

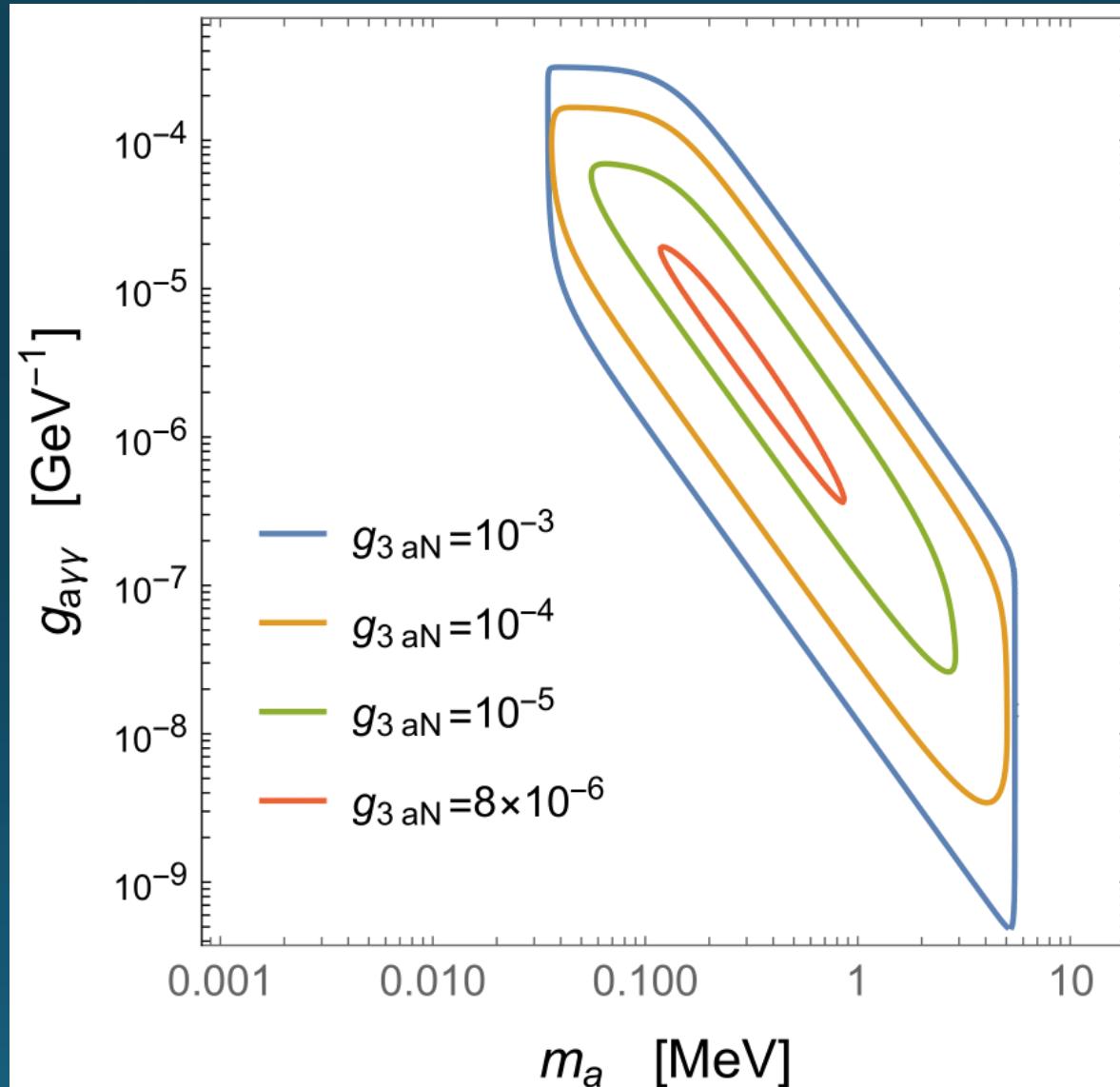
PIENU- [8] Bryman, D. A., & Shrock, R. (2019).
BeEST- [9] Friedrich, S., Kim, G. B., Bray, C., Cantor, R., Dilling, J., Fretwell, S., ... & Leach, K. G. (2021). Bellini, G., Benziger, J., Bick, D., Bonfini, G., Bravo, Borexino- [10] D., Avanzini, M. B., ... & Borexino Collaboration. (2013).

Solar Axion

Production



Decay



Parameters:

- g_{3aN} (isovector coupling of axions to nucleons)
- $g_{a\gamma\gamma}$ (coupling of axions to photons)
- m_a (axion mass)

Further Improvements

- Currently, we have no model for the solar background, so we place bounds where the BSM flux exceeds the observed flux. If we had a background model, then our exclusion could improve with exposure.
- We do not currently consider the angular distribution of the BSM flux. Doing so could reduce our background (we could see a “halo” of light from decays around the Sun).

References

- [1] Coloma, P., Machado, P. A., Martinez-Soler, I., & Shoemaker, I. M. (2017). Double-cascade events from new physics in IceCube. *Physical Review Letters*, 119(20), 201804.
- [2] Gustafson, R. A., Plestid, R., & Shoemaker, I. M. (2022). Neutrino portals, terrestrial upscattering, and atmospheric neutrinos. *Physical Review D*, 106(9), 095037.
- [3] Smith, D. M., Lin, R. P., Turin, P., Curtis, D. W., Primbsch, J. H., Campbell, R. D., ... & Schwartz, R. (2003). The RHESSI spectrometer. *The Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) Mission Description and Early Results*, 33-60.
- [4] Magill, G., Plestid, R., Pospelov, M., & Tsai, Y. D. (2018). Dipole portal to heavy neutral leptons. *Physical Review D*, 98(11), 115015.
- [5] Brdar, V., Greljo, A., Kopp, J., & Opferkuch, T. (2021). The neutrino magnetic moment portal: cosmology, astrophysics, and direct detection. *Journal of Cosmology and Astroparticle Physics*, 2021(01), 039.
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- [8] Bryman, D. A., & Shrock, R. (2019). Improved constraints on sterile neutrinos in the MeV to GeV mass range. *Physical Review D*, 100(5), 053006.
- [9] BeEST- Friedrich, S., Kim, G. B., Bray, C., Cantor, R., Dilling, J., Fretwell, S., ... & Leach, K. G. (2021). Limits on the Existence of sub-MeV Sterile Neutrinos from the Decay of Be 7 in Superconducting Quantum Sensors. *Physical Review Letters*, 126(2), 021803.
- [10] Bellini, G., Benziger, J., Bick, D., Bonfini, G., Bravo, D., Avanzini, M. B., ... & Borexino Collaboration. (2013). New limits on heavy sterile neutrino mixing in B 8 decay obtained with the Borexino detector. *Physical Review D*, 88(7), 072010.

Thank You!

Questions?

Extra Slide 1: Theory Equations

Dipole Lagrangian

$$L_{int} = \sum_a d_a F^{\mu\nu} \bar{N} \sigma_{\mu\nu} P_L \nu_a$$

Mass-Mixing Portal

$$\nu_e = U_{eN} N + \sum_{i=1}^3 U_{ei} \nu_i$$

Extra Slide 2: Flux Calculations

Photon Flux from HNL Flux

$$\Phi_\gamma = \Phi_N \left[\exp\left(-\frac{R_\odot}{\lambda}\right) - \exp\left(-\frac{d_\odot}{\lambda}\right) \right]$$

Mass-Mixing HNL Flux

$$\Phi_N = \Phi_\nu |U_{eN}|^2 \sqrt{1 - m_N^2/E_N^2}$$

Photon Flux for Axions

$$\Phi_\gamma = \Phi_\nu^{pp} |g_{3an}|^2 \left[\frac{p_a}{p_\gamma} \right]^2 \left[\exp\left(-\frac{R_\odot}{l_{abs}}\right) - \exp\left(-\frac{d_\odot}{\lambda}\right) \right]$$

Where $l_{abs}^{-1} = \lambda^{-1} + l_{scatter}^{-1}$