AMIDAS (Package and Website) for Direct Dark Matter Detection Experiments

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in collaboration with M. Drees and M. Kakizaki

based on JCAP 0706 011, JCAP 0806 012, 1103.0481, 1103.0482

Model-independent data analyses

Motivation

- Differential event rate for elastic WIMP-nucleus scattering

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

Here

$$v_{\rm min} = \alpha \sqrt{Q}$$

is the minimal incoming velocity of incident WIMPs that can deposit the recoil energy Q in the detector.

$$\mathcal{A} \equiv \frac{\rho_0 \sigma_0}{2 m_\chi m_{\rm r,N}^2} \qquad \alpha \equiv \sqrt{\frac{m_{\rm N}}{2 m_{\rm r,N}^2}} \qquad m_{\rm r,N} = \frac{m_\chi m_{\rm N}}{m_\chi + m_{\rm N}}$$

ρ_0: WIMP density near the Earth

σ_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

Reconstruction of the 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

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

$$\mathcal{N}(Q_{\rm thre}) = \frac{2}{\alpha} \left[\frac{2Q_{\rm thre}^{1/2}}{F^2(Q_{\rm thre})} \left(\frac{dR}{dQ} \right)_{Q=Q_{\rm thre}} + I_0(Q_{\rm thre}) \right]^{-1}$$

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

[M. Drees and CLS, JCAP 0706, 011]

Reconstruction of the WIMP velocity distribution

- Ansatz: the measured recoil spectrum in the nth Q-bin

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

- Logarithmic slope and shifted point in the nth Q-bin

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

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

- Reconstructing the one-dimensional WIMP velocity distribution

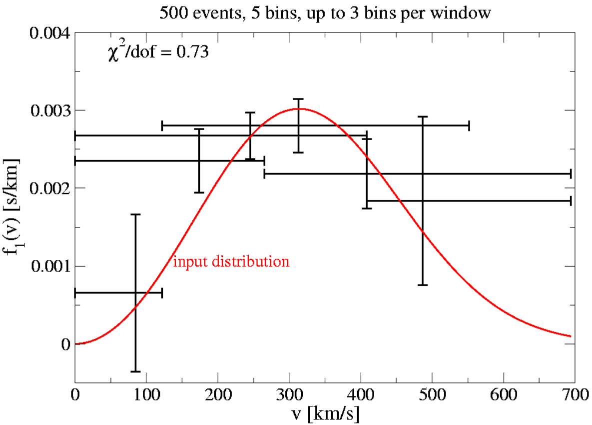
$$f_1(v_{s,n}) = \mathcal{N}\left[\frac{2Q_{s,n}r_n}{F^2(Q_{s,n})}\right]\left[\frac{d}{dQ}\ln F^2(Q)\Big|_{Q=Q_{s,n}} - k_n\right]$$

$$\mathcal{N} = \frac{2}{\alpha}\left[\sum_a \frac{1}{\sqrt{Q_a}\,F^2(Q_a)}\right]^{-1} \qquad v_{s,n} = \alpha\sqrt{Q_{s,n}}$$

[M. Drees and CLS, JCAP 0706, 011]

Reconstruction of the WIMP velocity distribution

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



[M. Drees and CLS, JCAP 0706, 011]

Determination of the WIMP mass

- Estimating the moments of the WIMP velocity distribution

$$\langle v^n \rangle = \alpha^n \left[\frac{2Q_{\rm min}^{1/2} r_{\rm min}}{F^2(Q_{\rm min})} + I_0 \right]^{-1} \left[\frac{2Q_{\rm min}^{(n+1)/2} r_{\rm min}}{F^2(Q_{\rm min})} + (n+1) I_n \right]$$

$$I_n = \sum_a \frac{Q_a^{(n-1)/2}}{F^2(Q_a)} \qquad r_{\rm min} = \left(\frac{dR}{dQ} \right)_{{\rm expt},\, Q=Q_{\rm min}} = r_1\, e^{k_1 (Q_{\rm min} - Q_{s,1})}$$

[M. Drees and CLS, JCAP 0706, 011]

- Determining the WIMP mass

$$m_\chi |_{\langle v^n \rangle} = \frac{\sqrt{m_X m_Y} - m_X \mathcal{R}_n}{\mathcal{R}_n - \sqrt{m_X / m_Y}}$$

$$\mathcal{R}_n = \left[\frac{2Q_{{\rm min},X}^{(n+1)/2} r_{{\rm min},X} / F_X^2(Q_{{\rm min},X}) + (n+1) I_{n,X}}{2Q_{{\rm min},X}^{1/2} r_{{\rm min},X} / F_X^2(Q_{{\rm min},X}) + I_{0,X}} \right]^{1/n} (X \longrightarrow Y)^{-1} \qquad (n \neq 0)$$

[CLS and M. Drees, arXiv:0710.4296]

- With the assumption of a dominant SI WIMP-nucleus interaction

$$m_\chi |_\sigma = \frac{(m_X / m_Y)^{5/2}\, m_Y - m_X \mathcal{R}_\sigma}{\mathcal{R}_\sigma - (m_X / m_Y)^{5/2}} \qquad \mathcal{R}_\sigma = \frac{\mathcal{E}_Y}{\mathcal{E}_X} \left[\frac{2Q_{{\rm min},X}^{1/2} r_{{\rm min},X} / F_X^2(Q_{{\rm min},X}) + I_{0,X}}{2Q_{{\rm min},Y}^{1/2} r_{{\rm min},X} / F_Y^2(Q_{{\rm min},Y}) + I_{0,Y}} \right]$$

[M. Drees and CLS, JCAP 0806, 012]

Determination of the WIMP mass

- χ^2-fitting

$$\chi^2(m_\chi) = \sum_{i,j} \left(f_{i,X} - f_{i,Y}\right) \mathcal{C}_{ij}^{-1} \left(f_{j,X} - f_{j,Y}\right)$$

where

$$f_{i,X} = \alpha_X^i \left[\frac{2 Q_{\min,X}^{(i+1)/2} r_{\min,X} / F_X^2(Q_{\min,X}) + (i+1) I_{i,X}}{2 Q_{\min,X}^{1/2} r_{\min,X} / F_X^2(Q_{\min,X}) + I_{0,X}} \right] \left(\frac{1}{300 \text{ km/s}} \right)^i$$

$$f_{n_{\max}+1,X} = \mathcal{E}_X \left[\frac{A_X^2}{2 Q_{\min,X}^{1/2} r_{\min,X} / F_X^2(Q_{\min,X}) + I_{0,X}} \right] \left(\frac{\sqrt{m_X}}{m_\chi + m_X} \right)$$

$$\mathcal{C}_{ij} = \text{cov}\left(f_{i,X}, f_{j,X}\right) + \text{cov}\left(f_{i,Y}, f_{j,Y}\right)$$

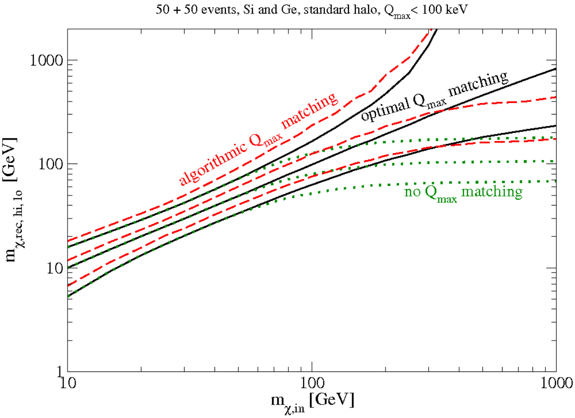
- Algorithmic $Q_{\max}$ matching

$$Q_{\max,Y} = \left(\frac{\alpha_X}{\alpha_Y} \right)^2 Q_{\max,X} \qquad \left(v_{\rm cut} = \alpha \sqrt{Q_{\max}} \right)$$

[M. Drees and CLS, JCAP 0806, 012]

Determination of the WIMP mass

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



[M. Drees and CLS, JCAP 0806, 012]

Estimation of the SI WIMP-nucleon coupling

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

$$\sigma_0^{\rm SI} = \left(\frac{4}{\pi}\right) m_{\rm r,N}^2 \left[Z f_{\rm p} + (A-Z) f_{\rm n}\right]^2 \simeq \left(\frac{4}{\pi}\right) m_{\rm r,N}^2 A^2 |f_{\rm p}|^2 = A^2 \left(\frac{m_{\rm r,N}}{m_{\rm r,p}}\right)^2 \sigma_{\chi{\rm p}}^{\rm SI}$$

$$\sigma_{\chi{\rm p}}^{\rm SI} = \left(\frac{4}{\pi}\right) m_{\rm r,p}^2 |f_{\rm p}|^2$$

$f_{\rm p}$, $f_{\rm n}$: effective SI WIMP-proton/neutron couplings

- Estimating the SI WIMP-nucleon coupling

$$|f_{\rm p}|^2 = \frac{1}{\rho_0} \left[\frac{\pi}{4\sqrt{2}} \left(\frac{1}{\mathcal{E}_Z A_Z^2 \sqrt{m_Z}}\right)\right] \left[\frac{2 Q_{{\rm min},Z}^{1/2} r_{{\rm min},Z}}{F_Z^2(Q_{{\rm min},Z})} + I_{0,Z}\right] (m_\chi + m_Z)$$

[M. Drees and CLS, arXiv:0809.2441]

Estimation of the SI WIMP-nucleon coupling

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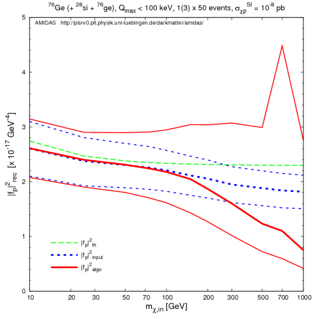
$$|f_{\rm p}|^2 = \frac{1}{\rho_0} \left[\frac{\pi}{4\sqrt{2}} \left(\frac{1}{\mathcal{E}_Z A_Z^2 \sqrt{m_Z}} \right) \right] \left[\frac{2 Q_{{\rm min},Z}^{1/2} r_{{\rm min},Z}}{F_Z^2(Q_{{\rm min},Z})} + I_{0,Z} \right] (m_\chi + m_Z)$$

[M. Drees and CLS, arXiv:0809.2441]

- $|f_{\rm p}|^2$ (^{76}Ge ($+^{28}$Si$+^{76}$Ge), $Q_{\rm max} < 100$ keV, $\sigma_{\chi{\rm p}}^{\rm SI} = 10^{-8}$ pb, 1(3) $\times$ 50 events)



[CLS, arXiv:1103.0481, submitted to JCAP]

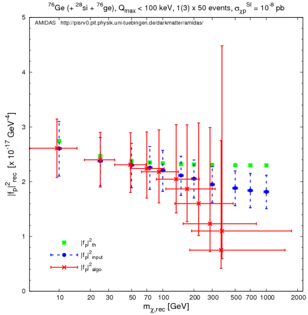
Estimation of the SI WIMP-nucleon coupling

- Estimating the SI WIMP-nucleon coupling

$$|f_{\rm p}|^2 = \frac{1}{\rho_0} \left[\frac{\pi}{4\sqrt{2}} \left(\frac{1}{\mathcal{E}_Z A_Z^2 \sqrt{m_Z}} \right) \right] \left[\frac{2 Q_{{\rm min},Z}^{1/2} r_{{\rm min},Z}}{F_Z^2(Q_{{\rm min},Z})} + I_{0,Z} \right] (m_\chi + m_Z)$$

[M. Drees and CLS, arXiv:0809.2441]

- $|f_{\rm p}|^2$ vs. m_χ (^{76}Ge ($+^{28}$Si$+^{76}$Ge), $Q_{\rm max} < 100$ keV, $\sigma_{\chi {\rm p}}^{\rm SI} = 10^{-8}$ pb, 1(3) $\times$ 50 events)



[CLS, arXiv:1103.0481, submitted to JCAP]

Determination of the ratio of two SD WIMP-nucleon couplings

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

$$\sigma_0^{\rm SD} = \left(\frac{32}{\pi}\right) G_F^2\, m_{\rm r,N}^2 \left(\frac{J+1}{J}\right) \left[\langle S_{\rm p}\rangle a_{\rm p} + \langle S_{\rm n}\rangle a_{\rm n}\right]^2$$

$$\sigma_{\chi{\rm p/n}}^{\rm SD} = \left(\frac{32}{\pi}\right) G_F^2\, m_{\rm r,p/n}^2 \cdot \left(\frac{3}{4}\right) a_{\rm p/n}^2$$

J: total nuclear spin

$\langle S_{\rm p}\rangle$, $\langle S_{\rm n}\rangle$: expectation values of the proton/neutron group spin

$a_{\rm p}$, $a_{\rm n}$: effective SD WIMP-proton/neutron couplings

- Determining the ratio of two SD WIMP-nucleon couplings

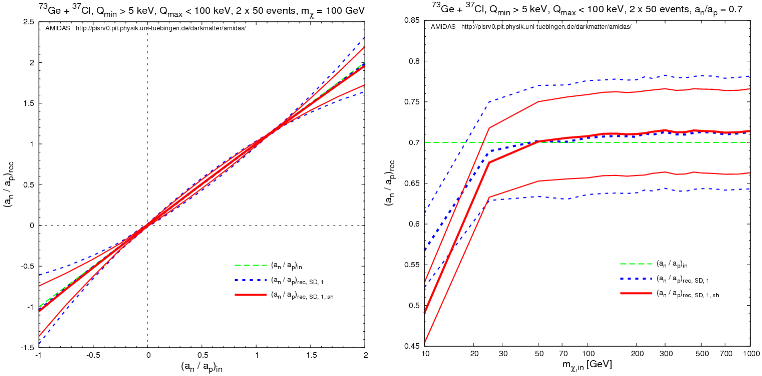
$$\left(\frac{a_{\rm n}}{a_{\rm p}}\right)_{\pm,n}^{\rm SD} = -\frac{\langle S_{\rm p}\rangle_X \pm \langle S_{\rm p}\rangle_Y \mathcal{R}_{J,n}}{\langle S_{\rm n}\rangle_X \pm \langle S_{\rm n}\rangle_Y \mathcal{R}_{J,n}}$$

$$\mathcal{R}_{J,n} \equiv \left[\left(\frac{J_X}{J_X+1}\right)\left(\frac{J_Y+1}{J_Y}\right)\frac{\mathcal{R}_\sigma}{\mathcal{R}_n}\right]^{1/2} \qquad (n \neq 0)$$

[M. Drees and CLS, arXiv:0903.3300]

Determination of the ratio of two SD WIMP-nucleon couplings

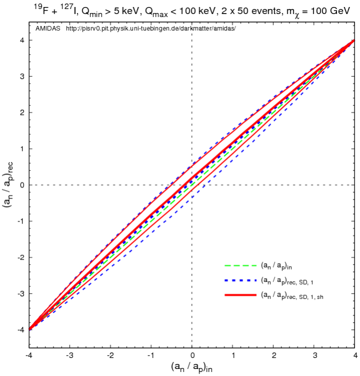
- Reconstructed $(a_n/a_p)^{SD}_{rec,1}$
  (^{73}Ge + ^{37}Cl, $Q_{min} > 5$ keV, $Q_{max} < 100$ keV, 2×50 events,
  $m_\chi = 100$ GeV or $a_n/a_p = 0.7$)

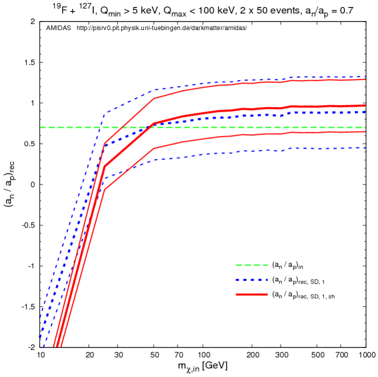


[M. Drees and CLS, arXiv:0903.3300; CLS, arXiv:1103.0482, submitted to JCAP]

Determination of the ratio of two SD WIMP-nucleon couplings

- Reconstructed $(a_n/a_p)^{SD}_{rec,1}$
  ($^{19}F + ^{127}I$, $Q_{min} > 5$ keV, $Q_{max} < 100$ keV, 2×50 events,
  $m_\chi = 100$ GeV or $a_n/a_p = 0.7$)





[CLS, arXiv:1103.0482, submitted to JCAP]

Determinations of ratios of WIMP-nucleon cross sections

- Differential rate for a combination of the SI and SD cross sections

$$\left(\frac{dR}{dQ}\right)_{\text{expt},\, Q=Q_{\text{min}}} = \mathcal{E}\left(\frac{\rho_0\sigma_0^{\text{SI}}}{2m_\chi m_{\text{r,N}}^2}\right)\left[F_{\text{SI}}^2(Q) + \left(\frac{\sigma_{\chi\text{p}}^{\text{SD}}}{\sigma_{\chi\text{p}}^{\text{SI}}}\right)\mathcal{C}_\text{p} F_{\text{SD}}^2(Q)\right]\int_{v_{\text{min}}}^{v_{\text{max}}}\left[\frac{f_1(v)}{v}\right]dv$$

$$\mathcal{C}_\text{p} \equiv \frac{4}{3}\left(\frac{J+1}{J}\right)\left[\frac{\langle S_\text{p}\rangle + (a_\text{n}/a_\text{p})\langle S_\text{n}\rangle}{A}\right]^2$$

- Determining the ratio of two WIMP-proton cross sections

$$\frac{\sigma_{\chi\text{p}}^{\text{SD}}}{\sigma_{\chi\text{p}}^{\text{SI}}} = \frac{F_{\text{SI},Y}^2(Q_{\text{min},Y})\mathcal{R}_{m,XY} - F_{\text{SI},X}^2(Q_{\text{min},X})}{\mathcal{C}_{\text{p},X}F_{\text{SD},X}^2(Q_{\text{min},X}) - \mathcal{C}_{\text{p},Y}F_{\text{SD},Y}^2(Q_{\text{min},Y})\mathcal{R}_{m,XY}}$$

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

- Determining the ratio of two SD WIMP-nucleon couplings

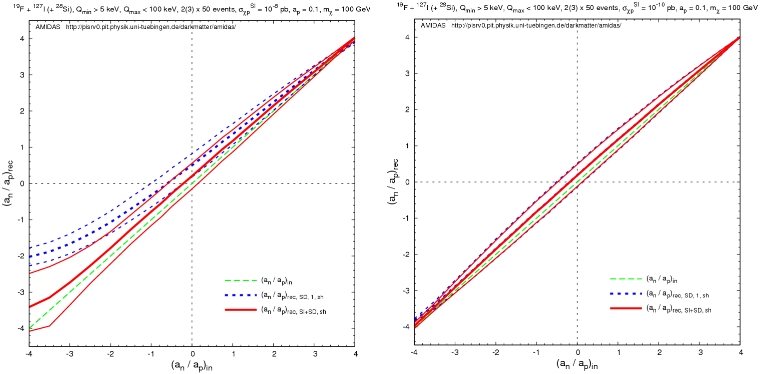
$$\left(\frac{a_\text{n}}{a_\text{p}}\right)_\pm^{\text{SI+SD}} = \frac{-\left(c_{\text{p},X}s_{\text{n/p},X} - c_{\text{p},Y}s_{\text{n/p},Y}\right) \pm \sqrt{c_{\text{p},X}c_{\text{p},Y}}\left|s_{\text{n/p},X} - s_{\text{n/p},Y}\right|}{c_{\text{p},X}s_{\text{n/p},X}^2 - c_{\text{p},Y}s_{\text{n/p},Y}^2}$$

$$c_{\text{p},X} \equiv \frac{4}{3}\left(\frac{J_X+1}{J_X}\right)\left[\frac{\langle S_\text{p}\rangle_X}{A_X}\right]^2\left[F_{\text{SI},Z}^2(Q_{\text{min},Z})\mathcal{R}_{m,YZ} - F_{\text{SI},Y}^2(Q_{\text{min},Y})\right]F_{\text{SD},X}^2(Q_{\text{min},X})$$

[M. Drees and CLS, arXiv:0903.3300]

Determinations of ratios of WIMP-nucleon cross sections

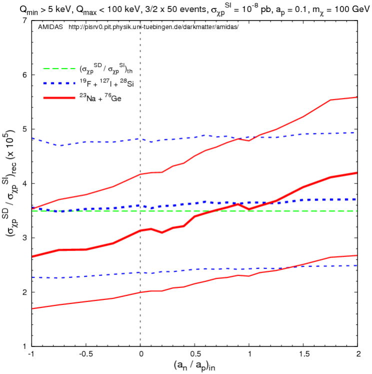
- Reconstructed $(a_n/a_p)^{SI+SD}_{rec}$ vs $(a_n/a_p)^{SD}_{rec,1}$
  ($^{19}F + {}^{127}I + {}^{28}Si$, $Q_{min} > 5$ keV, $Q_{max} < 100$ keV, 3×50 events,
  $\sigma^{SI}_{\chi p} = 10^{-8}$ / 10^{-10} pb, $a_p = 0.1$, $m_\chi = 100$ GeV)

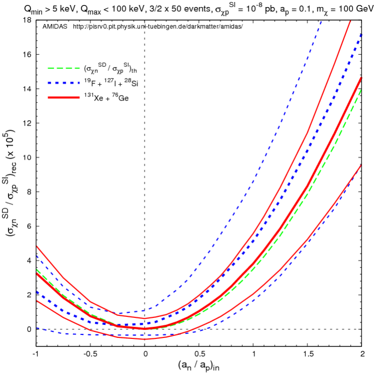


[CLS, arXiv:1103.0482, submitted to JCAP]

Determinations of ratios of WIMP-nucleon cross sections

- Reconstructed $(\sigma_{\chi p}^{SD}/\sigma_{\chi p}^{SI})_{rec}$ and $(\sigma_{\chi n}^{SD}/\sigma_{\chi p}^{SI})_{rec}$
  (^{19}F + ^{127}I + ^{28}Si vs. ^{23}Na/^{131}Xe + ^{76}Ge, $Q_{min} > 5$ keV, $Q_{max} < 100$ keV, $\sigma_{\chi p}^{SI} = 10^{-8}$ pb, $a_p = 0.1$, $m_\chi = 100$ GeV, 3/2 × 50 events)





[CLS, arXiv:1103.0482, submitted to JCAP]

AMIDAS package and website

AMIDAS package and website

- A Model-Independent Data Analysis System for direct Dark Matter detection experiments
  - DAMNED Dark Matter Web Tool (ILIAS Project)
    http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/amidas/
    [CLS, arXiv:0909.1459, 0910.1971]
  - Online interactive simulation/data analysis system
  - Full Monte Carlo simulations
  - Theoretical estimations
  - Real/user-uploaded data analyses
- Further projects/ideas
  - Analyze events with directional information
  - User account/security system (AMIDAS-II)
  - Combine with other simulation/data analysis packages for (in)direct detections

AMIDAS package and website

- Reconstructed results: m_χ (with Woods-Saxon form factor)

Results

Reconstructed WIMP mass

m_χ (GeV/c^2)	$m_{\chi,\text{combined}}$	$m_{\chi,2}$	$m_{\chi,1}$	$m_{\chi,-1}$	$m_{\chi,\sigma}$
$m_{\chi,\text{rec}}$	122.72	48.283	32.431	1.4779	36.369
$m_{\chi,\text{lo}}$	83.309	12.565	-1.0121	-57.873	-10.601
$m_{\chi,\text{hi}}$	196.31	92.53	75.3	107.25	125.66

The reconstructed WIMP mass and the upper and lower bounds of its 1σ statistical uncertainty. $m_{\chi,n}$ and $m_{\chi,\sigma}$ have been estimated by Eqs. (34) and (40) of Ref. [2], respectively; while $m_{\chi,\text{combined}}$ by the χ^2-fitting defined in Eq. (51) of Ref. [2], which combines the estimators for $m_{\chi,n}$ and $m_{\chi,\sigma}$ with each other. The reconstructed WIMP mass $m_{\chi,\text{combined}}$ as well as $m_{\chi,n}$ and $m_{\chi,\sigma}$ shown here have been corrected by the algorithmic $Q_{\max}$ matching described in Ref. [2].

Data

[http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/amidas/]

AMIDAS package and website

- Reconstructed results: m_χ (with exponential form factor)

Results

Reconstructed WIMP mass

m_χ (GeV/c^2)	$m_{\chi,\text{ combined}}$	$m_{\chi,\ 2}$	$m_{\chi,\ 1}$	$m_{\chi,\ -1}$	$m_{\chi,\ \sigma}$
$m_{\chi,\text{ rec}}$	113.26	50.279	36.874	0.048119	35.655
$m_{\chi,\text{ lo}}$	75.343	12.413	2.3131	-57.236	-10.108
$m_{\chi,\text{ hi}}$	180.44	89.574	72.862	106.59	127.92

The reconstructed WIMP mass and the upper and lower bounds of its 1σ statistical uncertainty. $m_{\chi,n}$ and $m_{\chi,\sigma}$ have been estimated by Eqs. (34) and (40) of Ref. [2], respectively; while $m_{\chi,\text{combined}}$ by the χ^2-fitting defined in Eq. (51) of Ref. [2], which combines the estimators for $m_{\chi,n}$ and $m_{\chi,\sigma}$ with each other. The reconstructed WIMP mass $m_{\chi,\text{combined}}$ as well as $m_{\chi,n}$ and $m_{\chi,\sigma}$ shown here have been corrected by the algorithmic $Q_{\max}$ matching described in Ref. [2].

Data

[http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/amidas/]

AMIDAS package and website

- Reconstructed results: $|f_{\rm p}|^2$ (with W-S form factor and input ρ_0)

Results

Reconstructed SI WIMP-nucleon coupling

$\lvert f_{\rm p}\rvert^2$ (c^6/GeV^4)	$\lvert f_{\rm p}\rvert^2_{\rm input}$	$\lvert f_{\rm p}\rvert^2_{\rm recon}$
$\lvert f_{\rm p}\rvert^2_{\rm rec}$	8.1686E-18	7.8443E-18
$\lvert f_{\rm p}\rvert^2_{\rm lo}$	6.7381E-18	5.7005E-18
$\lvert f_{\rm p}\rvert^2_{\rm hi}$	9.5293E-18	1.1103E-17

The reconstructed squared spin-independent WIMP-nucleon coupling $|f_{\rm p}|^2$ and the lower and upper bounds of its 1σ statistical uncertainty estimated by Eqs. (17) and (18) of Ref. [3] with the input WIMP mass (with an overall uncertainty of 0.1%) and the reconstructed WIMP mass (estimated by the algorithmic process described in Ref. [2]).

Data

[http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/amidas/]

AMIDAS package and website

- Reconstructed results: $|f_{\rm p}|^2$ (with ex form factor and standard ρ_0)

Results

Reconstructed SI WIMP-nucleon coupling

$\|f_{\rm p}\|^2$ (c^6/GeV^4)	$\|f_{\rm p}\|^2_{\rm input}$	$\|f_{\rm p}\|^2_{\rm recon}$
$\|f_{\rm p}\|^2_{\rm rec}$	9.3348E-18	1.0157E-17
$\|f_{\rm p}\|^2_{\rm lo}$	7.6996E-18	7.5775E-18
$\|f_{\rm p}\|^2_{\rm hi}$	1.0874E-17	1.4234E-17

The reconstructed squared spin-independent WIMP-nucleon coupling $|f_{\rm p}|^2$ and the lower and upper bounds of its 1σ statistical uncertainty estimated by Eqs. (17) and (18) of Ref. [3] with the input WIMP mass (with an overall uncertainty of 0.1%) and the reconstructed WIMP mass (estimated by the algorithmic process described in Ref. [2]).

Data

[http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/amidas/]

AMIDAS package and website

- Reconstructed results: a_n/a_p (with Woods-Saxon form factor)

Results

Reconstructed ratio between two SD WIMP-nucleon couplings

a_n / a_p	$(a_n / a_p)_{+, 1, sh}^{SD}$	$(a_n / a_p)_{-, 1, sh}^{SD}$	$(a_n / a_p)_{+, sh}^{SI+SD}$	$(a_n / a_p)_{-, sh}^{SI+SD}$
$(a_n / a_p)_{rec}$	16.441	0.97458	19.75	0.80541
$(a_n / a_p)_{lo}$	9.9344	0.59298	11.496	0.48606
$(a_n / a_p)_{hi}$	22.652	1.3532	27.389	1.1488

The reconstructed a_n / a_p ratios and the lower and upper bounds of their 1σ statistical uncertainties estimated by Eqs. (31) and (36) of Ref. [4] with n = -1, 1, and 2 as well as by Eqs. (57) and (60) of Ref. [4] at the shifted energy points (given by Eq. (38) of Ref. [4]).

Data

[http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/amidas/]

AMIDAS package and website

- Reconstructed results: a_n/a_p (with exponential form factor)

Results

Reconstructed ratio between two SD WIMP-nucleon couplings

a_n / a_p	$(a_n / a_p)_{+, 1, sh}^{SD}$	$(a_n / a_p)_{-, 1, sh}^{SD}$	$(a_n / a_p)_{+, sh}^{SI+SD}$	$(a_n / a_p)_{-, sh}^{SI+SD}$
$(a_n / a_p)_{rec}$	16.441	0.97458	19.745	0.80563
$(a_n / a_p)_{lo}$	9.9344	0.59298	11.496	0.48636
$(a_n / a_p)_{hi}$	22.652	1.3532	27.376	1.149

The reconstructed a_n / a_p ratios and the lower and upper bounds of their 1σ statistical uncertainties estimated by Eqs. (31) and (36) of Ref. [4] with n = -1, 1, and 2 as well as by Eqs. (57) and (60) of Ref. [4] at the shifted energy points (given by Eq. (38) of Ref. [4]).

Data

[http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/amidas/]

AMIDAS package and website

- Reconstructed results: $\sigma^{SD}_{(p,n),\chi}/\sigma^{SI}_{\chi p}$ (with W-S form factor)

Results

Reconstructed ratio between the SD and SI WIMP-proton cross sections

$\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI}$	$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{+,sh}^{XYZ}$	$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{-,sh}^{XYZ}$	$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{sh}^{XY}$
$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{rec}$	39390	913780	1008000
$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{lo}$	6036.9	615690	632860
$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{hi}$	74207	1216200	1373300

The reconstructed $\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI}$ ratios and the lower and upper bounds of their 1σ statistical uncertainties estimated by Eqs. (50) and (61) (with a_n / a_p estimated by Eq. (57)) as well as by Eqs. (65) and (69) of Ref. [4] at the shifted energy points (given by Eq. (38) of Ref. [4]).

Reconstructed ratio between the SD and SI WIMP-neutron cross sections

$\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI}$	$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{+,sh}^{XYZ}$	$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{-,sh}^{XYZ}$	$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{sh}^{XY}$
$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{rec}$	15164000	602750	487250
$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{lo}$	10220000	72093	269840
$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{hi}$	20193000	1152700	700660

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AMIDAS package and website

- Reconstructed results: $\sigma_{(\mathrm{p,n}),\chi}^{\mathrm{SD}} / \sigma_{\chi\mathrm{p}}^{\mathrm{SI}}$ (with exponential form factor)

Results

Reconstructed ratio between the SD and SI WIMP-proton cross sections

$\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI}$	$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{+,\,sh}^{XYZ}$	$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{-,\,sh}^{XYZ}$	$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{sh}^{XY}$
$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{rec}$	39334	911960	1001900
$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{lo}$	6044.5	614460	629110
$(\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI})_{hi}$	74084	1213800	1365300

The reconstructed $\sigma_{\chi p}^{SD} / \sigma_{\chi p}^{SI}$ ratios and the lower and upper bounds of their 1σ statistical uncertainties estimated by Eqs. (50) and (61) (with a_n / a_p estimated by Eq. (57)) as well as by Eqs. (65) and (69) of Ref. [4] at the shifted energy points (given by Eq. (38) of Ref. [4]).

Reconstructed ratio between the SD and SI WIMP-neutron cross sections

$\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI}$	$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{+,\,sh}^{XYZ}$	$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{-,\,sh}^{XYZ}$	$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{sh}^{XY}$
$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{rec}$	15132000	601930	484270
$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{lo}$	10199000	72257	268430
$(\sigma_{\chi n}^{SD} / \sigma_{\chi p}^{SI})_{hi}$	20153000	1150800	696420

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AMIDAS package and website

- Input setup for generating pseudodata
  - $m_\chi = 130$ GeV
  - $\sigma_{\chi\rm p}^{\rm SI} = 4 \times 10^{-9}$ pb
  - $a_{\rm p} = 0.1$, $a_{\rm n}/a_{\rm p} = 0.7$
  - Woods-Saxon and thin-shell elastic nuclear form factors
  - $\rho_0 = 0.4\ {\rm GeV/cm^3}$
  - $v_0 = 230$ km/s
  - $t_{\rm p} = 140$ d, $t_{\rm expt} = 300$ d
  - $|f_{\rm p}|^2 = 9.305 \times 10^{-18}\ {\rm GeV^{-4}}$ (for 130 GeV m_χ)
  - $\sigma_{\chi\rm p}^{\rm SD}/\sigma_{\chi\rm p}^{\rm SI} = 8.77 \times 10^5$, $\sigma_{\chi\rm n}^{\rm SD}/\sigma_{\chi\rm p}^{\rm SI} = 4.30 \times 10^5$ (for 130 GeV m_χ)

Summary

Summary

- Once two or more experiments with different target nuclei observe positive WIMP signals, we could estimate
  - WIMP mass m_χ
  - SI WIMP-proton coupling $|f_{\rm p}|^2$
  - ratio between the SD WIMP-nucleon couplings $a_{\rm n}/a_{\rm p}$
  - ratios between the SD and SI WIMP-nucleon cross sections $\sigma_{\chi({\rm p,n})}^{\rm SD}/\sigma_{\chi{\rm p}}^{\rm SI}$

- These analyses are independent of the velocity distribution, the local dentity, and the mass/couplings on nucleons of halo WIMPs (none of them is yet known).

- For a WIMP mass of 100 GeV, these quantities could be estimated with statistical uncertainties of 10% – 40% with only $\mathcal{O}(50)$ events from one experiment.

Summary on background effects

Summary on background effects

❍ References

➢ Y.-T. Chou and C.-L. Shan, *"Effects of Residue Background Events in Direct Dark Matter Detection Experiments on the Determination of the WIMP Mass"*, JCAP **1008**, 014 (2010).

➢ C.-L. Shan, *"Effects of Residue Background Events in Direct Dark Matter Detection Experiments on the Reconstruction of the Velocity Distribution Function of Halo WIMPs"*, JCAP **1006**, 029 (2010).

➢ C.-L. Shan, *"Effects of Residue Background Events in Direct Dark Matter Detection Experiments on the Estimation of the Spin–Independent WIMP–Nucleon Coupling"*, `arXiv:1103.4049 [hep-ph]` (2011).

➢ C.-L. Shan, *"Effects of Residue Background Events in Direct Dark Matter Detection Experiments on the Determinations of Ratios of WIMP–Nucleon Cross Sections"*, `arXiv:1104.5305 [hep-ph]` (2011).

Summary on background effects

- For determining WIMP properties, the maximal acceptable background ratio is $\sim$ 10% – 20%.

- For determining ratios between different WIMP couplings/cross sections, between results reconstructed under different assumptions and/or with different moments of the WIMP velocity distribution function and/or by using different target nuclei there could be an (in)compatibility.

- For determining ratios between different WIMP couplings/cross sections, background events in low energy ranges would be (much) more problematic than those in high energy ranges.

[More detailed discussions will be given at TAUP 2011 in Munich]

Thank you very much for your attention

[http://myweb.ncku.edu.tw/∼clshan/Publications/Talks/]