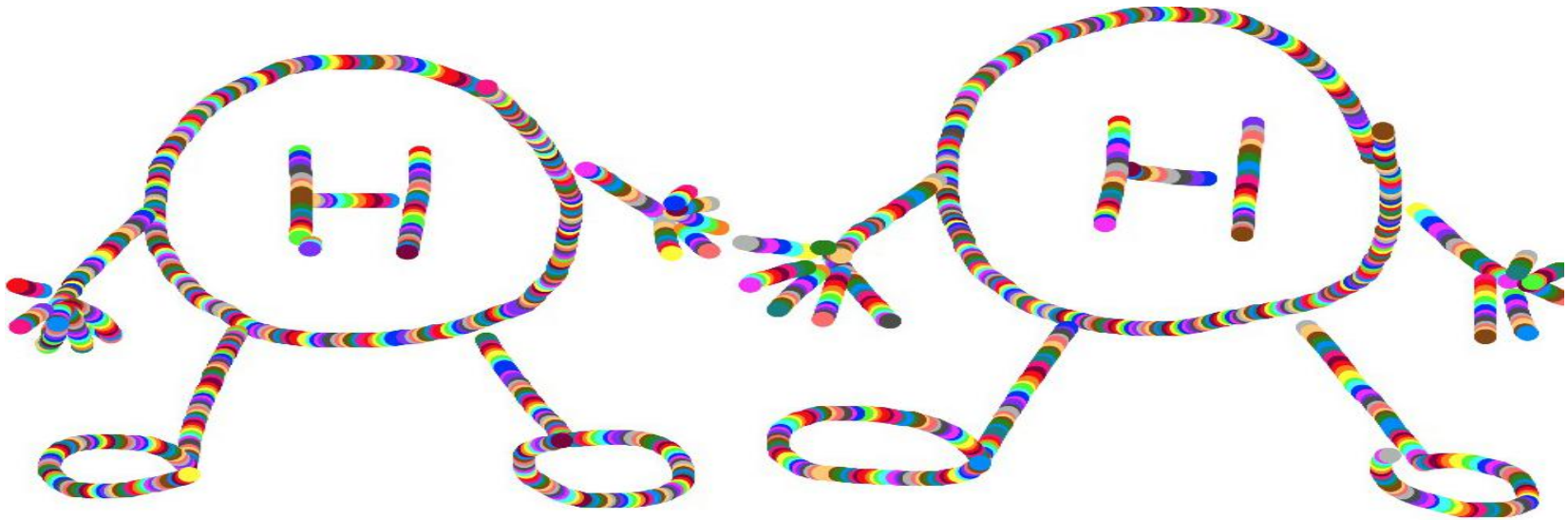
New Physics Deviations in Higgs Pair Production at the LHC

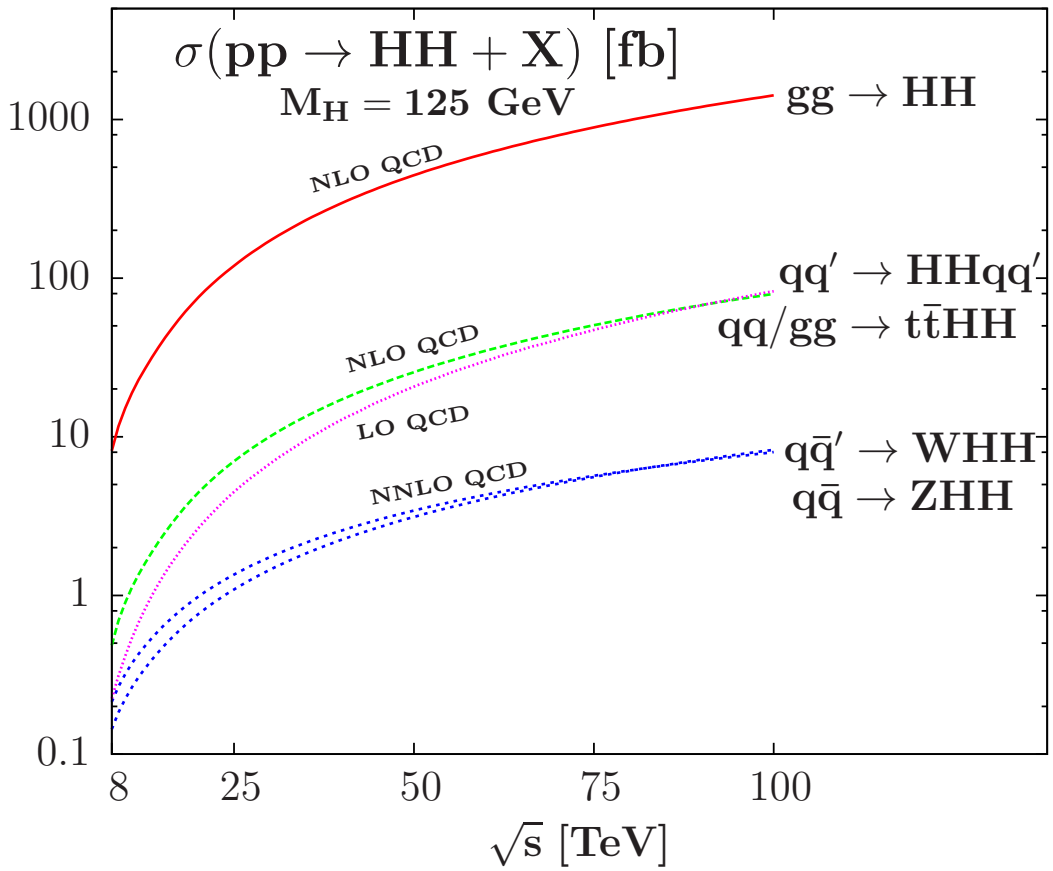
Ramona Gröber | 02/03/2017

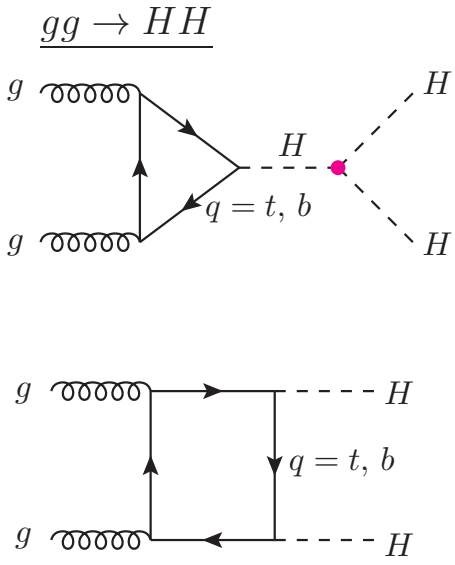
IPPP, Durham University



Higgs pair production in the SM

[Baglio, Djouadi, RG, Mühlleitner, Quevillon, Spira '12]





How can new physics modify *HH* production?

- Shift in the trilinear Higgs coupling.
  In most models: also shift in the other couplings.
  Exception e.g. singlet with zero VEV
- Shift in the other Higgs boson couplings.
- Additional Higgs bosons.
  E.g. in SUSY, [MSSM: Djouadi, Kilian, Mühlleitner, Zerwas '99; ... NMSSM: Ellwanger '13; Nhung, Mühlleitner, Streicher, Walz '13]
  Two Higgs Doublet Model [Baglio, Eberhardt, Nierste, Wiebusch '14; Arhrib, Benbrik, Chen, Guedes, Santos '09; ...]
  Singlet extended SM [Dawson, Lewis '15; ...]
- Additional particles in the loop.
  E.g. in SUSY or Composite Higgs Models [Dawson, Ismail, Low '15; CHM: Gillioz, RG, Grojean, Mühlleitner, Salvioni '12; Dolan, Englert, Spannowsky '12]
- Novel couplings.
  E.g. in Composite Higgs Models and Little Higgs Models [CHM: RG, Mühlleitner '10; Contino, Ghezzi, Moretti, Panico, Piccinini, Wulzer '12; LHM: Dib, Rosenfeld, Zerwekh '05]

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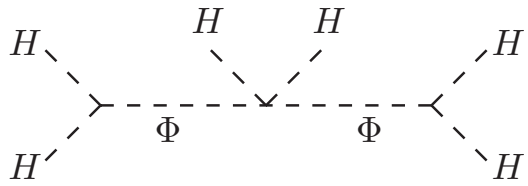
Trilinear Higgs self-coupling

based on work in collaboration with L. Di Luzio and M. Spannowsky

Shift in the trilinear Higgs self-coupling

In which model we expect the largest shifts in the trilinear Higgs self-couplings?
If there is a tree-level contribution to $\mathcal{L}_6 = \frac{c_6}{\Lambda^2}|H|^6$.

$$\mathcal{L} = HH\Phi \qquad \text{or} \qquad \mathcal{L} = HHH\Phi$$



All such scalar extensions can be classified.

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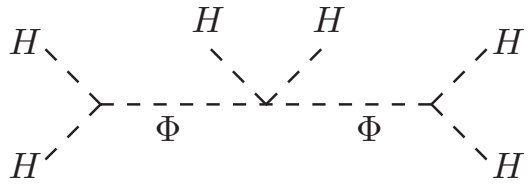

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Φ	$\mathcal{O}$
$(1,1,0)$	$\Phi HH^\dagger$
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$(1,4,\frac{1}{2})$	$\Phi HH^\dagger H^\dagger$
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How much can the trilinear Higgs self-coupling be in these models, taking into account indirect constraints?

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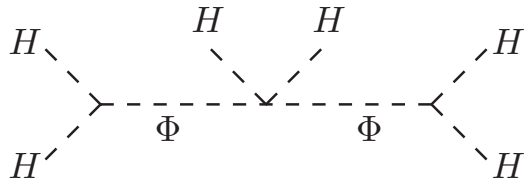

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SINGLET EXTENSION OF THE SM

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi)^2 + (D_\mu H)^\dagger (D^\mu H) + \mu_H^2 |H|^2 - \lambda_H |H|^4$$
$$- \frac{1}{2} m^2 \phi^2 - A|H|^2 \phi - \frac{1}{2} k |H|^2 \phi^2 - \frac{1}{3!}\mu \phi^3 - \frac{1}{4!}\lambda_\phi \phi^4$$

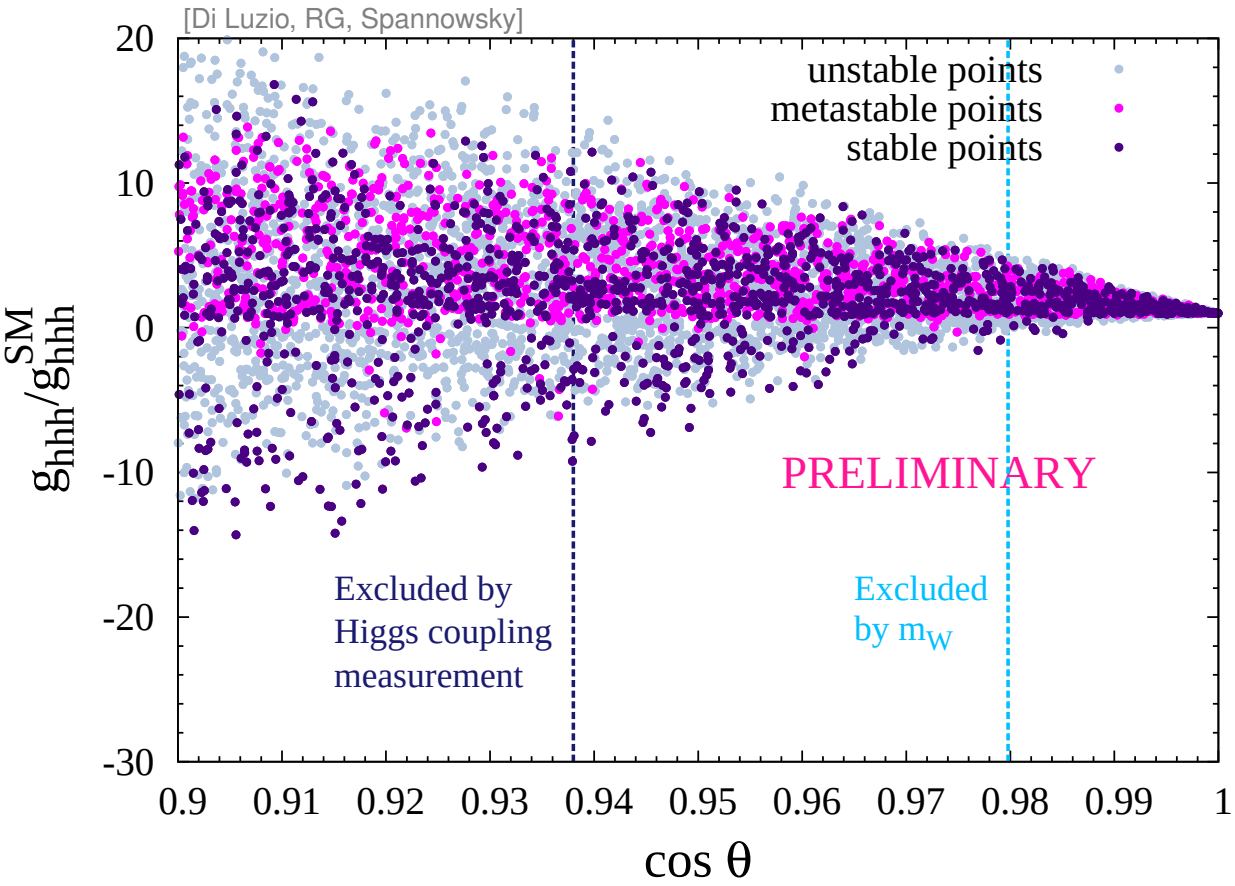
Pertubativity: [in analogy to: Di Luzio, Kamenik, Nardecchia '16]

$$\left| \frac{A^2}{\max(\mu_H^2,\, m^2)} \right| < (4\pi)^2 \,, \qquad \left| \frac{\mu^2}{m^2} \right| < (4\pi)^2 \,, \qquad 3(\lambda_H + \frac{\lambda_\phi}{6}) \pm \sqrt{9(\lambda_H - \frac{\lambda_\phi}{6})^2 + k^2} < 16\pi \,.$$

Scan:
Treat parameters for masses, VEVs and mixing angle

$$0 < \lambda_\phi < 16\pi,\ |k| < 16\pi,\ m_1 = 125 \text{ GeV},\ 800 \text{ GeV} < m_2 < 2000 \text{ GeV},$$
$$v_H = 246.2 \text{ GeV},\ |v_S| < m_2,\ 0.9 < \cos\theta < 1 \,.$$

TRILINEAR HIGGS SELF-COUPLING IN SINGLET EXTENSION



Singlet Model allows for deviations in the trilinear Higgs self-coupling of

$$\rightarrow \; -0.9 < g_{hhh}/g_{hhh}^{SM} < 5.0$$

Exclusion from m_W (Δr) from [Lopez-Val, Robens '14]

Higgs coupling measurement, see [ATLAS, arXiv:1509.00672]

2 Higgs 2 Fermion coupling

or

Can we see New Physics for the first time in Higgs pair production?

based on work in collaboration with M. Mühlleitner and M. Spira, JHEP 1606 (2016) 080

NEW PHYSICS FOR THE FIRST TIME IN *HH* PRODUCTION?

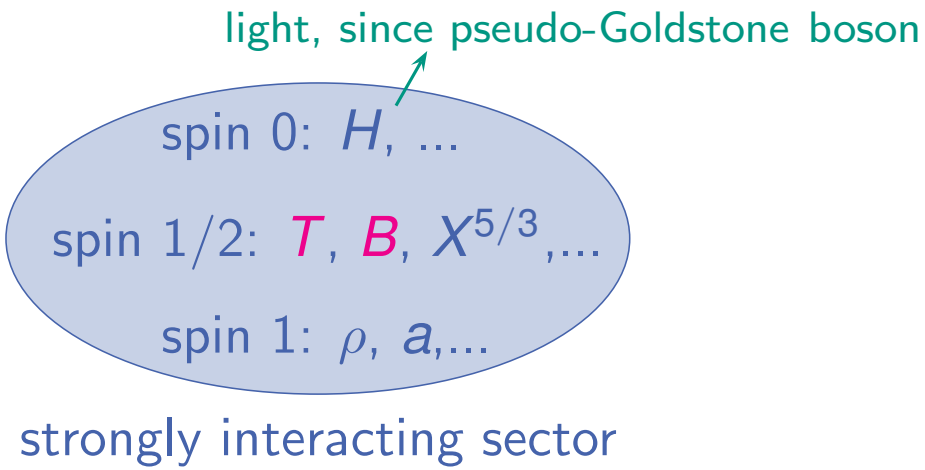
- The question must be answered in concrete models.
- Resonant production in *s* channel, with new resonance predominantly decaying to Higgs bosons
  $\rightarrow$ large increase in cross section
  $\rightarrow$ distinction from SM possible
- Here other case: No *s* channel resonance, just coupling modifications and new couplings
  $hhf\bar{f}$ coupling can lead to large increase of cross section [RG, Mühlleitner '10; Contino, Ghezzi, Moretti, Panico, Piccinini, Wulzer '12; Dib, Rosenfeld, Zerwekh '05]
  $\rightarrow$ Composite Higgs Models.

Composite Higgs models (CHM)

u	c	t
d	s	b
e^-	μ^-	τ^-
ν_e	ν_μ	ν_τ

elementary particles

gluon g
photon γ
$W^\pm, Z$



- Top quark t can mix with fermionic resonances of the strongly-interacting sector ("top partner" T)
- Higgs boson is pseudo-Goldstone boson of spontaneous symmetry breaking of global symmetry at scale f
  Here: $SO(5) \times U(1)/SO(4) \times U(1)$
- global symmetry explicitly broken $\rightarrow$ Higgs potential generated by quantum corrections

Composite Higgs Models

- Description by non-linear σ-model

$$\mathcal{L} = \frac{f^2}{2}(D_\mu \Sigma)^T (D^\mu \Sigma), \qquad \text{in unitary gauge:} \quad \Sigma = (0, 0, 0, \sin H/f, \cos H/f)$$

  $\sin H/f$ and $\cos H/f$ lead to non-linear Higgs couplings to gauge bosons and fermions

- Parameter $\xi = \frac{v^2}{f^2} = \sin \frac{\langle H \rangle}{f}$ describes departure from SM

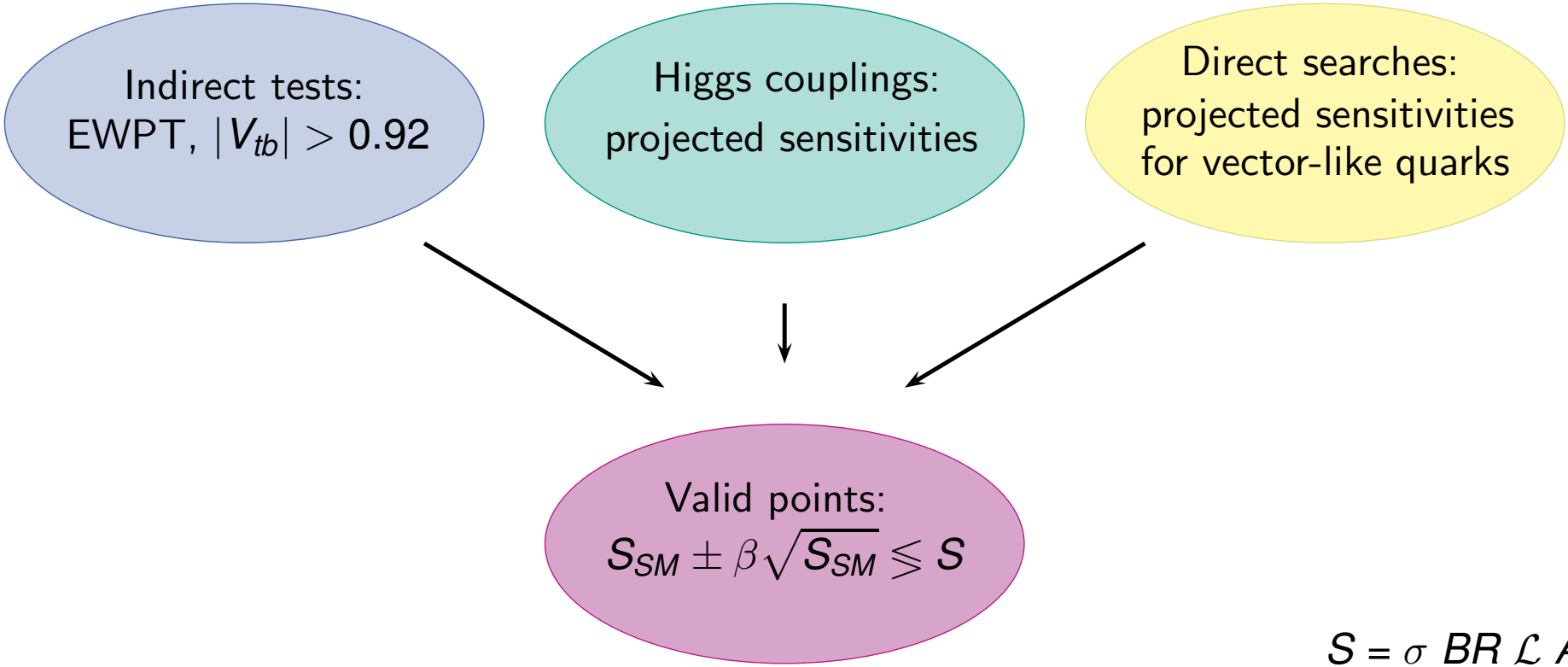
- Fermionic resonances
  Explicit breaking of global symmetry by linear couplings of SM fermions to strong sector

$$\mathcal{L} = -\left(\lambda_L \bar{q}_L Q_R + \lambda_R \overline{\tilde{T}}_L t_R\right)$$

  Leads to mixing of elementary quark with strong sector, mass generation for the top quark.

- MCHM10: Antisymmetric representation (10) contains both bottom and top partner.

Can New Physics be seen for the first time in HH production?



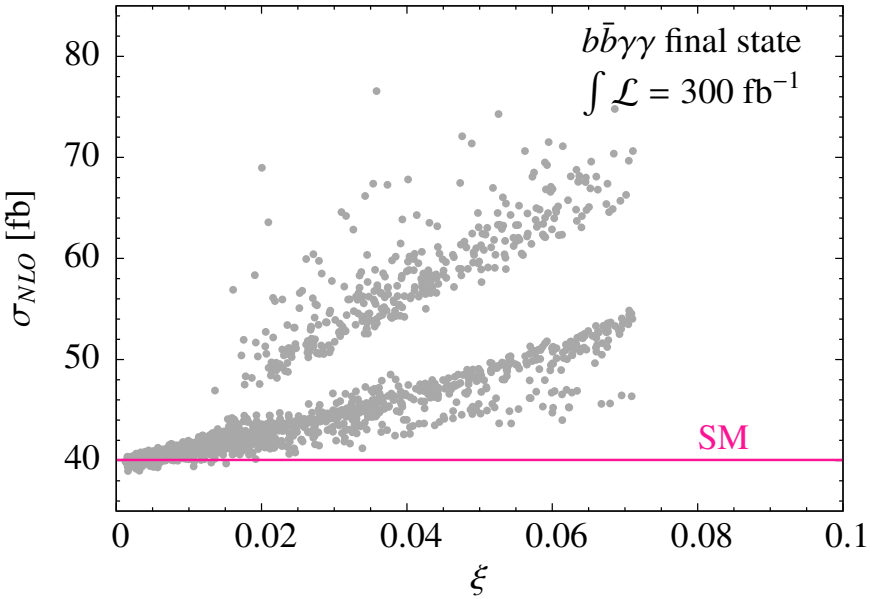
$S = \sigma\ BR\ \mathcal{L}\ A$

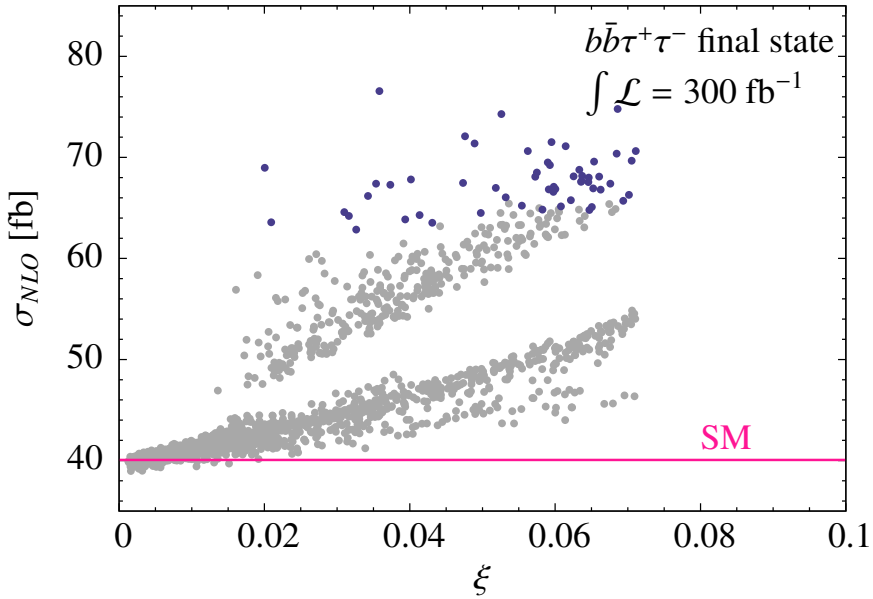
Consider two final states: $b\bar{b}\tau^+\tau^-$ and $b\bar{b}\gamma\gamma$

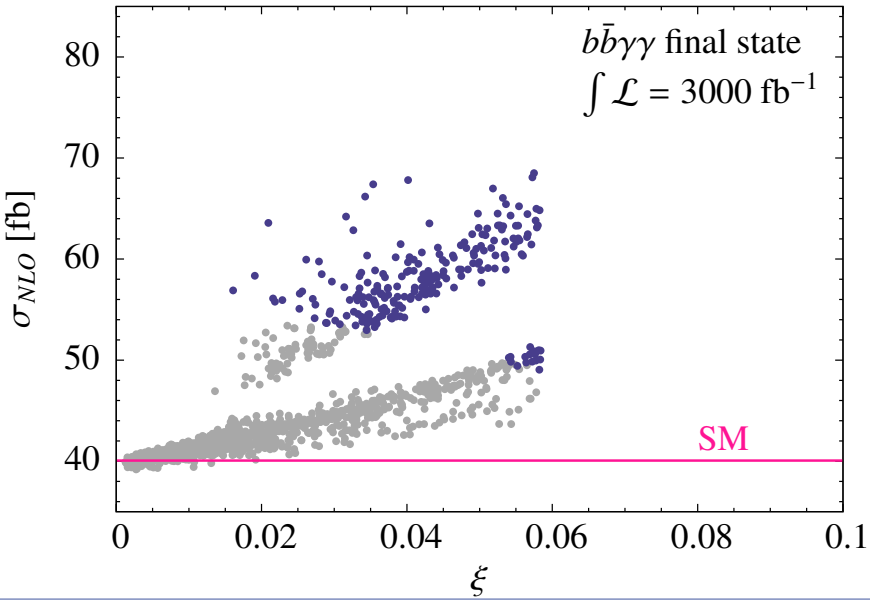
EWPTs from [Gillioz, RG, Kapuvari, Mühlleitner '14]
Higgs coupling sensitivity from [Englert, Freitas, Mühlleitner et. al'14]
Vector-like quarks, projected sensitivities $m \lesssim 1.5$ TeV

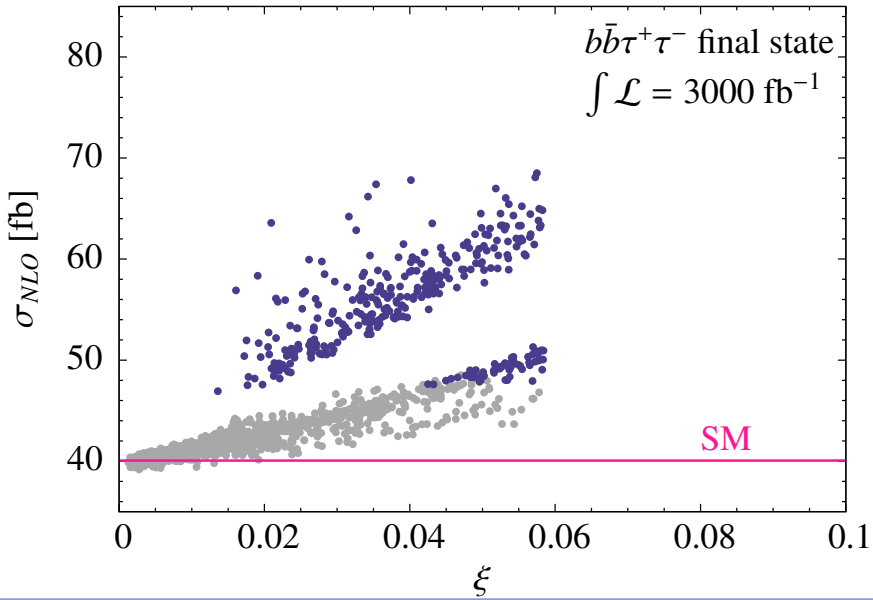
Results

[RG, Mühlleitner, Spira '16]









Conclusion

- Higgs pair production not only interesting for a measurement of trilinear Higgs self-coupling but New Physics can modify it in many different ways.
- In simple scalar extensions the trilinear Higgs self-coupling can be indirectly constrained.
- Here: Singlet $-0.9 < g_{hhh}/g_{hhh}^{SM} < 5.0$
- In certain models (with large $hhf\bar{f}$ coupling) New Physics might even be seen for the first time in Higgs pair production.

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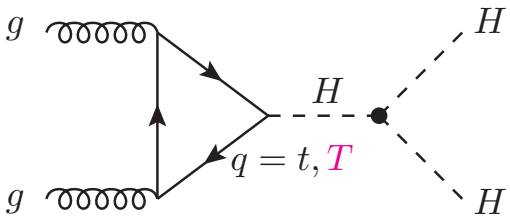
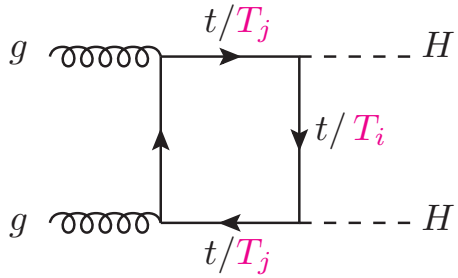
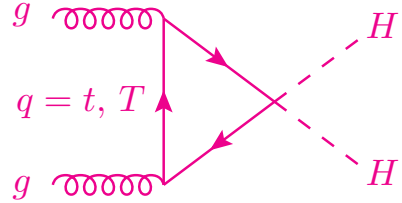
Thanks for your attention!

Higgs pair production in Composite Higgs Models







Model with pure Higgs non-linearities: Results

		$\sigma_{b\bar{b}\gamma\gamma}$ [fb]	$\Delta_{3\sigma}$	$\sigma_{b\bar{b}\tau^+\tau^-}$ [fb]	$\Delta_{3\sigma}$
MCHM4	$\xi = 0.12$ (LHC20.3)	0.119	no	3.26	no
	$\xi = 0.076$ (LHC300)	0.114	no	3.13	no
	$\xi = 0.051$ (LHC3000)	0.112	no	3.07	no
MCHM5	$\xi = 0.15$ (LHC20.3)	0.315	yes	5.35	yes
	$\xi = 0.068$ (LHC300)	0.175	no	3.96	no
	$\xi = 0.015$ (LHC3000)	0.119	no	3.14	no

$\longrightarrow$ MCHM4:
we cannot expect to see any significant deviation in *HH* production
$\longrightarrow$ MCHM5:
we will first see new physics in form of deviations in Higgs coupling measurements