ATLAS Experience with STXS Measurements

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Fiducial and Template Cross-section Subgroup

- New subgroup within the WG2 structure, for issues related to
  - **Fiducial cross-sections**
  - **Differential cross-sections**
  - **Simplified template cross-sections (STXS)**

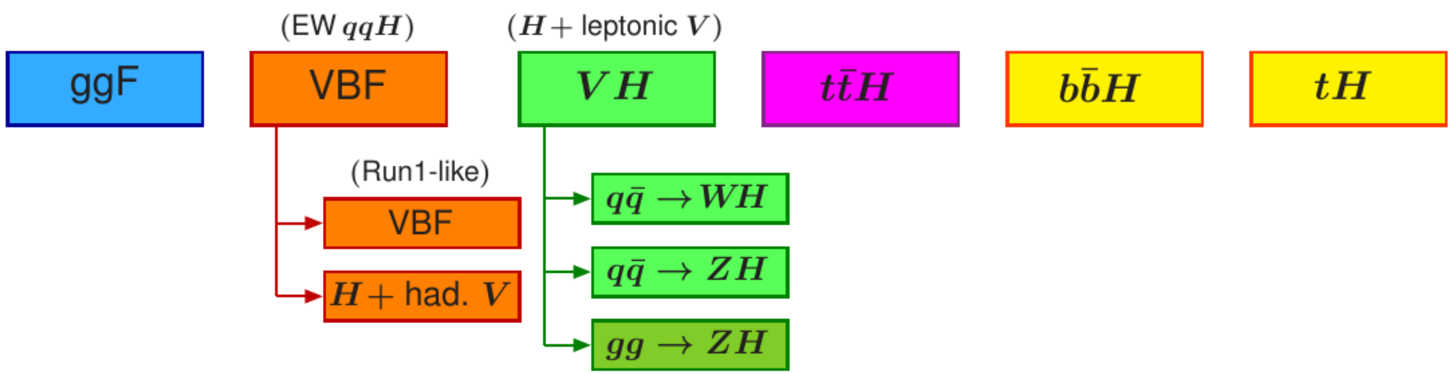
- **Conveners:**
  - Frank Tackmann (Theory)
  - Predrag Milenovic (CMS)
  - Nicolas Berger (ATLAS)

- **Mailing lists**
  - Group discussions: lhc-higgs-prop-fidSTXS@cern.ch
  - Contact with conveners: lhc-higgs-fidSTXS-convener@cern.ch

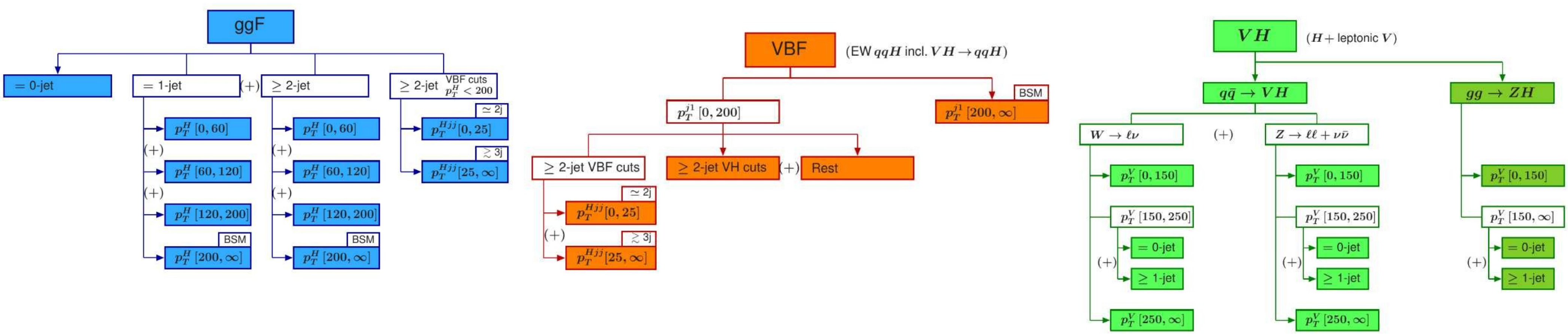
- **TWiki**: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGFiducialAndSTXS

Introduction

- STXS are described in YR4 (Section III.2), provide truth-level splitting of Higgs production processes
- Staged approach with increasingly fine splittings
- **Stage 0**



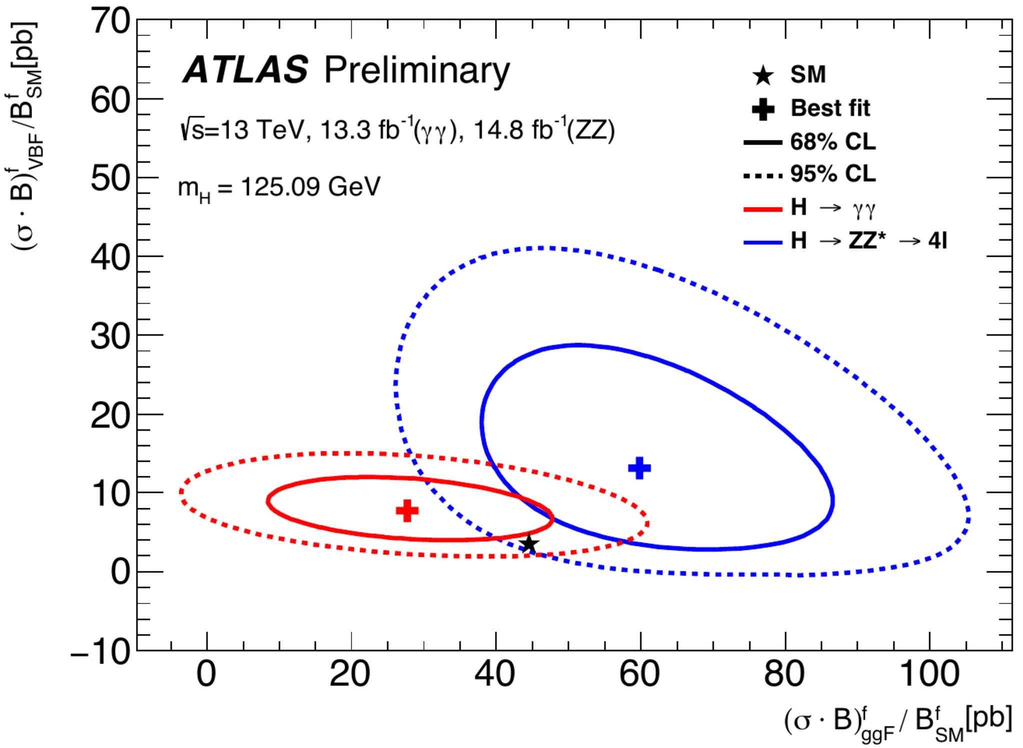
- **Stage 1**

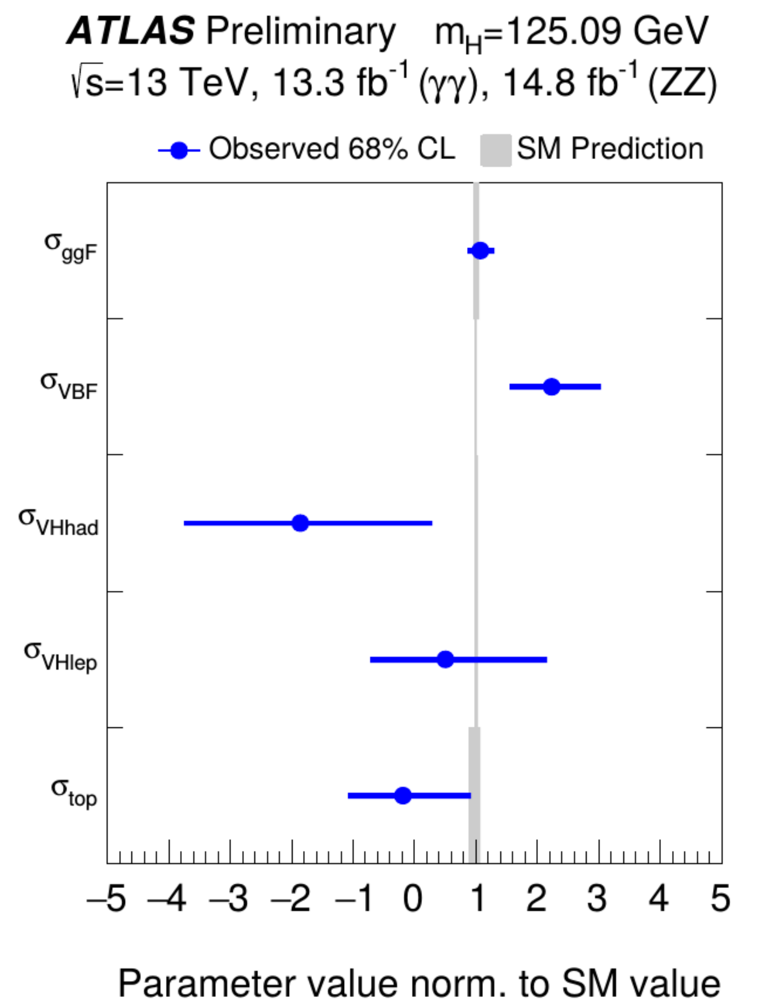


- Stage-0 and Stage-1 classifications implemented by Jim Lacey in a common RIVET tool now maintained by LHCHXSWG.

ATLAS Measurements

- ATLAS has reported **Stage-0** results in the 2016 Higgs Combination ($H \to \gamma\gamma + ZZ$)





- Aiming for **Stage-1** for upcoming measurements

- **In this talk:** summary of issues encountered, which would benefit from discussions with the wider community

Stage-1 Measurements

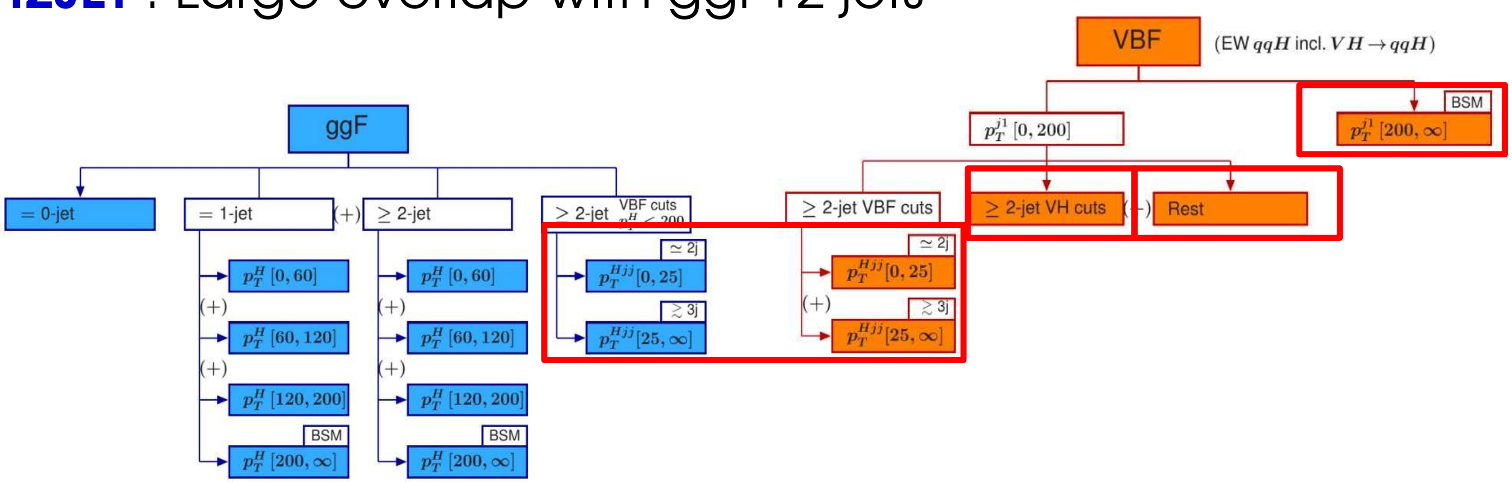
STXS separates "production modes" ⇒ full Stage-1 measurement requires to disentangle e.g. ggF/VBF. Issues e.g. in

- **VBF-like phase space** (**gg2H_JET3, gg2H_JET3VETO, VBF_JET3, VBF_JET3VETO**)
  → Only weak discrimination through loose vs. tight VBF-like selections.

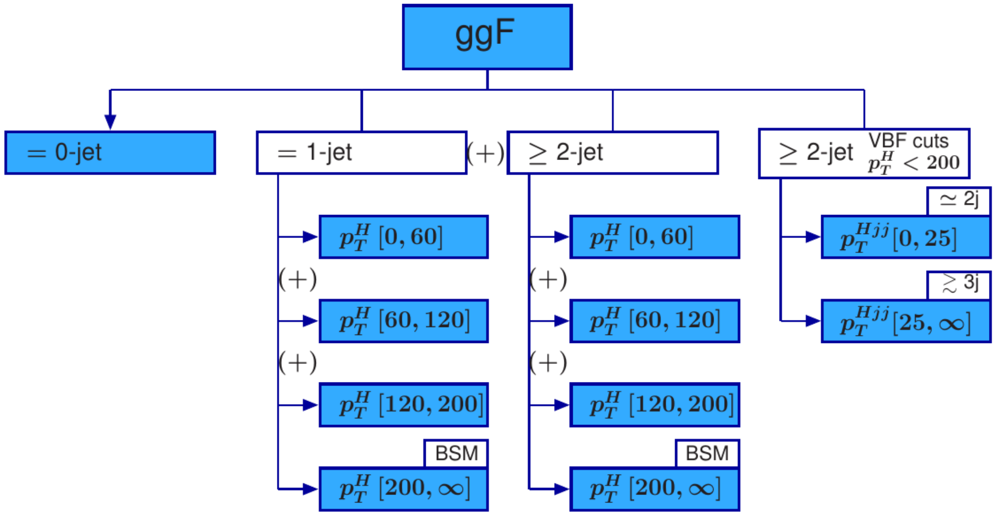
- **VBF_REST** : (56% of total VBF)

  → Corresponds to parts of VBF phase space that strongly overlap with ggF ⇒ Difficult to isolate

- **VBF_BSM** : Large overlap with ggF+jets
- **VBF_VH2JET** : Large overlap with ggF+2 jets



Merging truth bins



- Stage 1 provides already a quite fine-grained description of Higgs production
- Not all bins can be measured with high precision, especially in single channels

- Two main issues:
  - **Truth bins with ~ no sensitivity from experimental measurement** (e.g. no matching experimental selection)
  - **Heavily correlated truth bins** – i.e. bins that cannot be easily disentangled from the measurements.
    - e.g. VBF-like ggF (2j and 3j) and true VBF (2j and 3j)
      ⇒ In principle, 4 measurements in the "VBF-like" region

- **Possible solutions:**
  - **Provide results in "rotated" basis (e.g. (A+B, A-B)) in which correlations are weaker**
  - **Merge bins**

When to Merge ?

- **ATLAS approach**: merge truth bins when
  1. **There is no reco bin matching the truth bin**
  2. **The STXS POIs for 2 truth bins are >~80% correlated in a fit to Asimov**

- **Open points**:
  - Is the 80% threshold appropriate ?
  - For 1., some arbitrariness in how to merge (which STXS bins to "attach" the unconstrained bin to).
    ⇒ **Follow recommendations provided within the STXS framework ("(+)" in the diagrams)**

    → In 2., some arbitrariness also in the case of intercorrelations between 3 or more bins (e.g. ggF/2j, ggF/3j, VBF/2j and VBF/3j)
  - Possibility to also report **unmerged results** for case 2., if the correlation matrix is well defined (~Gaussian measurements).

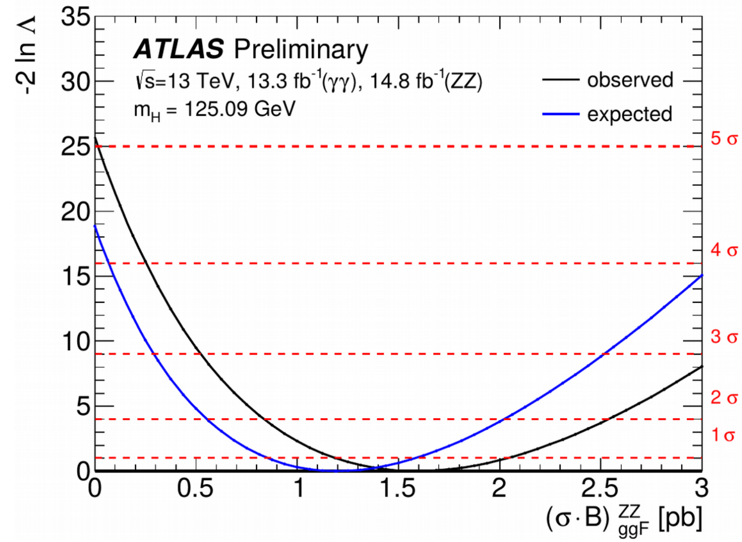
    → **Would this be useful ? (given the large correlations)**

Non-Gaussian Behavior

- **Baseline idea:**
  - Experiments report **central values + covariance matrix** for a set of STXS
  - Further interpretation performed based on these inputs

- Some measurements in 2016 Higgs Combination already not fully Gaussian

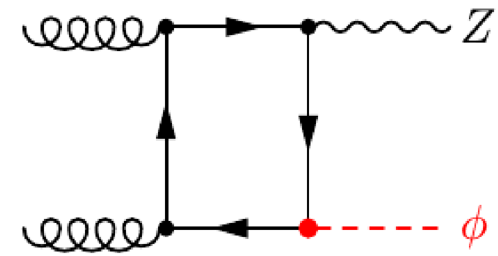
  → Will remain an issue even for larger datasets, since STXS staging designed to give finer splits with more data



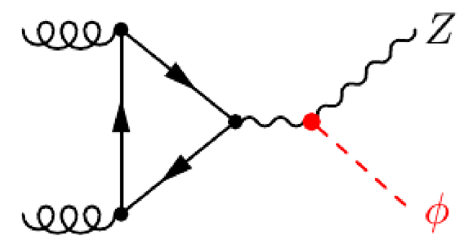
- Could lead to biases in particular for
  - Very non-Gaussian measurements (e.g. BSM bins)
  - Measurements with large correlations (e.g. ggF/VBF)

- Could be useful to perform checks by comparing
  - **Interpretations based on reparameterizing the full experimental likelihood**
  - **Interpretations using covariance matrix propagation**

gg→ZH



- STXS classification is final-state--based
  ⇒ gg→ZH (14% of pp→ZH at 13 TeV) distributed as:
  - **gg→Z(ll)H** ~ gg→Hll ⇒ classified within "**VH**" (Hll) in STXS
  - **gg→Z(qq)H** ~ gg→Hqq ⇒ classified within **ggF**, same as ggF+2jets
    - gg→ZH can be seen as part of EW corrections to ggF
      ⇒ should be included in ggF in any case
    - gg initial state ⇒ HO corrections probably
      closer than to e.g. qq→ZH



- **Remarks**
  - "Triangle graphs" not directly related to (Higgs) ggF diagrams

    ⇒ Different interpretation in terms of modified couplings
    → already implemented in κ-framework parameterization since Run 1.
  - Tiny fraction of gg→Hqq ⇒ will be swamped by pure-QCD processes

    ⇒ Could have a separate STXS bin with an $|m_{qq} - m_Z|$ cut, within ggF ?

ggF QCD Uncertainties for Stage-1 STXS

- Using "Interim 2017" uncertainty model agreed upon after last month's dedicated WG1 meeting
  - Extension of resummed ST described in YR4: Δ_{μ}, Δ_{ϕ}, $\Delta_{0/1}$ $\Delta_{1/2}$ $\Delta_{VBF,2j}$ $\Delta_{VBF,3j}$ $\Delta_{pTH,60}$ $\Delta_{pTH,120}$ Δ_{mt}

Large at high p_T^H, parameterizes the uncertainty in the p_T^H>200 GeV cut

- Uncertainty values obtained from NNLOPS
- In ATLAS, implemented as NNLOPS weight variations (TruthWeightTools-01-04-00)

Cross sections and fractional uncertainties

STXS	sig	stat	mu	res	mig01	mig12	VBF2j	VBF3j	pT60	pT120	qm_top	Tot
Incl	48.52	+/- 0.00	+4.6%	+2.1%	-0.0%	-0.0%	+0.3%	-0.0%	+0.0%	+0.2%	+0.2%	+5.1%
FWDH	4.27	+/- 0.01	+4.5%	+1.9%	-0.5%	-0.2%	+0.0%	+0.0%	-0.3%	-0.1%	+0.0%	+4.9%
VBF_J3V	0.27	+/- 0.00	+0.0%	+0.0%	+0.0%	+0.0%	+20.0%	-32.0%	-1.6%	+1.1%	+0.1%	+37.8%
VBF_J3	0.36	+/- 0.00	+0.0%	+0.0%	+0.0%	+0.0%	+20.0%	+23.5%	-0.2%	+2.5%	+0.2%	+31.0%
=0J	27.25	+/- 0.03	+3.8%	+0.1%	-4.1%	+0.0%	+0.0%	+0.0%	+0.0%	+0.0%	+0.0%	+5.6%
=1J_0-60	6.49	+/- 0.01	+5.2%	+4.5%	+7.9%	-6.8%	+0.0%	+0.0%	-4.8%	-1.6%	+0.0%	+13.5%
=1J_60-120	4.50	+/- 0.01	+5.2%	+4.5%	+7.9%	-6.8%	+0.0%	+0.0%	+4.8%	-0.9%	+0.0%	+13.4%
=1J_120-200	0.74	+/- 0.00	+5.2%	+4.5%	+7.9%	-6.8%	+0.0%	+0.0%	+10.0%	+10.1%	+0.5%	+18.9%
=1J_200->	0.15	+/- 0.00	+5.2%	+4.5%	+7.9%	-6.8%	+0.0%	+0.0%	+10.0%	+14.0%	+10.5%	+23.7%
>=2J_0-60	1.22	+/- 0.01	+8.9%	+8.9%	+4.4%	+18.2%	+0.0%	+0.0%	-5.9%	-1.6%	+0.0%	+23.3%
>=2J_60-120	1.86	+/- 0.01	+8.9%	+8.9%	+4.4%	+18.2%	+0.0%	+0.0%	-0.2%	-0.2%	+0.0%	+22.5%
>=2J_120-200	0.99	+/- 0.00	+8.9%	+8.9%	+4.4%	+18.2%	+0.0%	+0.0%	+6.6%	+10.6%	+0.6%	+25.8%
>=2J_200->	0.42	+/- 0.00	+8.9%	+8.9%	+4.4%	+18.2%	+0.0%	+0.0%	+10.0%	+14.0%	+11.8%	+30.7%
=0J	30.12	+/- 0.03	+3.8%	+0.1%	-4.1%	+0.0%	+0.0%	+0.0%	+0.0%	+0.0%	+0.0%	+5.6%
=1J	12.92	+/- 0.02	+5.2%	+4.5%	+7.9%	-6.8%	+0.0%	+0.0%	-0.1%	-0.4%	+0.2%	+12.5%
>=2J	5.47	+/- 0.01	+7.8%	+7.8%	+3.9%	+16.1%	+2.3%	-0.0%	+0.4%	+2.9%	+1.1%	+20.3%
>=1J 60-200	9.09	+/- 0.01	+6.2%	+5.8%	+6.4%	+1.9%	+0.9%	+0.1%	+4.2%	+1.7%	+0.1%	+11.8%
>=1J 120-200	1.96	+/- 0.01	+6.8%	+6.5%	+5.5%	+6.9%	+1.5%	+0.4%	+8.0%	+10.4%	+0.6%	+18.5%
>=1J >200	0.58	+/- 0.00	+7.9%	+7.7%	+5.4%	+11.6%	+0.0%	+0.0%	+10.0%	+14.0%	+11.4%	+26.7%
>=1J >60	9.68	+/- 0.01	+6.3%	+5.9%	+6.3%	+2.5%	+0.8%	+0.1%	+4.6%	+2.5%	+0.8%	+12.2%
>=1J >120	2.54	+/- 0.01	+7.0%	+6.8%	+5.5%	+8.0%	+1.2%	+0.3%	+8.4%	+11.2%	+3.0%	+19.9%
>=1	18.40	+/- 0.02	+6.0%	+5.5%	+6.7%	-0.0%	+0.7%	-0.0%	+0.0%	+0.5%	+0.4%	+10.6%

Dag Gillberg

ggF QCD Uncertainties for Stage-1 STXS

Separate uncertainties on

- $\sigma_i^{STXS,SM}$: SM values of STXS cross-sections

  → useful e.g. for denominators in $\mu=\sigma/\sigma^{SM}$, also bin merging, see below

- $(A\times\varepsilon)_{\alpha i}$ factors for each reco selection α and truth bin i
  - Useful to extract STXS from reco yields
  - Typically smaller than uncertainties on $\sigma_i^{STXS,SM}$
  - One uncertainty per (reco, truth) pair – but smaller truth contributions hard to obtain due to limited MC stats

$$N_\alpha^{reco} = \sum_i (A\times\epsilon)_{\alpha i} \sigma_i^{STXS}$$

QCD Uncertainties for Merging STXS bins

- STXS can be **merged** in some cases (see next slides).
  - e.g. $\sigma_{VBF} = \sigma_{VBF,2j} + \sigma_{VBF,3j}$

- In general need to reexpress the original STXS in terms of the merged one:

$$\sigma_{VBF,2j} = \left(\frac{\sigma^{SM}_{VBF,2j}}{\sigma^{SM}_{VBF}}\right)\sigma_{VBF} \qquad \sigma_{VBF,3j} = \left(\frac{\sigma^{SM}_{VBF,3j}}{\sigma^{SM}_{VBF}}\right)\sigma_{VBF}$$

⇒ **Requires to include extra uncertainties on the value of the ratios.**

- No effect if analysis is not sensitive to the split (i.e. same $(A\times\varepsilon)$ for 2j and 3j)

- Some effect in general : for 2j/3j merging, extra ~20% uncertainties in VBF-like selections

"Stage 0.5"

- Stage-1 results are already quite fine-grained (especially e.g. for ggF)
  → good for experts, but need to also show where we approach SM sensitivity

- Some suggestions:
  - Merge bins with **small cross-sections** (excluding the BSM bins)
  - Merge bins with **non-significant signal** (e.g. require $\delta\sigma/\sigma^{SM} < 2$ in reported bins)

- Specifically for ggF
  - Merge **all p_T^H bins for a given jet bin** (except perhaps BSM bins), as suggested in the STXS merging guidelines
  - **Is this direction preferable over merging N_{jets} bins ?**

- **Is it useful to uniformize a merged "Stage 0.5" scheme ?**
- **Is it still useful to report full Stage-1 results in addition to these ?**

bbH and tH

- **bbH** and **tH** included in the Stage 0 classification, but currently little or no sensitivity in the analyses

- **bbH**: STXS ($A\times\varepsilon$) values almost identical to ggF

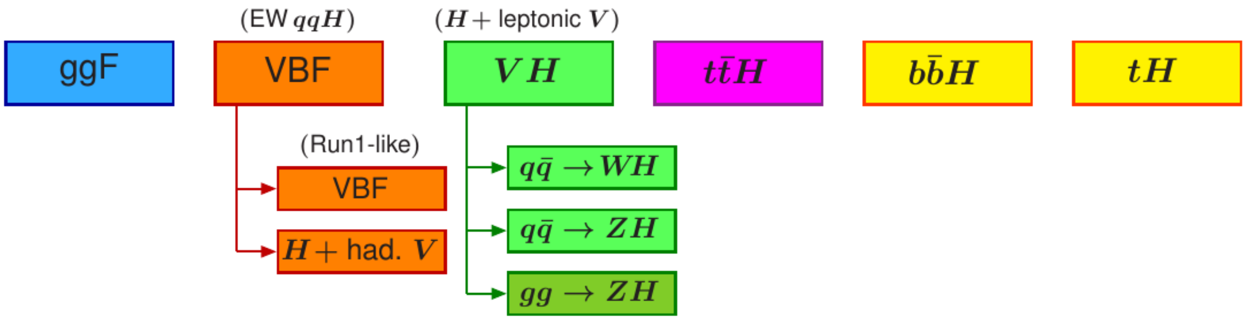
$$\sigma_{tH}^{\gamma\gamma} = \frac{\sigma_{tH} \times \Gamma(H \rightarrow \gamma\gamma)}{\Gamma_H}$$

- **Fix to SM ?** (optionally, up to theory uncertainties)
  → Leads to constraints on BR(H→X)
  ⇒ "measurement" of Γ_H e.g. within κ models.

$$\frac{\sigma_{VBF}^{\gamma\gamma}}{\sigma_{tH}^{\gamma\gamma}} = \frac{\kappa_V^2}{\sigma_{tH}^{SM}} \qquad \sigma_{VBF}^{ZZ} = \frac{\kappa_V^4}{\kappa_H^2}$$

$$\kappa_H^2 = \frac{1}{\sigma_{VBF}^{ZZ}} \left(\frac{\sigma_{VBF}^{\gamma\gamma}}{\sigma_{tH}^{\gamma\gamma}} \right)^2$$

- **Proposal:**
  - **Merge bbH with ggF**
    - In Stage 1, distribute into sub-bins according to SM acceptance values ?
  - **Merge tH with ttH**



Low-p_T^H binning

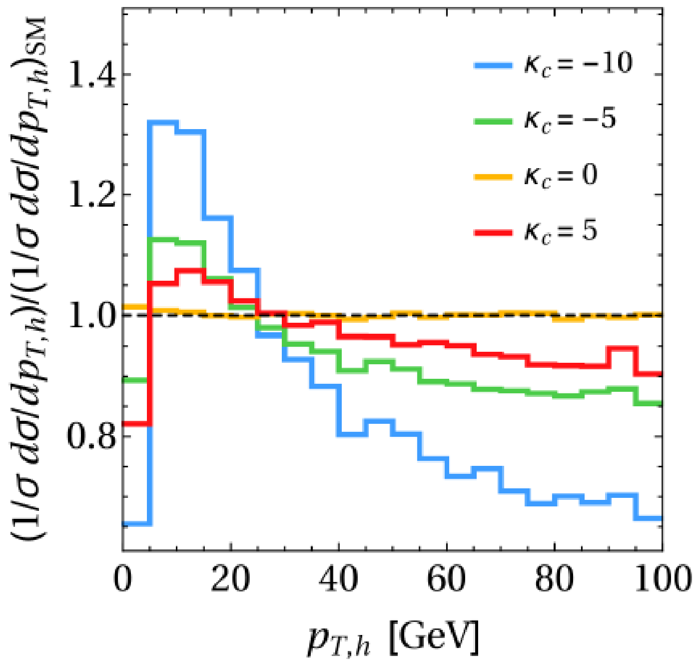
- Recent proposal to use p_T^H distribution to constraint light-quark Yukawas (Phys. Rev. Lett. 118, 121801 (2017), JHEP12(2016)045)

From A. Azatov

- Modifications of the light quark Yukawa couplings modify the differential distributions.
- Sudakov's dilogarithms *1606.09253* enhance the production cross-section

$$\sim k_Q \frac{m_Q^2}{m_h^2} \ln^2 \frac{p_\perp^2}{m_Q^2}$$

  modifications are especially important in the region $m_Q \ll p_\perp \ll m_h$.
- The main contribution appears from the interference with the top quark loop, which scales as y_Q not y_Q^2.



Would it be feasible/useful to add a new p_T^H bin boundary at 10-20 GeV ?

Discussion