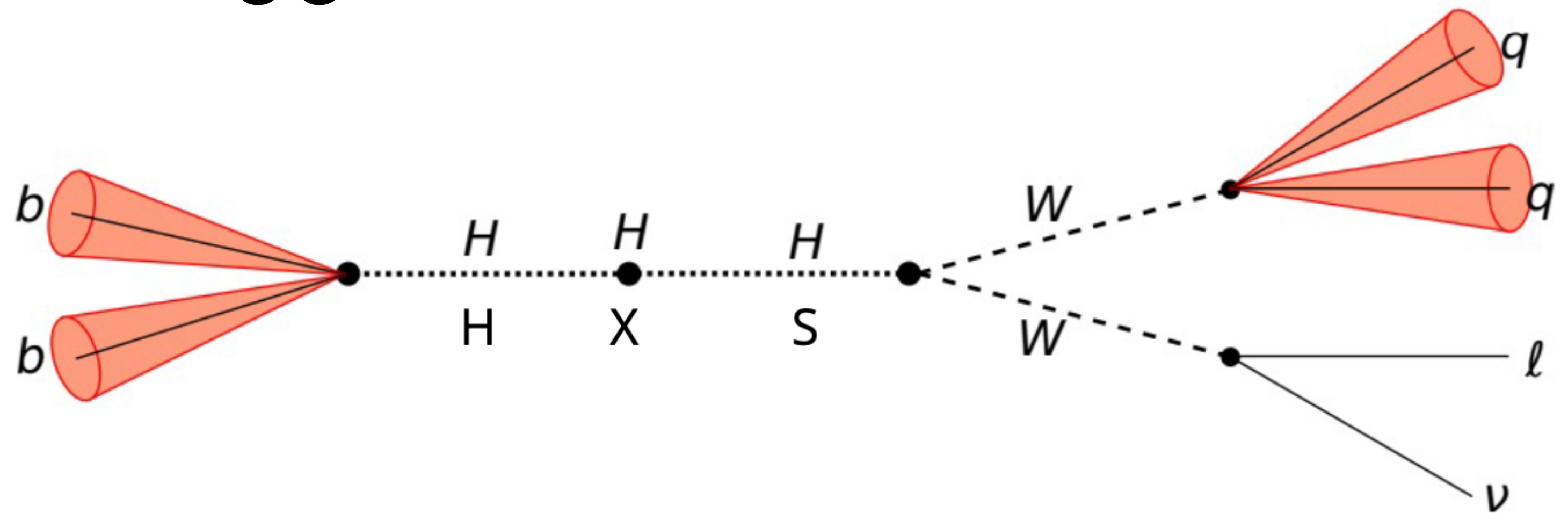


bbWW 1-lepton di-Higgs search

Jakob Novak

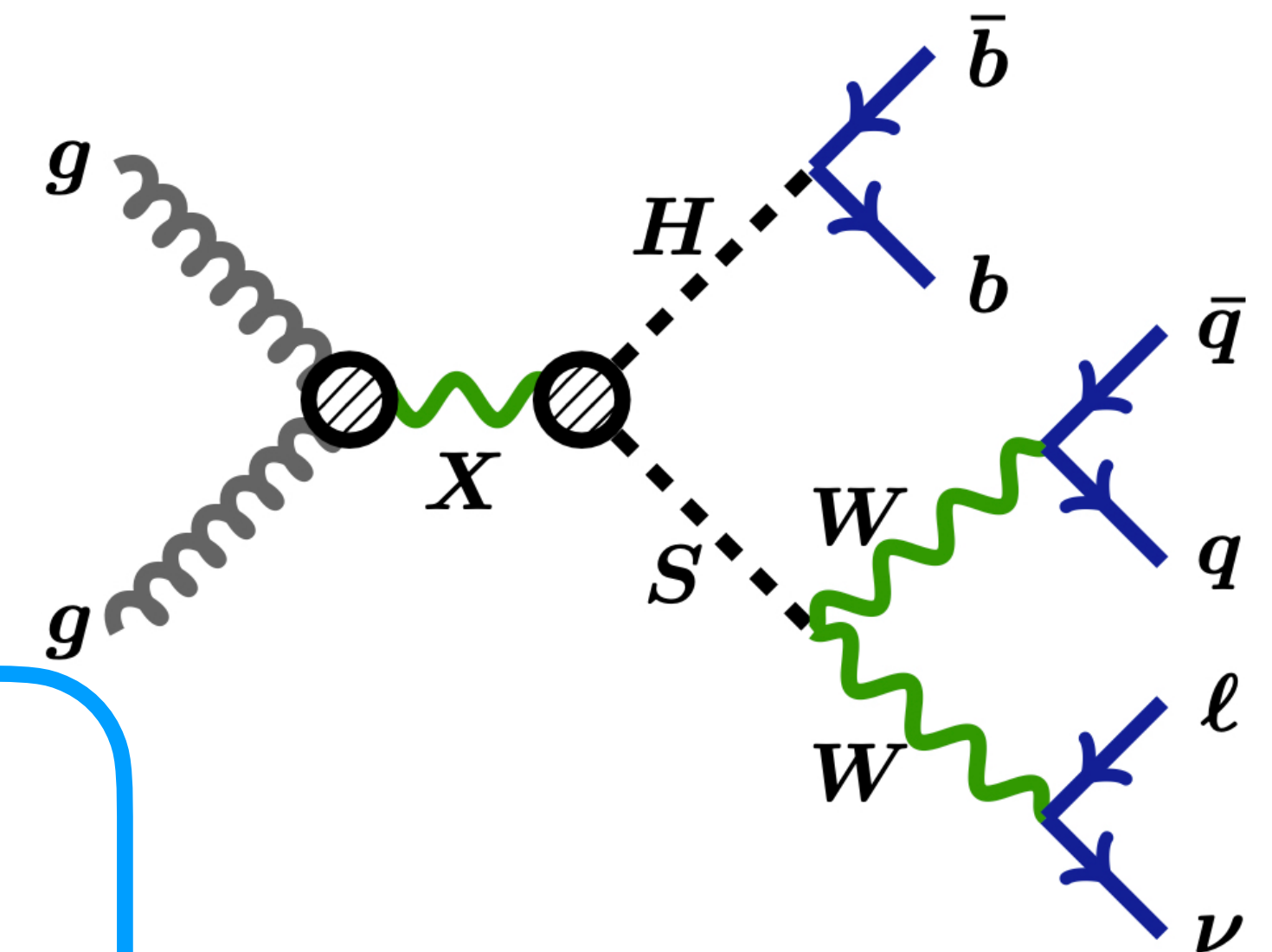
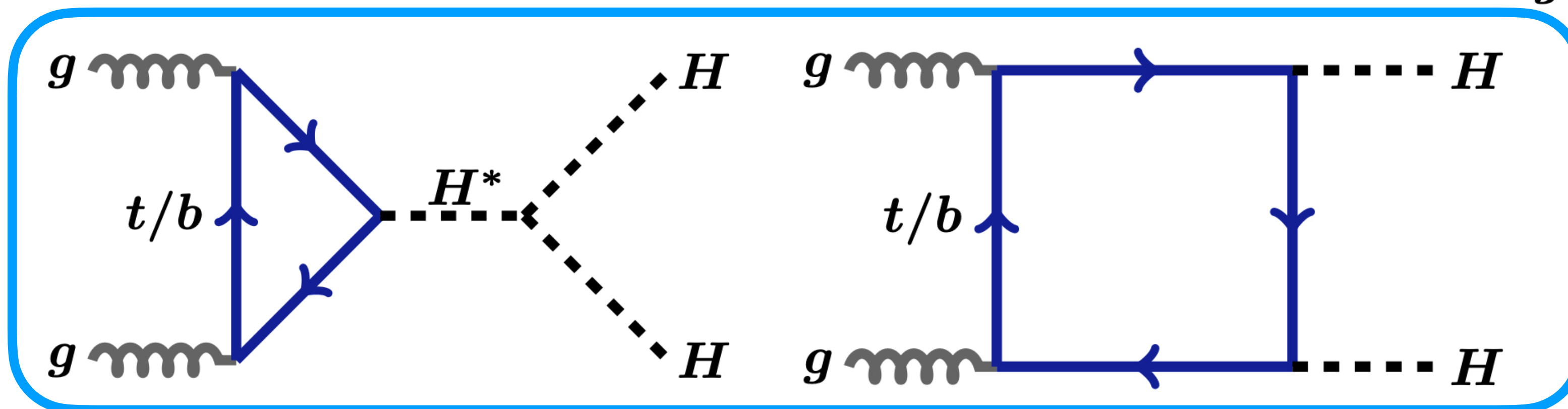
F9 strategic meeting,
Krvavec, 28/09/2026



Di-Higgs signal

- Gives access to the value of the Higgs self-coupling $\kappa_\lambda (= \lambda_3/\lambda_{3,SM})$, which describes the shape of the Higgs potential
- Higgs pair production process is predicted by the Standard Model with a tiny cross-section:
 - $\sigma(gg \rightarrow HH) = 31.1 \text{ fb}$, 20.000x smaller than $t\bar{t}$, $\sigma(gg \rightarrow t\bar{t}) = 730 \text{ pb}$
 - No single gold-plated channel: $bb\gamma\gamma$, $bb\tau\tau$, $bbbb$, $bbVV$ (1L, 2L, $\geq 3L$), ...
- Unexplored territory, BSM physics may show up as:
 - Cross-section enhancement
 - Distinct resonant experimental signature

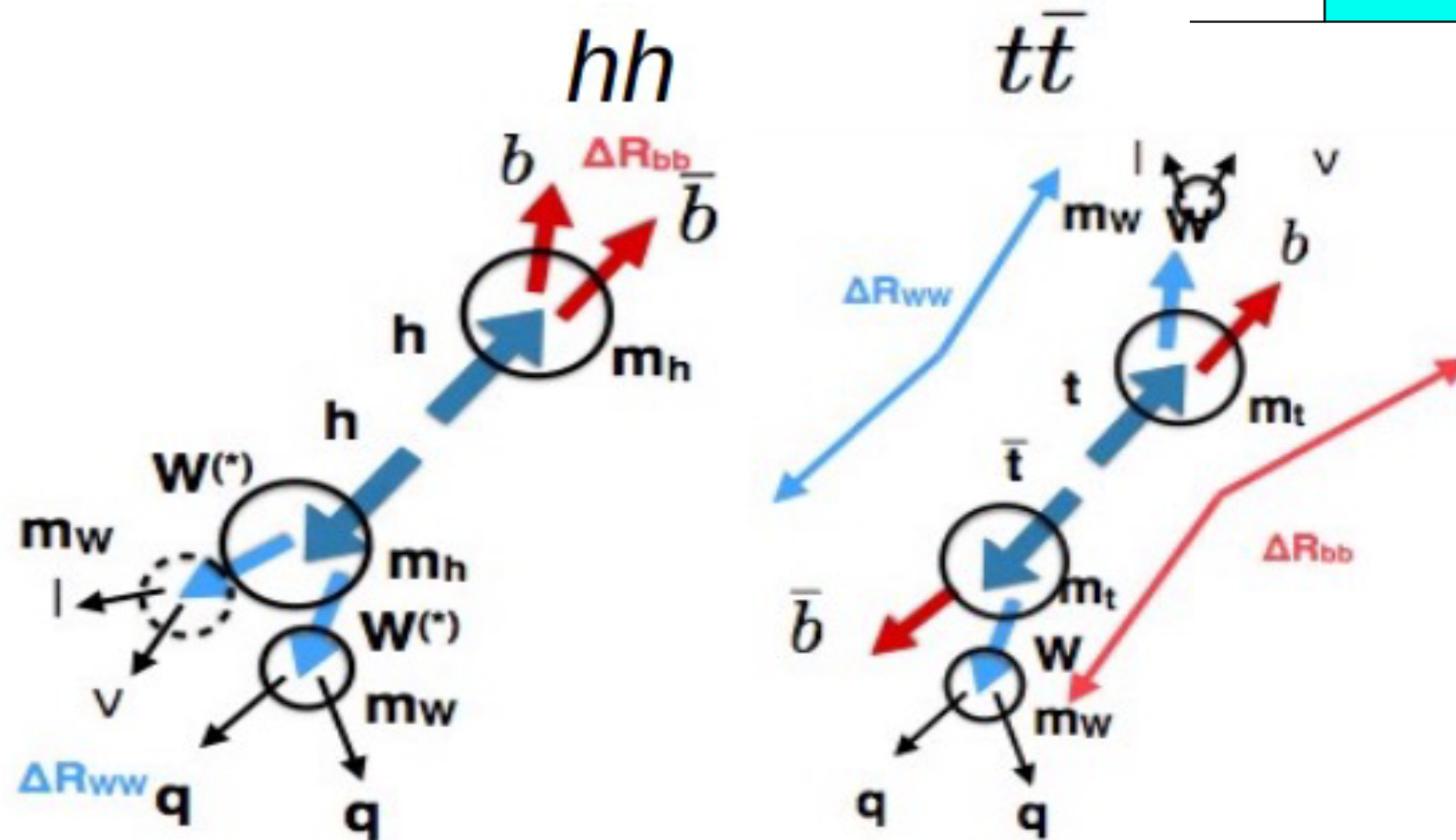
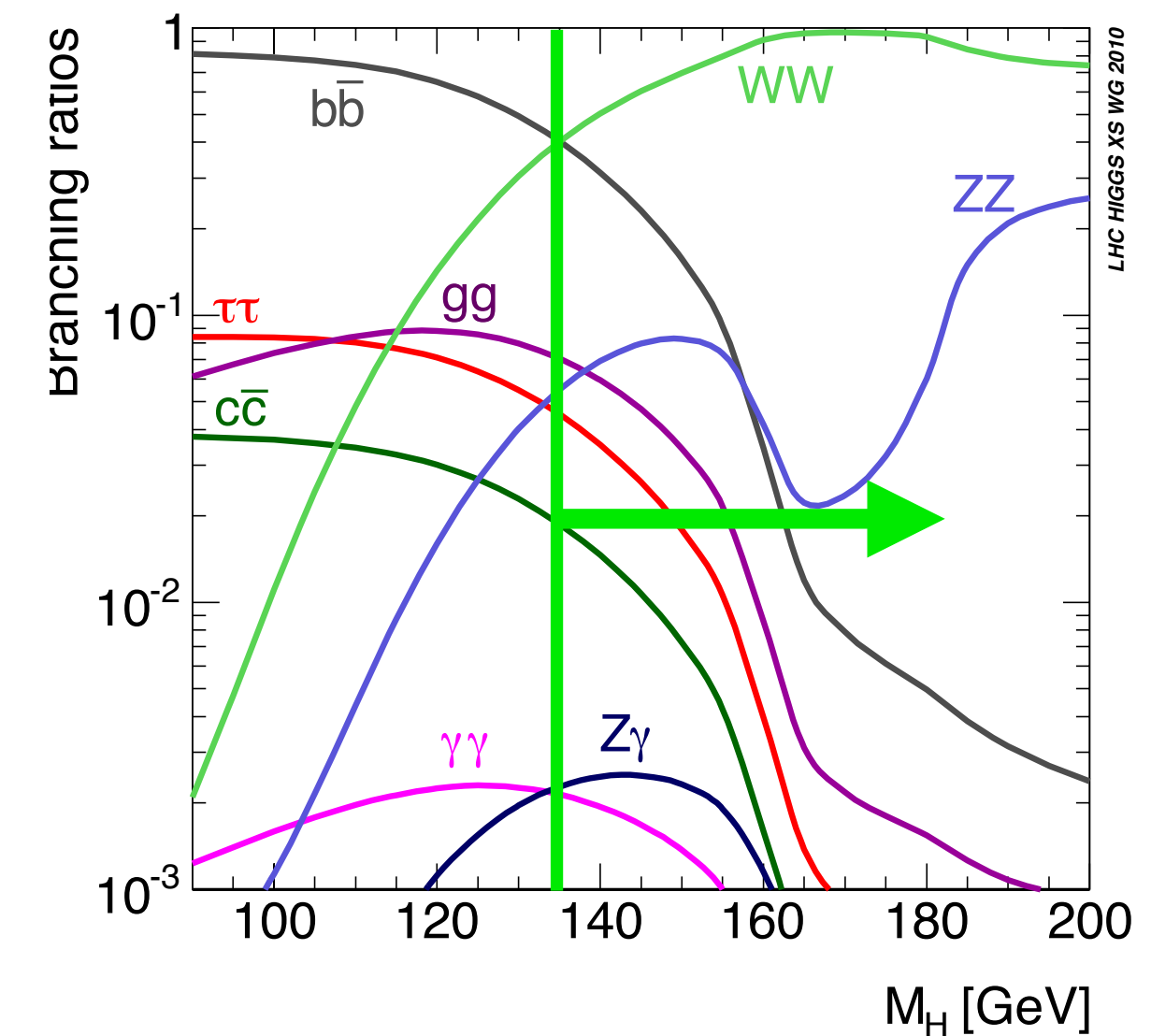
Interference



HH (SH) $\rightarrow$ bbqq channel

- Second largest HH Branching Ratio:
 $\mathcal{B}(HH \rightarrow bbWW^*) \sim 25\%$
- SH model consistent with:
 - Next-to-minimal Supersymmetric SM
 - Two Higgs Doublet Models with a singlet
 - SM with two additional singlets

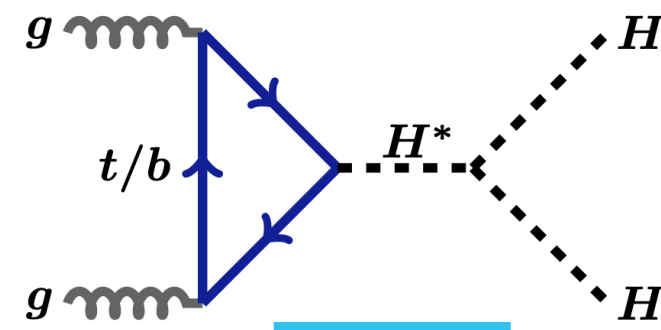
	bb	WW	$\tau\tau$	ZZ	$\gamma\gamma$
bb	33%				
WW	25%	4.6%			
$\tau\tau$	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
$\gamma\gamma$	0.26%	0.10%	0.029%	0.013%	0.0005%



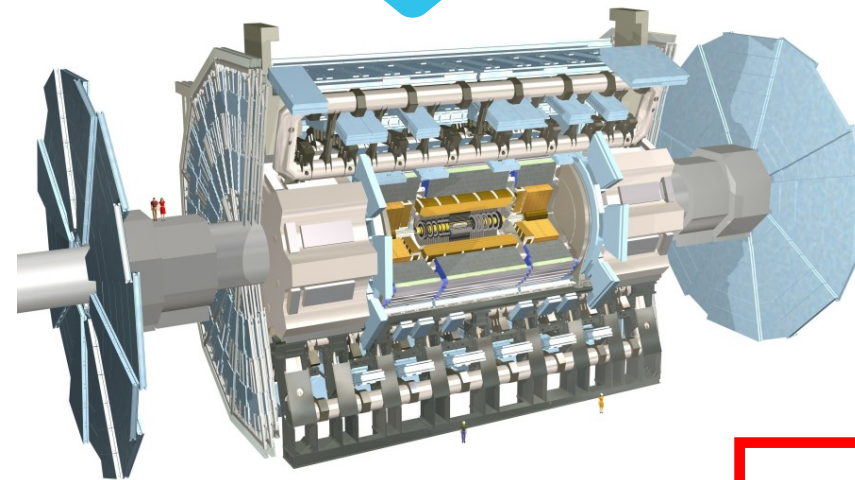
- Isolated lepton, MET, 2 resolved b-jets, 2 jets forming (off-shell) W
- Kinematic differences between the signal and the background:
 - Mass constraints: m_{WW} and m_{bb}
 - Presence of an off-shell W in the signal process
 - Angular variables: opening angles between b-jets

Analysis workflow

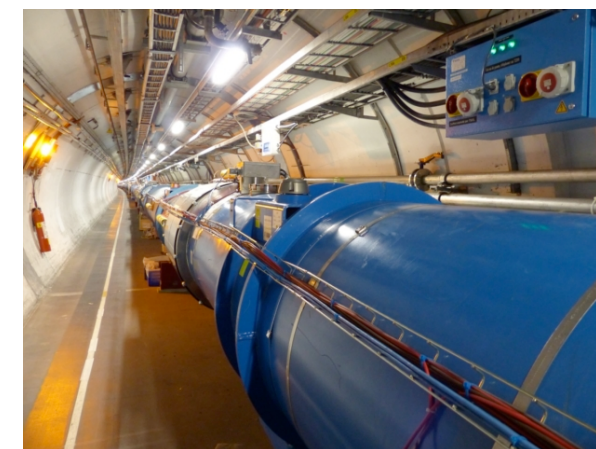
MC generator



Detector
simulation

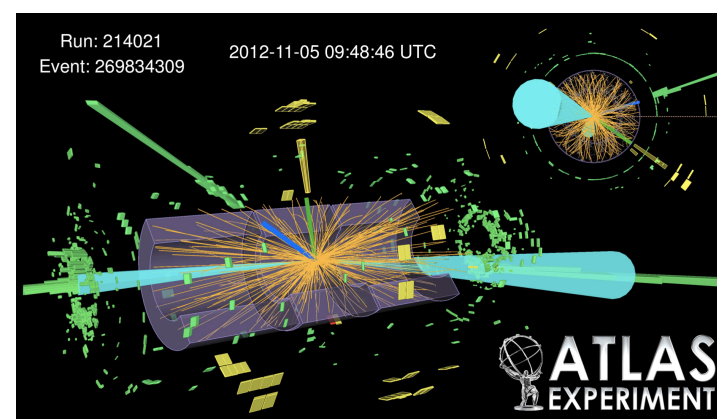


Trigger



LHC data

Event reconstruction



Event
selection

Trigger:

- Lepton or MET

Event selection (preselection):

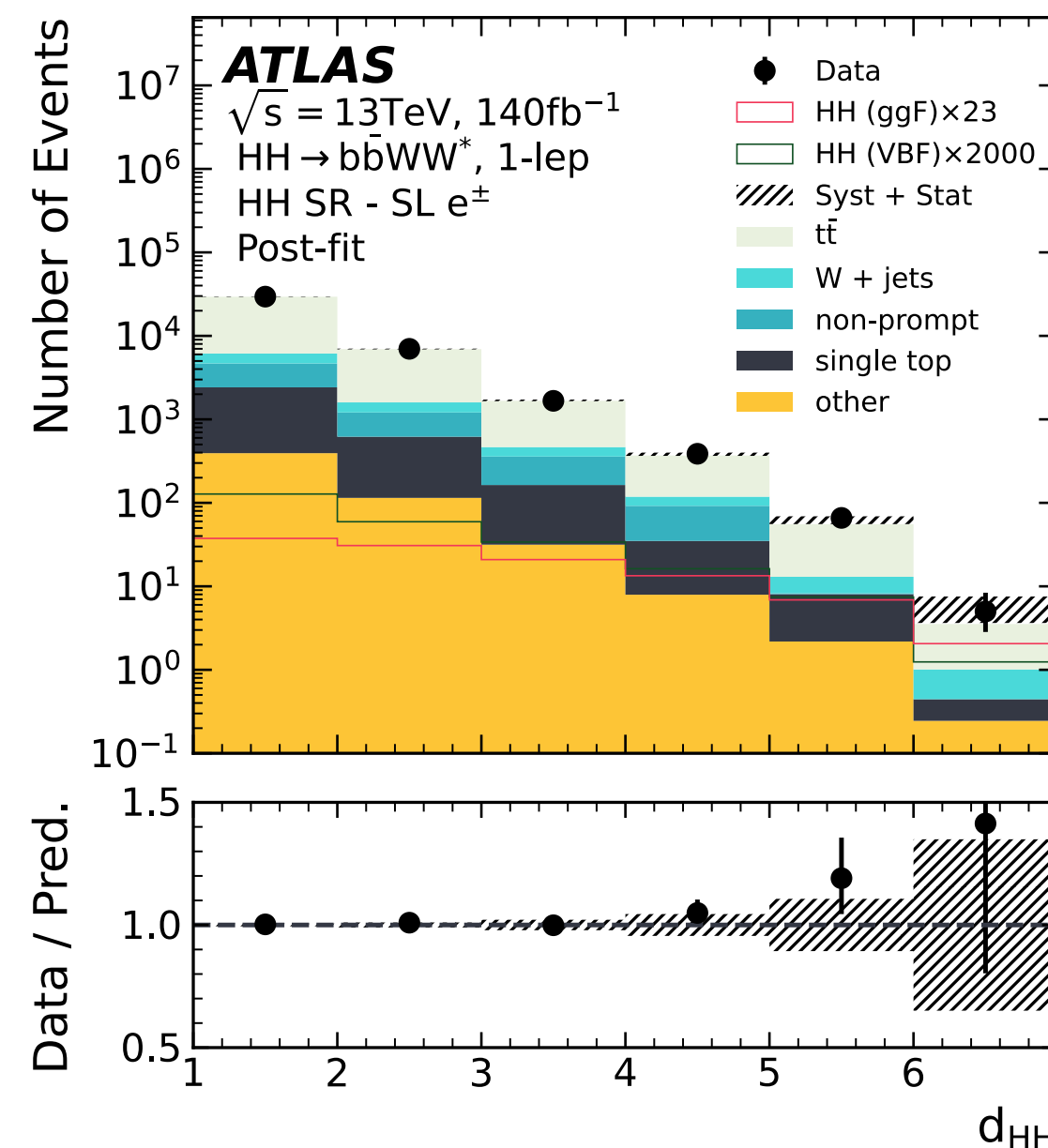
- 1 lepton, 2 b-tagged jets (DL1r at 77% WP), at least 2 light jets

Irreducible background:

- $t\bar{t}$, W+jets, single-top (Wt mainly), Z+jets, diboson
- Estimated using MC simulation
- Control region fit to correct for the normalisation mismodelling

Reducible background:

- Fakes (jets reconstructed as leptons)
- Non-prompt leptons (originating from secondary vertices due to interactions with detector material)
- Data-driven estimation



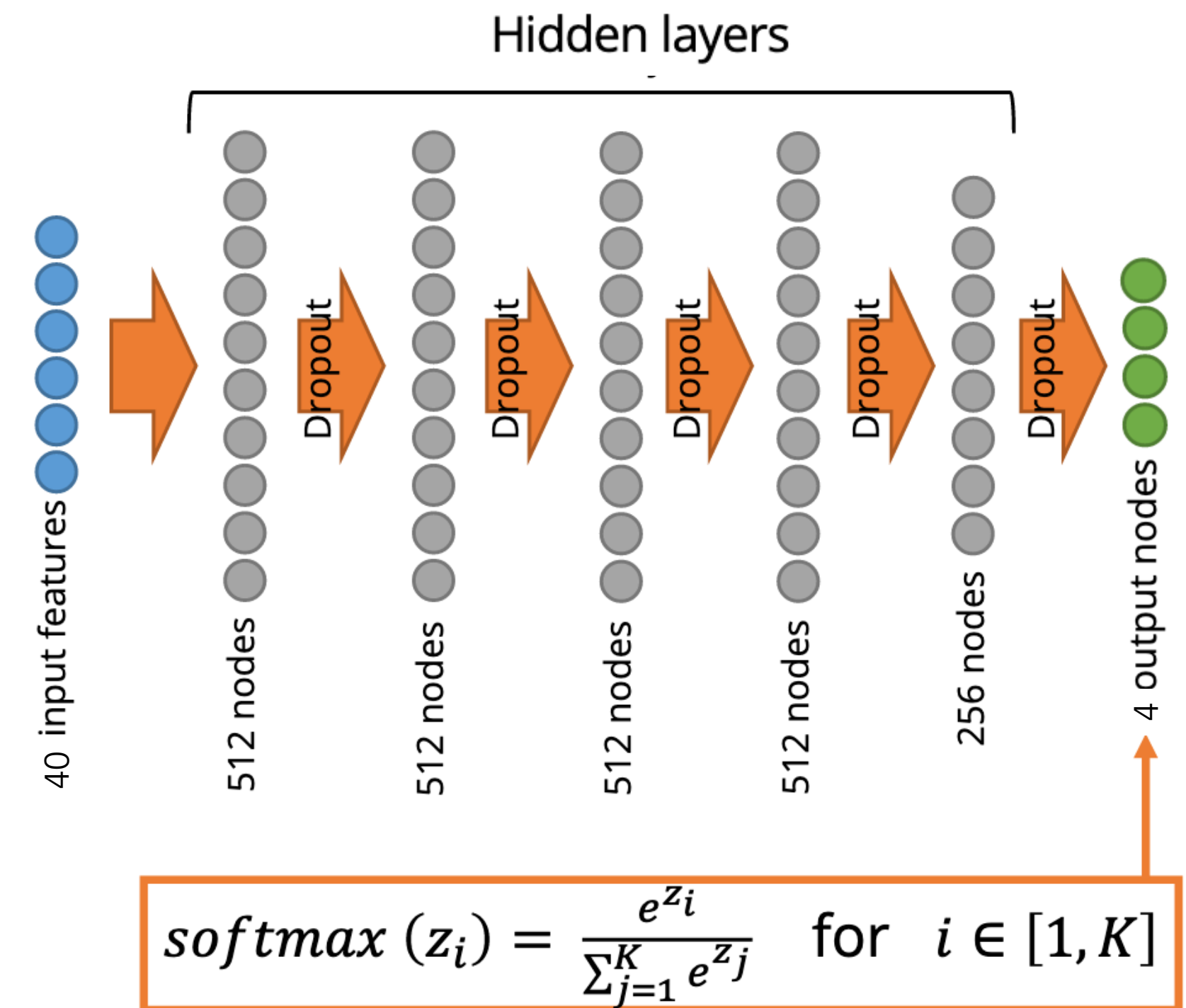
Machine learning

- Feed-forward neural network classifier for discrimination of the signal and 3 main backgrounds: $p_{\text{signal}}, p_{\text{ttbar}}, p_{\text{Wjets}}, p_{\text{stop}}$
- 40 input features
- 5 hidden layers, 0.5 dropout rate
- 5-fold cross-validation, 20% test set

$$d_{\text{signal}} = \log \left(\frac{p_{\text{signal}}}{1 - p_{\text{signal}}} \right)$$

Output scores

SH0 SH1 SH2 SH3 SH4 SH5



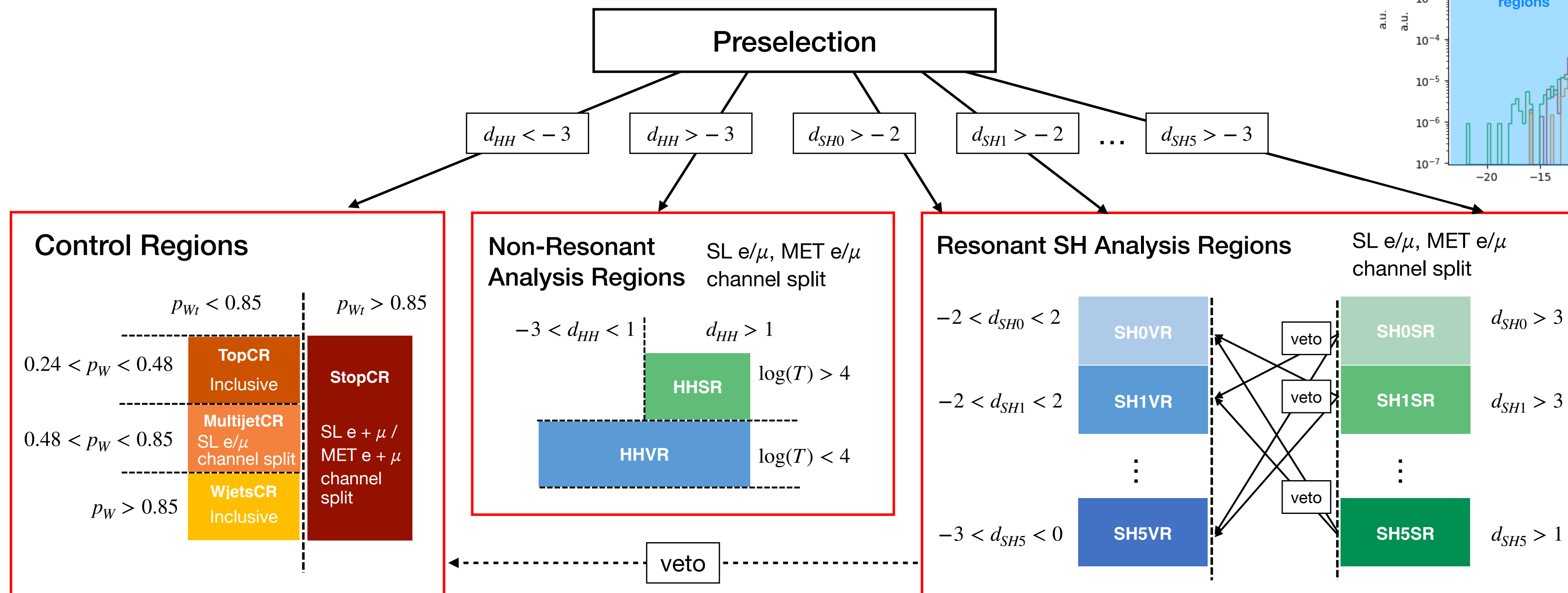
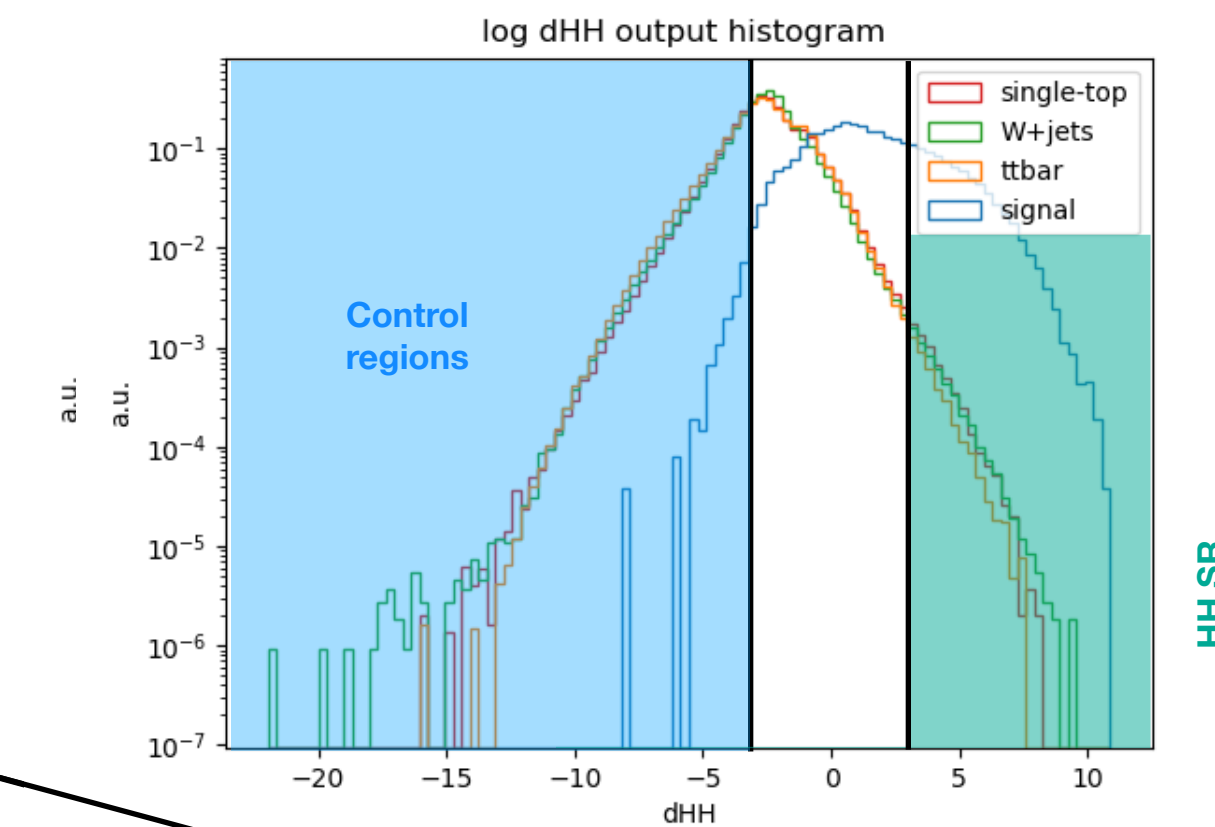
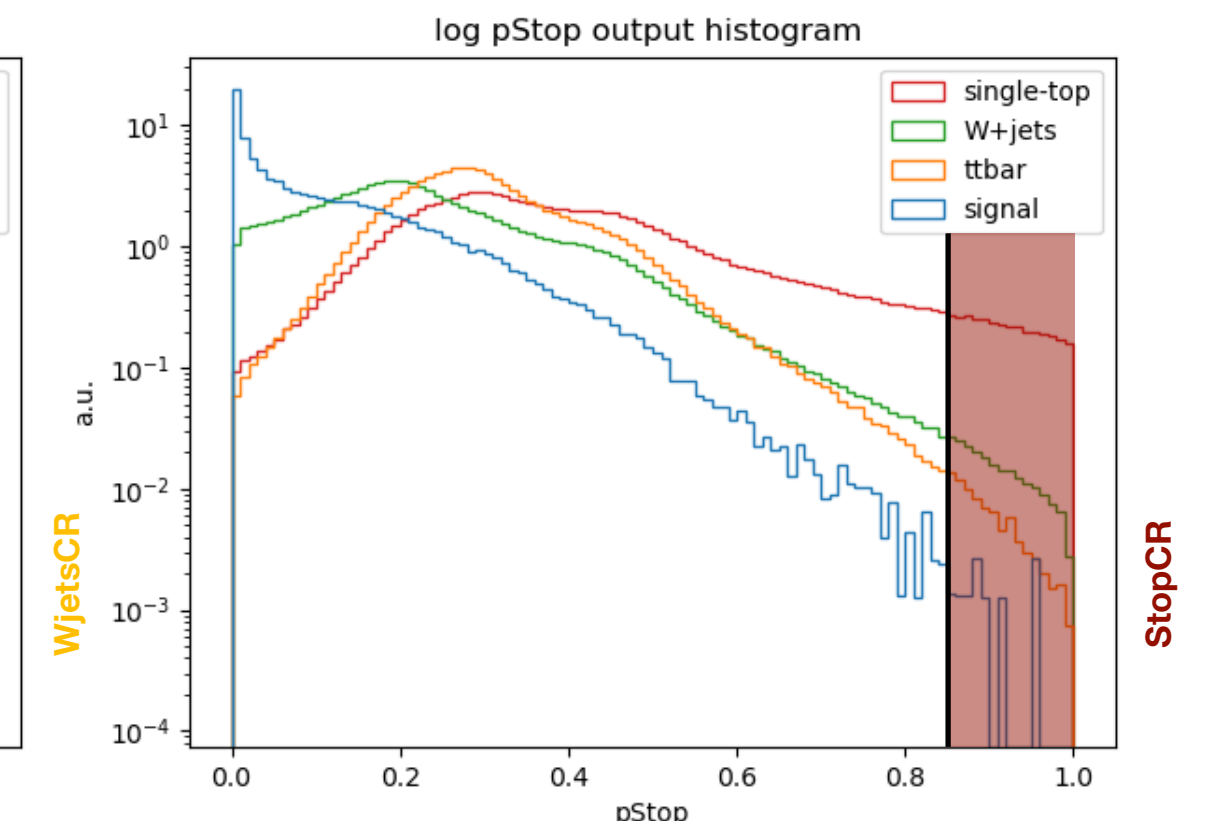
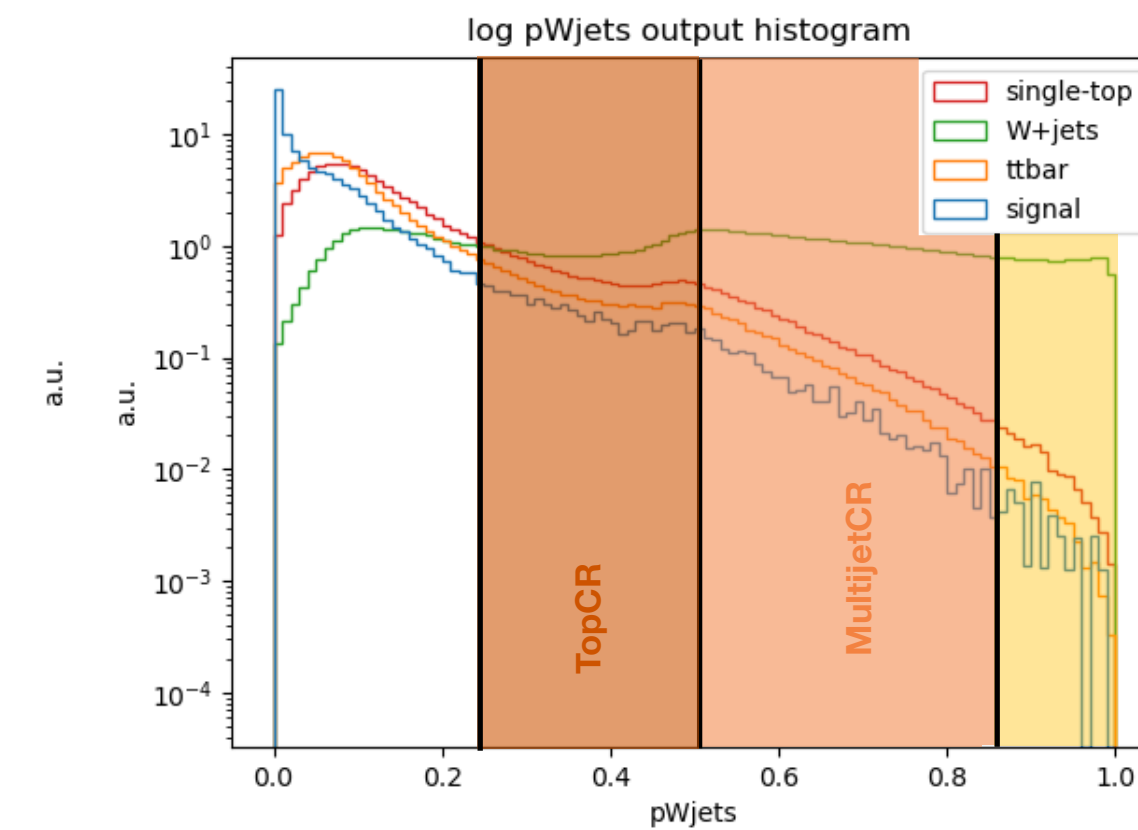
SH challenge:

- 42 mass hypotheses
- Single classifier sub-optimal, 42 classifiers overkill $\rightarrow$ 6 groups
- Train on a mix of mass points with a similar boost (m_s/m_x ratio)

$m_x \backslash m_s$	170 GeV	240 GeV	400 GeV	550 GeV	750 GeV	1 TeV	1.5 TeV	2 TeV	2.5 TeV
350 GeV	0.49								
500 GeV	0.34	0.48							
750 GeV	0.23	0.32	0.53	0.73					
1 TeV	0.17	0.24	0.40	0.55	0.75				
1.5 TeV	0.11	0.16	0.27	0.37	0.50	0.67			
2 TeV	0.08	0.12	0.20	0.27	0.37	0.50	0.75		
2.5 TeV	0.07	0.10	0.16	0.22	0.30	0.40	0.60	0.80	
3 TeV	0.06	0.08	0.13	0.18	0.25	0.33	0.50	0.67	0.83

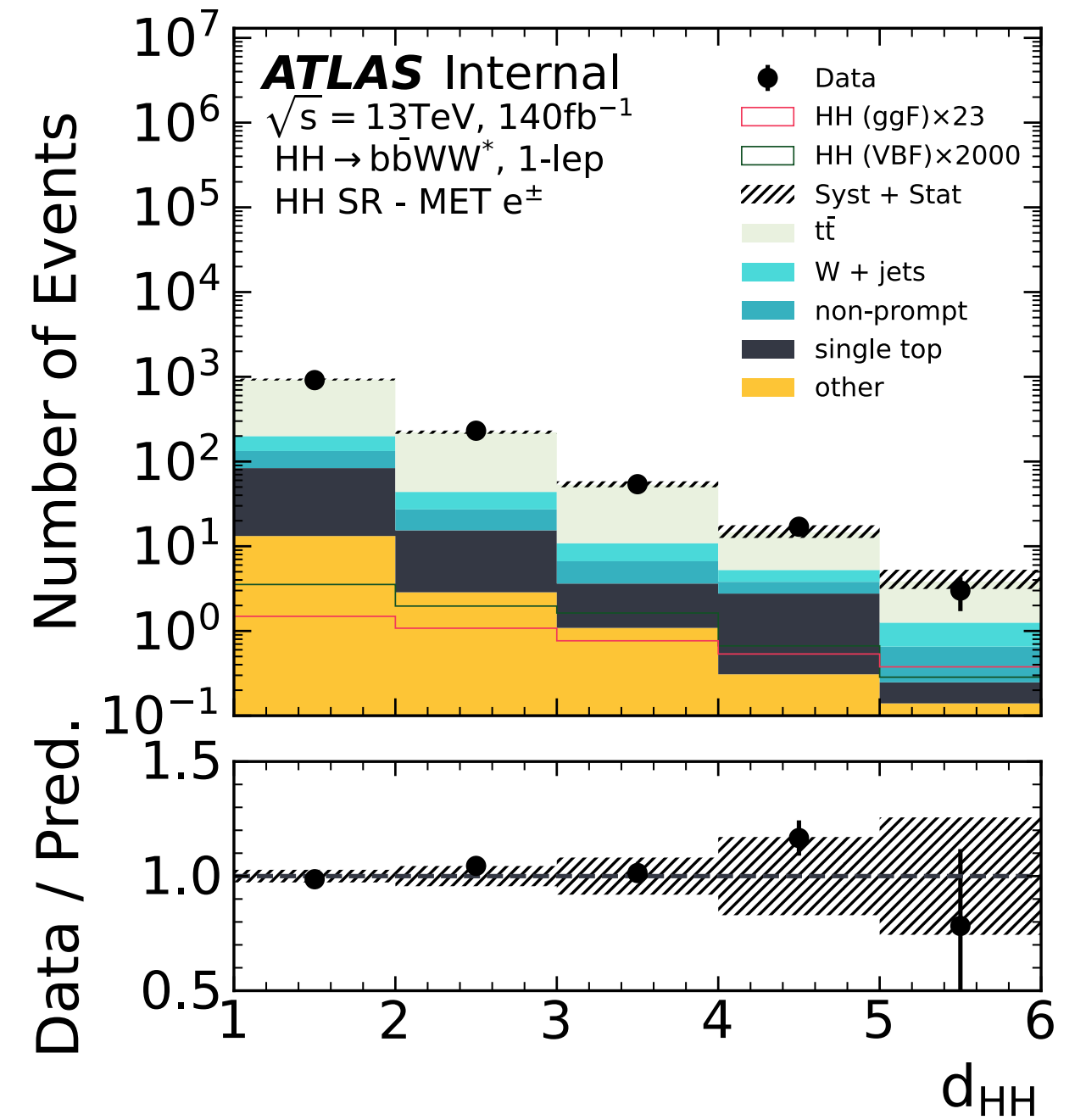
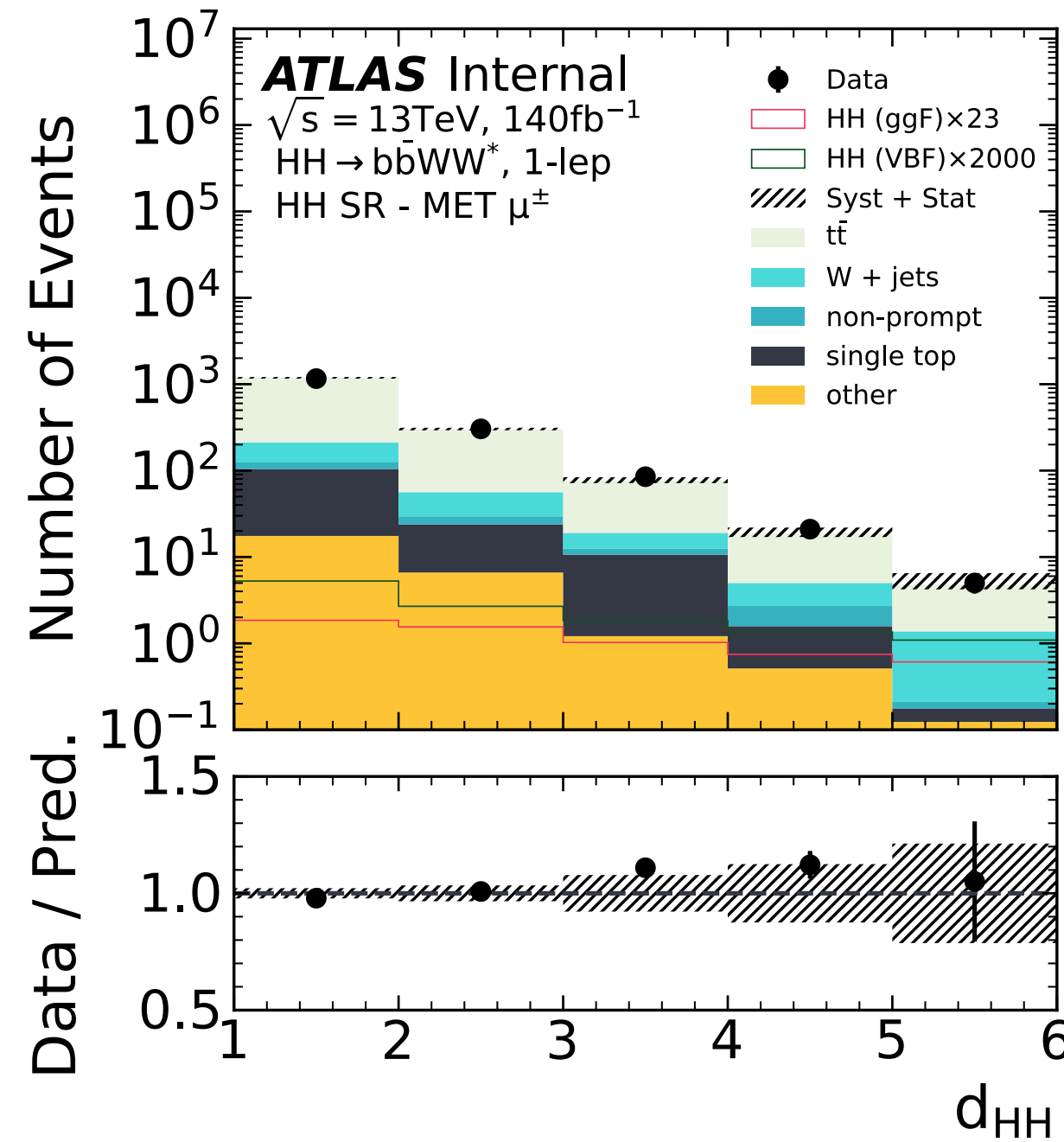
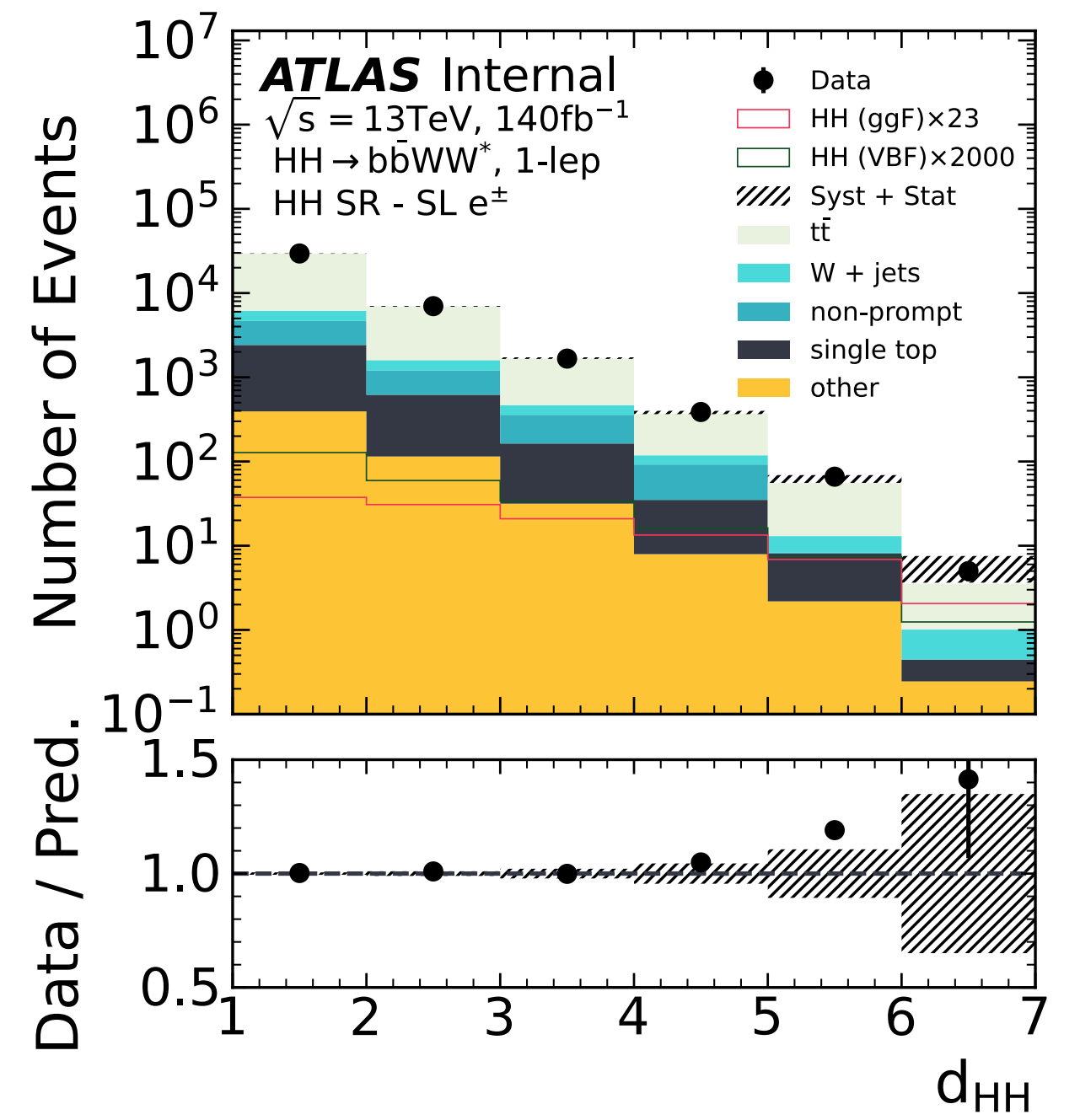
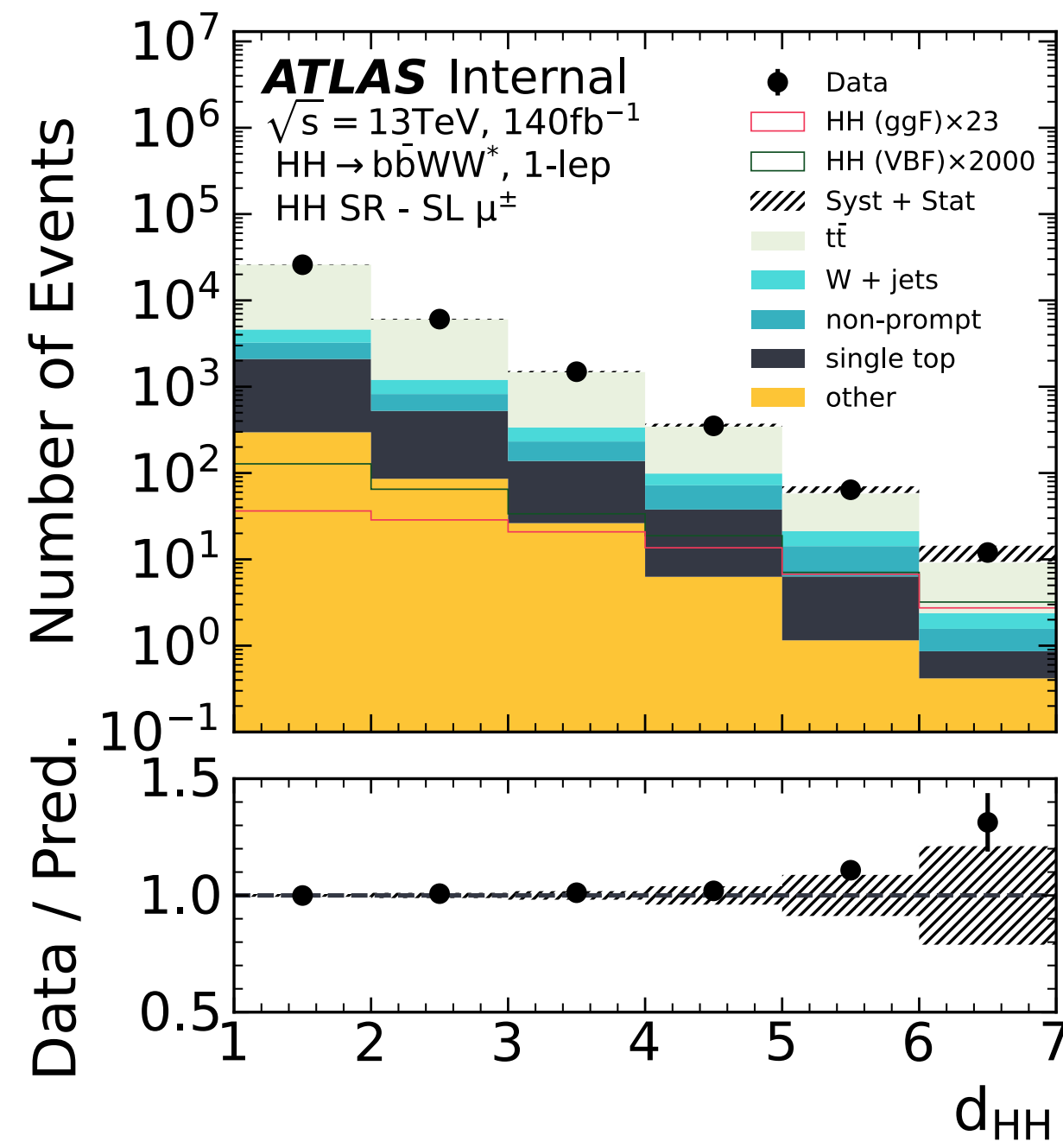
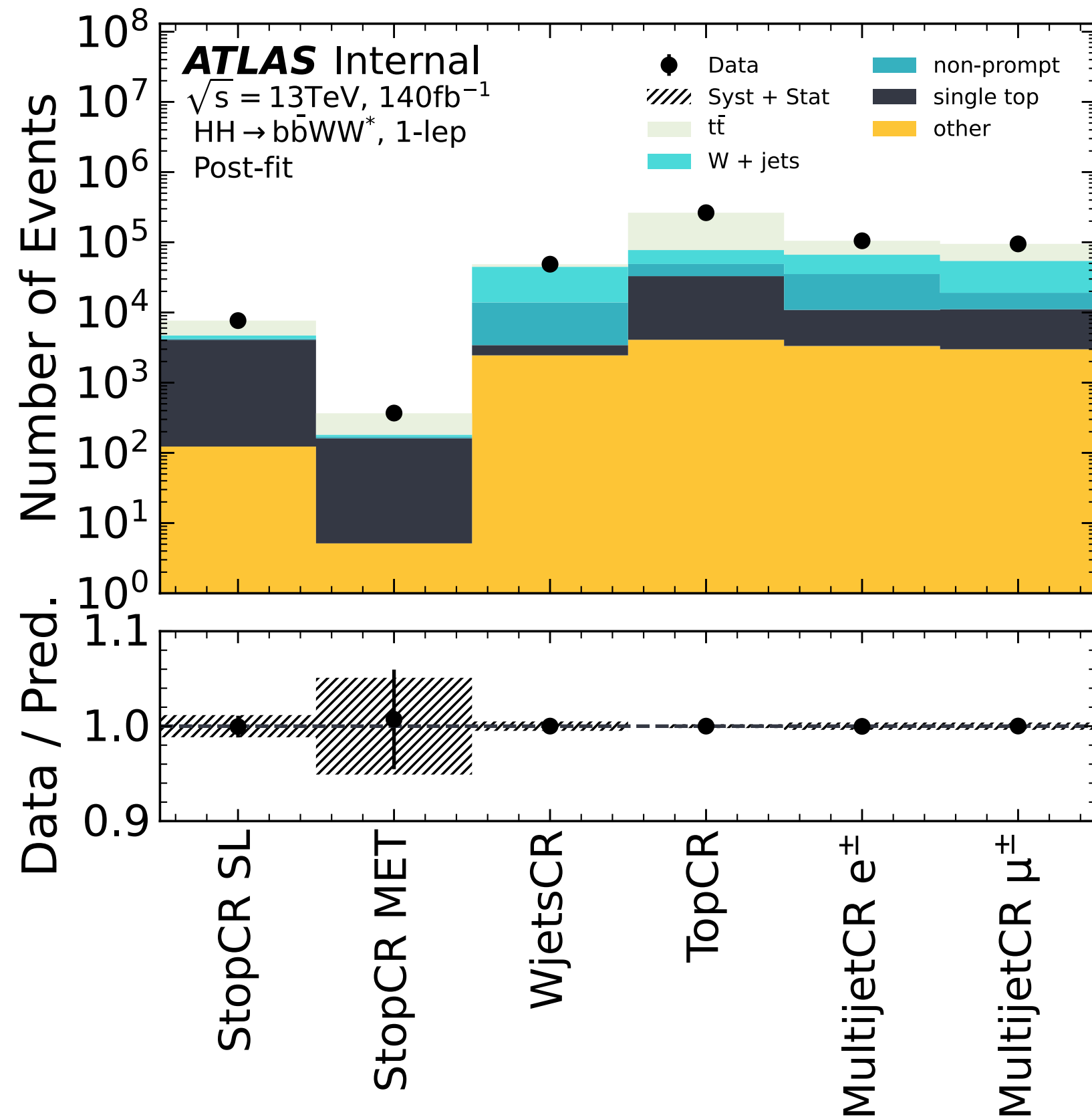
Analysis regions

- 4 control regions to correct the normalisation of the 4 dominant backgrounds: $t\bar{t}$, W+jets, single-top and fakes
- 7 validation regions to check background modelling in the signal region



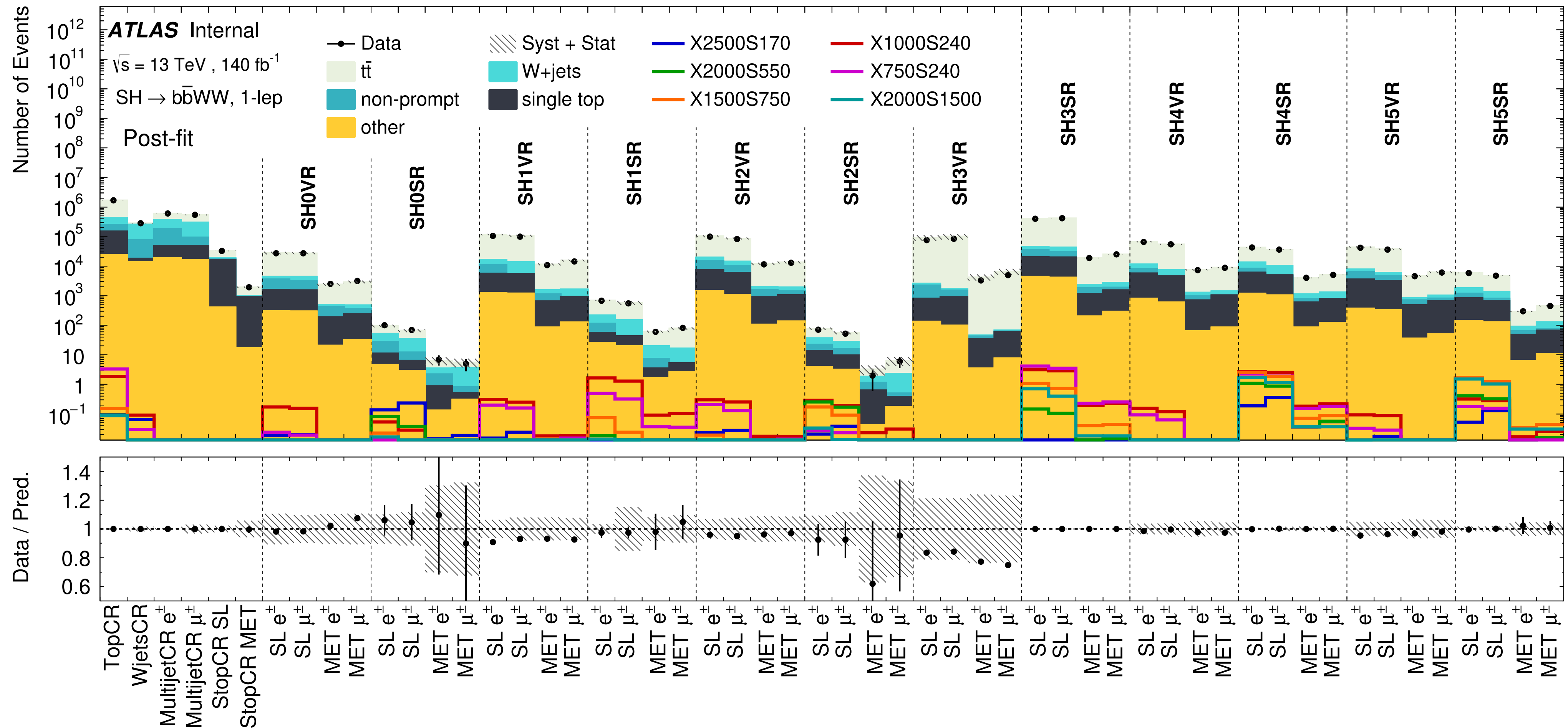
Fit results

- Good agreement in CRs
- 1 sigma excess observed in the non-resonant SR



Fit results

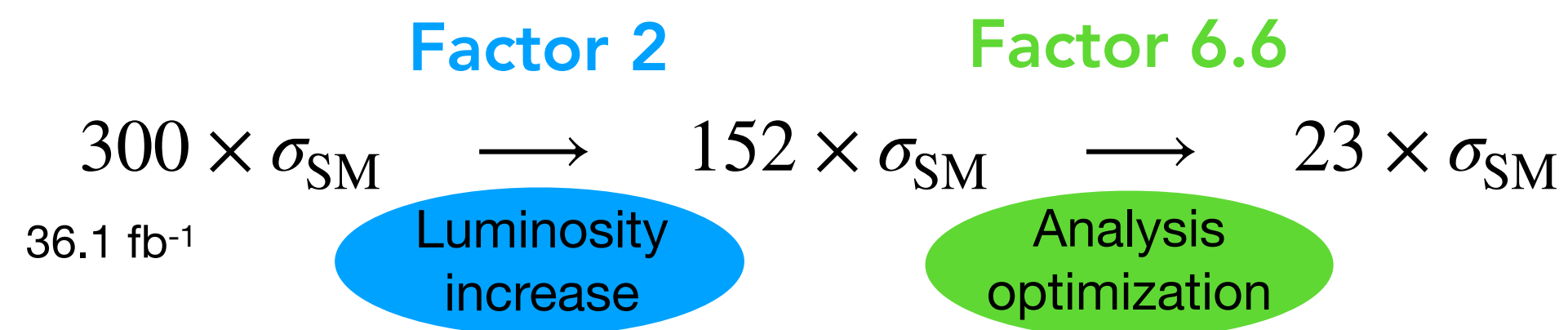
- 1 sigma excess in the SH3 VR, no excess in the SH SRs



Exclusion limits

Non-resonant analysis:

- 95% CL upper limit on the $HH \rightarrow bbWW^*$ cross-section:
 $\sigma(pp \rightarrow HH) < 34.6 \ (23.0^{+10.1}_{-7.0}) \times \sigma_{SM}(pp \rightarrow HH)$
- Factor 13 improvement wrt the previous ATLAS $HH \rightarrow bbWW^*$ [result](#) on 36.1 fb⁻¹
- Same ballpark as 138 fb⁻¹ [CMS](#) result $HH \rightarrow bbWW^*$ 1-lepton ($27 \times \sigma_{SM}$)
- Paper coming out in next weeks



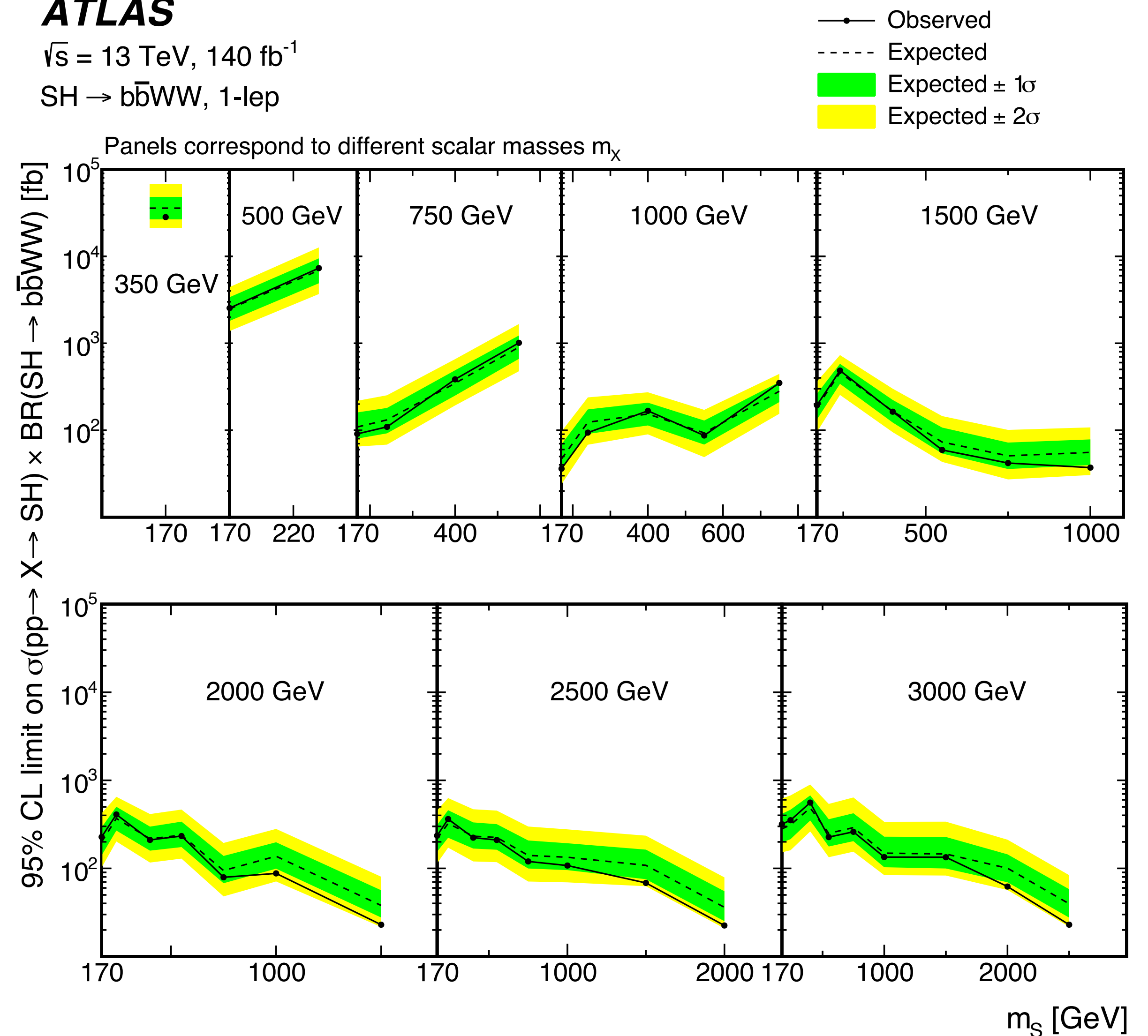
Resonant SH analysis:

- Competitive result in the range $m_X = [750, 1000]$ GeV

ATLAS

$\sqrt{s} = 13$ TeV, 140 fb⁻¹

SH $\rightarrow b\bar{b}WW$, 1-lep



Di-Higgs combination

- The dominant channels are $bb\gamma\gamma$, $bb\tau\tau$, $bbbb$
- $bbWW$ 1-lepton channel sub-dominant, ongoing discussions whether we should enter the combination
- 3σ anticipated at HL-LHC, however 5σ may not be out of reach

