Reconstructing WIMP Properties
[With ...(?) events]

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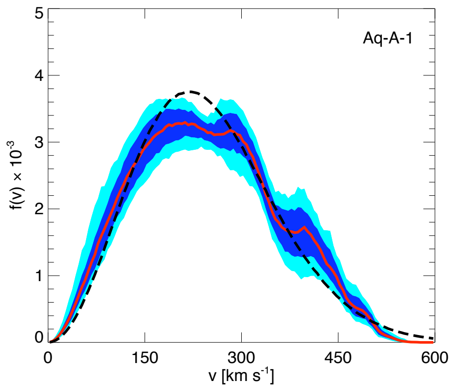
KIPAC

KITP: Direct, Indirect, and Collider Signals of Dark Matter
Dec. 15, 2009

Milky Way Dark Matter halos: Theory

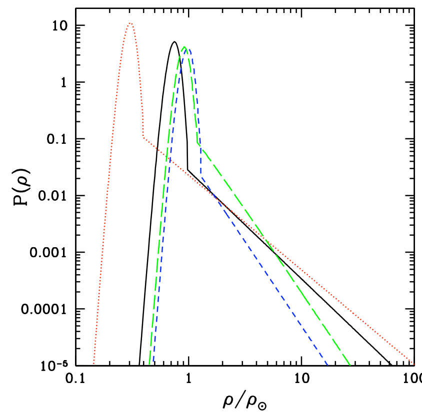


Vogelsberger et al., MNRAS 2009

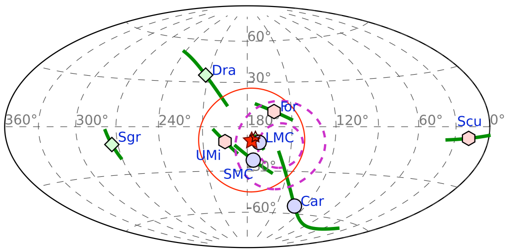
Measured distribution of speeds near solar circle implies 10% variation relative to multivariate gaussian fit

Including substructure, local density probably not less than 1/2 the canonical value

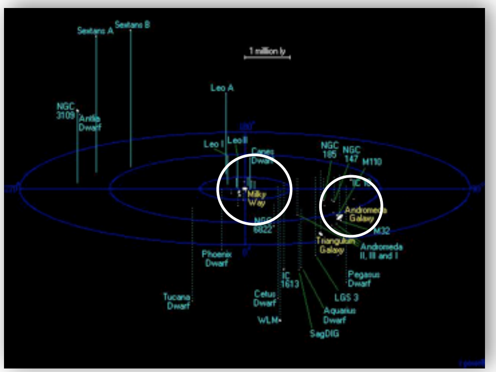
Kamionkowski & Koushiappas 2008



Dark Matter in Local Group



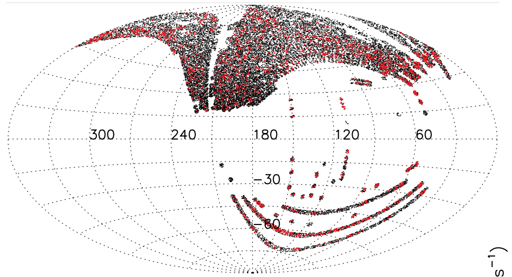
Metz & Kroupa 2008



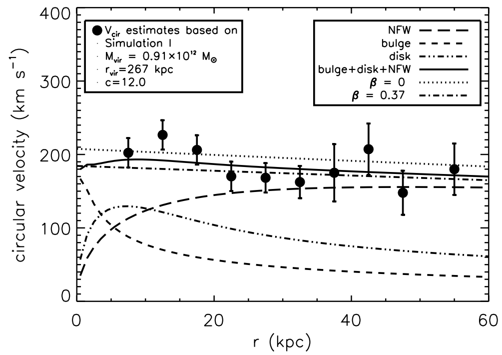
Updated applications of Timing argument imply Local Group mass of 5 x 10^{12} Msun and MW mass of 2 x 10^{12} Msun [van der Marel & Guthalakurta 2008, Li & White 2008]

- Ground-based proper motions: Scholz & Irwin 1994, Schweitzer et al. 1997, Ibata et al. 1997, Dinescu et al. 2005
- Space-based proper motions: Piatek et al. 2002-2007

The Milky Way Dark Matter Halo



Xue et al. 2008 uses population of 2000 BHB stars out to 60 kpc

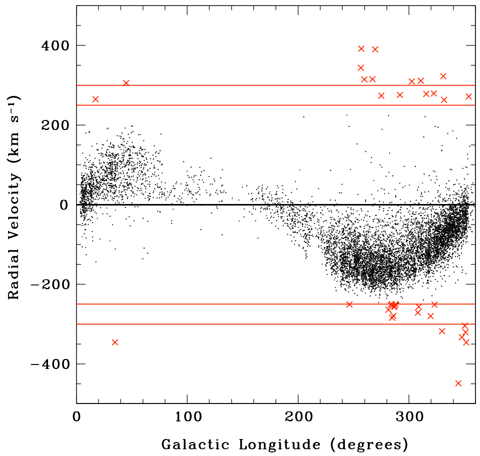


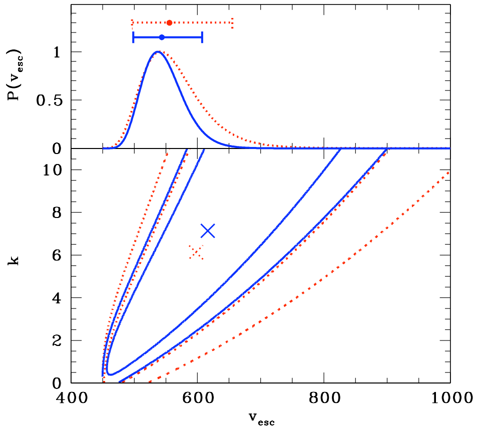
Mass estimates broadly consistent with those that use satellite dynamics (Frenk & White 1981, Little & Tremaine 1987, Kochanek 1996, Evans & Wilkinson 1999, Li & White 2008)

Escape Velocity

$$f(|\mathbf{v}|\,|\,v_{\rm esc},k) \propto (v_{\rm esc} - |\mathbf{v}|)^k, \quad |\mathbf{v}| < v_{\rm esc}$$

$$f(|\mathbf{v}|\,|\,v_{\rm esc},k) = 0, \quad |\mathbf{v}| \geqslant v_{\rm esc},$$

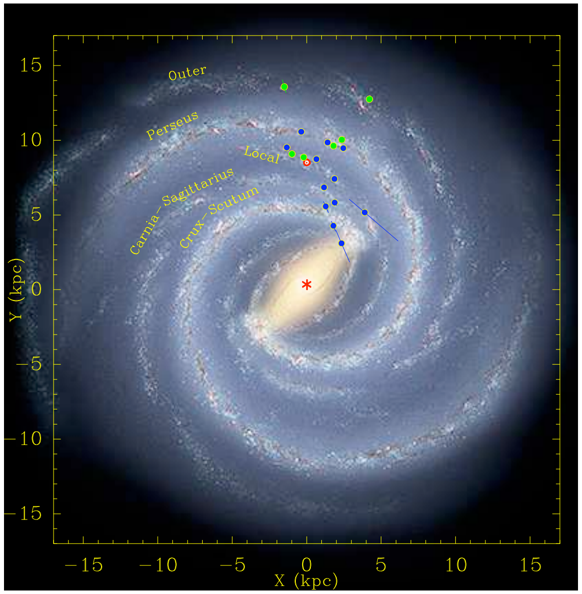




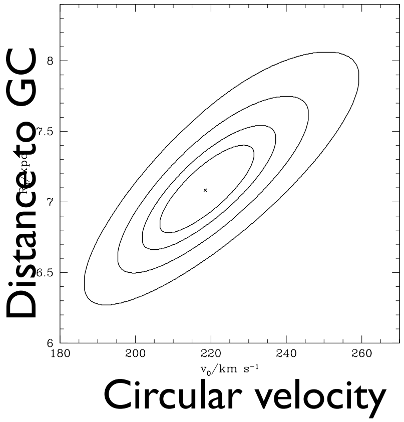
Escape Velocity

Smith et al.,
Mon.Not.Roy.Astron.Soc.379:755-772,2007

Circular velocity

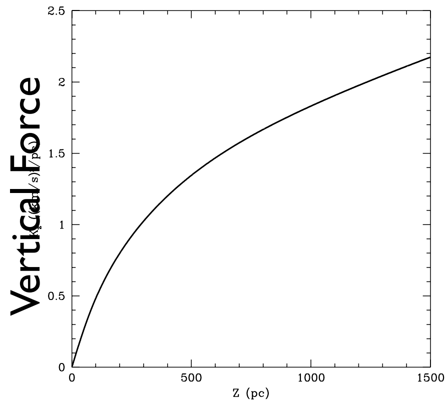


Reid et al. 2009

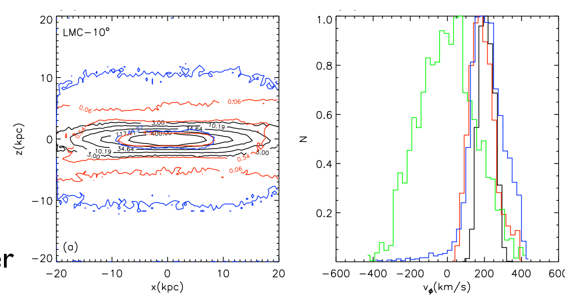


McMillan & Binney 2009

Disk Dark Matter



Constrains contribution from a ``dark matter disk”
Read, Bruch, et al. 2009



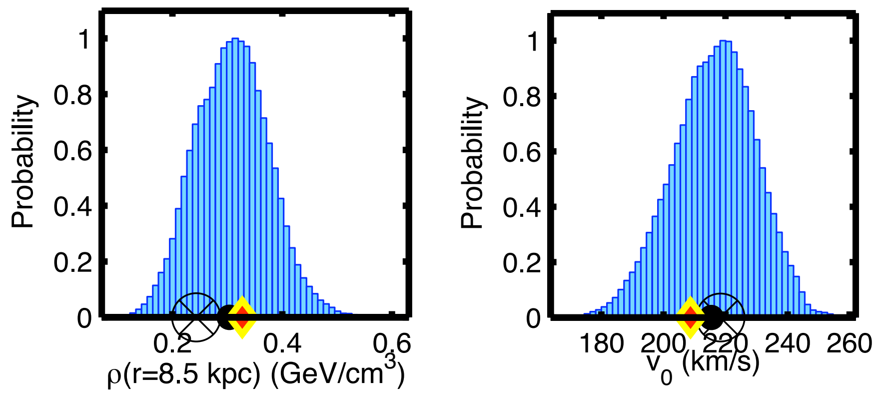
Oort, 1930
Bahcall 80’s-90’s
Kuijken & Gilmore 1991
Holmberg & Flynn 2004

Dynamical matter
$56 \pm 6\,\mathrm{M}_{\odot}\,\mathrm{pc}^{-2}$

Visible matter
$53\,\mathrm{M}_{\odot}\,\mathrm{pc}^{-2}$

How much dark matter in your coffee cup?

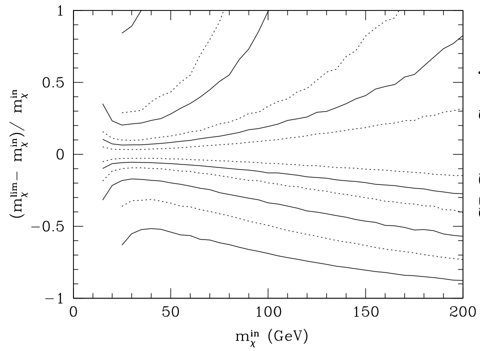
Metropolis-hastings method determine Galactic model parameters
[Dehnen & Binney 1998, Widrow et al. 2008, Catena & Ullio 2009, Strigari & Trotta 2009]



Strigari & Trotta in prep.

Example with SDSS stars and escape velocity constraints.

Constraining WIMPs w/o astrophysics

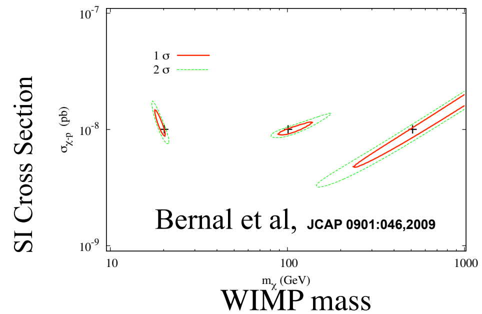


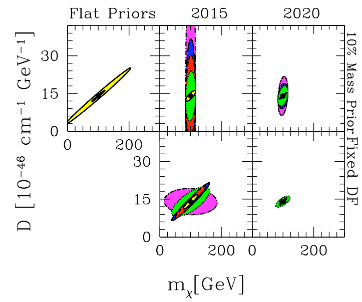
10^3-10^5 kg/day exposure for Ge

Low mass WIMPs more strongly constrained

Anne Green, **JCAP 0807:005,2008**

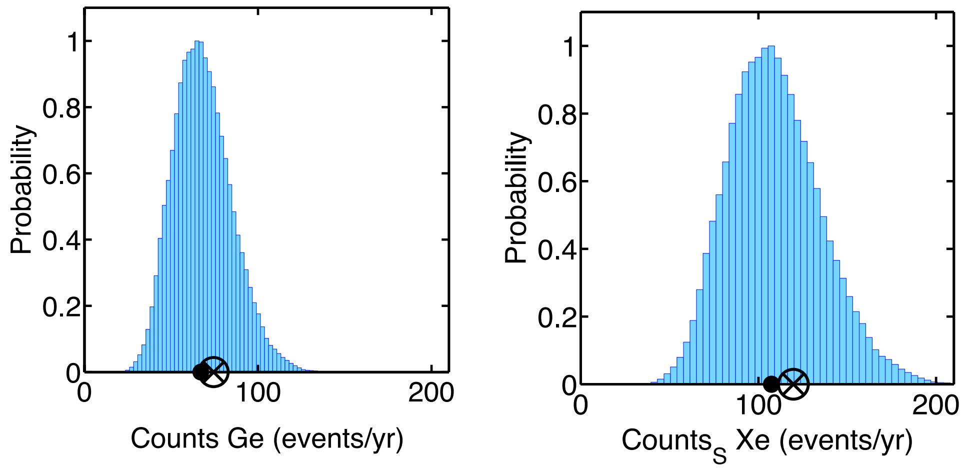
Shan, arXiv:0903.4320 [hep-ph]





A. Peter, arXiv:0910.4765v1

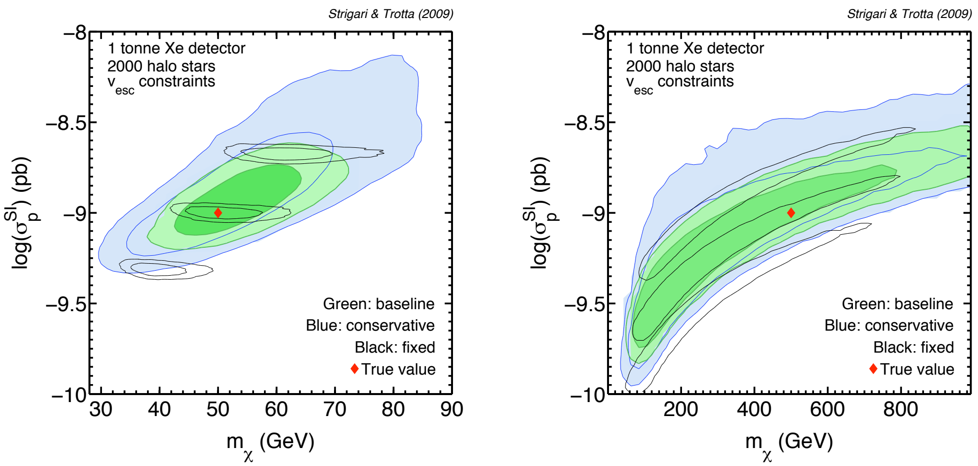
Ton scale detectors



Strigari & Trotta in prep.

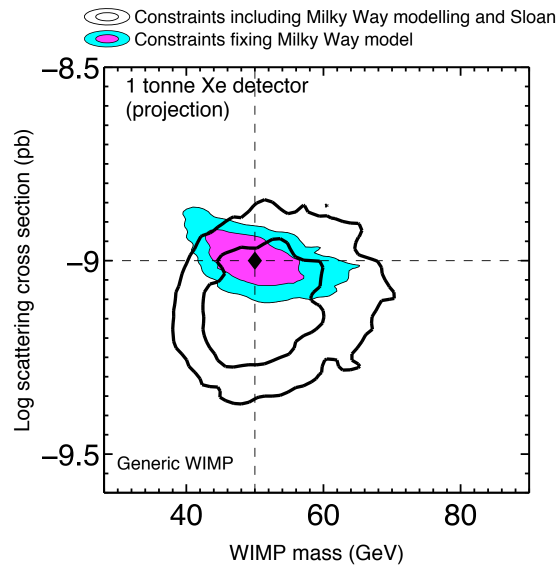
Example MCMC run with SDSS stars and escape velocity constraints.
For now assume a maxwellian velocity distribution

Projections



Approx. 300 (100) events for 50 (500) GeV WIMP

Constraints with data



Self-consistent Milky Way model

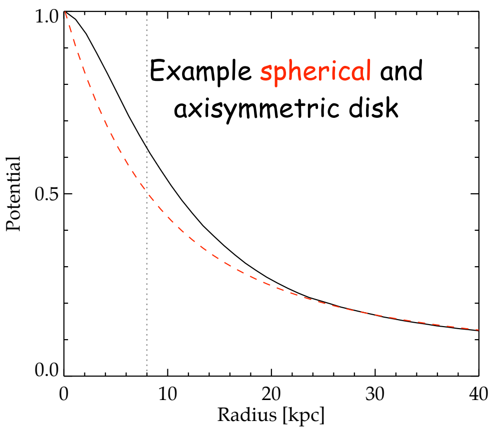
$$f\left(\mathcal{E},\, L_z,\, E_z\right) \;=\; f_{\rm disk}\left(\mathcal{E},\, L_z,\, E_z\right) \;+\; f_{\rm bulge}\left(\mathcal{E}\right) \;+\; f_{\rm halo}\left(\mathcal{E}\right)$$

Solve poisson equation for each component and sum to get the total potential

$$f_i\left(\mathcal{E}\right) = \frac{1}{\sqrt{8}\pi^2}\int_0^{\mathcal{E}} \frac{d^2\tilde{\rho}_i}{d\Psi_{\rm total}^2}\frac{d\Psi_{\rm total}}{\sqrt{\mathcal{E}-\Psi_{\rm total}}}$$

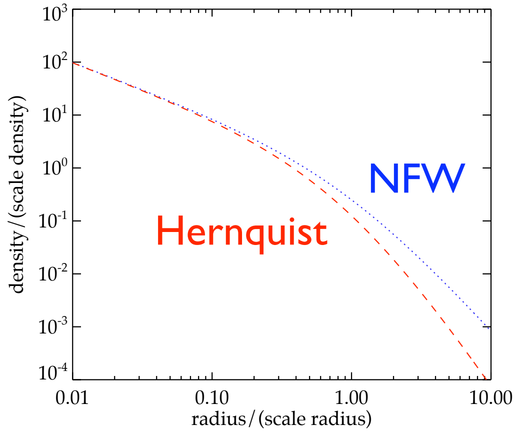
Stability requires integrand to be a monotonic function of energy

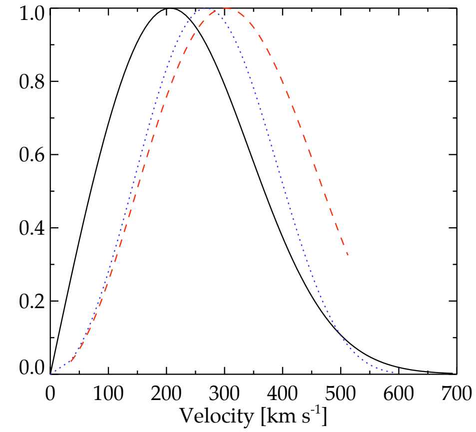
$$\phi_{\rm disk} = -GM_{\rm disk}(1 - e^{-r/b_{\rm disk}})/r$$



Realistic Velocity distributions

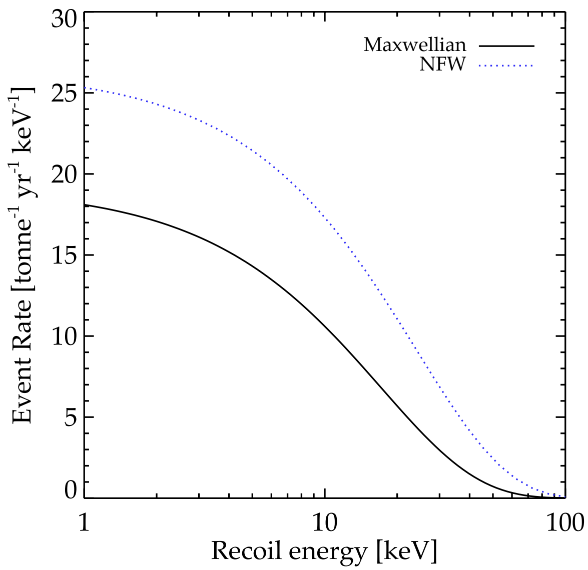
$$\rho(r) = \frac{\rho_0}{(r/r_0)^a[1+(r/r_0)^b]^{(c-a)/b}} \qquad g(v') = 2\pi\, v' \int_0^\pi d\alpha\ \sin\alpha\, \frac{F_{\rm dm}(\mathcal{E})}{\rho_0}$$





For halos that are normalized to the same circular velocity and local density

Event rate spectra



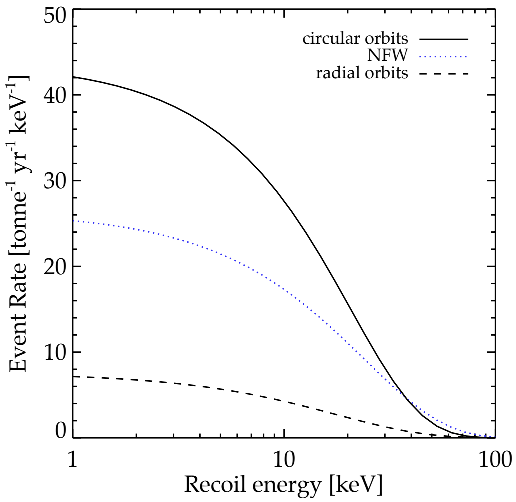
$\int_0^\epsilon f(\epsilon')d\epsilon'.$

$\epsilon = -v_{\rm min}^2/2 + \Psi(R_\odot)$

Event rate spectrum may probe flattening or rotation
[Kamionkowski & Kinkhabwala 1998]

Velocity spectrum more important for annual modulation
[Ullio & Kamionkowski 2001]

Event rate spectra: Anisotropic models



$$f(E,L) = L^{-2\beta} f_E(E)$$

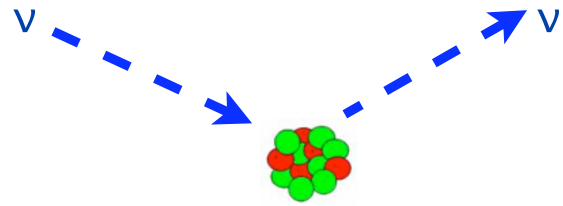
$$\beta = 1 - \langle v_T^2 \rangle / (2\langle v_r^2 \rangle)$$

$$f_E(E) = \frac{2^\beta (2\pi)^{-3/2}}{\Gamma(1-\lambda)\Gamma(1-\beta)} \frac{d}{dE} \int_0^E \frac{d\psi}{(E-\psi)^\lambda} \frac{d^n h}{d\psi^n},$$

$$h = r^{2\beta} \rho$$

In this model, enhanced event rates imply circular orbits

Neutrino Coherent Scattering



Cross Section: $\sigma \sim G_f^2 \, Q_w^2 \, E_\nu^2 \, F(Q^2)^2$

Weak charge: $Q_w^2 = N - (1 - 4\sin^2\theta_w)Z$

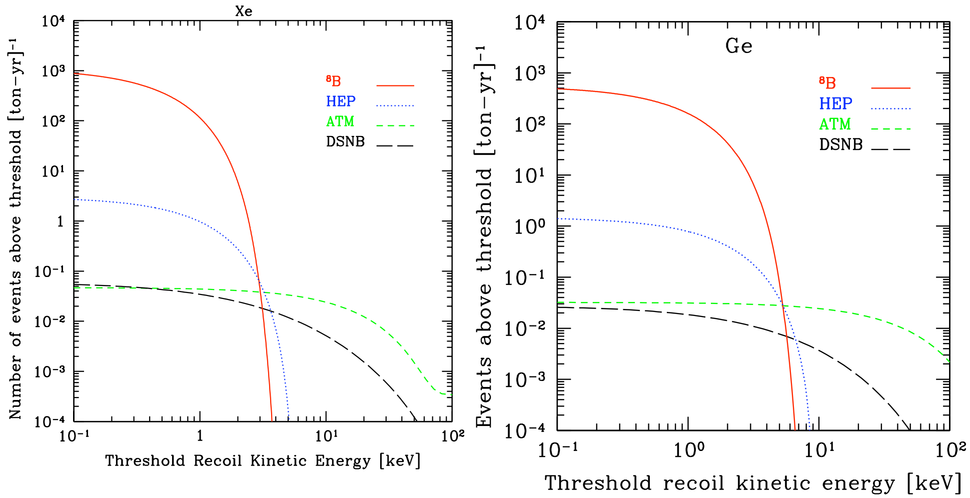
Coherence condition: [three-momentum] x [nuclear radius] ≤ 1

Implies sensitivity to neutrinos ~ 10 MeV

Fundamental prediction of the Standard Model, but not yet detected

Freedman 1974 PRD, Tubbs & Schramm 1975

Neutrino Backgrounds



Monroe and Fisher PRD 2008
Strigari, NJP 2009

Conclusion

- Assuming WIMPs are detected, over 100 events likely needed to determine mass
- ``Best way to determine the dark matter velocity distribution is to measure it directly"
  -H. Nelson, yesterday
- Era of ``Dark Matter Astronomy" close?