Direct WIMP Detection

Manuel Drees

Bonn University & Bethe Center for Theoretical Physics

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Contents

Introduction: WIMPs as Dark Matter

Several observations indicate existence of non-luminous Dark Matter (DM) (more exactly: missing force)

Introduction: WIMPs as Dark Matter

Several observations indicate existence of non-luminous Dark Matter (DM) (more exactly: missing force)

- Galactic rotation curves imply $\Omega_{\rm DM} h^2 \geq 0.05$.

Ω: Mass density in units of critical density; $\Omega = 1$ means flat Universe.
h: Scaled Hubble constant. Observation: $h = 0.72 \pm 0.07$ (?)

Introduction: WIMPs as Dark Matter

Several observations indicate existence of non-luminous Dark Matter (DM) (more exactly: missing force)

- Galactic rotation curves imply $\Omega_{\rm DM} h^2 \geq 0.05$.

Ω: Mass density in units of critical density; $\Omega = 1$ means flat Universe.
h: Scaled Hubble constant. Observation: $h = 0.72 \pm 0.07$ (?)

- Models of structure formation, X ray temperature of clusters of galaxies, ...

Introduction: WIMPs as Dark Matter

Several observations indicate existence of non-luminous Dark Matter (DM) (more exactly: missing force)

- Galactic rotation curves imply $\Omega_{\rm DM} h^2 \geq 0.05$.

Ω: Mass density in units of critical density; $\Omega = 1$ means flat Universe.
h: Scaled Hubble constant. Observation: $h = 0.72 \pm 0.07$ (?)

- 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))

Weakly Interacting Massive Particles (WIMPs)

- Exist in well–motivated extensions of the SM: SUSY, (Little Higgs with $T-$Parity), ((Universal Extra Dimension))
- Can also (trivially) write down “tailor–made” WIMP models

Weakly Interacting Massive Particles (WIMPs)

- Exist in well–motivated extensions of the SM: SUSY, (Little Higgs with $T-$Parity), ((Universal Extra Dimension))
- Can also (trivially) write down “tailor–made” WIMP models
- In standard cosmology, roughly weak cross section automatically gives roughly right relic density for thermal WIMPs! (On logarithmic scale)

Weakly Interacting Massive Particles (WIMPs)

- Exist in well–motivated extensions of the SM: SUSY, (Little Higgs with $T-$Parity), ((Universal Extra Dimension))
- Can also (trivially) write down “tailor–made” WIMP models
- 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

Detection of WIMP annihilation products (“indirect detection”) suffers from uncertainties in

- Backgrounds

Probing WIMPs

Detection of WIMP annihilation products ("indirect detection") suffers from uncertainties in

- Backgrounds
- Propagation, esp. for charged particles (e^+, $\bar{p}$, $\bar{d}$)

Probing WIMPs

Detection of WIMP annihilation products ("indirect detection") suffers from uncertainties in

- Backgrounds
- Propagation, esp. for charged particles (e^+, $\bar{p}$, $\bar{d}$)

WIMP production at colliders: Can't be sure that

- WIMP is stable on cosmological time scales

Probing WIMPs

Detection of WIMP annihilation products (“indirect detection”) suffers from uncertainties in

- Backgrounds
- Propagation, esp. for charged particles (e^+, $\bar{p}$, $\bar{d}$)

WIMP production at colliders: Can’t be sure that

- WIMP is stable on cosmological time scales
- Cosmology is right

Direct WIMP Detection

Look for elastic scattering of ambient WIMP off nucleus in detector; measure nuclear recoil energy.

Direct WIMP Detection

Look for elastic scattering of ambient WIMP off nucleus in detector; measure nuclear recoil energy.

Direct WIMP detection is easiest convincing way to prove that WIMPs form DM!

Direct WIMP Detection

Look for elastic scattering of ambient WIMP off nucleus in detector; measure nuclear recoil energy.

Direct WIMP detection is easiest convincing way to prove that WIMPs form DM! Other possibilities: γ line, high$-E$ ν's from Sun: less “likely” to work.

Direct WIMP Detection

Look for elastic scattering of ambient WIMP off nucleus in detector; measure nuclear recoil energy.

Direct WIMP detection is easiest convincing way to prove that WIMPs form DM! Other possibilities: γ line, high$-E$ ν's from Sun: less "likely" to work.

Can also be interesting probe!

Direct WIMP Detection: Formalism

Counting rate given by

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

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

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

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

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

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

Direct WIMP Detection: Formalism

Counting rate given by

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

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

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

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

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

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

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

Direct reconstruction of f_1

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

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

Direct reconstruction of f_1

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

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

$\mathcal{N}$: Normalization ($\int_0^\infty f_1(v) dv = 1$).

Direct reconstruction of f_1

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

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

$\mathcal{N}$: Normalization ($\int_0^\infty f_1(v) dv = 1$).

Need to know form factor $\Longrightarrow$ stick to spin–independent scattering.

Direct reconstruction of f_1

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

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

$\mathcal{N}$: Normalization ($\int_0^\infty f_1(v) dv = 1$).

Need to know form factor $\Longrightarrow$ stick to spin–independent scattering.

Need to know m_χ, but do *not* need σ_0, ρ.

Direct reconstruction of f_1

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

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

$\mathcal{N}$: Normalization ($\int_0^\infty f_1(v) dv = 1$).

Need to know form factor $\Longrightarrow$ stick to spin–independent scattering.

Need to know m_χ, but do *not* need σ_0, ρ.

Need to know *slope* of recoil spectrum!

Direct reconstruction of f_1

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

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

$\mathcal{N}$: Normalization ($\int_0^\infty f_1(v) dv = 1$).

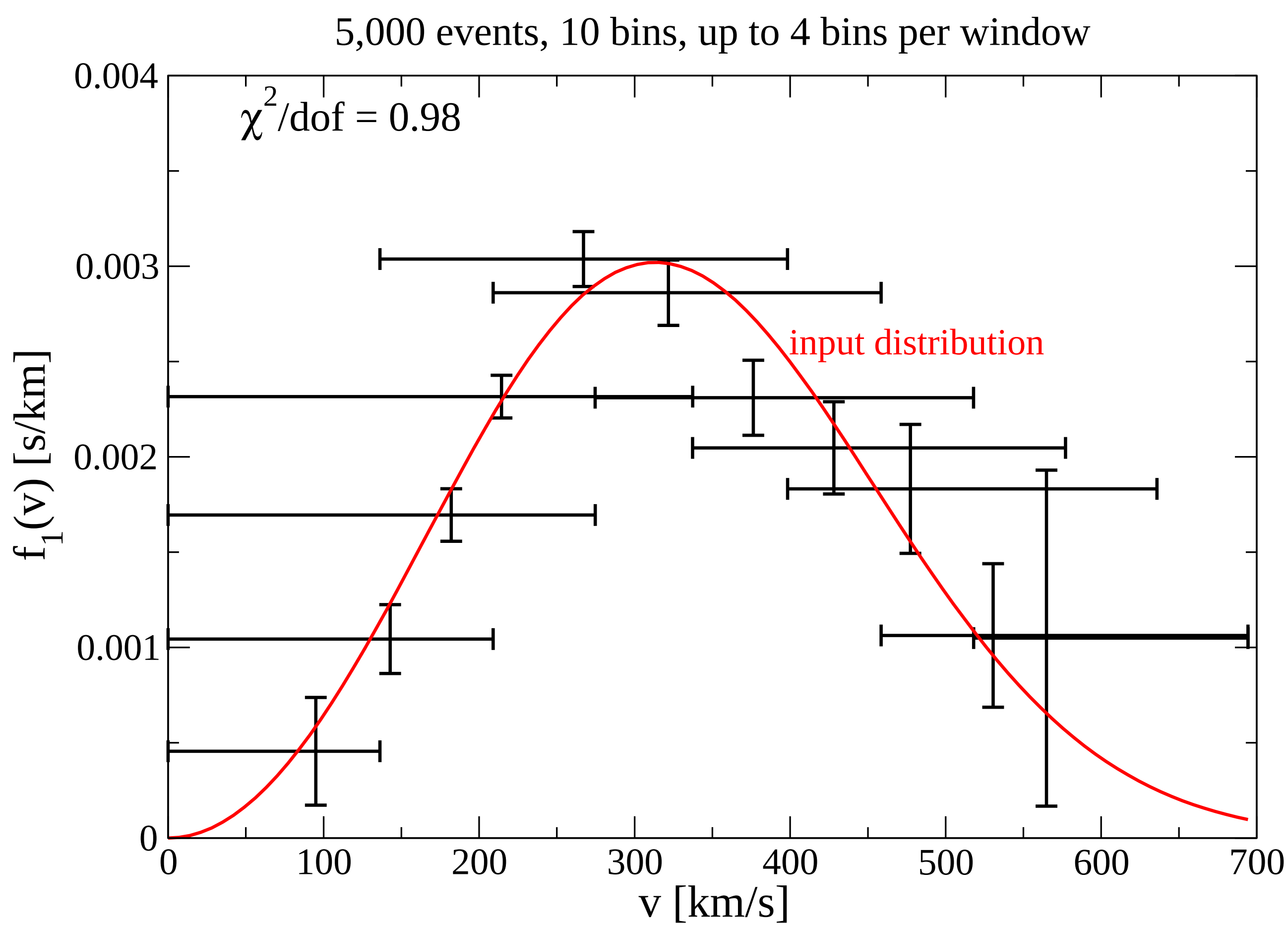
Need to know form factor $\Longrightarrow$ stick to spin–independent scattering.

Need to know m_χ, but do *not* need σ_0, ρ.

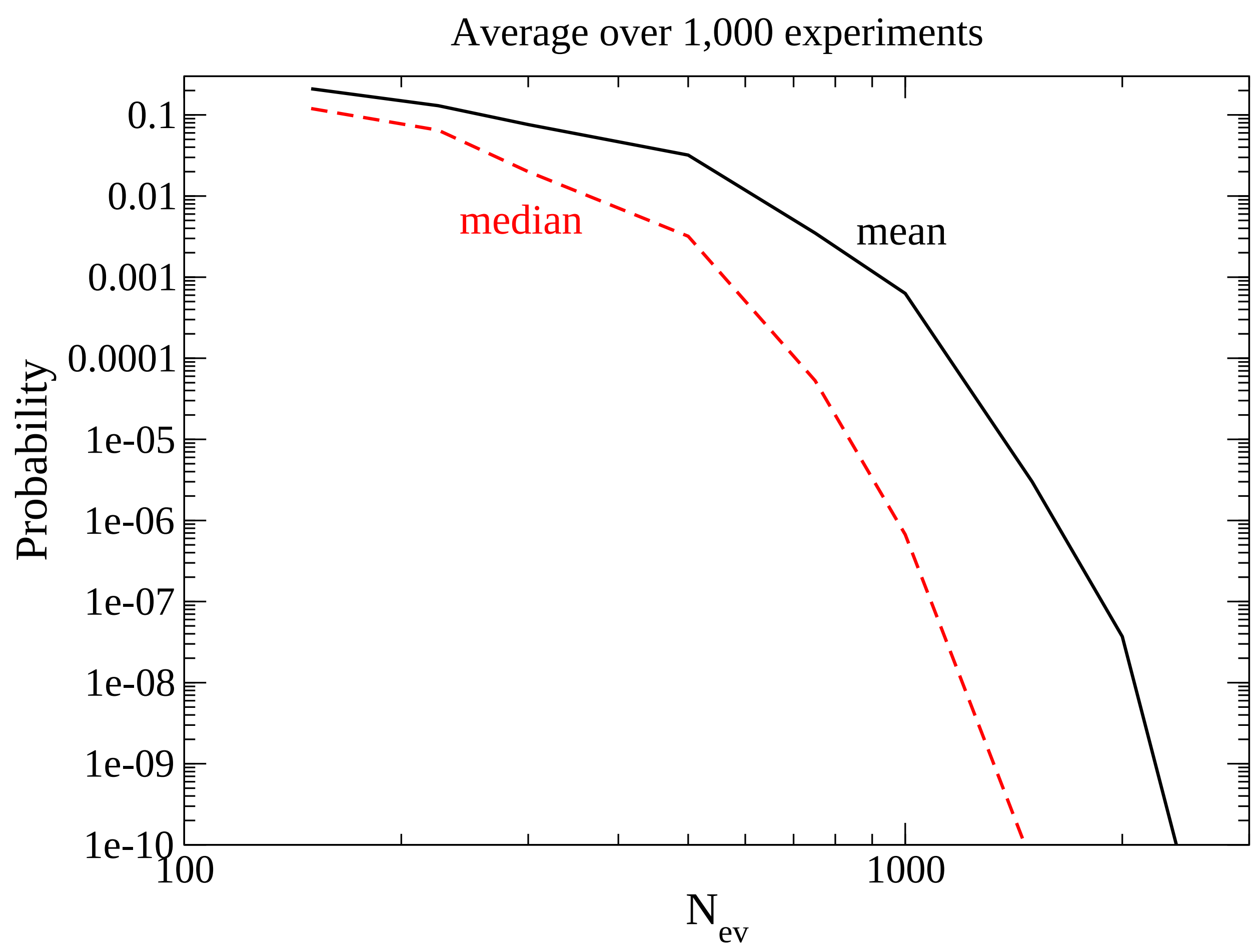
Need to know *slope* of recoil spectrum!

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

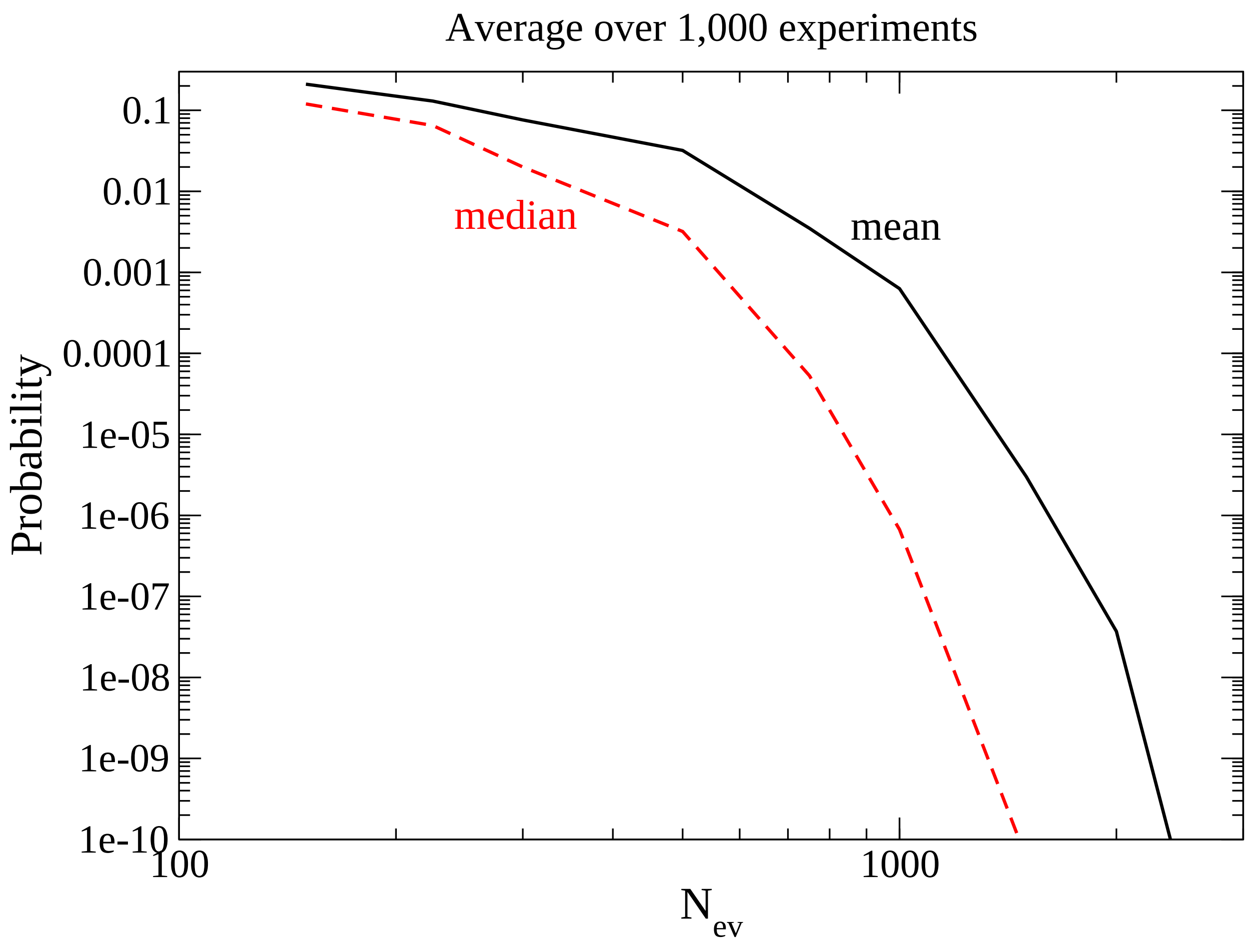
Recoil spectrum: prediction and simulated measurement



Statistical exclusion of constant f_1



Statistical exclusion of constant f_1



Need several hundred events to begin direct reconstruction!

Determining moments of f_1

$\langle v^n \rangle \equiv \int_0^\infty v^n f_1(v) dv$

Determining moments of f_1

$$\langle v^n \rangle \equiv \int_0^\infty v^n f_1(v) dv$$
$$\propto \int_0^\infty Q^{(n-1)/2} \frac{1}{F^2(Q)} \frac{dR}{dQ} dQ$$

Determining moments of f_1

$$\langle v^n \rangle \equiv \int_0^\infty v^n f_1(v) dv$$
$$\propto \int_0^\infty Q^{(n-1)/2} \frac{1}{F^2(Q)} \frac{dR}{dQ} dQ$$
$$\to \sum_{\text{events } a} \frac{Q_a^{(n-1)/2}}{F^2(Q_a)}$$

Determining moments of f_1

$$\langle v^n \rangle \equiv \int_0^\infty v^n f_1(v) dv$$
$$\propto \int_0^\infty Q^{(n-1)/2} \frac{1}{F^2(Q)} \frac{dR}{dQ} dQ$$
$$\to \sum_{\text{events } a} \frac{Q_a^{(n-1)/2}}{F^2(Q_a)}$$

Can incorporate finite energy (hence velocity) threshold

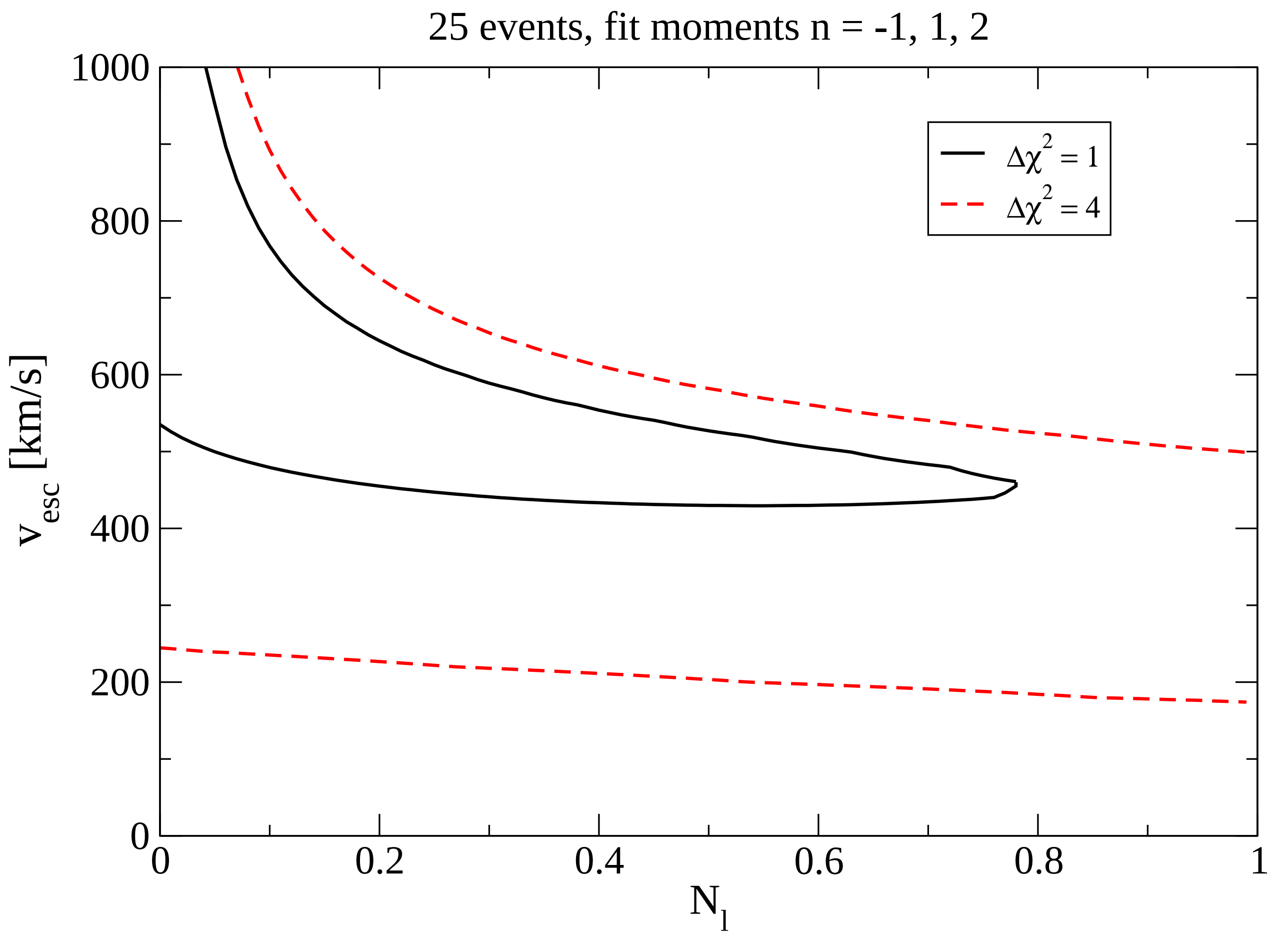
Determining moments of f_1

$$\langle v^n \rangle \equiv \int_0^\infty v^n f_1(v) dv$$
$$\propto \int_0^\infty Q^{(n-1)/2} \frac{1}{F^2(Q)} \frac{dR}{dQ} dQ$$
$$\to \sum_{\text{events } a} \frac{Q_a^{(n-1)/2}}{F^2(Q_a)}$$

Can incorporate finite energy (hence velocity) threshold

Moments are strongly correlated!

Constraining a “late infall” component



Determining the WIMP mass

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

- Method described above yields normalized $f_1(v)$ for *any* assumed m_χ

Determining the WIMP mass

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

- Method described above yields normalized $f_1(v)$ for *any* assumed m_χ
- $\Rightarrow$ *cannot* determine m_χ from single recoil spectrum, unless $f_1(v)$ is (assumed to be) known

Determining the WIMP mass

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

- Method described above yields normalized $f_1(v)$ for *any* assumed m_χ
- $\Rightarrow$ *cannot* determine m_χ from single recoil spectrum, unless $f_1(v)$ is (assumed to be) known
- *Can* determine m_χ model–independently from two (or more) measurement, by demanding that they yield the same (moments of) f_1!

Determining the WIMP mass

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

- Method described above yields normalized $f_1(v)$ for *any* assumed m_χ
- $\Rightarrow$ *cannot* determine m_χ from single recoil spectrum, unless $f_1(v)$ is (assumed to be) known
- *Can* determine m_χ model–independently from two (or more) measurement, by demanding that they yield the same (moments of) f_1!
- 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. $v_{\rm min} = 0$, $v_{\rm max} = \infty$.

Systematic errors

- Equality of moments of f_1 holds only if integrals run over identical ranges of v, e.g. $v_{\rm min} = 0$, $v_{\rm max} = \infty$.
- Real experiments have finite acceptance windows for Q, and hence for v

Systematic errors

- Equality of moments of f_1 holds only if integrals run over identical ranges of v, e.g. $v_{\rm min} = 0$, $v_{\rm max} = \infty$.
- Real experiments have finite acceptance windows for Q, and hence for v
- Ensuring $v_{{\rm min},X} = v_{{\rm min},Y}$ and $v_{{\rm max},X} = v_{{\rm max},Y}$ only possible if m_χ is known

Systematic errors

- Equality of moments of f_1 holds only if integrals run over identical ranges of v, e.g. $v_{\rm min} = 0$, $v_{\rm max} = \infty$.
- Real experiments have finite acceptance windows for Q, and hence for v
- Ensuring $v_{{\rm min},X} = v_{{\rm min},Y}$ and $v_{{\rm max},X} = v_{{\rm max},Y}$ only possible if m_χ is known
- For $v_{\rm min}$: Systematic effect not very large if $m_\chi \gtrsim 20$ GeV, $Q_{\rm min} \lesssim 3$ keV, $Q_{{\rm min},X} = Q_{{\rm min},Y}$ terms included in I_n.

Systematic errors

- Equality of moments of f_1 holds only if integrals run over identical ranges of v, e.g. $v_{\rm min} = 0$, $v_{\rm max} = \infty$.
- Real experiments have finite acceptance windows for Q, and hence for v
- Ensuring $v_{{\rm min},X} = v_{{\rm min},Y}$ and $v_{{\rm max},X} = v_{{\rm max},Y}$ only possible if m_χ is known
- For $v_{\rm min}$: Systematic effect not very large if $m_\chi \gtrsim 20$ GeV, $Q_{\rm min} \lesssim 3$ keV, $Q_{{\rm min},X} = Q_{{\rm min},Y}$ terms included in I_n.
- Use $Q_{\rm min} = 0$ from now on.

Effect of finite $Q_{\rm max}$

- (Higher) moments are very sensitive to high$-Q$ region, even to region with $\langle N_{\rm ev} \rangle < 1$

Effect of finite $Q_{\rm max}$

- (Higher) moments are very sensitive to high$-Q$ region, even to region with $\langle N_{\rm ev} \rangle < 1$
- Imposing finite $Q_{\rm max}$ can alleviate this problem,

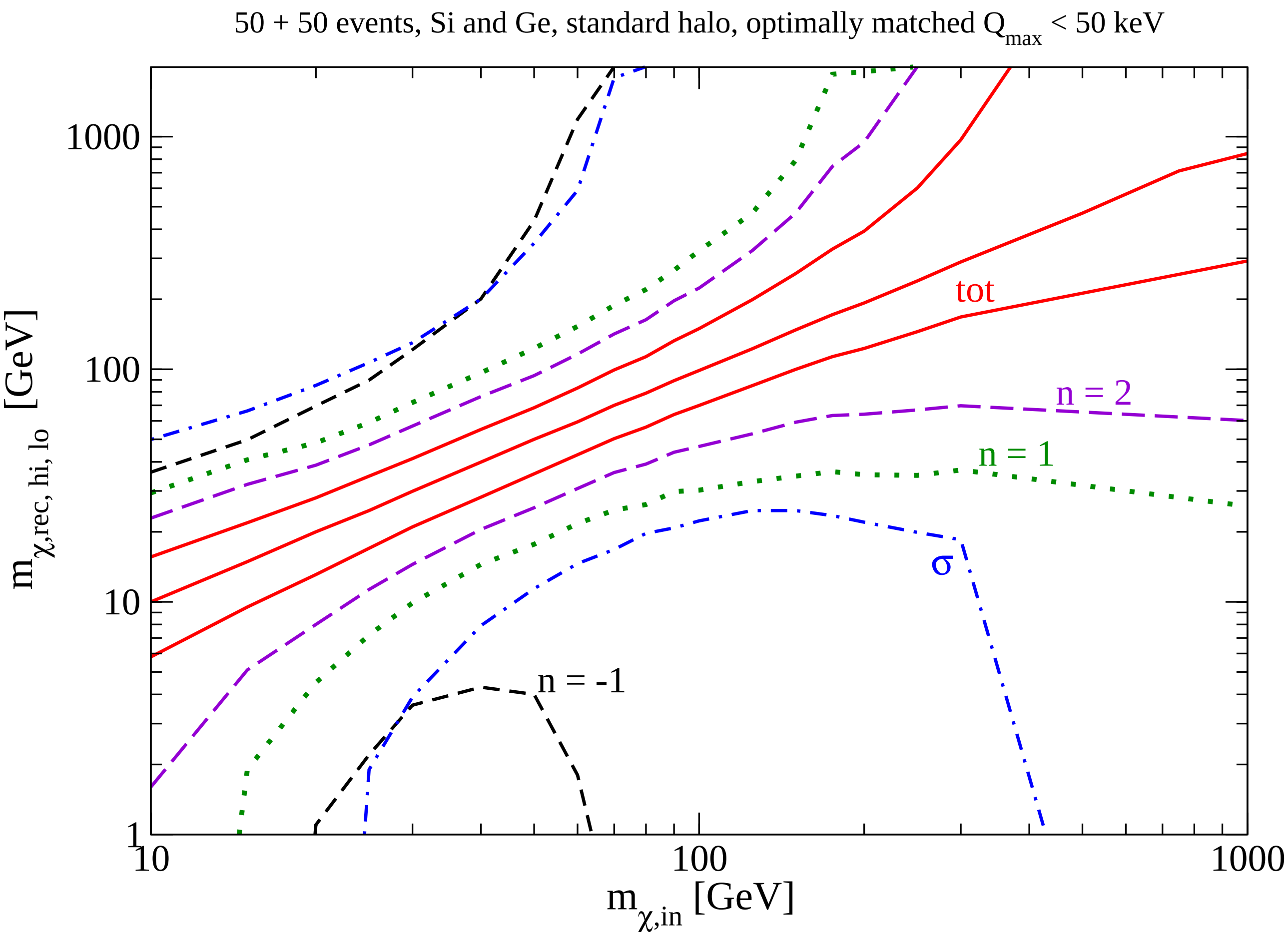
Effect of finite $Q_{\max}$

- (Higher) moments are very sensitive to high$-Q$ region, even to region with $\langle N_{\rm ev} \rangle < 1$
- Imposing finite $Q_{\max}$ can alleviate this problem,
- but introduces systematic error unless $Q_{\max}$ values of two targets are matched; matching depends on m_χ.

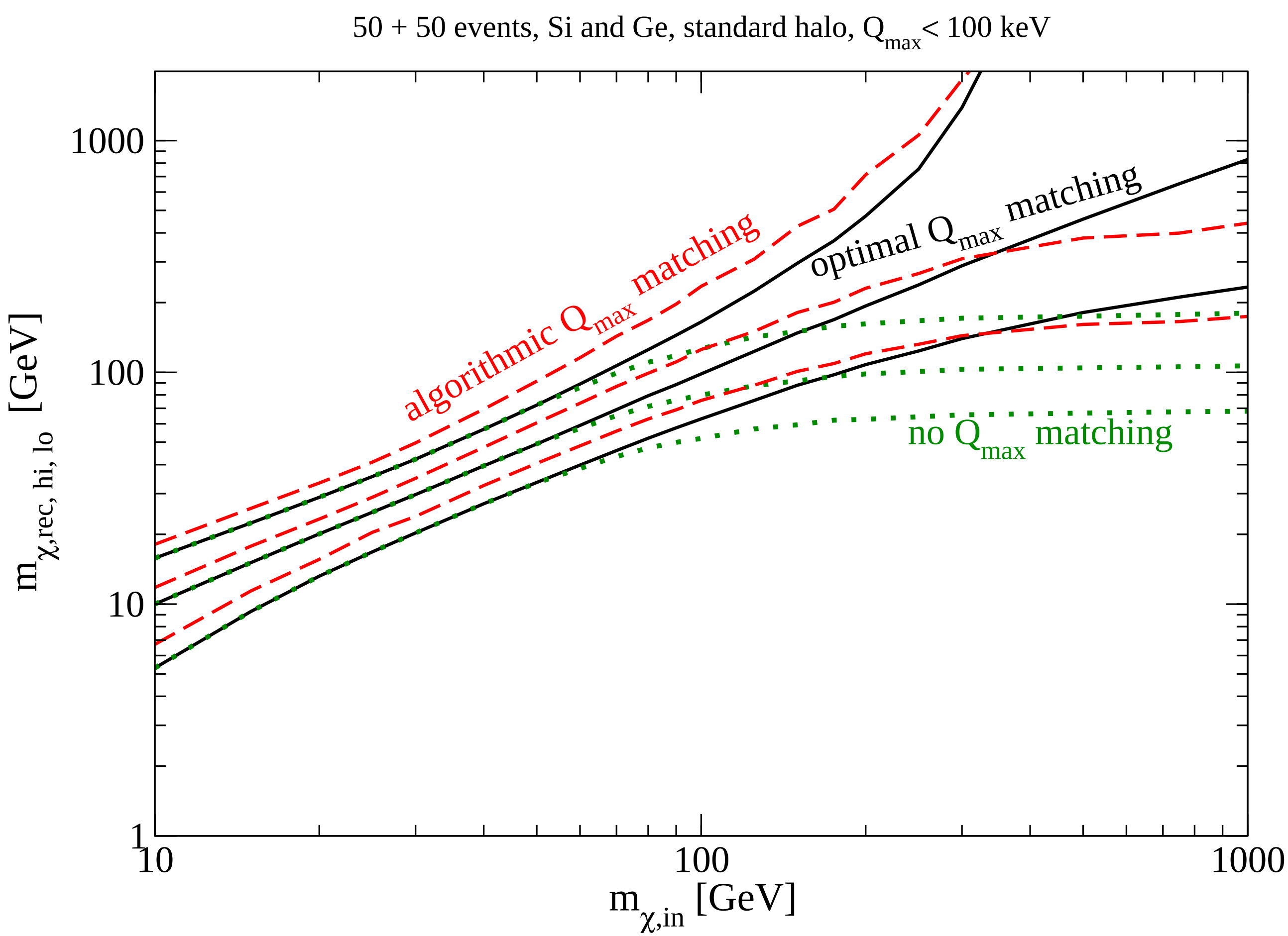
Effect of finite $Q_{\rm max}$

- (Higher) moments are very sensitive to high$-Q$ region, even to region with $\langle N_{\rm ev}\rangle < 1$
- 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.

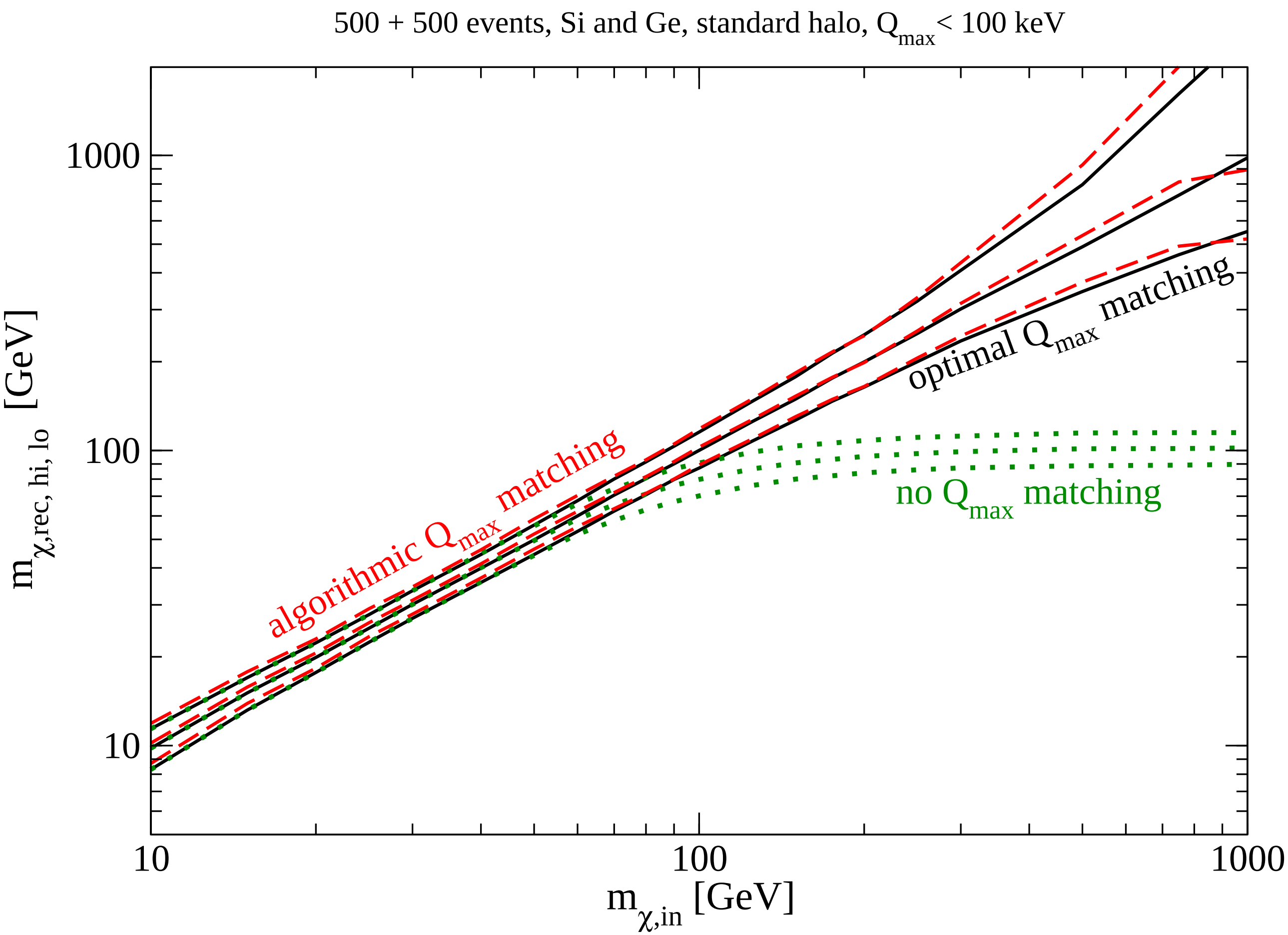
Median reconstructed WIMP mass



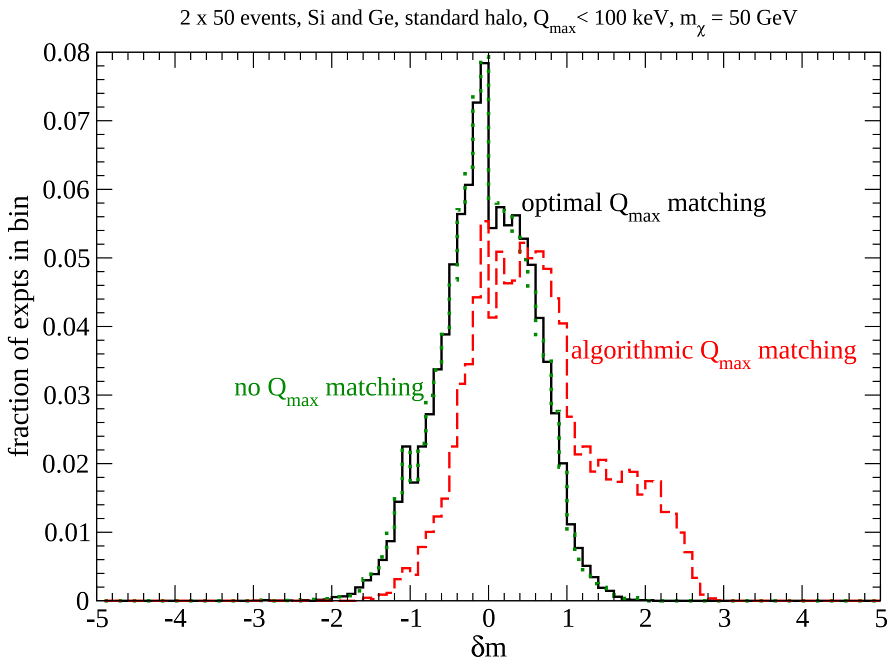
Median reconstructed WIMP mass

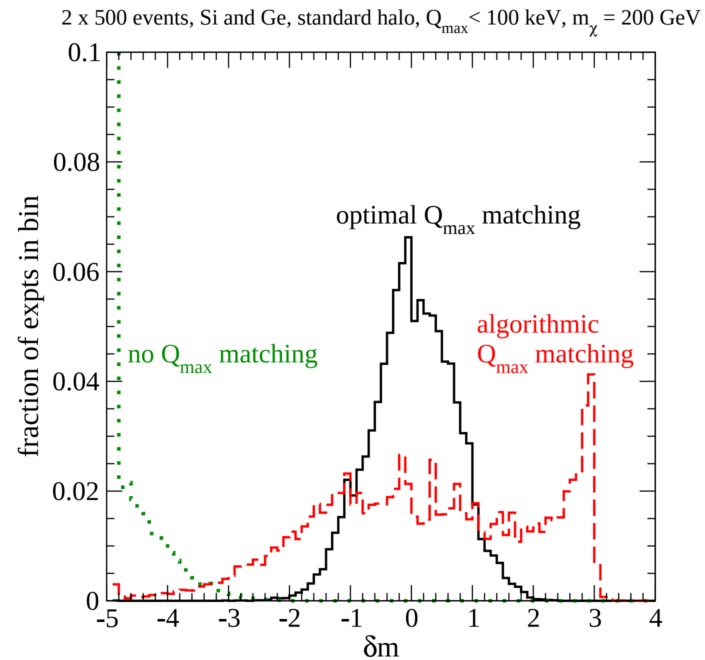


Median reconstructed WIMP mass



Distribution of measurements





WIMP Density times Cross Section

For spin–independent scattering:

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

$r(Q_{\rm min}) = \left. \frac{dR}{dQ} \right|_{Q=Q_{\rm min}}$

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

WIMP Density times Cross Section

For spin–independent scattering:

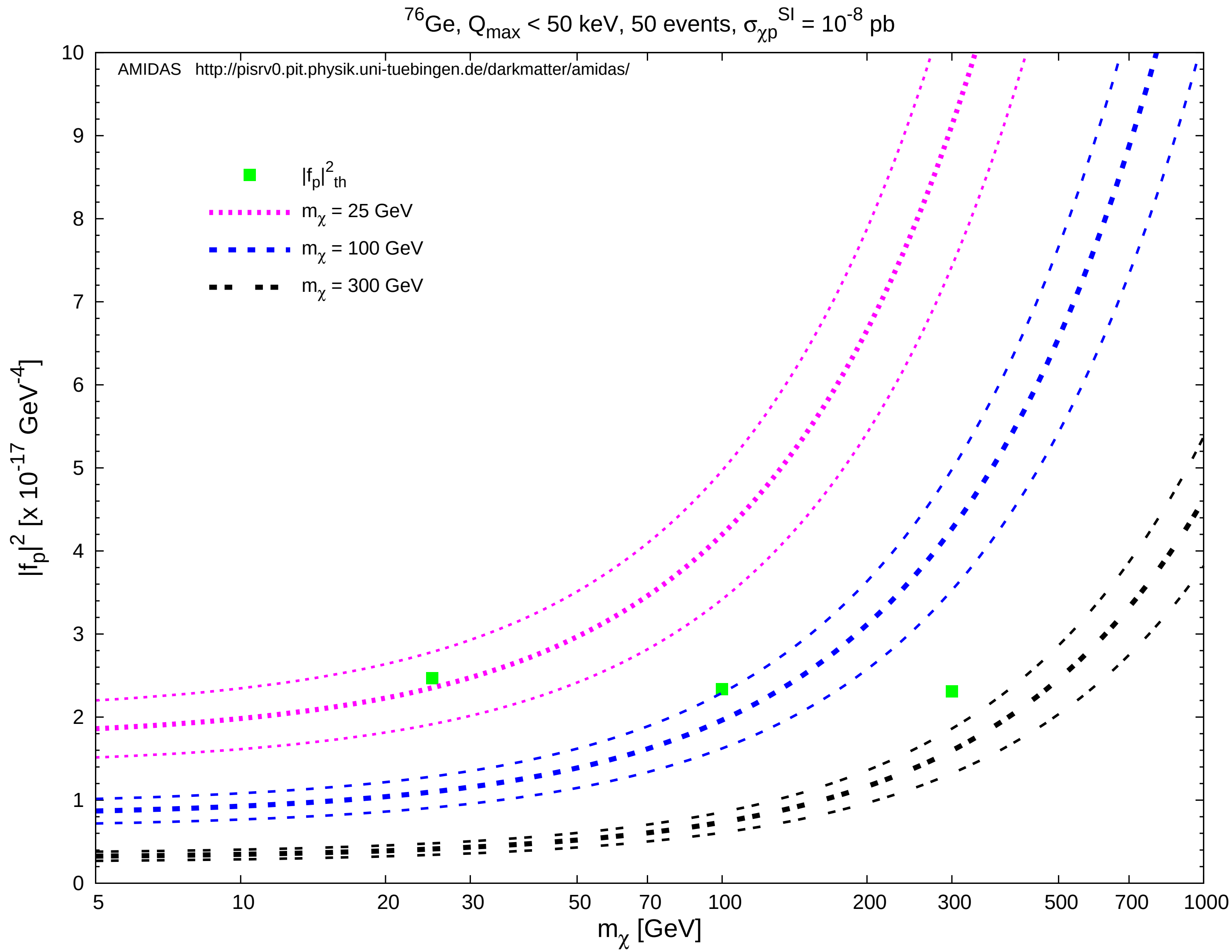
$$\rho_\chi \sigma_{\chi p} \propto \frac{r(Q_{\rm min})}{\langle v^{-1} \rangle} (m_\chi + m_N) \propto \left(\frac{2\sqrt{Q_{\rm min}} r(Q_{\rm min})}{F^2(Q_{\rm min})} + I_0 \right) (m_\chi + m_N) \, . \qquad (2)$$

$r(Q_{\rm min}) = \left. \frac{dR}{dQ} \right|_{Q=Q_{\rm min}}$

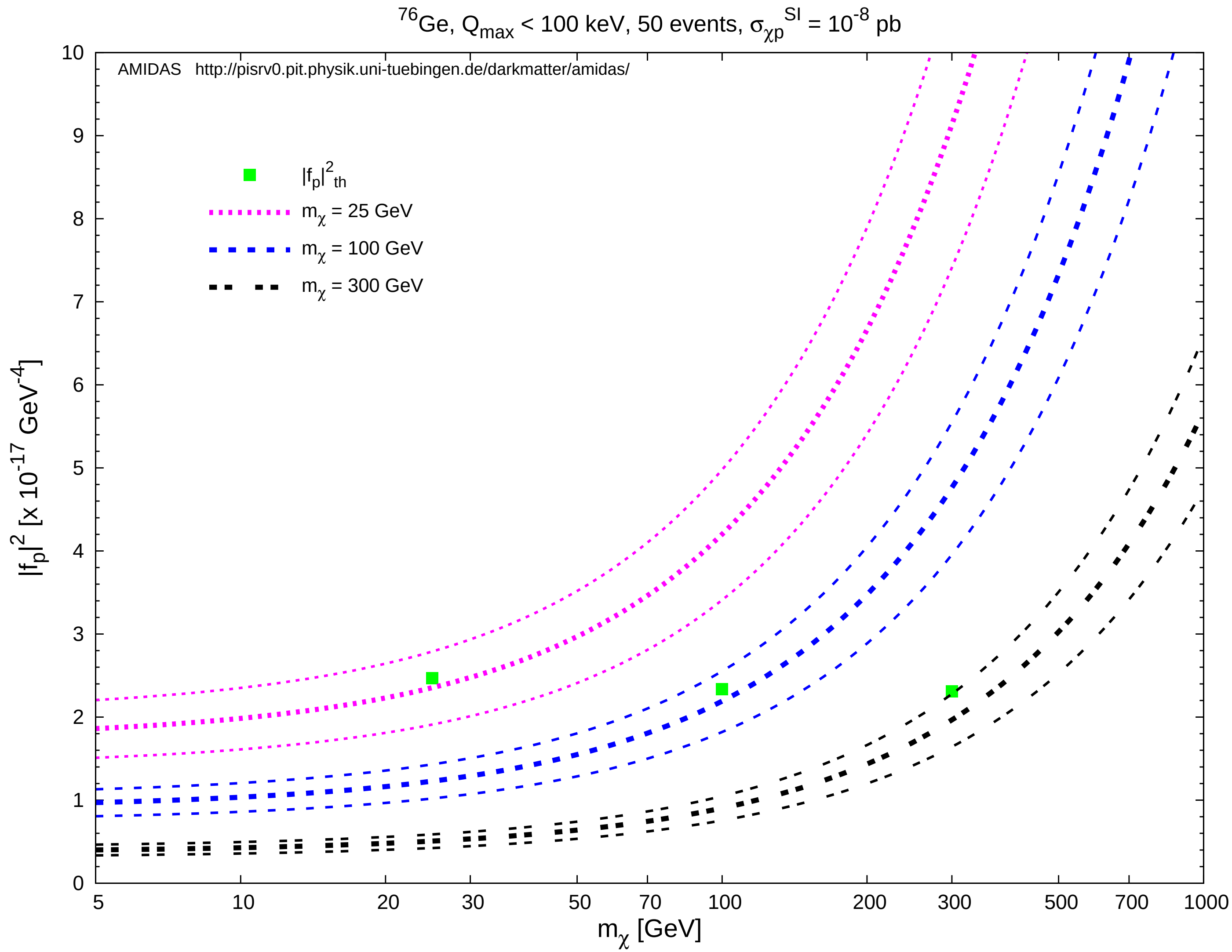
First factor on r.h.s. in 2nd line comes from normalization of $-1^{\rm st}$ moment.

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 $Q_{\max} = 100$ keV



WIMP–Proton Scattering in SUSY

WIMP is lightest neutralino $\tilde{\chi}_1^0$.

WIMP–Proton Scattering in SUSY

WIMP is lightest neutralino $\tilde{\chi}_1^0$.

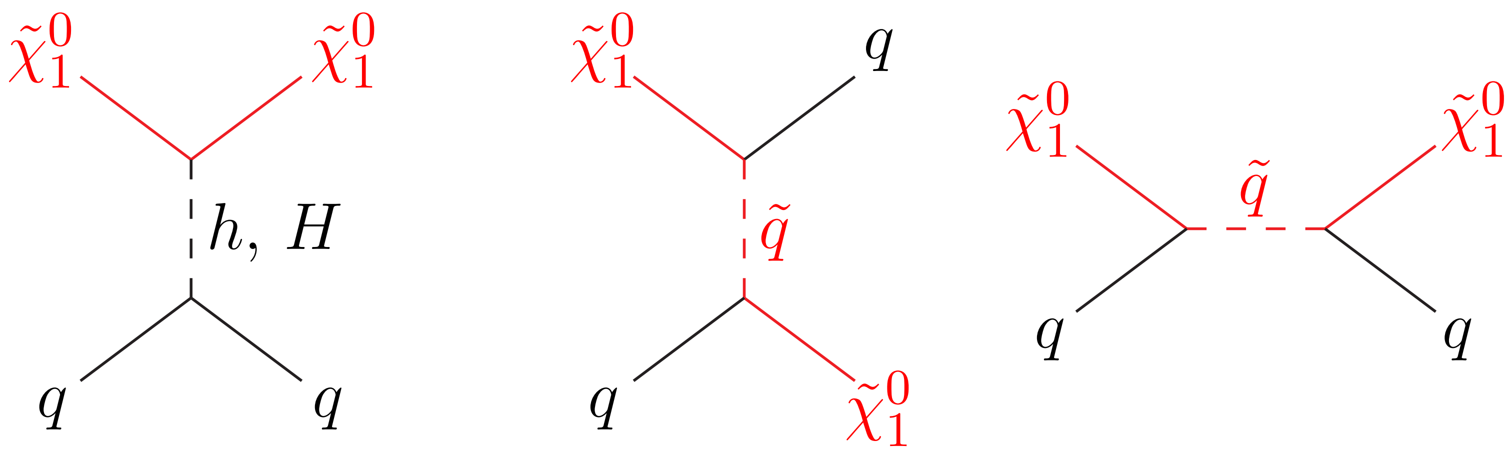
Stick to spin–independent contribution: $\mathcal{L}_{\rm eff} = f_p \bar{p} p \tilde{\chi}_1^0 \tilde{\chi}_1^0$

WIMP–Proton Scattering in SUSY

WIMP is lightest neutralino $\tilde{\chi}_1^0$.

Stick to spin–independent contribution: $\mathcal{L}_{\rm eff} = f_p \bar{p} p \tilde{\chi}_1^0 \tilde{\chi}_1^0$

Come from spin–independent $\tilde{\chi}_1^0 q$ interactions:

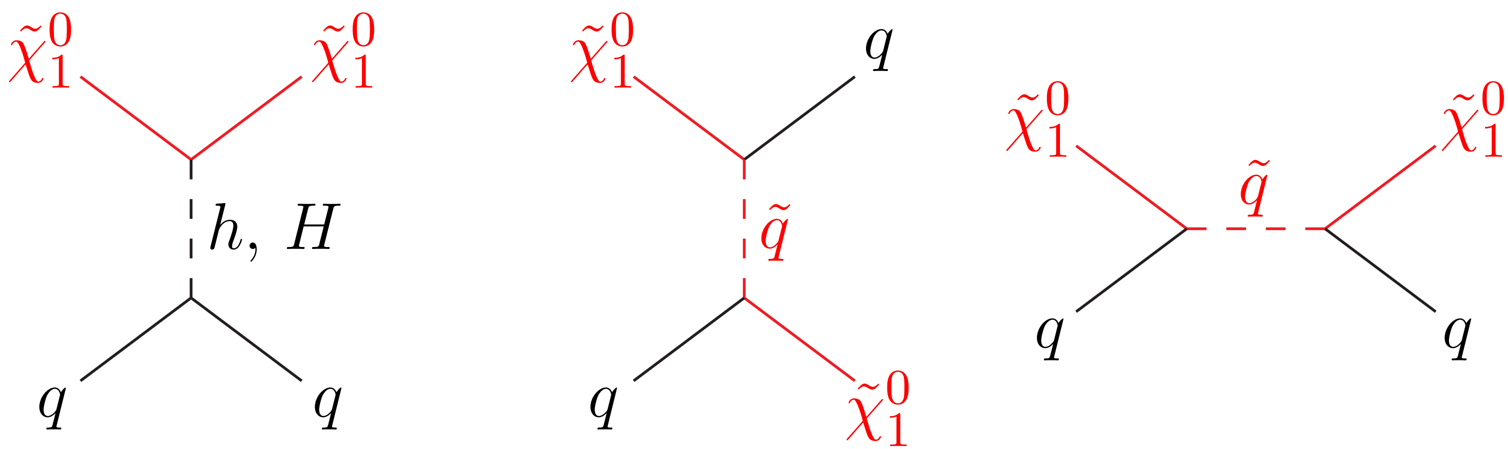


WIMP–Proton Scattering in SUSY

WIMP is lightest neutralino $\tilde{\chi}_1^0$.

Stick to spin–independent contribution: $\mathcal{L}_{\rm eff} = f_p \bar{p} p \tilde{\chi}_1^0 \tilde{\chi}_1^0$

Come from spin–independent $\tilde{\chi}_1^0 q$ interactions:



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

- For heavy quarks, $q = c,\ b,\ t$: Calculate perturbatively via gluon loop. Shifman et al. 1977. Result is independent of m_q. Need some modification for $\tilde{t}$ in loop. MD & Nojiri 1993

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

- For heavy quarks, $q = c,\ b,\ t$: Calculate perturbatively via gluon loop. Shifman et al. 1977. Result is independent of m_q. Need some modification for $\tilde{t}$ in loop. MD & Nojiri 1993
- Need current quark masses $\Rightarrow$ contributions from u, d are small

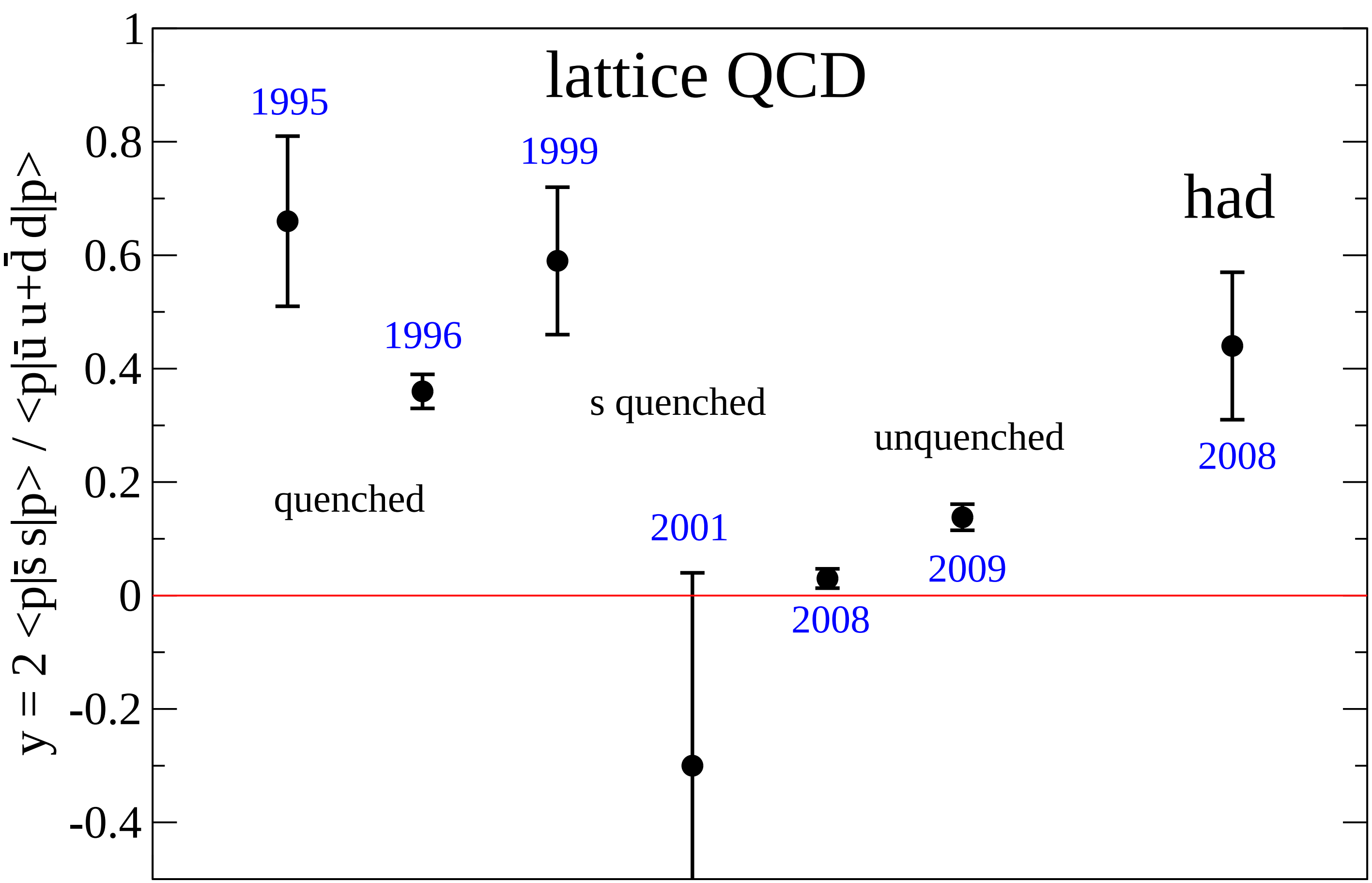
  $\Longrightarrow \sigma_{\tilde{\chi}_1^0 p} \simeq \sigma_{\tilde{\chi}_1^0 n}$ for spin–indep. contribution!

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

- For heavy quarks, $q = c,\ b,\ t$: Calculate perturbatively via gluon loop. Shifman et al. 1977. Result is independent of m_q. Need some modification for $\tilde{t}$ in loop. MD & Nojiri 1993
- Need current quark masses $\Rightarrow$ contributions from u, d are small

  $\Longrightarrow \sigma_{\tilde{\chi}_1^0 p} \simeq \sigma_{\tilde{\chi}_1^0 n}$ for spin–indep. contribution!
- Strange quark contribution important, but poorly known!

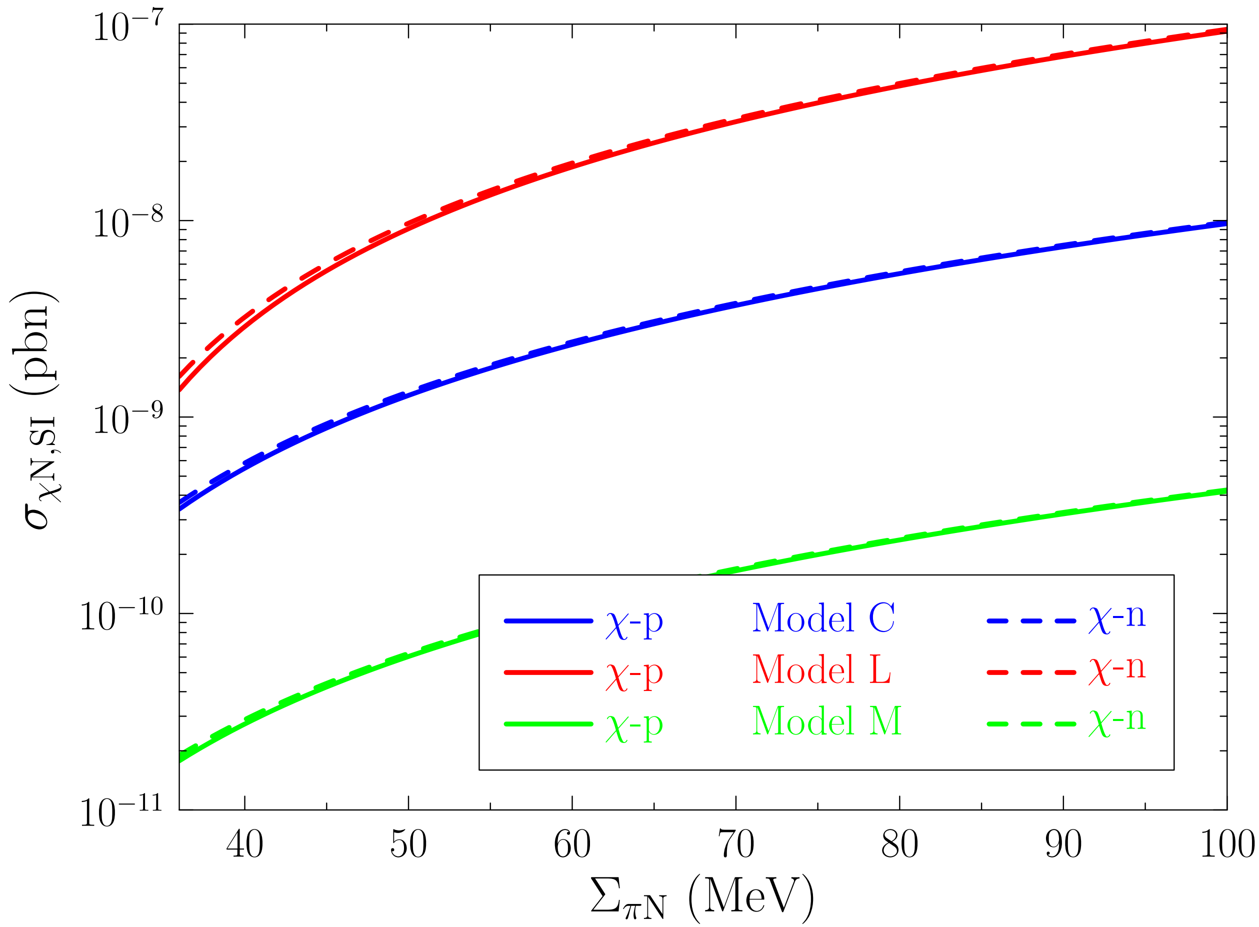
Determinations of $\langle p|\bar{s}s|p\rangle$



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

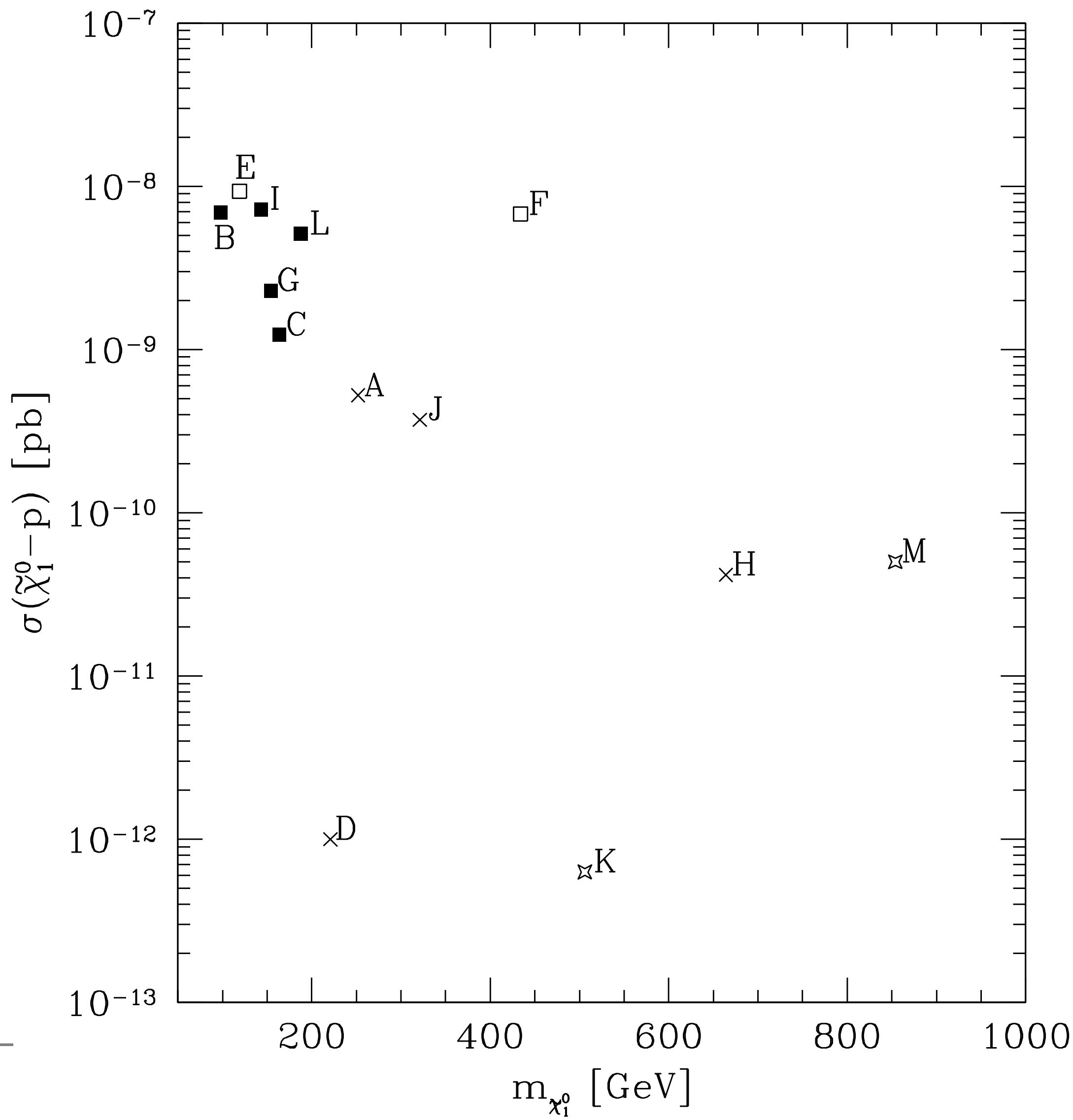
Ellis, Olive & Savage, arXiv:0801.3656



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

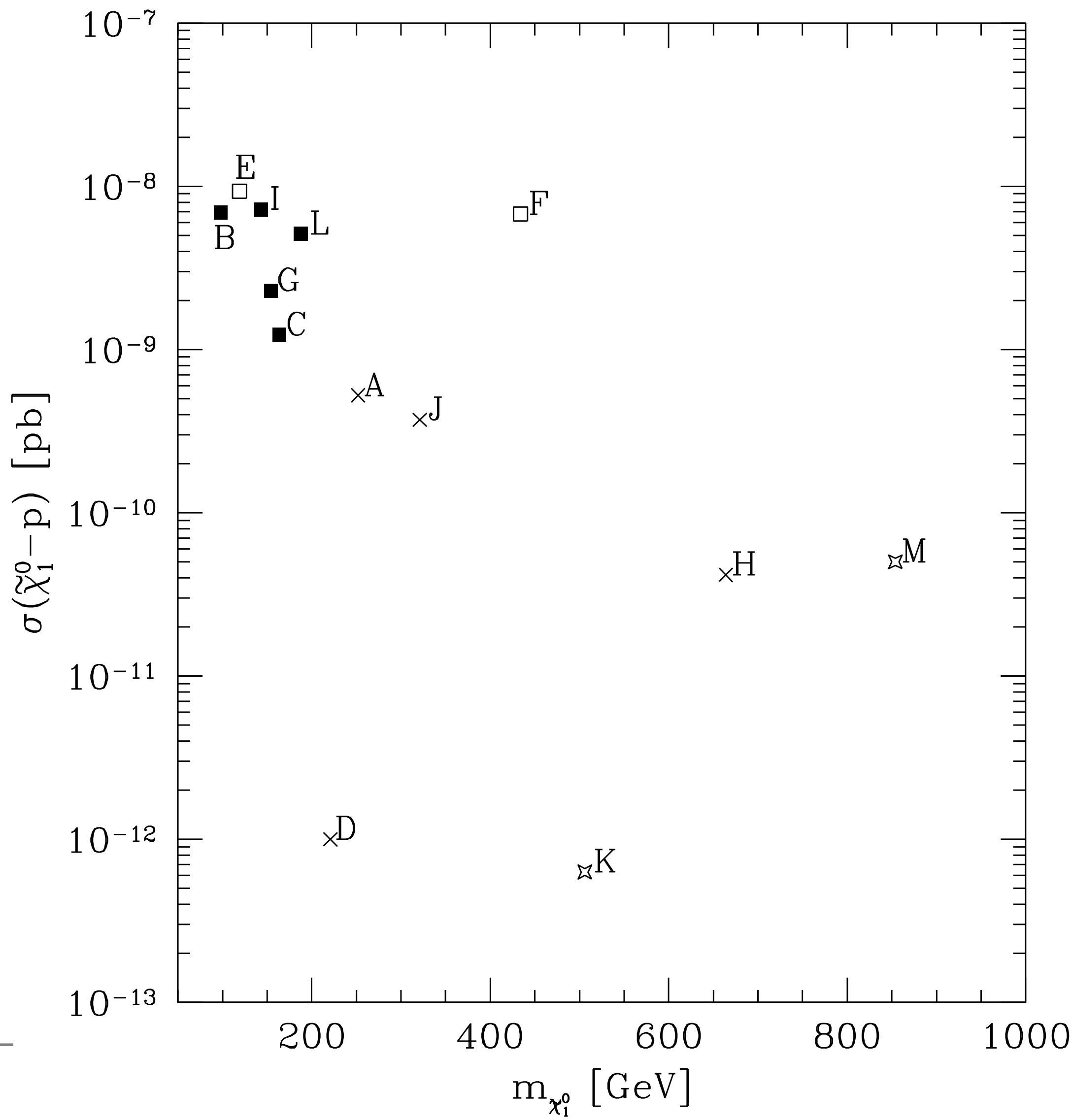
Open squares: focus point region

Crosses: Co–ann. region

Stars: Higgs funnel

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

Consider A, E, G!

Effect of Varying SUSY Parameter

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

Effect of Varying SUSY Parameter

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

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%

Lessons

- Relatively easily measurable squark mass has little influence: Higgs exchange dominates!

Lessons

- Relatively easily measurable squark mass has little influence: Higgs exchange dominates!
- $\sigma_{\tilde{\chi}_1^0 p}$ is most sensitive to μ, which determines gaugino–higgsino mixing: difficult to measure, except maybe in focus point region

Lessons

- Relatively easily measurable squark mass has little influence: Higgs exchange dominates!
- $\sigma_{\tilde{\chi}_1^0 p}$ is most sensitive to μ, which determines gaugino–higgsino mixing: difficult to measure, except maybe in focus point region
- 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

- WIMPs are still great CDM candidates!

Summary

- WIMPs are still great CDM candidates!
- Learning from direct detection:

Summary

- WIMPs are still great CDM candidates!
- Learning from direct detection:
  - Direct reconstruction of $f_1(v)$ needs several hundred events

Summary

- WIMPs are still great CDM candidates!
- Learning from direct detection:
  - Direct reconstruction of $f_1(v)$ needs several hundred events
  - Non–trivial statements about moments of f_1 possible with few dozen events

Summary

- WIMPs are still great CDM candidates!
- Learning from direct detection:
  - Direct reconstruction of $f_1(v)$ needs several hundred events
  - Non–trivial statements about moments of f_1 possible with few dozen events
  - With ≥ 2 experiments: can get m_χ!

Summary

- WIMPs are still great CDM candidates!
- Learning from direct detection:
  - Direct reconstruction of $f_1(v)$ needs several hundred events
  - Non–trivial statements about moments of f_1 possible with few dozen events
  - With ≥ 2 experiments: can get m_χ!
- Learning about direct detection ($\sigma_{\tilde{\chi}_1^0 p}$):

Summary

- WIMPs are still great CDM candidates!
- Learning from direct detection:
  - Direct reconstruction of $f_1(v)$ needs several hundred events
  - Non–trivial statements about moments of f_1 possible with few dozen events
  - With ≥ 2 experiments: can get m_χ!
- Learning about direct detection ($\sigma_{\tilde{\chi}_1^0 p}$):
  - Large hadronic uncertainty, especially from $m_s \langle p|\bar{s}s|p\rangle$ (almost equivalently, $\Sigma_{\pi N}$)

Summary

- WIMPs are still great CDM candidates!
- Learning from direct detection:
  - Direct reconstruction of $f_1(v)$ needs several hundred events
  - Non–trivial statements about moments of f_1 possible with few dozen events
  - With ≥ 2 experiments: can get m_χ!
- Learning about direct detection ($\sigma_{\tilde{\chi}_1^0 p}$):
  - Large hadronic uncertainty, especially from $m_s \langle p|\bar{s}s|p\rangle$ (almost equivalently, $\Sigma_{\pi N}$)
  - In SUSY: Have to measure parameters of Higgs(ino) sector! Probably difficult to do at LHC.

Summary

- WIMPs are still great CDM candidates!
- Learning from direct detection:
  - Direct reconstruction of $f_1(v)$ needs several hundred events
  - Non–trivial statements about moments of f_1 possible with few dozen events
  - With ≥ 2 experiments: can get m_χ!
- Learning about direct detection ($\sigma_{\tilde{\chi}_1^0 p}$):
  - Large hadronic uncertainty, especially from $m_s \langle p|\bar{s}s|p\rangle$ (almost equivalently, $\Sigma_{\pi N}$)
  - In SUSY: Have to measure parameters of Higgs(ino) sector! Probably difficult to do at LHC.
- Both $f_1(v)$ and $\sigma_{\chi p}$ are needed to determine ρ_χ: required input for learning about early Universe!