Determinations of Properties of Low-Mass WIMPs from Direct Dark Matter Detection Experiments with Non-Negligible Threshold Energy

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Motivation

Model-independent data analyses
Reconstruction of the 1-D WIMP velocity distribution
Determination of the WIMP mass
Estimation of the SI scalar WIMP-nucleon coupling
Determinations of ratios of WIMP-nucleon cross sections

Effects of a non-negligible threshold energy
Reconstruction of the 1-D WIMP velocity distribution
Reconstructions of WIMP particle properties (current work...)

Summary
Motivation
Motivation

- Differential event rate for elastic WIMP-nucleus scattering

\[
\frac{dR}{dQ} = \mathcal{A} F^2(Q) \int_{v_{\text{min}}(Q)}^{v_{\text{max}}} f_1(v) \frac{v}{v} \, dv
\]

Here

\[v_{\text{min}}(Q) = \alpha \sqrt{Q}\]

is the minimal incoming velocity of incident WIMPs that can deposit the recoil energy \(Q\) in the detector,

\[
\mathcal{A} \equiv \frac{\rho_0 \sigma_0}{2m_\chi m_{r,N}^2} \quad \alpha \equiv \sqrt{\frac{m_N}{2m_{r,N}^2}} \quad m_{r,N} = \frac{m_\chi m_N}{m_\chi + m_N}
\]

- \(\rho_0\): WIMP density near the Earth
- \(\sigma_0\): total cross section ignoring the form factor suppression
- \(F(Q)\): elastic nuclear form factor
- \(f_1(v)\): one-dimensional velocity distribution of halo WIMPs
Motivation

- Differential event rate for elastic WIMP-nucleus scattering

\[ \frac{dR}{dQ} = \mathcal{A} F^2(Q) \int_{v_{\text{min}}(Q)}^{v_{\text{max}}} \left[ \frac{f_1(v)}{v} \right] dv \]

Here \( v_{\text{min}}(Q) = \alpha \sqrt{Q} \) is the minimal incoming velocity of incident WIMPs that can deposit the recoil energy \( Q \) in the detector,

\[ v_{\text{min}}(Q) = \alpha \sqrt{Q} \]

\[ \mathcal{A} = \frac{\rho_0 \sigma_0}{2m_\chi m_{r,N}^2} \]

\[ \alpha = \sqrt{\frac{m_N}{2m_{r,N}^2}} \]

\[ m_{r,N} = \frac{m_\chi m_N}{m_\chi + m_N} \]

- \( \rho_0 \): WIMP density near the Earth
- \( \sigma_0 \): total cross section ignoring the form factor suppression
- \( F(Q) \): elastic nuclear form factor
- \( f_1(v) \): one-dimensional velocity distribution of halo WIMPs
Motivation

- Measured recoil spectrum
  ($^{76}\text{Ge}$, 0 - 100 keV, exponential bg 0 - 100 keV, 500 events, 20% bg, $m_\chi = 10$ GeV)

![Graph showing measured recoil spectrum with signal, background, and measured data.]

[Y.-T. Chou and CLS, JCAP 1008, 014 (2010)]
Motivation

- Measured recoil spectrum
  
  \(^{76}\text{Ge}, \text{0 - 100 keV}, \text{exponential bg 0 - 100 keV, 500 events, 20% bg, } m_\chi = 25 \text{ GeV}\)

[Y.-T. Chou and CLS, JCAP 1008, 014 (2010)]
Model-independent data analyses
Reconstruction of the 1-D WIMP velocity distribution
Reconstruction of the 1-D WIMP velocity distribution

- Normalized one-dimensional WIMP velocity distribution function

\[
 f_1(v) = \mathcal{N} \left\{ -2Q \cdot \frac{d}{dQ} \left[ \frac{1}{F^2(Q)} \left( \frac{dR}{dQ} \right) \right] \right\}_{Q=v^2/\alpha^2}
\]

\[
 \mathcal{N} = \frac{2}{\alpha} \left\{ \int_0^\infty \frac{1}{\sqrt{Q}} \left[ \frac{1}{F^2(Q)} \left( \frac{dR}{dQ} \right) \right] dQ \right\}^{-1}
\]

- Moments of the velocity distribution function

\[
 \langle v^n \rangle = \mathcal{N}(Q_{\text{thre}}) \left( \frac{\alpha^{n+1}}{2} \right) \left[ \frac{2Q_{\text{thre}}^{(n+1)/2}}{F^2(Q_{\text{thre}})} \left( \frac{dR}{dQ} \right) \right]_{Q=Q_{\text{thre}}} + (n+1)l_n(Q_{\text{thre}})
\]

\[
 \mathcal{N}(Q_{\text{thre}}) = \frac{2}{\alpha} \left[ \frac{2Q_{\text{thre}}^{1/2}}{F^2(Q_{\text{thre}})} \left( \frac{dR}{dQ} \right) \right]_{Q=Q_{\text{thre}}}^{-1}
\]

\[
 l_n(Q_{\text{thre}}) = \int_{Q_{\text{thre}}}^\infty Q^{(n-1)/2} \left[ \frac{1}{F^2(Q)} \left( \frac{dR}{dQ} \right) \right] dQ
\]

[M. Drees and CLS, JCAP 0706, 011 (2007)]
Reconstruction of the 1-D WIMP velocity distribution

- **Ansatz**: the measured recoil spectrum in the \( n \)th \( Q \)-bin

\[
\left( \frac{dR}{dQ} \right)_{\text{expt}, \ Q \simeq Q_n} \equiv r_n e^{k_n(Q - Q_{s,n})}
\]

\( r_n \equiv \frac{N_n}{b_n} \)
Reconstruction of the 1-D WIMP velocity distribution

- **Ansatz:** the measured recoil spectrum in the $n$th $Q$-bin

$$\left( \frac{dR}{dQ} \right)_{\text{expt}, \ Q \simeq Q_n} \equiv r_n e^{k_n(Q - Q_{s,n})} \quad r_n \equiv \frac{N_n}{b_n}$$

- **Logarithmic slope and shifted point** in the $n$th $Q$-bin

$$Q - Q_n |_n \equiv \frac{1}{N_n} \sum_{i=1}^{N_n} (Q_{n,i} - Q_n) = \left( \frac{b_n}{2} \right) \coth \left( \frac{k_n b_n}{2} \right) - \frac{1}{k_n}$$

$$Q_{s,n} = Q_n + \frac{1}{k_n} \ln \left[ \frac{\sinh(k_n b_n/2)}{k_n b_n/2} \right]$$

- **Reconstructing the one-dimensional WIMP velocity distribution**

$$f_1(v_{s,n}) = \mathcal{N} \left[ \frac{2Q_{s,n} r_n}{F^2(Q_{s,n})} \right] \left[ \frac{d}{dQ} \ln F^2(Q) \right]_{Q=Q_{s,n} - k_n}$$

$$\mathcal{N} = \frac{2}{\alpha} \left[ \sum_a \frac{1}{\sqrt{Q_a} F^2(Q_a)} \right]^{-1}$$

$$v_{s,n} = \alpha \sqrt{Q_{s,n}}$$

[M. Drees and CLS, JCAP 0706, 011 (2007)]
Reconstruction of the 1-D WIMP velocity distribution

- Reconstructed $f_{1,\text{rec}}(v_s, n)$
  - ($^{76}\text{Ge}$, 500 events, 5 bins, up to 3 bins per window)

![Graph showing reconstructed velocity distribution](image_url)

$\chi^2$/dof = 0.73

[M. Drees and CLS, JCAP 0706, 011 (2007)]
Determination of the WIMP mass
Determination of the WIMP mass

- Estimating the moments of the WIMP velocity distribution

\[
\langle v^n \rangle = \alpha^n \left[ \frac{2Q_{\text{min}}^{1/2} r_{\text{min}}}{F^2(Q_{\text{min}})} + l_0 \right]^{-1} \left[ \frac{2Q_{\text{min}}^{(n+1)/2} r_{\text{min}}}{F^2(Q_{\text{min}})} + (n + 1) l_n \right]
\]

\[
l_n = \sum_a \frac{Q_a^{(n-1)/2}}{F^2(Q_a)}
\]

\[
r_{\text{min}} = \left( \frac{dR}{dQ} \right)_{\text{expt}, Q=Q_{\text{min}}} = r_1 e^{k_1(Q_{\text{min}} - Q_s, 1)}
\]

[M. Drees and CLS, JCAP 0706, 011 (2007)]
Determinations of Properties of Low-Mass WIMPs from DMDD Experiments with Non-negligible Threshold Energy

Model-independent data analyses

Determination of the WIMP mass

- Estimating the moments of the WIMP velocity distribution

\[ \langle v^n \rangle = \alpha^n \left[ \frac{2Q^{1/2}_\text{min} r_{\text{min}}}{F^2(Q_{\text{min}})} + l_0 \right]^{-1} \left[ \frac{2Q^{(n+1)/2}_\text{min} r_{\text{min}}}{F^2(Q_{\text{min}})} + (n+1)I_n \right] \]

\[ I_n = \sum_a \frac{Q_a^{(n-1)/2}}{F^2(Q_a)} \]

\[ r_{\text{min}} = \left( \frac{dR}{dQ} \right)_{\text{expt, } Q=Q_{\text{min}}} = r_1 e^{k_1(Q_{\text{min}} - Q_s,1)} \]

[D. M. Drees and CLS, JCAP 0706, 011 (2007)]

- Determining the WIMP mass

\[ m_\chi \big|_{\langle v^n \rangle} = \sqrt{m_X m_Y} - m_\chi R_n \]

\[ R_n = \left[ \frac{2Q^{(n+1)/2}_\text{min,}X r_{\text{min,}X} / F_X^2(Q_{\text{min,}X}) + (n+1)l_{n,X}}{2Q^{1/2}_\text{min,}X r_{\text{min,}X} / F_X^2(Q_{\text{min,}X}) + l_0,X} \right]^{1/n} (X \rightarrow Y)^{-1} \]  

\[ (n \neq 0) \]

[CLS and M. Drees, arXiv:0710.4296]

- Assuming a dominant SI scalar WIMP-nucleus interaction

\[ m_\chi \big|_{\sigma} = \frac{(m_X / m_Y)^{5/2} m_Y - m_\chi R_\sigma}{R_\sigma - (m_X / m_Y)^{5/2}} \]

\[ R_\sigma = \frac{\mathcal{E}_Y}{\mathcal{E}_X} \left[ \frac{2Q^{1/2}_\text{min,}Y r_{\text{min,}Y} / F_Y^2(Q_{\text{min,}Y}) + l_0,Y}{2Q^{1/2}_\text{min,}Y r_{\text{min,}Y} / F_Y^2(Q_{\text{min,}Y}) + l_0,Y} \right] \]

[M. Drees and CLS, JCAP 0806, 012 (2008)]
Determinations of Properties of Low-Mass WIMPs from DMDD Experiments with Non-negligible Threshold Energy

Model-independent data analyses

Determination of the WIMP mass

- Reconstructed $m_{\chi,\text{rec}}$
  
  $(^{28}\text{Si} + ^{76}\text{Ge}, Q_{\text{max}} < 100 \text{ keV}, 2 \times 50 \text{ events})$

![Graph showing the relationship between $m_{\chi,\text{rec}}$ and $m_{\chi,\text{in}}$ for different matching cases: algorithmic, optimal, and no $Q_{\text{max}}$ matching.]

[M. Drees and CLS, JCAP 0806, 012 (2008)]
Estimation of the SI scalar WIMP-nucleon coupling
Estimation of the SI scalar WIMP-nucleon coupling

- Spin-independent (SI) scalar WIMP-nucleus cross section

\[
\sigma_{0}^{SI} = \left( \frac{4}{\pi} \right) m_{r,N}^2 [Z f_p + (A - Z) f_n]^2 \approx \left( \frac{4}{\pi} \right) m_{r,N}^2 A^2 |f_p|^2 = A^2 \left( \frac{m_{r,N}}{m_{r,p}} \right)^2 \sigma_{\chi p}^{SI}
\]

\[
\sigma_{\chi p}^{SI} = \left( \frac{4}{\pi} \right) m_{r,p}^2 |f_p|^2
\]

\( f_{(p,n)} \): effective SI scalar WIMP-proton/neutron couplings
Estimation of the SI scalar WIMP-nucleon coupling

- Spin-independent (SI) scalar WIMP-nucleus cross section

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\sigma_0^{SI} = \left(\frac{4}{\pi}\right) m_r,N \left[ Z f_p + (A - Z) f_n \right]^2 \approx \left(\frac{4}{\pi}\right) m_r,N A^2 |f_p|^2 = A^2 \left(\frac{m_r,N}{m_r,p}\right)^2 \sigma_{\chi p}^{SI}
\]

\[
\sigma_{\chi p}^{SI} = \left(\frac{4}{\pi}\right) m_r,p |f_p|^2
\]

\(f_{(p,n)}\): effective SI scalar WIMP-proton/neutron couplings

- Rewriting the integral over \(f_1(\nu)/\nu\)

\[
\left(\frac{dR}{dQ}\right)_{\text{expt, } Q=Q_{\text{min}}} = \frac{E \rho_0 A^2}{2m_\chi m_r,p^2} \left[ \left(\frac{4}{\pi}\right) m_r,p |f_p|^2 \right] F^2(Q_{\text{min}}) \left\{ m_r,N \sqrt{\frac{2}{m_N}} \left[ \frac{2 Q_{\text{min}}^{1/2} r_{\text{min}}}{F^2(Q_{\text{min}})} + l_0 \right] \right\}^{-1} \left[ \frac{2 r_{\text{min}}}{F^2(Q_{\text{min}})} \right]
\]

- Estimating the SI scalar WIMP-nucleon coupling

\[
|f_p|^2 = \frac{1}{\rho_0} \left[ \frac{\pi}{4\sqrt{2}} \left(\frac{1}{E_Z A_Z^2 \sqrt{m_Z}}\right) \right] \left[ \frac{2 Q_{\text{min},Z}^{1/2} r_{\text{min},Z}}{F^2(Z_{\text{min},Z})} + l_{0,Z} \right] (m_\chi + m_Z)
\]

Estimation of the SI scalar WIMP-nucleon coupling

- Reconstructed $|f_p|^2_{\text{rec}}$ vs. reconstructed $m_{\chi,\text{rec}}$

$(^{76}\text{Ge} + ^{28}\text{Si} + ^{76}\text{Ge})$, $Q_{\text{max}} < 100$ keV, $\sigma_{\chi p}^\text{SI} = 10^{-8}$ pb, $1(3) \times 50$ events

[CLS, arXiv:1103.0481]
Determination of the ratio of SD WIMP-nucleon couplings

- Spin-dependent (SD) axial-vector WIMP-nucleus cross section

\[ \sigma_{0}^{\text{SD}} = \left( \frac{32}{\pi} \right) G_{F}^{2} m_{r,N}^{2} \left( \frac{J + 1}{J} \right) \left[ \langle S_{p} \rangle a_{p} + \langle S_{n} \rangle a_{n} \right]^{2} \]

\[ \sigma_{\chi p/n}^{\text{SD}} = \left( \frac{32}{\pi} \right) G_{F}^{2} m_{r,p/n}^{2} \cdot \left( \frac{3}{4} \right) a_{p/n}^{2} \]

- \( J \): total nuclear spin
- \( \langle S_{(p,n)} \rangle \): expectation values of the proton/neutron group spin
- \( a_{(p,n)} \): effective SD axial-vector WIMP-proton/neutron couplings
Determination of the ratio of SD WIMP-nucleon couplings

- **Spin-dependent (SD) axial-vector WIMP-nucleus cross section**

\[
\sigma_{0}^{\text{SD}} = \left(\frac{32}{\pi}\right) G_{F}^{2} m_{r,N}^{2} \left(\frac{J+1}{J}\right) [\langle S_{p}\rangle a_{p} + \langle S_{n}\rangle a_{n}]^{2}
\]

\[
\sigma_{\chi p/n}^{\text{SD}} = \left(\frac{32}{\pi}\right) G_{F}^{2} m_{r,p/n}^{2} \cdot \left(\frac{3}{4}\right) a_{p/n}^{2}
\]

*J*: total nuclear spin  
*\langle S_{(p,n)}\rangle*: expectation values of the proton/neutron group spin  
*a_{(p,n)}*: effective SD axial-vector WIMP-proton/neutron couplings

- **Determining the ratio of two SD axial-vector WIMP-nucleon couplings**

\[
\left(\frac{a_{n}}{a_{p}}\right)^{\text{SD}}_{\pm,n} = - \frac{\langle S_{p}\rangle_{X} \pm \langle S_{p}\rangle_{Y} \mathcal{R}_{J,n}}{\langle S_{n}\rangle_{X} \pm \langle S_{n}\rangle_{Y} \mathcal{R}_{J,n}}
\]

\[
\mathcal{R}_{J,n} \equiv \left[ \left(\frac{J_{X}}{J_{X}+1}\right) \left(\frac{J_{Y}+1}{J_{Y}}\right) \frac{\mathcal{R}_{\sigma}}{\mathcal{R}_{n}} \right]^{1/2} \quad (n \neq 0)
\]

[M. Drees and CLS, arXiv:0903.3300]
Determination of the ratio of SD WIMP-nucleon couplings

- Reconstructed \( \left( \frac{a_n}{a_p} \right)_{\text{SD}} \) for \( 73\text{Ge} + 37\text{Cl} \) and \( 19\text{F} + 127\text{I} \), \( Q_{\min} > 5 \text{ keV}, Q_{\max} < 100 \text{ keV}, 2 \times 50 \text{ events, } m_\chi = 100 \text{ GeV} \)

\[
\left( \frac{a_n}{a_p} \right)_{\text{SD}} \text{ rec,} 1
\]

- Model-independent data analyses
- Determinations of ratios of WIMP-nucleon cross sections

[CLS, JCAP 1107, 005 (2011)]
Determinations of ratios of WIMP-nucleon cross sections

- Differential rate for combined SI and SD cross sections

\[
\left( \frac{dR}{dQ} \right)_{\text{expt}, Q=Q_{\text{min}}} = E \left( \frac{\rho_0 \sigma^\text{SI}_0}{2m \chi^2 r_n N} \right) \left[ F_{\text{SI}}^2(Q) + \left( \frac{\sigma^\text{SD}}{\sigma^\text{SI}} \right) C_p F_{\text{SD}}^2(Q) \right] \int_{v_{\text{min}}}^{v_{\text{max}}} \left[ \frac{f_1(v)}{v} \right] dv
\]

\[
C_p \equiv \frac{4}{3} \left( \frac{J + 1}{J} \right) \left[ \frac{\langle S_p \rangle + (a_n/a_p) \langle S_n \rangle}{A} \right]^2
\]
Determinations of ratios of WIMP-nucleon cross sections

- Differential rate for combined SI and SD cross sections

\[
\left( \frac{dR}{dQ} \right)_{\text{expt}, Q=Q_{\text{min}}} = \mathcal{E} \left( \frac{\rho_0 \sigma^{\text{SI}}_0}{2 m_\chi m^2_N} \right) \left[ F^2_{\text{SI}}(Q) + \left( \frac{\sigma^{\text{SD}}_{\chi p}}{\sigma^{\text{SI}}_{\chi p}} \right) c_p F^2_{\text{SD}}(Q) \right] \int_{v_{\text{min}}}^{v_{\text{max}}} \left[ \frac{f_1(v)}{v} \right] dv
\]

- Determining the ratio of two WIMP-proton cross sections

\[
\frac{\sigma^{\text{SD}}_{\chi p}}{\sigma^{\text{SI}}_{\chi p}} = \frac{F^2_{\text{SI}, Y}(Q_{\text{min}}, Y) R_{m, XY} - F^2_{\text{SI}, X}(Q_{\text{min}}, X)}{c_p, X F^2_{\text{SD}, X}(Q_{\text{min}}, X) - c_p, Y F^2_{\text{SD}, Y}(Q_{\text{min}}, Y) R_{m, XY}}
\]

\[
R_{m, XY} \equiv \left( \frac{r_{\text{min}, X}}{\mathcal{E}_X} \right) \left( \frac{\mathcal{E}_Y}{r_{\text{min}, Y}} \right) \left( \frac{m_Y}{m_X} \right)^2
\]

- Determining the ratio of two SD axial-vector WIMP-nucleon couplings

\[
\left( \frac{a_n}{a_p} \right)^{\text{SI+SD}} = - \left( c_p, X s_{n/p, X} - c_p, Y s_{n/p, Y} \right) \pm \sqrt{c_p, X c_p, Y} \left| s_{n/p, X} - s_{n/p, Y} \right|
\]

\[
c_p, X \equiv \frac{4}{3} \left( \frac{J_X + 1}{J_X} \right) \left[ \frac{\langle S_p \rangle_X}{A_X} \right]^2 \left[ F^2_{\text{SI}, Z}(Q_{\text{min}}, Z) R_{m, YZ} - F^2_{\text{SI}, Y}(Q_{\text{min}}, Y) \right] F^2_{\text{SD}, X}(Q_{\text{min}}, X)
\]

\[\text{M. Drees and CLS, arXiv:0903.3300}\]
Determinations of ratios of WIMP-nucleon cross sections

- Reconstructed \((a_n/a_p)_{\text{rec}}^{\text{SI+SD}}\) vs. \((a_n/a_p)_{\text{rec,1}}^{\text{SD}}\)

\[ ^{19}\text{F} + ^{127}\text{I} + ^{28}\text{Si}, \; Q_{\text{min}} > 5 \text{ keV}, \; Q_{\text{max}} < 100 \text{ keV}, \; 3 \times 50 \text{ events}, \sigma_{\chi p}^{\text{SI}} = 10^{-8} / 10^{-10} \text{ pb}, \; a_p = 0.1, \; m_\chi = 100 \text{ GeV} \]

[CLS, JCAP 1107, 005 (2011)]
Determinations of ratios of WIMP-nucleon cross sections

- Reconstructed \( (\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{\text{rec}} \) and \( (\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{\text{rec}} \)

\[ (^{19}\text{F} + ^{127}\text{I} + ^{28}\text{Si} \text{ vs. } ^{23}\text{Na} / ^{131}\text{Xe} + ^{76}\text{Ge}, \quad Q_{\text{min}} > 5 \text{ keV}, \quad Q_{\text{max}} < 100 \text{ keV}, \quad \sigma_{\chi p}^{SI} = 10^{-8} \text{ pb}, \quad a_p = 0.1, \quad m_\chi = 100 \text{ GeV}, \quad 3/2 \times 50 \text{ events}) \]
Effects of a non-negligible threshold energy
Reconstruction of the 1-D WIMP velocity distribution
Reconstruction of $f_1(v)$ with a non-negligible threshold energy

- Reconstructed $f_{1,\text{rec}}(v_s, n)$ (before correction!)

$^{76}\text{Ge}$, 2 - 50 keV, 500 events, $m_\chi = 25$ GeV

[CLS, IJMPD 24, 1550090 (2015)]
Reconstruction of $f_1(v)$ with a non-negligible threshold energy

- Modification of the renormalization constant

$$\mathcal{N} = \frac{2}{\alpha} \left[ \tilde{f}_{1, \text{rec}}(v^*_{\min}) Q^1_{\min}^{1/2} + \frac{2Q^1_{\min}^{1/2}}{F^2(Q_{\min})} \left( \frac{dR}{dQ} \right)_{\text{expt}, Q=Q_{\min}} + l_0(Q_{\min}, Q^*_{\text{max}}) \right]^{-1}$$

where

$$\tilde{f}_{1, \text{rec}}(v^*_{\min}) \equiv \left[ \frac{2Q_{\min} r(Q_{\min})}{F^2(Q_{\min})} \right] \left[ \frac{d}{dQ} \ln F^2(Q) \right]_{Q=Q_{\min}} - k_1$$

$$\left( \frac{dR}{dQ} \right)_{\text{expt}, Q=Q_{\min}} = r_1 e^{k_1(Q_{\min} - Q_{s,1})} \equiv r(Q_{\min})$$

$$I_n(Q_{\min}, Q^*_{\text{max}}) = \int_{Q_{\min}}^{Q^*_{\text{max}}} Q^{(n-1)/2} \left[ \frac{1}{F^2(Q)} \left( \frac{dR}{dQ} \right) \right] dQ \rightarrow \sum_a \frac{Q_a^{(n-1)/2}}{F^2(Q_a)}$$

$$Q^*_{\text{max}} \equiv \min \left( Q_{\text{max}}, Q_{\text{max,kin}} = \frac{v^2_{\text{max}}}{\alpha^2} \right)$$

[CLS, IJMPD 24, 1550090 (2015)]
Reconstruction of $f_1(v)$ with a non-negligible threshold energy

- Reconstructed $f_{1,\text{rec}}(v_s, n)$ with the input WIMP mass (after correction!) 
  ($^{76}$Ge, 2 - 50 keV, 500 events, $m_\chi = 25$ GeV)

[CLS, IJMPD 24, 1550090 (2015)]
Reconstruction of $f_1(v)$ with a non-negligible threshold energy

- Reconstructed $f_{1,\text{rec}}(v_{s,n})$ with the input WIMP mass (*after correction!*)
  
  $(^{76}\text{Ge}, \, 5 \, \text{ - } \, 50 \, \text{ keV}, \, 500 \, \text{ events}, \, m_\chi = 25 \, \text{ GeV})$

[C. L. Shan (XAO-CAS) TeVPA 2017, August 10, 2017 p. 27]
Reconstruction of $f_1(v)$ with a non-negligible threshold energy

- Theoretical bias estimate of

$$\Delta_v^{\nu_{\text{min}}^*} - \int_0^{\nu_{\text{min}}^*} f_1(v) \, dv / \int_0^{\nu_{\text{max}}} f_1(v) \, dv$$

[CLS, IJMPD 24, 1550090 (2015)]
Reconstruction of WIMP particle properties
(current work...)

C.-L. Shan (XAO-CAS)  TeVPA 2017, August 10, 2017 p. 29
Reconstruction of $|f_p|^2$ with a non-negligible threshold energy

- Reconstructed $|f_p|^2_{\text{rec}}$ (before correction...)

$(^{76}\text{Ge} + ^{28}\text{Si} + ^{76}\text{Ge}), \text{5 - 100 keV, 50 events}$

[CLS, arXiv:1103.0481]
Reconstruction of $|f_p|^2$ with a non-negligible threshold energy

- Reconstructed $|f_p|_{rec}^2$ (after correction)

$(^{76}\text{Ge}, 5 - 100$ keV, 50 events)
Reconstruction of $|f_p|^2$ with a non-negligible threshold energy

- Reconstructed $|f_p|_{\text{rec}}^2$ (after correction)
  ($^{76}\text{Ge}$, 2.5 - 100 keV, 50 events)
Reconstruction of $|f_p|^2$ with a non-negligible threshold energy

- Reconstructed $|f_p|_{\text{rec}}^2$ (after correction)

$(^{76}\text{Ge}, 0.5 - 100 \text{ keV}, 50 \text{ events})$
Determinations of\((a_n/a_p)\) with a non-negligible threshold energy

- Reconstructed \((a_n/a_p)_{\text{rec}}^{\text{SI}+\text{SD}}\) vs. \((a_n/a_p)_{\text{rec},1}^{\text{SD}}\) (before correction...)

\((^{73}\text{Ge} + ^{37}\text{Cl} (+ ^{28}\text{Si}) / ^{19}\text{F} + ^{127}\text{I} (+ ^{28}\text{Si}), \text{5 - 100 keV, } 2/3 \times 50 \text{ events, } a_n/a_p = 0.7)\)

[CLS, JCAP 1107, 005 (2011)]
Determinations of (a_n/a_p) with a non-negligible threshold energy

- Reconstructed \( (a_n/a_p)_{\text{rec}}^{\text{SI+SD}} \) vs. \( (a_n/a_p)_{\text{rec},1}^{\text{SD}} \) (after correction)

\( ^{19}\text{F} + ^{127}\text{I} (+^{28}\text{Si}), 5 - 100 \text{ keV, } 2 \times 50 \text{ events, } a_n/a_p = 0.7 \)
Determinations of properties of low-mass WIMPs from DMDD experiments with non-negligible threshold energy

Reconstructions of WIMP particle properties (current work...)

Determinations of $(a_n/a_p)$ with a non-negligible threshold energy

- Reconstructed $(a_n/a_p)^{SI+SD}_{rec}$ vs. $(a_n/a_p)^{SD}_{rec,1}$ (after correction)

$^{19}$F + $^{127}$I ($^{28}$Si), 2.5 - 100 keV, 2 × 50 events, $a_n/a_p = 0.7$
Determinations of \((a_n/a_p)\) with a non-negligible threshold energy

- Reconstructed \((a_n/a_p)_{\text{rec}}^{\text{SI+SD}}\) vs. \((a_n/a_p)_{\text{rec,1}}^{\text{SD}}\) (after correction)

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Thank you very much for your attention!