Spin-1 Top Partner: Phenomenology [arXiv:1406.1221]

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Introduction

•**Top partners** are a well motivated target for collider searches, as they are crucial in **cancellation of SM loop contributions** and need to be ~ O(500) GeV to satisfy naturalness criteria. The **current lore** has models with **top partners of spin 0 or ½.**

•**Spin - 1 top partner (swan)** was proposed in a supersymmetric (SUSY) gauge model by Cai, Cheng and Terning (CCT).[1] We have explored the phenomenology of this model in the light of current updates from LHC.

•The questions we attempt to answer are:

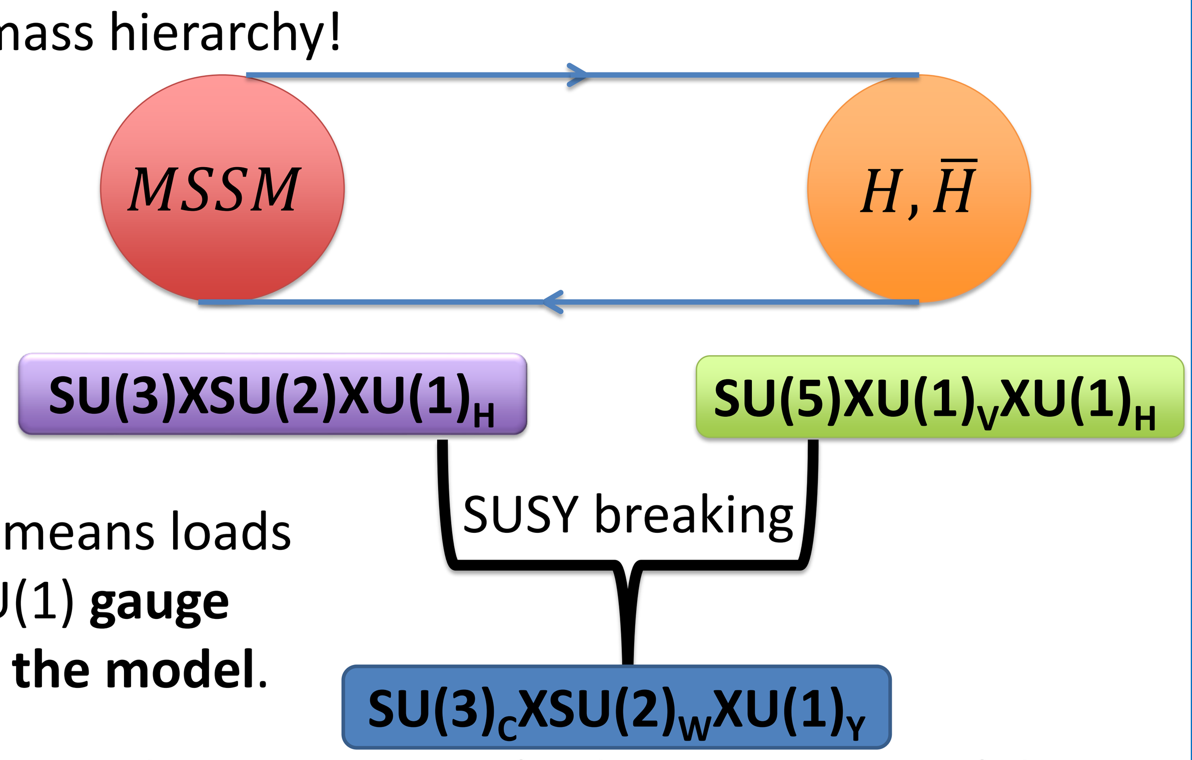
(i) What are the **current constraints** on the model?,

(ii) What are the implications of the **inclusion of 125 GeV Higgs**?, and,

(iii) What are the prospects of **discovering swans** in a 100 TeV collider.

Swan Lake

- **Right handed top** (t_R) and Higgs lies mostly in $\boldsymbol{H,\overline{H}}$ **chiral fields**.
- **Left handed top**(t_L) is mostly a **SU(5) gaugino** ⇒ **stop is an R-odd spin-1 vector boson**(SWAN, $\vec{Q}$). So, top **Yukawa(Y_t) is O(1),** while other quarks are MSSM like → solution to mass hierarchy!
- Enforcement of SM like gauge couplings & Y_t reduces **parameter space** to the **tanβ & U(1) mixing angle θ**.
- Extended gauge structure means loads of gauge bosons and the U(1) **gauge bosons strongly constrain the model**.



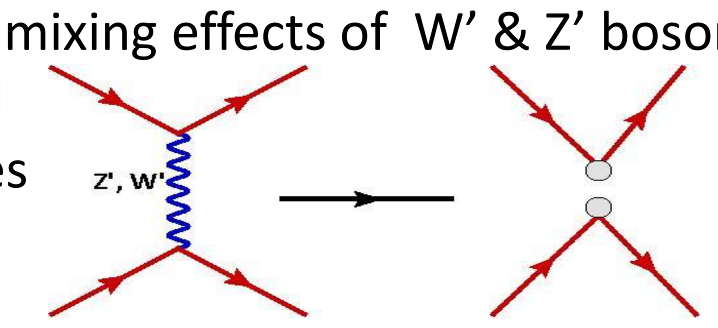
- Perturbativity of the gauge couplings requires a further restriction of the model parameters. $0.8 \lesssim \tan\beta \lesssim 4.0$, $0.2 \lesssim \sin\theta \lesssim 0.99$ & $m_{\vec{Q}} \gg mZ$.

Unlike MSSM, we get stronger constraints on tanβ

Constraints on the swan model:

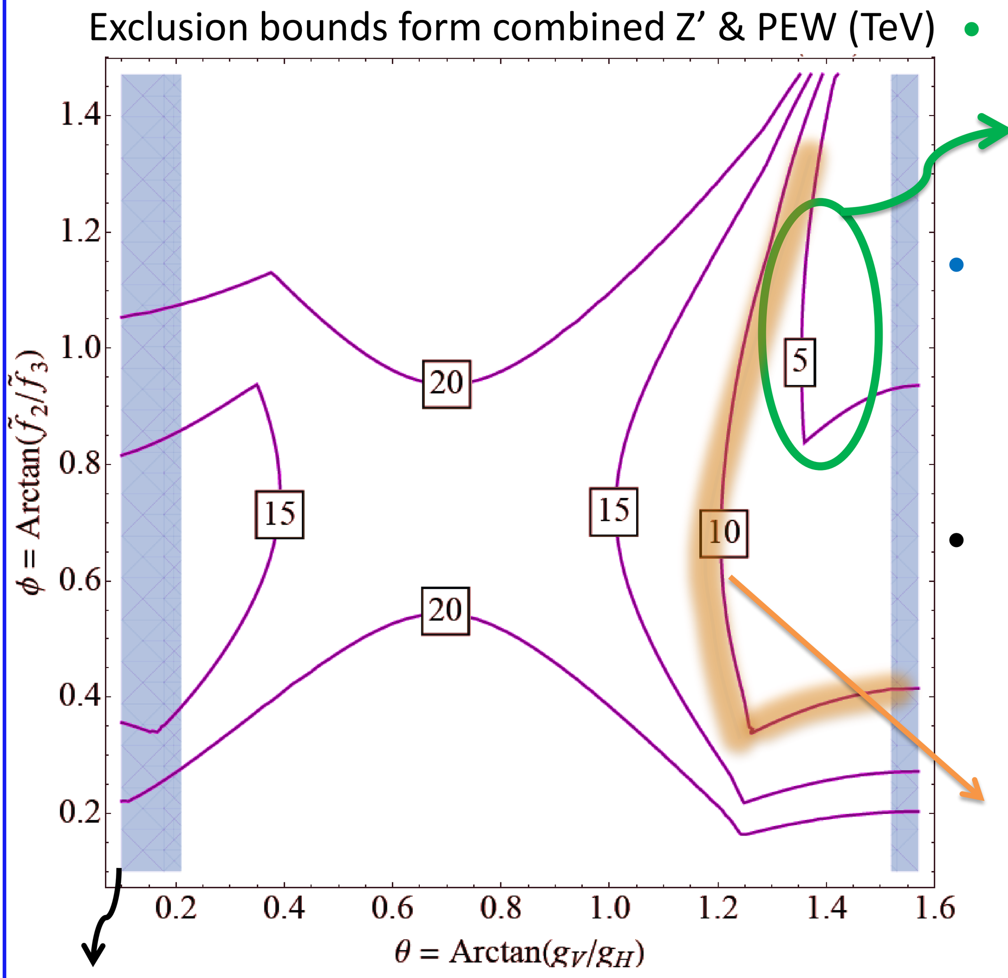
Precision electroweak (PEW) measurements[2,3] rein in:

- deviations to the Standard Model (SM) W & Z properties owing to mixing effects of W' & Z' bosons .
- tree level exchanges of Z' W'



effective four fermion interactions

Exclusion bounds form combined Z' & PEW (TeV)



Gray regions: regions where gauge couplings are non-perturbative

- **T parameter puts a lower bound of 4.5 TeV on swan** ⇒ pair production excluded from direct LHC searches
- **Direct Z' searches**[4] are also promising as R-even states can be produced singly. Z'→μ⁺μ⁻ channel gives the strongest bounds.
- We compute cross-sections for **pp →Z'→μ⁺μ⁻ as function of $m_{Z'}$** for LHC8 & then constrain the model parameter space using CMS LHC-8 data set.[4] This pushes lower bounds to $\mathbf{m_{\vec{Q}} \gtrsim 10}$ **TeV**.

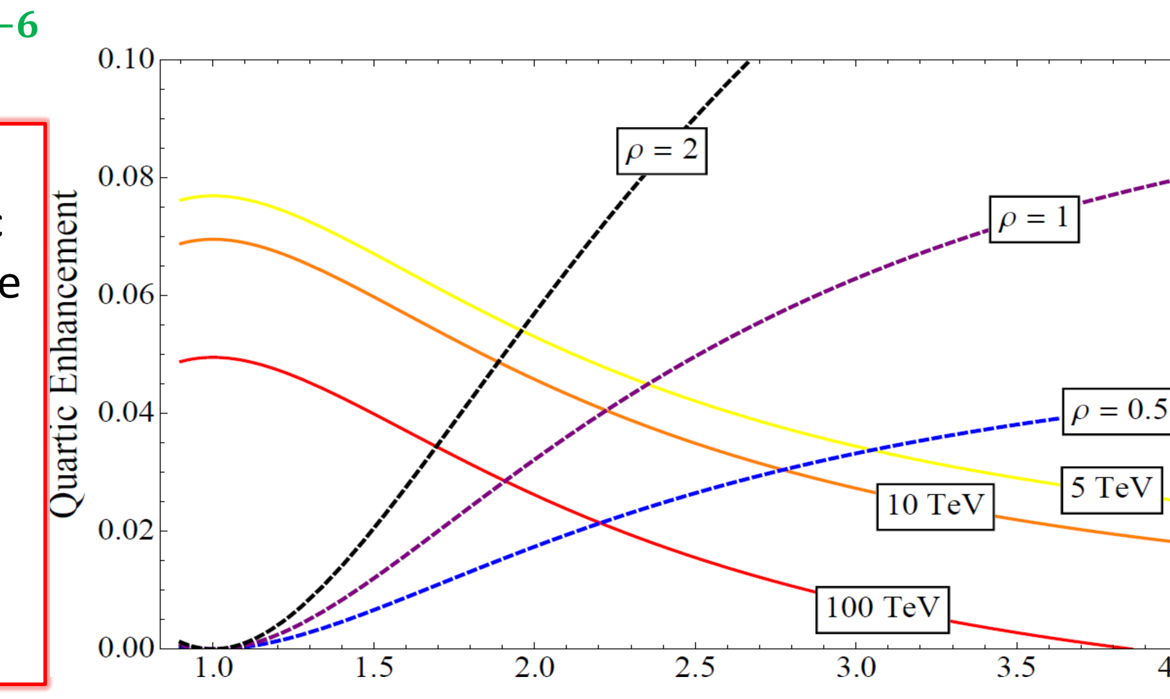
$m_{\vec{Q}} \gtrsim 10\,TeV$, for most of the parameter space, which **weakens to 4.5 TeV** when Z' couplings to fermion gets suppressed.

How does the Higgs fit in?

- For models with no non-decoupling D terms (eg. MSSM), **higgs quartic (λ_{susy}) is only enhanced by RG evolution** between SUSY breaking scale (Λ_{susy}) & EW scale to accommodate a 125 GeV Higgs as there is no contribution to λ_{susy} from superpotential and D-term contribution is insufficient.
- So, we get $\Lambda_{susy} \gtrsim 100 TeV$ with **significant fine tuning**: $(v/\Lambda_{susy})^2 \approx 10^{-6}$. This worsens for allowed tanβ values.

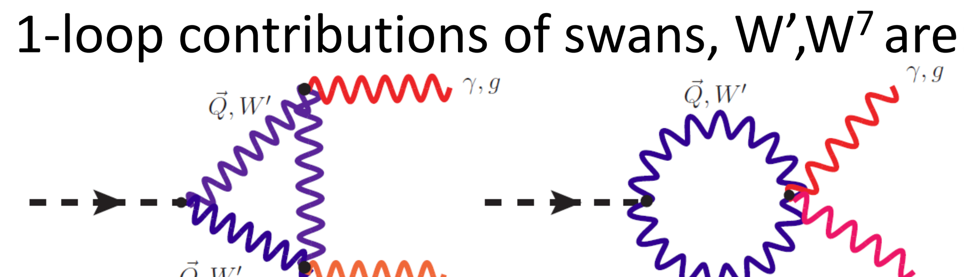
Remedy: **gauge symmetry breaking before SUSY breaking:** $f_i < \Lambda_{susy}$. λ_{susy} now gets additional contribution from D-terms[2,6] of non-SM gauge generators, $(v/\Lambda_{susy})^2 \approx 10^{-6}$

Solid lines: The difference δ between the value Higgs quartic $\lambda_{SM}(\Lambda_{susy})$ needed to allow for the 125 GeV Higgs, and the value predicted by a SUSY theory with the SM gauge group for Λ_{susy} = 5,10, 100 TeV
Dot dashed: non decoupling D term contributions.



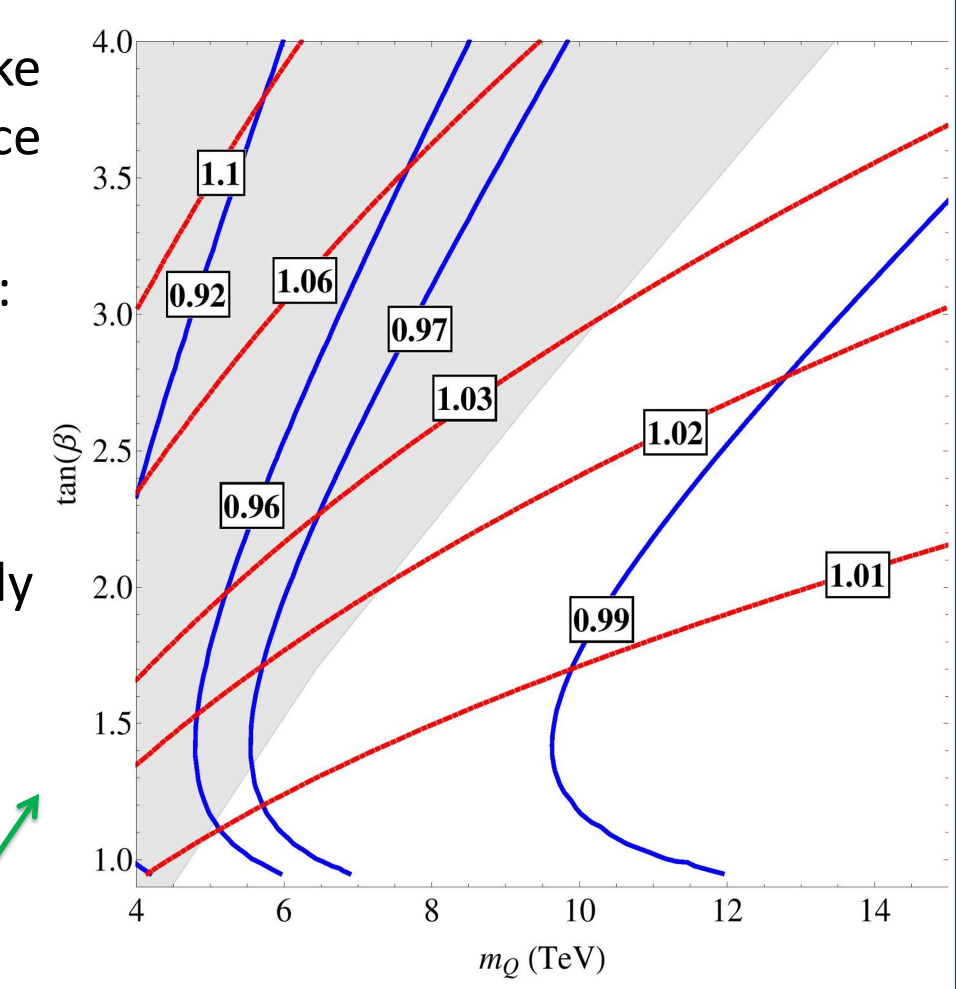
- Apart from the usual MSSM like contributions, swans, W & W' induce shifts in hgg & hγγ couplings[6] .

1-loop contributions of swans, W',W[7] are:



- A plethora of colored and/or electrically charged states also modify the hgg & hγγ couplings[6].

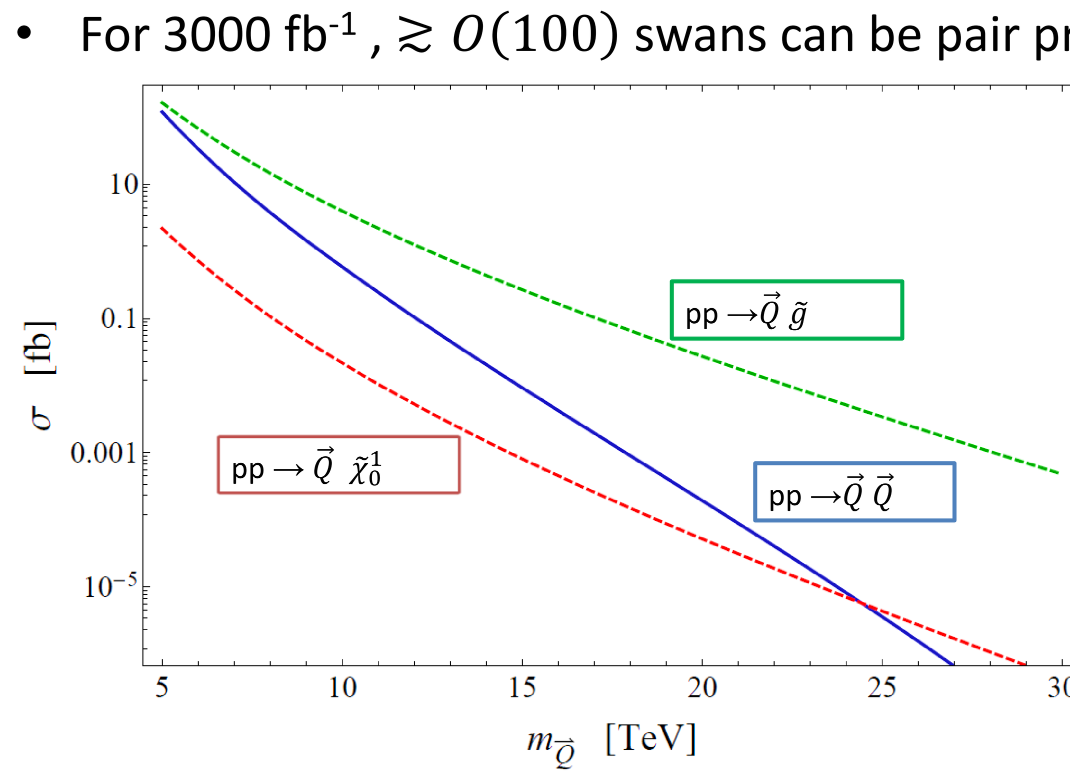
Fractional shifts in hγγ (red) & hgg (blue) are shown, where shaded region is disfavored by PEW & Z' direct searches.



Deviations ~ 5% in hgg & hγγ could be observed in future **e⁺e⁻ colliders**.

Swan sightings in future colliders

- **Swans pair productions** , along with **associated productions of gluino** ($m_{\tilde{g}} = 1\,TeV$) and **neutralino** ($m_{\tilde{\chi}^1_0}$ = 0.5 TeV) are estimated at a future 100 TeV pp collider.
- For 3000 fb^{-1} , $\gtrsim O(100)$ swans can be pair produced with $m_{\vec{Q}} \approx 15\,TeV$.



Swan production cross sections at 100 TeV pp collider:

And, in associated gluino production $m_{\vec{Q}} \approx 25\,TeV$.

- If $m_{\tilde{g}}/m_{\tilde{\chi}^1_0}$ increases, associated production cross-sections decreases.

Conclusions:

- Existing constraints from PEW and Z' searches place a strong bound on swans, $m_{\vec{Q}} \gtrsim 4.5\,TeV$, in fact $\gtrsim 10\,TeV$ in most parameter space.
- CCT model is quite **fine-tuned**. No direct swan discovery @ LHC.
- **Models with no Z' or R – odd Z'** can be interesting for the swan lake to become a reality! [8]

Acknowledgements:

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References:

1. Cai,Cheng&Terning-2008 **2.** Cai 2012 **3.** Baak&Kogler 2013 **4.** CMS-PAS-EXO-12-061 **5.** Batra et al. 2004, Maloney et al-2006 **6.** Farina et al-2013 **7.** Bunk et al- 2014