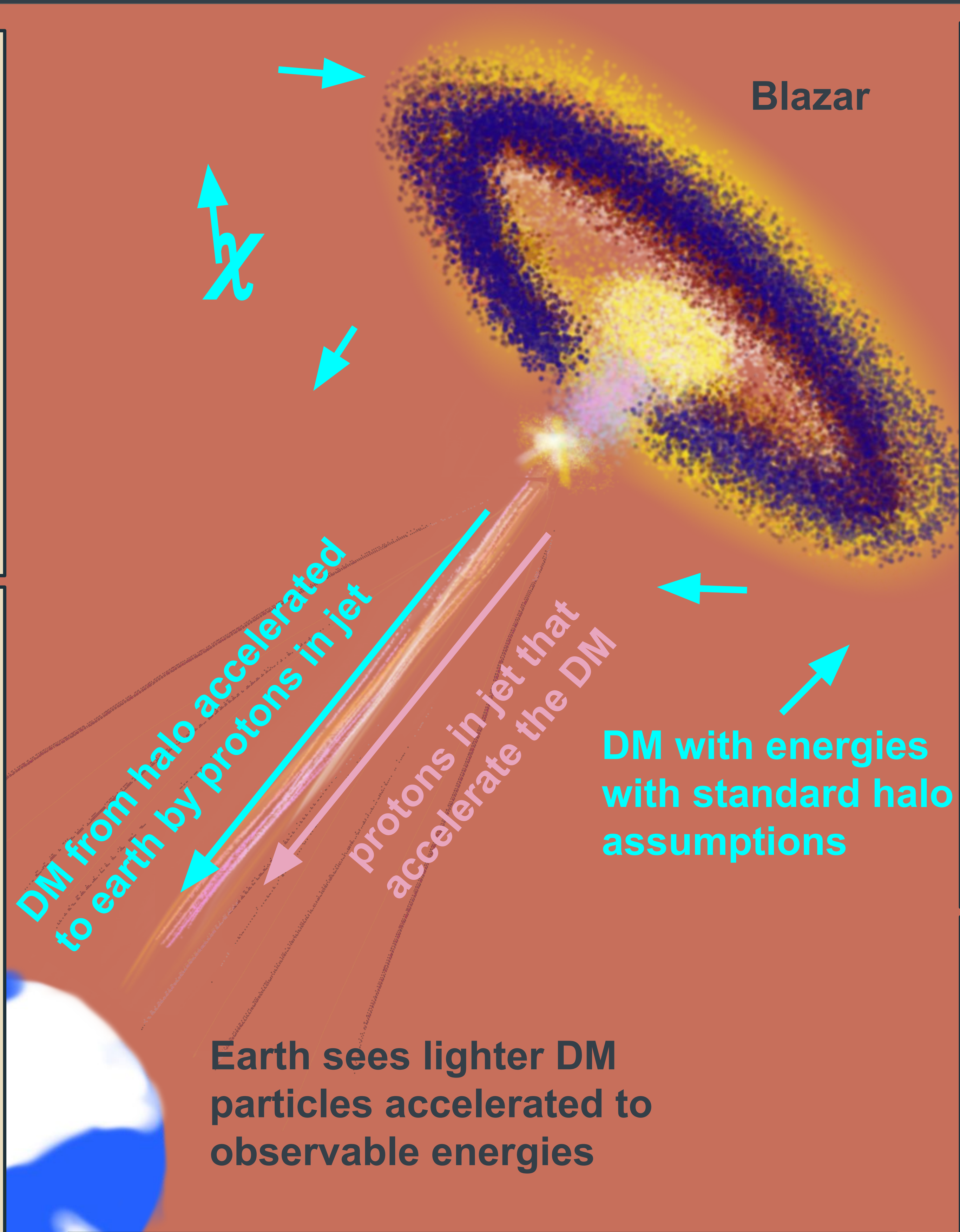
Blazar-Boosted Dark Matter: limits with xenon-based detectors

Contact: Erin Barillier erin.barillier@physik.uzh.ch

Why BBDM? What is it?

Blazar-boosted dark matter (BBDM) may allow for weakly-interacting massive particles (WIMPs) with lower (sub-GeV) energies to be accelerated to energies detectable by liquid xenon rare event detectors, which are mostly sensitive to 10-1000 GeV recoils. We combine astrophysical modeling of the blazar jet with several dark matter density profiles and a detailed detector response analysis using the published XENON1T likelihood and extended energy range public LZ WIMP Search 2022 data for the first time.



The Source

Blazar: TXS 0506+056
- z=0.3365±0.0010 [1]
- only blazar associated with high-energy neutrinos detected by IceCube (evidence of high energy protons in the jet and dominance of hadronic processes) [2]

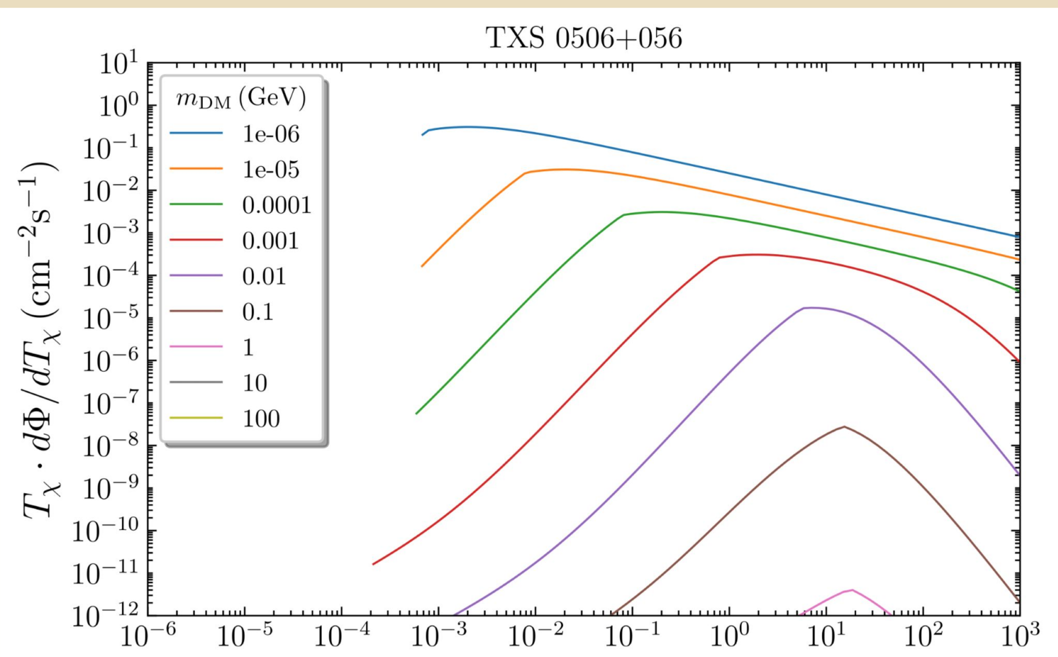
Boosting mechanism: **proton-WIMP** interactions within the jet
- same interaction at the source and detector
- assume that hadronic luminosities are dominant over leptonic luminosities in the jet

Dark matter density profile: **3-zone model [3]**
- central spike ($4R_s < r \leq R_{inf}$) + Gondolo-Silk ($R_{inf} < r \leq R_{spike}$)[4] + Navarro-Frenk-White ($r > R_{spike}$)[5]

$$\rho_{3z}(r) = \left(1 - \frac{4R_S}{r}\right)^3 \rho_{\rm NFW}(R_{\rm spike}) \times \begin{cases} 0 & r \leq 4R_S; \\ (R_{\rm spike}/R_{\rm inf})^{\alpha_{\rm GS}} (R_{\rm inf}/r)^{\alpha_{\rm B}} & 4R_S < r \leq R_{\rm inf}; \\ (R_{\rm spike}/r)^{\alpha_{\rm GS}} & R_{\rm inf} < r \leq R_{\rm spike}; \\ \rho_{\rm NFW}(r)/\rho_{\rm NFW}(R_{\rm spike}) & r > R_{\rm spike}. \end{cases}$$

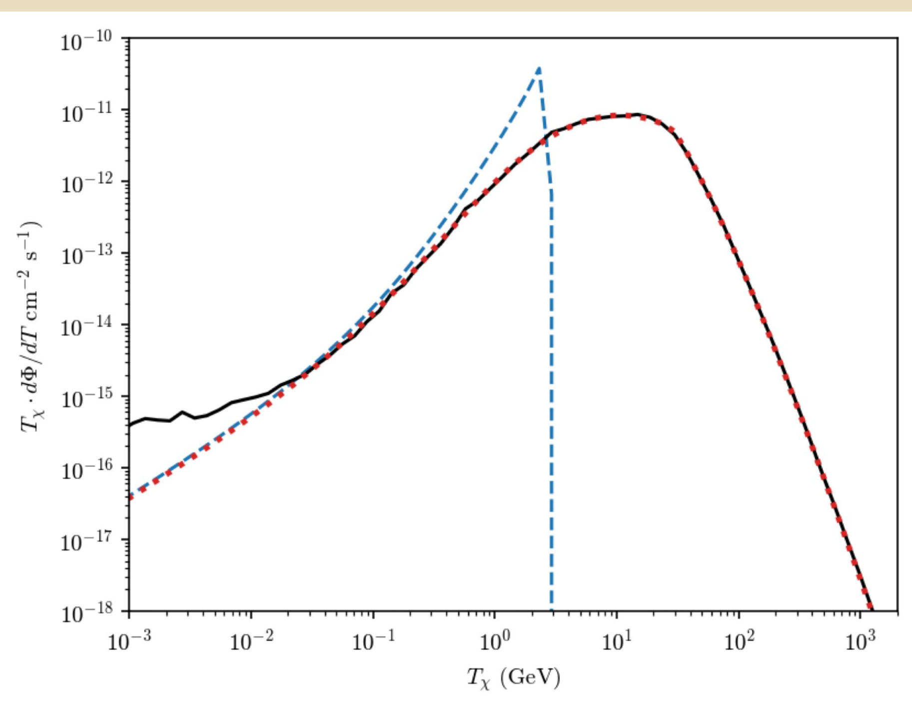
R_S = Schwarzschild radius of black hole (BH)
R_{spike} = radial extension of central density spike
R_{inf} = Radius of influence of BH
ρ_{NFW} = NFW density distribution

From Source to Earth



- We calculate DM flux spectra on Earth surface as function of WIMP masses

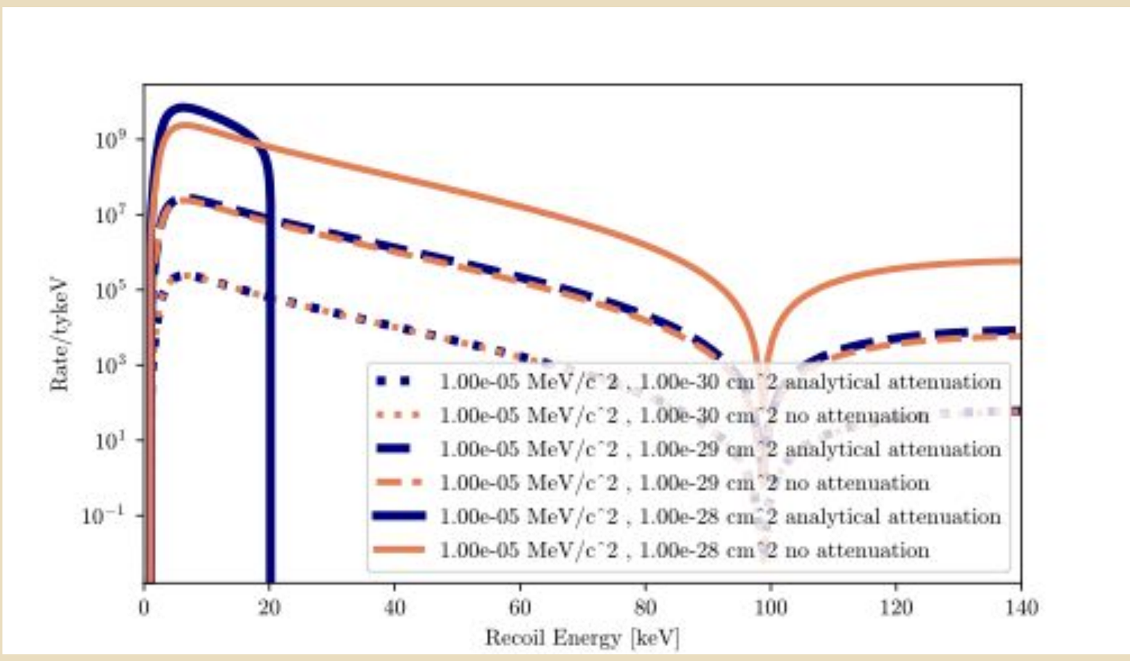
Earth attenuation:
Rare event LXe detectors are often placed deep underground as a way to minimize backgrounds. We need to factor the affect of this overburden on the flux actually seen by the detector.



$\sigma_{\chi p}$=1*10^{-31} cm^2, m_χ=100 MeV
black = un-attenuated flux
red dashed = numerically-calculated attenuated flux
blue dashed = analytically-calculated attenuated flux

At the detector

- We then translate the expected flux vs kinetic energy at the detector after attenuation to a predicted rate vs recoil energy spectrum.



How can we set limits using public data?

Collaborations make different amounts of information public with their results.

Re-using normal DM searches ("Rate matching")

LXe TPC results are reported in terms of a standard WIMP model that assumes that the WIMPS are orbiting the galaxy according to the standard halo model. These limits correspond to a certain rate of recoils in the detector. The rate matching approach is to **find the BBDM cross section that would give the same recoil rate within the detector**. This approach **ignores spectral differences** in the recoil spectra.

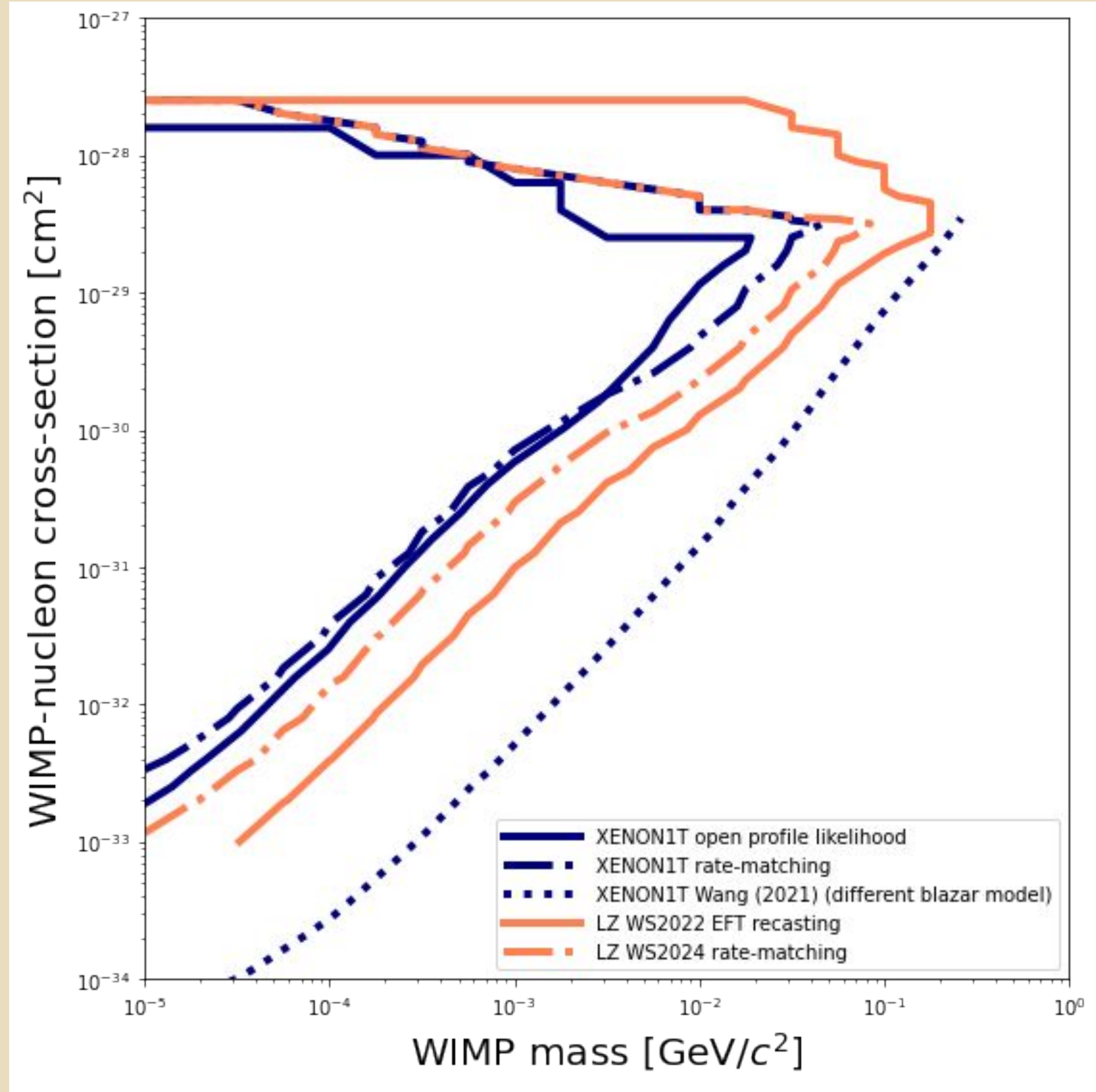
Recoil spectra matching

If experiments include models for many different recoil spectra (e.g. the LZ EFT 2024 paper[6]), we may **find the recoil spectrum that most closely matches each BBDM recoil spectrum** and use the recoil rate limit for this spectrum.

Open likelihoods

Some experiments release **complete statistical models of their data** (e.g. XENON1T[7]). With these, you can test any model against the data and compute discovery significances, confidence intervals, etc.

Results

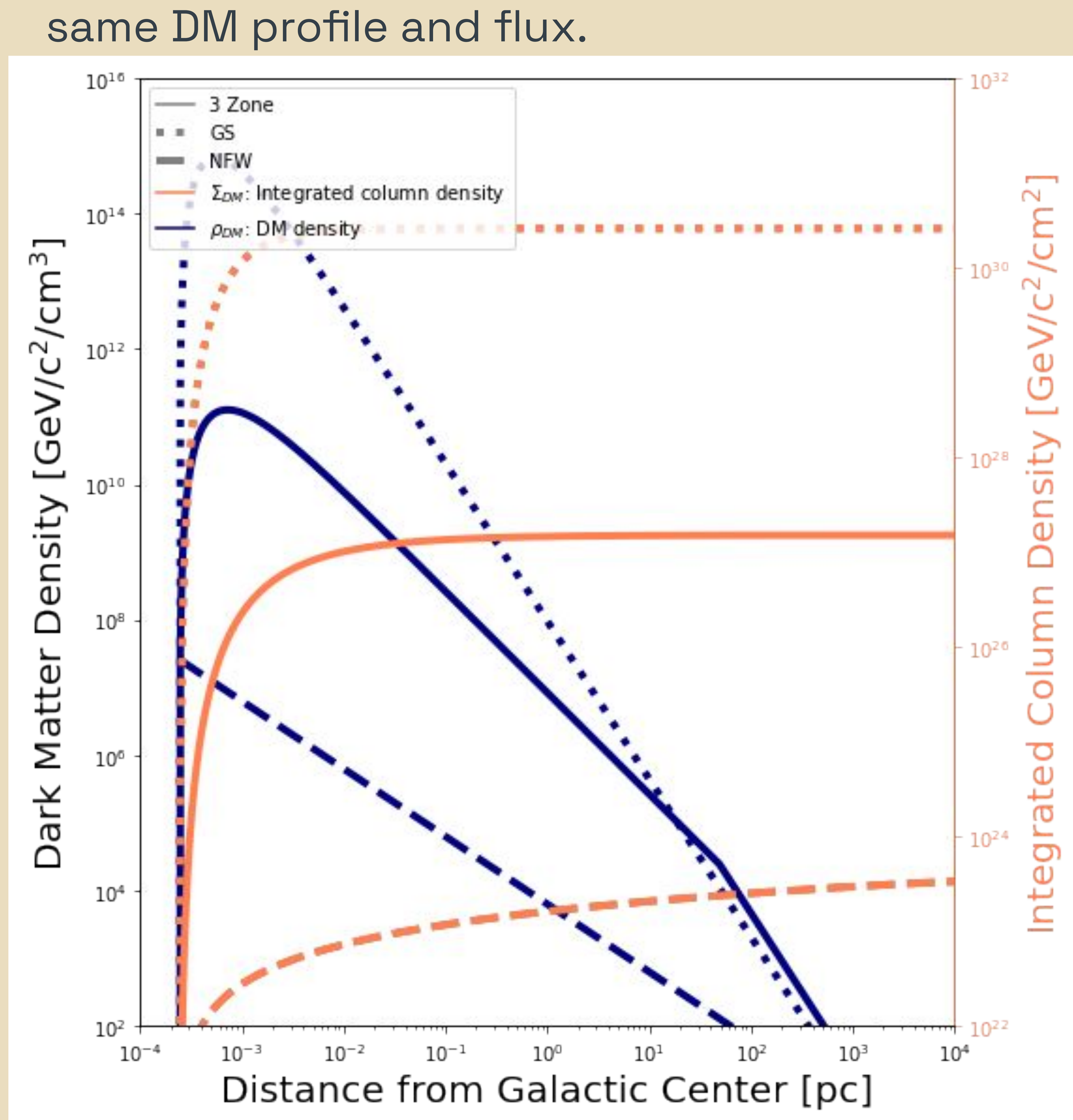


Discussion

Rate-matching vs profile likelihood:
- The simpler rate matching approximation comes close to the full profile likelihood result.

Rate-matching vs recasting:
- LZ's limits are improved considerably by including the detector response information and a wider energy range.

DM distribution model:
- Limits for different DM distribution models may differ greatly. The dotted line in the above plot utilized a different DM density normalization which would lead to increased DM flux at Earth's surface, and therefore led to lower limits set. LZ remains most sensitive when using the same DM profile and flux.



LXe rare event detectors like those used by the LZ and XENON collaborations make analyses like these possible due to long exposures, low backgrounds, and high sensitivities to individual particle interactions. In this work we chose methods based on what information was available for each result. Open likelihoods make these analyses both easier and more accurate!

References

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Authors

Erin Barillier, Alessandro Granelli, Laura Manenti, Knut Morå, Paolo Padovani, Björn Penning, Isaac Sarnoff, Yongheng Xu, and Francesco Arneodo