Top quark and Higgs boson physics at the LHC (a personal selection)

Rebeca Gonzalez Suarez

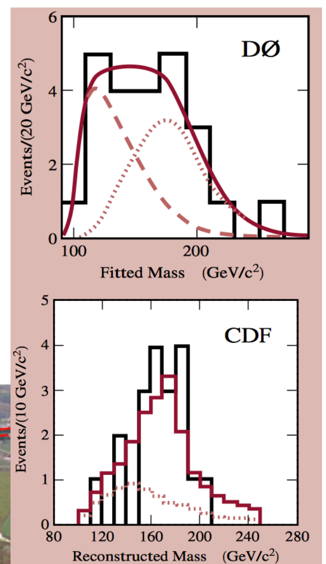
Two discoveries separated by 17 years

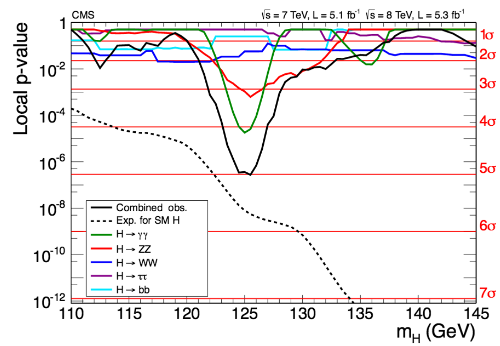
Top quark discovery

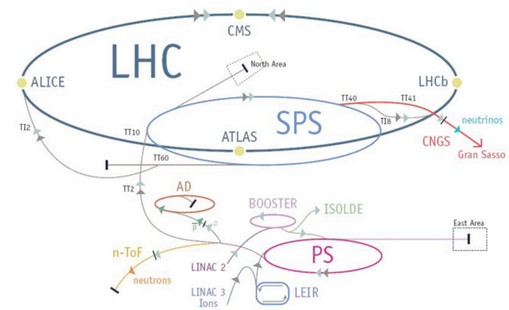
- February 24, 1995 – **Tevatron**
  - **CDF** → arXiv:9503002
  - **D0** → arXiv:9503003

Higgs boson discovery

- July 4, 2012 – **LHC**
  - **ATLAS** → arXiv:1207.7214
  - **CMS** → arXiv:1207.7235



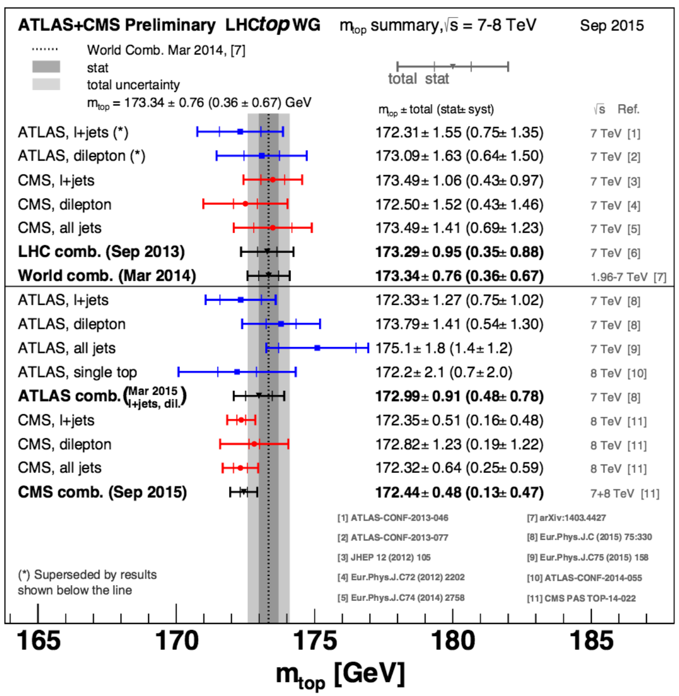




Two particles

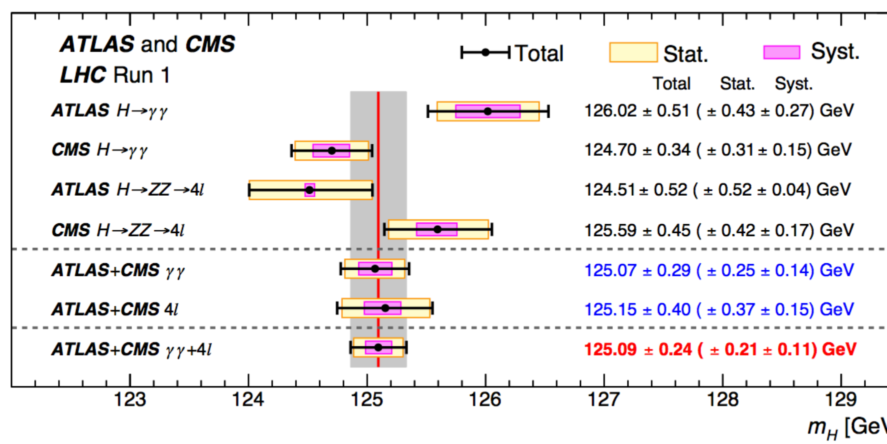
Top quark

- **Heaviest elementary particle known**
  - As heavy as an atom of gold
  - Only quark that decays before hadronizing



Higgs boson

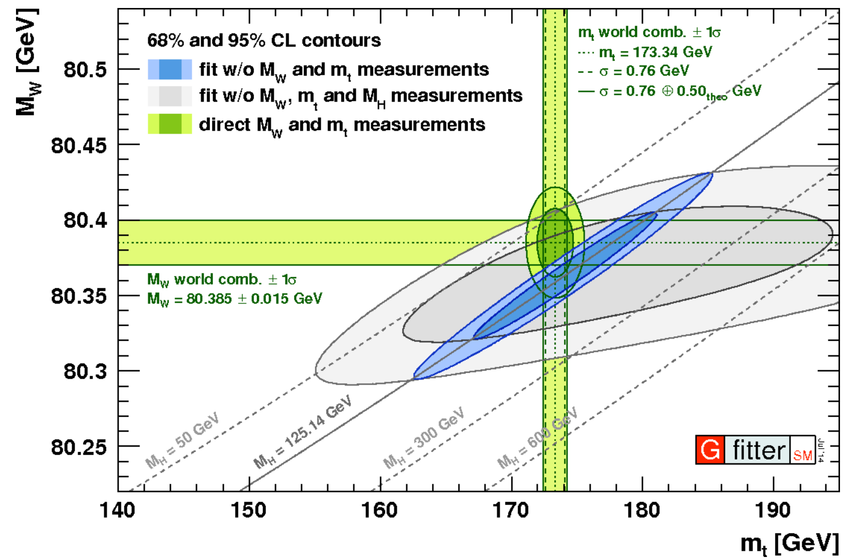
- **First scalar particle** observed in nature
- Confirms the Higgs mechanism of mass generation via spontaneous EW symmetry breaking



that are deeply related

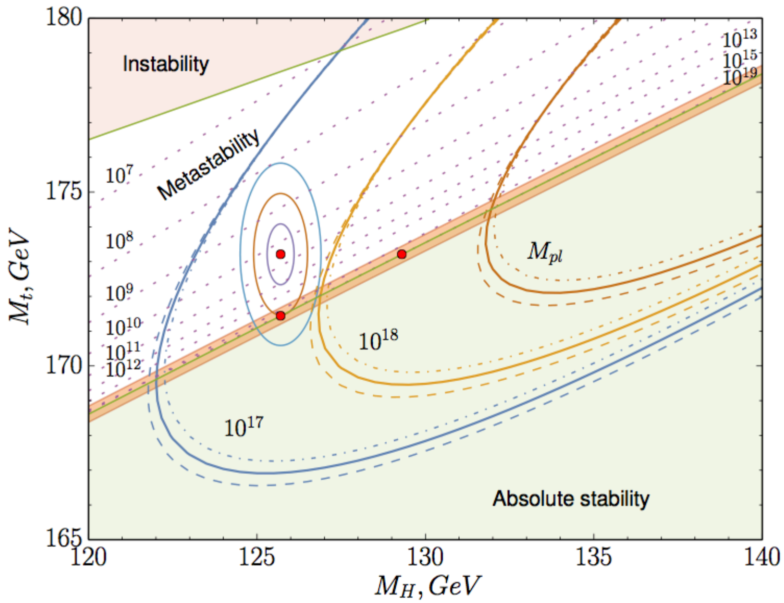
- The **top-Higgs coupling** is very strong in the Standard Model (SM) ~1

- **The Higgs mass is extremely sensitive to the top mass →** the masses of the top quark and the W boson directly constrain the mass of the SM Higgs



gfitter

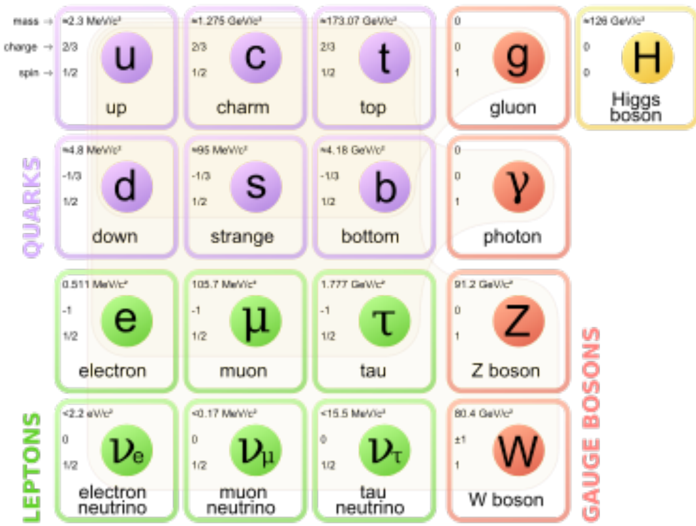
arXiv:1507.08833

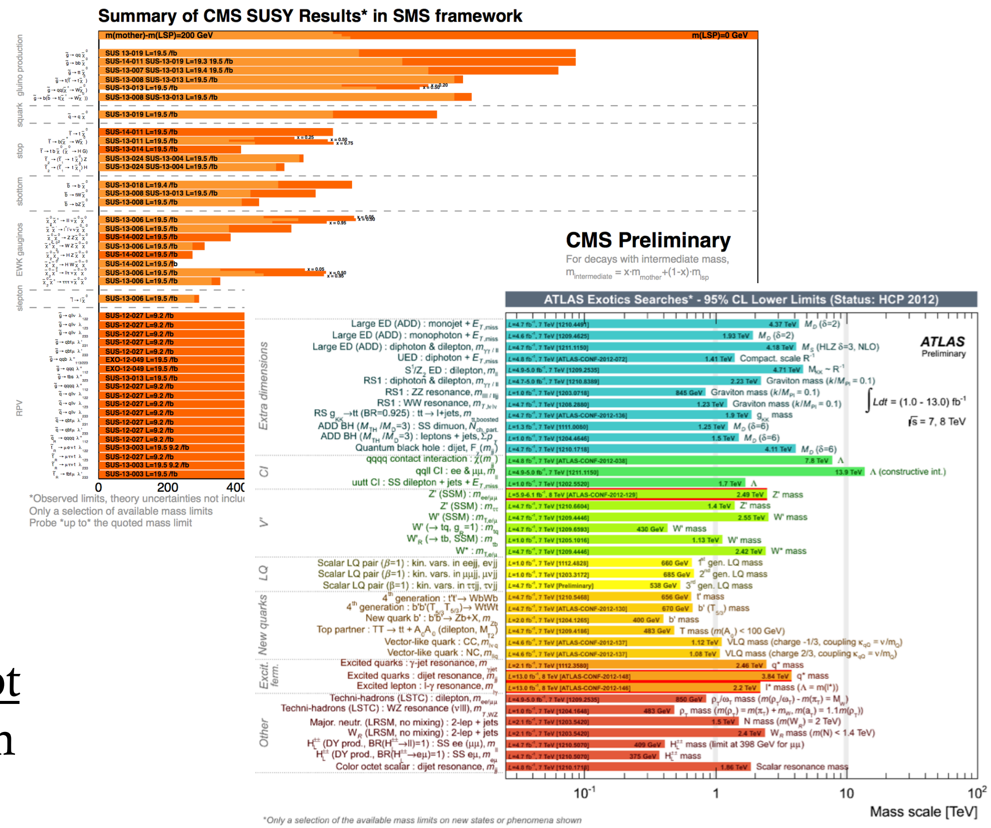


- The Higgs boson and the top quark also allow conclusions regarding **the fate of the Universe** via the analysis of the vacuum stability → related to the top and Higgs masses

The SM picture

- The top discovery completed the quark family, while the Higgs boson is consistent with the Standard Model so far
- However: no strong hints of physics beyond the SM (BSM) observed up to now





New physics are needed: there are <u>experimental facts that the SM cannot explain</u> (yet) and call for an extension

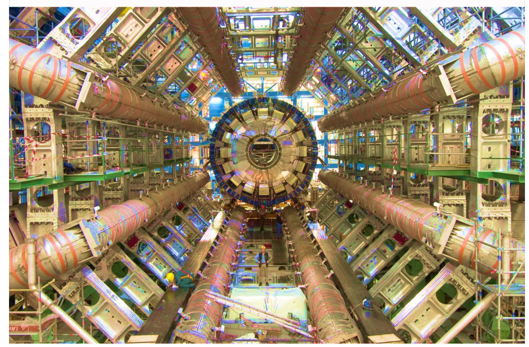
In fact, there are many open questions

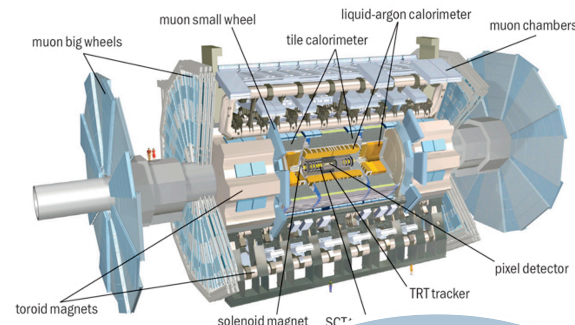
- Is m_H **natural** or fine-tuned? if natural → need new physics/symmetry
- Is the Higgs elementary or composite?
- Is there just one Higgs or many?
- Why only **three quark families**?
- Why do the **neutrinos have masses**?
- The **matter/anti-matter imbalance** in the Universe
- What is the nature of the **dark matter and dark energy**?
- Why is the scale of particle physics so much smaller than the Planck Scale and the observable Universe is so much bigger than the Planck Scale?
- How is **gravity** connected with the other forces?
- Do forces **unify** at high energy?

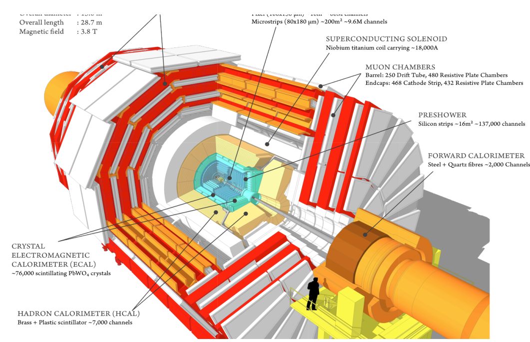
… to name a few

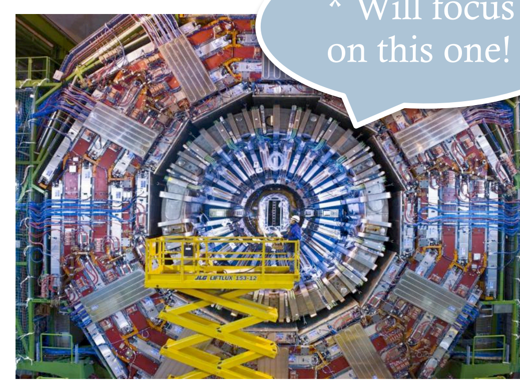
Looking for answers: the LHC

- The LHC is a proton-proton collider at CERN, in operation since 2010, occupying the LEP tunnel, underground between Switzerland and France
- Two general-purpose experiments: **ATLAS** and **CMS**, aim to answer some of these questions [and maybe unveil more unknowns!]









* Will focus on this one!

Finding new physics at the LHC

- A full program of searches is ongoing at the LHC experiments directly targeting an impressive number of scenarios

- Top quarks and Higgs bosons could be the **gateway to new physics at the LHC** in two ways

1. **BSM scenarios** in which they appear, separately or together that will be explored experimentally
    - Rare decays, heavy resonances decaying to top or/and Higgs, new particles produced together with top or/and Higgs, exotic partners…

2. **Precision measurements of properties**
    - Test the compatibility with the SM predictions

Outline of the talk

- **Run-1**
  - Top physics → precision regime, exploring rare processes
    - single top tW observation
  - Higgs physics → discovery and first properties
    - spin analysis $H \rightarrow WW$
  - Top and Higgs physics → early results
    - ttH, tHq
- **Run-2**
  - First results
    - Single top as SM candle
    - First Higgs plots:
      - ttH and ggH, $H \rightarrow WW$
  - What lays ahead?
    - Higgs/top for the next months/years

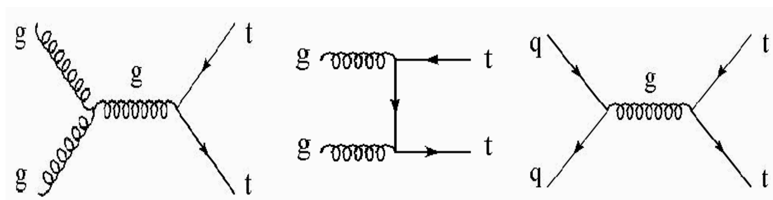
LHC Run-1

The top factory

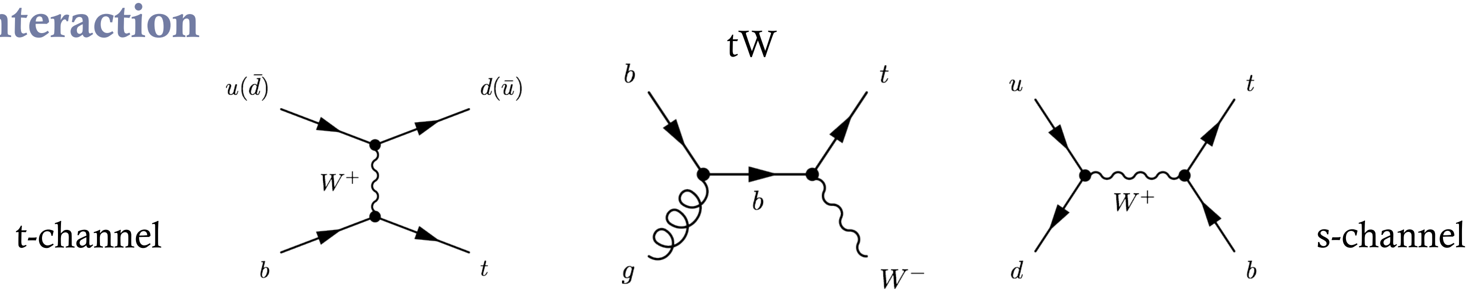
- The LHC has been competitive with the Tevatron legacy in top phyiscs since the start of the data taking

> *"The LHC is a top quark factory!"*
> *- Every speaker at every talk about top quarks at the LHC*

- At the LHC, top quarks are produced mainly in **ttbar pairs** → **strong interaction**



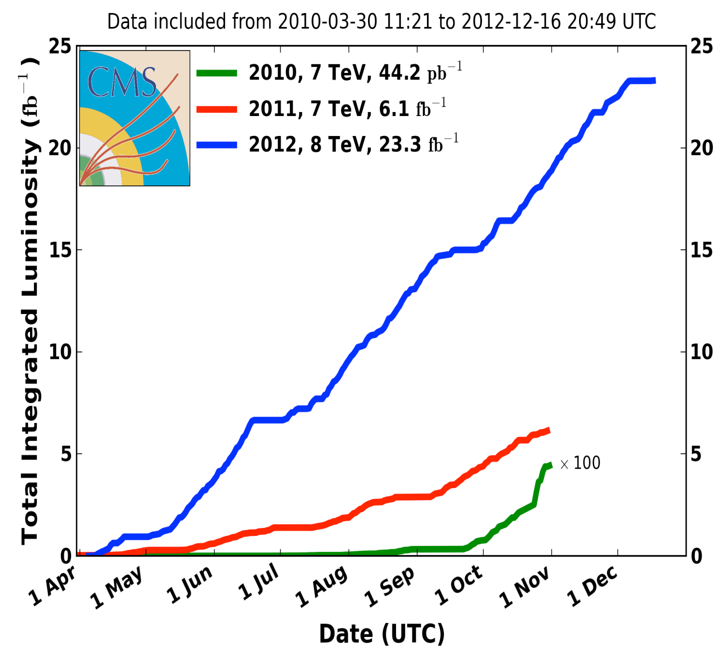
- Alternative mode, at a lower rate: **Single top quark production** → **EWK interaction**



The top factory, in numbers

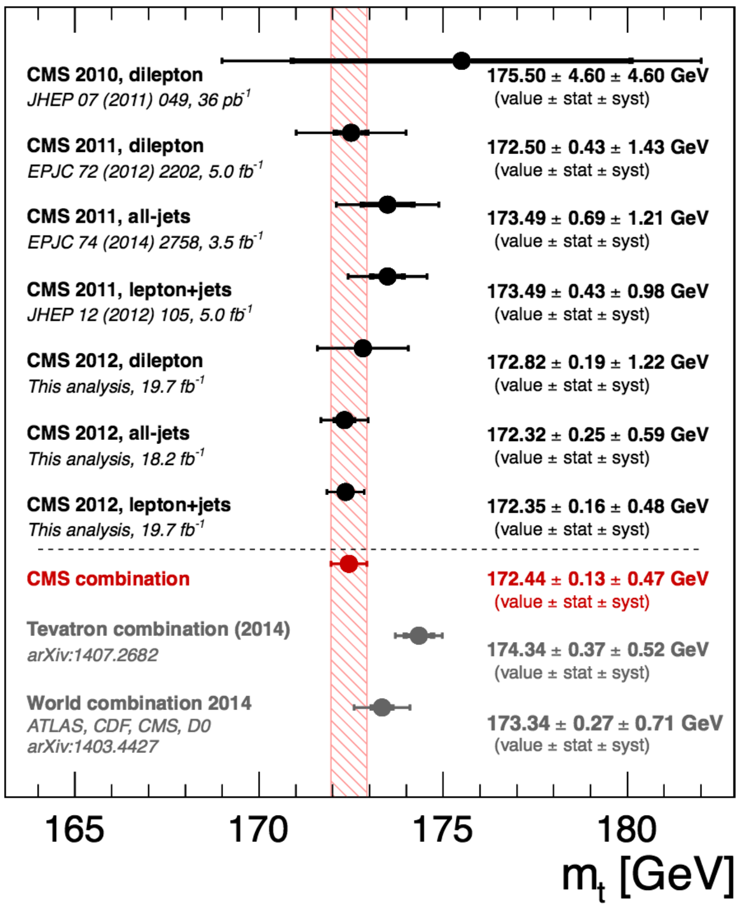
σ [pb]	ttbar	t-channel	tW	s-channel
Tevatron (1.96TeV)	7.08	2.08	0.22	1.046
LHC @ 7TeV	177.31	63.89	15.74	4.29
LHC @ 8TeV	252.89	84.69	22.2	5.24
LHC @ 13TeV	831.76	216.99	71.2	10.32

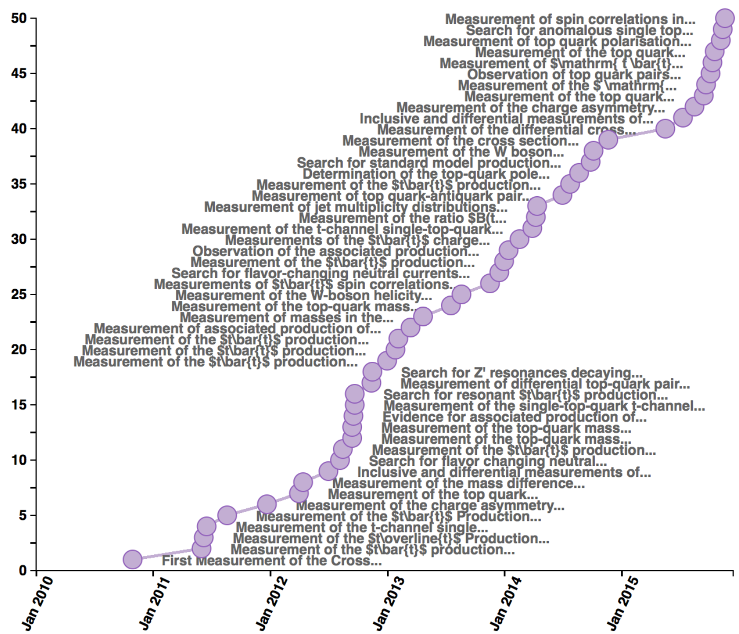
- Run-1 of the LHC lasted three years:
  - **~5fb^{-1} of pp collisions at 7TeV**
  - **~20fb^{-1} at 8TeV**
- CMS then registered
  - More than **5M ttbar pairs**
  - Around **2M of single top quarks** via t-channel
  - **Half a million of tW events**
  - a bit more than 100K of s-channel events



Top results

- 50 top papers submitted to journals, 49 of them at 7/8 TeV
- High precision regime → most precise mass measurement to date (±0.48 GeV)





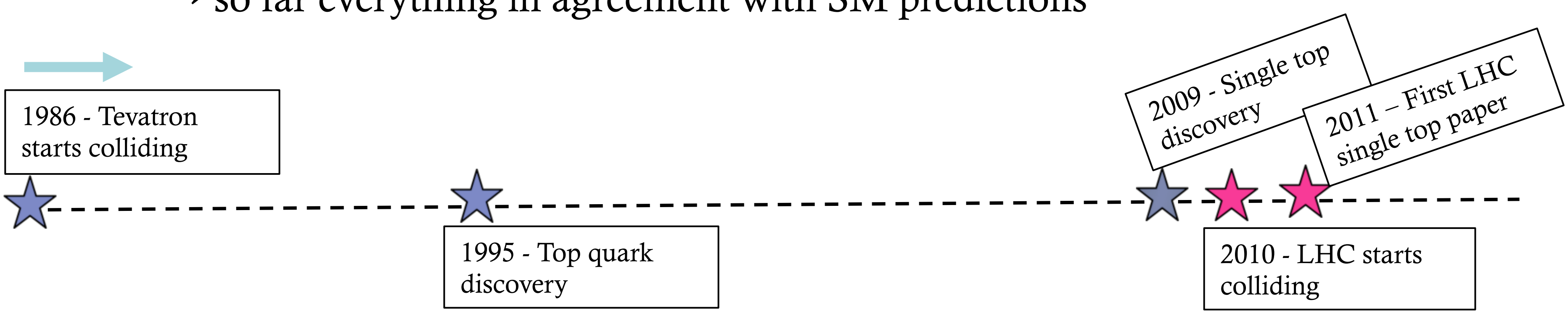
It would be the topic for a full talk (or several)
→ Let's focus on one kind of process that illustrates well the potential of the LHC for top physics

Single top physics

- Single top production was observed for the first time also at the Tevatron (2009)
- But it was still largely unexplored when the LHC started
  - **Rediscovery in 2010, first LHC single top papers in 2011**
    - **Today, all single top processes have been established** (the Tevatron data allowed for observation of the s-channel, after shutdown, in 2014)

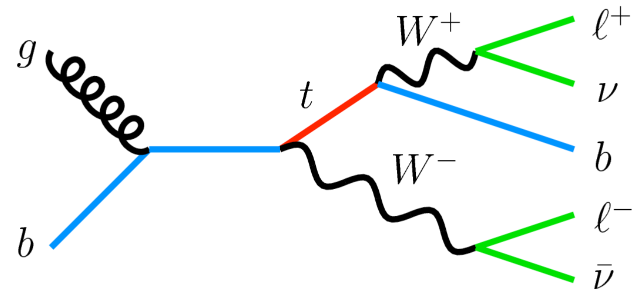
- The pioneering times are over → entering precision physics, **several properties already studied in t-channel production**
- **Single top processes are very sensitive to BSM effects**

  → so far everything in agreement with SM predictions

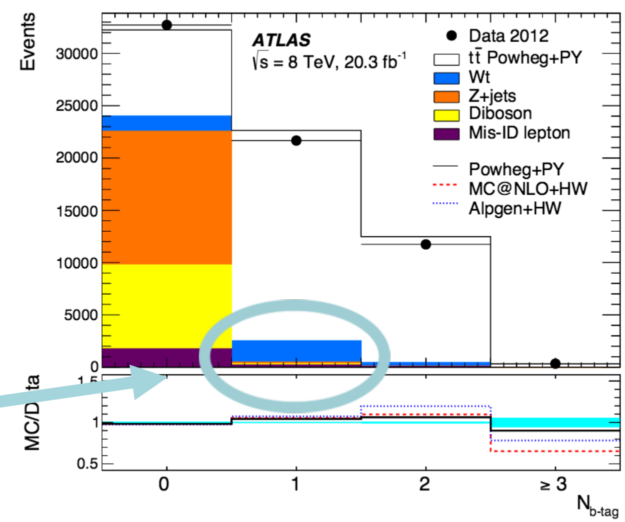


tW associated production

- This process could not be studied at the Tevatron, since its production rate was very low, but it is the second most common single top process at the LHC

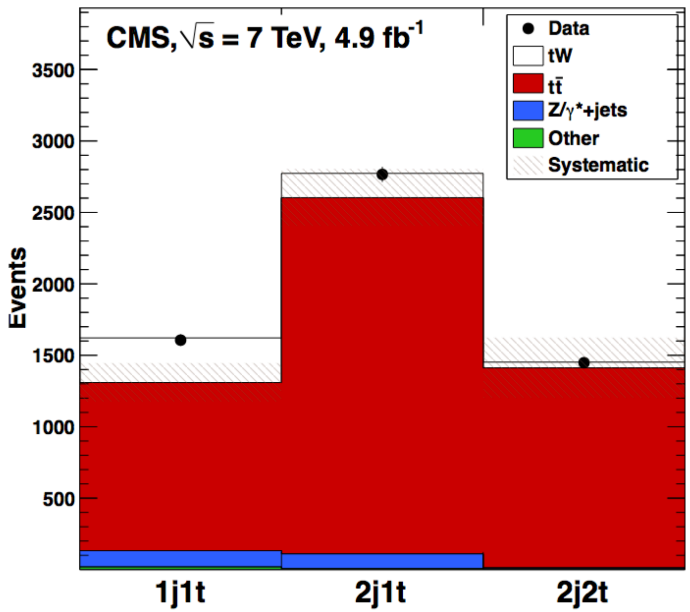


- Dilepton final state:
  - 2 opposite sign leptons
  - Missing transverse energy due to the neutrinos
  - One jet coming from a b-decay
- Main background: tt production
- But it is a main background on its own of:
  - H→ WW →2l2ν
  - tt →2l2ν2b



tW at 7TeV

- At 7 TeV, with the full luminosity recorded (4.9fb^{-1}) → analysis statistically limited

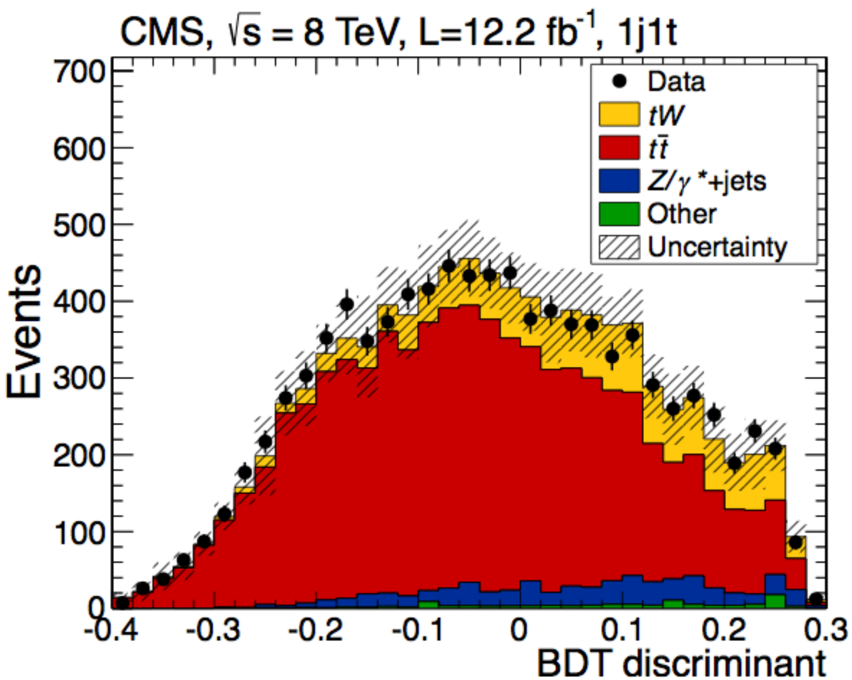


Phys. Rev. Lett. 110 (2013) 022003
arXiv:1209.3489

- Final states with electrons and/or muons
- Signal region (events with one b-tagged jet) supported by two control regions enriched in tt background designed to constrain this background:
  - 2 jets, one of them b-tagged
  - 2 jets, both of them b-tagged
- Analysis based on a BDT (tW Vs. tt)
  - cut-based analysis as cross-check
- Significance of **4.0 σ → strong evidence**

tW at 8TeV

- At 8 TeV, the analysis is no longer limited by statistics (12.2fb^{-1})

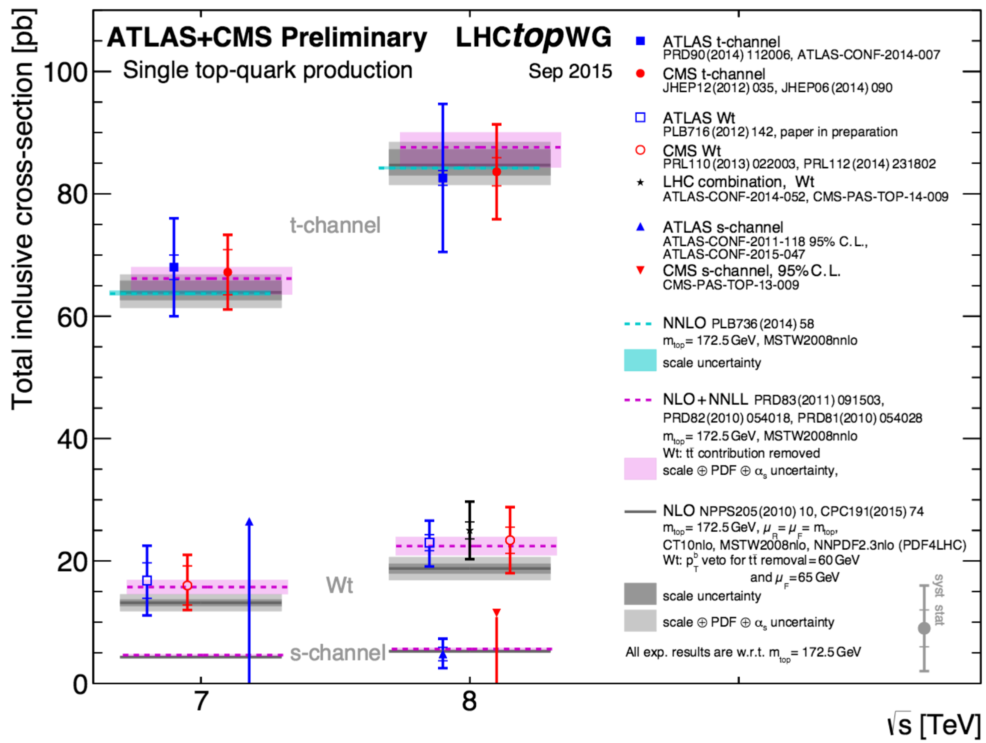


- A more sophisticated BDT (cross-checked with a cut-based analysis, and a shape-based analysis)
- The same control regions were used
- The key to a better sensitivity was the use of 'loose' jets
- The main uncertainties come from theory modeling of tt
- **6.1 σ → Observation**

Phys. Rev. Lett. 112 (2014) 231802
arXiv:1401.2942

Run-1 single top wrap-up

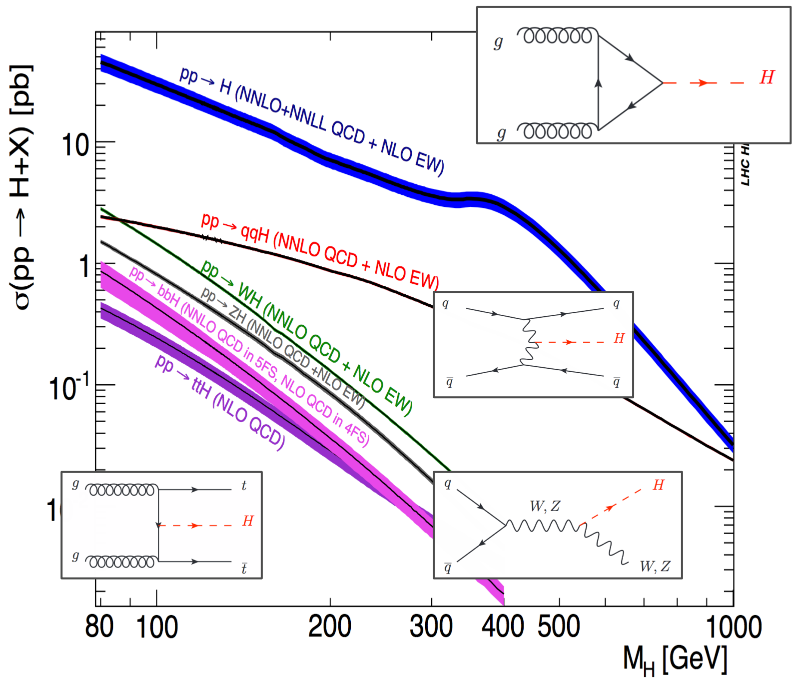
- The tW cross sections obtained at 7 and 8TeV, as well as the t- and s-channel measurements, are in good agreement with the SM expectations

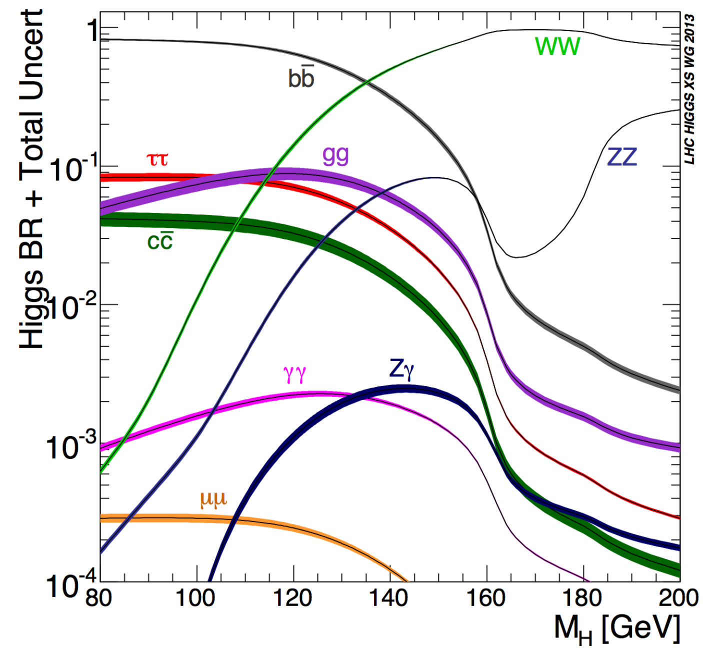


- During Run-1 the first properties were measured in t-channel events (top polarization, W helicities, $|V_{tb}|$..), and searches for FCNC (tZq, tγq) and anomalous couplings were performed

Searching for the Higgs

- Meanwhile, at the start of the Run-1 we looked for the Higgs everywhere
  - Production and decay modes determined by the mass of the Higgs





- We performed a **full mass scan from the LEP limit of 114.4 until above 600GeV**
  - We found it with a mass of ~125GeV

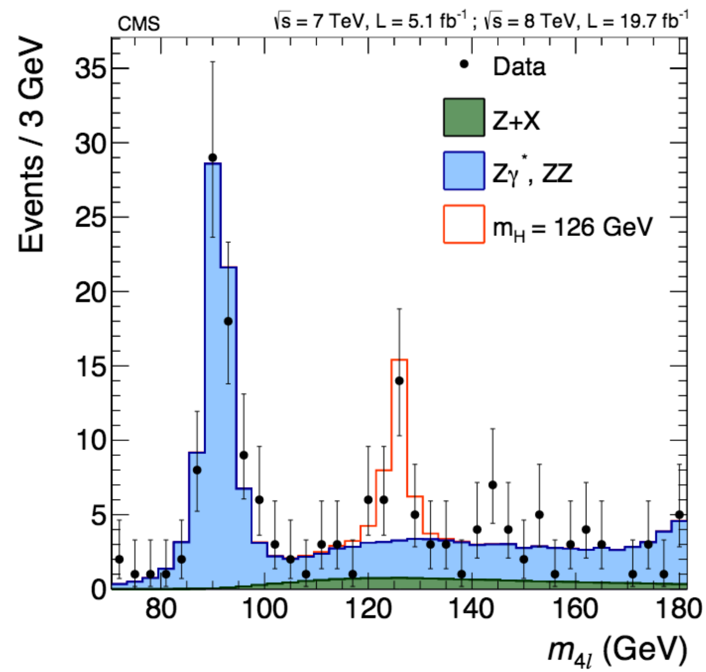
Higgs channels

- We observe it with different levels of confidence, in a variety of decay channels, exploiting all possible production modes

arXiv:1412.8662

Channel grouping	Significance (σ)	
	Observed	Expected
$H \to ZZ$ tagged	6.5	6.3
$H \to \gamma\gamma$ tagged	5.6	5.3
$H \to WW$ tagged	4.7	5.4
Grouped as in Ref. [22]	*4.3*	*5.4*
$H \to \tau\tau$ tagged	3.8	3.9
Grouped as in Ref. [23]	*3.9*	*3.9*
$H \to bb$ tagged	2.0	2.6
Grouped as in Ref. [21]	*2.1*	*2.5*
$H \to \mu\mu$ tagged	< 0.1	0.4

Observed and median expected significances of the excesses for each decay mode



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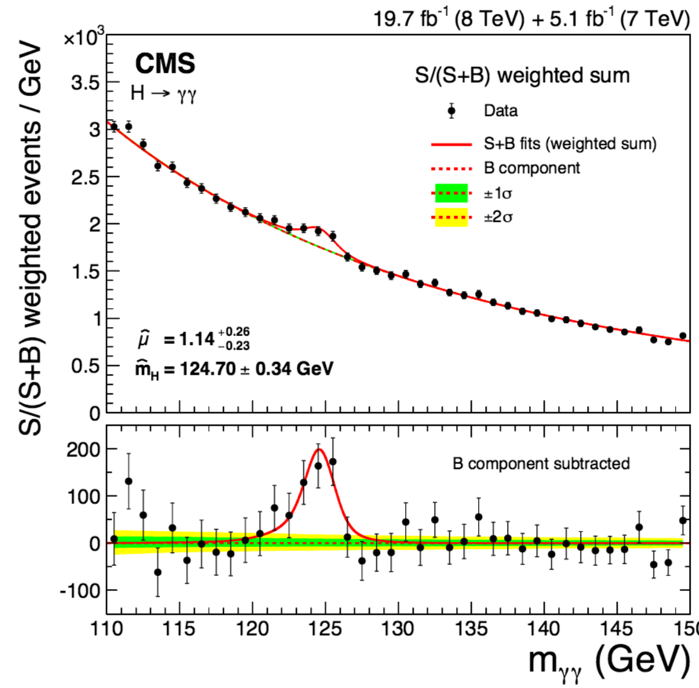

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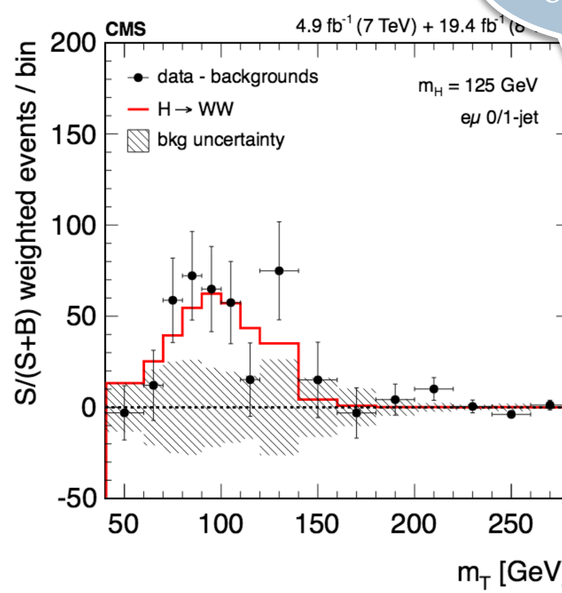
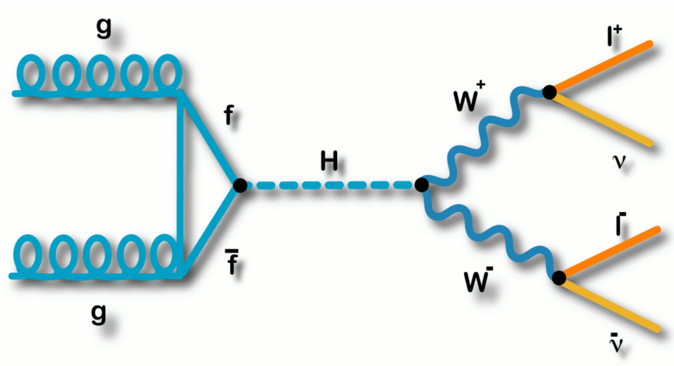


* Will focus on this one!

$H \rightarrow WW \rightarrow 2l2\nu$

- Sensitive in the intermediate mass range [120-200]
  - 2^{d} largest BR around 125 GeV → **BR $_{H\rightarrow WW}$ ~ 22%**
- Clear signature in leptonic decays ($BR_{W\rightarrow l\nu}$ ~ 10%)



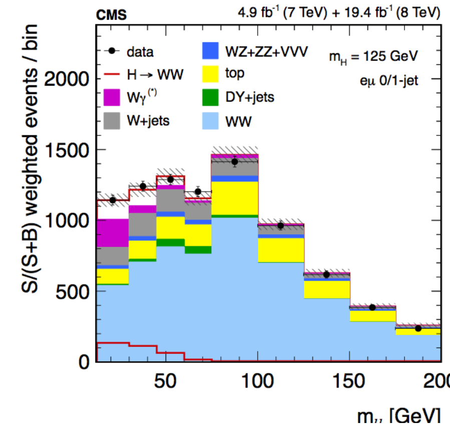
- Two leptons (e,μ) with opposite charge
- Substantial missing energy

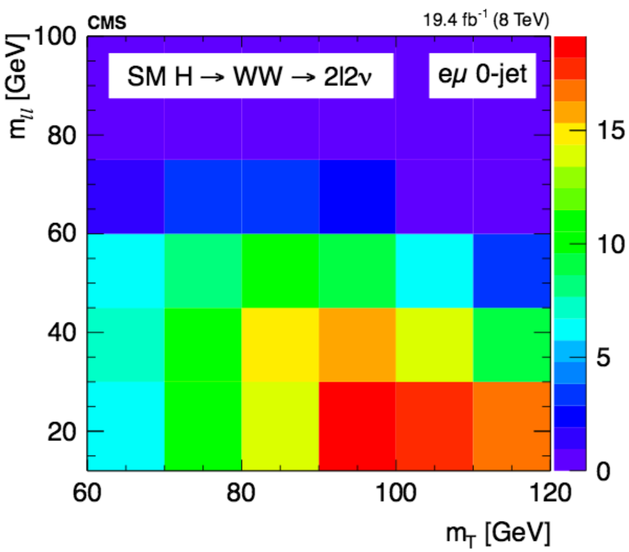
- Depending on the production mode: little to no jet activity (ggH), 2 forward jets (VBF)
  - other production modes (VH, ttH) provide even more specific signatures
- No mass peak, not possible to reconstruct full final state → neutrinos
- Large background contribution (genuine and instrumental):
  - WW (irreducible), top, Drell-Yan, W+jets, QCD…

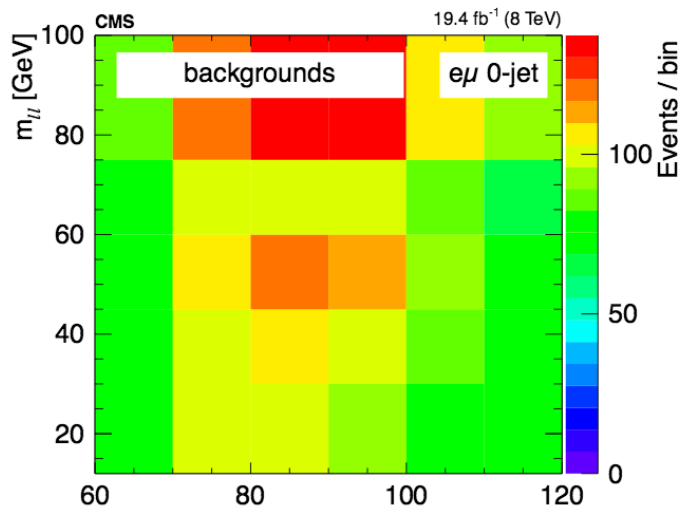
H→WW→ 2l2ν analysis

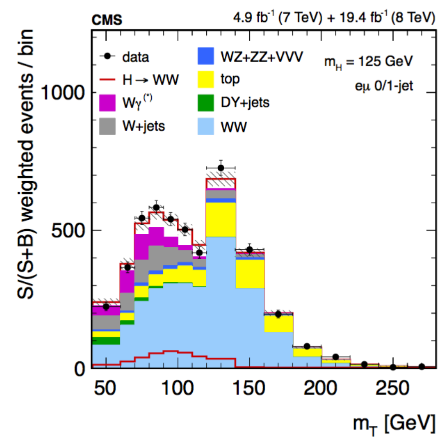
- Performed in categories with different approaches depending on production mode and the flavor (and charge) of the leptons
  - ggH, VBF, WH, ZH
- The **eμ ggH** analysis (0,1 jets) is the most sensitive
  - on its own achieves a sensitivity of > 4 σ
  - **2D shape analysis:** $m_T - m_{ll}$ distributions

JHEP 01 (2014) 096
arXiv:1312.1129









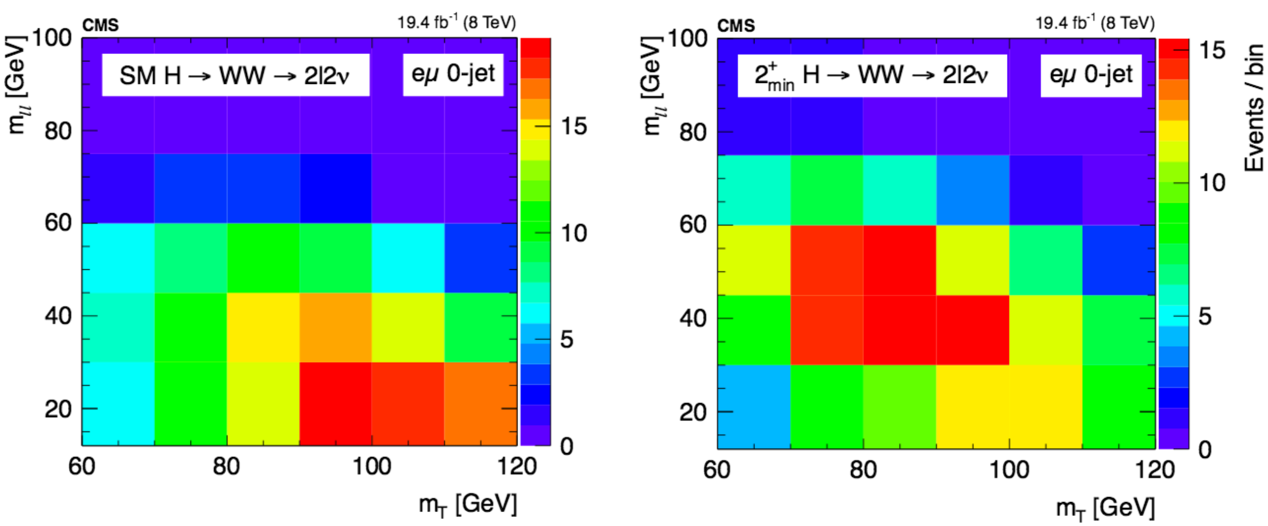
Higgs properties

- After the discovery the next step is to precisely measure the properties of the new particle to confirm it is (or not) the SM Higgs
  - **Charge** (easiest)**, Couplings, Spin, Parity, Mass, Width…**
- Some of the first measurements come together with the searches → dedicated studies followed right after

How much was explored already with Run-1 data?

Spin and tensor structure in H→VV decays

- (V=Z,W, γ)
- Done via the study of the **kinematic distributions of the decay products**, which are determined by the tensor structure of the HVV interactions
- The strategy in each channel depends on the number of kinematic variables available → is given by the decay of the Higgs
  - **H→ZZ→4l**: Full kinematic information accessible
  - **H→WW→eμ2ν**: limited sensitivity due to the neutrinos in the final state



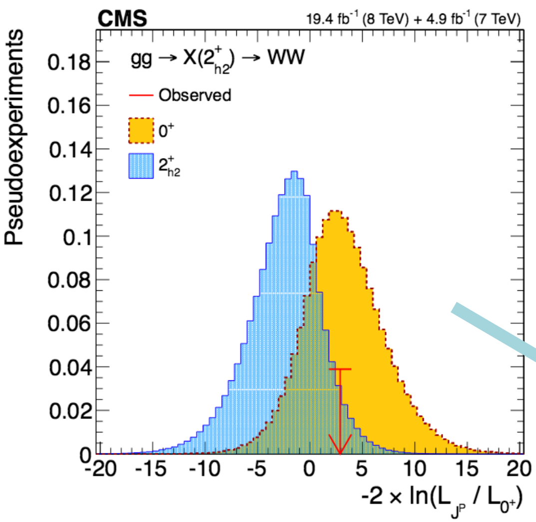
The H→WW analysis templates are optimal to discriminate against different spin hypothesis

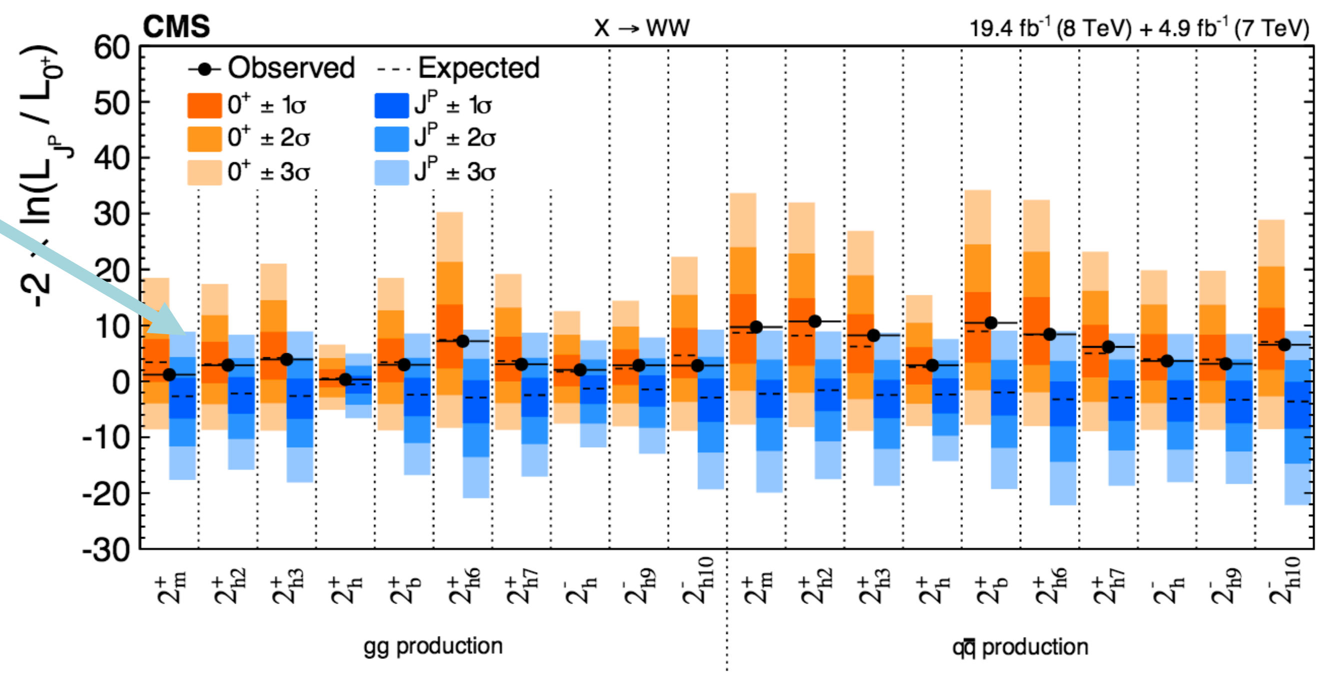
Phys. Rev. D 92, 012004 (2015)
arXiv:1411.3441

Exotic spin

- **Different BSM spin and CP hypotheses** tested using H→WW decays

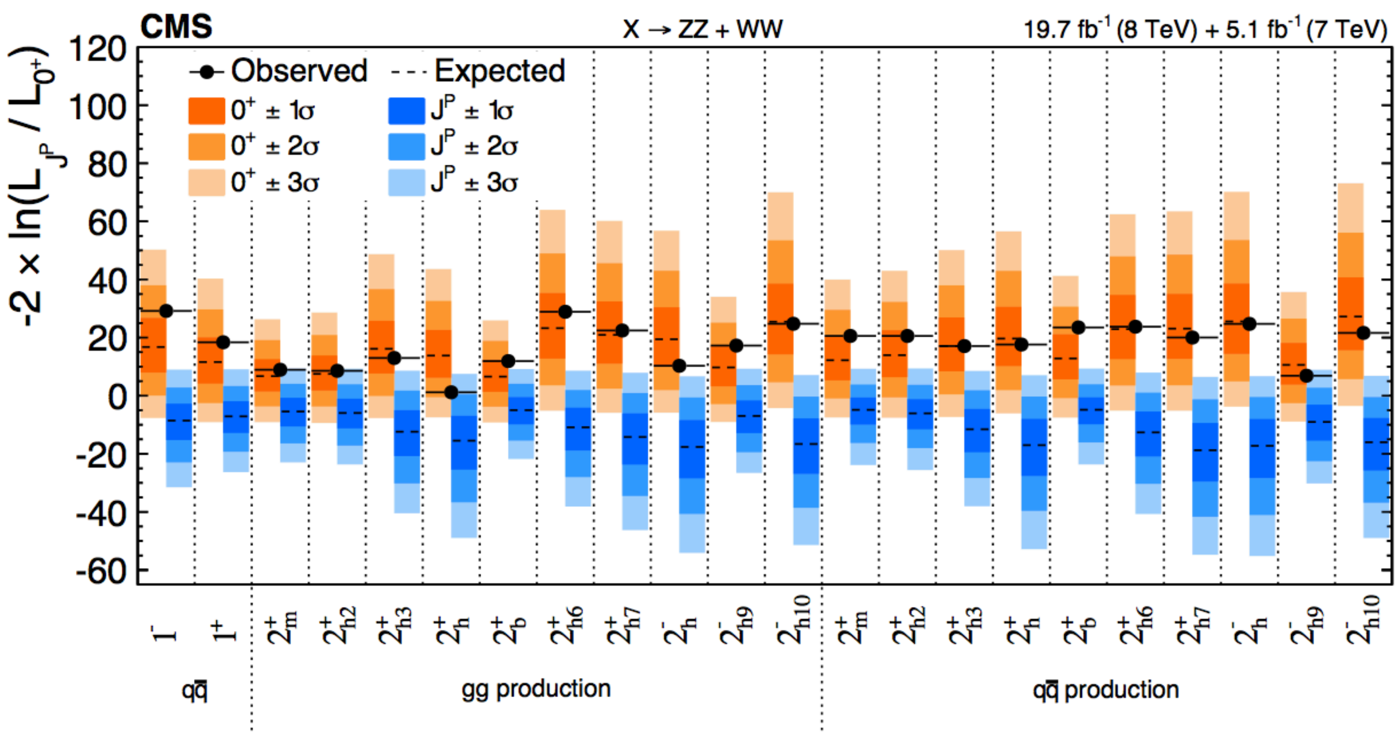
  → Exotic spin-1 or spin-2, BSM 0^- 0^+_h





Exotic spin: combination

- It is in the combination with H→ZZ when the best sensitivity is achieved:



All spin-1 hypotheses excluded at > 99.999% CL , Spin-2 boson 2^+_m, excluded at a 99.87% CL, other spin-2 hypotheses excluded at a ≥ 99% CL

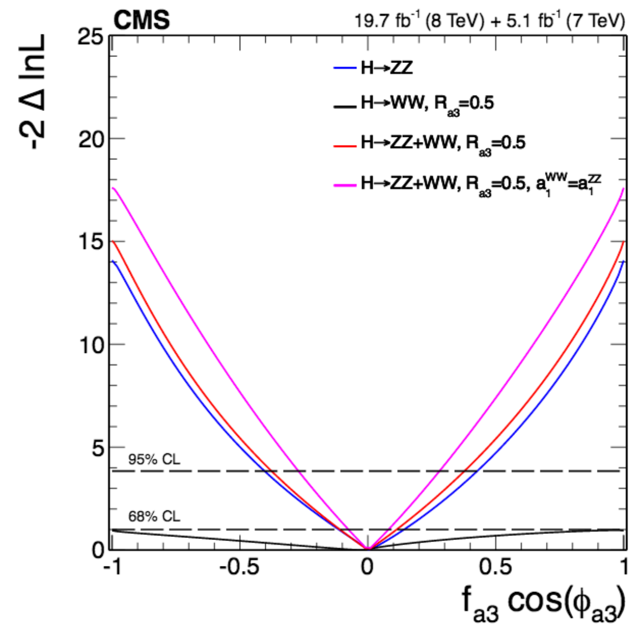
Spin 0 particle favored

Spin-0

- Once the exotic spin is ruled out → study of the tensor structure of the HVV interactions under spin-0 assumption
- The decay amplitude for a spin-0 boson to a pair of V bosons can be written as:

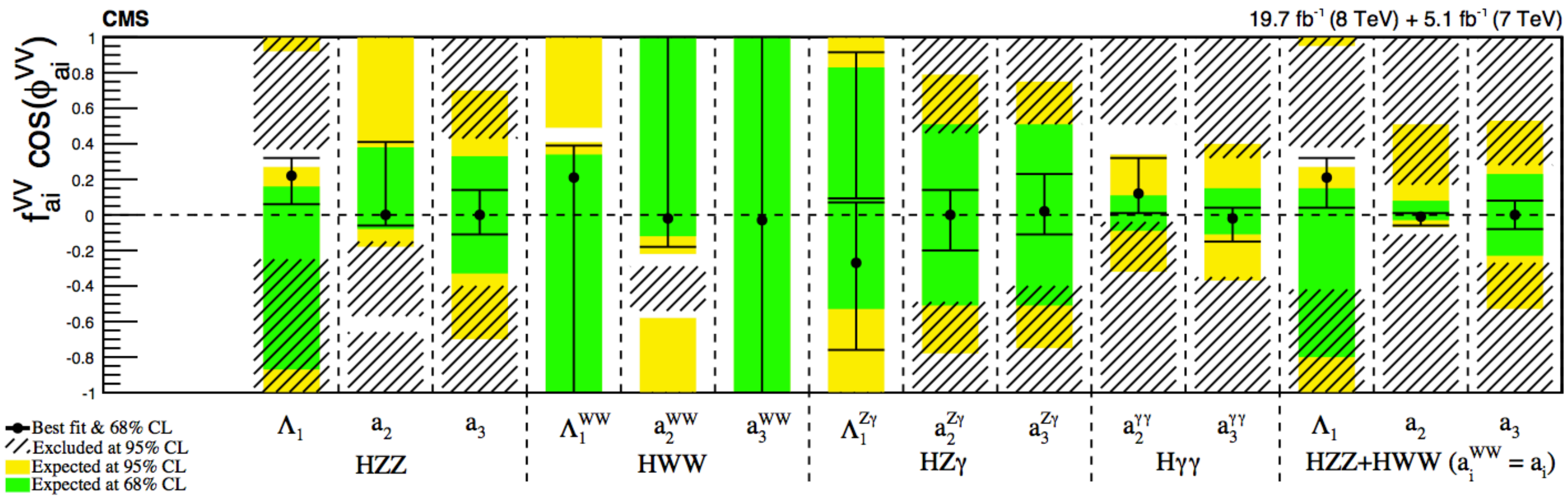
$$A(\mathrm{HV_1V_2}) \sim \left[\underbrace{a_1^{\mathrm{V_1V_2}} + \frac{\kappa_1^{\mathrm{V_1V_2}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{V_1V_2}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{V_1V_2}}\right)^2}}_{\Lambda_1 \text{ term, leading momentum expansion}} \right] m_{\mathrm{V}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + \underbrace{a_2^{\mathrm{V_1V_2}} f_{\mu\nu}^{*(\mathrm{V_1})} f^{*(\mathrm{V_2}),\mu\nu}}_{a_2 \text{ term, CP even state}} + \underbrace{a_3^{\mathrm{V_1V_2}} f_{\mu\nu}^{*(\mathrm{V_1})} \tilde{f}^{*(\mathrm{V_2}),\mu\nu}}_{a_3 \text{ term, CP odd state}}$$

- We use a parameterization that relates the anomalous couplings coefficients: a_2, a_3, and Λ_1 to cross sections fractions (**f_{a2}**, **f_{a3}**, **$f_{\Lambda 1}$**)
- The analysis sets limits on anomalous couplings by performing **likelihood scans of the three effective fractions**
  - Full set of scans in ZZ and WW decays
  - All consistent with the SM



Summary of anomalous couplings

- Allowed confidence level intervals for anomalous coupling parameters assuming real coupling ratios (π or 0)



Parameter	Observed	Expected
$(\Lambda_1\sqrt{\lvert a_1 \rvert})\cos(\phi_{\Lambda_1})$	$[-\infty, -100\,\mathrm{GeV}] \cup [103\,\mathrm{GeV}, \infty]$	$[-\infty, 43\,\mathrm{GeV}] \cup [116\,\mathrm{GeV}, \infty]$
a_2/a_1	$[-0.58, 0.76]$	$[-0.45, 1.67]$
a_3/a_1	$[-1.54, 1.57]$	$[-2.65, 2.65]$

- Assuming custodial symmetry: **pure 0_h^+ (related to f_{a2}) excluded at 99.93% CL and pure 0^- (pseudoscalar, related to f_{a3}) excluded at 99.99% CL**

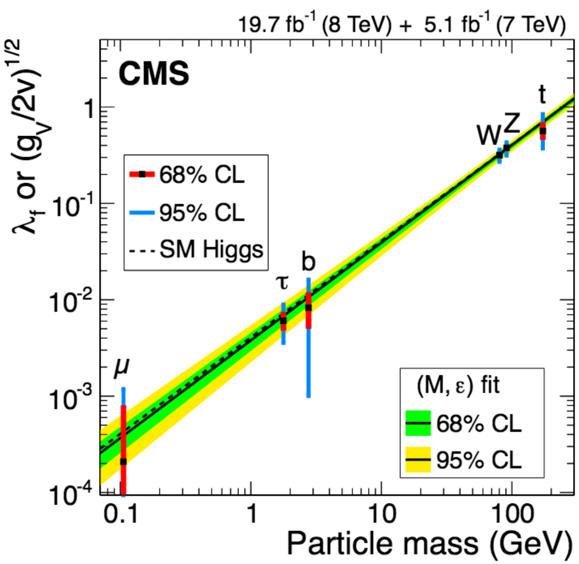
Mass and compatibility with the SM

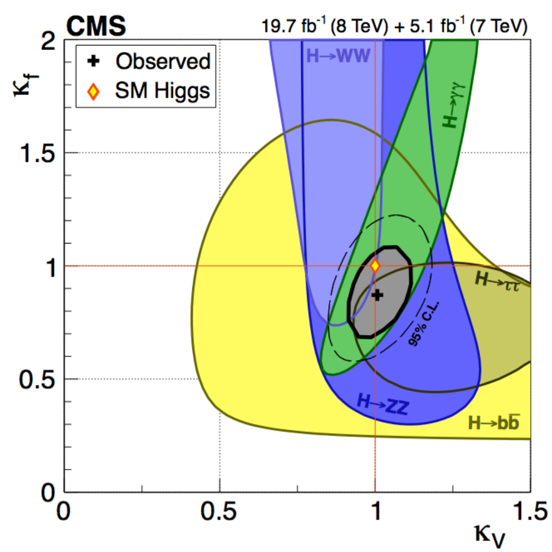
- Under the spin-0 assumption
  - Combined CMS and LHC Higgs measurements [arXiv:1412.8662] [arXiv:1503.07589]

	CMS combination	LHC combination
m_H ($\gamma\gamma$, ZZ) [GeV]	125.02 +0.26 (stat) +0.14 (syst)	125.09±0.21(stat) ±0.11(syst)
σ / σ_{SM}	1.00 ± 0.09 (stat) +0.08 (theo) ± 0.07 (syst)	1.09±0.11

- The couplings to massive vector bosons and fermions are also explored

CMS-PAS-HIG-15-002



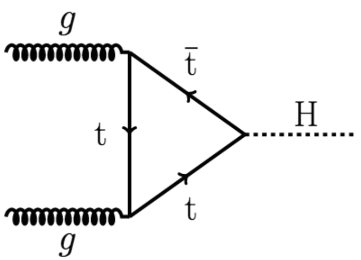


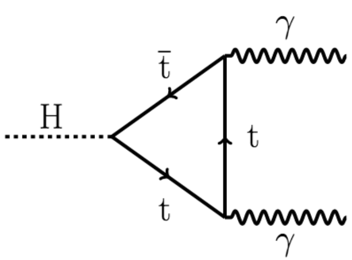
Looks very much like a SM Higgs so far…
But only more data will tell

Top and Higgs: Yukawa coupling

- **The top-Higgs coupling is very strong in the SM**, and because the top is heavier than the Higgs → it cannot be assessed by measuring Higgs decays to top quark pairs

It can be experimentally constrained in **gluon fusion production** → happens via a fermion loop, top provides the dominant contribution -assuming no new physics is contributing to the loop





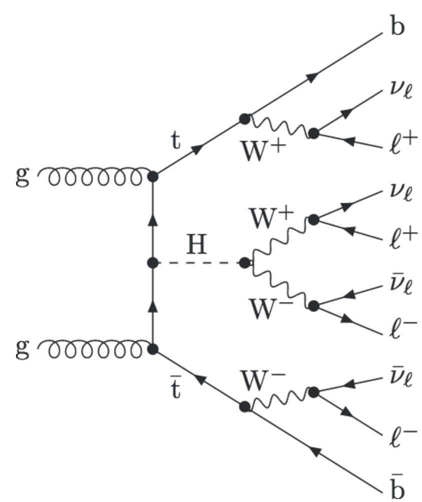
And in H→γγ decay: proceeds through a top loop and a W loop
Within uncertainties, current measurements are so far consistent with the SM expectations

Probing the top-Higgs Yukawa coupling directly requires a process that results in both a Higgs boson and top quarks explicitly reconstructed via their final-state decay products

ttH associated production

- SM Higgs production process that does not happen often:
  - It is the **sixth process** in terms of cross section at the LHC $\rightarrow$ 0.13pb at 8TeV
- But when it does, it is flashy:
  - Final states with a Higgs decay and two tops $\rightarrow$ [Higgs decay]+WW+bb
  - **Busy signatures: b-tagging, boosted objects, many leptons…**

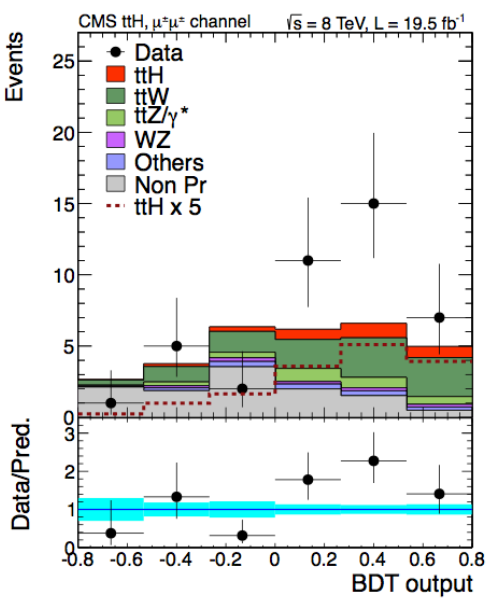
- With Run-1 data, we have studied this production in many channels
  - $H \rightarrow bb$
  - $H \rightarrow \gamma\gamma$
  - **H→WW (with 2, 3, and 4 leptons)**
  - $H \rightarrow ZZ$
  - $H \rightarrow \tau\tau$

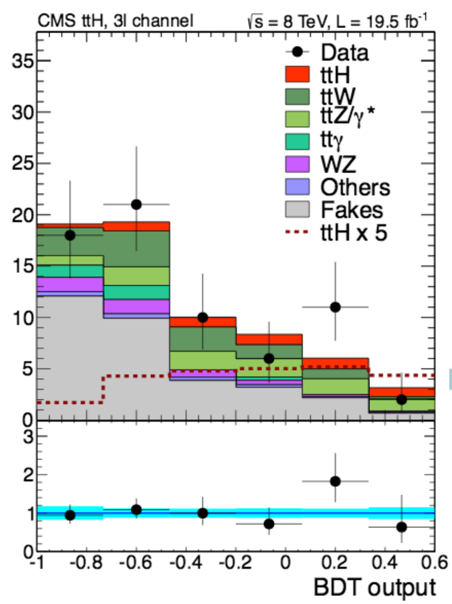


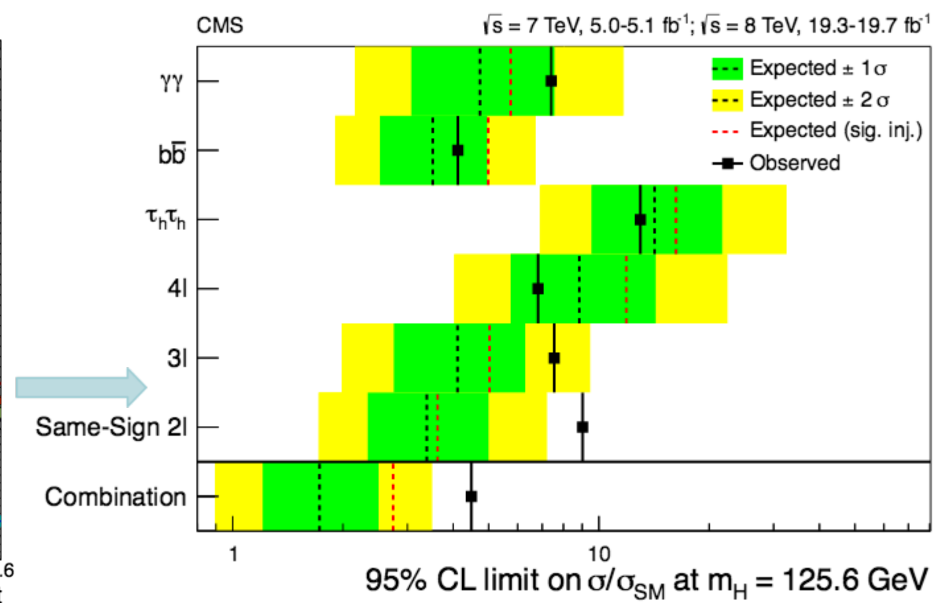
arXiv:1408.1682

ttH associated production: results

- **All channels are statistically limited**, no statement can be said regarding ttH production with Run-1 data, but limits are set
- All the channels combined give a best-fit value for the signal strength of 2.8 → excess above background-only of 3.4 standard deviations
  - <u>2σ upward deviation</u> with respect to the SM prediction
  - driven by ttH multilepton in H→WW

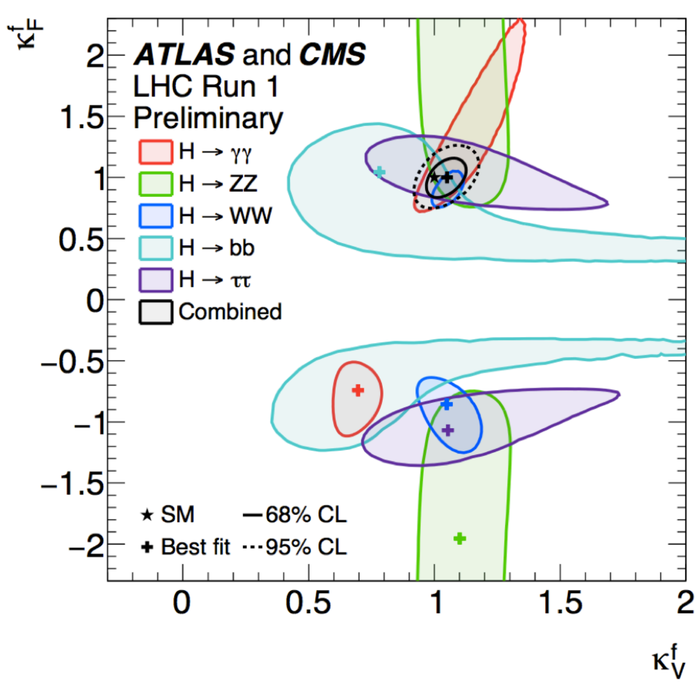


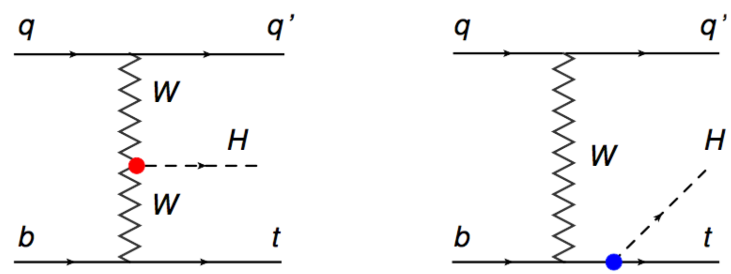




tHq associated production

- However, the only process in which top and Higgs are produced together sensitive to the sign of the top-Higgs coupling is single top plus Higgs production (**tHq**)

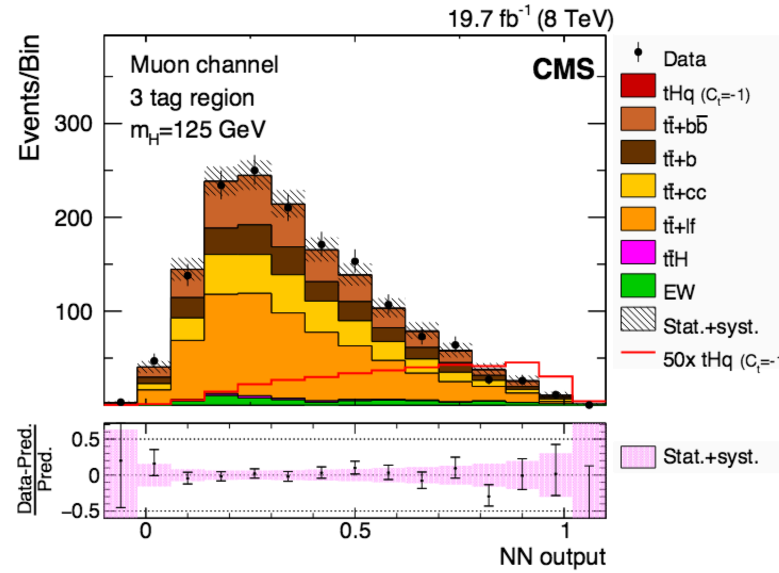


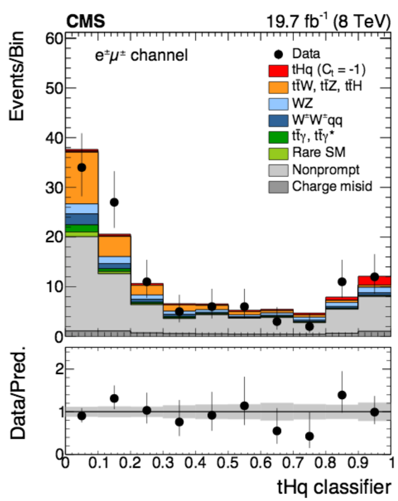


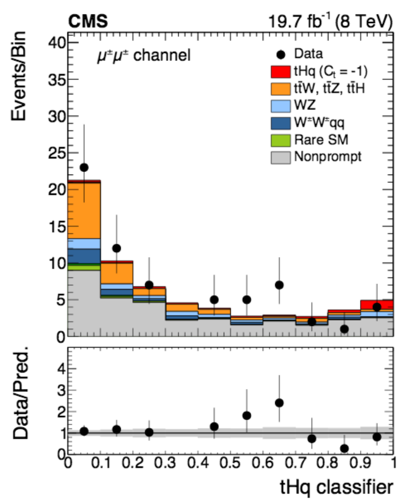
- **tHq is highly suppressed in the SM**
  - 0.018 pb at 8TeV
- However, its production rate could be affected by anomalous top-Higgs couplings
- For example: a negative value of the coupling would increase the tHq cross section x15

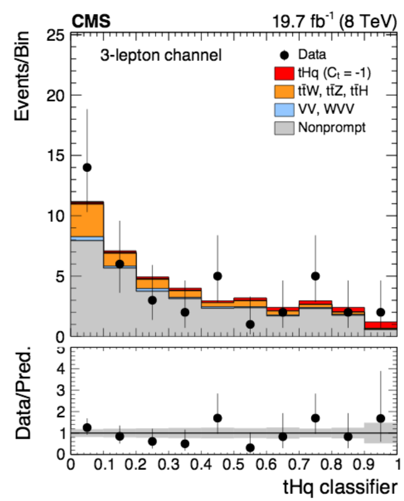
tHq associated production

- tHq production has very characteristic signatures:
  - Higgs decay, top decay (b-tagging), and a forward light jet (single top t-channel handle)
- Studied in Run-1, in almost as many channels as ttH:
  - **H→bb**, H → γγ , **H→WW**, H → ττ





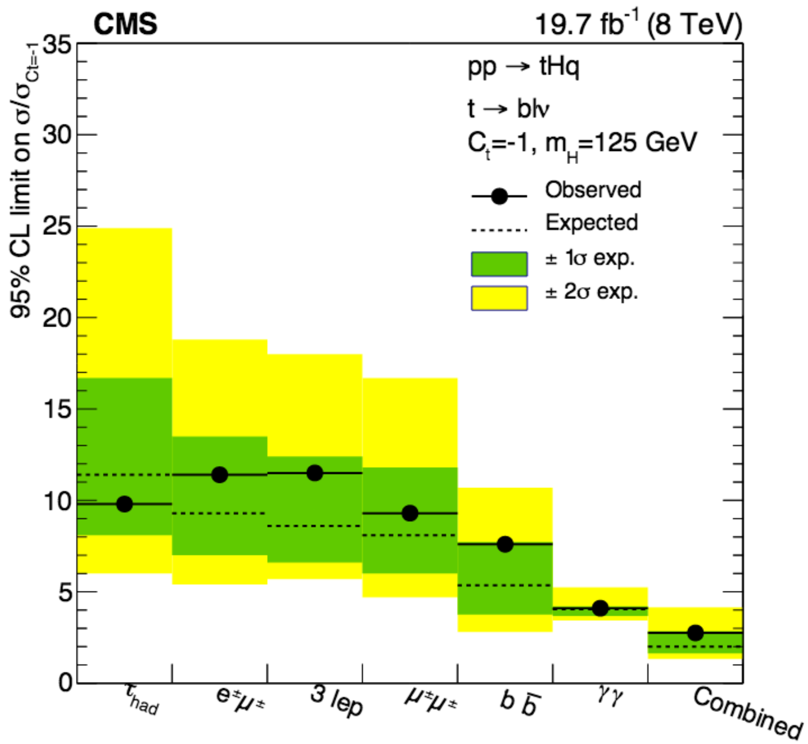




Submitted to JHEP
arXiv:1509.08159

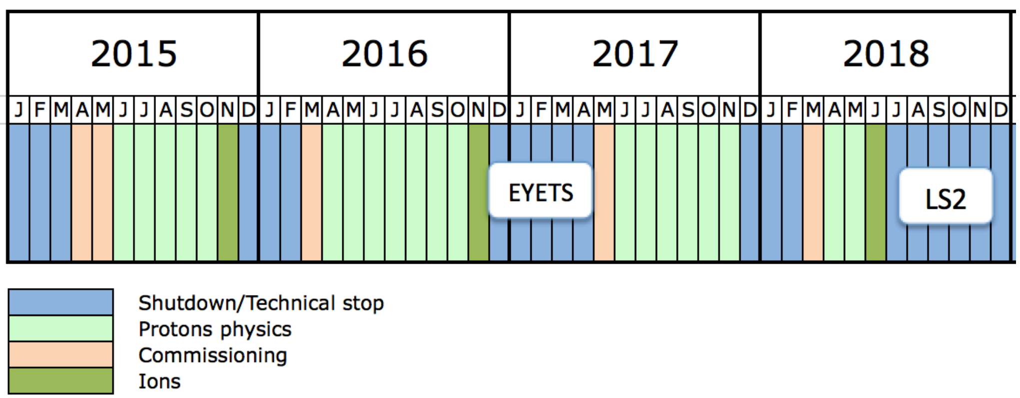
Single top + Higgs: Results

- The sensitivity to a SM tHq will not be reached until well into Run-2 (or 3)
- But sensitivity to a negative coupling will arrive much earlier



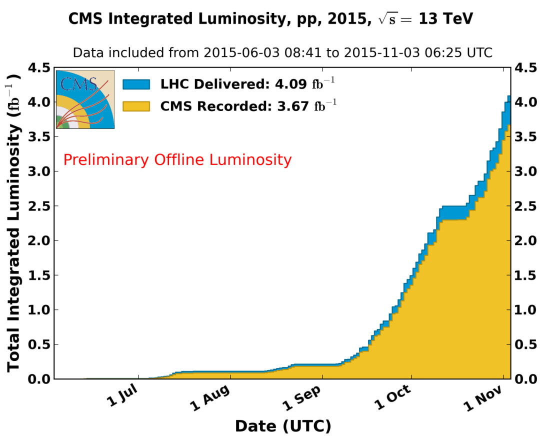
- **A large rate of single top plus Higgs** events could mean different BSM effects (FCNH, decay of new heavy particles)
- Moreover:
  - Negative values of k_f are disfavored with the current data → under the assumption that <u>no new particles contribute to the ggH and H→γγ loops</u>, and that there are no BSM decays

LHC Run-2

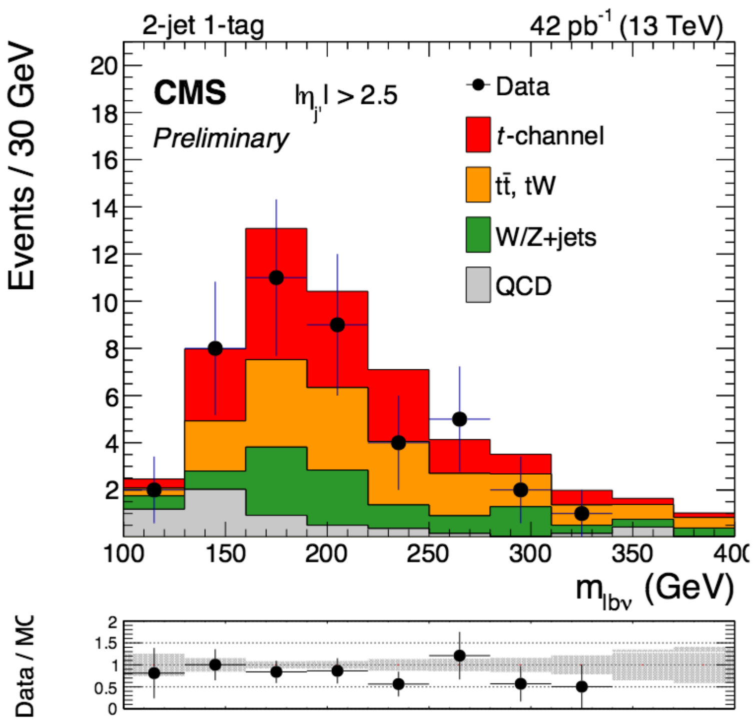

2015
2016
2017
2018
J F M A M J J A S O N D
EYETS
LS2
Shutdown/Technical stop
Protons physics
Commissioning
Ions

Current status of the LHC

- In 2015 the LHC started running again, entering a <u>new energy regime</u> → the pp run at 13TeV ended Nov. 4th
- Though the full potential of Run-2 is still ahead, the LHC already delivered $4fb^{-1}$ of integrated luminosity
- **<u>The first Run-2 results are arriving</u>**



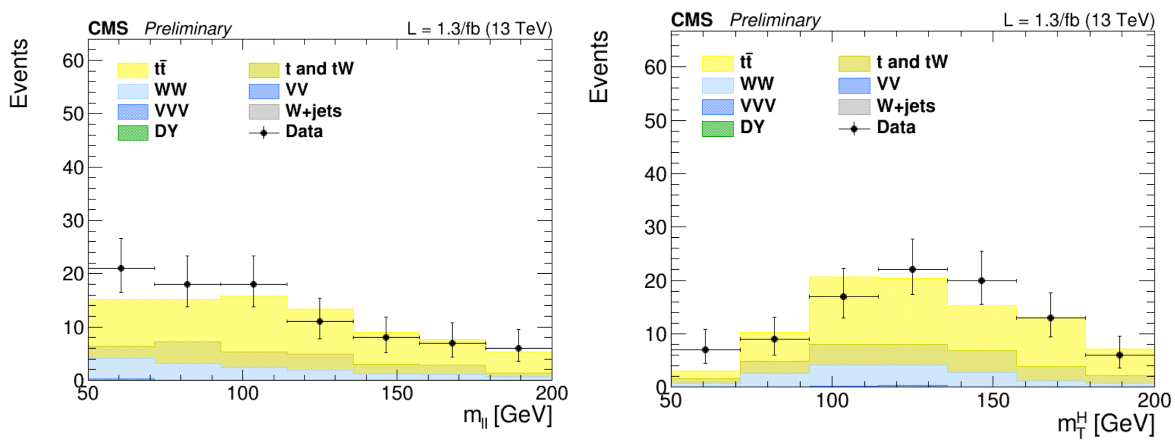
CMS-PAS-TOP-15-004



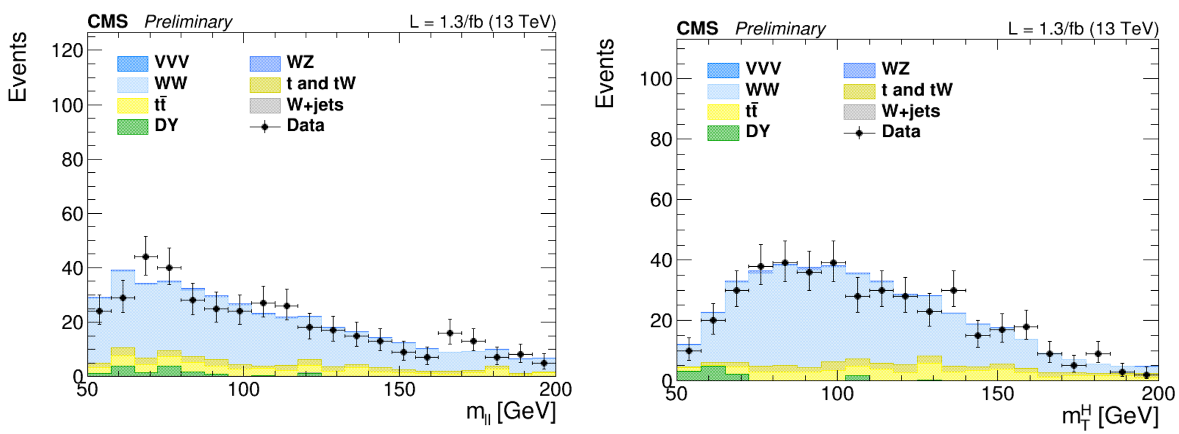
Already with $42pb^{-1}$ → **single top cross section was measured in the t-channel**

Single top production: Once a rare top production mode, has became a SM candle

Work is ongoing in H→WW too



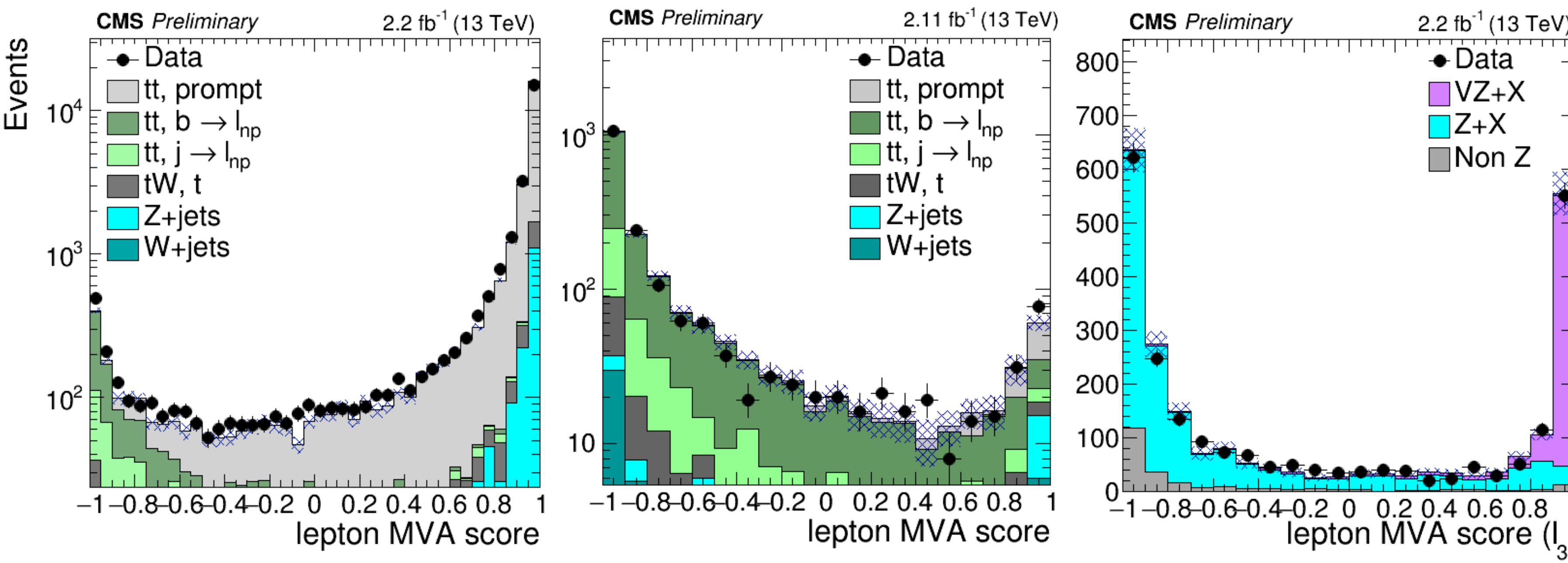
tt enriched region



WW enriched region

- First public 13TeV ggH, H→WW distributions
- Control regions of two main backgrounds
- Presented this Tuesday (Dec. 15th):
  - https://indico.cern.ch/event/442432/
- The amount of collected luminosity will not allow for rediscovery in this decay before the 2016 data, but the basis of the Run-2 analysis will be set

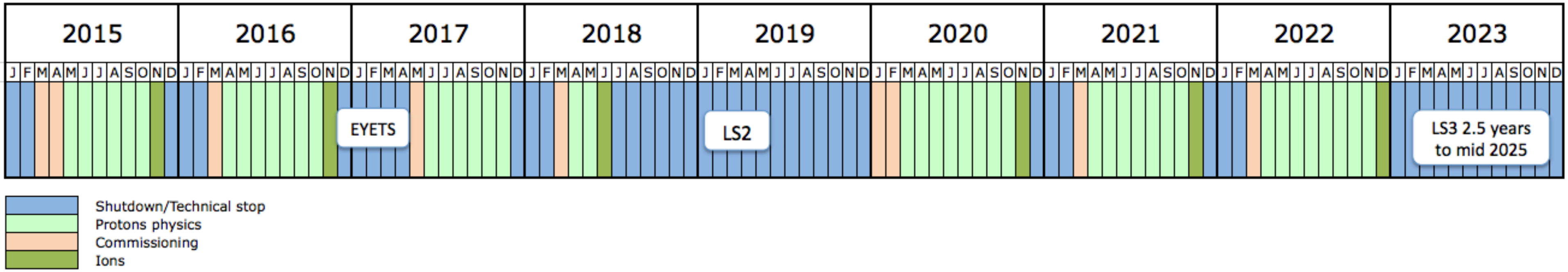
As in ttH, H→WW



The ttH, H→WW analysis (multilepton with 2,3, and 4 leptons) uses a multivariate discriminant to separate leptons from tt and ttH events

Distributions of the discriminants in different control regions → first 13TeV ttH plots also presented Tuesday:
https://indico.cern.ch/event/442432/

What's next?


2015
2016
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2023
J F M A M J J A S O N D
EYETS
LS2
LS3 2.5 years to mid 2025
Shutdown/Technical stop
Protons physics
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Ions

Next steps for Higgs

- During Run-2 we aim to collect ~100fb^{-1} (**~300 fb^{-1} by the end of Run-3**)
  - σ_{13}/σ_8: few fb^{-1} at 13TeV could be more sensitive than the full dataset at 8 TeV
- Run-2 and beyond:
  - Establish the main production mechanisms (**ggH**, **VBF**, **WH, ZH, ttH**) and all possible decay modes
  - **Measure properties**
    - Any deviation in the predicted properties → unambiguous sign of new physics

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$\sim -.4\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

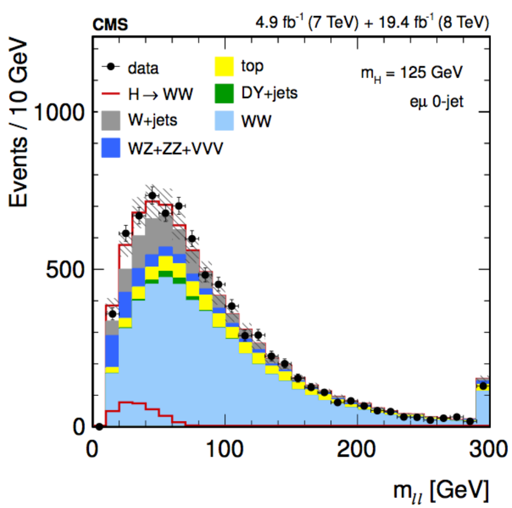
Higgs coupling modifications from the SM when new particles have M~1 TeV

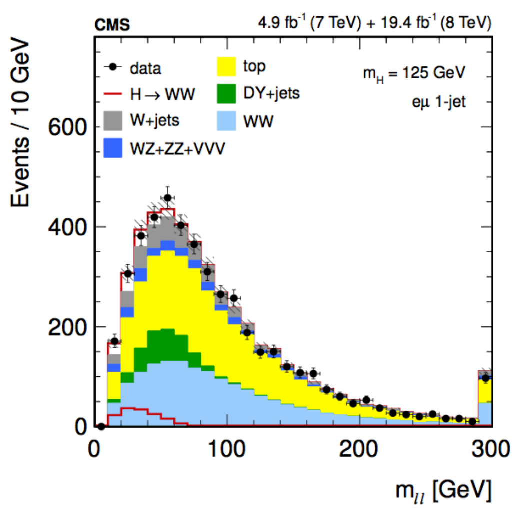
arXiv:1310.8361

    - mass, total width, spin, couplings, CP mixtures
  - Searches for multiple Higgs bosons, Higgs partners…

H→WW

- In particular in H→WW:
  - Production modes, establish VBF (Run-2), explore VH, ttH (bbH)
  - Achieve a better sensitivity to anomalous couplings
  - Study Higgs width, differential distributions, fiducial cross sections
  - Improve systematics and control of the backgrounds





Top background in H→WW is a mixture of tt and tW
0-jet bin: ~45% of top is tW
1-jet bin: ~25%

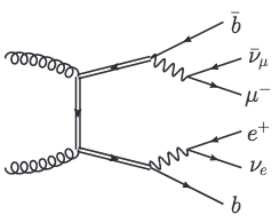
  - Top contribution to the 0/1 jet bins → Run-2 study directly linked to tW

Top physics: state of the art simulation

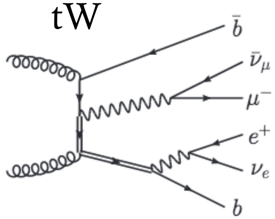
- In the next months, the **top sector** will be scrutinized in search for new phenomena
- **The measurement of top properties will continue to be refined**
- Clear need for an ever improving simulation
  - top mass, systematics related to modeling
  - Also other less obvious: single top tW

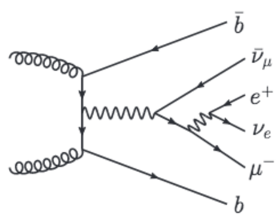
- Single top tW is well described at LO (5FS), but at NLO it mixes with tt
  - Problematic diagrams are either removed from the signal definition (Diagram Removal) or subtracted using a term (Diagram subtraction)
- A full 4FS NLO description of tt, tW and in general non-resonant WWbb will come next year, important to tt and tW, immediate use in H→WW

tt



tW





arXiv:1311.4893

ttH, tH, and top-Higgs coupling

- The slight excess hinted in the **ttH multilepton ($H \rightarrow WW$)** will be followed up in the next months
  - Can be done relatively soon → early analysis, large growth (4x) of ttH production rate at 13TeV
    - Either is a BSM effect or a fluctuation → we still want to continue exploring ttH production in order to establish it and measure it

- Exploring **tHq** will become easier (and will be useful!)
  - Increase of the cross section by a factor of 4 independently from the value of the top-Higgs coupling
  - Explore the **full k_V and k_f phase space** (including negative values)
    - 0 events with 20 fb^{-1} would rule out a negative top-Higgs coupling

Collider	LHC		ILC	ILC	CLIC
CM Energy [TeV]	14	14	0.5	1.0	1.4
Luminosity [fb^{-1}]	300	3000	1000	1000	1500
Top Yukawa coupling κ_t	(14 – 15)%	(7 – 10)%	10%	4%	4%

Expected precision of the top quark Yukawa coupling measurement
arXiv:1311.2028

Top and Higgs, BSM scenarios

- The high center of mass energy and high luminosity of Run-2 and Run-3 will allow for a thorough exploration of BSM scenarios with top and Higgs:
  - **FCNH decays ($t\rightarrow Hq$)**, as predicted in:
    - two-Higgs-doublet model, R-parity violating MSSM models, warped extra dimensions

CMS-PAS-TOP-14-020
CMS-PAS-TOP-14-019
CMS-PAS-TOP-13-017

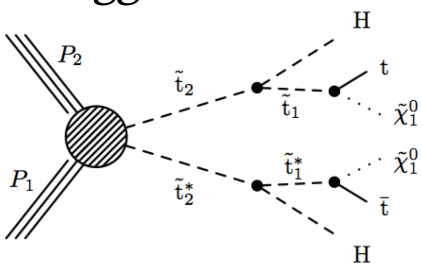
  - **Charged Higgs searches**
    - Light charged Higgs: $t\rightarrow H^{+}b$, $H^{+}\rightarrow\tau\nu$ or $H^{+}\rightarrow cs$
    - Heavy charged Higgs: $H^{+}\rightarrow tb$

arXiv:1508.07774
arXiv:1205.5736

  - Direct production of **heavy new particles ($T\rightarrow tH$)**
    - As predicted in composite and little Higgs models

arXiv:1503.01952

  - **SUSY**
    - Heavy top squark



arXiv:1405.3886

Summary

- With Run-1 data:
  - High precision for top physics and sensitivity to rare top processes
    - Single top well established
  - Higgs boson discovery and first properties
  - Groundwork for top+Higgs studies set in place:
    - SM and BSM
- With current Run-2 dataset:
  - Single top already observed
  - First preliminary studies of control regions in H→WW (including ttH)
- Next:
  - **Complete characterization of the Higgs boson**
  - **Explore Top and Higgs channels, that will become accessible**
    - Sensitivity to observe ttH production
    - top-Higgs coupling measurement
    - Exotic searches with top and Higgs will reach their full potential