Some Highlights of CMS Results

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中国科学院高能物理研究所
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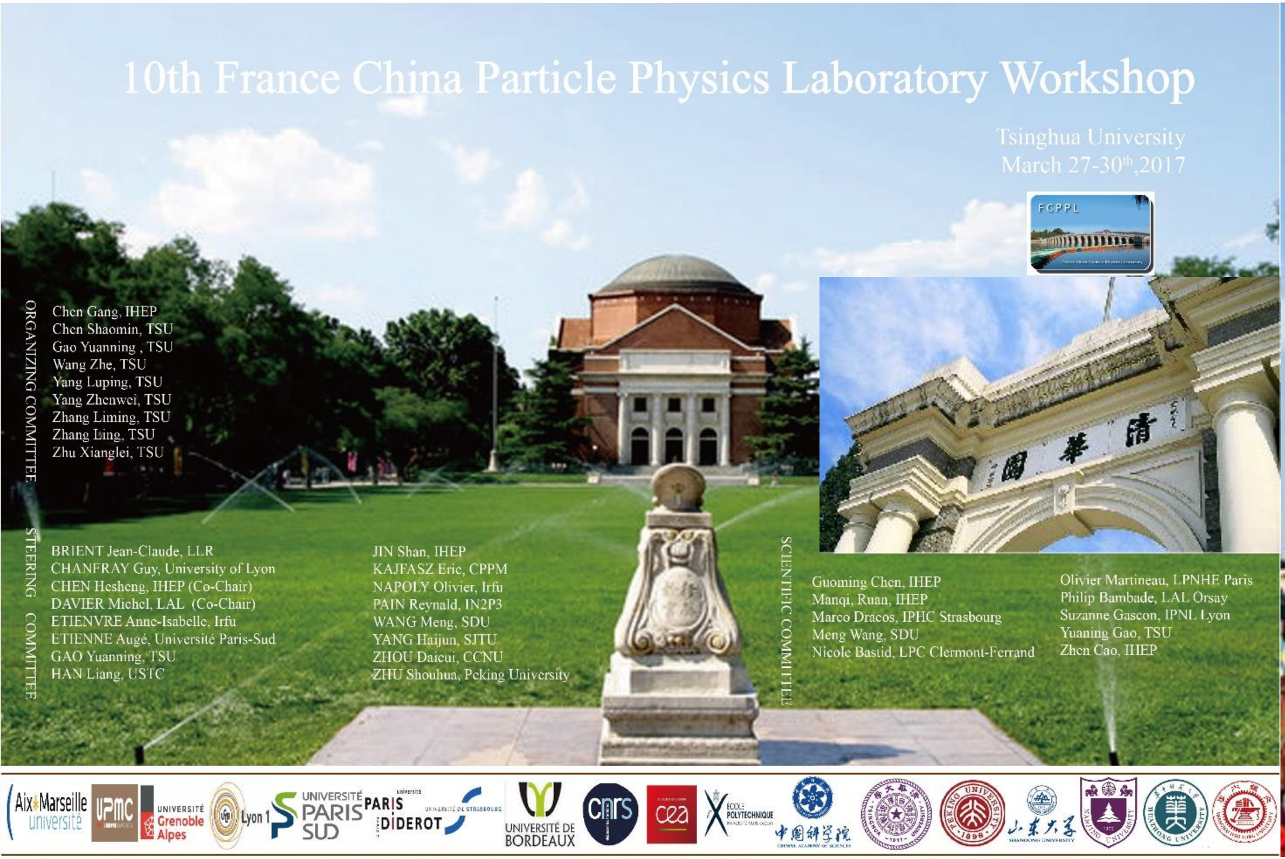
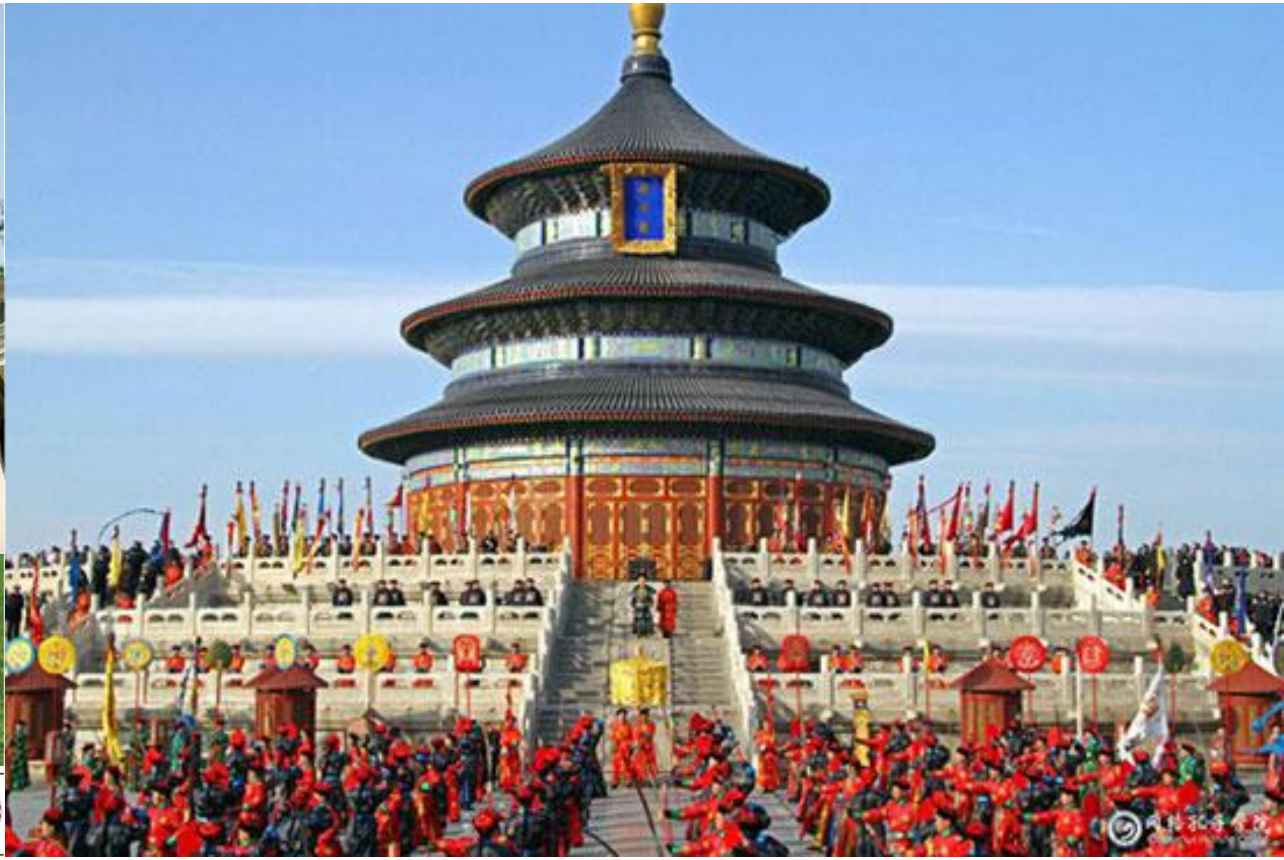




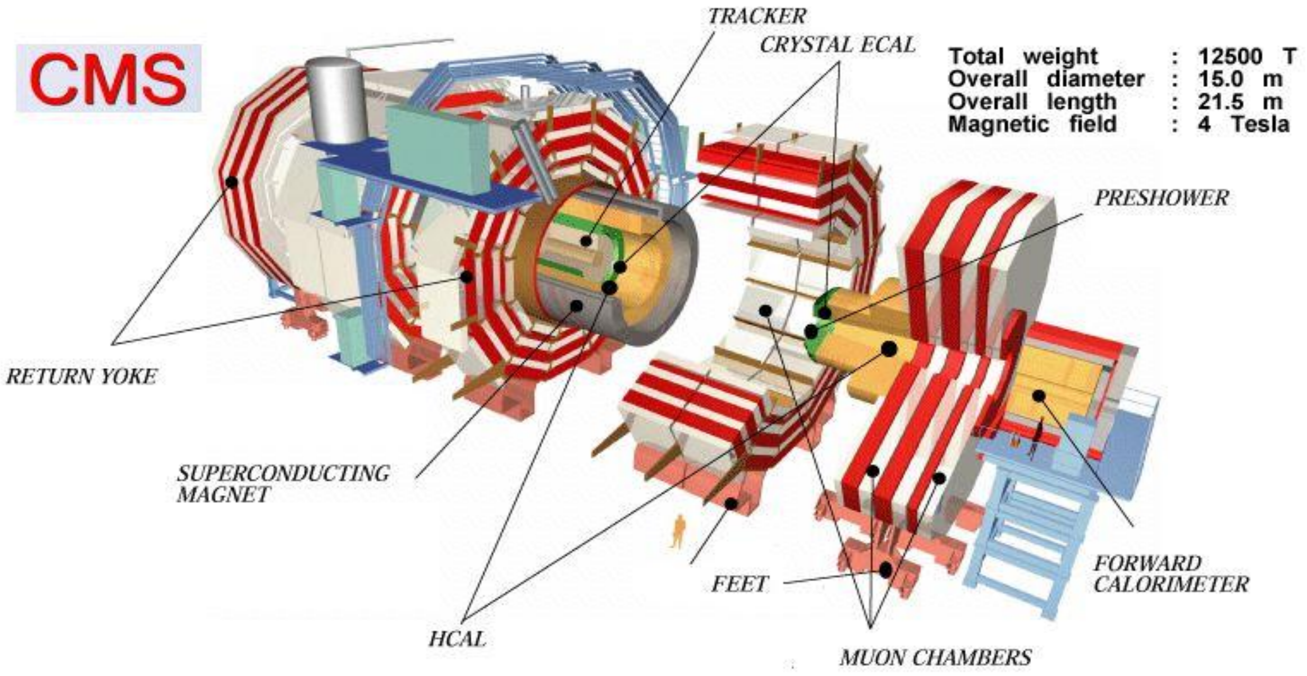
Outline

- CMS performance
- Some highlights from CMS
  - Higgs Physics
  - Standard Model Measurements
  - Beyond Standard Model Searches
- Summary

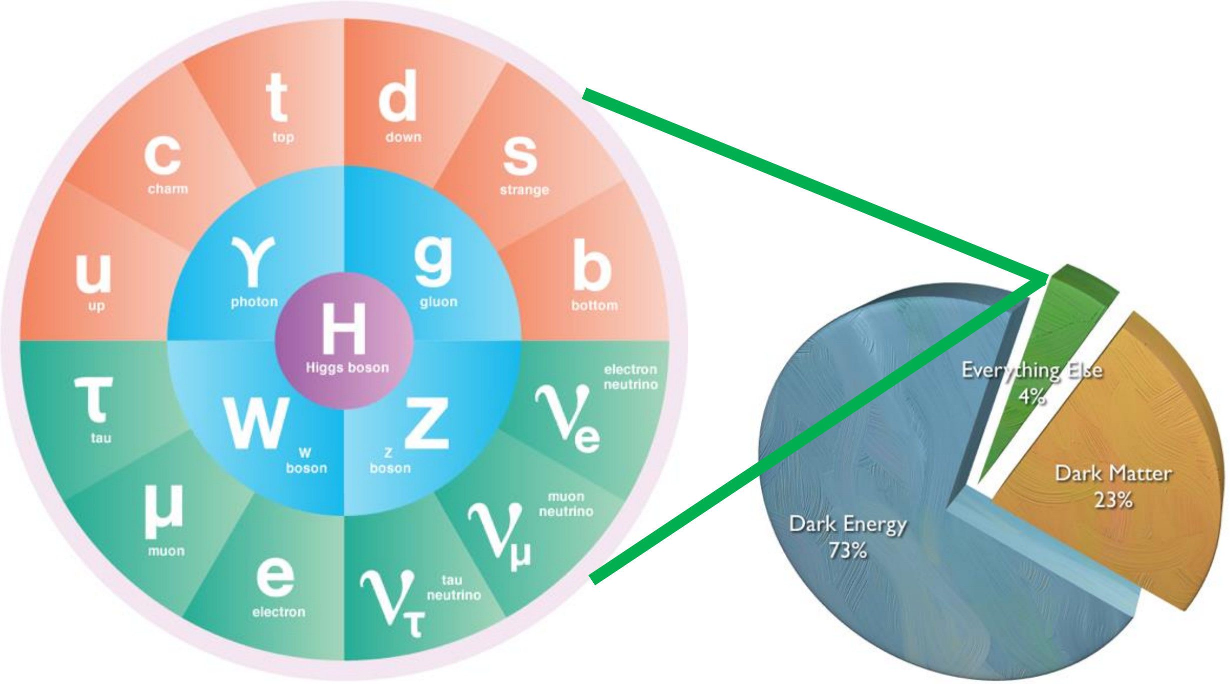
Apologize that can NOT include all the CMS recent results and can NOT tell the details of the analyses

Most results from ICHEP16 and Moriond17 after the 9^{th} FCPPL

CMS Collaboration and It’s Goals



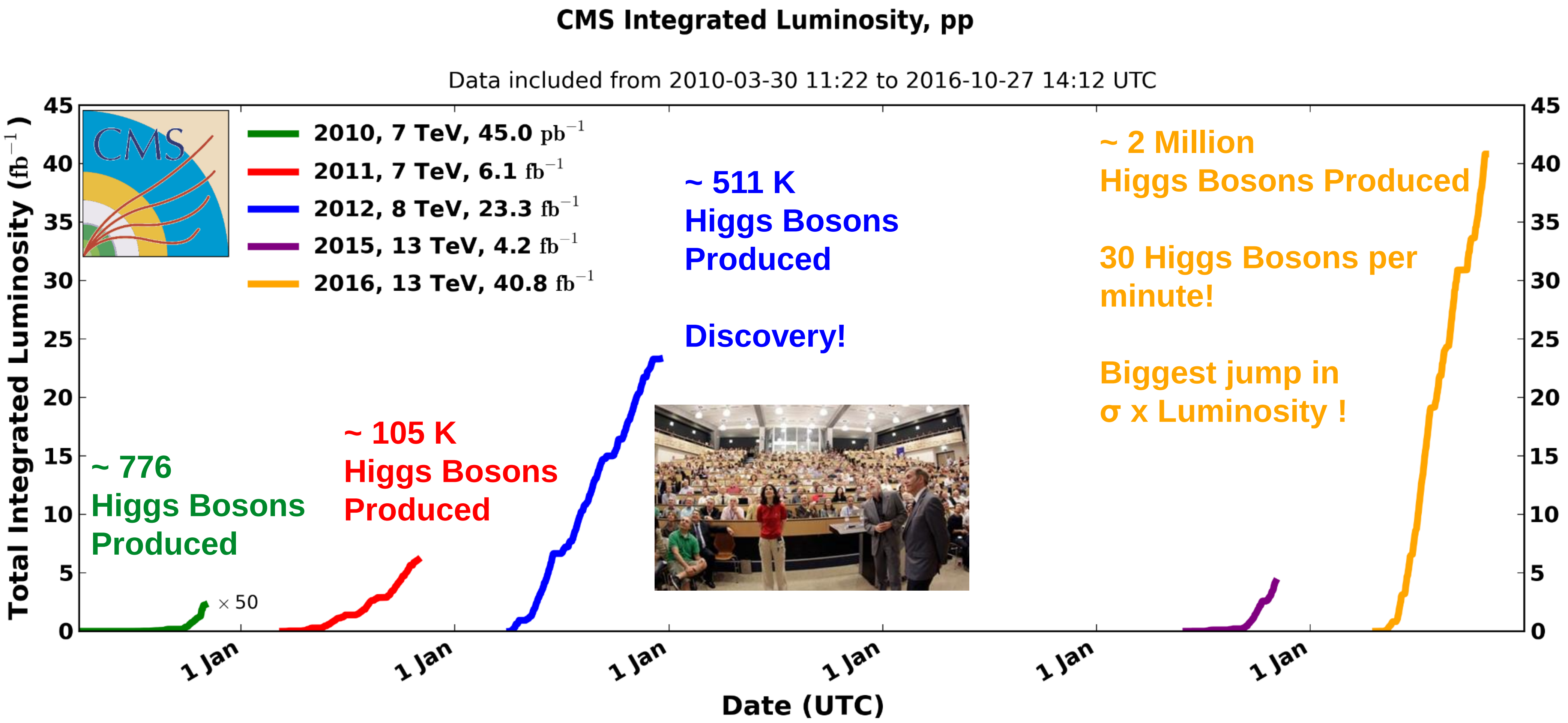
CMS experiment at LHC is an international **scientific collaboration**, involving **about 3500 scientists, engineers, and students** from **199 institutes in 46 countries**



Discovered the last Standard Model particle: **Higgs Boson**

but… there is **more than “just” the Higgs**

CMS Data Taking History



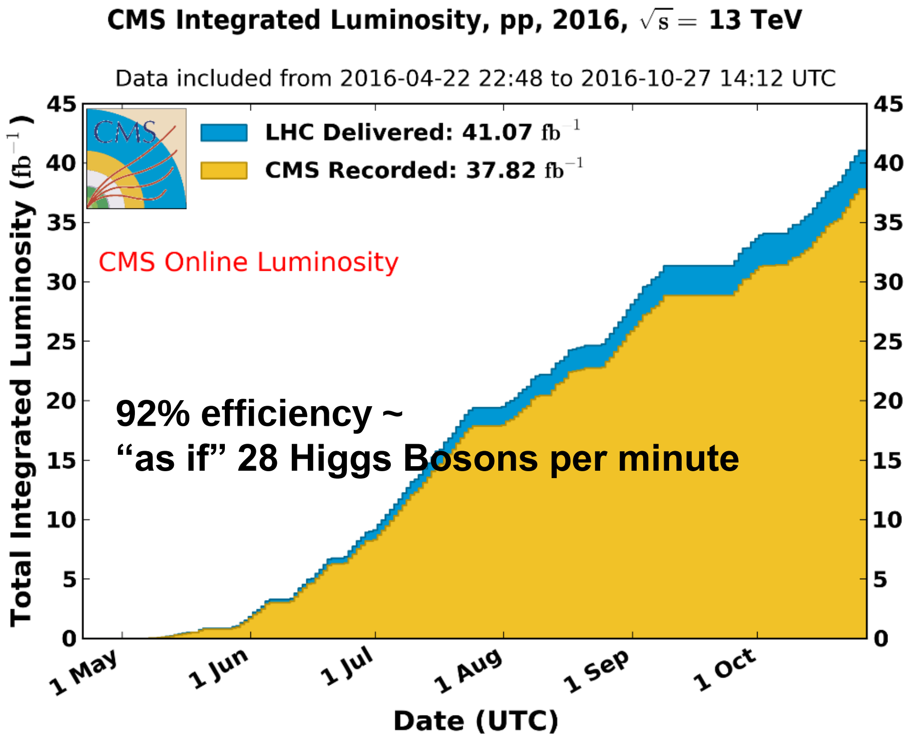
Run 1 **Run 2**

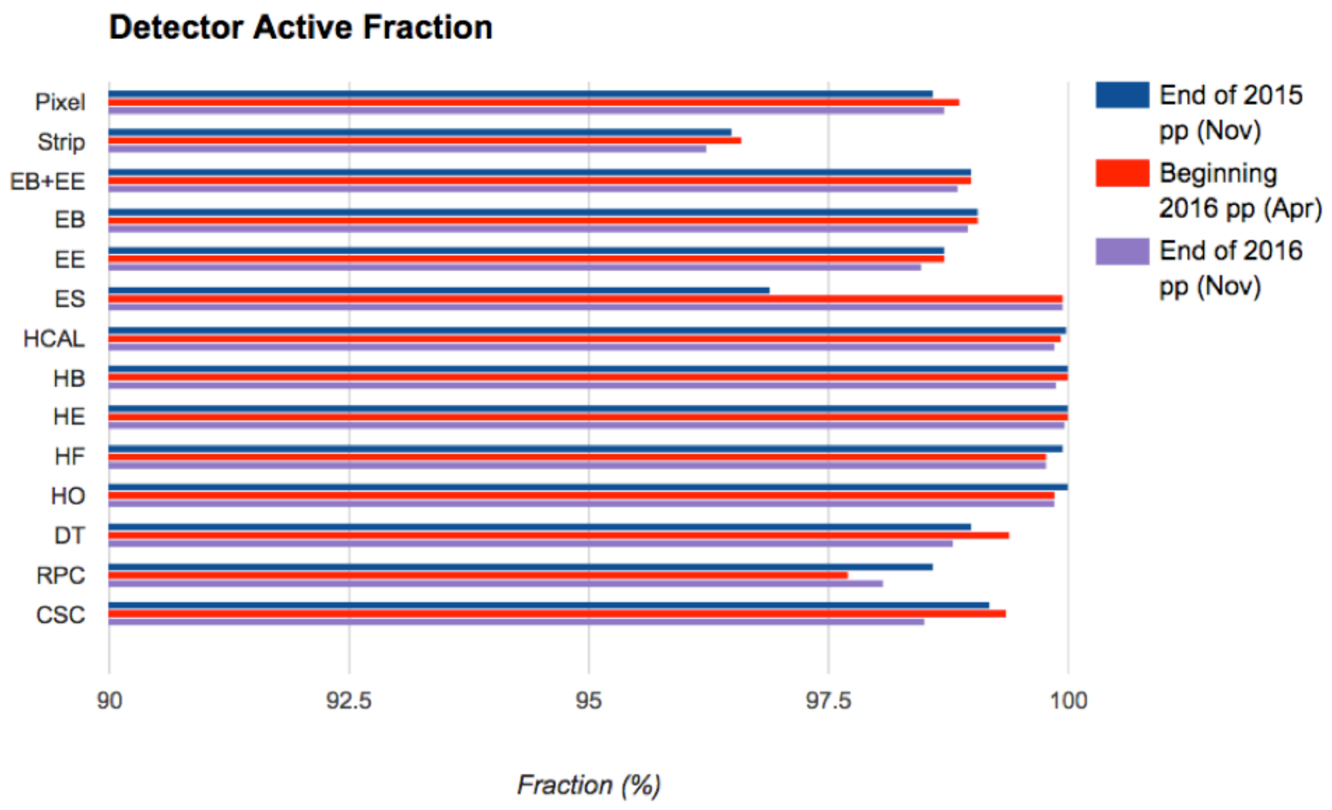
CMS Operations in Run 2

CMS in 2016 operated with high efficiency

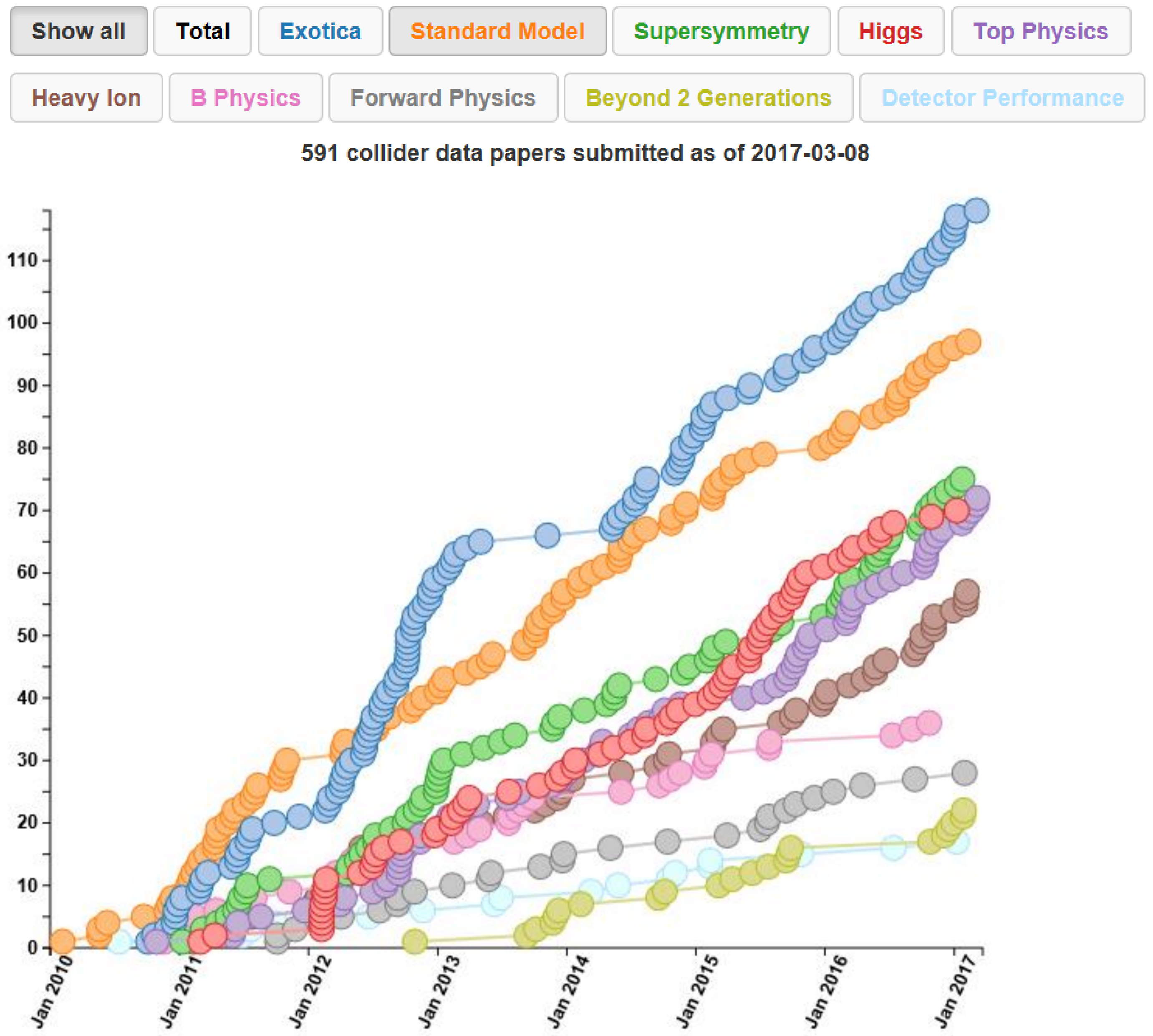
more than **96%** detector active

92% data taking efficiency



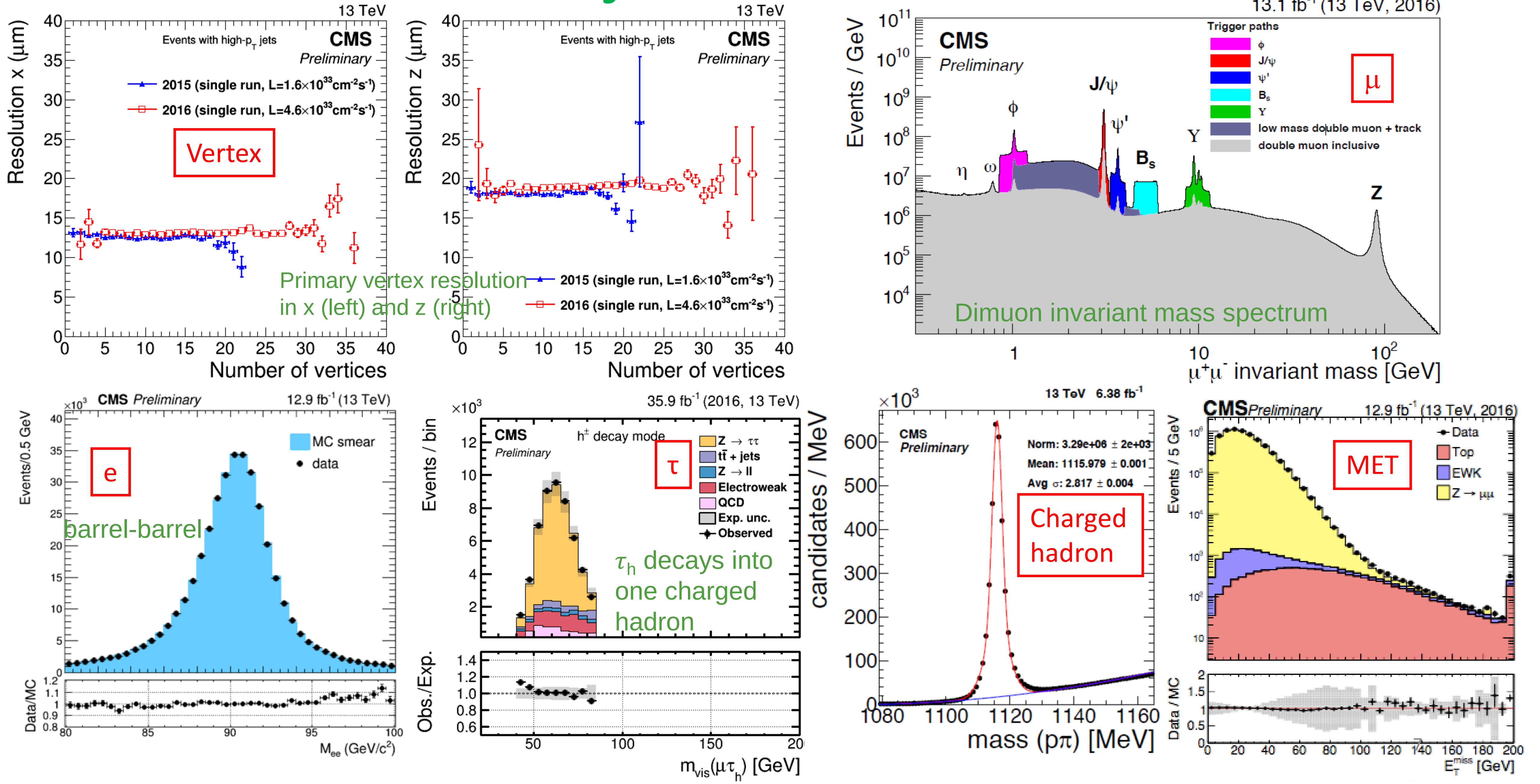


CMS physics results



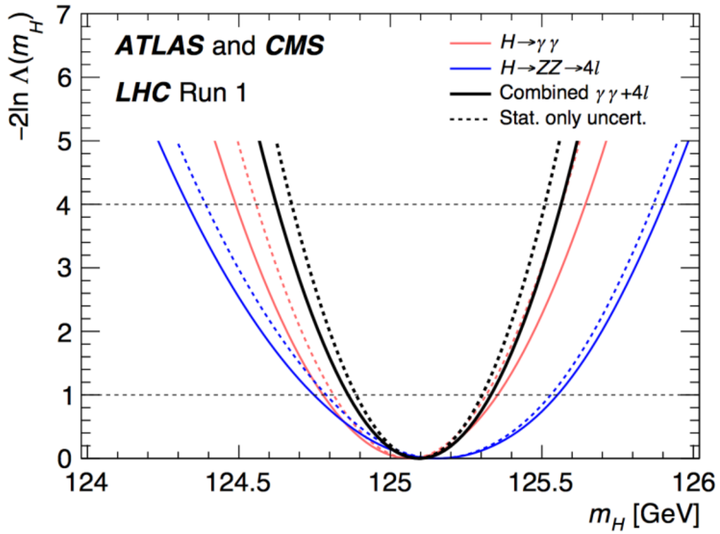
- Around 600 papers submitted/published
- ~200 public results already with Run2 data

CMS Object Reconstruction

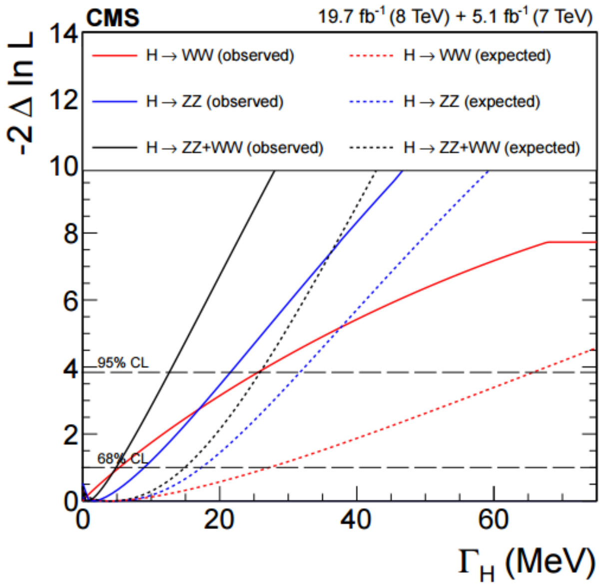


Higgs

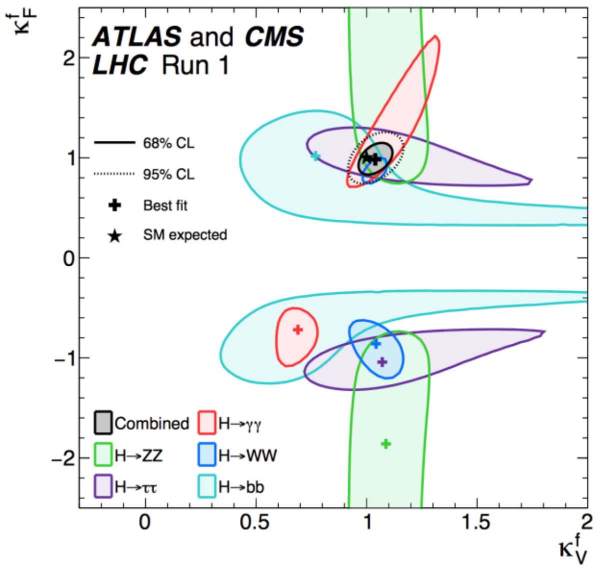
Brief Higgs Summary from Run-I



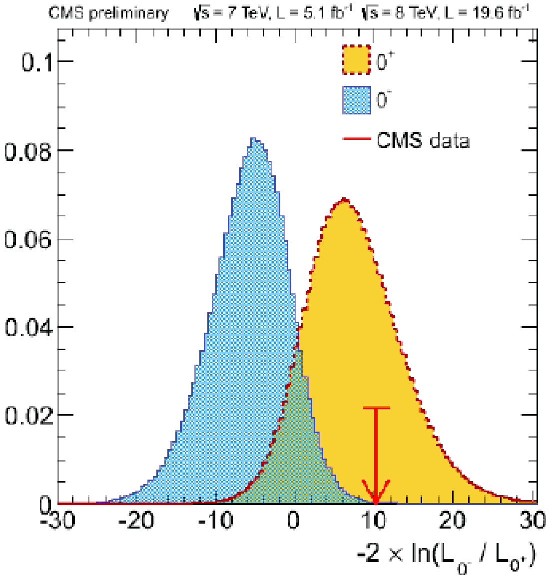
Higgs mass from ATLAS+CMS



Width < 13 MeV (95%CL)

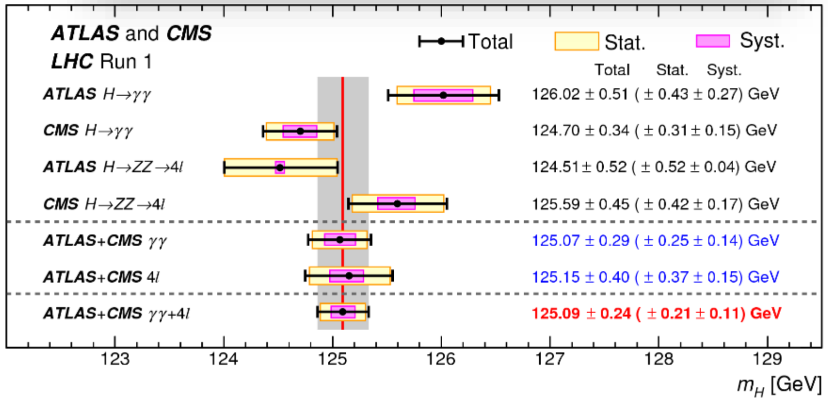


Couplings are within ~20% of the SM values



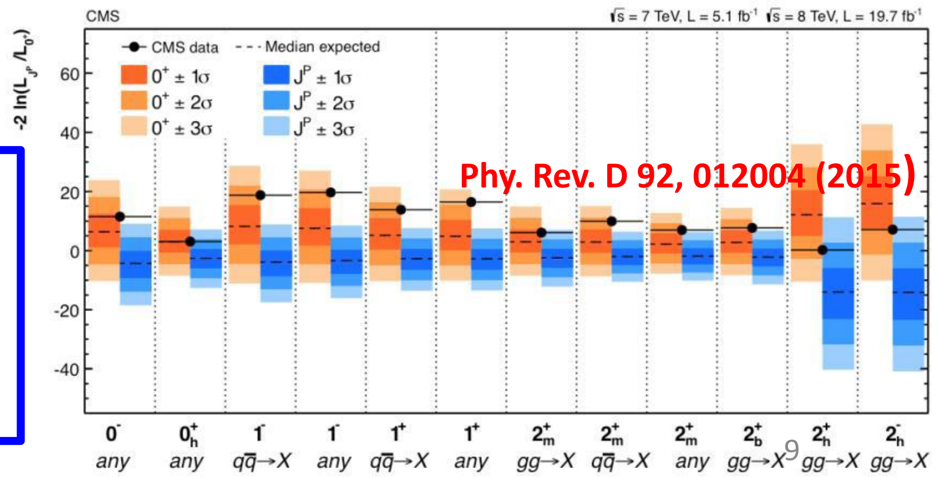
Spin: SM Higgs quantum numbers $0^{+(+)}$ preferred

125.09 ± 0.24 (± 0.21 ± 0.11) GeV



Phys. Rev. Letter 114, 191803(2015)

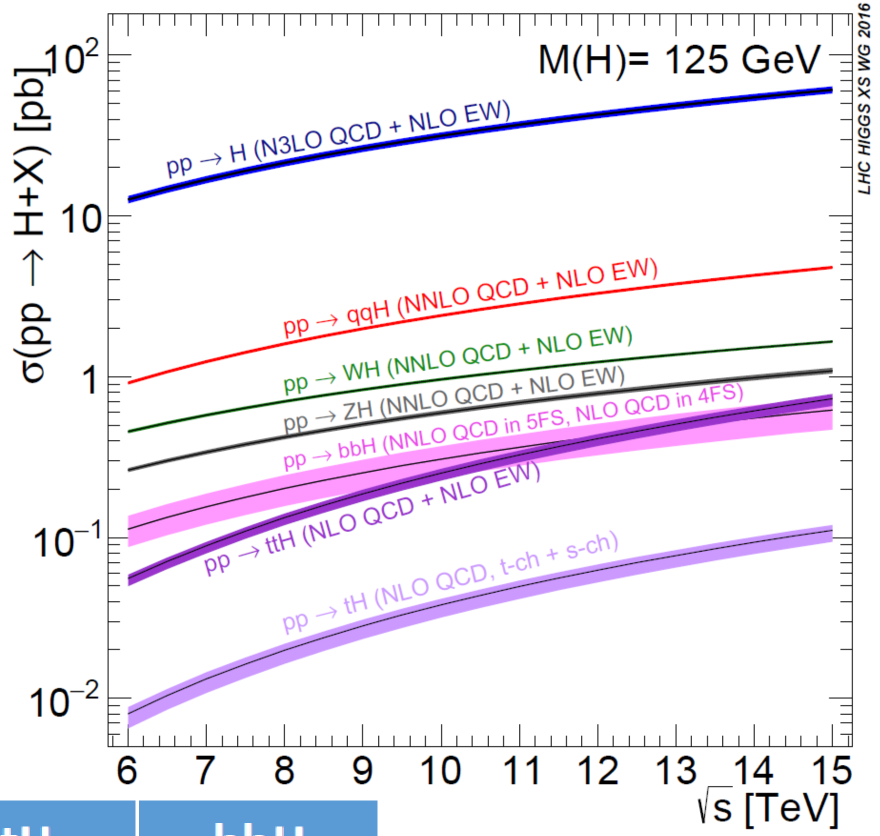
Many properties of the Higgs have been measured in Run I



Phy. Rev. D 92, 012004 (2015)

Higgs at LHC Run2 (13TeV)

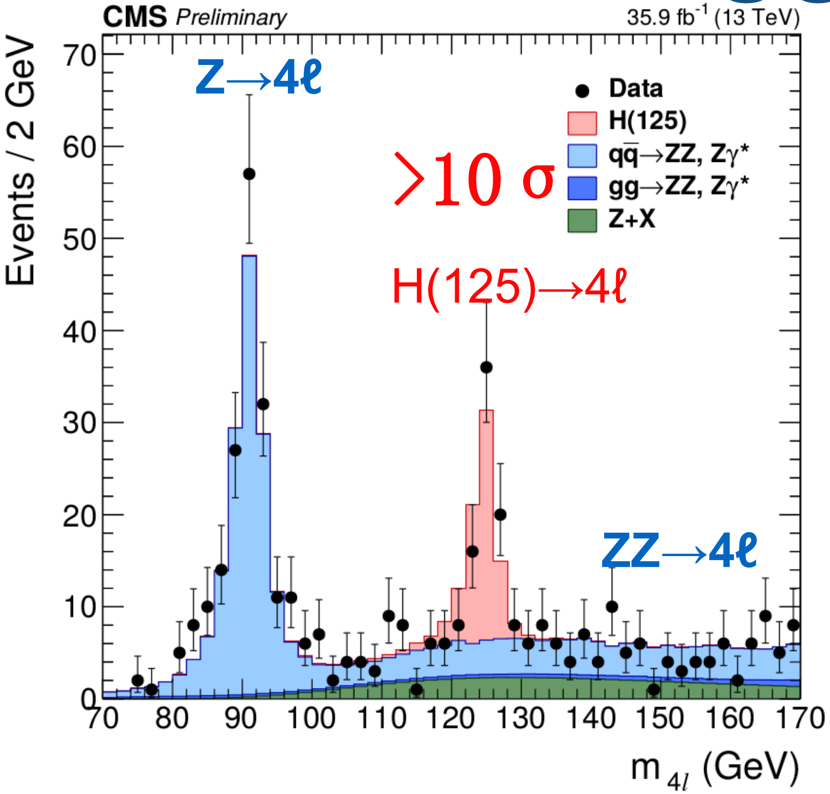
- Cross sections are increased by ~2.3 except for ttH 3.8 from 8 TeV to 13 TeV
- More than 100 fb^{-1} is expected in Run 2
  ~25 fb^{-1} in Run 1
- We expect 10 times more the BEH scalar events than Run 1
- Results with **12.9 - 35.9fb^{-1} data** are presented in the follows

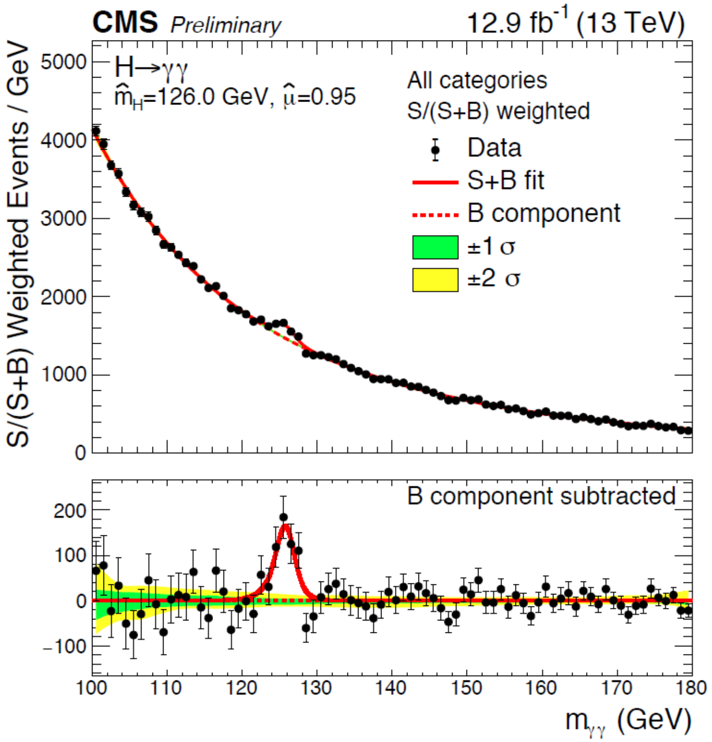


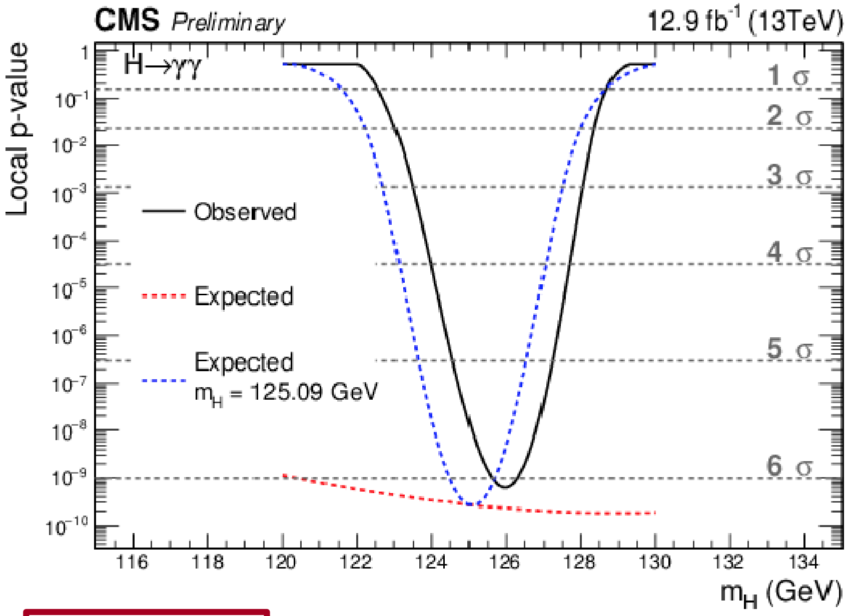
Cross section [pb] @125.09 GeV	ggF	VBF	WH	ZH	ttH	bbH
8 TeV	21.39	1.600	0.701	0.4199	0.1326	0.2015
13 TeV	48.52	3.779	1.369	0.8824	0.5065	0.4863
Ratio	2.27	2.36	1.95	2.10	3.82	2.41

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG

Higgs Re-Discovery







ICHEP16

CMS-HIG-16-020

Event signature:

CMS-HIG-16-041

- 4 leptons (4e, 4μ, 2e2μ)
- Large S/B ratio (> 2:1)
- Good mass resolution (1-2%)

New!

Background:

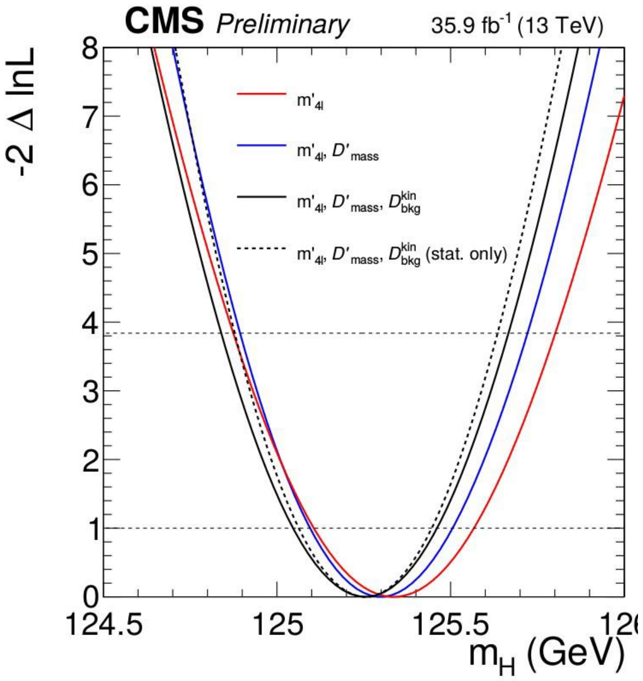
- ZZ (main): estimated from MC
- Reducible background (data driven)

Look for **small signal peak** (BR~0.2%, good mass resolution σ~ 1-2% $m_{\gamma\gamma}$) **over large background** (γγ, γj, jj)

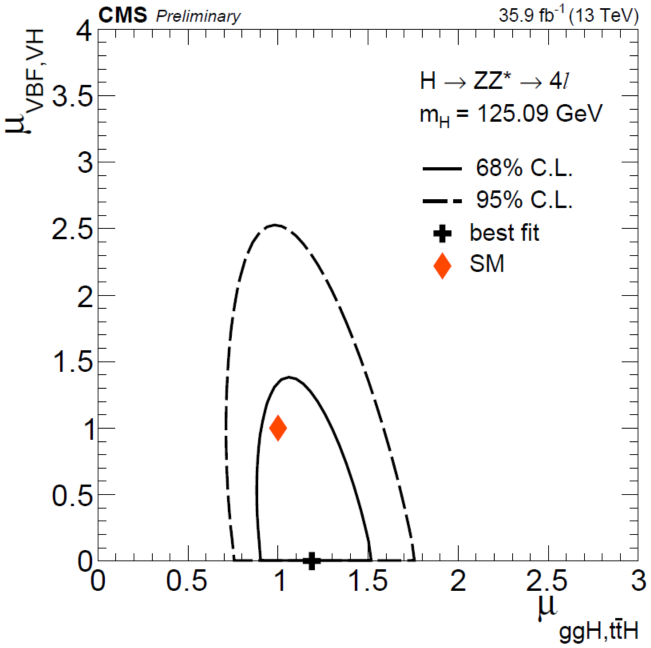
5.6σ at 125.09 GeV and max. 6.1σ at 125.97 GeV

Re-discovered by both H→ZZ→4l and H→γγ

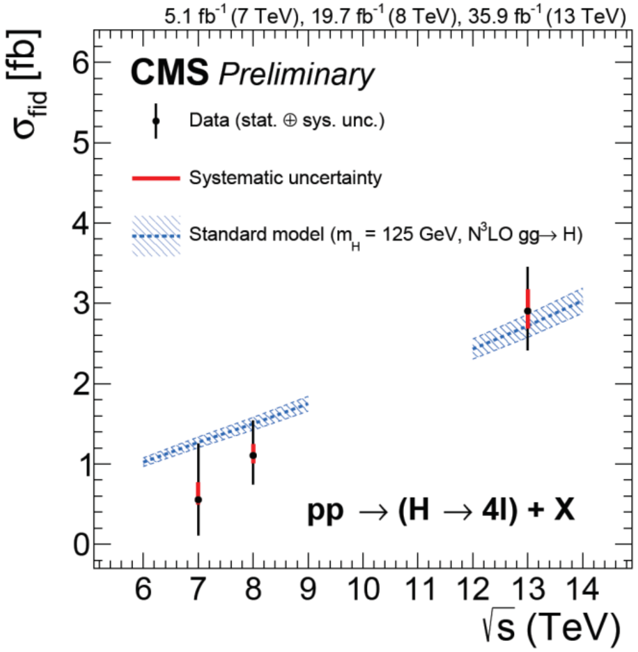
Measurements from H→ZZ→4l



125.26 ± 0.20 (stat.)
± 0.08 (sys.) GeV



$$\mu = 1.05^{+0.15}_{-0.14}(\text{stat.})^{+0.11}_{-0.09}(\text{syst.})$$

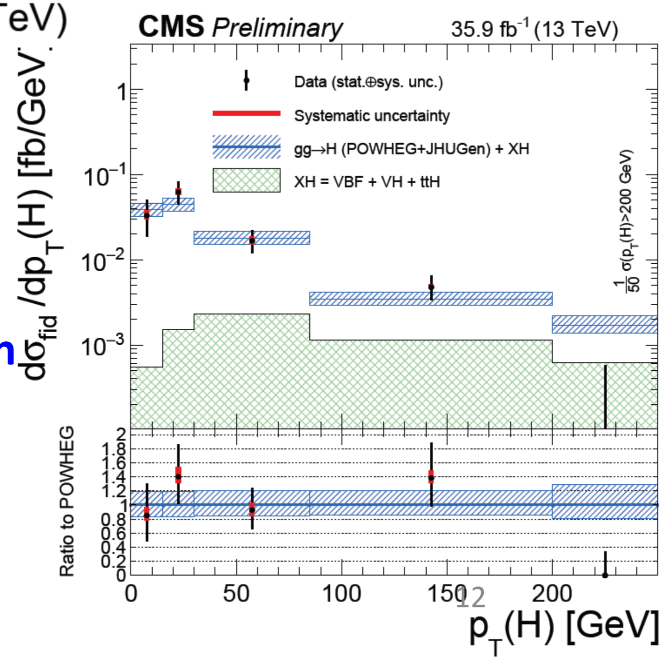


4ℓ fiducial cross section at 13 TeV (fb)

$\sigma = 2.90\ ^{+0.48}_{-0.44}(\text{stat})\ ^{+0.27}_{-0.22}(\text{syst})$

New!

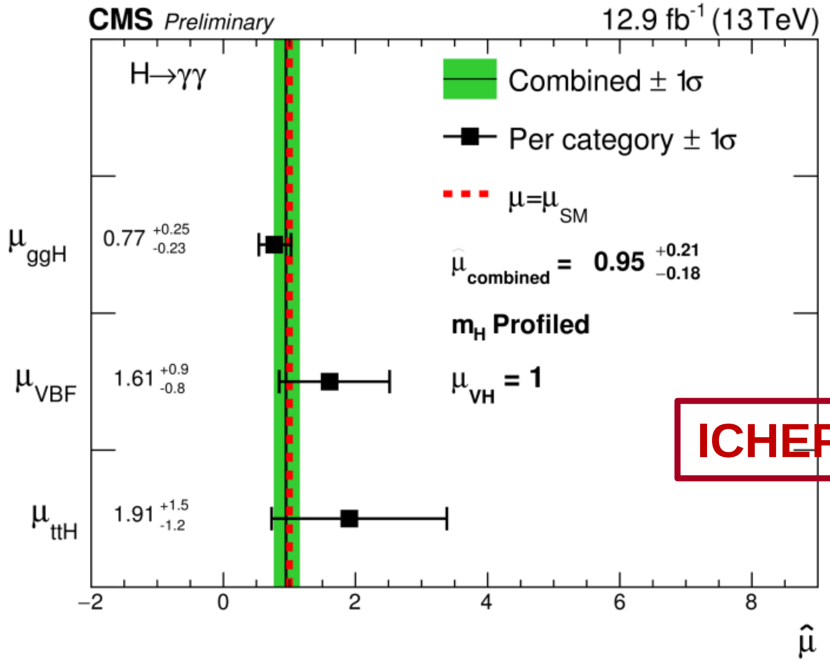
CMS-HIG-16-041



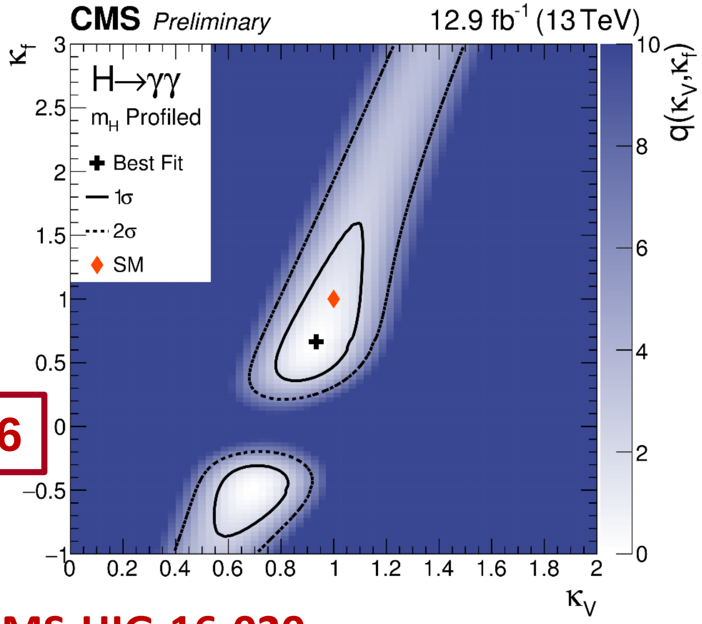
All results are compatible with the SM expectations

Differential cross-section with respect to $p_T(H)$: **consistent with the SM** expectations within uncertainty

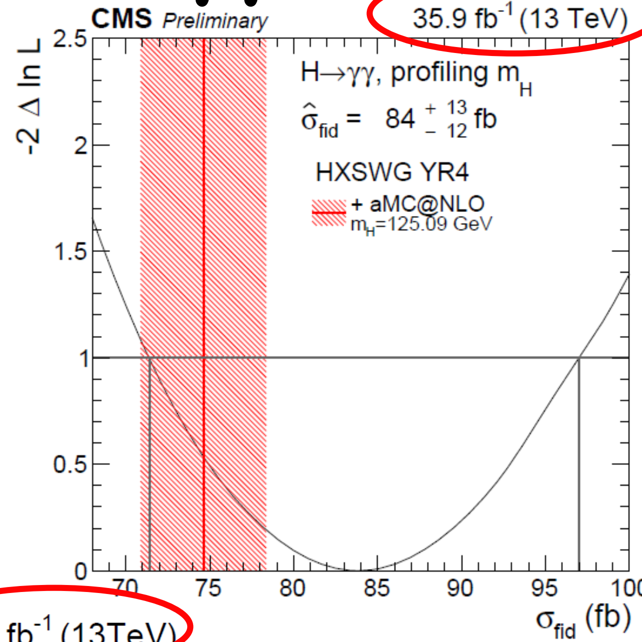
Measurements from H→γγ



ICHEP16

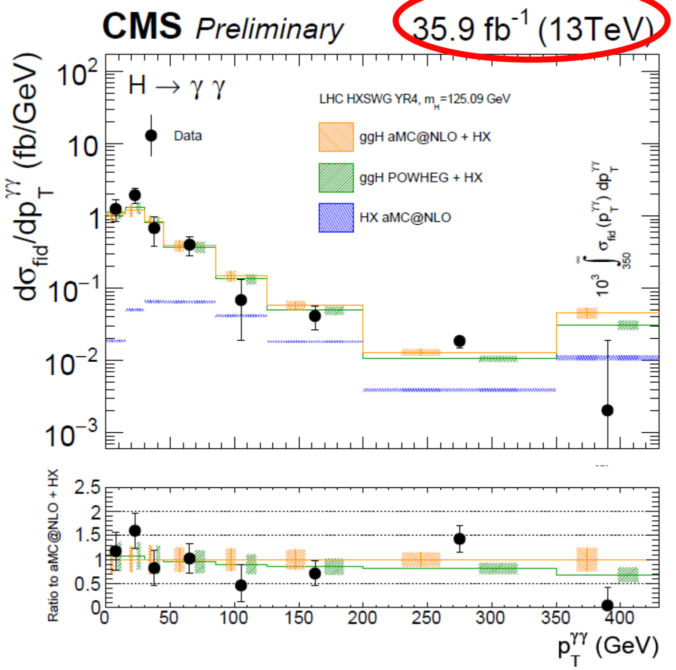


CMS-HIG-16-020



New!

- Signal strengths of individual production modes are consistent with SM expectations
- Couplings, k_V and k_F, are also consistent with SM expectation
- **fiducial and differential cross section with full 2016 dataset (35.9 fb^{-1})**



HIG-17-015

σ_{fid}= 83 ± 10 (stat) ± 7 (syst) fb

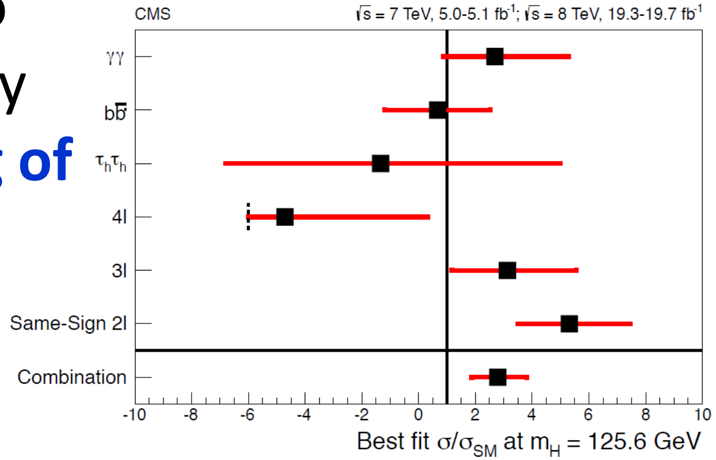
σ_{SM}= 74 ± 4 fb

See more details from L. FINCO 's talk later

ttH Production

- combine Run1:
  μ= 2.8±1.0, 3.4σ

Important to study directly the **coupling of top to Higgs**



ttH→multi-ℓ μ= 1.5 ± 0.5 (3.3σ)

$H^0 \to WW, ZZ, \tau\tau$ (35.9 fb⁻¹)

— 3 states: 2ℓeptons Same Sign
3ℓeptons
4ℓeptons

— veto τ_h

— main backgrounds:

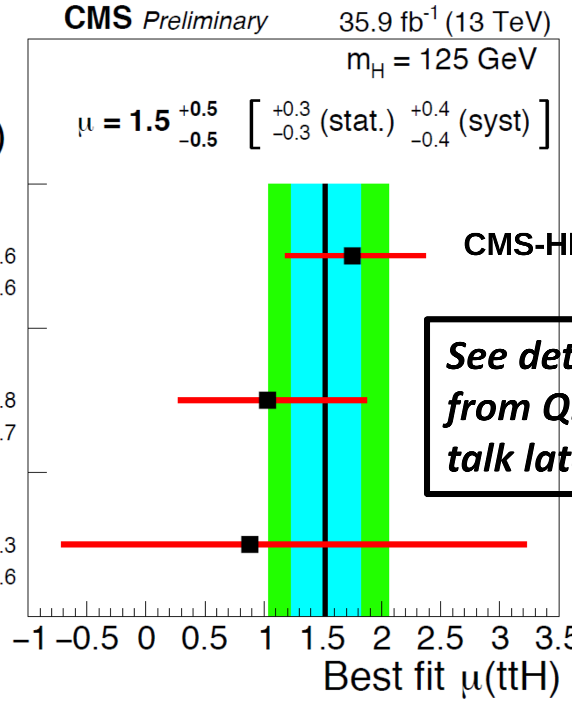
ttW, ttZ, non-prompt (tt, …), …

2l: $\mu = 1.8^{+0.6}_{-0.6}$

3l: $\mu = 1.0^{+0.8}_{-0.7}$

4l: $\mu = 0.9^{+2.3}_{-1.6}$

Run-2

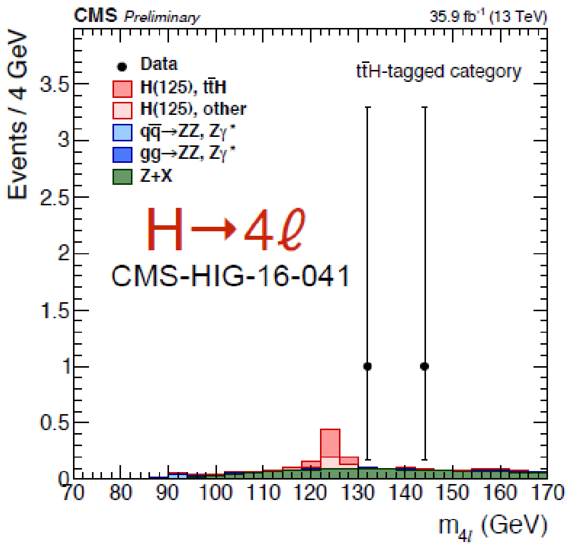


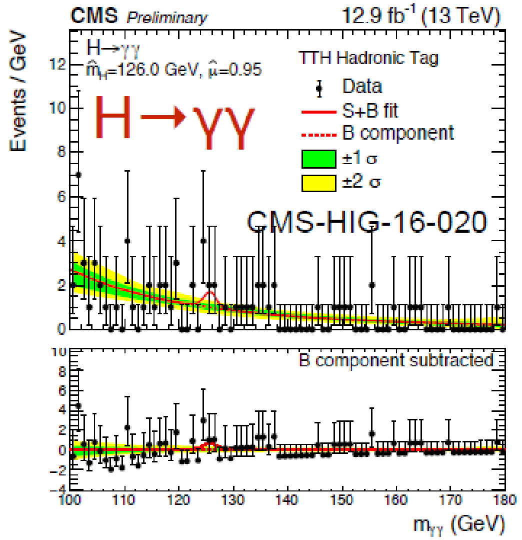
New!

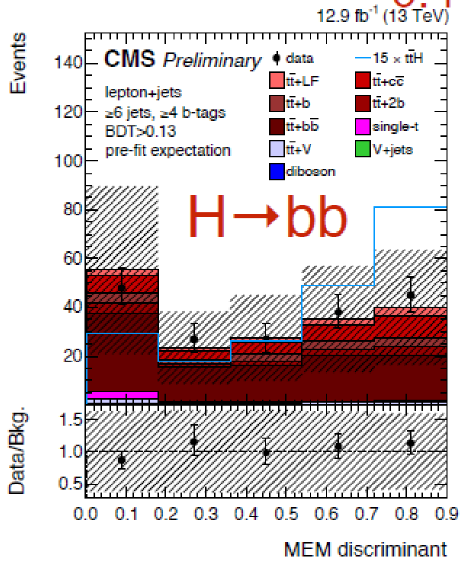
CMS-HIG-17-004

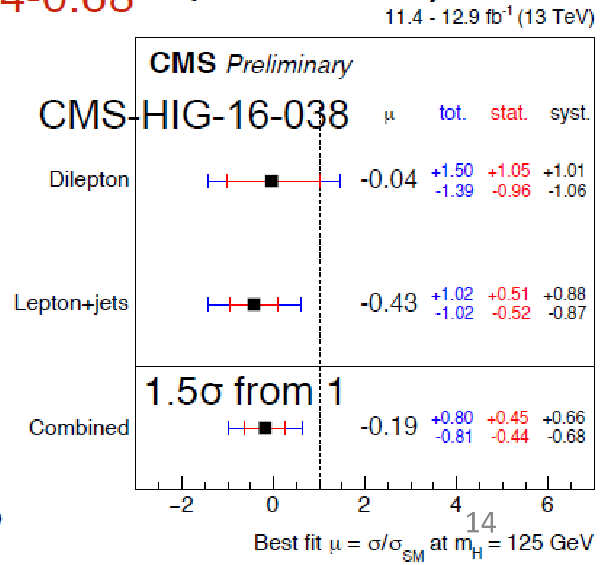
See details from Q. Li 's talk later

$\mu = 0.0^{+1.2}_{-0.0}$ (35.9 fb⁻¹) $\mu = 1.9^{+1.5}_{-1.2}$ (12.9 fb⁻¹) $\mu = -0.19^{+0.45+0.66}_{-0.44-0.68}$ (12.9 fb⁻¹)

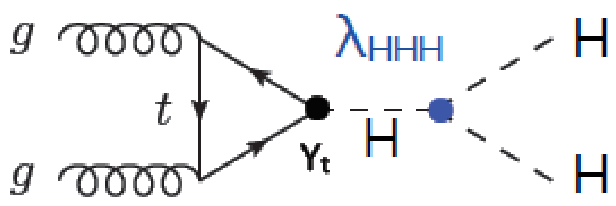


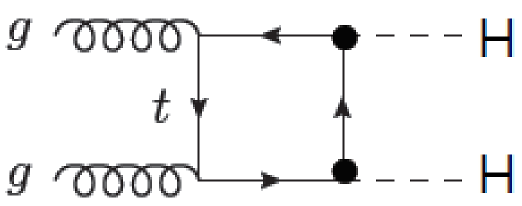






Double Higgs Production: H(125)H(125)





- Target $gg \to H^0H^0 \to (bb)+(\tau\tau)$ (35.9 fb^{-1})
  - — $\tau\tau$: 3 states $\mu\tau_h, e\tau_h, \tau_h\tau_h$
  - — bb: 3 types: 2b or 1b-tag, or boosted ak8 jet

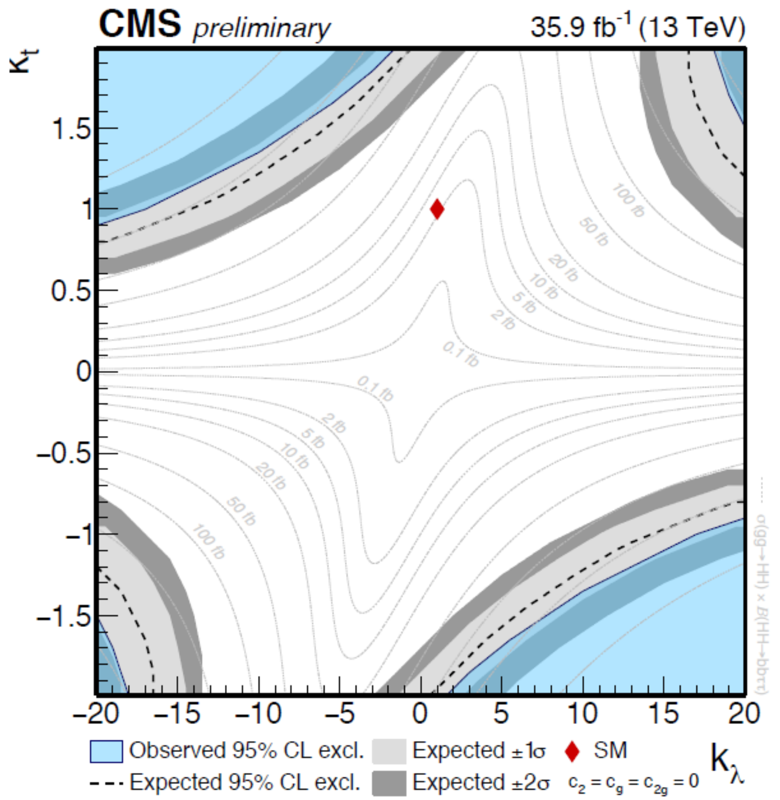
σ_{HH} : main way to extract Higgs trilinear coupling λ_{HHH}

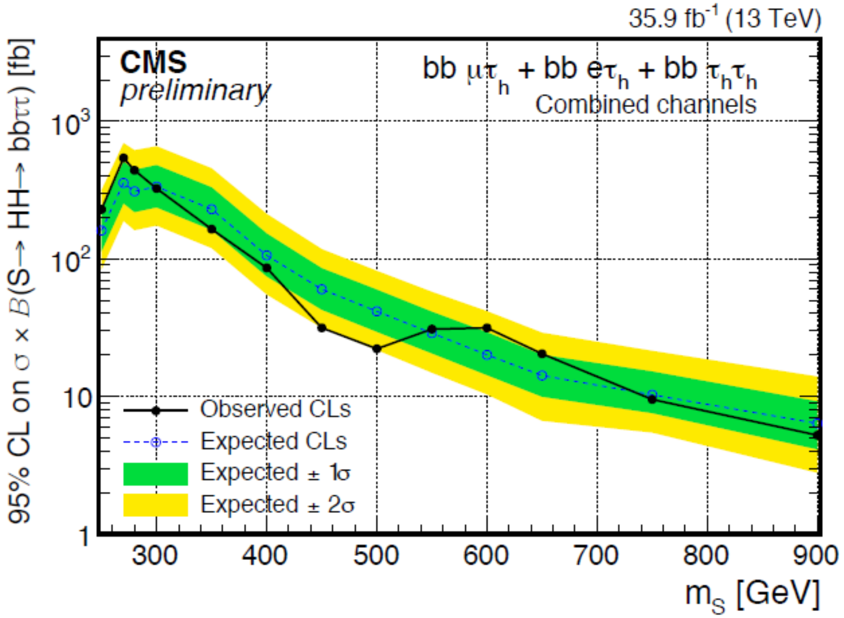
$\sigma_{gg\to HH} = 33.49^{+4.3}_{-6.0}$ (scale) ± 2.1 (PDF) ± 2.3 (α_s) fb

[13 TeV, NNLO + NNLL with top mass effects, HXSWG, arXiv:1610.07922]

CMS-HIG-17-002

New!





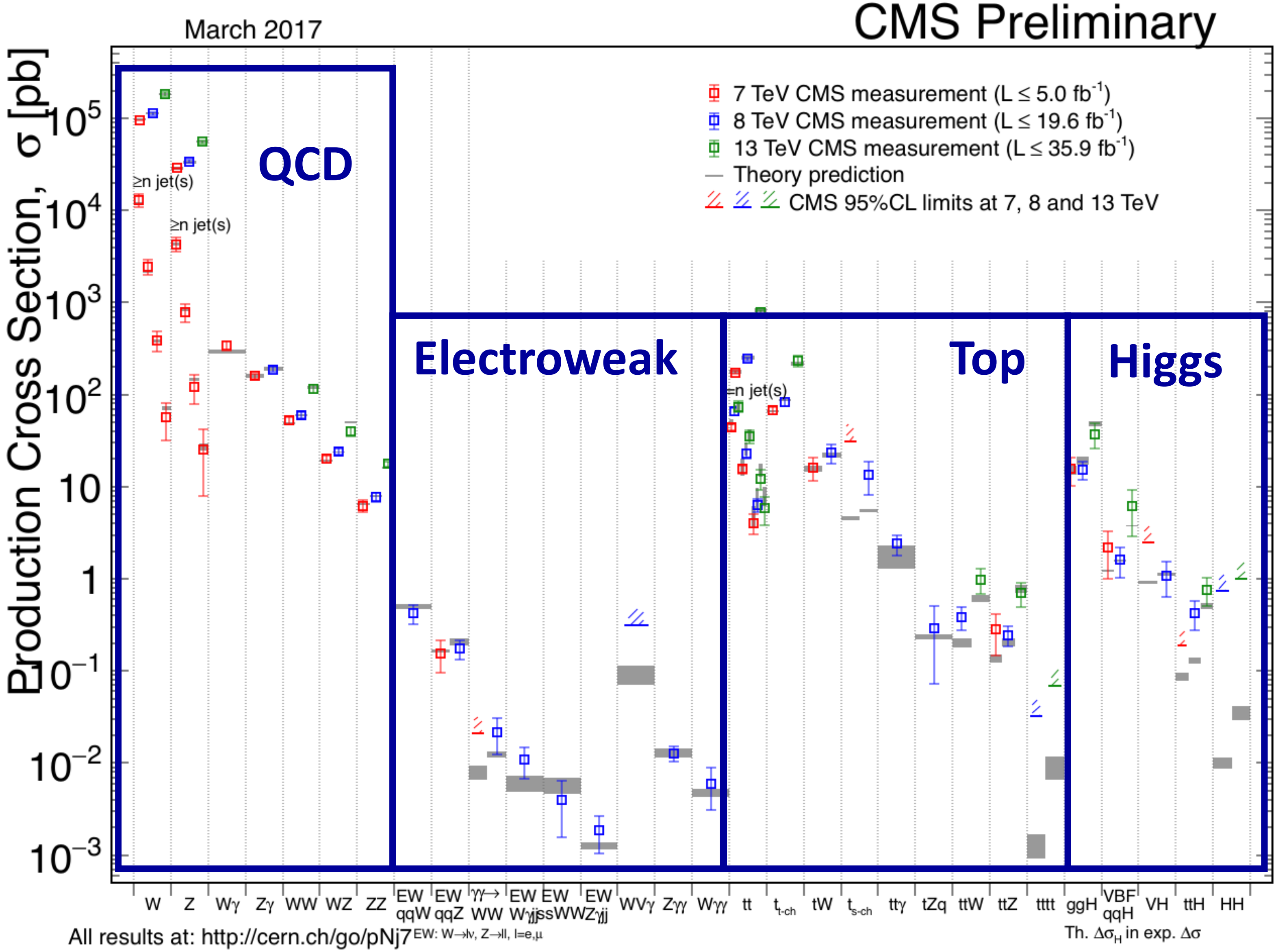
Non-resonant search excludes 28 times the SM

Resonant production tested up to mX = 900 GeV

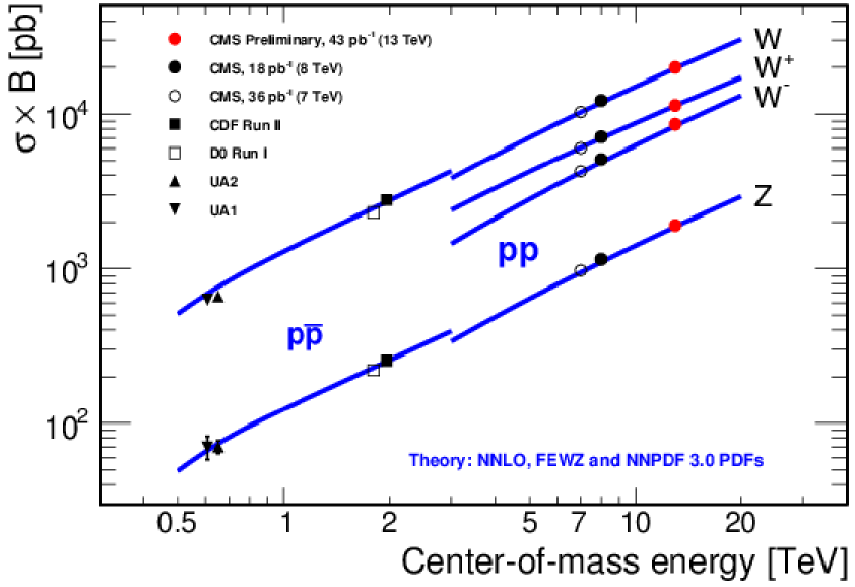
Standard Model Measurements

SM Cross Section measurements

All measurements consistent with standard model



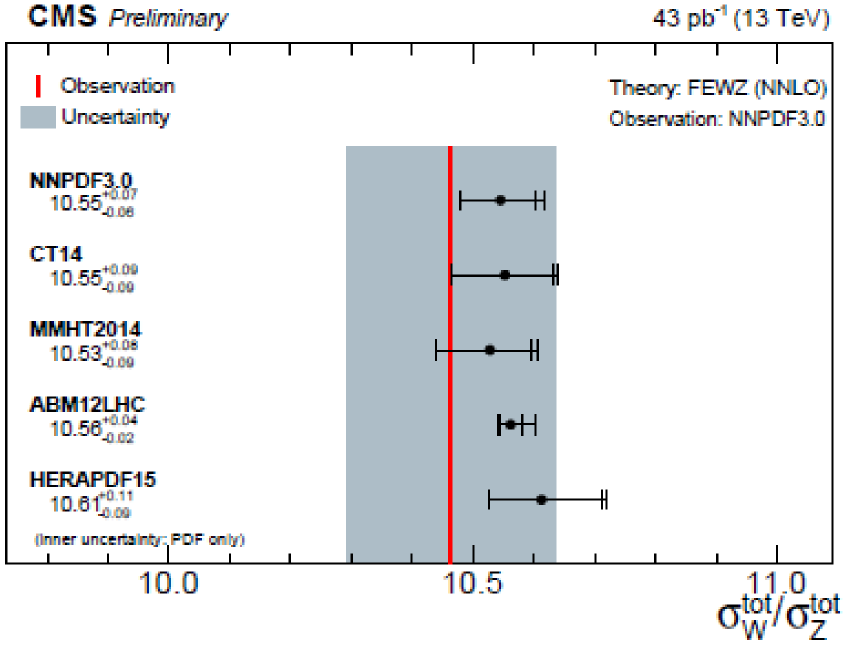
Inclusive W/Z production

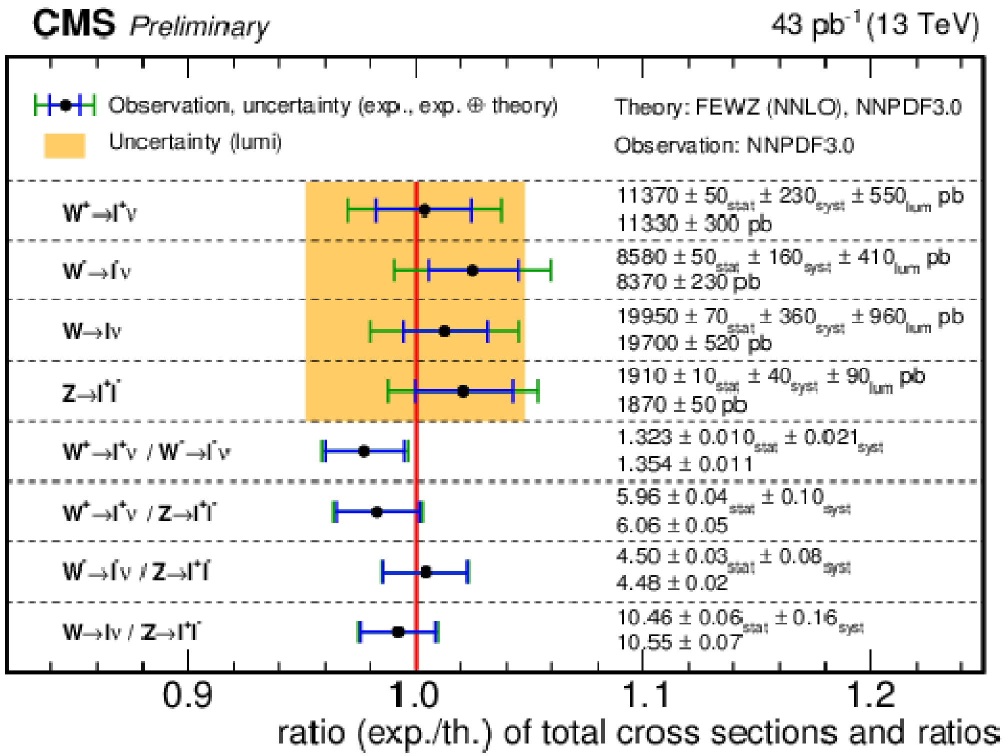


Measured values, including √s dependence, agree with NNLO QCD predictions

Ratios of production rates → tools to constrain PDFs

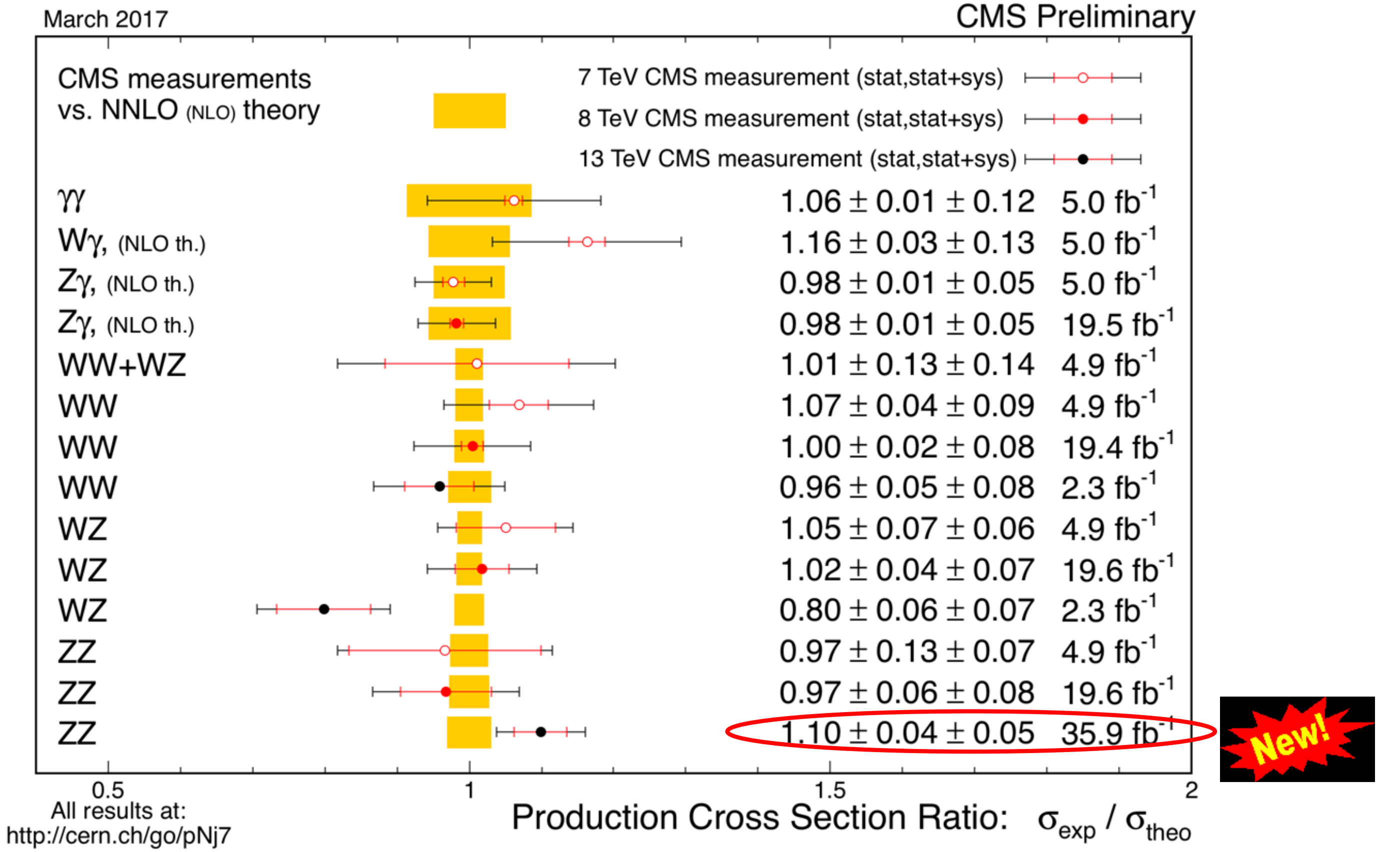
SMP-15-004
SMP-15-011





Diboson Production

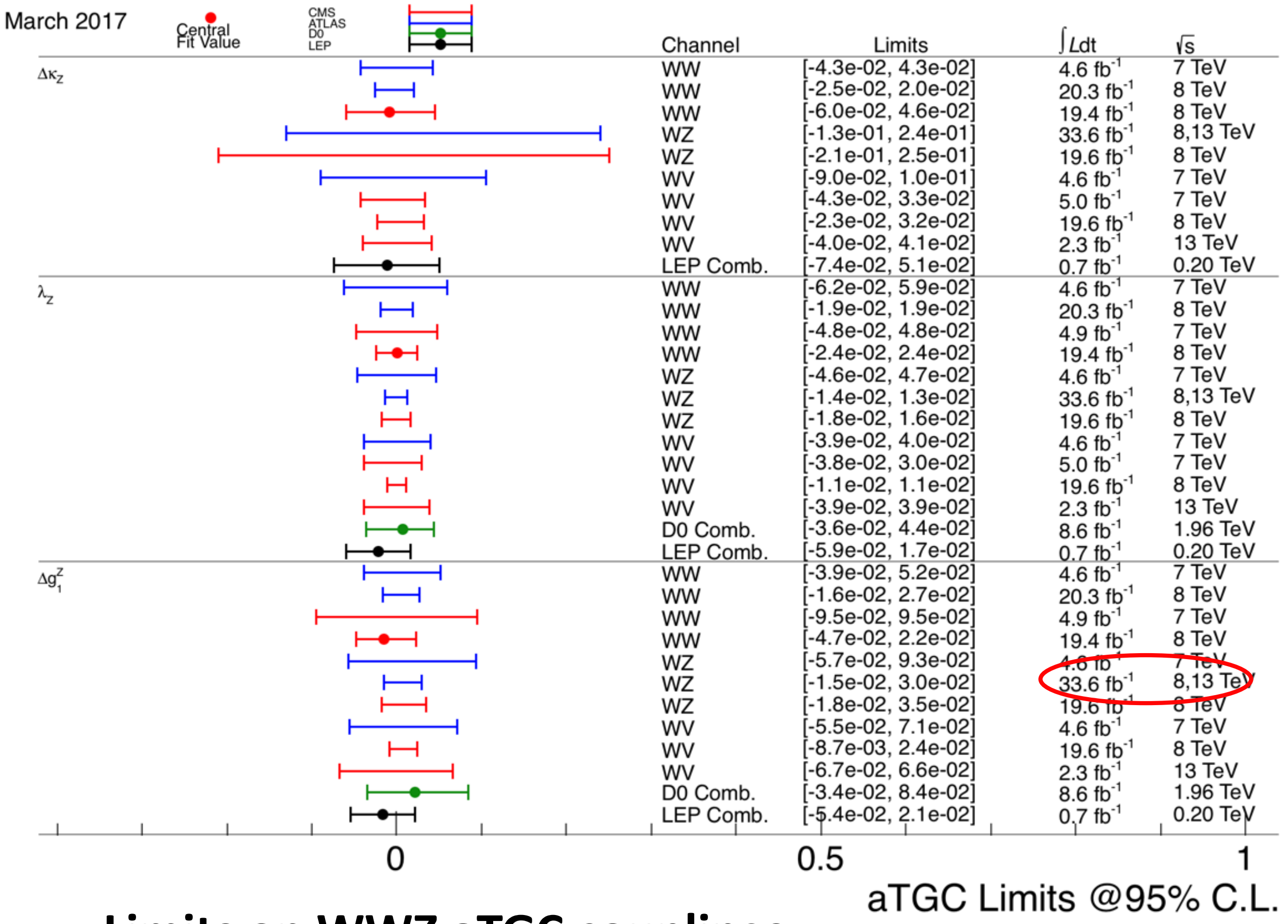
- Important test of the SM → probes gauge-boson self-interactions
- Background to many Higgs searches and new physics searches
- Relatively large diboson rates at the LHC
  - ✓ use mainly W/Z leptonic decays for clean signatures and high trigger efficiencies
  - ✓ add hadronic decays where possible to increase statistics



Very good agreement with SM expectations

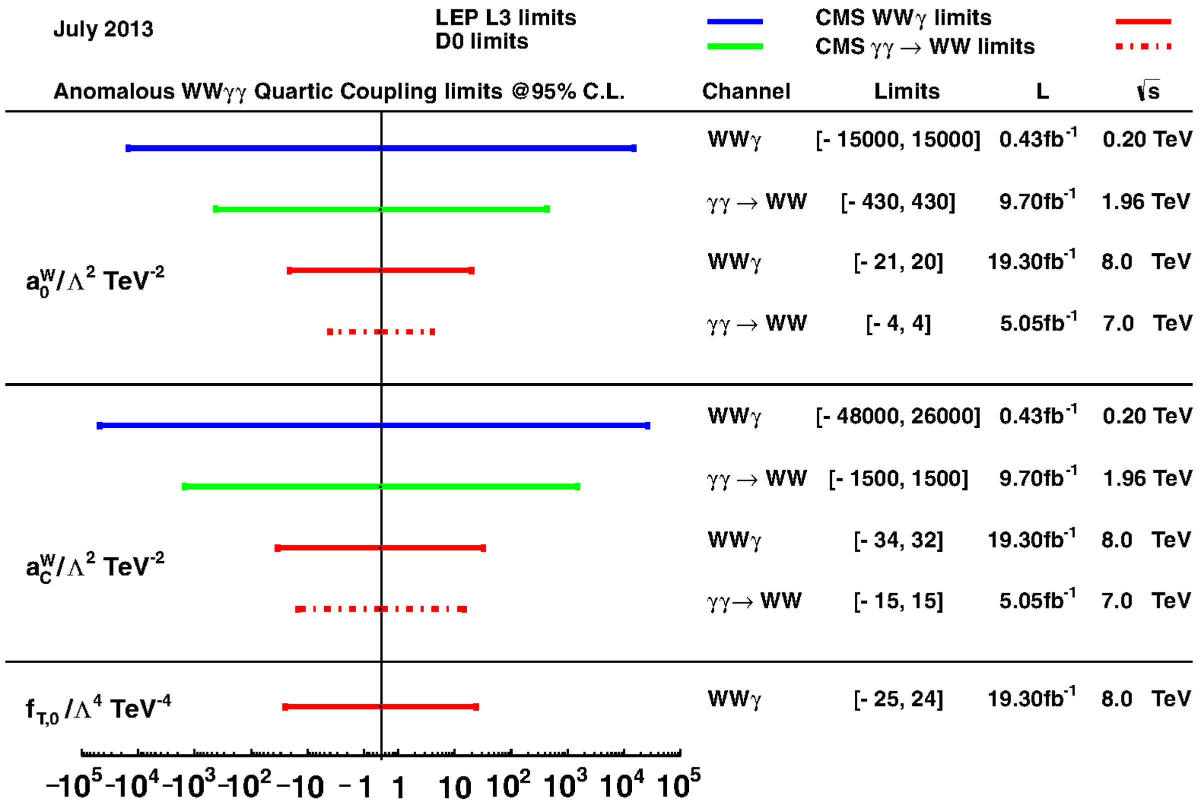
Anomalous triple and quartic gauge couplings (aTGC, aQGC)

Diboson and triboson measurements are the natural choice to search for anomalous gauge couplings



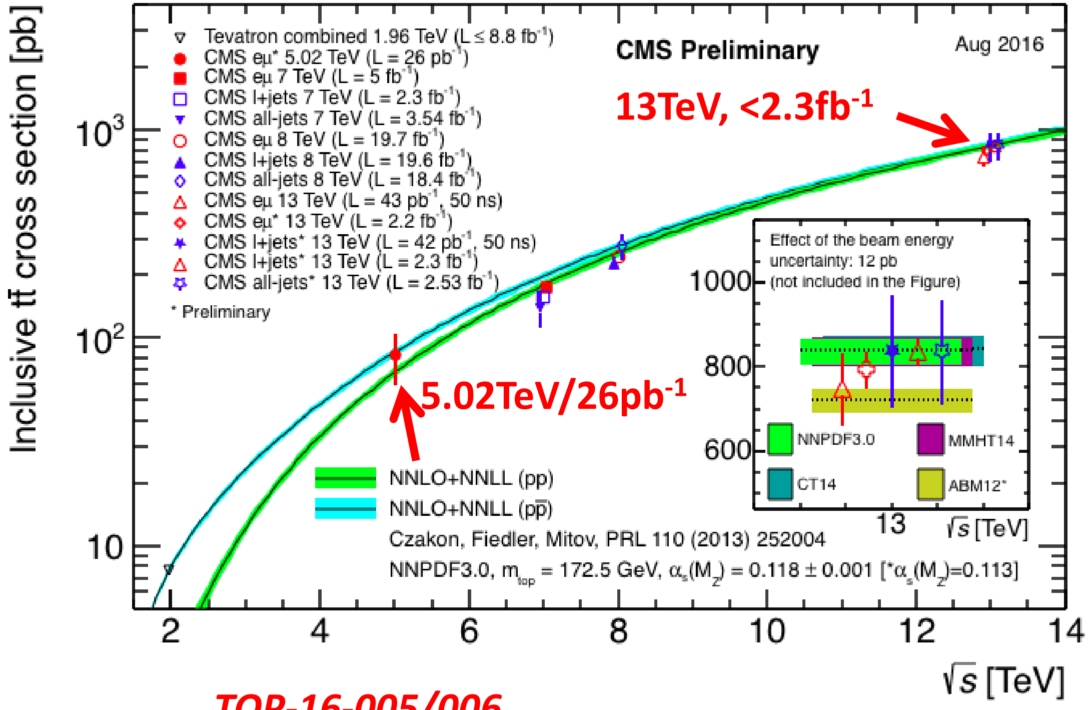
Limits on WWZ aTGC couplings

New!

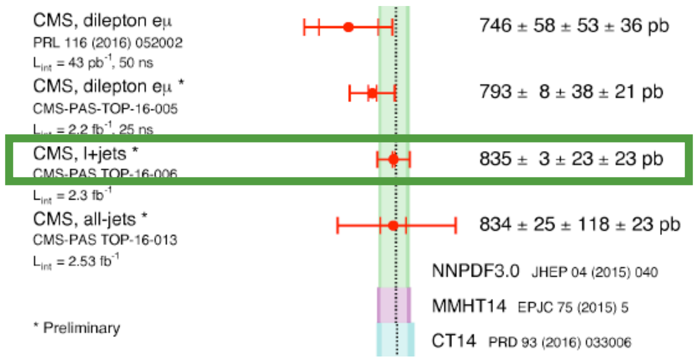


Limits on WWγγ

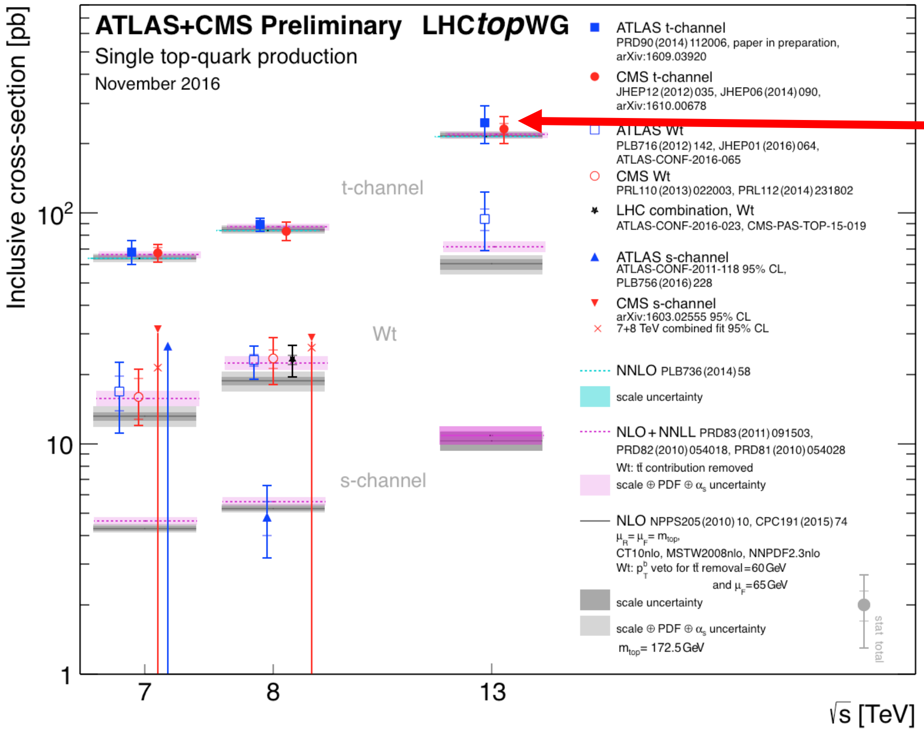
Top pair/single top production

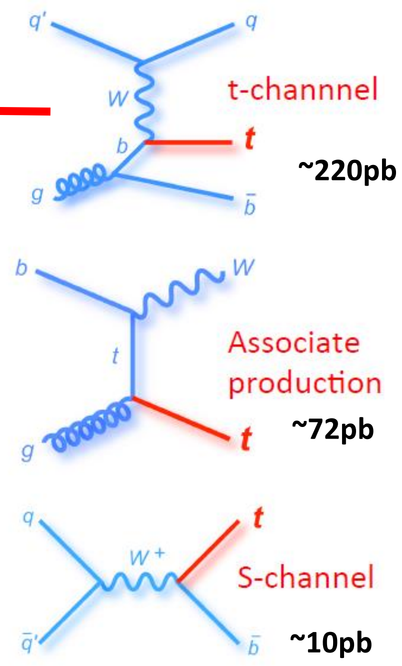


TOP-16-005/006



currently the most precise measurement





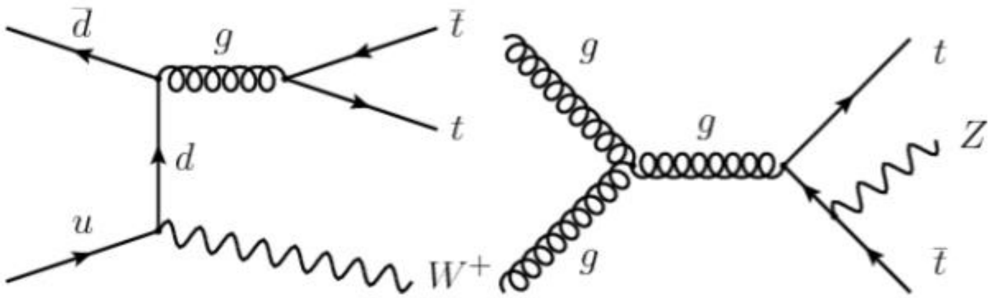
$$\sigma_{t\text{-ch.},t} = 149.6 \pm 9.9\,(\text{stat}) \pm 10.6\,(\text{exp})\,{}^{+18.1}_{-18.3}\,(\text{theo}) \pm 4.0\,(\text{lumi})\ \text{pb}$$

$$\sigma_{t\text{-ch.},\bar{t}} = 82.6 \pm 5.2\,(\text{stat}) \pm 8.1\,(\text{exp})\,{}^{+10.7}_{-11.2}\,(\text{theo}) \pm 2.2\,(\text{lumi})\ \text{pb}$$

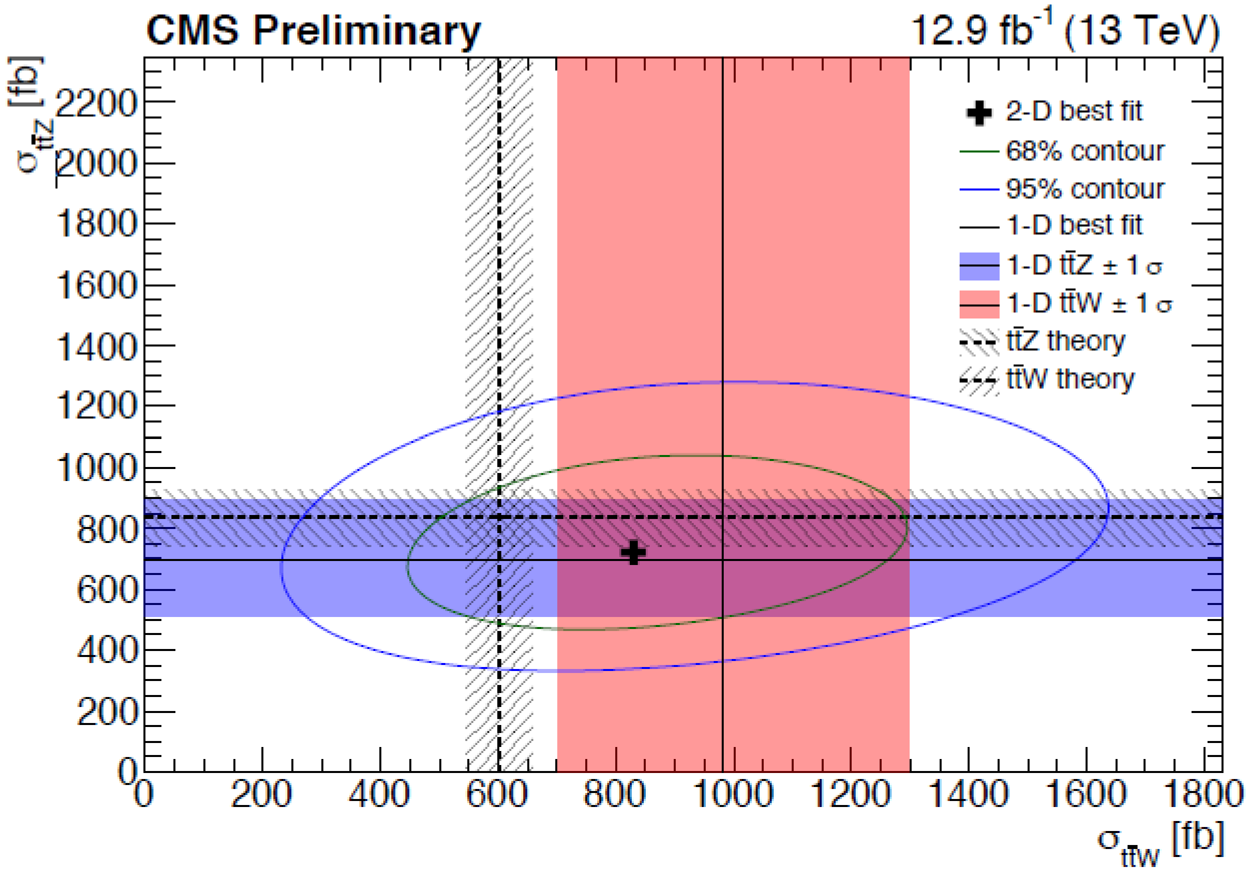
TOP-16-003

Within experimental uncertainty
no significant deviation observed

Top pair + W/Z production



CMS-PAS-TOP-16-017



Select event with 2 SameSign leptons(**ttW**) or 3 or 4 leptons (**ttZ**)

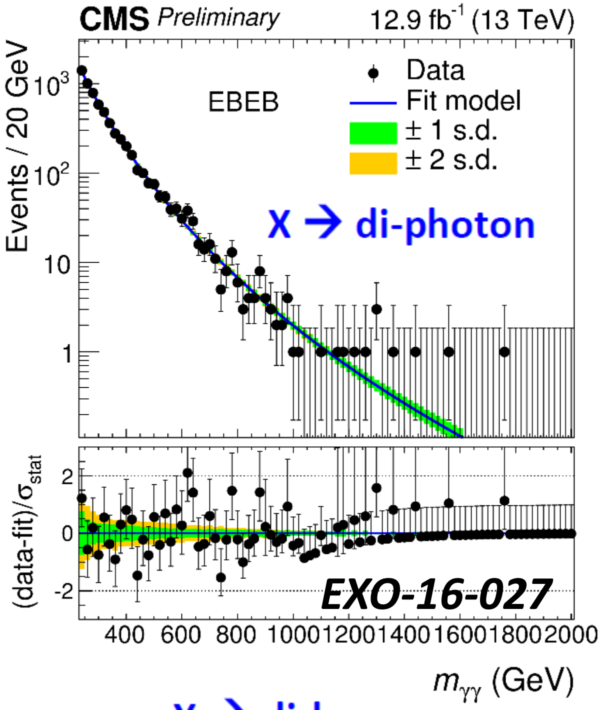
$$\sigma(t\bar{t}Z) = 0.70^{+0.16}_{-0.15}(\text{stat.})^{+0.14}_{-0.12}(\text{sys.})\ \text{pb}$$

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

Channel	Expected significance	Observed significance
$2\ell ss$ analysis ($t\bar{t}W$)	2.6	3.9
3ℓ analysis ($t\bar{t}Z$)	5.4	3.8
4ℓ analysis ($t\bar{t}Z$)	2.4	2.8
3ℓ and 4ℓ combined ($t\bar{t}Z$)	5.8	4.6

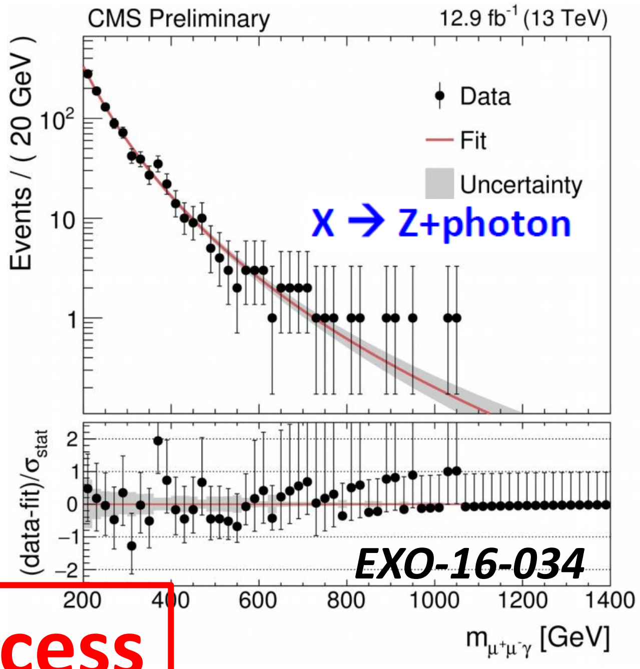
Beyond Standard Model Searches

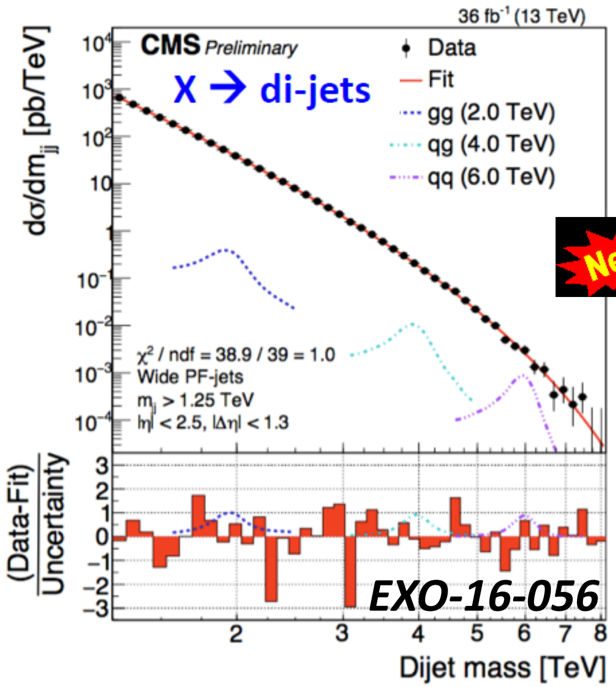
Search for new resonances (I)



~750GeV bump was not confirmed by 2016 data (ICHEP16)

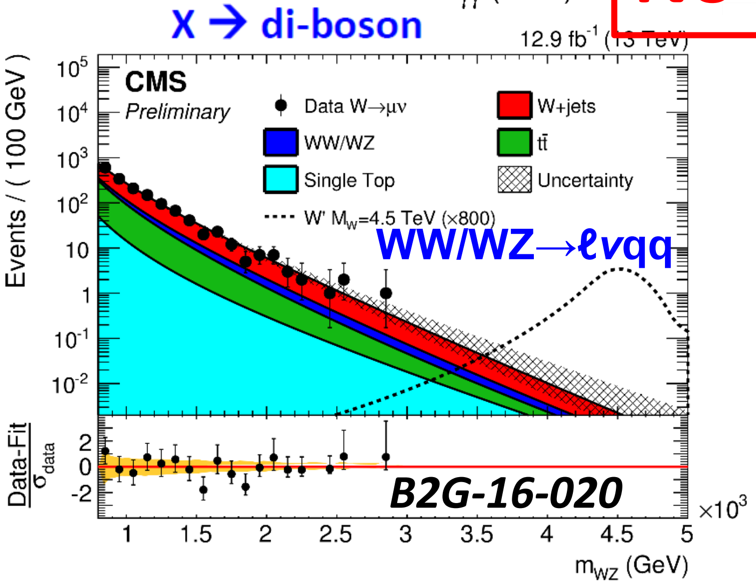
ICHEP16

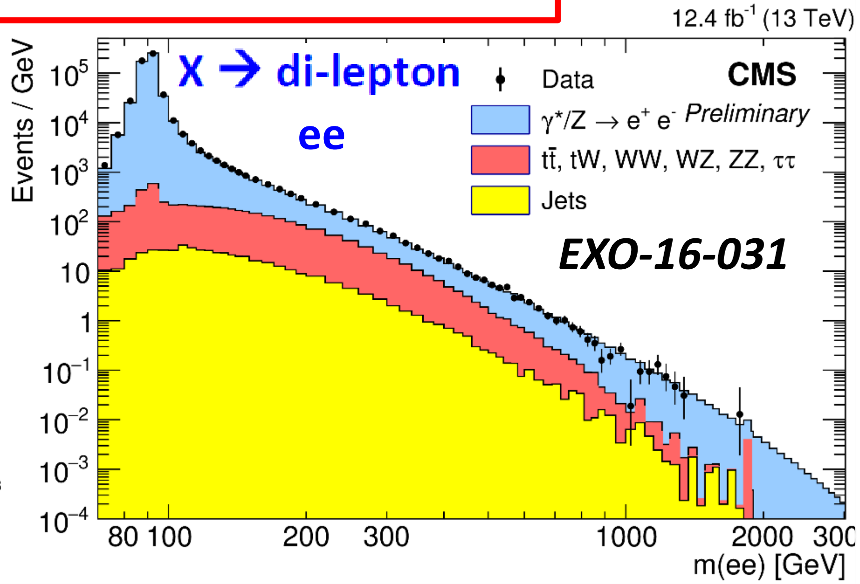


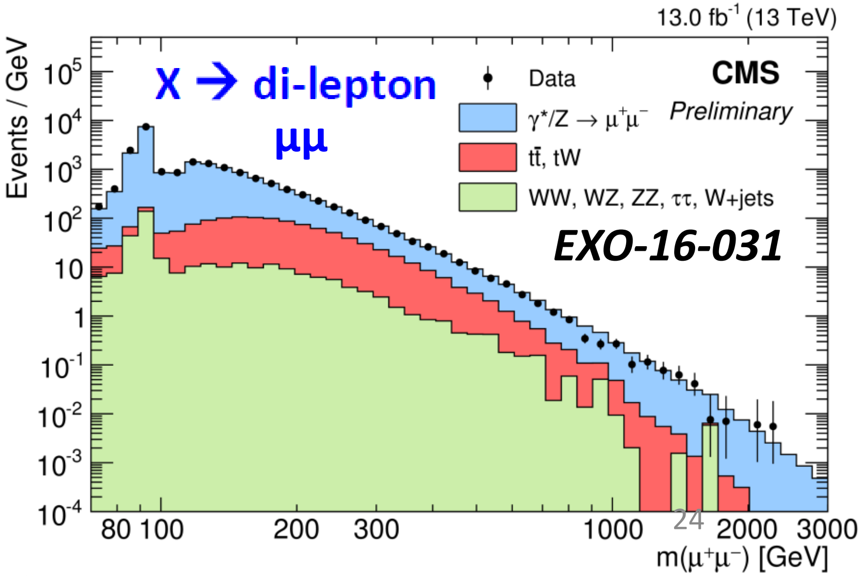


New!

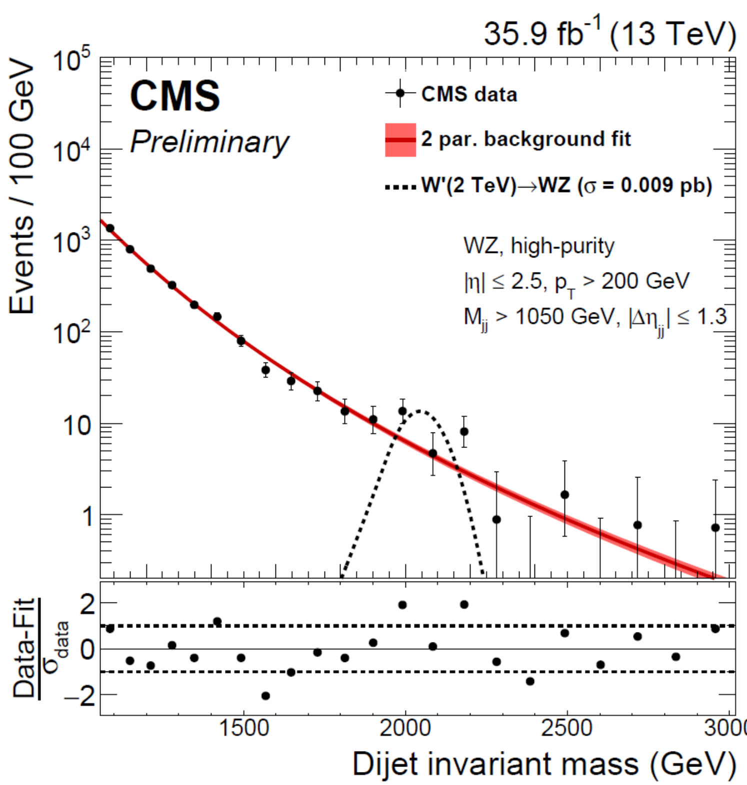
No obvious excess

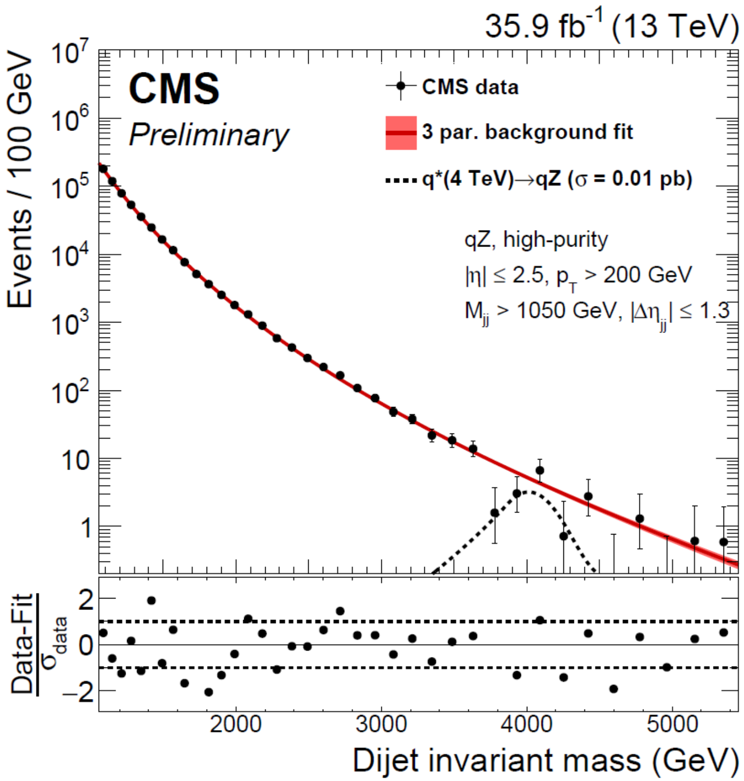






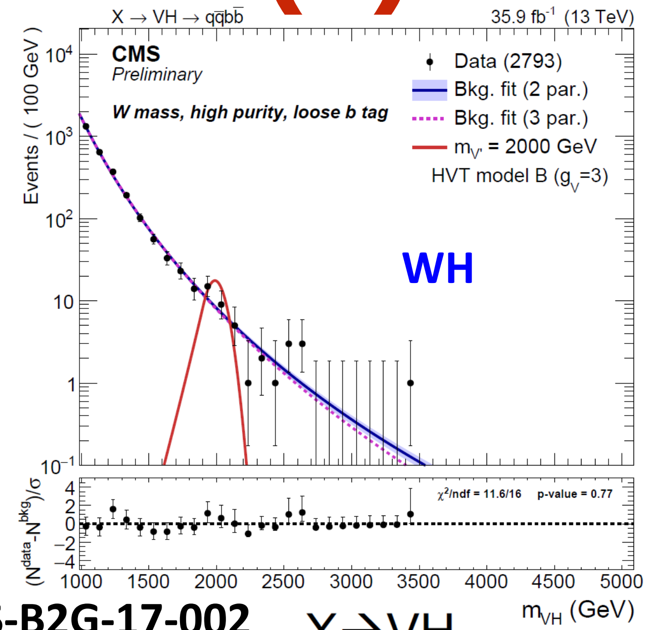
Search for new resonances (II)



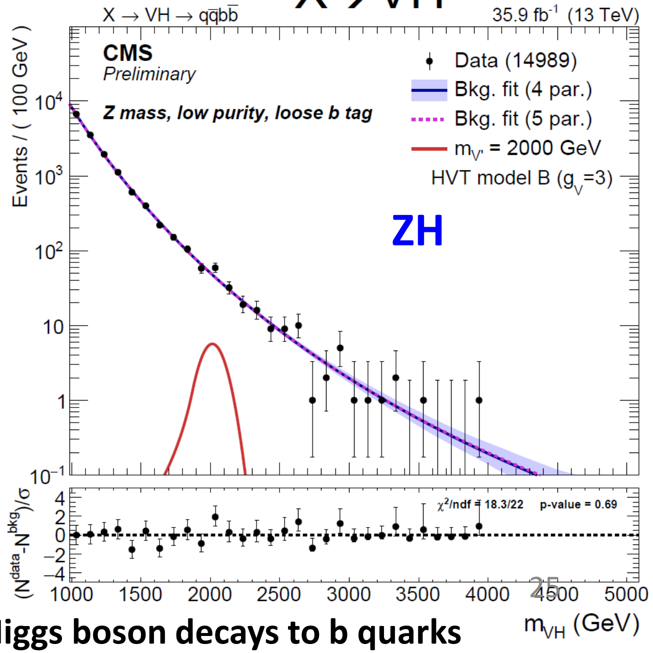


X→VV and Vq

CMS-PAS-B2G-17-001



CMS-PAS-B2G-17-002 X→VH

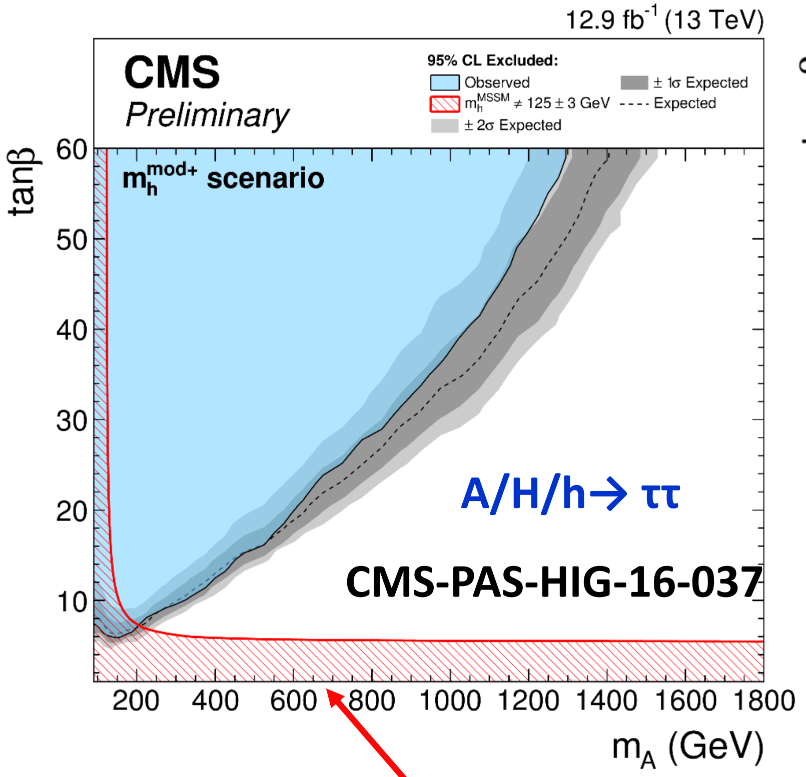


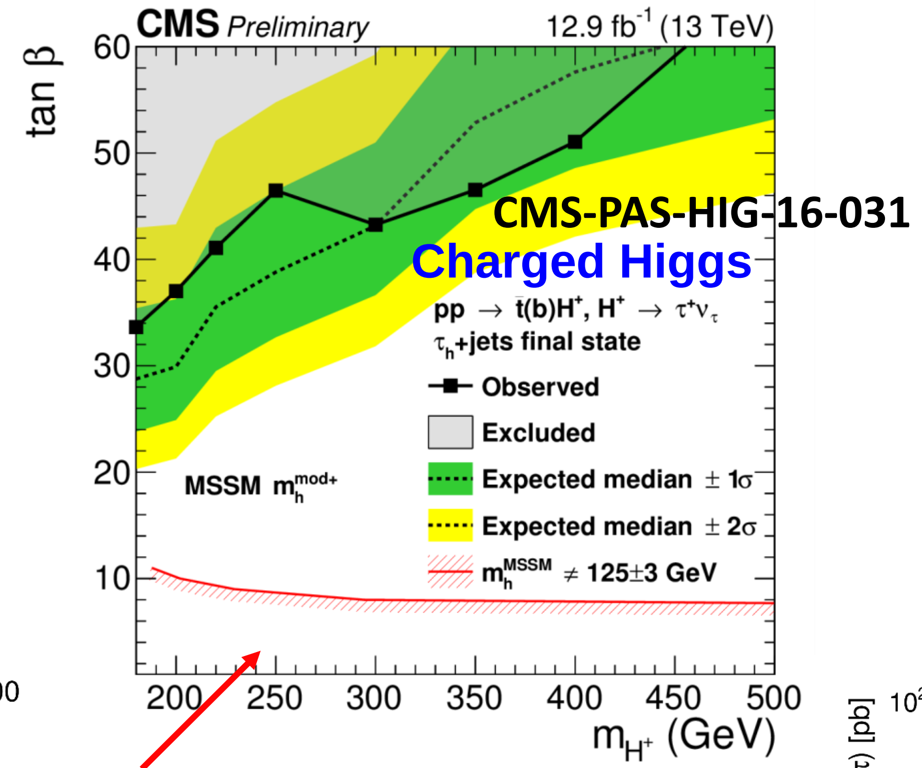
New!

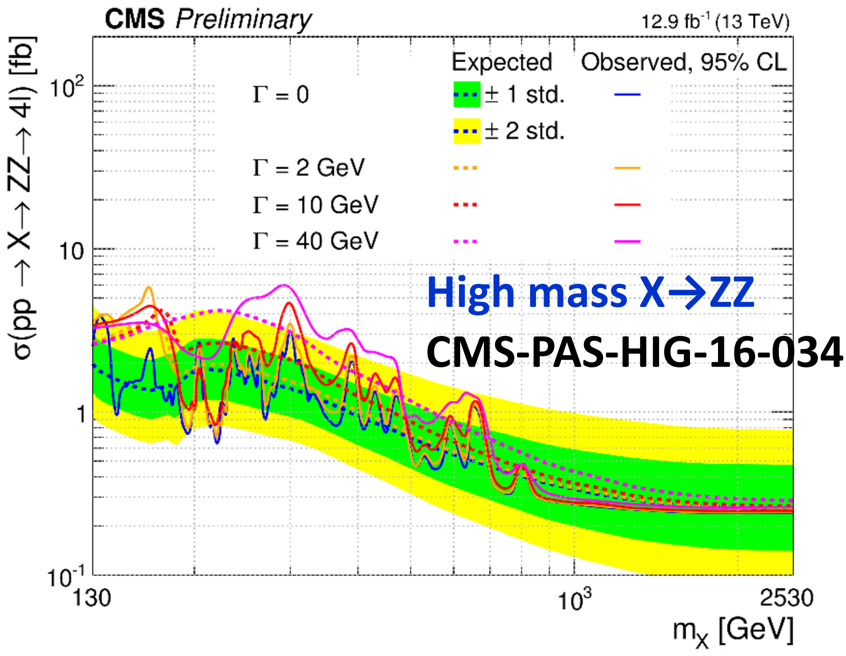
No obvious excess

Higgs boson decays to b quarks

Searches for BSM Higgs



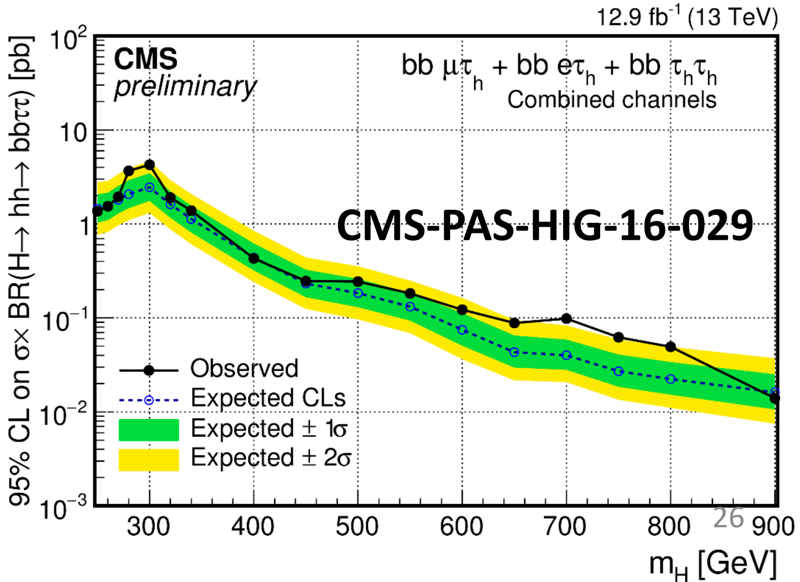




Excluded if h ≡ SM Higgs

Narrow resonance

H→2 SM Higgs → bbττ



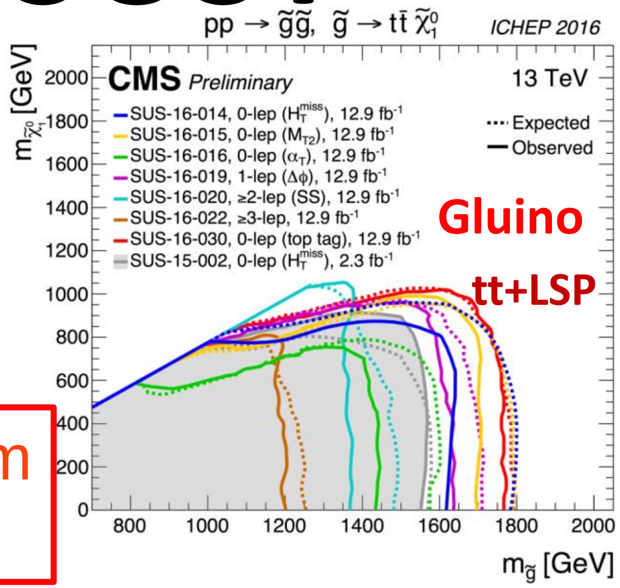
No excess is found above SM exp.

SUSY

- Hierarchy problem
- Unification of gauge couplings
- Dark matter (lightest SUSY particle)

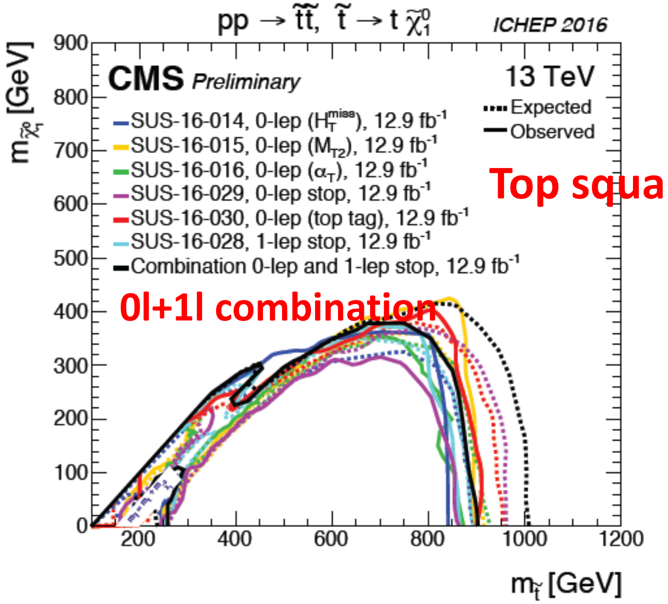
- **Many searches with jets, leptons , photons, missing energy in final state**

No significant deviation from Standard Model observed



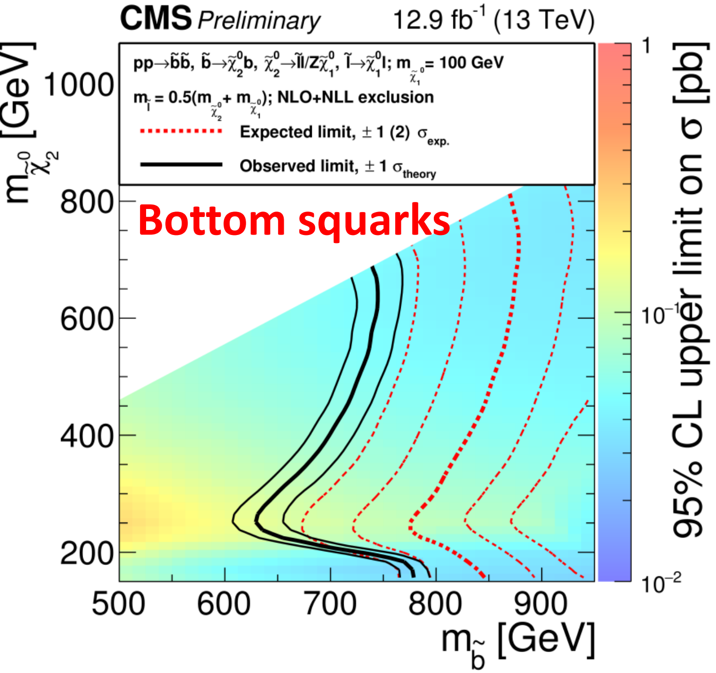
Gluino

tt+LSP



Top squarks

0l+1l combination

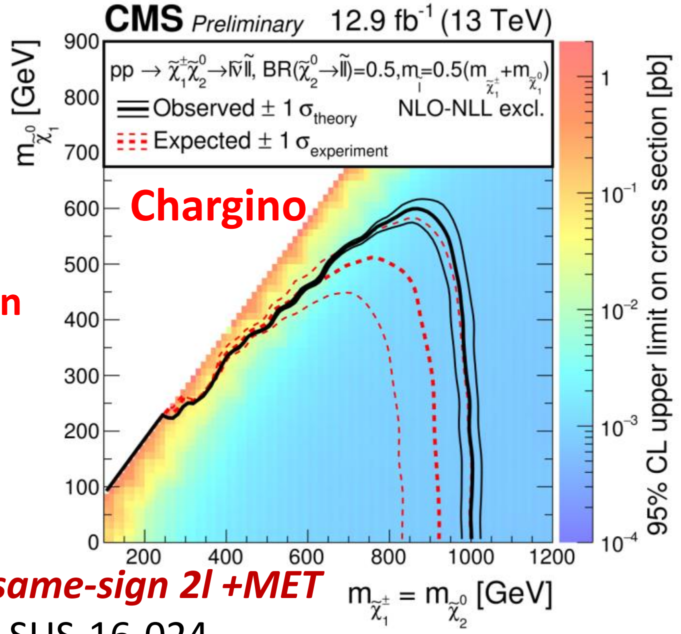


Bottom squarks

ICHEP16

Opposite-sign dilepton + Jet + MET

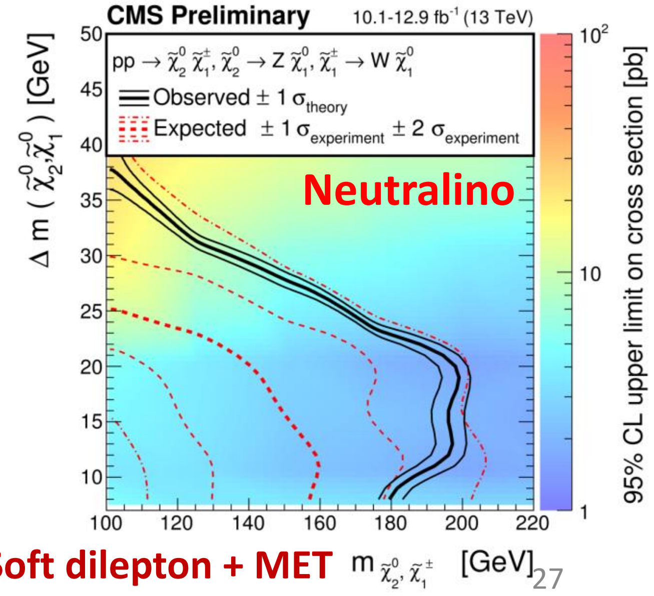
CMS-SUS-16-021



Chargino

3l + same-sign 2l +MET

CMS-SUS-16-024



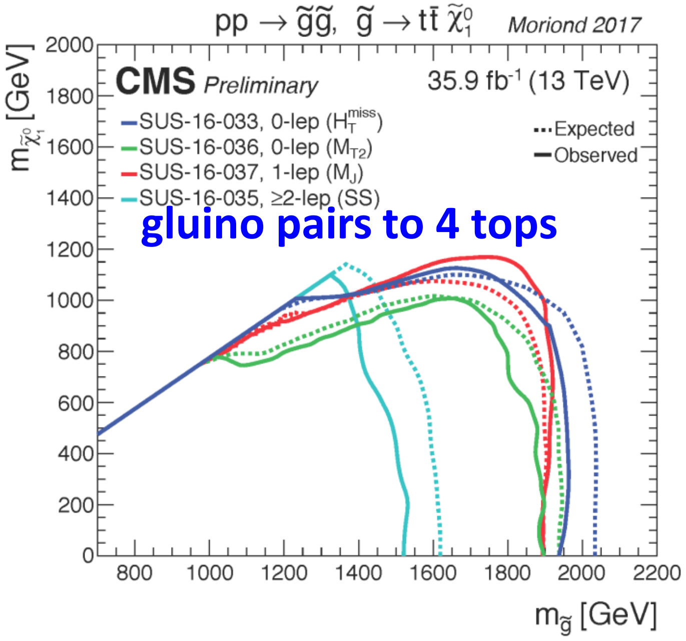
Neutralino

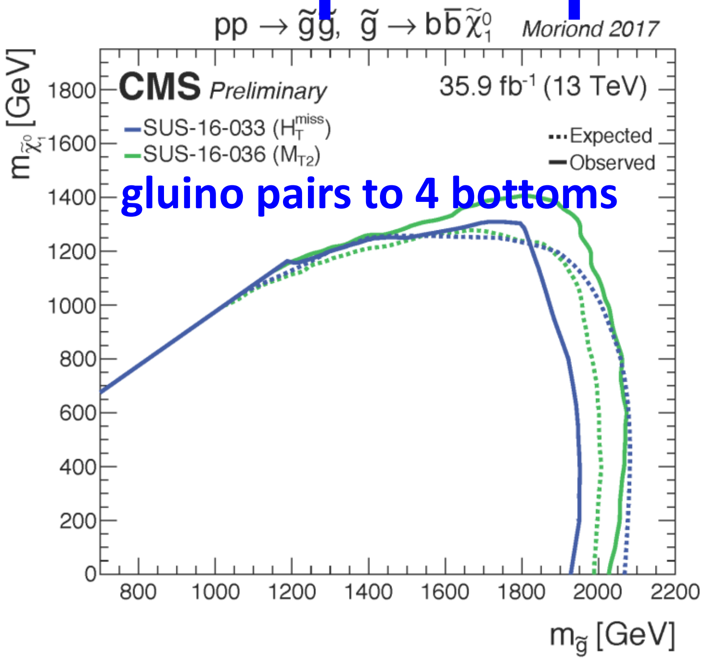
Soft dilepton + MET

CMS-SUS-16-025

SUSY : pair production

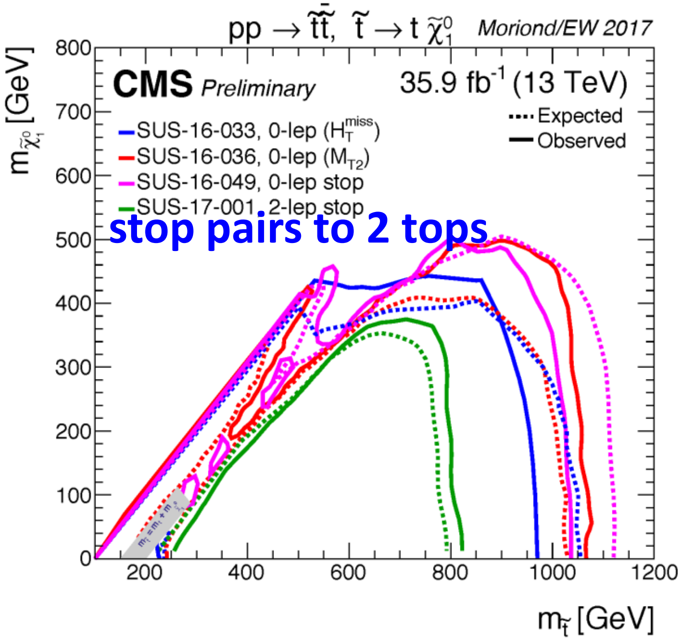
New!

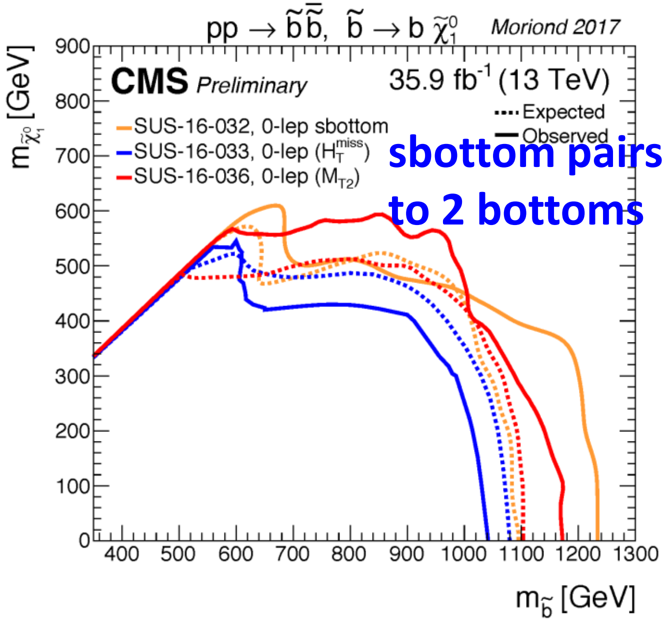


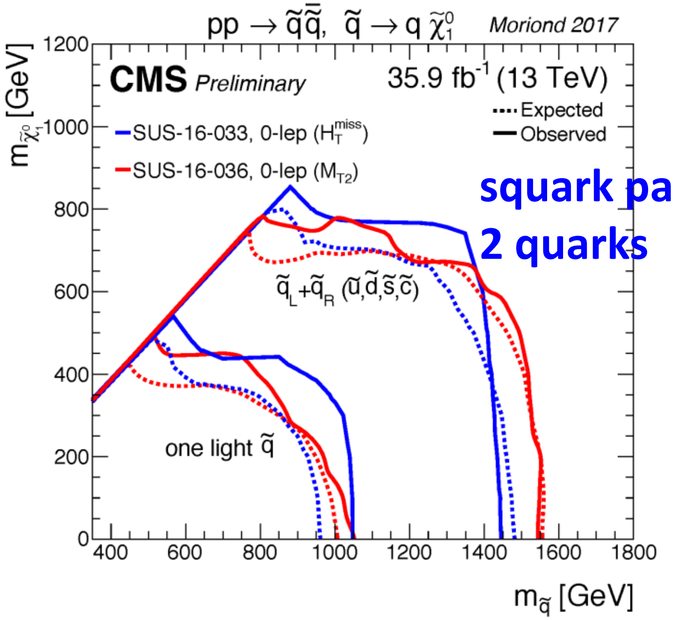


Now exclude gluino masses up to ~2 TeV

No significant deviation from Standard Model observed



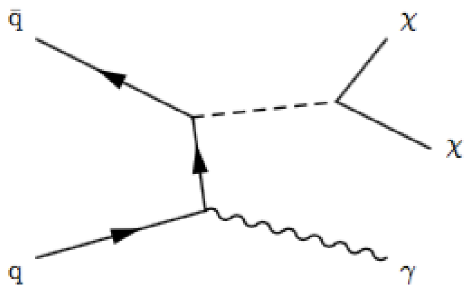




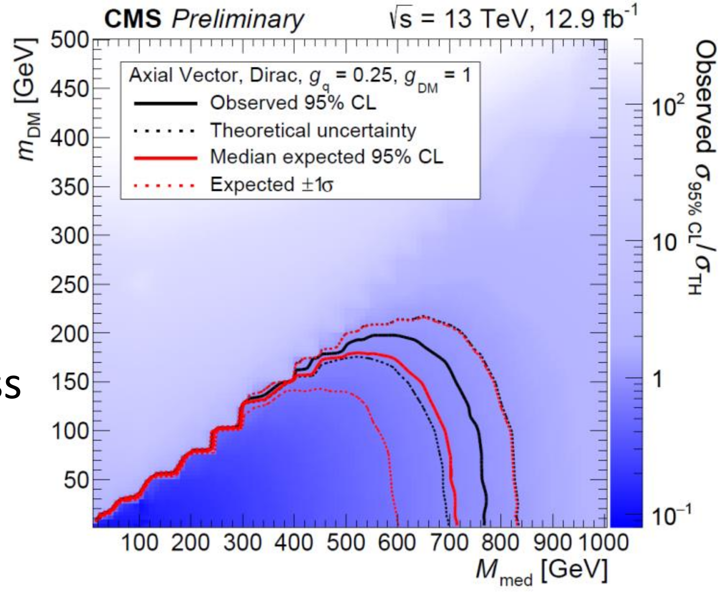
Dark Matter

Basic idea: search of **mono-object** recoiling against **MET**

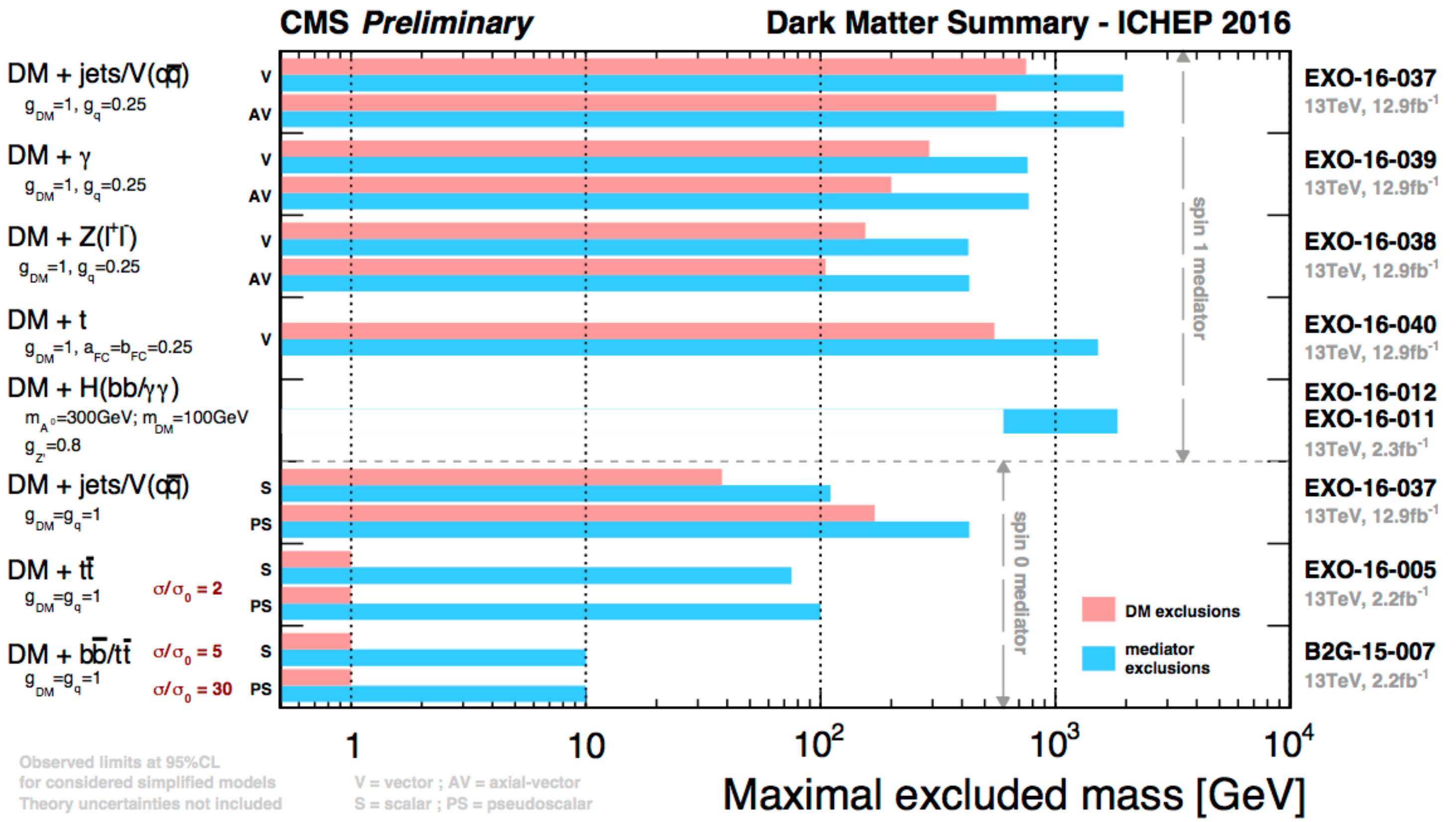
Mono-Photon



No excess observed, set limits on DM and mediator : Mediator mass up to 760 GeV excluded (vector/axial vector)



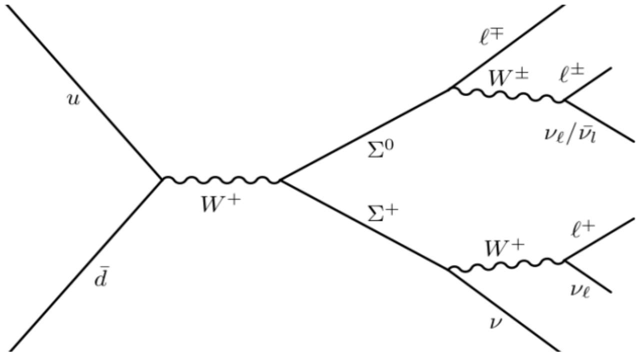
Summary of all Dark Matter Searches in **Run II :** Max and Min Limits on mediator search (blue) decaying to dark matter (red)



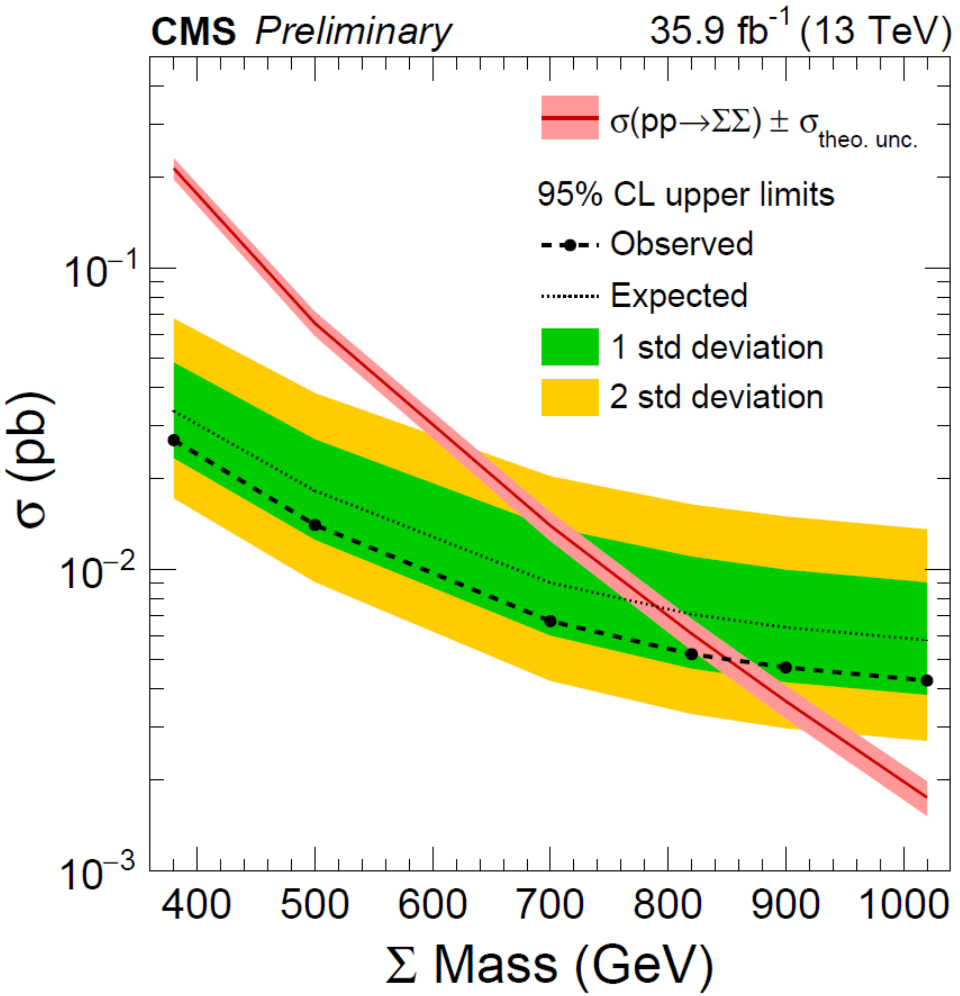
ICHEP16

Exotic : majorana neutrinos

A search for a **type-III seesaw** signal in events with three or more electrons or muons was performed



- **Constrains heavy majorana neutrinos**
- Limits **improved by ~400 GeV** from 2015

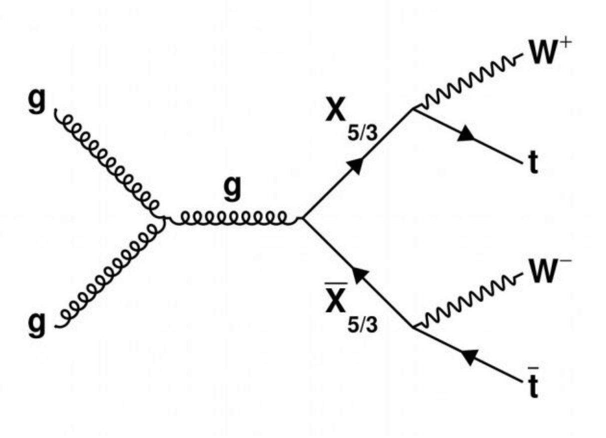


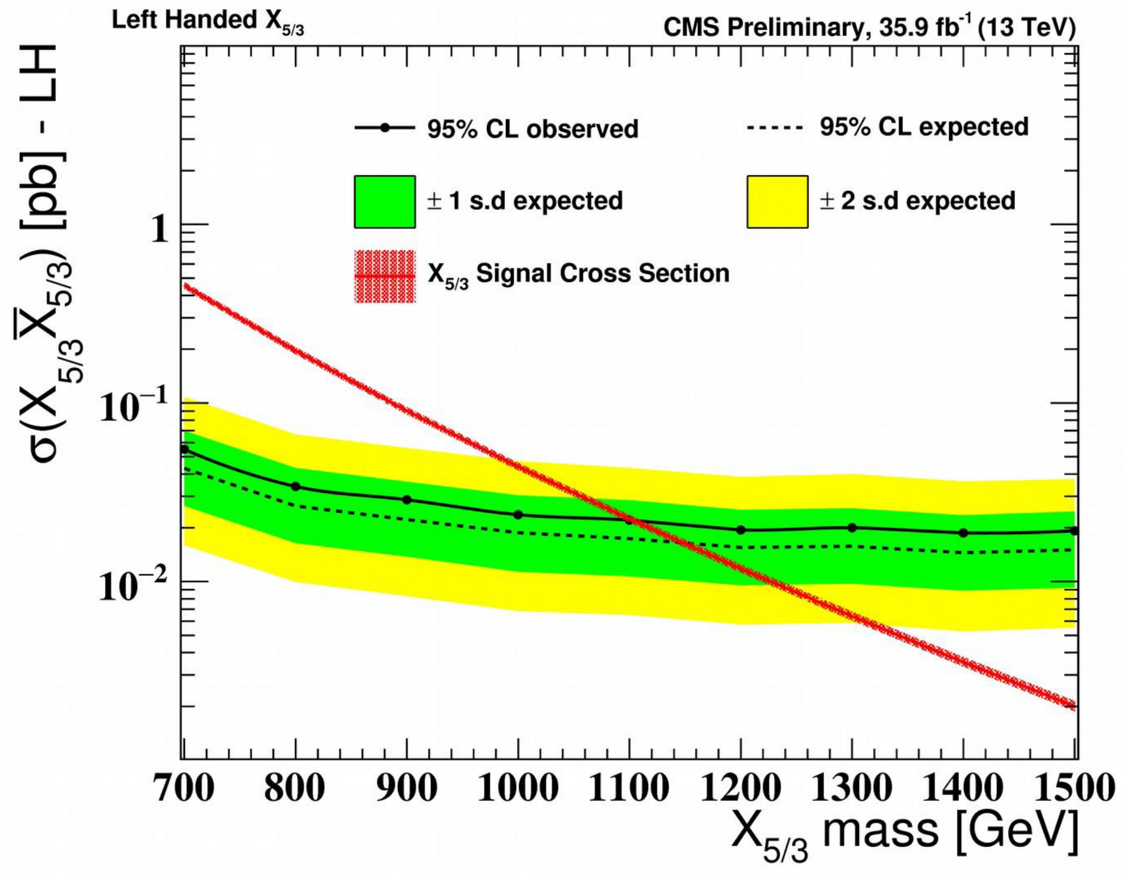
EXO-17-006

Beyond 2nd generation: $X_{5/3}$

B2G-16-019

SS 2ℓ events are used to constrain the top partner $X_{5/3}$





- No significant deviations
- **Limits on mass at 1.10 (1.16) TeV** on left(right)-handed $X_{5/3}$: **improved by ~200 GeV from 2015**

Summary

- Very **successful operation** of the LHC and CMS in 2016

- **Higgs** was rediscovered and measured with Run II data : its properties **consistent with the SM** expectations within uncertainty

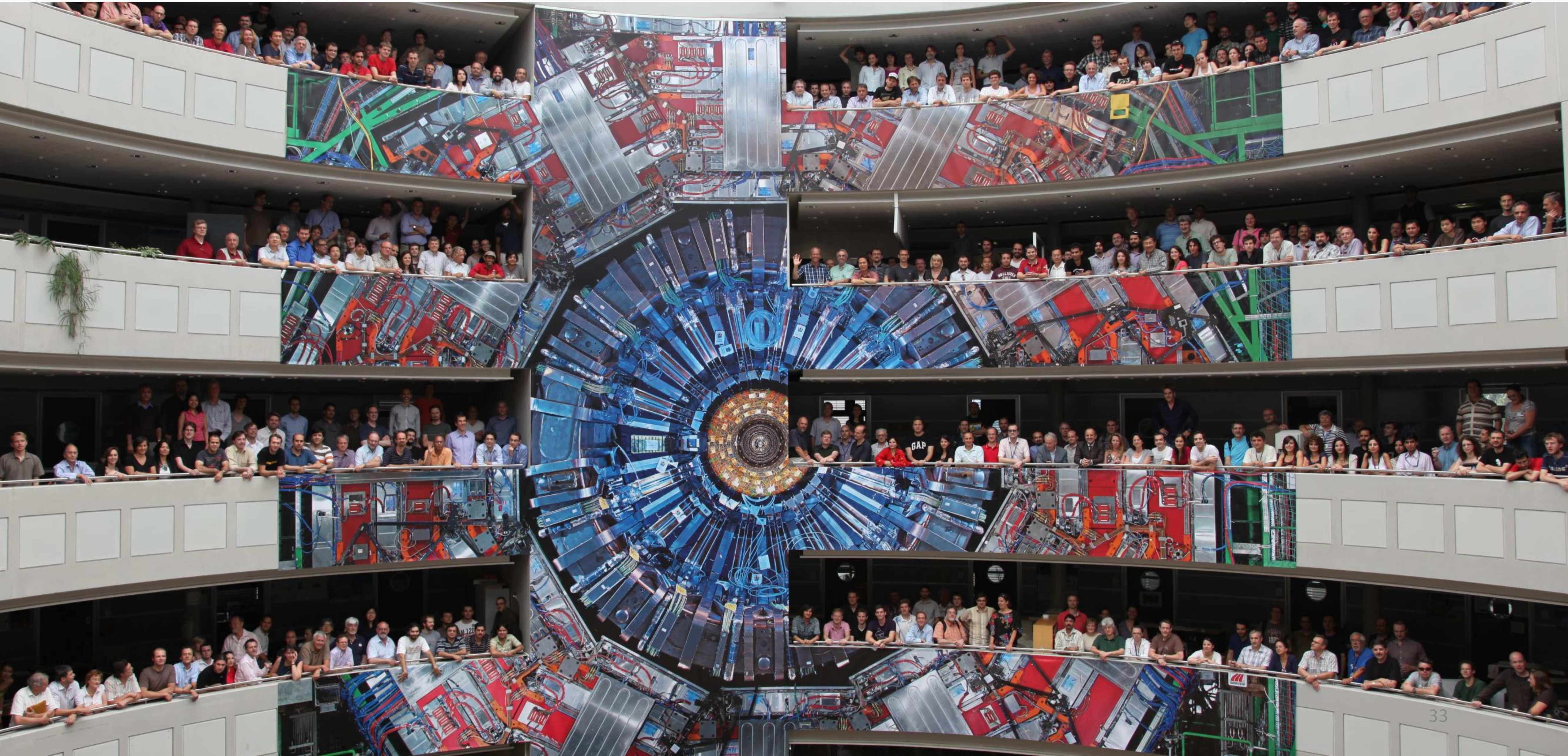
- **Precision results** on **SM process measurements** are crucial for better understanding of LHC physics : **consistent with standard model**

- **Known excesses** (such as diphoton in 2015) **not confirmed** using 2016 data

- Searches for **BSM physics**: **no new significant excesses observed**

- **Many more CMS analyses are public** and were not presented in this talk. **More CMS results will come with full 2016 data!**

Thanks for your attention!

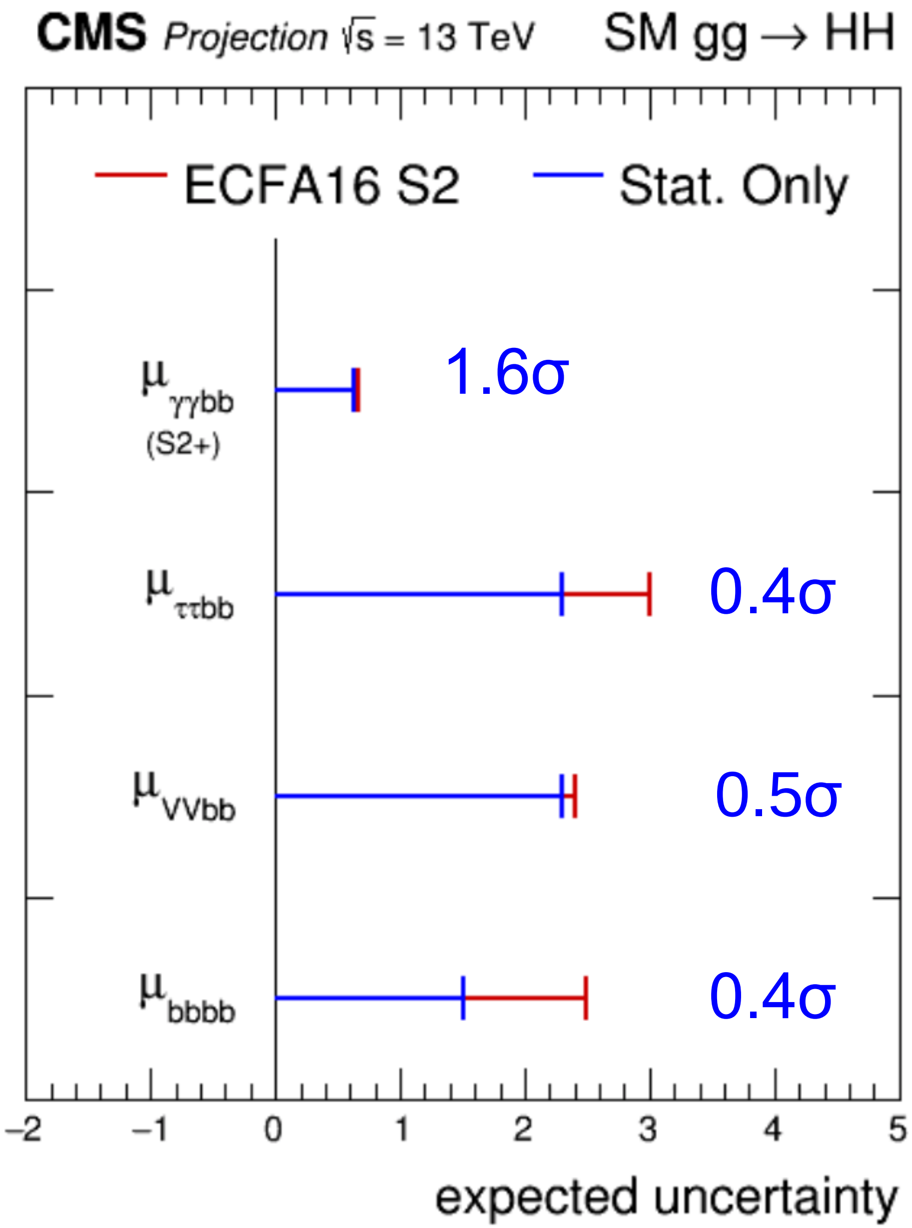


Backup slides

H(125)H(125) : 3000fb^{-1}

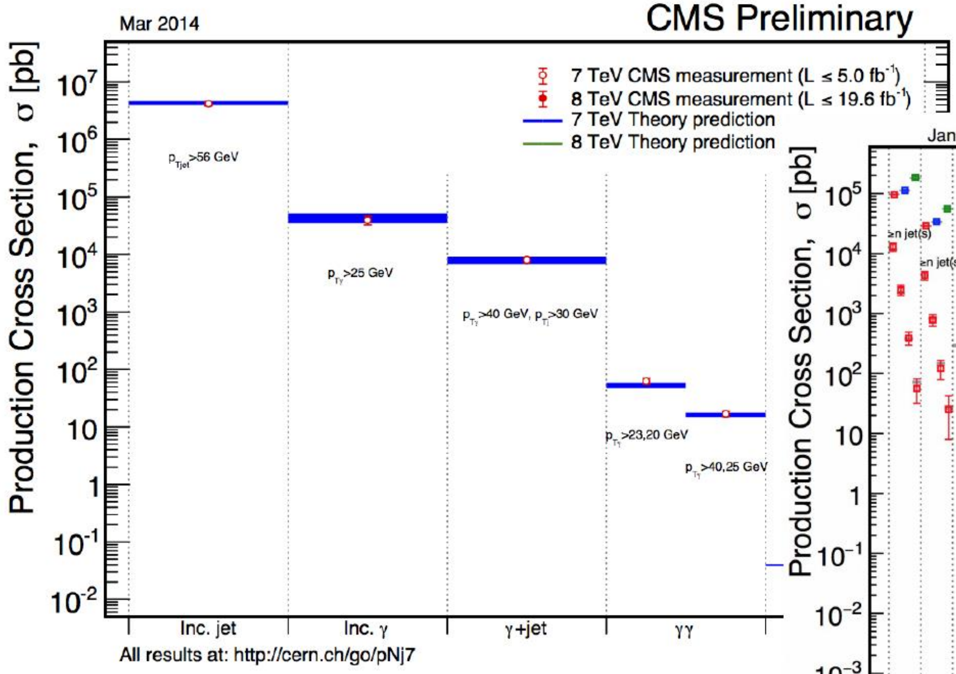
Extrapolation from 2015 to HL-LHC (3000 fb^{-1})
(but analyses improve fast)

CMS-FTR-16-002

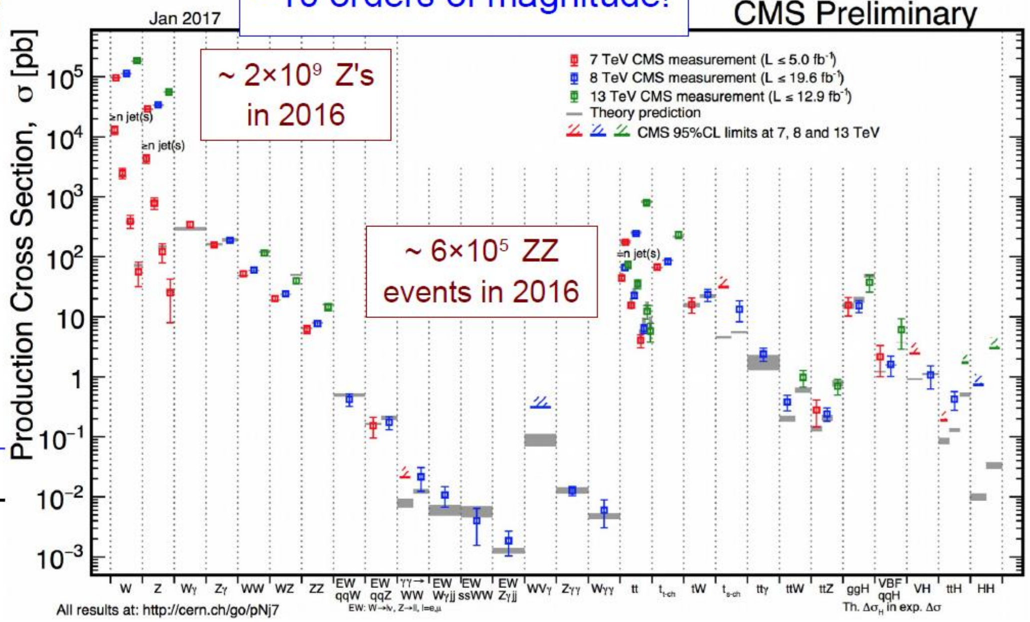


Why Standard Model Physics?

- SM precision measurements are important at the LHC
  - test a wide range of QCD and EW predictions to the highest energies available
  - tune theoretical calculations and MC generators
  - provide precise modeling of backgrounds to many searches
    - any deviation from the SM expectation may be a sign of new physics!



Test of the SM over ~10 orders of magnitude!



W/Z- boson production cross sections

Precise measurements using weak gauge Bosons:

- Huge statistic, clean signature
- Experimental uncertainties: **better than 1%**
- Excellent calibration and control of systematics
- Luminosity uncertainty: **2% - 3% => most precise measurements are ratios.**

CMS@8 TeV:

Phys.Rev.Lett.112(2014)191802

$\sigma(Z \to \ell\ell)$ = 1138 pb ±0.07% (stat) ±2.2% (theo) ±2.6% (lumi)

ATLAS@8 TeV:

$\sigma(Z \to \ell\ell)$ = 1154 pb ±<0.1% (stat) ±1.8%(syst) ±0.6%(beam) ±1.9% (lumi)

ATLAS@7 TeV:

JHEP 02 (2017) 117

$\sigma(Z \to \ell\ell)$ = 995 pb ±0.1% (stat) ±1.8%(syst) ±0.6%(beam) ±1.8% (lumi)

CMS@13 TeV:

CMS-PAS-SMP-15-011

$\sigma(Z \to \ell\ell)$ = 1870 pb ± 0.1% (stat) ±1.9% (syst) ±2.7% (lumi)

ATLAS@13 TeV:

JHEP 02 (2017) 117

$\sigma(Z \to \ell\ell)$ = 1969 pb ± 0.1% (stat) ±1.8%(syst) ±0.7%(beam) ±2.1% (lumi)

ATLAS@7 TeV:

JHEP 02 (2017) 117

$\sigma^{fiducial}(W \to e^+\nu)$ = 2726 ± 1 (stat) ± 28(syst) ± 49 (lumi) pb

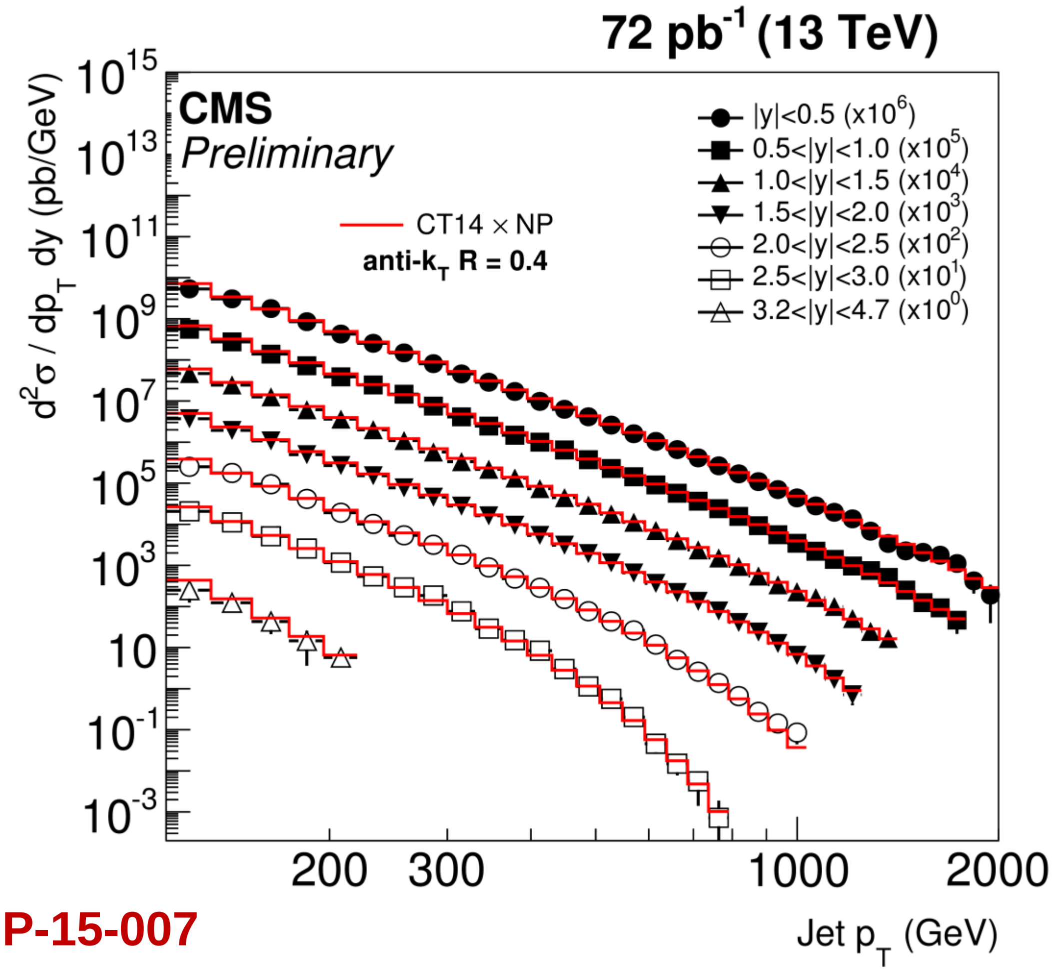
$\sigma^{fiducial}(W \to e^-\nu)$ = 1823 ± 1 (stat) ± 21(syst) ± 33 (lumi) pb

$\sigma^{fiducial}(W \to \mu^+\nu)$ = 2839 ± 1 (stat) ± 17(syst) ± 51 (lumi) pb

$\sigma^{fiducial}(W \to \mu^-\nu)$ = 1901 ± 1 (stat) ± 11(syst) ± 34 (lumi) pb

Jet Production

- Double- and triple-differential (di)jet cross section vs jet p_T and y ($|y_1 + y_2|$, $|y_1 - y_2|$)
- Measurement covers ~7 orders of magnitude, for jet p_T up to ~ 2 TeV
- Compared with NLO QCD predictions + NLO EW + nonperturbative effects



very good agreement over most of the phase space

SMP-15-007

Anomalous gauge couplings

- Triple and quartic gauge couplings
  - Non-zero in SM: WWγ / WWZ / WWγγ … etc.
  - Zero in SM: Zγγ / ZZγ / ZZZ / ZZγγ … etc.

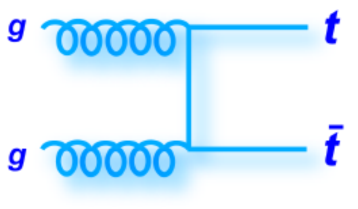
- Anomalous couplings defined in different approaches:
  - Modifying couplings in SM Lagrangian (Δg_1^V, $\Delta\kappa^V$, λ^V) or, equivalently, introducing effective extra vertices (h_3^V, h_4^V / f_4^V, f_5^V)
  - In effective field theory, in terms of Wilson coefficients c_i and New Physics scales

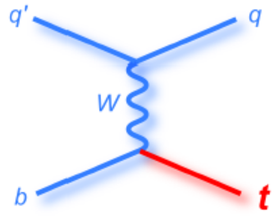
See e.g.: Degrande et al. , *Ann. Phys.* **335** (2013) 21

  - Caveat: the need for a form factor $\alpha_s(\hat{s}) = \frac{\alpha_s(0)}{(1+\hat{s}/\Lambda_{FF})^n}$ to preserve tree-level unitarity is often neglected in reporting experimental results ($\Lambda_{FF} \to \infty$) → not a large effect on aTGC limits

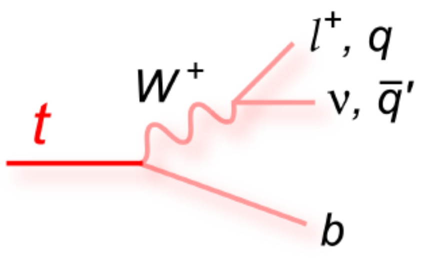
Top production & decay

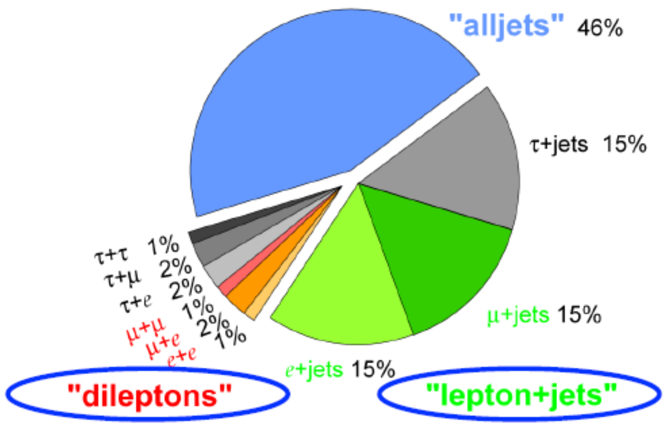
- Top production dominated by QCD production. EW production provides direct access to Wtb vertex:



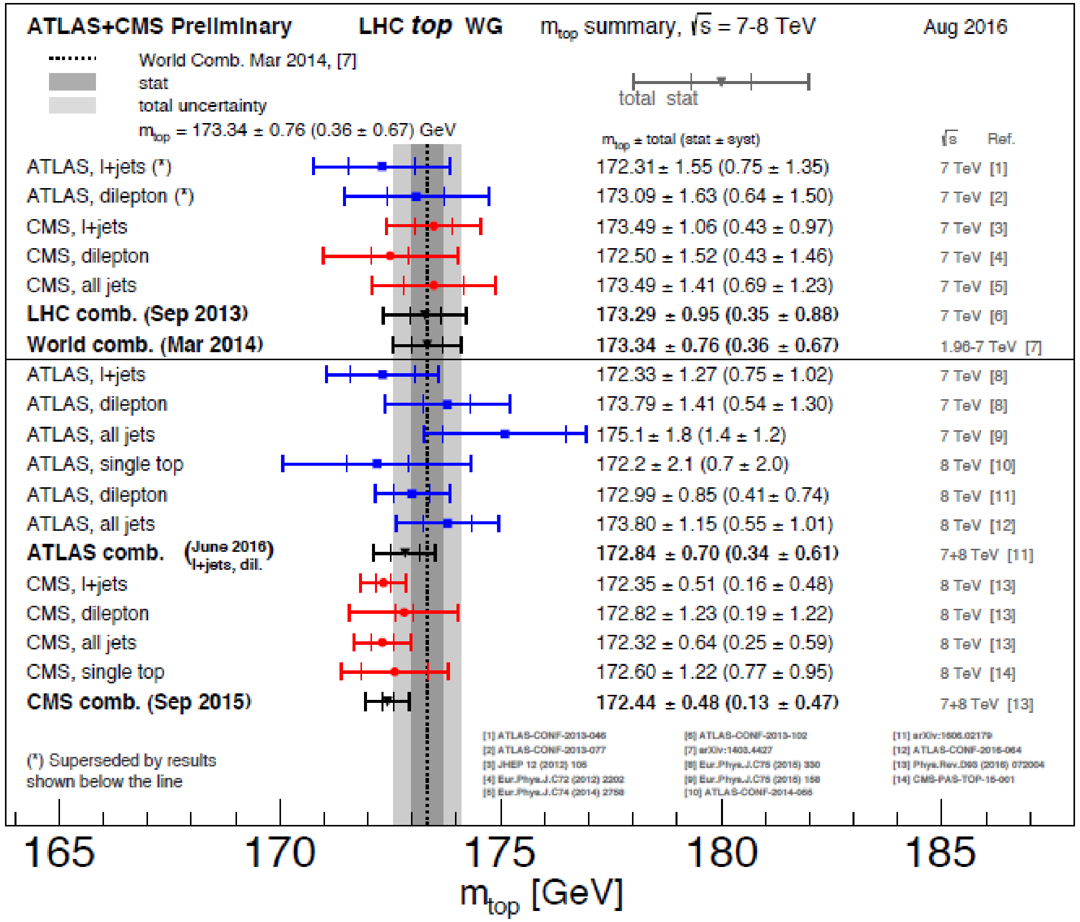


- In SM top decays to Wb:



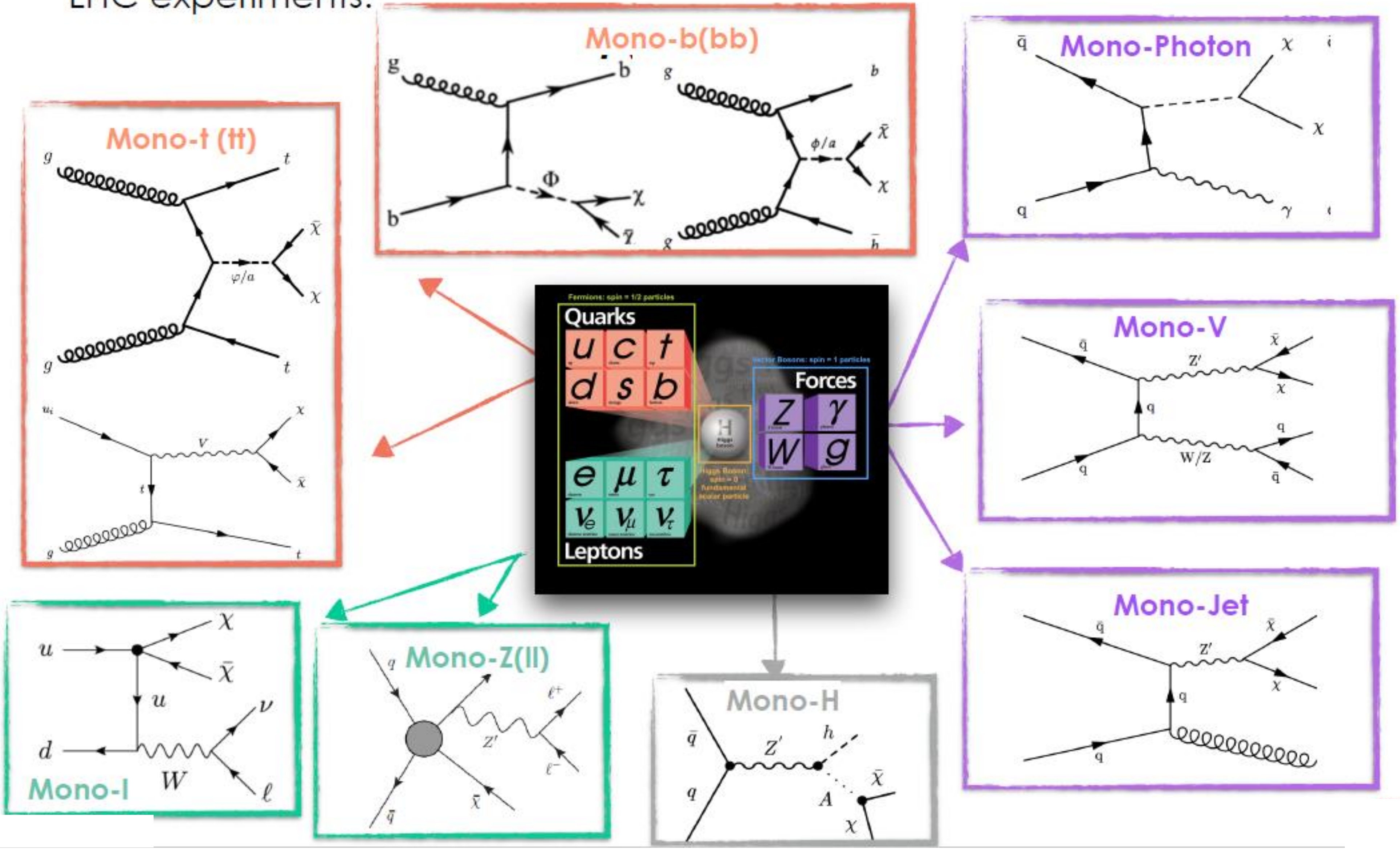


The top quark mass

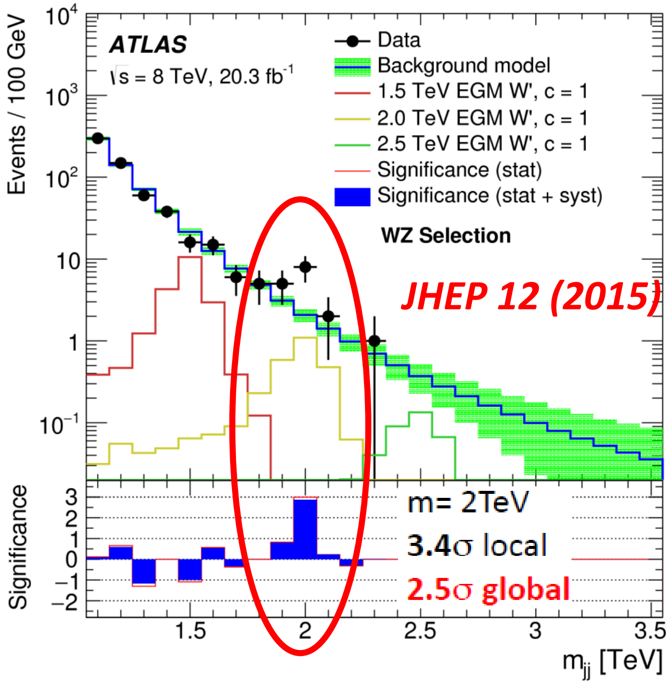


Dark Matter Searches at LHC

- A wide range of final states can be investigated exploiting the full potential of LHC experiments:



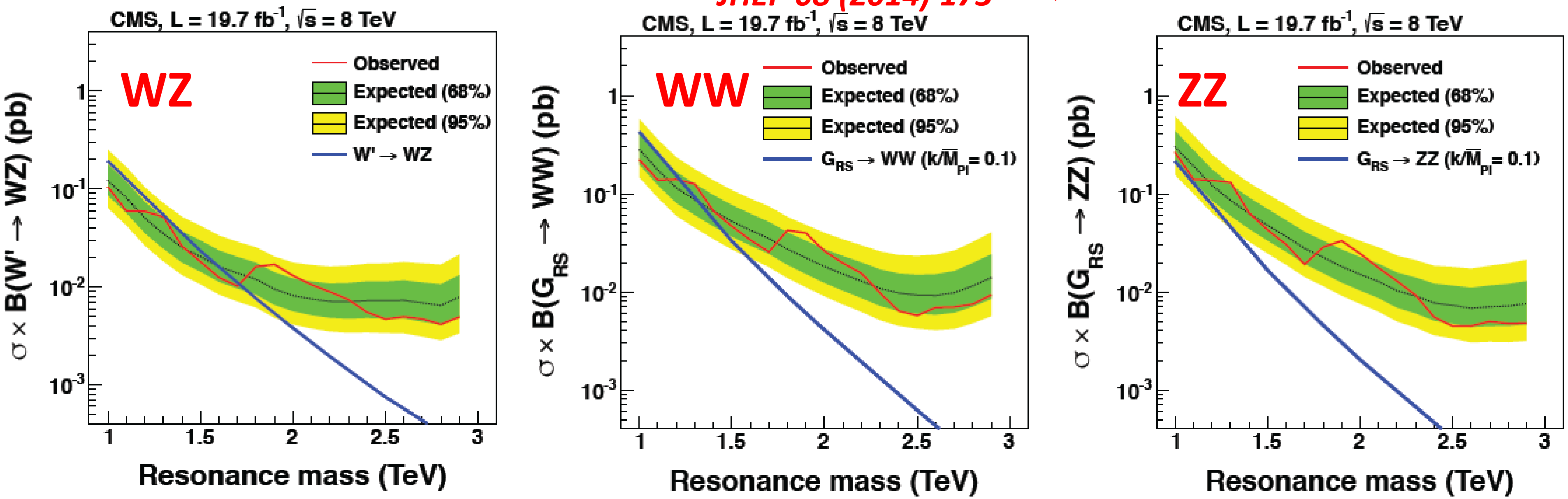
Search for Diboson VV Resonances



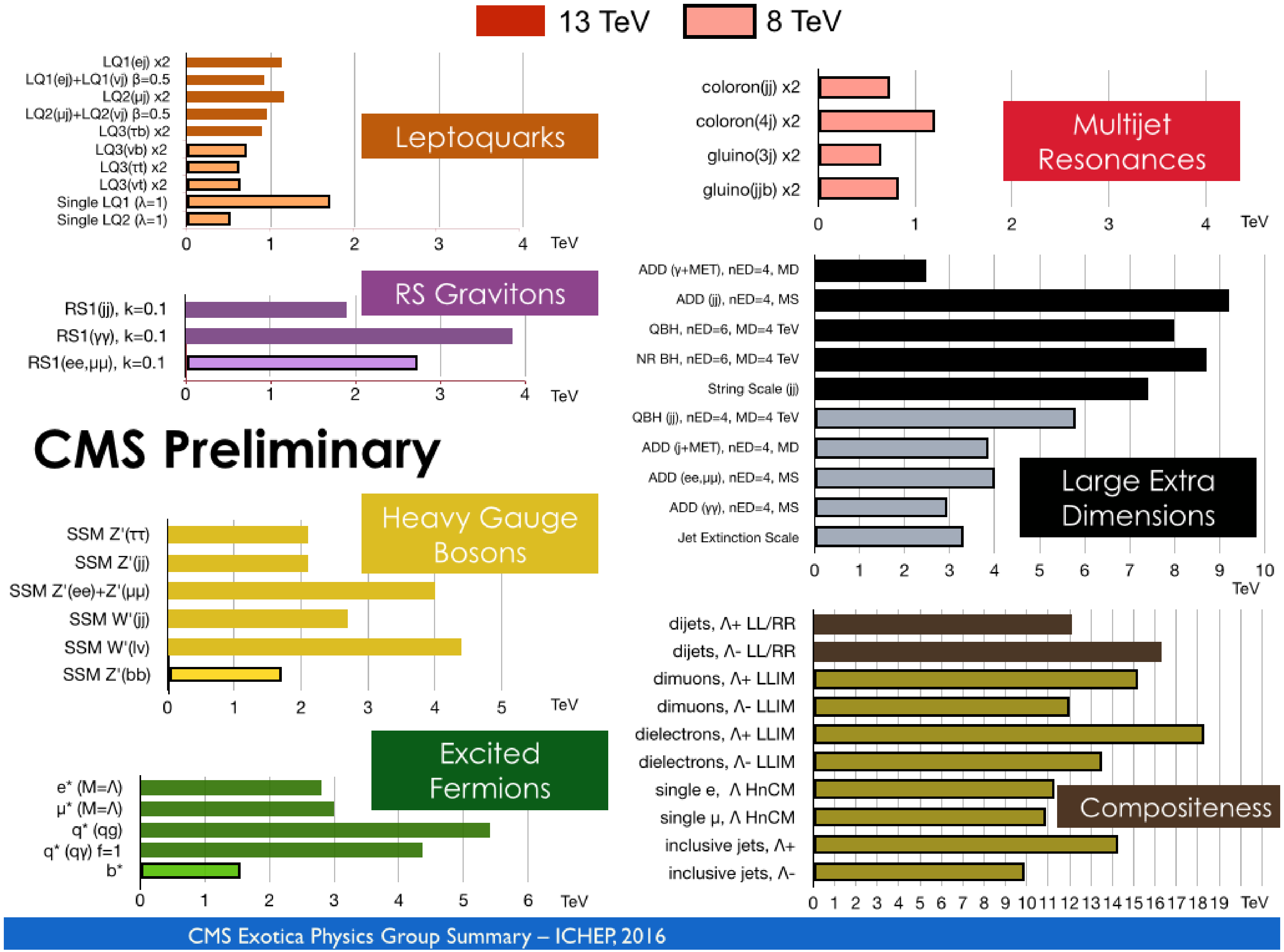
JHEP 12 (2015) 55

- **ATLAS Run1**: **~3σ excess** for all **hadronic** VV search (***~150 theory papers***), but **not confirmed** in the **semileptonic** channels
- **CMS Run1**: **a slight excess** is seen only in all-**hadronic** channels

JHEP 08 (2014) 173



EXO summary plot



Excluding Dark Matter and Long Lived particles searches

B2G summary plot