# DAMA/LIBRA and leptonically interacting Dark Matter

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based on Kopp, Niro, Schwetz, JZ, 0907.3159

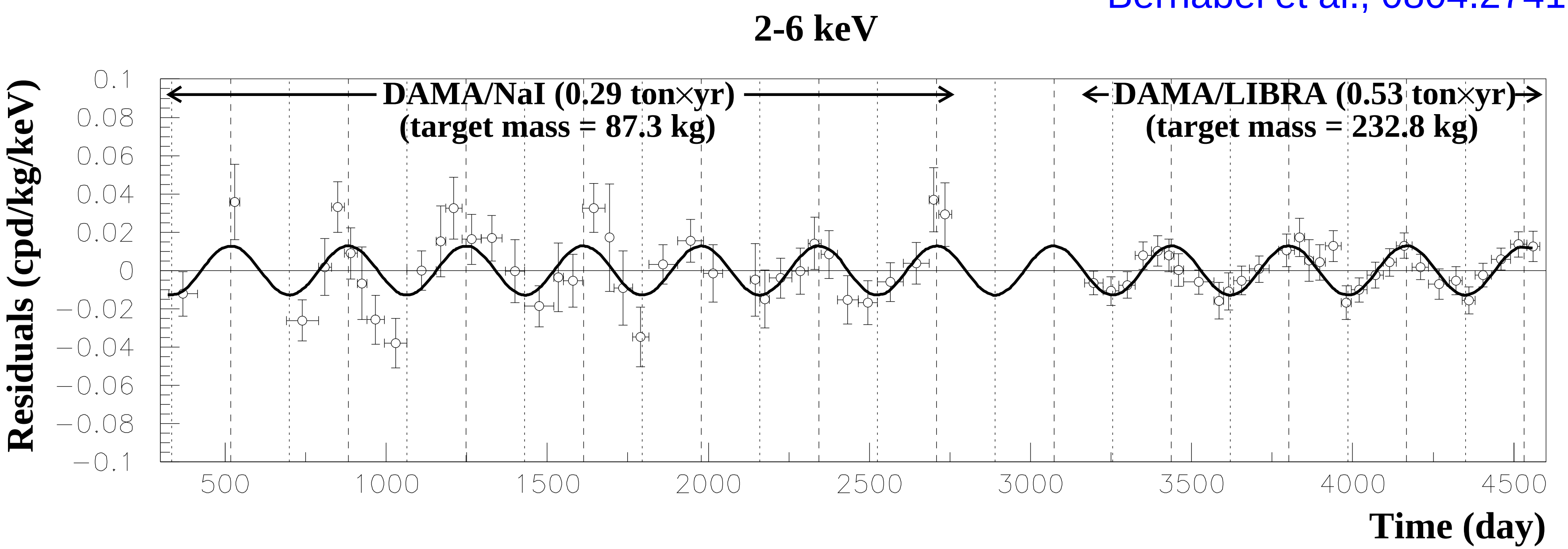
# Outline

- motivation
- setup
  - kinematics
  - effective field theory
- comparing with data
- conclusions

# DAMA/LIBRA result

- impressive data sample from DAMA/NaI+DAMA/LIBRA: $0.82\ \mathrm{ton} \times \mathrm{yr}$ exposure
- see $8.2\sigma$ evidence for annual modulation
- phase agrees with DM interpretation: max @ day $144 \pm 8$, expected June $2^{\mathrm{nd}}$= day $152$

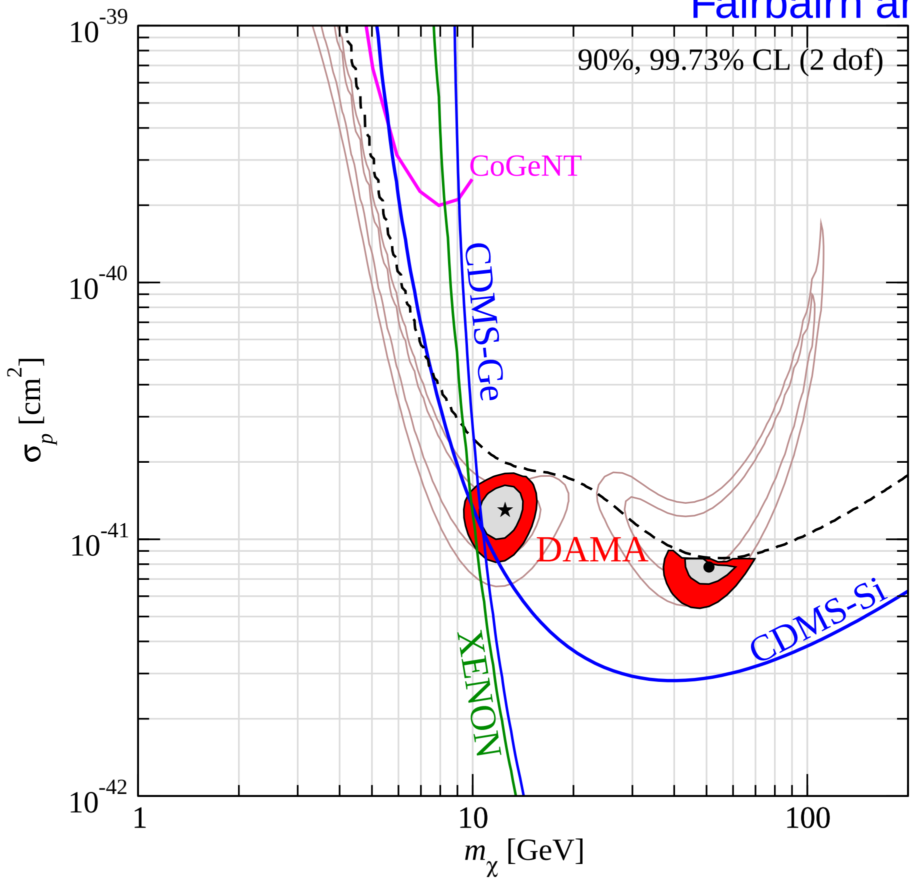
Bernabei et al., 0804.2741



# comparison with other experiments

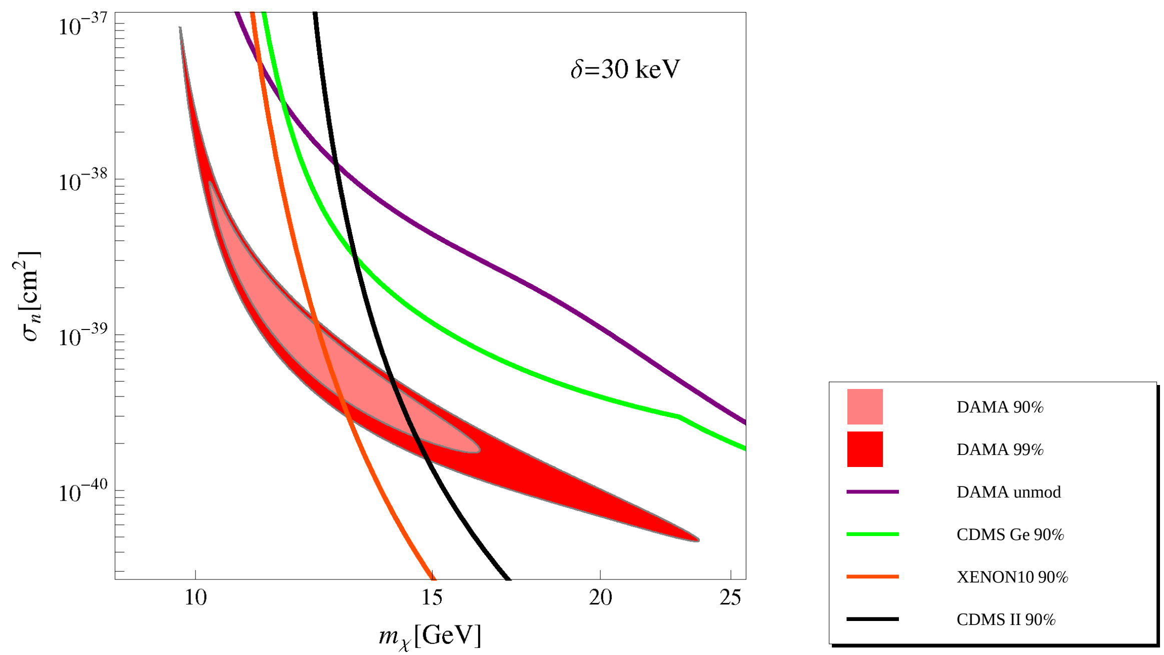
- spin independent scattering on nuclei
- tension with other experiments (XENON-10, CDMS,...)
- DAMA and other expts. consistent with prob. $O(10^{-5})$

Fairbairn and Schwetz, 0808.0704



# comparison - IDM

- comparison is model dependent
- depending on model can reconcile DAMA with the rest
- popular choice: inelastic DM Schmidt-Hoberg and Winkler, 0907.3940



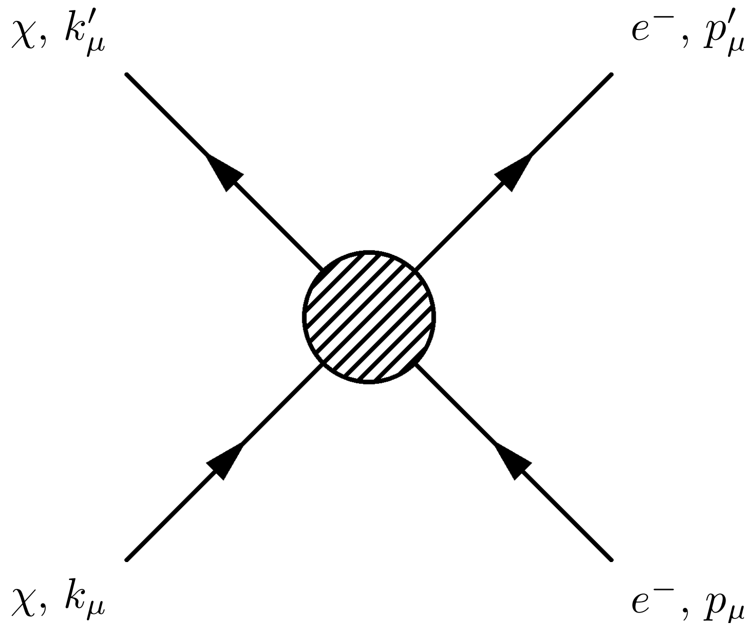

- high mass region excluded
- low mass region:
  - channeling
  - scattering on Iodine
- other suggestions: $q$ dependend DM scattering; mirror world DM; DM with electric, magnetic dipole moments,...

# Leptophilic DM

- models almost exclusively: DM scattering on nuclei
- if DM leptophilic: scatters off electrons Bernabei et al. 0712.0562
  - DAMA looks for the annual modulation in the count rate from scintillation light $\Rightarrow$ pure electron events fully contribute
  - CDMS, XENON10, CRESST, KIMS, ZEPLIN,. . . reject electron events to perform a low background search for nuclear recoils.
- other motivation for leptophilic DM: $e^+, e^-$ cosmic ray anomaly

# Assumptions

- DM couples to electrons (leptons)
- DM is leptophilic: direct coupling to quarks and photons suppressed
- DM does not change in the process



# Question

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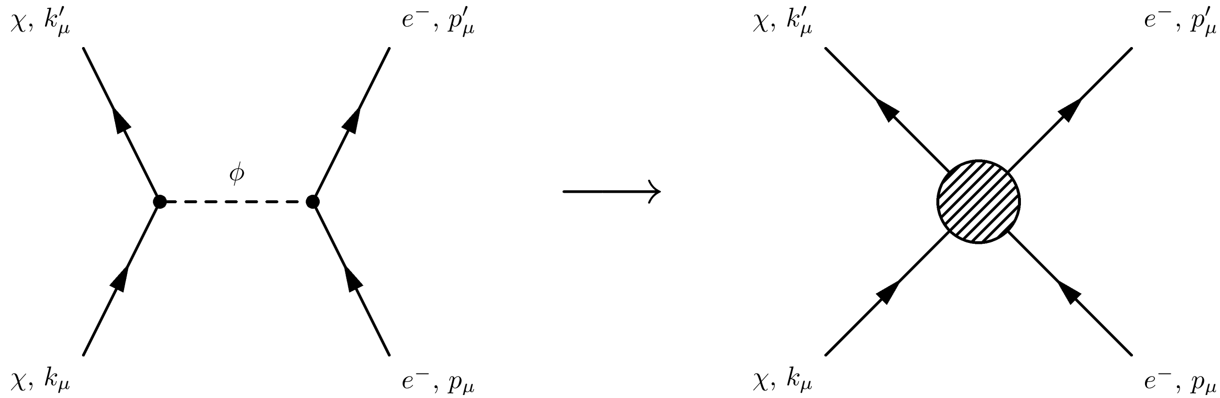
- will provide model independent answer:

**NO!**

# Model independent analysis

- for $\Lambda \gg O(\mathrm{MeV})$ can use effective field theory




- all DM-lepton interactions described by
  - 10 operators for fermionic $\chi$

    $$\mathcal{L}_{\rm eff} = \sum_i G\,(\bar\chi\Gamma^i_\chi\chi)\,(\bar\ell\Gamma^i_\ell\ell) \quad \text{with} \quad G = \frac{1}{\Lambda^2}$$

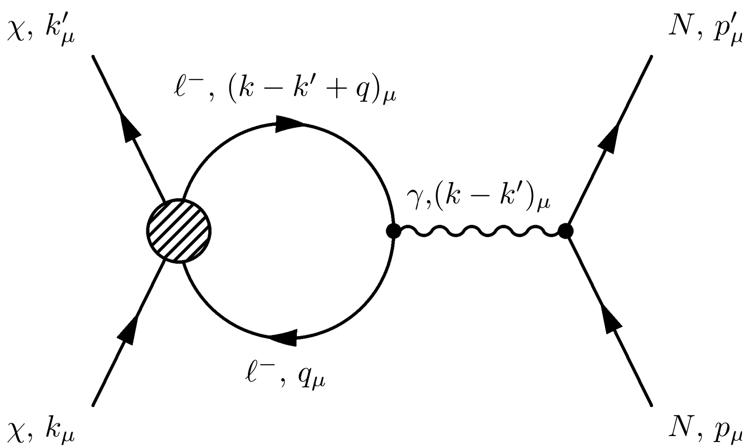
  - 2 operators for scalar $\chi$

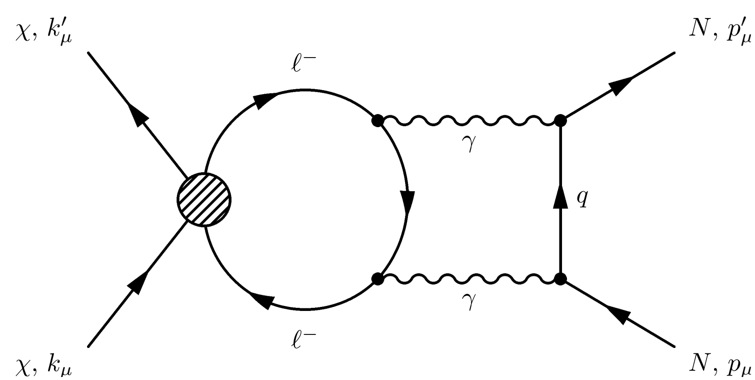
    $$\mathcal{L}_{\rm eff} = G_5(\chi^\dagger\chi)\left[\bar\ell(d_S + i d_P\gamma_5)\ell\right] \quad \text{with} \quad G_5 = \frac{1}{\Lambda}$$

- this description completely model independent

# Types of events

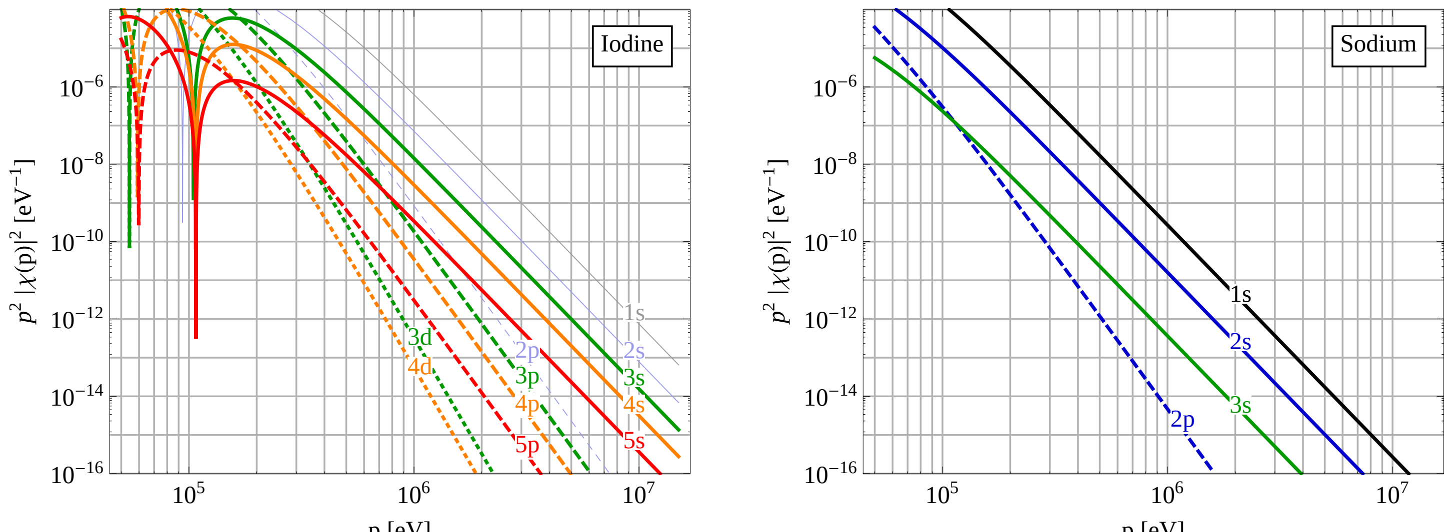
1. WIMP–electron scattering ($\mathrm{WES}$): electron kicked out of the atom
2. WIMP–atom scattering ($\mathrm{WAS}$): electron remains bound, recoil taken by the atom
3. WIMP–nucleus scattering ($\mathrm{WNS}$): interactions with quarks induced at loop level



# $\chi e^- \to \chi e^-$ kinematics

- $e^-$ at rest, $\chi$ velocity $v \sim 10^{-3}c$:
  - maximal recoil energy $E_d = 2mv^2 \sim O(\mathrm{eV})$
- electrons bound $\Rightarrow$ can have large momenta
- energy transfer $E_d \sim O(pv)$
  - for $p \sim O(\mathrm{MeV}) \Rightarrow E_d \sim O(\mathrm{keV})$
- such configurations are not very probable $\Rightarrow$ wave function suppression, $\epsilon_{\mathrm{WES}} \sim 10^{-6}$, $\epsilon_{\mathrm{WAS}} \sim 10^{-19}$



# Comparing rates

$$R^{\rm WAS} : R^{\rm WES} : R^{\rm WNS} \sim \epsilon_{\rm WAS} : \epsilon_{\rm WES} \frac{m_e}{m_N} : \left( \frac{\alpha_{\rm em} Z}{\pi} \right)^2$$
$$\sim 10^{-17} : 10^{-10} : 1$$

- loop induced $\chi N \to \chi N$ most important (even at two loop, where extra $O(10^{-6} Z^2)$ suppression)
- two types of operators
  - i) induce $\chi N \to \chi N$ at 1-loop or 2-loops ($S \otimes S$, $P \otimes S$, $V \otimes V$, $A \otimes V$, $T \otimes T$, $AT \otimes T$)
  - ii) does not induce $\chi N \to \chi N$ at any loop ($S \otimes P$, $P \otimes P$, $V \otimes V$, $V \otimes A$, $A \otimes A$)

# Two examples

| | fermionic DM | | |
|---|---|---|---|
| $\Gamma_\chi \otimes \Gamma_\ell$ | $\sigma(\chi e \to \chi e)/\sigma^0_{\chi e}$ | $\sigma(\chi N \to \chi N)/\sigma^1_{\chi N}$ | |
| $S \otimes S$ | $1$ | $\alpha^2_{\rm em}$ | [2-loop] |
| $S \otimes P$ | $\mathcal{O}(v^2)$ | $-$ | |
| $P \otimes S$ | $\mathcal{O}(r_e^2 v^2)$ | $\alpha^2_{\rm em} v^2$ | [2-loop] |
| $P \otimes P$ | $\mathcal{O}(r_e^2 v^4)$ | $-$ | |
| $V \otimes V$ | $1$ | $1$ | [1-loop] |
| $V \otimes A$ | $\mathcal{O}(v^2)$ | $-$ | |
| $A \otimes V$ | $\mathcal{O}(v^2)$ | $v^2$ | [1-loop] |
| $A \otimes A$ | $3$ | $-$ | |
| $T \otimes T$ | $12$ | $q_\ell^2$ | [1-loop] |
| $AT \otimes T$ | $\mathcal{O}(v^2)$ | $q_\ell^2 v^{-2}$ | [1-loop] |

| | scalar DM | | |
|---|---|---|---|
| $\Gamma_\ell$ | $\sigma(\chi e \to \chi e)/\sigma^0_{\chi e,5}$ | $\sigma(\chi N \to \chi N)/\sigma^1_{\chi N,5}$ | |
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| $V \otimes V$ | $1$ | $1$ | [1-loop] |
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| $P$ | $\mathcal{O}(v^2)$ | $-$ | |

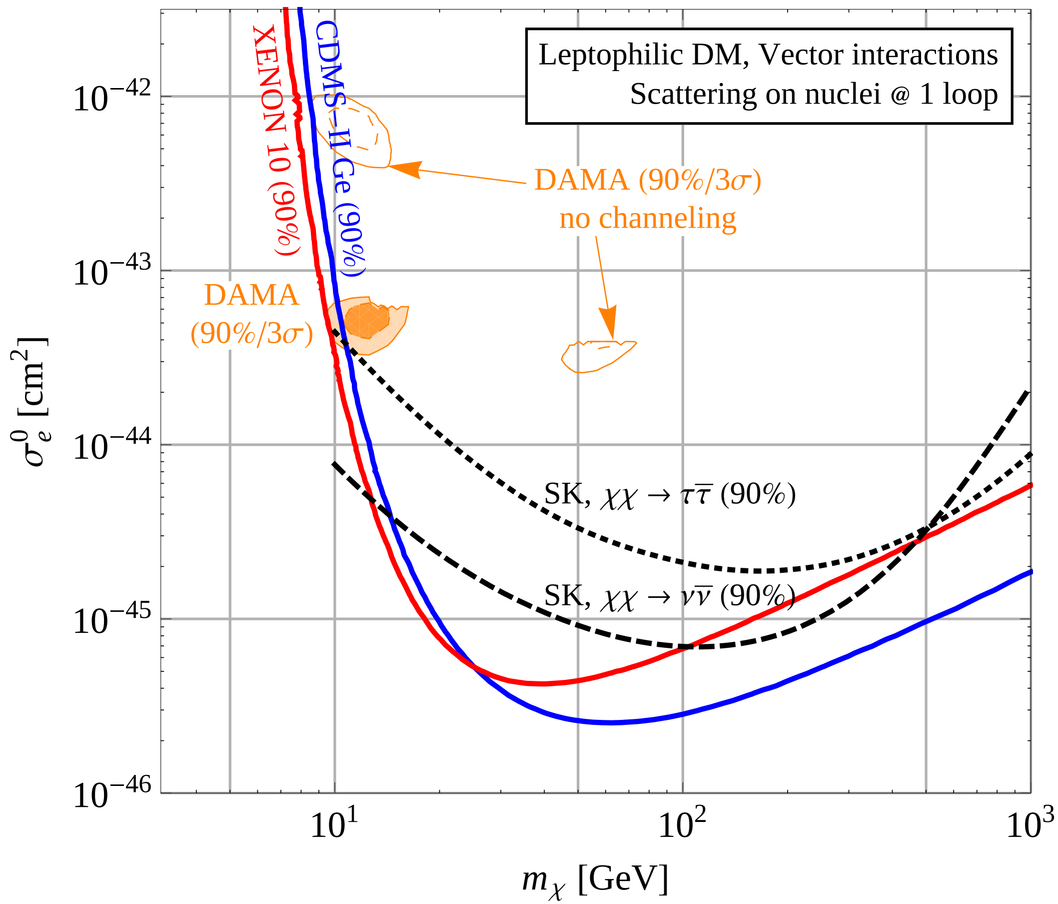
# Numerics

- in numerics will fix equal coupling to $e, \mu, \tau$
- constraints on $\Lambda$ translate to constr. on total Xsec for nonrel. $e^-$

$$\sigma^0_{\chi e} = \frac{m_e^2}{\pi \Lambda^4} \approx 3.1 \times 10^{-39}\,\mathrm{cm}^2 \left(\frac{10\,\mathrm{GeV}}{\Lambda}\right)^4$$

# $V \otimes V$ case: loop induced $\chi N \to \chi N$

- the same tension as for standard $\chi N \to \chi N$ scattering
  $\Rightarrow$ no improvement from leptophilic nature of $\chi$



# $A \otimes A$ case: scattering on electrons

- no coupl. to quarks through loops (at any order)
- important spectral shape of the event rate

$$\frac{dR^{\rm WES}}{dE_d} \simeq \frac{3\rho_0 m_e G^2}{4\pi(m_{\rm I}+m_{\rm Na})m_\chi} \sum_{nl} \sqrt{2m_e(E_d - E_{B,nl})}\,(2l+1) \int \frac{dp\,p}{(2\pi)^3}\,|\chi_{nl}(p)|^2\, I(v_{\rm min}^{\rm WES})$$

$\chi_{nl}(p)$ el. momentum w.f., $E_{B,nl}$ the binding energy,

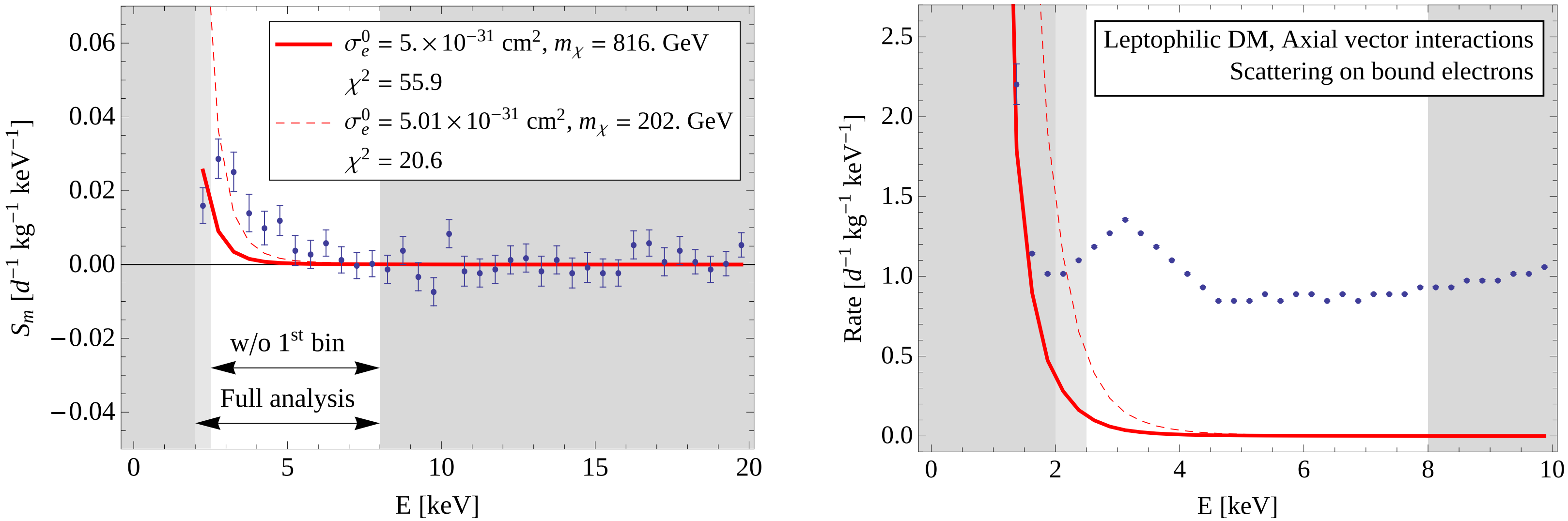
$I(v_{\rm min}) \equiv \int d^3v \frac{f_\odot(\mathbf{v})}{v}\,\theta(v - v_{\rm min})\,,$

- the minimal velocity to give signal

$$v_{\rm min}^{\rm WES} \approx \frac{E_d}{p} + \frac{p}{2m_\chi}$$

# $A \otimes A$ case: spectral shape

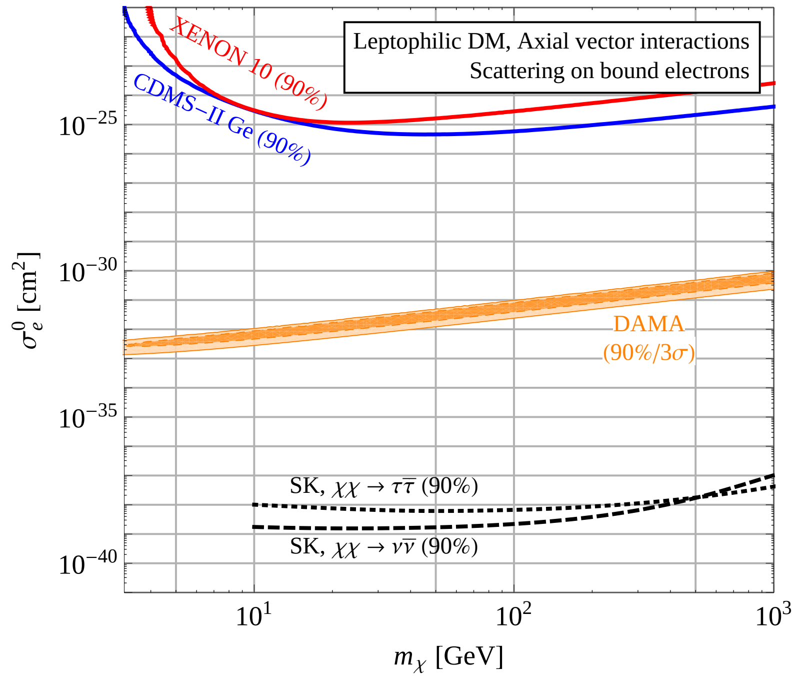
- best fit predictions for modulated, unmodulated rates




- spectral shape of modulated signal strongly disfavors this scenario: $\chi^2/dof = 55.9/10$
- improved to $\chi^2/dof = 20.6/9$ (prob. $1.4\%$) if no first bin
  - then unmodulated rate too large

# $A \otimes A$ case: best fit

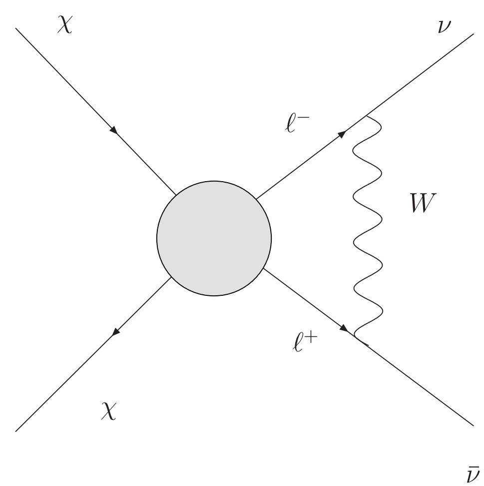
- ignoring these problems, the best fit region




- very large Xsec: $\sigma^0_{\chi e} \approx 3.1 \times 10^{-31}\,\mathrm{cm}^2\ \left(\frac{0.1\,\mathrm{GeV}}{\Lambda}\right)^4$
- requires $\Lambda < 0.1 GeV$
- allowed only, if no $\chi\chi \to \tau\bar{\tau}, \nu\bar{\nu}$

# Comments on neutrino constraints

- for relevant parameters capture and annihilation are in equilibrium in the sun $\Rightarrow$ result indep. of annihilation Xsec.
- by assumption $\chi$ couples to charged leptons $\Rightarrow$ $\chi\chi \rightarrow \ell^+\ell^-$
- but at one loop this produces $\chi\chi \rightarrow \nu\bar{\nu}$




- down by $(\frac{1}{16\pi^2})^2 \sim O(10^{-4})$, still enough to rule out Xsec needed for DAMA
- caveat: DM could be not self-conjugate and could have a large $\chi/\bar{\chi}$ asymmetry

# Conclusions

- presented model independent analysis of DAMA/LIBRA assuming leptophilic DM
- this class of models cannot explain DAMA/LIBRA results

# Backup slides