Measurement of the HZZ tensor structure in $pp \to H \to ZZ^* \to 4\ell$ decays with the ATLAS detector

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DPG 2016 (29.02-04.03. 2016, Hamburg)

Properties of the Higgs boson

1. Spin-0: Boson is scalar particle, as predicted by the Standard Model (SM).

   ATLAS: Physics Letters B 726 (2013) 120–144

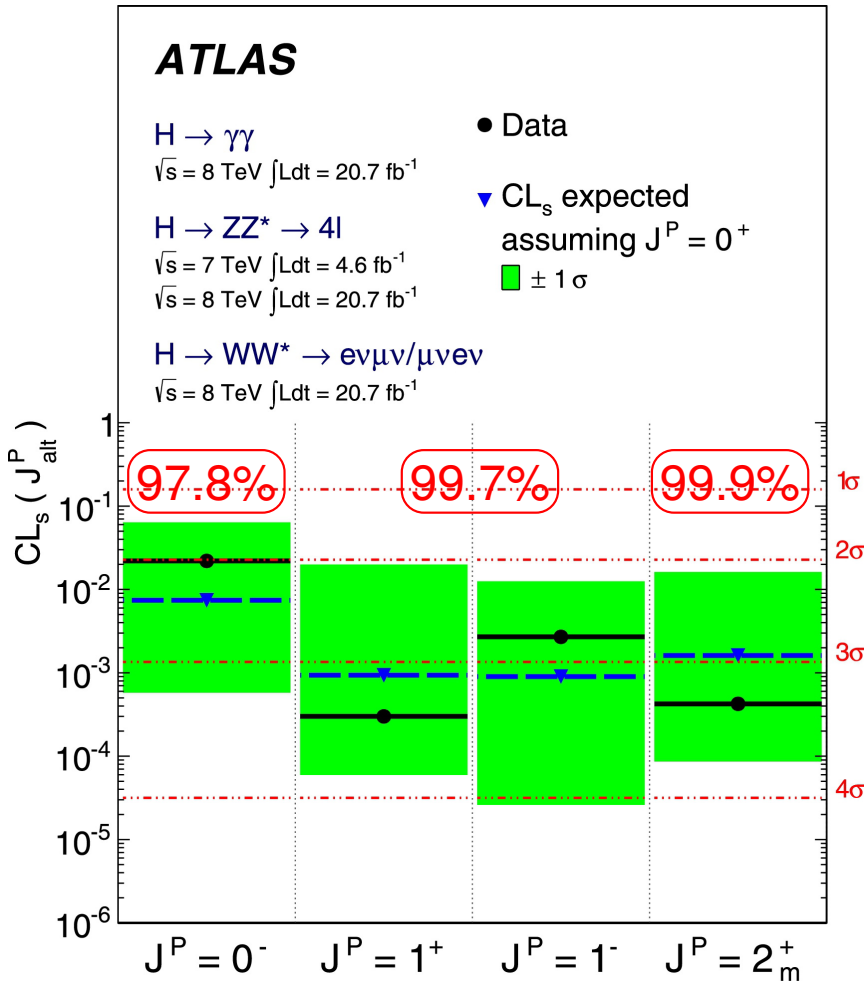
   und CMS: CMS PAS HIG-14-014

2. CP properties of the discovered boson?

   CP: Combination of parity and charge conjugation.

   - CP even eigenstate CP^+? SM
   - No CP eigenstate? Mixture of CP even and CP odd.

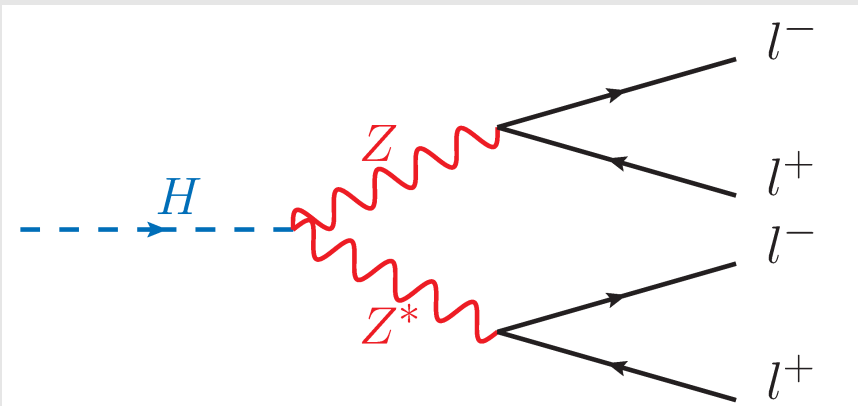
   → CP violation in Higgs sector could be explanation for matter antimatter asymmetrie.



- Additional, non-SM couplings in HVV vertex? „Anomalous couplings“

The $H \to ZZ^* \to 4\ell$ decay channel

Event signature $H \to ZZ^* \to 4\ell$ with $\ell = e, \mu$:



- Small branching ratio, but clean signal

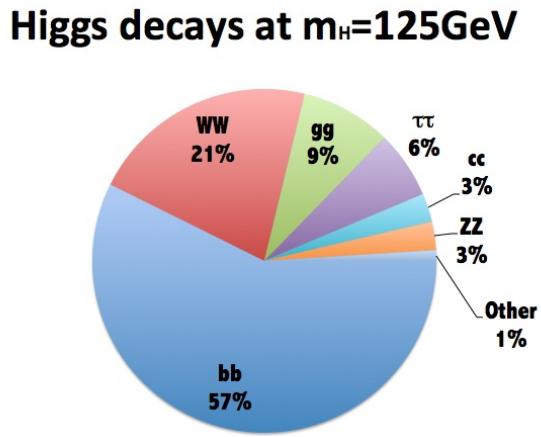


Abbildung: *

http://www.quantumdiaries.org/wp-content/uploads/2012/06/pie_chart.jpg

- Backgrounds
  1. Irreducible SM ZZ^*
  2. Reducible $Z + jets$

- Four final state leptons can be fully reconstructed by the detector:
  $\Rightarrow H \to ZZ^* \to 4\ell$ Channel suited for property measurements

CP measurement in the $H \to ZZ^* \to 4\ell$ channel

- Theoretical basis: EFT implemented in Higgs characterisation model (MadGraph5_aMC@NLO)

$$\mathcal{L}_0^V = \Big\{ \cos(\alpha)\kappa_{\rm SM} \left[\tfrac{1}{2} g_{HZZ} Z_\mu Z^\mu + g_{HWW} W_\mu^+ W^{-\mu}\right] - \tfrac{1}{4}\tfrac{1}{\Lambda}\left[\cos(\alpha)\kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + \sin(\alpha)\kappa_{AZZ} Z_{\mu\nu}\tilde{Z}^{\mu\nu}\right] - \tfrac{1}{2}\tfrac{1}{\Lambda}\left[\cos(\alpha)\kappa_{HWW} W_{\mu\nu}^+ W^{-\mu\nu} + \sin(\alpha)\kappa_{AWW} W_{\mu\nu}^+ \tilde{W}^{-\mu\nu}\right]\Big\} X_0.$$

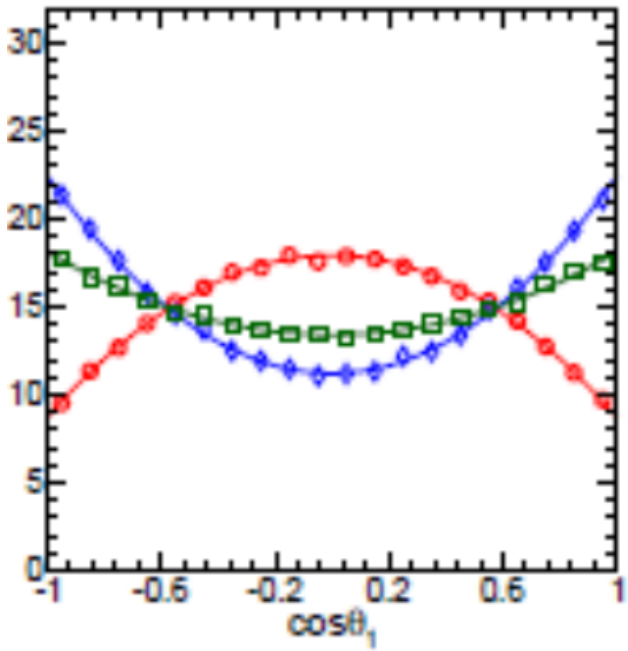
SM CP-even
BSM CP-even
BSM CP-odd

- CP violation: Mixture of CP even and CP odd.

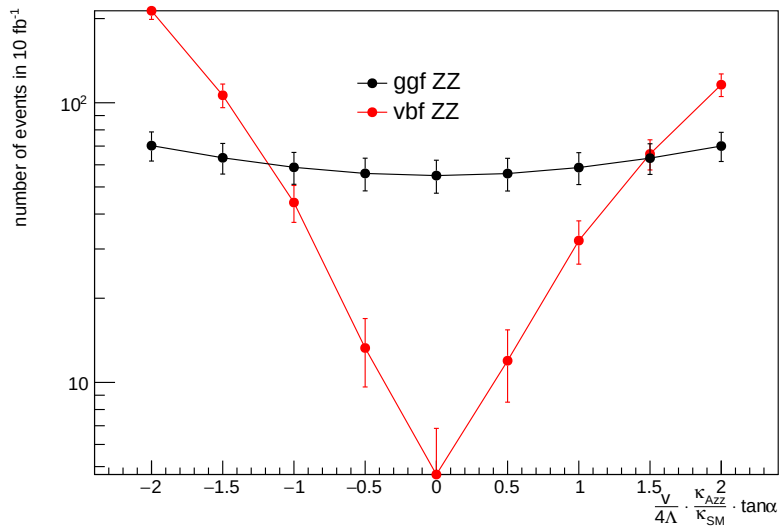
$\Rightarrow$ Search for non-SM admixtures in $H \to ZZ^* \to 4\ell$ decays.

Observables sensitiv to BSM admixtures in $H \to ZZ^* \to 4\ell$

Shape information (used in Run-1)



Rate information (planned to be added in Run-2)

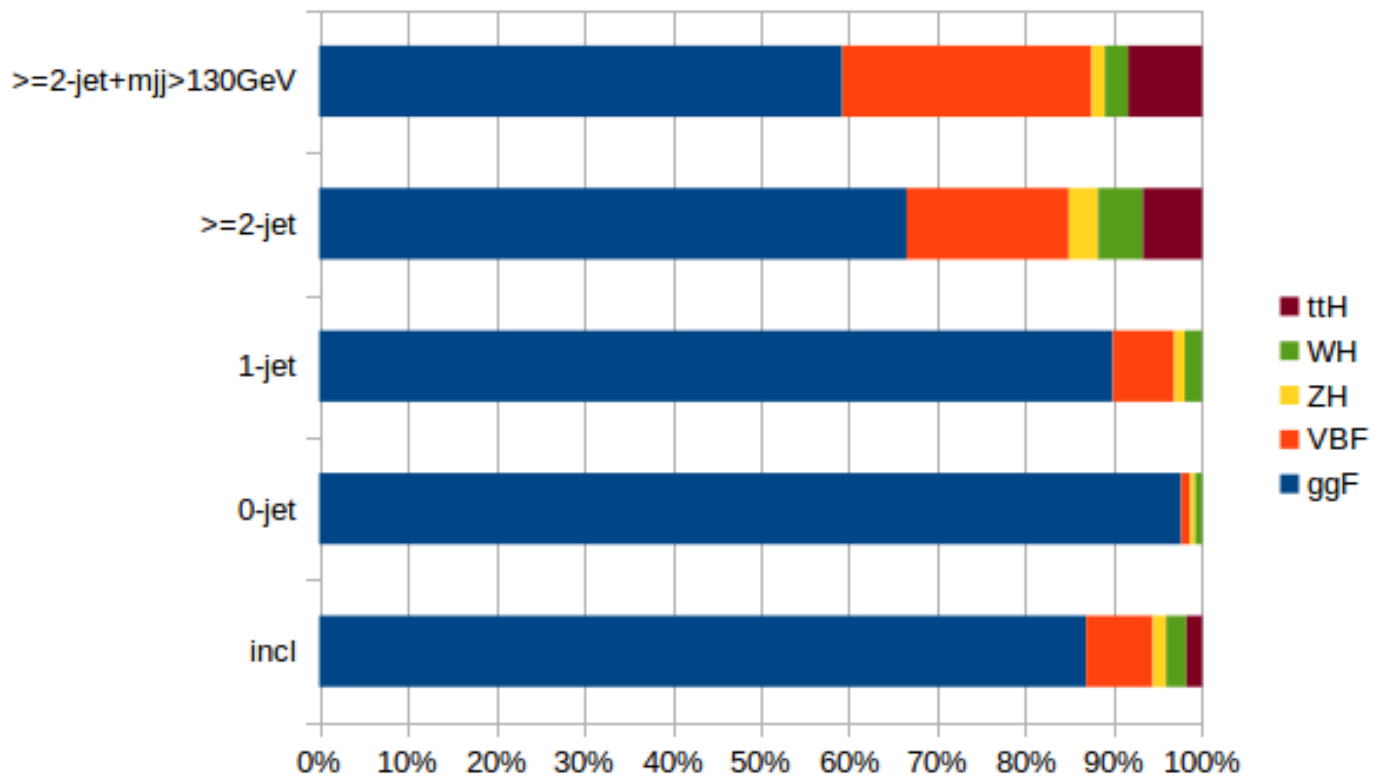


- $H \to ZZ^* \to 4\ell$ statistically limited: Which observables are available at a dataset of 10 fb^{-1} (LHC dataset expected in summer 2016)?

Expected Yields per decay channel for $\mathcal{L} = 10\,\text{fb}^{-1}$ and $p_{T,j} > 25$ GeV

****Events weight all:****

	4mu	4e	2mu2e	2e2mu	all
1 - all	5.5532120494	3.1357608068	3.3040145756	3.6708580523	15.6645036604
2 - masscut	5.29718151	2.9022997275	3.1158061013	3.4280807881	14.7437749995
3 - 0-jet	2.1331071601	1.1671558112	1.2290512989	1.4434581774	5.9727395387
4 - 1-jet	1.7164158118	0.9851132512	1.0498209462	1.1236413897	4.8746922278
5 - >=2-jet	1.447969676	0.7499857894	0.8369308646	0.8612145744	3.8958944764
6 - >=2-jet+mjj>130GeV	0.8263282444	0.4423183359	0.4802831354	0.504548895	2.2535055362



Fit model for $\mathcal{L} = 10\,\text{fb}^{-1}$

- Shape analysis in 0-jet category not possible with statistics at $\mathcal{L} = 10\,\text{fb}^{-1}$

$\Rightarrow$ Combined fit of expected number of events in 0-jet and 2-jet categories: {0-jet} x {2-jet}

- Number of expected events for ggF and VBF are a function of EFT parameters:

  $N_{\text{ggF}} = f(cos(\alpha), \kappa_{SM}, \kappa_B SM)$

  $N_{\text{VBF}} = f(cos(\alpha), \kappa_{SM}, \kappa_B SM)$
- Assumption: 0-jet category consists only of ggF events

  $N_{\text{0-jet}} = N_{\text{0-jet,ggF}}$
- Assumption: In 2-jet category ttH scales as ggF, and VH scales as VBF

  $N_{\text{2-jet}} = N_{\text{2-jet,ggF+ttH}} + N_{\text{2-jet,VBF+VH}}$

- Simplified model: Only looking at SM and BSM cp odd mixtures; no backgrounds added so far

BSM MC truth samples

- Generator: MG5 at LO interfaced to Pythia8 for BSM sample production

ggF	κ_{Hgg}	κ_{SM}	κ_{Azz}	$\cos\alpha$	σ X BR [pb]
hggsm	1.0	1.0	0.0	1.0	0.00205
hggazz	$\sqrt{2}$	1.0	13.938	$\frac{1}{\sqrt{2}}$	0.00114
hggsmazz	$\sqrt{2}$	$\sqrt{2}$	13.938	$\frac{1}{\sqrt{2}}$	0.002156

- ggF cross section at NNLO QCD and NLO EW from LHC cross section working group: 43 pb

→ K-factor LO MG5 to LHXSWG of 2.7

VBF	κ_{SM}	$\kappa_{Azz} = \kappa_{Aww}$	$\cos\alpha$	σ X BR [pb]

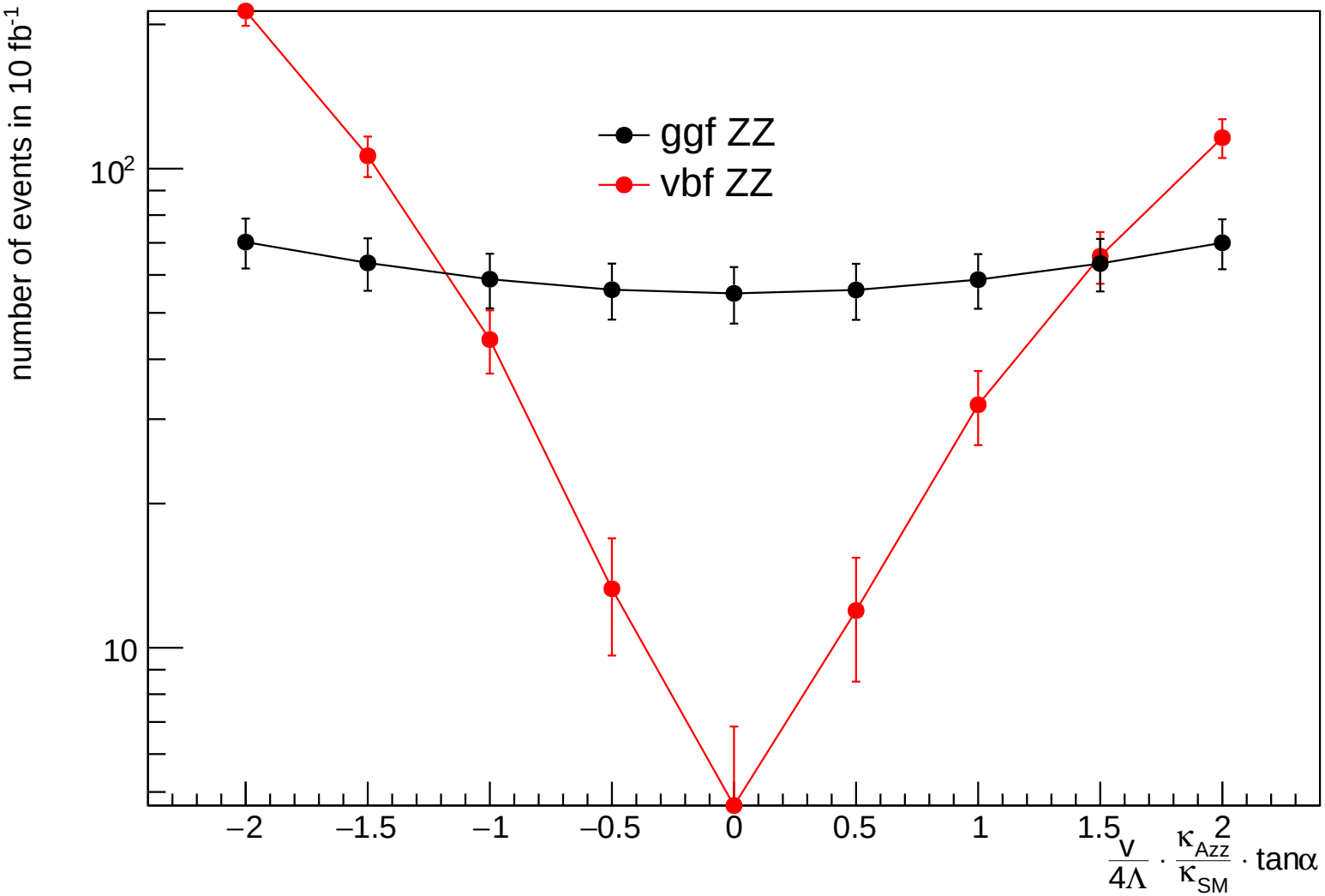
- VBF cross section at NNLO QCD and NLO EW from LHC cross section working group: 3.7 pb

→ K-factor LO MG5 to LHXSWG of 2.7

- All BSM samples will be scaled with $\frac{N_{SM,PowHeg}}{N_{SM,MG5}}$

⇒ This assumes that the scale factor for LO to NNLO production and $\frac{\epsilon_{SM,reco}}{\epsilon_{SM,truth}}$ is consant for all BSM samples

Final distribution of expected number of events: dummy



Summary

- Tensor structure measurement has information available from shape and rate predictions
- Simplified model shown in order to extract BSM parameter in the $H \to ZZ^* \to 4\ell$ channel with an available dataset of $\mathcal{L} = 10\,\text{fb}^{-1}$
- Only rate information used so far and backgrounds neglected
- Plan: Use model in order to extract sensitivity to different BSM parameters in $H \to ZZ^* \to 4\ell$