$(\mathrm{g}-2)_\mu$, CDF W and dark matter in ScotoZee neutrino mass model

PPC 2022

Ritu Dcruz[1]
In collaboration with Anil Thapa[2]

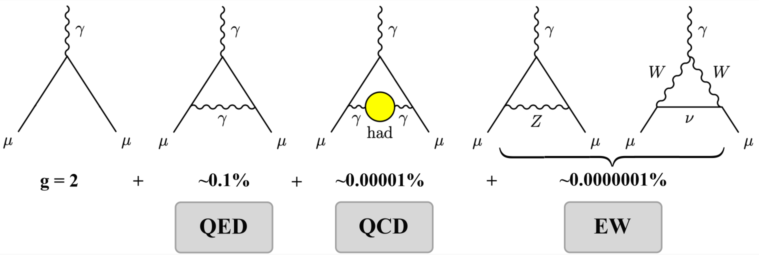
[1] Oklahoma State University

[2] University of Virginia

[arXiv : 2205.02217]

Anomalous Magnetic Moment

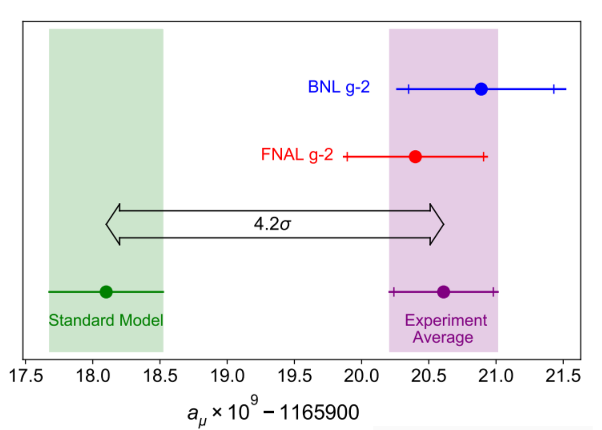
Magnetic moment $\vec{\mu}_{\mathrm{B}} = \mathrm{g}_\mu \frac{\mathrm{e}}{2\mathrm{m}_\mu}\vec{\mathrm{S}}$



Anomalous magnetic moment $a_\mu = \frac{(\mathrm{g}-2)_\mu}{2}$

$$a_\mu^{\mathrm{SM}} = a_\mu^{\mathrm{QED}} + a_\mu^{\mathrm{EW}} + a_\mu^{\mathrm{Had}}$$

Anomalous Magnetic Moment



(Muon g-2 Collaboration)

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (251 \pm 59) \times 10^{-11}$$

Neutrino mass

- $\nu_{iL} \leftrightarrow \nu_{jL} \Rightarrow M_\nu \neq 0$
- Seesaw mechanism
- Radiative corrections

Dark matter

- Relic abundance
- Stable particle

Motivation

Neutrino mass

Dark matter

Δa_μ

Motivation

Neutrino mass

Dark matter

Δa_μ

Scotogenic Model[1]

1-loop radiative neutrino mass

Heavy N_R

Fermionic and Scalar DM candidates

Requires mass enhancement

[1] E. Ma (Jan, 2006)

Neutrino mass	Dark matter	Δa_μ

Scotogenic Model[1] (Neutrino mass, Dark matter)

+ Charged Singlet (Δa_μ)

1-loop radiative neutrino mass

Heavy N_R

Fermionic and Scalar DM candidates

Right handed neutrino mass enhancement

[1] E. Ma (Jan, 2006)

The ScotoZee Model

- $SU(2)_L \times U(1)_Y \times \mathbb{Z}_2$

Scotogenic Model

$$L_i \sim (2, -1/2; +), \quad \ell_{R_i} \sim (1, -1; +), \quad N_{R_i} \sim (1, 0 : -)$$

$$\phi \sim (2, 1/2; +), \quad \eta \sim (2, 1/2; -), \quad S \sim (1, 1; -)$$

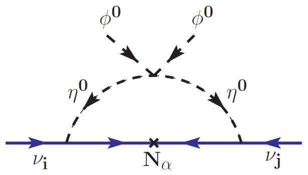
- $-\mathcal{L}_Y \supset \overbrace{\underbrace{Y_{ij} \overline{L}_{L_i} \widetilde{\eta} N_{R_j}}_{\text{Neutrino mass}} + f_{ij} \overline{\ell}_{R_i} S^- \overline{N}_{R_j}}^{\text{AMM}} + \text{h.c.}$

- Physical fields:

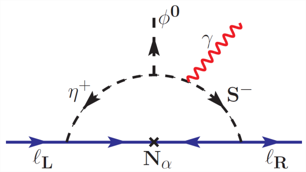
$$h$$
$$H_1^+, \ H_2^+$$
$$H, \ A$$

$$\sin 2\theta = \frac{-\sqrt{2}\mu v}{m^2_{H_1^+} - m^2_{H_2^+}}$$

- $\frac{1}{2} M_{N_i} N_i N_i$ along with the scalar quartic term $\frac{\lambda_5}{2}\{(\phi^\dagger \eta)^2 + \text{h.c.}\}$ breaks the lepton number by two units



Neutrino mass: Scotogenic model



AMM: Zee model-like

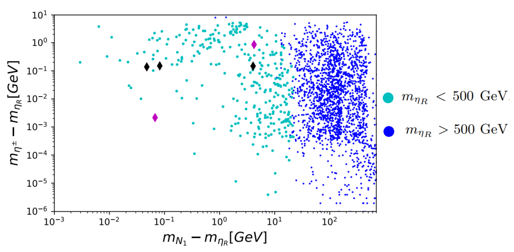
$$(\mathcal{M}_\nu)_{ij} = \sum_k Y_{ik}\Lambda_k Y^*_{kj}$$

$$\Lambda_k = \frac{M_{N_k}}{16\pi^2}\left[\frac{m_H^2}{m_H^2 - M_{N_k}^2}\log\frac{m_H^2}{M_{N_k}^2} - (m_H \leftrightarrow m_A)\right]$$

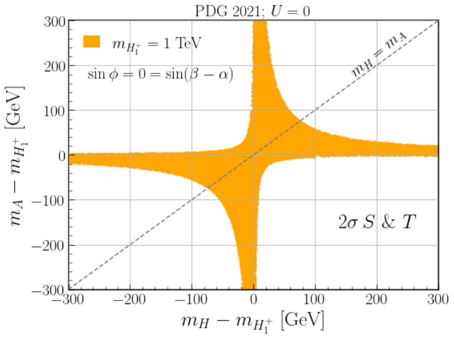
$$\Delta a_\ell^{H_i^+} \propto \frac{m_\ell^2}{16\pi^2}\left(\pm\frac{M_{N_i}}{m_\ell}\ \mathrm{Re}(Y_{\ell i} f^*_{\ell i}) \sin 2\theta\ G[m_{H_i^+}]\right)$$

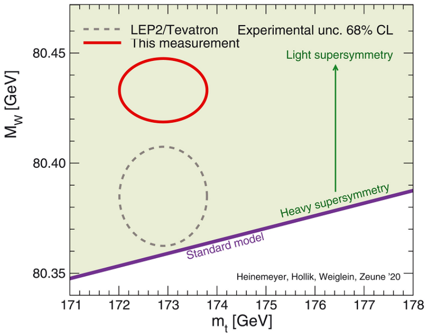
- $M_{N_i} < 15$ TeV for $f, Y \leq 1$
- $m_{H_i^+} < 6.5$ TeV
- $m_\nu \sim 0.1$ eV would naturally require $m_H \simeq m_A$

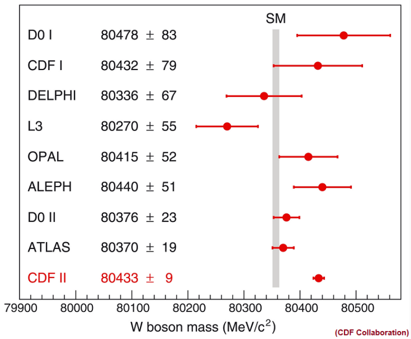
Parameter Space: Scalar DM in Scotogenic Model



Points satisfying total relic density in Scotogenic model I. Ávila, G. Cottin, M. Díaz, (Aug, 2021)

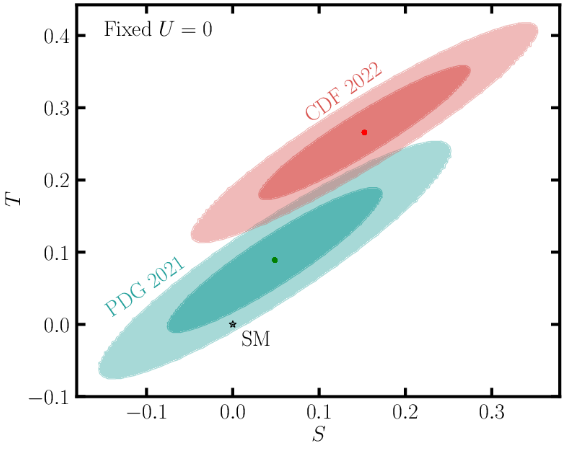






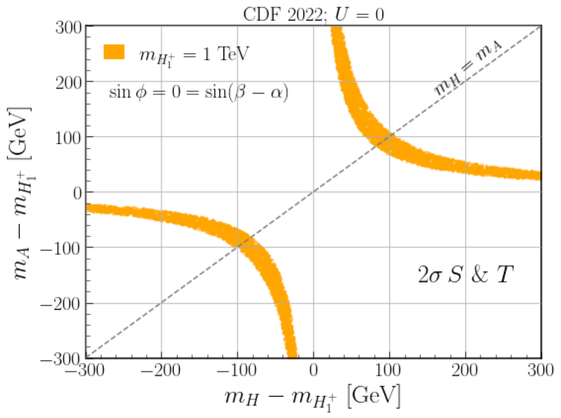
$$m_W^{CDF} = 80.4335 \pm 0.0094\text{GeV} \ @\ 7\sigma$$

Consequence of W mass shift



C. Lu, L. Wu,Y. Wu, B. Zhu (April, 2022)

Consequence of W mass shift

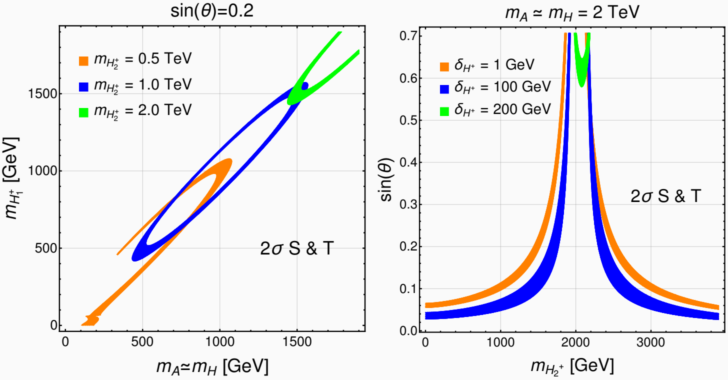


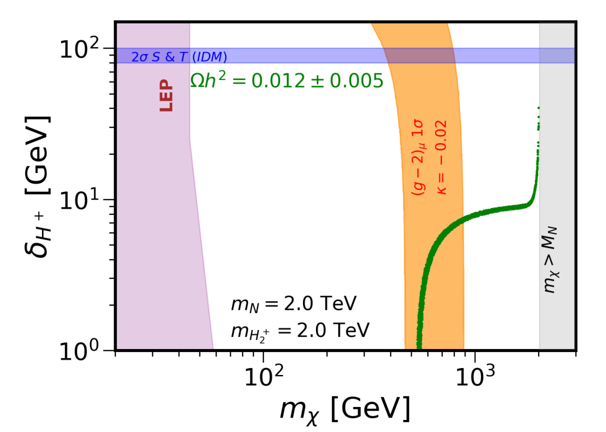
CDF result ⇒ mass splitting; scalar dark matter in Scotogenic model is disfavored

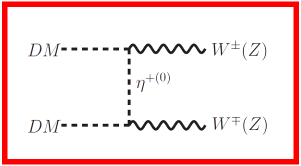
Role of S^+ in ScotoZee model

$S^+ - \eta^+$ mixing

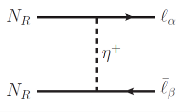
- $(g-2)_\mu$: N_R mass enhancement
- Scalar dark matter: $m_A \simeq m_H \sim m_{H_1^+}$ is possible

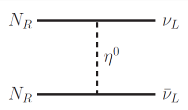


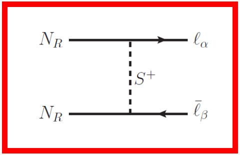

2σ S & T (IDM)
$\Omega h^2 = 0.012 \pm 0.005$
LEP
$(g-2)_\mu$ 1σ
$\kappa = -0.02$
$m_\chi > M_N$
$m_N = 2.0$ TeV
$m_{H_2^+} = 2.0$ TeV
δ_{H^+} [GeV]
m_χ [GeV]
10^0
10^1
10^2
10^2
10^3

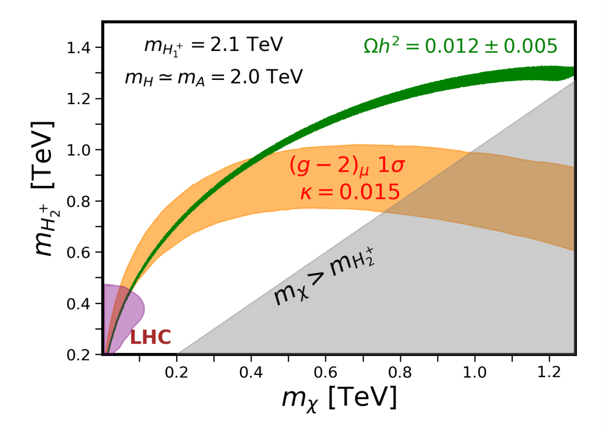

DM
DM
$W^\pm(Z)$
$W^\mp(Z)$
$\eta^{+(0)}$

Integrating Fermionic DM, $(g-2)_\mu$ and CDF W





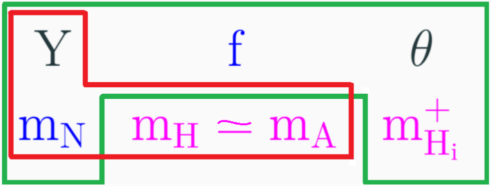




Neutrino Fit/ LFV

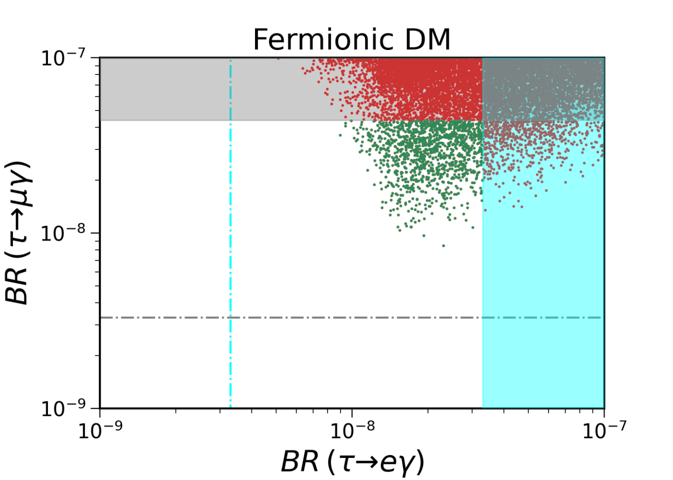
Casas-Ibarra parametrization: $\mathrm{Y} = \sqrt{\Lambda}^{-1} \mathrm{R} \sqrt{\mathcal{M}_\nu^{\mathrm{diag}}}\, \mathrm{U}^\dagger_{\mathrm{PMNS}}$

J. A. Casas, A. Ibarra (March, 2001)



Neutrino mass, AMM, LFV, Scalar DM, Fermionic DM

- $Y_{2i} f^*_{2i} \Rightarrow (g-2)_\mu$
- Large $\mu \to e\gamma$
- $f_{ii} (i = 1, 2) \neq 0$ & $Y_{12} = Y_{21} = 0$



Conclusions

- ScotoZee model: direct correlation between Δa_μ, W mass shift, neutrino mass and dark matter
- Parameters are tightly linked
- Bosonic and fermionic dark matter candidates
- Highly constraining LFV due to right-handed neutrino mass enhancement entering through mixing of charged scalars
- Scalar DM survives CDF measurement in contrast to simple Scotogenic model/IDM
- Predicts LFV radiative τ decays that can be tested in the future and probe the entire parameter space of the model

Thank You

Scalar Sector

Potential:

$$
\begin{aligned}
V = {} & \mu_h^2 \phi^\dagger \phi + \mu_S^2 S^- S^+ + \mu_\eta^2 \eta^\dagger \eta + \frac{\lambda_1}{2}(\phi^\dagger\phi)^2 + \frac{\lambda_2}{2}(\eta^\dagger\eta)^2 + \lambda_3(\phi^\dagger\phi)(\eta^\dagger\eta) \\
& + \lambda_4(\phi^\dagger\eta)(\eta^\dagger\phi) + \frac{\lambda_5}{2}\{(\phi^\dagger\eta)^2 + \text{h.c.}\} + \frac{\lambda_6}{2}(S^-S^+)^2 + \lambda_7(\phi^\dagger\phi)(S^-S^+) \\
& + \lambda_8(\eta^\dagger\eta)(S^-S^+) + \frac{\mu}{2}\{\epsilon_{\alpha\beta}\phi^\alpha\eta^\beta S^- + \text{h.c.}\}.
\end{aligned}
$$

Scalar fields in the physical basis:

$$
\begin{aligned}
& m_h^2 = \lambda_1 v^2,\ m_{H(A)}^2 = \mu_\eta^2 + \frac{v^2}{2}\left(\lambda_3 + \lambda_4 \pm \lambda_5\right), \\
& m_{H_i^+}^2 = \frac{1}{2}\left(\mu_2 + \mu_3 \pm \sqrt{(\mu_2 - \mu_3)^2 + 2\mu^2 v^2}\right),
\end{aligned}
$$

where, $\mu_2 = \mu_\eta^2 + \frac{\lambda_3}{2}v^2$, $\mu_3 = \mu_S^2 + \frac{\lambda_7}{2}v^2$.

Radiative Neutrino Mass

$\lambda_5 \to 0; \quad (m_H^2 - m_A^2 = \lambda_5 v^2) \ll (m_0^2 = (m_H^2 + m_A^2)/2)$:

$$(\mathcal{M}_\nu)_{ij} = \frac{\lambda_5 v^2}{16\pi^2} \sum_k \frac{Y_{ki}^* Y_{kj}^* M_N}{m_0^2 - M_N^2} \left[1 - \frac{M_N^2}{m_0^2 - M_N^2} \log \frac{m_0^2}{M_N^2} \right]$$

$M_N^2 \gg m_0^2$:

$$(\mathcal{M}_\nu)_{ij} = \frac{\lambda_5 v^2}{16\pi^2} \sum_k \frac{Y_{ki}^* Y_{kj}^*}{M_N} \left[\log \frac{M_N^2}{m_0^2} - 1 \right]$$

$m_0^2 \gg M_N^2$:

$$(\mathcal{M}_\nu)_{ij} = \frac{\lambda_5 v^2}{16\pi^2 m_0^2} \sum_k Y_{ki}^* Y_{kj}^* M_N$$

AMM

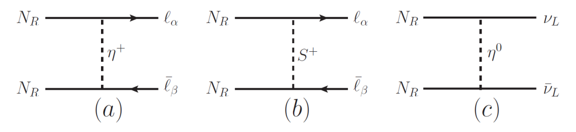
$$\Delta a_\ell^{H_1^+} = \frac{m_\ell^2}{16\pi^2}\Big(\left(|Y_{\ell i}|^2 \sin^2\theta + |f_{\ell i}|^2 \cos^2\theta\right) \; G[m_{H_1^+}, 2] + \frac{M_{N_i}}{m_\ell}\; \mathrm{Re}(Y_{\ell i} f_{\ell i}^*) \sin 2\theta \; G[m_{H_1^+}, 1]\Big),$$

where,

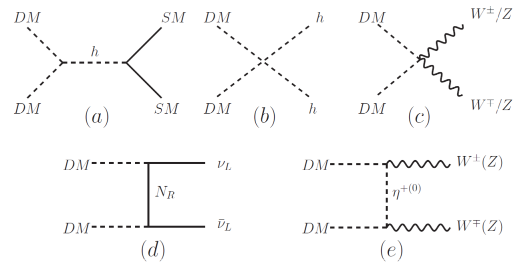
$$G[M, \epsilon] = \int_0^1 \frac{x^\epsilon (x-1)\; dx}{m_\ell^2 x^2 + (M^2 - m_\ell^2)x + M_{N_i}^2 (1-x)}$$

and $\Delta a_\ell^{H_2^+} = \Delta a_\ell^{H_1^+}(\theta \to \frac{\pi}{2} + \theta)$.

Dark Matter



Fermionic dark matter annihilations



Scalar dark matter annihilations