



Scientific highlights from ATLAS – LHC Run 2



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Two orbits of the earth ago...

- **CP** established
- m(H) at 2-per-mille
 ATLAS+CMS combination
- Decays:
 - $H \rightarrow ZZ$
 - $-H \rightarrow WW$
 - $\ H \rightarrow \gamma \gamma$
 - H \rightarrow tt (4.5 σ)
 - BR (H→ inv) < 0.28
- Production:
 - gg → H - VV → H (4.3σ)



Open questions from Scalars 2015

- H(125) questions
 Precision on all measurements?
 - ttH production?
 - H+V production?
 - Decays to **fermions**?
 - Self couplings HHH?

- Additional H bosons?
- Dark Matter Scalars?
- Supersymmetric scalars?
- Non-Higgs scalars?

What's new? 2017 - recorded 60 Delivered Luminosity [fb⁻¹] ATLAS Online Luminosity √s = 7 TeV 2011 pp 50 2012 pp √s = 8 TeV 2015 pp √s = 13 TeV √s = 13 TeV 2016 pp 40 2017 pp √s = 13 TeV 2016 results 30 20 Scalars 2015 - 8 TeV 10 alibration 2015 JUI A_br Oct Jan Month in Year

13 TeV x-section – predicted & measured



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What do these data look like?



"Only" 25 pileup vertices reconstructed here

They all come at once...



Mean Number of Interactions per Crossing

Controlling the rates...







http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/FTAG-2017-005/

Z = - 4 Fre Friv + ご ダダ + h.c. + 4: Yii 4:0+ h.c. + $D_{\mu}\phi l^2 - V(\phi)$

Higgs boson mass

= - 4 Fre Friv + i # # 4 + h.c. + Yi Yij Yig+ h. c. + $D_{\mu}\phi l^2 - V(\phi)$ $V(H^{\dagger}H) = \mu^2 H^{\dagger}H + \eta (H^{\dagger}H)^2$

m(H): it's all about precision



Per-mille agreement between MC and data on masses

1603.05598

Pushing down precision on the mass



Different measurements in good agreement

ATLAS-CONF-2017-046

Summary of m_H to date



H->ZZ* stats limited... room for improvement

ATLAS-CONF-2017-046

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Z = - 4 Fre FMV + i # # 4 + h.c. + Yi Yii Yig+ h.c. + $D_{\mu}\phi l^{2} - V(\phi)$

With increasing stats...



Differential $H \rightarrow 4I$



Z = - 4 Fre FMV titte +h.c. + Ψi Yij Yi\$+ h.c. + $D_{\mu}\phi l^2 - V(\phi)$





ttH [$H \rightarrow WW^*$, $\tau\tau$, ZZ*]



Various decay modes contribute to different Signal Regions

ATLAS-CONF-2017-077

ttH [H \rightarrow WW*, $\tau\tau$, ZZ*]





Boosted Decision Tree selects signal-like events

Multi-lepton final states

ATLAS-CONF-2017-077

ttH [H->bb]





ATLAS-CONF-2017-076



VH production $[H \rightarrow bb]$

$ZH \rightarrow vvbb\overline{}$, $WH \rightarrow lvbb\overline{}$ and $ZH \rightarrow llbb\overline{}$



VH distribution in m_{bb}



After subtraction of all backgrounds except for the WZ and ZZ diboson processes

See also: arXiv:1707.06958 for hadronic final state

VH [$H \rightarrow$ bb] production



VH, H \rightarrow cc



 σ (VH) x B (H -> cc) < **2.7 pb** observed (3.9 pb expected)

[SM:25.5 fb – about two orders of magnitude larger]

Barr Scalars 2017

ATLAS-CONF-2017-078

1708.00212

Other "tough" modes

1705.04582





https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

SUSY-2016-18

g



Something heavy?



See also

arXiv:1710.07235

Fat-jet pair invariant mass





Doubly charged Higgs



Higgs triplet with low vev

- \rightarrow decays to leptons
- \rightarrow does not prefer heavy flavour

 σ x B <~ 0.1 fb

$$\begin{aligned} \mathcal{L} &= -\frac{1}{4} \mathcal{F}_{\mu\nu} \mathcal{F}^{\mu\nu} \mathcal{V} \\ &+ i \mathcal{\Psi} \mathcal{\Psi} \mathcal{\Psi} + h.c. \\ &+ \mathcal{\Psi}_i \mathcal{Y}_{ij} \mathcal{\Psi}_j \mathcal{\Psi} + h.c. \\ &+ \mathcal{\Psi}_i \mathcal{H}_i \mathcal{\Psi}_i \mathcal{\Psi}_i \mathcal{\Psi} + h.c. \\ &+ \mathcal{\Psi}_i \mathcal{\Psi}$$

Di-Higgs measurements



Prospects @ 3000/fb (bb $\gamma\gamma$) Single analysis: -0.8 < λ/λ SM < 7.7

ATL-PHYS-PUB-2017-001

ATLAS-CONF-2016-049

[SM: 11 fb]

Barr Scalars 2017

i.e. factor of <u>29 x SM</u>



Finding out more



words to filter the results.

tion row are combined with a logical OR, while selections among different section rows are combined with a logical AND.

	Show All Deselect All Show Latest 20			
	7 TeV 8 TeV 13 TeV			
	Higgs to 2 photons Higgs to 4 lepton Higgs to 2 muons Higgs to ZZ Higgs to WW Higgs to bb Higgs to tautau Higgs to i			
	Higgs to meson+photon Gluon fusion production VH production bbH production bH production tH production ttH production			
	Di-Higgs production Off-shell Higgs H(125) measurements Mass measurement Coupling measurements Simplified template cross-sect			
	Pseudo-observables Exotic Higgs decays Exotic Higgs production BSM Higgs searches Charged Higgs searches kappa NMSS			
	Spin / CP			
	W Z Photon WW WZ ZZ Di-photon Vphoton			
	Charged tracks			
	0 lepton 1 leptons (same charge) >=3 leptons			
	Taus Photons			
	0 jets 1 jet 2 jets >=3 jets All hadronic c-jets b-jets			
etice	ISR MVA / machine learning EFT High luminosity upgrade studies Statistical combination VBF BSM reinterpretation			
51105	Long-lived massive particles			
	0 🔅 fb 💠 ⁻¹ Filter by minimum integrated luminosity			
	YYYY-MM-DD			

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

Conclusions

- Larger luminosity and detector improvements
- Precision increases e.g. in mass H(125)
- Evidence for VH, VBF, ttH production
- Direct >3 σ evidence for couplings to **tt,bb**
- H(125) differential cross sections in several variables
- Tough decays (μμ, Ζγ, cc) being squeezed
- Self couplings beyond current reach
- Other scalars currently being shy









Barr Scalars 2017



Process	Branching ratio	Uncertainty	
$H \rightarrow bb$	5.77 x 10-1	+3.2%	-3.3%
$H \rightarrow \tau \tau$	6.32 x 10-2	+5.7%	-5.7%
$H ightarrow \mu \mu$	2.20 x 10 -4	+6.0%	-5.9%
$H \rightarrow cc$	2.91 x 10-2	+12.2%	-12.2%
$H \rightarrow gg$	8.57 x 10-2	+10.2%	-10.0%
$H \rightarrow \gamma \gamma$	2.28 x 10-3	+5.0%	-4.9%
$H \rightarrow Z\gamma$	1.54 x 10-з	+9.0%	-8.8%
$H \rightarrow WW$	2.15 x 10 -1	+4.3%	-4.2%
$H \rightarrow ZZ$	2.64 x 10-2	+4.3%	-4.2%
Г _Н [GeV]	4.07 x 10 -з	+4.0%	-3.9%

https://twiki.cern.ch/twiki/bin/view/ LHCPhysics/CERNYellowReportPageBR2

Production methods



LHC Schedule



Commissioning

Ions





Additional muon chambers in the feet region



$H \rightarrow \Phi \gamma, \rho \gamma$

ATLAS-CONF-2017-057



A search for the decays of Higgs and Z bosons to $\phi\gamma$ and $\rho\gamma$ has been performed with $\sqrt{s} = 13$ TeV pp collision data samples collected with the ATLAS detector at the LHC corresponding to integrated luminosities of 35.6 and 32.3 fb⁻¹, respectively. No significant excess of events above the background expectations is observed, in agreement with the SM expectation. The obtained 95% CL upper limits are $\mathcal{B}(H \to \phi\gamma) < 4.8 \times 10^{-4}$ and $\mathcal{B}(Z \to \phi\gamma) < 0.9 \times 10^{-6}$ for the $\phi\gamma$ final state. 95% CL upper limits of $\mathcal{B}(H \to \rho\gamma) < 8.8 \times 10^{-4}$ and $\mathcal{B}(Z \to \rho\gamma) < 25 \times 10^{-6}$ for the $\rho\gamma$ final state are obtained.



SUSY Higgs – Run 1



SUSY Higgs



Interpretation in EFT

ATLAS Preliminary cG [10⁻⁴] √s = 13 TeV, 36.1 fb⁻¹ cA [10⁻⁴] cu cHW [10⁻¹] cHB [10⁻¹] $cWW - cB [10^{-1}]$ -2 2 0 Parameter value

Observed HEL constraints with $H \to ZZ^*$ and $H \to \gamma\gamma$

ATL-PHYS-PUB-2017-018/

H(125) invisible width

VBF H(125) production

- 8 TeV
- 20.3 /fb
- Expect BR < 31%
- **Observe** <u>BR < 28%</u>
- arXiv:1508.0769

Associated H(125) + Z

- 13 TeV
- 36.1/fb
- Expect BR < 39%
- **Observe BR < 67%**
 - 2.2σ excess reduces exclusion
- <u>1708.09624</u>

H(125) total width

- Measure WW and ZZ final states
- Look at off-resonance contributions
- Interpret as total width constraint:
- $\Gamma_{\rm H} / \Gamma_{\rm H}^{\rm SM} < 4.5 \rightarrow 7.5 @ 95\%$ CL – Depending on k-factor
- i.e. Γ_H < 22.7 MeV (obs)
 < 33.0 MeV expected
- arXiv:1503.01060