

# LHC Higgs WG2 summary and outlook

LHC Higgs WG workshop 2023



Daniele Barducci

Sarah Heim

Ken Mimasu

Giacomo Ortona

## Focus: Higgs Properties

### Conveners:

WG2 convenors			
ATLAS	<a href="#">Sarah Heim</a>	DESY	01/2023
CMS	<a href="#">Giacomo Ortona</a>	Torino	12/2022
Theory	<a href="#">Ken Mimasu</a>	University of Southampton	07/2021
	<a href="#">Daniele Barducci</a>	University and INFN Pisa	02/2022

### Changes since the last meeting:

Giacomo Ortona took over from Mauro Donega

Sarah Heim took over from Nicolas Berger

*HUGE THANKS TO  
MAURO AND NICOLAS!*

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Daniele



Giacomo



Ken



Sarah

## Focus: Higgs Properties

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REPLACEMENT IN  
PROGRESS



WG2 subgroups	Subgroup mailing list	Mail to conveners	ATLAS	CMS	Theory
<a href="#">Fiducial, Differential and Template XS</a>	<a href="#">Mailing List</a>	<a href="#">Mail</a>	<a href="#">Hongtao Yang, LBNL</a> (08/2020)	<a href="#">Matteo Bonanomi, UHH</a> (10/2022)	<a href="#">Frank Tackmann, DESY</a> (05/2017)

Twiki link: [https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG#WG2\\_Higgs\\_properties](https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG#WG2_Higgs_properties)

Indico link: <https://indico.cern.ch/category/5848/> (topical meetings)

## **Simplified Template Cross Sections (STXS)**

- STXS uncertainties (documentation of Run-2 procedure and results)
- STXS in the future
  - CPV, other reasons for additional splitting
  - STXS in decays

## **CPV**

- CPV in (extended) Higgs sectors (Joint activity with WG3)
- CPV in  $ttH$
- CPV benchmarks & common parameterizations

## **Synergy with LHC EFT WG**

- SMEFT
- EFT  $H+HH$  combination, joint w/ WG4 (See WG4 summary talk)

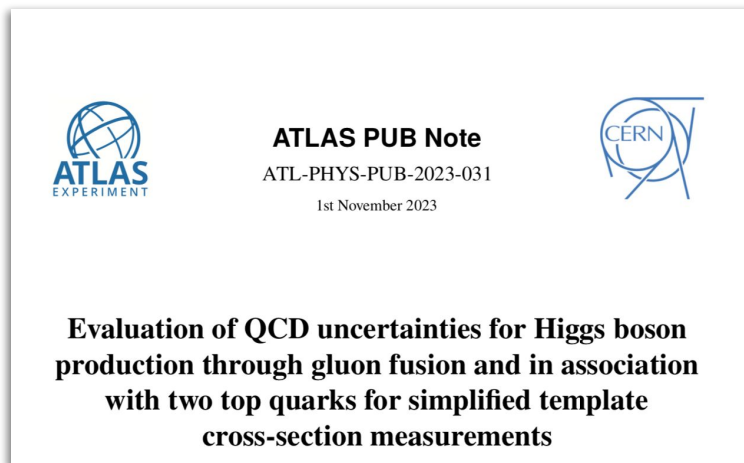


## Goal: A paper about Run-2 uncertainty scheme

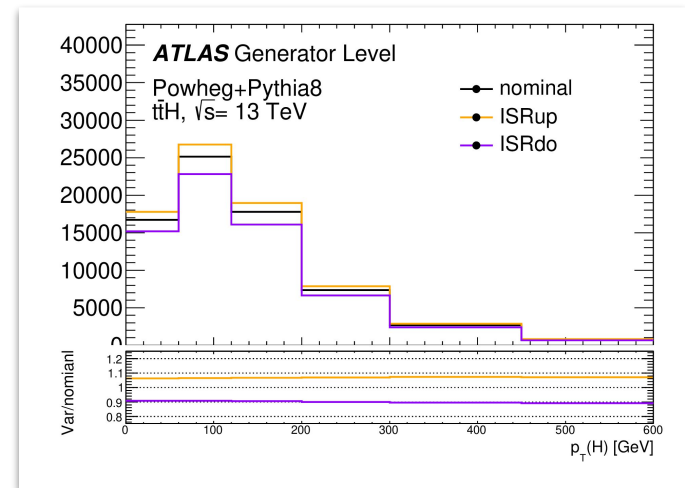
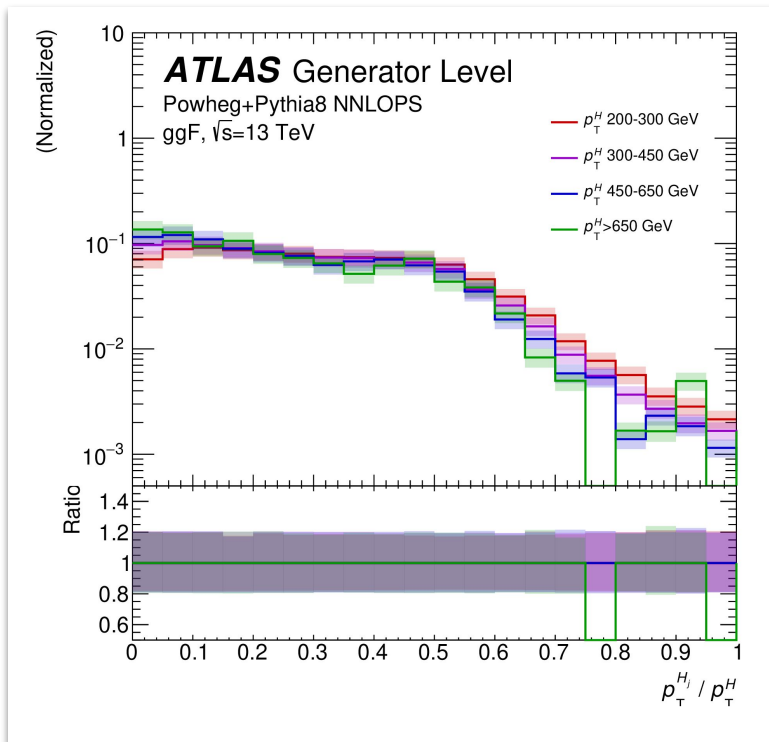
- numbers for ggF and ttH from ATLAS
  - In order to put this into a non-ATLAS paper, needed to publish numbers in a Pub Note first
- numbers for VBF, VH from CMS

## Where we are now

- Numbers are all calculated and have been used
- ATLAS Pub Note is now public: <https://cds.cern.ch/record/2878797>
- Paper discussion started (would be nice in time for ATLAS-CMS combination)



- Tables and plots for the different regions in ggF and ttH
- Discusses also details of derivations, corrections applied, etc.



	ggF	Powheg NNLOPS	
$p_T^H$ [GeV] bin in $\geq 1$ -jet region	< 60	[60,120)	[120,200)
$\lambda_y$ [%]	13.1	13.1	13.1
$\lambda_{p_T^H=60}$ [%]	-8.1	+7.6	+7.6
$\lambda_{p_T^H=120}$ [%]		-2.9	+10.3
Total [%]	15.4	15.5	18.3



- Motivation for binning beyond STXS 1.2
  - Growing data set (improve BSM and SM sensitivity)
  - CPV
  - Decays
- Discussion ongoing for some time, now it's time for concrete steps

=> Dedicated (discussion) session  
this morning

=> two targets

- STXS 1.3 for Run 3 (and 2?)
  - clear plan ahead, timeline for next steps planned
- STXS 2 for  $1 \text{ a}^{-1}$  at HL-LHC

Wed 15/11					
	Print	PDF	Full screen	Detailed view	Filter
09:00	<b>Update on common format &amp; toolchain for SMEFT parametrisations, STXS &amp; beyond (15'+7')</b>				Eleonora Rossi
	30/7-018 - Kjell Johnsen Auditorium, CERN				09:00 - 09:22
	<b>STXS beyond 1.2 (CPV and other considerations), experimental view (15'+7')</b>				Benedict Tobias Winter
	30/7-018 - Kjell Johnsen Auditorium, CERN				09:22 - 09:44
	<b>STXS in decays (15'+7')</b>				Michael Duehrssen-Debling
	30/7-018 - Kjell Johnsen Auditorium, CERN				09:44 - 10:06
10:00	<b>STXS beyond 1.2, BSM view (15'+7', remote)</b>				Tilman Plehn
	30/7-018 - Kjell Johnsen Auditorium, CERN				10:06 - 10:28
11:00	<b>STXS - SM view and discussion intro</b>				Frank Tackmann
	30/7-018 - Kjell Johnsen Auditorium, CERN				11:00 - 11:20
	<b>Discussion - The path to the next STXS binning</b>				Frank Tackmann
	30/7-018 - Kjell Johnsen Auditorium, CERN				11:20 - 12:05
12:00	<b>Constraints on EFT operators from Higgs property fits (20'+10', remote)</b>				Andrei Gritsan
	30/7-018 - Kjell Johnsen Auditorium, CERN				12:05 - 12:30

# STXS for Run 3 and beyond – ideas for STXS 1.3 binning 10

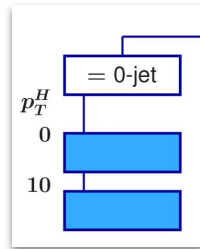
See talk by Benedict/Frank

## ggF

Add more low pTH bins in 0-jet

More at high pTH

( $\Delta\phi_{jj}$  for STXS 2)



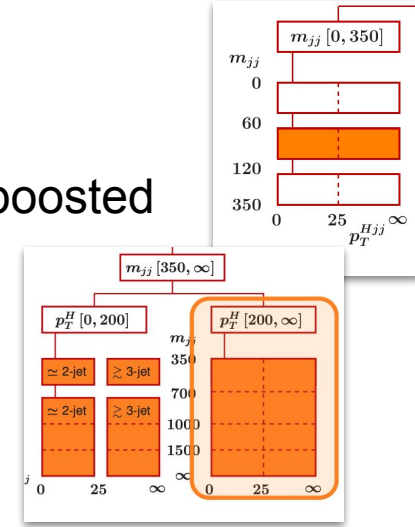
## Hqq

Split VH into pTV bins

Add high pTH bin for boosted

Add  $\Delta\phi_{jj}$  bins for CP

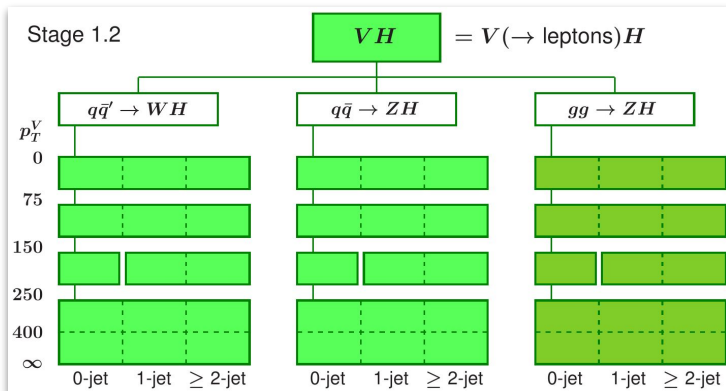
(VBF+ $\gamma$  for STXS 2)



## V(lep)H

more high pTV bins

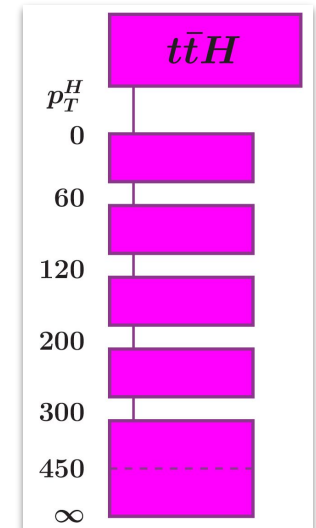
(Second variable (p.ex.  $\Delta\phi_{ll}$ ) for STXS 2)



## ttH

Additional pTH bins

(add var STXS 2?)

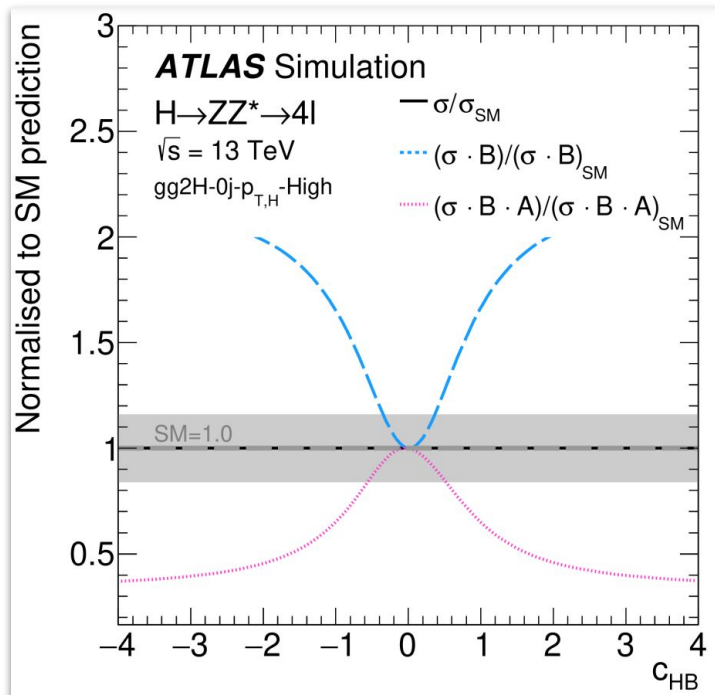


Recent meeting on 25/09 <https://indico.cern.ch/event/1327457/>

See talk by Michael

Idea:

- Clean way to define and label Higgs decay modes for measurements
- Provide a fiducial phase space for what we call H->ZZ, p.ex., approximating the experimental selection
- Avoid model-dependent extrapolations



- Most important for the decays with > 2 final state particles
- $ZZ \rightarrow 4l$ ,  $Z/\gamma^* \gamma$ ,  $WW \rightarrow e\nu\mu\nu$

Status

- First simple fiducial volume successfully flattens the reco/fit ratio for the different models for the ATLAS 4l analysis
- Not so successful in CMS => adjustment/compromise of fiducial definition needed

## Is there an additional source of CP in the Higgs sector?

See talk by Henning Bahl on Monday

### Activities in WG2

- ttH
- Extended scalar sectors
- Common parameters and benchmarks



Googledoc: summary of activities, mailing list sign up sheet, all welcome!

<https://docs.google.com/document/d/1qX5Ypq0Frw47HzltEqtXEt8PG9NM3Z5vkl8BGT2OZtk/edit?usp=sharing>

Several meetings & round-table discussions in last 12 months

$$\mathcal{L}_{\text{top-Yuk}} = -\frac{y_t^{\text{SM}}}{\sqrt{2}} \bar{t}(c_t + i\gamma_5 \tilde{c}_t)tH$$

$$|\mathcal{M}_{t\bar{t}H}|^2 = c_t^2 |\mathcal{M}_{t\bar{t}H}^{\text{CP-even}}|^2 + 2c_t \tilde{c}_t \text{Re}[\mathcal{M}_{t\bar{t}H}^{\text{CP-even}} \mathcal{M}_{t\bar{t}H}^{\text{CP-odd}*}] + \tilde{c}_t^2 |\mathcal{M}_{t\bar{t}H}^{\text{CP-odd}}|^2$$

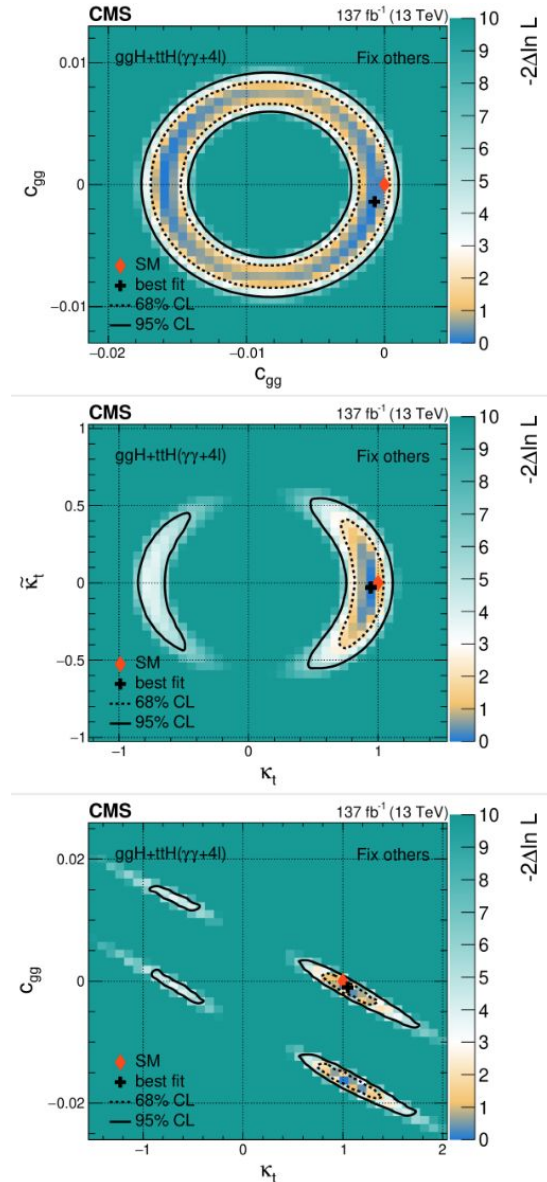
## Including interference in the multivariate analysis

- Parametrized models depending on CP-angle, not only pure odd
- New methods: NN Classifiers, Simulation-based inference

## More global analyses/combinations between ggH and ttH

- Do not only probe one coupling in isolation
- Considered in one CMS analysis so far

Contacts: Henning Bahl & Haichen Wang



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See talk by Tanja Robens

Common activity with WG3 (BSM Higgs)

Extended Higgs sectors can provide CP-even and CP-odd eigenstates that mix.

=> Maybe our Higgs@125GeV is one of those mixed states

=> constraints on benchmark models from Higgs searches and CP studies

Goal:

- Establish benchmark models and identify interesting parameter space regions for CPV studies
- Focus on complementarity between explicit BSM signatures and Higgs properties
- Lots of interesting aspects, not yet converged on something that could be written up

- Idea is to give guidelines/  
recommend benchmark  
models for CP combinations  
and global interpretations
- Reviews/dictionaries for  
parameterization:
  - ‘UV’ benchmarks:  
bottom-up & top-down
  - Note in (slow) progress

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**See Eleonora Rossi's talk in WG2 parallel session**

Joint activity with LHCEFTWG, **currently gathering feedback!**

Proposal for a `.json` data format to publish SMEFT parametrisations

- Avoid duplication of efforts for challenging computations
- Simple comparison/validation of results
- Re-use of predictions in subsequent analyses or global fits

```
{
  "metadata": {
    "coefficients": [ "ch13", "chbox", "chl1", "chwb", "chwbt1l", "che", "chdd", "chb", "chbt1l", "chw", "cll1", '
    "observable_shape": "(1,)",
    "observable_names": [ "ZZ" ],
  }
  "data": {
    "central": {
      "a_ch13": [ -0.24003945767276533 ],
      ...
    "u_MC": {
      "a_ch13": [ 0.00010054876156563025 ],

```

*Example file attached on  
indico, will also upload to  
WG2 TWiki page*

Associated toolchain based on `EFT2Obs`

- Easily reproduce numbers or generate new parametrisations for e.g. different cuts or processes



Note in progress, planned for **early 2024**

- Introduction of format & tool
- Comparison exercise between ATLAS & CMS

~~LHC HIGGS WORKING GROUP~~

PUBLIC NOTE

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**Publishing SMEFT parametrisations for HEP measurements: a proposal for a common data format and simulation toolchain for Higgs simplified template cross sections**

Working title...

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Ilaria Brivio<sup>1</sup>, Ana Cueto<sup>1</sup>, Charlotte Knight<sup>1</sup>, Jonathon Langford<sup>1</sup>, Ken Mimasu<sup>1</sup> and Eleonora Rossi<sup>1\*\*</sup>

## Table of Contents

1. Introduction
2. Setup for MC toolchain
3. Usage of EFT2Obs to obtain parametrisation
4. CMS/ATLAS validation exercise
5. Data format for SMEFT parametrisations

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Continue activities in all areas, in particular

- STXS
  - Uncertainty paper
  - Define STXS 1.3 binning
- CPV
  - Publish benchmarks & common parameterization note
  - **Refocus effort? One idea would be a dedicated subgroup**
- SMEFT
  - Parameterization note
  
- Start discussion meetings on YR5, some important points:

- **WG2:**

- STXS, EFT interpretations - work out granularity that is needed for Run 4
- CP studies (binning, precision of ttH)
- High precision for EFTs
- kappa framework -> embed into HEFT
- Library of models to have a uniform starting point for ATLAS/CMS/theory.

Thanks for all the work!

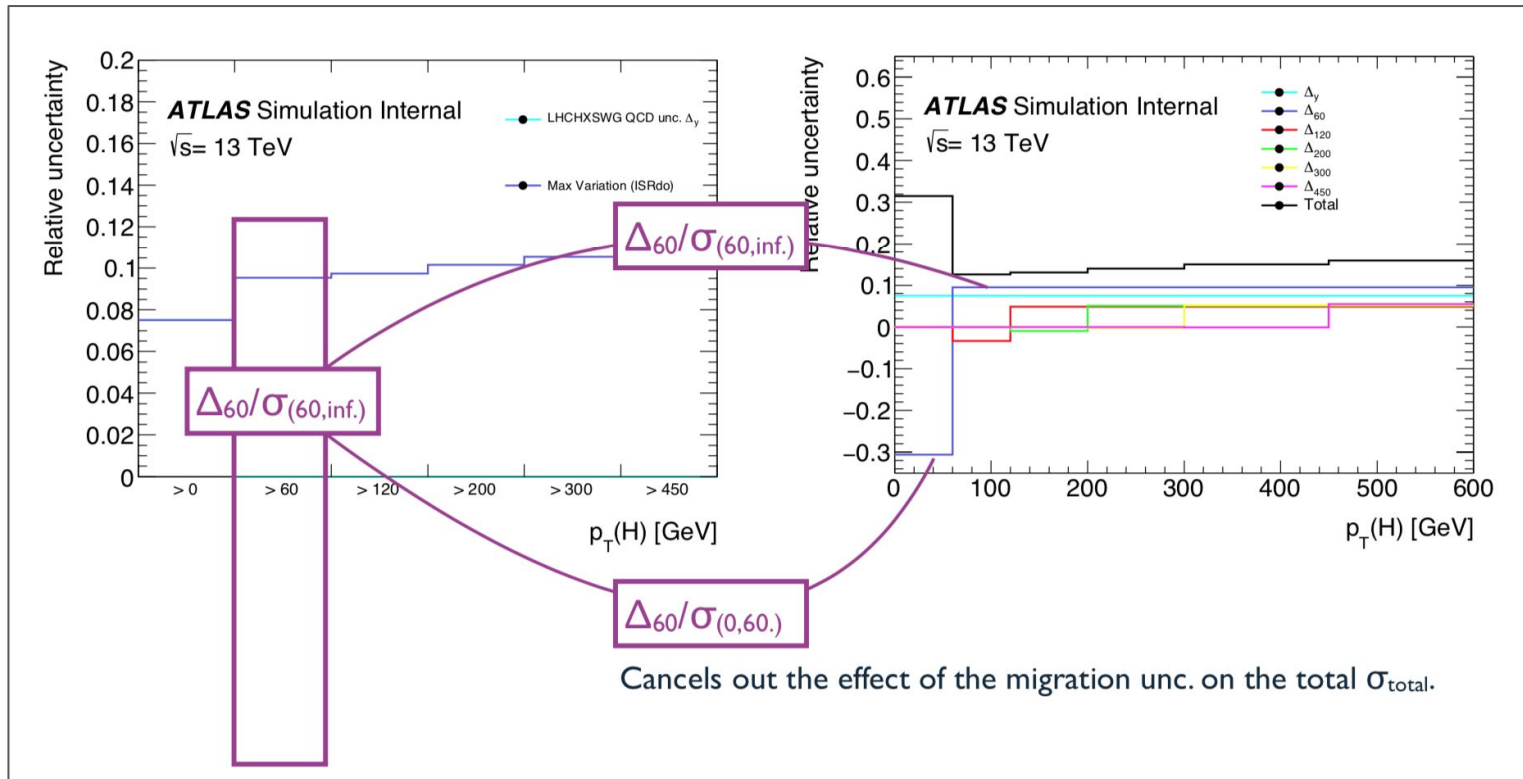


Why we cannot just use  $\mu_r$  and  $\mu_f$  scale variations

- in some regions of phase space, the standard variations can lead to unrealistically small uncertainty estimates for fixed order calculations through cancellation effects
- standard variation gives incorrect uncertainty correlations between bins, as there is no division into different sources
- we normalize our MC predictions to the best available cross sections, which makes the scale variation in the respective sample not applicable any more

What we use instead: Long-Range Stewart-Tackmann procedure

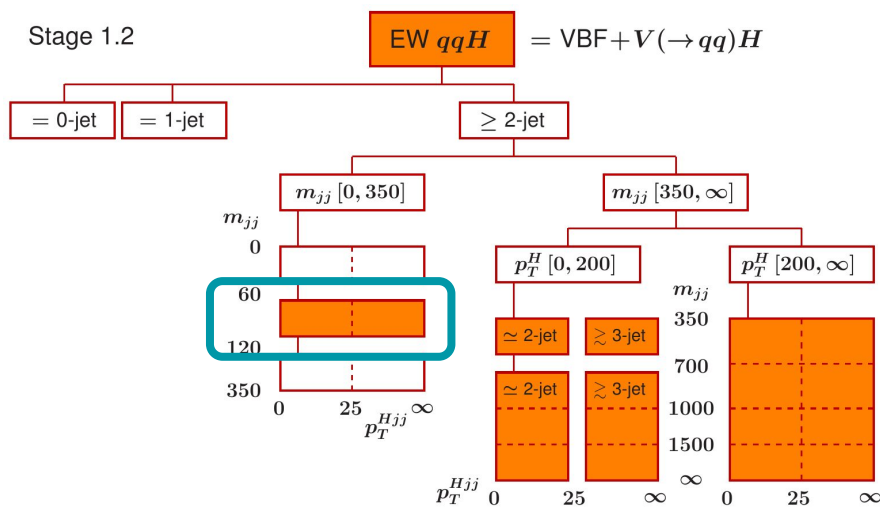
- Use QCD scale variations to determine uncertainties for **inclusive cross sections**, and use these to extract uncertainties for **exclusive cross sections**
- uncertainties split into **two types**
  - **Yield** uncertainties which affect the overall normalization and, if they are not flat in all observables, also the shape.
  - **Migration** uncertainties which affect the shape but not the normalization, and hence will have impacts that sum to 0 across all regions of phase



from Jelena Jovicevic

Remember, some bin boundaries are currently mostly used for uncertainty evaluation, but not split due to lack in sensitivity

- ggF - add more pTH bins in 0-jet?
- qqH - add the  $\Delta\phi_{jj}$ , split VH into pTV bins, add VBF $\gamma$ ?

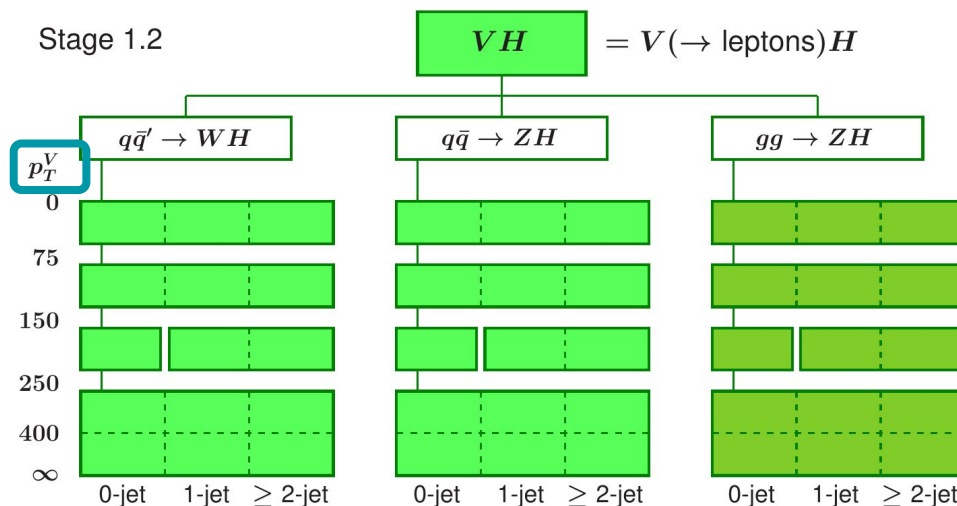


=> also here, need more concrete suggestions, supported by numbers: if you want to have a say in this, please contact Hongtao or me!

Remember, some (dashed) bin boundaries are currently mostly used for uncertainty evaluation, but not split due to lack in sensitivity

- ggF - add more pTH bins in 0-jet?
- Hqq - add the  $\Delta\phi_{jj}$ , split VH into pTV bins, add VBF $\gamma$ ?

- VH - split in pTH vs PTV?  
More high pTV bins?



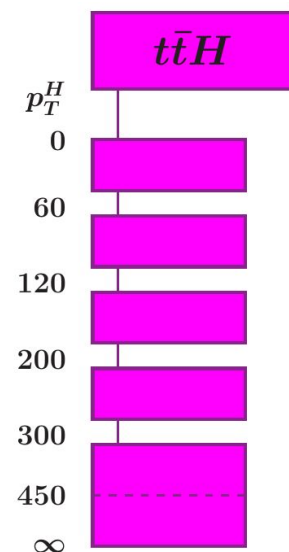
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Remember, some bin boundaries are currently mostly used for uncertainty evaluation, but not split due to lack in sensitivity

- ggF - add more  $p_{TH}$  bins in 0-jet?
- Hqq - add the  $\Delta\phi_{jj}$ , split VH into  $p_{TV}$  bins, add  $VBF\gamma$ ?
- VH - split in  $p_{TH}$  vs  $p_{TV}$ ?  
More high  $p_{TV}$  bins?
- $t\bar{t}H$  - choose additional variables?

Stage 1.2



=> also here, need more concrete suggestions, supported by numbers: if you want to have a say in this, please contact Hongtao or me!

- One of the Sakharov conditions for explaining matter-antimatter asymmetry: CP violation
- SM does not have enough CP-violation to explain the effect
- Additional source of CP in Higgs sector?
  - In SM: Higgs is CP even
  - Many BSM models: CP-odd Higgs or mixed state

Important: CP of Higgs couplings is checked separately for bosons and fermions

For bosons suppressed:

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

Wilson coefficients

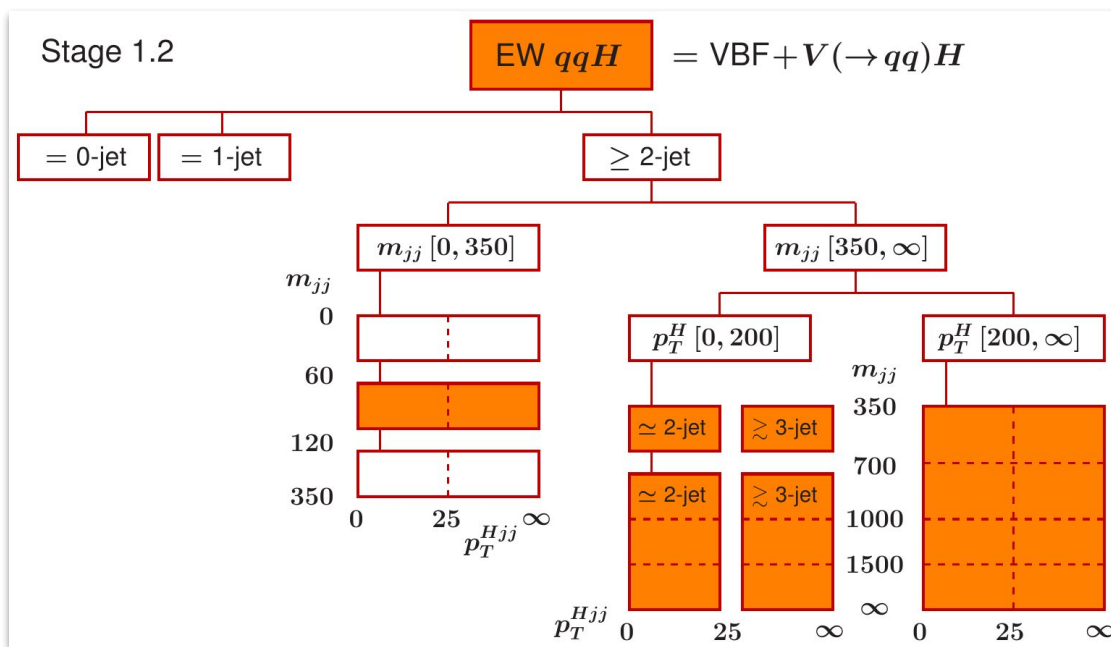
Operators (CP even or CP odd)

For fermions can happen at tree level:

$$\mathcal{L}_{Hff} = -\frac{m_f}{\nu} \kappa_f (\cos \alpha \bar{\psi} \psi + \sin \alpha \bar{\psi} i \gamma_5 \psi) H. \quad \text{SM: } \alpha = 0$$

MORE ON EFT LATER..

See talk by Benedict



- All STXS observables are CP even
- First step: add  $\Delta\phi_{jj}$  to VBF bins? (ggF harder)
- Might need to reshuffle  $m_{jj}$  binning

