# Current status, scope and future developments for STXS and differential Higgs measurements

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### The Why

- differential cross sections allow to probe Higgs production and decay
  - confront measurements with SM and BSM predictions
- cross sections rather than event counts for easier interpretability
  - examples in many Higgs talks during this conference!
- avoid extrapolations as much as possible => improved model independence





### The Why

- differential cross sections allow to probe Higgs production and decay
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  - examples in many Higgs talks during this conference!
- avoid extrapolations as much as possible => improved model independence
- most prominent example: Higgs transverse momentum







transverse momentum  $(p_T)$ 





### The How (1): Differential (fiducial) cross sections

- usually inclusive in production mode (dominated by ggF)
- traditionally performed with high-resolution, high S/B channels
- fiducial volume to avoid extrapolations, includes branching ratio
- unfolding with regularization if needed









Cross sections







## Diff and total XS - the classics: 41, $\gamma\gamma$

- "Golden channels": excellent signal resolution and S/B, but suffer from low event counts
- $\bullet$  Combination of 4I and  $\gamma\gamma$  channels effectively doubles the dataset
  - necessary extrapolation to total phase space introduces model dependence







### Diff XS - the classics: 41, $\gamma\gamma$



h

mass of the off-shell Z boson

sensitive to dark Z bosons, contact interaction



- Higgs rapidity
  - probes PDF, QCD radiative corrections









### Diff XS - Higgs transverse momentum



![](_page_6_Picture_3.jpeg)

![](_page_6_Picture_4.jpeg)

![](_page_7_Picture_0.jpeg)

## Diff XS - Higgs transverse momentum

- H→bb adds at high Higgs transverse momenta
  - collimated: one large-R jet, substructure to find H→bb
  - not unfolded to fiducial phase space

![](_page_7_Figure_5.jpeg)

![](_page_7_Figure_6.jpeg)

![](_page_7_Picture_7.jpeg)

![](_page_7_Picture_8.jpeg)

![](_page_8_Picture_0.jpeg)

## Diff XS - the special one: $H \rightarrow WW \rightarrow ev\mu v$

- large branching ratio
- but: poor resolution (neutrinos!), and large backgrounds

- ATLAS: split into ggF and VBF, CMS: inclusive
- ATLAS VBF measurement
  - BDT discriminants for signal extraction (no cuts)
  - Response matrices quite diagonal!
  - no regularization necessary

![](_page_8_Figure_9.jpeg)

![](_page_8_Figure_11.jpeg)

- in VBF phase space
- angle between the two jets
- CP sensitive

![](_page_8_Picture_15.jpeg)

![](_page_8_Figure_16.jpeg)

![](_page_9_Picture_0.jpeg)

### Diff XS - the newcomer: H→TT

- large branching fraction, poor mass resolution
- resolved and boosted analysis

- boosted  $\Delta R(TT) < 0.8$ 
  - dedicated algorithm to reconstruct close-by taus
  - multiclass NN for signal/background separation
- Probing high transverse momenta!

![](_page_9_Figure_8.jpeg)

![](_page_9_Figure_9.jpeg)

![](_page_9_Picture_10.jpeg)

![](_page_10_Picture_0.jpeg)

## Fiducial XS - the exotic one: $\gamma\gamma$ + X

- model independent search for  $H(\rightarrow \gamma \gamma) + X$
- sensitivity to exotics Higgs boson production
- models in which the Higgs is produced together with other particles
  - SUSY decays
  - exotic top quark decays (FCNC), top partners
  - hidden sectors

![](_page_10_Figure_8.jpeg)

![](_page_10_Figure_9.jpeg)

![](_page_10_Picture_10.jpeg)

### Diff XS - selected interpretations

![](_page_11_Figure_1.jpeg)

![](_page_11_Figure_2.jpeg)

DESY.

![](_page_11_Figure_3.jpeg)

Covered in topical talks!

Just a few examples from the experiments

- Yukawa couplings

- trilinear self-coupling

- effective field theory & CP studies

![](_page_11_Figure_9.jpeg)

![](_page_11_Figure_10.jpeg)

![](_page_12_Picture_0.jpeg)

### Diff XS - future

- more data
  - more variables, finer binning, higher dimensionalities
  - additional decay channels ( $||\gamma\rangle$ )
- also for STXS, discussed next:
  - Feedback welcome on what is needed to make the measurements as useful as possible
  - (besides likelihoods see last talk)

[bb × GeV  $\frac{d\sigma(p_T^H)}{dp_T^H}$ 

Ratio

![](_page_12_Figure_9.jpeg)

![](_page_13_Picture_0.jpeg)

### The How (2): Simplified template cross sections (STXS)

- divided into production modes and kinematic/jet properties
- centralized binning definition (through LHC Higgs WG), current version: STXS 1.2
  - binning compromise between maximizing BSM sensitivity and minimizing theory uncertainties
- performed in all available channels
- cross sections given without decay BR

![](_page_13_Figure_7.jpeg)

![](_page_13_Figure_8.jpeg)

![](_page_14_Picture_0.jpeg)

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- centralized binning definition (through LHC Higgs) WG), current version: STXS1.2
  - binning compromise between maximizing BSM sensitivity and minimizing theory uncertainties
- performed in all available channels
- cross sections given without decay BR
- extrapolations
- The harmonized categories are extremely useful for combinations and the base for further interpretations
  - also for consistent calculation of theory uncertainties

![](_page_14_Figure_10.jpeg)

"Unfolding" with a likelihood fit to reco-level categories that try to match the truth categories to avoid

![](_page_15_Picture_0.jpeg)

### STXS - example H→WW

### Truth bins

![](_page_15_Figure_4.jpeg)

![](_page_15_Figure_5.jpeg)

### **Reco bins**

- simultaneous fit to signal and control regions
- observables: transverse mass (ggF), DNN (VBF)
- POIs: XS in STXS categories

![](_page_15_Figure_10.jpeg)

![](_page_15_Figure_12.jpeg)

![](_page_16_Picture_0.jpeg)

### **STXS - Combination of decay channels**

### ATLAS Run 2

### Example ATLAS Nature paper (2022)

(CMS: Nature 607 (2022) 60)

Input channels: Η->γγ H->ZZ(4) H->WW(evµv) H->77 H->bb

30 م 20 م

10

SM prediction

![](_page_16_Figure_10.jpeg)

Data (Total uncertainty) Syst. uncertainty

Correlation matrix in appendix

![](_page_16_Picture_13.jpeg)

![](_page_17_Picture_0.jpeg)

### **STXS - Combination of decay channels**

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10

SM prediction

![](_page_17_Figure_10.jpeg)

Correlation matrix in appendix

![](_page_17_Figure_12.jpeg)

![](_page_17_Picture_13.jpeg)

![](_page_18_Picture_0.jpeg)

### **STXS - Combination of decay channels**

### Example ATLAS Nature paper (2022)

(CMS: Nature 607 (2022) 60)

![](_page_18_Figure_5.jpeg)

![](_page_18_Figure_7.jpeg)

![](_page_18_Figure_8.jpeg)

Correlation matrix in appendix

![](_page_18_Figure_10.jpeg)

![](_page_18_Picture_11.jpeg)

![](_page_19_Picture_0.jpeg)

Events / bir

10-

Data / MC

### STXS - beyond the Nature papers

Z+2b

Z+c

Single t

VH(bb)

0.8

DNN score

 since the Nature combinations, updated measurements, in particular in the fermion channels

 $10^{-1}$ 

0.2

0.4

0.6

Data / MC

• example CMS H→bb

0.6

V(lep)H, resolved and boosted

![](_page_19_Figure_5.jpeg)

• fit to DNN discriminants

expect updated combinations

DNN score

![](_page_19_Figure_9.jpeg)

![](_page_19_Figure_10.jpeg)

![](_page_20_Picture_0.jpeg)

### STXS - a word about scale uncertainties

- uncertainties derived for STXS 1.2 binning with long-range Stewart-Tackmann method
- idea Stewart-Tackmann:  $\Delta(1jet) = \sqrt{\Delta(\geq 1jet)^2 + \Delta(\geq 2jet)^2}$ 
  - avoids cancellation effects in usual fixed order scale variations
- long-range: assign uncertainty to inclusive cross sections and to migrations at bin boundaries
  - uncorrelated uncertainties: nuisance parameters in fits, which can be correlated between measurements
  - also used in many other Higgs measurements
  - very useful for combinations, also between experiments!

<u> Phys.Rev.D 85 (2012) 03401</u>

![](_page_20_Figure_10.jpeg)

![](_page_20_Figure_11.jpeg)

![](_page_20_Picture_12.jpeg)

![](_page_20_Figure_13.jpeg)

![](_page_20_Figure_14.jpeg)

![](_page_21_Picture_0.jpeg)

### **STXS - selected interpretations**

- on the experimental side, usually reparametrization of the STXS likelihoods
  - effective field theory
  - 2HDM, MSSM
- Examples from outside the experiments
  - Lilith to constrain new physics from Higgs measurements (eg 2012.11408
  - HiggsSignals to compare the predictions of BSM Higgs sectors with the existing measurements (eg Eur. Phys. J.C 81 (2021) 2, 145
  - SMEFT fits (eg <u>2111.05876</u>)

![](_page_21_Figure_10.jpeg)

![](_page_22_Picture_0.jpeg)

### STXS for the future

## LHC Higgs WG working on STXS 1.3 for Run 3 (iterations with community ongoing)

- add higher transverse momentum bins in almost all production channels
- $\bullet$  add CP sensitive  $\Delta\phi_{jj}$  bins to VBF and possibly to ggF
- try to improve match of VH categories for boosted hadronic analyses with merged jets

### Longer time-scale: STXS 2.0 for HL-LHC (~1 ab<sup>-1</sup>)

- changes that do not make it into 1.3
- VBF+γ?
- CP-sensitive observable for ttH

ost all production to ggF

![](_page_22_Figure_11.jpeg)

![](_page_22_Picture_12.jpeg)

![](_page_23_Picture_0.jpeg)

## STXS and decays

![](_page_23_Picture_2.jpeg)

- **Example problem:** Acceptance of the ATLAS  $H \rightarrow 4I$  STXS measurement depends on EFT parameters
- Solution:
  - Lorentz invariant fiducial selection per decay mode
  - Higgs scalar: production and decay decouple
  - two-body decays: No kinematic information
  - the others  $(H \rightarrow II\gamma, H \rightarrow WW^* \rightarrow I \vee I \vee, H \rightarrow ZZ^* \rightarrow 4I)$  need more work

![](_page_23_Figure_9.jpeg)

![](_page_23_Picture_10.jpeg)

![](_page_24_Picture_0.jpeg)

## **STXS and decays**

![](_page_24_Picture_2.jpeg)

- **Example problem**: Acceptance of the ATLAS  $H \rightarrow 4I$  STXS measurement depends on EFT parameters
- Solution:
  - Lorentz invariant fiducial selection per decay mode
  - Higgs scalar: production and decay decouple
  - two-body decays: No kinematic information
  - the others  $(H \rightarrow II\gamma, H \rightarrow WW^* \rightarrow I \vee I \vee, H \rightarrow ZZ^* \rightarrow 4I)$  need more work

### • Status

- $H \rightarrow 4I$  compromise selection for ATLAS and CMS
  - cuts on lepton pt in Higgs rest frame, invariant mass CUts
- implementation in LHC H XS WG STXS Rivet ongoing
- further future: Stage 1, binning in decay variable (e.g. m34)

![](_page_24_Figure_14.jpeg)

m<sub>34</sub> [GeV]

![](_page_24_Picture_16.jpeg)

![](_page_25_Picture_0.jpeg)

### Conclusions and outlook

Wealth of differential measurements to characterize Higgs boson production and decays

- traditional differential cross sections
- simplified template cross sections

Measurements can be used as base for various interpretations: EFT, MSSM, Yukawa couplings, ...

Interplay/communication between experiment and theory important to make the measurements as useful as possible!

![](_page_25_Picture_7.jpeg)

![](_page_25_Picture_8.jpeg)

![](_page_26_Picture_0.jpeg)

### Backup

### **Correlation matrix ATLAS STXS**

	A	17	ΓL		IS	5													m	<sub>H</sub> =	- 12	<b>√</b> <i>s</i> 25	= .09	13 9 G	T ie	eV V, j	, 139 / <sub>H</sub>   <	9 fb <sup>-1</sup> < 2.5	
$gg \rightarrow H$ , 0-jet, $p_{\tau}^{H} < 10 \text{ GeV}$	1	-0.26	0.05	-0.05	-0.03 0.	.04 -0.03	3 0.00	-0.06 -0	.02 -0.01	0.00	0.01	0.02 -0	01 0.00	0.00	0.01 -0	.01 0.0	0.01	0.00	0.00 0.0	00 0.01	0.00 0	.00 0.00	0.00 0	0.00 0.00	0.00	0.00 0.0	0 0.00 0.02		
$gg \rightarrow H$ , 0-jet, 10 $\leq \rho_{T}^{H} <$ 200 GeV	-0.26	1	-0.22	0.25	0.17 -0	0.10 0.08	0.00	0.18 0	08 0.03	-0.10	-0.01 -	0.01 0.	05 0.04	0.06	0.02 0	.03 0.0	0 0.02	0.01	0.01 0.0	00 0.01	0.01 0	.00 0.00	0.00 0	0.01 0.01	0.00	0.00 -0.0	01 0.00 0.02		
$gg \rightarrow H$ , 1-jet, $p_{\tau}^{H} < 60 \text{ GeV}$	0.05	-0.22	2 1	0.19	0.22 -0	0.08 -0.01	0.01	0.09 0	07 0.04	-0.35	0.01	0.03 0.	03 0.04	0.06	0.05 0	.00 0.0	02 -0.01	0.00	0.00 0.0	00.00	0.01 0	.00 0.00	0.00 0	0.00 0.01	0.00	0.00 0.0	0.00 0.00		
$gg \rightarrow H$ , 1-jet, $60 \le p_{\tau}^{H} < 120 \text{ GeV}$	-0.05	0.25	0.19	1	0.38 -0	0.25 0.05	0.01	0.24 0	15 0.06	-0.56	0.00	0.02 0.	06 0.07	0.10	0.05 0	.02 0.0	00 0.01	0.00	0.01 0.0	00.00	0.00 0	.00 0.00	0.00 0	0.00 0.00	0.00	0.00 0.0	0.00 0.00		$0.8 \times$
$gg \rightarrow H$ , 1-jet, $120 \le p_{\tau}^{H} < 200 \text{ GeV}$	-0.03	0.17	0.22	0.38	1 -0	0.04 -0.09	9 0.00	0.19 0.	15 0.06	-0.59	0.02	0.02 0.	05 0.06	6 0.11	0.04 0	.02 0.0	0.01	0.00	0.01 0.0	00.00	-0.01 0	.00 0.00	0.00 0	0.00 0.00	0.00	0.00 0.0	0.00 0.00		
$gg \rightarrow H, \ge 2$ -jet, $m_j < 350 \text{ GeV}, p_{\tau}^H < 120 \text{ GeV}$	0.04	-0.10	0 -0.08	-0.25	-0.04	1 0.08	-0.06	0.09 0.	10 0.05	0.01	-0.18 -	0.42 0.	04 0.01	-0.01	0.00 -0	.03 -0.0	02 -0.01	0.00	0.00 0.0	00 0.00	0.00 0	.00 0.00	0.00 0	0.00 0.01	0.01	0.01 0.0	01 0.01 -0.02		
$gg \rightarrow H, \ge 2$ -jet, $m_{jj} < 350 \text{ GeV}, 120 \le p_{\tau}^{H} < 200 \text{ GeV}$	-0.03	0.08	-0.01	0.05	-0.09 0.	.08 1	-0.03	0.19 0.	17 0.07	0.04	-0.34	0.51 0.	04 0.00	0.00	-0.03 -0	0.01 -0.0	03 0.00	0.00	0.01 0.0	00 0.00	0.00 0	00.0 0.00	0.00 0	0.01 0.00	0.00	0.01 0.0	01 0.00 -0.02		
$gg \rightarrow H, \ge 2$ -jet, $m_j \ge 350 \text{ GeV}, p_T^H < 200 \text{ GeV}$	0.00	0.00	0.01	0.01	0.00 -0	0.06 -0.03	3 1	0.05 0	06 0.03	-0.06	0.03 -	0.10 <mark>-0</mark>	58 -0.3	3 -0.20	-0.16 -0	0.04 0.0	0.01	0.01	0.00 0.0	00.00	0.00 0	.00 0.00	0.00	0.01 0.02	0.02	0.02 0.0	3 0.02 <mark>-0.09</mark>		0.0
$gg \rightarrow H, 200 \le p_{\tau}^H < 300 \text{ GeV}$	-0.06	0.18	0.09	0.24	0.19 0.	.09 0.19	0.05	1 0.	14 0.10	-0.26	-0.18	0.31 0.	04 0.02	2 0.04	0.01 -0	0.21 -0.0	03 0.01	0.01	0.00 0.0	00.00	0.01 0	.00 0.00	0.00 0	0.01 0.02	0.01	0.00 0.0	2 0.01 -0.05		
$gg \rightarrow H, 300 \le p_{\tau}^H < 450 \text{ GeV}$	-0.02	0.08	0.07	0.15	0.15 0.	.10 0.17	0.06	0.14	1 -0.10	0 -0.22	-0.13 -	0.25 0.	02 0.01	0.03	0.00 -0	0.17 -0.0	01 0.01	0.00	0.00 0.0	00.00	0.01 0	.00 0.00	0.00 0	0.01 0.01	0.02	0.01 -0.0	02 0.01 -0.03		
$gg \rightarrow H, p_{\tau}^{H} \ge 450 \text{ GeV}$	-0.01	0.03	0.04	0.06	0.06 0.	.05 0.07	0.03	0.10 -0	.10 1	-0.09	-0.03 -	0.12 0.	00 0.01	0.01	0.00 -0	0.09 0.0	00 0.01	0.00	0.00 0.0	00.00	0.00 0	.00 0.00	0.00 0	0.01 0.01	0.02	0.01 0.0	4 -0.06 -0.02		04
$qq \rightarrow Hqq$ , $\leq$ 1-jet	0.00	-0.10	0 -0.35	-0.56	-0.59 0.	.01 0.04	-0.06	-0.26 -0	.22 -0.09	9 1	0.00 -	0.03 -0.	06 -0.0	9 -0.16	-0.08 -0	0.01 -0.0	01 -0.01	0.00	0.00 0.0	00 0.00	-0.01 0	00.00	0.00 0	0.00 0.00	0.00	0.00 0.0	0 0.00 0.01		
$qq \rightarrow Hqq$ , $\geq$ 2-jet, $m_{jj}$ < 350 GeV, VH topo	0.01	-0.01	0.01	0.00	0.02 -0	0.18 -0.34	4 0.03	-0.18 -0	.13 -0.03	3 0.00	1	0.22 -0.	02 0.00	0.00	0.01 0	.05 0.0	0.01	0.00	0.01 0.0	00.00	-0.01 0	.01 -0.01	0.00 0	0.00 0.00	0.00	0.00 0.0	01 0.00 -0.01		
$qq \rightarrow Hqq$ , $\geq$ 2-jet, $m_{jj}$ < 350 GeV, VH veto	0.02	-0.01	0.03	0.02	0.02 -0	0.42 -0.51	-0.10	-0.31 -0	.25 -0.12	2 -0.03	0.22	1 0.	00 0.06	6 0.04	0.06 0	.06 0.0	0.01	0.00	0.01 0.0	00 0.00	-0.01 0	.01 0.00	0.00 0	0.01 0.00	0.01	0.00 0.0	0 0.00 -0.01		
$qq \rightarrow Hqq$ , $\geq 2$ -jet, $350 \leq m_j < 700 \text{ GeV}, p_\tau^H < 200 \text{ GeV}$	-0.01	0.05	0.03	0.06	0.05 0.	.04 0.04	-0.58	0.04 0.	02 0.00	-0.06	-0.02	0.00	0.12	2 0.19	0.18 -0	0.03 0.0	0.00	0.00	0.00 0.0	00.00	0.00 0	.00 0.00	0.00 0	0.00 0.00	-0.01	-0.01 -0.0	01 -0.01 0.03		0.2
$qq \rightarrow Hqq$ , $\geq$ 2-jet, $700 \leq m_{jj} < 1000 \text{ GeV}, p_{\tau}^{H} < 200 \text{ GeV}$	0.00	0.04	0.04	0.07	0.06 0.	.01 0.00	-0.33	0.02 0.	01 0.01	-0.09	0.00	0.06 0.	12 1	-0.14	0.19 -0	0.03 0.0	0 0.01	0.00	0.01 0.0	00 0.00	0.00 0	00.00	0.00 0	0.00 0.00	0.00	0.00 -0.0	01 0.00 0.02		
$qq \rightarrow Hqq$ , $\geq 2$ -jet, $1000 \leq m_{jj} < 1500 \text{ GeV}, p_{\tau}^{H} < 200 \text{ GeV}$	0.00	0.06	0.06	0.10	0.11 -0	0.01 0.00	-0.20	0.04 0.	03 0.01	-0.16	0.00	0.04 0.	19 -0.14	4 1	-0.22 0	.02 -0.0	04 0.01	0.00	0.00 0.0	00.00	0.00 0	.00 0.00	0.00 0	0.00 0.00	0.00	0.00 0.0	0 0.00 0.01		
$qq \rightarrow Hqq$ , $\geq 2$ -jet, $m_{jj} \geq 1500 \text{ GeV}, p_{T}^{\prime\prime} < 200 \text{ GeV}$	0.01	0.02	0.05	0.05	0.04 0.	.00 -0.03	8 -0.16	0.01 0.	00 0.00	-0.08	0.01	0.06 0.	18 0.19	-0.22	1 0.	.04 <u>-0.</u>	10 0.01	0.00	0.01 0.0	00 0.00	0.00 0	.00 0.00	0.00 0	0.00 0.01	0.00	0.00 0.0	0 0.00 0.01		0
$qq \rightarrow Hqq$ , $\geq 2$ -jet, $350 \leq m_{jj} < 1000 \text{ GeV}$ , $p_{\tau}^{\prime\prime} \geq 200 \text{ GeV}$	-0.01	0.03	0.00	0.02	0.02 -0	0.03 -0.01	-0.04	-0.21 -0	.17 -0.09	-0.01	0.05	0.06 -0.	03 -0.03	3 0.02	0.04	1 –0.:	28 0.00	0.00	0.00 0.0	00 0.00	0.00 0	.00 0.00	0.00 0	0.00 0.00	0.00	0.00 0.0	0 0.00 -0.01		
$qq \rightarrow Hqq, \ge 2$ -jet, $m_{jj} \ge 1000 \text{ GeV}, p_{\tau}^{\prime} \ge 200 \text{ GeV}$	0.01	0.00	0.02	0.00	0.01 -0	0.02 -0.03	3 0.02	-0.03 -0	.01 0.00	-0.01	0.01	0.05 0.	03 0.00	0 -0.04	-0.10 -0	.28	0.00	0.00	0.01 0.0	00 0.00	0.00 0	.00 0.00	0.00 0	0.00 0.00	0.00	0.00 0.0	0.00 0.00		
$qq \rightarrow Hiv, p_{\tau}^{2} < 75 \text{ GeV}$	0.01	0.02	-0.01	0.01	0.01 -0	0.01 0.00	0.01	0.01 0.	01 0.01	-0.01	0.01	0.01 0.	00 0.01	0.01	0.01 0	.00 0.0	00 1	-0.15	0.02 0.0	00 0.01	-0.04 0	.01 0.00	0.00 0	0.00 0.01	0.02	0.02 0.0	2 0.02 -0.07		
$qq \rightarrow HIV$ , $T5 \leq p_T^V < 150$ GeV	0.00	0.01	0.00	0.00	0.00 0.	.00 0.00	0.01	0.01 0.	00 0.00	0.00	0.00	0.00 0.	00 0.00	0.00	0.00 0	.00 0.0	0 -0.15	1	-0.10 0.0	02 0.00	-0.09 0	.00 0.00	0.00 0	).01 0.01	0.01	0.01 0.0	2 0.01 -0.07		-0.2
$qq \rightarrow H_V$ , $150 \le p_T^V < 250$ GeV	0.00	0.01	0.00	0.01	0.01 0.	0.00 0.01	0.00	0.00 0.	00 0.00	0.00	0.01	0.01 0.	00 0.01	0.00	0.01 0	.00 0.0	0.02	-0.10	1 -0.	06 0.04	-0.01 -0	01 0.03	0.00 0	0.00 0.01	0.00	0.01 0.0	2 0.00 -0.03		
$qq \rightarrow r \pi v, 250 \le p_{T} < 400 \text{ GeV}$	0.00	0.00	0.00	0.00	0.00 0.	.00 0.00	0.00	0.00 0.	00 0.00	0.00	0.00	0.00 0.	00 0.00	0.00	0.00 0	.00 0.0	0 0.00	0.02	-0.06	1 -0.17	0.02 0	.02 -0.06	0.02 0	0.00 0.00	0.01	0.01 0.0	0.00 -0.01		
$qq \rightarrow HV, p_{T}^{V} \ge 400 \text{ GeV}$	0.01	0.01	0.00	0.00	0.00 0.	0.00 0.00	0.00	0.00 0.	00 0.00	0.00	0.00	0.00 0.	00 0.00	0.00	0.00 0	.00 0.0	0 0.01	0.00	0.04 -0.	17 1	0.00 0	.03 -0.02	-0.15 0	0.00 0.00	0.00	0.00 0.0	0 0.00 -0.01		-0.4
$gg/qq \rightarrow H_{\mu}, p_{\tau} < 150 \text{ GeV}$	0.00	0.01	0.01	0.00	-0.01 0.	.00 0.00	0.00	0.01 0.	01 0.00	-0.01	-0.01	0.01 0.	00 0.00	0.00	0.00 0	.00 0.0	0 -0.04	-0.09	-0.01 0.0	02 0.00	1 -0	.03 0.02	-0.01 0	0.00 0.00	-0.01	0.00 0.0	0 0.00 -0.01		0.4
$gg(qq \rightarrow H)$ , $150 \le p_{\tau}^{V} < 400 \text{ GeV}$	0.00	0.00	0.00	0.00	0.00 0.	.00 0.00	0.00	0.00 0.	00 0.00	0.00	0.01	0.01 0.	00 0.00	0.00	0.00 0	.00 0.0	0 0.01	0.00	-0.01 0.0	02 0.03	-0.03	1 0.03	0.01 0	.00 0.00	0.00	0.01 0.0	0 0.00 -0.01		
$gg/qq \rightarrow Hil, 250 \leq p_{T}^{-} < 400 \text{ GeV}$	0.00	0.00	0.00	0.00	0.00 0.	.00 0.00	0.00	0.00 0.	00 0.00	0.00	-0.01	0.00 0.	00 0.00	0.00	0.00 0	.00 0.0	0 0.00	0.00	0.03 -0.	06 -0.02	0.02 0	03 1	-0.11	0.00 0.00	0.00	0.01 0.0	0 0.00 -0.01		
$\frac{1}{99}$	0.00	0.00	0.00	0.00	0.00 0.	00 0.00	0.00	0.00 0.	00 0.00	0.00	0.00	0.00 0.	00 0.00	0.00	0.00 0	.00 0.0	0 0.00	0.00	0.00 0.0	02 -0.15	-0.01 0	00 0.00	1 0	.00 0.00	0.00	0.00 0.0	0 0.00 0.00		-0.6
$tTH, B_{T} < 60 \text{ GeV}$	0.00	0.01	0.00	0.00	0.00 0.	01 0.00	0.01	0.01 0.	01 0.01	0.00	0.00	0.01 0.	00 0.00	0.00	0.00 0	.00 0.0	0 0.00	0.01	0.00 0.0	00 0.00	0.00 0	00 0.00	0.00	0.11	-0.02	0.01 0.0	15 0.02 -0.11		
$t_{T}^{\text{F}}$ $H_{120}$ $c_{T}^{\text{H}}$ $c_{200}$ $C_{0}$	0.00	0.01	0.01	0.00	0.00 0.	01 0.00	0.02	0.02 0	00 0.01	0.00	0.00	0.00 0.	01 0.00	0.00	0.01 0	.00 0.0	0 0.01	0.01	0.01 0.1	01 0.00	0.00 0	00 0.00	0.00		-0.05	0.00 0.0			
$t_{T}^{T}H 200 \le p_{T}^{H} < 300 \text{ GeV}$	0.00	0.00	0.00	0.00	0.00 0.	01 0.00	0.02	0.01 0.	02 0.02	0.00	0.00	0.01 -0.	01 0.00	0.00	0.00 0	.00 0.0	0 0.02	0.01	0.00 0.0	01 0.00	0.00 0	01 0.00	0.00 0	0.02 -0.03	-0.04	-0.04 0.0	000000 = 0.24		L_0 8
$t_{T}^{H}$ , 200 $\leq p_{\tau}^{H} < 450$ GeV	0.00	-0.01	0.00	0.00	0.00 0.	01 0.01	0.02	0.02 -0	02 0.04	0.00	0.01	0.00 -0	01 -0.0	1 0.00	0.00 0	.00 0.0	0 0.02	0.02	0.02 0.0	01 0.00	0.00 0	00 0.00	0.00 0	0.03 0.05	0.04	-0.01 1	-0.36 -0.32		0.0
$t_{\tau}^{H}$ $h_{\tau}^{H} > 450 \text{ GeV}$	0.00	0.00	0.00	0.00	0.00 0	01 0.00	0.02	0.01 0	01 -0.06	0.00	0.00	0.00 -0	01 0.00	0.00	0.00 0	00 0.0	0 0.02	0.01	0.00 0.0	00 0.00	0.00 0	00 0.00	0.00 0	0.02 0.04	0.06	0.08 -0.3	36 1 -0.21		
μ	0.02	0.02	0.00	0.00	0.00 -0	0.02 -0.02	-0.09	-0.05 -0	.03 -0.02	2 0.01	-0.01	0.01 0.	03 0.02	2 0.01	0.01 -0	0.01 0.0	0 -0.07	-0.07 -	-0.03 -0.	01 -0.01	-0.01 -0	01 -0.01	0.00 -	0.11 -0.20	0.00	-0.23 -0.3	32 -0.21		
נדע	20.02	>	>	2.00	2 2	> >	>	2 2	2 2	10.0	0.01	2 3	2 2	2	2 2	> >	>	>	> >	2 2	2 2	2 2	2	> >	>	> >			'–1
	0 Ge	0 Ge	0 Ge	0 G	000	ë ë	0 Ge	0 0 0 0 0 0	j č		H top	H ve	, Ö	0 Ge	0 0 0 0 0	9 8 0 0	5 Ge	0 Ge	000	, ő	0 Ge	ů č	0 Ge	8 8 0 8	0 Ge	9 0 0 0 0	0.06		•
	х Р Г	< 20	у 9 9	×15	< 20	< 20 < 20	< 20	< 30	× ∨ ₹ ₹	, ppł	eV,V	V,Ve 70,V	× 50 × 50	< 20	~ 20	~ ~ ~	~ ~	1	< 25 < 40	/ ∧ }	41 s	× × ×	∨	* < 6 < 12	< 20	<ul> <li>30</li> <li>45</li> <li>45</li> </ul>	, ∨		
	et, p	≥ p <sup>H</sup>	et, p	$\leq p_T^H$	r P <sup>H</sup> T PH	rd' rd' rd'	V, P_T^H	+d ≥ +d	, p + d - 1	d → F	Ū O	50 5	, <sup>7</sup> , <sup>7</sup>	', p <sup>H</sup> _T	1, P_T	, P, T, H, C, H, C	V, P	≤ p <sup>v</sup>	∠d ≥ ⊤ ∧d >	r d,	, p <sup>v</sup>	d d d	', p'	H, P, F	_ <sup>+</sup> d ≥	+ 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	- <sup>-</sup>		
	ł, 0-j	19	í, 1-j	. 60	120	120	Ge	200	noc ⊥+£	õ	т v	v d	ge (	) Ge/	Ge	Ge/	± ⊥	, 75	150	E E	± cir	250	± 1	t1 , 60	120	300	tith t		
	Ť	0-je	J→F	1-jei	l-jet,	< 35( GeV,	35(	, T , T	é ð		, m	, m //	1000	1500	1500	1000	bb bb	ΥH,	HV,	60	bb/f	Ë,	bb/£	tĨh	t <b>T</b> Η,	tтн, tтн,	n 1 1 1		
	6	, ⊤	96	→ <i>H</i> ,	, T, E	m 350 (	m " 2	66	ññ		2-jet	je je	, v , ii	,	7 <sub>∭</sub> ≥	× ^	-	-bb	↑ ↑	Į.	6	- 1 50	6						
		- <i>66</i>		66	<i>gg</i> _	r_jet, ∥ <	-jet,				, ⊳	< bd	u = >(	<i>m</i> ≥ (	let, n	u≤u et.m.				,		66							
					c /	f,≥ 2 et,m	~`,				₹	s F	1, 700	100(	≥ 2-J	-2 -2 <													
					,	2→F	7→ H.				-bb	99	2-jet	2-jet,	Hqq,	z-je faa													
					5	, U, D	36					bot	tq,≥	q, ≥ 1	t∼b	v, h	5												
						-66						1	÷ Ť	→ Hq	9	ĕ <sup>5</sup> ↑	F												
												Ċ	, <u>6</u>	-bb		bb													

![](_page_27_Picture_3.jpeg)

![](_page_27_Picture_4.jpeg)

![](_page_28_Picture_0.jpeg)

### STXS V(lep)H

![](_page_28_Figure_2.jpeg)

![](_page_29_Picture_0.jpeg)

### Likelihood for H4I STXS

$$\mathcal{L}(\vec{\sigma}, \vec{\theta}) = \prod_{j=1}^{N_{\text{categories}}} \prod_{i=1}^{N_{\text{bins}}} P\left(N_{i,j} \mid L \cdot \frac{1}{2}\right)$$

### $\cdot \vec{\sigma} \cdot \mathcal{B} \cdot \vec{A}_{i,j}(\vec{\theta}) + B_{i,j}(\vec{\theta}) \times \prod^{N_{\text{nuisance}}} C_m(\vec{\theta})$ m

![](_page_29_Figure_5.jpeg)

![](_page_30_Picture_0.jpeg)

### Regularization

Matrix inversion: creates large negative off-diagonals  $\rightarrow$  statistical fluctuations of the data are amplified

Regularization can be applied (encourage smooth-ness)

Bayesian unfolding with limited number of iterations: some level of regularization (update the MC prior with data)

![](_page_30_Picture_5.jpeg)

### H->bb ATLAS

![](_page_31_Figure_1.jpeg)

![](_page_31_Figure_2.jpeg)

WH, 150 < 
$$p_T^{W,t}$$
 < 250 GeV  
WH, 250 <  $p_T^{W,t}$  < 400 GeV  
WH,  $p_T^{W,t}$  > 400 GeV  
ZH, 75 <  $p_T^{Z,t}$  < 150 GeV  
ZH, 150 <  $p_T^{Z,t}$  < 250 GeV  
ZH, 250 <  $p_T^{Z,t}$  < 400 GeV

	.			
iinary V	'H, H →	b <mark>b</mark> √s=	13 TeV, 1	39 fb <sup>-1</sup>
. unc.	-Stat.	unc.	Theo.	unc.
		Tot.	(Stat.,	Syst.)
	0.70	+0.52 0.52	( +0.34 -0.33 ,	+0.39 -0.39 <b>)</b>
	1.10	+0.41 0.38	( +0.35 -0.34 ,	+0.20 -0.18
	1.54	+0.92 0.82	( +0.77, -0.72,	+0.49 -0.40
4	0.98	+0.74 0.72	( +0.52 , -0.51 ,	+0.53 <b>)</b> -0.51 <b>)</b>
	1.06	+0.35 -0.33	( +0.27, -0.27,	+0.22 <b>)</b> -0.19 <b>)</b>
	0.97	+0.40 0.39	( +0.36 -0.36	+0.17 -0.14
	0.29	+0.92 0.85	( +0.76 -0.69 <b>,</b>	+0.53)
2	3 4	5	6	7 8
σ	$\times B n$	orma	alised t	to SM

![](_page_31_Picture_5.jpeg)