Investigation of Z+heavy flavour Background in the $HH \to b\bar{b}\tau^+\tau^-$ Search at the ATLAS Experiment

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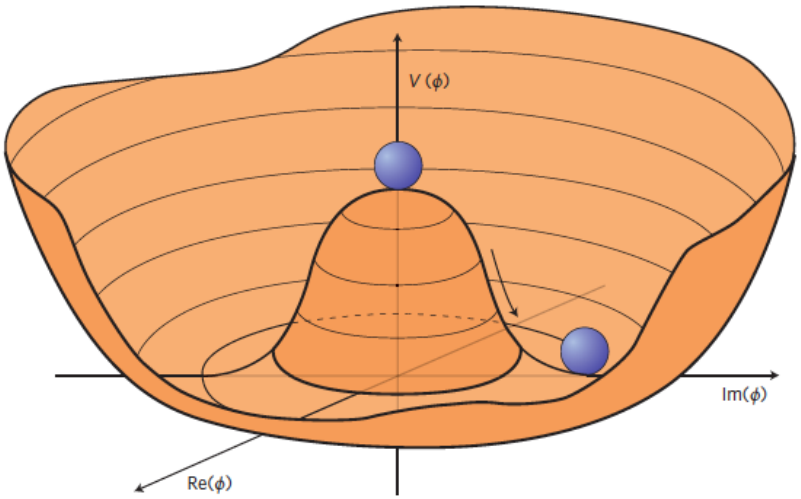
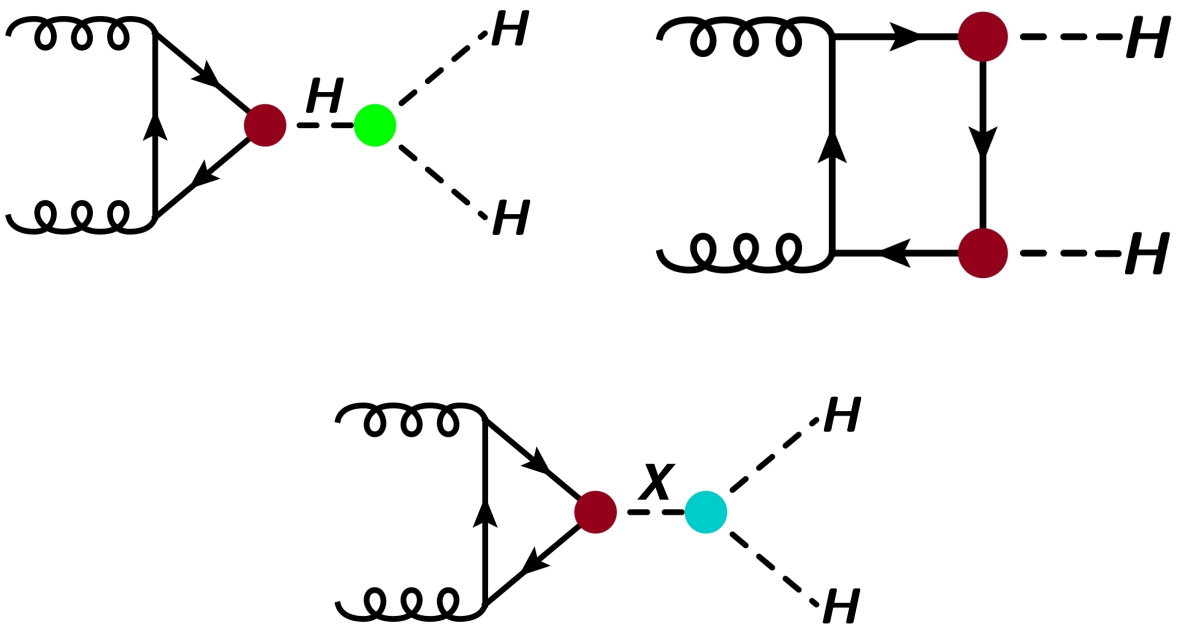
Motivation

- Higgs pair production predicted by the SM $\rightarrow$ Higgs potential yields 3-point vertices with the coupling constant $\lambda_{hhh}^{SM} = \frac{3m_h^2}{v^2}$
- Probing Higgs self-coupling



$$V = -\mu^2\phi^\dagger\phi + \lambda(\phi^\dagger\phi)^2$$

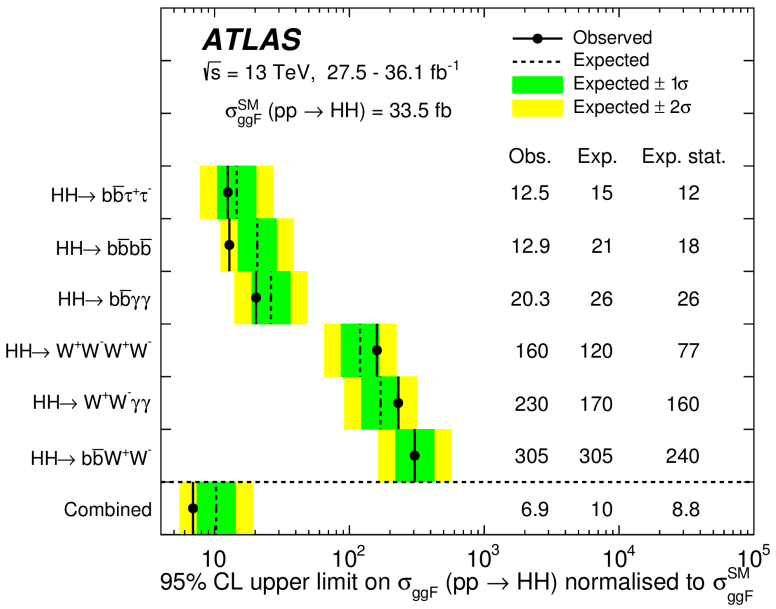
Di-Higgs Searches

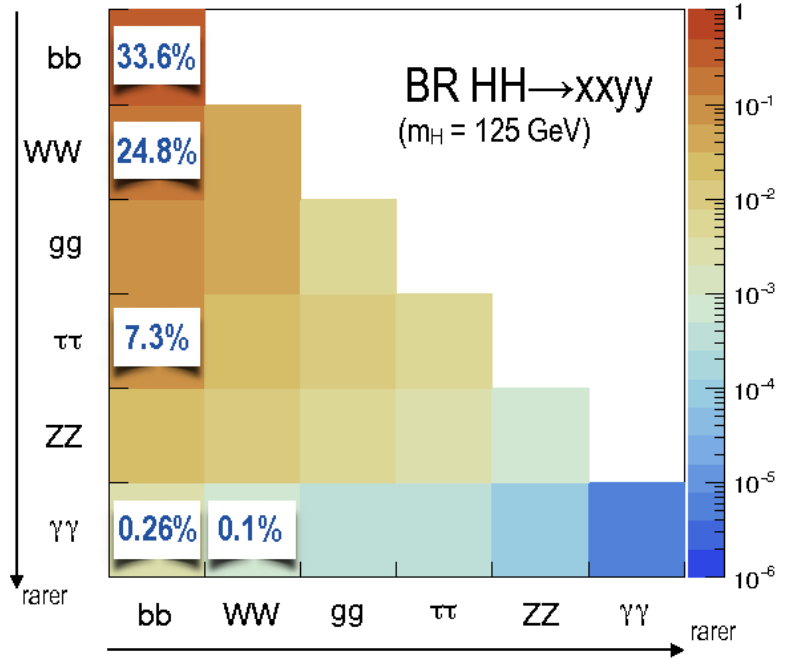


- Higgs self-coupling
- Problem: Destructive interference $\rightarrow$ cross section expected to be very low (31 fb for $\sqrt{s} = 13$ TeV)
- Heavier boson could decay into 2 SM Higgs boson $\rightarrow$ Door to BSM?

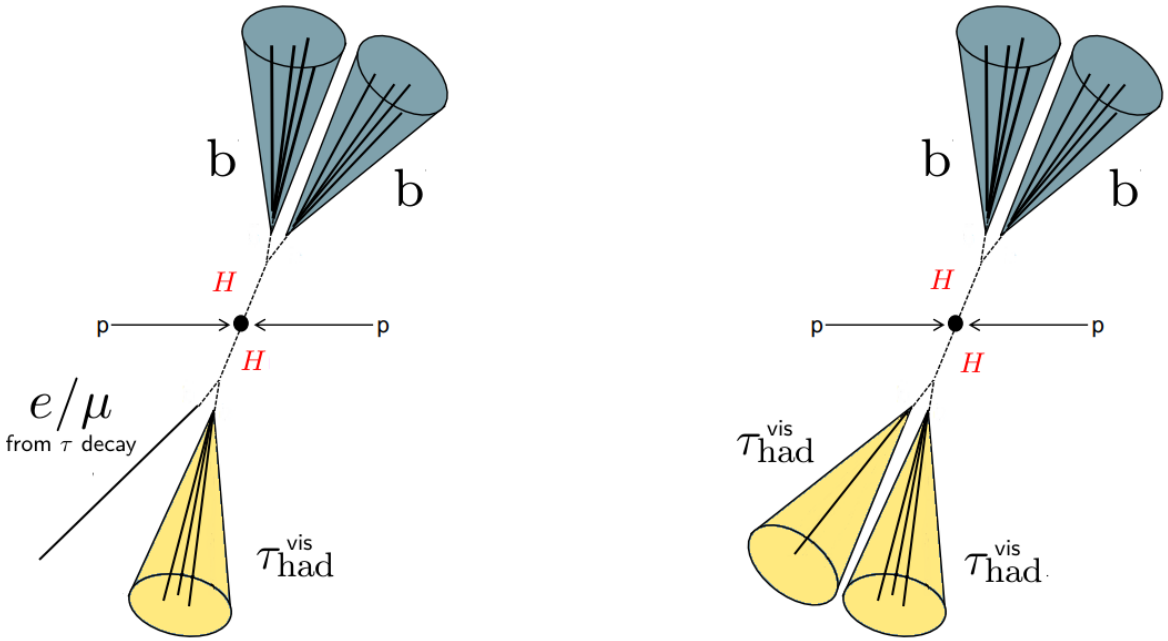
Decay Channel

- $HH \to b\bar{b}\tau^+\tau^-$ does not have the highest BR, but is one of the most sensitive channels
- Lower QCD induced multijet Background than e.g. $HH \to b\bar{b}b\bar{b}$



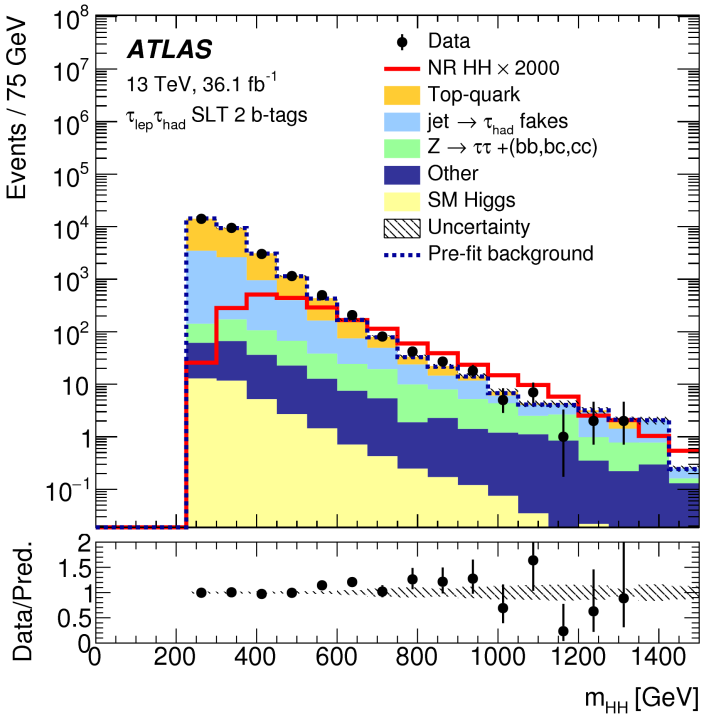


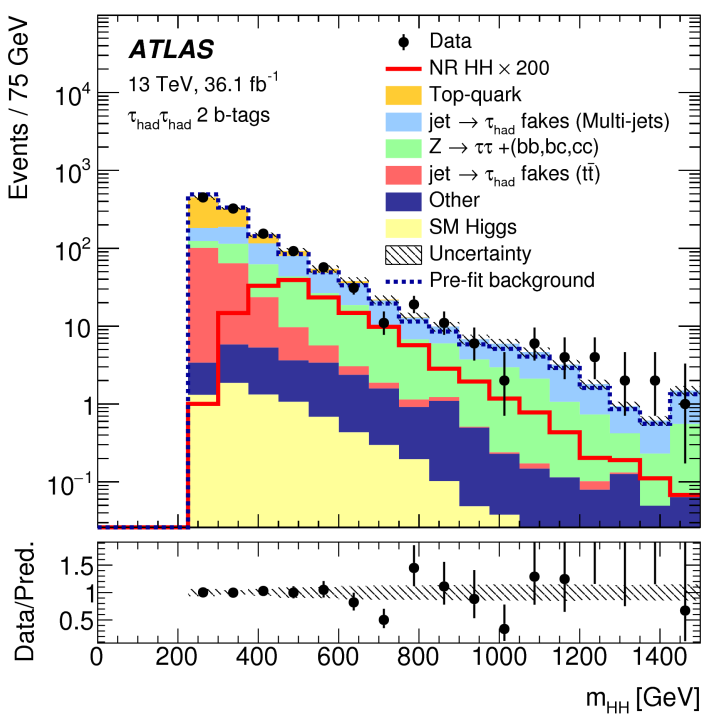
The $HH \to b\bar{b}\tau^+\tau^-$-Channel



- Distinguish between $\tau_{lep}\tau_{had}$ (46%) and $\tau_{had}\tau_{had}$ (42%)
- Boosted decision tree used to distinguish between signal and background in the signal regions

Backgrounds





- Constrain background normalisation from data
- Important for $Z \rightarrow \tau^+\tau^- + hf$, but defining a pure enough CR was found to be difficult
- Normalisation factor: 1.35 ± 0.17 (from 36.1 fb^{-1} analysis)

$Z \to \tau^+\tau^- + hf$ Normalisation

- Use $Z \to \mu\mu$ as CR (high purity, negligible signal contamination)
- Very loose pre-selection
- Try to improve high uncertainties
- Single muon trigger

Cut	Value
Number of Leptons	$\mu = 2,\ e = 0$
Lepton Charge	Opposite sign
reconstr. Z Mass	$m_{\mu\mu} > 40$ GeV
Z Lepton p_T	$p_T(\mu_0) > 27$ GeV, $p_T(\mu_1) > 7$ GeV
Jets Cut	$p_T(J_0) > 45$ GeV, $p_T(J_1) > 20$ GeV

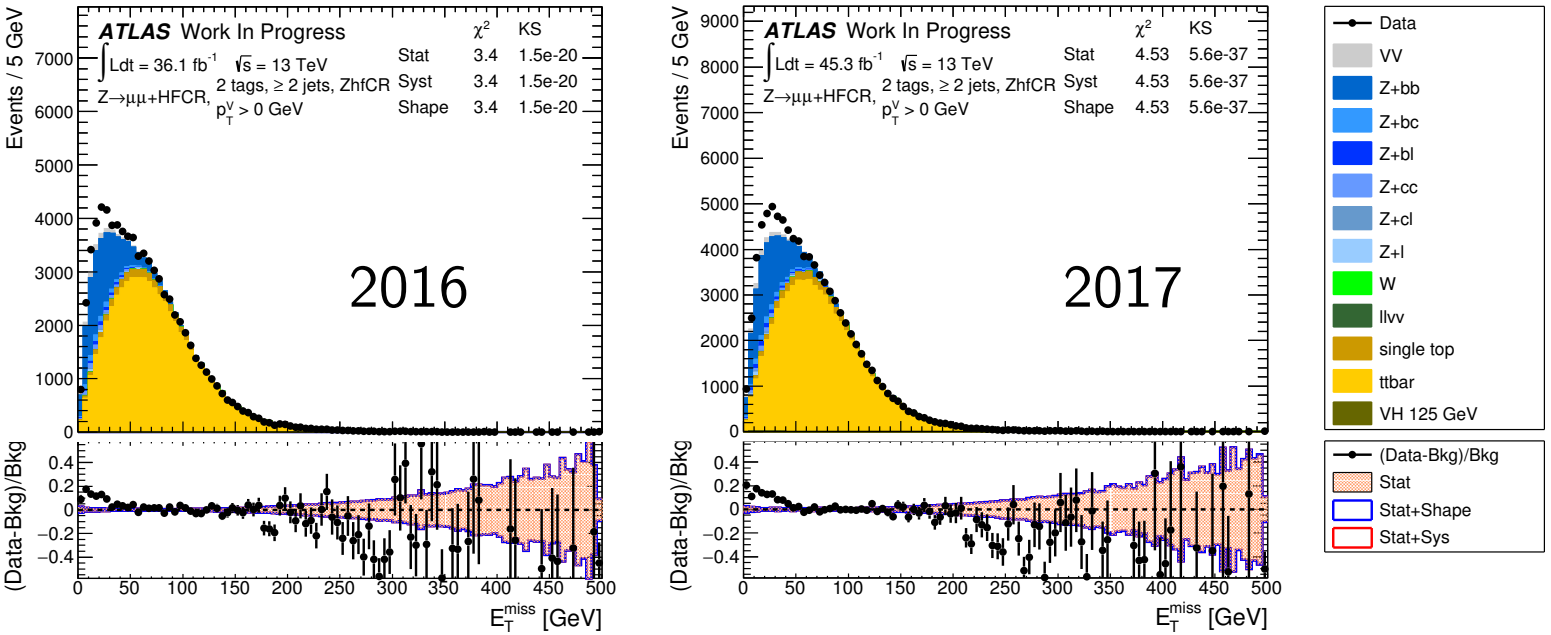
Cuts

Variable cuts (units in GeV)	$\mu_0^{p_T}$	$\mu_1^{p_T}$	$J_0^{p_T}$	$J_1^{p_T}$
Pre-selection	27	7	45	20
Lephad like Analysis	27	27	45	20
Hadhad like Analysis(1)	60	45	80	20
Hadhad like Analysis(2)	60	45	45	45

- Mimic lephad and hadhad with event selection to see how the SF change
- Lephad and hadhad additionally have cuts on m_{bb}, where events in the range 80 GeV $< m_{bb} <$ 140 GeV are vetoed

Cuts

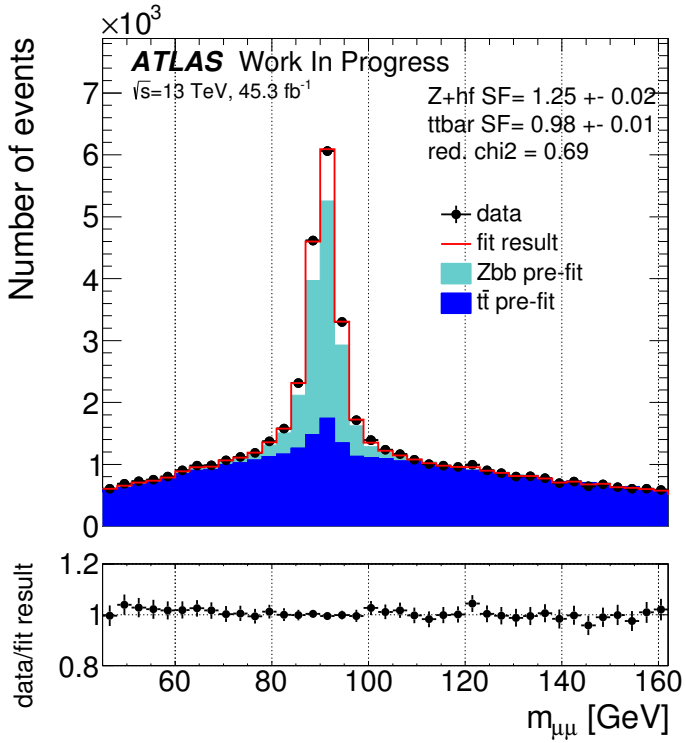
- Investigating additional cuts to increase the Z+hf purity
- Missing transverse Energy (MET) $\rightarrow$ cut out events over 50 GeV to reduce the $t\bar{t}$-bkg



Extracting SFs from Pre-Fit Distribution

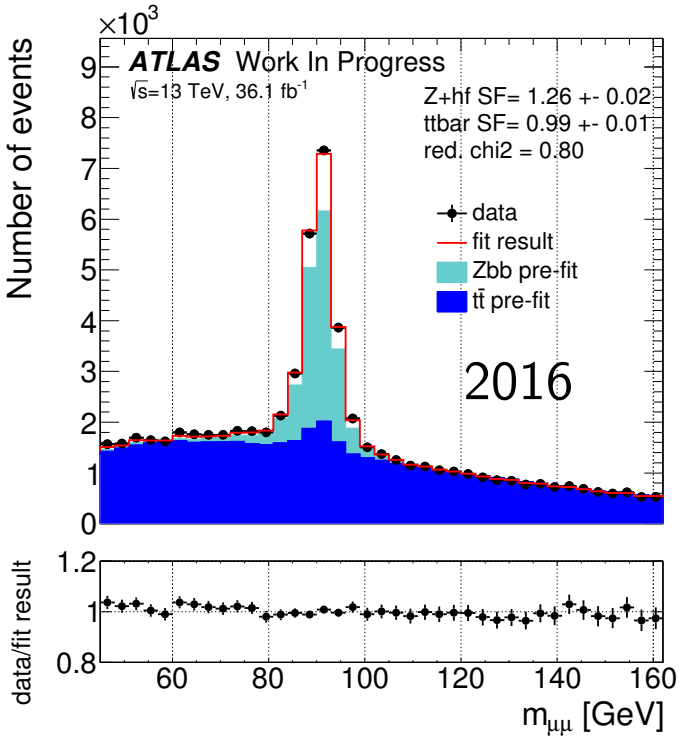
- Fitting $m_{\mu\mu}$ distribution
- Performed with 2-tag distributions
- Template fit with two templates:
  - Zbb template: Z+bb, Z+bc, Z+cc
  - $t\bar{t}$ template: Rest of the backgrounds (incl. Z+ light flavour, single top, ttbar, etc.)

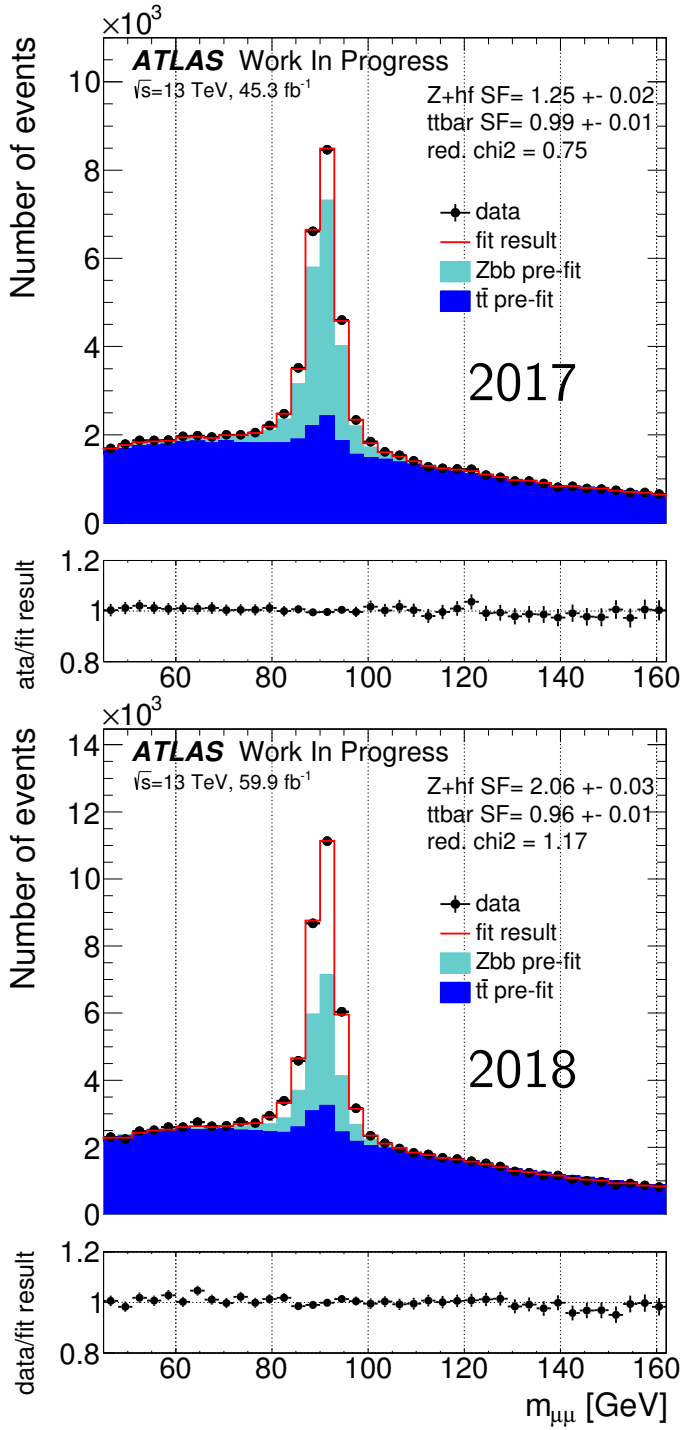
$\rightarrow$ Final SF from combined profile likelihood fit



Pre-Sel. Fits - SHERPA

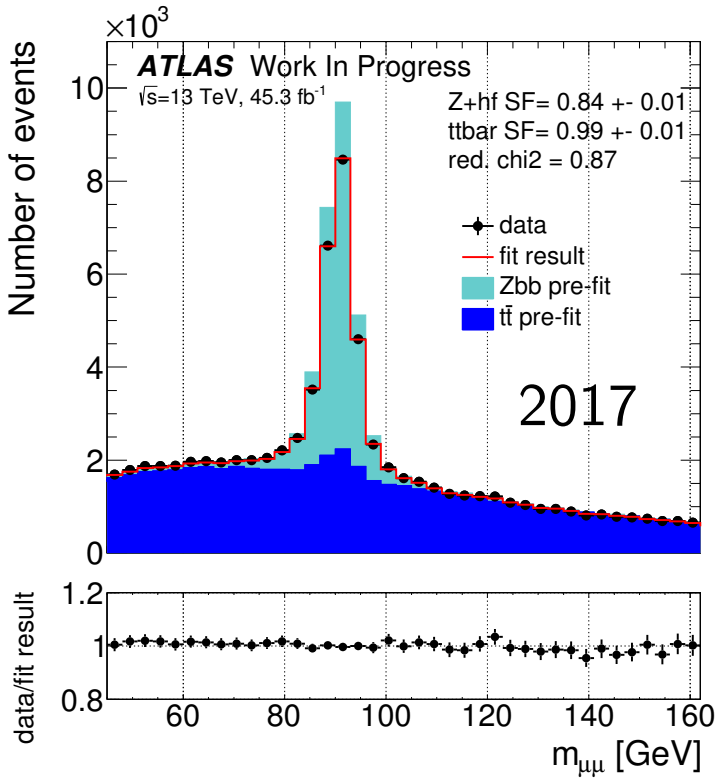
- 2018 SF very high relative to the years before → technical issue
- Z+hf SF = 1.25

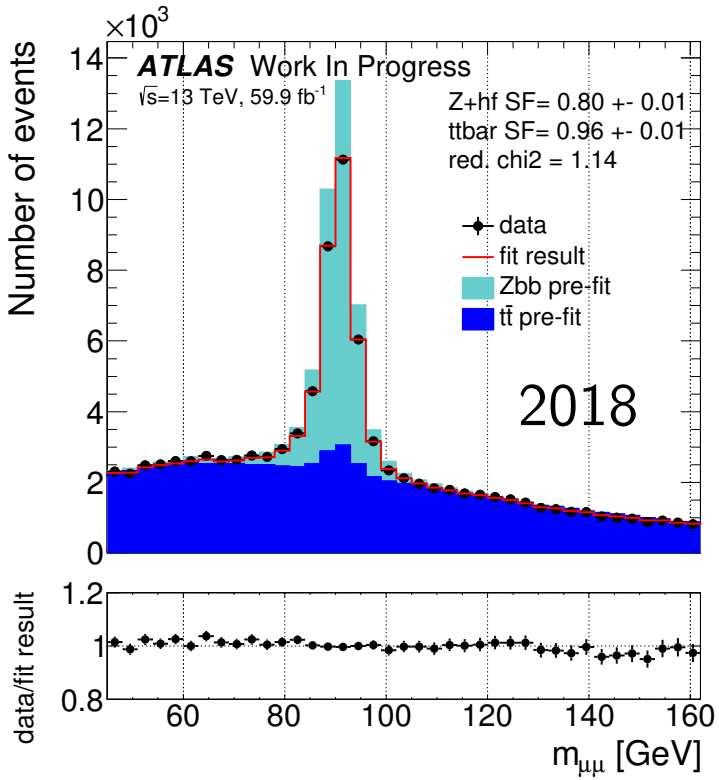




Pre-Sel. Fits - MadGraph

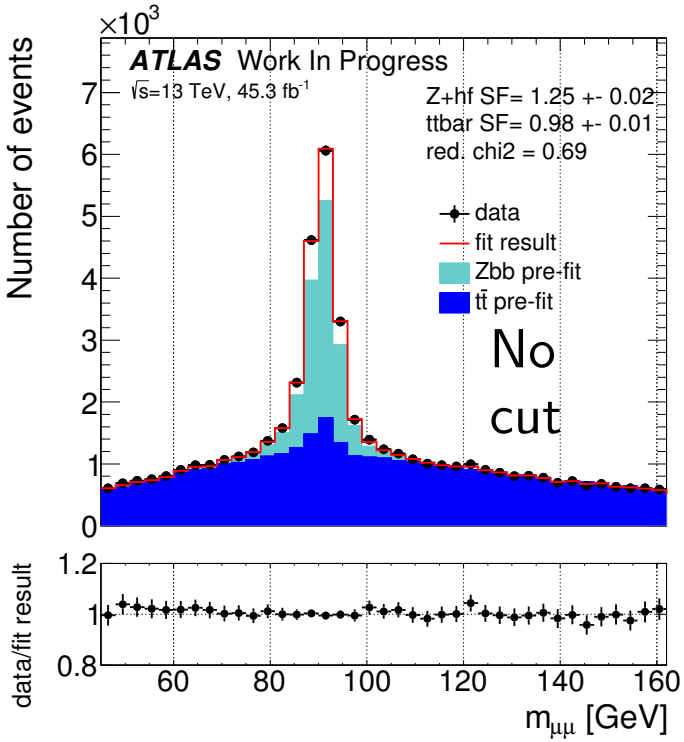
- MadGraph overestimates the data
- The high 2018 SF seems to be an issue with SHERPA only

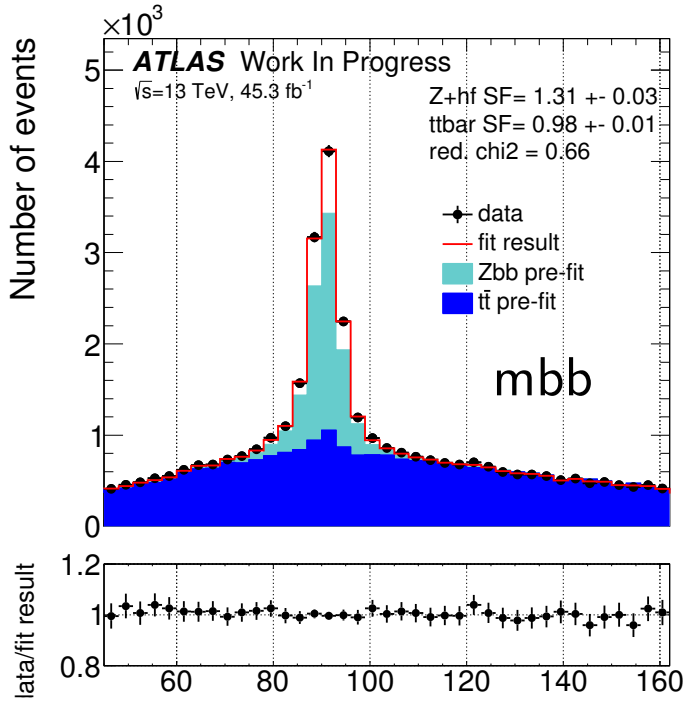


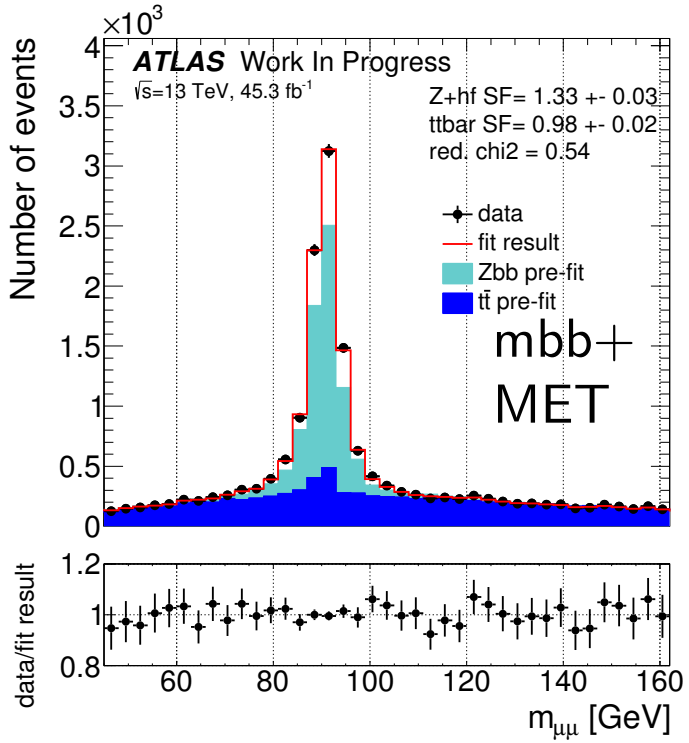


Varying Cuts

- MET cut gets rid of lots of ttbar bkg
- Combining cuts loses many Z+hf events

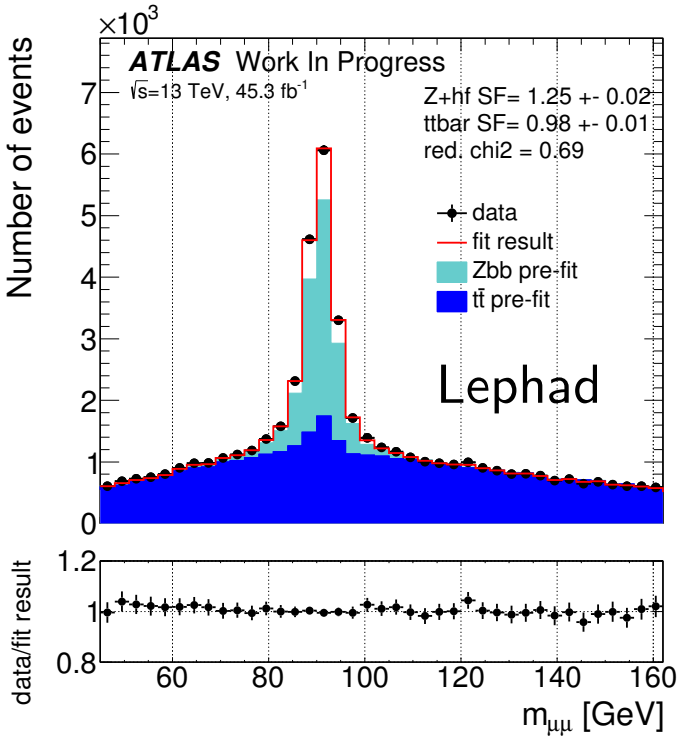


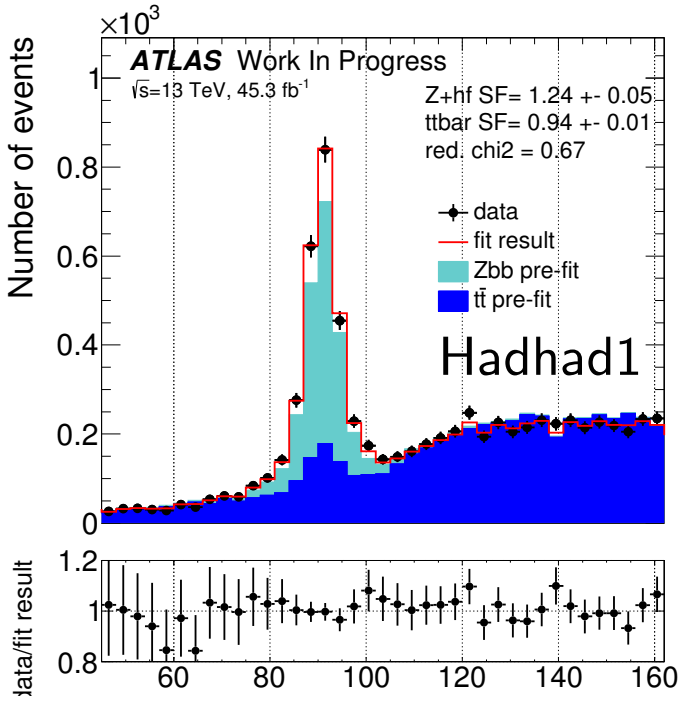


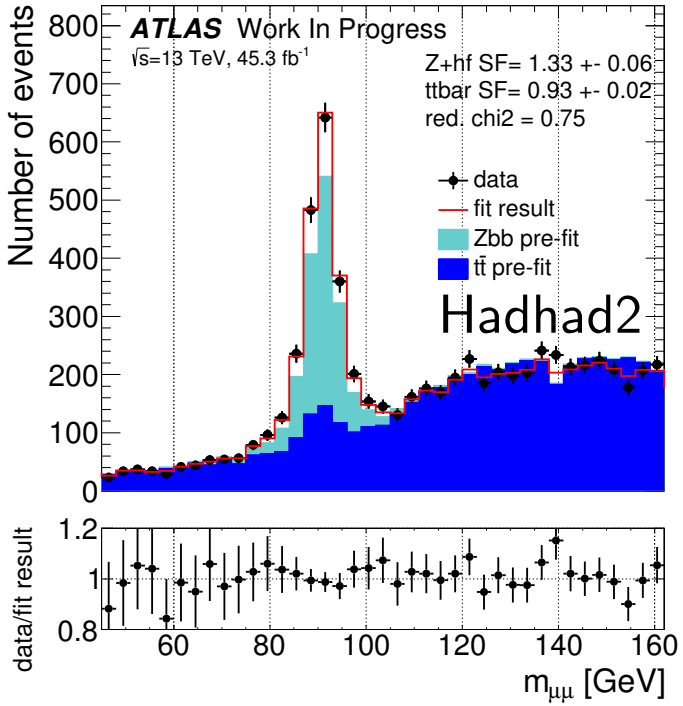


Comparing the Selections

- Hadhad selection cuts out a lot of Z+jets → could explain the large extrapolation uncertainties







Summary + Outlook

- Investigated a data-driven normalisation for $Z \rightarrow \tau\tau$ background for Run-II data
- Comparisons with other generators important for deriving the systematic uncertainties
- Further investigations of 2018 data + MC samples necessary
- Full systematic treatment of background estimate to be carried out

Thank you for your attention!

Backup slides

Comparing the Selections

- SF behave consistent between the different MC samples