5th International Conference on Particle Physics and Astrophysics (ICPPA-2020), Moscow, Russia
from Monday, 5 October 2020 to Friday, 9 October 2020

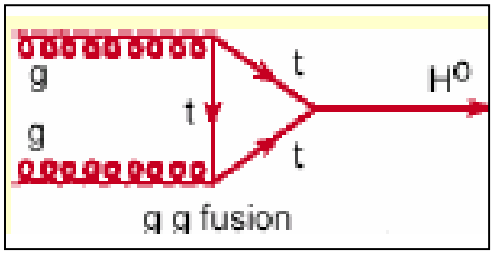
Observation of the VBF production in the $h \to WW^* \to e\nu\mu\nu$ decay channel with the ATLAS experiment

Ramakoti E.N.[1]

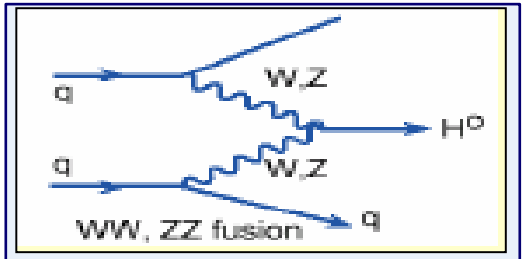
[1]NRC "Kurchatov Institute" — ITEP
ekaterina.ramakoti@cern.ch

Standard Model (SM) Higgs Boson (*h*)

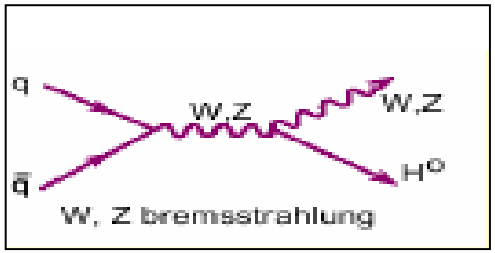
The Higgs boson production modes (link)



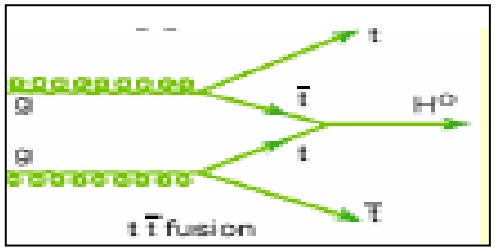
gluon fusion (ggF)



vector boson fusion (VBF)



associated WH/ZH (VH)



associated top quark (ttH)

- ✔ the only signal process in VBF analysis
- ✔ with two highly energetic jets going at small polar angles

- ✔ pure electroweak
- ✔ with no color flow between the Higgs system and the incoming protons
- ✔ the boson coupling constant

not included in VBF analysis (to be negligible)

The Higgs boson decay channel (link)

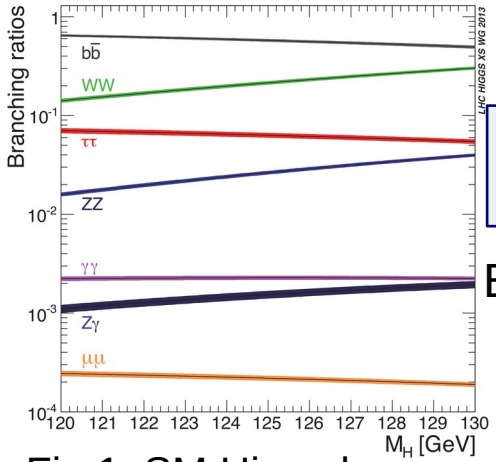


Fig.1. SM Higgs boson decay branching ratios $\mathcal{B}$

$h \to WW^* \to e\nu\mu\nu$

m_h = 125.09 GeV

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

clean final state ($\mathcal{B}(\ell\nu\ell\nu)$~5%)

Background processes (the same final state $\ell\ell$):

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

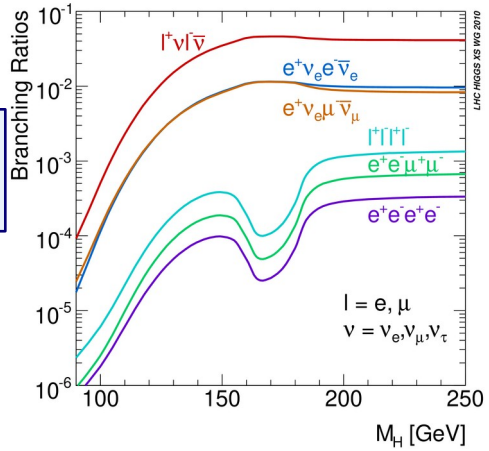


Fig.2. SM Higgs boson decay branching ratios $\mathcal{B}$ for 4-fermion final states

VBF analysis

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

What's new?

- increase in data statistics: 36 fb^{-1} → 139 fb^{-1}
- a new multi-variate discriminant using a Deep Neural Network (DNN) instead of usual Boosted Decision Trees (BDT)

	BDT	DNN
Discriminant variable input variable	$\Delta\varphi_{\ell\ell}$, $m_{\ell\ell}$, m_T, Δy_{jj}, m_{jj}, p_T^{tot}, $\Sigma_\ell C_\ell$, $\Sigma_{\ell,j} m_{\ell j}$	$\Delta\varphi_{\ell\ell}$, $m_{\ell\ell}$, m_T, Δy_{jj}, m_{jj}, p_T^{tot}, $\Sigma_\ell C_\ell$, $m_{\ell j1}$, $m_{\ell j2}$, $m_{\ell 2j1}$, $m_{\ell 2j2}$, p_T^{jet1}, p_T^{jet2}, p_T^{jet3} and E_T^{miss} significance

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

What are the results?

The signal strength parameter:

$$\mu_{VBF}^{BDT} = 0.62^{+0.37}_{-0.36}$$
$$\mu_{VBF}^{DNN} = 1.04^{+0.24}_{-0.20}$$

The observed (expected) signal significantce:

$$\mathbb{Z}^{BDT} = 1.9\ (2.7)\sigma$$
$$\mathbb{Z}^{DNN} = 7.0\ (6.2)\sigma$$

The cross-sections times branching fractions:

$$\sigma_{VBF} \cdot \mathscr{B}_{h\to WW^*}^{BDT} = 0.50^{+0.24}_{-0.23}\ pb$$
$$\sigma_{VBF} \cdot \mathscr{B}_{h\to WW^*}^{DNN} = 0.85^{+0.20}_{-0.17}\ pb$$
$$\sigma_{VBF} \cdot \mathscr{B}_{h\to WW^*}^{SM} = 0.81^{+0.02}_{-0.02}\ pb$$

What are the results?

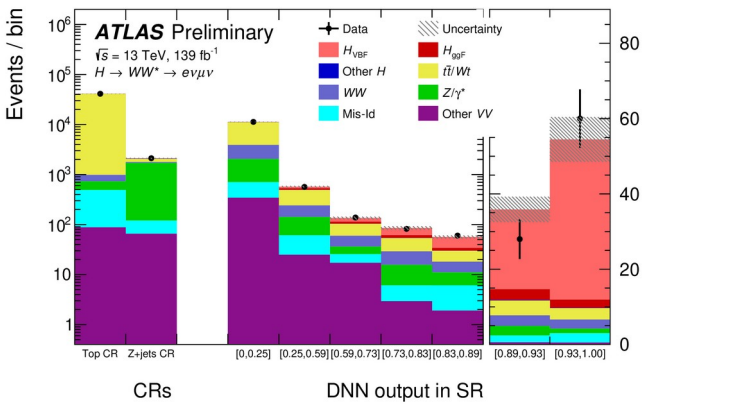


Fig.3. Post-fit distribution of the DNN output in the VBF signal region, together with the top and Z+jets control regions.

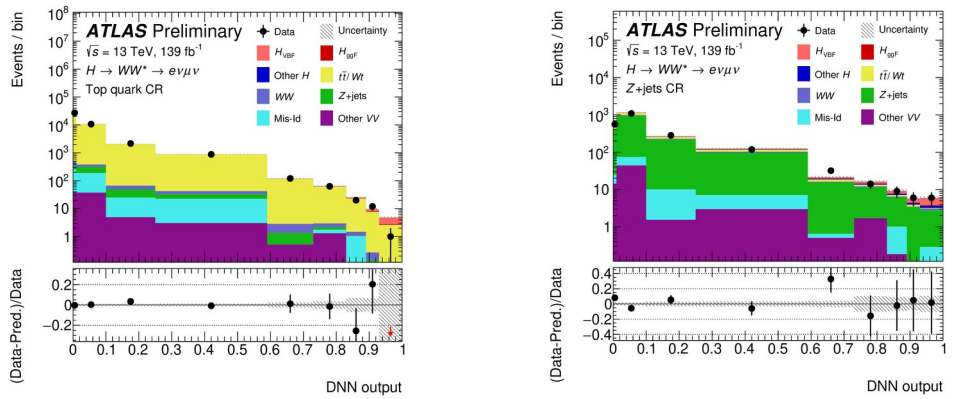


Fig.4. Post-fit distributions of the DNN output in the top quark CR (left) and Z+jets CR (right).
The first 3 bins are concluded in the 1st bin.

Observation of the VBF production in the h→WW*→eνμν decay channel with the ATLAS experiment

Ramakoti E.N.
NRC "Kurchatov Institute" — ITEP, ekaterina.ramakoti@cern.ch

Introduction

New Run2 results for vector-boson-fusion (VBF) production of Higgs bosons in the $h \to WW^* \to e\nu\mu\nu$ decay channel at 13 TeV with the ATLAS detector are presented.

New results with several improvements (w.r.t. [1]):

- increase in data statistics: 36 fb^{-1} → 139 fb^{-1}
- a new multi-variate discriminant using a Deep Neural Network (DNN) instead of usual BDT
- improved object reconstruction (leptons, jets, E_T^{miss})

The ATLAS detector

The ATLAS is a multipurpose detector with the main aims to test Standart Model (SM) in the new energy range, to study SM Higgs boson properties and to find new heavy particles.

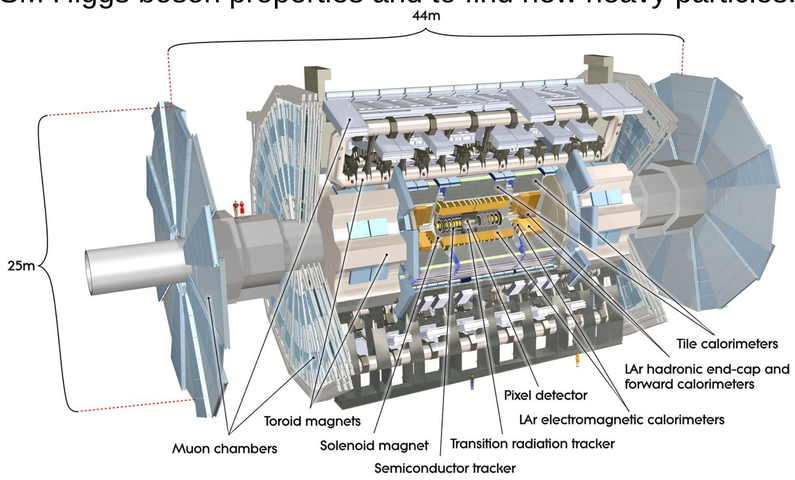


Fig.1. The ATLAS detector [2]

Signal and background processes

The Higgs boson production modes (signal):

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

m_h = 125.09 GeV

Background processes (the same final state ℓℓ):

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

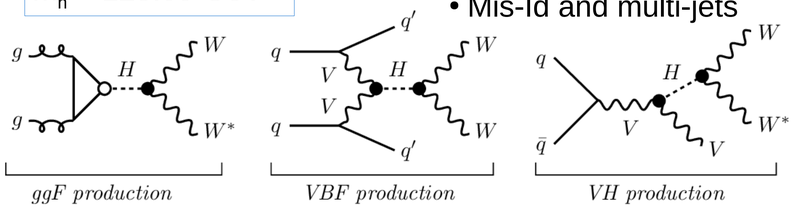


Fig.2. The main production modes [3]

Event selection and multivariate analysis

	SR	Z+jets CR	Top quark CR
Pre-selection	Two isolated, different-flavour leptons (ℓ=e,μ) with opposite charge $p_T^{lead} > 22$ GeV, $p_T^{sublead} > 15$ GeV $M_{\ell\ell} > 10$ GeV, $N_{jet(pT>30\ GeV;\ \lvert\eta\rvert<4.5)} \geq 2$		
	$N_{b\text{-}jet\ (pT>20\ GeV)} = 0$	$N_{b\text{-}jet\ (pT>20\ GeV)} = 0$	$N_{b\text{-}jet\ (pT>20\ GeV)} = 1$
Selection	$m_{\tau\tau} < 66.2$ GeV $m_{jj} > 120$ GeV -	$\lvert m_{\tau\tau} - m_Z\rvert < 25$GeV - $m_{\ell\ell} > 70$ GeV	$m_{\tau\tau} < 66.2$ GeV - -
	central jet veto outside lepton veto		
DNN is applied in the SR that uses 15 dicriminant variables: $\Delta\varphi_{\ell\ell}$, $m_{\ell\ell}$, m_T, Δy_{jj}, m_{jj}, p_T^{tot}, $\Sigma_\ell C_\ell$, $m_{\ell 1 j 1}$, $m_{\ell 1 j 2}$, $m_{\ell 2 j 1}$, $m_{\ell 2 j 2}$, p_T^{jet1}, p_T^{jet2}, p_T^{jet3} and E_T^{miss} significance			

Table 1. Event selection criteria used to define the signal and control regions in the analysis.

The VBF process:

- with two highly energetic jets going at small polar angles
- pure electroweak
- with no color flow between the Higgs system and the incoming protons

Control Regions (CRs):

- top-quark and Z+jets proceses
- orthogonal to the Signal Region (SR)
- normalise the corresponding backgrounds in the SR

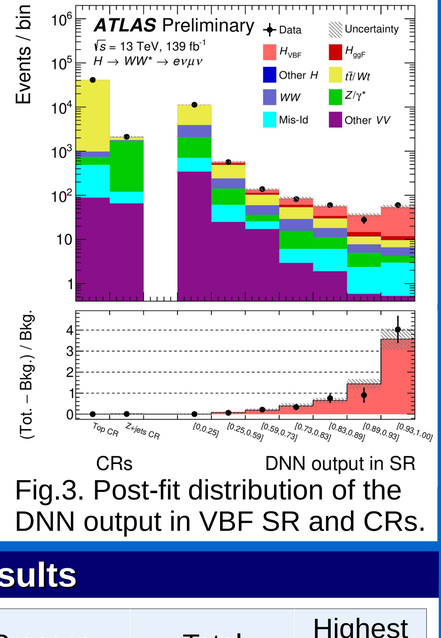
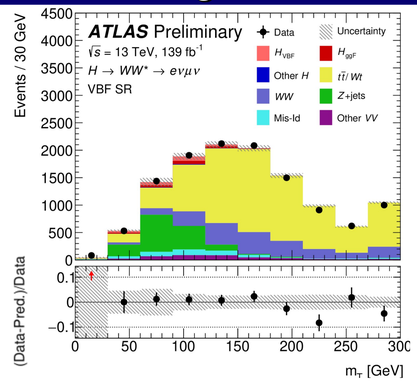


Fig.3. Post-fit distribution of the DNN output in VBF SR and CRs.

Background estimation in SR and CRs



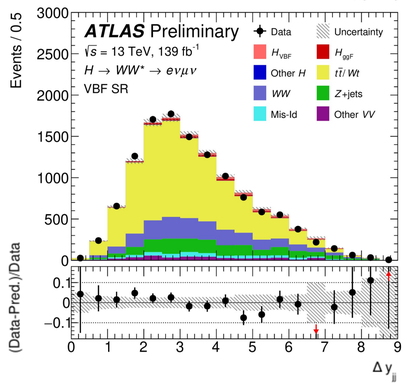
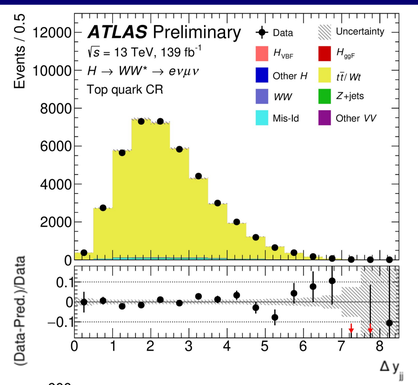


Fig.4. Post-fit m_T (top) and Δy_{jj} (bottom) distribution in the VBF SR.



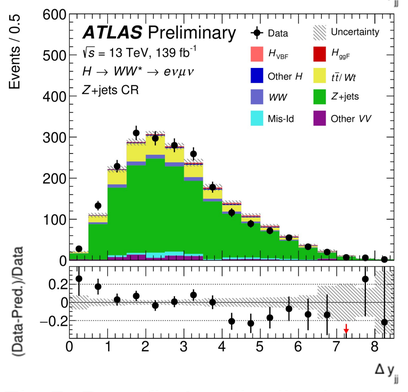


Fig.5. Post-fit Δy_{jj} distribution in the top quark (top) and Z+jets (bottom) CRs.

Statistical and systematic uncertainties are included.

Results

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

Table 2. Breakdown of impacts on the signal strength μ_{VBF}.

Process	Total	Highest DNN bin
H_{VBF}	209±37	43±7
H_{ggF}	169±62	2±1
tt/Wt	7525±827	3±2
Z/γ^*	1460±372	1±1
WW	1997±347	2±1
Mis-Id	416±58	2±2
VV	392±64	1±1
Total	12196±122	54±6
Observed	12186	60

Table 3. Post-fit MC and data yields in the VBF SR and the highest DNN output bin.

The **signal strength parameter** [4]:

$$\mu_{VBF} = 1.04\ ^{+0.24}_{-0.20}$$
$$= 1.04\ ^{+0.13}_{-0.12}\ (\text{stat.})\ ^{+0.09}_{-0.08}\ (\text{exp syst.})\ ^{+0.17}_{-0.12}\ (\text{sig. theo.})\ ^{+0.08}_{-0.07}\ (\text{bkg. theo.})$$

The observed (expected) **significance** of 7.0 (6.2) σ.

References

[1] PL B789 (2019) 508
[2] JINST 3 (2008) S08003
[3] PR D 92 (2015) 012006
[4] ATL-CONF-2020-045