SENSITIVITY OF THE SABRE EXPERIMENT TO WIMP SIGNALS AND SEASONAL BACKGROUNDS

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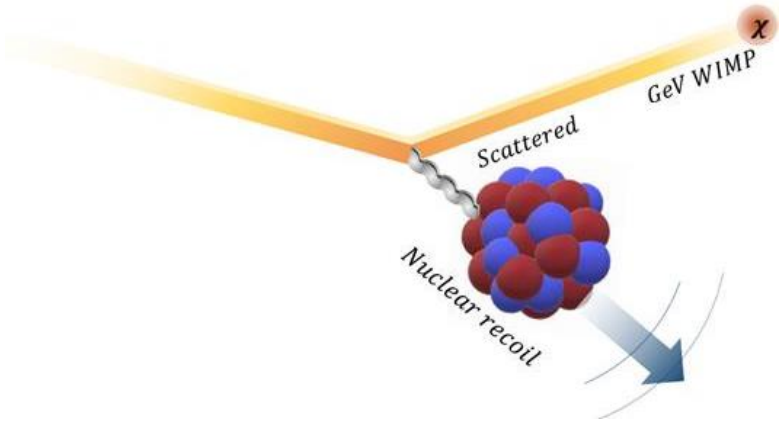
The University of Adelaide

Annual Modulation Signal

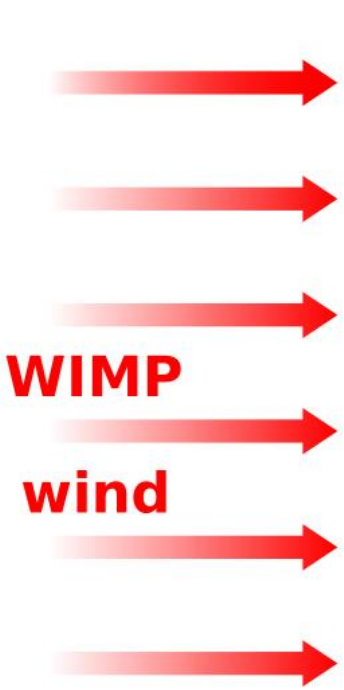


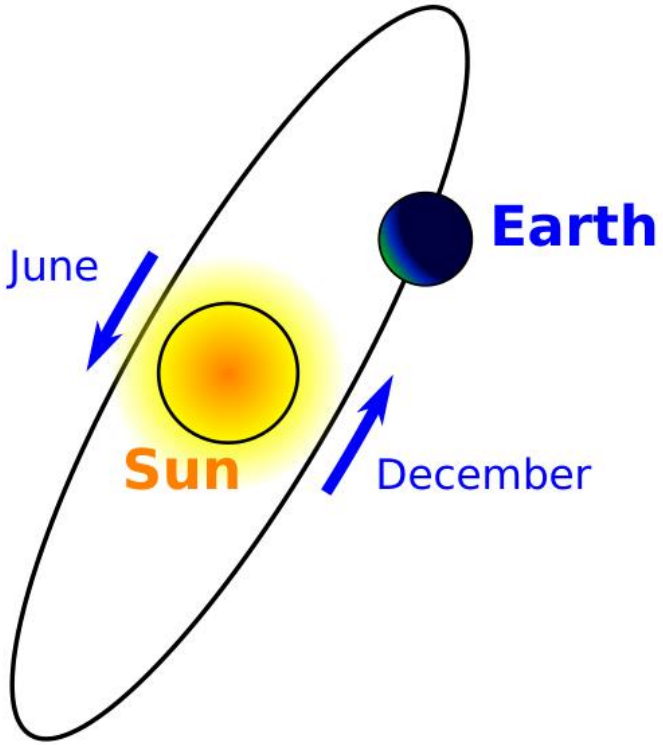
$$R(E,t) = B(E,t) + S_0(E) + S_m(E) * \cos(t - t_0)/T$$

Difficult to separate WIMP constant rate from background.

Low amplitude, but unique signature which can be distinguished from known backgrounds.

Hypothesis: DM Halo composed of WIMPs



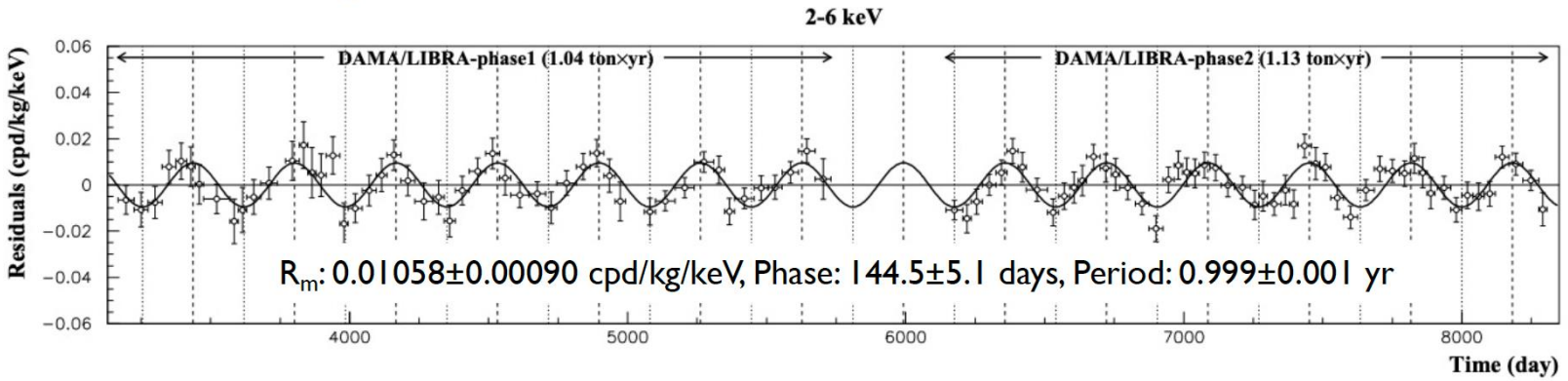


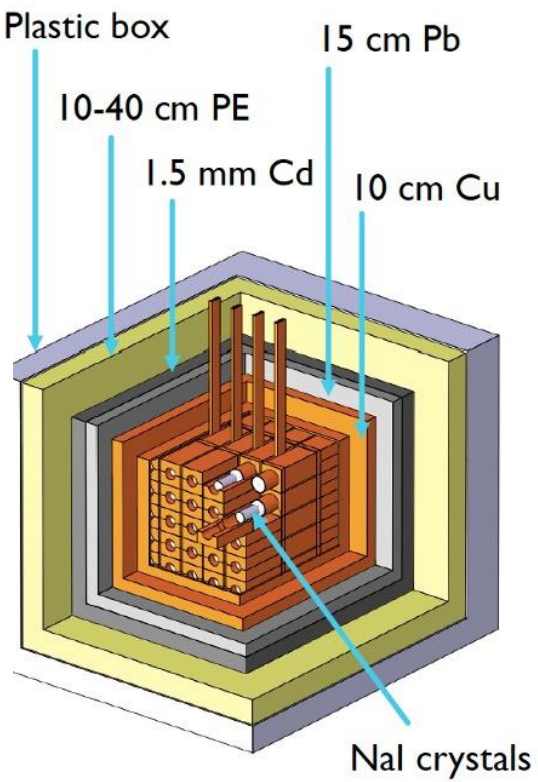
Freese, Lisanti, and Savage, "Colloquium: Annual modulation of dark matter"
https://doi.org/10.1103/RevModPhys.85.1561

DAMA/LIBRA

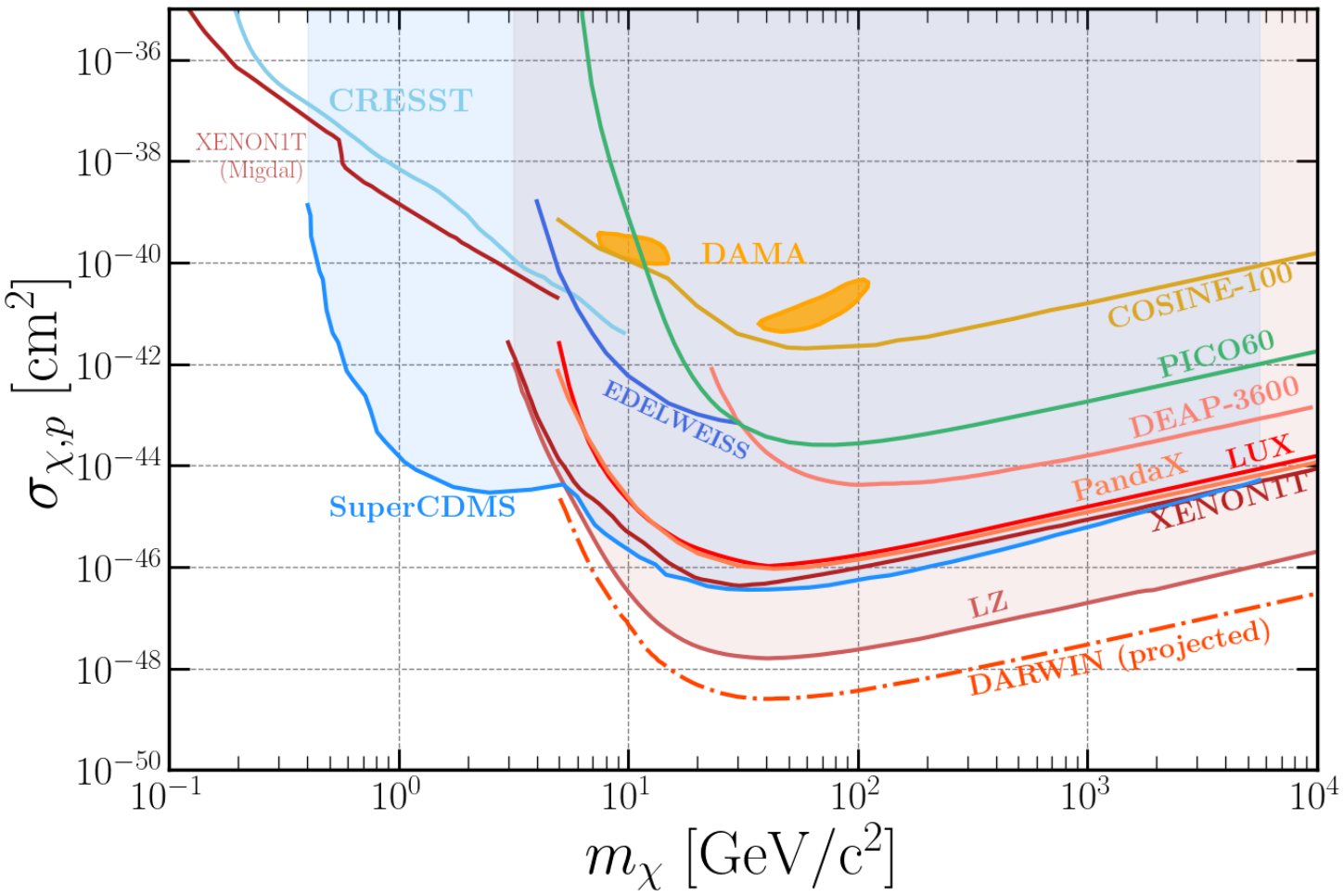
Looks for scintillation in NaI(Tl) crystals due to nuclear recoils. Located in Italy at LNGS. Has observed modulation signal with expected energy, phase, period, amplitude for around 20 years.

12.9σ rejection of no modulation hypothesis





R. Bernabei, et al. The dama project: Achievements, implications and perspectives. Progress in Particle and Nuclear Physics, 114:103810, 2020



Problems with DAMA/LIBRA

- In spin-independent models the DAMA results are strongly excluded by more sensitive experiments.
- More complex models required for DM interpretation of DAMA results.
- Require independent test with same NaI(Tl) target material.
- COSINE-100 and ANAIS NaI experiments taking data, but slow to reach significant results due to high backgrounds.

Plot:
https://github.com/cajohare/NeutrinoFog

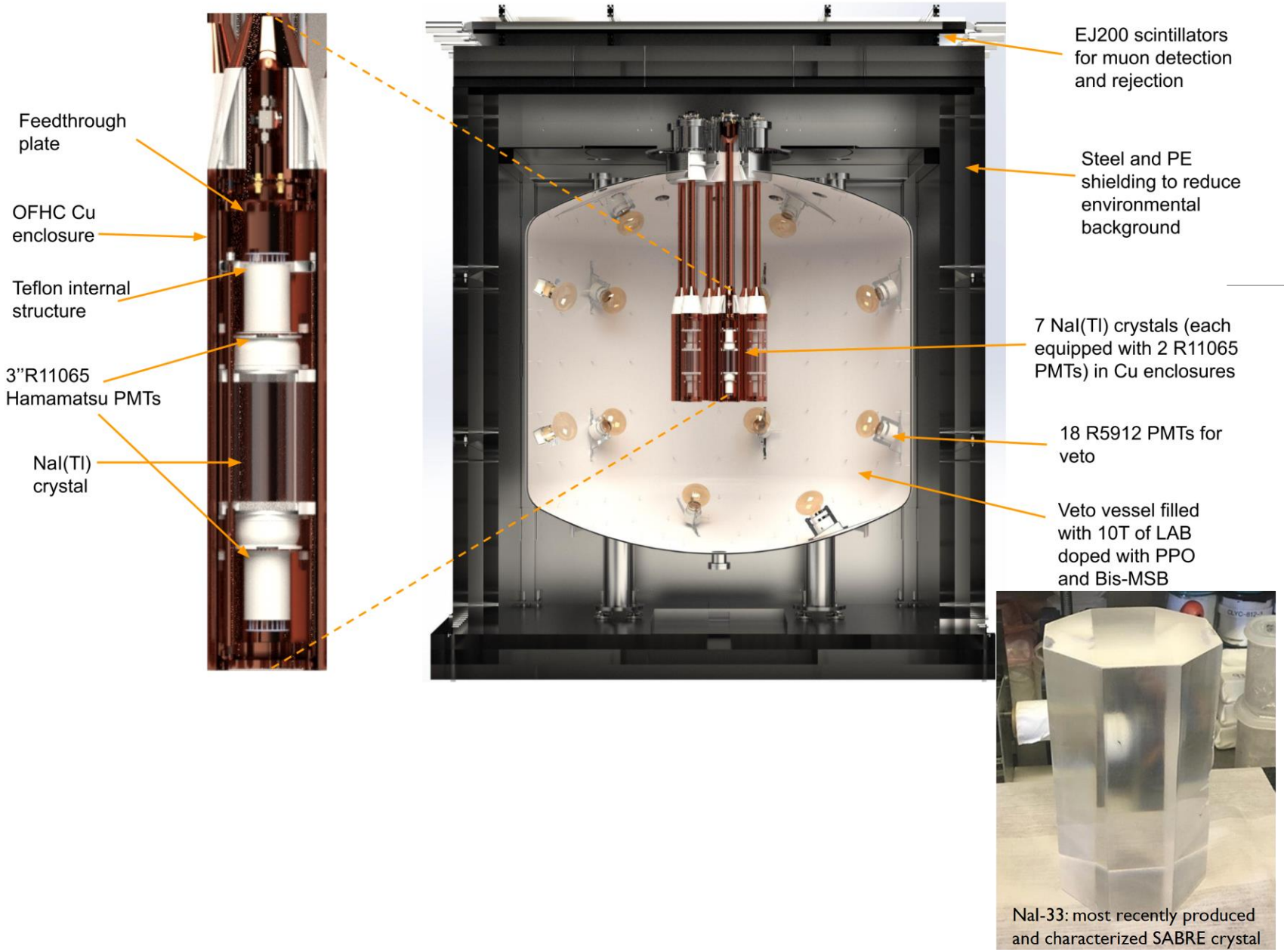
SABRE: a dual site experiment

The ambitious program of SABRE foresees two detectors in two underground locations:

- SABRE North at Laboratori Nazionali del Gran Sasso (LNGS) in Italy
- SABRE South at Stawell Underground Physics Laboratory (SUPL) in Australia

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

STAWELL UNDERGROUND PHYSICS LAB



NaI-33: most recently produced and characterized SABRE crystal

SABRE South Detector

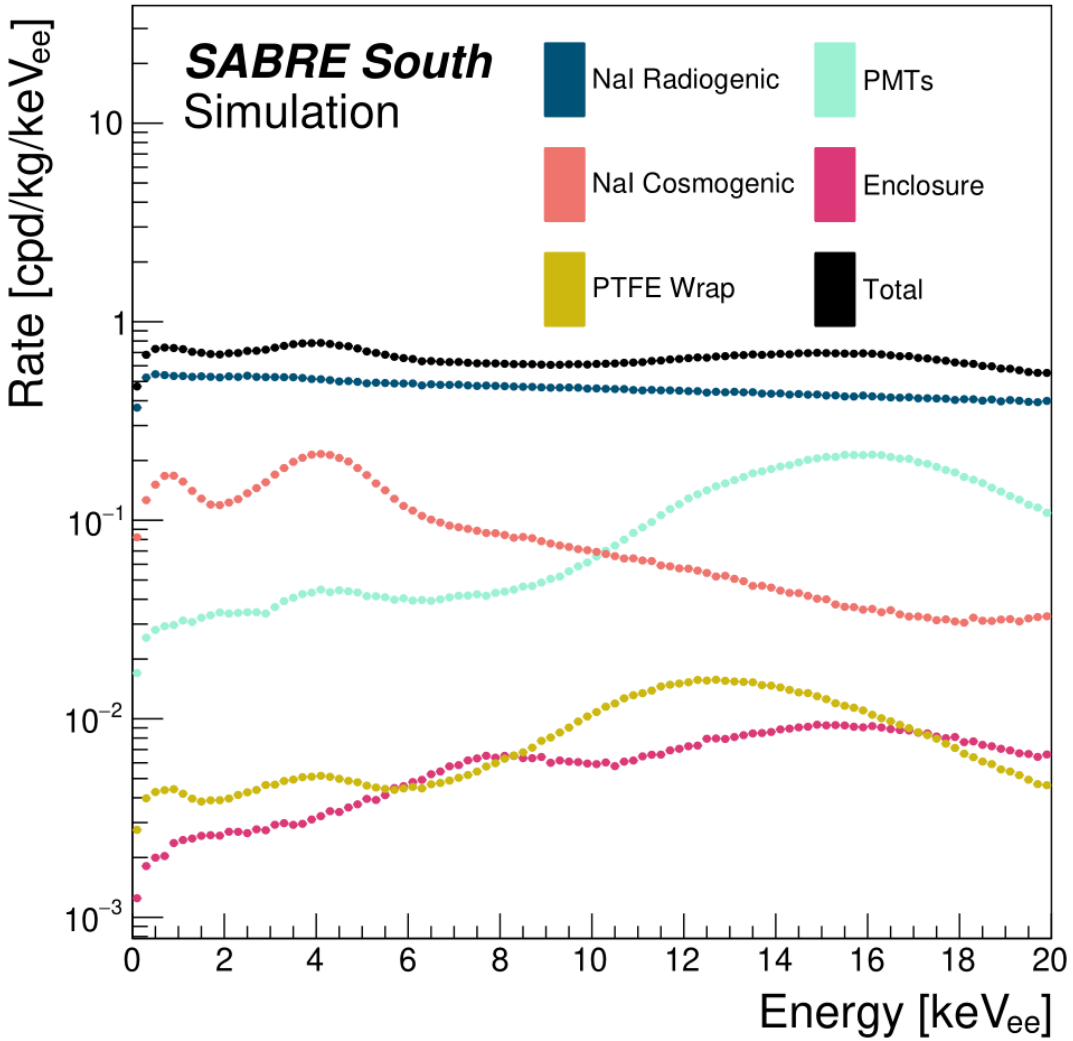
See Talks:

Irene Bolognino: The SABRE South Experiment. *Wed 4pm Room E3*

Ferdos Dastgiri: Intrinsic Background Characterisation of an Ultra-pure NaI test Crystal for SABRE South. *Thursday 3:15pm Room E3.*

Nathan Spinks: Pulse Shape Discrimination of low-energy nuclear and electron recoils in NaI:Tl for dark matter direct-detection. *Thursday 5pm Room E3.*

SABRE South Simulation Background



- From simulation based on measurements and requirements of detector materials.
- Does not include PMT noise. Especially significant in 1-2 keVee range.
- Average of 0.72 cpd/kg/keVee in 1-6 keVee region of interest.

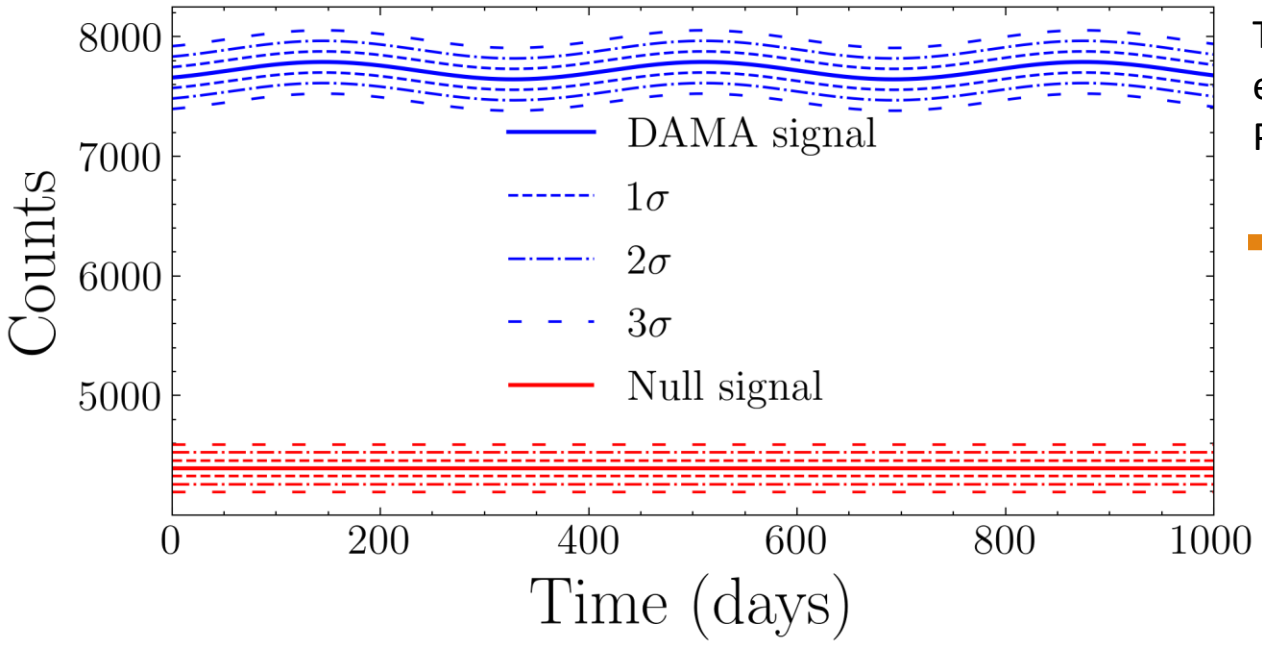
https://arxiv.org/abs/2205.13849

Model Independent Sensitivity

Problem: Expected modulation signal is so small (~1%) compared with background. How long will it take SABRE South to reach statistically significant results?

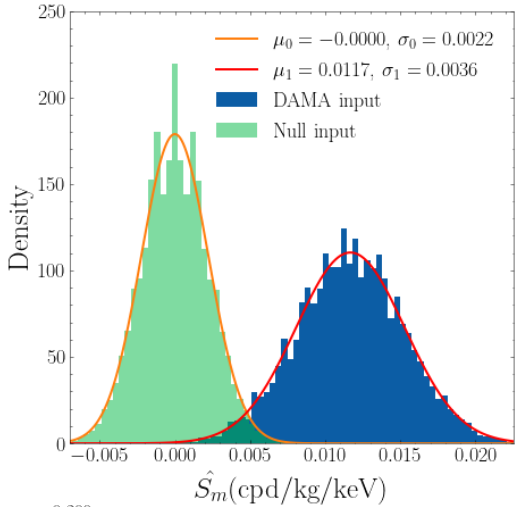
- Determine SABRE South sensitivity for DAMA-like modulation.
- Unclear question of how to include DAMA constant rate into calculations.
- Two sets of results presented: Independent results from my honours project, SABRE South collaboration results (arxiv: 2205.13849).

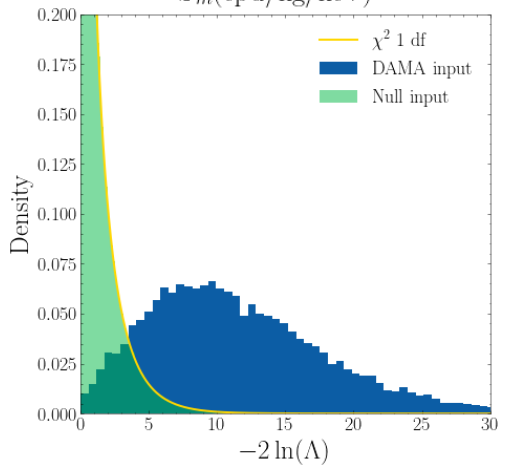
Sensitivity Method



Thousands of pseudo-experiments via Poisson fluctuations.

or

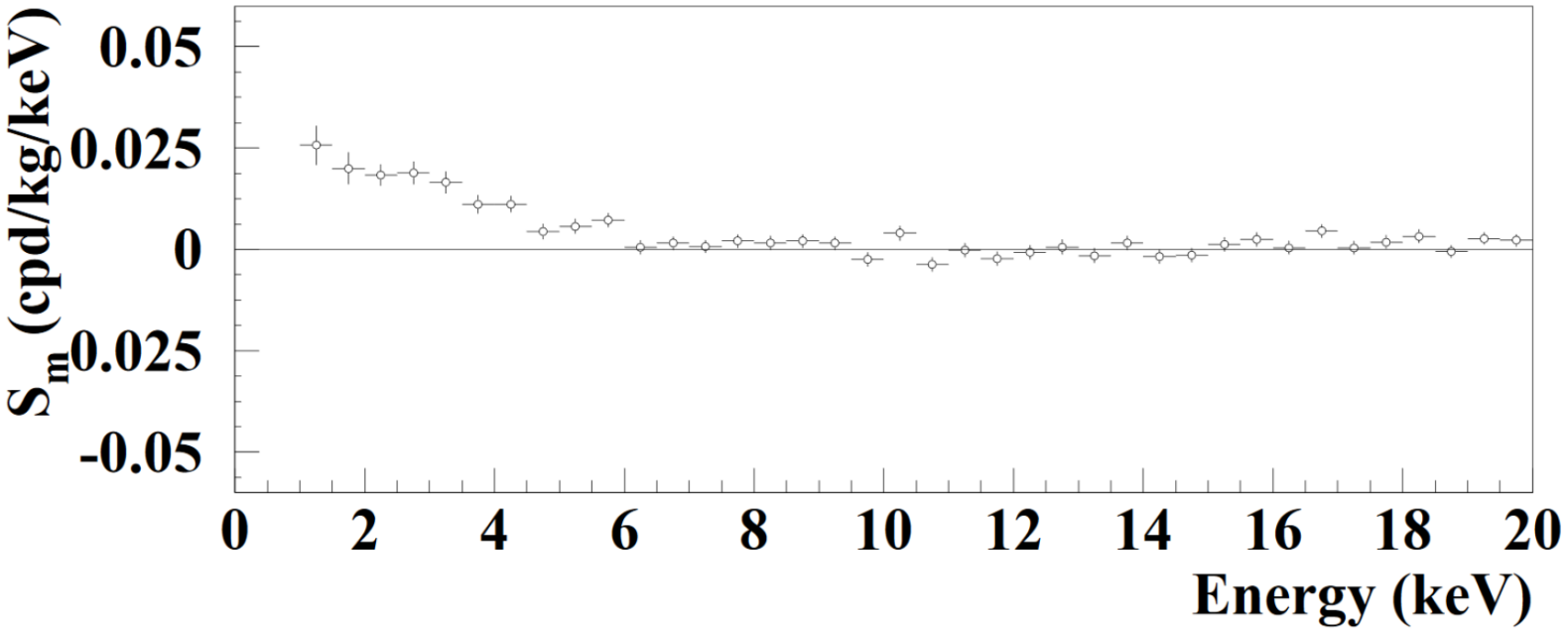




$$\text{Counts} = \Delta E \cdot \Delta t \cdot M * R(E,t)$$

Sensitivity Assumptions

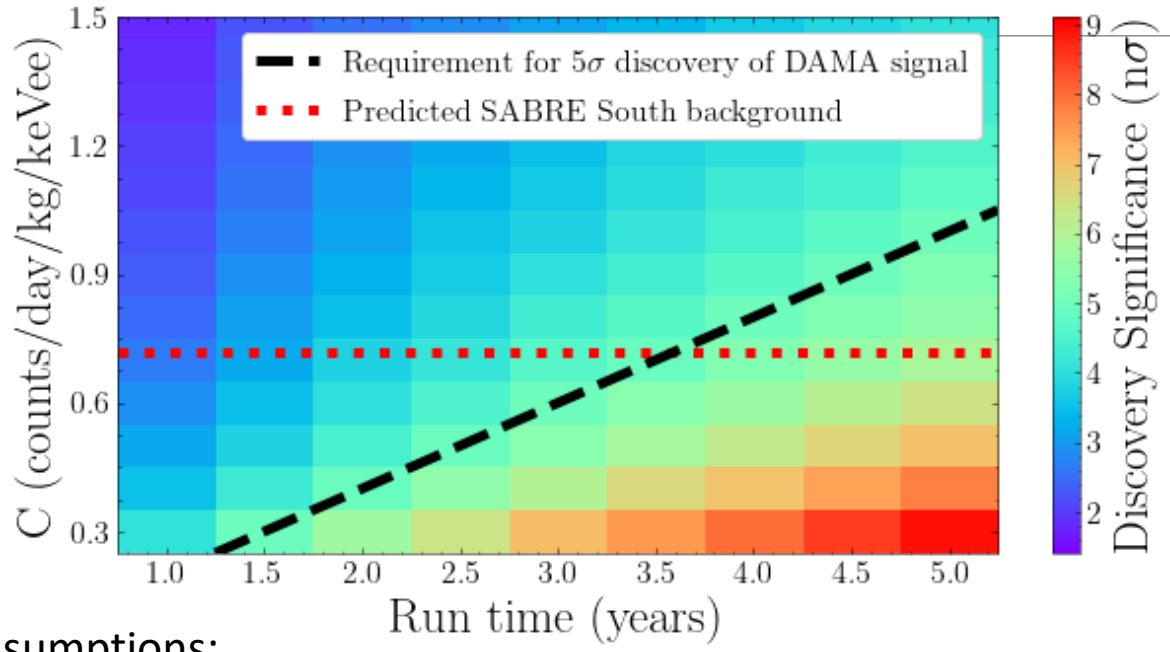
- The results of model independent sensitivity analyses depend strongly on assumptions about background rates and DM constant rates.
- Honours project results and SABRE South Simulation results compatible under same assumptions.
- Detailed background modelling, smaller energy bins, and inclusion of the 1-2 keVee energy range result in the greatest increases to sensitivity.

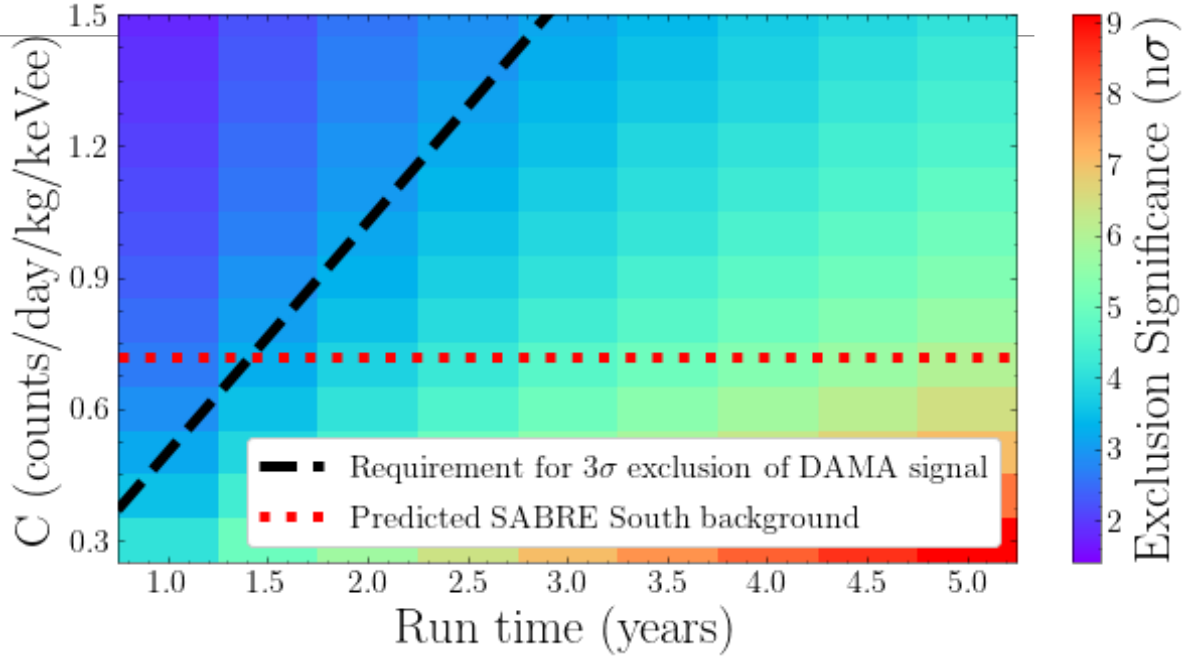


DAMA results show the strongest modulation in the 1-2 keVee energy range.

R. Bernabei, et al. The dama project: Achievements, implications and perspectives. Progress in Particle and Nuclear Physics, 114:103810, 2020

Sensitivity Results - Honours





Assumptions:

- 0.0117 cpd/kg/keVee DAMA-like signal, average across 2-6 keVee energy bins.
- No inclusion of detector efficiency or quenching factor differences between experiments.
- Assumes background in 2-6keVee is equal to average SABRE South Simulation background over 1-6 keVee.
- Modulation and no modulation hypothesis have same constant rates.

Results:

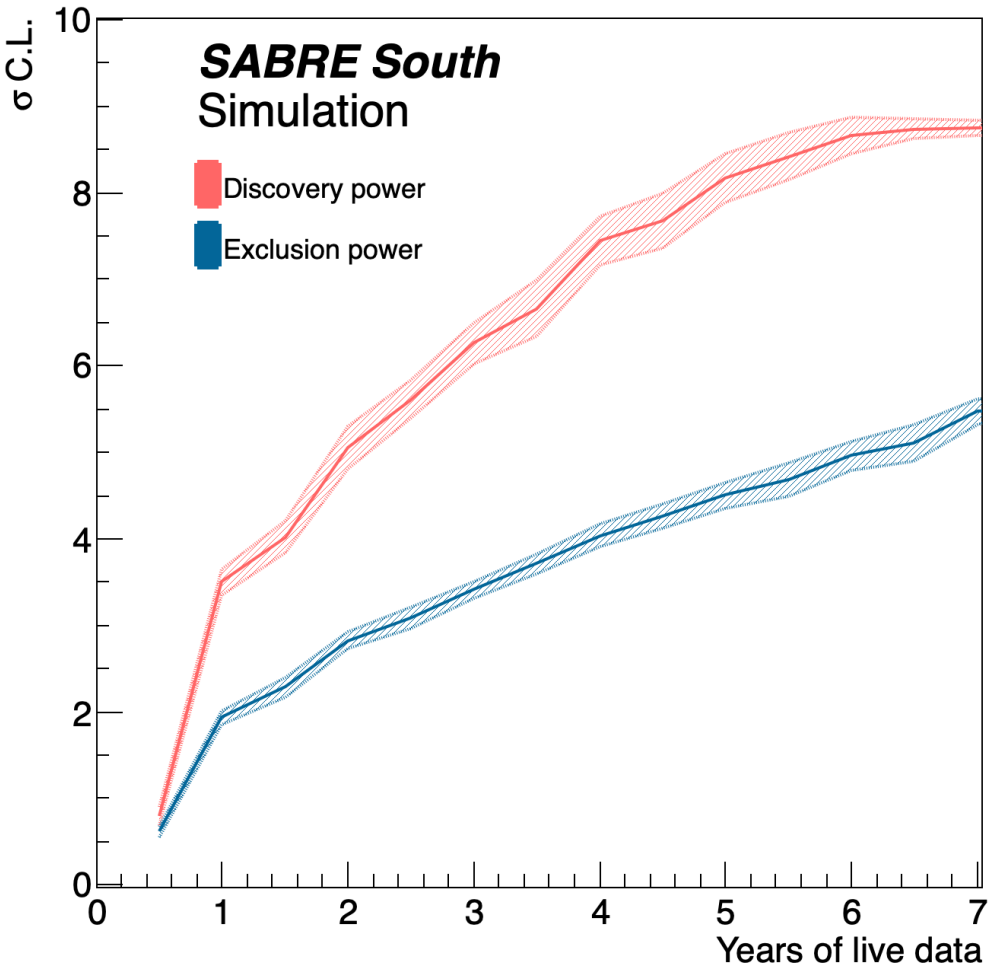
- 3.5 years data taking for 5σ discovery of DAMA signal.
- 1.5 years for 3σ exclusion of DAMA signal.

Compare with SABRE South Simulation Results

More detailed assumptions lead to higher sensitivity for discovery:

- Uses results for DAMA modulation signal per 0.5 keVee energy bin.
- Considers larger 1-6 keVee region.
- Analysis per 0.5 keVee energy bin with detailed background model.

Modulation and no modulation hypothesis have <u>different</u> constant rates. This increases the time for 3σ exclusion.



Results:

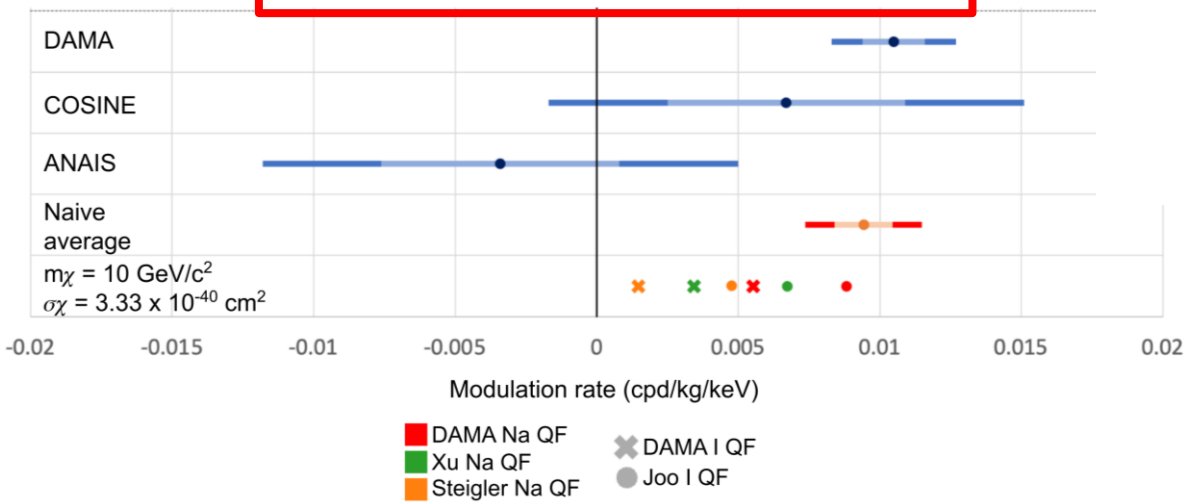
- 2 years for 5σ discovery of DAMA signal.
- 2.3 years for 3σ exclusion of DAMA signal.

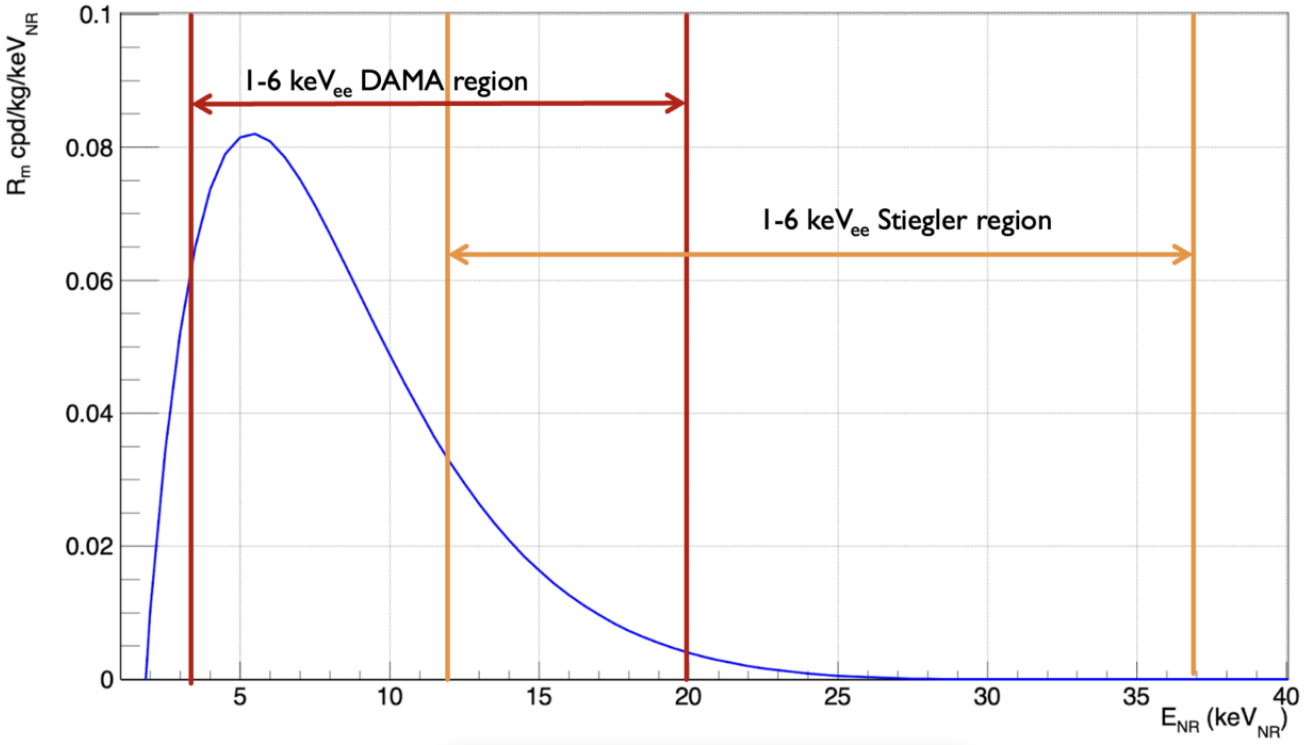
https://arxiv.org/abs/2205.13849
https://doi.org/10.1088/1742-6596/2156/1/012212

Sensitivity Limitations

These results aren't the whole story:

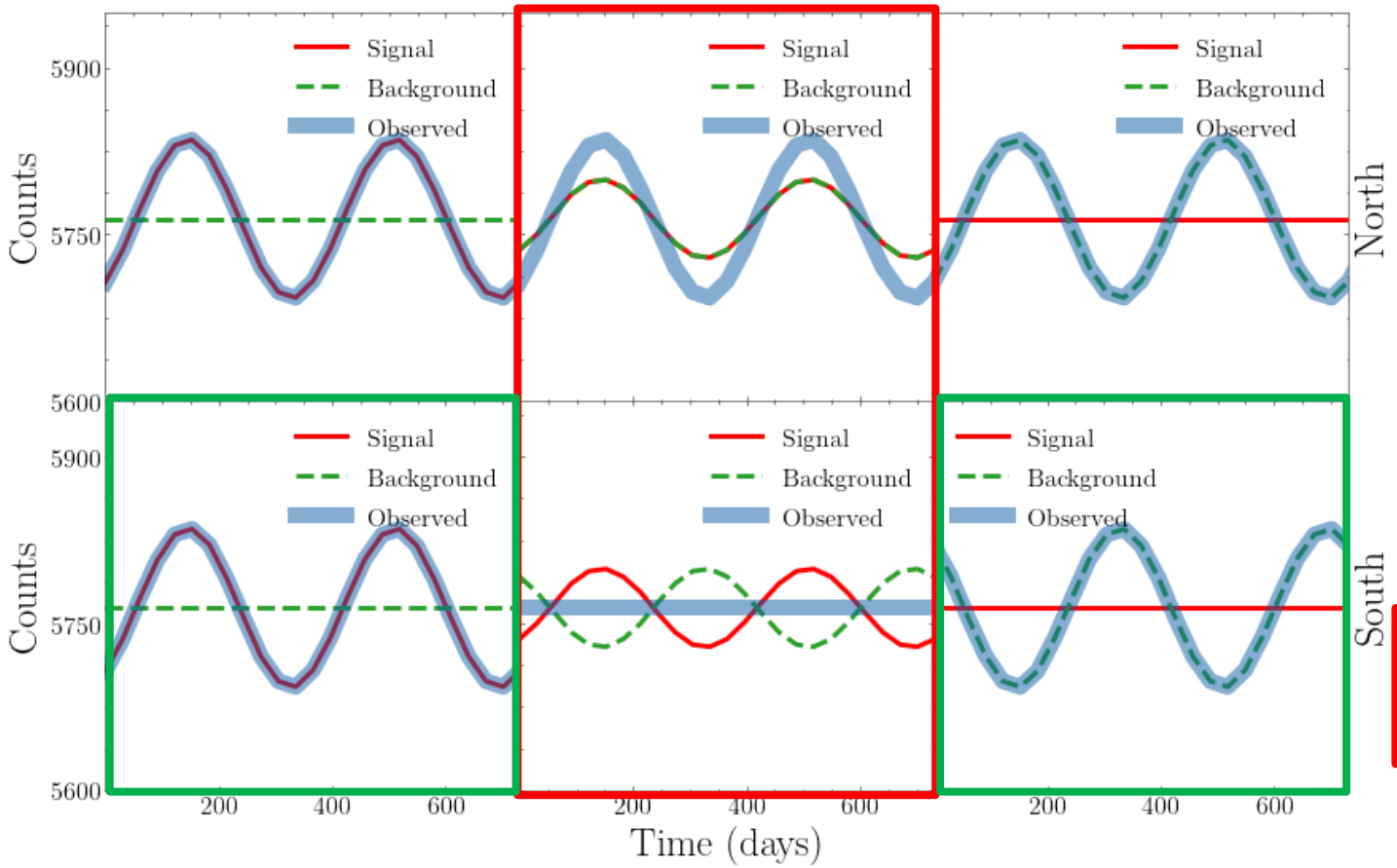
- Based on best fit amplitude of cosine with fixed phase.
- Doesn't include gravitational focusing.
- Averaging across energy bins.
- Modulation amplitude sensitive to dark matter mass.
- Differing quenching factors (relation of E_{nr} to E_{er}) between NaI(Tl) experiments can have a large impact on sensitivity.





M. J. Zurowski IDM2022
https://arxiv.org/abs/2211.15861

Seasonal Backgrounds

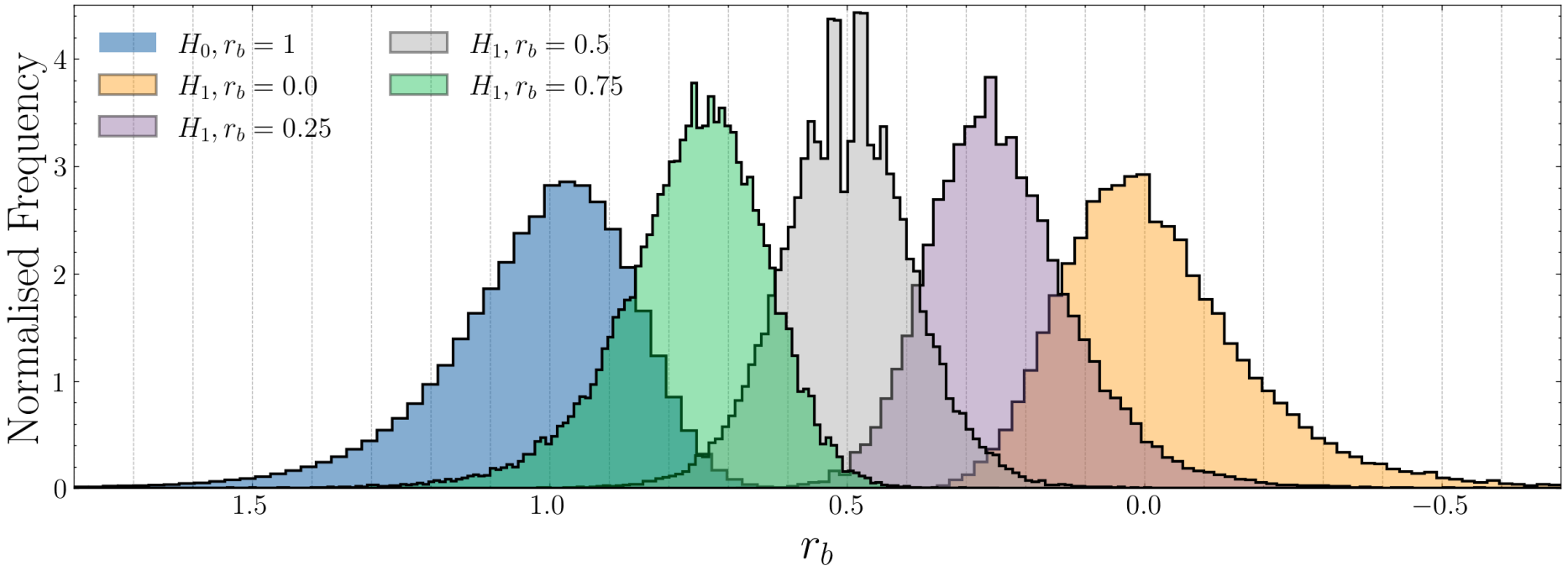


- Superposition of unidentified in-phase seasonal background and WIMP annual modulation in DAMA results could ease tension with other experiments.
- Seasonal background in Southern Hemisphere will have opposite phase.
- Zero modulation observation in southern hemisphere could be compatible with WIMP hypothesis.
- Need North and South detectors to separate degenerate scenarios.

Resolving Seasonal Backgrounds and Annual Modulation

Test ability for SABRE North and South combined to resolve DAMA signal composed of modulating background (B_m) and modulating WIMP signal (S_m).

$$r_b = \frac{B_m}{B_m + S_m}$$



- Assume identical North and South detectors.
- Many pseudo experiments for each background hypothesis.
- Infer ratio of seasonal background from modulation amplitude in each hemisphere.

Summary

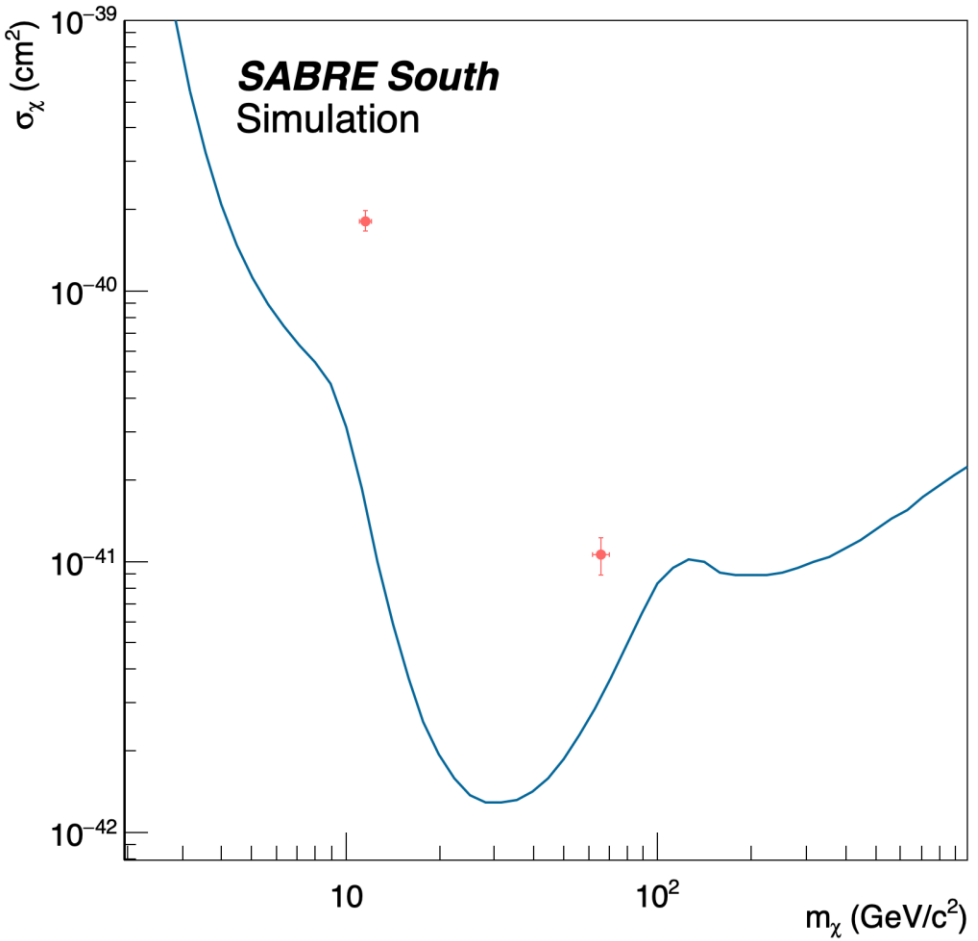
- SABRE South is an ultra low background NaI(Tl) DM direct detection experiment with the primary goal to test the DAMA experiment results.
- SABRE South will obtain statistically significant results on the annual modulation signal within 2.3 years data taking.
- Dual detectors in opposite hemispheres will be able to distinguish between DM signal and seasonal background.

END

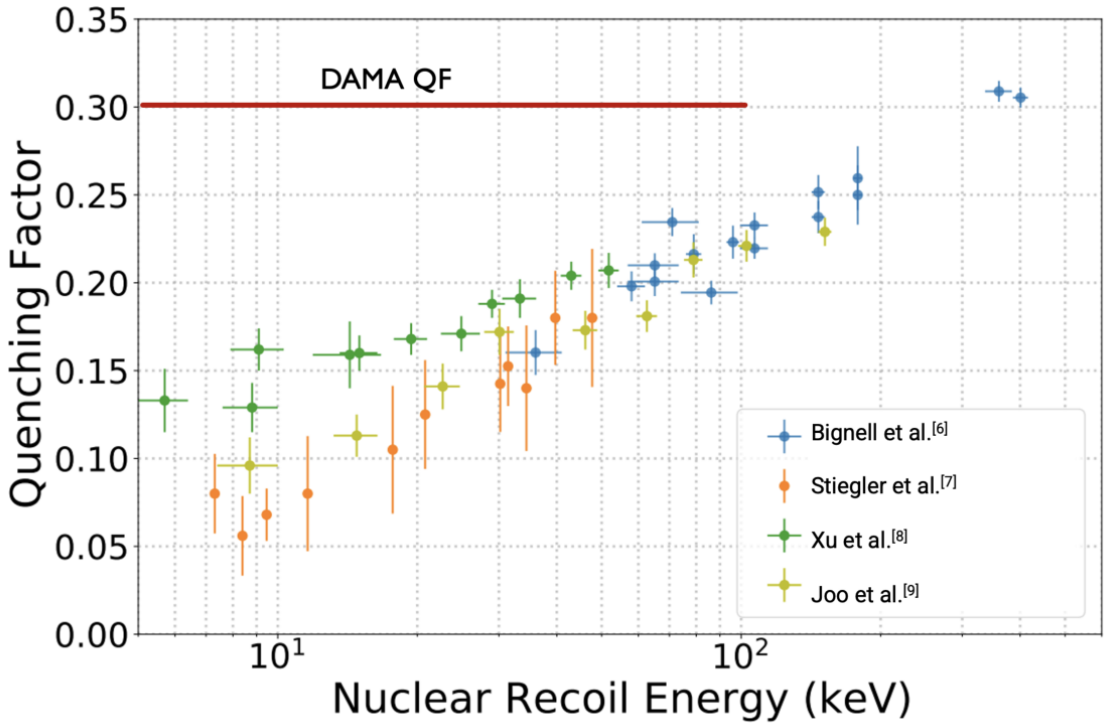
Extra: Model Dependent Sensitivity

- Blue line: 90% exclusion curve for SABRE South after 3 years data taking.
- Red: Best fits from DAMA/LIBRA data.
- Based on SABRE South simulated background (Slide 7)

https://arxiv.org/abs/2205.13849



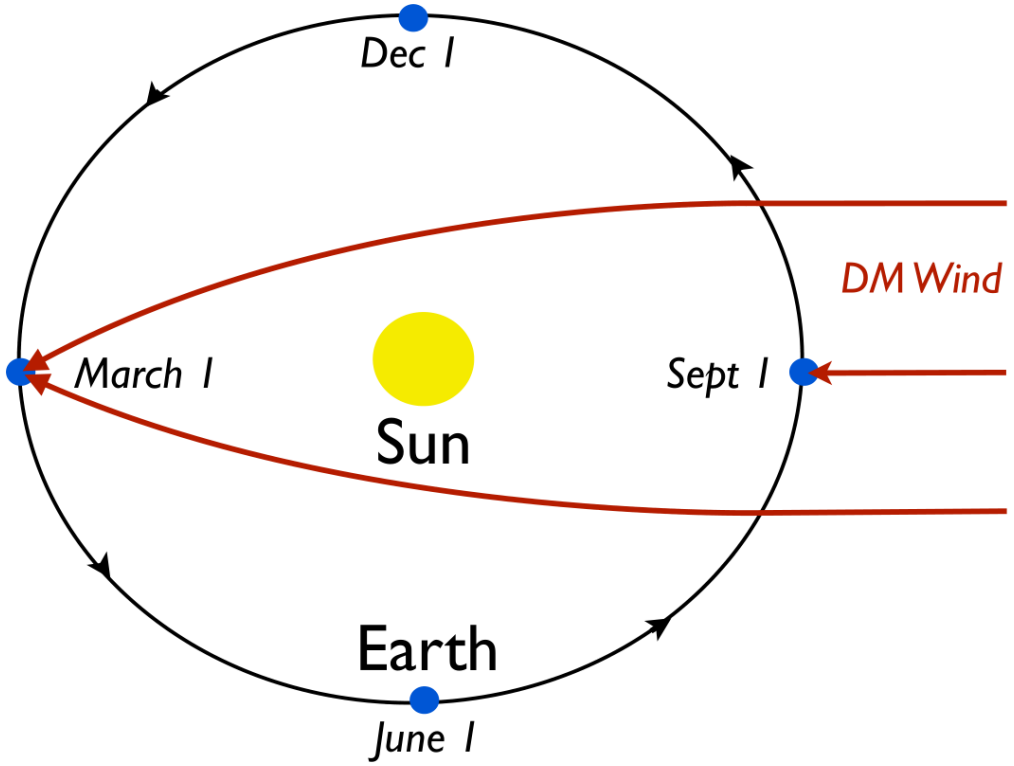
Extra: Quenching Factor

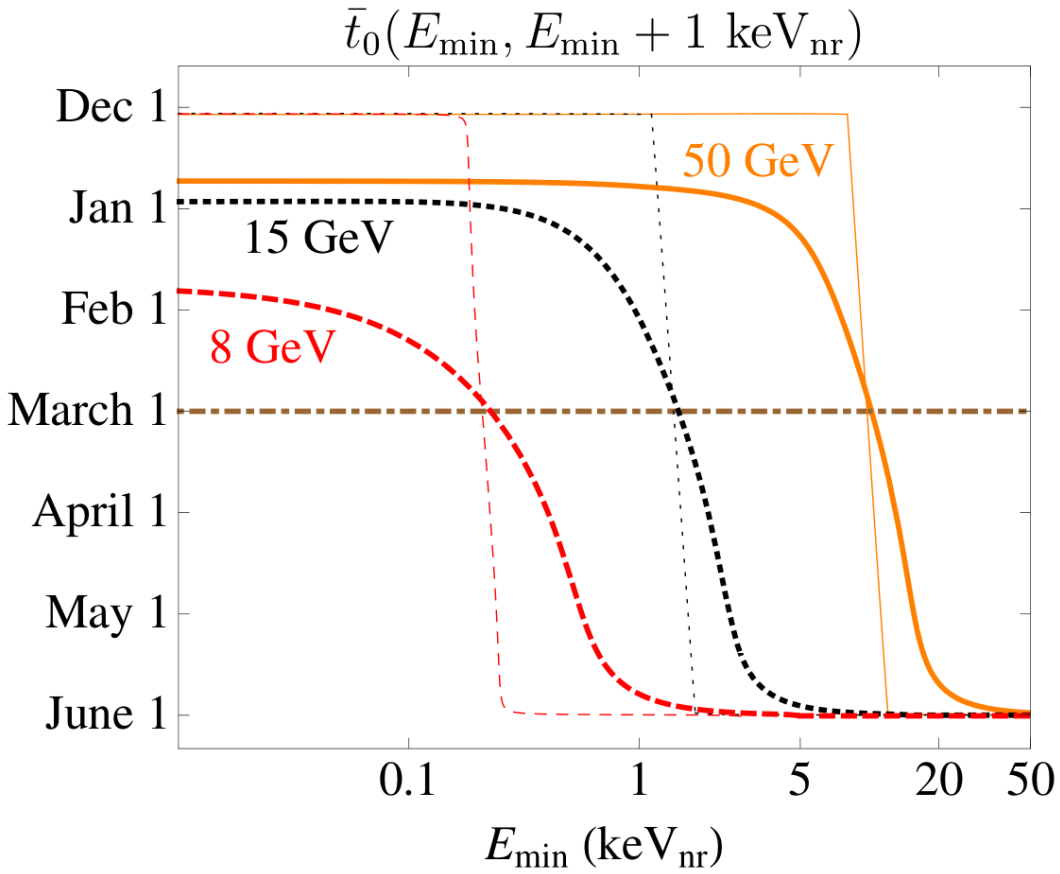


https://arxiv.org/abs/2211.15861

- NaI(Tl) scintillators measure scintillation light L from nuclear and electron recoils.
- Detectors are calibrated using gamma sources which produce electron recoils.
- The Quenching factor relates the energy of nuclear recoils to those of electron recoils with equivalent L.
- $Q(E_{nr}) = \frac{E_{nr}}{E_{ee}}$

Extra: Gravitational Focusing





https://arxiv.org/abs/1308.1953v2

Example of how the time of maximum rate can change with different minimum energies in DM direct detection experiments. Thin lines GF off, Thick lines GF on.