Vulcano 2018: Highlights from ATLAS and CMS

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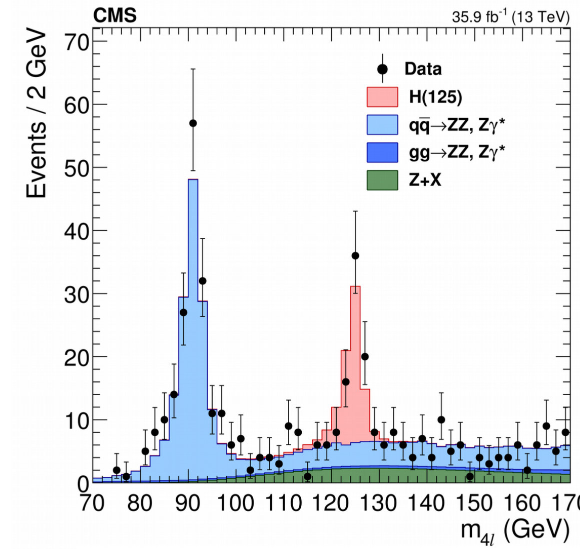
Outline

- Higgs Sector
  - Mass
  - Coupling to Bosons
  - Coupling to Fermions
- Standard Model Precision measurements
  - W Mass
  - Top Mass
  - Standard Model Fits
- Searches
  - Exotics
  - SUSY



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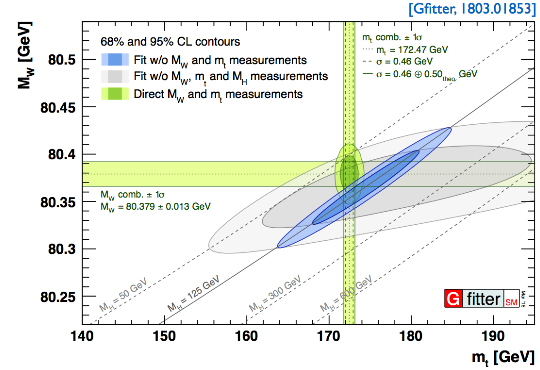
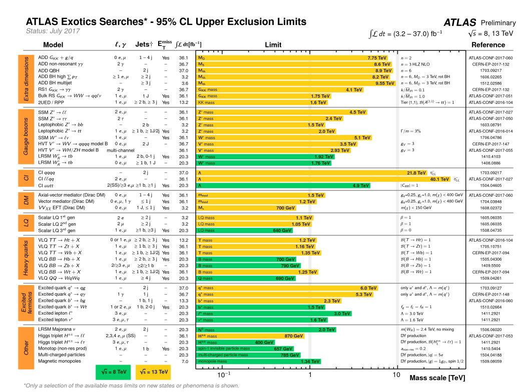
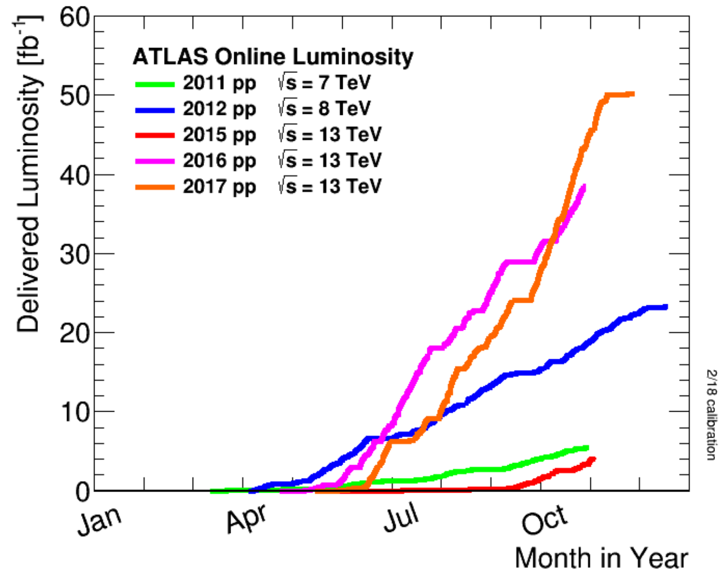


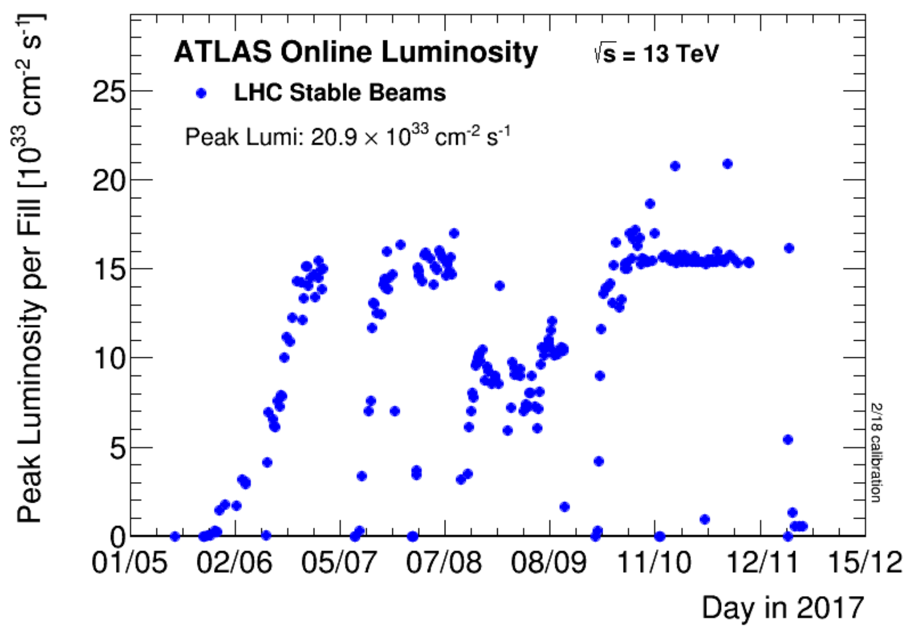


Data sample: LHC Run I and Run II

- Excellent performance of the LHC
- ~25 fb^{-1} delivered in RUN 1 and ~100 fb^{-1} in Run 2

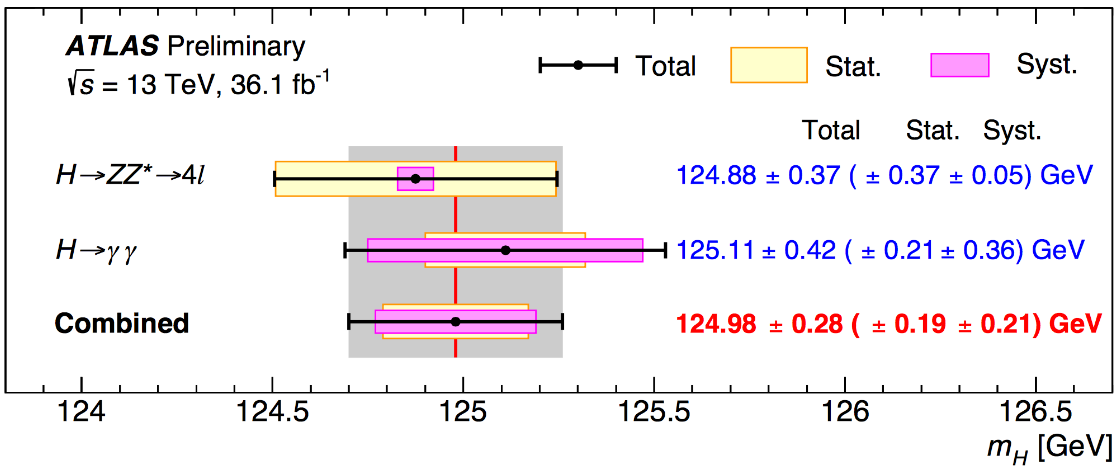


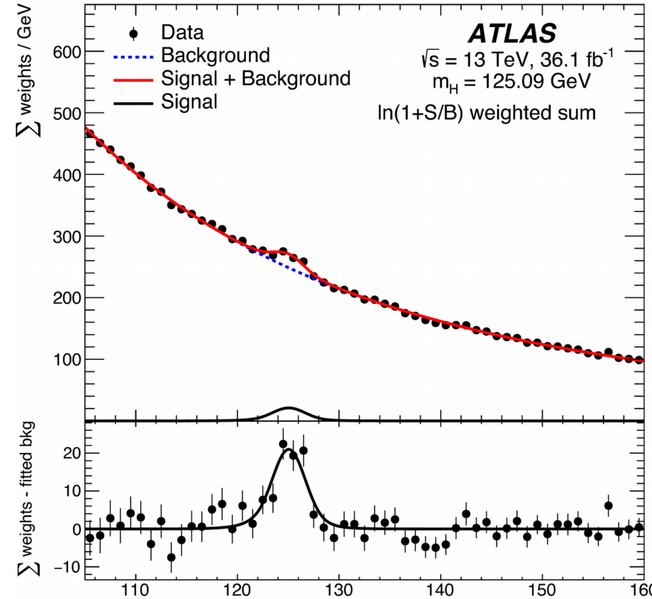
- The instantaneous luminosity in RUN 2 reached $2x10^{34}$ $cm^{-2}s^{-1}$ (twice the design value)



The Higgs Sector: Mass

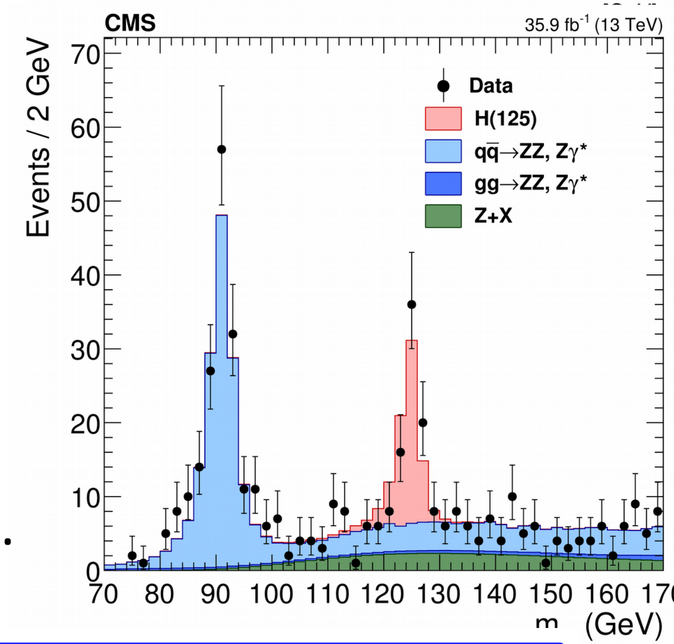
- Higgs Boson Mass measured with high precision by ATLAS and CMS using the fully reconstructed final states: H-> γγ and H->ZZ->4l (e,μ)
- All measurements in good agreement





CMS Mass Measurement using only H->4l

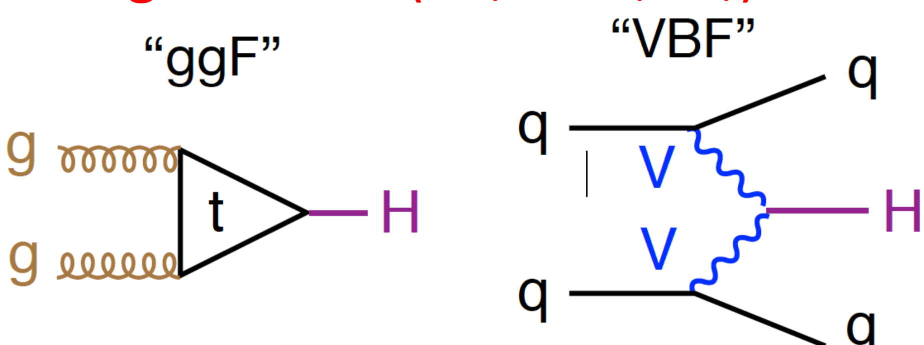
12% more precise than Run 1 ATLAS+ CMS comb.



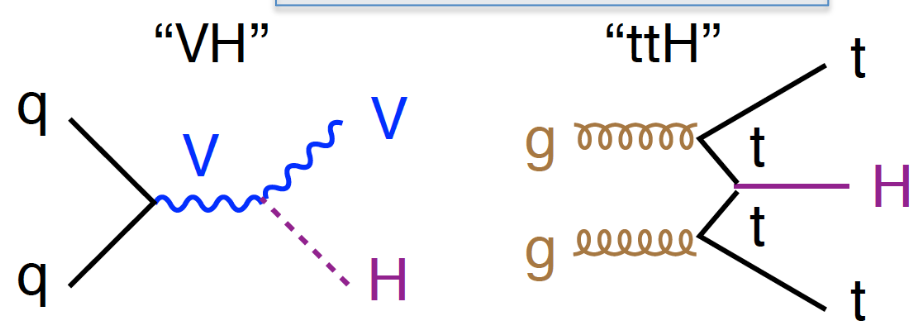
$$m_{\mathrm{H}} = 125.26 \pm 0.21\ (\pm 0.20\ \text{stat.} \pm 0.08\ \text{sys.})\ \text{GeV}$$

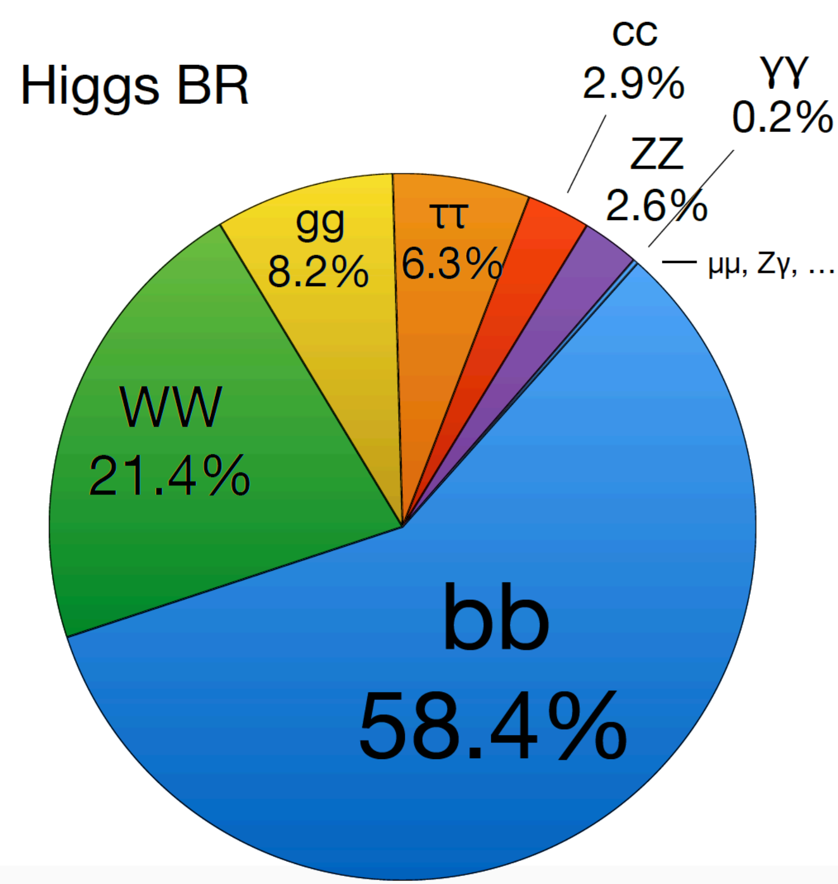
Higgs Production and Branching fraction

- Many different production mechanisms and decays: aim to measure as many as possible
- Use of different experimental signatures to measure them
- Some very clean decays with low BR (γγ, 4l), other very difficult with higher rates (bb, WW, ττ,)



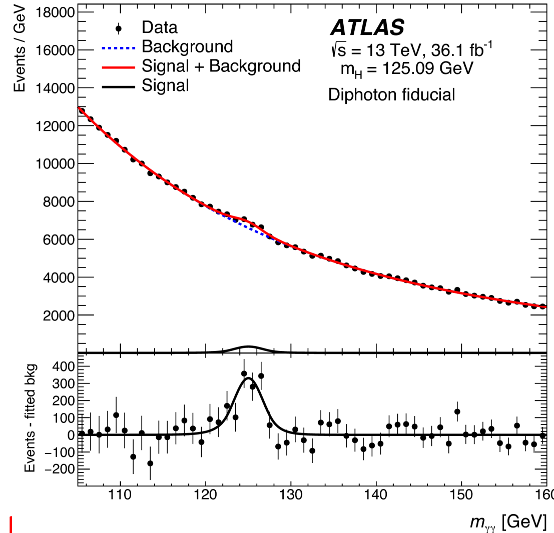
49 pb	3.8 pb	At 13 TeV
2.2 pb	0.51 pb	



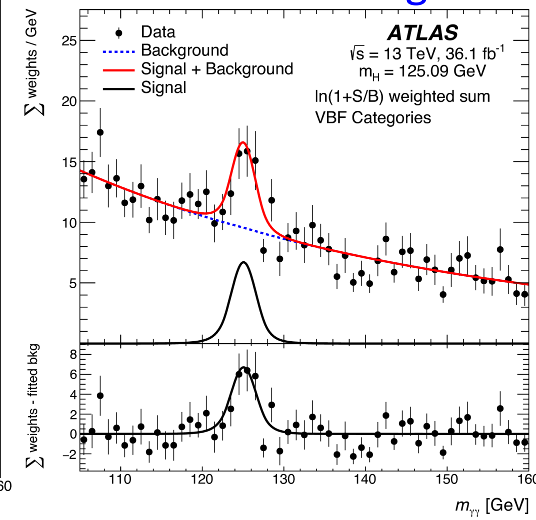


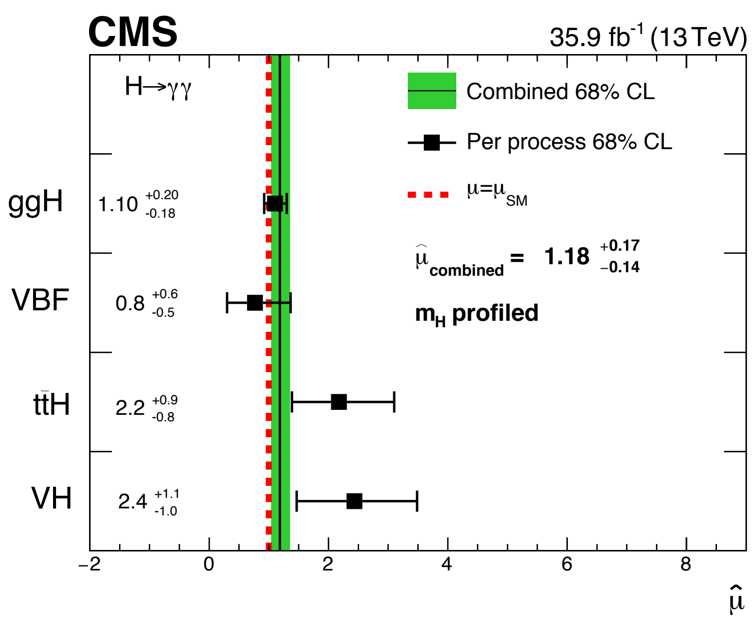
The Higgs Sector: Coupling to Bosons H->γγ

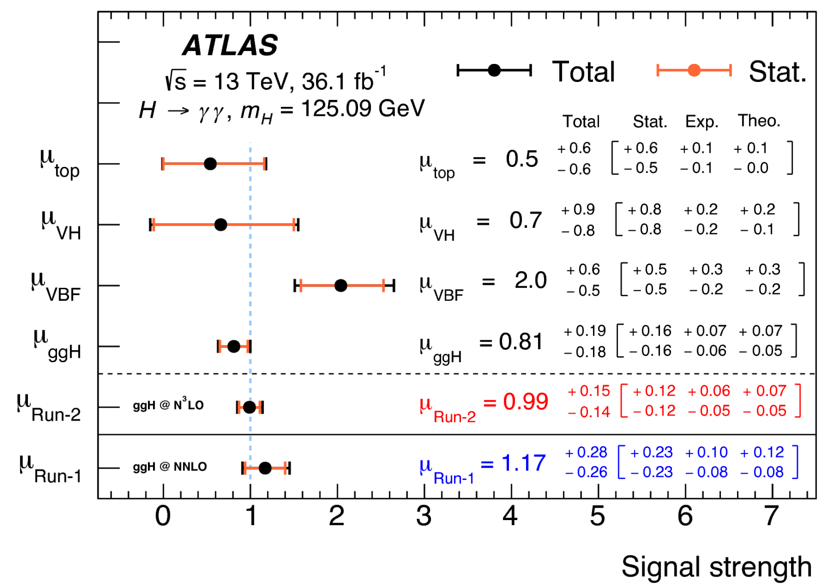
- The Higgs decay in γγ has a clean signature over a smooth background
- It is used to disentangle the different production mechanisms allowing a measurement of their signal strenght : μ



VBF Categories

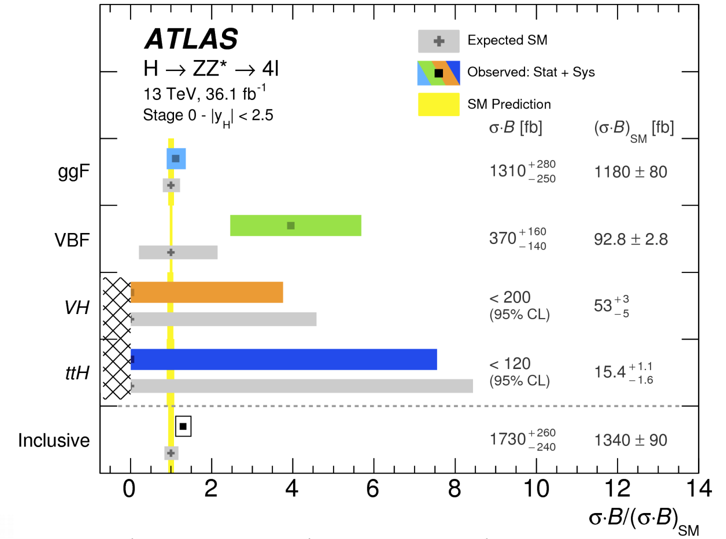


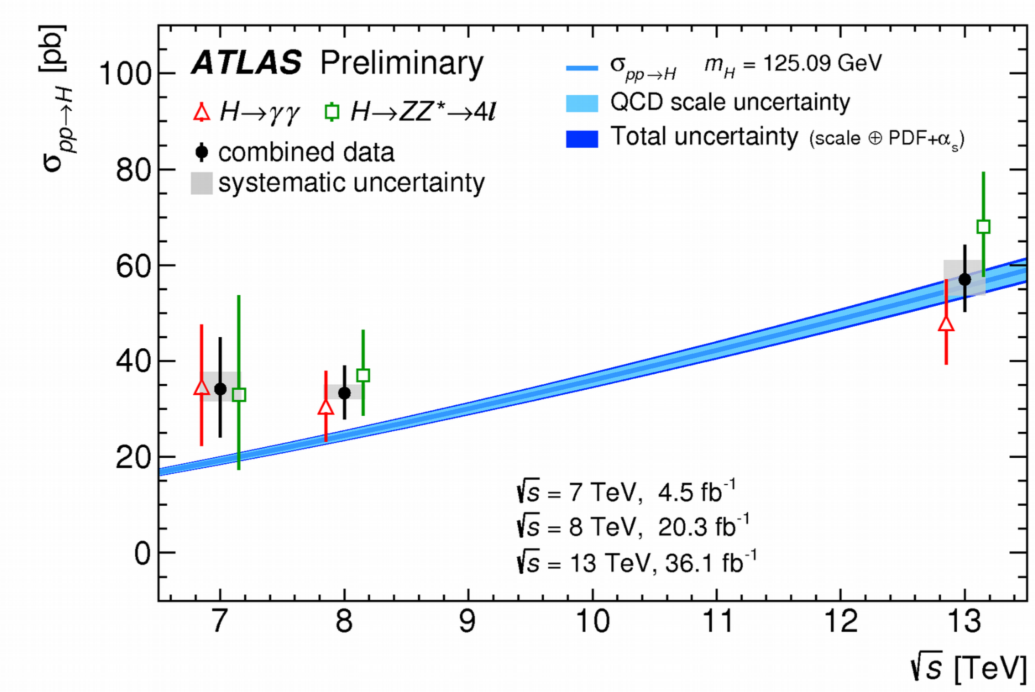


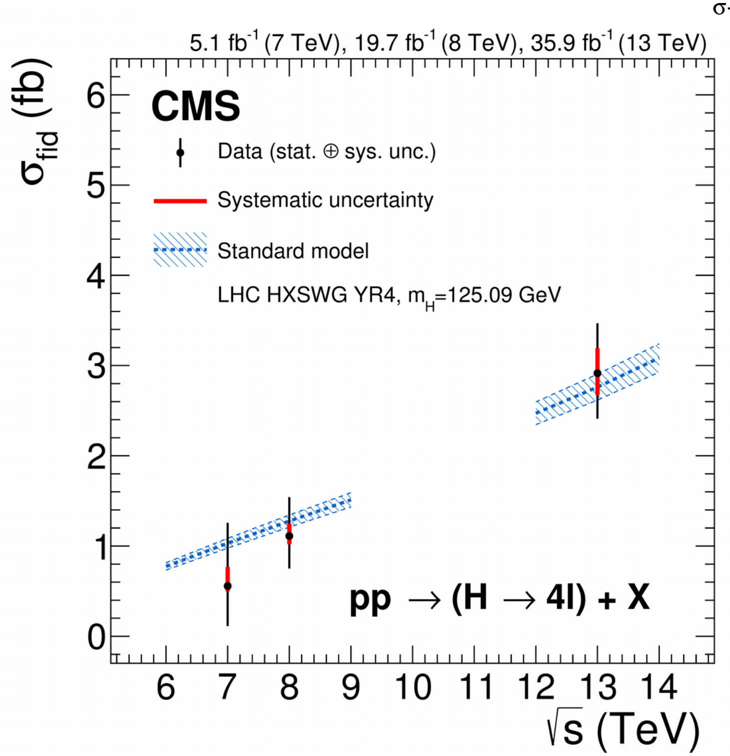


The Higgs Sector: Coupling to Bosons H-> ZZ

- Very clean signature but very low rate
- Measurement of ggH and VBF production
- Measurement of total fiducial cross section

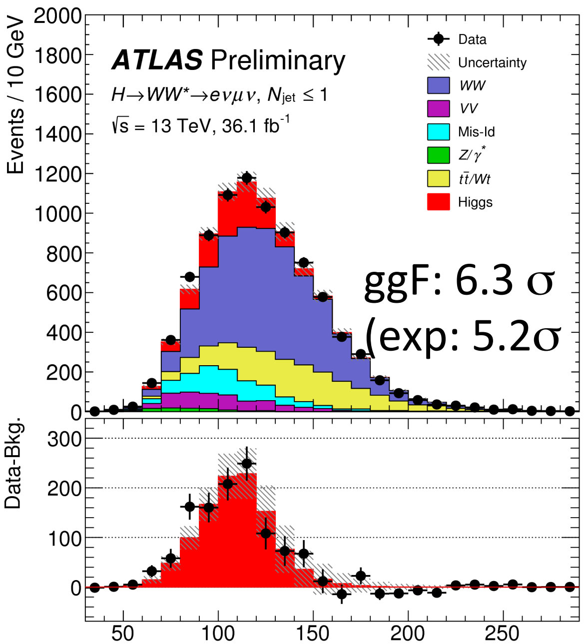




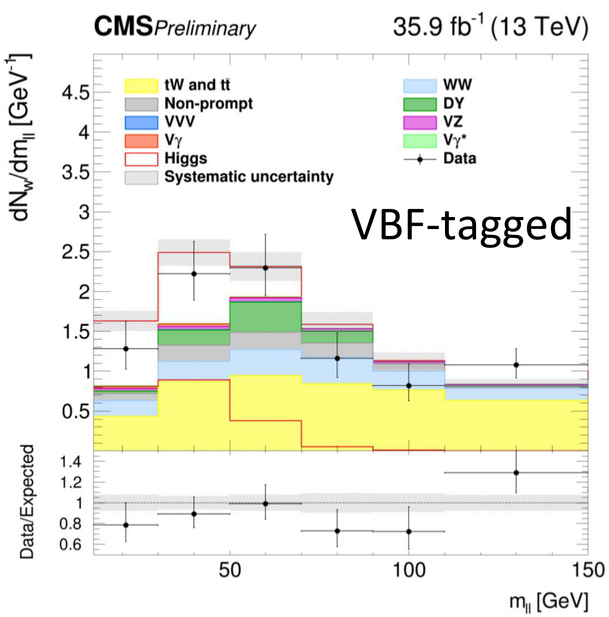


The Higgs Sector: Coupling to Bosons H-> WW

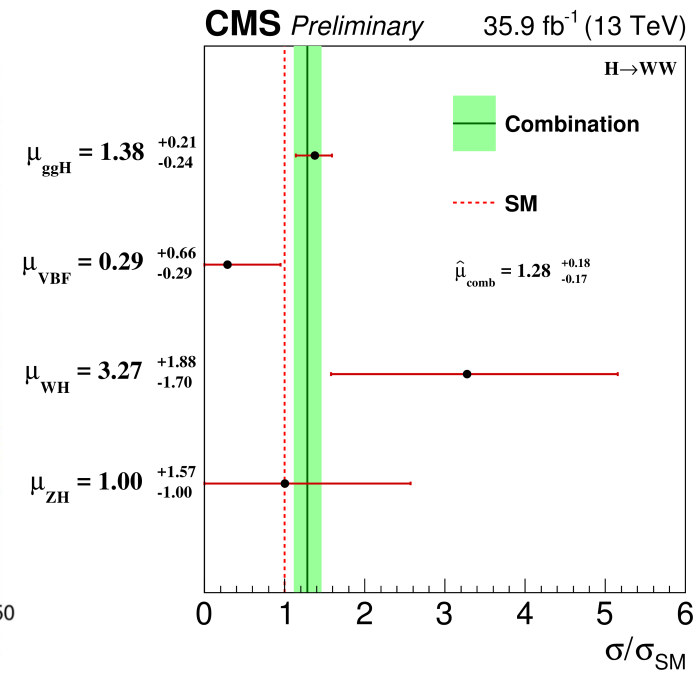
- Larger usable branching fraction (2l2ν) but much larger background
- No Higgs mass reconstruction, rely on lepton kinematics (Mt, Mll, θ_{ll})



ggF: 6.3 σ (exp: 5.2σ



VBF-tagged



CMS

$$\hat{\mu} = 1.28^{+0.18}_{-0.17} = 1.28 \pm 0.10(\text{stat})^{+0.11}_{-0.11}(\text{syst})^{+0.10}_{-0.07}(\text{theo.})$$

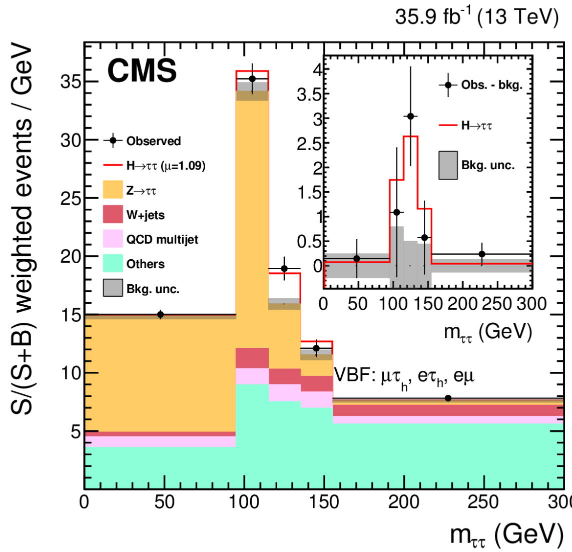
ATLAS

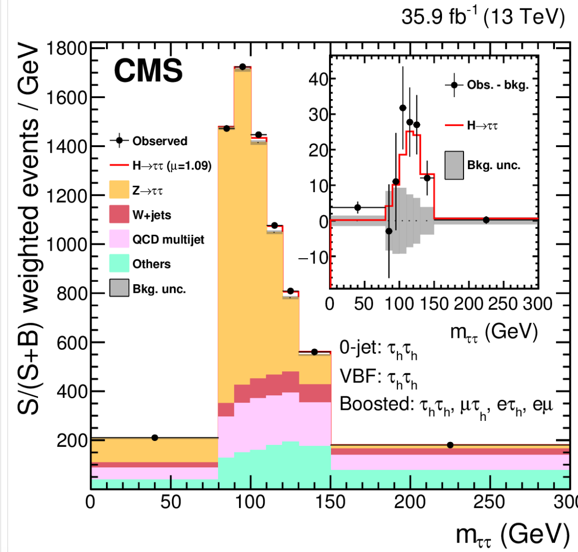
$$\mu_{\text{ggF}} = 1.21^{+0.12}_{-0.11}(\text{stat.})^{+0.18}_{-0.17}(\text{sys.}) = 1.21^{+0.22}_{-0.21}$$

$$\mu_{\text{VBF}} = 0.62^{+0.30}_{-0.28}(\text{stat.}) \pm 0.22(\text{sys.}) = 0.62^{+0.37}_{-0.36}$$

The Higgs Sector: Coupling to Fermions H-> $\tau\tau$

- Search for H->$\tau\tau$ with τ decaying in $e\mu$, $\mu\tau_h$, $e\tau_h$ and $\tau_h\tau_h$
- Largest background from Z->$\tau\tau$ and hadronic multijet events
- Search in categories aiming at ggH and VBF production

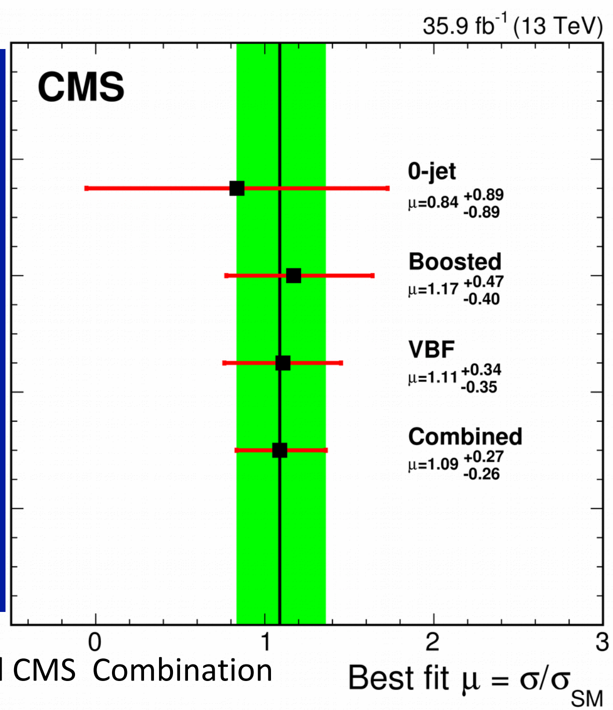


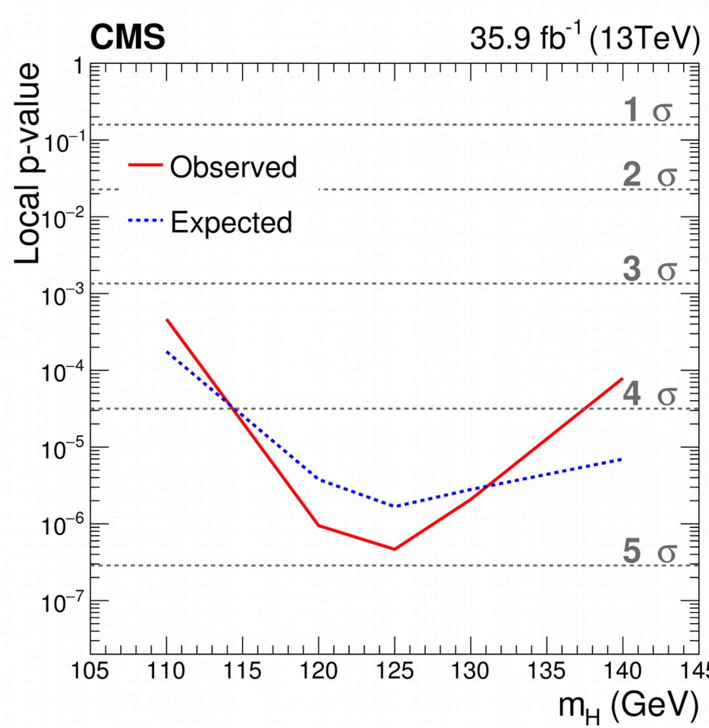


Observation of H-> $\tau\tau$

μ= 1.09 ± 0.26

Significance: 4.9 σ (5.9 σ for comb. of 13 & 7-8 TeV)

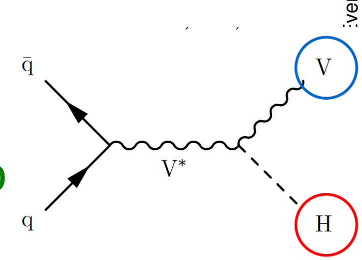


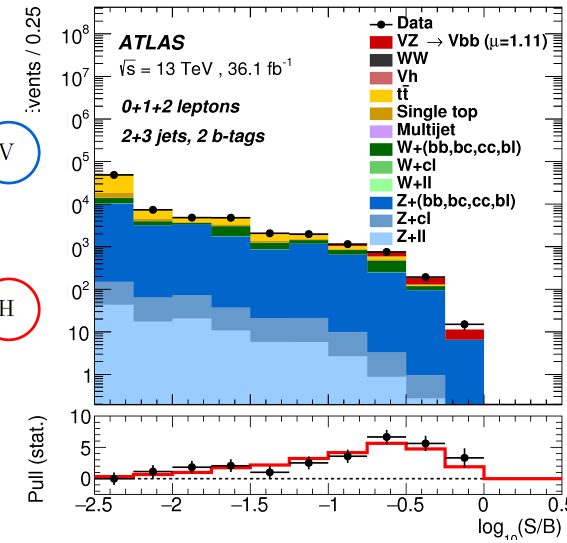


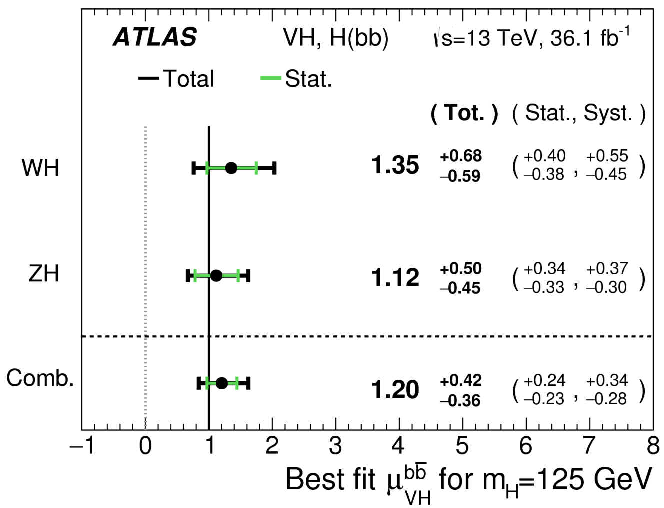
First observed in run 1 by ATLAS and CMS Combination

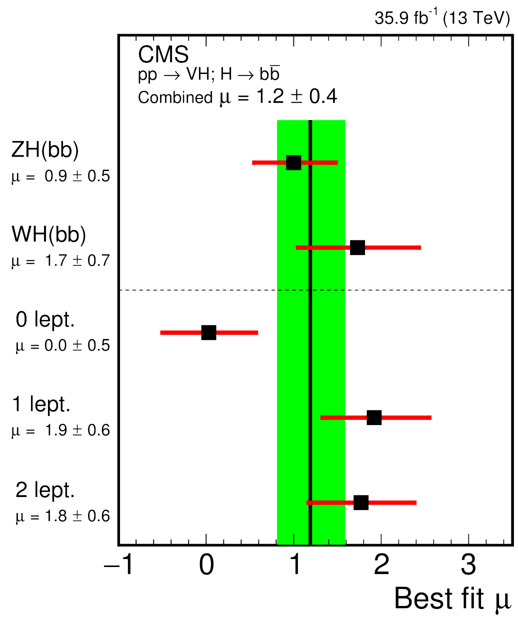
The Higgs Sector: Coupling to Fermions H-> bb

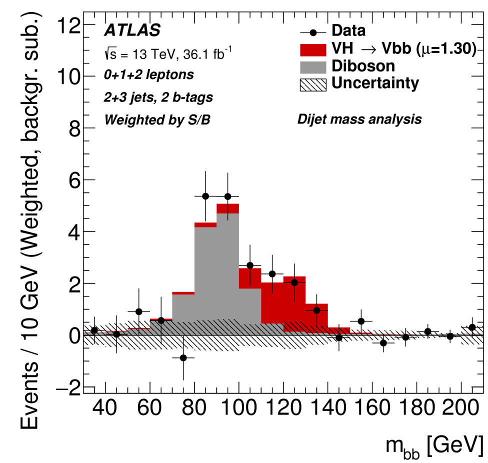
- Largest branching fraction (58.4%) but huge background from heavy flavour production
- Need to use exclusive (rare) production mechanism to gain sensitivity: VH H->bb (V=W or Z)
- Final states with 2 tagged b Jets and 0,1 or 2 leptons







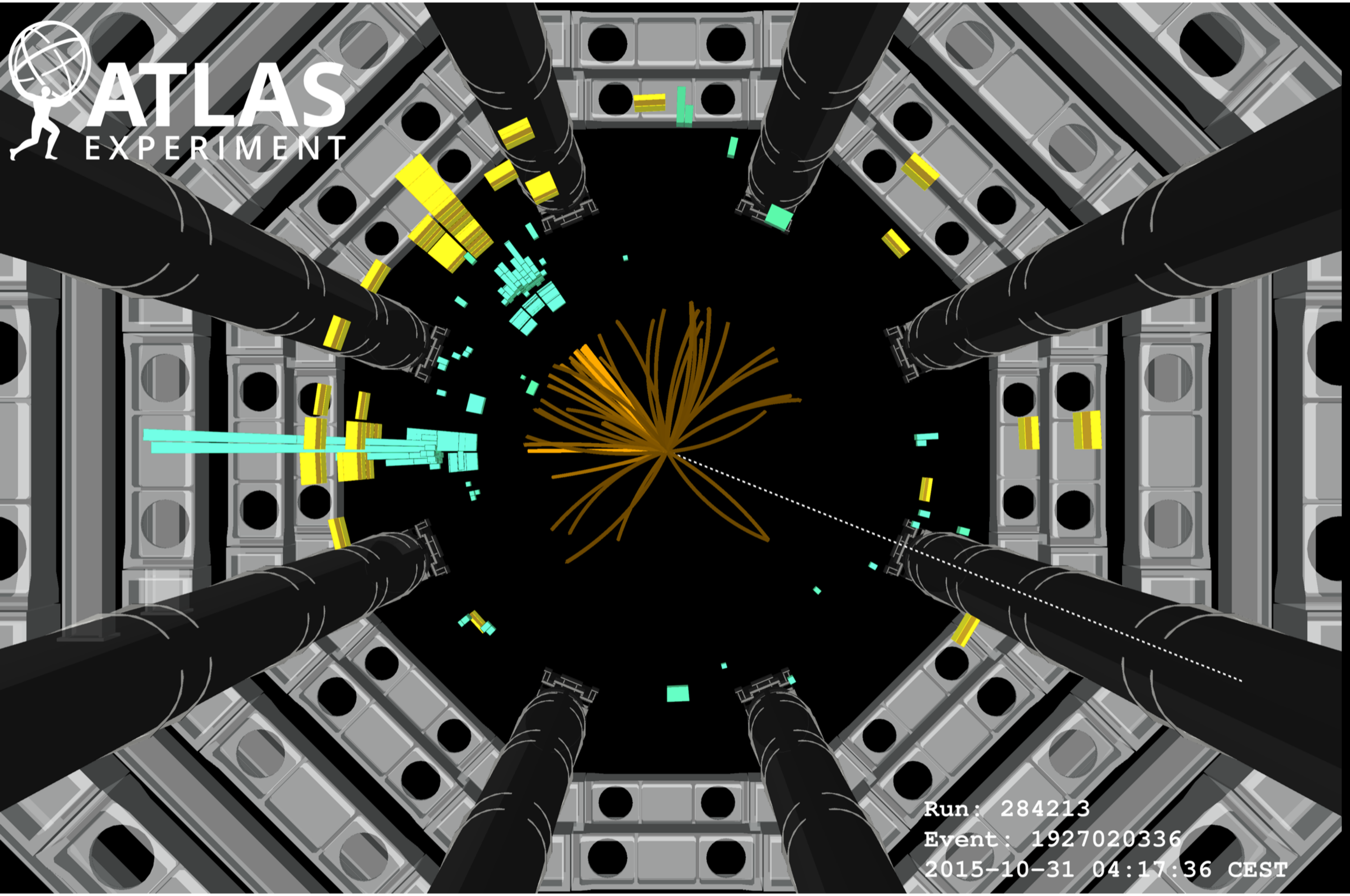




Evidence of VH(bb) production

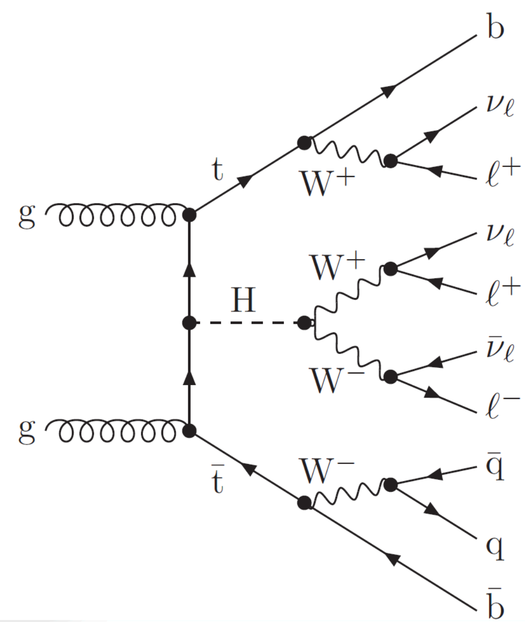
Observed (expected) significance

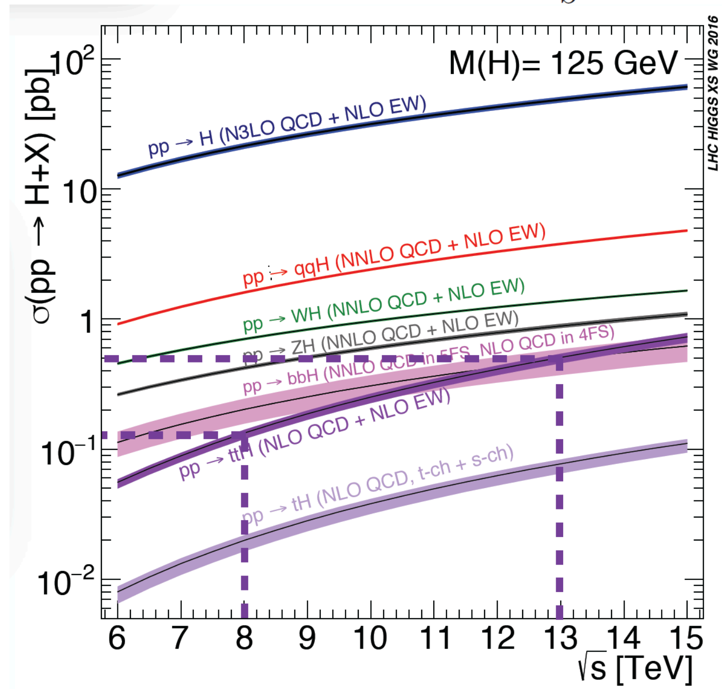
	Run II	Run I+II
ATLAS	3.5 (3.0)	3.6 (4.0)
CMS	3.3 (2.8)	3.8 (3.8)


ATLAS
EXPERIMENT
Run: 284213
Event: 1927020336
2015-10-31 04:17:36 CEST

The Higgs Sector: Coupling to Fermions: ttH

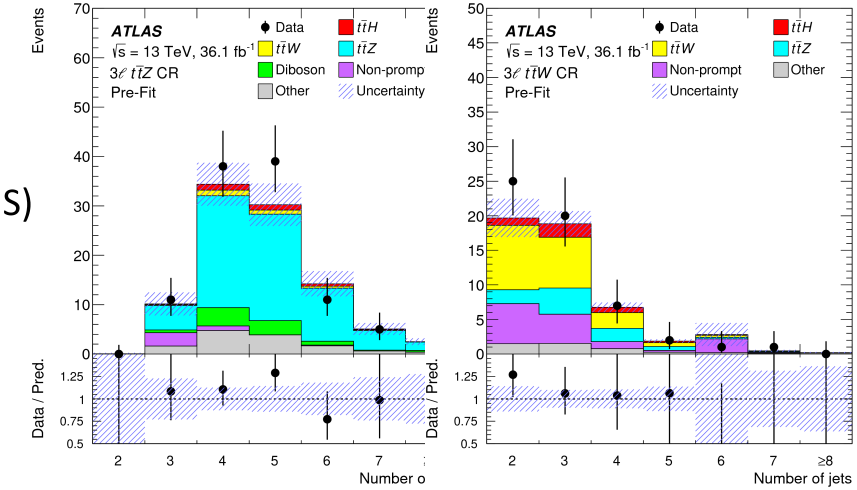
- Very interesting:
  - give direct acces to the Yukawa coupling between the top quark and the Higgs
- Very challenging:
  - Very small production cross section (O(0.5)pb @ 13 TeV
  - Many complex final states and large irreducible backgrounds
- Complex analyses:
  - Use of BDTs, MVA, Deep Machine Learning techniques
- Results from ttH-> Multilepton final states and ttH, (H-bb)



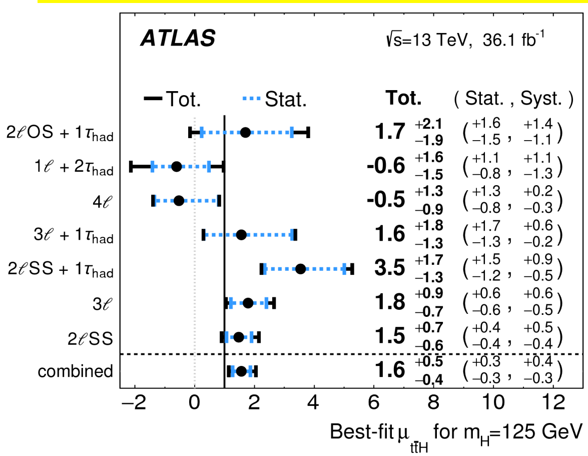


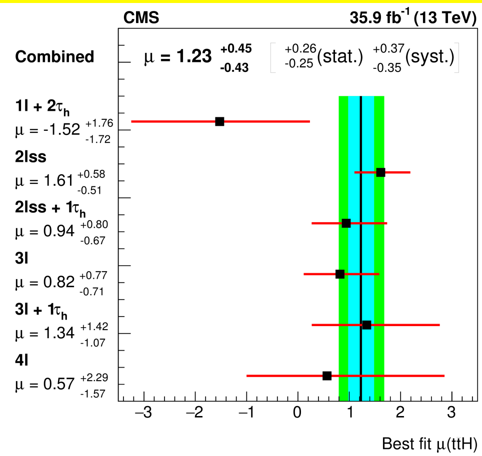
The Higgs Sector: ttH-> Multileptons

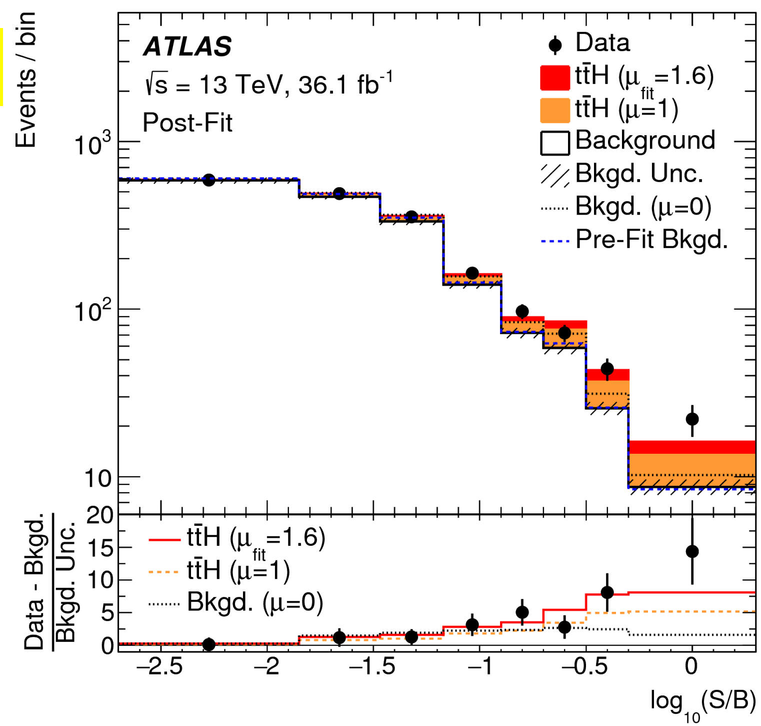
- Target Higgs decays to WW, ττ and ZZ
  - Two same sign or >=3 charged leptons+ additional requirements on b-jet multiplicities (and/or τ_h for CMS)
    - CMS uses also 1 lepton and $2\tau_h$
- Irreducible background: ttW, ttZ, with prompt leptons
- Reducible background: mostly tt+γ with mis-reconstructed leptons



ATLAS comb. $\mu=1.6^{+0.5}_{-0.4}$ CMS comb. $\mu=1.23^{+0.5}_{-0.4}$







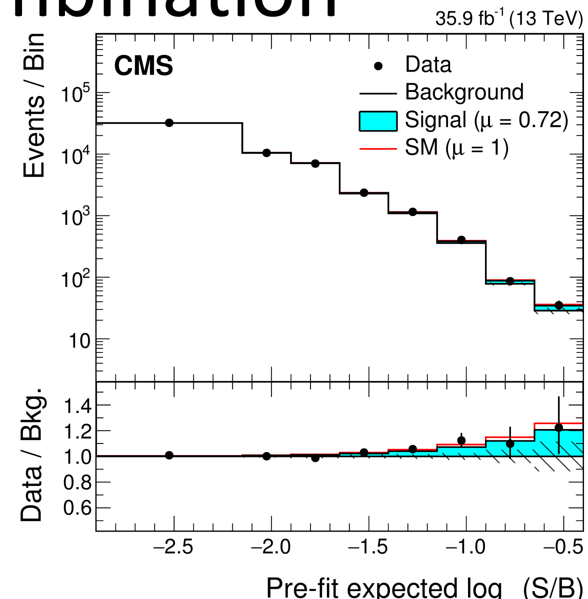
Evidence for ttH production in leptonic final states

CMS : 3.2 σ (2.8 σ exp.)

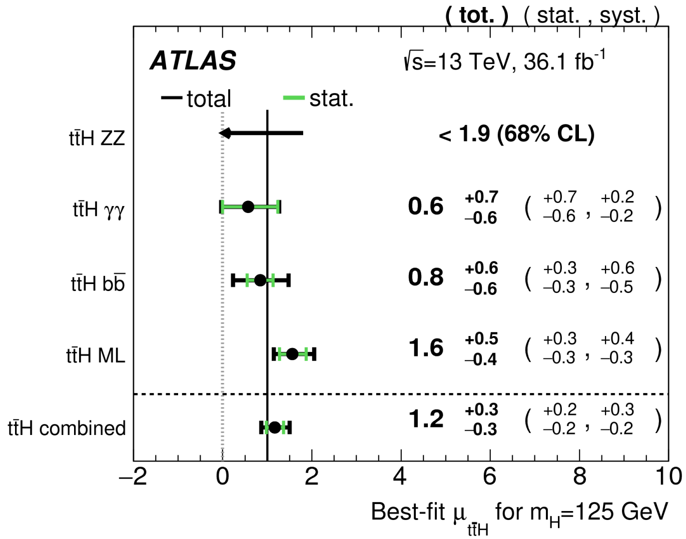
ATLAS: 4.1 σ (2.8 σ exp.)

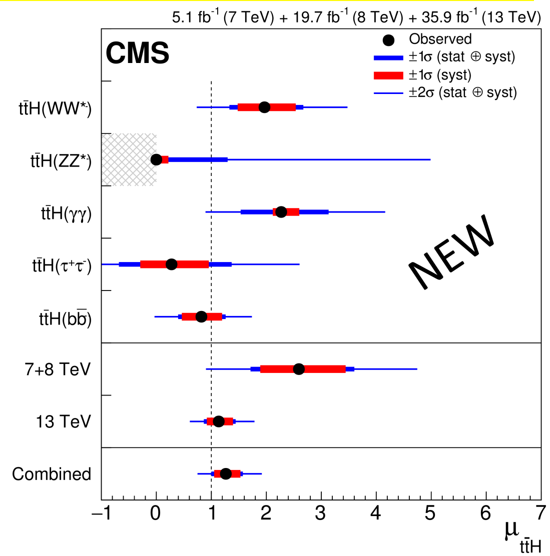
The Higgs Sector: ttH (H->bb) and Combination

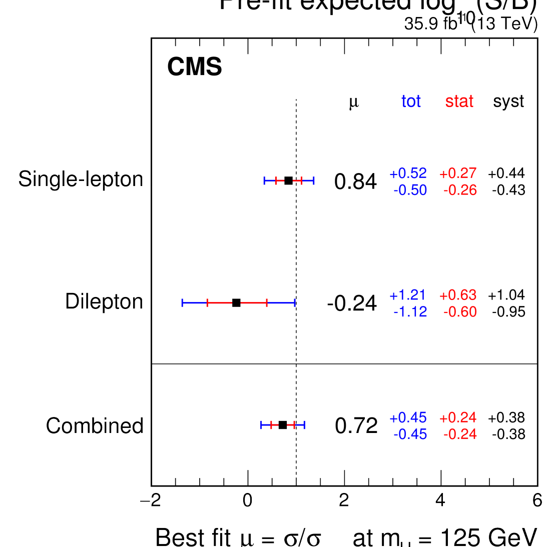
- ATLAS and CMS use channels with 1 or 2 leptons and N_{jet}>= 4, >=3b, to exploit leptonic t decays to reduce huge backgrounds
- CMS also uses the all hadronic final state: higher rates but even larger background



Combined signal strength of all ttH channels in agreement with SM predictions







ATLAS Combination Run2 μ=1.2+-0.3 Evidence ttH Prod. 4.2σ (3.8σ exp.)

CMS Combination Run2 μ=1.18+0.31-0.27 Evidence tth Prod 4.2 σ

CMS Combination Run1+Run2 μ=1.26+0.31-0.26 Obs. of ttH with 5.2σ (4.2σ exp)

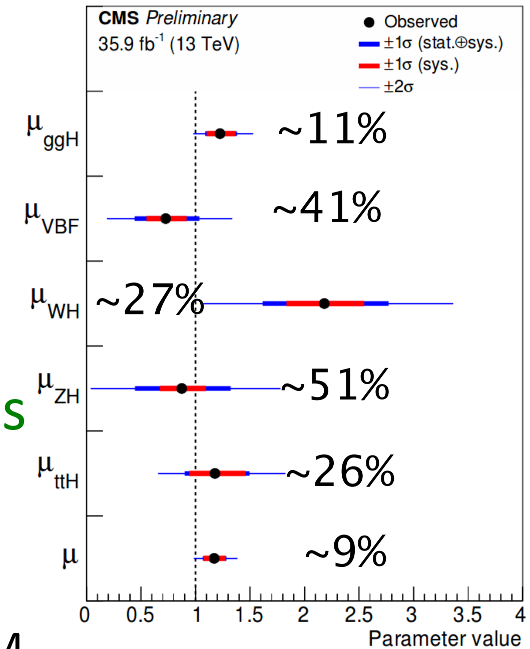
The Higgs Sector: Putting all together

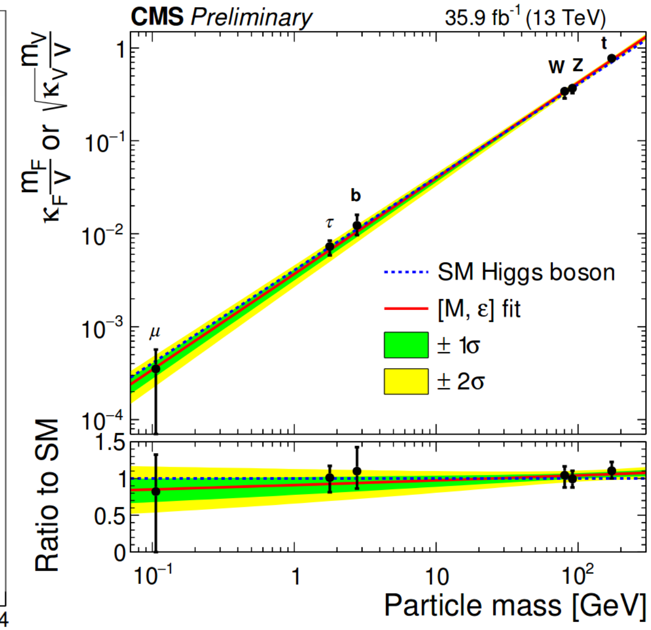
- CMS μ combination:

$$\mu = 1.17^{+0.10}_{-0.10}$$

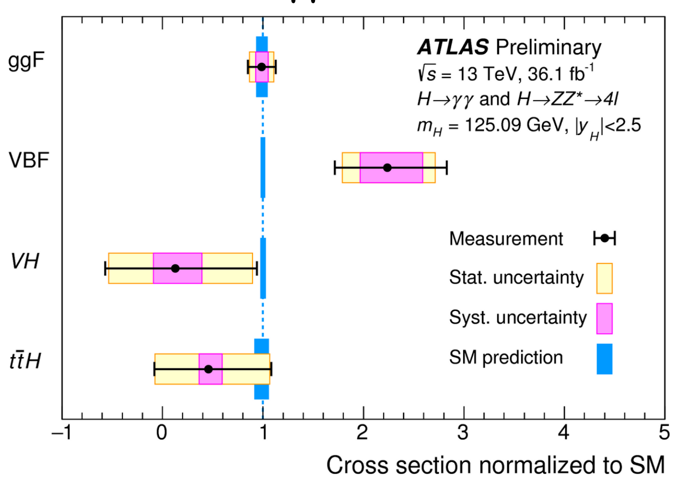
- Cross sections measurements in agreement with SM
- Differential Cross Sections also in good agreement with SM

Higgs production

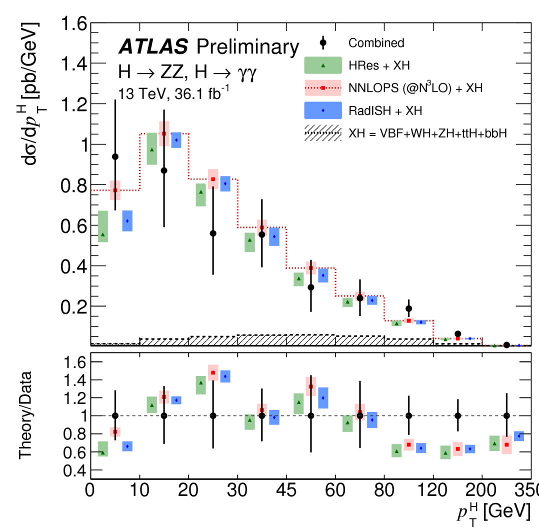




Cross sections normalised to SM from ZZ and γγ combination



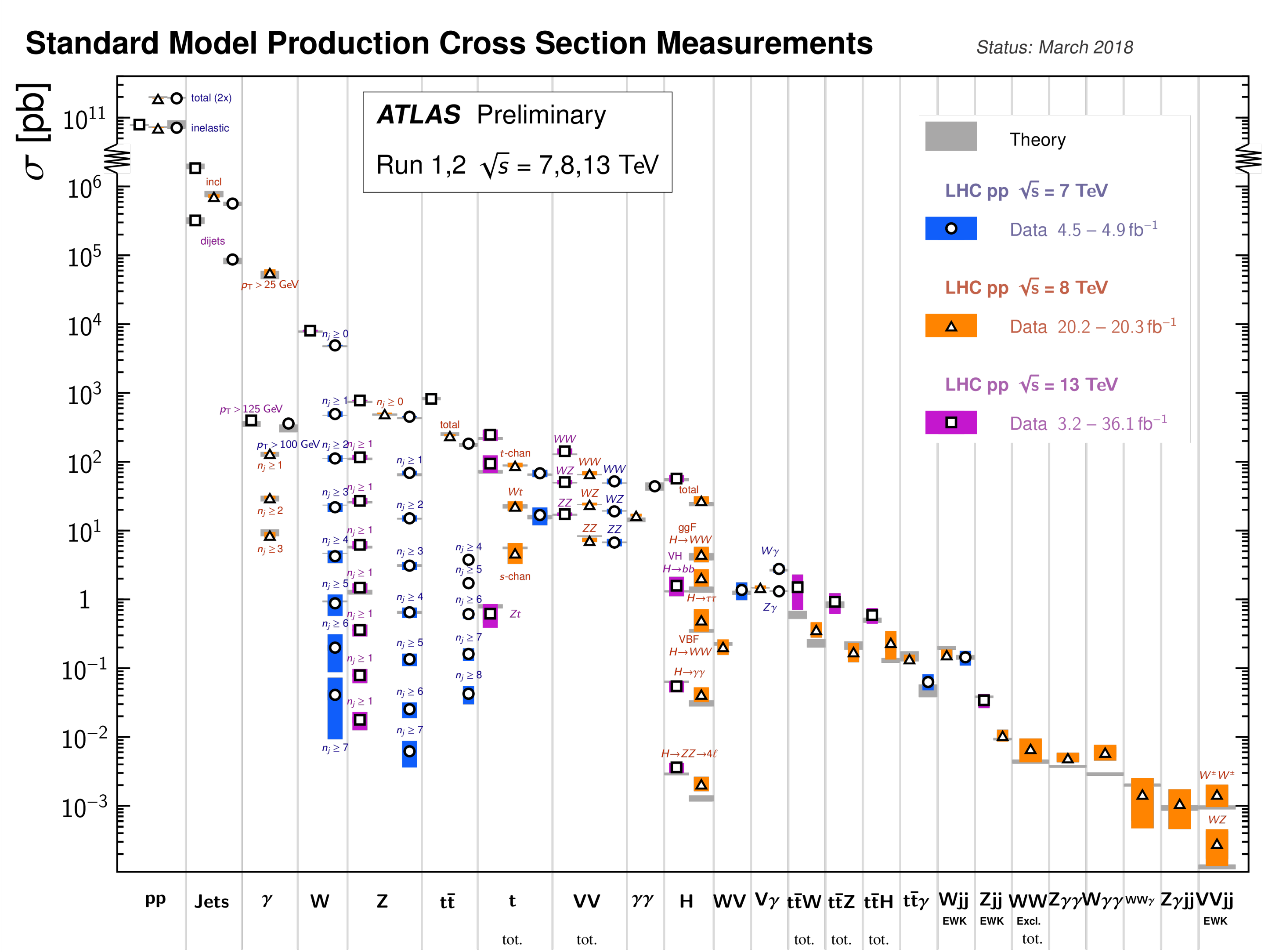
Higgs Pt Differential cross section



Standard Model Precision Measurements

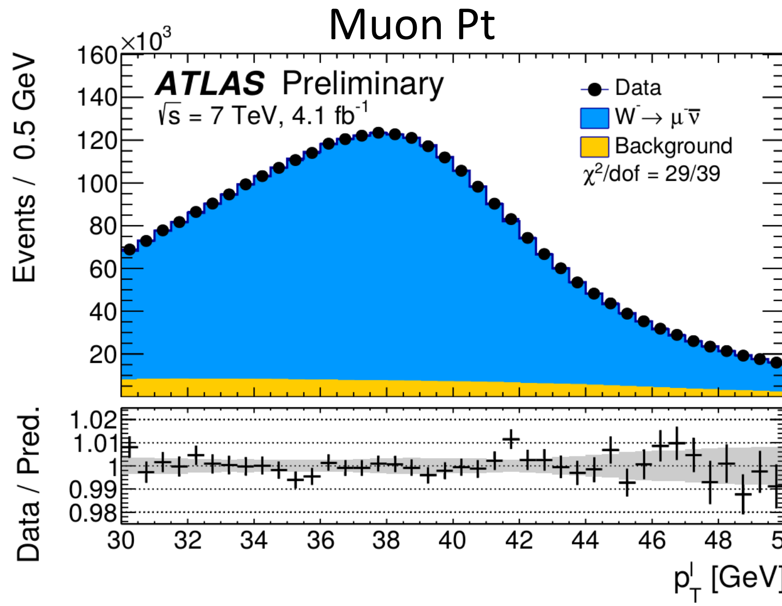
SM and QCD

- Impressive number of SM and QCD cross sections measured in very good agreement with expectations



Measurement of the W-boson mass

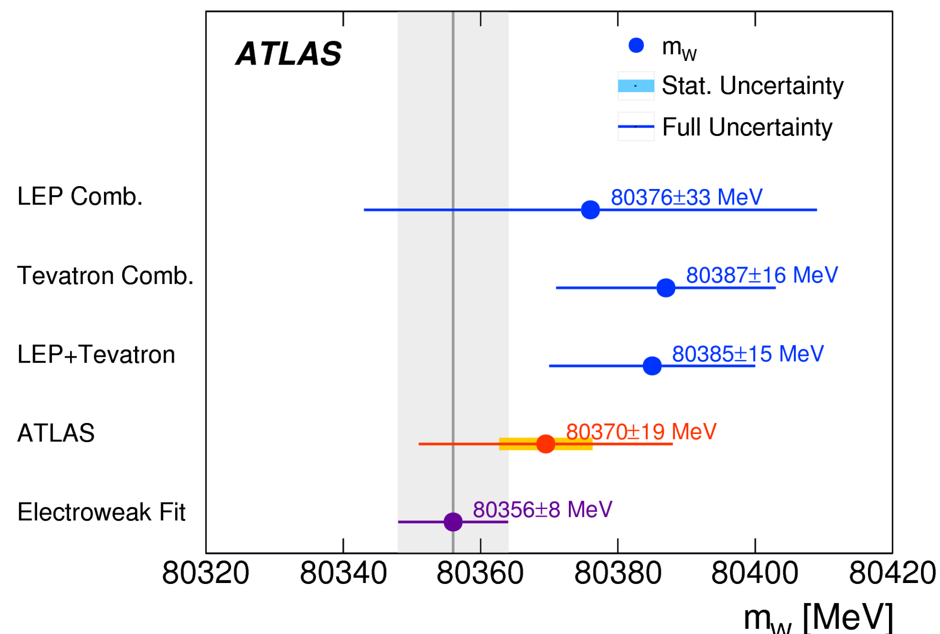
- Based on early data (2011) at $\sqrt{s}$ = 7 TeV (4.6 fb^{-1}) with low Pile-Up
- Huge amount of work to understand detector response and the modelling of kinematic quantities (Mt, P_t^l) (relies on large Z → ℓℓ sample)



Similar precision reached as for current best measurement from CDF

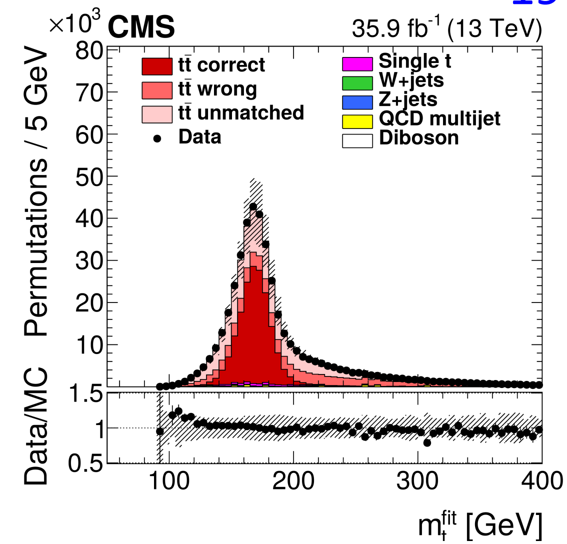
m_W = 80.370 ± 0.019 GeV

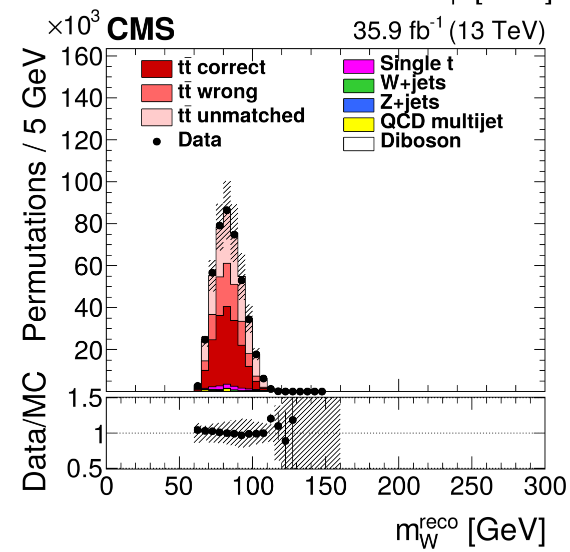
± 7 MeV statistical
± 11 MeV systematic
± 14 MeV modeling

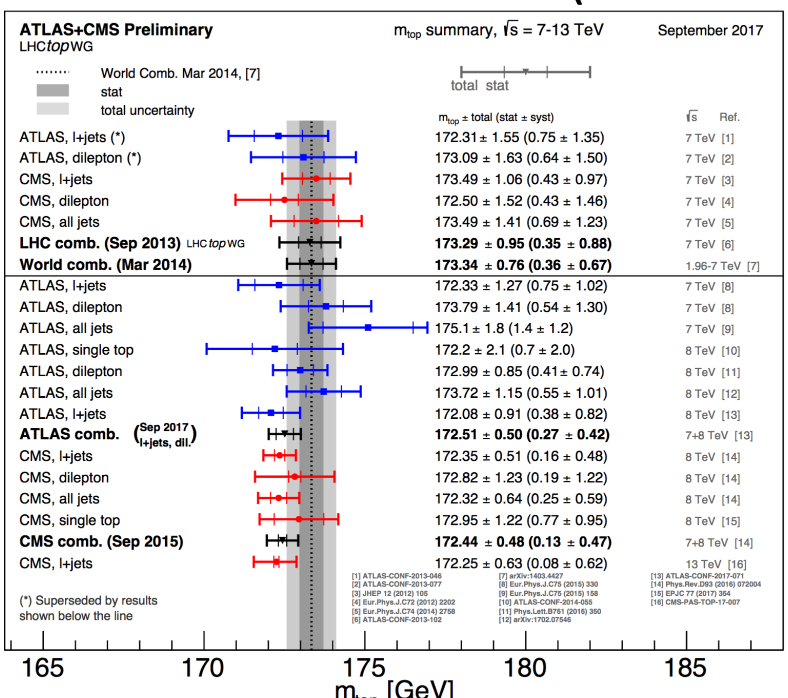


Measurement of the Top Mass

- Large Top production cross section
  - Many precision measurements on Top Properties
- Many differenet methods and final states used to extract Top Mass
  - Direct methods, (Templates, Ideograms)
  - Indirect method (based on measured Xsect.)





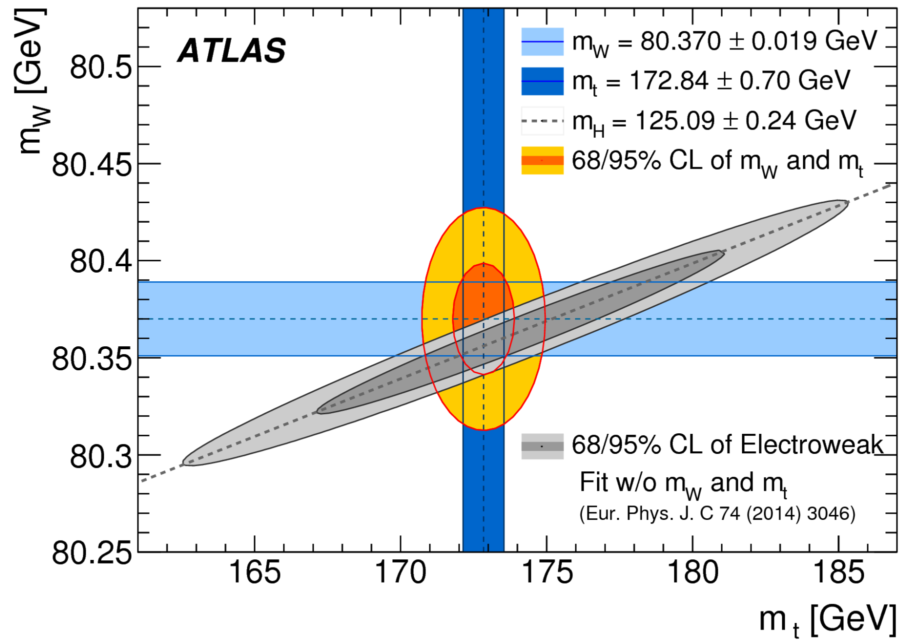


ATLAS Combination m_{top}=172.51+-0.5

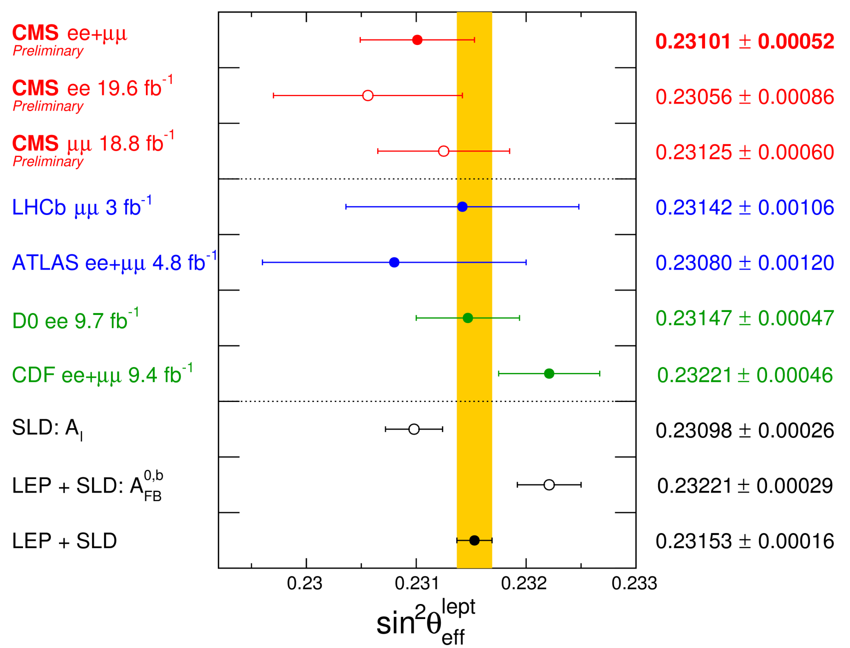
CMS Combination m_{top}=172.44+-0.48

Standard Model

- A precision measurement of m_{top} m_W and m_H allows a stringent test of the SM
  - Aim at improving further the precision on Mw with dedicated runs



- Precision measurement of $\sin^2\theta_w$ by A_{fb} consistent with previous measurements and with SM



BSM Searches

Exotics

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 37.0)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 8, 13 TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e, \mu$	$1-4$ j	Yes	36.1	M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	$\geq 1\ e, \mu$	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	$1\ e, \mu$	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e, \mu$	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	3.2	Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	36.1	W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	$0\ e, \mu$	2 J	–	36.7	V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	$1\ e, \mu$	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	$0\ e, \mu$	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η^-_{LL}		1703.09217
	CI $\ell\ell qq$	$2\ e, \mu$	–	–	36.1	Λ 40.1 TeV η^-_{LL}		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	$0\ e, \mu$	$1-4$ j	Yes	36.1	m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	$0\ e, \mu$, $1\ \gamma$	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	$0\ e, \mu$	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	$2\ e$	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	$2\ \mu$	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	$1\ e, \mu$	$\geq$1 b, $\geq$3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	$1\ e, \mu$	≥ 1 b, ≥ 3 j	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	$1\ e, \mu$	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	$1\ \gamma$	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	$3\ e, \mu$	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	$3\ e, \mu, \tau$	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	$2\ e, \mu$	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	$3\ e, \mu, \tau$	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	$1\ e, \mu$	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

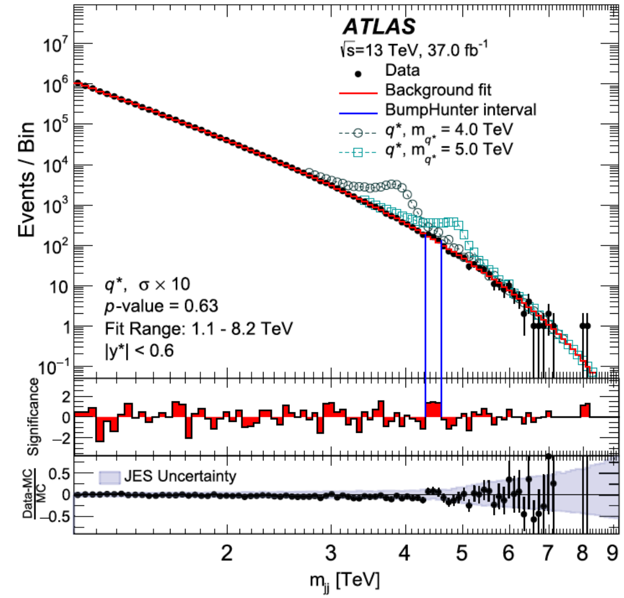
Mass scale [TeV]: 10^{-1}, 1, 10

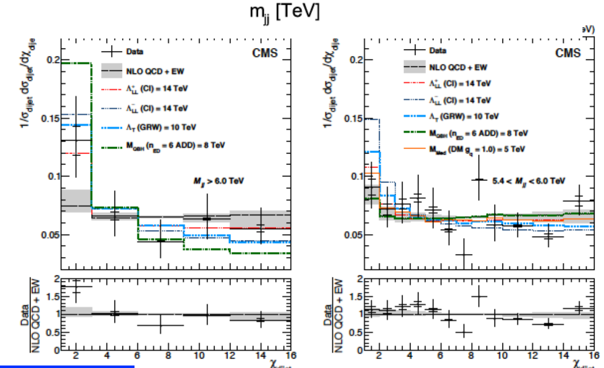
*Only a selection of the available mass limits on new states or phenomena is shown.

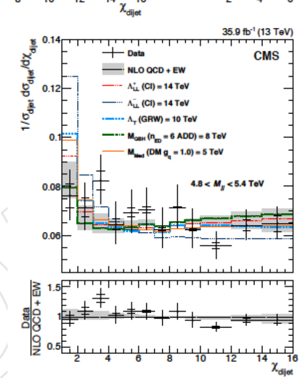
†Small-radius (large-radius) jets are denoted by the letter j (J).

Di-Jet Resonances, substructures

- Look for new resonances using high Pt di-Jet in the central region of the detector
- Background estimated by a sliding window fit
  - No significant excess observed
- Look for substructure using angular distribution of two jets
  - $\chi = e^{2|y^*_{12}|} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*}$
  - Look for rise at low χ, high m_{jj}





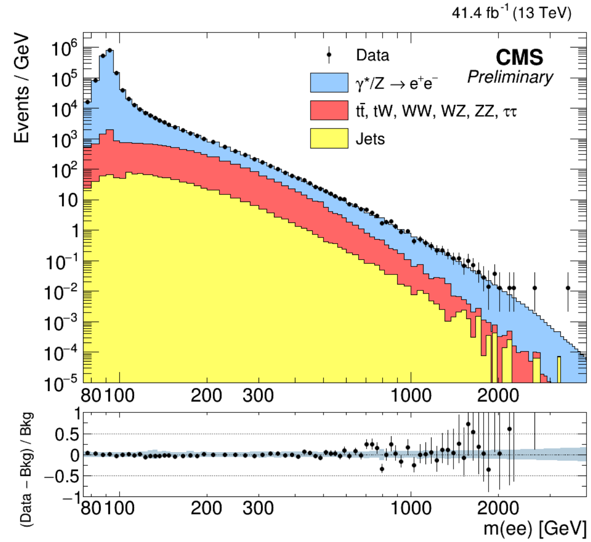


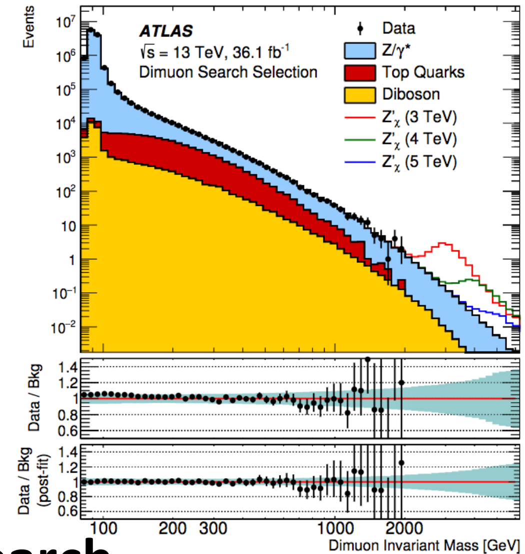
Limits on masses and couplings on many BSM scenarios

Quantum Black hole	8.9 TeV (8.9 TeV)	ATLAS
W'	3.6 TeV (3.7 TeV)	
Excited Quarks	6.0 TeV (5.8 TeV)	
Contact Inter. (Λ)	9.2-22.4 TeV	CMS

New Bosons

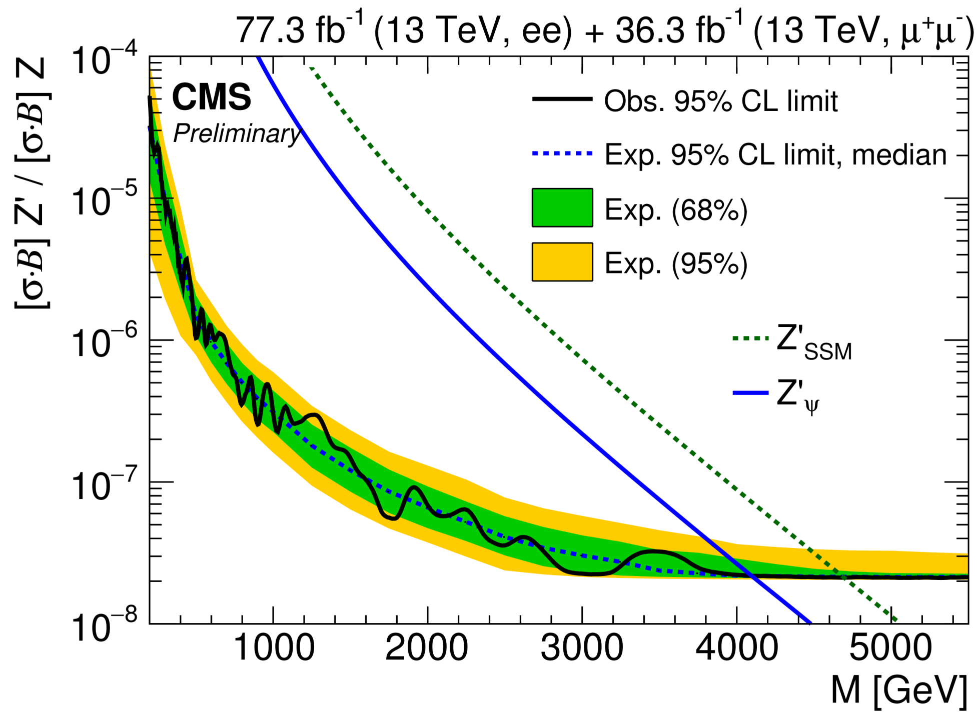
- Di-lepton (ee, μμ), (eν,μν) final states offer a very clean signature to searches of new Heavy Bosons eg Z', W'





Z' search

- No significant excess observed



- Results interpreted in many models e.g.:
  - M (Z'_{SSM}) > 4.7 TeV
  - M (Z'_ψ) > 4 TeV

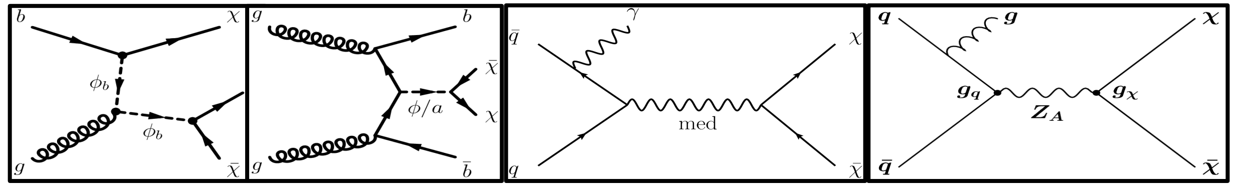
Dark Matter

- Searches in the Mono-X final states
  - One well reconstructed object with large Missing Energy due to WIMP
  - Many models constrained up to 1-2 TeV
- Searches also in the Di-Jet final states exclude up to 2.7 TeV for almost whole DM range

Mono b

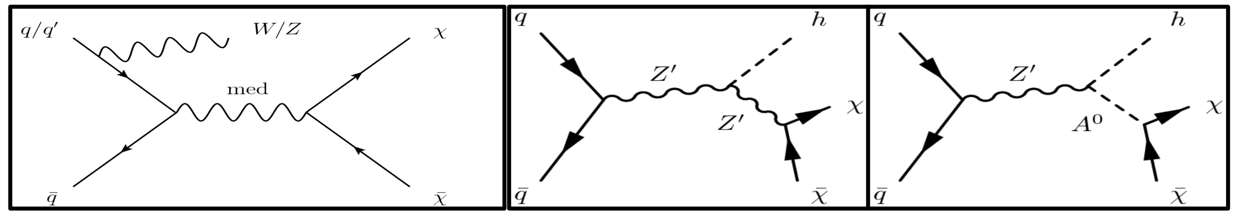
Mono γ

Mono Jet

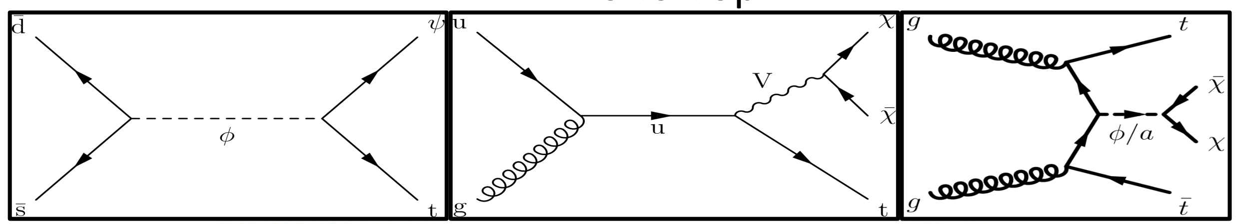


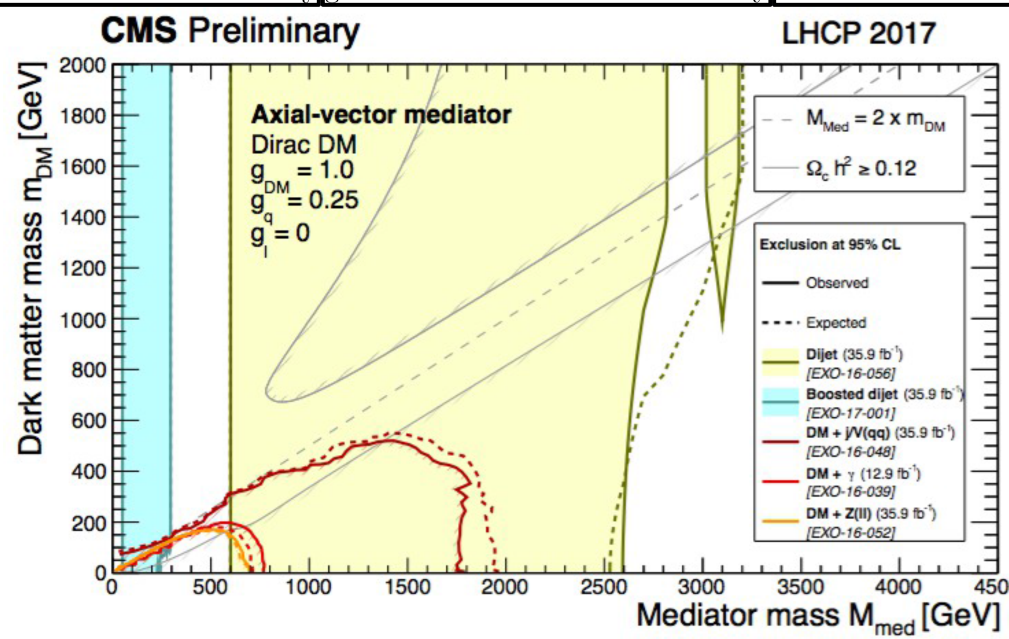
Mono V

Mono H

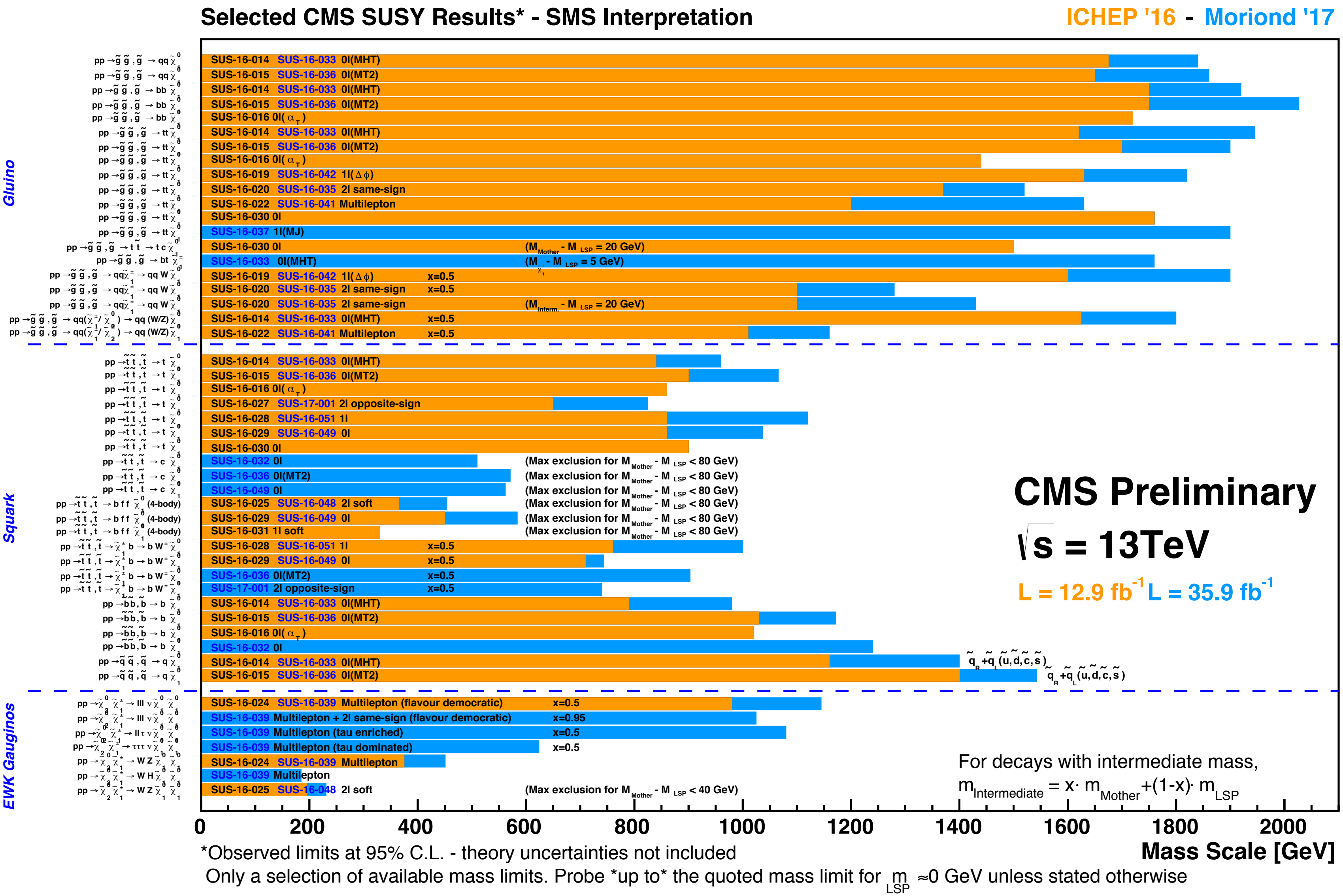


Mono Top





SUSY Searches

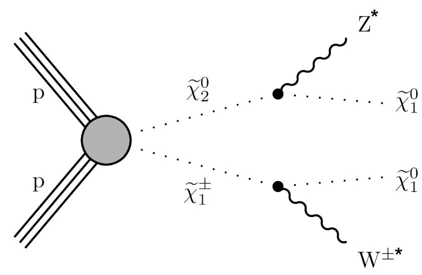


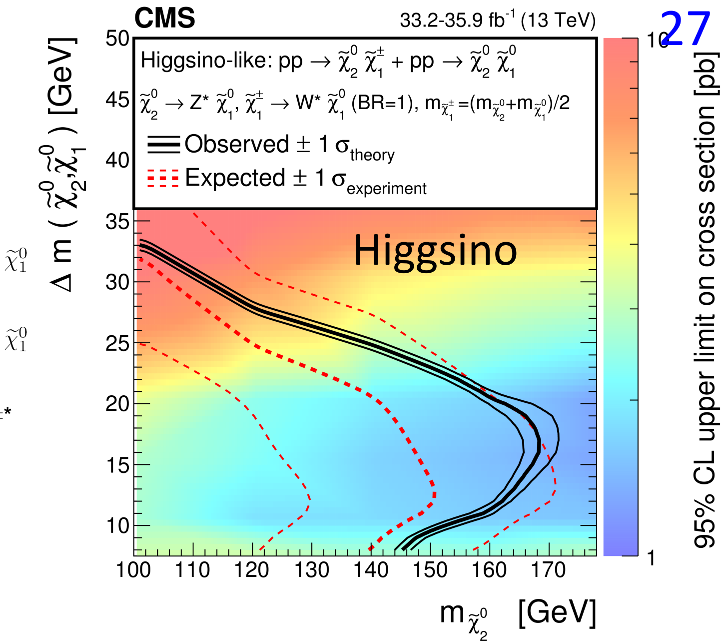
Strong Production (Gluino and Squark) well tested: Limits in TeV range

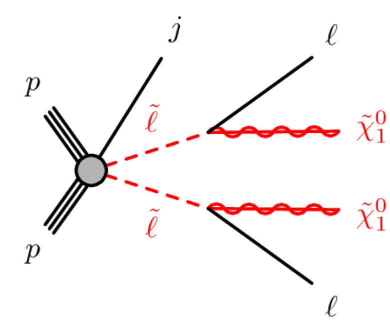
Moving to electroweak production and non-conventional signatures

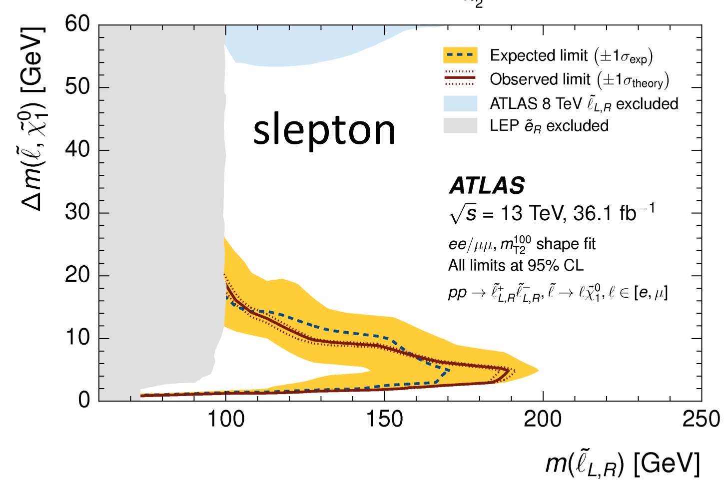
Electroweek SUSY

- Complex Electroweak signatures due to:
  - Complex mixing structure
  - Low Cross Sections
  - Degenerate spectra (compression)
- Use of very soft lepton in final states
  - Large backgrounds
  - Very good understading of detector response
- Use of unconventional signatures
  - Disappearing tracks

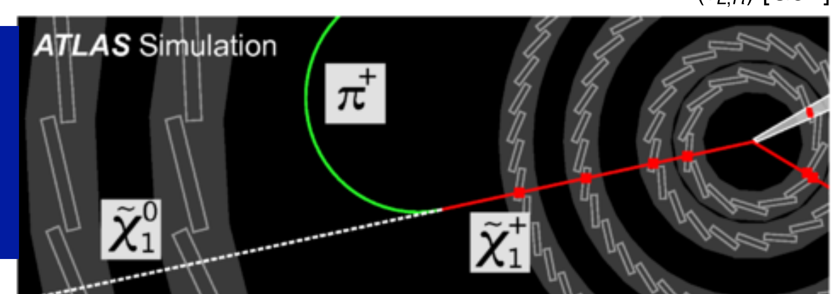








Exclusion of Higgsino masses up to 170 GeV
Exclusion of slepton masses up to 190 GeV
(extending the LEP limits)

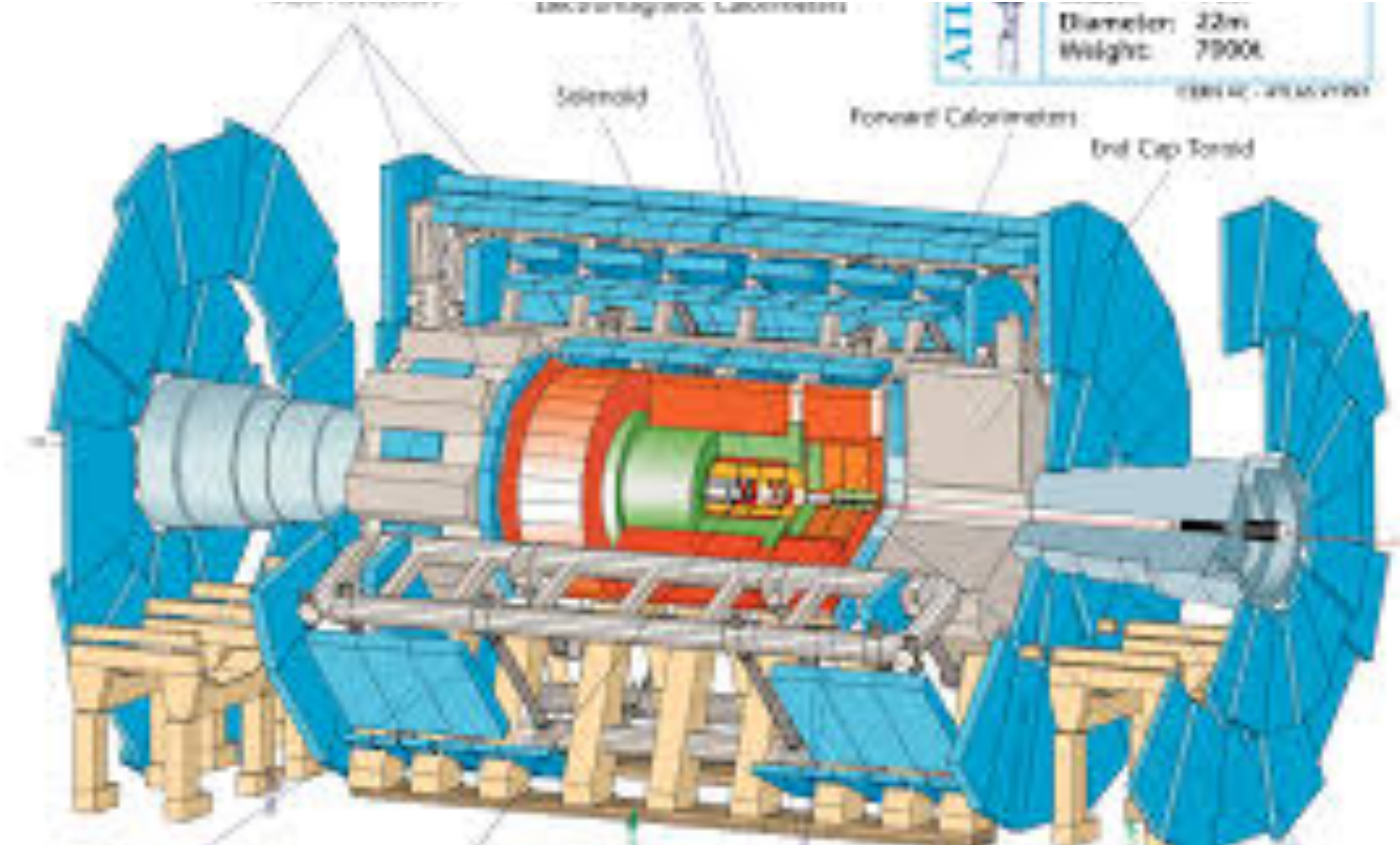


Conclusions

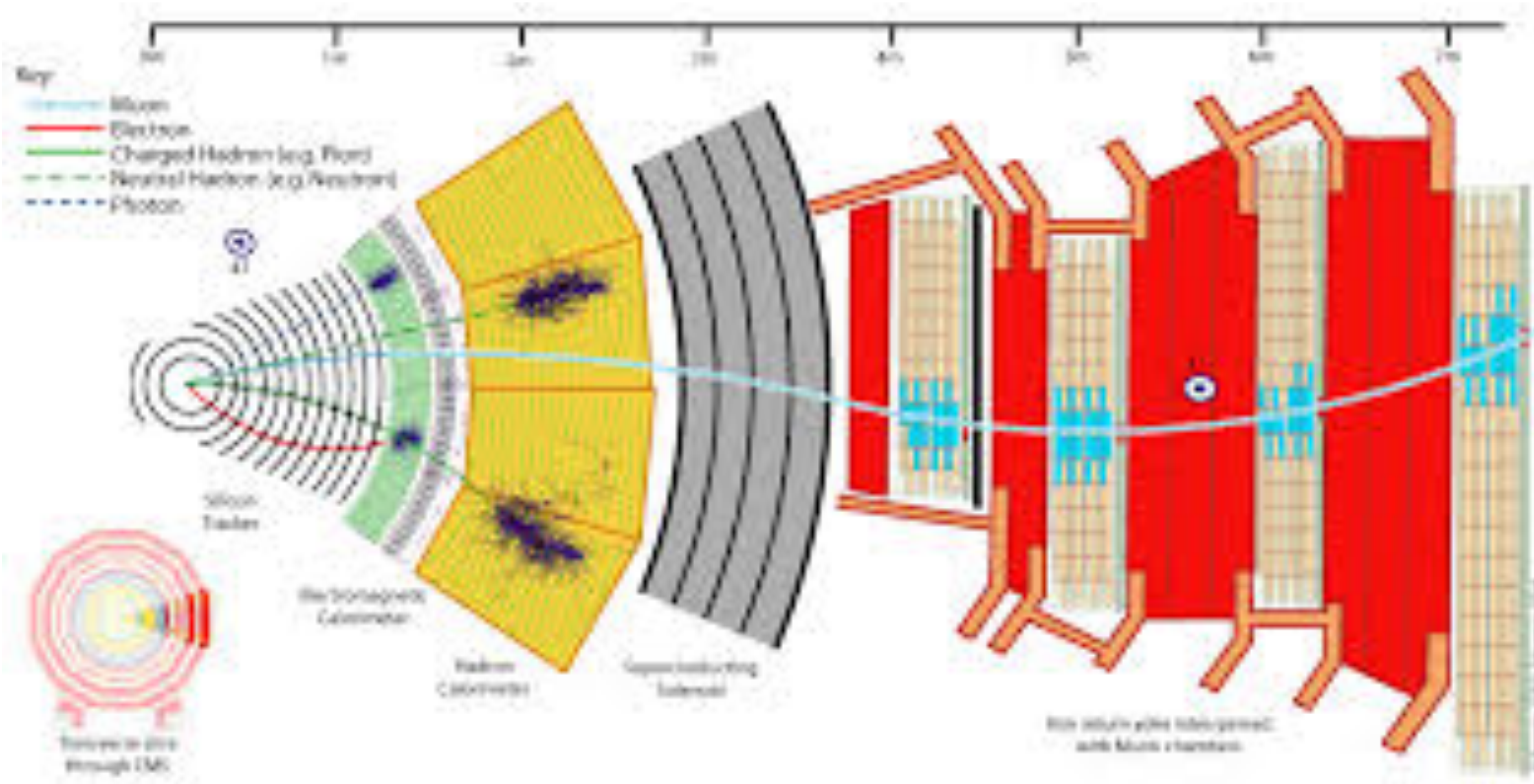
- Already ~ 100 fb^{-1} delivered by LHC
  - Only 3% of the full LHC program
- Precision measurements in the Higgs sector start to be feasable
  - No sign of tension with the SM in the Higgs sector
- Very high precision Standard Model measurement possible also at LHC (M_w, M_{top} +…)
- Exotics and SUSY searches are extending limits both towards high new particles masses and towards low masses in compressed scenarios

Back Up

The ATLAS Detector



The CMS Detector



The Higgs Sector: Coupling to Fermions

- muons

The Higgs Sector: Coupling to Fermions

- C and light quarks