Higgs and New Physics at ATLAS and CMS

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for the ATLAS and CMS Collaborations

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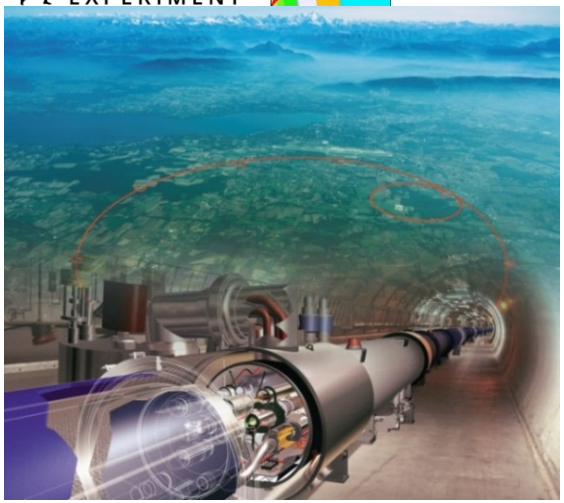
ATLAS and CMS experiments @ LHC

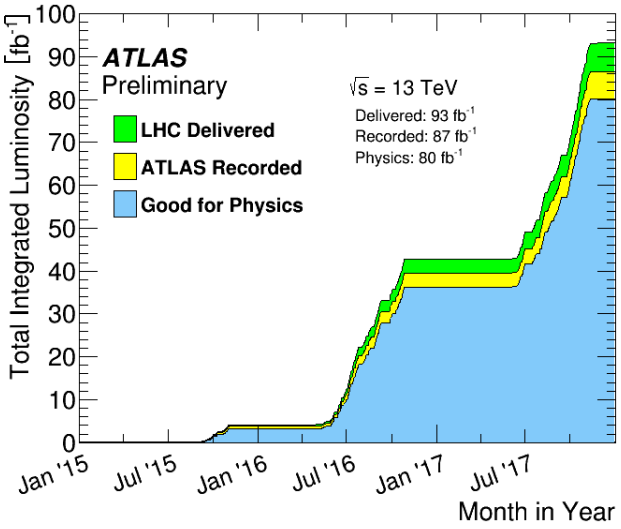


pp collisions

Run1: 7,8 TeV (27 fb^{-1})

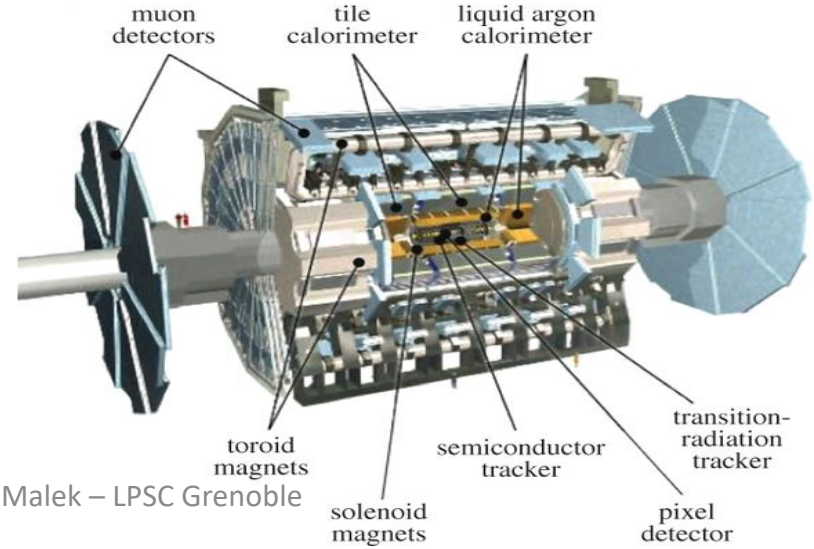
Run2: 13 TeV (~80 fb^{-1})

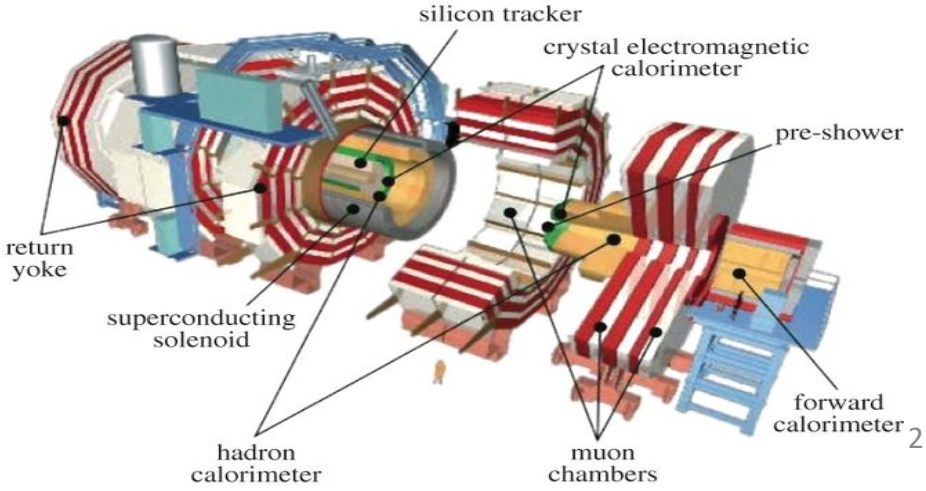
Results presented here are based on a subset of the total data



CMS: excellent reconstruction of secondary vertices in the inner tracker, fast response and excellent energy and time resolution of ECAL

ATLAS: segmented ECAL/HCAL, air core and standalone tracking in a large muon system





Outline

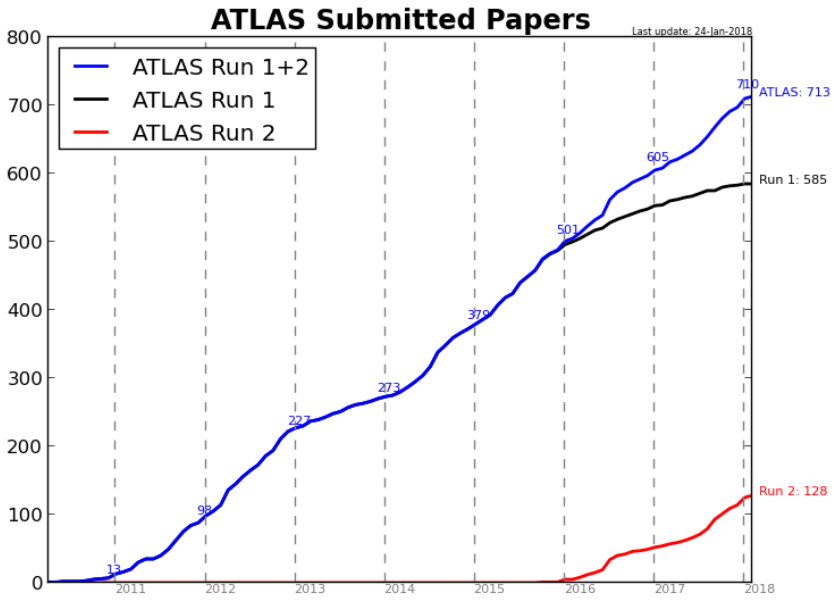
ATLAS and CMS have greatly intensified the search program for signs of physics beyond the SM exploiting the increase in energy (8 → 13 TeV) and data from LHC Run-2 (2015→now) engaging the problem from several sides: Higgs precision measurements, search for additional Higgs bosons, direct search for new particles not necessarily related to the Higgs.

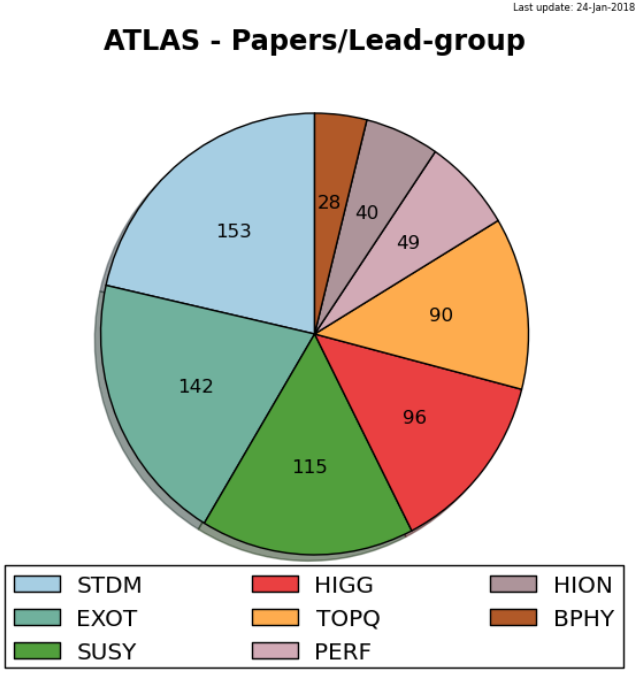
This presentation is a selection of the most recent results on

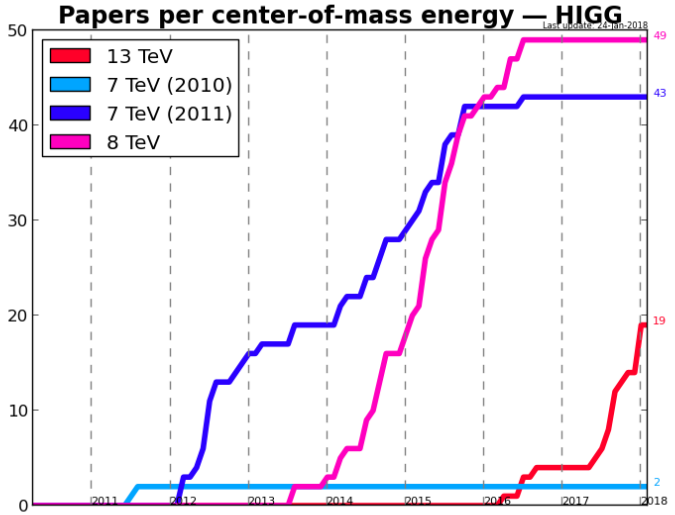
- higgs(125) production and decays:
  - ❑ tth, Vh(Z)
  - ❑ h→bb, cc, ττ
- BSM Higgs searches
- SUSY and Exotics searches

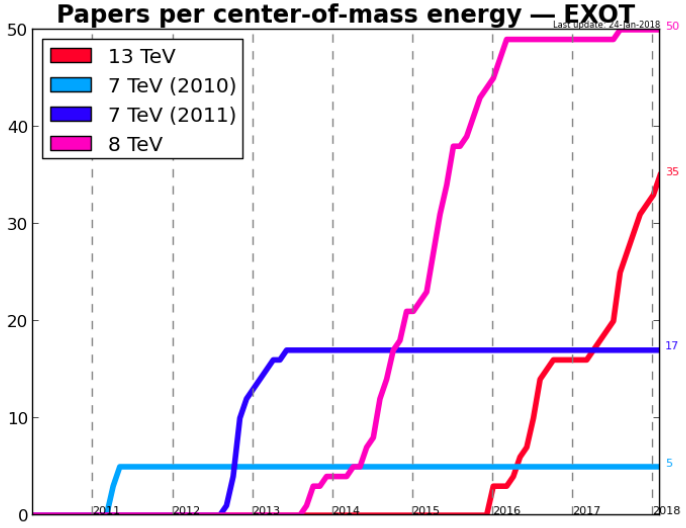
NOTE: A full updated list of results from ATLAS and CMS experiments, with details on each analysis, are available here:
ATLAS Public Results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome
CMS Public Results: http://cms-results.web.cern.ch/cms-results/public-results/publications/

Public Results/Searches



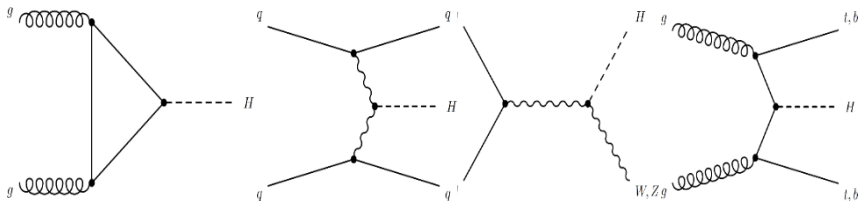






SM higgs(125 GeV) production and decays

h(125) production



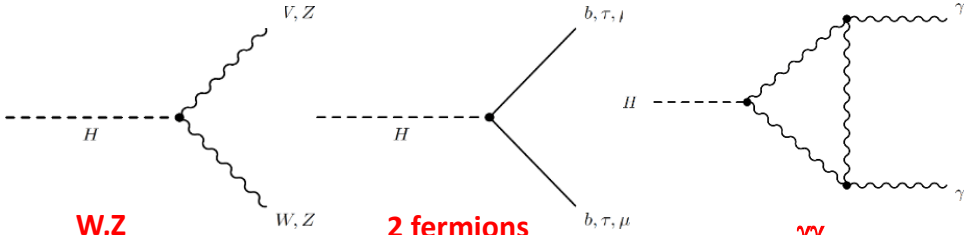
ggF 88%

VBF 7%

qq→VH 5%

gg→tt(bb)H 0.6%

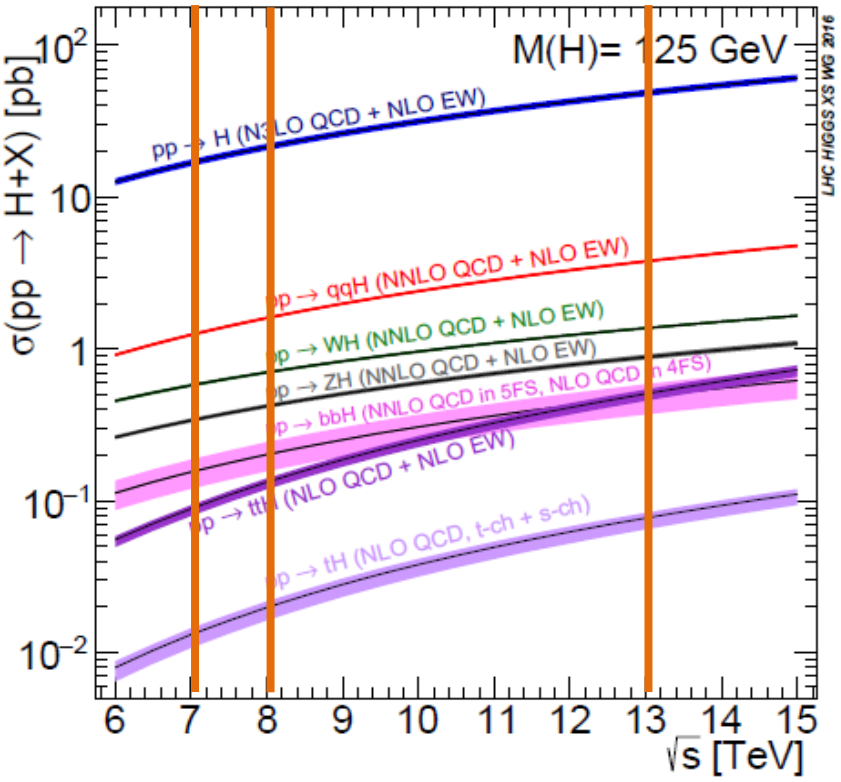
h(125) decay

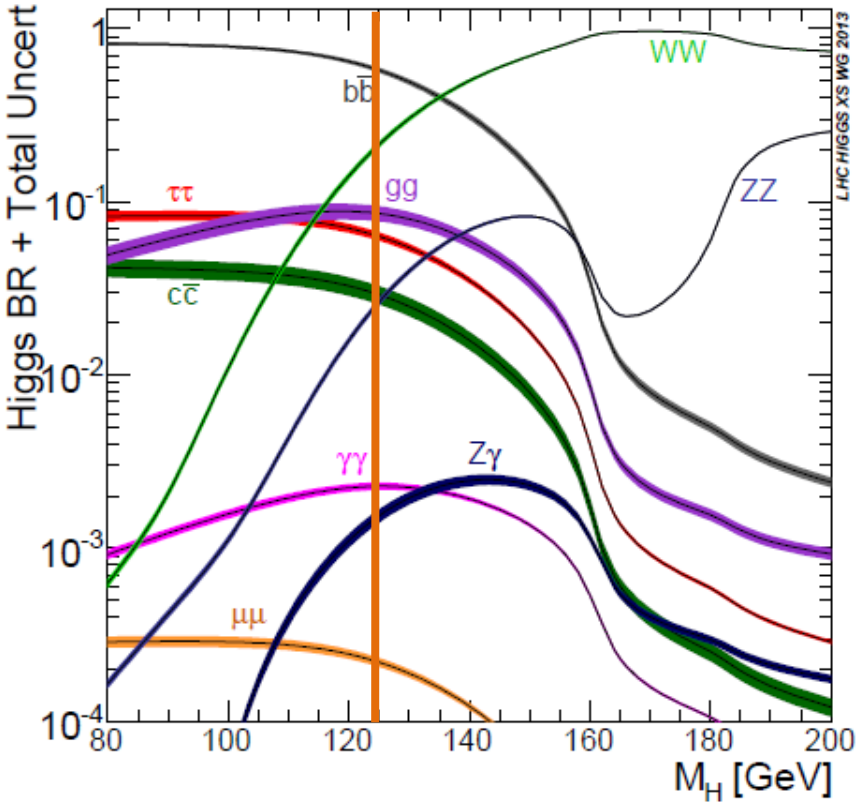


W,Z 24%

2 fermions 68%

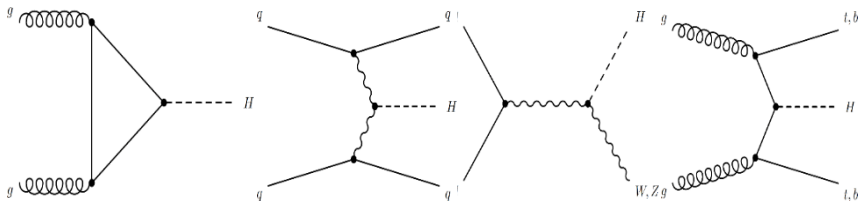
γγ





SM higgs(125 GeV) production and decays

h(125) production



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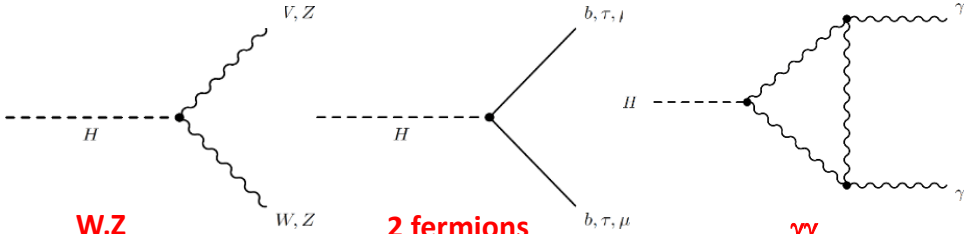
h(125) decay



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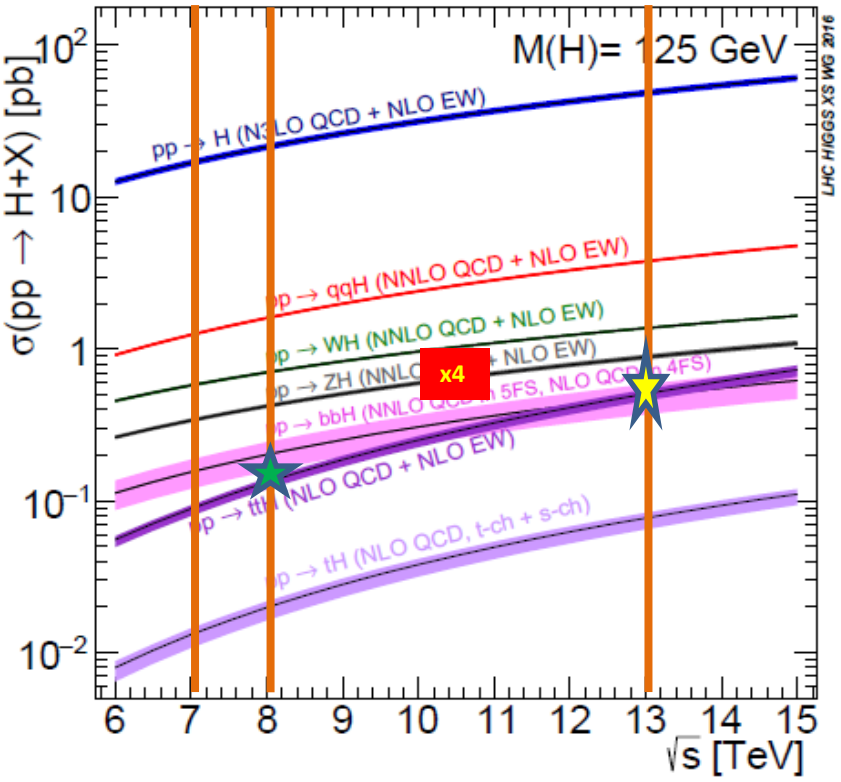
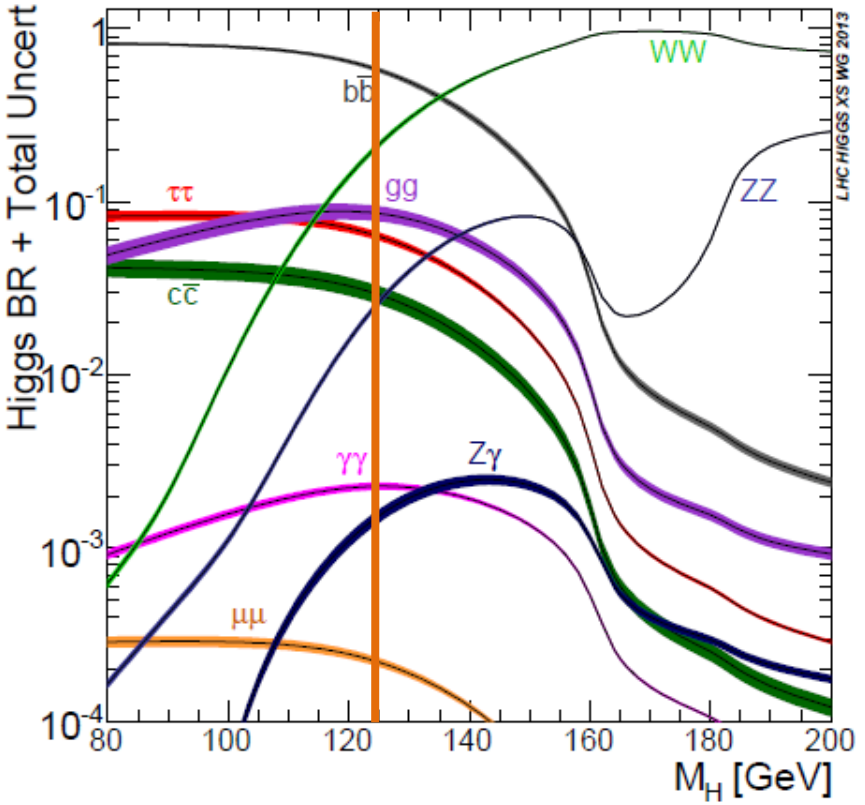
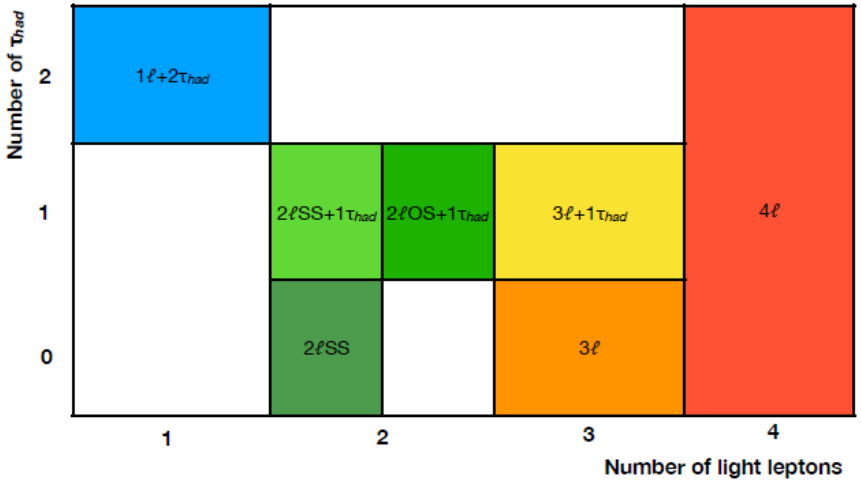


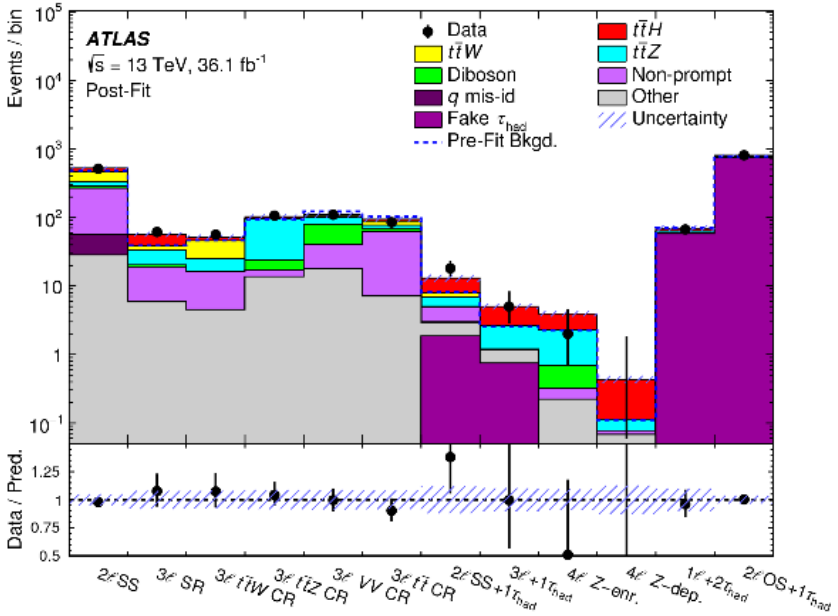


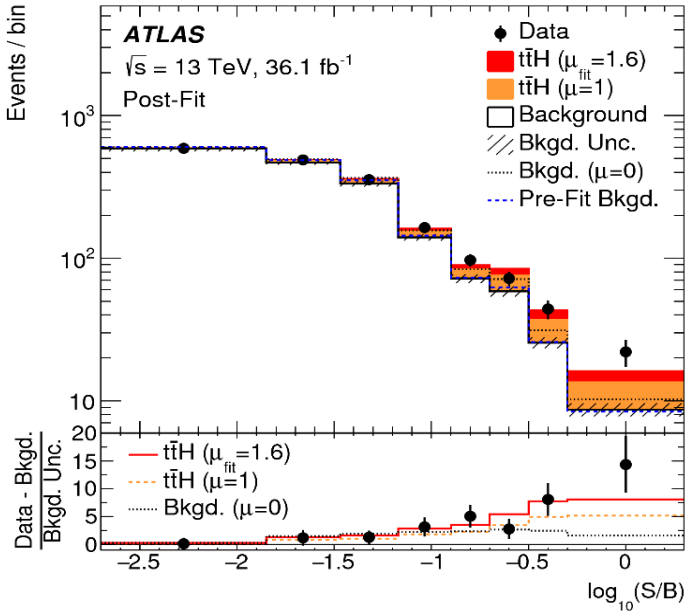
tth(125)/ttV

ATLAS:HIGG-2017-02; HIGG-2017-03

ATLAS: 7 final states, categorized by the number and flavor of charged-lepton candidates: eight signal and four control regions → a BDT is trained in the Z-enriched category to further discriminate the signal from the t tZ background.







The best fit for the *ttH* production cross section is ***σ*(*ttH*)=790+230−210 fb**, in agreement with the SMprediction of 507+35−50 fb.

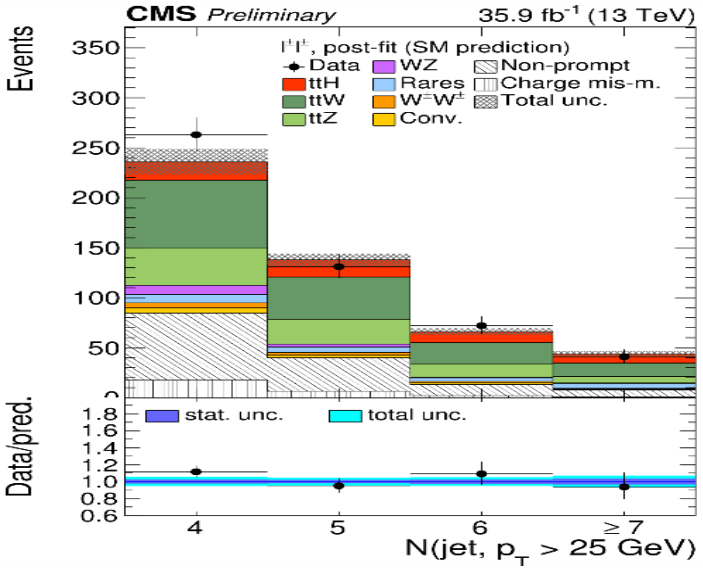
Combined 2015+2016 and all ttH →bb, γγ, ZZ*→4ℓ → Observed (expected) significance of 4.2 σ (3.8 σ).

tth(125)/ttV

CMS-PAS-HIG-17-004; CMS-PAS-HIG-17-003

CMS: Higgs →WW∗, ZZ∗ or $\tau\tau$

- requiring two same-sign leptons or at least 3 leptons, 4 leptons
- 3 more final states from CMS-PAS-HIG-17-003 with tau leptons



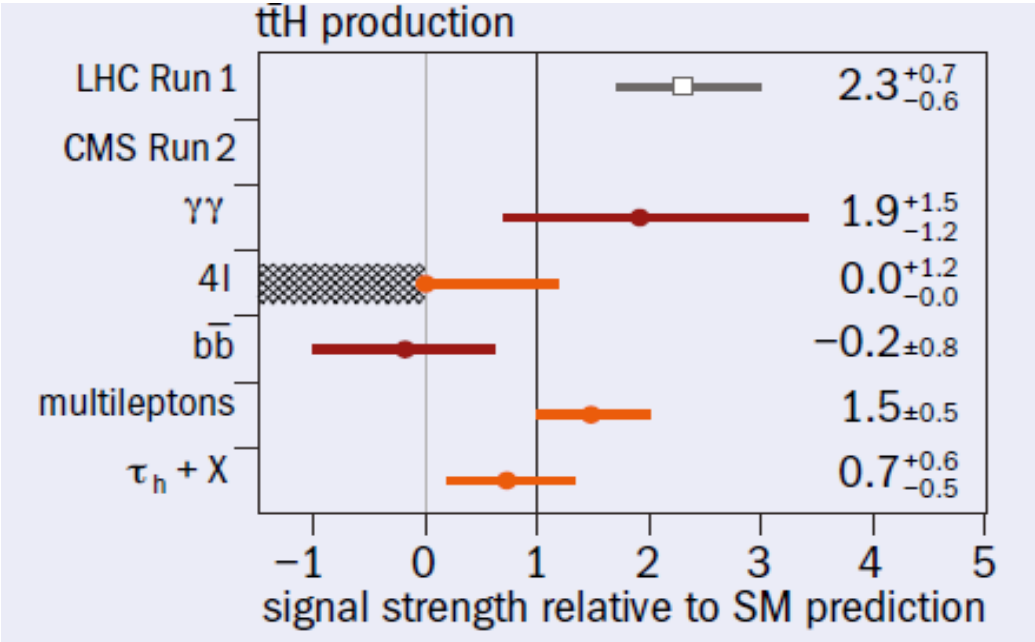
Combined 2015+2016:

observed (expected) best fit **tth yield is obtained** with a significance of **3.3σ** (2.5σ).

The top section summarises the ATLAS andCMS combined analysis of the Run 1 data, which exhibit a 2.3 standard-deviation excess above the SM prediction

***lower section shows the latest CMS resultsfrom Run 2**. Results that include the full 2016 Data are indicated in orange.*

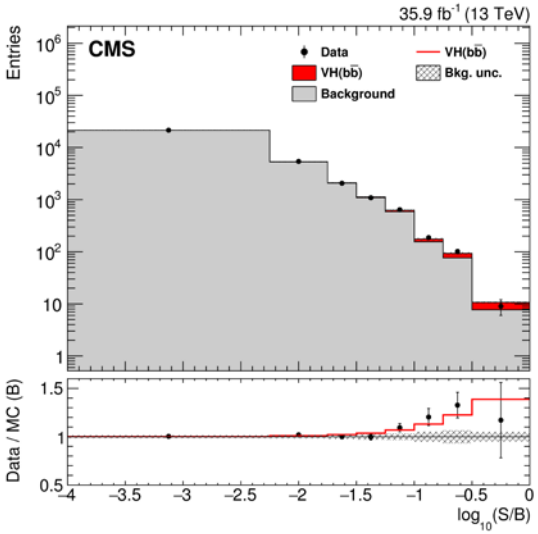
CERN Courrier May 2017

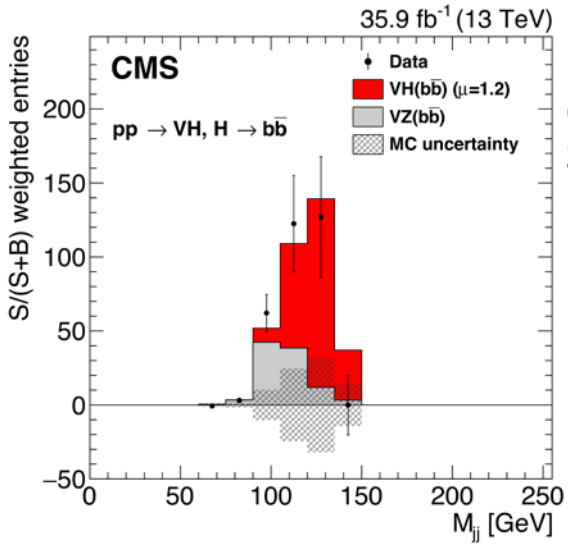


Vh(125)/VZ –> bb

ATLAS: JHEP 12 (2017) 024;
CMS:arXiv:1709.07497

CMS: Reconstruction of h(125) → two b-tagged jets; Reconstruction of the leptonic decay modes of the vector boson using 0- 1- 2-leptons categories

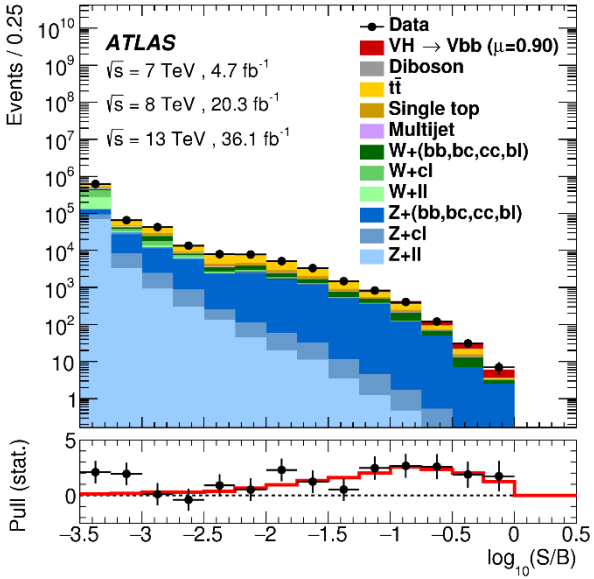




Observed (expected) signal significance is **3.3σ** (2.8σ) → signal strength μ= 1.2 ± 0.4.

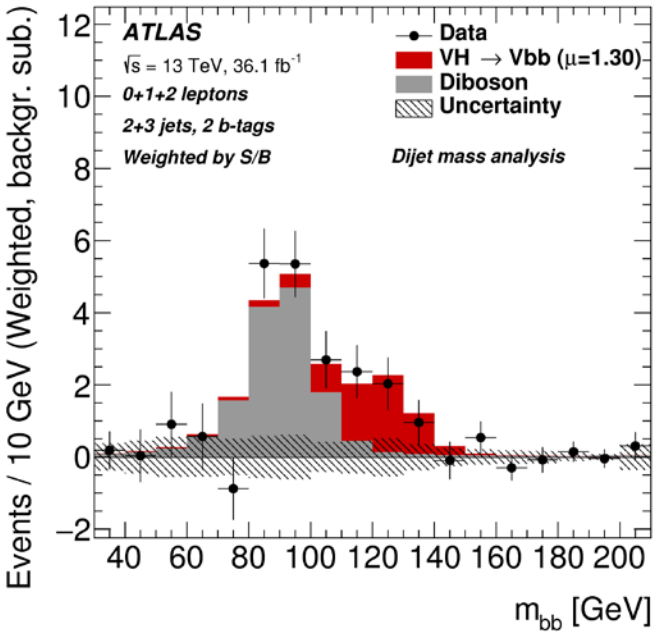
Combined Run1+Run2 :
Vh(125)→bb excess→3.8 σ
Expected=3.8 . σ
→ signal strength μ= 1.06 + 0.31. -0.29

ATLAS: Final states containing zero, one and two charged leptons; targeting the decays $Z\to\nu\nu$, $W\to\ell\nu$ and $Z\to\ell\ell$



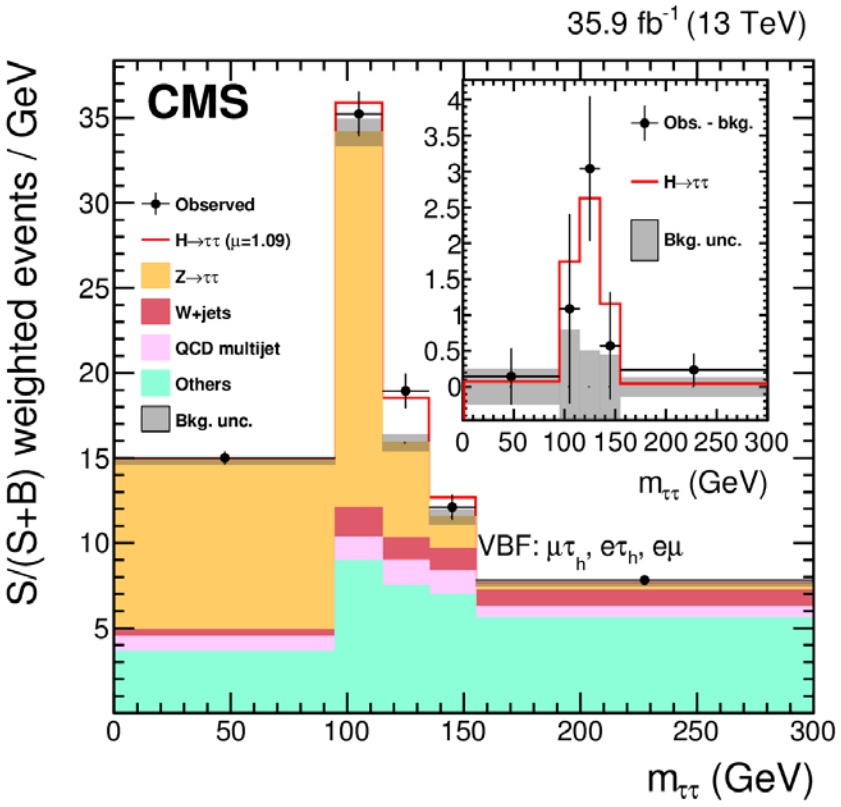
The Higgs boson signal contribution is shown after rescaling the SM cross-section according to the value of signal strength extracted from data

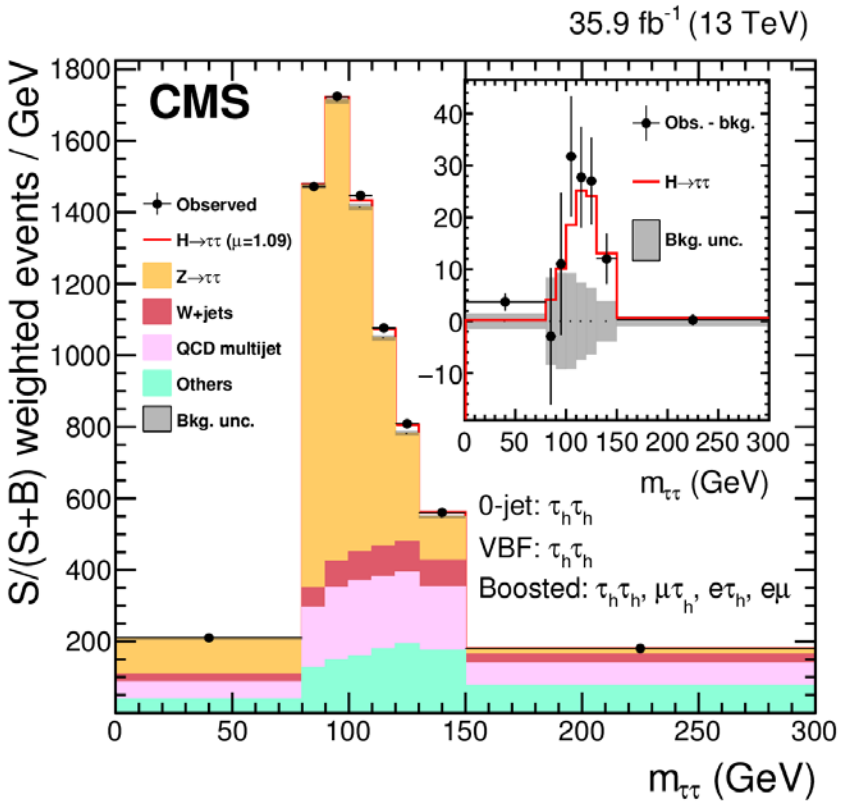
Combined Run1+Run2:
Vh(125)→bb excess→3.6 σ
Expected=4.0. σ
→ signal strength μ= 0.90+0.28-0.26

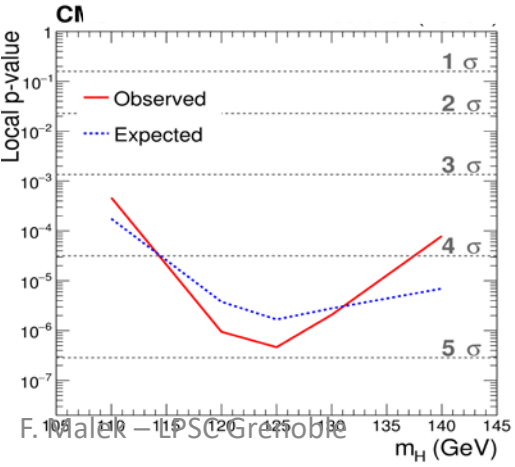


2016 LHC flagship result : h(125) –>ττ

CMS:arXiv:1708.00373







h→ττ signal significance = **4.9** σ. →signal strength μ= 1.09+0.27−0.26.

h→ττ expected significance = **4.7** σ.

→Combination (7,8, 13 TeV) → 5.9 σ.

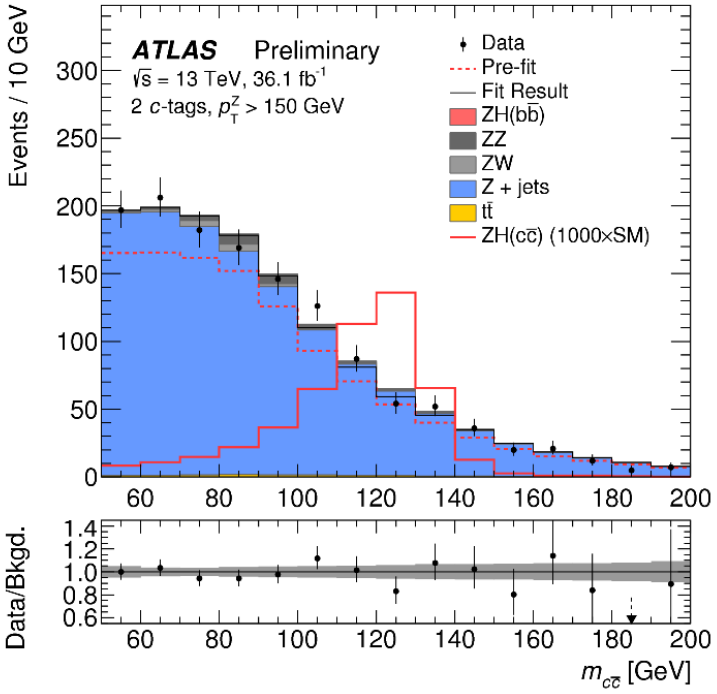
For the first time: Vh(125) –>cc

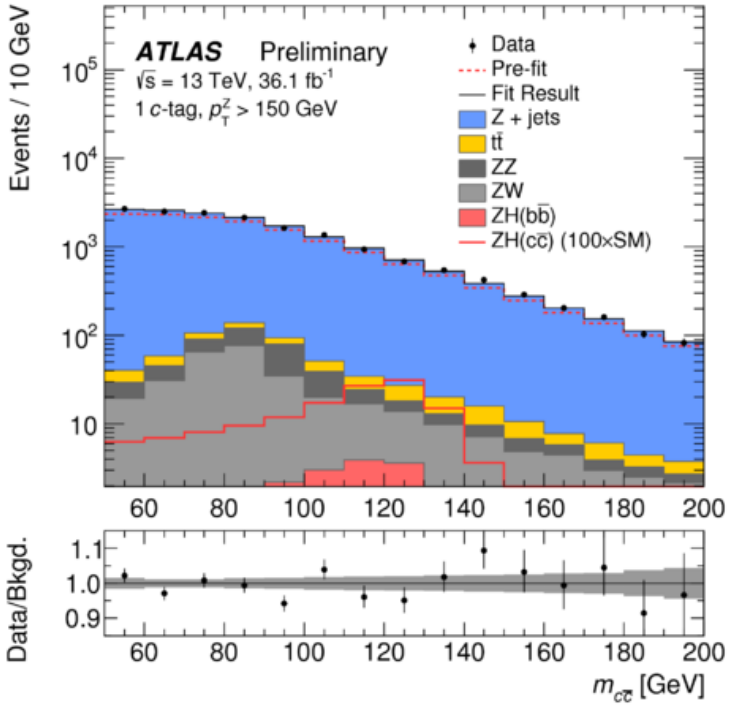
ATLAS-CONF-2017-078

Analysis:

→ In 4 categories: 2 P_T^Z regions + number of c-tags in leading jets (1 or 2).

→ m_{cc}: dijet system with 2 highest p_T jets





obs (exp) Upper limits @95%CL:

$\sigma(pp \to Zh) \times B(h \to cc)$) =2.7 ($3.9^{+2.1}_{1.1}$) pb

→ Inclusive $\sigma(pp \to Zh) \times B(h \to cc)$ is 25.5 fb @13 TeV

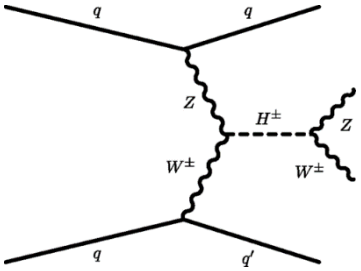
BSM Higgs searches

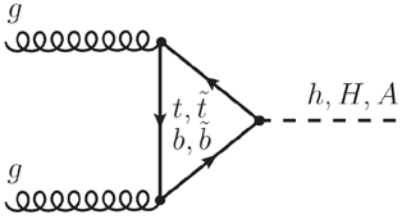
Understand the structure of the Higgs sector or extended as predicted in several BSM models.

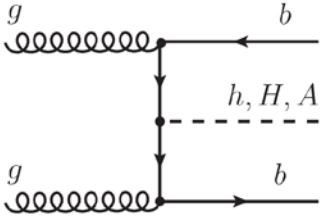
- Two Higgs Doublets Models (2HDM) have the role of standard benchmark scenarios
  - 5 scalar Higgs bosons: **h, H, A, H+, H-**
  - 6 main parameters: **mh, mH, mA, mH±, tanβ** and the mixing angle between h and H: **α**

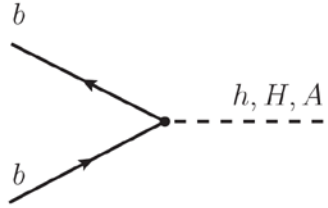
- in MSSM (type II) spectrum governed by only 2 parameters mA & tanβ
- beyond tree-level: common scenarios used as benchmarks: $mh^{mod}+$, hMSSM, HTM:

  - neutrals: H/A→bb,ττ,μμ, di-bosons, X→HH
  - charged: H±→τν, tb, cb, cs









Next 2 slides are examples of a much larger set of new results.

BSM Higgs searches

CMS:*PRL 119 (2017) 141802* ; **CMS**-PAS-HIG-17-020; **ATLAS**: HIGG-2016-12

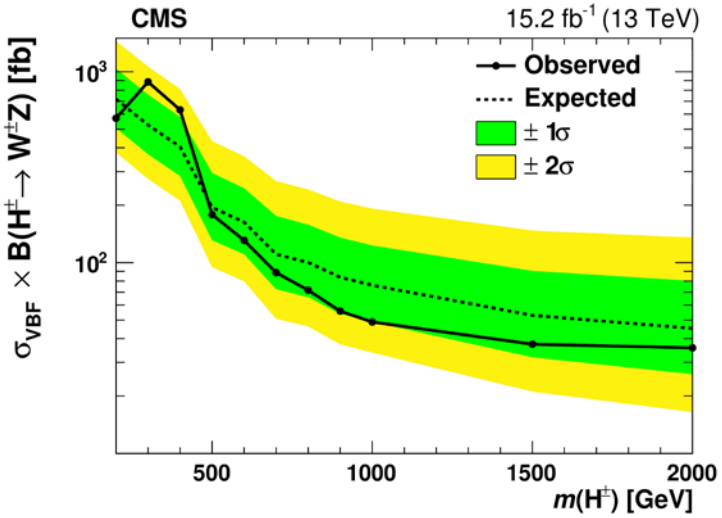
Charged Higgs produced via VBF

Interpretation in the context of Higgs triplet models (HTM).

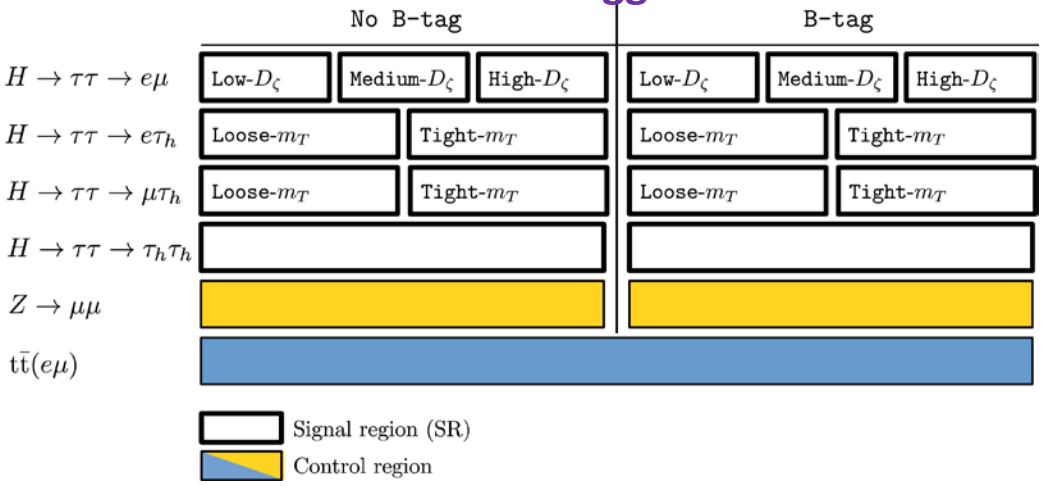
Event selection :

- 3 leptons (e or μ)
- high dijet mass+ large η sep.
- Large MET

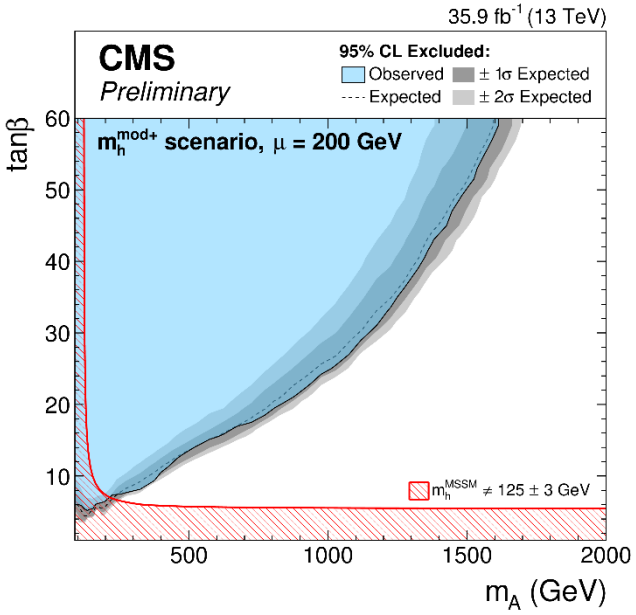
Data set	2015	2016
Data	9	62
WZ	7.5 ± 1.2	44.4 ± 5.7
ZZ	0.2 ± 0.1	1.6 ± 0.2
VVV	0.8 ± 0.2	5.5 ± 0.9
$Z\gamma$	0.2 ± 0.1	1.0 ± 0.6
Nonprompt	1.3 ± 1.0	7.4 ± 5.4
Total bkg.	10.0 ± 1.6	59.9 ± 8.0
Signal ($m(H^{\pm}) = 700$ GeV)	0.9 ± 0.1	4.7 ± 0.5



Additional neutral MSSM Higgs bosons →di-tau



In the m_h^{mod+} scenario these limits translate into an exclusion of tanβ> 6 for *m*h< 200 GeV.



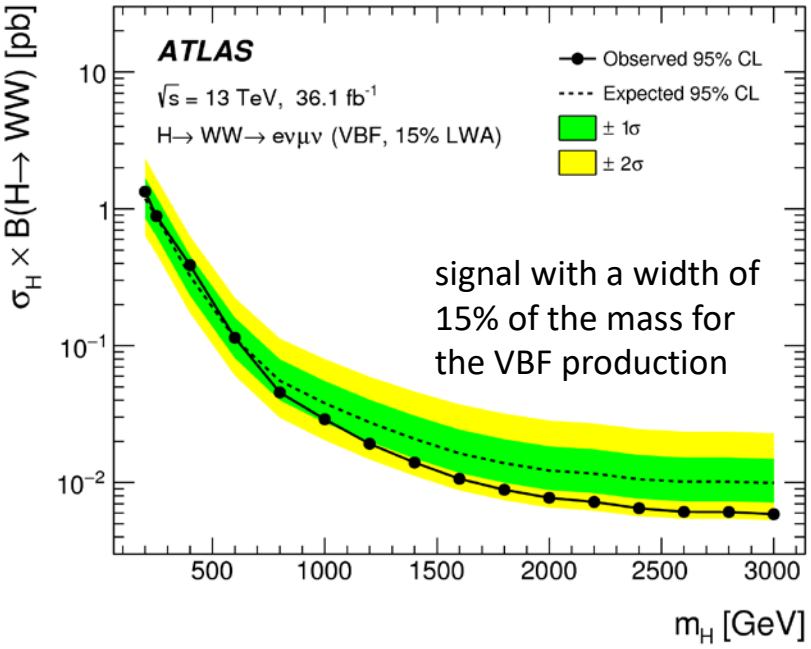
BSM Higgs Searches

[Eur. Phys. J. C 78 (2018) 24](#)

[arXiv:1712.06386](#)

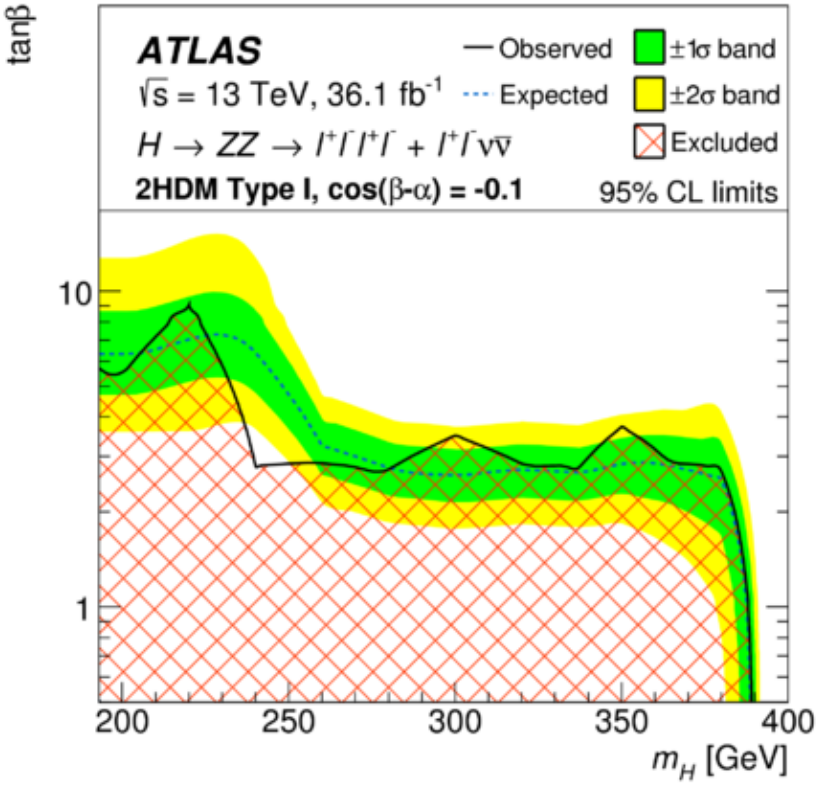
New heavy Resonances → WW → evμν

Model	Resonance spin	Production mode ggF	qqA	VBF
NWA	Spin-0	x		x
2HDM		x		x
LWA		x		x
GM				x
HVT	Spin-1		x	x
Bulk RS	Spin-2	x		
ELM				x



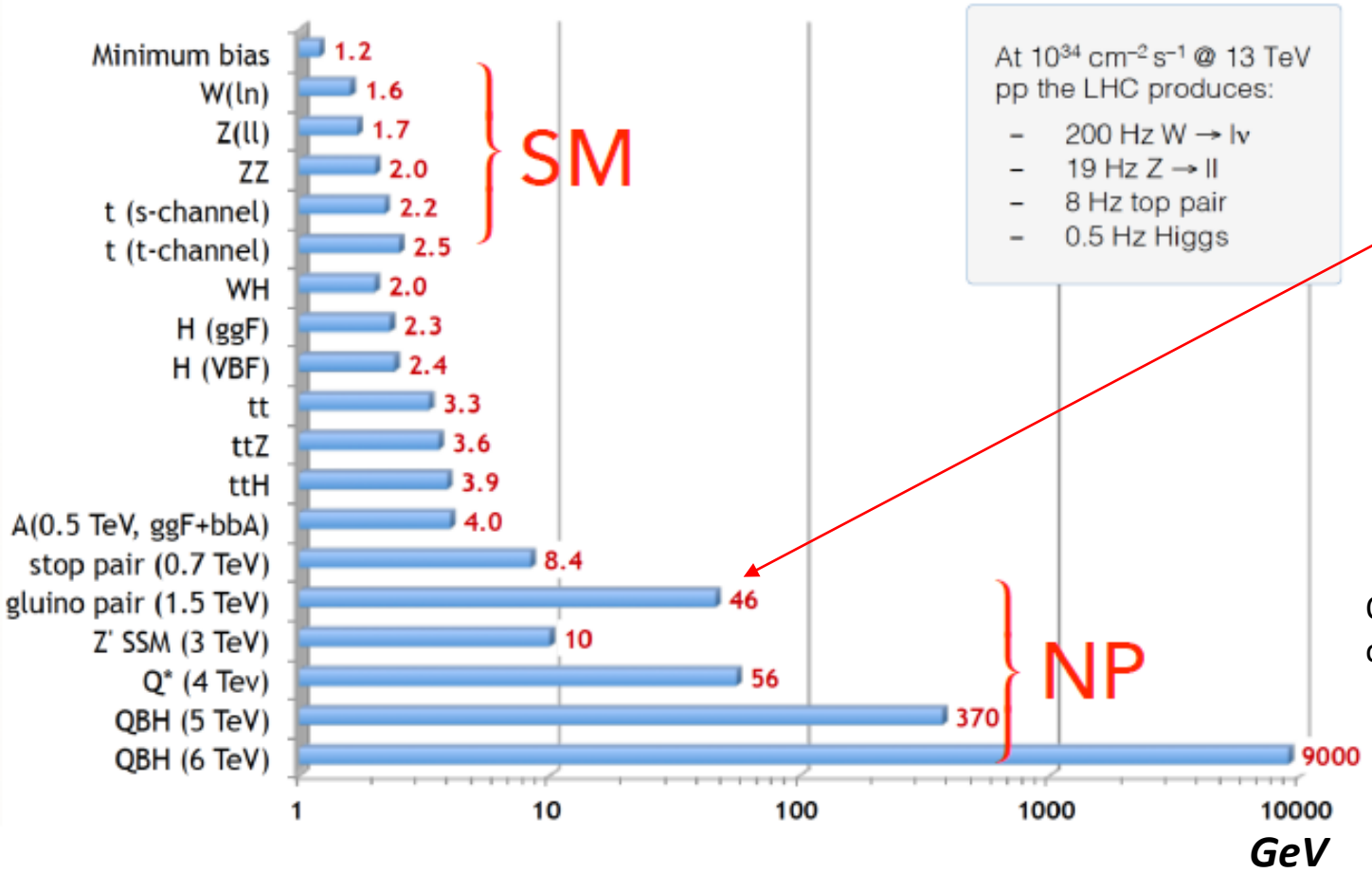
New heavy resonances →ZZ bosons → ℓ+ℓ−ℓ+ℓ− and ℓ+ℓ−νν

- upper limits on the production cross section of a spin 0 or spin 2 resonance are extracted.
- For **the spin 0 resonance** -> exclusion contours in the context of Type I and Type II two-Higgs-doublet models



BSM searches

The new energy (13 TeV) and the higher luminosity of Run2 provided the ideal condition for direct searches of new particles in the so called SuSy and Exotics

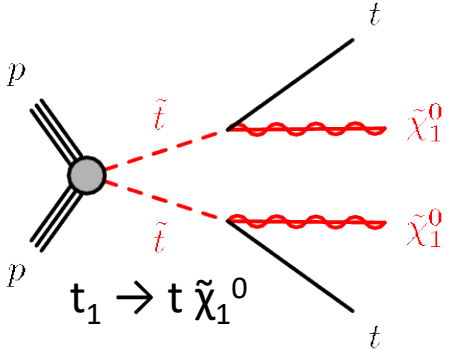


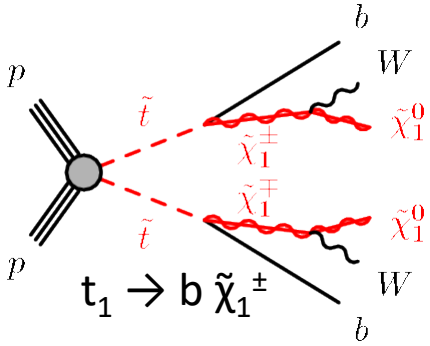
8 to 13 TeV
σ scaling factors

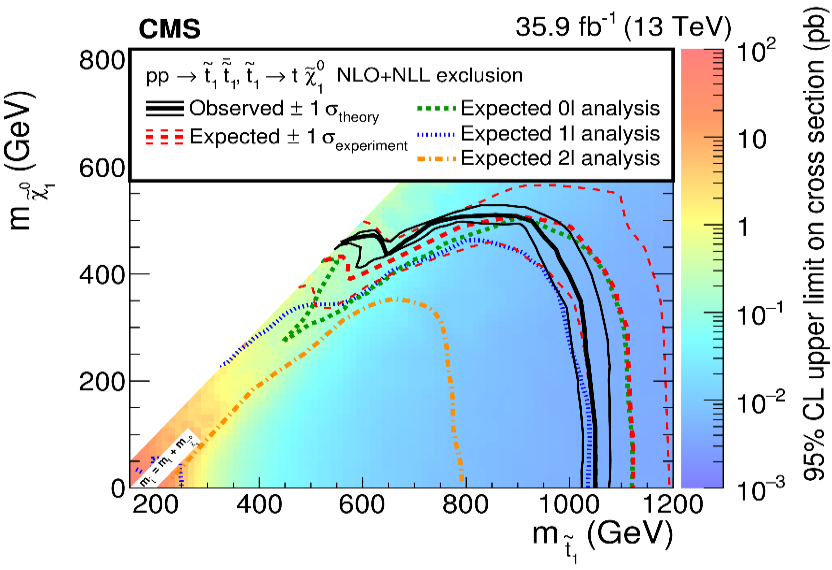
Only a small selected set of analyses are shown here

SuSy Searches: top-squark pairs

ATLAS: Combined analysis; **CMS**:arXiv:1711.00752







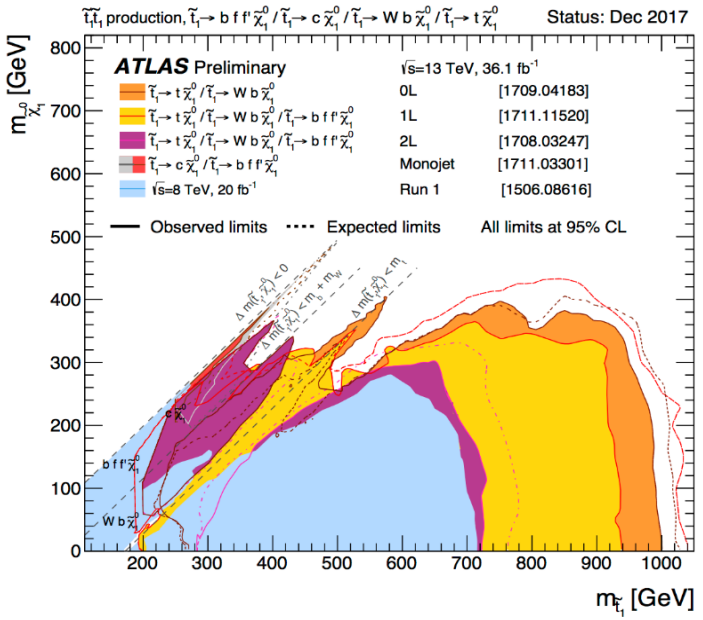
CMS:

→ Exclusion limits are set in the context of simplified supersymmetric models with pair-produced top squarks

→ two oppositely charged leptons, jets from b quarks, MET

→ stop masses up to 1050 GeV are excluded

→ neutralino up to 500 GeV are excluded



ATLAS:

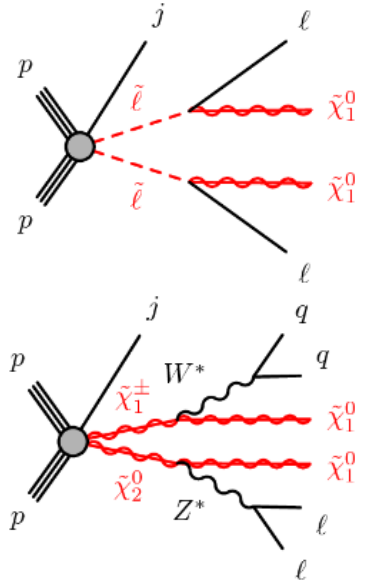
→ one lepton, jets, MET, BDT analysis

→ Four decay modes are considered separately with 100% BR: stop1 → t+neutralino1, stop →, stop → c + neutralino1, stop → f+f'+b+neutralino1

→ stop masses up to 940 GeV are excluded

SuSy Searches: higgsino

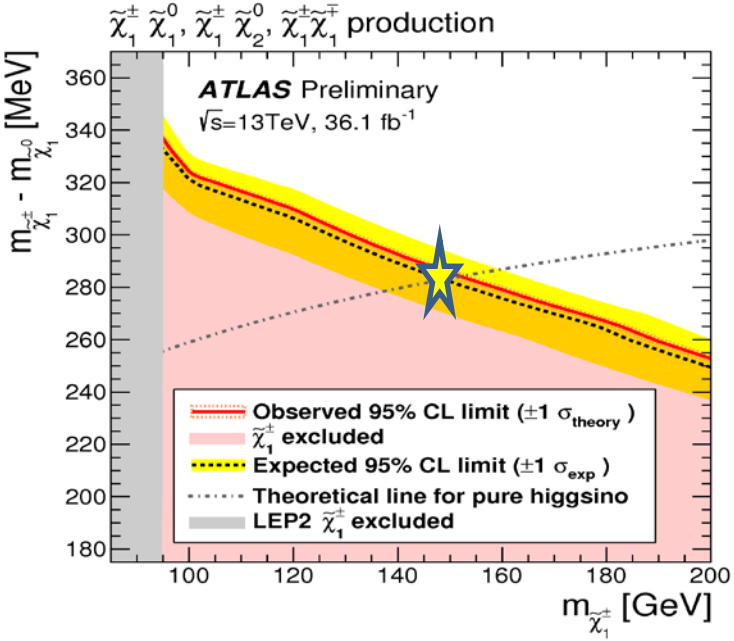
ATLAS: Combined analysis; arXiv:1712.08119; **ATL**-PHYS-PUB-2017-019

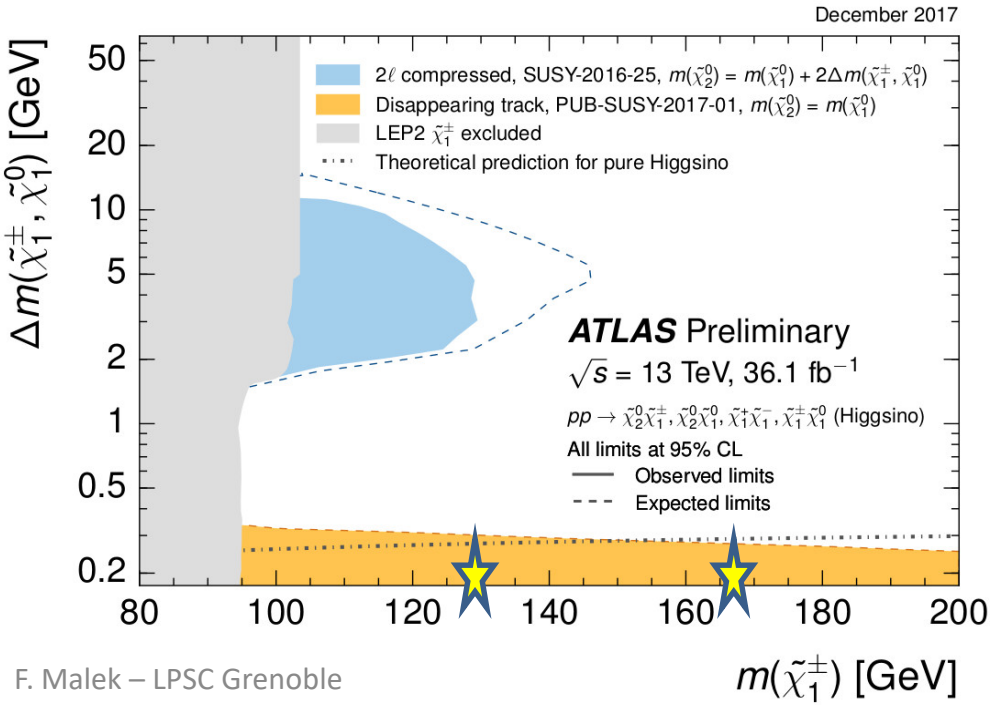


Reinterpretation of the disappearing track search (LLP wino LSP signature)

→ targeting the pure-higgsino signature.

→ Chargino masses up to 152 GeV are excluded in the pure-higgsino LSP model.





In R-parity-conserving SuSy:

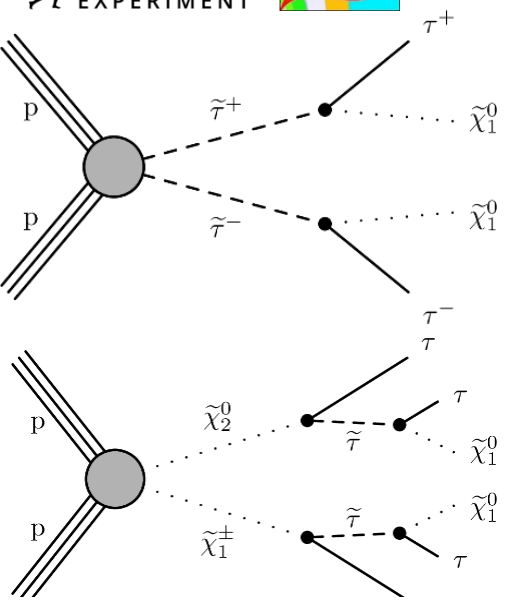
- masses of up to 130 GeV for higgsino production and 170 GeV for wino production are excluded @95% CL.

In Compressed Mass regime, exclusion limits extend down to mass splittings of

- 3 GeV for higgsino production
- 2.5 GeV for wino production

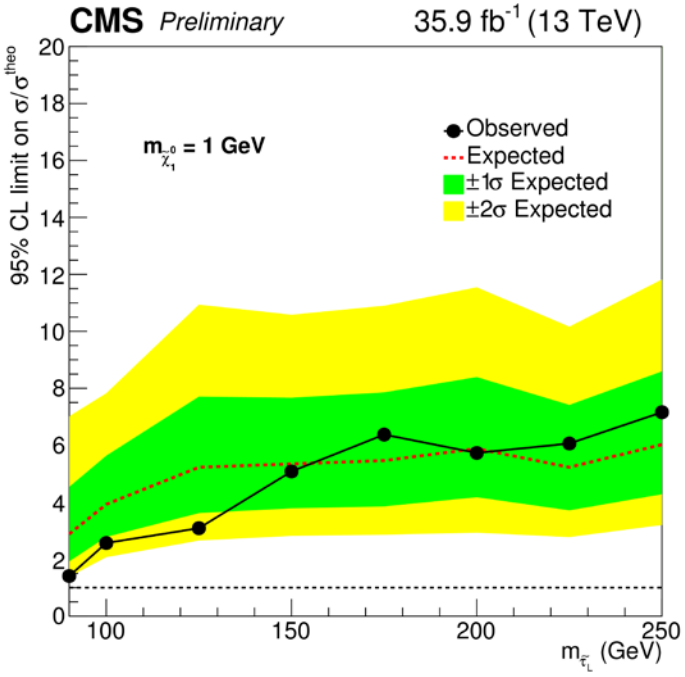
SuSy Searches: $\tilde{\tau}$-pair production

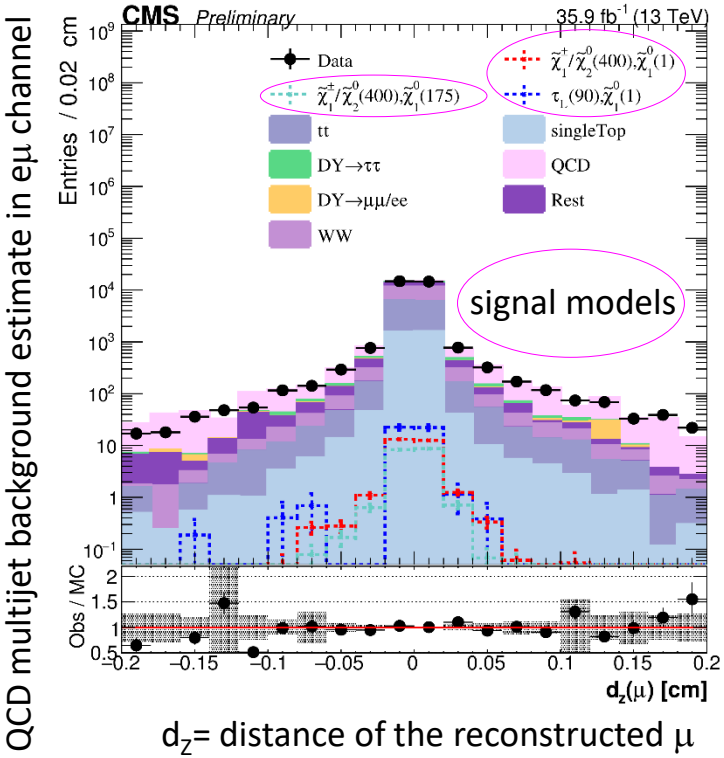
CMS-PAS-SUS-17-002



Final states:

- one hadronically decaying τ lepton and an e or μ from the decay of the second τ
- one e and one μ from the decay of the τ leptons.





d_Z= distance of the reconstructed μ to the primary vertex in *z* direction

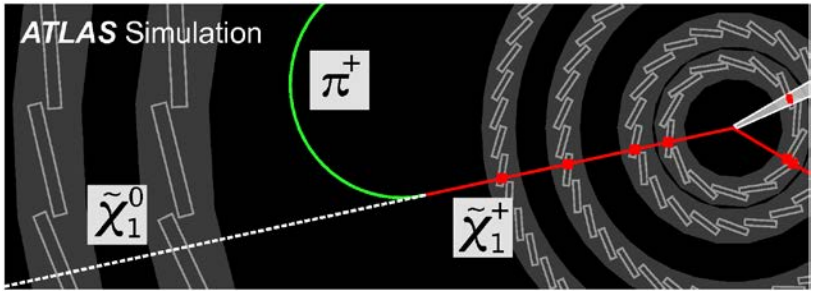
Example of results:

upper limit on cross section times the square of the branching fraction is set to be 0.66 pb, for a $\tilde{\tau}$ mass of 90 GeV and a $\tilde{\chi}^0_1$ mass of 1 GeV

SuSy/Exotics Searches: Long Lived Part.

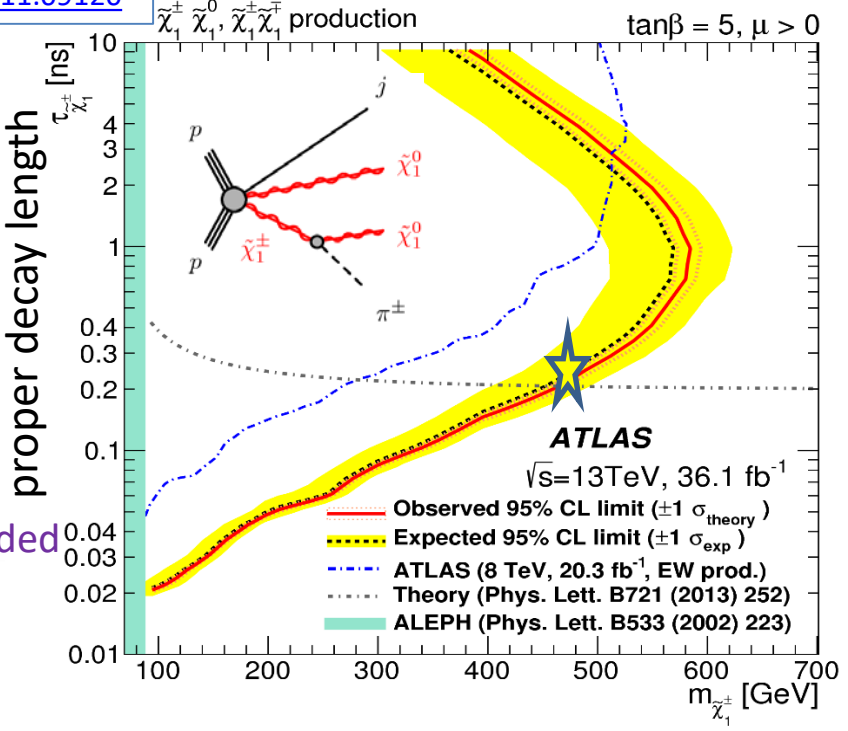
ATLAS: arXiv:1712.02118; **CMS**:arXiv:1711.09120

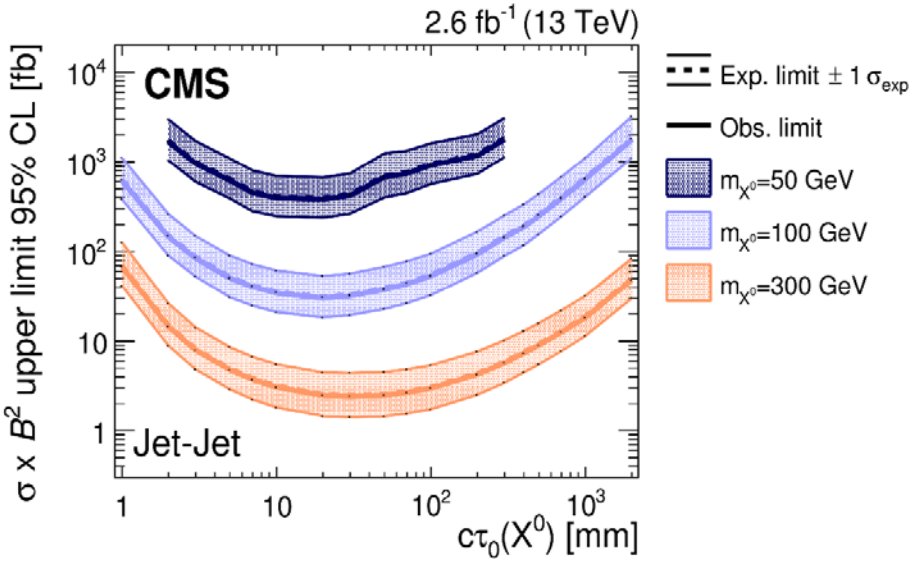
Disappearing tracks



pp→ $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ → jet event+ MET+ long-lived chargino
(almost pure wino LSP scenario at the two-loop level)

For a τ ~0.2 ns, chargino masses up to 460 GeV are excluded





Displaced jets: search for the presence of a signal decay occurring at distances between 1 and 1000 mm

N_{tags}	Expected	Observed
2	1.09 ± 0.16	1
≥3	$(4.9 \pm 1.0) \times 10^{-4}$	0

For pair-produced LLPs → 2 b + 2 leptons with equal decay rates between lepton flavors,
σ > 2.5 fb are excluded for 70 < τ < 100 mm.

Exotics Searches

CMS-PAS-HIG-17-012

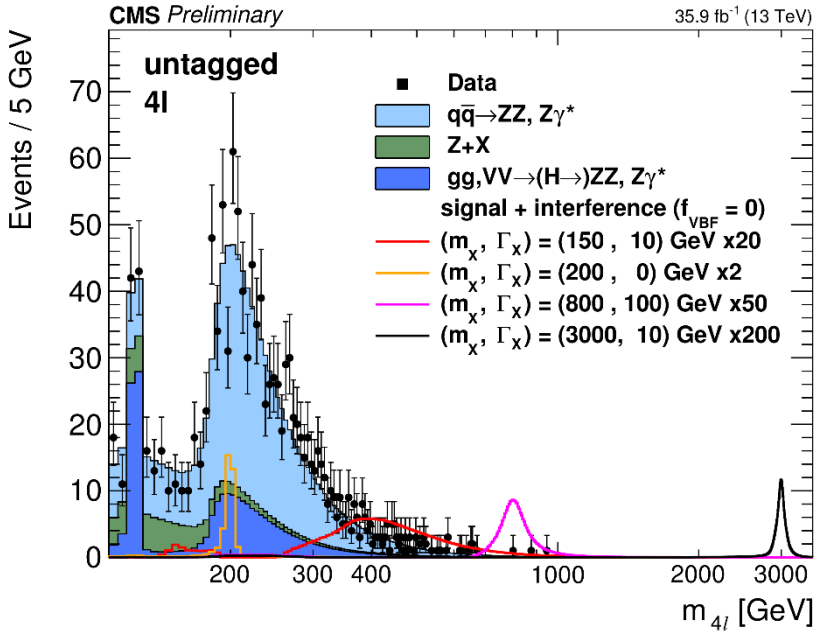
New resonances decaying into a pair of ***Z*** bosons

ggH, gg→X→ZZ→(ℓ+ℓ−)($f\bar{f}$) and VBF qq′→qq′X→qq′ZZ

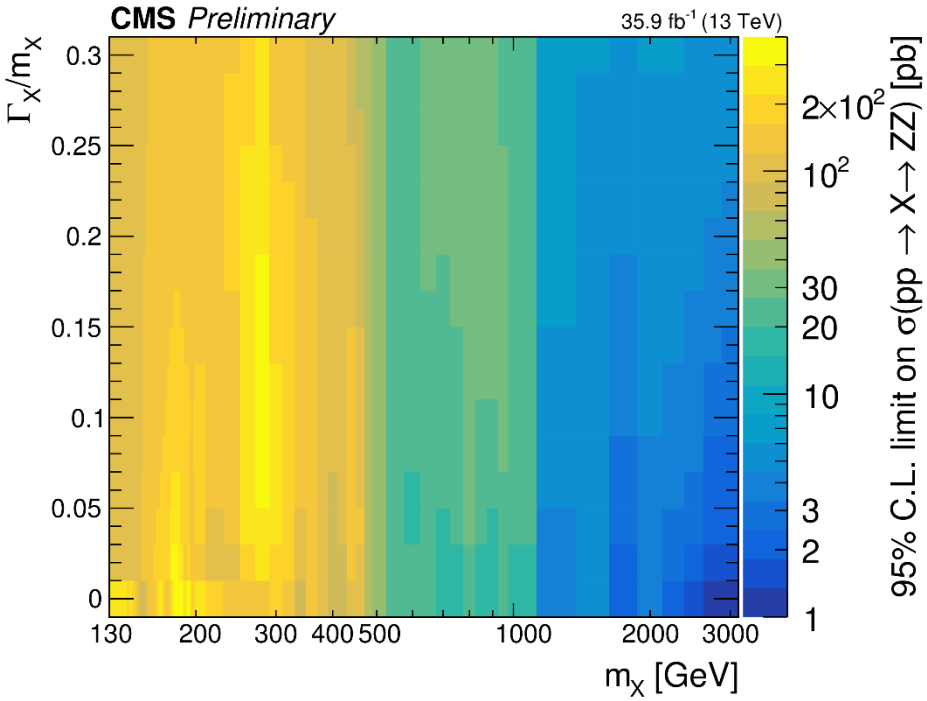
Analysis:

- ZZ→4ℓ, 2ℓ2q, and 2ℓ2*v*
- associated jets to increase the sensitivity

Both gluon fusion and electroweak production of the scalar resonance are considered with a free parameter describing their relative cross sections.



mass scanned from 130 GeV to 3 TeV; **width** scanned from 0 to 30%.

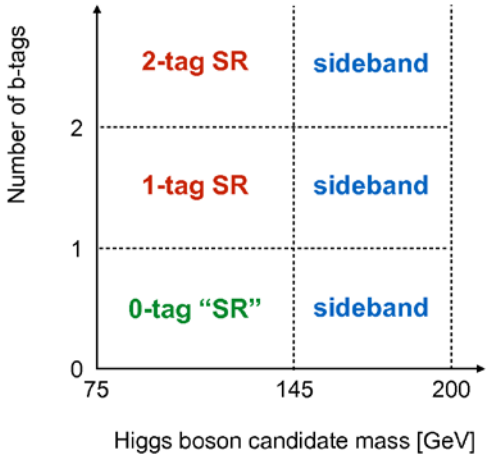


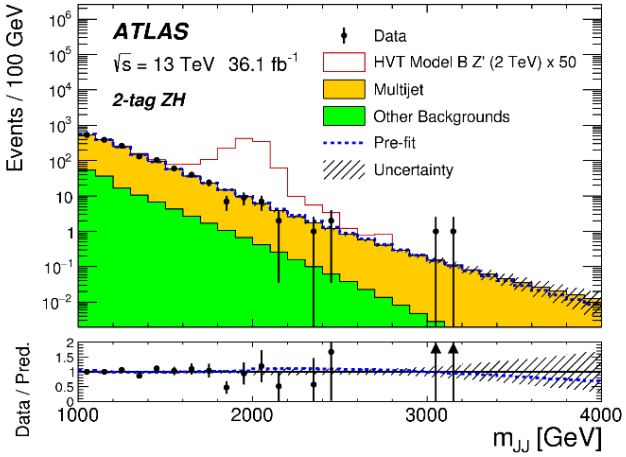
Exotics searches

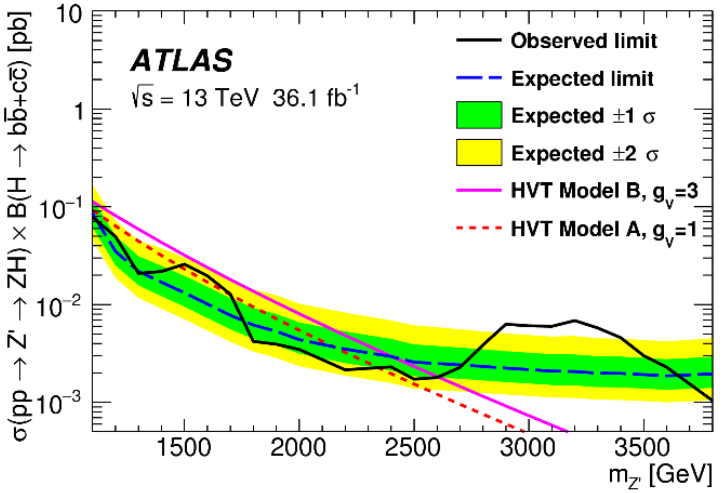
ATLAS: Phys. Lett. B 774 (2017) 494

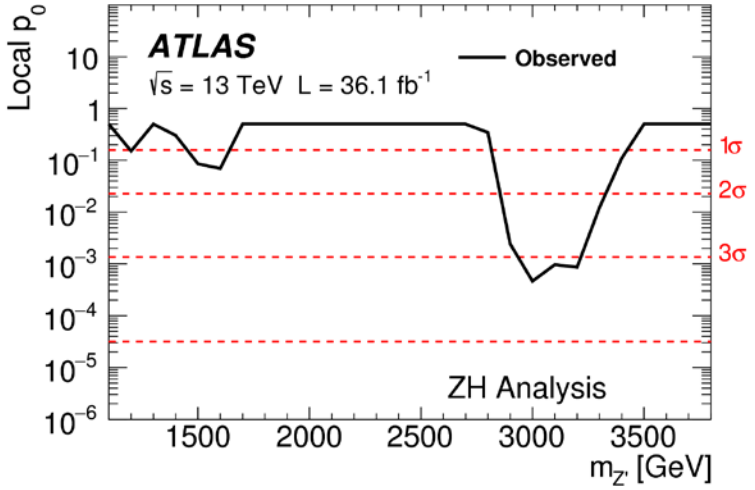
New resonances X decaying into a ***W*** or ***Z*** boson and a h(125) boson

Final states:qqbb









The largest **excess** found at a resonance mass of **3.0 TeV** with a **local** (global) significance of **3.3** (2.1)~***σ***

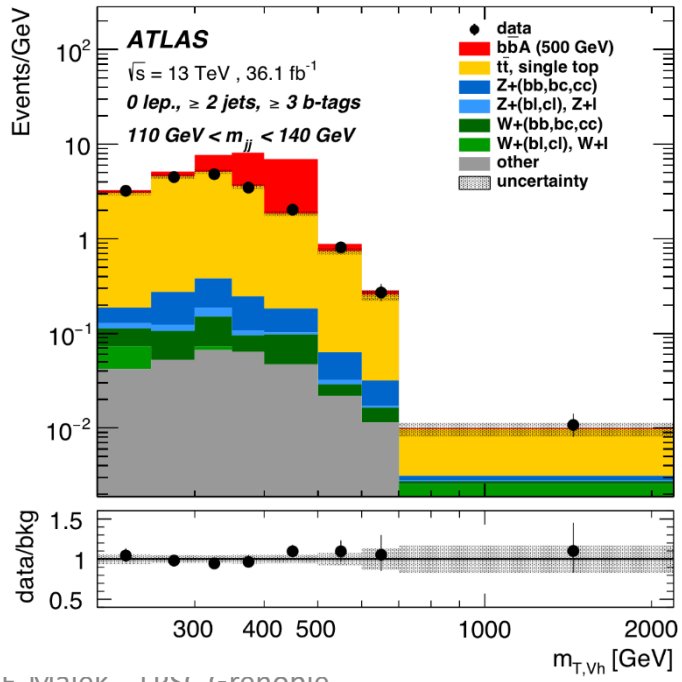
Exotics Searches

ATLAS: arXiv:1712.06518

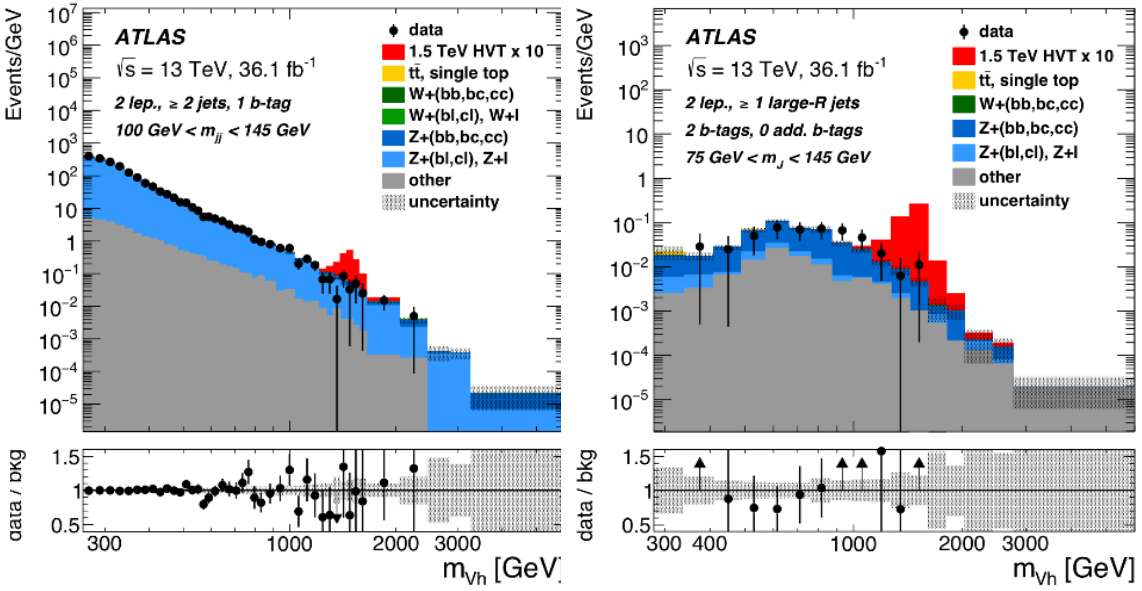
New resonances X → a ***W*** or ***Z*** boson and a h(125) boson

Final states: *ννbb*, $\ell^{\pm}\nu bb$, and $\ell^{+}\ell^{-}bb$

Analysis : reconstructed invariant or transverse mass distributions of *Wh* and *Zh* candidates for evidence of a localised excess in the mass range of 220 GeV up to 5 TeV.



Signal for the benchmark HVT Model A with $m_{V'}$ = 1.5 TeV



A boson with mass of 500 GeV is shown in red using a cross-section of 5 pb

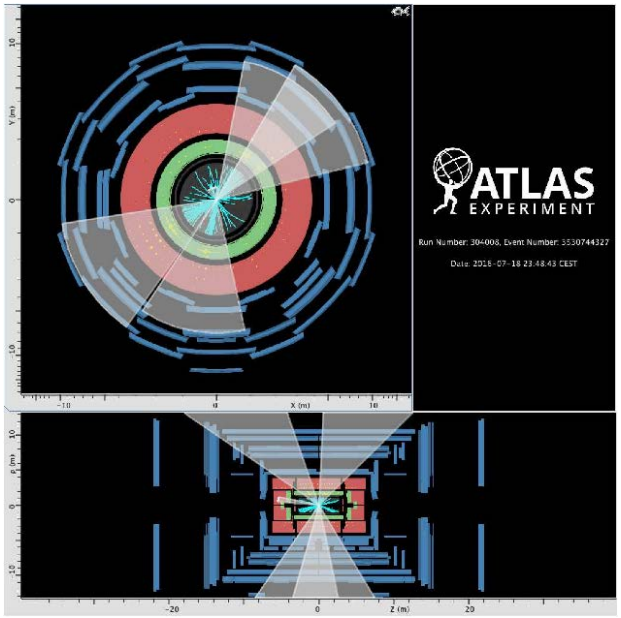
Exotics Searches

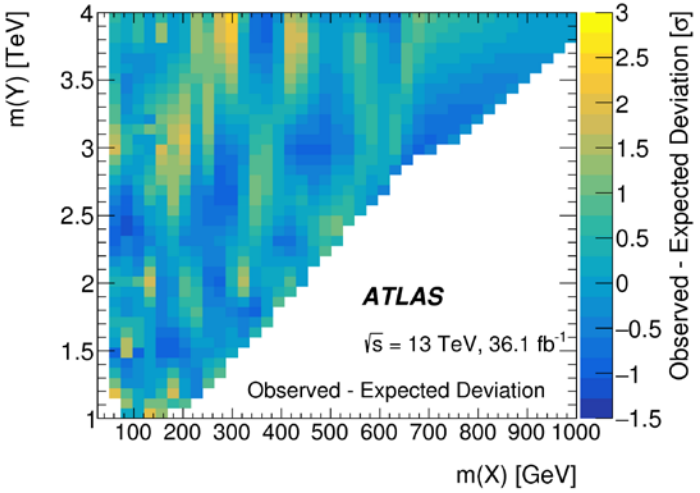
ATLAS: arXiv:1709.06783

New resonances decaying into a new Particle X and a H boson

pp→ Y→ XH → qqbb

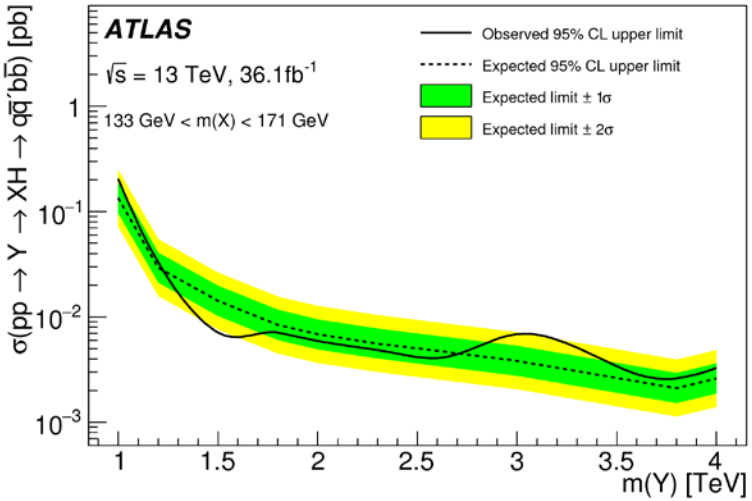
X and *H* bosons are both highly Lorentz-boosted and reconstructed using a single jet with large radius parameter





Within the framework of a modified Heavy Vector Triplet model, only small discrepancies are observed, with local (global) significance of no more than 2.5 (1.2).

2-tag signal region, with m_{JJ} = 3172 GeV and m_J = 949 GeV for the X candidate jet



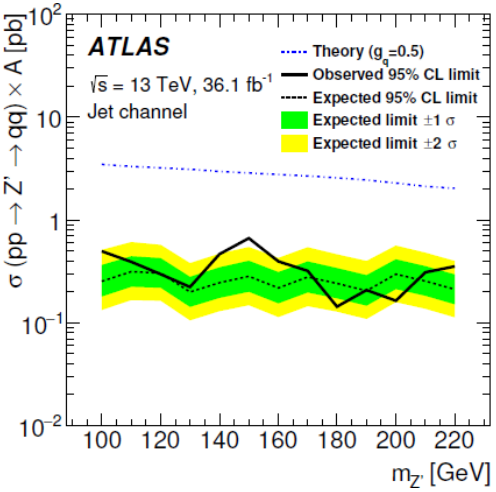
Low mass dijet resonances with ISR@13 TeV

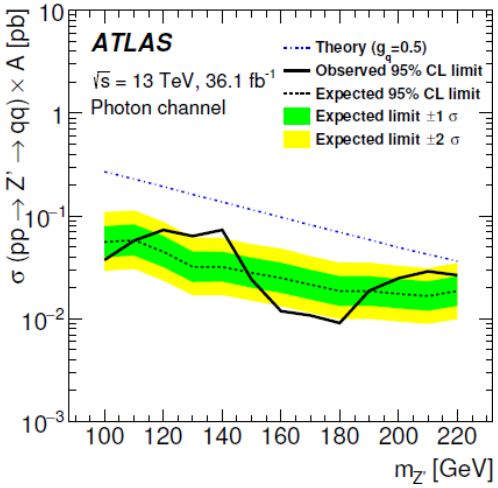
ATLAS: ATLAS-EXOT-2017-01; CERN-EP-2017-280

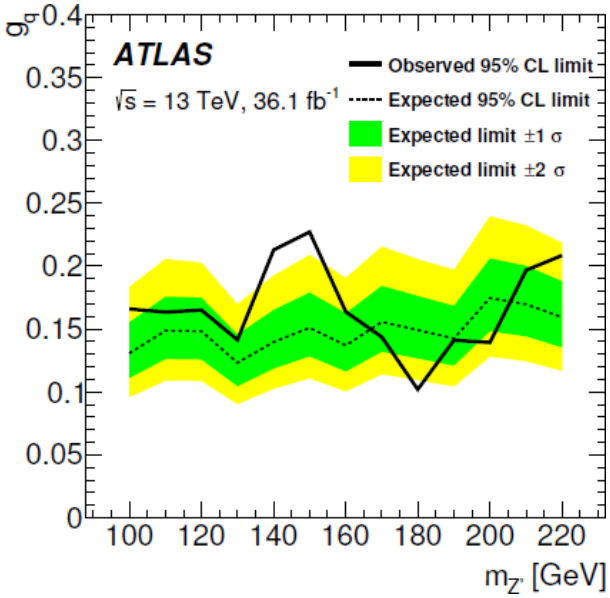
Event selection and analysis:

- primary vertex with 2tracks with p_T > 400 MeV each.
- γ are "tight" and $|\eta| < 2.37$, excluding $1.37 < |\eta| < 1.52$.
- *large-R* jets (R = 1 and $|\eta| < 2.0$)
- *narrow* jets (R = 0.4 and $|\eta| < 2.4$)
- **jet substructure techniques** to identify the expected two-body quark-pair signal-like events within a single large-R jet

Limits on the cross section and couplings of a leptophobic axial-vector Z' benchmark model



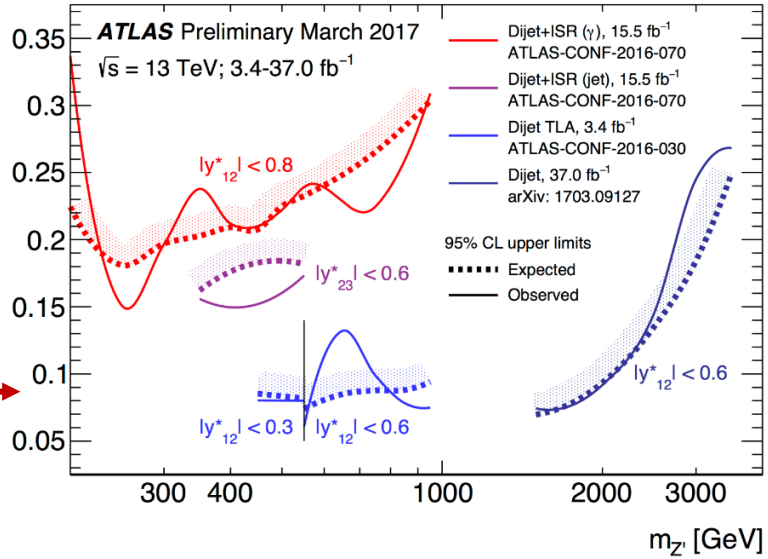




The observed upper limits on the coupling gq:

- 0.17 for $m_{Z'}$ = 100 GeV
- 0.21 for $m_{Z'}$ = 220 GeV

complementarity



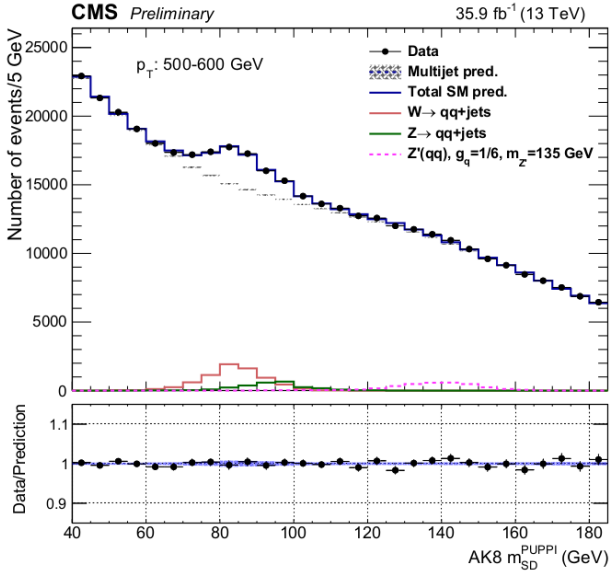
Low mass dijet resonances with ISR@13 TeV

CMS: CMS-PAS-EXO-17-001

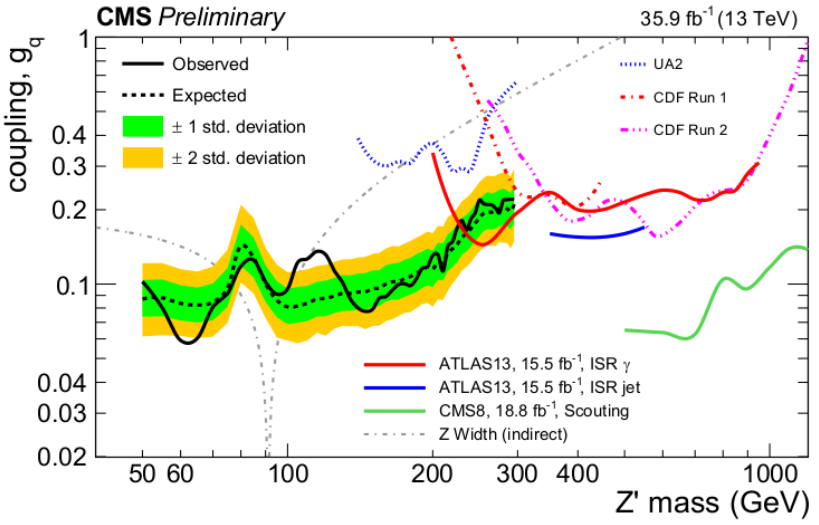
Event selection and analysis:

- hypothetical resonance with high p_T → single jet with two-prong substructure.
- **jet substructure techniques** are to identify the expected two-body quark-pair signal-like events within a single large-R jet

Limits on the cross section and couplings of a leptophobic axial-vector Z' benchmark model



Soft drop jet mass distribution



→ sensitive to new physics down to 50 GeV compared to 100 GeV for ATLAS

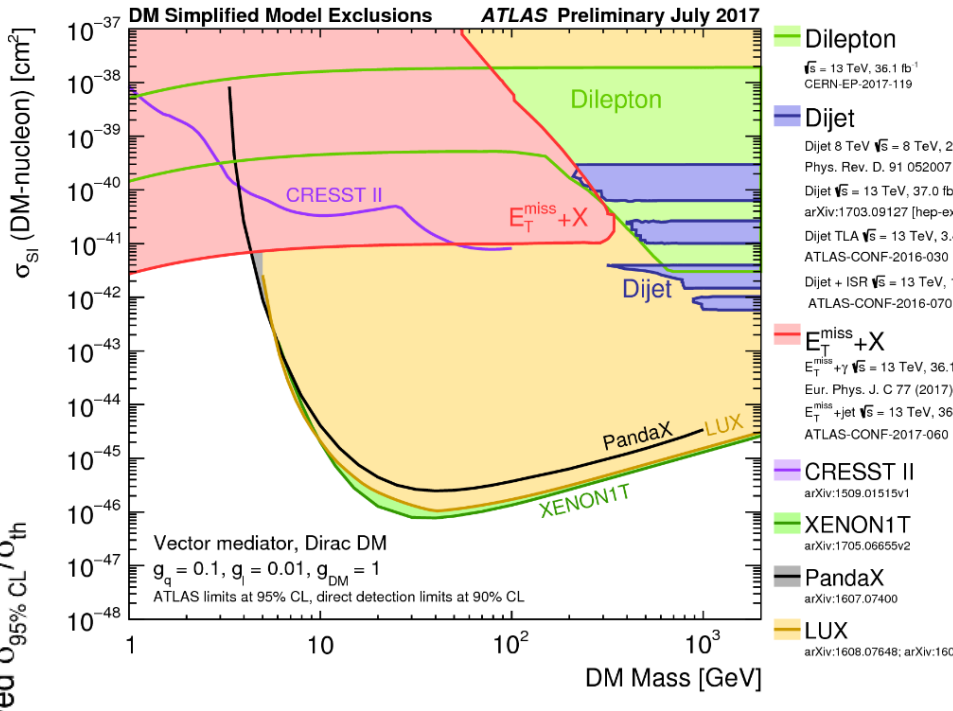
→ Strong constraints on masses < 200 GeV

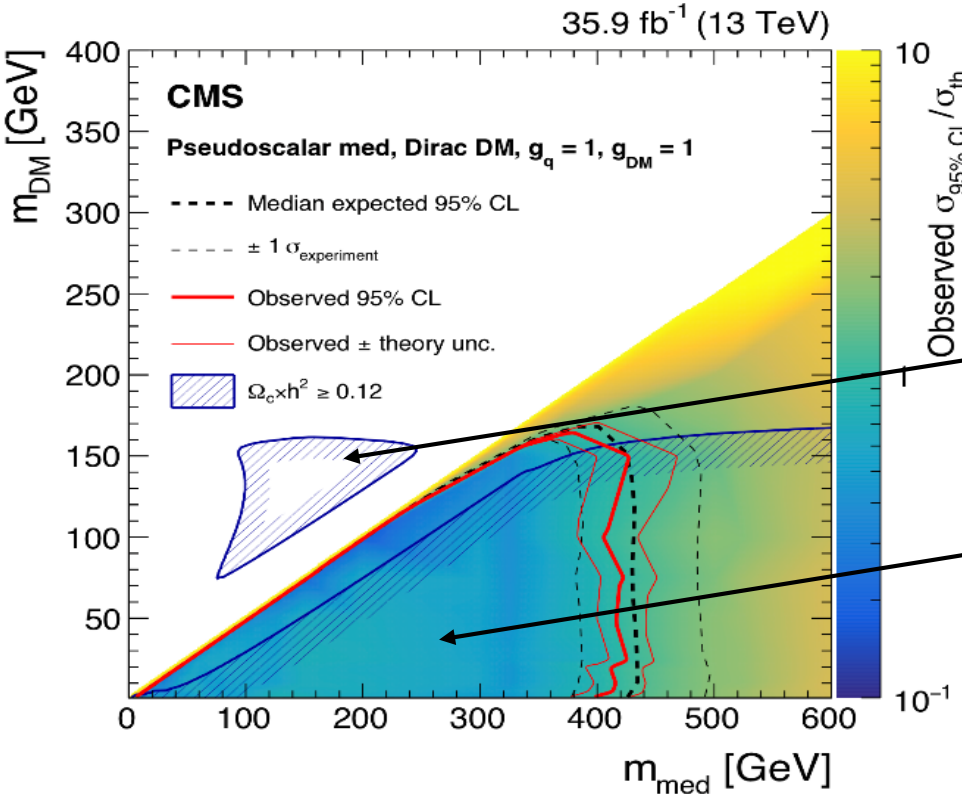
→ Coupling values of *g*q'>0.25 are excluded over the Z' mass range from 50 to 300 GeV

Dark Matter compilation

ATLAS:DM compilation;
CMS: arXiv:1711.00431; arXiv:1712.02345

Constraints from direct detection experiments on the spin-Independent WIMP-nucleon scattering cross section in the context of the Z'-'like simplified model with vector couplings. LHC limits are shown at 95% CL and direct detection limits at 90% CL → validity
NB: mediator width fixed by the dark matter mass and coupling values





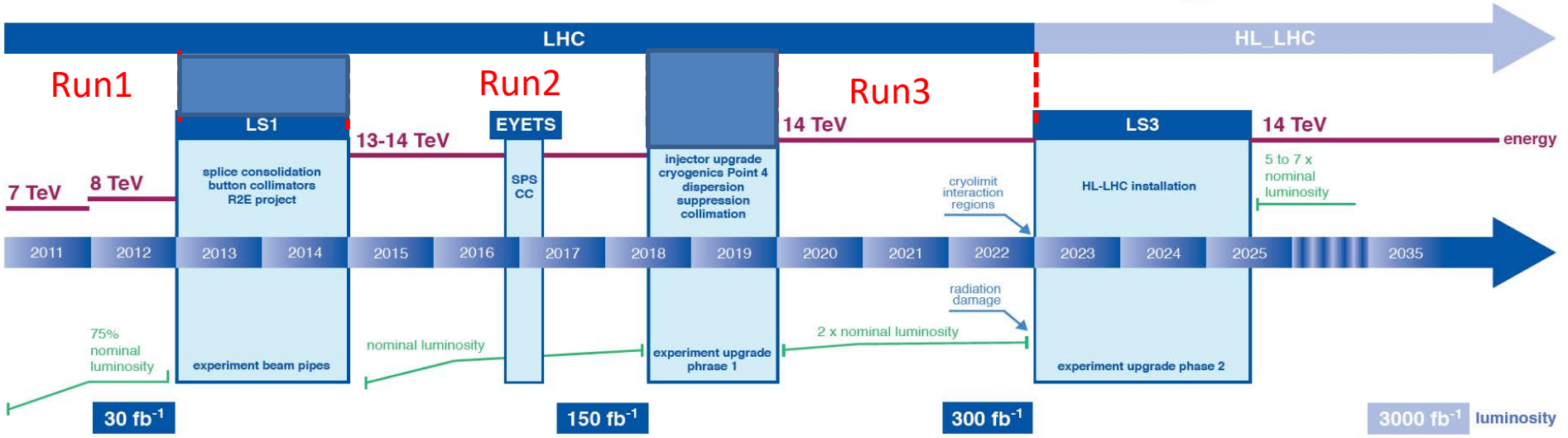
DM is overabundant

Constraints from the Planck satellite experiment

Conclusion

- Precision measurements in the Higgs sector and searches for new physics effects from ATLAS and CMS using Run1 and Run2 (2015 to 2017) data, collecting up to 80 fb^{-1}@Run2.
- Exploration of New Physics models
- No evidence of new particles or anomalies up to now, but 2017 data as well as the coming 2018 data collection are still to be analyzed
- Many regions and models still unexplored and substantial space for surprises is available

LHC / HL-LHC Plan



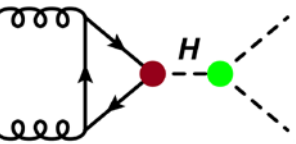
μ≈20 μ≈40 μ≈50-80 μ≈150

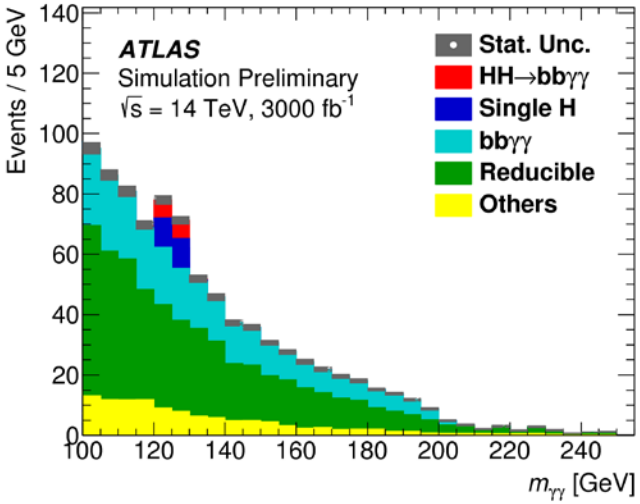
Double Higgs production channel H(-> bb)H(->γγ)

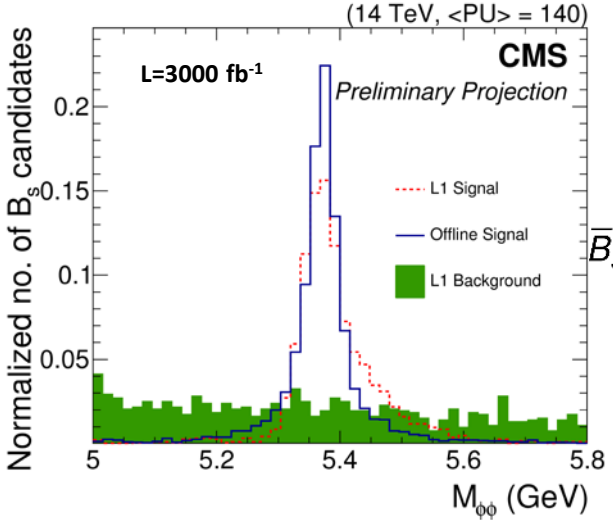
ATL-PHYS-PUB-2017-001

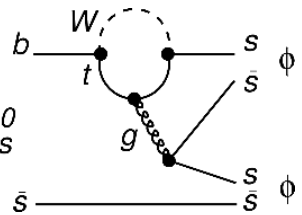
Bs→ϕϕ decay studies

CMS-PAS-FTR-16-006





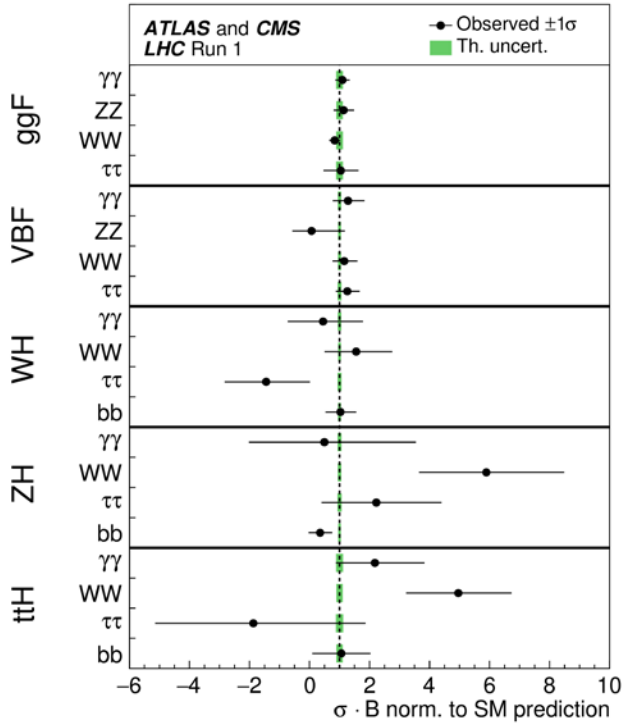


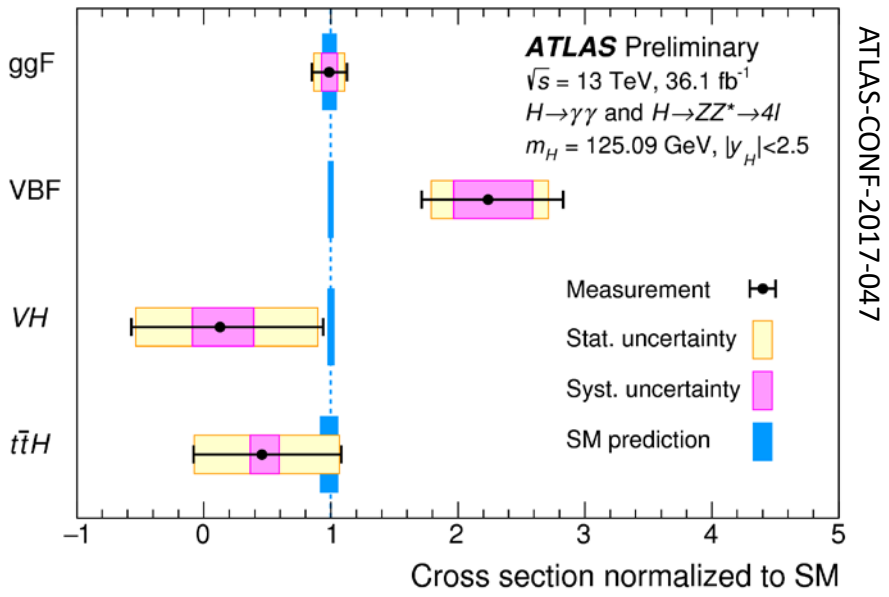


Back up

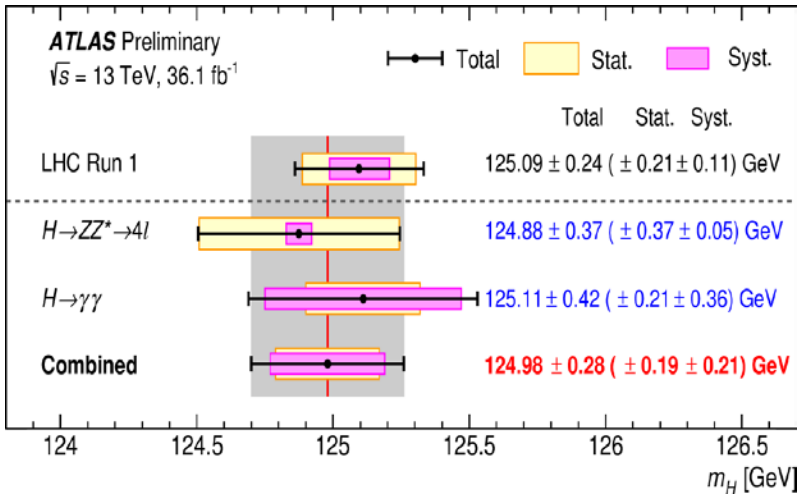
SM higgs(125) properties

J. High Energy Phys. 08 (2016) 045

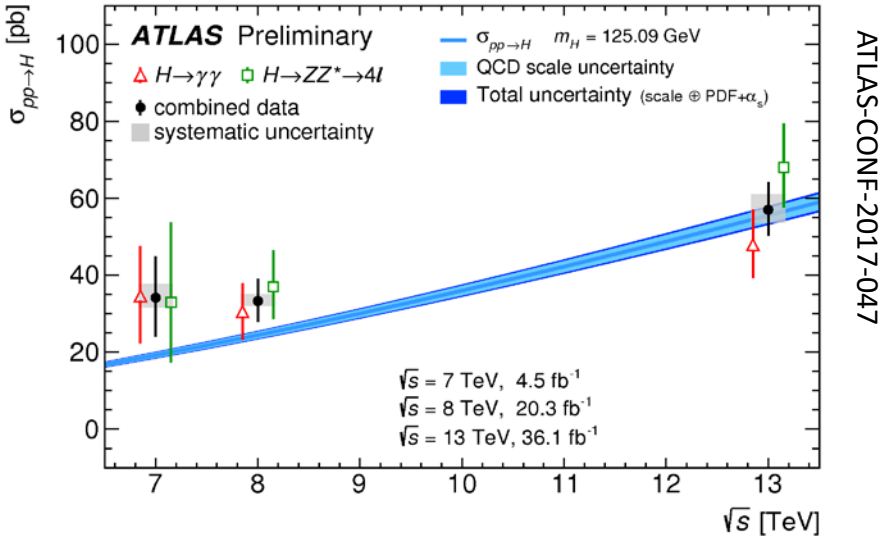




ATLAS-CONF-2017-047



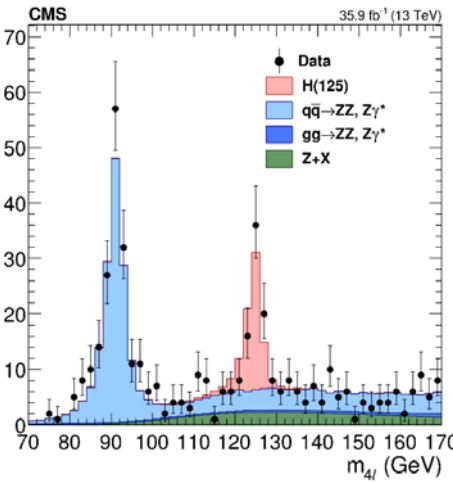
ATLAS-CONF-2017-046



ATLAS-CONF-2017-047

h(125) → γγ and 4l

- 4l: High resolution mass peak with large S/B, matrix-element based discriminants to reduce non – resonant ZZ* → 4l background, event categorization applied to different production modes.
- γγ: Narrow peak over a large smooth falling background: γγ, γ-jet, jet-jet and background modelled on data; Sensitivity maximized using event categorization.



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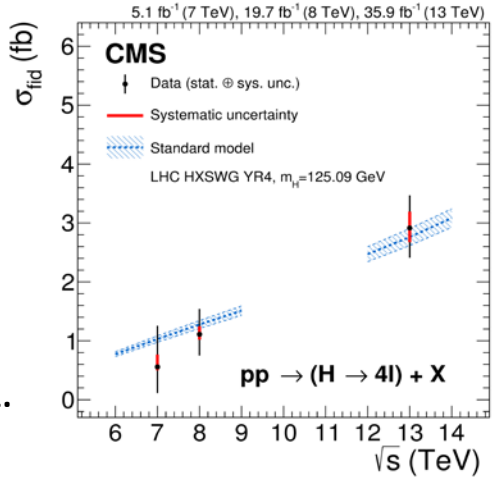
- σ in the fiducial phase space = 2.92 +0.48/-0.44 (stat) +0.28/-0.24 (syst) fb
- σ_{SM}= 2.76 +/- 0.14 fb.
- **m_h = 125.26 +/- 0.21 GeV**
- The width, constrained using on-shell production is $\Gamma[h] < 1.10$ GeV @95% CL.



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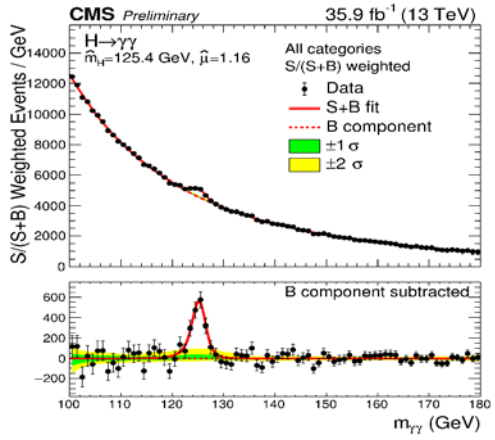
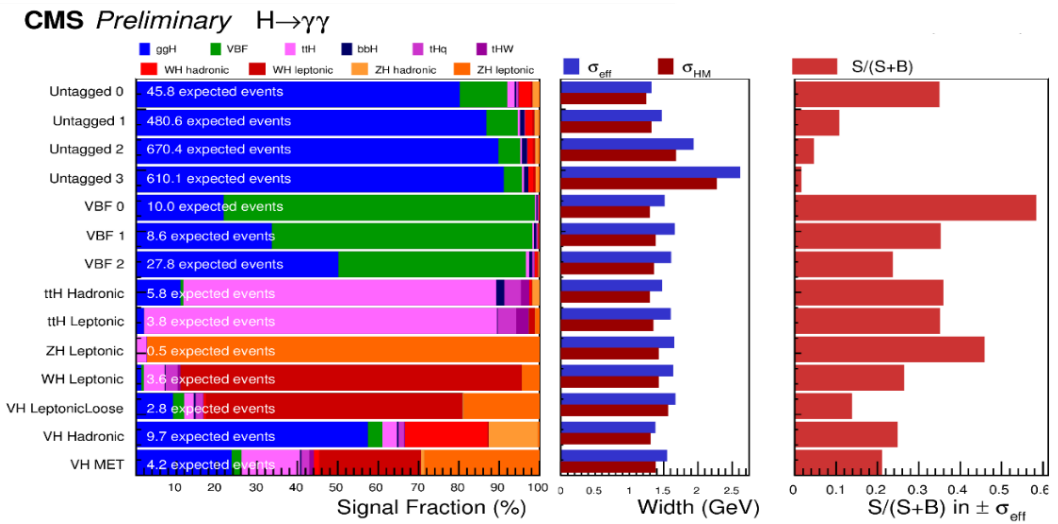
CMS-PAS-HIG-16-040





CMS-PAS-HIG-16-040