

Christoph Englert

## The Quest for a natural Higgs

Higgs-Maxwell Workshop The Royal Society of Edinburgh 26.02.2014



`t Hooft, "Under the Spell of the Gauge Principle"



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- **Import of this in 1964** [Higgs `64] [Brout, Englert `64] [Guralnik, Hagen, Kibble `64]
- non-linear realisation of gauge symmetry in a Yang Mills+scalar sector is compatible with ⟨H⟩ ≠ 0
  r "spontaneous" symmetry breaking
- massive gauge bosons, but no ghost problems at small distances

renormalizability, unitarity



SM seemingly complete after July 4th 2012 and evidence for  $J^{CP}=0^+$  and couplings to (longitudinal) massive gauge bosons



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#### Higgs properties sui generis:

particle relates to unitarity conservation and an excitation of an isotropic and translationally invariant background field.

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➡ ultraviolet catastrophe of the 21<sup>st</sup> century











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- bosonic and fermionic thresholds enter differently, RS dependent
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  - Supersymmetry: "play with particle content"

enhanced external symmetry removes sensitivity to the UV,

good properties persist when SUSY is softly broken, only logarithmic sensitivity to UV scales reintroduced





## Stabilizing Hierarchies: Conformal dynamics

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Coleman-Weinberg sector generates scale dynamically and transmits it via marginal couplings

+ "resummation"

[Meissner, Nicolai `08] [CE, Jaeckel, Khoze Spannowsky `13] [Abel, Mariotti `13]

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t

H

H

 $Z, W^{\pm}$ 

H

H

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- no sensitivity to the quartic coupling at present and future colliders.
- look at the trilinear Higgs coupling and hope for the best!
- large backgrounds, small signal, but feasible in  $b\bar{b}\tau\tau$ ,  $b\bar{b}\gamma\gamma$
- boosted regime unavoidable for  $b\bar{b} au au$





## The Higgs quartic gauge couplings

• directly accessible in WBF  $pp \rightarrow hhjj$ ,  $\mathcal{O}(fb)$  cross section

t,b

 gluon fusion contribution beyond EFT calculations completely unknown until recently and key to this channel

ZW

	Signal with $\zeta \times \{g_{WWhh}, g_{ZZhh}\}$			Background	
	$\zeta = 0$	$\zeta = 1$	$\zeta = 2$	$tar{t}jj$	Other BG
tau selection cuts	1.353	0.091	0.841	3101.0	57.06
Higgs rec. from taus	1.352	0.091	0.840	683.5	31.92
Higgs rec. from $b$ jets	0.321	0.016	0.207	7.444	0.303
2 tag jets/re-weighting	0.184	0.010	0.126	5.284	0.236
incl. GF after cuts/re-weighting	0.273	0.099	0.214	5.284	0.236

#### challenging, but we'll keep working on it!



[Dolan, CE, Greiner, Spannowsky`13]

## The top-Higgs coupling

• of course  $t\bar{t}h$  production

[Soper, Spannowsky `12, `14] [Artoisenet et al. `13]

[Farina et al. `12] [Biswas et al. `13]

[Ellis et al. `13]...

but also thj production



- angular observables! [CE, Re`14]
- even in rare (and clean) final states  $c_t \gtrsim 0.5$  at >95% confidence level

- cross sections are small but highly sensitive through interference
- somewhat reminiscent of radiation zeros in  $W^{\pm}\gamma$  [Fisher, Becker, Kirkby `95]



#### What the future holds...

• obviously direct LHC measurements will have their sensitivity saturated by systematics



250 GeV linear collider full EW corrections

[Craig, CE, McCullough `13]

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- Higgs physics (& Particle Physics) is at the naturalness crossroads
- not an impasse
  - symmetry-driven model-building: TeV scale dofs?
  - good prospects to phenomenologically dissect the Higgs sector
  - "no hide" precision statements can resolve 10% tuning
  - fresh data for the first time in decades !
  - something new?