# Weekly Updates

Ryuta

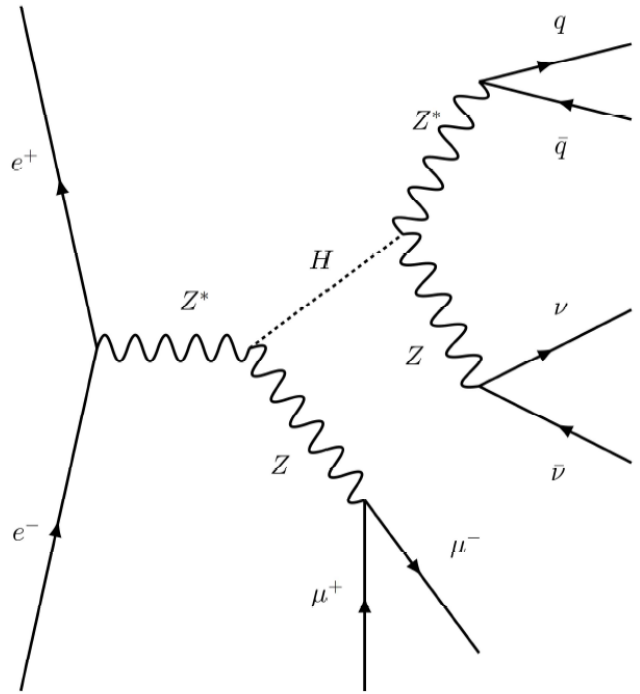
04/22/2020

# Updates on the draft

- update the feynman diagram by a drawing tool

  -> have tried  from https://feynman.aivazis.com

  … some functions (“text” button, “+” signal) seem to be not working ? which prevented (me) to make it lastweek,
  at any rate, finally the diagram is made !

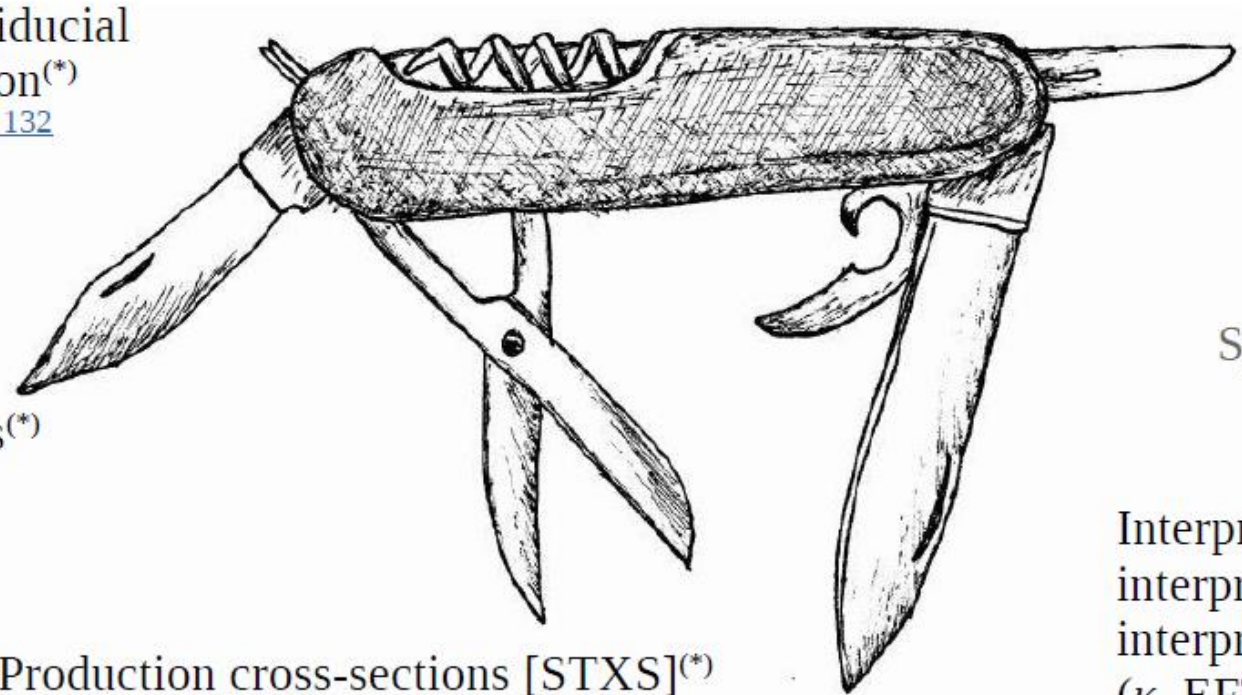


# Investigation around HZZ topics from the recent LHC results

# The "Swiss army knife": $H \to ZZ^*$

(*) ATLAS-CONF-2019-025

Inclusive fiducial cross-section(*)
JHEP 10 (2017) 132



Mass
Phys. Lett. B 784 (2018) 345

(Double) differential fiducial cross-sections(*)
JHEP 10 (2017) 132

Spin/CP

Interpretations, interpretations, interpretations… ($\kappa$, EFT, PO,..)

Production cross-sections [STXS](*)
JHEP 03 (2018) 095

*Baseline/reference: previously published results*



-- I have quickly viewed those materials

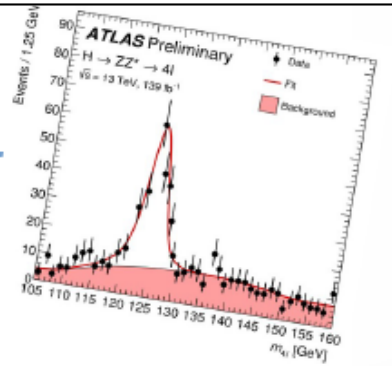
# Summary

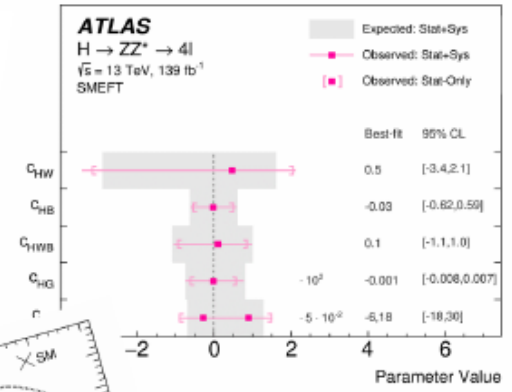
New Higgs measurements from ATLAS using the full Run-2 dataset

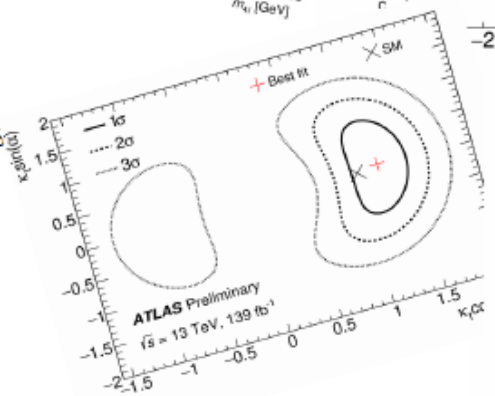
Some highlights:

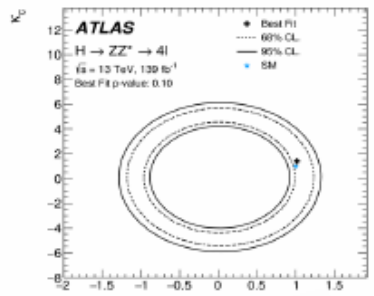
- $H \to ZZ^*$ **mass measurement** using new per-event resolution method → ***Total unc.: 1.6‰***
- *Indirect* constraint on ***c*-quark Yukawa coupling** from differential Higgs boson momentum measurement in $H \to ZZ^*$
- Extract EFT limits from $H \to ZZ^*$ STXS measurement, taking acceptance effects into account
- Search for **CP-violation in top-Yukawa couplings** using $ttH+tH$ production → $|\alpha| > 43°$ ***excluded at the 95% CL; pure* CP-odd at 3.9σ**
- Most stringent **limit on *tH* production:** ***< 12 x SM prediction at the 95% CL***
- **Observation of $ZH(\to bb)$ production**
- **Direct measurement of $VH(\to bb)$ production for $p_T(V) > 400$ GeV**

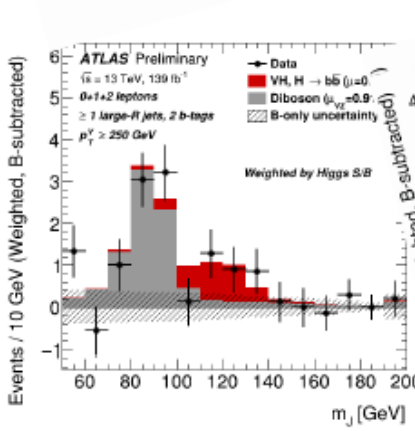
**All measurements in good agreement with the SM prediction**

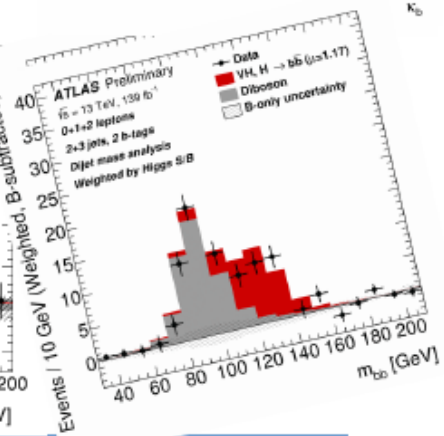





-- summary page from the previous slide

Phys. Lett. B 784 (2018) 345
DOI: 10.1016/j.physletb.2018.07.050

# Measurement of the Higgs boson mass in the $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$ channels with $\sqrt{s} = 13$ TeV $pp$ collisions using the ATLAS detector

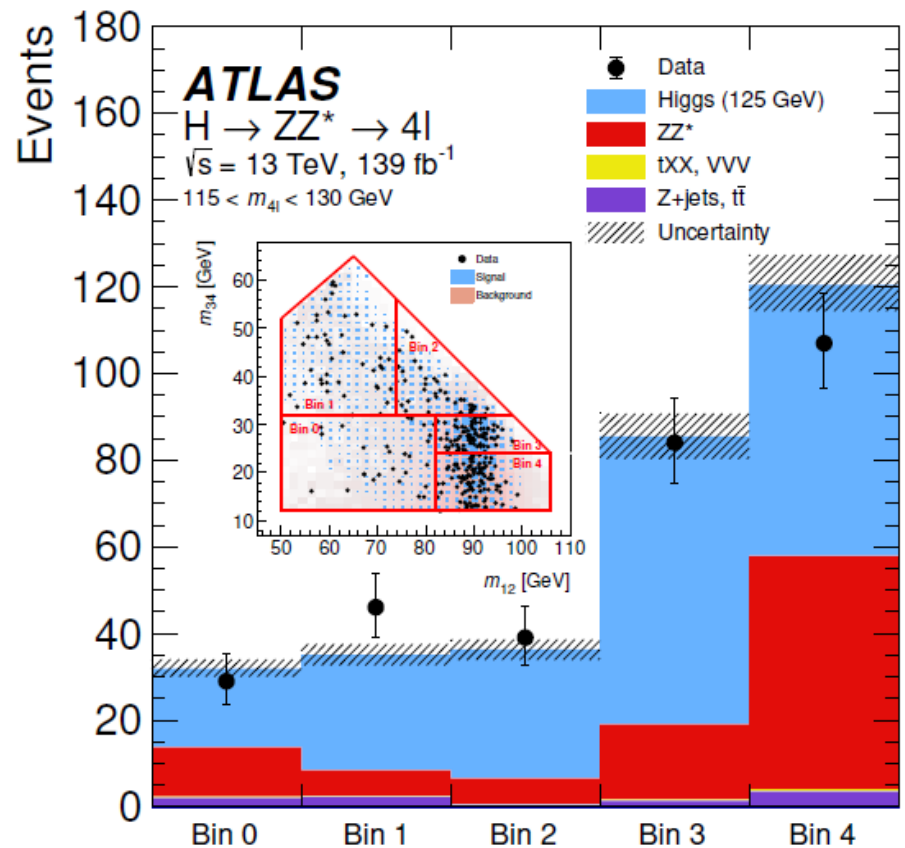
## Contents



Submitted to: EPJC

# Measurements of the Higgs boson inclusive and differential fiducial cross sections in the $4\ell$ decay channel at $\sqrt{s} = 13$ TeV

arXiv:2004.03969v2 [hep-ex] 9 Apr 2020




$m_{12}$ vs. $m_{34}$

# Higgs boson production cross-section measurements and their EFT interpretation in the $4\ell$ decay channel at $\sqrt{s}$ =13 TeV with the ATLAS detector

arXiv:2004.03447v1 [hep-ex] 7 Apr 2020

roughly, the statistics of this channel with 139 $fb^{-1}$ is

N(signal) ~ 200

N(background) ~ 100

Table 9: The expected and observed confidence intervals at 68% and 95% CL on the SMEFT Wilson coefficients for an integrated luminosity of 139 $fb^{-1}$ at $\sqrt{s}$ = 13 TeV. Only one Wilson coefficient is fitted at a time while all others are set to zero.

| EFT coupling | Expected | | Observed | | Best-fit | Best-fit |
|---|---|---|---|---|---|---|
| parameter | 68% CL | 95% CL | 68% CL | 95% CL | value | $p$-value |
| $c_{HG}$ | [−0.004, 0.004] | [−0.007, 0.008] | [−0.005, 0.003] | [−0.008, 0.007] | −0.001 | 0.79 |
| $c_{uH}$ | [−8, 20] | [−14, 26] | [−12, 6] | [−18, 30] | −6, 18 | 0.50 |
| $c_{HW}$ | [−1.6, 0.9] | [−2.9, 1.6] | [−1.5, 1.3] | [−3.4, 2.1] | 0. | |
| $c_{HB}$ | [−0.43, 0.38] | [−0.62, 0.60] | [−0.42, 0.37] | [−0.62, 0.59] | −0.0 | |
| $c_{HWB}$ | [−0.75, 0.63] | [−1.09, 0.99] | [−0.71, 0.63] | [−1.06, 0.99] | 0. | |
| $c_{H\tilde{G}}$ | [−0.022, 0.022] | [−0.031, 0.031] | [−0.019, 0.019] | [−0.029, 0.029] | 0.00 | |
| $c_{u\tilde{H}}$ | [−26, 26] | [−40, 40] | [−37, 37] | [−50, 50] | ±2 | |
| $c_{H\tilde{W}}$ | [−1.3, 1.3] | [−2.1, 2.1] | [−1.5, 1.5] | [−2.4, 2.4] | ±0. | |
| $c_{H\tilde{B}}$ | [−0.39, 0.39] | [−0.57, 0.57] | [−0.37, 0.37] | [−0.56, 0.56] | 0.0 | |
| $c_{H\tilde{W}B}$ | [−0.71, 0.71] | [−1.05, 1.05] | [−0.69, 0.69] | [−1.03, 1.03] | 0.0 | 1.00 |

$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{C_i^{(d)}}{\Lambda^{(d-4)}} O_i^{(d)} \quad \text{for } d > 4.$$

This factor(s) is $c_{HG}$, etc.

| CP-even | | | CP-odd | | |
|---|---|---|---|---|---|
| Operator | Structure | Coeff. | Operator | Structure | Coeff. |
| $O_{uH}$ | $HH^\dagger \bar{q}_p u_r \check{H}$ | $c_{uH}$ | $O_{uH}$ | $HH^\dagger \bar{q}_p u_r \check{H}$ | $c_{\tilde{u}H}$ |
| $O_{HG}$ | $HH^\dagger G^A_{\mu\nu} G^{\mu\nu A}$ | $c_{HG}$ | $O_{H\tilde{G}}$ | $HH^\dagger \tilde{G}^A_{\mu\nu} G^{\mu\nu A}$ | $c_{H\tilde{G}}$ |
| $O_{HW}$ | $HH^\dagger W^I_{\mu\nu} W^{\mu\nu I}$ | $c_{HW}$ | $O_{H\tilde{W}}$ | $HH^\dagger \tilde{W}^I_{\mu\nu} W^{\mu\nu I}$ | $c_{H\tilde{W}}$ |
| $O_{HB}$ | $HH^\dagger B_{\mu\nu} B^{\mu\nu}$ | $c_{HB}$ | $O_{H\tilde{B}}$ | $HH^\dagger \tilde{B}_{\mu\nu} B^{\mu\nu}$ | $c_{H\tilde{B}}$ |
| $O_{HWB}$ | $HH^\dagger \tau^I W^I_{\mu\nu} B^{\mu\nu}$ | $c_{HWB}$ | $O_{H\tilde{W}B}$ | $HH^\dagger \tau^I \tilde{W}^I_{\mu\nu} B^{\mu\nu}$ | $c_{H\tilde{W}B}$ |

This calue can be compared. But the formula is different , so that , I have no confidence with the factor level

# EFT model

*from past slide*

-- We have referred :

"Resolving the tensor structure of the higgs coupling to Z-bosons via Higgs-strahlung", Shankha Banerjee, Rick S. Gupta, Joey Y. Reiness and Michael Spannowsky, arXiv:1905.02728

$$\Delta\mathcal{L}_6^{hZ\bar{f}f} \supset \delta\hat{g}^h_{ZZ}\frac{2m_Z^2}{v}h\frac{Z^\mu Z_\mu}{2} + \sum_f g^h_{Zf}\frac{h}{v}Z_\mu\bar{f}\gamma^\mu f + \kappa_{ZZ}\frac{h}{2v}Z^{\mu\nu}Z_{\mu\nu} + \tilde{\kappa}_{ZZ}\frac{h}{2v}Z^{\mu\nu}\tilde{Z}_{\mu\nu}.$$

This form is obtained after re-organizing the previous equation though I do not follow it yet...
( e.g. arXiv 1406.1361)

-- Amplitude is given in analytical form at first order ($\sqrt{s}/Mz$), and we have tried to reproduce the differential observables based on the formula.

-- Application to our analysis with this approximation would be an issue.

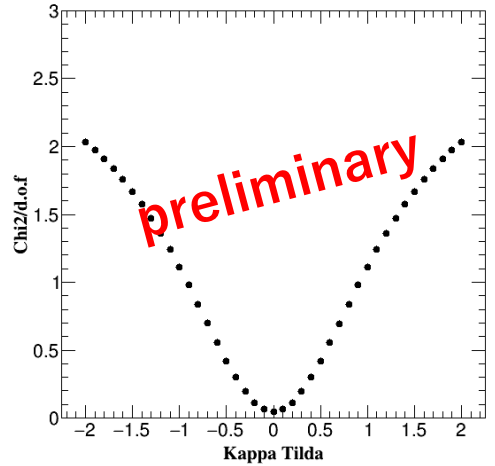
# My personal consideration

*from past slide*

1) Now, the same channel as the HZZ analysis has been chosen, expecting the better S/B, though the Background(=B) is not included yet.

-- total number of signal events ~ 100 (or less )

-- if we deduce the first order from the right figure, it is, with my eye, $-0.8 < \tilde{\kappa} < 0.8$ where this range is decided by $Chi2/N_{dof} < 1$

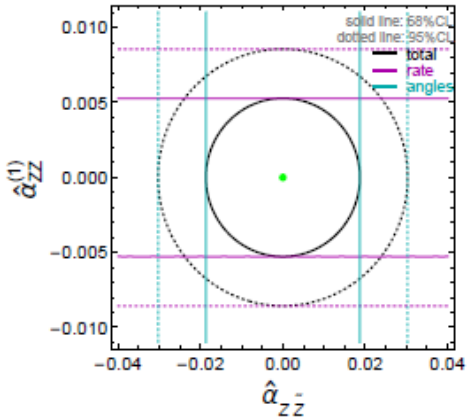



2) from the studies, using the production channel, it is as follows:

-- total number of signal events ~ several * 10000

-- depending on the parameters, the order is such as $-0.03(5) < \text{param.} < 0.03(5)$

It just shows that the limitation range reflects the statistical uncertainty.




from arXiv 1512.06877 (Liantao/Jiyayin point me) but it shows the same order in the CEPC white paper

# Short summary

・ EFT study , but statistics is clearly an issue.
(Technically,  the generator, and of course, interpretation would be another )

・ differential cross-section could be a point

・ Mass, cross-section (<--actually we are doing)

・ Purely compose the paper with the current analysis

-- BDT & simultaneous signal handling

-- adding electron channel.  with IP information ?

・ At least, we have to present/prepare answers between our current results and the result in the white paper

# Backup

# Beyond (only in my head)

- Since I'm going to touch the jet algorithm ( LCFIplus),

  -- analysis and evaluation of HZZ channel with 4 or 6 quarks

  -- EFT model with those status

  or

  -- Trying to think about the application of quantum computing …

-- but those could be considered at least a few months later