Inert Higgs Doublet Dark Matter Type-II Seesaw

(arXiv : 1404.2996)

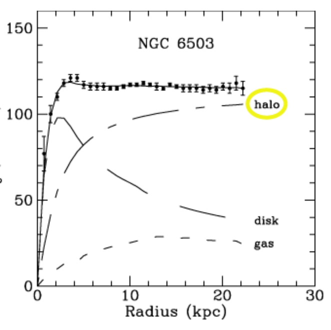
Takaaki Nomura, Chuan-Hung Chen

Astronomical evidence of dark matter

❖Rotation of spiral galaxies

$v(r) \propto \sqrt{M(r)/r}$

M(r)∝ mass inside r

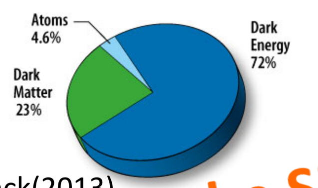


❖Clusters of galaxies

❖Gravitational lensing

❖Formation of Large scale structure

❖CMB anisotropy : WMAP, Planck



➡ $\Omega_{DM} h^2 = 0.1187 \pm 0.0017$ Planck(2013)

Two issues requiring Beyond the SM

Non-Zero Neutrino Mass

$$\Delta m^2_{21} = (7.50 \pm 0.20) \times 10^{-5} eV^2,$$
$$|\Delta m^2_{31}| = (2.32^{+0.12}_{-0.08}) \times 10^{-3} eV^2,$$
$$\sin^2(2\theta_{12}) = 0.857 \pm 0.024,\ \sin^2(2\theta_{23}) > 0.95,$$
$$\sin^2(2\theta_{13}) = 0.095 \pm 0.01.$$

(PDG 2012)

❖At least two massive neutrinos

❖Very small masses

❖What is the origin of mass ?

Inert Higgs Doublet (IHD)

E. Ma, N.G. Deshpande (1977)

❖Introduce two Higgs doublet: H and Φ

❖Introduce discrete Z_2 symmetry

H : Z_2 even Φ : Z_2 odd (Inert Higgs)

Neutral component of Z_2 odd particle is DM candidate

Phenomenologically interesting

- Collider physics
- Improved vacuum stability

R. Barbieri, L.J. Hall, V.S. Rychkov (2006)

Type-II seesaw mechanism

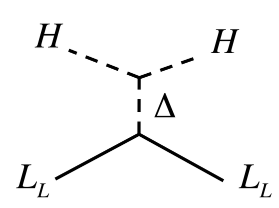
W.Konetschny, W.Kummer (1977)
T. P. Chen, L. F. Li (1980)
J. Schechter, J. W. F. Valle (1980)

❖Introduce SU(2) triplet Higgs

❖Small triplet VEV -> Neutrino masses

❖Provide 6 new scalar bosons

$\delta^0 \quad \eta^0 \quad \delta^\pm \quad \delta^{\pm\pm}$



❖Experimental search for doubly charged Higgs

Doubly charged Higgs decays into

➤l+l+ $v_\Delta << 10^{-4}\, GeV$ ➤W+W+ $v_\Delta >> 10^{-4}\, GeV$

➤Mass limits $m_{H\pm\pm}$ > 400 GeV for leptonic decay case (in some BPs) (ATLAS and CMS 2012)

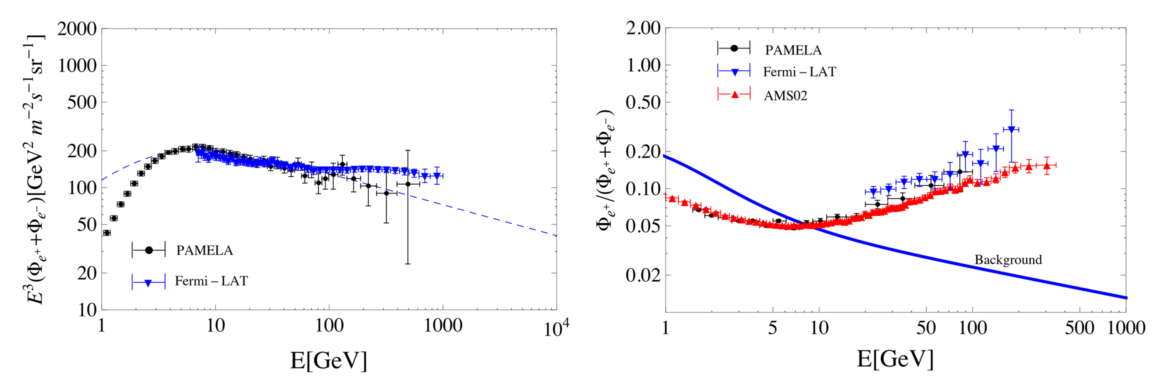
Combining two models

New interactions in combining IHD & Type-II seesaw

❖Triplet Higgs boson couple to leptons but not to quarks

❖Implications to cosmic-ray would be interesting

❖It would explain excess of positron/electron flux



PAMELA (2011) Fermi-LAT(2010) AMS-02 (2013) PAMELA (2009) Fermi-LAT(2012)

❖The excess is observed O(10)-O(100) GeV energy

❖Is it astrophysical origin like pulsars?

❖It could be flux from DM annihilation

We search for the possibility of accommodating

The relic abundance of the Dark Matter

The positron/electron flux and positron fraction excess

Neutrino mass generation

The Model

The structure of the model

❖Symmetry ➡ $G_{SM} \times Z_2$

❖New particles [SU(2)(U(1)$_Y$)]

$\Phi : 2(1)$ *Inert Higgs doublet $\qquad \Delta : 3(2)$ *Higgs triplet

$$\Phi = \begin{pmatrix} H^+ \\ (S+iA)/\sqrt{2} \end{pmatrix} \qquad \Delta = \begin{pmatrix} \delta^+/\sqrt{2} & \delta^{++} \\ (v_\Delta + \delta^0 + i\eta^0)/\sqrt{2} & -\delta^+/\sqrt{2} \end{pmatrix}$$

❖New Lagrangian

$$\mathcal{L}_{NP} = (D_\mu \Phi)^\dagger D^\mu \Phi + (D_\mu \Delta)^\dagger D^\mu \Delta - \left[\frac{1}{2} L^T C (\mathbf{y} + \mathbf{y^T}) i\sigma_2 \Delta P_L L + h.c.\right] - V(H, \Phi, \Delta)$$

$$\begin{aligned} V(H,\Phi,\Delta) = {} & \mu^2 H^\dagger H + \lambda_1 (H^\dagger H)^2 + m^2_\Phi \Phi^\dagger \Phi + \lambda_2 (\Phi^\dagger\Phi)^2 + \lambda_3 H^\dagger H \Phi^\dagger \Phi + \lambda_4 H^\dagger \Phi \Phi^\dagger H \\ & + \frac{\lambda_5}{2}\left[(H^\dagger\Phi)^2 + h.c.\right] + m^2_\Delta Tr\Delta^\dagger\Delta + \mu_1 \left(H^T i\tau_2 \Delta^\dagger H + h.c.\right) + \mu_2 \left(\Phi^T i\tau_2 \Delta^\dagger \Phi\right) \\ & + \lambda_6 H^\dagger H Tr\Delta^\dagger\Delta + \bar\lambda_6 \Phi^\dagger\Phi Tr\Delta^\dagger\Delta + \lambda_7 H^\dagger \Delta\Delta^\dagger H + \bar\lambda_7 \Phi^\dagger\Delta\Delta^\dagger\Phi + \lambda_8 H^\dagger\Delta^\dagger\Delta H \\ & + \bar\lambda_8 \Phi^\dagger\Delta^\dagger\Delta\Phi + \lambda_9 (Tr\Delta^\dagger\Delta)^2 + \lambda_{10} Tr(\Delta^\dagger\Delta)^2 . \end{aligned} \quad (17)$$

SSB and mass of new particles

VEVs

$$\langle V \rangle (v_0, v_\Delta) = \frac{\mu^2}{2} v_0^2 + \frac{\lambda_1}{4} v_0^4 + \frac{m^2_\Delta}{2} v_\Delta^2 + \frac{\lambda_6 + \lambda_7}{4} v_0^2 v_\Delta^2 + \frac{\lambda_9 + \lambda_{10}}{4} v_\Delta^4 - \frac{\mu_1}{\sqrt{2}} v_0^2 v_\Delta$$

➡ $v_0 \approx \sqrt{\dfrac{-\mu^2}{\lambda_1}} \qquad v_\Delta \approx \dfrac{\mu_1 v_0^2}{\sqrt{2}(m^2_\Delta + (\lambda_6 + \lambda_7) v_0^2/2)}$

Masses of scalar bosons

$$m_S^2 = m_\Phi^2 + \lambda_L v_0^2 \quad m_A^2 = m_S^2 - \lambda_5 v_0^2 \quad m^2_{H^\pm} = m_\Phi^2 + \lambda_3 v_0^2/2$$

$$m^2_{\delta^0} \approx m^2_{\eta^0} \approx m^2_\Delta + \frac{\lambda_6 + \lambda_7}{2} v_0^2 \qquad (v_\Delta << v_0)$$

$$m^2_{\delta^{++}} \approx m^2_\Delta + \frac{\lambda_6 + \lambda_8}{2} v_0^2 \qquad m^2_{\delta^+} \approx \frac{1}{2}(m^2_{\delta^{++}} + m^2_{\delta^0})$$

Yukawa coupling and neutrino masses

❖Yukawa couplings

$$-L_Y = \frac{1}{2} h_{ij} \nu_i^T C P_L \nu_j \frac{v_\Delta + \delta^0 + i\eta^0}{\sqrt{2}} - h_{ij} \nu_i^T C P_L l_j \frac{\delta^+}{\sqrt{2}} - \frac{1}{2} h_{ij} l_i^T C P_L l_j + h.c.$$

❖Neutrino mass matrix

$$m_\nu^{ij} = v_\Delta h^{ij}/\sqrt{2} \quad ➡ \quad h = \frac{\sqrt{2}}{v_\Delta} U^*_{PMNS} m_\nu^{diagonal} (U^*_{PMNS})^T$$

$$U_{\rm PMNS} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \times {\rm diag}(1, e^{i\alpha_{21}/2}, e^{i\alpha_{31}/2})$$

Small triplet VEV give small neutrino masses

Analysis

The points of our analysis

❖DM is CP-even neutral component of inert doublet S

❖We focus on the inert doublet-triplet interaction

❖We are interested in explaining excess of positron fraction

- Assuming triplet Higgs bosons decays 100% into leptons
- We require boost factor(BF) to enhance current annihilation ratio $\langle \sigma v \rangle_{boosted} = BF \langle \sigma v \rangle_{original}$
- BF is constrained by anti-proton flux

Interactions:

$\chi_A SS\delta^{++}\delta^{--}$

$\chi_B H^+H^-\delta^{++}\delta^{--}$

$(\chi_A + \chi_B)/2SS\delta^+\delta^-$

$\chi_B SS\delta^0\delta^0(\eta^0\eta^0)$

$\mu_2 SH^\pm\delta^\mp$

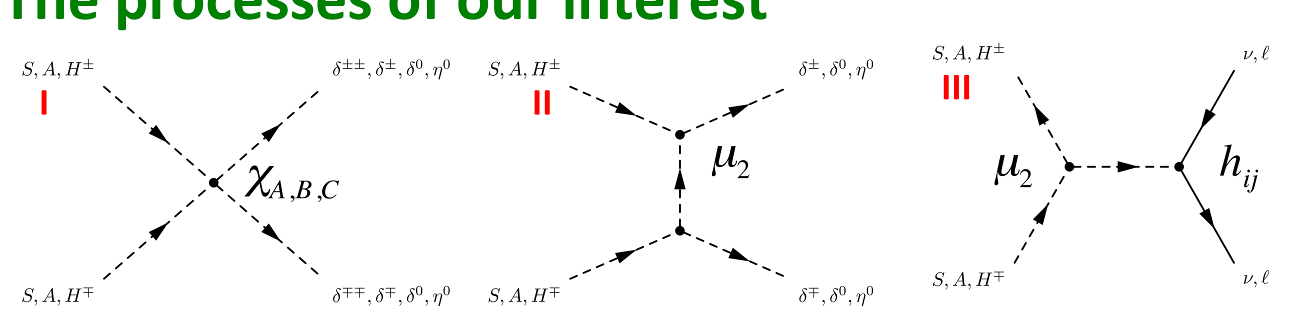
$\sqrt{2}\mu_2 SS\delta^0$

$(\chi_A = \bar\lambda_7 + \bar\lambda_8, \chi_B = \bar\lambda_6 + \bar\lambda_7)$

❖We focus on the parameters in our new interactions

$\{ \lambda_L = 0, m_S = m_A - 1GeV, m_{H^+} = m_A \}$

The processes of our interest



The free parameters

$\{m_S, \chi_A, \chi_B, \mu_2, h_{ij}\}$

$(m_\delta = 500\ GeV)$

Several cases $(I_a)\chi_A >> \chi_B, (I_b)\chi_A = \chi_B, (I_c)\chi_A << \chi_B$

We consider cases where each process is dominant

Numerical Analysis

❖The numerical calculation of relic density and cosmic-ray flux

➡ We apply micrOMEGAs package (G. Belanger, F. Boudjema, A. Pukhov and A. Semenov)

- Positron and anti-proton flux from DM annihilation is calculated
- Navarro-Frenk-White (NFW) galactic halo DM density profile is used
- Propagation of charged particle and solar modulation effect

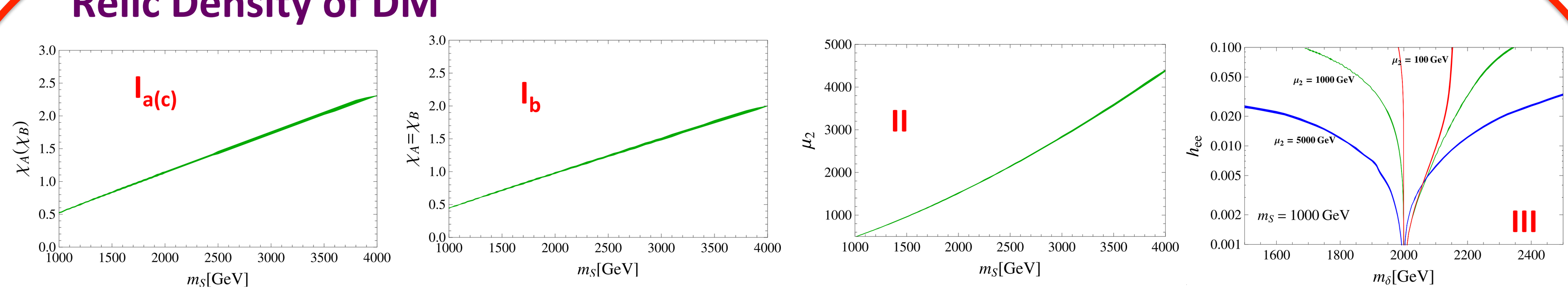
❖For cosmic-ray background we apply fitted functions $\langle \sigma v \rangle_{boosted} = BF \langle \sigma v \rangle_{original}$

❖We apply boost factor (BF) in explaining positron excess

BF is constrained by anti-proton flux observation

Results for each cases

Relic Density of DM



❖The parameter region giving observed relic density of 90% CL $0.1159 \le \Omega h^2 \le 0.1215$

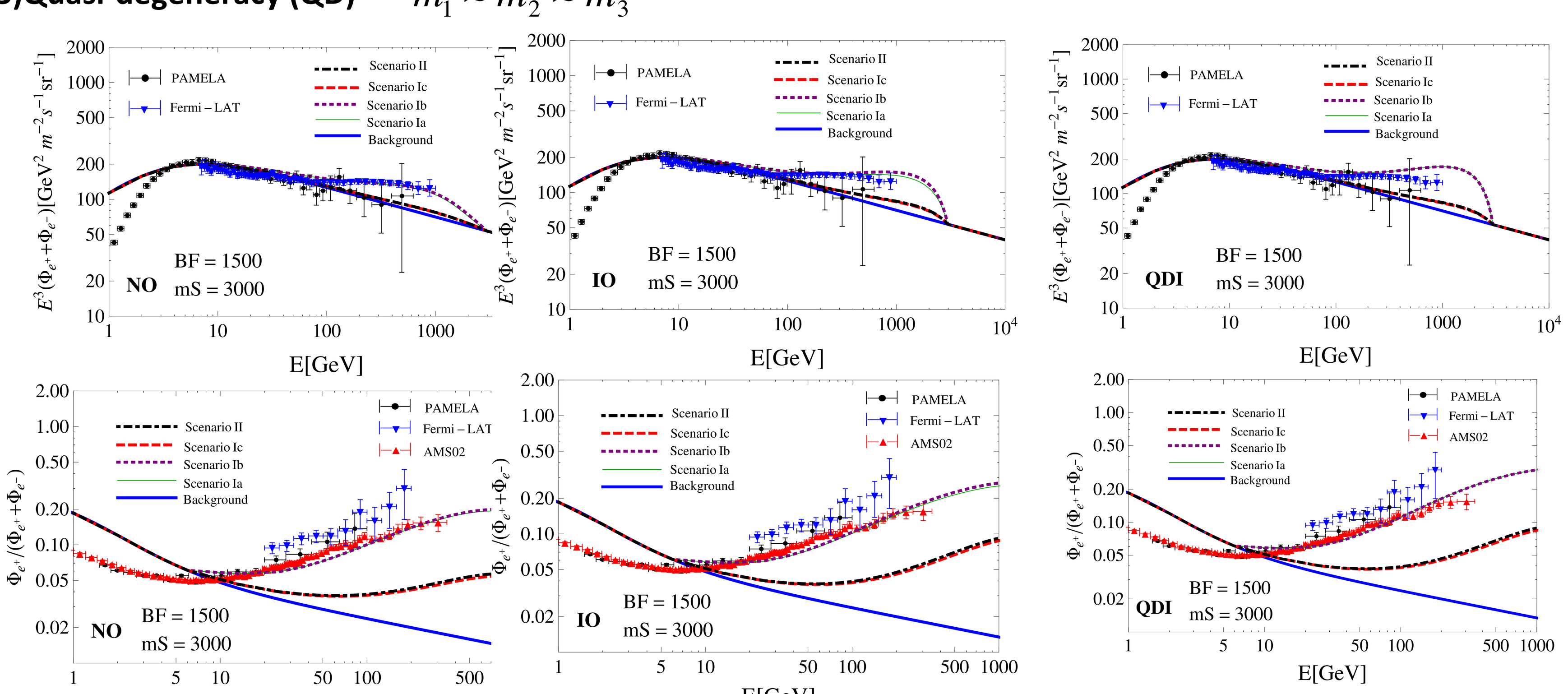
Positron/electron Distributions for some neutrino mass pattern

(1)Normal ordering (NO) $m_1 < m_2 < m_3$

(2)Inverted ordering (NO) $m_3 < m_1 < m_2$

(3)Quasi-degeneracy (QD) $m_1 \approx m_2 \approx m_3$

	$\ell_e\ell_e$	$\ell_e\ell_\mu$	$\ell_e\ell_\tau$	$\ell_\mu\ell_\mu$	$\ell_\mu\ell_\tau$	$\ell_\tau\ell_\tau$
NO	0.01 [0.02]	0.1 [0.06]	0[0]	0.3 [0.39]	0.29 [0.18]	0.28 [0.35]
IO	0.17 [0.23]	0.08 [0.06]	0.2 [0.14]	0.08 [0.11]	0.26 [0.17]	0.21[0.29]
QDI	0.39 [0.40]	0 [0]	0 [0]	0.29 [0.29]	0.02 [0]	0.30 [0.31]



Required BF

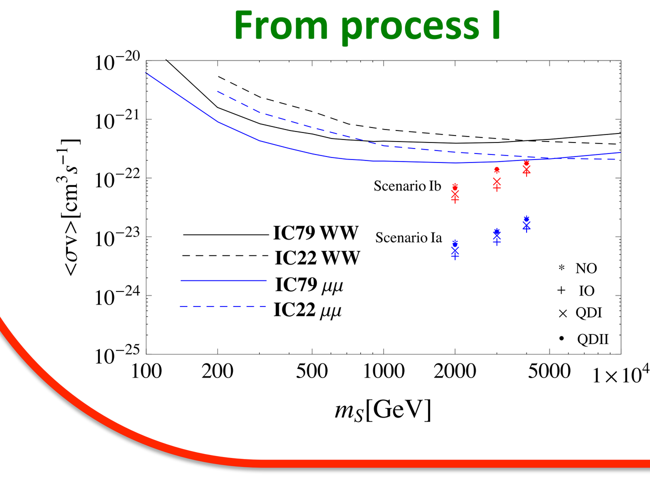
Limit of BF from proton flux

m_S [GeV]	1000	2000	3000	4000
BF	$\lesssim 30$	$\lesssim 500$	$\lesssim 1800$	$\lesssim 4500$

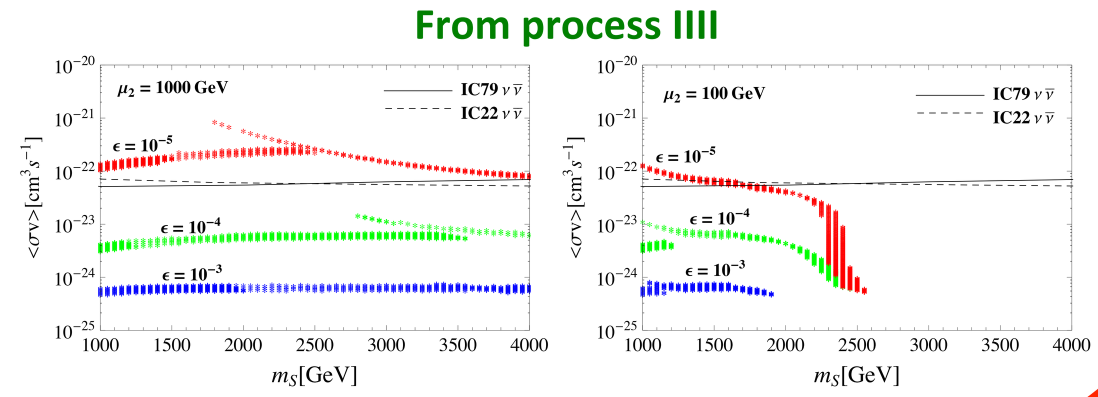
m_S	1000 GeV	2000 GeV	3000 GeV	4000 GeV
I_a	$BF > BF_{max}$	(500, 500, 500, 500)	(1400, 1200, 900, 1100)	(2000, 1900, 1500, 1900)
I_b	$BF > BF_{max}$	(500, 500, 500, 500)	(1400, 1200, 900, 1200)	(2000, 1900, 1500, 1800)
I_c	$BF > BF_{max}$	$BF > BF_{max}$	$BF > BF_{max}$	$BF > BF_{max}$
II	$BF > BF_{max}$	$BF > BF_{max}$	$BF > BF_{max}$	$BF > BF_{max}$

Galactic Neutrino flux prediction

From process I



From process IIII



Compared with IceCube (2011,2013)

Summary

We proposed the model which have Inert Higgs Doublet and Higgs Triplet. The IHD provides dark matter candidate. The Higgs triplet gives Neutrino masses via triplet VEV: Type-II seesaw. We discussed the parameter region where new interaction of the model is dominant. Especially, we search for the possibility to accommodate relic density of the DM, Neutrino mass, observed excess of positron/electron flux and positron fraction.