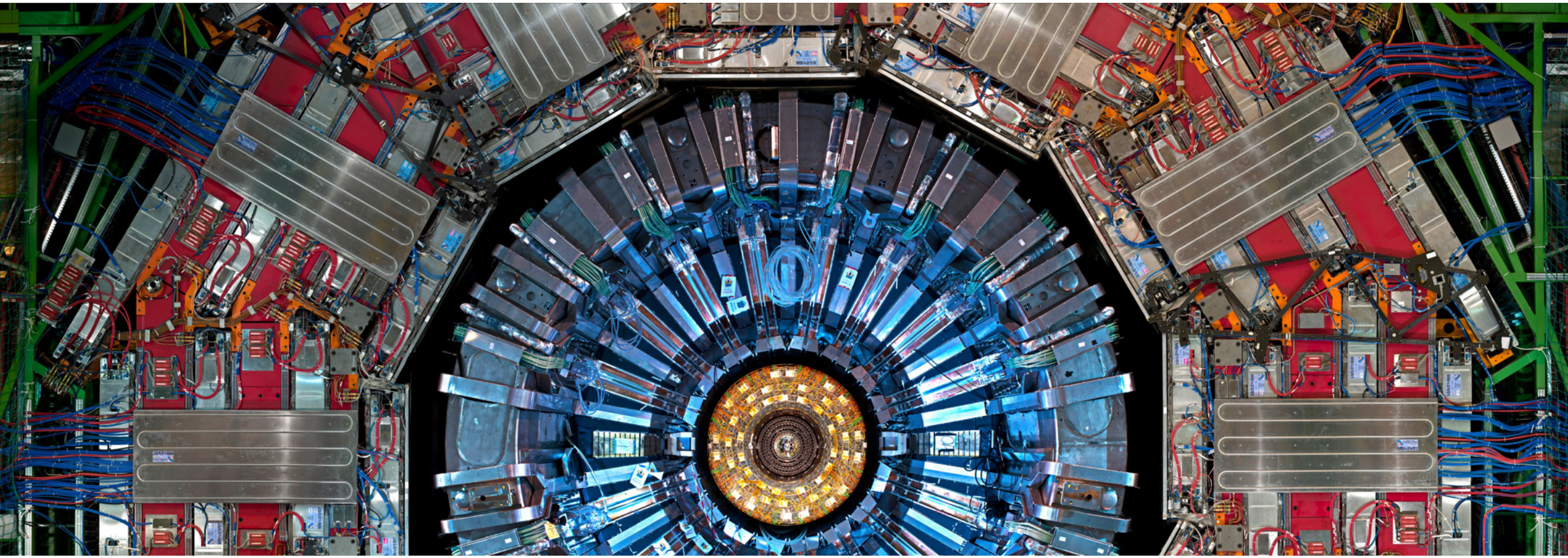


Recent results from the CMS Experiment

TeV Particle Astrophysics
CERN, 12-16 Sept. 2016

Francesco Costanza
on behalf of the CMS Collaboration

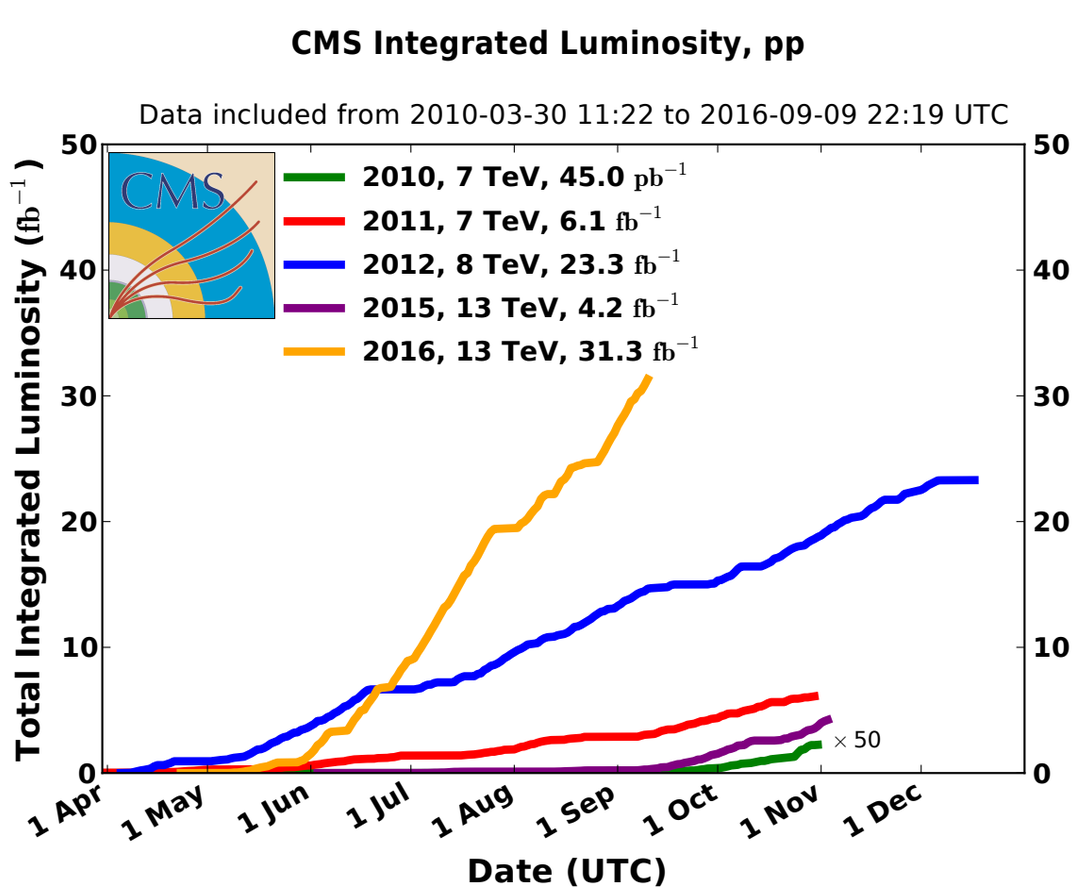
Outline

- ✓ LHC and CMS performance during 2016.
- ✓ Rediscovery of the Standard Model.
- ✓ Is H(125) still there?
- ✓ Search for Physics beyond the Standard Model:
  - Search for heavy resonances.
  - Dark matter searches.
  - Search for supersymmetric particles.

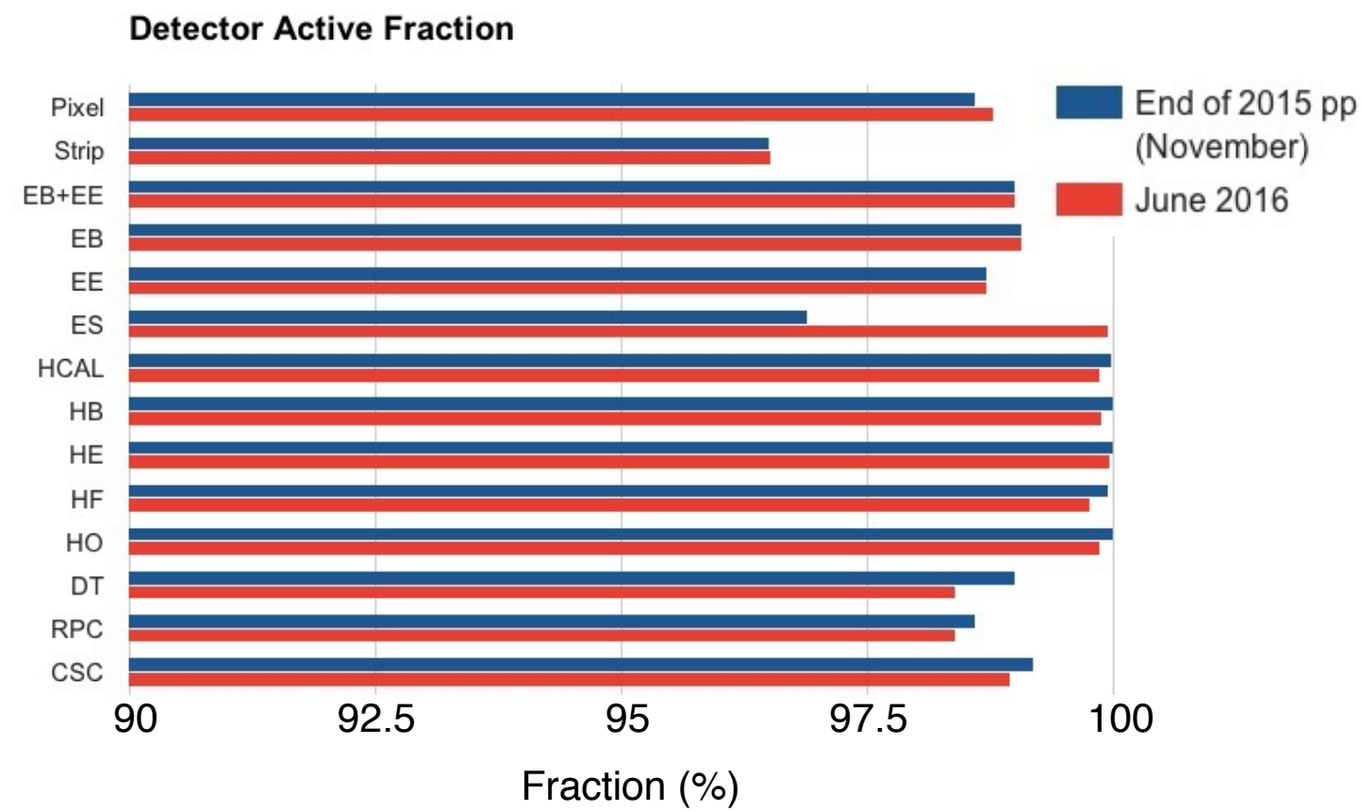
- ✓ In this talk:
  - Collection of highlights, not a comprehensive review.
  - Focus on 13TeV recently published results.

Taking data at $\sqrt{s}$ = 13 TeV

- ✓ LHC is breaking records after records with a maximum peak instantaneous luminosity of **1.2e97 $cm^{-2}s^{-1}$** already exceeding its design value and both ATLAS and CMS have collected more than **30fb^{-1}** since the beginning of 2016 data taking
- ✓ The CMS detector has been working spectacularly well, with no performance degradation over 3 years RunI and 2 years RunII operation.
  - ✓ Temporary performance losses were always recovered!

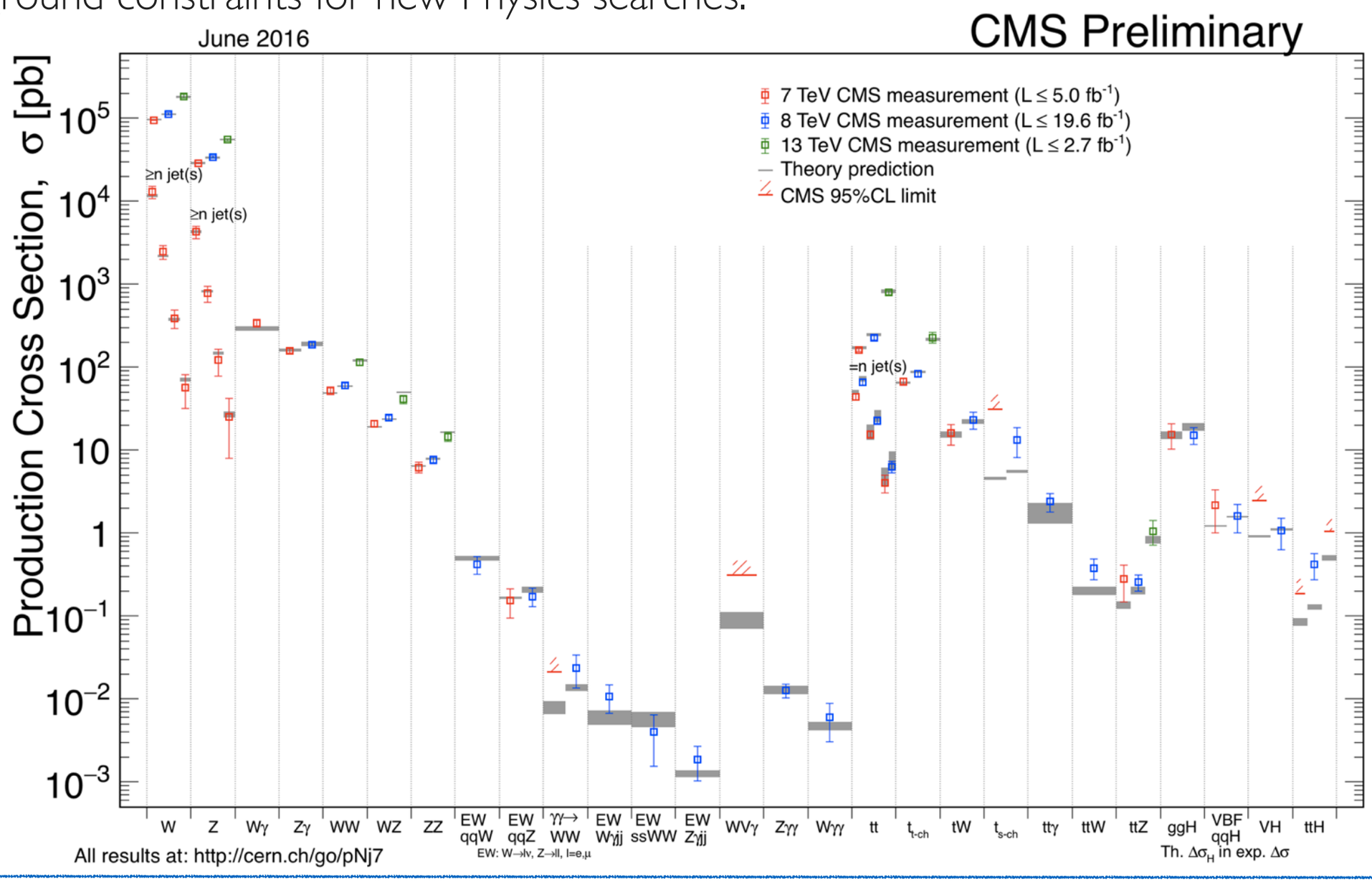


CMS status, June 2016



The Stairway Plot

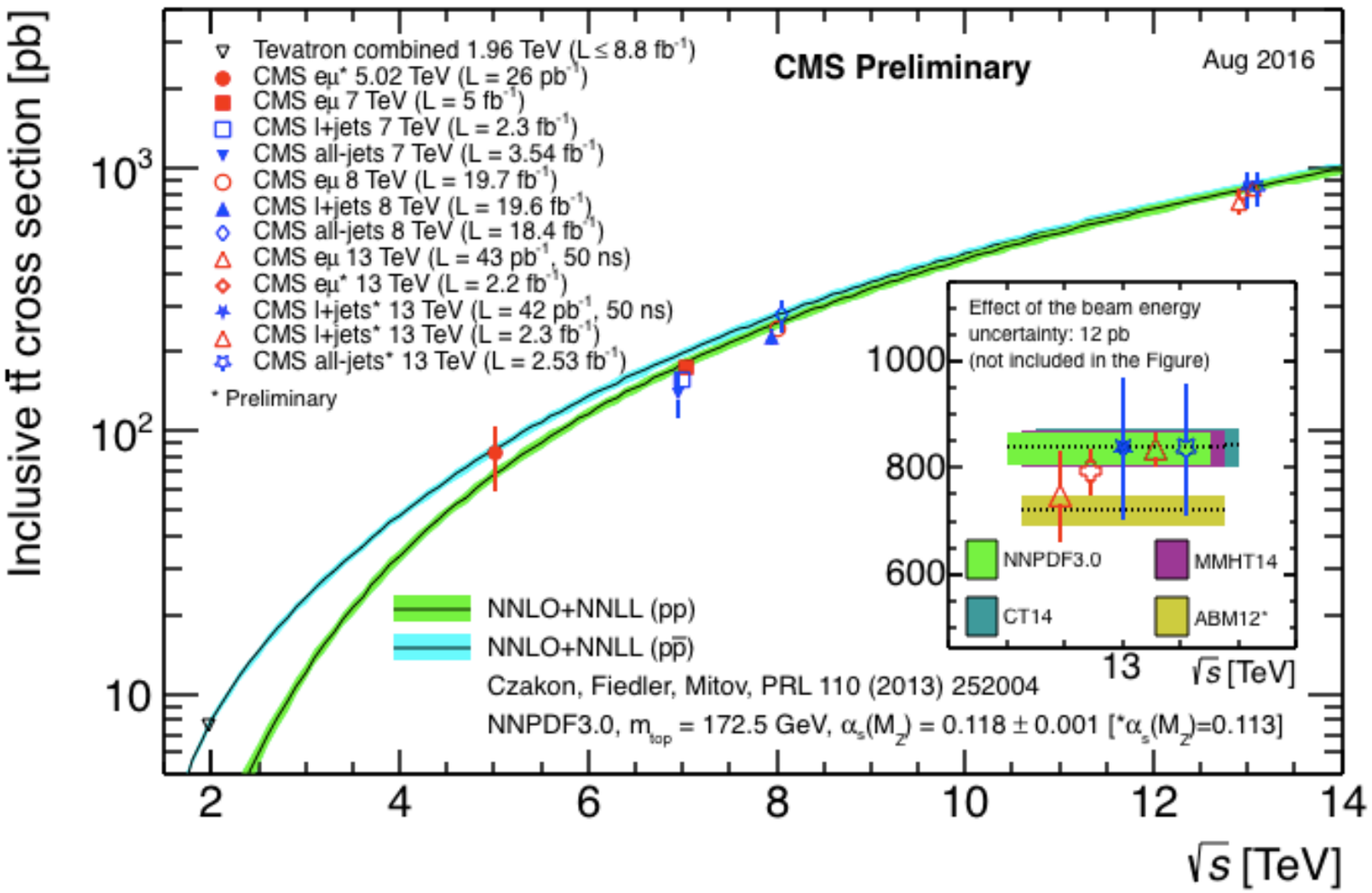
- ✓ The SM is extremely successful in predicting the x-sections for Z, W, dibosons, $t\bar{t}$, single top, $t\bar{t}V$,…
- ✓ Experimental precision now approaching theory precision.
- ✓ Huge data samples allows to probe phase space corners never probed before.
- ✓ Background constraints for new Physics searches.



LHC: a top quark factory

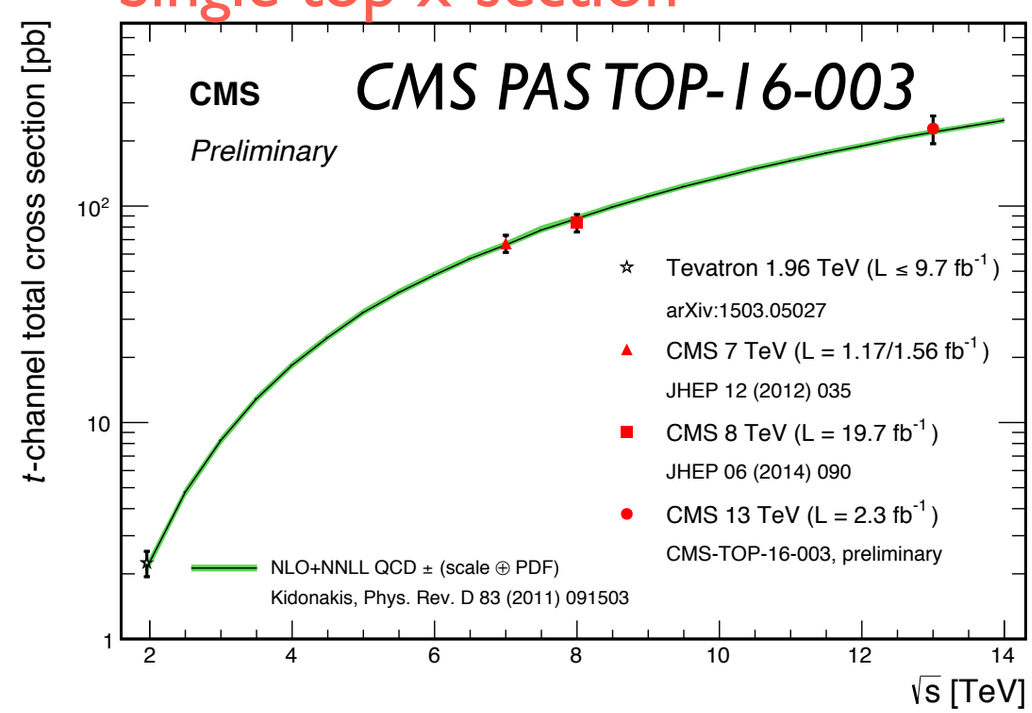
$t\bar{t}$ x-section

CMS PAS TOP-16-006



- ✓ $t\bar{t}$ x-section measured at 4 $\sqrt{s}$.
- ✓ Most precise measurement at 13TeV from l+jets analysis.

Single top x-section

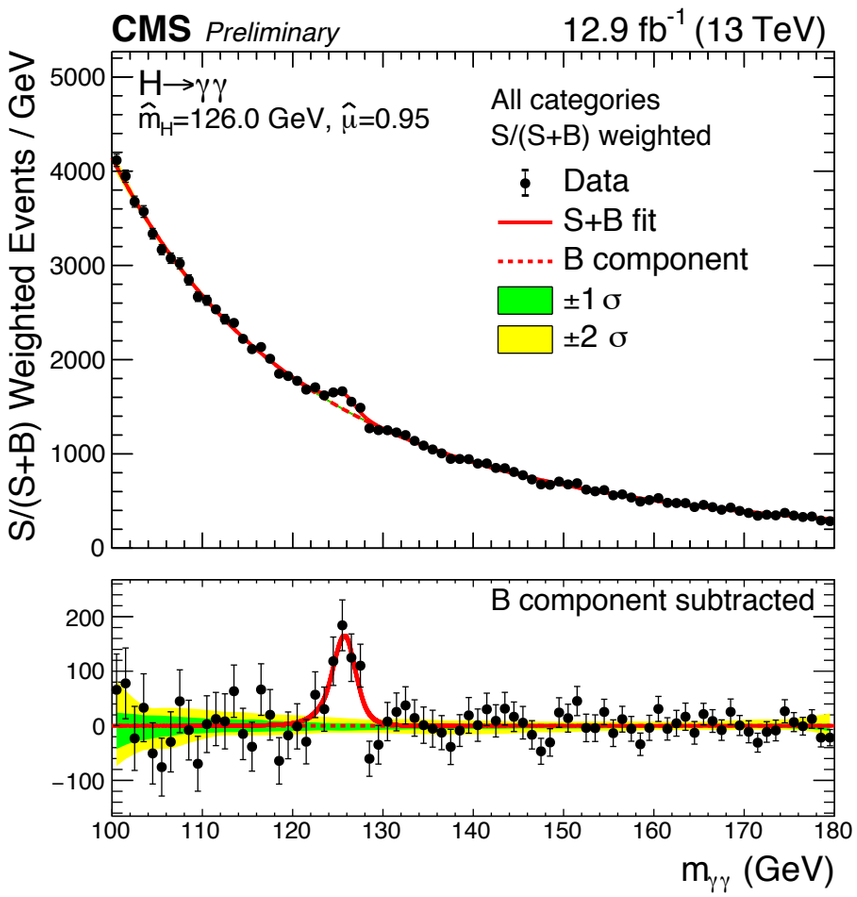


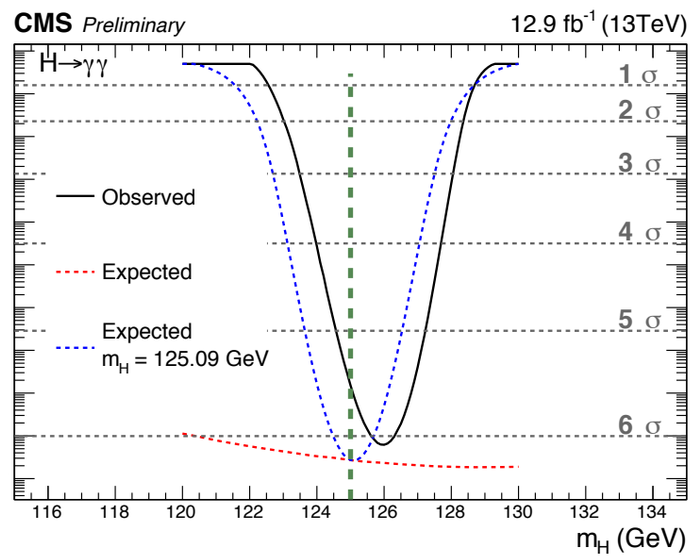
$$|f_{\mathrm{LV}} V_{tb}| = \sqrt{\frac{\hat{\sigma}_{\text{t-ch}}}{\sigma^{\text{th}}_{\text{t-ch}}}} = 1.02 \pm 0.07(\text{exp}) \pm 0.02(\text{th})$$

Higgs→$\gamma\gamma$

CMS PAS HIG-16-020

- ✓ Small BR predicted by the SM (~0.2%), huge background, but.. clean signature:
  - Two isolated photons giving an invariant mass peak.
  - Leptons, jets, and b-tagged jets are used for event categorization.
- ✓ Production modes addressed: **ggH, VBF, ttH.**

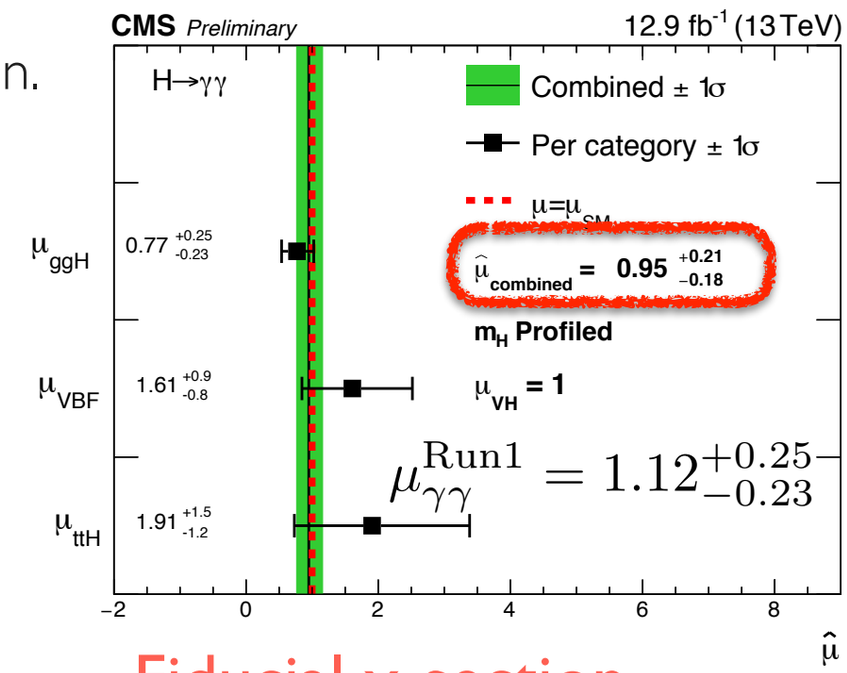




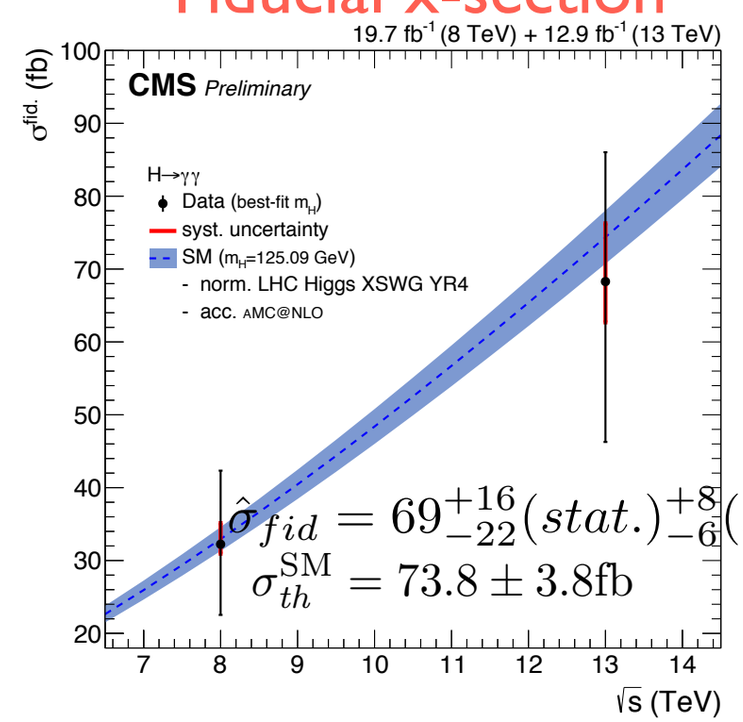
5.6σ observed

(6.2σ expected)

@ m$\gamma\gamma$=125.09 GeV

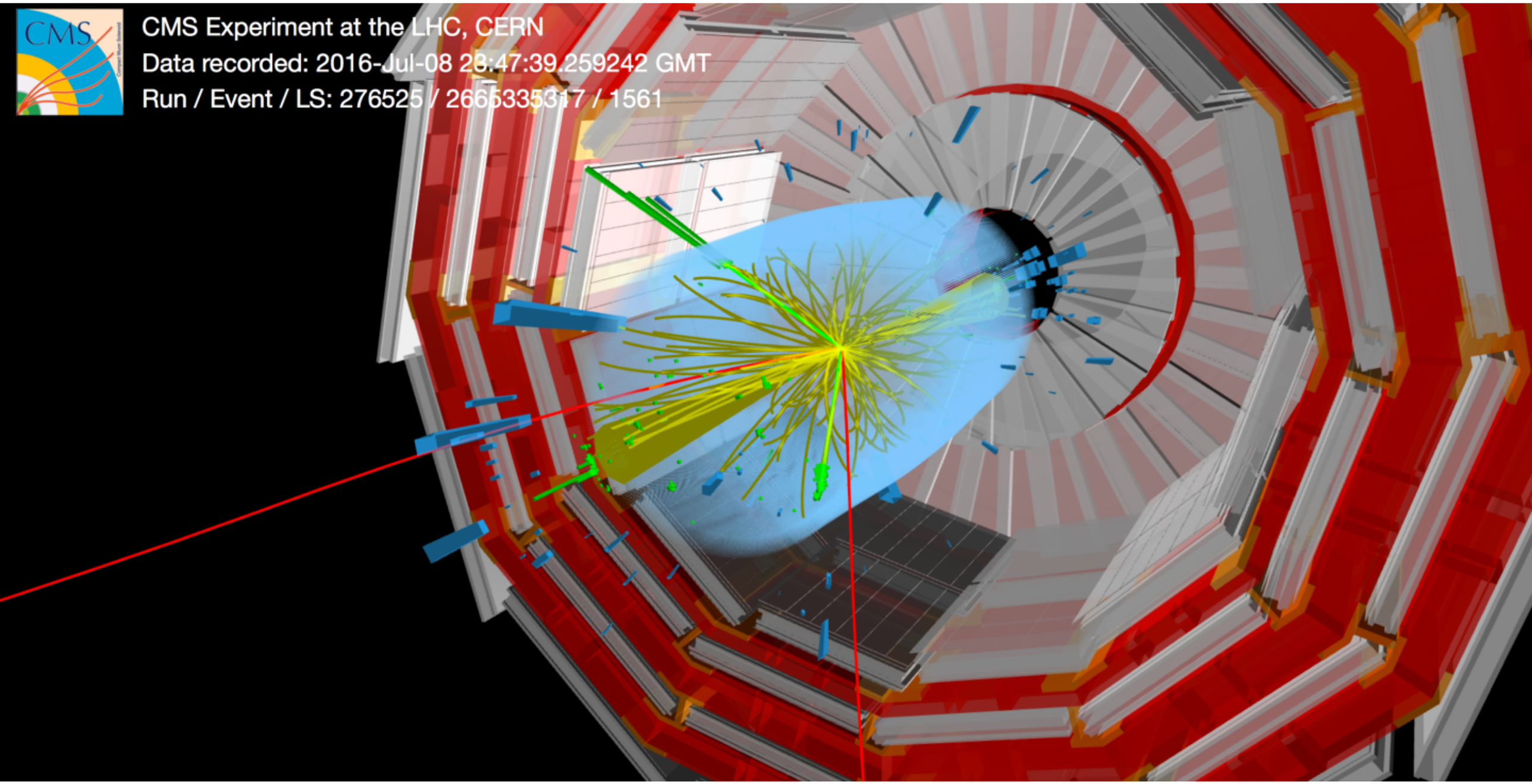


Fiducial x-section



- ✓ Measurement compatible with SM.
- ✓ Achieved similar precision to Run I.
- ✓ Results still dominated by statistical uncertainties.

Higgs→ZZ*→4l (l=e,μ)

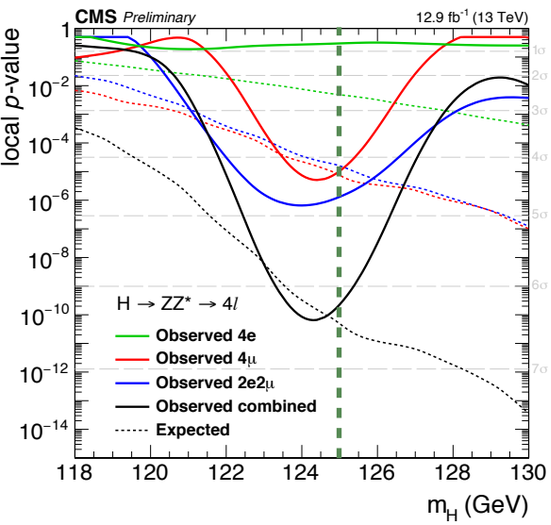


Spectacular H→ZZ→2e2μ candidate compatible with VBF!

Higgs→ZZ*→4l (l=e,μ)

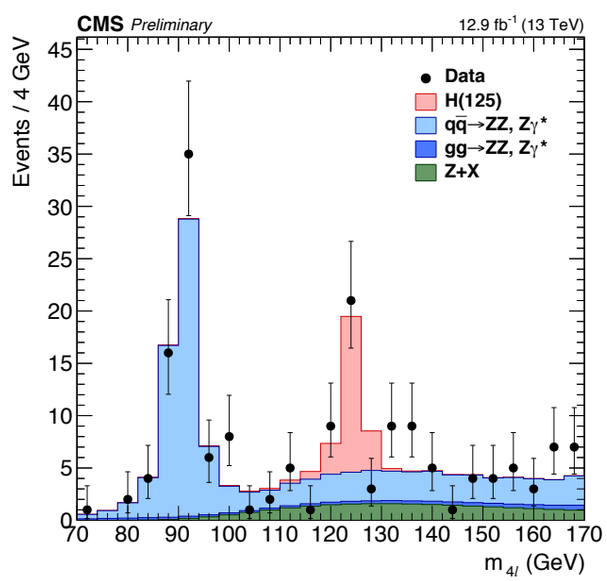
- ✓ Tiny signal but clean signature over a small background:
  - Two pairs of opposite-sign same-flavor electrons/muons.
- ✓ All production modes addressed: **ggH, VBF, VH, ttH.**

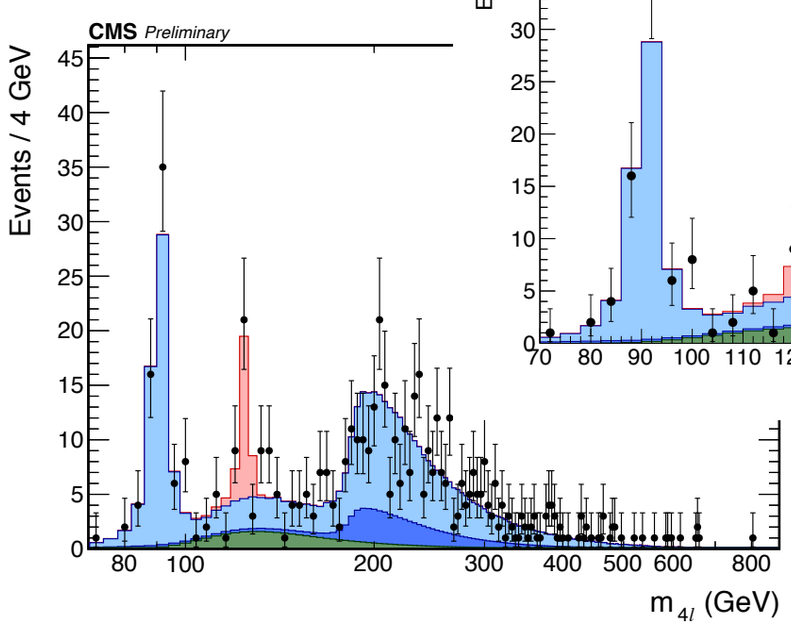
$$m_H = 124.50^{+0.48}_{-0.46}\ \text{GeV}$$
$$= 124.50^{+0.47}_{-0.45}(\text{stat.})^{+0.13}_{-0.11}(\text{sys.})\ \text{GeV}$$



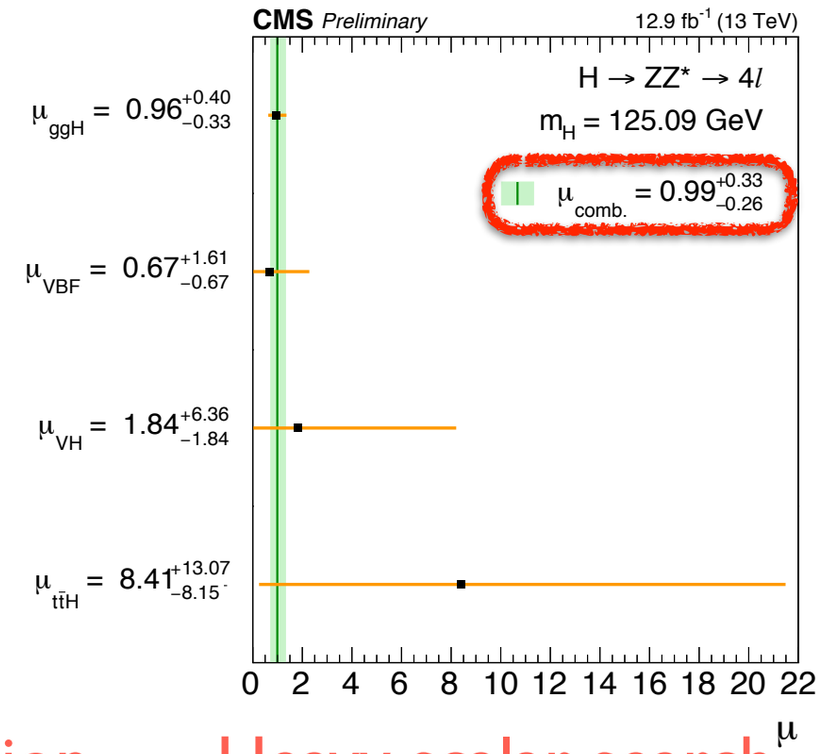
6.2σ observed
(6.5σ expected)
@125 GeV

Γ_H<41 MeV (using off-shell events)
No anomalies wrt to 0^+ hypothesis

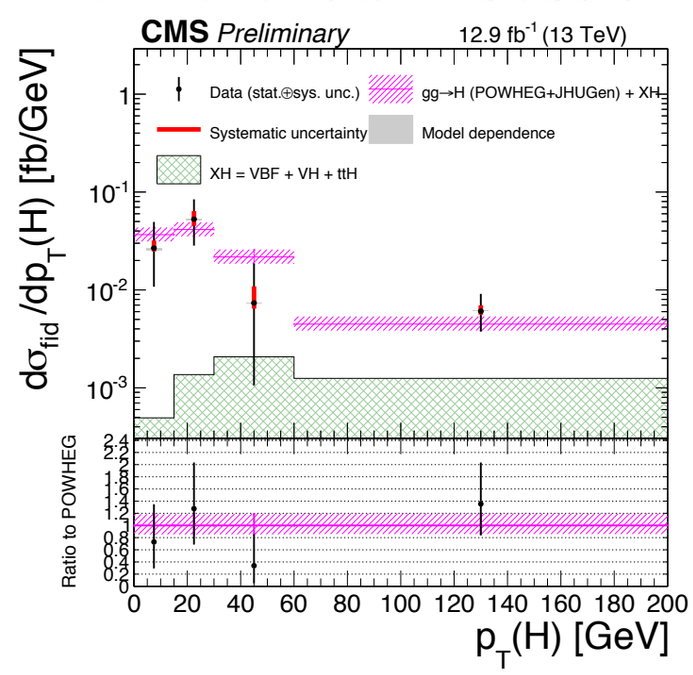




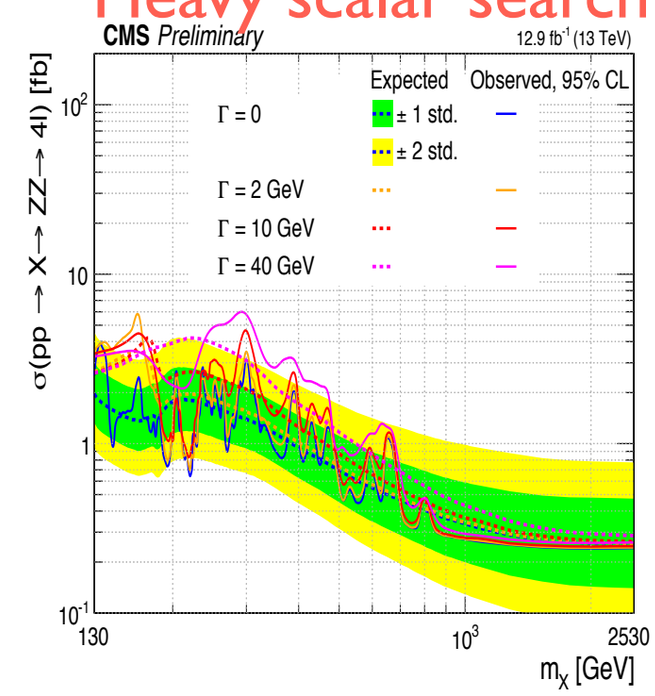
CMS PAS HIG-16-033



Differential x-section



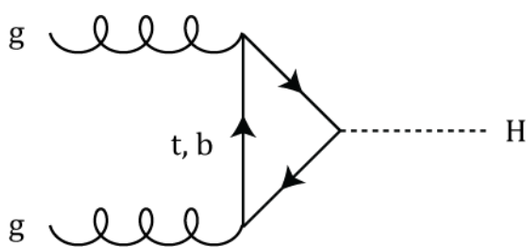
Heavy scalar search

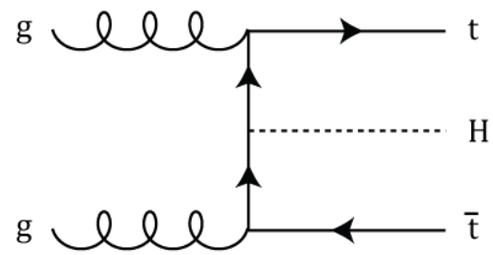


$\Delta\sigma/\sigma \sim 30\%$

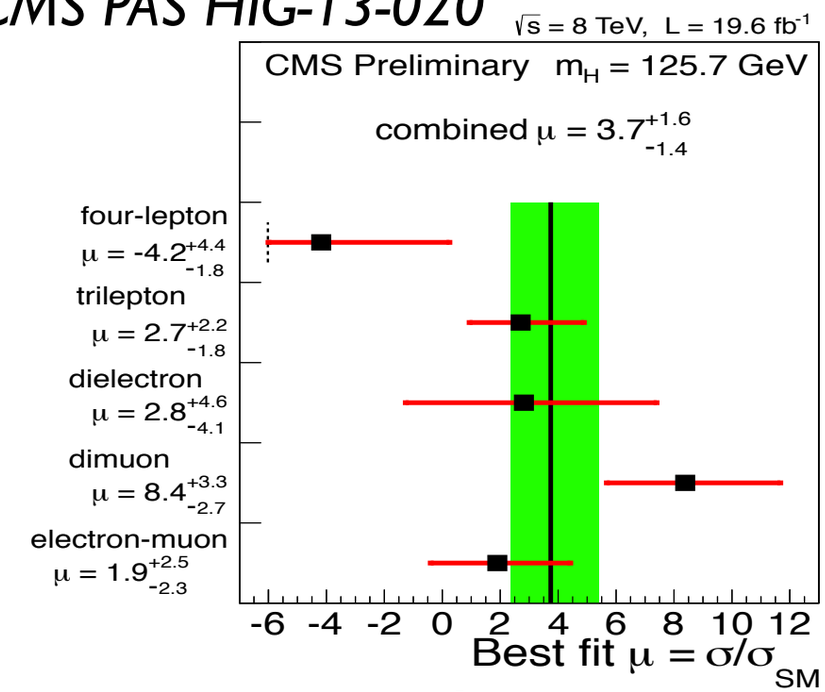
ttH searches

- Probing the top-Higgs Yukawa coupling at LHC:
  - Indirect: through ggH measurements, assuming no BSM particle in the loop.
  - Direct: associate ttH production.





CMS PAS HIG-13-020



ttH(→$b\bar{b}$) CMS PAS HIG-16-004
$t\bar{t}$ decaying in 1 or 2 leptons.

ttH(multilepton) CMS PAS HIG-16-022
addressing H → ZZ, WW, $\tau\tau$, additional leptons from top quark decays.

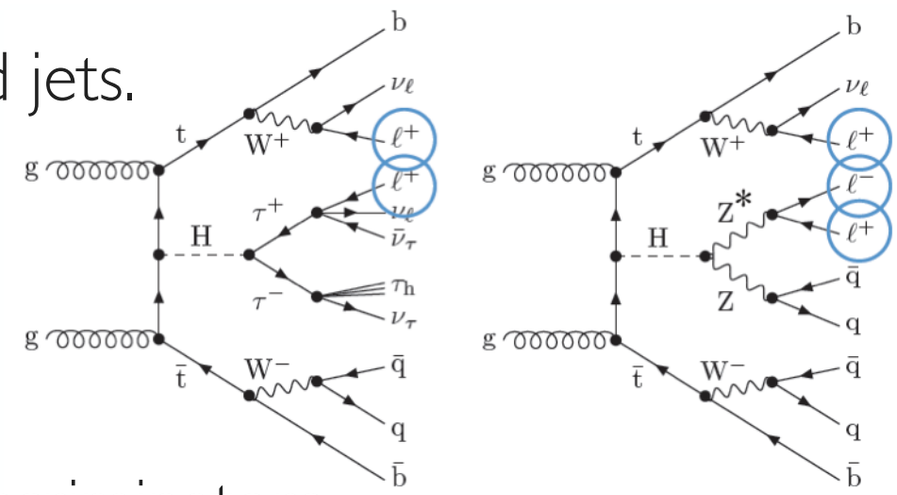
ttH(→$\gamma\gamma$) CMS PAS HIG-16-020
part of overall analysis.

Decay mode	BR (%)
H→$b\bar{b}$	58.1
H→WW	(<) 21.5
H→$\tau\tau$	(<) 6.3
H→ZZ	(<) 2.6
H→$\gamma\gamma$	0.23

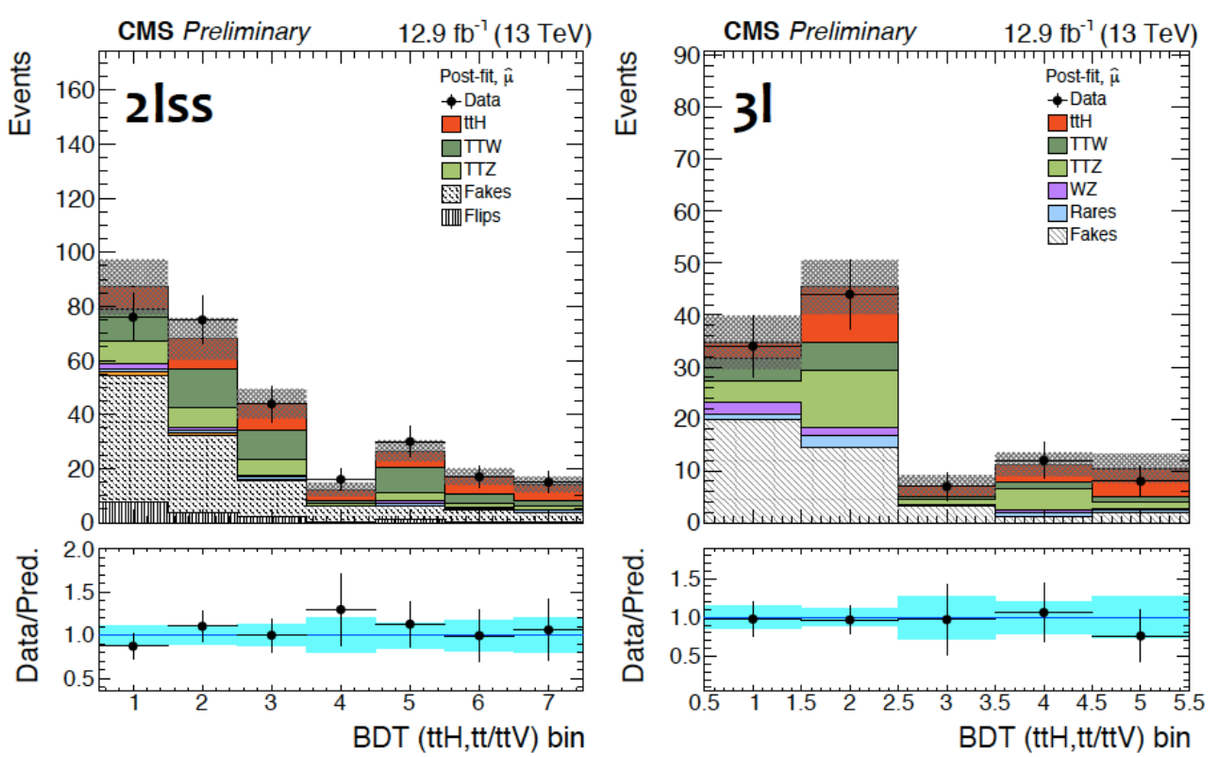
ttH multilepton

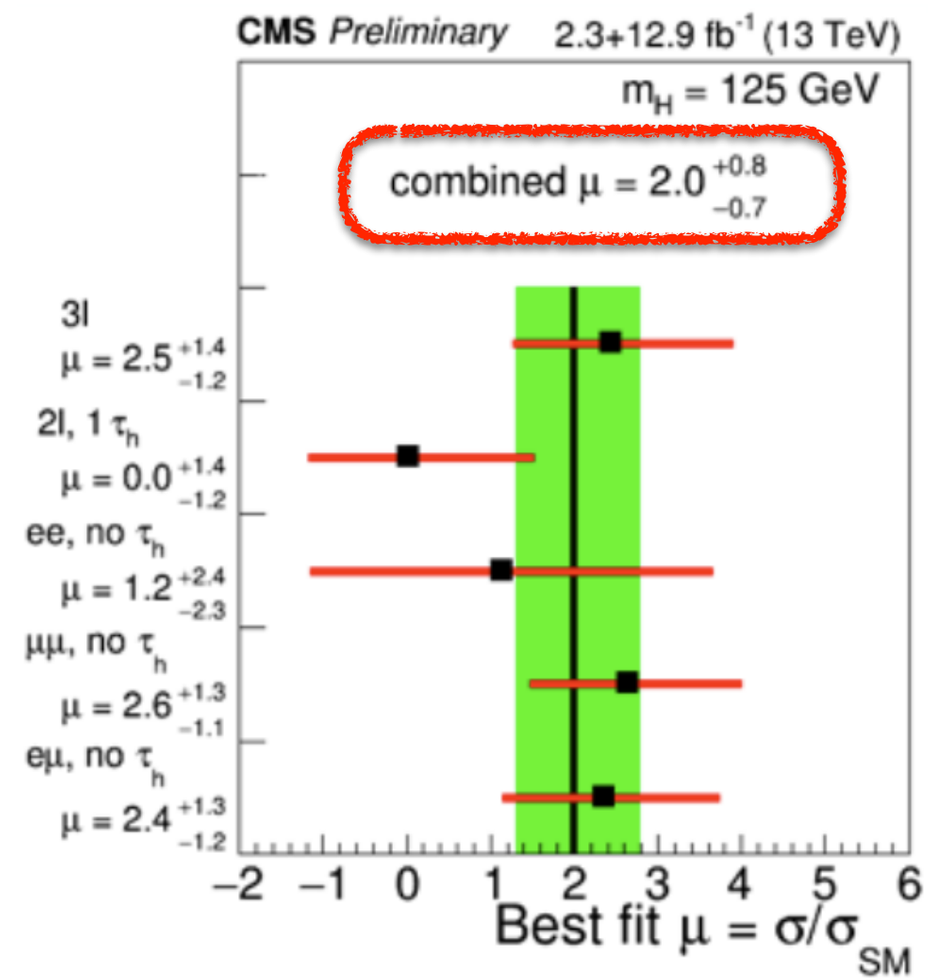
CMS PAS HIG-16-022

- ✓ Signature: two same-charge leptons or at least three charged leptons, b-tagged jets.
- ✓ Main Backgrounds:
  - ✓ Irriducibile: ttV and diboson.
  - ✓ reducible: non-prompt leptons in $t\bar{t}$ events and charge mis-ID.
- ✓ Signal extraction: 2D fit on the BDT discriminators specifically optimized for $t\bar{t}$ and $t\bar{t}V$ rejection.



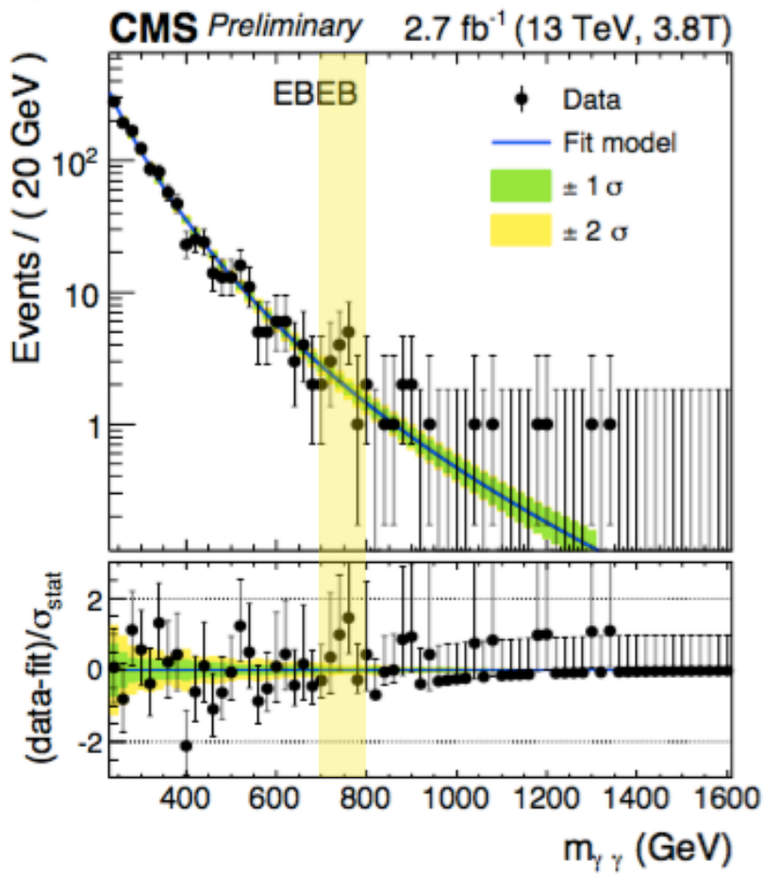
BDT classifiers used for signal extraction



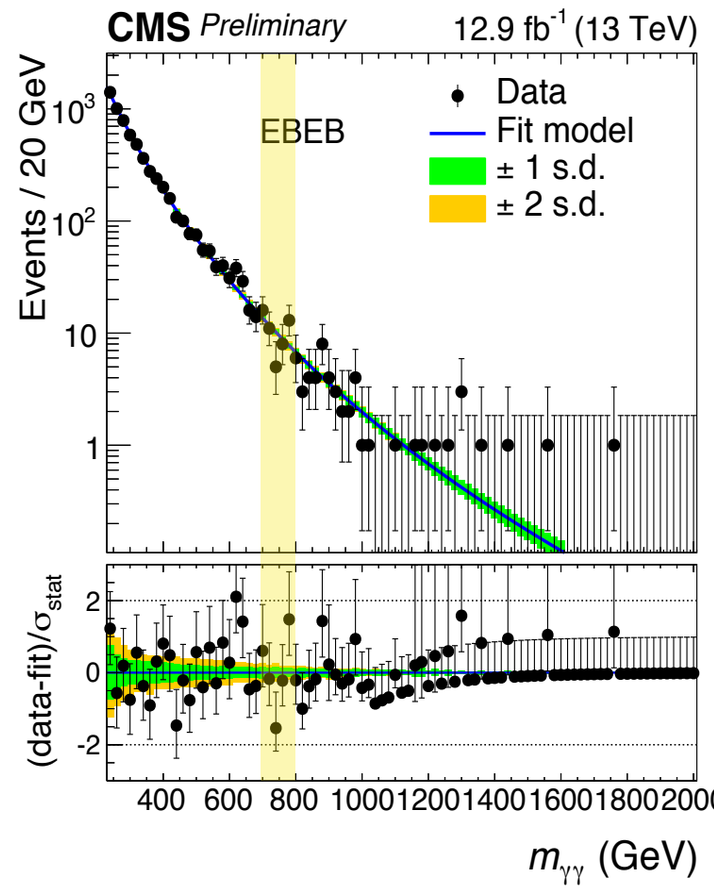


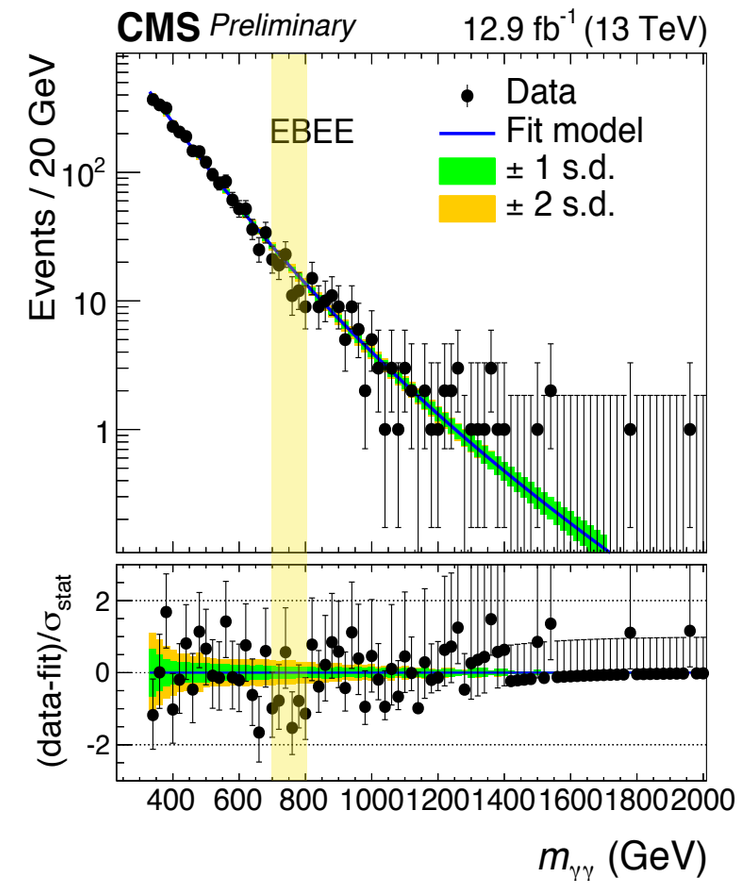
Search for diphoton resonances

Phys. Rev. Lett. 117 (2016) 051802

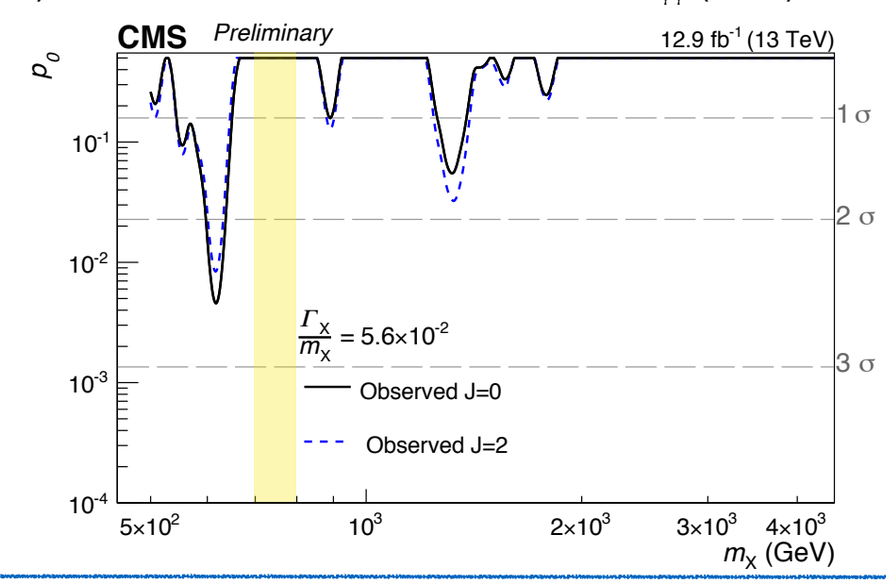


CMS PAS EXO-16-027





- ✓ 2015 dataset:
  - Local/global significance for narrow resonance = 3.4/1.6 σ
  - Similar observation from ATLAS (for sure you saw in the previous talk!)
- ✓ 2016 strategy: 2015 reloaded
  - Event deficiency observed around 750 GeV



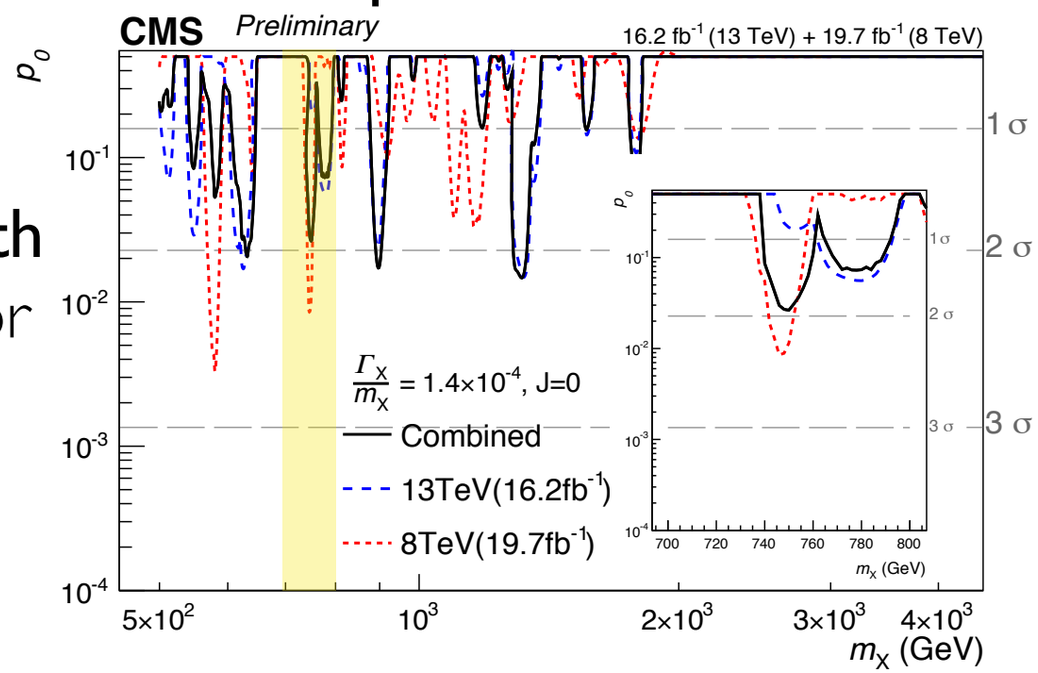
Diphoton: combined results

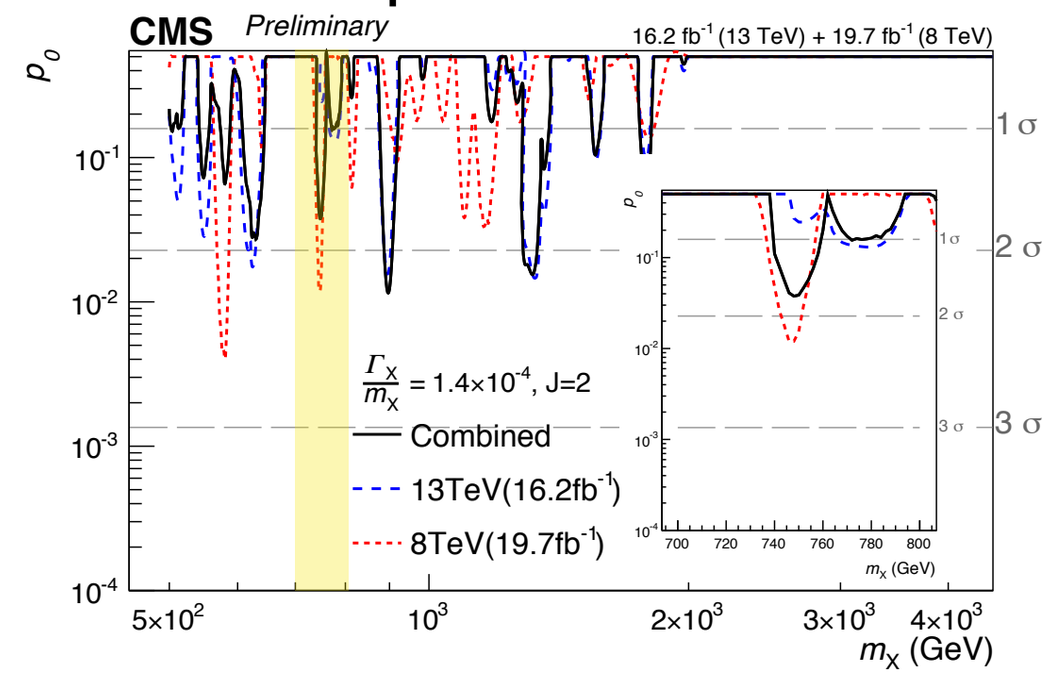
- ✓ Combination of 2012, 2015, and 2016 results.

CMS PAS EXO-16-027

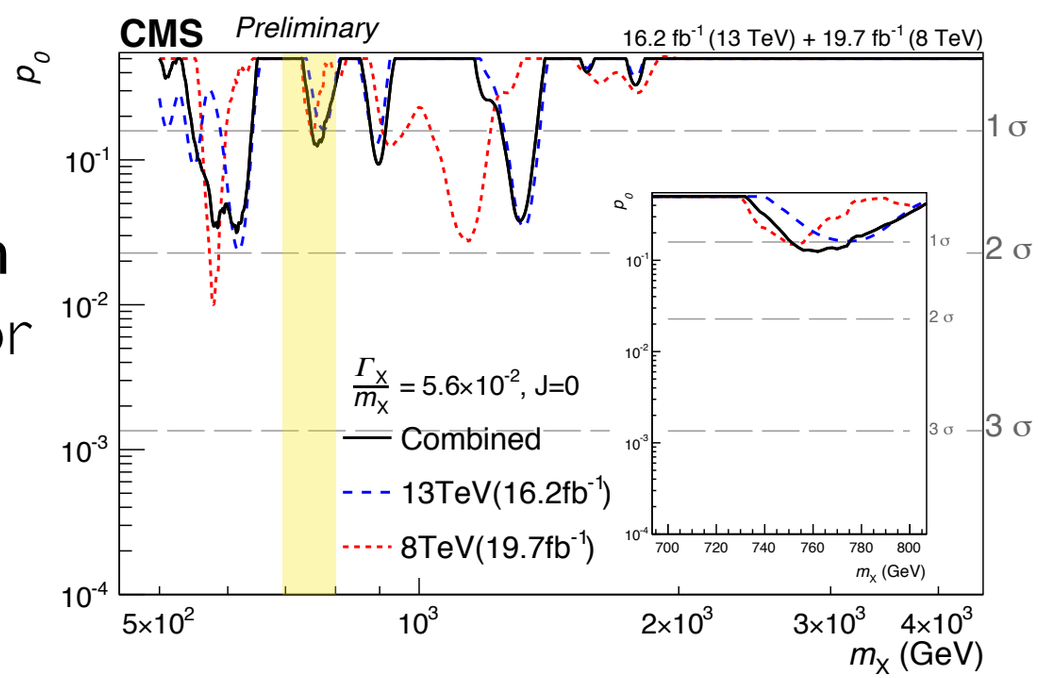
Spin-0 resonance | **Spin-2 resonance**

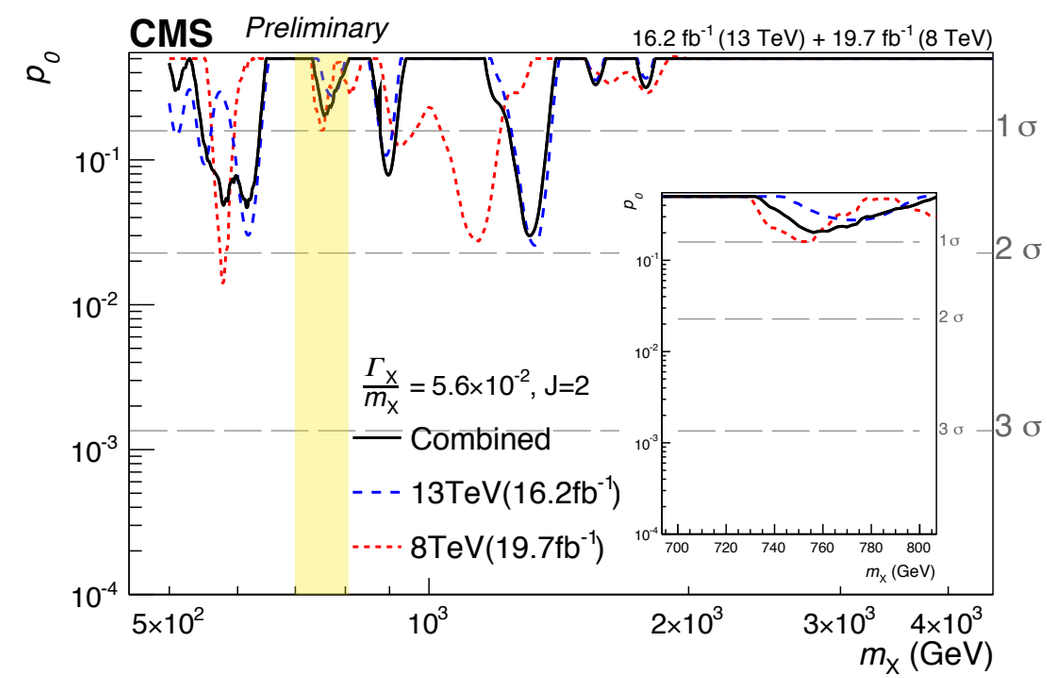
Narrow width (wrt detector resolution)





Wide width (wrt detector resolution)



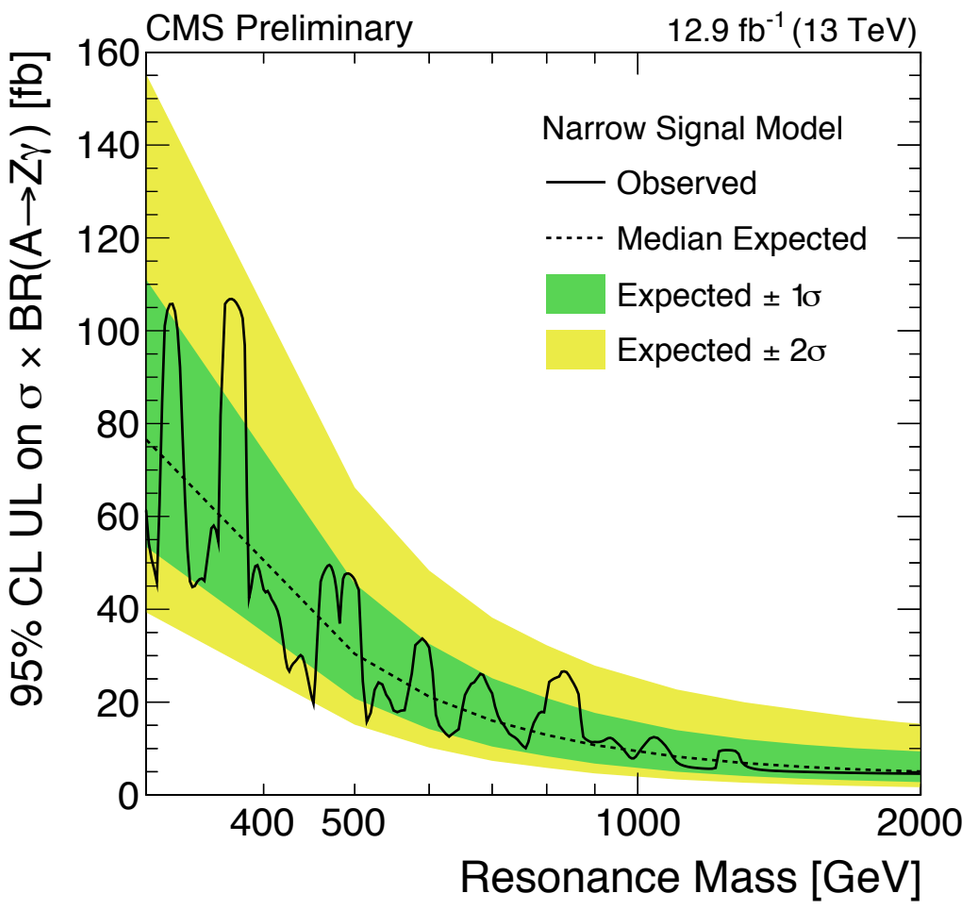


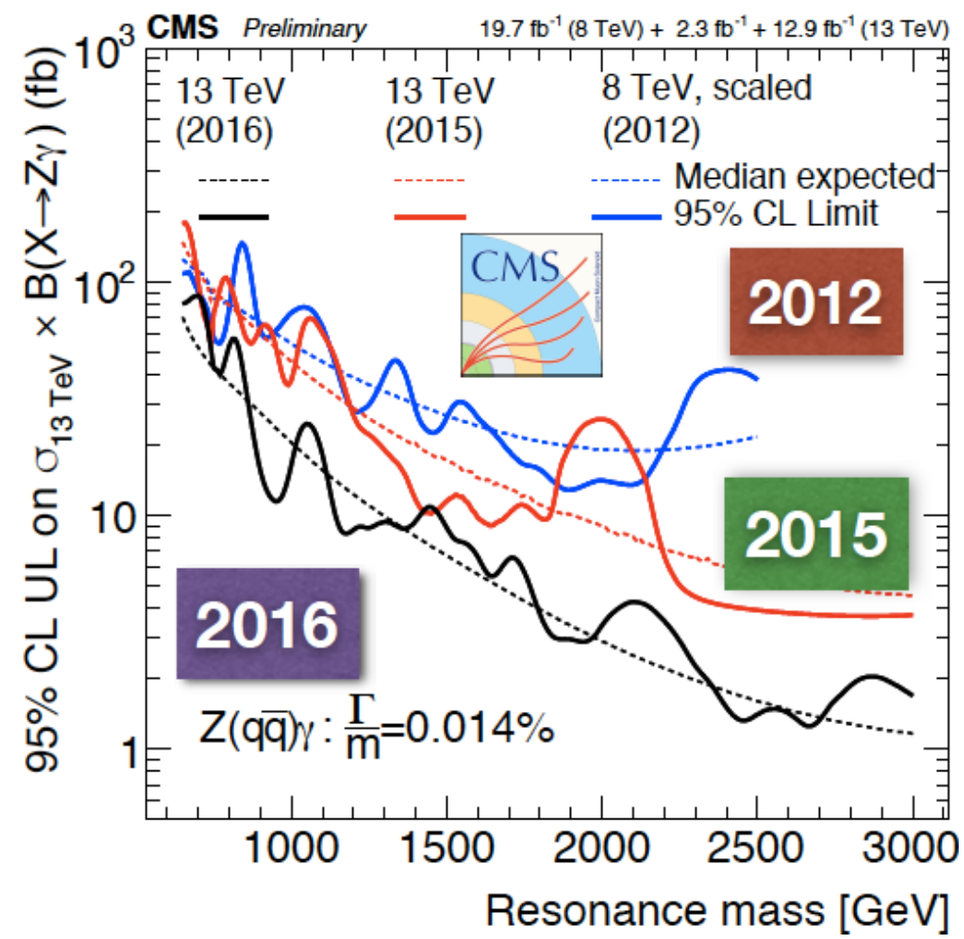
Search for $Z\gamma$ resonances

- Two types of searches pursued:
  - Leptonic search $Z(ll)\gamma$ - best at low mass.
  - Boosted hadronic search $Z(qq)\gamma$, w/ categorization using b-tagging info and jet substructure - best at for M > 1.5TeV.

CMS PAS EXO-16-025
CMS PAS EXO-16-020
CMS PAS EXO-16-035

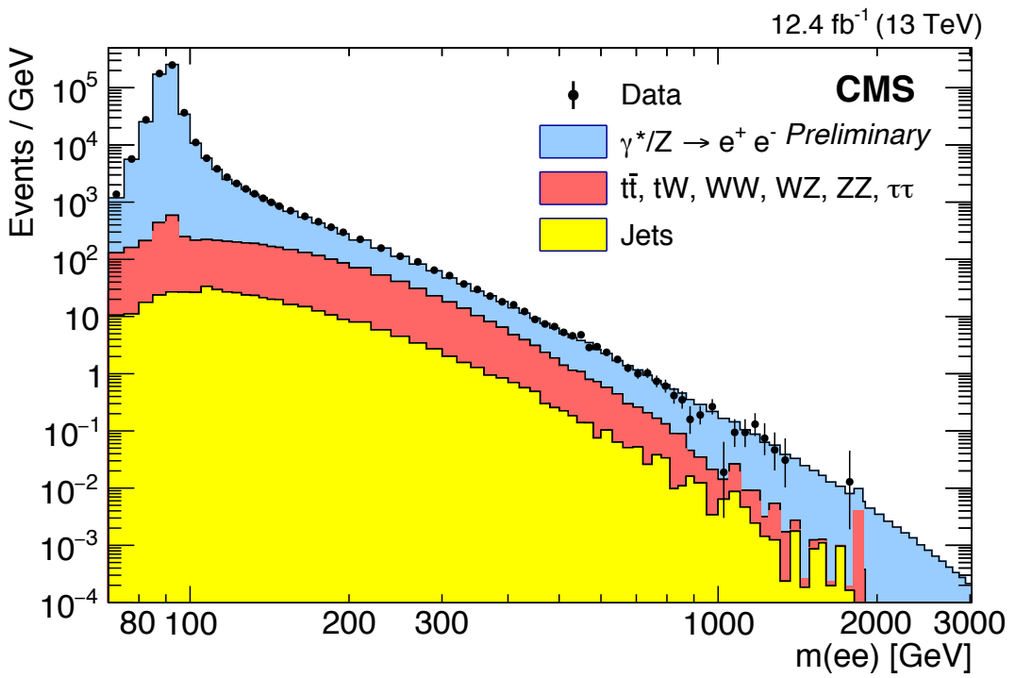
CMS PAS EXO-16-034

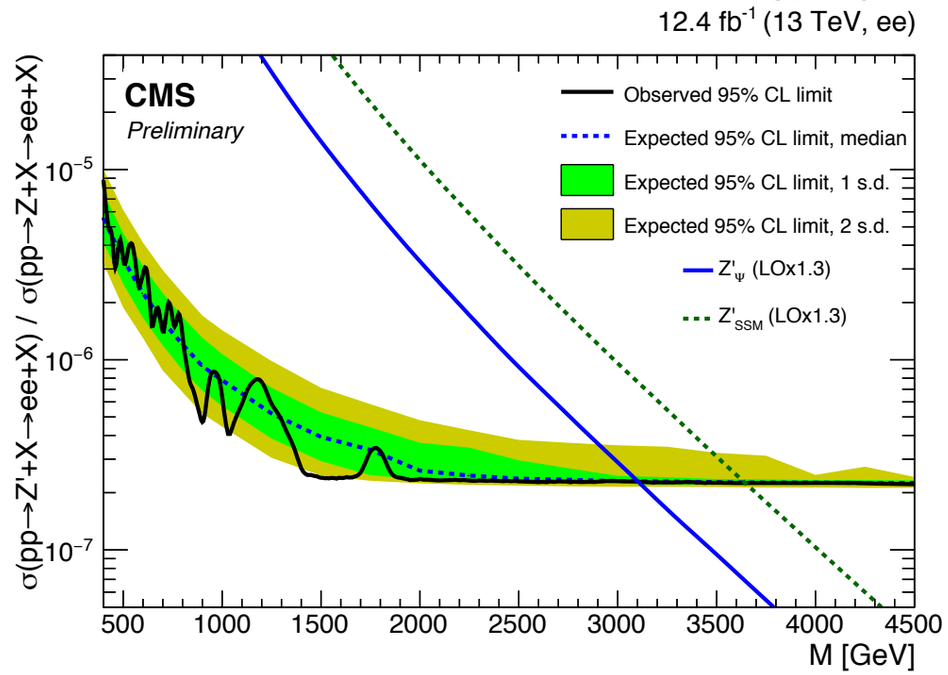




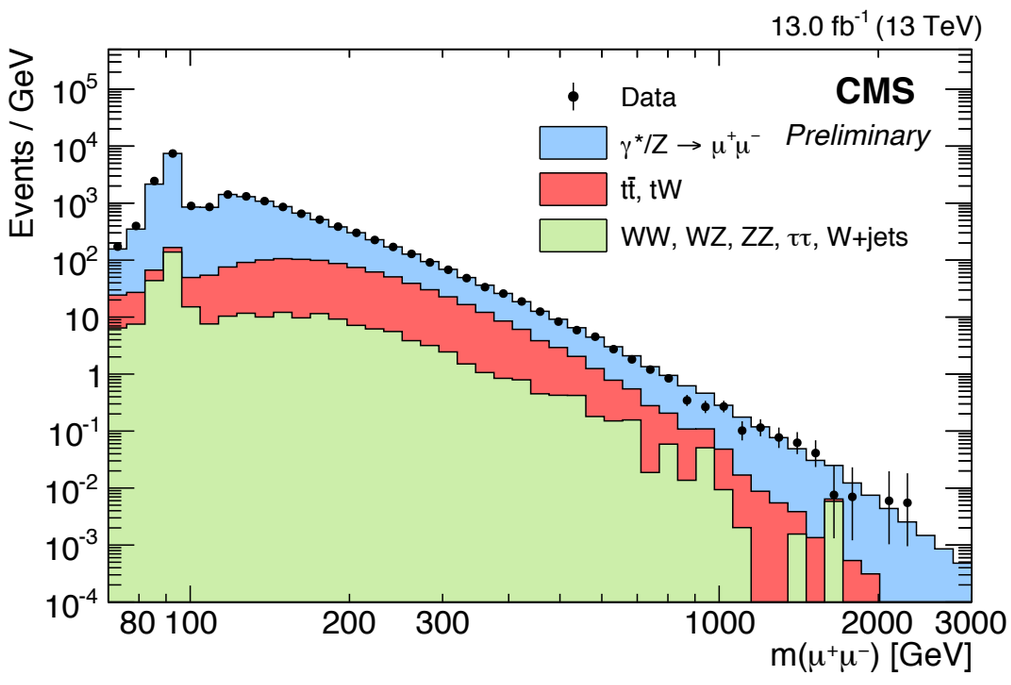
Search for dilepton resonances

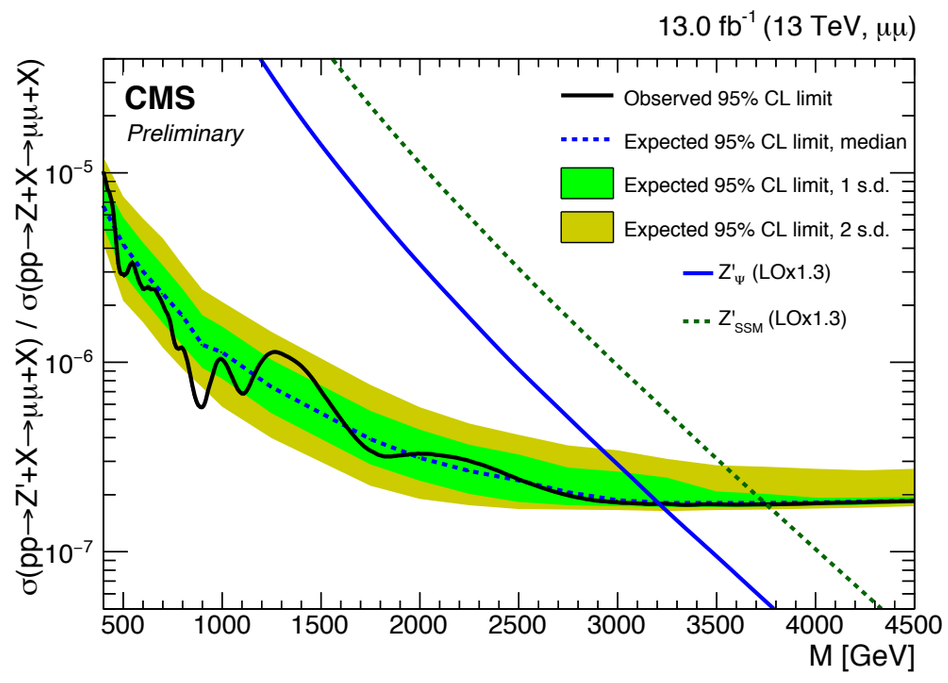
CMS PAS EXO-16-031





$m(Z'_{SSM})$ > 3.65 TeV @ 95% CL



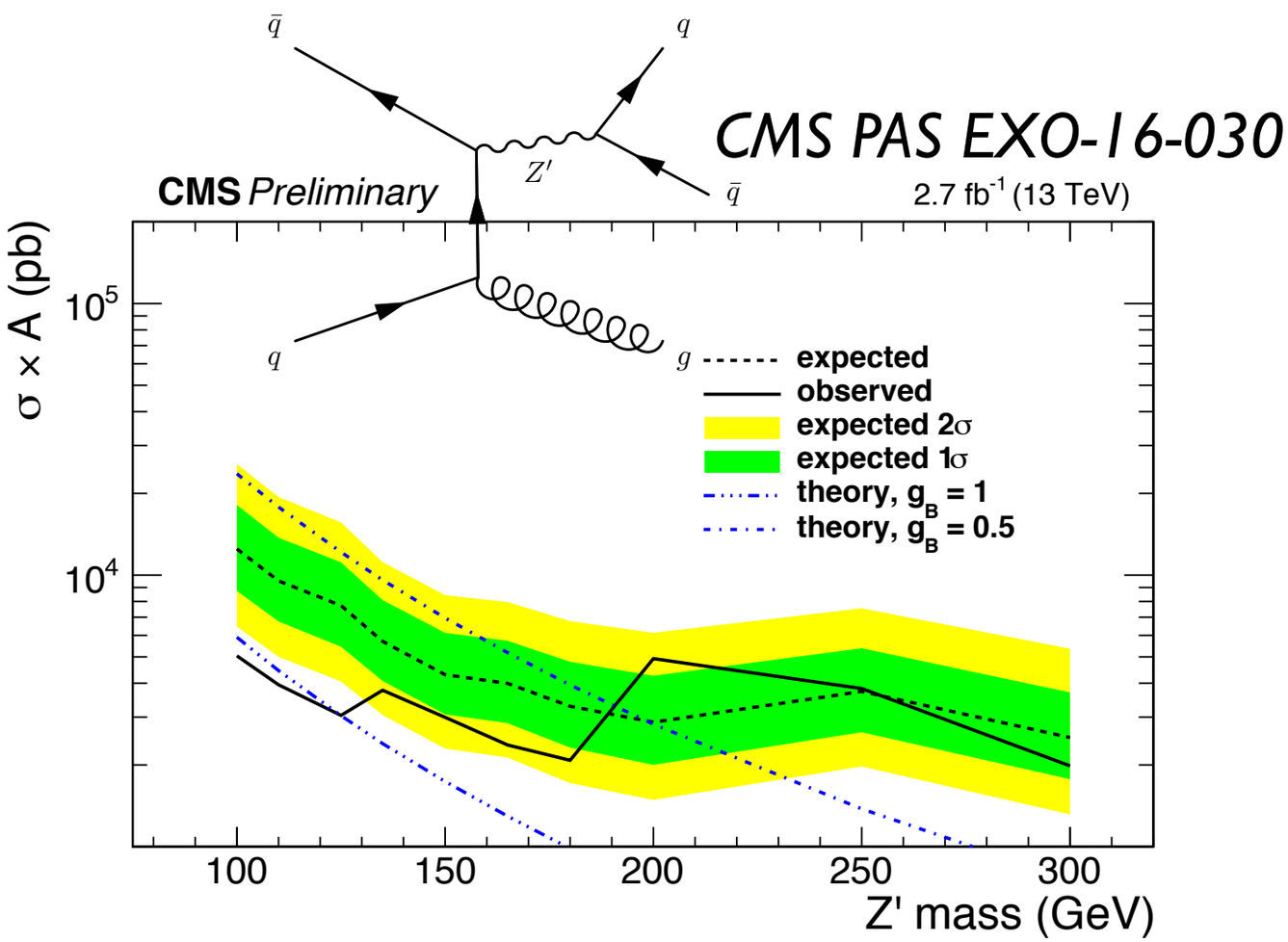


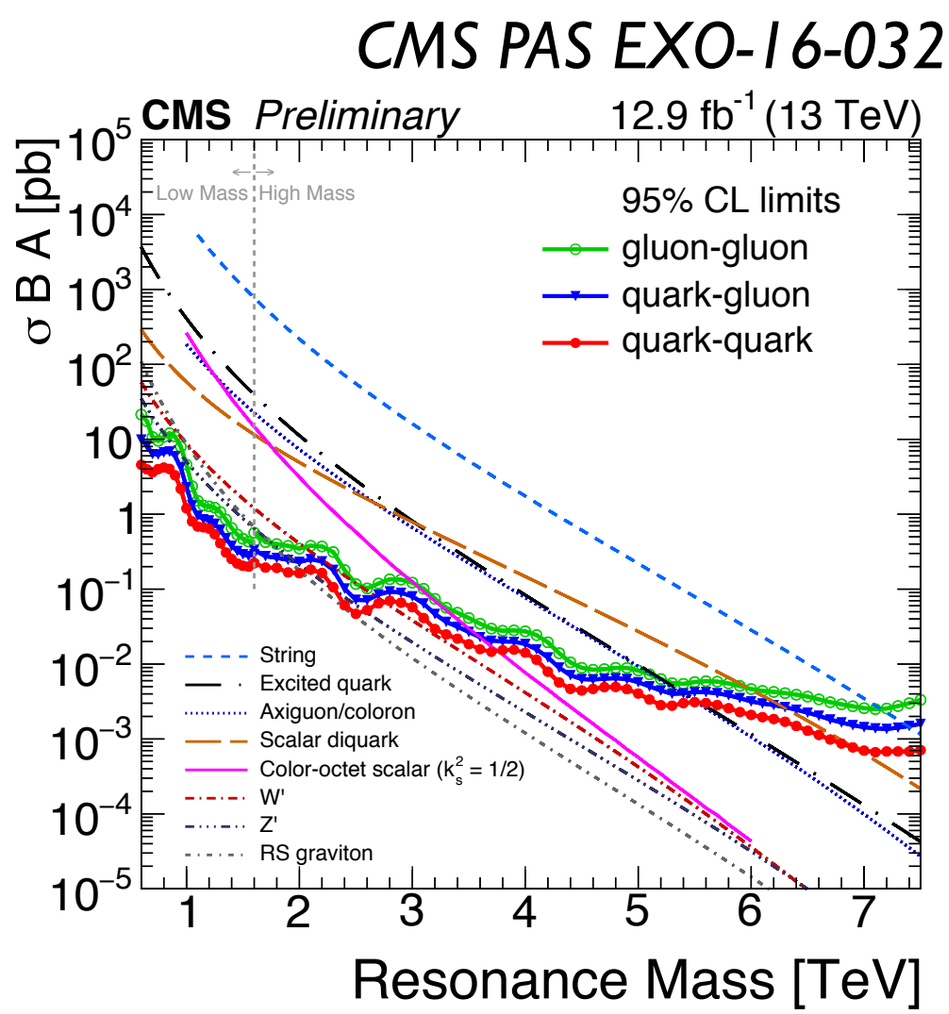
$m(Z'_{SSM})$ > 3.75 TeV @ 95% CL

The m(ee)=2.9 TeV detected early last year is still the highest mass dilepton observed at 13 TeV!

Search for dijet resonances

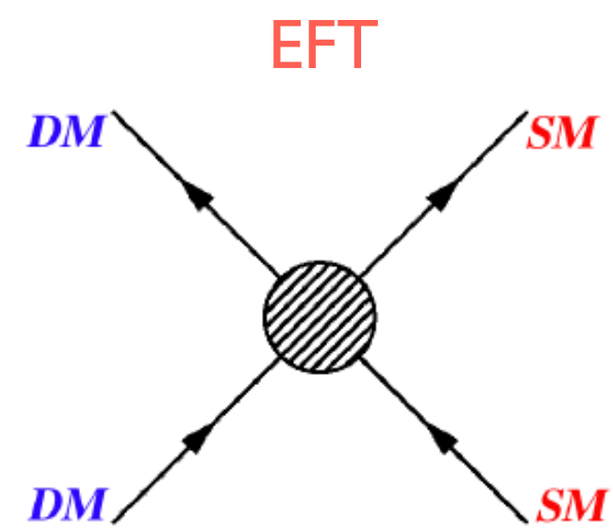
- Invariant mass spectrum of dijet system. Two complementary strategies:
  - low mass: hard jet recoiling against a jet with substructure.
  - high mass: 2 "wide" jets (add jets to the closest of the two leading jets).
    - Data scouting: lower trigger thresholds by storing reduced event info.

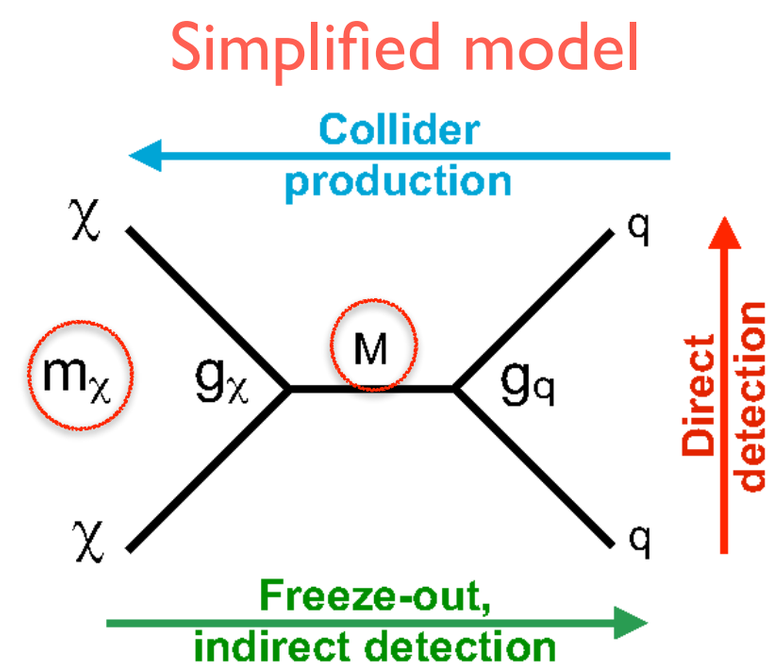




Dark Matter at the LHC

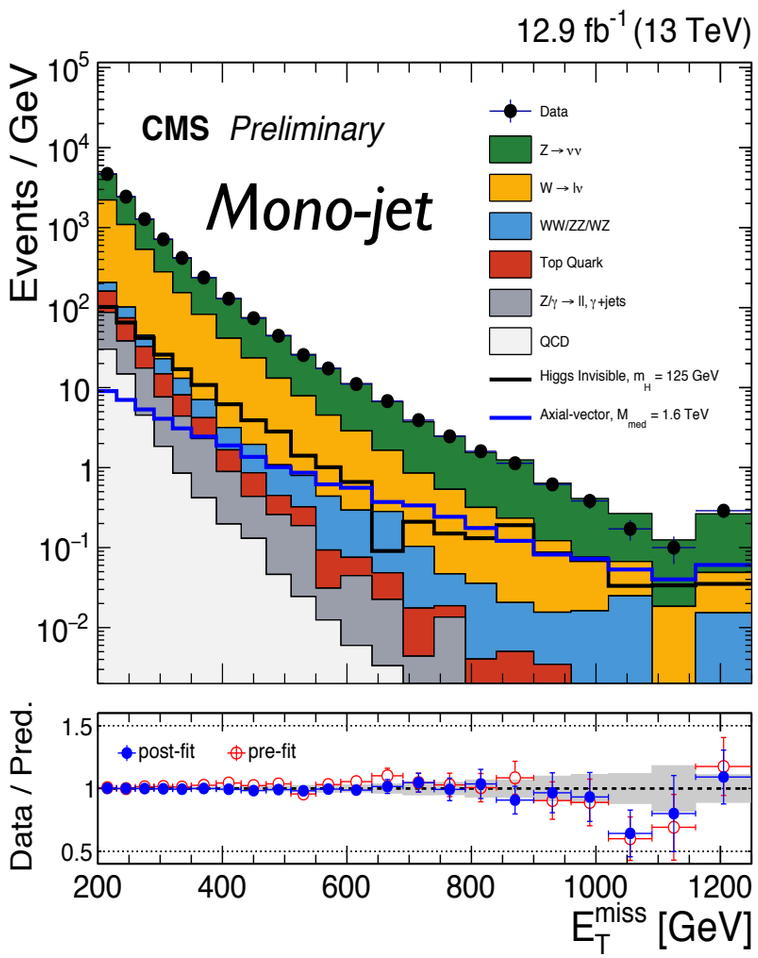
- Three main complementary approaches to detect DM (crossing symmetry of the same Feynman diagram):
  - Direct detection (i.e. DM-nucleon scattering).
  - Indirect detection (i.e. annihilation).
  - Pair production at colliders.
- Run I modeling: interpretation within EFTs assuming contact interactions between DM and SM particles.
  - This approach works well only for heavy mediators.
- RunII modeling: interpretation within Simplified models
  - Easier to compare LHC results with I/DD.
  - 4D problem: m_χ, M, g_χ, g_q.
  - LHC DM Working group (arXiv:1603.04156) recommends to set $g_\chi = 1$, $g_q = 0.25$ (V/A casse) or $g_\chi = g_q = 1$ (S/P case).
  - The choice of couplings is motivated by requiring the mediator width to be below ~10% of its mass.
    In the case of V/A mediators, $g_q = 0.25$ is required to avoid previous dijet constraints.

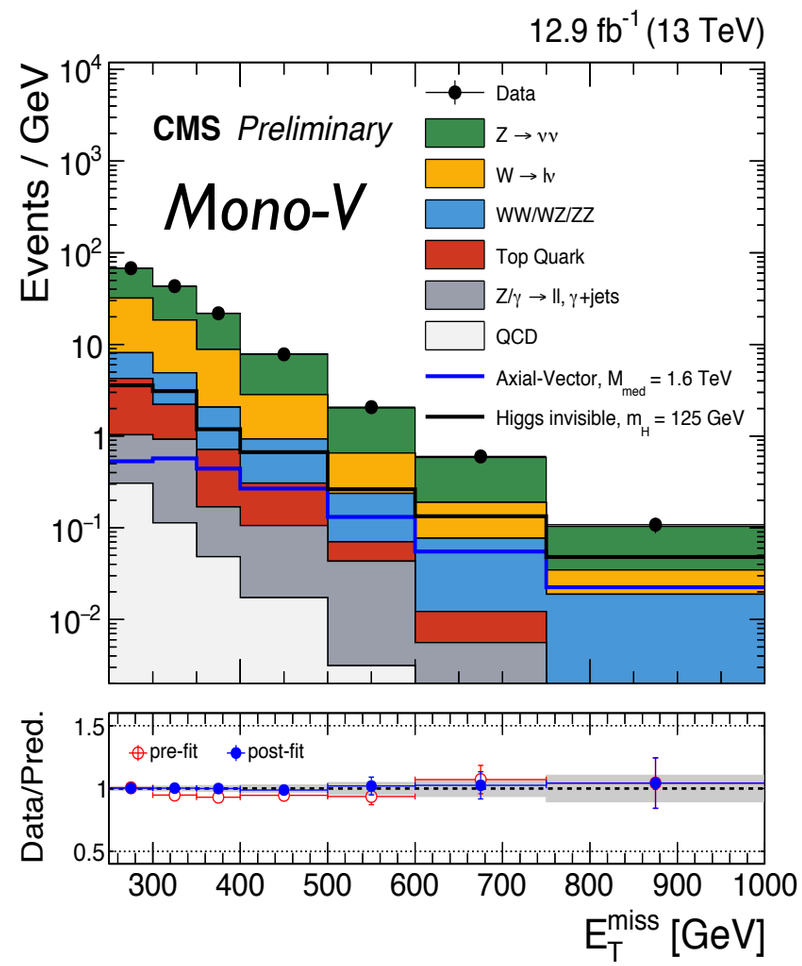


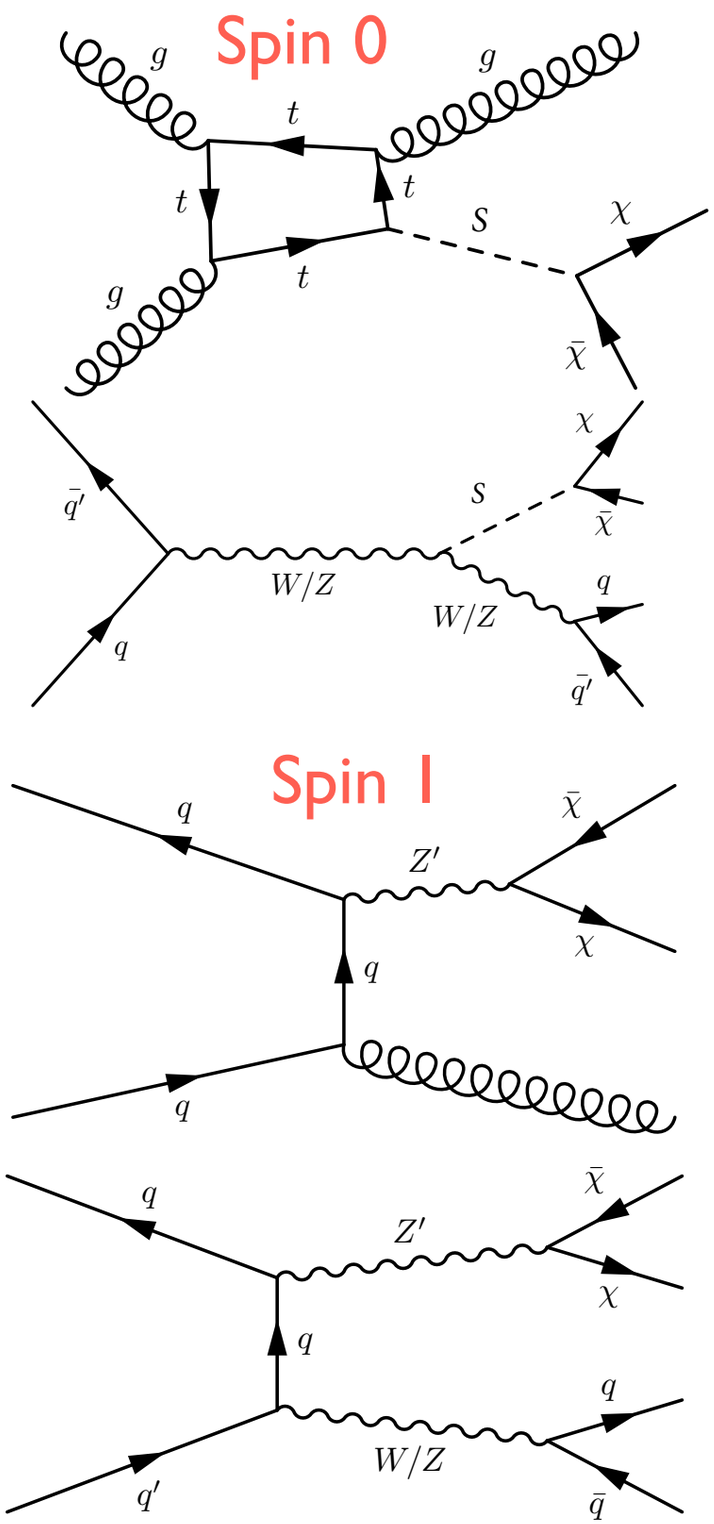


Mono-X signatures

- How can we trigger on DM particles at colliders?
  ISR (g, γ, W/Z, h,…) to rescue!
- Example: Mono-jet and Mono-V search ***CMS PAS EXO-16-037***
- Main backgrounds: Z($\nu\nu$)+jets (irreducible), W($l\nu$)+jets (lost lepton).
- Background estimation: control region with ll+jets, γ+jets, l+jets (leptons are ignored in the calculation of MET).

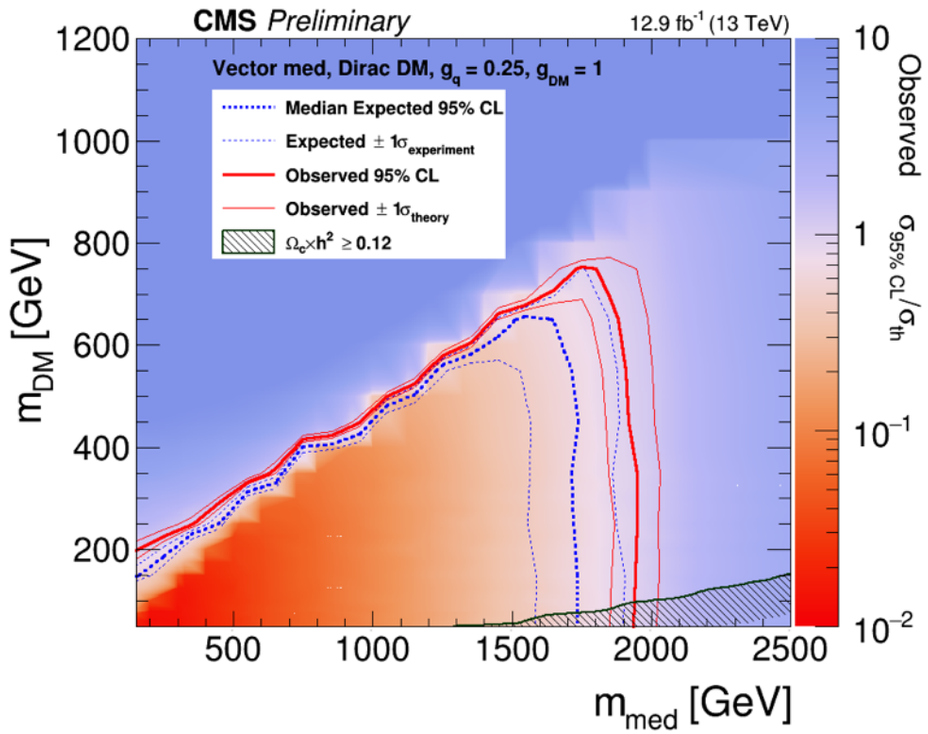


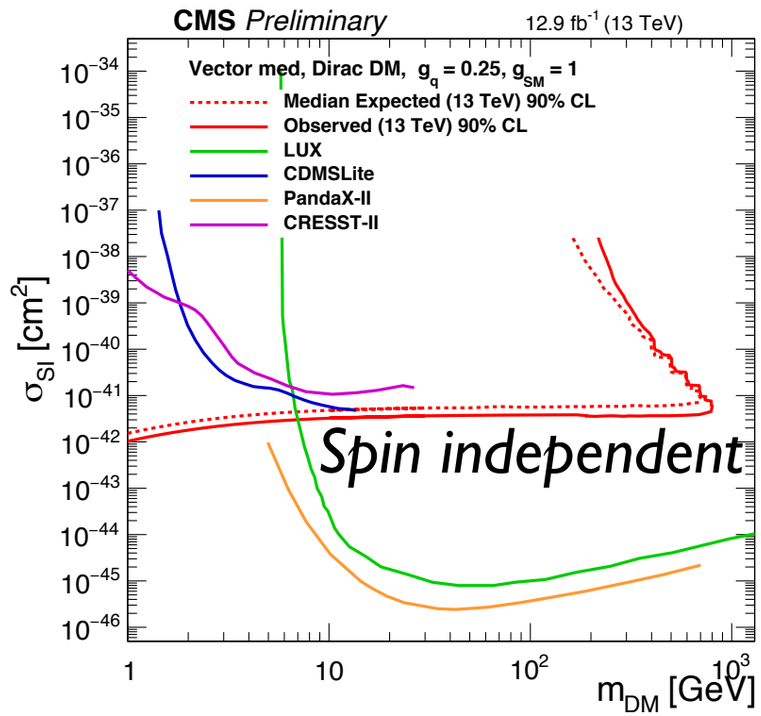




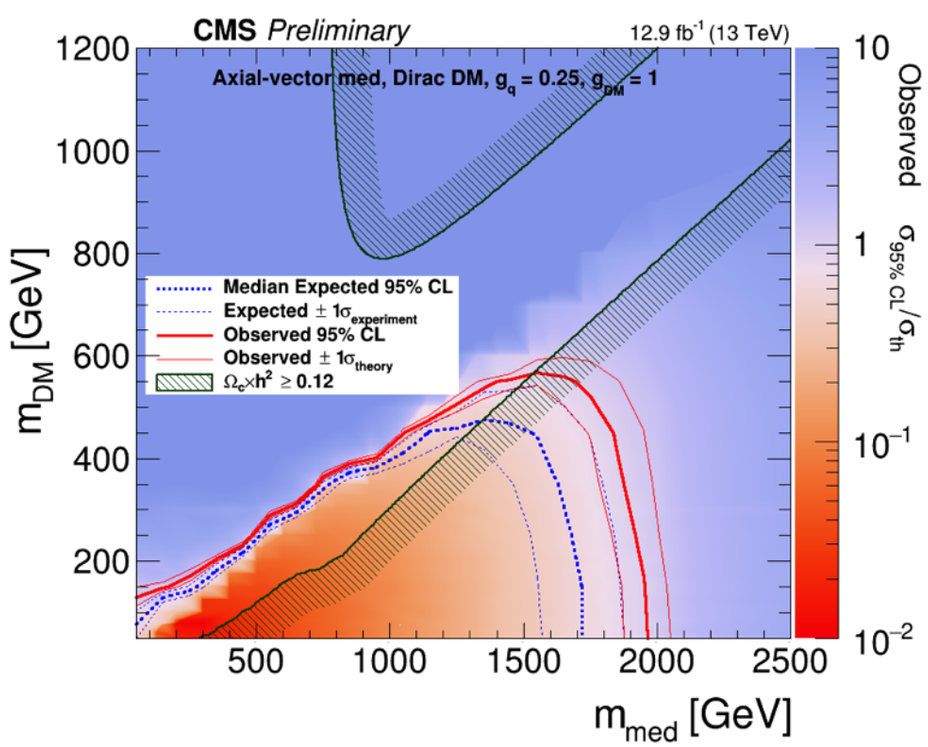
Mono-jet and Mono-V interpretations

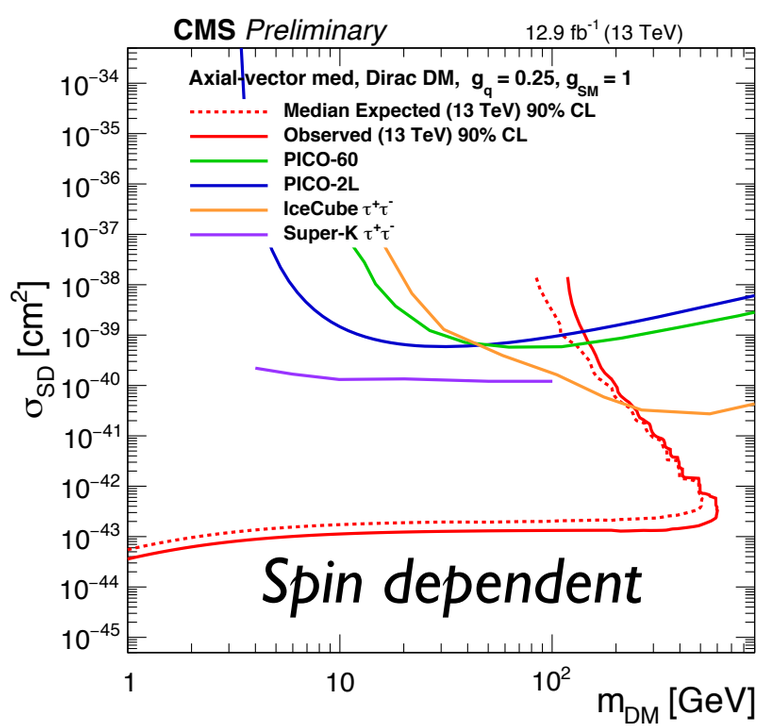
Vector mediator





Axial-vector mediator





Limit comparisons:

- ✓ Vector mediator: CDMSLite, LUX, PandaX−II and CRESST−II.
- ✓ Axial mediator: PICO−2L, PICO−60, IceCube and Super−Kamiokande.

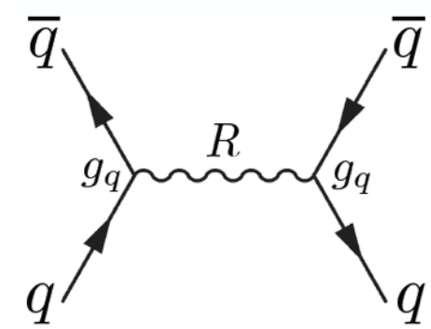
Also available:

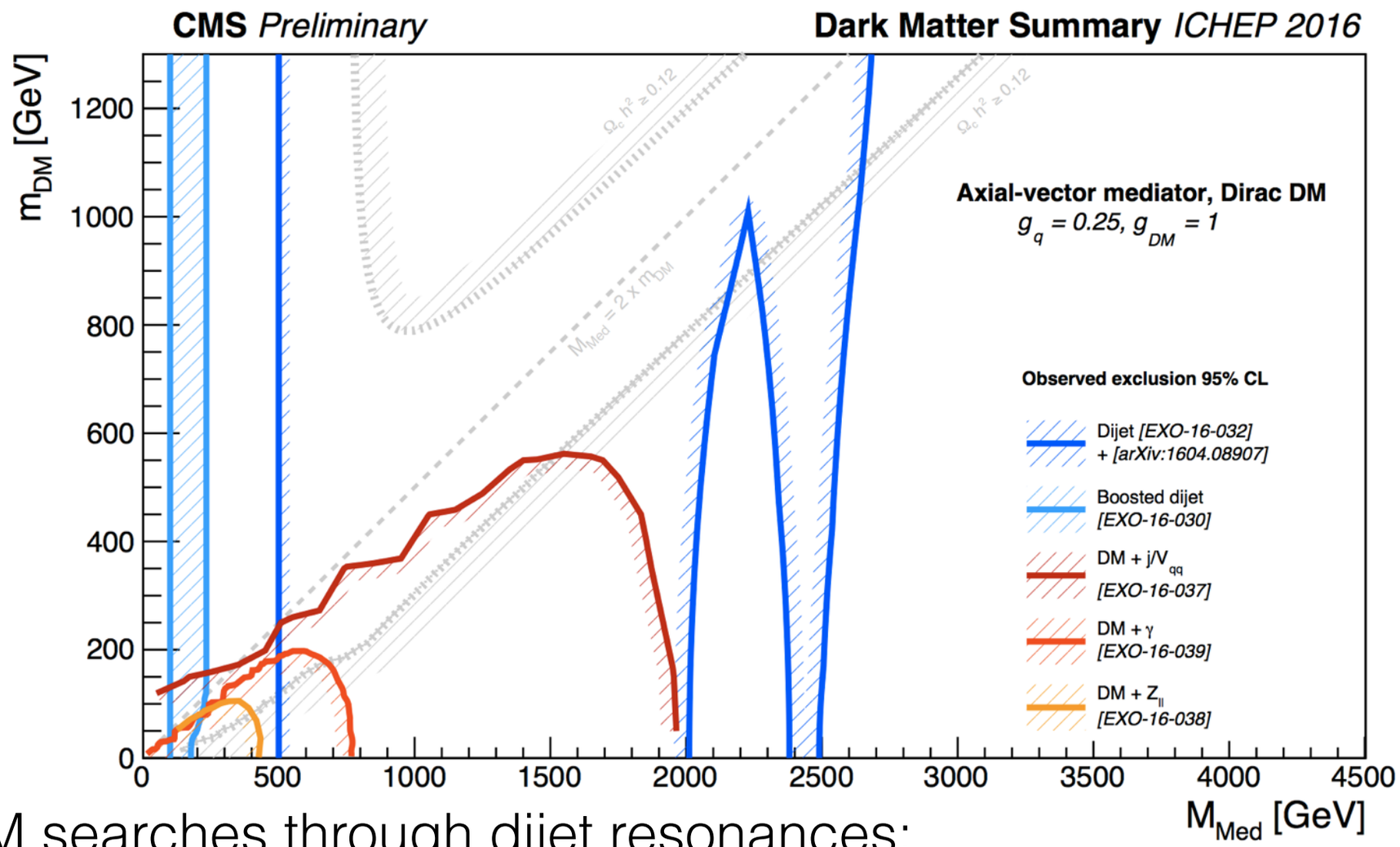
- ✓ scalar and pseudo-scalar mediators

More on Mono-X searches: “DM searches using missing ET at LHC” by C.-S. Moon, DM &colliders session this afternoon

Searching for the mediator

- LHC does not need to produce DM to look for the mediator.
  - Since the mediator it is coupled with the initial state, we can recycle dijet resonance searches!

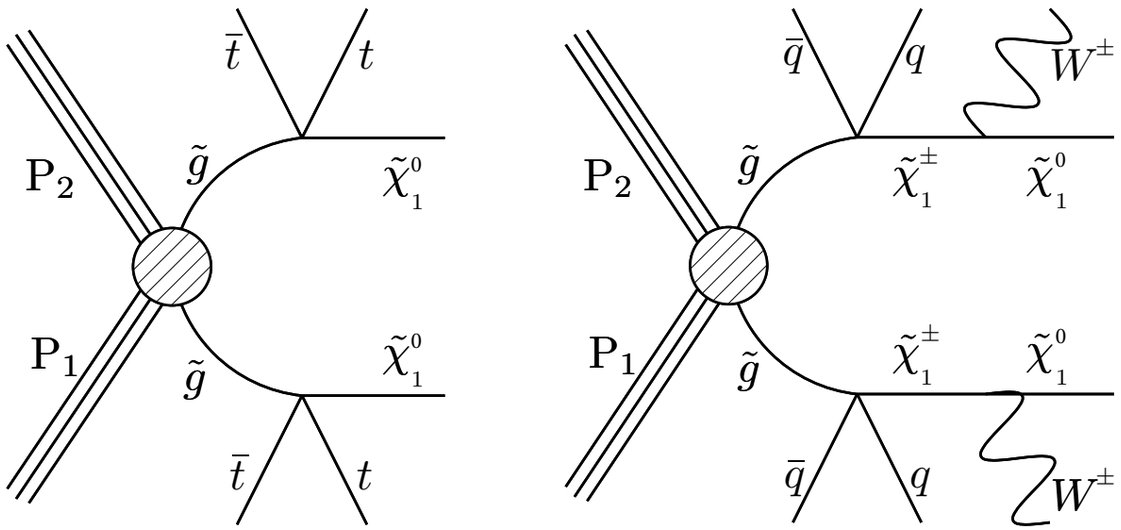




More on DM searches through dijet resonances:
"Searches for light dark matter through dijets and long-lived particles at the LHC"
by R.C. Rosten, DM &colliders session this afternoon

SUSY searches: strong production

- Typical signatures:
  - (b-tagged) Jets + MET
  - 0*l* powerful, but depending on the addressed decay leptonic channels and boson tags add sensitivity



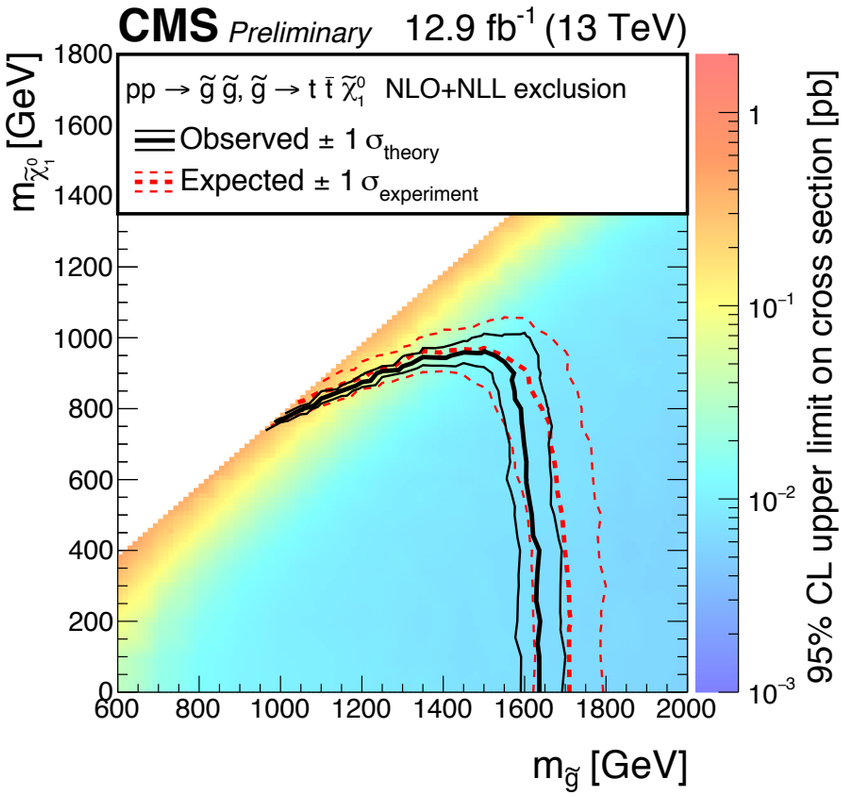
An example: ***CMS PAS SUS-16-019***

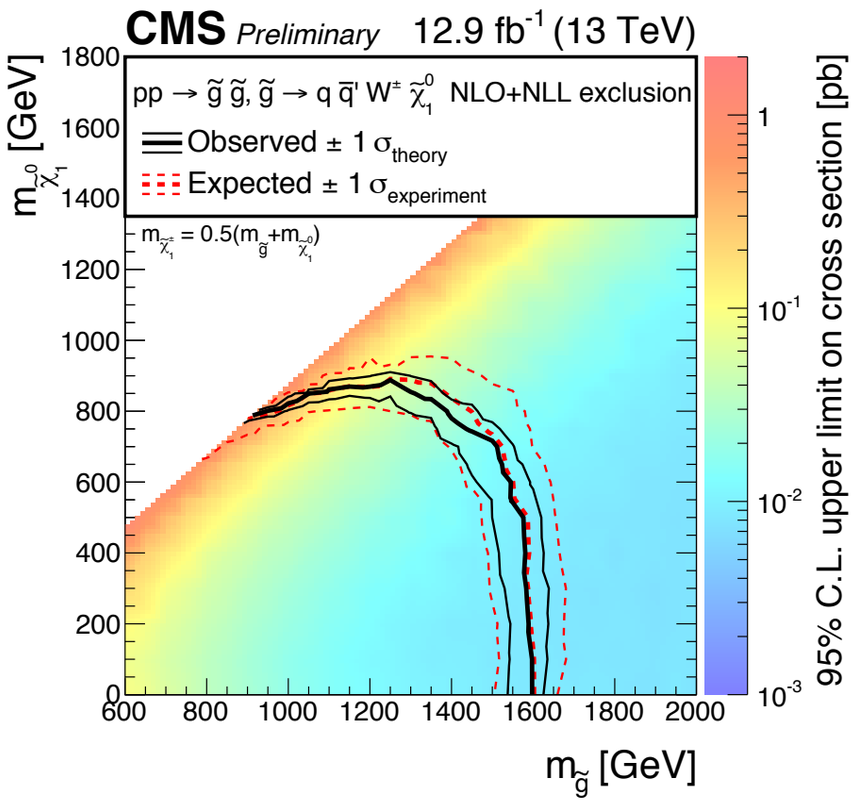
Search variables:

- $H_T, \Delta\phi(\vec{\mathrm{MET}} + \vec{l}, \vec{l})$
  $L_T = \mathrm{MET} + p_T^l$
  $N_{\mathrm{jets}} \geq 5$

Main backgrounds:

- W and $t\bar{t}$ production (data-driven estimation)



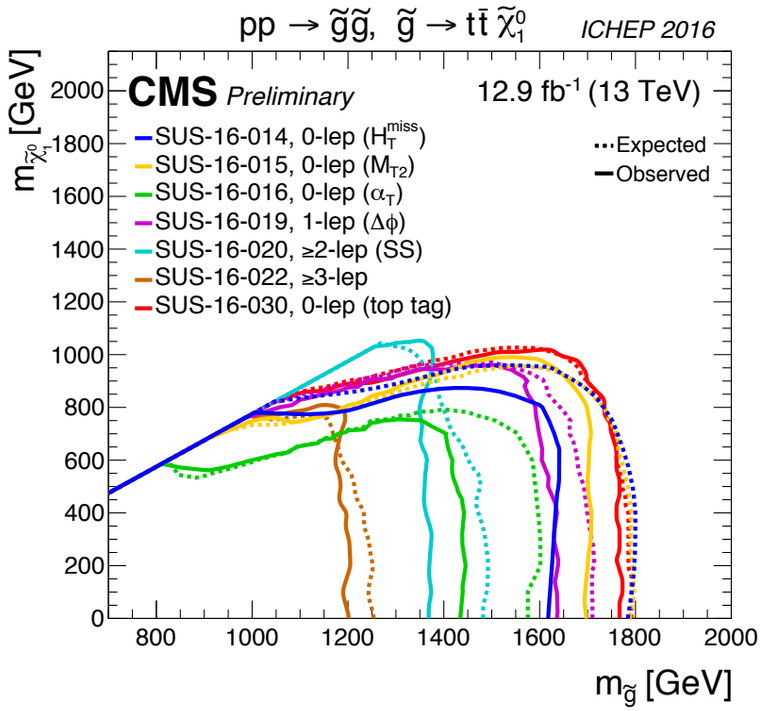


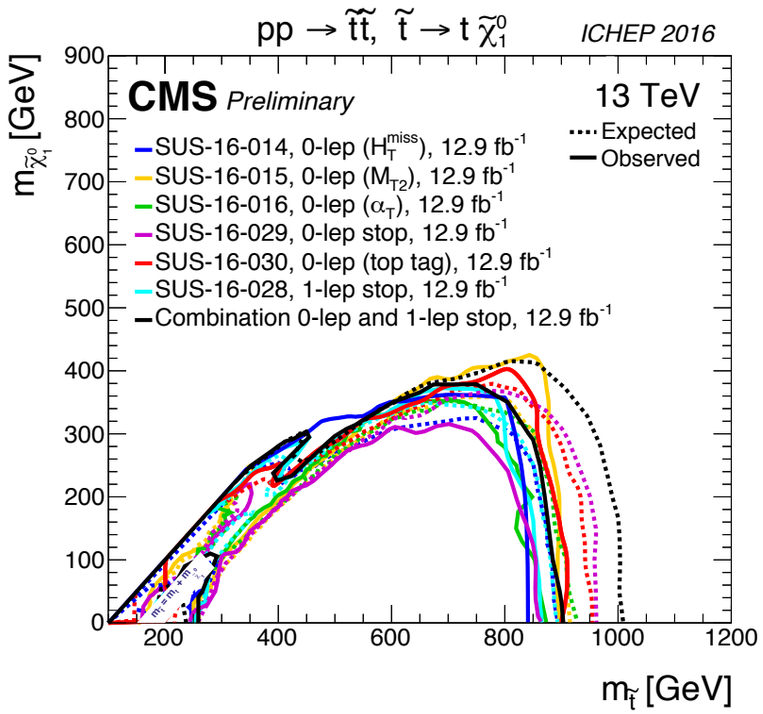
SUSY: Strong production summary

gluino production

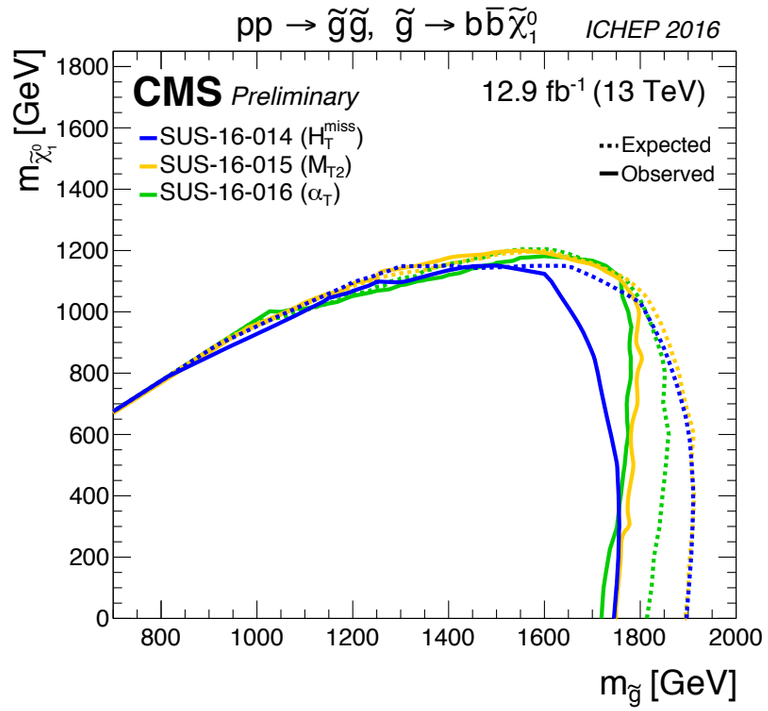
squark production

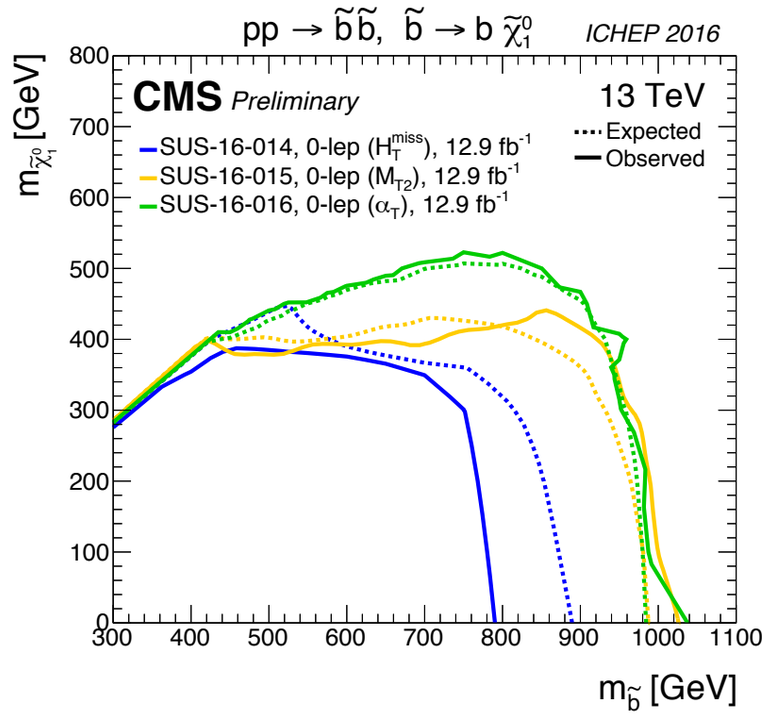
top



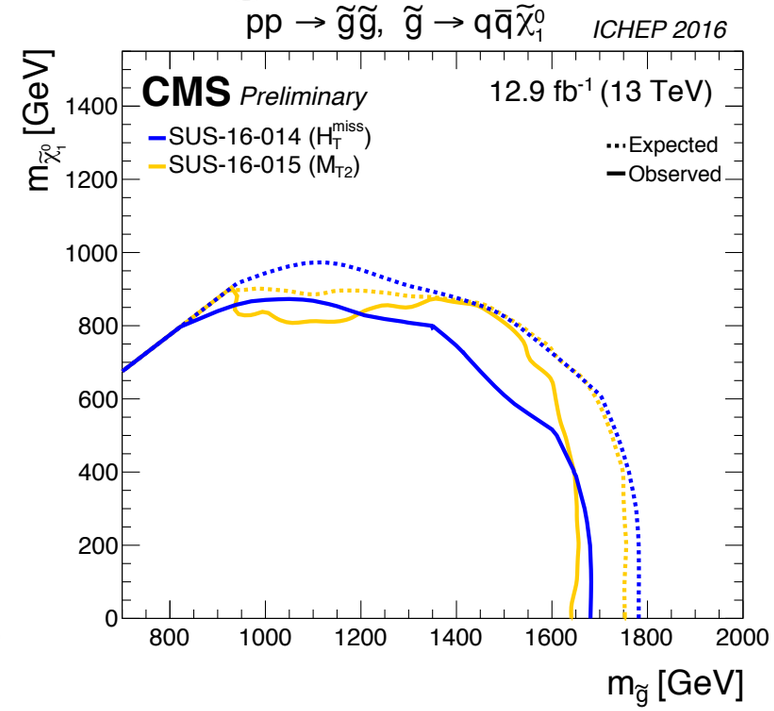


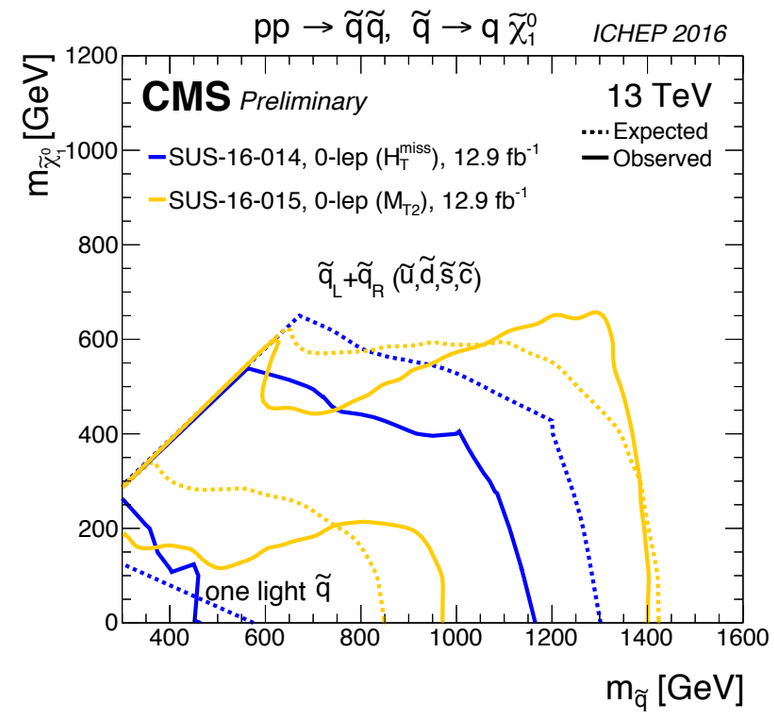
bottom





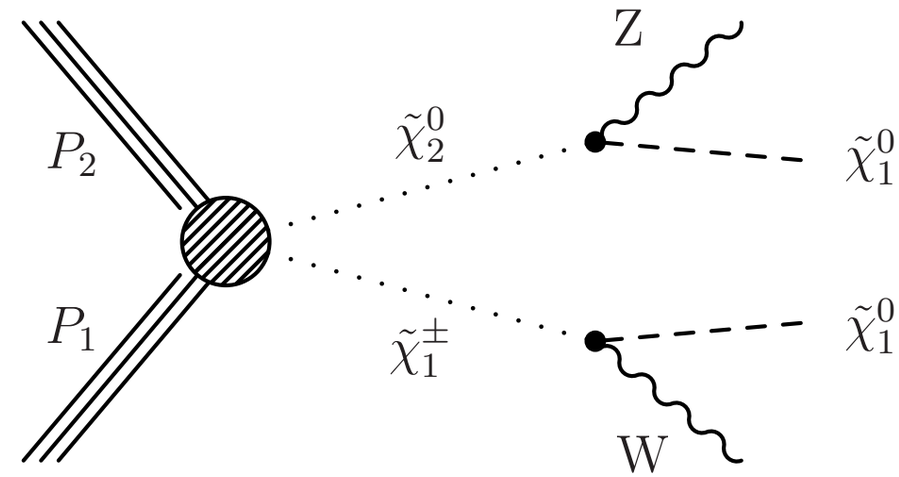
light quarks





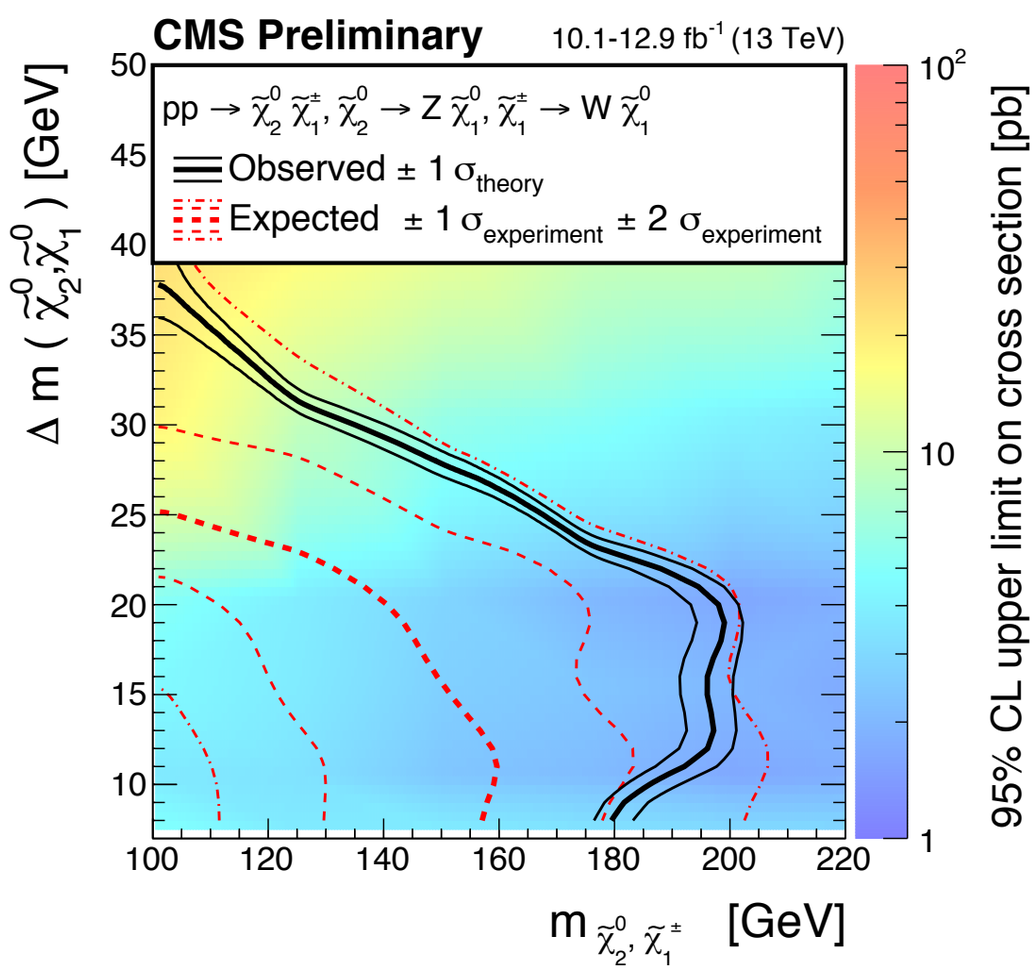
SUSY searches: EW production

- Typical signatures:
  - Few jets
  - Many leptons
  - W/Z/h bosons



An example: ***CMS PAS SUS-16-025***

- ✓ Compressed spectra: small $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$
- ✓ Signature: MET and soft leptons [5,30] GeV
- ✓ Two trigger strategy:
  - ✓ MET > 200GeV
  - ✓ MET > 125GeV and soft muon pair
- ✓ Main background: DY+ jets, $t\bar{t}$ and VV
- ✓ Signal extraction: fit on M(ll) and $p_T(l_1)$
- ✓ First analysis covering 5 < Δm < 30GeV



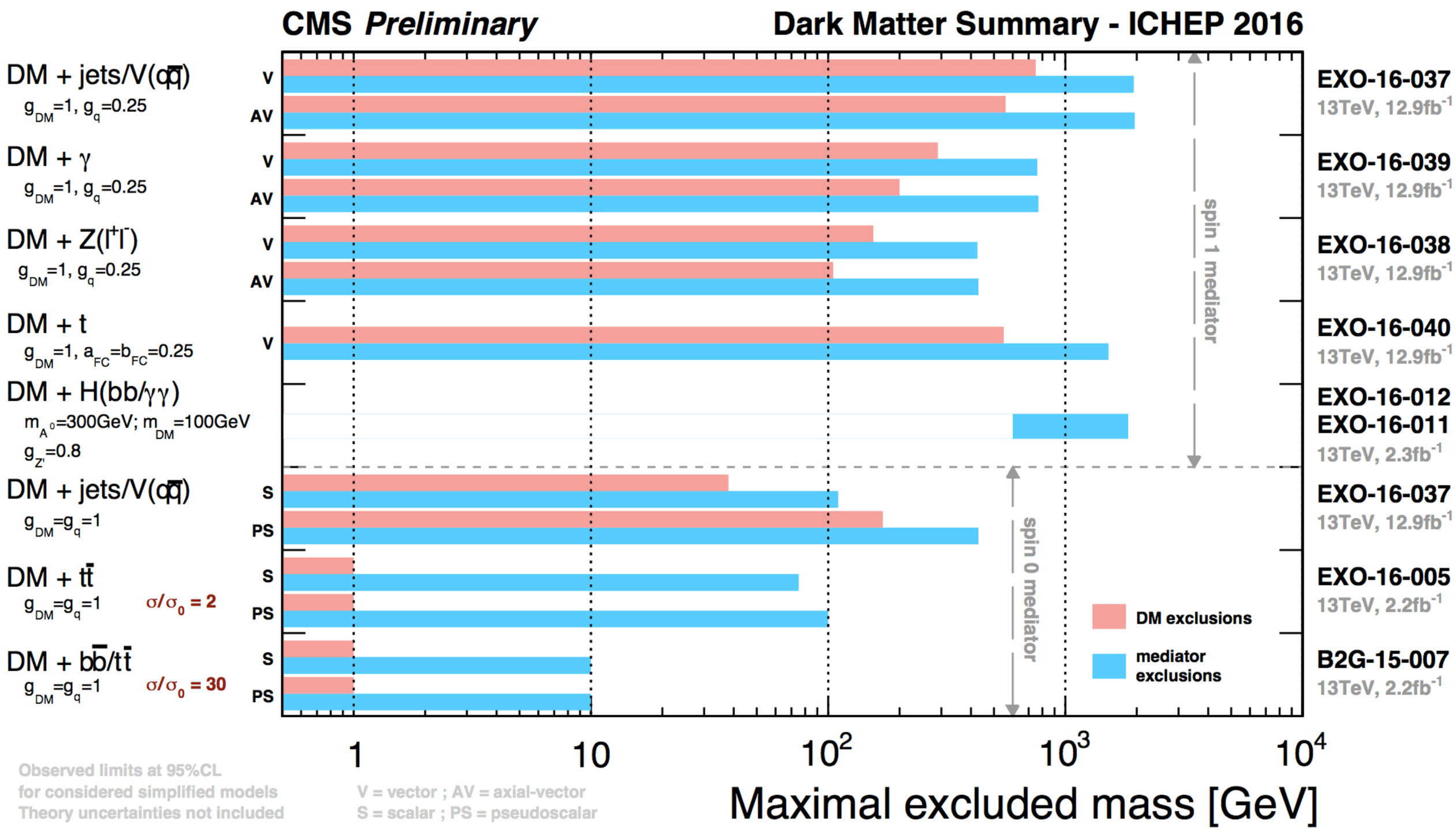
Summary

- ✓ Very successful operation of LHC and CMS during 2016.
- ✓ SM processes and its particles properties are being studied with great precision. H(125) is back!
- ✓ A first broad scan of beyond the SM scenarios have been performed.
- ✓ No significant deviation from the SM expectations yet..
- ✓ but only few percent of the expected LHC dataset has been analyzed! New channels are opening and new searches become possible!
- ✓ Run II has just started, exciting times are in front of us!

- ✓ You can find all CMS results at: http://cms-results.web.cern.ch/cms-results/public-results/publications/

Backup

Dark Matter bar plot summary



Exotica Grand Summary