

New Results from CMS

**Stathes Paganis (National Taiwan University)
on behalf of the CMS collaboration
NCTS Annual Meeting, Hsinchu, Taiwan, 8-12-2016**

Outline

- Introduction to CMS
- Standard Model and Higgs
- Supersymmetry
- Exotics / BSM
 - Resonances: Dijet, dilepton, tau-tau, diphoton
- Dark Matter searches / Invisible Higgs

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 ($100 \times 150 \mu\text{m}$) $\sim 16\text{m}^2 \sim 66\text{M}$ channels
Microstrips ($80 \times 180 \mu\text{m}$) $\sim 200\text{m}^2 \sim 9.6\text{M}$ channels

SUPERCONDUCTING SOLENOID

Niobium titanium coil carrying $\sim 18,000\text{A}$

MUON CHAMBERS

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

PRESHOWER

Silicon strips $\sim 16\text{m}^2 \sim 137,000$ channels

FORWARD CALORIMETER

Steel + Quartz fibres $\sim 2,000$ Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)

$\sim 76,000$ scintillating PbWO_4 crystals

HADRON CALORIMETER (HCAL)

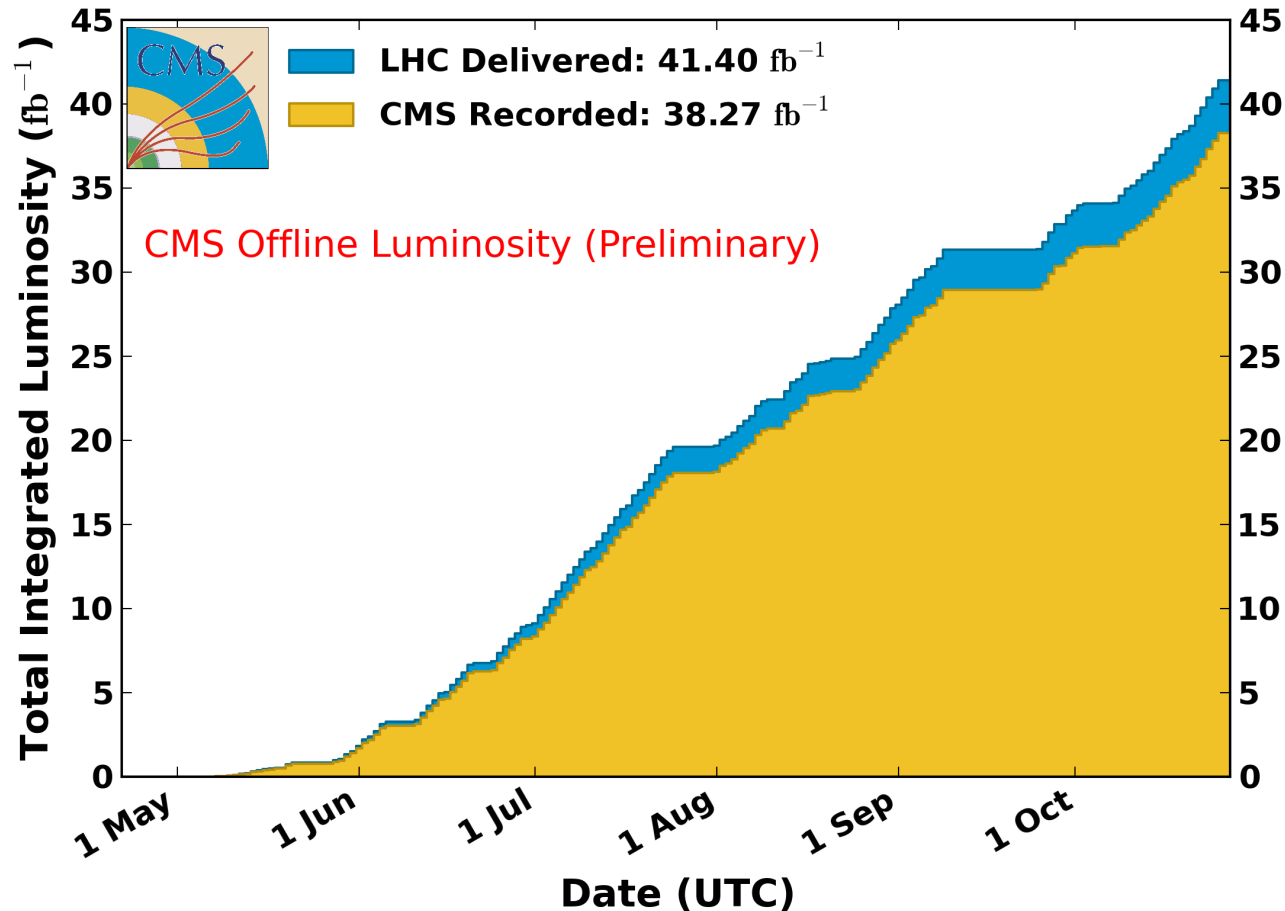
Brass + Plastic scintillator $\sim 7,000$ channels

8-Dec-2016

Data Collected in 2016

CMS Integrated Luminosity, pp, 2016, $\sqrt{s} = 13$ TeV

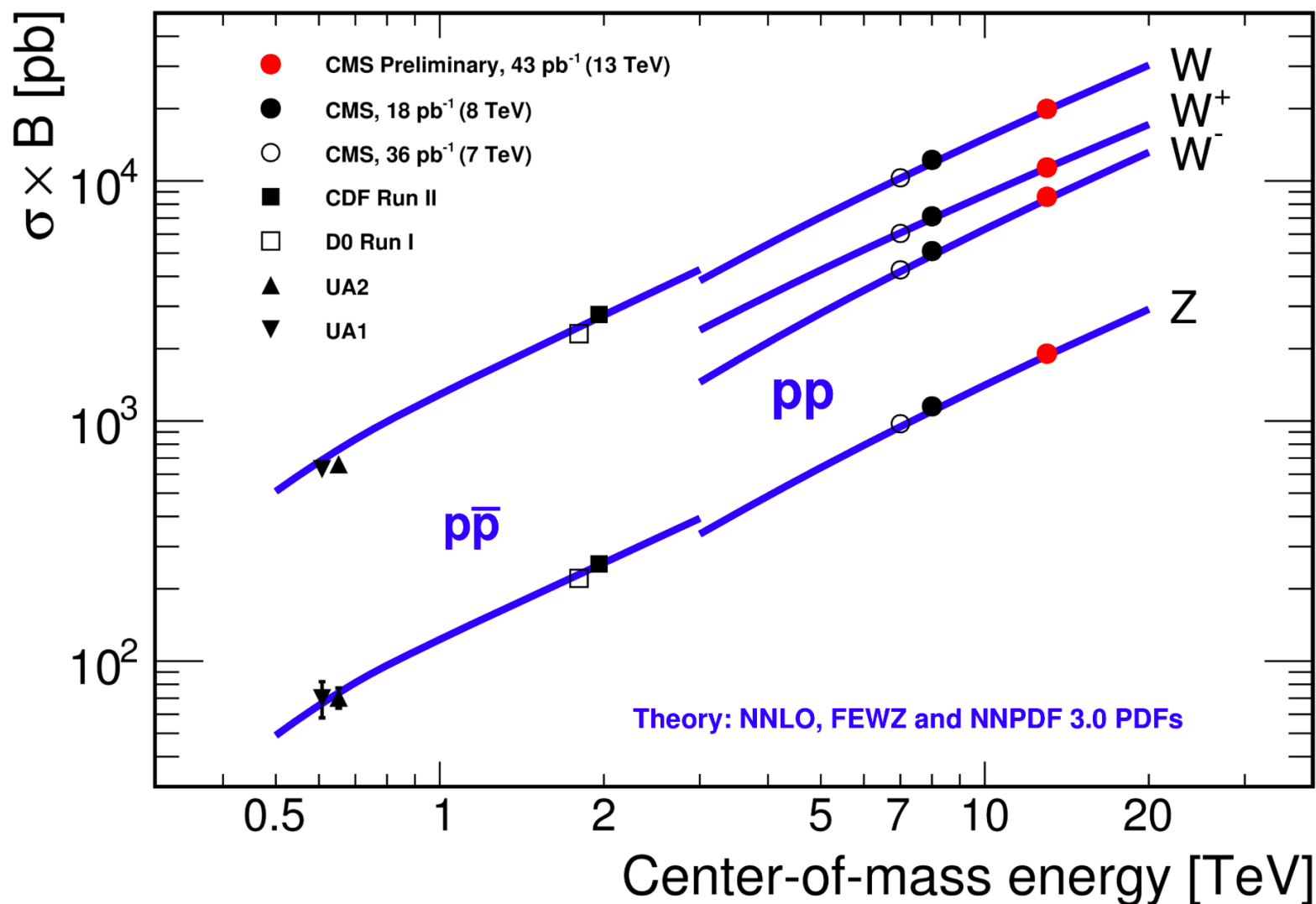
Data included from 2016-04-22 22:48 to 2016-10-27 14:12 UTC



At 13TeV collected **38.27** fb^{-1} (2016) and 3.8 fb^{-1} (2015).
Thanks to the amazing machine performance.

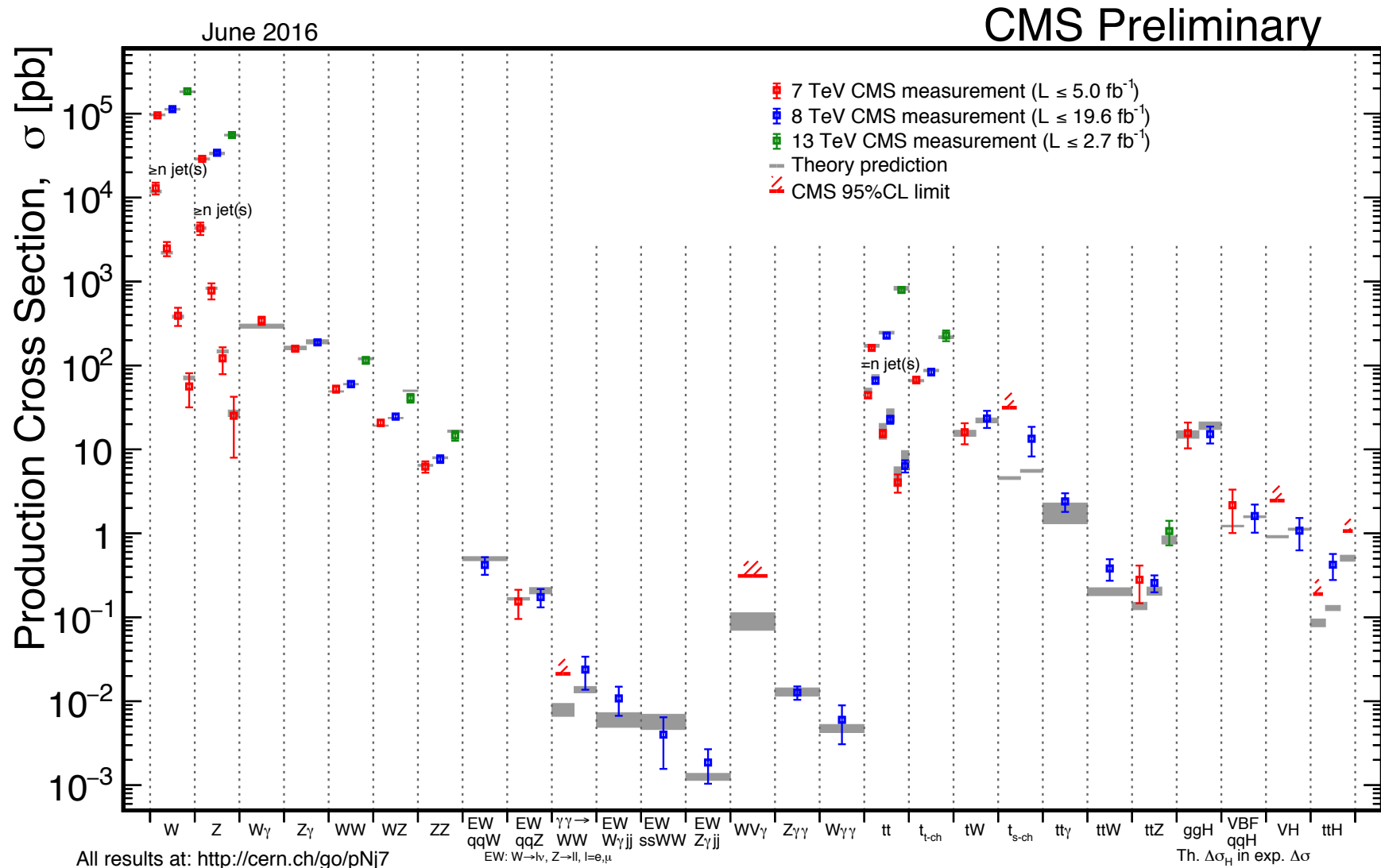
SM W and Z production

CMS-PAS-SMP-15-004



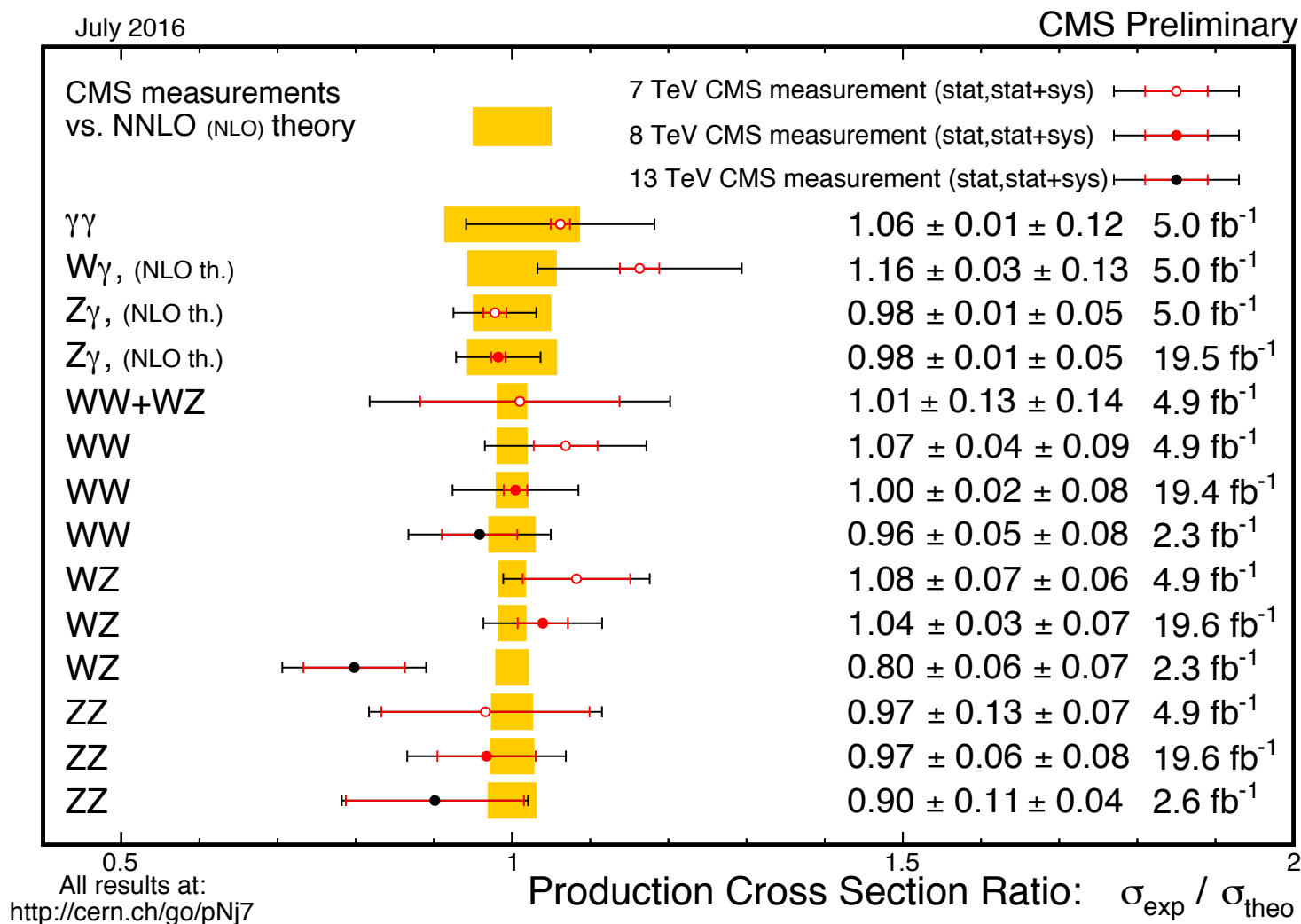
Measured inclusive Z/W cross sections and differential W+jets cross sections.

SM Inclusive cross sections



A wealth of SM measurements in 7, 8 and 13 TeV.

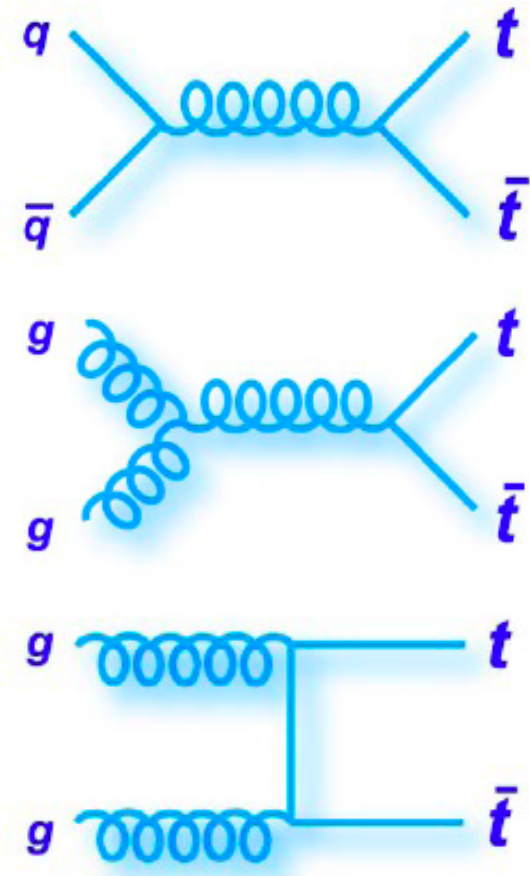
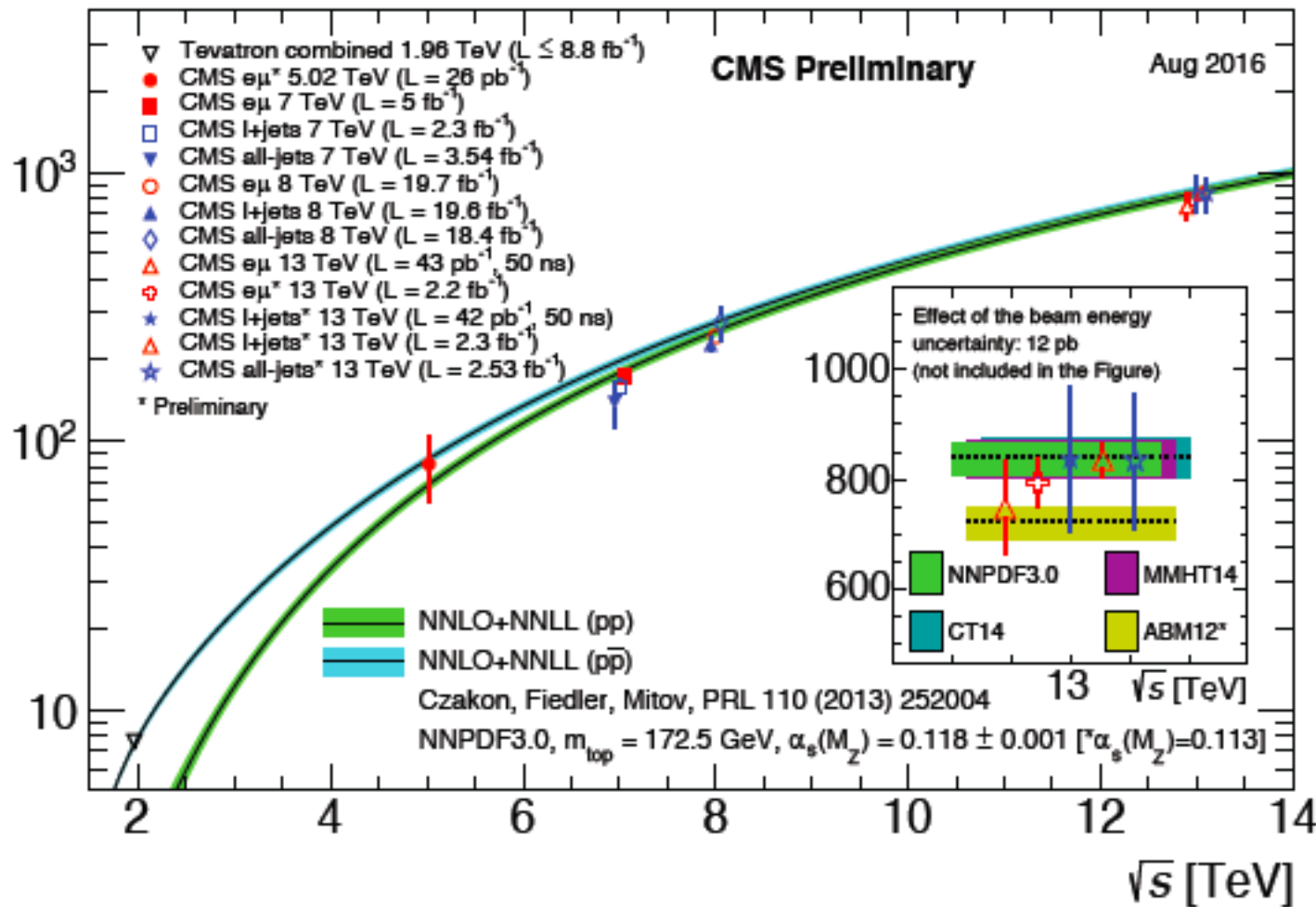
SM Inclusive cross sections (2)



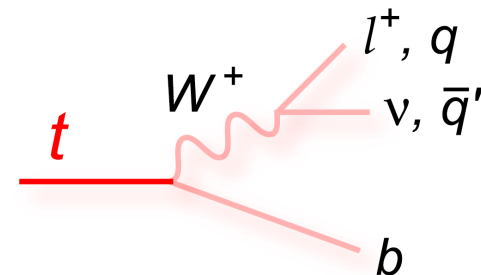
Diboson SM production cross sections.

Top-pair production

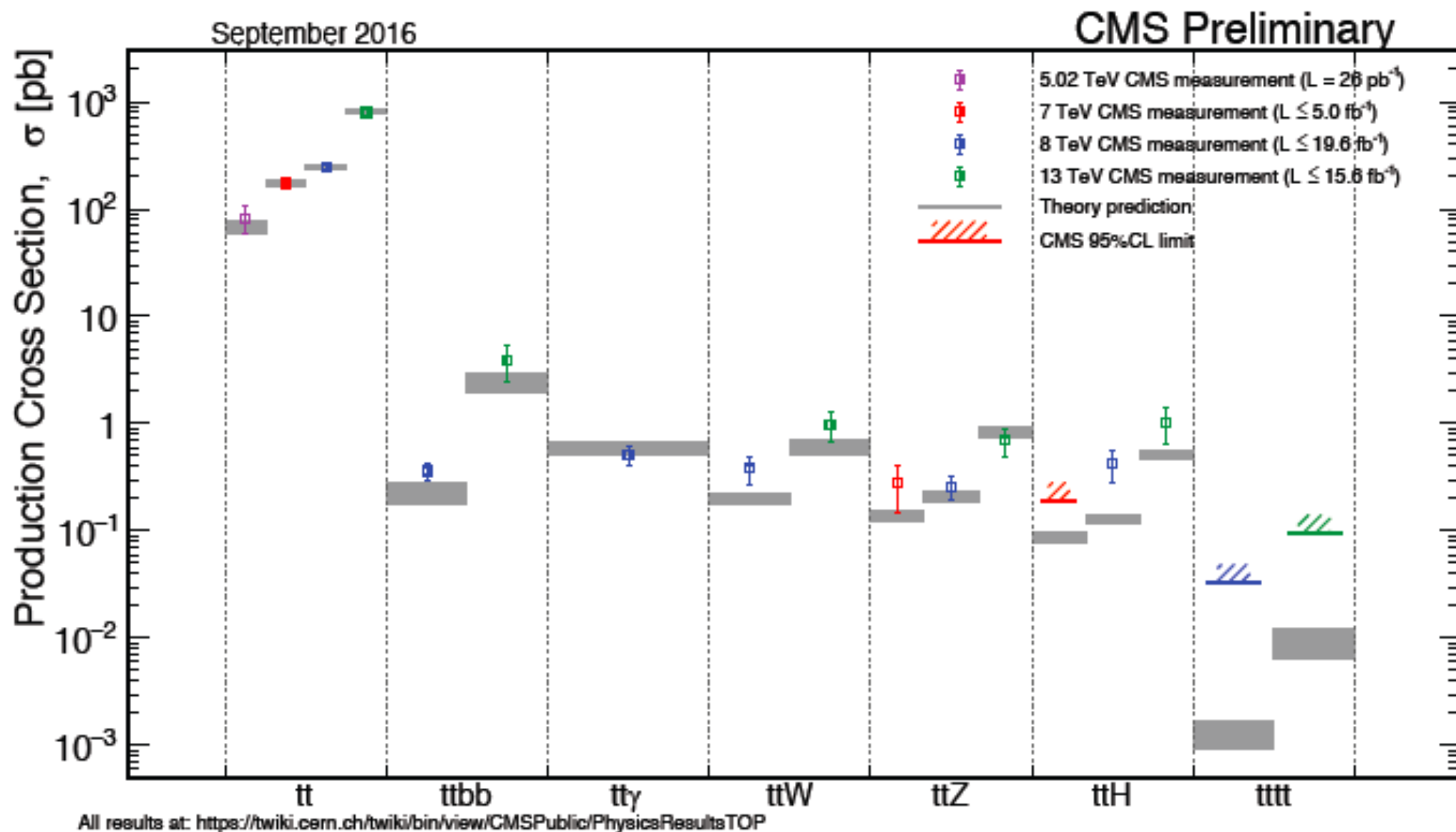
Inclusive $t\bar{t}$ cross section [pb]



- Top cross section: $\sigma \sim 800 \text{ pb}$, rate $\sim 10 \text{ Hz}$.
- LHC is a top factory.



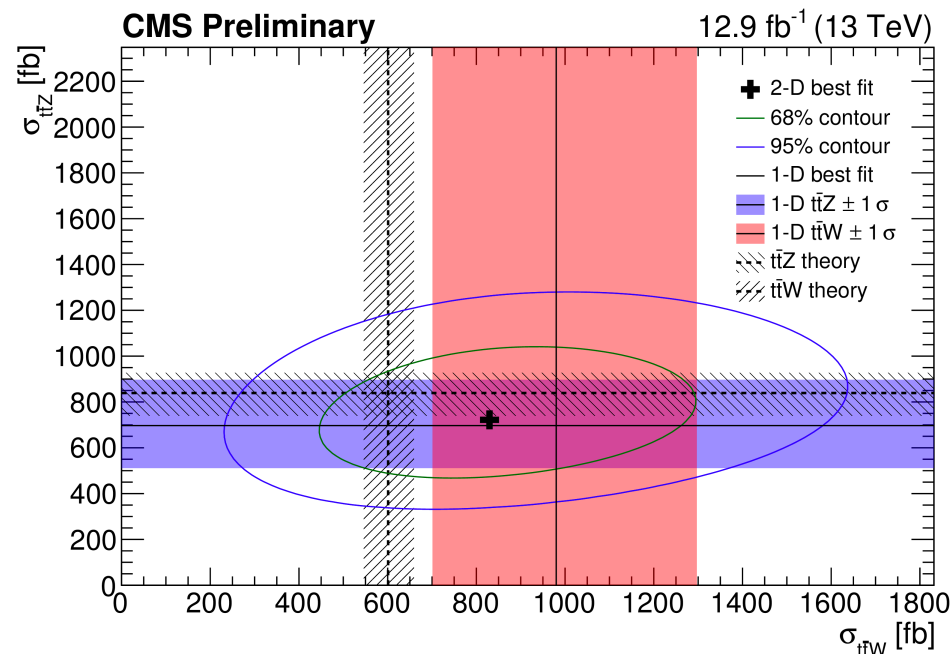
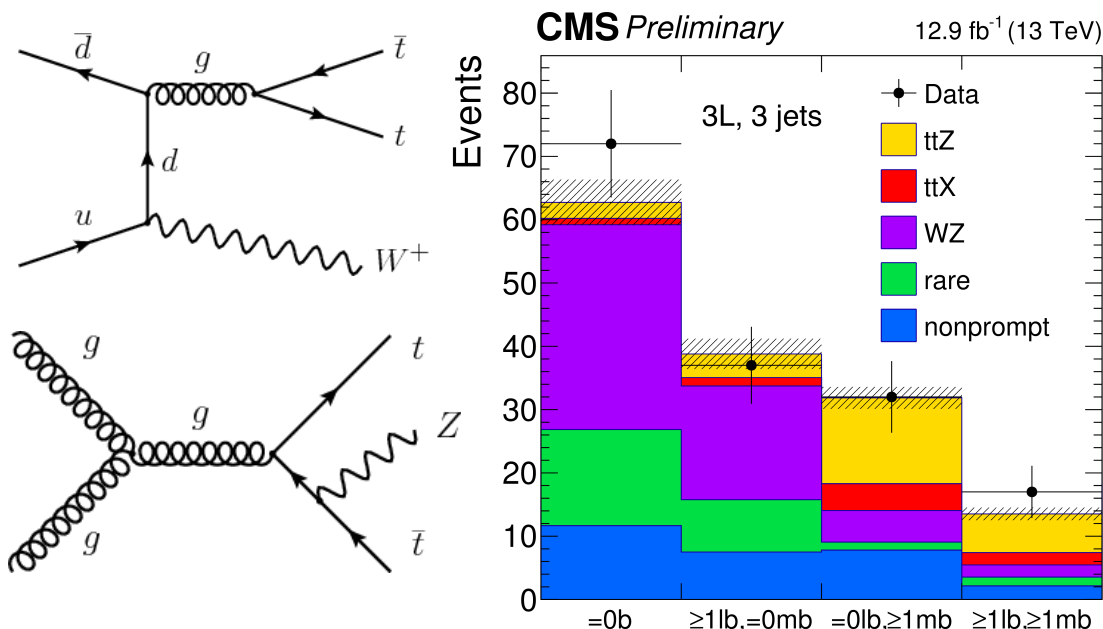
Top-pair production (2)



ttH shows a mild excess wrt SM in both run1 and run2.

tt+W/Z production

CMS-PAS-TOP-16-017



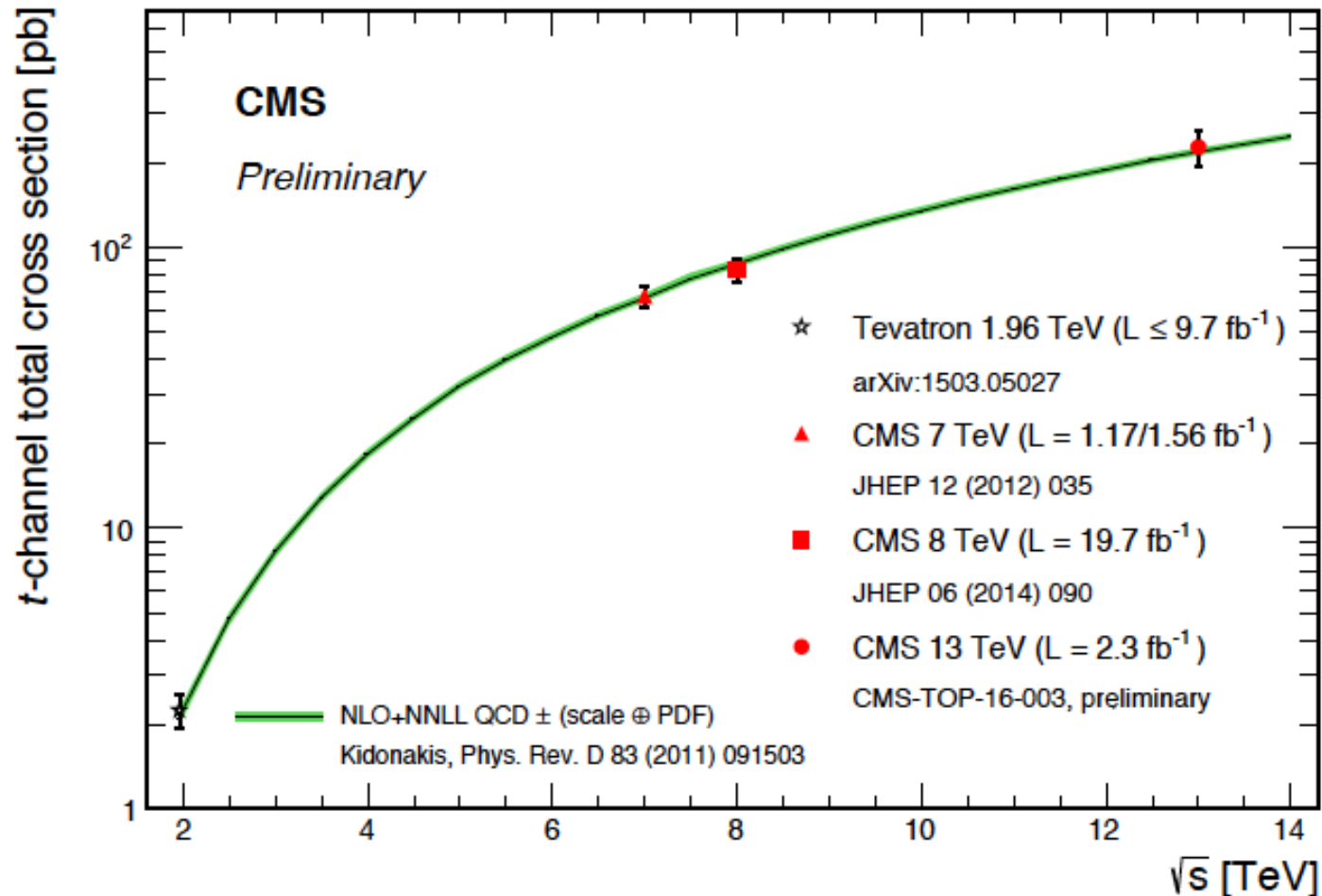
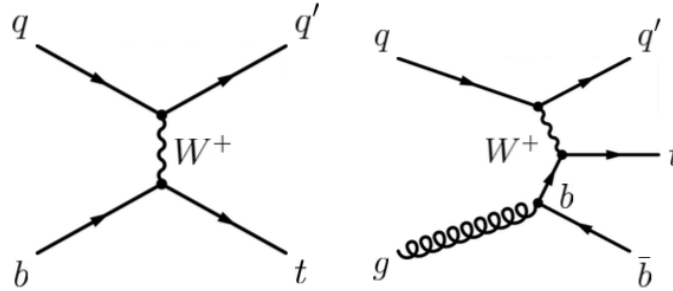
$$\sigma(pp \rightarrow t\bar{t}Z) = 0.70^{+0.16}_{-0.15}(\text{stat.})^{+0.14}_{-0.12}(\text{sys.}) \text{ pb}$$

$$\sigma(pp \rightarrow t\bar{t}W) = 0.98^{+0.23}_{-0.22}(\text{stat.})^{+0.22}_{-0.18}(\text{sys.}) \text{ pb}$$

- ttW: 2 same-sign leptons.
- ttZ : 3 or 4 leptons.

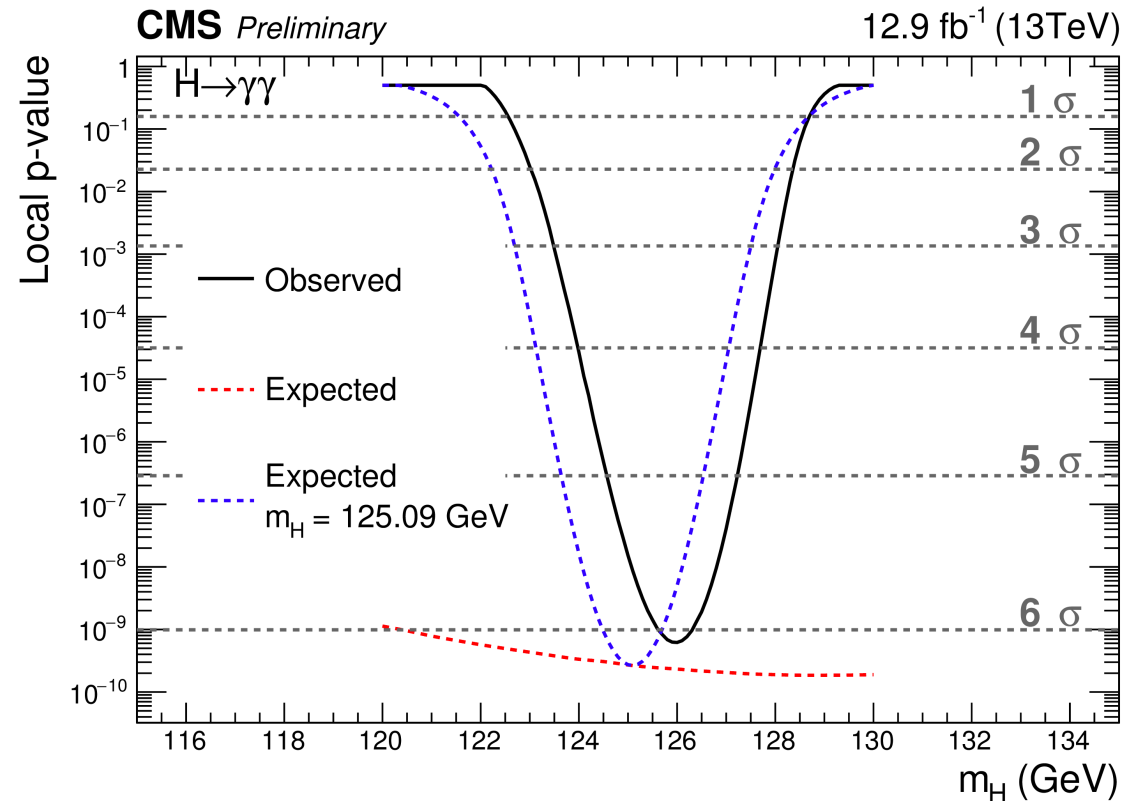
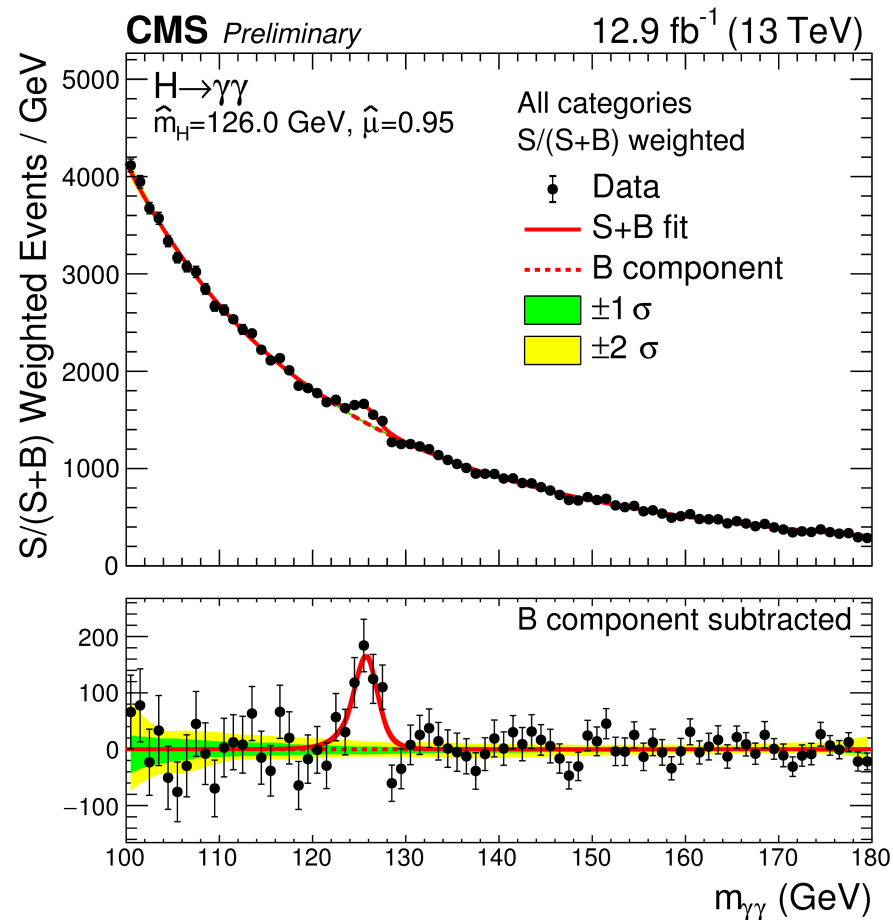
Single top production

CMS-PAS-TOP-16-003



Good agreement with NLO+NNLL QCD predictions.

$H \rightarrow \gamma\gamma$ production at 13 TeV

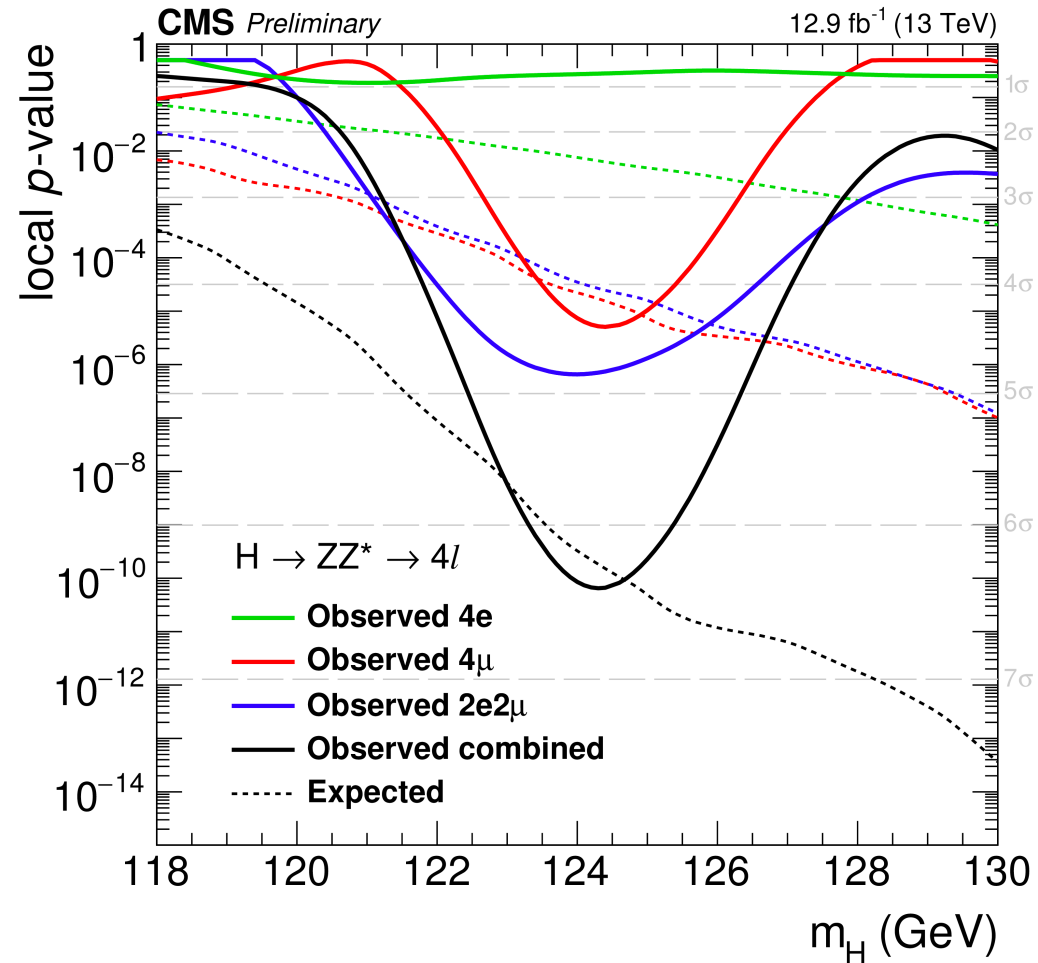
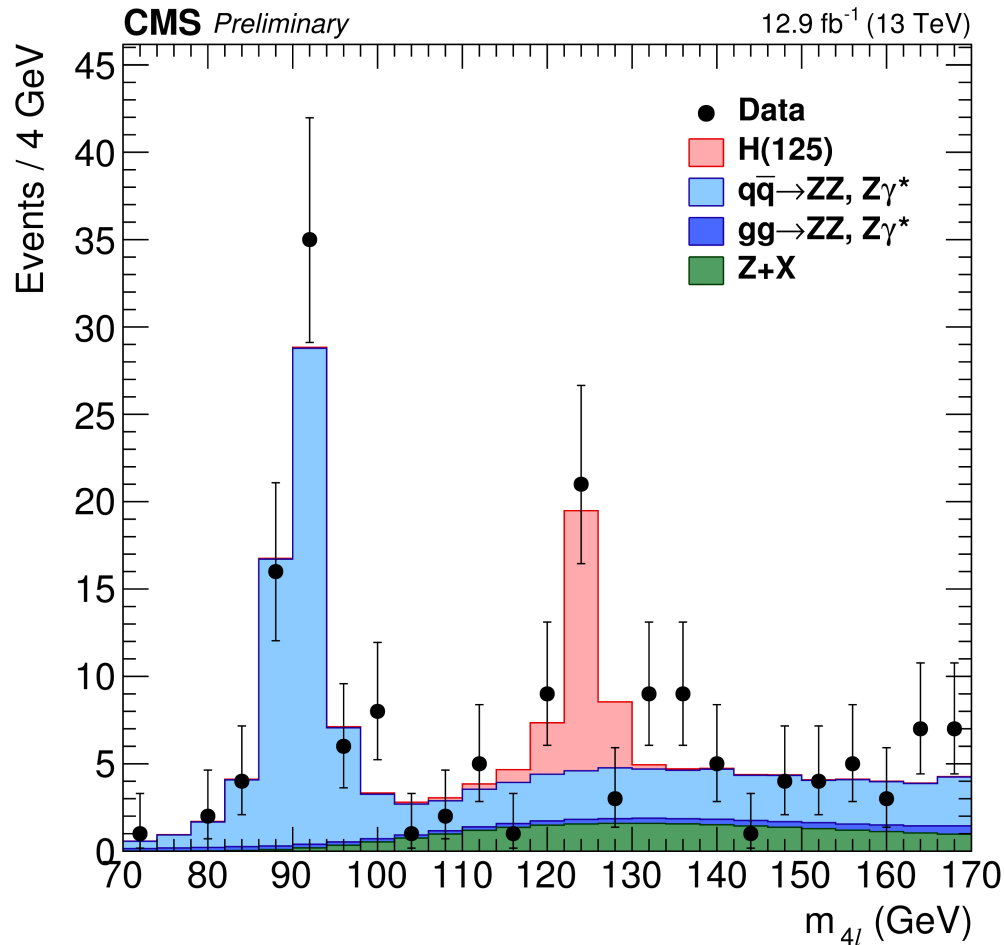


Higgs rediscovery in run2.

- MVA photon ID & vertex selection.
- Fit signal + bkg in 8 categories.
- Observed (exp) sig: 5.6 σ (6.2 σ).

H $\rightarrow$ ZZ $\rightarrow$ 4l production at 13TeV

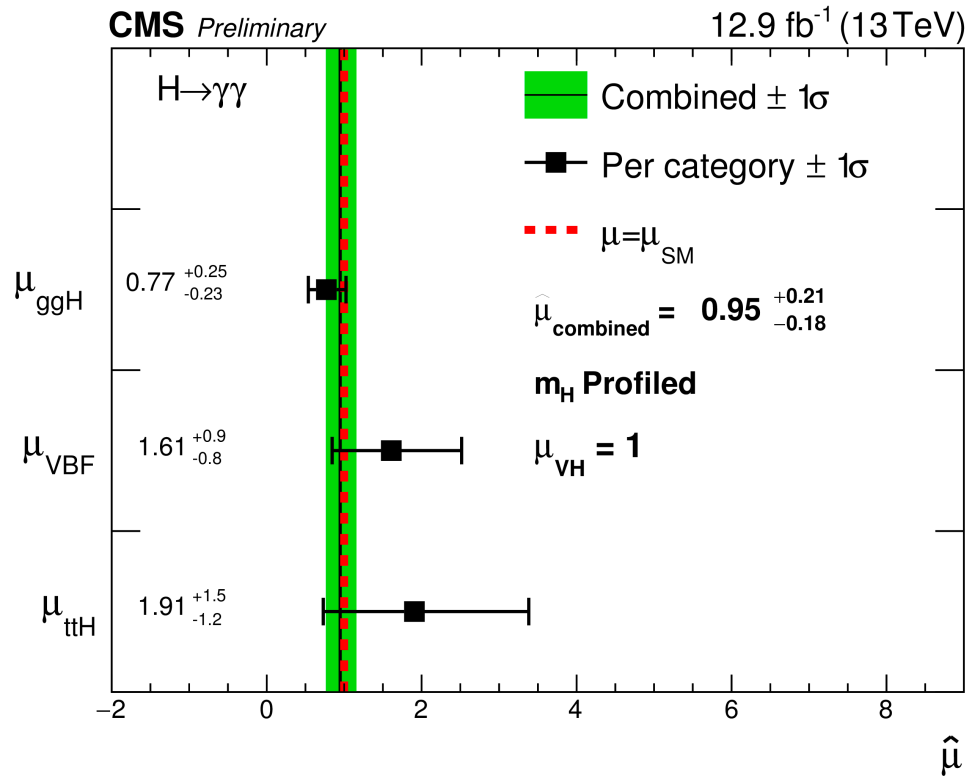
CMS-PAS-HIG-16-033



- Narrow peak with high S/B.
- 2D fit of m_{4l} & matrix element discriminant.
- Observed (expected) significance = 6.2 σ (6.5 σ).

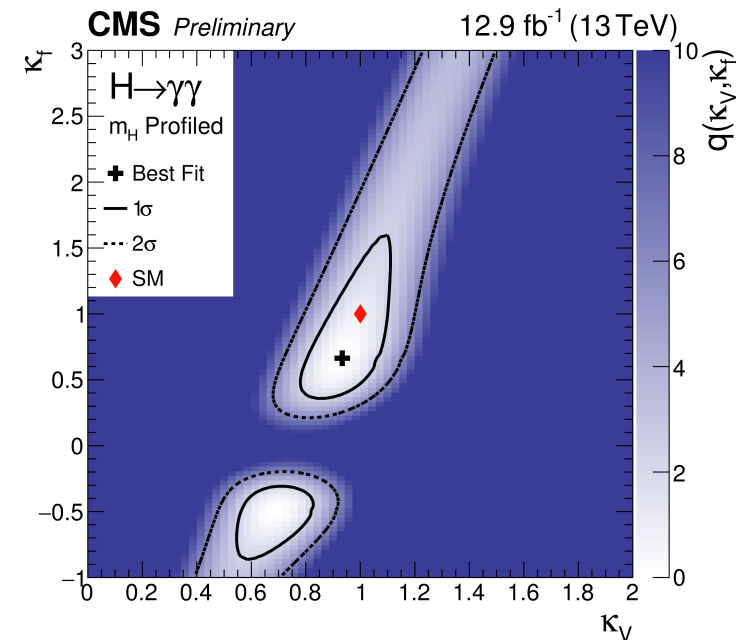
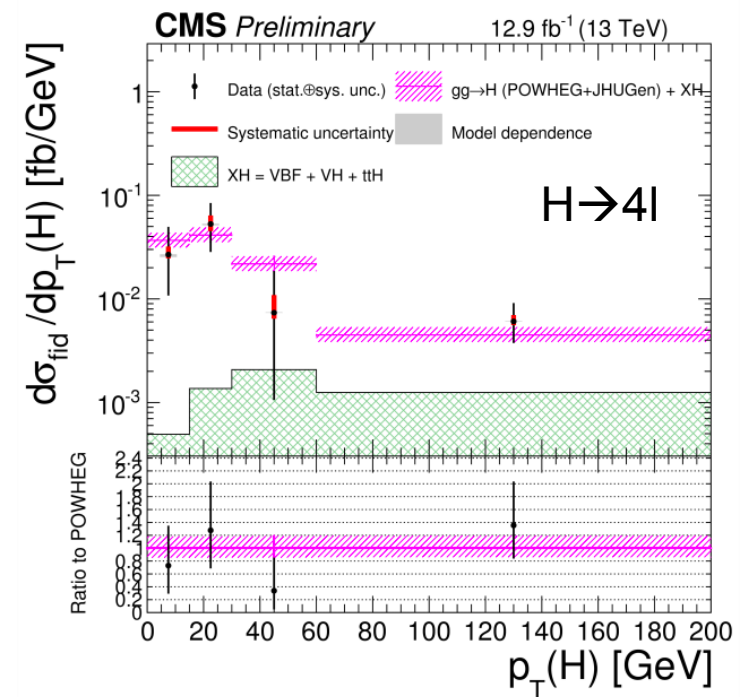
$$m_H = 124.50^{+0.48}_{-0.46} \text{ GeV}$$

Properties: $H \rightarrow \gamma\gamma, 4l$ at 13 TeV



A mild VBF excess is seen in both run1 and run2.

tth also measured in VV/ $\tau\tau$ (next slides)



ttH production: multi-lepton final state

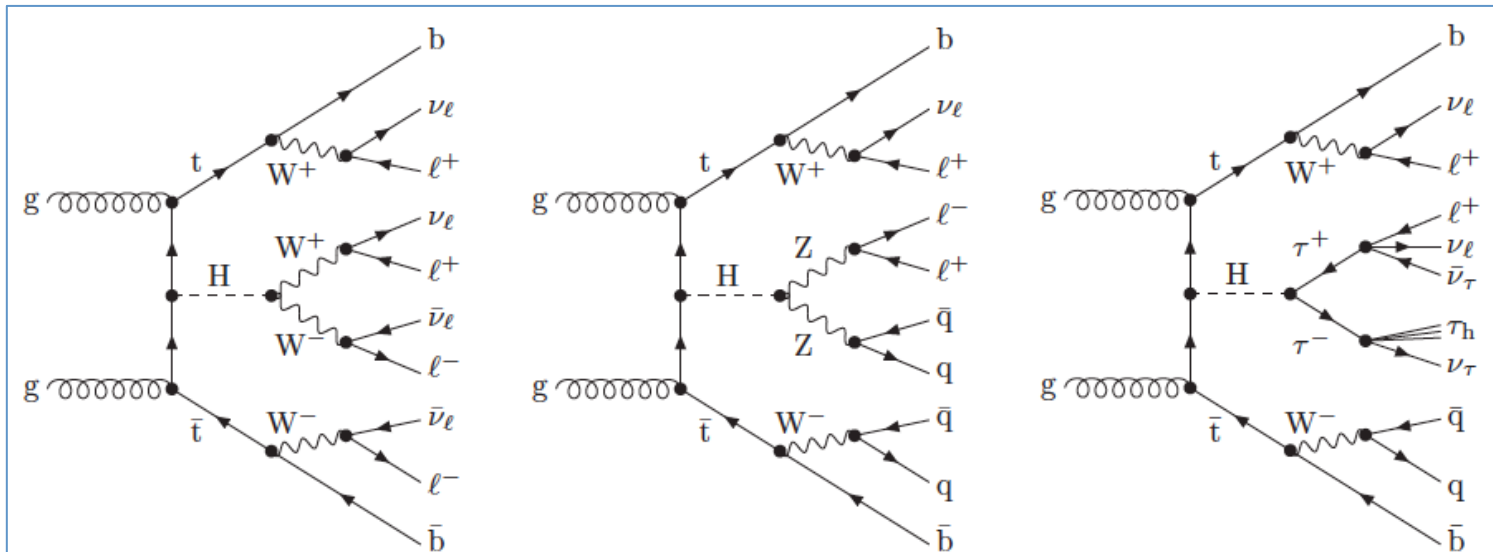
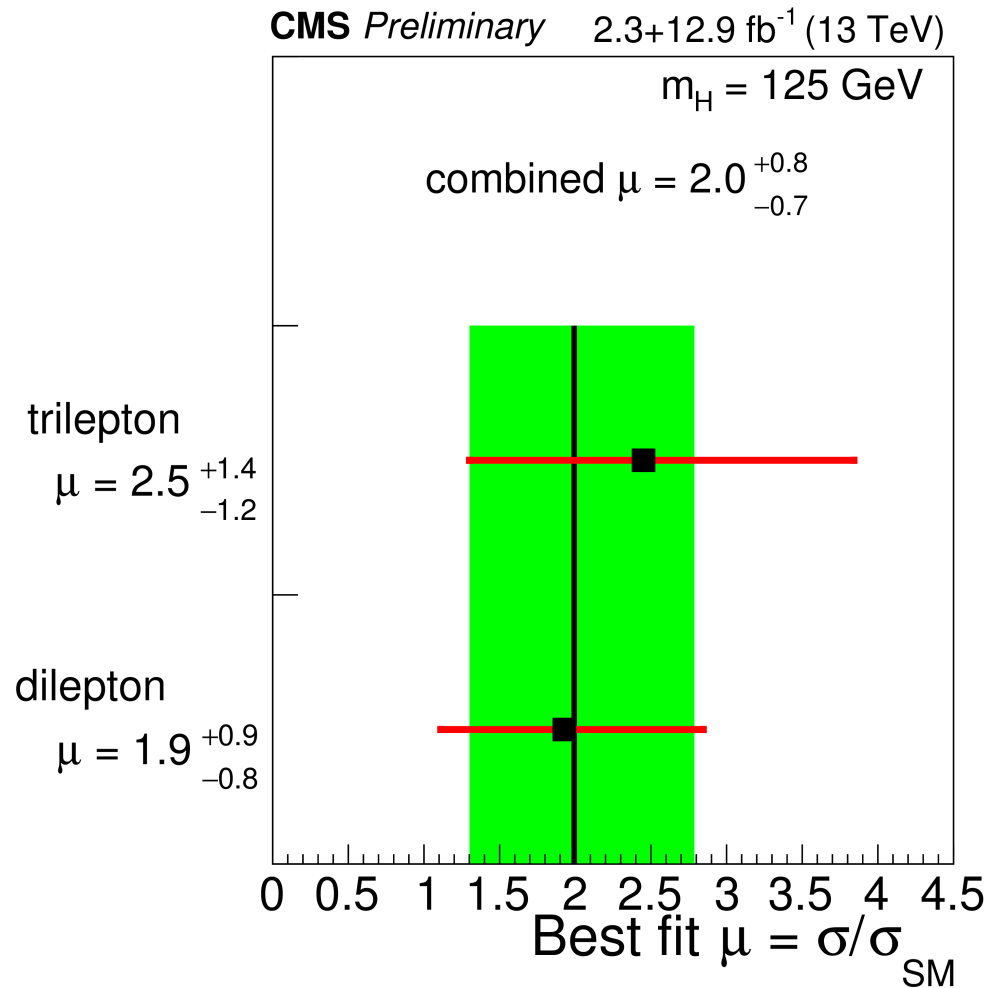
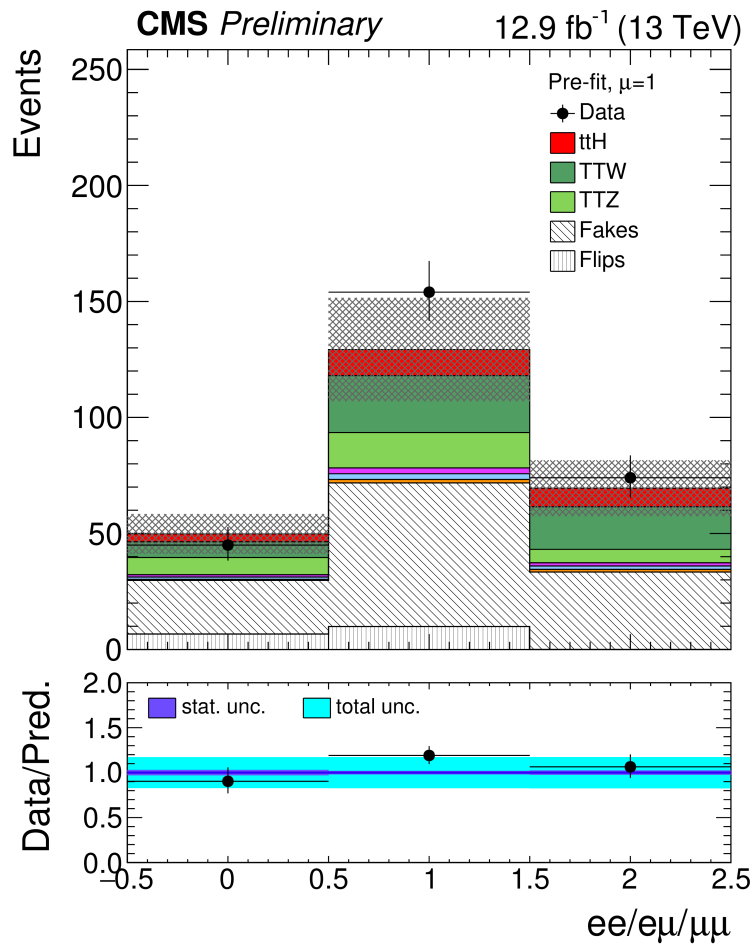


Figure 1: Possible Feynman diagrams for $t\bar{t}H$ production at pp colliders, where the Higgs boson decays to WW^* , ZZ^* , and $\tau\tau$ (from left to right). Subsequent W, Z, and t decays are shown representing examples of final states with four leptons, three leptons, and two same-sign leptons, respectively.

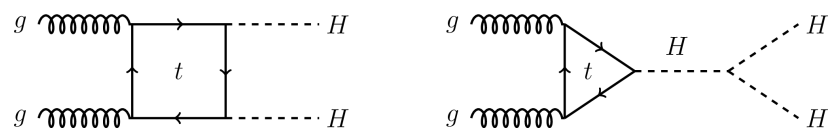
- Direct probe of top Yukawa coupling.
- Modes measured: $H \rightarrow WW/ZZ/\tau\tau$.
- Irreducible background from $t\bar{t}V$.
- Reducible background from $t\bar{t}$ +jets.
- Categories: 2 same sign leptons or ≥ 3 leptons.
- Signal strength of $2^{+0.8}_{-0.7} \times \sigma_{SM}$ 2015+2016 data.

ttH production: multileptons

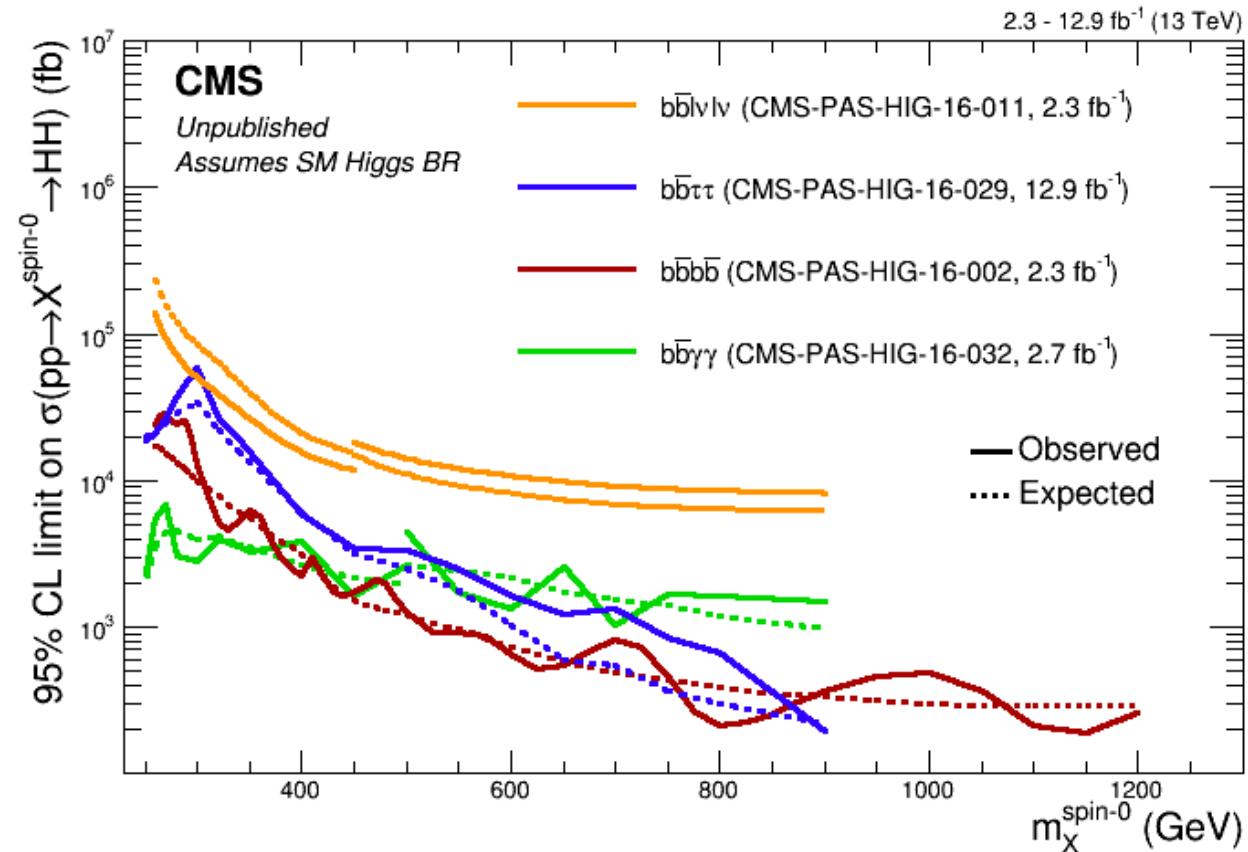
CMS-PAS-HIG-16-022



di-Higgs production



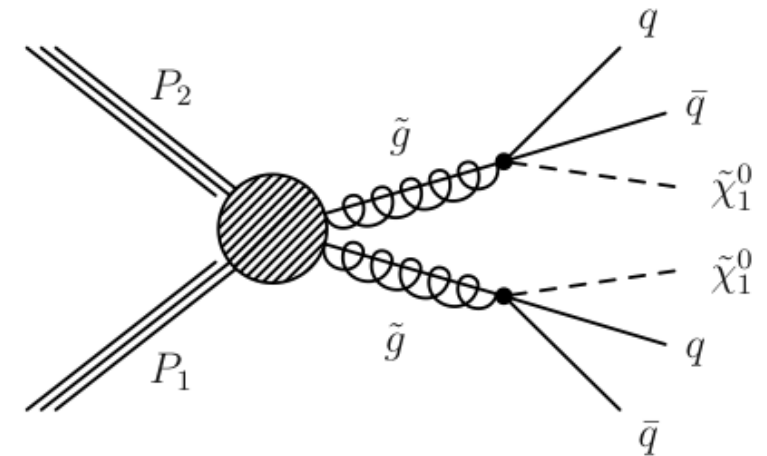
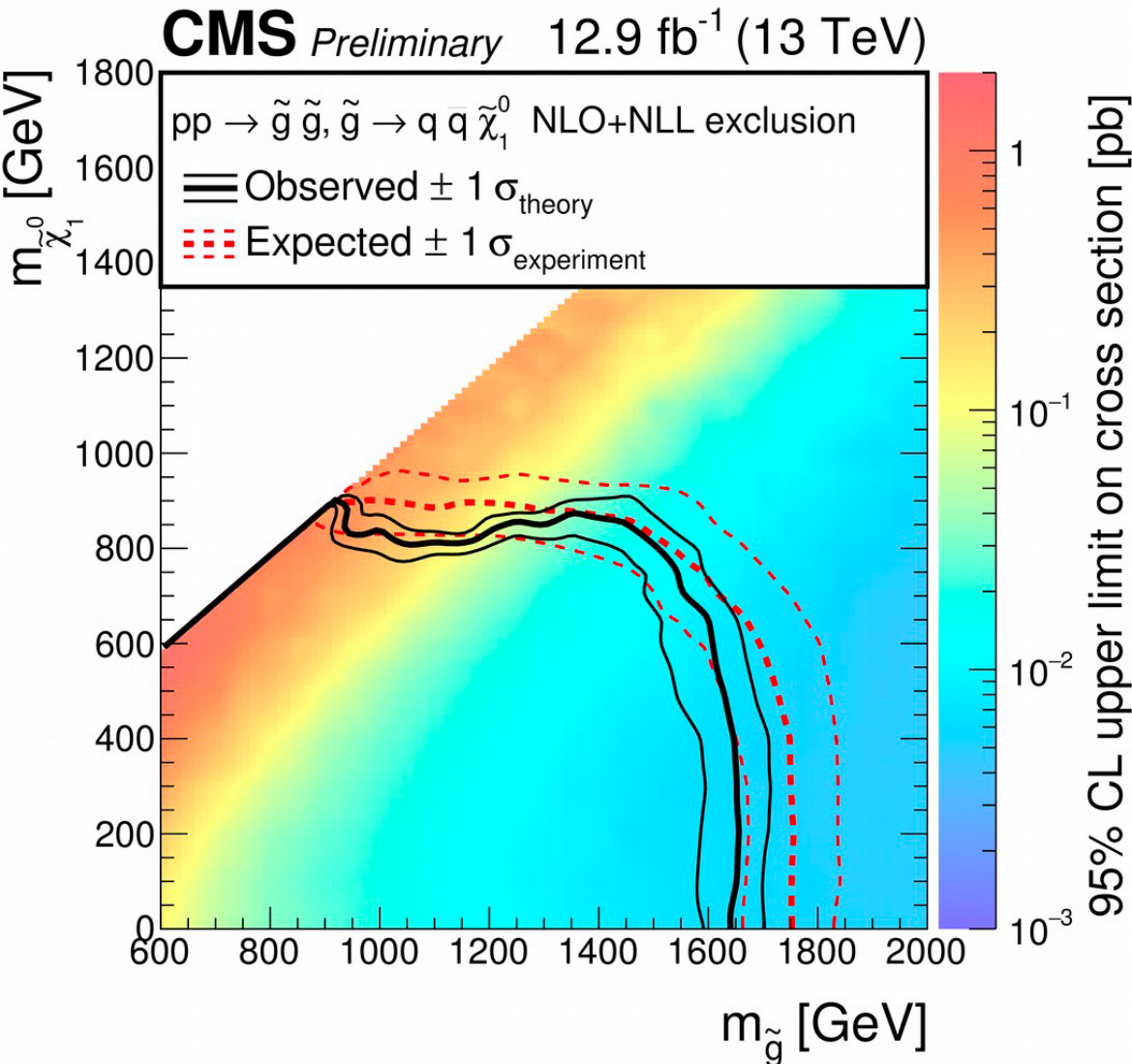
Probe of Higgs self coupling



- Sensitivity to SM HH is low, but production enhanced by BSM.
- $b\bar{b}b\bar{b}$: high statistics; best sensitivity at high mass.
- $b\bar{b}\gamma\gamma$: low statistics, cleaner FS with $\gamma\gamma$; best sensitivity at low mass.

SUSY: strong production

CMS-PAS-SUS-16-015



- Variety of CMS SUSY searches.
- R-parity conserving:
 - Squark & gluino.
 - 3rd generation squark.
 - Electroweak gaugino.
 - Compressed spectra.
- R-parity violating sparticle decays
- Gauge-mediated SUSY breaking
- Typically highest cross-section for gluino/squark pairs with decays to jets + MET.

SUSY: strong production

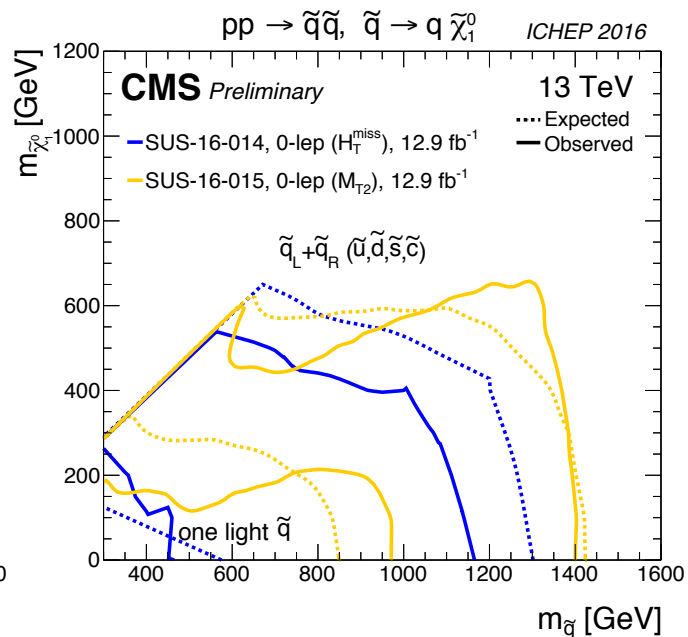
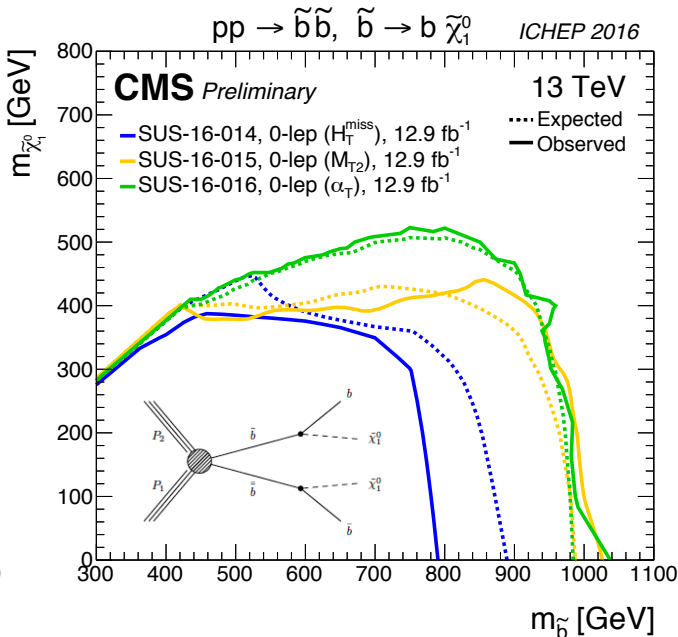
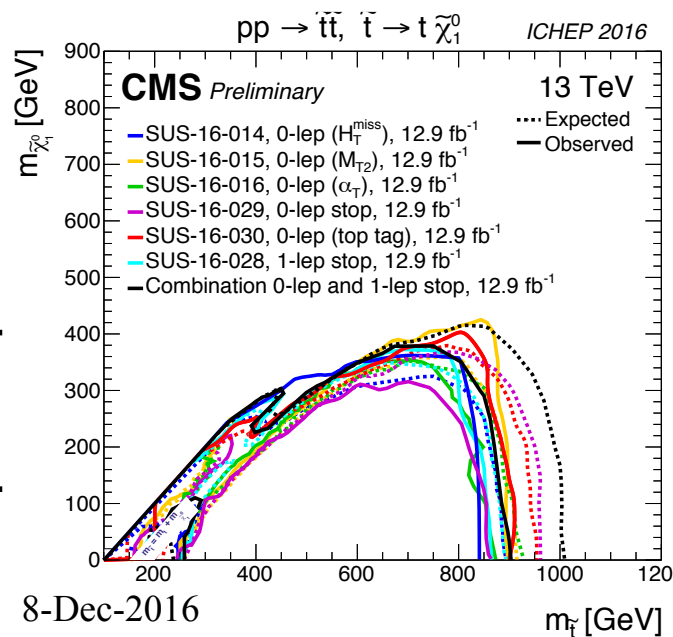
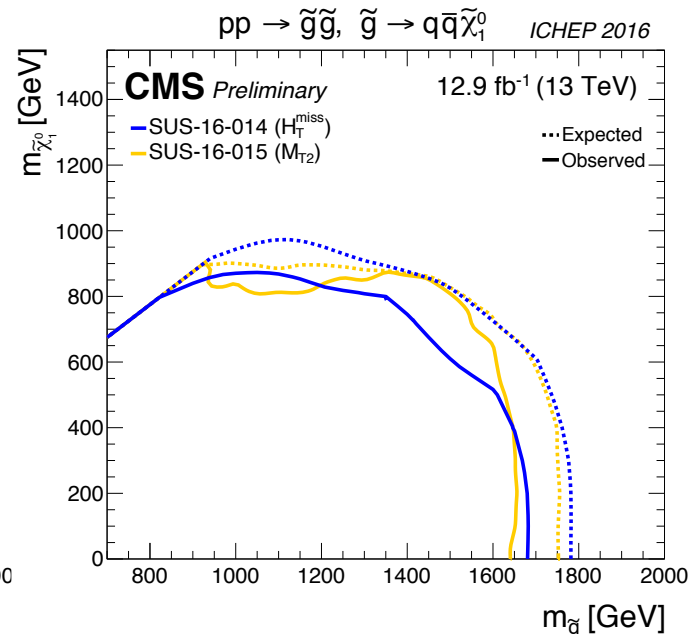
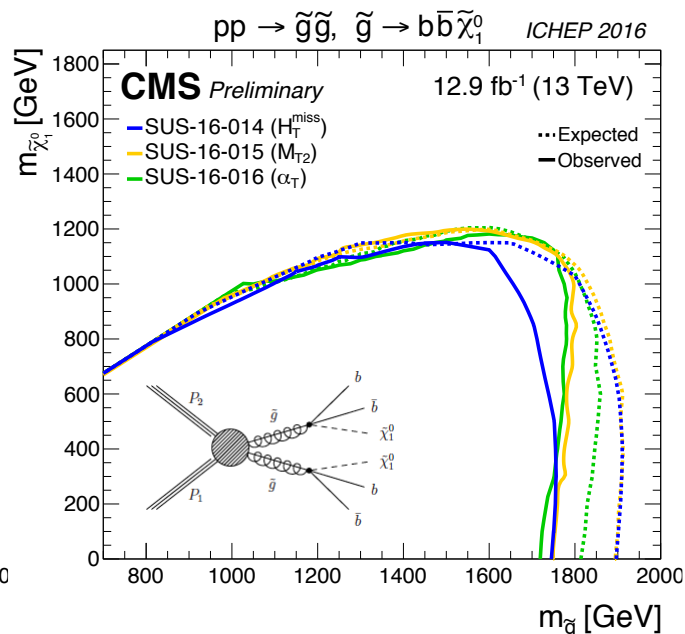
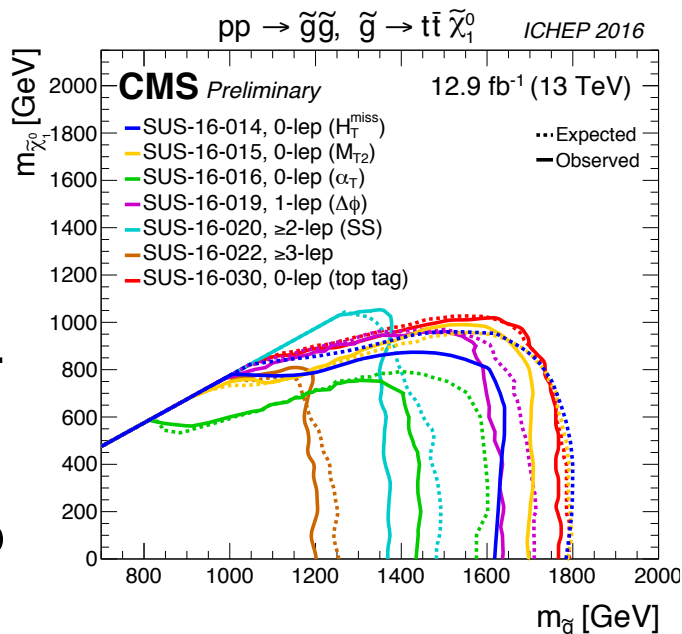
Top

bottom

light quarks

gluino production

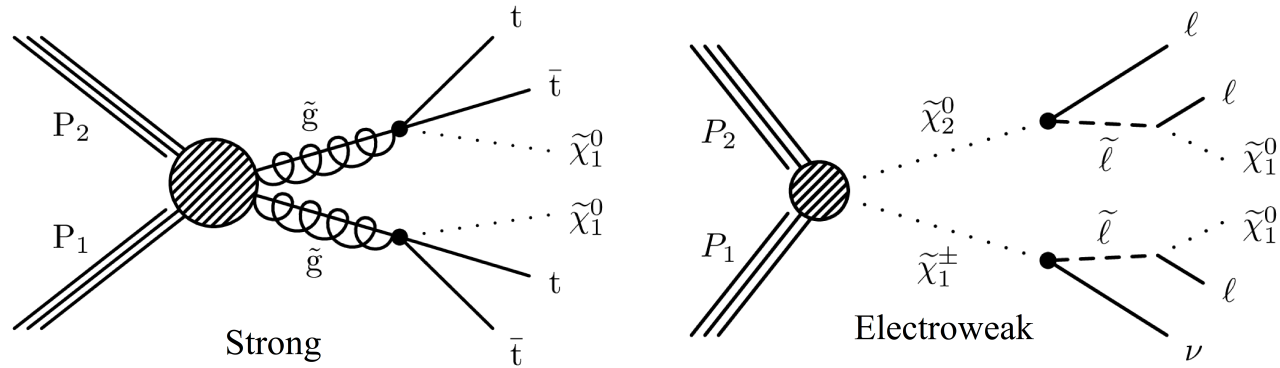
squark production



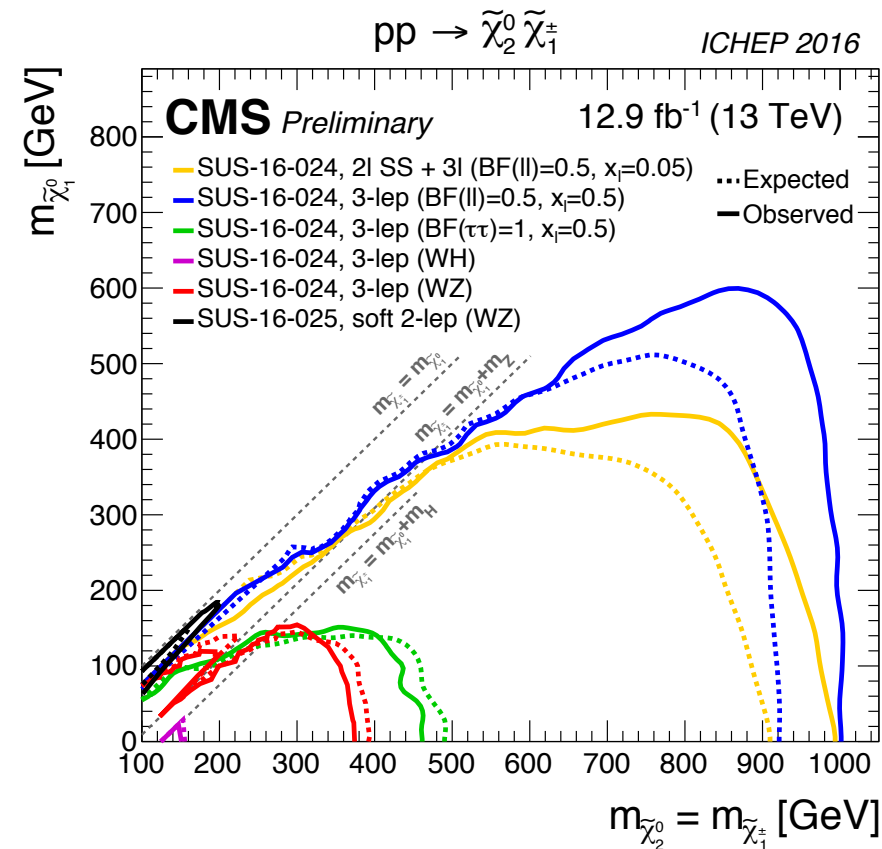
8-Dec-2016

SUSY: multileptons

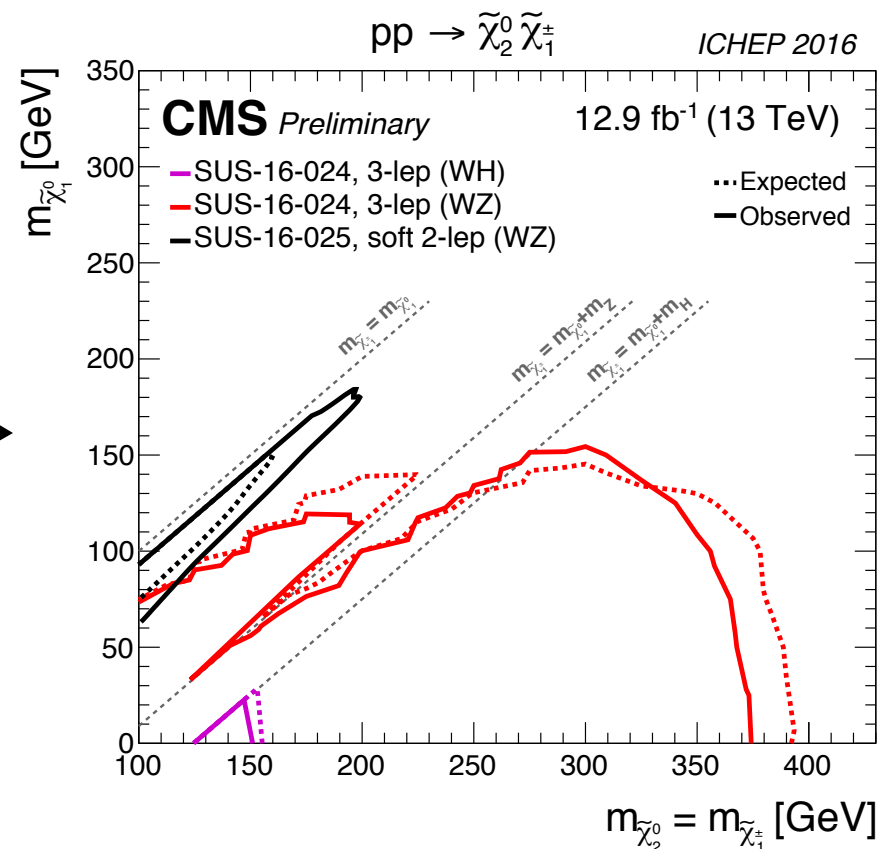
- With strong production limits saturating, searches extending to more challenging scenarios.
- Clean signature: based on jet activity can be sensitive to strong or electroweak SUSY production.



Strong: exclude gluino < 1250 GeV and LSP < 750 GeV.
EWK: exclude chargino < 1 TeV.

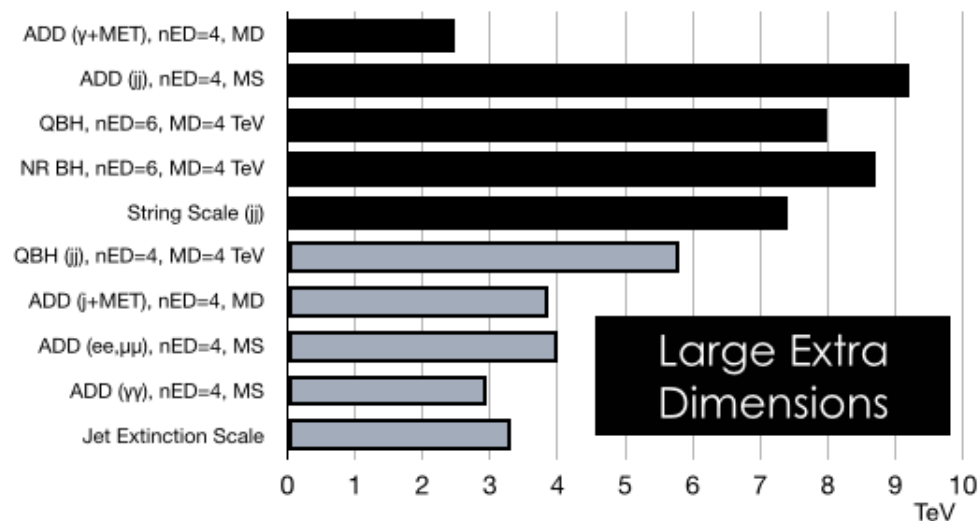
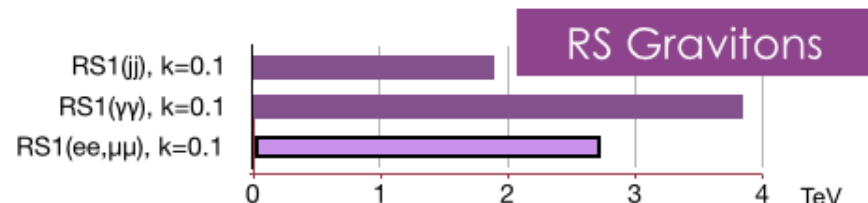
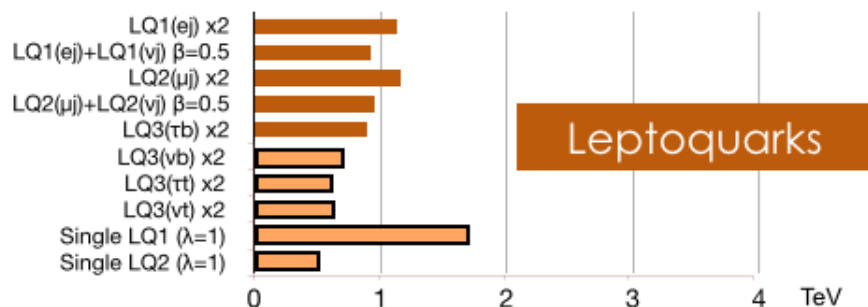


zoom

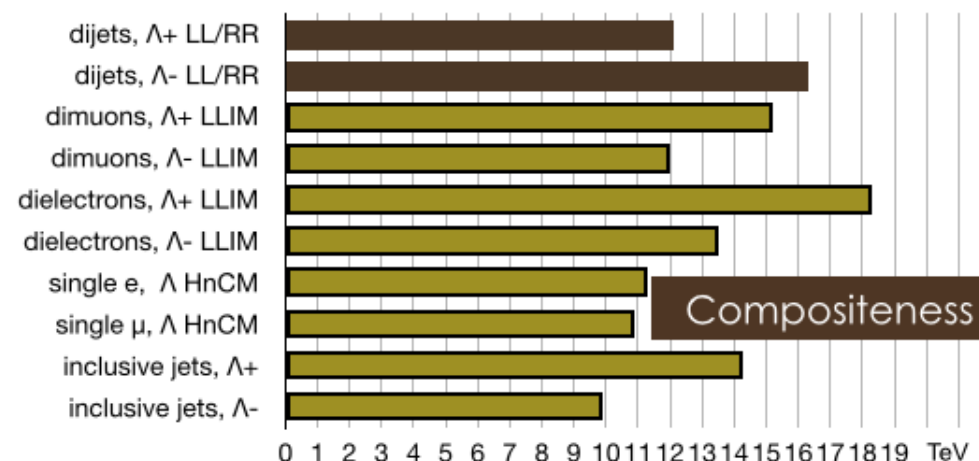
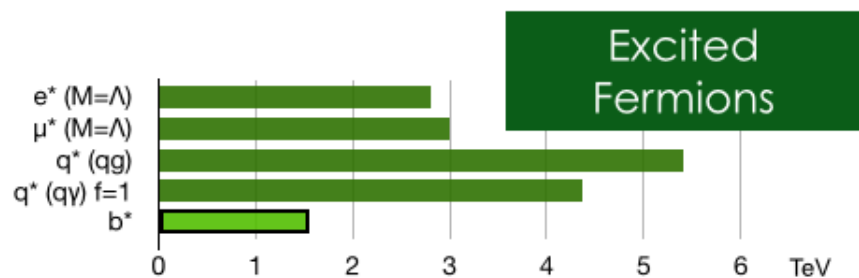
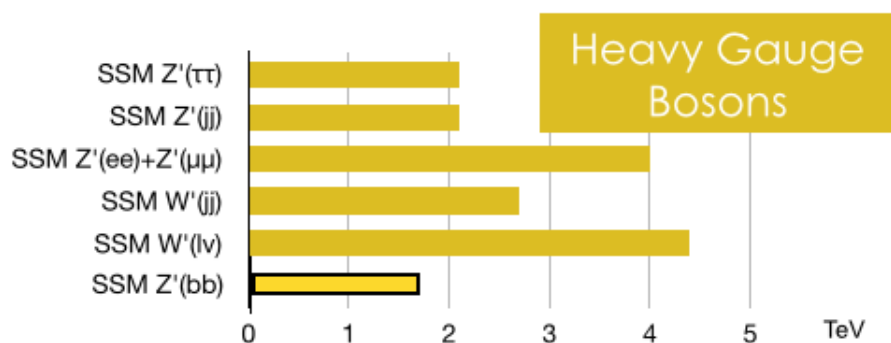


BSM exotics limits

13 TeV 8 TeV



CMS Preliminary

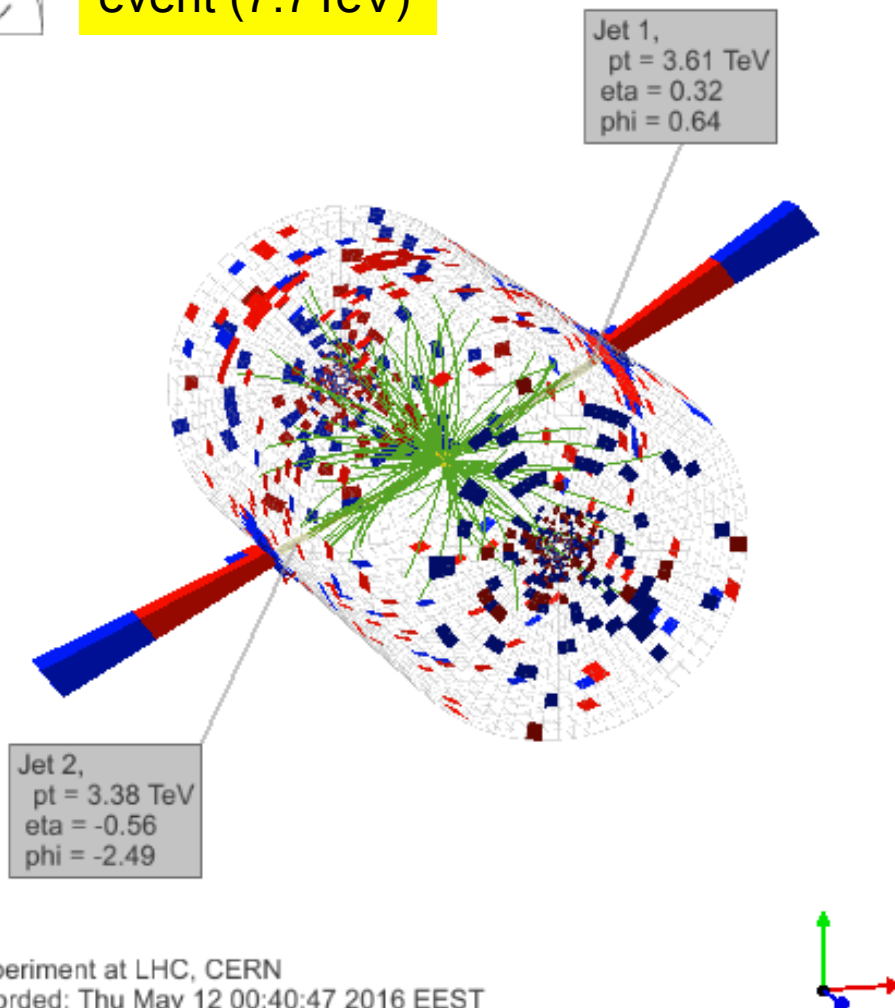


Dijet resonances

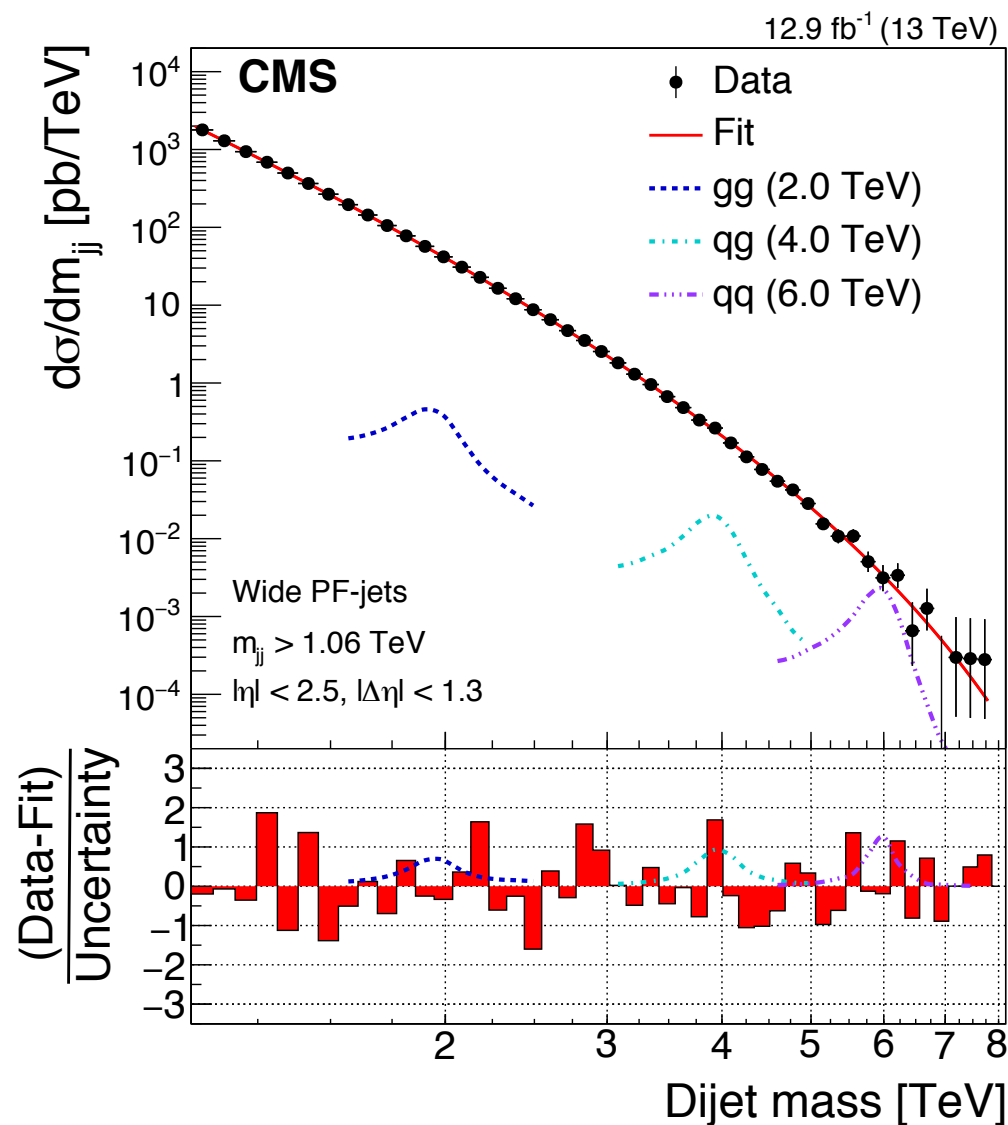
CMS-EXO-16-032
11-Nov-2016



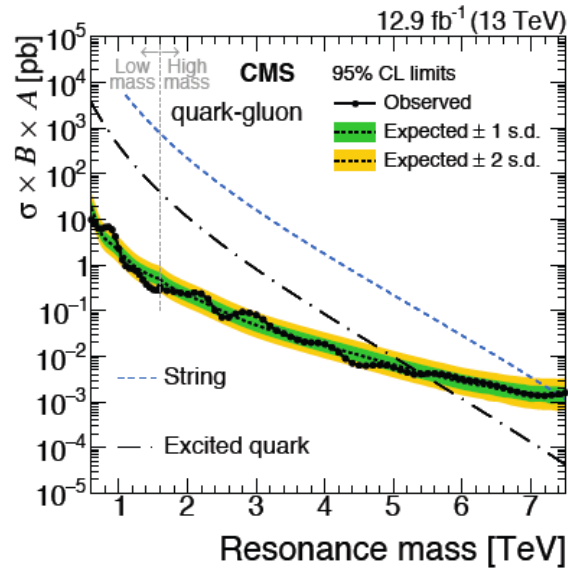
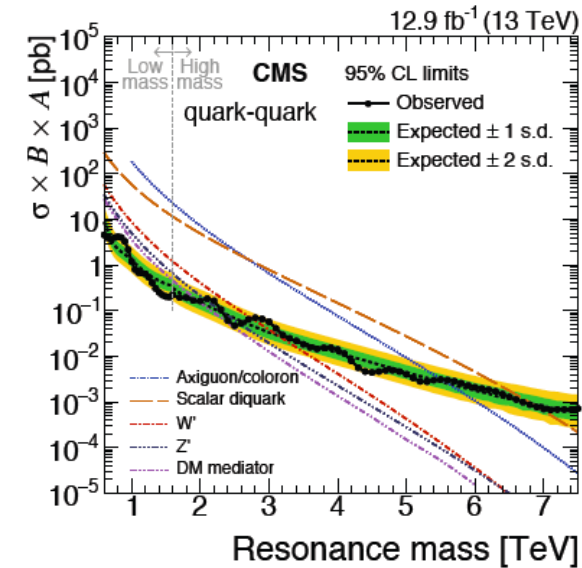
Highest m_{jj}
event (7.7 TeV)



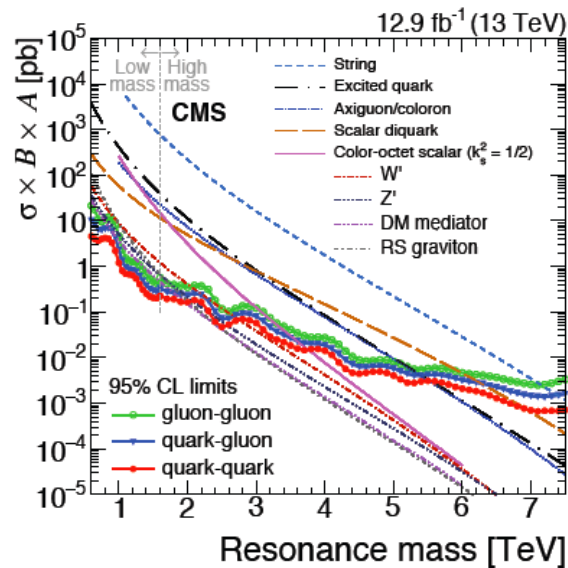
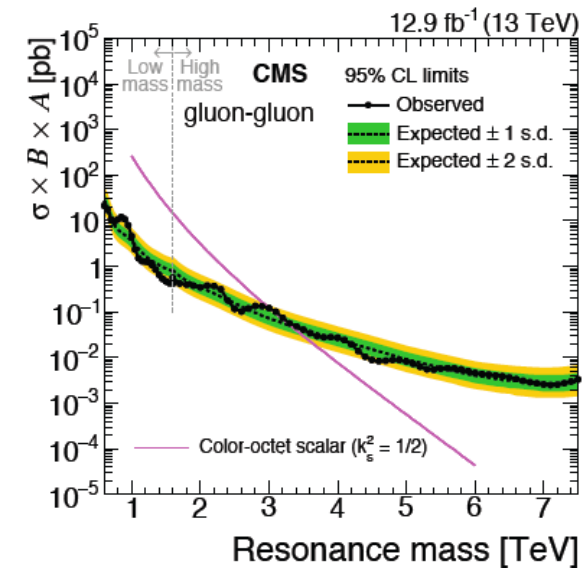
CMS Experiment at LHC, CERN
Data recorded: Thu May 12 00:40:47 2016 EEST
Run/Event: 273158 / 238962455
Lumi section: 150
Dijet Mass: 7.7 TeV



Dijet resonances: new limits

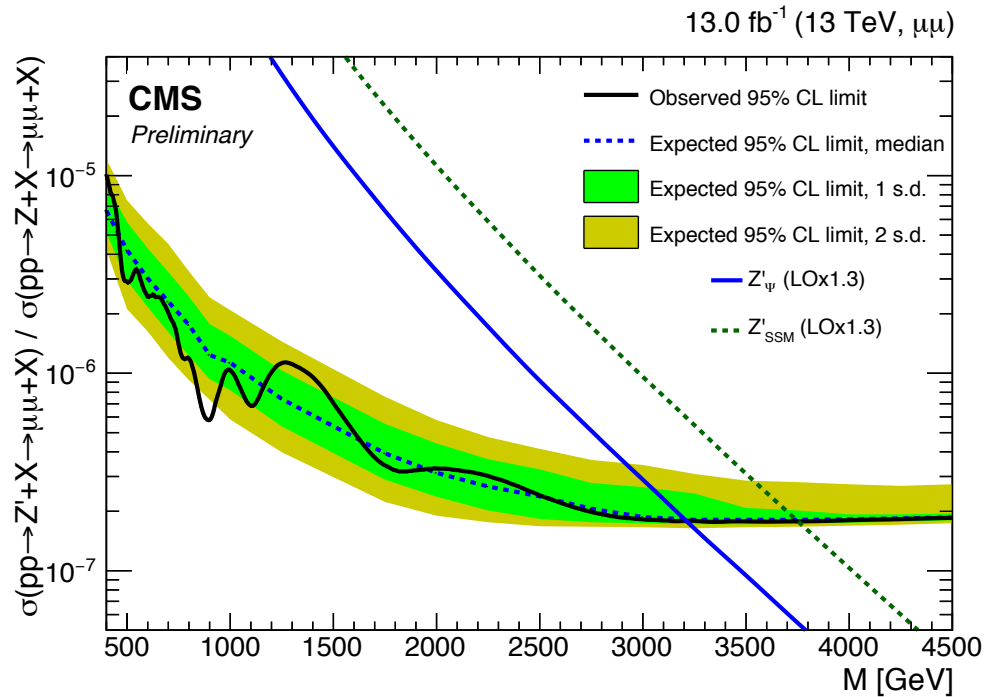
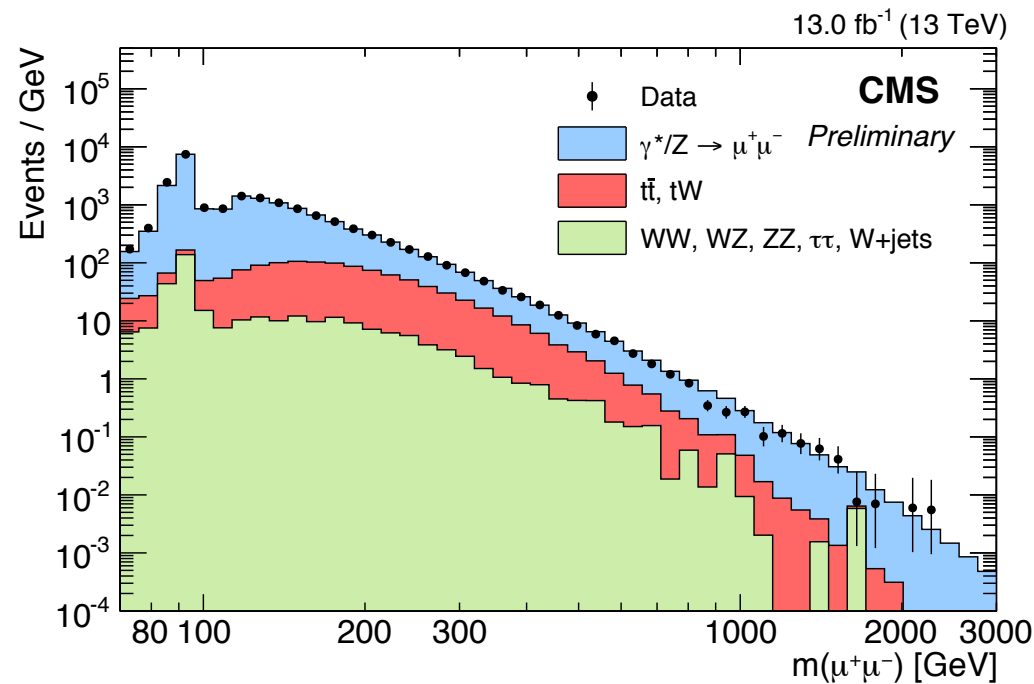
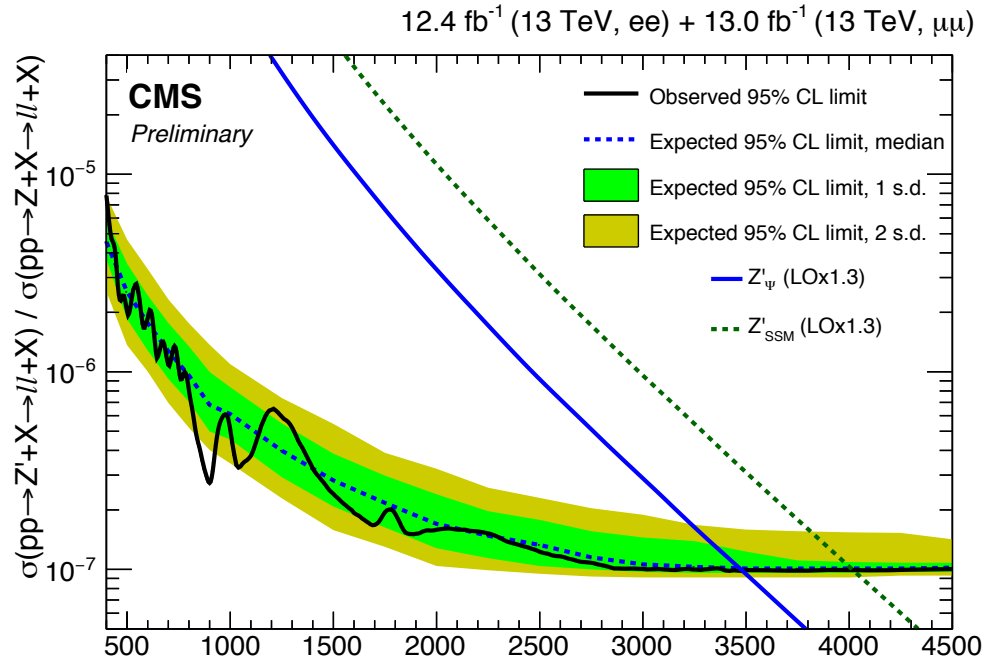
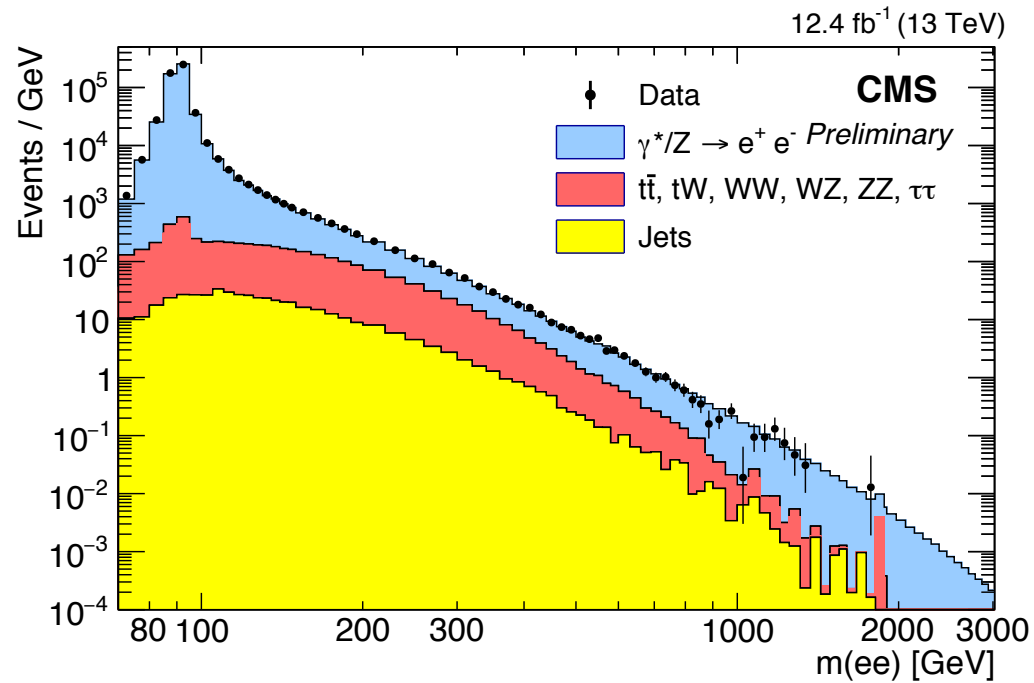


Model	Final state	Limit [TeV]	
		Obs.	Exp.
String	qg	7.4	7.4
Scalar diquark	qq	6.9	6.8
Axiguon/coloron	q $\bar{q}$	5.5	5.6
Excited quark	qg	5.4	5.4
Color-octet scalar ($k_s^2 = 1/2$)	gg	3.0	3.3
W'	q $\bar{q}$	2.7	3.1
Z'	q $\bar{q}$	2.1*	2.3
DM mediator ($m_{\text{DM}} = 1\text{GeV}$)	q $\bar{q}$	2.0	2.0
RS graviton	q $\bar{q}$, gg	1.9	1.8



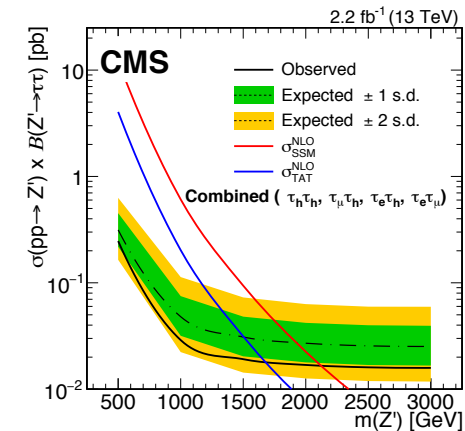
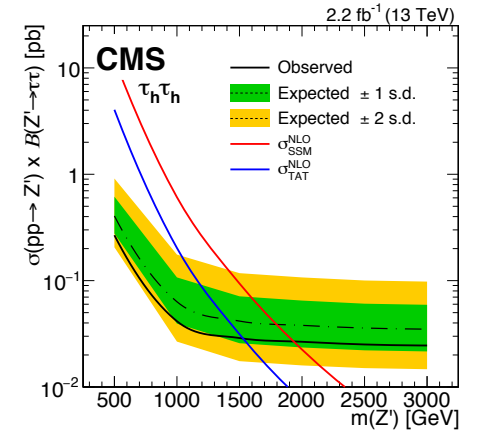
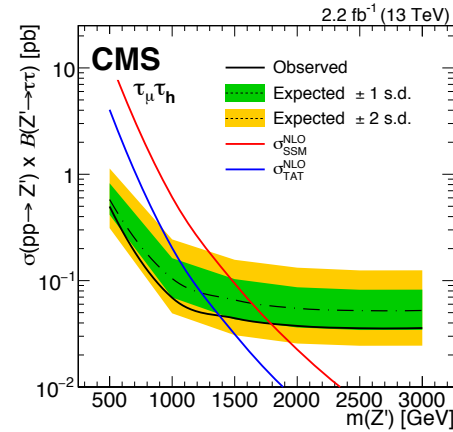
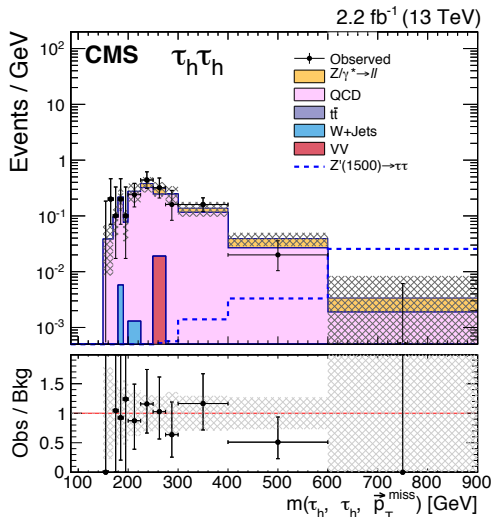
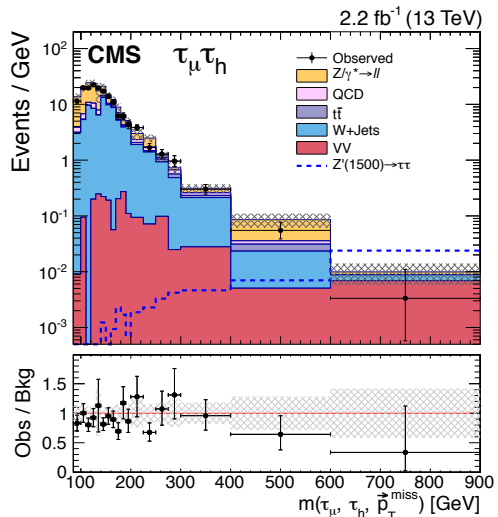
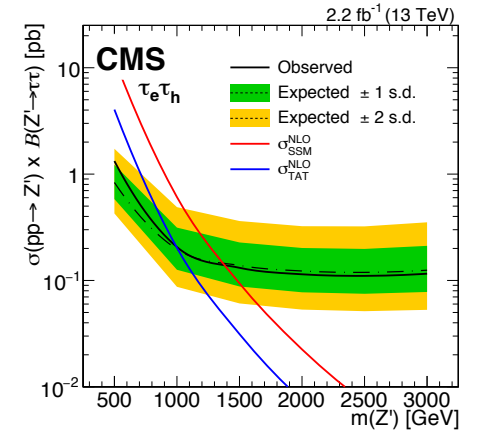
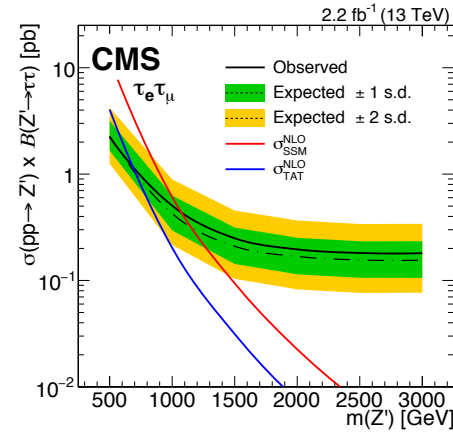
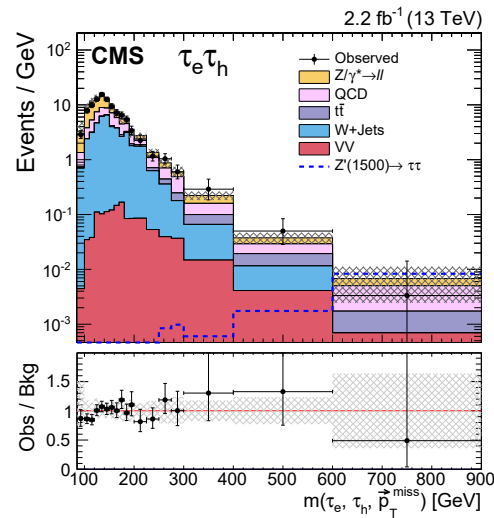
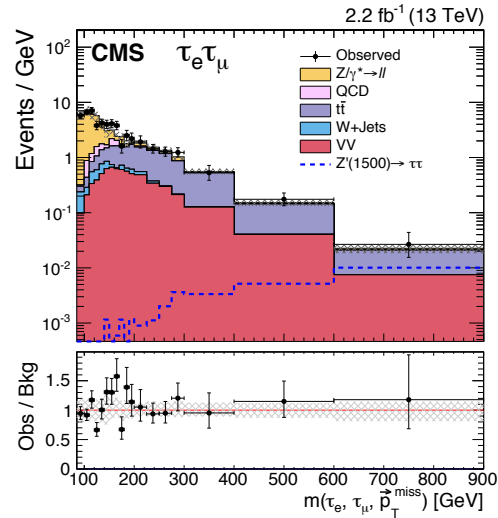
Dilepton resonances

CMS-PAS-EXO-16-031



tau-tau resonances

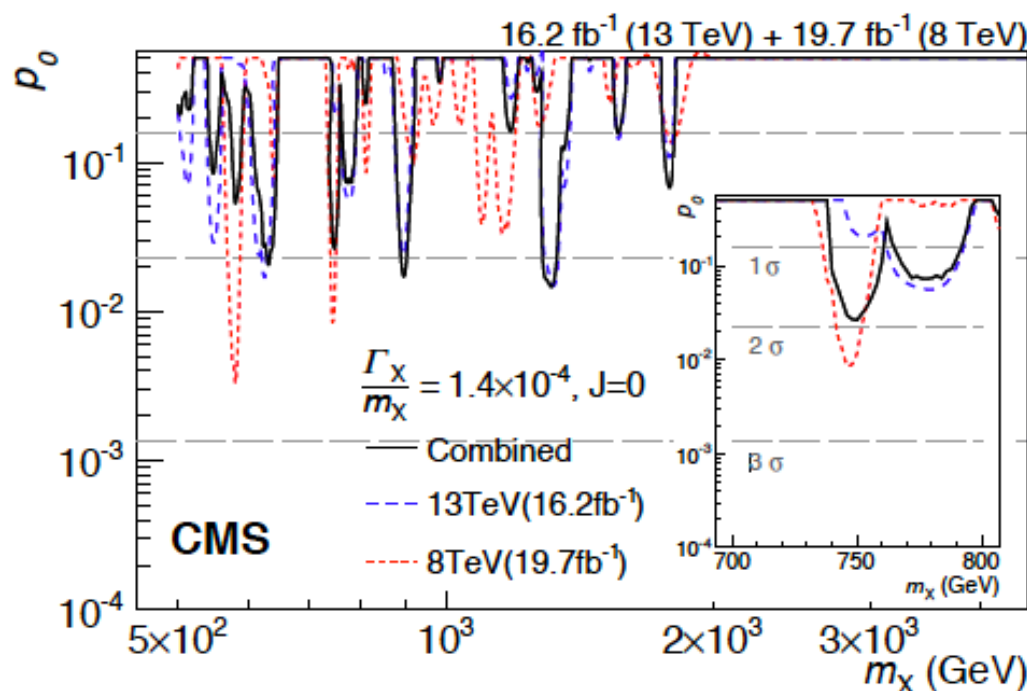
CMS-EXO-16-008
(20-Nov-2016)



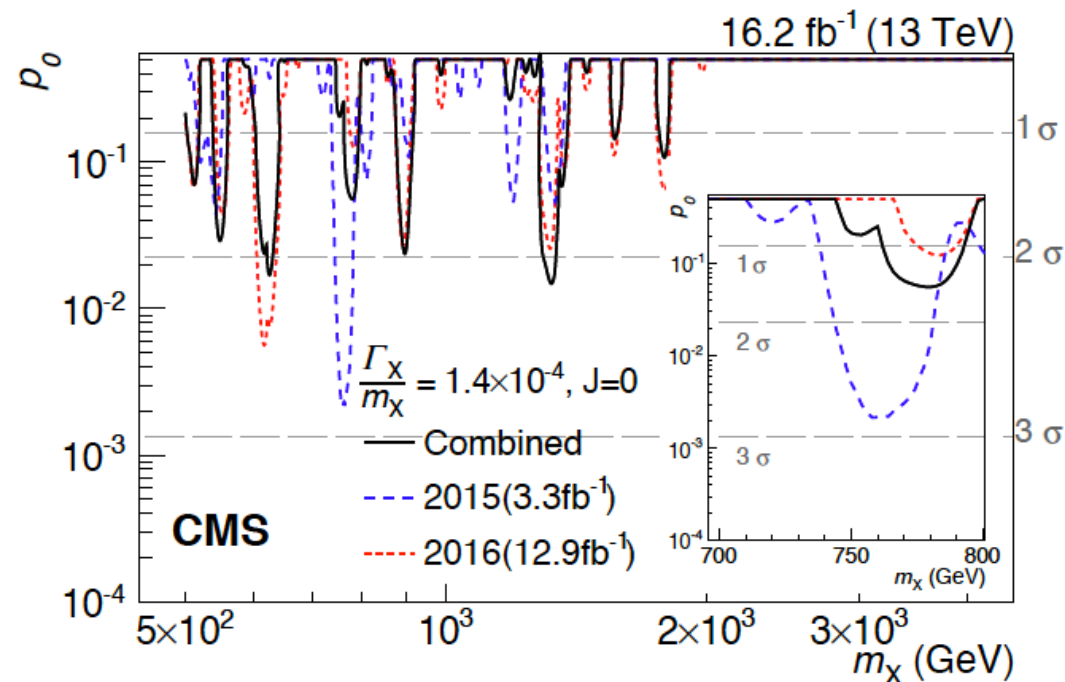
Diphoton Resonances

CMS PAS EXO-16-027

13TeV vs 8TeV

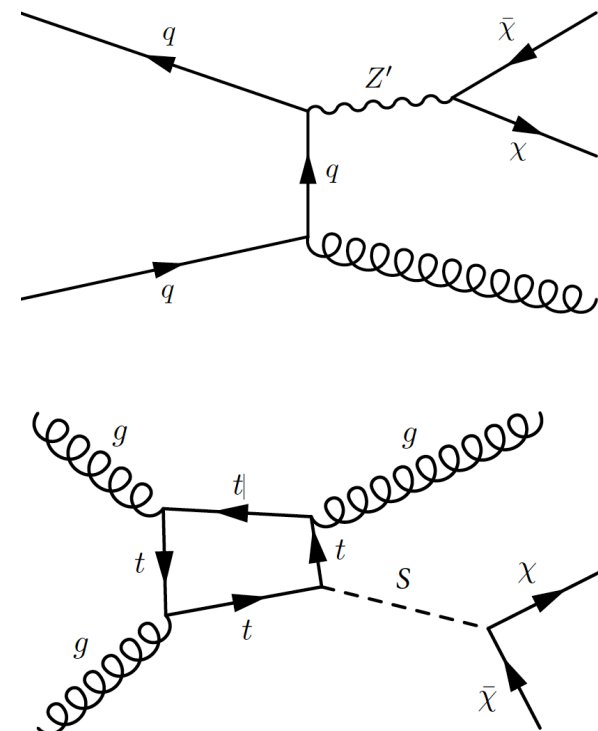
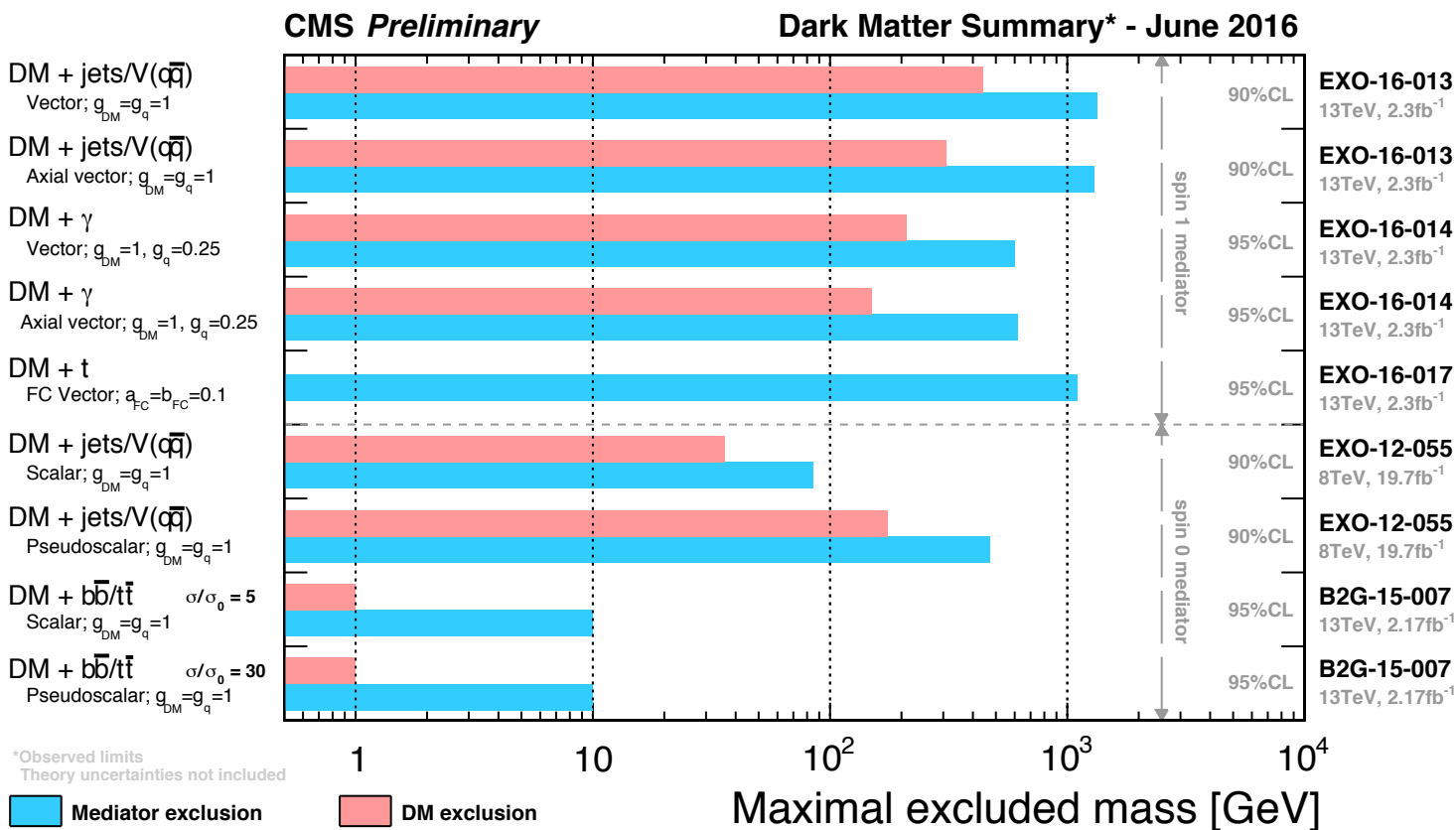


2015 vs 2016



2015 + 2016 + 8 TeV data give $<2\sigma$ significance at 750GeV.

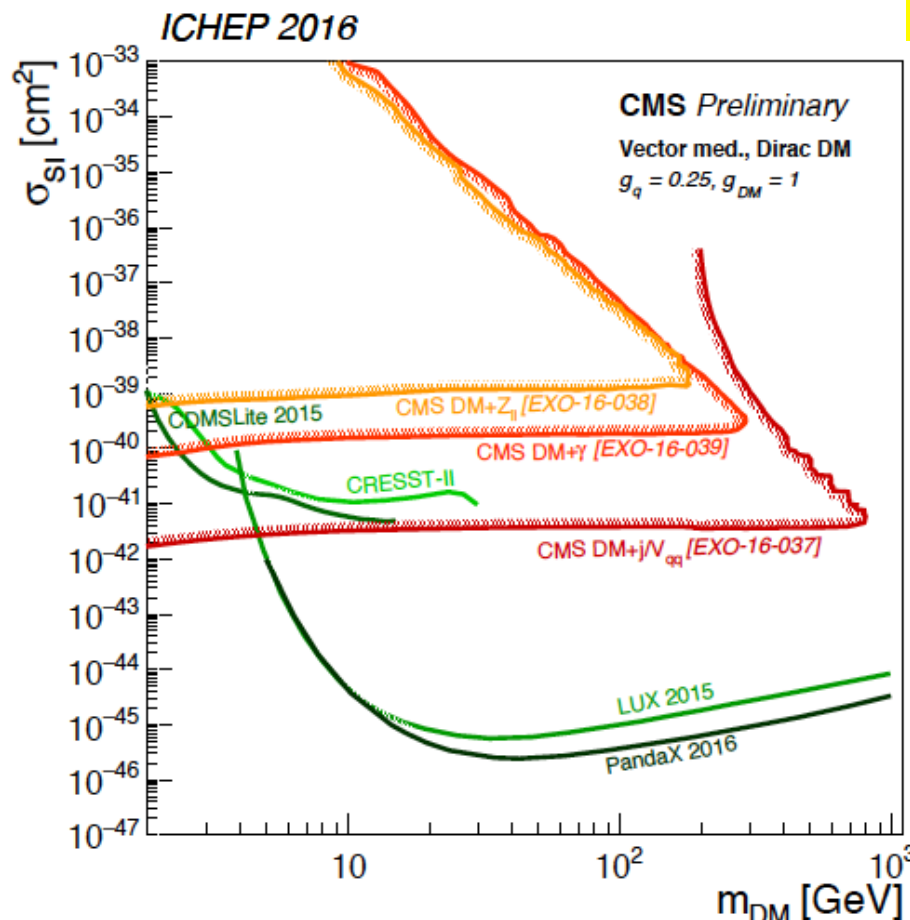
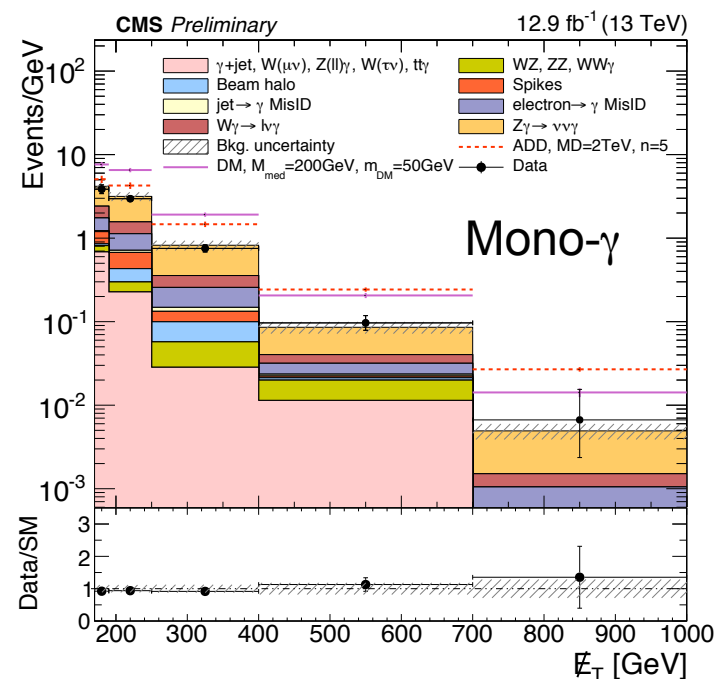
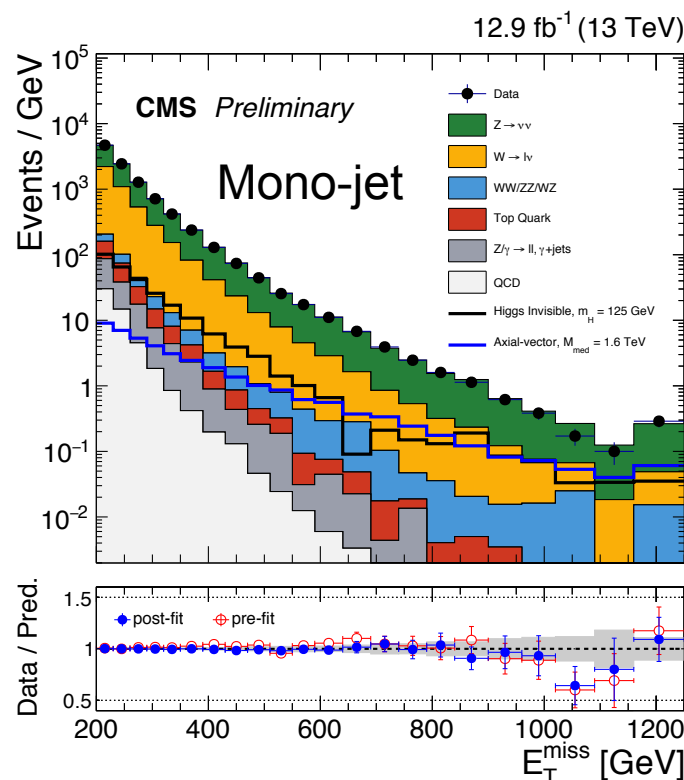
Dark Matter searches



Summary of Dark Matter searches using 13TeV data.

DM searches

CMS-DP-2016-057



CMS observed exclusion 90% CL

CMS DM+h ν_{qq} [EXO-16-037]
 CMS DM+ γ [EXO-16-039]
 CMS DM+Z $_{\ell}$ [EXO-16-038]

DD observed exclusion 90% CL

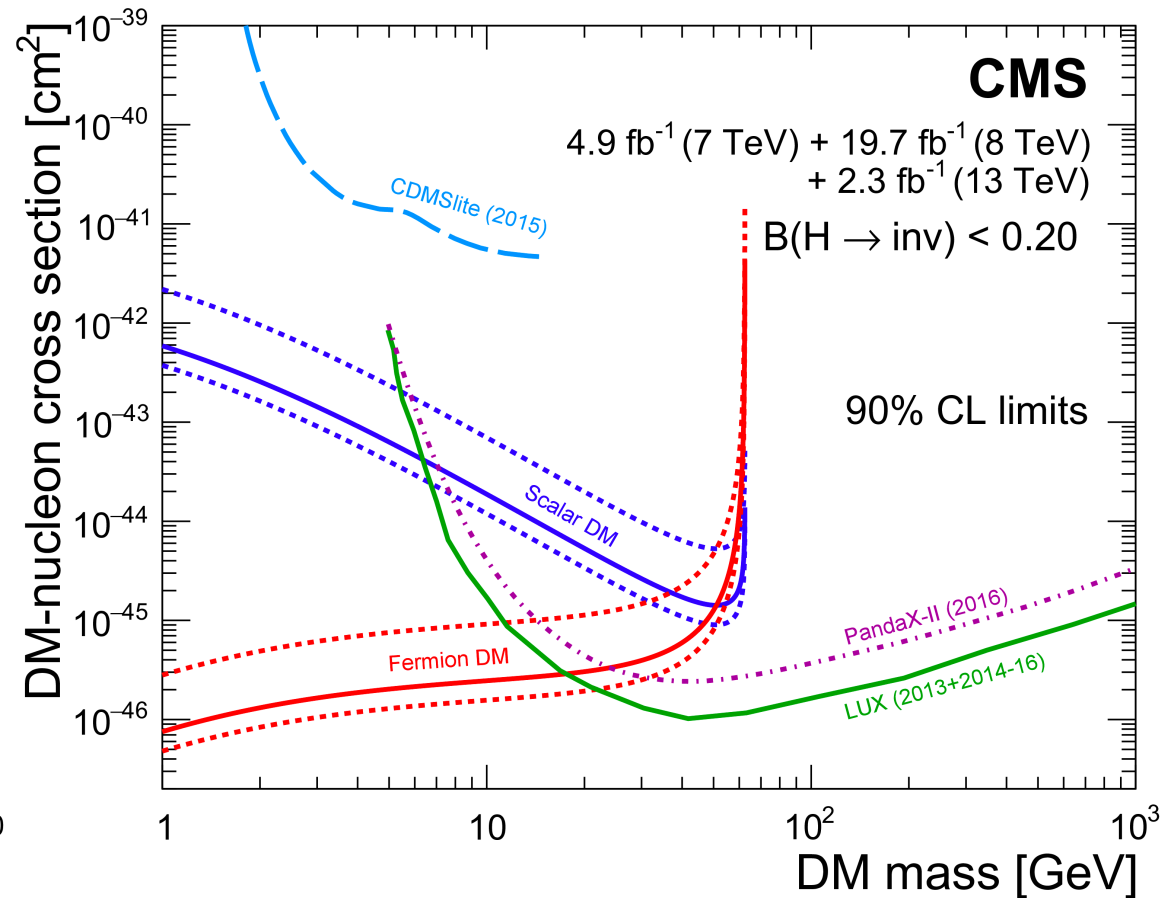
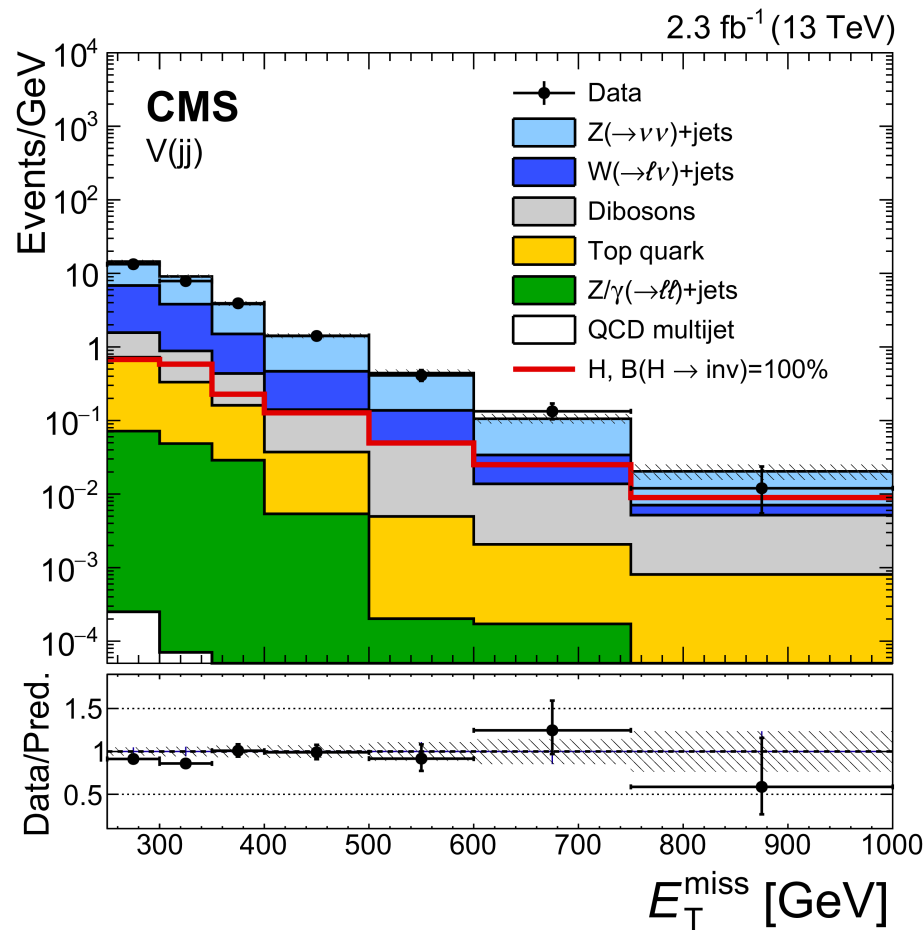
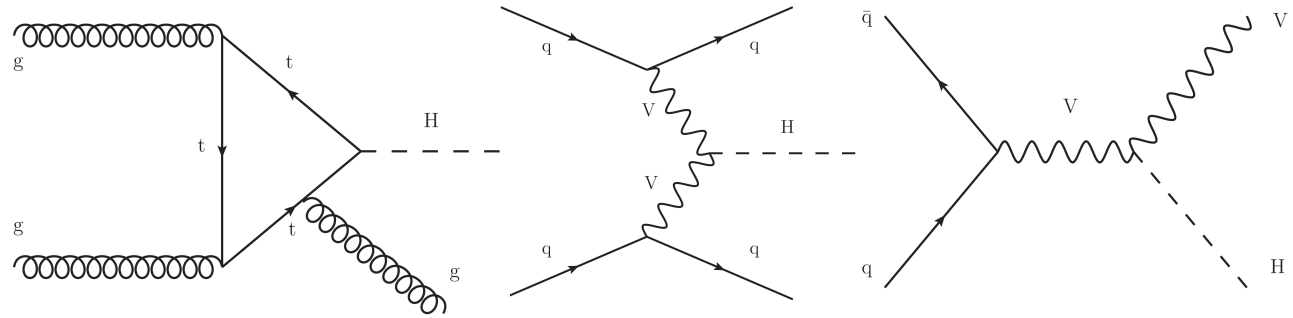
CRESST-II [arXiv:1509.01515]
 CDMSLite 2015 [arXiv:1509.02448]
 LUX 2015 [arXiv:1512.03506]
 PandaX 2016 [arXiv:1607.07400]

- DM masses excluded up to about 550 GeV
- Vector mediator exclusion to 1.95 TeV

EXO-16-037, 038, 039

Invisible Higgs decays

Observed (expected) upper
limit on invisible BR:
0.24 (0.23) at 95% C.L.



Summary

- We presented new results from CMS including 2016 data.
- CMS has performed a host of analyses, ranging from SM measurements, to a variety of BSM searches.
 - No significant deviations from the SM observed.
- Looking forward to results with full $> 35/\text{fb}$ of 13 TeV data, luminosity available thanks to the exceptional performance of LHC.
- Talk focused on a small subset of CMS results; full set of CMS results can be accessed at:

<http://cms-results.web.cern.ch/cmsresults/public-results/publications/>

Backup

Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.6
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
$H \rightarrow \tau\tau$	5.5	5.0
$H \rightarrow bb$	2.6	3.7

- Combination of ATLAS and CMS measurements leads to a higher than 5 sigma observation of the VBF production process and the $H \rightarrow \tau\tau$ decay channel.

Higgs Decay Channels

Decay mode	Branching fraction [%]
$H \rightarrow bb$	57.5 ± 1.9
$H \rightarrow WW$	21.6 ± 0.9
$H \rightarrow gg$	8.56 ± 0.86
$H \rightarrow \tau\tau$	6.30 ± 0.36
$H \rightarrow cc$	2.90 ± 0.35
$H \rightarrow ZZ$	2.67 ± 0.11
$H \rightarrow \gamma\gamma$	0.228 ± 0.011
$H \rightarrow Z\gamma$	0.155 ± 0.014
$H \rightarrow \mu\mu$	0.022 ± 0.001

$H \rightarrow gg, cc, Z\gamma$ not included in the measurement but their contribution is included in the total width.

Strengths/Couplings

Signal Strengths

for a specific process $i \rightarrow H \rightarrow f$

$$\mu_i = \frac{\sigma_i}{(\sigma_i)_{SM}} \quad \text{and} \quad \mu^f = \frac{B^f}{(B^f)_{SM}}$$

$$\mu_i^f = \mu_i \cdot \mu^f$$

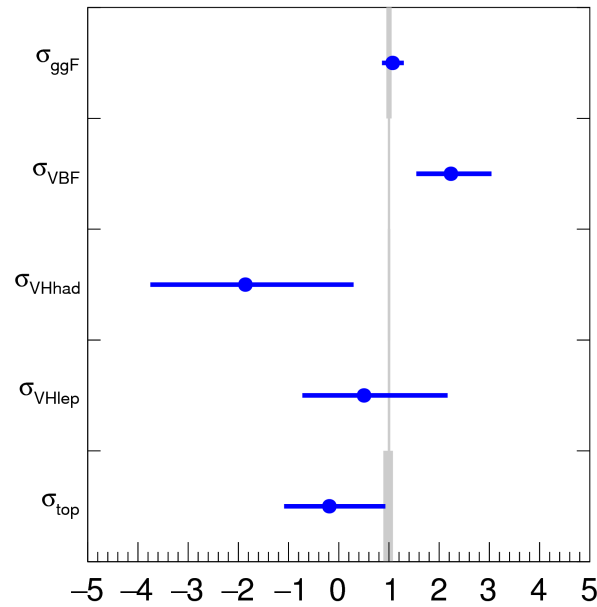
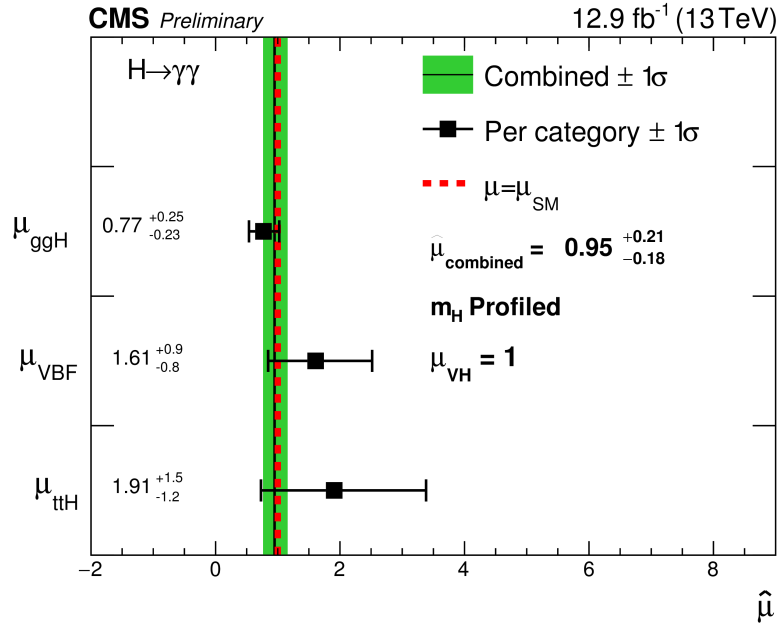
Coupling Modifiers

$$\kappa_j^2 = \sigma_j / \sigma_j^{SM} \quad \text{or} \quad \kappa_j^2 = \Gamma^j / \Gamma_{SM}^j$$

Run-2 2016 μ 's

ATLAS Preliminary $m_H=125.09$ GeV
 $\sqrt{s}=13$ TeV, $13.3 \text{ fb}^{-1} (\gamma\gamma)$, $14.8 \text{ fb}^{-1} (ZZ)$

● Observed 68% CL ■ SM Prediction

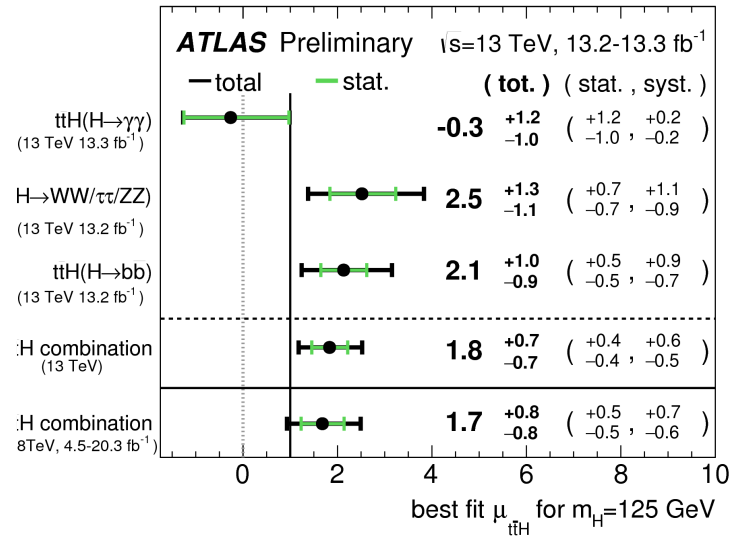
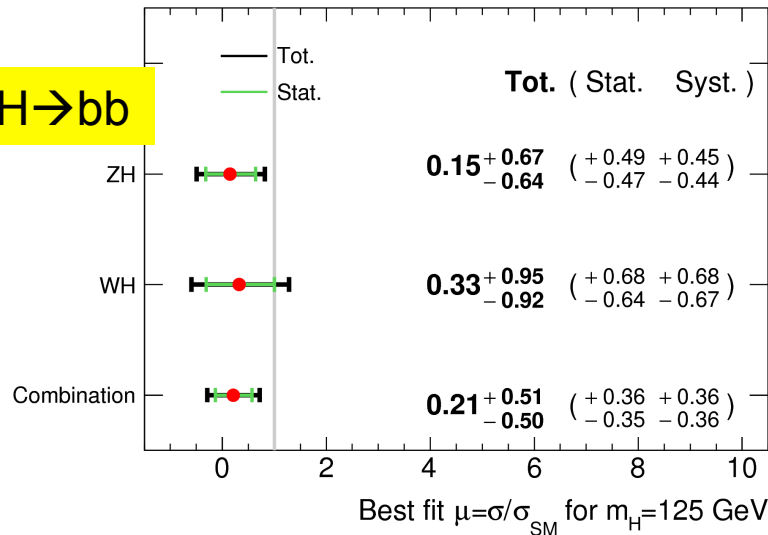


ATLAS-CONF-2016-091
 ATLAS-CONF-2016-081
 ATLAS-CONF-2016-068
 CMS-PAS-HIG-16-020

$H \rightarrow \gamma\gamma, H \rightarrow ZZ$

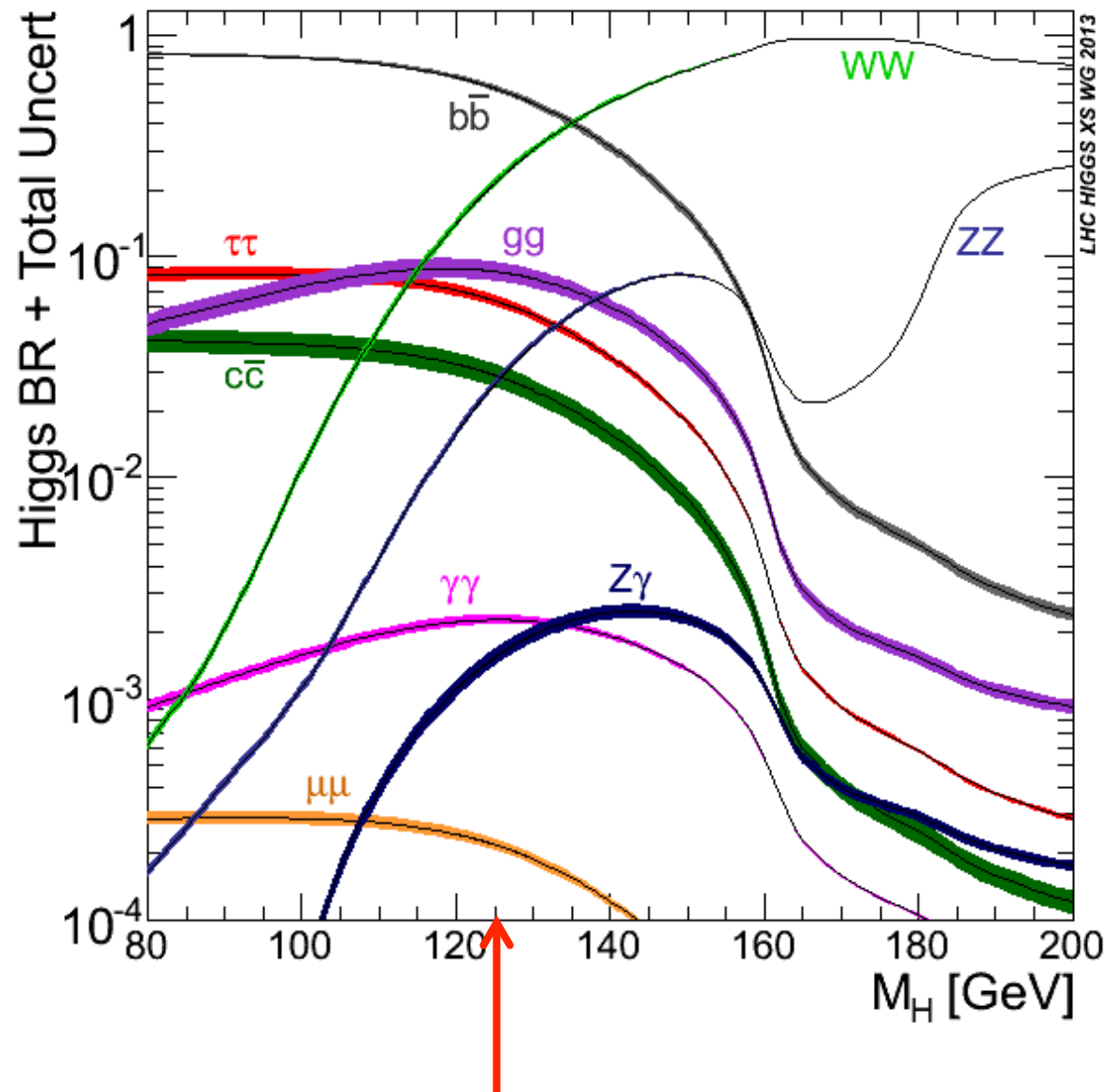
Parameter value norm. to SM value

ATLAS Preliminary $\sqrt{s}=13$ TeV, $\int \mathcal{L} dt = 13.2 \text{ fb}^{-1}$



ttH

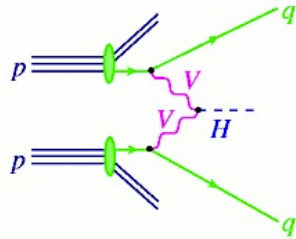
SM Higgs branching ratios



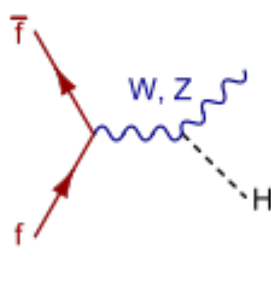
SM Higgs production modes

The main Higgs production mechanisms depend on V-H or top-H couplings

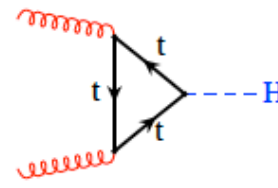
V-H
couplings



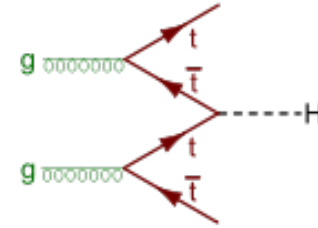
VBF



VH

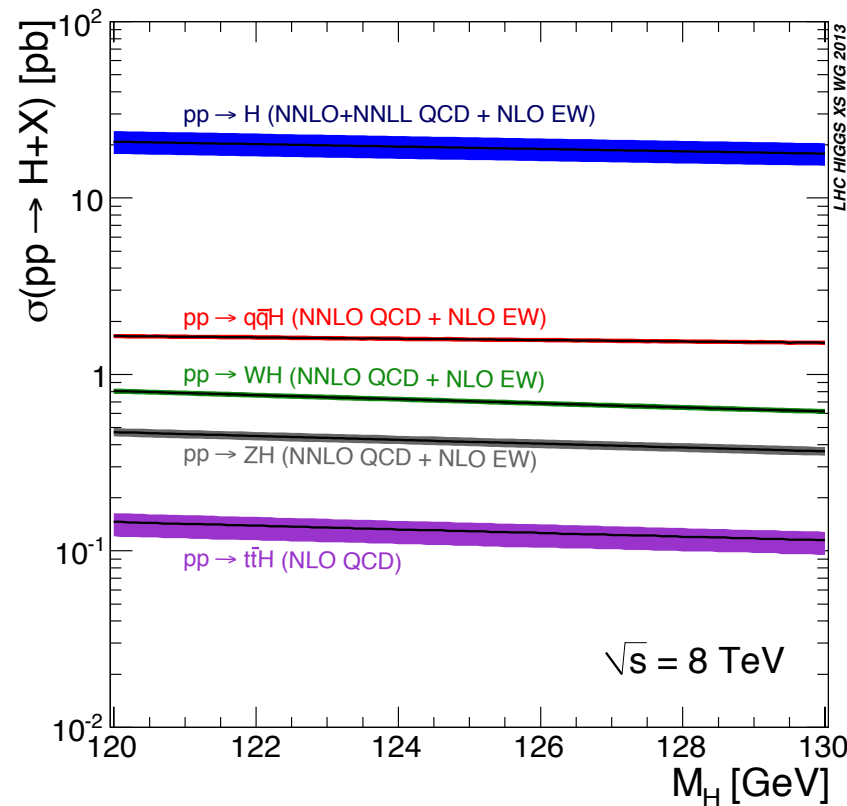


ggF



top-H
couplings

ttH



ggF $\sim 90\%$

VBF $\sim 7\text{-}8\%$

VH $\sim 3\text{-}4\%$

ttH $\sim 0.5\text{-}0.8\%$