NLO corrections to general scalar singlet models and dark matter

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Planck 2017, Warsaw

Acknowledgments

- **Collaborators:**

  J. E. Camargo-Molina, A. P. Morais, R. Pasechnik, M.O.P.S., J. Wessén, JHEP 1608 (2016) 073.

  R. Costa, M.O.P.S., R. Santos, arXiv:1704.02327.

- **Funding & Institutions**

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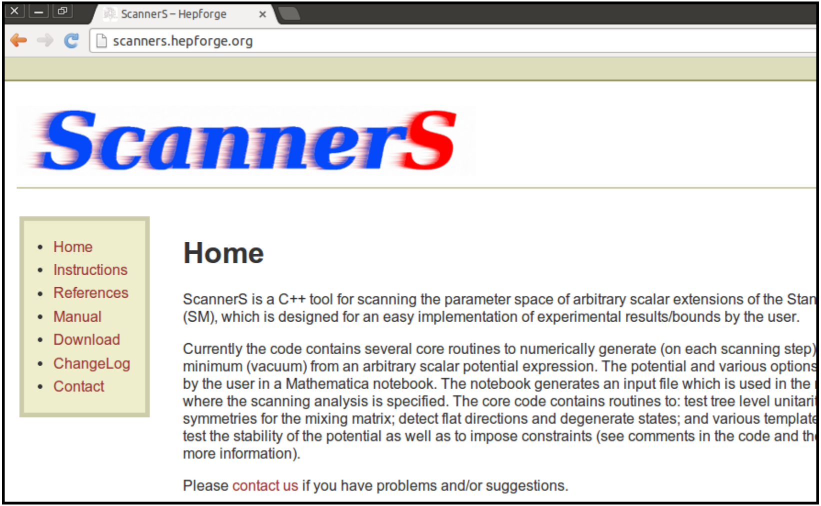

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- **RxSM-broken**: 2 Higgs mixing ($\mathbb{Z}_2$ spont.broken)

- **CxSM-dark**: 2 Higgs mixing + 1 Dark
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- **TwoHDM**: T1,T2,T3,T4

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- **C2HDM**: NOT PUBLIC YET.

Pheno3 tomorrow ⇒ Rui Santos': Higgs sectors comparison

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Outline

1. Scalar singlet models overview
   - Motivation
   - LO phenomenology/constraints
2. NLO-EW corrections
   - NLO-EW gluon fusion
   - Numerical results
3. Final Remarks

Outline

General scalar singlets & the Higgs portal

- Scalar sector prone to coupling to hidden sectors!
  Only SM singlets with dimension < 4 are: $H^\dagger H$, $B_{\mu\nu}$, HL

$$V_{\mathrm{GxSM}} = V_{\mathrm{SM}}(H^\dagger H) + H^\dagger H \times \Delta(S) + V_{New}(S)$$

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} G^+ \\ v + h + iG^0 \end{pmatrix} \quad \text{and} \quad S_k = v_k + s_k \ .$$

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- Some s_k may mix with Higgs, otherwise they are dark.

- LO couplings to SM through mixing (dilutes higgs):

$$\text{Higgs fluctuation} \leftarrow h = \sum_a \kappa_a H_a \ , \ \sum_a |\kappa_a|^2 = 1$$

Our benchmarks – RxSM

A. Datta, A. Raychaudhuri, Phys.Rev., D57:2940-2948, 1998

R. Schabinger, J. D. Wells, Phys.Rev., D72:093007, 2005 $+\ldots$ lots

SM plus S (real field) $\mathbb{Z}_2$ symmetry $S \to -S$

$$V = \frac{m^2}{2} H^\dagger H + \frac{\lambda}{4}(H^\dagger H)^2 + \frac{\lambda_{HS}}{2} H^\dagger H S^2 + \frac{m_S^2}{2} S^2 + \frac{\lambda_S}{4!} S^4$$

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- Improve stability of SM @ high energies

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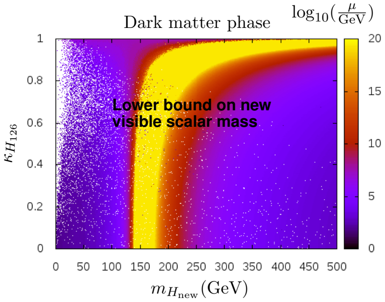

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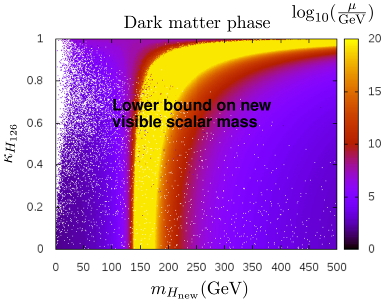

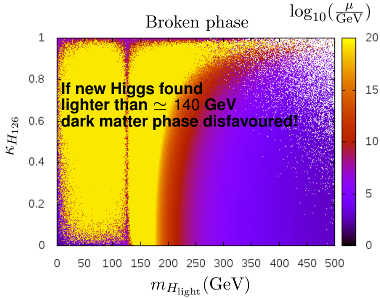

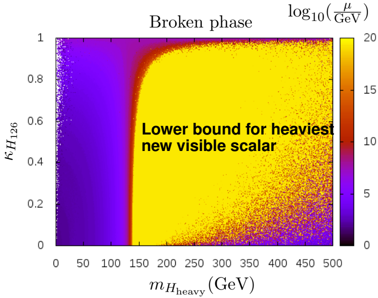

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LHC HE runs $\rightarrow$ start probing Higgs self couplings
$\Rightarrow$ opportunity also to probe extended Higgs sectors

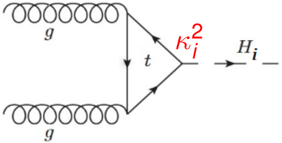
Outline

New Higgs production and decays

In singlet models, various LO (in EW corrections) observables, related to SM by a factor of κ^2:

- **Production cross sections:**

  $$\sigma_i = \kappa_i^2 \sigma_{SM}$$



- **Decay widths to SM particles:**

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- **Total decay width:**

  $$\Gamma_i^{total} = \kappa_i^2 \Gamma_{SM}^{total} + \sum_{jk} \Gamma_{i \to jk}$$

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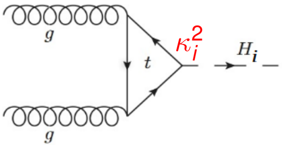

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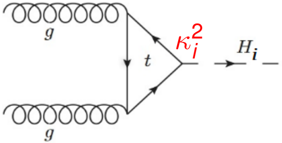

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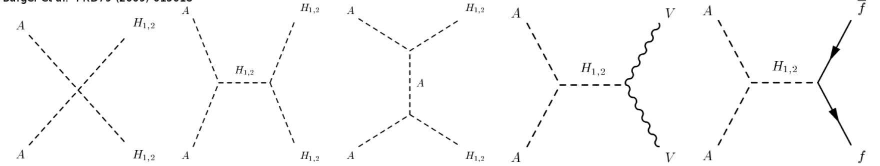
Pheno constraints (CxSM & RxSM) imposed in ScannerS:

- Electroweak precision observables – STU
- Collider bounds (LEP, Tevatron, LHC) HiggsBounds
- Used ATLAS+CMS global signal rate $\mu_{h_{125}} = 1.09 \pm 0.11$
- Dark matter relic density below Planck measurement & bounds from LUX2016 on σ_{SI} (micrOMEGAS)

Barger et al. PRD79 (2009) 015018



Outline

Why go NLO-EW?

- The LHC has only found 125 GeV Higgs
- If no new states measured, can we probe them through radiative corrections of Higgs observables?
- We focus on corrections to **gluon fusion** production
- But SM couplings of new mixing scalars suppressed by $\kappa_h^2 - 1$
- What about contributions from new scalar sector couplings? In particular dark loops?

Previous studies focusing on other effects

- Couplings & Decay widths:

  S. Kanemura, M. Kikuchi, K. Yagyu, arXiv:1511.06211.

  F. Bojarski, G. Chalons, D. Lopez-Val, T. Robens, arXiv:1511.08120.

- Interference effects:

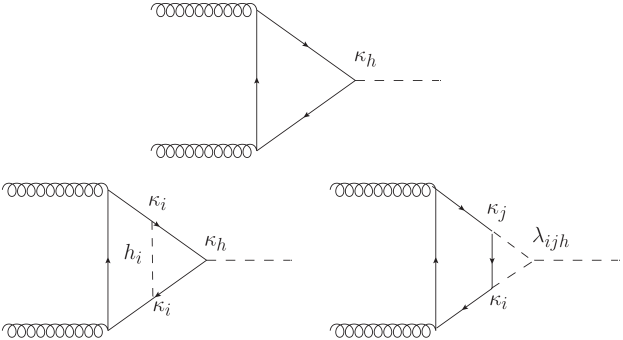
  E. Maina arXiv:1501.02139.

  N. Kauer, C. OBrien, arXiv:1511.06211.

- W boson mass corrections:

  D. López-Val and T. Robens, arXiv:1406.1043.

Near decoupling limit approximation $\kappa_h^2 \to 1$



Then

$$\sigma_{ggF}^{(NLO)} = \sigma_{ggF}^{(LO)} \left(1 + \delta_{\mathrm{SM}} + \delta_{\mathrm{GxSM}}\right)$$

with

$$\delta_{\mathrm{GxSM}} \simeq \left(\frac{\kappa_h \lambda_{hhh}}{\lambda_{hhh}^{SM}} - 1\right) C_{hhf} + \delta Z_h - \delta Z_h^{SM}$$

NLO corrections calculation

$$\delta_{\mathrm{GxSM}} \simeq \left(\frac{\kappa_h \lambda_{hhh}}{\lambda_{hhh}^{SM}} - 1 \right) C_{hhf} + \delta Z_h - \delta Z_h^{SM}$$

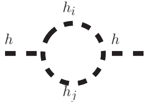
- $C_{hhf} \simeq 0.0066$ obtained in:

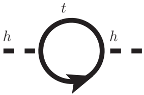
  G. Degrassi, P. P. Giardino, F. Maltoni, D. Pagani, JHEP 1612 (2016) 080.

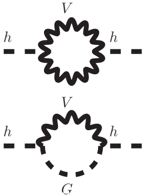
- Wave function renormalisation factors, δZ_h

  $\Rightarrow$ Computed NLO-EW scalar propagator corrections with:

  * Leading top sector contributions
  * In $\overline{\mathrm{MS}}$ scheme

$\Rightarrow \delta Z_h \simeq \Big\{ \partial_s$ 

$+ \kappa_h^2 \partial_s \Big[$ 

$+$ 

$\Big] \Big\}_{s=m_h^2}$

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Corrections to gluon fusion – RxSM

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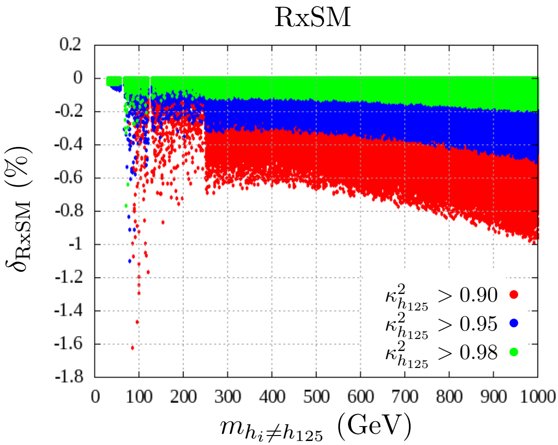

Corrections to gluon fusion – CxSM dark

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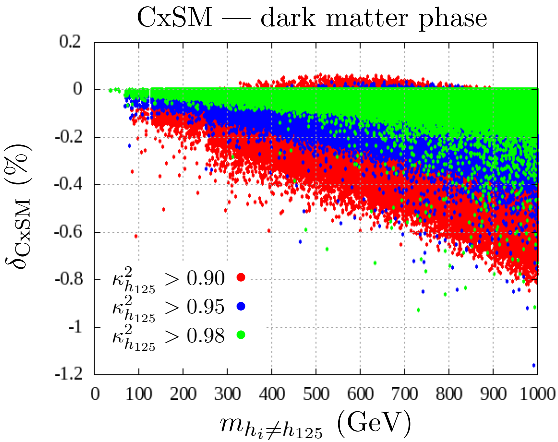

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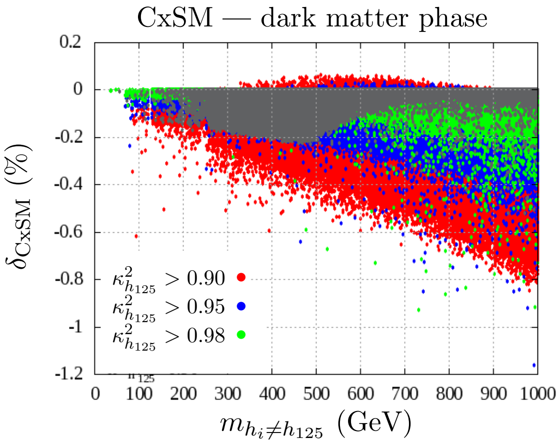
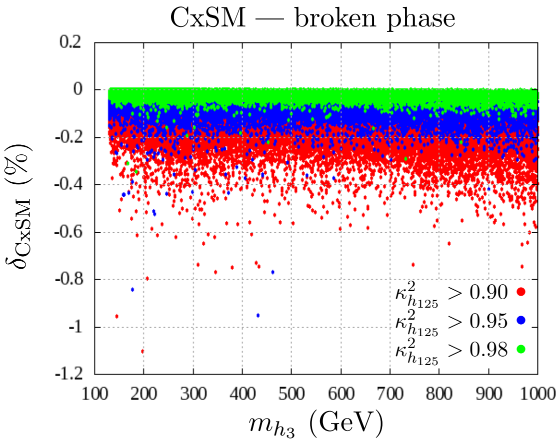


Corrections to gluon fusion – CxSM broken

$$\delta_{\mathrm{GxSM}} \simeq \left(\frac{\kappa_h \lambda_{hhh}}{\lambda_{hhh}^{SM}} - 1\right) C_{hhf} + \delta Z_h - \delta Z_h^{SM}$$



Summary

1. The RxSM and CxSM are interesting benchmarks which can provide dark matter candidates
2. They may also assist with solving other BSM problems and provide interesting signatures at colliders
3. When evaluating NLO-EW corrections to gluon fusion single Higgs production:
   - Radiative corrections without dark matter are vanishingly small when we approach the decoupling limit
   - Despite larger corrections being possible due to the dark loops the CxSM-dark is very constrained and corrections are at most of order a few percent.

$\Rightarrow$ These models need to be probed through direct searches.

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BACKUP

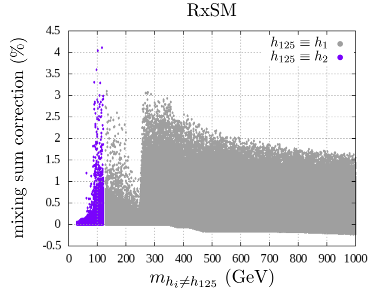
Mixing sum shifts

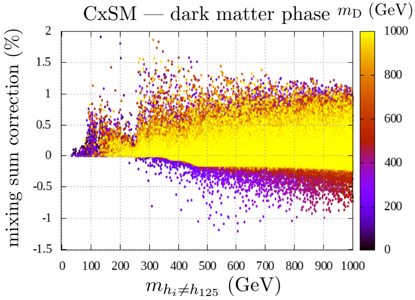
At the level of the scalar propagator corrections we can assess magnitude of NLO corrections by looking at ($\varepsilon \equiv \hbar/(4\pi)^2$):

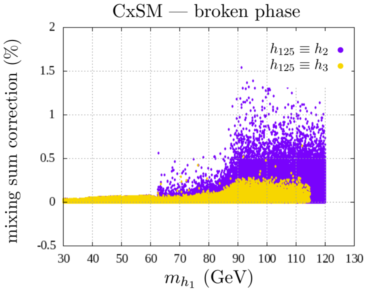
$$\sum_x \kappa_x^2 - 1 = \frac{\varepsilon}{2} \sum_{x,j\neq x} \kappa^{(0)j} \kappa^{(0)x} \frac{\Re\left[\Delta\Sigma_{jx}^{(1)} - \Delta\Sigma_{xj}^{(1)}\right]_{\text{tree}}}{m_x^{2(0)} - m_j^{2(0)}} + O(\varepsilon^2) \ .$$

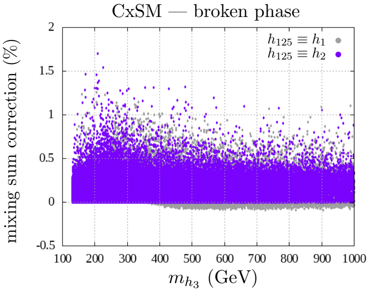
- Fixed within schemes with normalised pole eigenstates.
- Measures deviations from tree level mixing sum.
- Good indicator of magnitude NLO corrections.

Mixing sum shifts









micrOMEGAS – relic density & direct detection

Implemented micrOMEGAS interface $\Rightarrow$ present relic density

Involves:

- Creating LanHep model file
- Link and compile micrOMEGAS routines with ScannerS

Physical idea:

- Only 1 dark A out of equilibrium
- A non-relativistic (CDM)
- relic number density n_A governed by the Boltzmann eq.

$$\frac{dn_A}{dt} + 3H\, n_A = -\langle \sigma_A |v| \rangle \left(n_A^2 - (n_A^{EQ})^2 \right)$$

Barger et al. PRD79 (2009) 015018