

5th International Conference on Particle Physics and Astrophysics  
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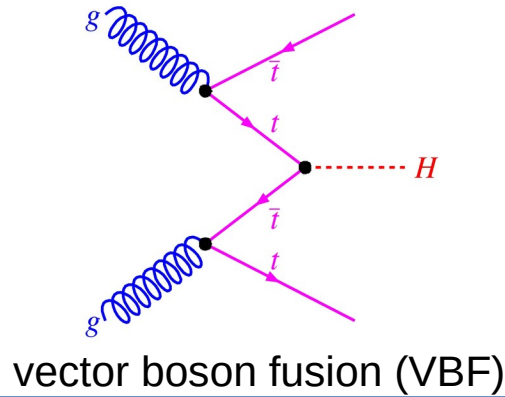
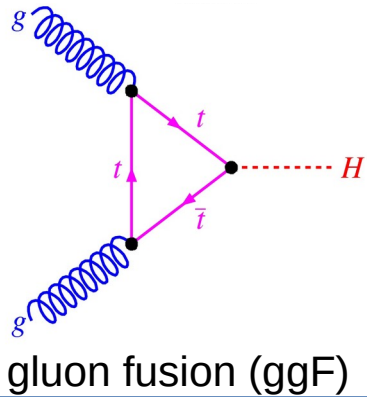
# Observation of the VBF production in the $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ decay channel with the ATLAS detector

Ramakoti E.N.<sup>1</sup>

<sup>1</sup>NRC "Kurchatov Institute" — ITEP  
ekaterina.ramakoti@cern.ch

# Standard Model (SM) Higgs Boson (H)

## The main Higgs boson production modes (link)



The VBF process:

- ✓ two highly energetic forward jets
- ✓ pure electroweak
- ✓ no color flow between colliding protons within hard interaction

## The Higgs boson decay channel (link)

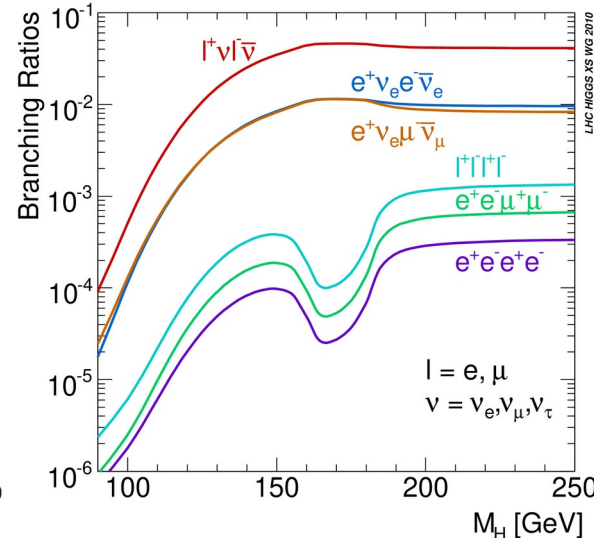
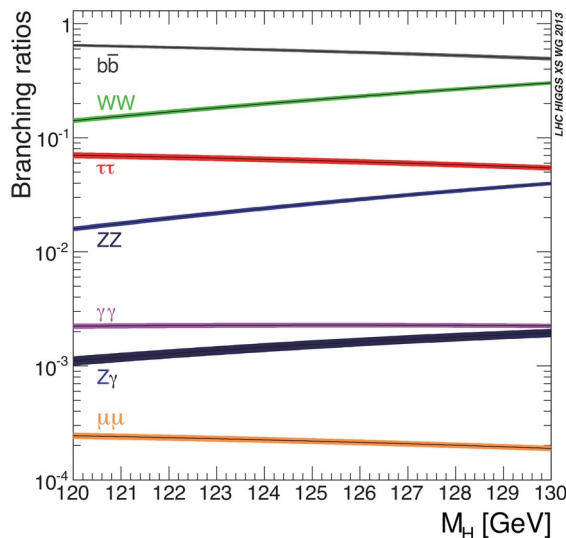
$m_H = 125.09 \text{ GeV}$

the 2nd largest ( $\mathcal{B}(WW) \sim 22\%$ )

$H \rightarrow WW^* \rightarrow e\nu\mu\nu$

clean final state

only  $m_T$  measurement due to  $\nu$



SM Higgs boson decay branching ratios  $\mathcal{B}$

VBF is the only process considered as signal in the analysis.

Background processes:

- ggF and VH
- top quark production ( $tW$  and  $t\bar{t}$ )
- dibosons (non-resonant  $WW$ )
- other  $VV$  ( $WZ$ ,  $ZZ$ ,  $W\gamma$ ,  $W\gamma^*$ )
- Drell-Yan ( $Z+jets$  or  $Z/\gamma^* \rightarrow \tau\tau$ )
- Mis-Id ( $W+jets$ ) and multi-jets (QCD)

# Analysis

New: ATL-CONF-2020-045 Old: PL B789 (2019) 508

## What's new?

- full run 2 dataset:  $139 \text{ fb}^{-1} \rightarrow 36 \text{ fb}^{-1}$  at 13 TeV
- enhanced signal tagging via Deep Neural Network (DNN), previously Boosted Decision Trees (BDT)

discriminant variables (used in DNN only)

$\Delta\phi_{\ell\ell'}$ ,  $m_{\ell\ell'}$ ,  $m_T$ ,  $\Delta y_{jj'}$ ,  $m_{jj'}$ ,  $p_T^{\text{tot}}$ ,  $\sum_{\ell} C_{\ell}$ ,  
 $m_{\ell 1 j 1'}$ ,  $m_{\ell 1 j 2'}$ ,  $m_{\ell 2 j 1'}$ ,  $m_{\ell 2 j 2'}$ ,  $p_T^{\text{jet1}}$ ,  $p_T^{\text{jet2}}$ ,  
 $p_T^{\text{jet3}}$  and  $E_T^{\text{miss}}$  significance

- improved object reconstruction (leptons, jets,  $E_T^{\text{miss}}$ )

## What are the results?

The observed (expected) signal significance:

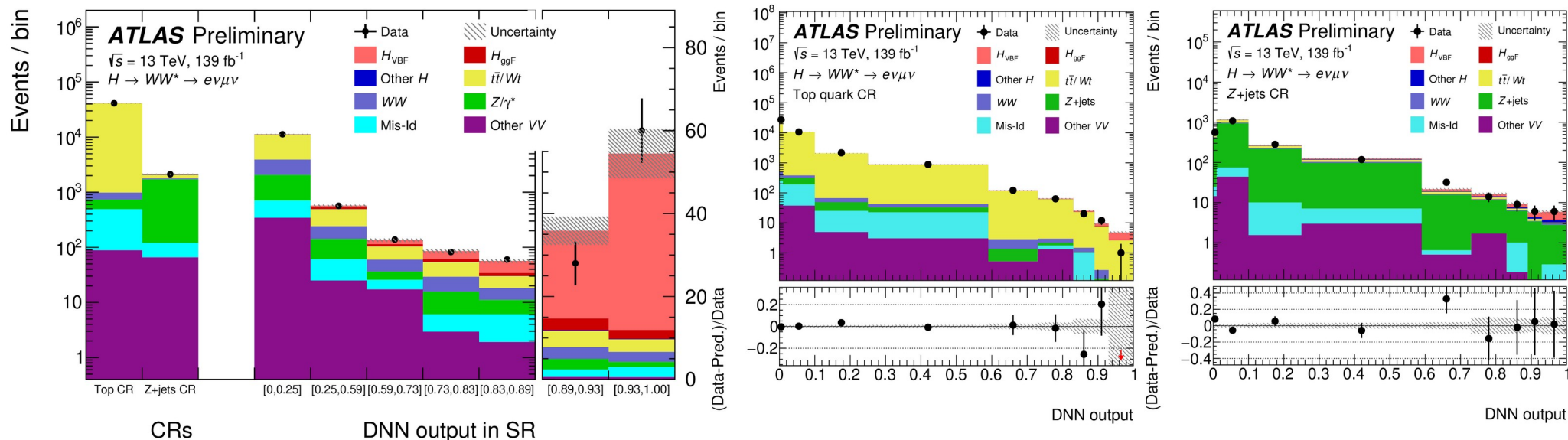
$$\mathcal{Z}^{\text{old}} = 1.9 (2.7)\sigma \quad \mathcal{Z}^{\text{new}} = 7.0 (6.2)\sigma$$

The cross-sections times branching fractions:

$$\sigma_{VBF} \cdot \mathcal{B}_{H \rightarrow WW^*} = 0.85_{-0.17}^{+0.20} \text{ pb}$$

in agreement with SM.

## Post-fit distributions of DNN output in SR and CRs



The first 3 bins are concluded in the 1st bin.

# Observation of the VBF production in the $H \rightarrow WW^* \rightarrow e\nu\mu\nu$ decay channel with the ATLAS detector

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## Introduction

Observed vector-boson-fusion (VBF) Higgs production in the  $H \rightarrow WW^* \rightarrow e\nu\mu\nu$  channel at ATLAS.

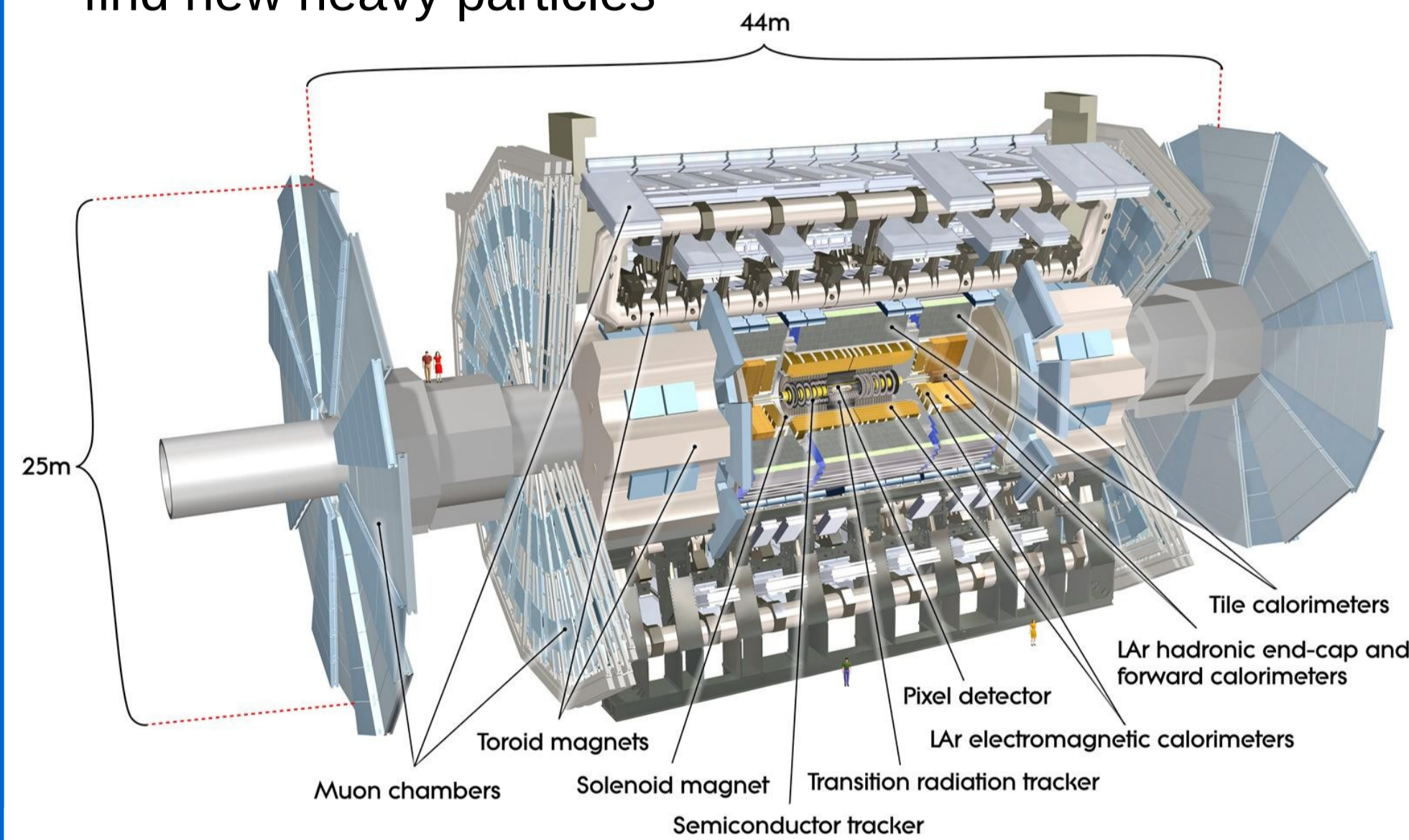
Several improvements (w.r.t. [1]):

- full run 2 dataset:  $139 \text{ fb}^{-1}$  at 13 TeV
- enhanced signal tagging via Deep Neural Network (DNN), previously BDT
- improved object reconstruction (leptons, jets,  $E_T^{\text{miss}}$ )

## ATLAS detector

ATLAS is a multipurpose detector:

- test Standard Model (SM) in the new energy range
- study SM Higgs boson properties
- find new heavy particles



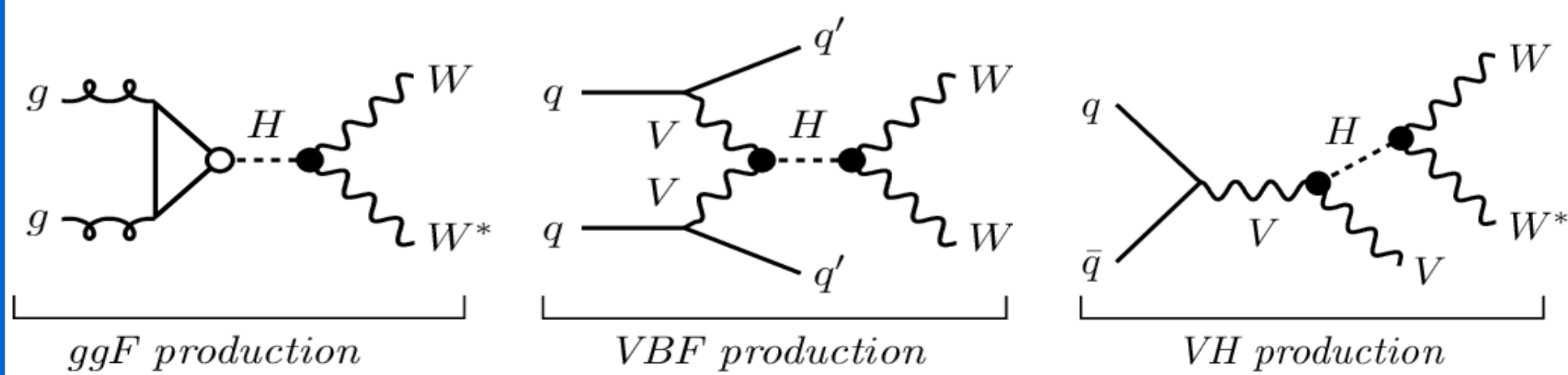
## Signal and background processes

The Higgs boson production modes:

- gluon fusion (ggF)
- VBF (signal)
- associated WH/ZH (VH)

Other background processes:

- top quark production
- dibosons (WW)
- other VV
- Drell-Yan ( $Z/\gamma^* \rightarrow \tau\tau$ )
- Mis-Id and multi-jets



## Event selection and multivariate analysis

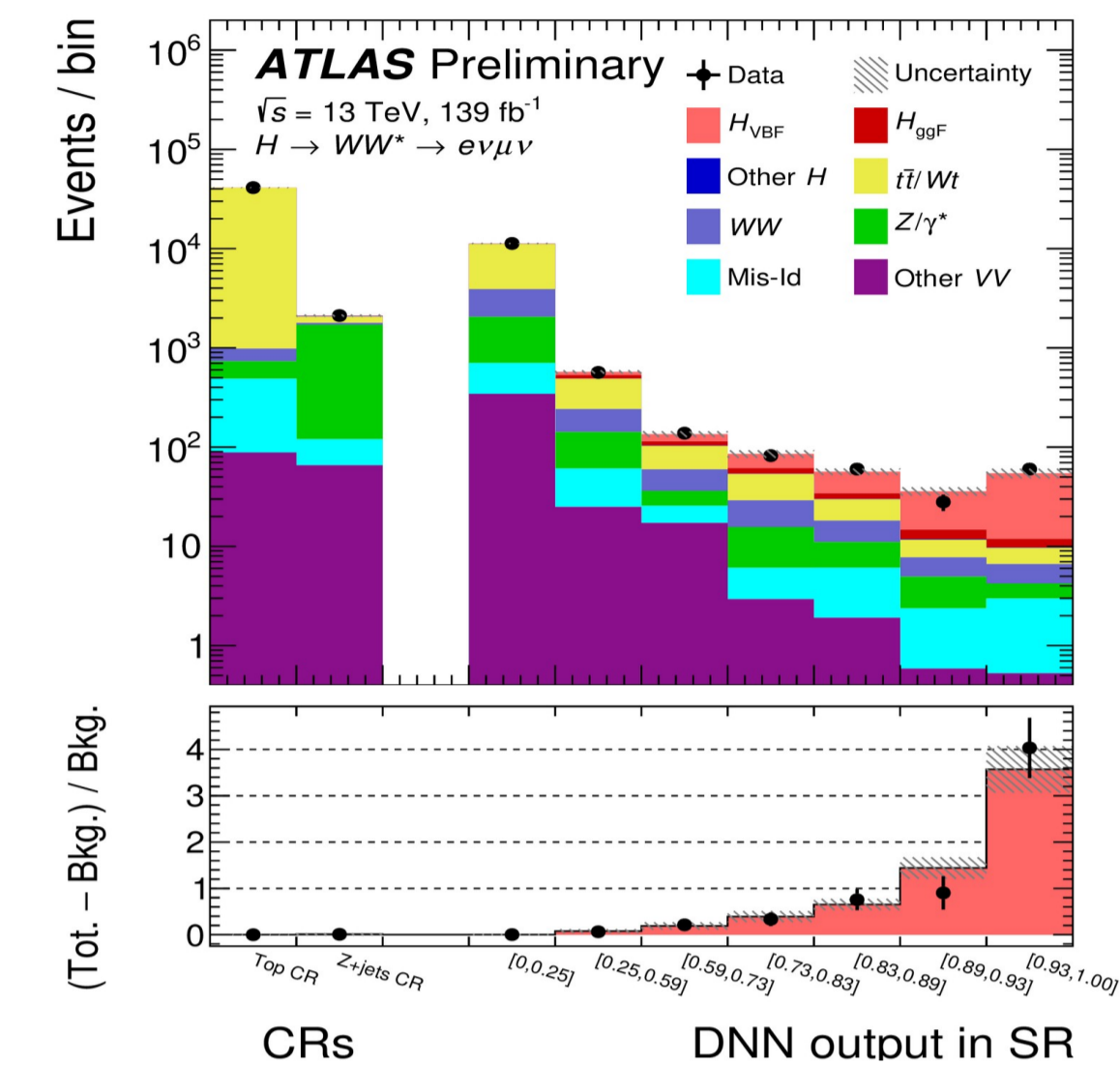
	SR	Z+jets CR	Top quark CR
Pre-selection	Two isolated, different-flavour leptons ( $\ell=e,\mu$ ) with opposite charge $p_{T,\text{lead}} > 22 \text{ GeV}$ , $p_{T,\text{sublead}} > 15 \text{ GeV}$ $M_{\ell\ell} > 10 \text{ GeV}$ , $N_{\text{jet}(p_{T>30 \text{ GeV}},  \eta <4.5)} \geq 2$		
	$N_{b\text{-jet}(p_{T>20 \text{ GeV}})} = 0$	$N_{b\text{-jet}(p_{T>20 \text{ GeV}})} = 0$	$N_{b\text{-jet}(p_{T>20 \text{ GeV}})} = 1$
Selection	$m_{\tau\tau} < m_{Z-25 \text{ GeV}}$ $m_{jj} > 120 \text{ GeV}$ -	$ m_{\tau\tau} - m_Z  < 25 \text{ GeV}$ - $m_{\ell\ell} > 70 \text{ GeV}$	$m_{\tau\tau} < m_{Z-25 \text{ GeV}}$ - -
	lepton outside && additional jet with $p_{T>30 \text{ GeV}}$ in veto		the interval between the two tagging jets in $\eta$
DNN is applied in the SR that uses 15 discriminant variables: $\Delta\phi_{\ell\ell}$ , $m_{\ell\ell}$ , $m_{\tau\tau}$ , $\Delta y_{jj}$ , $m_{jj}$ , $p_{T,\text{tot}}$ , $\sum C_{\ell}$ , $m_{\ell 1 j 1}$ , $m_{\ell 1 j 2}$ , $m_{\ell 2 j 1}$ , $m_{\ell 2 j 2}$ , $p_{T,\text{jet}1}$ , $p_{T,\text{jet}2}$ , $p_{T,\text{jet}3}$ and $E_T^{\text{miss}}$ significance			

The VBF process:

- two highly energetic forward jets
- pure electroweak
- no color flow between colliding protons within hard interaction

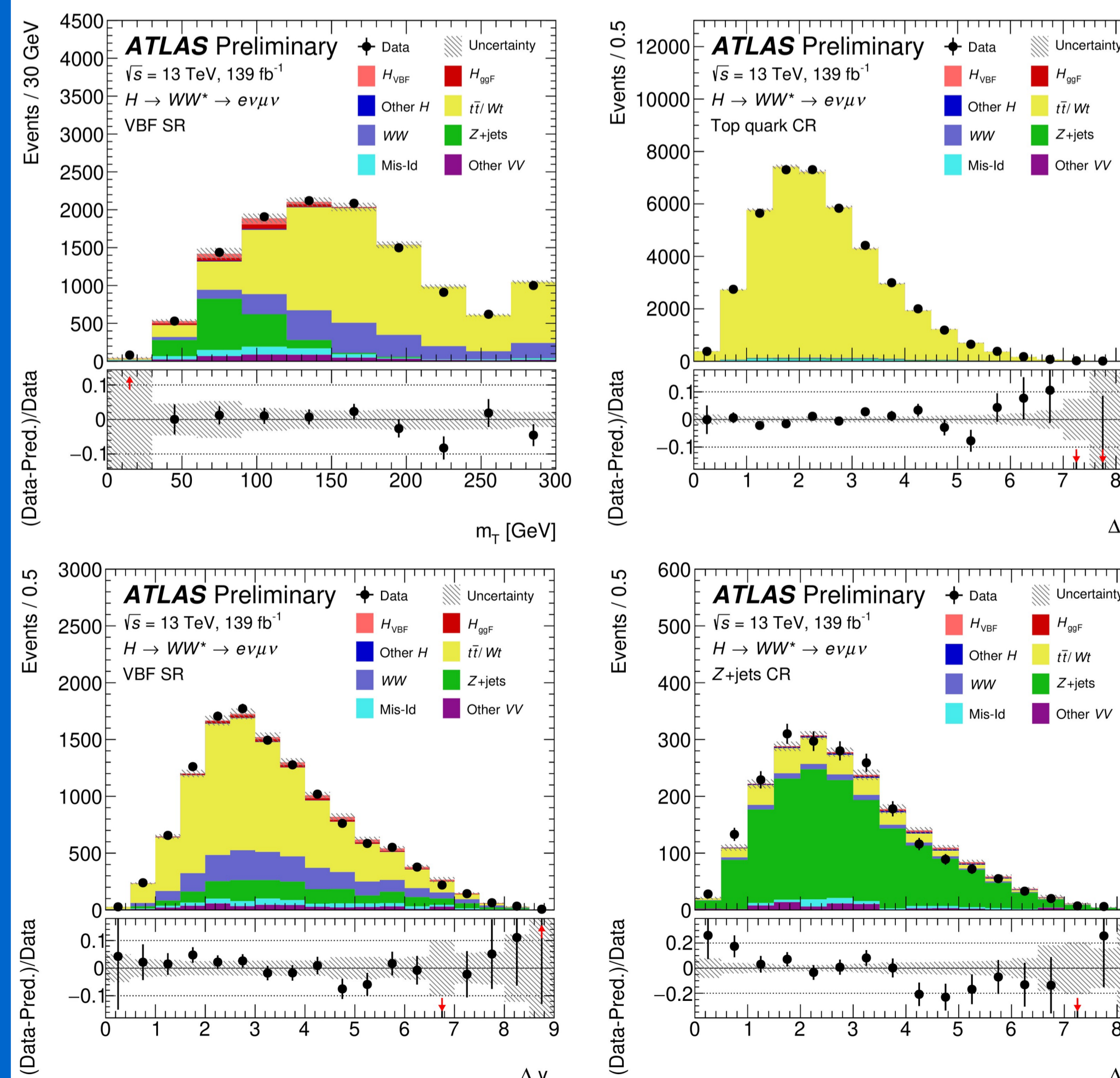
Control Regions (CRs):

- normalise the corresponding backgrounds in the Signal Region (SR)



DNN output in VBF SR and CRs.

## Pos-fit distributions in SR and CRs



$m_T$  (top) and  $\Delta y_{jj}$  (bottom) in the VBF SR.

$\Delta y_{jj}$  in the top quark (top) and Z+jets (bottom) CRs.

## Results

Process	Total	Highest DNN bin
$H_{VBF}$	$209 \pm 37$	$42.5 \pm 6.5$
$H_{ggF}$	$169 \pm 62$	$2.2 \pm 1.5$
Other Higgs	$28 \pm 2$	$0.1 \pm 0.3$
$t\bar{t}/Wt$	$7520 \pm 830$	$3.0 \pm 1.7$
$Z/\gamma^*$	$1460 \pm 370$	$1.2 \pm 1.1$
WW	$2000 \pm 350$	$2.4 \pm 1.6$
Mis-Id	$416 \pm 58$	$2.5 \pm 1.6$
Other VV	$392 \pm 64$	$0.5 \pm 0.7$
Total	$12200 \pm 120$	$54.5 \pm 6.0$
Observed	12189	60

MC and data yields in the VBF SR and the highest DNN output bin.

The **signal strength parameter** [2]:

$$\mu_{VBF} = 1.04^{+0.24}_{-0.20}$$

$$\mu_{VBF} = 1.04^{+0.13}_{-0.12}(\text{stat})^{+0.09}_{-0.08}(\text{exp.syst})^{+0.17}_{-0.12}(\text{sig.theo})^{+0.08}_{-0.07}(\text{bkg.theo})$$

The observed (expected) **significance** of 7.0 (6.2)  $\sigma$ .

Breakdown of impacts on the signal strength  $\mu_{VBF}$ .

Source	$\Delta\mu/\mu$ [%]
Total systematics	17.8
Data Statistics	12.5
Experimental	8.8
Missing ET	4.7
MC statistics	3.1
Jet energy scale	2.2
...	...
Signal theory	14.4
Bkg. theory	7.7
ggF	5.2
Top-quark	3.3
WW	2.5
Z+jets	1.9
TOTAL	22

## References

[1] PL B789 (2019) 508

[2] ATL-CONF-2020-045