Search for a High-mass Resonance with WW Final State

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Shandong University

the 11th FCPPL Workshop

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Outline

- Introduction
- Signals and Backgrounds
- Event selection and signal acceptance
- MC corrections
- Systematics
- Results

Introduction: Project 2017

LHC-SDU/USTC-LAL-ATLAS: Searches for heavy heavy boson in the WW channel and new physics in inclusive Z boson events at large transverse momentum

French Group			**Chinese Group**		
Name	**Title**	**Affiliation** (institute)	**Name**	**Title**	**Affiliation** (institute)
Leader Zhiqing Zhang	Dr	LAL	*Leader* Lianliang MA	Prof.	SDU
Yongke Zhao	PhD student	LAL-SDU	Yongke Zhao	PhD student	LAL-SDU
Weimin Song	Postdoc	LAL-SDU	Weimin Song	Postdoc	LAL-SDU
Kunlin Han	Student	LAL-USTC	Kunlin Han	Student	LAL-USTC
			Yingchun Zhu	Assoc. Prof.	USTC

Zhiqing & Lianliang: contact editors (Zhiqing also analsis contact person)

Yonkge: event selections, systematic estimation, input preparation

Weiming: W+jets estimation

Kunlin: WW and top theoretical estimation

Zhi &Lianliang: limit setting

Introduction: Motivation

- Motivation: search for a heavy neutral Higgs boson and other resonances decaying via R→WW→eνμν
- Data: full 2015+2016 datasets (36.1 fb^{-1}) @ 13 TeV
- Publication: Eur. Phys. J C (2018) 78:24
- Signal models

Model	Resonance spin	Production mode		
		ggF	qqA	VBF
NWA	Spin-0	x		x
2HDM		x		x
LWA		x		x
GM				x
HVT	Spin-1		x	x
Bulk RS	Spin-2	x		
ELM				x

Introduction: Backgrounds

- Main backgrounds: Top (ttbar and single-top), WW (qq→WW and gg→WW), normalized to the data in control regions (CRs)
- W+jets: large cross section but little contribution, estimated with using fake-factor method (data-driven)
- Small backgrounds: estimated using MC prediction: Z+jets (NNLO), Non-WW diboson (NLO), H125
- Event categorization according to the production mode:
  - ✓ **ggF** category (quasi-inclusive ggF, VBF phase spaces excluded)
  - ✓ **VBF 1-jet & 2-jet** categories

Event selection

$\mathrm{SR}_{\mathrm{ggF}}$	$\mathrm{SR}_{\mathrm{VBF1J}}$	$\mathrm{SR}_{\mathrm{VBF2J}}$
Preselection: $p_{\mathrm{T}}^{\ell,\mathrm{lead}} > 25$ GeV, $p_{\mathrm{T}}^{\ell,\mathrm{sublead}} > 25$ GeV, $m_{\ell\ell} > 10$ GeV, veto if $p_{\mathrm{T}}^{\ell,\mathrm{other}} > 15$ GeV		
$N_{b\text{-jet}} = 0$ $\lvert\Delta\eta_{\ell\ell}\rvert < 1.8$ $m_{\ell\ell} > 55$ GeV $p_{\mathrm{T}}^{\ell,\mathrm{lead}} > 45$ GeV $p_{\mathrm{T}}^{\ell,\mathrm{sublead}} > 30$ GeV $\max(m_{\mathrm{T}}^{W}) > 50$ GeV		
Inclusive in N_{jet} but excluding VBF1J and VBF2J phase space	$N_{\mathrm{jet}} = 1$ $\lvert\eta_j\rvert > 2.4$, $\min(\lvert\Delta\eta_{j\ell}\rvert) > 1.75$	$N_{\mathrm{jet}} \geq 2$ $m_{jj} > 500$ GeV, $\lvert\Delta y_{jj}\rvert > 4$

Signal Regions

WW $\mathrm{CR}_{\mathrm{ggF}}$	Top $\mathrm{CR}_{\mathrm{ggF}}$	WW $\mathrm{CR}_{\mathrm{VBF1J}}$	Top $\mathrm{CR}_{\mathrm{VBF}}$
Preselection: $p_{\mathrm{T}}^{\ell,\mathrm{lead}} > 25$ GeV, $p_{\mathrm{T}}^{\ell,\mathrm{sublead}} > 25$ GeV, $m_{\ell\ell} > 10$ GeV, veto if $p_{\mathrm{T}}^{\ell,\mathrm{other}} > 15$ GeV			
$N_{b\text{-jet}} = 0$ $\lvert\Delta\eta_{\ell\ell}\rvert > 1.8$	$N_{b\text{-jet}} = 1$ $\lvert\Delta\eta_{\ell\ell}\rvert < 1.8$	$N_{b\text{-jet}} = 0$ $(\lvert\Delta\eta_{\ell\ell}\rvert > 1.8$ or $m_{\ell\ell} < 55$ GeV$)$	$N_{b\text{-jet}} \geq 1$ – –
$m_{\ell\ell} > 55$ GeV $p_{\mathrm{T}}^{\ell,\mathrm{lead}} > 45$ GeV $p_{\mathrm{T}}^{\ell,\mathrm{sublead}} > 30$ GeV $\max(m_{\mathrm{T}}^{W}) > 50$ GeV		$p_{\mathrm{T}}^{\ell,\mathrm{lead}} > 25$ GeV $p_{\mathrm{T}}^{\ell,\mathrm{sublead}} > 25$ GeV –	$p_{\mathrm{T}}^{\ell,\mathrm{lead}} > 25$ GeV $p_{\mathrm{T}}^{\ell,\mathrm{sublead}} > 25$ GeV –
Excluding VBF1J and VBF2J phase space		VBF1J phase space	VBF1J and VBF2J phase space

Control Regions

Corrections to MCs

Corrections to MC samples considered in the analysis as below:

- top leading lepton pt reweighting in ggF SR and CRs
- qq→WW Sherpa-to-Matrix correction applied in ggF SR and WW CR
- gg→WW NLO k-factor: 1.7 (60% uncertainty quoted)
- ggF NWA signal Powheg-to-MadGraph reweighting in VBF SRs

Dominant systematics (Bkgs.)

Top

Source	Jet	b-tag	ME+PS	Scale	Single top	PDF	Total
SR_{ggF}	5.2	17	1.3	3.0	4.2	2.9	19
Top CR_{ggF}	2.2	4.8	0.34	0.21	2.6	4.3	7.3
WW CR_{ggF}	5.3	18	1.1	6.3	4.0	3.8	20
$\alpha_{ggF} = N_{SR_{ggF}}/N_{Top\ CR_{ggF}}$	3.0	13	0.99	3.2	1.3	1.5	13
$\beta_{ggF} = N_{WW\ CR_{ggF}}/N_{Top\ CR_{ggF}}$	3.1	13	1.4	6.5	1.4	0.90	15
SR_{VBF1J}	9.6	7.8	1.0	1.6	5.9	3.5	15
SR_{VBF2J}	9.7	14	9.5	5.0	2.1	3.6	21
Top CR_{VBF}	8.2	3.5	10	1.5	1.3	3.6	14
WW CR_{VBF1J}	9.9	8.3	9.4	3.9	5.3	3.4	18
$\alpha_{VBF1J} = N_{SR_{VBF1J}}/N_{Top\ CR_{VBF}}$	9.4	11	10	3.0	4.6	0.19	19
$\alpha_{VBF2J} = N_{SR_{VBF2J}}/N_{Top\ CR_{VBF}}$	2.4	18	0.7	3.4	0.83	1.6	19
$\beta_{VBF1J} = N_{WW\ CR_{VBF1J}}/N_{Top\ CR_{VBF}}$	12	12	0.8	5.3	4.0	0.53	19

WW

Source	Jet	Pile-up	ME+PS	μ_R	Resummation	PDF	Total
SR_{ggF}	1.2	1.8	2.4	1.7	3.1	1.3	5.0
WW CR_{ggF}	1.1	1.8	2.6	0.95	2.9	2.3	5.2
$\alpha_{ggF} = N_{SR_{ggF}}/N_{WW\ CR_{ggF}}$	0.3	0.24	4.9	0.75	0.26	1.2	5.2
SR_{VBF1J}	17	2.8	11	7.3	5.0	1.0	23
SR_{VBF2J}	18	3.1	38	18	1.4	1.3	47
WW CR_{VBF1J}	16	4.5	12	11	2.3	1.6	23
$\alpha_{VBF1J} = N_{SR_{VBF1J}}/N_{WW\ CR_{VBF1J}}$	4.8	1.8	1.1	4.0	2.7	0.76	8.9

"Total" includes all systematics (not only the dominant ones in the tables)

✓ Shape uncertainties also considered in the analysis

Dominant systematics(signals)

➢ QCD scale, PDF and PS uncertainties on signal acceptance

- The uncertainties have some dependences on the masses
- PS shower model uncertainties are significantly larger

ggF induced signals

Sources(%)	ggF SR	VBF 1J SR	VBF 2J SR
Scale	-	-	0.2 ~ 2.5
PDF	< 0.4	< 1.5	< 1.6
PS model	1.3 ~ 3.1	13 ~ 28	2.3 ~ 15

VBF induced signals

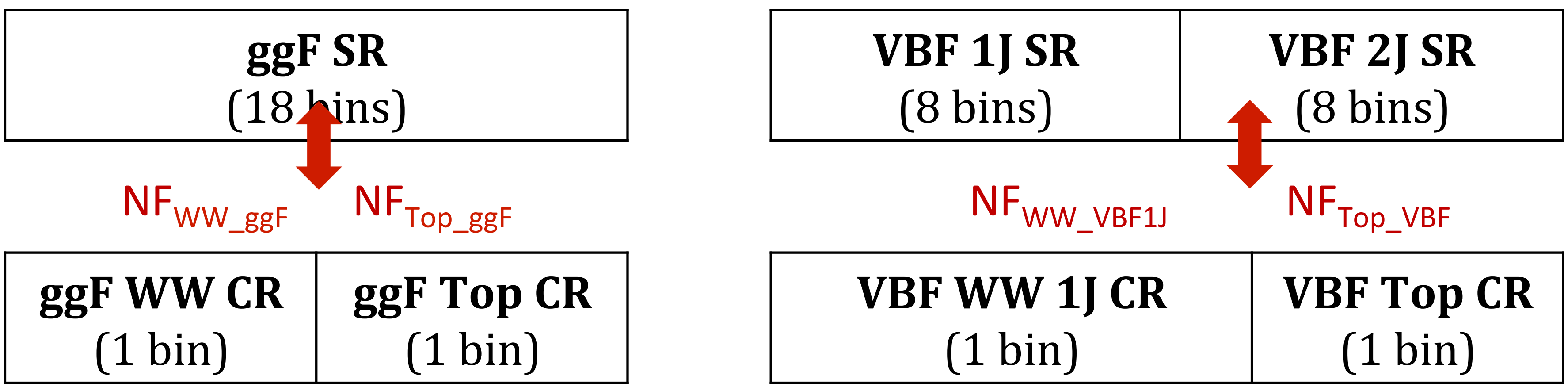
Sources(%)	ggF SR	VBF 1J SR	VBF 2J SR
Scale	0.9 ~ 2.8	1.9 ~ 3.6	1.0 ~ 7.3
PDF	< 1.7	< 1.2	< 1.5
PS model	4.3 ~ 19	5.1 ~ 9.0	3.3 ~ 8.0

➢ QCD scale uncertainties on event category migration

3% - 10% for ggF SR, 4% - 30% (30% - 60%) for VBF 1J (2J) SRs

Statistical Analysis

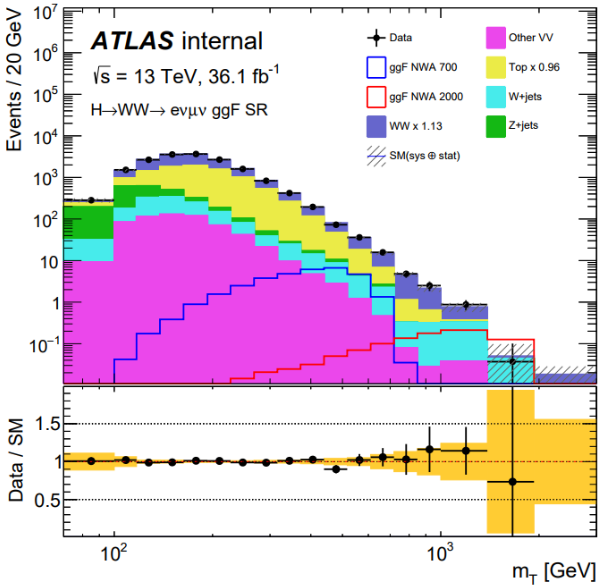
- The transverse mass (m_T) distribution as the discrimination variable
- Physics results obtained from a simultaneous fit to all SRs and CRs
- Modified frequentist method (CLs) used for the statistical treatment



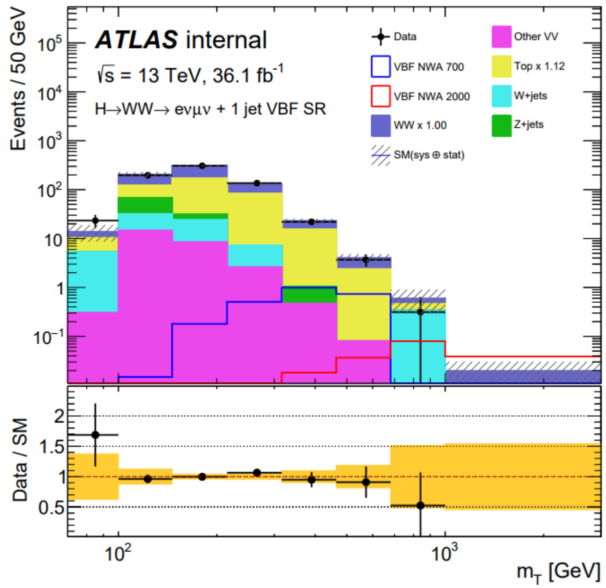
MT plots in SRs

- Post-fit plots
- Signals are normalized to expected limits

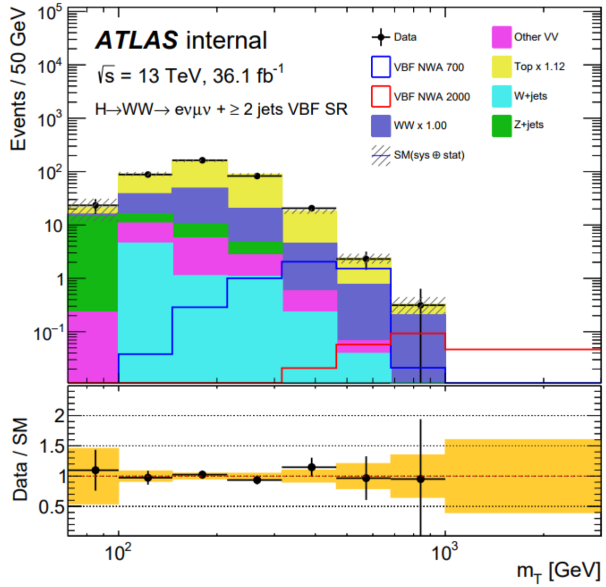
ggF SR



VBF 1J SR



VBF 2J SR



Post-fit NFs

$$\mathrm{NF}^{\mathrm{top}}_{\mathrm{ggF}} = 0.96 \pm 0.05 \qquad \mathrm{NF}^{\mathrm{top}}_{\mathrm{VBF}} = 1.12 \pm 0.1$$

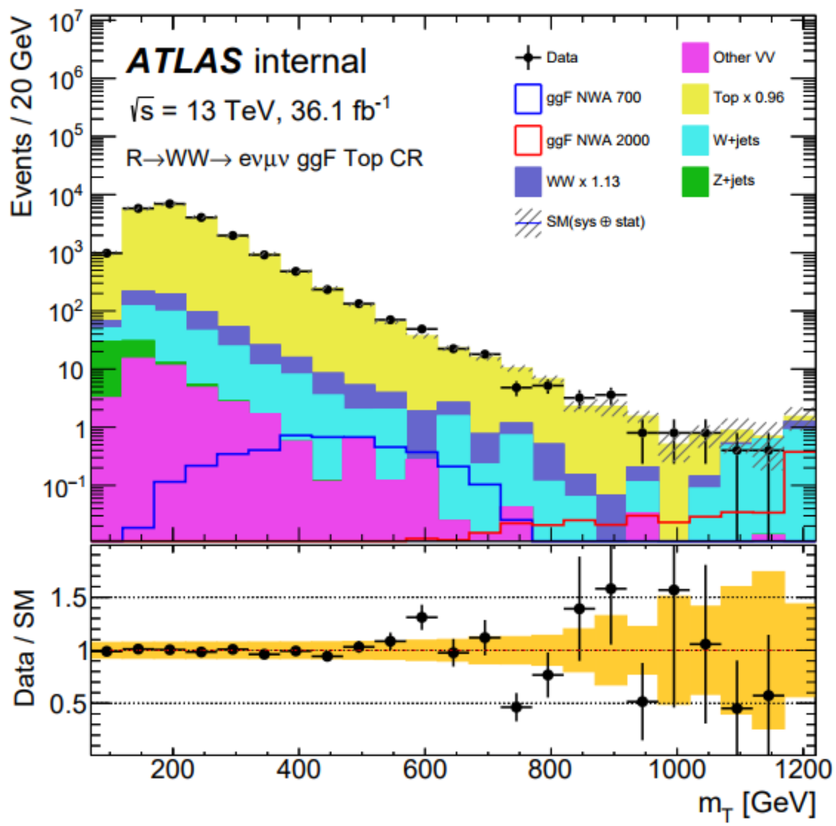
$$\mathrm{NF}^{\mathrm{WW}}_{\mathrm{ggF}} = 1.14 \pm 0.1 \qquad \mathrm{NF}^{\mathrm{WW}}_{\mathrm{VBF,1J}} = 1.00 \pm 0.2$$

(stat. ⊕ sys.)

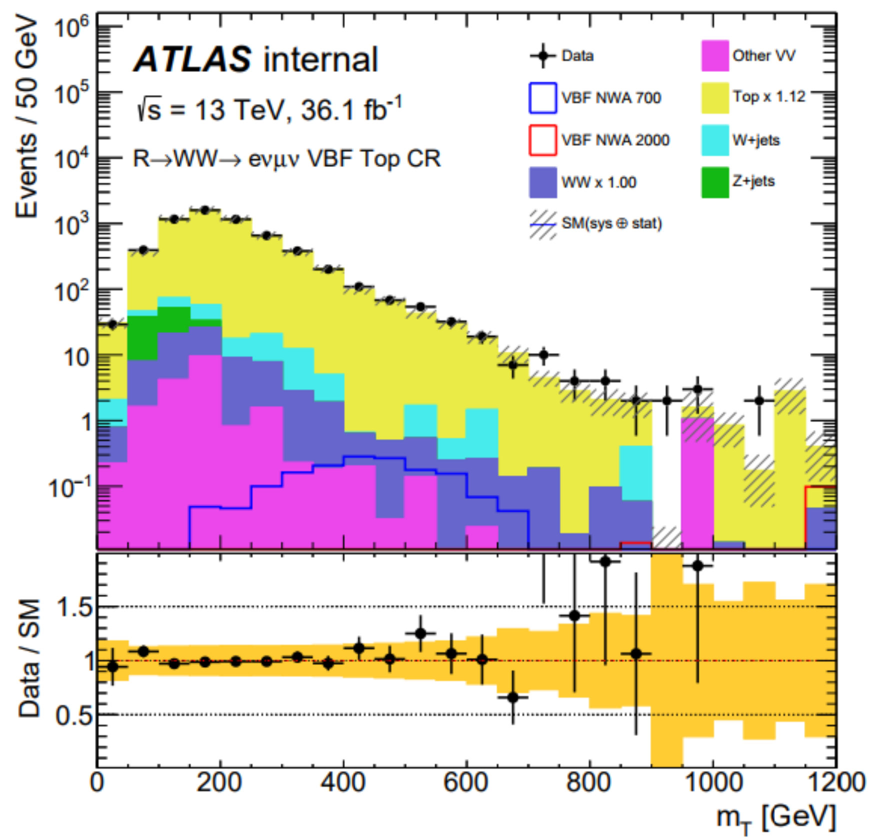
MT plots in Top CRs

- Backgrounds are normalized to the post-fit event yields
- Signals are normalized to expected limits

ggF Top CR $NF^{top}_{ggF} = 0.96 \pm 0.05$



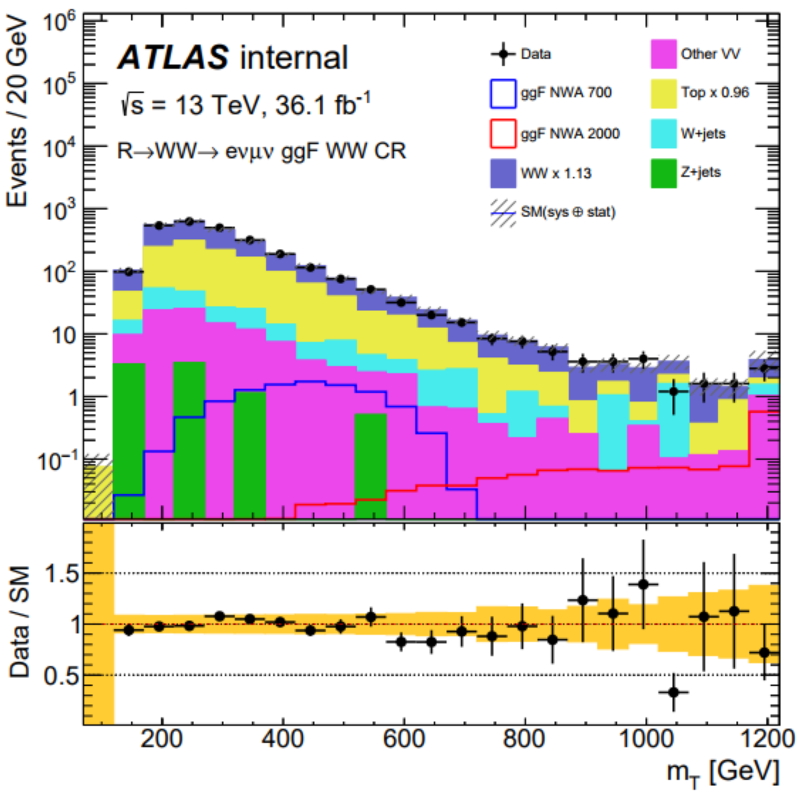
VBF Top CR $NF^{top}_{VBF} = 1.12 \pm 0.1$



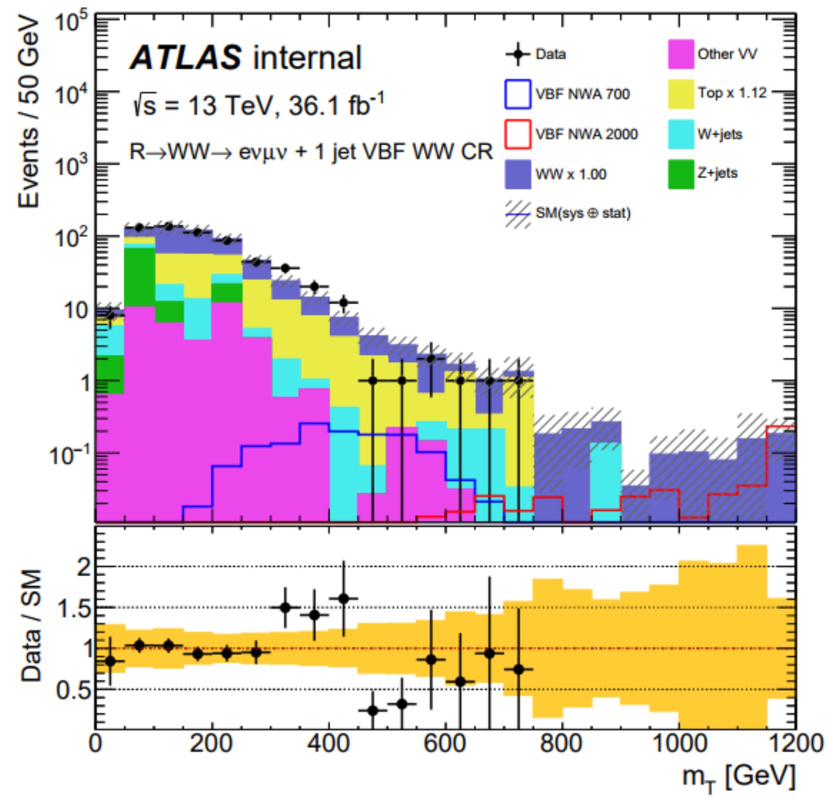
MT plots in WW CRs

- Backgrounds are normalized to the post-fit event yields
- Signals are normalized to expected limits

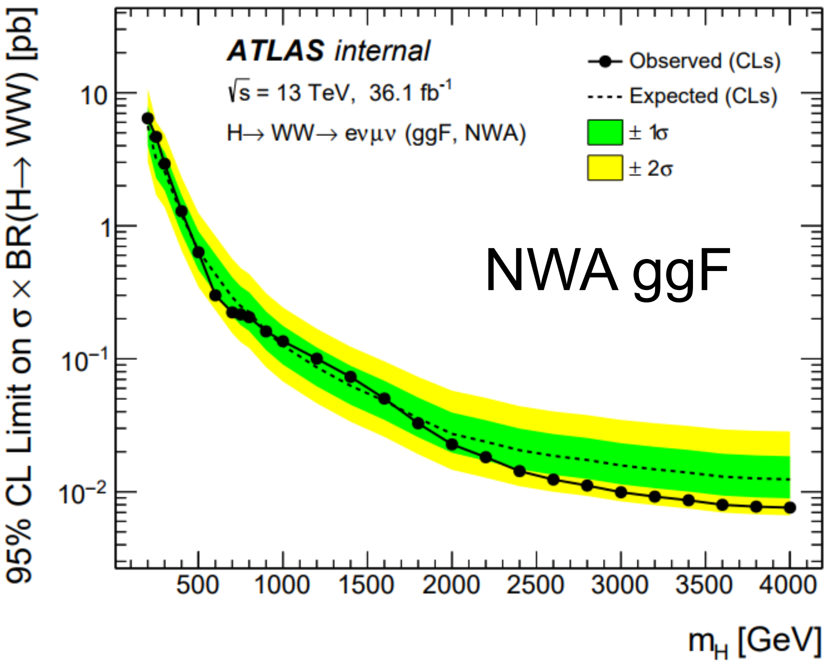
ggF WW CR $\mathrm{NF}^{\mathrm{WW}}_{\mathrm{ggF}} = 1.14 \pm 0.1$

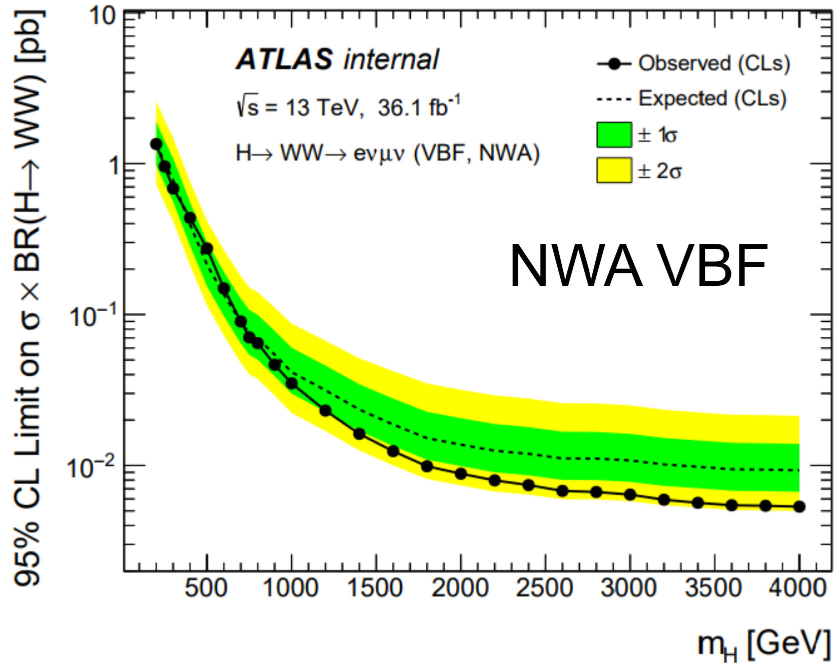


VBF 1J WW CR $\mathrm{NF}^{\mathrm{WW}}_{\mathrm{VBF,1J}} = 1.00 \pm 0.2$



Limits for NWA

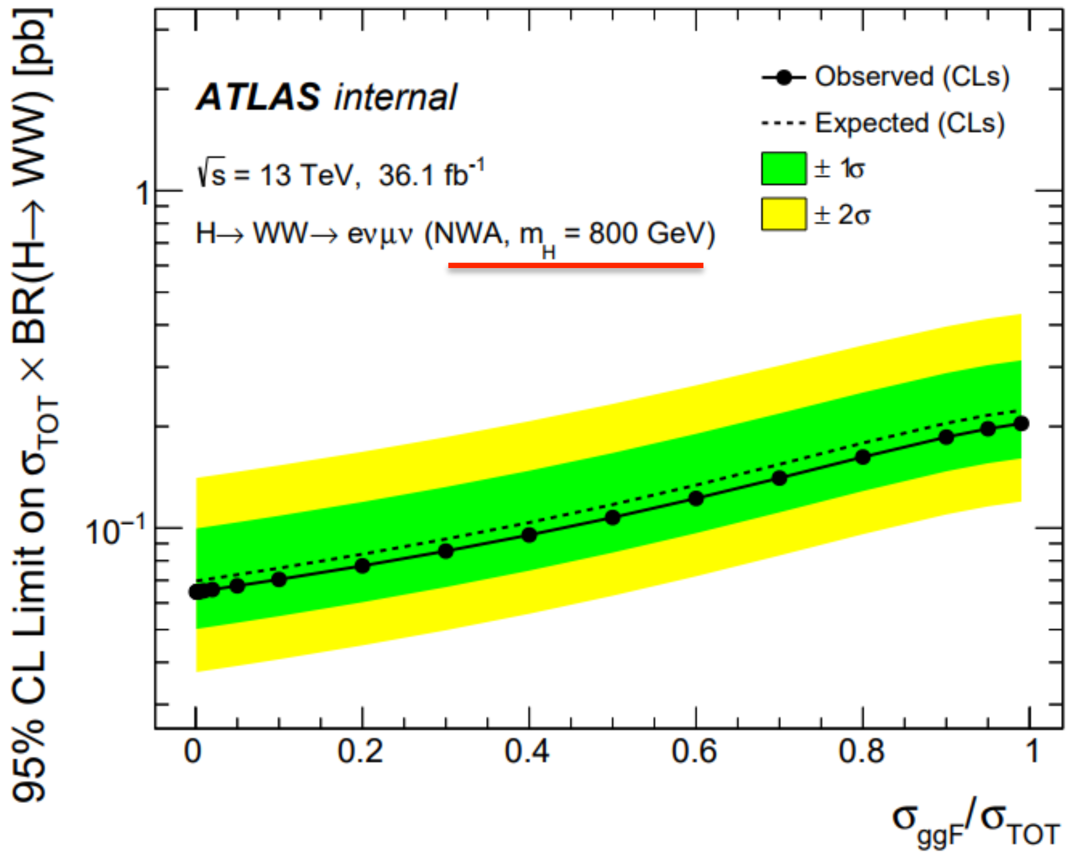




- Values above 6.4 pb at 200 GeV and above 0.008 pb at 4 TeV are excluded for ggF
- Values above 1.3 pb at 200 GeV and above 0.005 pb at 4 TeV are excluded for VBF
- Run 1 mass range: [300 GeV, 1500 GeV]

Limits extension for NWA

- Limits on "σ_{total} (ggF + VBF) * BR", as a function of "σ_{ggF} / σ_{total}"



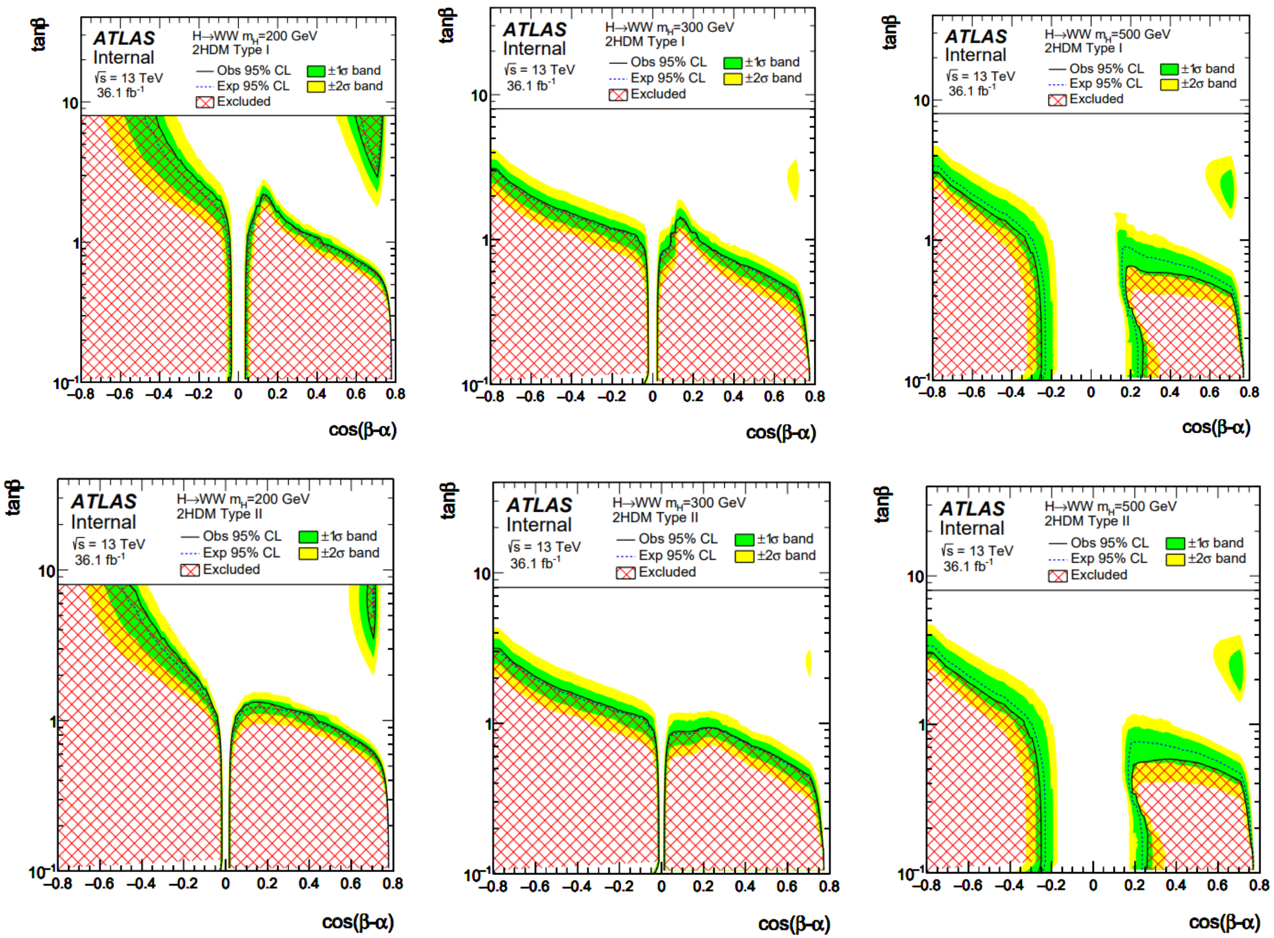
Similar plots for 200 GeV and 1800 GeV reported

2HDM interpretation

- The limits for NWA are further interpretated to exclusion contours in the 2HDM model for the phase space where NWA is valid

Type I

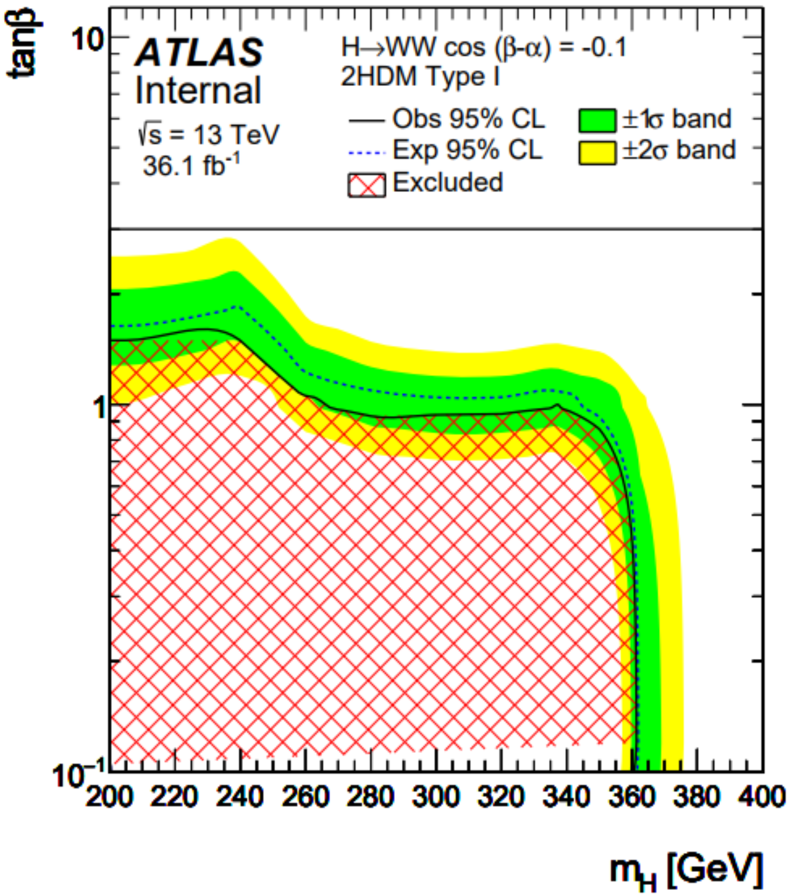
Type II



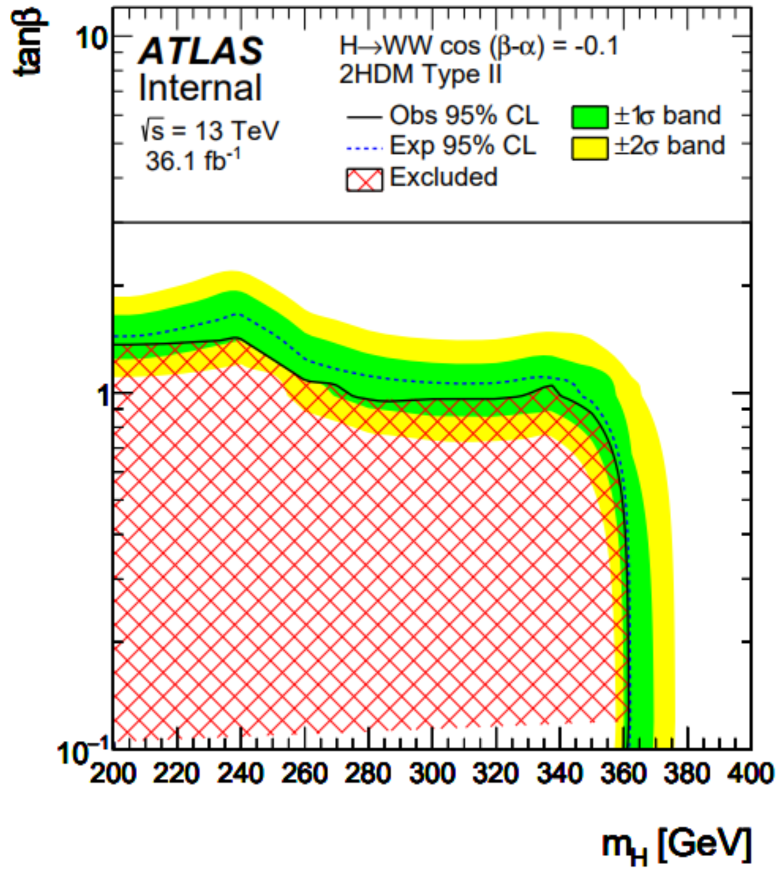
$m_H = 200\,\mathrm{GeV}$ $m_H = 300\,\mathrm{GeV}$ $m_H = 500\,\mathrm{GeV}$

2HDM interpretation

$$\cos(\beta - \alpha) = -0.1$$

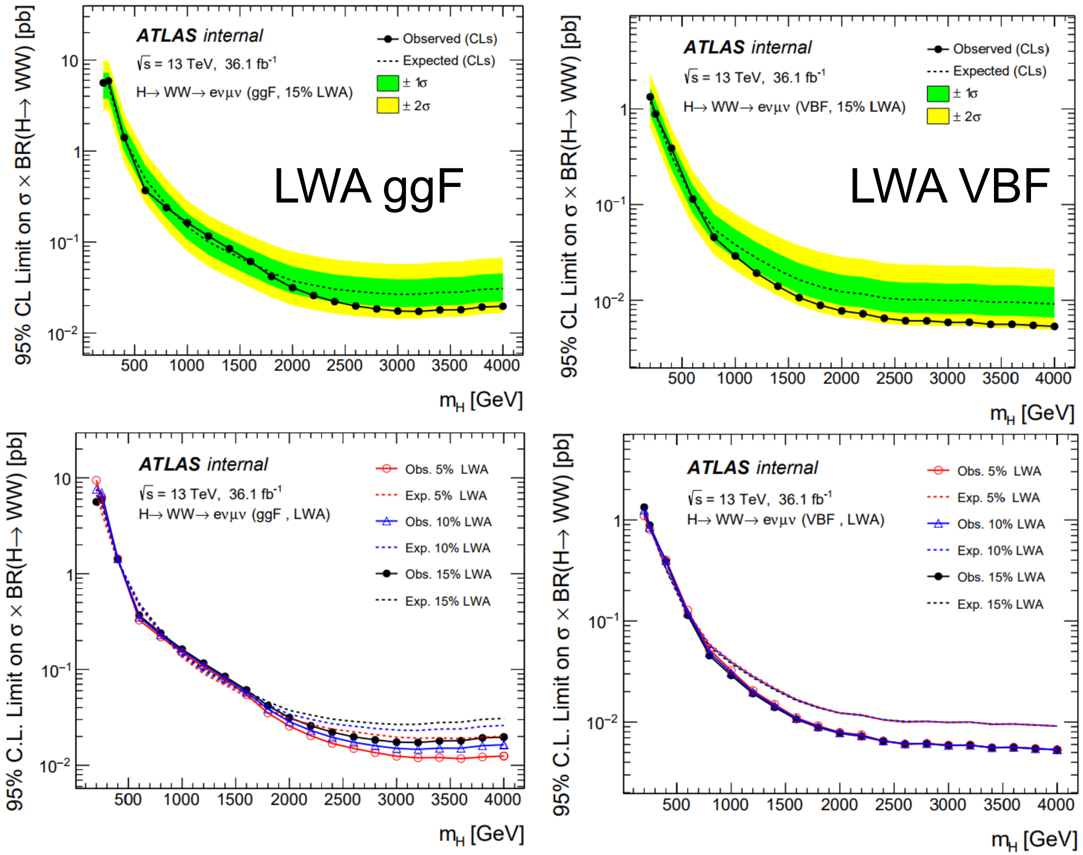


Type I



Type II

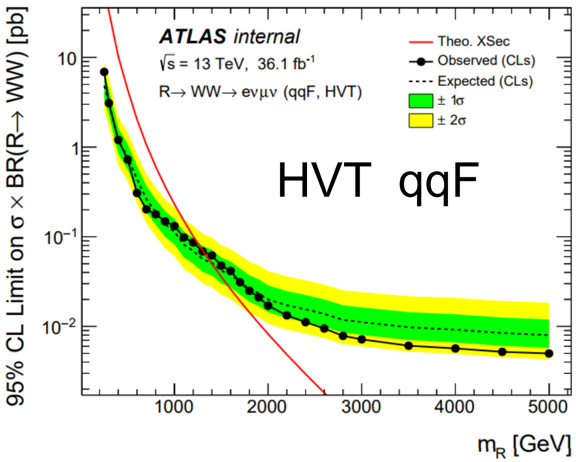
Limits for LWA



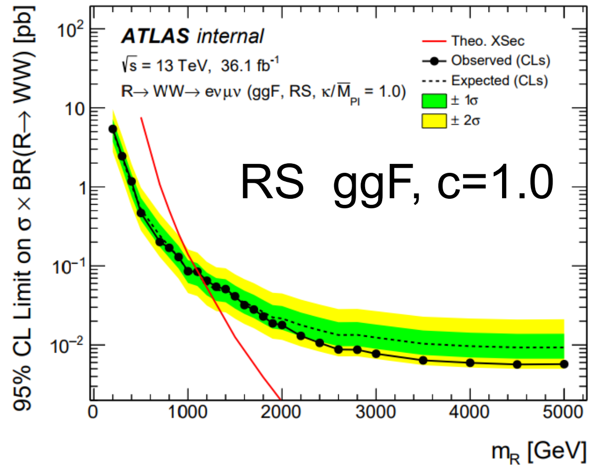
Similar plots for widths of 10%*m_H and 5%*m_H could be found in the auxilairy materials

- Values above 5.2 pb at 200 GeV and above 0.02 pb at 4 TeV are excluded for ggF LWA (width = 15%*m_H)
- Values above 1.3 pb at 200 GeV and above 0.005 pb at 4 TeV are excluded for VBF LWA (width = 15%*m_H)
- Interference effects between signals and backgrounds also studied and found to be negligible

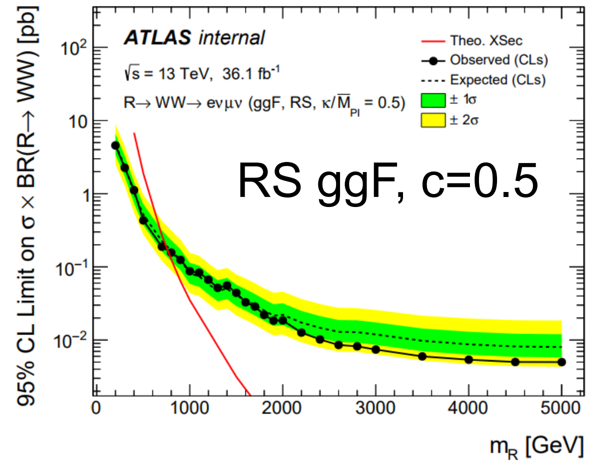
Limits for other models



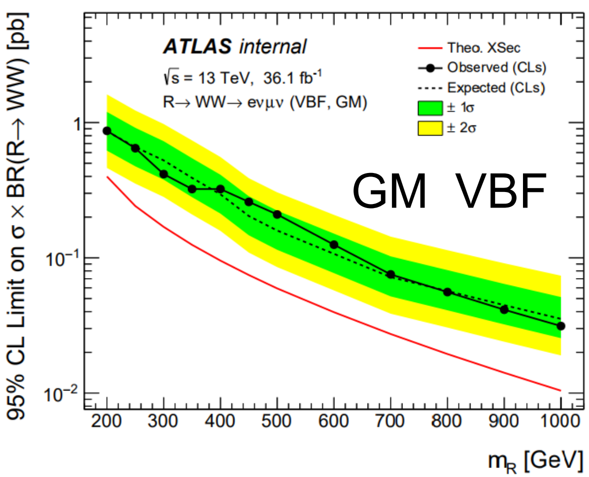
below 1.3 TeV excluded

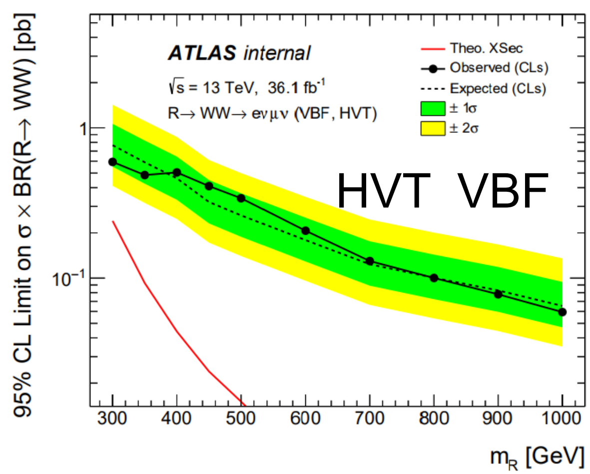


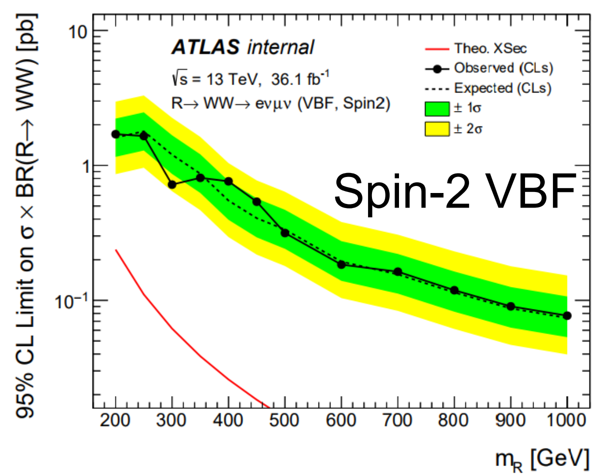
below 1.1 TeV excluded



below 750 GeV excluded







Conclusion

High mass resonance searches completed:

- A search for heavy resonances performed in the $WW \rightarrow e\nu\mu\nu$ final state at 13 TeV with Run 2 data of 36.1 fb^{-1}
- No significant excess or evidence of new heavy resonance found
- Upper limits given for different signal models

New projects started:

- New physics searches with Z+jets final state
- EW precision measurement

Project 2018

LHC-SDU/USTC-LAL-ATLAS: **Search for new physics in inclusive Z events at large transverse momentum and EW precision measurement**					
French Group			**Chinese Group**		
Name	**Title**	**Affiliation** (institute)	**Name**	**Title**	**Affiliation** (institute)
Leader Zhiqing Zhang	Dr	LAL	*Leader* Lianliang MA	Prof	SDU
Yongke Zhao	PhD student	LAL-SDU	Yongke Zhao	PhD student	LAL-SDU
Kunlin Han	PhD student	LAL-USTC	Kunlin Han	PhD student	LAL-USTC
Hicham Atmani	PhD student	LAL	Yingchun Zhu	Assoc. Prof	USTC
Artur Trofymov	Postdoc	LAL	Haiping Peng	Prof	USTC

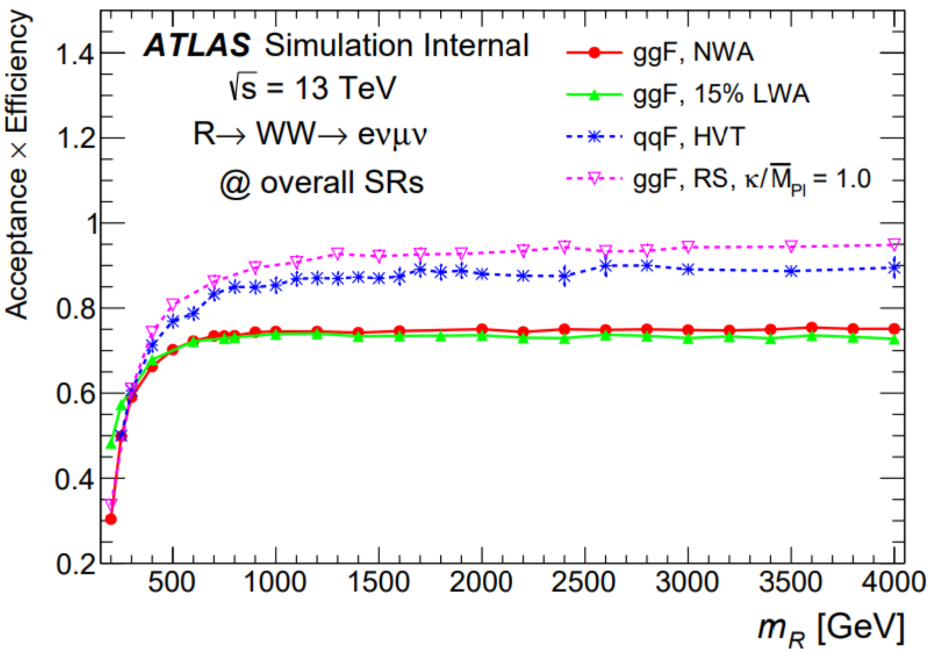
Please provide here details on members of your FCPPL project participating in exchange programs (now and future) between laboratories involved in this proposal:

NAME	**Funding program (Eiffel, CSC, lab, CNRS…)**	**Funding status (submitted, accepted)**	**Status (PhD student, Post doc…)**	**Expected date of defense**	**Lab of origin**	**Host lab**	**Expected dates in host lab**
Yongke Zhao	Eiffel, SDU	Accepted	PhD student	May/June 2018	SDU	LAL	Until July 2017
Kunlin Han	CSC, USTC	CSC to be submitted	PhD student	2020	USTC	LAL	April-Dec. 2017, Sept. 2018-

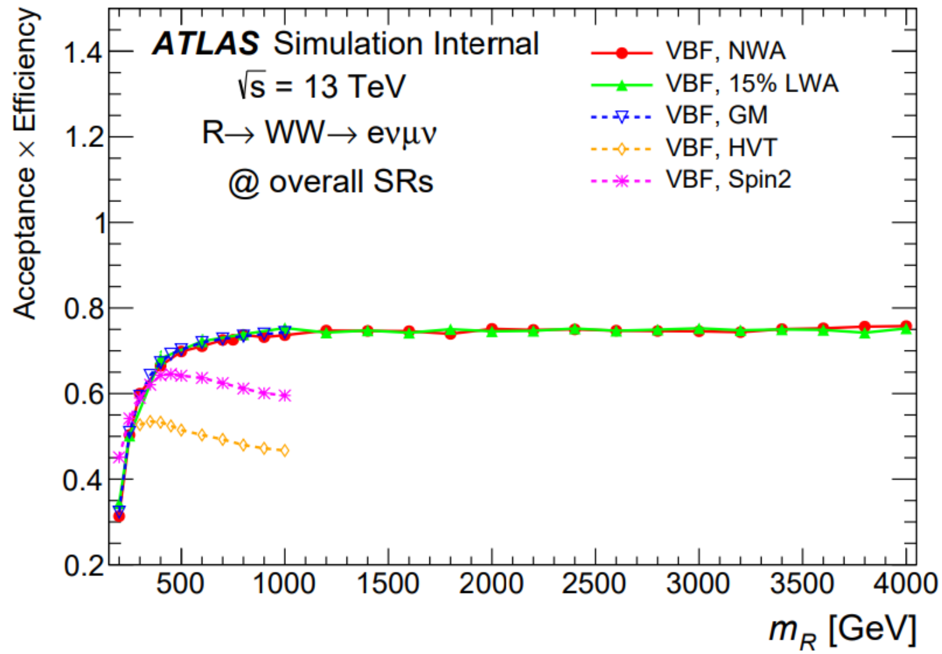
BACKUP

Signal acceptance

- Signal selection acceptance * efficiency in combined 3 SRs



ggF (qqF) signals

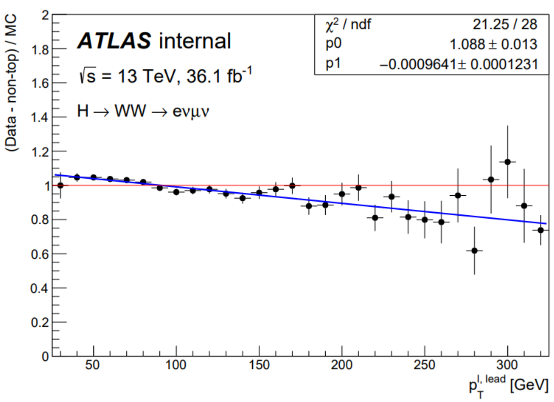


VBF signals

Large difference mainly coming from different $\Delta\eta_{ll}$ distributions

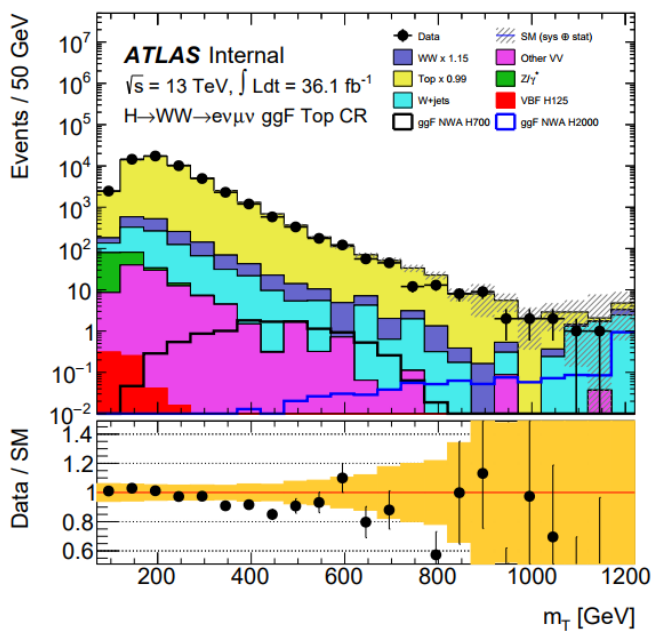
Top leading lepton pt reweighting

- The reweighting was applied only for ggF category

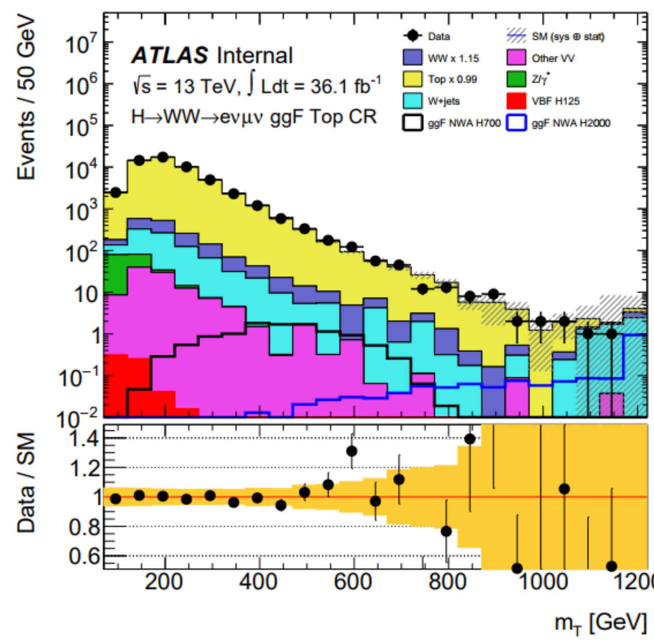


reweighting fit function

Before reweighting



After reweighting

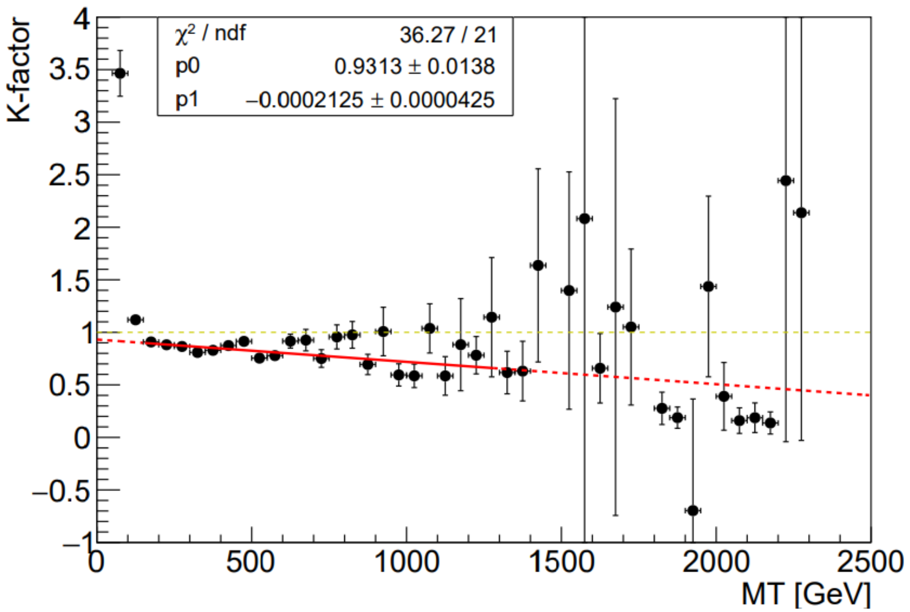


m_T in ggF Top CR

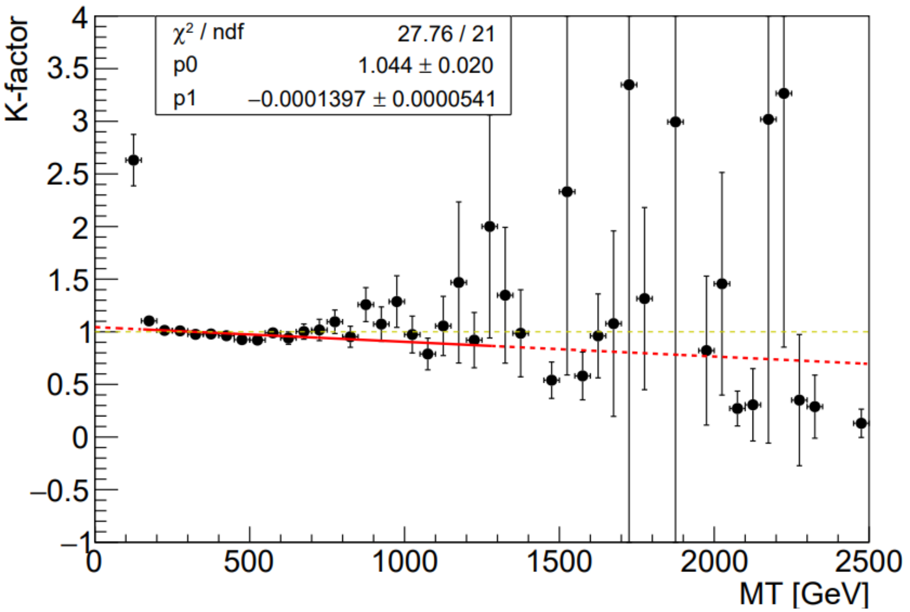
All other variable distributions also checked and found to have better agreement between data and MC after reweighting

WW Sherpa-to-Matrix correction

- qq→WW with Sherpa 2.2.1 : not fully a NLO sample
- A reweighting to Matrix NNLO calculation + NLO EW correction
- The total uncertainty on the correction considered to be the 100% of the correction (±50% assigned for up and down)



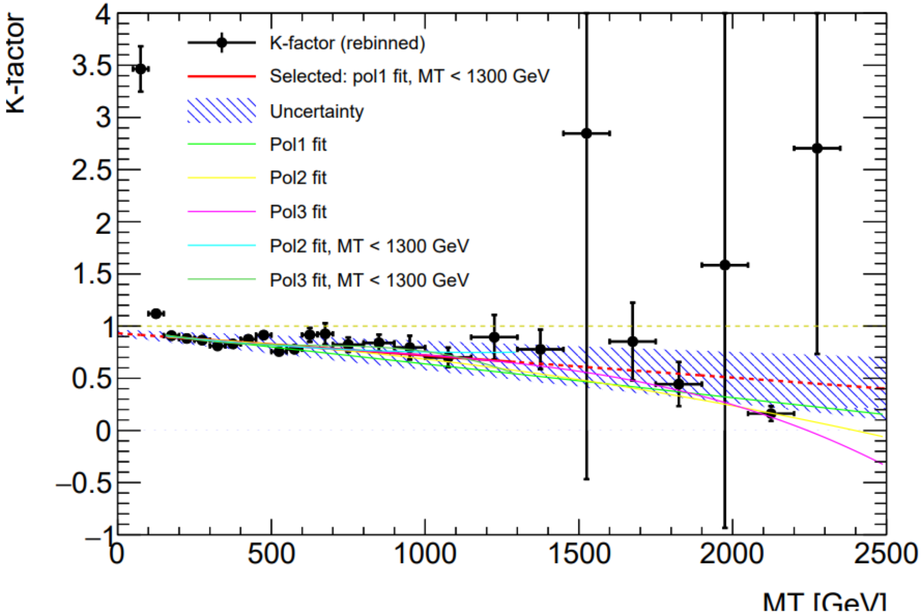
ggF SR



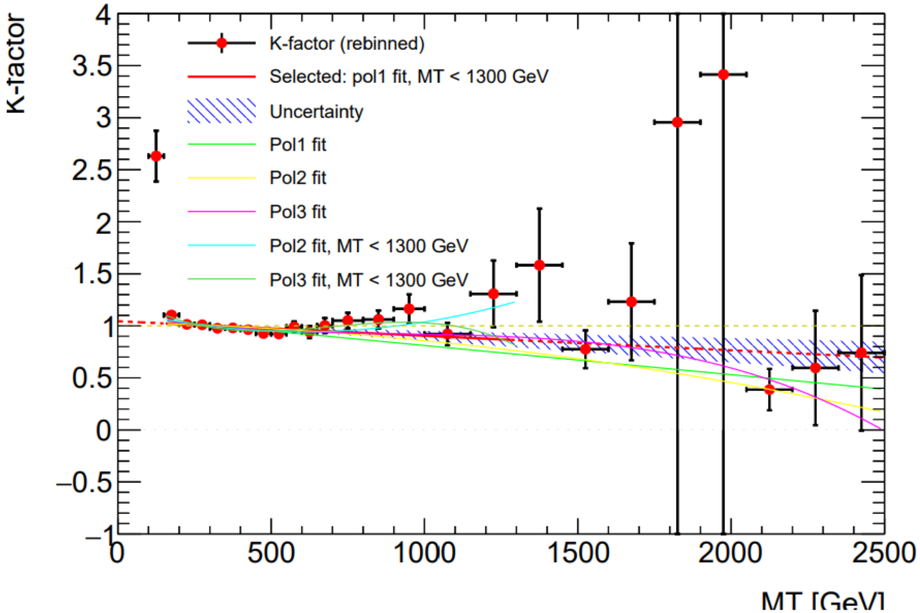
ggF WW CR

WW Sherpa-to-Matrix correction

- Sherpa 2.2.1 qq→WW reweighted to Matrix NNLO + NLO EW
- Total uncertainty: 100% of the correction



ggF SR



ggF WW CR

WW NLO EW k-factor

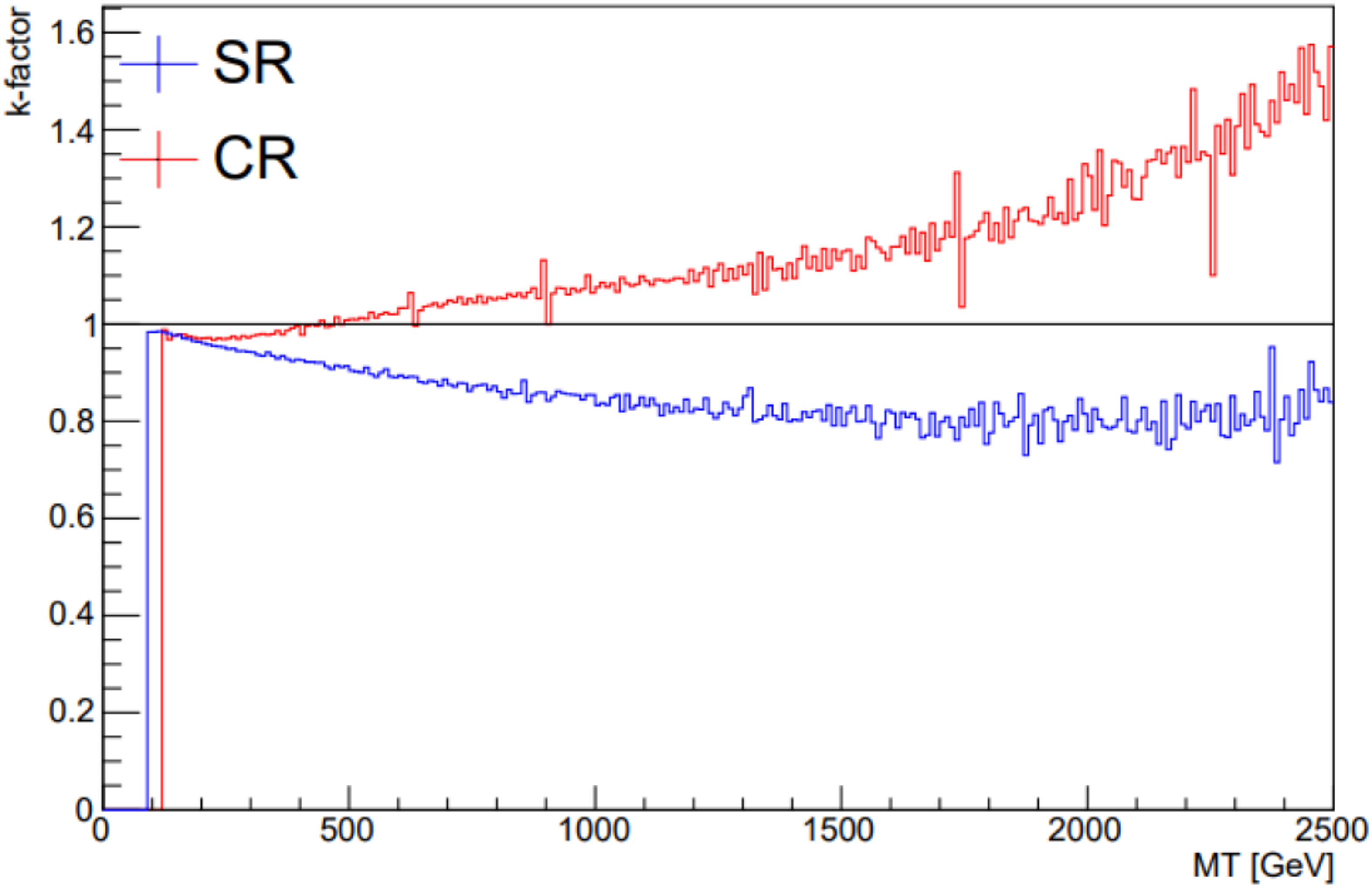


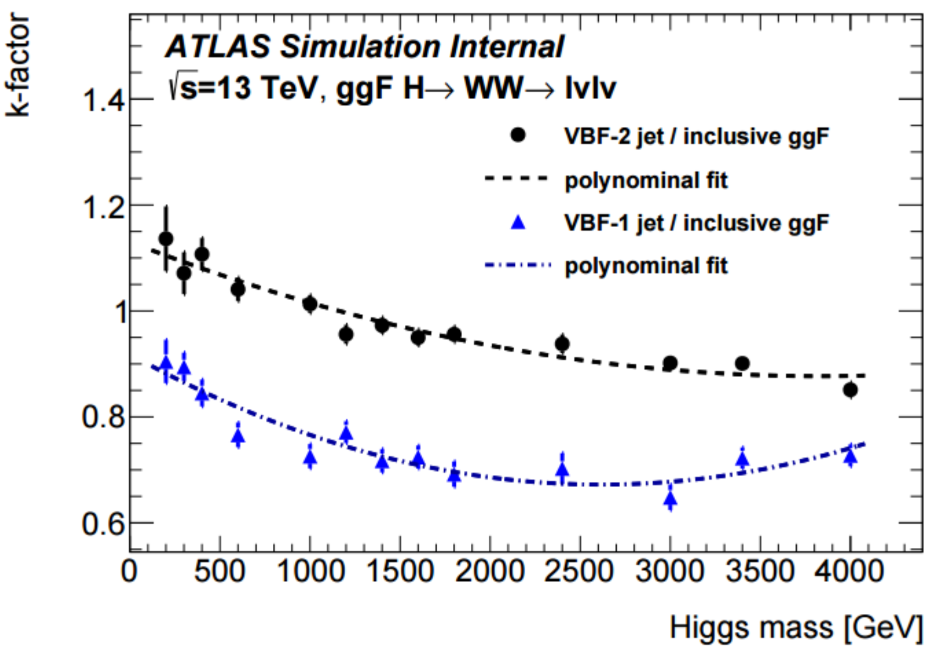
Figure 32: NLO EW corrections as a function of m_T in the ggF inclusive SR and CR.

Powheg-to-MadGraph correction

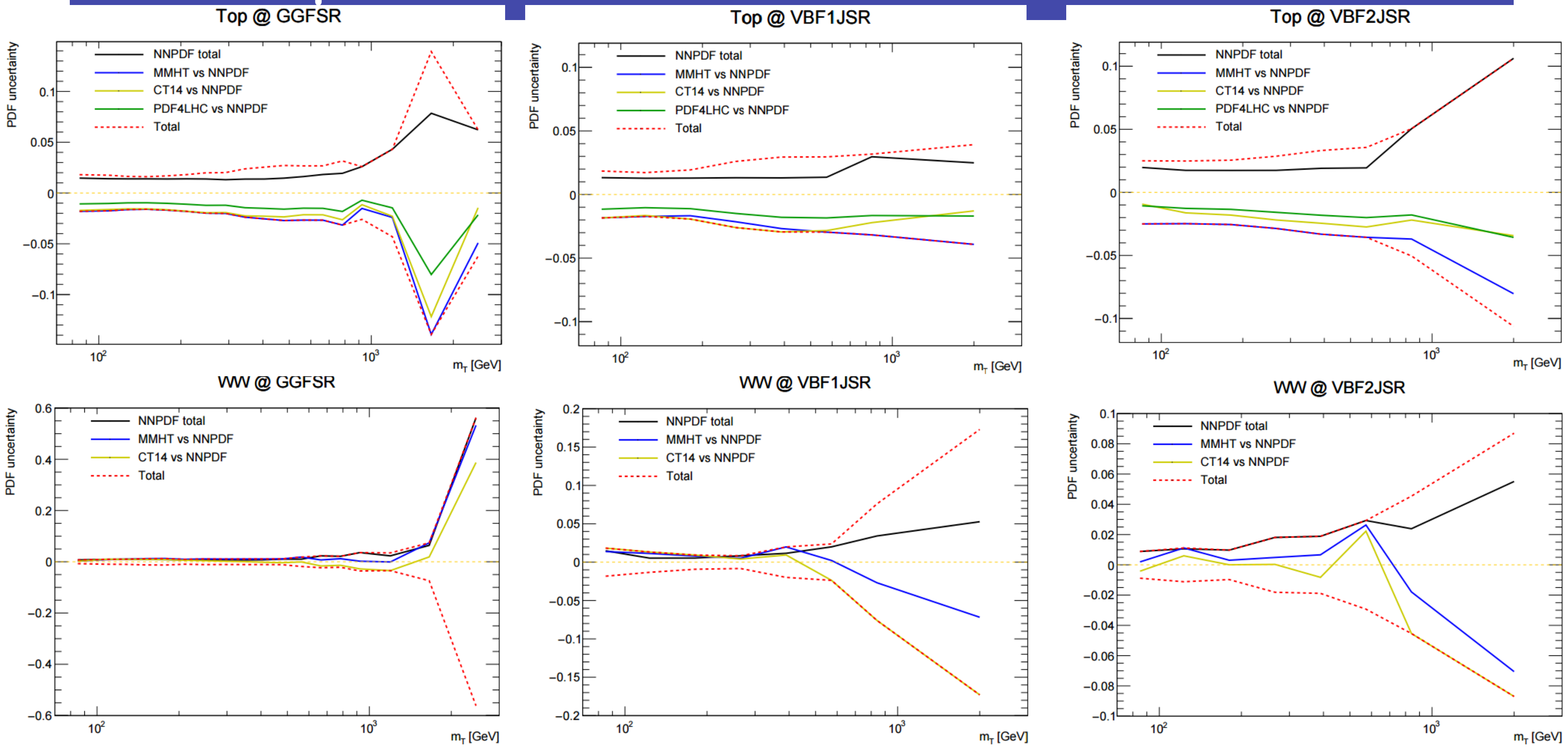
- Powheg (ggF NWA signals) provides only events with only up-to-one jet at the ME, therefore higher jet multiplicities are expected to be insufficiently described

- Scale factor for 2J (similar for 1J):

$$k = \frac{N^{\text{2-jet VBF}}_{\text{MadGraph5}} / N^{\text{inclusive ggF}}_{\text{MadGraph5}}}{N^{\text{2-jet VBF}}_{\text{Powheg}} / N^{\text{inclusive ggF}}_{\text{Powheg}}}$$



Top and WW PDF uncert. in SRs



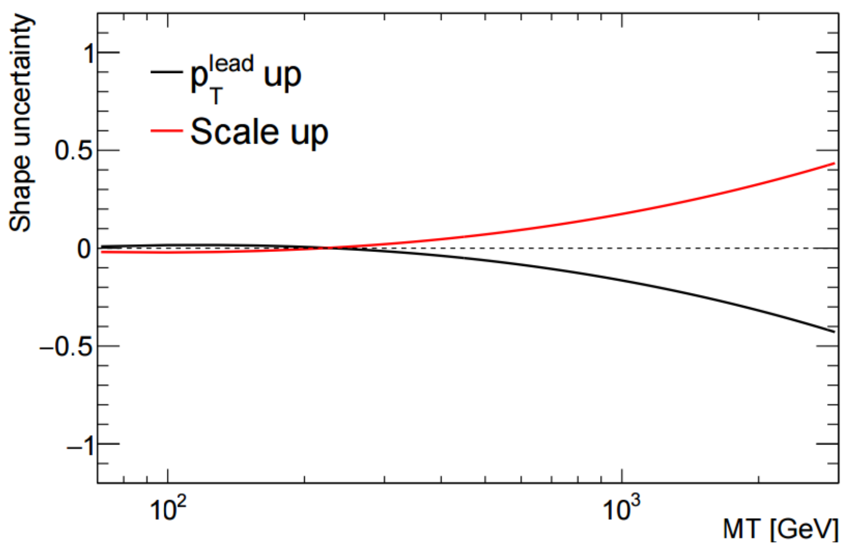
- Following PMG recommendations for NNPDF PDF set

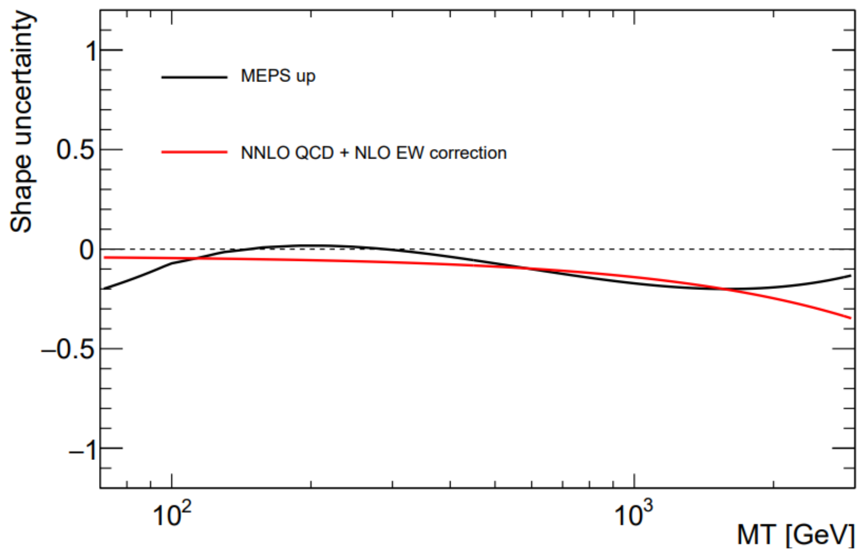
https://twiki.cern.ch/twiki/bin/view/AtlasProtected/PdfRecommendations#Standard_deviation

- Envelope of different PDF sets taken as total uncertainty as a function of MT in 3 SRs (overall uncertainty used in CRs)

Shape uncertainties

- All shape uncertainties that are considered in the analysis
  - Except for PDF uncertainties

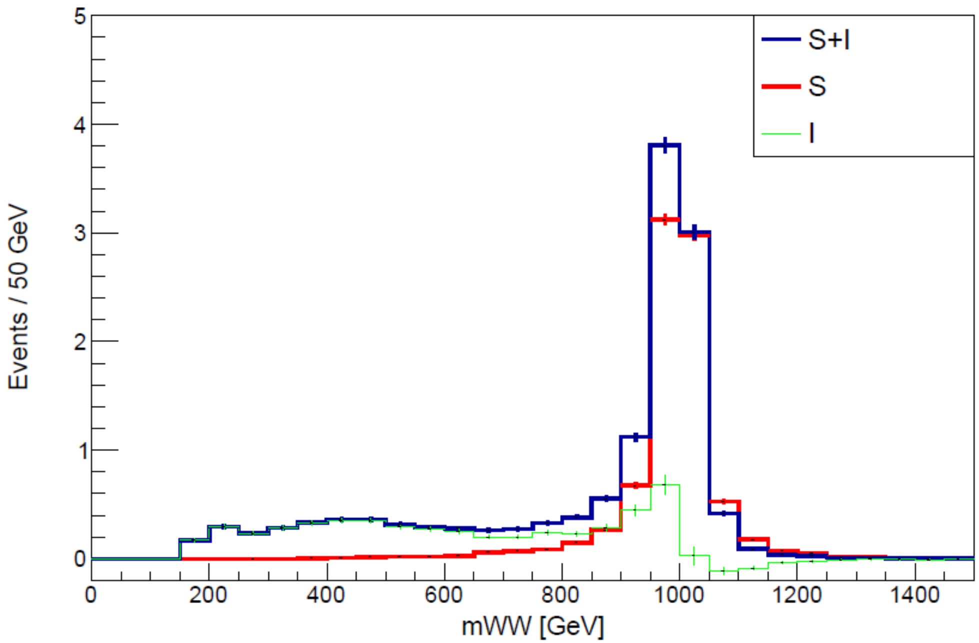




- Experimental shape uncertainties have been checked and found to be small and negligible

Interference effects

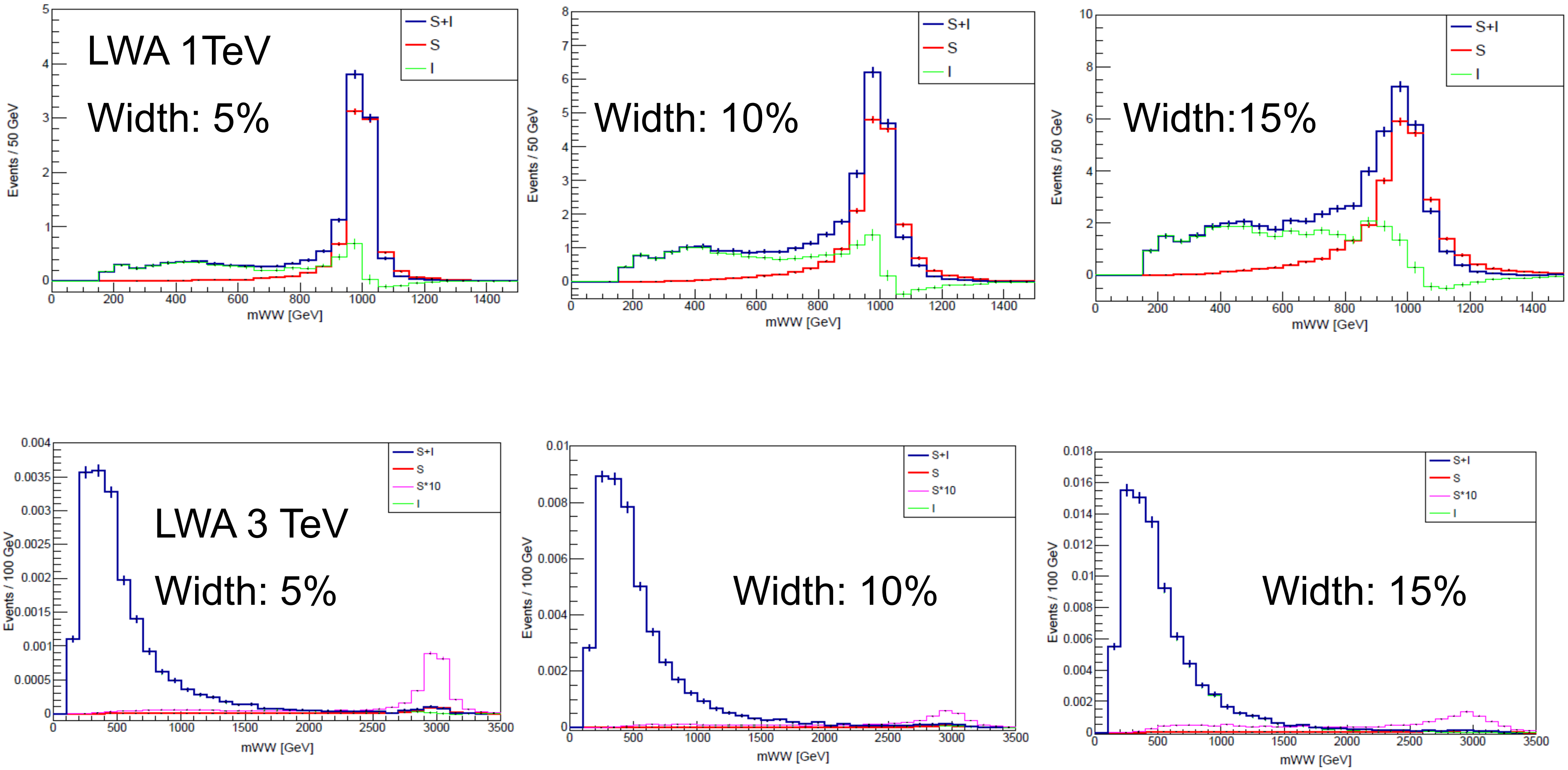
- Generator: gg2VV
- The interference effects considered here include the interference effects between a heavy resonance and the SM WW continuum and the SM Higgs boson at 125 GeV
- The lineshape has been compared with MadGraph5_aMc@Nlo for SM-like heavy Higgs and good agreement observed



The yields are normalised to the integrated luminosity of the data 2015 and 2016 (36.1 fb^{-1})

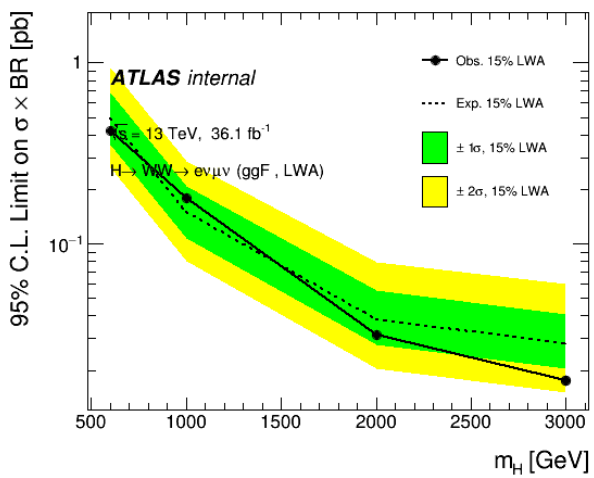
Interference effects

- Interference effects increase with larger masses and widths

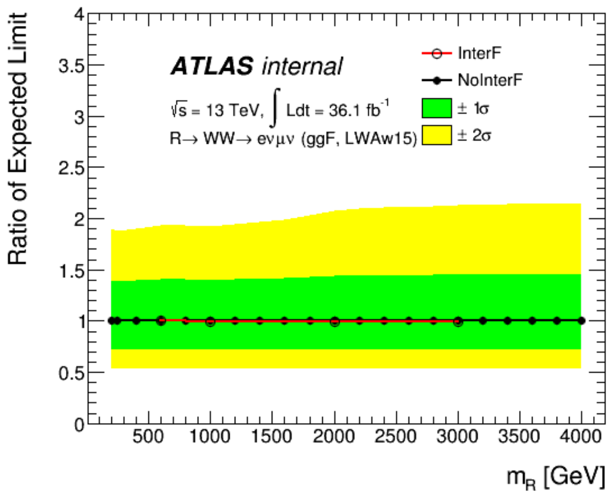


Interference effects

- Expected limits for LWA (width: 15%·m_H) [pb]
  - Only a few mass points have been studied
  - Signal cross section scaled to $\sigma_{H\rightarrow WW}$ = 1 pb in the input



Limits with interference



Compared to expected limits without interference

The effects for ggF LWA are negligible

The interference effects for VBF are smaller than ggF, and neglected