SM Physics and SM Higgs at the LHC

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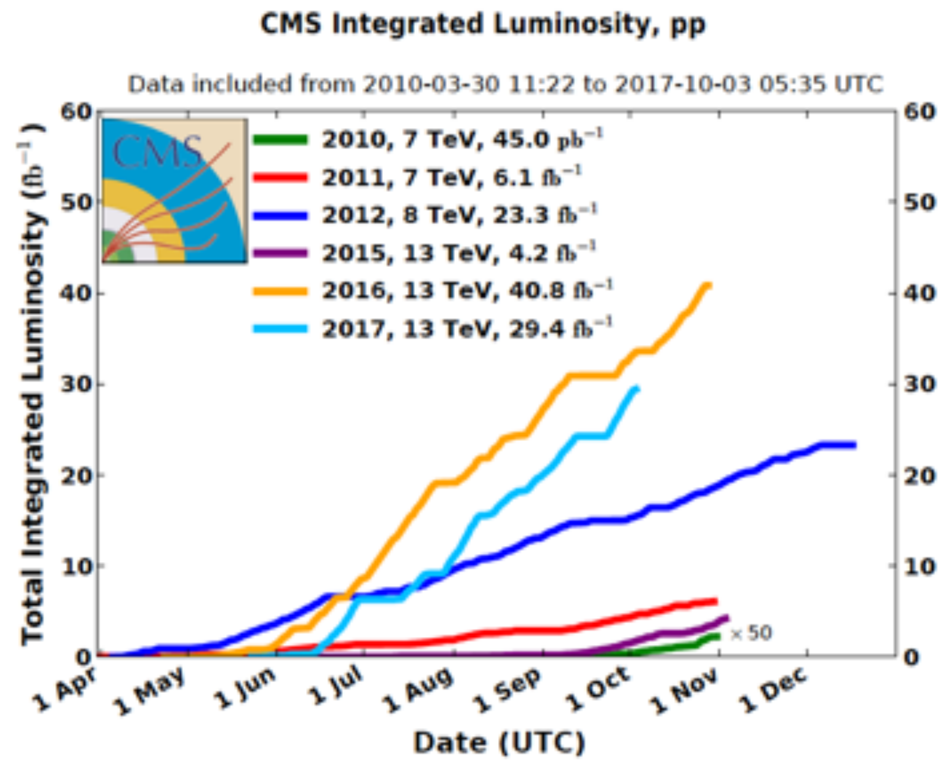
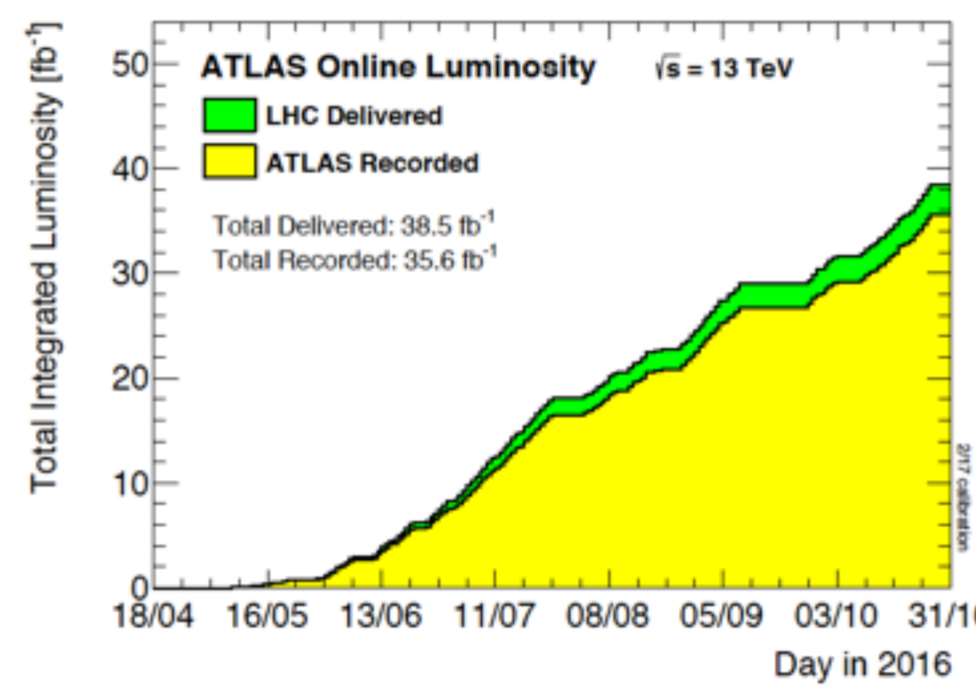
Disclaimer

- many new and interesting results from ATLAS and CMS in SM and SM Higgs physics covering the full 2015+2016 dataset at 13 TeV
- not possible to show all results in this talk
- 2015-2016: more than 36/fb of LHC pp collision data recorded by ATLAS and CMS
- peak luminosity of $1.4\times10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  - pile-up of ~25 on average (~45 maximum)





Outline

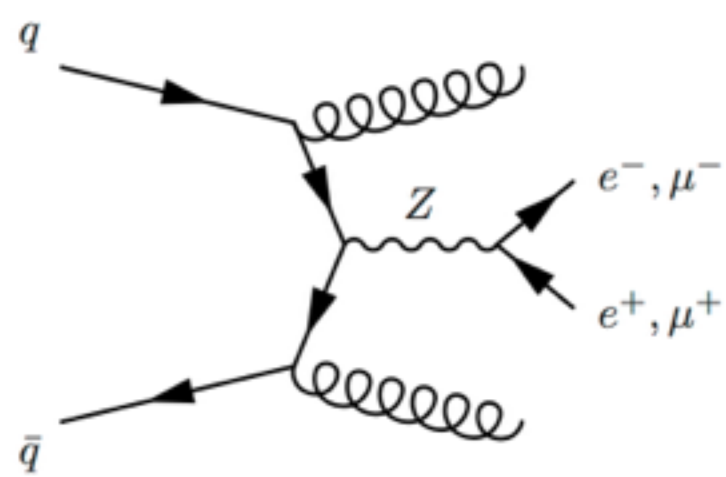
- **vector boson fusion** (VBF) production:
  - SM electroweak (EW) Z + jets
  - VBF Higgs boson
- **ttH production** and **tt+HF, ttW/Z backgrounds**
  - **ttH(bb)** and **ttH multilepton** from ATLAS and CMS
  - **ttH combination** from ATLAS: evidence with the full 2015+16 data set
- **W/Z+H (VH) production** and **V+jets backgrounds**
  - evidence with the full 2015+16 data set @ ATLAS and CMS

Vector Boson Fusion

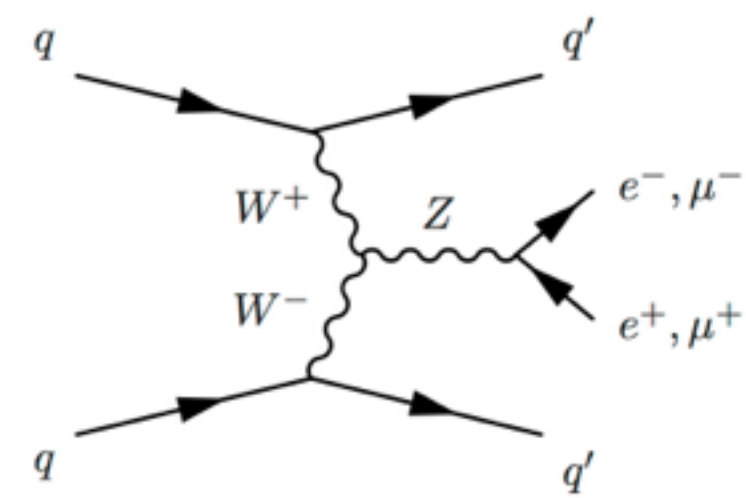
Electroweak Production of Z + jet events

- important background e.g. to Higgs physics

QCD production



Electroweak production

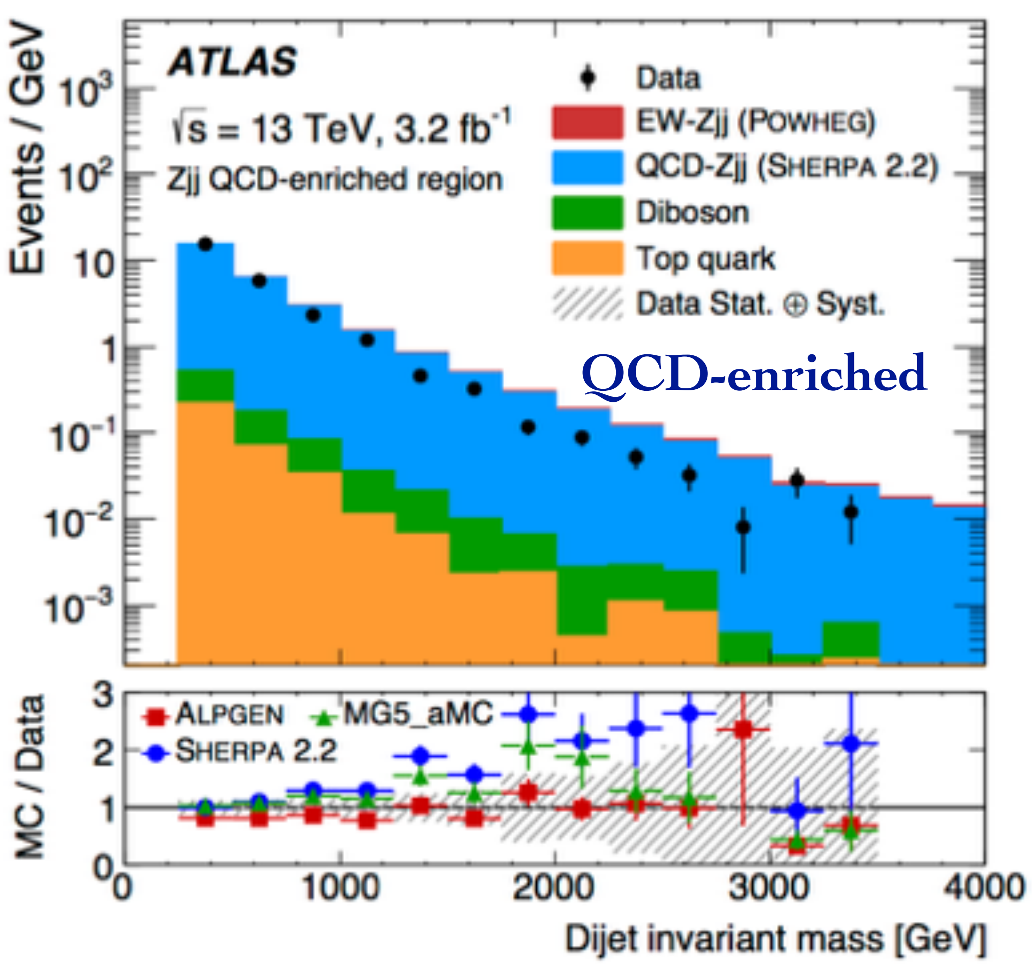


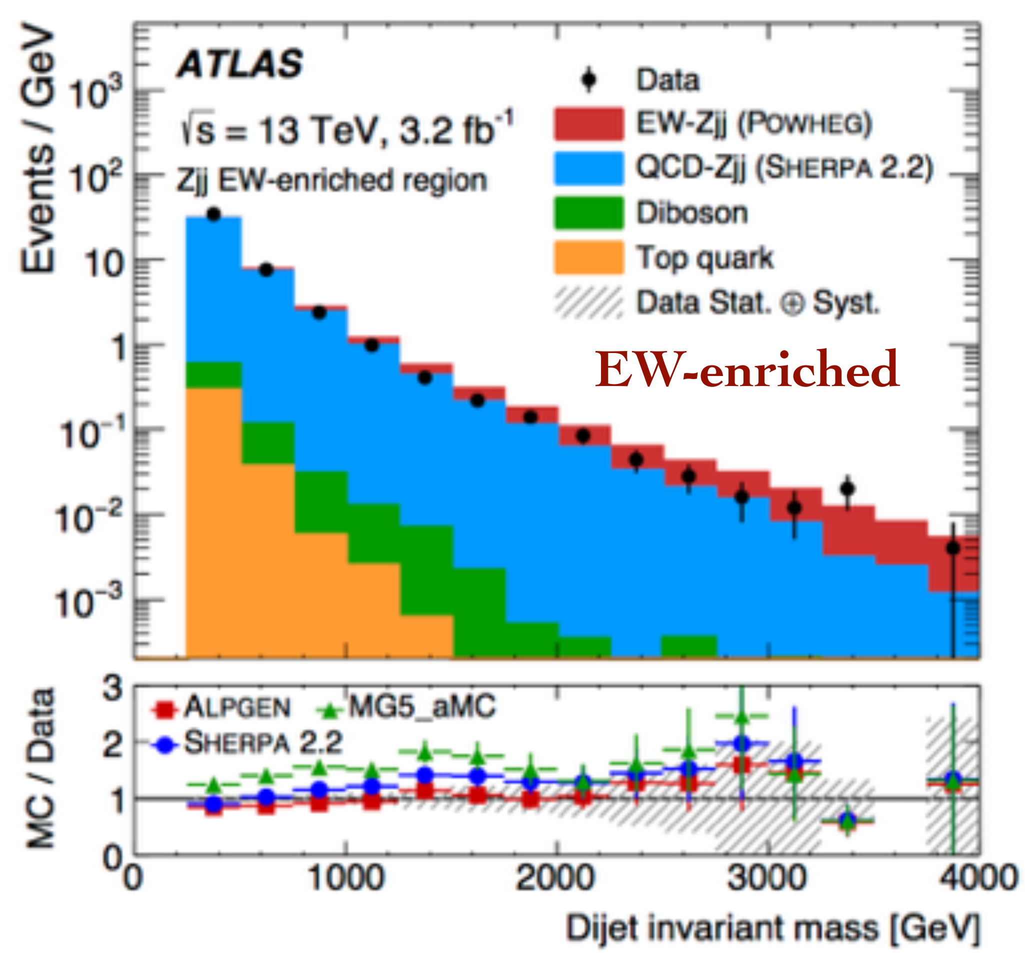
- EW production is about 10 times smaller than QCD production
- to enhance the **EW component**:
  - less hadronic activity in the gap between the high momenta forward jets
  - large rapidity interval between the two forward jets lead to a large dijet invariant mass

ATLAS: EW and QCD Z + jets @ 13 TeV

arXiv:1709.10264

- split events in EW- and QCD-enriched regions:
  - EW-Zjj signal fraction is 2 to 4% (at mjj > 1 TeV) in the QCD-enriched region and 5 to 26% (at mjj > 1 TeV) in the EW-enriched region
- QCD-Zjj is largely mis-modelled by MadGraph5_aMC@NLO and Sherpa 2.2 at high dijet invariant mass



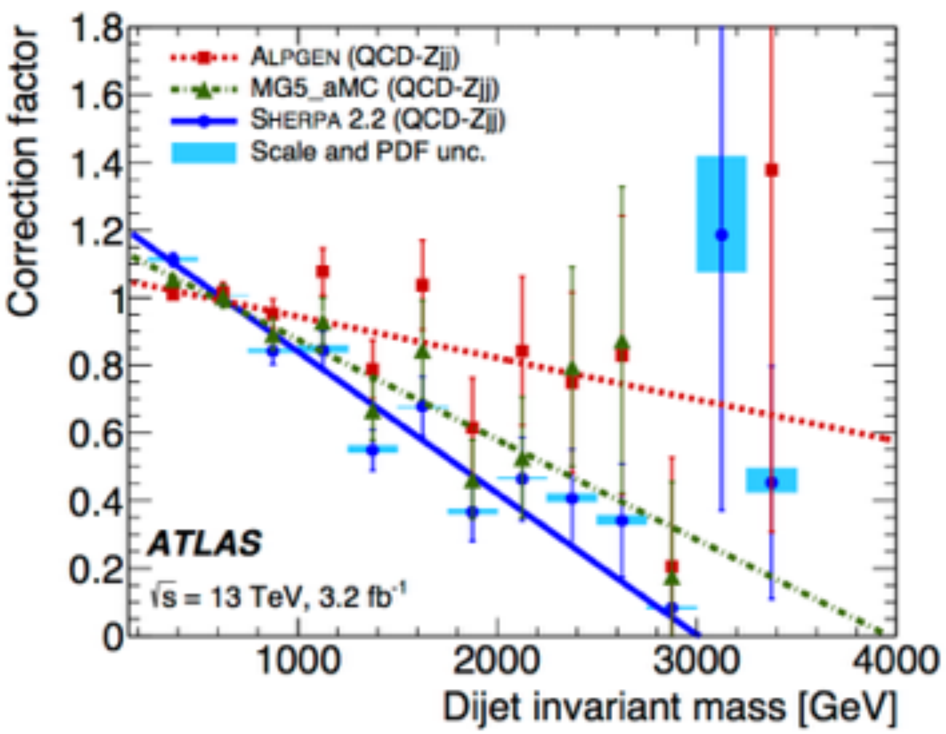


ATLAS: EW and QCD Z + jets @ 13 TeV

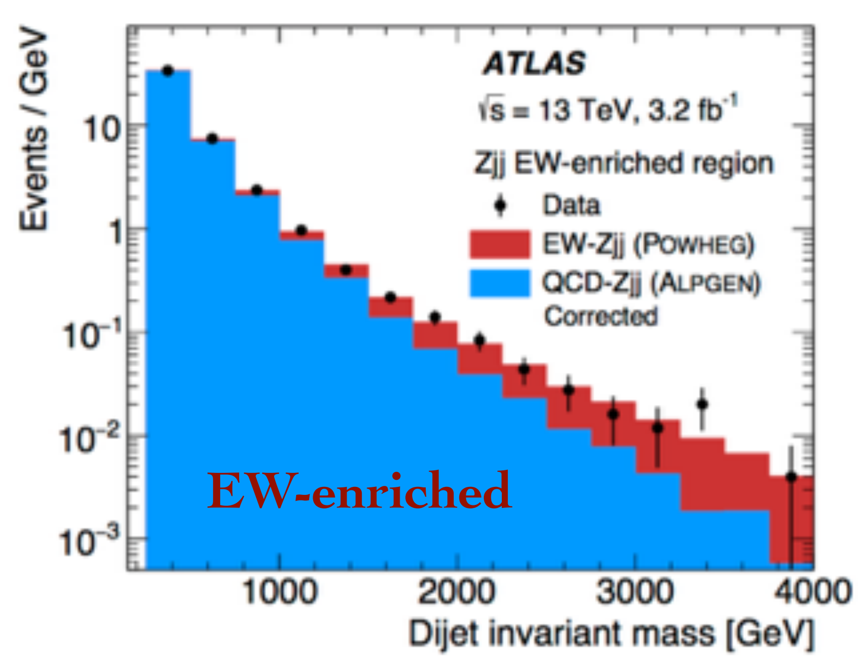
arXiv:1709.10264

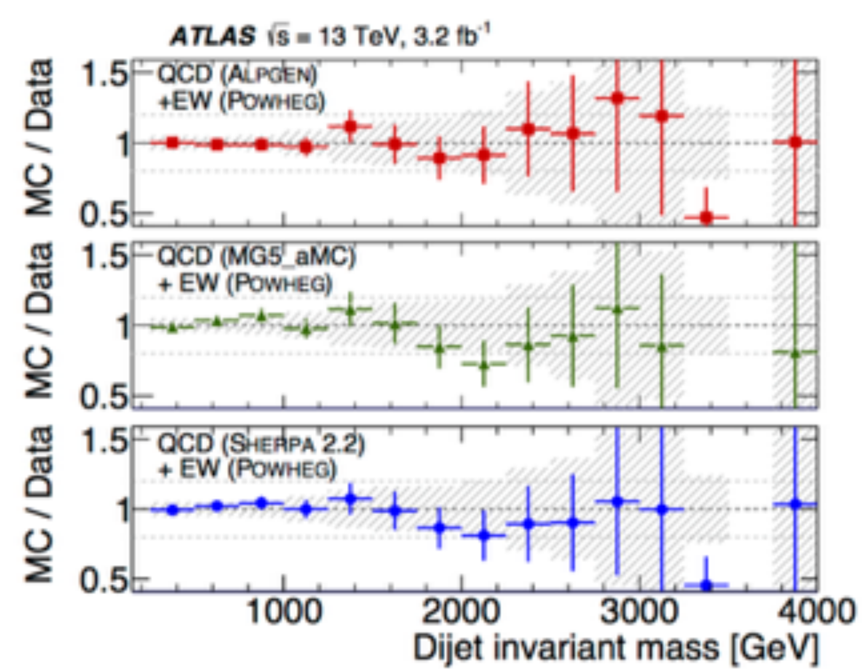
- QCD-Zjj is corrected using data-derived correction factors in mjj-bins
- fit templates in the EW-enriched region to measure EW-Zjj fiducial cross section
  - total uncertainty: ~17%
  - largest uncertainty: modelling of the QCD-Zjj background (~13%)

QCD-Zjj correction factors



post-fit distributions after subtraction of non-Zjj background

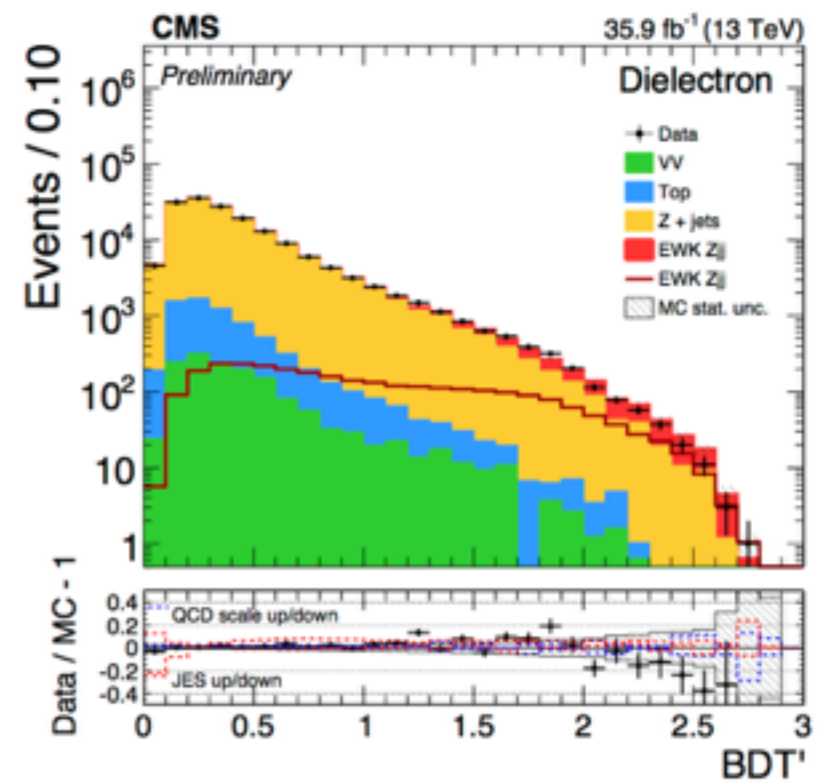


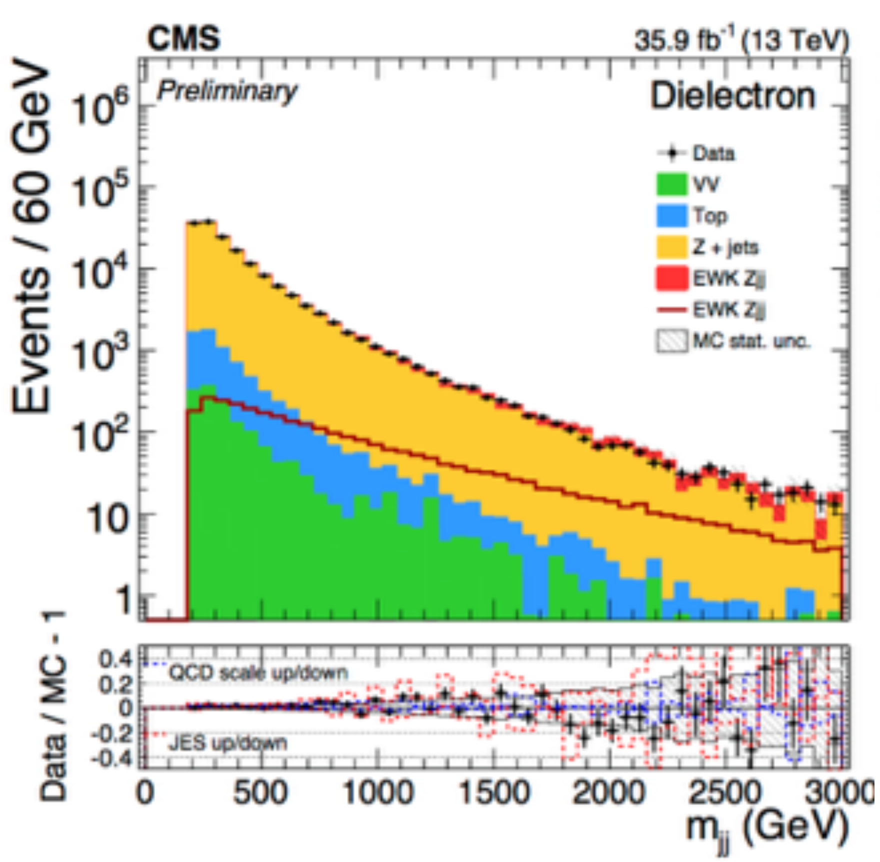


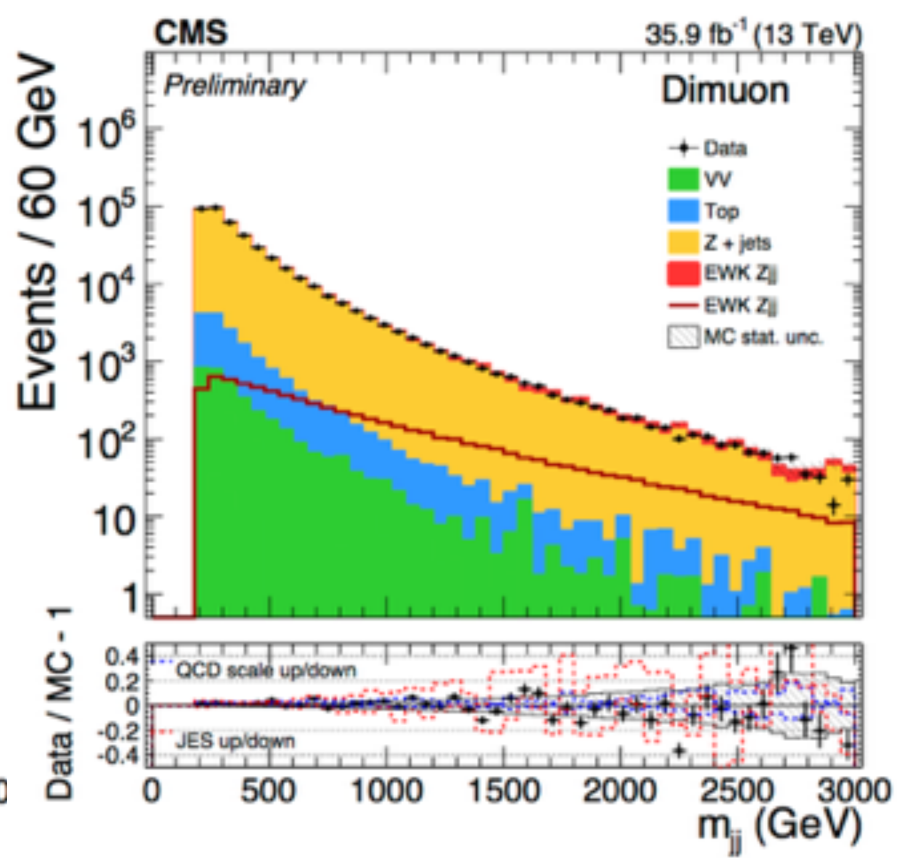
CMS: EW and QCD Z + jets @ 13 TeV

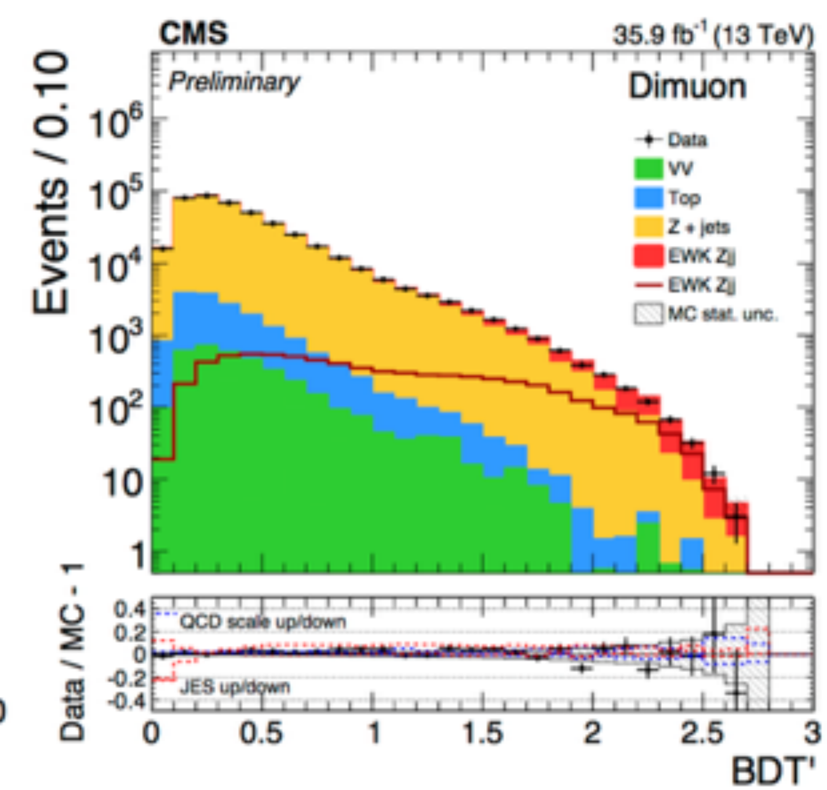
CMS-PAS-SMP-16-018

- multivariate classifier to separate QCD-Zjj and EW-Zjj processes
- good agreement between data and MC predictions (using MadGraph5_aMC@NLO)
  - EW-Zjj at LO
  - QCD-Zjj at NLO (up to 3 partons)





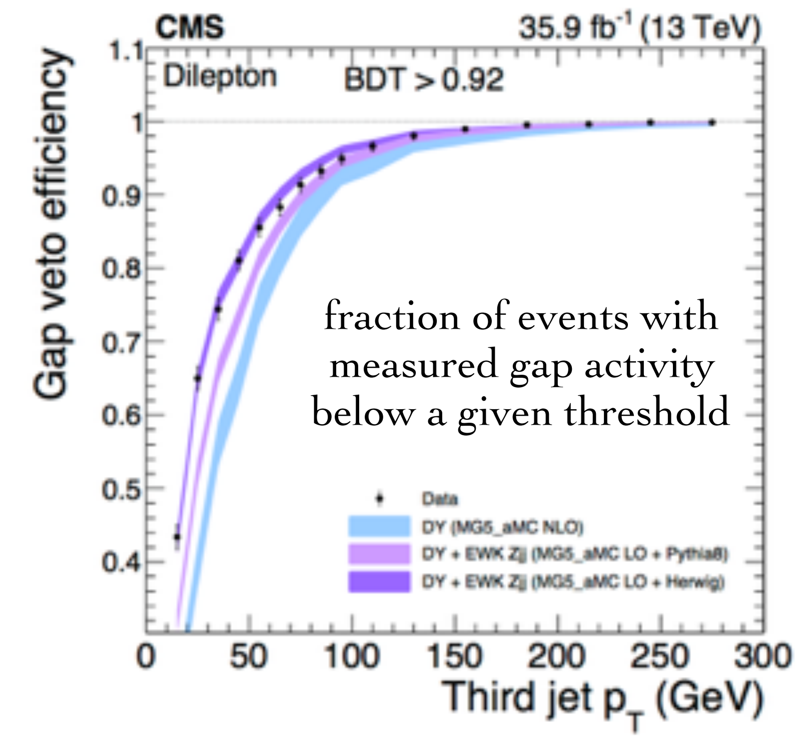


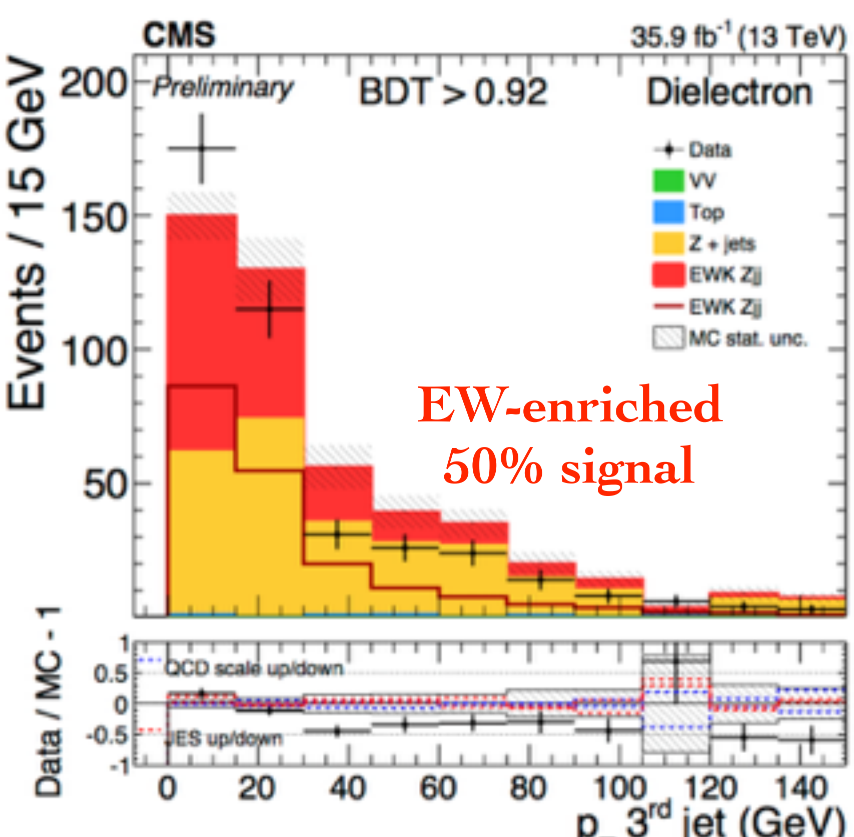


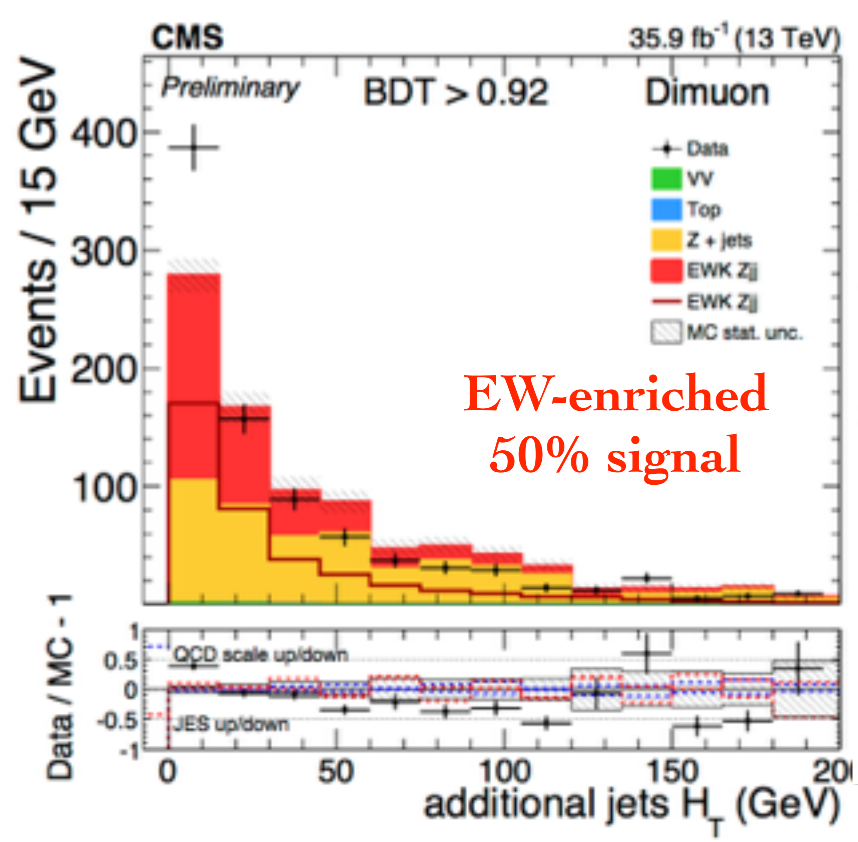
CMS: EW and QCD Z + jets @ 13 TeV

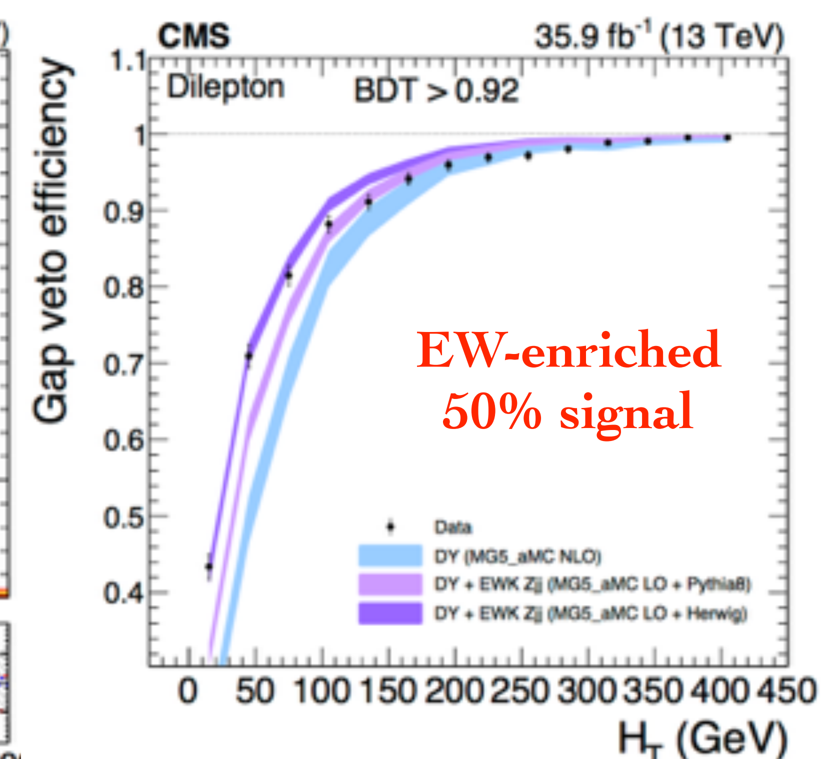
CMS-PAS-SMP-16-018

- distribution of BDT discriminant used to extract the cross section
  - simultaneous fit of EW and QCD components
  - dominant uncertainties: JES and QCD scale
- studied **hadronic activity** in the EW-enriched region (BDT > 0.92, signal contribution ~50%)
  - good agreement between data and QCD predictions with either Pythia and Herwig++









EW Z + jets Results @ 13 TeV

- **ATLAS**:

Fiducial region	EW-Zjj cross-sections [fb]	
	Measured	POWHEG+PYTHIA
EW-enriched, $m_{jj} > 250$ GeV	$119 \pm 16 \pm 20 \pm 2$	125.2 ± 3.4
EW-enriched, $m_{jj} > 1$ TeV	$34.2 \pm 5.8 \pm 5.5 \pm 0.7$	38.5 ± 1.5

arXiv:1709.10264

- **CMS** (mjj > 120 GeV):

$$\mu = 1.017 \pm 0.035\,(\text{stat}) \pm 0.101\,(\text{syst}) = 1.017 \pm 0.106\,(\text{total}),$$

$$\sigma(\text{EW}\,\ell\ell\text{jj}) = 552 \pm 19\,(\text{stat}) \pm 55\,(\text{syst})\,\text{fb} = 552 \pm 58\,(\text{total})\,\text{fb}$$

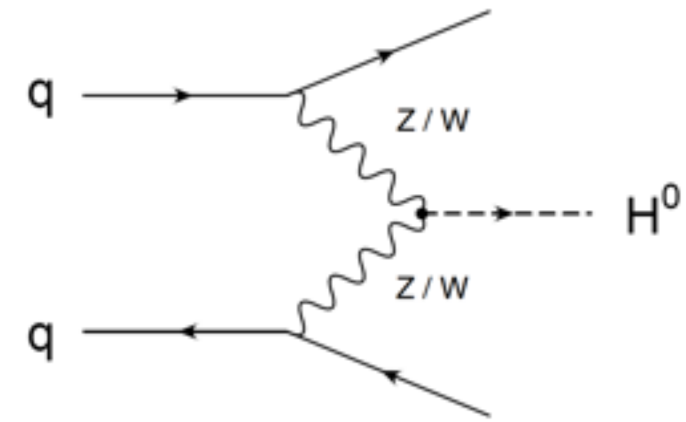
CMS-PAS-SMP-16-018

$$\text{SM prediction}\ \sigma_{\text{LO}}(\text{EW}\,\ell\ell\text{jj}) = 543 \pm 24\,\text{fb}$$

- uncertainty on the modelling of QCD-Zjj process in the VBF phase space (largest uncertainty for ATLAS measurement) found to be negligible for CMS

VBF Higgs boson Production

- electroweak Higgs boson production has the same kinematic properties as the electroweak Z + jj production

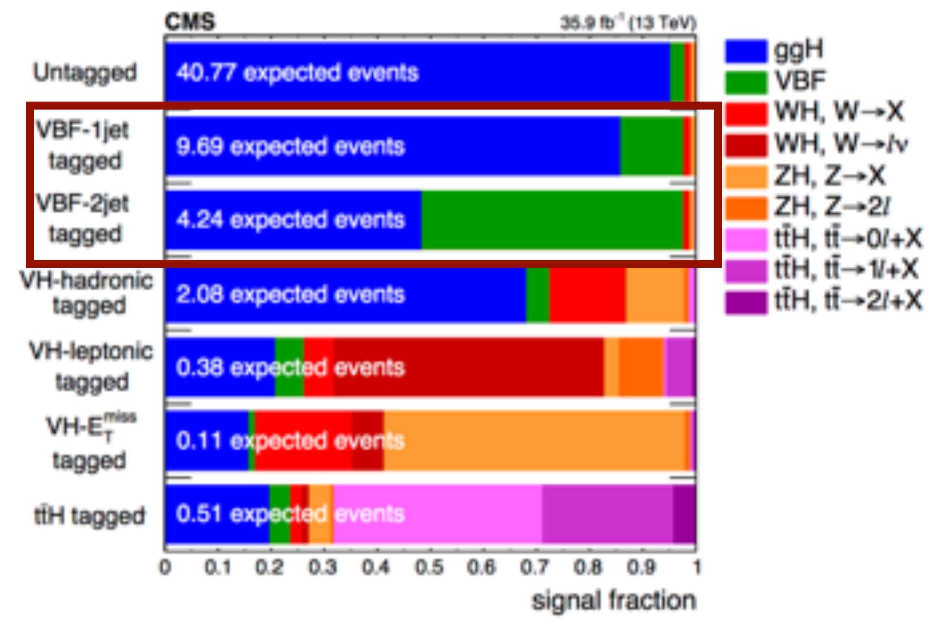


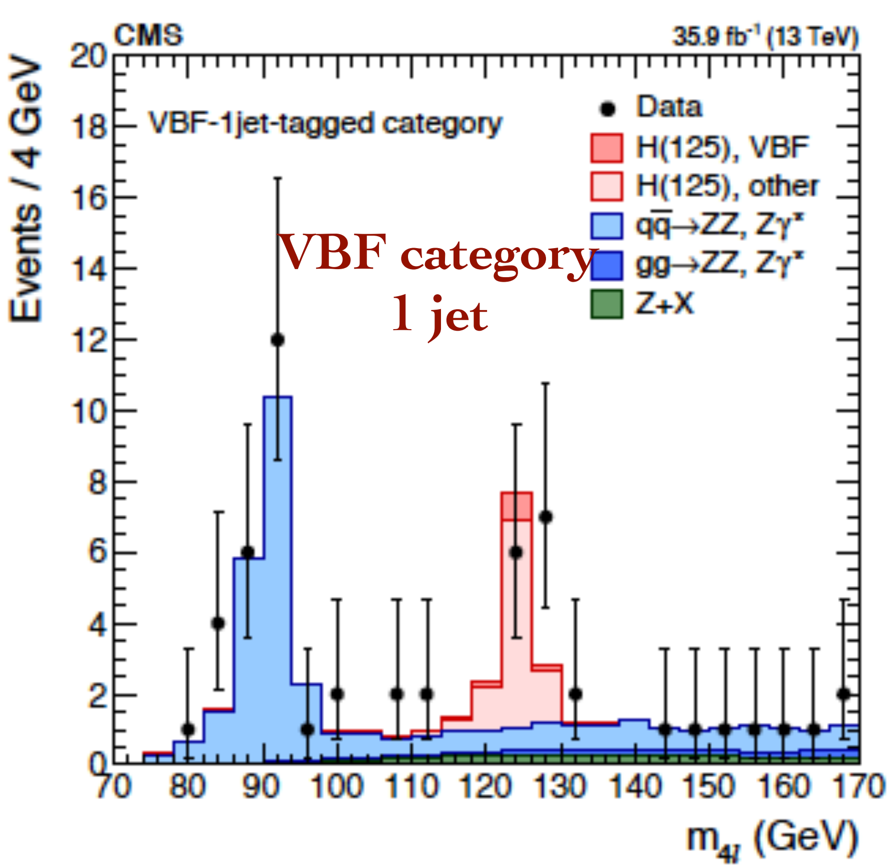
  - **not enough data statistics** to define a control region for the gluon fusion (ggF) H + jj production
  - can access only **theoretical uncertainties** on the modelling of the ggF H + jj process in the VBF phase space
- use **Higgs boson coupling measurements** to extract the VBF Higgs boson production
  - various categories enriched in specific production modes
  - combination of many different final discriminant distributions

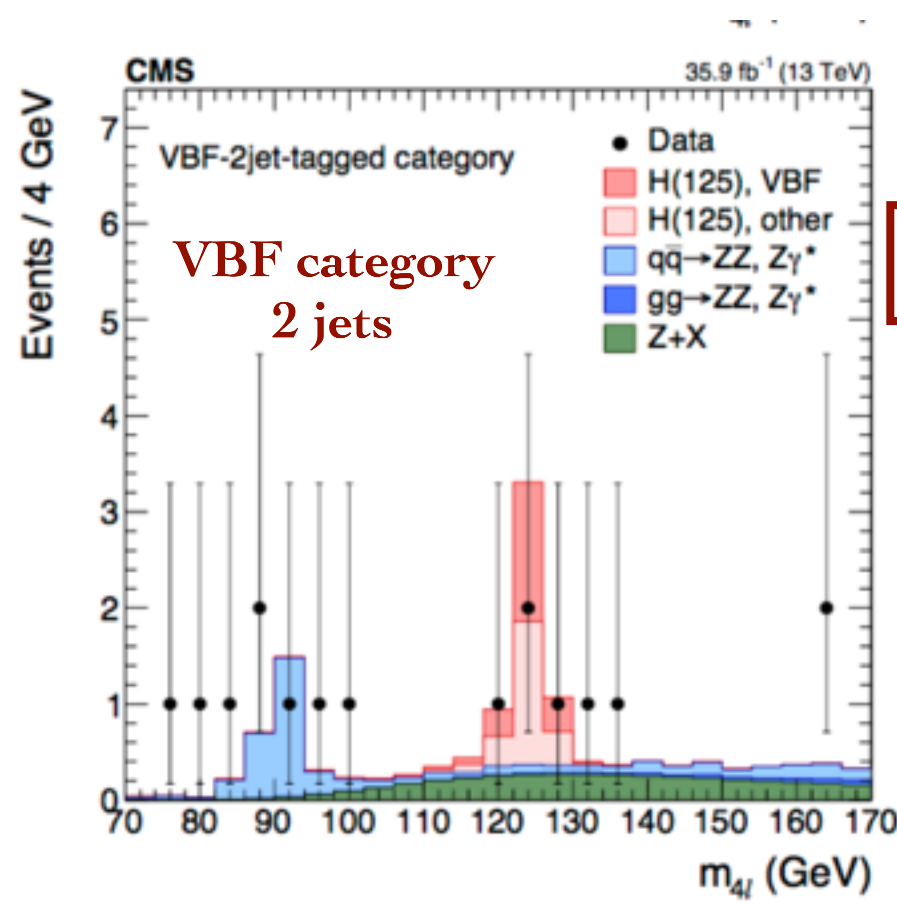
CMS: H->ZZ->4l Channel

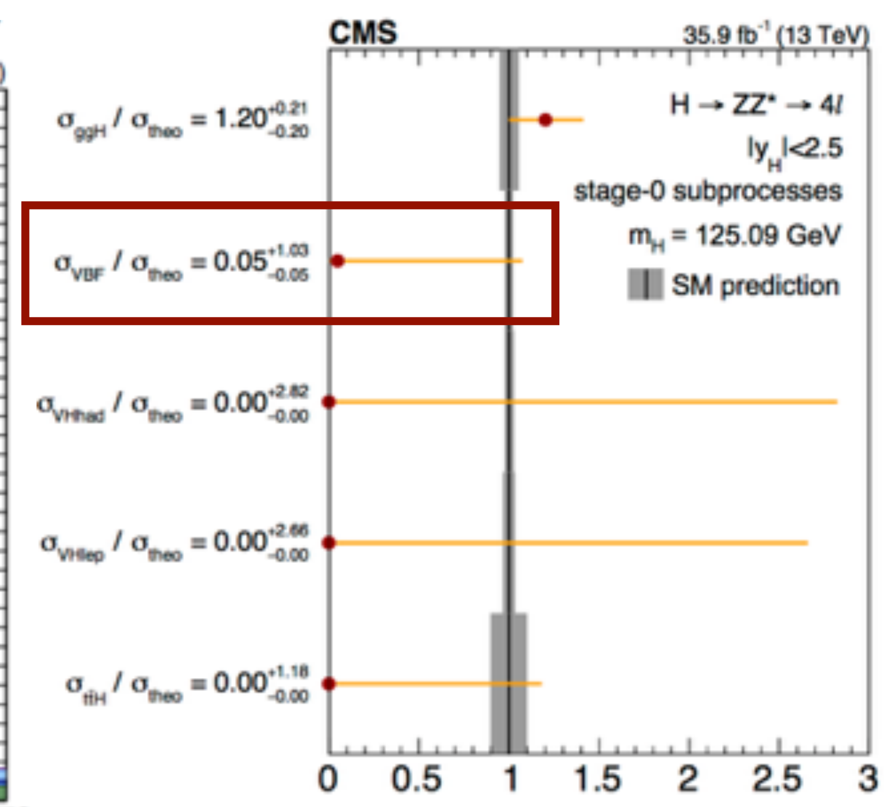
CMS-HIG-16-041

- **VBF selection:**
  - exactly 4 leptons
  - 1 jet tagged: exactly one additional jet; a cut on the VBF Matrix Element discriminant
  - 2 jet tagged: 2 or 3 jets, at most one b-tagged or 4 or more jets, not b-tagged; a cut on the VBF Matrix Element discriminant





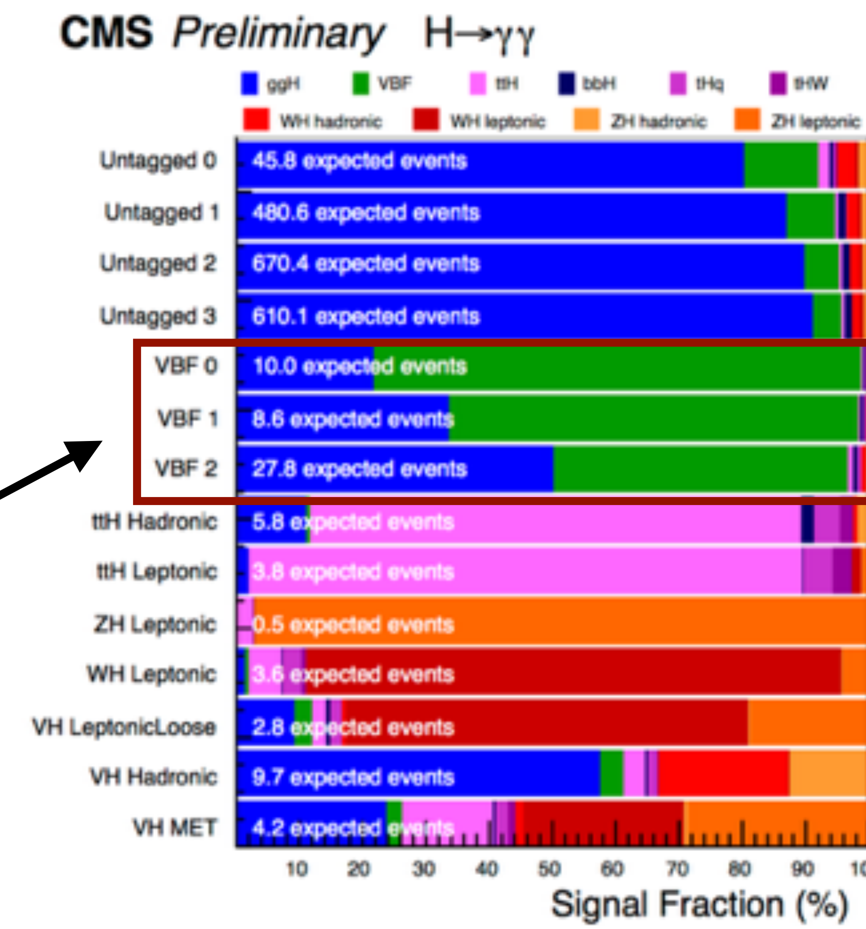


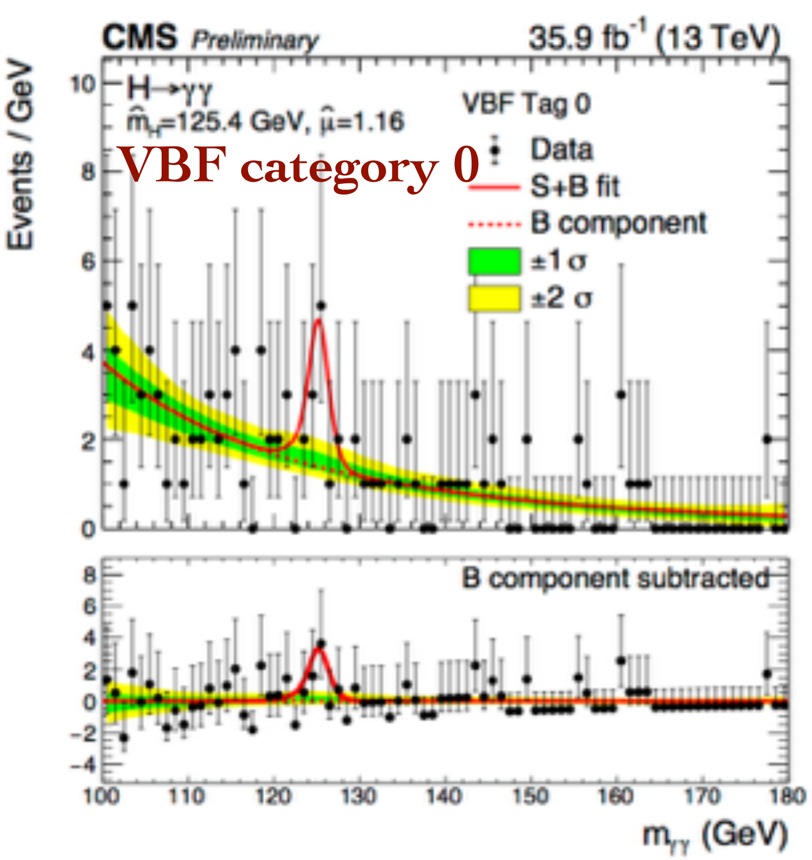


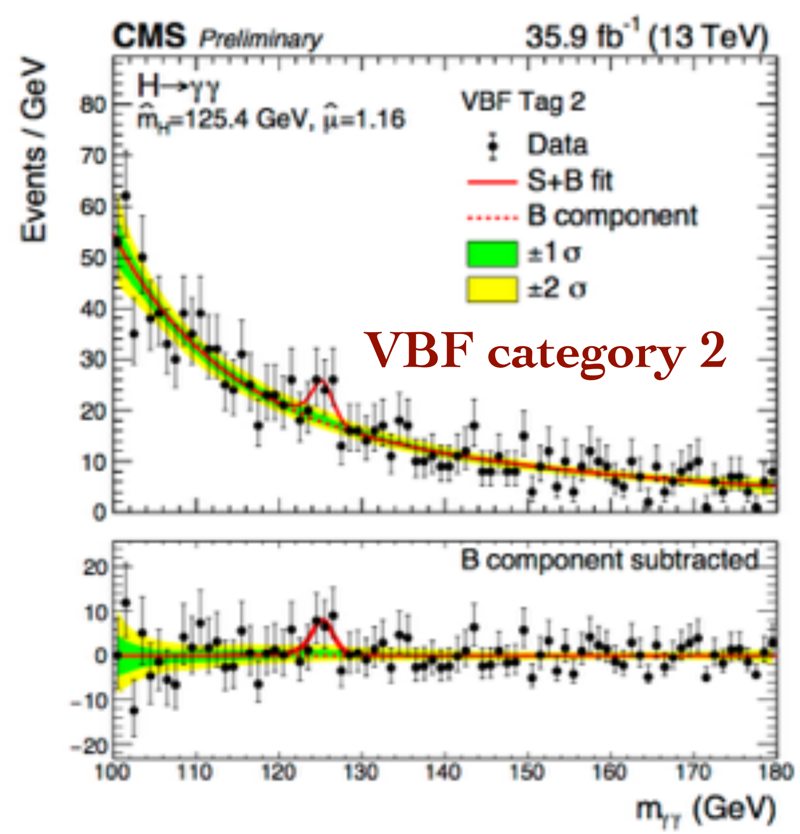
CMS: H->γγ Channel

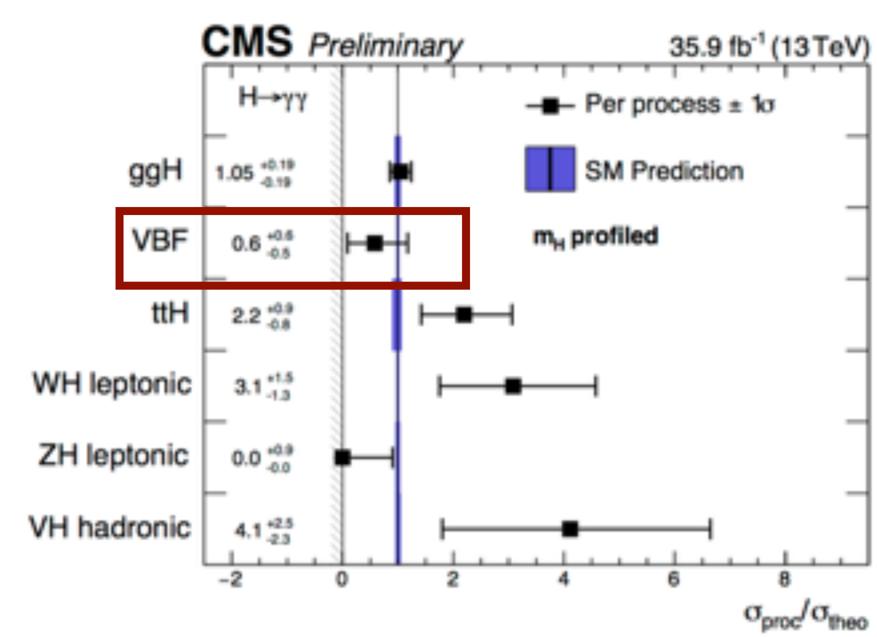
CMS-HIG-16-040

- **VBF selection:**
  - two high pT photons
  - two high-pT jets with mjj > 250 GeV
  - multivariate classifier which combines the scores of the VBF jets kinematics and the photon identification classifiers and the ratio $p_{T\gamma\gamma}/m_{\gamma\gamma}$
    - score of classifier divided in 3 bins



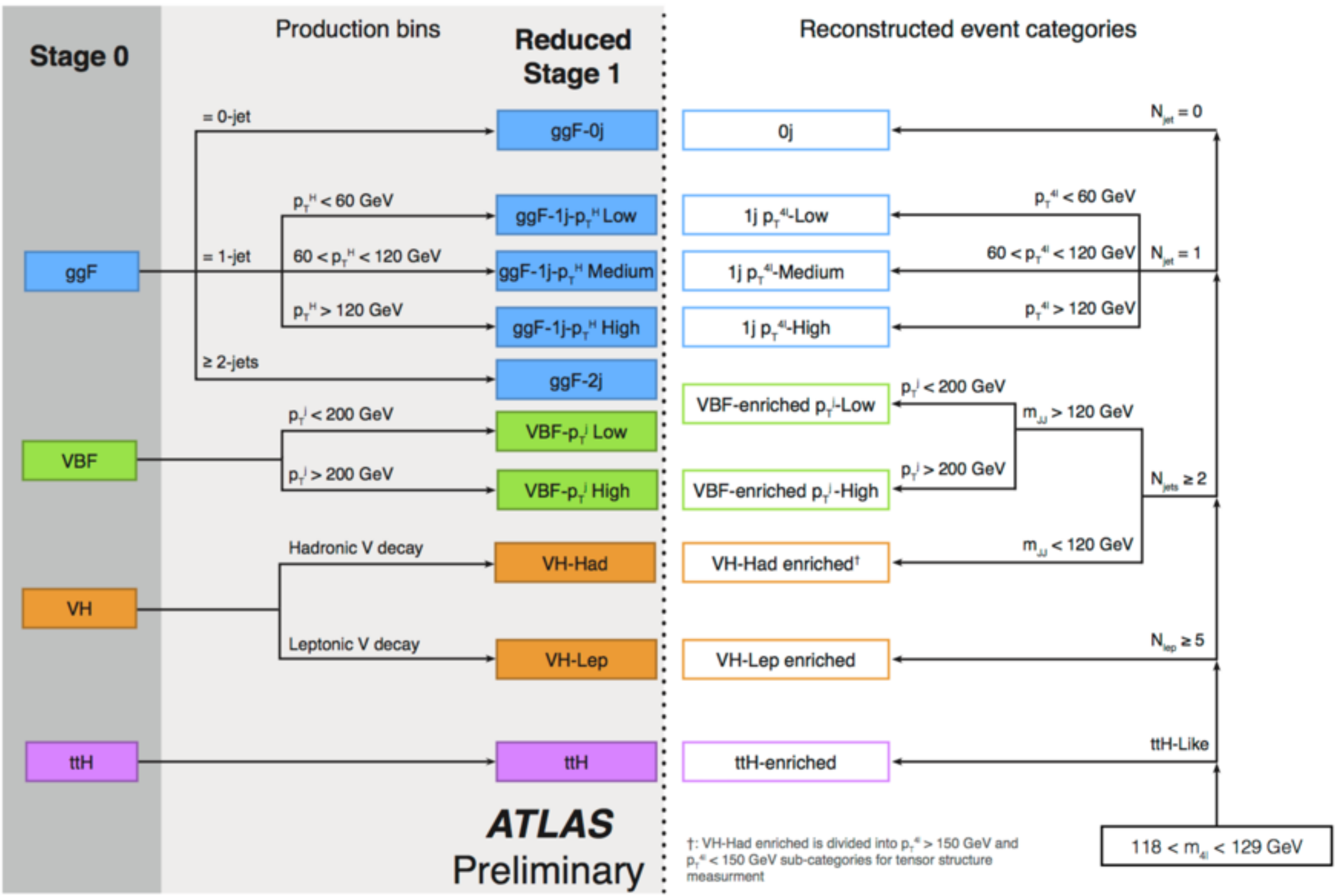






ATLAS: Simplified Template Cross Sections Framework

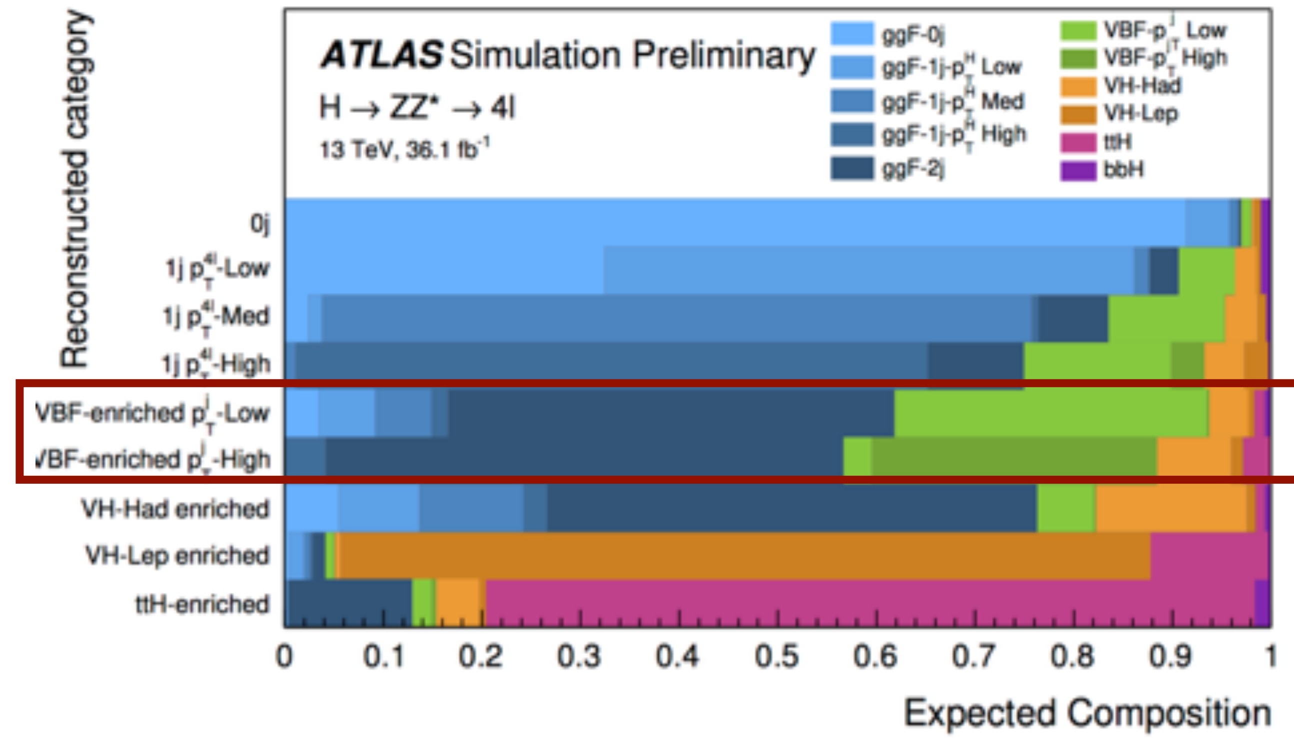
ATLAS-CONF-2017-043

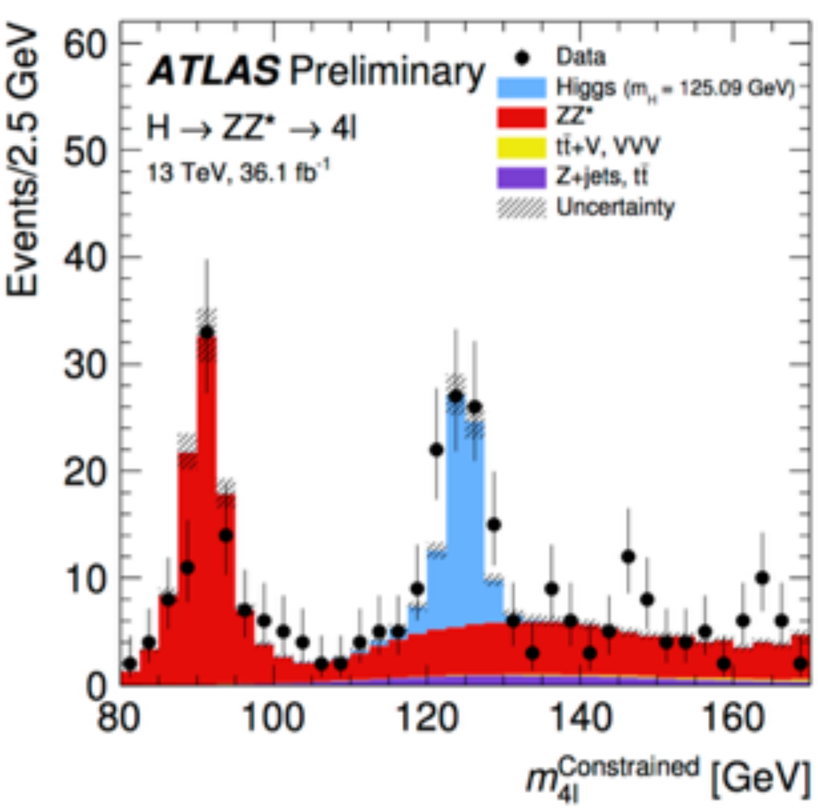


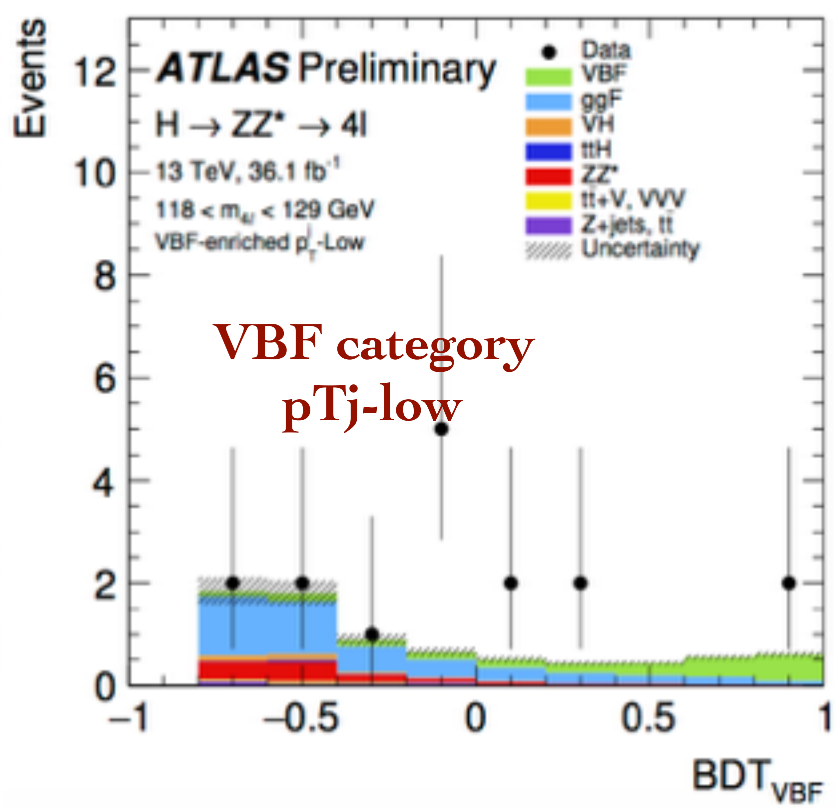
ATLAS: H->ZZ->4l Channel

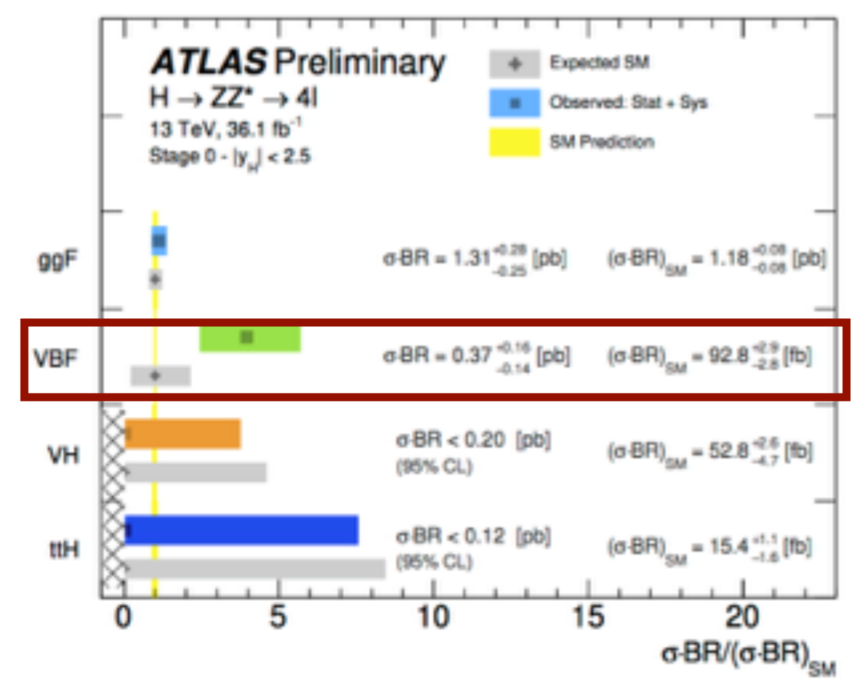
ATLAS-CONF-2017-043

- in addition to kinematic requirements multivariate classifier is used in the pTj-low category trained to separate VBF signal from ggF background
- pTj-high category has no sufficient statistics for the training





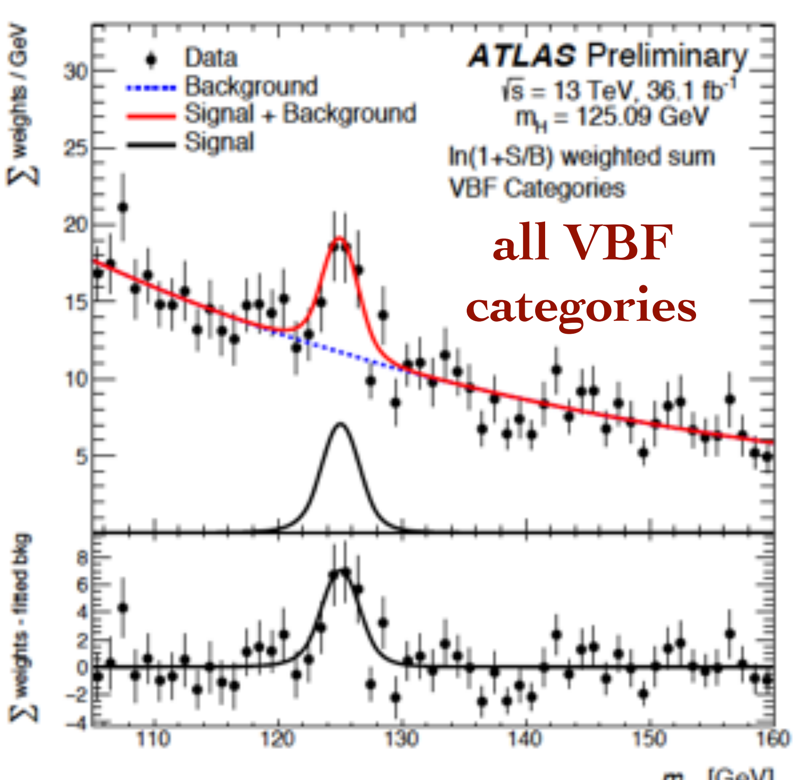


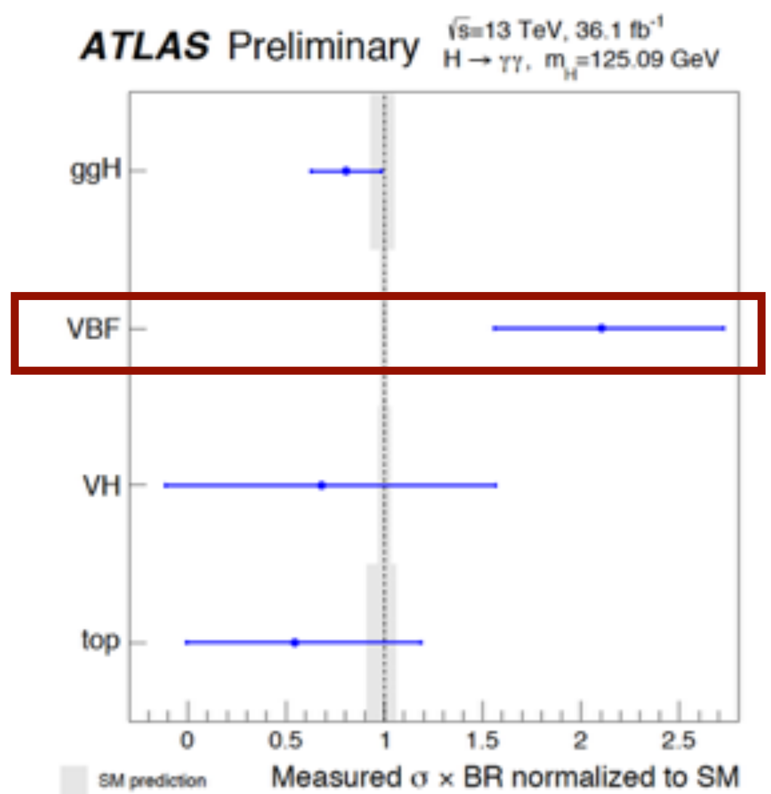


ATLAS: H->γγ Channel

arXiv:1708.03299

- **VBF selection**:
  - two leading high pT jets with a large separation in the pseudorapidity > 2
  - $|\eta_{\gamma\gamma} - 0.5(\eta_{j1} + \eta_{j2})| < 5$
  - high and low pT(Hjj) categories (pT < or > 25 GeV)
  - multivariate classifier trained to separate VBF signal from ggF Higgs and other backgrounds using kinematic variables divided in 2 bins





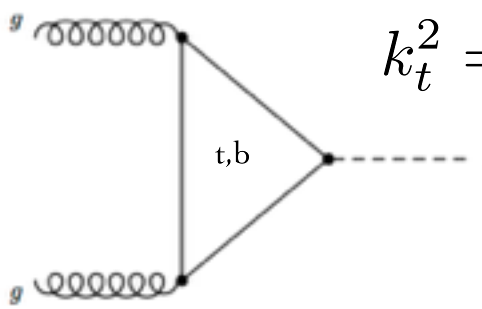
Uncertainties

- **largest** uncertainty is the **theoretical uncertainty on the ggF contamination** in VBF categories
  - estimated using Stewart-Tackmann procedure arXiv:1107.2117 arXiv:1302.5437
  - CMS H->γγ channel: overall normalisation uncertainty ~ 30%, migration between VBF categories ~10%
  - CMS H->ZZ channel: overall normalisation uncertainty ~ 20%
- **experimental uncertainties**:
  - CMS H->ZZ channel: jet energy scale ~15% on the ggF yield in the VBF category
- ATLAS measurements have similar uncertainties
- VBF measurements are dominated by **statistical uncertainties** but **theory uncertainties** will play a larger role in the future
  - unless **experimental measurements constrain the theory** like for VBF Z+jets process or **theory improves**

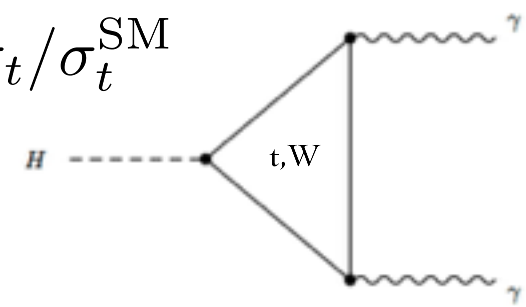
Top Quark Couplings to H and Z Bosons

Top Quark Yukawa Coupling @ Run 1

- **indirect constraints** on the top quark Yukawa coupling from **gluon-gluon fusion** and **H to γγ** decays



$$k_t^2 = \sigma_t/\sigma_t^{\mathrm{SM}}$$

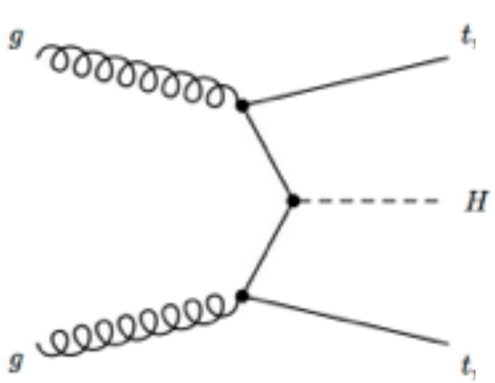


loop process, assuming SM contributions only:

Parameter	ATLAS+CMS	ATLAS	CMS
k_t	0.87 ± 0.15	$0.98^{+0.21}_{-0.20}$	$0.77^{+0.20}_{-0.18}$

JHEP08(2016)045

- **direct measurement** from **ttH production**



$$\mu_{\mathrm{ttH}} = \sigma_{\mathrm{ttH}}/\sigma_{\mathrm{ttH}}^{SM}$$

tree level process, cross section is proportional to k_t^2

Process	ATLAS+CMS	ATLAS	CMS
μ_{ttH}	$2.3^{+0.7}_{-0.6}$	$1.9^{+0.8}_{-0.7}$	$2.9^{+1.0}_{-0.9}$

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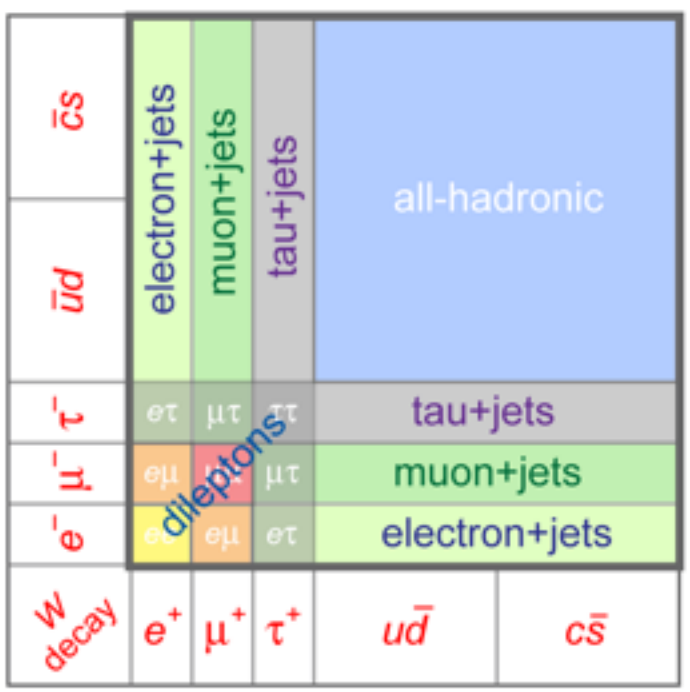
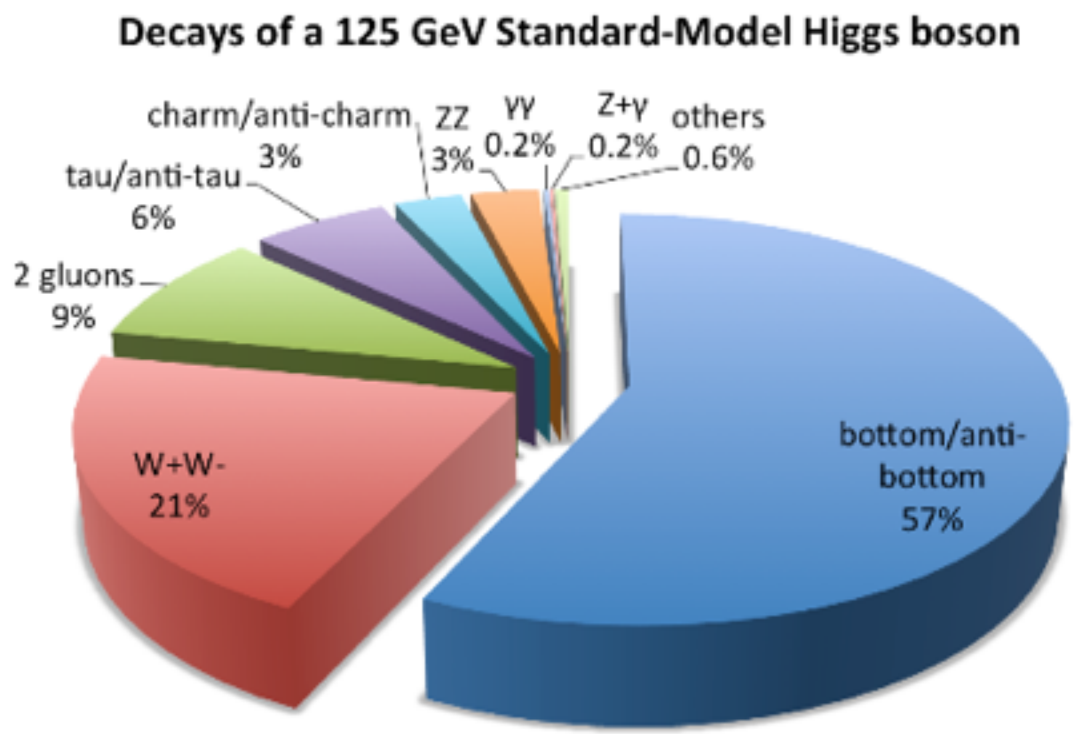
ttH Production

- complex final state, rich spectrum of possible signatures from top quark pair and Higgs boson decays

Top Pair Decay Channels





$$\sigma^{\mathrm{SM}}_{\mathrm{ttH}} = 0.507 \text{ pb } ^{+5.8\%}_{-9.2\%} \text{ (QCD scale) } \pm 3.6\% \text{ (PDF,}\alpha_s\text{)}$$

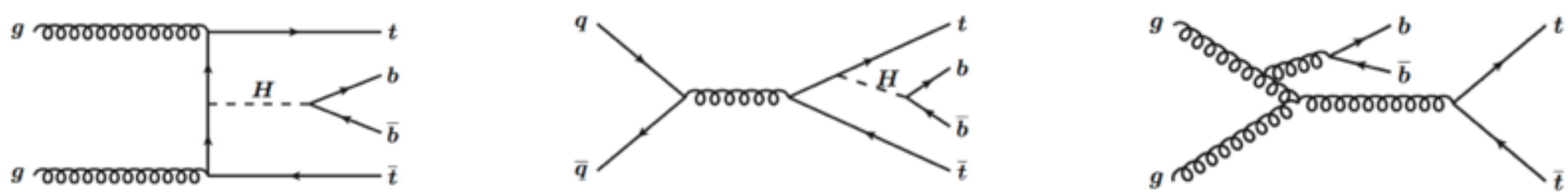
1% of the total Higgs boson production cross section

Current ttH Results

Process	ATLAS	CMS
ttH (bb) tt-> 1-2 lep.	ATLAS-CONF-2017-076	CMS-PAS-HIG-16-038
ttH multilepton tt->1-2 lep./had. τ H->WW, ZZ, ττ	ATLAS-CONF-2017-077	CMS-PAS-HIG-17-004 CMS-PAS-HIG-17-003
ttH (ZZ->4l) tt->0-2 lep.	ATLAS-CONF-2017-043	CMS-HIG-16-041
ttH (γγ) tt->0-2 lep.	ATLAS-CONF-2017-045	CMS-PAS-HIG-16-040

ttH (bb) Channel

- benefiting from large H->bb branching ratio (~ 58%) and leptonic top quark decays
- large irreducible background from tt + heavy flavour (HF) production, O(15 pb)
- **uncertainty on the tt + HF process** is the **dominant** uncertainty for this search

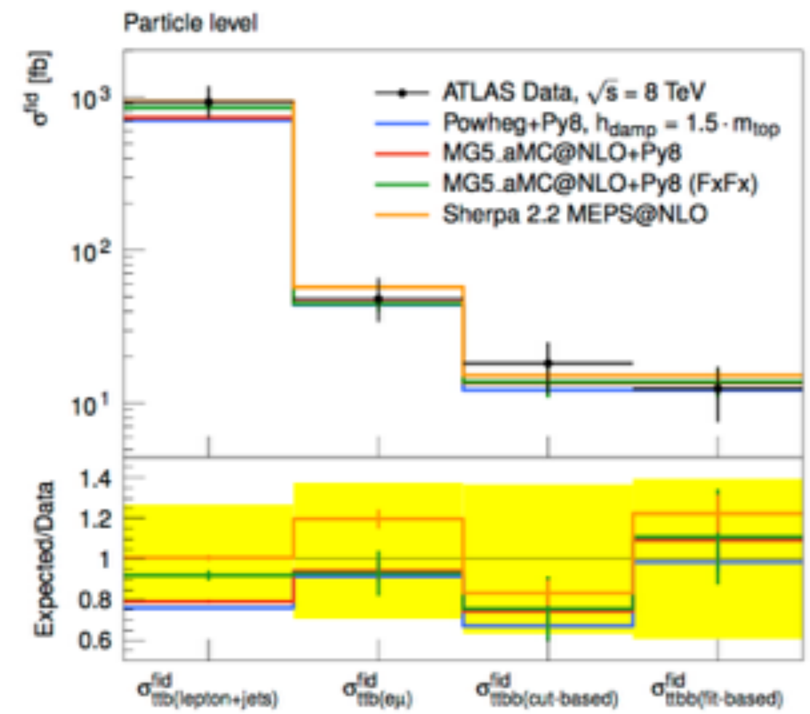


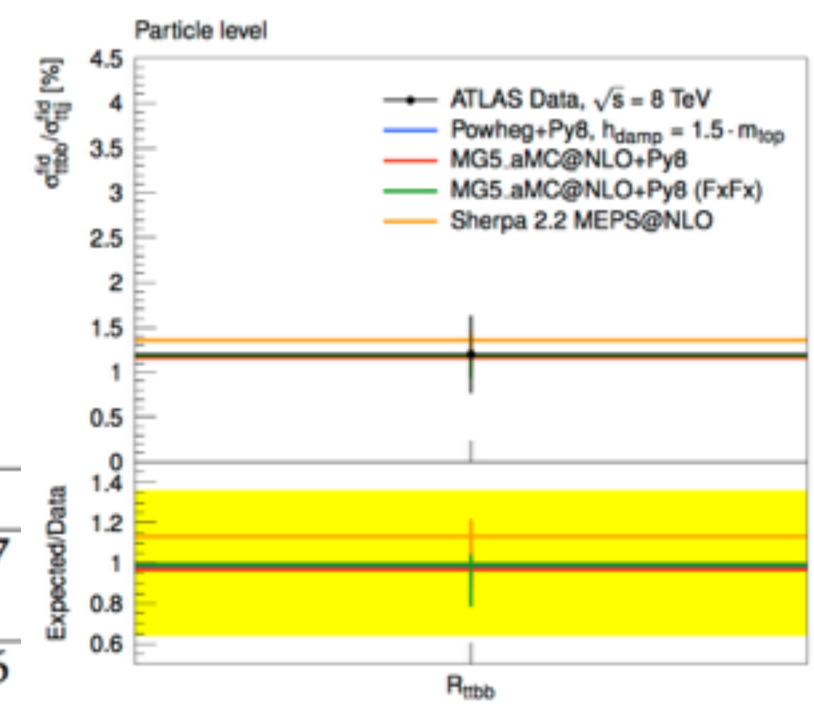
- **tt + HF modelling** extensively studied in 7, 8 and 13 TeV data by ATLAS and CMS
  - latest results: ATLAS-PHYS-PUB-2016-020, CMS-TOP-16-010

tt + HF Modelling

ATLAS-PHYS-PUB-2016-020

- calculations of inclusive cross section for tt and additional jets at NLO in pp collisions at 7, 8 and 13 TeV arXiv:1403.2046
- dominant uncertainties from the choice of the factorisation and renormalisation scales
  - presence of two different scales: the top quark mass and the jet transverse momentum
- measurements of tt + HF cross sections from ATLAS and CMS important to cross check theory predictions

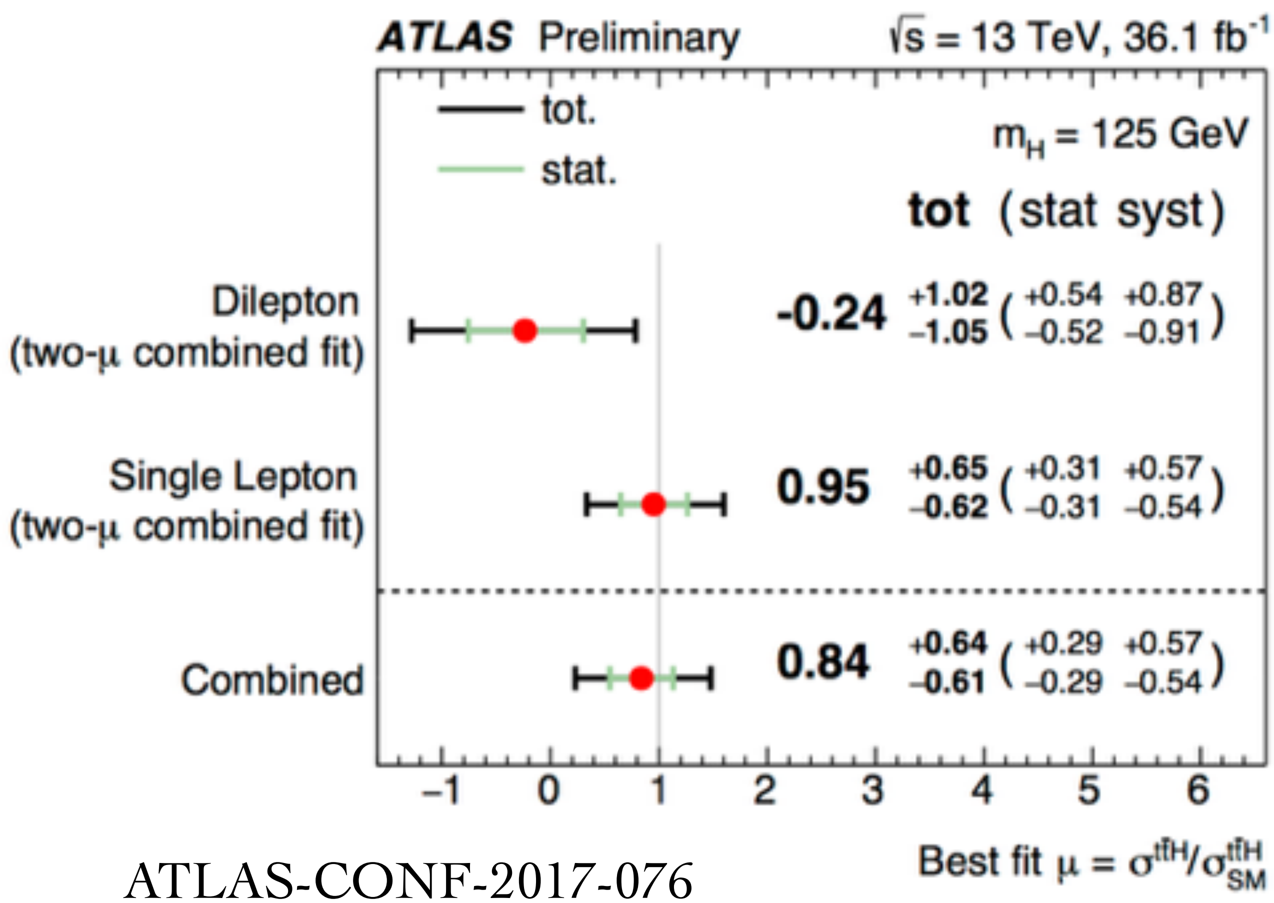




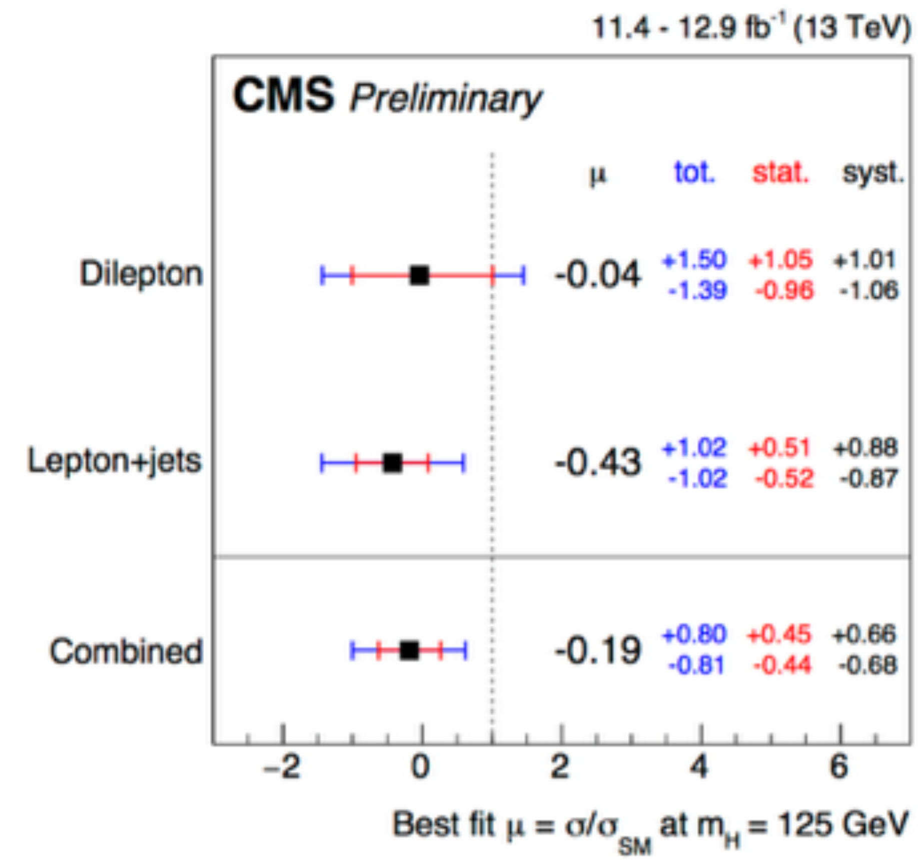
recent result @ 13 TeV, CMS-TOP-16-010

Phase space		$\sigma_{t\bar{t}b\bar{b}}$ [pb]	$\sigma_{t\bar{t}jj}$ [pb]	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$
Visible	Measurement	$0.088 \pm 0.012 \pm 0.029$	$3.7 \pm 0.1 \pm 0.7$	$0.024 \pm 0.003 \pm 0.007$
	SM (POWHEG)	0.070 ± 0.009	5.1 ± 0.5	0.014 ± 0.001
Full	Measurement	$4.0 \pm 0.6 \pm 1.3$	$184 \pm 6 \pm 33$	$0.022 \pm 0.003 \pm 0.006$
	SM (POWHEG)	3.2 ± 0.4	257 ± 26	0.012 ± 0.001

ttH(bb) Results



ATLAS-CONF-2017-076



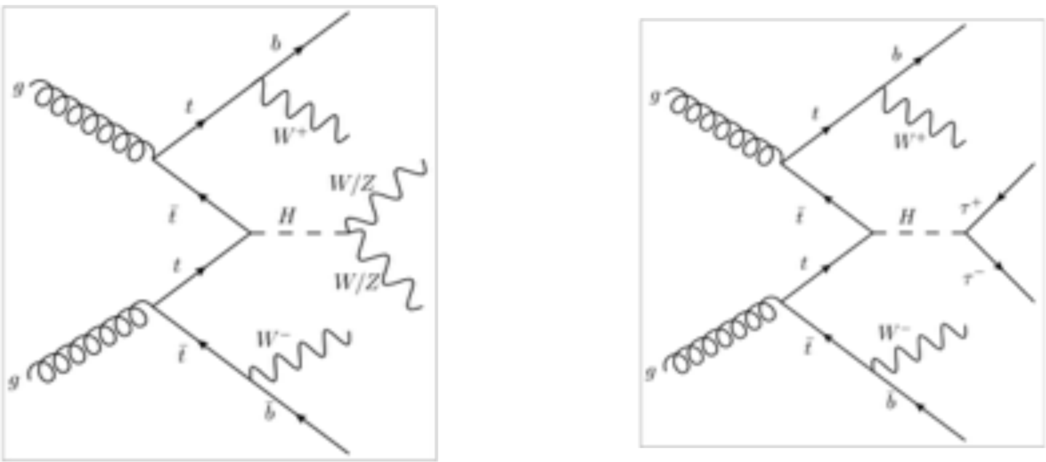
CMS-PAS-HIG-16-038

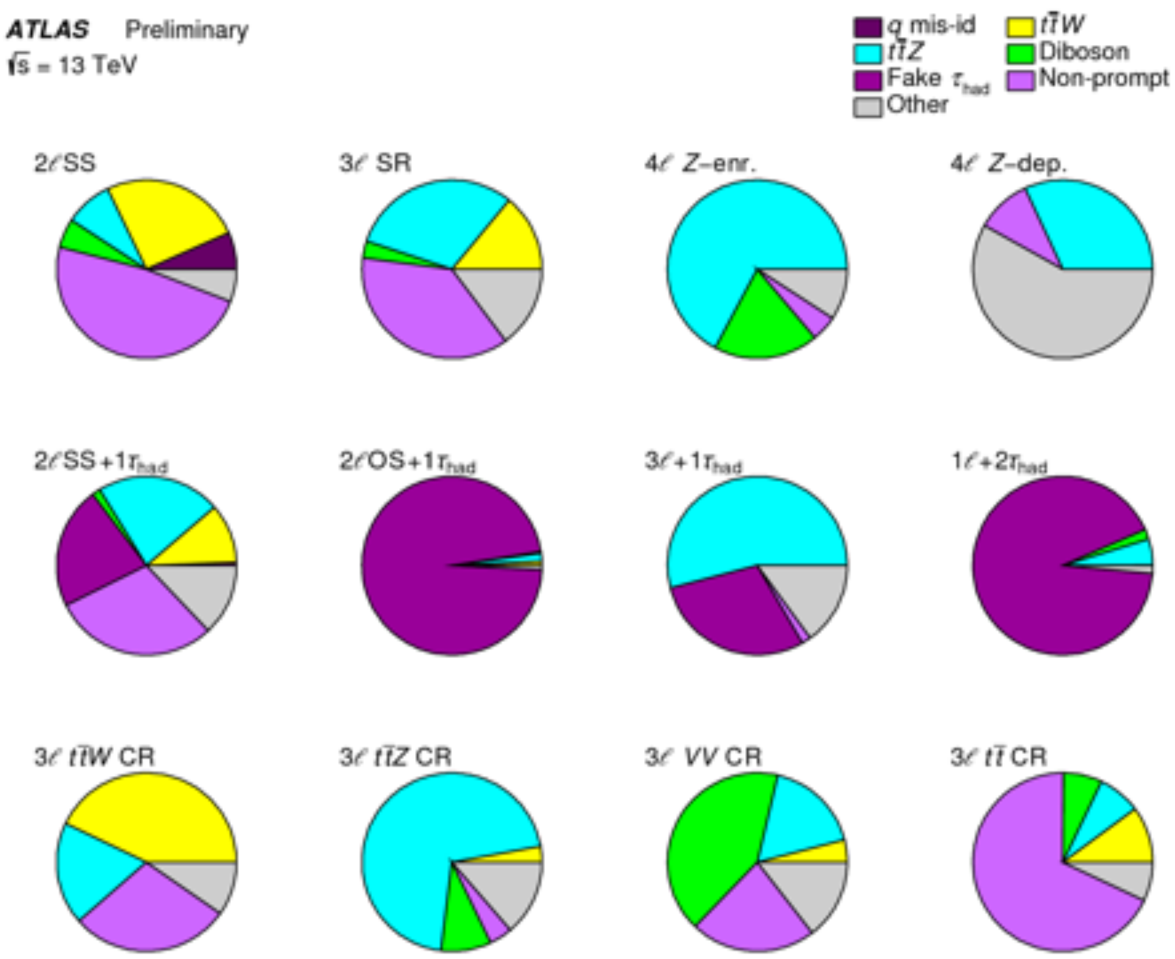
- signal strength: $0.84^{+0.64}_{-0.61}$
  - single lepton channel is most sensitive
- can exclude $\mu_{\mathrm{ttH}} > 2.0$ @ 95% CL

- signal strength: $-0.19^{+0.80}_{-0.81}$
  - single lepton channel is most sensitive
- can exclude $\mu_{\mathrm{ttH}} > 1.5$ @ 95% CL

ttH Multilepton Channel

- target H->WW, ττ, ZZ decay modes combined with leptonic tt decays
- main background: tt => rely on same sign or three leptons signatures
- different background compositions:
  - fake/non-prompt light and tau-leptons estimated with data-derived methods
  - irreducible ttV backgrounds (~1.5 pb) and other rare SM processes
- sensitivity enhanced with multivariate classifiers



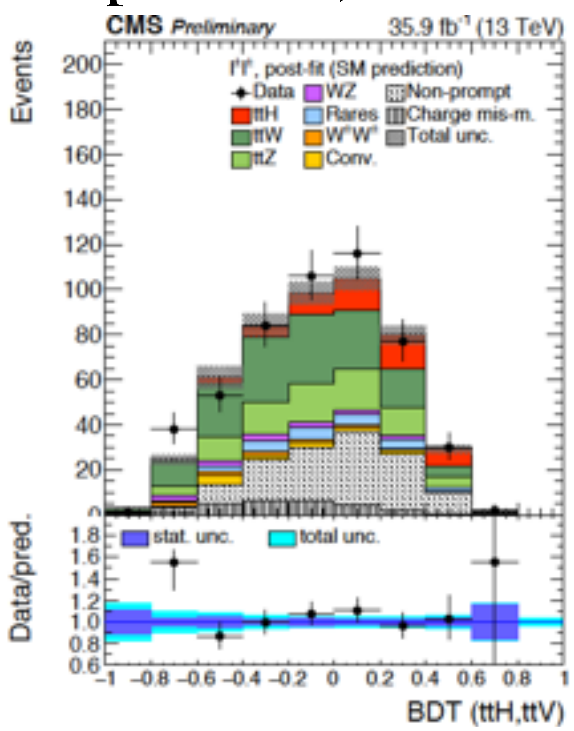


ATLAS-CONF-2017-077

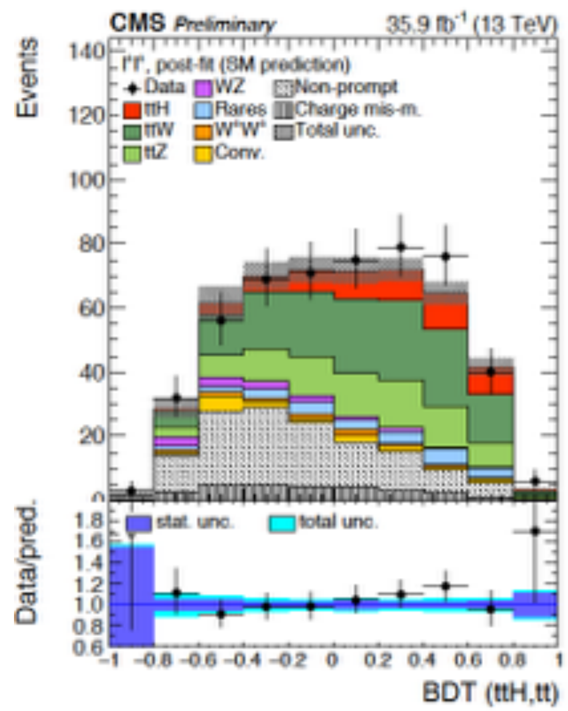
ttH Multilepton Results

CMS-PAS_HIG-17-004
ATLAS-CONF-2017-077

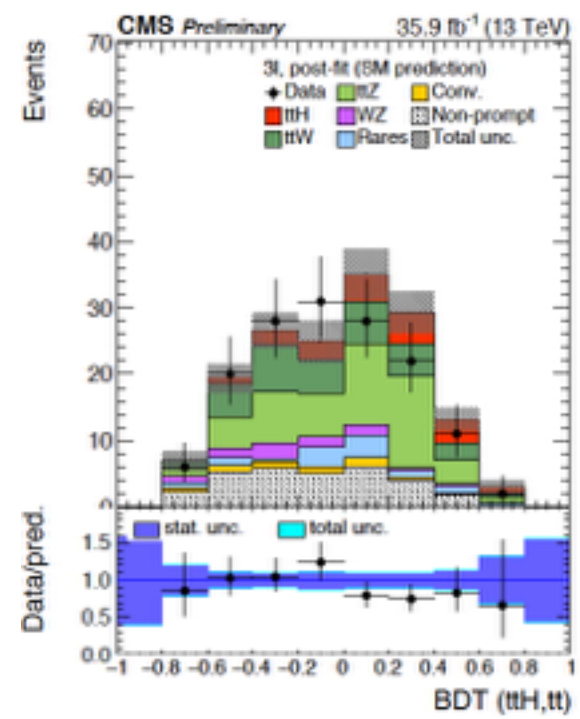
dilepton BDT, ttH vs ttV



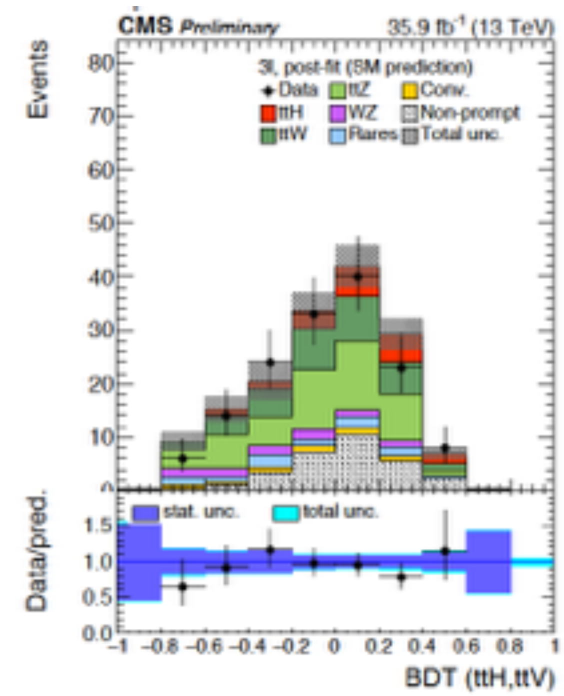
dilepton BDT, ttH vs tt



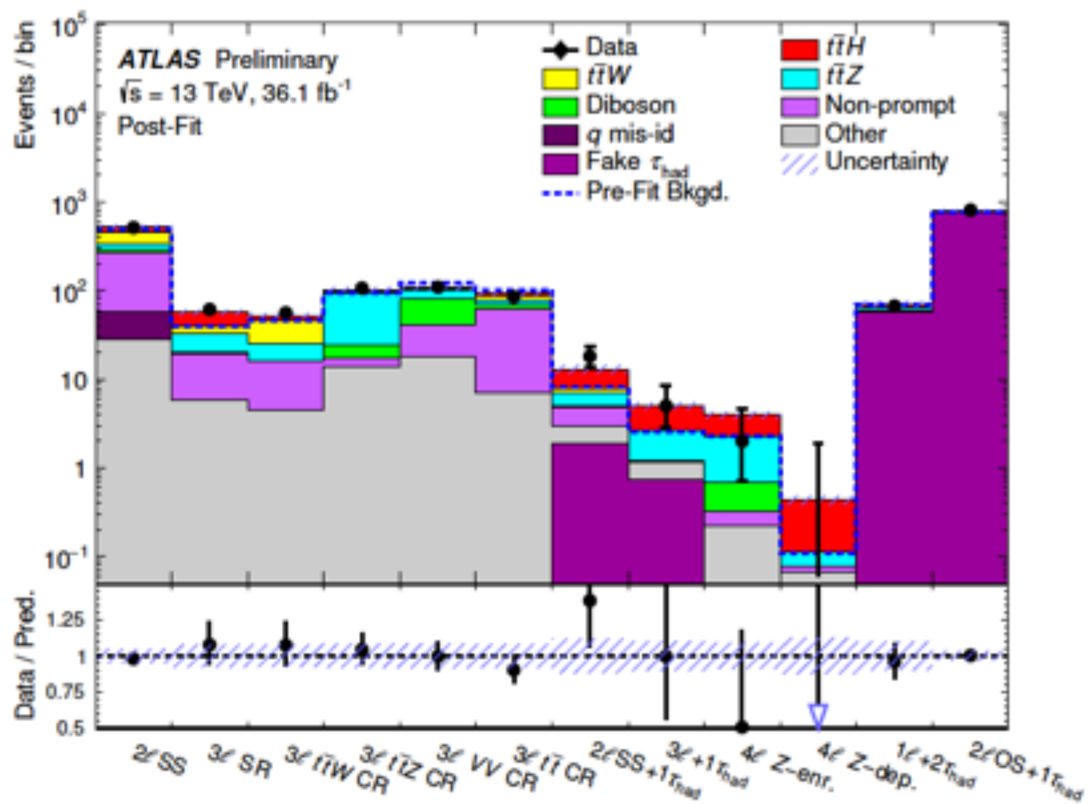
trilepton BDT, ttH vs ttV



trilepton BDT, ttH vs tt



ATLAS:
BDT
discriminant
used in 5 SRs



CMS observed result:

$$\mu_{\rm ttH} = \sigma_{\rm ttH}/\sigma^{\rm SM}_{\rm ttH} =$$

$$1.5 \pm 0.29\ ({\rm stat})\ \pm 0.24\ ({\rm theo})\ \pm 0.32\ ({\rm syst})$$

significance: 3.3σ

ATLAS observed result:

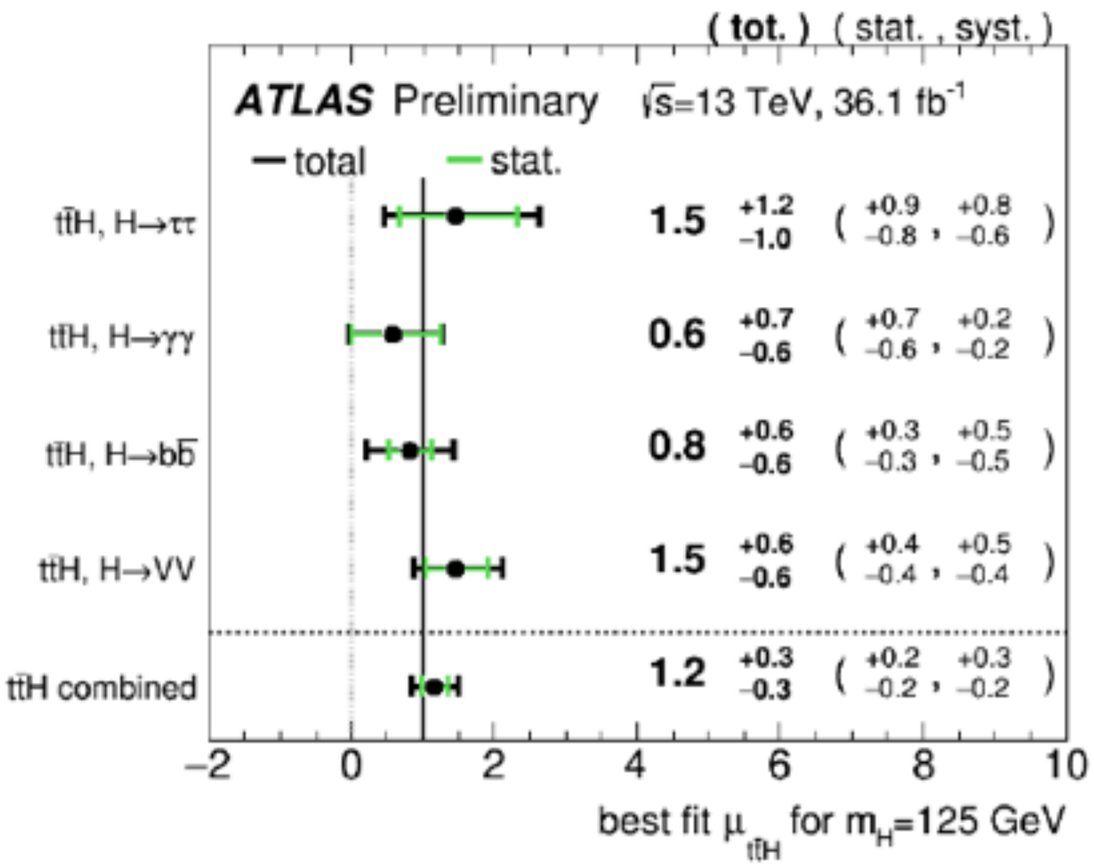
$$\mu_{\rm ttH} = 1.6^{+0.3}_{-0.3}\ ({\rm stat})\ ^{+0.4}_{-0.3}\ ({\rm syst})$$

significance: 4.1σ

ATLAS: ttH Combination

ATLAS-CONF-2017-077

- combining bb, multilepton, γγ, and ZZ->4 lep. channels
  - included only ttH enhanced categories in γγ and ZZ channels
- non-ttH production mechanisms fixed to the SM predictions
- correlating almost all signal, background and detector uncertainties

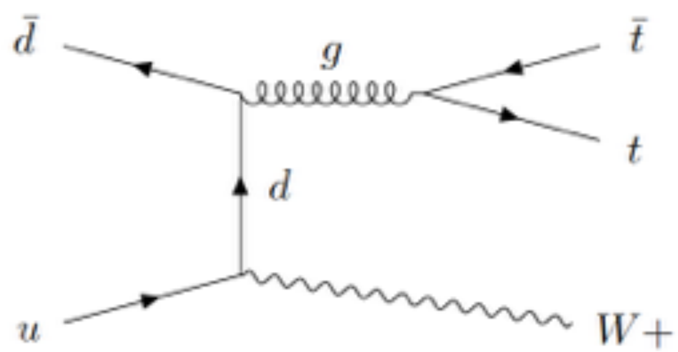


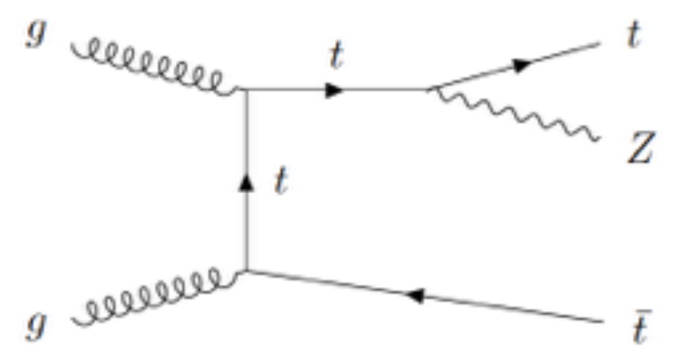
Uncertainty Source	$\Delta\mu$	
$t\bar{t}$ modelling in $H \to b\bar{b}$ analysis	+0.15	−0.14
$t\bar{t}H$ modelling (cross section)	+0.13	−0.06
Non-prompt light-lepton and fake τ_{had} estimates	+0.09	−0.09
Simulation statistics	+0.08	−0.08
Jet energy scale and resolution	+0.08	−0.07
$t\bar{t}V$ modelling	+0.07	−0.07
$t\bar{t}H$ modelling (acceptance)	+0.07	−0.04
Other non-Higgs boson backgrounds	+0.06	−0.05
Other experimental uncertainties	+0.05	−0.05
Luminosity	+0.05	−0.04
Jet flavour tagging	+0.03	−0.02
Modelling of other Higgs boson production modes	+0.01	−0.01
Total systematic uncertainty	+0.27	−0.23
Statistical uncertainty	+0.19	−0.19
Total uncertainty	+0.34	−0.30

Channel	Best fit μ		Significance	
	Observed	Expected	Observed	Expected
Multilepton	$1.6^{+0.5}_{-0.4}$	$1.0^{+0.4}_{-0.4}$	4.1σ	2.8σ
$H \to b\bar{b}$	$0.8^{+0.6}_{-0.6}$	$1.0^{+0.6}_{-0.6}$	1.4σ	1.6σ
$H \to \gamma\gamma$	$0.6^{+0.7}_{-0.6}$	$1.0^{+0.8}_{-0.6}$	0.9σ	1.7σ
$H \to 4\ell$	< 1.9	$1.0^{+3.2}_{-1.0}$	—	0.6σ
Combined	$1.2^{+0.3}_{-0.3}$	$1.0^{+0.3}_{-0.3}$	4.2σ	3.8σ

ttV Measurements

- direct measurement of the coupling of the top quark and the Z boson





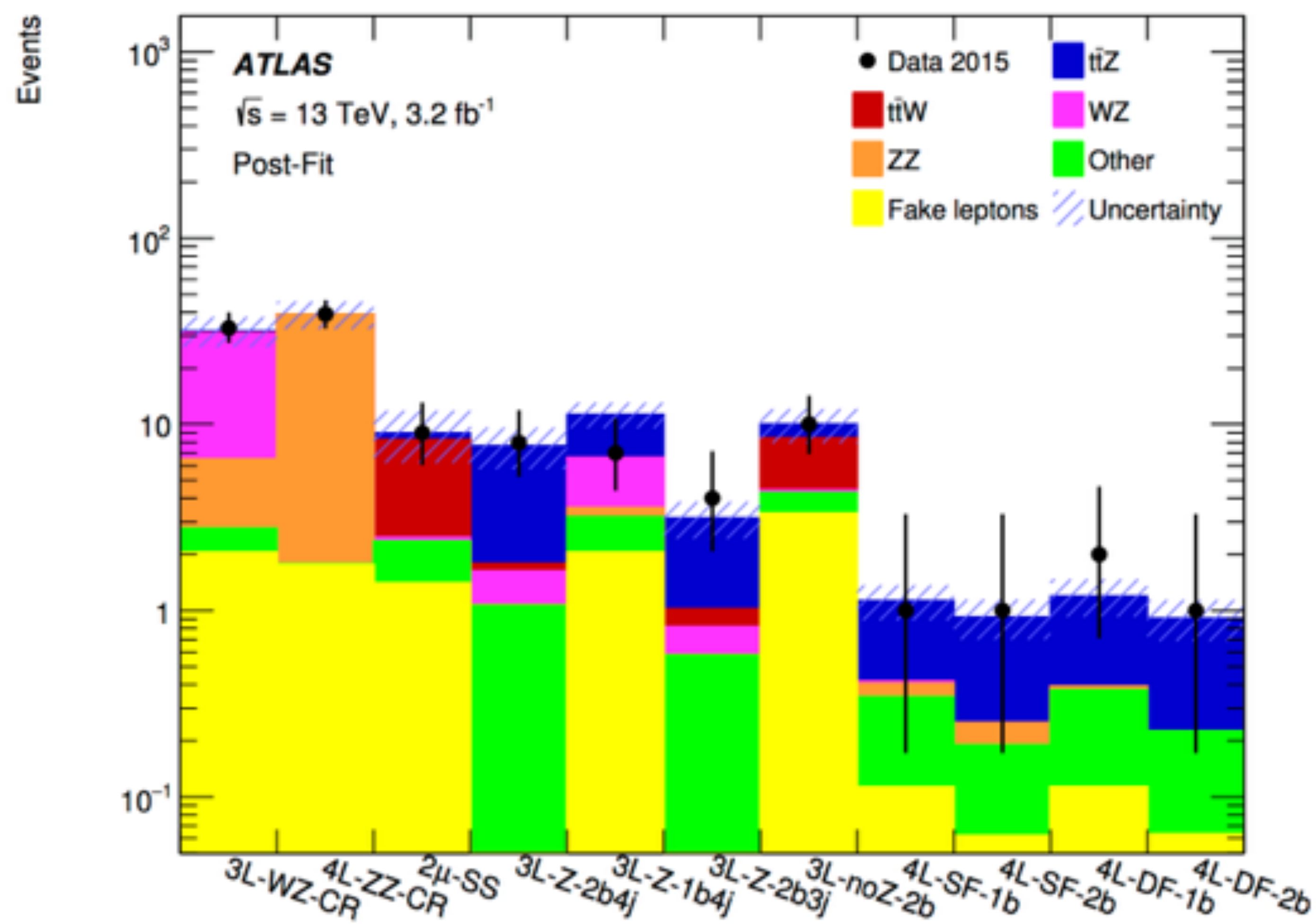
- background to ttH and searches for new physics
- 7 TeV measurement ~50% uncertainty, 8 TeV measurement ~30% uncertainty
- ttW signal: events with two same-charge leptons
- ttZ signal: events with three or four leptons with a lepton pair of same flavour and opposite charge
- events are divided in categories according to the numbers of jets and number of b-jets
- simultaneous fit in all categories to constrain background and to extract signal

ATLAS: ttV Measurements @ 13 TeV

arXiv:1609.01599

- control regions are used to constrain WZ, ZZ backgrounds in data
- data-driven methods to estimate fake leptons background

Uncertainty	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}W}$
Luminosity	2.6%	3.1%
Reconstructed objects	8.3%	9.3%
Backgrounds from simulation	5.3%	3.1%
Fake leptons and charge misID	3.0%	19%
Signal modelling	2.3%	4.2%
Total systematic	11%	22%
Statistical	31%	48%
Total	32%	53%



observed @ 13 TeV:

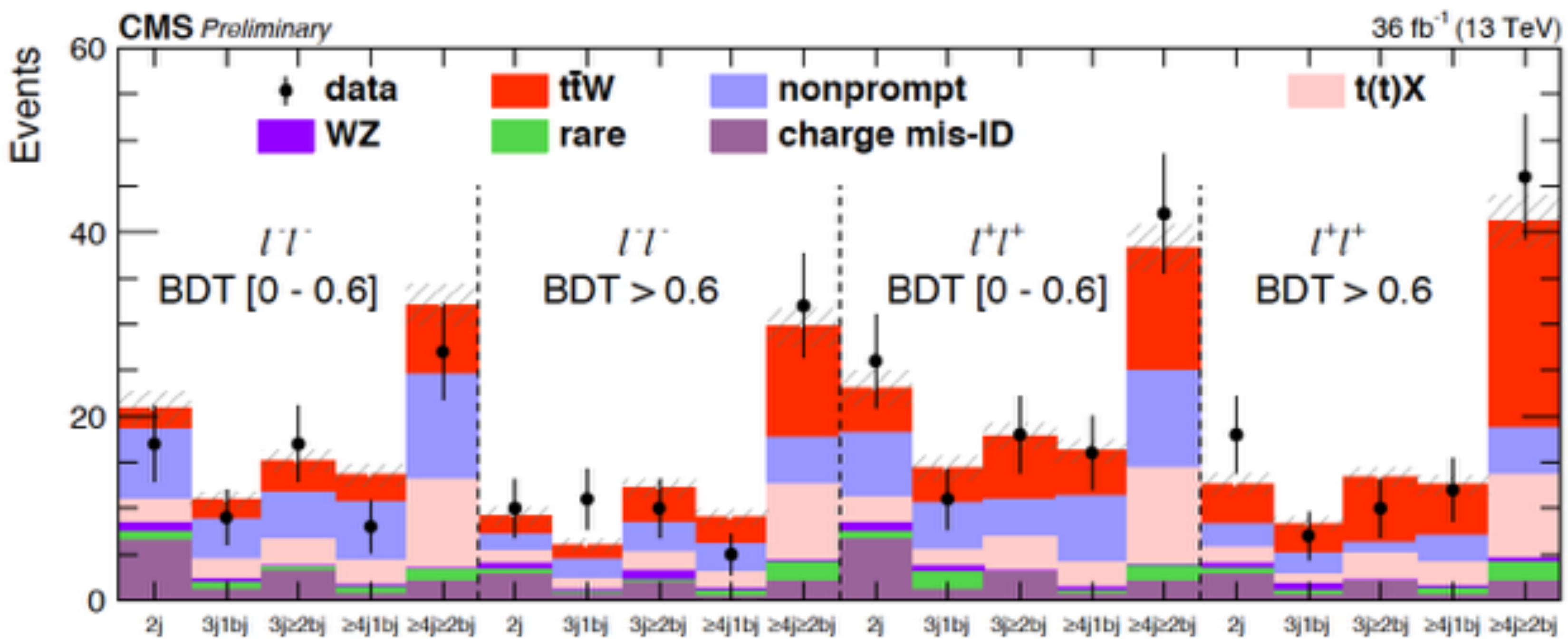
$$\sigma_{t\bar{t}Z} = 0.9 \pm 0.3 \text{ pb and } \sigma_{t\bar{t}W} = 1.5 \pm 0.8 \text{ pb.}$$

NLO prediction @ 13 TeV:

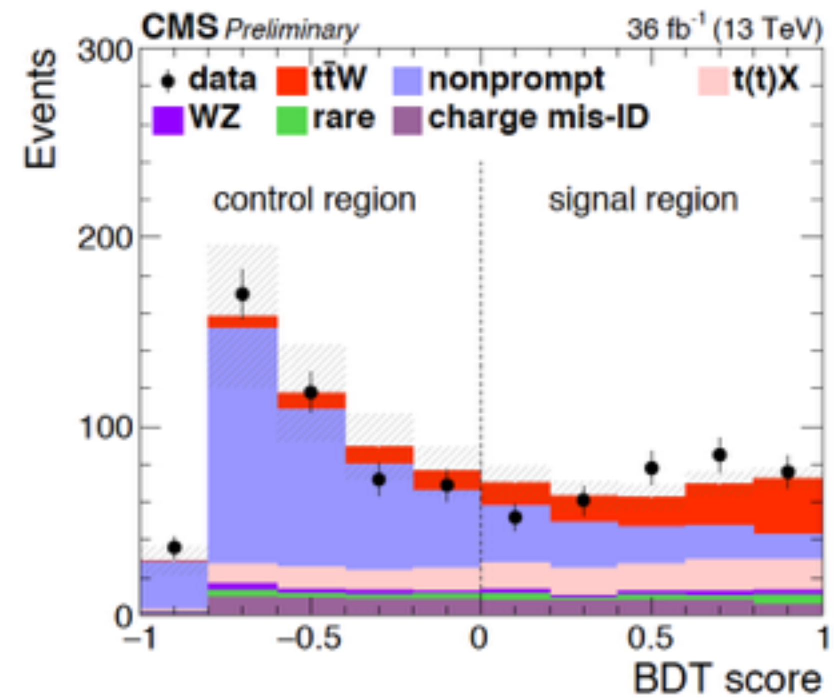
$$\sigma_{t\bar{t}Z} = 0.84 \pm 0.09 \text{ pb and } \sigma_{t\bar{t}W} = 0.60 \pm 0.08 \text{ pb.}$$

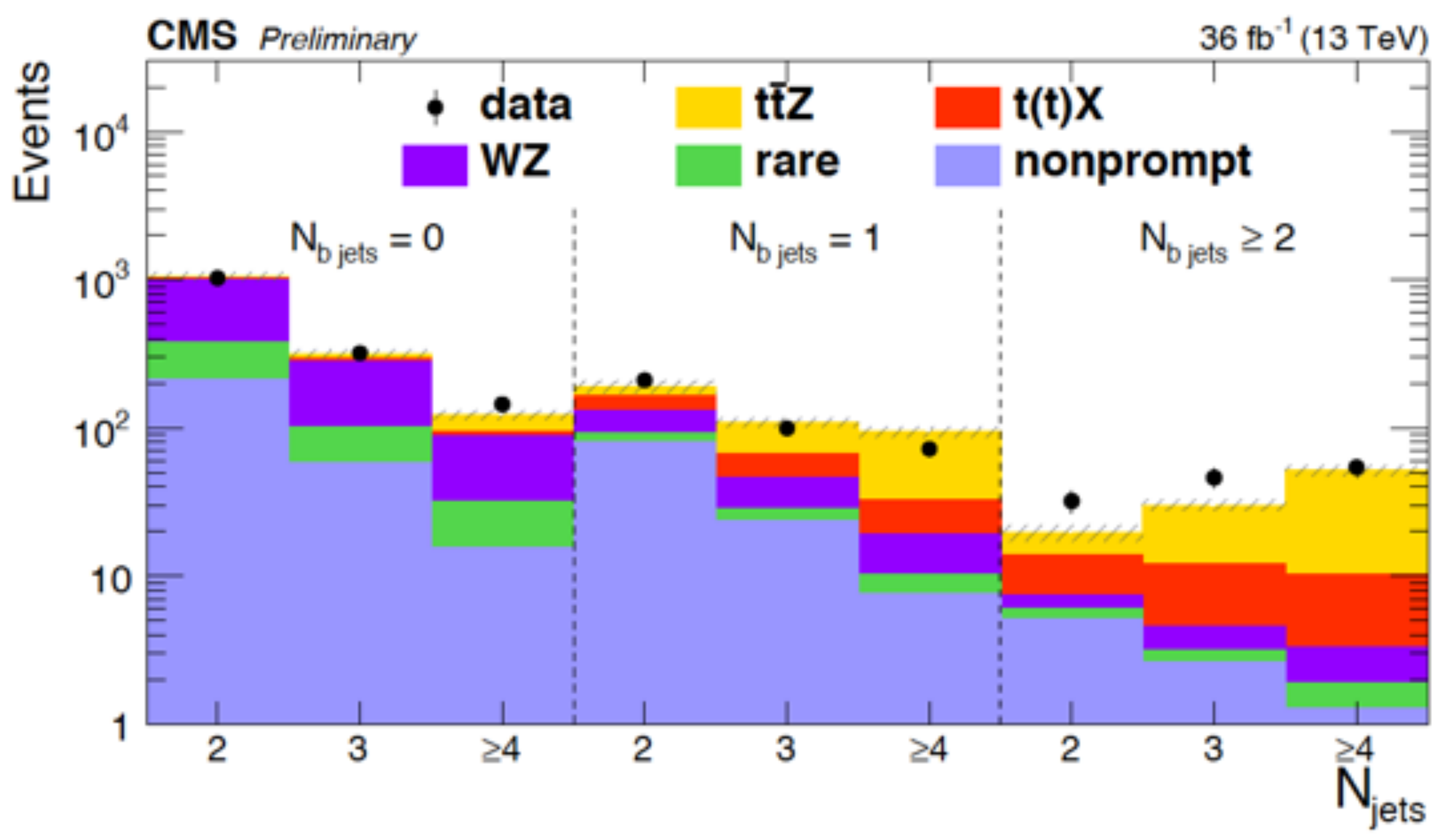
CMS: ttV Measurements @ 13 TeV

CMS-PAS-TOP-17-005



multivariate classifier to separate ttW signal from backgrounds





$$\sigma(pp \to t\bar{t}Z) = 1.00^{+0.09}_{-0.08}(\text{stat.})\ ^{+0.12}_{-0.10}(\text{sys.})\ \text{pb}$$

$$\sigma(pp \to t\bar{t}W) = 0.80\ ^{+0.12}_{-0.11}(\text{stat.})\ ^{+0.13}_{-0.12}(\text{sys.})\ \text{pb}$$

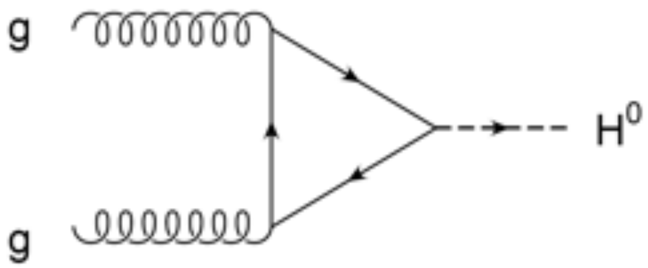
largest uncertainties due to
trigger, JES/JER, b-tagging,
lepton ID/eff, ttX bkg
3 - 7% each
total 12-14%

ttV Measurements Conclusions

- measured ttV cross sections are in agreement with the SM predictions within the uncertainties
  - systematic and statistical uncertainties are of the same size
- normalisation of the ttV background is determined in the ttH fit as a cross check
  - fitted $\mu_{\mathrm{ttH}} = 1.6^{+0.6}_{-0.5}$
  - fitted $\mu_{\mathrm{ttW}} = 0.92 \pm 0.32$ ATLAS-CONF-2017-077
  - fitted $\mu_{\mathrm{ttZ}} = 1.17^{+0.25}_{-0.22}$
- larger uncertainties but compatible with individual measurements

Higgs boson to bottom quark coupling

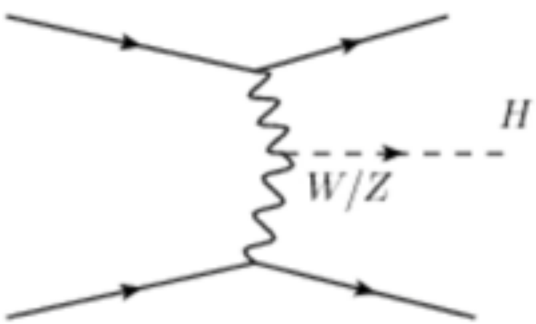
Hbb Channel



bb final state

87%

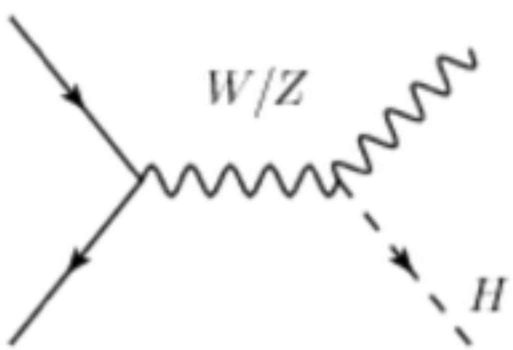
QCD production of b-quarks is 10^7 bigger
new CMS analysis exploiting high pT regime
CMS-HIG-17-010 (1.5 σ)



jjbb final state

7%

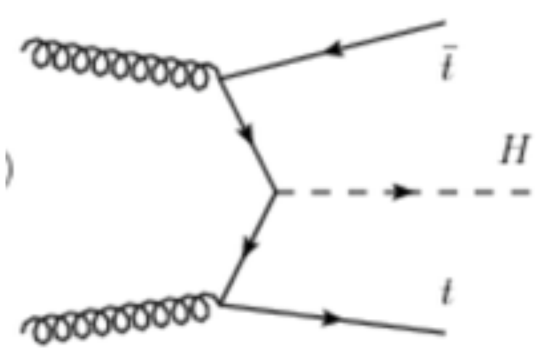
peculiar topology but still full hadronic final state dominated by multijet background
additional photon helps (similar sensitivity, higher S/B)



llbb, vvbb, lvbb

5%

leptonic signature for trigger and suppression of multijet background,
dominant bkg is V + jets
main search channel at LHC



4j4b, lv2j4b, 2l2v4b

1%

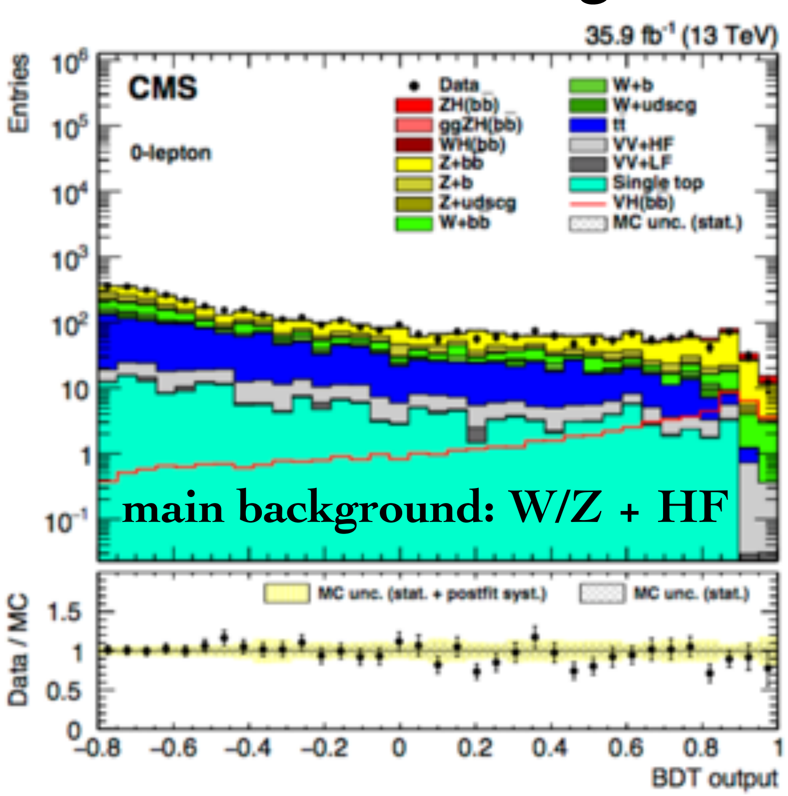
leptonic signature for trigger but combinatorics, dominant background is tt + jets

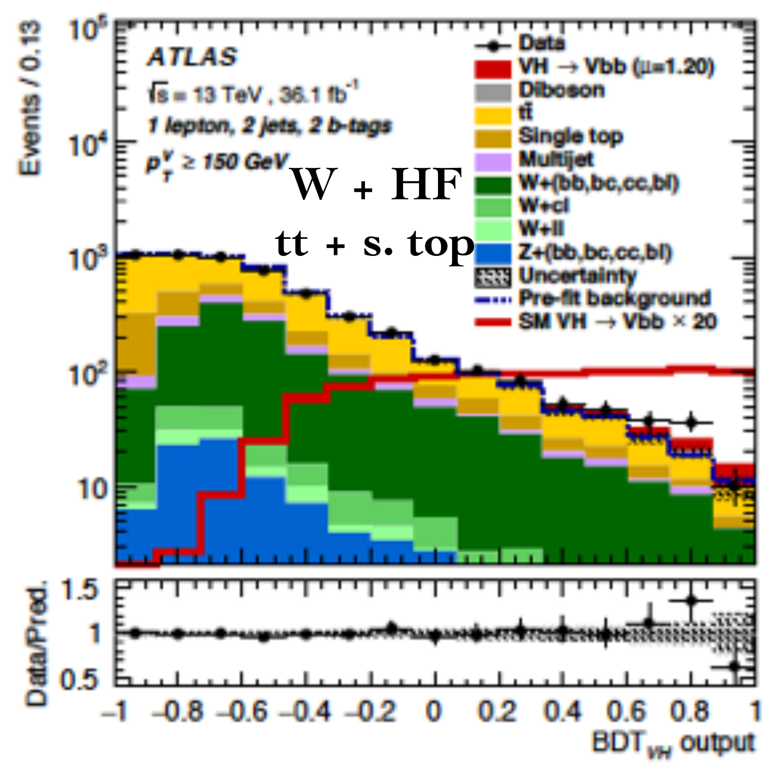
VH Analysis Strategy

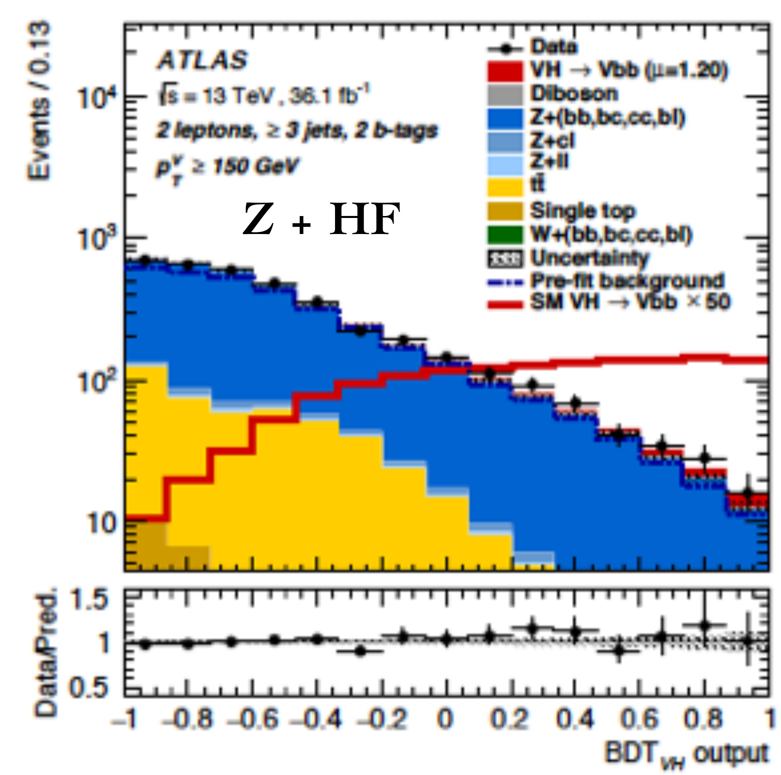
ATLAS: arXiv:1708.03299

CMS: arXiv:1709.07497

- categorise events based on number of leptons and pt(V) regions
- reconstruct Higgs from 2 b-tagged jets
  - b-jet regression (CMS) / b-jet pT corrections (ATLAS) to improve the mbb mass resolution
- multivariate techniques to separate VH signal from backgrounds
- simultaneous fit of signal and control regions
  - control regions used to constrain V + jets and tt backgrounds using data





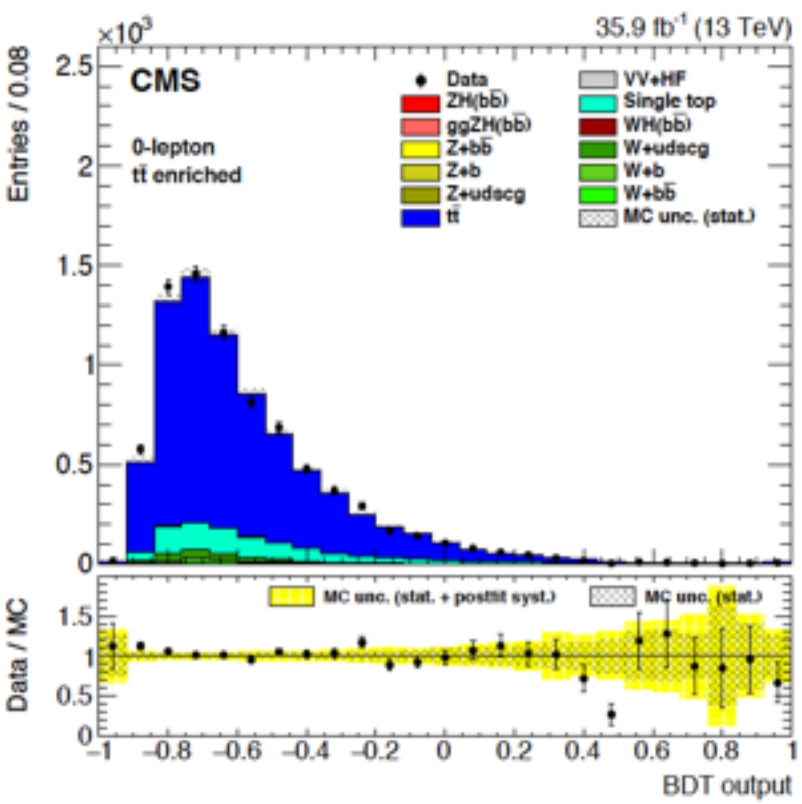


SM Backgrounds

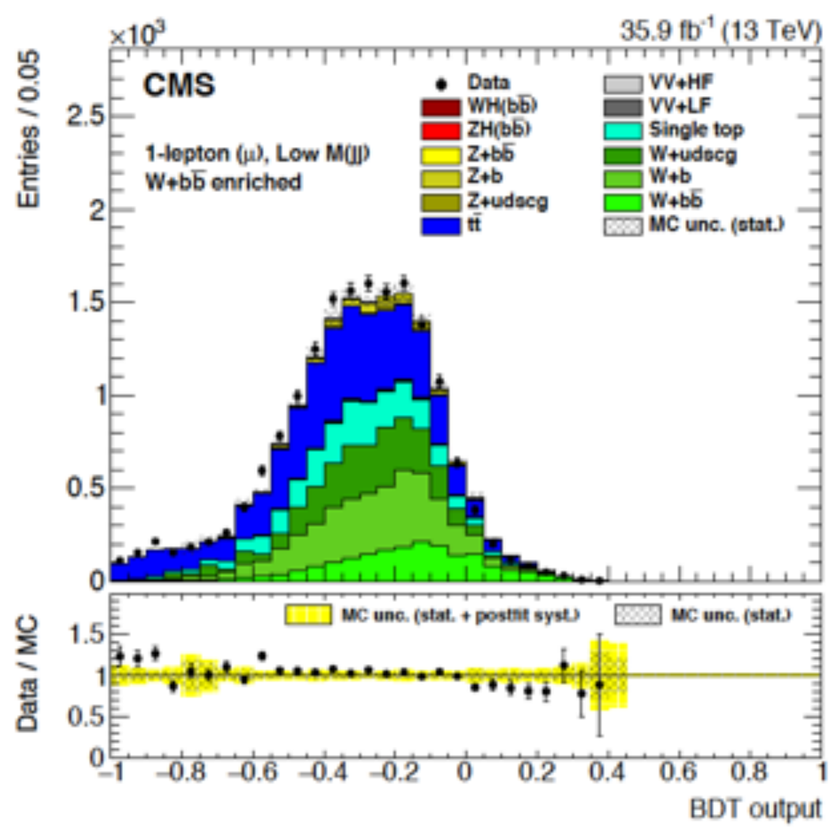
CMS: arXiv:1709.07497

some examples from CMS

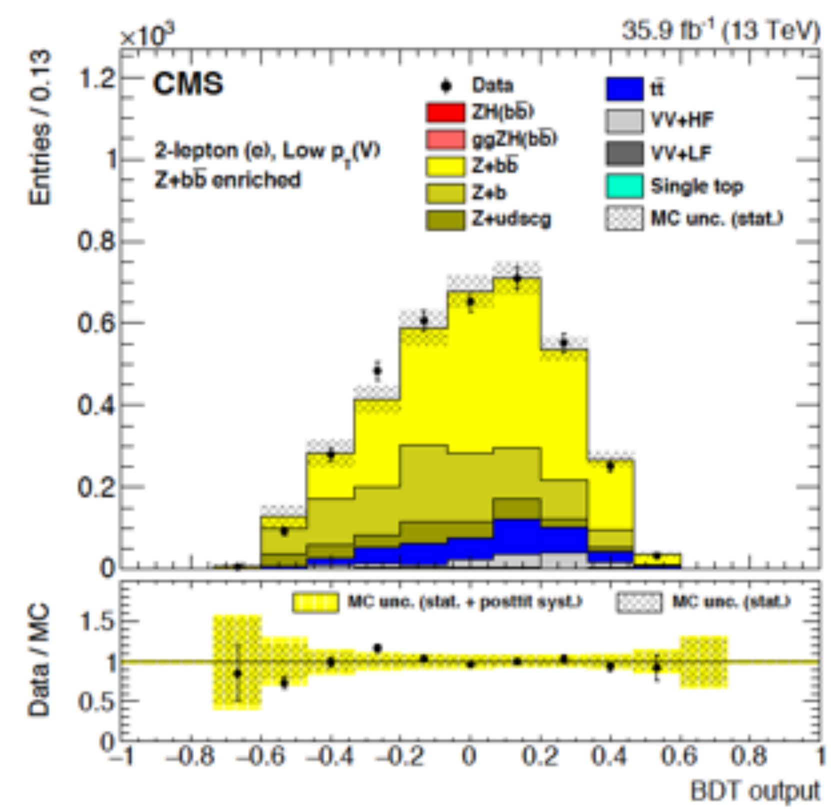
one or more additional jets
to define tt control region



invert mjj requirement
to define W + HF
control region



invert mjj requirement
to define Z + HF
control region



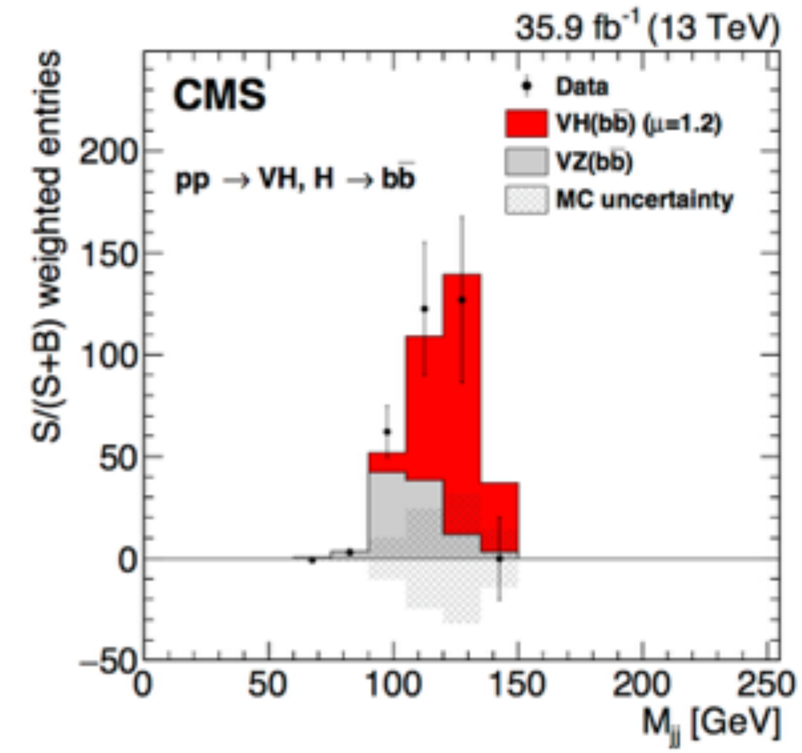
similar for ATLAS

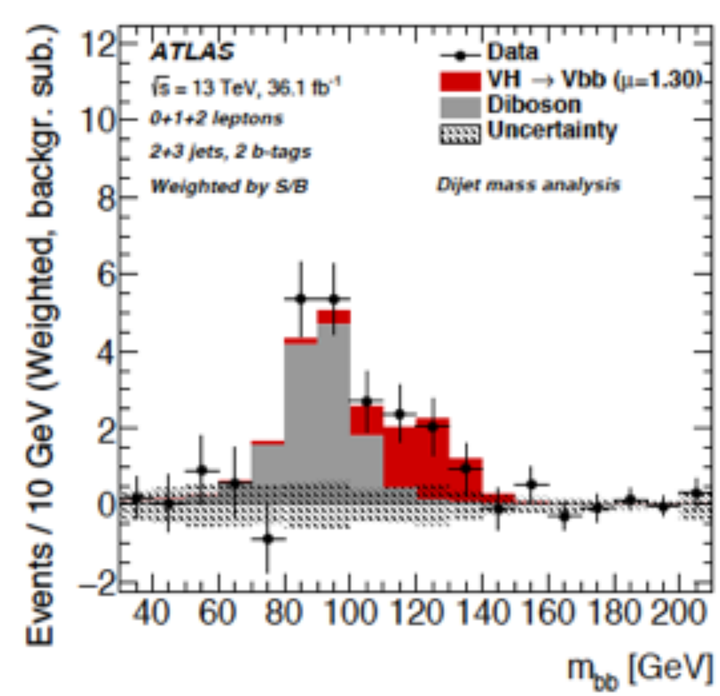
VH Results

ATLAS: arXiv:1708.03299

CMS: arXiv:1709.07497

- **main uncertainties @ CMS**
  - background modelling (9.4%) tt and V+jets
  - b-jet calibration uncertainty (7.9%)
  - MC statistics (8.1%)
  - signal cross section (5.3%)
  - modelling of pt(W) in tt and W+jets (4.1%)
- **main uncertainties @ ATLAS**
  - signal modelling (17%) dominated by extrapolation uncertainty from high pT(V) to inclusive phase space (Pythia 8 vs Herwig 7)
  - background modelling (7% each) from V + jets, tt and single top
  - MC statistics (13%)
  - b-jet calibration uncertainty (9%)



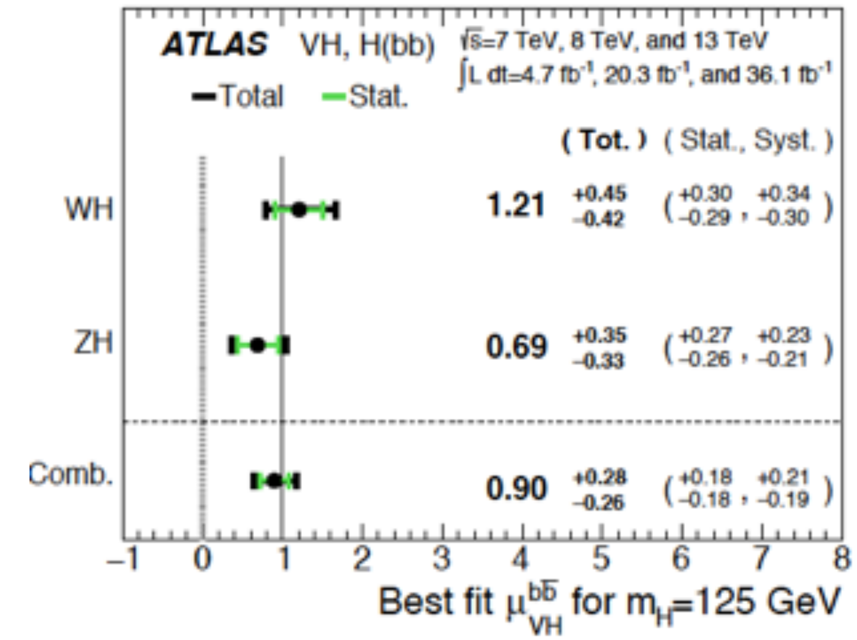


VH Results

ATLAS: arXiv:1708.03299

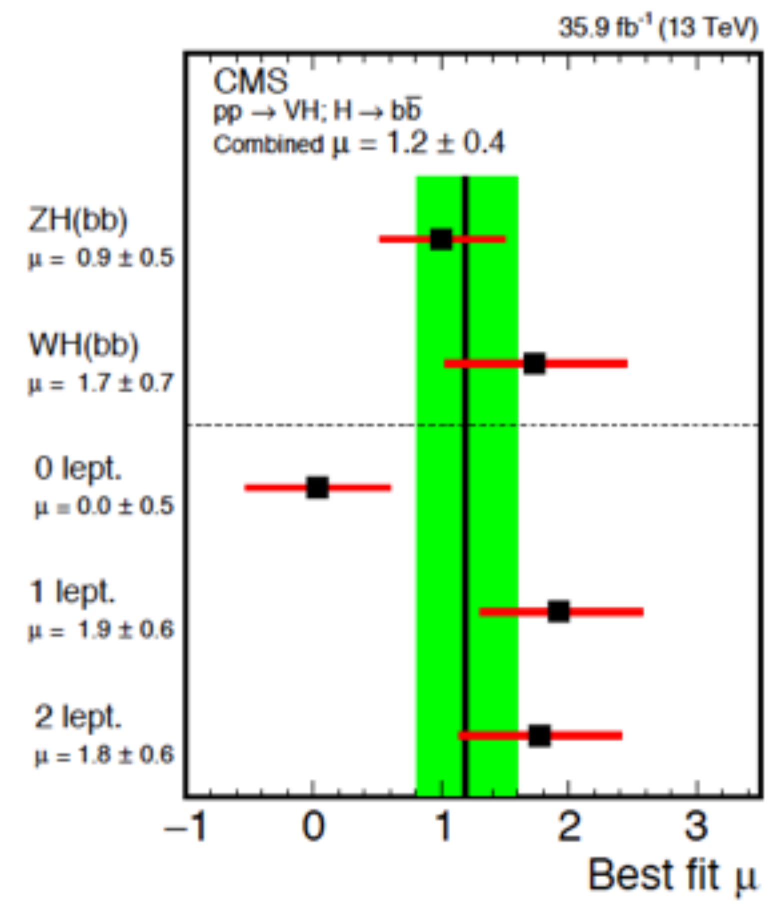
CMS: arXiv:1709.07497

- ATLAS has 3.5σ evidence for Higgs boson decays to b-jets in the VH channel
- signal strength $\mu = 0.90 \pm 0.18(\mathrm{stat})\ ^{+0.21}_{-0.19}(\mathrm{syst})$
- CMS has 3.8σ evidence for Higgs boson decays to b-jets in the VH channel
- signal strength is $1.06^{+0.31}_{-0.29}$
- compatible with SM @ 30% uncertainty



CMS
pp → VH; H → bb̄ 35.9 fb-1 (13 TeV)

Data used	Significance expected	Significance observed	Signal strength observed
Run 1	2.5	2.1	$0.89^{+0.44}_{-0.42}$
Run 2	2.8	3.3	$1.19^{+0.40}_{-0.38}$
Combined	3.8	3.8	$1.06^{+0.31}_{-0.29}$



Conclusions

- ATLAS and CMS pursue studies on Higgs boson production and decay properties
    - ttH, VBF and VH production modes require more data to improve the uncertainties
    - **dedicated control regions** are usually used to constrain the SM backgrounds but also **dedicated SM measurements** give guidance on the cross sections and their uncertainties
- to reduce uncertainties on the Higgs boson measurements it is **crucial to understand the SM backgrounds**
- ATLAS and CMS results compare very well, some differences in uncertainties

BACKUP

ATLAS: EW and QCD Z + jets @ 13 TeV

arXiv:1709.10264

- systematic uncertainty contributing to the measurement of the EW-Zjj cross section

EW-signal modelling

QCD-Zjj background modelling

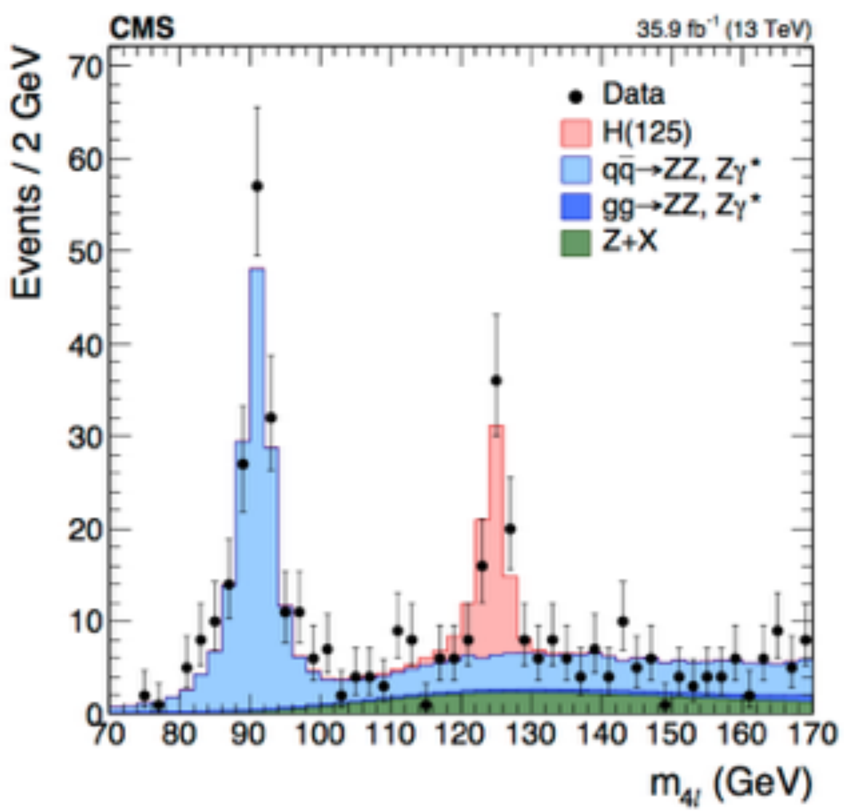
non-Zjj backgrounds

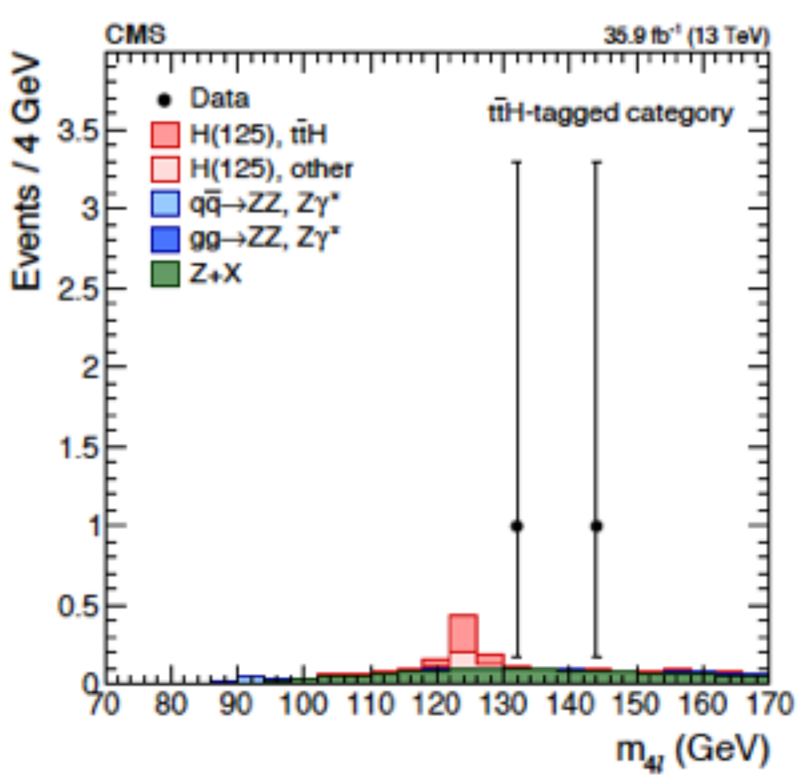
experimental sources

Source	Relative systematic uncertainty [%] $\sigma_{\mathrm{EW}}^{m_{jj}>250\ \mathrm{GeV}}$	$\sigma_{\mathrm{EW}}^{m_{jj}>1\ \mathrm{TeV}}$
EW-*Zjj* signal modelling (QCD scales, PDF and UEPS)	± 7.4	± 1.7
EW-*Zjj* template statistical uncertainty	± 0.5	± 0.04
EW-*Zjj* contamination in QCD-enriched region	−0.1	−0.2
QCD-*Zjj* modelling (m_{jj} shape constraint / third-jet veto)	± 11	± 11
Stat. uncertainty in QCD control region constraint	± 6.2	± 6.4
QCD-*Zjj* signal modelling (QCD scales, PDF and UEPS)	± 4.5	± 6.5
QCD-*Zjj* template statistical uncertainty	± 2.5	± 3.5
QCD–EW interference	± 1.3	± 1.5
$\bar{t}t$ and single-top background modelling	± 1.0	± 1.2
Diboson background modelling	± 0.1	± 0.1
Jet energy resolution	± 2.3	± 1.1
Jet energy scale	+5.3/−4.1	+3.5/−4.2
Lepton identification, momentum scale, trigger, pile-up	+1.3/−2.5	+3.2/−1.5
Luminosity	± 2.1	± 2.1
Total	± 17	± 16

CMS: H->ZZ->4l Channel

CMS-HIG-16-041





Number of expected and observed events

	Event category							
	Untagged	VBF-1j	VBF-2j	VH-hadr.	VH-lept.	VH-E_T^{miss}	$t\bar{t}$H	Inclusive
$q\bar{q}\to ZZ$	19.18	2.00	0.25	0.30	0.27	0.01	0.01	22.01
$gg\to ZZ$	1.67	0.31	0.05	0.02	0.04	0.01	<0.0	2.09
Z+X	10.79	0.88	0.78	0.31	0.17	0.30	0.27	13.52
Sum of backgrounds	31.64	3.18	1.08	0.63	0.49	0.32	0.28	37.62
uncertainties	$^{+4.30}_{-3.42}$	$^{+0.37}_{-0.32}$	$^{+0.29}_{-0.21}$	$^{+0.13}_{-0.09}$	$^{+0.07}_{-0.07}$	$^{+0.14}_{-0.11}$	$^{+0.09}_{-0.07}$	$^{+5.19}_{-4.18}$
$gg\to H$	38.78	8.31	2.04	1.41	0.08	0.02	0.10	50.74
VBF	1.08	1.14	2.09	0.09	0.02	<0.01	0.02	4.44
WH	0.43	0.14	0.05	0.30	0.21	0.03	0.02	1.18
ZH	0.41	0.11	0.04	0.24	0.04	0.07	0.02	0.93
$t\bar{t}$H	0.08	<0.01	0.02	0.03	0.02	<0.01	0.35	0.50
Signal	40.77	9.69	4.24	2.08	0.38	0.11	0.51	57.79
uncertainties	$^{+3.69}_{-3.62}$	$^{+1.13}_{-1.17}$	$^{+0.55}_{-0.55}$	$^{+0.23}_{-0.23}$	$^{+0.03}_{-0.03}$	$^{+0.01}_{-0.02}$	$^{+0.06}_{-0.06}$	$^{+4.89}_{-4.80}$
Total expected	72.41	12.88	5.32	2.71	0.86	0.43	0.79	95.41
uncertainties	$^{+7.35}_{-6.27}$	$^{+1.25}_{-1.21}$	$^{+0.78}_{-0.65}$	$^{+0.34}_{-0.28}$	$^{+0.10}_{-0.09}$	$^{+0.15}_{-0.12}$	$^{+0.14}_{-0.12}$	$^{+9.86}_{-8.32}$
Observed	73	13	4	2	1	1	0	94

ATLAS: H->ZZ->4l Channel

ATLAS-CONF-2017-043

impact of dominant systematic uncertainties on the production cross section

Production bin	Experimental uncertainties [%] Lumi	$e, \mu,$ pileup	Jets, flavour tagging	Higgs mass	Reducible backgr.	Theory uncertainties [%] ZZ backgr.	PDF	Signal theory QCD scale	Shower
Inclusive cross section									
	4	3	1	1	1	2	< 1	1	1
Stage-0 production bin cross sections									
ggF	4	3	1	1	1	2	< 1	2	1
VBF	3	3	10	1	< 1	2	2	11	5
VH	3	3	11	2	2	6	2	12	4
ttH	4	3	19	< 1	2	2	3	8	2

event yields in the Higgs mass window

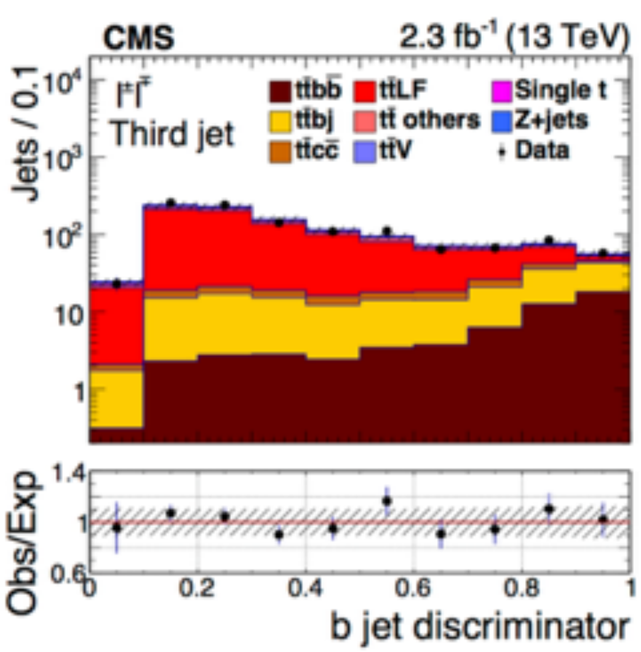
Reconstructed category	Signal	ZZ^*	Other backgrounds	Total expected	Observed
$0j$	26.8 ± 2.5	13.7 ± 1.0	2.23 ± 0.31	42.7 ± 2.7	49
$1j$ $p_T^{4\ell}$-Low	8.8 ± 1.1	3.1 ± 0.4	0.53 ± 0.07	12.5 ± 1.2	12
$1j$ $p_T^{4\ell}$-Med	5.4 ± 0.7	0.88 ± 0.12	0.38 ± 0.05	6.7 ± 0.7	9
$1j$ $p_T^{4\ell}$-High	1.47 ± 0.24	0.139 ± 0.022	0.045 ± 0.007	1.65 ± 0.24	3
VBF-enriched p_T^j-Low	6.3 ± 0.8	1.08 ± 0.32	0.40 ± 0.04	7.7 ± 0.9	16
VBF-enriched p_T^j-High	0.57 ± 0.10	0.093 ± 0.032	0.054 ± 0.006	0.72 ± 0.10	3
VH-Had-enriched $p_T^{4\ell}$-Low	2.9 ± 0.5	0.63 ± 0.16	0.169 ± 0.021	3.7 ± 0.5	3
VH-Had-enriched $p_T^{4\ell}$-High	0.64 ± 0.09	0.029 ± 0.008	0.0182 ± 0.0022	0.69 ± 0.09	0
VH-Lep enriched	0.318 ± 0.019	0.049 ± 0.008	0.0137 ± 0.0019	0.380 ± 0.020	0
ttH-enriched	0.39 ± 0.04	0.014 ± 0.006	0.07 ± 0.04	0.47 ± 0.05	0
Total	54 ± 4	19.7 ± 1.5	3.9 ± 0.5	77 ± 4	95

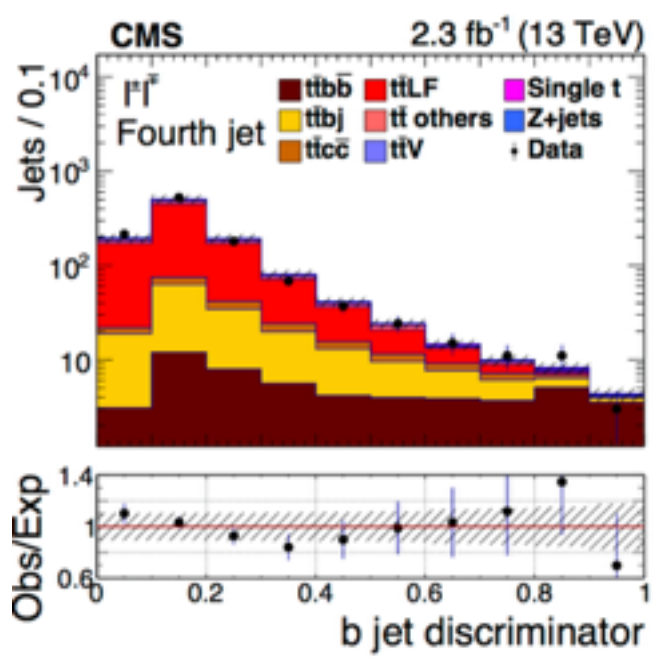
tt + Heavy Flavour Measurement @ CMS

CMS-TOP-16-010

- select di-lepton events with at least 4 jets
- first and second jet in decreasing order of btagging discriminator usually correspond to b-jet from top quark decay
- distributions of the btagging discriminator of the third and the forth jets are used to separate tt+HF from other processes

Source	$\sigma_{t\bar{t}b\bar{b}}$	$\sigma_{t\bar{t}jj}$	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$
Pileup	0.4	<0.1	0.4
JES & JER	7.8	7.4	2.6
b tag (b quark flavour)	19	4.7	19
b tag (c quark flavour)	14	1.3	14
b tag (light flavour)	14	9.8	9.7
Ratio of ttbb and ttbj	2.6	0.5	2.6
Background modelling	3.8	3.5	1.6
$t\bar{t}c\bar{c}$ fraction in the fit	5.2	1.9	4.8
Lepton trigger/identification	3.0	3.0	0
MC generator	9.4	6.2	3.0
μ_F and μ_R scale	2.0	2.0	1.0
scale in PS	13	9.9	10
PDFs	0.5	0.5	<0.1
Efficiency ($t\bar{t}c\bar{c}$ fraction)	0	1.3	1.3
Jet multiplicity modelling	5.0	5.0	5.0
Top quark p_T modelling	0.8	0.3	0.5
Simulation (statistical)	1.5	1.5	1.5
Integrated Luminosity	2.3	2.3	0
Total uncertainty	34	19	28

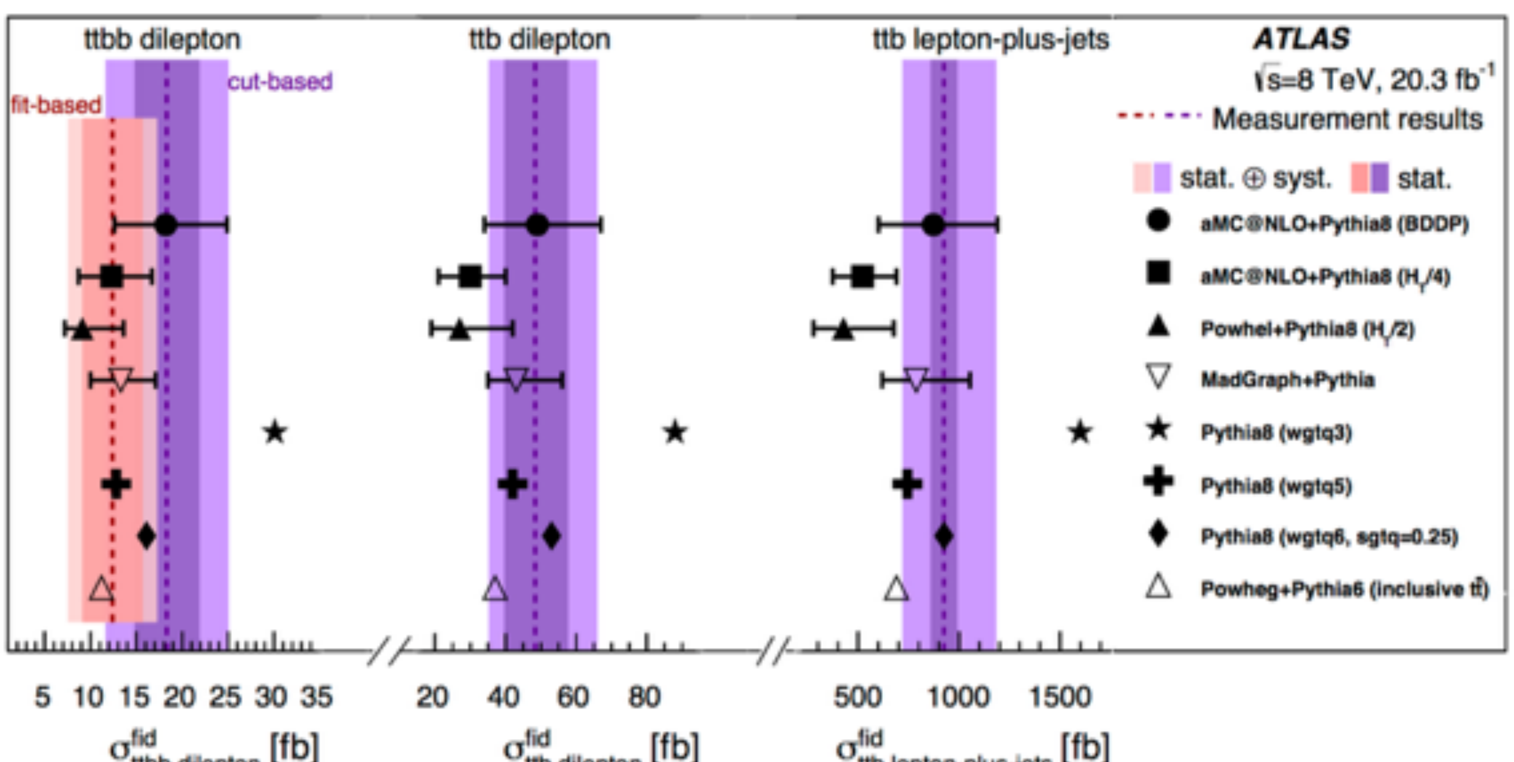


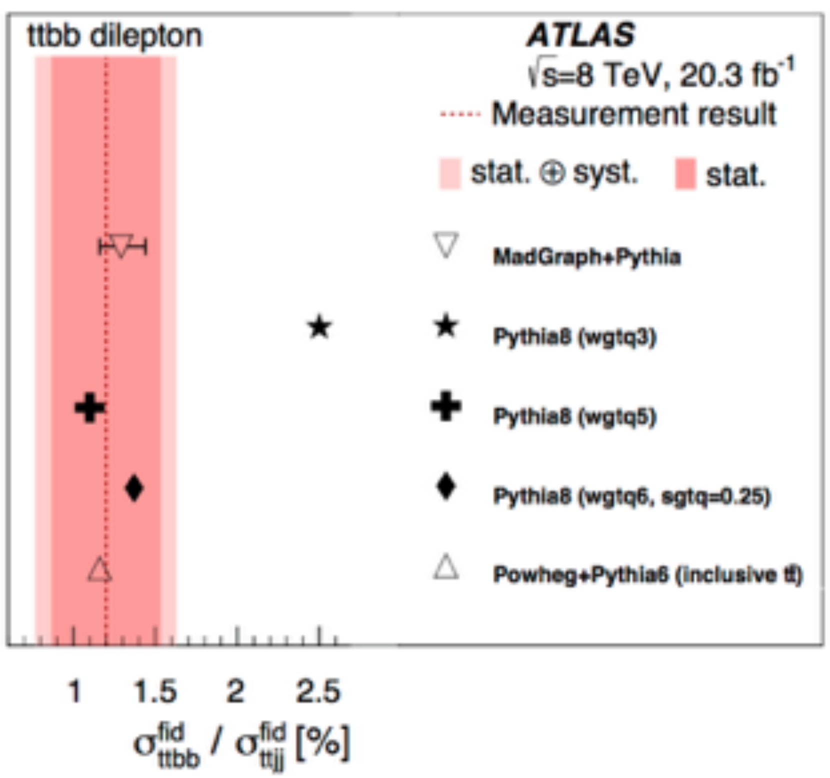


tt + Heavy Flavour Measurement @ ATLAS

- lepton + jets channel for tt + 1 b-jet and di-lepton channel for tt + 1 or 2 b-jets fiducial cross section measurement
- two methods:
  - cut-based with a tight signal selection and a requirement of 4 b-tagged jets
  - fit-based with a loose signal selection and a fit to the multivariate discriminant used to identify b-tagged jets

CERN-PH-EP-2015-200





tt + Heavy Flavour Measurement @ ATLAS
Uncertainties

CERN-PH-EP-2015-200

Source	$\sigma^{\rm fid}_{ttb}$ Lepton-plus-jets uncertainty (%)	$\sigma^{\rm fid}_{ttb}$ ttb $e\mu$ uncertainty (%)	$\sigma^{\rm fid}_{ttbb}$ Cut-based uncertainty (%)	$\sigma^{\rm fid}_{ttbb}$ Fit-based uncertainty (%)	R_{ttbb} Fit-based uncertainty (%)
Total detector	+17.5 −14.4	+11.6 −8.0	±14.5	+11.9 −13.1	+10.9 −12.5
Jet (combined)	+3.9 −2.7	+10.1 −6.1	±5.5	+6.0 −8.5	+8.7 −10.7
Lepton	±0.7	+1.0 −0.5	±2.0	+2.4 −2.7	+0.8 −1.6
b−tagging effect on b−jets	+4.4 −4.0	+3.6 −3.1	±12.9	+9.4 −9.0	+6.0 −5.8
b−tagging effect on c−jets	+16.2 −13.4	+4.0 −3.6	±1.7	± 1.4	+1.2 −1.3
b−tagging effect on light jets	+3.1 −2.0	+1.9 −2.0	±4.3	+3.3 −2.9	+2.2 −1.9
Total $t\bar{t}$ modelling	+13.1 −13.7	+23.8 −16.1	±23.8	±21.7	±16.1
Generator	+1.1 −1.4	+23.3 −15.1	±16.9	±17.4	±12.4
Scale choice	±4.3	+1.1 −2.7	±14.2	±9.5	±6.0
Shower/hadronisation	+11.4 −12.1	+3.0 −3.4	±8.2	±8.7	±7.1
PDF	+4.7 −4.5	±3.3	±3.3	±0.8	±4.1
Removing/doubling $t\bar{t}V$ and $t\bar{t}H$	±0.4	+1.1 −0.9	±1.5	+3.1 −2.7	+3.0 − 2.6
Other backgrounds	±0.8	+0.9 −0.8	±1.6	+3.5 −3.3	±2.5
MC sample size	< 1	< 1	±9.6	±7.4	±7.4
Luminosity	±2.8	±2.8	±3.2	±2.9	±0.1
Total systematic uncertainty	+25.5 −19.2	+30.5 −19.9	±29.5	+26.4 −26.9	+21.1 −21.9
Statistical uncertainty	±7.1	+19.2 −17.9	±18.4	±24.6	±25.2
Total uncertainty	+26.5 −20.5	+36.0 −26.8	±35.2	+36.1 −36.4	+32.9 −33.4

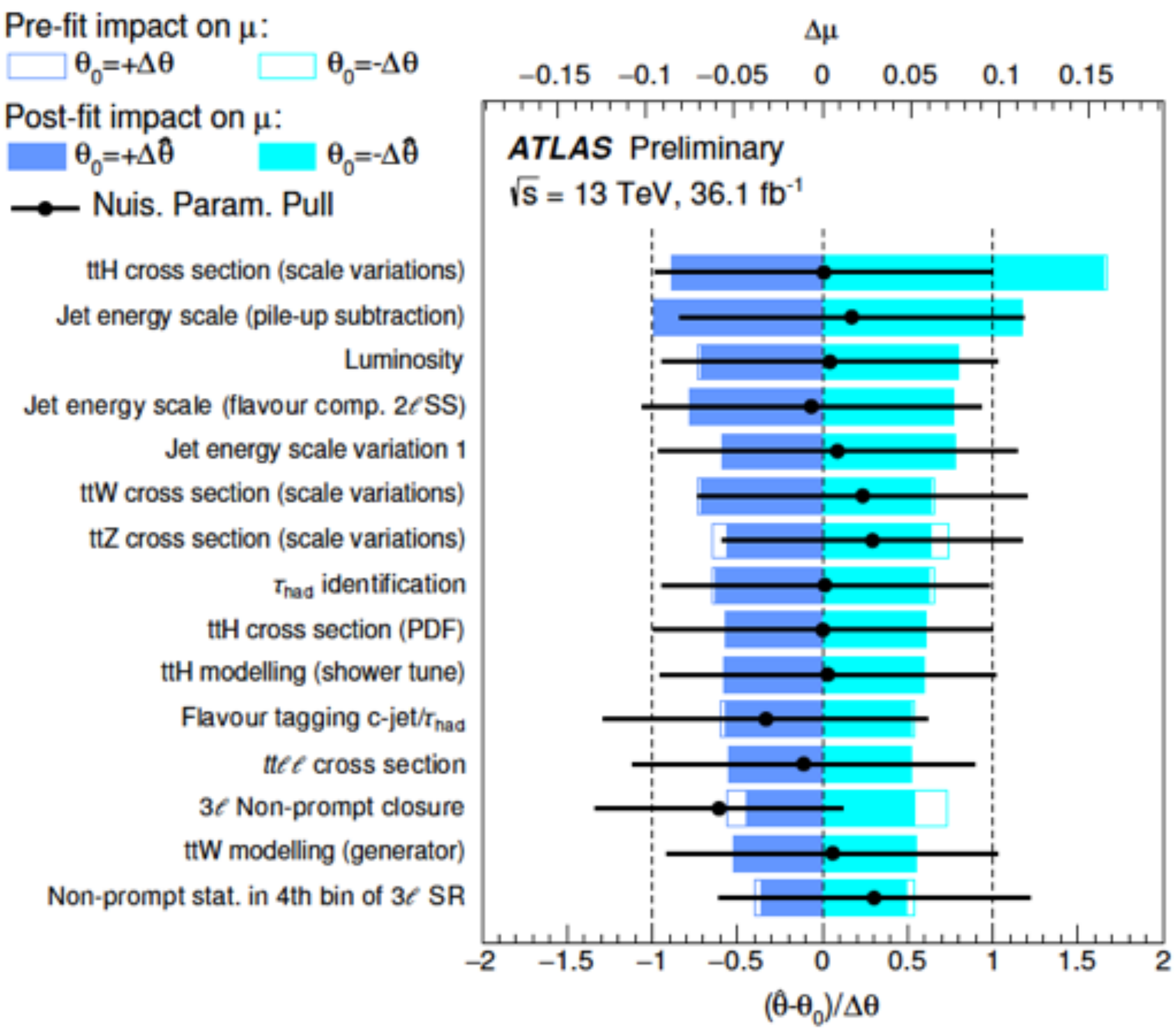
CMS: ttV Measurements Uncertainties

CMS-PAS-TOP-17-005

Source	Uncertainty range	Impact on ttW cross-section	Impact on ttZ cross-section
Luminosity	2.5%	4%	3%
Jet Energy Scale/Resolution	2-5%	3%	3%
Trigger	2-4%	4-5%	5%
B tagging	1-5%	2-5%	4-5%
PU modeling	1%	1%	1%
Lepton ID, efficiency	2-7%	3%	6-7%
μ_R/μ_F scale choice	1%	$<$1%	1%
PDF choice	1%	$<$1%	1%
Nonprompt background	30%	4%	$<$ 2%
WZ cross section	10-20%	$<$1%	2%
ZZ cross section	20%	-	1%
Charge misidentification	20%	3%	-
Rare SM background	50%	2%	2%
ttX background	10-15%	4%	3%
Stat. unc. for nonprompt	5-50%	4%	2%
Stat. unc. rare SM processes	20-100%	1%	$<$ 1%
Total systematic	-	14%	12%

ATLAS: ttH Multilepton Uncertainties

ATLAS-CONF-2017-077



Uncertainty Source	$\Delta\mu$	
$t\bar{t}H$ modelling (cross section)	+0.20	−0.09
Jet energy scale and resolution	+0.18	−0.15
Non-prompt light-lepton estimates	+0.15	−0.13
Jet flavour tagging and τ_{had} identification	+0.11	−0.09
$t\bar{t}W$ modelling	+0.10	−0.09
$t\bar{t}Z$ modelling	+0.08	−0.07
Other background modelling	+0.08	−0.07
Luminosity	+0.08	−0.06
$t\bar{t}H$ modelling (acceptance)	+0.08	−0.04
Fake τ_{had} estimates	+0.07	−0.07
Other experimental uncertainties	+0.05	−0.04
Simulation statistics	+0.04	−0.04
Charge misassignment	+0.01	−0.01
Total systematic uncertainty	+0.39	−0.30

Some Recent CMS Publications
SM/Top Physics

92	SMP-16-017	Measurements of the $\mathrm{pp} \to \mathrm{ZZ}$ production cross section and the $\mathrm{Z} \to 4\ell$ branching fraction, and constraints on anomalous triple gauge couplings at $\sqrt{s} = 13$ TeV	Submitted to EPJC	25 September 2017
91	SMP-17-004	Observation of electroweak production of same-sign W boson pairs in the two jet and two same-sign lepton final state in proton-proton collisions at $\sqrt{s} = 13$ TeV	Submitted to PRL	18 September 2017
90	SMP-17-006	Measurement of vector boson scattering and constraints on anomalous quartic couplings from events with four leptons and two jets in proton-proton collisions at $\sqrt{s} = 13$ TeV	PLB 774 (2017) 682	9 August 2017
89	SMP-16-005	Measurement of the differential cross sections for the associated production of a W boson and jets in proton-proton collisions at $\sqrt{s} = 13$ TeV	PRD 96 (2017) 072005	19 July 2017
76	SMP-16-001	Measurement of the ZZ production cross section and $\mathrm{Z} \to \ell^+\ell^-\ell'^+\ell'^-$ branching fraction in pp collisions at $\sqrt{s} = 13$ TeV	PLB 763 (2016) 280	29 July 2016
74	SMP-16-002	Measurement of the WZ production cross section in pp collisions at $\sqrt{s} = 13$ TeV	PLB 766 (2017) 268	23 July 2016
75	TOP-16-010	Measurements of $\mathrm{t\bar{t}}$ cross sections in association with b jets and inclusive jets and their ratio using dilepton final states in pp collisions at $\sqrt{s} = 13$ TeV	Accepted by PLB	29 May 2017
80	TOP-17-005	Measurement of the cross section for top quark pair production in association with a W or Z boson in proton-proton collisions at $\sqrt{s} = 13$ TeV	Submitted to JHEP	7 November 2017

Some Recent ATLAS Publications SM/Top Physics

Measurement of the ttZ and ttW cross-sections using 3.2 fb-1 at 13 TeV	Eur. Phys. J. C77 (2017) 40	06-SEP-16	13	3.2 fb^{-1}	Documents | 1609.01599 | Inspire Internal
Theoretical uncertainties on ttbar+ccbar production using MadGraph5_aMC@@NLO	ATL-PHYS-PUB-2016-011	17-MAY-16	13		Documents Internal
MC generator modelling of ttX processes as used in Run2	ATL-PHYS-PUB-2016-005	12-JAN-16	13		Documents Internal
Electroweak production of dijets in association with a Z boson at 13 TeV	Physics Letters B 775 (2017) 206	29-SEP-17	13	3.2 fb^{-1}	Documents | 1709.10264 | Inspire Internal
Z+jet cross sections with early 13 TeV data	Eur. Phys. J. C77 (2017) 361	19-FEB-17	13	3.2 fb^{-1}	Documents | 1702.05725 | Inspire HepData | Internal
WW cross-section at 13 TeV	Phys. Lett. B 773 (2017) 354	15-FEB-17	13	3.2 fb^{-1}	Documents | 1702.04519 | Inspire Internal
ZZ cross-section at 13 TeV	Figures | Phys. Rev. Lett. 116, 101801 (2016)	16-DEC-15	13	3.2 fb^{-1}	Documents | 1512.05314 | Inspire HepData | Internal
WZ cross section at 13 TeV	Phys. Lett. B 762 (2016) 1	13-JUN-16	13	3.2 fb^{-1}	Documents | 1606.04017 | Inspire HepData | Internal
WZ boson pair-production at 13 TeV and limits on aTGCs	ATLAS-CONF-2016-043	28-JUL-16	13	13 fb^{-1}	Documents Internal
Studies on the DiBoson Modelling	ATL-PHYS-PUB-2016-002	10-JAN-16	13		Documents Internal