Effects of Residue Background Events in Direct Detection Experiments on Identifying WIMP Dark Matter

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based on JCAP 1008, 014

Model-independent data analyses

Motivation

- Differential event rate for elastic WIMP-nucleus scattering

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

Here

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

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

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

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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Determination of the WIMP mass

- 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

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

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

- Estimating the moments of the WIMP velocity distribution

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

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

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

Determination of the WIMP mass

- Determining the WIMP mass

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

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

[CLS and M. Drees, arXiv:0710.4296]

- With the assumption of a dominant SI WIMP interaction

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

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

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

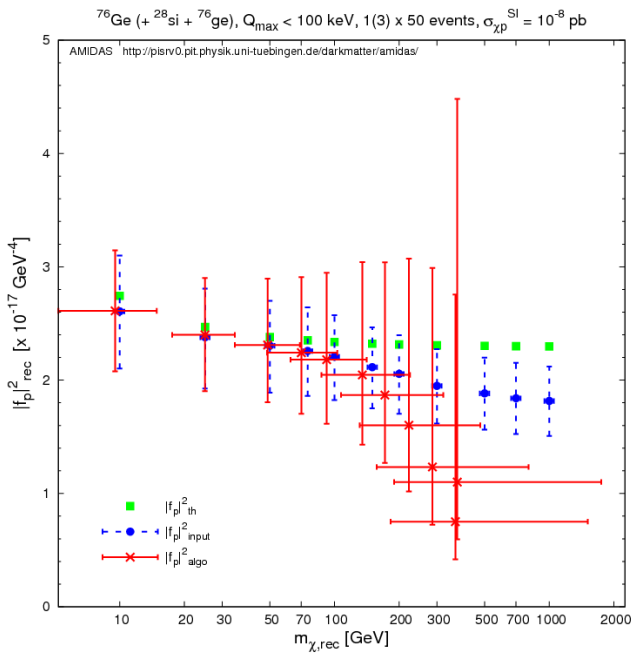
Estimation of the SI WIMP-nucleon coupling

- Estimating the SI WIMP-nucleon coupling

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

[M. Drees and CLS, arXiv:0809.2441]

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



[M. Drees and CLS, in progress]

Effects of residue background events

Measured recoil spectrum

- Background spectrum
  - Target-dependent exponential background spectrum

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

  - Constant background spectrum

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

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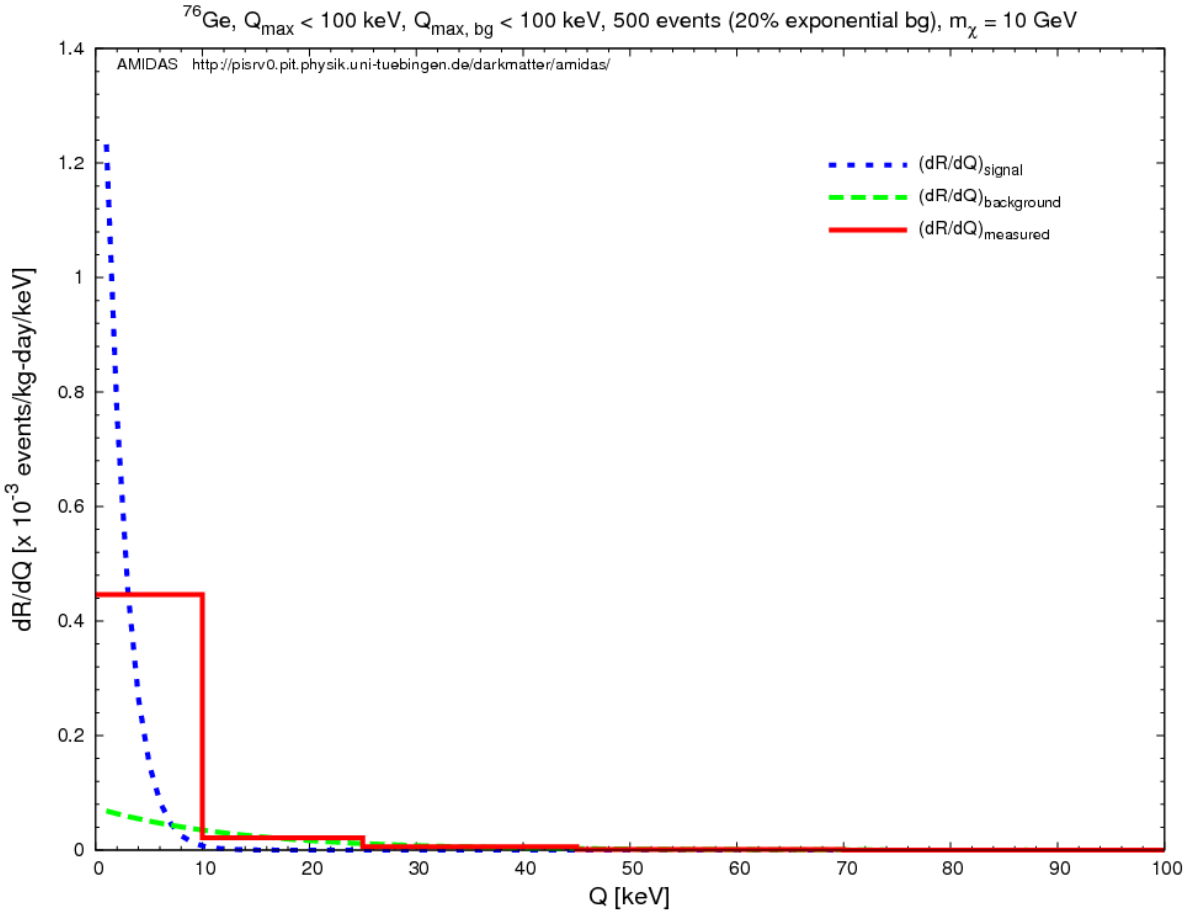
- (Naively) simulate
  - only a few residue background events
  - induced by two or more different sources

Measured recoil spectrum

- Measured recoil spectrum

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

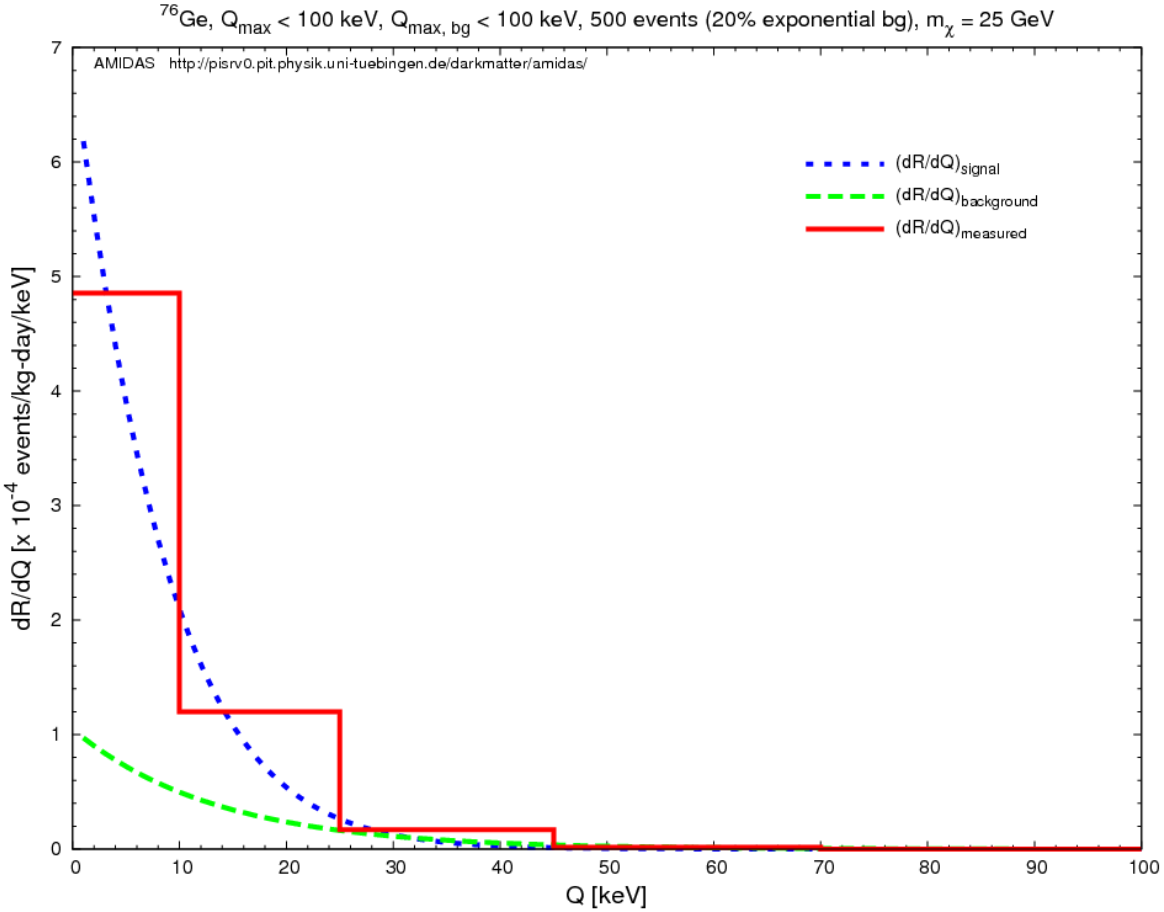


[Y. T. Chou and CLS, JCAP 1008, 014]

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, JCAP 1008, 014]

Measured recoil spectrum

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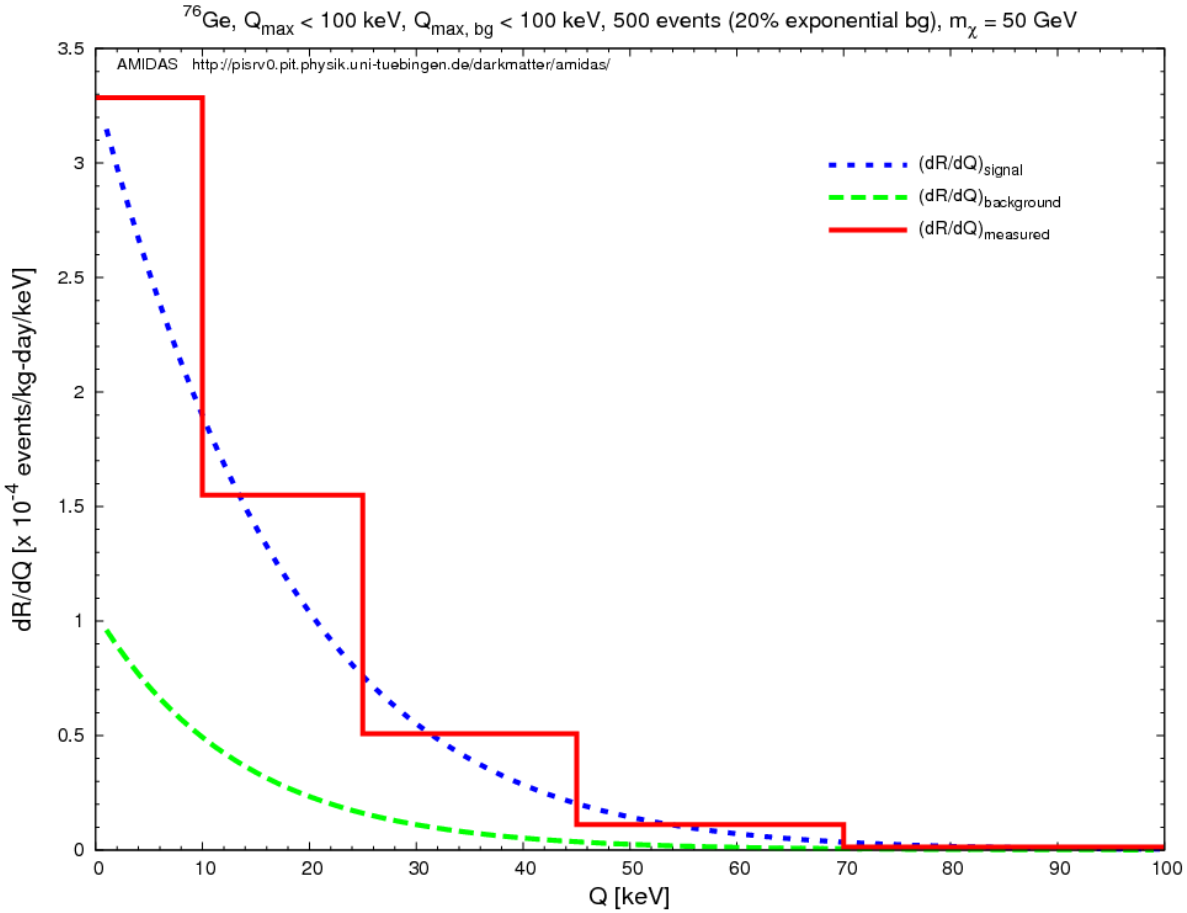
  (^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, 20% bg, $m_\chi = 50$ GeV)



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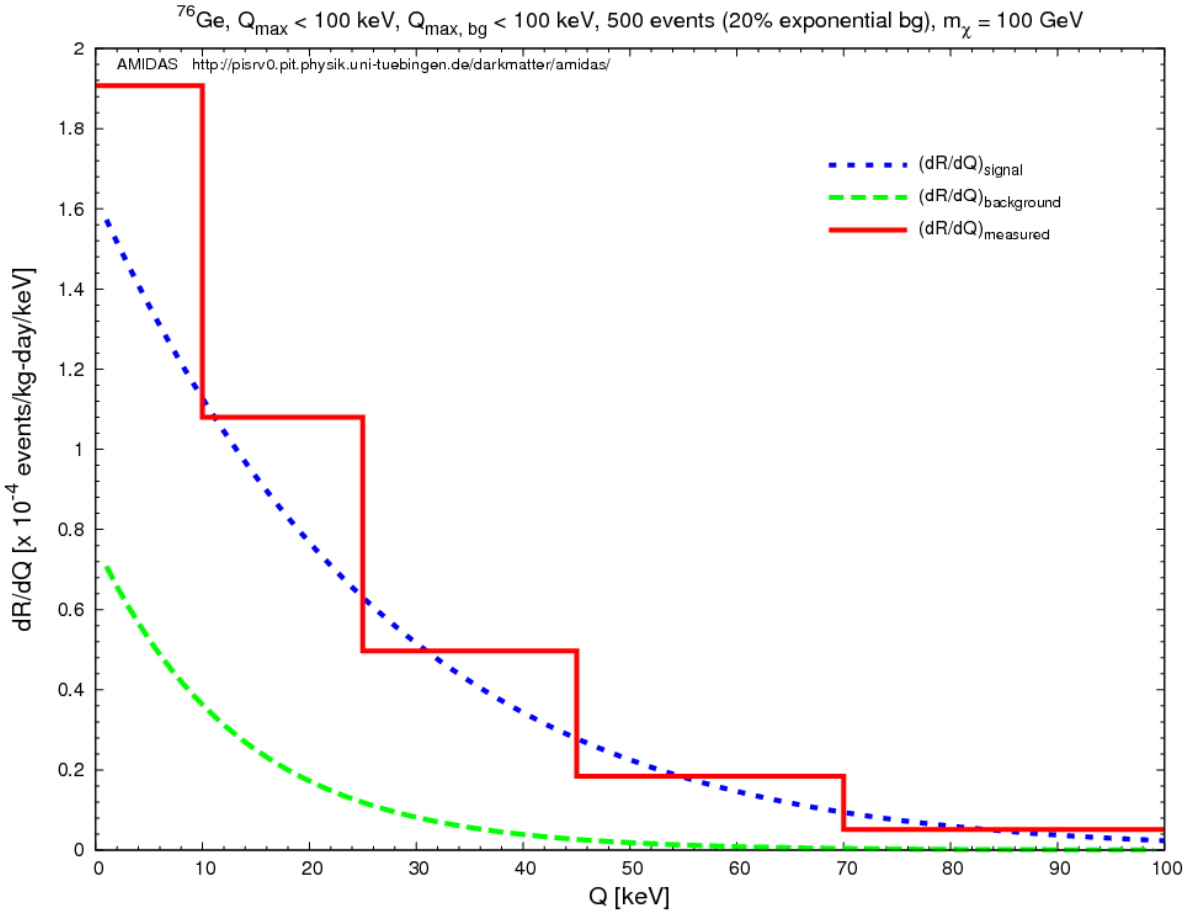

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Measured recoil spectrum

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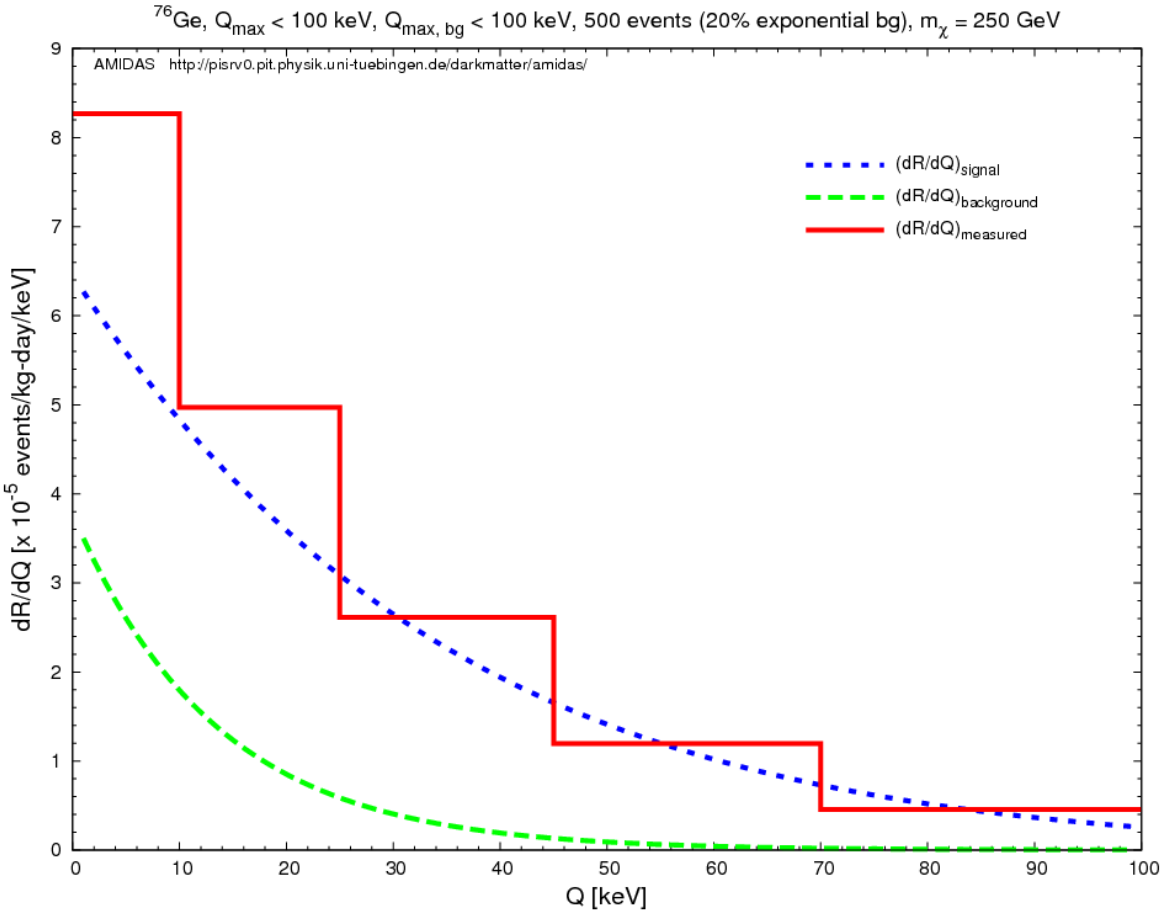
  (^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 500 events, 20% bg, $m_\chi = 250$ GeV)



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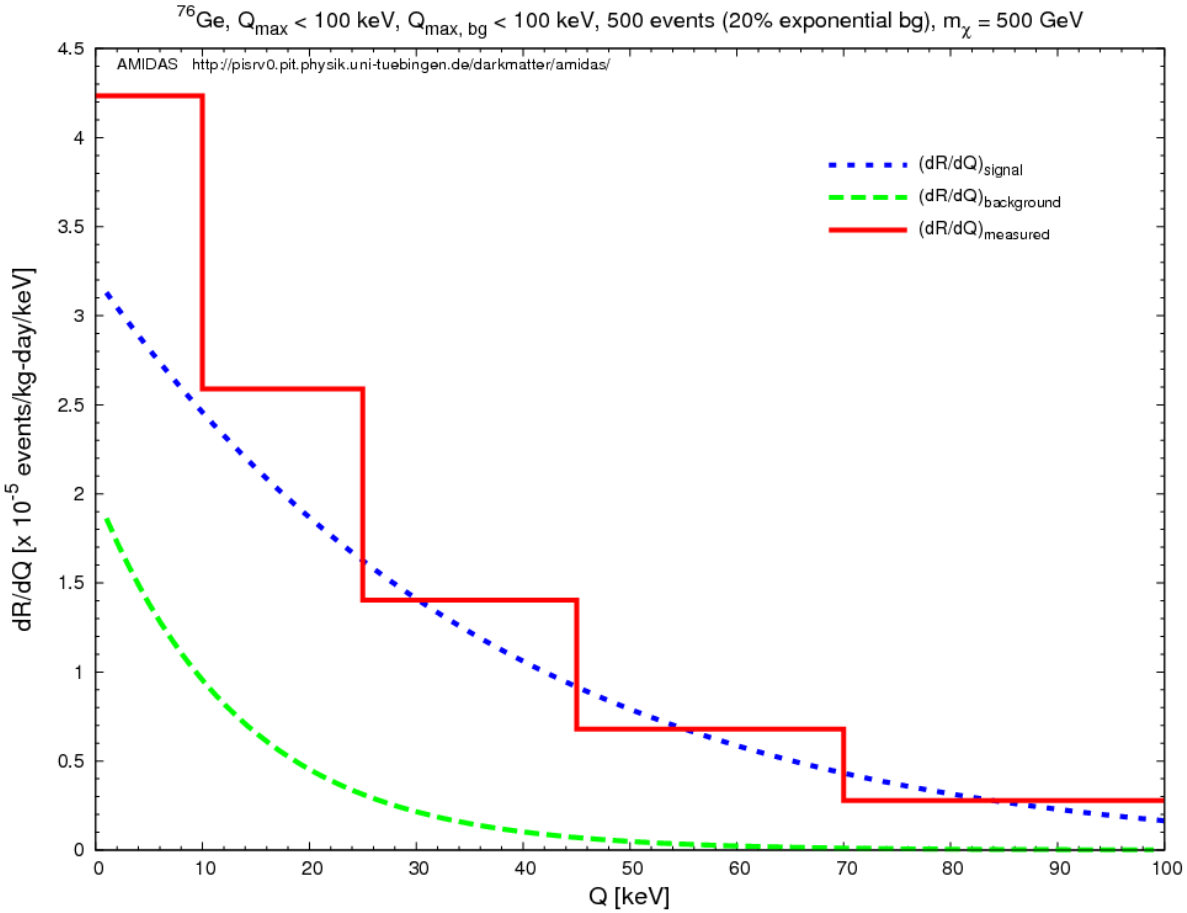

[Y. T. Chou and CLS, JCAP 1008, 014]

On the determination of the WIMP mass

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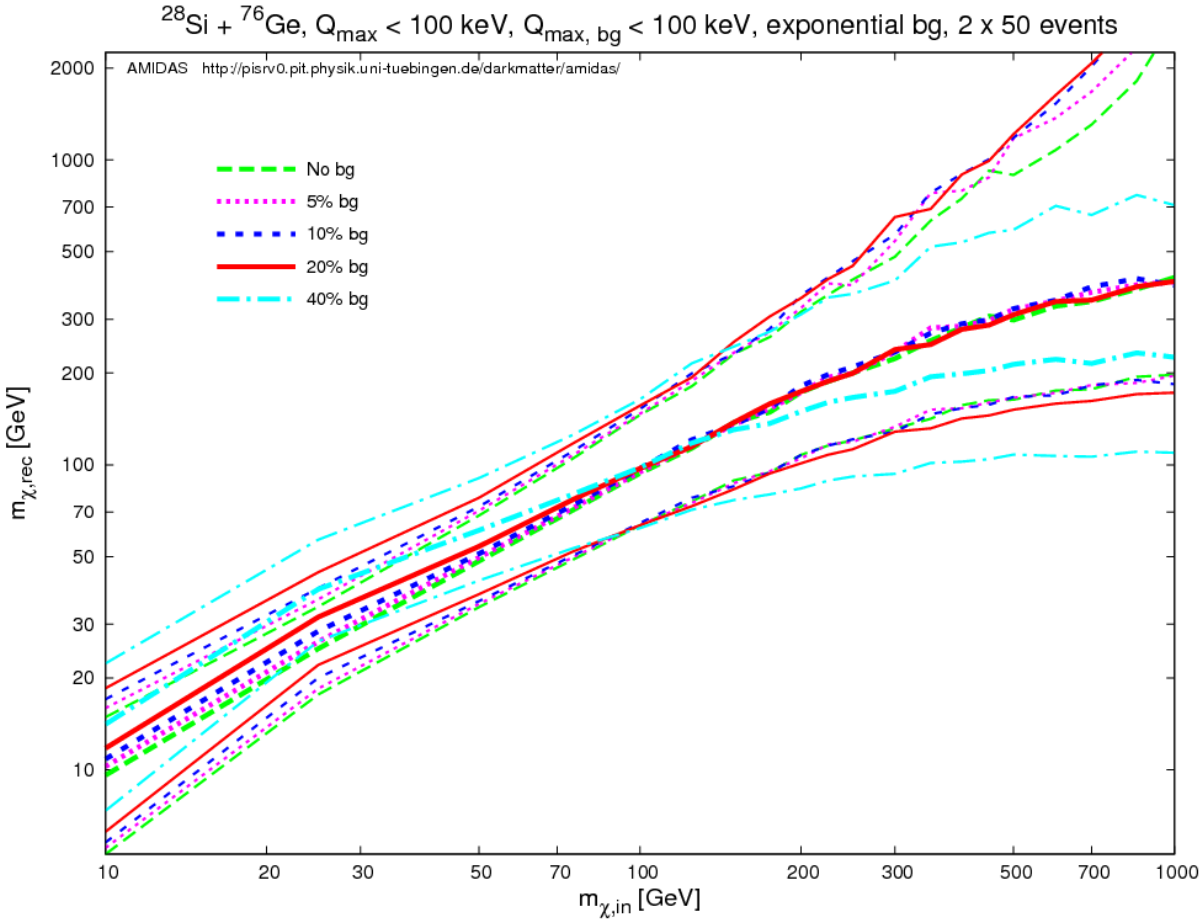
- Reconstructed $m_{\chi,\mathrm{rec}}$

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



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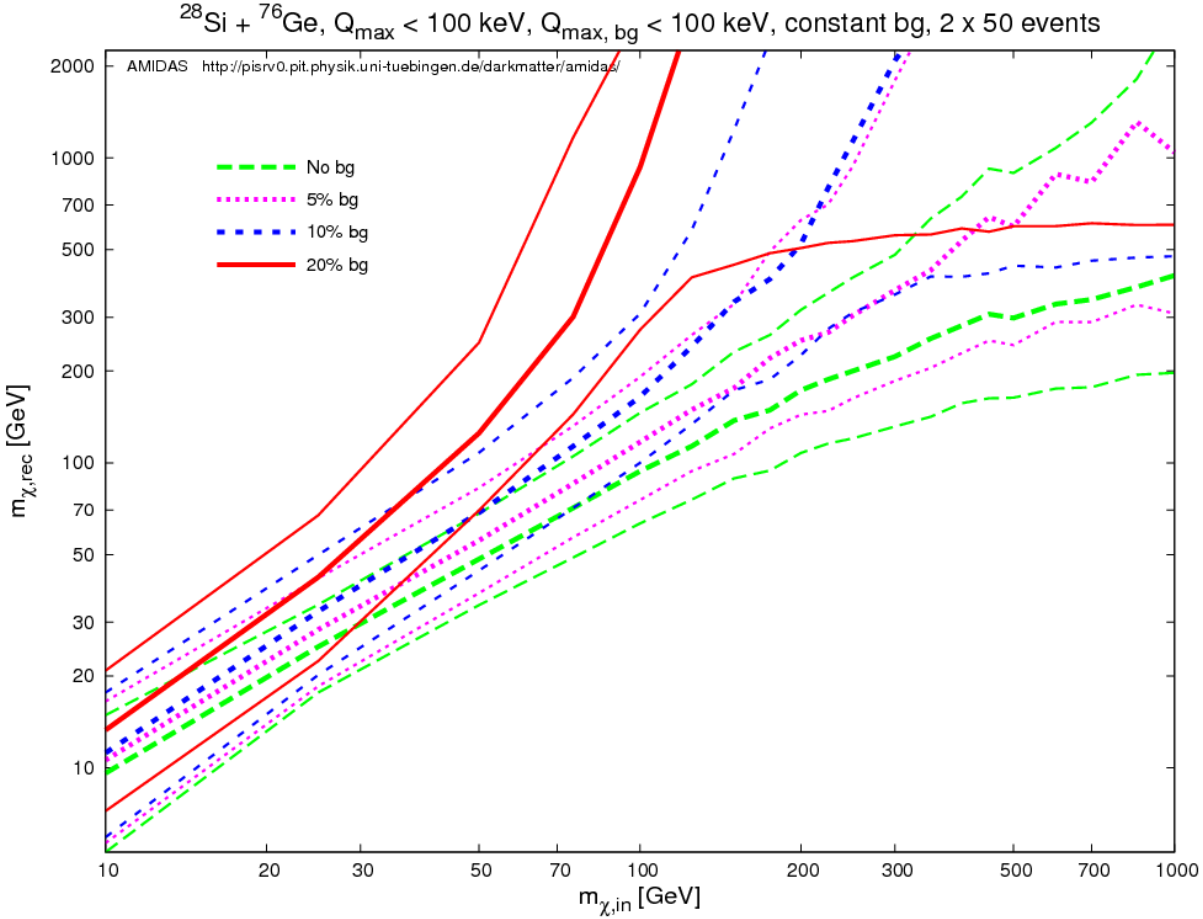

[Y. T. Chou and CLS, JCAP 1008, 014]

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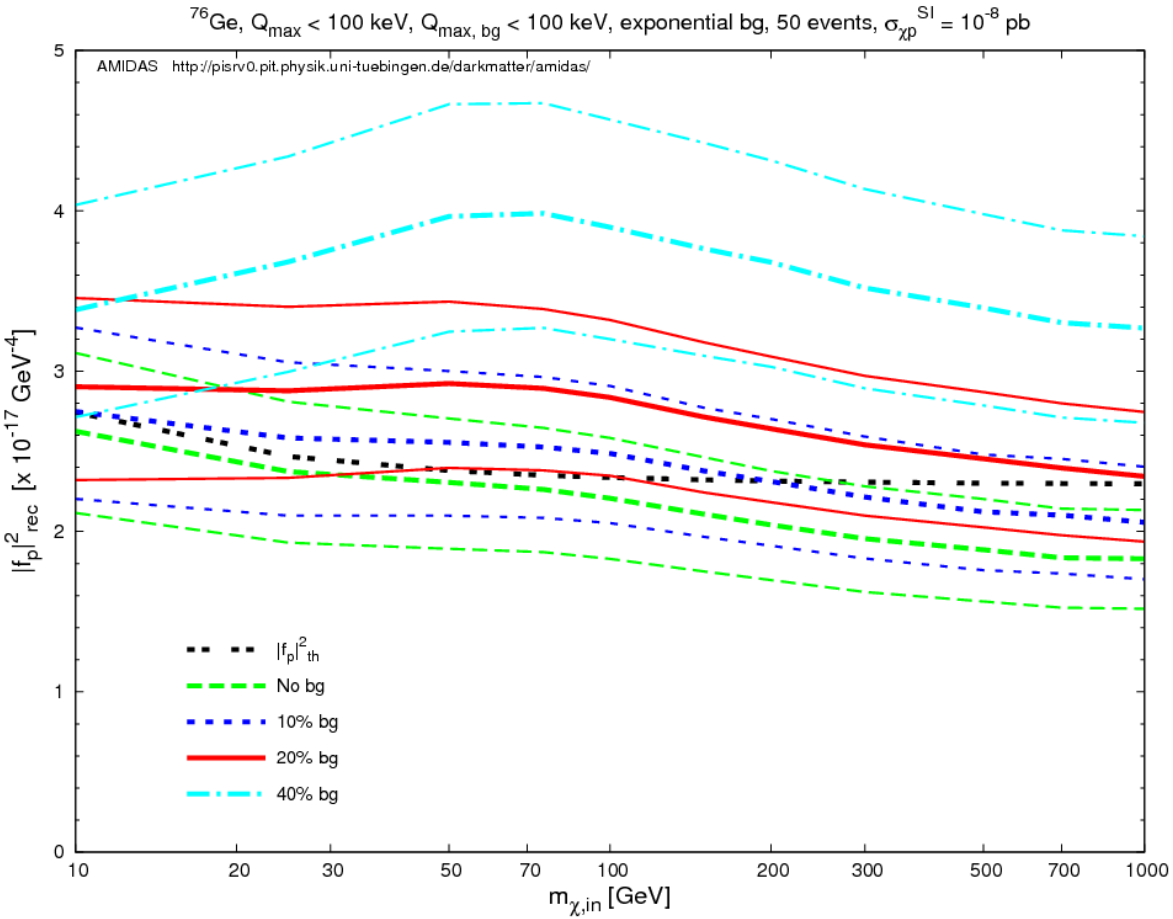
- Reconstructed $|f_p|^2_{rec}$ with a known m_χ

  (^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 50 events)

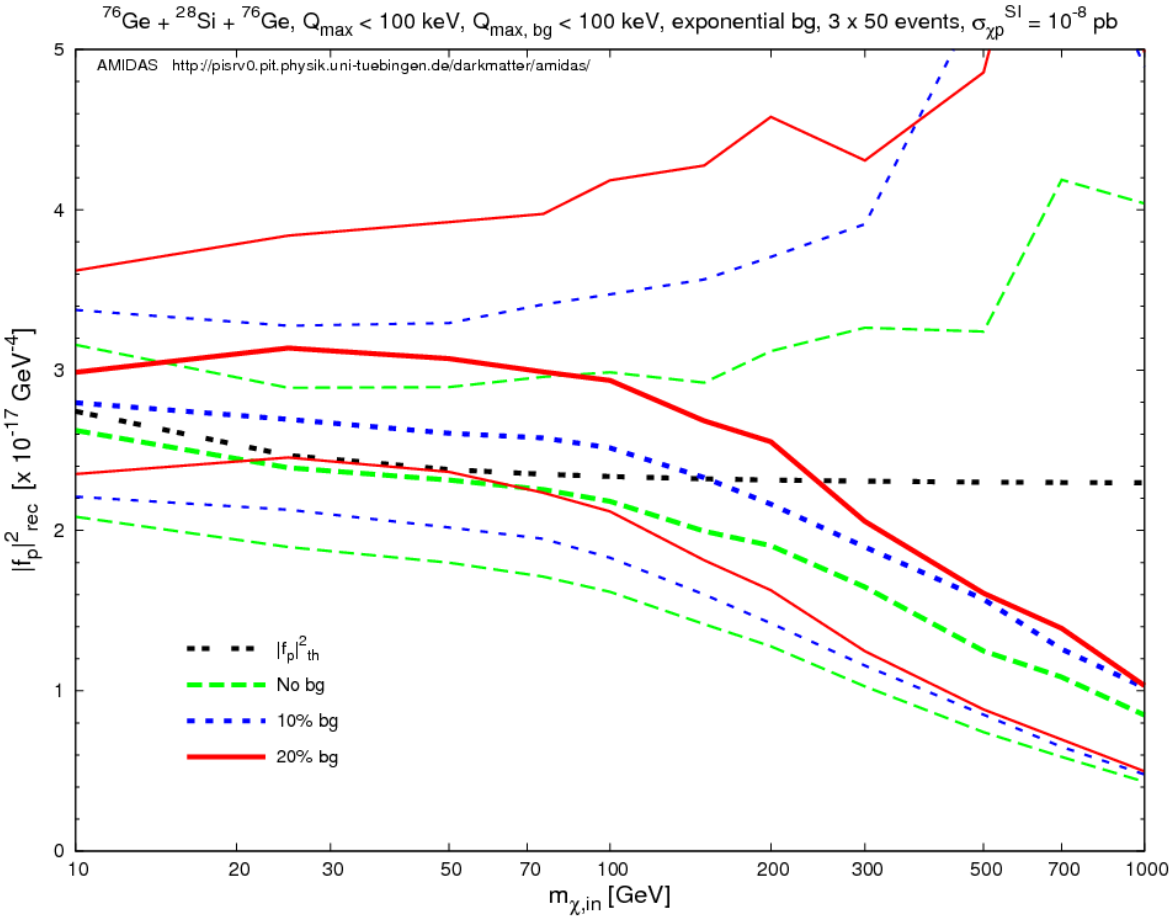


[CLS, in progress]

On the estimation of the SI WIMP-nucleon coupling

- Reconstructed $|f_p|^2_{rec}$ with a reconstructed $m_{\chi,rec}$

  (^{76}Ge + ^{28}Si + ^{76}Ge, 0 – 100 keV, exponential bg 0 – 100 keV, 3 × 50 events)



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- For determining m_χ
  - Due to background contribution in high/low energy ranges, the reconstructed WIMP mass would be over-/underestimated, especially if WIMPs are lighter/heavier than $\sim$ 50/200 GeV.
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Thank you very much for your attention

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