Highlights of Higgs Results from ATLAS

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Hadron Physics Workshop, Weihai

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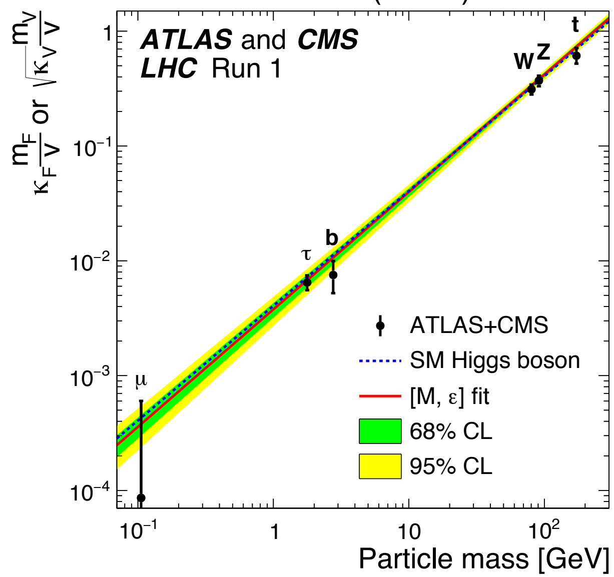
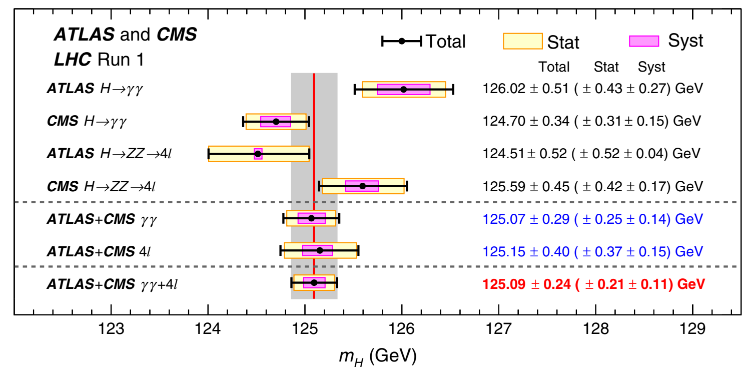
Introduction

- The discovery of the Higgs boson is a triumph of the SM.

JHEP 08 (2016) 045

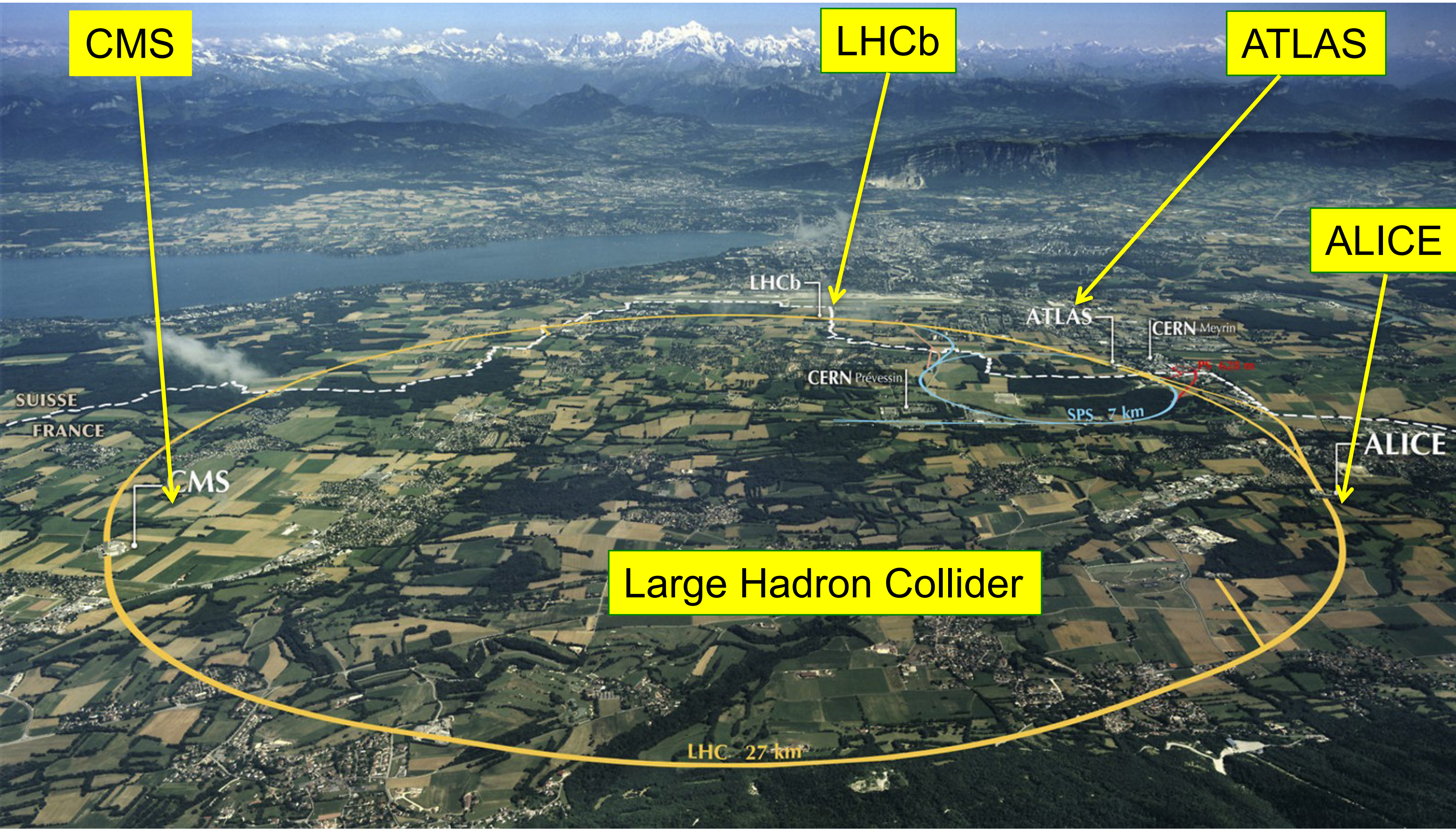


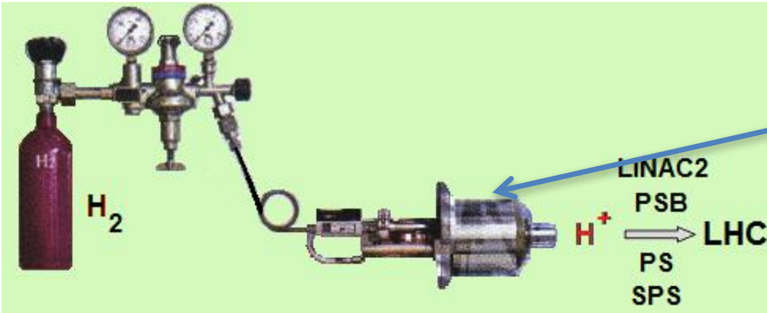
PRL 114, 191803 (2015)



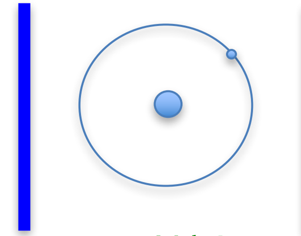
- Need to measure the property of Higgs boson with precision
- Probe other decay modes
- Any deviation from SM prediction is a sign of new physics

Status of LHC Data Taking

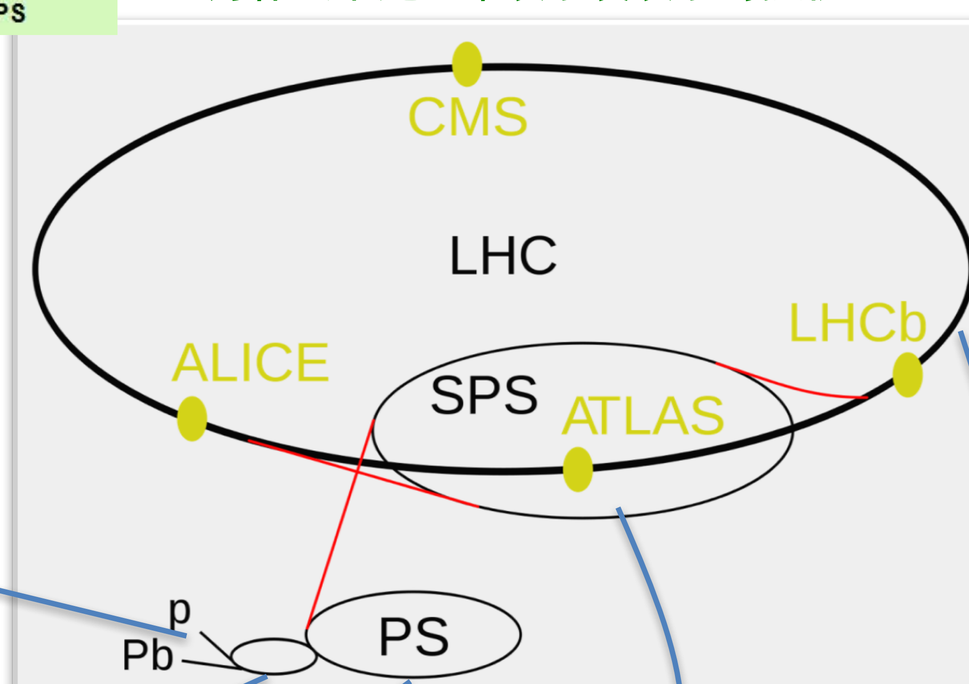




高电压



为什么不建一个质子反质子对撞机？



质子束流的制备

Linac2: 50 MeV

PS Booster: 1.4 GeV

PS: 25 GeV

CERN的第一个同步加速器

SPS: 450 GeV

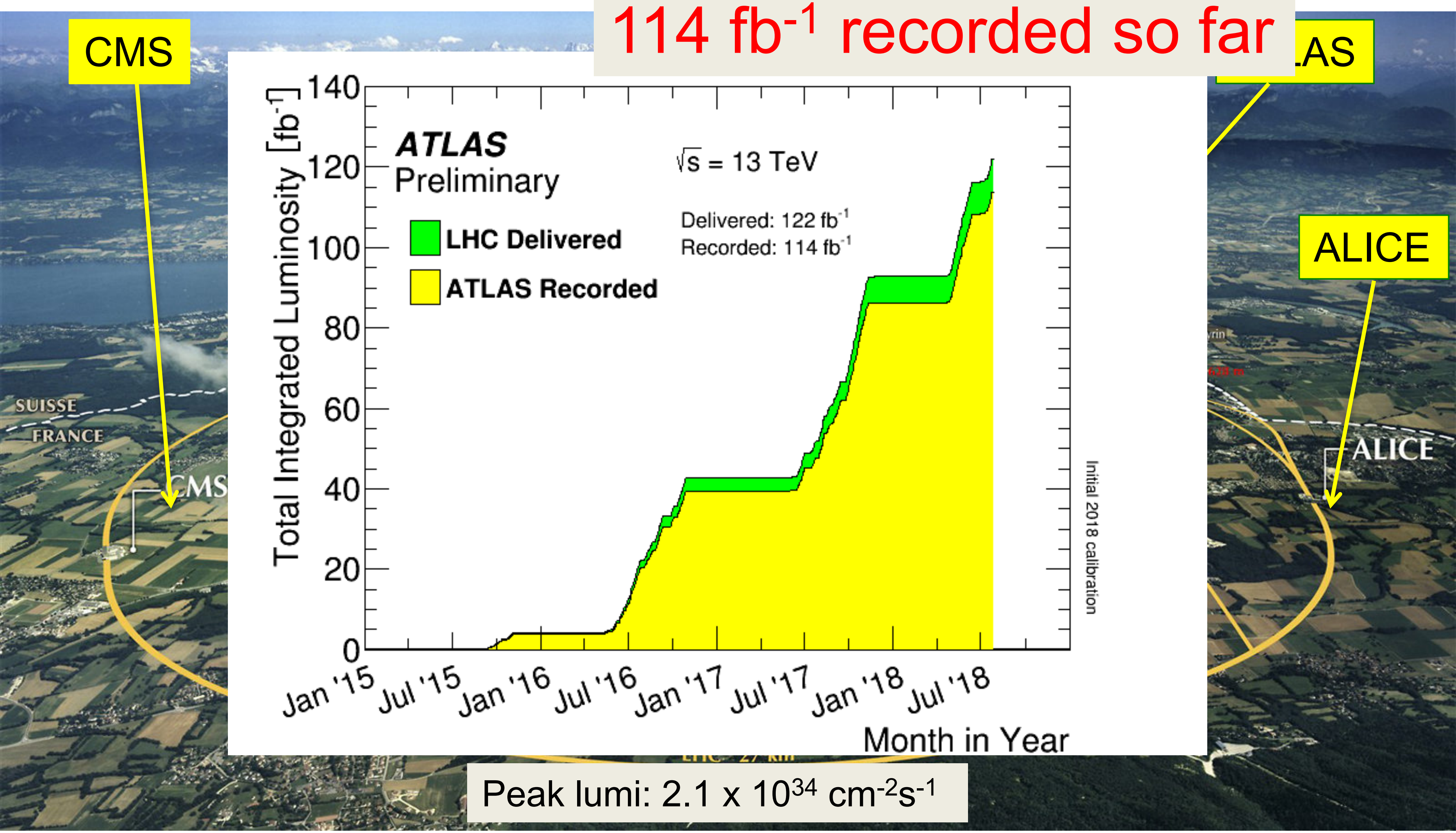
W, Z Discovery

LHC: 6.5 TeV

Higgs Discovery

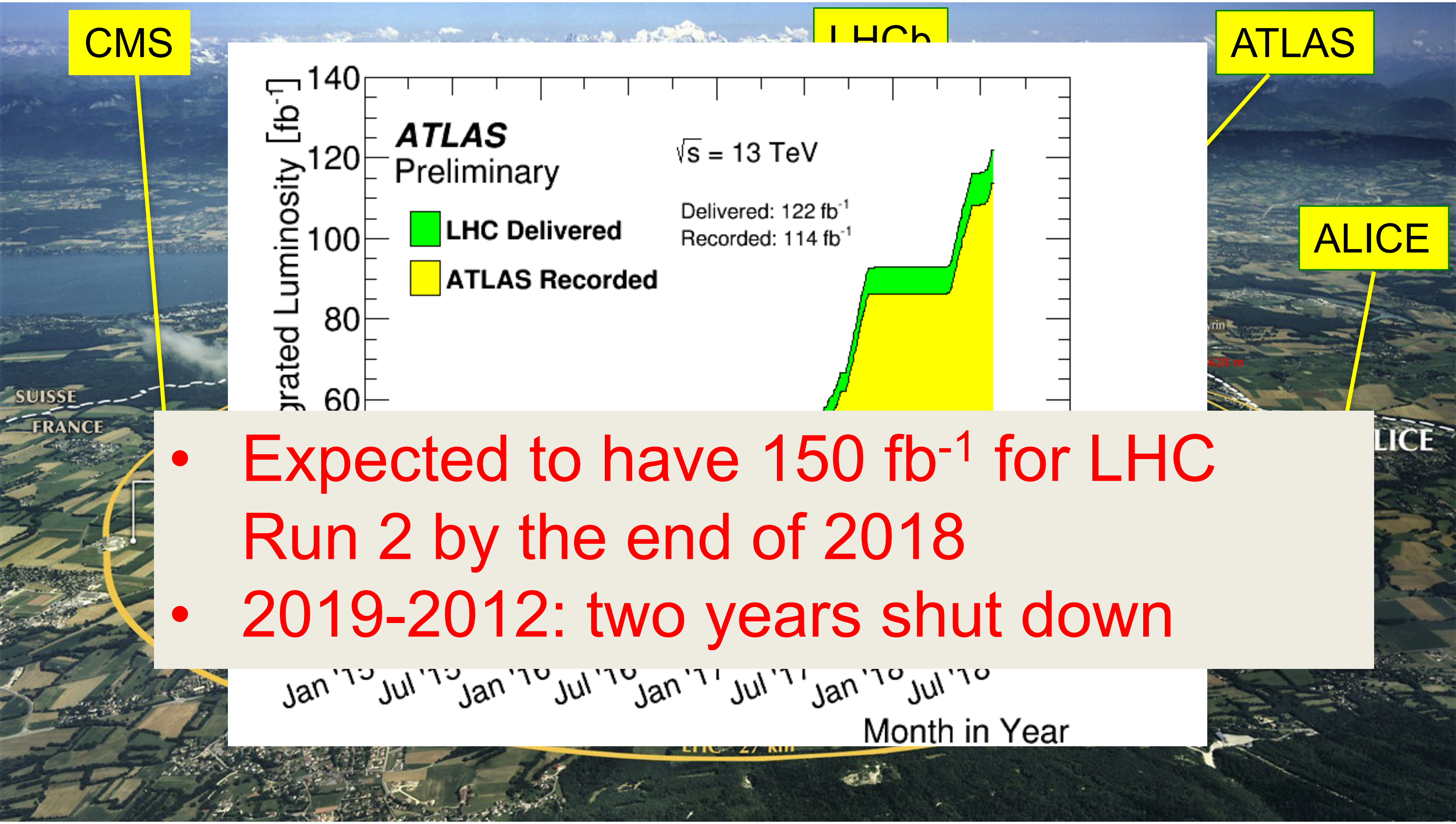
Status of LHC Data Taking

$114\ fb^{-1}$ recorded so far



Peak lumi: $2.1 \times 10^{34}\ cm^{-2}s^{-1}$

Status of LHC Data Taking

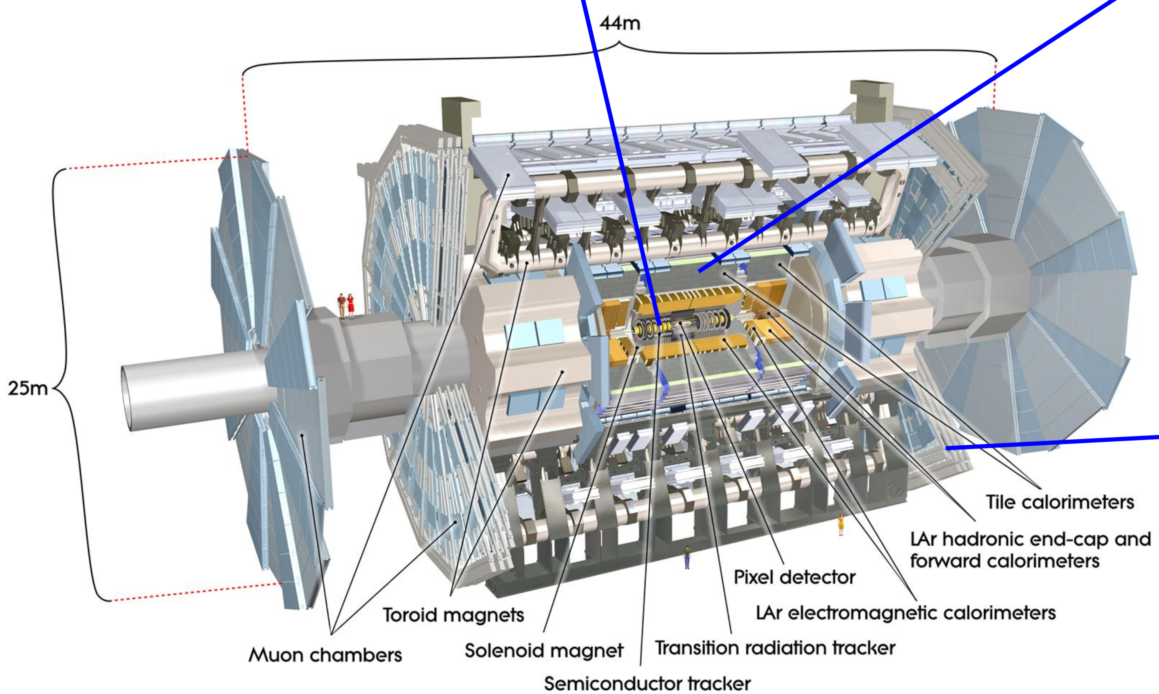


- Expected to have 150 fb^{-1} for LHC Run 2 by the end of 2018
- 2019-2012: two years shut down

ATLAS Detector

Inner Detector;
$|\eta| < 2.5$
Solenoid 2 T
Tracking and vertexing
$\sigma/p_T \sim 0.05\% \cdot p_T \oplus 1\%$

Calorimeter;
$|\eta| < 4.9$
EM : Pb-LAr; $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
Had : Fe-Scint.; $\sigma/E \sim 50\%/\sqrt{E} \oplus 4\%$

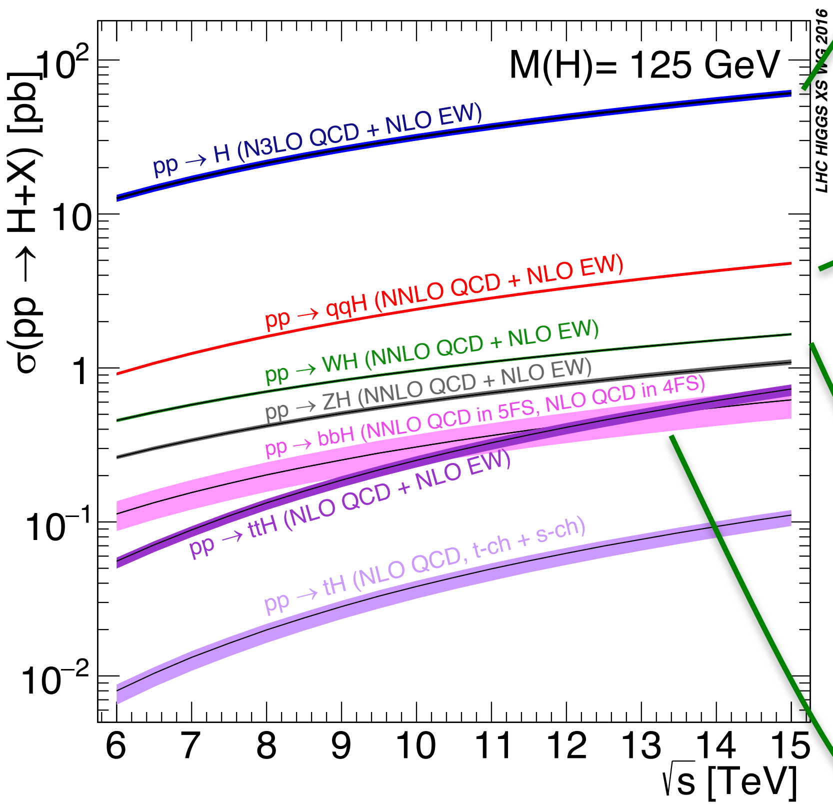


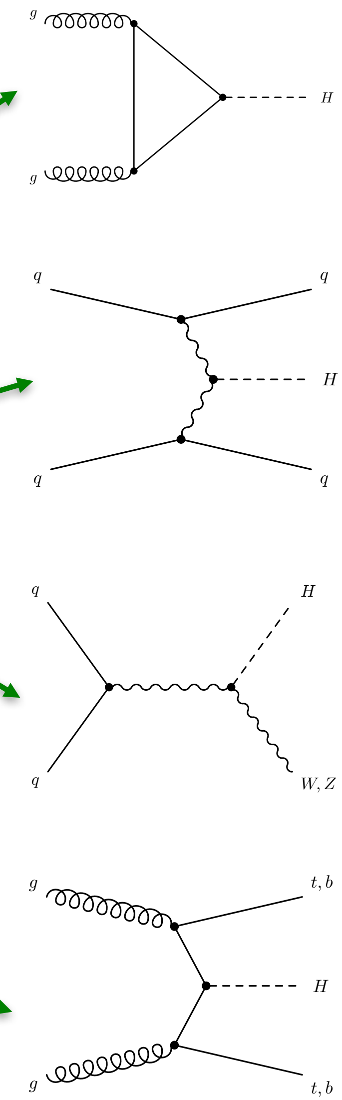
Muon Spectrometer;
$|\eta| < 2.7$
Air-core toroidal & gas chambers
$\sigma/p_T \sim 2\%$ @ 50 GeV
$\sigma/p_T \sim 10\%$ @ 1 TeV

40 m long, 25 m high. 100 M read-out channels

Higgs Boson Production at LHC

LHC Higgs Cross Section Working Group





ggF: dominant, larger initial state radiation from gluons

VBF: two forward jets with high mass and large rapidity gap

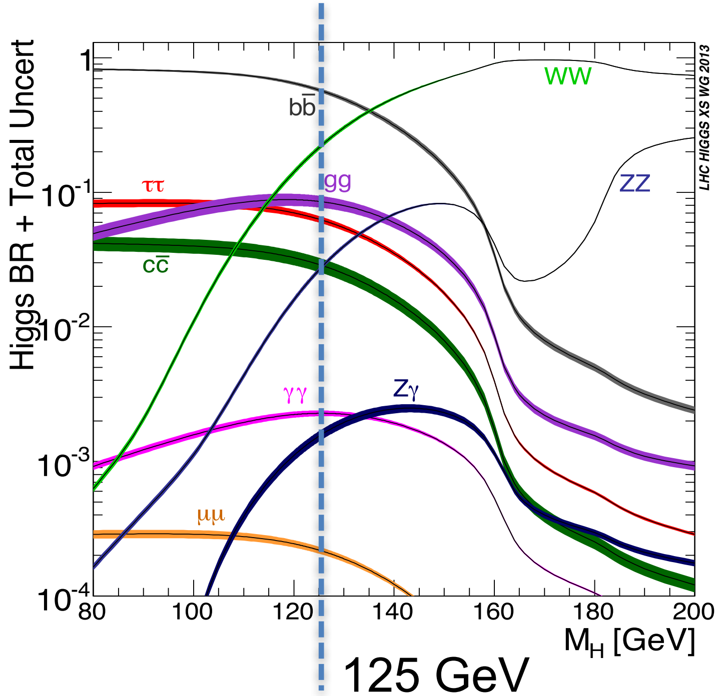
VH: vector boson (lv, ll', qq')

ttH: many b-jets, leptons, E_T^{miss}

With 80 fb-1, about 4M ggF events, 300K VBF, 200K VH and 40K ttH events

Higgs Boson Decays

LHC Higgs Cross Section Working Group



Decay mode	Branching fraction [%]
$H \to bb$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to cc$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001

- Observations: low BR channels ($ZZ \to 4l$, γγ, Zγ and μμ) have better mass resolutions but small rate. Channels with higher BRs (the rest) are challenging experimentally

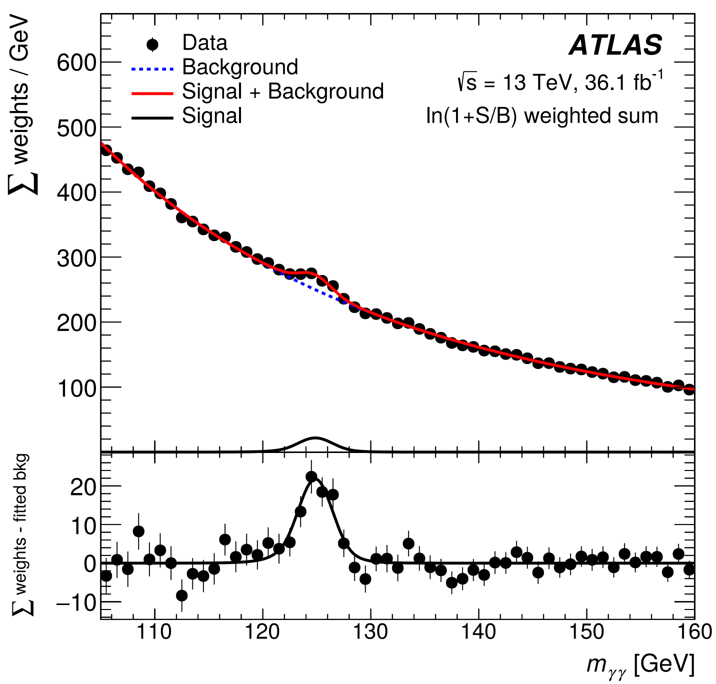
Higgs Mass

Higgs Boson Mass

arXiv: 1806.00242

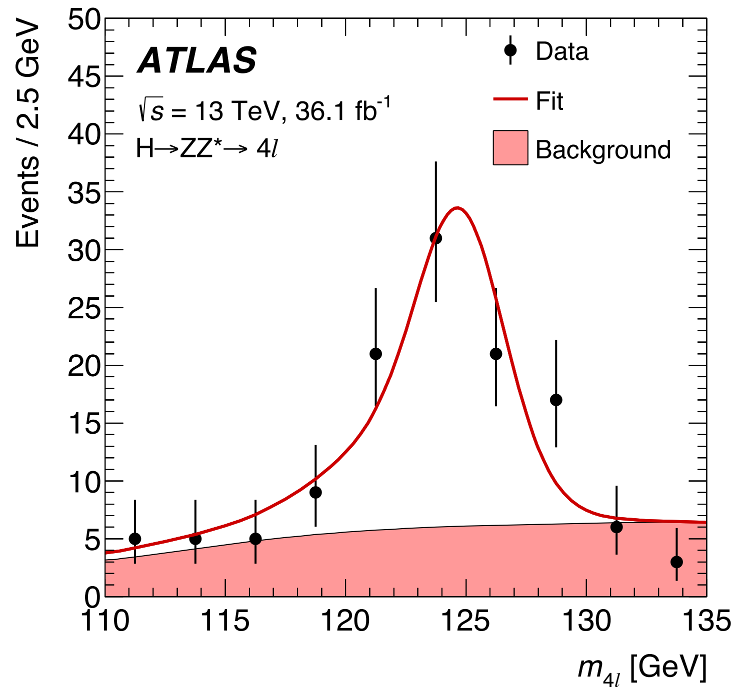
- Higgs mass is the only free parameter in BEH mechanism
- Use 36 fb^{-1} LHC Run 2 data, with $H \to ZZ \to 4l$ and $H \to \gamma\gamma$

$H \to \gamma\gamma$



$$m_H = 124.93 \pm 0.40 \text{ GeV}$$

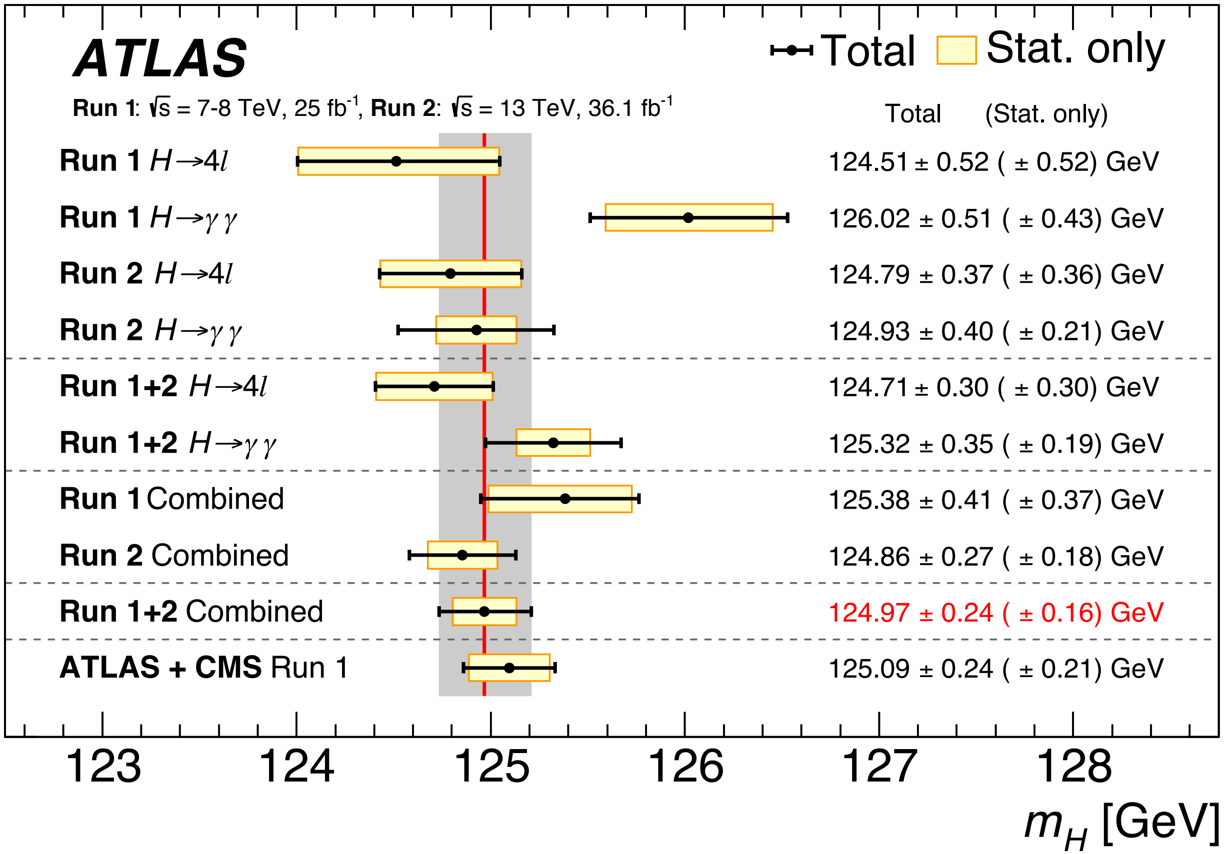
$H \to ZZ \to 4l$



$$m_H = 124.79 \pm 0.37 \text{ GeV}$$

Higgs Boson Mass

arXiv: 1806.00242



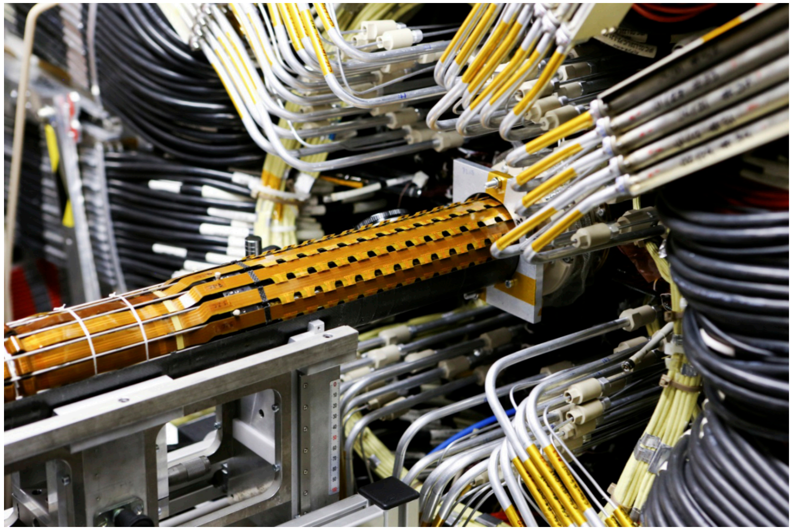
ATLAS Run1+2 combined: $m_H = 124.97 \pm 0.24$ GeV

- Precise object reconstruction is important for this measurement
- H→ZZ is still statistics limited; H→$\gamma\gamma$ is systematics limited (photon energy scale)

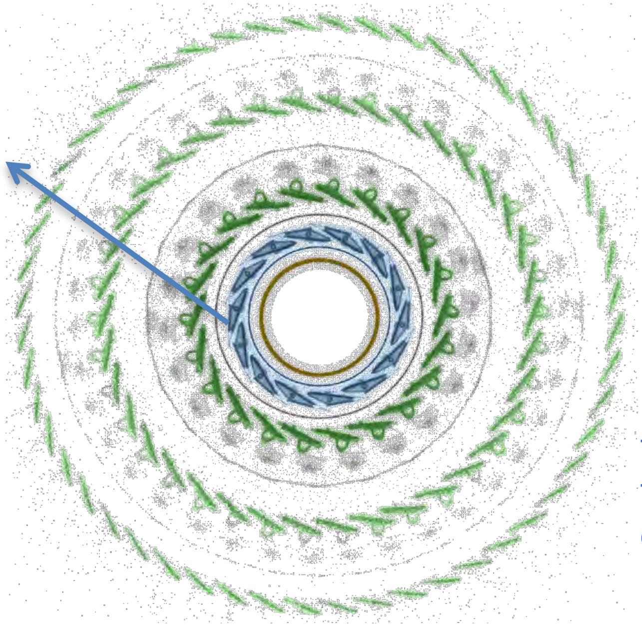
ttH

ATLAS Upgrade Phase-0

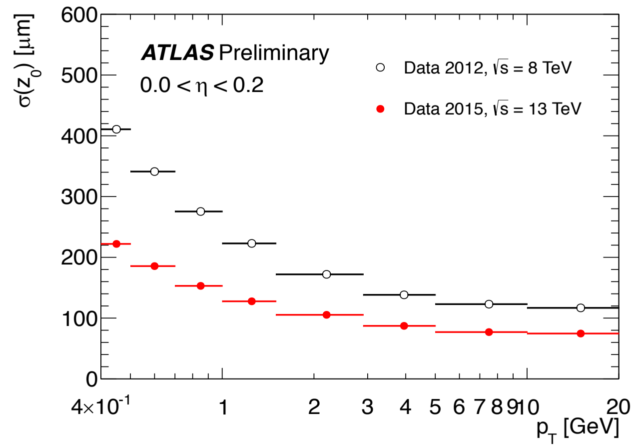
- Innermost silicon pixel detector layer (IBL)
- 33 mm from beam
- Improve tracking and bjet tagging (~4 times better for light flavor jet rejection)



IBL



B hadron with p_T=50 GeV will travel 3 mm in the transverse direction

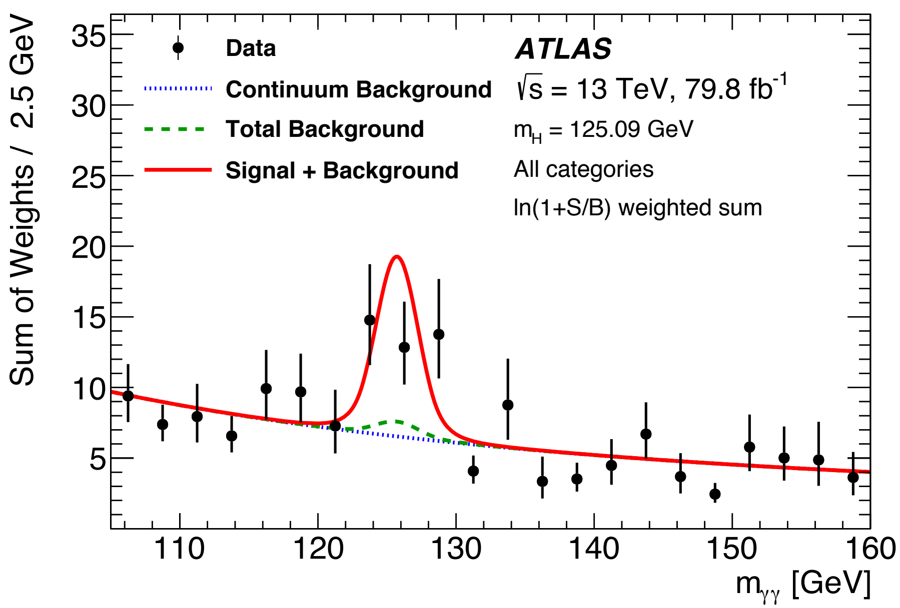


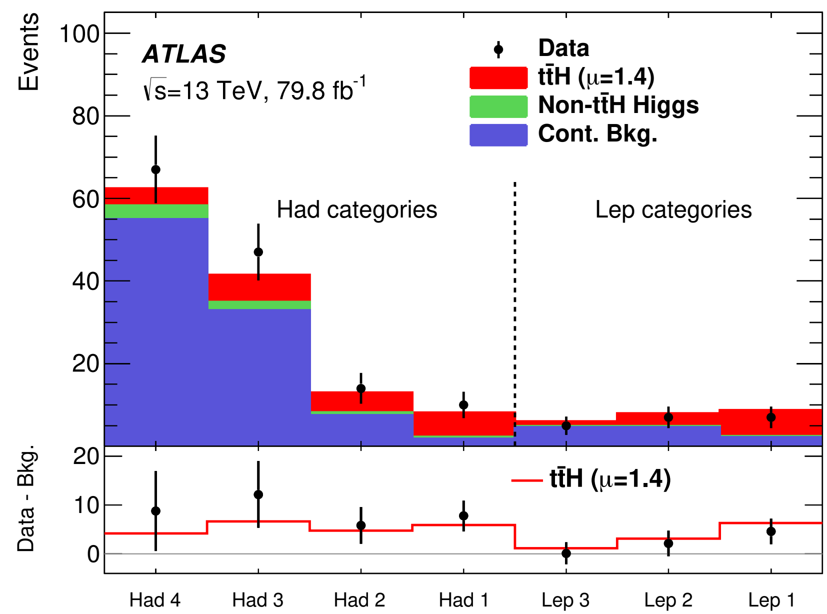
ttH

arXiv:1806.00425

ttH allows direct probe of top Higgs Yukawa coupling

ttH, H→$\gamma\gamma$

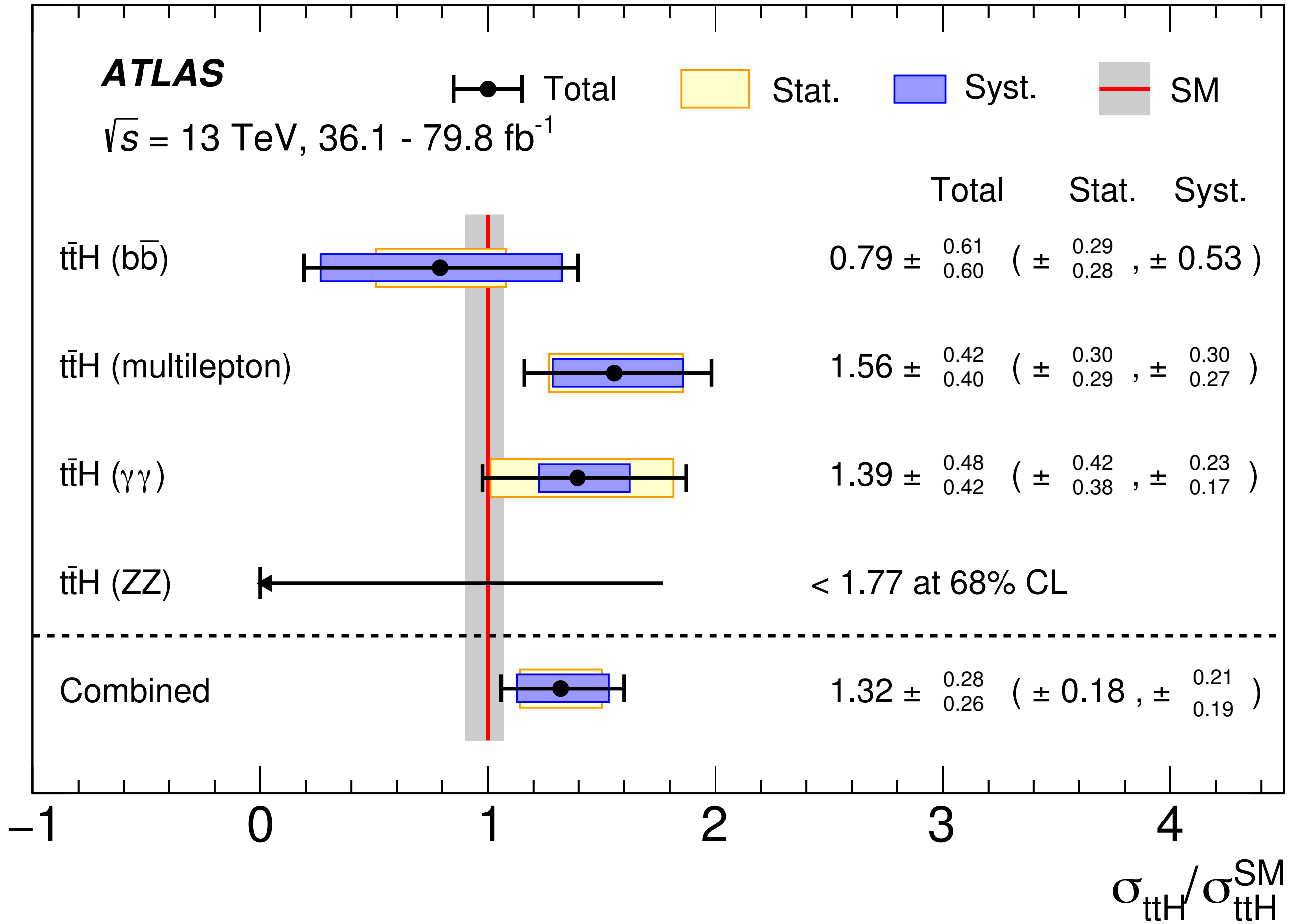




Significance: 4.1σ (3.7σ exp.)

ttH

arXiv:1806.00425



Combined with Run 1 data,
Significance: 6.3σ (5.1σ exp.)

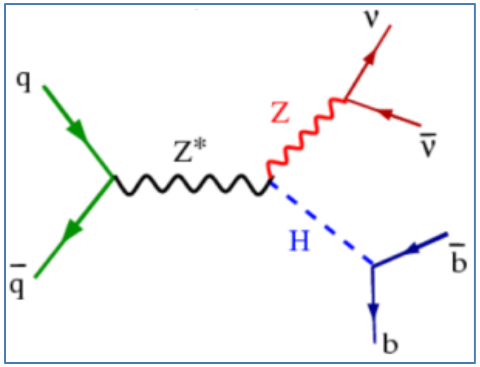
Observation of ttH production mode

$H \rightarrow bb$

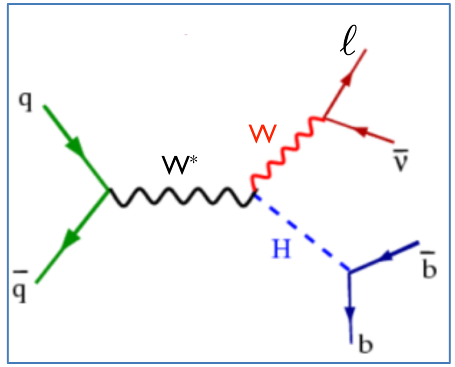
H→bb

- About 58% of Higgs decay to bb

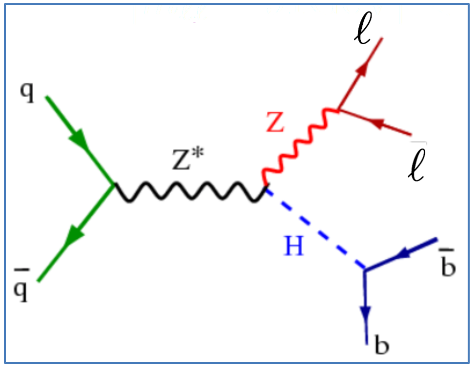
0-lepton

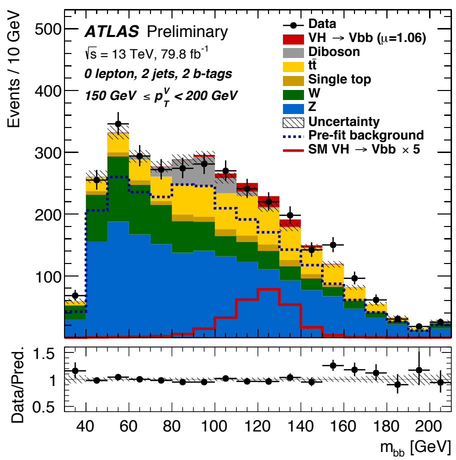


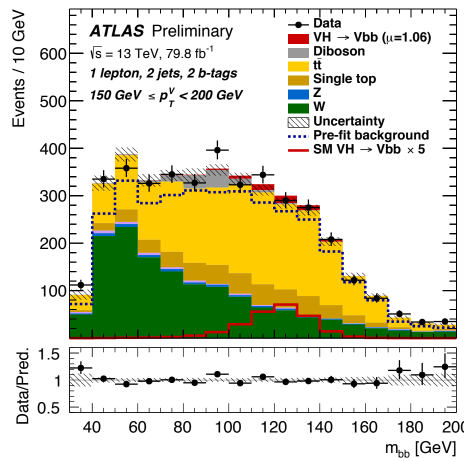
1-lepton

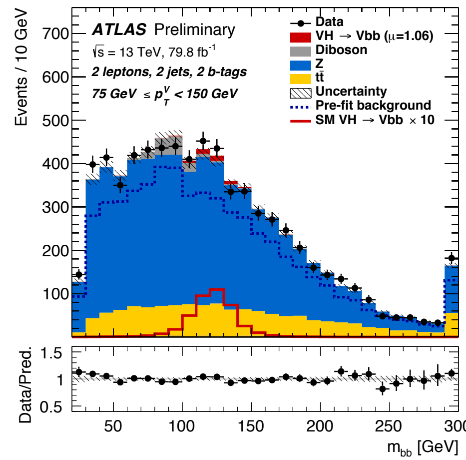


2-lepton









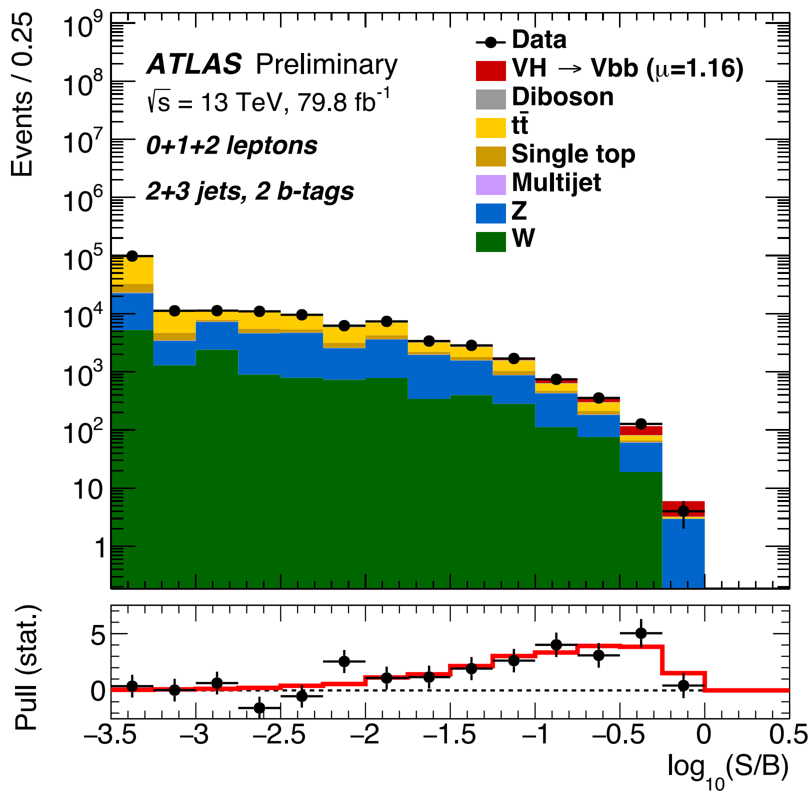
Select 2 b-tagged jets and pT(V) > 75 GeV or 150 GeV

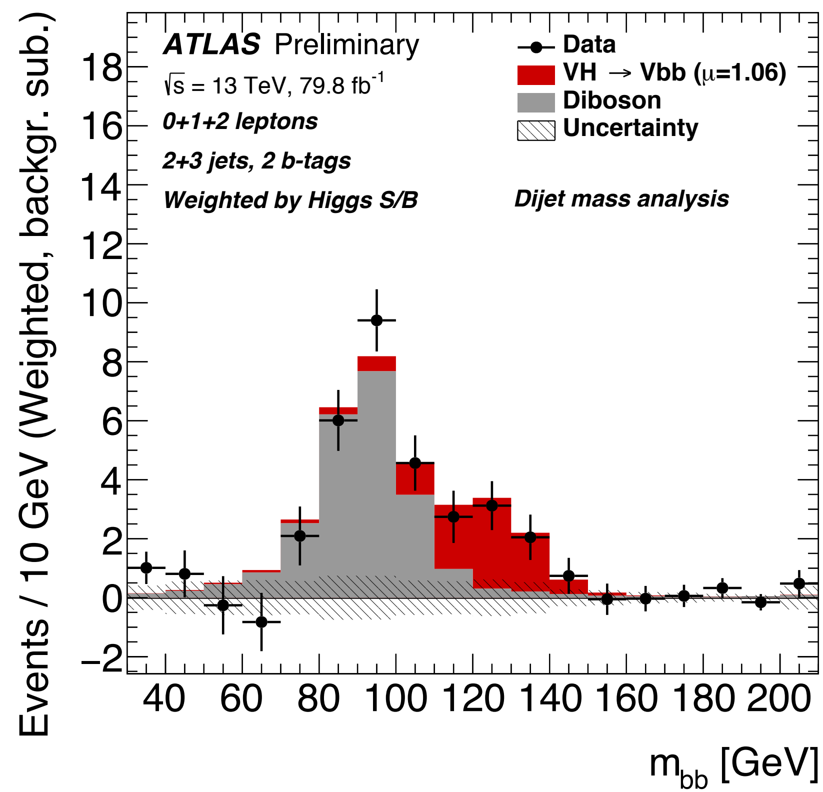
H→bb

ATLAS-CONF-2018-036

- Combine several variables with BDT (m_{bb}, p_T^V, ΔR_{bb} etc.)

Event yields





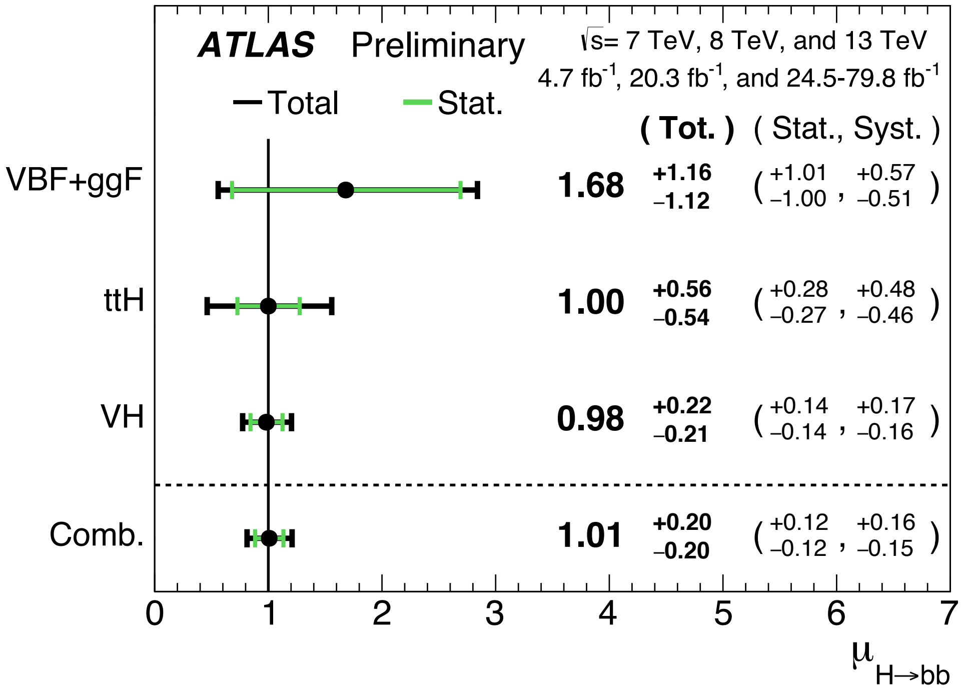
Combined with Run 1 data,
Significance: 4.9σ (5.1σ exp.)

$$\mu_{VH}^{bb} = 1.06^{+0.36}_{-0.33} = 1.06 \pm 0.20(\text{stat.})^{+0.30}_{-0.26}(\text{syst.}),$$

(Run 2 data)

H→bb

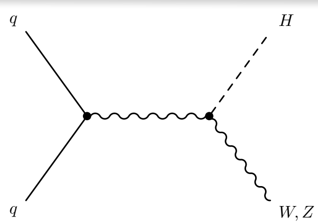
ATLAS-CONF-2018-036



- Combined Run 1 and Run 2 data
- Include VH, H→bb; VBF+ggF, H→bb; ttH, H→bb

Significance: 5.4σ (5.5σ exp.)

Observation of H→bb



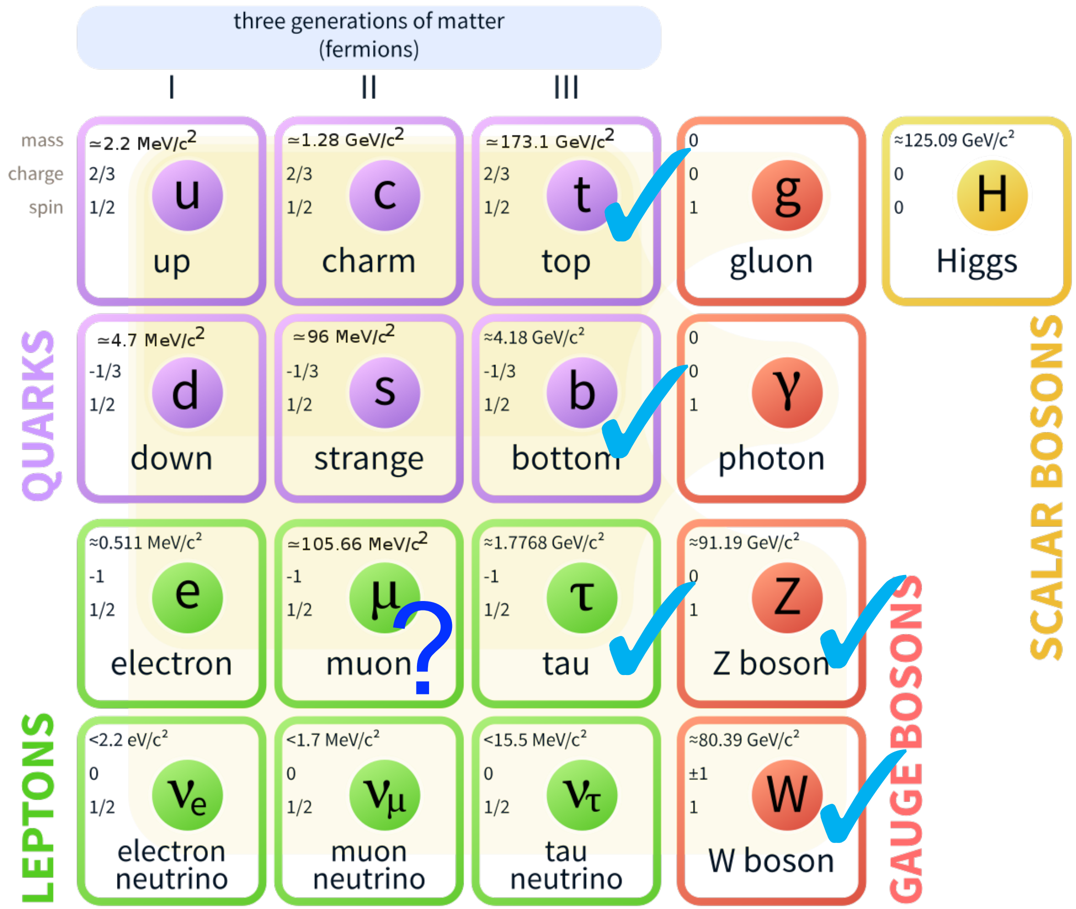
Include VH, H→bb;
VH, H→$\gamma\gamma$;
VH, H→ZZ

Significance: 5.3σ (4.8σ exp.)

Observation of VH production mode

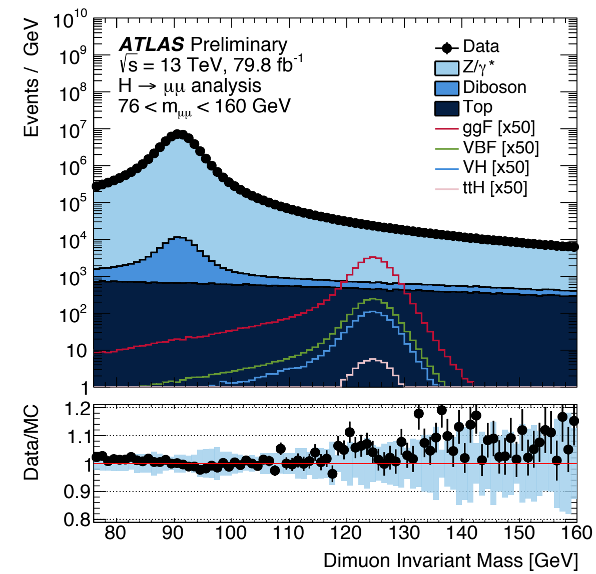
H$\rightarrow \mu\mu$

Higgs Couplings to Massive Elementary Particles



H→$\mu\mu$ Event Selections

- Data: LHC 2015-2017 *pp* collisions data, 79.8 fb^{-1}
- Dominant background is Drell-Yan process
- Dedicated categories for ggF and VBF
- Use analytic functions to model signal and background



ATLAS-CONF-2018-026

Event selections

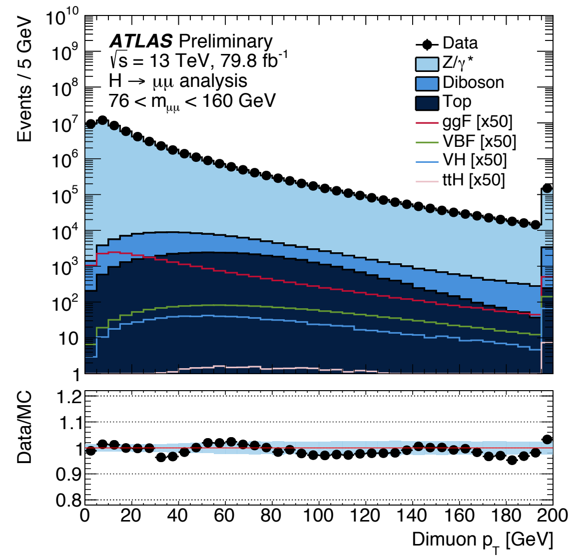
- At least one primary vertex associated with at least two tracks
- Exactly have two muons. Leading muon $p_T > 27$ GeV
- $E_T^{miss} < 80$ GeV. Veto events with any *b*-jet
- Signal region: $110 < m_{\mu\mu} < 160$ GeV

H→$\mu\mu$

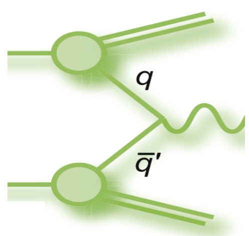
Categories make use of better $S/\sqrt{B}$ for different regions

- Signal has more ISR than background. Signal tends to have large $p_T^{\mu\mu}$ than background

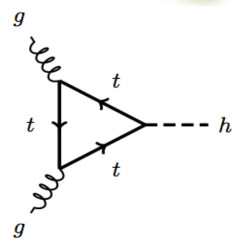
ATLAS-CONF-2018-026



Background



Signal



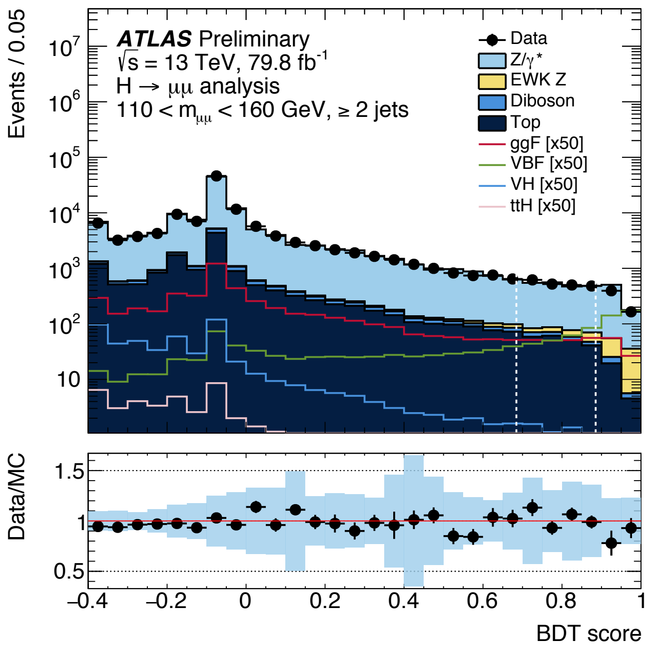
(1) $p_T^{\mu\mu} < 15$ GeV; (2) $15 < p_T^{\mu\mu} < 50$ GeV; (3) $p_T^{\mu\mu} > 50$ GeV;

H→$\mu\mu$

Categories make use of better $S/\sqrt{B}$ for different regions

- Multivariate analysis method is used for VBF category to get better sensitivity
- 14 variables are used to train a BDT (most sensitive ones: m_{jj}, $\Delta\eta_{jj}$, $p_T^{\mu\mu}$, ΔR_{jj})
- Cut on BDT score to have `VBF Tight` (BDT $>$ 0.885) and `VBF Loose` (0.685$<$ BDT $<$ 0.885) [1]
- Events with BDT $<$ 0.685 are classified as ggF-like events

ATLAS-CONF-2018-026



H$\rightarrow\mu\mu$

BDT$<$ 0.685

	Both muons $|\eta| < 1$	Rest	
	Central low $p_T^{\mu\mu}$	Non-cent. low $p_T^{\mu\mu}$	$p_T^{\mu\mu} < 15$ GeV
	Central med. $p_T^{\mu\mu}$	Non-cent. med. $p_T^{\mu\mu}$	$15 < p_T^{\mu\mu} < 50$ GeV
	Central high $p_T^{\mu\mu}$	Non-cent. high $p_T^{\mu\mu}$	$p_T^{\mu\mu} < 50$ GeV

VBF Loose
0.685$<$BDT$<$ 0.885

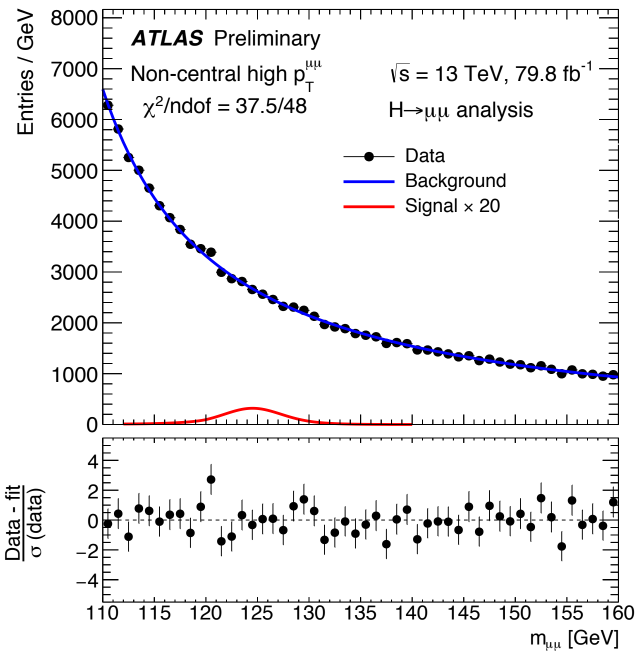
VBF Tight
BDT$>$ 0.885

H→$\mu\mu$

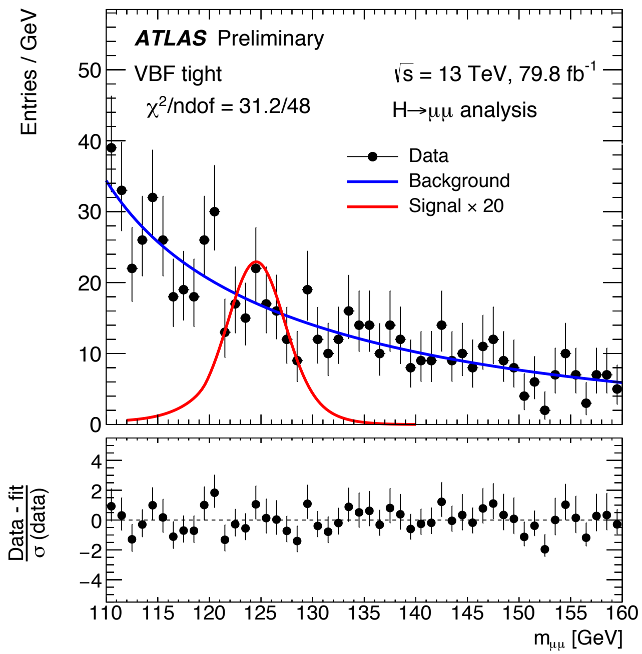
Background $m_{\mu\mu}$ distributions are modelled by

$$f \times [\mathrm{BW}(m_{\mathrm{BW}}, \Gamma_{\mathrm{BW}}) \otimes \mathrm{GS}(\sigma^{\mathrm{B}}_{\mathrm{GS}})](m_{\mu\mu}) + (1 - f) \times \mathrm{e}^{A \cdot m_{\mu\mu}} / m^3_{\mu\mu},$$

Non-central high $p_T^{\mu\mu}$



VBF tight



H→$\mu\mu$ Results ATLAS-CONF-2018-026

No obvious excess is observed around $m_H = 125$ GeV

Upper limit on signal strength

	Observed	Expected
Run-2	2.1	2.0

Measurement of signal strength

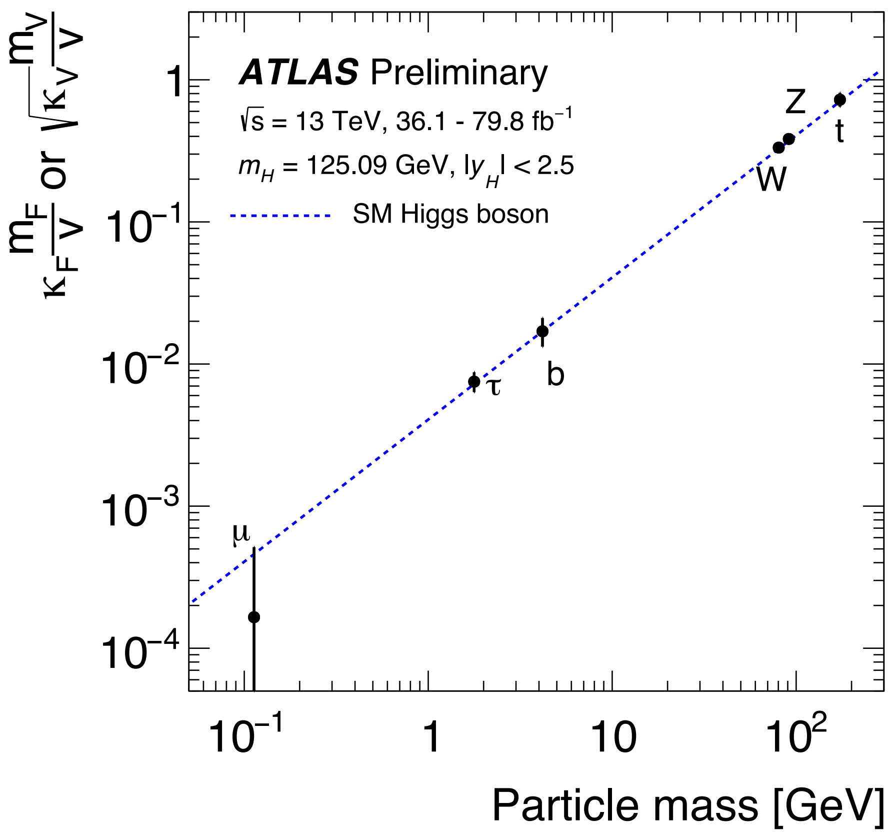
	$\hat{\mu}$
Run-2	$0.1^{+1.0}_{-1.1}$

Significance

	Observed	Expected
Run-2	0.0 σ	0.9 σ

Combined measurement of Higgs couplings

ATLAS-CONF-2018-031



Analysis	Integrated luminosity (fb^{-1})
$H \to \gamma\gamma$ (including $t\bar{t}H$, $H \to \gamma\gamma$)	79.8
$H \to ZZ^* \to 4\ell$ (including $t\bar{t}H$, $H \to ZZ^* \to 4\ell$)	79.8
$H \to WW^* \to e\nu\mu\nu$	36.1
$H \to \tau\tau$	36.1
VH, $H \to b\bar{b}$	36.1
$H \to \mu\mu$	79.8
$t\bar{t}H$, $H \to b\bar{b}$ and $t\bar{t}H$ multilepton	36.1

Summary

- ATLAS has performed Higgs measurements using 80 fb^{-1} LHC Run 2 data
- Observed ttH and VH production modes
- Observed $H \to bb$ decay mode
- For $H \to \mu\mu$, upper limit is 2.1 times SM prediction at 95% CL

- No obvious deviation from SM is found at Higgs sector at LHC

Backup

Higgs mass measurement systematics

Source	Systematic uncertainty in m_H [MeV]
EM calorimeter response linearity	60
Non-ID material	55
EM calorimeter layer intercalibration	55
$Z \to ee$ calibration	45
ID material	45
Lateral shower shape	40
Muon momentum scale	20
Conversion reconstruction	20
$H \to \gamma\gamma$ background modelling	20
$H \to \gamma\gamma$ vertex reconstruction	15
e/γ energy resolution	15
All other systematic uncertainties	10