constraints on a light scalar in a singlet Higgs extension of the SM at Belle-II

*Miki Yonemura , Fumina Hiiro, Gi-Chol Cho
Particle Physics Group, Ochanomizu University

Complex Singlet Extension of the SM(CxSM)

Ref: V. Barger et al.Pyhs. Rev.D79(2009)015018

SM + S : Gauge Singlet Complex Scalar Field

$$V=\frac{m^2}{2}|H|^2+\frac{\lambda}{4}|H|^4+\frac{\delta_2}{2}|H|^2|S|^2+\frac{b_2}{2}|S|^2+\frac{d_2}{4}|S|^4+\left(a_1 S+\frac{b_1}{4}S^2+\text{c.c.}\right)$$

soft breaking of the global U(1)

H,S take the vacuum expectation values (vev)

$$H=\frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v+h\end{pmatrix},\quad S=\frac{1}{\sqrt{2}}(v_s+s+i\xi)$$

mass eigenstates (h1,h2) described in the mixing angle α

$$\begin{pmatrix}h\\ s\end{pmatrix}=\begin{pmatrix}\cos\alpha & -\sin\alpha\\ \sin\alpha & \cos\alpha\end{pmatrix}\begin{pmatrix}h_1\\ h_2\end{pmatrix}$$

diagonalization of M^2

$$O^TM^2O=\text{diag.}\left(m_{h_1}^2,m_{h_2}^2\right),\quad O\equiv\begin{pmatrix}\cos\alpha & -\sin\alpha\\ \sin\alpha & \cos\alpha\end{pmatrix}$$

$$m_{h_1,h_2}^2=\frac{1}{2}\left(\frac{\lambda}{2}v^2+\overline{\Lambda}_S^2\mp\sqrt{\left(\frac{\lambda}{2}v^2-\overline{\Lambda}_S^2\right)^2+4\left(\frac{\delta_2}{2}vv_S\right)^2}\right)$$

$$\cos 2\alpha=\frac{\frac{\lambda}{2}v^2-\overline{\Lambda}_S^2}{m_{h_1}^2-m_{h_2}^2}$$

S : interaction between H

→ h_1,h_2 : interaction with SM just through H

$$h=h_1\cos\alpha-h_2\sin\alpha$$
$$s=h_1\sin\alpha+h_2\cos\alpha\qquad\begin{pmatrix}h_1: 10\text{ GeV}\\ h_2: 125\text{ GeV}\end{pmatrix}$$

$$h_2\to h_{SM}\ @\ \alpha=-\frac{\pi}{2}$$

theoretical restriction on parameters

① For the potential V to have a global minimum

$$\lambda>0,\quad d_2>0,\quad \lambda d_2>\delta_2^2$$

$$\lambda\left(d_2+\frac{2\sqrt{2}a_1}{v_S^3}\right)>\delta_2^2$$

②perturbativity limit

$$\lambda,d_2\le\frac{16\pi}{3}$$

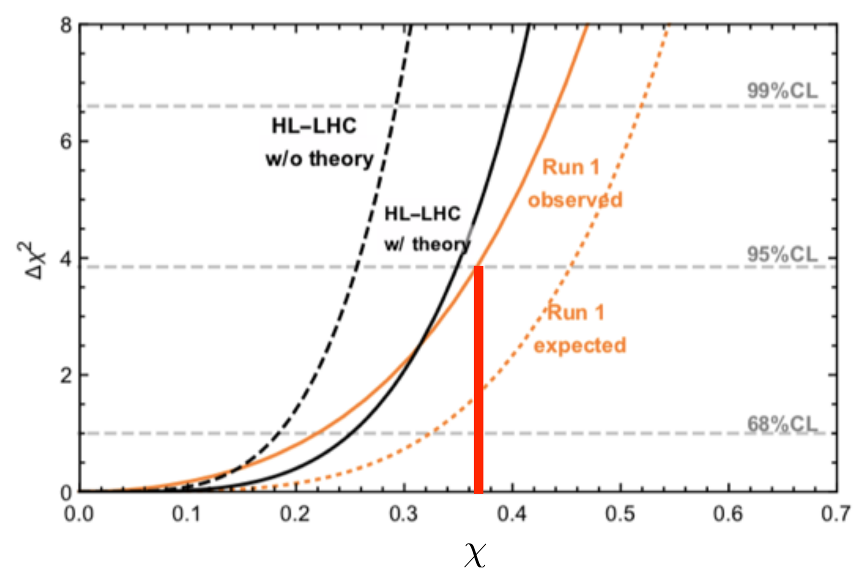
allowed region of mixing angle α

signal strength

$$\mu\equiv\frac{[\sigma(XX\to h)\text{Br}(h\to YY)]_{\text{exp}}}{[\sigma(XX\to h)\text{Br}(h\to YY)]_{\text{SM}}}=1-\chi^2$$

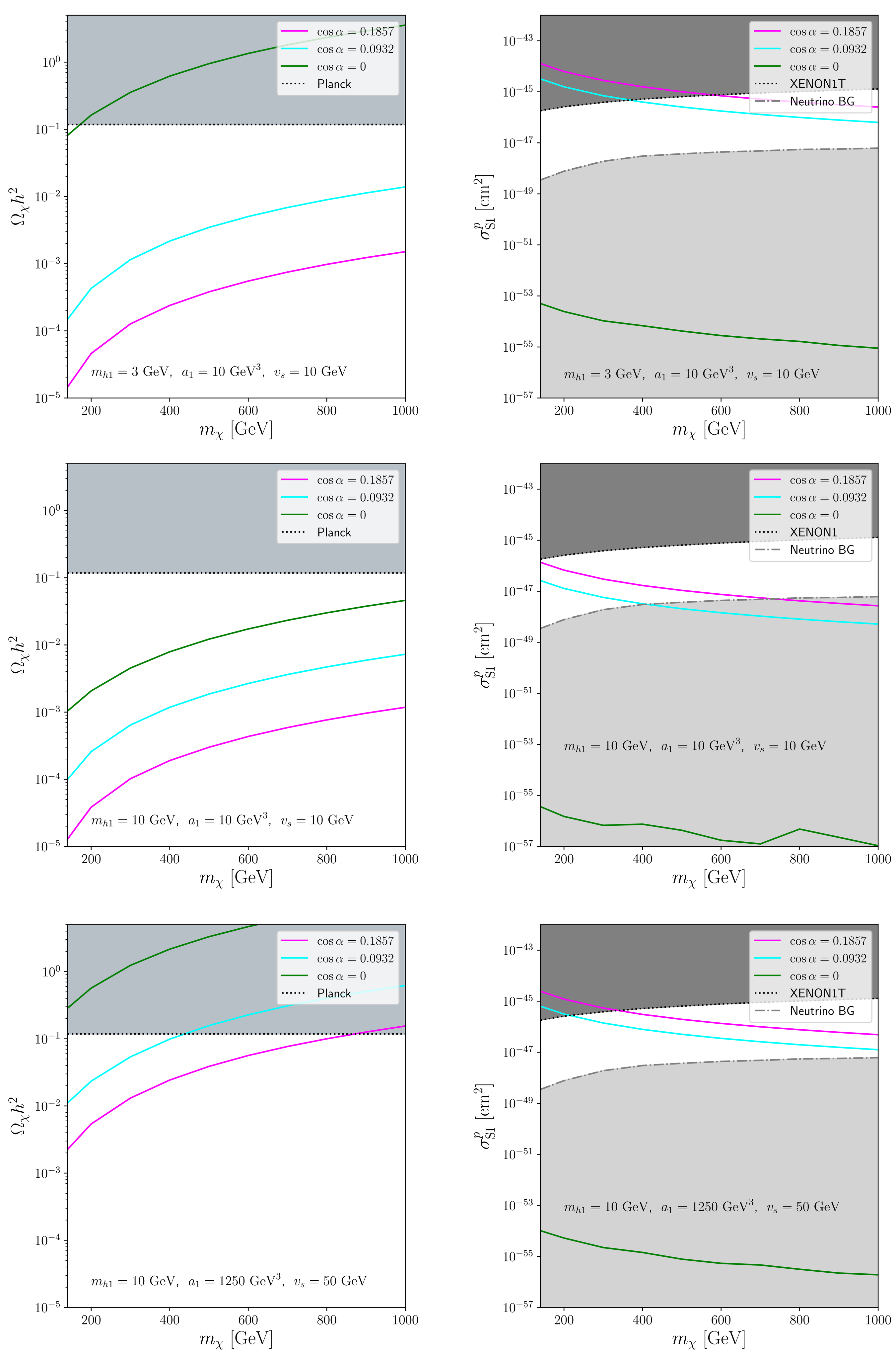
$$\hat{\mu}\equiv\frac{[\sigma(XX\to h)\text{Br}(h\to YY)]_{\text{CxSM}}}{[\sigma(XX\to h)\text{Br}(h\to YY)]_{\text{SM}}}$$

$$=\sin^2\alpha\cdot\frac{1}{1+\frac{1}{\sin^2\alpha}\frac{\Gamma(h_2\to h_1h_1)}{\Gamma_{\text{SM}}^{tot}}}\quad\to\frac{1-\chi^2}{\sin^2\alpha}=\frac{1-\chi^2}{1-\cos^2\alpha}$$



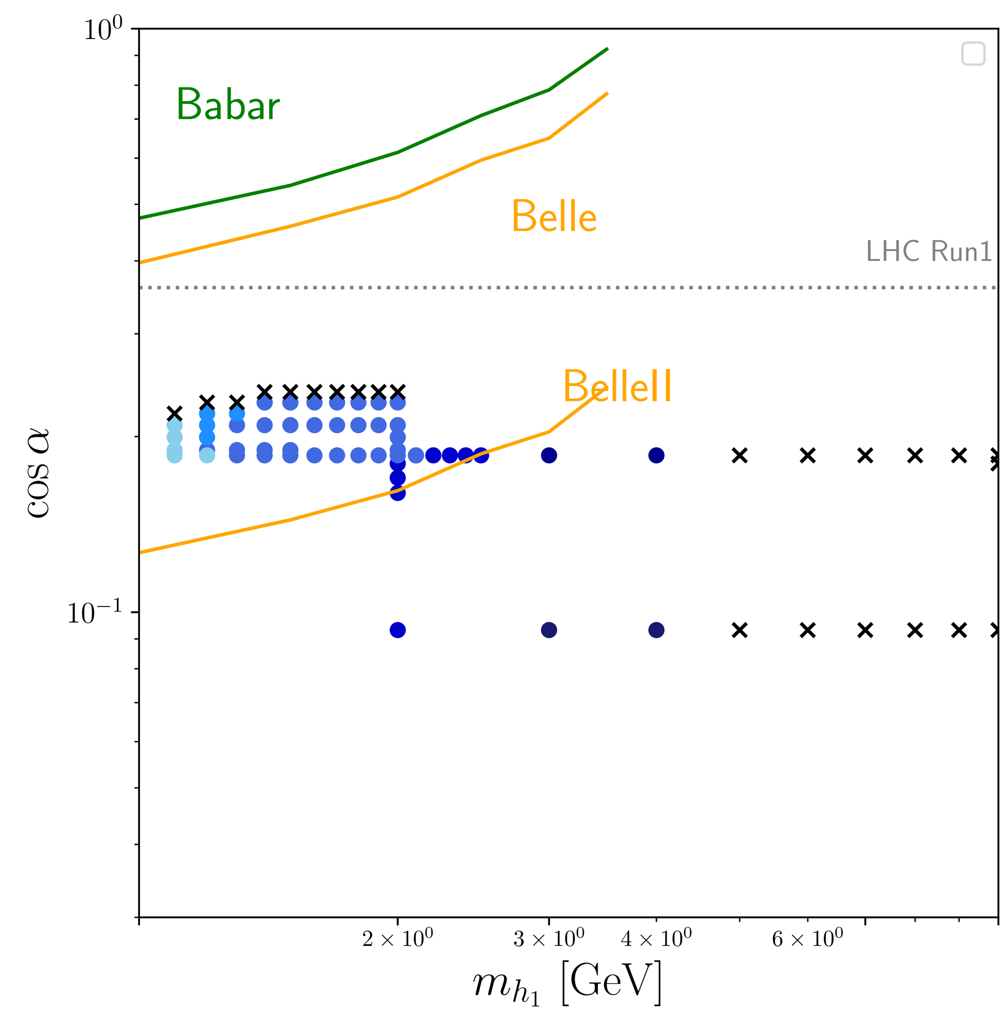
Ref: Marcela Carena et. al (arXiv : 1801.00794)

①allowed region of the relic density @Planck and the direct detection @XENON1T



Ref : XENON1T(2018)
Ref : PLANCK 2018 (arXiv : 1807.06209)

② comparison with Model–independent constraints



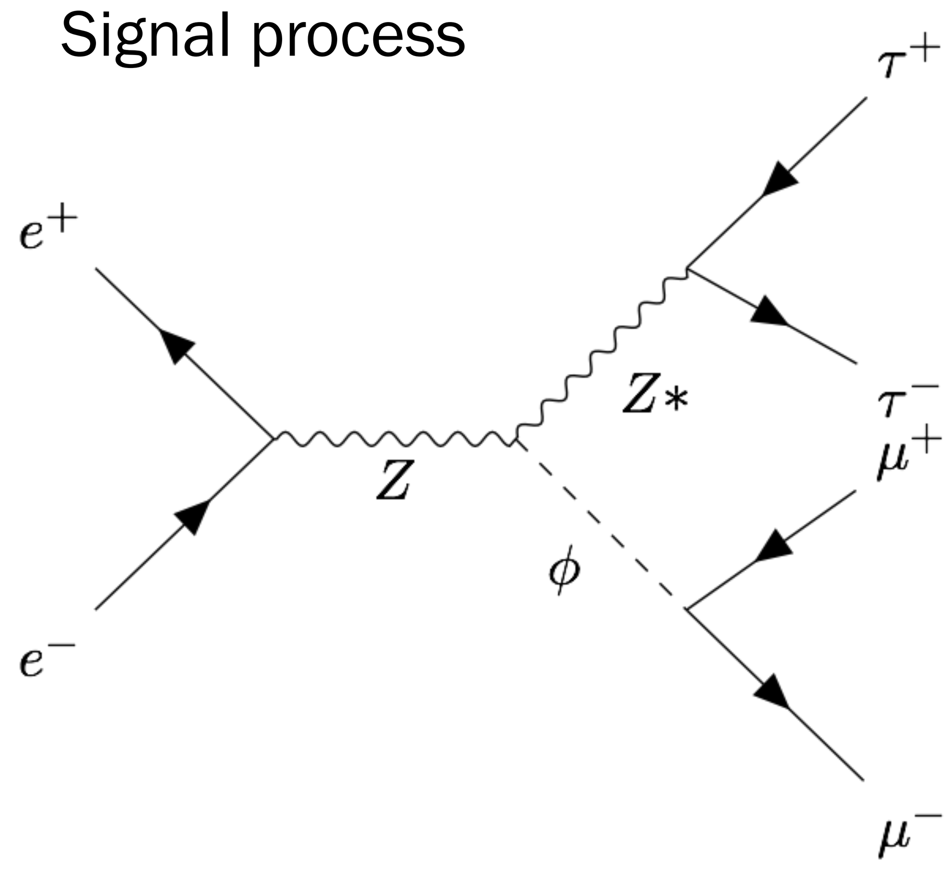
fix : $a_1=10\text{ GeV}^3,\ v_s=10\text{ GeV}$

DMmass : 400GeV - 3TeV

Ref : The Belle II Physics Book (arXiv : 1808.10567)

③ calculation (event generation by MadGraph5)

Signal process



Background process

$$e^+e^-\to\mu^+\mu^-\tau^+\tau^-$$

Background cross-section :

$$5.833\times10^{-3}\pm2.4\times10^{-5}\text{pb}$$

set electron beams $\sqrt{s}=10$ GeV

set default cuts $p_t^j>1$GeV, $p_t^l>1$GeV