Search for Higgs Pair Production in *bbWW** Decay Channel With the ATLAS Detector

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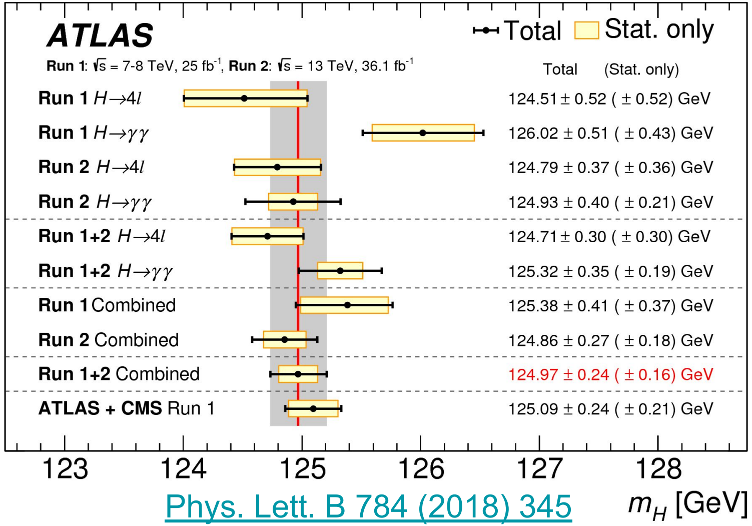
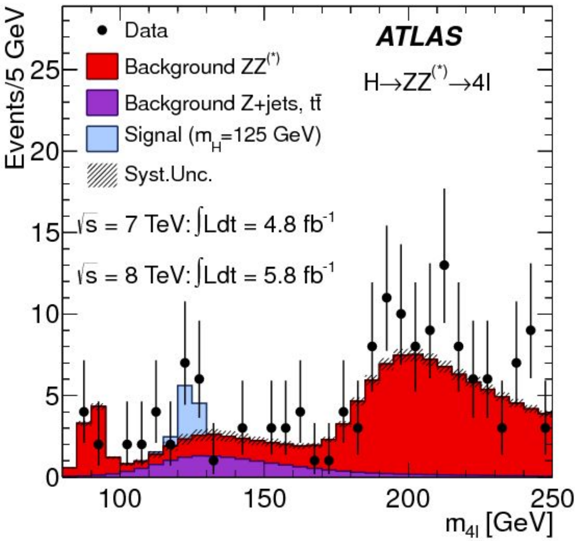
Introduction

★ The discovery of the SM Higgs boson with a mass of about 125 GeV was made by ATLAS and CMS in 2012.



[Phys. Lett. B 784 (2018) 345]



[Phys.Lett. B716 (2012) 1-29]

★ Part of the LHC program consist of measuring the properties of the Higgs Boson.

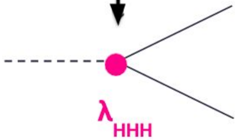
Higgs Potential

The Higgs potential has 3 parts:

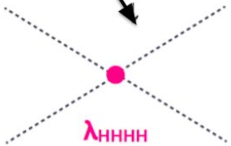
$$V(h) \simeq \frac{1}{2} m_H^2 h^2 + \lambda v h^3 + \frac{1}{4} \lambda h^4 \quad \ldots.$$

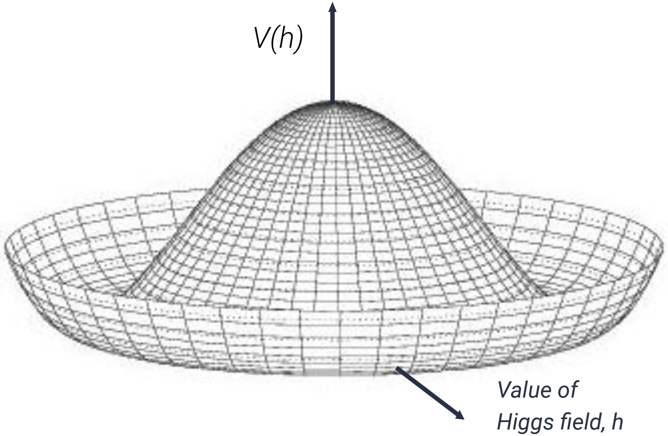
Related to the Higgs mass

$$m_H = \sqrt{2\lambda v} \approx 125 \text{ GeV}$$



Trilinear self coupling





Shape of the Higgs potential

The Trilinear coupling leads to Di-Higgs production.

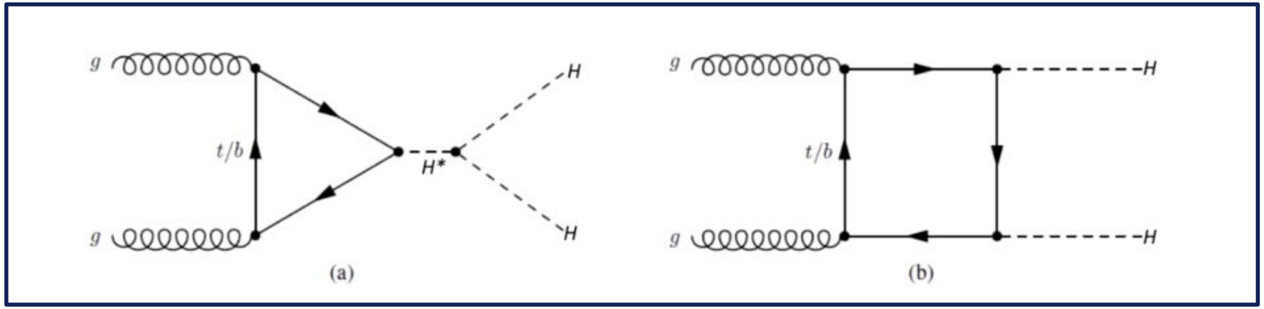
➢ Help to study the shape of the Higgs potential and solve important problem by measuring λ_{HHH}

Higgs Pair Production in the SM

HH production is a rare process with a unique sensitivity for certain Higgs properties

The cross section is very small ~ 31.05 fb. ~1000x smaller than single Higgs

The main HH production mode is by gluon-gluon fusion :

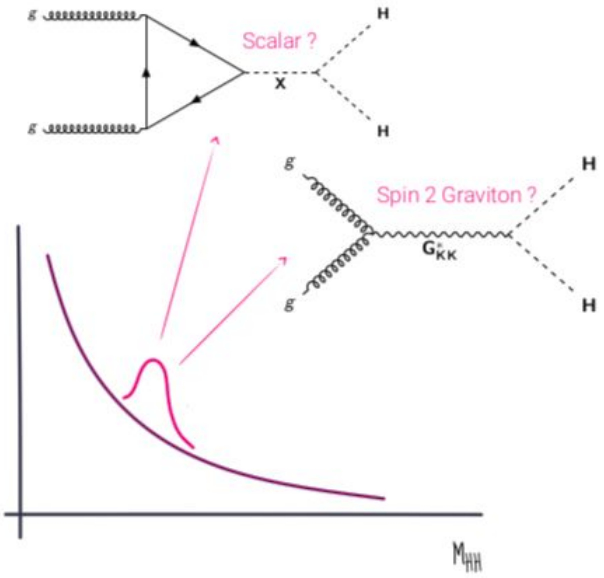


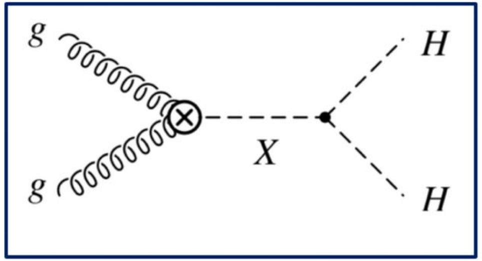
The Di-Higgs production is motivated by the non-resonant and resonant production

- Non-resonant: leads to direct measurements of the trilinear self-coupling constant λ_{HHH}
- Resonant: study the presence of new particles decaying to HH

Higgs Pair Production Beyond the SM

- The Physics beyond SM can manifest in the resonant mode HH production.
- New Particle X decay to a pair of SM Higgs





The decaying particle X can be:

- ➢ Heavy scalar as in 2HDM and MSSM models.
- ➢ Spin 2 graviton as predicted by Randal-Sundrum Model (RS)

Di-Higgs Decay Channels

	bb	WW	$\tau\tau$	ZZ	$\gamma\gamma$
bb	34				
WW	25	4.6			
$\tau\tau$	7.3	2.7	0.39		
ZZ	3.1	1.1	0.33	0.07	
$\gamma\gamma$	0.26	0.1	0.02	0.01	$<10^{-3}$

Branching ratio (%)

The Di-Higgs system can decay to many channels:

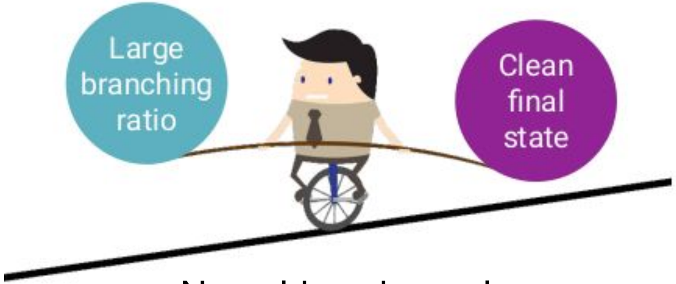
$HH \rightarrow bbbb$ ATLAS-CONF-2021-035

- ★ The largest Branching ratio.
- ★ Challenging multi-jet backgrounds.

No channel with large branching ratio & clean final state

This talk focus on :

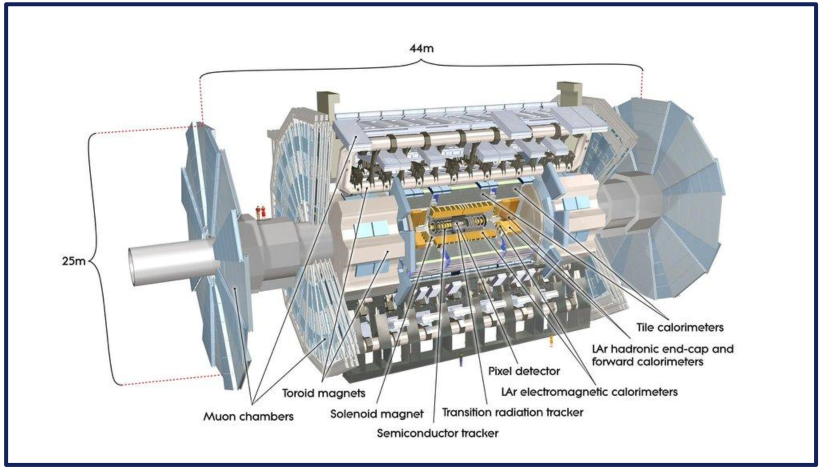
$HH \rightarrow bbWW$: the second largest Branching ratio.



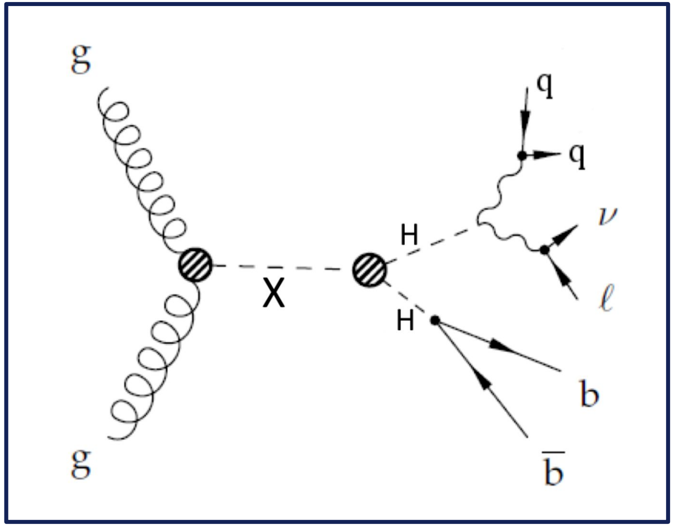
No golden channel

Analysis Strategy

- Data collected with ATLAS Detector
- Using full Run 2, $\int Ldt = 139fb^{-1}$



ATLAS Detector

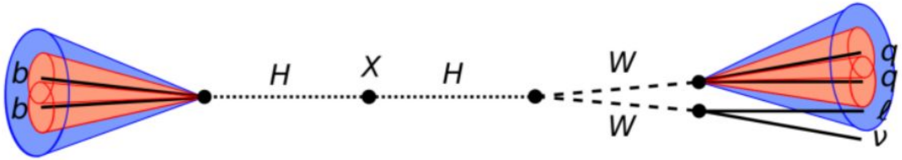


- We are studying Di-Higgs resonant production in the bbWW 1 lepton final state:
  - ★ $H \rightarrow bb$ and $H \rightarrow WW$
  - ★ $W \rightarrow qq$ and $W \rightarrow lv$ (1 lepton + neutrino)

Boosted Topology

Search for a heavy resonance X decaying to a paire of SM Higgs:

Boosted topology: HH decaying from a heavy BSM particle causing the decay products of the H's to be merged.



Challenge:

Decay product appears so close to each other in the detector.

- ➢ Individual reconstruction is very difficult.
- ➢ Overlap between jet and the lepton.

Leads to miss reconstruction of the jet substructure

Track-Assisted Reclustred jet (TAR jet): designed to perform well in dense environments.

- Combined information (ID + had calorimeter)
- Inputs: small-R jets which have been overlap removed against lepton.

➡ Excellent resolution and flexibility

Background

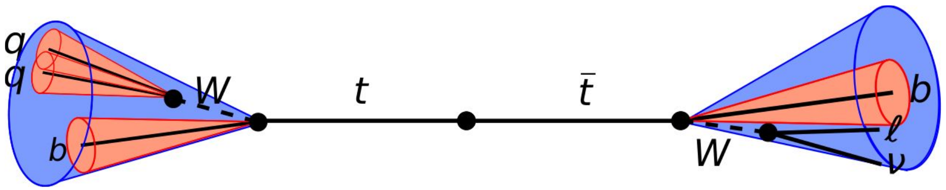
The background processes that imitate this signature in the detector are:

The dominant SM background:

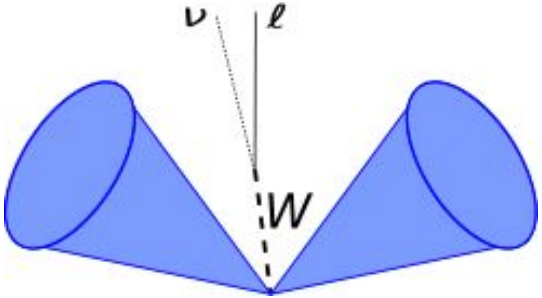
★ Top process (tt) & W+jets.

Other backgrounds:

★ single Top, diboson.



Top process



W+jets process

While those backgrounds can be well simulated with MC generators, **The Multijet background** requires a data-driven approach for a reasonable estimate.

We use **Matrix Method** for the estimation.

Matrix Method

- We use two level selection (loose and tight) leptons to estimate non-prompt lepton

$$N_L = N_{prompt} + N_{QCD}$$

$$N_T = \epsilon \times N_{prompt} + f \times N_{QCD}$$

Loose	Tight
loose ID and no isolation	medium ID and tight track only isolation

requirements for loose & tight selection

$$\epsilon = \frac{N_T^{prompt}}{N_L^{prompt}}$$ fraction of prompt leptons passing tight selection (Real rates)

$$f = \frac{N_T^{QCD}}{N_L^{QCD}}$$ fraction of non-prompt leptons passing tight selection (Fake rates)

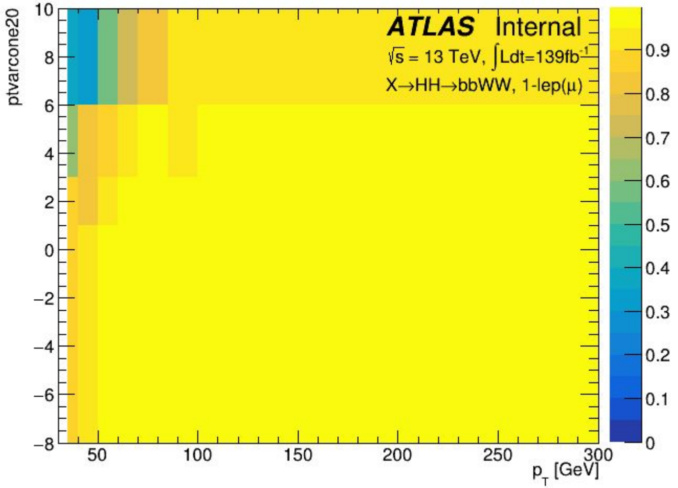
- Event-weight: $$w_{QCD}(N_T, N_A) = f \times N_{QCD} = \frac{(\epsilon - 1)\, f}{\epsilon - f} N_T + \frac{\epsilon\, f}{\epsilon - f} N_A$$

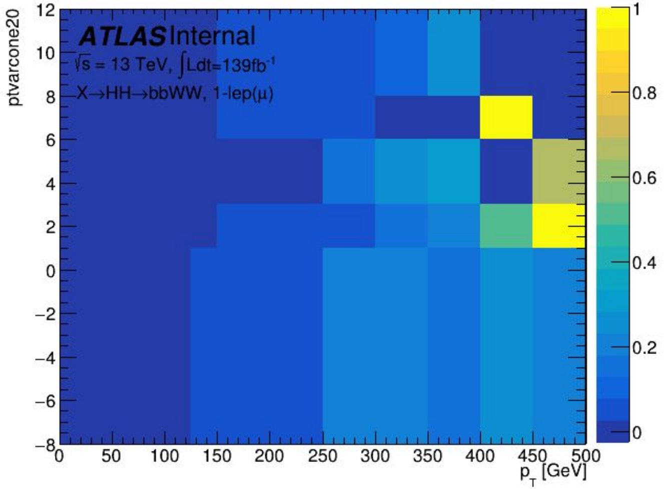
- Use event-weight to weight data event to estimate Multijet background.

Anti-tight

Real & Fake Rates

- 2D rates using lepton p_T and $ptvarcone20$:





Real Rates (ϵ) : obtained from MC in the SR

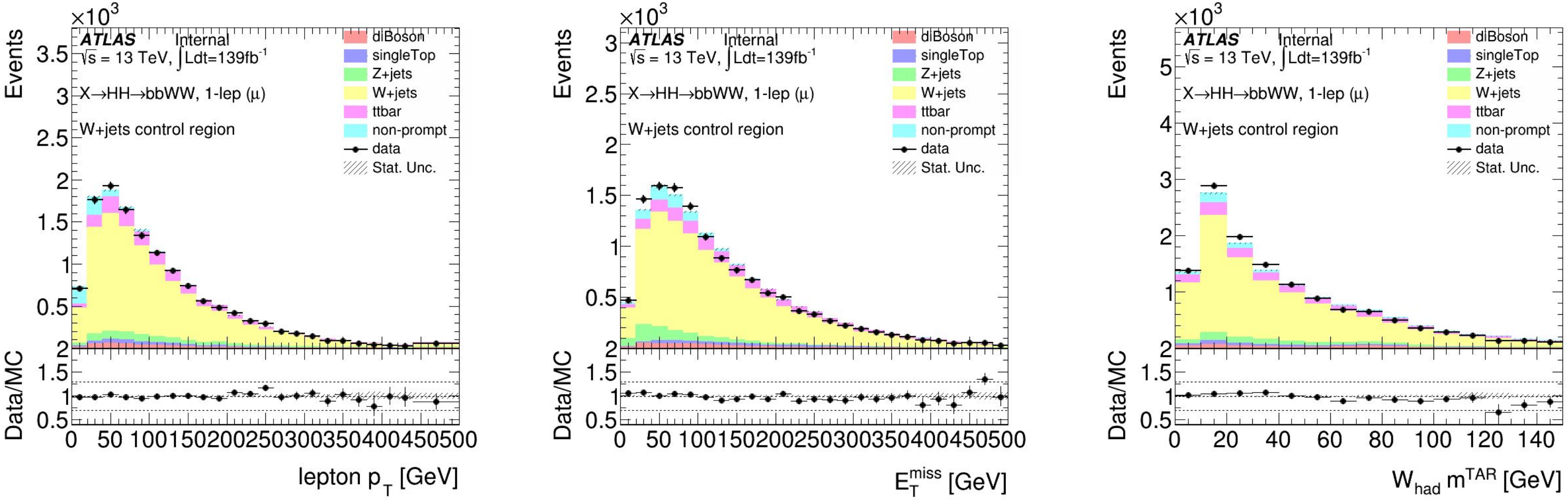
$$\epsilon = \frac{N_T^{prompt}}{N_L^{prompt}}$$

Fake Rates (f): measured from MC & data in QCD CR.

$$f = \frac{N_T^{QCD}}{N_L^{QCD}}$$

Multijet Estimation

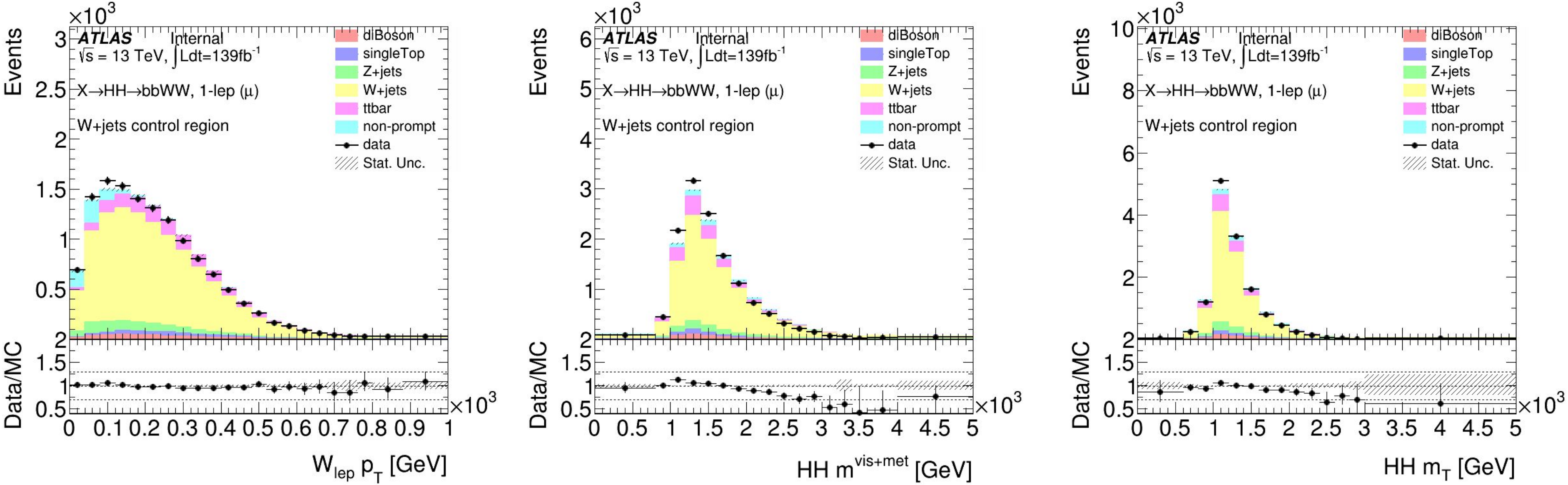
- Kinematic variables distributions:



- Good agreement between MC prediction and data in W+jets CR.

Multijet Estimation

- Kinematic variables distributions:



- Good agreement between MC prediction and data in W+jets CR.

Conclusion

- The Higgs pair production is a rare process, but it can :
  - ➢ Lead to direct measurements of the trilinear self-coupling constant λ_{HHH}.
  - ➢ Indicate the existence of new physics BSM.

- The Multijet background require a data driven methods to be estimated
  - ➢ Matrix method performs well.
  - ➢ Good agreement between MC prediction and data

Thank you !