Study of Dark Matter Sensitivity for the SABRE Experiment

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WIMP-nucleus interactions

➢ Assuming **elastic scattering**:

Spin independent cross section
$$\sigma_{SI} = \frac{\mu_\chi}{\mu_p} A^2 \sigma_{SI,p}$$

Nuclear form factor

Relative velocity WIMP-target

$$\frac{dR}{dE_R}(E_R,t) = \frac{\rho_D}{m_D} \frac{\sigma_{SI} \cdot [F_T(E_R)]^2}{2\mu_\chi^2} \int_{v \geq v_{min}} \frac{f_G(\boldsymbol{v} + \boldsymbol{v}_E(t))}{v} d^3v$$

Rate expression from *K. Freese et al. "Annual Modulation of Dark Matter: A Review"*

➔ ρ_D: Dark Matter density (ρ_D= 0.3 GeV/cm^3)

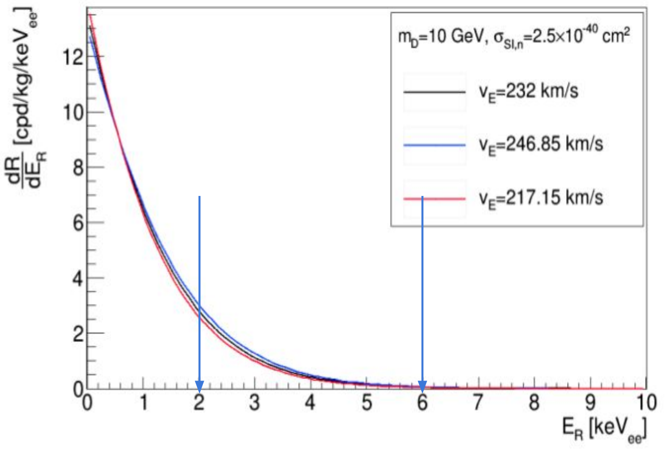
➔ m_D: WIMPs mass

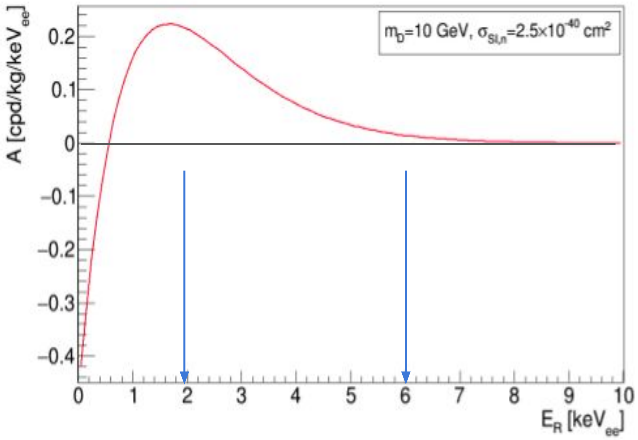
➔ μ_x: WIMP-nucleus reduced mass

Differential rate expressed in *counts per day/ kilogram/ keV electron equivalent* (**$cpd/kg/keV_{ee}$**)

Differential rate vs recoil energy

- EXAMPLE: Rate and modulation amplitude for **sodium target** (best fit to DAMA/LIBRA from *C.Savage et al. "Compatibility of DAMA/LIBRA dark matter detection with other searches"*)
- Assumptions:
  - Detector resolution and efficiency **not** included
  - Quenching factors (**0.30 for *Na*** and **0.09 for *I*** from DAMA) included
  - Region of interest [2-6] keV_{ee}





m_D = 10 GeV
σ_{SI} = 2.5 x 10^{-40} cm^2

Modulation signal

- To obtain the modulation signal for a NaI(Tl) target we have to take into account the contribution of each element to the mass of the target:

$$\left(\frac{dR}{dE_R}\right)_{NaI(Tl)} = C_{T_{Na}}\left(\frac{dR}{dE_R}\right)_{Na} + C_{T_I}\left(\frac{dR}{dE_R}\right)_I$$

Mass fractions of Na and I

- Assumptions:
  - Quenching factors from DAMA
  - Neither detector resolution nor detector efficiency considered

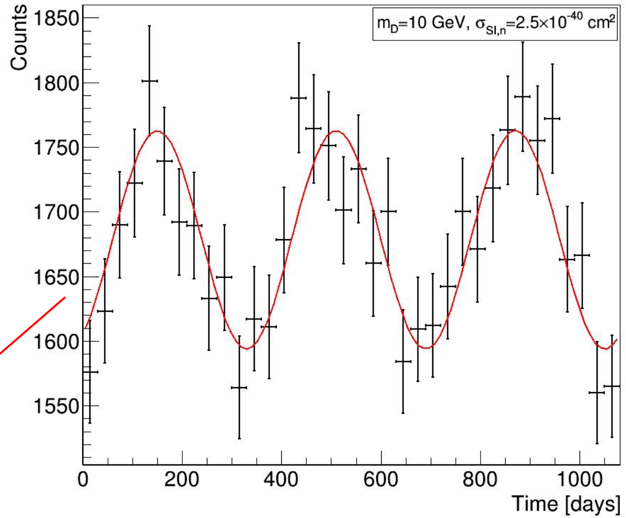
Fit function:

$$y = c + A\cos\frac{2\pi}{T}(t - t_0)$$

T: 1 *year*

t_0: 0.416 *years* (*~June 2*)

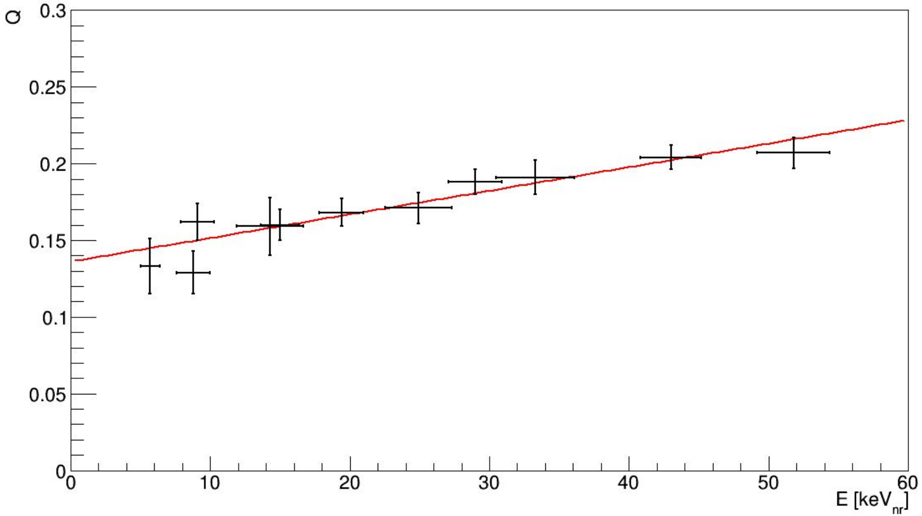
50 *kg* NaI(Tl), background: 0.2 *cpd/kg/keV$_{ee}$*, (2-6) *keV$_{ee}$*



- Time bin width: 30 days
- Total number of events (signal + background) generated from a Poisson distribution

New sodium quenching factor

- *New Na quenching factor included:*
  - ➔ Measurement of Na quenching factor from *Jingke Xu et al. "Scintillation efficiency measurement of Na recoils in NaI(Tl) below the DAMA/LIBRA energy threshold"*



Linear fit:

$$Q = c + m \cdot E[keV_{nr}]$$

$c = (0.1363 \pm 0.0074)$

$m = (0.00154 \pm 0.00025)\ keV_{nr}^{-1}$

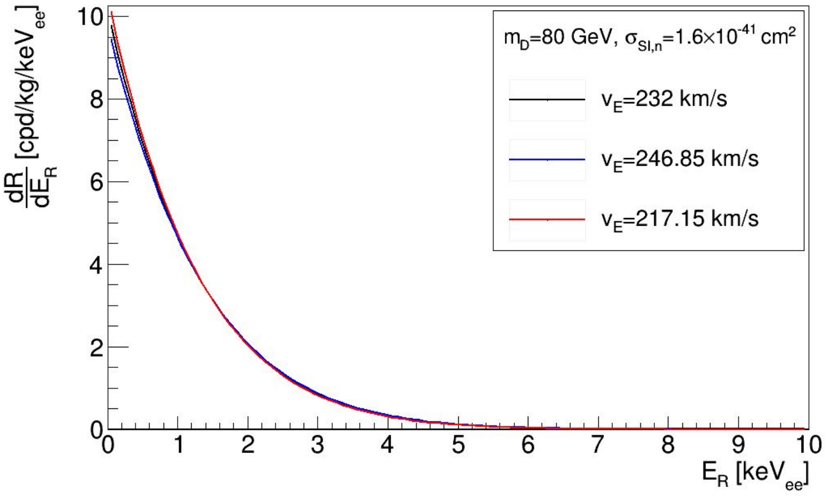
- *Resolution also included*:

$$R = \frac{0.02}{\sqrt{E}}$$

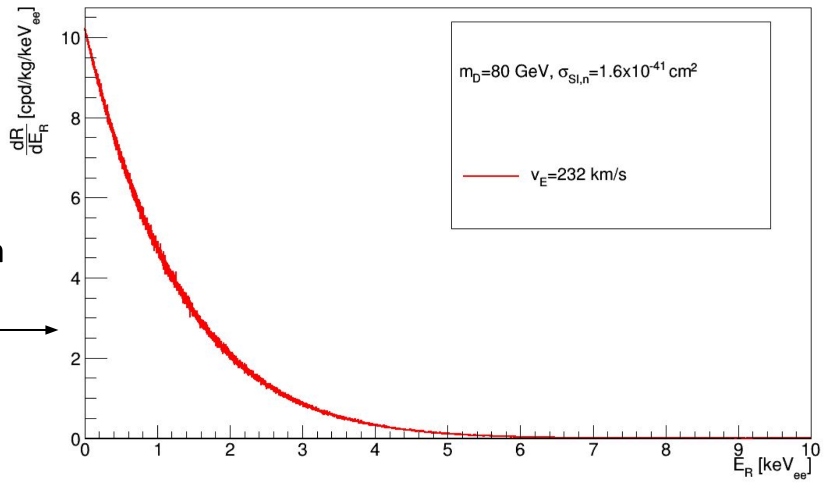
Differential rate comparison: Iodide target

➢ Differential rate with no resolution included vs differential rate with resolution included for a iodide target

m_D= 80 *GeV*, $\sigma_{SI,n}$= 1.6 x 10^{-41} *cm²*



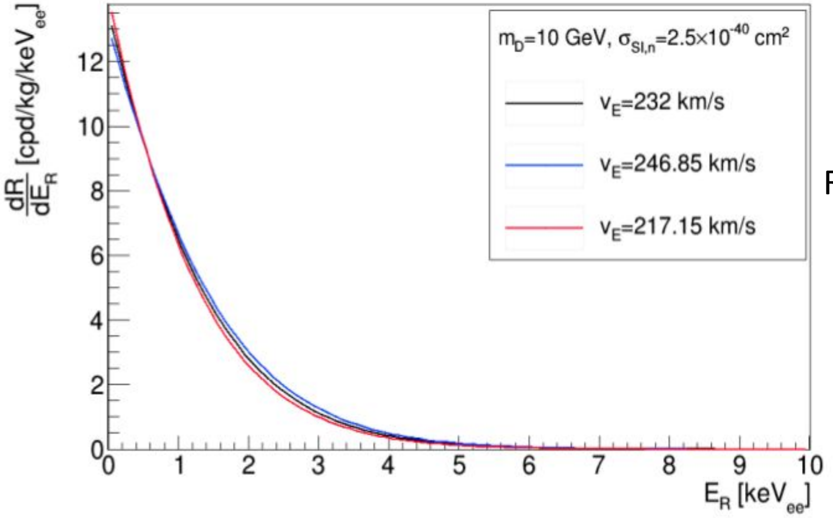
Resolution included



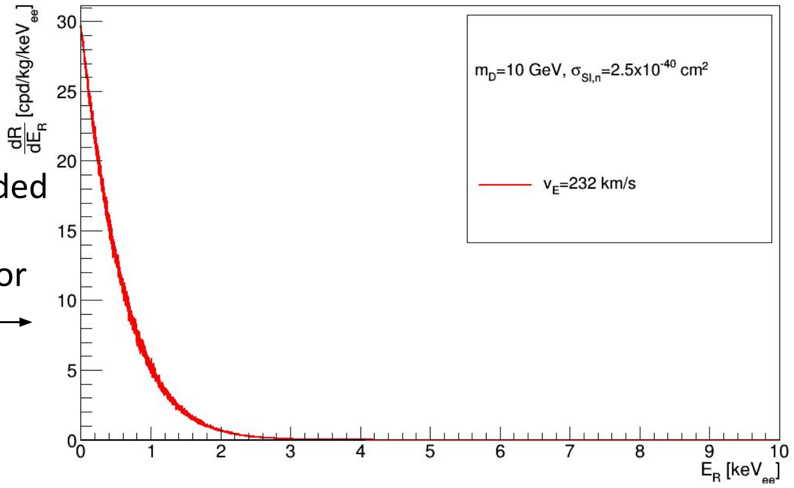
Differential rate comparison: Sodium target

- ➢ Differential rate with *Na* DAMA quenching factor and no resolution included vs differential rate with *Na* quenching factor measured by Jingke Xu et al. and resolution included for a sodium target

m_D= 10 *GeV*, $\sigma_{SI,n}$= 2.5 x 10^{-40} *cm^2*



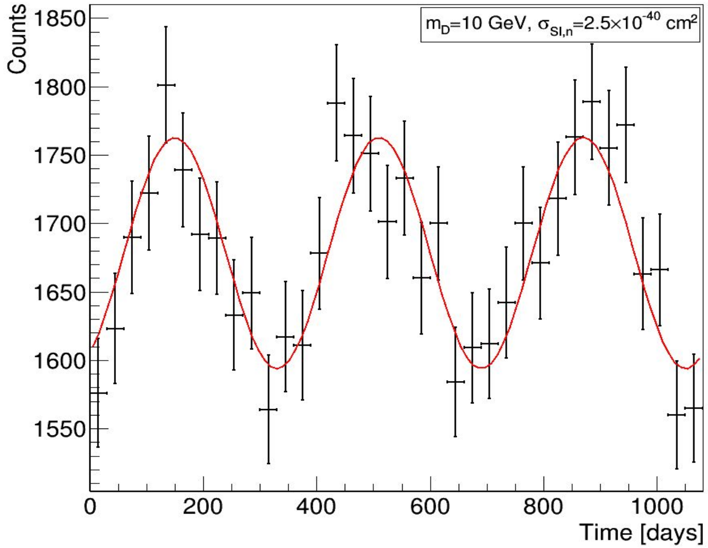
Resolution included + new *Na* quenching factor →



Modulation signal comparison: light WIMP

- Modulation signal with *Na* DAMA quenching factor and no resolution included vs modulation signal with *Na* quenching factor measured by Jingke Xu et al. and resolution included for a NaI(Tl)

m_D= 10 *GeV*, $\sigma_{SI,n}$= 2.5 x 10^{-40} *cm^2*, 50 *kg* NaI(Tl), background: 0.2 *cpd/kg/keV_{ee}*, (2-6) *keV_{ee}*



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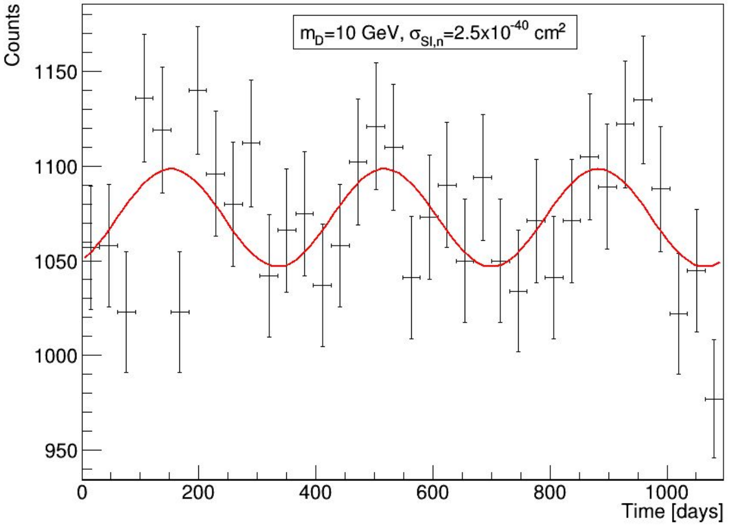
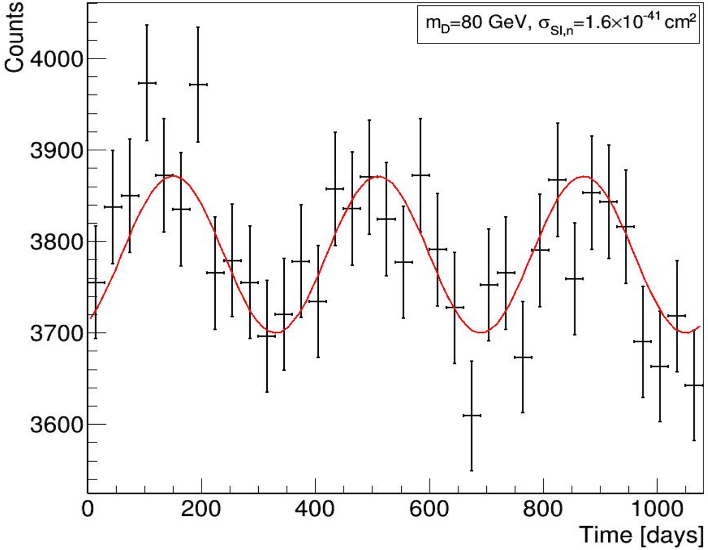


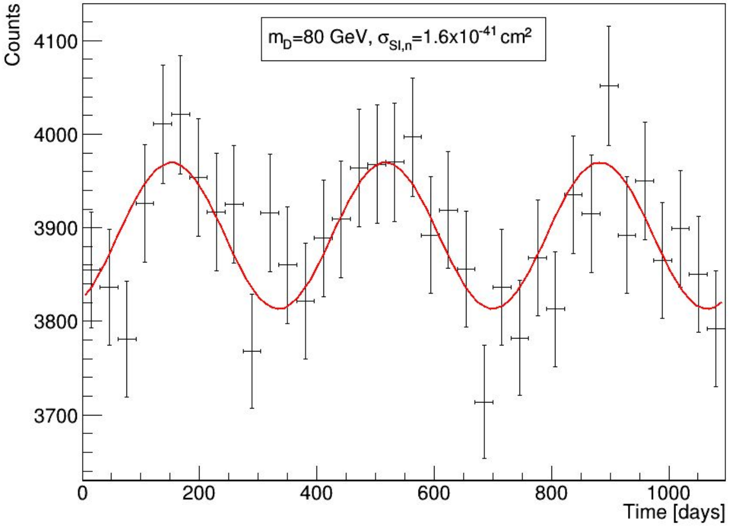
Modulation signal comparison: heavy WIMP

- Modulation signal with *Na* DAMA quenching factor and no resolution included vs modulation signal with *Na* quenching factor measured by Jingke Xu et al. and resolution included for a NaI(Tl)

m_D= 80 *GeV*, $\sigma_{SI,n}$= 1.6 x 10^{-41} *cm^2*, 50 *kg* NaI(Tl), background: 0.2 *$cpd/kg/keV_{ee}$*, (2-6) *keV_{ee}*



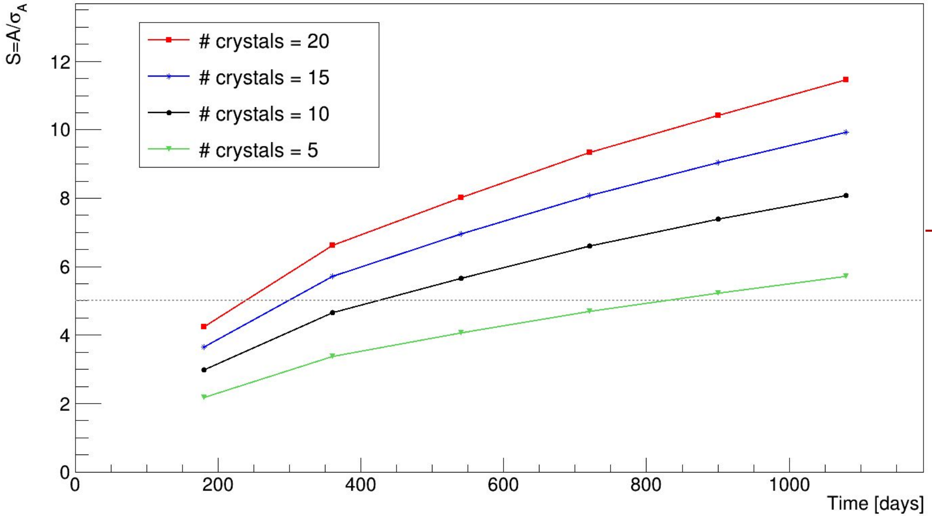
Resolution included + new *Na* quenching factor



Statistical significance

- Statistical significance defined as: $S = \frac{A}{\sigma_A}$ → amplitude from the fit (A); amplitude error from the fit (σ_A)
- Each NaI(Tl) crystal has a mass of 5 *kg*
- 1000 toy model

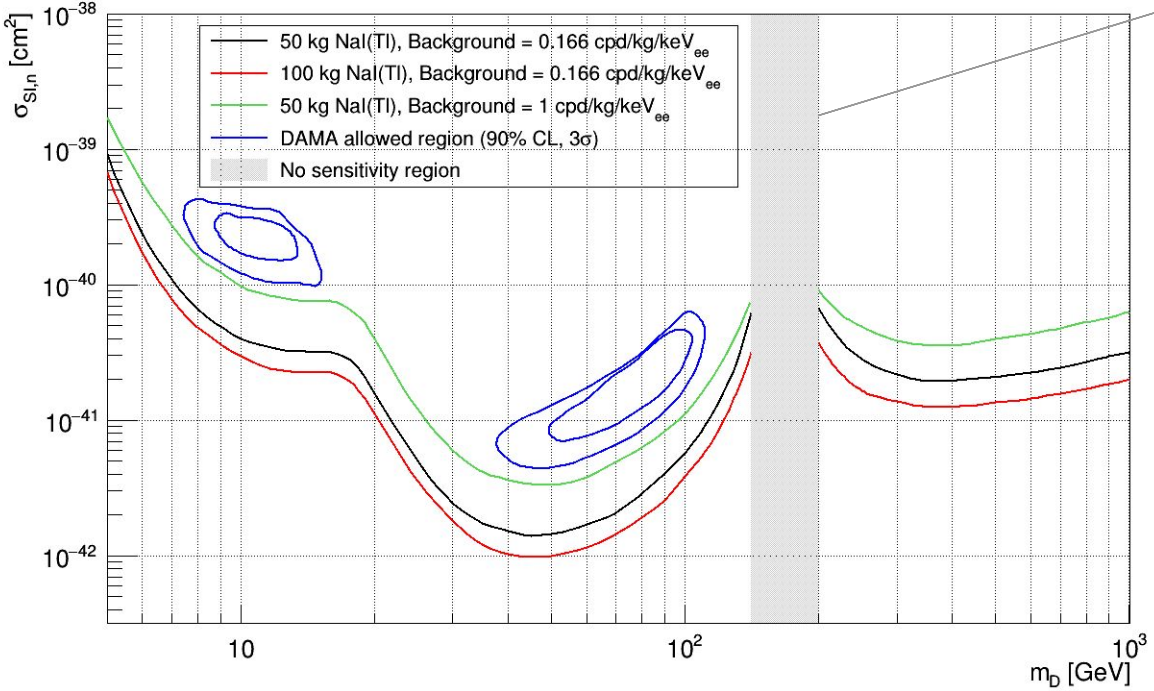
m_D= 10 *GeV*, $\sigma_{SI,n}$= 2.5 x 10^{-40} *cm^2*, background: 0.2 *cpd/kg/keV_{ee}*, (2-6) *keV_{ee}*



With a total NaI(Tl) mass of 50 *kg* and a background of 0.2 *cpd/kg/keV_{ee}* a statistical significance of *S*=5 is reached in less than 3 years

Sensitivity plots

- 1000 modulation signals generated for every couple (m_D, $\sigma_{SI,n}$)
- Data taking period: 3 years
- 90 % C.L. sensitivity plots



No sensitivity in this region because in the energy range (2-6) keV_{ee} the modulation amplitude goes to 0

Background reduction has a greater impact on the sensitivity plot than the increase of the NaI(Tl) total mass

Good agreement with the results from previous simulations

Sensitivity plots explanation

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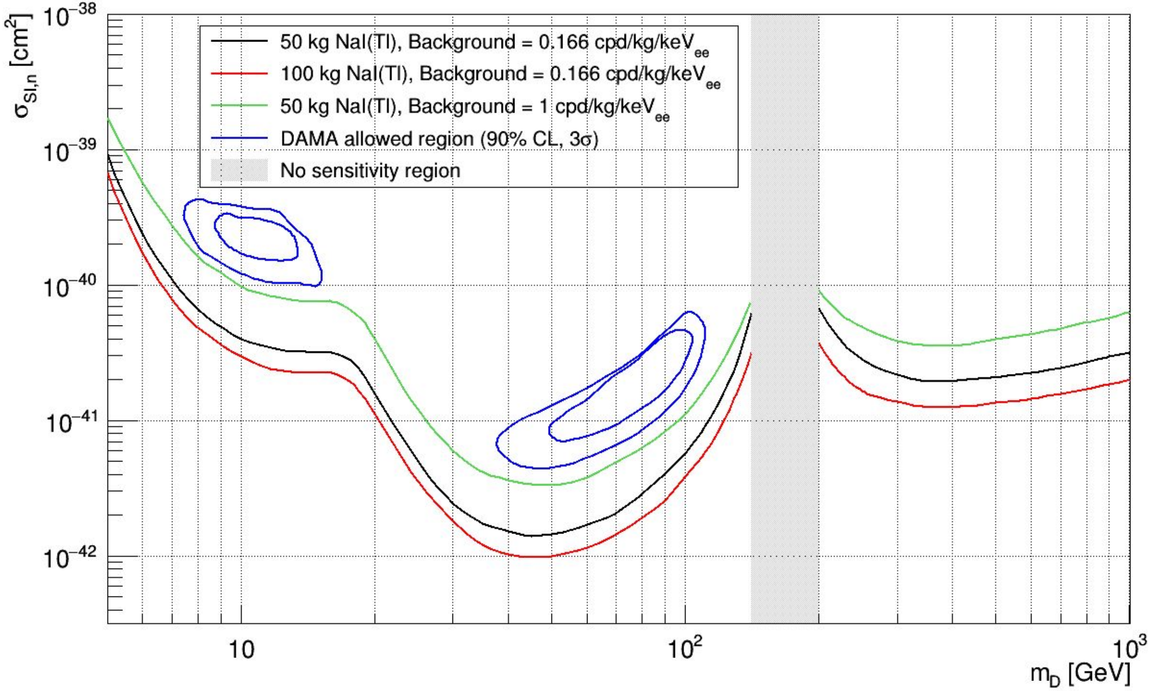

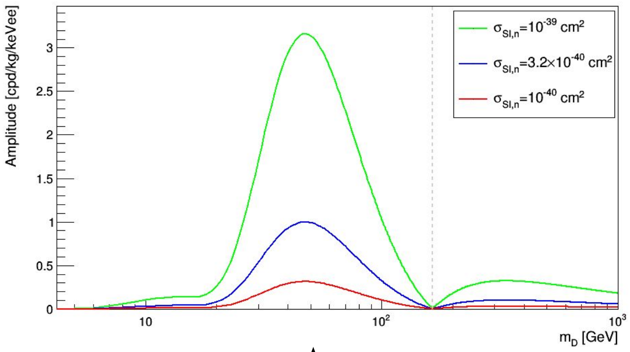

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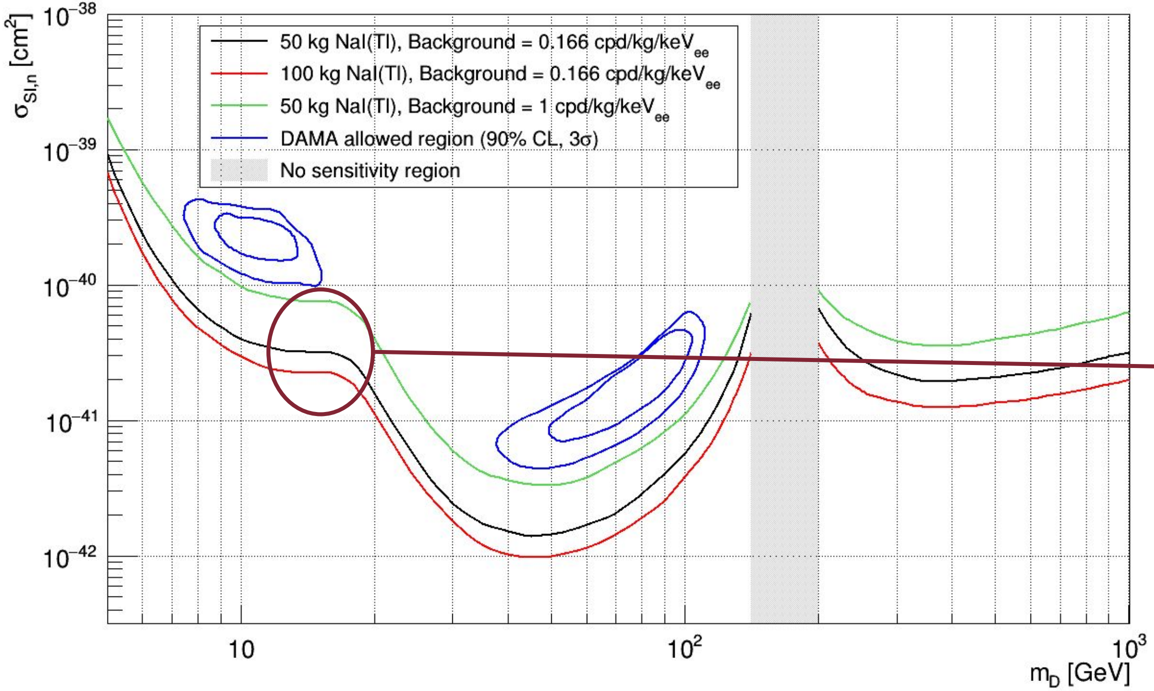

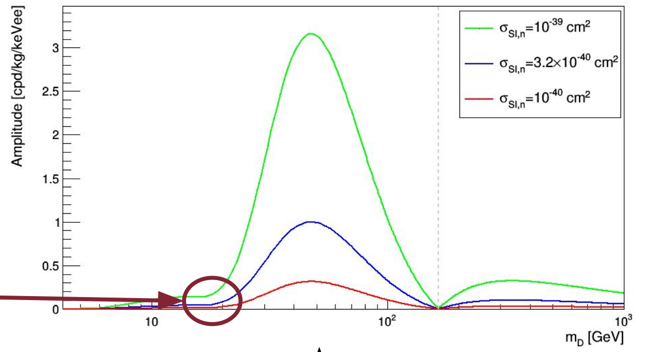

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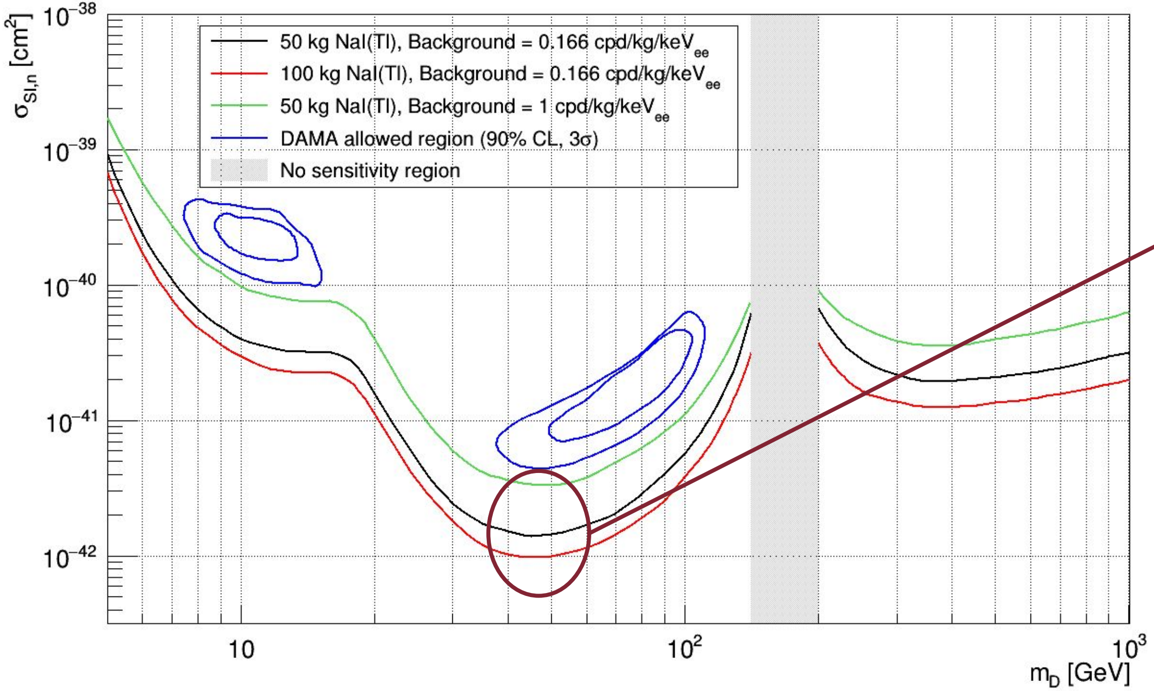

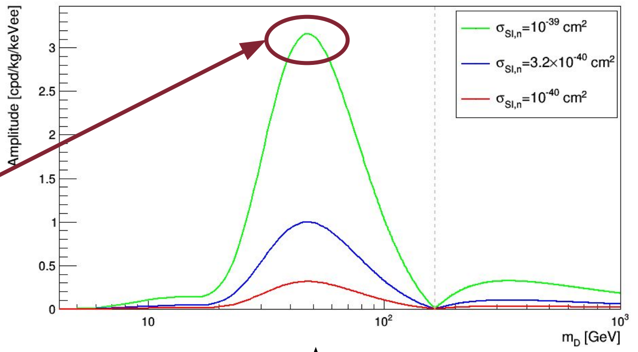

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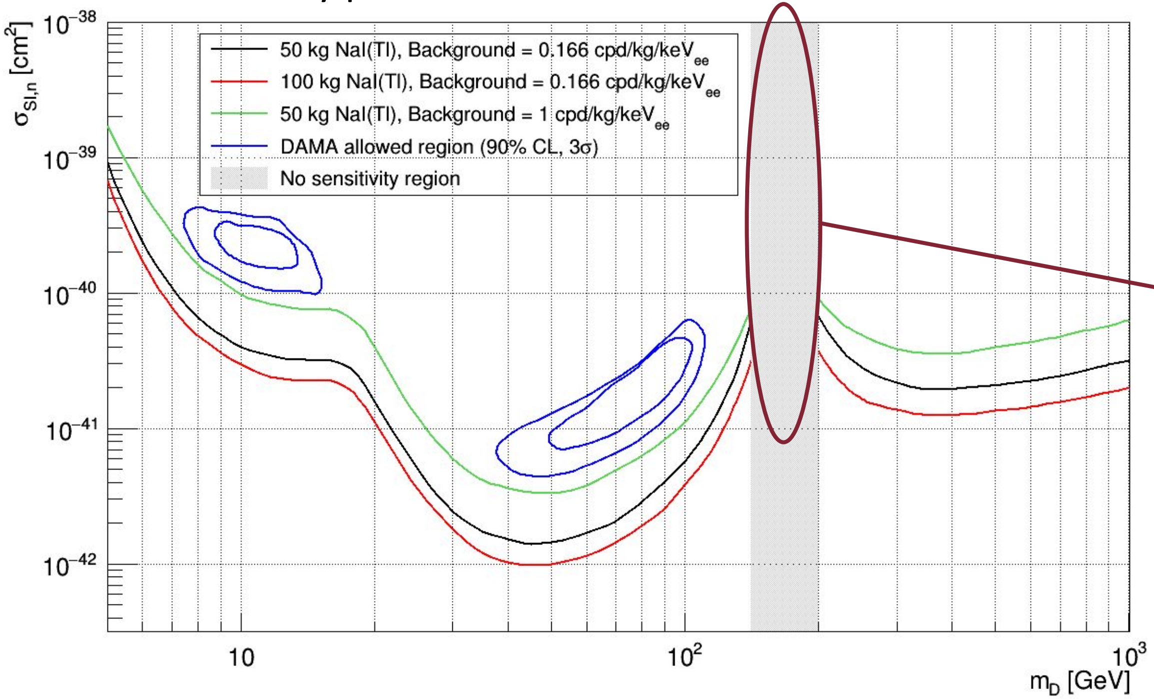

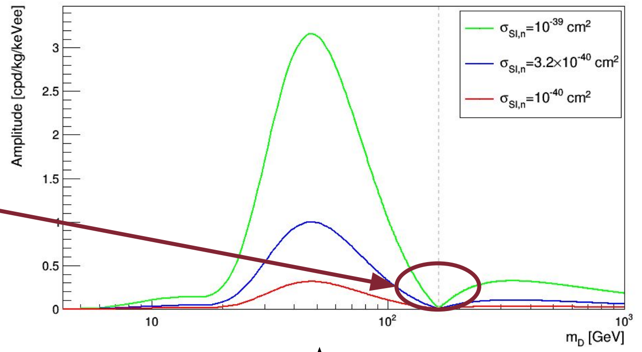

Modulation amplitude vs WIMPs mass

Conclusions

➔ Assuming the Standard Halo Model, we developed a tool to study how the SABRE experimental rate changes according to the the Dark Matter parameters and the background

➔ Using the best fit to DAMA/LIBRA from C.Savage et al., we studied the statistical significance versus the data taking time for different values of the total NaI(Tl) mass

➔ A statistical significance of *S*=5 is reached in less than 3 years with a 50 *kg* total NaI(Tl) mass for a modulation signal of the same entity of that measured by DAMA-LIBRA

➔ A sensitivity plot for the SABRE experiment was produced (using the DAMA quenching factors)

➔ We studied how the differential rate and the modulation signal change according to the quenching factor and the resolution (work still in progress)

➔ Different possible approaches to the sensitivity study (see Valerio talk)

Differential rate vs recoil energy

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- ➢ Assumptions:
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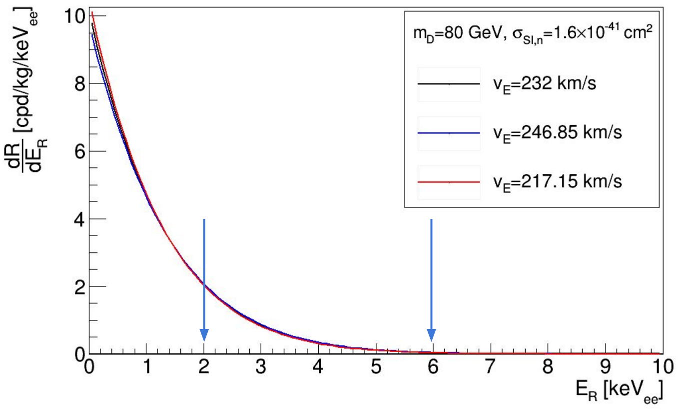

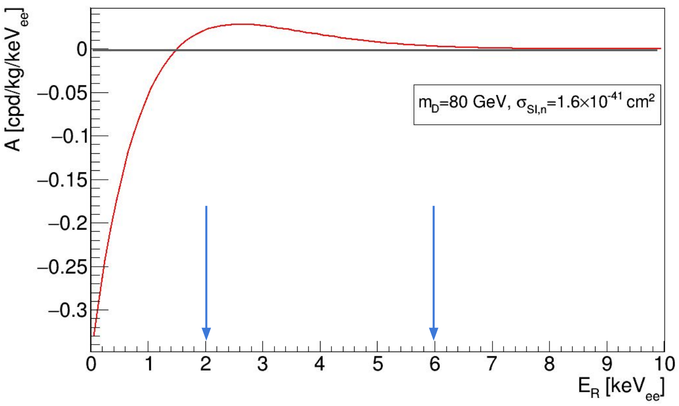

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Mass fractions of Na and I

- Background ~0.2 *cpd/kg/keV*$_{ee}$ from Monte Carlo simulation

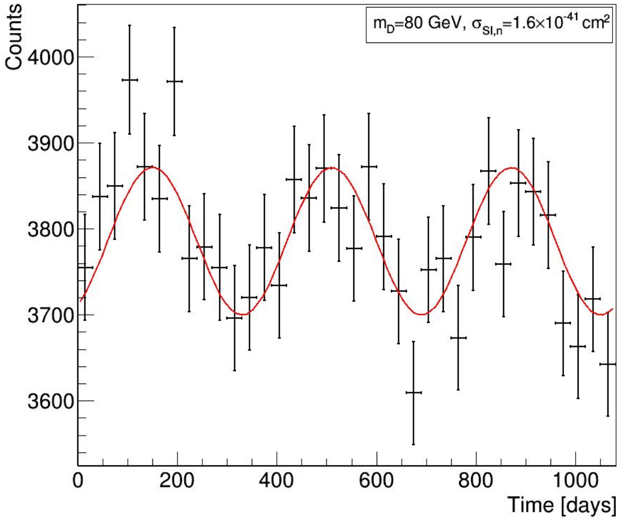
Fit function:

$$y = c + A\cos\frac{2\pi}{T}(t - t_0)$$

T: Fixed to 1 *year*

t_0: Fixed to 0.416 *years* (~*June 2*)

50 *kg* NaI(Tl), background: 0.2 *cpd/kg/keV*$_{ee}$, [2-6] *keV*$_{ee}$



- ➢ Total number of events generated from a Poisson distribution with mean: $B+S_0+S_m$ (signal + background)
- ➢ Time bin width: 30 days

Statistical significance

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- Each NaI(Tl) crystal has a mass of 5 *kg*
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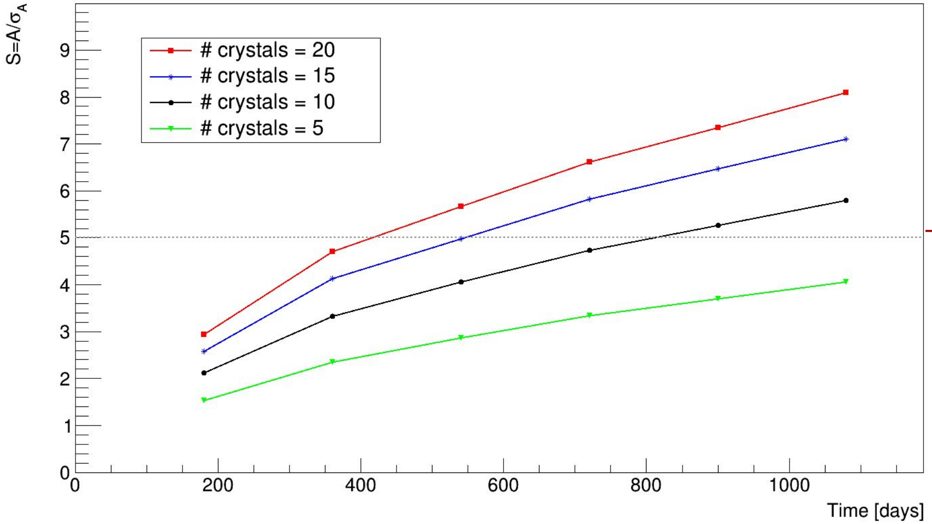
m_D= 80 *GeV*, $\sigma_{SI,n}$= 1.6 x 10^{-41} *cm*^{2}, background: 0.2 *cpd/kg/keV*$_{ee}$, [2-6] *keV*$_{ee}$



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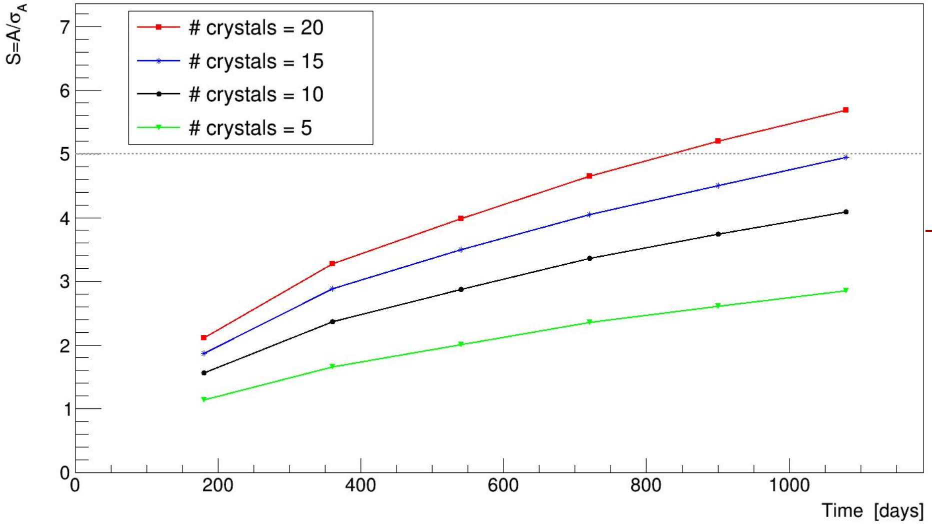

With a total NaI(Tl) mass of 50 *kg* and a background of 1 *cpd/kg/keV_{ee}* 3 years are not enough to reach a statistical significance of *S*=5

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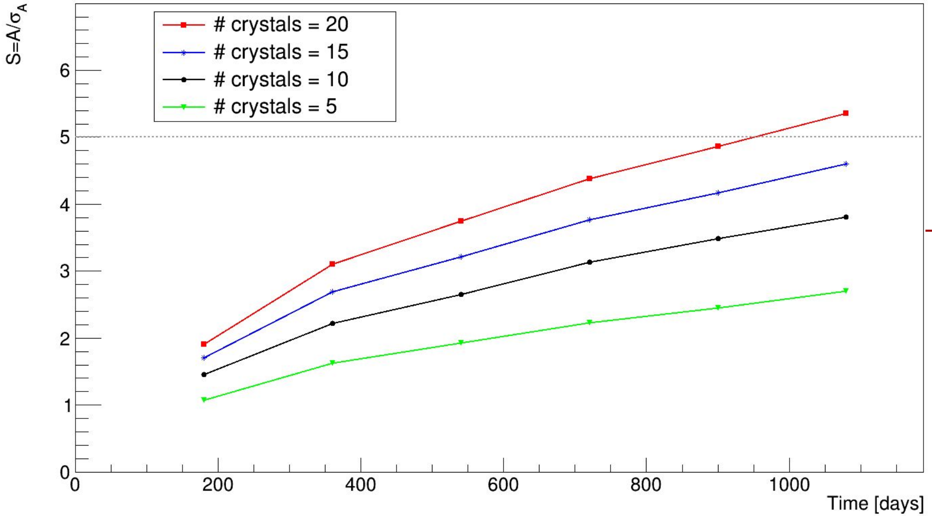

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Velocity distribution

$$f_G(\boldsymbol{v}) = \frac{e^{-\frac{\boldsymbol{v}^2}{v_0^2}}}{(\pi v_0^2)^{\frac{3}{2}} N_{esc}} \theta(v_{esc} - |\boldsymbol{v}|)$$

Galactic escape velocity

v_{esc}=544 km/s

v_0=220 km/s

Normalization

$$N_{esc} = Erf(\frac{v_{esc}}{v_0}) - \frac{2v_{esc}}{\sqrt{\pi}\ v_0}\ e^{-\frac{v_{esc}^2}{v_0^e}}$$