## 2. *The AKS model*

In the model in Ref. [6], which we here refer to as the AKS model, it is intended that not only the tiny neutrino masses and DM but also baryon asymmetry of Universe are explained at the TeV scale. In addition to the TeV-scale right-handed neutrinos $N_R^\alpha$ ($\alpha = 1, 2$), the Higgs sector is composed of $Z_2$-even two Higgs doublets $\Phi_i$ ($i = 1, 2$) and $Z_2$-odd charged singlets $S^\pm$ and a $Z_2$-odd neutral real singlet $\eta^0$. Therefore the physical states in the $Z_2$-even sector are $H$ (CP-even), $A$ (CP-odd), $H^\pm$ and $h$ (CP-even).

The neutrino mass matrix is generated at the three-loop level via the diagram in Fig. 1 (right), and is expressed as

$$M_{ij}^\nu \equiv \sum_{\alpha=1}^{2}\left(\frac{1}{16\pi^2}\right)^3 \frac{(y_{\ell_i} h_i^\alpha)(y_{\ell_j} h_j^\alpha)(\kappa \tan\beta)^2 v^2}{M_{N_R^\alpha}} I_2(m_{H^\pm}, m_{S^\pm}, m_{N_R^\alpha}, m_\eta), \qquad (6)$$

where $m_{H^\pm}$, $m_{S^\pm}$, $m_{N_R^\alpha}$ and $m_\eta$ are the masses of the doublet originated charged Higgs boson $H^\pm$, $S^\pm$, $N_R^\alpha$ and $\eta^0$, respectively; $h_i^\alpha$ and $\kappa v$ are the coupling constants of $\overline{N_R^\alpha} e_R^i S^\pm$ and $H^+ S^- \eta^0$, respectively; $\tan\beta = \langle\Phi_2^0\rangle/\langle\Phi_1^0\rangle$, and

$$I_2(x, y, z, w) = \frac{-4z^2}{z^2 - w^2}\int_0^\infty u du \left\{\frac{B_1(-u; x, y) - B_1(-u; 0, y)}{x^2}\right\}^2 \left(\frac{z^2}{u + z^2} - \frac{w^2}{u + w^2}\right), \qquad (7)$$

where $B_1$ is the tensor coefficient function in the Passarino-Veltman's formalism [25]. Although the Higgs sector is rather complicated to make it possible for the electroweak baryogenesis scenario, the flavor structure is determined only by the combination of $h_i^\alpha$ and $m_{N_R^\alpha}$ just as in the Ma model. The mass matrix has the three loop factor $1/(16\pi^2)^3$ with additional suppression factor by $y_{\ell_i}$. They are enough to reproduce the neutrino mass scale. Thus, the electron associated coupling constants $h_e^{1,2}$ and the scalar coupling $\kappa$ are of $\mathcal{O}(1)$ for $m_{N_R}^{1,2} \sim \mathcal{O}(1)$ TeV. The Yukawa coupling constants $h_i^\alpha$ are hierarchical as $h_e^{1,2} (\simeq \mathcal{O}(1)) \gg h_\mu^{1,2} \gg h_\tau^{1,2}$.

The parameter sets which satisfy the current data from neutrino oscillation, LFV, relic abundances of DM and the condition for strongly first order electroweak phase transition are studied in Ref. [6, 14]. To reproduce the neutrino data, the mass of $H^\pm$ should be 100 - 200 GeV. This is an important prediction of the model. In order to avoid the constraint from $b \to s\gamma$, the Yukawa interaction for the doublet fields takes the form of so-called Type-X [20],[4] where only one of the doublets couples to leptons and the rest does to quarks. The

[4] Type-X is referred to as Type-IV in Ref. [26] and Type-I' in Ref. [27].