

Searches for BSM Higgs bosons at ATLAS

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(On behalf of ATLAS collaboration)

Phenomenology 2021 Symposium

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מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE



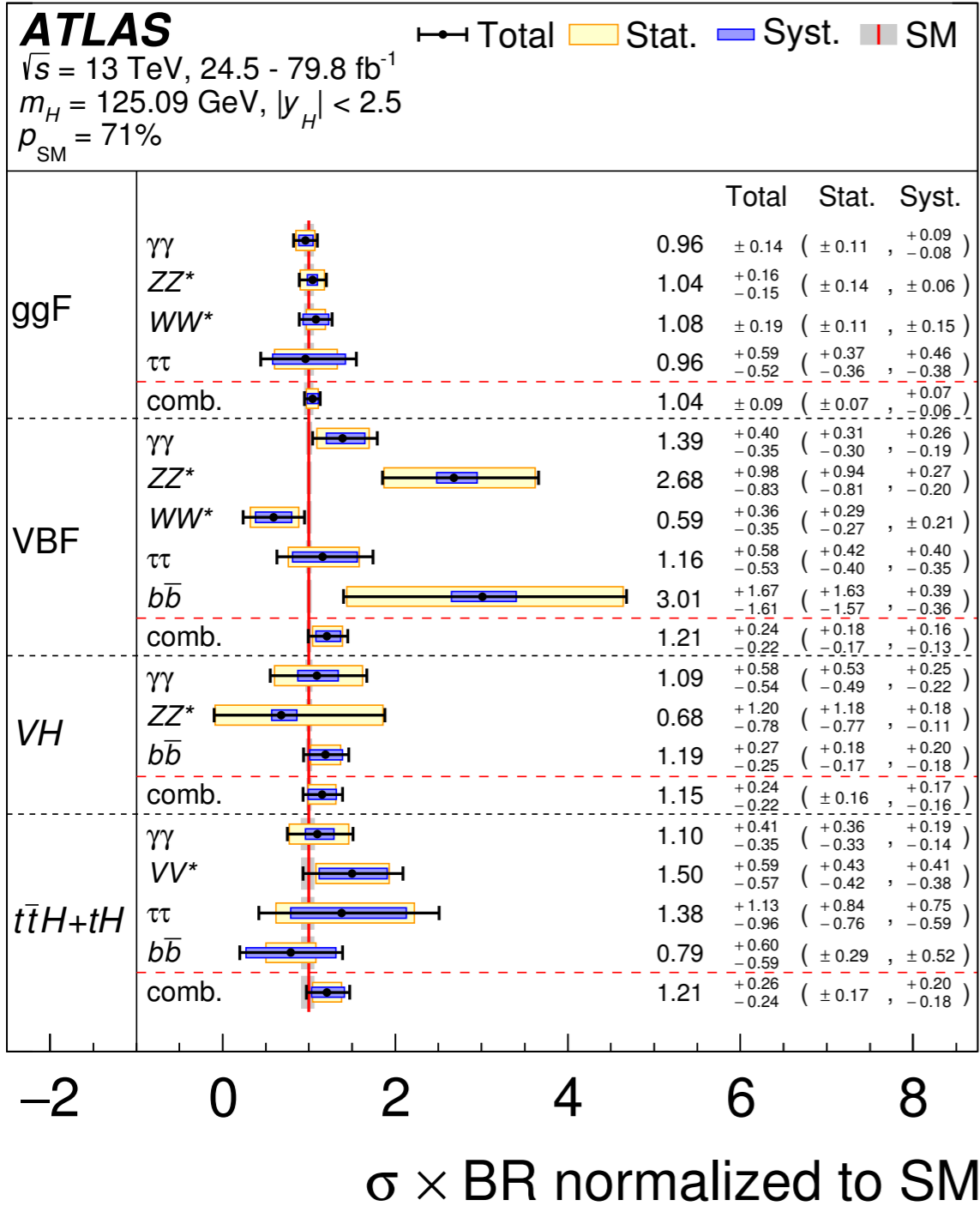
ATLAS
EXPERIMENT

Outline

► Motivation

- $H(125) \rightarrow aa \rightarrow (b\bar{b})(\mu^+\mu^-)$
- $H(125) \rightarrow aa(\text{LLP}) \rightarrow (b\bar{b})(b\bar{b})$
- Resonance search in Z boson pair
- Charged Higgs boson to gauge boson
- Summary

Motivation: What is the scalar with $m = 125 \text{ GeV}$?

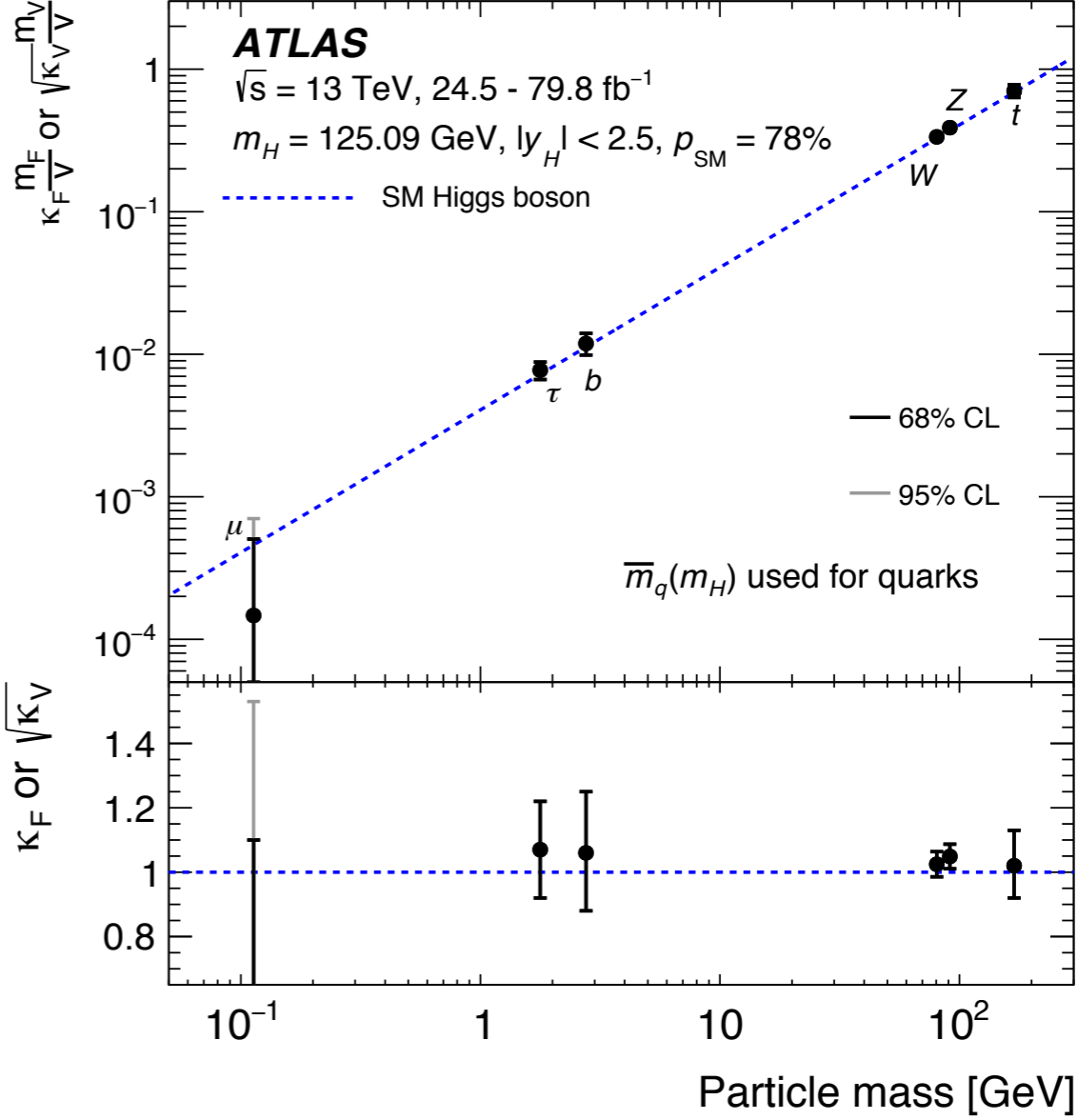


Phys. Rev. D 101, 012002

Both ATLAS and CMS have observed a scalar particle, consistent with the SM **Is it the SM Higgs ?**

Almost all extensions of SM have a neutral, CP even scalar component.

Which model is more favoured ?



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$H(125) \rightarrow aa(\text{LLP}) \rightarrow (b\bar{b})(b\bar{b})$

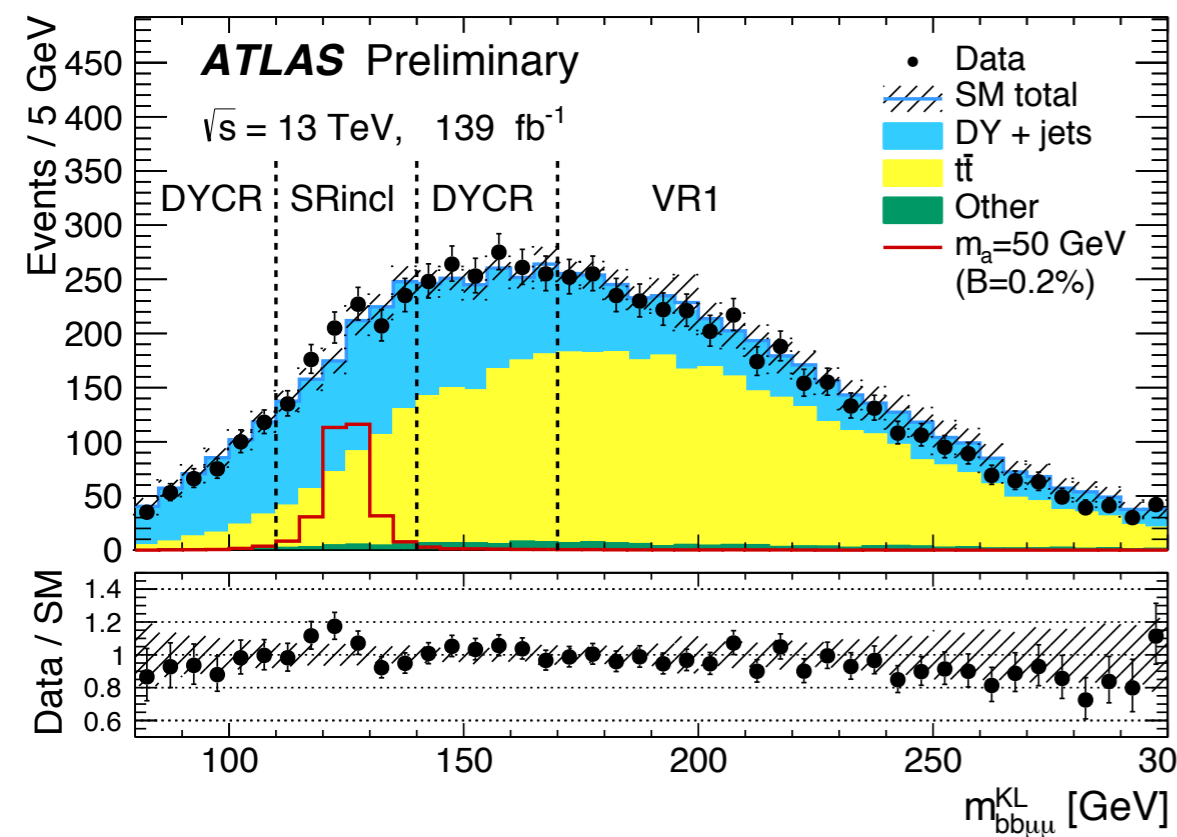
Resonance search in Z boson pair

Charged Higgs boson to gauge boson

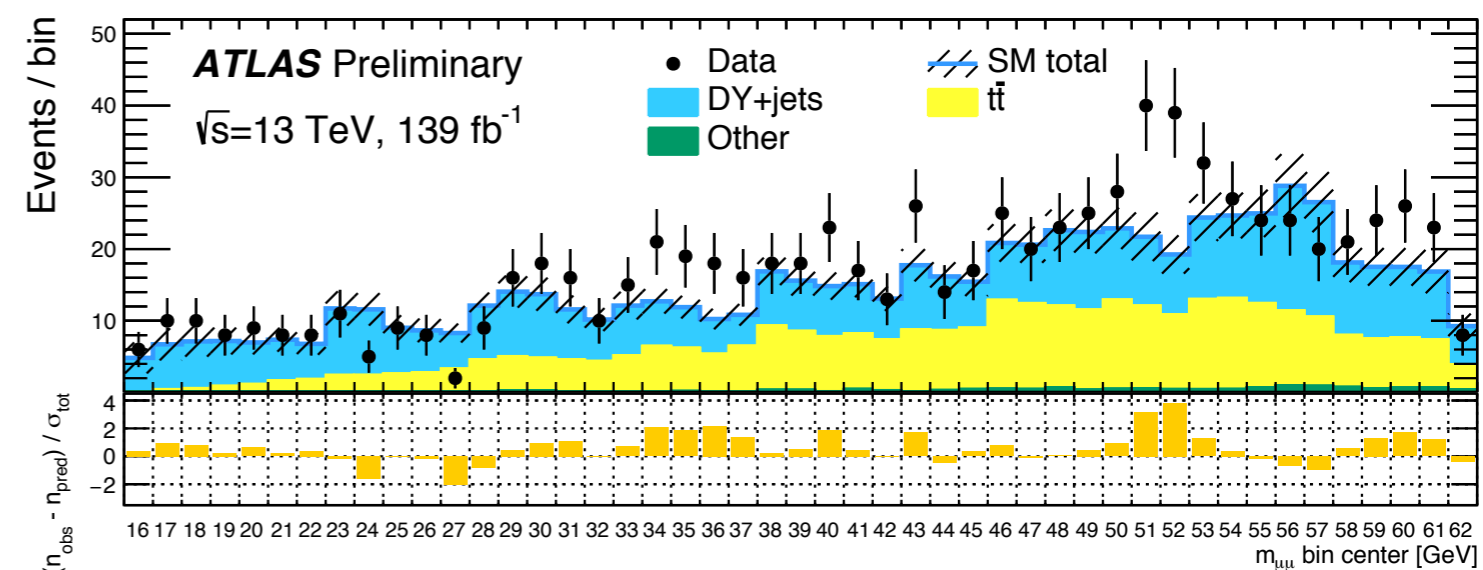
Summary

$H(125) \rightarrow aa \rightarrow (b\bar{b})(\mu^+\mu^-)$

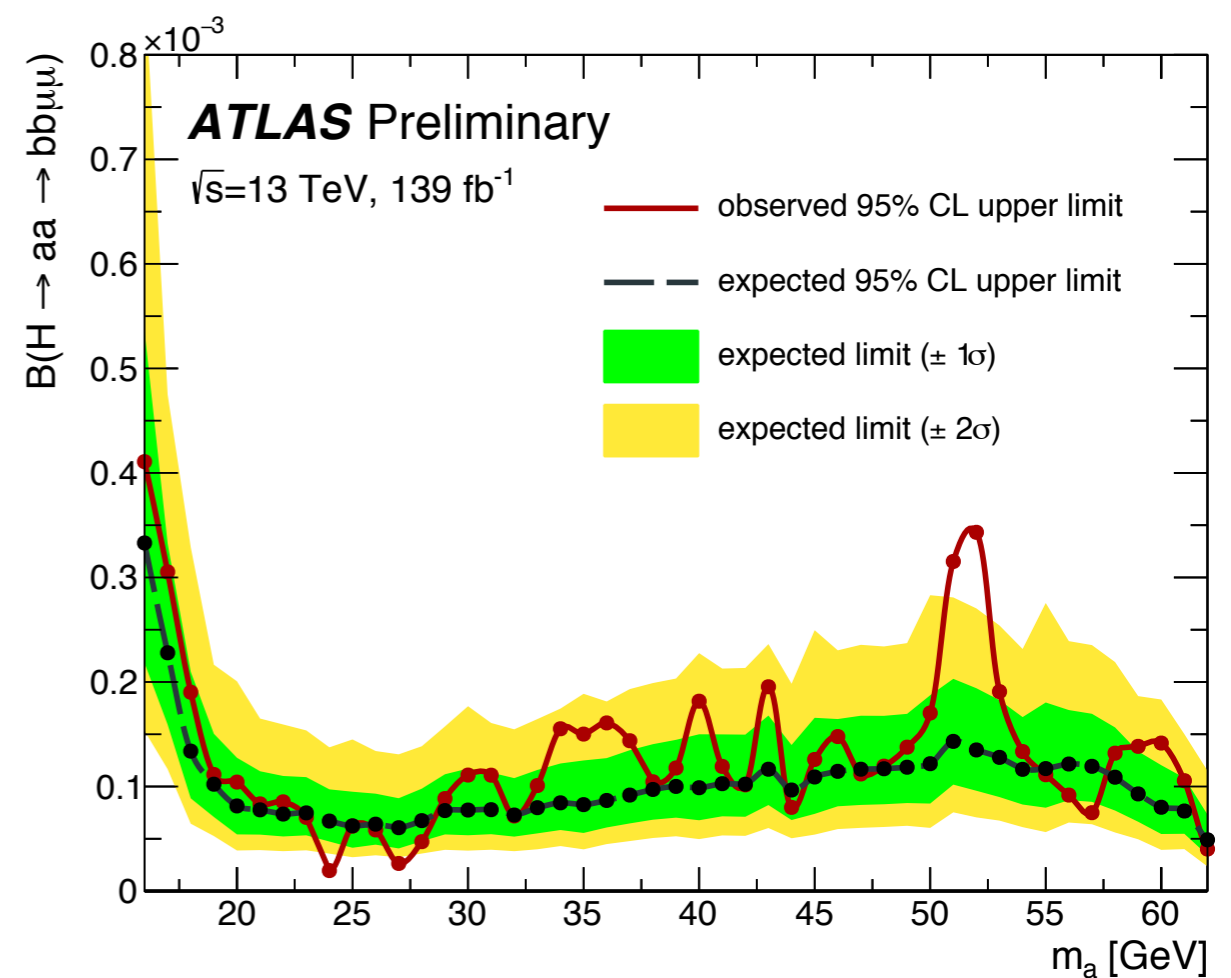
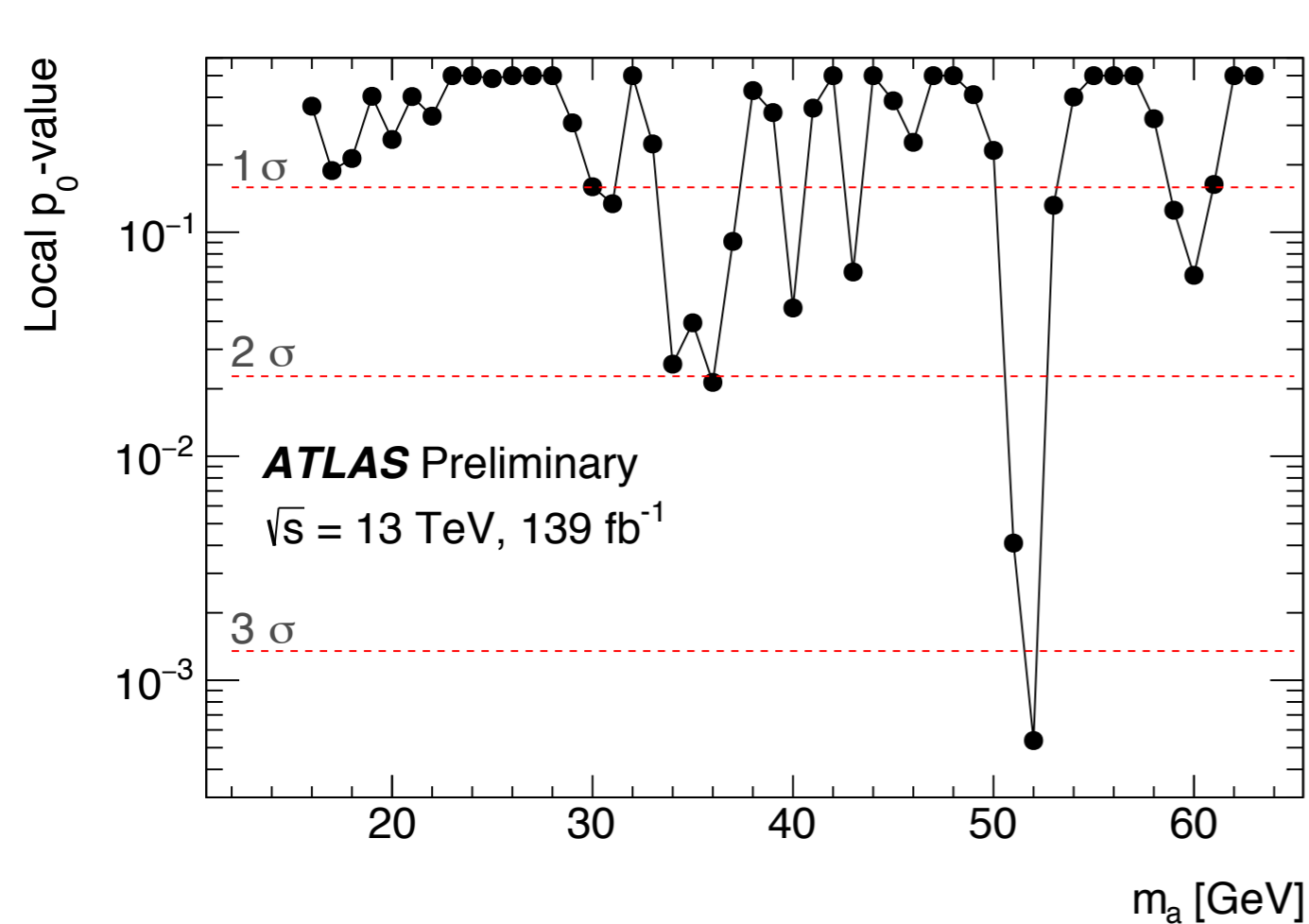
- ✓ A search of SM Higgs decaying to a pair of light pseudo scalar bosons is carried out.
- ✓ A kinematic likelihood fit exploiting m_a symmetry of $H \rightarrow aa$ decays is implemented to improve $m_{bb\mu\mu}$ resolution.
- ✓ The fit maximizes the likelihood by shifting the b-jet energies within the resolution to satisfy $m_{\mu\mu} \simeq m_{bb}$



	TCR	DYCR	SRincl	VR1	VR2
$m_{\mu\mu} \text{ [GeV]}$		$15 < m_{\mu\mu} < 65$			
$m_{bb\mu\mu}^{KL} \text{ [GeV]}$	[110,140]	[80,110] or [140,170]	[110,140]	[170,300]	[110,140]
$E_T^{\text{miss}} \text{ [GeV]}$	> 60	< 60			
$\ln(L^{\text{max}})$		> -8			[-11,-8]
SR bins	SRincl & BDT(m_a) > 0.2 2 GeV (3 GeV) wide $m_{\mu\mu}$ bins for $m_a \leq 45 \text{ GeV}$ ($m_a > 45 \text{ GeV}$)				



$H(125) \rightarrow aa \rightarrow (b\bar{b})(\mu^+\mu^-)$



Key features :

- A narrow di-muon resonance is searched within the range 16 GeV to 62 GeV.
- No significant excess is observed.
- The lowest local p-value is 0.00054 of observed at 52 GeV, corresponding to a local(global) significance of $3.27\sigma(1.7\sigma)$
- The 95% CL limit on $\mathcal{B}(H \rightarrow aa \rightarrow (b\bar{b})(\mu^+\mu^-))$ varies between 2.2×10^{-5} and 4.0×10^{-4} .

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- $H(125) \rightarrow aa \rightarrow (b\bar{b})(\mu^+\mu^-)$**

- $H(125) \rightarrow aa(\text{LLP}) \rightarrow (b\bar{b})(b\bar{b})$**

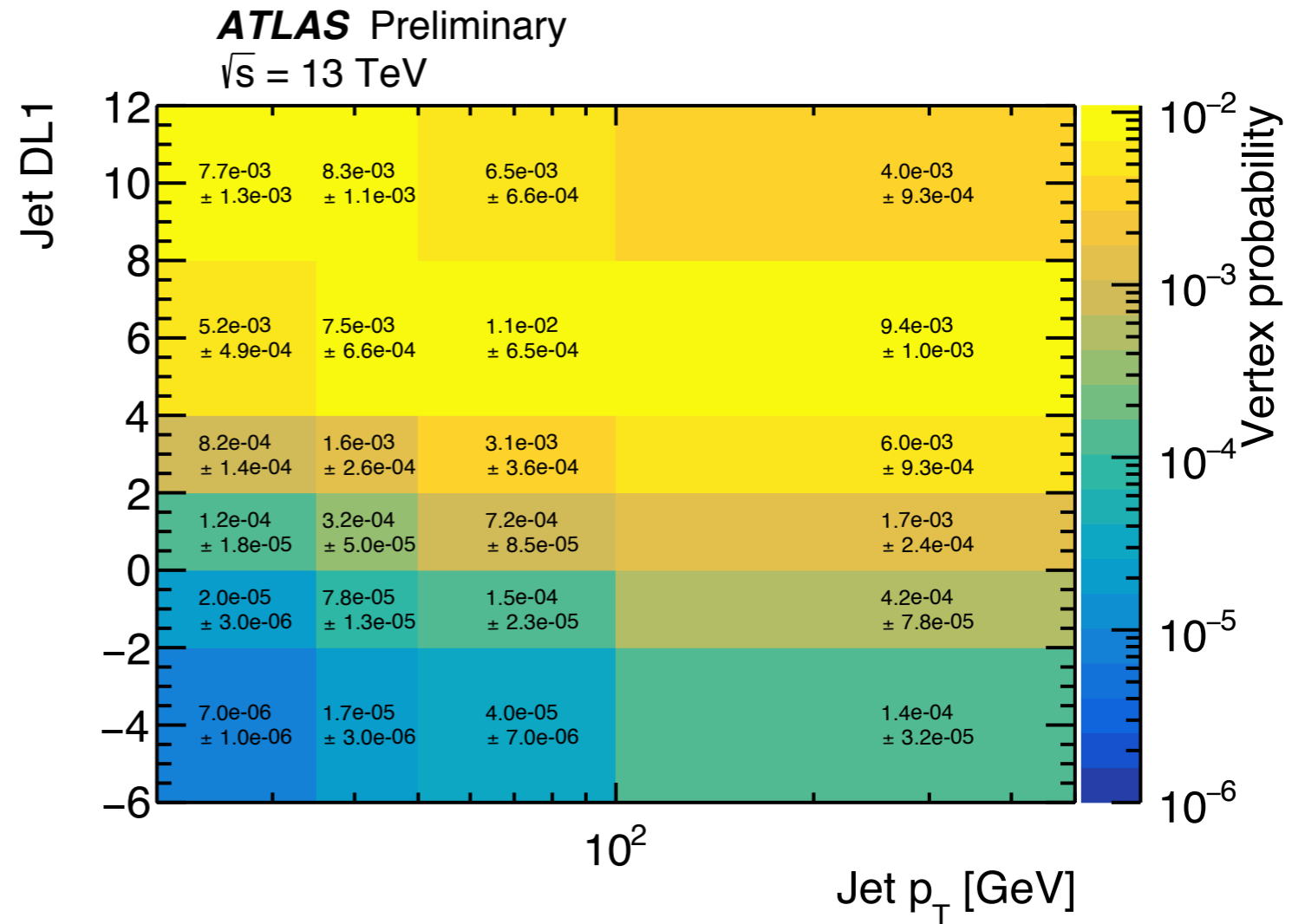
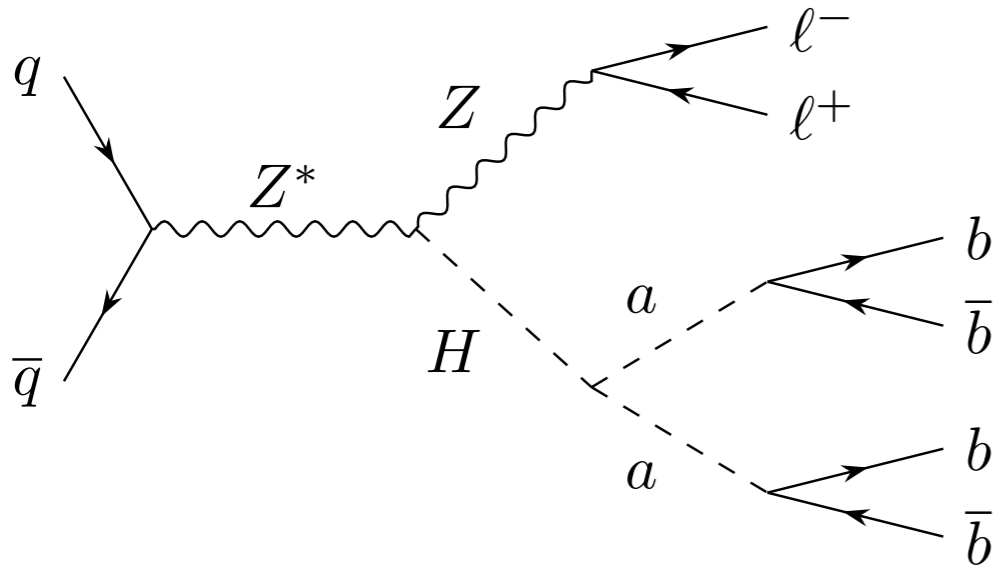
- Resonance search in Z boson pair**

- Charged Higgs boson to gauge boson**

- Summary**

$H(125) \rightarrow aa(LLP) \rightarrow (b\bar{b})(b\bar{b})$

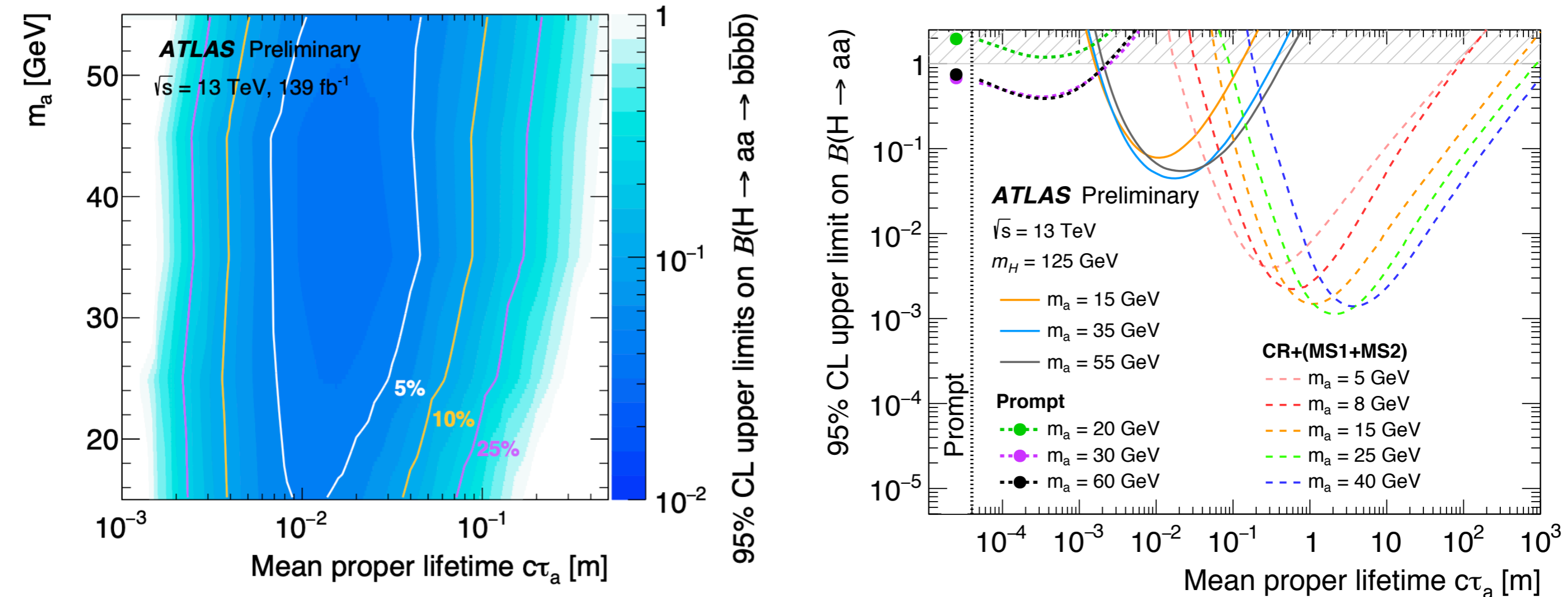
ATLAS-CONF-2021-005



✓ A search of SM Higgs decaying to a pair of light boson is carried out, with $c\tau_a$ and m_a As free parameters.

✓ The search looks for at least two displaced vertices, reconstructed from inner detector tracks.

$H(125) \rightarrow aa(LLP) \rightarrow (b\bar{b})(b\bar{b})$



Key features :

- ✓ A search for Higgs boson decaying to a pair of LLP pseudo-scalar (a) is carried out.
- ✓ The presence of displaced vertices, originating from the decay of a-bosons (with high mass and track multiplicity compared to SM process) is used for background rejection.
- ✓ For $m_a = 15(55) \text{ GeV}$, a branching ratio of $> 10\%$ is excluded at $3.8 < c\tau_a < 36$ ($5.2 < c\tau_a < 110$) mm.
- ✓ For masses below 40 GeV, these are the strongest limit in this lifetime range

ATLAS-CONF-2021-005

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► Resonance search in Z boson pair

Charged Higgs boson to gauge boson

Summary

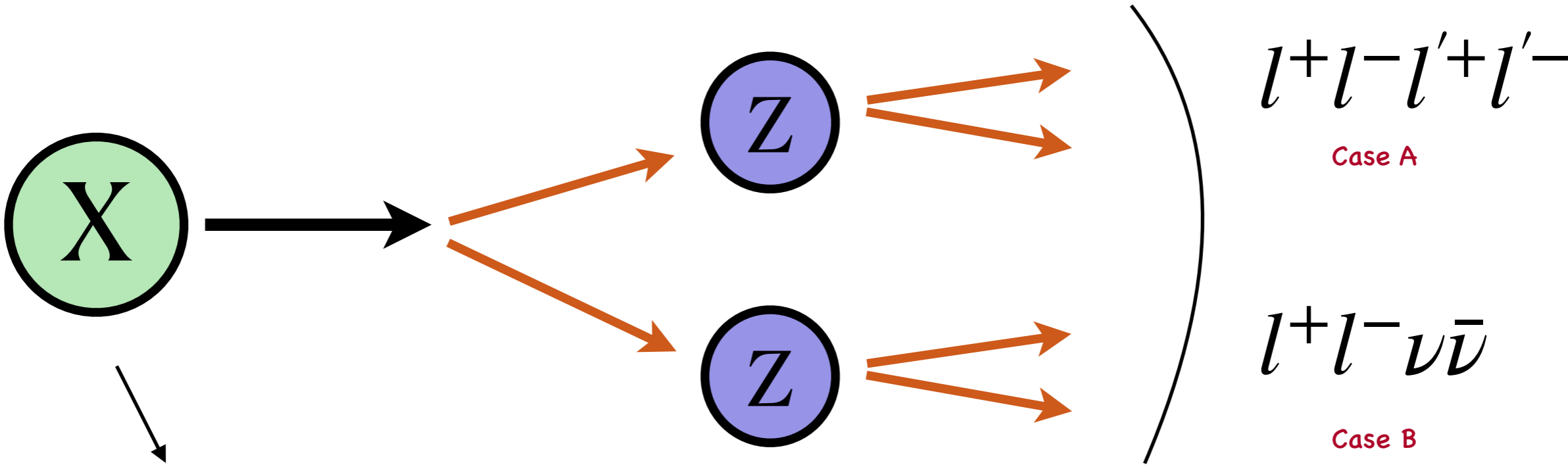
Search for a resonance decay into a Z boson pair

Main production modes : ggF/VBF

Eur. Phys. J. C (2021) 81:332

Case A : m_{4l}

Case B : $m_T \equiv \sqrt{\left[\sqrt{m_Z^2 + (\mathbf{p}_T^{\parallel})^2} + \sqrt{m_Z^2 + (\mathbf{E}_T^{\text{miss}})^2} \right]^2 - |\vec{\mathbf{p}}_T^{\parallel} + \vec{\mathbf{E}}_T^{\text{miss}}|^2}$



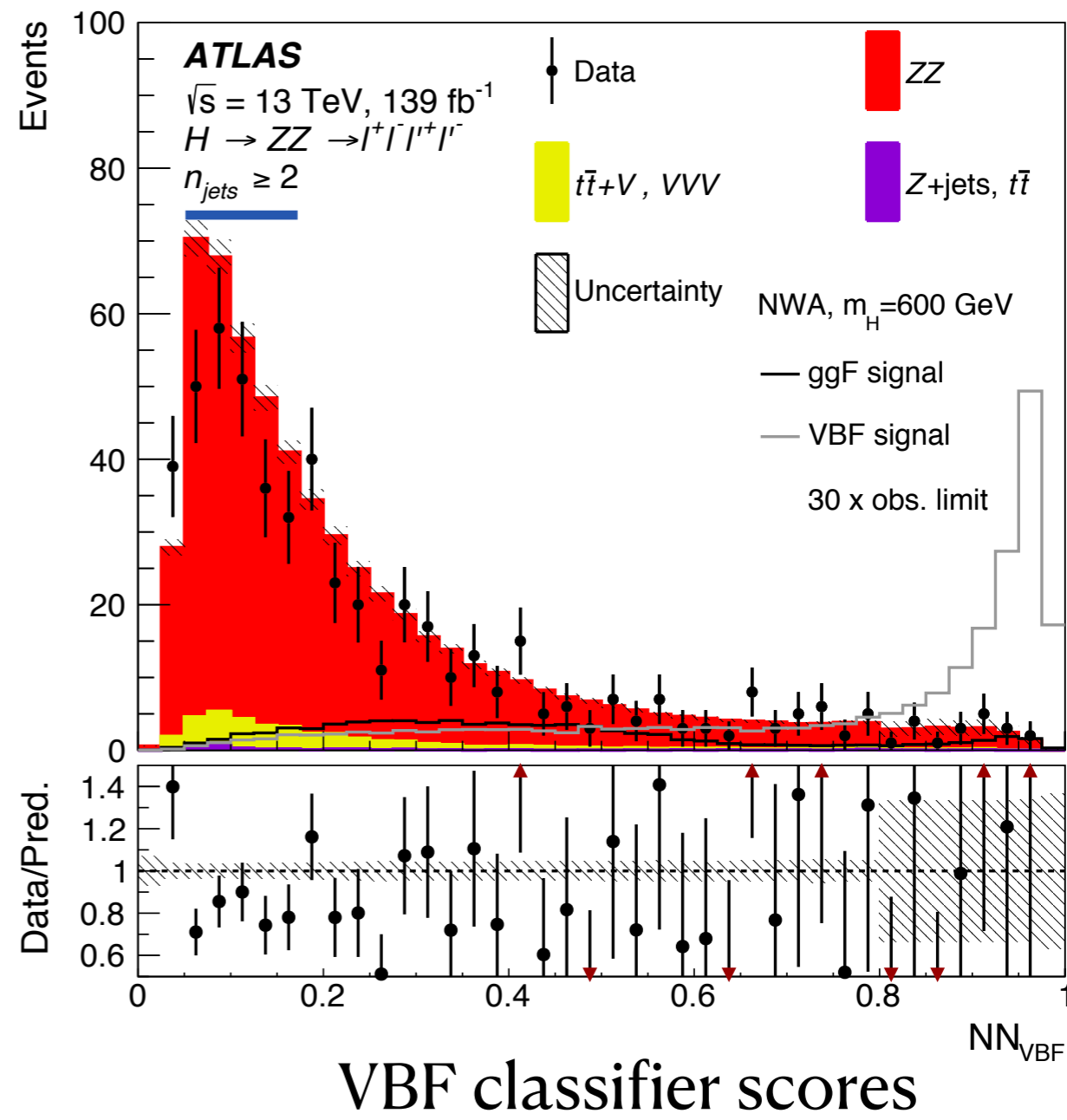
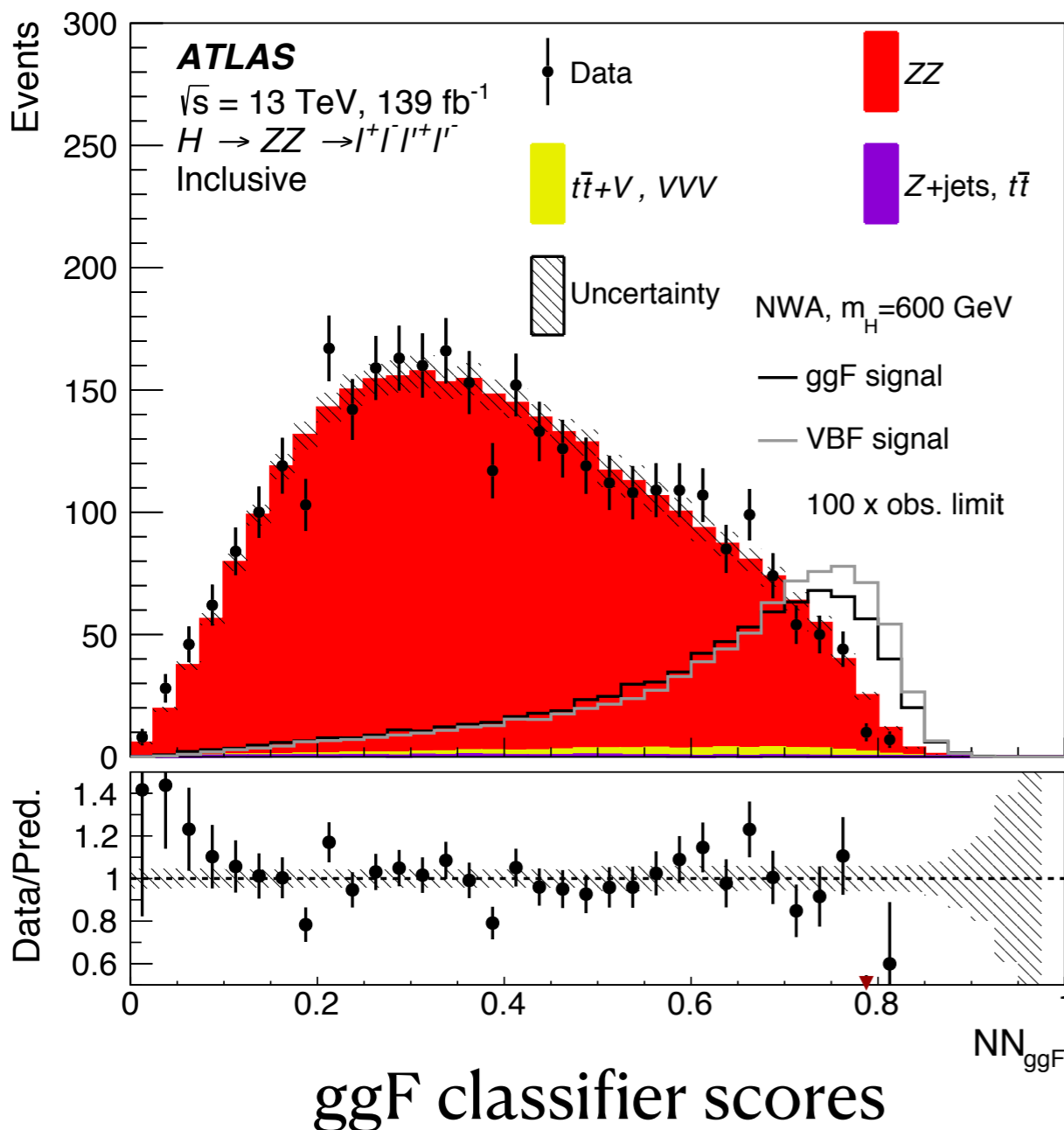
Type-1 / Type-2 2-HDM / KK-Graviton

ggF classifier : 1-rNN + MLP :
rNN input : pT and eta of four leptons + 2 leading jets

VBF classifier : 2-rNN + MLP :
rNN input : pT and eta of four leptons

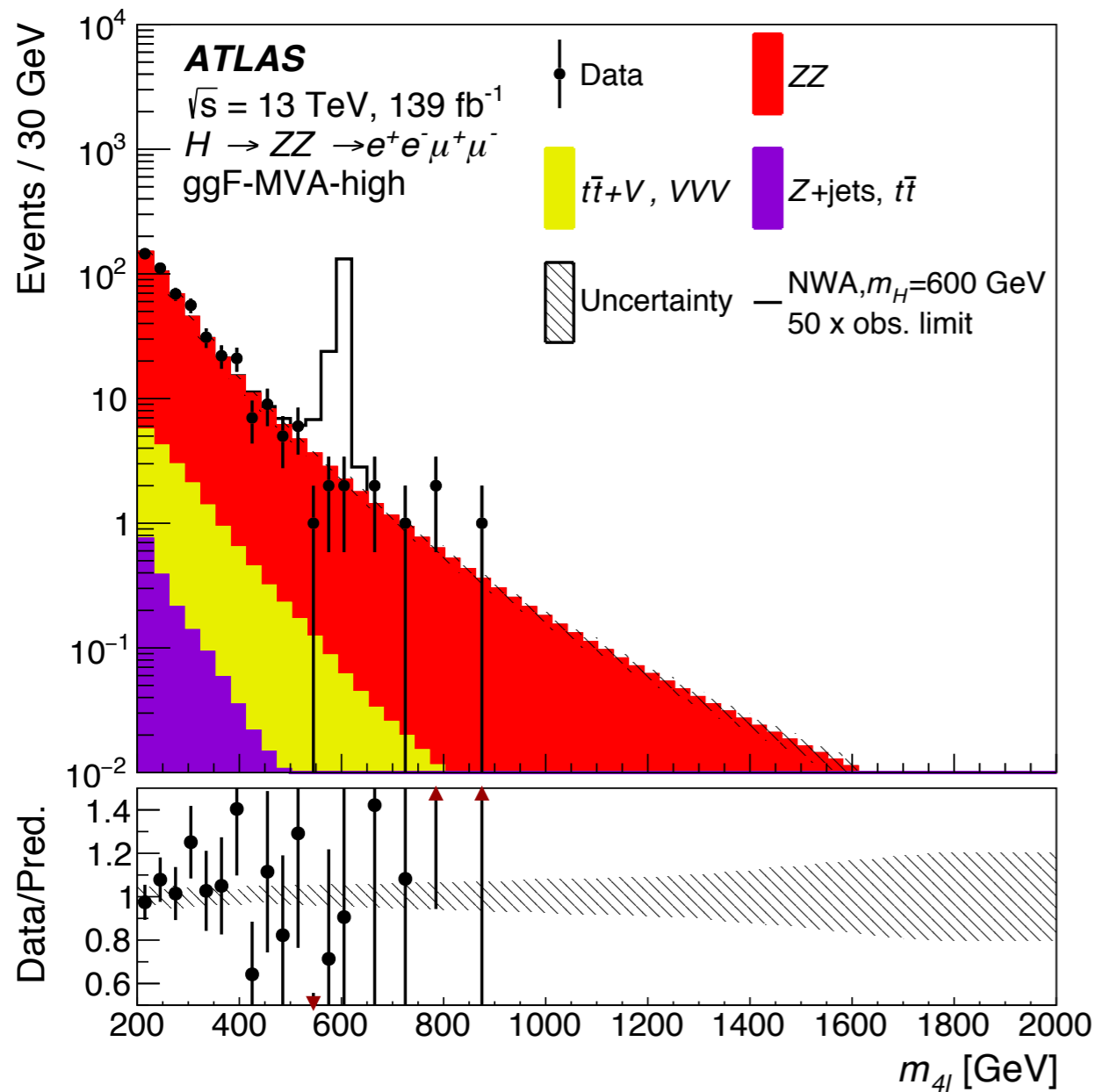
While searching for large-width signals , ggF enriched cut based analysis is used.

ggF vs VBF classification

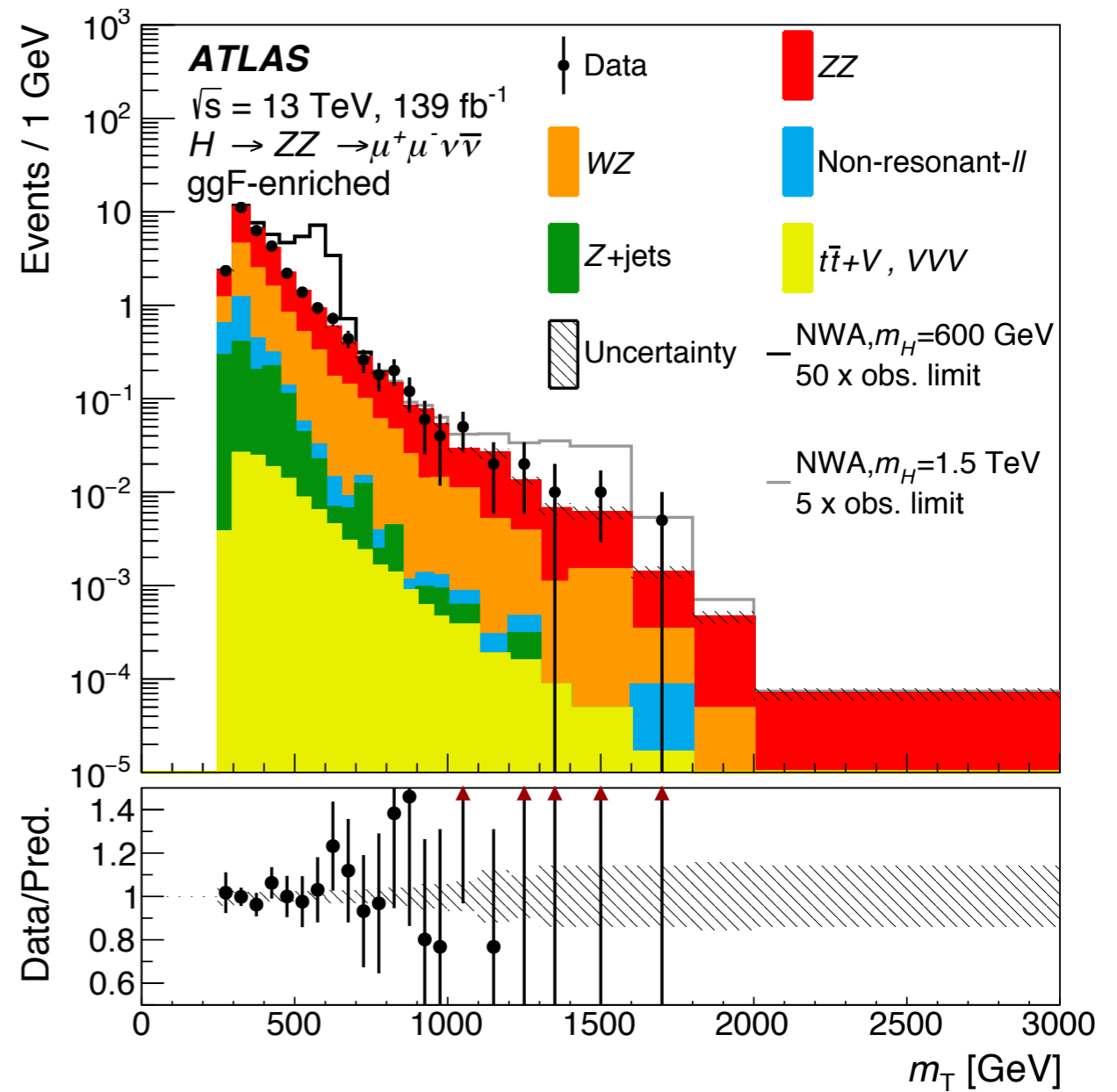


Example signal with $m_H = 600 \text{ GeV}$

Distribution of the observables



$4l$ distribution



m_T distribution

Example signal with $m_H = 600 \text{ GeV} / 1.5 \text{ TeV}$

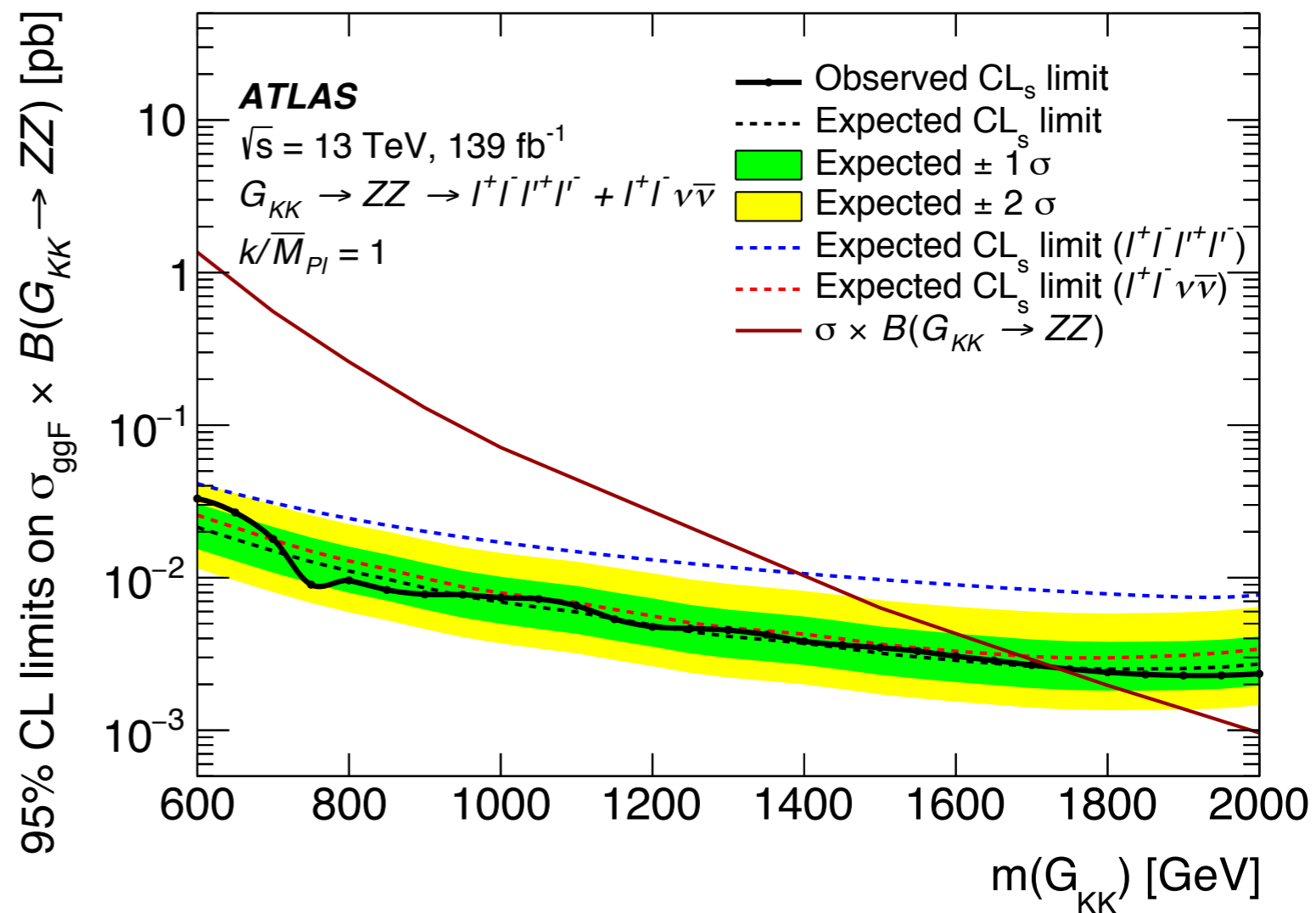
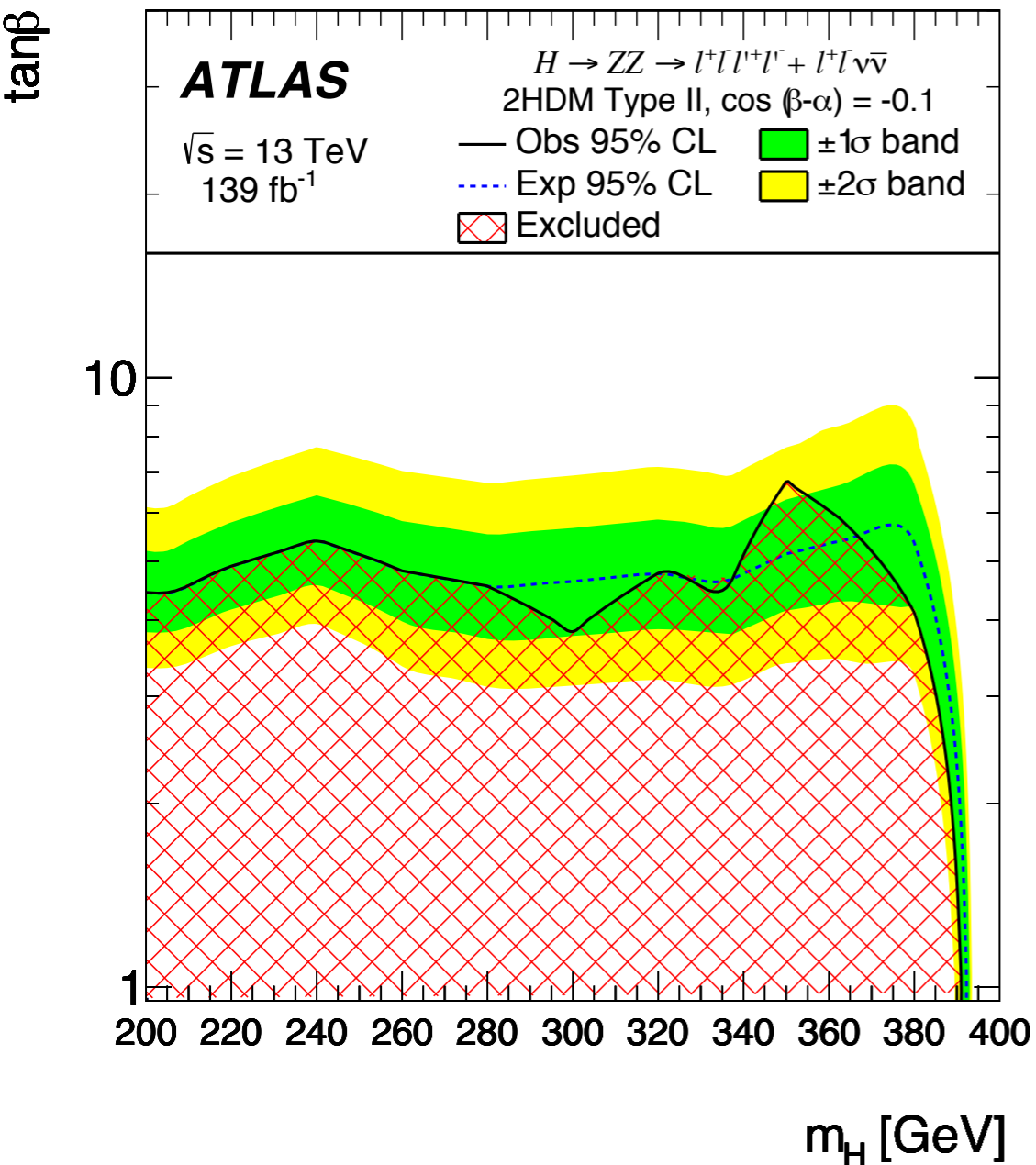
Exclusion limits

Type-2 2-HDM :

60% more $\tan \beta$ region excluded
(Compared to previous ATLAS result)

KK graviton :

Excluded up-to 1750 GeV



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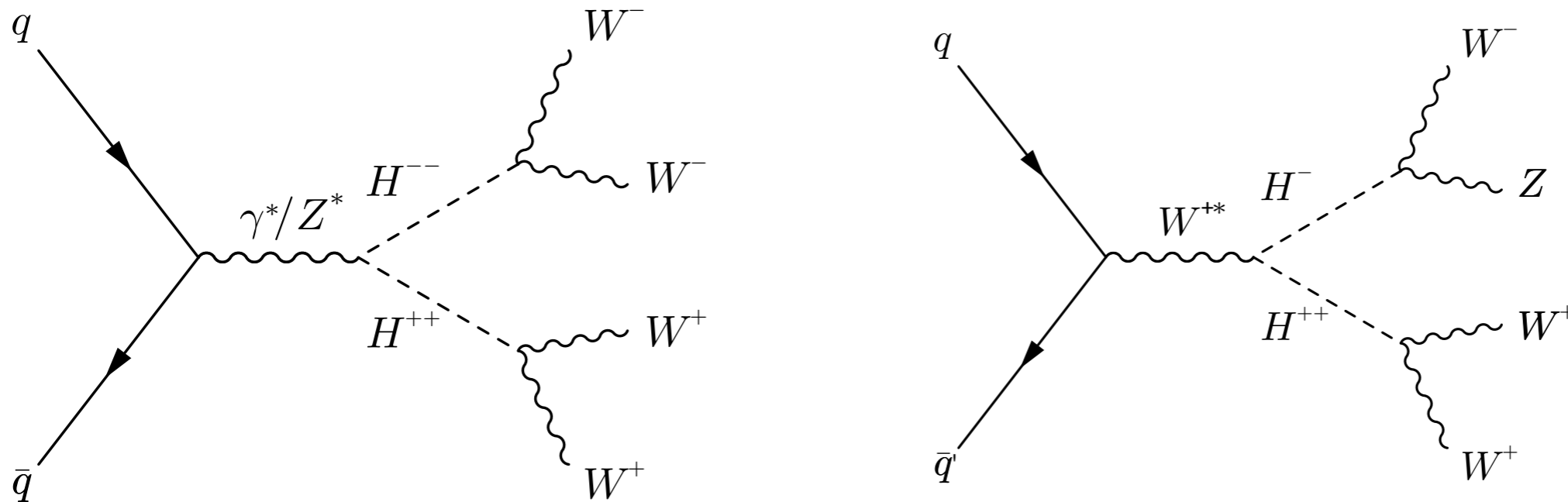
$H(125) \rightarrow aa(\text{LLP}) \rightarrow (b\bar{b})(b\bar{b})$

Resonance search in Z boson pair

▶ Charged Higgs boson to gauge boson

Summary

(Doubly)Charged Higgs boson to gauge bosons



arXiv : 2101.11961

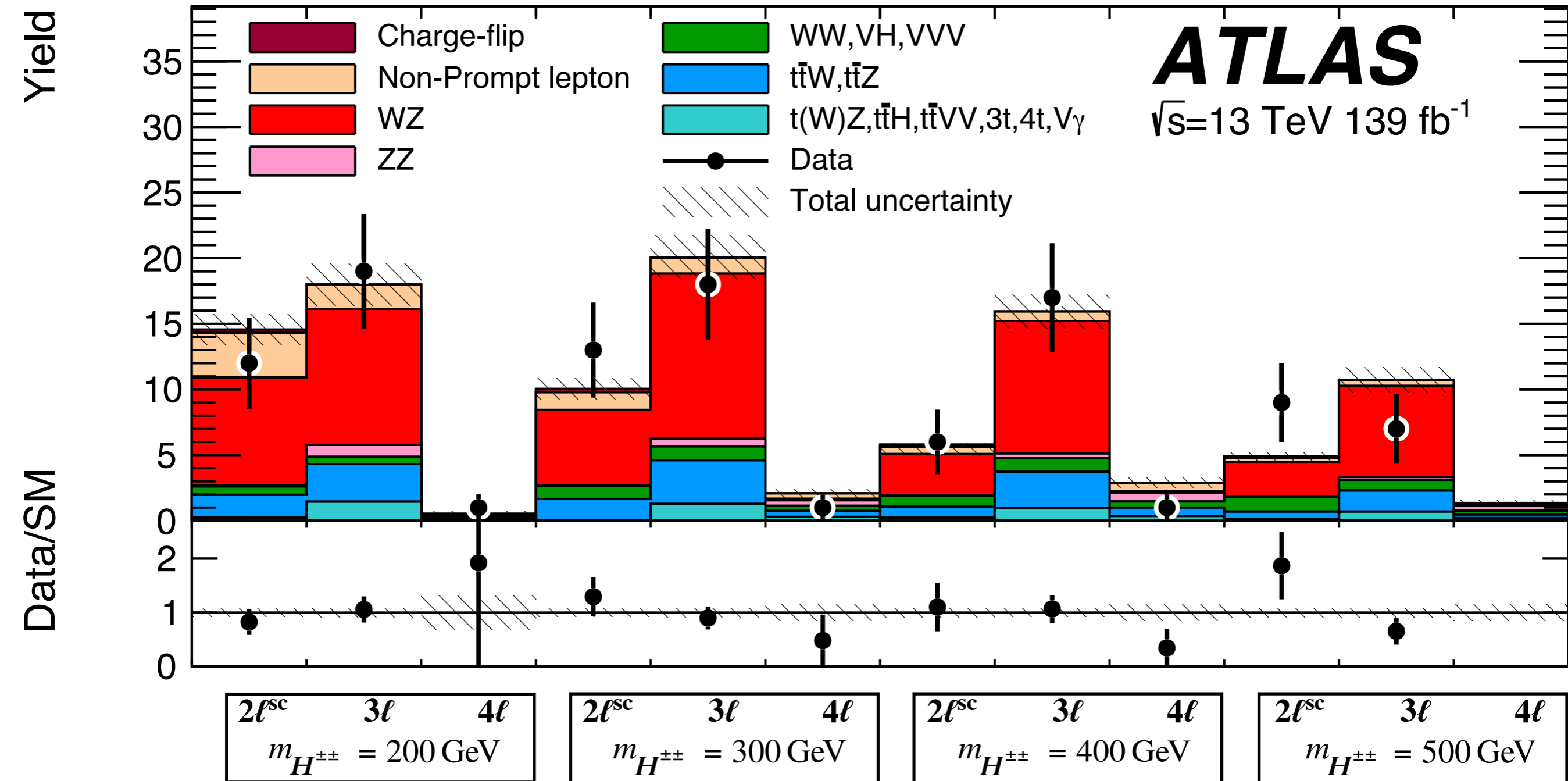
Key features :

- ✓ Search for (doubly) charged Higgs boson in to $W^\pm W^\pm$, $W^\pm Z$ final state
- ✓ The search is guided by type-2 seesaw model (extension of SM with a scalar triplet).
- ✓ Both $H^{\pm\pm}$ and H^\pm are searched for in pair production or associated production mode.

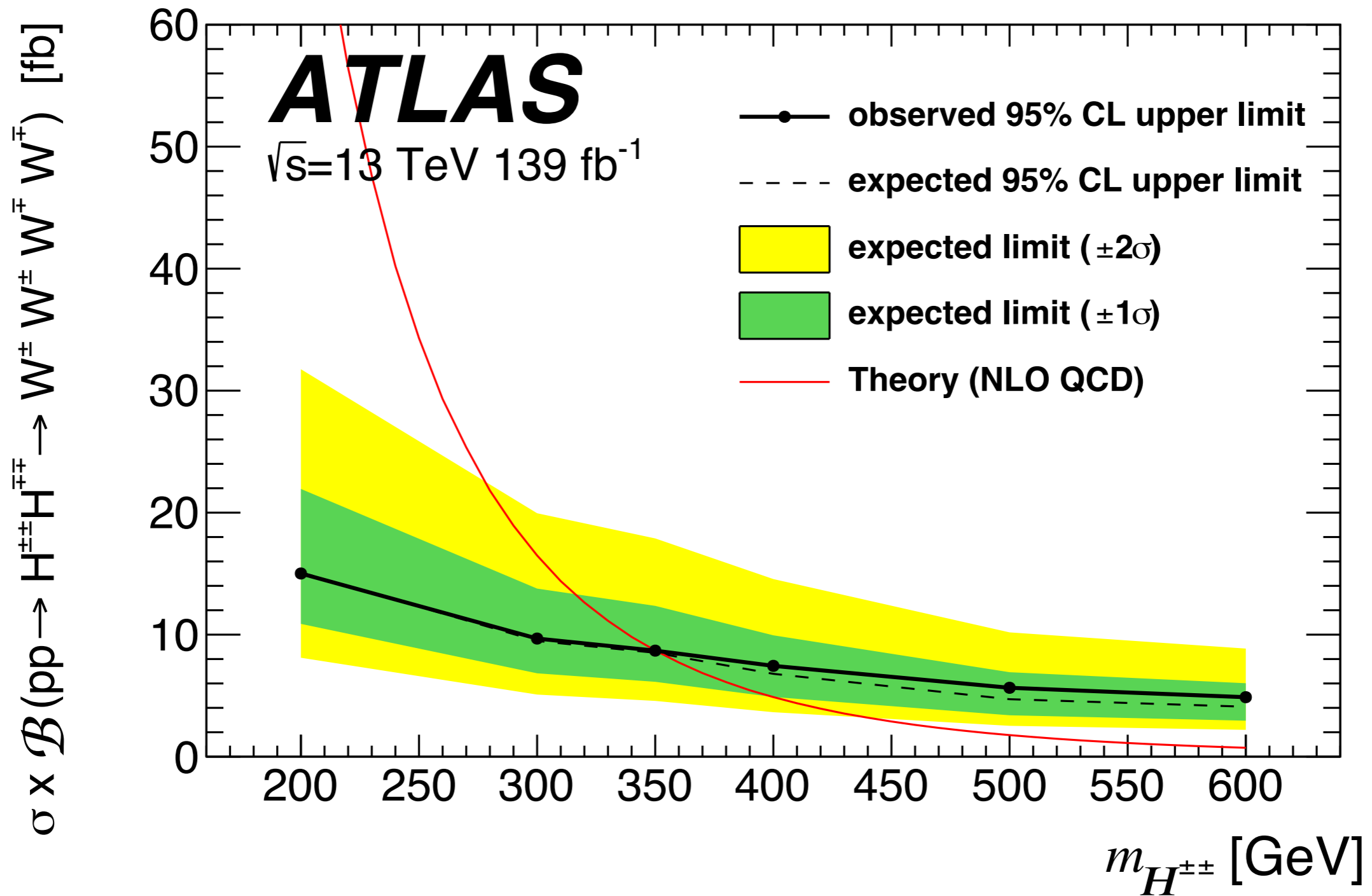
Event selection categorisation

Selection criteria	$2\ell^{\text{sc}}$	3ℓ	4ℓ
At least one offline tight lepton with $p_{\text{T}}^{\ell} > 30$ GeV that triggered the event			
N_{ℓ} (type L)	=2	=3	=4
N_{ℓ} (type L*)	–	–	=4
N_{ℓ} (type T)	=2	≥ 2 ($\ell_{1,2}$)	≥ 1
$ \sum Q_{\ell} $	=2	=1	$\neq 4$
Lepton p_{T}	$p_{\text{T}}^{\ell_{1,2}} > 30, 20$ GeV	$p_{\text{T}}^{\ell_{0,1,2}} > 10, 20, 20$ GeV	$p_{\text{T}}^{\ell_{1,2,3,4}} > 10$ GeV
$E_{\text{T}}^{\text{miss}}$	> 70 GeV	> 30 GeV	> 30 GeV
N_{jets}	≥ 3	≥ 2	–
$N_{b\text{-jets}}$	=0		
Low SFOC $m_{\ell\ell}$ veto	–	$m_{\ell\ell}^{\text{oc}} > 15$ GeV	
Z boson decay veto	$ m_{ee}^{\text{sc}} - m_{\text{Z}} > 10$ GeV	$ m_{\ell\ell}^{\text{oc}} - m_{\text{Z}} > 10$ GeV	

Total yield in different channels



Exclusion limit



The signal is ruled out up to $m_{H^{\pm\pm}} = 350 \text{ GeV}$
(In the associated production mode, the limit is 250 GeV)

The current measurement pushes the limit up
by 130 GeV compared to previous measurement

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Summary

Existence of BSM Higgs bosons are well motivated from theoretical perspective.

BSM Higgs search is a robust program within ATLAS.

In this talk we have presented the following new results :

H(125) \rightarrow aa \rightarrow (b \bar{b})($\mu^+\mu^-$) search :

For the low mass di-mu resonance, lowest local p-value of 0.00054 is observed at 52 GeV, corresponding to a local(global) significance of **3.27 σ (1.7 σ)**

H(125) \rightarrow aa(LLP) \rightarrow (b \bar{b})(b \bar{b}) search :

For $m_a = 15(55)$ GeV, a branching ratio of $> 10\%$ is excluded at **3.8 $< c\tau_a < 36$ (5.2 $< c\tau_a < 110$)** mm.

ZZ resonance search :

KK-gravitons are excluded up to **1750 GeV**.

(Doubly)Charged Higgs boson search :

$m_{H^{\pm\pm}}$ is ruled out up to **350 GeV** (the limit is pushed up by **130 GeV** compared to previous measurement)

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults>

<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HDBSPublicResults>

Backup

ggF vs VBF classification for ZZ resonance

Model	Inputs	Description
rNN	p_T^{j0}, p_T^{j1}	transverse momenta of the two leading jets
	η^{j0}, η^{j1}	pseudorapidity of the two leading jets
	$p_T^{\ell0}, p_T^{\ell1}, p_T^{\ell2}, p_T^{\ell3}$	transverse momenta of the four leptons
	$\eta^{\ell0}, \eta^{\ell1}, \eta^{\ell2}, \eta^{\ell3}$	pseudorapidity of the four leptons
MLP	$m_{4\ell}$	invariant mass of the four-lepton system
	m_{jj}	invariant mass of the two-leading-jet system
	p_T^{jj}	transverse momentum of the two-leading-jet system
	$\Delta\eta_{H,j}$	difference in pseudorapidity between the four-lepton system and the leading jet
	$\min\Delta R_{jZ}$	minimum distance between one of the two lepton pairs and a jet

VBF classifier inputs

Model	Inputs	Description
rNN	$p_T^{\ell0}, p_T^{\ell1}, p_T^{\ell2}, p_T^{\ell3}$	transverse momenta of the four leptons
	$\eta^{\ell0}, \eta^{\ell1}, \eta^{\ell2}, \eta^{\ell3}$	pseudorapidity of the four leptons
MLP	$m_{4\ell}$	invariant mass of the four-lepton system
	$p_T^{4\ell}$	transverse momentum of the four-lepton system
	$\eta^{4\ell}$	pseudorapidity of the four-lepton system
	$\cos\theta^*$	production angle of the leading Z defined in the four-lepton rest frame
	$\cos\theta_1$	angle between the negative final state lepton and the direction of flight of leading Z in the Z rest frame
	$\cos\theta_2$	angle between the negative final state lepton and the direction of flight of sub-leading Z in the Z rest frame
	Φ	angle between the decay planes of the four final state leptons expressed in the four-lepton rest frame
	p_T^{j0}	transverse momentum of the leading jet
η^{j0}	pseudorapidity of the leading jet	

ggF classifier inputs