

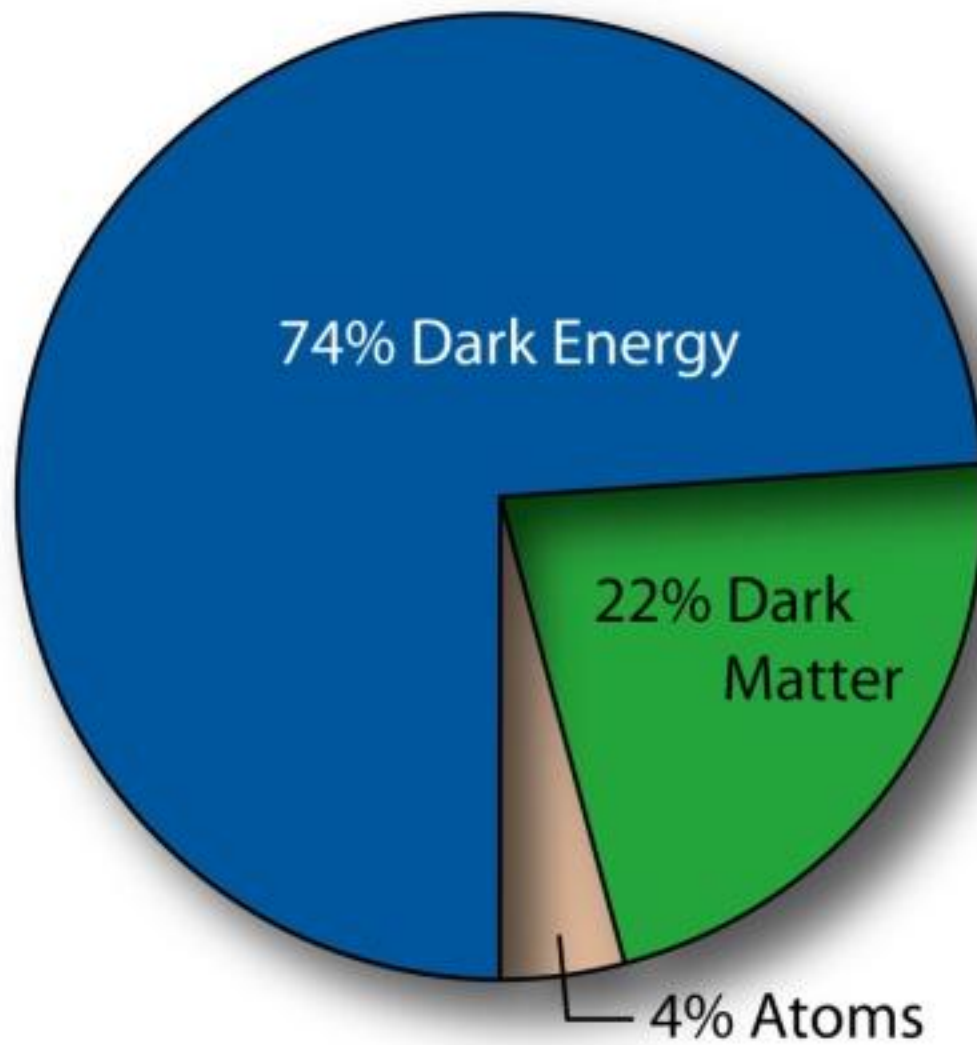
Constraining Scalar Singlet Dark Matter with CDMS, XENON and DAMA and Prediction for Direct Detection Rates

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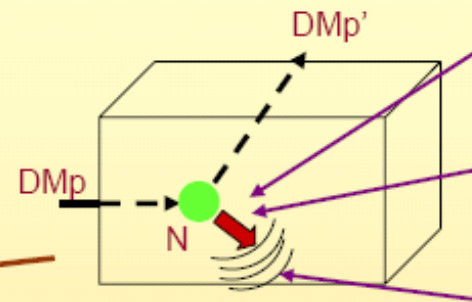


Detection of DM

- **Direct Detection (Dark Matter hits the target and the recoil energy due to the impact is measured)**
- **Indirect Detection (Dark Matter trapped in massive body due to gravity, (e.g. sun) annihilates and produce gamma and/or neutrinos etc. The annihilation product would be detected)**

Some direct detection processes:

- Scatterings on nuclei
→ detection of nuclear recoil energy



Ionization:

Ge, Si

Bolometer:

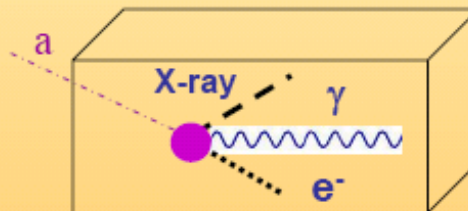
TeO₂, Ge, CaWO₄, ...

Scintillation:

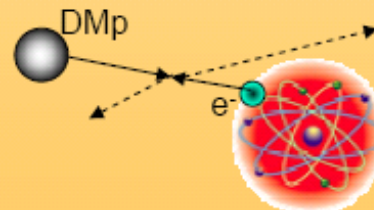
NaI(Tl),
LXe, CaF₂(Eu), ...

- Excitation of bound electrons in scatterings on nuclei
→ detection of recoil nuclei + e.m. radiation

- Conversion of particle into electromagnetic radiation
→ detection of γ , X-rays, e^-



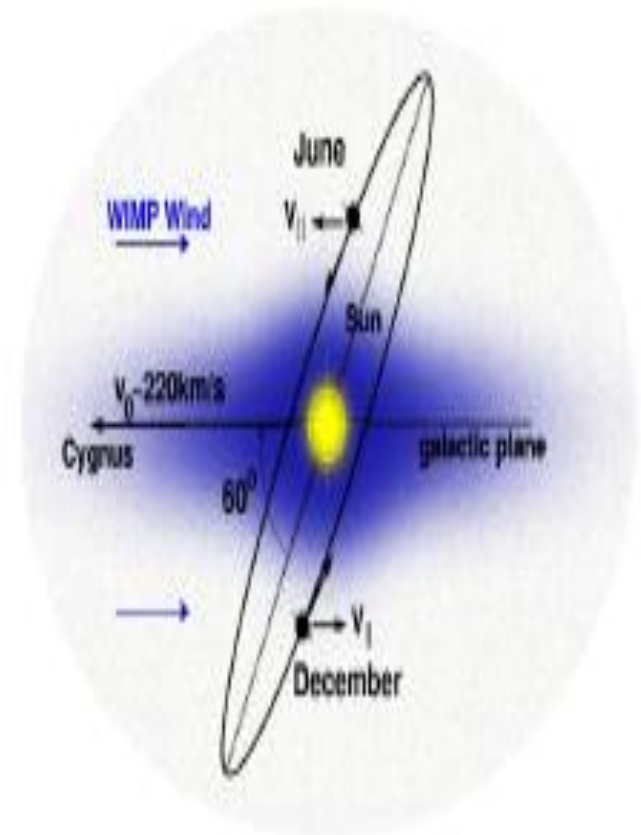
- Interaction only on atomic electrons
→ detection of e.m. radiation



e.g. signals from these candidates are **completely lost** in experiments based on "rejection procedures" of the electromagnetic component of their counting rate

- ... and more

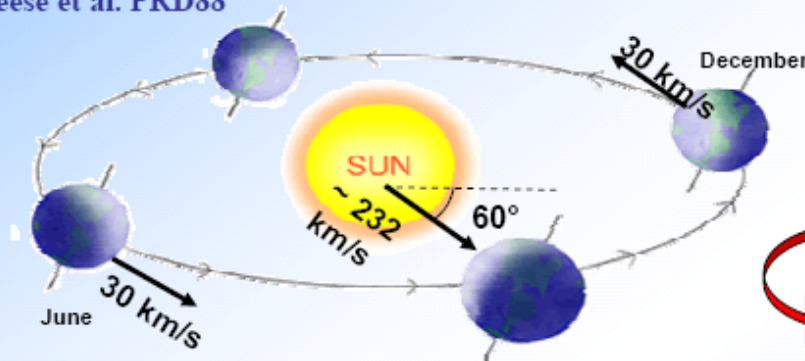
- **Because of the earth's annual revolution around the sun the WIMP flux encountered by the earth continually changes over the period of the year.**



The annual modulation: a model independent signature for the investigation of Dark Matter particles component in the galactic halo

With the present technology, the annual modulation is the main model independent signature for the DM signal. Although the modulation effect is expected to be relatively small **a suitable large-mass, low-radioactive set-up with an efficient control of the running conditions would point out its presence.**

Drukier, Freese, Spergel PRD86
Freese et al. PRD88



- $v_{\text{sun}} \sim 232$ km/s (Sun velocity in the halo)
- $v_{\text{orb}} = 30$ km/s (Earth velocity around the Sun)
- $\gamma = \pi/3$
- $\omega = 2\pi/T$ $T = 1$ year
- $t_0 = 2^{\text{nd}}$ June (when v_{\oplus} is maximum)

$$v_{\oplus}(t) = v_{\text{sun}} + v_{\text{orb}} \cos\gamma \cos[\omega(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R} dE_R \cong S_{0,k} + S_{m,k} \cos[\omega(t-t_0)]$$

Expected rate in given energy bin changes because the annual motion of the Earth around the Sun moving in the Galaxy

Requirements of the annual modulation

- 1) Modulated rate according cosine
- 2) In a definite low energy range
- 3) With a proper period (1 year)
- 4) With proper phase (about 2 June)
- 5) For single hit events in a multi-detector set-up
- 6) With modulation amplitude in the region of maximal sensitivity must be <7% for usually adopted halo distributions, but it can be larger in case of some possible scenarios

To mimic this signature, spurious effects and side reactions must not only - obviously - be able to account for the whole observed modulation amplitude, but also to satisfy contemporaneously all the requirements

Some Dark Matter Experiments

- **DAMA - NaI (scintillator detector)**
- **CDMS - ^{73}Ge at low temp. (^{28}Si also)**
- **CoGeNT – Ge**
- **ArDM – 1 ton liquid Ar (TPC technique)**
- **DRIFT – CS_2 (TPC) (Boulby mines)**
- **NEWAGE – CF_4 (TPC) (Kamioka)**
- **PICASSO -**

$$\frac{dR}{d|\mathbf{q}|^2} = N_T \Phi \frac{d\sigma}{d|\mathbf{q}|^2} \int f(v) dv$$

$$\frac{dR}{dE_R} = 2 \frac{\rho_\chi}{m_\chi} \frac{d\sigma}{d|\mathbf{q}|^2} \int_{v_{\min}}^{\infty} v f(v) dv,$$

$$v_{\min} = \left[\frac{m_{\text{nuc}} E_R}{2m_{\text{red}}^2} \right]^{1/2}$$

$$\frac{d\sigma}{d|\mathbf{q}|^2} = \frac{\sigma_{\text{scalar}}}{4m_{\text{red}}^2 v^2} F^2(E_R)$$

$$E_R = |\mathbf{q}|^2 / 2m_{\text{nuc}}$$

$$= m_{\text{red}}^2 v^2 (1 - \cos \theta) / m_{\text{nuc}}$$

$$m_{\text{red}} = \frac{m_\chi m_{\text{nuc}}}{m_\chi + m_{\text{nuc}}}$$

$$F(E_R) = \left[\frac{3j_1(qR_1)}{qR_1} \right] \exp\left(\frac{q^2 s^2}{2}\right)$$

$$R_1 = (r^2 - 5s^2)^{1/2}$$

$$r = 1.2A^{1/3}$$

$$\mathbf{V} = \mathbf{V}_{\text{gal}} - \mathbf{V}_{\oplus}$$

$$v_{\oplus} = v_{\odot} + v_{\text{orb}} \cos \gamma \cos \left(\frac{2\pi(t - t_0)}{T} \right)$$

$$v_{\odot} = v_0 + v_{\text{pec}}$$

$$\frac{dR}{dE_R} = \frac{\sigma_{\text{scalar}} \rho_{\chi}}{4v_{\oplus} m_{\chi} m_{\text{red}}^2} F^2(E_R) \left[\text{erf} \left(\frac{v_{\text{min}} + v_{\oplus}}{v_0} \right) - \text{erf} \left(\frac{v_{\text{min}} - v_{\oplus}}{v_0} \right) \right]$$

Properties of Dark Matter

- Should have zero or very very weak interaction with other particles
- **Must be neutral**
- **Must be stable (no decay)**
- **Possibly not the Standard Model Particles**

Popular belief → Cold Dark Matter
(CDM) WIMPS

Scalar singlet Dark Matter

- **Simplest scalar sector extension of SM**
- **Addition of a real scalar singlet field to the SM Lagrangian**
- **The stability of singlet S is achieved by assuming that the potential has a Z_2 symmetry under which $S \rightarrow -S$**

$$V(H, S) = \frac{m^2}{2} H^\dagger H + \frac{\lambda}{4} (H^\dagger H)^2 + \frac{\delta_1}{2} H^\dagger H S + \frac{\delta_2}{2} H^\dagger H S^2 + \left(\frac{\delta_1 m^2}{2\lambda} \right) S + \frac{\kappa_2}{2} S^2 + \frac{\kappa_3}{3} S^3 + \frac{\kappa_4}{4} S^4$$

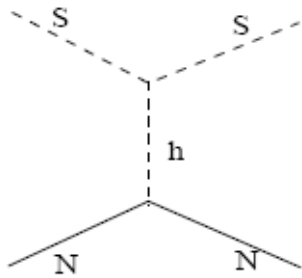
vertices involving odd number of singlet fields S ($\delta_1 = \kappa_3 = 0$)

$$H = \begin{pmatrix} 0 \\ \frac{v+h}{\sqrt{2}} \end{pmatrix}$$

$$V_{\text{mass}} = \frac{1}{2} (M_h^2 h^2 + M_S^2 S^2)$$

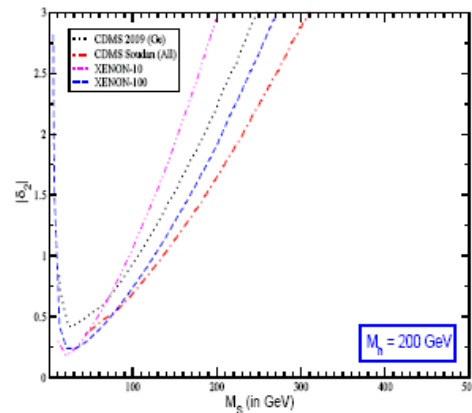
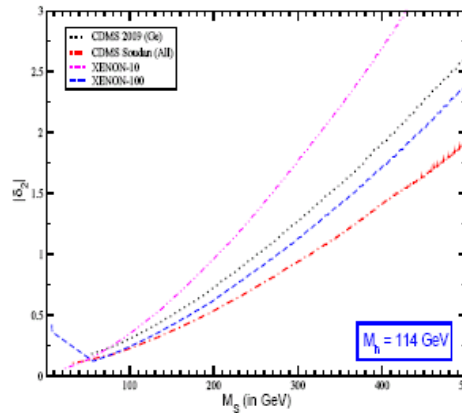
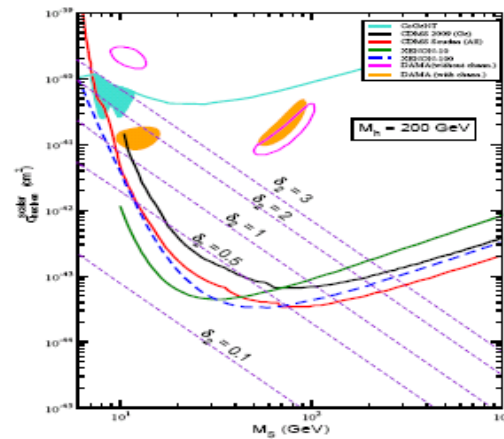
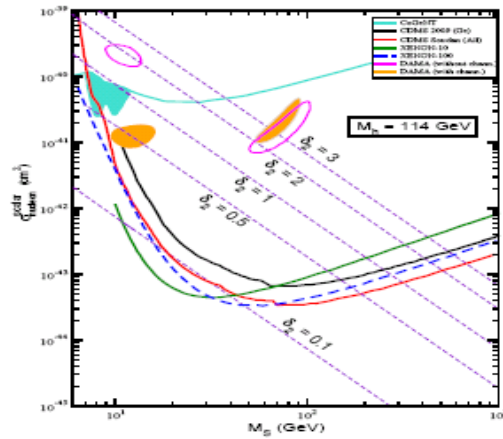
$$M_h^2 = -m^2 = \lambda v^2/2$$

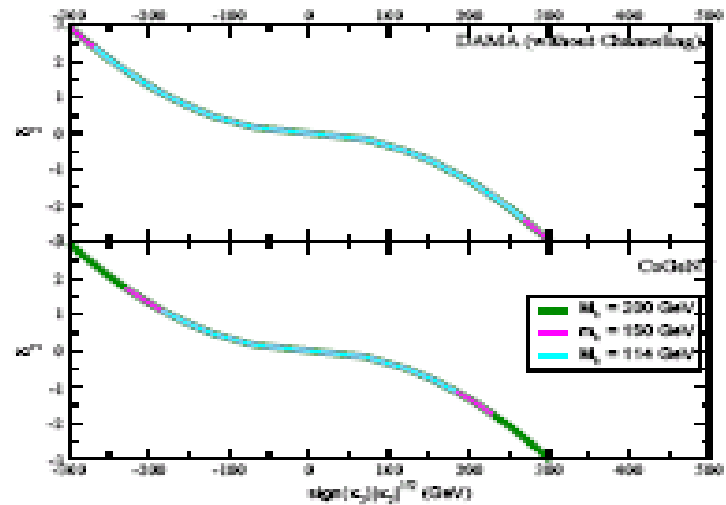
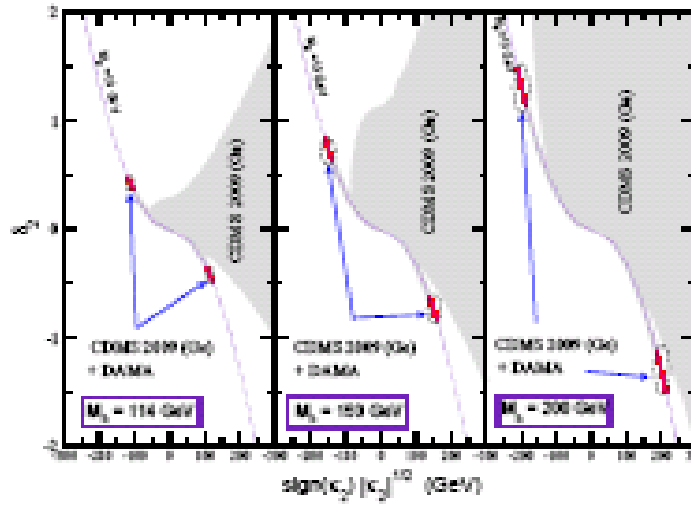
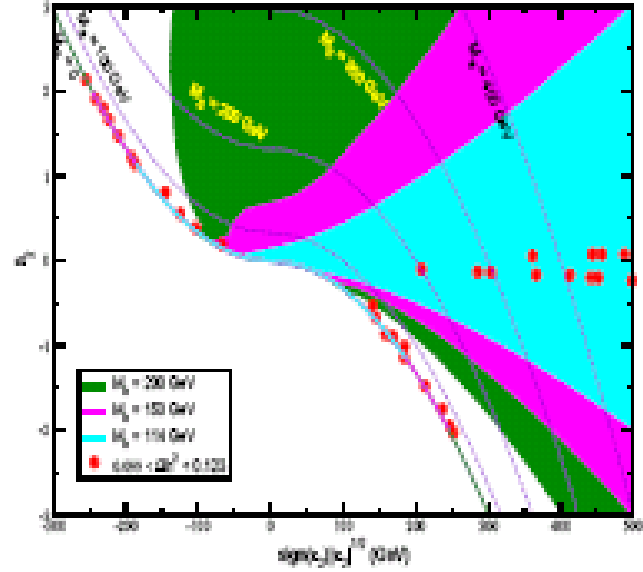
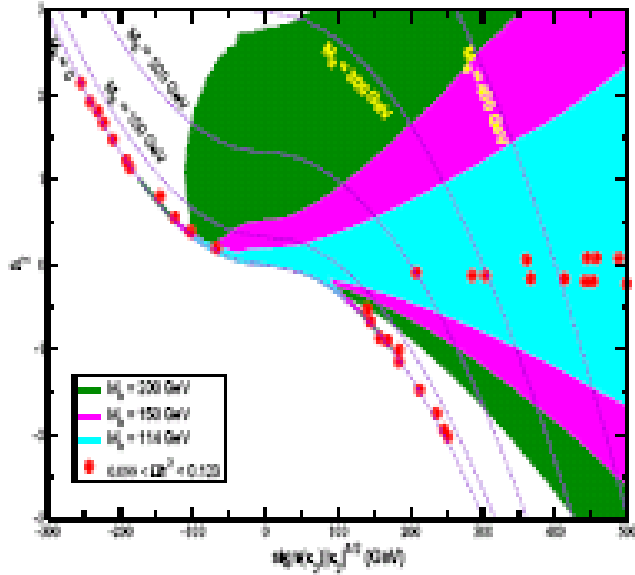
$$M_S^2 = \kappa_2 + \delta_2 v^2/2$$



$$\sigma_N^{\text{scalar}} = \frac{\delta_2^2 v^2 |\mathcal{A}_N|^2}{4\pi} \left(\frac{m_\nu^2}{M_S^2 M_h^4} \right)$$

$$\sigma_{\text{nucleon}}^{\text{scalar}} = (\delta_2)^2 \left(\frac{100 \text{ GeV}}{M_h} \right)^4 \left(\frac{50 \text{ GeV}}{M_S} \right)^2 (5 \times 10^{-42} \text{ cm}^2).$$





Ar detector (ArDM)

- A noble liquid detector. Liquified noble gas is used as target.
- High atomic number, the event rate is expected to be large.
- Capable of effectively discriminating nuclear recoils from other backgrounds
- 3D imaging for the events

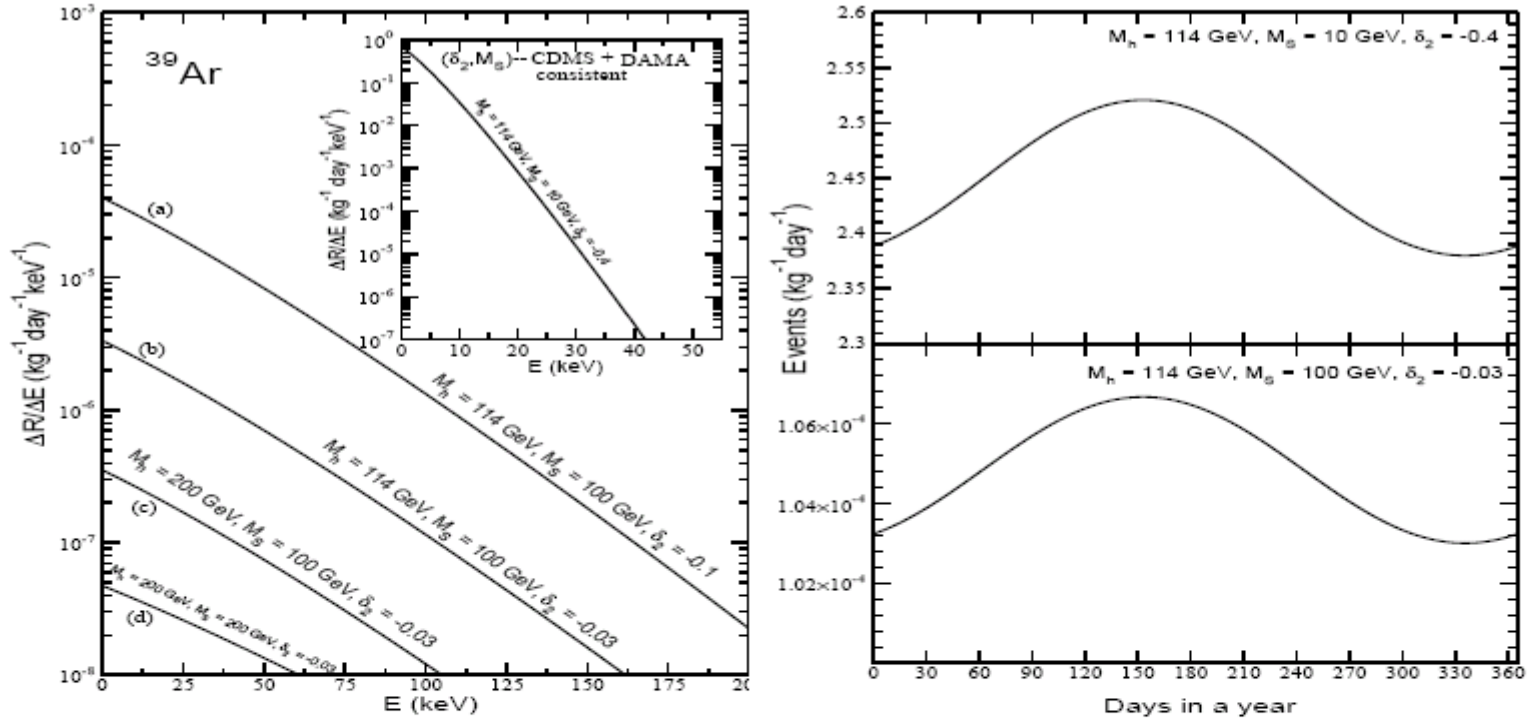
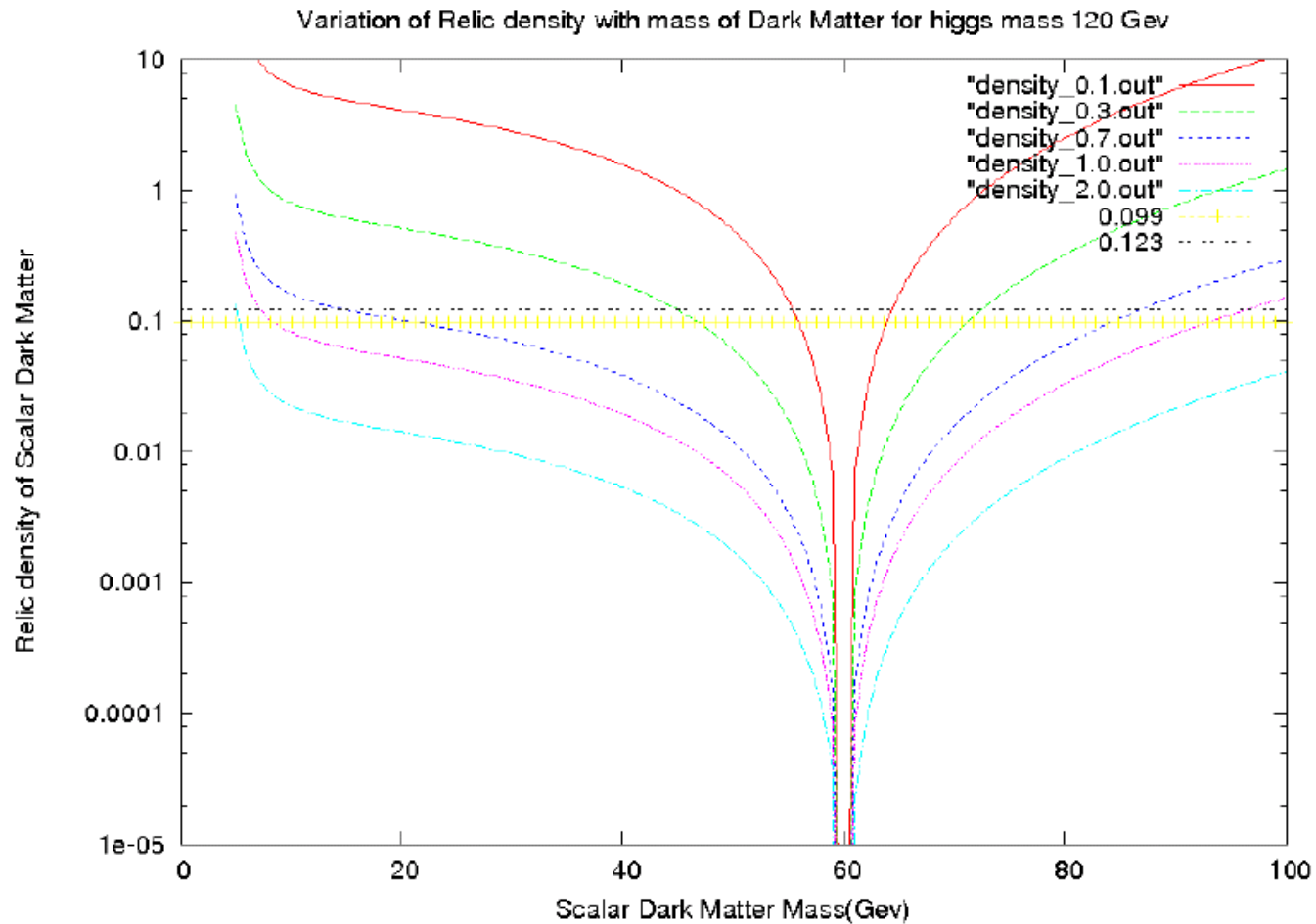


Figure 6: Left Panel: Plot of predictions for dark matter detection rates (per kg per day per keV) in Argon detector as a function of observed recoil energy. The plots are shown for two values of M_h - 114 GeV and 200 GeV and for two sets of (M_S, δ_2) values which are consistent with CDMS limits as well as observed relic density of dark matter (WMAP). In the inset we show the corresponding plot for $M_h = 114$ GeV and for two sets of (M_S, δ_2) values simultaneously consistent with limits on scattering cross section from CDMS 2009 (Ge) and DAMA and also with WMAP. Right panel: Predicted annual variation of event rates in Argon detector over one year for $M_h = 114$ (GeV). The upper panel corresponds to a (M_S, δ_2) value consistent with CDMS+DAMA+WMAP while the lower panel corresponds to a (M_S, δ_2) value consistent with CDMS+WMAP.

Relic density



Thank you