Determination of WIMP Mass (and Cross Section) with Direct Detection

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Direct Detection Mass Determination Basics

- Measure number of WIMP recoils and their recoil energies
  - Assume for this talk that detector cannot determine directionality (so no diurnal modulation), not enough statistics/stability to search for annual modulation
- Energy spectrum results from assumed WIMP velocity distribution + elastic scattering kinematics
  - Standard assumption is Maxwellian (isothermal halo)
  - See Lewin & Smith, *Astropart. Phys.* 6, 87 (1996) for review of details.
  - Recoil energy spectrum is roughly exponential e^{-aE} with coefficient

$$a \propto \frac{\left(1+\frac{M_T}{M}\right)^2}{v_0^2}$$

M_T ← Mass of target nucleus

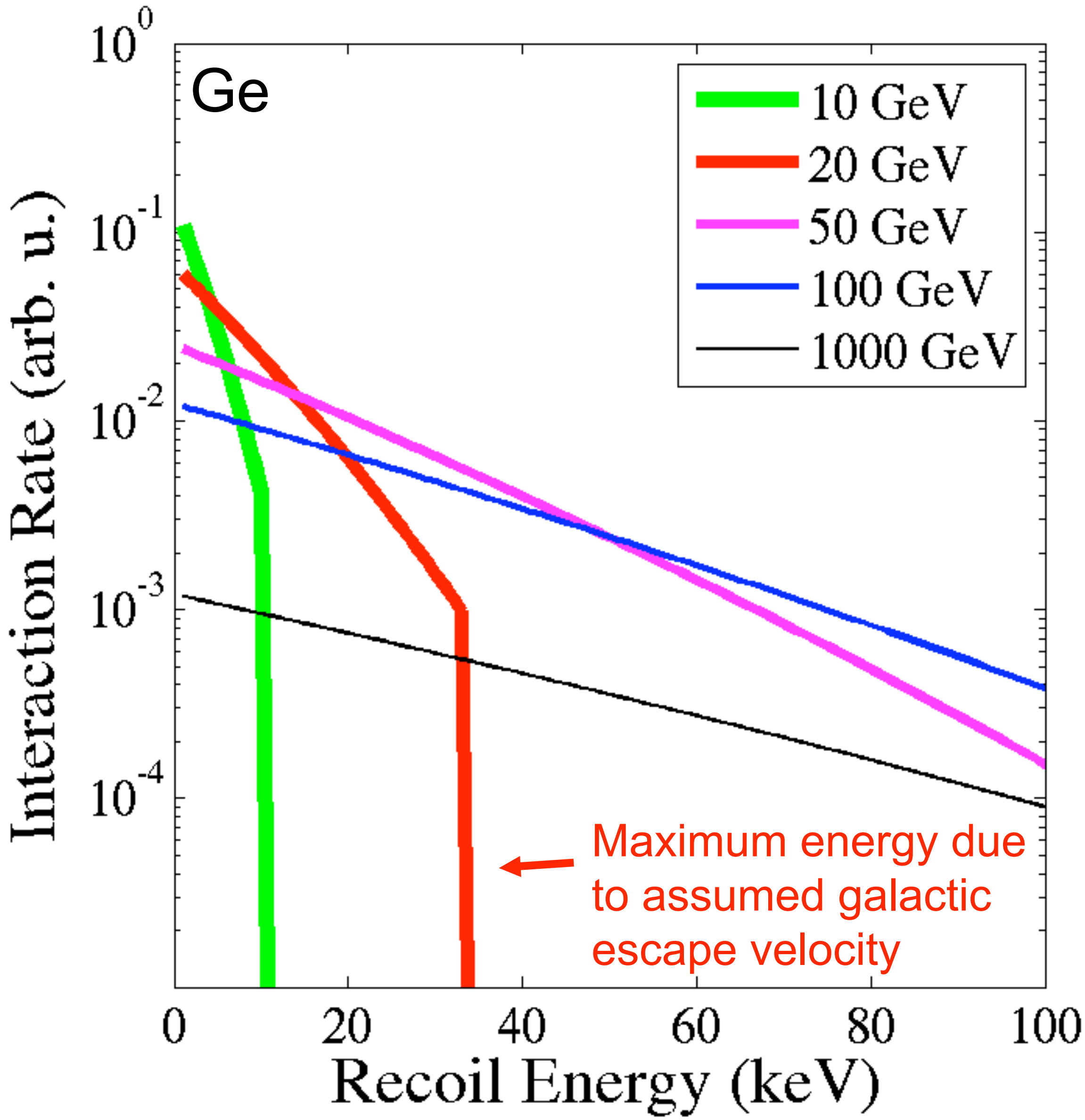
M ← WIMP Mass

v_0 ← Characteristic galactic velocity

So $a \propto M^{-2}$ for $M \ll M_T$

a = constant for $M \gg M_T$

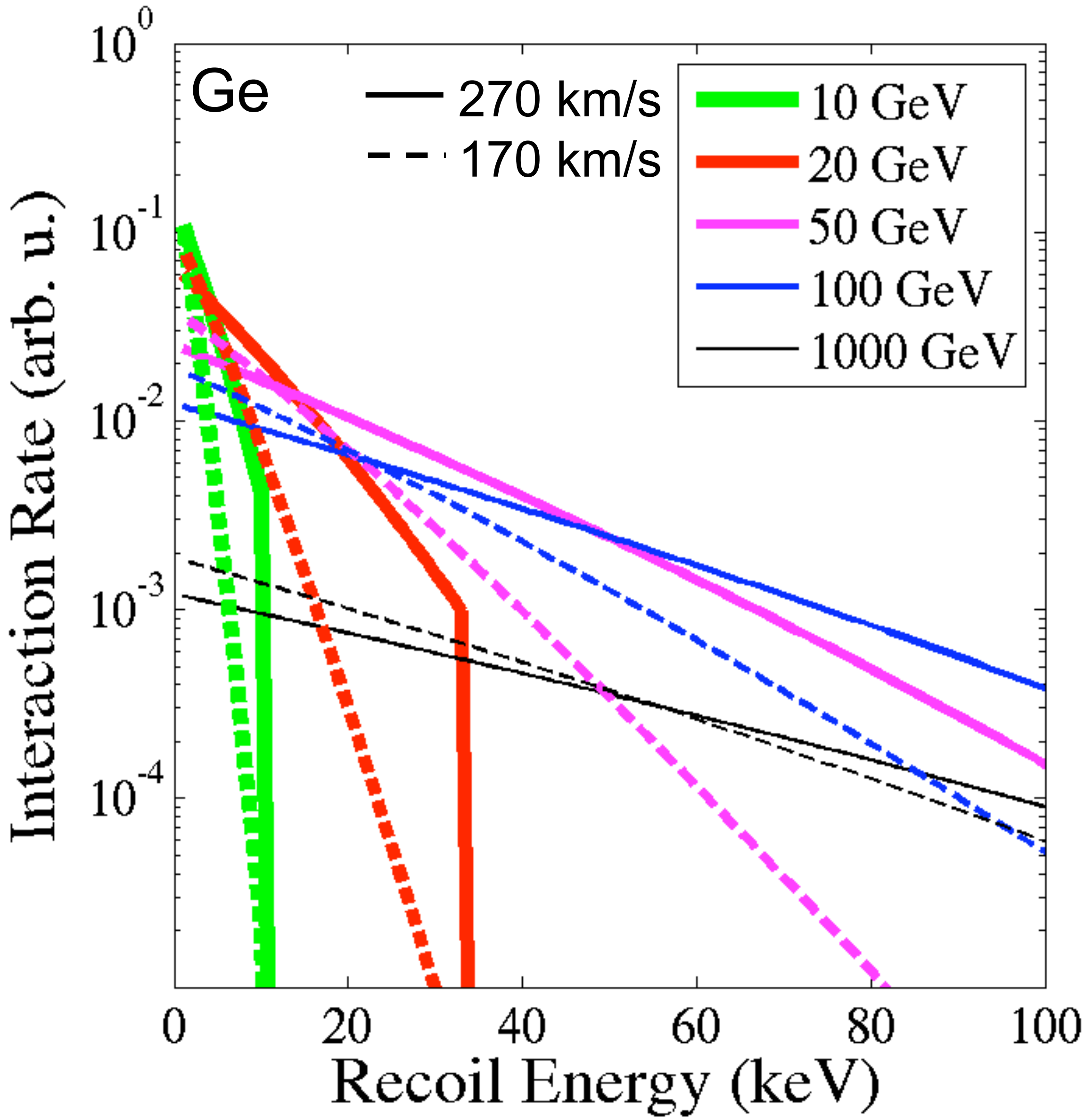
Dependence of Spectrum on Mass



$$a \propto \frac{\left(1 + \frac{M_T}{M}\right)^2}{v_0^2}$$

- Larger WIMP mass *M* yields harder energy spectrum (but small effect for large masses)

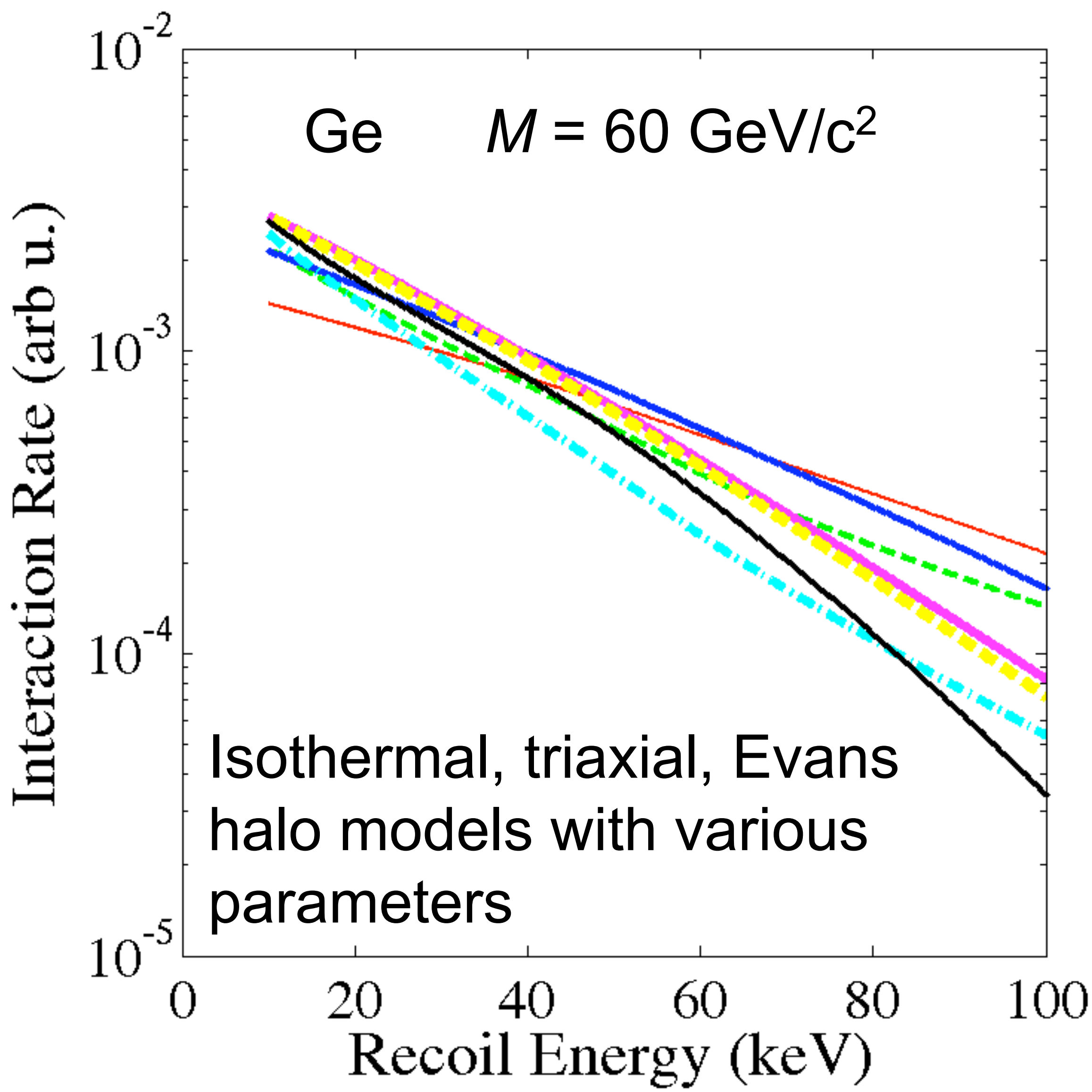
Dependence of Spectrum on Mass, v_0



$$a \propto \frac{\left(1 + \frac{M_T}{M}\right)^2}{v_0^2}$$

- Larger WIMP mass *M* yields harder energy spectrum (but small effect for large masses)
- Uncertainty on v_0 translates into uncertainty on *M*
  - For small *M*, $\frac{\Delta M}{M} = \frac{\Delta v_0}{v_0}$

Dependence of Spectrum on Halo Model

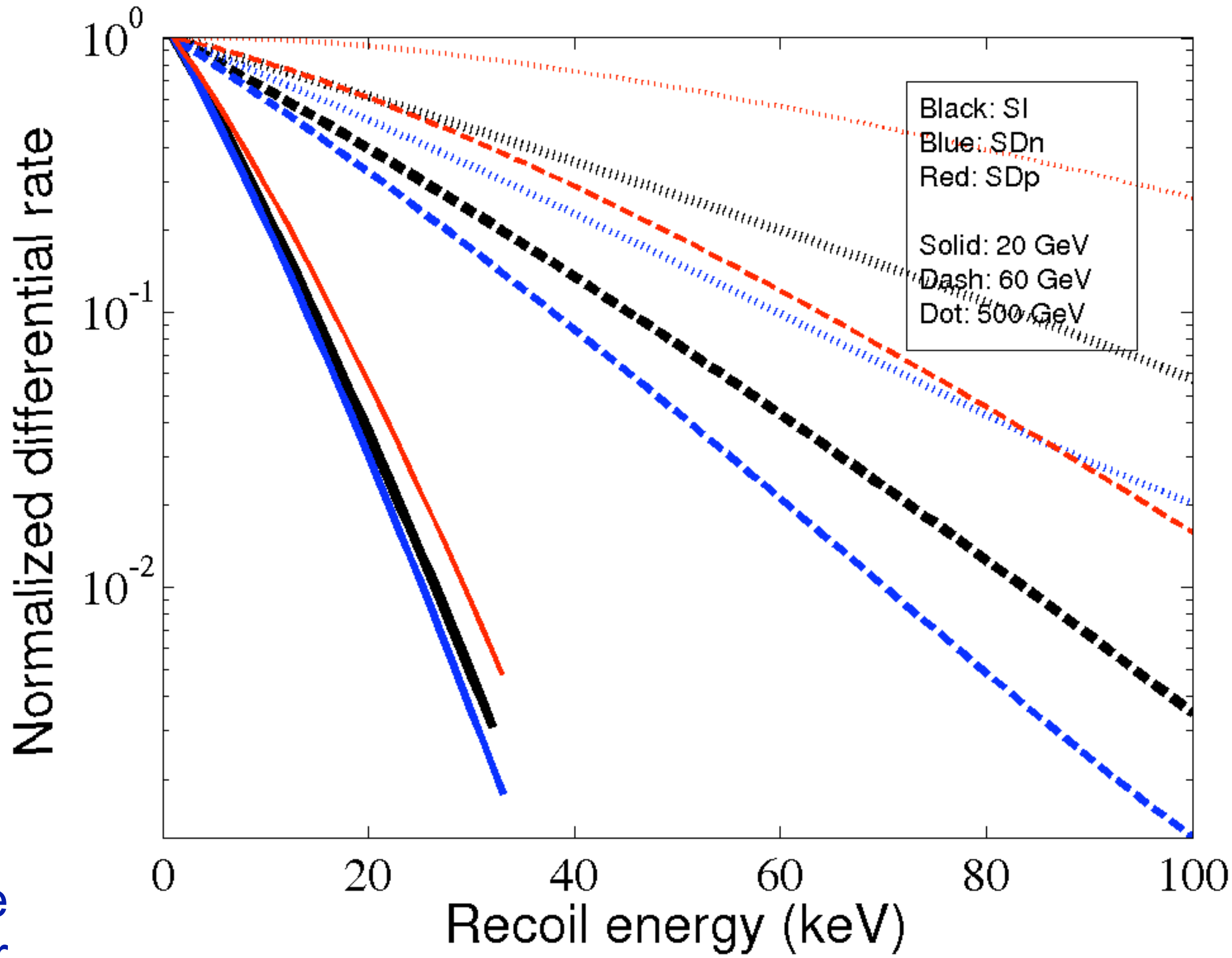


- Dark matter velocity distribution is not well known
- Different halo models result in different energy spectra
- Double-edge sword
  - At first, will increase uncertainty on *M*
  - Ultimately, may allow inference of which halo model is right

Craig Copi (Case Western)

Dependence of Spectrum on Interaction(s)

- Different nuclear form factors
  - spin-independent
  - spin-dependent on p
  - spin-dependent on n
- With a single target isotope, distinguish only by difference in energy spectrum
  - Unless assume SD interactions are insignificant
  - Detections with several detector isotopes would make problem much easier.



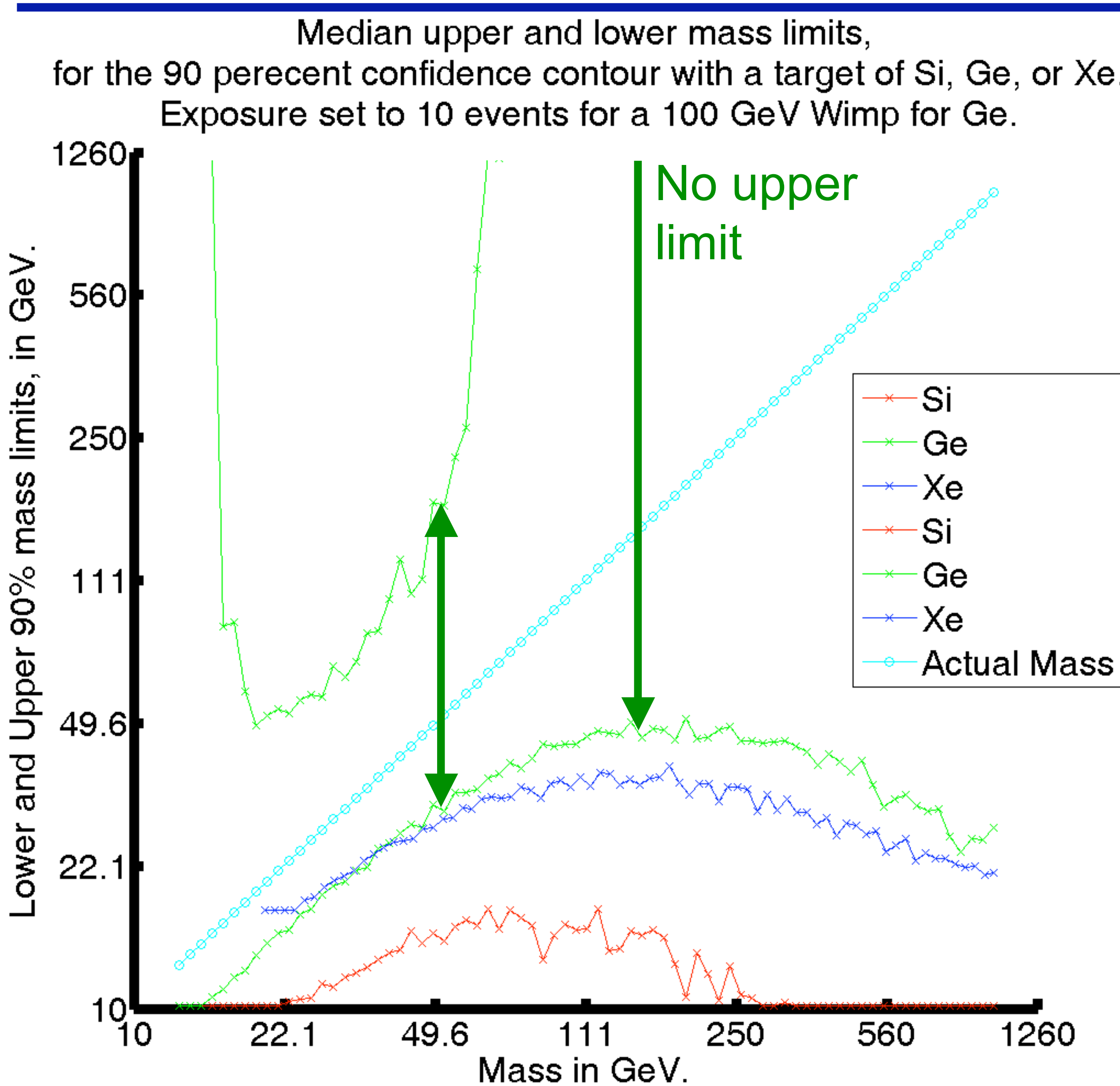
- Spectral shapes are very similar for low WIMP masses
  - Differences for high WIMP masses may confuse mass determination for small statistics

Jeff Filippini (UC Berkeley)

First Exploration of Mass Determination

- There are a lot of useful (and mostly easy) studies to do. Include effects of
  - Halo uncertainties
  - Interaction uncertainties
  - Finite resolution
  - Experimental backgrounds
  - Several isotopes
  - Annual modulation
  - Diurnal modulation
  - Combination with collider results
- We have barely started.
- Sweep all uncertainties and confusion under the rug
  - Assume SI interaction only, with well-known velocity distribution
- If dominated by experimental statistical uncertainties, how well do we measure WIMP mass & WIMP-nucleon cross section for given # events detected?

Mass Determination with Ge, Xe, Si



- Same exposure for each
  - 10 keV threshold for Ge, Si
  - 16 keV threshold for Xe
  - Ge gives slightly better precision than Xe, followed by Si
- 50 GeV WIMP typically measured to range 25-160 GeV with 10 events in Ge
- Get only lower limits for more massive WIMP

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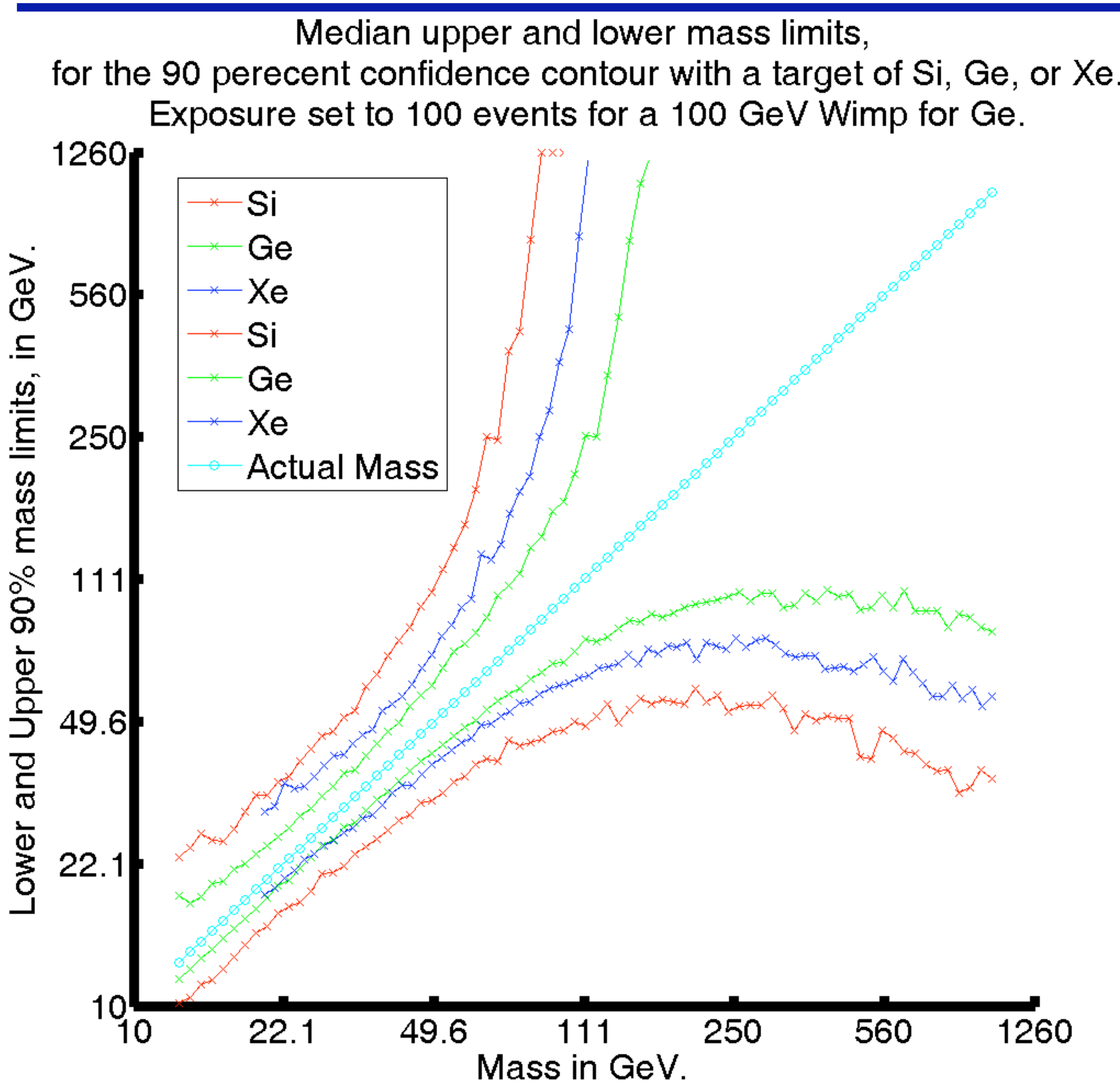
Mass Determination with Ge, Xe, Si



- Same exposure for each
  - 10 keV threshold for Ge, Si
  - 16 keV threshold for Xe
  - Ge gives slightly better precision than Xe, followed by Si
- 50 GeV WIMP typically measured to range 43-70 GeV with 100 events in Ge

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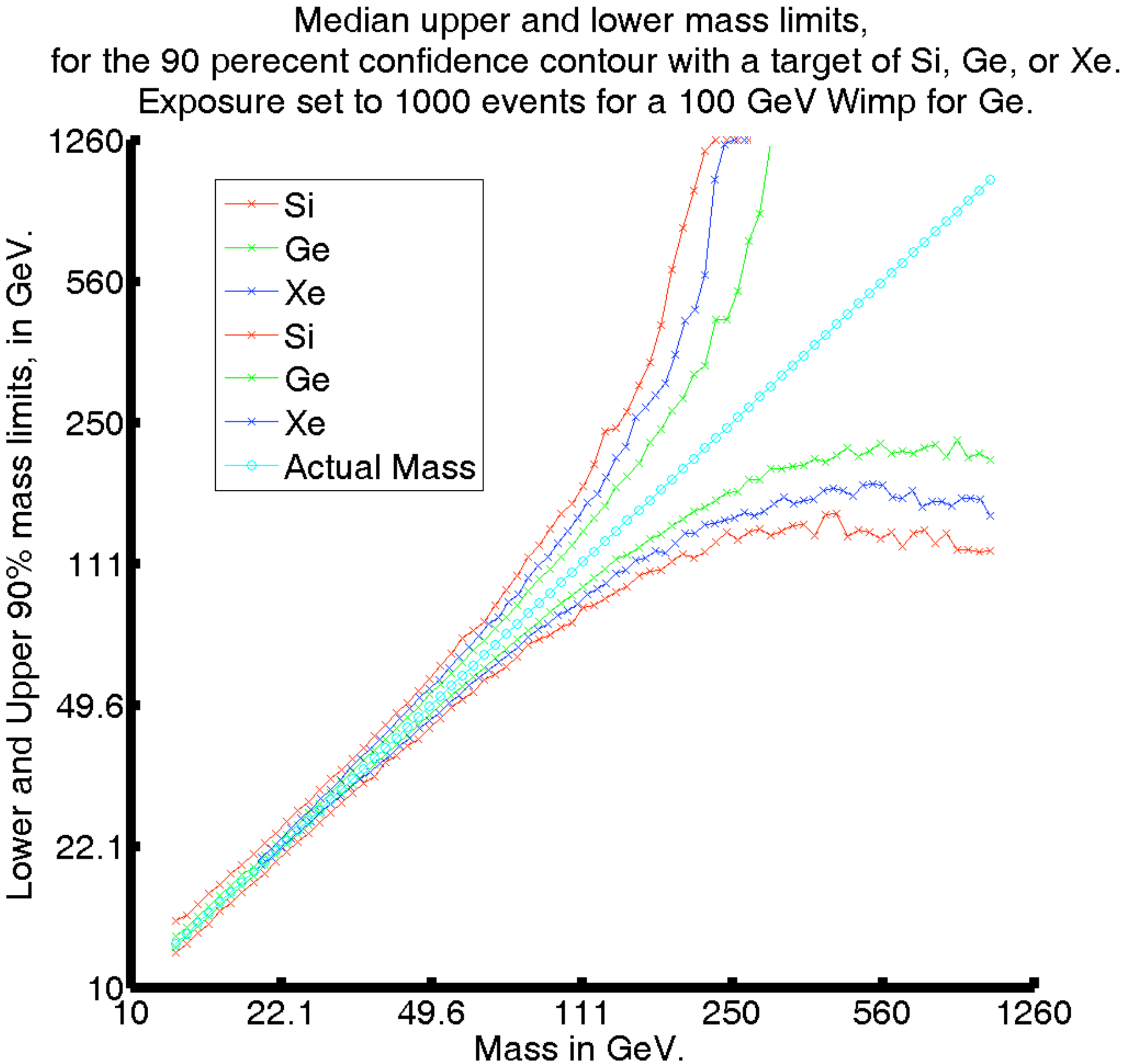
Mass Determination with Ge, Xe, Si



- Same exposure for each
  - 10 keV threshold for Ge, Si
  - 16 keV threshold for Xe
  - Ge gives slightly better precision than Xe, followed by Si
- 50 GeV WIMP typically measured to ±10% with 1000 events in Ge

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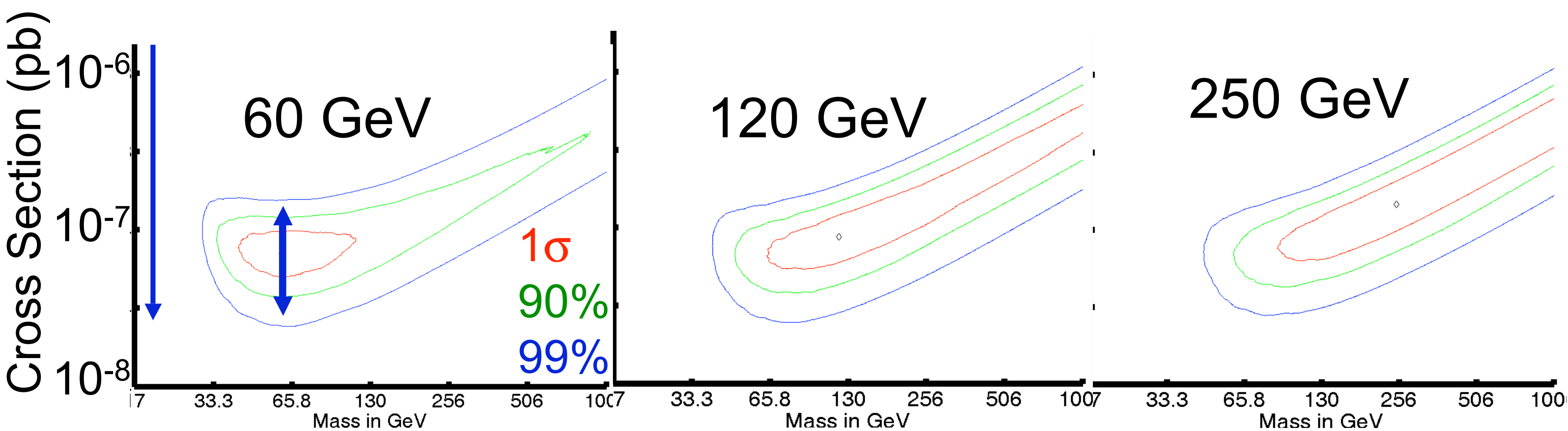
Mass and Cross Section Determination

- Uncertainties on mass can translate into uncertainties on WIMP-nucleon cross section σ
  - All under the assumption we know the WIMP local mass density

10 events expected (30% Poisson uncertainty on σ)



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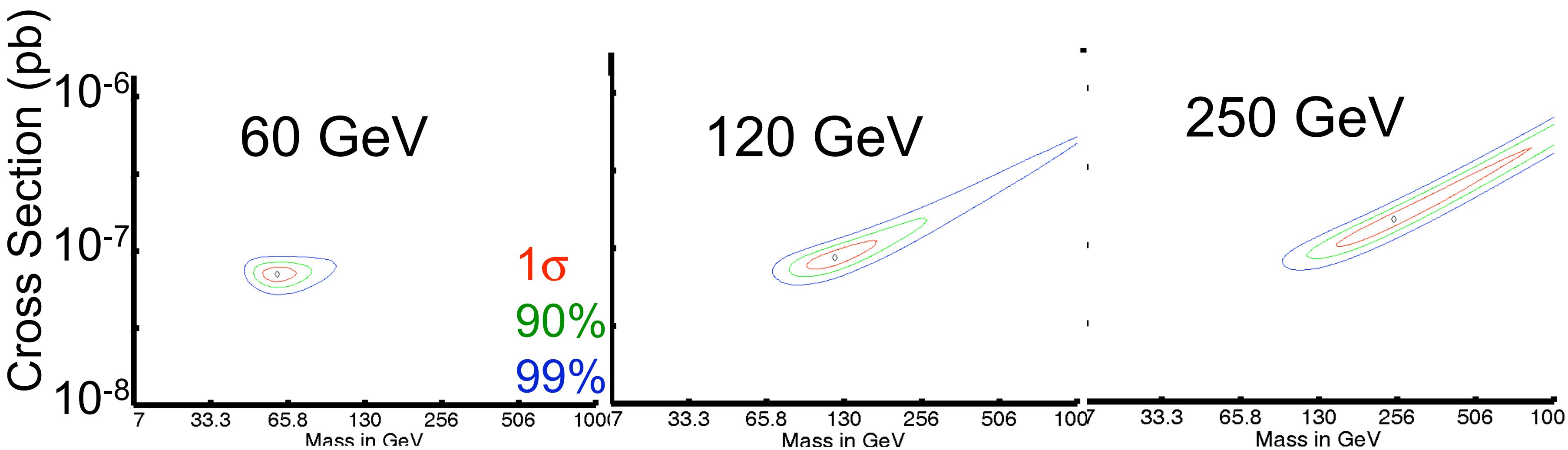

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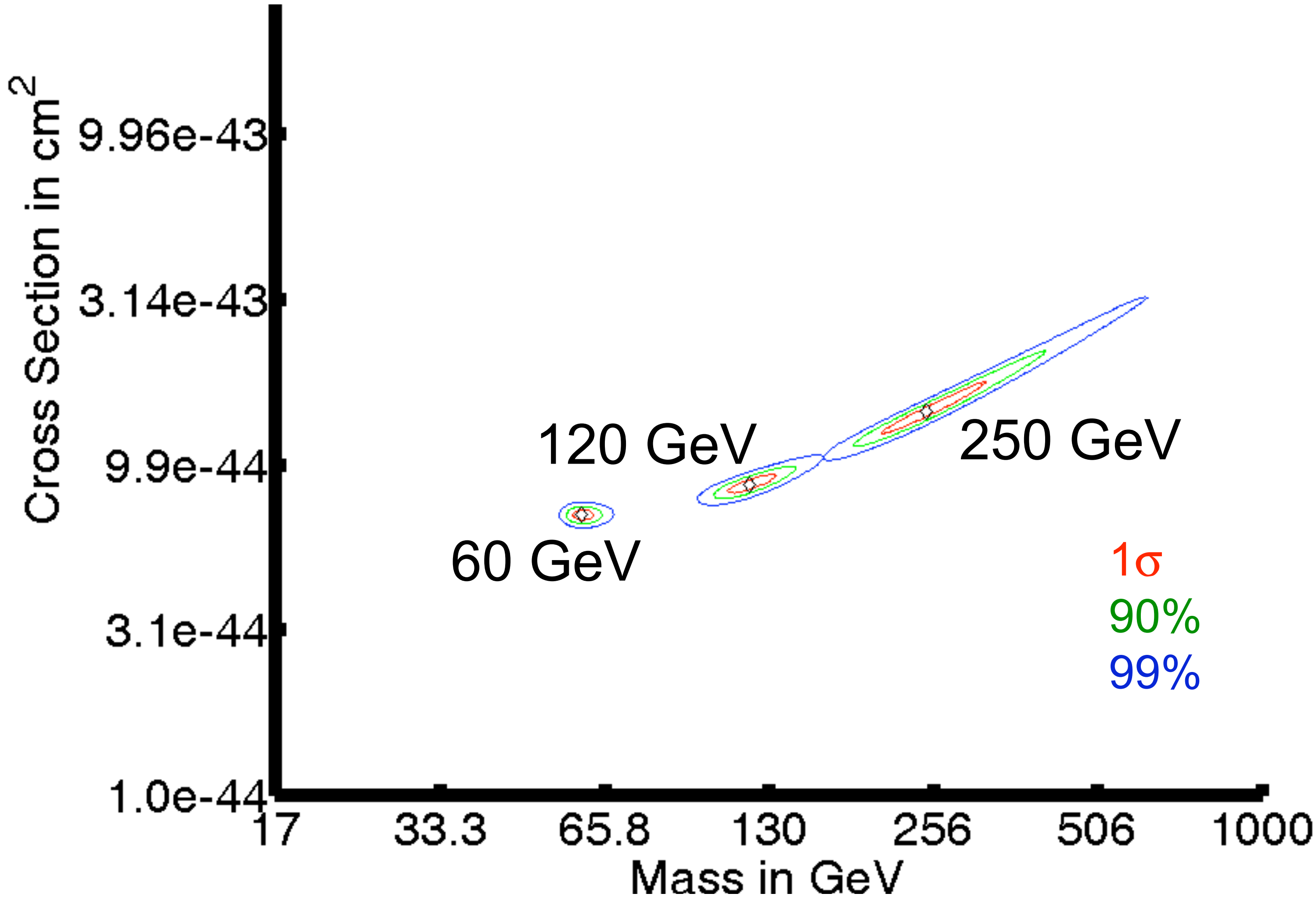
Mass and Cross Section Determination

1000 events expected (3% Poisson uncertainty on σ)



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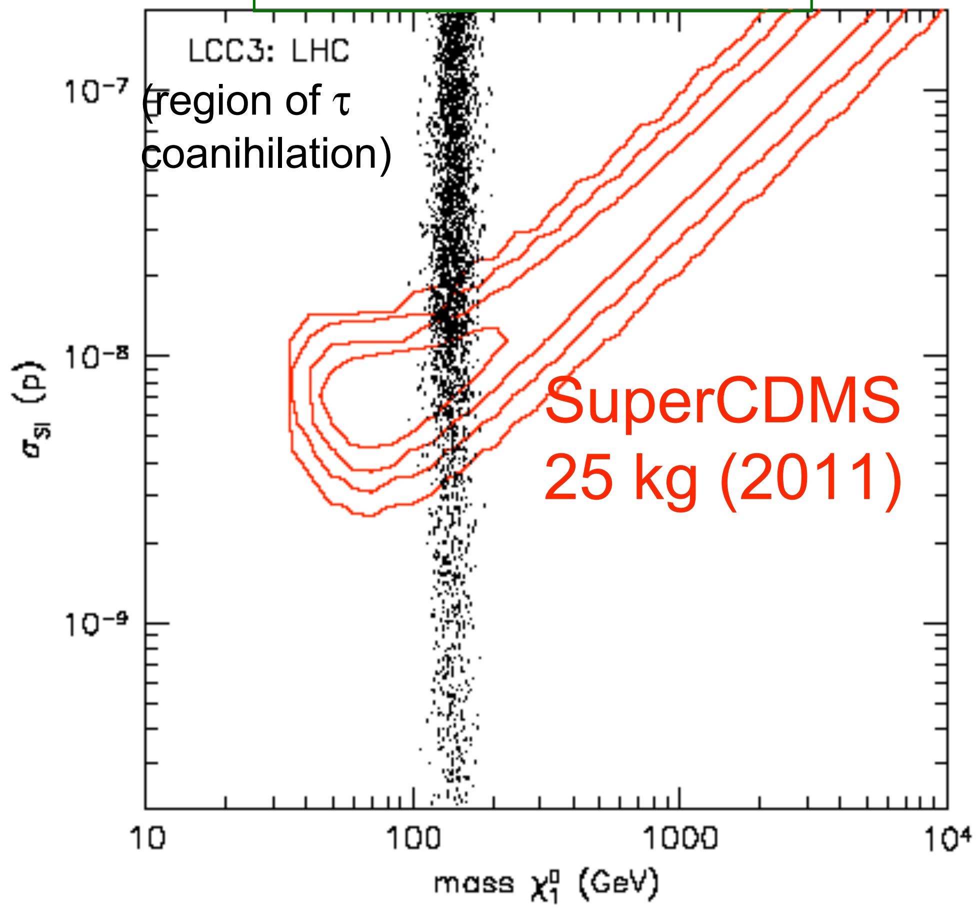
Direct Detection and LHC

- For many models, LHC will constrain WIMP mass to 10%
- However, it is difficult to measure WIMP properties well
- Given WIMP mass from LHC, direct detection can determine WIMP-nucleon cross section much better than LHC alone
  - ◆ Statistical uncertainties simply Poisson based on number of WIMPs detected
  - ◆ Presumes same particle for both, WIMP comprises entire halo
  - ◆ If relax second assumption, direct detection provides lower limit on WIMP-nucleon cross section

Baltz, Battaglia, Peskin & Wizansky hep-ph/0602187



Conclusions

- Determination of WIMP mass is much better for low WIMP masses

	For 60 GeV WIMP		No upper limit for WIMPs with M >
Events Detected	Lower 99% Limit	Upper 99% Limit	
10	30 GeV	none	50 GeV/c^2
100	45 GeV	101 GeV	100 GeV/c^2
1000	55 GeV	69 GeV	250 GeV/c^2

- Systematic uncertainties on WIMP mass due to halo are of order ± 20% - ±50% (should be explored in more detail)
- Better measurements of WIMP mass from colliders may be combined with information from direct detection to better constrain WIMP-nucleon cross section (and hence SUSY parameters)