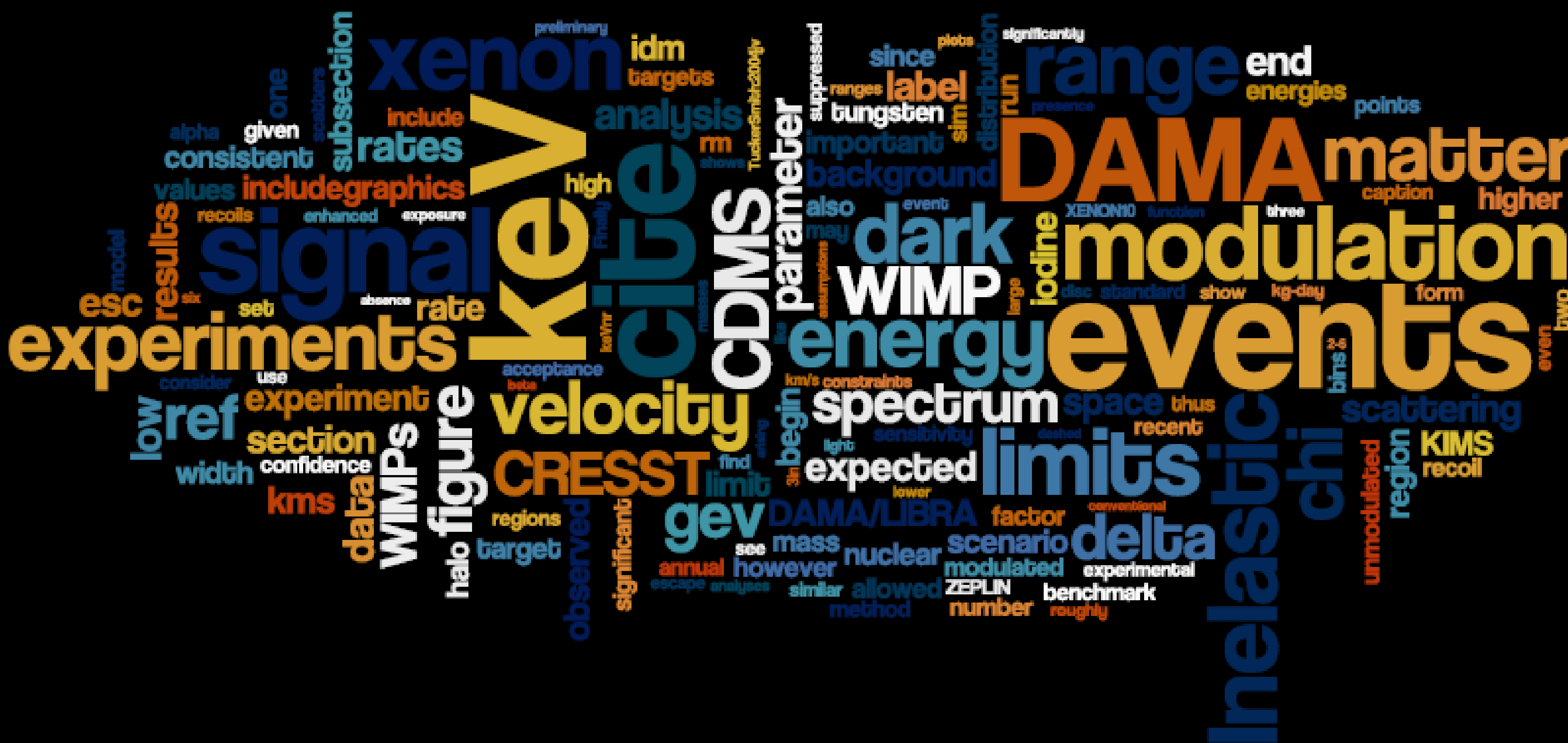
Dark Matter Consistent with DAMA



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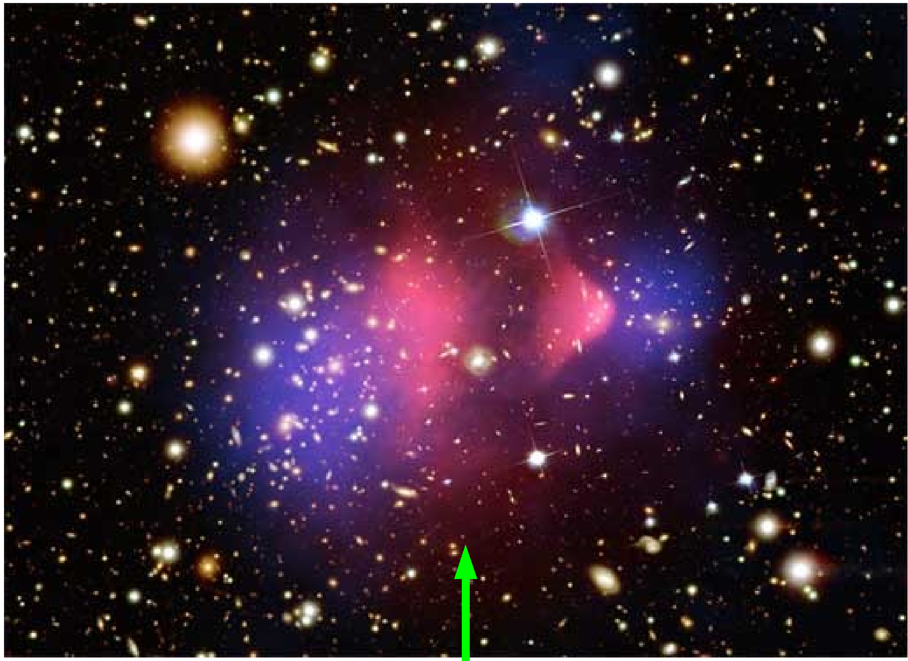
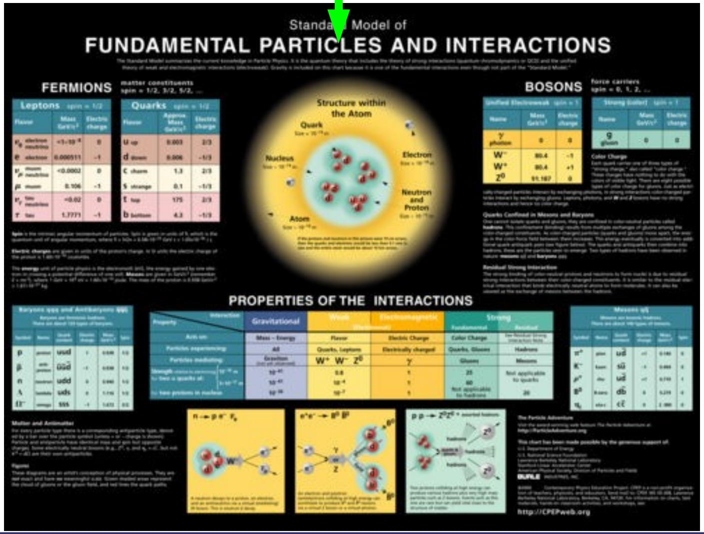
work in collaboration with
G. Kribs, A. Pierce,
D. Tucker-Smith, N. Weiner

hep-ph:0807.2250
hep-ph:0808.0196

Dark Matter Mystery

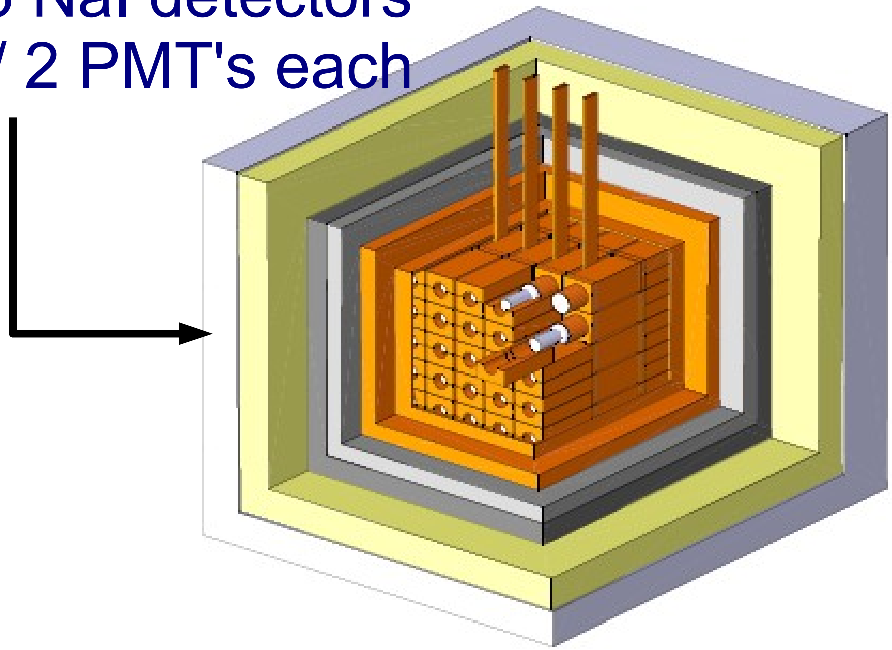
- Dark matter implied by astronomy and cosmology, but mysterious from particle physics view
- Many experiments will probe it: collider, direct and indirect detection experiments





DAMA/NaI and DAMA/LIBRA

25 NaI detectors
w/ 2 PMT's each

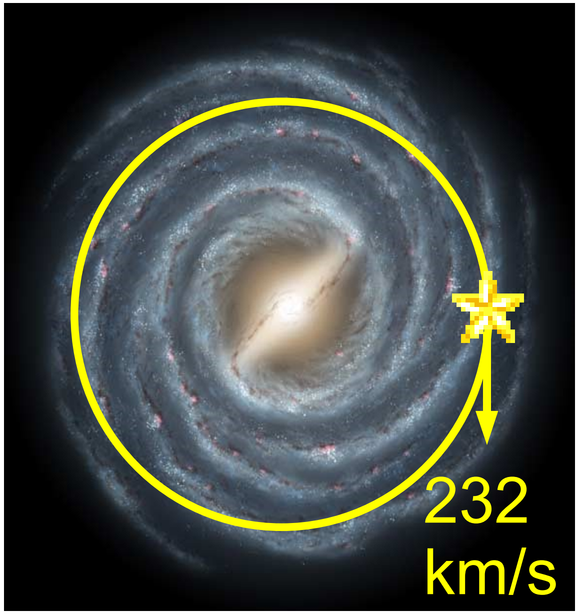


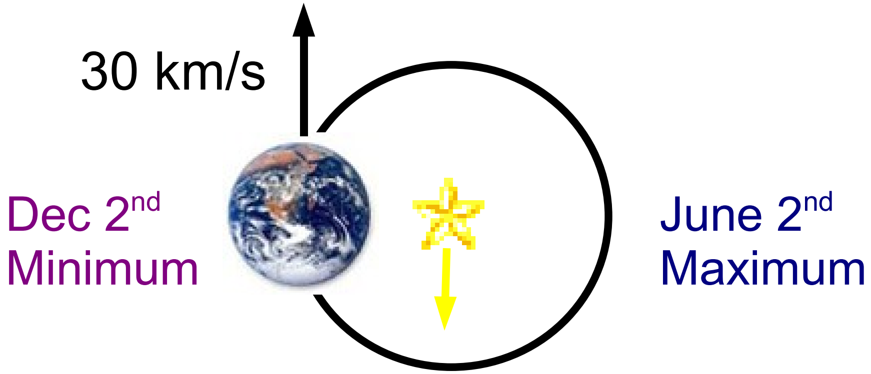
- DAMA only experiment focusing on modulation
- Has seen an excess consistent with expected behavior of DM scattering

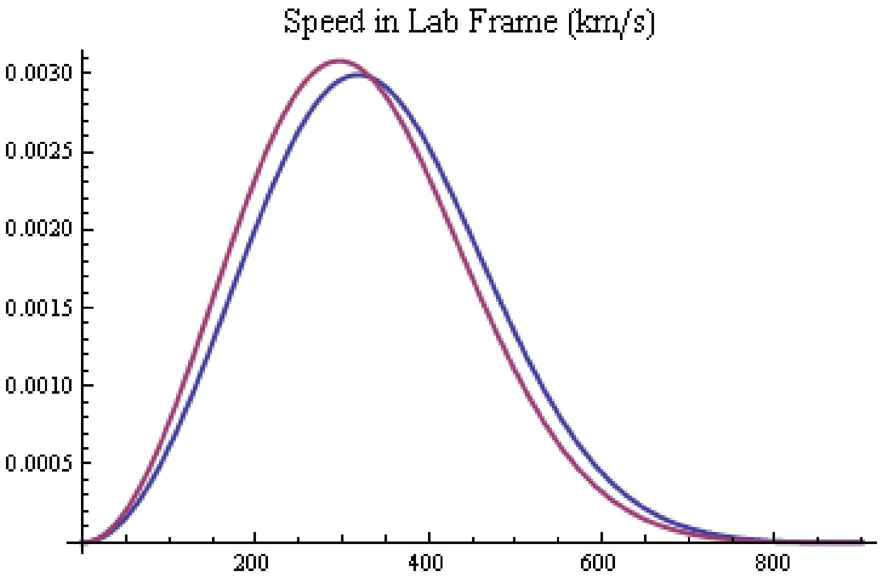
Modulation

Drukier, Freese, Spergel

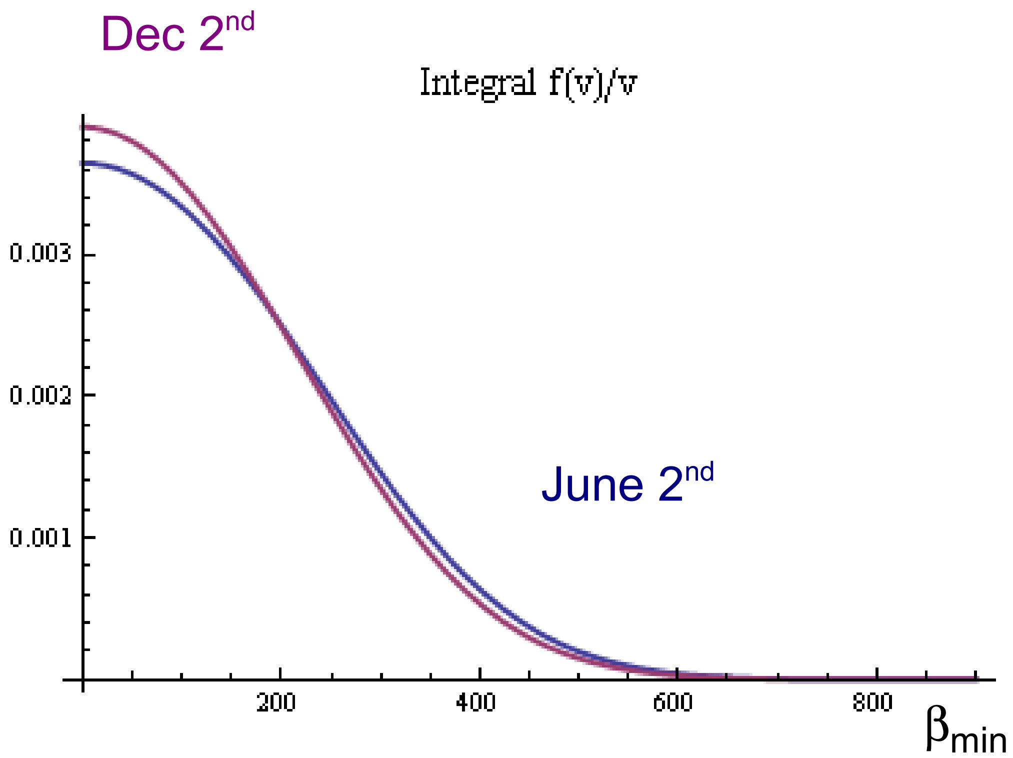
- Due to earth's (and sun's) orbit, velocity distribution changes seasonally







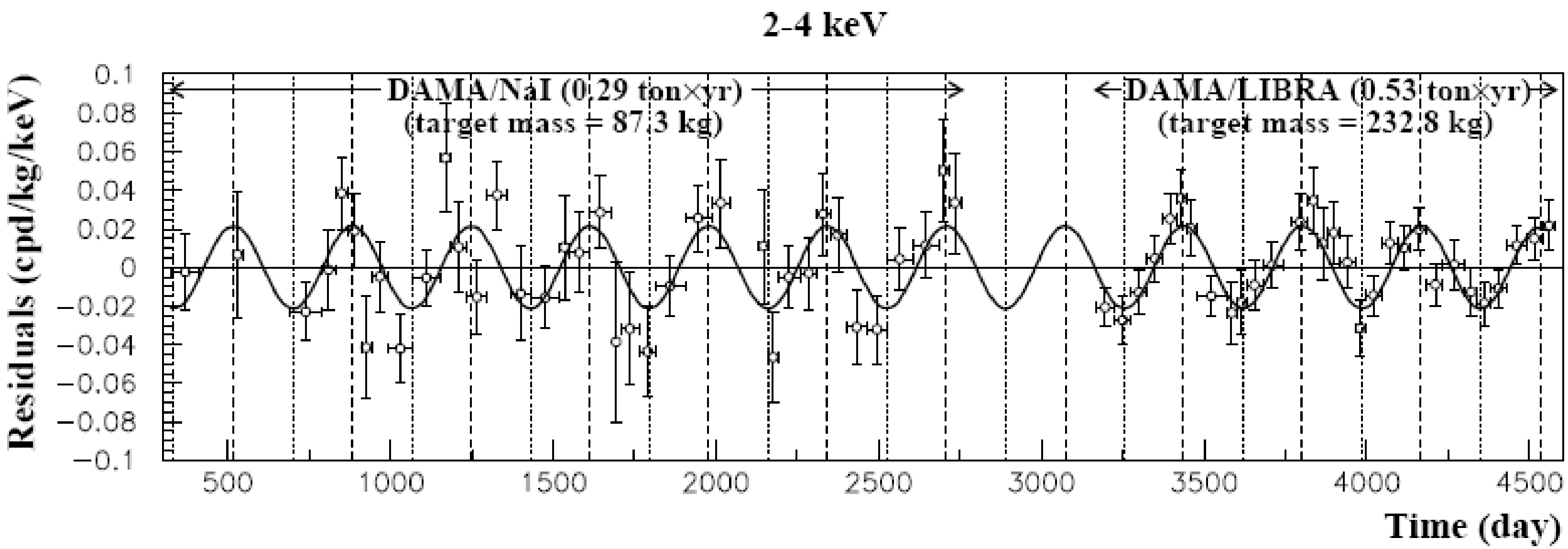
Modulation (cont.)



$$\beta_{min} = \sqrt{\frac{m_N E_R}{2\mu_N^2}}$$

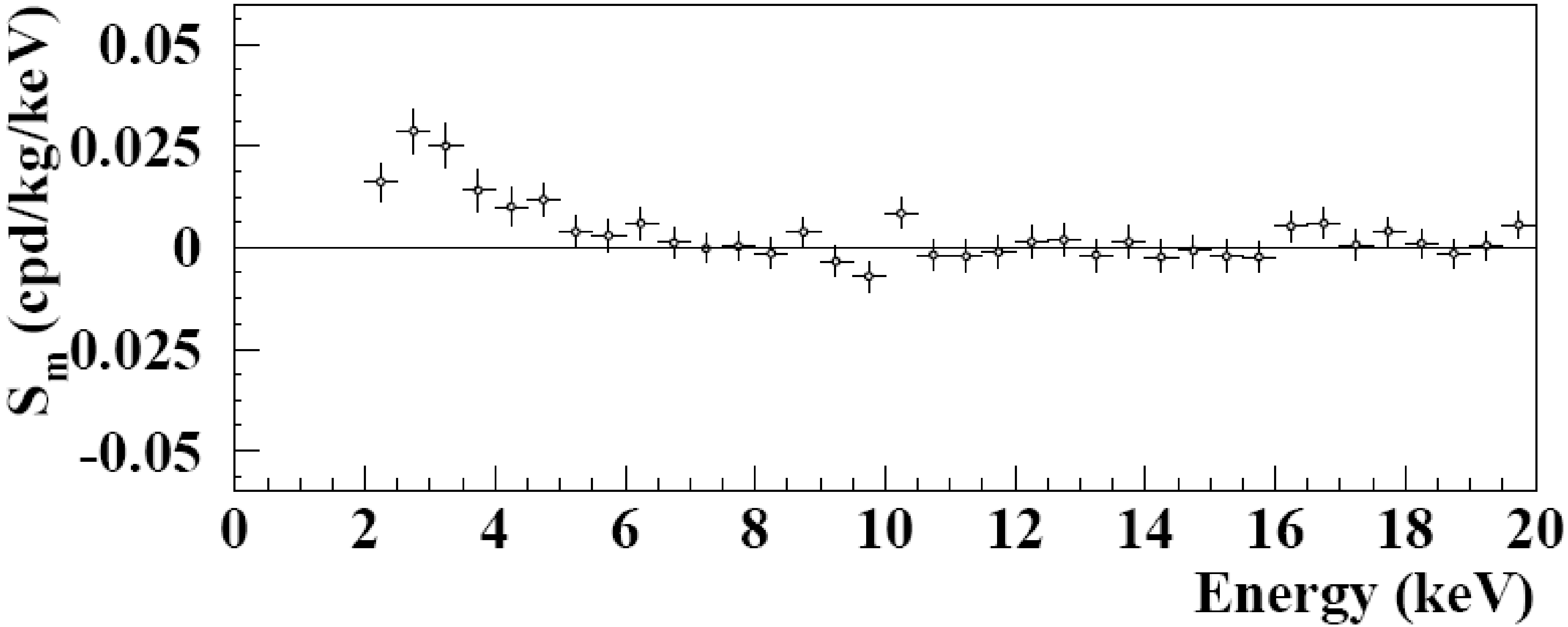
- $dR/dE_R = S_0 + S_m \cos[2\pi(t-t_0)/T]$
- Expect T = 1 year, t_0 = June 2nd (152nd day), S_m positive (negative) for large (small) ER

Data Consistent with DM modulation



	A (cpd/kg/keV)	$T = \frac{2\pi}{\omega}$ (yr)	t_0 (day)	C.L.
DAMA/NaI				
(2–4) keV	0.0252 ± 0.0050	1.01 ± 0.02	125 ± 30	5.0σ
(2–5) keV	0.0215 ± 0.0039	1.01 ± 0.02	140 ± 30	5.5σ
(2–6) keV	0.0200 ± 0.0032	1.00 ± 0.01	140 ± 22	6.3σ
DAMA/LIBRA				
(2–4) keV	0.0213 ± 0.0032	0.997 ± 0.002	139 ± 10	6.7σ
(2–5) keV	0.0165 ± 0.0024	0.998 ± 0.002	143 ± 9	6.9σ
(2–6) keV	0.0107 ± 0.0019	0.998 ± 0.003	144 ± 11	5.6σ
DAMA/NaI+ DAMA/LIBRA				
(2–4) keV	0.0223 ± 0.0027	0.996 ± 0.002	138 ± 7	8.3σ
(2–5) keV	0.0178 ± 0.0020	0.998 ± 0.002	145 ± 7	8.9σ
(2–6) keV	0.0131 ± 0.0016	0.998 ± 0.003	144 ± 8	8.2σ
	Expectations	1	152	

•Modulation Spectra



Most events expected at low energy

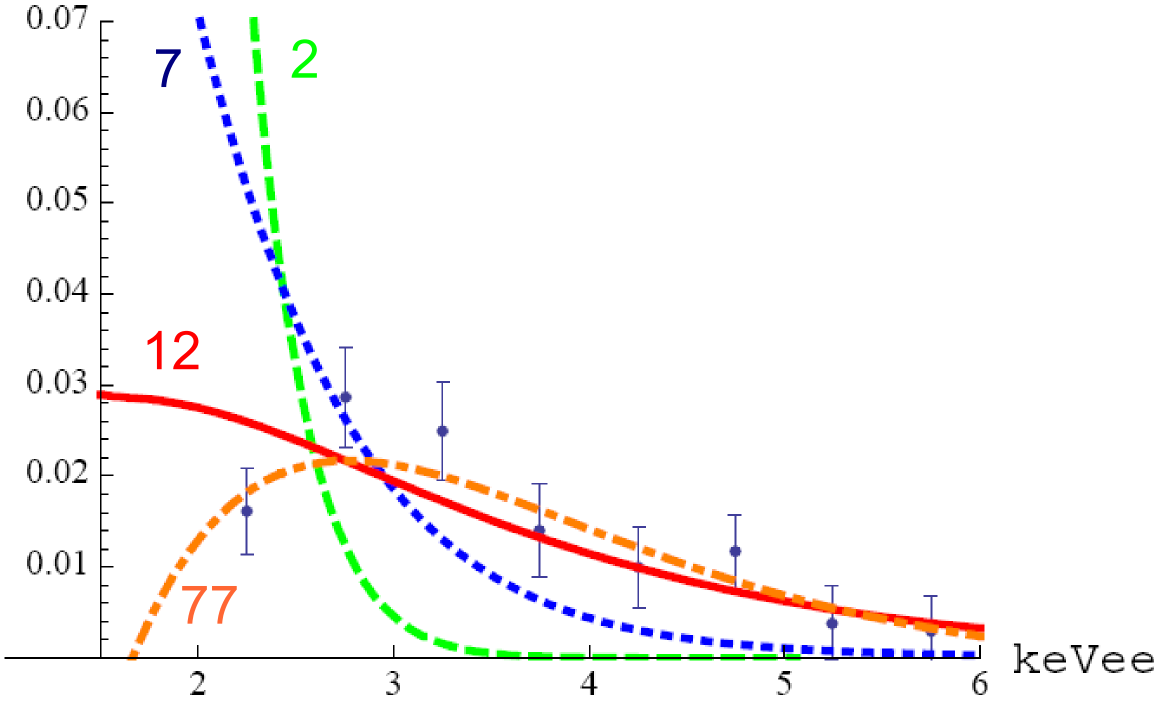
Consistent Models vs DAMA

- DAMA/LIBRA data is now detailed enough to pin down parameter space of dark matter candidates
- Can check if those models are allowed by other data
- Consider spin-independent scattering
  - Elastic case, requires light dark matter
  - Inelastic dark matter

Elastic DM

SC, Pierce, Weiner
See also Fairbairn, Schwetz and Freese et.al.

DAMA spectra for different masses (GeV)

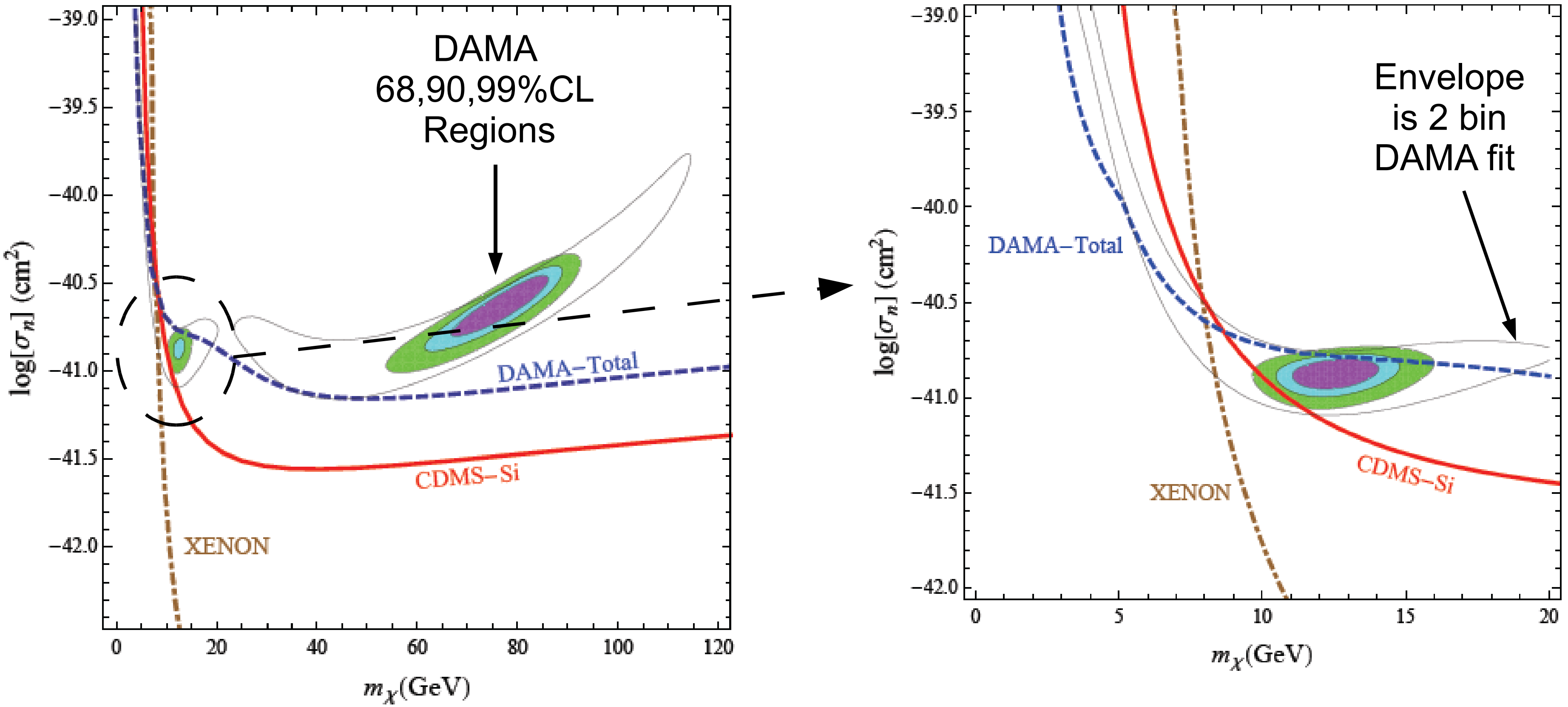


Data points pick out preferred mass regions

Fact that the first few points are “low” drives the fit

LDM Plots

SC, Pierce, Weiner



Spectral information disfavors m < 10 GeV
Need nonstandard astrophysics/expt'l issues
for consistency

•Inelastic Dark Matter

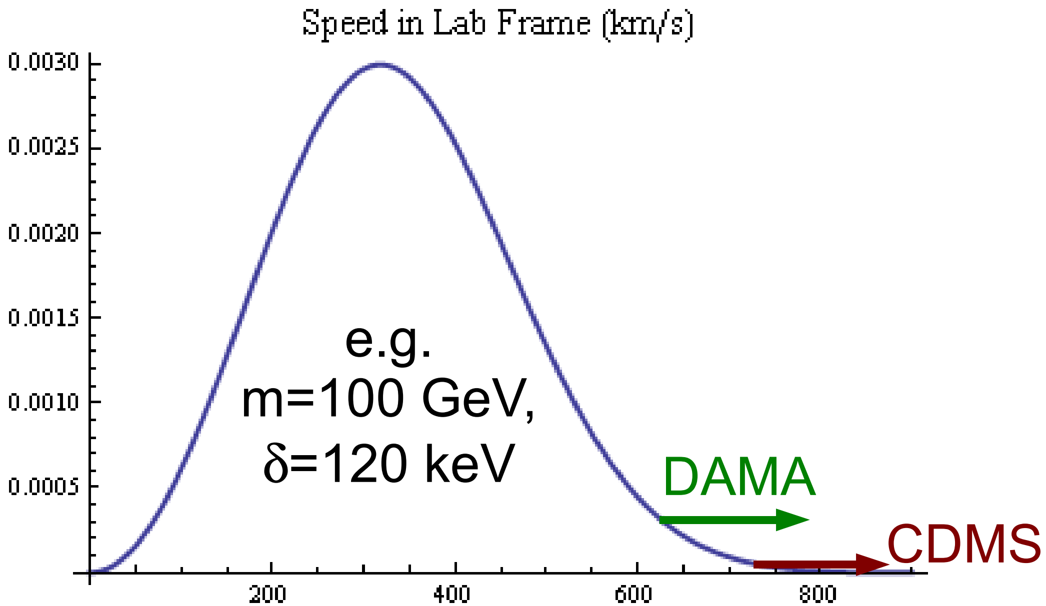
Smith, Weiner
SC, Kribs, Smith, Weiner

- Models where dark matter scatters dominantly inelastically off nuclei
- Adds extra parameter δ, mass splitting to heavier state
- Kinematics produces a few effects
- Originally proposed to reconcile CDMS and DAMA

Preference for Heavy Targets

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

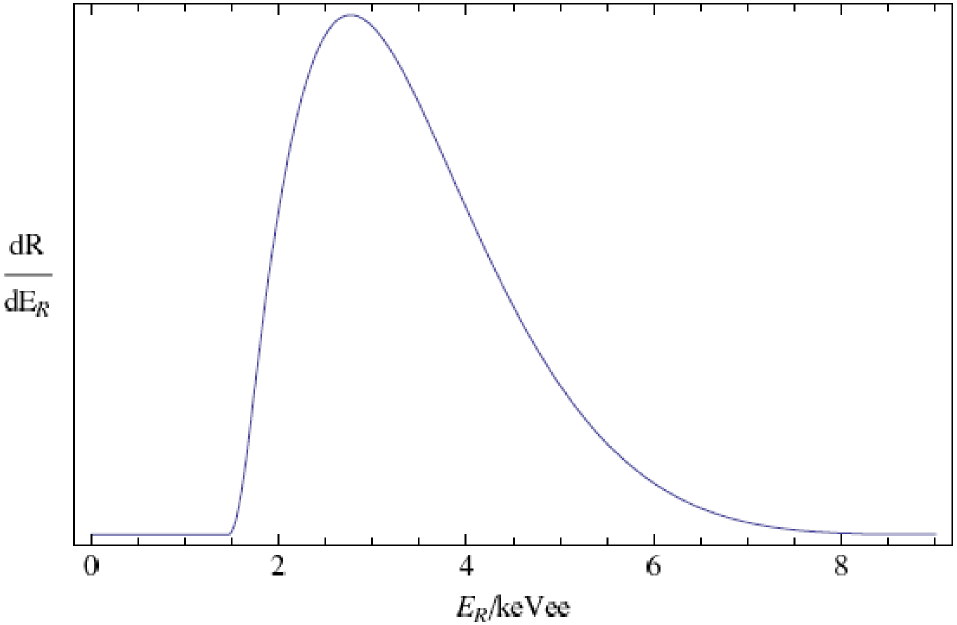
$$\beta_{threshold} = \sqrt{\frac{2\delta}{\mu_N}}$$



- Threshold velocity in order to excite to higher DM state
- Heavier targets sample lower velocities, giving enhanced rates

Distinct Spectra

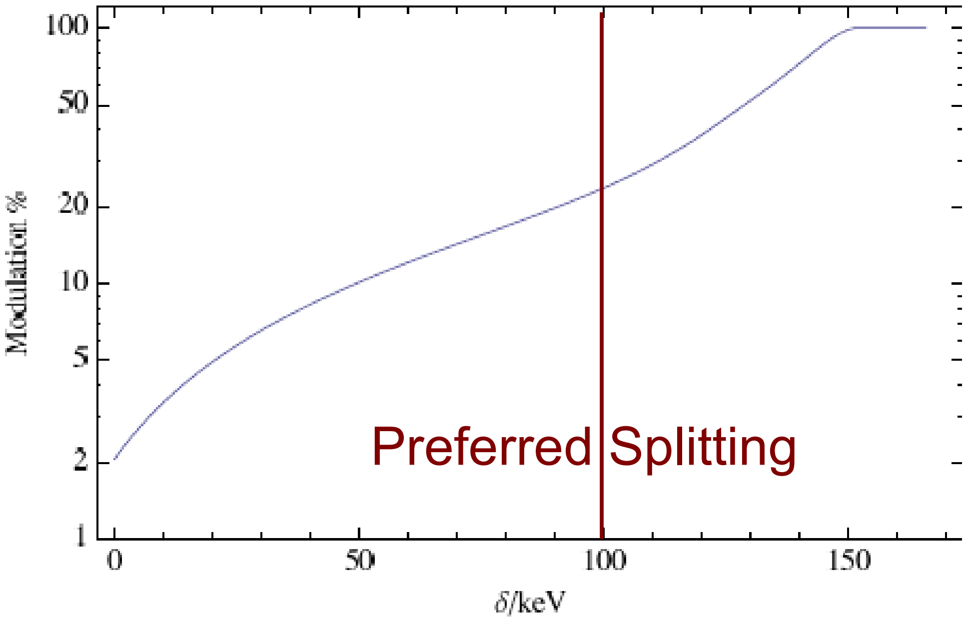
$$\beta_{min} = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu_N} + \delta \right)$$



- Low energy recoils require higher velocities
- Full expt'l spectra is important, model, constraints depend strongly on event distribution

Enhanced Modulation

- Sampling of higher velocity tail, means more modulation
- Expt: Dates of data taking crucial to setting limits. Can search for enhanced modulation

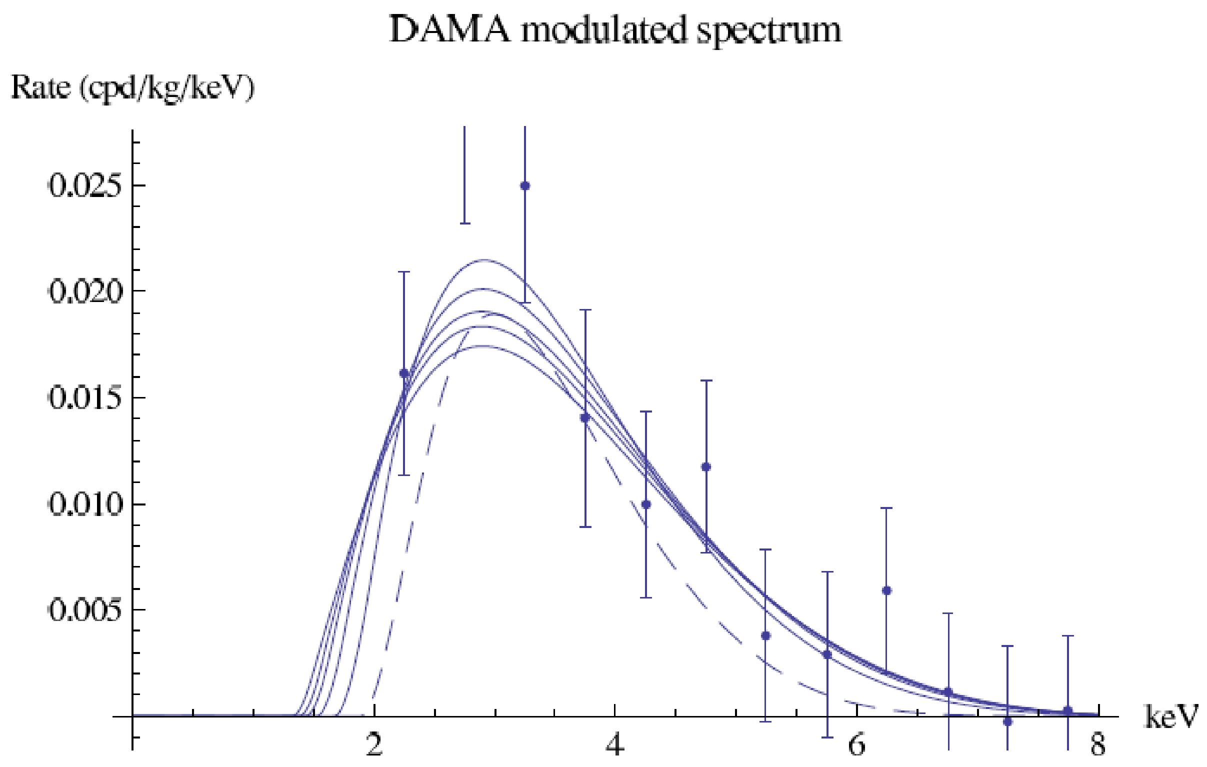


Modulation in observed DAMA range

Benchmark Values

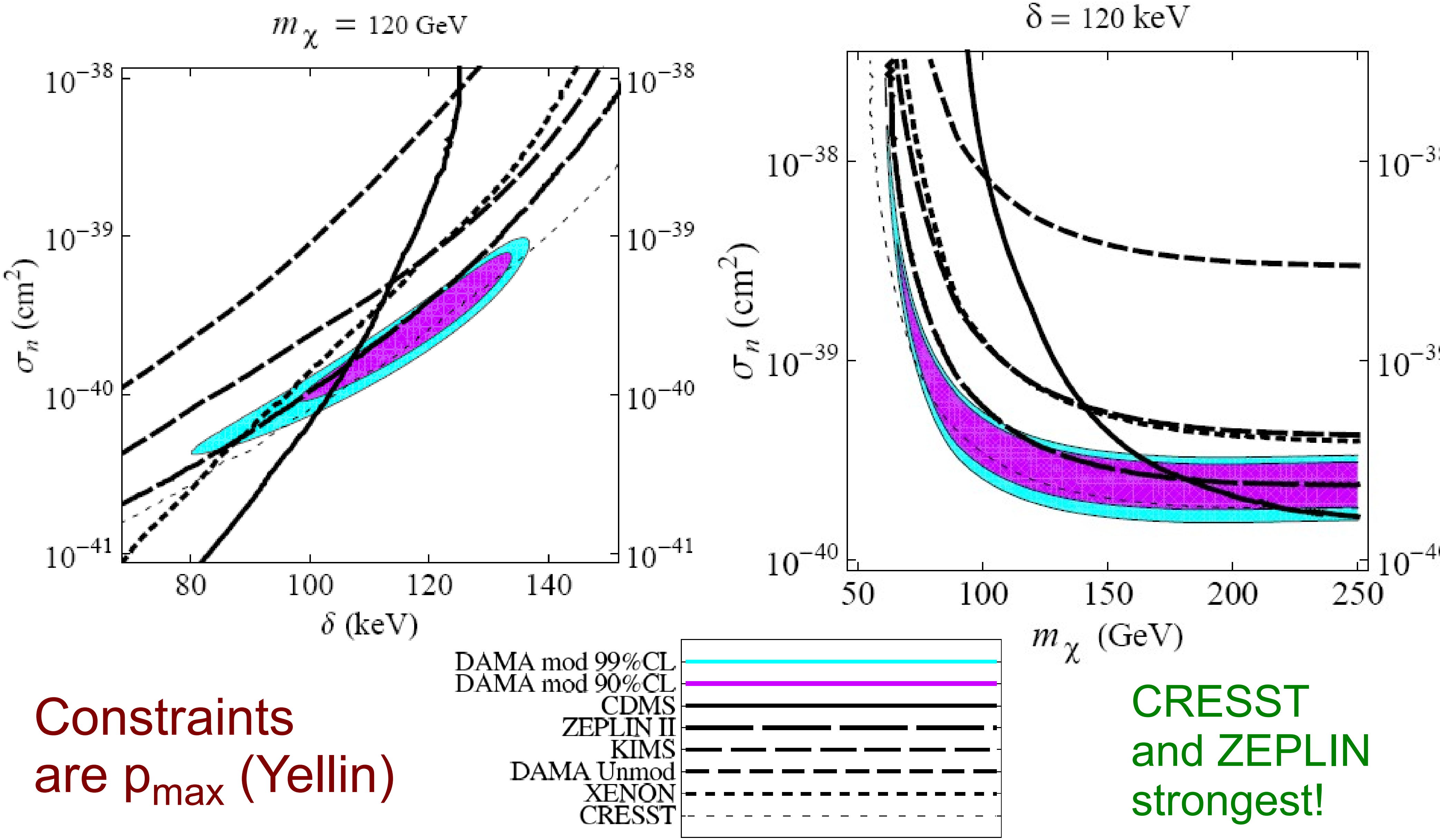
#	m_χ (GeV)	σ_n (10^{-40} cm^2)	δ (keV)	DAMA 2-6 keVee (10^{-2} dru)	XENON 4.5-45 keV (counts)	CDMS 10-100 keV (counts)	ZEPLIN 5-20 keVee (counts)	KIMS 3-8 keVee (10^{-2} dru)	CRESST 12-100 keV (counts)
expt				1.31 ± 0.16	24 (31.6)	2 (5.3)	29 (37.2)	5.65 ± 3.27	7 (11.8)
1	70	11.85	119	0.89	1.39	0	8.46	0.65	8.76
2	90	5.75	123	1.21	5.52	0	14.40	1.52	9.75
3	120	3.63	125	1.22	9.06	0.13	18.09	2.18	10.7
4	150	2.92	126	1.18	11.17	0.95	19.93	2.53	11.2
5	180	2.67	126	1.15	12.46	1.93	21.01	2.74	11.6
6	250	2.62	127	1.11	14.01	3.60	23.32	3.00	12.1

DAMA Spectra Benchmarks



For different dark matter masses, each fit prefers a range for δ, as it shifts the peak

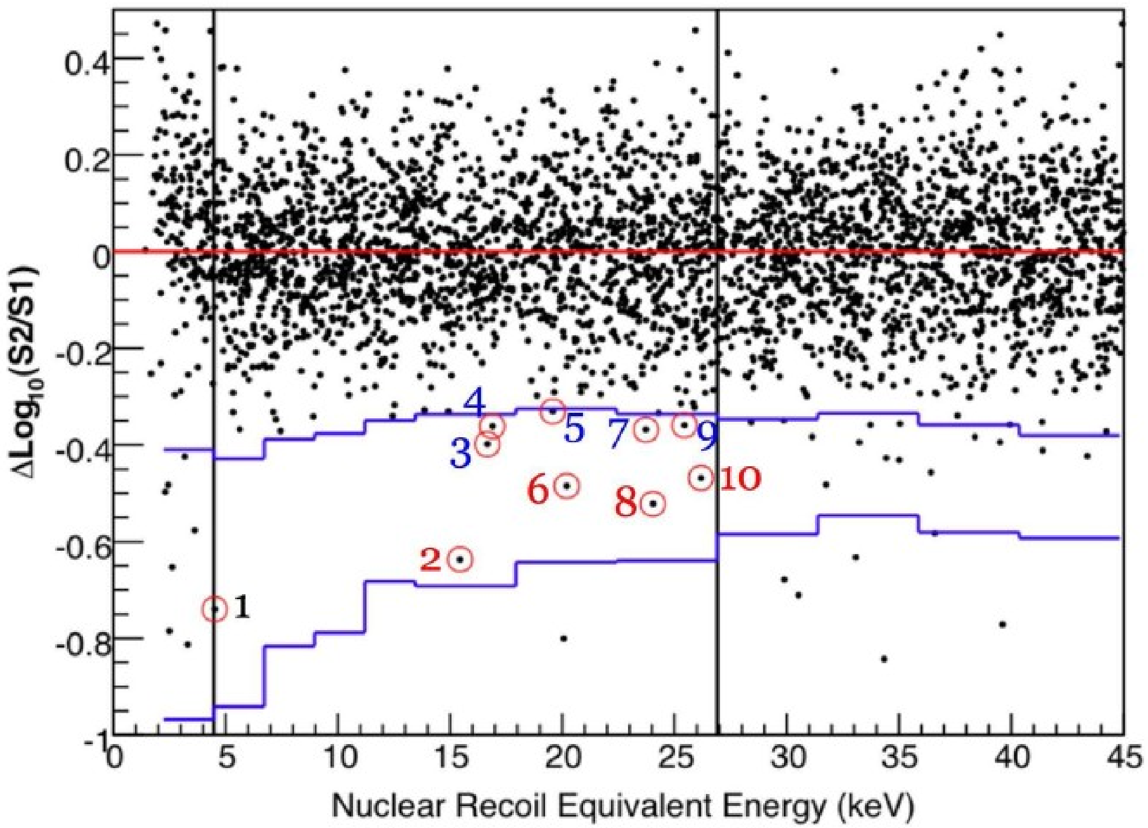
IDM Plots



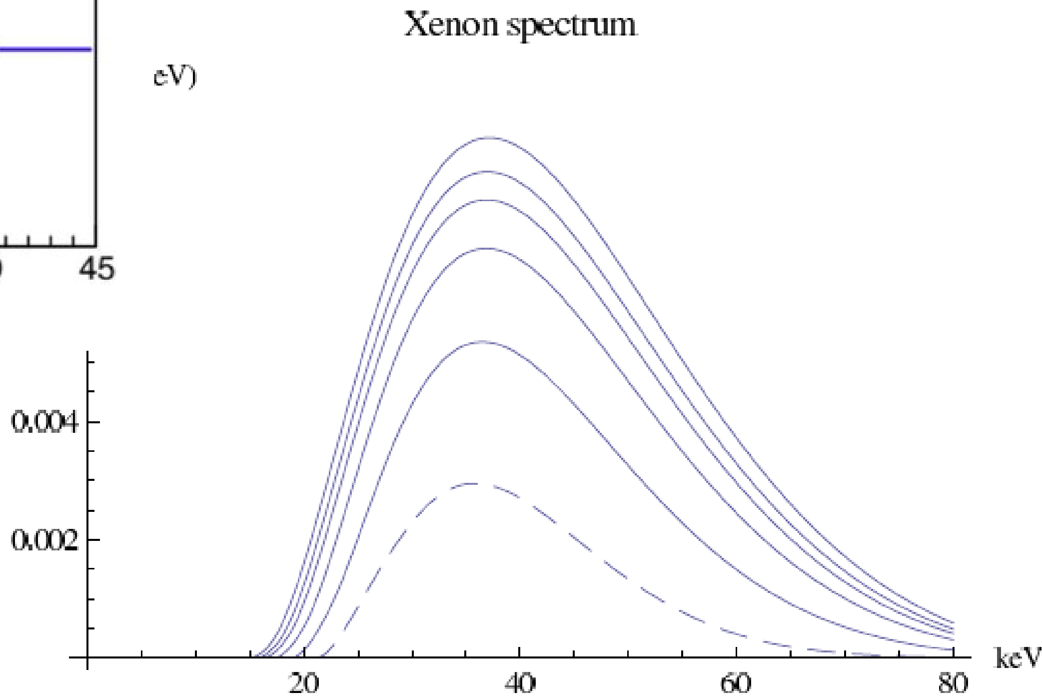
Constraints are p_{max} (Yellin)

CRESST and ZEPLIN strongest!

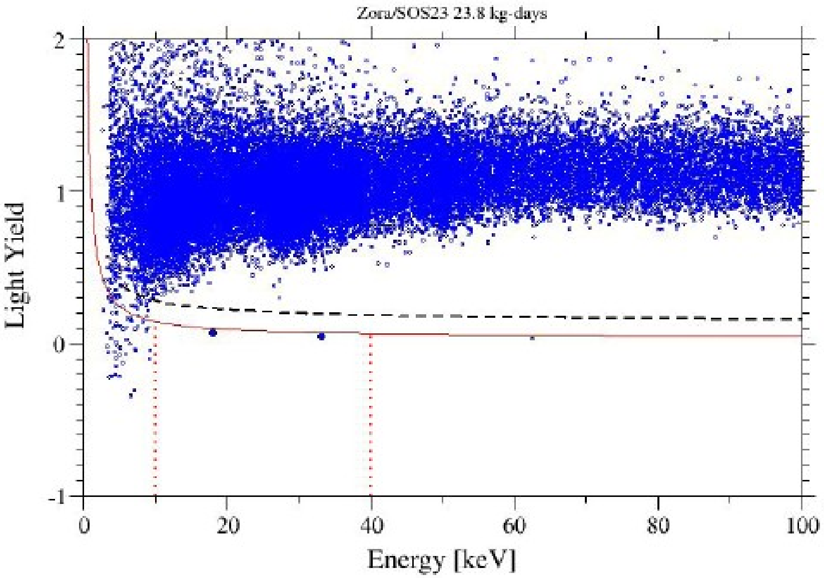
XENON Data

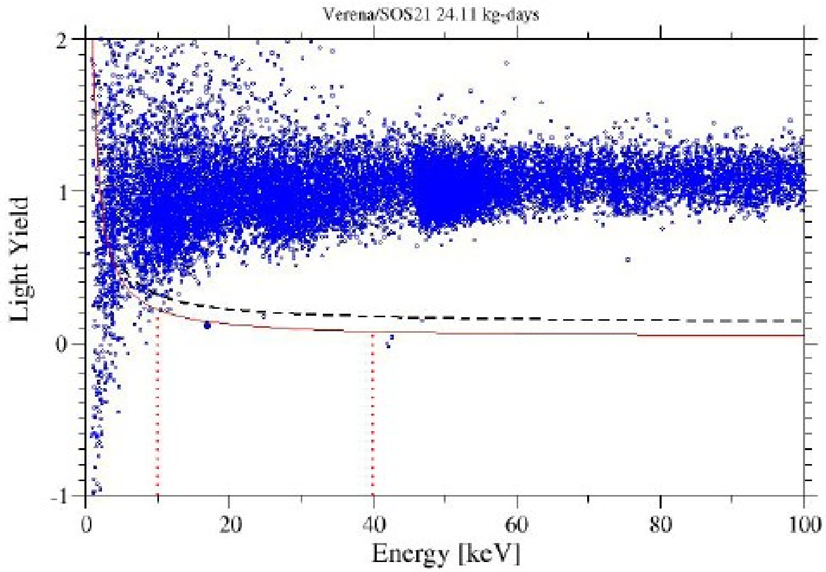


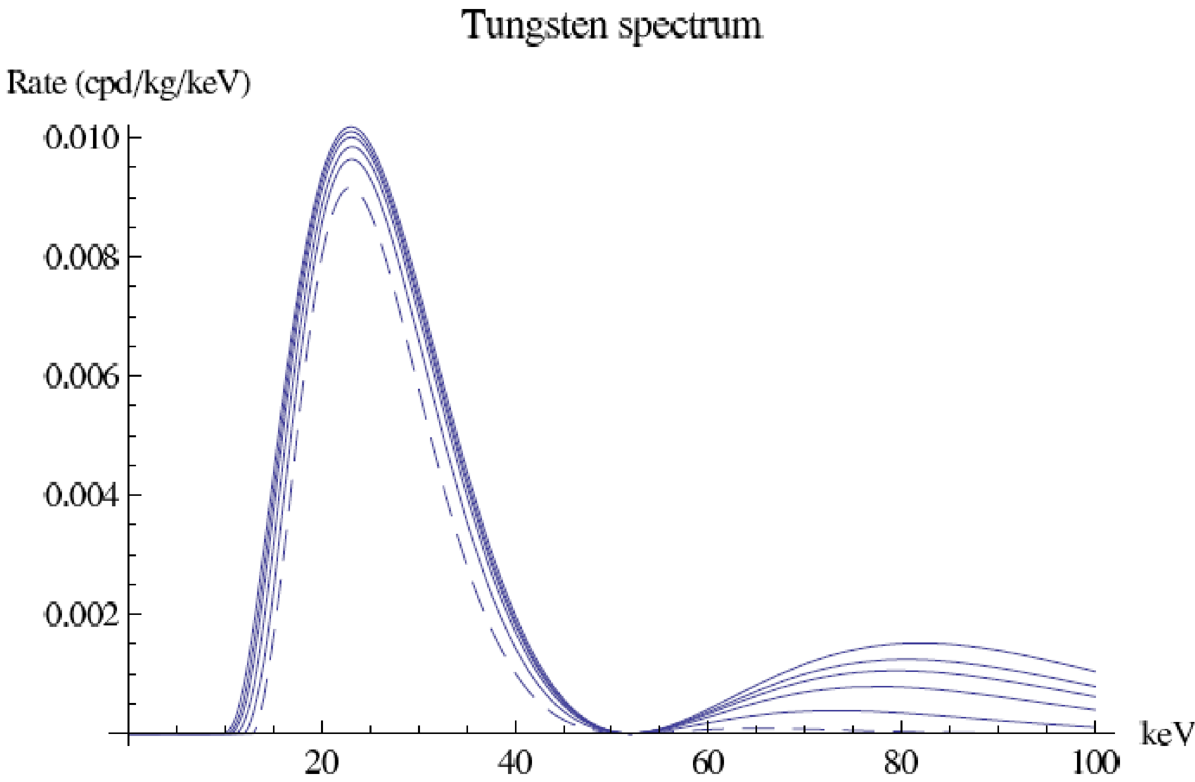
Analysis region (< 27 keV) misses most of the IDM recoils



CRESST Data







Seven events observed, lower than we expect, but inconsistent with expected background

Conclusions

- DAMA's new data is predictive enough to set up a non-moving target
- Light Dark Matter
  - Low threshold expts: CDMS, CoGeNT, and even XENON will probe further
- Inelastic Dark Matter
  - Heavy target expts: CRESST, XENON, LUX, KIMS, ZEPLIN should see high energy events and possibly modulation

Extra Slides

Direct Detection Rates (SI)

$$\frac{dR}{dE_R} = N_T M_N \frac{\rho_\chi \sigma_n}{2 m_\chi \mu_{ne}^2} \frac{(f_p Z + f_n (A-Z))^2}{f_n^2} F^2[E_R] \int_{\beta_{min}}^{\infty} \frac{f(v)}{v} dv$$

Particle Physics

Astrophysics

Experimental

Total convolution must be unraveled to connect to fundamental physics

Models of IDM

- Sneutrino with lepton number violation

$$\Phi = (R + i\, I)/\sqrt{2}$$

$$\bar{\Phi}\,\partial_\mu \Phi\, Z^\mu \supset (R\,\partial_\mu I - R\,\partial_\mu I)\, Z^\mu$$

- Pseudo-Dirac Neutrino

$$\Psi = \begin{pmatrix} \xi \\ \bar{\eta} \end{pmatrix} \qquad \chi_\pm = \xi \pm \eta$$

$$\bar{\Psi}\,\gamma_\mu Z^\mu \Psi \supset \bar{\chi}_+ \gamma_\mu Z^\mu \chi_-$$

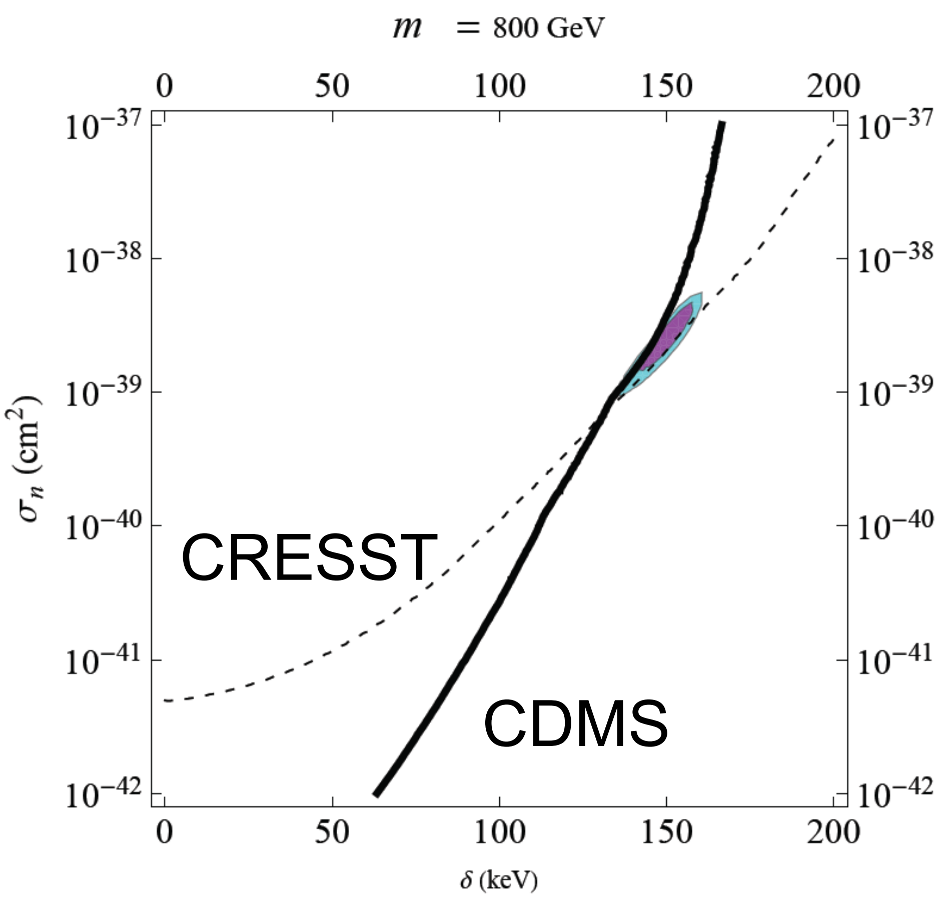
Mass splitting technically natural due to breaking of U(1) symmetry

Theory of Dark Matter

- Dark matter mass due to ATIC is 800 GeV – 1 TeV
- Attempts to get DAMA by inelastic scattering
  - Plots from before rule out m > 250 GeV
- However, the inelastic scattering is mediated by light vector ϕ, giving $1/(q^2-m_\phi^2)^2$ in rate

Preliminary Results: Pushes to larger δ

$m_\phi \sim 8$ MeV



$m_\phi \sim 80$ MeV