Toward the observation of 2nd and 3rd generation BEH couplings with 13 TeVdata

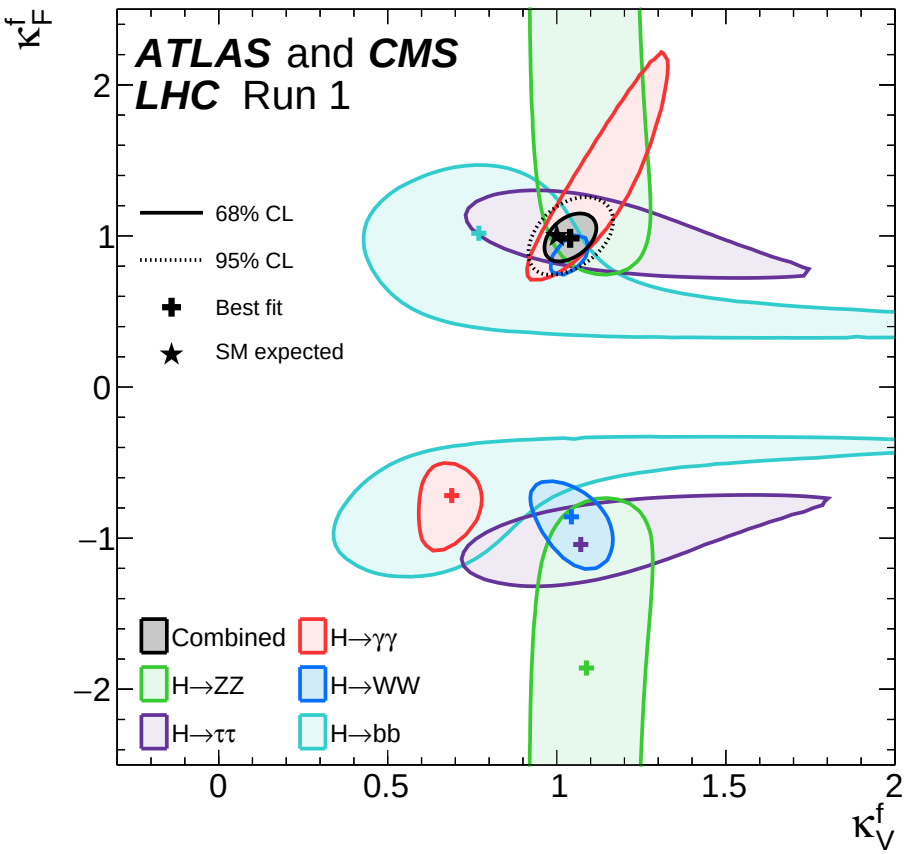
G. Gaycken on behalf of the ATLAS and CMS Collaboration

La Thuile, March 19, 2017

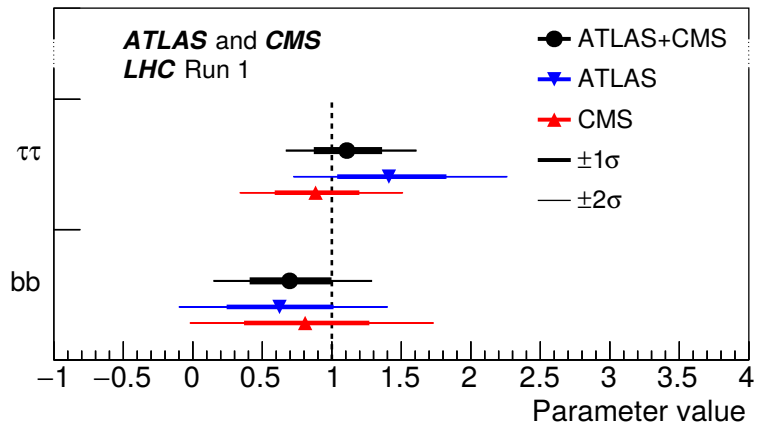
Introduction

Couplings to fermions and bosons strongly constrained by Run I measurements.

JHEP 08 (2016) 045

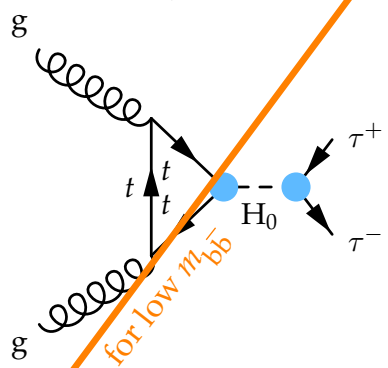


- In combination, search for $H \to \tau^+\tau^-$ exceeds 5σ.
- But, despite being the dominant decay mode, coupling to $b\bar{b}$ not yet observed.



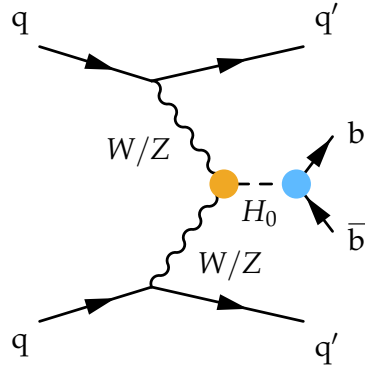
Search for H → $b\bar{b}$

Gluon fusion



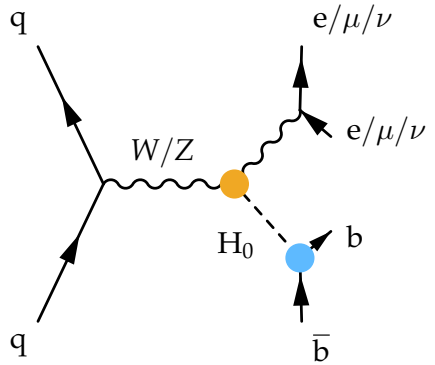
- large multijet background
- challange for the trigger

Vector Boson Fusion(VBF)



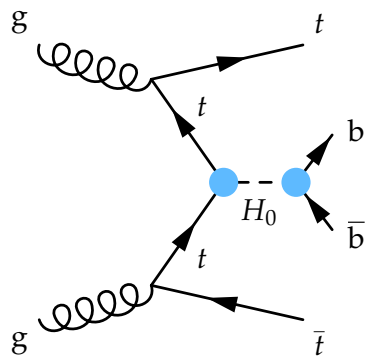
- challange for the trigger

Associate production with vector bosons(VH)



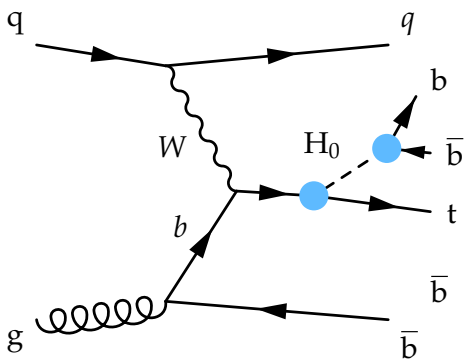
- leptons, $E_{\mathrm{T}}^{\mathrm{mis.}}$ to trigger and suppress backgrounds

Associate production with $t\bar{t}$



- see previous talk

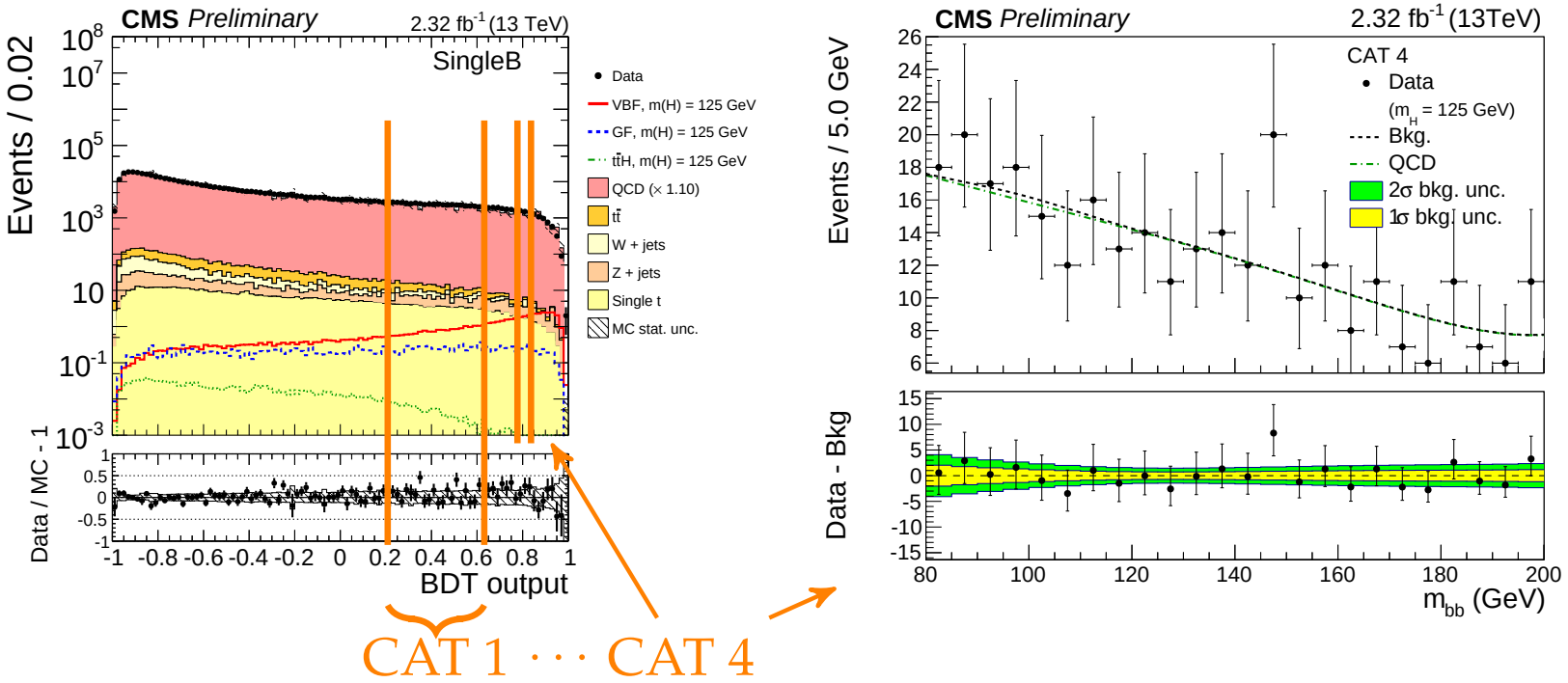
Associate production with signle top



- small cross-section

VBF, $H \to b\bar{b}$

Multivariate classifier to identify VBF like events for events with 1 and 2 b-tagged jets:



Signal extract in simultaneous fit to $m_{b\bar{b}}$ spectrum in all categories.

CMS-PAS-HIG-16-003

m_{bb} resolution

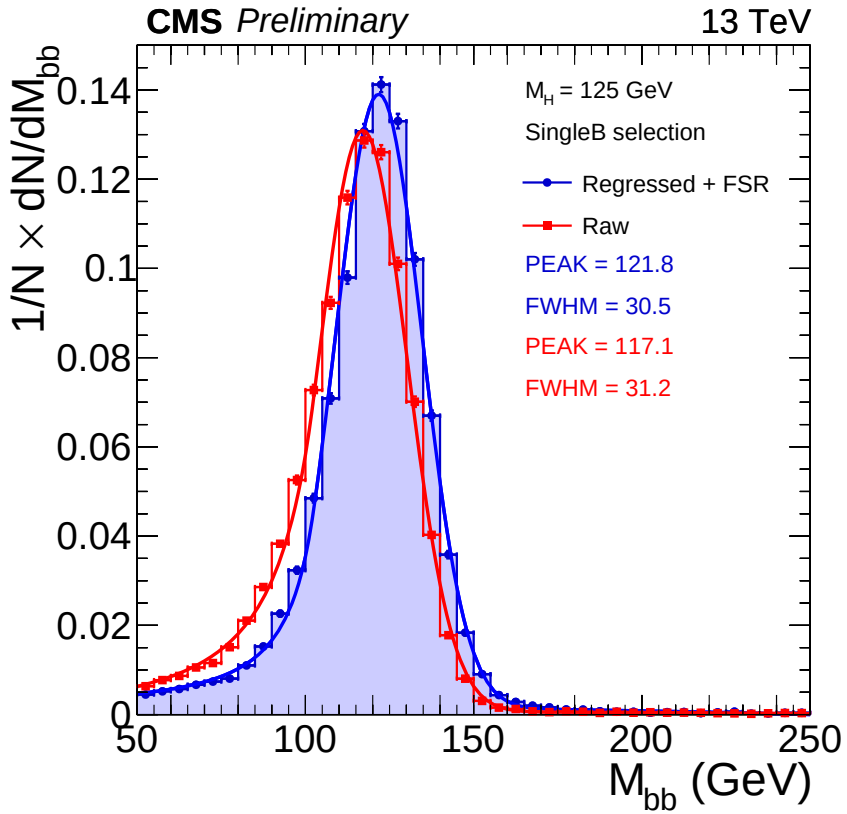
m_{bb} resolution significantly reduced by semileptonic b-decays and gluon radiation outside jet "cone"
$\rightarrow$ improve b-jet energy resolution with regression.

Regression inputs:

- jet kinematic,
- EM energy fraction,
- information about soft leptons in the jet,
- secondary vertex information,
- pileup.

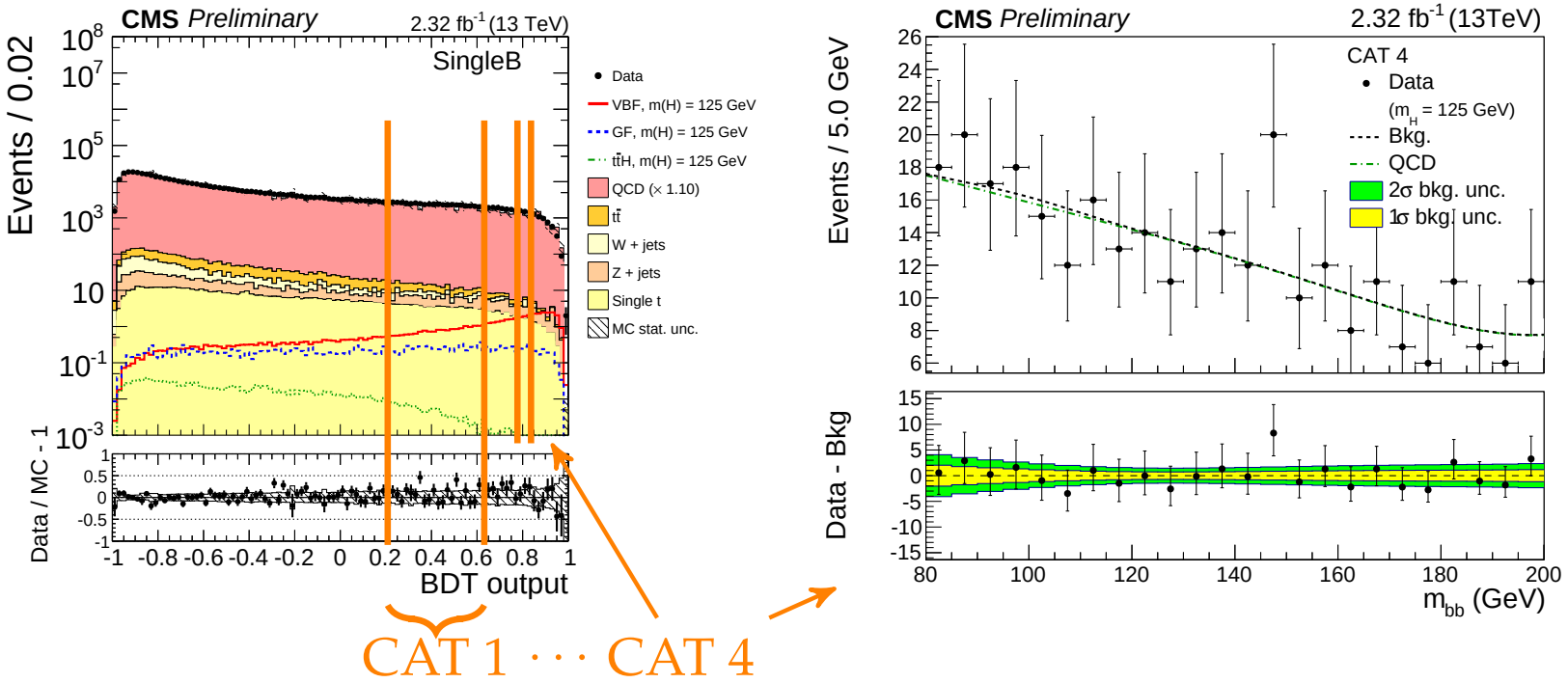
FSR correction:

Add jets with $\Delta R < 0.8$.



VBF, $H \to b\bar{b}$

Multivariate classifier to identify VBF like events for events with 1 and 2 b-tagged jets:



Signal extract in simultaneous fit to $m_{b\bar{b}}$ spectrum in all categories.

Result using $2.3\,\mathrm{fb}^{-1}$ @ $\sqrt{s} = 13\,\mathrm{TeV}$: $\mu = -3.7^{+2.4}_{-2.5}$

Combination with Run I ($18 - 19\,\mathrm{fb}^{-1}$ @ $8\,\mathrm{TeV}$): $\mu = 1.3^{+1.2}_{-1.1}$

CMS-PAS-HIG-16-003

VBF+γ, $H \to b\bar{b}$

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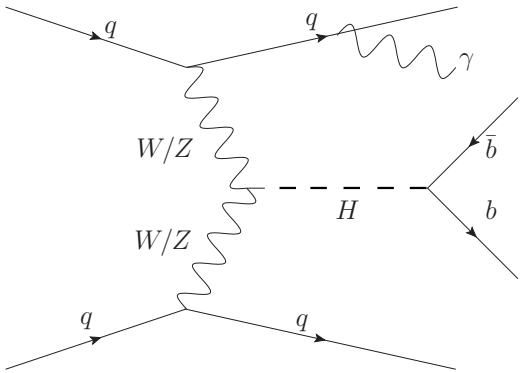
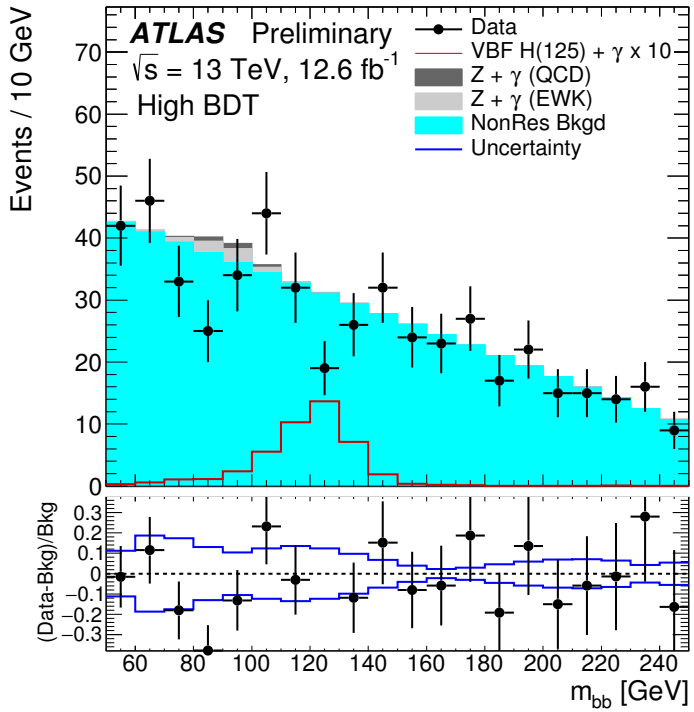
- Multijet background in (q/g)qb$\bar{b}$ significantly reduced by extra high p_T γ (destructive interference in bg. but not in WWH).



- Analysis strategy:
  - MVA for categorisation.
  - unbinned log $\mathcal{L}$-fit as function of $m_{b,\bar{b}}$ in various categories.

$m_{b,\bar{b}}$ in high BDT category



Signal strength:

$$\mu = -3.9^{+2.8}_{-2.7}$$

Limit: $\frac{\sigma}{\sigma_{SM}} < 4.0$ at the 95% CL

$VH, H \to b\bar{b}$

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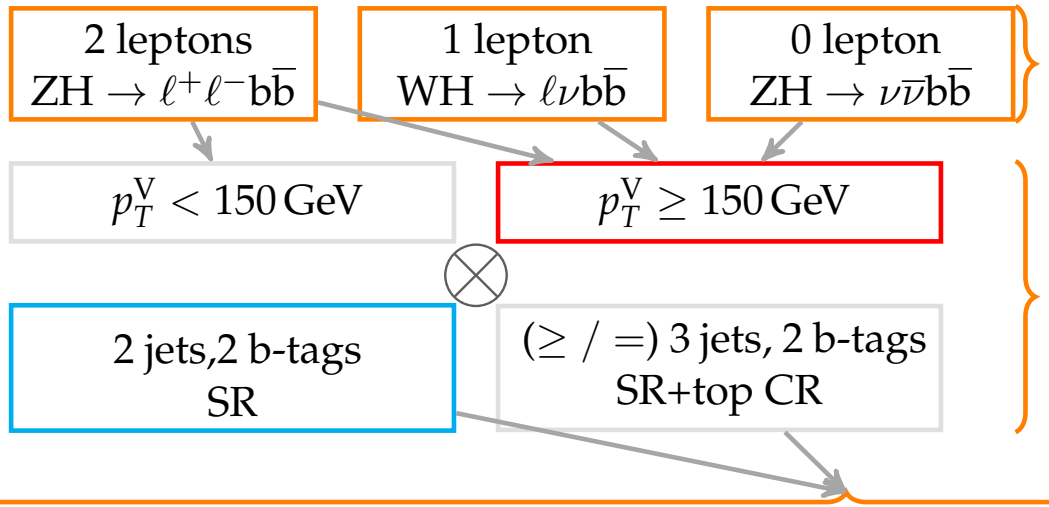
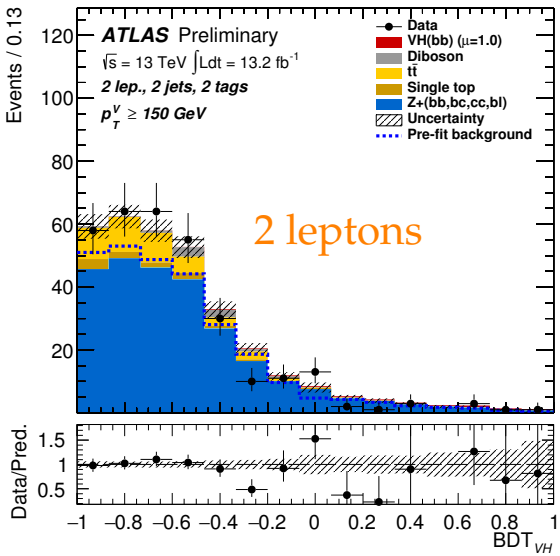
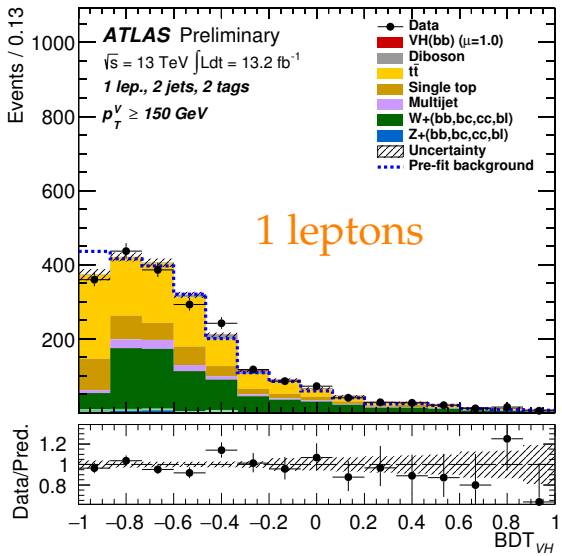
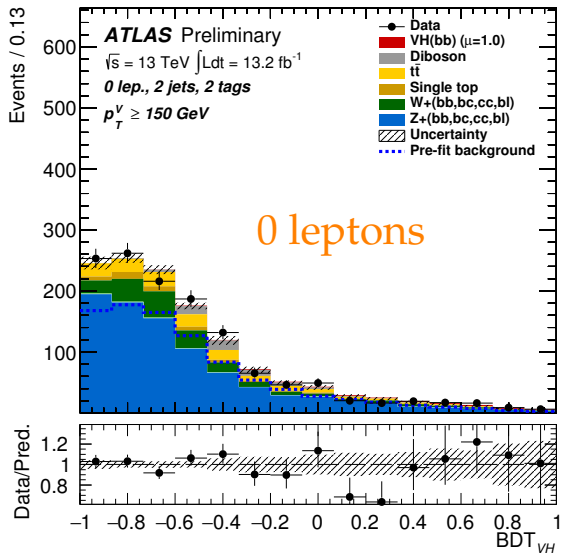


- Categories per number of selected charged leptons
- sub categories to increase significance.

One multivariate discriminant per category e.g. 2 jet, $p_T^V \geq 150\,\text{GeV}$, ...



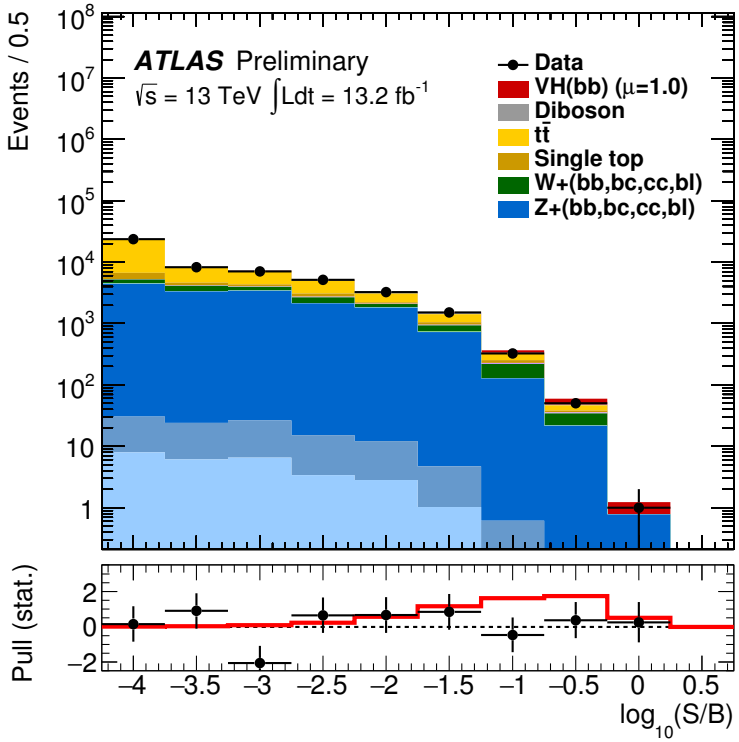


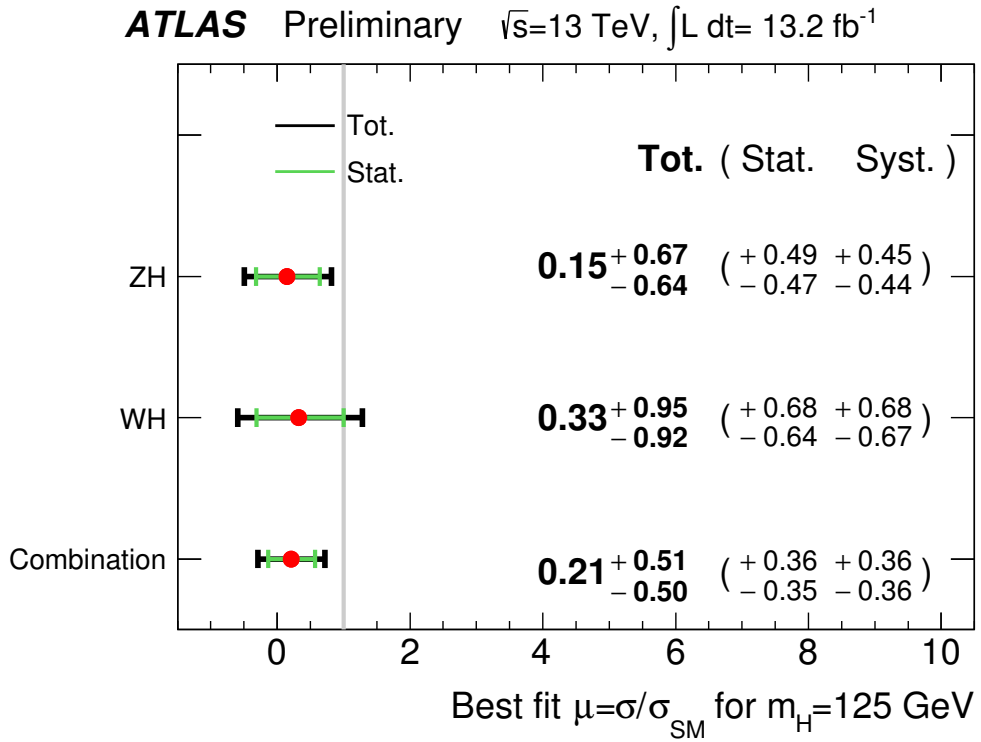


VH, H → bb̄

- Signal strength μ extracted in simultaneous likelihood fit of the binned mmultivariate discriminants in all categories.

Candidate events





Run I result @7+8 TeV(4.7+20.3 fb^{-1}):
$0.52 \pm 0.32(\text{stat.}) \pm 0.24(\text{syst.})$

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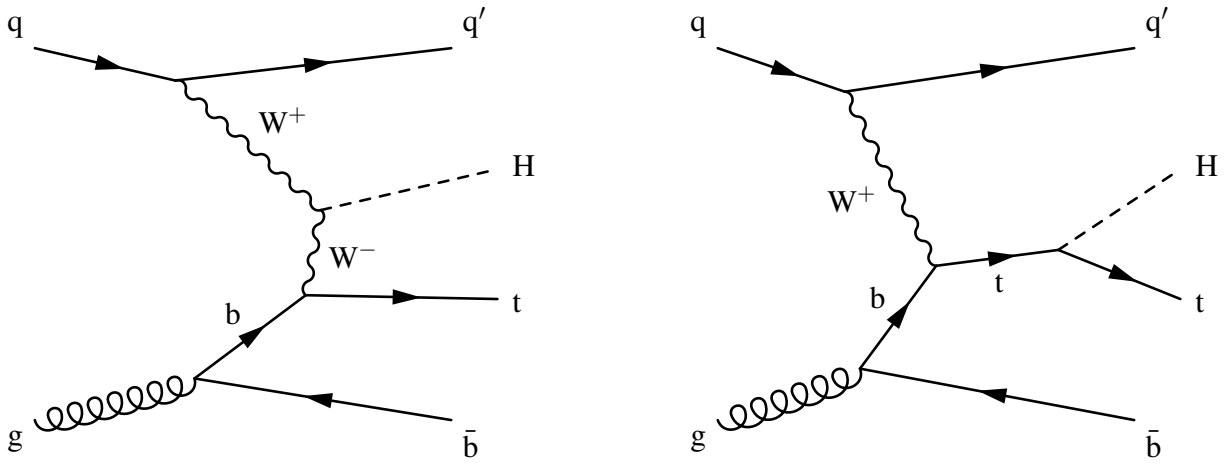
Higgs production in single top



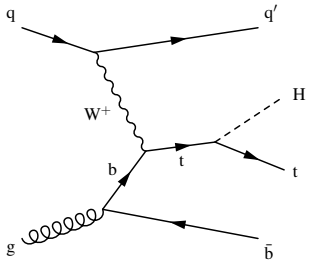
t-channel

- In SM diagrams interfere destructively.
- In BSM scenarios not necessarily e.g. inverted top coupling scenario
  $\rightarrow$ effective theory with possibly CP violating top Yukawa couplings, and modified couplings to vector bosons.

Eur. Phys. J. C 75 (2015), no. 6, 267

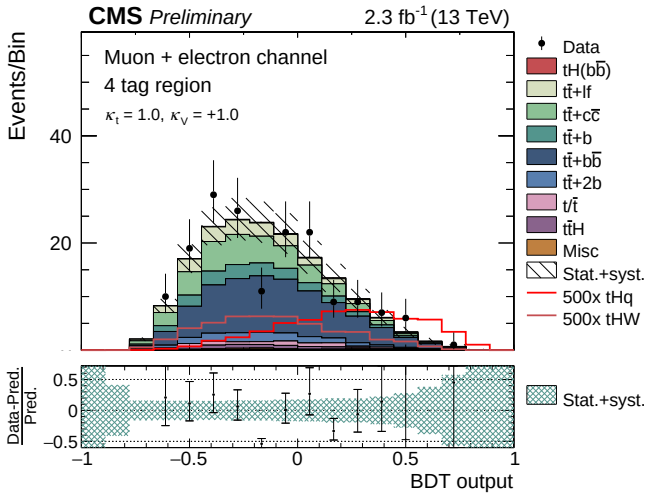
Modified top Yukawa coupling

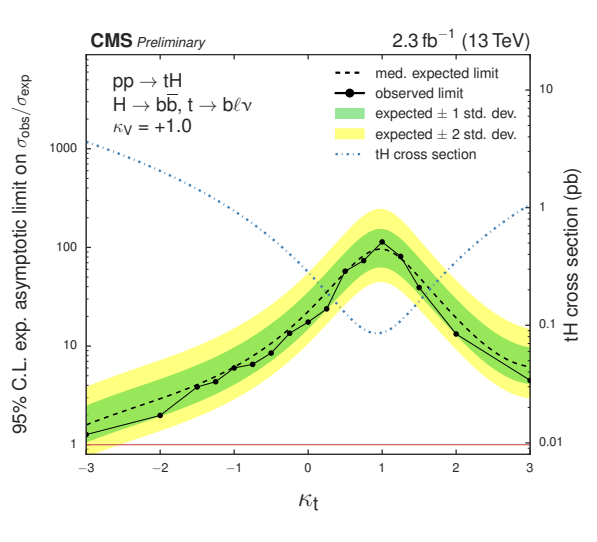
Search for $H \to b\bar{b}$ in association with a single top ($t \to b\,e\nu / b\,\mu\nu$)



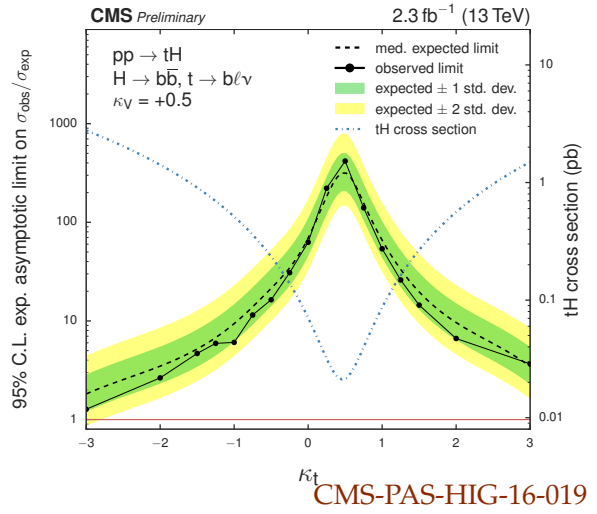
- final state e/μ + 3 or 4 b-tagged jets, one non b-tagged jet

1. MVA to find jet assignment for $t\bar{t}$ and tHq hypothesis
2. final discrimination MV classifier kinematics + kinematics interpreted in the two hypothesis.





SM coupling to W, Z

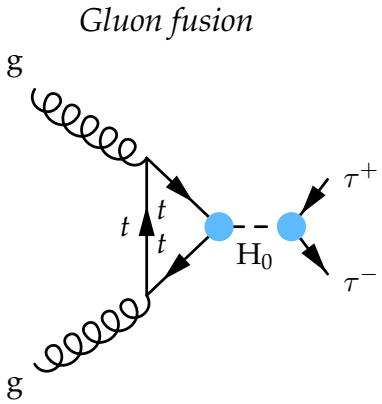


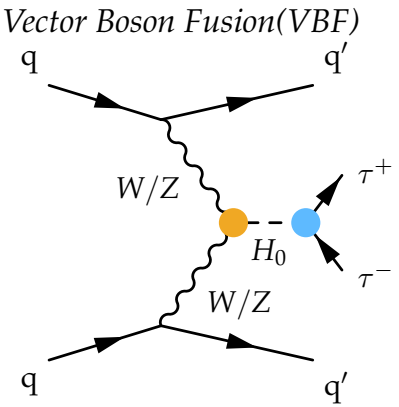
CMS-PAS-HIG-16-019

Reduced coupling to W, Z

Search for H $\rightarrow \tau^+\tau^-$

- All Higgs production modes accessible:

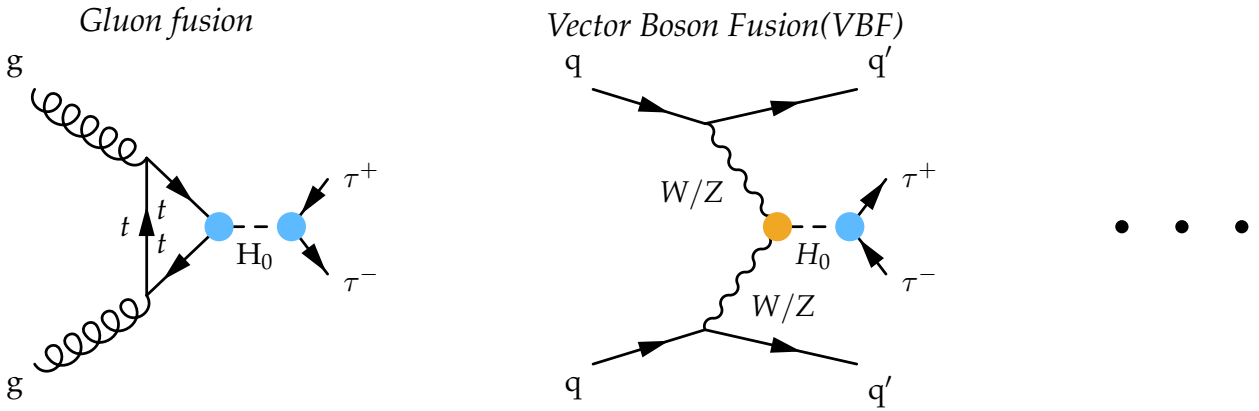




- Mass reconstruction challanging, due to neutrinos in the final state.

Search for $H \to \tau^+\tau^-$

- All Higgs production modes accessible:



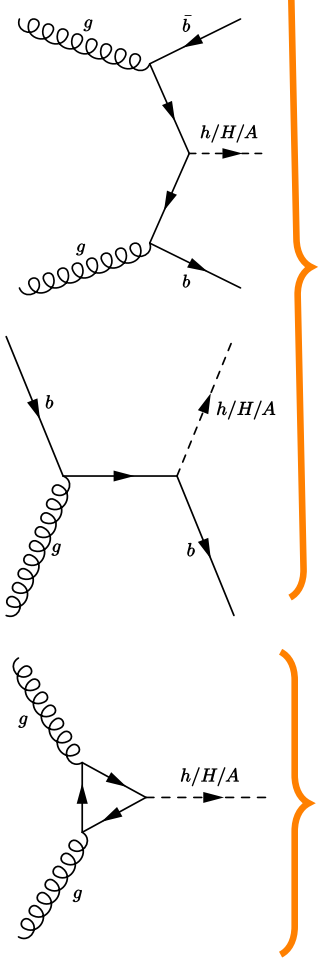
- Mass reconstruction challanging, due to neutrinos in the final state.

No 13 TeV updates to SM analyses for $H \to \tau^+\tau^-$ yet, but ...

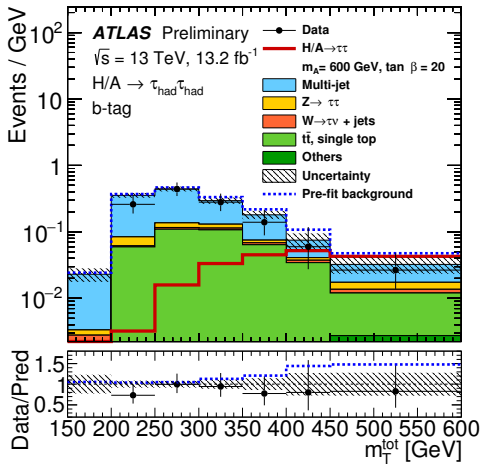
$\Phi \to \tau^+\tau^-$

ATLAS-CONF-2016-085
CMS → CMS-PAS-HIG-16-037

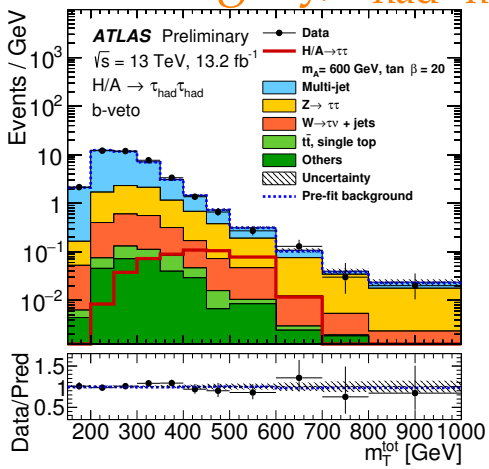
In some MSSM scenarios, coupling to down-type fermions enhanced
→ motivates search for scalar boson in association with bottom.



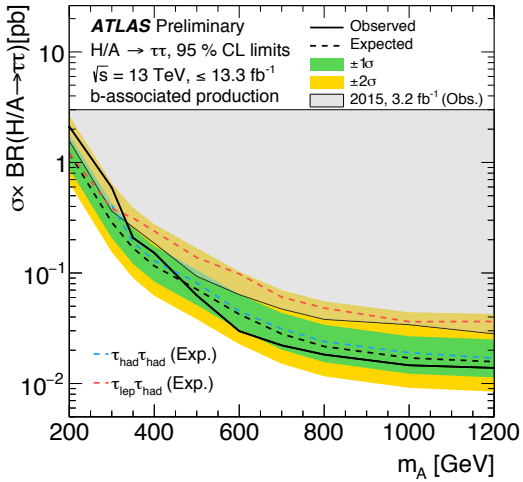
b-tag category, $\tau_{had}\tau_{had}$

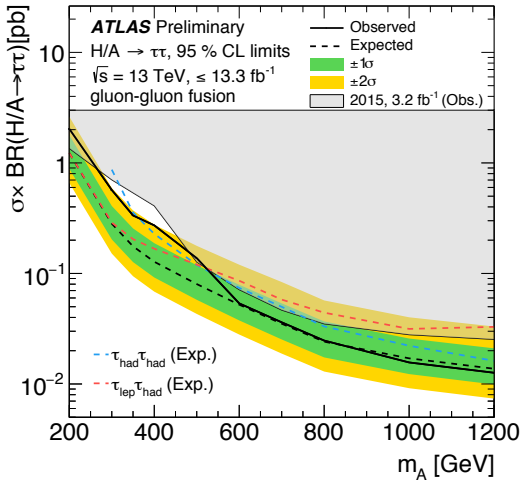


b-veto category, $\tau_{had}\tau_{had}$



Limit on $\sigma \times$ Br





$\Phi \rightarrow \tau^+\tau^-$

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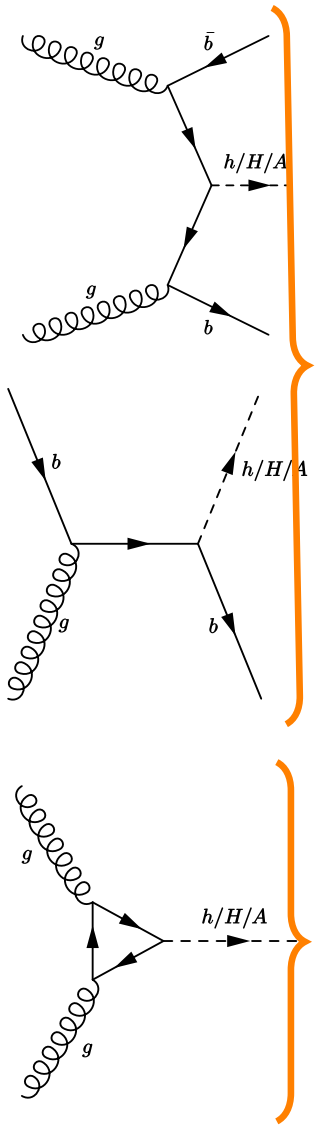
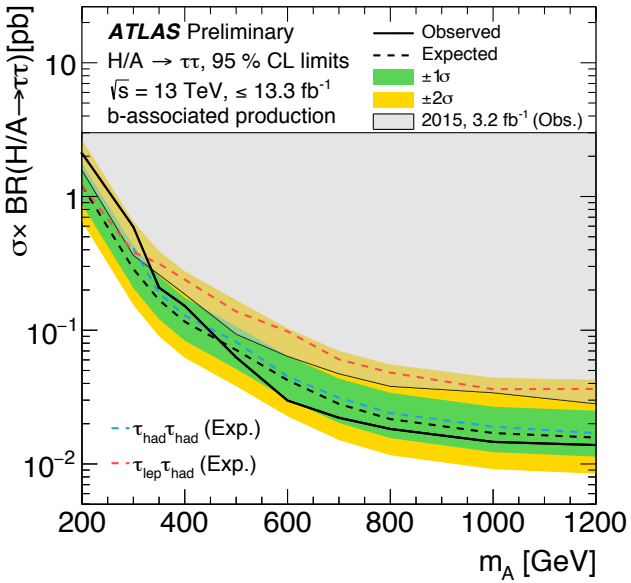
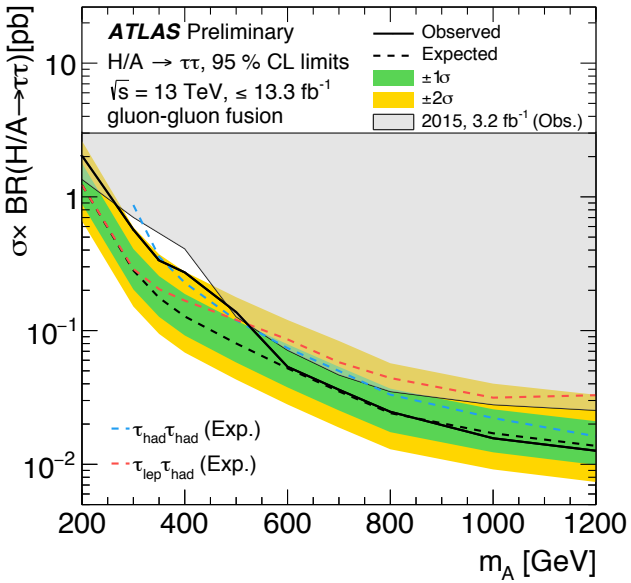
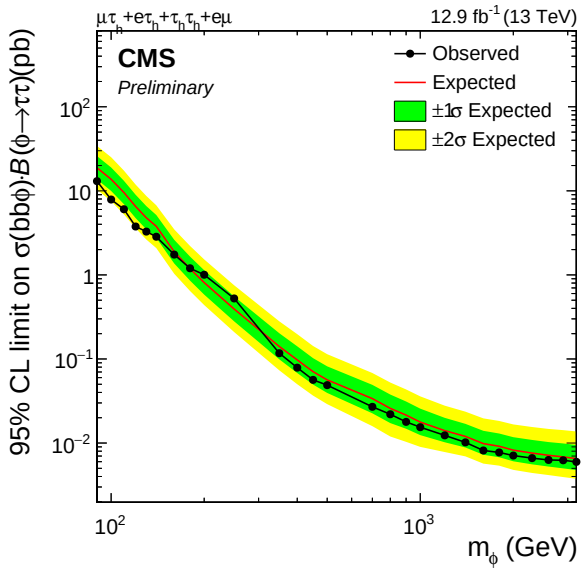
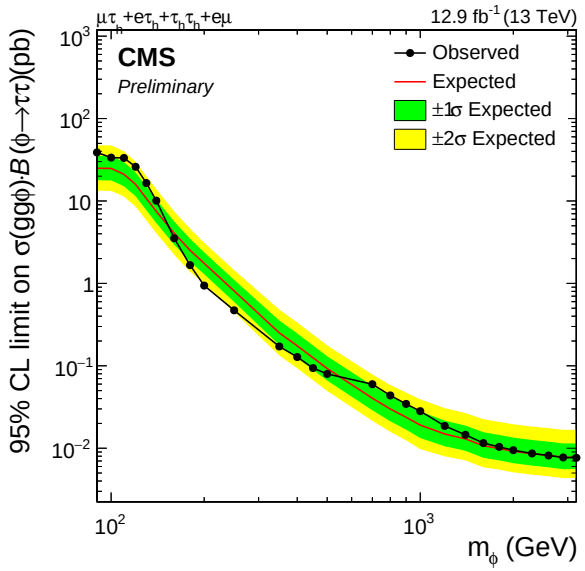




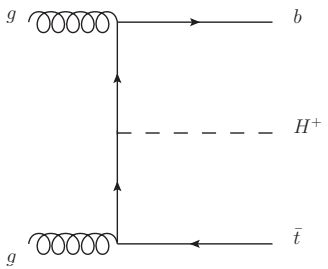






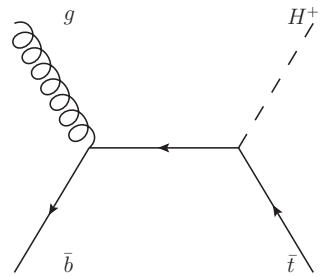
$H^{\pm} \to \tau\nu$, tb

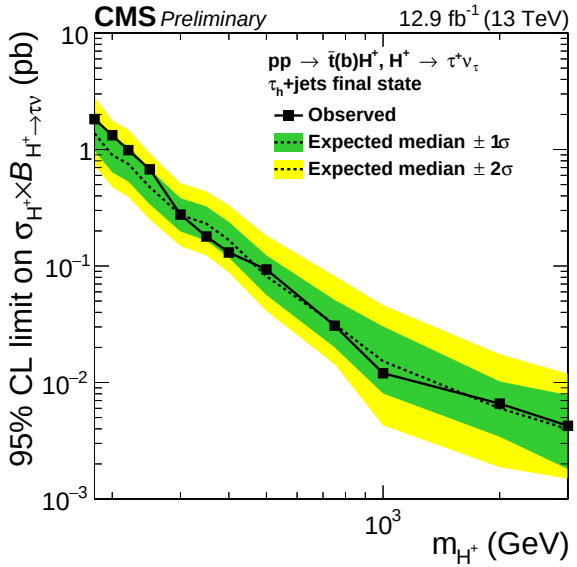
Couplings to fermions might be modified in case of an extended Higgs sector (MSSM, 2HDM, . . .). In such models a charged Higgs is predicted.



Search for $H^{\pm} \to \tau\nu$ in events with ≥ 3 jets, ≥ 1 b-tags ($pp \to tbH^{\pm}, H^{\pm}W^{\mp}b\bar{b}$).

Search for $H^{\pm} \to tb$ in events with ≥ 4 jets, ≥ 2 b-tags.





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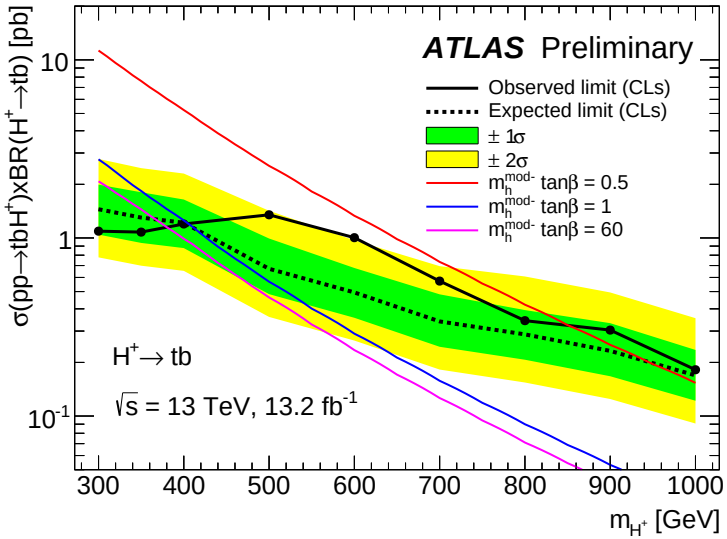
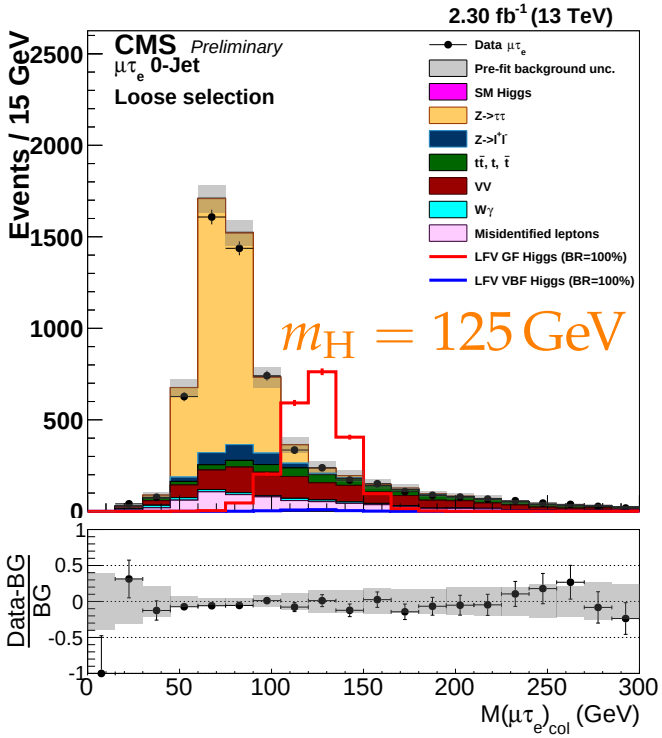


ATLAS-CONF-2016-089

$H \to \tau\mu$

- A more complicated Higgs-sector could allow for lepton flavour violation.
- Search for $H \to \mu\tau_e/\tau_{had}$, in categories of 0-2 extra jets.



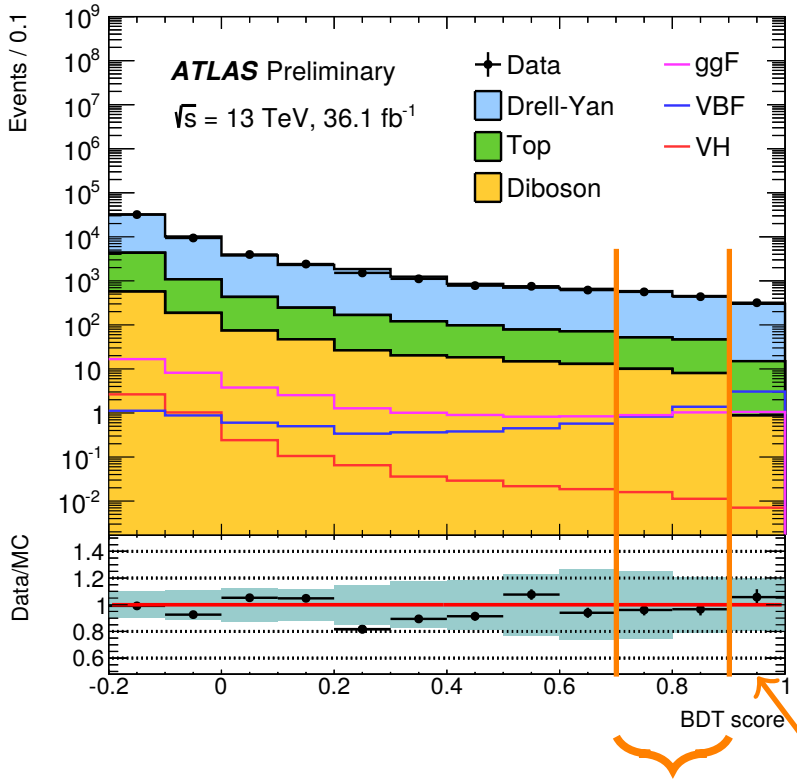
- Final discriminant visible mass corrected by estimated energy loss from ν_τ
- Limit on LFV Yukawa coupling ($m_H = 125\,\text{GeV}$):

$$\sqrt{|y_{\mu\tau}|^2 + |y_{\tau\mu}|^2} < 3.16 \times 10^{-3}$$

CMS-PAS-HIG-16-005

$H \rightarrow \mu^+\mu^-$

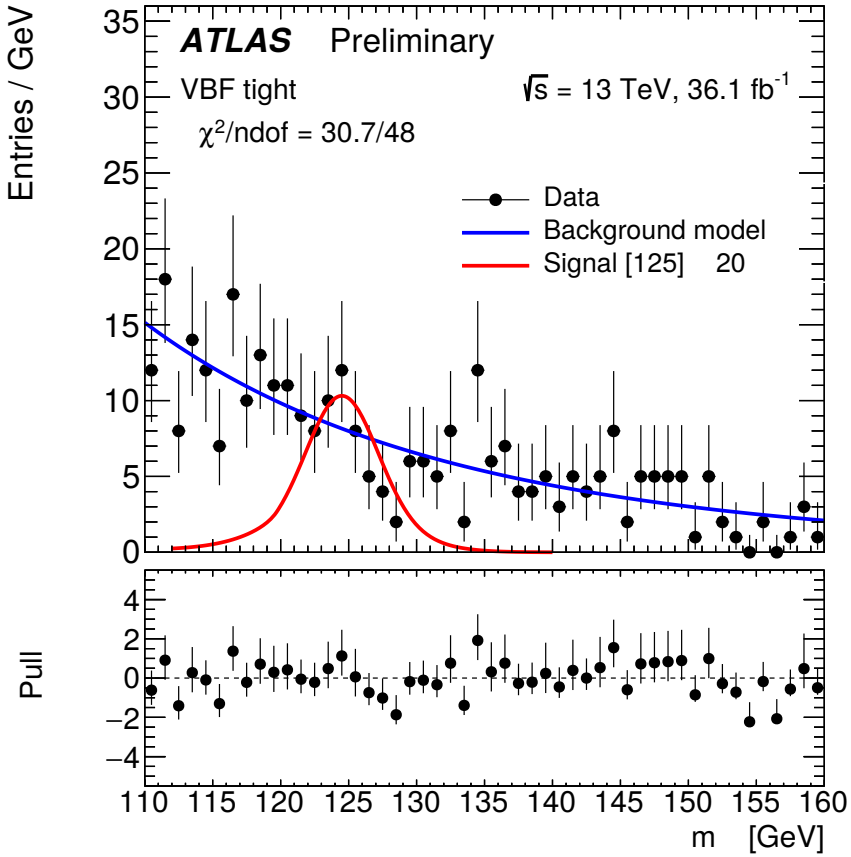
- Search for di-muon resonance in ggF and VBF like events.
- b-veto to reject $t\bar{t}$
- MVA to identify VBF-like events,
- to enhance significance categorisation in $p_T^{\mu\mu}$, η^{μ} and the multivariate discrimant to identify VBF.



ATLAS-CONF-2017-014

$H \to \mu^+\mu^-$

$m_{\mu\mu}$ in VBF tight category



Signalstrength μ extracted from simultaneous fit to $m_{\mu\mu}$ in all categories.

- signal: Crystal-ball +Gaussian
  Shape fixed to prediction of simulation.
- background:
  exponential
  + BW $\otimes$ Gaussian (Z)

ATLAS-CONF-2017-014

$H \to \mu^+\mu^-$

Event yields in mass window around peak position ($m_H = 125\,\text{GeV}$)

For $m_H = 125\,\text{GeV}$:

	Signal	Background	$S/\sqrt{B}$	FWHM	Data
Central low $p_T^{\mu\mu}$	10.9	7400	0.13	5.6 GeV	7885
Non-central low $p_T^{\mu\mu}$	31.6	36000	0.17	7.0 GeV	38777
Central medium $p_T^{\mu\mu}$	23.4	6200	0.30	5.7 GeV	6585
Non-central medium $p_T^{\mu\mu}$	66.5	29000	0.39	7.1 GeV	31291
Central high $p_T^{\mu\mu}$	15.5	3300	0.27	6.3 GeV	3160
Non-central high $p_T^{\mu\mu}$	39.7	13000	0.35	7.7 GeV	12829
VBF loose	3.4	250	0.22	7.6 GeV	274
VBF tight	3.4	71	0.40	7.5 GeV	79

prediction of the simulation

	Signal Strength μ	Limit @ 95% CL
13 TeV:	$-0.07^{+1.5}_{-1.5}$	$< 3.0\,(3.1)$
7+8+13 TeV:	$-0.13^{+1.4}_{-1.4}$	$< 2.8\,(2.9)$

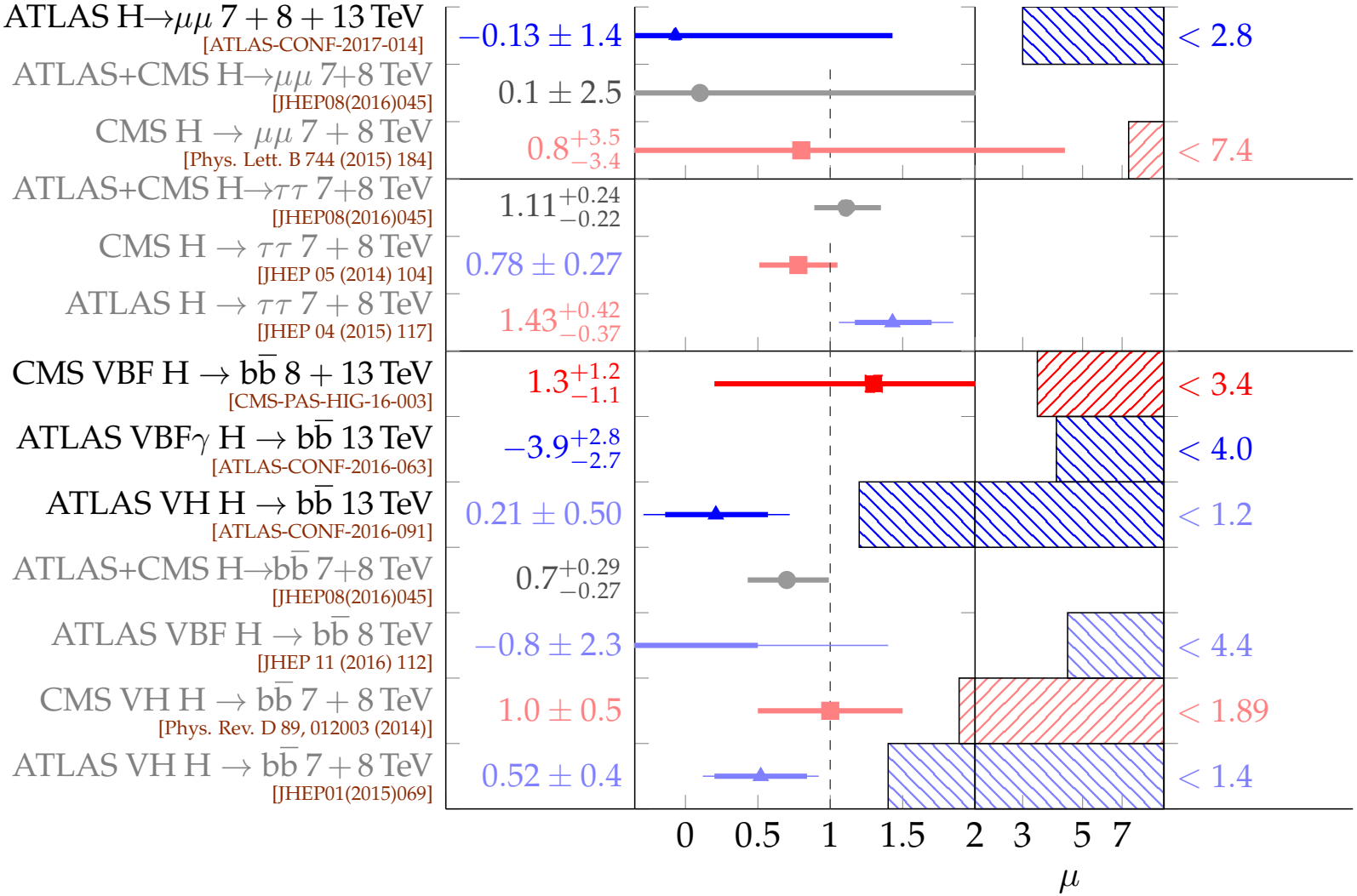
expected

observed

ATLAS-CONF-2017-014

2nd, 3rd generation couplings

Measured signal strength μ and 95% CL limit on $\sigma \times$ Br relative to the SM expectation for $m_{\mathrm{H}} = 125\,\mathrm{GeV}$:

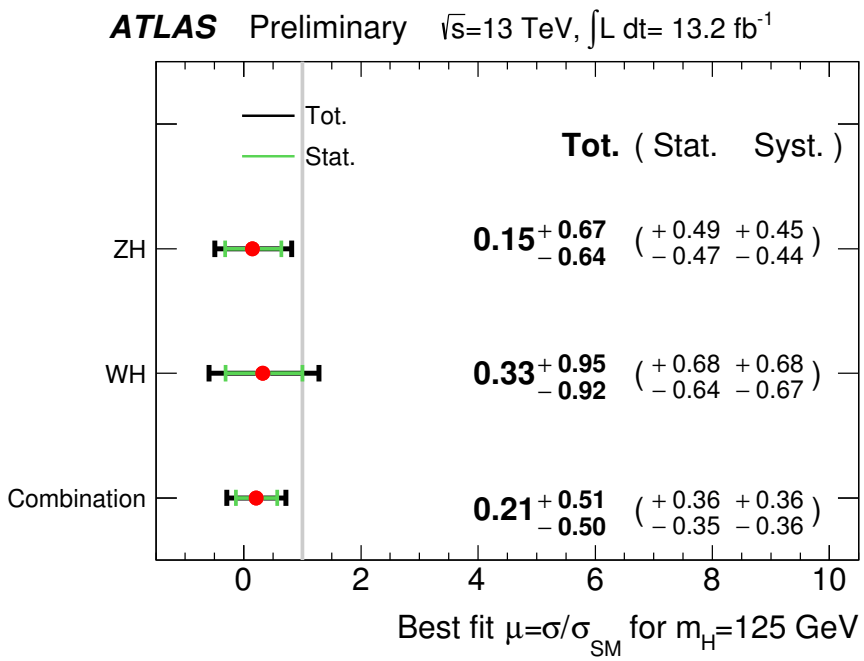


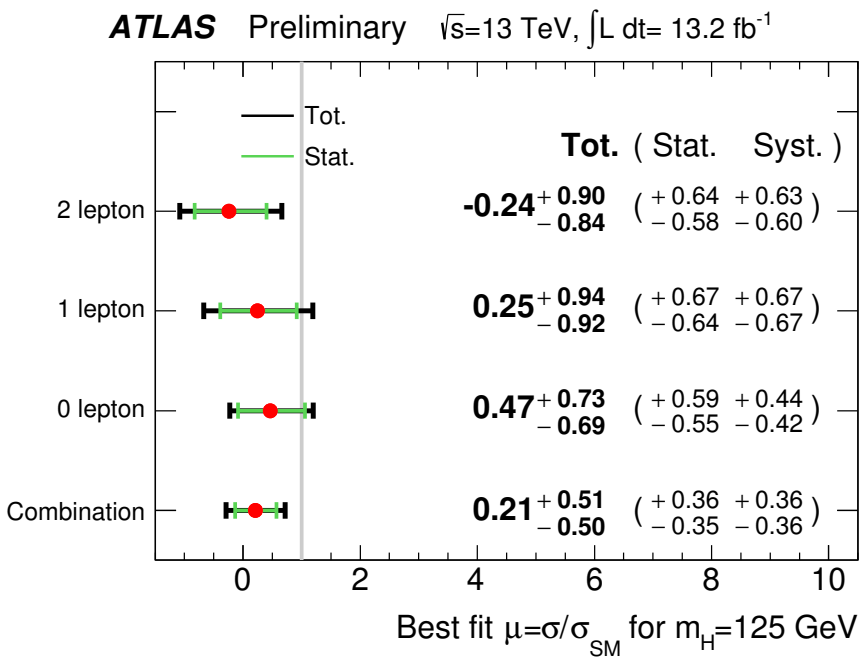
Summary

- First searches for $H \to b\bar{b}$, $\mu\mu$ using 13 TeV data performed.
- No deviation from SM predictions observed.
- Not yet senstivie to $H \to b\bar{b}$ (assuming SM couplings).
- Not all analyses updated to all available data
  $\to$ updates in the very near future.
- By the end of this year, 13 TeV data expected to double at least.

Backup

VH, H → $b\bar{b}$ – ATLAS





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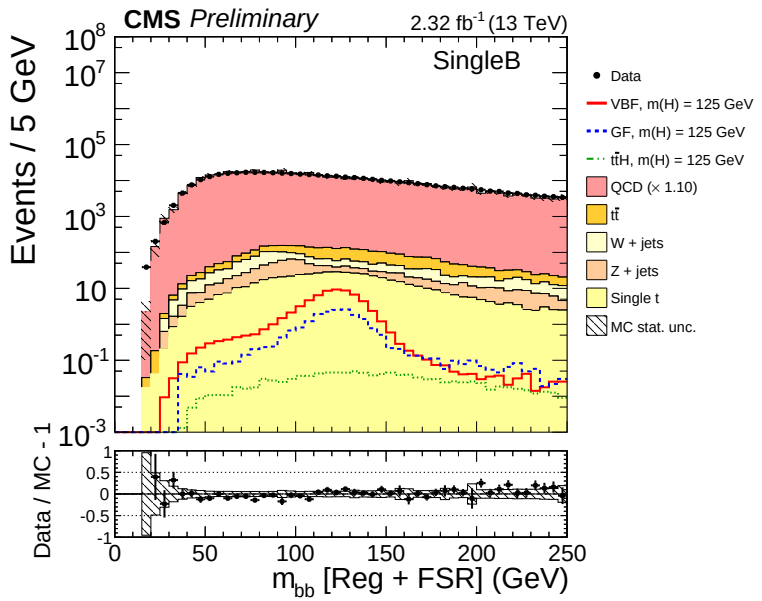
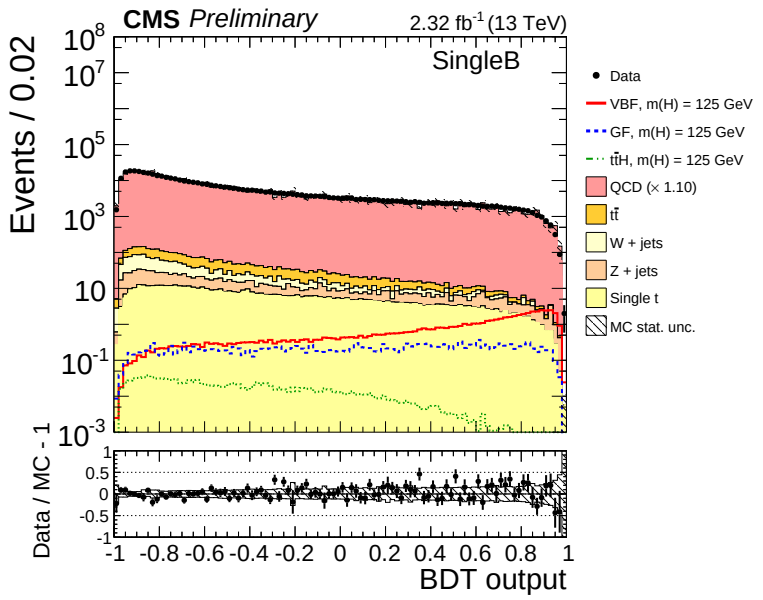
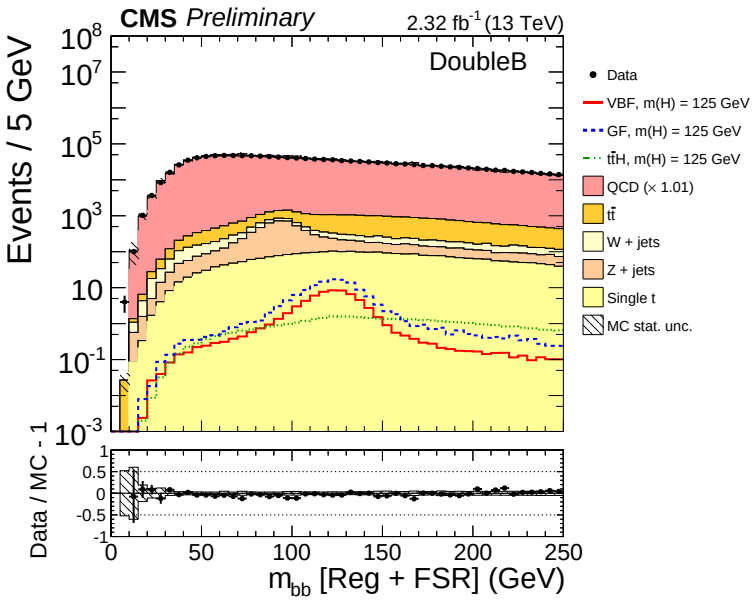
VBF $m_{b\bar{b}}$ and BDT output

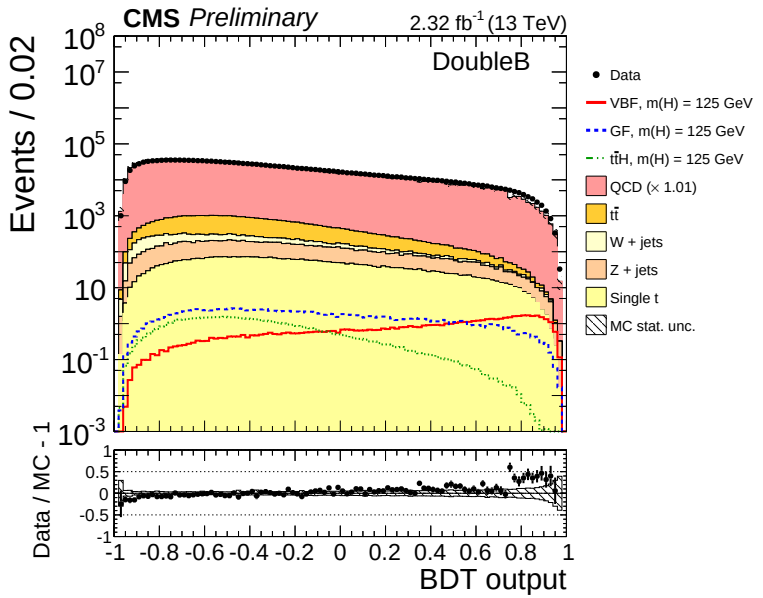
Single B





Double B





CMS-PAS-HIG-16-003

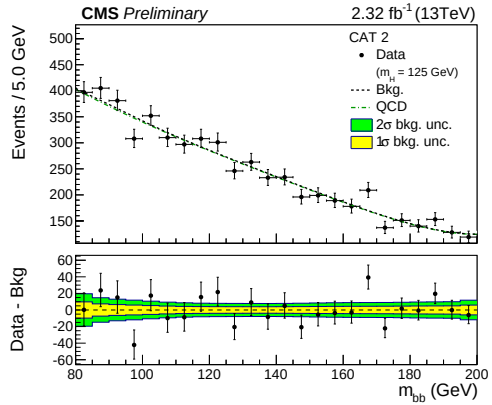
VBF – CMS categories

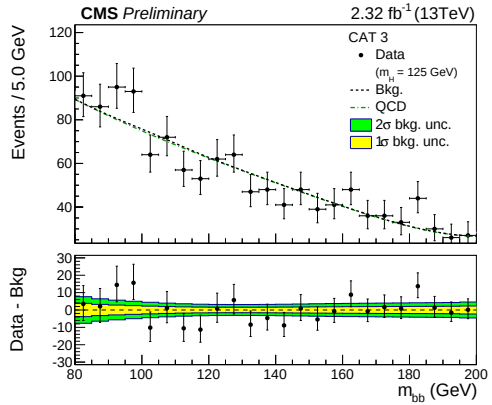
BDT boundary values	SingleB				DoubleB		
	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Cat. 6	Cat. 7
	0.28 – 0.72	0.72 – 0.87	0.87 – 0.93	0.93 – 1.0	0.36 – 0.76	0.76 – 0.89	0.89 – 1.0
Data	25298	5834	1281	302	69963	9831	1462
Z +jets	49± 4	12.5± 2.0	4.1± 1.1	1.7± 0.7	448± 11	50± 4	8.4± 1.7
W +jets	25.8± 3.5	1.6± 0.9	0.1± 0.1	<0.1	74± 6	4.6± 1.3	0.9± 0.6
$t\bar{t}$	53± 1	5.1± 0.2	0.7± 0.1	0.2± 0.04	534± 2	22.6± 0.4	1.1± 0.1
Single t	52± 1	9.7± 0.5	1.8± 0.2	0.4± 0.1	221± 3	23.2± 0.8	1.8± 0.2
VBF $m_{\mathrm{H}}(125)$	19.5± 0.2	13.7± 0.1	7.2± 0.1	4.2± 0.1	21.7± 0.2	10.5± 0.1	3.8± 0.1
GF $m_{\mathrm{H}}(125)$	5.5± 0.2	1.8± 0.1	0.6± 0.07	0.2± 0.04	18.7± 0.4	3.1± 0.1	0.6± 0.07

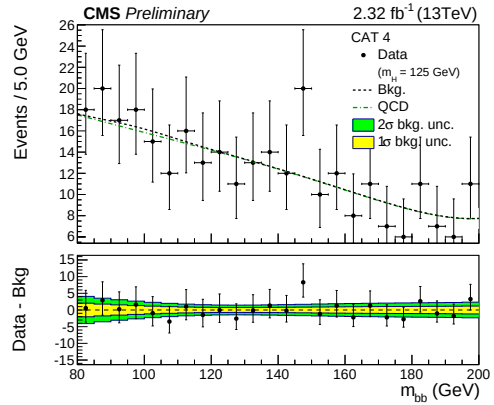
CMS-PAS-HIG-16-003

VBF $m_{b\bar{b}}$ fit – background hypo

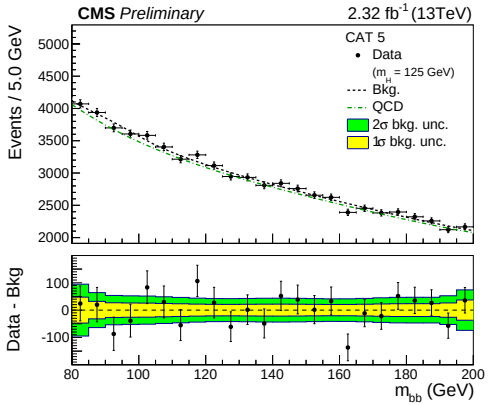
Single B

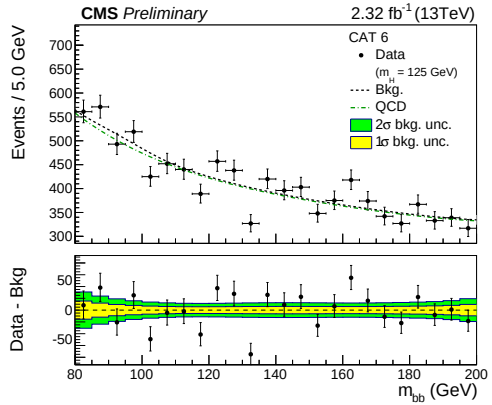


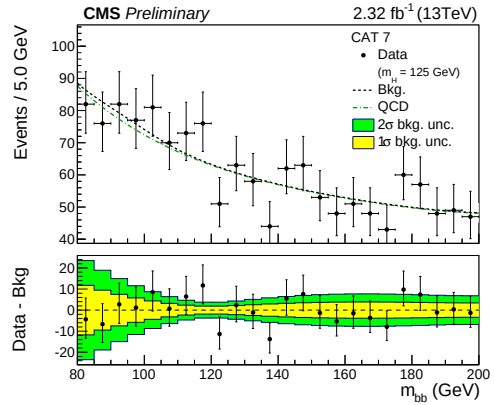




Double B

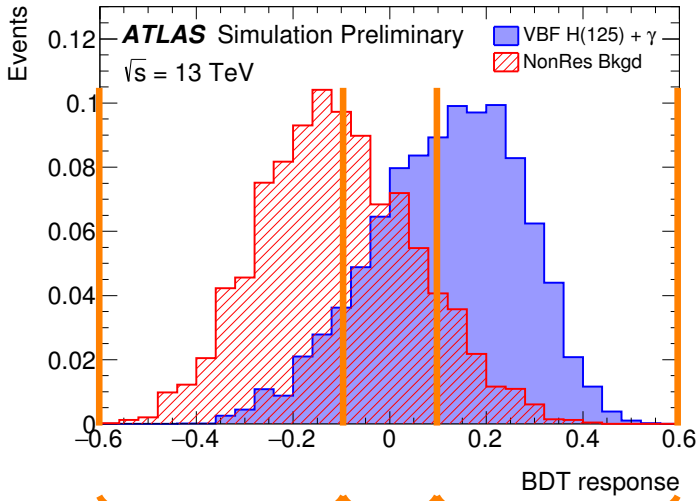




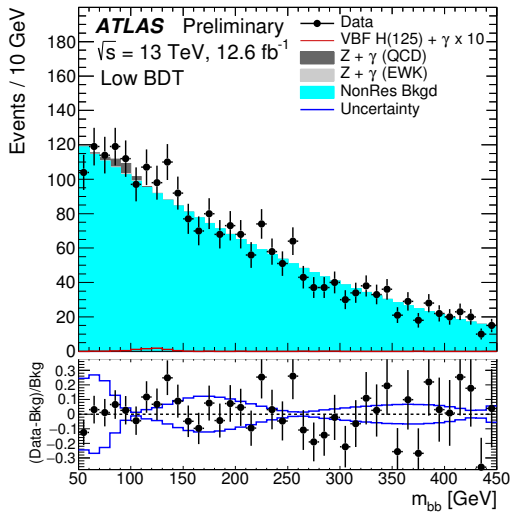


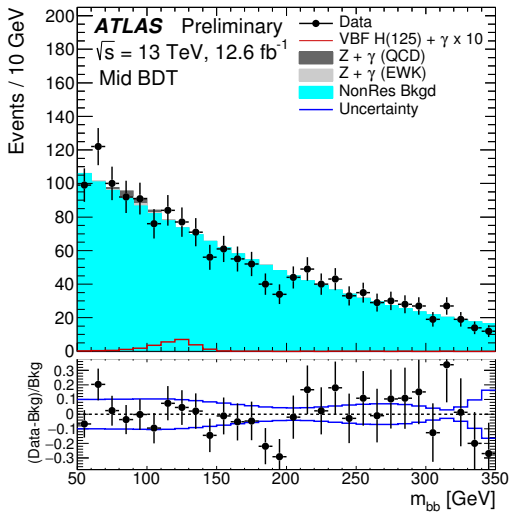
CMS-PAS-HIG-16-003

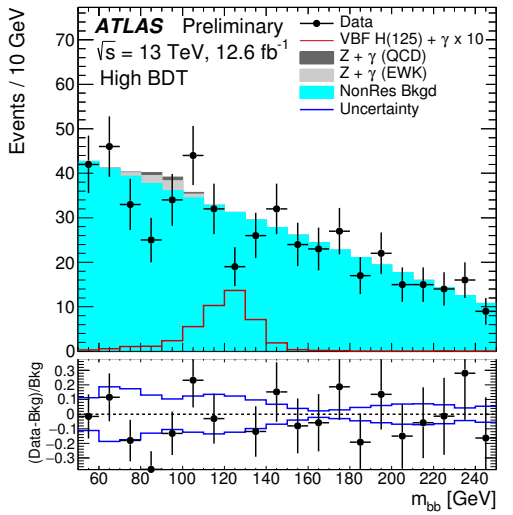
VBF+γ, $H \to b\bar{b}$



- BDT used to define categories.
- BDT inputs uncorrelated with $m_{b\bar{b}}$.
- Signal strength μ computed in unbinned likelihood fit as a function of $m_{b\bar{b}}$.







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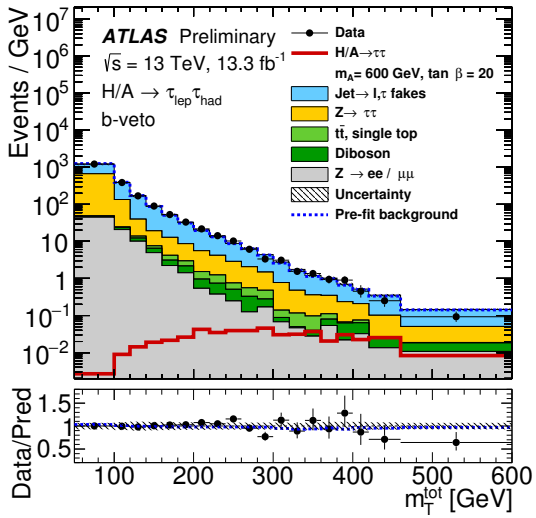
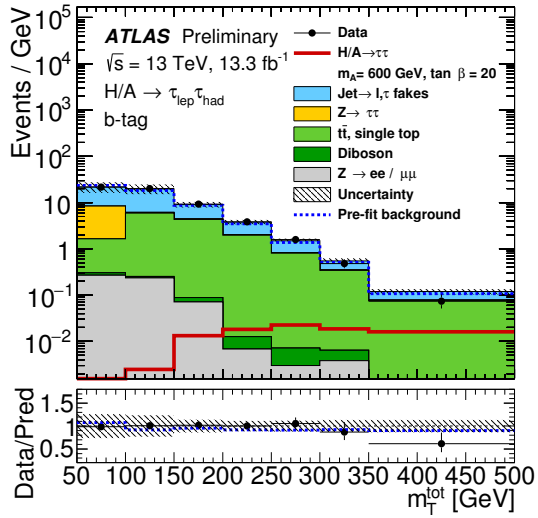
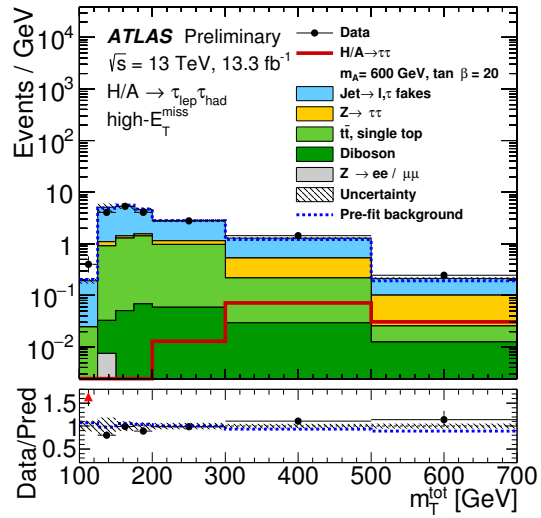
$\Phi \to \tau^+\tau^-$ – signal categories

b-veto | b-tag | E_T^{mis}

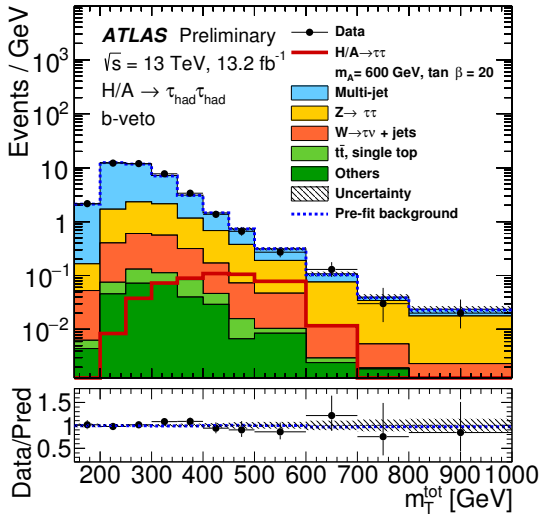
$\tau_\ell\tau_{\text{had}}$

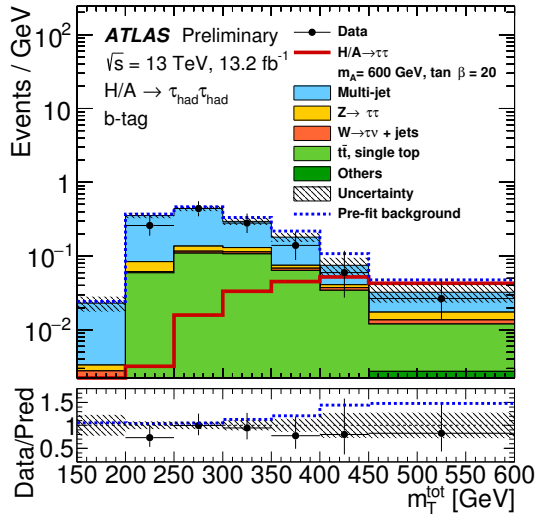






$\tau_{\text{had}}\tau_{\text{had}}$





- $m_{\text{T}}^{\text{tot}}$ total transverse mass of $\tau\tau$ system.

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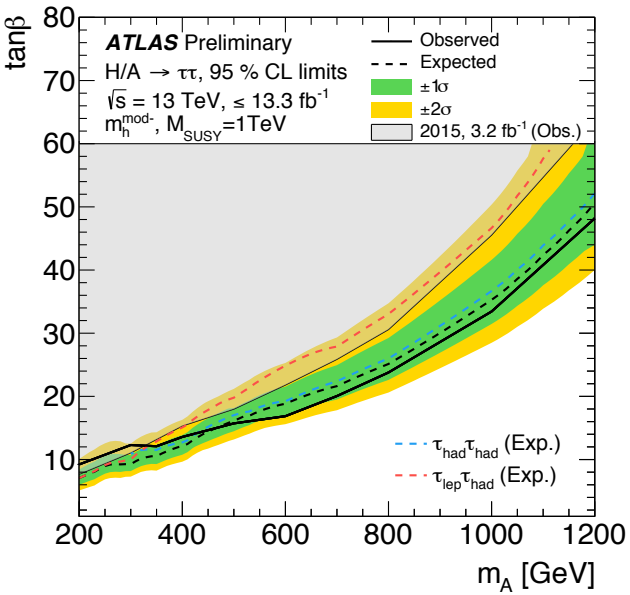
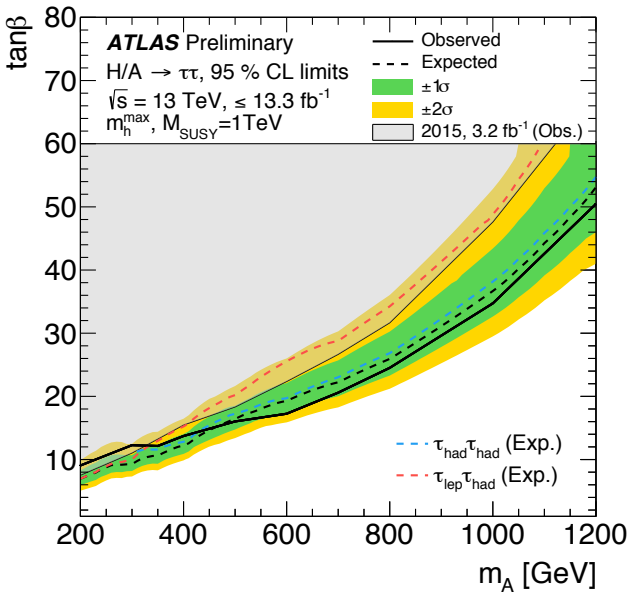
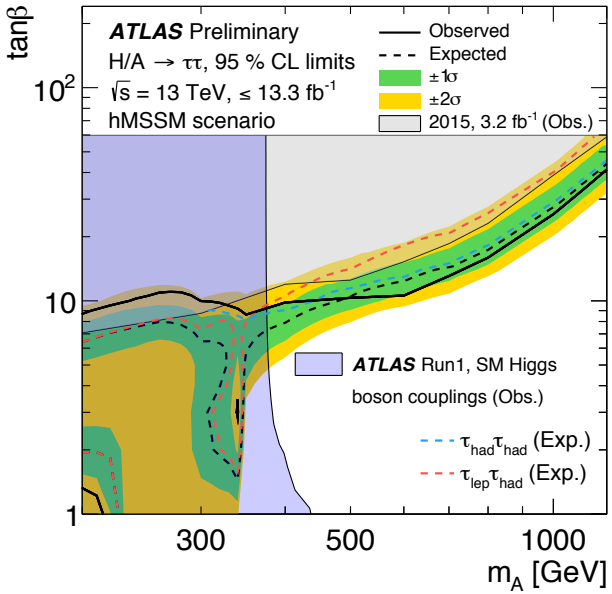
$\Phi \to \tau^+\tau^-$ – Combined limits







- limits $\tau_\ell \tau_{\text{had}}$, $\tau_{\text{had}}\tau_{\text{had}}$ combined

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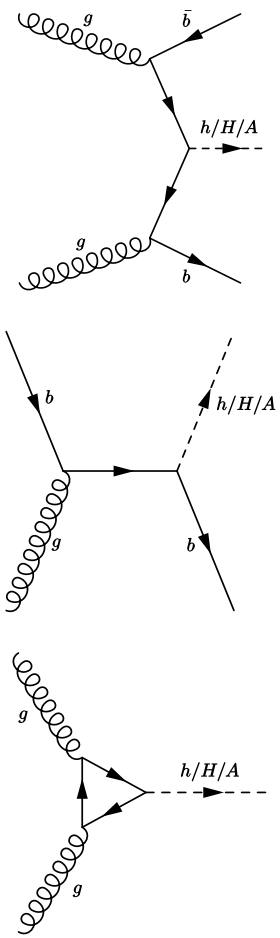
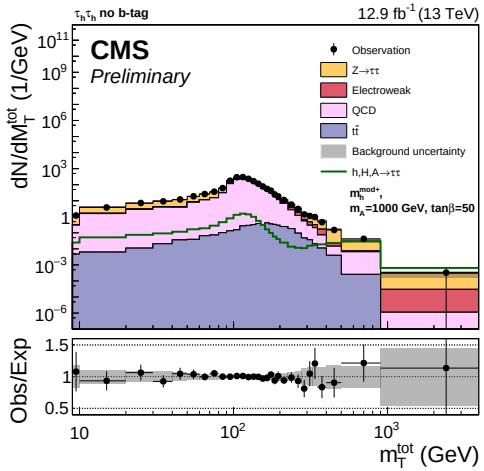
$\Phi \to \tau^+\tau^-$

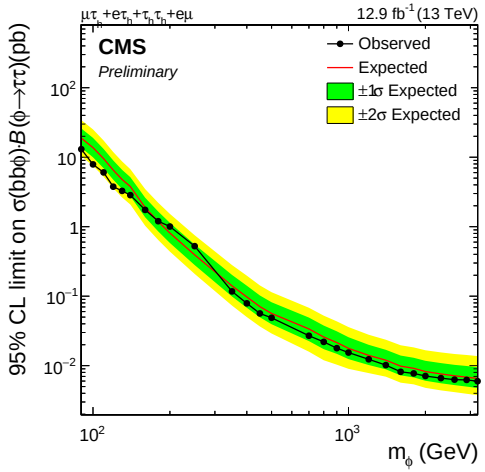
In some MSSM scenarios, coupling to down-type fermions enhanced
$\to$ motivates search for scalar boson in association with bottom.



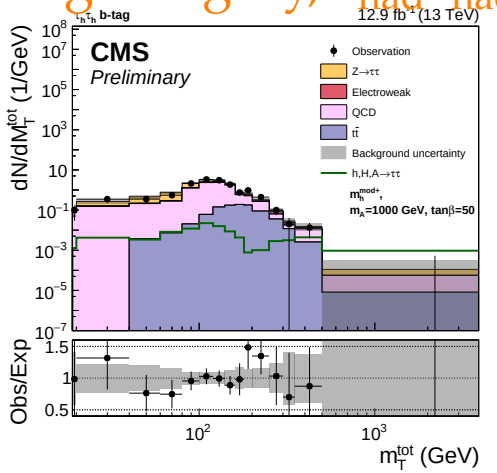
b-tag category, $\tau_\ell\tau_{\text{had}}$

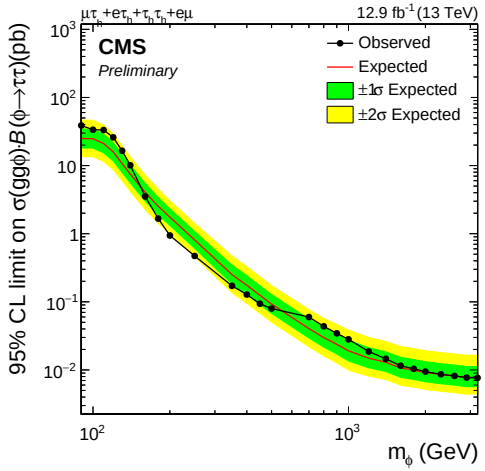


Limit on $\sigma \times$ Br



b-tag category, $\tau_{\text{had}}\tau_{\text{had}}$

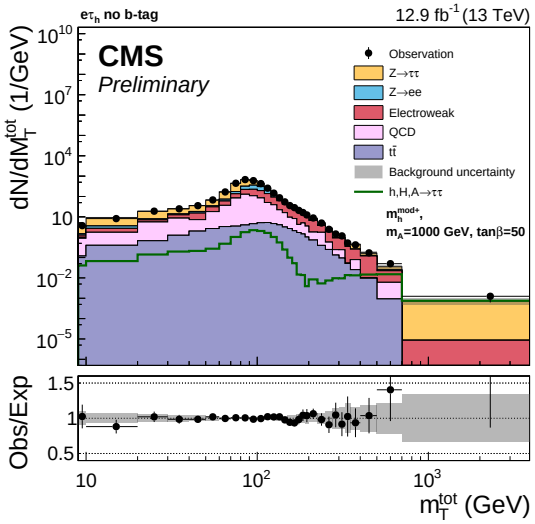


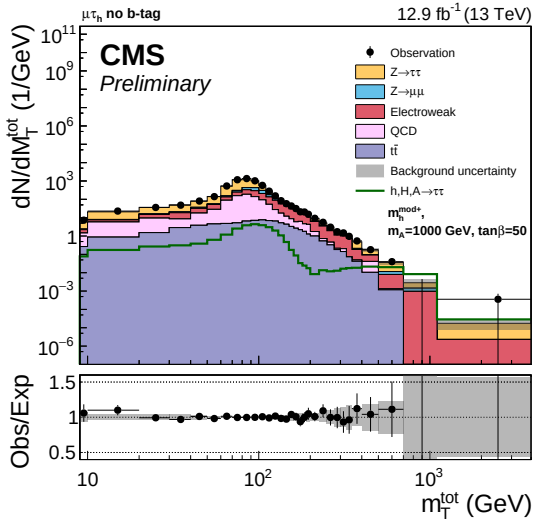


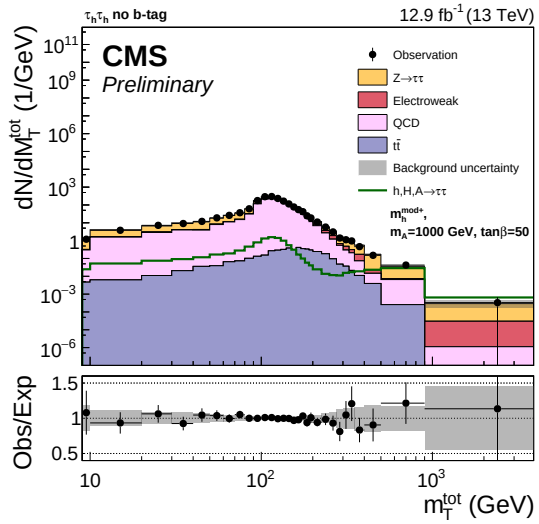
$\Phi \rightarrow \tau^+\tau^-$ – signal categories

$e\tau_{had}$ $\mu\tau_{had}$ $\tau_{had}\tau_{had}$

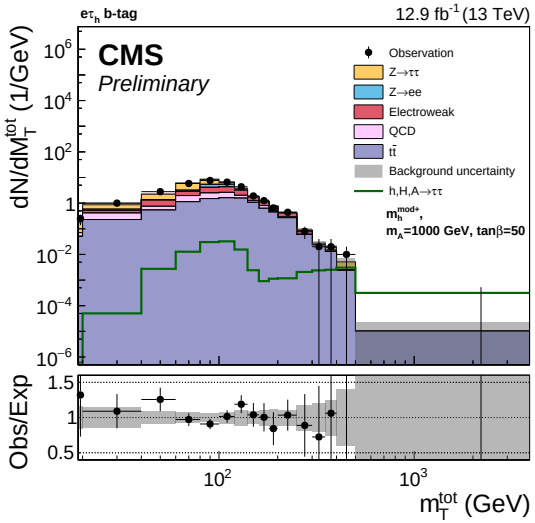
b-veto

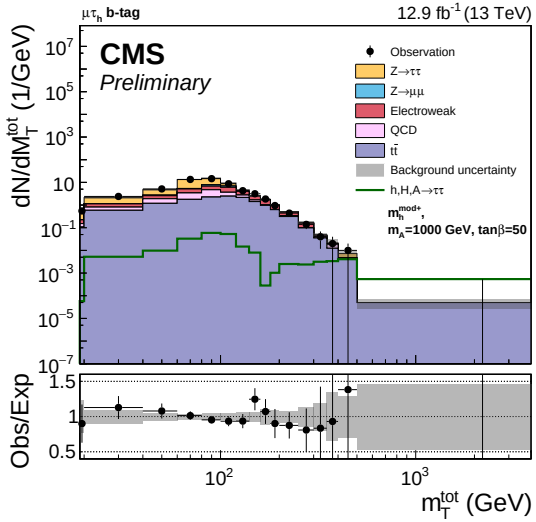


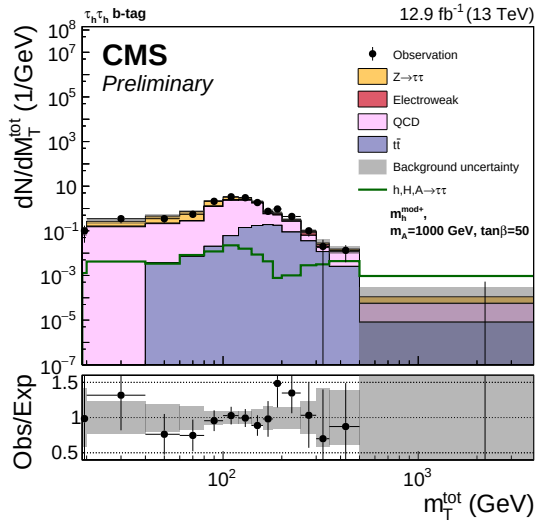




b-tag







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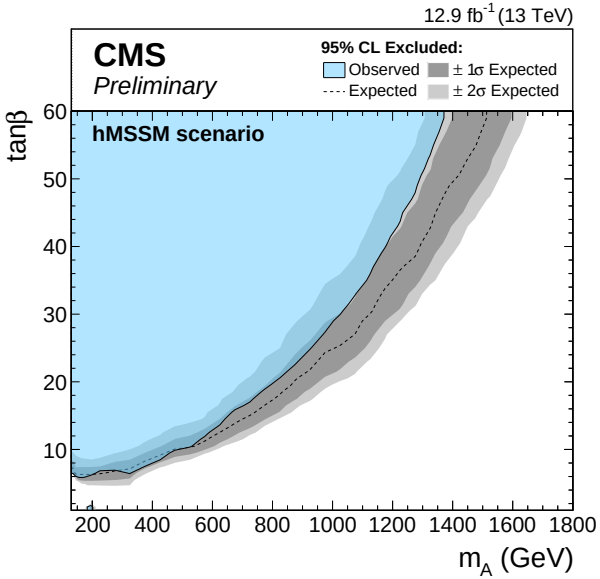
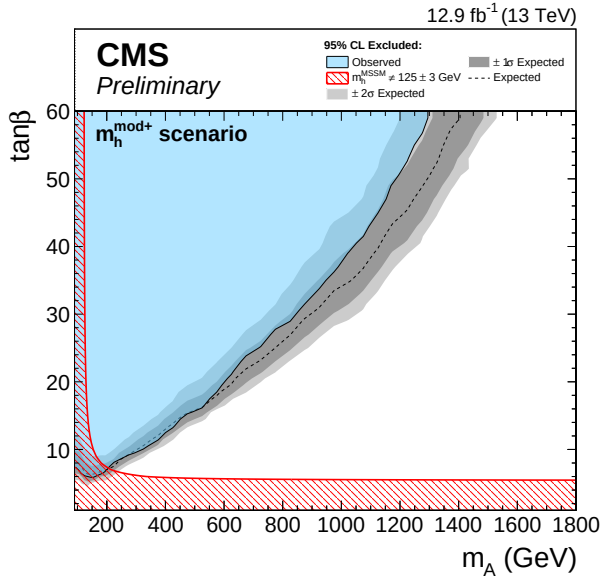
$\Phi \to \tau^+\tau^-$ – Combined limits

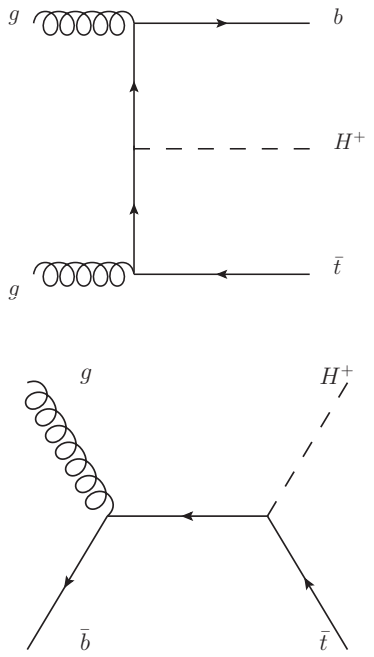




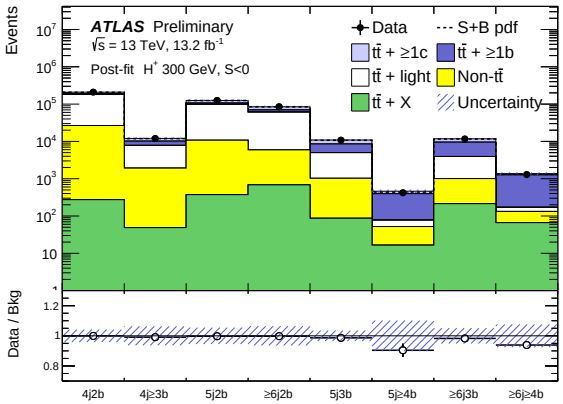
- limits using $e\mu$, $e\tau_{had}$, $\mu\tau_{had}$, $\tau_{had}\tau_{had}$ combined

CMS-PAS-HIG-16-037

$H^{\pm}tb/t\bar{t}$, $H^{\pm} \rightarrow tb$

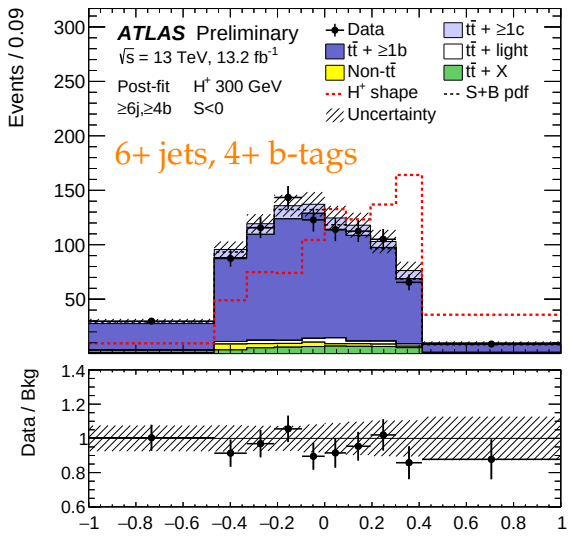


Categories



4 jets, 2 b-tags . . . 6+ jets, 4+ b-tags

phase space dependent classifier per category



$m_{H^+} = 300$ GeV

Couplings to fermions might be modified in case of an extended Higgs sector

→ Search in more exotic scenarios

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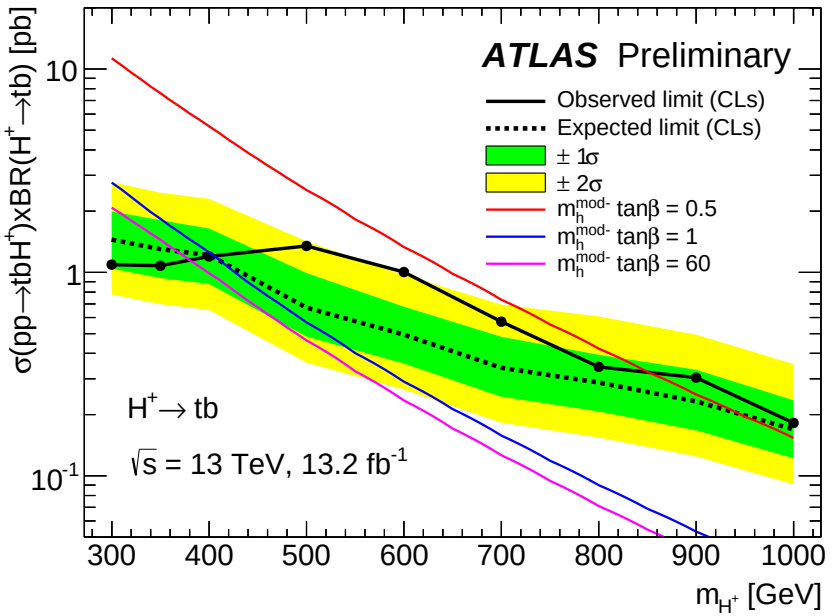
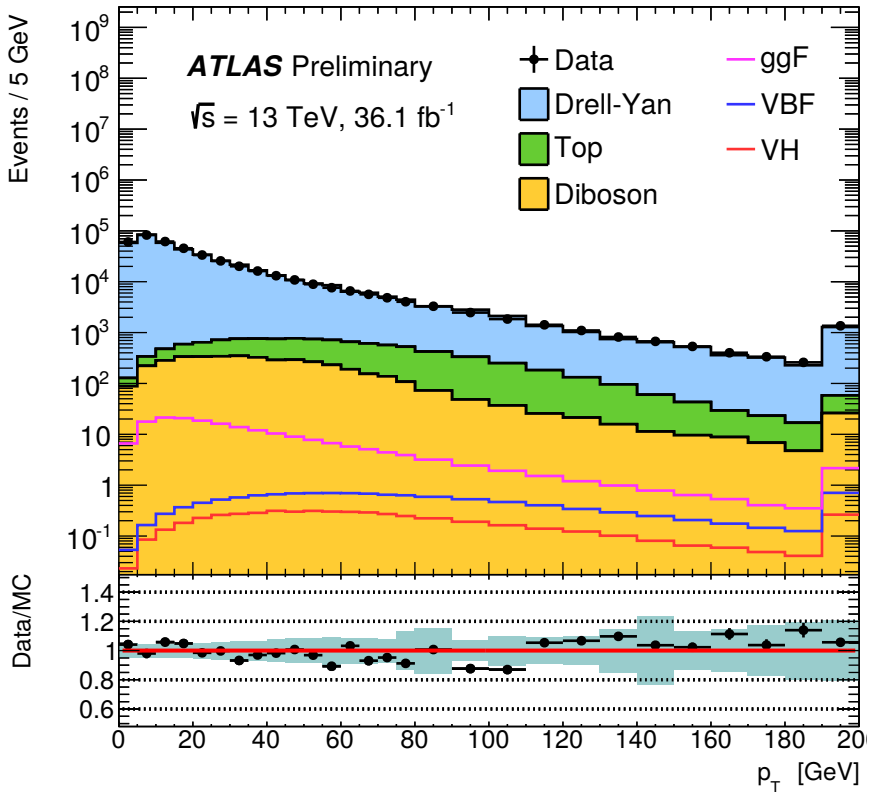
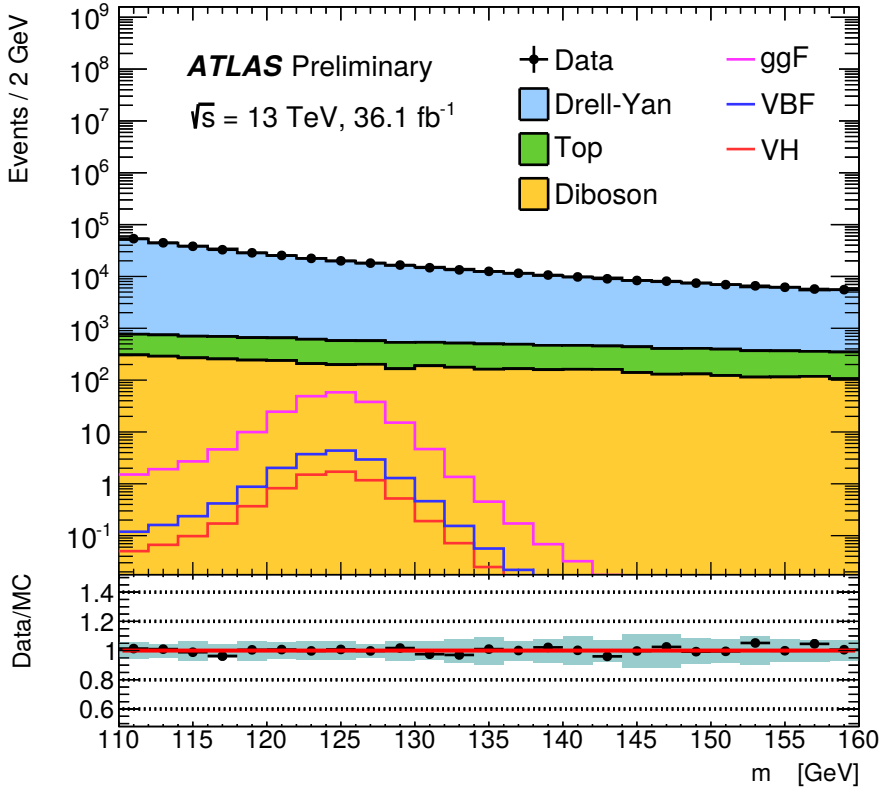


$H \to \mu^+\mu^-$

$p_T^{\mu\mu}$



$m_{\mu\mu}$



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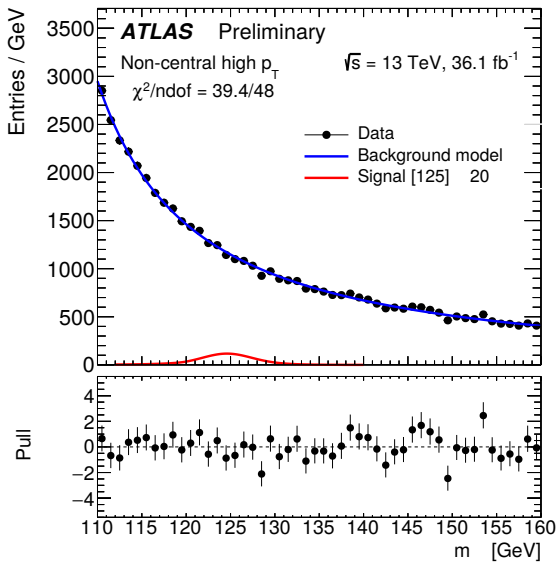
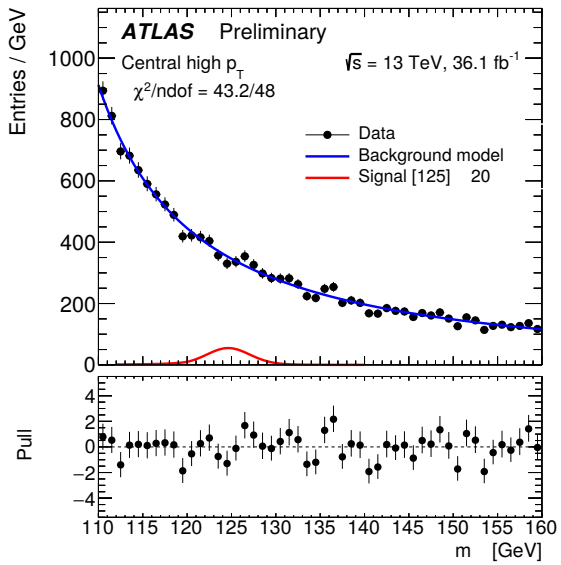
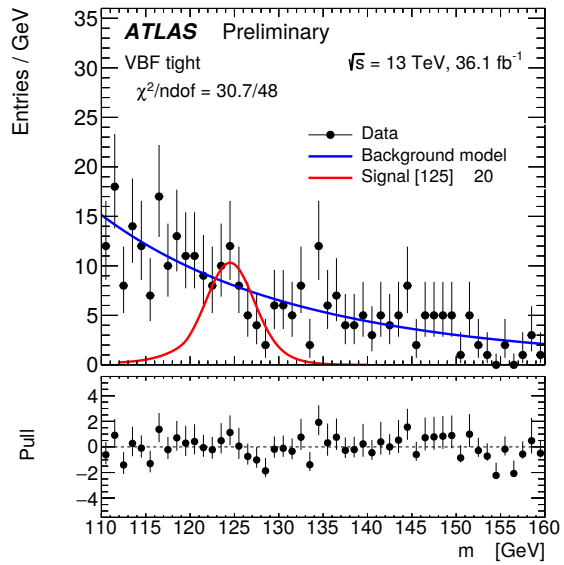
$H \to \mu^+\mu^-$ – fit results

non-central | central | VBF

$p_T^{\mu\mu}$ high

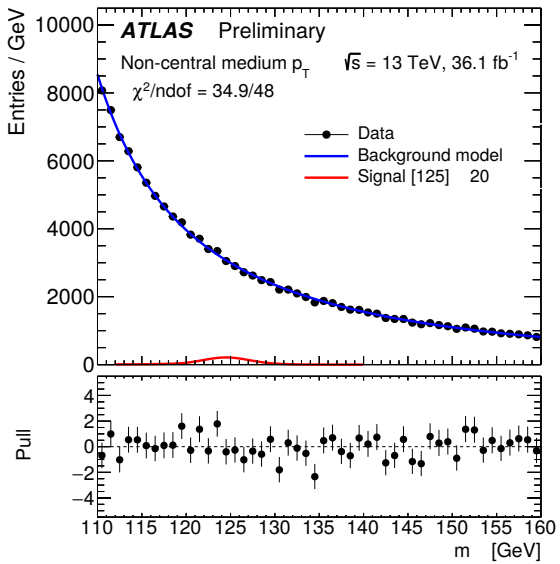


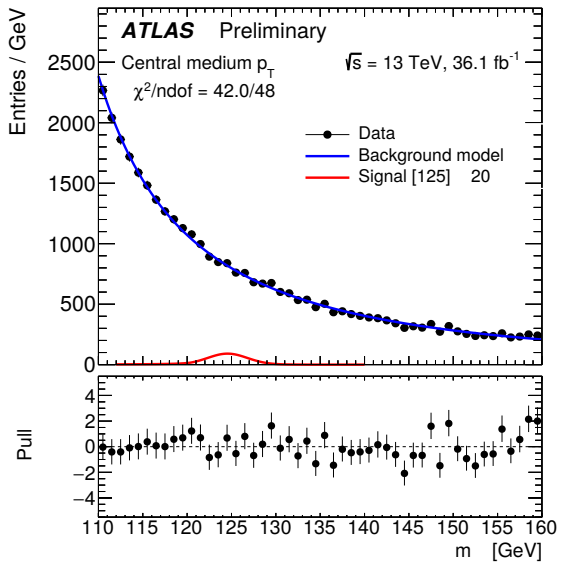


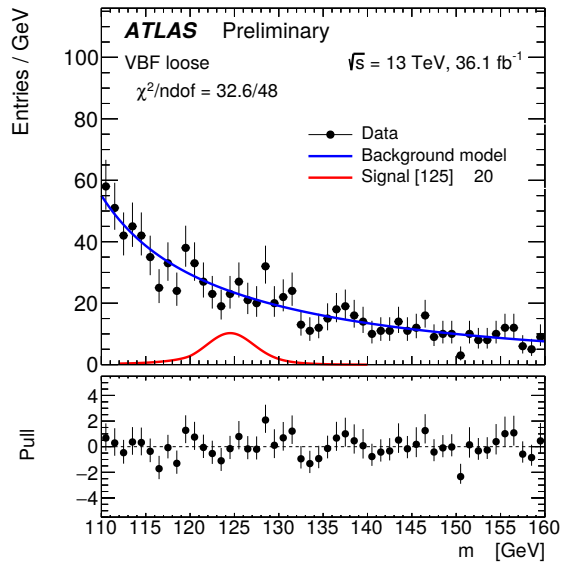


VBF high

$p_T^{\mu\mu}$ medium







VBF low

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