Higgs Physics at CMS

P. Cirkovic (University of Belgrade)
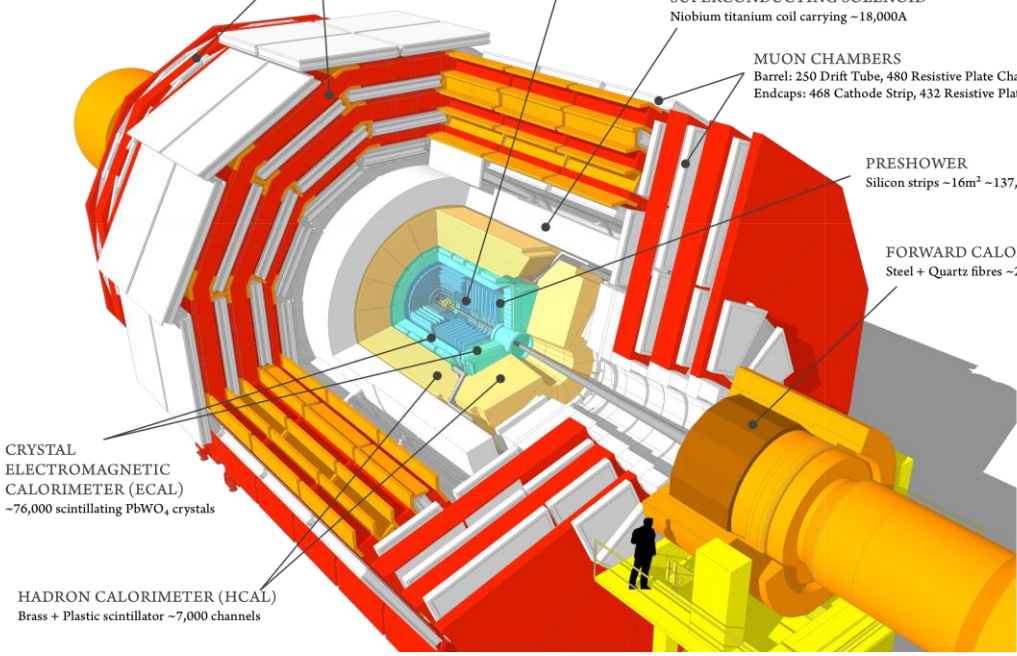
on behalf of the CMS Collaboration

Outline

- Introduction
  - Experimental facilities
  - Theory overview

- SM Higgs measurements
  - The main Higgs analysis channels
  - Higgs properties

- Rare processes and BSM Higgs searches

- Future prospects

- Summary and outlook

- Most recent results: NEW
  - Mass in $4l$
  - Fiducial cross section in $4l$ and di-photon
  - Higgs coupling in $t\bar{t}H$
  - Search for (non-)resonant HH

- Many results use full $13\ TeV$ dataset recorded in 2016: $35.9\ fb^{-1}$
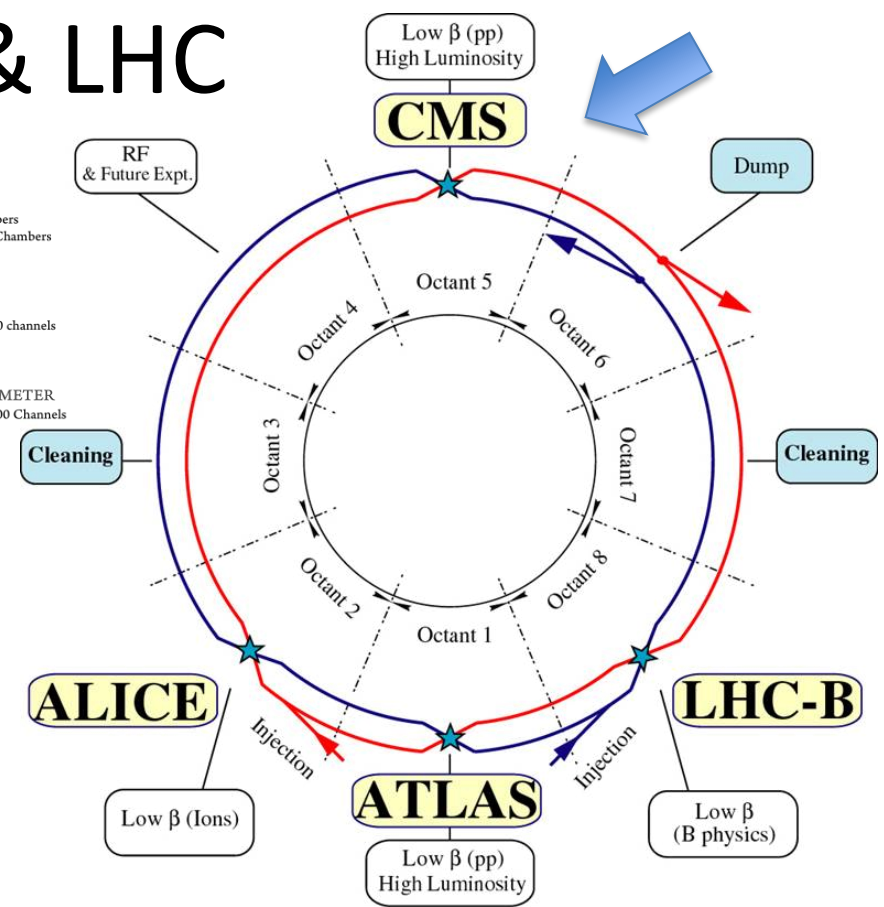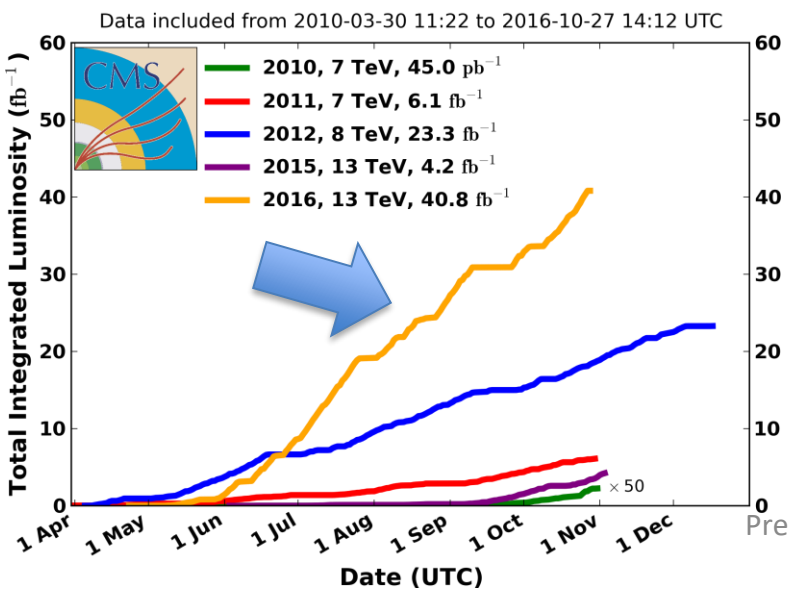
CMS & LHC

CMS DETECTOR

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO₄ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Low β (pp)
High Luminosity

CMS

Dump

RF & Future Expt.

Octant 5
Octant 4
Octant 6
Octant 3
Octant 7

Cleaning

Cleaning

Octant 2
Octant 8
Octant 1

ALICE

LHC-B

Injection

Injection

Low β (Ions)

ATLAS

Low β (B physics)

Low β (pp)
High Luminosity

CMS Integrated Luminosity, pp

Data included from 2010-03-30 11:22 to 2016-10-27 14:12 UTC

- 2010, 7 TeV, 45.0 pb⁻¹
- 2011, 7 TeV, 6.1 fb⁻¹
- 2012, 8 TeV, 23.3 fb⁻¹
- 2015, 13 TeV, 4.2 fb⁻¹
- 2016, 13 TeV, 40.8 fb⁻¹

Total Integrated Luminosity (fb⁻¹)

× 50

Date (UTC)

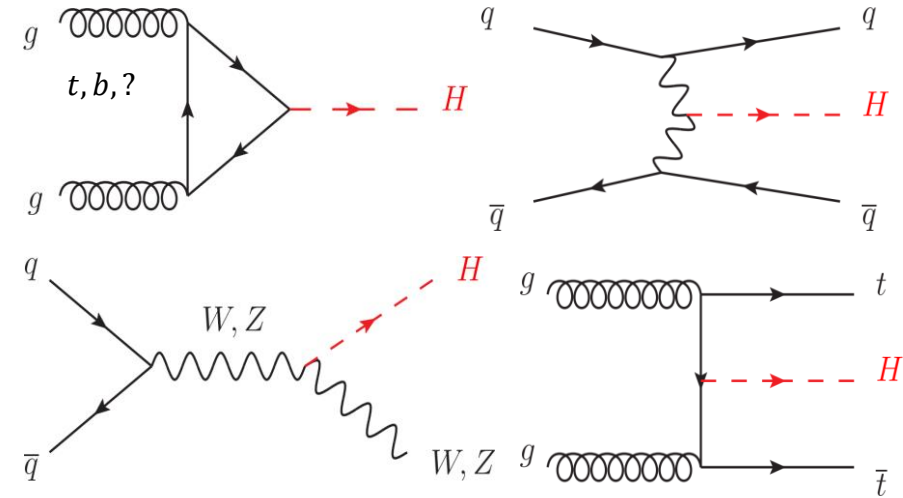CMS: a general-purpose detector at the LHC

Broad physics programme:
- Studying the SM (including the Higgs boson)
- Searching for extra dimension and DM particles

Good operating conditions in 2016

Predrag Cirkovic @ QFTHEP 2017
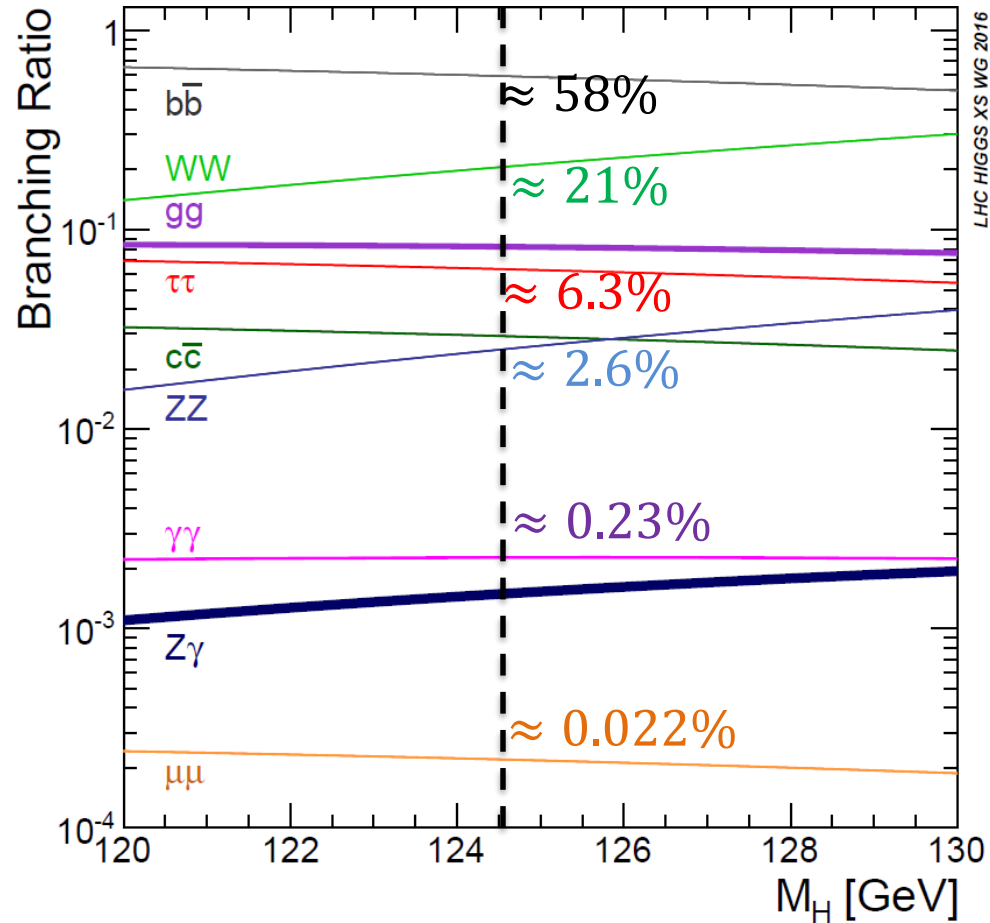
3

Higgs production and decay

CERN YR 4: **arXiv:1610.07922**

Production

- ggH
- VBF
- VH
- $t\bar{t}H$

Decay

- $H \to b\bar{b}$
- $H \to WW$
- $H \to \tau\tau$
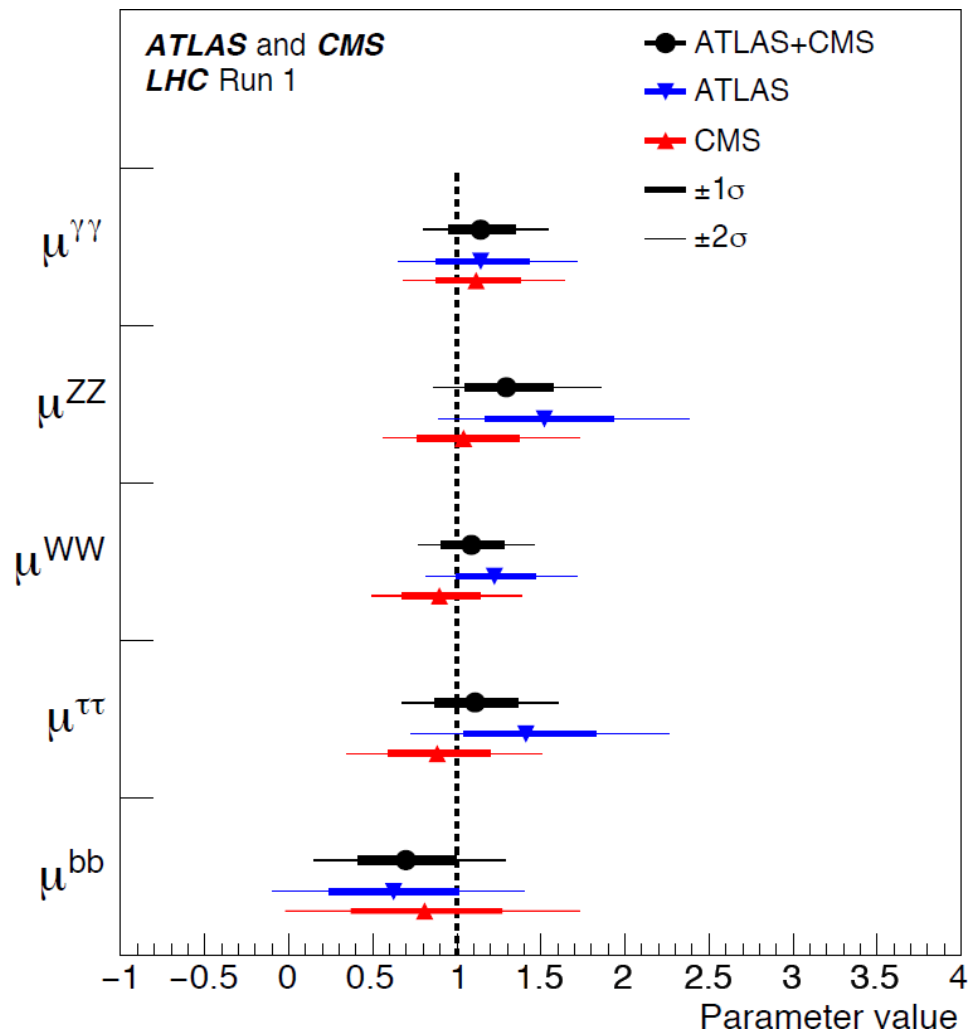- $H \to ZZ$
- $H \to \gamma\gamma$

Individual signal strengths (production and decay)

Production

Decay

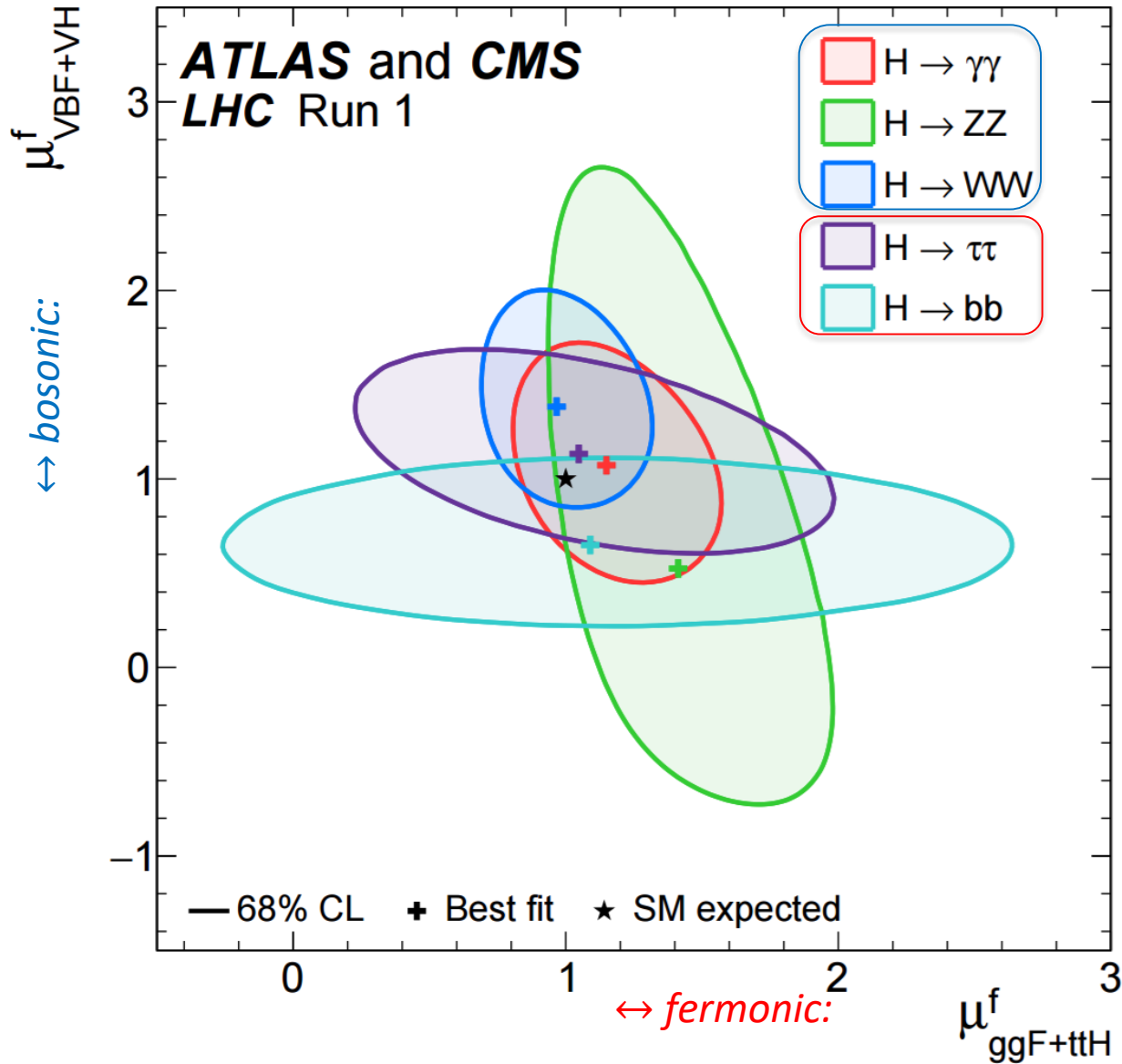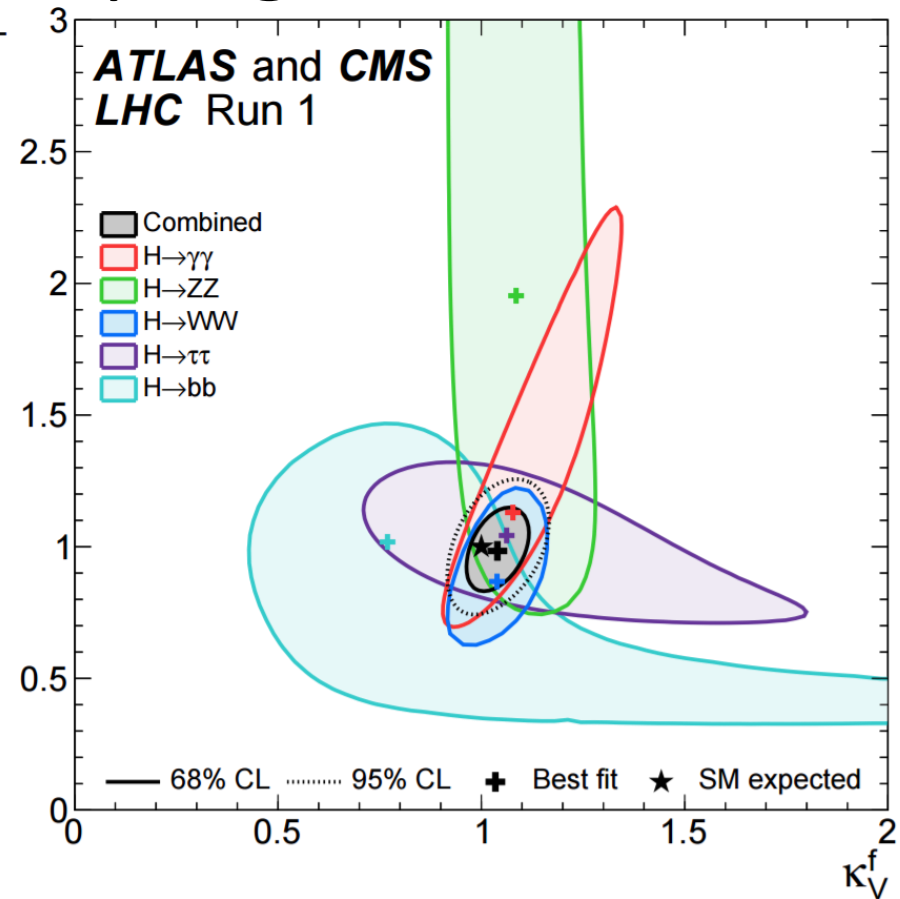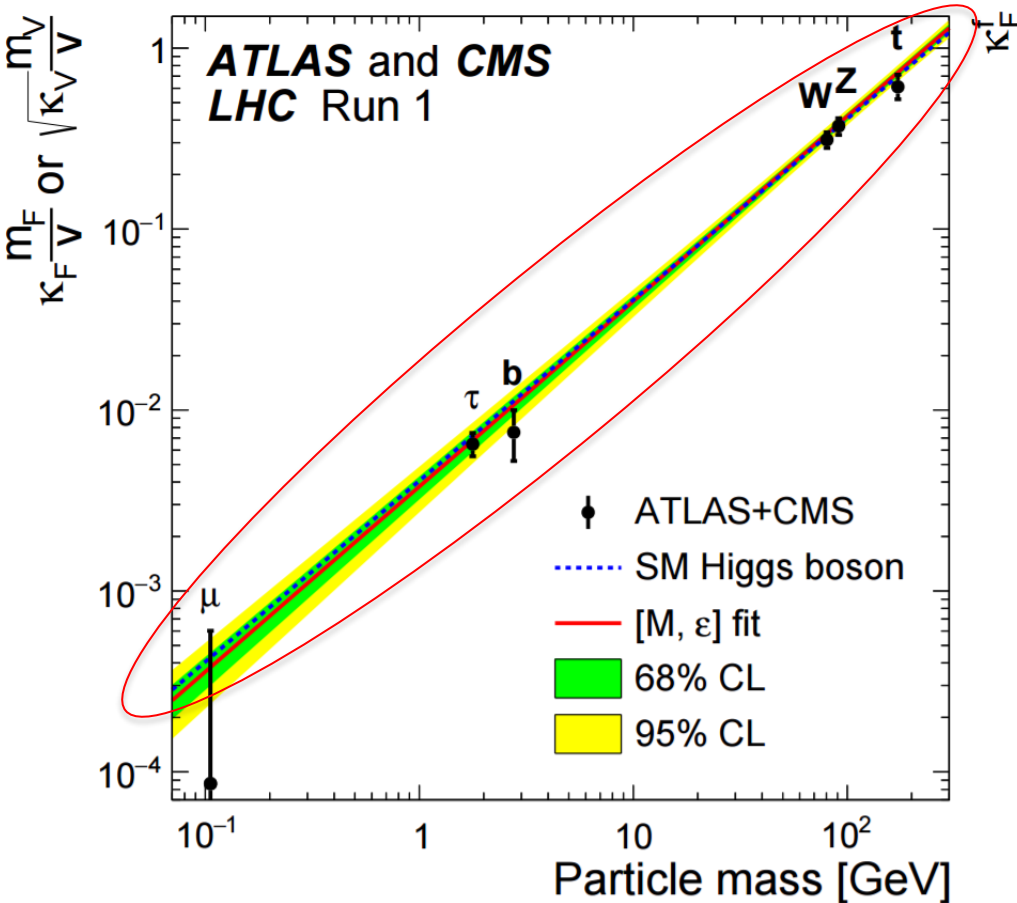CMS + ATLAS Run 1 legacy

JHEP 08 (2016) 045
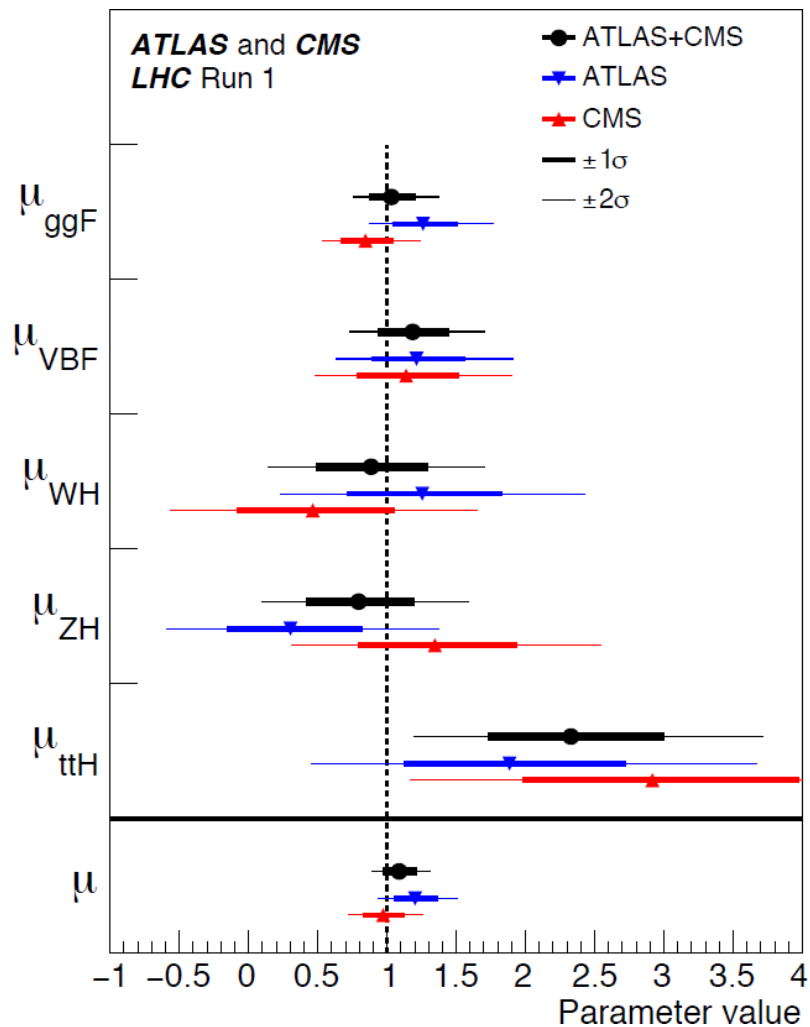
Individual signal strengths (fermionic vs bosonic)
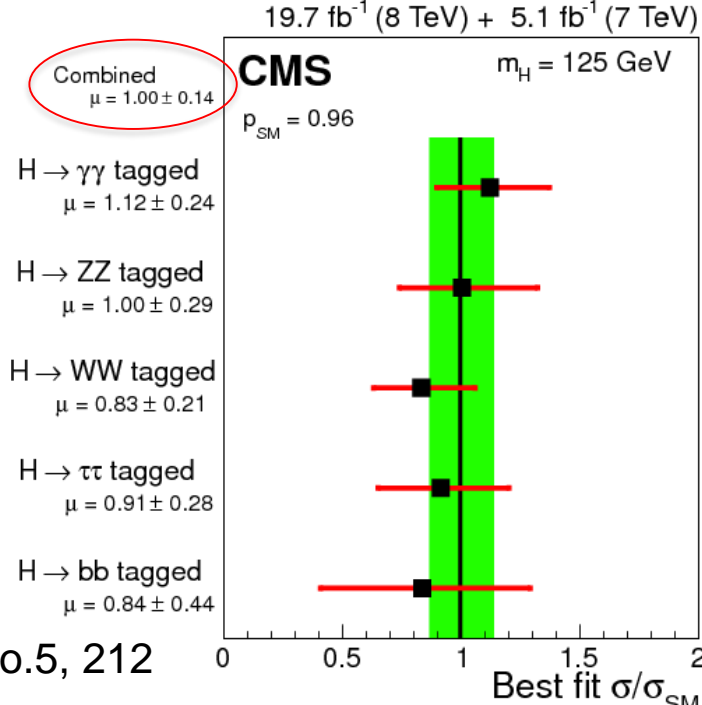
Individual couplings

- κ_V and κ_F used to quantify deviation from SM
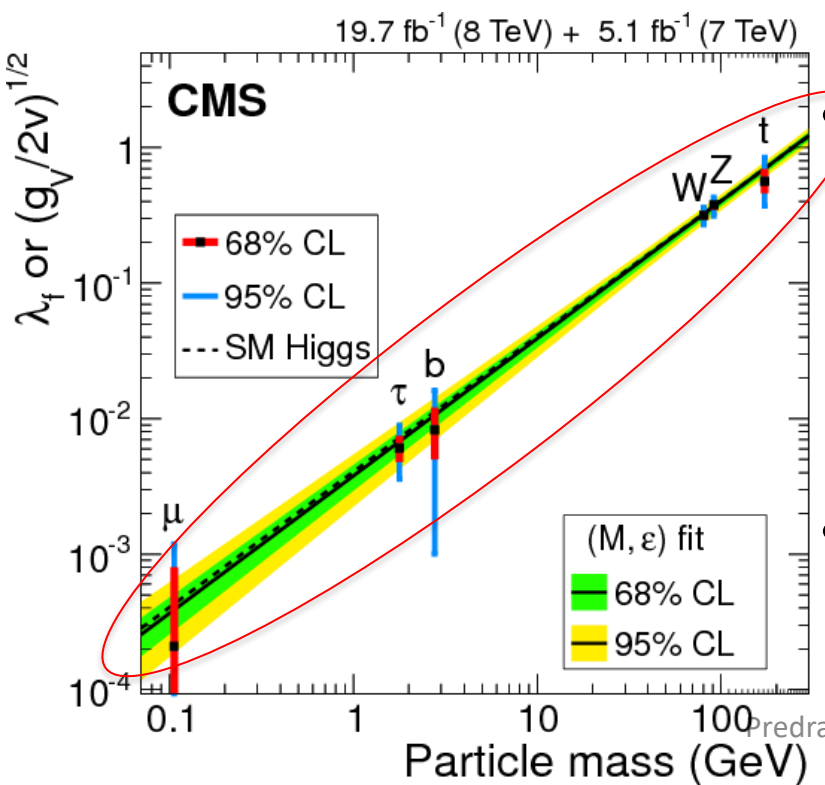
- Couplings constrained by Run-I measurements

- All channels compatible with $\kappa_V = 1$ and $\kappa_F = 1$

- Result consistent with the SM expectations

7

CMS-only $7\,TeV + 8\,TeV$ results on signal strengths and couplings

- $19.7\,fb^{-1}(8\,TeV) + 5.1\,fb^{-1}(7\,TeV)$ complete Run I CMS dataset

- Individual signal strengths in the main Higgs decay channels compatible with 1.0
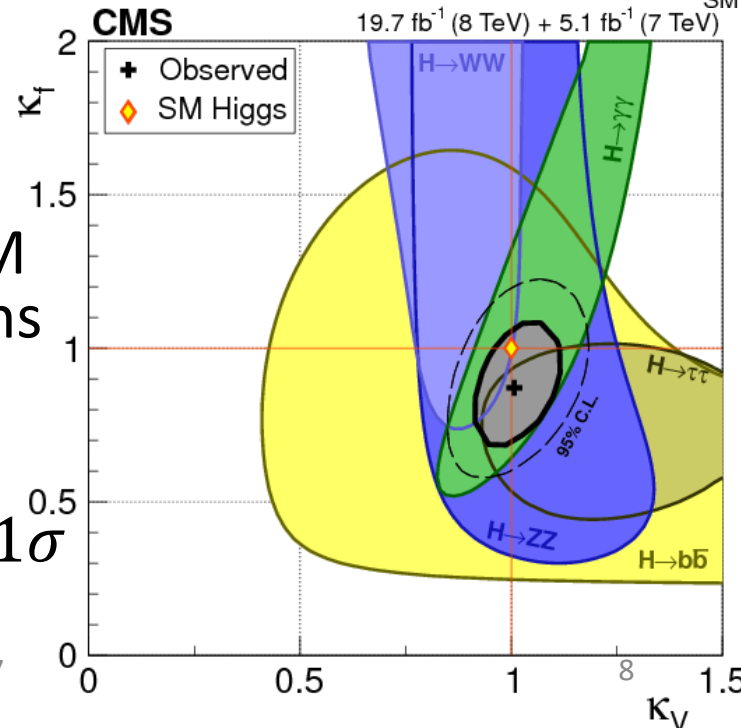
EPJC75 (2015) no.5, 212

- Individual couplings compatible with the SM expectations

- Agreement within the 1σ region
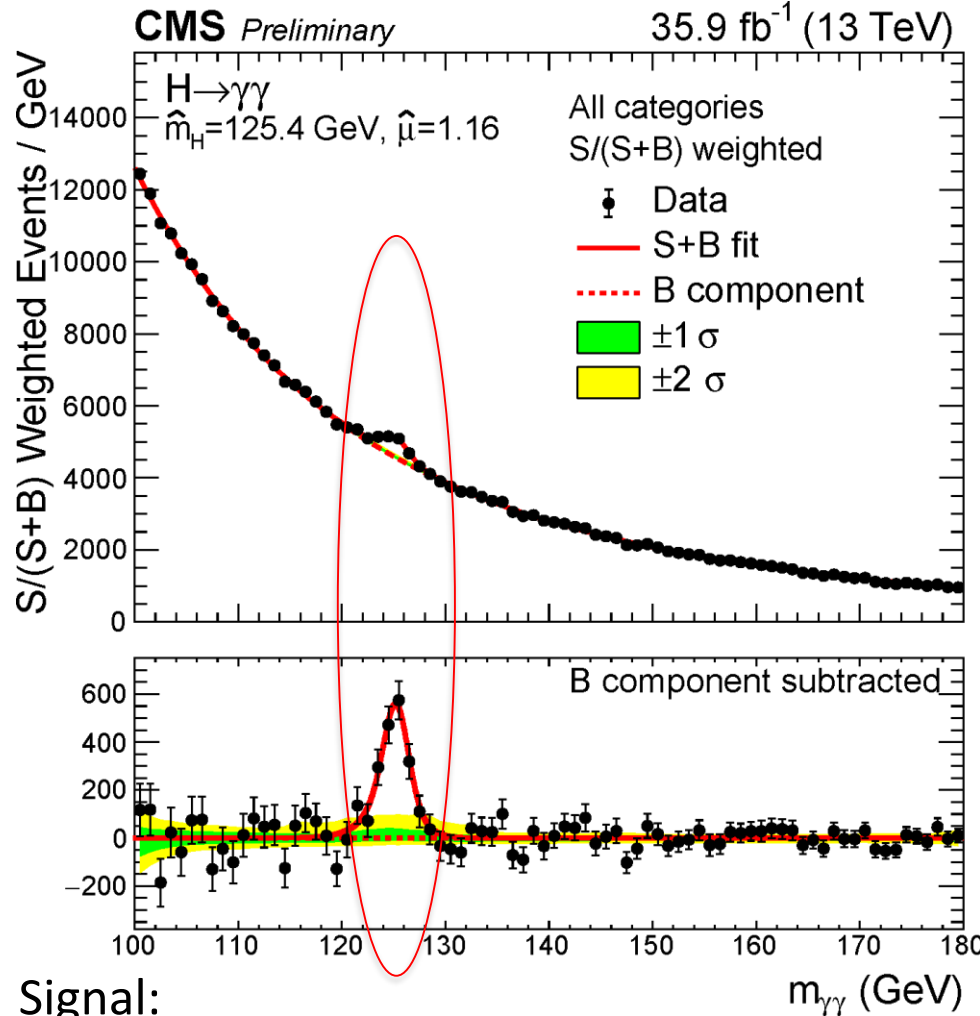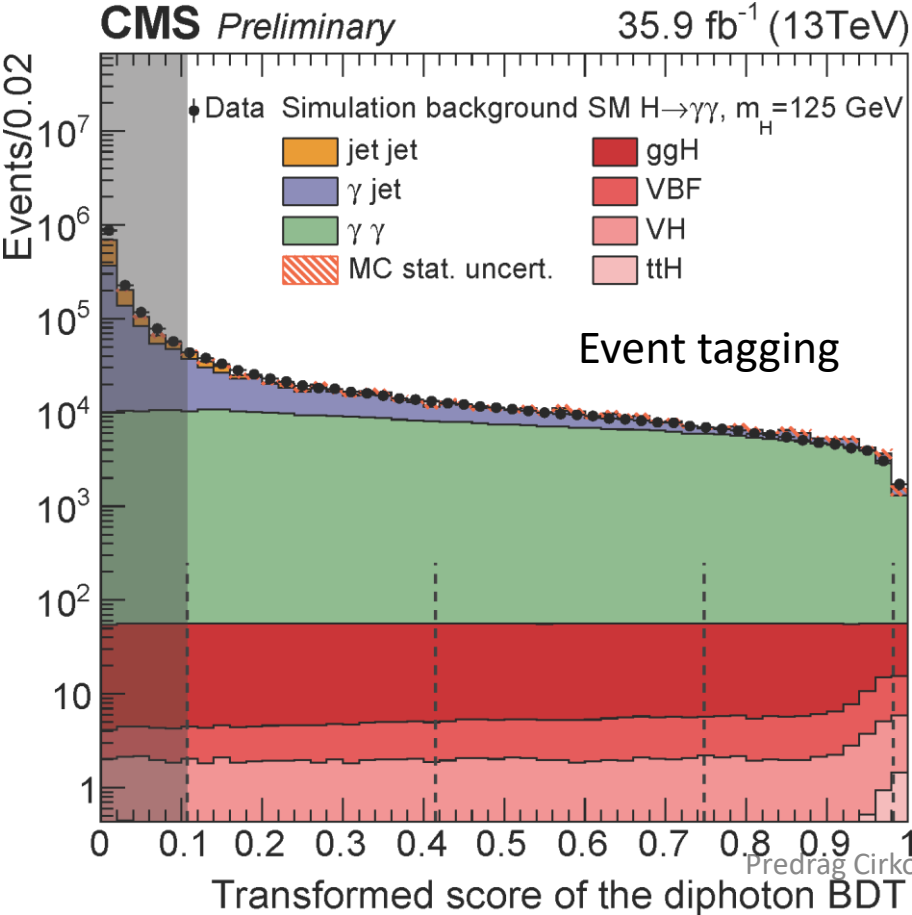
$H \rightarrow \gamma\gamma$

CMS-PAS-HIG-16-040

Characteristics:
- High resolution: $\sigma \sim 1 - 2\% \, m_{\gamma\gamma}$
- Clean final state
- Small BR

BDT usage
- Photon ID
- Selection of $\gamma\gamma$ Vx
- Selection of $\gamma\gamma$ events

Event tagging

Signal:
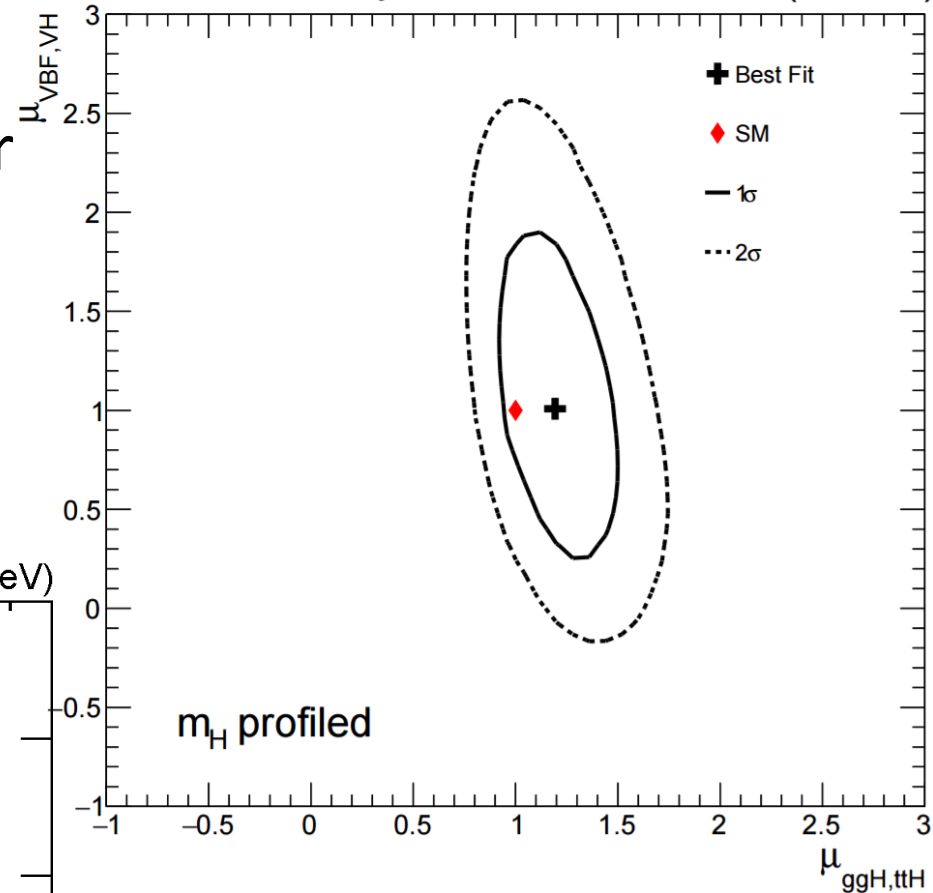- Two isolated and high E_T photons

Background:
- Continuum $\gamma\gamma$ (irreducible)
- Fakes from γ+jet/jet+jet (reducible)

$H \to \gamma\gamma$ signal strength

- Individual signal strengths for each of the Higgs production modes

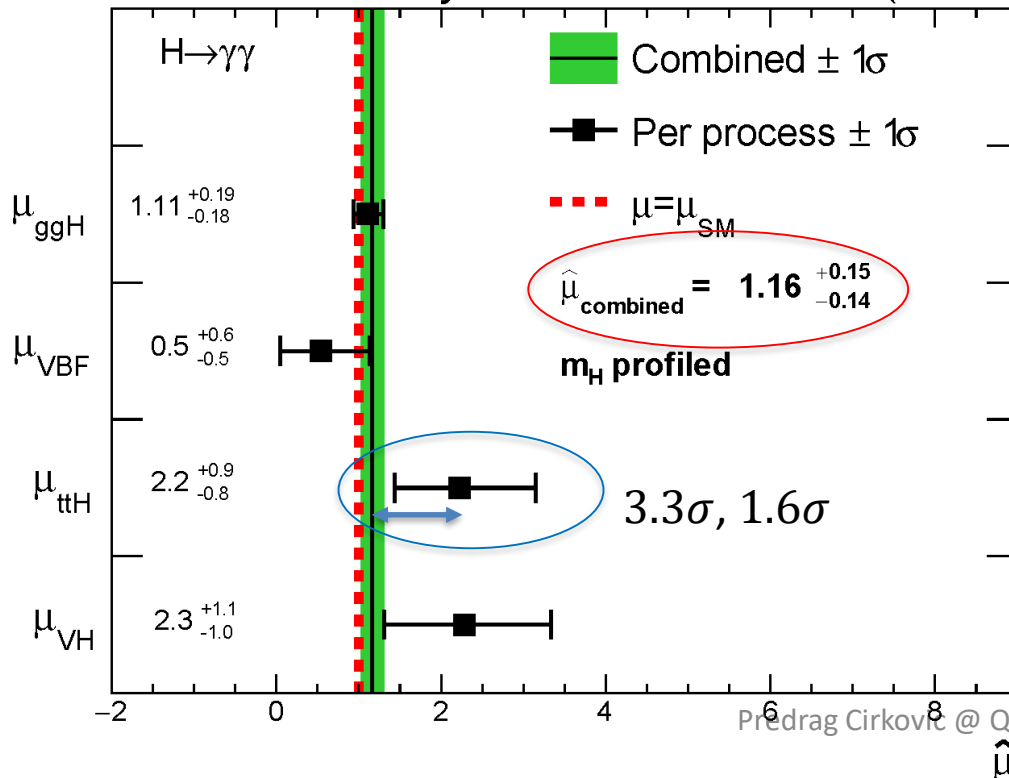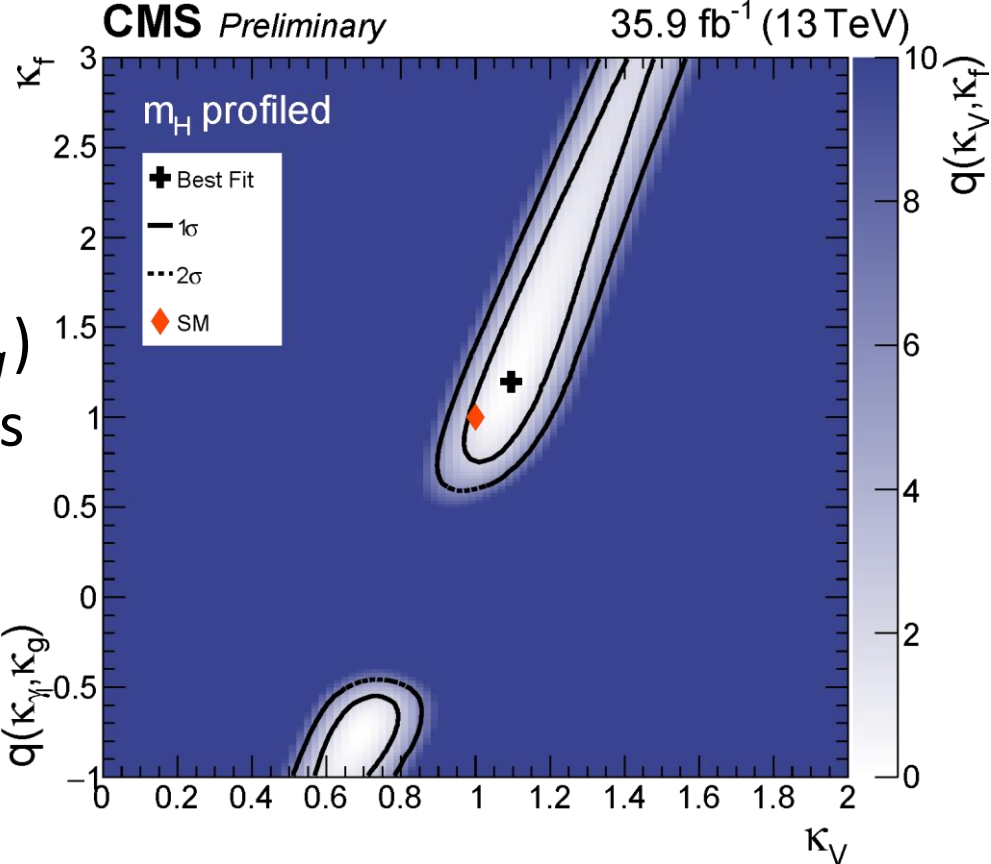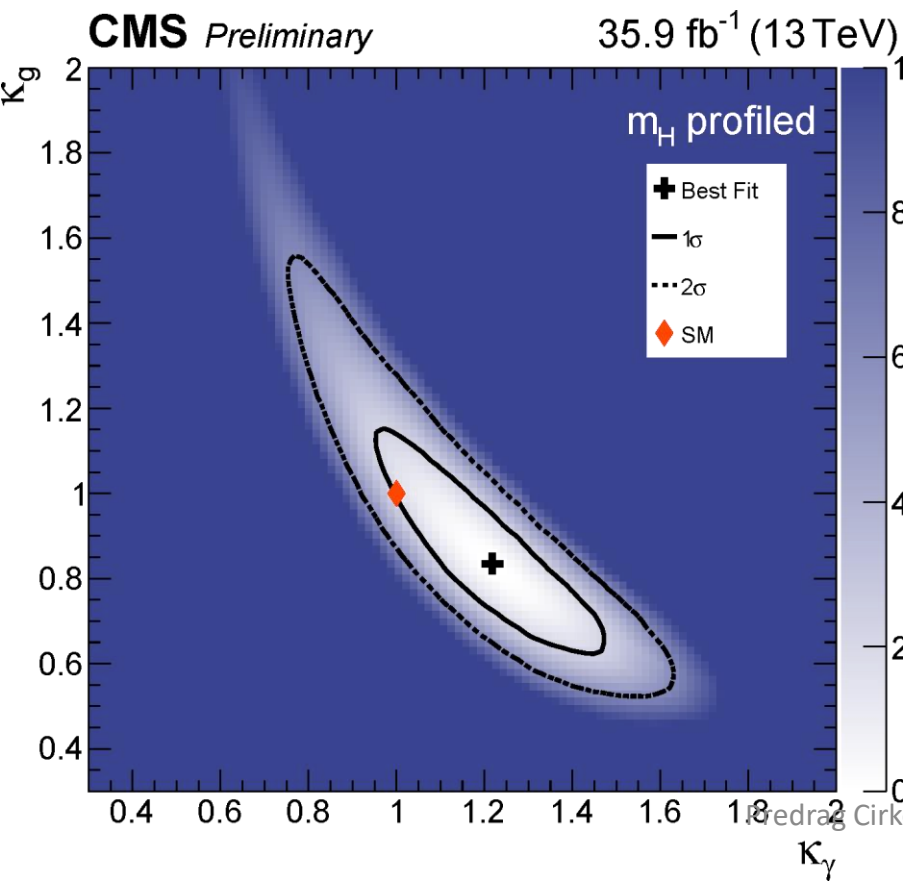- Signal strengths measured in bosonic and fermionic parts

Standard Model consistent

CMS-PAS-HIG-16-040

$H \rightarrow \gamma\gamma$ couplings

Measurements of coupling modifiers

- To photons and gluons $(\kappa_\gamma, \kappa_g)$
- To vector bosons and fermions (κ_V, κ_f)

CMS *Preliminary*   35.9 fb^{-1} (13 TeV)

m_H profiled

- **+** Best Fit
- — 1σ
- ···· 2σ
- ◆ SM

CMS *Preliminary*   35.9 fb^{-1} (13 TeV)

m_H profiled

- **+** Best Fit
- — 1σ
- ···· 2σ
- ◆ SM

Both results

compatible with the SM

CMS-PAS-HIG-16-040

# $H \rightarrow \gamma\gamma$ differential fiducial σ

CMS requires two high-p_T isolated photons within the fiducial volume

No classification based on production mode, implicitly focus on ggH

Event classification based on mass resolution estimator $\sigma_m/m_{\gamma\gamma}$ improves sensitivity by 10%

Simultaneously extract signal and unfold distributions using a ML fit

CMS-PAS-HIG-17-015

$84^{+13}_{-12}\ fb$ ($75^{+4}_{-4}\ fb$ theoretically)
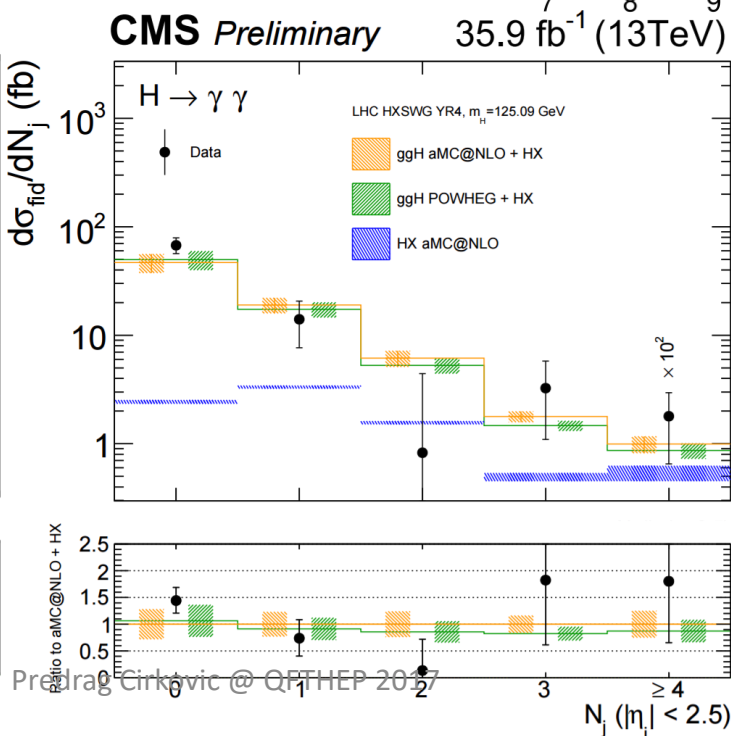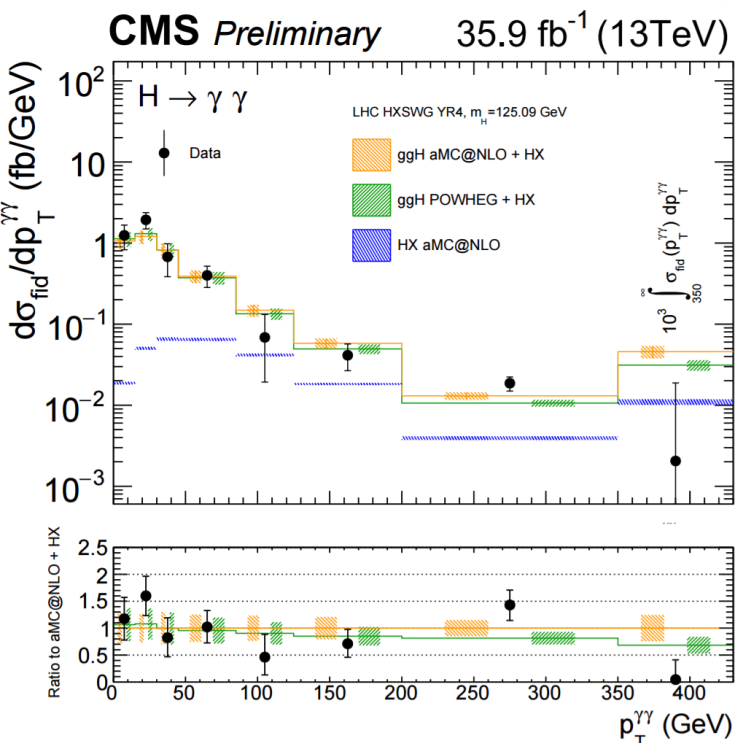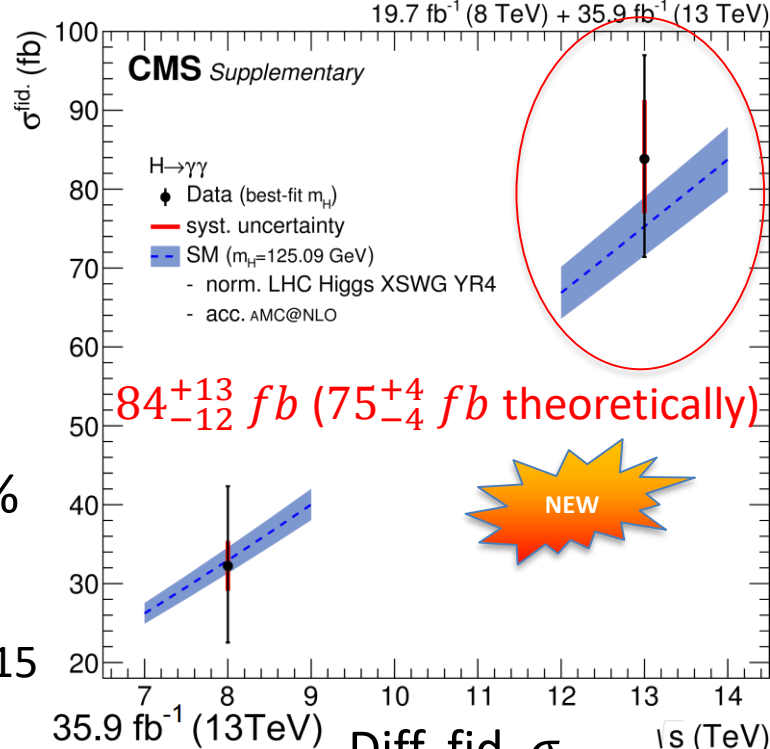
Diff. fid. σ measured for p_T and N_{jets}

No significant deviations of distributions from the SM predictions

Most precise fid. measurement to date

12

# $H \rightarrow ZZ^* \rightarrow 4l$
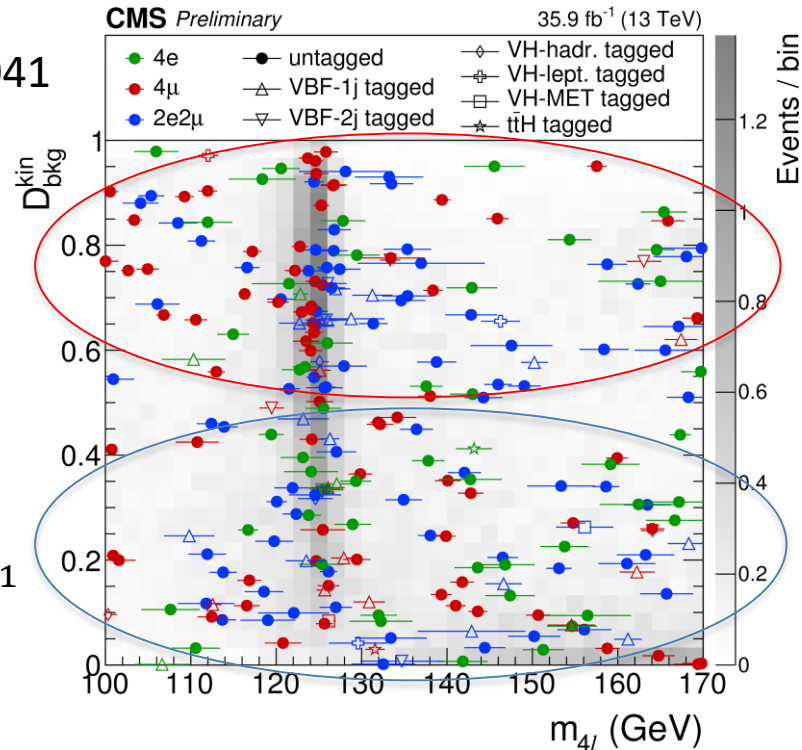
CMS PAS HIG-16-041

Signal:

- 4 isolated leptons (e, μ) with excellent momentum resolution: two pairs of same flavour, opposite sign leptons ($4e$, 4μ, $2e2\mu$, or $2\mu2e$)
- Fully reconstructed mass peak
- Large S/B ratio (>2:1)

$$\mathcal{D}_{bkg}^{kin} = \left[1 + \frac{\mathcal{P}_{bkg}^{q\bar{q}}\left(\vec{\Omega}^{H\rightarrow 4l}|m_{4l}\right)}{\mathcal{P}_{sig}^{gg}\left(\vec{\Omega}^{H\rightarrow 4l}|m_{4l}\right)}\right]^{-1}$$

Backgrounds:

- SM ZZ (main background, irreducible) estimated from MC
- $Z + X$: fakes from Z+jets, ... (reducible) estimated from data-driven methods

- Events split into 7 categories according to Higgs productions modes to increase sensitivity, based on: # of leptons, # of (b-)jets, E_T^{miss} and selections on kinematic discriminants ($\mathcal{D}_{bkg}^{kin}$)
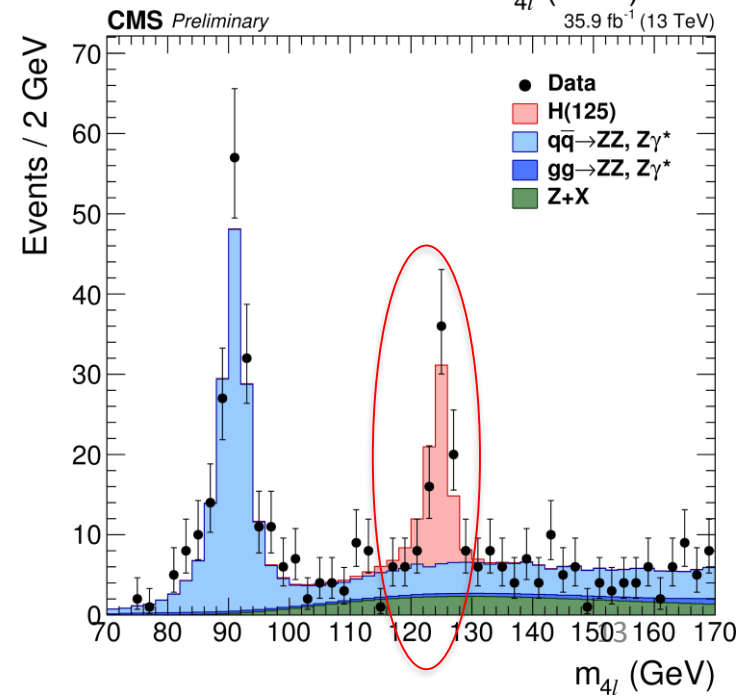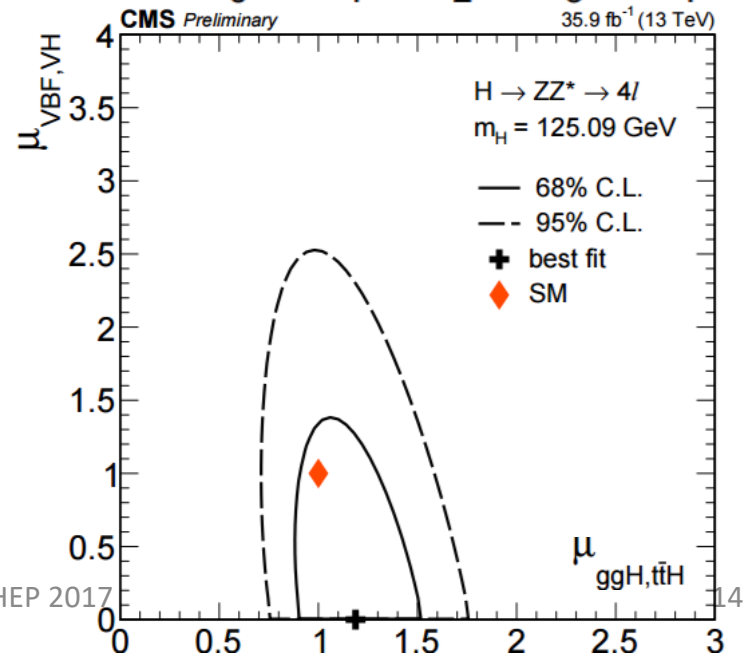
$H \to 4l$ signal strength

- Vs event category
- Vs production mode
- 2D likelihood scan

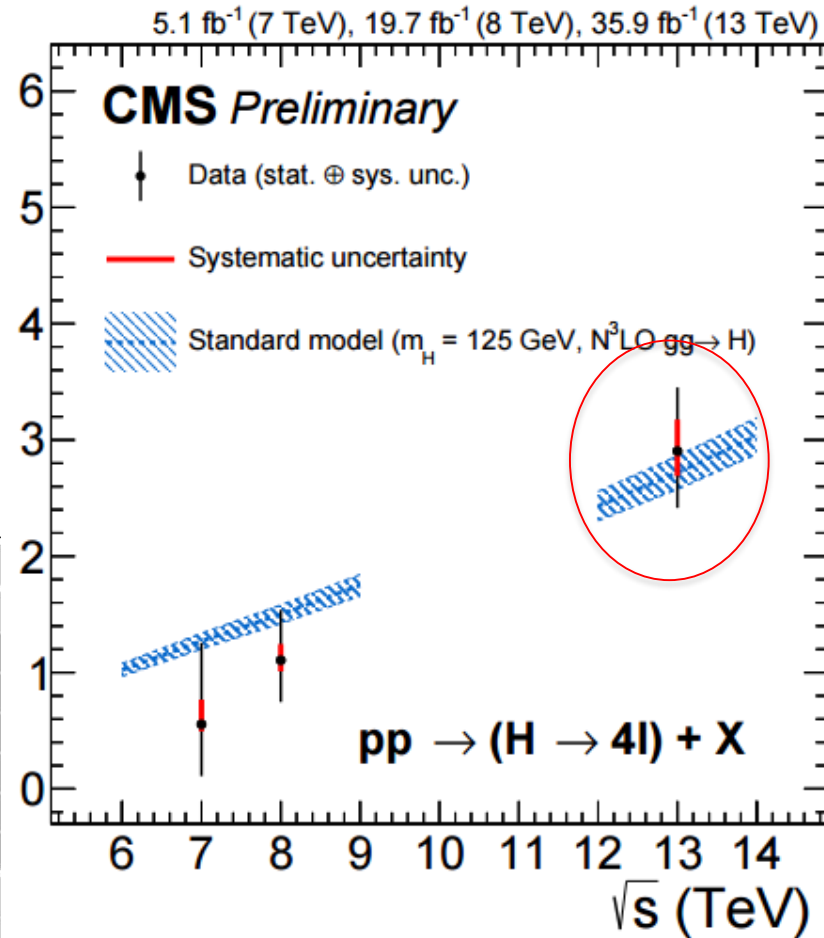All compatible within the present uncertainties
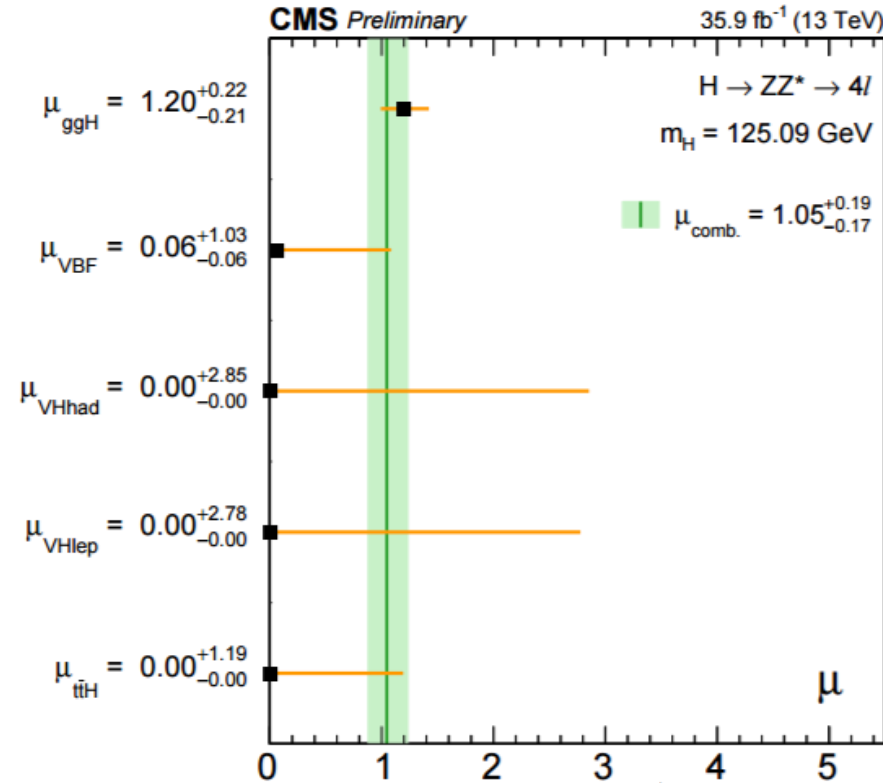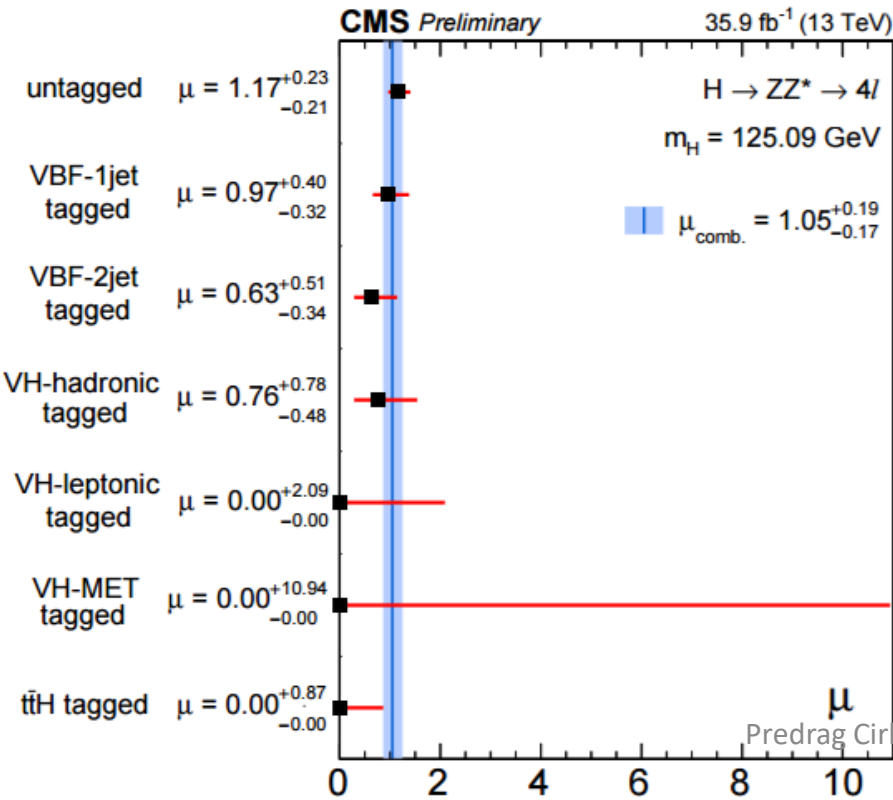
CMS PAS HIG-16-041

$H \to 4l$ fiducial cross section

NEW

Minimal dependence on the assumptions of the relative fraction or kinematic distributions of the separate production modes

No significant deviations from SM predictions

Requirements for the $H \to 4\ell$ fiducial phase space	
Lepton kinematics and isolation	
Leading lepton p_T	$p_T > 20$ GeV
Next-to-leading lepton p_T	$p_T > 10$ GeV
Additional electrons (muons) p_T	$p_T > 7(5)$ GeV
Pseudorapidity of electrons (muons)	$|\eta| < 2.5(2.4)$
Sum of scalar p_T of all stable particles within $\Delta R < 0.3$ from lepton	$< 0.35 \cdot p_T$
Event topology	
Existence of at least two same-flavor OS lepton pairs	
Inv. mass of the Z_1 candidate	40 GeV $< m_{Z_1} < 120$ GeV
Inv. mass of the Z_2 candidate	12 GeV $< m_{Z_2} < 120$ GeV
Distance between selected four leptons	$\Delta R(\ell_i, \ell_j) > 0.02$ for any $i \neq j$
Inv. mass of any opposite sign lepton pair	$m_{\ell^+ \ell'^-} > 4$ GeV
Inv. mass of the selected four leptons	105 GeV $< m_{4\ell} < 140$ GeV

5.1 fb⁻¹ (7 TeV), 19.7 fb⁻¹ (8 TeV), 35.9 fb⁻¹ (13 TeV)

CMS *Preliminary*

Data (stat. ⊕ sys. unc.)

Systematic uncertainty

Standard model (m_H = 125 GeV, N³LO gg→H)

pp → (H → 4l) + X

$\sigma_{fid.} = 2.90^{+0.48}_{-0.44}(stat.)^{+0.27}_{-0.22}(syst.) \, fb$

$\sigma^{SM}_{fid.} = 2.72 \pm 0.14 \, fb$ (theoretically.)

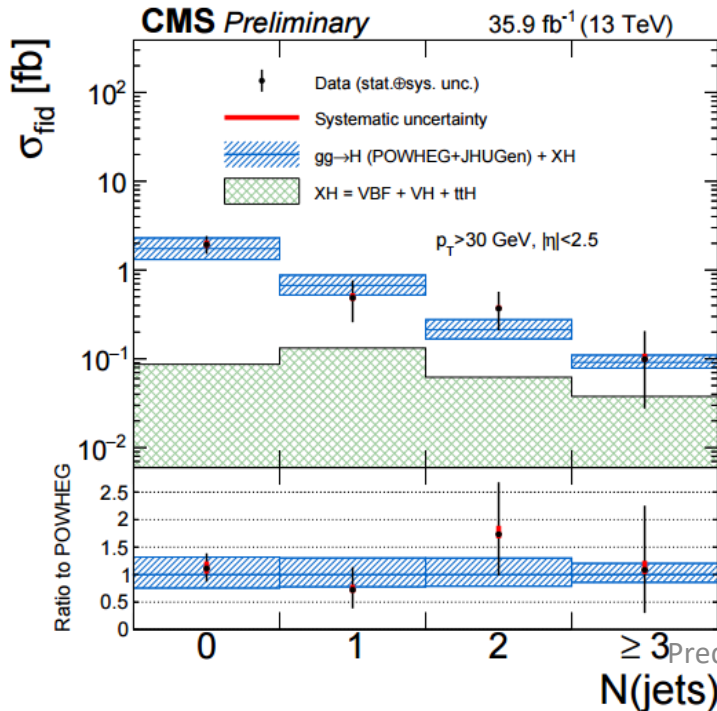# $H \rightarrow 4l$ differential fiducial cross section

Differential cross sections vs:
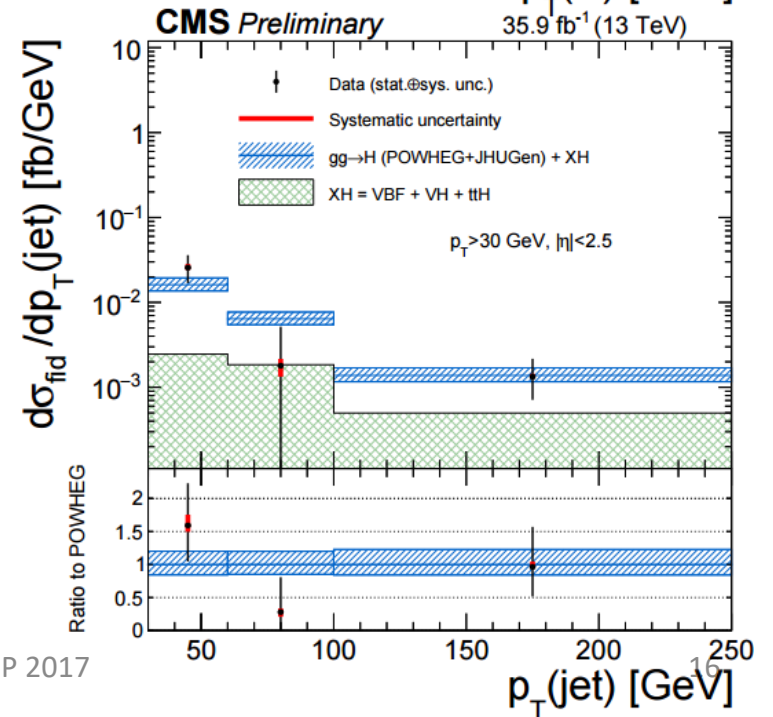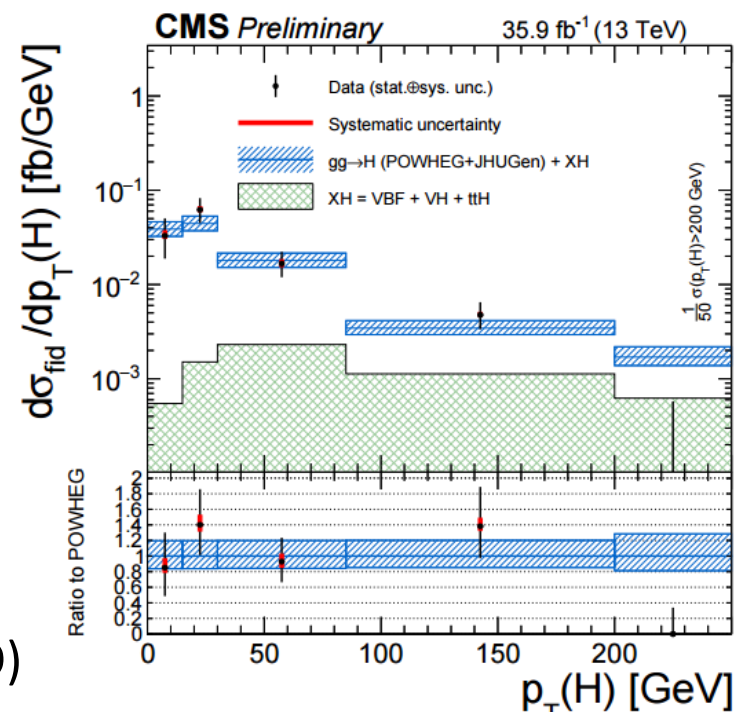
- $p_T(H)$
- N(jets)
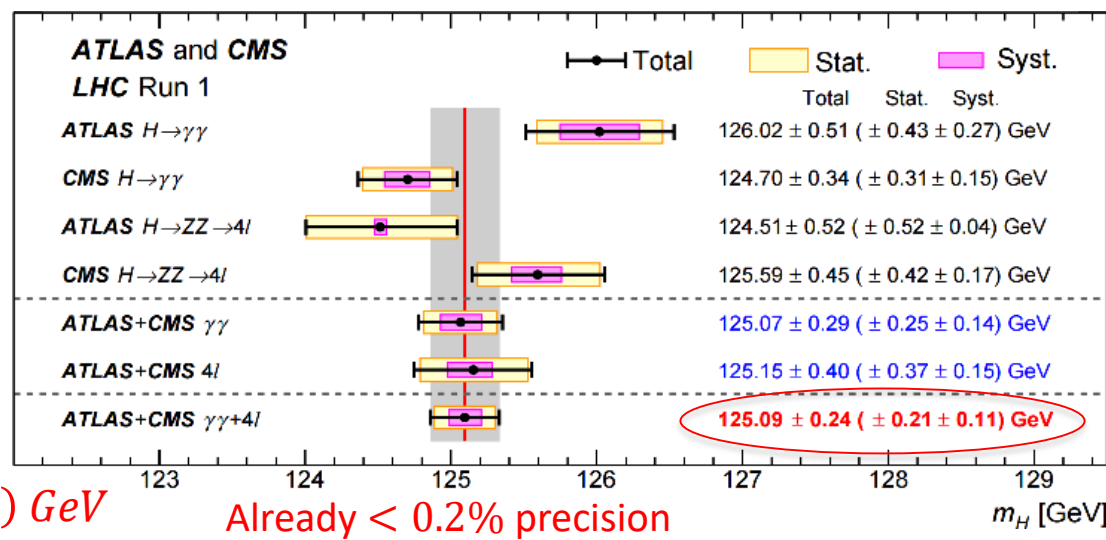- $p_T(jet)$

NEW

Compared with predictions from POWHEG (NLO)

CMS PAS HIG-16-041

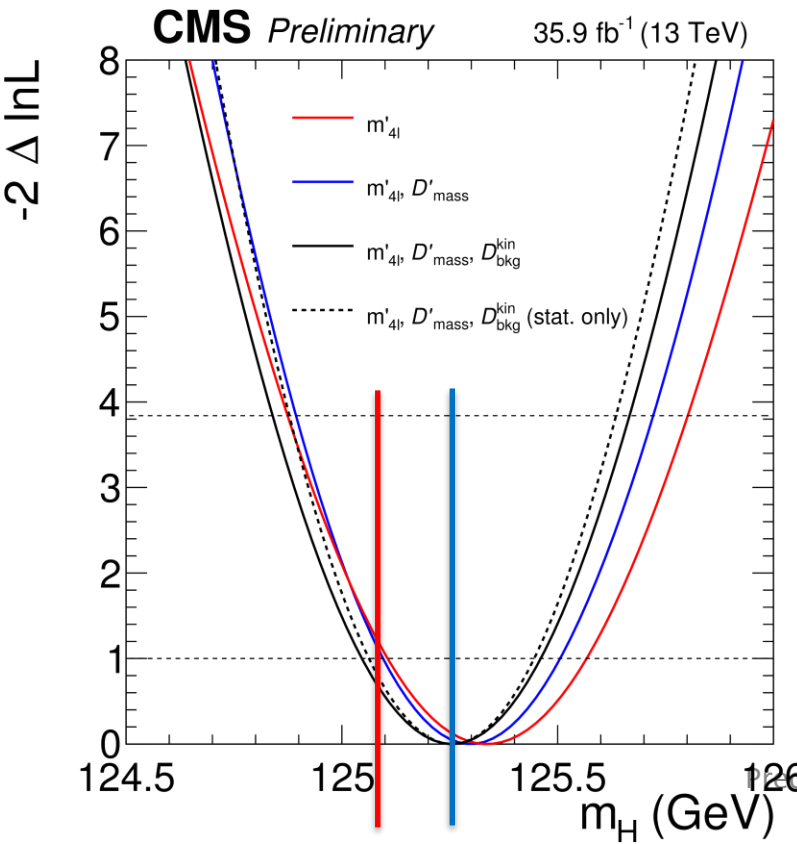# $H \to 4l$ mass and width
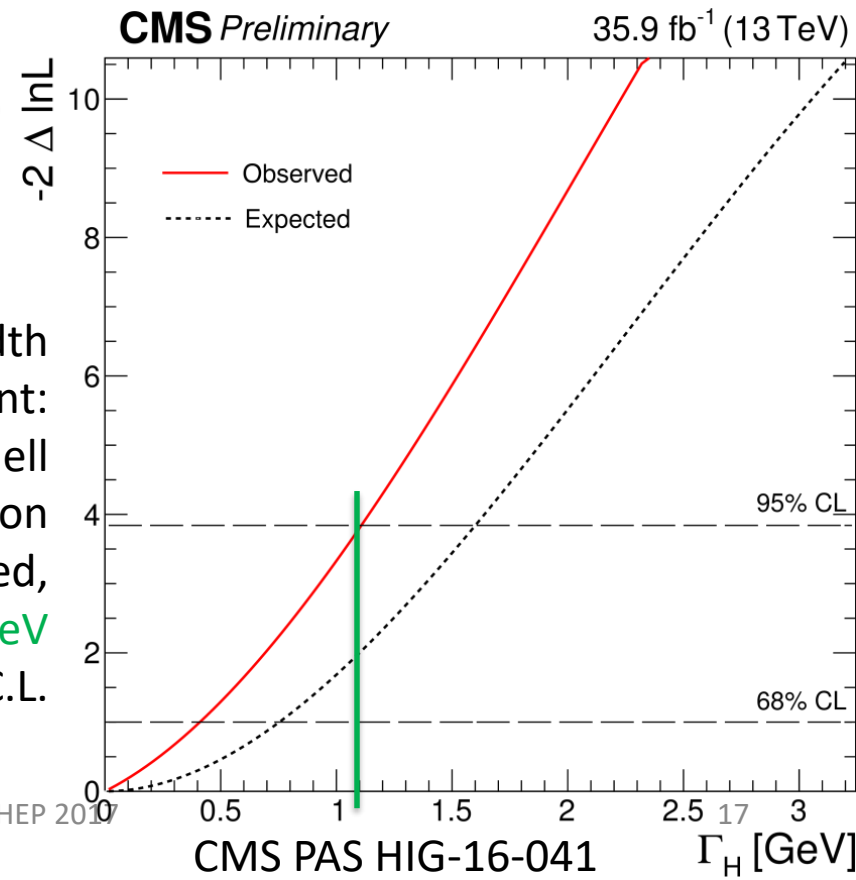
Mass measurement based on 3D fit on the

- invariant mass
- expected uncertainty on mass
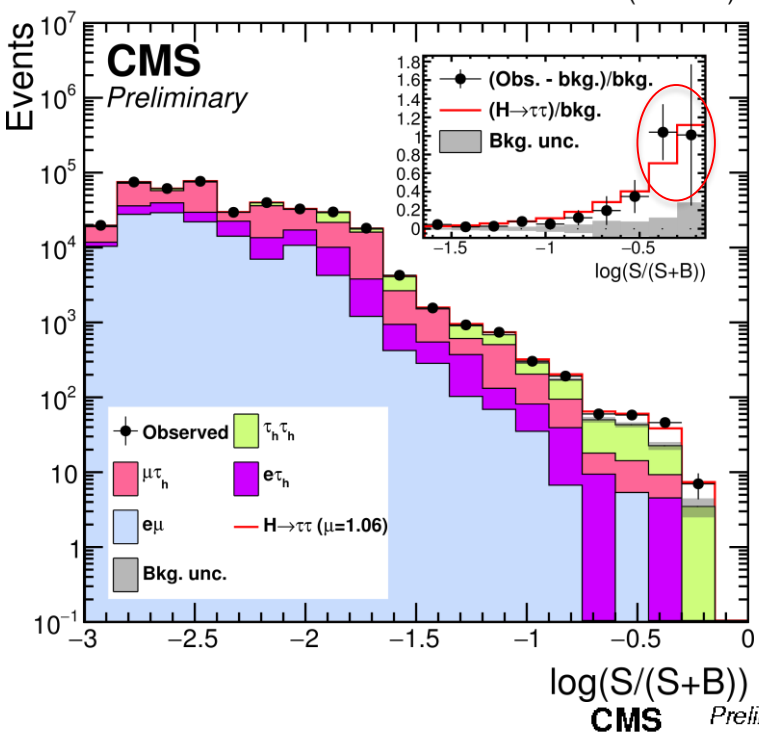- the discriminant $\mathcal{D}_{bkg}^{kin}$

$m_H = 125.09 \pm 0.21(stat.) \pm 0.11(syst.)\ GeV$

$m_H = 125.26 \pm 0.20(stat.) \pm 0.08(syst.)\ GeV$

Already < 0.2% precision

NEW

Width measurement: using on-shell production
If m_H floated,
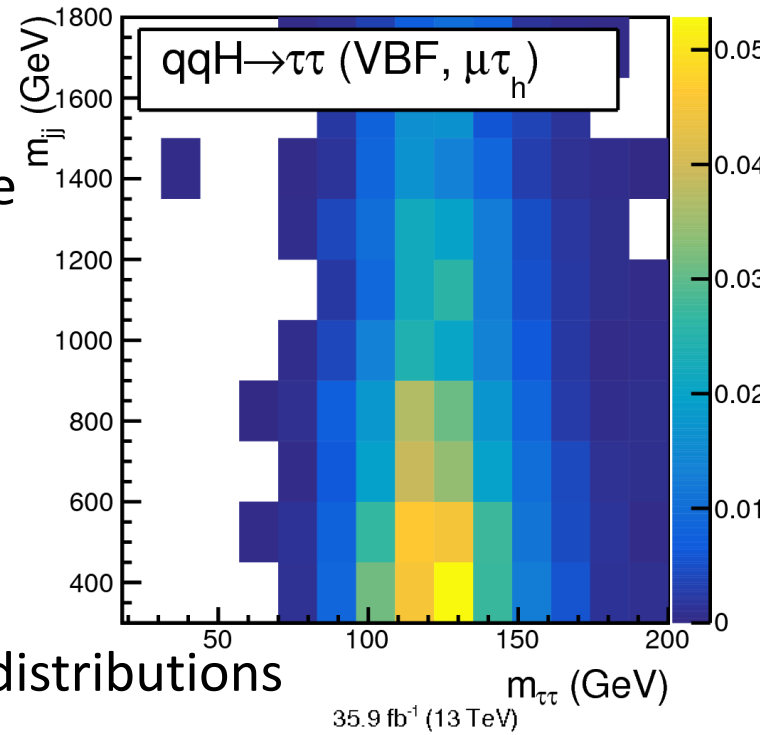$\Gamma_H < 1.1$ GeV
@ 95% C.L.

CMS PAS HIG-16-041
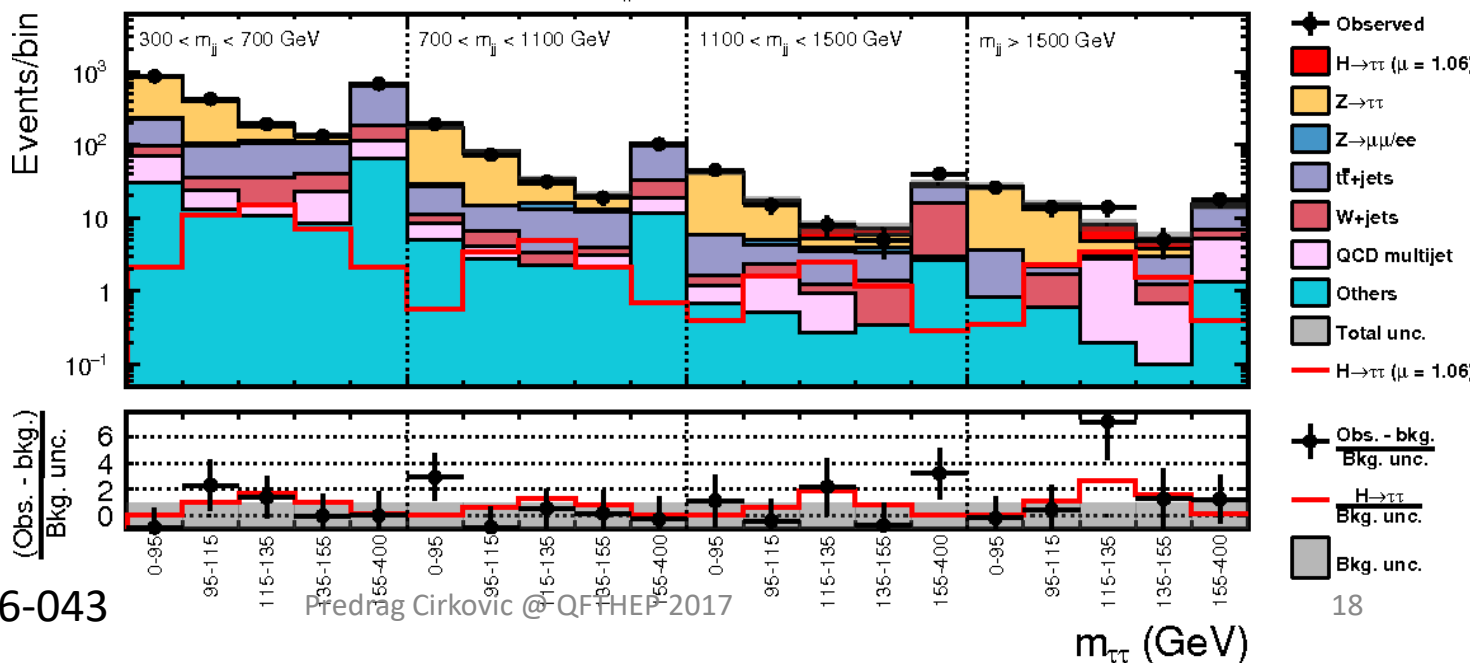
$$H \to \tau\tau$$

Four decay mode combinations:

- $e\tau_h$
- $\mu\tau_h$
- $\tau_h\tau_h$
- $e\mu$

ML fit with 2D distributions

Main backgrounds:
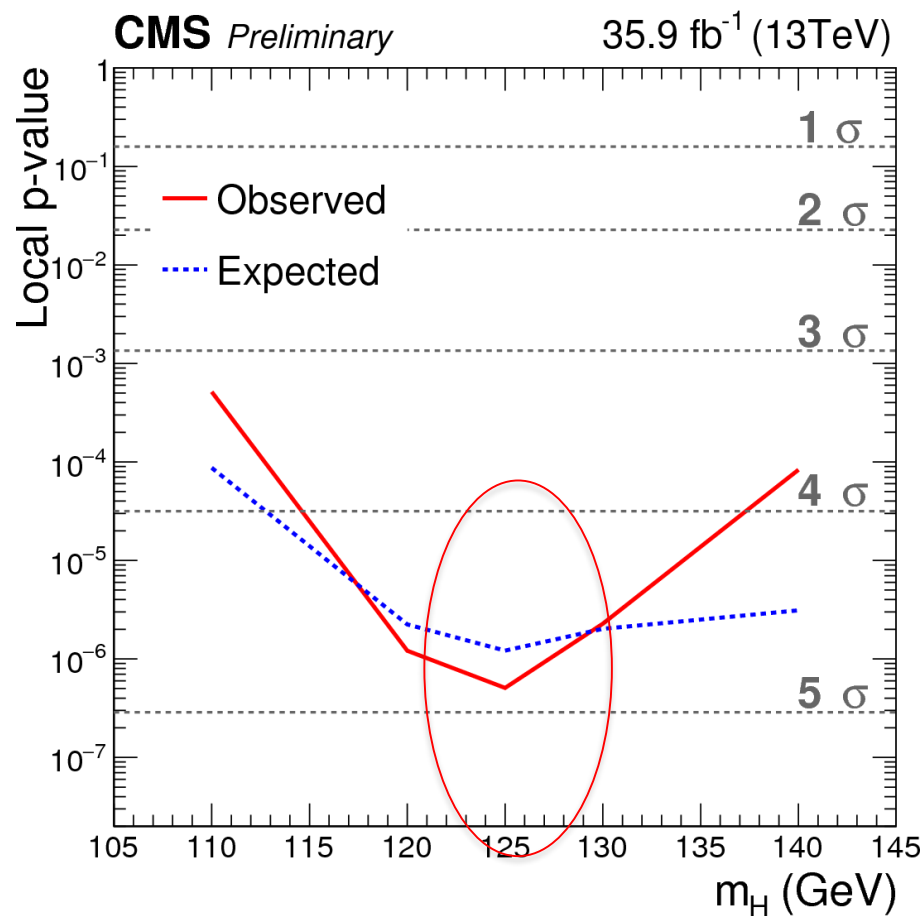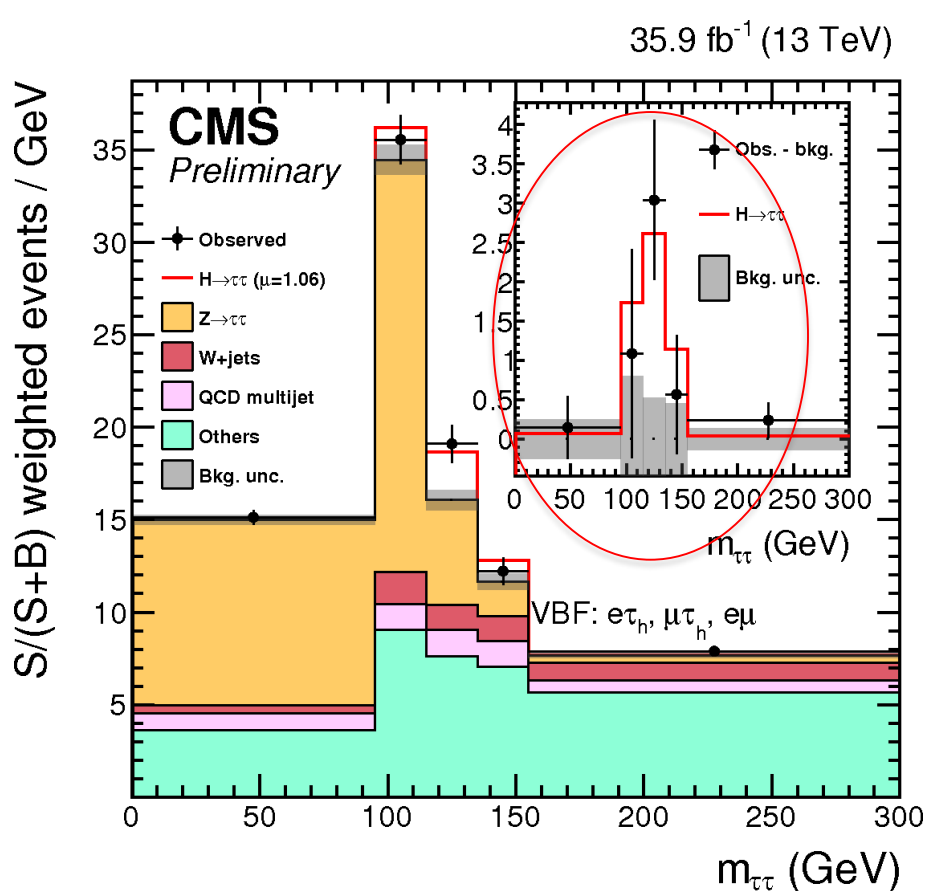
- Drell-Yan
- W/Z+jets
- $t\bar{t}$
- QCD

CMS PAS HIG-16-043

Predrag Cirkovic @ QFTHEP 2017
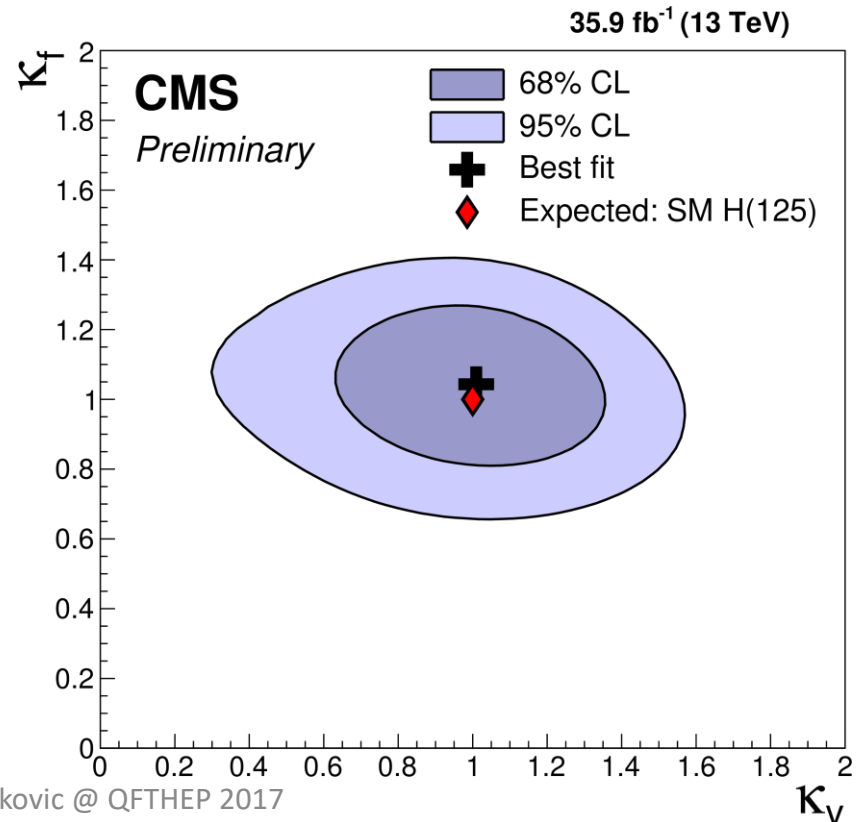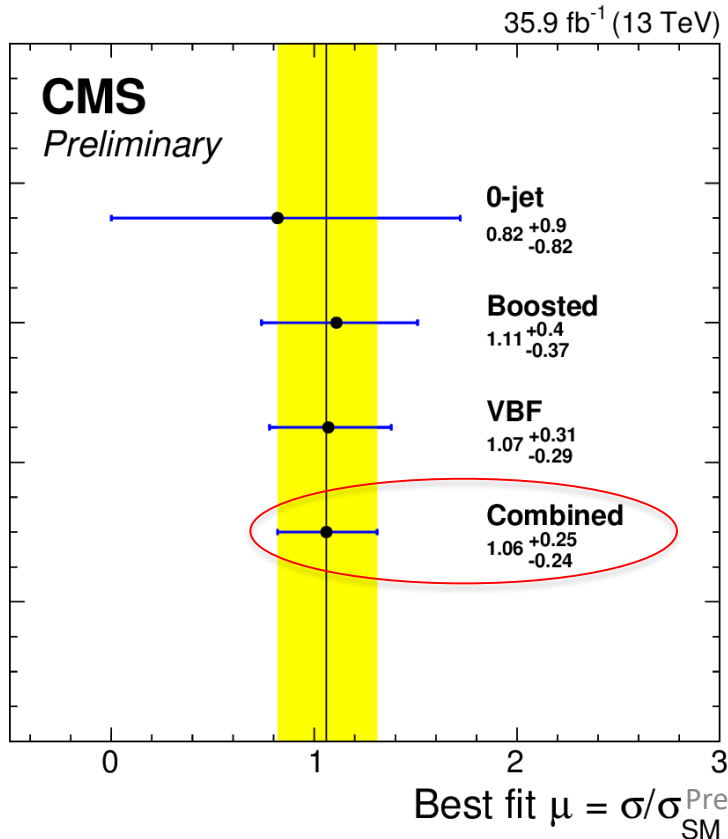
18

Excess in $H \rightarrow \tau\tau$

Clearly visible at
$m_H = 125\ GeV$

Observed significance: 4.9σ

Expected significance: 4.7σ

Higgs to $\tau\tau$ signal strengths and couplings

Categories:
- 0-jet
- VBF
- Boosted

Best-fit for the signal strength at $m_H = 125\ GeV$:
$$\mu = 1.06 \pm 0.25$$

Coupling modifiers compatible with the expectations

35.9 fb^{-1} (13 TeV)

CMS
Preliminary

0-jet
0.82 $^{+0.9}_{-0.82}$

Boosted
1.11 $^{+0.4}_{-0.37}$

VBF
1.07 $^{+0.31}_{-0.29}$

Combined
1.06 $^{+0.25}_{-0.24}$

Best fit $\mu = \sigma/\sigma_{SM}$

35.9 fb^{-1} (13 TeV)

CMS
Preliminary

68% CL
95% CL
Best fit
Expected: SM H(125)

CMS PAS HIG-16-043

ttHgg hadronic

ttHbb

$t\bar{t}\ H$

all jets
47%

τ+jets
15%

bb
57%

WW
21%

μ+jets
15%

gg
9%

e+jets
14%

ττ
6%

τ+τ
1%

τ+μ
2%

τ+e
2%

μ+μ
1%

μ+e
2%

e+e
1%

others
<1%

γγ
0.2%

ttHgg

ZZ
3%

cc
3%

ttHττ

ttHbb dilepton

ttHbb l+jets

ttH→multilepton
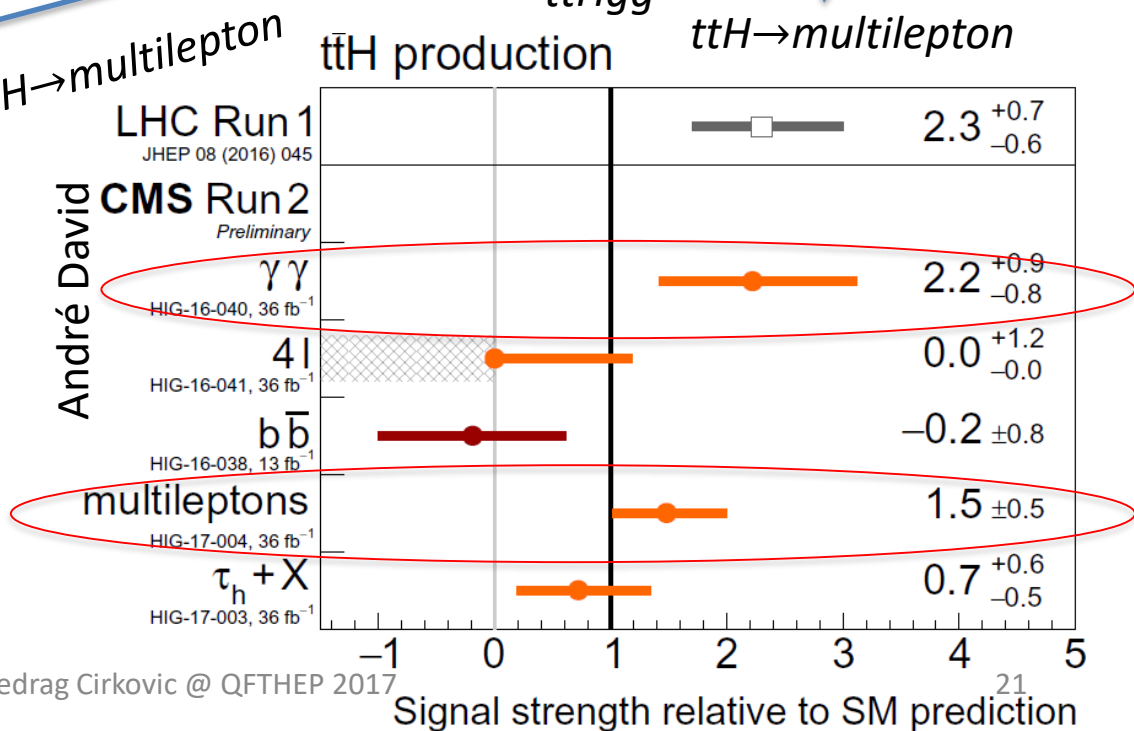
ttHgg leptonic, ttH→multilepton

$t\bar{t}H$:

- $H \rightarrow b\bar{b}$
- $H \rightarrow \gamma\gamma$
- $H \rightarrow \tau\tau$
- $H \rightarrow 4l$
- multilepton

NEW

In $H \rightarrow \gamma\gamma$ and multilepton, significance $> 3\sigma$

t̄tH production

André David

	Signal strength relative to SM prediction
LHC Run 1 JHEP 08 (2016) 045	$2.3^{+0.7}_{-0.6}$
CMS Run 2 Preliminary	
γ γ HIG-16-040, 36 fb⁻¹	$2.2^{+0.9}_{-0.8}$
4 l HIG-16-041, 36 fb⁻¹	$0.0^{+1.2}_{-0.0}$
b b̄ HIG-16-038, 13 fb⁻¹	-0.2 ± 0.8
multileptons HIG-17-004, 36 fb⁻¹	1.5 ± 0.5
$\tau_h + X$ HIG-17-003, 36 fb⁻¹	$0.7^{+0.6}_{-0.5}$

$t\bar{t}H, H \rightarrow b\bar{b}$

Selected events compatible with

1. Dilepton (minimal non-$t\bar{t}$ background, and jet combinatorics)
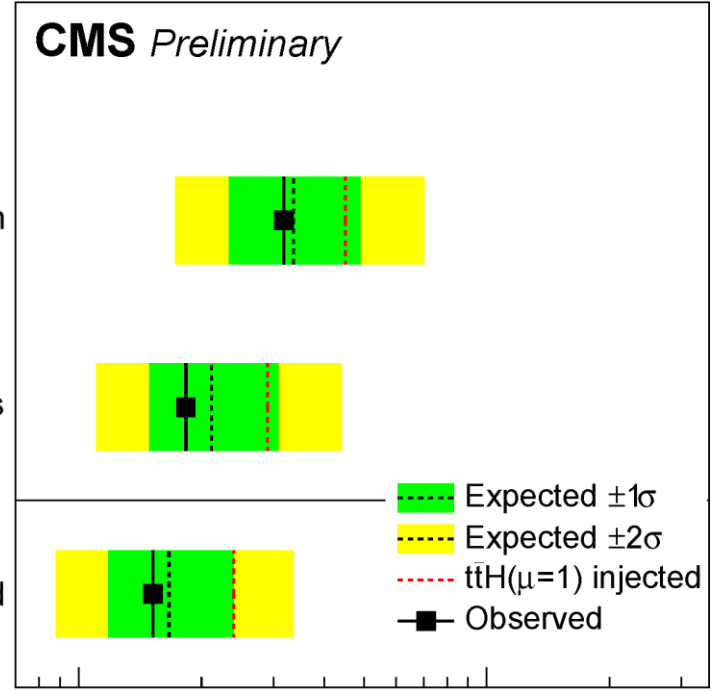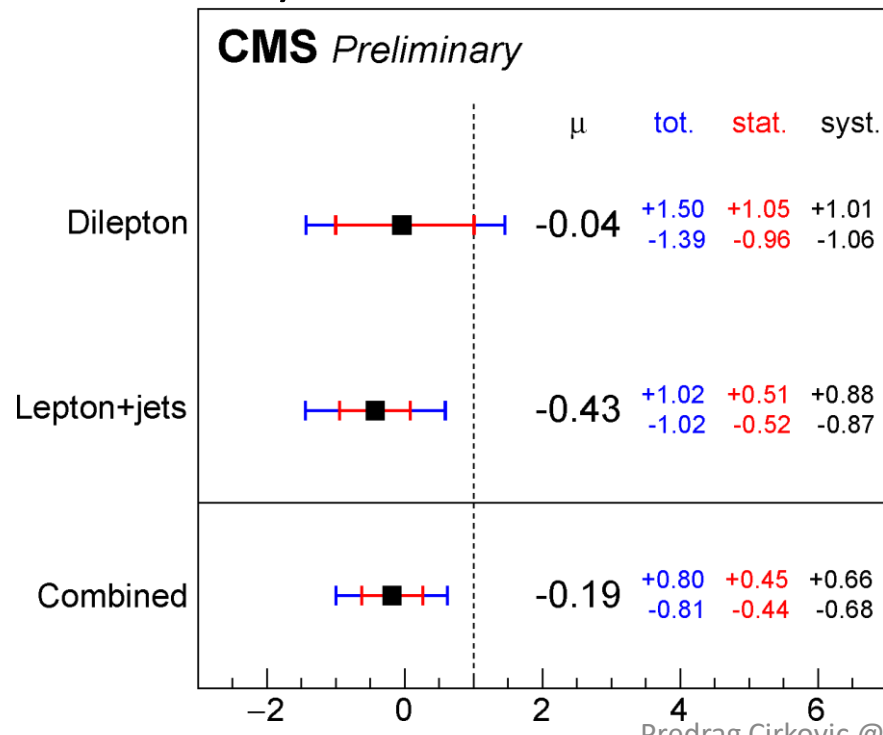
2. Lepton+jets (high statistics)

Lepton+jets
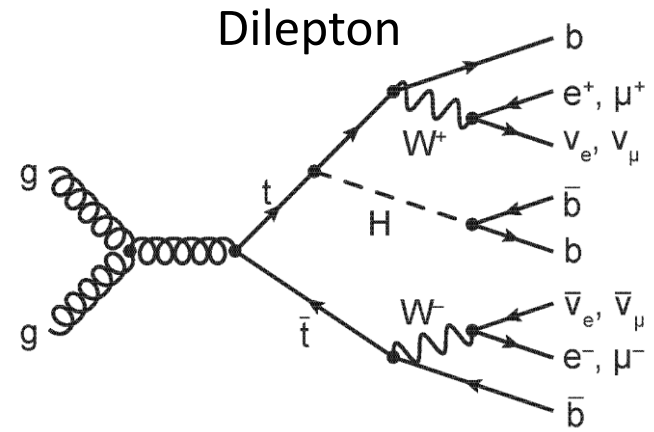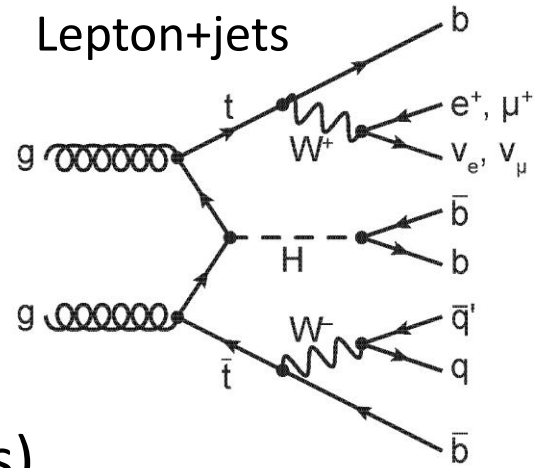
Dilepton

No clear evidence for $t\bar{t}H$ (H → $b\bar{b}$) yet:

• Waiting for results from full 2016 dataset

11.4 - 12.9 fb⁻¹ (13 TeV)
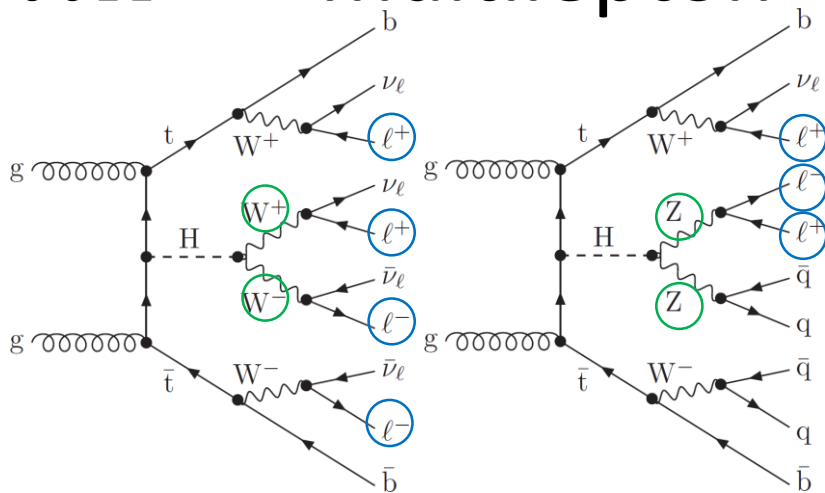
11.4 - 12.9 fb⁻¹ (13 TeV)

CMS-PAS-HIG-16-038

	μ	tot.	stat.	syst.
Dilepton	-0.04	+1.50 / -1.39	+1.05 / -0.96	+1.01 / -1.06
Lepton+jets	-0.43	+1.02 / -1.02	+0.51 / -0.52	+0.88 / -0.87
Combined	-0.19	+0.80 / -0.81	+0.45 / -0.44	+0.66 / -0.68

CMS *Preliminary*

CMS-PAS-HIG-16-038   Best fit μ = σ/σ$_{SM}$ at m$_H$ = 125 GeV

**CMS** *Preliminary*

Expected ±1σ
Expected ±2σ
t̄tH(μ=1) injected
Observed

95% CL limit on μ = σ/σ$_{SM}$ at m$_H$ = 125 GeV

$t\bar{t}H \rightarrow$ multilepton

Category	Observed limit	Expected limit $\pm 1\sigma$
Same-sign di-lepton	2.8	$0.9\,(-0.3)\,(+0.4)$
Three lepton	2.5	$1.4\,(-0.4)\,(+0.7)$
Four lepton	5.9	$4.9\,(-1.7)\,(+3.1)$
Combined	2.5	$0.8\,(-0.2)\,(+0.3)$

Category	Observed μ fit $\pm 1\sigma$	Expected μ fit $\pm 1\sigma$
Same-sign di-lepton	$1.7\,(-0.5)\,(+0.6)$	$1.0\,(-0.5)\,(+0.5)$
Three lepton	$1.0\,(-0.7)\,(+0.8)$	$1.0\,(-0.7)\,(+0.8)$
Four lepton	$0.9\,(-1.6)\,(+2.3)$	$1.0\,(-1.6)\,(+2.4)$
Combined (2016 data)	$1.5\,(-0.5)\,(+0.5)$	$1.0\,(-0.4)\,(+0.5)$
Combined (2015 data) [42]	$0.6\,(-1.1)\,(+1.4)$	$1.0\,(-1.1)\,(+1.3)$
Combined (2015+2016 data)	$1.5\,(-0.5)\,(+0.5)$	$1.0\,(-0.4)\,(+0.5)$
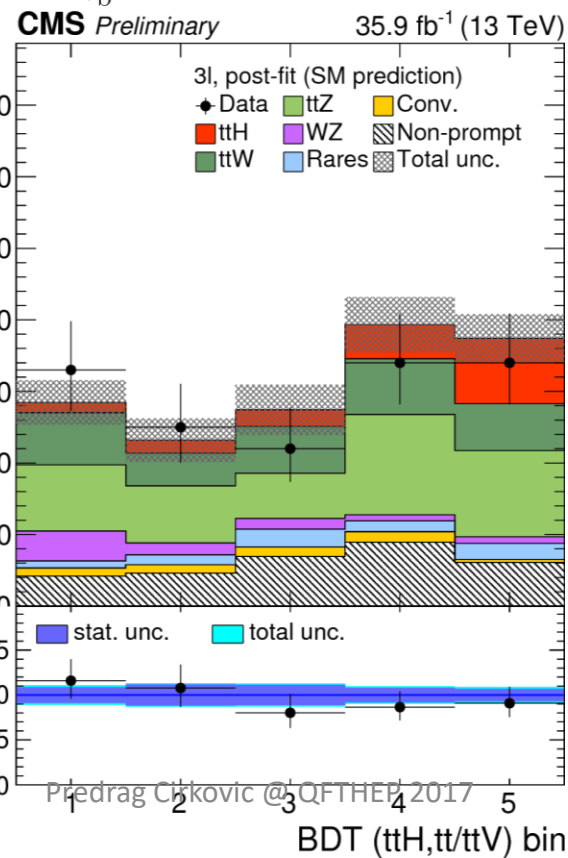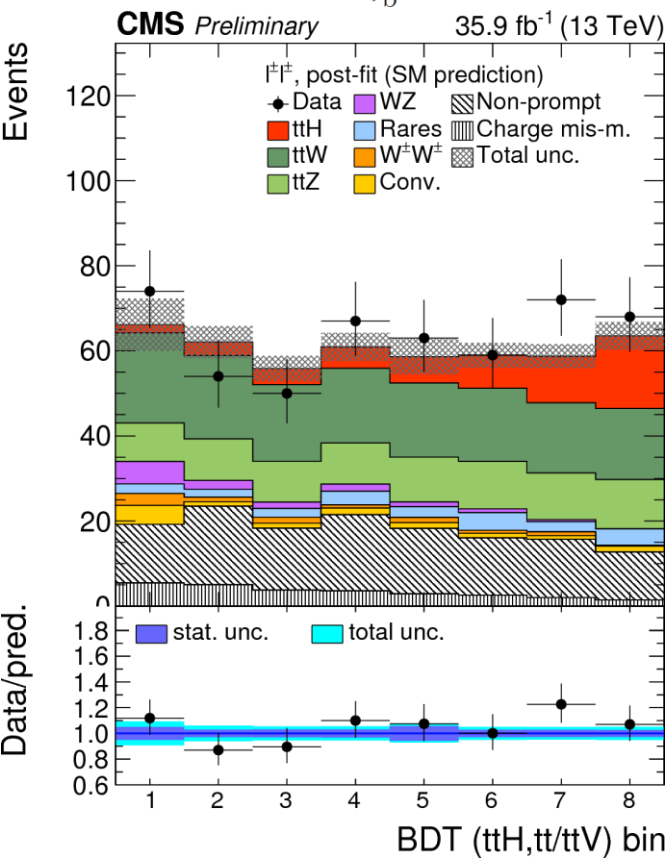
$t\bar{t} + WW$ or $t\bar{t} + ZZ$ final states categories:

- $2lss$
- $3l$
- $4l$

An evidence for $t\bar{t}H$ production

Predrag Cirkovic @ QFTHEP 2017

CMS-PAS-HIG-17-004

23

$t\bar{t}H, H \to \tau\tau$

NEW

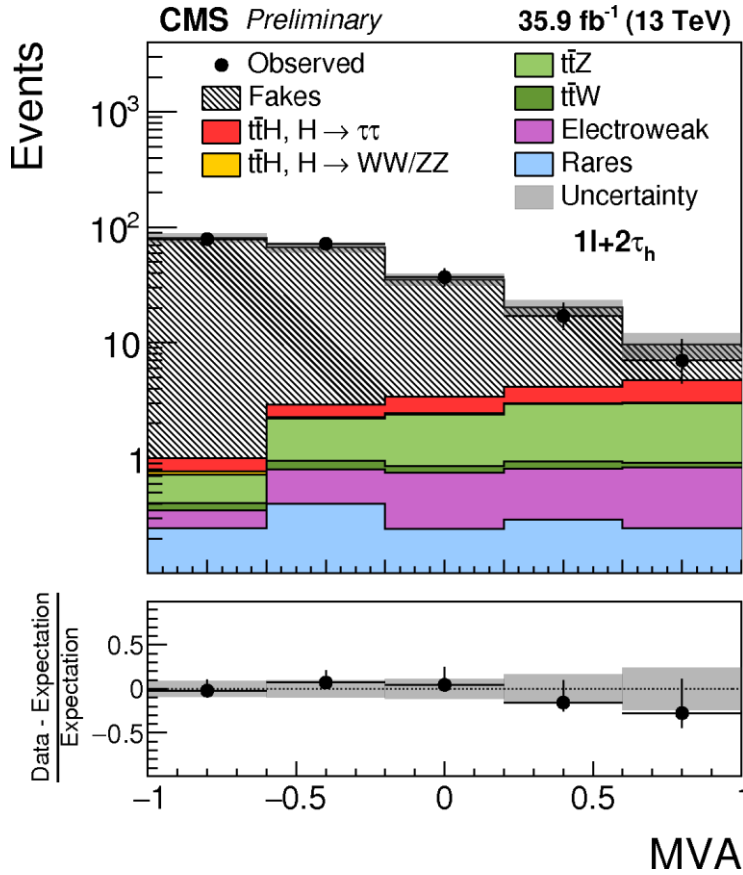Complementary to $t\bar{t}H \to$multilepton

Event categories:
- $1l + 2\tau_h$
- $2lss + 1\tau_h$
- $3l + 1\tau_h$

Backgrounds:
- Non-prompt lepton
- Jet to τ_h
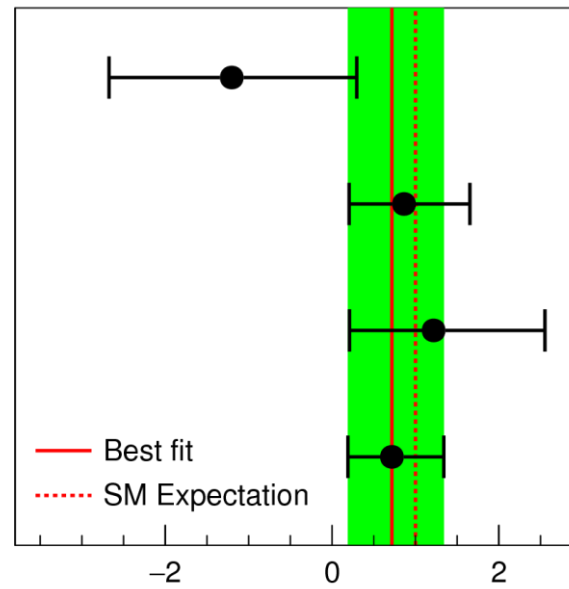- Charge-flip

Signal extraction using MEM and BDT

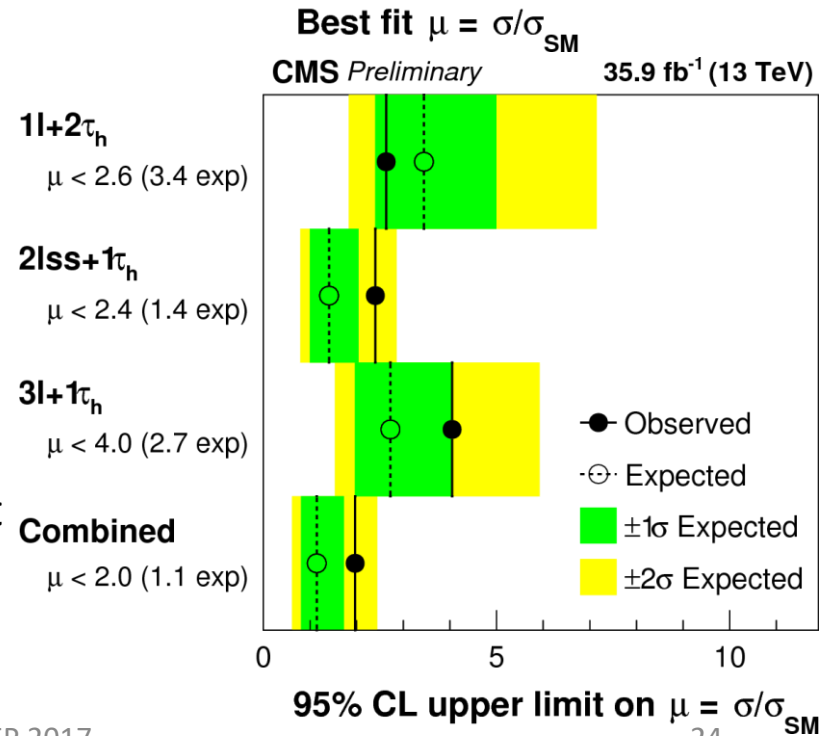**CMS** *Preliminary*   35.9 fb^{-1} (13 TeV)

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

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

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

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

— Best fit
⋯ SM Expectation

Best fit $\mu = \sigma/\sigma_{SM}$

Results in agreement with the SM

Significance:
Observed: 1.4σ
Expected: 1.8σ

Upper limit on signal rate set at 2.0 x SM production rate at 95% C.L.

CMS *Preliminary*   35.9 fb^{-1} (13 TeV)

- Observed: ● Fakes, tt̄Z, tt̄W, $t\bar{t}H, H \to \tau\tau$, $t\bar{t}H, H \to WW/ZZ$, Electroweak, Rares, Uncertainty

$1l+2\tau_h$

Data - Expectation / Expectation

MVA

CMS *Preliminary*   35.9 fb^{-1} (13 TeV)

$1l+2\tau_h$
$\mu < 2.6$ (3.4 exp)

$2lss+1\tau_h$
$\mu < 2.4$ (1.4 exp)

$3l+1\tau_h$
$\mu < 4.0$ (2.7 exp)

Combined
$\mu < 2.0$ (1.1 exp)

- ● Observed
- ⊙ Expected
- ±1σ Expected
- ±2σ Expected

95% CL upper limit on $\mu = \sigma/\sigma_{SM}$

CMS-PAS-HIG-17-003
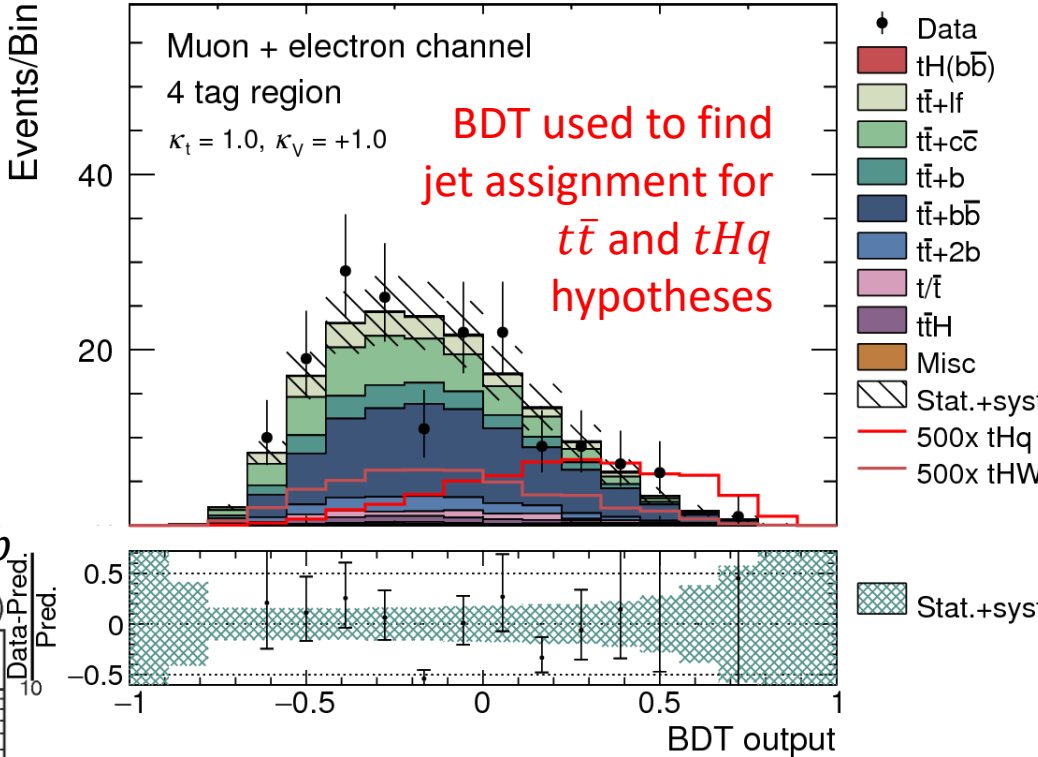
$tH, H \rightarrow b\bar{b}$

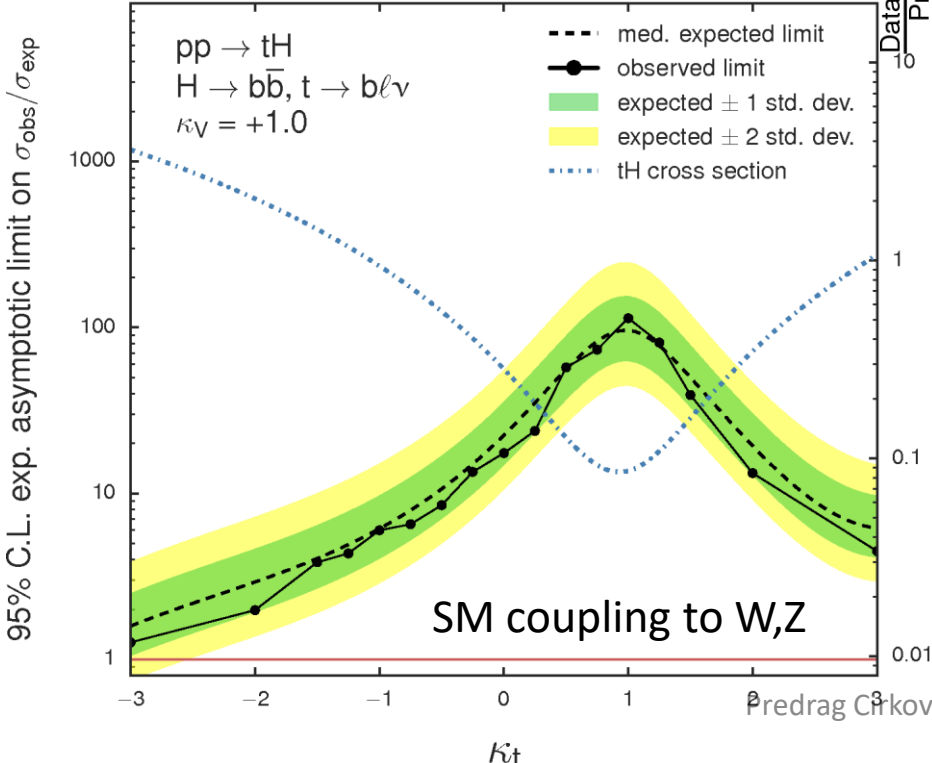Search for $H \rightarrow b\bar{b}$ in association with a single top ($t \rightarrow b\,e(\mu)\nu$)

κ_t

κ_V
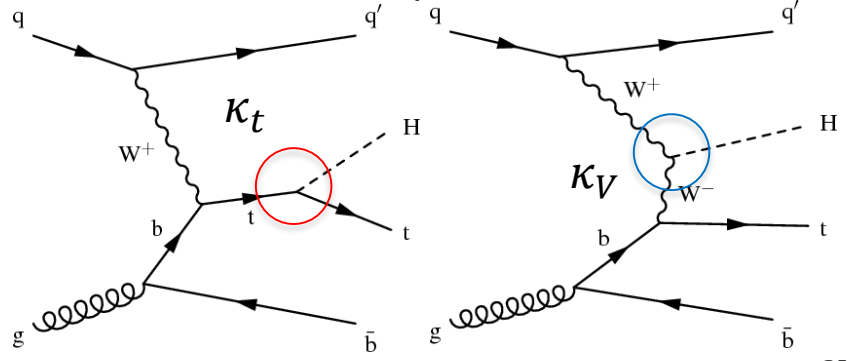
Destructive interference in SM $\Rightarrow \sigma \approx 90\ fb$

BDT used to find jet assignment for $t\bar{t}$ and tHq hypotheses

Signal region:

- e/μ + 3 or 4 b-tagged jets
- 1 non-tagged jet

Obs. (exp.) 95% CL upper limit:

- 113.7 (98.6) $\times$ σ_{SM} for the SM
- 6.0 (6.4) $\times$ σ_{SM} for ITC scenario ($\kappa_t = -1$)

CMS-PAS-HIG-16-019

$tH \to$ multilepton

The process exposes relative sign of t-Higgs and W-Higgs couplings via interference

Irreducible bkg (MC):

- $t\bar{t} + X \ (X = W, Z, H, \mathrm{y}^*)$
- Photon conversions
- Rare SM tZq, tWZ, tri-bosons, $WWqq$, $t\bar{t}t\bar{t}$
- Di-bosons WZ, ZZ

Reducible background (data-driven):

- Fakes due to non-prompt leptons and miss-ID of jets passing lepton selection
- Charge flips:
  - Charge mis-ID ($2lss$)
  - Opposite-sign processes (e.g. $t\bar{t}/Z$+jets)

Analysis strategy:

- $2lss$: 1 W from Higgs decays hadronically, others decay leptonically
- $3l$: $H \to WW/\tau\tau/ZZ$, & where W from t decays leptonically

Benefit from enhanced production σ in case of anomalous top-Higgs couplings

Predrag Cirkovic @ QFTHEP 2017

26

CMS-PAS-HIG-17-005
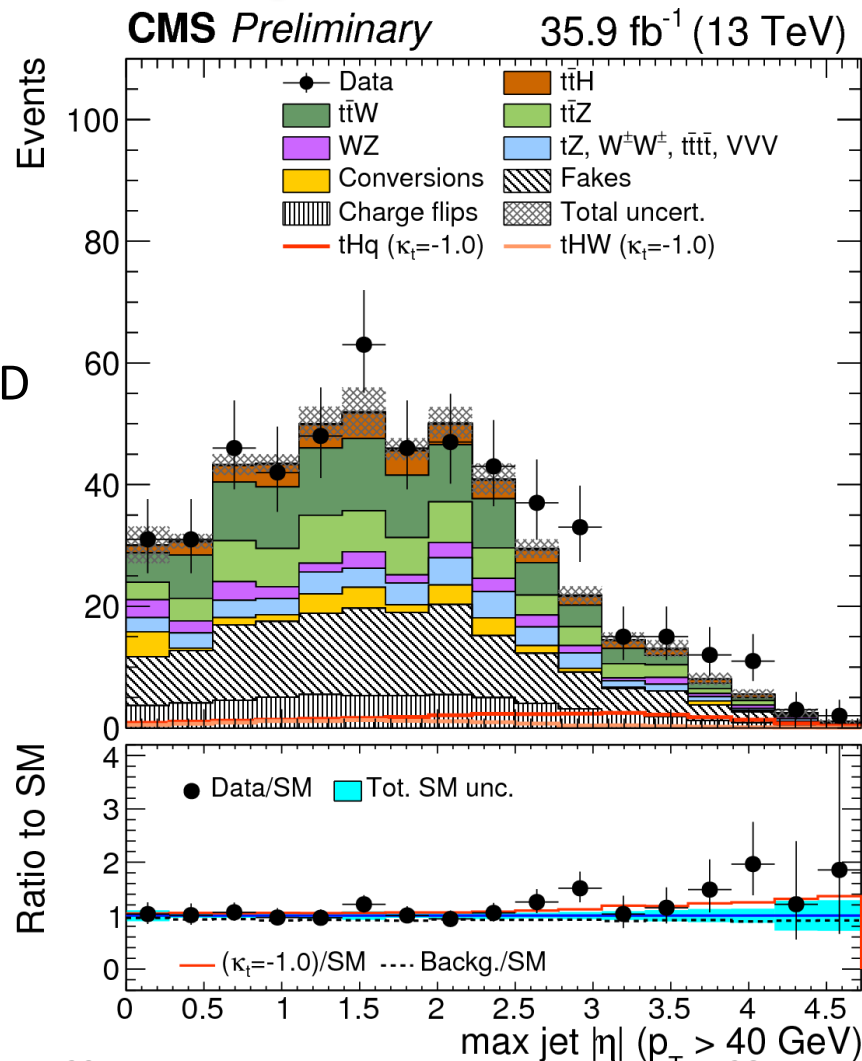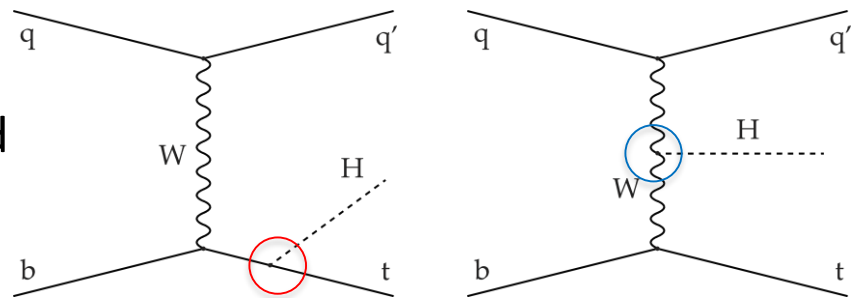
VBF Higgs ($H \rightarrow b\bar{b}$)

	SingleB	DoubleB
Trigger	one b-tagged jet	two b-tagged jets
jets p_T	$p_T^{1,2,3,4} > 92, 76, 64, 30$ GeV	
jets $|\eta|$	< 4.7	
b tag	no cut	two jets with CSV>0.5
$\Delta\phi_{bb}$	<1.6 radians	<2.4 radians
	$m_{qq} > 460$ GeV	$m_{qq} > 200$ GeV
VBF topology		
	$|\Delta\eta_{qq}| > 4.1$	$|\Delta\eta_{qq}| > 1.2$
Veto	None	Events that belong to SingleB
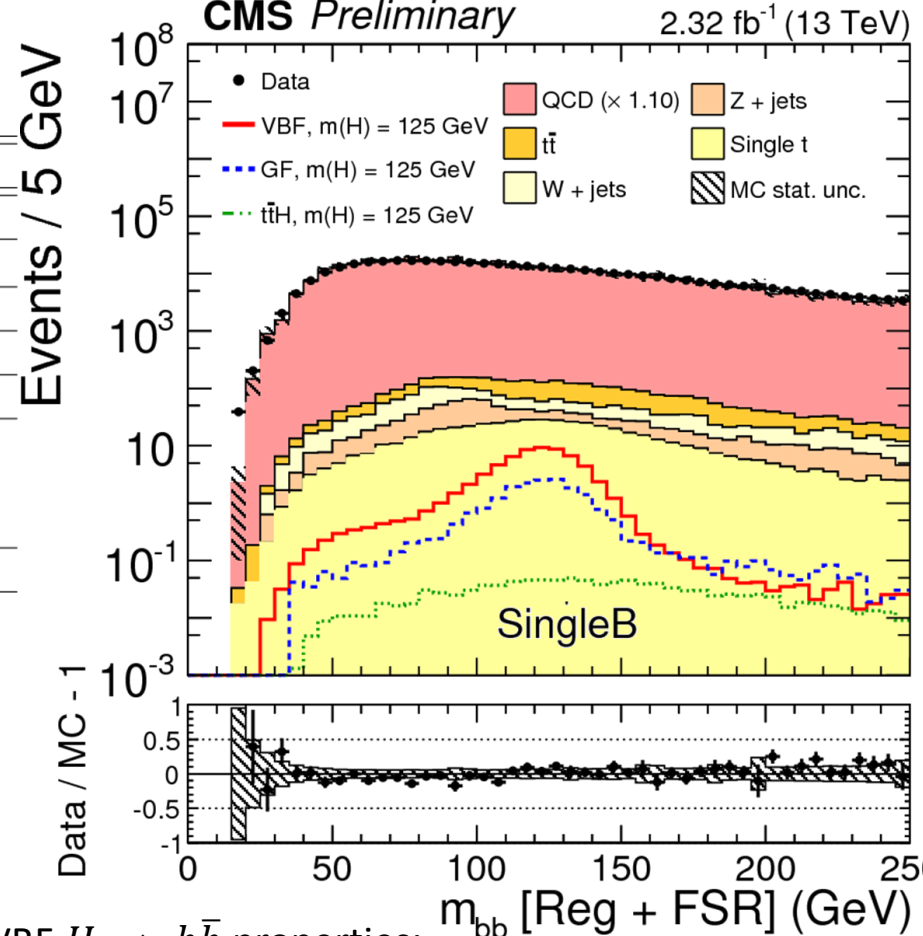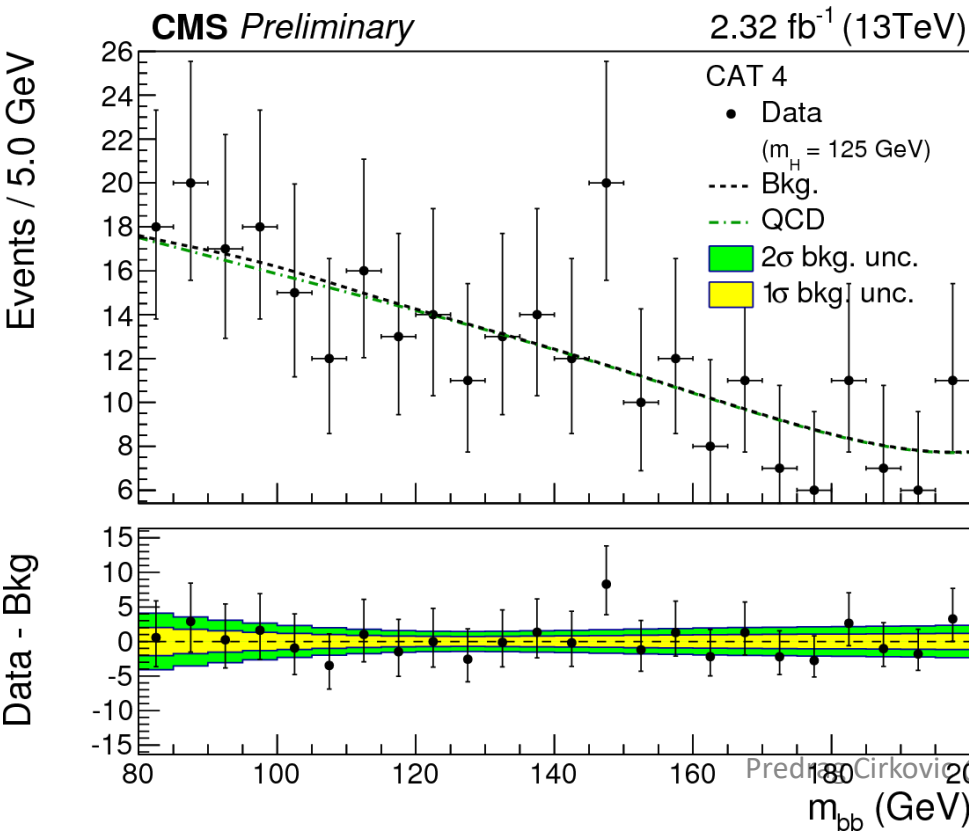
VBF $H \rightarrow b\bar{b}$ properties:

- σ significantly larger than VH or $t\bar{t}H$ production
- Very large QCD production of multijet backg.
- BDT to ID VBF-like events in 4-jet signal event topology with 1 or 2 b-tagged jets

Using 2.3 fb^{-1} @ 13 TeV only: $\mu = -3.7^{+2.4}_{-2.5}$
Combined with $18 - 19\ fb^{-1}$ @ 8 TeV: $\mu = 1.3^{+1.2}_{-1.1}$

CMS PAS HIG-16-003

MSSM Higgs (decaying to $\tau\tau$)

- Final-state channels $\tau_h\tau_h$, $\mu\tau_h$, $e\tau_h$ and $e\mu$

- Two event categories based on the number of b-tagged jets

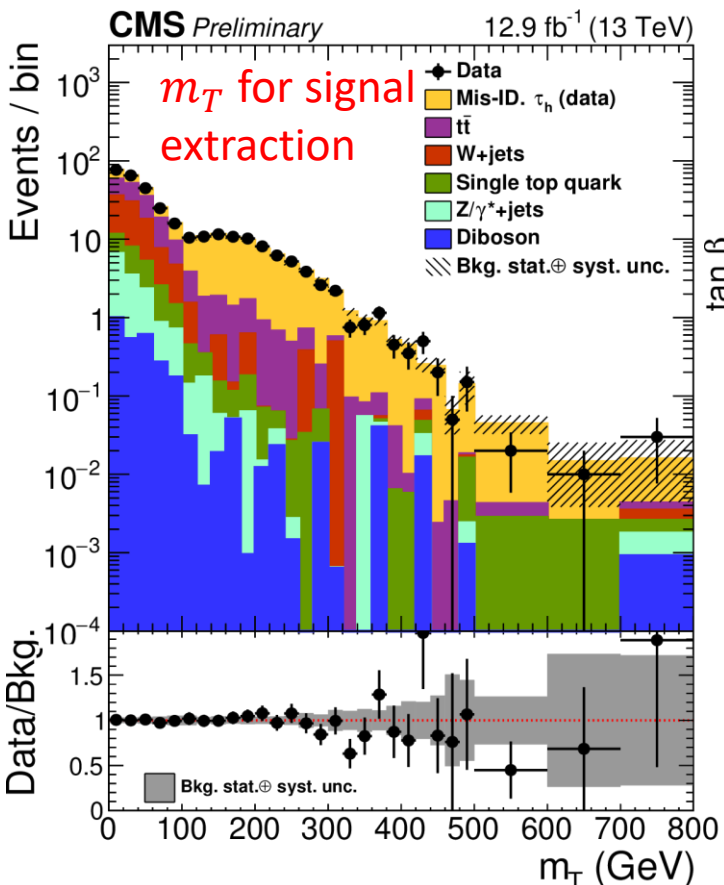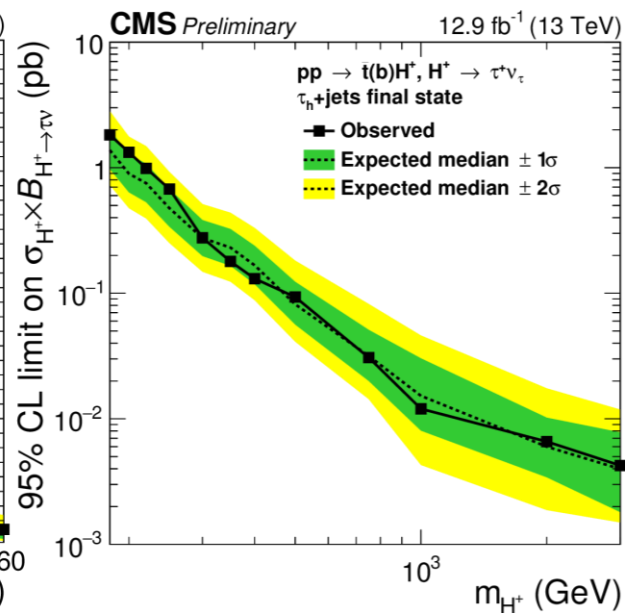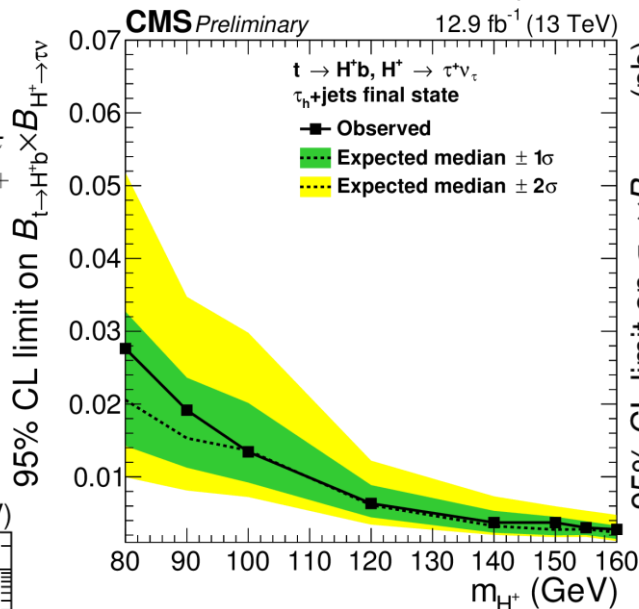- Main backgrounds: $Z/\gamma^* \longrightarrow \tau\tau$, QCD, $t\bar{t}$

Model independent
95% C.L. limits

No excess
in the mass range
$100\ GeV - 3\ TeV$

Exclusion limits in the m_A-tan β plane in the context of the h_{MSSM}

CMS PAS HIG-16-037
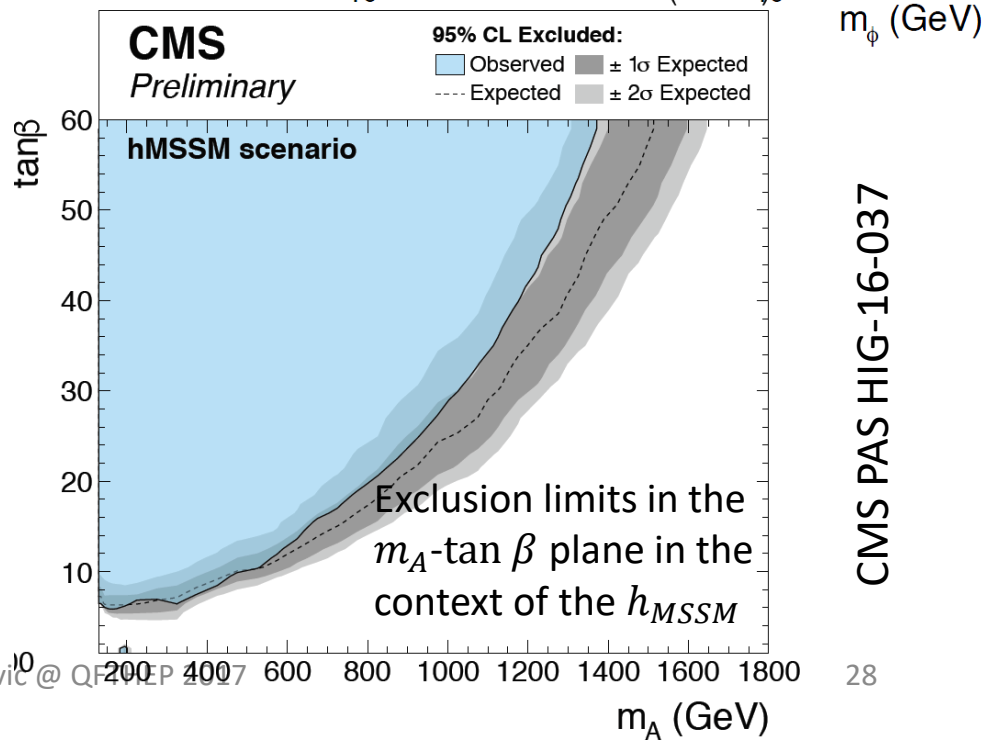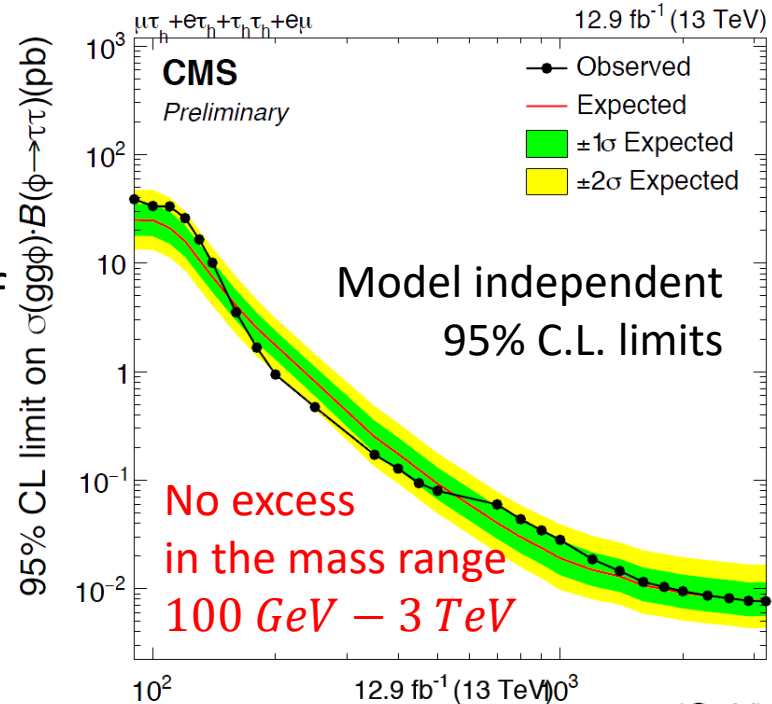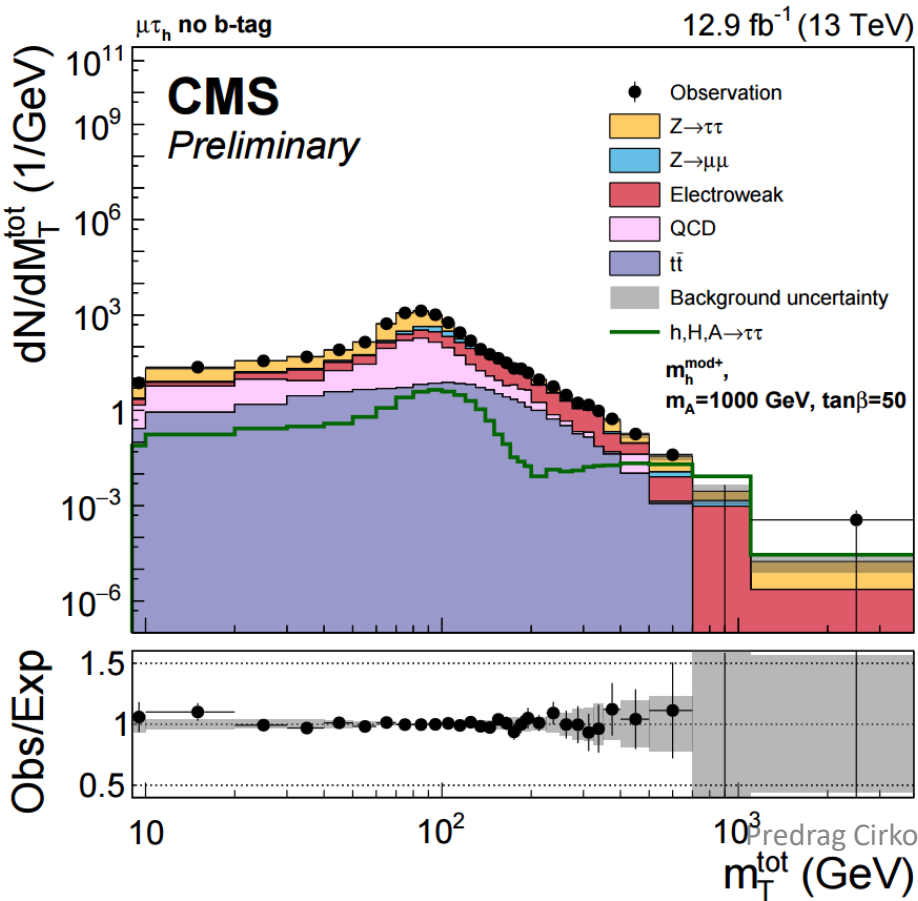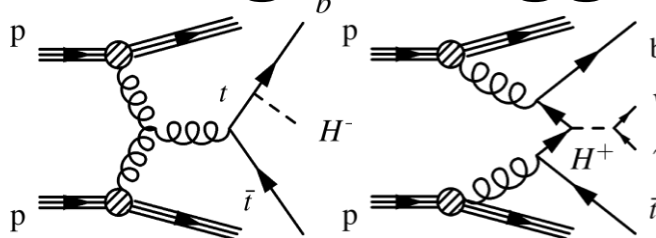
Charged Higgs

- The 2HDM models predict a charged Higgs
- No excess in the mass range from $80\ GeV - 3\ TeV$

m_T for signal extraction

MSSM m_h^{mod+} exclusion limits in m_{H^+} - $\tan\beta$ plane

Predrag Cirkovic @ QFTHEP 2017
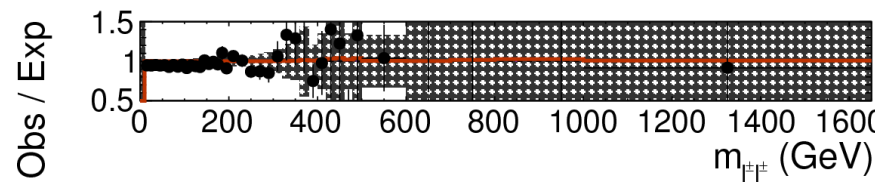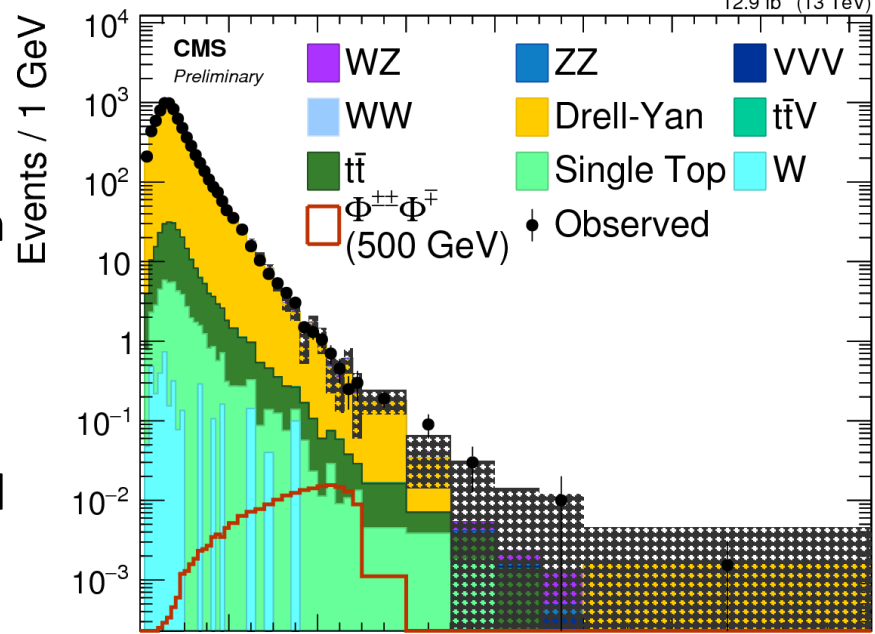
CMS-PAS-HIG-16-031

29
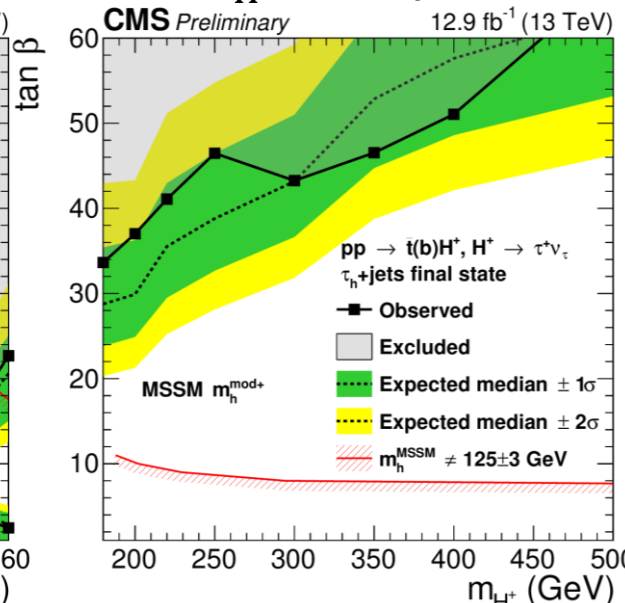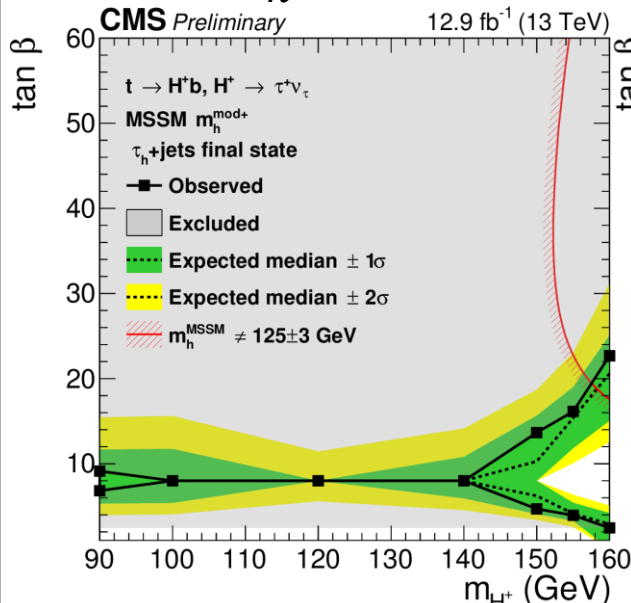
Doubly-charged Higgs
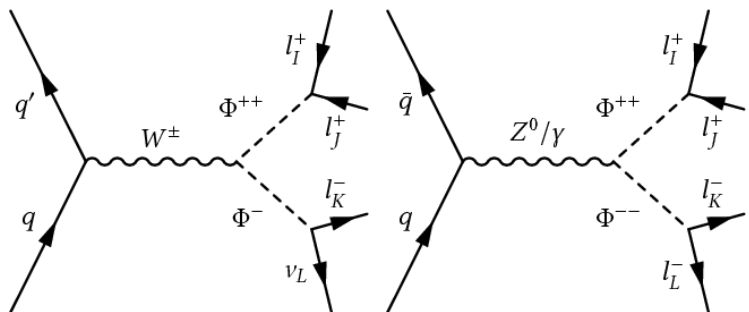
Final-state channels: ee, $e\mu$, $\mu\mu$, $e\tau$, $\mu\tau$, $\tau\tau$
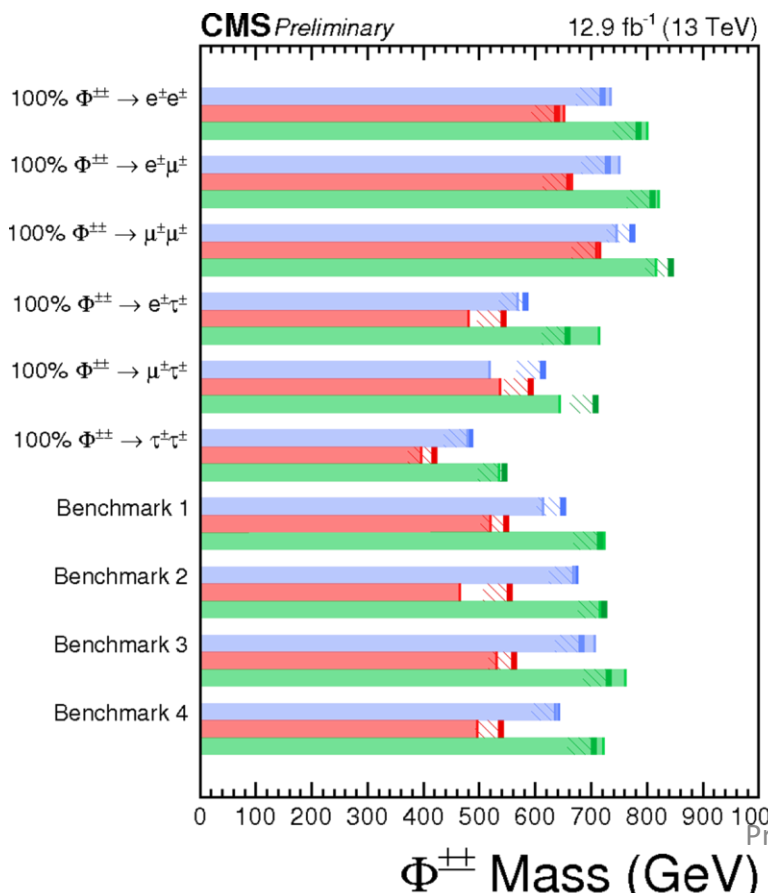
Selection:
- scalar sum of lepton p_T
- difference between *best Z* and *PDG Z* mass
- ΔR between same sign leptons
- E_t^{mis}
- same sign invariant mass

- Extension of the SM with a scalar triplet Φ
- Model independent limits set assuming 100% decays to single pair of leptons
- Limits also set for four benchmarks targeting several neutrino mass hypotheses
- No significant excess observed

CMS PAS HIG-16-036

Invisible Higgs

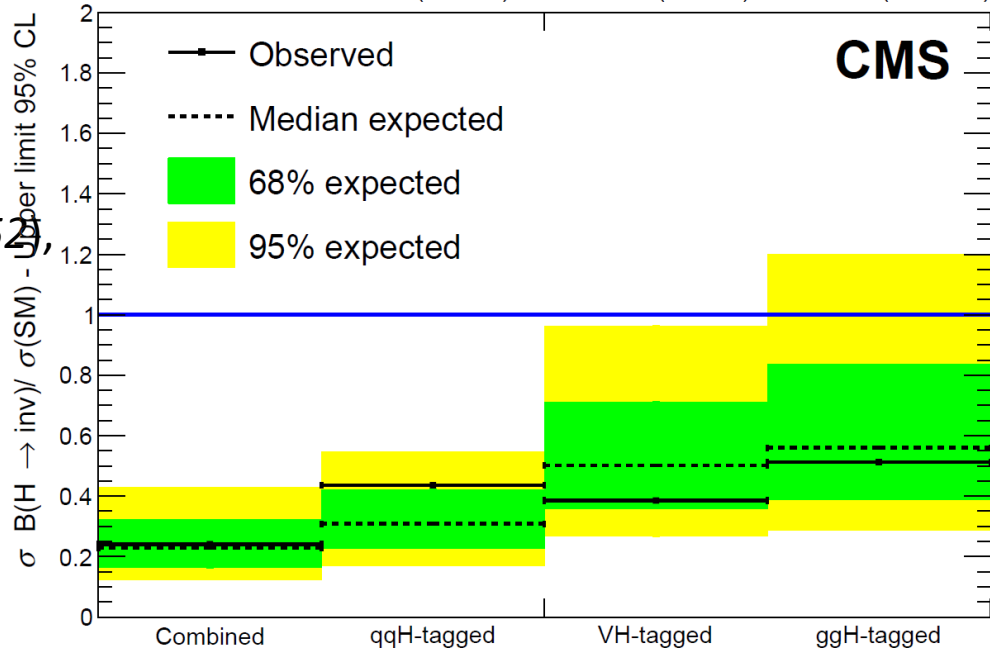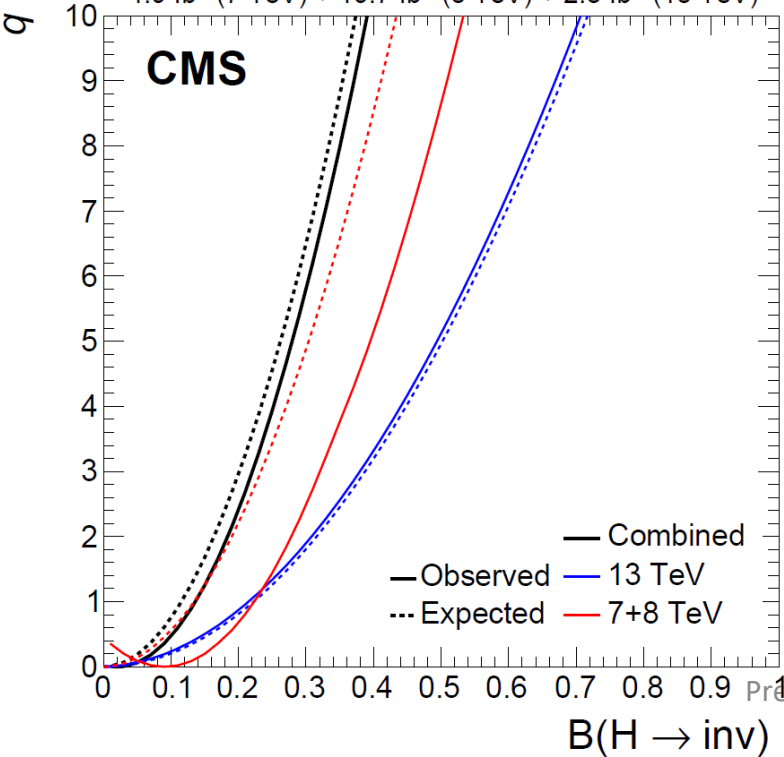Many models allow Higgs decays to invisibles:

- SUSY models with Higgs decays to a pair of LSP
- Large extra dimension models with mixing of graviscalars with the Higgs boson
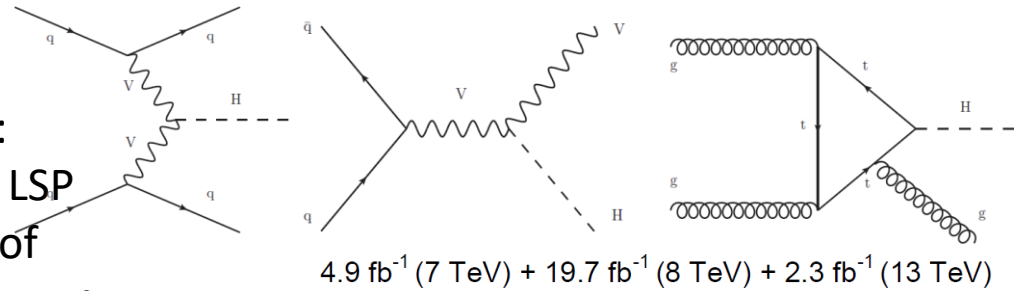
Analyses target different production modes:

- VBF production: 2 forward jets
- VH production with: $Z \to ee/\mu\mu$ (*EXO-16-052*), $Z \to bb$, $W/Z \to qq$
- ggH production in association with ISR

4.9 fb^{-1} (7 TeV) + 19.7 fb^{-1} (8 TeV) + 2.3 fb^{-1} (13 TeV)

Combination of $7\ TeV$, $8\ TeV$ and $13\ TeV$ (2015):

- B(H→invisible) < 0.24/0.23 (obs./exp.) at 95% CL, where the largest sensitivity comes from the VBF

Z(ll)+ MET analysis updated with full 2016 dataset:

- B(H→invisible) < 0.40/0.42 (obs./exp.)

Monojet and V(jj) analyses with full 2016 dataset:

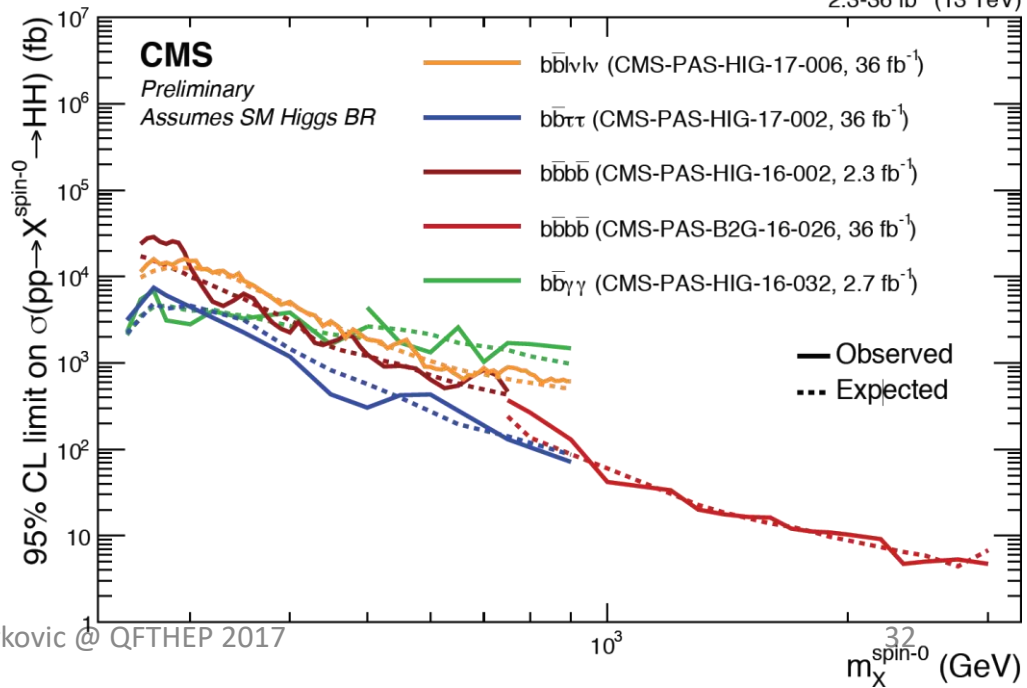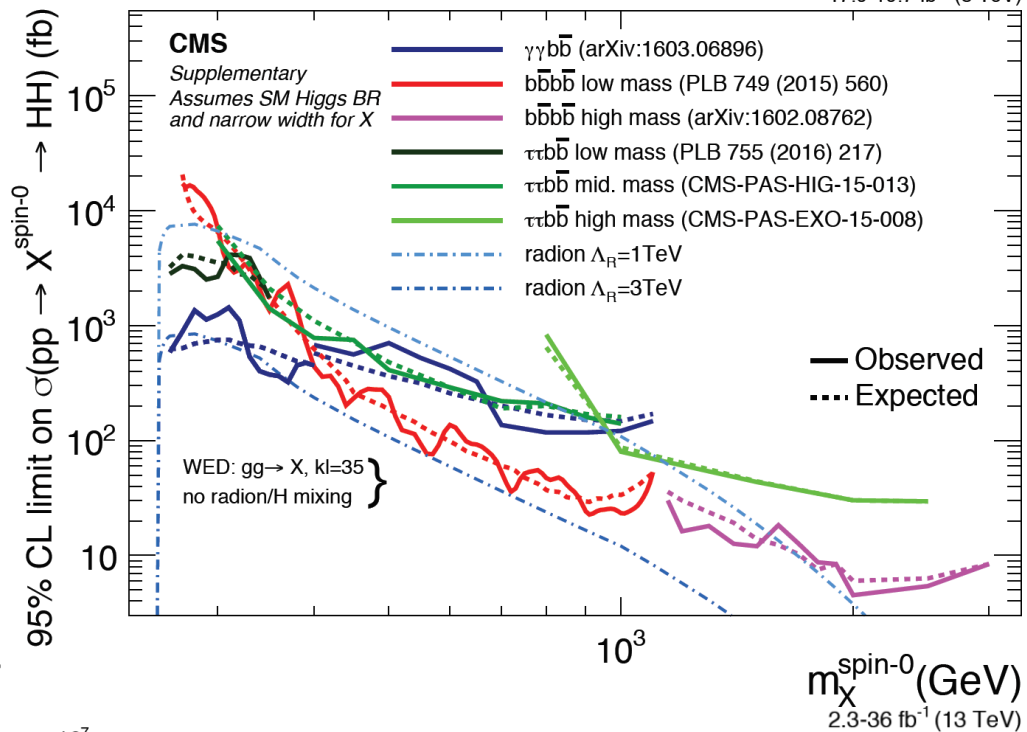- B(H→invisible) < 0.53/0.40 (obs./exp.)

JHEP 02 (2017) 135

Di-Higgs

Non-resonant SM di-Higgs production provides a crucial test of EWSB

Many BSM models predict $X \to HH$ production

Large number of possible final states require one $H \to b\bar{b}$ to keep BF higher

| 13TeV non-resonant observed (expected) σ/σ_{SM} 95% CL limits		
$b\bar{b}\tau\tau$	28 (25)	35.9 fb^{-1}
$b\bar{b}\ell\nu\ell\nu$	79 (89)	35.9 fb^{-1}
$b\bar{b}\gamma\gamma$	91 (90)	2.7 fb^{-1}
$b\bar{b}b\bar{b}$	342 (308)	2.3-2.7 fb^{-1}

NEW

Future prospects

Results extrapolated to fit:

- Upgraded detector for the HL LHC

- Higher integral luminosities $300\ fb^{-1}$ and $3000\ fb^{-1}$

Projections dominated by statistical uncertainties:

- $\delta_{Run\ 1}/(3\text{-}4)$, up to $300\ fb^{-1}$

- $\delta_{Run\ 1}/(5\text{-}10)$, at HL i.e. $3000\ fb^{-1}$

CMS-DP2016-064
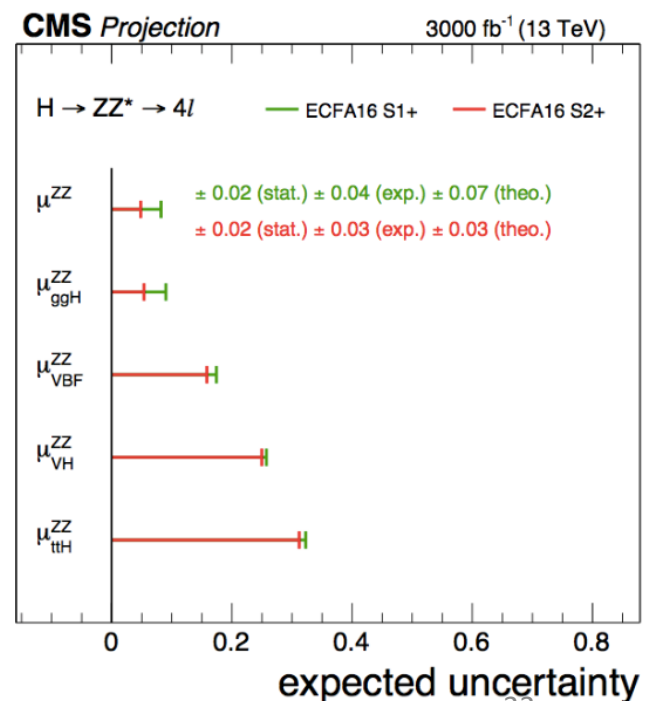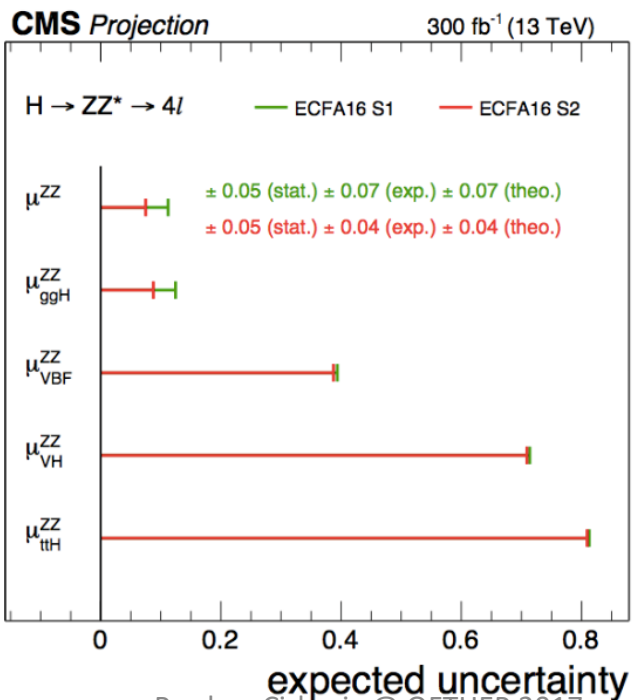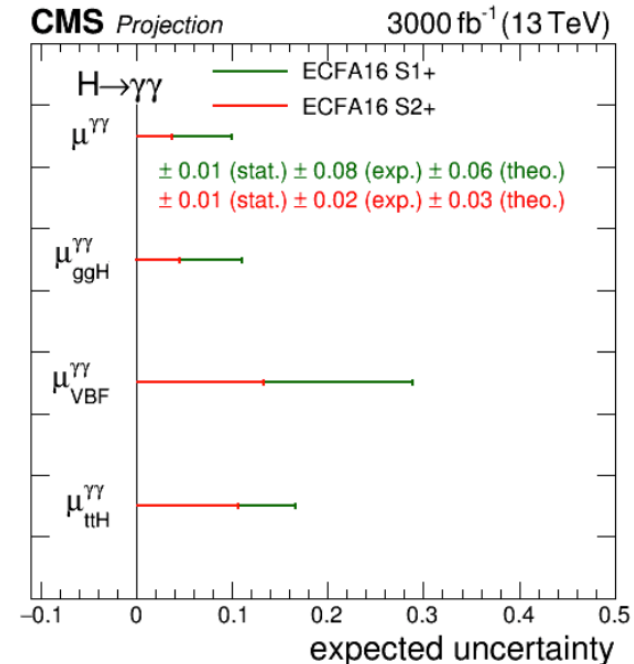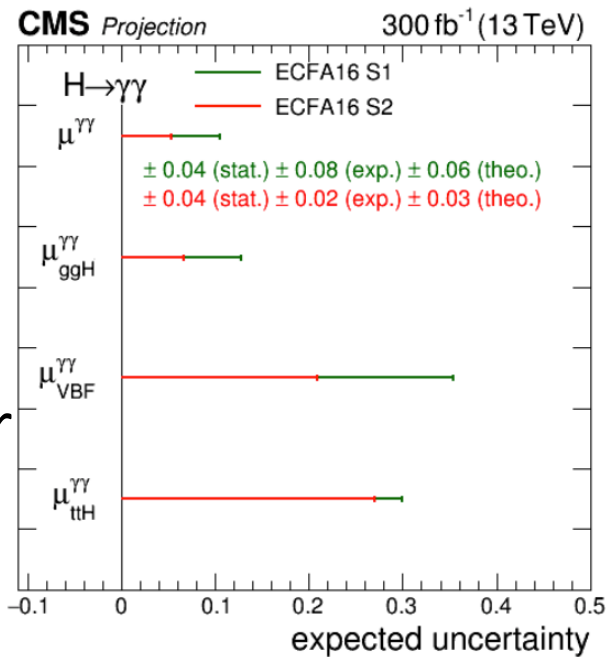
Summary and Outlook

- Improving precision of $H \to \gamma\gamma$ and $H \to 4l$ with $\approx 40\ fb^{-1}$ at $13\ TeV$

- Observation of the SM $H \to \tau\tau$ with $\approx 5\ \sigma$ excess

- Increased sensitivity of the search for the production of the Higgs associated to top quarks

- No significant deviations from the SM, no extra Higgs bosons, no sign of BSM

- Expecting an update of the presented analyses with even more data

- $\sim 100\ fb^{-1}$ of data to be delivered by the end of the LHC Run 2
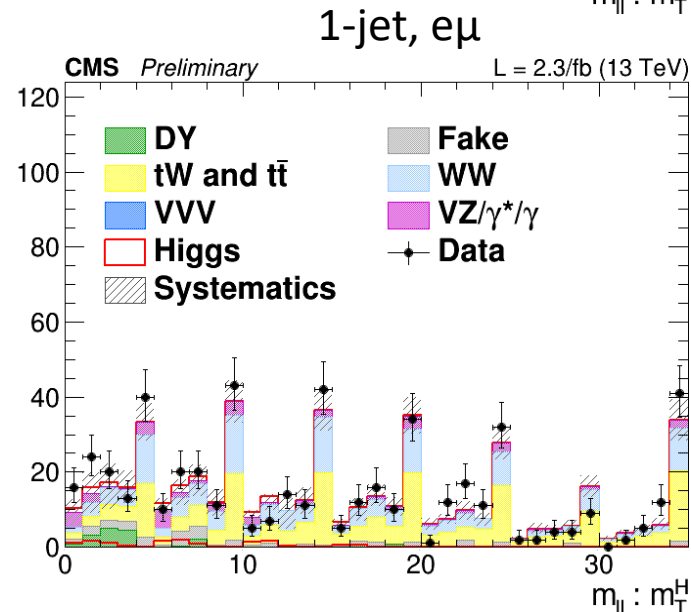
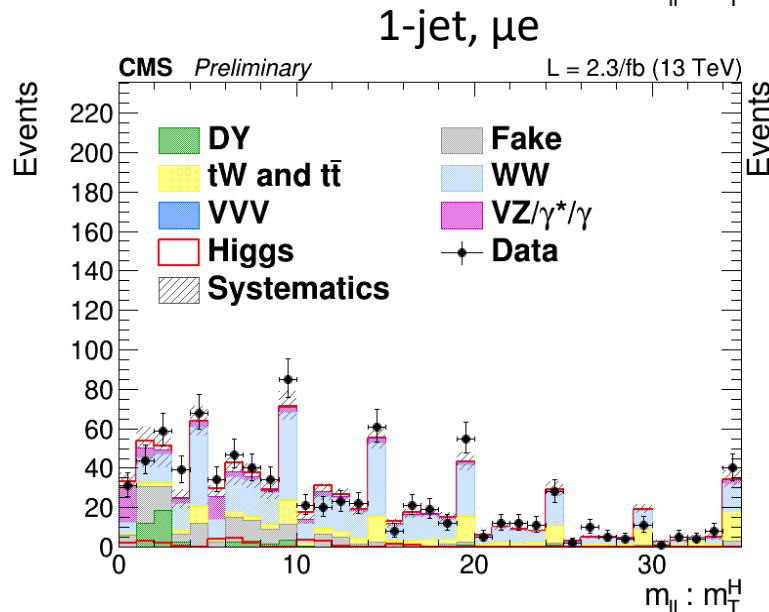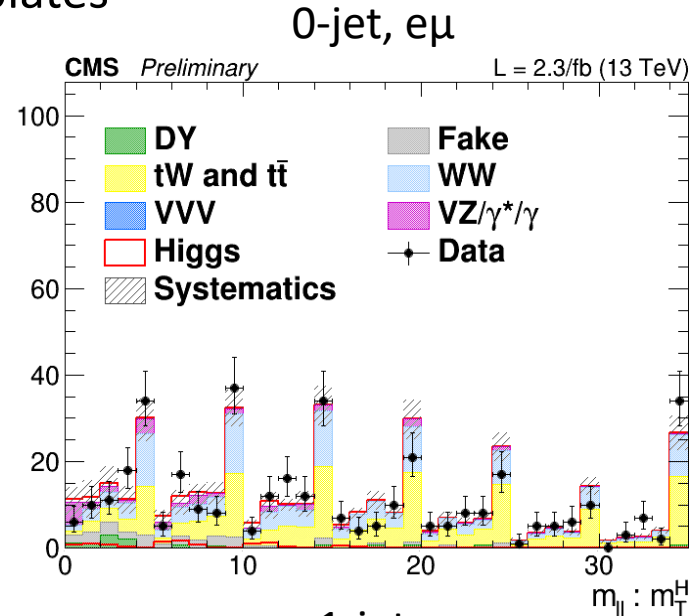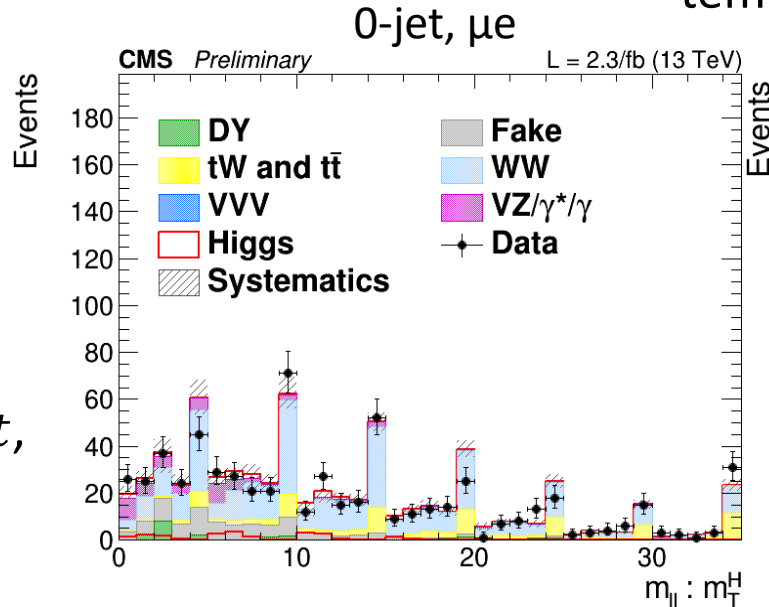# BACKUP

$H \rightarrow WW$

- 1 electron + 1 muon + large missing ET + up to 1 jet

- Main backgrounds: WW, $t\bar{t}$, single t, DY, W+jets etc.

- The events categorized to 0/1 jets and $e\mu$ or μe

- The obs (exp) significance: 0.7σ (2.0σ)

- The best fit signal strength: 0.3 ± 0.5

Unrolled bi-dimensional distributions of the m_{ll} and m_T^H templates

0-jet, μe

0-jet, eμ

1-jet, μe

1-jet, eμ

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CMS-PAS-HIG-15-003
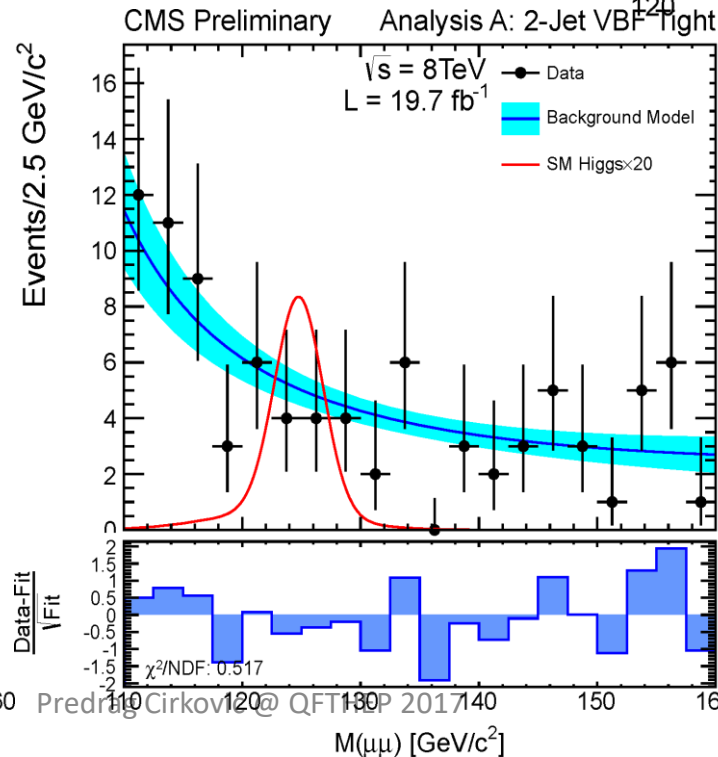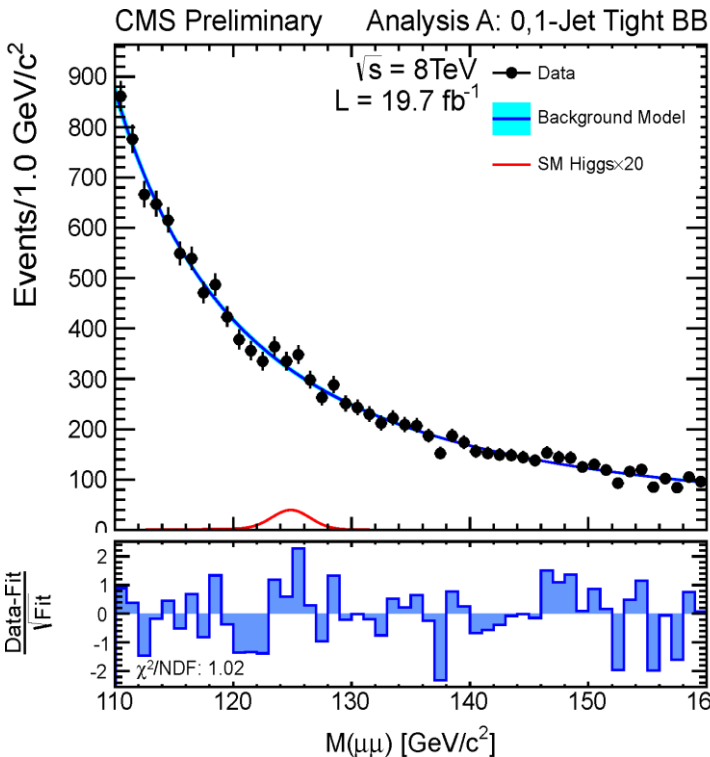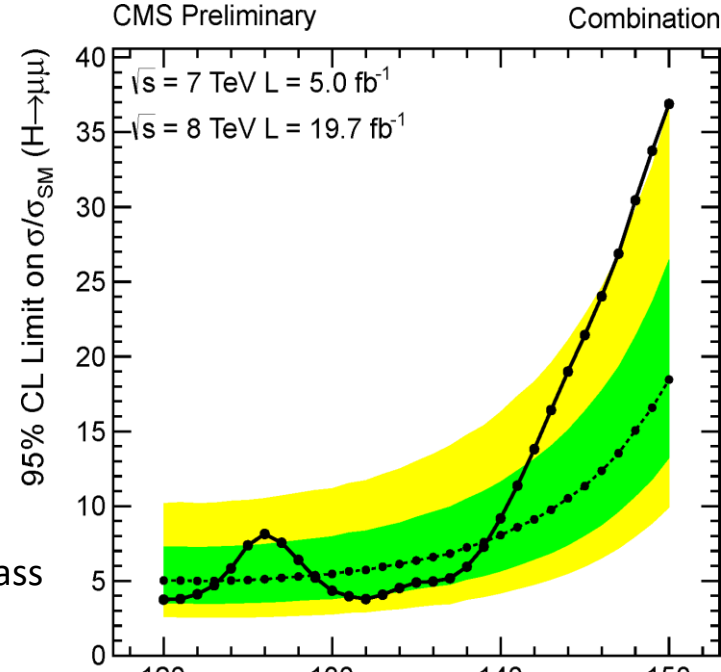
$H \rightarrow \mu\mu$

Phys. Lett. B744 (2015) 184

Main background: $Z/\gamma^* \rightarrow \mu\mu$

Small signal rate in SM: $BR(H \rightarrow \mu\mu) = 2 \times 10^{-4}$

15 event categories:

- 2-jet events further classified into VBF/non-VBF
- 0-jet and 1-jet events categorized on the di-muon p_T
  - further divided based on muon η to exploit the difference in mass resolution between barrel and endcap

Background and signal modeled by parametric function

Best fit σ/σ_{SM}: $0.8^{+3.5}_{-3.4}$

Obs. (exp.) upper limit on the production rate: $7.4\ (6.5)^{+2.8}_{-1.9} \times \sigma_{SM}$

Higgs combination (CMS + ATLAS)

	ggH	VBF	VH	ttH
$H \to \gamma\gamma$	✓	✓	✓	✓
$H \to ZZ \to 4l$	✓	✓	✓	✓
$H \to WW \to 2l2\nu$	✓	✓	✓	✓
$H \to \tau\tau$	✓	✓	✓	✓
$H \to bb$	?	?	✓	✓
$H \to \mu\mu$	✓	✓	?	?
$H \to Z\gamma$	?	?	?	?