IMPACT OF OPERATOR INTERFERENCE IN DARK MATTER DIRECT DETECTION EXPERIMENTS

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DARK MATTER IN THE UNIVERSE

2000, Corbelli et. al.

2013, NASA

2011, Caltech
DARK MATTER DETECTION

- Particle production
- Indirect detection
- Direct detection

→ Upper limit on the dark matter-nucleon scattering rate $R$
Consider the interaction Hamiltonian \( H = c^p(\bar{p}\chi)(\bar{\chi}p) \).

Interaction rate \( (R) \propto |<\text{final}|H|\text{initial}>)^2 \)

\[ \Rightarrow R = (c^p)^2 \mathbb{R} \quad \Rightarrow \text{constrain coupling strength } c^p \text{ for given upper limit on } R \]

detector material
dark matter velocity distribution
local dark matter density
dark matter mass
LIMITS ON DARK MATTER–NUCLEON SCATTERING CROSS-SECTION

Assuming that $H = c^p(\bar{p}\chi)(\bar{\chi}p)$

\[ \rightarrow \sigma_{\chi p} \propto (c^p)^2 \]

BUT: What if other interactions are possible, too?
INTERACTION INTERFERENCE

In general, dark matter interacts with protons AND neutrons

\[ H = c^p(\bar{p}\chi)(\bar{\chi}p) + c^n(\bar{n}\chi)(\bar{\chi}n) \]

\[ R = (c^p c^n) \begin{pmatrix} R_{pp} & R_{pn} \\ R_{np} & R_{nn} \end{pmatrix} \begin{pmatrix} c^p \\ c^n \end{pmatrix} = c^T R c \]

Dark matter may interact also through other interactions (Fitzpatrick et. al. 2012)

\[ H = \sum_i c^p_{i} \Theta^p_{i} + c^n_{i} \Theta^n_{i} \]

4 independent operators for spin-0 dark matter
14 for spin-1/2 dark matter

\[ R = c^T R c \]

Remember:

\[ H = c^p(\bar{p}\chi)(\bar{\chi}p) \]

\[ R = (c^p)^2 R \]

\[ R \triangleq 8x8 \text{-matrix (spin-0)} \]

\[ R \triangleq 28x28 \text{-matrix (spin-1/2)} \]
CURRENT XENON1T AND PICO60 LIMITS

Assuming that $c^p = c^n$

BUT: What happens if $c^p \neq c^n$?
**EFFECT OF INTERACTION INTERFERENCE**

Example: interference between $c^p$ and $c^n$

$$R = (c^p \ c^n) \left( \begin{array}{cc} \mathbb{R}_{pp} & \mathbb{R}_{pn} \\ \mathbb{R}_{np} & \mathbb{R}_{nn} \end{array} \right) \left( \begin{array}{c} c^p \\ c^n \end{array} \right) \leq R^{u.l.} \quad \rightarrow \text{2D ellipse}$$

- X Ruled out by "plot", but not by data!
- Green Ruled out in model independent way

$\max\{c^p\} = \sqrt{\left(\mathbb{R}^{-1}\right)_{pp}} R^{u.l.}$
EFFECT OF INTERACTION INTERFERENCE ON XENON1T AND PICO60 RESULTS
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Remember:

$$H = \sum_i c_{i}^{p} \phi_{i}^{p} + c_{i}^{n} \phi_{i}^{n}$$

14 for spin-1/2 dark matter
EFFECT OF INTERACTION INTERFERENCE ON XENON1T AND PICO60 RESULTS
EFFECT OF INTERACTION INTERFERENCE ON XENON1T AND PICO60 RESULTS

![Graphs showing the effect of interaction interference on XENON1T and PICO60 results.](image-url)
COMBINING EXPERIMENTS

Combine experiments

\[
\max\{c^p\} = \sqrt{\left(\mathbb{R}^{-1}\right)_{pp} R^{u,l}}.
\]

\[
\max\{c^p\} = \max\{c^p\}_A \cup \max\{c^p\}_B
\]

\[
\max\{c^p\} = \left(\mathbb{R} - \mathbb{1}\right)_{pp} R^{u,l}.
\]

\[
\max\{c^p\}(\mathbb{R}, N_{j}^{obs}, N_{j}^{back})
\]
RESULTS: COMBINING EXPERIMENTS

[Graphs showing the scattering cross-sections for different experiments as a function of the mass of the neutralino ($m_\chi$) in GeV.]
RESULTS: COMBINING EXPERIMENTS

\[ \sigma_{SI}^{\chi p} \] vs. \( m_\chi \) [GeV] for different experiments and operators.
SUMMARY

- common assumption for limits on the dark matter-nucleon coupling strength: dark matter couples equally to protons and neutrons
- new method to get most conservative limits on the coupling strength
  → taking interaction interference into account can relax the cross-section limits by up to two orders of magnitude
- apply method to get combined limits
  → stronger limits for the cross-section