Complex Singlet Benchmarks

PRELIMINARY

arXiv: 2111:xxxx

Shekhar Adhikari, Samuel D. Lane,
Ian M. Lewis, Matthew Sullivan

Outline

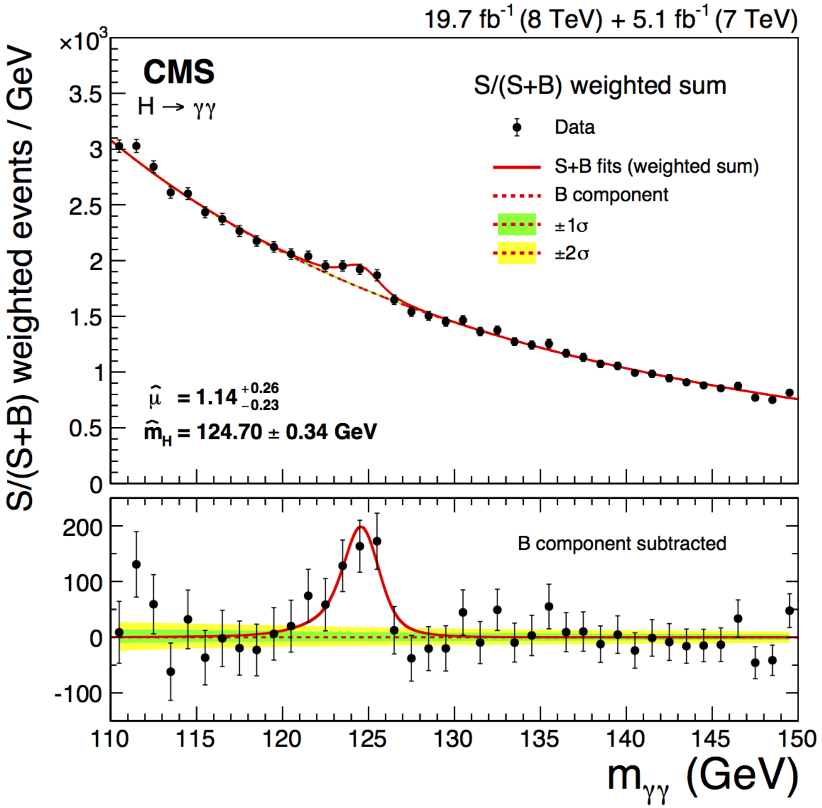
- Introduction/Motivation
- Model
- Constraints
- Preliminary Results
- Conclusion

Outline

- **Introduction/Motivation**
- Model
- Constraints
- Preliminary Results
- Conclusion

Introduction/Motivation

- Is this the predicted standard model Higgs?
  - Spin-0, fits well into SM predictions
- Is the Higgs boson part of some extended scalar sector?
  - Will we find more “bumps”?
- What is the new scalar sector?
  - New singlets, doublets, symmetries, etc.



Eur. Phys. J. C 74 (2014) 10, 3076

Introduction/Motivation

- Why the complex singlet?
  - 3 Massive Scalars with “relatively” few parameters

- Goal: Find parameters that maximize the production of new scalars

Outline

MATH INCOMING

- Introduction/Motivation
- **Model**
- Constraints
- Preliminary Results
- Conclusion

The General Complex Singlet

- Add a new complex scalar uncharged under SM and with no new svmmetries.
- $S_c = (S_0 + i\,A)/\sqrt{2}$
- Write the most general potential

$$
\begin{aligned}
V(\Phi, S_c) \;=\; & \frac{\mu^2}{2}\Phi^\dagger\Phi + \frac{\lambda}{4}(\Phi^\dagger\Phi)^4 + \frac{b_2}{2}|S_c|^2 + \frac{d_2}{4}|S_c|^4 + \frac{\delta_2}{2}\Phi^\dagger\Phi|S_c|^2 \\
& + \left(a_1\, S_c + \frac{b_1}{4}\, S_c^2 + \frac{e_1}{6}\, S_c^3 + \frac{e_2}{6} S_c|S_c|^2 + \frac{\delta_1}{4}\Phi^\dagger\Phi\, S_c + \frac{\delta_3}{4}\Phi^\dagger\Phi\, S_c^2 \right. \\
& \left. + \frac{d_1}{8} S_c^4 + \frac{d_3}{8} S_c^2|S_c|^2 + \text{h.c.} \right)
\end{aligned}
$$

Simplifying the Complex Singlet

- By appropriate choice of parameters can set $\langle S_c \rangle = 0$

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} \qquad R(\theta_1, \theta_2, \theta_3) \qquad \begin{pmatrix} h \\ S_0 \\ A \end{pmatrix}$$

Simplifying the Complex Singlet

- By appropriate choice of parameters can set $\langle S_c \rangle = 0$

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} \Longleftarrow R(\theta_1, \theta_2, \cancel{\theta_3}) \Longrightarrow \begin{pmatrix} h \\ S_0 \\ A \end{pmatrix}$$

- Can remove one mixing angle using phase of singlet

Scalar Mixing

- Take limit $|\theta_2| \ll 1.$

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = \begin{pmatrix} \cos\theta_1 & -\sin\theta_1 & 0 \\ \sin\theta_1 & \cos\theta_1 & \sin\theta_2 \\ \sin\theta_1 \sin\theta_2 & \cos\theta_1 \sin\theta_2 & -1 \end{pmatrix} \begin{pmatrix} h \\ S_0 \\ A \end{pmatrix} + \mathcal{O}(\sin^2\theta_2)$$

Masses/Couplings

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix}$$

SM Higgs, mass 125 GeV
Couples in usual way

Mass range ~ 0.3 to ~10 TeV
SM Couplings ~ $\sin(\theta_1)$

Masses 130, 200, 270 GeV
SM Couplings ~ $\sin(\theta_1)\sin(\theta_2)$

Outline

- Introduction/Motivation
- Model
- **Constraints**
- Preliminary Results
- Conclusion

Theory Constraints

- Narrow widths (10% of Mass)
- Bounded Below and Electroweak global minimum
  - Enforced numerically
- Perturbative Unitarity

$$\mathcal{M} = 16\pi \sum_{j=0}^{\infty} (2j+1) a_j P_j(\cos\theta),$$

Pert. Unit.

$$|\delta_2|\,, |\Re\left(\delta_3\right)|\,, |\Im\left(\delta_3\right)| \;\le\; 16\sqrt{\frac{2}{3}}\pi$$

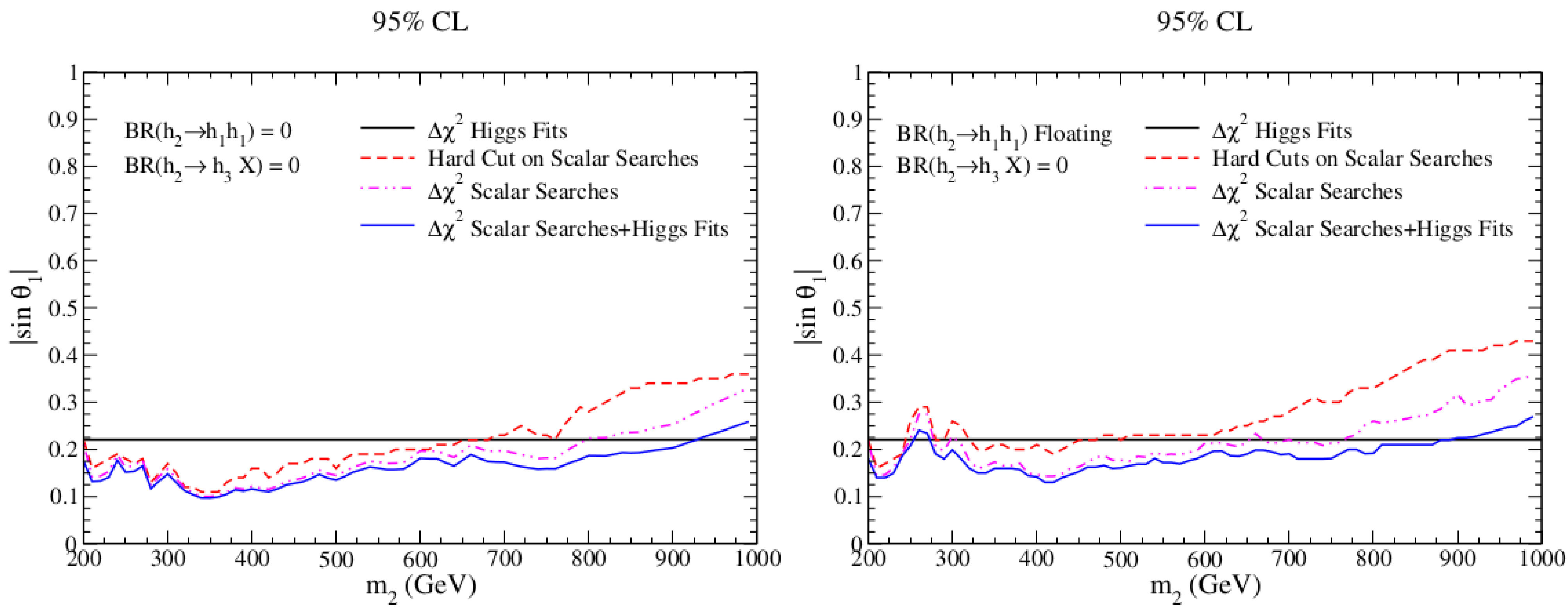
$$|\lambda| \;\le\; \frac{16\pi}{3},\quad |d_2| \;\le\; 8\pi\,,$$

Experimental Constraints

- Can combine direct searches and higgs signal strengths to place limit on $\sin\theta_1$ see Phys. Rev. D 103, 075027 for details and assumptions
- Heavy resonance chi square

$$\left(\chi^f_{i,h_2}\right)^2 = \begin{cases} \left(\dfrac{\sigma_i(pp\to h_2)\mathrm{BR}(h_2\to f)+\hat{\sigma}^f_{i,Exp}-\hat{\sigma}^f_{i,Obs}}{\hat{\sigma}^f_{i,Exp}/1.96}\right)^2 & \text{if } \hat{\sigma}^f_{i,Obs}\geq\hat{\sigma}^f_{i,Exp} \\ \left(\dfrac{\sigma_i(pp\to h_2)\mathrm{BR}(h_2\to f)}{\hat{\sigma}^f_{i,Obs}/1.96}\right)^2 & \text{if } \hat{\sigma}^f_{i,Obs}<\hat{\sigma}^f_{i,Exp}. \end{cases}$$

Experimental Constraints



Outline

- Introduction/Motivation
- Model
- Constraints
- **Preliminary Results**
- Conclusion

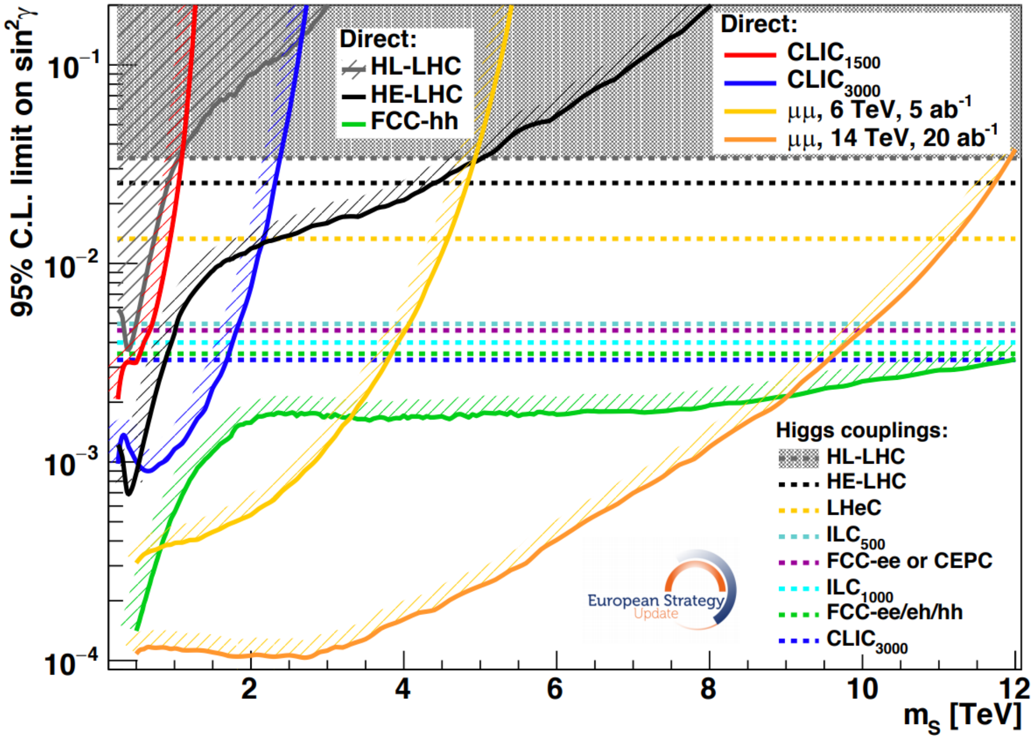
Preliminary Results

- Maximize production of scalars
- h_2 $\sigma_i(pp \to h_2) = \sin^2\theta_1 \sigma_{i,\mathrm{SM}}(pp \to h_2)$
- Want to maximize $\sin(\theta_1)$
- Additional Di-higgs production from $h_2 \longrightarrow h_1 h_1$
- h_3 comes from decays of h_2
  - Maximize $Br(h_2 \to h_1 h_3)$ and $Br(h_2 \to h_3 h_3)$

Preliminary Results

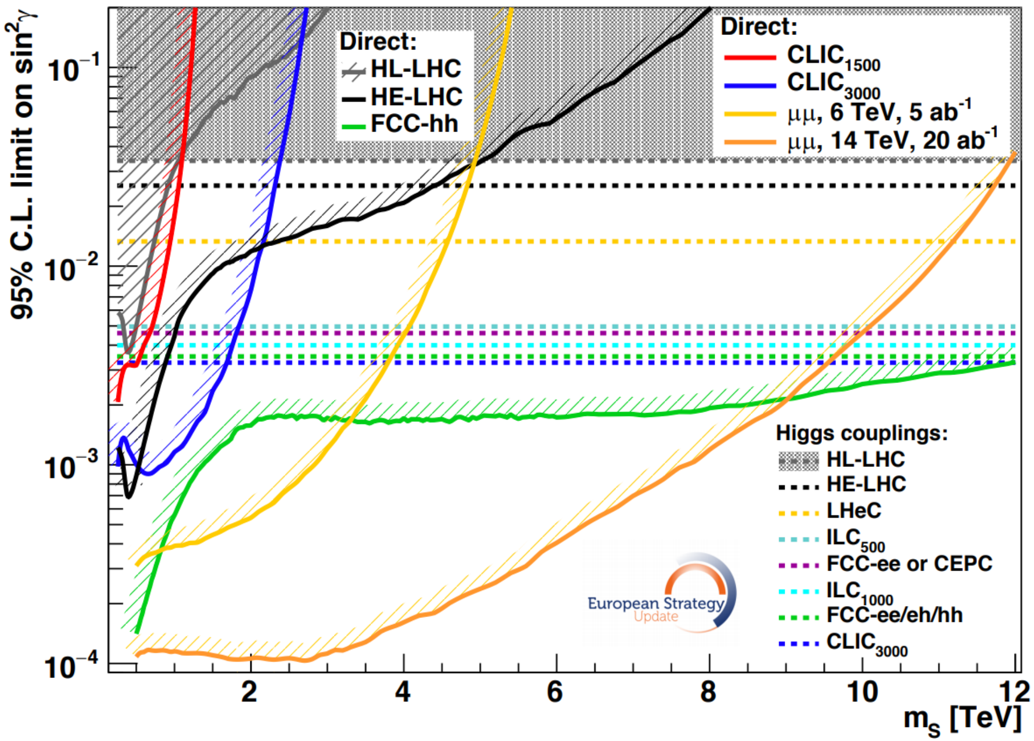
Maximize production, take $\sin(\theta_1)$ constraints from

- Projected HL – LHC
- Projected ILC-500
- Projected FCC-hh
- Current LHC Data

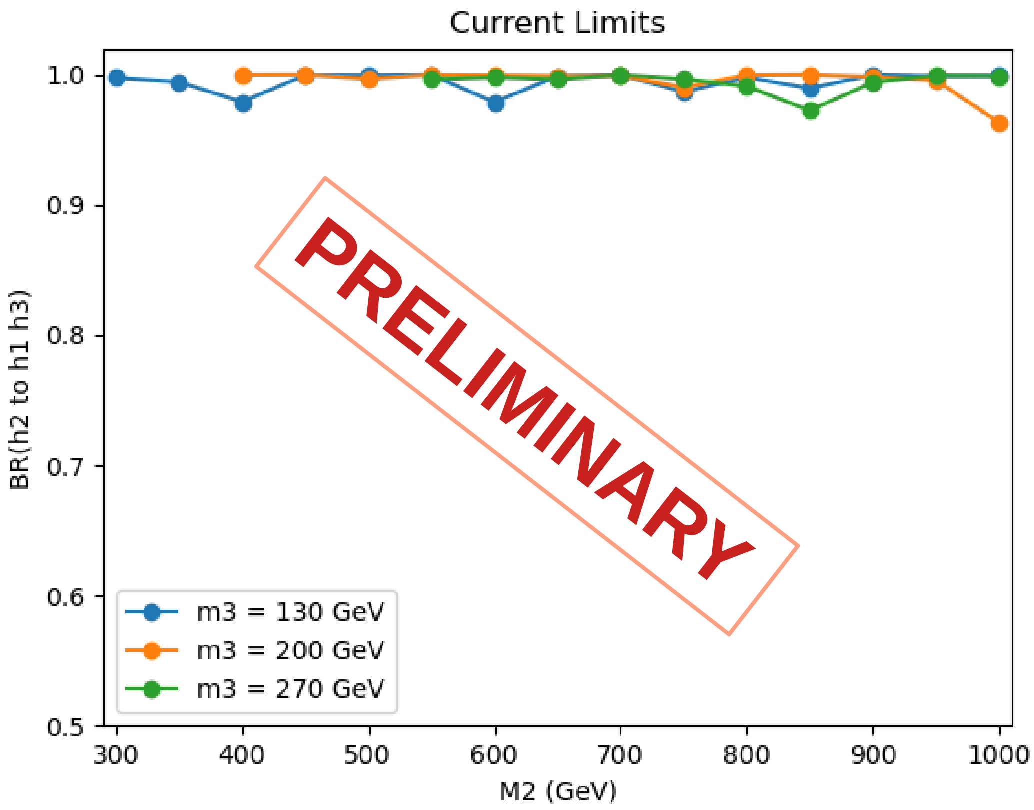


Preliminary Results

- Projected HL – LHC
- Projected ILC-500
- Projected FCC-hh
- **Current LHC Data**



Preliminary Results



Preliminary Results

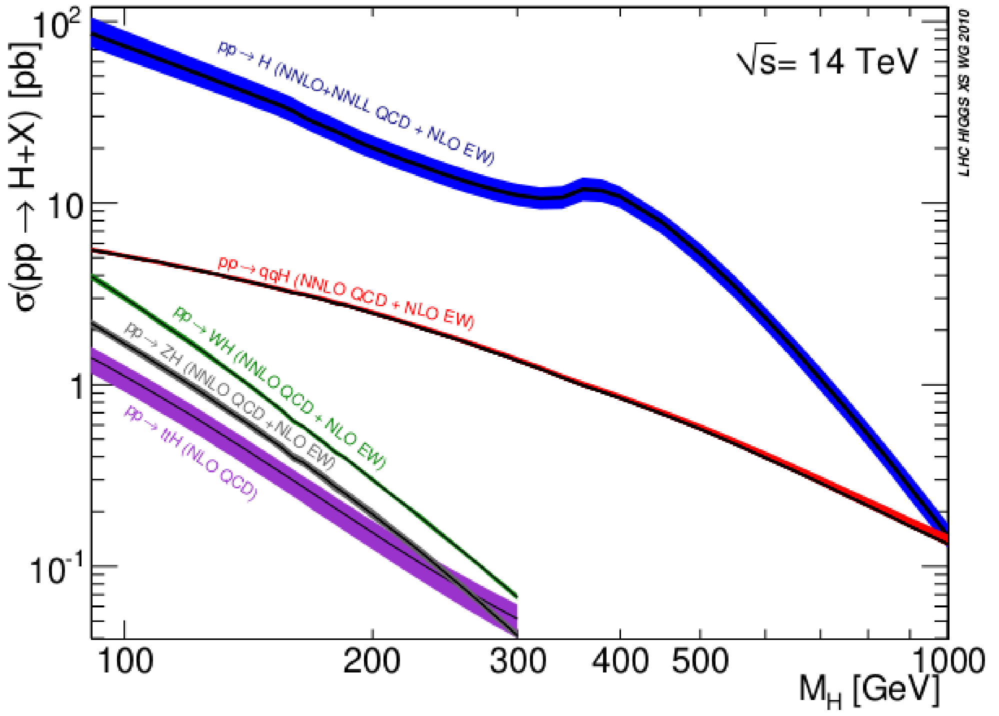
- Can get branching ratios > 95%
- $\sin^2\theta_1$ ~ 0.04

$$\sigma_i(pp \to h_2)\,\mathrm{BR}(h_2 \to h_3\,X)$$

= .04*.98*1 pb = 0.0392 pb

- Get ~0.1 pb level production
- Future colliders/upgrades should begin to probe these cross sections

arXiv: 1101.0593



Outline

- Introduction/Motivation
- Model
- Constraints
- Preliminary Results
- **Conclusion**

Conclusion

- The generic complex singlet is a interesting extension to the SM with an rich phenomenology
- We are able to get multi-scalar production channels
- Total production cross section will be of order 0.1 pb
- Future colliders/upgrades will begin to probe these cross sections
- Look out for our paper on arXiv for more details

Thanks for your attention!