

Dec. 11, 2017
TIFR, Mumbai



Standard Model

SUSY 2017 Higgs @ LHC

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Princeton University

**On Behalf of the ATLAS
and CMS Collaborations**

Outline

Introduction

Higgs to VV

Higgs Properties

Higgs to $\gamma\gamma$

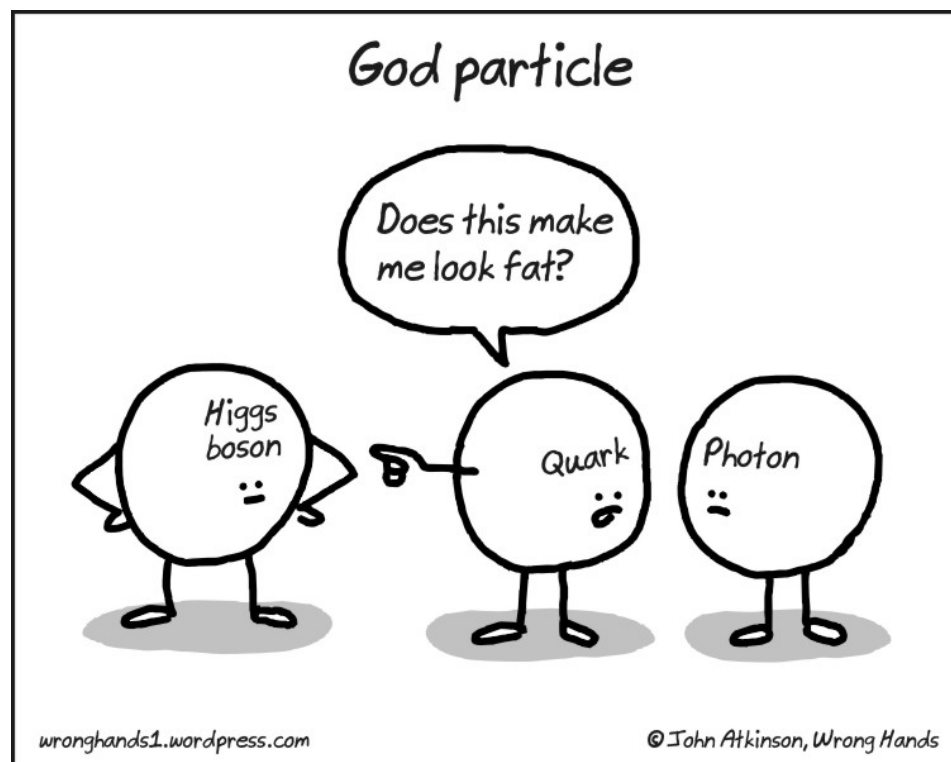
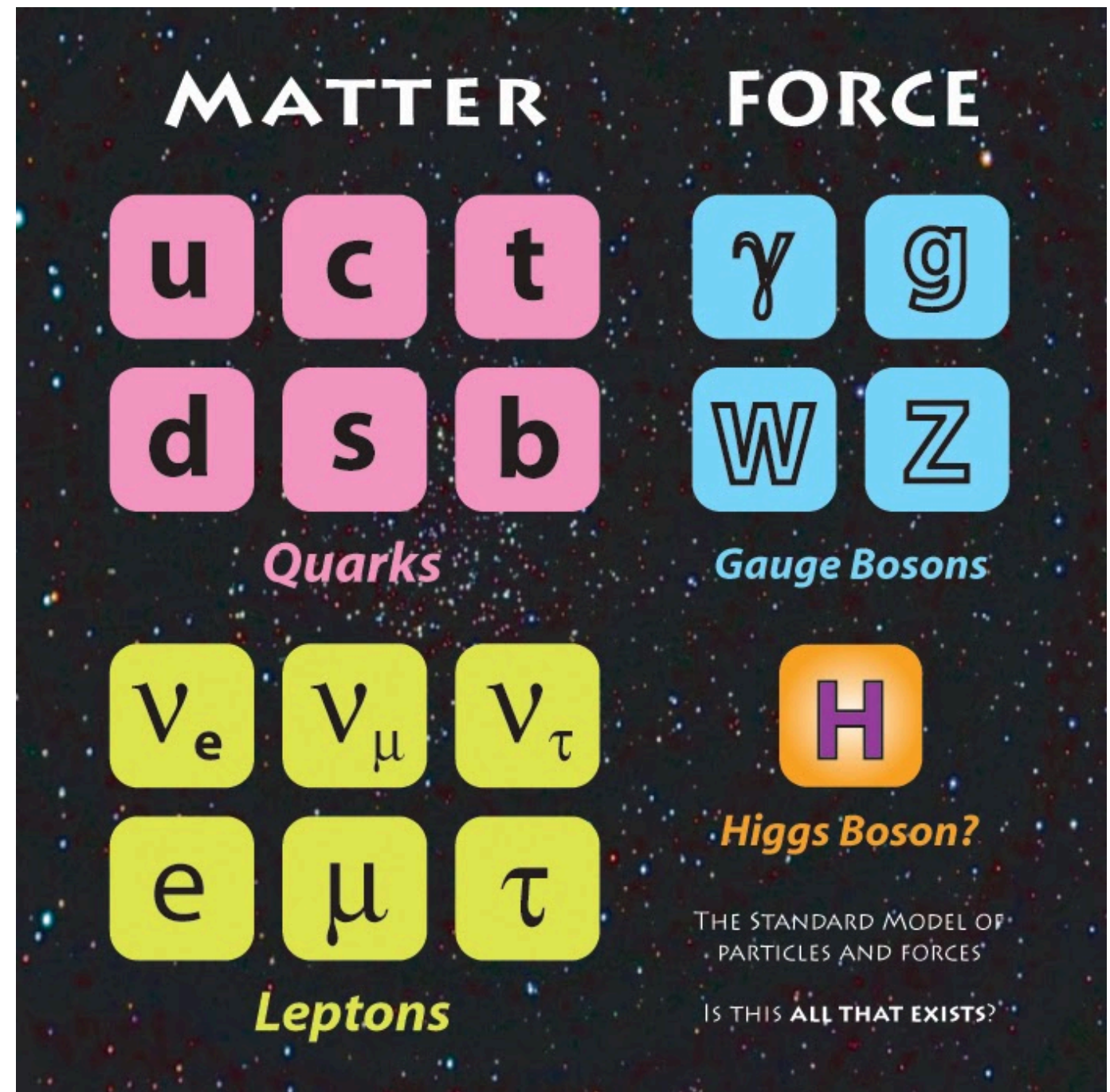
Higgs to **Fermions**

bb and $\tau\tau$

$t\bar{t}H$

Rare Decays

Summary and Outlook

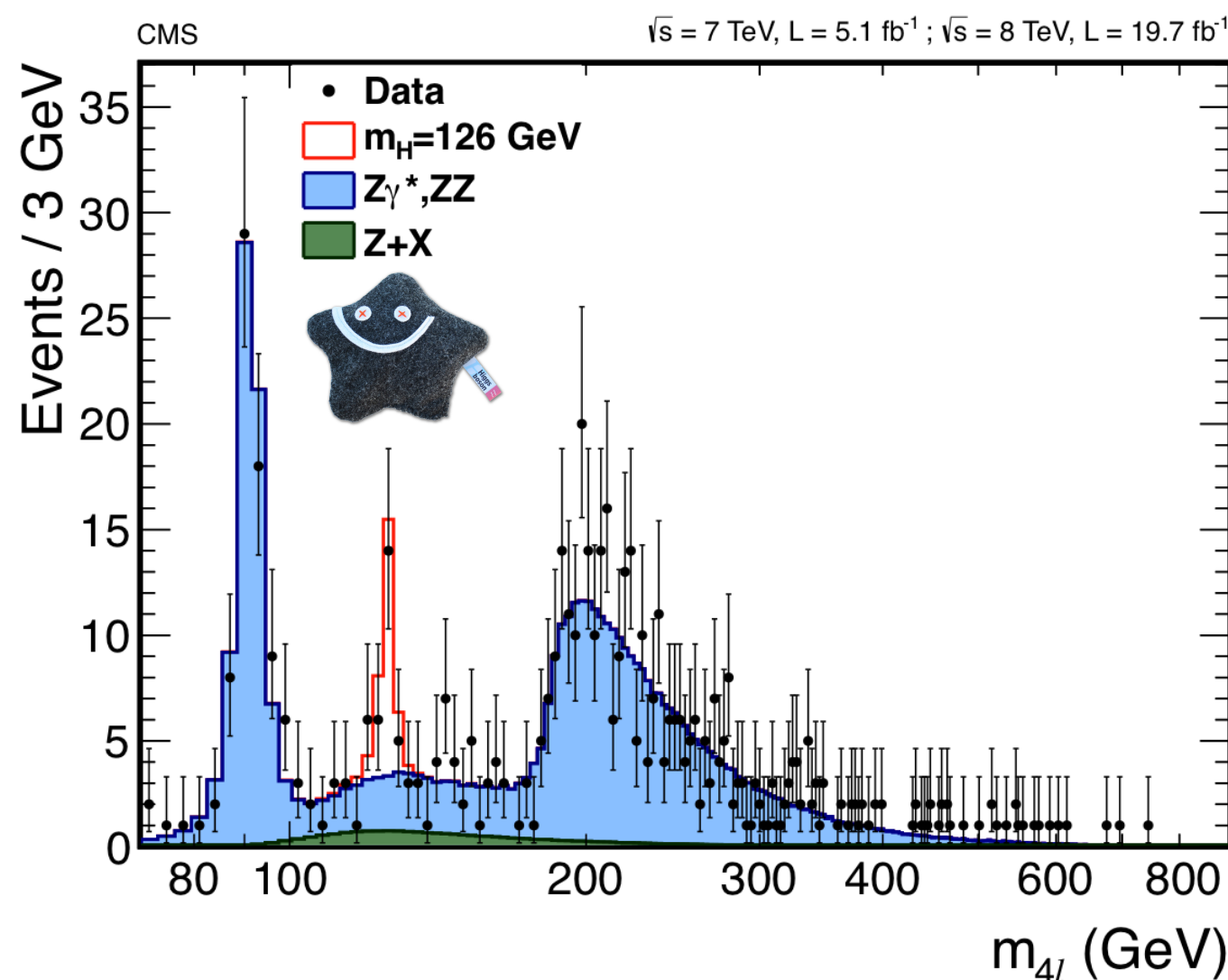


The SM Higgs Boson In Run I



Higgs discovery and many **properties** measured using the **Run I dataset** delivered by the **Large Hadron Collider**

- ➔ Discovery of the higgs via decays to ZZ and $\gamma\gamma$
- ➔ **Some excess** seen in $t\bar{t}H$
- ➔ Individual experiments saw evidence for couplings to fermions
 - Combination across CMS and ATLAS $> 5\sigma$
- ➔ Combination of **ATLAS** and **CMS** results leads to a total higgs boson **cross-section** of 1.09 ± 0.11 times the SM rate



Run I Legacy Papers:

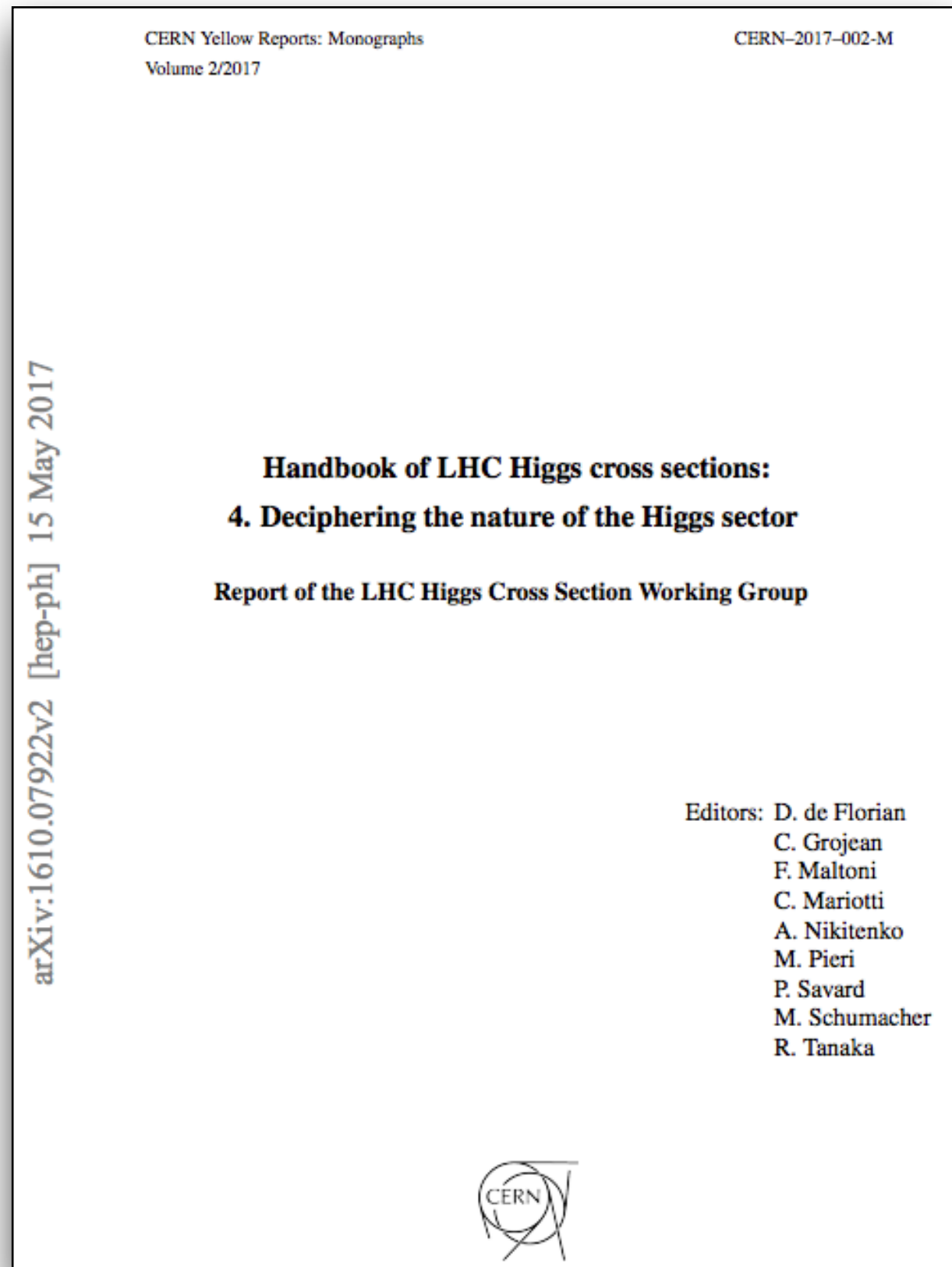
- Couplings ATLAS: Eur. Phys. J. C76 (2016) 6
CMS: Eur. Phys. J. C (2015) 75:212
- Mass Combination: PRL 114, 191803 (2015)
- **Bibliography in Backup**

Run II brings a larger dataset at a higher center of mass energy!
➔ **Continue diving into the properties of this new particle**

LHC Higgs Cross Section Working Group



Thanks to the long-standing collaboration between Theorists and Experimentalists many interpretations analyzed

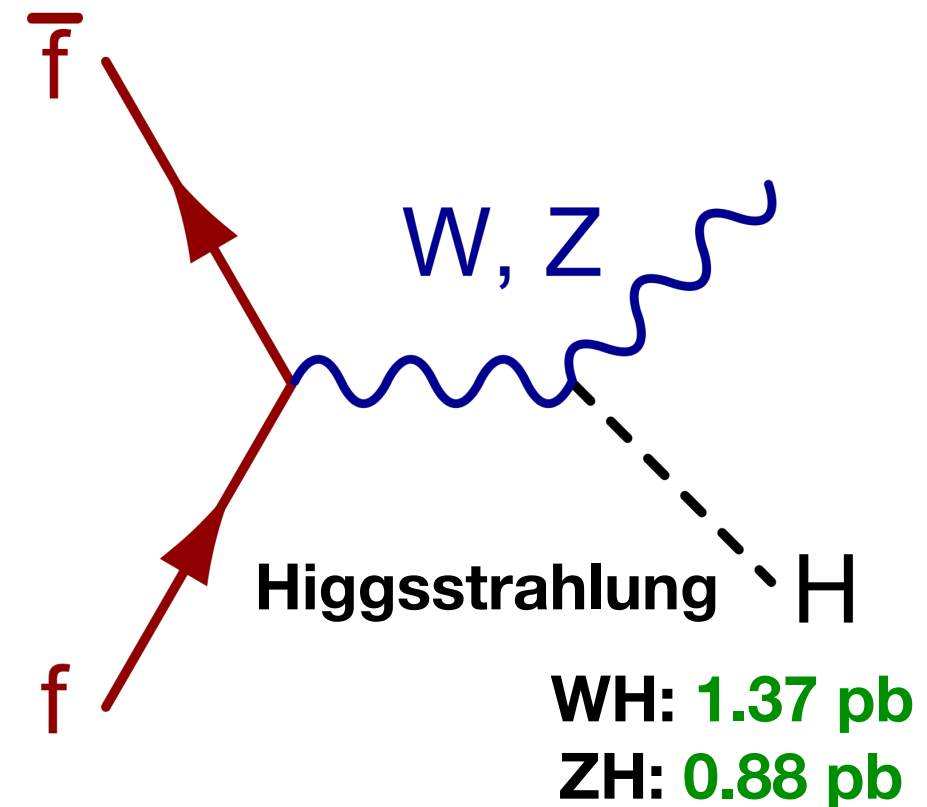
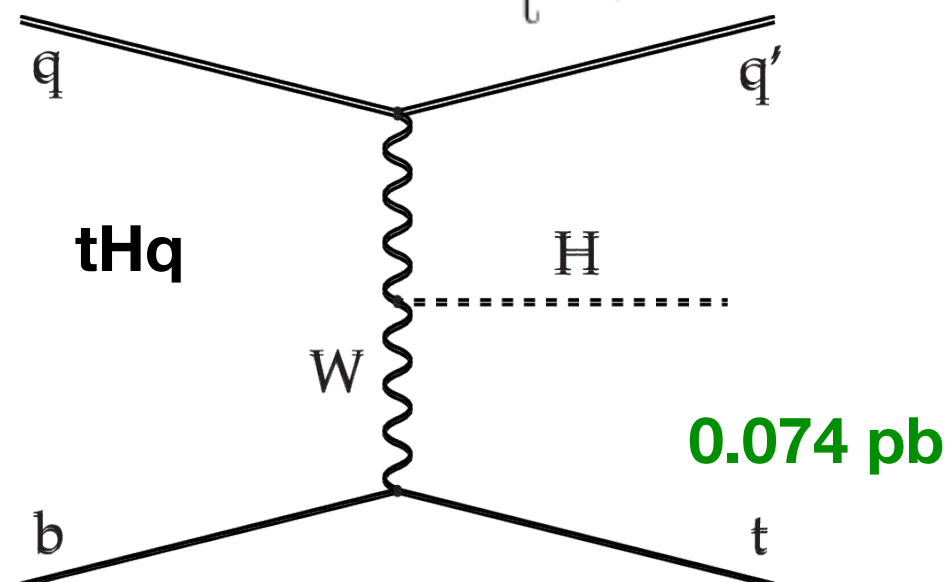
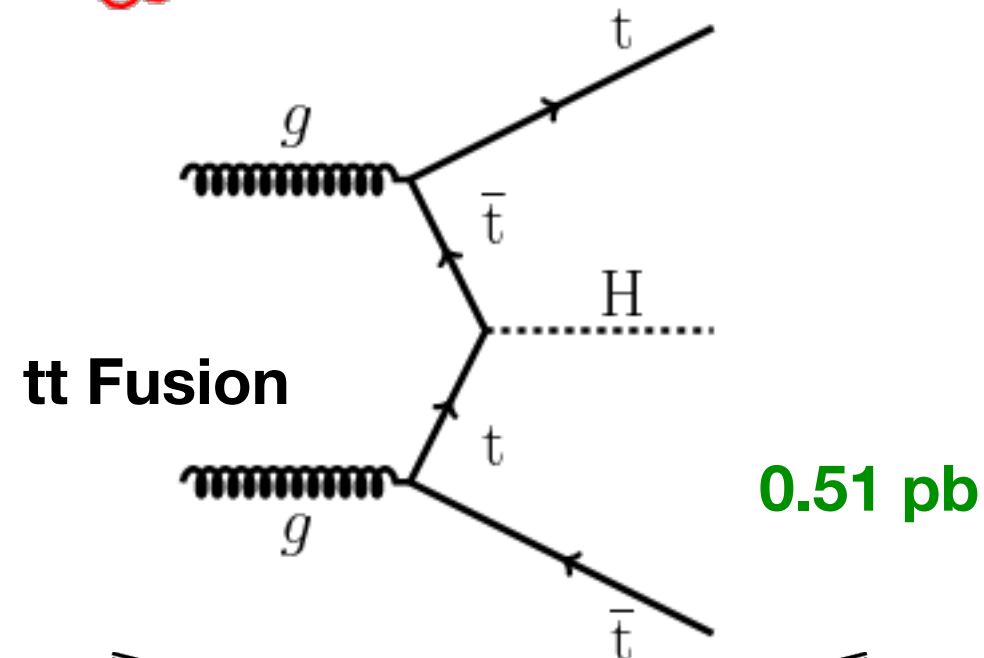
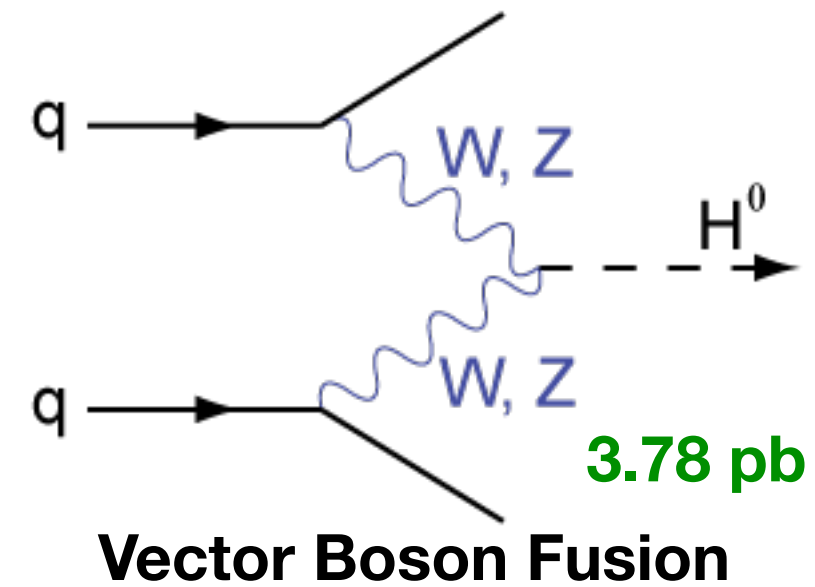
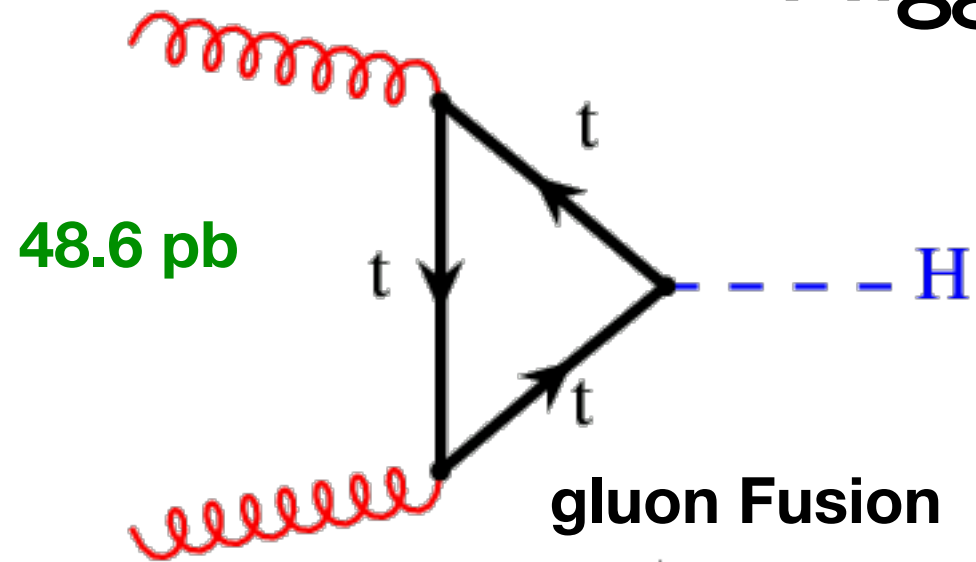


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SUSY SM Higgs

Dr. I.Ojalvo

Higgs Production



Higgs Decay Modes

Standard Model Higgs with $m_H = 125$ GeV:

bb - 57% of decays

- Large branching fraction but also has a **large background rate**

WW - 21% of decays

- Large number of events, complicated kinematics

gg - 9%

$\tau\tau$ - 6%

- Accessible with good τ Identification and Acquisition

cc - 3%

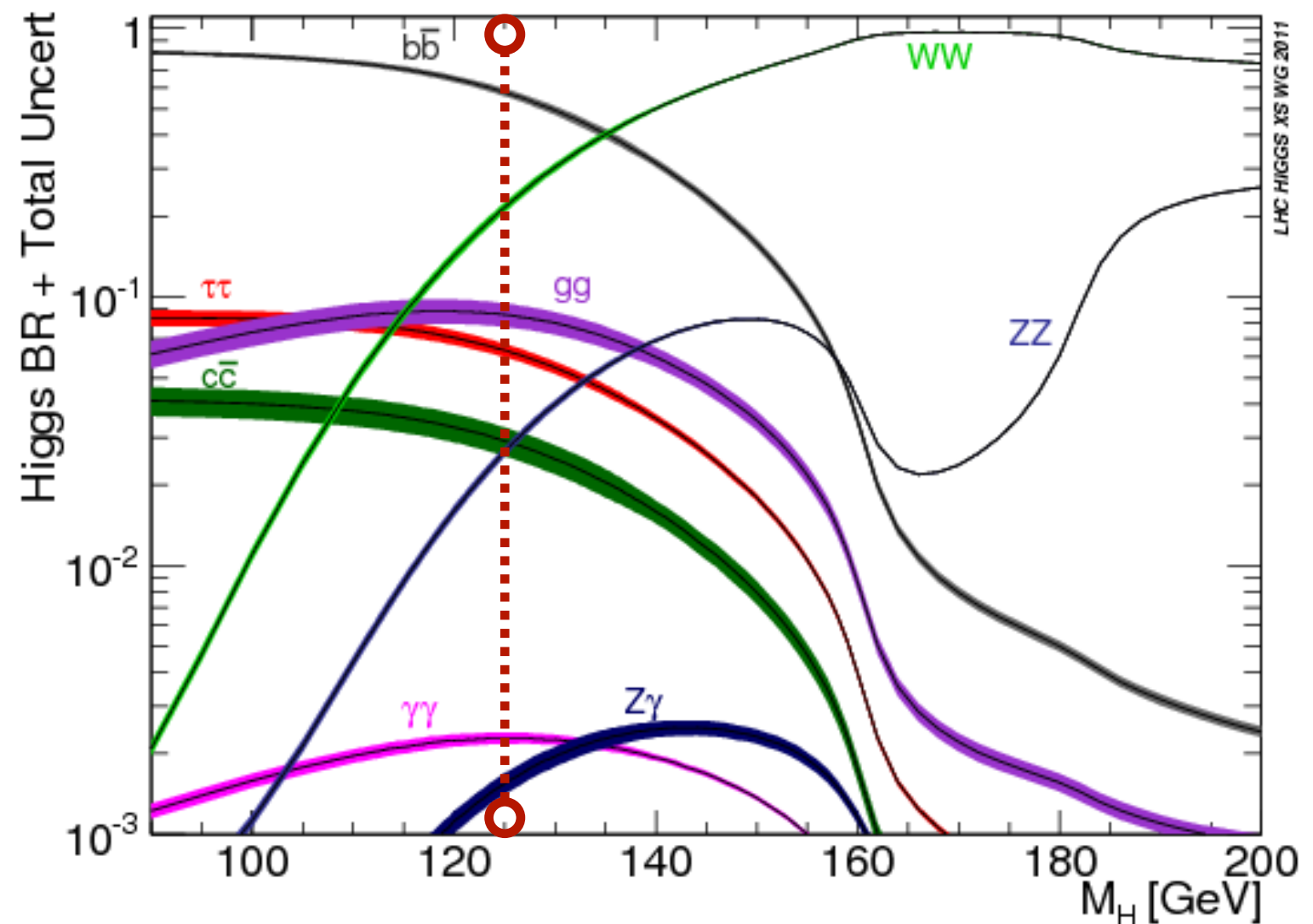
ZZ - 3 %

- Very **pure final state**, low Yield, **discovery channel!**

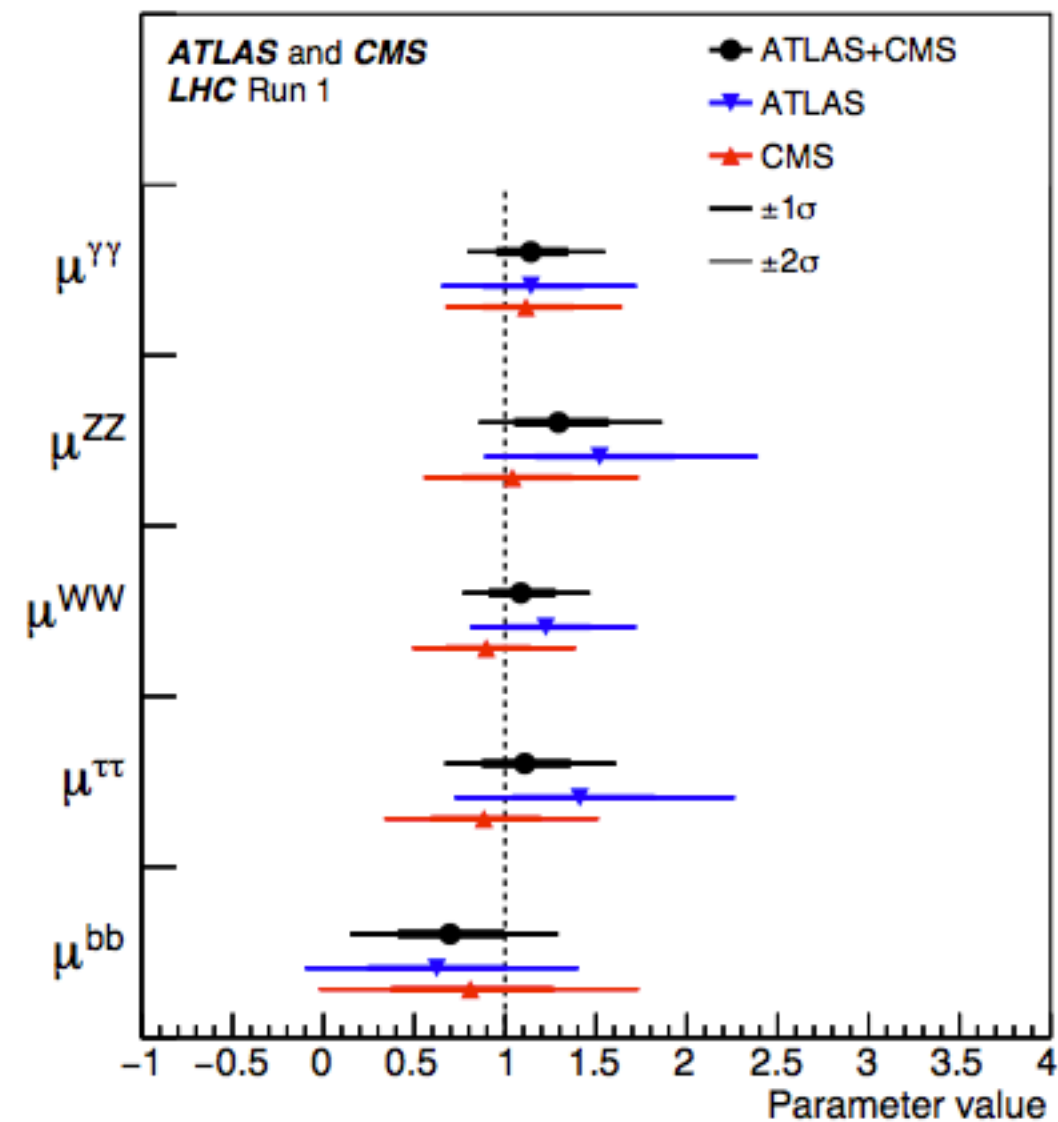
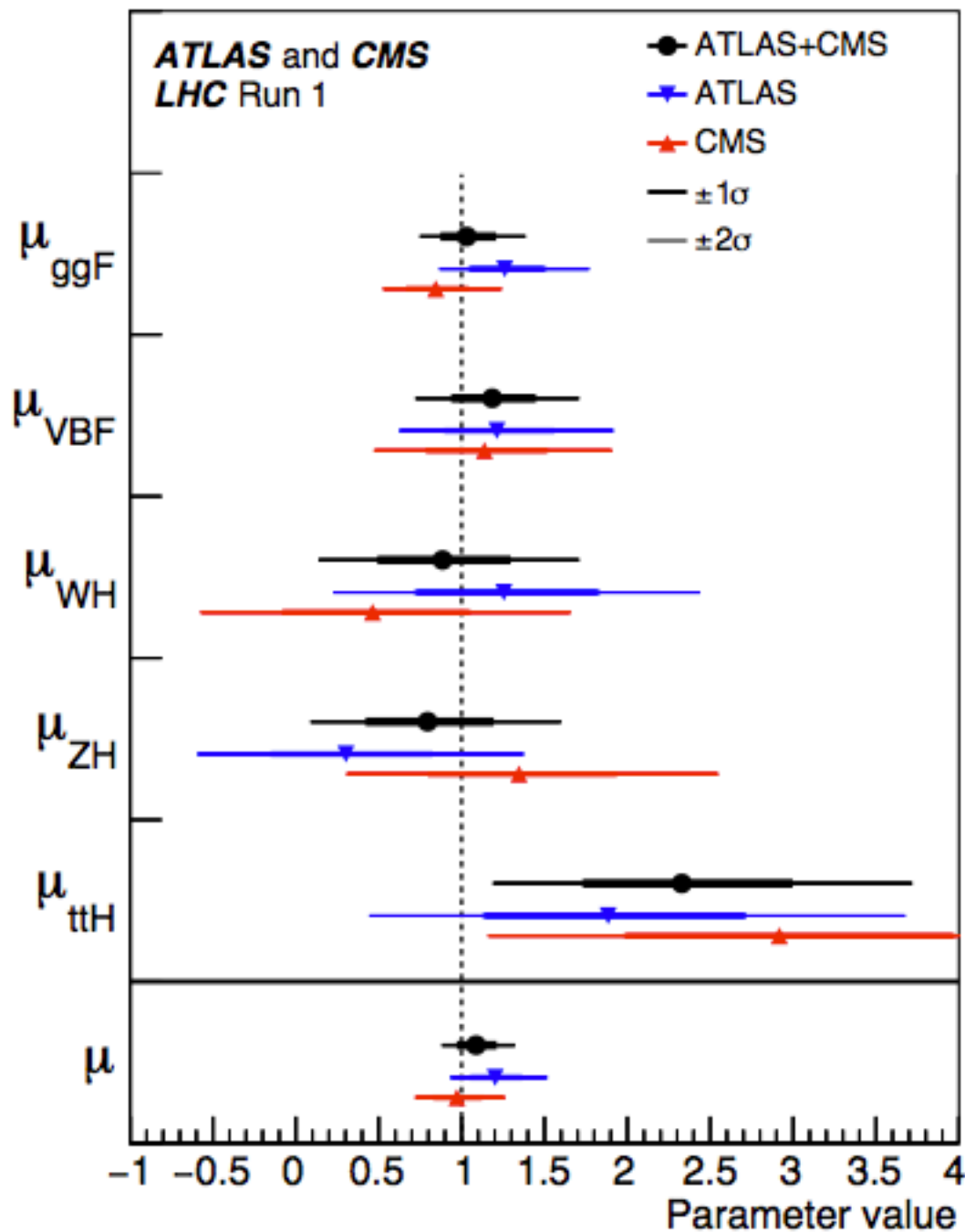
$\gamma\gamma$ - 0.2%

- Well parameterized background, **discovery channel!**

LHC X-Section Working Group



Run I Results



Typically Run I measurements
followed SM expectation*

*Slight excess in ttH

SM Higgs Talks at SUSY 2017



Talk Title	Day	Time	Speaker
Measurement of the SM Higgs boson mass in the diphoton and 4l decay channels using the ATLAS detector	Monday	14:00	Marcello Fanti (University of Milano and INFN)
Measurement of the Higgs Boson cross sections and properties in the diphoton, ZZ and WW decay channels using the ATLAS detector	Monday	14:20	Marco Sessa (INFN Roma Tre)
H(125) Decay to Fermions at CMS	Monday	14:40	Tyler Ruggles (University of Wisconsin- Madison)
H(125) Decay To Muons at CMS	Monday	15:00	Adrian Perieanu (University of Hamburg)
Measurement of the Higgs boson cross sections and properties using the bb, $\tau\tau$, and $\mu\mu$ decay channels with the ATLAS detector	Monday	15:20	Quentin Buat (CERN)
$h \rightarrow bb$ at the LHC and an e+e- collider	Monday	15:40	Siddharth Dwivedi (Harish-Chandra Institute, Allahabad)
Search for Standard Model Higgs production in association with top quark pairs using 13 TeV at CMS	Tuesday	14:00	Ram Krishna Dewanjee (NICPB Tallin Estonia)
Search for associated production of Higgs boson with a single top at CMS	Tuesday	14:20	Hamed Bakhshiansohi (CP3,UCL)
Search for the SM Higgs boson in the ttH production channel using the ATLAS detector	Tuesday	14:40	Vadim Kostyukhin (Bonn University)
Search for rare Higgs decays at CMS	Tuesday	15:00	Shilpi Jain (National Central University, Taiwan)
Search for invisible Higgs boson decay at CMS	Tuesday	15:20	Kajari Mazumdar (TIFR)
Search for non-standard, rare or invisible decays of the Higgs boson with the ATLAS detector	Tuesday	15:40	Daniela Bortoletto (TIFR)

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SUSY SM Higgs

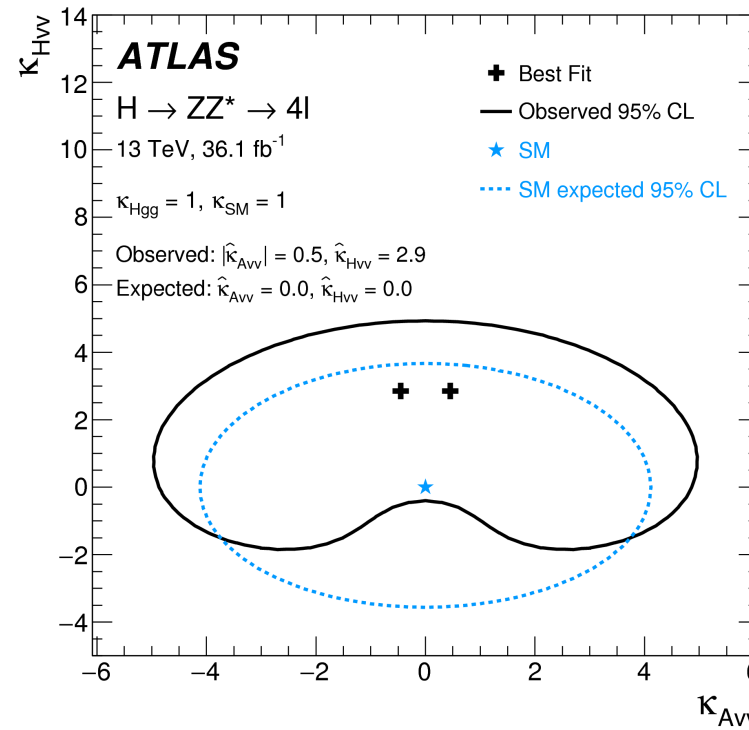
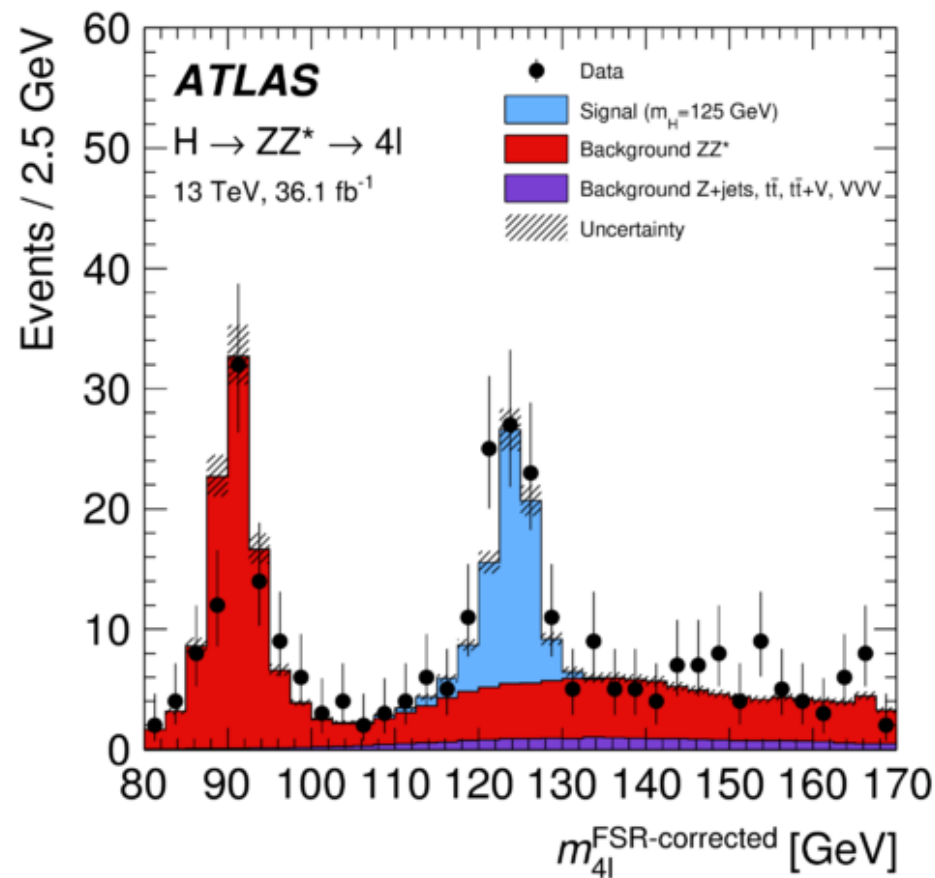
Dr. I.Ojalvo

Run II Results by Experiment

13 TeV	WW	ZZ	$\gamma\gamma$	bb	$\tau\tau$	$\mu\mu$	cc
ggH	CMS	ATLAS CMS	ATLAS CMS		CMS	ATLAS CMS	
VBF	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS	CMS	ATLAS CMS	
WH	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS			
ZH	CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS			ATLAS
ttH	ATLAS	ATLAS CMS	ATLAS CMS	ATLAS CMS	ATLAS CMS		

Bosons $H \rightarrow ZZ$

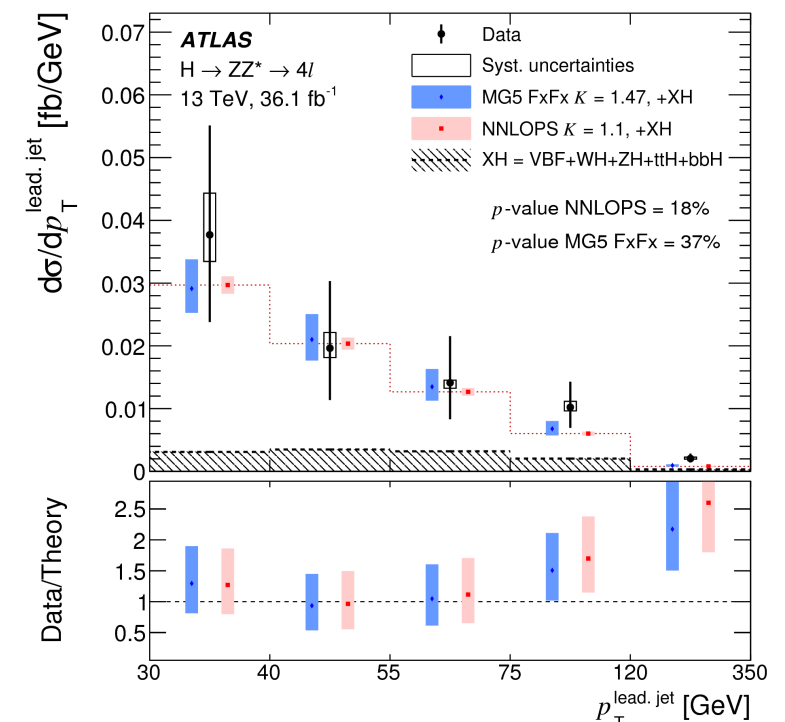
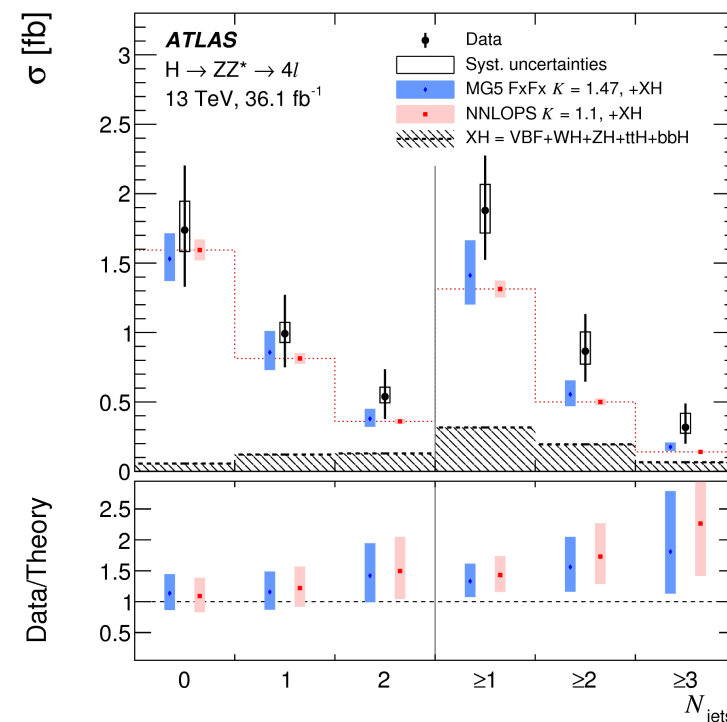
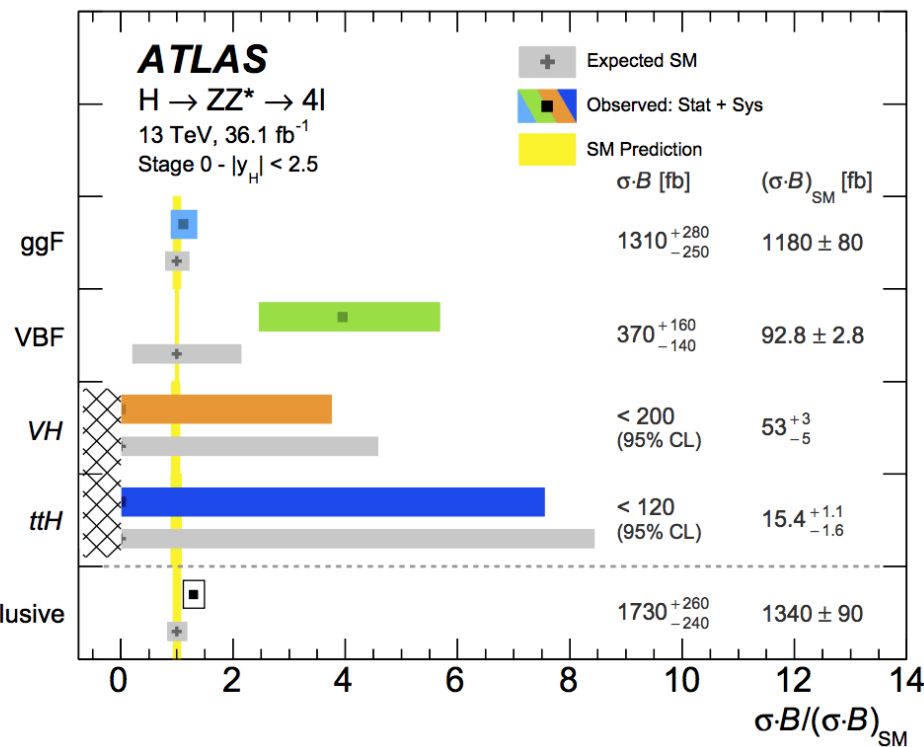
ATLAS EXPERIMENT



$$\mathcal{L}_0^V = \left\{ \kappa_{SM} \left[\frac{1}{2} g_{HZZ} Z_\mu Z^\mu + g_{HWW} W_\mu^+ W^{-\mu} \right] - \frac{1}{4} \left[\kappa_{Hgg} g_{Hgg} G_{\mu\nu}^a G^{a,\mu\nu} + \tan \alpha \kappa_{Agg} g_{Agg} G_{\mu\nu}^a \tilde{G}^{a,\mu\nu} \right] - \frac{1}{4} \frac{1}{\Lambda} \left[\kappa_{HZZ} Z_{\mu\nu} Z^{\mu\nu} + \tan \alpha \kappa_{AZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu} \right] - \frac{1}{2} \frac{1}{\Lambda} \left[\kappa_{HWW} W_{\mu\nu}^+ W^{-\mu\nu} + \tan \alpha \kappa_{AWW} W_{\mu\nu}^+ \tilde{W}^{-\mu\nu} \right] \right\} \mathcal{X}_0.$$

$\mathcal{X}_0$ defines a new bosonic state
 Coupling terms describe CP-even and CP-odd interactions

Study of the tensor structure of the Higgs through **additional BSM terms** added to the effective Lagrangian
 - No significant deviation from SM observed



Precise **Production** and **Different Cross Section** measurements made using the $H \rightarrow ZZ$ channel
2.2 σ excess in VBF

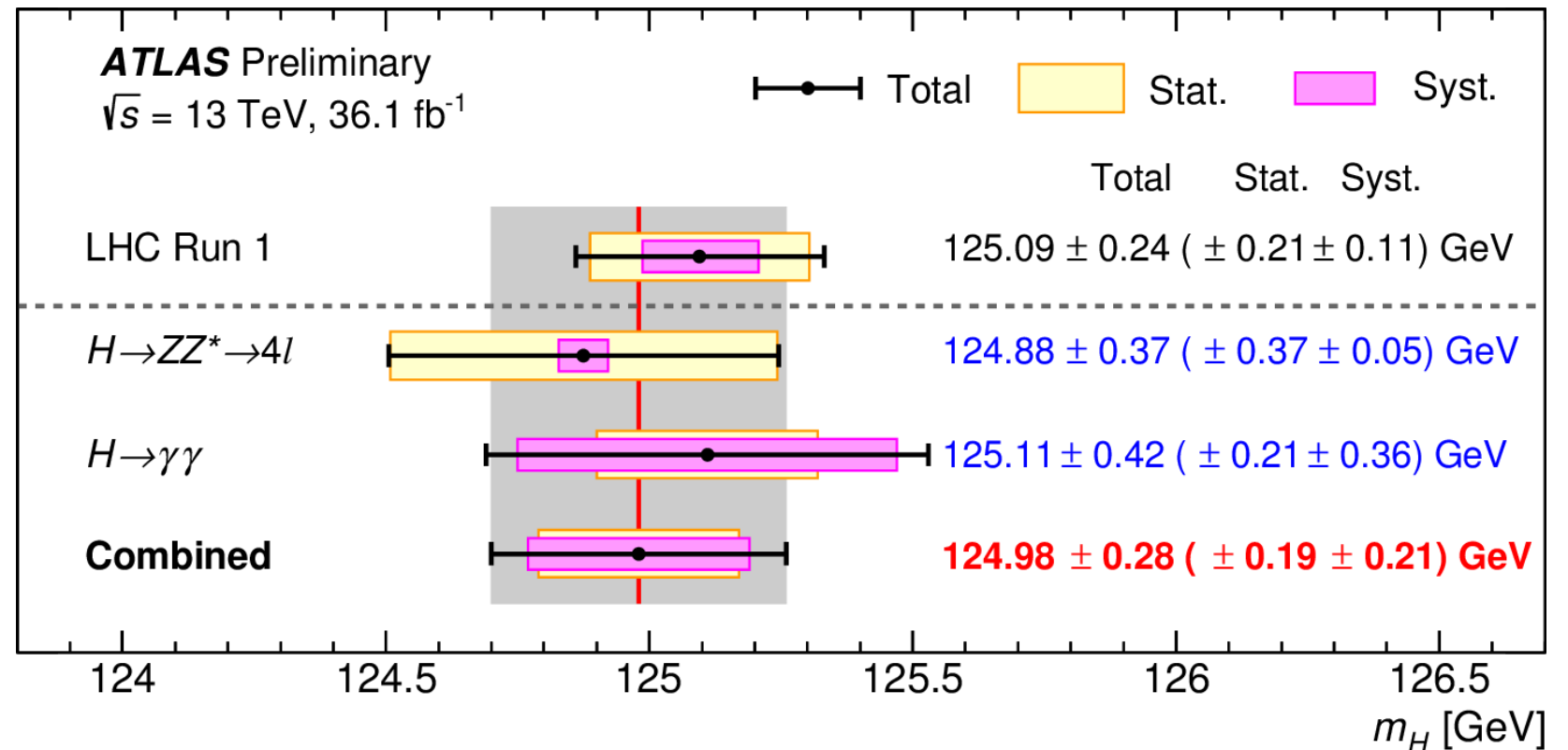
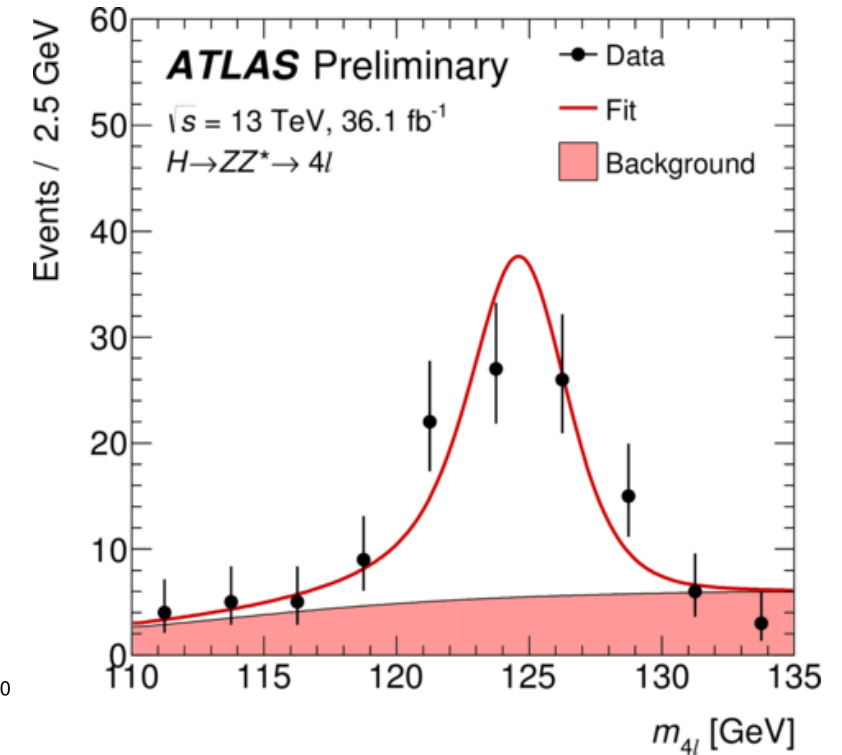
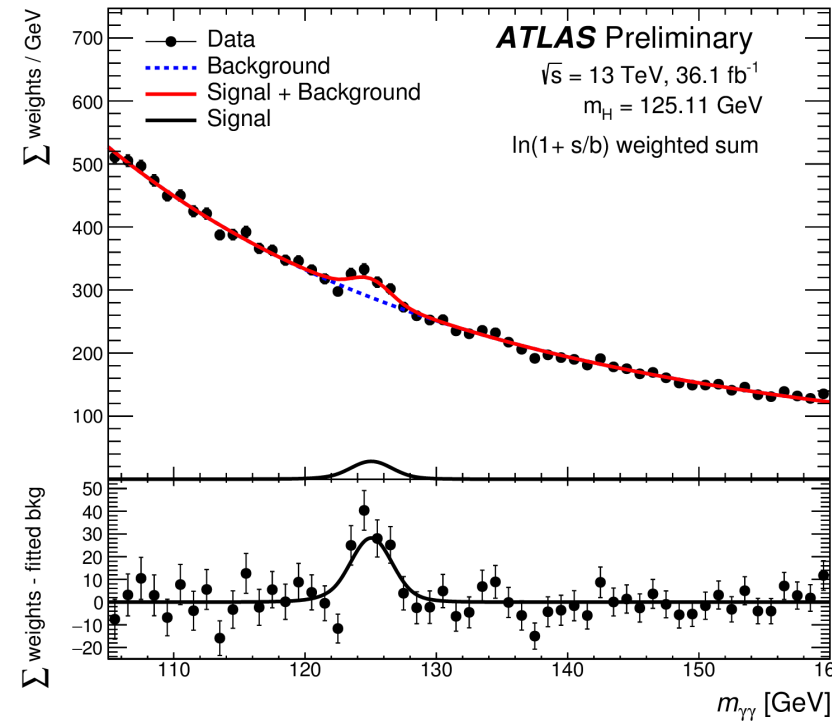
Higgs Mass Measurement using $H \rightarrow ZZ/H \rightarrow \gamma\gamma$ ATLAS EXPERIMENT

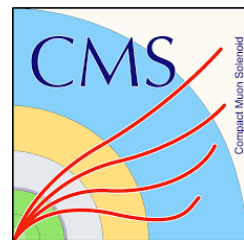


$H \rightarrow ZZ^* \rightarrow 4\ell$ channel
measured mass
is 124.88 ± 0.37 GeV

$H \rightarrow \gamma\gamma$ channel measured
mass is 125.10 ± 0.42 GeV

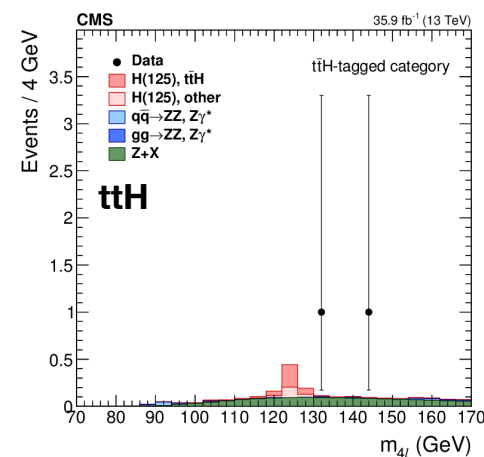
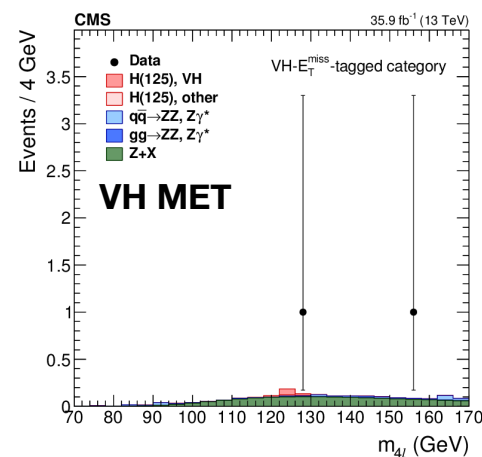
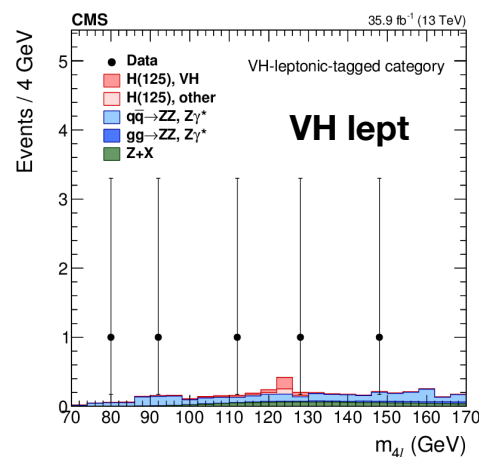
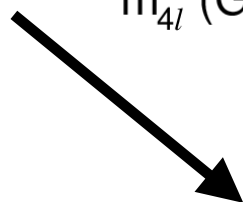
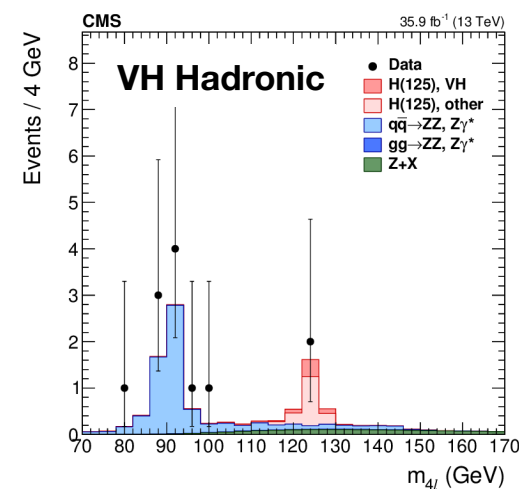
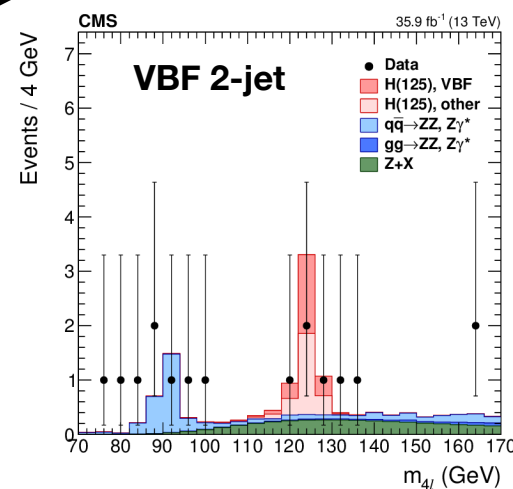
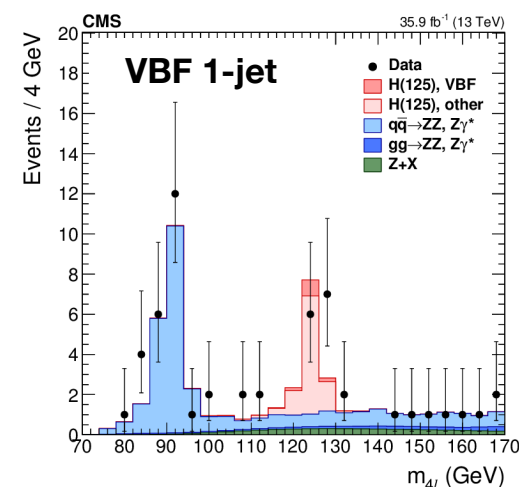
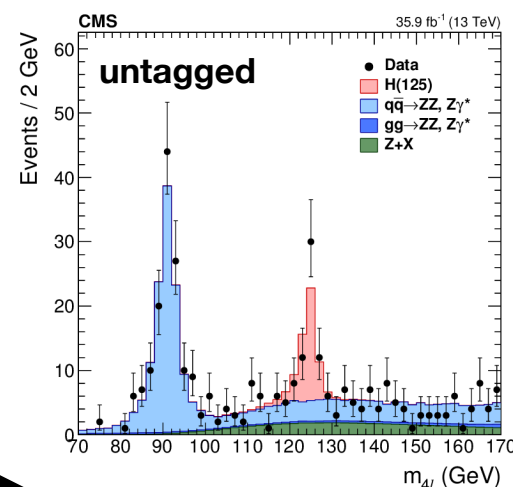
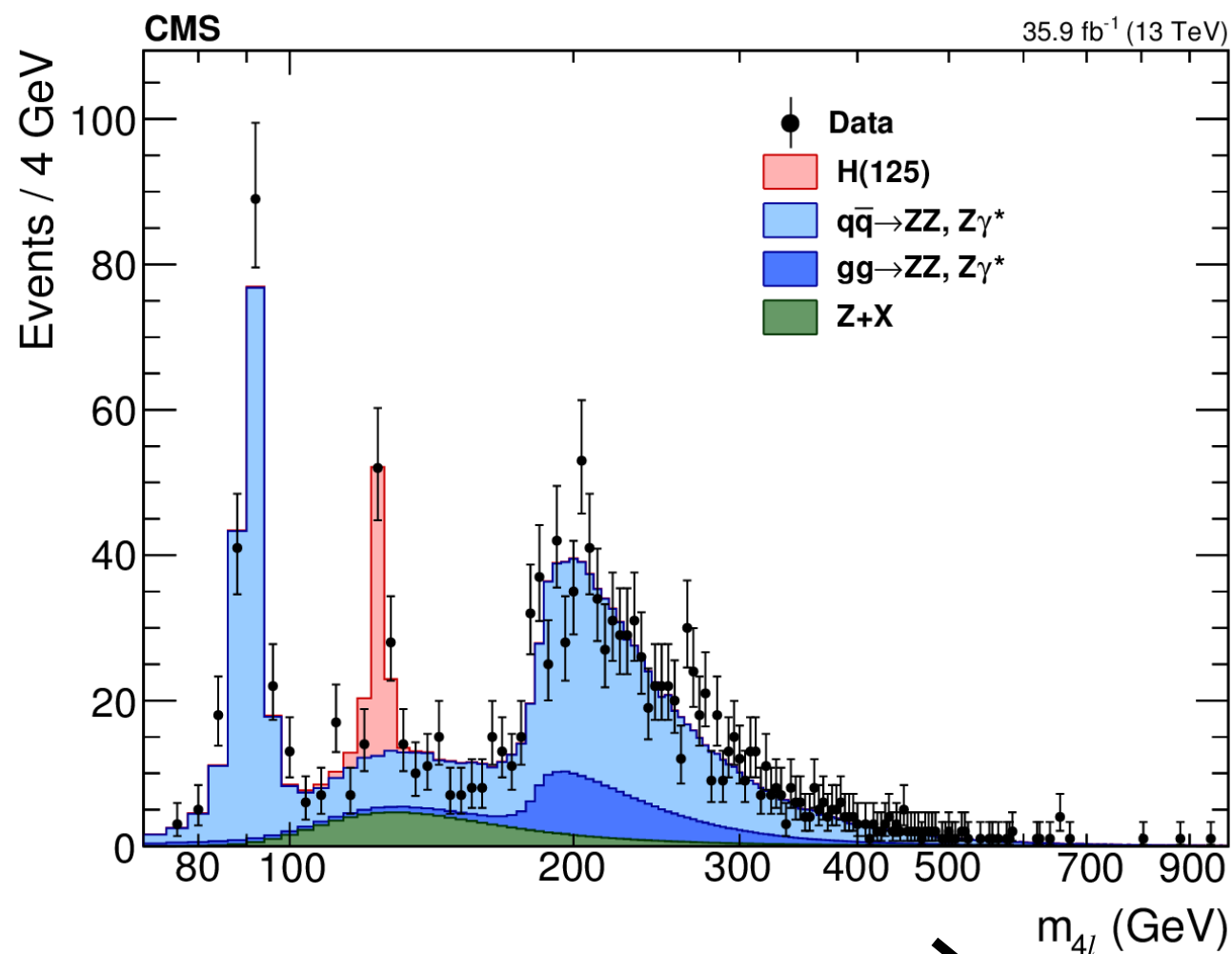
Simultaneous fit to the
invariant mass distributions
in the two channels
is 124.97 ± 0.28 GeV





Bosons $H \rightarrow ZZ$

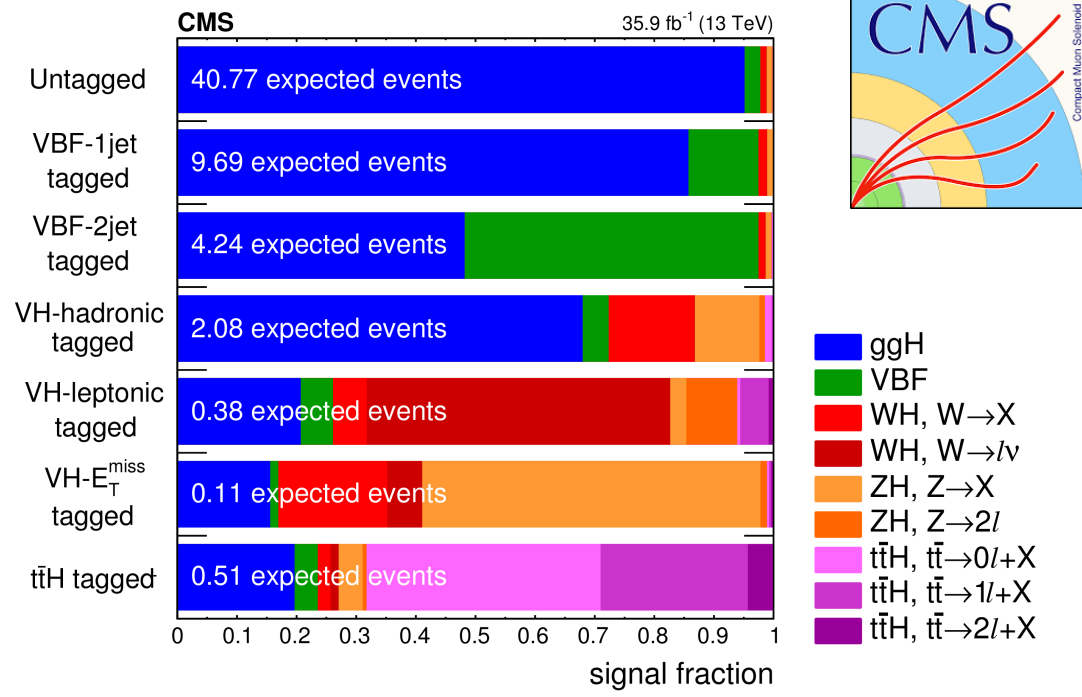
CMS EXPERIMENT



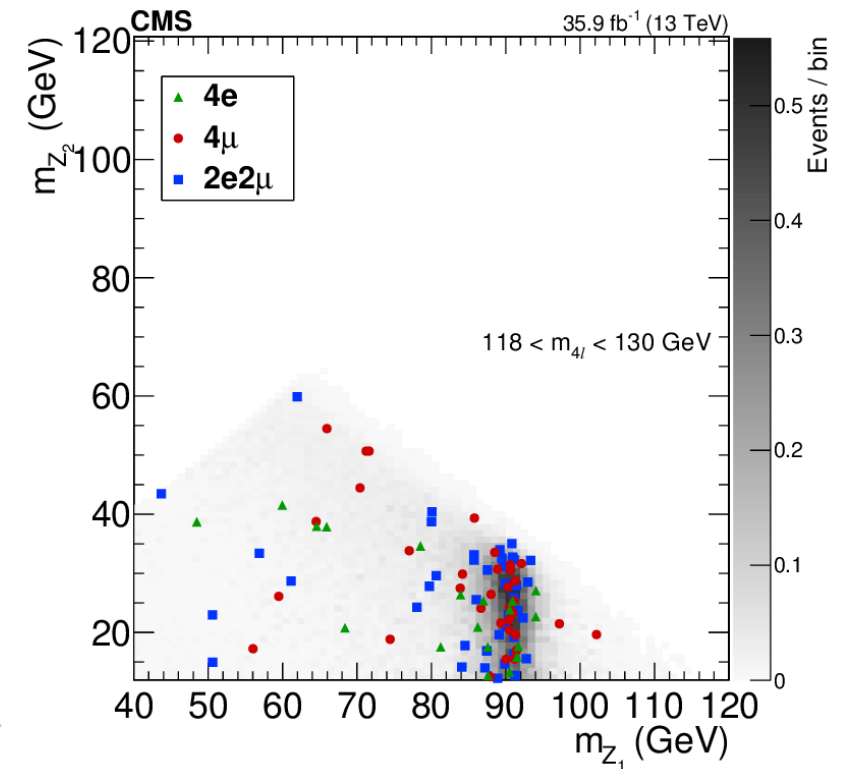
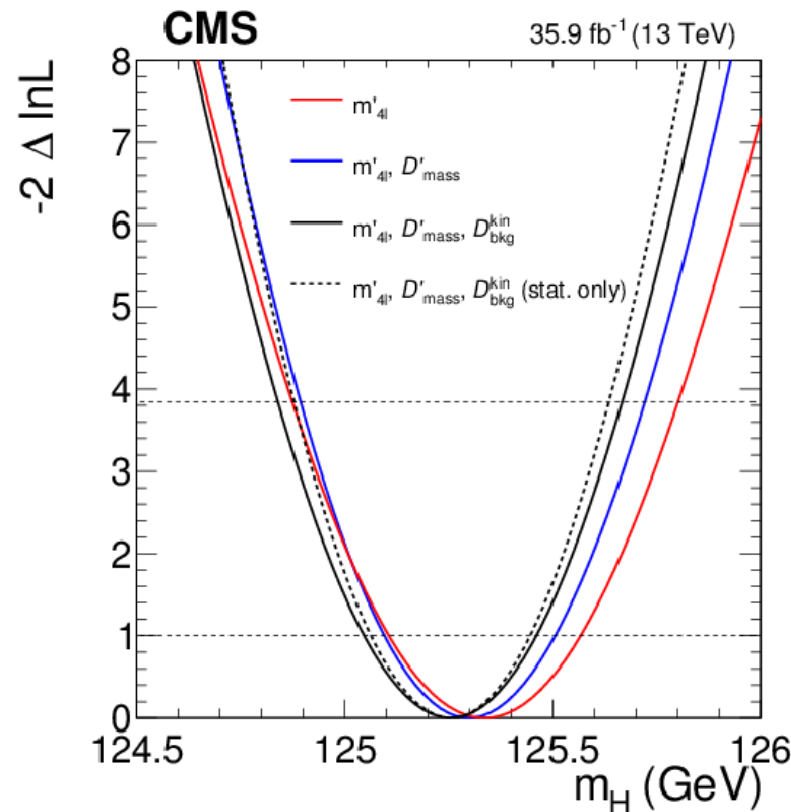
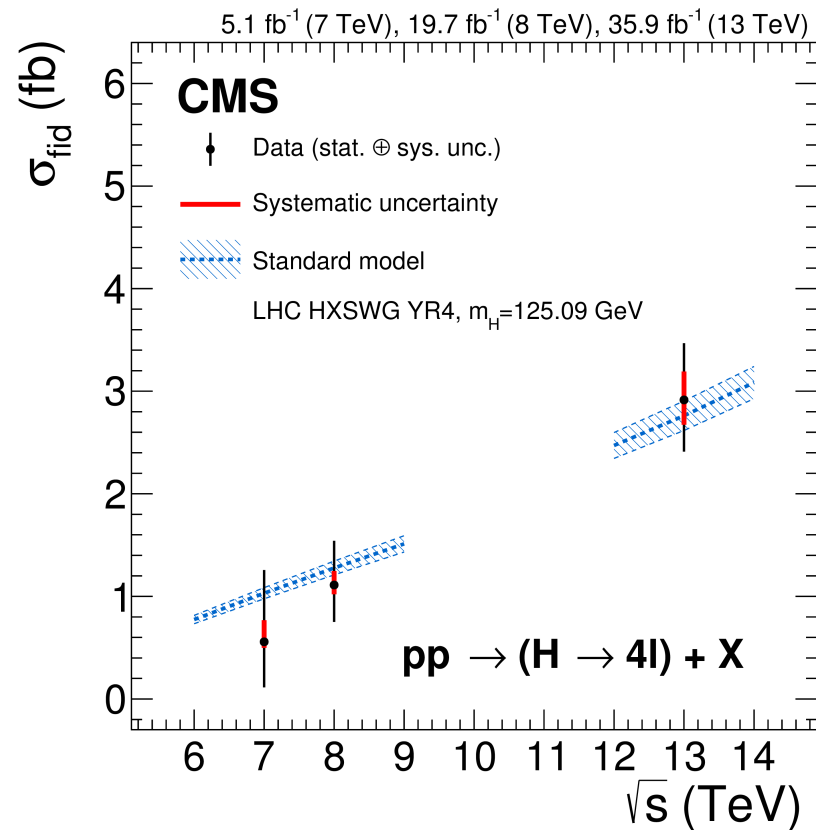
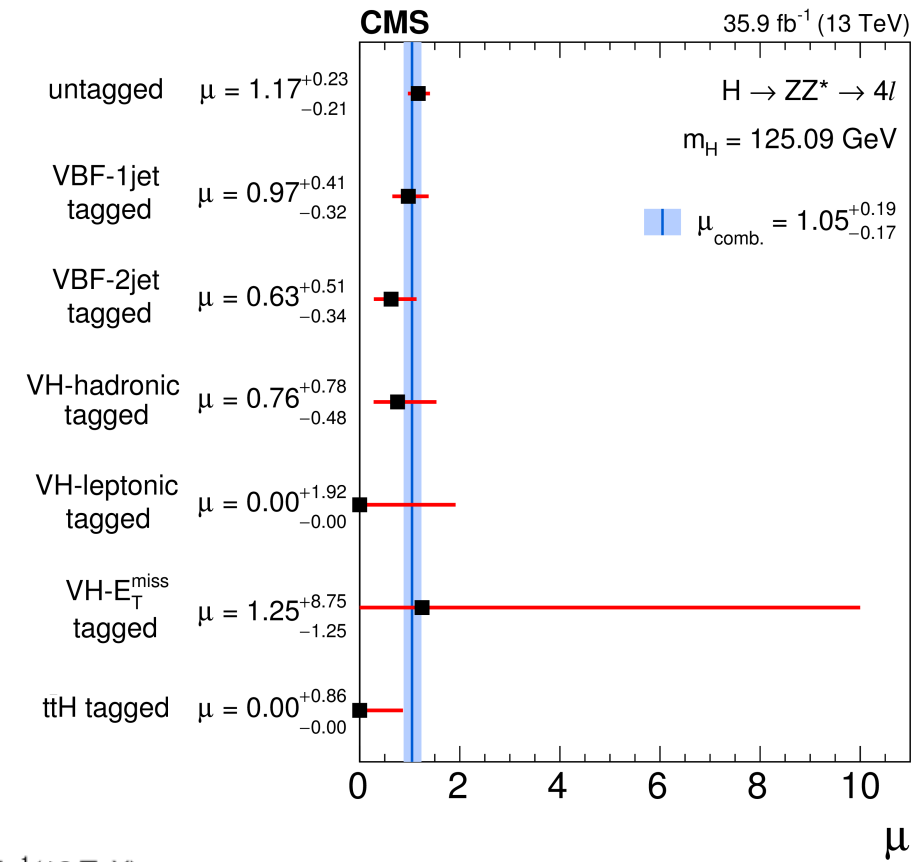
CMS also uses this channel to probe the higgs production mechanisms and compare to prediction

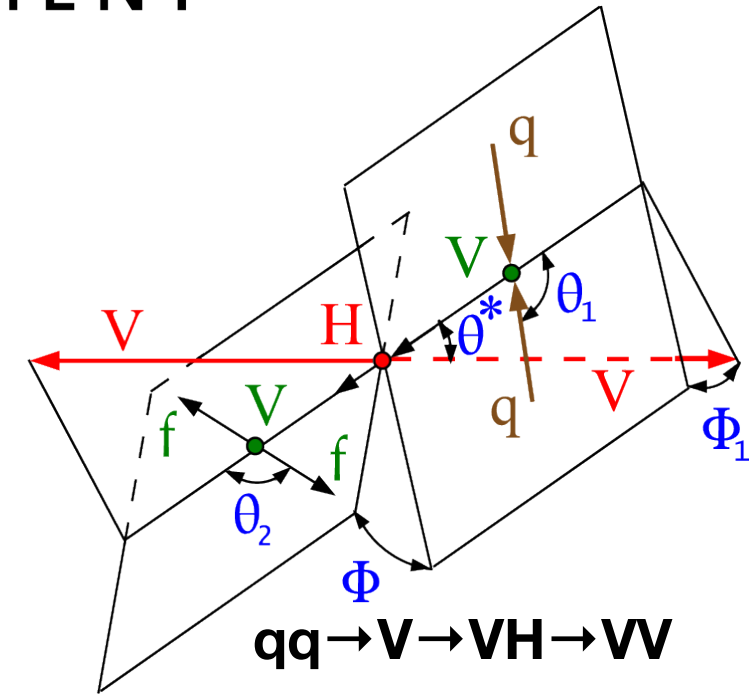
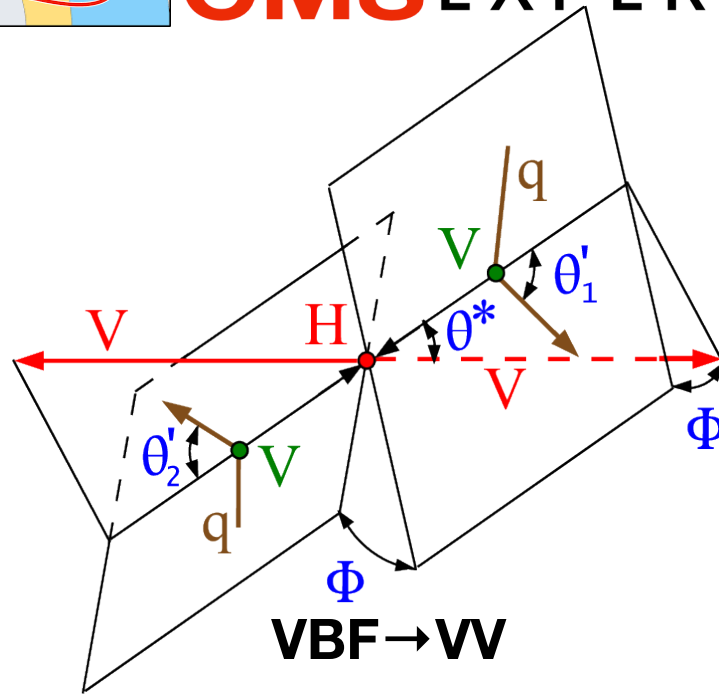
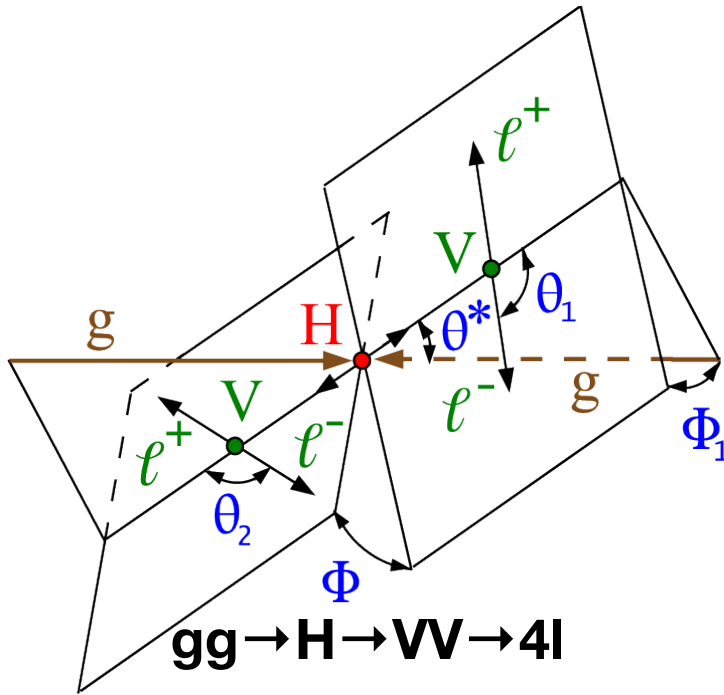
Bosons $H \rightarrow ZZ$

CMS EXPERIMENT



No $m(Z_1)$ constraint	3D: $\mathcal{L}(m_{4l}, \mathcal{D}_{\text{mass}}, \mathcal{D}_{\text{bkg}}^{\text{kin}})$	2D: $\mathcal{L}(m_{4l}, \mathcal{D}_{\text{mass}})$	1D: $\mathcal{L}(m_{4l})$
Expected m_H uncertainty change	+8.1%	+11.2%	+21%
Observed m_H (GeV)	125.28 ± 0.22	125.36 ± 0.24	125.39 ± 0.25
With $m(Z_1)$ constraint	3D: $\mathcal{L}(m'_{4l}, \mathcal{D}'_{\text{mass}}, \mathcal{D}_{\text{bkg}}^{\text{kin}})$	2D: $\mathcal{L}(m'_{4l}, \mathcal{D}'_{\text{mass}})$	1D: $\mathcal{L}(m'_{4l})$
Expected m_H uncertainty change	—	+3.2%	+10.7%
Observed m_H (GeV)	125.26 ± 0.21	125.30 ± 0.21	125.34 ± 0.23



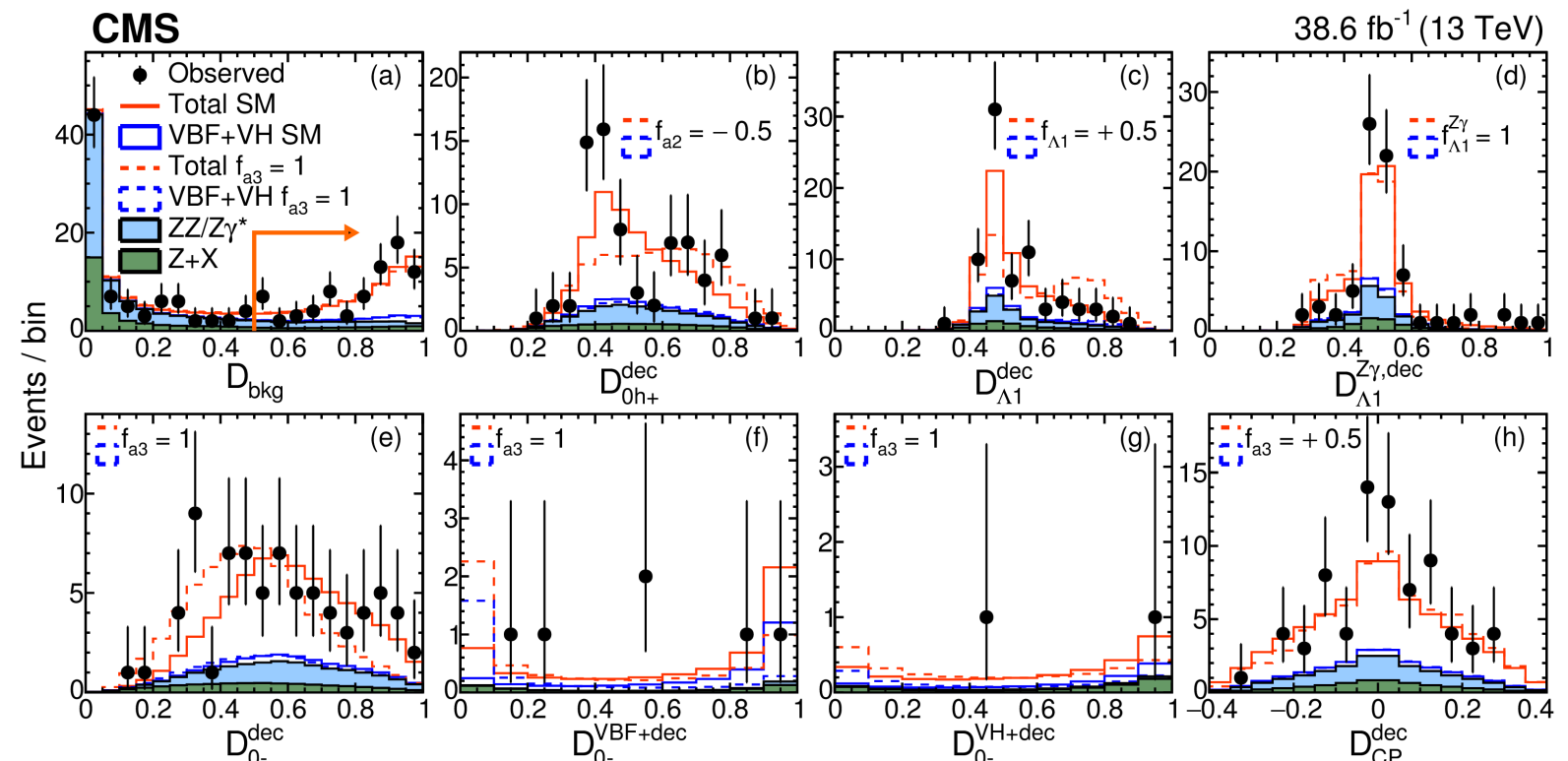


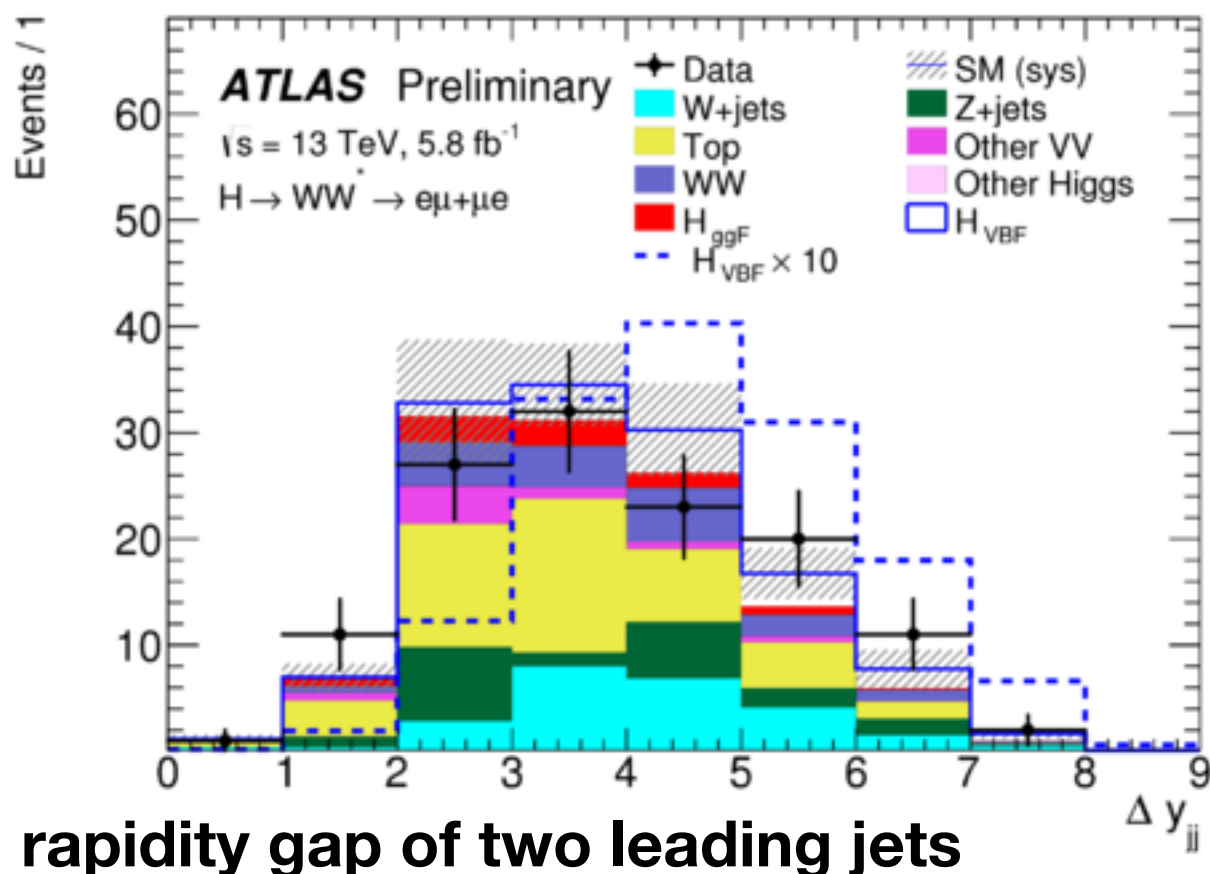
$$A(HVV) \sim \left[a_1^{VV} + \frac{\kappa_1^{VV} q_1^2 + \kappa_2^{VV} q_2^2}{(\Lambda_1^{VV})^2} \right] m_{V1}^2 \epsilon_{V1}^* \epsilon_{V2}^* + a_2^{VV} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{VV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu},$$

Anomalous interactions of a spin-zero H boson with two spin-one gauge bosons VV, such as ZZ, Zγ, γγ, WW, and gg, are parameterized with a scattering amplitude that includes three tensor structures

Discriminants are defined which test the four parameters sensitive to the four anomalous couplings

Three categories of events analyzed **no deviation from SM expectations observed**





rapidity gap of two leading jets

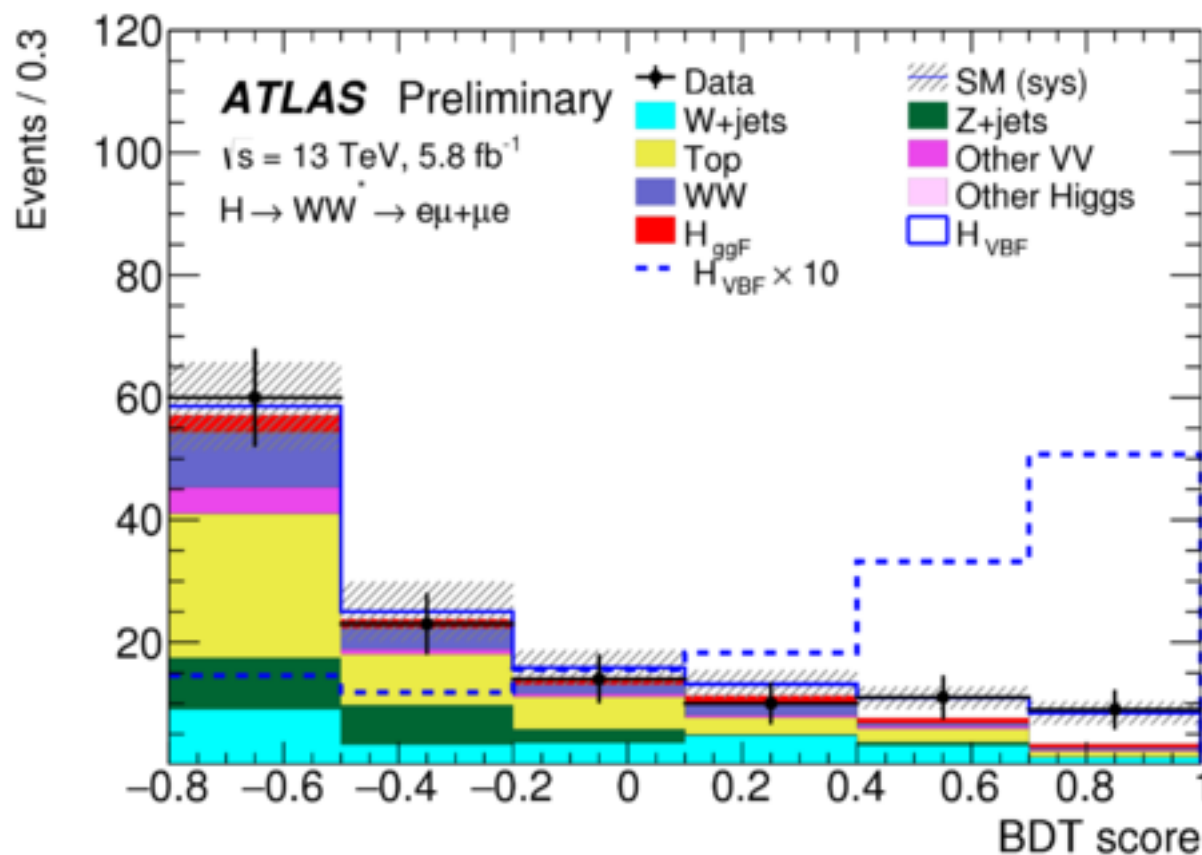
Targets VBF and WH production

VBF: one e, one μ and at least two jets

WH: 3 light leptons with total charge of ± 1

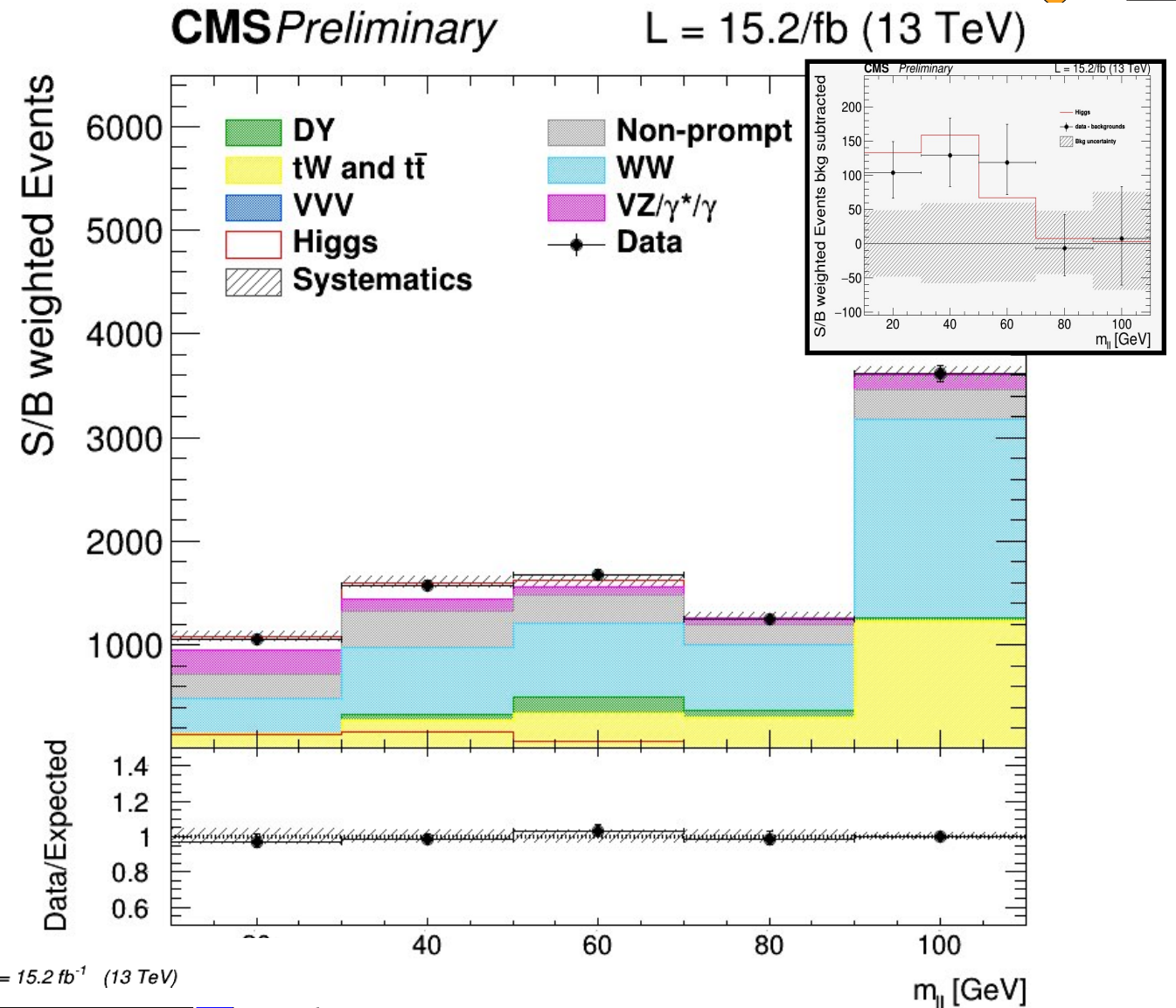
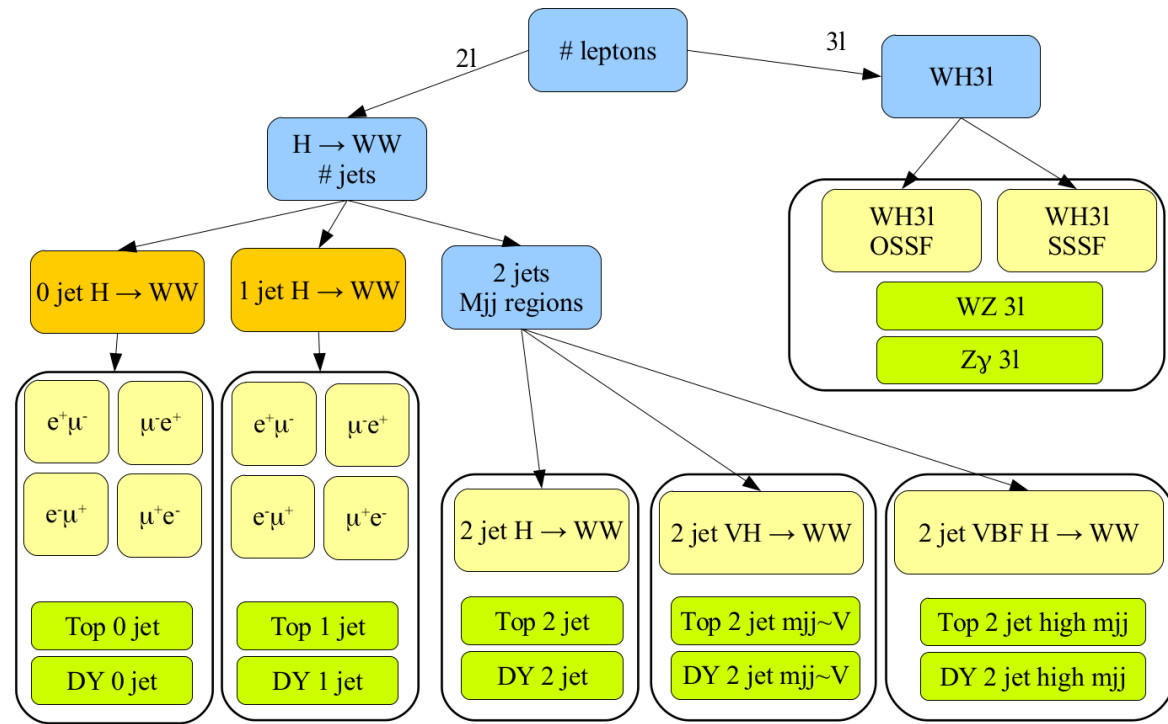
Eight kinematic variables used for BDT

$$\mu_{VBF} = 1.7^{+1.1}_{-0.9} \text{ and } \mu_{WH} = 3.2^{+4.4}_{-4.2}$$



Category	Z-dominated	Z-depleted
WH	2.6 ± 1.0	2.0 ± 0.8
Other Higgs	0.1 ± 0.0	0.1 ± 0.0
VV	13.0 ± 1.6	1.3 ± 0.4
VVV	0.5 ± 0.1	0.4 ± 0.1
Top quark	3.4 ± 0.9	2.8 ± 0.8
Z+jets	2.0 ± 1.6	1.1 ± 1.1
Total background	19.1 ± 2.4	5.6 ± 1.5
Observed	19	9

Upper limits on the cross section times branching fraction of 3.0 pb and 3.3 pb are set for VBF and WH production

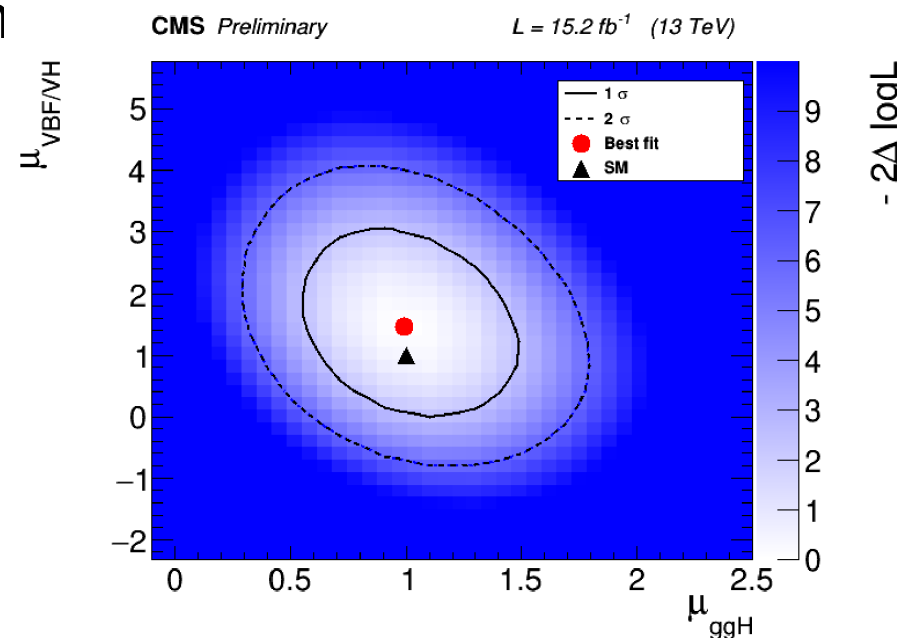


Events selected with an oppositely signed $e\mu$ pair and MET

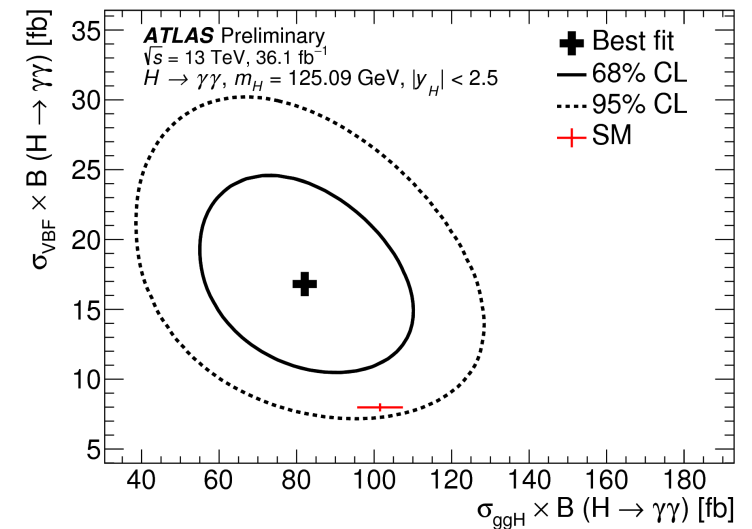
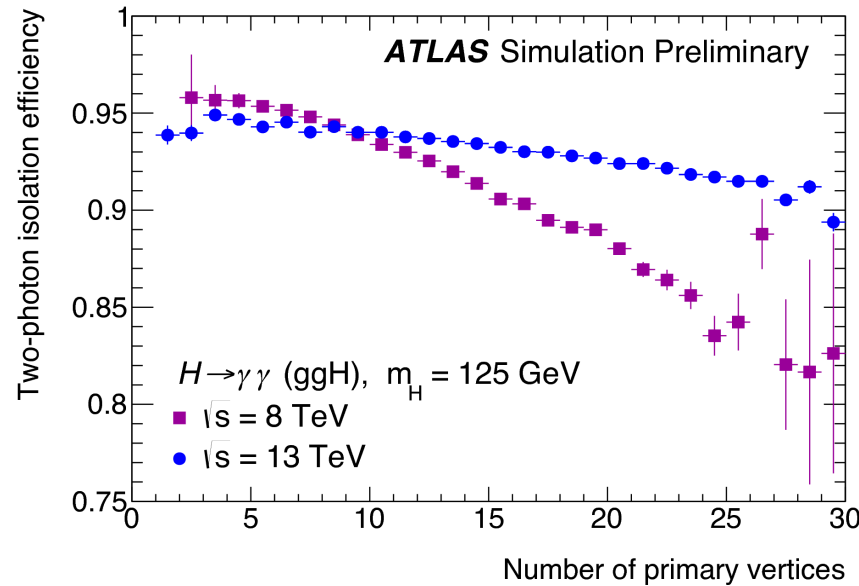
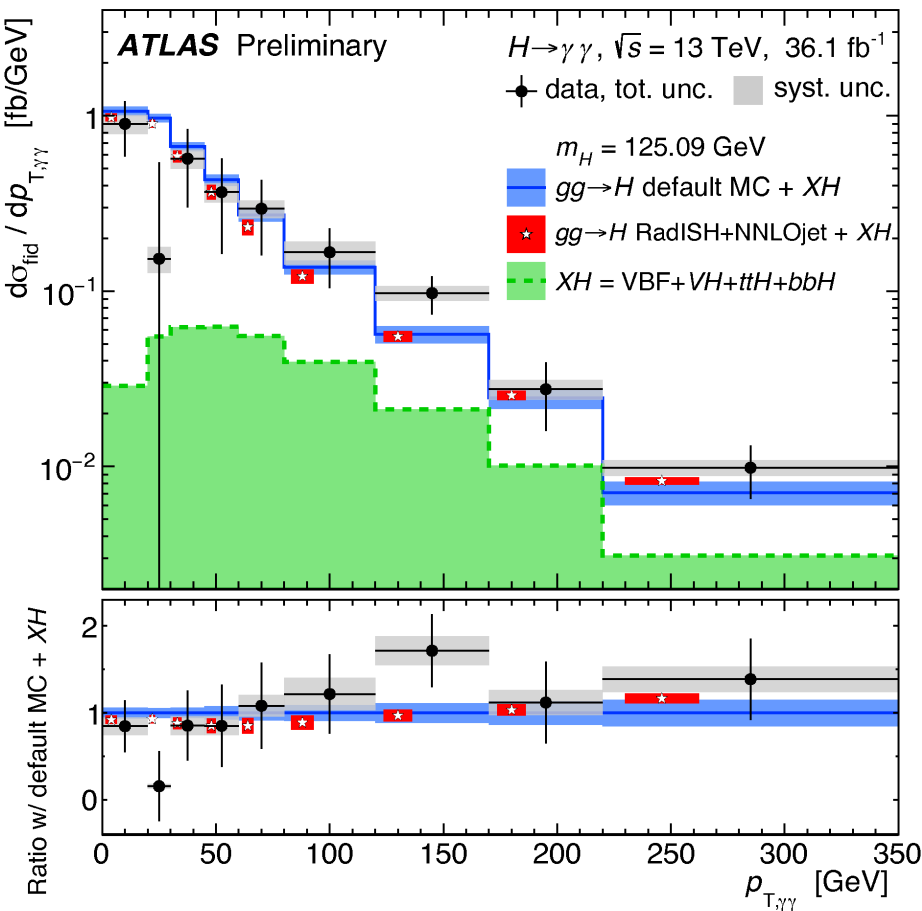
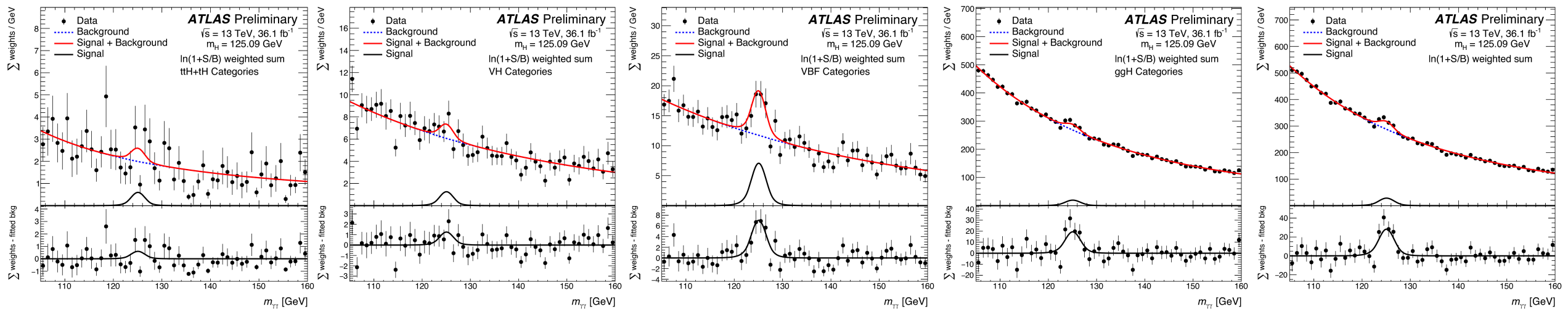
Primary background is from WW

Split by production mechanism

observed (expected) significance is 4.3σ (4.1σ)
observed cross section times BR of 1.05 ± 0.26 SM

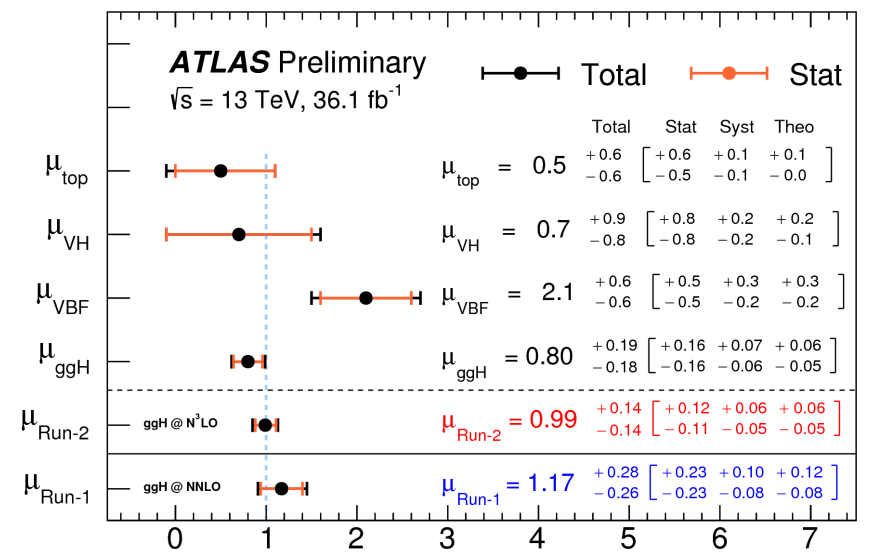


category	significance	σ/σ_{SM}
0-jet	2.7 (2.9)	$0.9^{+0.4}_{-0.3}$
1-jet	2.1 (2.5)	$1.1^{+0.4}_{-0.4}$
2-jet	2.0 (1.0)	$1.3^{+1.0}_{-1.0}$
VBF 2-jet	2.2 (1.5)	$1.4^{+0.8}_{-0.8}$
VH 2-jet	1.0 (0.4)	$2.1^{+2.3}_{-2.2}$
WH 3-lep	0.0 (0.5)	$-1.4^{+1.5}_{-1.5}$
combination	4.3 (4.1)	$1.05^{+0.27}_{-0.25}$



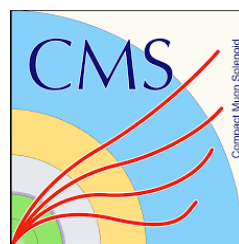
Improved Isolation as compared to Run I

Targeting ttH, VH, VBF, ggH production modes!



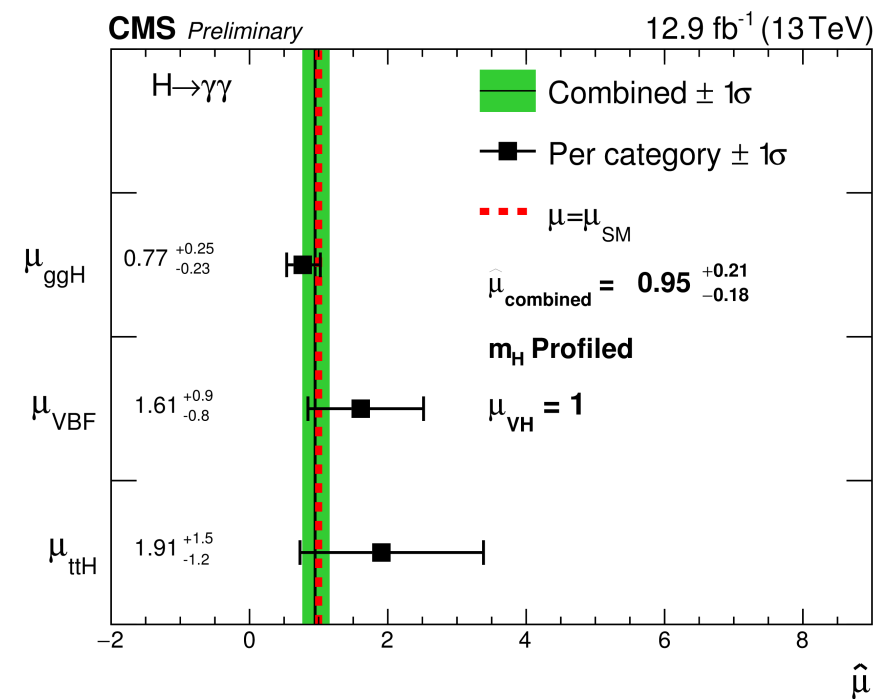
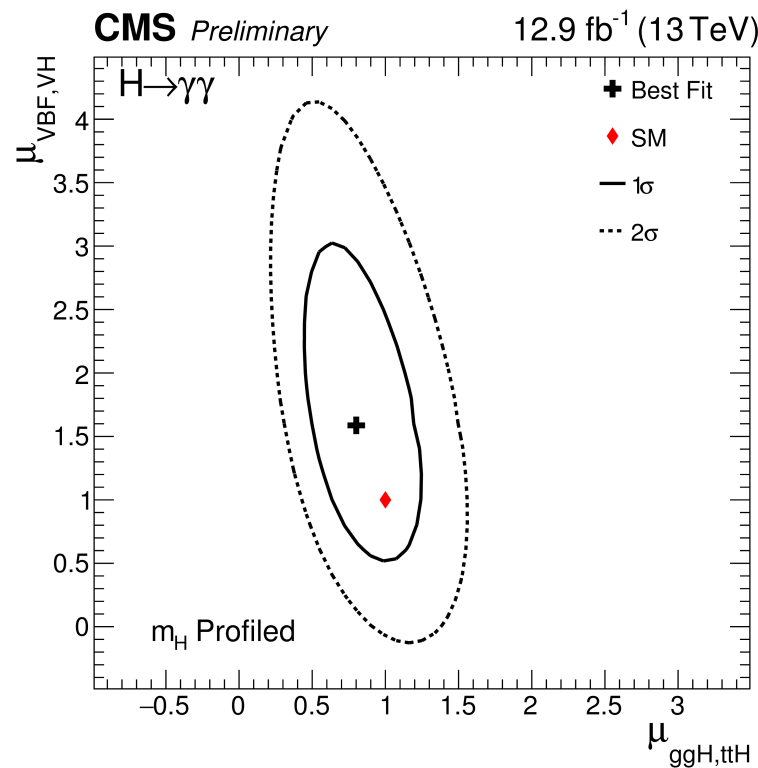
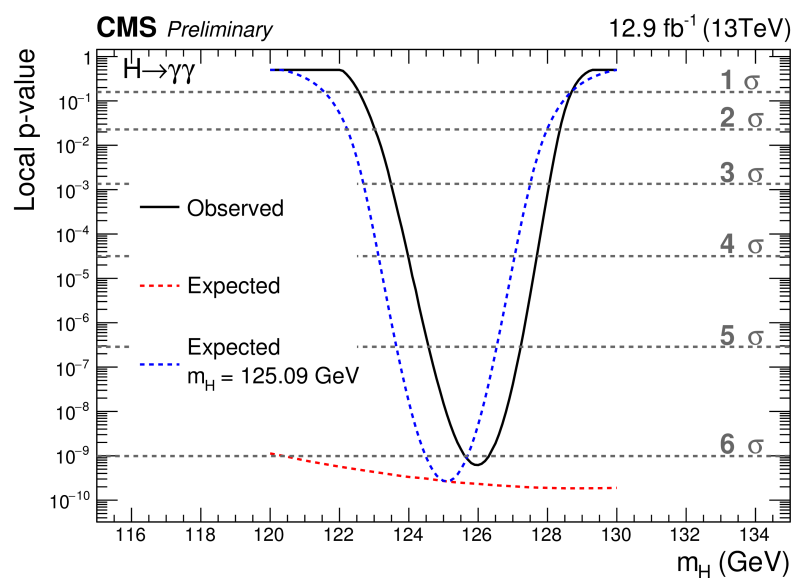
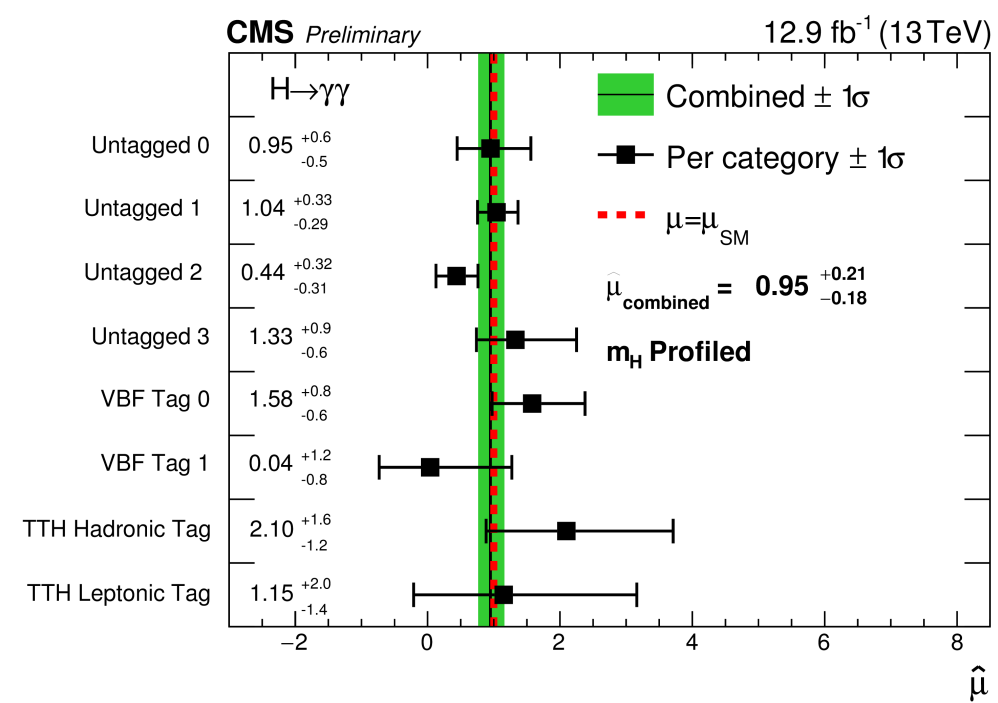
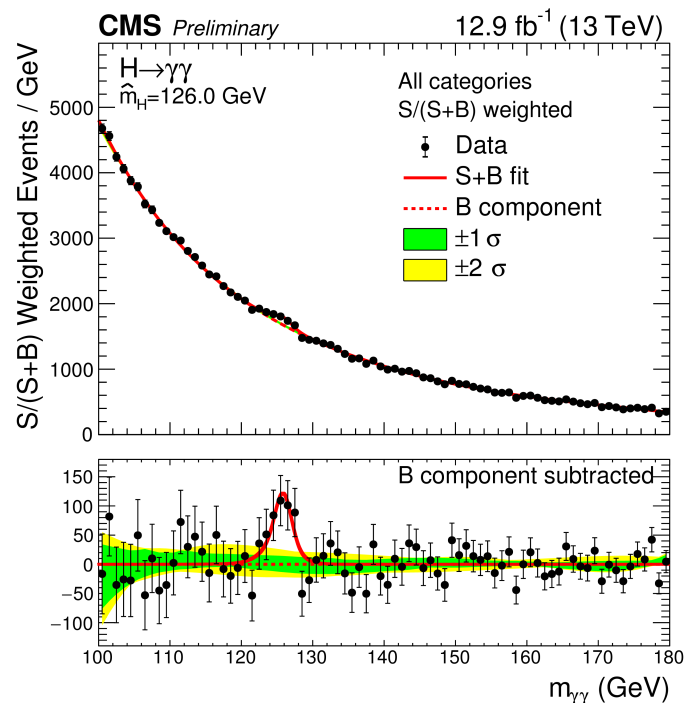
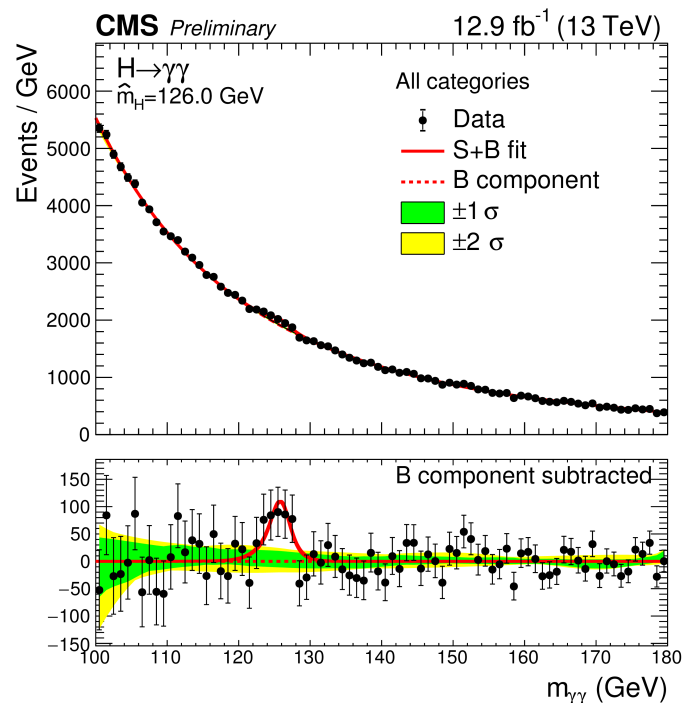
Differential cross-section measured as a function of $p_{T,\gamma\gamma}$, $|y_{\gamma\gamma}|$, and $p_{T,t,\gamma\gamma}$

Signal Strength



$H \rightarrow \gamma\gamma$

CMS EXPERIMENT

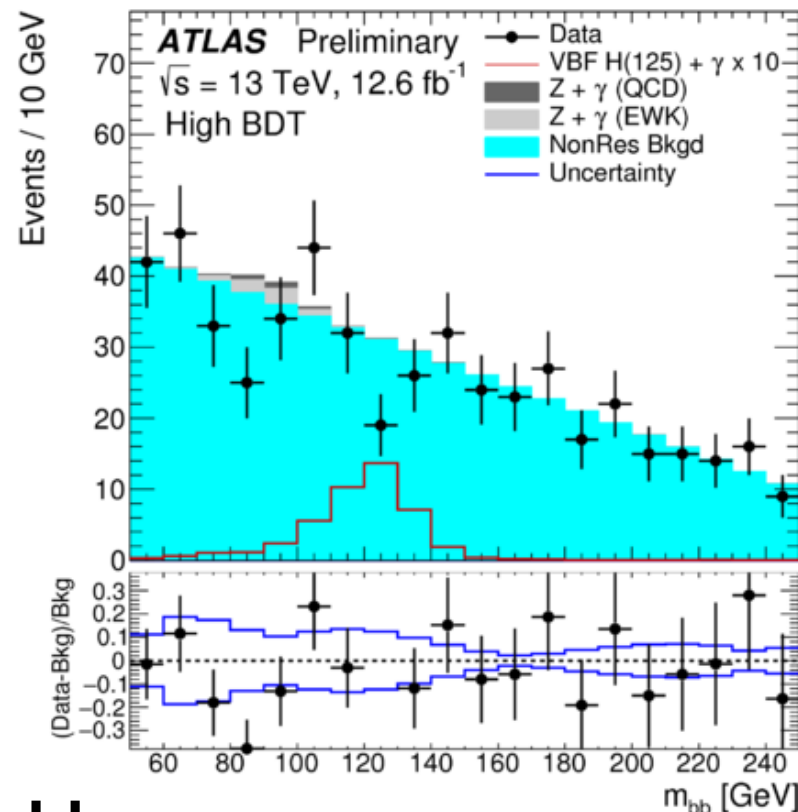
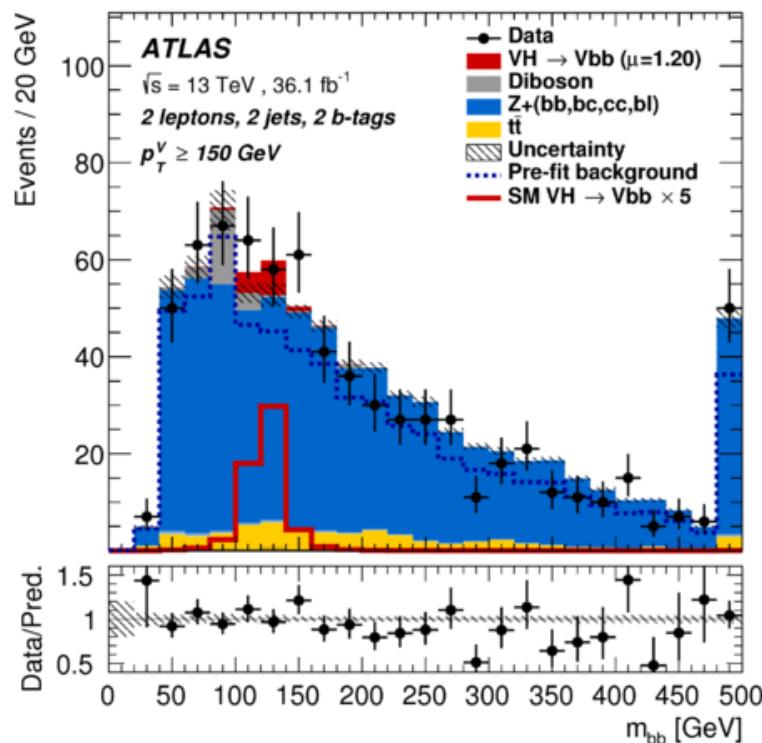
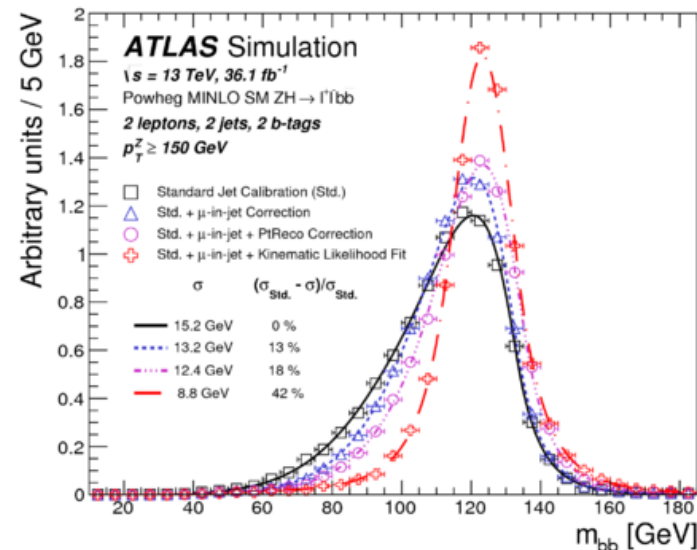
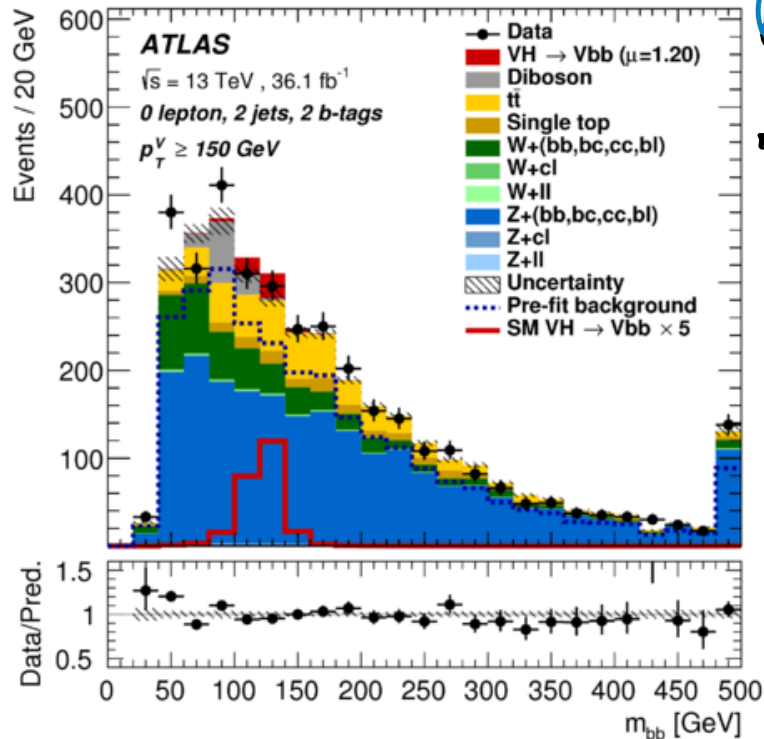


Targeting ttH, VH, VBF, ggH production modes!
Slight excess in VBF mode, but less than ATLAS

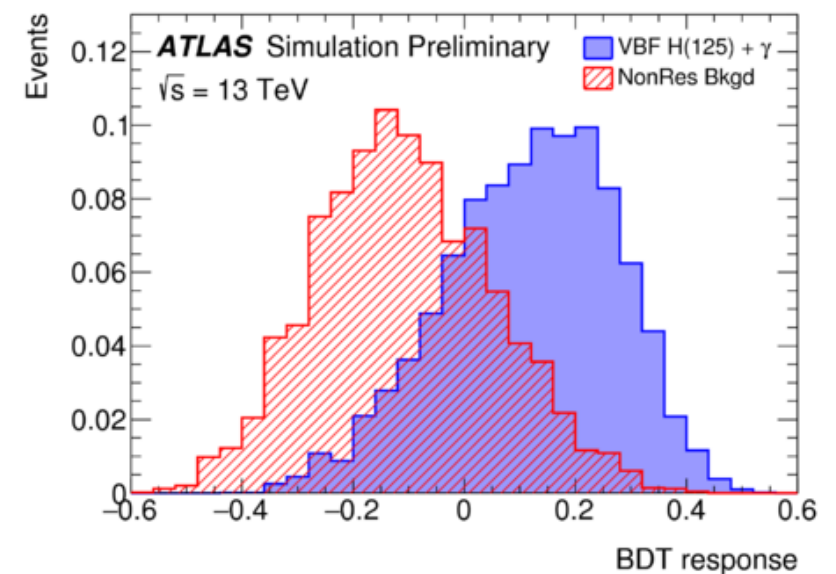


Fermions $H \rightarrow bb$

ATLAS EXPERIMENT



Variable	0-lepton	1-lepton	2-lepton
p_T^V	$\equiv E_T^{\text{miss}}$	×	×
E_T^{miss}	×	×	×
p_{Tb_1}	×	×	×
p_{Tb_2}	×	×	×
p_T	×	×	×
m_{bb}	×	×	×
$\Delta R(b_1, b_2)$	×	×	×
$ \Delta\eta(b_1, b_2) $	×	×	×
$\Delta\phi(V, bb)$	×	×	×
$ \Delta\eta(V, bb) $	×	×	×
m_{eff}	×	×	×
$\min[\Delta\phi(\ell, b)]$	×	×	×
m_T^W	×	×	×
$m_{\ell\ell}$	×	×	×
m_{top}	×	×	×
$ \Delta Y(V, bb) $	×	×	×
Only in 3-jet events			
$p_{T}^{\text{jet}_3}$	×	×	×
m_{bbj}	×	×	×



$ZH \rightarrow \nu\nu bb$, $ZH \rightarrow ll bb$, $WH \rightarrow l\nu bb$,

0- 1- and 2- lepton Categorization (e/ μ)

b-tagging used to select $H \rightarrow bb$ jets per event

Event kinematics + topology used as input to an MVA

Simultaneous binned fit of MVA discriminant across three channels

Dec 11, 2017

SUSY SM Higgs

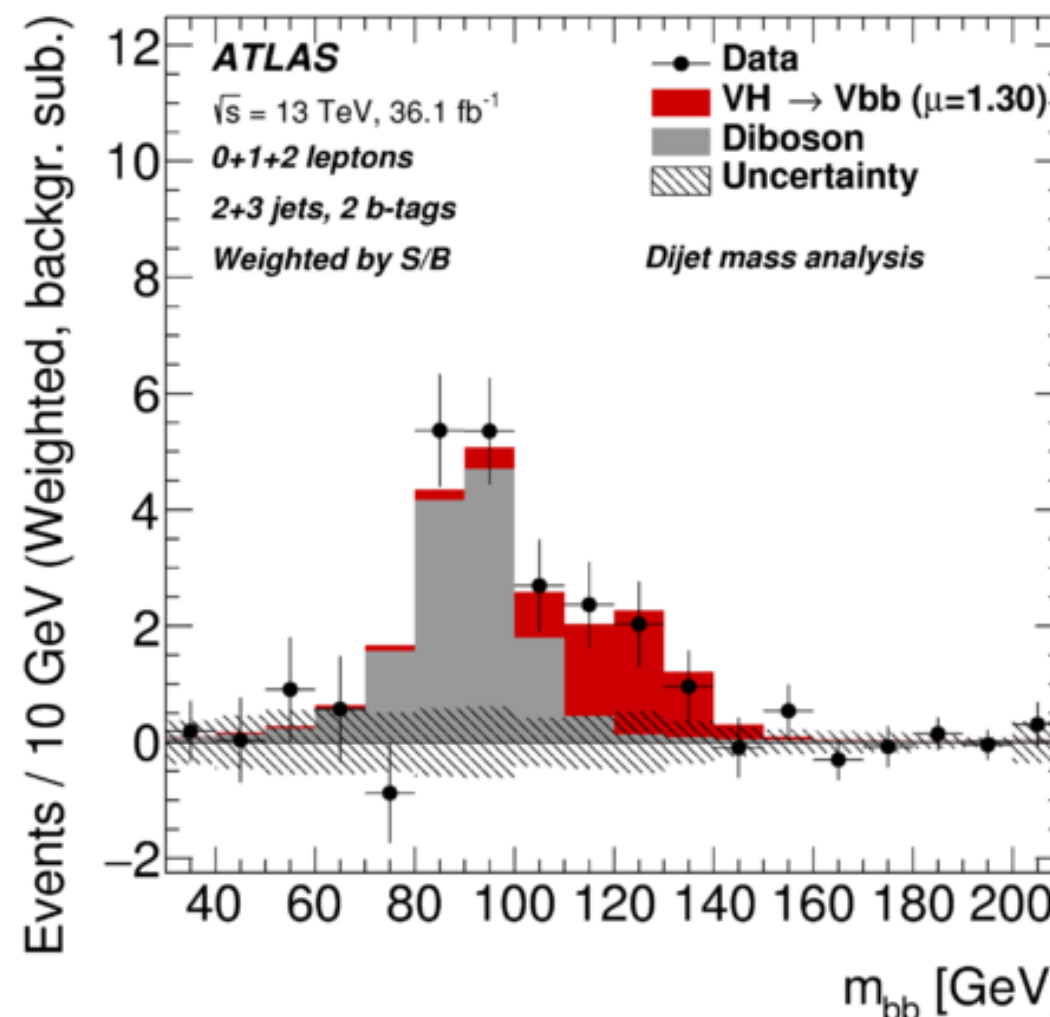
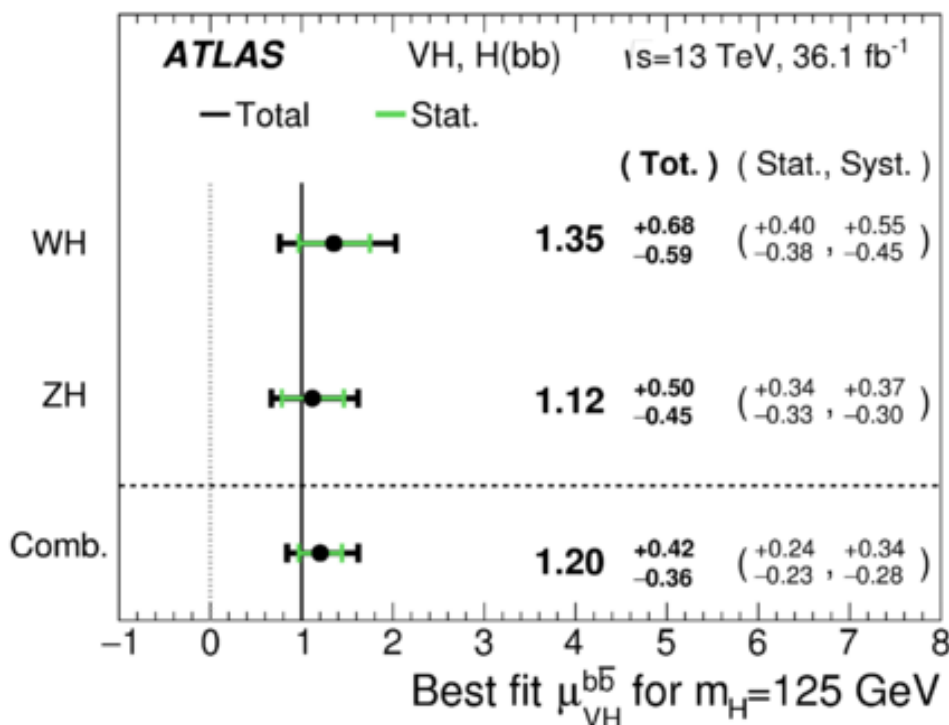
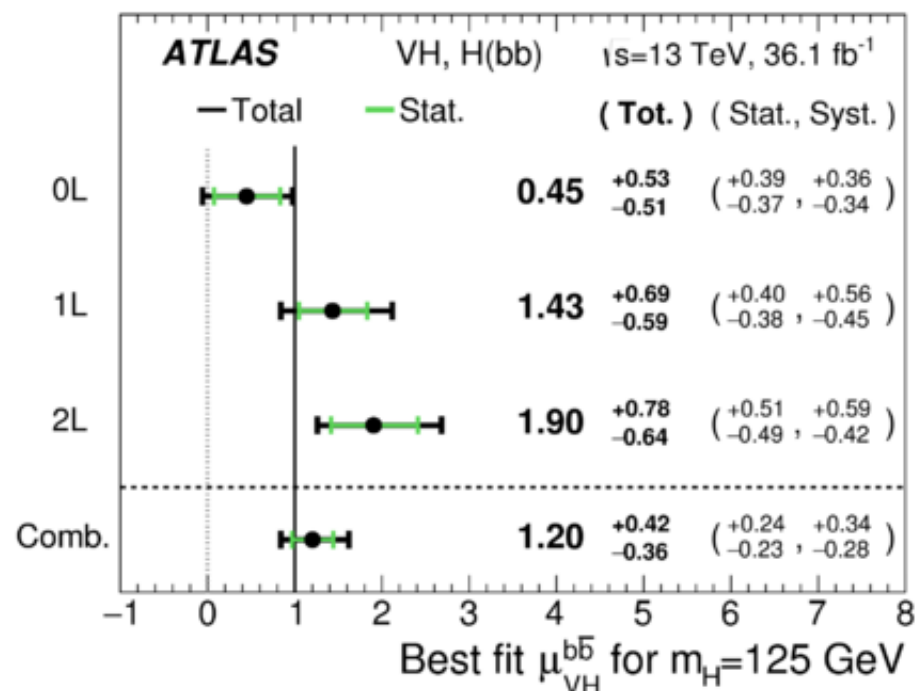
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Targeting:
 $ZH \rightarrow \nu\nu bb$, $ZH \rightarrow ll bb$, $WH \rightarrow l\nu bb$,

Fermions $H \rightarrow bb$

ATLAS EXPERIMENT

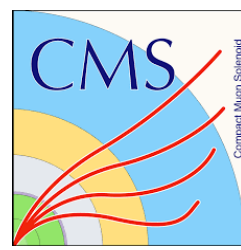
Evidence for the Higgs boson decay into b-quarks with $VH \rightarrow bb$ channel



H-> bb search also performed in VBF

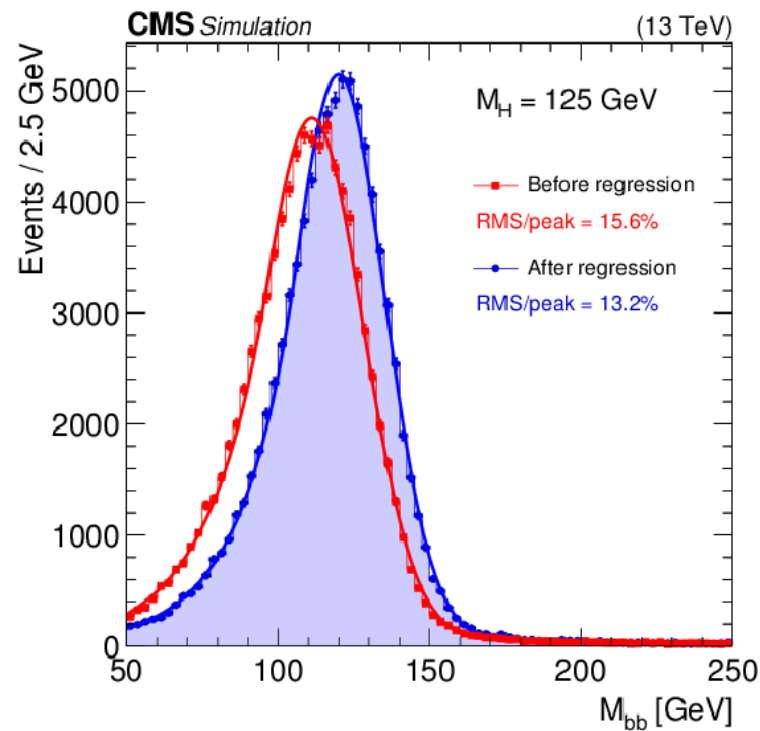
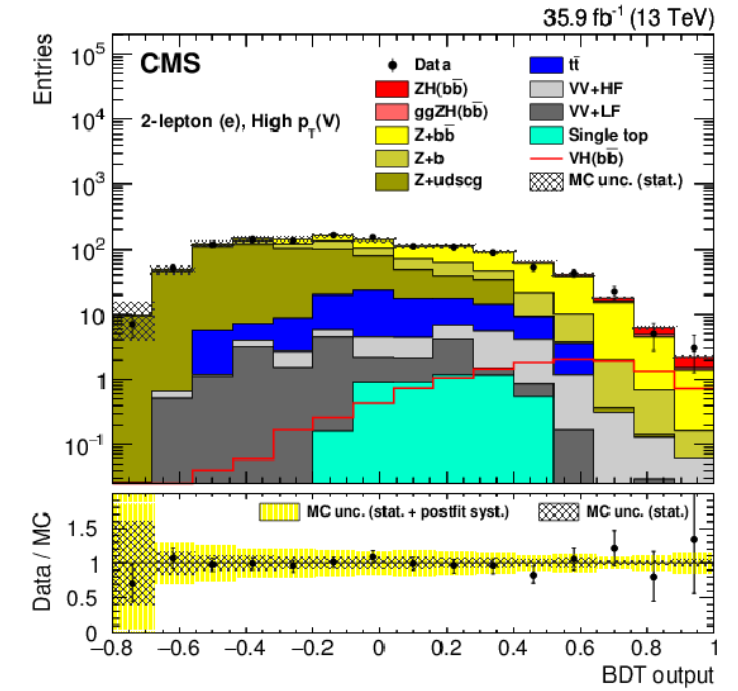
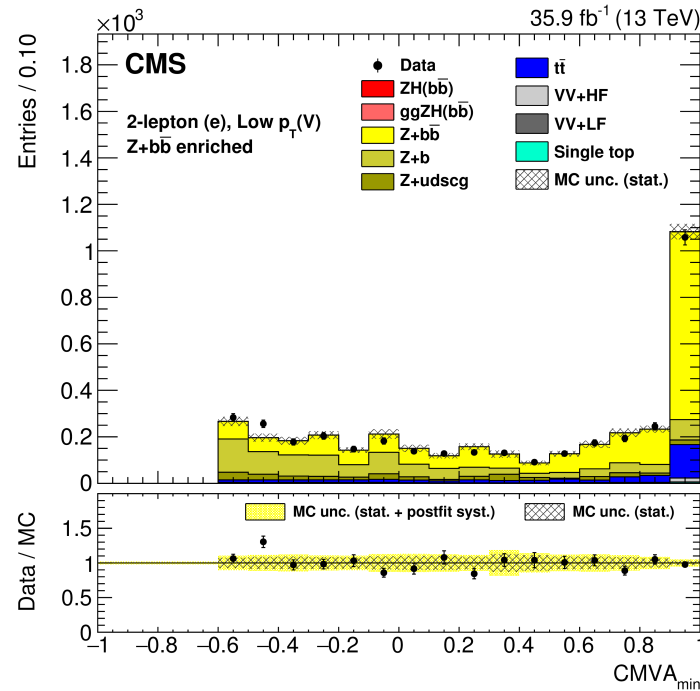
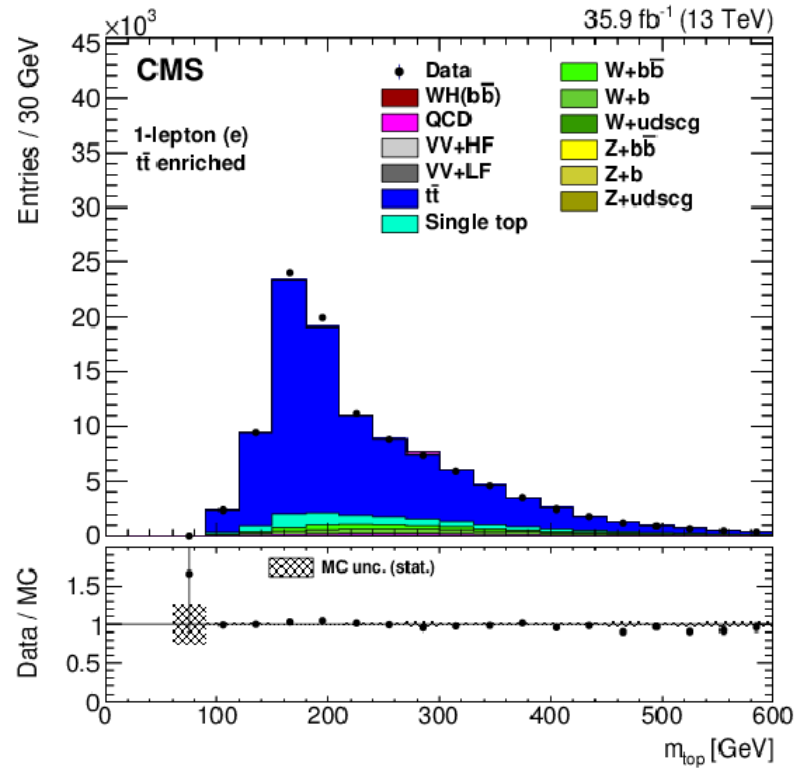
Result	$H(\rightarrow b\bar{b}) + \gamma jj$	$Z(\rightarrow b\bar{b}) + \gamma jj$
Expected significance	0.4	1.3
Expected p -value	0.4	0.1
Observed p -value	0.9	0.4
Expected limit	6.0 $^{+2.3}_{-1.7}$	1.8 $^{+0.7}_{-0.5}$
Observed limit	4.0	2.0
Observed signal strength μ	-3.9 $^{+2.8}_{-2.7}$	0.3 ± 0.8

Observed significance of 3.5 compared to an expected significance of 3.0 standard deviations



Fermions $H \rightarrow bb$

CMS EXPERIMENT



Variable	Description	Channels
$M(jj)$	dijet invariant mass	All
$p_T(jj)$	dijet transverse momentum	All
$p_T(j_1), p_T(j_2)$	transverse momentum of each jet	0- and 2-lepton
$\Delta R(jj)$	distance in η - ϕ between jets	2-lepton
$\Delta \eta(jj)$	difference in η between jets	0- and 2-lepton
$\Delta \phi(jj)$	azimuthal angle between jets	0-lepton
$p_T(V)$	vector boson transverse momentum	All
$\Delta \phi(V, jj)$	azimuthal angle between vector boson and dijet directions	All
$p_T(jj)/p_T(V)$	p_T ratio between dijet and vector boson	2-lepton
$M(\ell\ell)$	reconstructed Z boson mass	2-lepton
$CMVA_{max}$	value of CMVA discriminant for the jet with highest CMVA value	0- and 2-lepton
$CMVA_{min}$	value of CMVA discriminant for the jet with second highest CMVA value	All
$CMVA_{add}$	value of CMVA for the additional jet with highest CMVA value	0-lepton
p_T^{miss}	missing transverse momentum	1- and 2-lepton
$\Delta \phi(\vec{p}_T^{miss}, j)$	azimuthal angle between $\vec{p}_T^{miss}$ and closest jet ($p_T > 30$ GeV)	0-lepton
$\Delta \phi(\vec{p}_T^{miss}, \ell)$	azimuthal angle between $\vec{p}_T^{miss}$ and lepton	1-lepton
m_T	mass of lepton $\vec{p}_T + \vec{p}_T^{miss}$	1-lepton
m_{top}	reconstructed top quark mass	1-lepton
N_{aj}	number of additional jets	1- and 2-lepton
$p_T(add)$	transverse momentum of leading additional jet	0-lepton
SA5	number of soft-track jets with $p_T > 5$ GeV	All

$ZH \rightarrow \nu\nu bb$, $ZH \rightarrow ll bb$, $WH \rightarrow l\nu bb$,
0- 1- and 2- lepton Categorization (e/ μ)

b-tagging used to select $H \rightarrow bb$ jets per event

Event kinematics + topology used as input to an BDT

Simultaneous binned fit of BDT discriminant across all channels

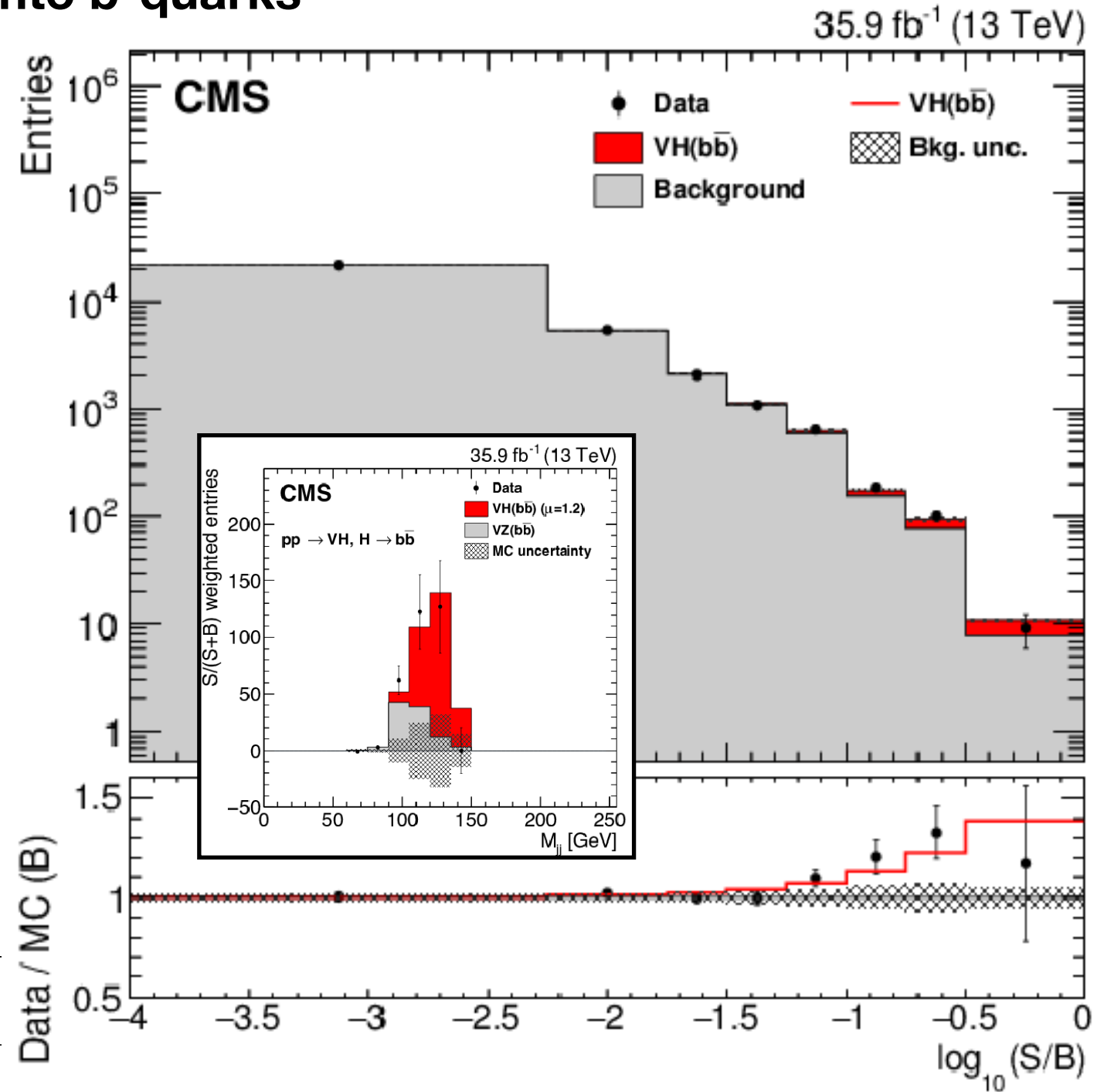
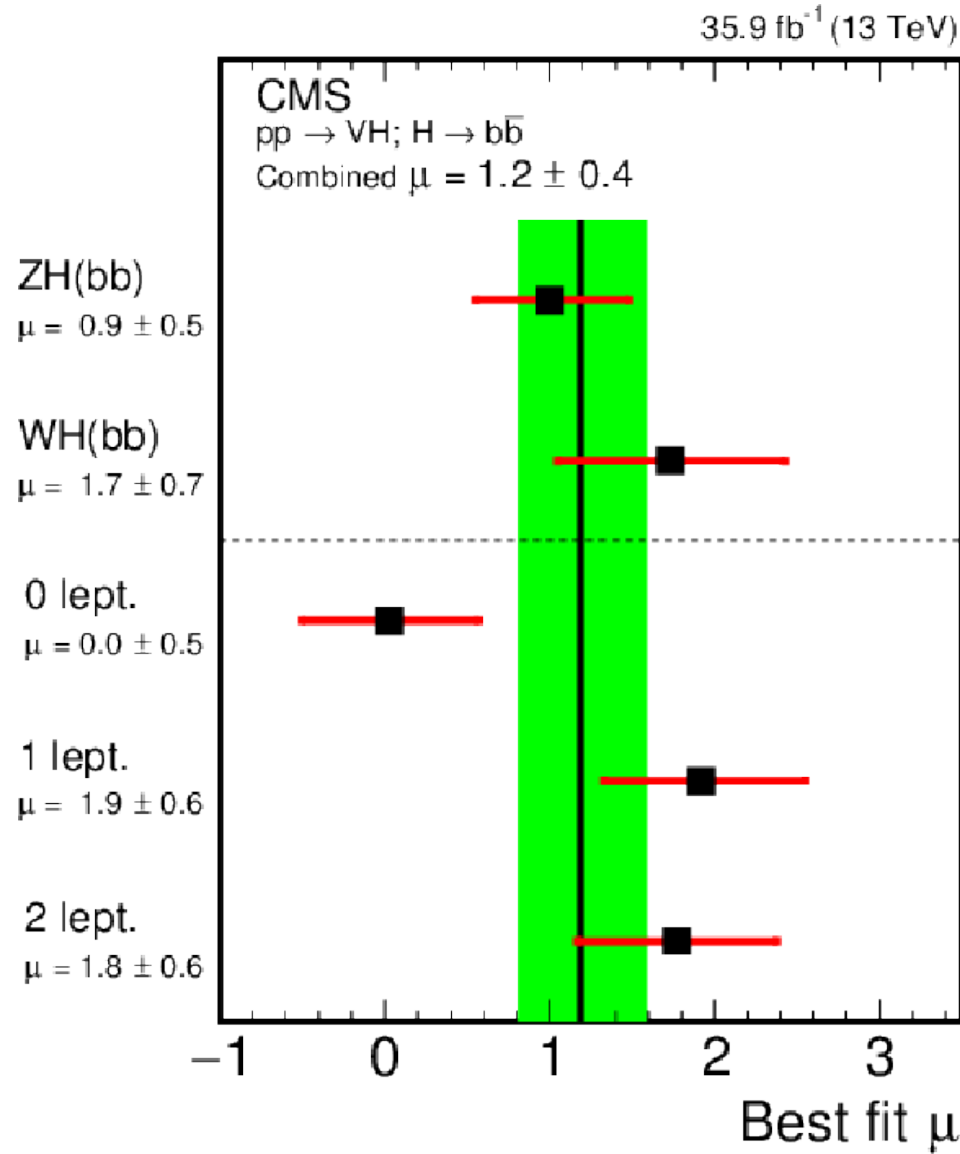
Dec 11, 2017

SUSY SM Higgs

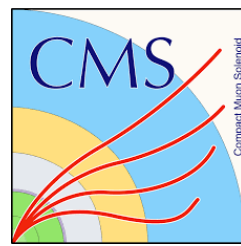
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Evidence for the Higgs boson decay into b-quarks



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	$1.06^{+0.31}_{-0.29}$



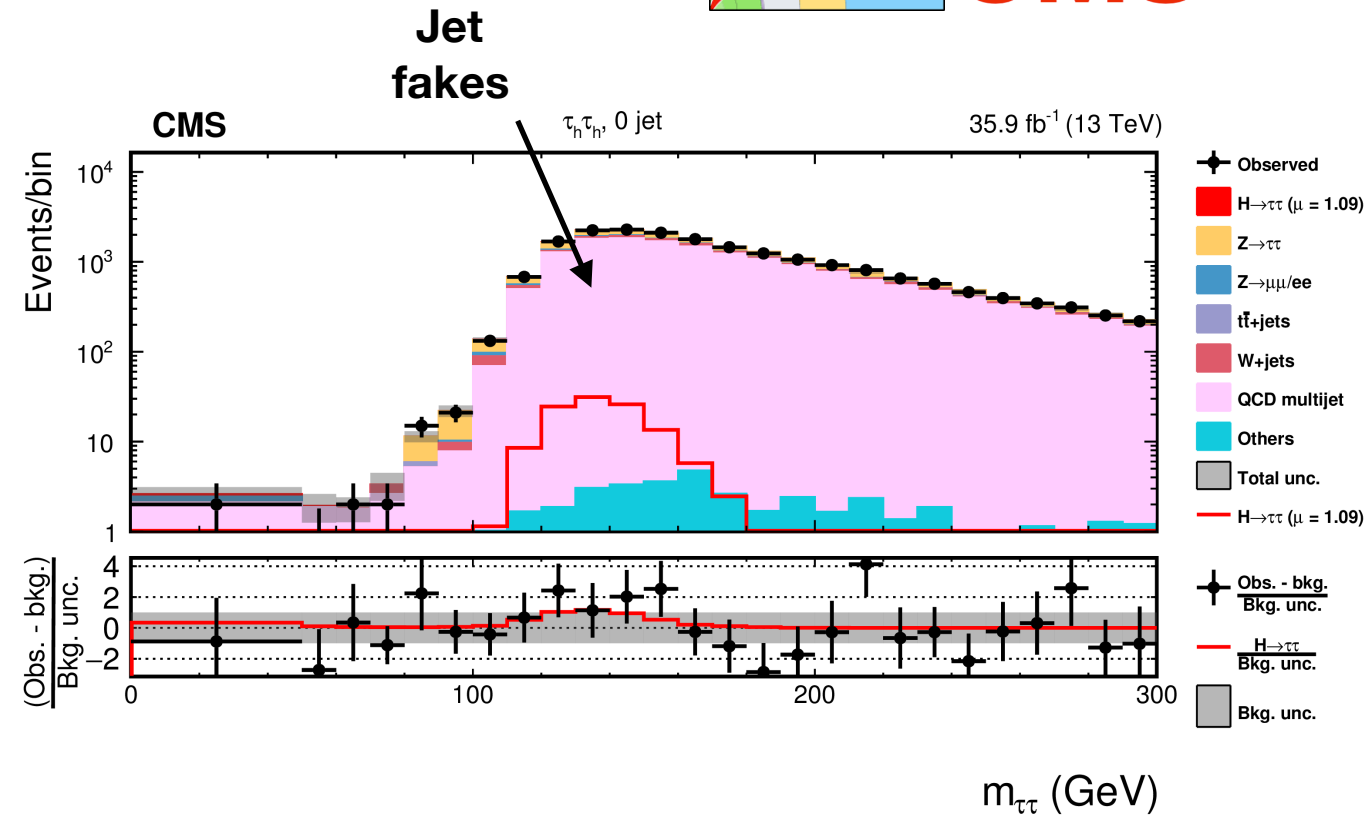
Fermions $H \rightarrow \tau\tau$

CMS EXPERIMENT



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5Y SM Higgs



Three final States Analyzed $e\tau, \mu\tau, \tau\tau$

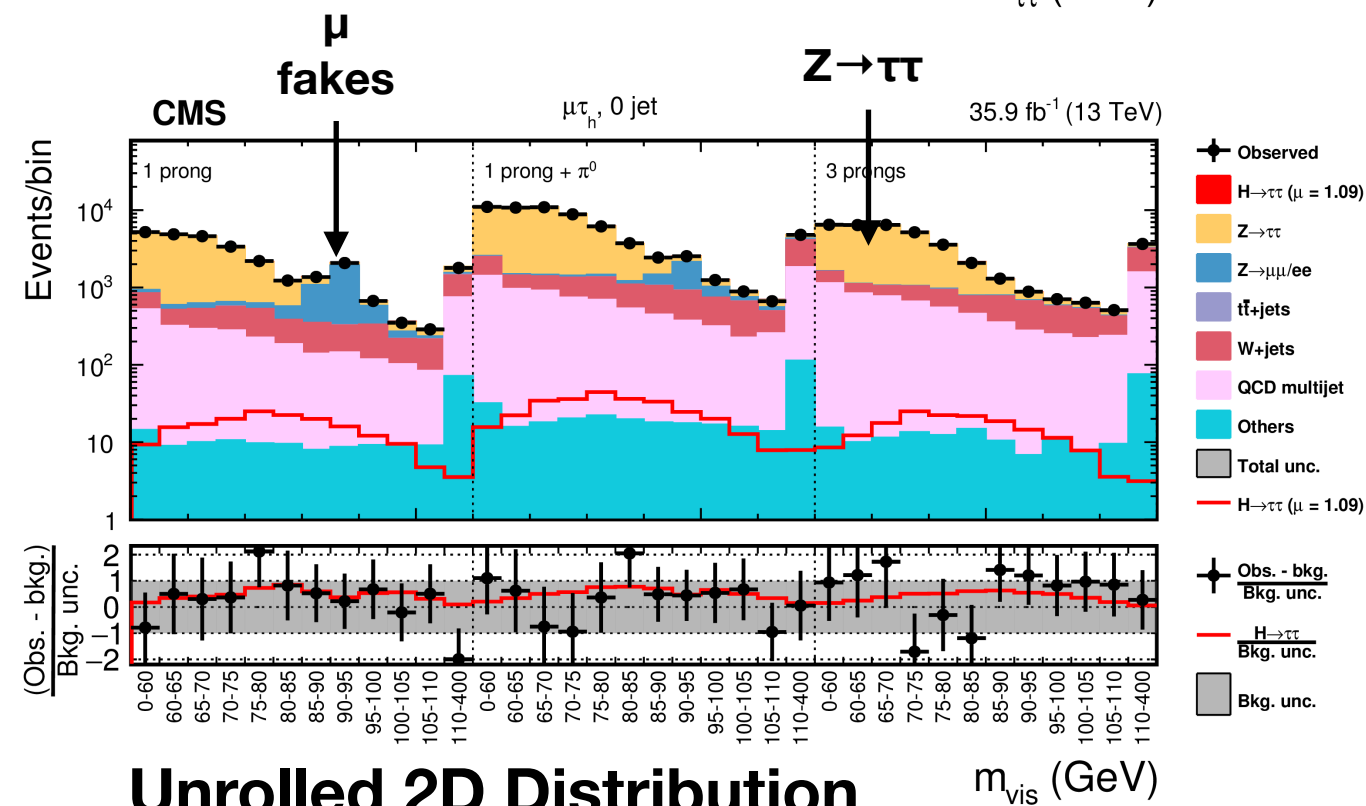
Focus on VBF, ggH and 0-Jet

VBF - Highest Signal Significance

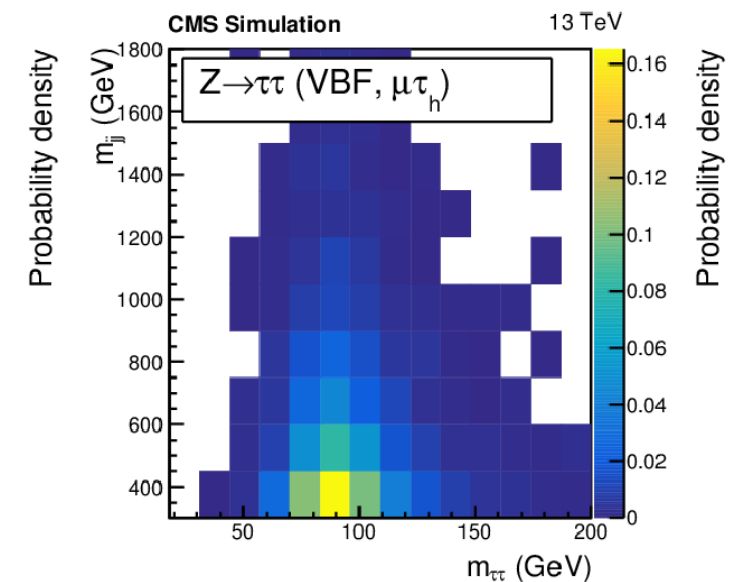
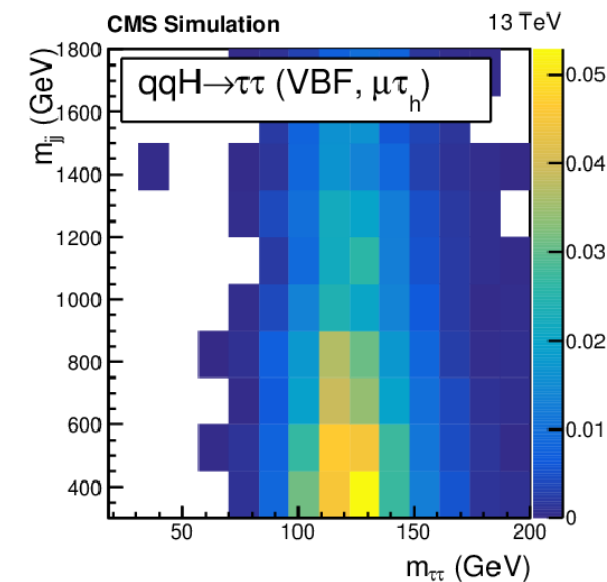
ggH - larger Cross-section

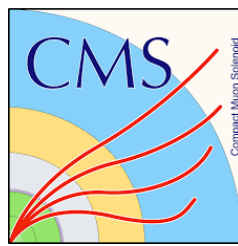
0-Jet - Used to control the many true and fake backgrounds

Two Dimensional distributions for signal extraction which exploit event kinematics



Unrolled 2D Distribution



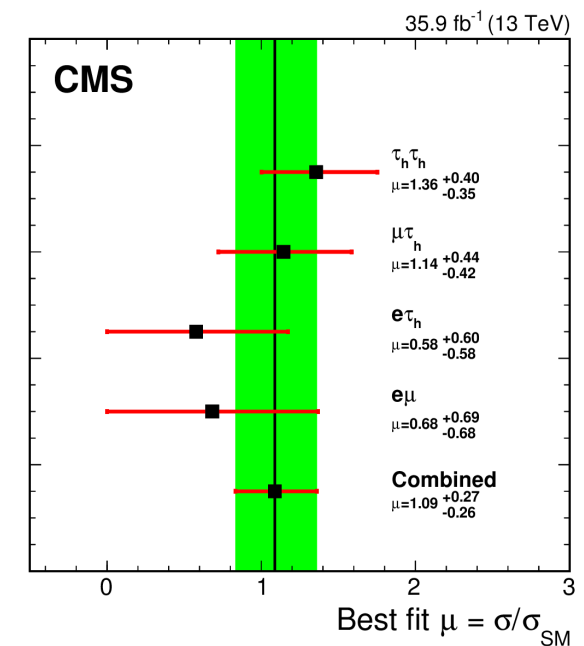
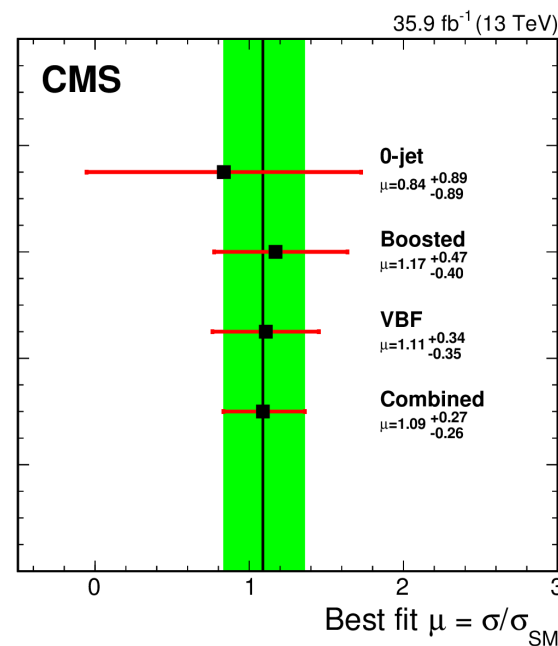
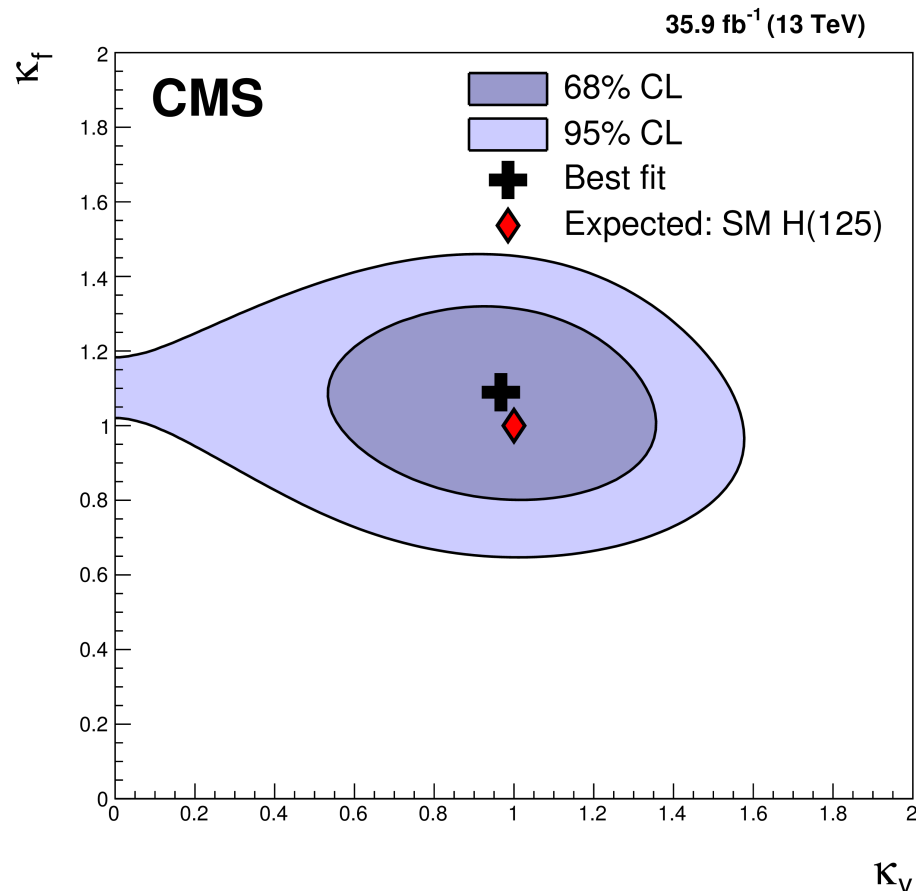
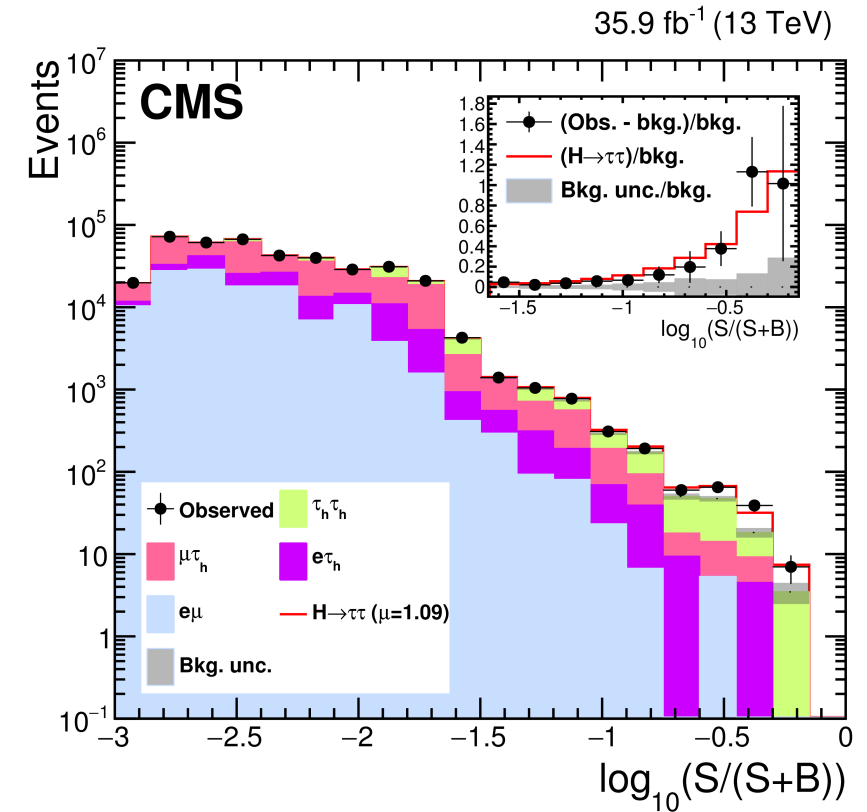
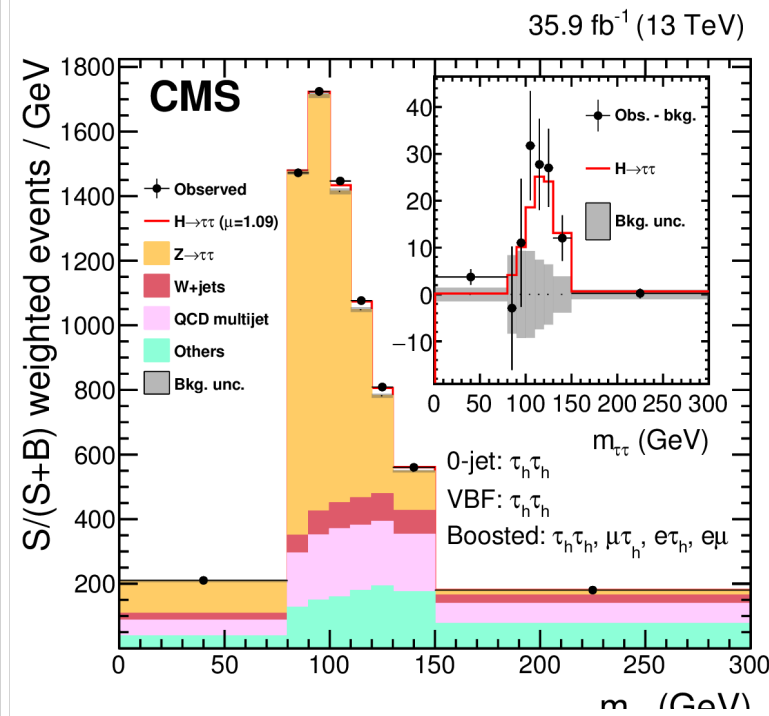
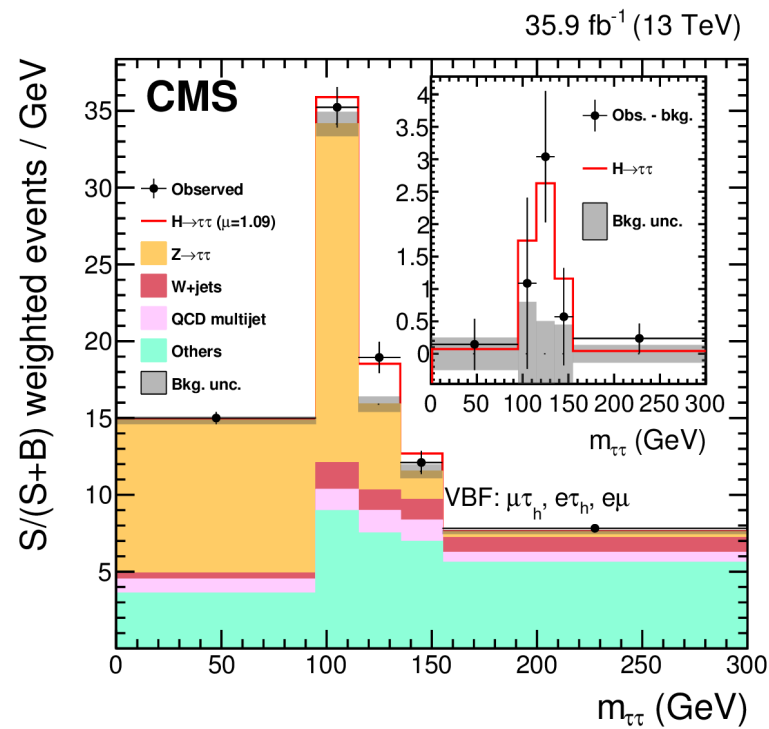


Fermions $H \rightarrow \tau\tau$

CMS EXPERIMENT



Evidence for the Higgs boson decay into τ Leptons



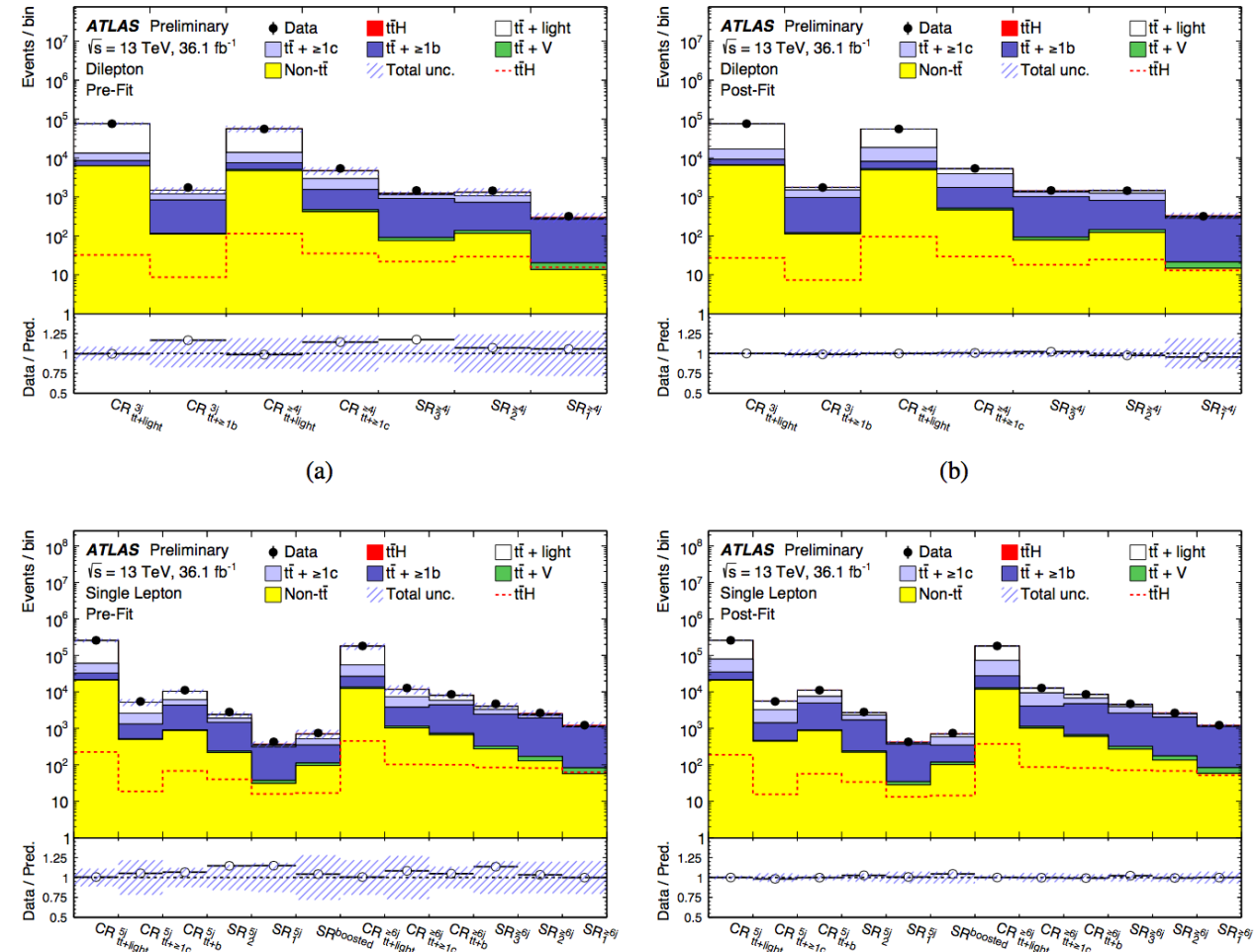
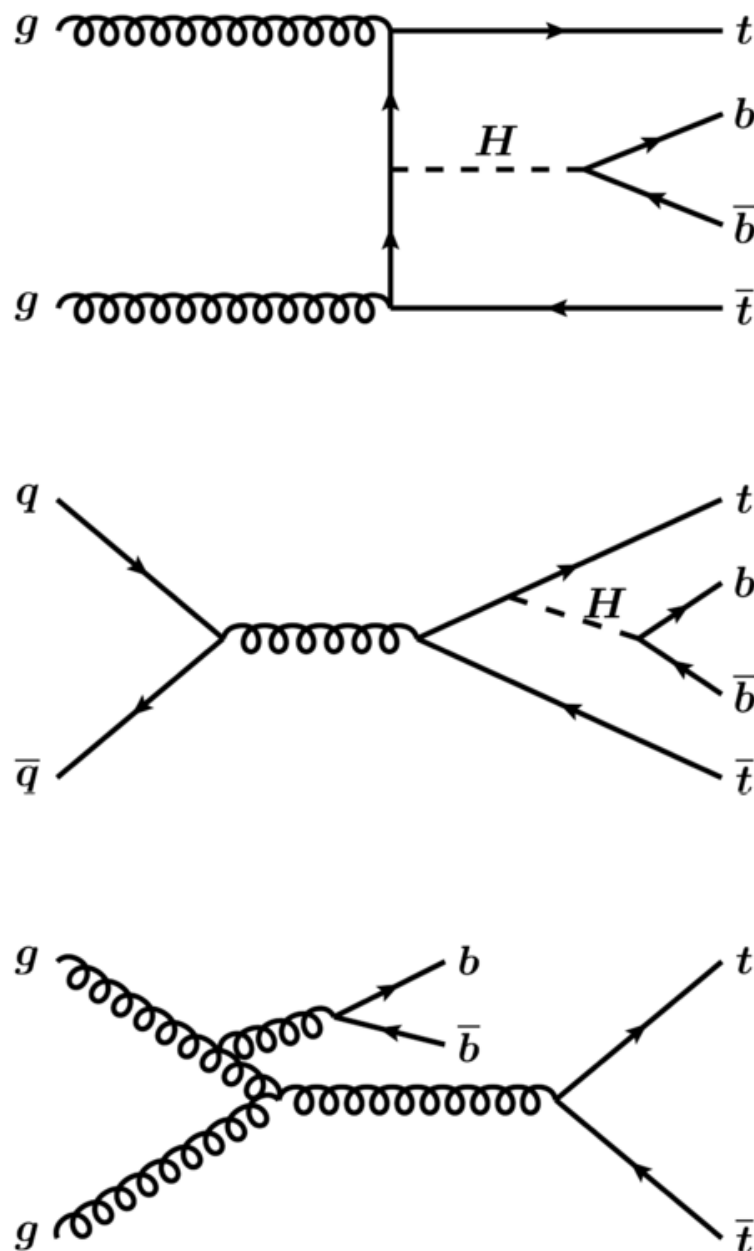
$$\sigma \cdot BR = 1.09^{+0.27}_{-0.26}$$

Consistent with SM coupling strength

5.9 Observed Significance when combining Run I and Run II (7,8,13 TeV)

Higgs boson decays to $b\bar{b}$ are targeted

Comparison of predicted and observed yields in the 9 signal and 10 control regions pre and post fit



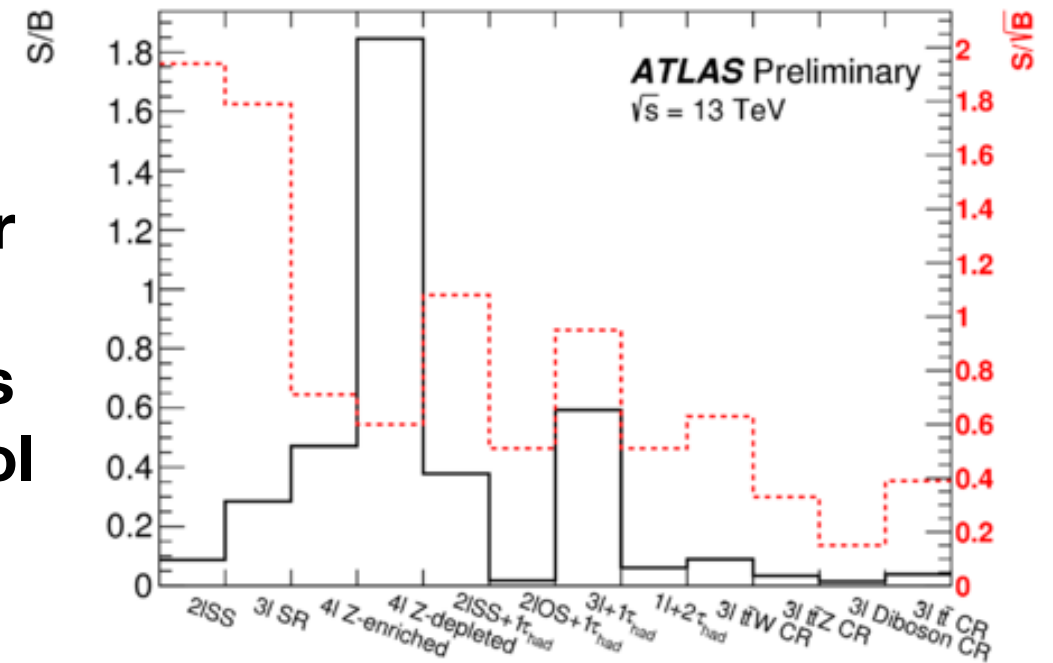
New “Boosted” category targets events where top-quarks and Higgs-boson decay into collimated hadronic final states

- Jets have radius parameter $R = 1.0$

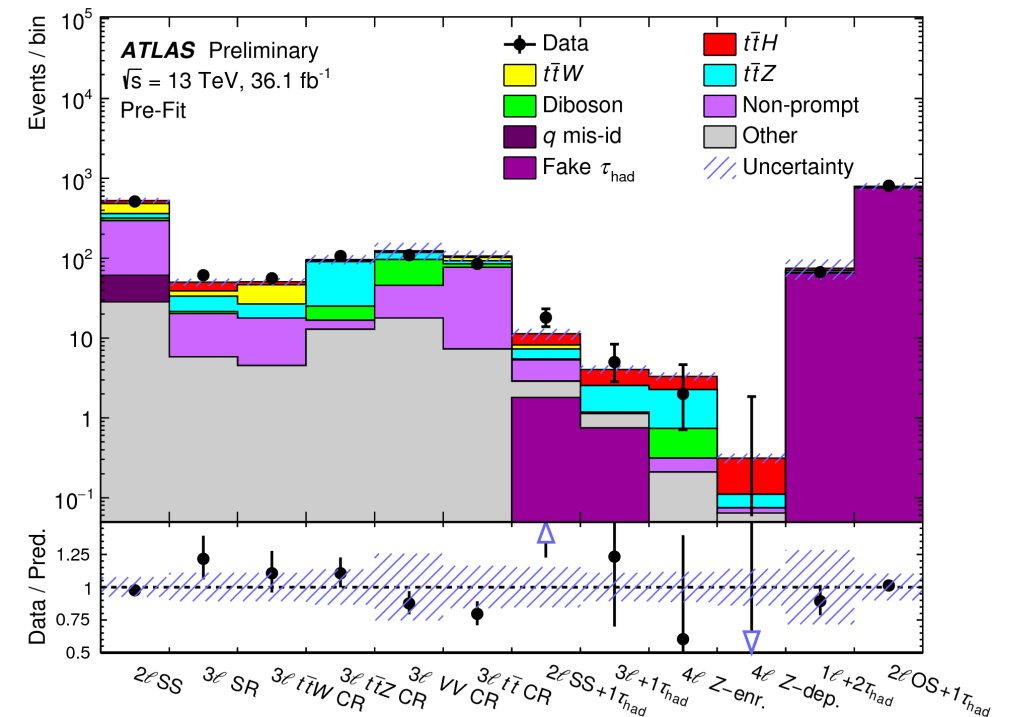
Ratio of measured cross-section to SM expectation $\mu = 0.84^{+0.64}_{-0.61}$

Higgs boson decays to WW^* , $\tau\tau$, and ZZ are targeted

S/B (black) and $s/\sqrt{B}$ (red) for twelve analysis signal categories and four 3l control regions



Comparison of prediction to data before the fit in the eight signal and four control regions



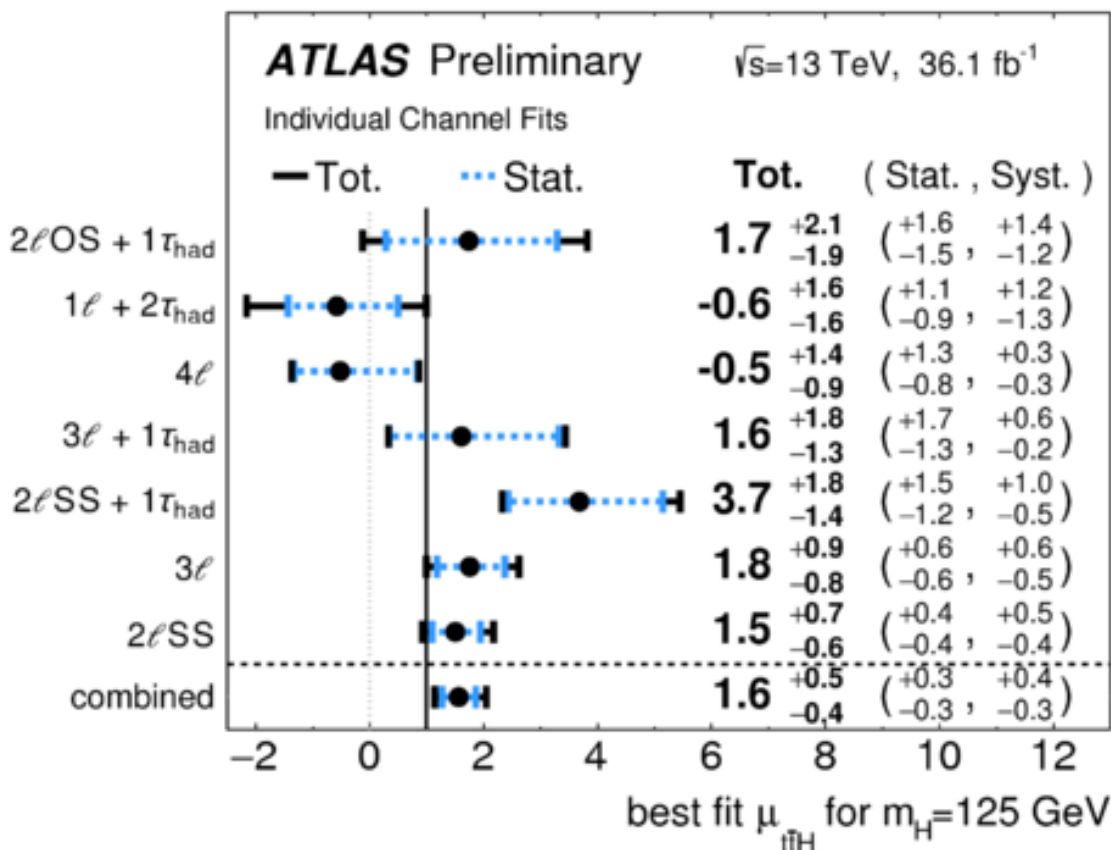
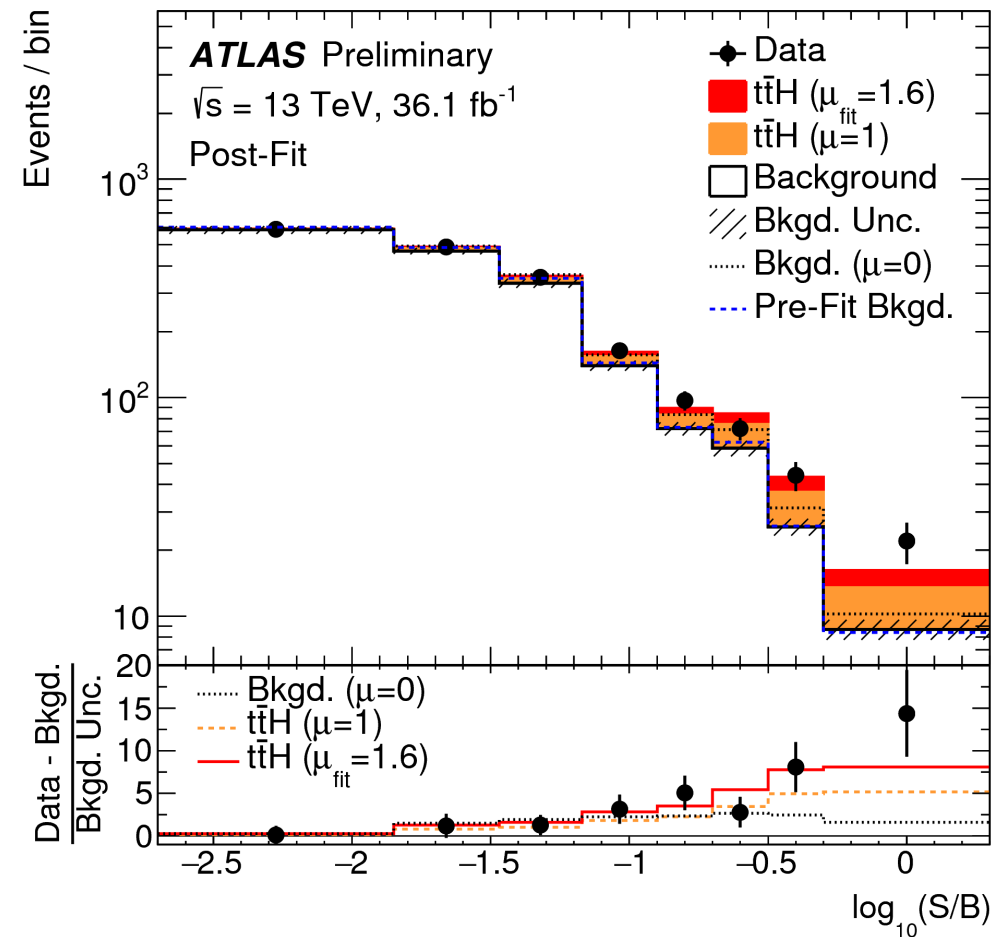
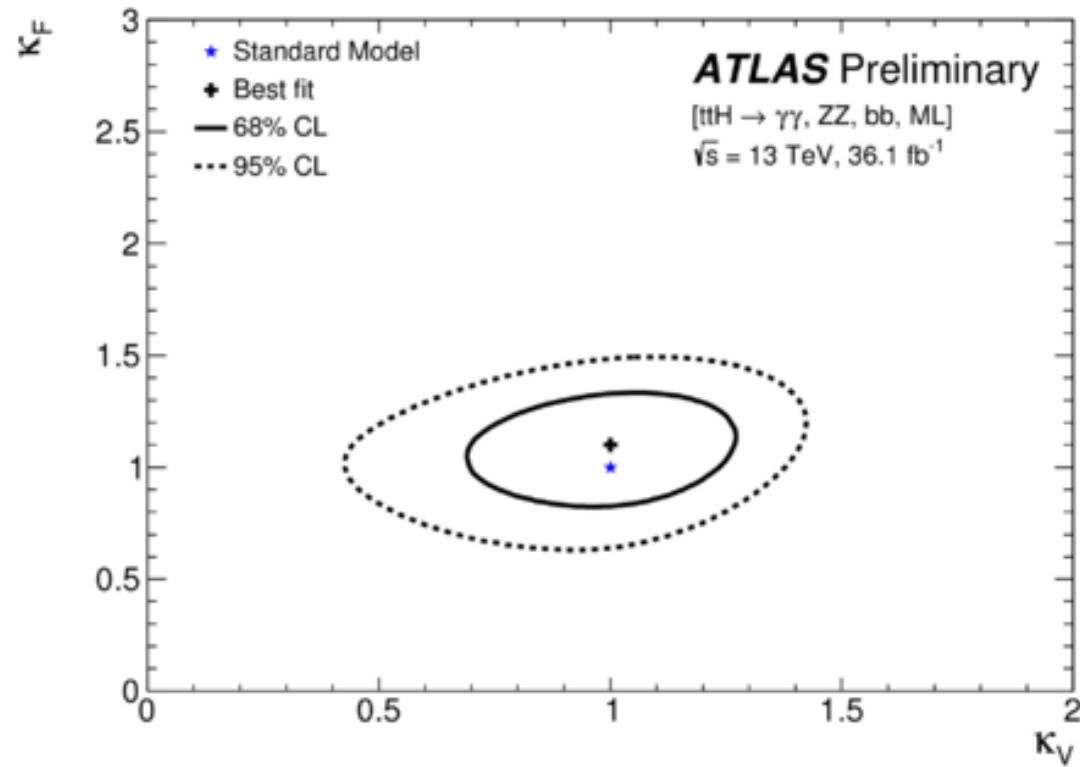


$t\bar{t}H \rightarrow WW/ZZ/\tau\tau$ **ATLAS EXPERIMENT**

Higgs boson decays to WW^* , $\tau\tau$, and ZZ are targeted

Evidence for the $t\bar{t}H$ Higgs production

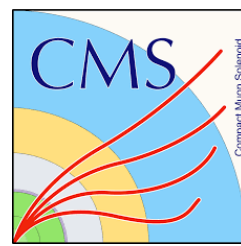
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Excess of events over the expected background is found with an observed (expected) significance of 4.1 (2.8) standard deviations

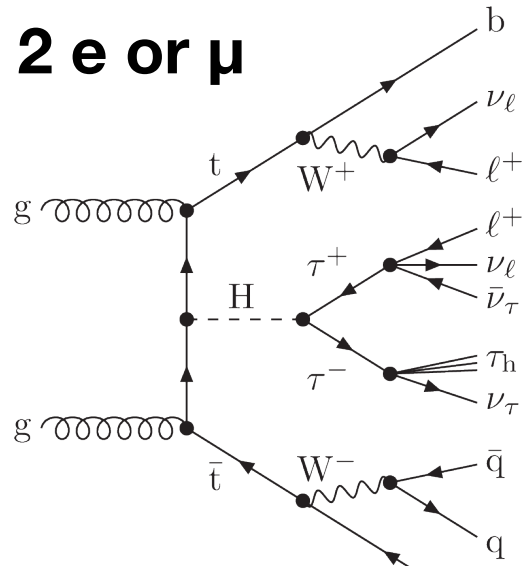
When combined with other $t\bar{t}H$ analyses at ATLAS: 4.2 σ observed compared to 3.8 σ expectation

- Overall, slight excess above SM still observed

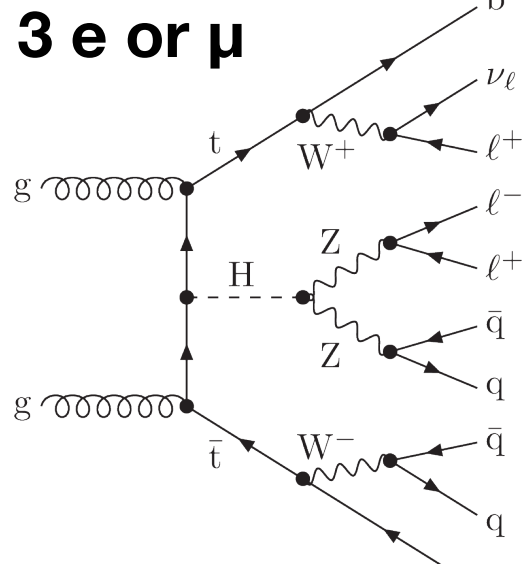


$t\bar{t}H: \ell\ell, \ell\ell\ell, \ell\ell\ell\ell$ **CMS** EXPERIMENT

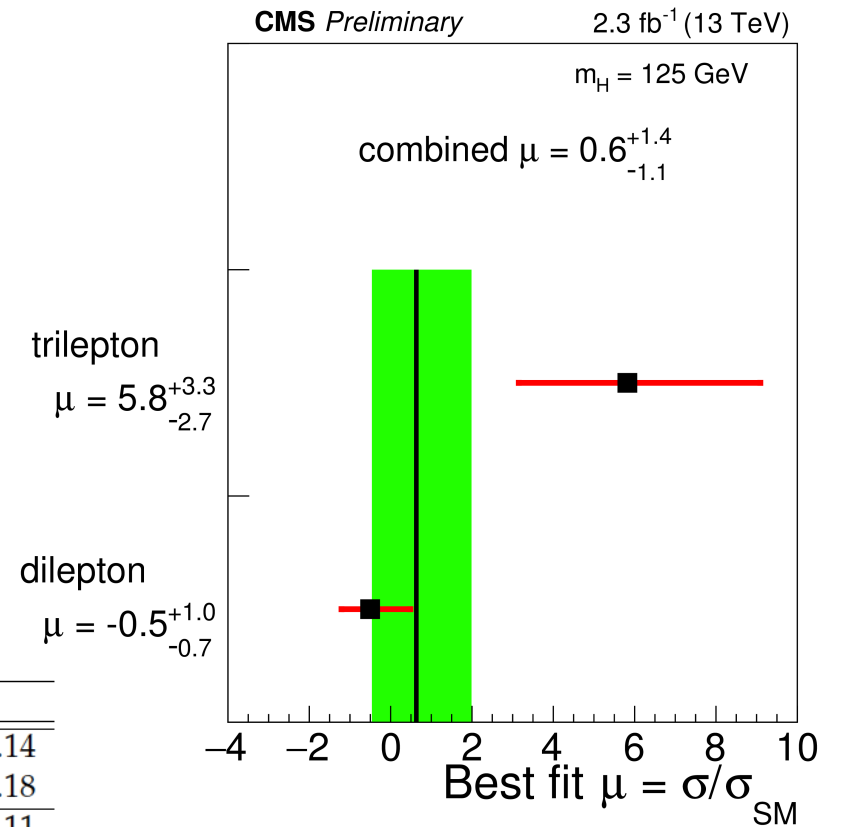
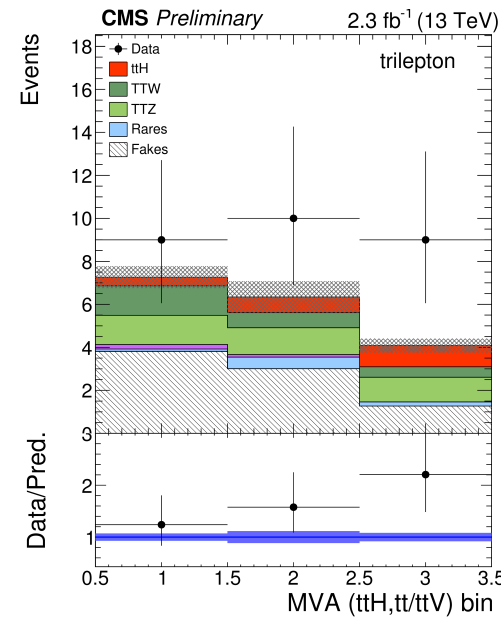
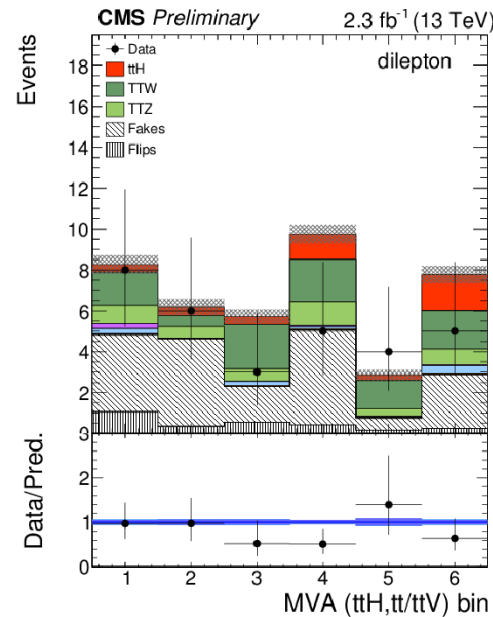
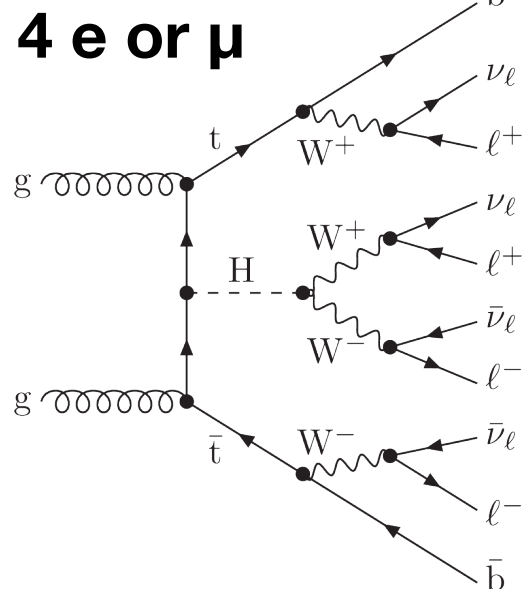
2 e or μ



3 e or μ



4 e or μ



	$\mu\mu$	ee	$e\mu$	3ℓ
$t\bar{t}W$	3.22 ± 0.16	1.47 ± 0.11	4.95 ± 0.19	2.56 ± 0.14
$t\bar{t}Z/\gamma^*$	0.82 ± 0.03	1.14 ± 0.14	2.42 ± 0.17	3.75 ± 0.18
WZ	0.09 ± 0.05	0.06 ± 0.06	0.25 ± 0.11	0.33 ± 0.11
$t\bar{t}t\bar{t}$	0.19 ± 0.03	0.11 ± 0.02	0.28 ± 0.03	0.22 ± 0.03
$t\bar{t}Zq$	0.10 ± 0.06	0.00 ± 0.00	0.12 ± 0.13	0.44 ± 0.17
rare SM bkg.	0.06 ± 0.03	0.04 ± 0.04	0.13 ± 0.06	0.16 ± 0.59
non-prompt (data)	3.99 ± 0.38	3.58 ± 0.38	10.10 ± 0.65	8.08 ± 0.67
charge mis-ID (data)		1.11 ± 0.05	1.65 ± 0.05	
all backgrounds	8.47 ± 0.42	7.52 ± 0.44	19.90 ± 0.73	15.55 ± 0.95
$t\bar{t}H$ signal	1.53 ± 0.08	0.69 ± 0.05	2.27 ± 0.10	2.12 ± 0.09
data	9	11	11	28

Primary backgrounds of $t\bar{t}W$, $t\bar{t}Z$ and $t\bar{t}$ +jets

With respect to Run I the cross-sections of main backgrounds increased by 3X while $t\bar{t}H$ increased by 4X

Category	μ best fit $\pm 1\sigma$
same-sign dileptons	$-0.5 (+1.0) (-0.7)$
trileptons	$5.8 (+3.3) (-2.7)$
combined	$0.6 (-1.1) (+1.4)$

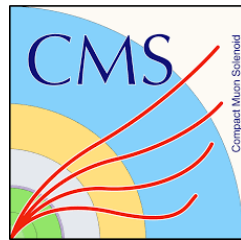
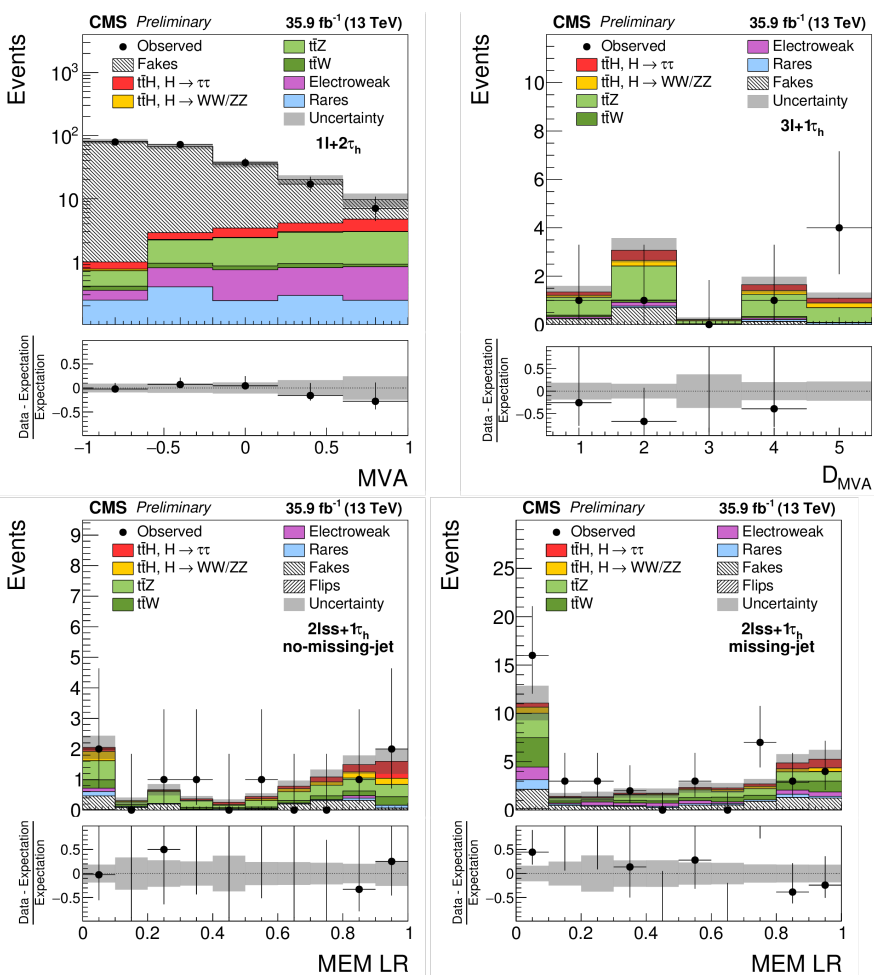


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SUSY SM Higgs

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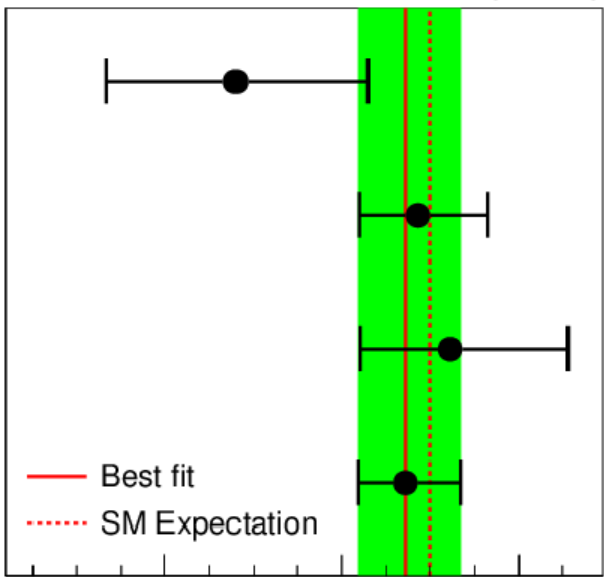
29



ttH → ττ/bb

CMS EXPERIMENT

CMS Preliminary 35.9 fb⁻¹ (13 TeV)



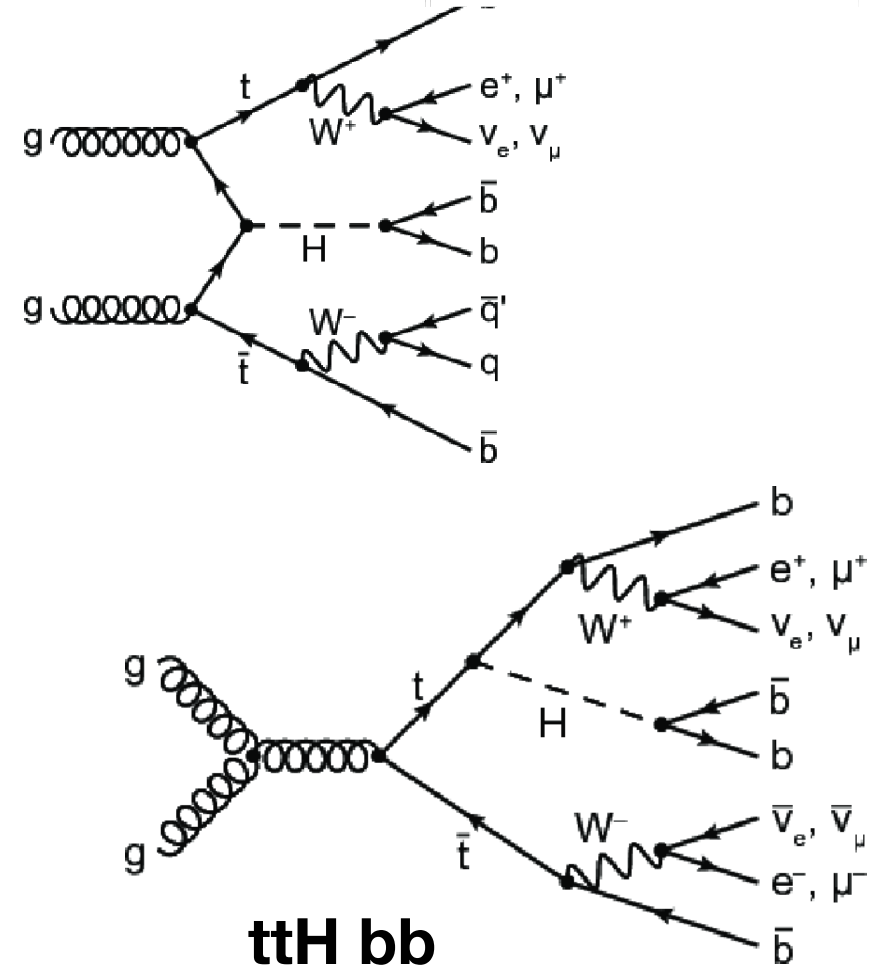
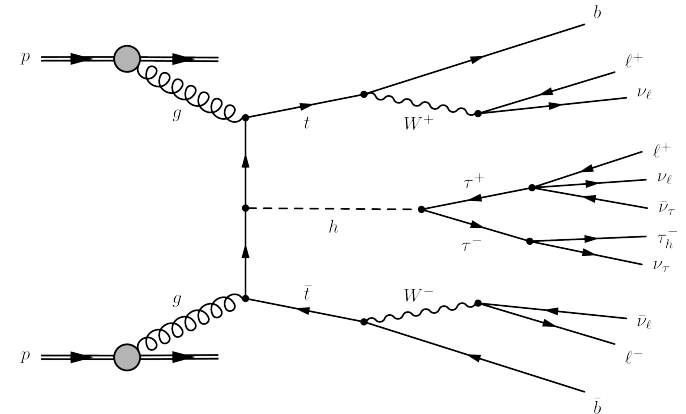
$$1l+2\tau_h$$
$$\mu = -1.20^{+1.50}_{-1.47}$$

$$2lss+1\tau_h$$
$$\mu = 0.86^{+0.79}_{-0.66}$$

$$3l+1\tau_h$$
$$\mu = 1.22^{+1.33}_{-1.01}$$

$$\text{Combined}$$
$$\mu = 0.72^{+0.62}_{-0.53}$$

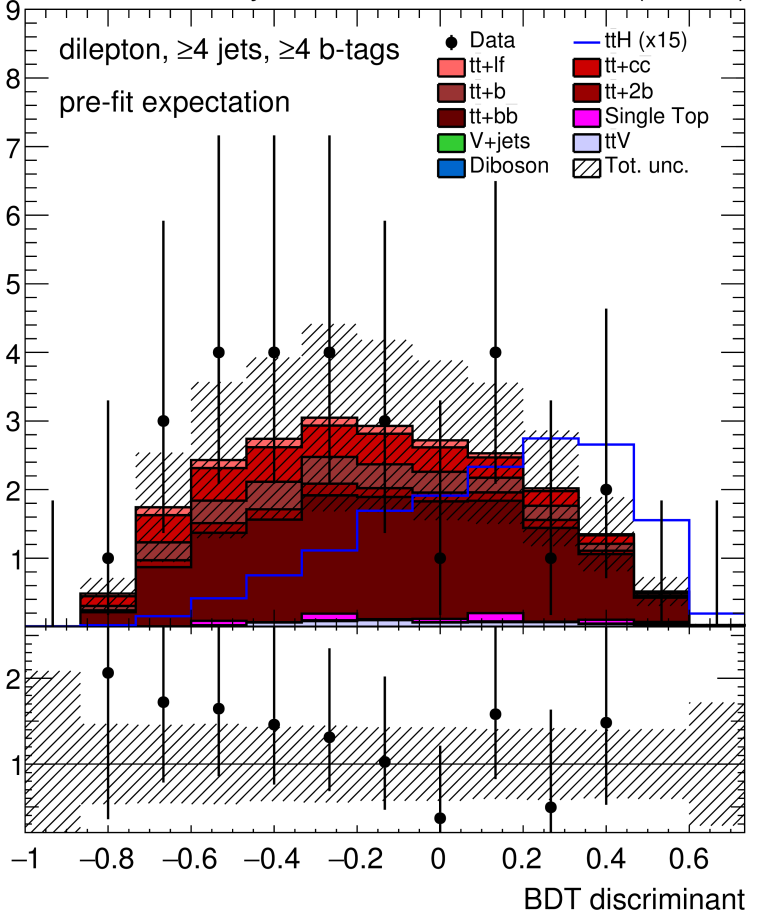
ttH → ττ



Category	Observed	Expected
3 jets, 2 b-tags	186.0	114.8 ^{+52.6} _{-34.1}
≥ 3 jets, 3 b-tags	104.9	48.6 ^{+26.2} _{-15.9}
≥ 4 jets, 2 b-tags	32.4	40.1 ^{+16.8} _{-11.3}
≥ 4 jets, 3 b-tags	7.4	10.8 ^{+5.2} _{-3.3}
≥ 4 jets, ≥ 4 b-tags	9.1	12.2 ^{+7.5} _{-4.3}
dilepton combined	5.2	7.7 ^{+3.6} _{-2.3}

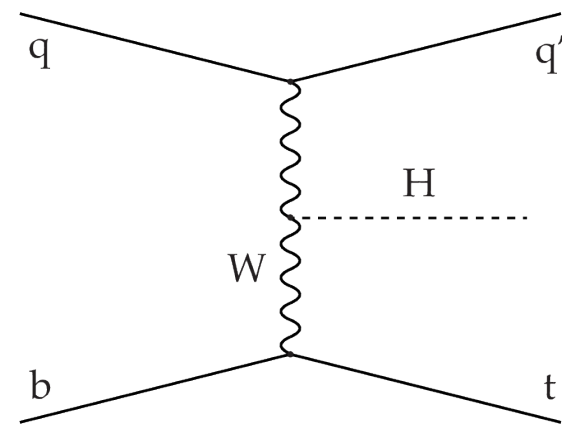
Combination of BDT and MEM techniques for signal, background separation

CMS Preliminary 2.7 fb⁻¹ (13 TeV)

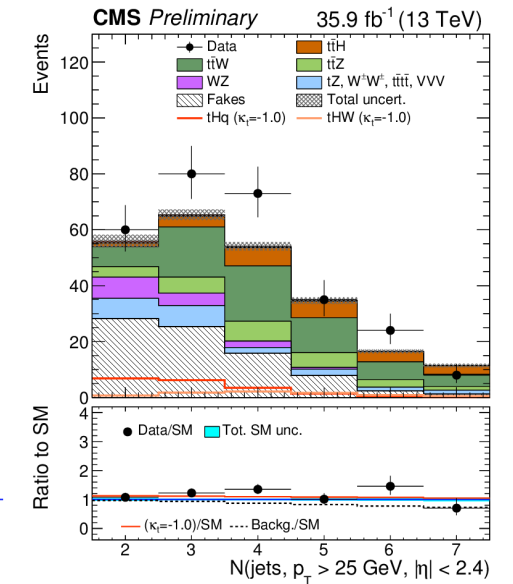
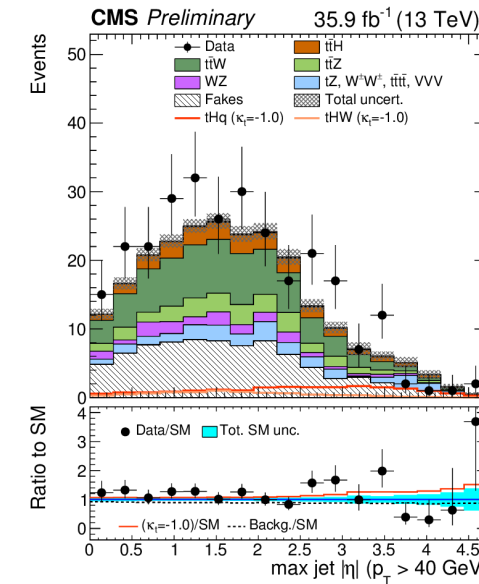
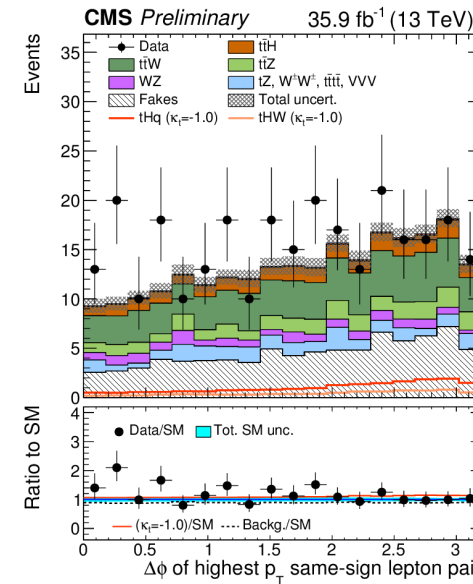
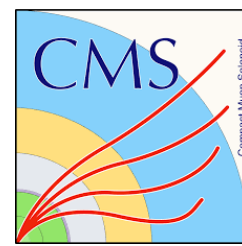
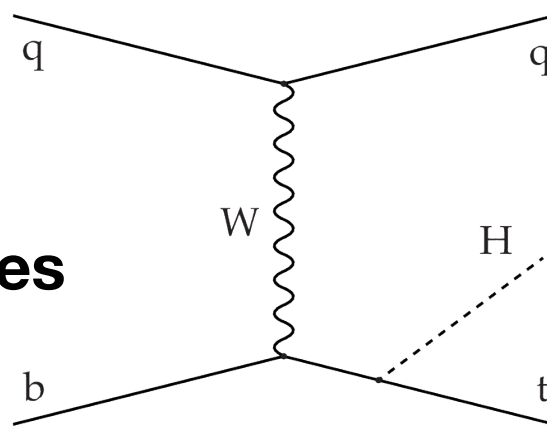


Single Top Quark Production

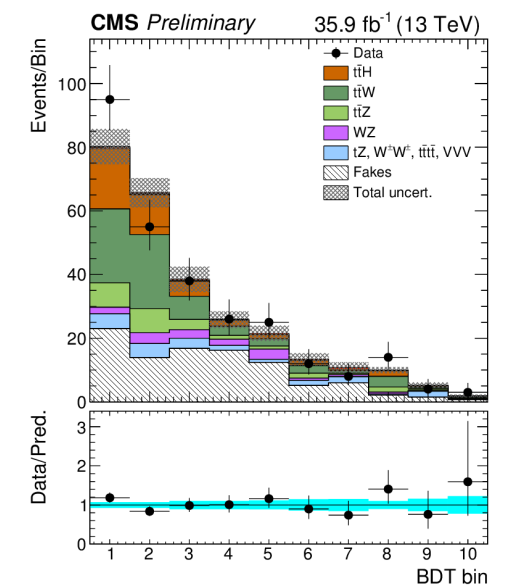
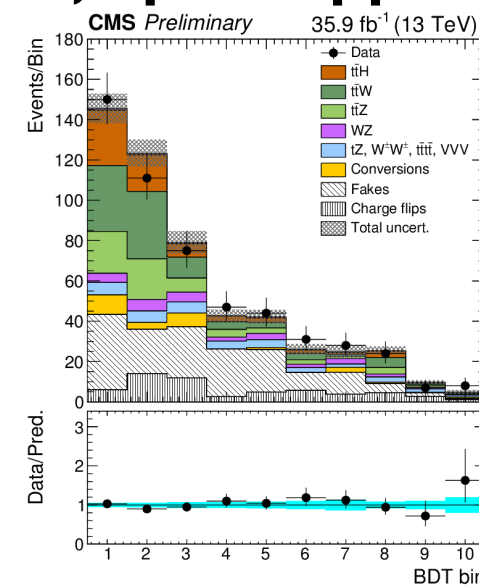
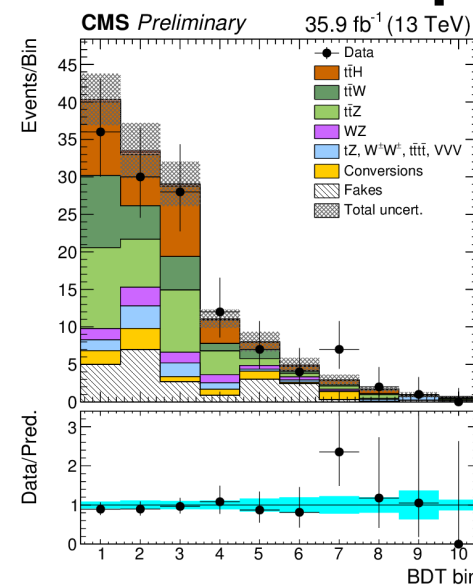
CMS EXPERIMENT



**H → WW,
H → ττ,
H → ZZ
decay modes**

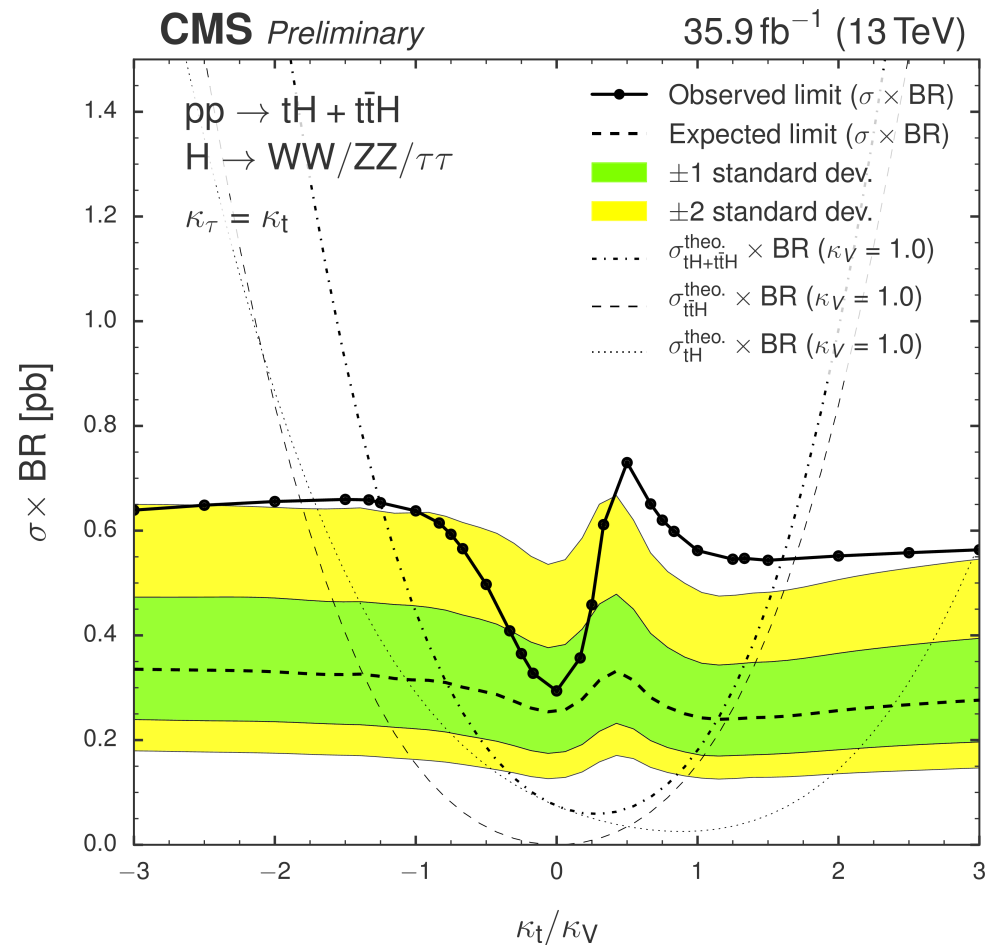


Three lepton, eμ and μμ



**Input Variables
for BDT
Signal
Extraction**

- Number of jets with $p_T > 25 \text{ GeV}$, $|\eta| < 2.4$
- Maximum $|\eta|$ of any (non-b-tagged) jet ("forward jet")
- Sum of lepton charges
- Number of non-b-tagged jets with $|\eta| > 1.0$
- $\Delta\eta$ between forward light jet and leading b-tagged jet
- $\Delta\eta$ between forward light jet and sub-leading b-tagged jet
- $\Delta\eta$ between forward light jet and closest lepton
- $\Delta\phi$ of same-sign lepton pair
- Minimum ΔR between any two leptons
- p_T of sub-leading (or 3rd) lepton



**95% CL Limit of 0.64 pb cross section observed
compared to 0.32 pb expected - slight excess above SM**



Rare: $H \rightarrow \mu\mu$

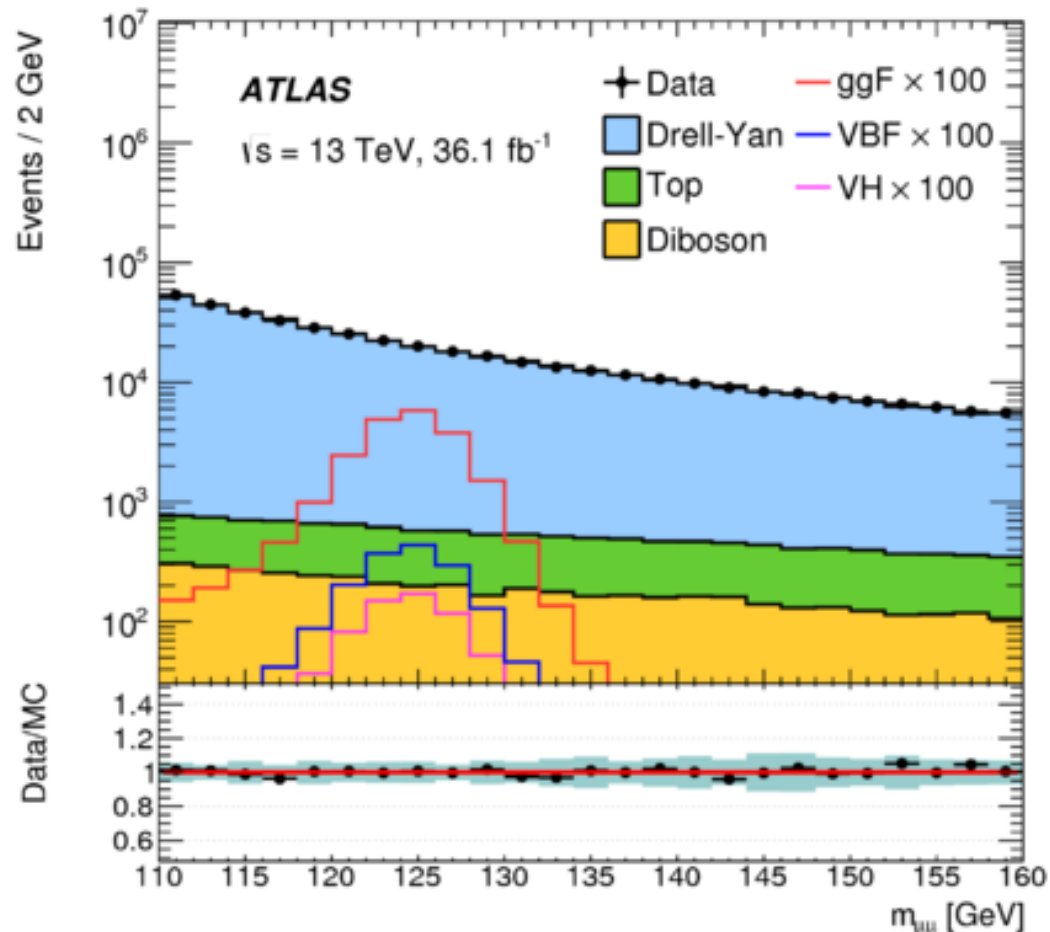
ATLAS EXPERIMENT

Dec 11, 2017

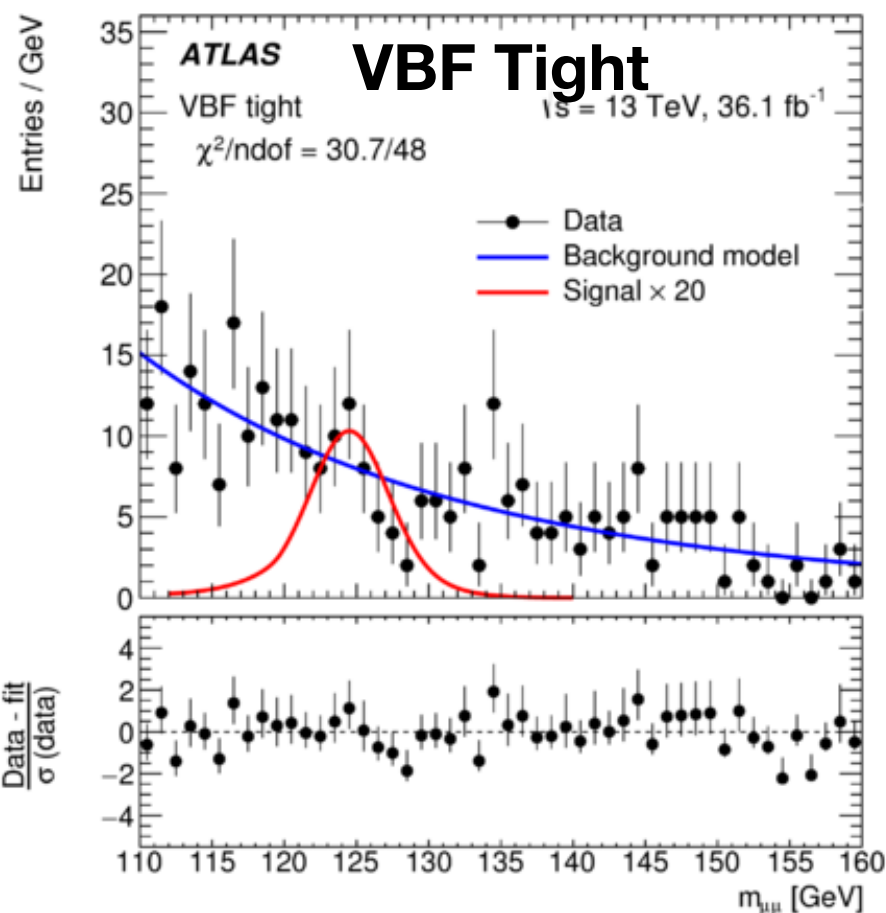
SUSY SM Higgs

Dr. I.Ojalvo

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	S	B	$S/\sqrt{B}$	FWHM	Data
Central low $p_T^{\mu\mu}$	11	8000	0.12	5.6 GeV	7885
Non-central low $p_T^{\mu\mu}$	32	38000	0.16	7.0 GeV	38777
Central medium $p_T^{\mu\mu}$	23	6400	0.29	5.7 GeV	6585
Non-central medium $p_T^{\mu\mu}$	66	31000	0.37	7.1 GeV	31291
Central high $p_T^{\mu\mu}$	16	3300	0.28	6.3 GeV	3160
Non-central high $p_T^{\mu\mu}$	40	13000	0.35	7.7 GeV	12829
VBF loose	3.4	260	0.21	7.6 GeV	274
VBF tight	3.4	78	0.38	7.5 GeV	79



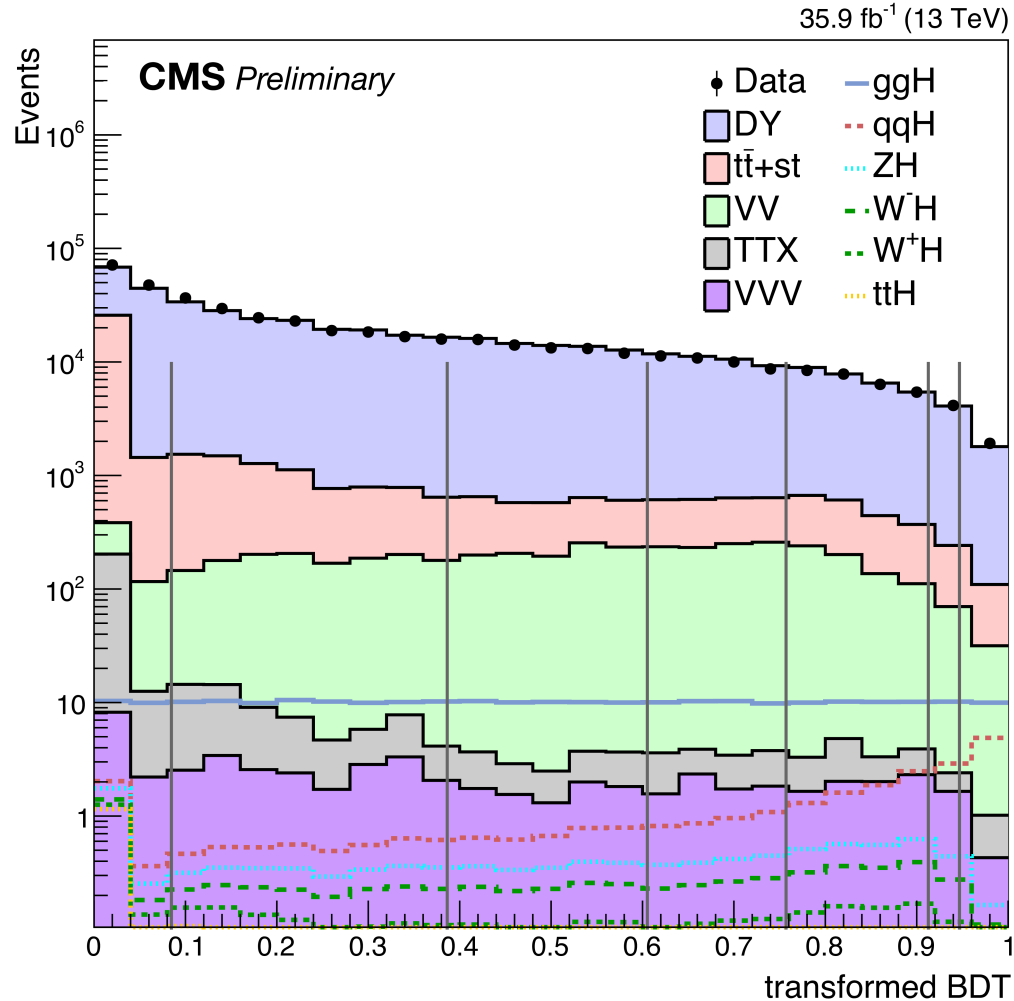
Six categories total:

4 target ggH production, while 2 target VBF

BDT used to separate VBF from ggH

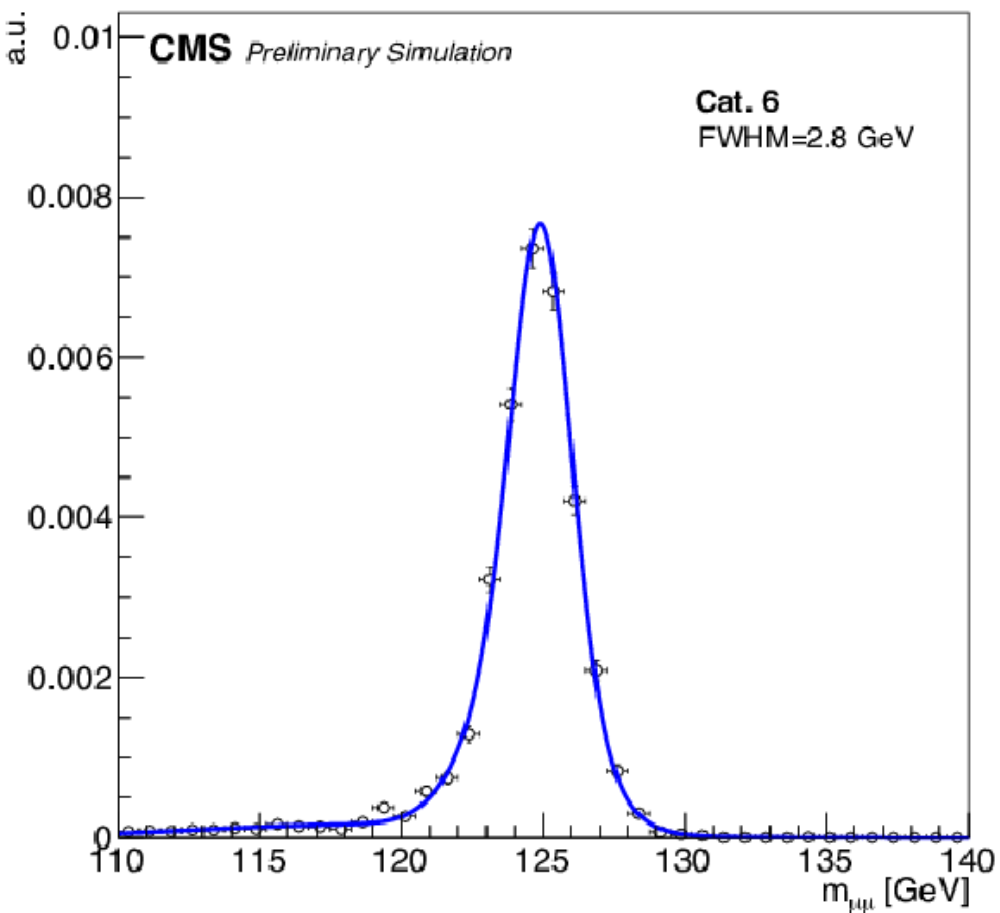
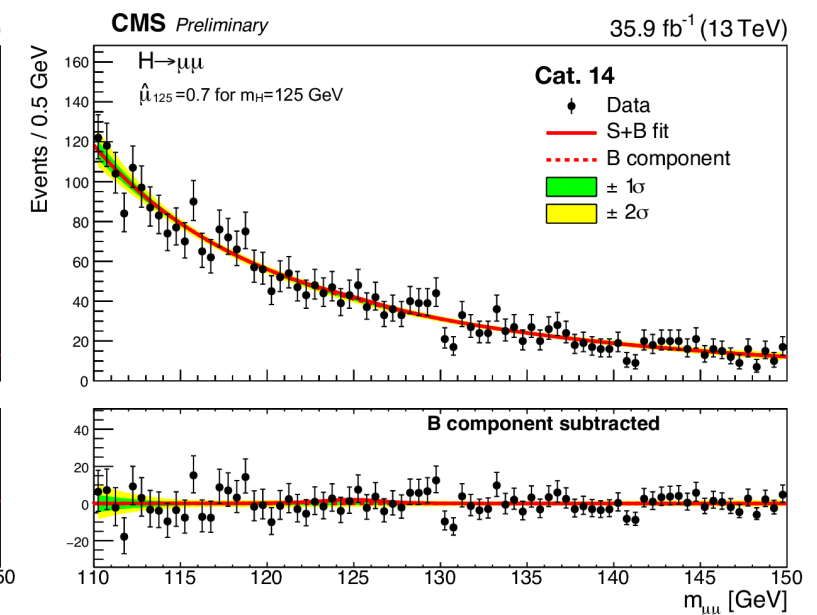
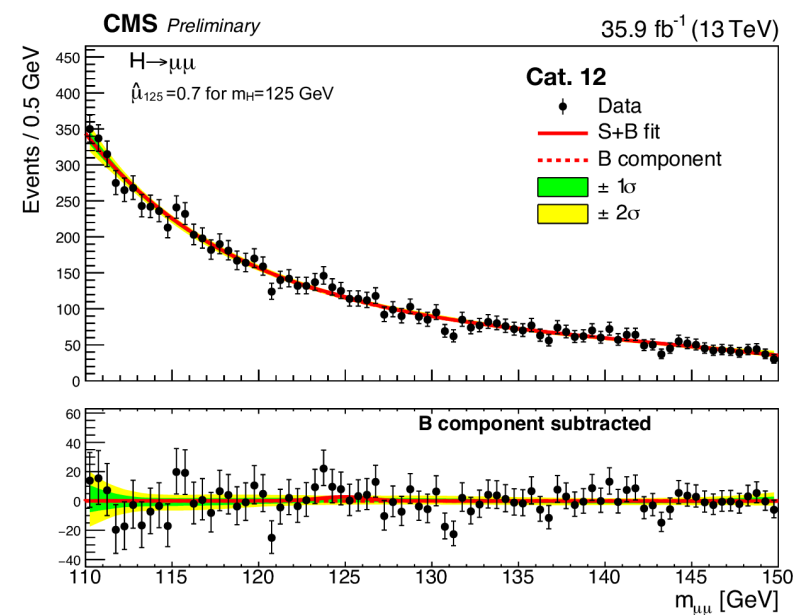
- Most sensitive training variables are m_{jj} , di-muon p_T and difference in jet pseudorapidity
- **Signal extracted simultaneously** in all categories using **binned maximum-likelihood fit to the $\mu\mu$ mass**

Observed (expected) upper limit on $\sigma \times \text{BF}$ is 2.8 (2.9) times the SM when combined with Run I



Rare: $H \rightarrow \mu\mu$

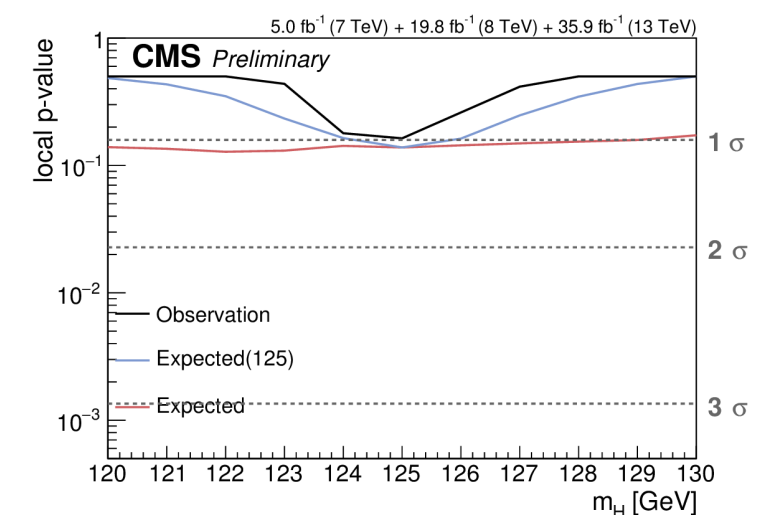
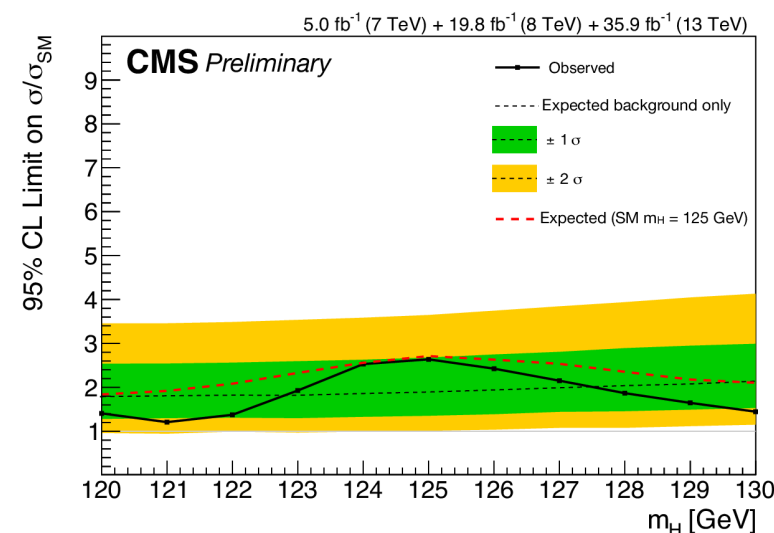
CMS EXPERIMENT



Event **categories** are created based on a **BDT score**

Invariant mass of signal modeled using empirical parametric shapes to extract signal

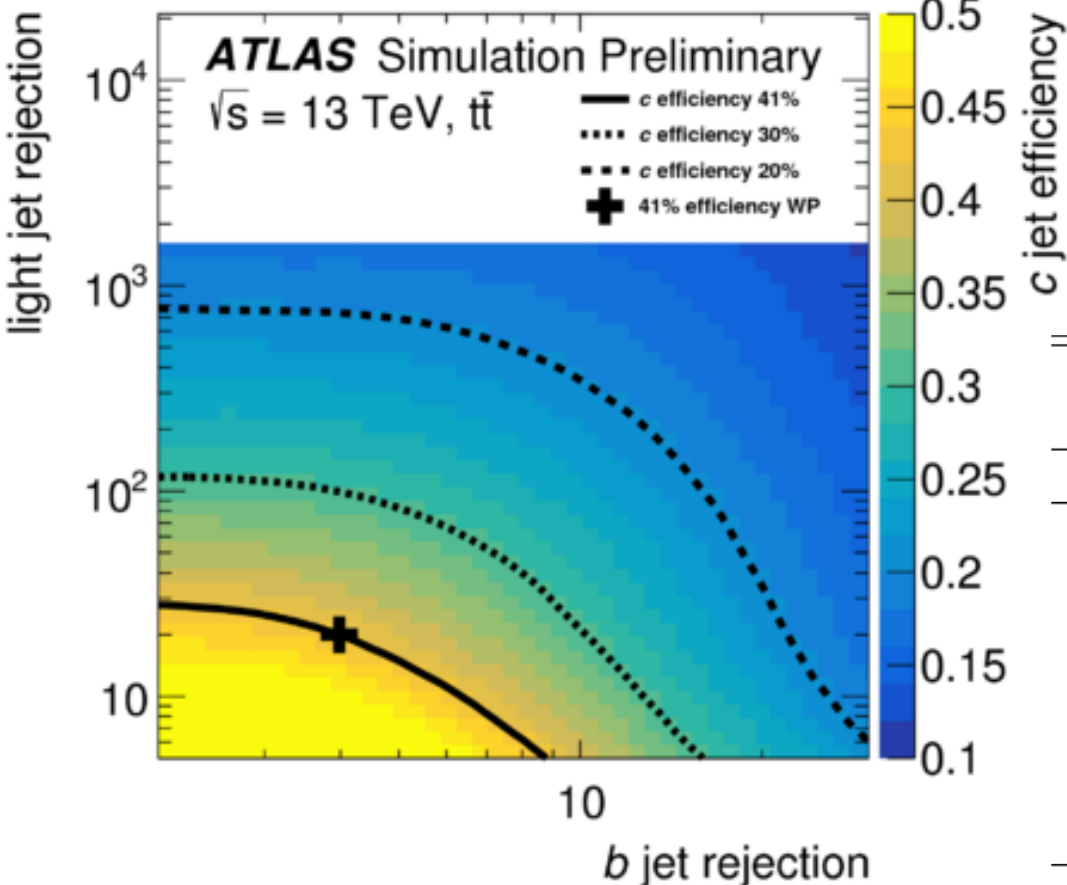
Observed (expected) upper limit on $\sigma \times \text{BF}$ is 2.64 (1.89) times the Standard Model



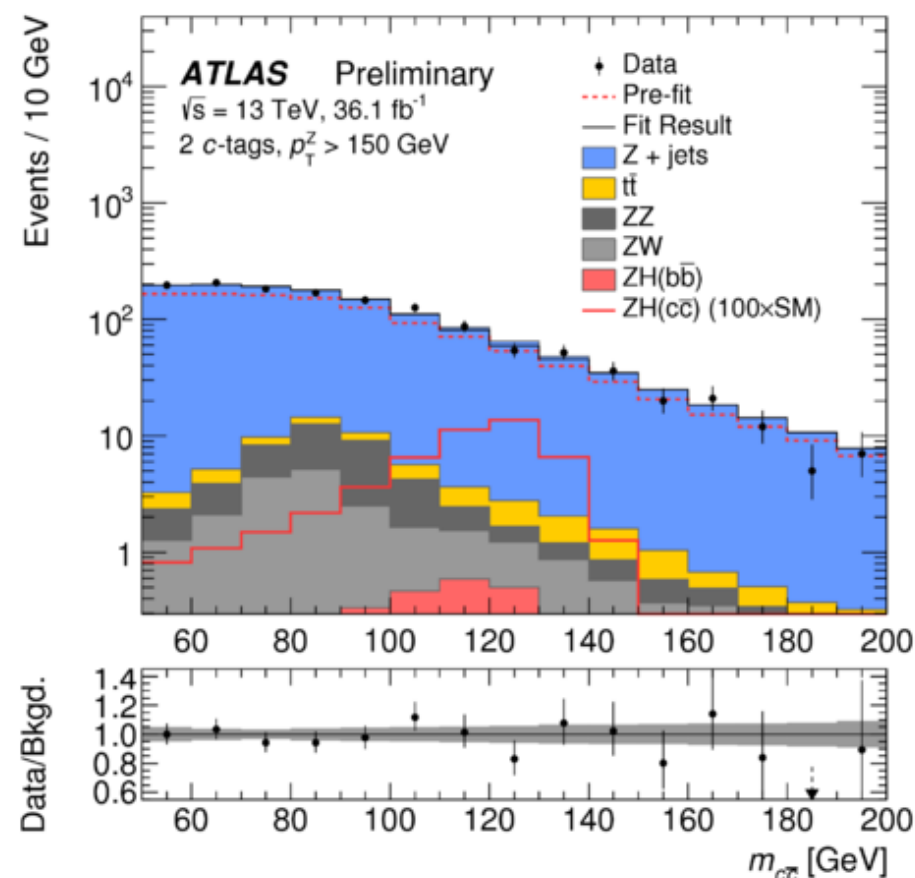
Dec 11, 2017

SUSY SM Higgs

Dr. I.Ojalvo

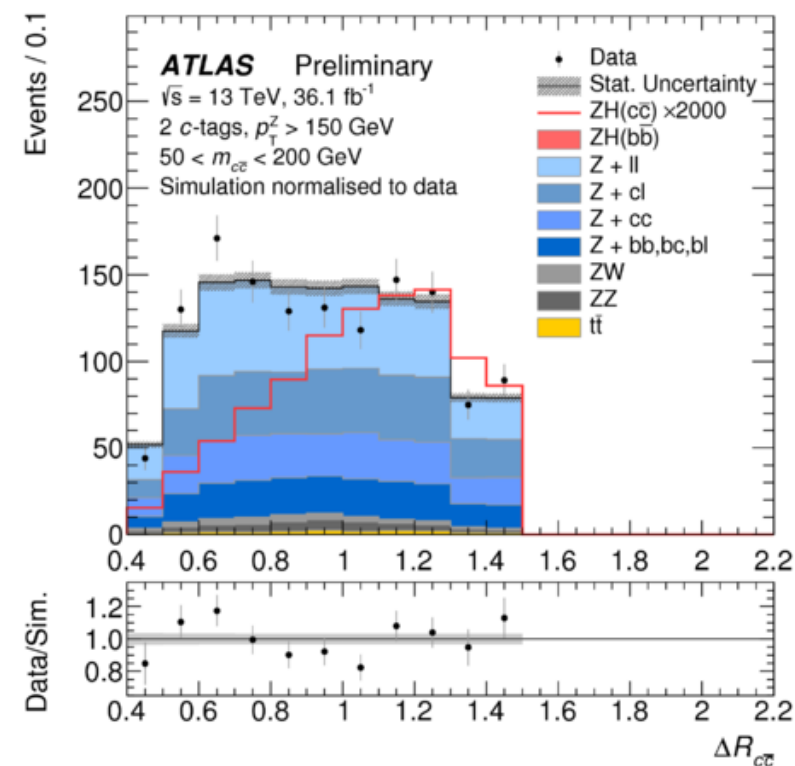
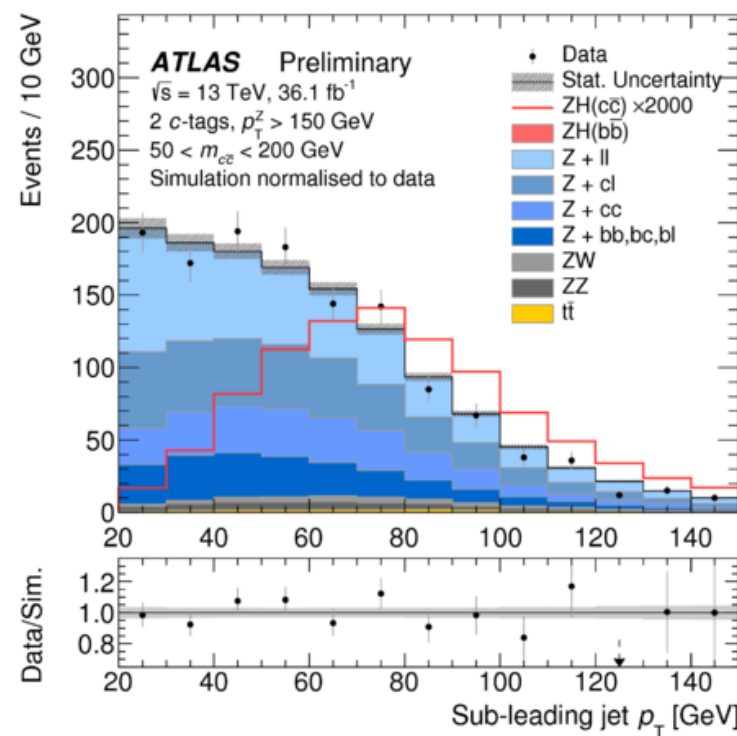


Use of Charm Tagging



Associated production of the Higgs and Z bosons,

$$\sigma(pp \rightarrow ZH) \times \mathcal{B}(H \rightarrow c\bar{c}) \text{ is } 2.7 (3.9^{+2.1}_{-1.1}) \text{ pb}$$



Rare: $ZH \rightarrow cc$
 ATLAS EXPERIMENT



Dec 11, 2017

SUSY SM Higgs

Dr. I.Ojalvo

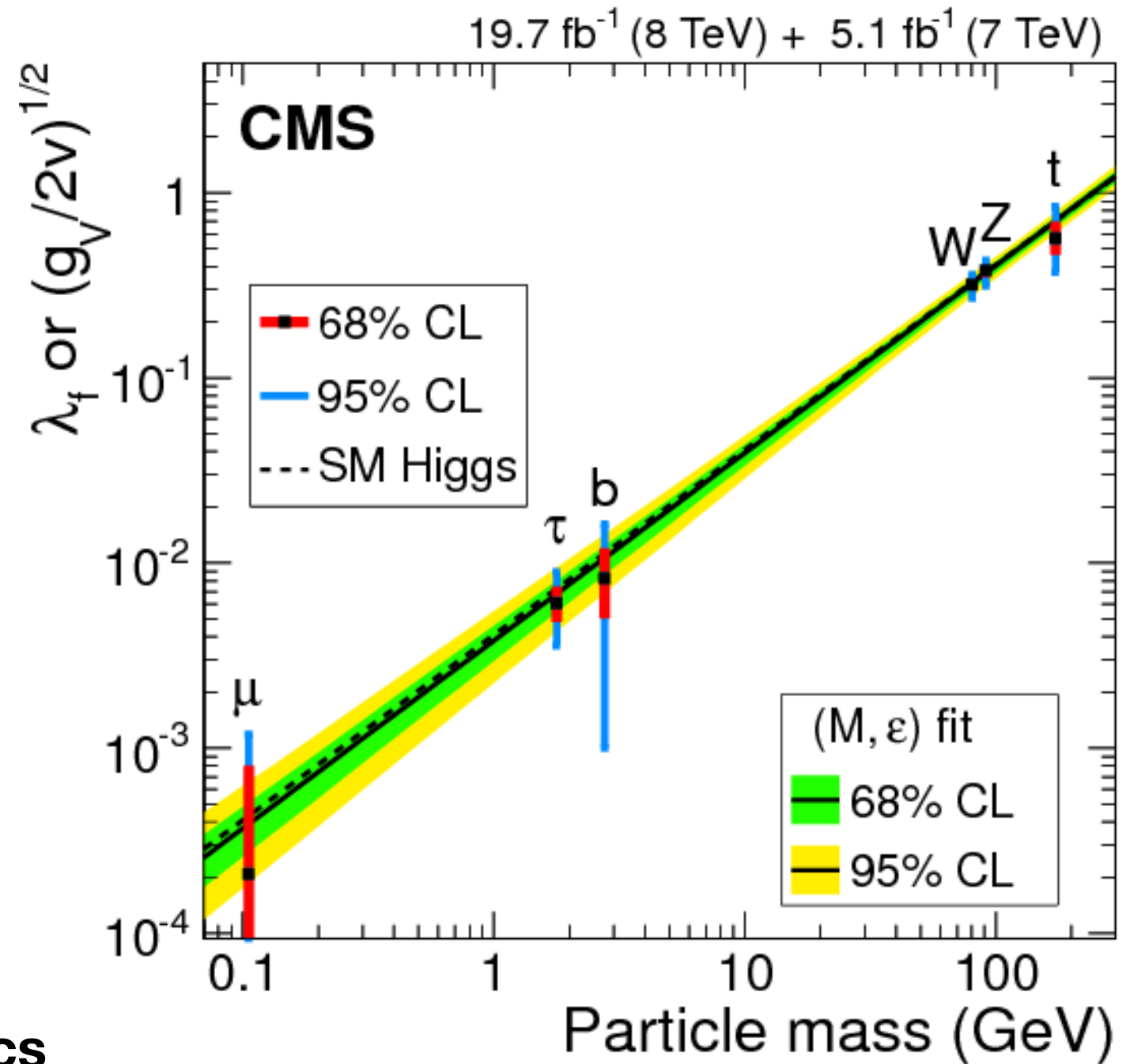
Summary

Run II has brought with it a *triumph* of the **SM Higgs**!

- All major decay modes have shown **Evidence**
- **Observation of $h \rightarrow b\bar{b}$ should be accessible with recently acquired data**
- couplings are **consistent** with **SM expectation**

Focus of the major experiments is **property measurements** and **Higgs as a probe for BSM physics**

- Searching for deviations using precise EW measurements
- And for rare or forbidden decays



Outlook



In the next years LHC Run 2 should provide roughly 150 fb⁻¹ (if we follow current projections)

We have observed the $\tau\tau$ decays and found evidence for bb at single experiments!

Continuing on our search for deviations from the SM as well as improving current measurements

**Plenty of room for new results, new ideas
...and, maybe, surprises!**

Bibliography

	Channel	URL
<u>ATLAS</u>	VHbb	https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2016-29/
	h->4l	https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2016-25/
	h->mumu	https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2016-10/
	VHcc	https://cds.cern.ch/record/2292061
	ttH ll	https://cds.cern.ch/record/2291405
	ttH bb	https://cds.cern.ch/record/2291393
	h->gg	https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-045/
	h-> bb	https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2016-22/
	h->gg/4l	https://cds.cern.ch/record/2273854
	mass h gg/4l	https://cds.cern.ch/record/2273853
	h->WW	https://cds.cern.ch/record/2231811
	VBF h->bb	https://cds.cern.ch/record/2206201
<u>CMS</u>	h->TauTau	http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG-16-043/index.html
	h->4l properties	http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG-16-041/index.html
	ttH ll	http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-15-008/index.html
	ttH tautau	http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-020/index.html
	h->4l anomalous couplings	http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG-17-011/index.html
	h->WW	http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-15-003/index.html
	h->gg	http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-16-020/index.html
	h->mumu	http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-17-019/index.html
	tHq	http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/HIG-17-019/index.html
<u>ATLAS+CMS</u>	Combination	http://cms-results.web.cern.ch/cms-results/public-results/publications/HIG-15-002/index.html