Determining Properties of Dark Matter Particles with Direct Detection Experiments as Model Independently as Possible

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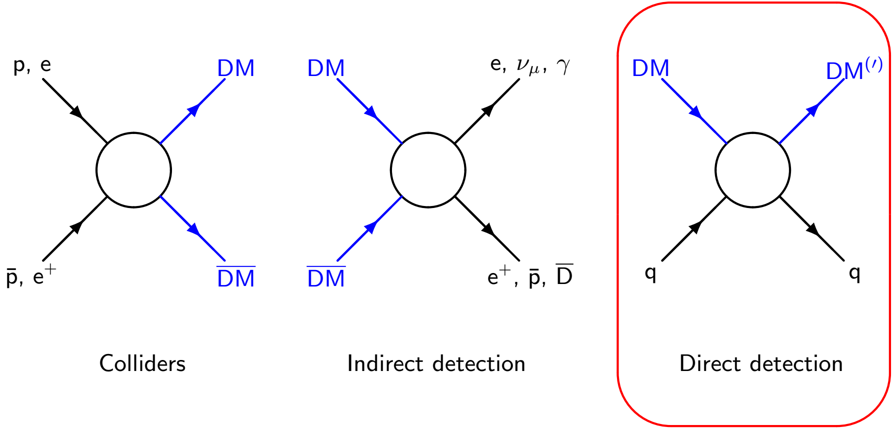
Direct Dark Matter detection

Direct Dark Matter detection

DM should have small, but non-zero interactions with ordinary matter.



Direct Dark Matter 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 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 would be with energies less than 50 keV.

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

Direct Dark Matter detection: elastic WIMP-nucleus scattering

- 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.

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

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

Direct Dark Matter detection: elastic WIMP-nucleus scattering

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Astrophysics

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Direct Dark Matter detection: elastic WIMP-nucleus scattering

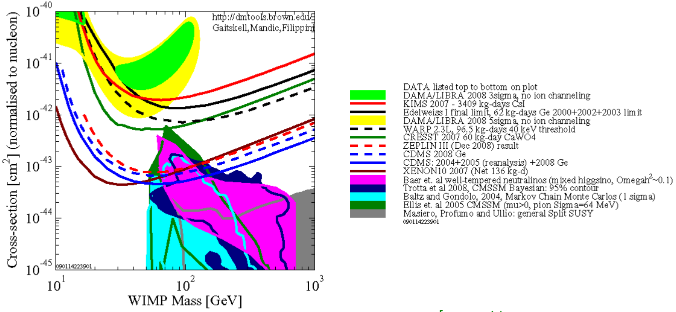
- Spin-independent (SI) WIMP-nucleus cross section

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

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

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

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



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

Direct Dark Matter detection: elastic WIMP-nucleus scattering

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

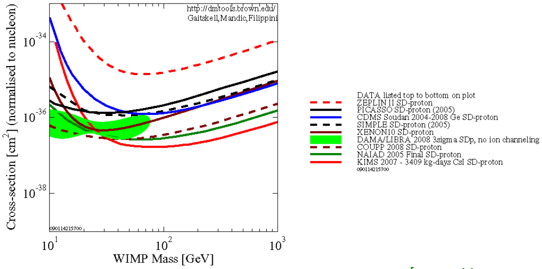
$$\sigma_0^{\rm SD} = \left(\frac{32}{\pi}\right) G_F^2\, m_{\rm r,N}^2 \left(\frac{J+1}{J}\right) \Big[\langle S_{\rm p}\rangle a_{\rm p} + \langle S_{\rm n}\rangle a_{\rm n}\Big]^2$$

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

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

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

- Exclusion limits on the SD WIMP-proton cross section



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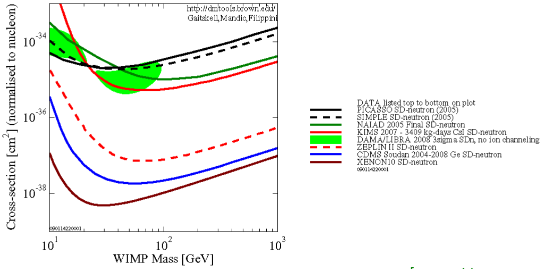
- Exclusion limits on the SD WIMP-neutron cross section



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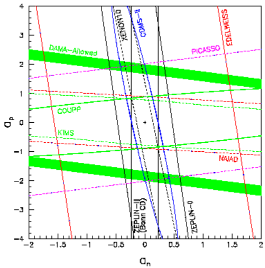
- Exclusion limits on the $a_{\rm p}$ and $a_{\rm n}$ couplings



[V. N. Lebedenko et al., PRL 103, 151302 (2009)]

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

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ρ_0: WIMP density near the Earth

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$f_1(v)$: 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: reconstructing 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

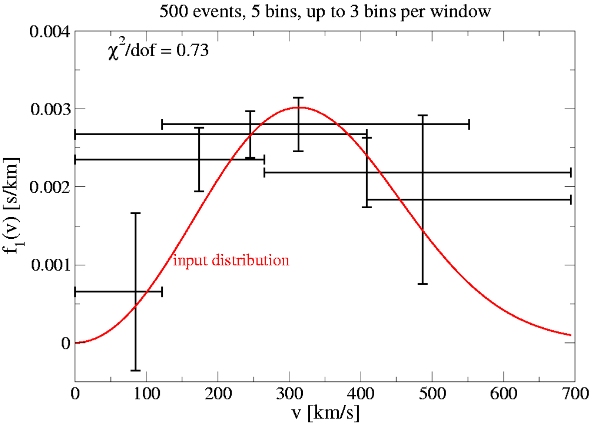
$$f_1(v_{s,n}) = \mathcal{N}\left[\frac{2Q_{s,n}r_n}{F^2(Q_{s,n})}\right]\left[\frac{d}{dQ}\ln F^2(Q)\bigg|_{Q=Q_{s,n}} - k_n\right]$$

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

[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

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

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

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

- Determining the WIMP mass

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

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

[CLS and M. Drees, arXiv:0710.4296]

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

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

[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

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

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

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

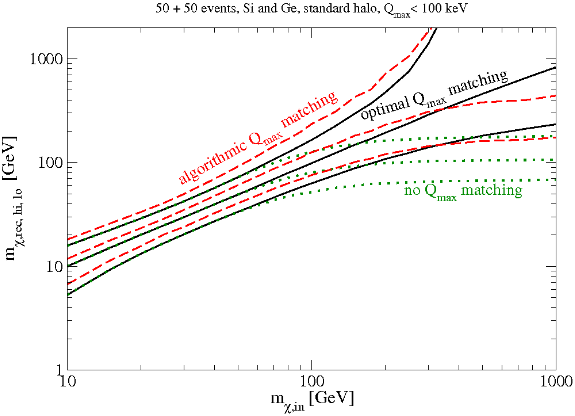
- Algorithmic $Q_{\max}$ matching

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

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

Determination of the WIMP mass

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



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

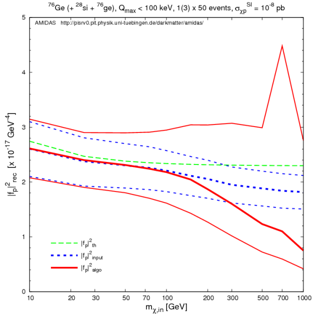
Estimation of the SI WIMP-nucleon coupling

- Estimating the SI WIMP-nucleon coupling

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

[M. Drees and CLS, arXiv:0809.2441]

- $|f_{\rm p}|^2_{\rm rec}$ (^{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)



[M. Drees and CLS, in progress]

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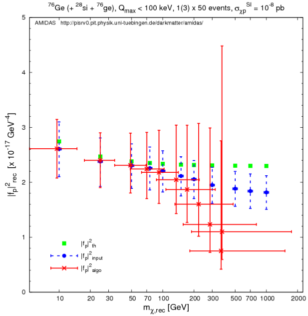
$$|f_{\rm p}|^2 = \frac{1}{\rho_0}\left[\frac{\pi}{4\sqrt{2}}\left(\frac{1}{\mathcal{E}_Z A_Z^2 \sqrt{m_Z}}\right)\right]\left[\frac{2Q_{\min,Z}^{1/2} r_{\min,Z}}{F_Z^2(Q_{\min,Z})} + I_{0,Z}\right](m_\chi + m_Z)$$

[M. Drees and CLS, arXiv:0809.2441]

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



[M. Drees and CLS, in progress]

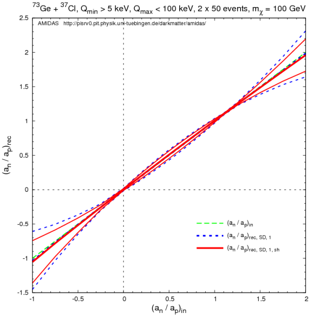
Determinations of ratios of WIMP-nucleon cross sections

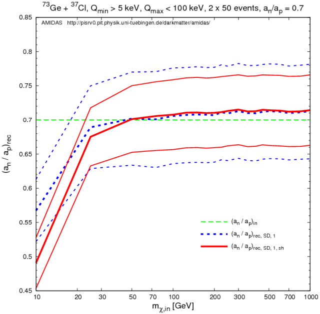
- Determining the ratio of two SD WIMP-nucleon couplings

$$\left(\frac{a_{\rm n}}{a_{\rm p}}\right)^{\rm SD}_{\pm,n} = -\frac{\langle S_{\rm p}\rangle_X \pm \langle S_{\rm p}\rangle_Y \mathcal{R}_{J,n}}{\langle S_{\rm n}\rangle_X \pm \langle S_{\rm n}\rangle_Y \mathcal{R}_{J,n}} \qquad \mathcal{R}_{J,n} \equiv \left[\left(\frac{J_X}{J_X+1}\right)\left(\frac{J_Y+1}{J_Y}\right)\frac{\mathcal{R}_\sigma}{\mathcal{R}_n}\right]^{1/2} \qquad (n \neq 0)$$

[M. Drees and CLS, arXiv:0903.3300]

- $(a_{\rm n}/a_{\rm p})^{\rm SD}_{{\rm rec},n}$ (5 – 100 keV, ^{73}Ge + ^{37}Cl, 2 × 50 events, m_χ = 100 GeV or $a_{\rm n}/a_{\rm p}$ = 0.7)





[M. Drees and CLS, arXiv:0903.3300; in progress]

Determinations of ratios of WIMP-nucleon cross sections

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

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

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

- 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

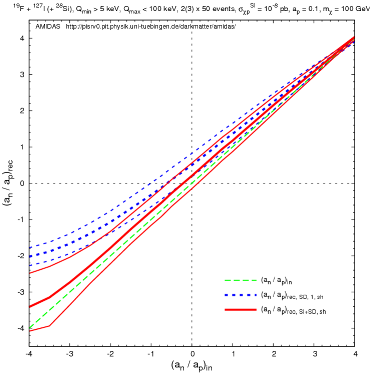
$$\left(\frac{a_{\rm n}}{a_{\rm p}}\right)_{\pm}^{\rm SI+SD} = \frac{-\left(c_{{\rm p},X} s_{{\rm n/p},X} - c_{{\rm p},Y} s_{{\rm n/p},Y}\right) \pm \sqrt{c_{{\rm p},X} c_{{\rm p},Y}}\left|s_{{\rm n/p},X} - s_{{\rm n/p},Y}\right|}{c_{{\rm p},X} s_{{\rm n/p},X}^2 - c_{{\rm p},Y} s_{{\rm n/p},Y}^2}$$

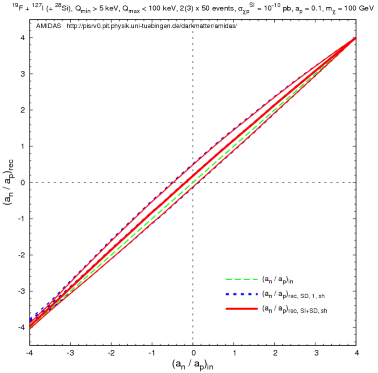
$$c_{{\rm p},X} \equiv \frac{4}{3}\left(\frac{J_X+1}{J_X}\right)\left[\frac{\langle S_{\rm p}\rangle_X}{A_X}\right]^2 \left[F_{{\rm SI},Z}^2(Q_{\min,Z}) \mathcal{R}_{m,YZ} - F_{{\rm SI},Y}^2(Q_{\min,Y})\right] F_{{\rm SD},X}^2(Q_{\min,X})$$

[M. Drees and CLS, arXiv:0903.3300]

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)

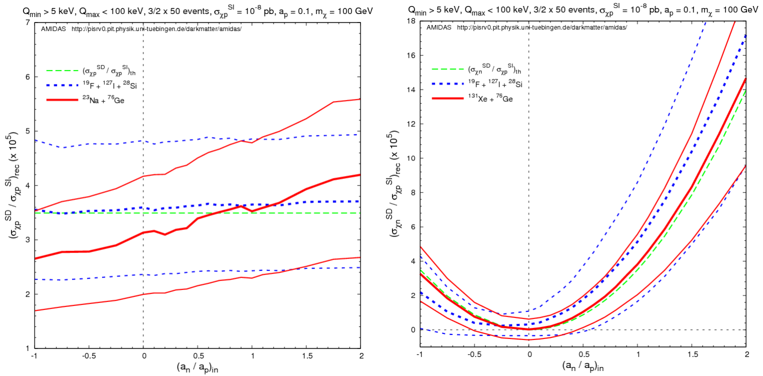




[M. Drees, M. Kakizaki and CLS, in progress]

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. $^{76}Ge + ^{23}Na/^{131}Xe$, $Q_{min} > 5$ keV, $Q_{max} < 100$ keV, $\sigma_{\chi p}^{SI} = 10^{-8}$ pb, $a_p = 0.1$, $m_\chi = 100$ GeV, $3/2 \times 50$ events)



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

Effects of residue background events

Measured recoil spectrum

- Background spectrum
  - Target-dependent exponential background spectrum

$$\left(\frac{dR}{dQ}\right)_{\rm bg,ex} = \exp\left(-\frac{Q/{\rm keV}}{A^{0.6}}\right)$$

  - Constant background spectrum

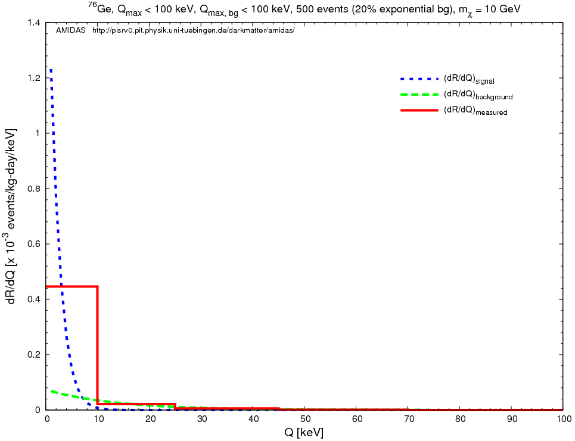
- Background window
  - Entire experimental possible energy range (0 – 100 keV)
  - Low energy range (0 – 50 keV)
  - High energy range (50 – 100 keV)

- (Naively) simulate
  - only a few residue background events
  - induced by two or more different sources

Measured recoil spectrum

- Measured recoil spectrum

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

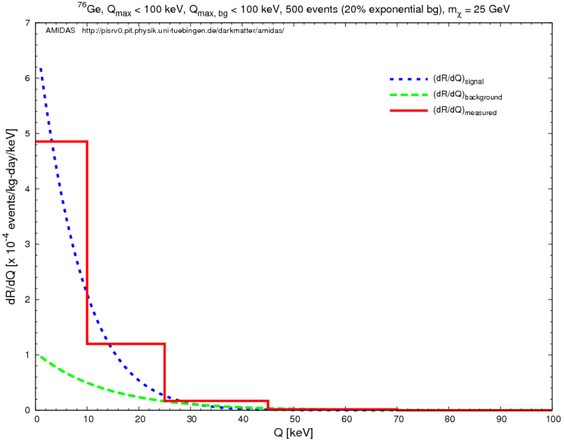


[Y. T. Chou and CLS, arXiv:1003.xxxx]

Measured recoil spectrum

- Measured recoil spectrum

(^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, 20% bg, $m_\chi = 25$ GeV)

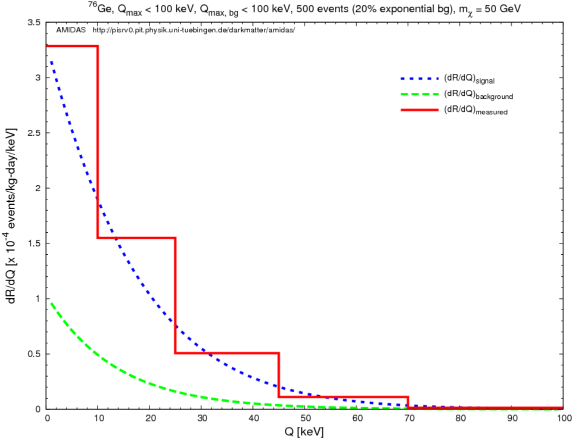


[Y. T. Chou and CLS, arXiv:1003.xxxx]

Measured recoil spectrum

- Measured recoil spectrum

(^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, 20% bg, $m_\chi = 50$ GeV)

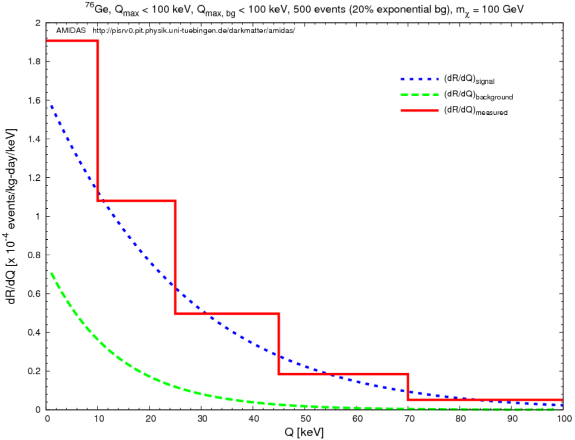


[Y. T. Chou and CLS, arXiv:1003.xxxx]

Measured recoil spectrum

- Measured recoil spectrum

(^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, 20% bg, $m_\chi = 100$ GeV)

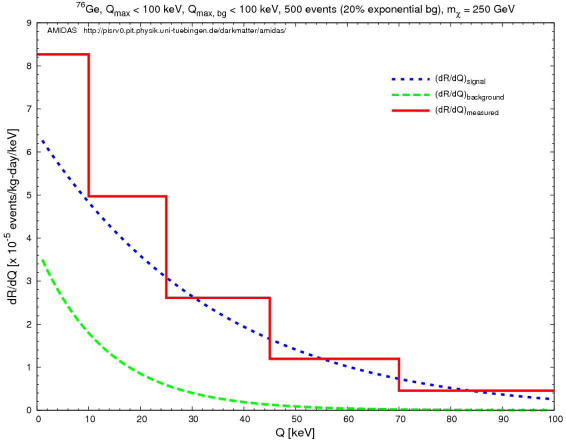


[Y. T. Chou and CLS, arXiv:1003.xxxx]

Measured recoil spectrum

❍ Measured recoil spectrum

(^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, 20% bg, $m_\chi = 250$ GeV)

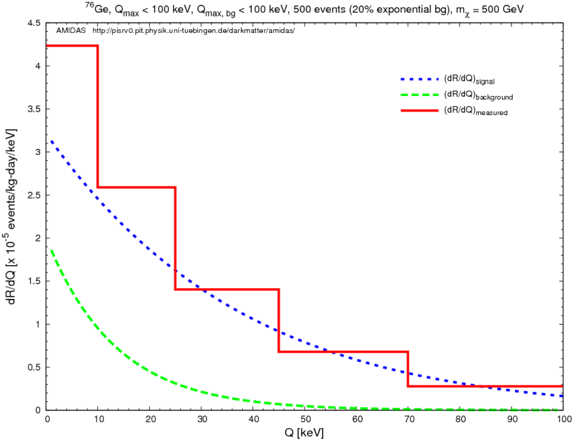


[Y. T. Chou and CLS, arXiv:1003.xxxx]

Measured recoil spectrum

- Measured recoil spectrum

(^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, 20% bg, m_χ = 500 GeV)

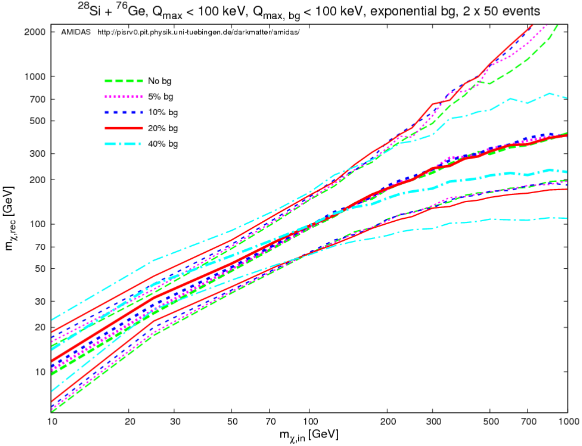


[Y. T. Chou and CLS, arXiv:1003.xxxx]

On the determination of the WIMP mass

- Reconstructed $m_{\chi,\rm rec}$

  (^{28}Si + ^{76}Ge, 0 − 100 keV, exponential bg 0 − 100 keV, 2 × 50 events)



[Y. T. Chou and CLS, arXiv:1003.xxxx]

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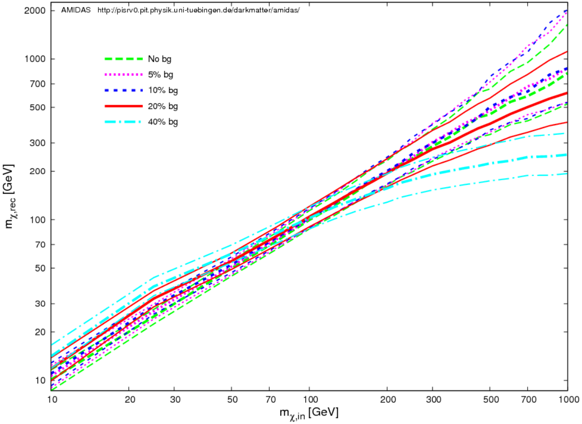


[Y. T. Chou and CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

- Kinematic maximal cut-off of the recoil energy

$$Q_{\rm max,kin} = \frac{v_{\rm esc}^2}{\alpha^2}$$

- Reconstruction of the one-dimensional WIMP velocity distribution

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

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

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

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

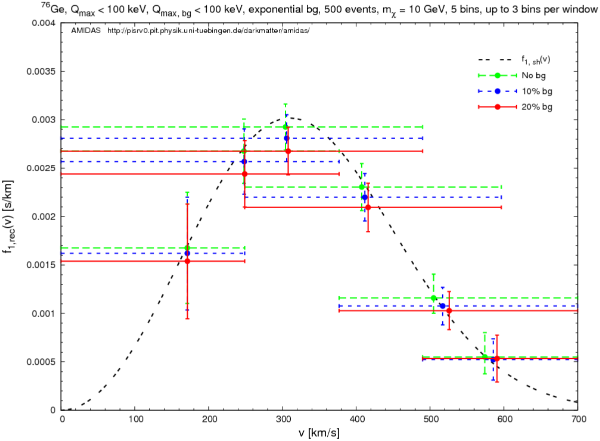
$$\alpha \equiv \sqrt{\frac{m_{\rm N}}{2 m_{\rm r,N}^2}} = \frac{1}{\sqrt{2 m_{\rm N}}} \left(1 + \frac{m_{\rm N}}{m_\chi} \right)$$

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

On the reconstruction of the WIMP velocity distribution

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

(^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, $m_\chi = 10$ GeV)

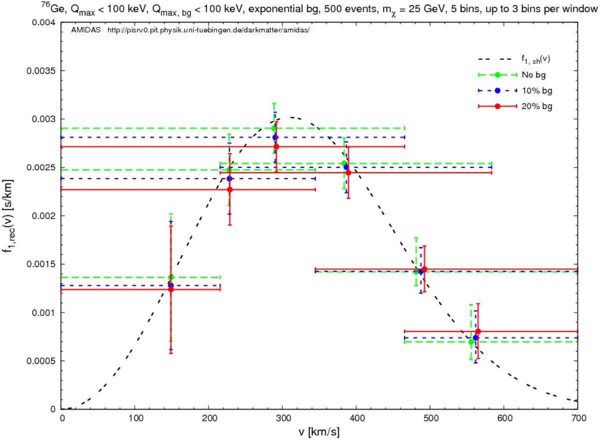


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

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

(^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, $m_\chi = 25$ GeV)

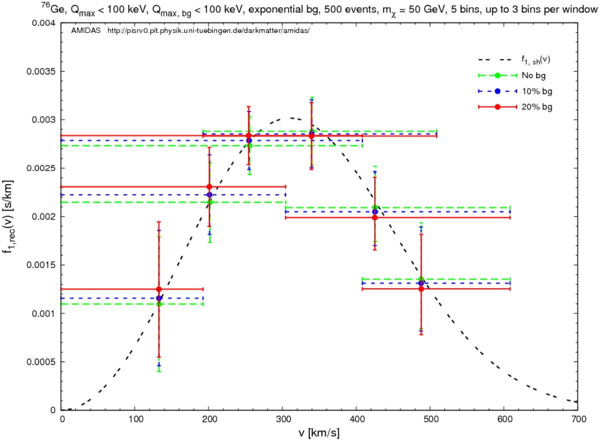


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

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

  (^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, $m_\chi = 50$ GeV)

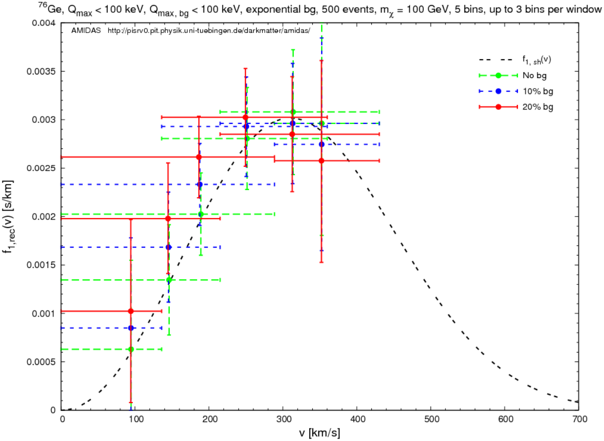


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

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

  (^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, $m_\chi = 100$ GeV)

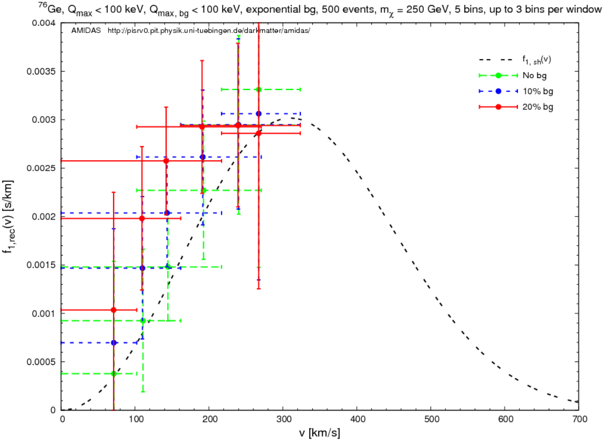


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

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

(^{76}Ge, 0 − 100 keV, exponential bg 0 − 100 keV, 500 events, $m_\chi = 250$ GeV)

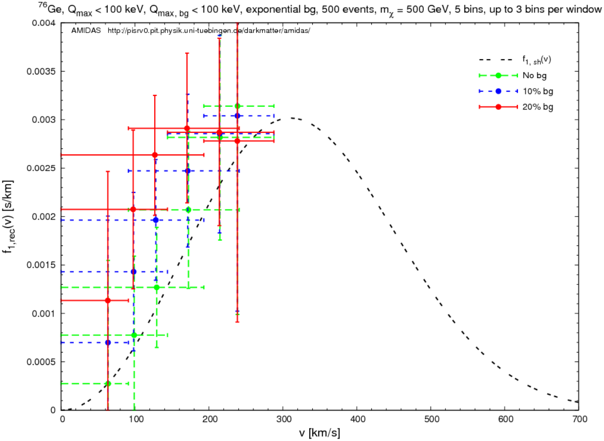


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

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

  (^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, $m_\chi = 500$ GeV)

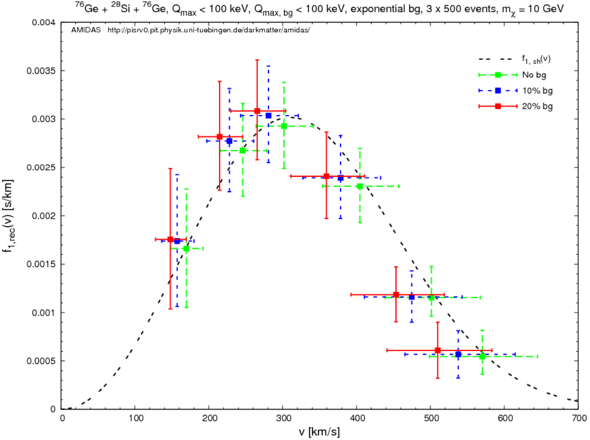


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

❍ Reconstructed $f_{1,\text{rec}}(v_{s,n})$ with reconstructed $m_{\chi,\text{rec}}$

(^{76}Ge + ^{28}Si + ^{76}Ge, 0 − 100 keV, exponential bg, 3 × 500 events, $m_\chi = 10$ GeV)

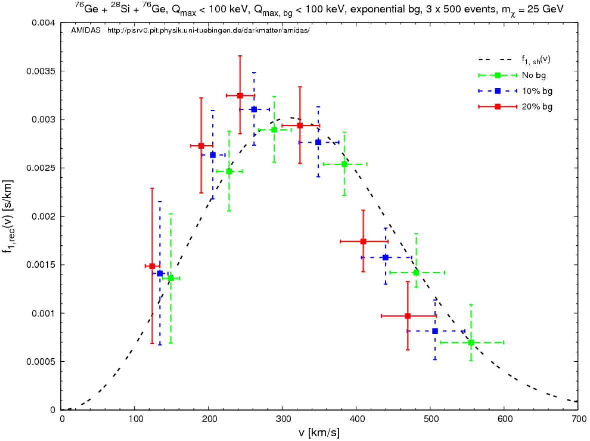


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

- Reconstructed $f_{1,\mathrm{rec}}(v_{s,n})$ with reconstructed $m_{\chi,\mathrm{rec}}$

(^{76}Ge + ^{28}Si + ^{76}Ge, 0 − 100 keV, exponential bg, 3 × 500 events, m_χ = 25 GeV)

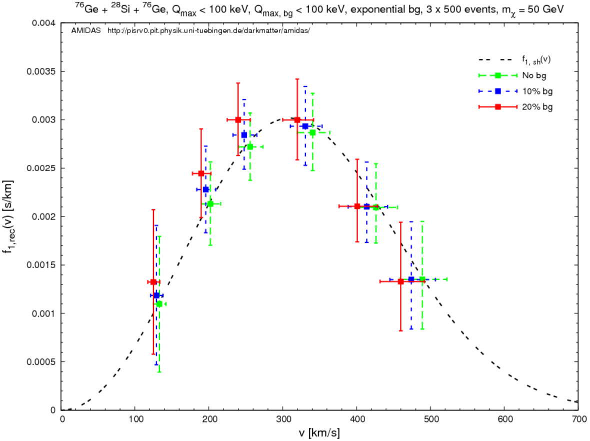


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

- Reconstructed $f_{1,\rm rec}(v_{s,n})$ with reconstructed $m_{\chi,\rm rec}$

  (^{76}Ge + ^{28}Si + ^{76}Ge, 0 – 100 keV, exponential bg, 3 × 500 events, $m_\chi = 50$ GeV)

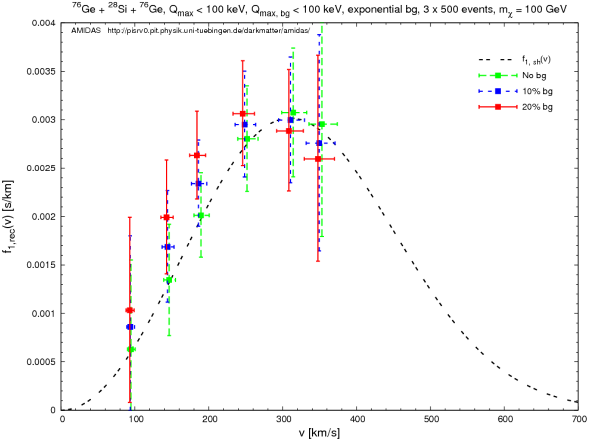


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

- Reconstructed $f_{1,\rm rec}(v_{s,n})$ with reconstructed $m_{\chi,\rm rec}$

(^{76}Ge + ^{28}Si + ^{76}Ge, 0 − 100 keV, exponential bg, 3 × 500 events, $m_\chi = 100$ GeV)

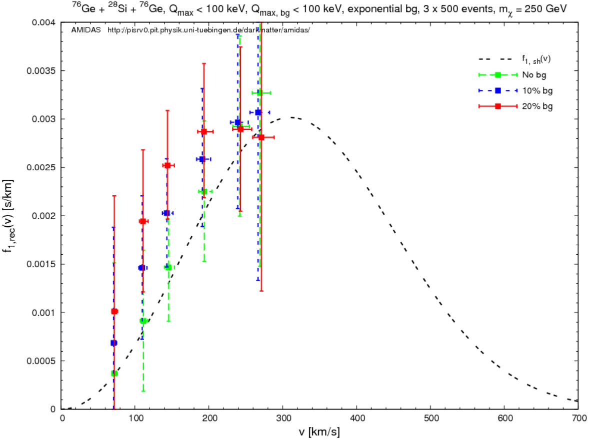


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

- Reconstructed $f_{1,\rm rec}(v_{s,n})$ with reconstructed $m_{\chi,\rm rec}$

  (^{76}Ge + ^{28}Si + ^{76}Ge, 0 − 100 keV, exponential bg, 3 × 500 events, $m_\chi = 250$ GeV)

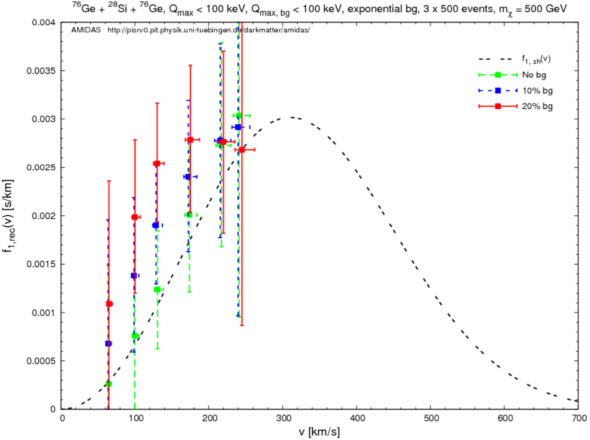


[CLS, arXiv:1003.xxxx]

On the reconstruction of the WIMP velocity distribution

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

(^{76}Ge + ^{28}Si + ^{76}Ge, 0 – 100 keV, exponential bg, 3 × 500 events, m_χ = 500 GeV)



[CLS, arXiv:1003.xxxx]

AMIDAS code and website

AMIDAS code 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 improvements/ideas
  - More well-motivated velocity distributions and form factors
  - More options for target materials
  - Users' personal setup uploading, storing and reloading
  - Generating events with directional information

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 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.*, NJP 11, 105026 (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
  - ......

Summary

- With an exponential-like residue background spectrum:
  - The reconstructed WIMP mass could be over-/underestimated, if WIMPs are lighter/heavier than $\sim 50/200$ GeV.
  - Data sets with $\sim 10\% - 20\%$ residue background events could still be used for determining the WIMP mass.
  - Background contribution in high/low energy ranges would shift the reconstructed WIMP velocity distribution to higher/lower velocities.
  - Over-/underestimated WIMP mass (more strongly) would shift the reconstructed WIMP velocity distribution to lower/higher velocities.
  - Data sets with $\sim 5\% - 10\%$ residue background events could still be used for reconstructing the WIMP velocity distribution.

Summary

Studies of effects of residue background events
on the estimation of SI WIMP-nucleon coupling and
on the determinations of ratios of WIMP-nucleon cross sections
are currently under investigation.

Thank you very much for your attention
[http://myweb.ncku.edu.tw/∼clshan/Publications/Talks/]