Direct Detection Constraints on a Magnetic Fluffy WIMP

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Motivation

- The nature of Dark Matter is one of the fundamental questions we are trying to find the answer to
- One approach to resolving the tension between different direct detection experiments has been to exploit differences in kinematics and couplings introduced by using different target nuclei
- This has been done for example in the inelastic Dark Matter (iDM) and Magnetic inelastic Dark Matter (MiDM) models

D. Smith,N. Weiner, arXiv : 0101138, S. Chang,N. Weiner,I. Yavin PRD82, 125011 (2010)

- iDM typically has a small splitting ($\delta \sim$ 100 keV) relative to the WIMP mass ($m_\chi \sim$ 100 GeV)

Motivation

- This splittings can be generated in extra dimensional models with a large compactification radius
- This leads to higher Kaluza Klein modes that a WIMP can scatter to
- Can this scenario make it easier to resolve the tension between current data from Direct Detection Experiments?

Fluffy WIMP

- A simple generalization of iDM where an incoming WIMP can scatter off of a nucleus to a tower of states
- To be excited to each state there is a minimum velocity the WIMP

$$v_{\rm min}^{j} = \sqrt{\frac{1}{2m_N E_R}}\left(\frac{m_N E_R}{\mu} + \delta^{j}\right)$$

- For simplicity we assumed that $\delta^j = j\delta$ and σ_n is a constant for excitations to each state in the tower

Fluffy WIMP

- The differential rate of scattering is given by

$$\frac{dR}{dE_R d\cos\gamma} = \frac{\kappa F^2(E_R)}{n(v_0, v_{\rm esc})}\pi v_0^2 \Big[\exp\left(-\frac{(\vec{v}_E\cdot\hat{v}_R + v_{\rm min})}{v_0^2}\right) - \exp\frac{v_{\rm esc}^2}{v_0^2}\Big]\Theta(v_{\rm esc} - |\vec{v}_E\cdot\hat{v}_R + v_{\rm min}|)$$

D.P. Finkbeiner, T. Lin, N. Weiner, arXiv : 0906.0002

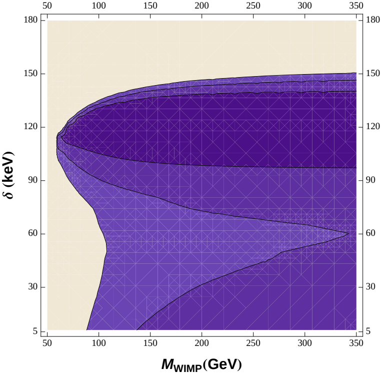
- γ is the angle between the earth's velocity and the recoil velocity of the WIMP in the earth's frame

$$\kappa = N_T \frac{\rho_\chi}{m_\chi}\frac{\sigma_n m_N}{2\mu_n}\frac{(f_p Z + A - Z) f_n)^2}{f_n^2}$$

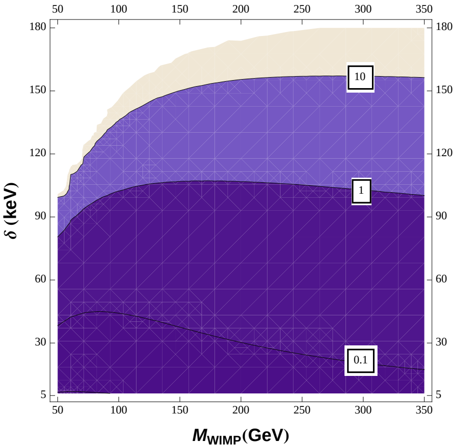
- The scattering rate is proportional to σ_n

General Procedure for Parameter Space scans

- Fit 12 bins (2-8 keVee) DAMA annual modulation amplitude spectrum
- There are three free parameters - m_χ,δ and σ_n
- As σ_n is an overall constant in the rate we can scale this to find the best fit for a fixed m_χ and δ
- We plot contours for a χ^2 of 1,1.5 and 2 per degree of freedom
- This is what a sample plot for the DAMA fit would look like

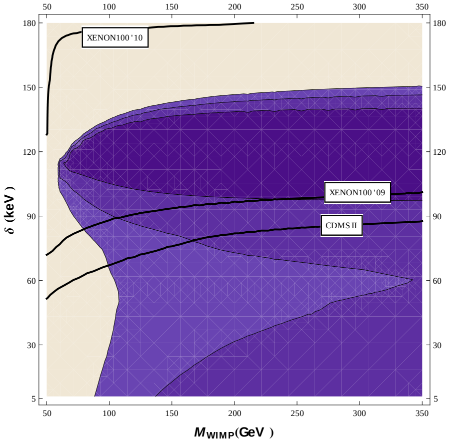


- The corresponding plot for the σ_n scaling factor values that minimized χ^2



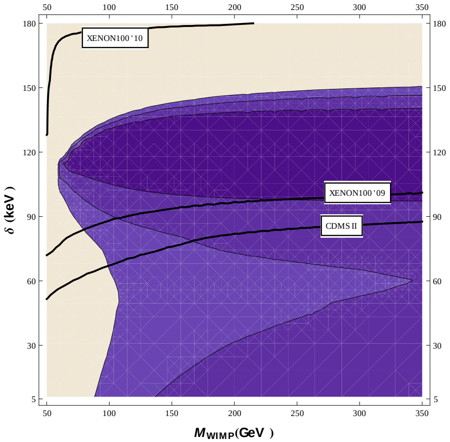
- $\sigma_n =$ scaling factor$\times 10^{-40}$ cm^2

- Next we mark out regions of the DAMA allowed space that are excluded at 90% CL by each relevant Direct Detection experiment



- XENON100 ’09 : 161 kg days , 7.4 - 29.1 keV
- XENON100 ’10 : 48x100.9 kg days, 8.4 - 44.6 keV
- CDMS II : 194.1 kg days, 10-100 keV

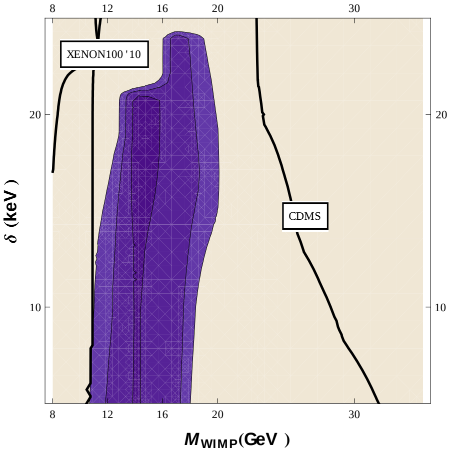
- For a given m_χ the region of high δ corresponds to iDM.



- This is consistent with iDM being ruled out by the latest XENON100 results.

Farina et al, arXiv:1104.3572)

- We look at lower m_χ and δ values to see if this region of parameter space is allowed



- CDMS (low threshold) : 241 kg days, 2 - 5 keV window considered

Magnetic Fluffy WIMP

- As was done in the Magnetic inelastic Dark Matter model one way of suppressing rates relative to DAMA is to consider WIMPs with a magnetic dipole moment

Chang,Weiner,Yavin PRD82, 125011 (2010)

- This allows for dipole-dipole interactions as well as dipole-charge interactions

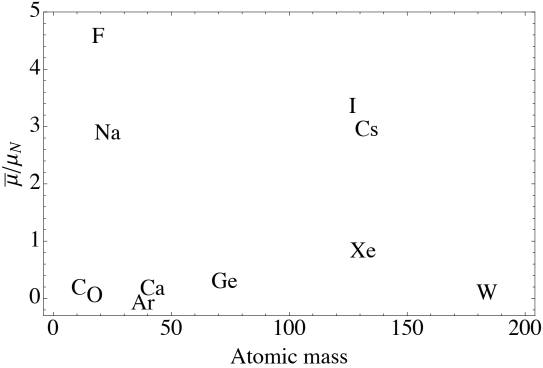
$$\frac{d\sigma}{dE_R} = \frac{d\sigma_{DD}}{dE_R} + \frac{d\sigma_{DZ}}{dE_R}$$

- The DZ term has a smaller contribution due to destructive interference

$$\begin{aligned} \frac{d\sigma_{DZ}}{dE_R} &= \frac{4\pi Z^2\alpha^2}{E_R}\left(\frac{\mu_\chi}{e}\right)^2\left[1-\frac{E_R}{v^2}\left(\frac{1}{2m_N}+\frac{1}{m_\chi}\right)\right. \\ &- \left.\frac{\delta}{v^2}\left(\frac{1}{\mu_{N\chi}}+\frac{\delta}{2m_N E_R}\right)\right]\left(\frac{S_\chi+1}{3S_\chi}\right)F^2[E_R] \end{aligned}$$

- The DD term is proportional to μ_{nuc} and so one would expect a suppression when going from Iodine as a target to Xenon

$$\frac{d\sigma_{DD}}{dE_R} = \frac{16\pi\alpha^2 m_N}{v^2}\left(\frac{\mu_{nuc}}{e}\right)^2\left(\frac{\mu_\chi}{e}\right)^2\left(\frac{S_\chi+1}{3S_\chi}\right)\left(\frac{S_N+1}{3S_N}\right)F_D{}^2[E_R]$$



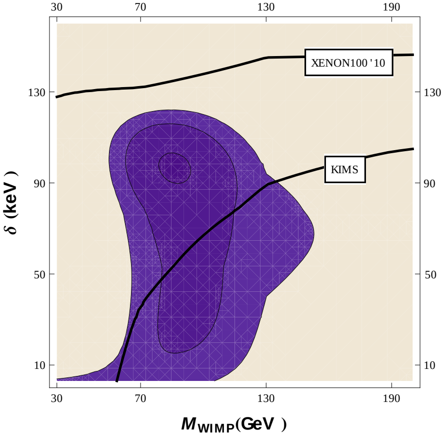
Chang,Weiner,Yavin PRD82, 125011 (2010)

- The overall rate is proportional to ${\mu_\chi}^2$

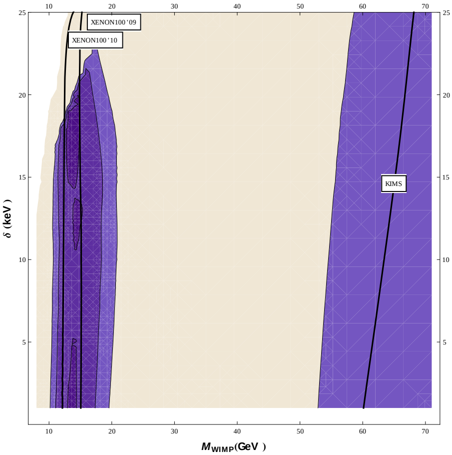
- Again we have three free parameters - m_χ,δ and μ_χ and we follow the same procedure as earlier, except we scale μ_χ this time

- $\mu_\chi =$(scaling factor)$^{\frac{1}{2}} \times$ (0.001) μ_N

- The constraints from KIMS is expected to be strong as the target is CsI and both Cs and I have high magnetic moments
- KIMS : 3409 kg days, 20 - 100 keV
- XENON100 excludes this entire region despite having a low magnetic moment

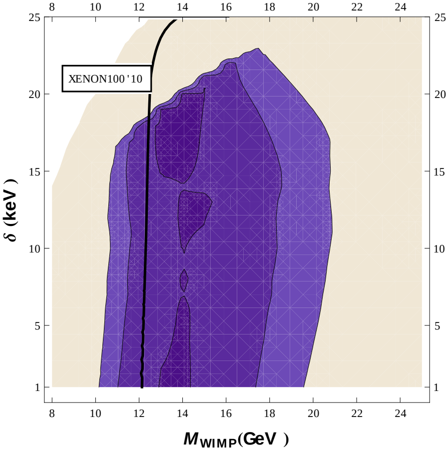


- We look at lower m_χ and δ and include scattering from Na which also has a high magnetic moment



- Other experiments considered which do not exclude any part of the allowed parameter space were - ZEPLIN III, CRESST II (W) and CDMS with a low threshold

- The strongest constraints are from XENON100 '10. However, there is still an allowed region from 10-12 GeV .

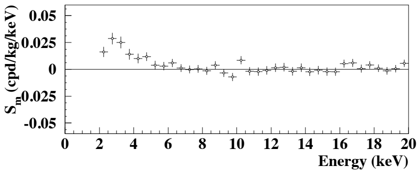


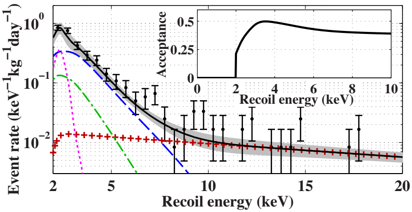
- CRESST oxygen channel does not exclude the allowed region. A definitive signal at CRESST would most likely be hard to explain with Magnetic Fluffy WIMPs as the magnetic moment of Ge is small.

Conclusions

- Fluffy WIMPS are excluded by the latest XENON100 data and low threshold CDMS bounds
- Magnetic Fluffy WIMPS with $m_\chi \sim 10 - 12$ GeV and $\delta < 15$keV are allowed
- CDMS with its low threshold of 2 keV should be very sensitive to this region with more exposure as the recoil energies

Backup slides





Backup slides

Experiment	Element	Ref	Effective Exposure	Period of run	Signal Window	Obs Events	Exp background	Nsig(fiDM)
CDMS II	Ge		194.1 kg days	Jul 1st '07 - Sep 1st '08	10 - 100 keV	2		4.42
CDMS low th	Ge		241?		2 - 5 keV	324	281	67
XENON10	Xe		0.3x316.4	Oct 6 '06 - Feb 14 '07	4.5 - 75 keV	13		18.96
XENON100	Xe		161	Oct 20 '09 - Nov 12 '09	7.4 - 29.1	0		2.3
XENON100 recent	Xe	1104.	48*100.9	Jan 13- Jun 8 2010	8.4 - 44.6 keV	3	1.8+-0.6	4.88
ZEPLIN III	Xe		0.5x63.3	Feb 27 - May 20, 2008	17.5-78.8 keV	5		
CRESST II	W		0.59x0.9x48	Mar 27 '07 - Jul 23 '07	12-100 keV	7		
CRESST latest	O?		564	Jul 11 '09 - May 17 '10	~10 - 40 keV	32 + 2 triple coincidences		
				Aug 11 - Oct 6 2010	~10-40 keV			
KIMS	CsI		3409	not mentioned	20-100		0.28+-0.16	0.6