Higgs Measurements in ATLAS

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Thursday

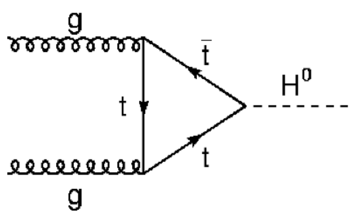
CoEPP Workshop 2017 Adelaide

from Run 1 to Run 2

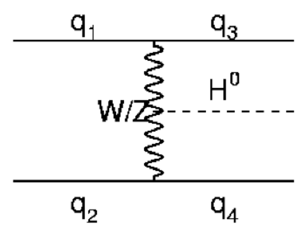
Higgs Production and Decay

production

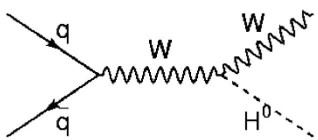
ggF



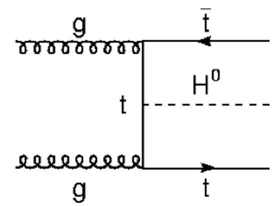
VBF



Wh(Zh)

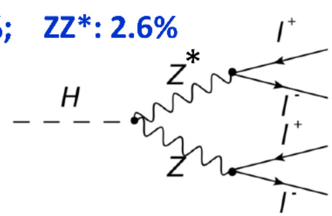


tth

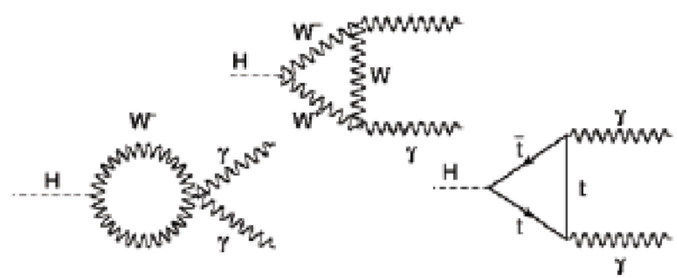


decay

- $b\bar{b}$: 58 % ; $\tau\tau$: 6.3%; $\mu\mu$: $2{\cdot}10^{-4}$
- WW^*: 22 %; ZZ^*: 2.6%

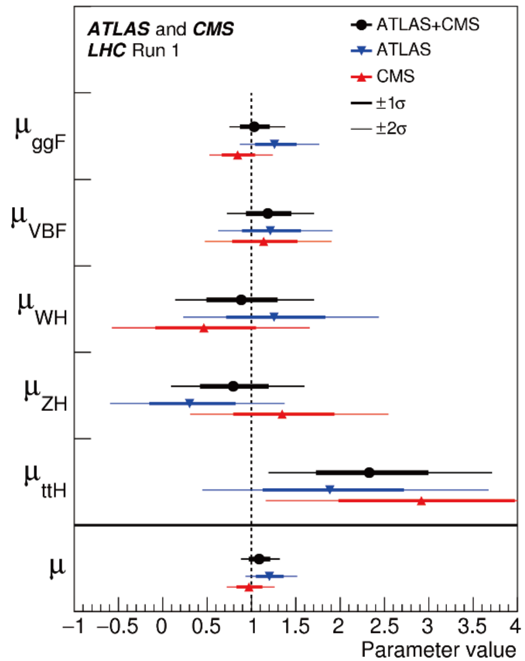


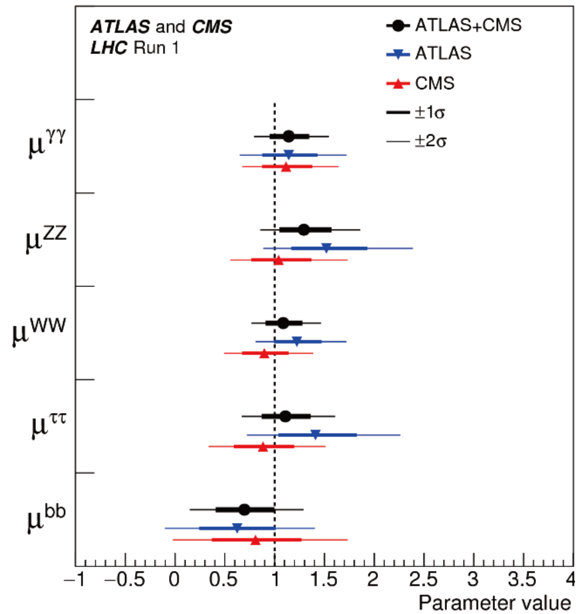
$\gamma\gamma$: $2.3{\cdot}10^{-3}$ $Z\gamma$: $1.5{\cdot}10^{-3}$



Run 1 Higgs Coupling ATLAS+CMS Combination

- **ATLAS+CMS combination**
  - combine all results on production modes and decays channels from both experiments
- **Extract the signal strengths μ:**
  - $$\mu_i = \frac{\sigma_i}{(\sigma_i)_{SM}}$$





JHEP08(2016)045

- global signal strength: $\mu = 1.09^{+0.11}_{-0.10} = 1.09^{+0.07}_{-0.07}\,(\text{stat})\,^{+0.04}_{-0.04}\,(\text{expt})\,^{+0.03}_{-0.03}\,(\text{thbgd})^{+0.07}_{-0.06}\,(\text{thsig})$
- VBF production: 5.4σ; ttH: 4.4σ (2.0σ expected)
- decay to ττ: 5.5σ; bb: 2.6σ.

Other Run 1 Higgs Results

- Mass and width
  - Mass measured at the 2 per mil level:

    ATLAS-CMS mass measurement $\gamma\gamma/ZZ$ *Phys. Rev. Lett. 114, 191803*

    m_H=125.09±0.21(stat.)±0.11(syst.) GeV
  - Indirect limits on its width of ~5 times the SM prediction

- Spin/CP
  - Spin-0, CP-even state strongly preferred

    ATLAS spin/CP measurements
    - $\gamma\gamma$/ZZ/WW: spin, CP *Eur. Phys. J. C 75 (2015) 476*
    - $\tau\tau$ *VBF CP analysis* *ArXiv 1602.04516*

- Kinematics

  differential distributions
  - combined $\gamma\gamma/ZZ$ *Phys. Rev. Lett. 115 (2015) 091801*
  - WW (dec 2015) *J. High Energy Phys. 08 (2016) 104*

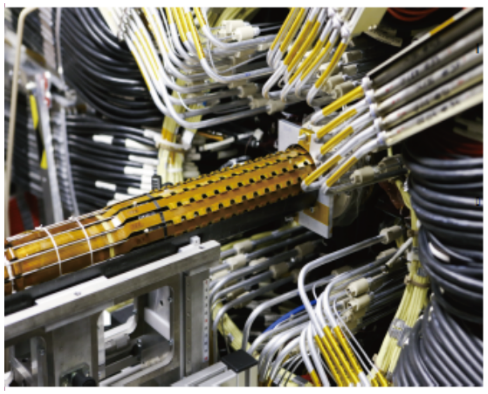
Key Performance in Run 2

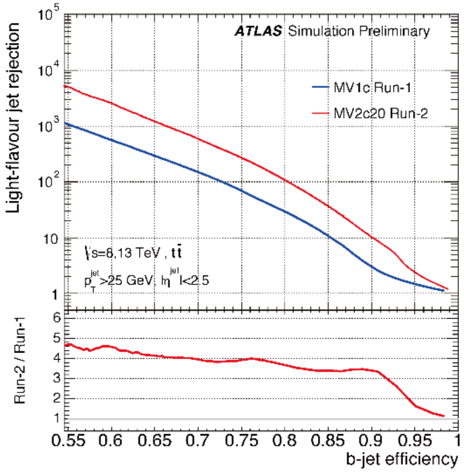
Inclusion of an additional layer (IBL) very close to the beam pipe (3.3 cm)

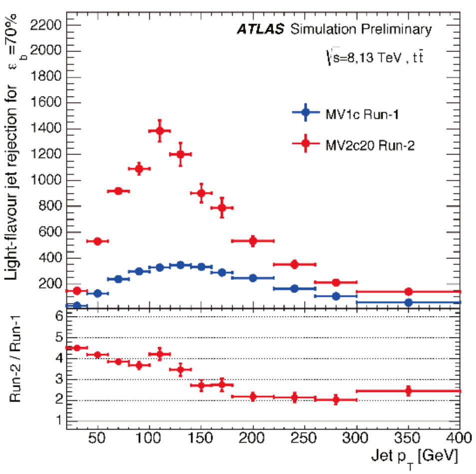
better track resolution and more robust pattern recognition

ATLAS-PHYS-PUB-2016-012

optimization campaign on tracking/b-tagging performance deployed for Run 2 data-taking







Very small uncertainty on the measurement of the physics objects

muon momentum scale to ~0.1%, electron energy scale to ~0.2%, jet energy scale to ~1%

ATLAS-PHYS-PUB-2016-015

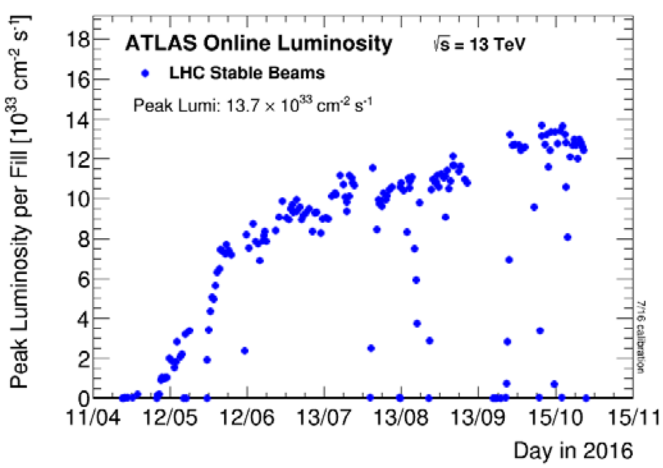
ATLAS-PHYS-PUB-2015-036

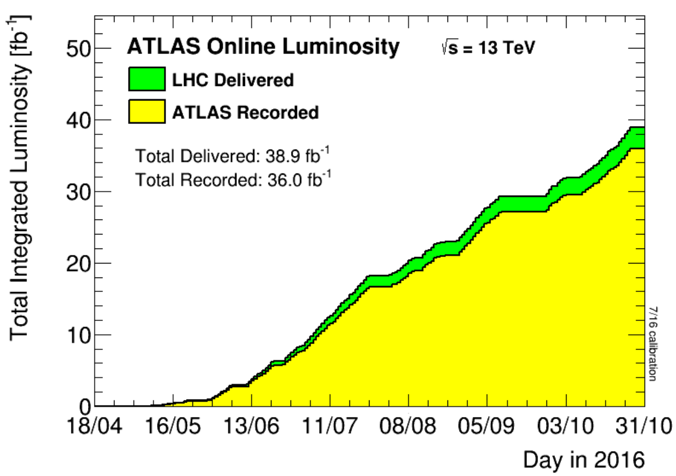
EPJC 2016 (2016) 76:292

Key Performance in Run 2

- Upgrades
  - Trigger: Level 1, 75 kHz -> 100 kHz
  - DAQ: event recording, 300 Hz -> 1 kHz
  - Improved algorithms in track reconstruction, MissingET, electron, photons, flavour tagging etc..

- Very good data quality (91% efficiency) and large pile up (>20)

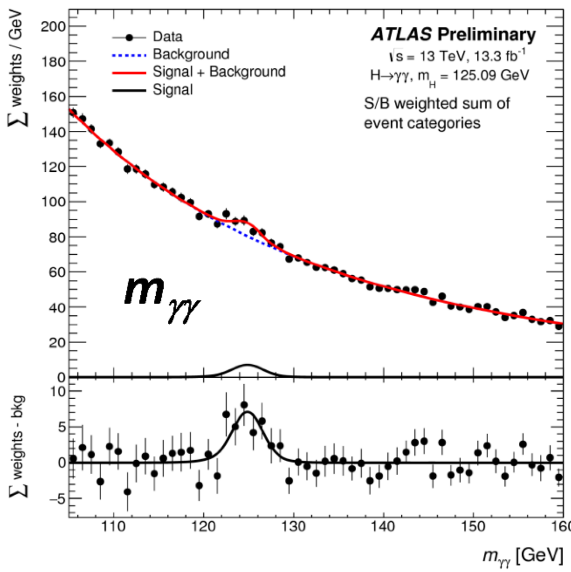




Bosonic Channels

H->γγ

- Low branching ratio but with relatively large signal yields
  - simple signature with two isolated photons
  - high photon reconstruction and identification efficiency
- Excellent mass resolution



- **Analysis similar to run-1**
  - **basic selection:**

  p_T (1) > 0.35 m(γγ), p_T(2) > 0.25 m(γγ)

- **Fiducial cross-sections in 3 fiducial regions:**
  - **Inclusive, VBF-enhanced, single-lepton**
- **Differential cross-sections in 6 variables:**
  - **p_T(γγ), y(γγ), cosθ*, N(jets), p_T(jet1), Δϕ(j1,j2)**
- **Cross-sections per production mode:**
  - **13 categories targeting different production modes and optimal S/B**
  - **simplified template cross-sections (STXS), total cross-sections, *and signal strengths***

H->γγ Signal Strengths

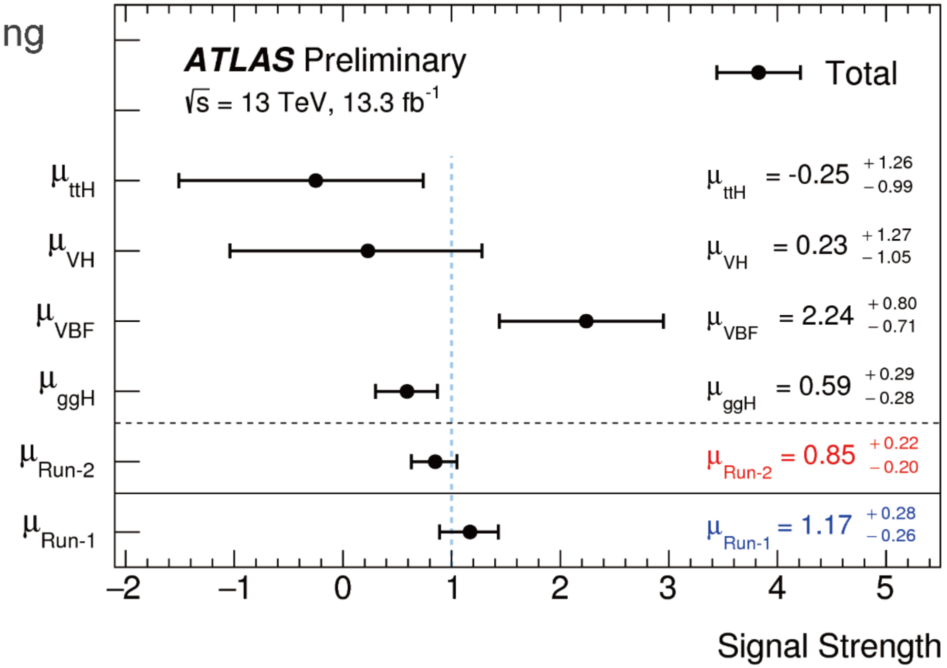
- Categories enriched in a given production mode:
  - ttH: jets, b-jets and leptons
  - VH: leptons and/or missing transverse energy, jets (V hadronic decays)
  - VBF: two well separated jets
  - ggF: untagged events

ATLAS-CONF-201-067

- Check consistency with SM by measuring the signal strengths μ:

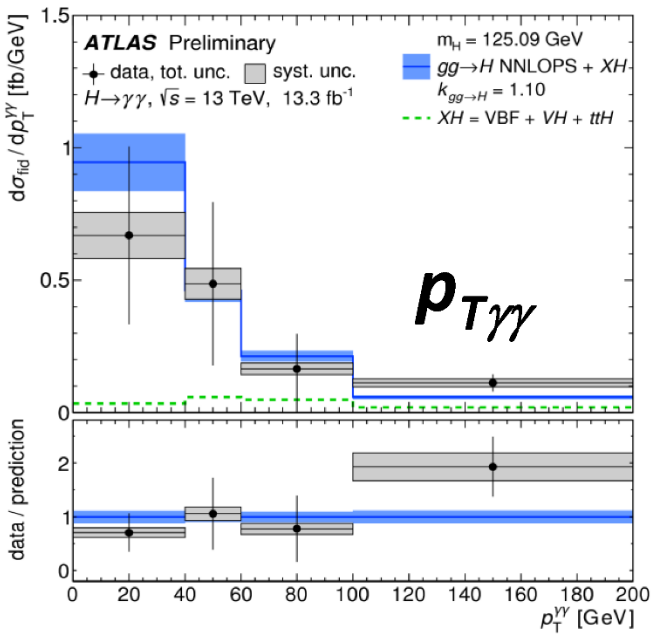
$$\mu_i = \frac{\sigma_i}{(\sigma_i)_{SM}}$$

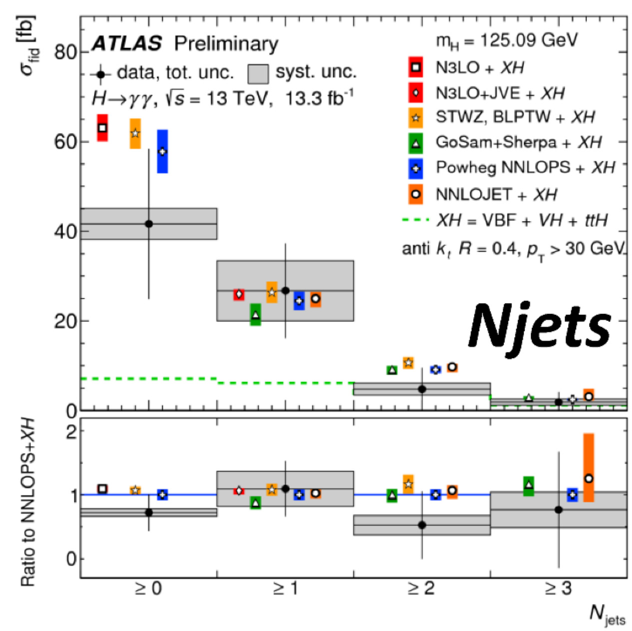
- all results compatible with SM
- accuracy already better than run1



H->γγ Fiducial and Differential Cross Section Measurements

Fiducial region	Measured cross section (fb)	SM prediction (fb)
Baseline	$43.2 \pm 14.9\,(\text{stat.}) \pm 4.9\,(\text{syst.})$	$62.8\,^{+3.4}_{-4.4}$ [N^{3}LO + XH]
VBF-enhanced	$4.0 \pm 1.4\,(\text{stat.}) \pm 0.7\,(\text{syst.})$	2.04 ± 0.13 [NNLOPS + XH]
single lepton	$1.5 \pm 0.8\,(\text{stat.}) \pm 0.2\,(\text{syst.})$	0.56 ± 0.03 [NNLOPS + XH]

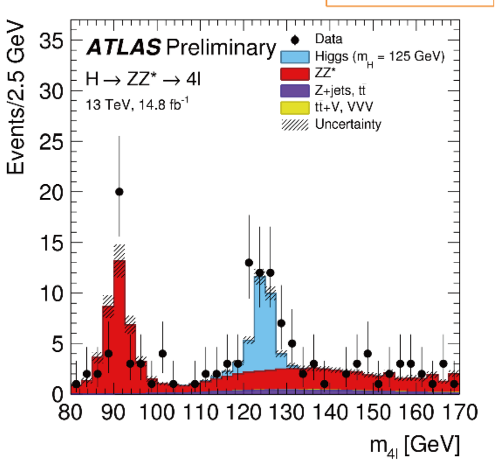




H->ZZ*->4l

- Analysis:
  - select two pairs of isolated electrons/muons - 4e, 4μ, 2e2μ, 2μ2e
    - IBL helps reducing conversions and heavy flavour contamination
  - require one on-shell Z
- Background dominated by ZZ continuum, Z+X, ttbar
  - BDT MVA to distinguish the signal from the irreducible SM ZZ background
  - reducible background like Z+jets, tt are estimated using data driven techniques

ATLAS-CONF-2016-079



measured

$$\sigma_{ggF+b\bar{b}H+t\bar{t}H} \cdot \mathcal{B}(H \to ZZ^*) = 1.80^{+0.49}_{-0.44}\ \text{pb}$$

$$\sigma_{VBF} \cdot \mathcal{B}(H \to ZZ^*) = 0.37^{+0.28}_{-0.21}\ \text{pb}$$

$$\sigma_{VH} \cdot \mathcal{B}(H \to ZZ^*) = 0^{+0.15}\ \text{pb}$$

predicted

$$\sigma_{SM,ggF+b\bar{b}H+t\bar{t}H} \cdot \mathcal{B}(H \to ZZ^*) = 1.31 \pm 0.07\ \text{pb}$$

$$\sigma_{SM,VBF} \cdot \mathcal{B}(H \to ZZ^*) = 0.100 \pm 0.003\ \text{pb}$$

$$\sigma_{SM,VH} \cdot \mathcal{B}(H \to ZZ^*) = 0.059 \pm 0.002\ \text{pb}$$

Compatibility: ggF+bbH+ttH: 1.1 σ, VBF: 1.4 σ

H->γγ and H->ZZ*->4l Combination

- **Total cross-section extrapolated from fiducial cross section**
  - inclusive gg and 4 leptons samples
  - assume SM branching ratios and acceptances
  - compare to theory prediction at N3LO

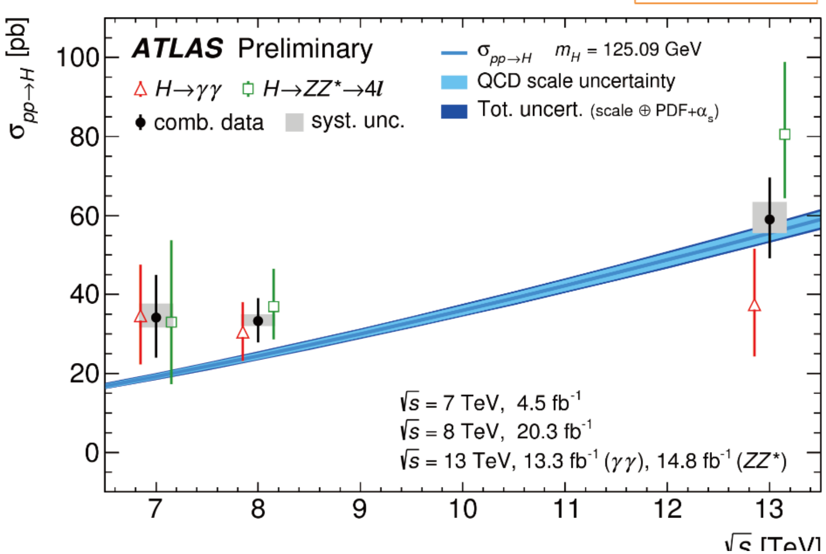
Measurement at 13TeV:

$$59.0^{+9.7}_{-9.2}\ (\text{stat.})\ ^{+4.4}_{-3.5}\ (\text{syst.})\ \text{pb}$$

SM prediction:

$$55.5^{+2.4}_{-3.4}\ \text{pb}$$

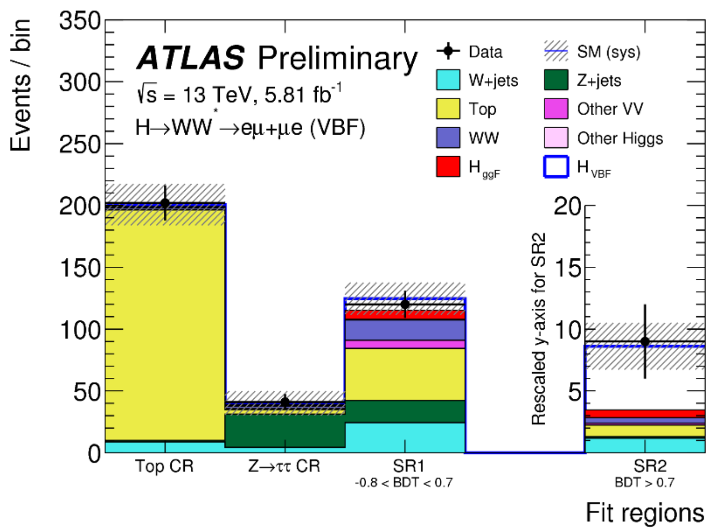
ATLAS-CONF-2016-081

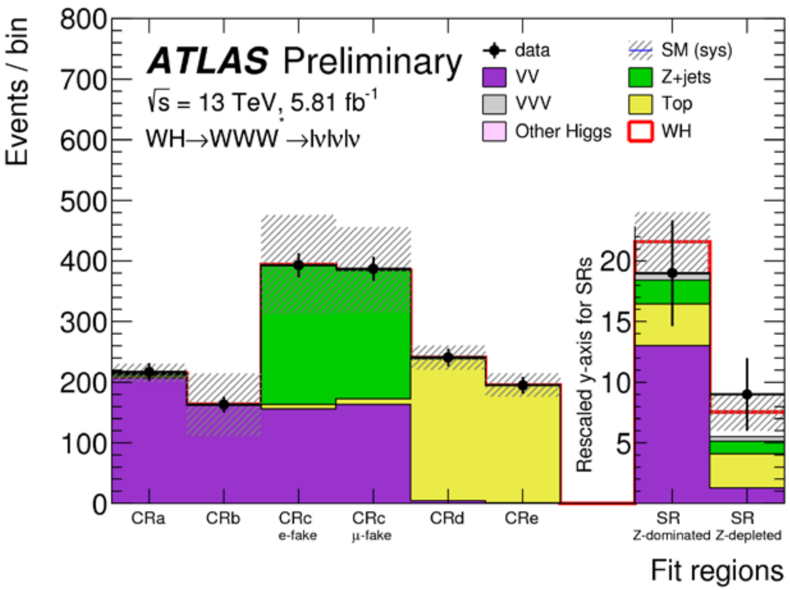


- Uncertainties dominated by statistics and a clear re-discovery of Higgs in Run 2

H → WW

- ATLAS-CONF-2016-112, 5.8 fb-1 13TeV data
- VBF and WH production channel
  - measured μ_VBF = 1.7 +1.1 -0.9, μ_WH = 3.2 +4.4 – 4.2





Fermionic Channels

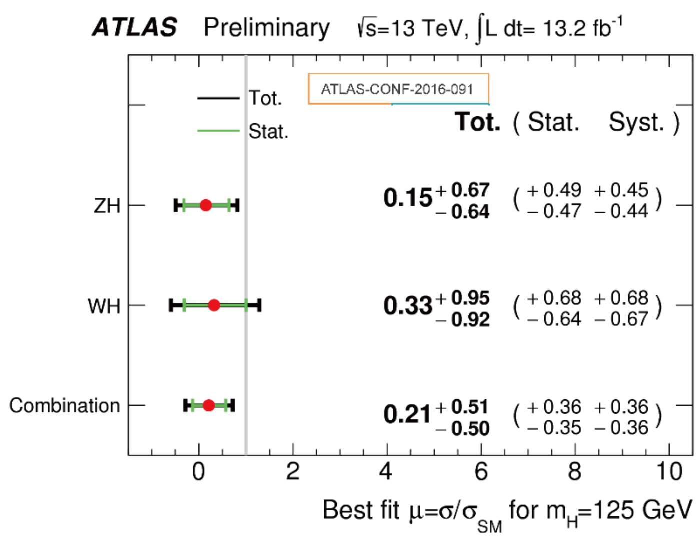
H->bb

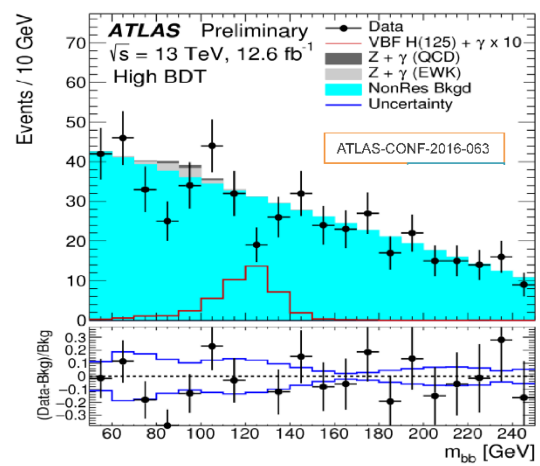
- Most significant channels for bb analysis: VH, ttH
  - impossible in ggF, very hard in VBF
  - run 1 result inconclusive VH(bb) : $\mu = 0.5 \pm 0.4$ with 2.6 σ significance

- Run 2 VH analysis similar to run-1
  - 0-lepton *(vvbb),* ETmiss>150 GeV, “anti-QCD” cuts
  - 1-lepton *(lvbb),* 1 tight e/mu, ETmiss>30 GeV, pT(V) > 150 GeV
  - 2-leptons (*llbb),* 2 loose e/mu, pT(V) >150 GeV
  - 2 b-jets
  - categories with 2, 3 (or ≥ 3) jets, with BDT discriminants explored in each signal region to enhance the sensitivity
- Main backgrounds:
  - Zbb, top, W+jets, multijets

H->bb

- Alternative: VBF H->bb + high-pT γ
  - signature: 2 b-jets + 2 VBF jets + 1 central γ
  - efficient triggering using the high pT photon
  - gg-induced background suppressed
  - destructive interference between ISR and FSR quark induced backgrounds
- fit m(bb) distribution to get limits on μ<4.0 (expected 6.0 +2.3 -1.7)



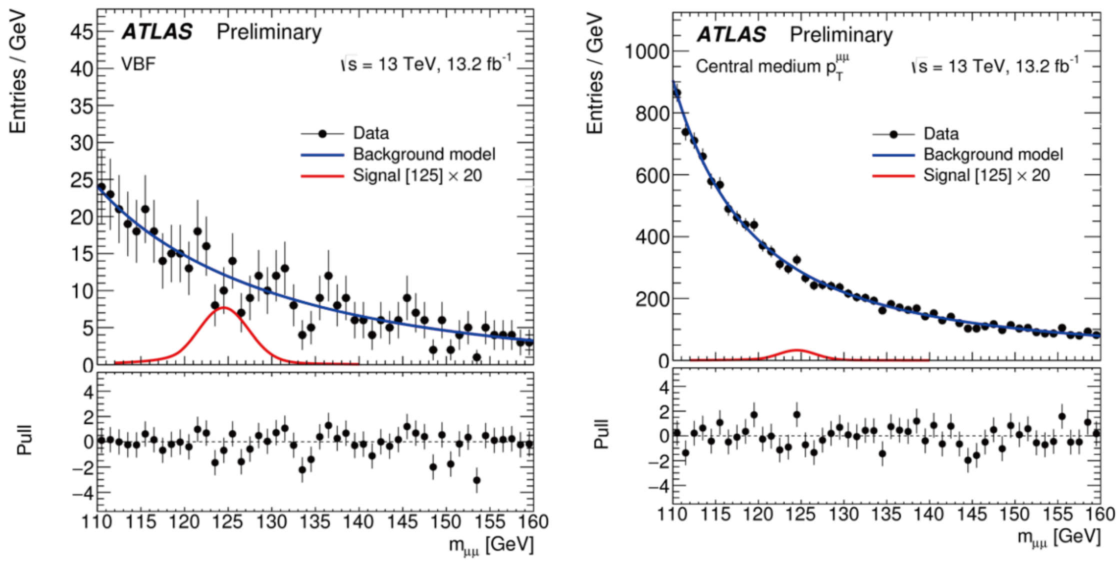


no discovery yet..

H->μμ

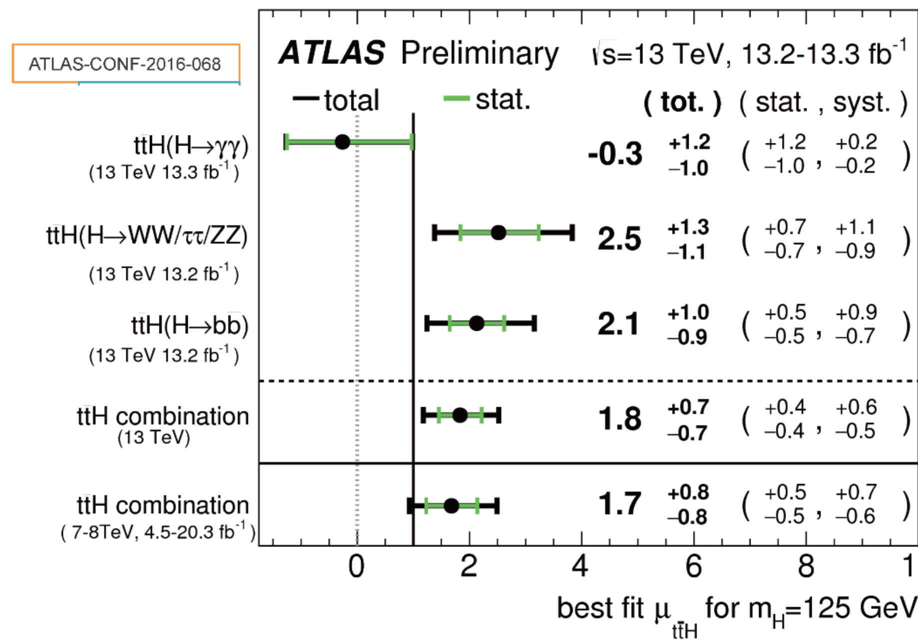
- Clean final state signature, difficult analysis due to the very small branching ratio in μμ
  - opposite sign di-muon events (pT > 25,15 GeV) selected + MET requirement
  - 7 analysis categories on pT (μμ) and VBF-sensitive jet signatures

- Measured signal strength μ=-2.3±2.7
  - expected (observed) limits on μ are 4.4 (5.5) times SM
  - combined (Run1+Run2) observed (expected) limit on μ=3.5 (4.3) times SM
  - ATLAS-CONF-2016-041



ttH

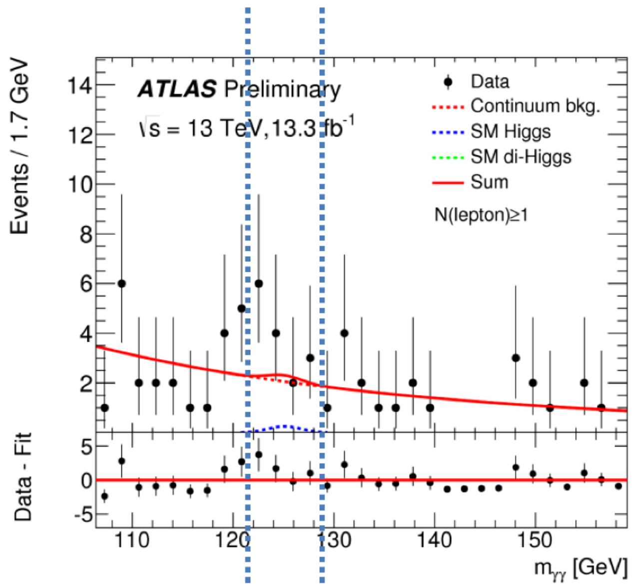
- ttH: direct measurement of Higgs-top Yukawa coupling
- Run-1: relatively large signal strength measured by ATLAS and CMS
- Run 2: tth cross-section increased by ~ 3.8 from 8 to 13 TeV (but also the main backgrounds)
  - ttH, H->multilepton analysis in ZZ*,WW* and ττ: ATLAS-CONF-2016-058
  - ttH, H->bb analysis with 1 or 2 leptons + jets: ATLAS-CONF-2016-080
  - ttH, H->γγ analysis with ttH-enriched categories: ATLAS-CONF-2016-067
- Run 2 combined results
  - Observed (exp) significance: 2.8σ (1.8σ)
  - better sensitivity than run 1: 1.5σ exp
  - μ is still large but results agree with SM predictions



BSM Searches

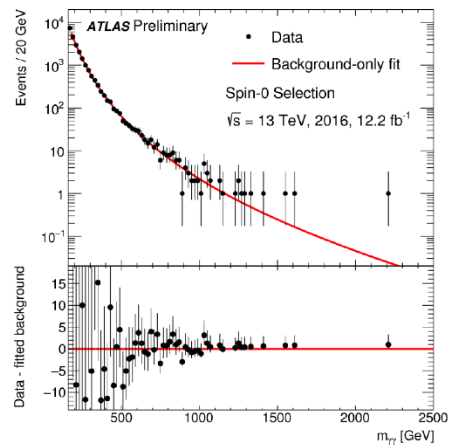
Di-Higgs

- hh production
  - small in the SM (h3, h4 couplings)
  - resonant or non-resonant enhanced in BSM models
- Run 1 : bbbb, bbττ, bbγγ (small excess at 300GeV), WWγγ
- Run 2 results:
  - bbγγ with 3.2 fb-1 (no excess) ATLAS-CONF-2016-004
  - bbbb (13.3 fb-1) improved limits ATLAS-CONF-2016-049
  - WWγγ (lν qq) ATLAS-CONF-2016-071
    - signal: one-lepton; control: 0-lepton, m(γγ) in [105,160]
    - fit smooth background
    - number counting in signal m(γγ) in mh ± 2*1.7 GeV
  - resonant and non-resonant limits: slight excess (15 evts obs for 7.88 ±1.24 expected)

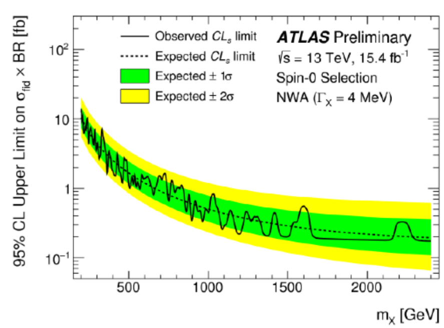


High Mass γγ

- result with 2015 data published J. High Energy Phys. 09 (2016) 001
  - broad excess at 750 GeV in spin-0 and spin-2 analyses
  - maximum for M=750 GeV, with local significance 3.9/3.8σ, global 2.1 σ



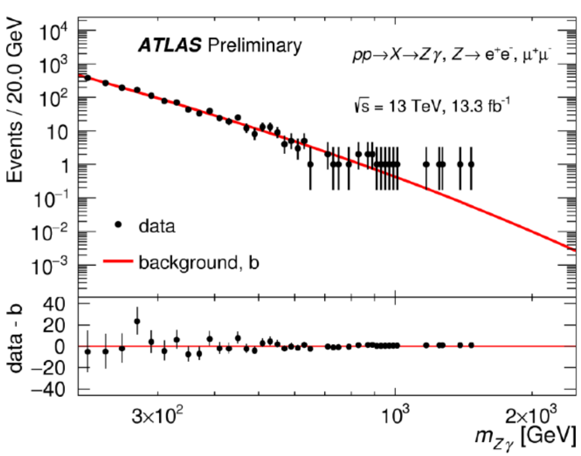
- 2015 (reprocessed) + 2016 = 15.4 fb-1 ATLAS-CONF-2016-059
  - improved photon reconstruction and calibration
  - similar spin-0 analysis
- Results:
  - narrow width largest excess at 1.6 TeV: 2.4 σ local
  - variable width 10%: M=710GeV with 2.3 σ local

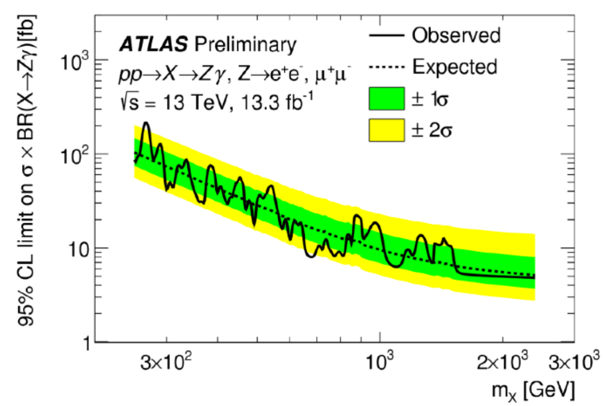


High Mass Zγ

- 2015 data: Z(ll)γ and Z(qq)γ winter confs
  - submitted to PLB with combination arXiv:1607.06363

- 2016 data: update Z(ll)γ , 13.3 fb-1, ATLAS-CONF-2016-044
  - similar to γγ scalar selection
  - background function fit, spurious signal…
  - no significant excess





Other Rare Decay and BSM Searches

- Higgs to φγ , Physics Review Letter 117, 111802
- H/A->ttbar (8 TeV result): ATLAS-CONF-2016-073
- H/A->ττ: ATLAS-CONF-2016-085
- Charged Higgs to tb and to τν: ATLAS-CONF-2016-088, ATLAS-CONF-2016-089
- h(γγ) + missing ET ATLAS-CONF-2016-087
- H(ZZ), 4 leptons and llvv ATLAS-CONF-2016-079
- H(WW) eνμν ATLAS-CONF-2016-074
- H(V , V) llqq, lvqq, vvqq ATLAS-CONF-2016-082 ATLAS-CONF-2016-062 ATLAS-CONF-2016-083

Conclusion

Conclusion and Outlook

- Run 2: 13 TeV , many results with > 13 fb-1
  - SM h(125) clearly rediscovered
  - several searches already surpassed run-1 sensitivity
  - **leading/significant contributions from CoEPP researchers in channels of γγ, Zγ, ττ, WW, high mass and BSM searches …)**

- For 2017, expect 45 fb-1 data with pileup up to 50, 13TeV
- Full Run 2 >120 fb-1 at 13 TeV
- We expect ~30 papers by Winter/Spring 2017
  - ~3-6 SM
  - ~22-24 Searches
- next round of most search papers based on full Run2