Direct Detection and Identification of WIMP Dark Matter

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based on arXiv:0903.3300 [hep-ph]

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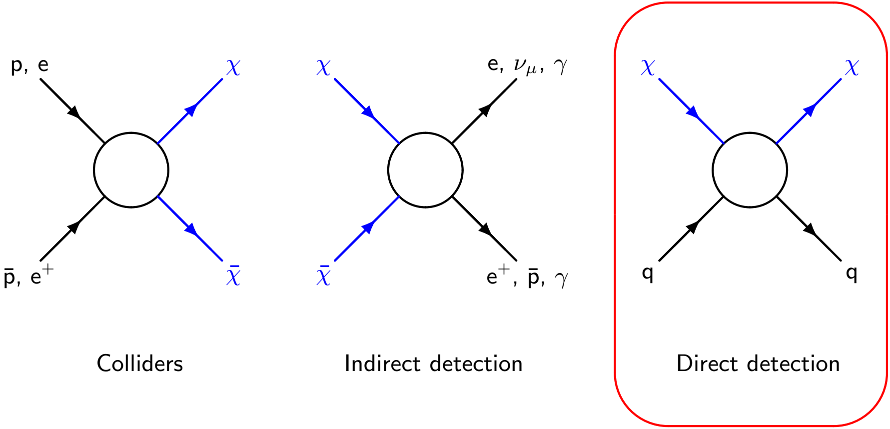
Dark Matter searches

WIMPs should have small, but non-zero couplings to ordinary matter.



Direct detection: elastic WIMP-nucleus scattering

- WIMPs could scatter elastically off target nuclei and produce nuclear recoils which deposit energy in the detector.

  - The event rate depends on the WIMP density near the Earth, the WIMP-nucleus cross section, the WIMP mass and the velocity distribution of the incident WIMPs.

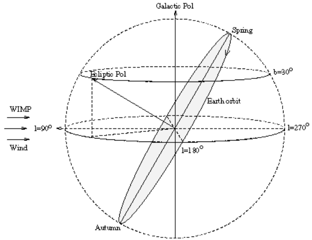
  - In typical SUSY models with neutralino WIMPs, the WIMP-nucleus cross section is about $10^{-1} \sim 10^{-6}$ pb, the optimistic expected event rate is then $\sim 10^{-3}$ events/kg-day, but could be < 1 event/ton-yr.

  - The recoil energy spectrum is approximately exponential and most events should be with energies less than 50 keV.

  - Typical background events due to cosmic rays and ambient radioactivity is much larger.

Direct detection: elastic WIMP-nucleus scattering

- Annual modulation of the WIMP event rate

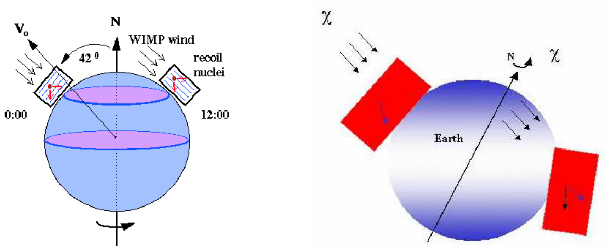


[Y. Ramachers, Nucl. Phys. Proc. Suppl. 118, 341 (2003)]

- Due to the orbital motion of the Earth around the Sun.
- A cosinusoidal function with a one-year period, a peak around June 2nd, and a modulation amplitude $\sim$ 5%.
- The peak could be shifted by $\sim$ 3 weeks!
  [T. Bruch, J. Read, L. Baudis, and G. Lake, Astrophys. J. 696, 920 (2009)]
- The signal identification should also be performed!
  [M. Drees and G. Gerbier, Review of Particle Physics 2008]

Direct detection: elastic WIMP-nucleus scattering

- Diurnal modulation of the event rate



[Y. Ramachers (2003); M. de Jesus, Int. J. Mod. Phys. A19, 1142 (2004)]

- Due to the rotation of the Earth.
- Directionality of the WIMP wind
  A daily forward/backward asymmetry of the nuclear recoil direction.
- Shielding of the detector by the Earth of the incident WIMP flux.
- requires a large WIMP-nucleus cross section.

Direct detection: elastic WIMP-nucleus scattering

- Target material dependence

  - Spin-independent (SI) coupling
    a scalar (and/or vector) interaction
    the cross section for scalar interaction is approximately proportional to the square of the mass of the nucleus.

  - Spin-dependent (SD) coupling
    an axial-vector (spin-spin) interaction

  - For nuclei with $A \geq 30$, the SI interaction almost always dominates the SD interaction.

  - The scattering event rate and the detector sensitivity depend on the mass of the target material directly.

Basic expression

- Differential event rate for elastic WIMP-nucleus scattering

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

Astrophysics

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.

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

Particle Physics

ρ_0: WIMP density near the Earth

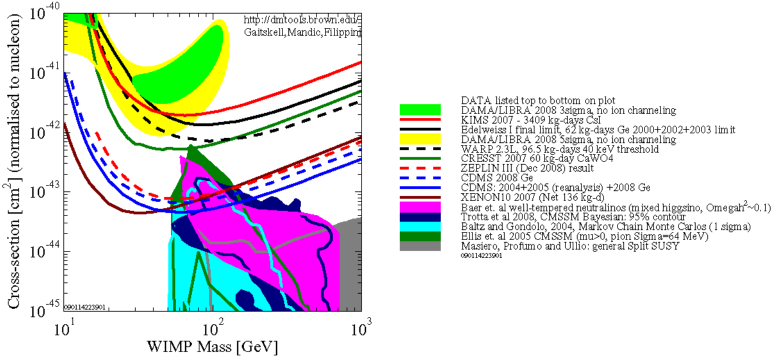
σ_0: total cross section ignoring the form factor suppression

$F(Q)$: elastic nuclear form factor

$f_1(v)$: one-dimensional velocity distribution of halo WIMPs

Basic expression

- Exclusion limits on the (predicted) SI WIMP-nucleon cross section



[http://dmtools.berkeley.edu/limitplots/]

Basic expression

- 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

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

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

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

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Reconstruction of the velocity distribution of halo WIMPs

- Normalized one-dimensional 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 velocity distribution of halo WIMPs

- Ansatz for the reconstructed recoil spectrum in the nth Q-bin

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

- 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 velocity distribution

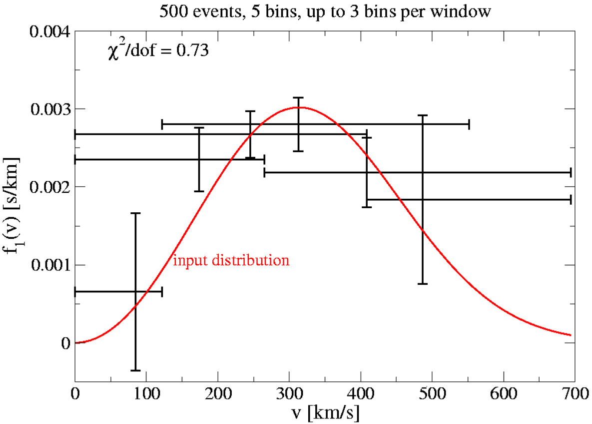
$$f_{1,\mathrm{rec}}(v_{s,n}) = \mathcal{N}\left[\frac{2Q_{s,n}r_n}{F^2(Q_{s,n})}\right]\left[\frac{d}{dQ}\ln F^2(Q)\bigg|_{Q=Q_{s,n}} - k_n\right]$$

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

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

Reconstruction of the velocity distribution of halo WIMPs

- Reconstructed $f_{1,\text{rec}}(v_{s,n})$
  (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

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

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

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

- Determining the WIMP mass

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

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

[CLS and M. Drees, arXiv:0710.4296]

Determination of the WIMP mass

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

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

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

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

- Determining the WIMP mass

$$m_\chi\big|_\sigma = \frac{(m_X/m_Y)^{5/2}\, m_Y - m_X \mathcal{R}_\sigma}{\mathcal{R}_\sigma - (m_X/m_Y)^{5/2}}$$

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

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

Determination of the WIMP mass

- χ^2-fit

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

where

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

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

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

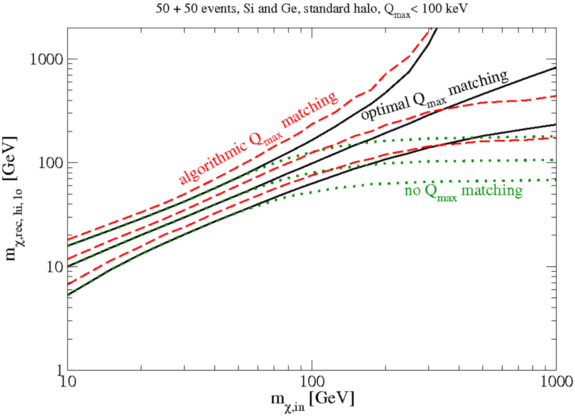
- Algorithmic $Q_{\max}$ matching

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

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

Determination of the WIMP mass

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



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

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Determinations of ratios of WIMP-nucleon cross sections

- -1-st moment of the WIMP velocity distribution

$$\left(\frac{dR}{dQ}\right)_{\text{expt},\ Q=Q_{\min}} = \mathcal{E}\mathcal{A}F^2(Q_{\min})\int_{v(Q_{\min})}^{v(Q_{\max})}\left[\frac{f_1(v)}{v}\right]dv$$

$$= \mathcal{E}\left(\frac{\rho_0\sigma_0}{2m_\chi m_{\mathrm{r,N}}^2}\right)F^2(Q_{\min})\cdot\frac{1}{\alpha}\left[\frac{2r_{\min}/F^2(Q_{\min})}{2Q_{\min}^{1/2}r_{\min}/F^2(Q_{\min})+I_0}\right]$$

- Product of the local density times the WIMP-nucleus cross section

$$\rho_0\sigma_0 = \left(\frac{1}{\mathcal{E}}\right)m_\chi m_{\mathrm{r,N}}\sqrt{\frac{m_{\mathrm{N}}}{2}}\left[\frac{2Q_{\min}^{1/2}r_{\min}}{F^2(Q_{\min})}+I_0\right]$$

[M. Drees, M. Kakizaki, and CLS, UCLA Dark Matter 2008]

- Ratio of two WIMP-nucleus cross sections

$$\frac{\sigma_{0,X}}{\sigma_{0,Y}} = \left(\frac{\mathcal{E}_Y}{\mathcal{E}_X}\right)\frac{m_{\mathrm{r},X}\sqrt{m_X}}{m_{\mathrm{r},Y}\sqrt{m_Y}}\left[\frac{2Q_{\min,X}^{1/2}r_{\min,X}+I_{0,X}F_X^2(Q_{\min,X})}{2Q_{\min,Y}^{1/2}r_{\min,Y}+I_{0,Y}F_Y^2(Q_{\min,Y})}\right]\left[\frac{F_Y^2(Q_{\min,Y})}{F_X^2(Q_{\min,X})}\right]$$

Determination of the ratio of two SD WIMP-nucleon couplings

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

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

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

J: total nuclear spin

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

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

- Determining the ratio of two SD WIMP-nucleon couplings

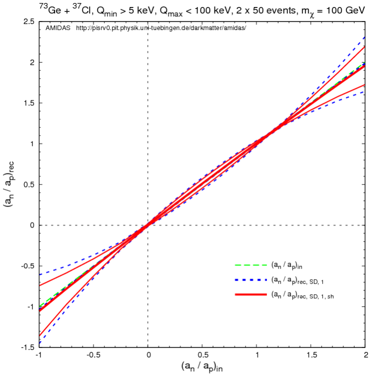
$$\left(\frac{a_{\rm n}}{a_{\rm p}}\right)_{\pm,n}^{\rm SD} = -\frac{\langle S_{\rm p}\rangle_X \pm \langle S_{\rm p}\rangle_Y \mathcal{R}_{J,n}}{\langle S_{\rm n}\rangle_X \pm \langle S_{\rm n}\rangle_Y \mathcal{R}_{J,n}}$$

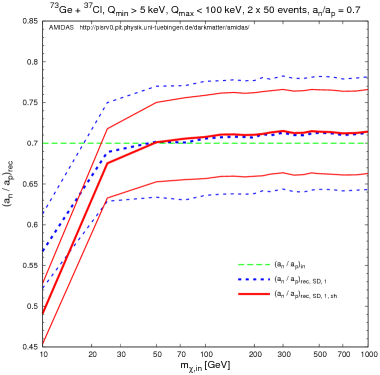
$$\mathcal{R}_{J,n} \equiv \left[\left(\frac{J_X}{J_X+1}\right)\left(\frac{J_Y+1}{J_Y}\right)\frac{\mathcal{R}_\sigma}{\mathcal{R}_n}\right]^{1/2} \qquad (n \neq 0)$$

[M. Drees and CLS, arXiv:0903.3300]

Determination of the ratio of two SD WIMP-nucleon couplings

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





[M. Drees, M. Kakizaki, and CLS, in progress]

Determination of the ratio of two WIMP-proton cross sections

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

$$\left(\frac{dR}{dQ}\right)_{\text{expt},\,Q=Q_{\min}} = \mathcal{E}\left(\frac{\rho_0\sigma_0^{\rm SI}}{2m_\chi m_{\rm r,N}^2}\right) F_{\rm SI}'^2(Q_{\min})\cdot\frac{1}{\alpha}\left[\frac{2r_{\min}/F_{\rm SI}'^2(Q_{\min})}{2Q_{\min}^{1/2}r_{\min}/F_{\rm SI}'^2(Q_{\min})+I_0}\right]$$

$$F_{\rm SI}'^2(Q)\equiv F_{\rm SI}^2(Q)+\left(\frac{\sigma_{\chi{\rm p}}^{\rm SD}}{\sigma_{\chi{\rm p}}^{\rm SI}}\right)\mathcal{C}_{\rm p}F_{\rm SD}^2(Q) \qquad \mathcal{C}_{\rm p}\equiv\frac{4}{3}\left(\frac{J+1}{J}\right)\left[\frac{\langle S_{\rm p}\rangle+(a_{\rm n}/a_{\rm p})\langle S_{\rm n}\rangle}{A}\right]^2$$

- Determining the ratio of two WIMP-proton cross sections

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

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

- Determining the ratio of two SD WIMP-nucleon couplings

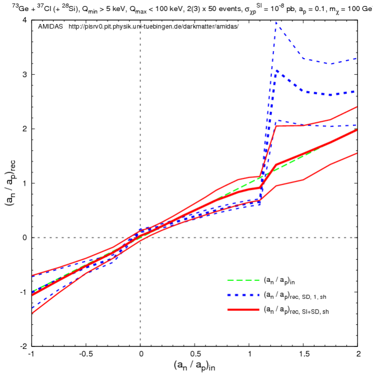
$$\left(\frac{a_{\rm n}}{a_{\rm p}}\right)_{\pm}^{\rm SI+SD}=-\frac{\sqrt{c_{{\rm p},X}}\mp\sqrt{c_{{\rm p},Y}}}{\sqrt{c_{{\rm p},X}}\,s_{{\rm n/p},X}\mp\sqrt{c_{{\rm p},Y}}\,s_{{\rm n/p},Y}} \qquad \left(s_{{\rm n/p},X}>s_{{\rm n/p},Y},\ s_{\rm n/p}\equiv\langle S_{\rm n}\rangle/\langle S_{\rm p}\rangle\right)$$

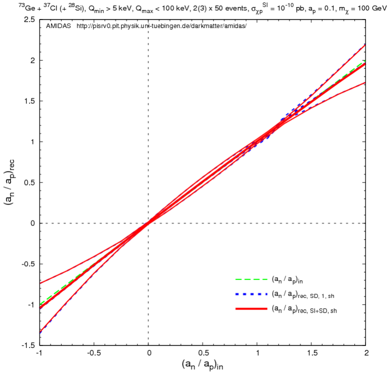
$$c_{{\rm p},X}\equiv\frac{4}{3}\left(\frac{J_X+1}{J_X}\right)\left[\frac{\langle S_{\rm p}\rangle_X}{A_X}\right]^2\left[F_{{\rm SI},Z}^2(Q_{\min,Z})\mathcal{R}_{m,YZ}-F_{{\rm SI},Y}^2(Q_{\min,Y})\right]F_{{\rm SD},X}^2(Q_{\min,X})$$

[M. Drees and CLS, arXiv:0903.3300]

Determination of the ratio of two WIMP-proton cross sections

- Reconstructed $(a_{\rm n}/a_{\rm p})_{\rm rec}^{\rm SI+SD}$ vs $(a_{\rm n}/a_{\rm p})_{\rm rec,1}^{\rm SD}$
  ($Q_{\rm min} > 5$ keV, $Q_{\rm max} < 100$ keV, ${}^{73}{\rm Ge} + {}^{37}{\rm Cl} + {}^{28}{\rm Si}$, 3×50 events, $\sigma_{\chi{\rm p}}^{\rm SI} = 10^{-8}$ / 10^{-10} pb, $a_{\rm p} = 0.1$, $m_\chi = 100$ GeV)

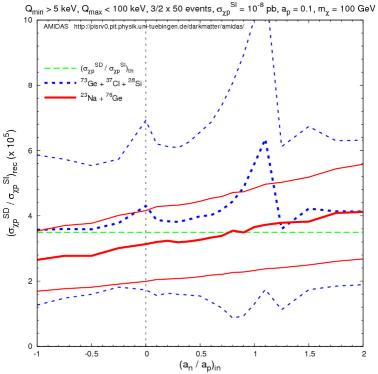


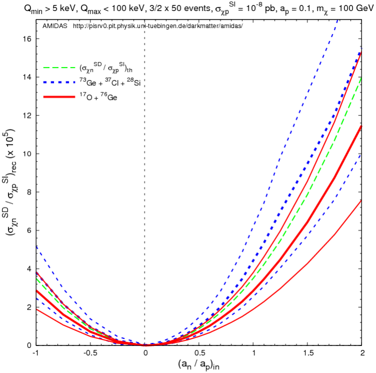


[M. Drees, M. Kakizaki, and CLS, in progress]

Determination of the ratio of two WIMP-proton cross sections

- Reconstructed $(\sigma_{\chi p}^{SD}/\sigma_{\chi p}^{SI})_{rec}$ and $(\sigma_{\chi n}^{SD}/\sigma_{\chi p}^{SI})_{rec}$ ($Q_{min} > 5$ keV, $Q_{max} < 100$ keV, $^{73}Ge + {}^{37}Cl + {}^{28}Si$ vs $^{76}Ge + {}^{23}Na/{}^{17}O$, $\sigma_{\chi p}^{SI} = 10^{-8}$ pb, $a_p = 0.1$, $m_\chi = 100$ GeV, $3/2 \times 50$ events)

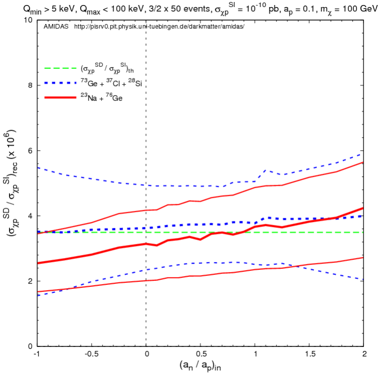


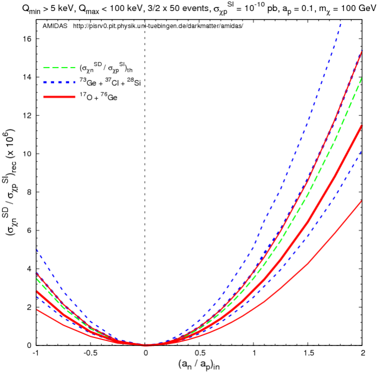


[M. Drees, M. Kakizaki, and CLS, in progress]

Determination of the ratio of two WIMP-proton cross sections

- Reconstructed $\left(\sigma_{\chi p}^{SD}/\sigma_{\chi p}^{SI}\right)_{rec}$ and $\left(\sigma_{\chi n}^{SD}/\sigma_{\chi p}^{SI}\right)_{rec}$
  ($Q_{min} > 5$ keV, $Q_{max} < 100$ keV, ${}^{73}Ge + {}^{37}Cl + {}^{28}Si$ vs ${}^{76}Ge + {}^{23}Na/{}^{17}O$, $\sigma_{\chi p}^{SI} = 10^{-10}$ pb, $a_p = 0.1$, $m_\chi = 100$ GeV, $3/2 \times 50$ events)





[M. Drees, M. Kakizaki, and CLS, in progress]

Estimation of the SI WIMP-nucleon coupling

- We can estimate ratios of each two of the three WIMP-nucleon cross sections model-independently.
  - Can we estimate any one of them further?
  - Unfortunately, no!
  - Expression for the product of the local density times the WIMP-nucleus cross section

$$\rho_0 \sigma_0^{\rm SI} = \left(\frac{1}{\mathcal{E}} \right) m_\chi m_{\rm r,N} \sqrt{\frac{m_{\rm N}}{2}} \left[\frac{2 Q_{\rm min}^{1/2} r_{\rm min}}{F_{\rm SI}^2(Q_{\rm min})} + I_0 \right]$$

  ➥ Making an assumption for the local WIMP density

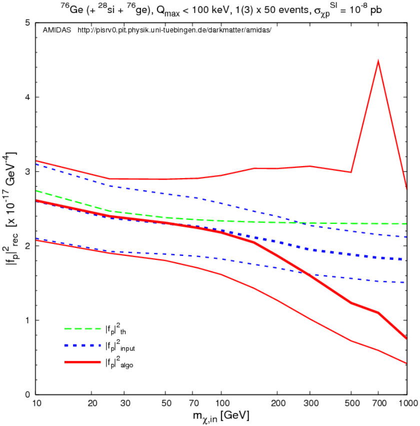
- Estimating the SI WIMP-nucleon coupling

$$|f_{\rm p}|^2 = \frac{1}{\rho_0} \left[\frac{\pi}{4\sqrt{2}} \left(\frac{1}{\mathcal{E} A^2 \sqrt{m_{\rm N}}} \right) \right] \left[\frac{2 Q_{\rm min}^{1/2} r_{\rm min}}{F_{\rm SI}^2(Q_{\rm min})} + I_0 \right] (m_\chi + m_{\rm N})$$

[M. Drees and CLS, arXiv:0809.2441]

Estimation of the SI WIMP-nucleon coupling

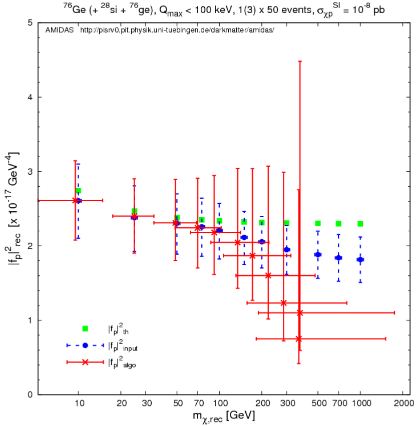
- Reconstructed $|f_{\rm p}|^2_{\rm rec}$
  ($Q_{\rm max} < 100$ keV, ^{76}Ge $(+\,^{28}$si $+\,^{76}$ge), $\sigma_{\chi{\rm p}}^{\rm SI} = 10^{-8}$ pb, $1(3) \times 50$ events)



[M. Drees and CLS, in progress]

Estimation of the SI WIMP-nucleon coupling

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



[M. Drees and CLS, in progress]

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 errors of $10 - 40\%$ with only $\mathcal{O}(50)$ events from one experiment.

Summary

- These information will help us to
  - constrain the parameter space
  - distinguish the (neutralino) LSP from the (first KK hypercharge) LKP

    G. Bertone *et al.*, PRL 99, 151301 (2007); V. Barger *et al.*, PRD 78, 056007 (2008);
    G. Belanger *et al.*, PRD 79, 015008 (2009); R. C. Cotta *et al.*, arXiv:0903.4409 (2009)
  - identify the particle produced at colliders to be indeed halo WIMP
  - predict the WIMP annihilation cross section $\langle \sigma_{\rm anni} v \rangle$
  - ......
- Furthermore, we could
  - determine the local WIMP density ρ_0
  - predict the indirect detection event rate $d\Phi/dE$
  - test our understanding of the early Universe
  - ......

Current projects and related research interests

- With direct DM detection experiments
  - Identifying the annual modulation of WIMP events
  - Extracting directional information of WIMP signals
  - Taking background events into account
  - (Online interactive) simulation/data analysis system: AMIDAS
    http://pisrv0.pit.physik.uni-tuebingen.de/darkmatter/amidas/
- With indirect DM detection experiments
  - Predicting the WIMP annihilation cross section and the event rate
  - Information on the spin-dependent WIMP-proton coupling
  - Information on (the anisotropy of) the halo structure

Thank you very much for your attention

[http://dmrc.snu.ac.kr/∼cshan/]