BEH Mechanism: round table

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- Higgs self-coupling
- EWK symmetry breaking mechanism
- Mass, spin and BSM decays

Higgs Boson Couplings

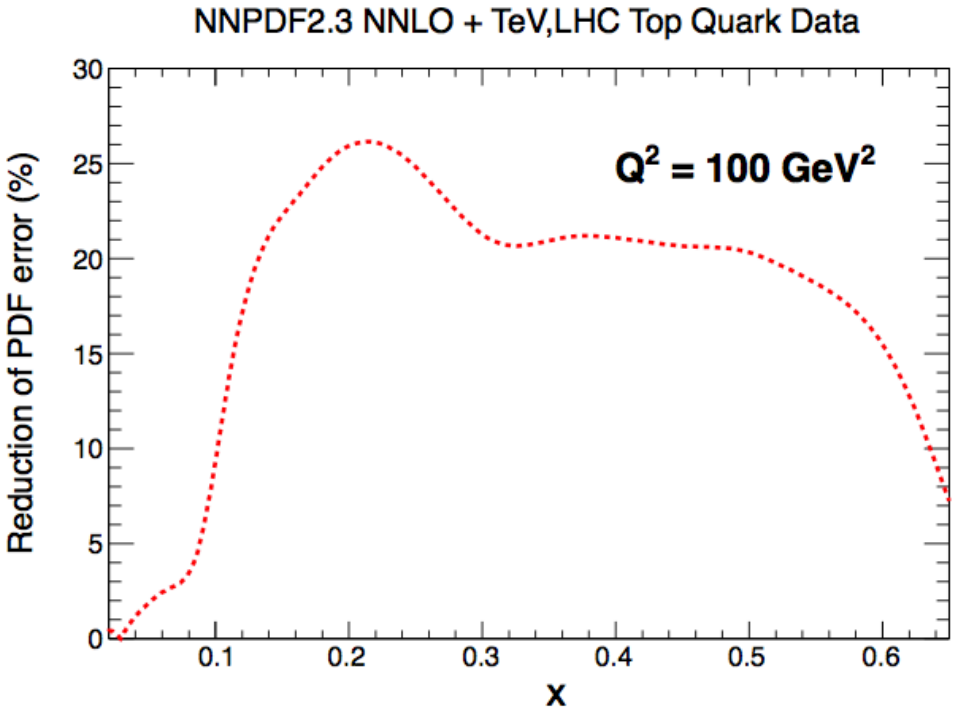
Coupling	HL-LHC	FCCee	ILC(500)	ILC(1000)	CLIC(3000)
$\sqrt{s}$, GeV	14000	240+350	250+500	+1000	++3000
L, ab^{-1}	3+3	10+2.6	0.25+0.5	0.25+0.5+1	0.5+1.5+2
k_W	2-5%	0.19%	1.2%	1.2%	2.1%
k_Z	2-4%	0.15%	1.0%	1.0%	2.1%
k_g	3-5%	0.8%	2.3%	1.6%	2.2%
k_γ	2-5%	1.5%	8.4%	4.0%	5.9%
k_μ	7%	6.2%	–	16	5.6%
$\boldsymbol{k_c}$	–	0.71%	2.8%	1.8%	2.2%
$\boldsymbol{k_\tau}$	2-5%	0.54%	2.3%	1.7%	2.5%
$\boldsymbol{k_b}$	4-7%	0.42%	1.6%	1.3%	2.1%
k_t	~5%	13%(indir.)	14%	**3.1%**	4.5%
λ	~30%	(indirect?)	83%	21%	**10%**
$\mathbf{BR_{inv}}$	≤10%	≤0.2%	0.9%	0.9%	NA
$\mathbf{\Gamma_{tot}}$	–	1.0%	5.0%	4.6%	NA

Higgs Boson Couplings

1. What precision is required for the coupling measurement?
2. Challenges for reaching *O*(1%) precision at HL-LHC:
   - Theory uncertainties: we need to reduce primarily Higgs x-section uncertainties (see also talks from Radja on exclusive H+jets calculations, and from Claude) and PDFs uncertainties → see next slides;
   - "kappa" model: current implementation is not sufficient → see next slides

Higgs Boson Couplings: PDF Uncertainties

- Example of the gluon PDF uncertainty reduction from an early study using LHC data



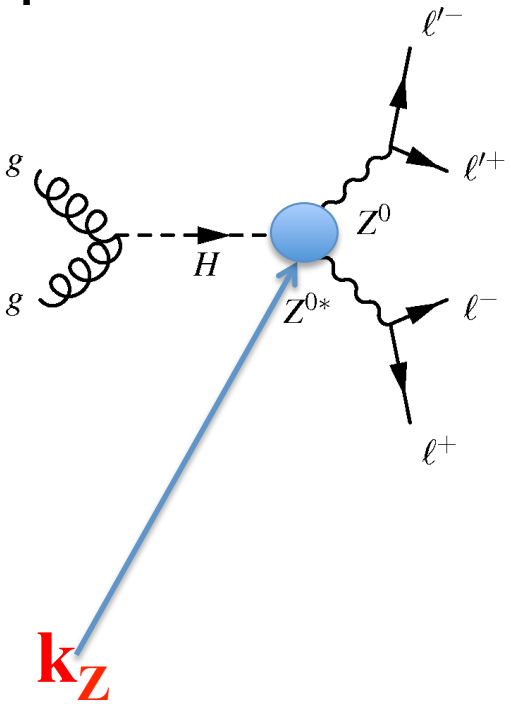
arXiv:1303.7215v3

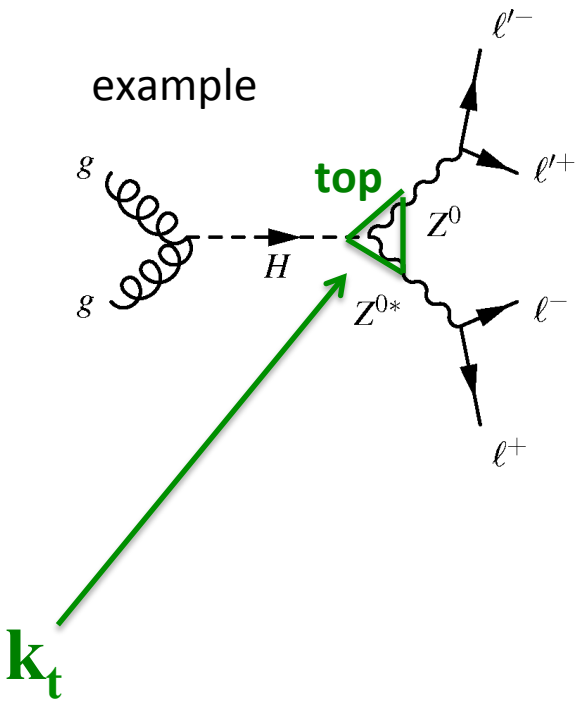
Michal Czakon,[a] Michelangelo L. Mangano,[b] Alexander Mitov[b] and Juan Rojo[b]

- relative reduction of PDF uncertainties thanks to the inclusion of **LHC** top **data** in the PDF fit

Higgs Boson Couplings: k - model

Approaching the few % accuracy on Higgs coupling accuracy, we need to extend the k-framework adopted at LHC



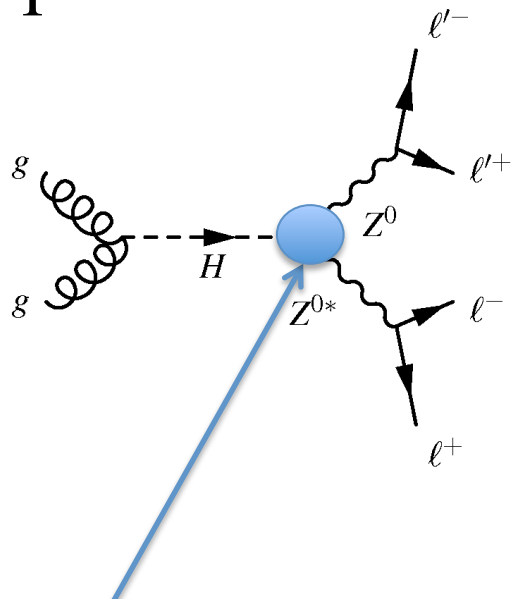


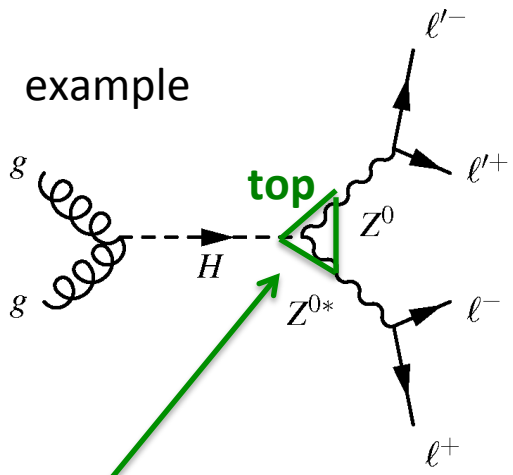
What we do today

To be evaluated/done

Higgs Boson Couplings: k - model

Approaching the few % accuracy on Higgs coupling accuracy, we need to extend the k-framework adopted at LHC



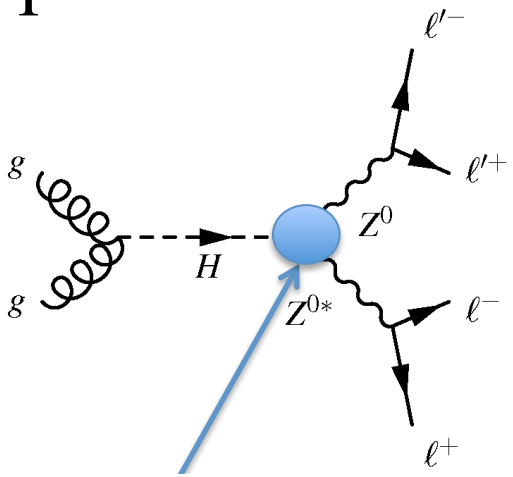


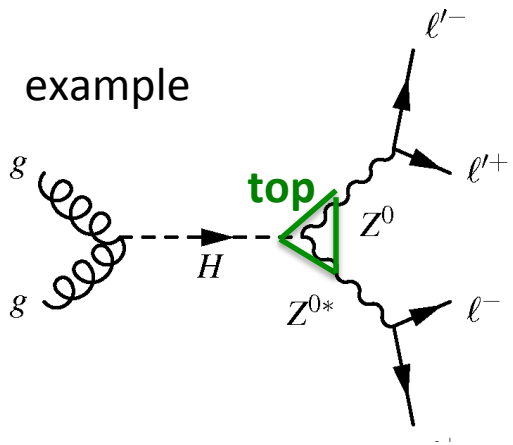
The situation is even more complex when performing BSM interpretation of the observed event rates

More diagrams need to be considered to include e.g. dimension-6 operator contributions

Higgs Boson Couplings: k - model

Approaching the few % accuracy on Higgs coupling accuracy, we need to extend the k-framework adopted at LHC





- ➔ **Important to continue the effort of the LHC Higgs Cross-Section WG: this group contributed to the Higgs boson discovery success, and it will play an important role also in future when LHC will be called to provide Higgs boson couplings with an accuracy of *O*(few %)**

Higgs boson couplings: width

- The first experimental constraints on the Higgs total width using off-shell H(125) production were presented
- CMS: PLB 736 (2014) 64, ATLAS: ATLAS-CONF-2014-042
- This technique proved to be a powerful tool in constraining Γ_H
- Observed (Expected) $4l$ and $2l2\nu$ combined results:
  - CMS:
    $\Gamma_H = 1.8^{+7.7}_{-1.8}$, $(4.2^{+13.5}_{-4.2})$, $\Gamma_H < 22$ (33) MeV, $\Gamma_H/\Gamma_{SM} < 5.4$ (8.0)
  - ATLAS:
    $\Gamma_H/\Gamma_{SM} = 0.3^{+1.4}_{-0.3}$, $\Gamma_H/\Gamma_{SM} < 5.7$ (8.5), $4.8 < \Gamma_H^{95\%}/\Gamma_{SM} < 7.7$ $(7.0 < \Gamma_H^{95\%}/\Gamma_{SM} < 12.0)$
  - Very similar results from the 2 experiments
- 3 orders of magnitude improvement wrt to direct limits
- The CMS results hold for BSM models as long as the couplings ratios between on and off-shell contributions are unchanged
- Model indipendent constraint on $\mu_{\text{off-shell}} < 6.7$ (7.9) from ATLAS
- The presence of anomalous HVV coupling would enhance the off-shell contributions, making the constraint tighter

Higgs boson couplings: width

3. What the "ultimate" determination of the Higgs boson width (using all bosonic channels) could be?
4. Can we use this determination to extract high accuracy absolute couplings in a ~ **model independent framework**?

- it will be important for the hep community to have results as soon as possible also on run-1 ATLAS+CMS Higgs combination

Higgs self-coupling

- Higgs self-coupling is one of the most important Higgs property we need to access in order to fully test the validity of the SM and to search for New Physics (directly and/or directly)

HH – Higgs self-coupling

J.F. Zurita

Scalar boson (H) potential: self couplings

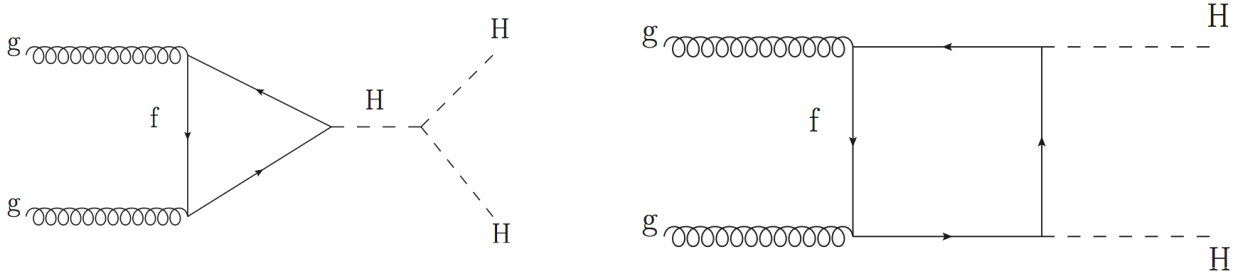
After EWSB : $V(H) = \frac{1}{2}M_H^2 H^2 + \lambda_{HHH} v H^3 + \frac{1}{4}\lambda_{HHHH} H^4 .$

- Single boson: $M_H \approx 125$ GeV ⟶ Is it the SM Higgs? Need to measure its properties.
- HHH prod. very difficult @ HC $\sigma_{HHH} = 0.06(9.5)$ fb 14 TeV LHC (200 TeV VLHC) .

Plehn, Rauch, Phys. Rev D 72, 053008.

↘

Linear Collider? TESLA TDR (hep-ph/0106315) ~ 1000 fb^{-1} for 20% accuracy.



2 topologies, each with 2 Lorentz structures (1 and 2):

$$\sigma_{LO} = |\alpha_1 C_{tri}^{(1)} + \beta_1 C_{box}^{(1)}|^2 + \gamma_1^2 |C_{box}^{(2)}|^2$$

SM: $\alpha_1 = y_t \lambda$, $\beta_1 = \gamma_1 = y_t^2$

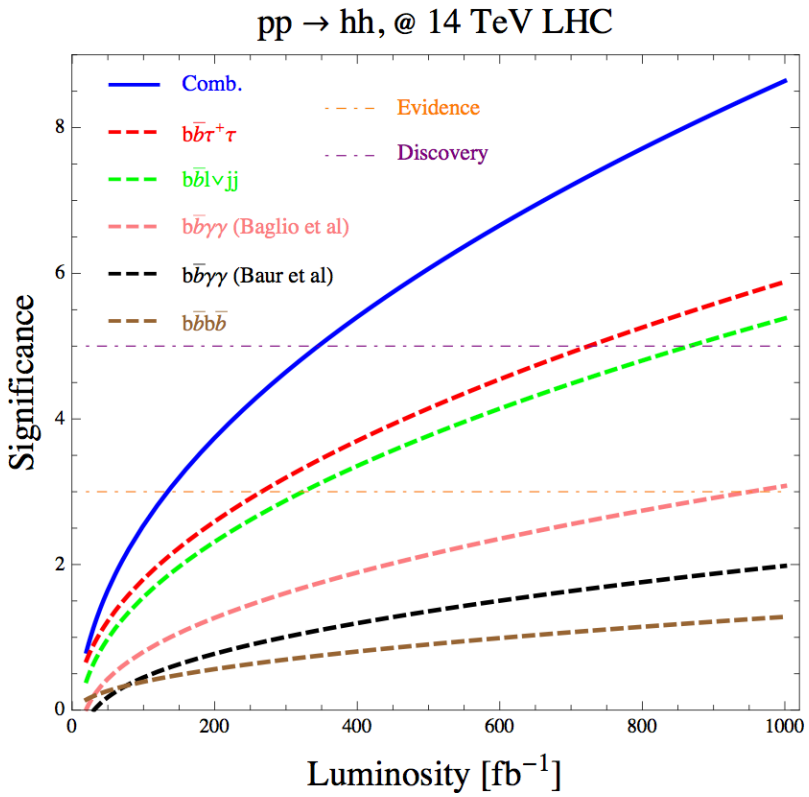
HH – Higgs self-coupling

- Compilation and combination by JF Zurita, based on available public results from several early studies; analyses from ATLAS and CMS on going, hopefully preliminary results will be relased early
- These early estimates are (in my view) very optimistic!

HL-LHC

Expected events

bbWW	30000
bbττ	9000
WWWW	6000
γγbb	320
γγγγ	1



HH – Higgs self-coupling

- One of the most important physics processes for the HL-LHC physics programme
- At the same time is one of the most challenging experimental (and theoretical) process at HL-LHC and at future (e+e-) colliders
  - HH demands O(1 TeV) collision energy for e+e- machines
  - HH rates at High-Energy hh colliders are much larger than at LHC (but detailed investigation of background is needed)
- Regardless of the (hopefully) approval of future machines, HL-LHC will be for a long time the only place where to investigate HH physics

Higgs Higgs self-coupling

5. Higgs self-coupling is one of the most important Higgs property we need to access in order to fully test the validity of the SM and hence to probe for New Physics
6. Is it possible to be in a scenario where Higgs couplings are ~ those from SM **but** the Higgs potential is not?

EWK & Unitarization

7. Complete the study of the Electroweak Symmetry breaking and of the WW x-section unitarization: is the BEH the only mechanism? ➔ study WW scattering (possibly W_L-W_L) [for example see talk by Benjamin Grinstein];
   - Are the current available theory tools sufficient to prepare the data analysis at high LHC energy and luminosity?

Comments and Questions

MASS

8. What precision is required for the mass measurement?

SPIN

9. Spin 2: discussion started yesterday; LHC Collaborations do not exclude ALL spin-2 models, but spin-2 scenarios under physics assumptions that are well stated in the published papers

BSM Higgs decays

10. Should ATLAS and CMS start searches for non SM Higgs boson decays? [see for example arXiv:1312.4992v1]