Inelastic Dark Matter and DAMA/Libra: An *Experimentum Crucis*

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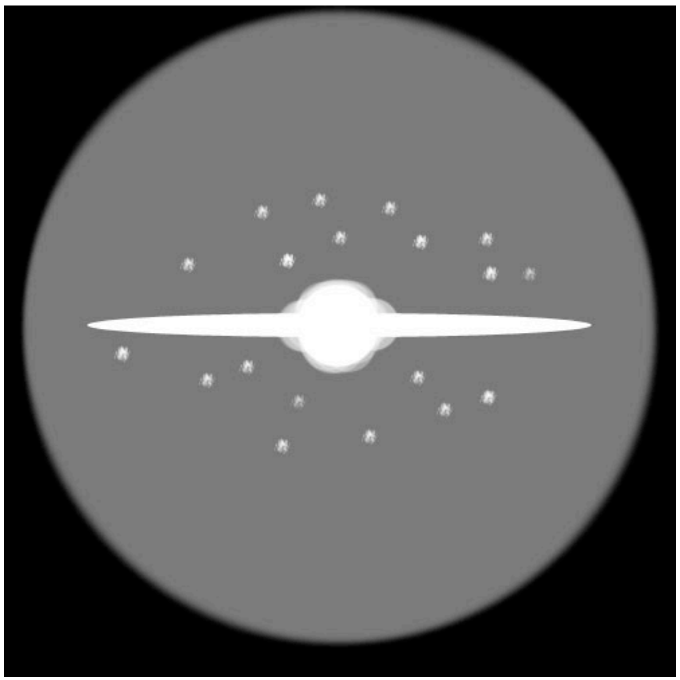
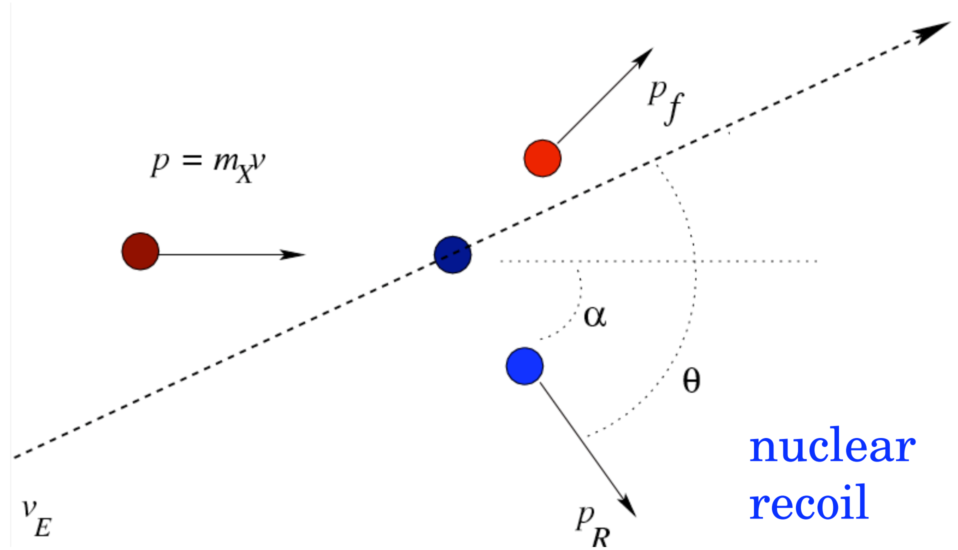
w/ Doug Finkbeiner, Neal Weiner 0906.0002

Direct detection of dark matter



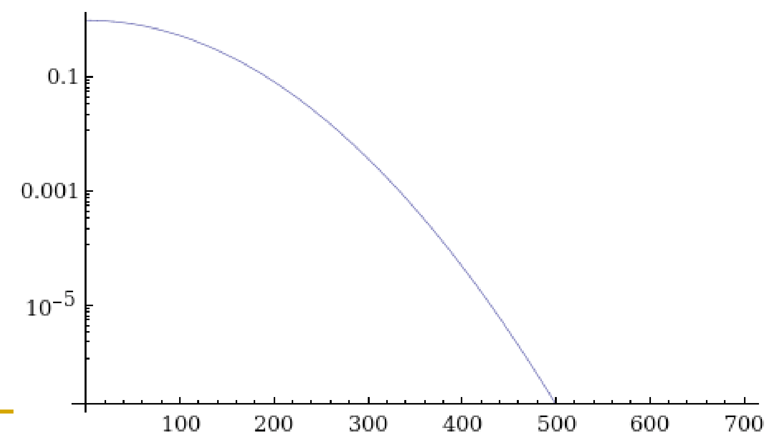


- Velocity ~ 220 km/s, 10^{-3}
- Energy ~ 100 keV (if WIMPs)

Spin-independent scattering

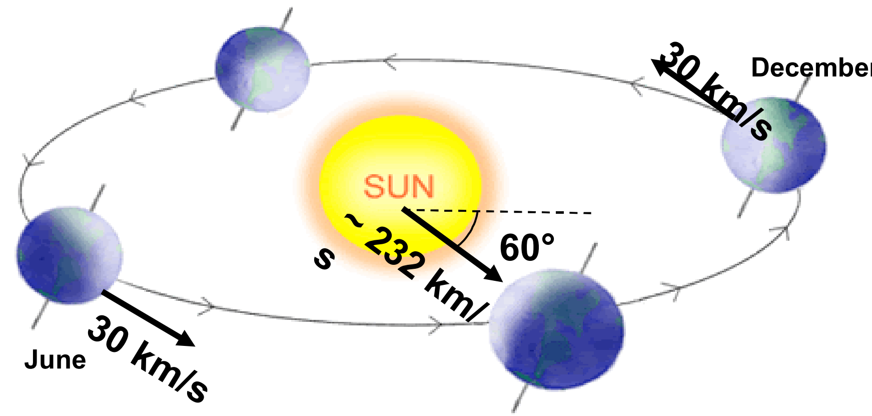
$$\frac{dR}{dE_R d\cos\gamma} = N_T \frac{\rho_X}{m_\chi} \int d^3v\ v\ f(\vec{v}+\vec{v}_E) \frac{d\sigma}{dE_R d\cos\gamma} F^2(E_R)$$

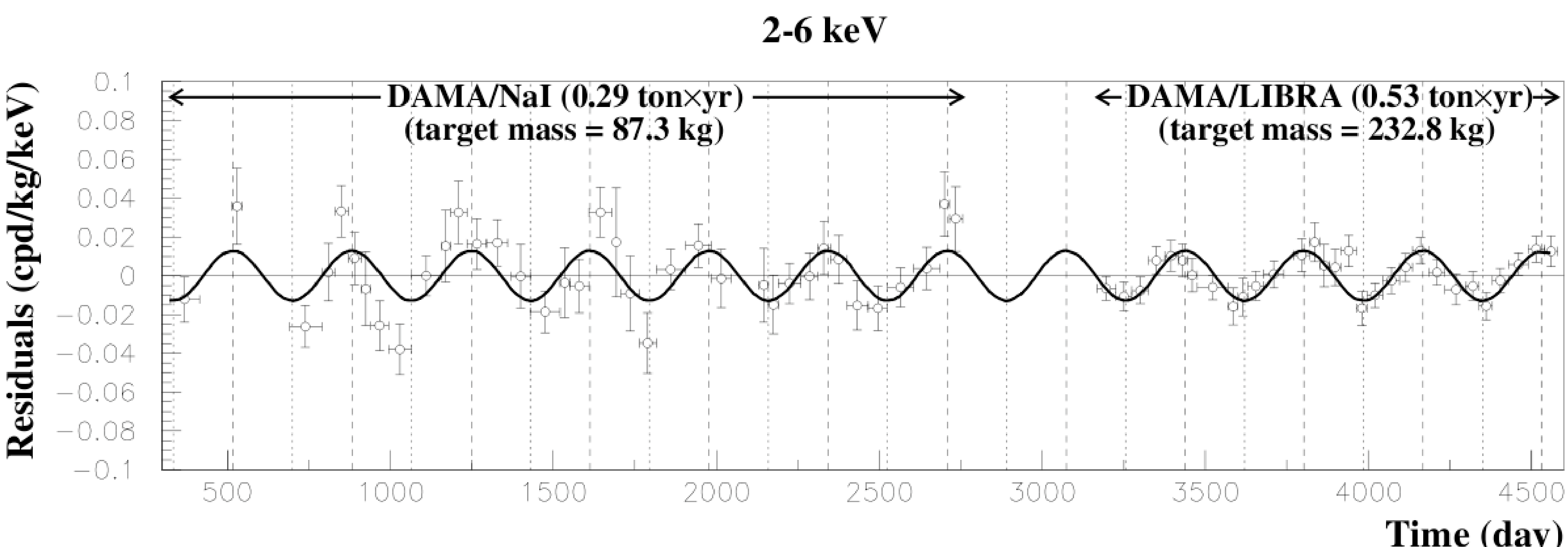
- Local dark matter density .3 GeV/cm[3]
- Local dark matter velocity distribution
- Scattering cross section
- Nuclear form factor



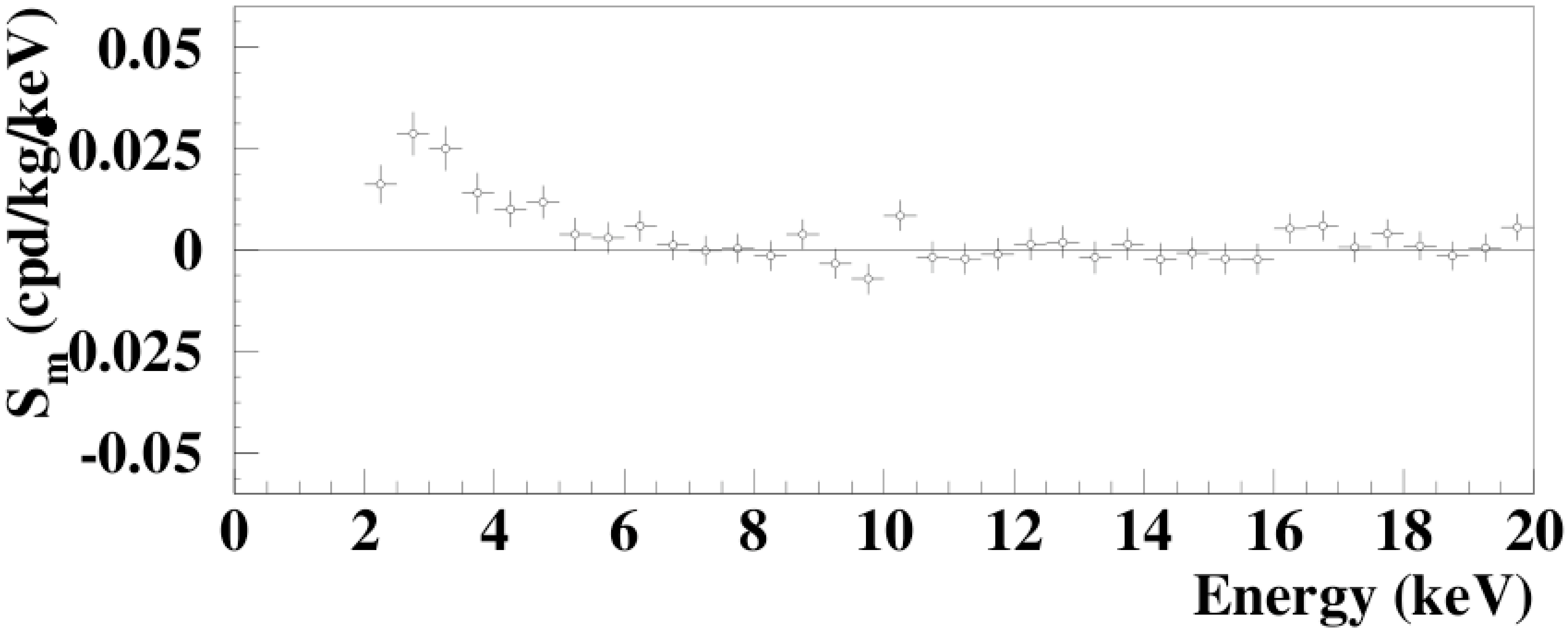
DAMA

- NaI scintillator
- 260,000 kg day

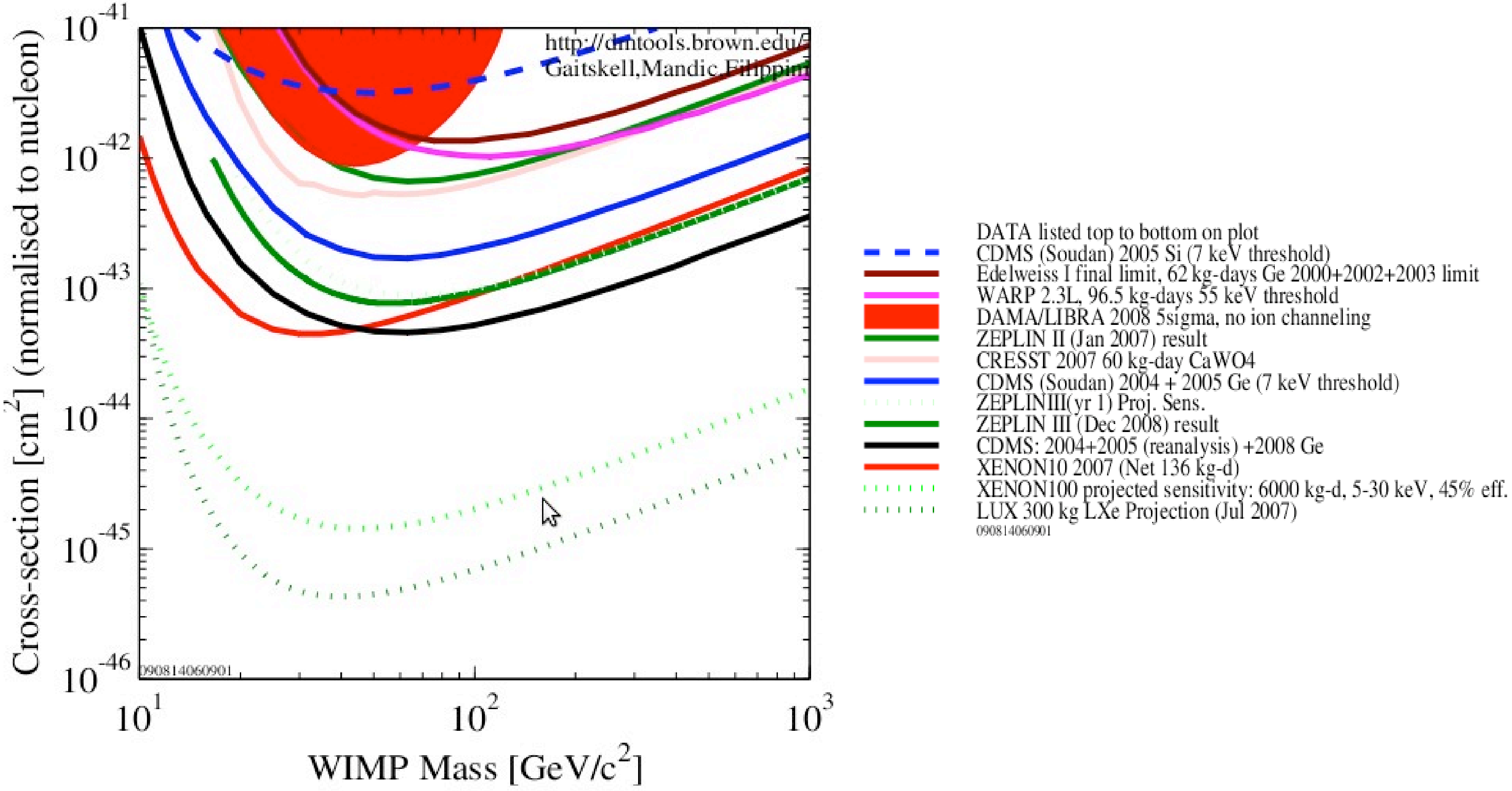




DAMA Spectrum



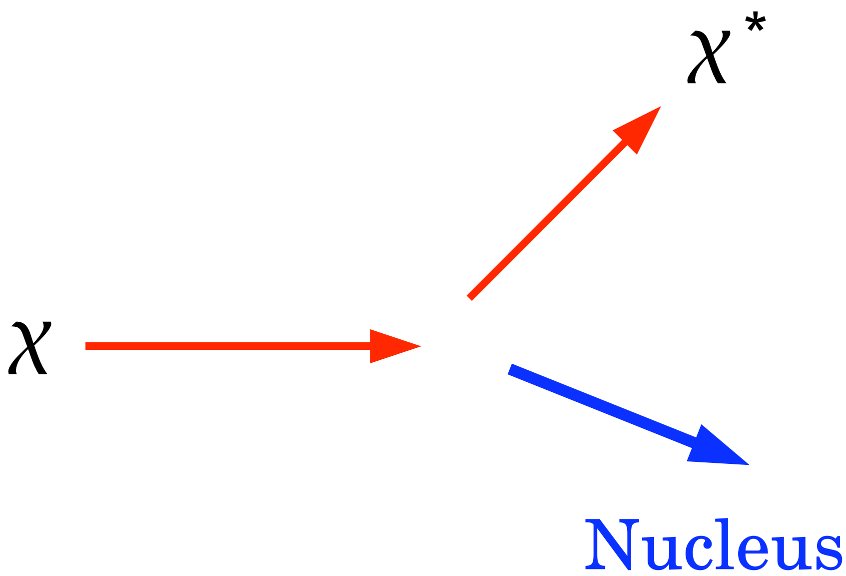
Constraints from other direct detection experiments?



Explanations of DAMA?

- Dark Matter
  - Inelastic dark matter
  - Light dark matter (channeling)
  - DM-Electron scattering
- Systematics
  - Bananas
  - ??
- Other??

Inelastic Dark Matter



$$m_{\chi^*} = m_\chi + \delta$$

Models of iDM?

- Composite States
- Neutrinos/Sneutrinos
- Neal's talk tomorrow?
- ...

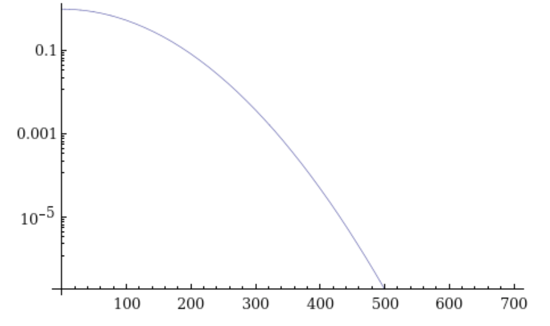
$$\beta_{\min} = \sqrt{\frac{1}{2 m_N E_R}\left(\frac{m_N E_R}{\mu} + \delta\right)},$$

Inelastic Dark Matter

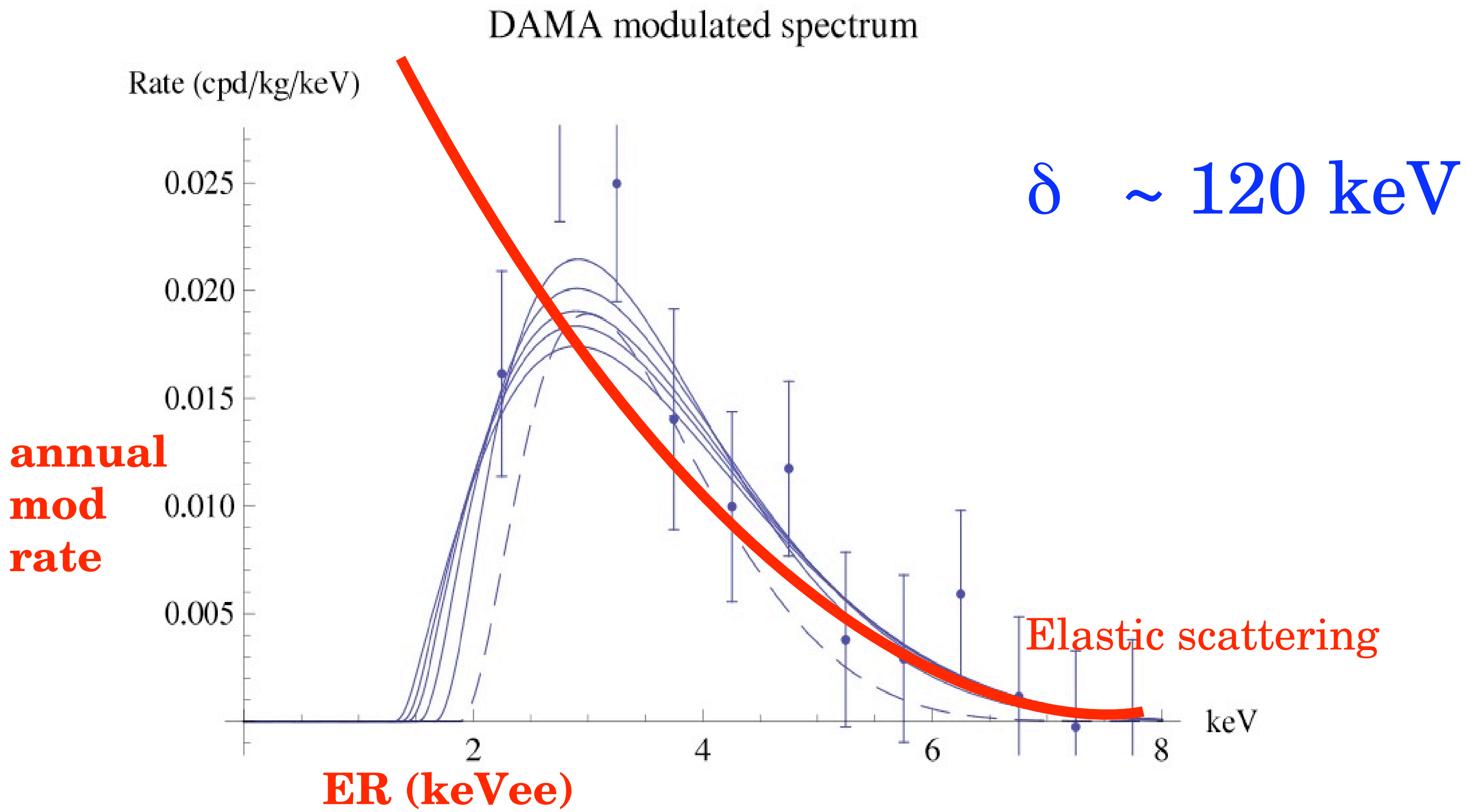
- Enhanced annual modulation
- Scattering off heavy nuclei preferred
- Low energy recoil events suppressed

$$\frac{dR}{dE_R d\cos\gamma} = N_T \frac{\rho_X}{m_\chi} \int d^3v \; v \; f(\vec{v}+\vec{v}_E) \frac{d\sigma}{dE_R d\cos\gamma} F^2(E_R)$$

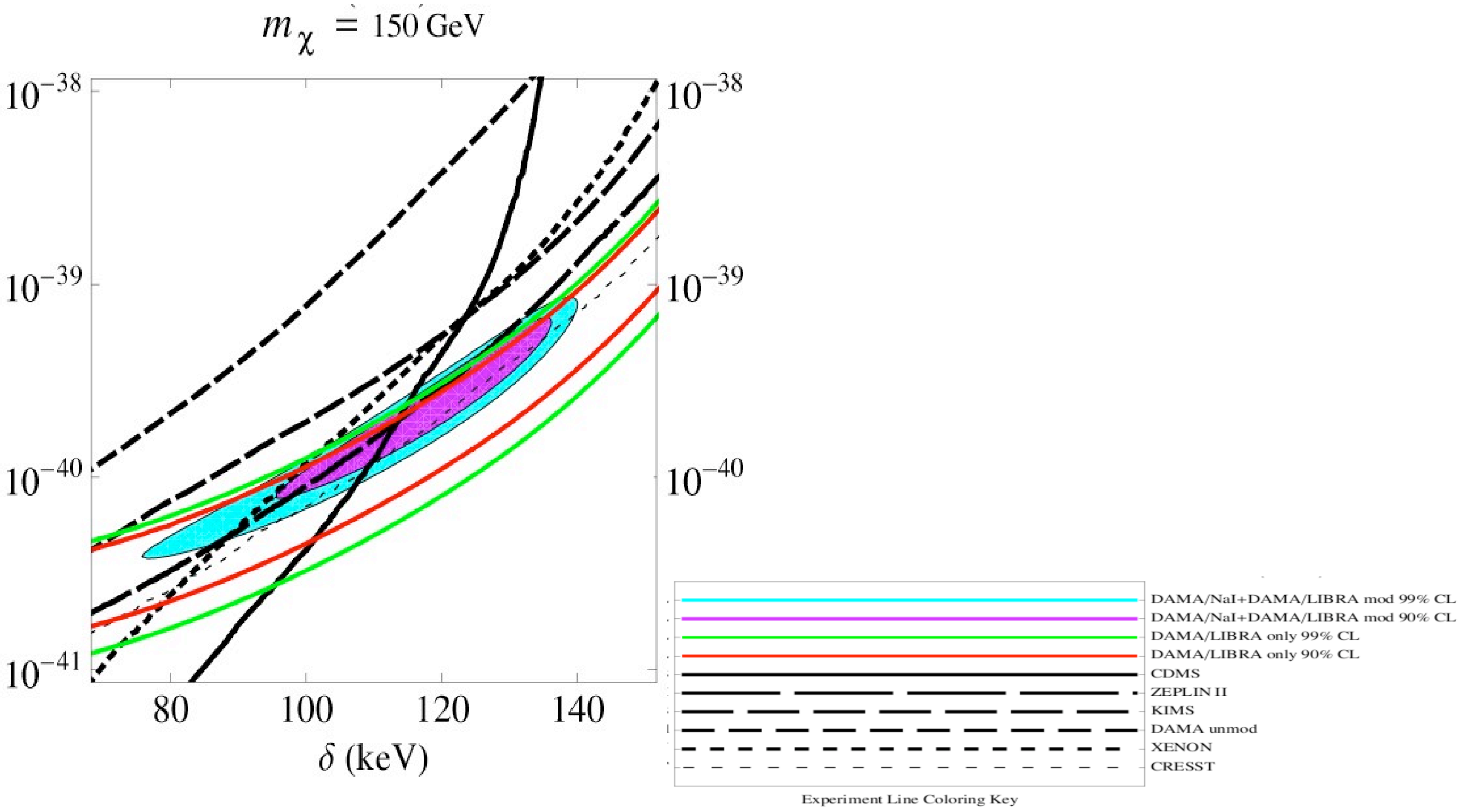
- Local dark matter density
- Local dark matter velocity distribution
- Scattering cross section
- Nuclear form factor



Inelastic dark matter & DAMA



Inelastic dark matter & DAMA



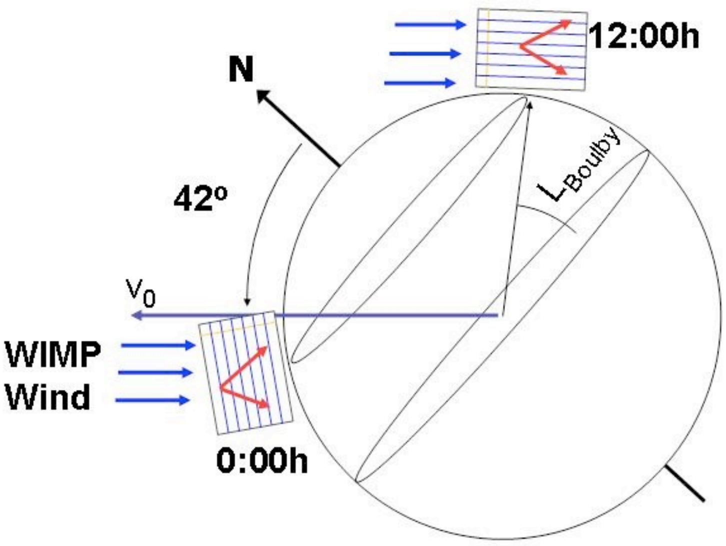
Inelastic Dark Matter Benchmarks

- Uncertainties
  - Halo model
  - Astro parameters
  - Form factors
  - Quenching factors

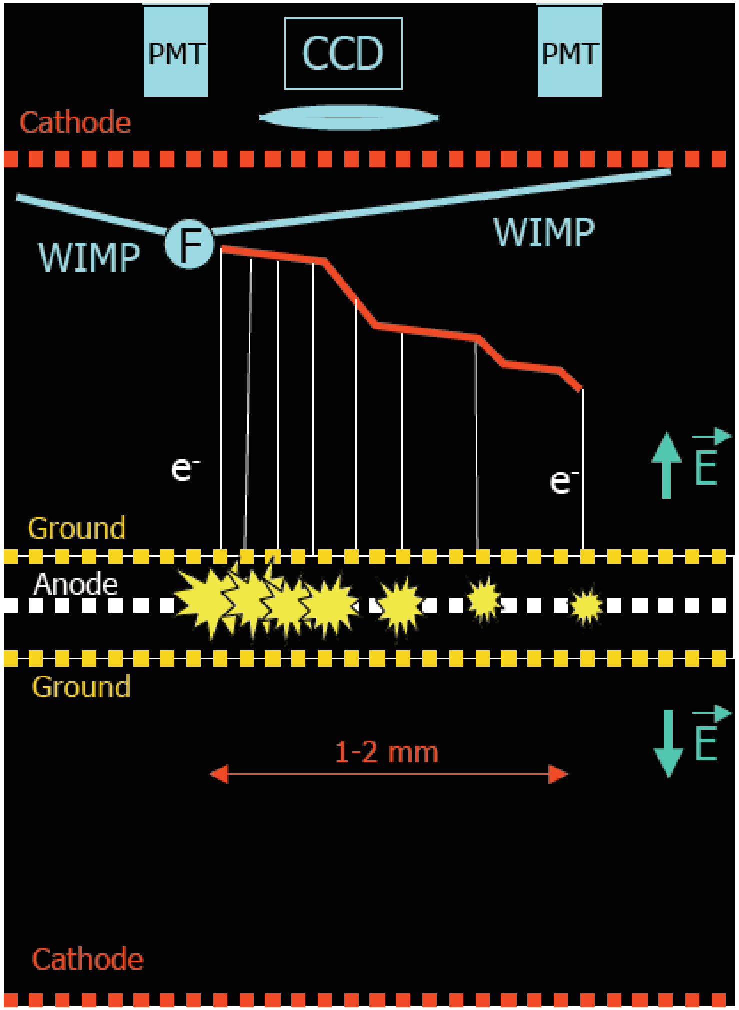
#	m_χ (GeV)	σ_n (10^{-40} cm^2)	δ (keV)
1	70	11.85	119
2	90	5.75	123
3	120	3.63	125
4	150	2.92	126
5	180	2.67	126
6	250	2.62	127

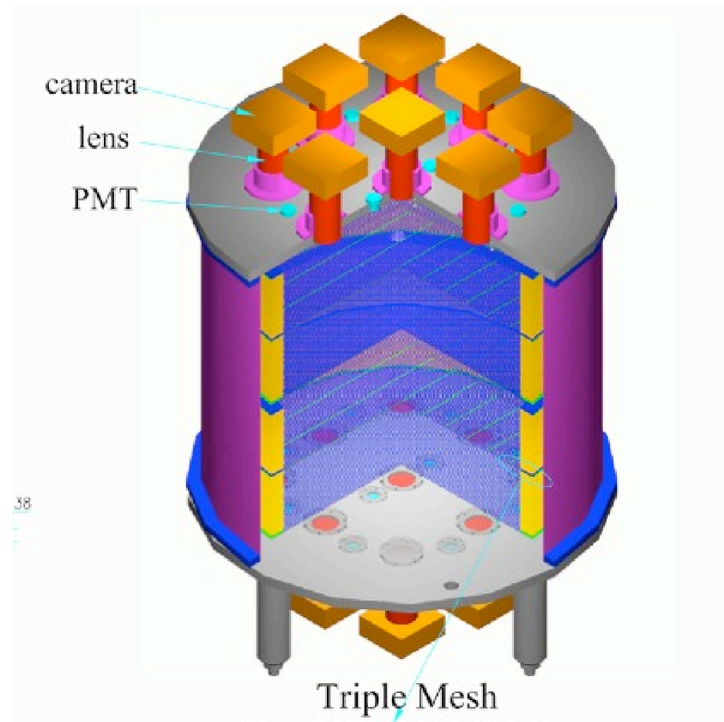
Directional Detection

- Advantages
  - Daily modulation
  - Sidereal day –
    out of phase with solar day
  - Enhanced modulation

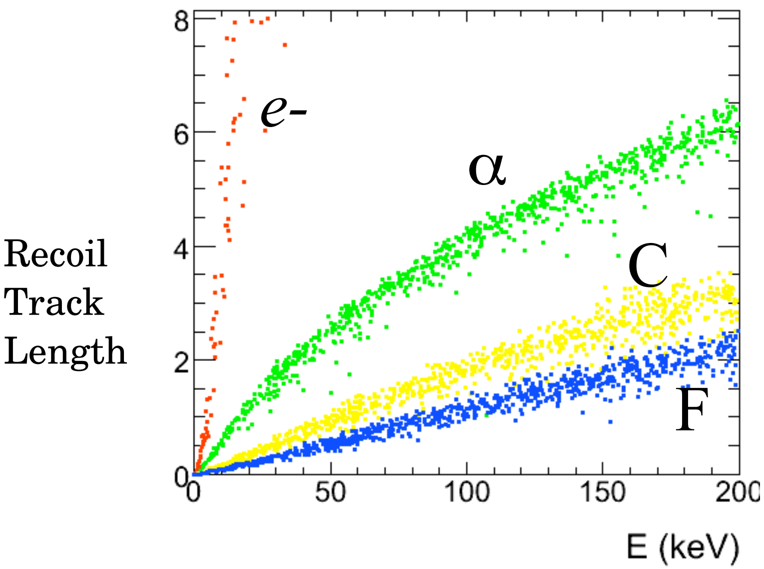


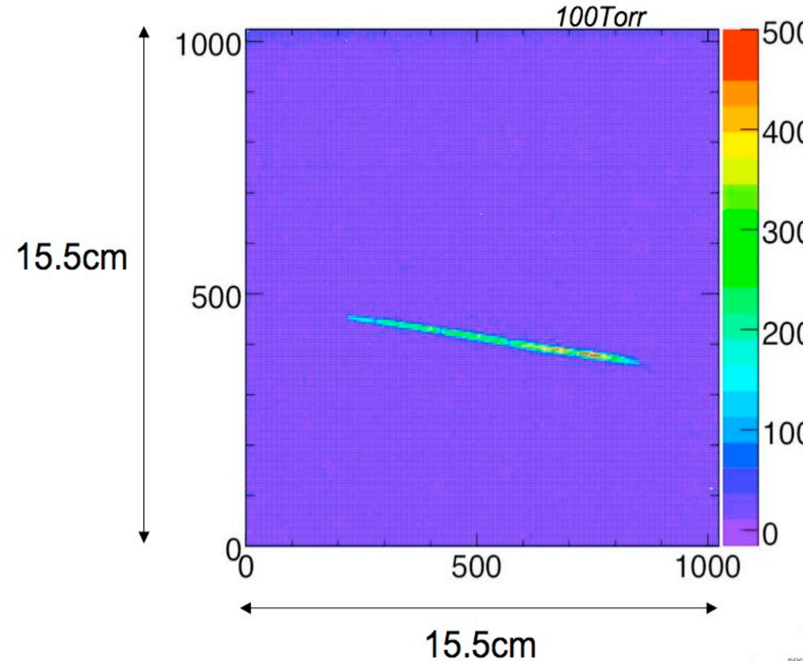
Directional Detection / DM-TPC

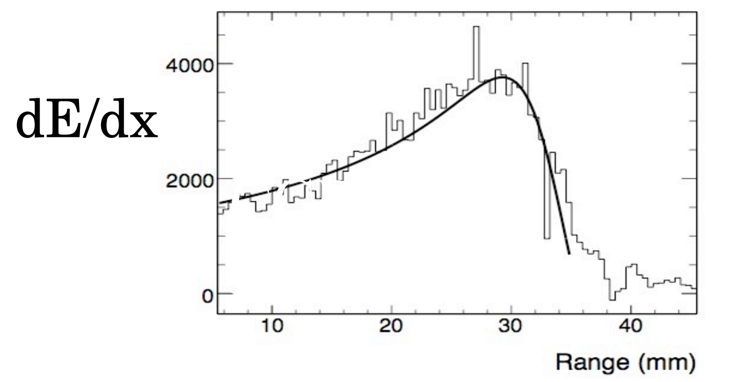




Directional Detection / DM-TPC

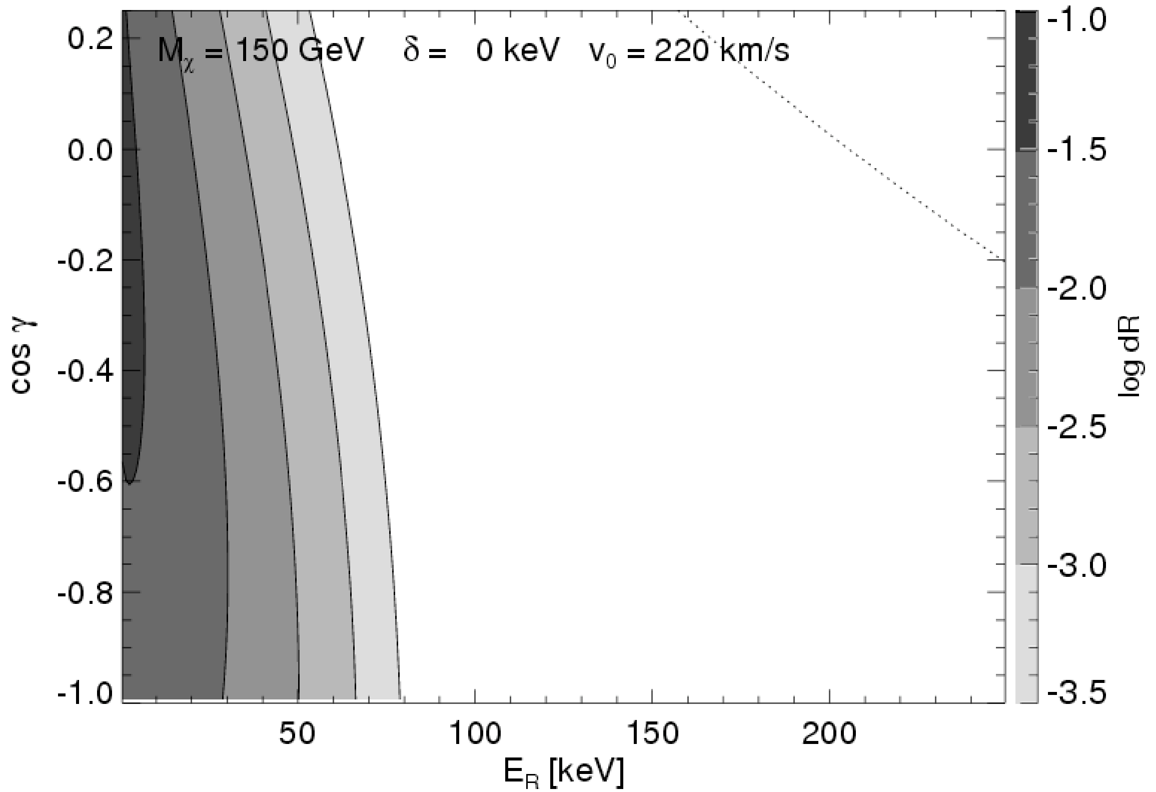






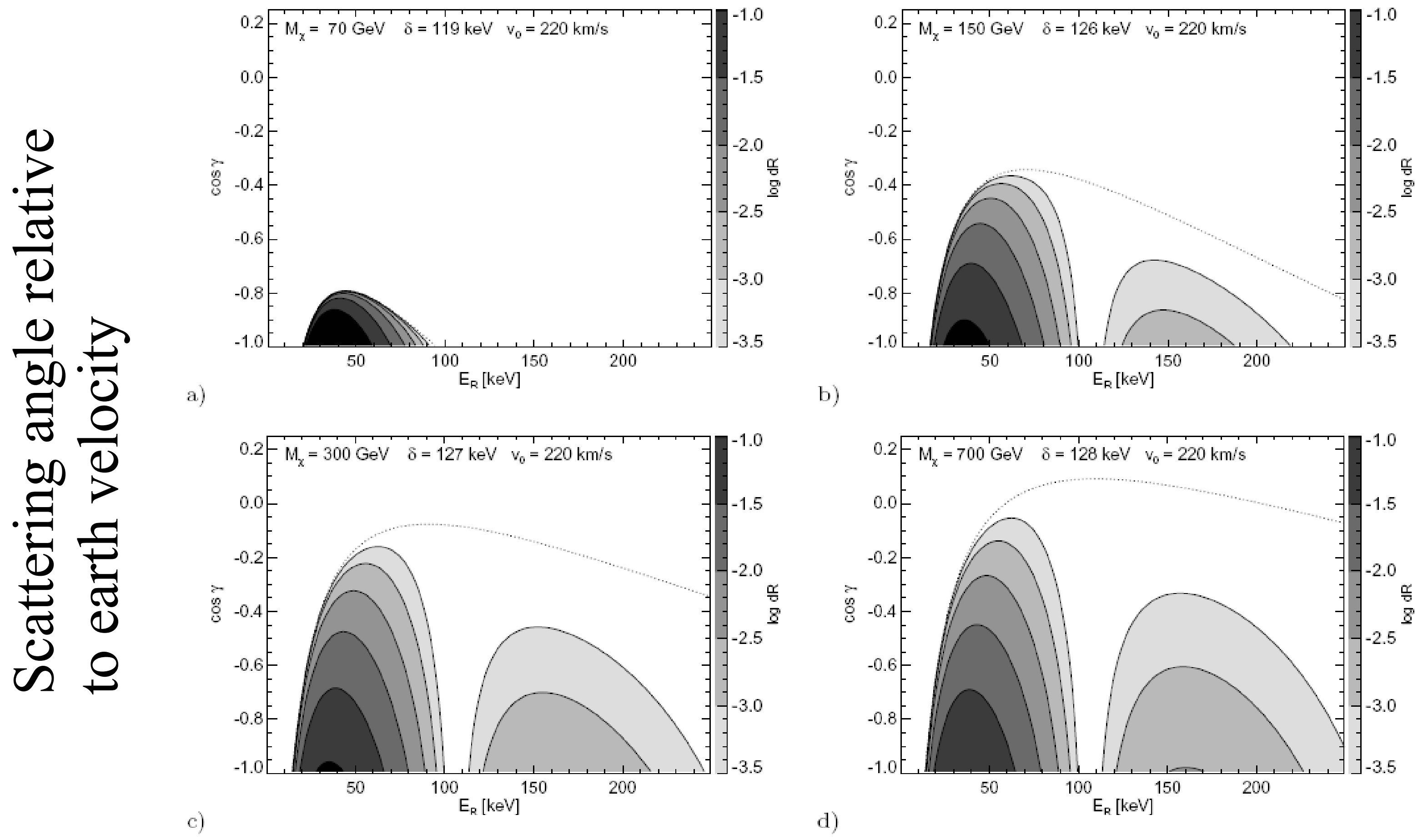
Spectrum (in angle/energy) for elastic dark matter

Scattering angle relative to earth velocity



Nuclear Recoil Energy

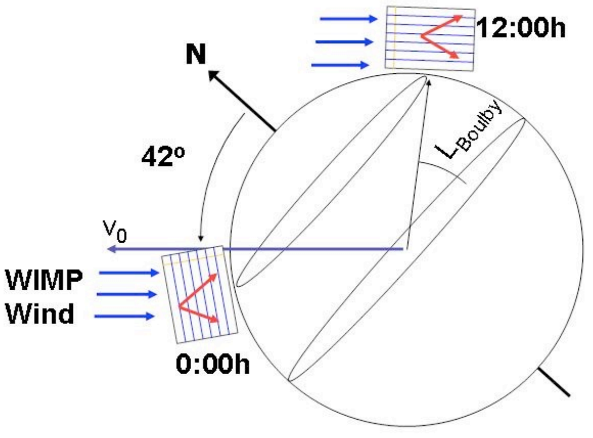
Spectrum for inelastic dark matter



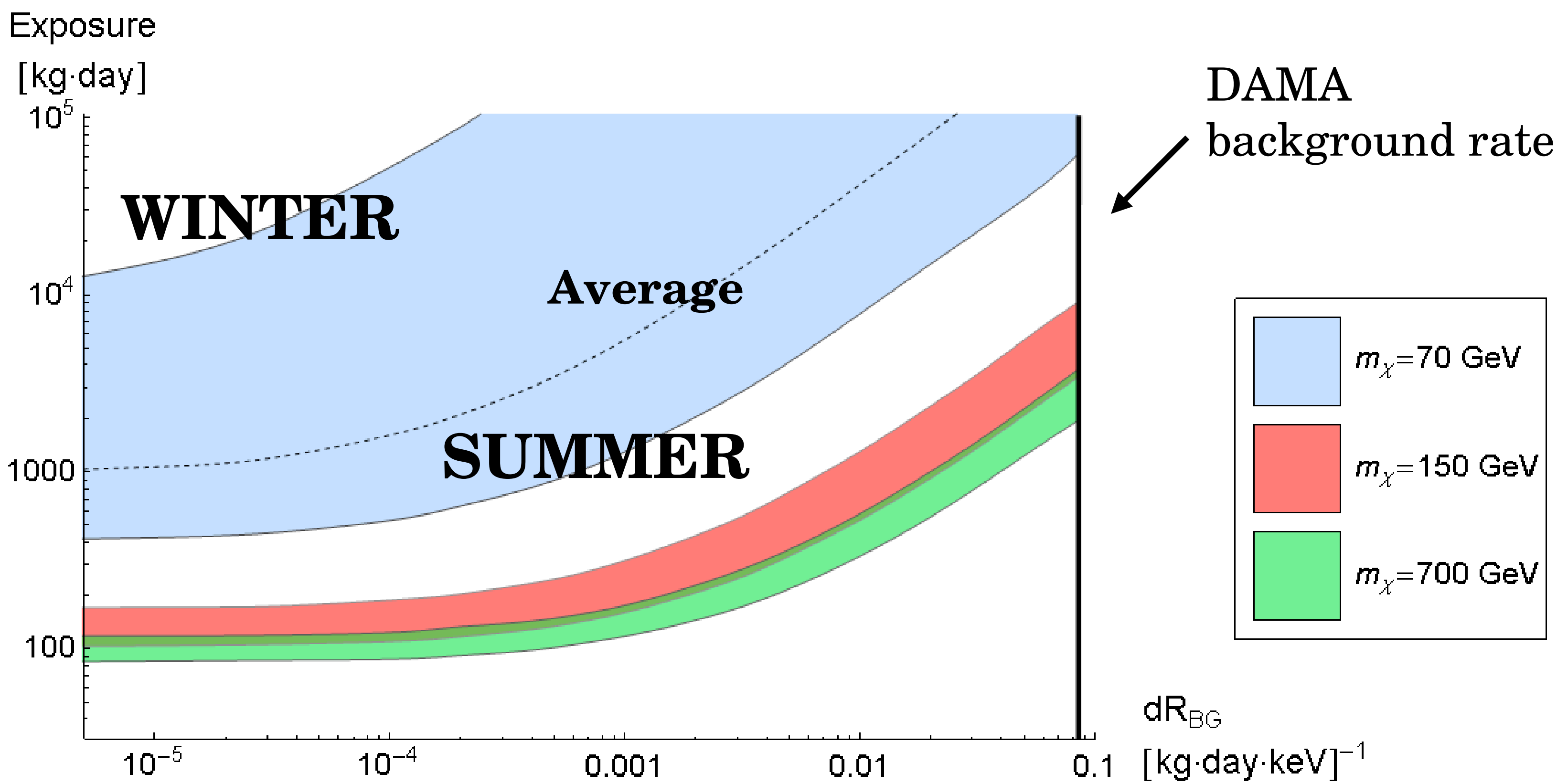
Nuclear Recoil Energy

Directional Detection

- Advantages
  - Daily modulation
  - Sidereal day –
    out of phase with solar day
  - Enhanced modulation
- Advantages for inelastic dark matter
  - Even more enhanced modulation
  - Enhanced cross section at higher energies



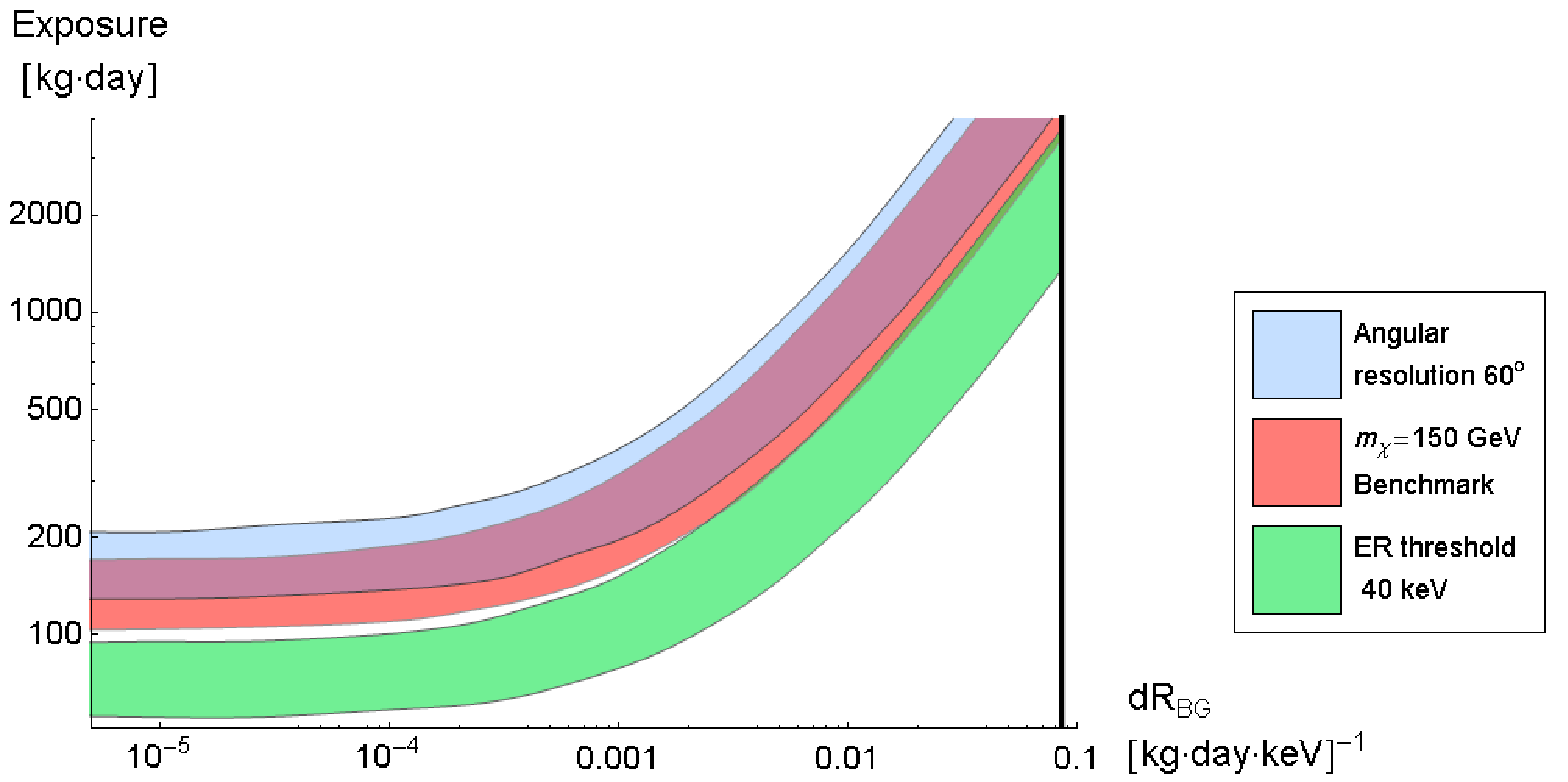
Exposure to achieve 3σ result 95% of the time



E_R = [50,80] keV, angular resolution 15 degrees

V_e = 225 km/s, v_{esc} = 500 km/s

Lowering the energy threshold is more important than improving angular resolution



Parameter Estimation from 1000 kg day

log (m /σ)

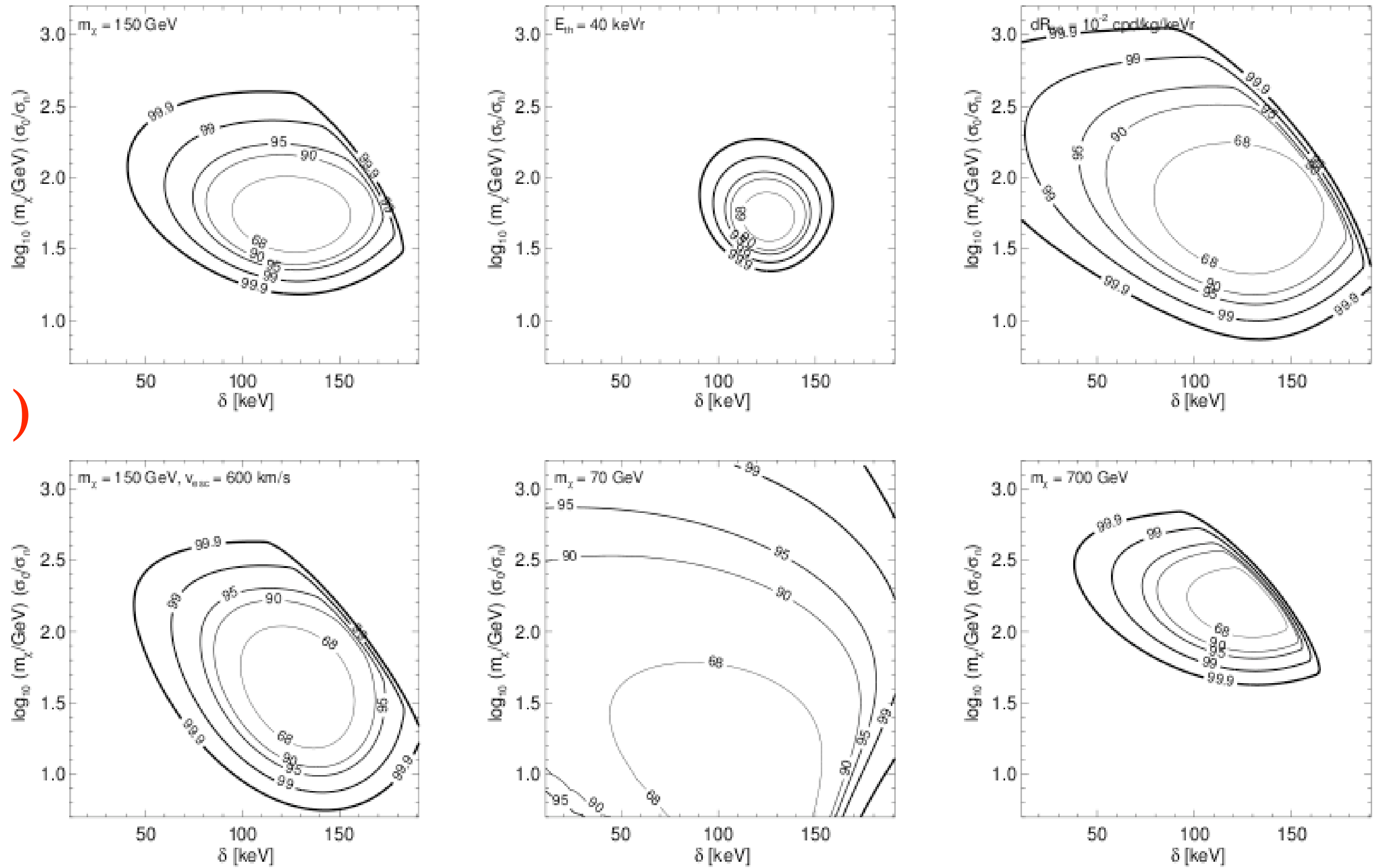


FIG. 9: Confidence levels for determining δ and m_χ/σ_n, where m_χ is unknown, with an exposure of 1000 kg · day, taking $\sigma_0 = 10^{-40}$ cm^2. Over most of the parameter space, some value of m_χ (and therefore σ_n) can be found to produce enough events for the given δ. However, in the case of large δ and large m_χ/σ_n, no solution is possible in some cases.

δ

Conclusions

- iDM can explain DAMA and other experiments
  - Mass ~ 100-1000 GeV, δ ~ 120 keV
- DAMA+iDM will be tested by LUX, XENON, etc, very soon
- Direct Detection
  - Daily modulation
  - Enhanced modulation
  - if DAMA/iDM is correct, clear signal of WIMP detection with few hundred, ~1000 kg day

Exposure to achieve 3σ result 95% of the time