Direct WIMP Detection

Manuel Drees

Bonn University & Bethe Center for Theoretical Physics

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Introduction: WIMPs as Dark Matter

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- Models of structure formation, X ray temperature of clusters of galaxies, ...
- Cosmic Microwave Background anisotropies (WMAP) imply $\Omega_{\rm DM} h^2 = 0.105^{+0.007}_{-0.013}$ **Spergel et al., astro–ph/0603449**

Weakly Interacting Massive Particles (WIMPs)

- Exist in well–motivated extensions of the SM: SUSY, (Little Higgs with $T-$Parity), ((Universal Extra Dimension))

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- In standard cosmology, roughly weak cross section automatically gives roughly right relic density for thermal WIMPs! (On logarithmic scale)
- Roughly weak interactions may allow both indirect and *direct* detection of WIMPs

Probing WIMPs

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Can also be interesting probe!

Direct WIMP Detection: Formalism

Counting rate given by

$$\frac{dR}{dQ} = AF^2(Q) \int_{v_{\rm min}}^{v_{\rm max}} \frac{f_1(v)}{v} dv$$

Q: recoil energy

$A = \rho\sigma_0/(2m_\chi m_r) =$ const.: encodes particle physics

$F(Q)$: nuclear form factor

v: WIMP velocity in lab frame

$v_{\rm min}^2 = m_N Q/(2m_r^2)$ (m_r: reduced mass)

$v_{\rm max}$: Maximal velocity of WIMPs bound to galaxy

$f_1(v)$: normalized one–dimensional WIMP velocity distribution

Note: $Q^2 \propto v^2(1-\cos\theta^*) \Rightarrow \frac{d\sigma}{dQ} \propto \frac{1}{v^2}\frac{d\sigma}{d\cos\theta^*}$.

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Can invert this relation to measure $f_1(v)$!

Direct reconstruction of f_1

MD & C.L. Shan, astro-ph/0703651

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

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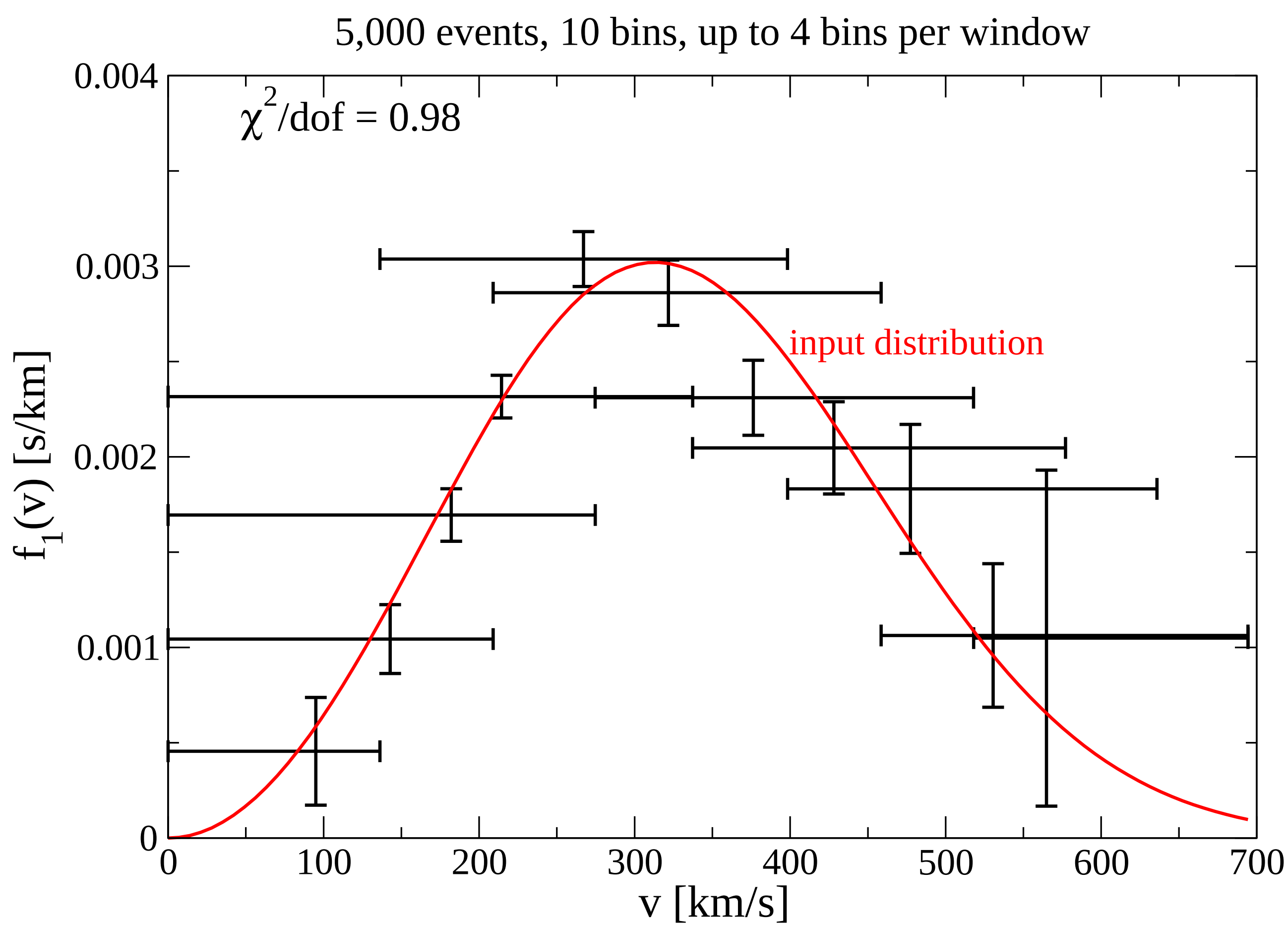
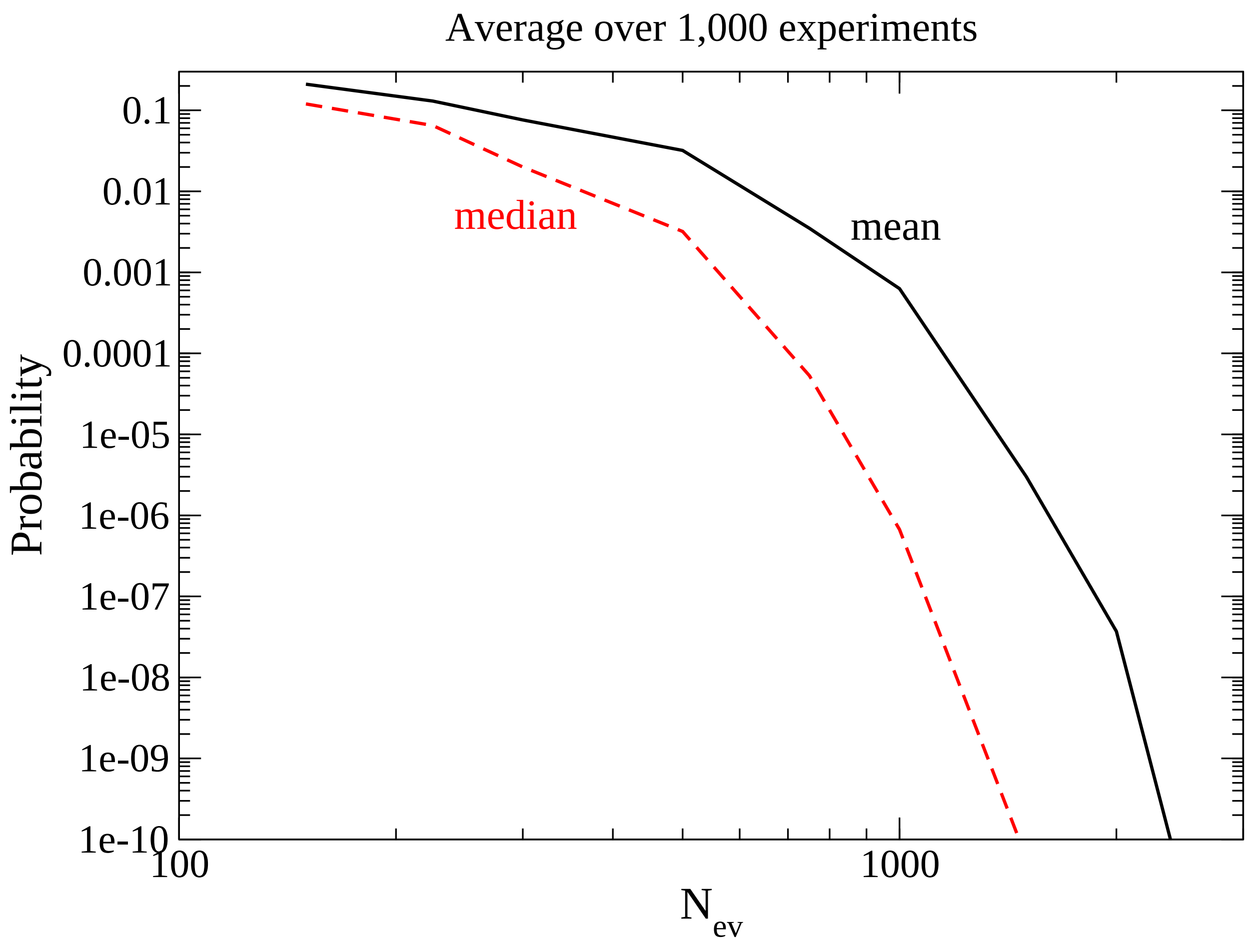
dR/dQ is approximately exponential: better work with logarithmic slope: from $\langle Q \rangle$ in bin!

Recoil spectrum: prediction and simulated measurement



Statistical exclusion of constant f_1



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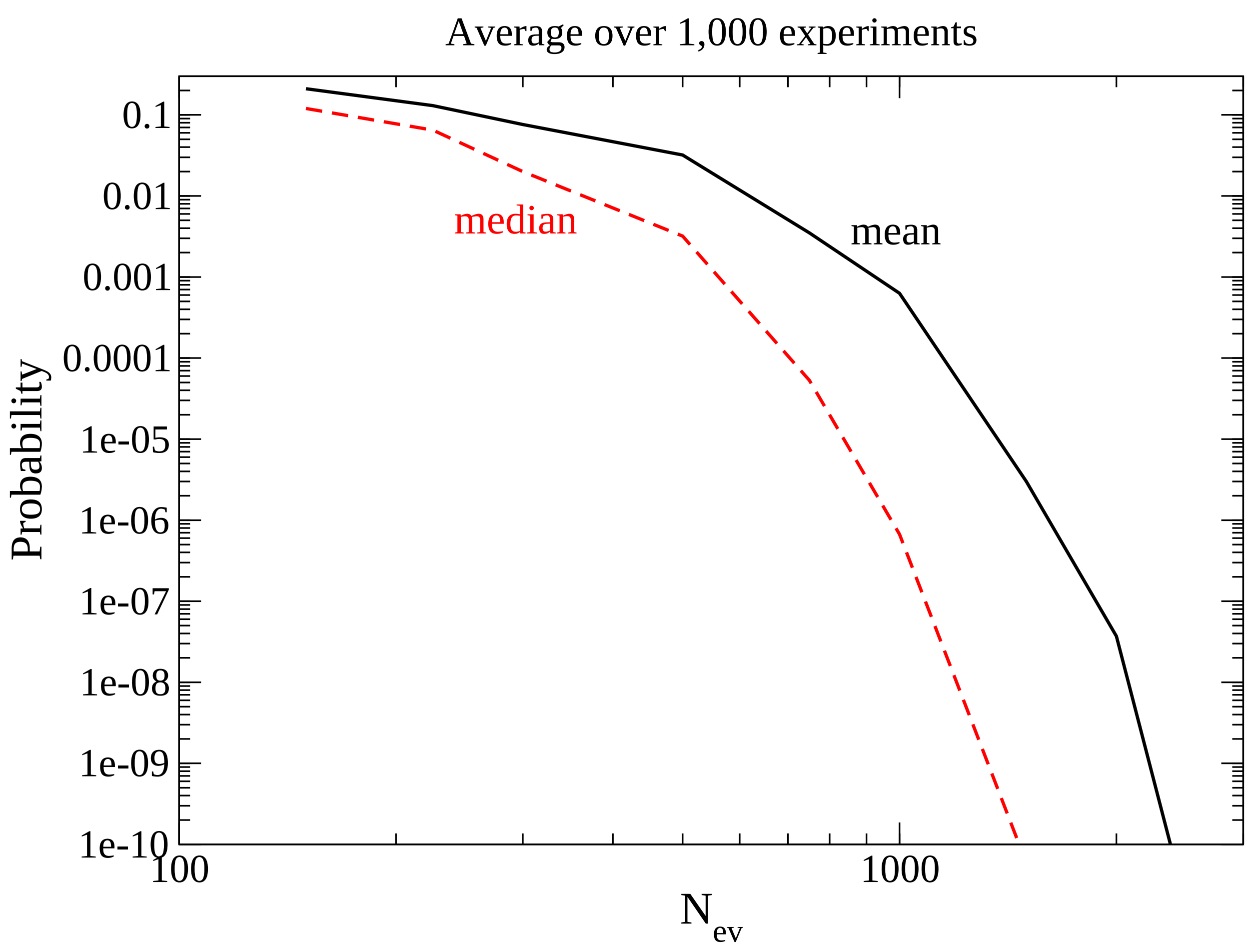

Need several hundred events to begin direct reconstruction!

Determining moments of f_1

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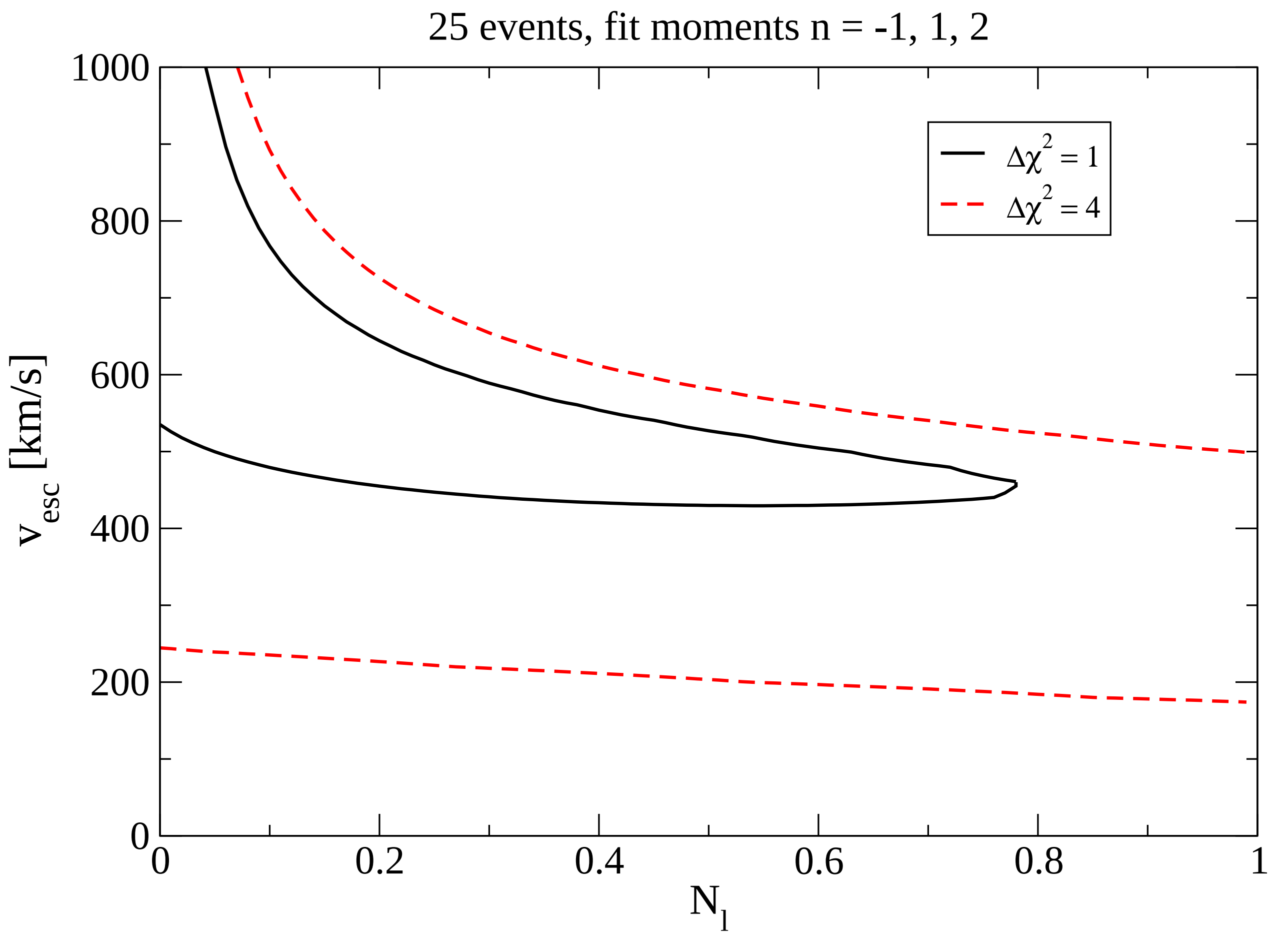
Moments are strongly correlated!

Constraining a “late infall” component



Determining the WIMP mass

MD & C.L. Shan, arXiv:0803447 (hep–ph)

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- Can also get m_χ from comparison of event rates, assuming equal cross section on neutrons and protons.

Systematic errors

- Equality of moments of f_1 holds only if integrals run over identical ranges of v, e.g. $v_{\rm min} = 0$, $v_{\rm max} = \infty$.

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- Use $Q_{\rm min} = 0$ from now on.

Effect of finite $Q_{\rm max}$

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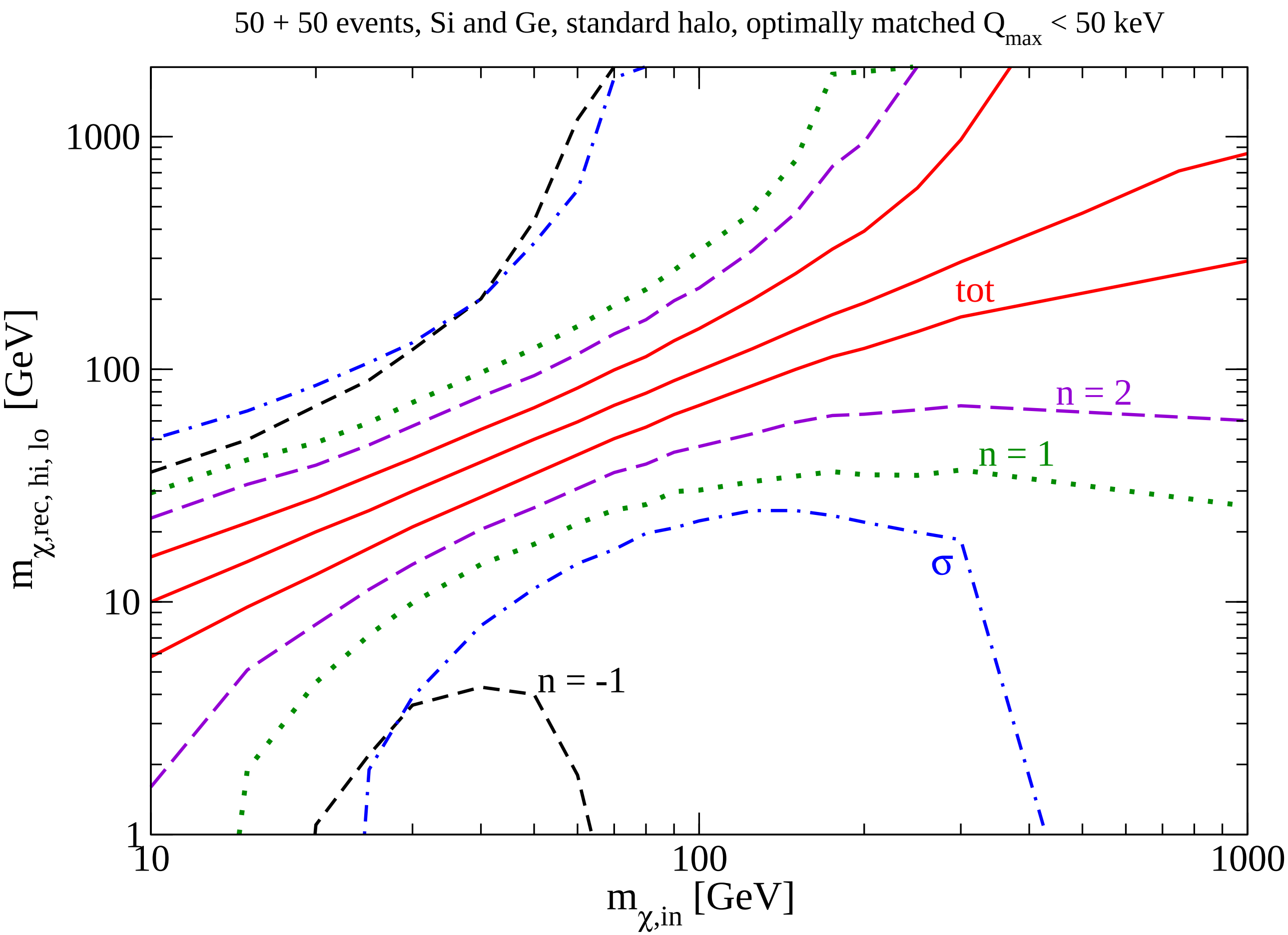
- Imposing finite $Q_{\rm max}$ can alleviate this problem,
- but introduces systematic error unless $Q_{\rm max}$ values of two targets are matched; matching depends on m_χ.
- Developed a method for this matching, based on χ^2 fit of several moments.

Median reconstructed WIMP mass



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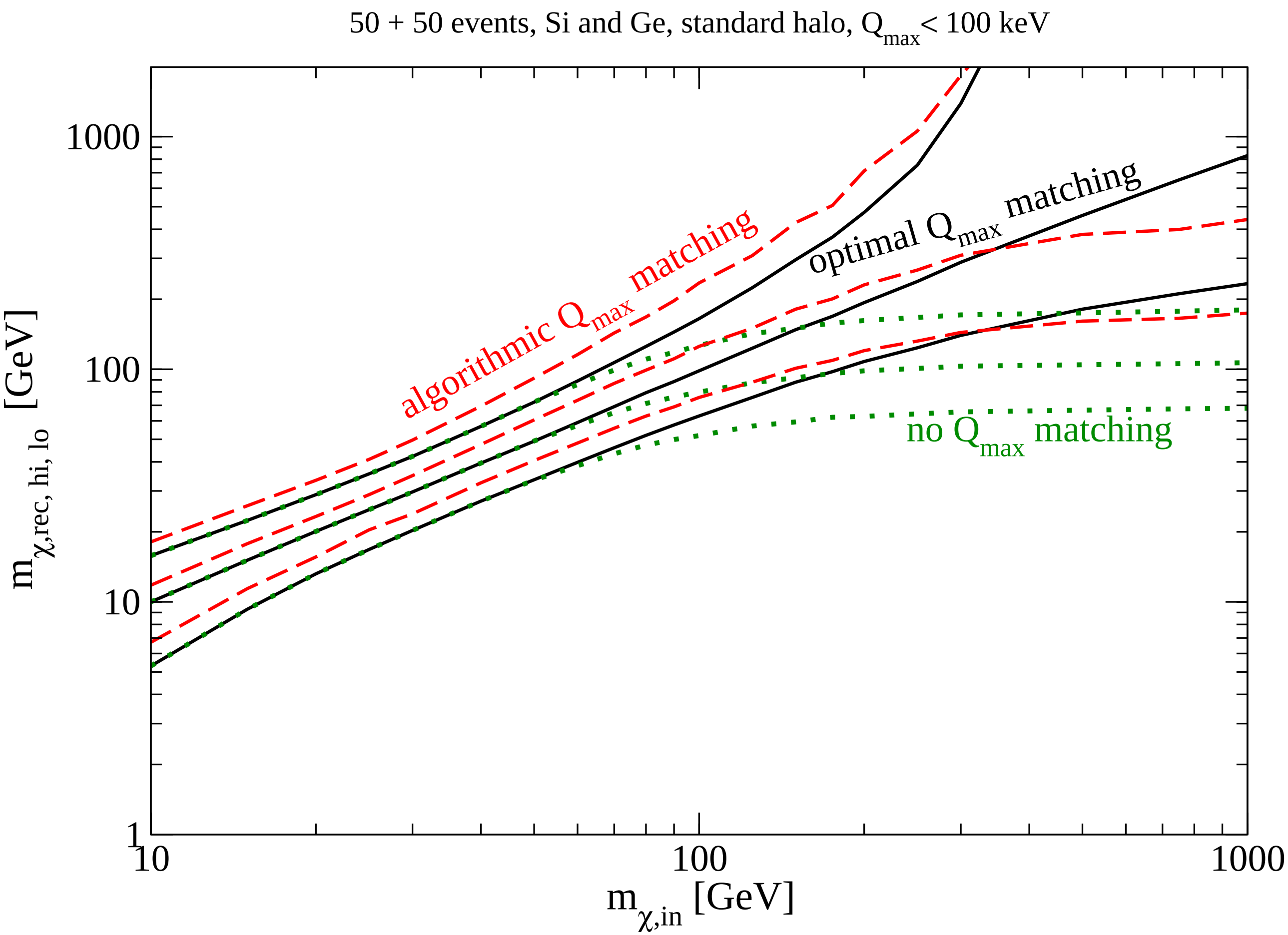

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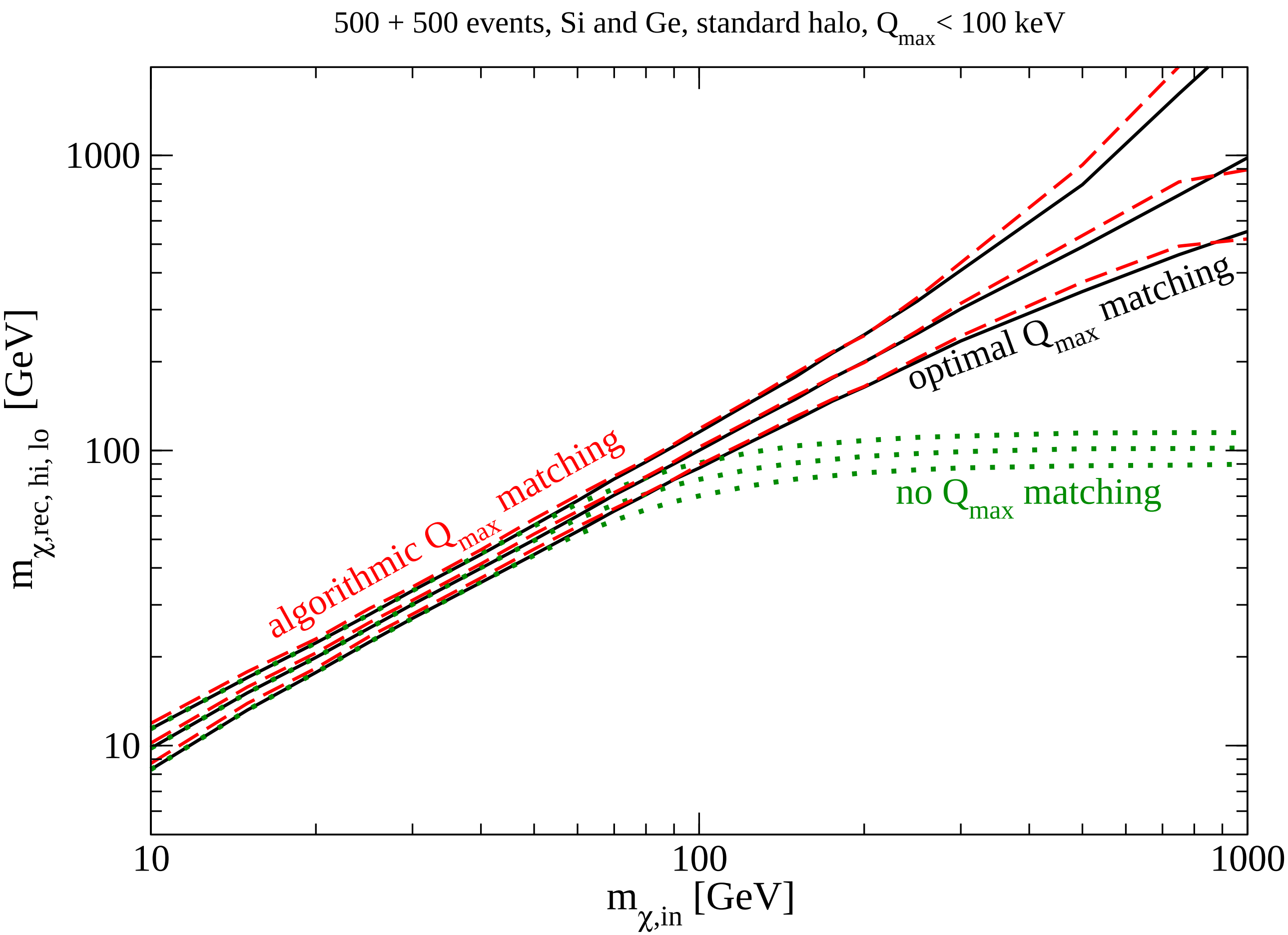
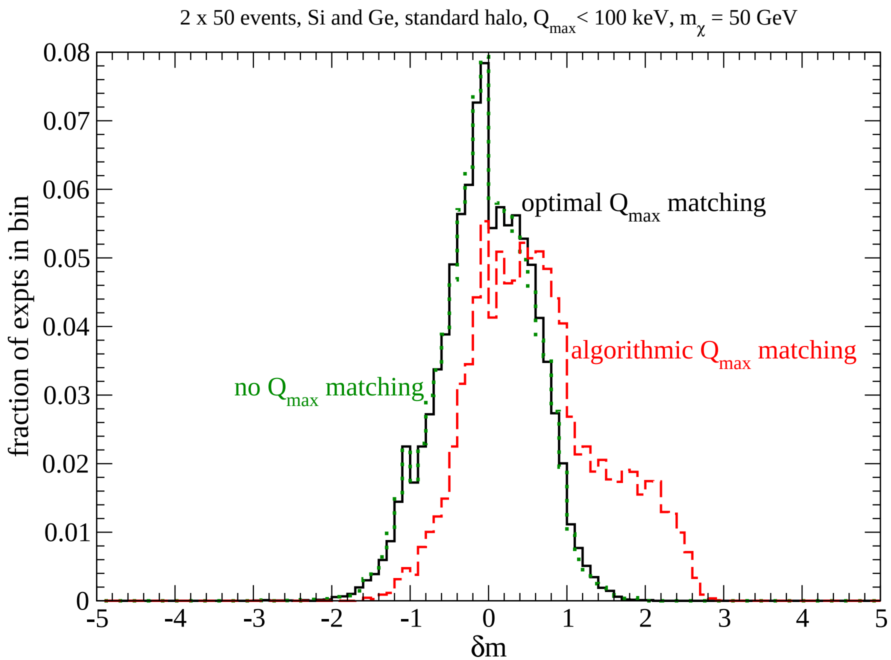
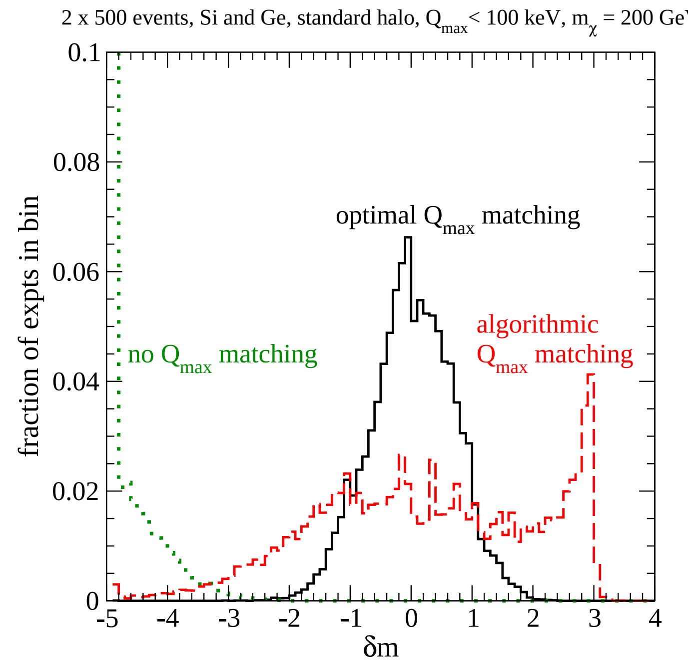


Distribution of measurements





WIMP Density times Cross Section

For spin–independent scattering:

$$\rho_\chi \sigma_{\chi p} \propto \frac{r(Q_{\rm min})}{\langle v^{-1} \rangle} (m_\chi + m_N)$$
$$\propto \left(\frac{2\sqrt{Q_{\rm min}}\, r(Q_{\rm min})}{F^2(Q_{\rm min})} + I_0 \right) (m_\chi + m_N)\,. \qquad (1)$$

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First factor on r.h.s. in 2nd line comes from normalization of $-1^{\rm st}$ moment.

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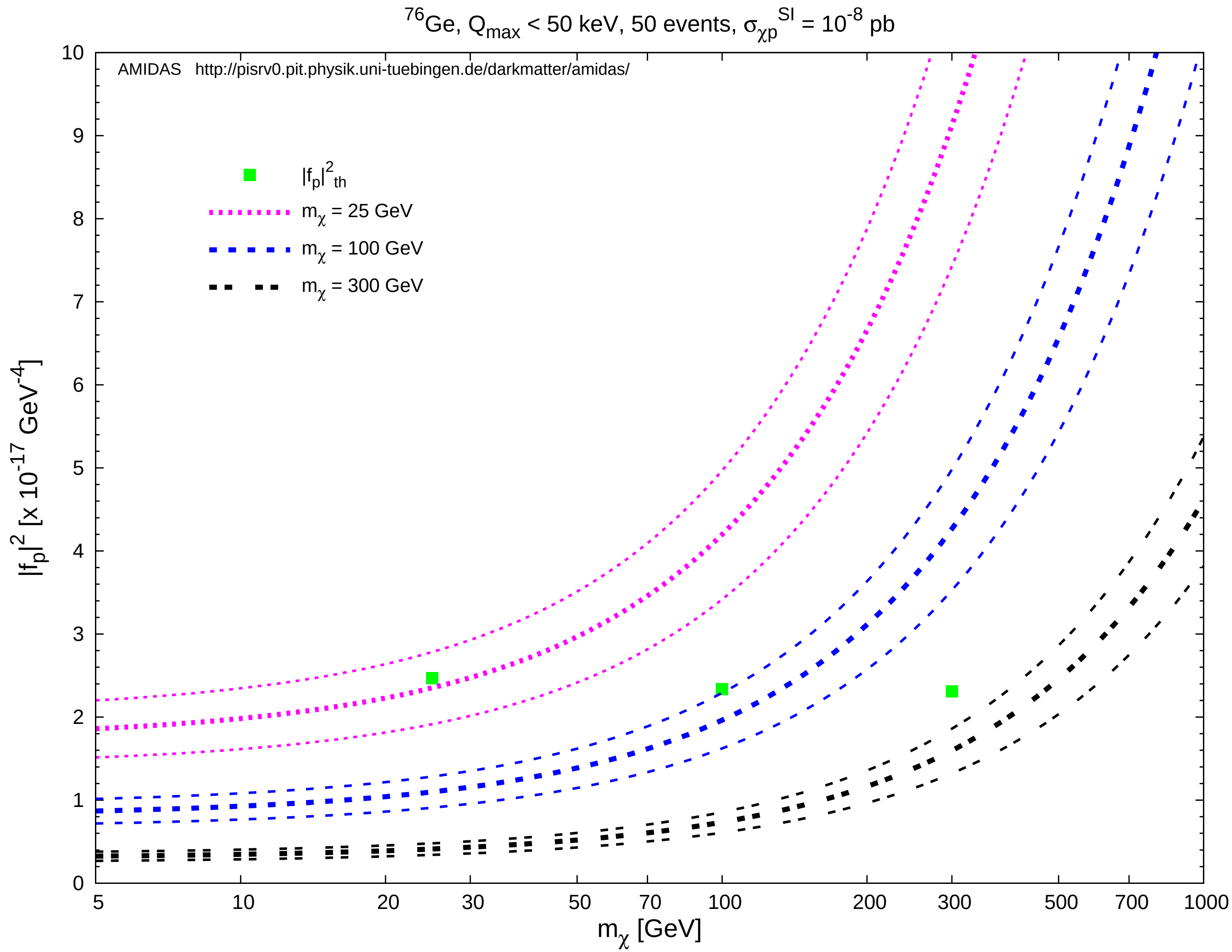
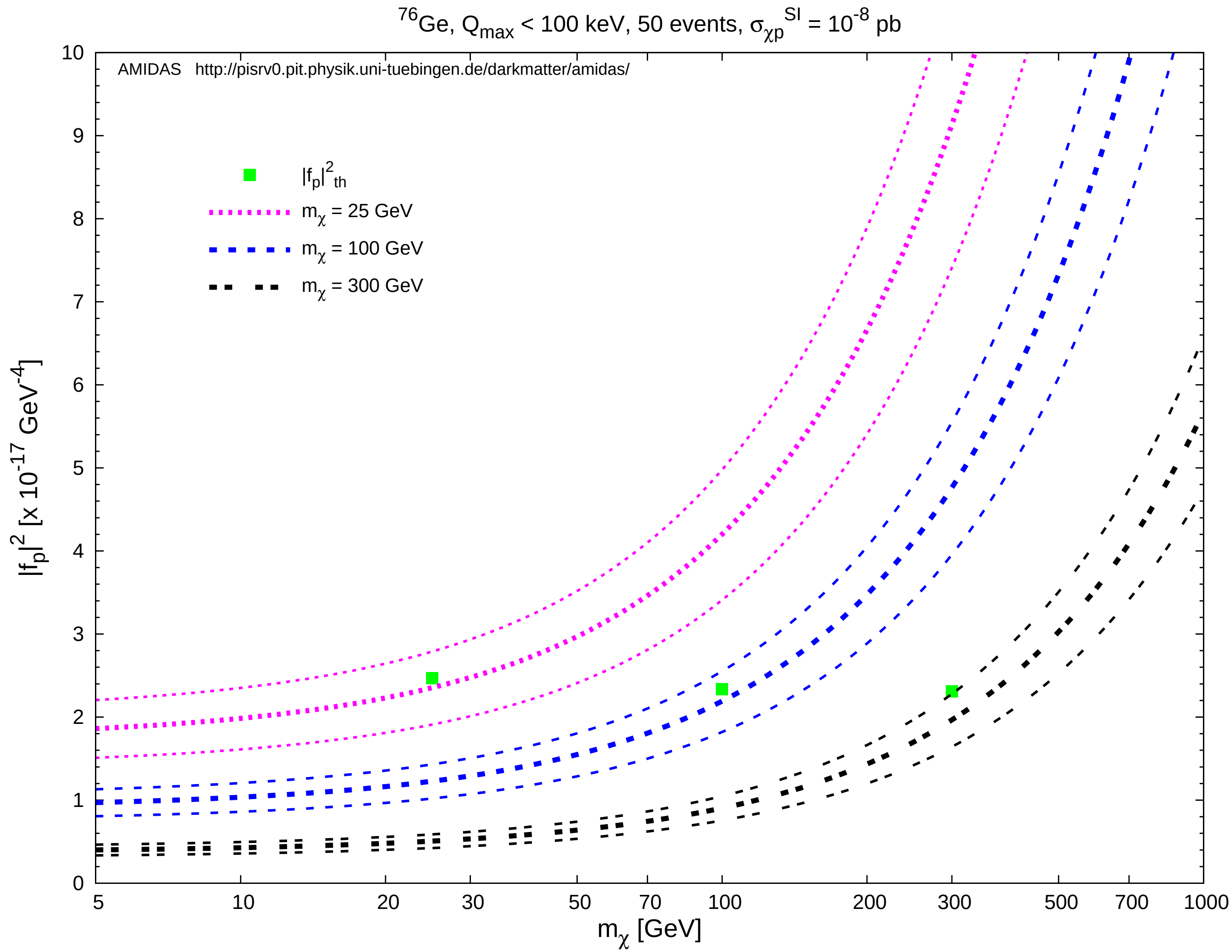
Can model–independently determine cross section times density from scattering data! MD & C.–L. Shan, to appear

Results for $Q_{\rm max} = 50$ keV



Results for $Q_{\rm max} = 100$ keV



WIMP–Proton Scattering in SUSY

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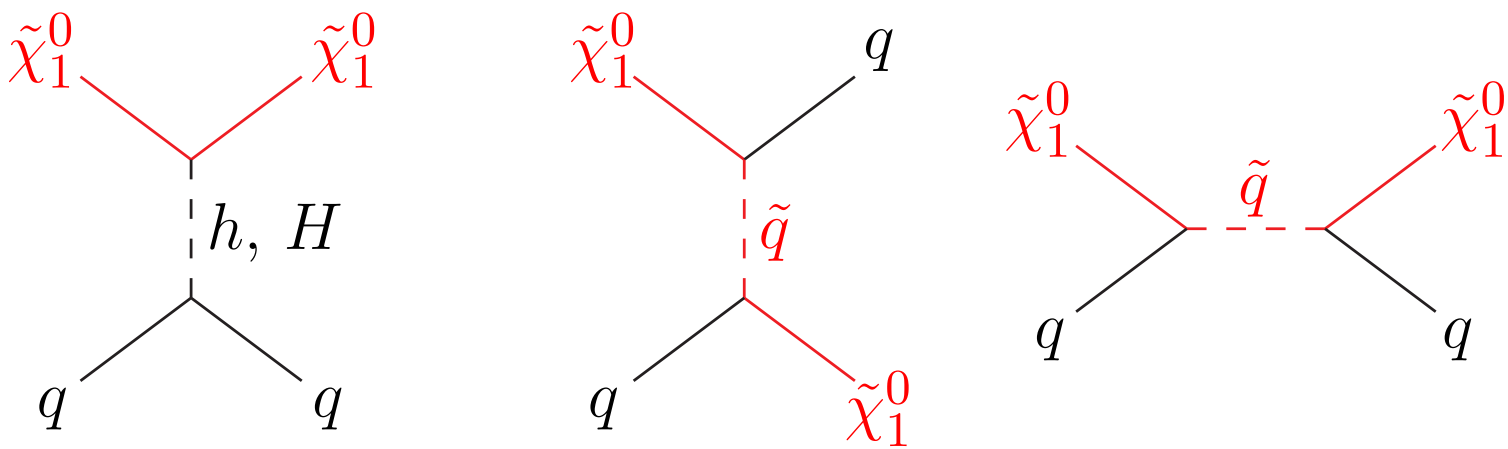

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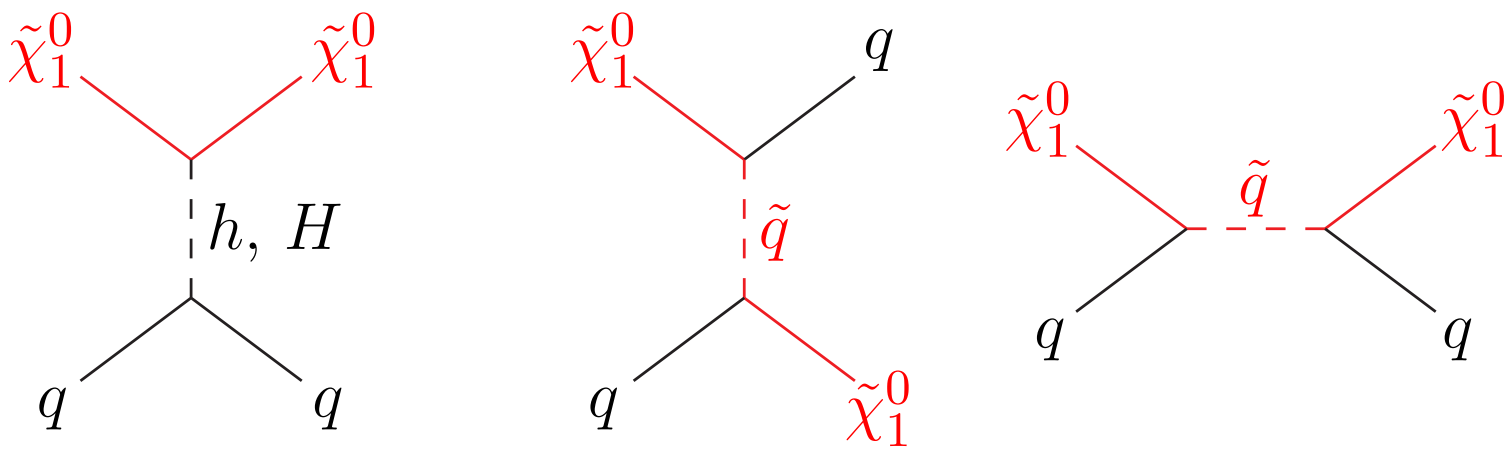

To $\mathcal{O}(m_{\tilde{q}}^{-2})$: Interaction $\propto m_q$! From Higgs(ino) Yukawa, $\tilde{q}_L - \tilde{q}_R$ mixing.

$\Longrightarrow$ need matrix elements $m_q \langle p | \bar{q} q | p \rangle$!

Matrix Elements $m_q\langle p|\bar{q}q|p\rangle$

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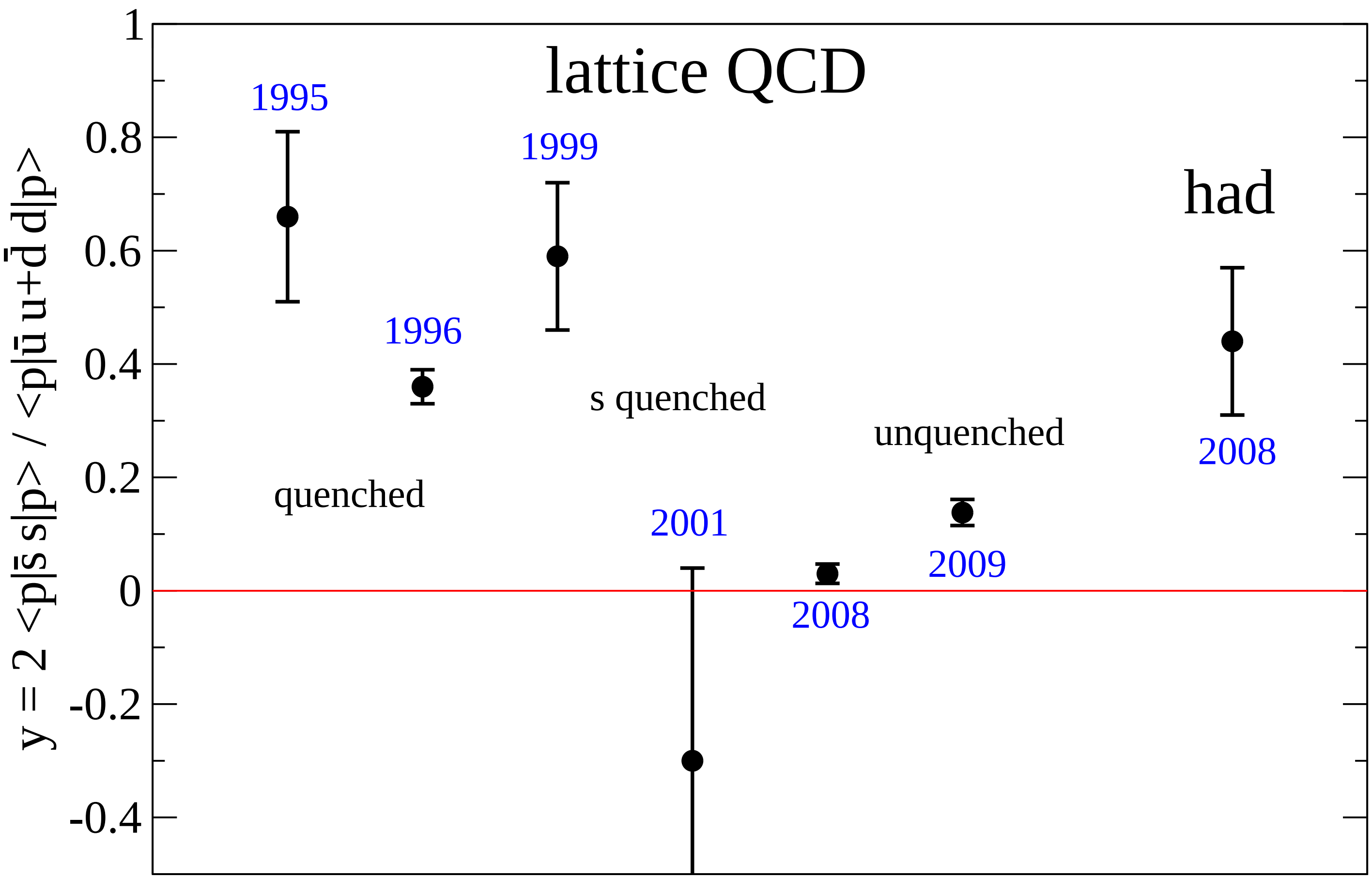
- Strange quark contribution important, but poorly known!

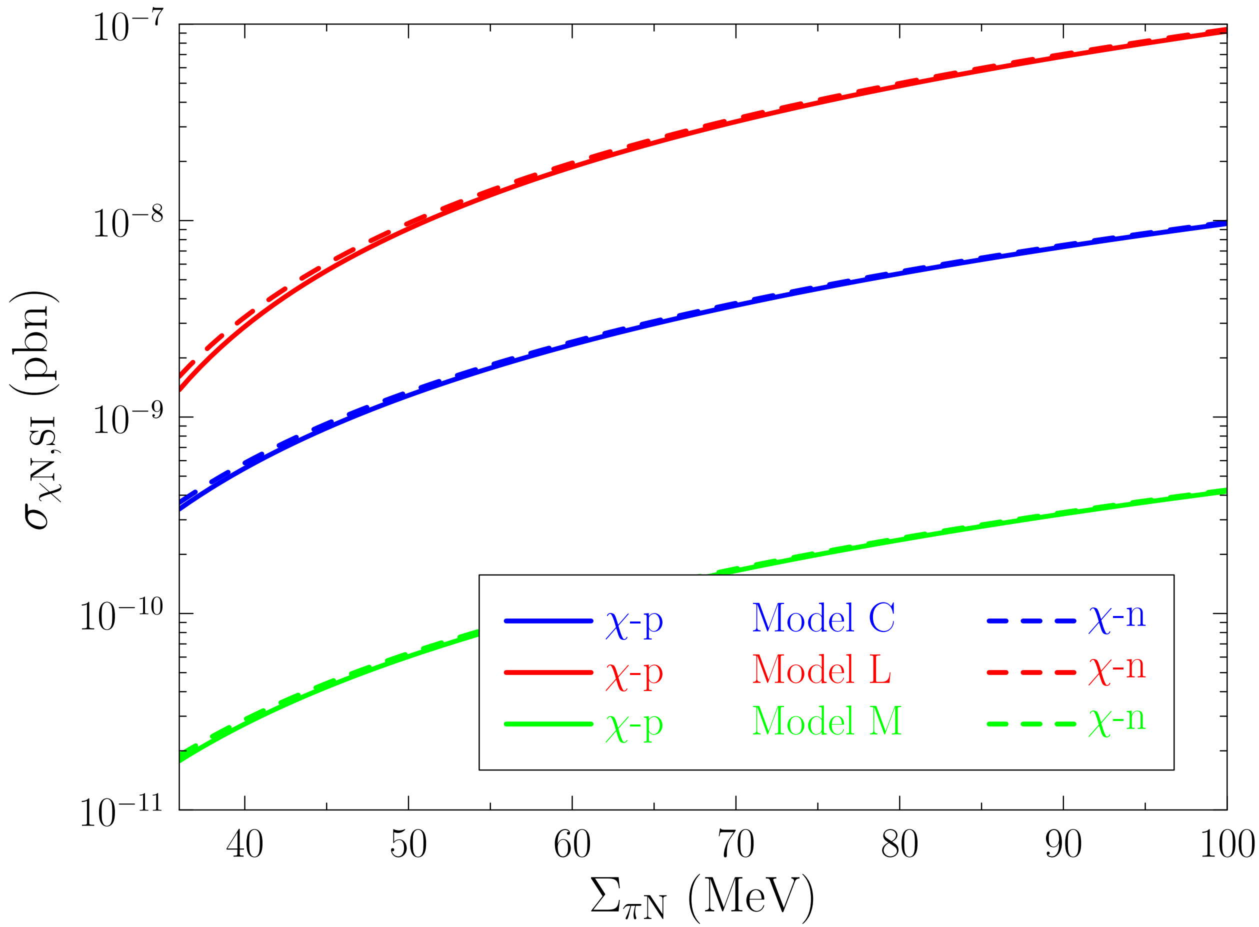
Determinations of $\langle p|\bar{s}s|p\rangle$



Fukugita et al. (1995); Dong et al. (1996); Güsken et al. (1999); Michael et al. (2001); Ohki et al. (2008); Toussaint & Freeman (2009); Ellis et al. (2008)

Effect of this uncertainty

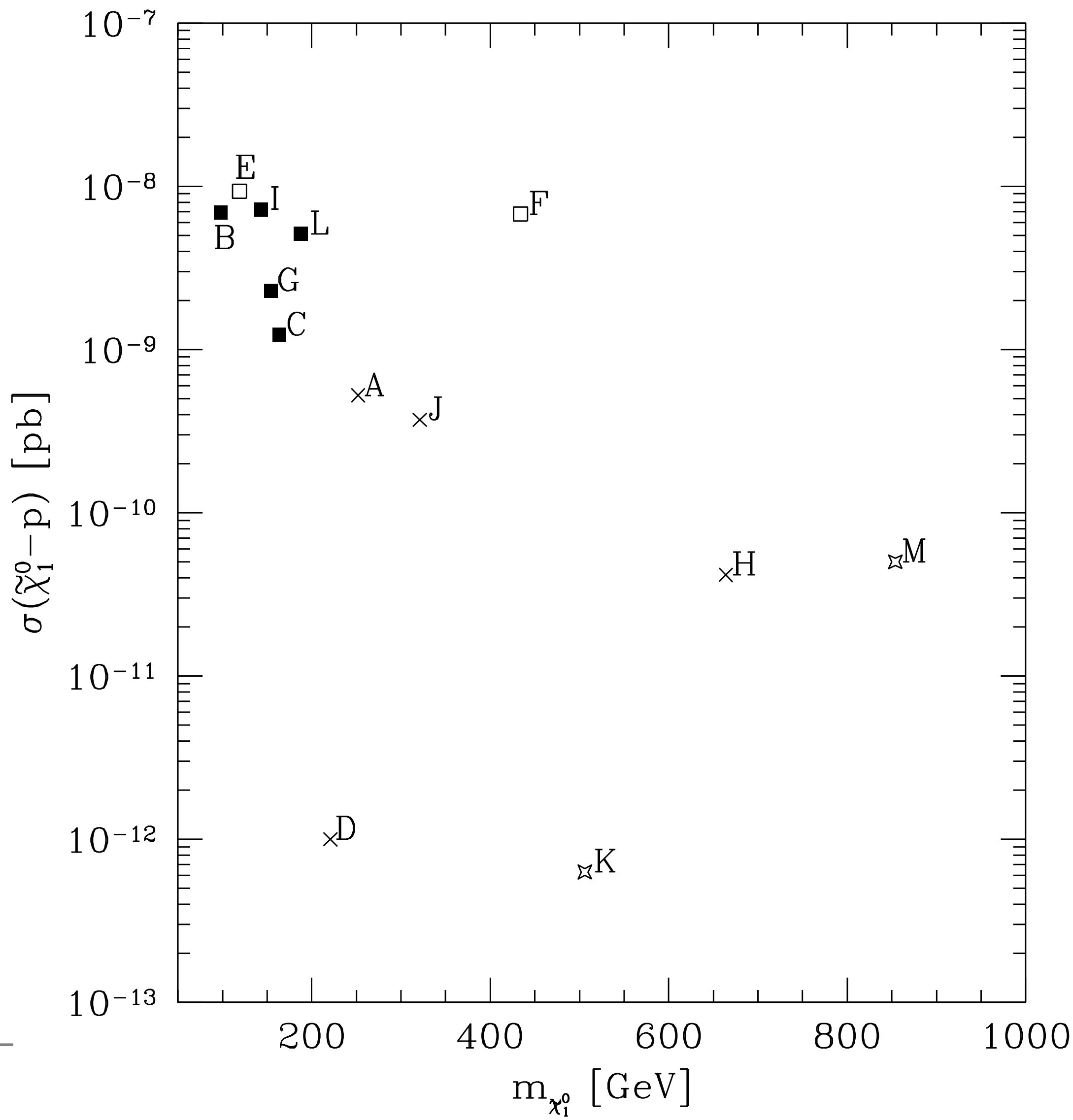
Ellis, Olive & Savage, arXiv:0801.3656



Larger $\Sigma_{\pi N}$ implies larger $\langle p|\bar{s}s|p\rangle$.

Survey of Benchmark Points

Points from Battaglia et al. (2003)



Solid squares: Bulk region

Open squares: focus point region

Crosses: Co–ann. region

Stars: Higgs funnel

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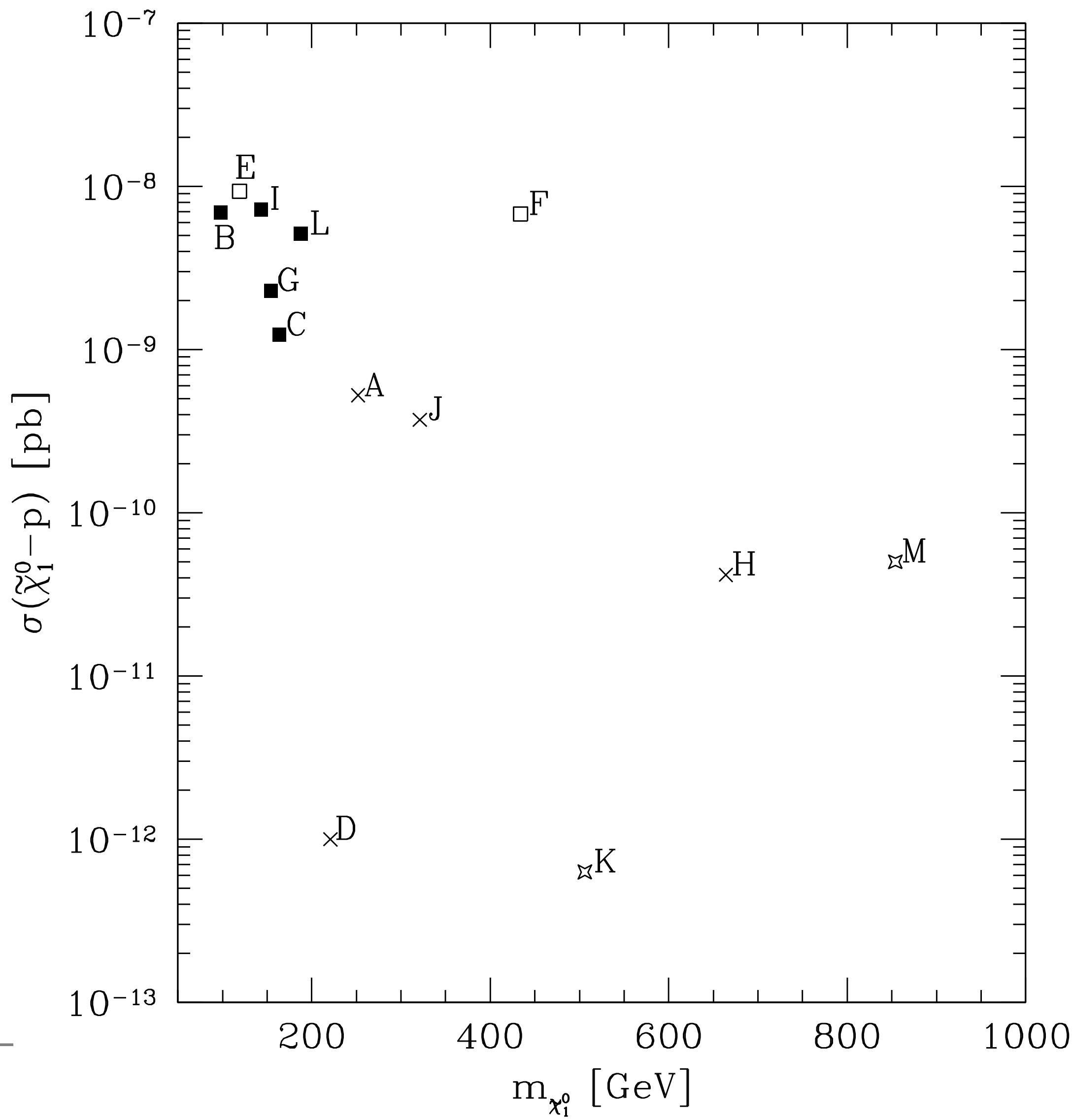

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Consider A, E, G!

Effect of Varying SUSY Parameter

Let's vary one (weak–scale) parameter by 20%, and compute the resulting change of $\sigma_{\tilde{\chi}_1^0 p}$!

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Point	$\sigma_{\tilde{\chi}_1^0}$ [pb]	$\delta\sigma(m_{\tilde{q}})$	$\delta\sigma(\mu)$	$\delta\sigma(\tan\beta)$	$\delta\sigma(m_A)$
A	0.49×10^{-9}	-1.7%	-45.3%	-15.8%	-4.7%
E	18.6×10^{-9}	-6.3%	-60.3%	-8.5%	-2.9%
G	2.54×10^{-9}	-4.7%	-44.5%	+18%	-28%

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- If $\tan\beta \gg 1$ (point G): $\sigma_{\tilde{\chi}_1^0 p} \propto \tan^2\beta / m_H^4$: need parameters of Higgs sector!

Summary

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- Both $f_1(v)$ and $\sigma_{\chi p}$ are needed to determine ρ_χ: required input for learning about early Universe!