Measuring the dark matter mass – in spite of astrophysical uncertainties

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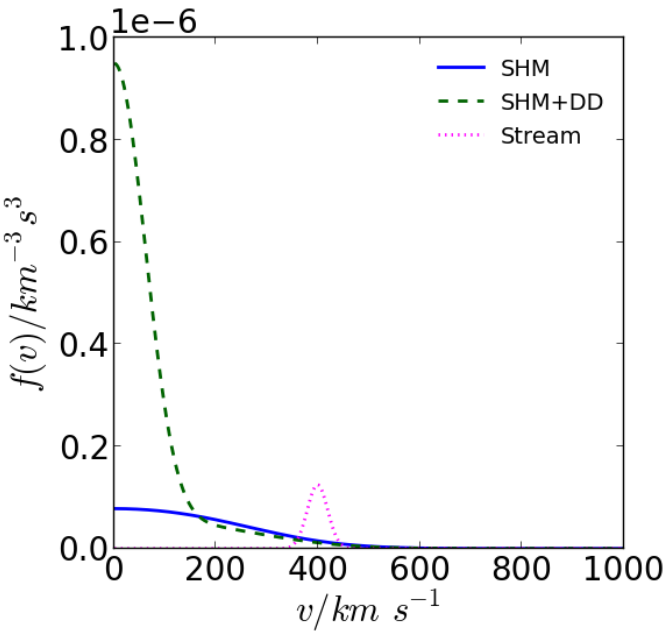
Based on work with Anne Green and Mattia Fornasa:

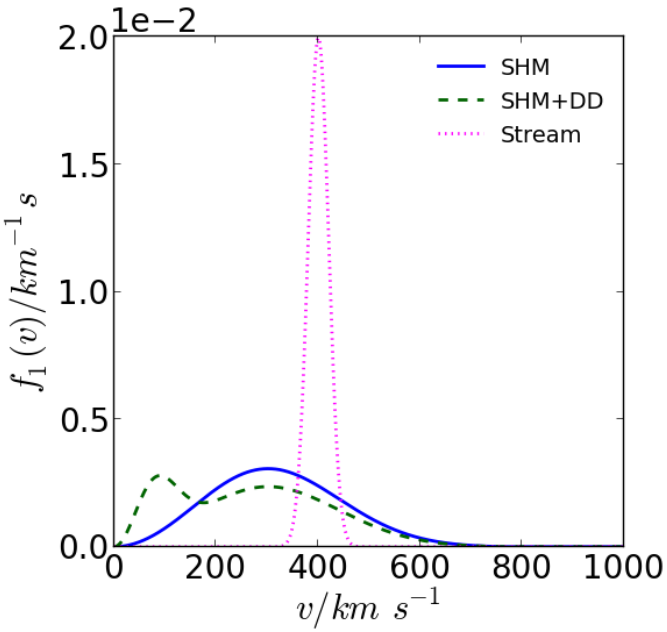
B J Kavanagh and A M Green, PRL 111 (2013) 031302 [arXiv:1303.6868]
B J Kavanagh, PRD 89 (2014) 085026 [arXiv:1312.1852]
M Fornasa, A M Green and **B J Kavanagh** (2014) [arXiv:1407.XXXX]

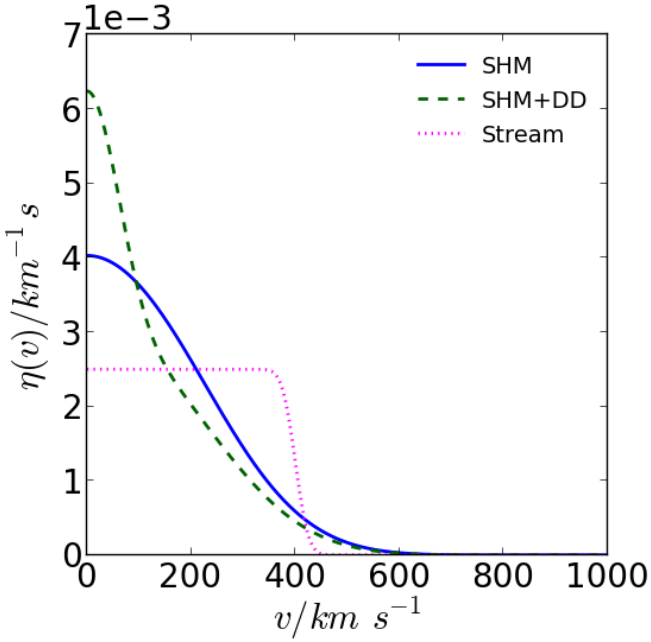
Astroparticle Physics 2014, Amsterdam
23/06/2014

Speed distribution uncertainties

SHM ——— SHM + 30% dark disk – – – Stream ·····







$$f(v) = \int f(\mathbf{v})\,\mathrm{d}\Omega_v \qquad f_1(v) = v^2 f(v) \qquad \eta(v) = \int_v^\infty \frac{f_1(v')}{v'}\,\mathrm{d}v'$$

Possible approaches

- Incorporate uncertainties in SHM parameters

  Strigari & Trotta [arXiv:0906.5361]

- Attempt to measure $\eta(v_{\min})$ from the data (assuming a particular value for m_χ)

  Fox, Liu & Weiner [arXiv:1011.1915]
  Frandsen et al. [arXiv:1111.0292]

- Write $\eta(v_{\min})$ as a large number of steps and optimise the step heights

  Feldstein & Kahlhoefer [arXiv:1403.4606]
  See talk by Felix Kahlhoefer this afternoon

- Write down a general parametrisation for $f(v)$ and fit the parameters to data

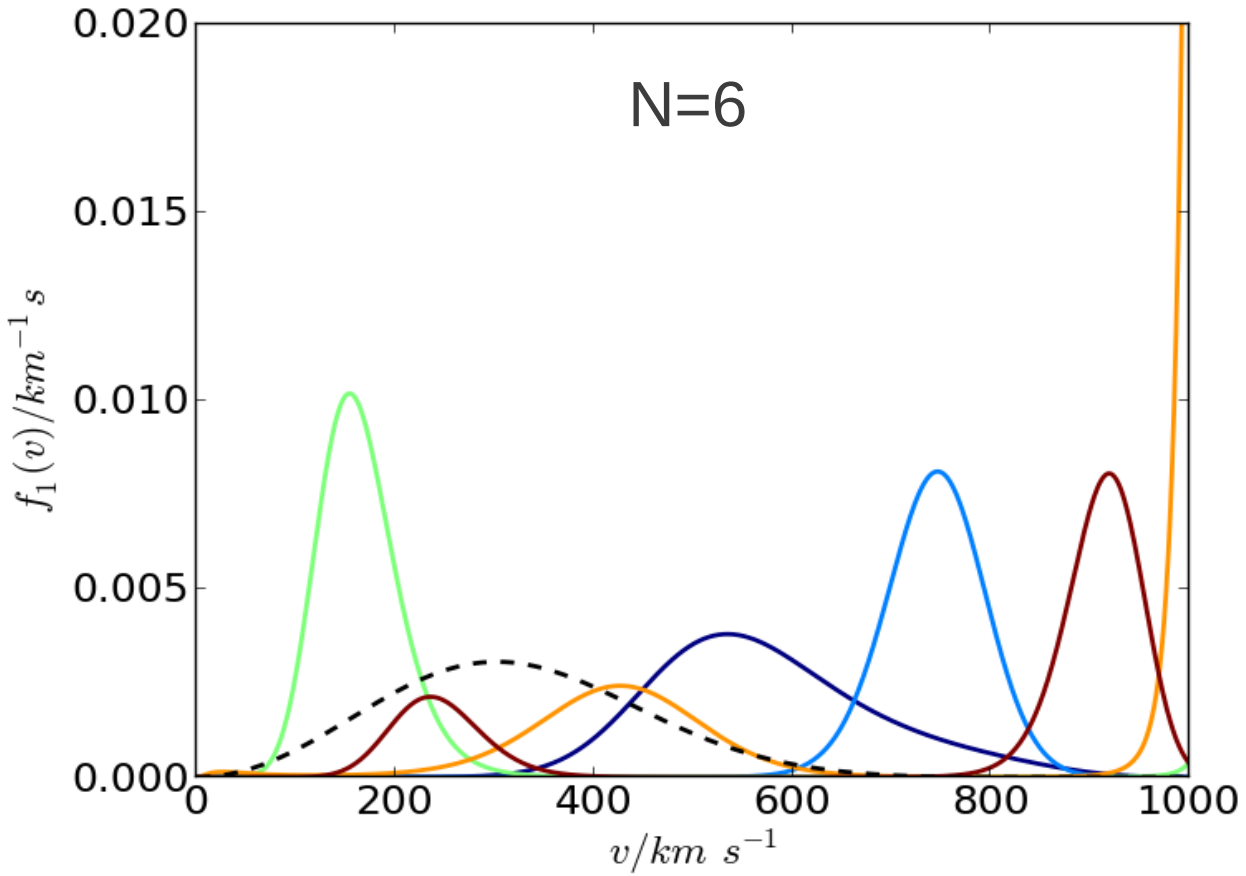
  Peter [arXiv:1103.5145]

A general parametrisation

$$\ln f(v) = \sum_{k=0}^{N-1} a_k P_k(v)$$

Polynomial basis functions

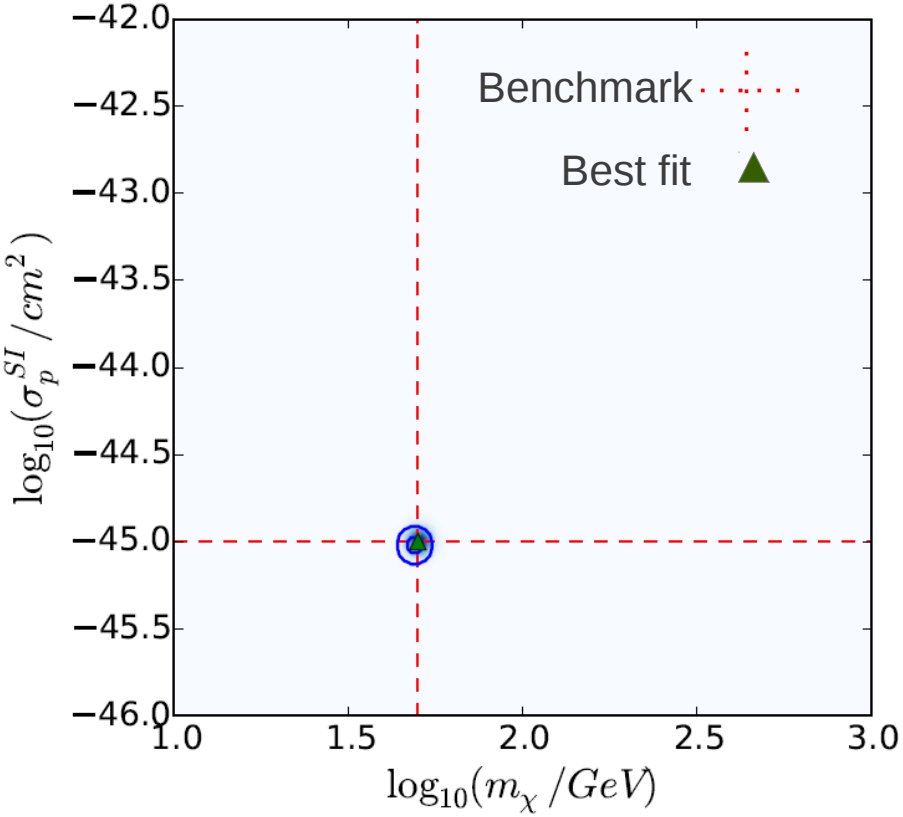
Parameters



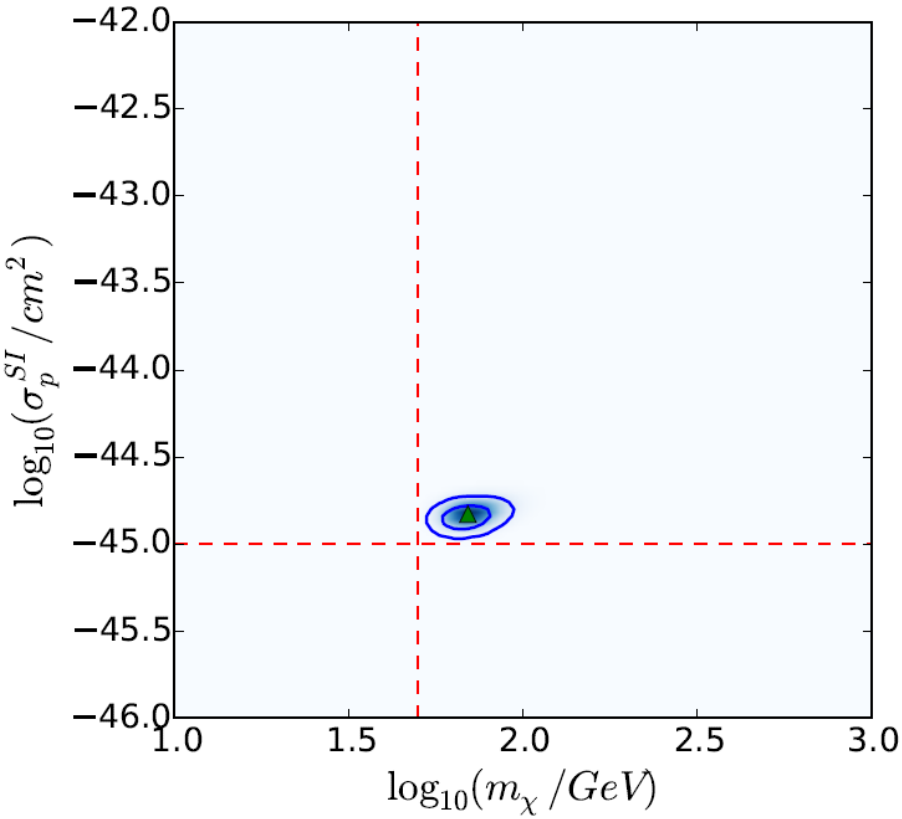
Impact of uncertainties

Generate mock data for 3 future experiments (Xe, Ar, Ge), for a stream distribution function. Reconstruct $(m_\chi, \sigma_{\rm p}^{\rm SI})$ assuming:

(correct) stream distribution



(incorrect) SHM distribution



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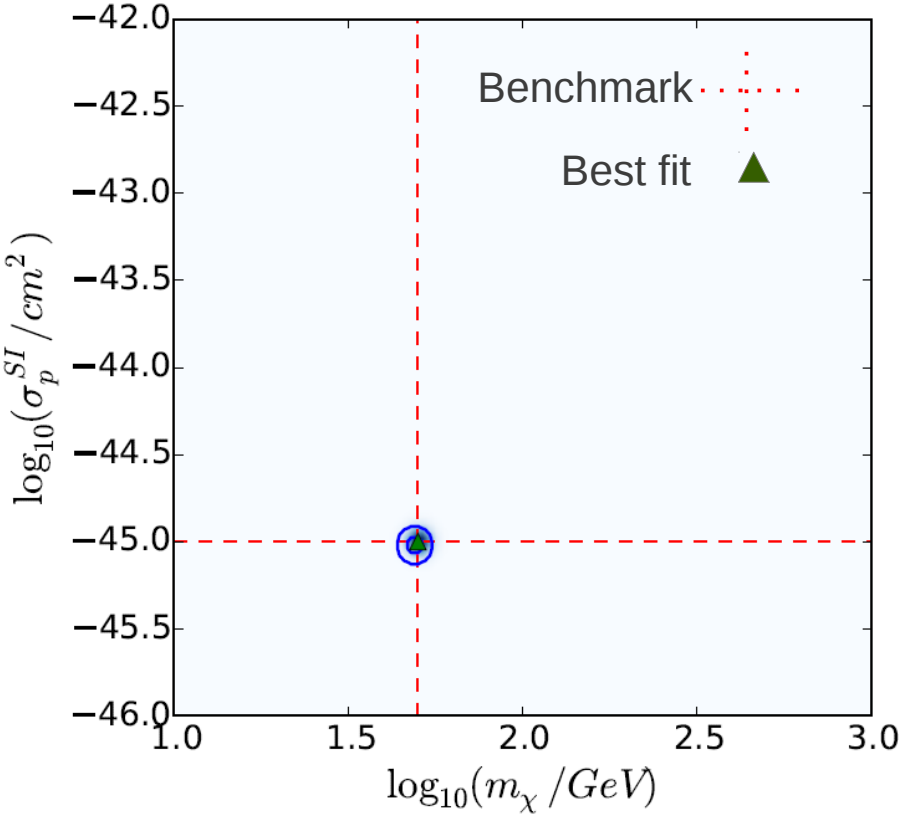
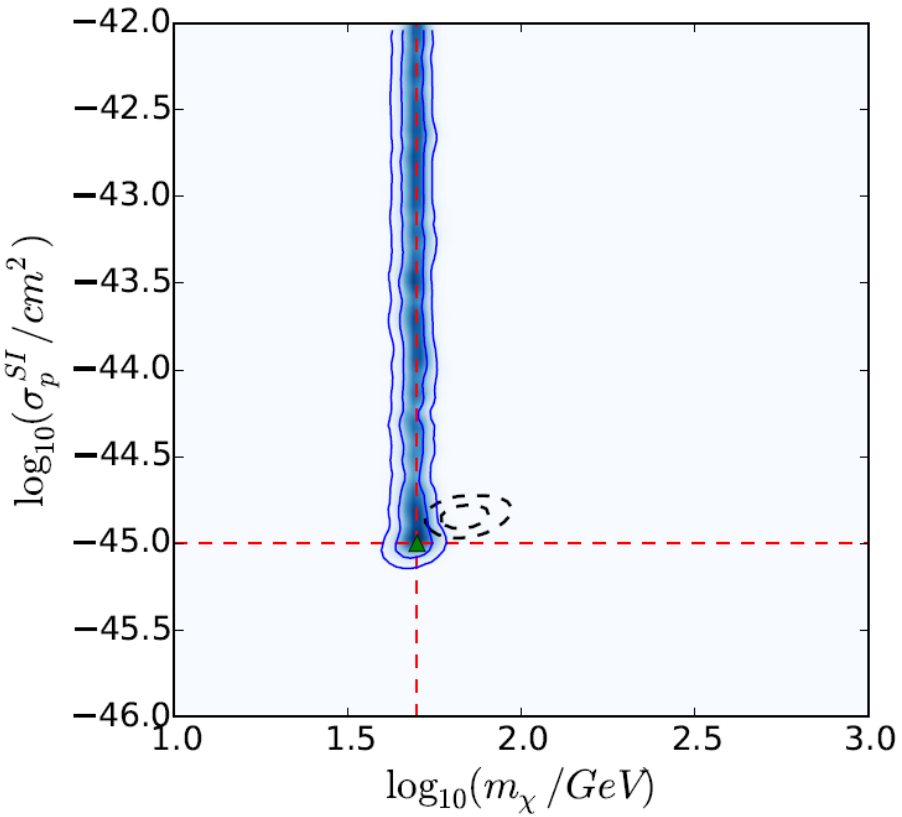


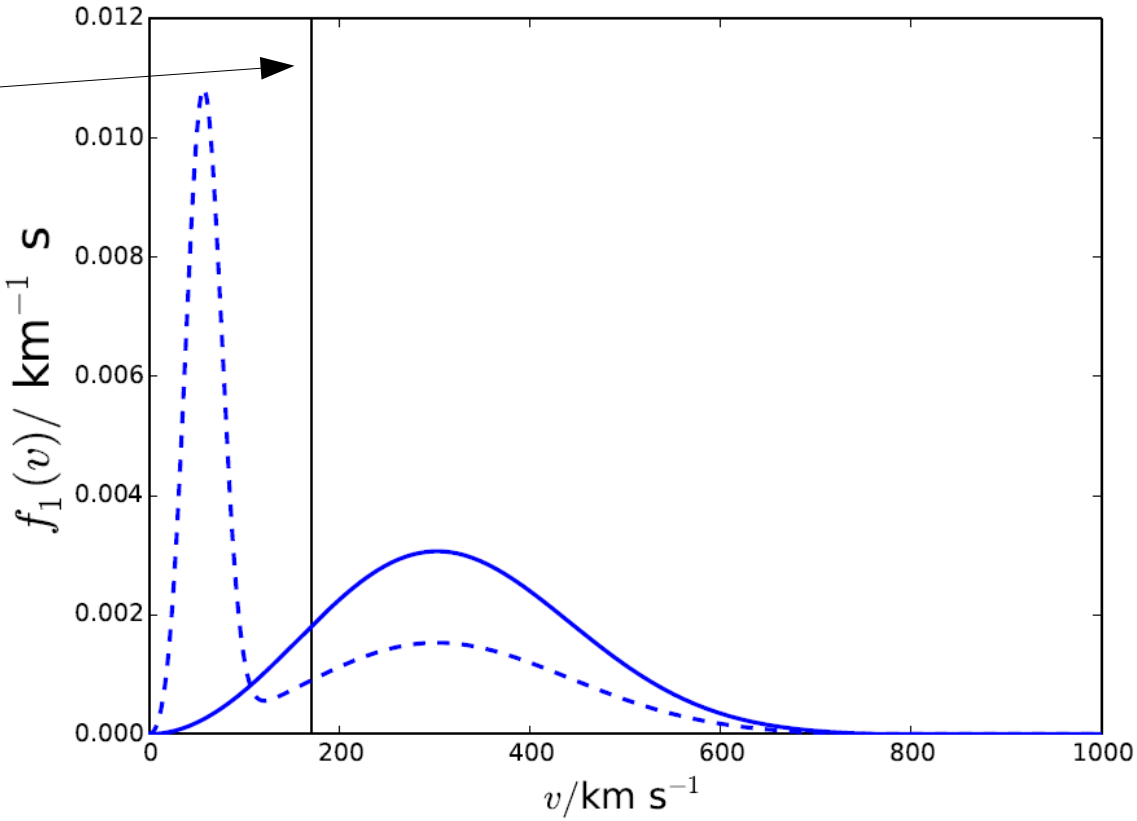
using our parametrisation



The cross-section degeneracy

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} \propto \sigma \int_{v_{\mathrm{min}}}^{\infty} \frac{f_1(v)}{v}\,\mathrm{d}v$$

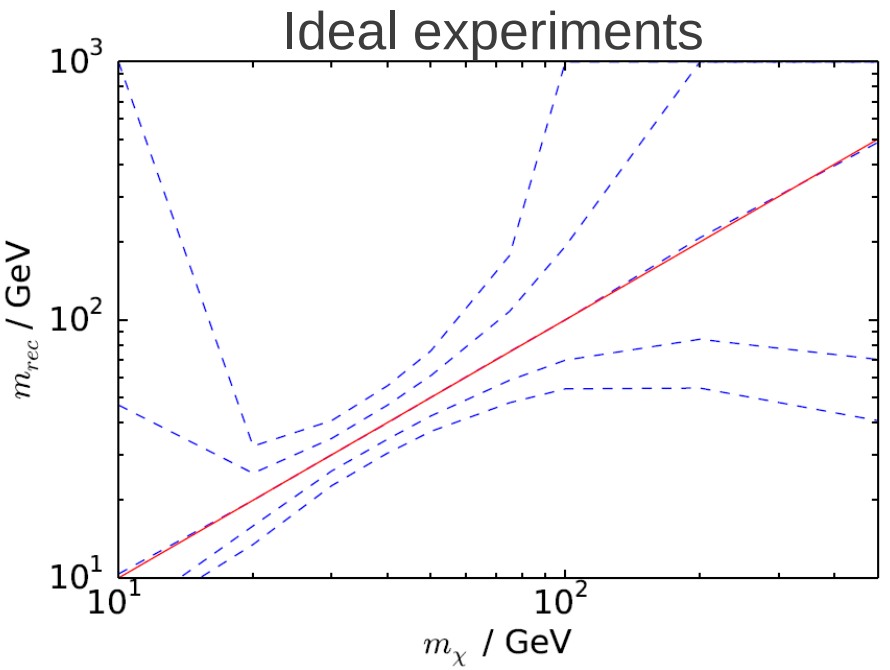
Minimum WIMP speed accessible with Xenon for $E_{\mathrm{th}} = 5\ \mathrm{keV}$ and $m_\chi = 50\ \mathrm{GeV}$

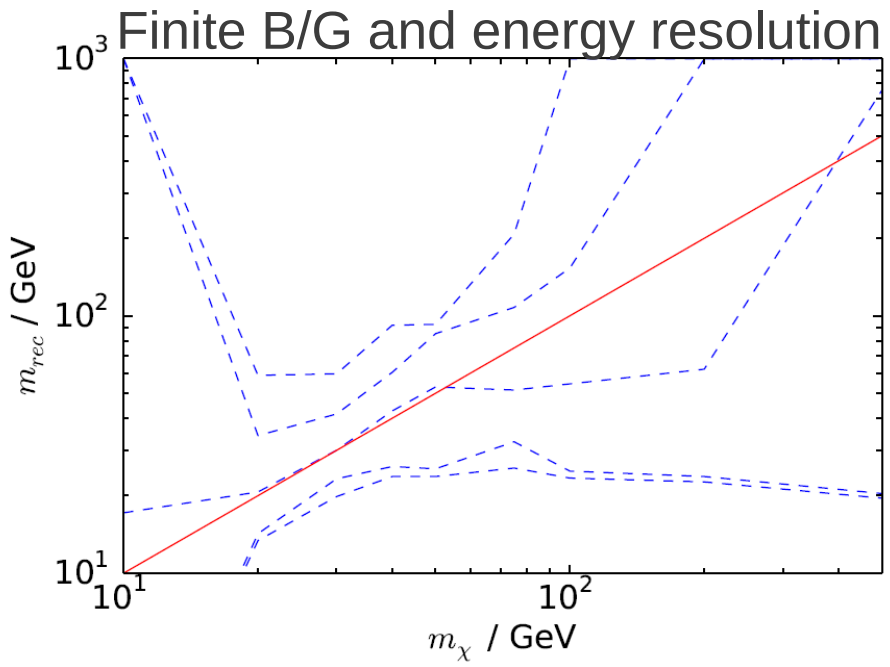


WIMP mass reconstruction

WIMP mass accurately reconstructed for :

- Wide range of input WIMP masses
- Range of input speed distributions
- Finite backgrounds and energy resolution
- Data including Poisson noise





Incorporating IceCube

IceCube detector is sensitive to neutrinos from annihilating WIMPs captured in the Sun

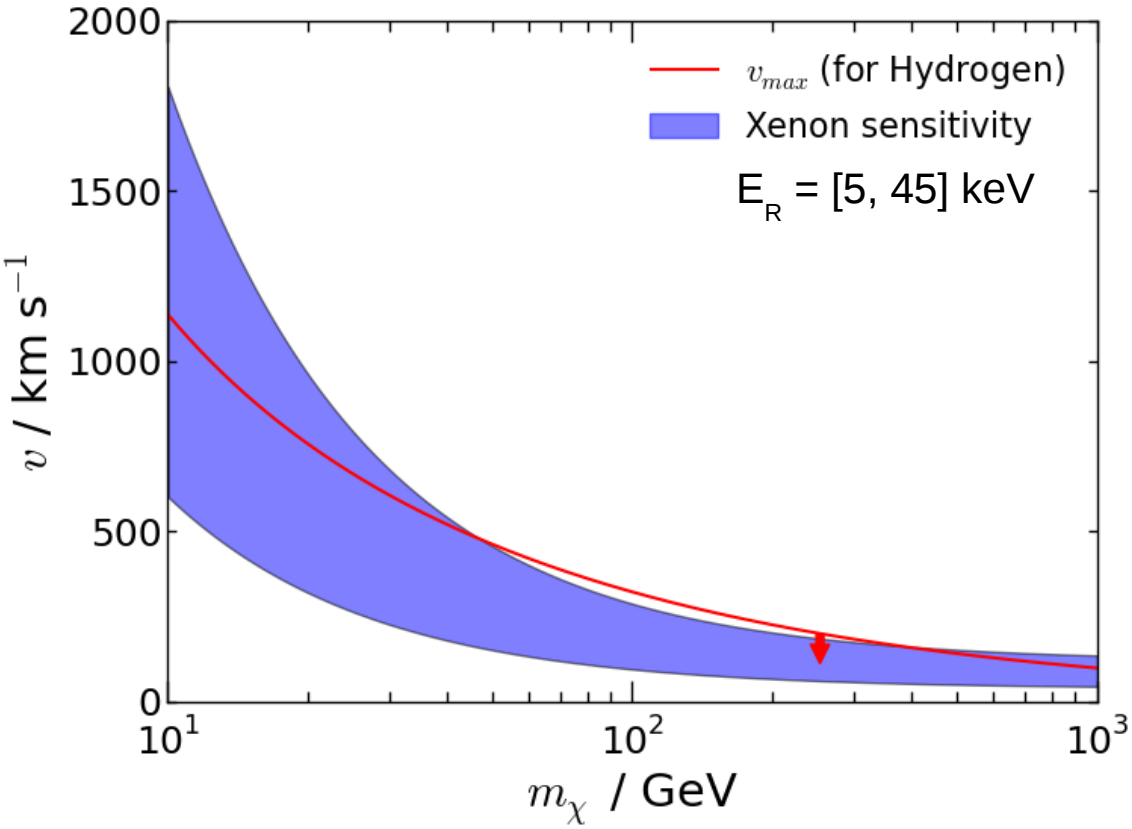
WIMP capture rate in the Sun due to species i:

$$\frac{\mathrm{d}C_i}{\mathrm{d}V} = \int_0^{v_{\mathrm{max}}} \mathrm{d}v \, \frac{f_1(v)}{v} \, w \, \Omega^-_{v_{\mathrm{esc}},i}(w)$$

"down-scatter rate"

Low speed WIMPs preferentially captured

NB: Need to include SD scattering

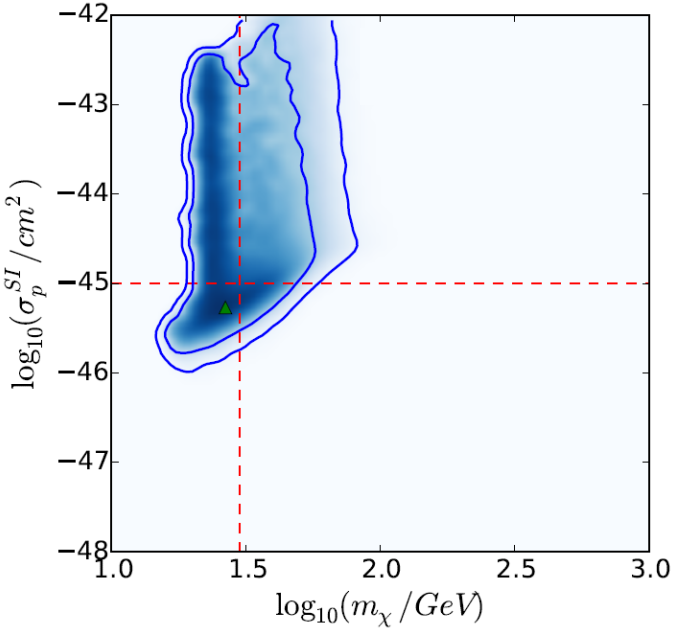


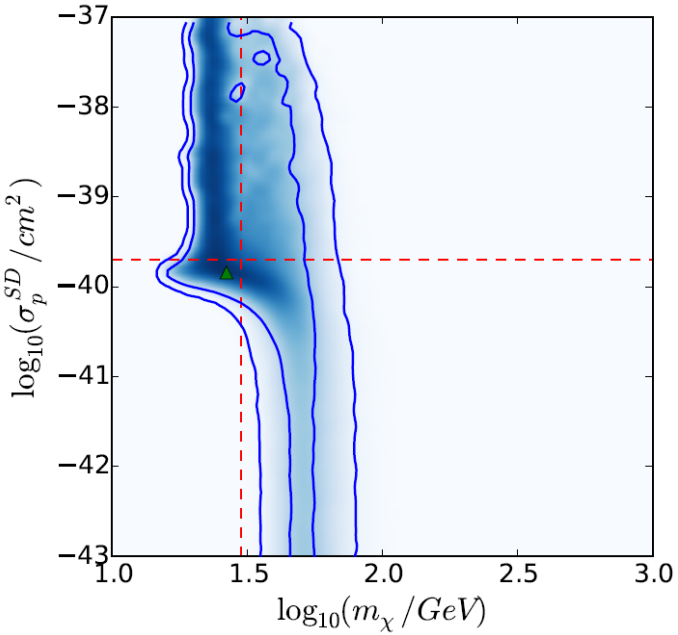
Reconstruction without IceCube

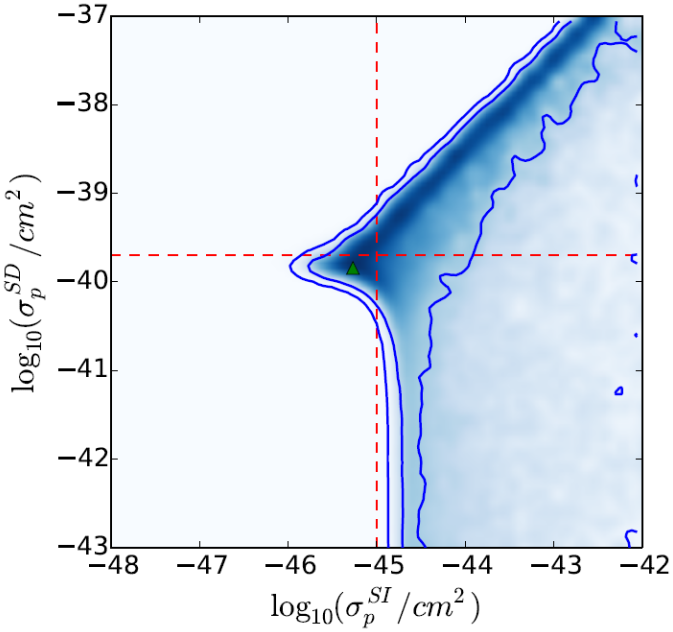
Benchmark: $m_\chi = 30\ \mathrm{GeV}$,

annihilation to $\nu_\mu \bar{\nu}_\mu$, SHM + dark disk distribution

Reconstructed using polynomial $\ln f(v)$ parametrisation (N=6)







Reconstruction *with* IceCube

Benchmark: $m_\chi = 30\ \mathrm{GeV}$,

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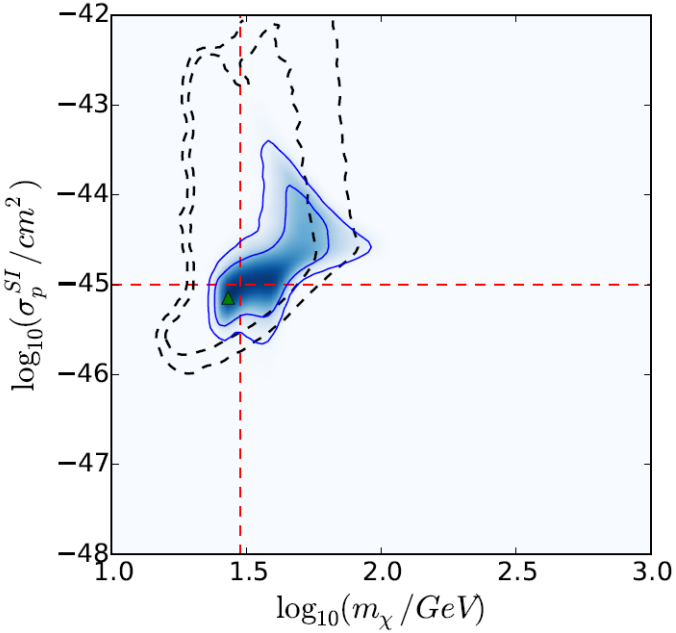
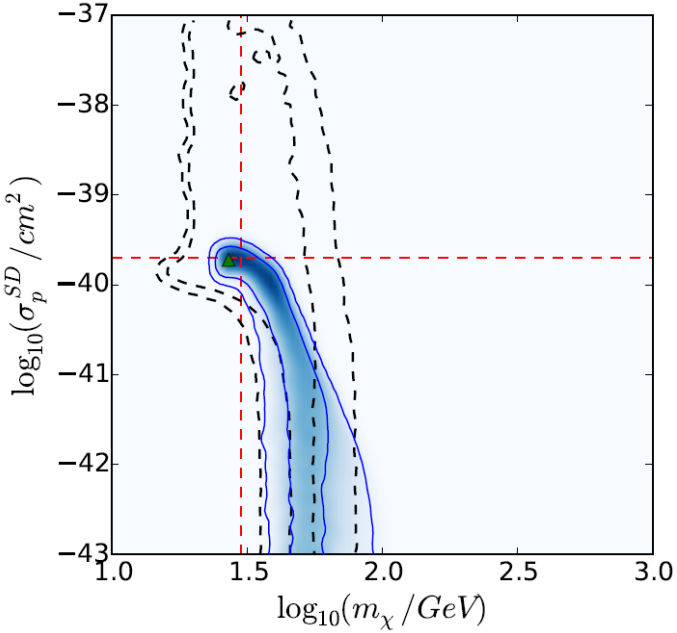
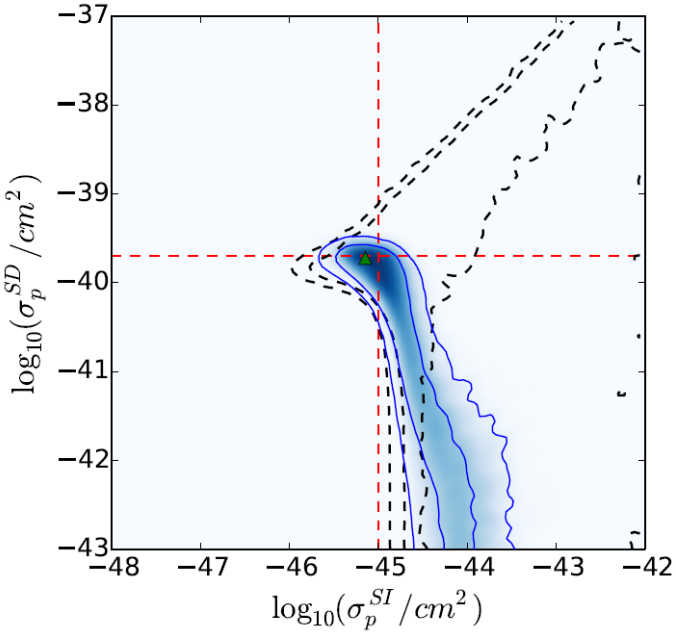




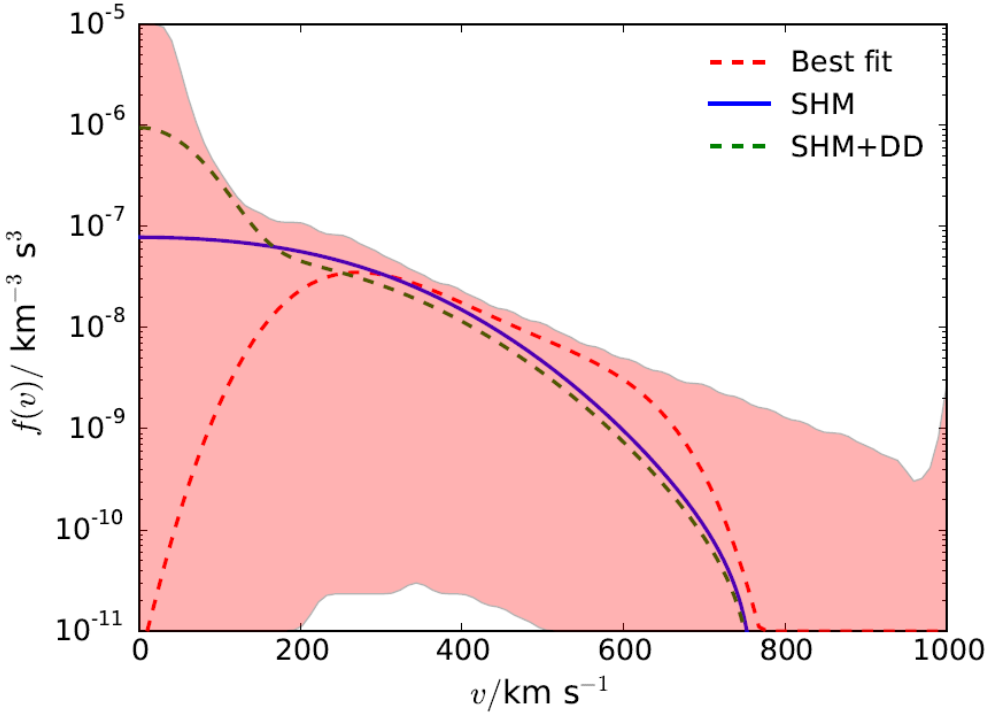


Reconstructing the speed distribution

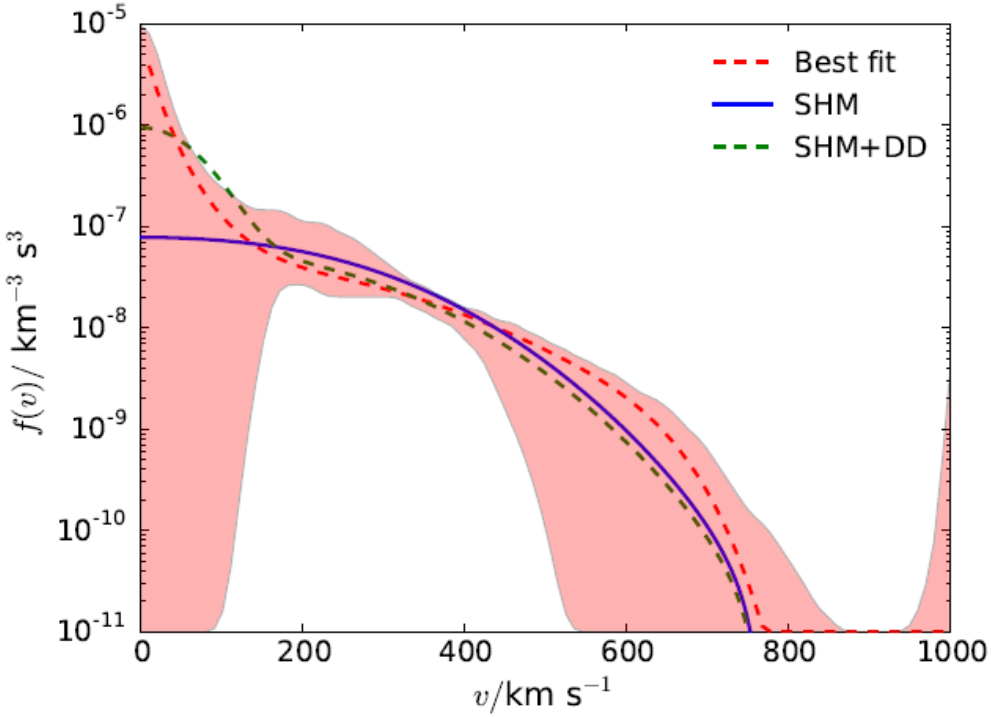
Benchmark is: $m_\chi = 30\ \mathrm{GeV}$, SHM + dark disk distribution

Reconstructed using polynomial $\ln f(v)$ parametrisation...

Without IceCube data



With IceCube data



Conclusions

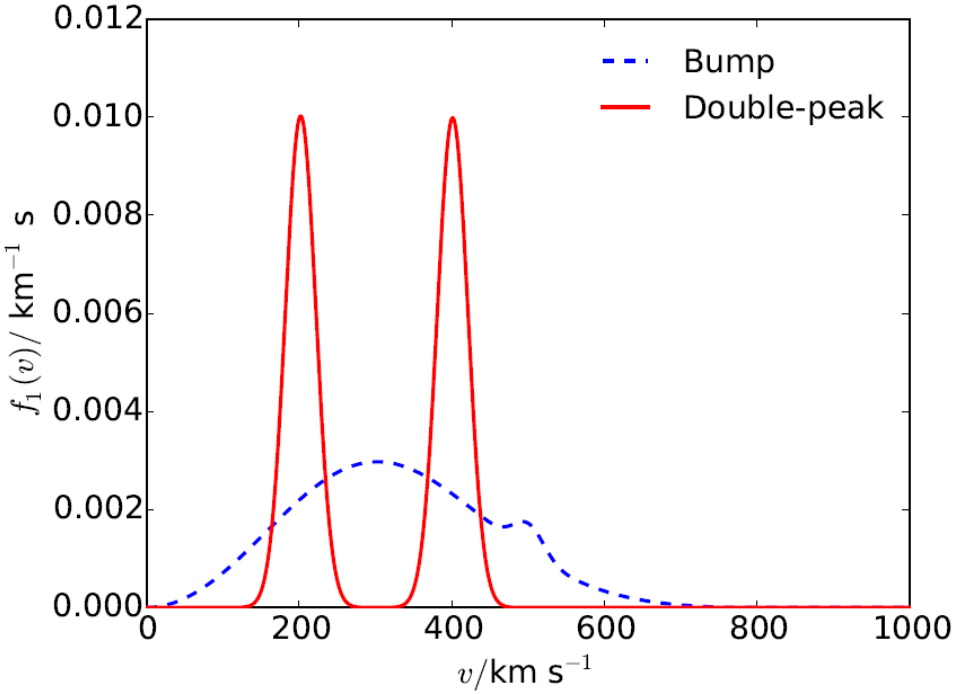
- Astrophysical uncertainties are important in direct detection analysis
- We propose a new parametrisation:

$$\ln f(v) = \sum_{k=0}^{N-1} a_k P_k(v)$$

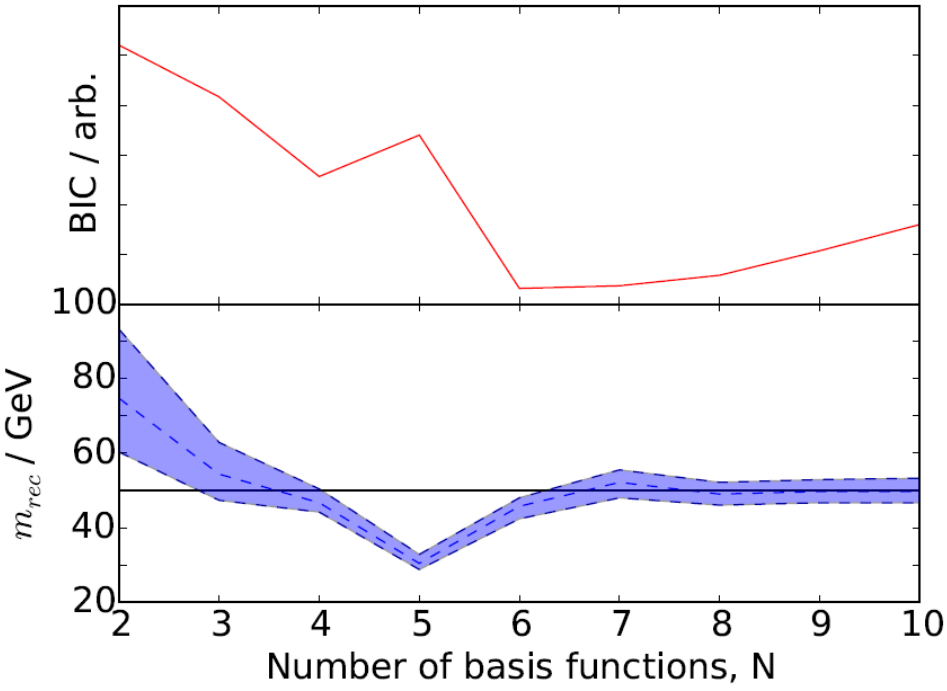
- WIMP mass can be recovered from direct detection experiments with *no assumptions* about the speed distribution
- Including IceCube data means the WIMP mass, SI and SD cross sections *and* speed distribution can all be reconstructed

Back-up slides

Number of basis functions

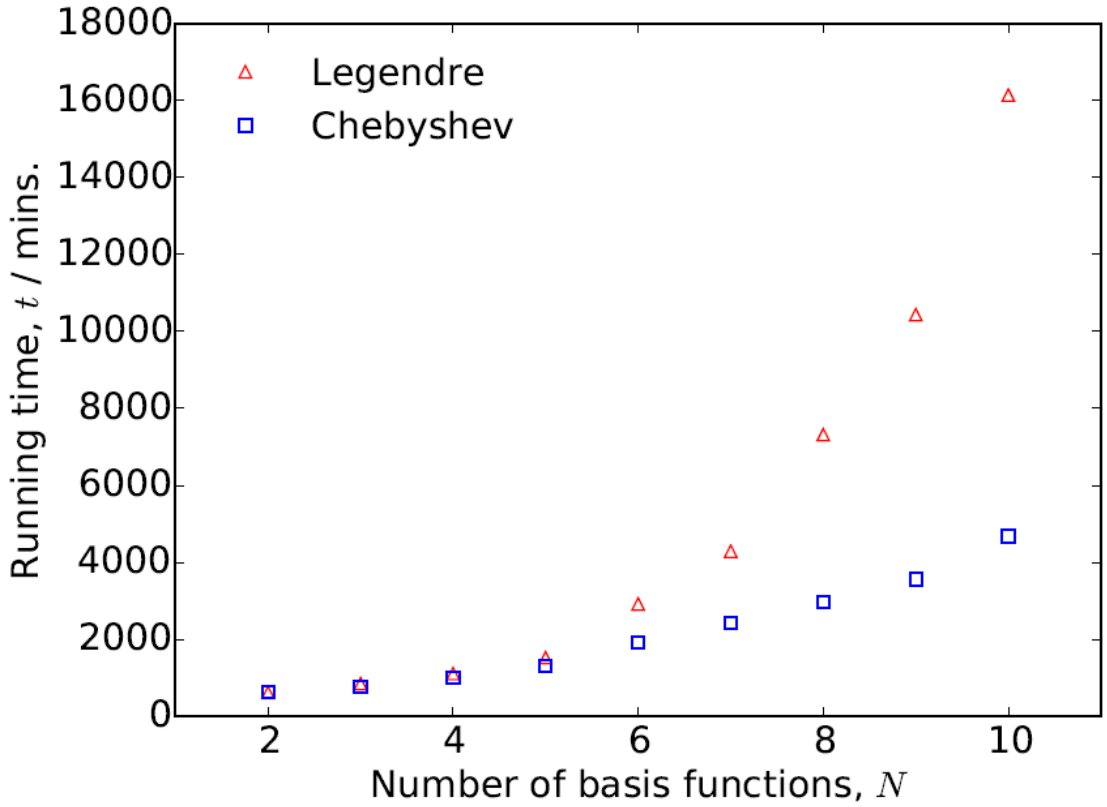


Double-peak distribution function



$$BIC = 2N_p \ln(N_m) - \ln(\mathcal{L}_{\max})$$

Choice of basis function



Reconstructing the speed distribution

Benchmark is: $m_\chi = 100\ \mathrm{GeV}$, SHM distribution

Reconstructed using polynomial $\ln f(v)$ parametrisation...

With IceCube data