# Influence of NaI background and mass on testing the DAMA modulation[1]

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NaI experiments should be sensitive to the same DM-SM interactions proposed to explain the observed DAMA modulation. As such, they are often called a 'model independent' test of the signal. While the same signal will be produced at all NaI detectors, the ability to observe it is strongly dependent on the experimental set up – in particular the mass and background of the target. We present here a study on how changes to these values influence the ability of a detector to observe a characteristic DM modulation. We consider both the standard elastic, spin independent WIMP and a model independent analysis assuming exactly the modulation signal observed by DAMA (i.e., making no assumptions about the particle interaction model producing this signal), and find that in both cases a lower background is favoured over a higher exposure mass (based on currently achievable levels).

## Analysis procedure:

Event rates at a detector are simulated by randomly sampling from a Poissonian centred on

$$N_{s+b} = M_E\, \Delta T\, \Delta E(R_b + R_0 + R_m \cos \omega t) \text{ (for signal + background model)}$$

or

$$N_b = M_E\, \Delta T\, \Delta E(R_b) \text{ (for background only model)}$$

where

- $M_E$ is the exposure mass
- $\Delta T$ is the data taking time period
- $\Delta E$ is the energy bin of interest
- $R_b$ is the background rate in cpd/kg/keV
- $R_0$ is the constant signal rate in cpd/kg/keV
- $R_m$ is the modulating signal rate in cpd/kg/keV

Experimental lifetime is simulated 100s of times and fit to a cosine to find the probability function for modulation observation for background only and signal + background cases.

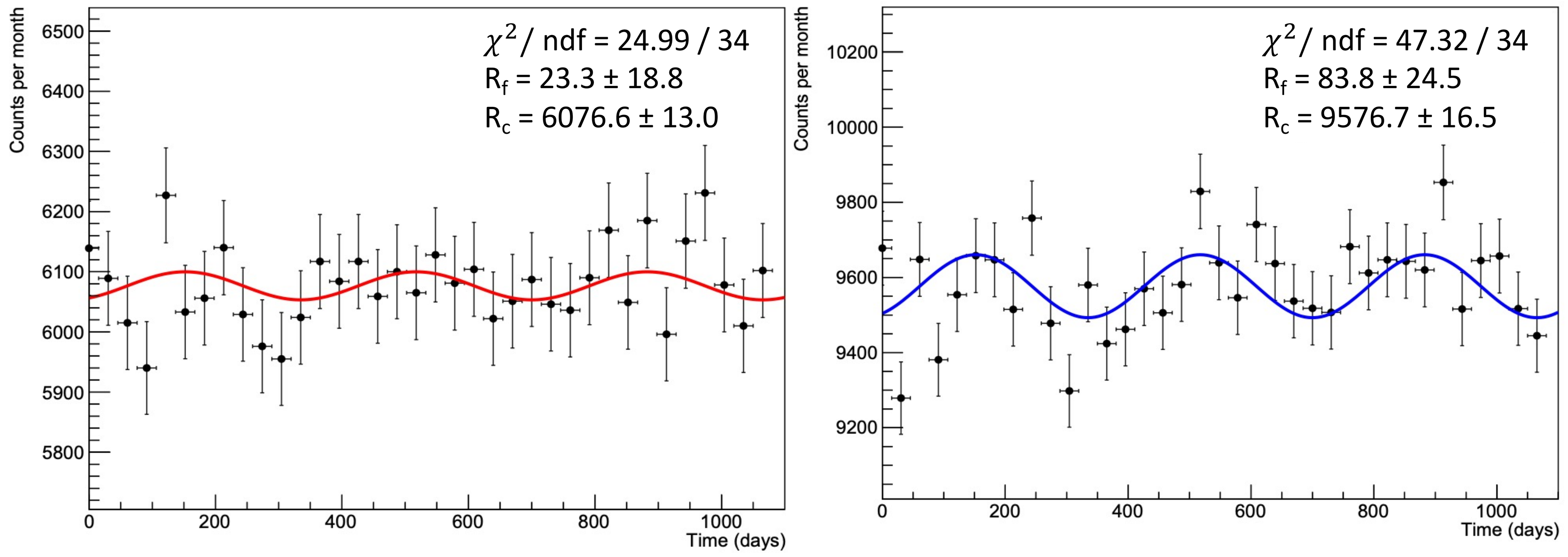



Fig. 1: simulated event rate for background only (left) and signal + background (right) models

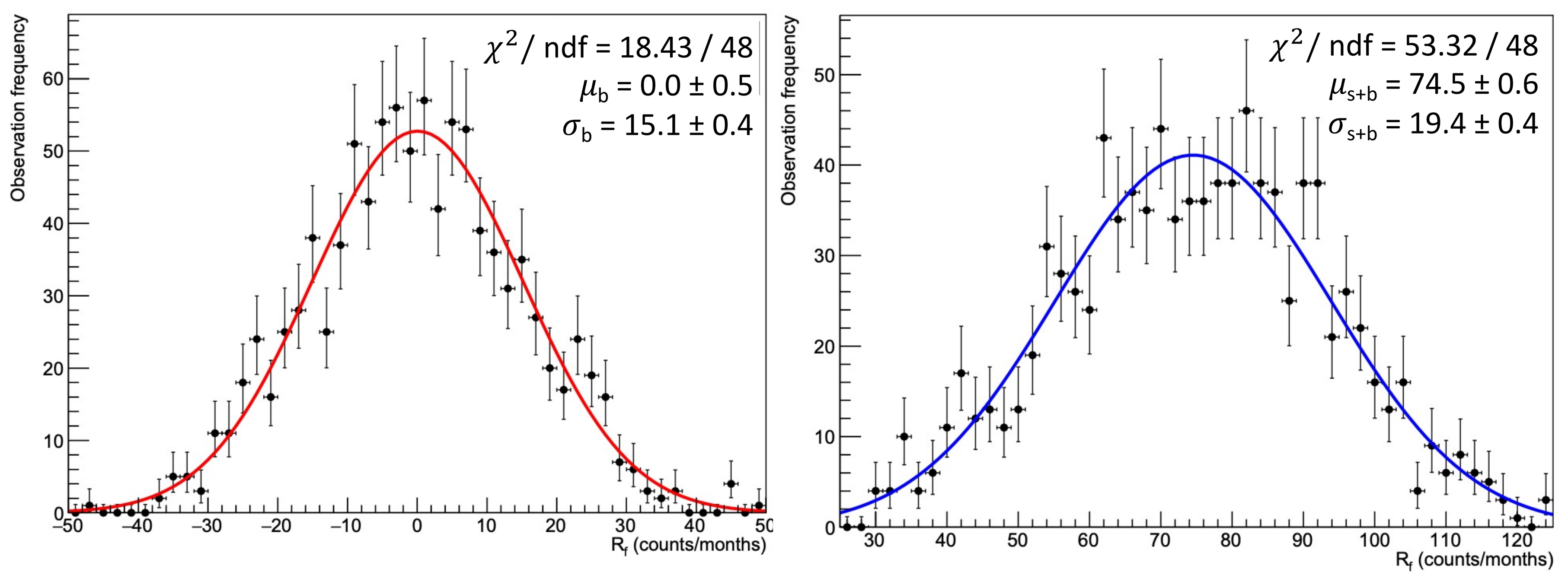



Fig. 2: probability distribution function for modulation rate in background only (L) and signal + background (R) models

Mean and standard deviation values are interpreted as the observed modulation and its uncertainty for a given model and used to construct the test statistics used for analysis.

This methodology accounts for the fact that although we are comparing a modulating rate to a constant background, in some cases statistical uncertainties in constant rates (either from the signal component or the background) can mask or magnify the signature modulation.

## Test statistics:

Exclusion $n\sigma$ C.L.: how well a signal can be identified assuming signal + background hypothesis. Depends on signal + background uncertainty.

$$n = \frac{|\mu_{sb} - \mu_b|}{\sigma_{sb}}$$

Discovery $n\sigma$ C.L.: how well a signal can be identified assuming background only hypothesis. Depends on background uncertainty.

$$n = \frac{|\mu_{sb} - \mu_b|}{\sigma_b}$$

For the usual 90% C.L. curves in the $m_\chi$-$\sigma_\chi$ plane these can also be transformed into p-values.

## Model dependent results:

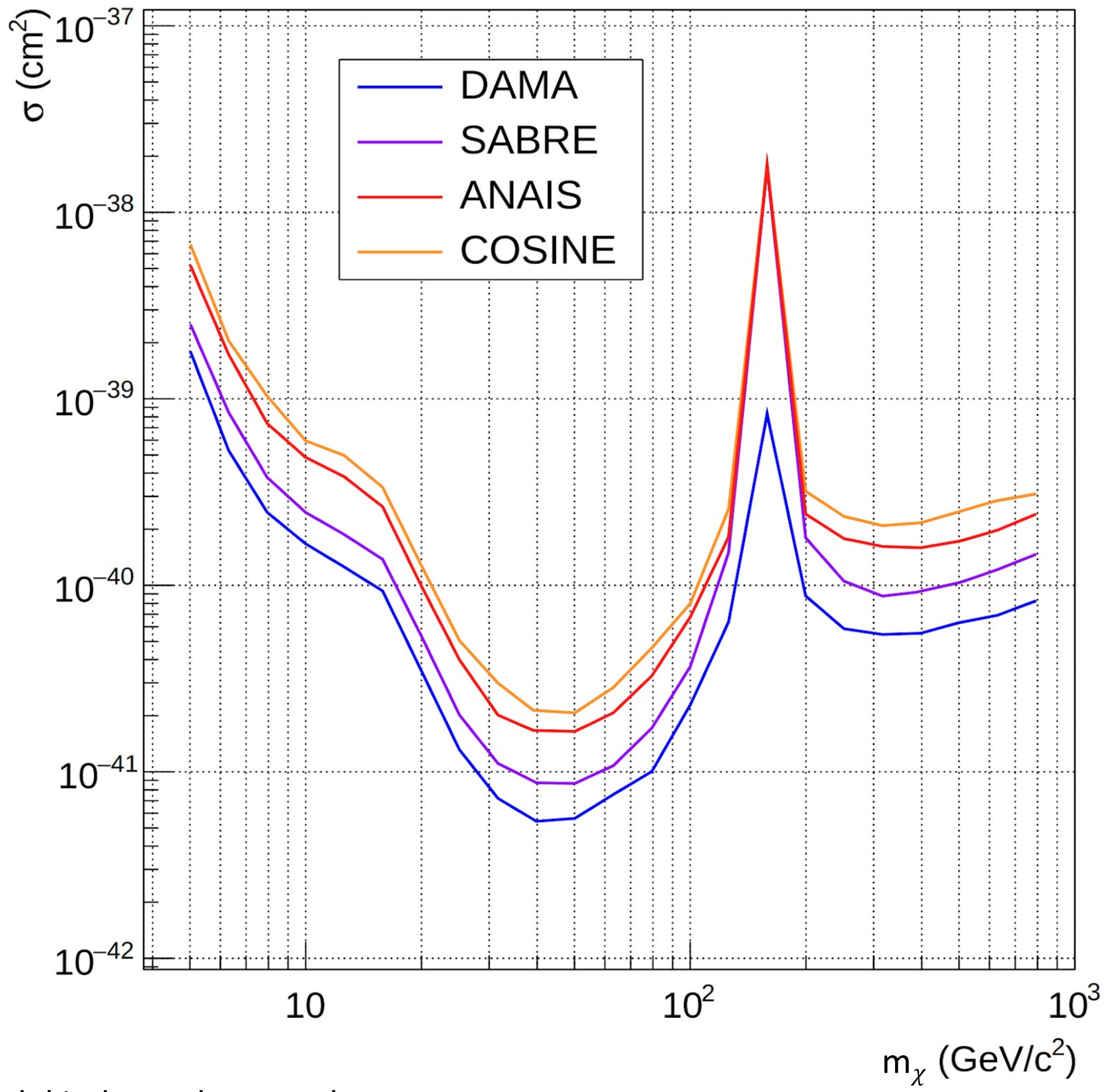
Results for 90% CL exclusion for a spin independent, elastic WIMP after 3 years of operation are shown in Fig. 3. Properties assumed for each experiment are given in table below, taken from published/projected values.

| Experiment | Mass (kg) | $R_b$ (cpd/kg/keV) |
|---|---|---|
| ANAIS | 112 | 3.2 [2] |
| COSINE | 57.5 | 2.7 [3] |
| DAMA | 250 | 0.8 [4] |
| SABRE | 50 | 0.36 [5] |

For a given $m_\chi$ the benchmark $\sigma_\chi$ scales between detectors as approx. $\sqrt{\frac{M_E}{R_b}}$, allowing us to scale sensitivity with respect to the limit set by DAMA. These values are given below.

| Experiment | DAMA | SABRE | ANAIS | COSINE |
|---|---|---|---|---|
| Scaling | 1.0 | 1.5 | 3.0 | 3.8 |

Fig. 3: 90% exclusion limits for various detectors under assumption of SI elastic WIMP




## Model independent results:

For model independent tests, instead of using different values of $m_\chi$ and $\sigma_\chi$ to compute $R_0$ and $R_m$ we take the values observed by DAMA. This allows us to calculate the required time each detector takes to exclude (or 'discover') this signal with some confidence without assuming any particle interaction model. (Though as DAMA have not published their constant rate we assume the standard halo model distribution for dark matter to derive a value for $R_0 = 0.02/R_m$).

The results for each detector are shown in Figs. 4 and 5, with the table below giving the expected time frame for benchmark exclusion and discovery significance.

| Experiment | Current excl. | For 3σ excl. | For 5σ disc. |
|---|---|---|---|
| ANAIS | 2.5 | 3 yrs | 7 yrs |
| COSINE | 1.6 | 5 yrs | >7yrs |
| SABRE | 0 | 2 yrs | 2 yrs |

Fig. 4: Exclusion CL as a function of run time

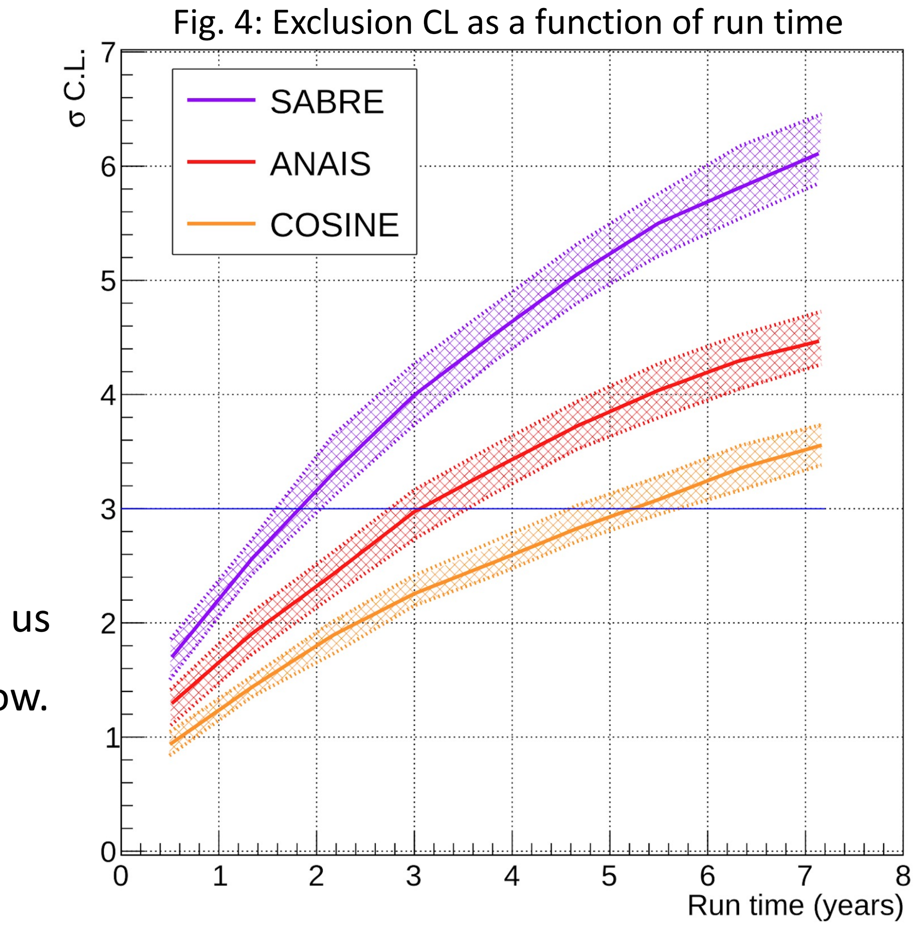
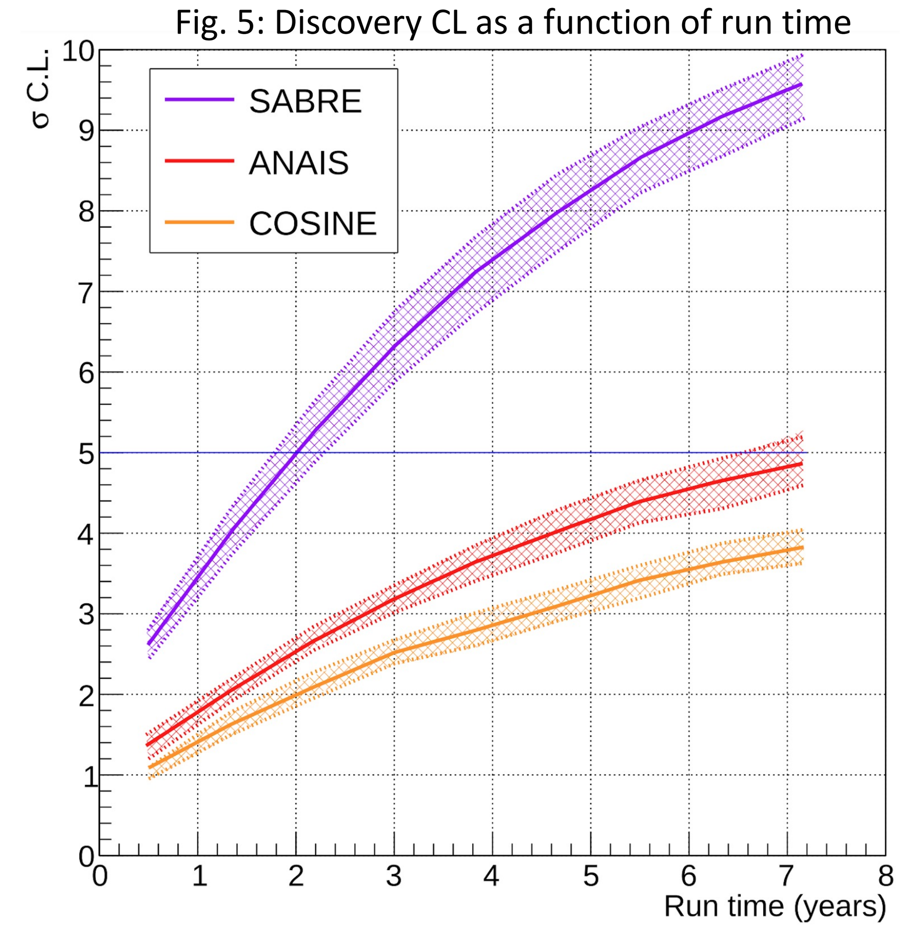



Fig. 5: Discovery CL as a function of run time




These results highlight the difference between the two test statistics – that is whether they depend on uncertainty of the background or signal + background modulation. Experiments with a lower background rate (like SABRE) naturally have a lower uncertainty (as this scales with $\sqrt{N_b}$ ), leading to the noticeably larger discovery level.

## Mass vs background requirements:

This analysis method can also be used to understand allowable mass and background requirements to achieve certain sensitivity levels to the DAMA signal.

In Fig. 6 for example, we plot the combinations that give a $3\sigma$ exclusion C.L. after 3 years of operation. Mass and background levels below the line can achieve this sensitivity.

This can be useful for the R&D for new detectors, or in the event of upgrades to existing NaI detectors where funding and/or space considerations need to be taken into account during the design.

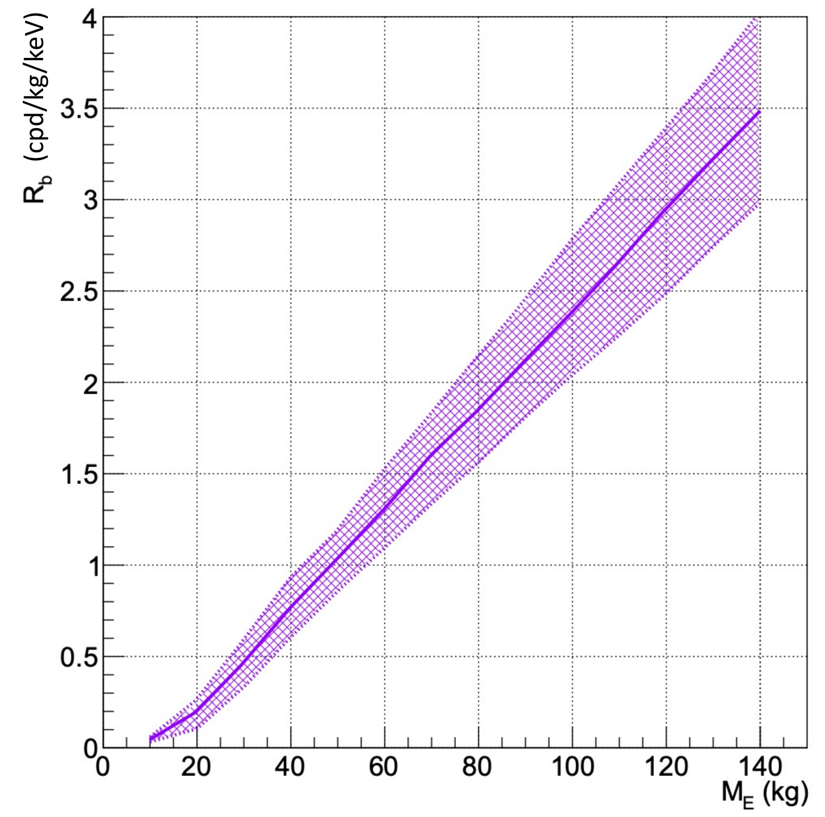



Fig. 6: Mass and background combinations for $3\sigma$ after 3 years

## Conclusions:

For both model dependent and dependent limits the lowest background (SABRE) has performed the best of the three new experiments, despite having the lowest exposure mass. This makes clear how important a low background is for DM searches in order to observe the small modulation in an already low interaction rate, further motivating the purification and veto techniques presently explored by these collaborations.

Based on this analysis, should the projected exposure mass and backgrounds be achieved, and data taking commence in the next 18 months, SABRE will be positioned to provide statistically significant exclusion or discovery of the DAMA signal within 3-4 years.

In this event (and even more so in the event of a positive DM-like signal), it will be beneficial to compare the results from the Northern and Southern hemispheres, to further elucidate clues as to nature of the modulating DAMA signal - DM or not.

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