LHC. ATLAS Detector. Higgs Boson. Yukawa coupling.

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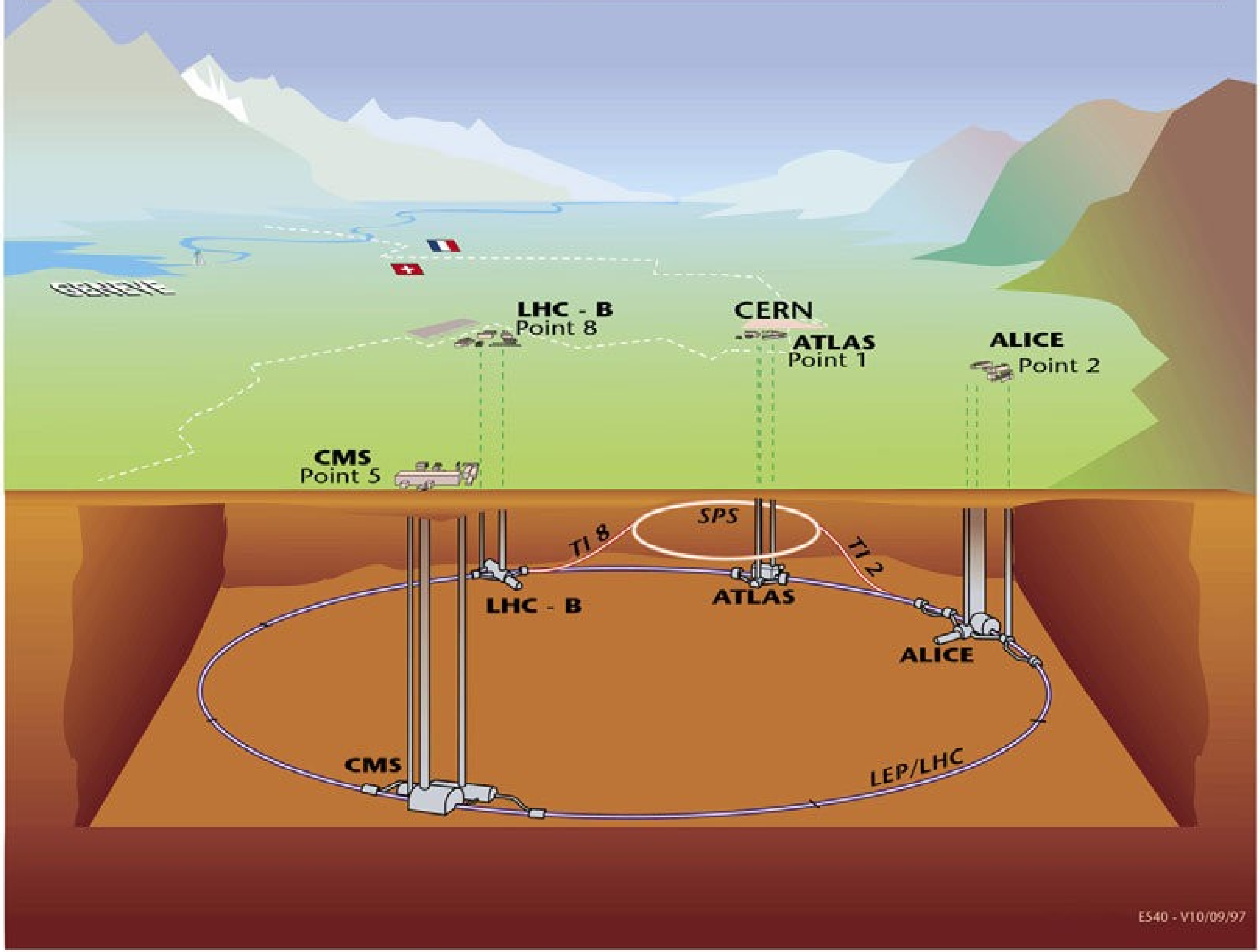
Outline

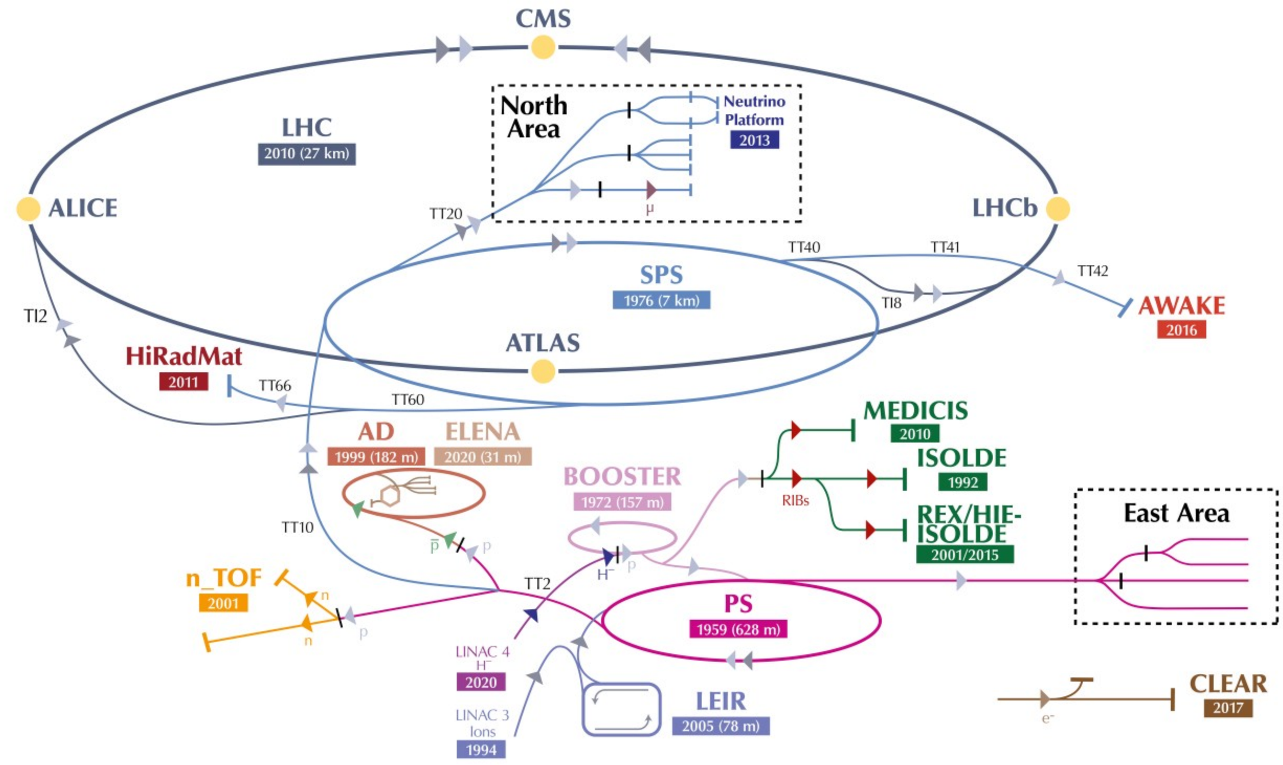
I. Large Hadron Collider
II. ATLAS Detector
III. Standard Model
IV. Higgs Boson
V. Yukawa coupling

Large Hadron Collider

Overall view of the LHC experiments.



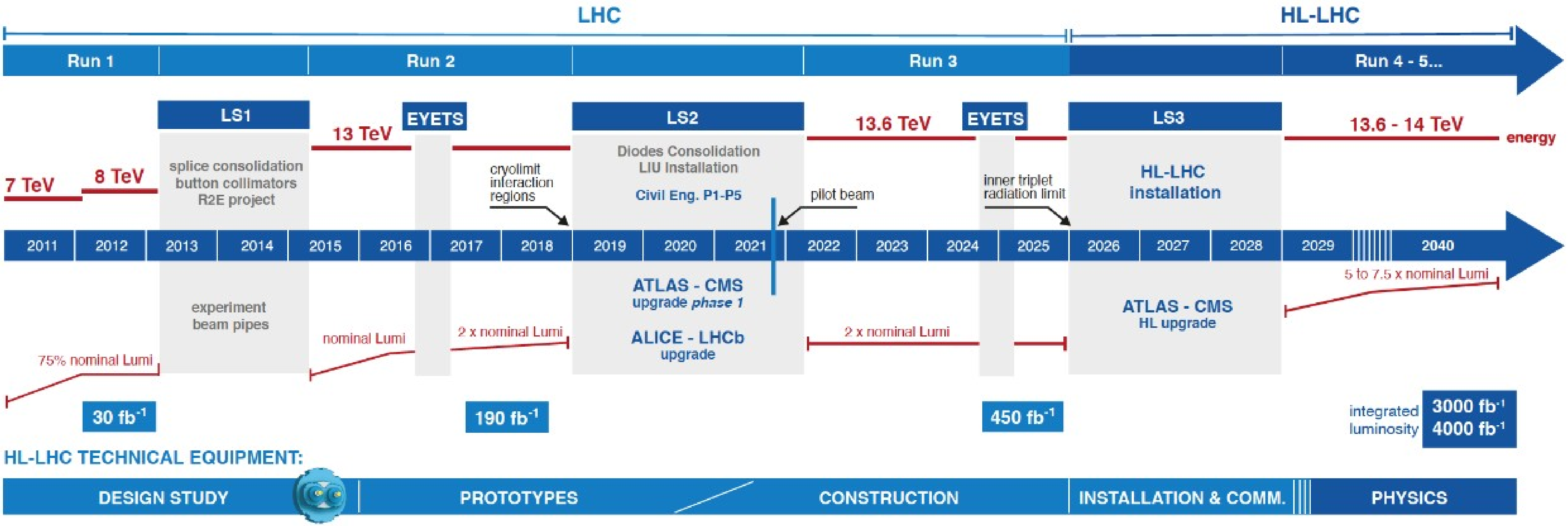
The CERN accelerator complex
Complexe des accélérateurs du CERN



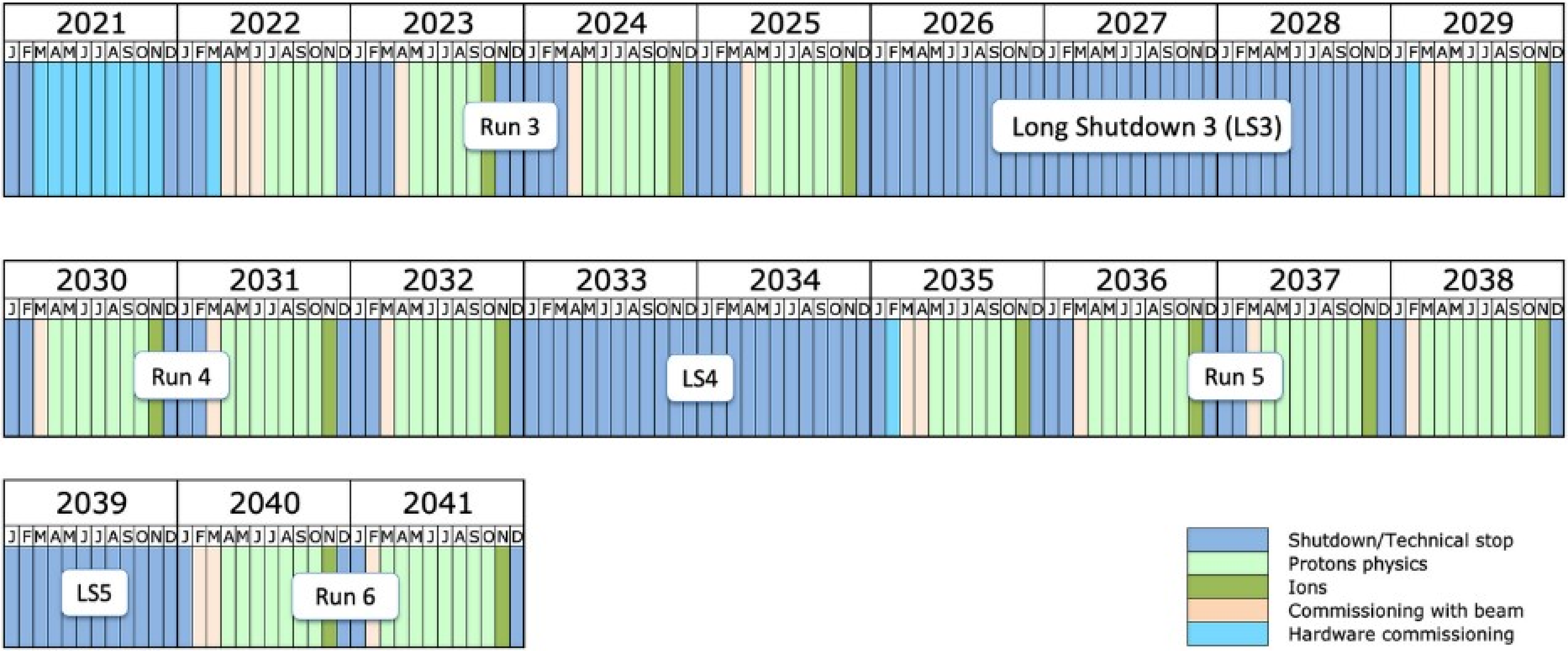
H⁻ (hydrogen anions) p (protons) ions RIBs (Radioactive Ion Beams) n (neutrons) p̄ (antiprotons) e⁻ (electrons) μ (muons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive EXperiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

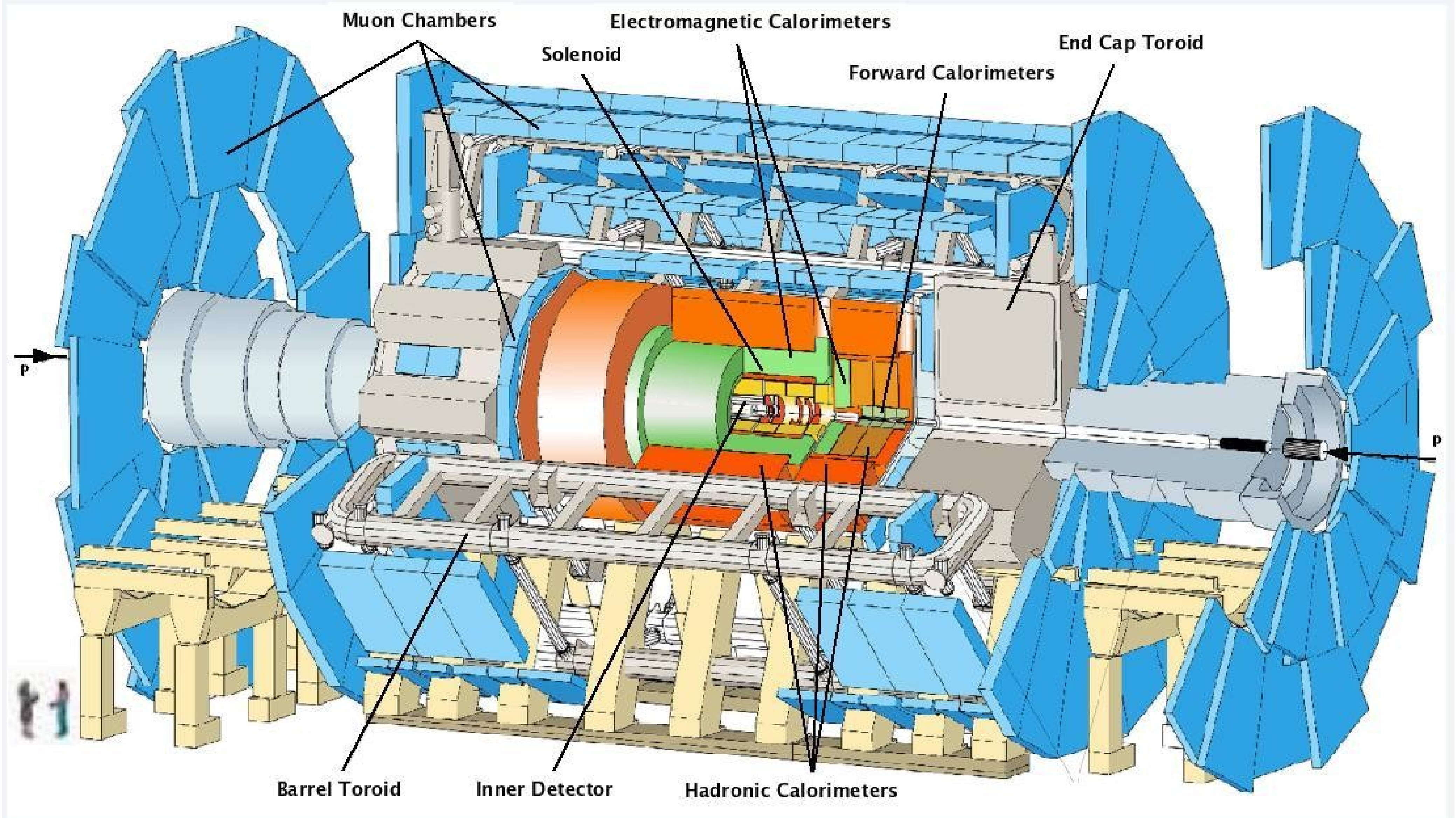
LHC / HL-LHC Plan

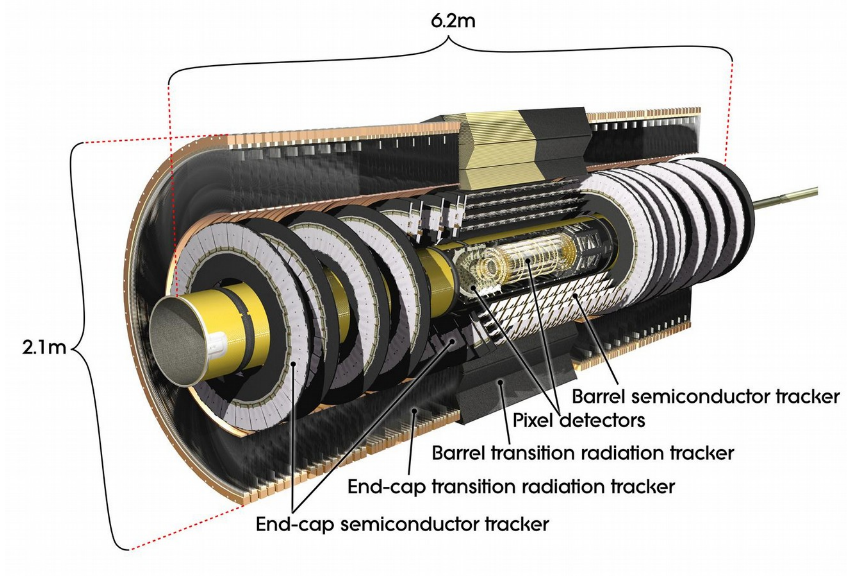


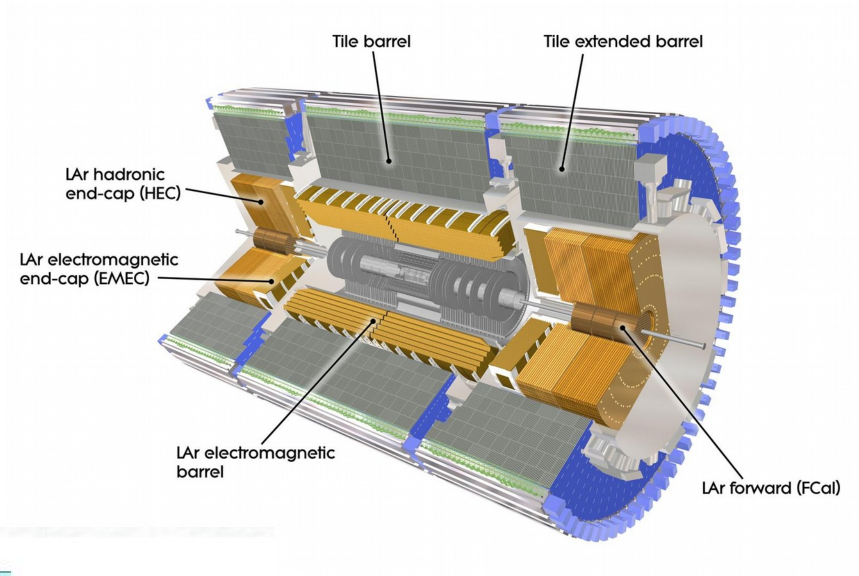
Work schedule of LHC

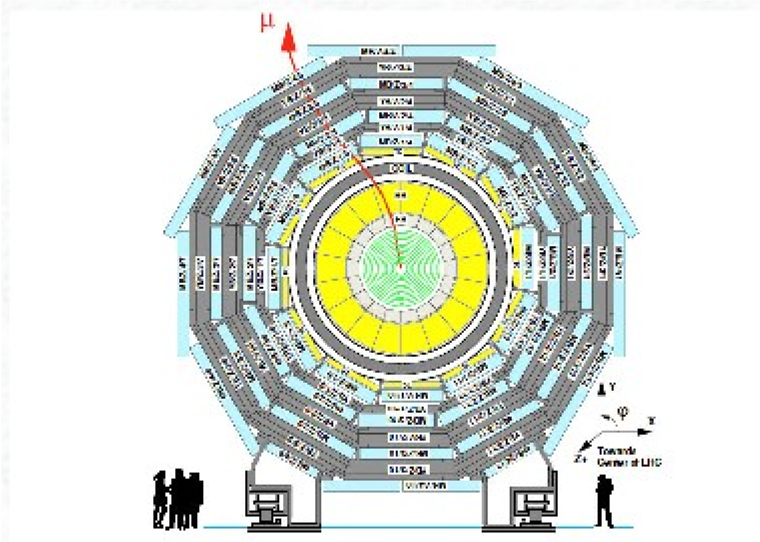


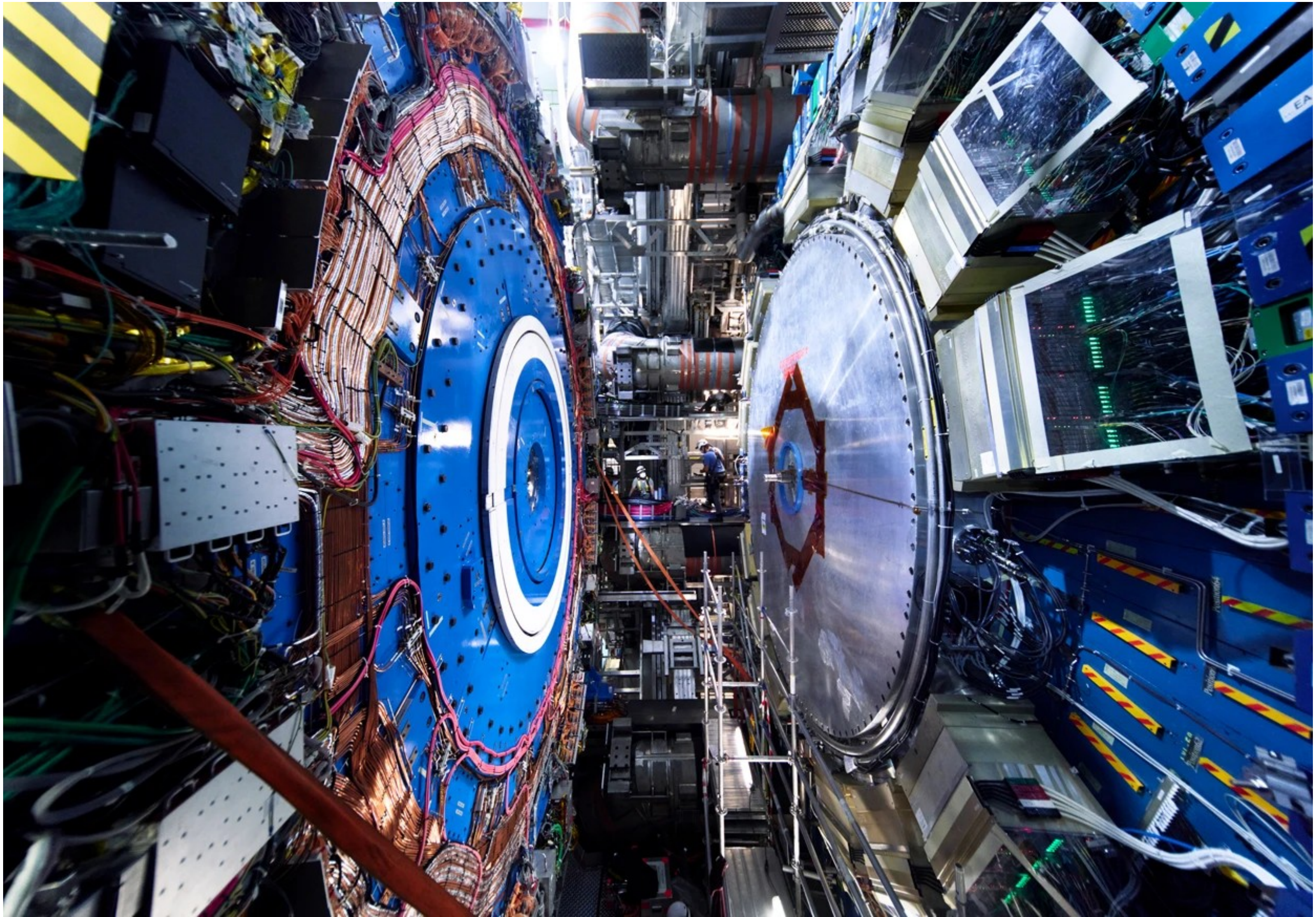
A Toroidal LHC ApparatuS Detector

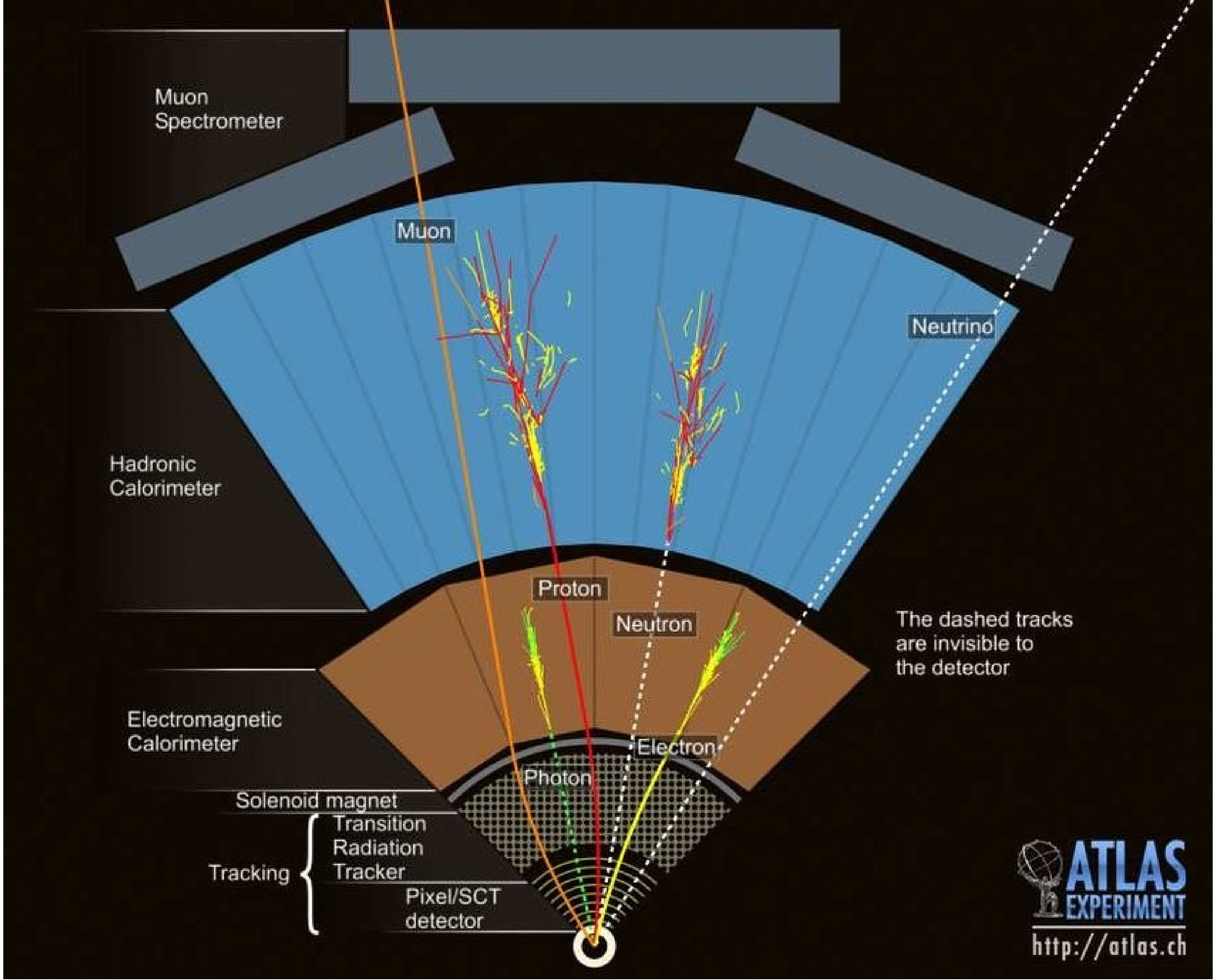

Muon Chambers
Electromagnetic Calorimeters
Solenoid
End Cap Toroid
Forward Calorimeters
p
p
Barrel Toroid
Inner Detector
Hadronic Calorimeters

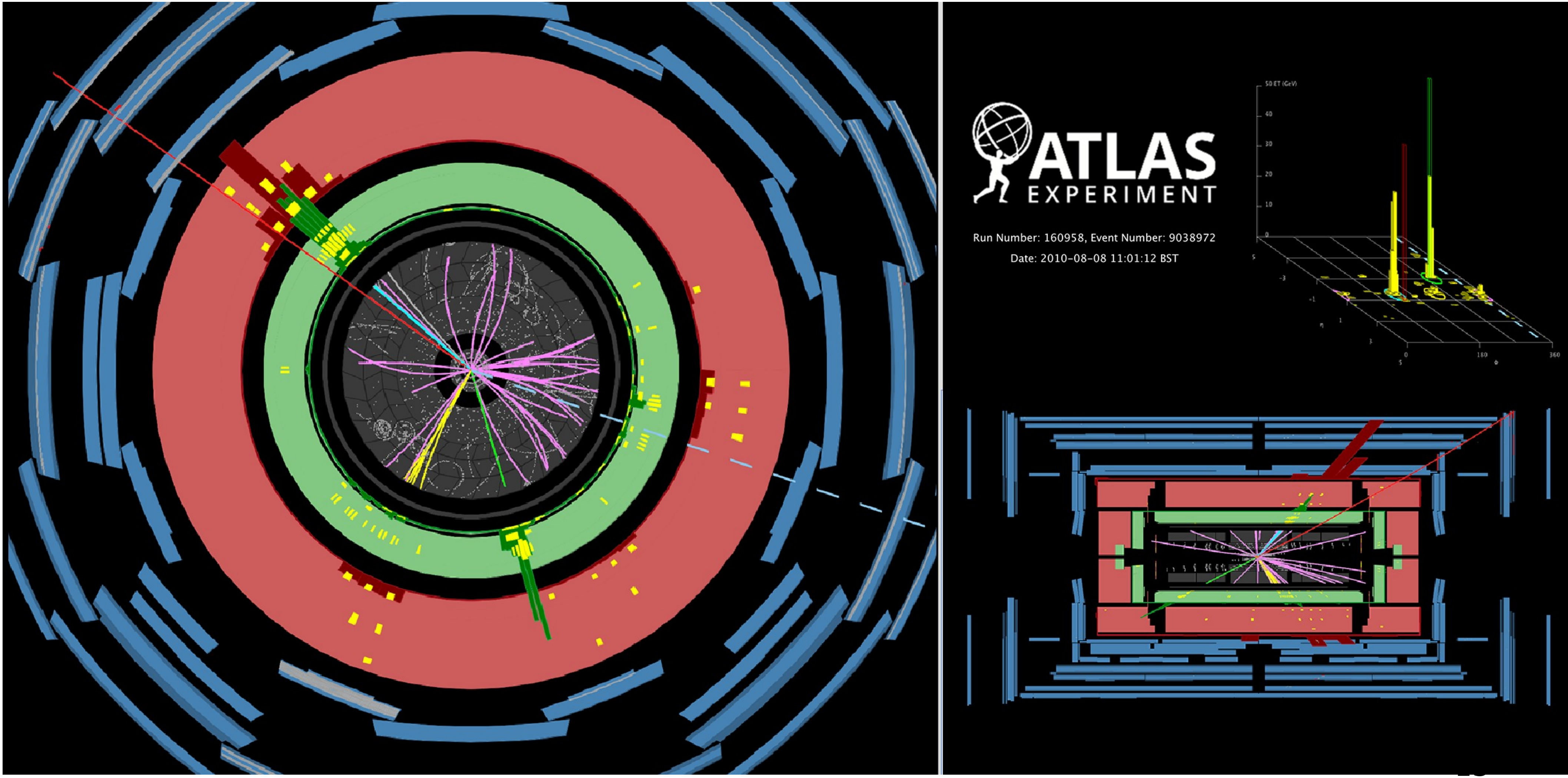

6.2m
2.1m
Barrel semiconductor tracker
Pixel detectors
Barrel transition radiation tracker
End-cap transition radiation tracker
End-cap semiconductor tracker


Tile barrel
Tile extended barrel
LAr hadronic
end-cap (HEC)
LAr electromagnetic
end-cap (EMEC)
LAr electromagnetic
barrel
LAr forward (FCal)

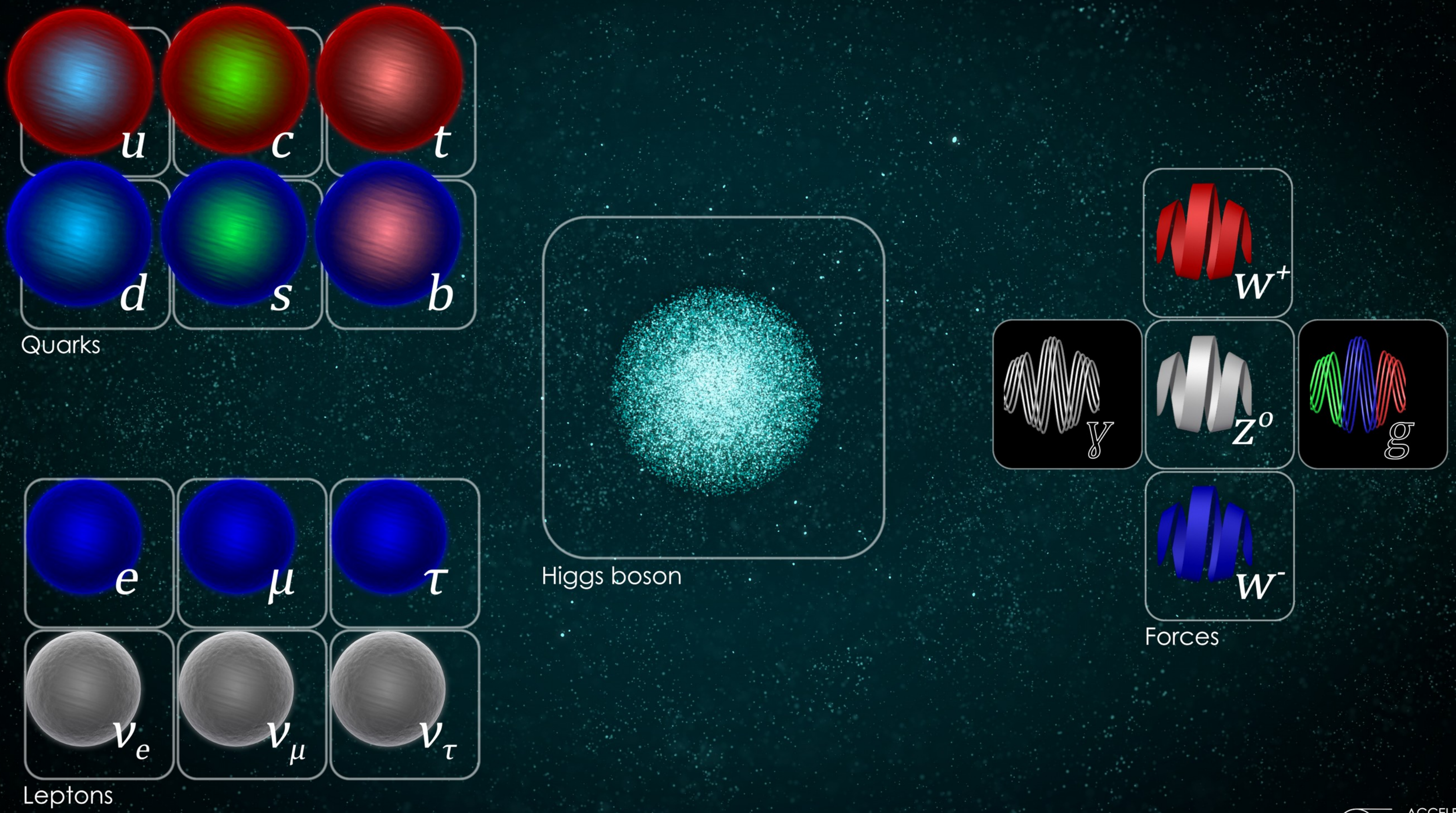




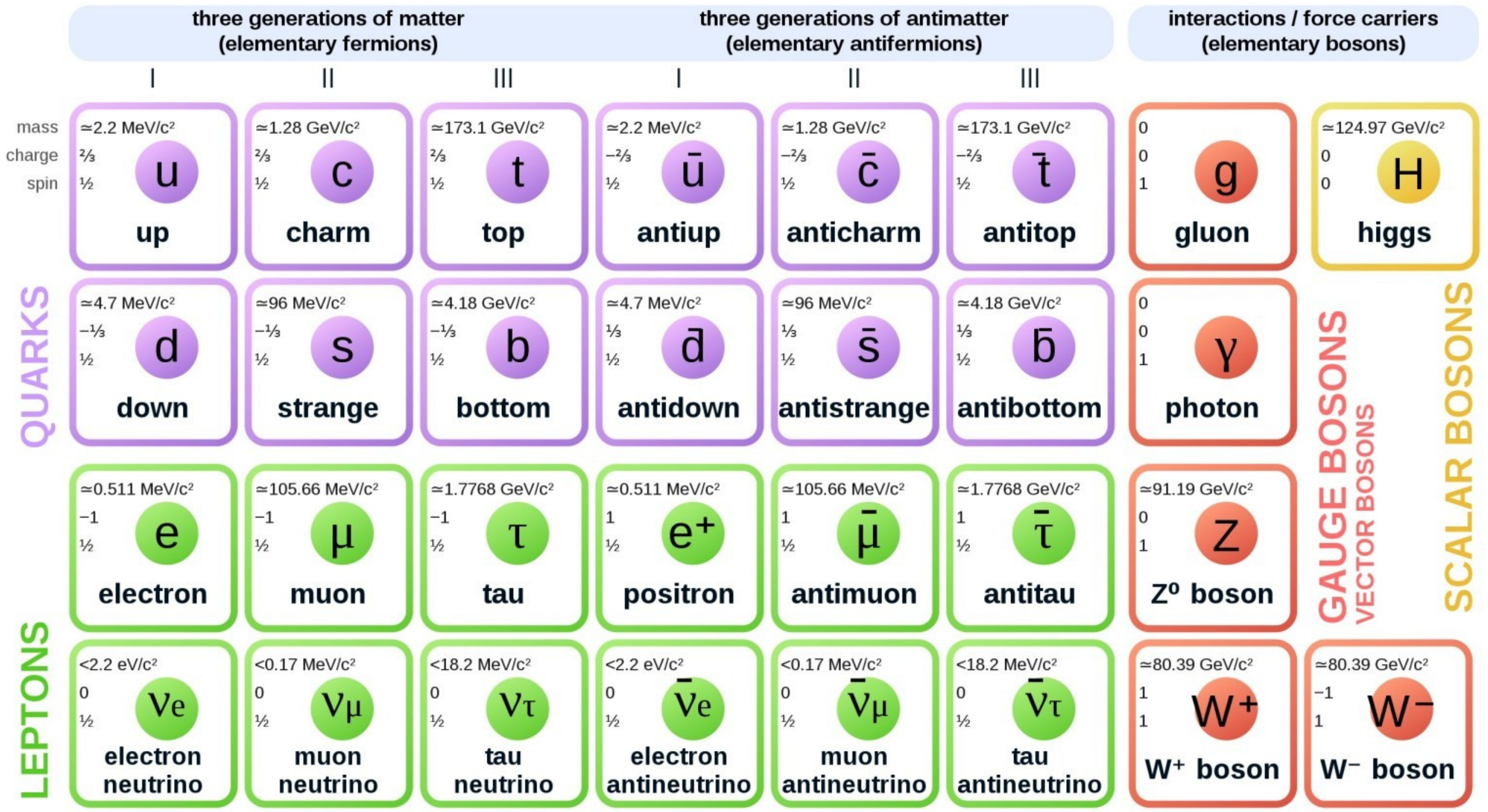

Muon
Spectrometer
Muon
Hadronic
Calorimeter
Neutrino
Proton
Neutron
The dashed tracks
are invisible to
the detector
Electromagnetic
Calorimeter
Electron
Photon
Solenoid magnet
Transition
Radiation
Tracker
Tracking
Pixel/SCT
detector
ATLAS
EXPERIMENT
http://atlas.ch

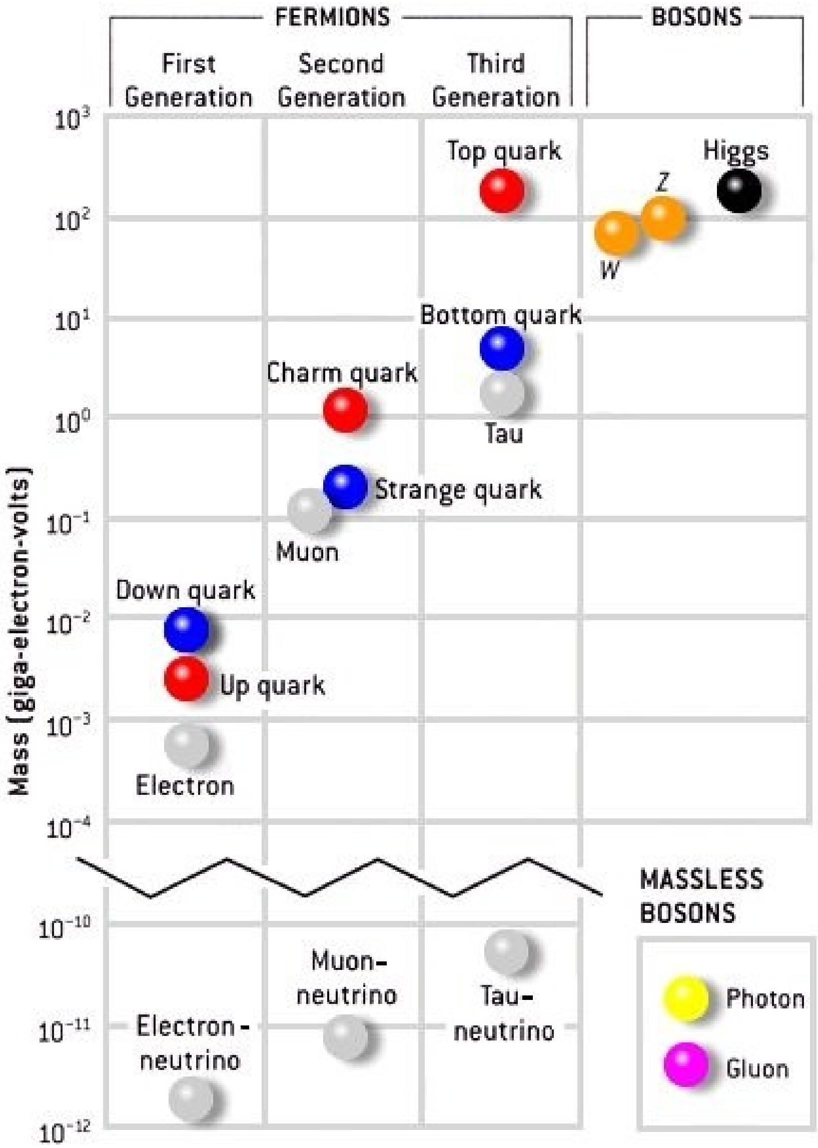

ATLAS
EXPERIMENT
Run Number: 160958, Event Number: 9038972
Date: 2010-08-08 11:01:12 BST

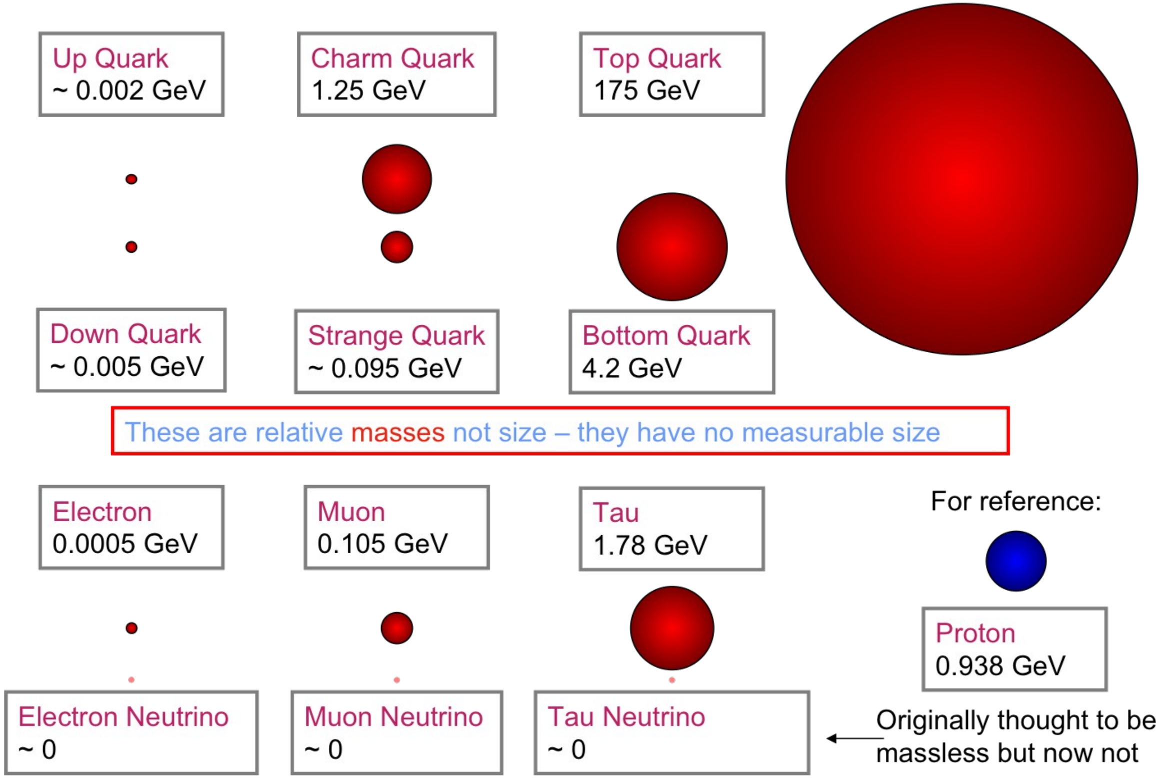
Standard Model


u
c
t
d
s
b
Quarks
e
μ
τ
νe
νμ
ντ
Leptons
Higgs boson
W+
γ
Z0
g
W-
Forces

Standard Model of Elementary Particles

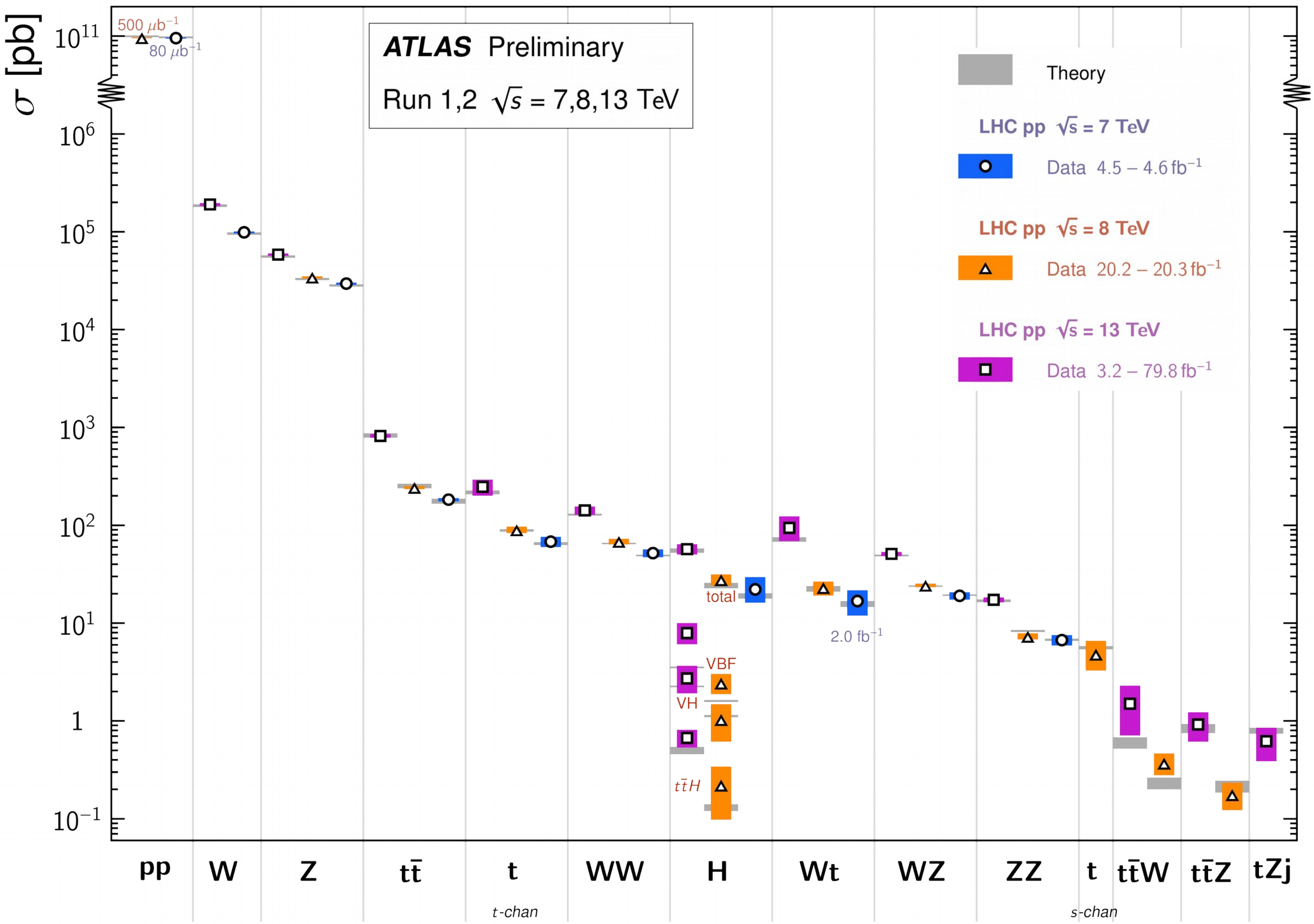


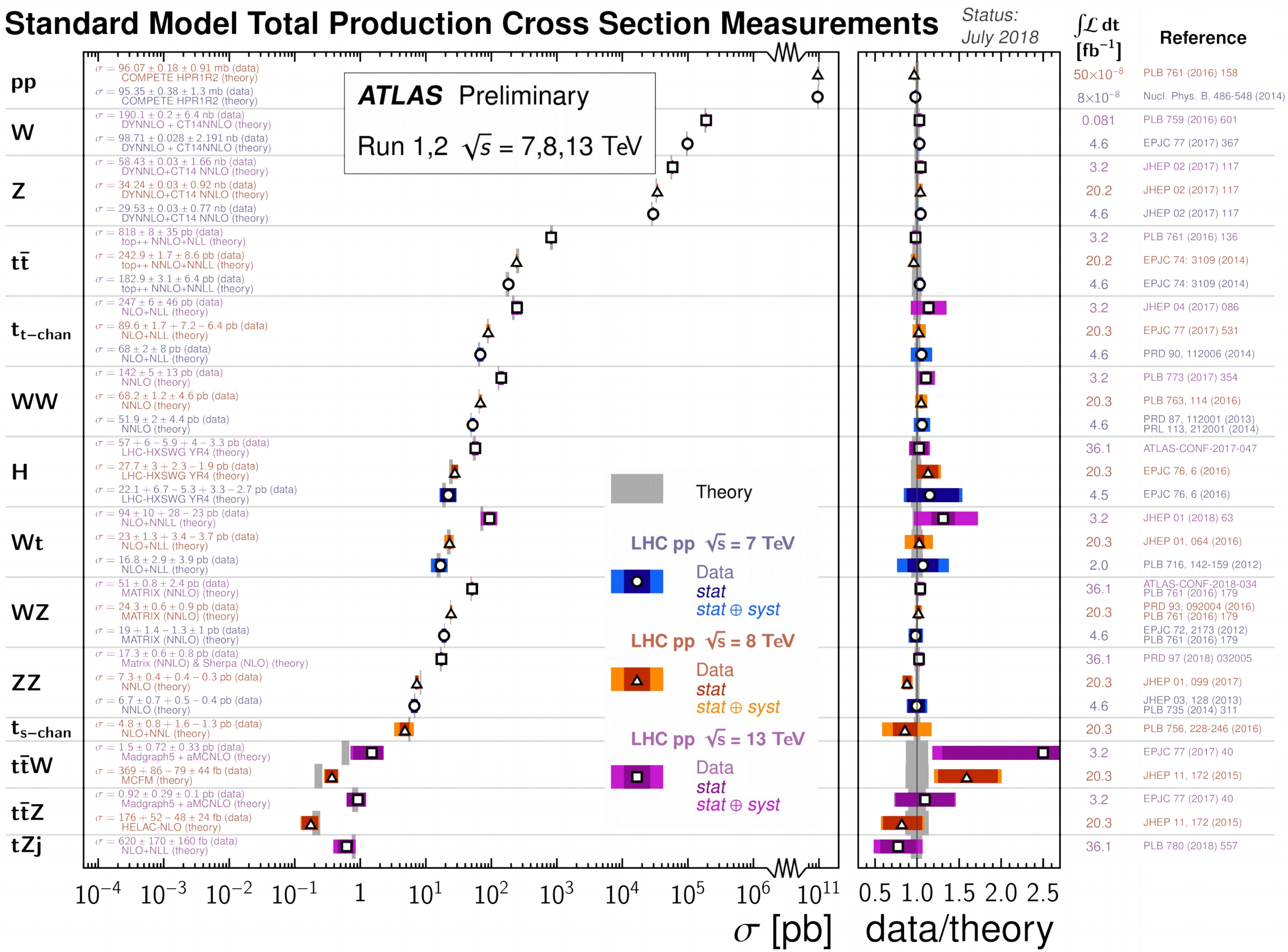

FERMIONS
BOSONS
First Generation
Second Generation
Third Generation
Mass (giga-electron-volts)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-10}
10^{-11}
10^{-12}
Top quark
Z
Higgs
W
Bottom quark
Charm quark
Tau
Strange quark
Muon
Down quark
Up quark
Electron
MASSLESS BOSONS
Muon-neutrino
Tau-neutrino
Electron-neutrino
Photon
Gluon

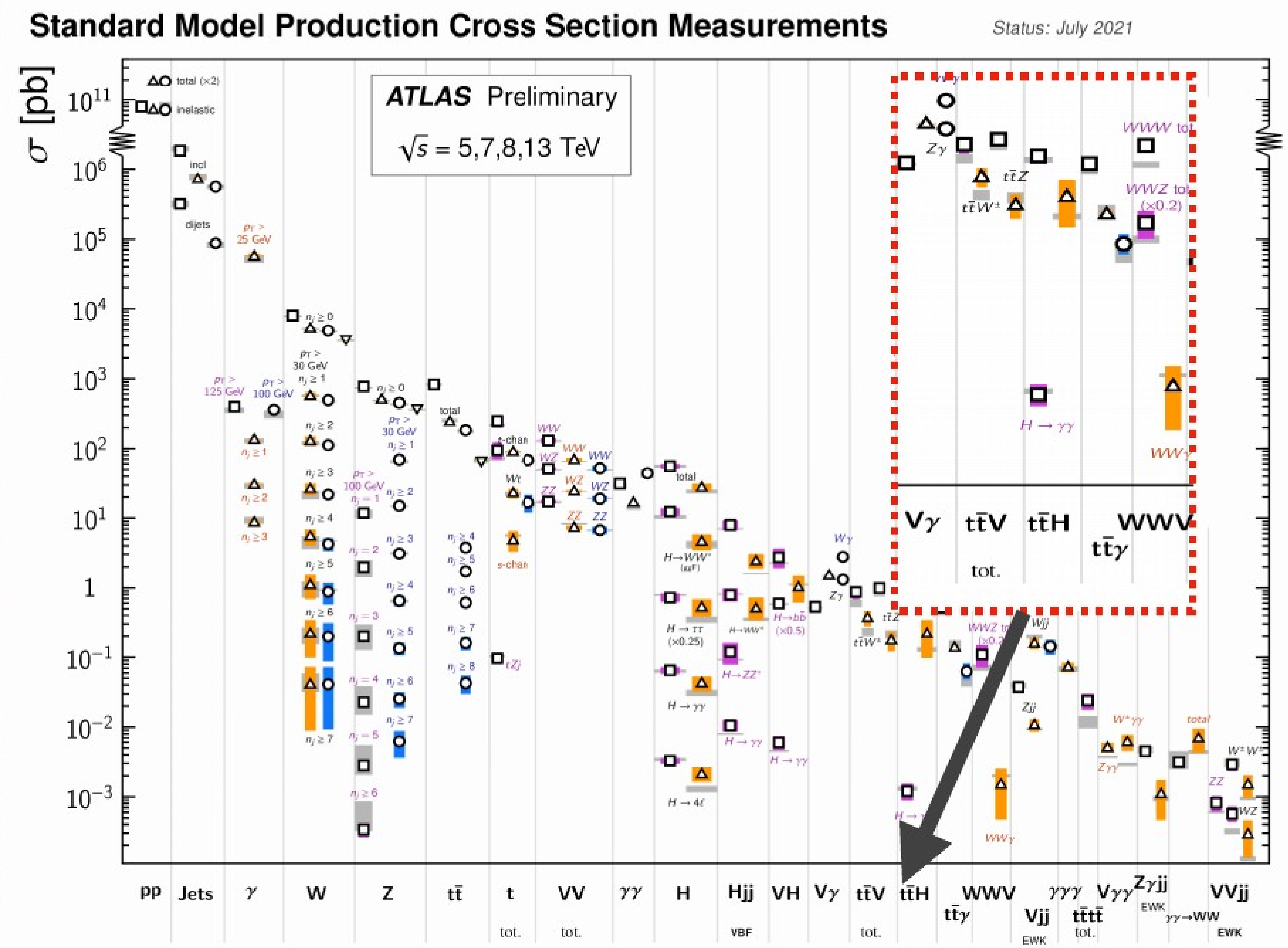

Up Quark
~ 0.002 GeV
Charm Quark
1.25 GeV
Top Quark
175 GeV
Down Quark
~ 0.005 GeV
Strange Quark
~ 0.095 GeV
Bottom Quark
4.2 GeV
These are relative masses not size – they have no measurable size
Electron
0.0005 GeV
Muon
0.105 GeV
Tau
1.78 GeV
For reference:
Proton
0.938 GeV
Electron Neutrino
~ 0
Muon Neutrino
~ 0
Tau Neutrino
~ 0
Originally thought to be massless but now not

Standard Model Total Production Cross Section Measurements

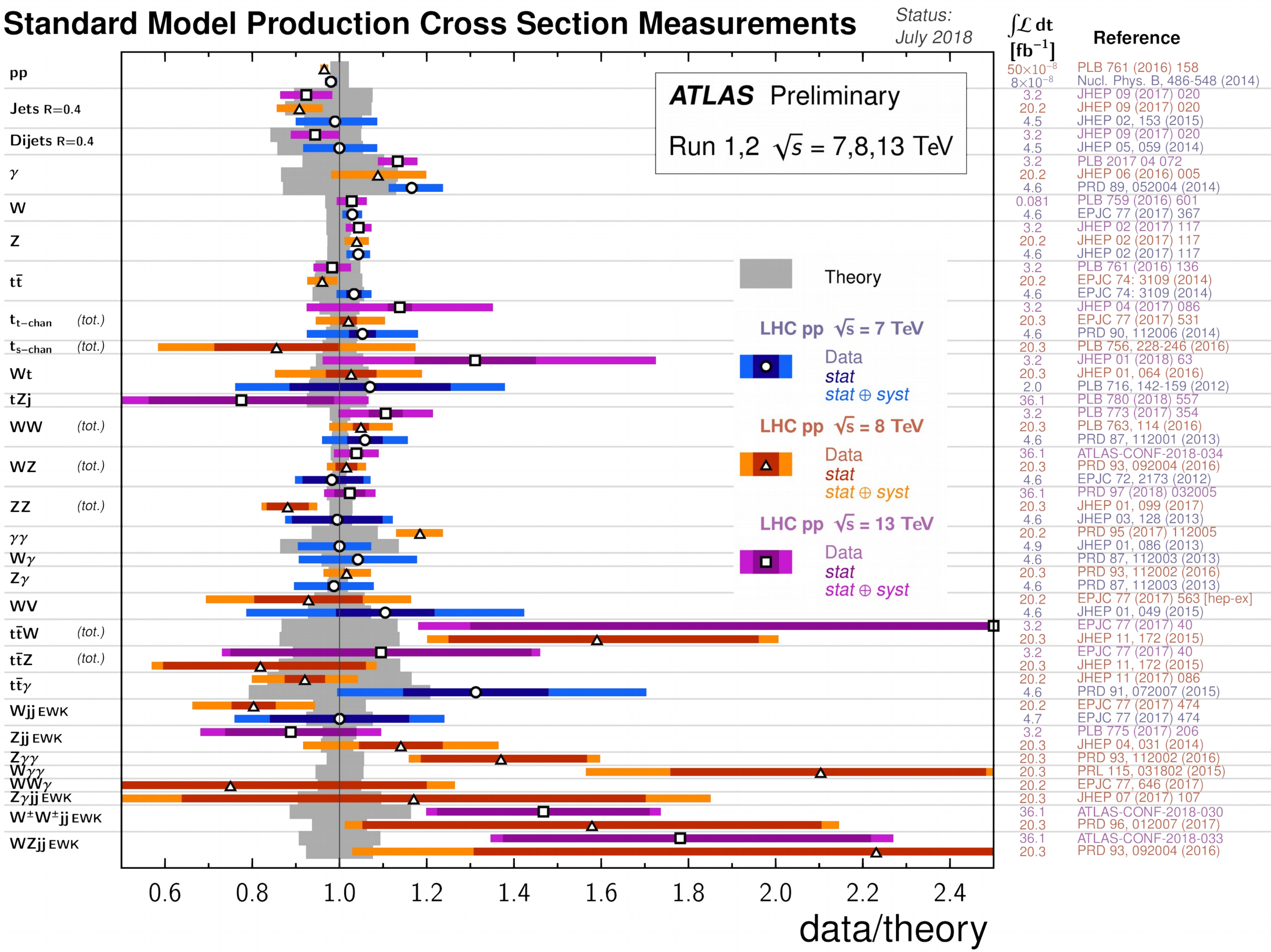
Status: July 2018




Standard Model Total Production Cross Section Measurements
Status: July 2018
ATLAS Preliminary
Run 1,2 √s = 7,8,13 TeV
∫ℒ dt [fb⁻¹]
Reference
pp
σ = 96.07 ± 0.18 ± 0.91 mb (data) COMPETE HPR1R2 (theory)
σ = 95.35 ± 0.38 ± 1.3 mb (data) COMPETE HPR1R2 (theory)
W
σ = 190.1 ± 0.2 ± 6.4 nb (data) DYNNLO + CT14NNLO (theory)
σ = 98.71 ± 0.028 ± 2.191 nb (data) DYNNLO + CT14NNLO (theory)
Z
σ = 58.43 ± 0.03 ± 1.66 nb (data) DYNNLO+CT14 NNLO (theory)
σ = 34.24 ± 0.03 ± 0.92 nb (data) DYNNLO+CT14 NNLO (theory)
σ = 29.53 ± 0.03 ± 0.77 nb (data) DYNNLO+CT14 NNLO (theory)
tt̄
σ = 818 ± 8 ± 35 pb (data) top++ NNLO+NLL (theory)
σ = 242.9 ± 1.7 ± 8.6 pb (data) top++ NNLO+NNLL (theory)
σ = 182.9 ± 3.1 ± 6.4 pb (data) top++ NNLO+NNLL (theory)
tt−chan
σ = 247 ± 6 ± 46 pb (data) NLO+NLL (theory)
σ = 89.6 ± 1.7 + 7.2 − 6.4 pb (data) NLO+NLL (theory)
σ = 68 ± 2 ± 8 pb (data) NLO+NLL (theory)
WW
σ = 142 ± 5 ± 13 pb (data) NNLO (theory)
σ = 68.2 ± 1.2 ± 4.6 pb (data) NNLO (theory)
σ = 51.9 ± 2 ± 4.4 pb (data) NNLO (theory)
H
σ = 57 + 6 − 5.9 + 4 − 3.3 pb (data) LHC-HXSWG YR4 (theory)
σ = 27.7 ± 3 + 2.3 − 1.9 pb (data) LHC-HXSWG YR4 (theory)
σ = 22.1 + 6.7 − 5.3 + 3.3 − 2.7 pb (data) LHC-HXSWG YR4 (theory)
Wt
σ = 94 ± 10 + 28 − 23 pb (data) NLO+NNLL (theory)
σ = 23 ± 1.3 + 3.4 − 3.7 pb (data) NLO+NLL (theory)
σ = 16.8 ± 2.9 ± 3.9 pb (data) NLO+NLL (theory)
WZ
σ = 51 ± 0.8 ± 2.4 pb (data) MATRIX (NNLO) (theory)
σ = 24.3 ± 0.6 ± 0.9 pb (data) MATRIX (NNLO) (theory)
σ = 19 + 1.4 − 1.3 ± 1 pb (data) MATRIX (NNLO) (theory)
ZZ
σ = 17.3 ± 0.6 ± 0.8 pb (data) Matrix (NNLO) & Sherpa (NLO) (theory)
σ = 7.3 ± 0.4 + 0.4 − 0.3 pb (data) NNLO (theory)
σ = 6.7 ± 0.7 + 0.5 − 0.4 pb (data) NNLO (theory)
ts−chan
σ = 4.8 ± 0.8 + 1.6 − 1.3 pb (data) NLO+NNL (theory)
tt̄W
σ = 1.5 ± 0.72 ± 0.33 pb (data) Madgraph5 + aMCNLO (theory)
σ = 369 + 86 − 79 ± 44 fb (data) MCFM (theory)
tt̄Z
σ = 0.92 ± 0.29 ± 0.1 pb (data) Madgraph5 + aMCNLO (theory)
σ = 176 + 52 − 48 ± 24 fb (data) HELAC-NLO (theory)
tZj
σ = 620 ± 170 ± 160 fb (data) NLO+NLL (theory)
Theory
LHC pp √s = 7 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 8 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 13 TeV
Data
stat
stat ⊕ syst
10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 1 10¹ 10² 10³ 10⁴ 10⁵ 10⁶ 10¹¹
σ [pb]
0.5 1.0 1.5 2.0 2.5
data/theory
50×10⁻⁸ PLB 761 (2016) 158
8×10⁻⁸ Nucl. Phys. B, 486-548 (2014)
0.081 PLB 759 (2016) 601
4.6 EPJC 77 (2017) 367
3.2 JHEP 02 (2017) 117
20.2 JHEP 02 (2017) 117
4.6 JHEP 02 (2017) 117
3.2 PLB 761 (2016) 136
20.2 EPJC 74: 3109 (2014)
4.6 EPJC 74: 3109 (2014)
3.2 JHEP 04 (2017) 086
20.3 EPJC 77 (2017) 531
4.6 PRD 90, 112006 (2014)
3.2 PLB 773 (2017) 354
20.3 PLB 763, 114 (2016)
4.6 PRD 87, 112001 (2013) PRL 113, 212001 (2014)
36.1 ATLAS-CONF-2017-047
20.3 EPJC 76, 6 (2016)
4.5 EPJC 76, 6 (2016)
3.2 JHEP 01 (2018) 63
20.3 JHEP 01, 064 (2016)
2.0 PLB 716, 142-159 (2012)
36.1 ATLAS-CONF-2018-034 PLB 761 (2016) 179
20.3 PRD 93, 092004 (2016) PLB 761 (2016) 179
4.6 EPJC 72, 2173 (2012) PLB 761 (2016) 179
36.1 PRD 97 (2018) 032005
20.3 JHEP 01, 099 (2017)
4.6 JHEP 03, 128 (2013) PLB 735 (2014) 311
20.3 PLB 756, 228-246 (2016)
3.2 EPJC 77 (2017) 40
20.3 JHEP 11, 172 (2015)
3.2 EPJC 77 (2017) 40
20.3 JHEP 11, 172 (2015)
36.1 PLB 780 (2018) 557



Standard Model Production Cross Section Measurements
Status: July 2021
ATLAS Preliminary
√s = 5,7,8,13 TeV
σ [pb]
pp
Jets
γ
W
Z
tt̄
t
VV
γγ
H
Hjj
VH
Vγ
tt̄V
tt̄H
tt̄γ
WWV
Vjj
γγγ
Vγγ
tt̄tt̄
Zγjj
γγ→WW
VVjj


Standard Model Production Cross Section Measurements
Status: July 2018
ATLAS Preliminary
Run 1,2 √s = 7,8,13 TeV
Theory
LHC pp √s = 7 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 8 TeV
Data
stat
stat ⊕ syst
LHC pp √s = 13 TeV
Data
stat
stat ⊕ syst
pp
Jets R=0.4
Dijets R=0.4
γ
W
Z
tt̄
tt-chan (tot.)
ts-chan (tot.)
Wt
tZj
WW (tot.)
WZ (tot.)
ZZ (tot.)
γγ
Wγ
Zγ
WV
tt̄W (tot.)
tt̄Z (tot.)
tt̄γ
Wjj EWK
Zjj EWK
Zγγ
Wγγ
WWγ
Zγjj EWK
W±W±jj EWK
WZjj EWK
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
data/theory
∫ℒ dt [fb⁻¹]
Reference
50×10⁻⁸ PLB 761 (2016) 158
8×10⁻⁸ Nucl. Phys. B, 486-548 (2014)
3.2 JHEP 09 (2017) 020
20.2 JHEP 09 (2017) 020
4.5 JHEP 02, 153 (2015)
3.2 JHEP 09 (2017) 020
4.5 JHEP 05, 059 (2014)
3.2 PLB 2017 04 072
20.2 JHEP 06 (2016) 005
4.6 PRD 89, 052004 (2014)
0.081 PLB 759 (2016) 601
4.6 EPJC 77 (2017) 367
3.2 JHEP 02 (2017) 117
20.2 JHEP 02 (2017) 117
4.6 JHEP 02 (2017) 117
3.2 PLB 761 (2016) 136
20.2 EPJC 74: 3109 (2014)
4.6 EPJC 74: 3109 (2014)
3.2 JHEP 04 (2017) 086
20.3 EPJC 77 (2017) 531
4.6 PRD 90, 112006 (2014)
20.3 PLB 756, 228-246 (2016)
3.2 JHEP 01 (2018) 63
20.3 JHEP 01, 064 (2016)
2.0 PLB 716, 142-159 (2012)
36.1 PLB 780 (2018) 557
3.2 PLB 773 (2017) 354
20.3 PLB 763, 114 (2016)
4.6 PRD 87, 112001 (2013)
36.1 ATLAS-CONF-2018-034
20.3 PRD 93, 092004 (2016)
4.6 EPJC 72, 2173 (2012)
36.1 PRD 97 (2018) 032005
20.3 JHEP 01, 099 (2017)
4.6 JHEP 03, 128 (2013)
20.2 PRD 95 (2017) 112005
4.9 JHEP 01, 086 (2013)
4.6 PRD 87, 112003 (2013)
20.3 PRD 93, 112002 (2016)
4.6 PRD 87, 112003 (2013)
20.2 EPJC 77 (2017) 563 [hep-ex]
4.6 JHEP 01, 049 (2015)
3.2 EPJC 77 (2017) 40
20.3 JHEP 11, 172 (2015)
3.2 EPJC 77 (2017) 40
20.3 JHEP 11, 172 (2015)
20.2 JHEP 11 (2017) 086
4.6 PRD 91, 072007 (2015)
20.2 EPJC 77 (2017) 474
4.7 EPJC 77 (2017) 474
3.2 PLB 775 (2017) 206
20.3 JHEP 04, 031 (2014)
20.3 PRD 93, 112002 (2016)
20.3 PRL 115, 031802 (2015)
20.2 EPJC 77, 646 (2017)
20.3 JHEP 07 (2017) 107
36.1 ATLAS-CONF-2018-030
20.3 PRD 96, 012007 (2017)
36.1 ATLAS-CONF-2018-033
20.3 PRD 93, 092004 (2016)

Standard Model Production Cross Section Measurements II

Status: July 2018

ATLAS Preliminary

Run 1,2 $\sqrt{s}$ = 7, 8, 13 TeV

Model	E_{CM} [TeV]	$\int\mathcal{L}\,dt[fb^{-1}]$	Measurement	Theory	Reference
$\sigma^{fid}(W)$ [n_{jet}=2, n_{b-jet}=1]	7	4.6	σ = 2.2 ± 0.2 ± 0.5 pb	σ = 1.69 ± 0.4 pb (MCFM+D.P.I.)	JHEP 06, 084 (2013)
$\sigma^{fid}(W)$ [n_{jet}=1, n_{b-jet}=1]	7	4.6	σ = 5 ± 0.5 ± 1.2 pb	σ = 3.01 ± 0.83 pb (MCFM+D.P.I.)	JHEP 06, 084 (2013)
$\sigma^{fid}(W \to e\nu, \mu\nu)$	13	0.081	σ = 8.03 ± 0.01 ± 0.23 nb	σ = 7.82 + 0.26 − 0.3 nb (DYNNLO + CT14NNLO)	PLB 759 (2016) 601
$\sigma^{fid}(W \to e\nu, \mu\nu)$	8	20.2	σ = 5281.62866 ± 0.70464 ± 265.51798 pb	σ = 5728.10957 + 27.24156 − 49.84255 pb (Sherpa 2.2.1 NLO)	JHEP 05 (2018) 077
$\sigma^{fid}(W \to e\nu, \mu\nu)$	7	4.6	σ = 4.911 ± 0.001 ± 0.092 nb	σ = 4.777 + 0.12 − 0.14 nb (DYNNLO + CT14NNLO)	EPJC 77 (2017) 367
$\sigma^{fid}(W,Z \to qq)$	7	4.6	σ = 8.5 ± 0.8 ± 1.5 pb	σ = 5.1 ± 0.5 pb (MCFM)	NJP 16, 113013 (2014)
$\sigma^{fid}(Z \to bb)$	8	19.5	σ = 2.02 ± 0.2 ± 0.26 pb	σ = 2.02 + 0.25 − 0.19 pb (Powheg)	PLB 738, 25-43 (2014)
$\sigma^{fid}(Z)$ [$n_{b-jet} \geq 2$]	7	4.6	σ = 520 ± 20 + 74 − 72 fb	σ = 410 ± 61 fb (MCFM)	JHEP 10, 141, (2014)
$\sigma^{fid}(Z)$ [$n_{b-jet} \geq 1$]	7	4.6	σ = 4820 ± 60 + 360 − 380 fb	σ = 5230 + 691 − 711 fb (MCFM)	JHEP 10, 141, (2014)
$\sigma^{fid}(Z \to \tau\tau)$	7	4.6	σ = 1690 ± 35 + 95 − 121 fb	σ = 1468.27 + 35.942 − 40.604 fb (MC@NLO + HERAPDFNLO)	PRD 91, 052005 (2015)
$\sigma^{fid}(Z \to ee, \mu\mu)$	13	3.2	σ = 776 ± 1 ± 18 pb	σ = 744 + 22 − 28 pb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117
$\sigma^{fid}(Z \to ee, \mu\mu)$	8	20.2	σ = 506 ± 0.2 ± 11 pb	σ = 486 + 13.6 − 16 pb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117
$\sigma^{fid}(Z \to ee, \mu\mu)$	7	4.6	σ = 451 ± 0.4 ± 8.8 pb	σ = 432 + 12.5 − 13.8 pb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117
γ	13	3.2	σ = 399 ± 0.4 ± 16 pb	σ = 352 + 36 − 30 pb (JETPHOX+MMHT2014 (NLO))	PLB 2017 04 072
γ	8	20.2	σ = 56.8 ± 0.1 + 5.8 − 5.6 nb	σ = 52.2 ± 7 nb (PETER (NLO+N^3LL))	JHEP 06 (2016) 005
γ	7	4.6	σ = 359 ± 3 + 22 − 16 pb	σ = 308 ± 40 pb (JETPHOX (NLO))	PRD 89, 052004 (2014)
$\sigma^{fid}(\gamma+X)$ [1.52< $\lvert\eta^{\gamma}\rvert$ < 2.37]	7	4.6	σ = 123 ± 1 + 9 − 7 pb	σ = 105 ± 15 pb (JETPHOX (NLO))	PRD 89, 052004 (2014)
$\sigma^{fid}(\gamma+X)$ [1.56< $\lvert\eta^{\gamma}\rvert$ < 1.81]	8	20.2	σ = 6.7 ± 0.02 ± 0.71 nb	σ = 5.7 ± 0.7 nb (PETER (NLO+N^3LL))	JHEP 06 (2016) 005
$\sigma^{fid}(\gamma+X)$ [1.81< $\lvert\eta^{\gamma}\rvert$ < 2.37]	8	20.2	σ = 14.3 ± 0.03 + 1.43 − 1.33 nb	σ = 12.7 ± 1.8 nb (PETER (NLO+N^3LL))	JHEP 06 (2016) 005
$\sigma^{fid}(\gamma+X)$ [$\lvert\eta^{\gamma}\rvert$ <1.37]	7	4.6	σ = 236 ± 2 + 13 − 9 pb	σ = 203 ± 25 pb (JETPHOX (NLO))	PRD 89, 052004 (2014)
$\sigma^{fid}(\gamma+X)$ [$\lvert\eta^{\gamma}\rvert$ <0.6]	8	20.2	σ = 15.6 ± 0.02 ± 1.43 nb	σ = 14.8 ± 2 nb (PETER (NLO+N^3LL))	JHEP 06 (2016) 005
$\sigma^{fid}(\gamma+X)$ [0.6< $\lvert\eta^{\gamma}\rvert$ < 1.37]	8	20.2	σ = 20.2 ± 0.03 + 2.24 − 2.14 nb	σ = 19 ± 2.5 nb (PETER (NLO+N^3LL))	JHEP 06 (2016) 005
γ [njet ≥ 1]	13	3.2	σ = 300 ± 0.4 ± 12 pb	σ = 319 + 55 − 46 pb (SHERPA (NLO))	PLB 780 (2018) 578
γ [njet ≥ 1]	8	20.2	σ = 134 ± 0.1 ± 4 pb	σ = 128 + 11 − 9 pb (JETPHOX (NLO))	Nucl. Phys. B, 918 (2017) 257
γ [njet ≥ 2]	8	20.2	σ = 30.4 ± 0.04 ± 1.8 pb	σ = 29.2 + 2.8 − 2.7 pb (NLOBlackhat+CT10)	Nucl. Phys. B, 918 (2017) 257
γ [njet ≥ 3]	8	20.2	σ = 8.7 ± 0.02 ± 0.8 pb	σ = 9.5 + 0.9 − 1.2 pb (NLOBlackhat+CT10)	Nucl. Phys. B, 918 (2017) 257
$t\bar{t}\gamma$	8	20.2	σ = 139 ± 7 ± 17 fb	σ = 151 ± 25 fb (MadGraph+PRD 83 (2011) 074013)	JHEP 11 (2017) 086
$t\bar{t}\gamma$	7	4.6	σ = 63 ± 8 + 17 − 13 fb	σ = 48 ± 10 fb (Whizard+NLO)	PRD 91, 072007 (2015)
$t\bar{t}W$	13	3.2	σ = 1.5 ± 0.72 ± 0.33 pb	σ = 0.6 ± 0.08 pb (Madgraph5 + aMCNLO)	EPJC 77 (2017) 40
$t\bar{t}W$	8	20.3	σ = 369 + 86 − 79 ± 44 fb	σ = 232 ± 32 fb (MCFM)	JHEP 11, 172 (2015)
$\sigma^{fid}(W \to e\nu, \mu\nu)/\sigma^{fid}(Z \to ee, \mu\mu)$ [$n_{jet} \geq 4$]	7	4.6	Ratio = 7.62 ± 0.19 ± 0.94	Ratio = 8.87 ± 0.16 (Blackhat)	EPJC 74: 3168 (2014)
$\sigma^{fid}(W \to e\nu, \mu\nu)/\sigma^{fid}(Z \to ee, \mu\mu)$ [$n_{jet} \geq 3$]	7	4.6	Ratio = 8.18 ± 0.08 ± 0.51	Ratio = 8.97 ± 0.1 (Blackhat)	EPJC 74: 3168 (2014)
$\sigma^{fid}(W \to e\nu, \mu\nu)/\sigma^{fid}(Z \to ee, \mu\mu)$ [$n_{jet} \geq 2$]	7	4.6	Ratio = 8.64 ± 0.04 ± 0.32	Ratio = 8.789 ± 0.046 (Blackhat)	EPJC 74: 3168 (2014)
$\sigma^{fid}(W \to e\nu, \mu\nu)/\sigma^{fid}(Z \to ee, \mu\mu)$ [$n_{jet} \geq 1$]	7	4.6	Ratio = 8.54 ± 0.02 ± 0.25	Ratio = 8.676 ± 0.031 (Blackhat)	EPJC 74: 3168 (2014)
$\sigma^{fid}(W \to e\nu, \mu\nu)/\sigma^{fid}(Z \to ee, \mu\mu)$	13	0.081	Ratio = 10.31 ± 0.04 ± 0.2	Ratio = 10.54 ± 0.12 (DYNNLO + CT14NNLO)	PLB 759 (2016) 601
$\sigma^{fid}(W \to e\nu, \mu\nu)/\sigma^{fid}(Z \to ee, \mu\mu)$	7	4.6	Ratio = 9.78 ± 0.006 ± 0.049	Ratio = 9.92 ± 0.1 (old)	EPJC 77 (2017) 367
W [njet ≥ 7]	8	20.2	σ = 0.041 ± 0.003 ± 0.032 pb	σ = 0.052 + 0.007 − 0.02 pb (Sherpa 2.2.1 NLO)	JHEP 05 (2018) 077
W [njet ≥ 7]	7	4.6	σ = 0.041 ± 0.0068 ± 0.031 pb		EPJC 75, 82 (2015)
W [njet ≥ 6]	8	20.2	σ = 0.22 ± 0.006 ± 0.121 pb	σ = 0.239 + 0.03 − 0.084 pb (Sherpa 2.2.1 NLO)	JHEP 05 (2018) 077
W [njet ≥ 6]	7	4.6	σ = 0.199 ± 0.019 ± 0.11 pb		EPJC 75, 82 (2015)
W [njet ≥ 5]	8	20.2	σ = 1.107 ± 0.013 ± 0.423 pb	σ = 1.1 + 0.13 − 0.38 pb (Sherpa 2.2.1 NLO)	JHEP 05 (2018) 077
W [njet ≥ 5]	7	4.6	σ = 0.877 ± 0.032 ± 0.301 pb	σ = 0.933 ± 0.027 pb (Blackhat)	EPJC 75, 82 (2015)
W [njet ≥ 4]	8	20.2	σ = 5.47 ± 0.03 ± 1.47 pb	σ = 5 + 0.5 − 1.4 pb (Sherpa 2.2.1 NLO)	JHEP 05 (2018) 077
W [njet ≥ 4]	7	4.6	σ = 4.241 ± 0.056 ± 0.885 pb	σ = 4.67 ± 0.06 pb (Blackhat)	EPJC 75, 82 (2015)
W [njet ≥ 3]	8	20.2	σ = 26.38 ± 0.06 ± 5.34 pb	σ = 23.6 + 1.3 − 5 pb (Sherpa 2.2.1 NLO)	JHEP 05 (2018) 077
W [njet ≥ 3]	7	4.6	σ = 21.82 ± 0.1 ± 3.23 pb	σ = 23.47 ± 0.22 pb (Blackhat)	EPJC 75, 82 (2015)
W [njet ≥ 2]	8	20.2	σ = 128.35 ± 0.12 ± 20.39 pb	σ = 126.5 + 2.1 − 14.4 pb (Sherpa 2.2.1 NLO)	JHEP 05 (2018) 077
W [njet ≥ 2]	7	4.6	σ = 111.7 ± 0.2 ± 12.2 pb	σ = 111.98 ± 0.44 pb (Blackhat)	EPJC 75, 82 (2015)
W [njet ≥ 1]	8	20.2	σ = 564.71 ± 0.24 ± 72.13 pb	σ = 584 + 8 − 37 pb (Sherpa 2.2.1 NLO)	JHEP 05 (2018) 077
W [njet ≥ 1]	7	4.6	σ = 493.8 ± 0.5 ± 45.1 pb	σ = 474.22 ± 0.84 pb (Blackhat)	EPJC 75, 82 (2015)
W	13	0.081	σ = 190.1 ± 0.2 ± 6.4 nb	σ = 184.9 + 6 − 6.1 nb (DYNNLO + CT14NNLO)	PLB 759 (2016) 601
W	7	4.6	σ = 98.71 ± 0.028 ± 2.191 nb	σ = 95.9 ± 2.9 nb (DYNNLO + CT14NNLO)	EPJC 77 (2017) 367
Z [njet ≥ 7]	13	3.2	σ = 0.0178 ± 0.0019 ± 0.0049 pb		ATLAS-CONF-2016-04
Z [njet ≥ 7]	7	4.6	σ = 0.0062 ± 0.001456 ± 0.00214 pb		JHEP 07, 032 (2013)
Z [njet ≥ 6]	13	3.2	σ = 0.079 ± 0.004 ± 0.018 pb		EPJC 77 (2017) 361
Z [njet ≥ 6]	7	4.6	σ = 0.0253 ± 0.00265 ± 0.00595 pb		JHEP 07, 032 (2013)
Z [njet ≥ 5]	13	3.2	σ = 0.36 ± 0.01 ± 0.07 pb		EPJC 77 (2017) 361
Z [njet ≥ 5]	7	4.6	σ = 0.135 ± 0.006 ± 0.027 pb		JHEP 07, 032 (2013)
Z [njet ≥ 4]	13	3.2	σ = 1.48 ± 0.02 ± 0.23 pb	σ = 1.33 + 0.04 − 0.15 pb (Blackhat+Sherpa)	EPJC 77 (2017) 361
Z [njet ≥ 4]	7	4.6	σ = 0.65 ± 0.01 ± 0.11 pb	σ = 0.646 ± 0.031 pb (Blackhat)	JHEP 07, 032 (2013)
Z [njet ≥ 3]	13	3.2	σ = 6.2 ± 0.04 ± 0.83 pb	σ = 5.88 + 0.1 − 0.39 pb (Blackhat+Sherpa)	EPJC 77 (2017) 361
Z [njet ≥ 3]	7	4.6	σ = 3.09 ± 0.03 ± 0.4 pb	σ = 3.1 ± 0.14 pb (Blackhat)	JHEP 07, 032 (2013)
Z [njet ≥ 2]	13	3.2	σ = 27 ± 0.1 ± 2.9 pb	σ = 26.08 + 0.45 − 1.24 pb (BlackHat+Sherpa)	EPJC 77 (2017) 361
Z [njet ≥ 2]	7	4.6	σ = 15.05 ± 0.06 ± 1.51 pb	σ = 14.9 ± 0.4 pb (Blackhat)	JHEP 07, 032 (2013)
Z [njet ≥ 1]	13	3.2	σ = 116 ± 0.3 ± 10 pb	σ = 109.9 + 4.54 − 4.16 pb (Blackhat+Sherpa)	EPJC 77 (2017) 361
Z [njet ≥ 1]	7	4.6	σ = 68.84 ± 0.13 ± 5.15 pb	σ = 64.8 ± 3.1 pb (Blackhat)	JHEP 07, 032 (2013)
Z	13	3.2	σ = 58.43 ± 0.03 ± 1.66 nb	σ = 55.96 + 1.5 − 1.7 nb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117
Z	8	20.2	σ = 34.24 ± 0.03 ± 0.92 nb	σ = 32.94 + 0.8 − 0.92 nb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117
Z	7	4.6	σ = 29.53 ± 0.03 ± 0.77 nb	σ = 28.31 + 0.68 − 0.8 nb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117

Standard Model Production Cross Section Measurements III

ATLAS Preliminary

Run 1,2 $\sqrt{s}$ = 7, 8, 13 TeV

Status: July 2018

Model	E_{CM} [TeV]	$\int\mathcal{L}$ dt[fb^{-1}]	Measurement	Theory	Reference
pp	8	50×10^{-8}	$\sigma = 96.07 \pm 0.18 \pm 0.91$ mb	$\sigma = 99.55 \pm 2.14$ mb (COMPETE HPR1R2)	PLB 761 (2016) 158
pp	7	8×10^{-8}	$\sigma = 95.35 \pm 0.38 \pm 1.3$ mb	$\sigma = 97.26 \pm 2.12$ mb (COMPETE HPR1R2)	Nucl. Phys. B, 486-548 (2014)
pp inelastic	13	6×10^{-8}	$\sigma = 79.3 \pm 2.9$ mb	$\sigma = 78.4 \pm 2$ mb (Schuler/Sjöstrand)	PRL 117, 182002 (2016)
pp inelastic	8	50×10^{-8}	$\sigma = 71.73 \pm 0.15 \pm 0.69$ mb	$\sigma = 73 \pm 2$ mb (Schuler/Sjöstrand)	PLB 761 (2016) 158
pp inelastic	7	8×10^{-8}	$\sigma = 71.34 \pm 0.36 \pm 0.83$ mb	$\sigma = 71.5 + 20 - 2$ mb (Schuler/Sjöstrand)	Nucl. Phys. B, 486-548 (2014)
$2.5 < y^* < 3.0$, $2 < m_{jj} < 5$ TeV	13	3.2	$\sigma = 850 \pm 53 + 68 - 91$ pb	$\sigma = 955 + 56 - 199$ pb (NLOJet++, CT14)	JHEP 09 (2017) 020
$2.5 < y^* < 3.0$, $2 < m_{jj} < 5$ TeV	7	4.5	$\sigma = 16 \pm 2 + 5.4 - 4.3$ pb	$\sigma = 18.4 + 2.2 - 4.3$ pb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$2.0 < y^* < 2.5$, $1.3 < m_{jj} < 5$ TeV	13	3.2	$\sigma = 6.39 \pm 0.14 + 0.47 - 0.54$ nb	$\sigma = 6.7 + 0.5 - 1.3$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$2.0 < y^* < 2.5$, $1.3 < m_{jj} < 5$ TeV	7	4.5	$\sigma = 371 \pm 9.7 + 81.5 - 72.1$ pb	$\sigma = 410.6 + 31 - 77.8$ pb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$1.5 < y^* < 2.0$, $0.8 < m_{jj} < 4.6$ TeV	13	3.2	$\sigma = 16.13 \pm 0.17 \pm 1.09$ nb	$\sigma = 17.4 + 0.7 - 3.3$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$1.5 < y^* < 2.0$, $0.8 < m_{jj} < 4.6$ TeV	7	4.5	$\sigma = 3.57 \pm 0.04 + 0.51 - 0.49$ nb	$\sigma = 3.7 + 0.21 - 0.62$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$1.0 < y^* < 1.5$, $0.5 < m_{jj} < 4.6$ TeV	13	3.2	$\sigma = 68.7 \pm 0.4 + 4 - 4.2$ nb	$\sigma = 68.5 + 7.7 - 10.3$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$1.0 < y^* < 1.5$, $0.5 < m_{jj} < 4.6$ TeV	7	4.5	$\sigma = 10.12 \pm 0.07 + 1.02 - 1.03$ nb	$\sigma = 10.2 + 0.5 - 1.5$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$0.5 < y^* < 1.0$, $0.3 < m_{jj} < 4.3$ TeV	13	3.2	$\sigma = 117.6 \pm 0.5 + 6.8 - 6.9$ nb	$\sigma = 127.3 + 5.7 - 19$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$0.5 < y^* < 1.0$, $0.3 < m_{jj} < 4.3$ TeV	7	4.5	$\sigma = 37.33 \pm 0.2 + 3.25 - 3.03$ nb	$\sigma = 37.3 + 1.6 - 5.1$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$y^* < 0.5$, $0.3 < m_{jj} < 4.3$ TeV	13	3.2	$\sigma = 111.2 \pm 0.4 + 6.2 - 6.3$ nb	$\sigma = 118.6 + 5.5 - 18.8$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$y^* < 0.5$, $0.3 < m_{jj} < 4.3$ TeV	7	4.5	$\sigma = 35.47 \pm 0.15 + 2.79 - 2.66$ nb	$\sigma = 35.3 + 1.5 - 5.1$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
Dijet R=0.4, $\lvert y\rvert < 3.0$, $y^* < 3.0$	13	3.2	$\sigma = 321 \pm 0.8 + 18.6 - 19$ nb	$\sigma = 340 + 17 - 54$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
Dijet R=0.4, $\lvert y\rvert < 3.0$, $y^* < 3.0$	7	4.5	$\sigma = 86.87 \pm 0.26 + 7.56 - 7.2$ nb	$\sigma = 86.9 + 4.7 - 12.4$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$2.5 < y^* < 3.0$, $2 < m_{jj} < 5$ TeV	7	4.5	$\sigma = 26.9 \pm 4.2 + 7.7 - 6.4$ pb	$\sigma = 23.5 + 2.7 - 2.8$ pb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$2.0 < y^* < 2.5$, $1.3 < m_{jj} < 5$ TeV	7	4.5	$\sigma = 505 \pm 15.1 + 102.4 - 92.4$ pb	$\sigma = 526.9 + 37.5 - 46.3$ pb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$1.5 < y^* < 2.0$, $0.8 < m_{jj} < 4.6$ TeV	7	4.5	$\sigma = 4.93 \pm 0.06 + 0.69 - 0.65$ nb	$\sigma = 4.78 + 0.23 - 0.34$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$1.0 < y^* < 1.5$, $0.5 < m_{jj} < 4.6$ TeV	7	4.5	$\sigma = 13.82 \pm 0.11 + 1.44 - 1.42$ nb	$\sigma = 13.2 + 0.5 - 0.8$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$0.5 < y^* < 1.0$, $0.3 < m_{jj} < 4.3$ TeV	7	4.5	$\sigma = 51.47 \pm 0.32 + 4.76 - 4.44$ nb	$\sigma = 48.7 + 1.3 - 2.5$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$y^* < 0.5$, $0.3 < m_{jj} < 4.3$ TeV	7	4.5	$\sigma = 48.21 \pm 0.23 + 4.03 - 3.8$ nb	$\sigma = 46.1 + 1.2 - 2.5$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
Dijet R=0.6, $\lvert y\rvert < 3.0$, $y^* < 3.0$	7	4.5	$\sigma = 119 \pm 0.4 + 10.9 - 10.3$ nb	$\sigma = 113.3 + 3.1 - 6.1$ nb (NLOJet++, CT10)	JHEP 05, 059 (2014)
$2.5 < \lvert y\rvert < 3.0$, $p_T > 100$ GeV	13	3.2	$\sigma = 157 \pm 1 \pm 13$ nb	$\sigma = 165 + 13 - 18$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$2.5 < \lvert y\rvert < 3.0$, $p_T > 100$ GeV	8	20.2	$\sigma = 45.3 \pm 0.3 + 3.9 - 3.8$ nb	$\sigma = 50.4 + 4.1 - 7.4$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$2.5 < \lvert y\rvert < 3.0$, $p_T > 100$ GeV	7	4.5	$\sigma = 29.13 \pm 0.31 + 7.5 - 6.38$ nb	$\sigma = 32.6 + 2.1 - 3.2$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$2.0 < \lvert y\rvert < 2.5$, $p_T > 100$ GeV	13	3.2	$\sigma = 222 \pm 1 + 19 - 20$ nb	$\sigma = 241 + 19 - 26$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$2.0 < \lvert y\rvert < 2.5$, $p_T > 100$ GeV	8	20.2	$\sigma = 79.8 \pm 0.4 \pm 5.4$ nb	$\sigma = 88.8 + 6.4 - 11.7$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$2.0 < \lvert y\rvert < 2.5$, $p_T > 100$ GeV	7	4.5	$\sigma = 57.1 \pm 0.4 + 10.4 - 9.1$ nb	$\sigma = 60.7 + 3.3 - 5.1$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$1.5 < \lvert y\rvert < 2.0$, $p_T > 100$ GeV	13	3.2	$\sigma = 288 \pm 1 \pm 21$ nb	$\sigma = 317 + 24 - 33$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$1.5 < \lvert y\rvert < 2.0$, $p_T > 100$ GeV	8	20.2	$\sigma = 111 \pm 0.4 + 6.9 - 6.8$ nb	$\sigma = 124.7 + 9.5 - 15.4$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$1.5 < \lvert y\rvert < 2.0$, $p_T > 100$ GeV	7	4.5	$\sigma = 83.5 \pm 0.6 + 11.1 - 9.7$ nb	$\sigma = 88.3 + 4.7 - 7.1$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$1.0 < \lvert y\rvert < 1.5$, $p_T > 100$ GeV	13	3.2	$\sigma = 350 \pm 2 \pm 24$ nb	$\sigma = 383 + 28 - 38$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$1.0 < \lvert y\rvert < 1.5$, $p_T > 100$ GeV	8	20.2	$\sigma = 145.4 \pm 0.5 + 8.9 - 8.6$ nb	$\sigma = 157 + 12 - 19$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$1.0 < \lvert y\rvert < 1.5$, $p_T > 100$ GeV	7	4.5	$\sigma = 112.2 \pm 0.7 + 11 - 10.2$ nb	$\sigma = 113.1 + 5.8 - 9.2$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$0.5 < \lvert y\rvert < 1.0$, $p_T > 100$ GeV	13	3.2	$\sigma = 401 \pm 2 \pm 24$ nb	$\sigma = 431 + 33 - 44$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$0.5 < \lvert y\rvert < 1.0$, $p_T > 100$ GeV	8	20.2	$\sigma = 167.9 \pm 0.5 + 9.6 - 9.4$ nb	$\sigma = 182 + 14 - 23$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$0.5 < \lvert y\rvert < 1.0$, $p_T > 100$ GeV	7	4.5	$\sigma = 136.9 \pm 0.8 + 10.9 - 10.5$ nb	$\sigma = 132.3 + 6.9 - 10.7$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$\lvert y\rvert < 0.5$, $p_T > 100$ GeV	13	3.2	$\sigma = 427 \pm 2 \pm 24$ nb	$\sigma = 459 + 35 - 49$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$\lvert y\rvert < 0.5$, $p_T > 100$ GeV	8	20.2	$\sigma = 177 \pm 0.5 + 9.6 - 9.4$ nb	$\sigma = 196 + 14 - 25$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$\lvert y\rvert < 0.5$, $p_T > 100$ GeV	7	4.5	$\sigma = 145.1 \pm 0.8 + 10.7 - 10.6$ nb	$\sigma = 142.7 + 7.4 - 11.5$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
Incl. jet R=0.4, $\lvert y\rvert < 3.0$	13	3.2	$\sigma = 1845 \pm 4 + 119 - 120$ nb	$\sigma = 1997 + 152 - 208$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
Incl. jet R=0.4, $\lvert y\rvert < 3.0$	8	20.2	$\sigma = 726.4 \pm 1.1 + 42.7 - 41.8$ nb	$\sigma = 800 + 59 - 100$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
Incl. jet R=0.4, $\lvert y\rvert < 3.0$	7	4.5	$\sigma = 563.9 \pm 1.5 + 55.4 - 51.4$ nb	$\sigma = 569.8 + 29.5 - 46.3$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$2.5 < \lvert y\rvert < 3.0$, $p_T > 100$ GeV	8	20.2	$\sigma = 58.6 \pm 0.8 + 5.8 - 5.6$ nb	$\sigma = 59.8 + 4.1 - 6.6$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$2.5 < \lvert y\rvert < 3.0$, $p_T > 100$ GeV	7	4.5	$\sigma = 37.5 \pm 0.4 + 9.4 - 8.4$ nb	$\sigma = 36.9 + 3.7 - 2.4$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$2.0 < \lvert y\rvert < 2.5$, $p_T > 100$ GeV	8	20.2	$\sigma = 100.5 \pm 1.1 + 8.6 - 8.3$ nb	$\sigma = 105.8 + 6.6 - 11.4$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$2.0 < \lvert y\rvert < 2.5$, $p_T > 100$ GeV	7	4.5	$\sigma = 69.7 \pm 0.6 + 13.5 - 12.7$ nb	$\sigma = 68.6 + 6.3 - 4.3$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$1.5 < \lvert y\rvert < 2.0$, $p_T > 100$ GeV	8	20.2	$\sigma = 140.3 \pm 1.2 + 11.1 - 10.8$ nb	$\sigma = 149.8 + 9.4 - 14.6$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$1.5 < \lvert y\rvert < 2.0$, $p_T > 100$ GeV	7	4.5	$\sigma = 105.5 \pm 0.7 + 16 - 15.2$ nb	$\sigma = 100.2 + 9.2 - 5.9$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$1.0 < \lvert y\rvert < 1.5$, $p_T > 100$ GeV	8	20.2	$\sigma = 190.7 \pm 1.4 + 15 - 14.6$ nb	$\sigma = 189 + 11 - 18$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$1.0 < \lvert y\rvert < 1.5$, $p_T > 100$ GeV	7	4.5	$\sigma = 139.8 \pm 0.9 + 16.5 - 16.2$ nb	$\sigma = 128.8 + 11.7 - 7.4$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$0.5 < \lvert y\rvert < 1.0$, $p_T > 100$ GeV	8	20.2	$\sigma = 221.6 \pm 1.5 + 16.5 - 15.8$ nb	$\sigma = 220 + 13 - 21$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$0.5 < \lvert y\rvert < 1.0$, $p_T > 100$ GeV	7	4.5	$\sigma = 172.7 \pm 0.9 + 15.9 - 14.3$ nb	$\sigma = 151 + 13.8 - 8.6$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$\lvert y\rvert < 0.5$, $p_T > 100$ GeV	8	20.2	$\sigma = 239.3 \pm 1.6 + 16.5 - 15.9$ nb	$\sigma = 237 + 14 - 24$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
$\lvert y\rvert < 0.5$, $p_T > 100$ GeV	7	4.5	$\sigma = 187 \pm 0.9 + 15.1 - 15$ nb	$\sigma = 162.9 + 15 - 9.2$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
Incl. jet R=0.6, $\lvert y\rvert < 3.0$	8	20.2	$\sigma = 951 \pm 3 + 72 - 70$ nb	$\sigma = 961 + 58 - 95$ nb (NLOJet++, CT14)	JHEP 09 (2017) 020
Incl. jet R=0.6, $\lvert y\rvert < 3.0$	7	4.5	$\sigma = 712.3 \pm 1.9 + 79.9 - 76$ nb	$\sigma = 648.3 + 58.96 - 37.1$ nb (NLOJet++, CT10)	JHEP 02, 153 (2015)
$t\bar{t}$	13	3.2	$\sigma = 818 \pm 8 \pm 35$ pb	$\sigma = 832 + 40 - 46$ pb (top++ NNLO+NLL)	PLB 761 (2016) 136
$t\bar{t}$	8	20.2	$\sigma = 242.9 \pm 1.7 \pm 8.6$ pb	$\sigma = 252.9 + 13.3 - 14.5$ pb (top++ NNLO+NNLL)	EPJC 74: 3109 (2014)
$t\bar{t}$	7	4.6	$\sigma = 182.9 \pm 3.1 \pm 6.4$ pb	$\sigma = 177 + 10 - 11$ pb (top++ NNLO+NNLL)	EPJC 74: 3109 (2014)
$t\bar{t}$ [$n_{jet} = 3$]	7	4.7	$\sigma = 4.34 \pm 0.06 \pm 0.64$ pb		JHEP 01, 020 (2015)
$t\bar{t}$ [$n_{jet} = 4$]	7	4.7	$\sigma = 3.76 \pm 0.05 \pm 0.27$ pb		JHEP 01, 020 (2015)
$t\bar{t}$ [$n_{jet} = 5$]	7	4.7	$\sigma = 1.72 \pm 0.04 \pm 0.16$ pb		JHEP 01, 020 (2015)
$t\bar{t}$ [$n_{jet} = 6$]	7	4.7	$\sigma = 0.611 \pm 0.024 \pm 0.083$ pb		JHEP 01, 020 (2015)
$t\bar{t}$ [$n_{jet} = 7$]	7	4.7	$\sigma = 0.161 \pm 0.007 \pm 0.033$ pb		JHEP 01, 020 (2015)
$t\bar{t}$ [$n_{jet} \geq 8$]	7	4.7	$\sigma = 0.0425 \pm 0.004 \pm 0.012$ pb		JHEP 01, 020 (2015)
tZj	13	36.1	$\sigma = 620 \pm 170 \pm 160$ fb	$\sigma = 800 + 50 - 60$ fb (NLO+NLL)	PLB 780 (2018) 557
Wt	13	3.2	$\sigma = 94 \pm 10 + 28 - 23$ pb	$\sigma = 71.7 \pm 3.9$ pb (NLO+NNLL)	JHEP 01 (2018) 63
Wt	8	20.3	$\sigma = 23 \pm 1.3 + 3.4 - 3.7$ pb	$\sigma = 22.4 \pm 1.5$ pb (NLO+NNLL)	JHEP 01, 064 (2016)
Wt	7	2.0	$\sigma = 16.8 \pm 2.9 \pm 3.9$ pb	$\sigma = 15.7 \pm 1.1$ pb (NLO+NNLL)	PLB 716, 142-159 (2012)
t_{t-chan}	13	3.2	$\sigma = 247 \pm 6 \pm 46$ pb	$\sigma = 217 \pm 10$ pb (NLO+NLL)	JHEP 04 (2017) 086
t_{t-chan}	8	20.3	$\sigma = 89.6 \pm 1.7 + 7.2 - 6.4$ pb	$\sigma = 87.8 + 3.4 - 1.9$ pb (NLO+NLL)	EPJC 77 (2017) 531
t_{t-chan}	7	4.6	$\sigma = 68 \pm 2 \pm 8$ pb	$\sigma = 64.6 + 2.7 - 2$ pb (NLO+NLL)	PRD 90, 112006 (2014)
t_{s-chan}	8	20.3	$\sigma = 4.8 \pm 0.8 + 1.6 - 1.3$ pb	$\sigma = 5.61 \pm 0.22$ pb (NLO+NNL)	PLB 756, 228-246 (2016)

The LHC tests the Standard Model
to a very high precision
many of these measurements
have percent precision
and some even permille
[error of 19 MeV on the W mass]

Celebrating the Standard Model

Those are impressive achievements

a single theory, developed long time ago
based on rather simple building blocks

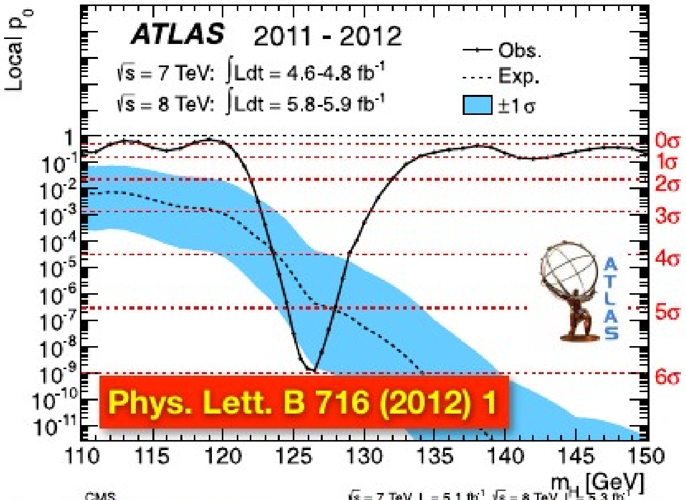
can predict Nature's behaviour
in a huge range of energies
with unparalleled precision
in many kinematic situations
involving numerous different particles

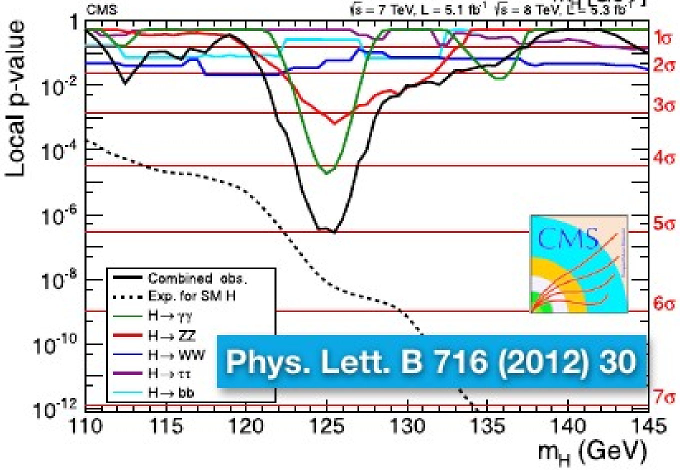
So why aren't we just happy?

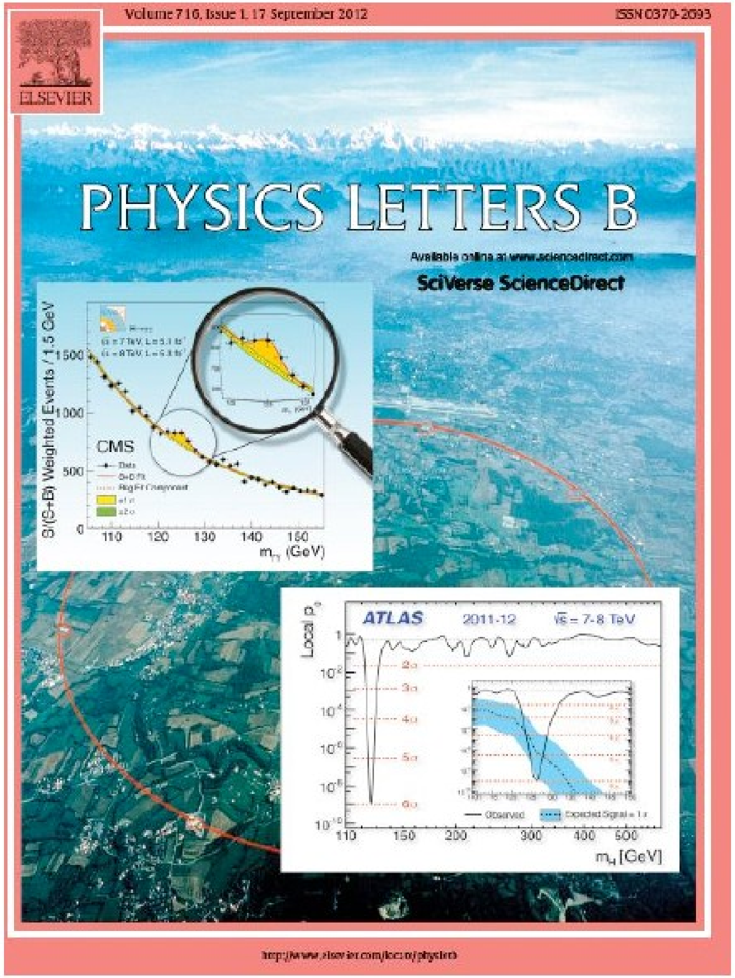
So here we are

Higgs Boson

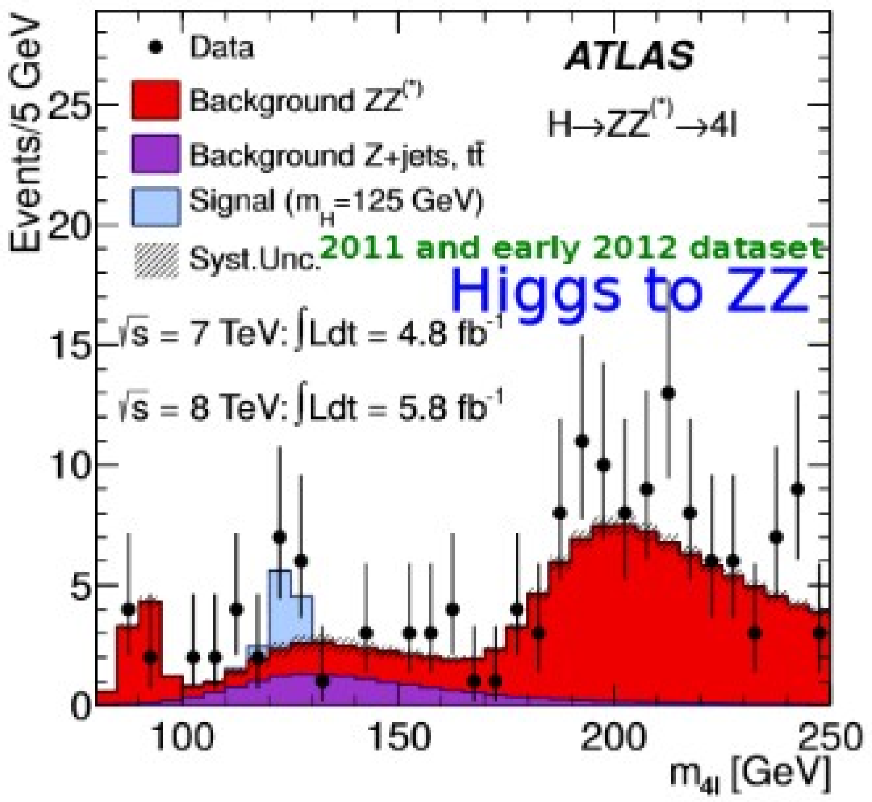
A New Boson Discovery

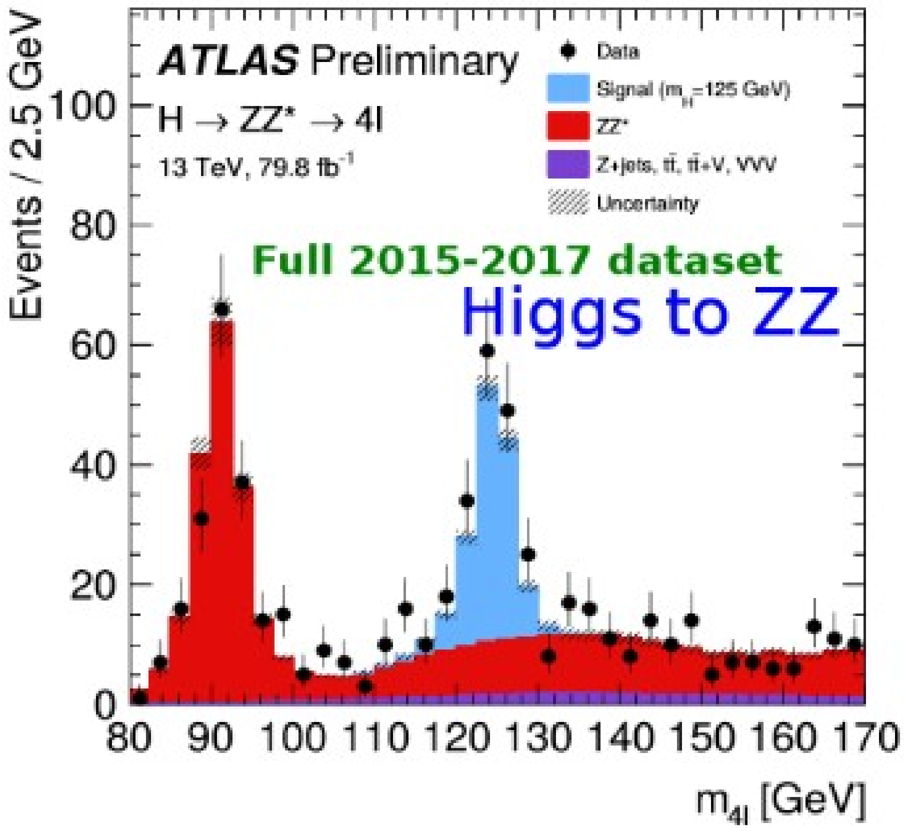




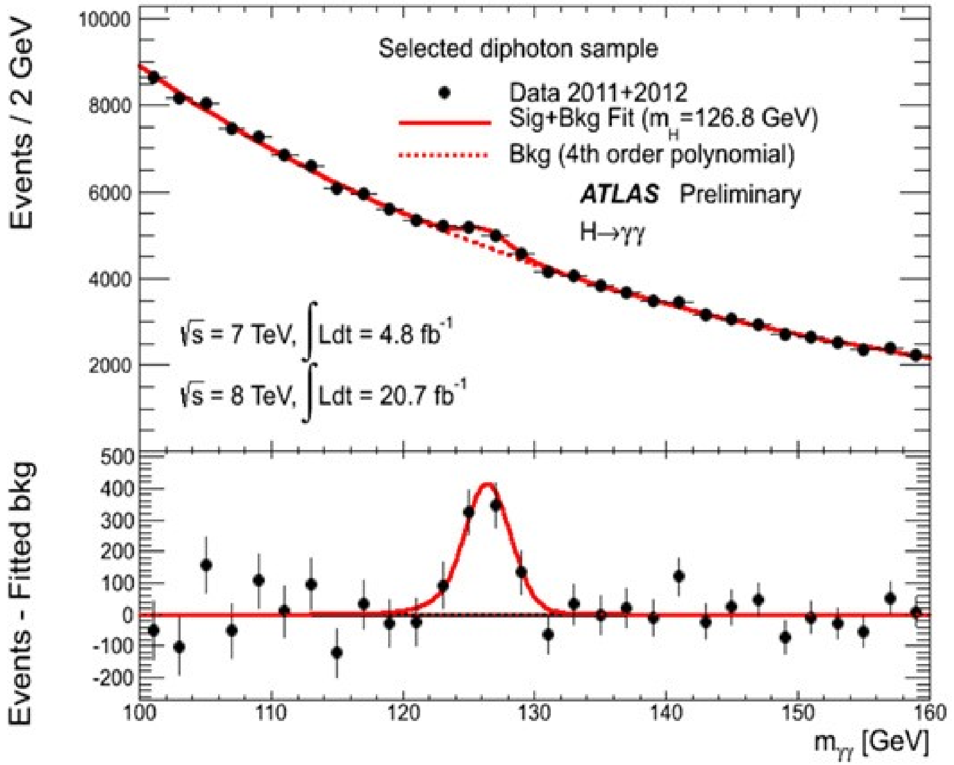


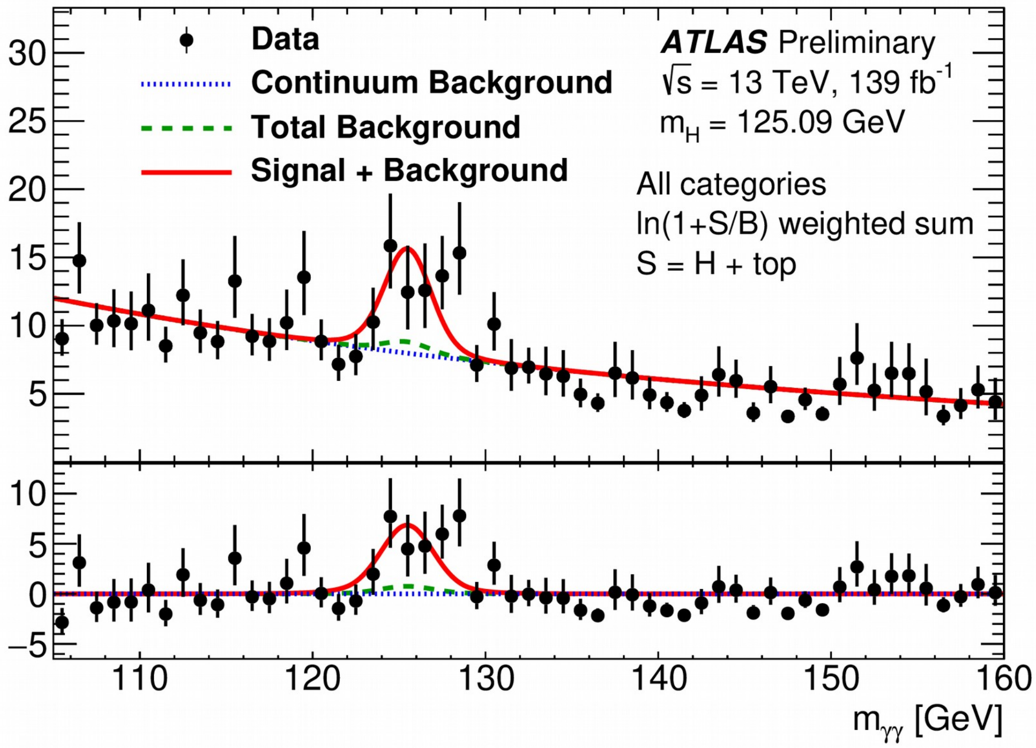
- We have also measured these boson couplings more precisely



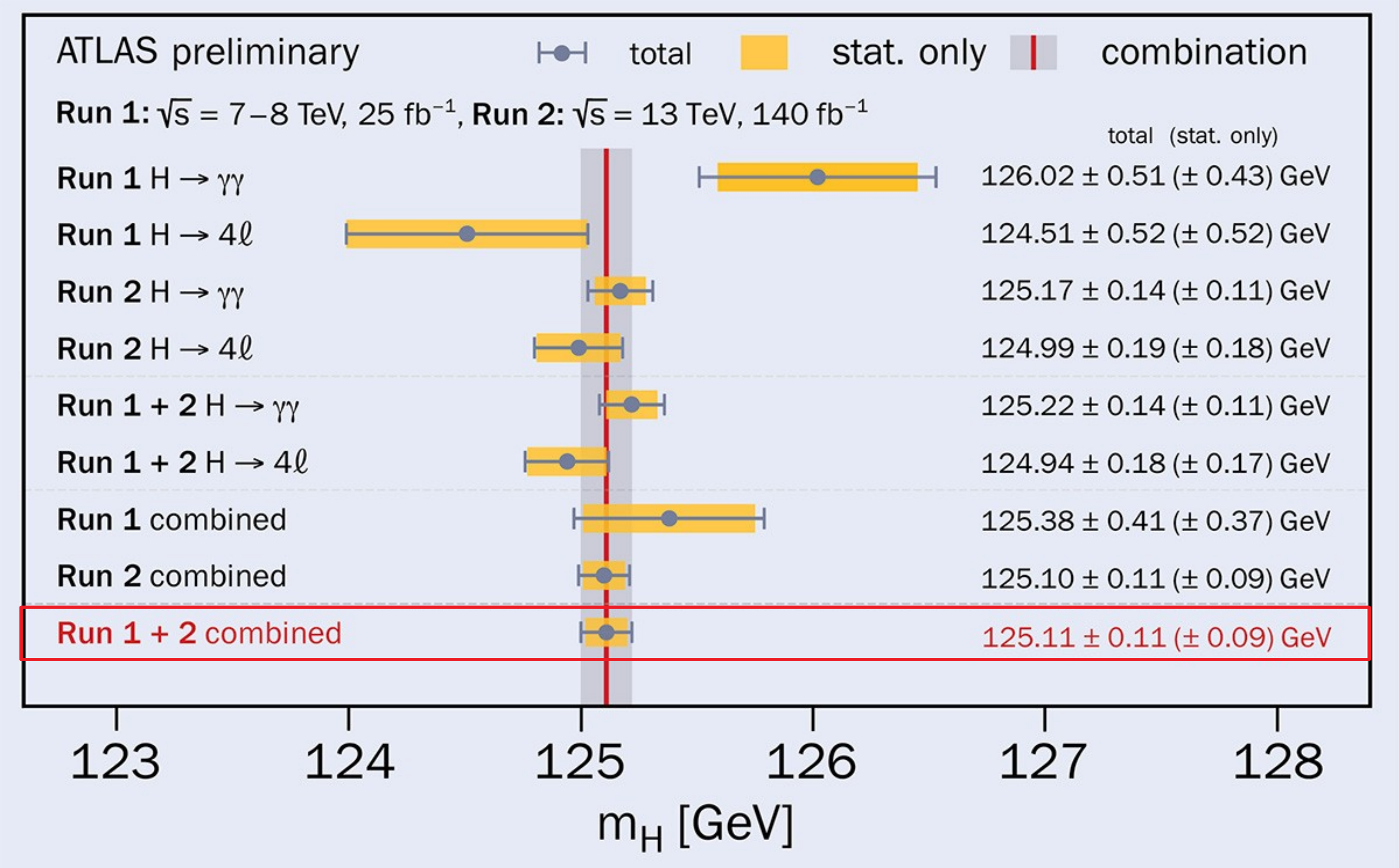


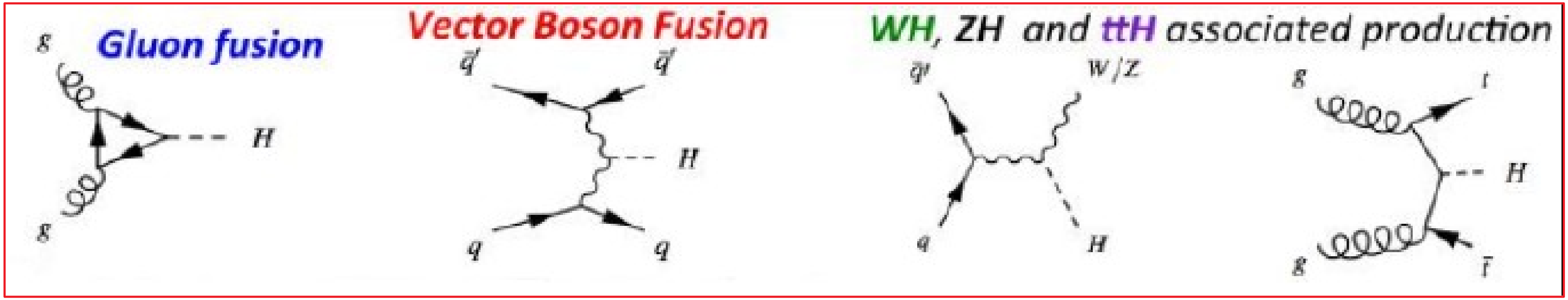
Higgs → γγ


Selected diphoton sample
Data 2011+2012
Sig+Bkg Fit (m_H=126.8 GeV)
Bkg (4th order polynomial)
ATLAS Preliminary
H→γγ
√s = 7 TeV, ∫Ldt = 4.8 fb⁻¹
√s = 8 TeV, ∫Ldt = 20.7 fb⁻¹
Events / 2 GeV
Events - Fitted bkg
m_γγ [GeV]

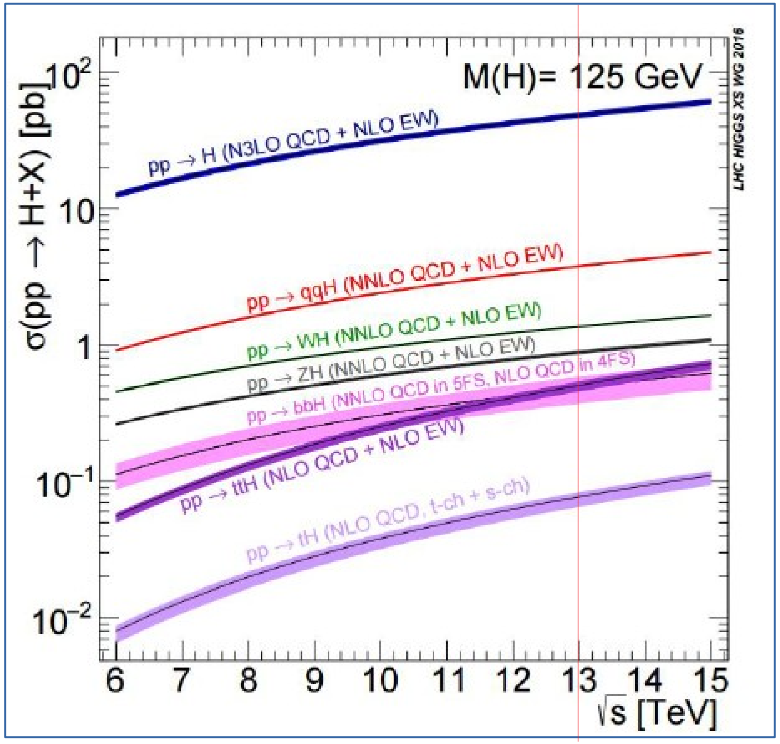

Data
Continuum Background
Total Background
Signal + Background
ATLAS Preliminary
√s = 13 TeV, 139 fb⁻¹
m_H = 125.09 GeV
All categories
ln(1+S/B) weighted sum
S = H + top
m_γγ [GeV]

Precision progress on the Higgs boson

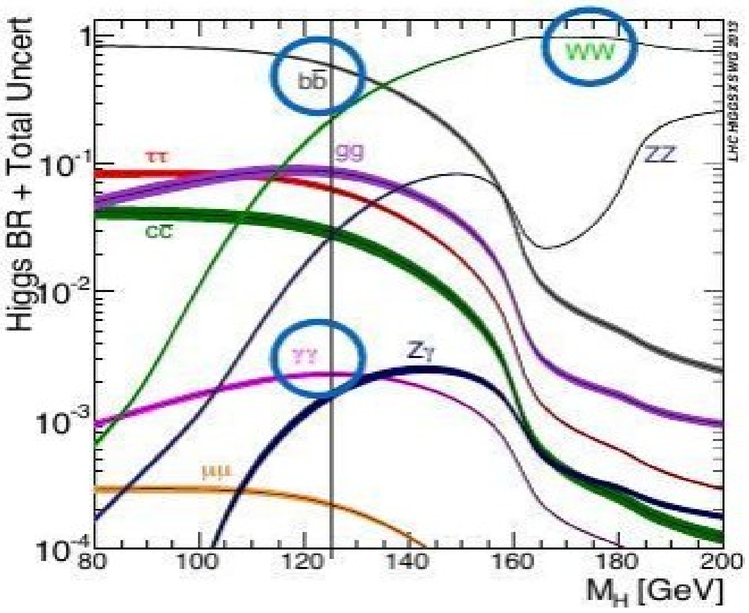


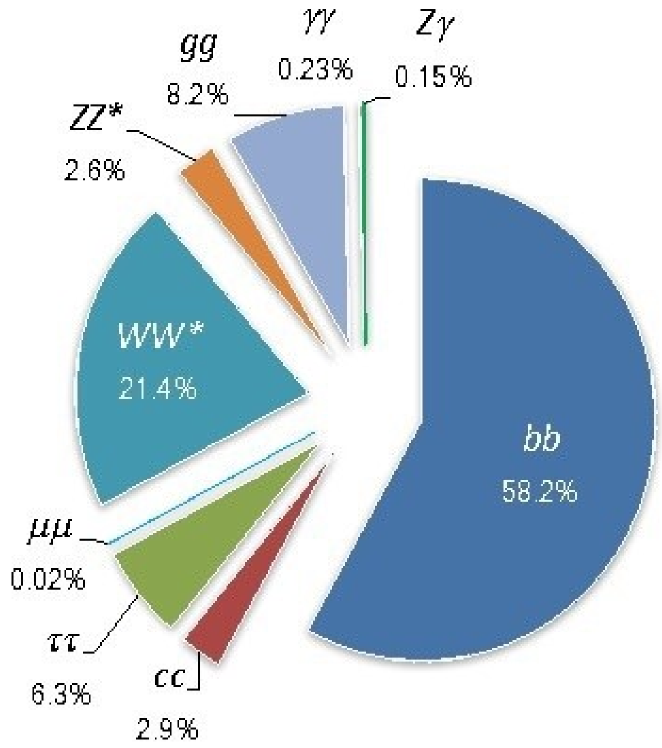


- gg→H (87%)
- pp → VVqq → Hqq (7%
- qq → V* → VH (4%)
- gg → tttt → ttH (1%)



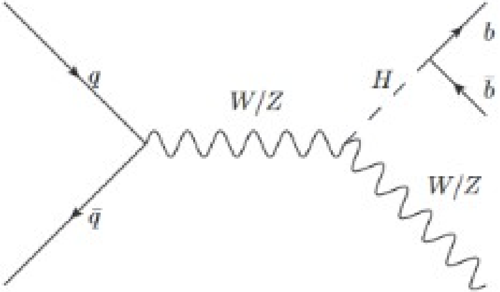
Higgs Boson decay modes

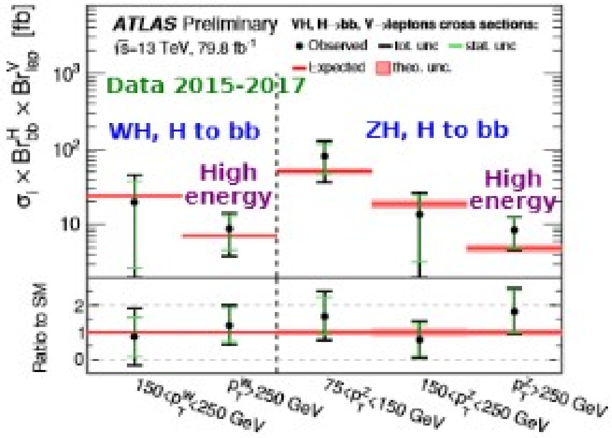


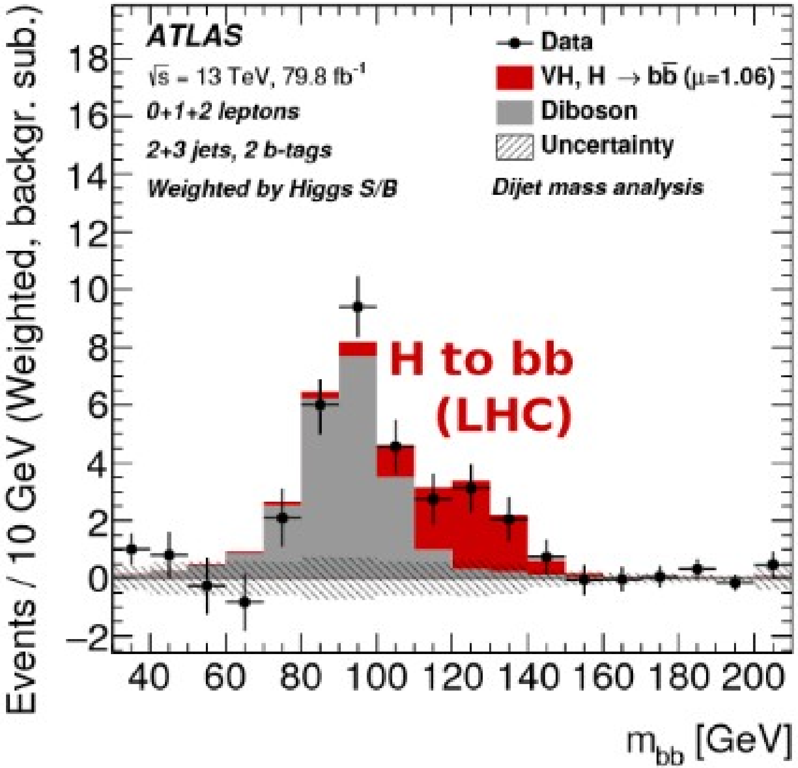


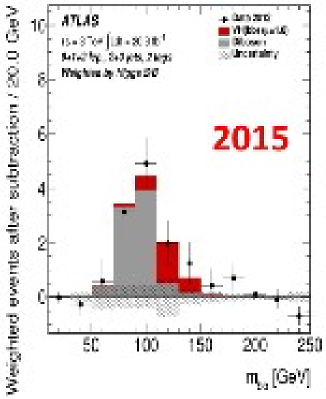
Observation of new production and decay modes

- Observed VH production (5.3σ) and H$\rightarrow$bb decay modes (5.4σ)
- Higgs to *bb* is the most common Higgs decay, but very hard to study
  - Just observed, but already performing differential measurements!



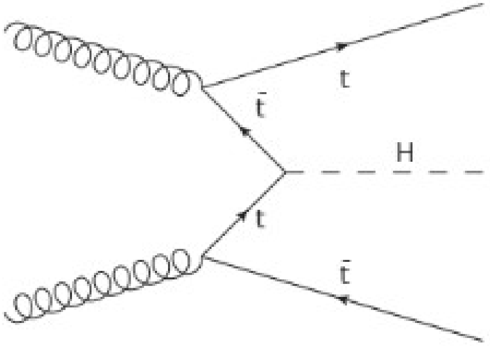




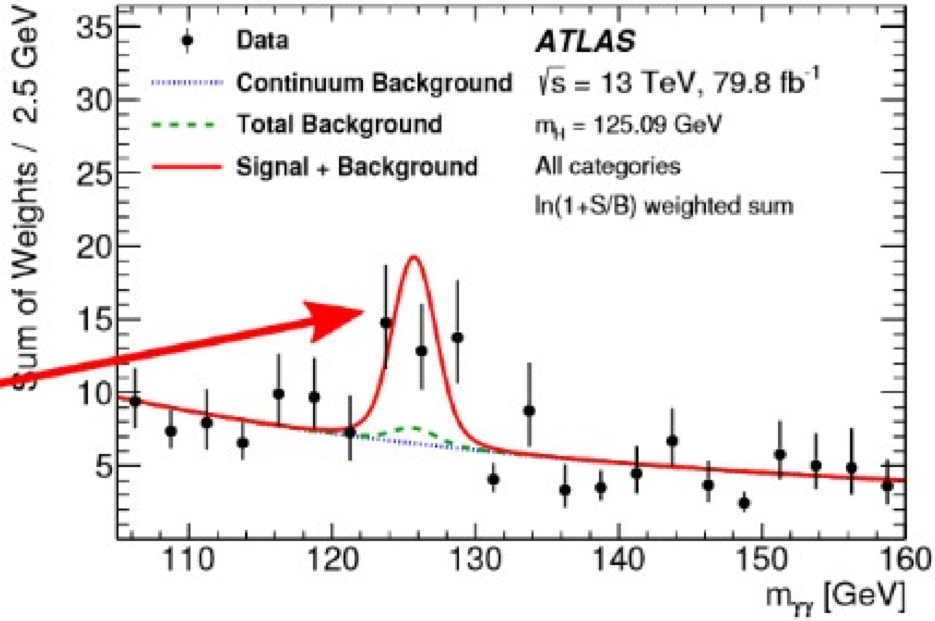


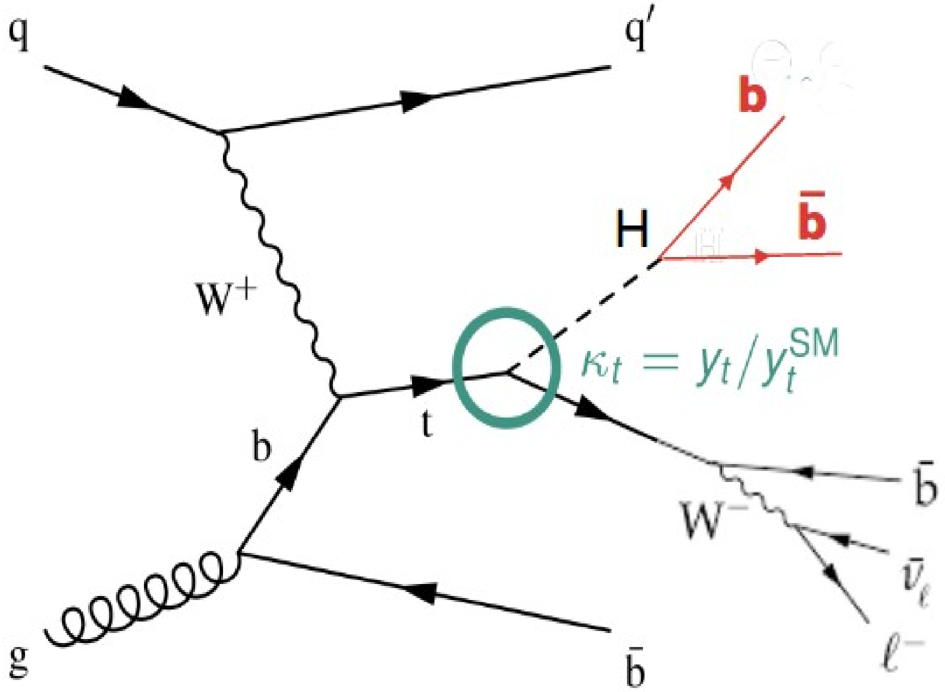
Observation of the ttH production mechanism

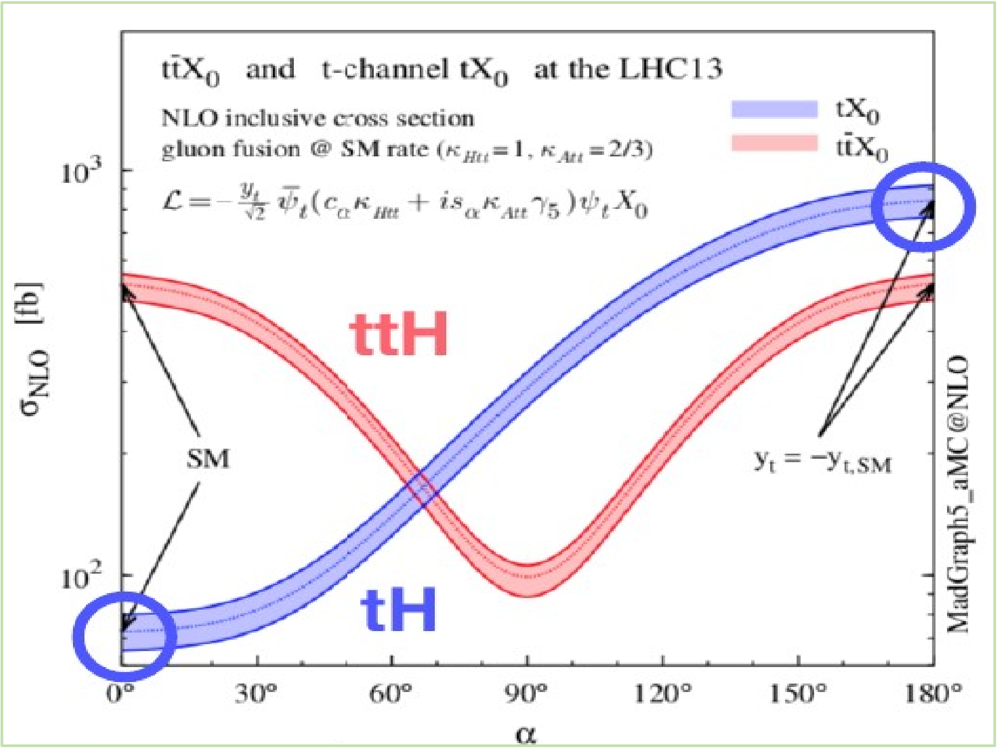
- ATLAS observed the ttH production mechanism in 2018
  - Confirms Yukawa coupling (Higgs + fermion interactions)



Process	Obs. Sig.
H to γγ	4.1
H to multilep	4.1
H to bb	1.4
H to ZZ to 4l	0
Comb (13 TeV)	5.8
Comb (7, 8, 13 TeV)	**6.3**







- For ttH: $\sigma(ttH) \sim |y_t|^2 \kappa^2 (A\cos^2\alpha + B\sin^2\alpha)$
  For tH : $\sigma(tH) \sim |y_t|^2 \kappa^2 (A\cos^2\alpha + B\sin^2\alpha) + C y_t \kappa \cos\alpha + D y_t \kappa \sin\alpha + E$

  t-H and W-H vertex interference
- In SM, Higgs is CP-even:
  - $\alpha = 0$, interference term destructive
- For $\alpha = 180^\circ$ or $y_t = -y_{t,SM}$, interference term constructive, and $\sigma(tH) \sim 10 * \sigma(tH)_{SM}$
- Also get enhancement of $\sigma(tH)$ for CP-odd Higgs, with $\alpha = 90^\circ$

Thank you for your attentions