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Dark Matter Interpretation of Neutron Multiplicity Anomalies

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Introduction. As it was reported at ICRC 2021 [1], TAUP 2021 [2], and VCI 2022 [3], subterrestrial neutron spectra show weak but consistent anomalies at multiplicities ~100 and above. The data of the available measurements are still of low statistical significance [4] but indicate an excess of events not correlated with the underground muon flux. The origin of the anomalies remains ambiguous, but, in principle, it could be a signature of a WIMP Dark Matter (DM) annihilation-like interaction with a massive Pb target. Here we outline a model consistent with this WIMP hypothesis. We use an extended Standard Model approach called the Radiation Gauge Model (RGM) [5] that identifies the scalar neutrino-antineutrino wave function component of WIMP DM responsible for the weak interaction leading to annihilation with ordinary matter.

RGM-SM Phenomenology. RGM is a simple extension of the spin dependent SM, mixing **four radiation gauge boson Fields,** pseudoscalar (Higgs), vector (EM), axial vector (WZ) and tensor (graviton) with **complimentary Yang-Mills (Y-M) Fields** producing four EW isospin symmetry breaking (EWISB) (2x2) mixing matrices. The four-gauge boson spin Fields consisting of Weak (1+), EM (1-), Strong (0-) and Gravitational (2+) are constructed with SM Yang-Mills-Dirac-Higgs-Yukawa Lagrangian

$$L_{SM} = L_D[\psi, A] + L_H[\phi, A] + L_Y[\psi_L, \phi, \psi_R] + L_{YM}[A]$$

and four-complementary Yang-Mills Fields, one abelian $SU(1)_Y$ and three non-abelian $SU(2)_L$

$$L_{YM}[A] = -\frac{1}{4} F_{\mu\nu}^{A\alpha} F_{\alpha}^{A\mu\nu}$$

The EWSB interaction removes the degeneracy of the neutral gauge Fields by off-diagonal mixing via 2x2 matrices with complementary Y-M Fields, i.e., the W-boson Field removes the isospin degeneracy of the Z-particle with EWSB

$$M_{WZ}^2 = \begin{vmatrix} W & Z^0 \\ A'_{EW} & A_{EW} \end{vmatrix}$$

EWSB matrices coupled with the Supersymmetry Breaking (SSB) [6] Higgs potential provides broken symmetry for the QCD scalar matrix and $SU(3)_C$ symmetry for the EWSB-SSB matrix.

$$M_{EWSB-SSB}^2 = \begin{pmatrix} M_{WZ}^2(1^+) & M_H^2(0^-) \\ M_G^2(2^+) & M_{EM}^2(1^-) \end{pmatrix} \otimes M_h^2(0^+)$$

Dark Matter Properties. Dark Matter is identified as the massive residual Y-M tensor boson resulting from the solution of the gravity tensor matrix solution

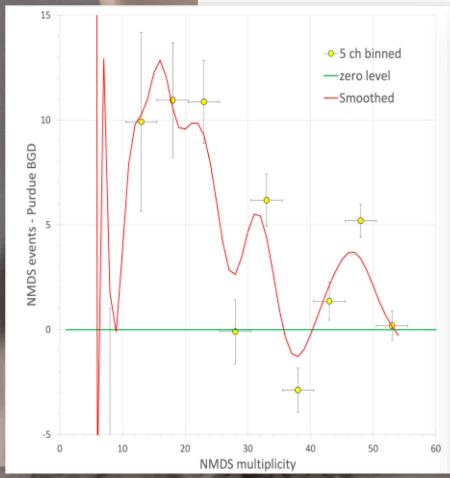
$$M_G^2(J^\pi = 2^+) = \begin{vmatrix} G & \chi^0(DM) \\ g(graviton) & A_{EWS} \end{vmatrix}$$

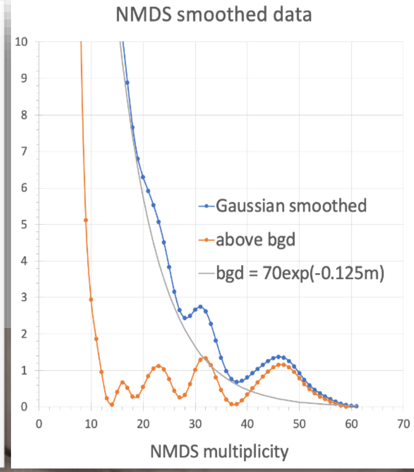
$$M_{DM} = 7.93 \pm 0.12\,GeVc^{-2}$$

The composition of DM with scalar pairs of leptons (54%), quarks (23%) and nucleons (23%) follow from the EWSB-SSB matrix. Scalar pairs deeply bound within the 8 GeV DM potential allow only neutrinos to take part in the weak interaction decay or annihilation. WIMP annihilation with baryonic matter deposits roughly half the DM particle energy (about 4 GeV) to the baryonic matter annihilating it into neutrons, protons, charged particles and gamma-rays, with the remainder of energy carried by the final state leptons.

DM-Baryon Annihilation: Four Indirect reactions result in Pb target annihilation with large neutron multiplicities in the NMDS and NEMESIS experiments

The four Indirect annihilation anomalies are observed in the NMDS spectrum





Indirect Inelastic NC

(m=16.3, M=75)

$$\begin{bmatrix} \nu \\ \bar{\nu} \end{bmatrix}_{\chi^0}^{e,\mu,\tau} + \begin{bmatrix} nn \\ pp \end{bmatrix}_{Pb}^3 \xrightarrow[Z^0]{Z^0} \begin{bmatrix} \nu' \\ \bar{\nu}' \end{bmatrix}_{\chi'} \oplus \begin{bmatrix} n'n \\ p'p \end{bmatrix}_{Pb'}^3$$

Indirect CC

(m=22.3, M=102)

$$\begin{bmatrix} \nu \\ \bar{\nu} \end{bmatrix}_{\chi^0}^{e,\mu,\tau} + \begin{bmatrix} nn \\ pp \end{bmatrix}_{Pb}^3 \xrightarrow[W^+]{Z^0} \begin{bmatrix} \nu \\ l^+ \end{bmatrix}_{\chi^0} \oplus \begin{bmatrix} nn \\ np \end{bmatrix}_{Pb}^3$$

(m=31.7, M=146)

$$\begin{bmatrix} \nu \\ \bar{\nu} \end{bmatrix}_{\chi^0}^{e,\mu,\tau} + \begin{bmatrix} nn \\ pp \end{bmatrix}_{Pb}^3 \xrightarrow[Z^0]{W^-} \begin{bmatrix} l^- \\ \bar{\nu} \end{bmatrix}_{\chi^0} \oplus \begin{bmatrix} pn \\ pp \end{bmatrix}_{Pb}^3$$

(m=46.8, M=215)

$$\begin{bmatrix} \nu \\ \bar{\nu} \end{bmatrix}_{\chi^0}^{e,\mu,\tau} + \begin{bmatrix} nn \\ pp \end{bmatrix}_{Pb}^3 \xrightarrow[W^+]{W^-} \begin{bmatrix} l^- \\ l^+ \end{bmatrix} \oplus \begin{bmatrix} p'n \\ n'p \end{bmatrix}_{Pb'}^3$$

RGM provides spin-dependent cross-sections which can be compared to the experimental anomalies

RGM-SM Spin Dependent (SD) WIMP Annihilation Cross-Sections

Anomaly	Measured Cross-Section	Calculated Cross-Section
0 Inelastic NC (M=75)	$(1.08\pm0.77)x10^{-42} cm^2N^{-1}$	$(1.22\pm0.40)x10^{-42} cm^2N^{-1}$
I Indirect CC (M=102)	$(1.85\pm1.07)x10^{-42} cm^2N^{-1}$	$(2.20\pm0.05)x10^{-42} cm^2N^{-1}$
II Indirect CC (M=146)	$(2.67\pm1.28)x10^{-42} cm^2N^{-1}$	$(4.46\pm0.10)x10^{-42} cm^2N^{-1}$
III Indirect CC (M=215)	$(5.26\pm1.79)x10^{-42} cm^2N^{-1}$	$(5.85\pm0.13)x10^{-42} cm^2N^{-1}$
Sum Total	$(1.09\pm0.49)x10^{-41} cm^2N^{-1}$	$(1.37\pm0.07)x10^{-41} cm^2N^{-1}$

[1] https://doi.org/10.22323/1.395.0514
[2] http://doi.org/10.1088/1742-6596/2156/1/012029
[3] https://doi.org/10.1016/j.nima.2022.167223
[4] See abstract by W.H. Trzaska et al. ***"New Evidence for DM-Like Anomalies in neutron multiplicity spectra". Tuesday 29 17:15,***
[5] T. Ward, ***"Electroweak Mixing and the Generation of Massive Gauge Bosons"***, in "Beyond *the Desert 2002"*, edited by H. V. Klapdor-Kleingrothhaus, IOP publishing, Bristol and Philadelphia, 2003. Page 171. Also, NDM2022, 15-21 May 2022, Ashville, N.C. USA.
[6] L. O'Raifeartaigh, ***"Spontaneous Symmetry Breaking for chiral Scalar Superfields"***, Nucl. Phys. **B96**, 331 (1975).