A light pseudoscalar in the NMSSM

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Based on arXiv:1301.1325, arXiv:1307.7601,
and work in progress

Next-to-minimal MSSM

- The MSSM has always been the starting point of the studies for SUSY phenomenology because of its minimal structure.
- The MSSM already encounters various problems, which include
  - necessity of fine-tuning in the Higgs sector to obtain 125 GeV Higgs,
  - μ problem: dimensionful SUSY parameter μ set "by hand" to be $\sim \mathcal{O}(m_{\rm soft})$.

$$W_{\rm NMSSM} = W'_{\rm MSSM} + \lambda \hat{S} \hat{H}_u \hat{H}_d + \frac{\kappa}{3} \hat{S}^3.$$

- After EWSB, the tree-level Higgs mass uplifts as

$$m_h^2 = m_h^2({\rm MSSM}) + \lambda^2 v^2 \sin^2 2\beta.$$

- μ-term is dynamically generated as $\mu_{\rm eff} = \lambda v_s$.

Higgses and neutralinos in the NMSSM

- 7 physical Higgs bosons: s, h, $H + a$, $A + H^{\pm}$.
- 5 neutralinos: one of them can be mostly singlino-like or with a sizable Higgsino mixing.
- The distinguishing scenario is the light scalar/pseudoscalar states with the singlino-like LSP ($\Rightarrow$ dark matter).
- A pseudoscalar a can be light due to spontaneously broken global $U(1)$ like in the
  - Peccei-Quinn limit: κ, $A_\kappa \to 0$ or
  - R-symmetry limit: A_λ, $A_\kappa \to 0$.

  $\Rightarrow a$ is either PQ axion or R-axion, and dominantly singlet-like.
- $h \to aa$ process is an important non-standard Higgs channel to probe the light pseudoscalar (the search has been performed and set upper limits in both Tevatron and LHC).
- Depending on the mass hierarchy in the light Higgses (s, a, h), there can be various different scenarios (ex: $h \to ss^{(*)} \to 4a$).

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Decay modes of a depend on both its mass and coupling structure.

- $a \to f\bar{f}$ via mixing with the MSSM-like pseudoscalar.
- $a \to \gamma\gamma$ is typically loop suppressed.

$h \to aa \to 4\tau,\ 2\tau 2\mu,\ 4\mu,\ \cdots$

- $a \to \mu^+\mu^-$ is now stringently constrained by CMS search (CMS-PAS-HIG-13-010) and LHCb ($B \to K\mu\mu$) (See ex. Schmidt-Hoberg *et al.*, arXiv:1310.6752)
- For $m_a > 2m_\tau$, $a \to \tau\tau$ is dominant, and receives constraints from LEP ($e^+e^- \to as \to 6\tau$), but still viable when dominantly singlet-like.

$\widetilde{\chi}_2^0 \to a\widetilde{\chi}_1^0 \to f\bar{f}\chi_1^0$

It is often dominant when light neutralinos are singlino-Higgsino admixtures and sleptons are heavy. In the collider search, this channel is challenging since visible fermions are quite collinear.

$$\Delta R_{f\bar{f}} \sim \frac{4m_{\tilde{\chi}_2^0} m_a}{m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{\chi}_1^0}}.$$

A different criterion for identifying the isolated lepton might be necessary.

Light neutralino dark matter and Fermi bubble

Caution: *work in progress*[1] $\cdots$ do not trust this for now

$\widetilde{S}$ can be a good candidate of light dark matter.
$\Rightarrow$ receive constraints from current dark matter results (ex. LUX) and/or give us a distinguished prediction.

- Fermi bubble
  - Two large structures in gamma-rays about 50° above and below the Galatic Center.
  - The latitude above 30° of Galatic plane can be explained by inverse Compton scattering, while within 20°, the photon spectrum has a peak energy around 1 – 4 GeV. ($\Rightarrow$ dark matter annihilation?)
  - It was claimed that 10 GeV DM with $\tau\tau$ or 30 GeV DM with $b\bar{b}$ final states or a combination of both could be possible signal. (For recent study, Hooper *et al*, arXiv:1302.6589, Gordon *et al*, arXiv:1306.5725)
  - We found that there is another possibility with the light scalars, for example, $\chi\chi \to sa \to aaa \to 6\gamma$ by testing their energy spectrum.
  - A natural mechanism for enhancing $a \to \gamma\gamma$ over $a \to f\bar{f}$ should be considered in the NMSSM.
  - We also take into account the recent LUX result (arXiv:1310.8214) as well as all the constraints from LEP and LHC on the light Higgses.

[1] In collaboration with H. M. Lee and M. Park, former CERN TH fellows.

On the other hand, $\cdots$ $t\bar{t}$ spin correlation

to introduce my other interest $\cdots$

- I have also great interest in the kinematic variables or methods for measuring particle mass and spin in various decay topology.
- Top quark is important for theoretical, phenomenological, and experimental reasons.
- The reconstruction of di-leptonic $t\bar{t}$ process is challenging due to two undetectable neutrinos in hadron colliders.
- We have recently proposed a kinematic method using M_{T2} to reconstruct the $t\bar{t}$ process in an event-by-event basis, and applied to measure the $t\bar{t}$ spin correlation. Please find arXiv:1308.2226. A direct comparison with conventional methods will proceed by communicating with experimentalists.
- Since the kinematic method is model-independent, it can be directly applied to the new physic processes (ex. SUSY with R-parity conservation) with the similar decay topology.