Interpretation of the XENON1T anomaly via large neutrino magnetic moment

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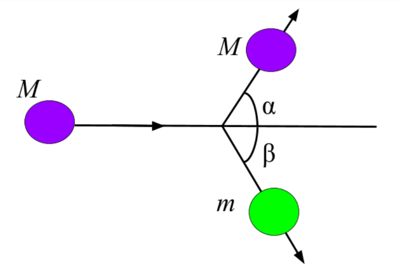
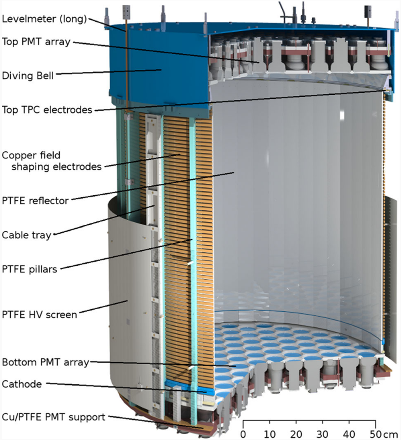
Direct detection of dark matter particles

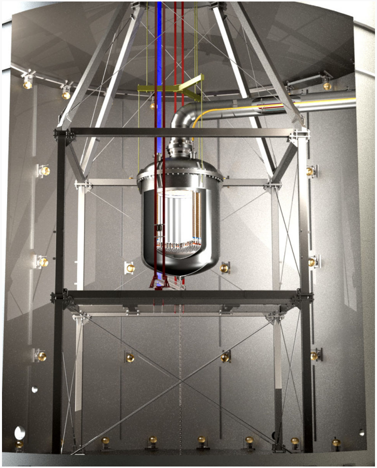


$m \sim 100$ GeV — mass of a xenon atom, M — mass of a dark matter particle with a value from several GeV to several TeV .

$$\mathbf{E \sim keV}$$

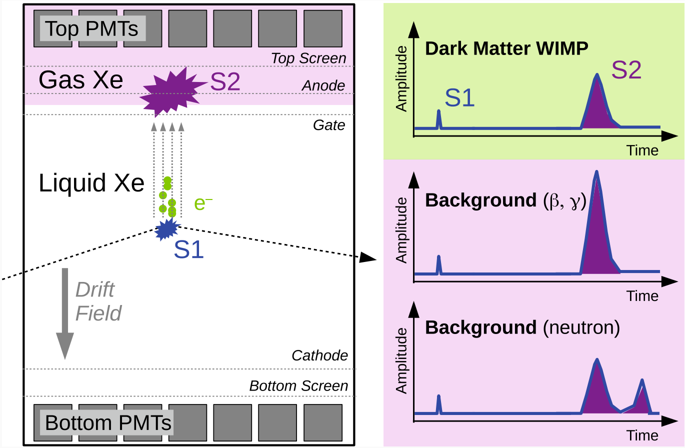
E — kinetic energy of a xenon atom.


Levelmeter (long)
Top PMT array
Diving Bell
Top TPC electrodes
Copper field
shaping electrodes
PTFE reflector
Cable tray
PTFE pillars
PTFE HV screen
Bottom PMT array
Cathode
Cu/PTFE PMT support
0
10
20
30
40
50cm



Working principles, signals S1 and S2

S1 signal — primary scintillations in the liquid phase of the detector. S2 signal — secondary scintillations induced by primary ionization electrons in the gas phase of the detector.

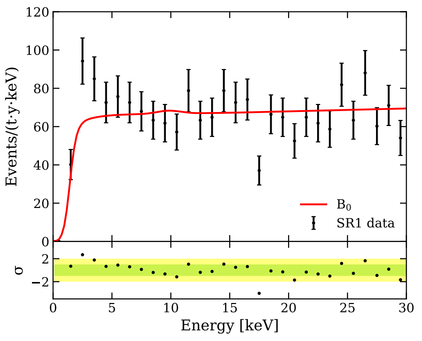


Anomaly in XENON1T data

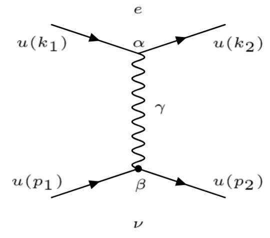
In the data accumulated by the XENON1T detector, there is a signal uncharacteristic for WIMPs, detected in the range of electron recoil energy from 1 to 7 keV.

$$\text{Background model:}\quad \mathrm{B}_0 = \begin{cases} \beta - \text{decays } {}^{214}\mathrm{Pb},\ {}^{85}\mathrm{Kr} \\ \beta\beta - \text{decay } {}^{136}\mathrm{Xe} \\ \text{detector's material radiation, solar neutrinos } (Z_0, W^{\pm}) \end{cases}$$

235 ± 15 background events vs. 285 detected events.



Scattering of neutrinos by electrons



Neutrino vertex of interaction

$$\Gamma_\alpha = -\frac{\mu'_\nu}{2m_e}\sigma_{\alpha\beta}q^\beta, \tag{1}$$

here μ'_ν — magnetic moment of neutrino in Bohr's magnetons μ_B.

Magnetic moment of the Standard model
$\mu'_\nu = 3{,}2 \times 10^{-19}(m_\nu/\text{eV})$

Scattering of neutrinos by electrons

Calculation result of diagram

$$\frac{\mathrm{d}\sigma}{\mathrm{d}T} = \frac{e^4}{16\pi}\frac{\mu_\nu'^{\,2}}{m_e^2}\Big(\frac{1}{T} - \frac{1}{E_\nu}\Big) = \frac{\pi\alpha^2\mu_\nu'^{\,2}}{m_e^2}\Big(\frac{1}{T} - \frac{1}{E_\nu}\Big) = \alpha\mu_\nu^2\Big(\frac{1}{T} - \frac{1}{E_\nu}\Big), \qquad (2)$$

here T — kinetic energy of an electron, E_ν — neutrino energy, α — constant of the fine structure, μ_ν — magnetic moment of neutrino.

Taking into account the binding energy of an electron

$$\frac{\mathrm{d}\sigma_{\mathrm{Xe}}}{\mathrm{d}T} = \alpha\mu_\nu^2\sum_{i=1}^{54}\Big(\frac{1}{T+B_i} - \frac{1}{E_\nu}\Big), \qquad \left(\frac{\mathrm{d}\sigma}{\mathrm{d}T} = \sum_{i=1}^{54}\theta(T-B_i)\frac{\mathrm{d}\sigma_0^{(i)}}{\mathrm{d}T}\right) \qquad (3)$$

here B_i — binding energy of an electron in a xenon atom with index $i \in \{1...54\}$.

Number of events from ν scattering on an e

$$\text{Magnetic moment model:} \;\; \mu_\nu = \left\{ \frac{\mathrm{d}N}{\text{ton} \times \text{year} \times \mathrm{d}T} = \frac{j_{pp} n_{\mathrm{Xe}}}{\rho}\frac{\mathrm{d}\sigma_{\mathrm{Xe}}}{\mathrm{d}T}, \right. \qquad (4)$$

$$j_{pp} = 5{,}94(1 \pm 0{,}1) \times 10^{10}\ \mathrm{cm}^{-2} \times \mathrm{sec}^{-1},$$

ρ — density of liquid xenon, n_{Xe} — concentration of xenon atoms.

Three cases flux of neutrinos

1. When the magnetic moment of the neutrino for each neutrino $(\nu_e, \nu_\mu, \nu_\tau)$ is the same. $j_{pp} = 5{,}94(1 \pm 0{,}1) \times 10^{10}$ cm^{-2} $\times$ sec^{-1}

2. When the magnetic moment for ν_μ, ν_τ is zero. $P_{ee} = 0{,}55$, if into account $E_\nu = 0{,}26$ MeV $j_{pp,\,e} = P_{ee} \times j_{pp} = 3{,}27(1 \pm 0{,}1) \times 10^{10}$ cm^{-2} $\times$ sec^{-1}

3. When the magnetic moment for ν_e is zero.
   $j_{pp,\,\mu,\tau} = (1 - P_{ee}) \times j_{pp} = 2{,}67(1 \pm 0{,}1) \times 10^{10}$ cm^{-2} $\times$ sec^{-1}
   P.S.: individually, the probabilities of survival for ν_μ, ν_τ were not found, so case 3 is as it is.

XENON1T data processing results

Optimal magnetic moment, when it is the same for $(\nu_e, \nu_\mu, \nu_\tau)$.
$\mu_\nu = 1{,}87^{+0{,}48}_{-0{,}69} \times 10^{-11} \mu_B$

90% confidence level: $\mu_\nu \in (0{,}22,\, 2{,}61) \times 10^{-11}\ \mu_B$

Optimal magnetic moment, when $\mu_{\nu_{\mu,\,\tau}} = 0$.
$\mu_{\nu_e} = 2{,}52^{+0.65}_{-0{,}92} \times 10^{-11} \mu_B$

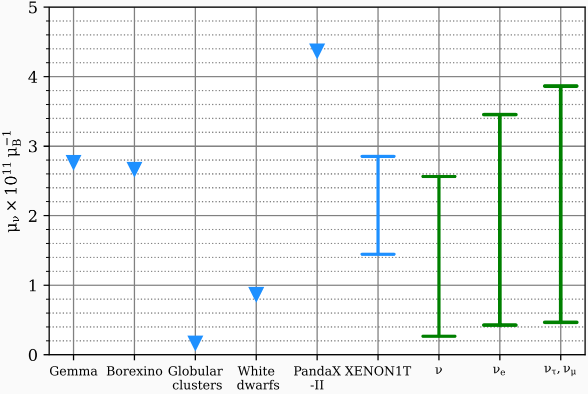
90% confidence level: $\mu_{\nu_e} \in (0{,}37,\, 3{,}51) \times 10^{-11}\ \mu_B$

Optimal magnetic moment, when $\mu_{\nu_e} = 0$.
$\mu_{\nu_{\mu,\tau}} = 2{,}78^{+0{,}72}_{-1{,}01} \times 10^{-11} \mu_B$

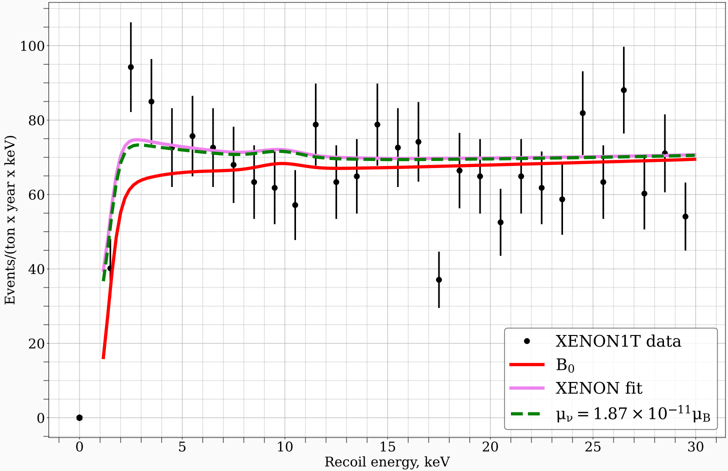
90% confidence level: $\mu_{\nu_{\mu,\tau}} \in (0{,}42,\, 3{,}91) \times 10^{-11}\ \mu_B$

Magnetic moment in the Standard model
$\mu_\nu = 3{,}2 \times 10^{-19} (m_\nu/\mathrm{eV}) \mu_B$

XENON1T data processing results



XENON1T data processing results



Magnetic moments of our calculation

$$\mu_\nu = 1{,}87^{+0{,}48}_{-0{,}69} \times 10^{-11}\mu_B, \quad \mu_{\nu_e} = 2{,}52^{+0.65}_{-0{,}92} \times 10^{-11}\mu_B,$$

$$\mu_{\nu_{\mu,\tau}} = 2{,}78^{+0{,}72}_{-1{,}01} \times 10^{-11}\mu_B, \quad \mathrm{SM:}\ \mu_\nu = 3{,}2 \times 10^{-19}(m_\nu/)\mu_B$$

According to our calculations, the model $\mathrm{B}_0 + \mu_\nu$ is preferable to the background model B_0 with statistical significance 1.64σ for all the above cases. This value turned out to be slightly lower than stated by the XENON collaboration, in which the statistical significance was 3,2 σ.

Thanks for attention!