



# Improving dark matter direct detection analysis

Bradley J. Kavanagh  
University of Nottingham

arXiv:1207.2039 with Anne M. Green



# Speed dependence

# Speed dependence

$$\frac{dR}{dE_R} \sim \eta(v_{\min})$$

$$\mu_{AB} = \frac{m_A m_B}{m_A + m_B}$$

# Speed dependence

$$\frac{dR}{dE_R} \sim \eta(v_{\min})$$

$$\eta(v_{\min}) = \int_{v_{\min}}^{\infty} \frac{f(\mathbf{v})}{v} d^3\mathbf{v}$$

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}}$$

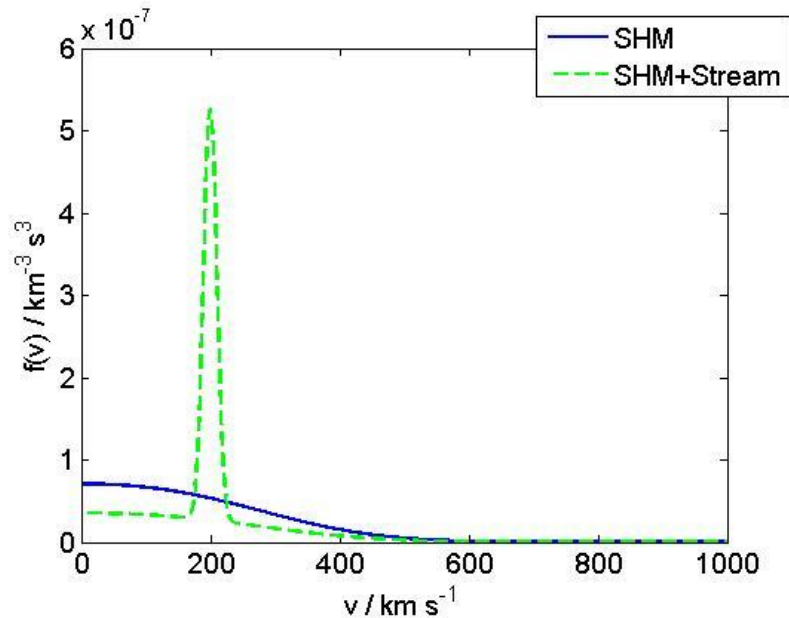
# Speed dependence

$$\mu_{AB} = \frac{m_A m_B}{m_A + m_B}$$

$$\frac{dR}{dE_R} \sim \eta(v_{\min})$$

$$\eta(v_{\min}) = \int_{v_{\min}}^{\infty} \frac{f(\mathbf{v})}{v} d^3\mathbf{v}$$

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}}$$



$$f(v)$$

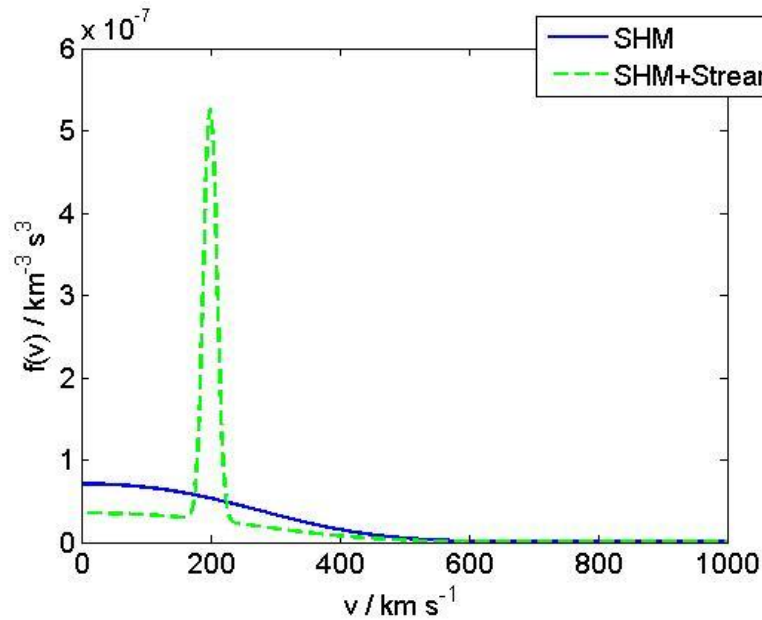
# Speed dependence

$$\mu_{AB} = \frac{m_A m_B}{m_A + m_B}$$

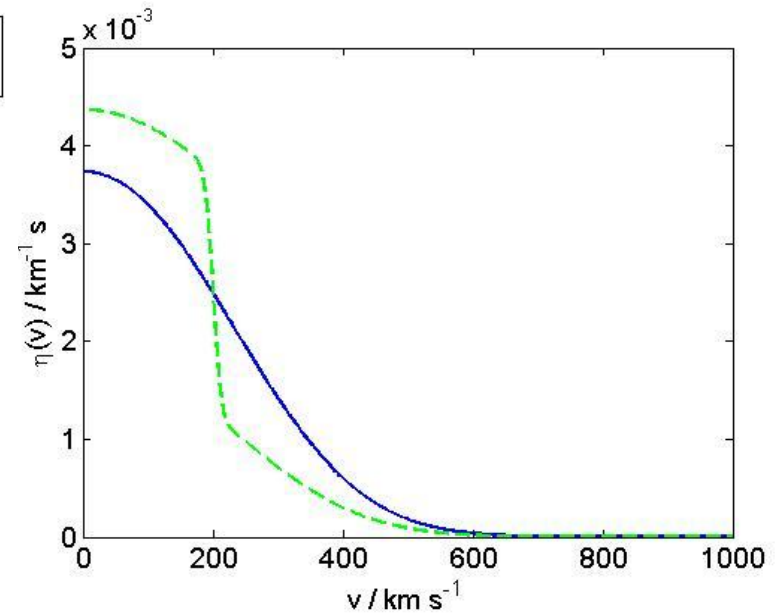
$$\frac{dR}{dE_R} \sim \eta(v_{\min})$$

$$\eta(v_{\min}) = \int_{v_{\min}}^{\infty} \frac{f(\mathbf{v})}{v} d^3\mathbf{v}$$

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}}$$



$f(v)$



$\eta(v_{\min})$

# Speed parametrisation method

A. H. G. Peter – [arXiv:0910.4765](https://arxiv.org/abs/0910.4765), [arXiv:1103.5145](https://arxiv.org/abs/1103.5145)

# Speed parametrisation method

A. H. G. Peter – arXiv:0910.4765, arXiv:1103.5145

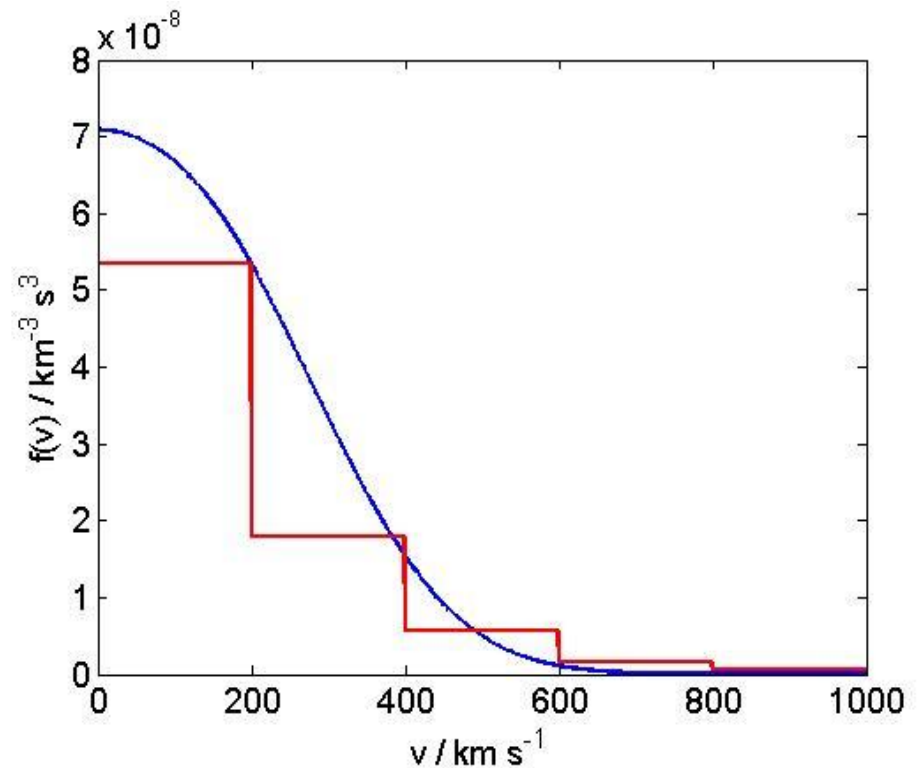
- Model independent method - empirical parametrisation of  $f(v)$



# Speed parametrisation method

A. H. G. Peter – arXiv:0910.4765, arXiv:1103.5145

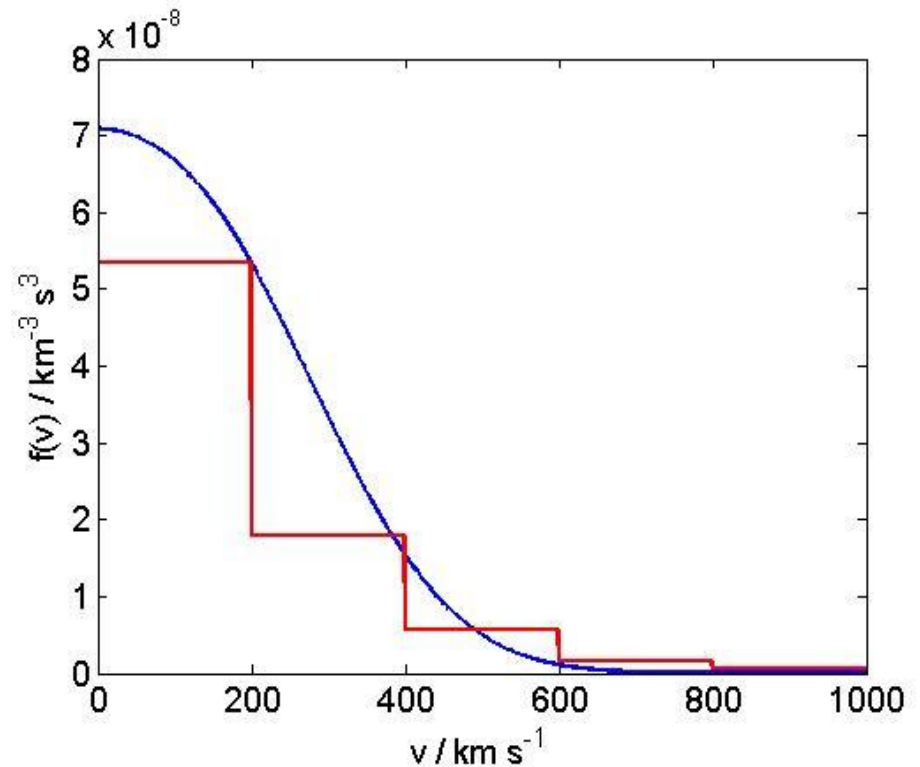
- Model independent method - empirical parametrisation of  $f(v)$
- Series of constant bins – bin values used as additional parameters



# Speed parametrisation method

A. H. G. Peter – arXiv:0910.4765, arXiv:1103.5145

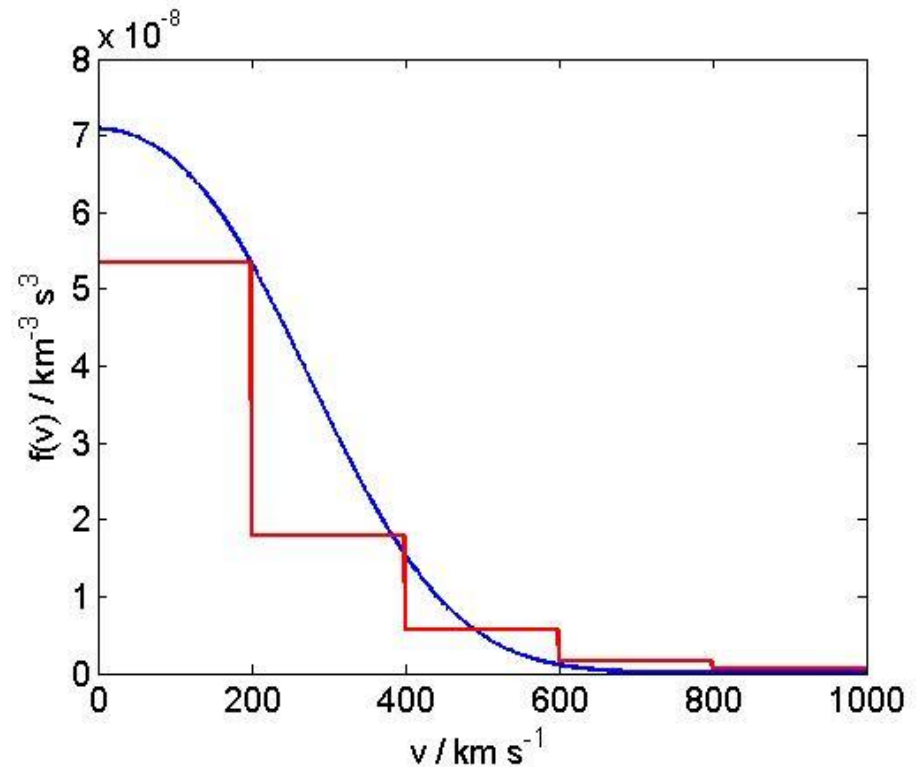
- Model independent method - empirical parametrisation of  $f(v)$
- Series of constant bins – bin values used as additional parameters
- Should be acceptable for small numbers of events



# Speed parametrisation method

A. H. G. Peter – arXiv:0910.4765, arXiv:1103.5145

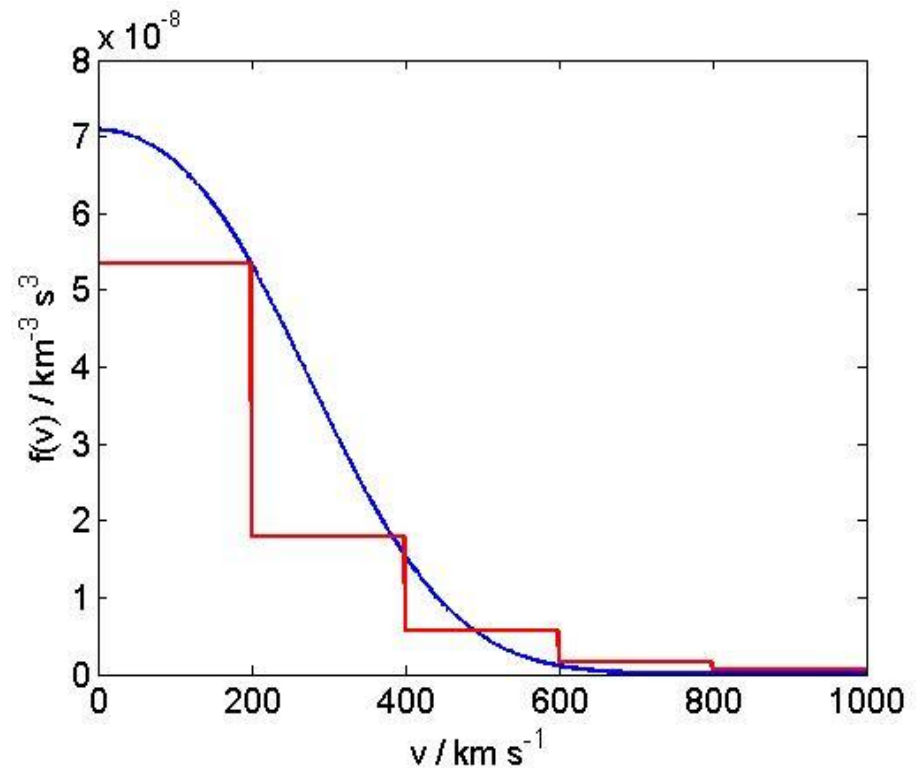
- Model independent method - empirical parametrisation of  $f(v)$
- Series of constant bins – bin values used as additional parameters
- Should be acceptable for small numbers of events
- Unfortunately – IT DOESN'T WORK!



# Speed parametrisation method

A. H. G. Peter – arXiv:0910.4765, arXiv:1103.5145

- Model independent method - empirical parametrisation of  $f(v)$
- Series of constant bins – bin values used as additional parameters
- Should be acceptable for small numbers of events
- Unfortunately – IT DOESN'T WORK!
- Still leads to a bias in the reconstructed mass and cross-section





**What goes wrong?**

# What goes wrong?

- We're attempting to reconstruct the event rate as a function of recoil energy

# What goes wrong?

- We're attempting to reconstruct the event rate as a function of recoil energy
- Bins in velocity space correspond to bins in energy space, with width:

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}} \Rightarrow \Delta E_R \sim \mu_{\chi N}^2 \Delta v^2$$

# What goes wrong?

- We're attempting to reconstruct the event rate as a function of recoil energy
- Bins in velocity space correspond to bins in energy space, with width:

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}} \Rightarrow \Delta E_R \sim \mu_{\chi N}^2 \Delta v^2$$

- By going to lower masses, we can reduce the size of bins in energy space. This allows us to get a better fit to the data with our empirical parametrisation



# What goes wrong?

- We're attempting to reconstruct the event rate as a function of recoil energy
- Bins in velocity space correspond to bins in energy space, with width:

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}} \Rightarrow \Delta E_R \sim \mu_{\chi N}^2 \Delta v^2$$

- By going to lower masses, we can reduce the size of bins in energy space. This allows us to get a better fit to the data with our empirical parametrisation
- Instead parametrise the *momentum*:

# What goes wrong?

- We're attempting to reconstruct the event rate as a function of recoil energy
- Bins in velocity space correspond to bins in energy space, with width:

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}} \Rightarrow \Delta E_R \sim \mu_{\chi N}^2 \Delta v^2$$

- By going to lower masses, we can reduce the size of bins in energy space. This allows us to get a better fit to the data with our empirical parametrisation
- Instead parametrise the *momentum*:

$$p = \mu_{\chi N} v$$
$$f(v) \rightarrow f(p)$$

# What goes wrong?

- We're attempting to reconstruct the event rate as a function of recoil energy
- Bins in velocity space correspond to bins in energy space, with width:

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}} \Rightarrow \Delta E_R \sim \mu_{\chi N}^2 \Delta v^2$$

- By going to lower masses, we can reduce the size of bins in energy space. This allows us to get a better fit to the data with our empirical parametrisation
- Instead parametrise the *momentum*:

$$\left. \begin{array}{l} p = \mu_{\chi N} v \\ f(v) \rightarrow f(p) \end{array} \right\} \Delta E_R \sim \Delta p^2$$

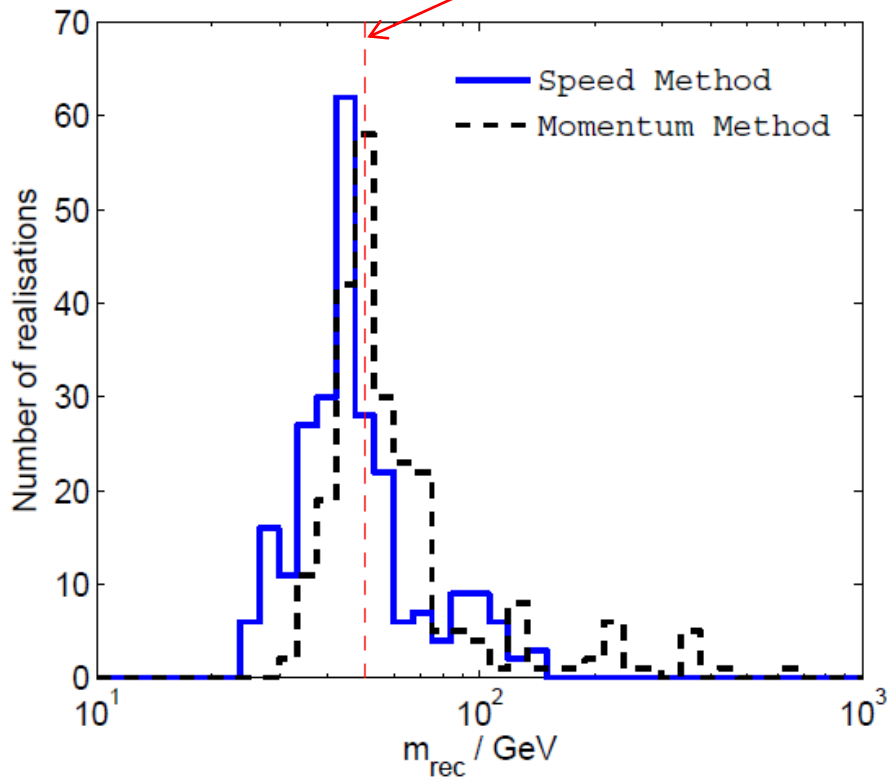
# Momentum parametrisation

$$p = \mu_{\chi N} v$$

# Momentum parametrisation

$$p = \mu_{\chi N} v$$

50 GeV  
benchmark

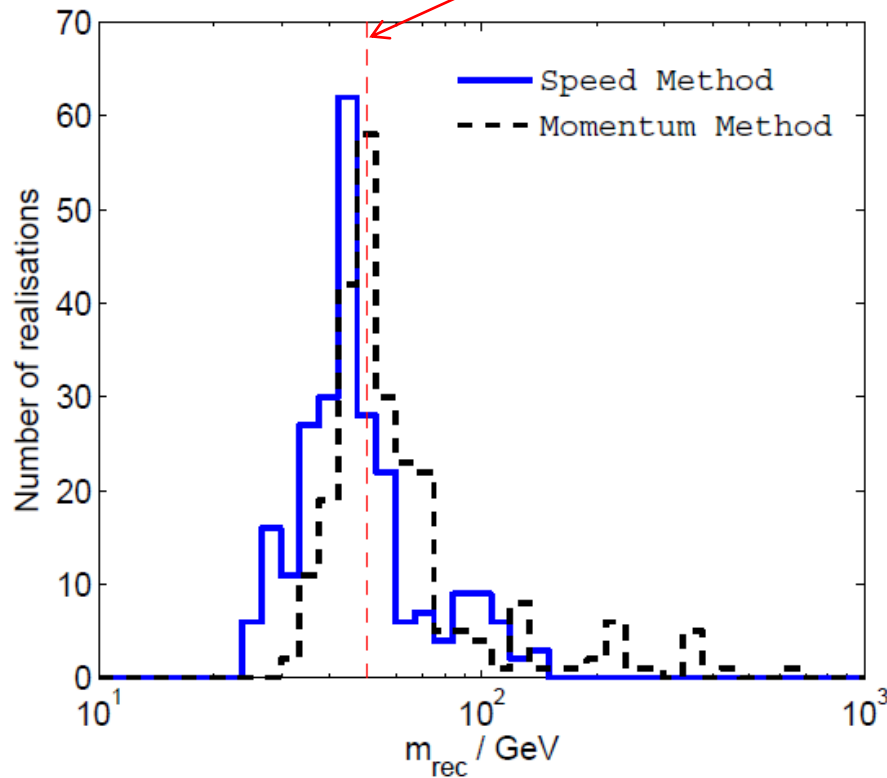


SHM

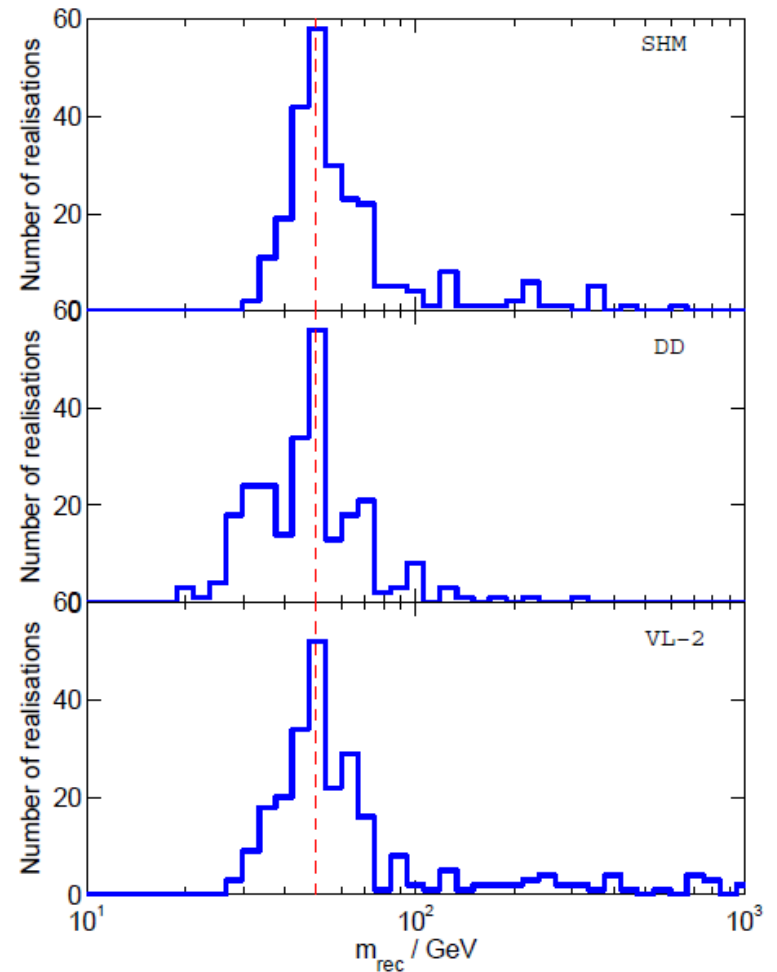
# Momentum parametrisation

$$p = \mu_{\chi N} v$$

50 GeV  
benchmark



SHM





# Reconstructing $f(v)$

# Reconstructing $f(v)$

- Reconstructing  $f(v)$  is complicated (errors strongly correlated)

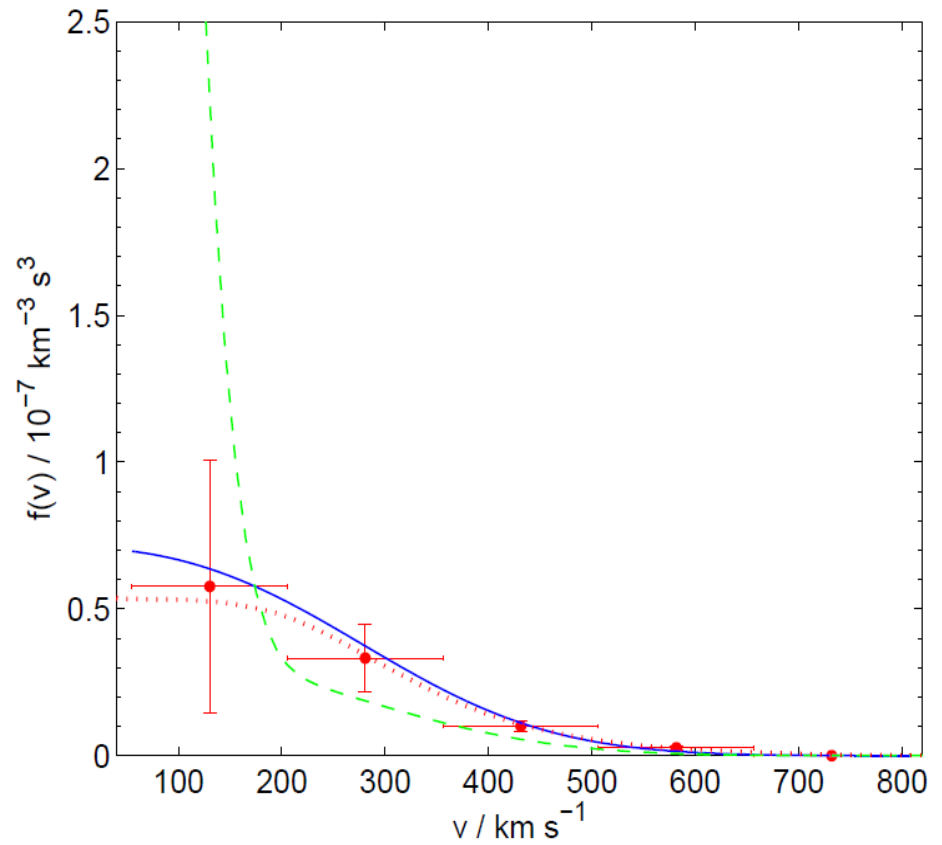


# Reconstructing $f(v)$

- Reconstructing  $f(v)$  is complicated (errors strongly correlated)
- Simple estimates lead to consistent results

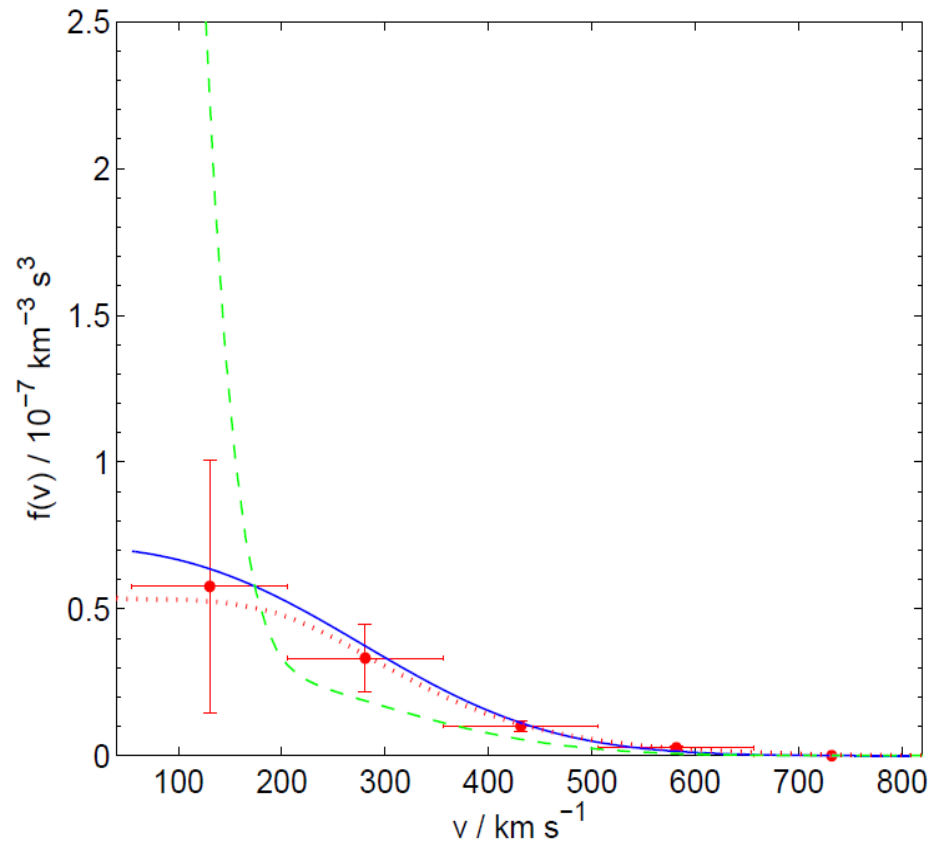
# Reconstructing $f(v)$

- Reconstructing  $f(v)$  is complicated (errors strongly correlated)
- Simple estimates lead to consistent results



# Reconstructing $f(v)$

- Reconstructing  $f(v)$  is complicated (errors strongly correlated)
- Simple estimates lead to consistent results
- Small statistics means discriminating between underlying  $f(v)$  is difficult





# Conclusion

# Conclusion

- Hope to extract WIMP parameters from DM direct detection

# Conclusion

- Hope to extract WIMP parameters from DM direct detection
- Need to account for uncertainties owing to poor understanding of  $f(v)$

# Conclusion

- Hope to extract WIMP parameters from DM direct detection
- Need to account for uncertainties owing to poor understanding of  $f(v)$
- Naïve attempts to parametrise  $f(v)$  fail

# Conclusion

- Hope to extract WIMP parameters from DM direct detection
- Need to account for uncertainties owing to poor understanding of  $f(v)$
- Naïve attempts to parametrise  $f(v)$  fail
- Instead parametrise the momentum  $\rightarrow$  reduced bias and more accurate errors



# Conclusion

- Hope to extract WIMP parameters from DM direct detection
- Need to account for uncertainties owing to poor understanding of  $f(v)$
- Naïve attempts to parametrise  $f(v)$  fail
- Instead parametrise the momentum  $\rightarrow$  reduced bias and more accurate errors
- Drawbacks

# Conclusion

- Hope to extract WIMP parameters from DM direct detection
- Need to account for uncertainties owing to poor understanding of  $f(v)$
- Naïve attempts to parametrise  $f(v)$  fail
- Instead parametrise the momentum  $\rightarrow$  reduced bias and more accurate errors
- Drawbacks
  - cannot yet distinguish between different underlying  $f(v)$

# Conclusion

- Hope to extract WIMP parameters from DM direct detection
- Need to account for uncertainties owing to poor understanding of  $f(v)$
- Naïve attempts to parametrise  $f(v)$  fail
- Instead parametrise the momentum  $\rightarrow$  reduced bias and more accurate errors
- Drawbacks
  - cannot yet distinguish between different underlying  $f(v)$
  - Experiments not sensitive to all speeds/momenta  $\rightarrow$  can only place limits on  $\sigma_p$

# Conclusion

- Hope to extract WIMP parameters from DM direct detection
- Need to account for uncertainties owing to poor understanding of  $f(v)$
- Naïve attempts to parametrise  $f(v)$  fail
- Instead parametrise the momentum  $\rightarrow$  reduced bias and more accurate errors
- Drawbacks
  - cannot yet distinguish between different underlying  $f(v)$
  - Experiments not sensitive to all speeds/momenta  $\rightarrow$  can only place limits on  $\sigma_p$

# Conclusion

- Hope to extract WIMP parameters from DM direct detection
- Need to account for uncertainties owing to poor understanding of  $f(\mathbf{v})$
- Naïve attempts to parametrise  $f(\mathbf{v})$  fail
- Instead parametrise the momentum  $\rightarrow$  reduced bias and more accurate errors
- Drawbacks
  - cannot yet distinguish between different underlying  $f(\mathbf{v})$
  - Experiments not sensitive to all speeds/momenta  $\rightarrow$  can only place limits on  $\sigma_p$
- Future – extending to directional detectors which give full 3D information about  $f(\mathbf{v})$



**Thanks for listening**