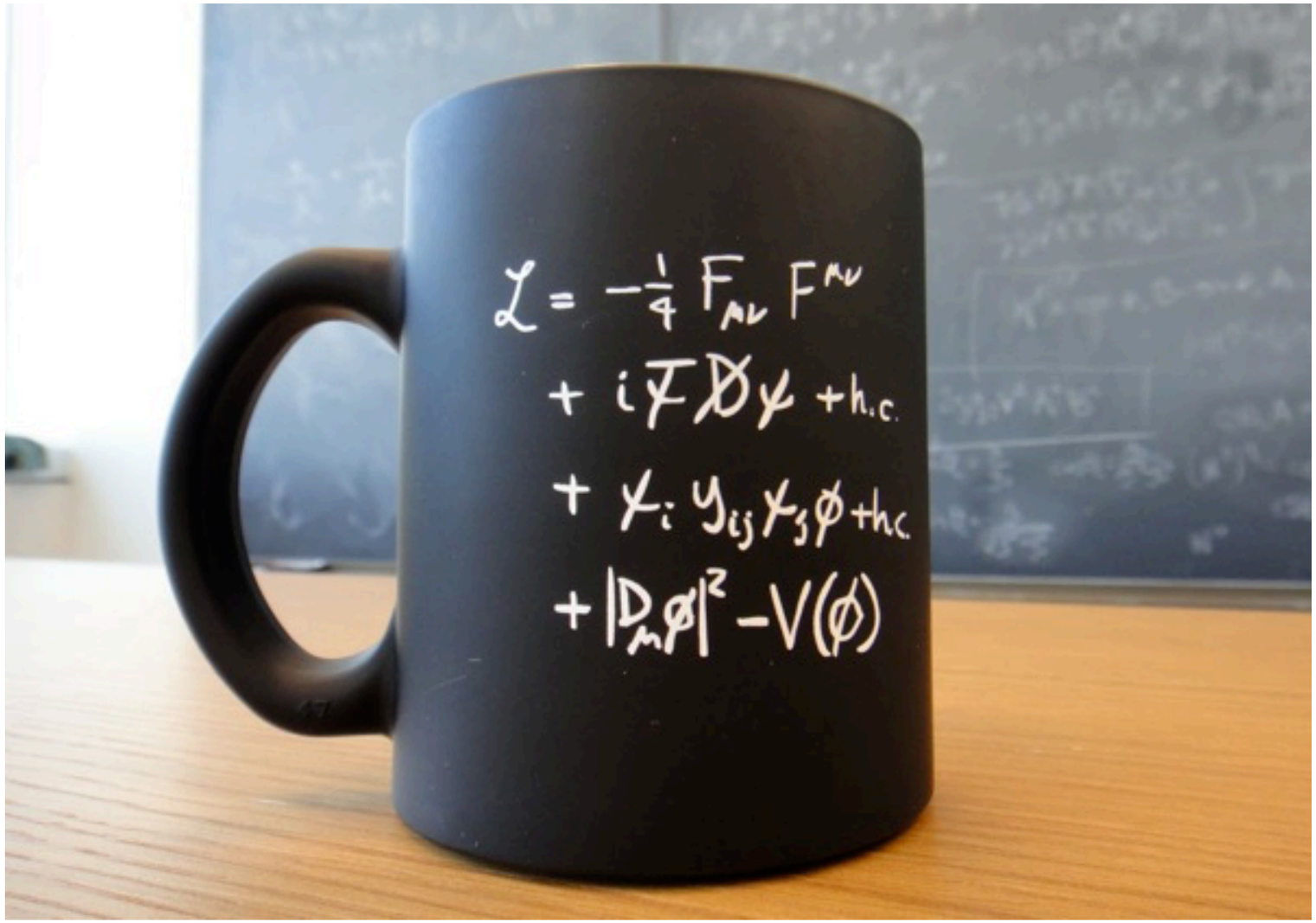
Standard Model and Higgs results from ATLAS

Riccardo Di Sipio, University of Toronto
On behalf of the ***ATLAS*** Collaboration



@rdisipio #topquark
http://disipio.wordpress.com

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

W/Z, WW bosons cross-sections

W boson mass

$$+ i \bar{\psi} \not{D} \psi + h.c.$$

tt, ttW, ttZ, ttH cross-sections

$$+ \bar{\psi}_i y_{ij} \psi_j \phi + h.c.$$

Top quark mass

$$+ |D_\mu \phi|^2 - V(\phi)$$

Higgs boson couplings

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu}$$

W/Z, WW bosons cross-sections

Theorist's view

The Standard Model is incomplete, we need to find a more complete theory whose low-energy limit is the SM

Z, ttH
tions

Experimentalist's view

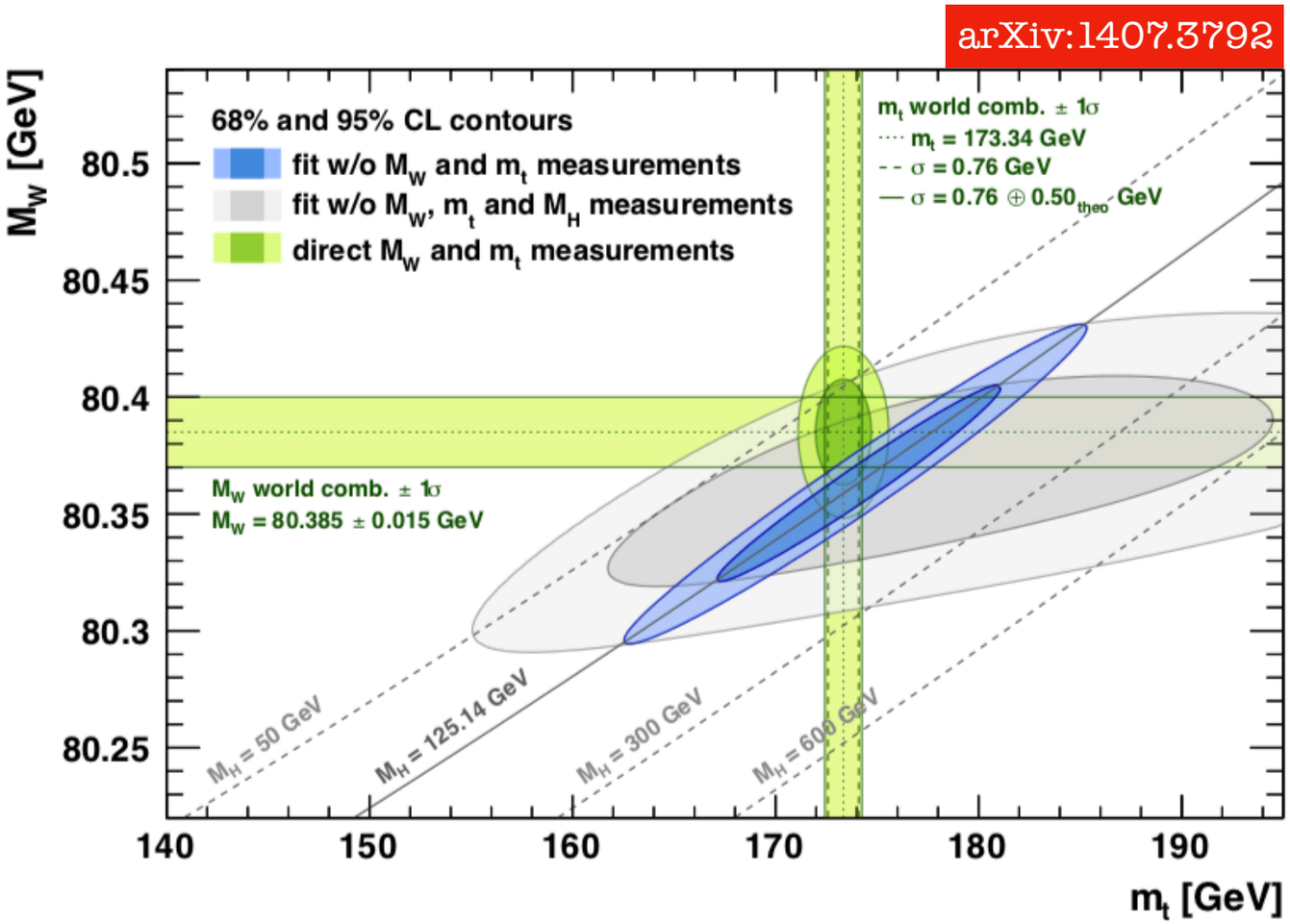
Ask not what the SM can do for you - ask what you can do for the SM

k mass

$$+ |D_\mu \phi|^2 - V(\phi)$$

W boson mass

Higgs boson couplings

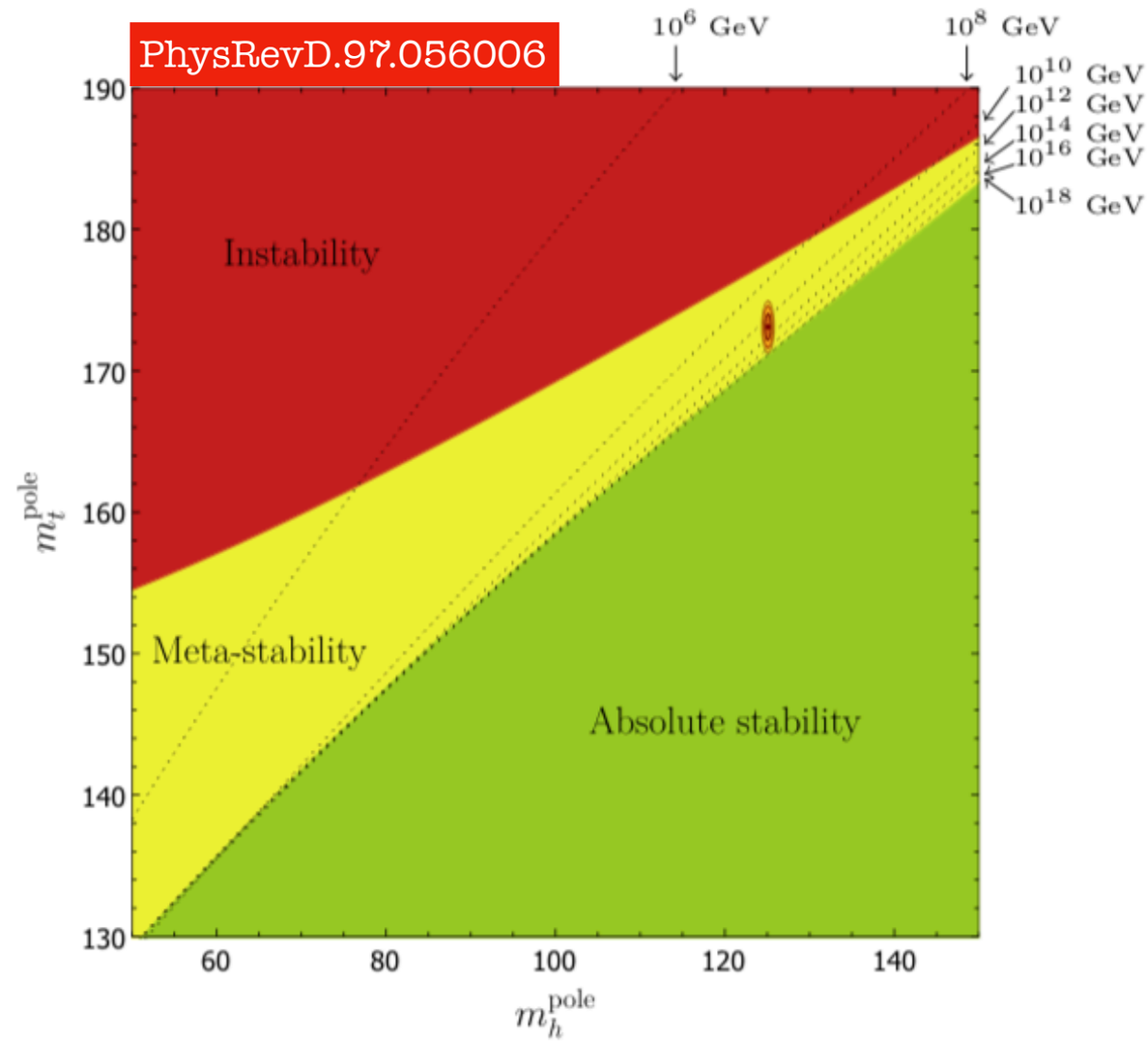


CONSISTENCY OF THE STANDARD MODEL

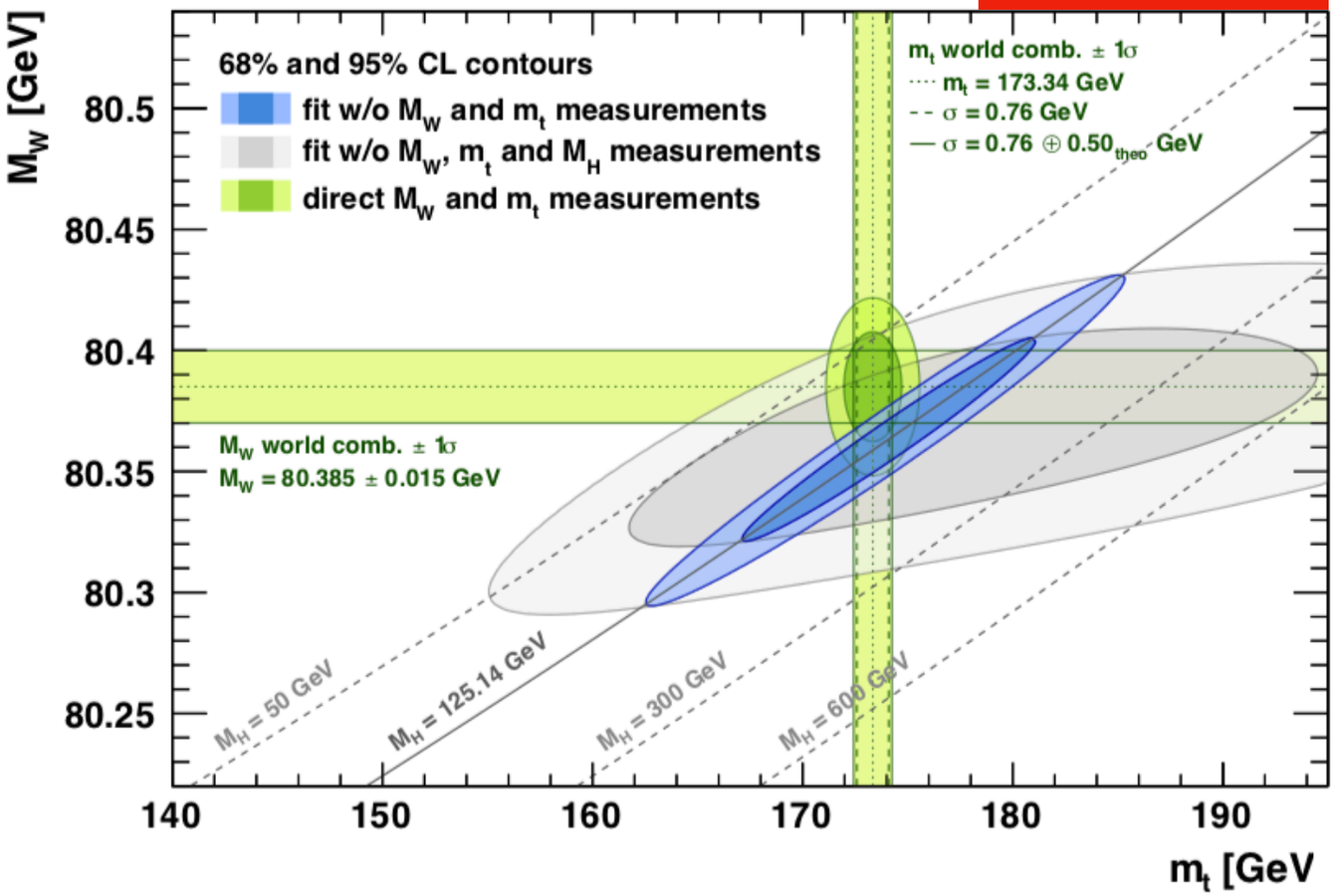
The m_W-m_t-m_H plot from EWK fits tells you about the **allowed mass** for a **SM Higgs** considering the **current knowledge** of the **top** quark and ***W*** boson masses

VACUUM STABILITY OF THE UNIVERSE

How **stable** is the Universe if we take into account the measured values of the **top quark** and the **Higgs boson** masses? If the answer is "not much" we need **new physics**, judge for yourself!



arXiv:1407.3792



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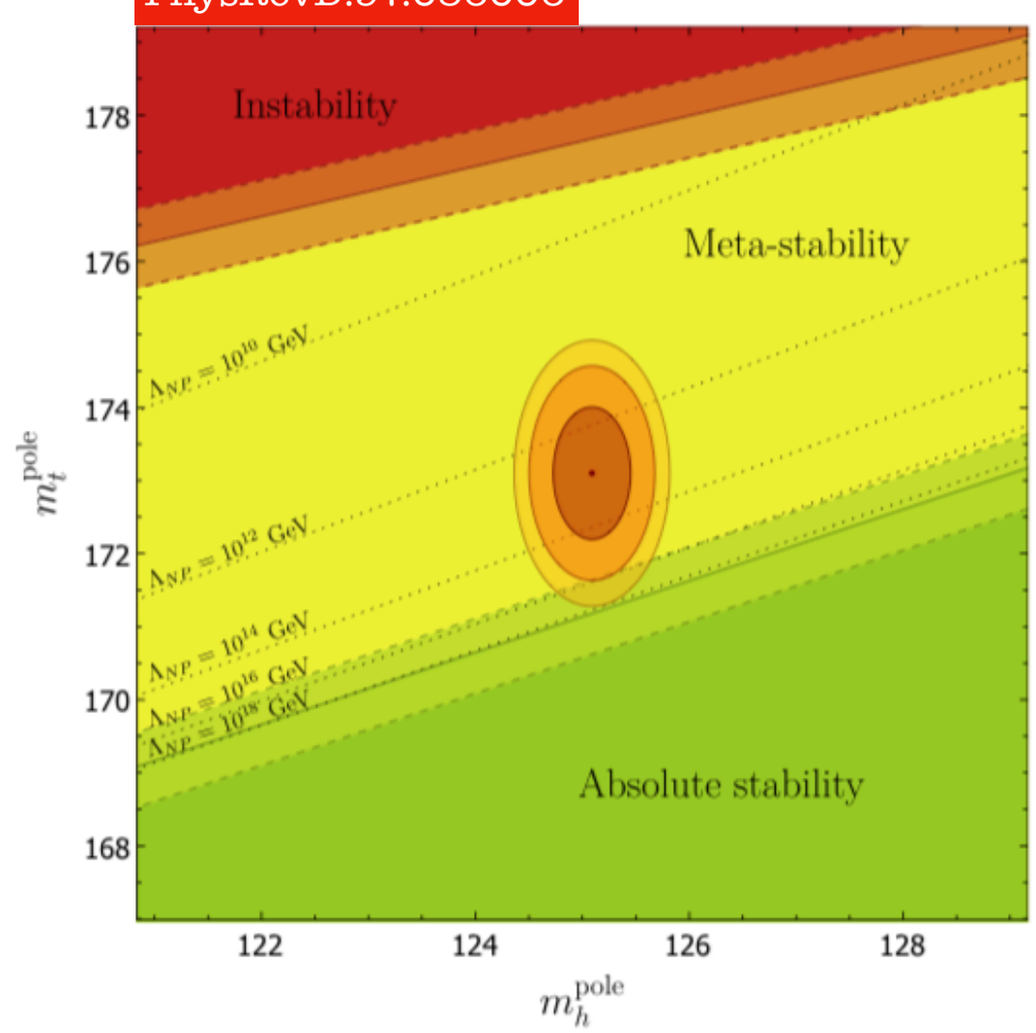
PhysRevD.97.056006



VACUUM STABILITY OF THE UNIVERSE

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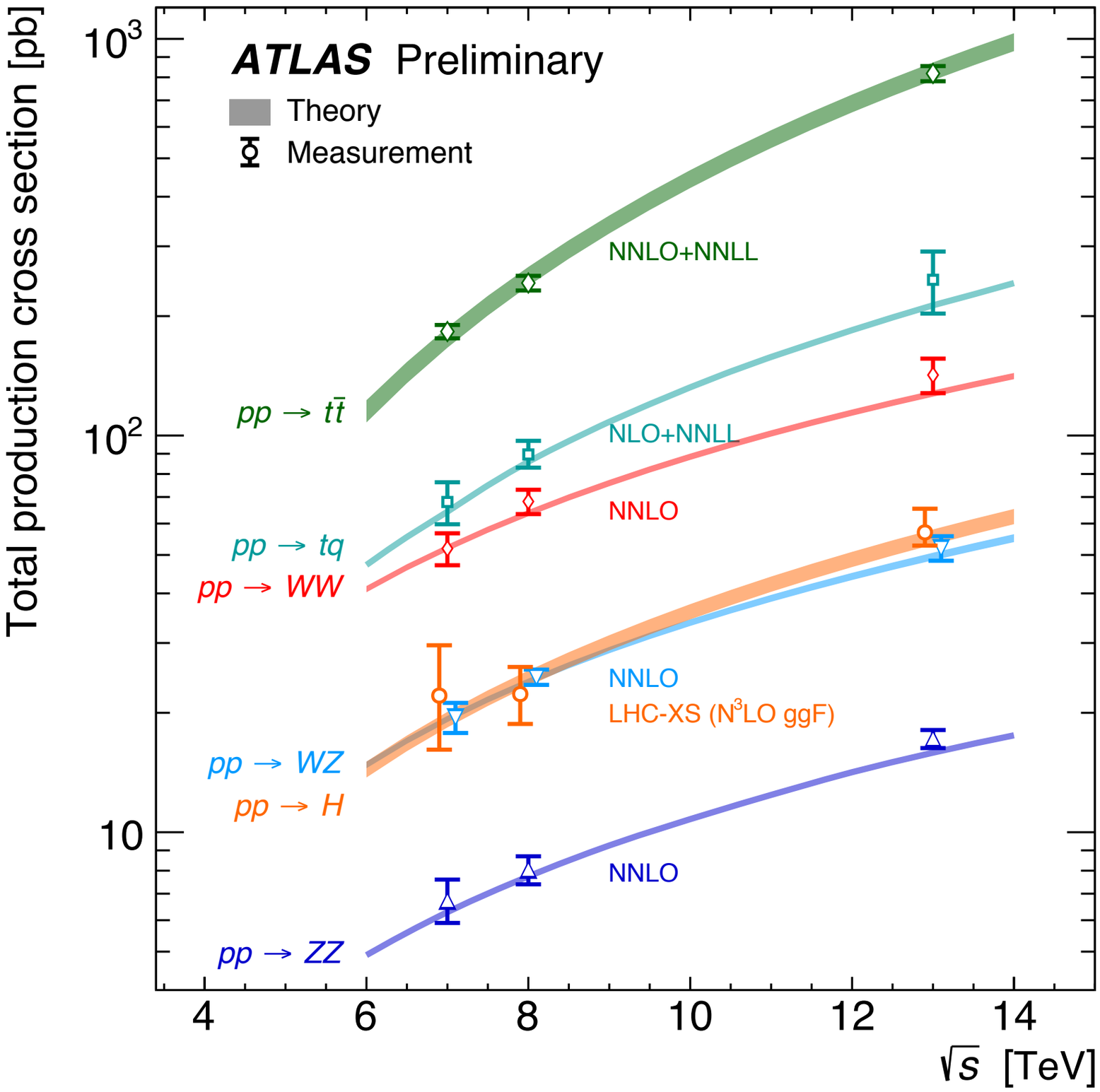
Extensive program at the LHC to measure Standard Model processes



$pp \to t\bar{t}$
7 TeV, 4.6 fb^{-1}, Eur. Phys. J. C 74:3109 (2014)
8 TeV, 20.3 fb^{-1}, Eur. Phys. J. C 74:3109 (2014)
13 TeV, 3.2 fb^{-1}, arXiv:1606.02699

$pp \to tq$
7 TeV, 4.6 fb^{-1}, PRD 90, 112006 (2014)
8 TeV, 20.3 fb^{-1}, arXiv:1702.02859
13 TeV, 3.2 fb^{-1}, arXiv:1609.03920

$pp \to WW$
7 TeV, 4.6 fb^{-1}, PRD 87, 112001 (2013)
8 TeV, 20.3 fb^{-1}, JHEP 09 029 (2016)
13 TeV, 3.2 fb^{-1}, arXiv:1702.04519

$pp \to WZ$
7 TeV, 4.6 fb^{-1}, Eur. Phys. J. C (2012) 72:2173
8 TeV, 20.3 fb^{-1}, PRD 93, 092004 (2016)
13 TeV, 3.2 fb^{-1}, Phys. Lett. B 762 (2016)

$pp \to H$
7 TeV, 4.5 fb^{-1}, Eur. Phys. J. C76 (2016) 6
8 TeV, 20.3 fb^{-1}, Eur. Phys. J. C76 (2016) 6
13 TeV, 36.1 fb^{-1}, ATLAS-CONF-2017-047

$pp \to ZZ$
7 TeV, 4.6 fb^{-1}, JHEP 03, 128 (2013)
8 TeV, 20.3 fb^{-1}, JHEP 01, 099 (2017)
13 TeV, 36.1 fb^{-1}, ATLAS-CONF-2017-031

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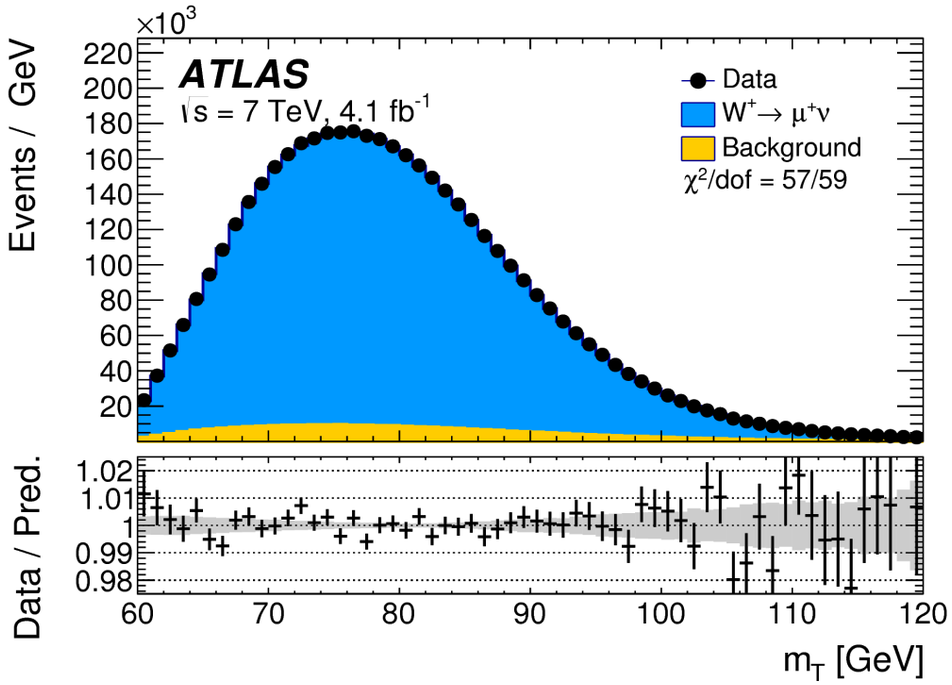
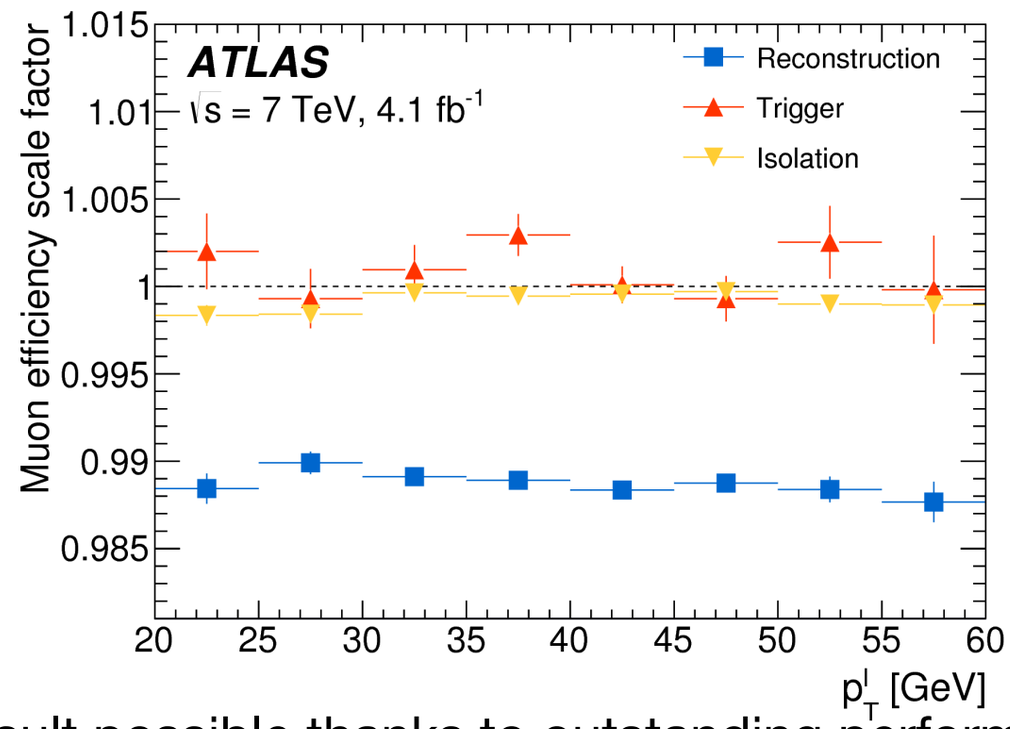
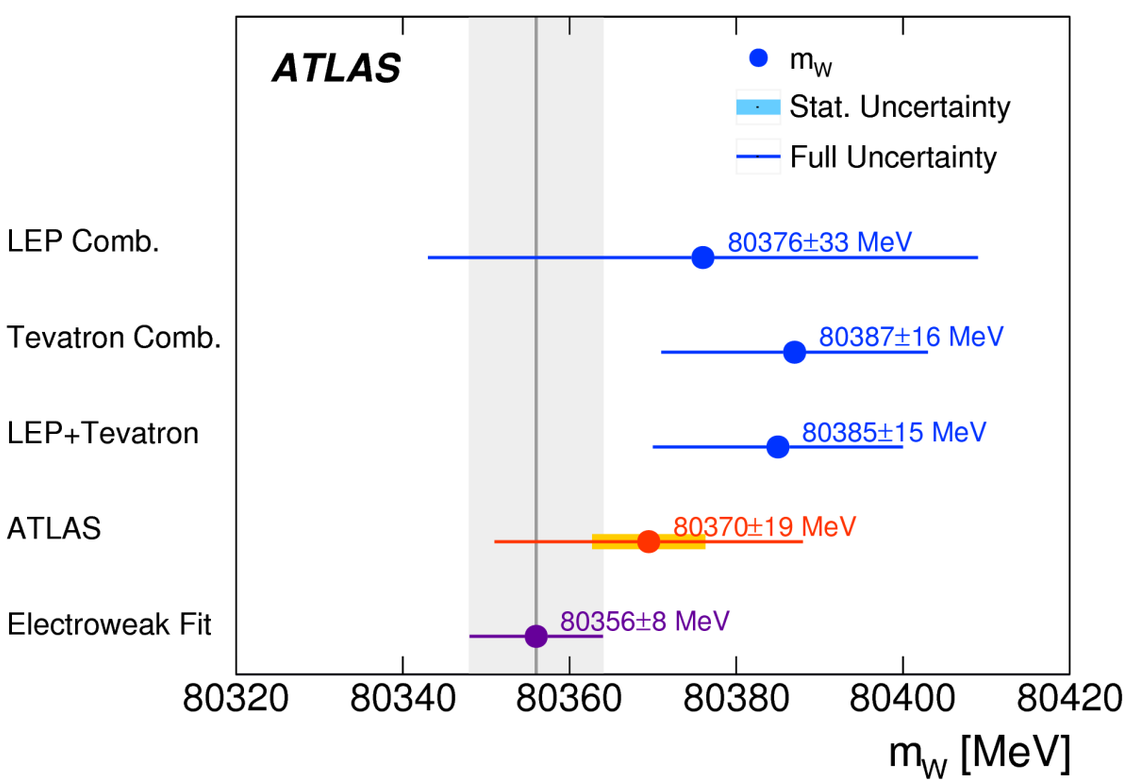
W boson mass



- Reconstruct (*l*,*ν*) system transverse mass
- Template fit



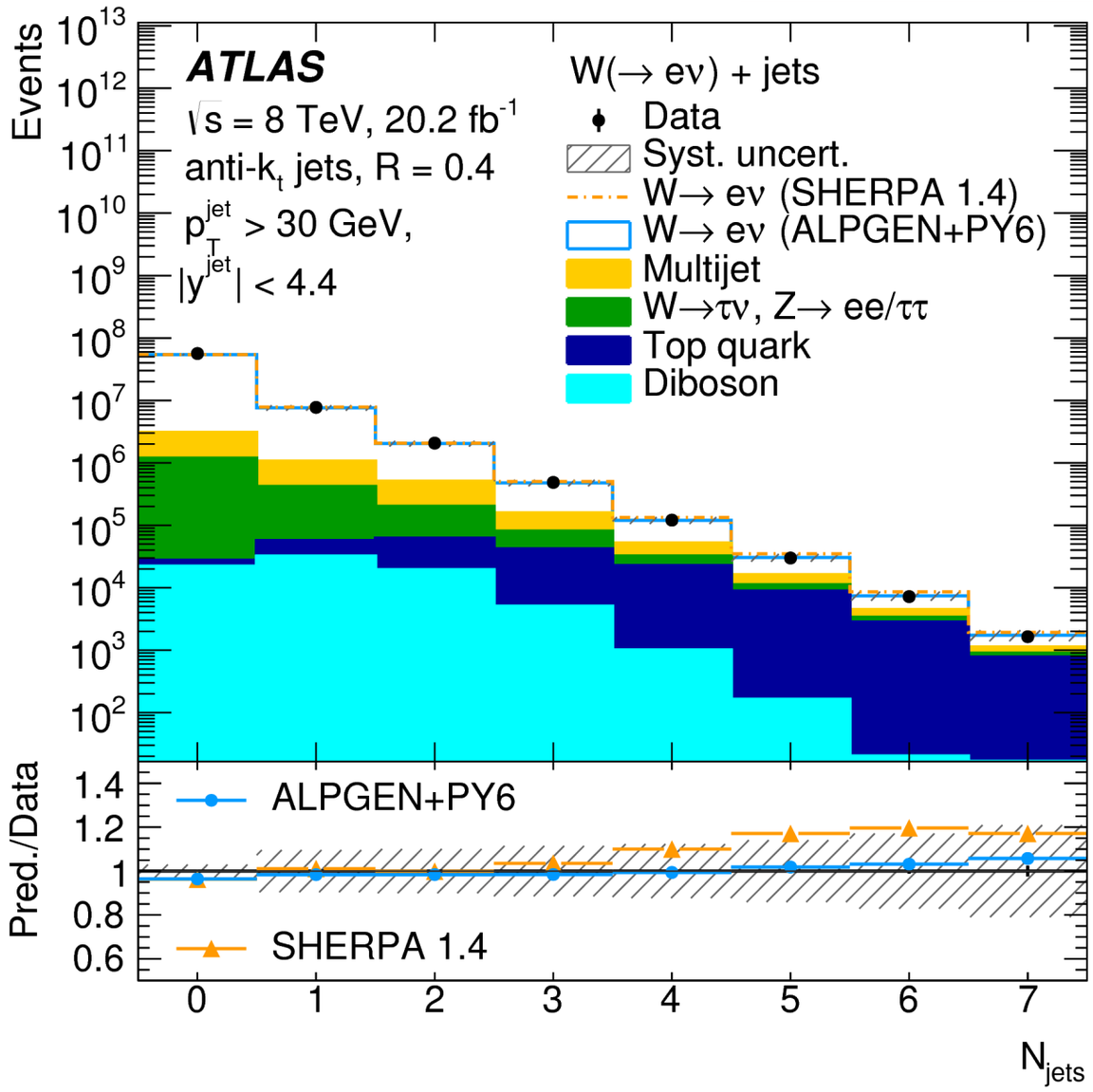


- Result possible thanks to outstanding performance in lepton reconstruction

$$m_W = 80370 \pm 19\,\mathrm{MeV}$$

W/Z cross-sections

arXiv:1711.03296



W+/W- production asymmetric at the LHC
Critical test of MC generators

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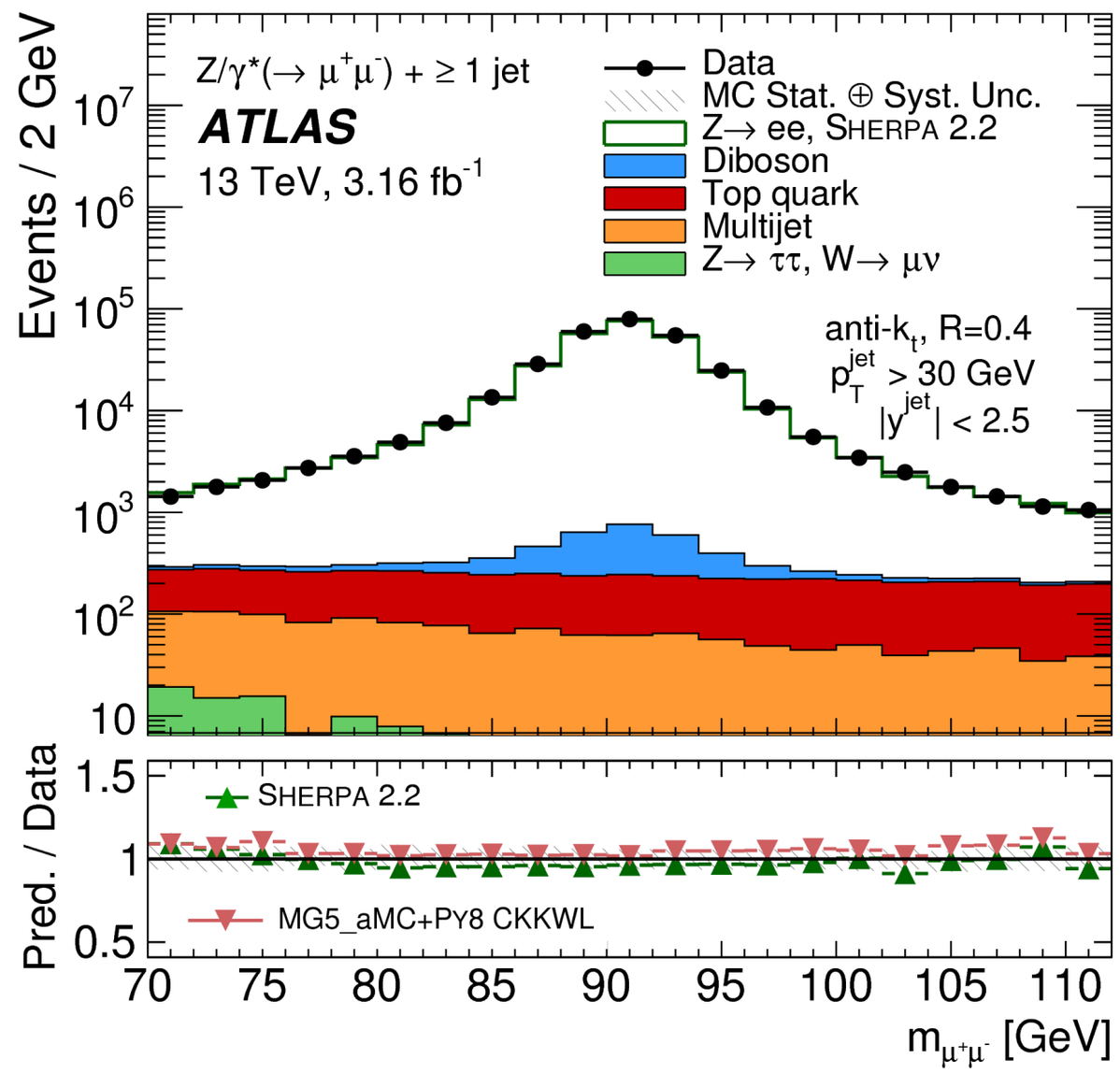
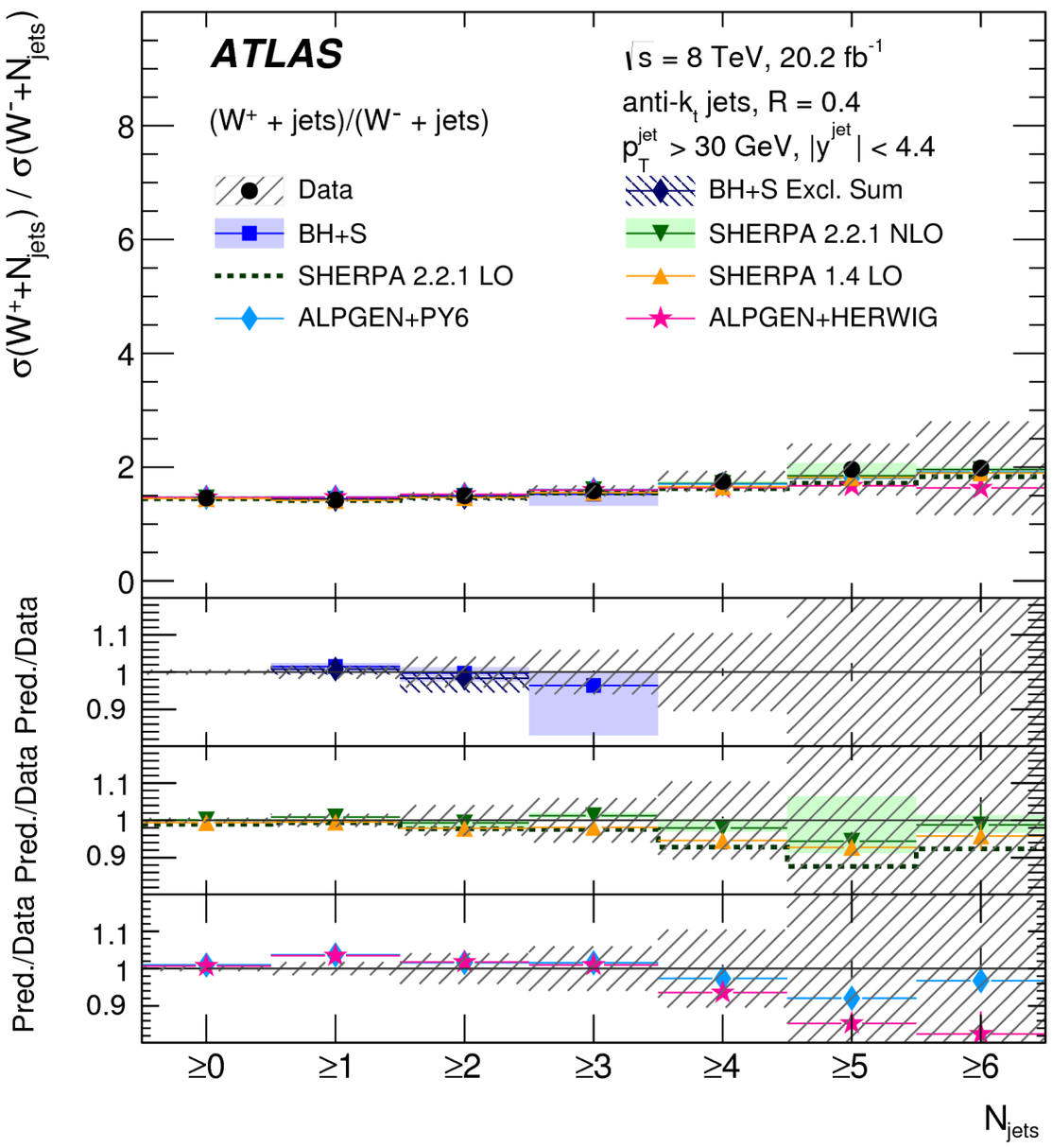


Z mass peak "standard candle"
Used ubiquitously for calibrations

W/Z cross-sections

***W*+jets**

arXiv:1711.03296



***Z*+jets**

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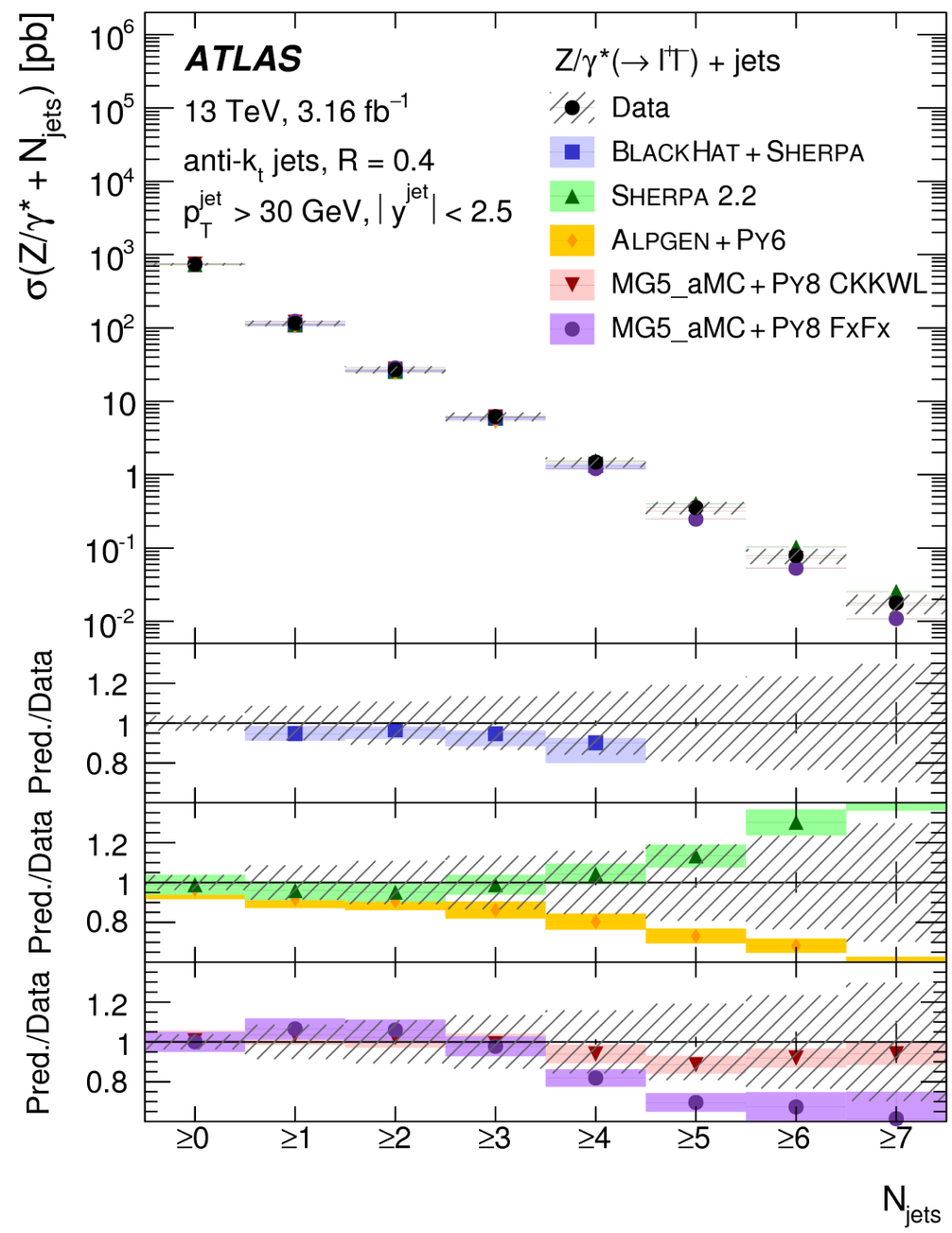
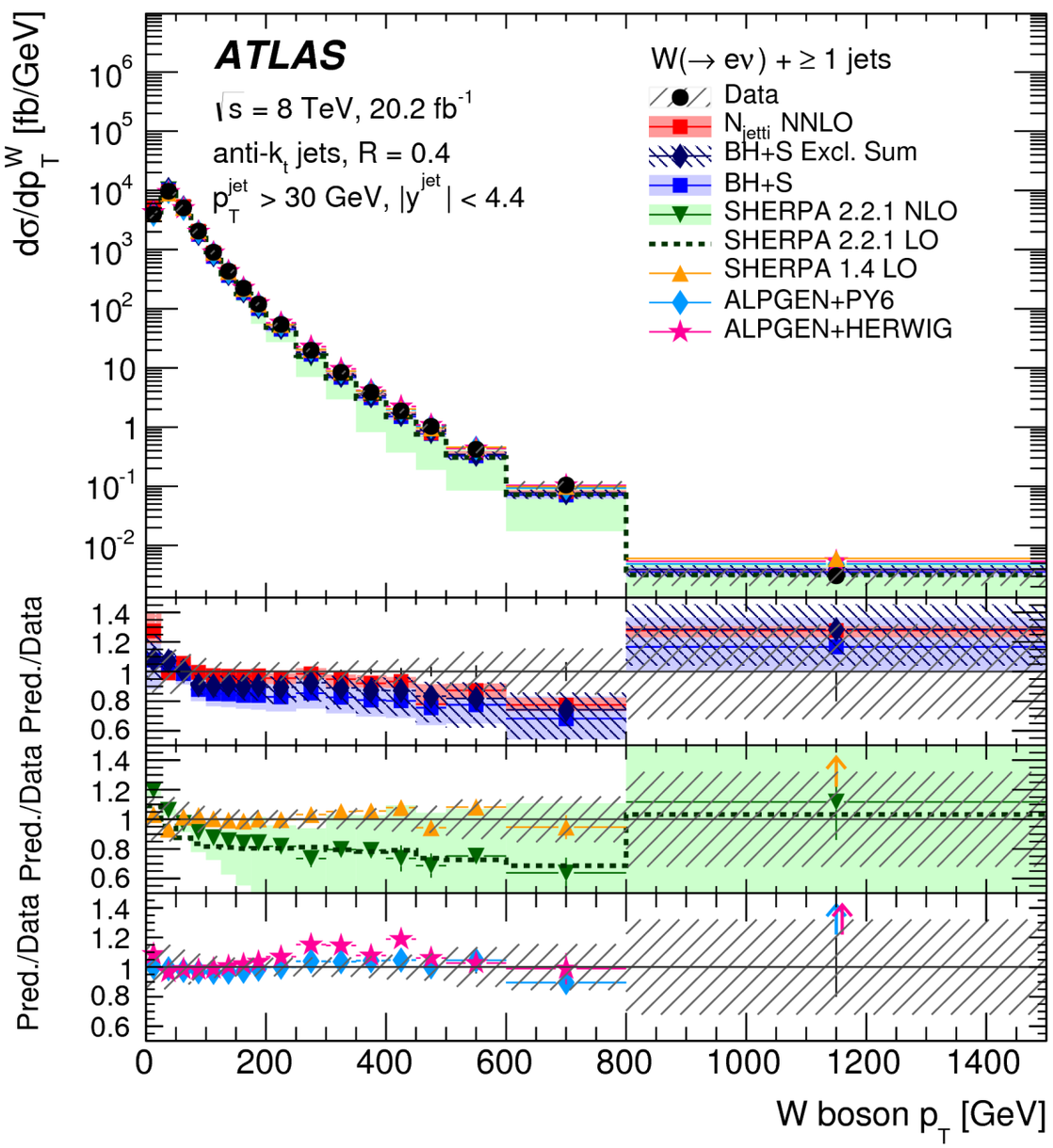


W/Z cross-sections

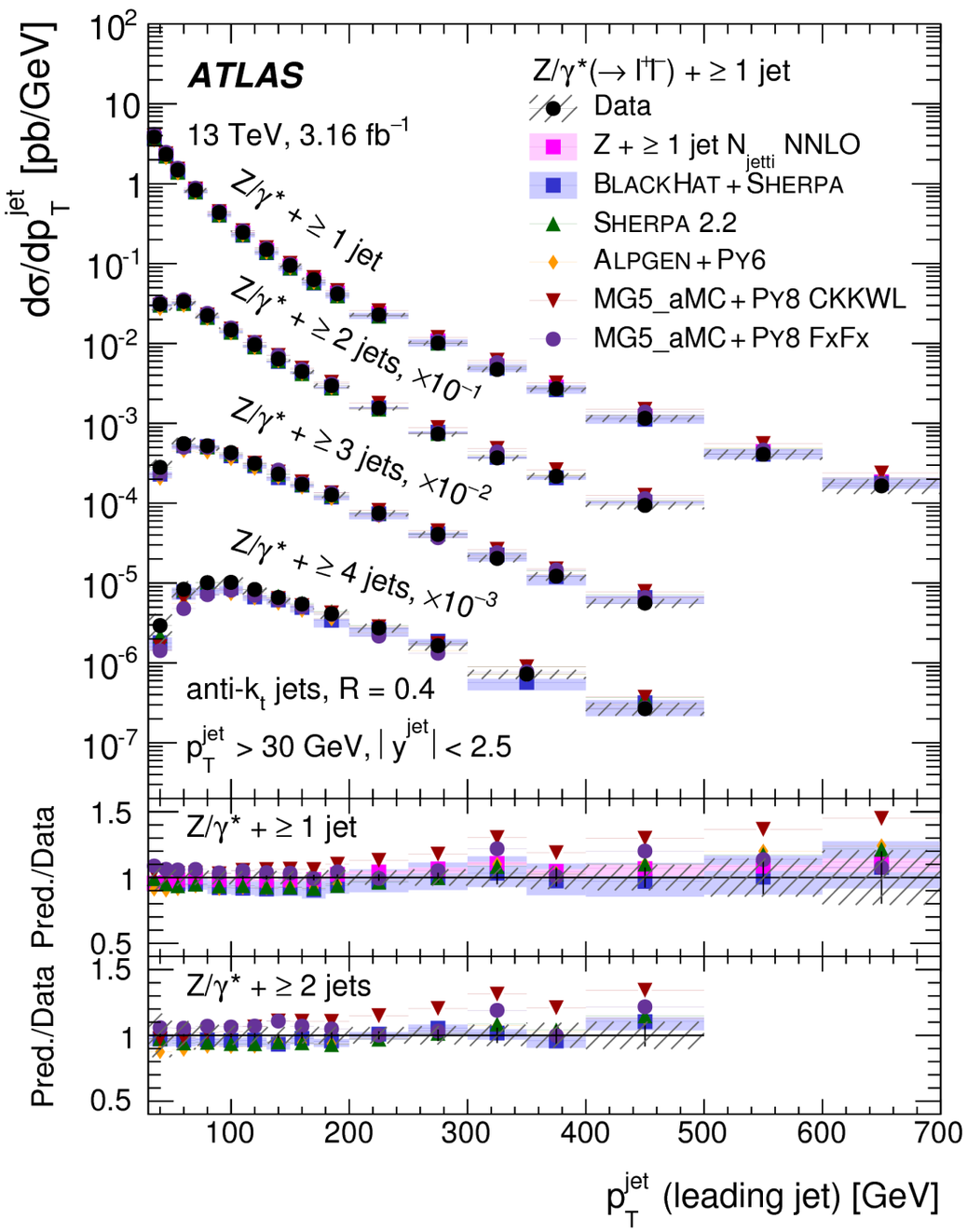
***W*+jets**

arXiv:1711.03296



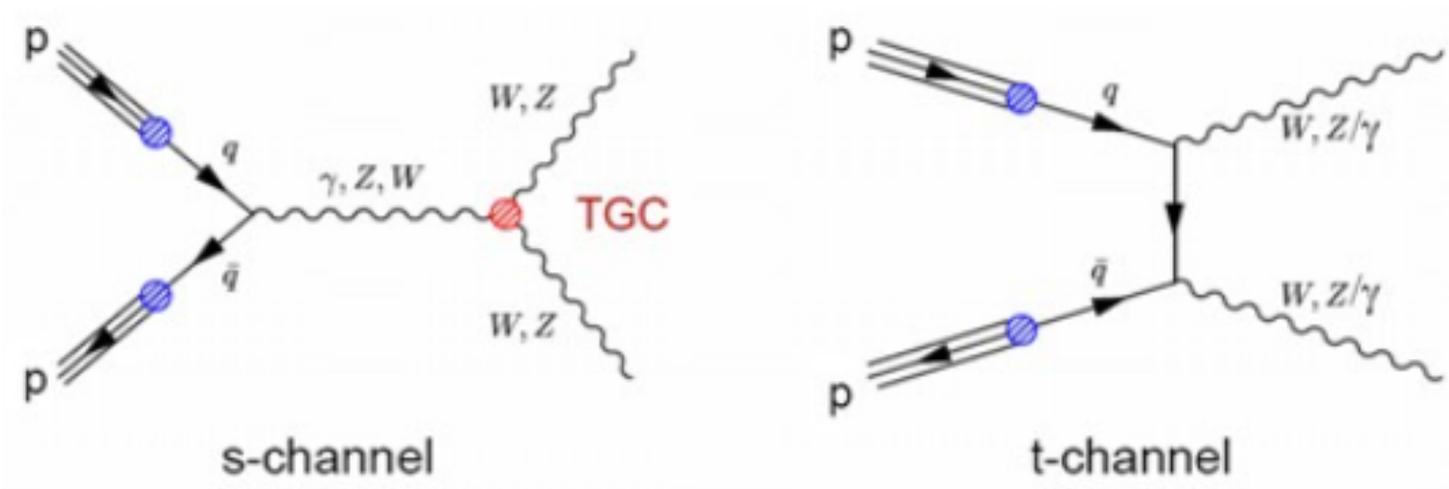
***Z*+jets**

Eur. Phys. J. C77 (2017) 361



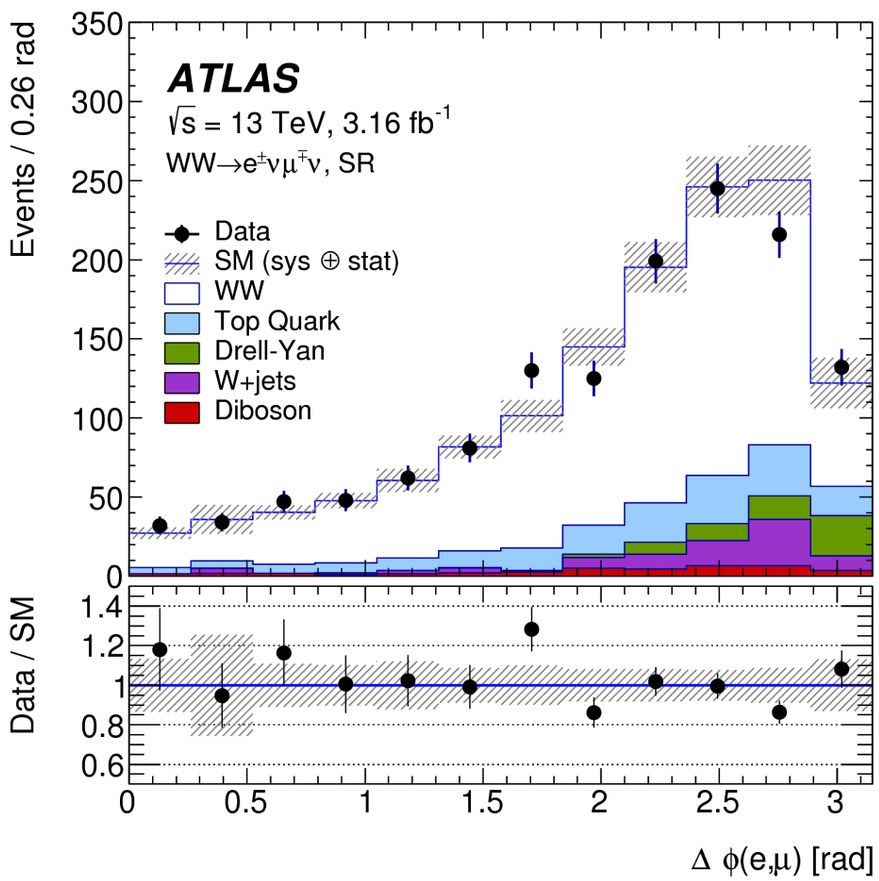
Phys. Lett. B 773 (2017) 354

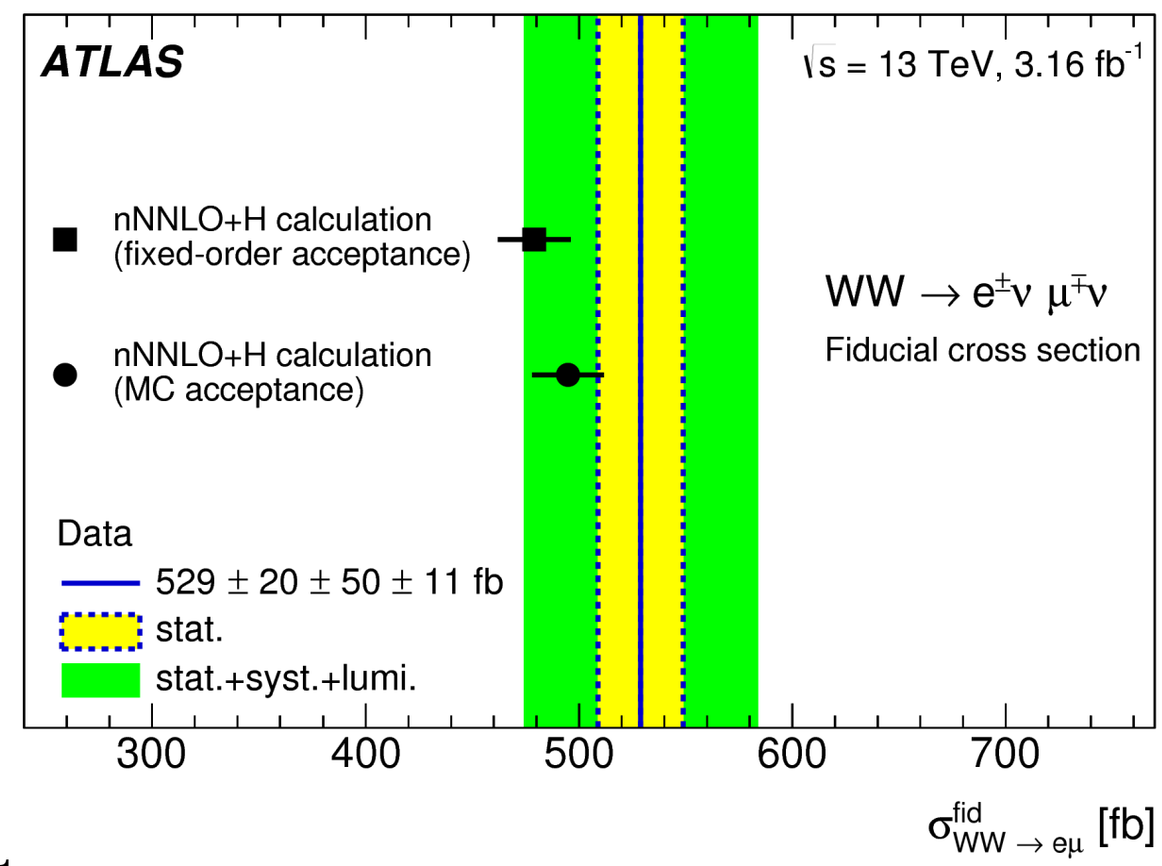
$W^{\pm}W^{\mp}$ cross-section (OS)



Resonant and non-resonant Vector Boson Scattering (VBS) probes EW gauge structure of the SM

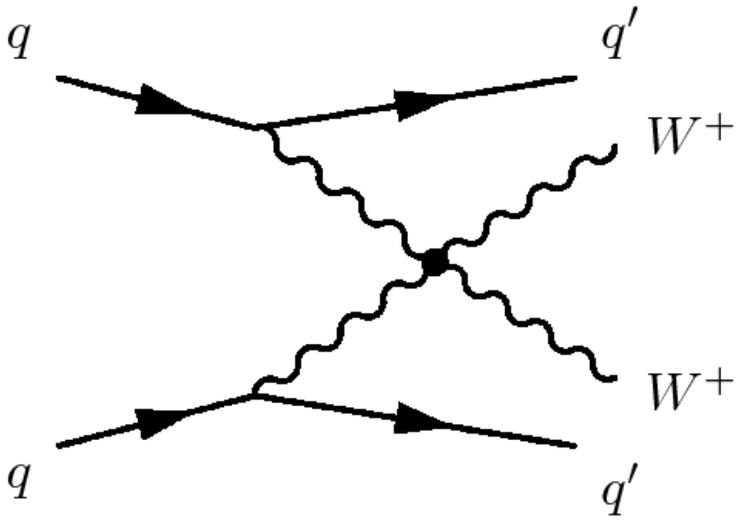
Could provide direct (WW resonance) or indirect (Anomalous Triple Gauge Couplings) evidence of BSM physics

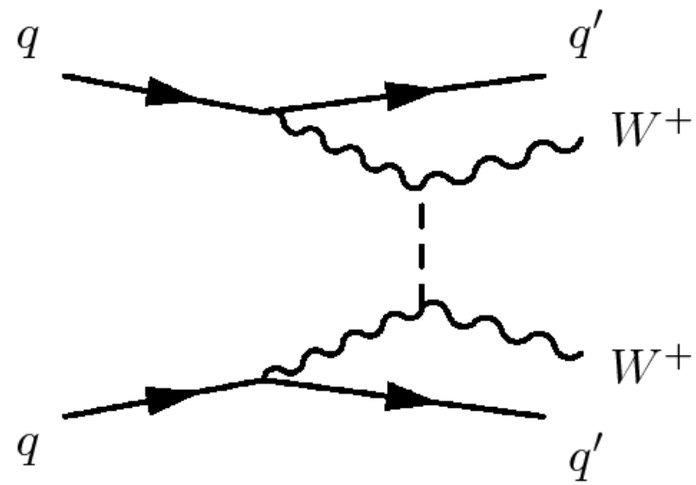




Phys. Rev. Lett. 113, 141803

$W^{\pm}W^{\pm}jj$ cross-section (SS)





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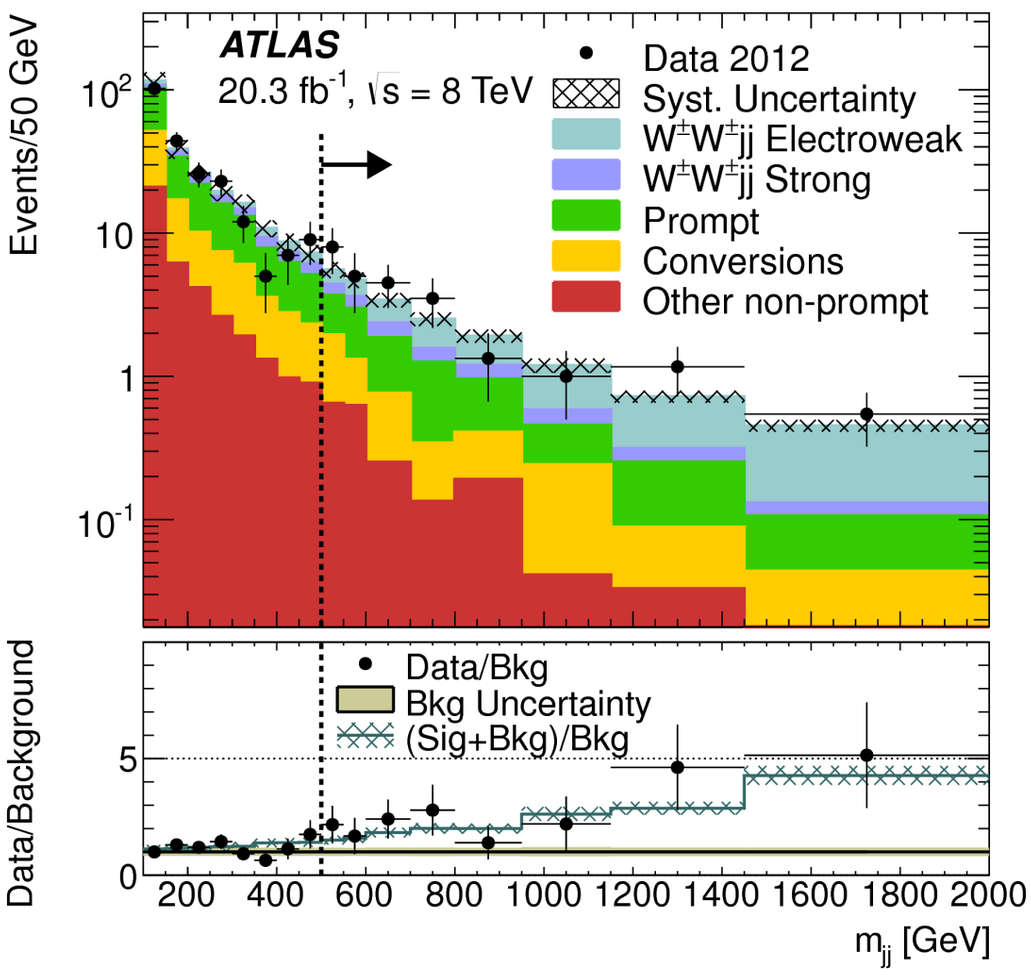

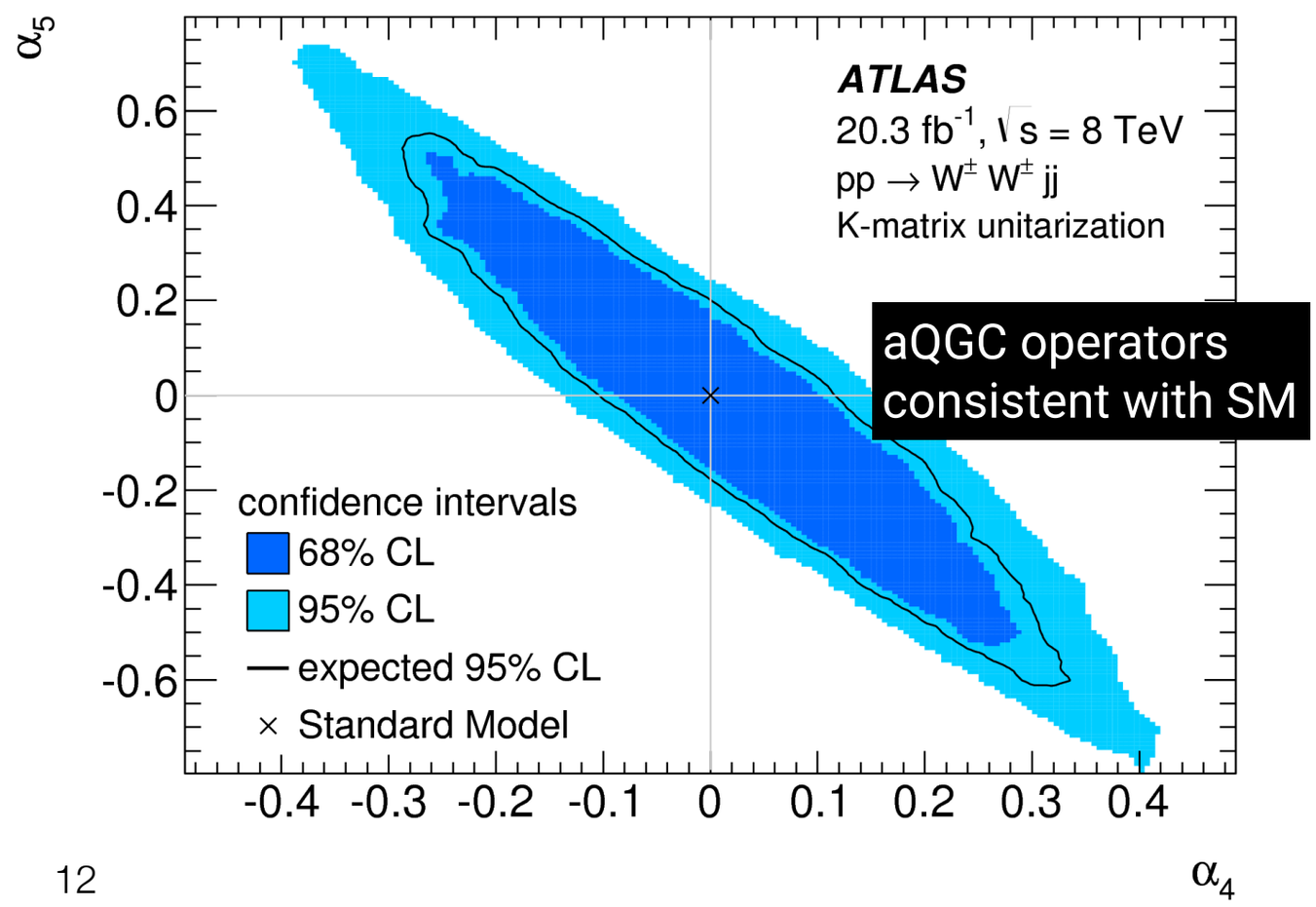

aQGC operators consistent with SM

LHCTopWGSummaryPlots

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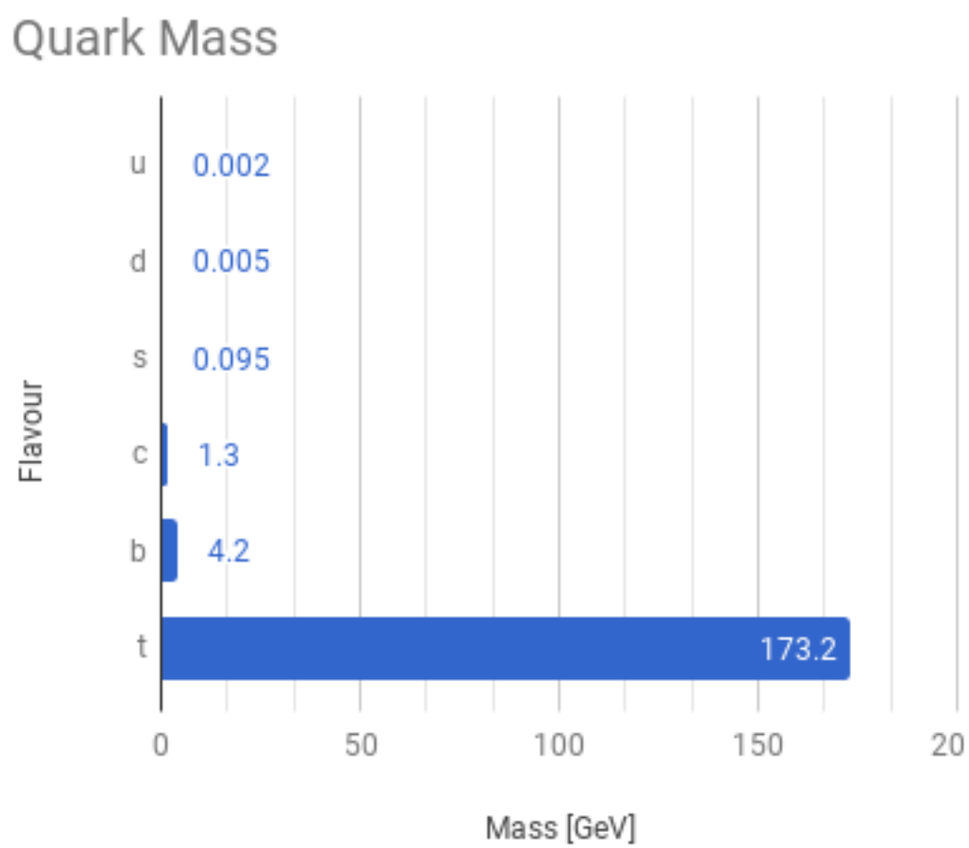
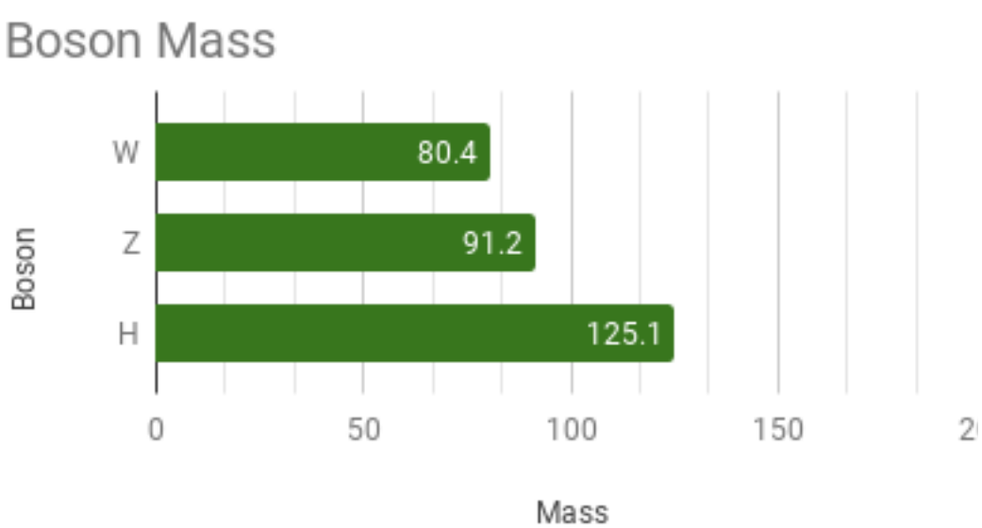
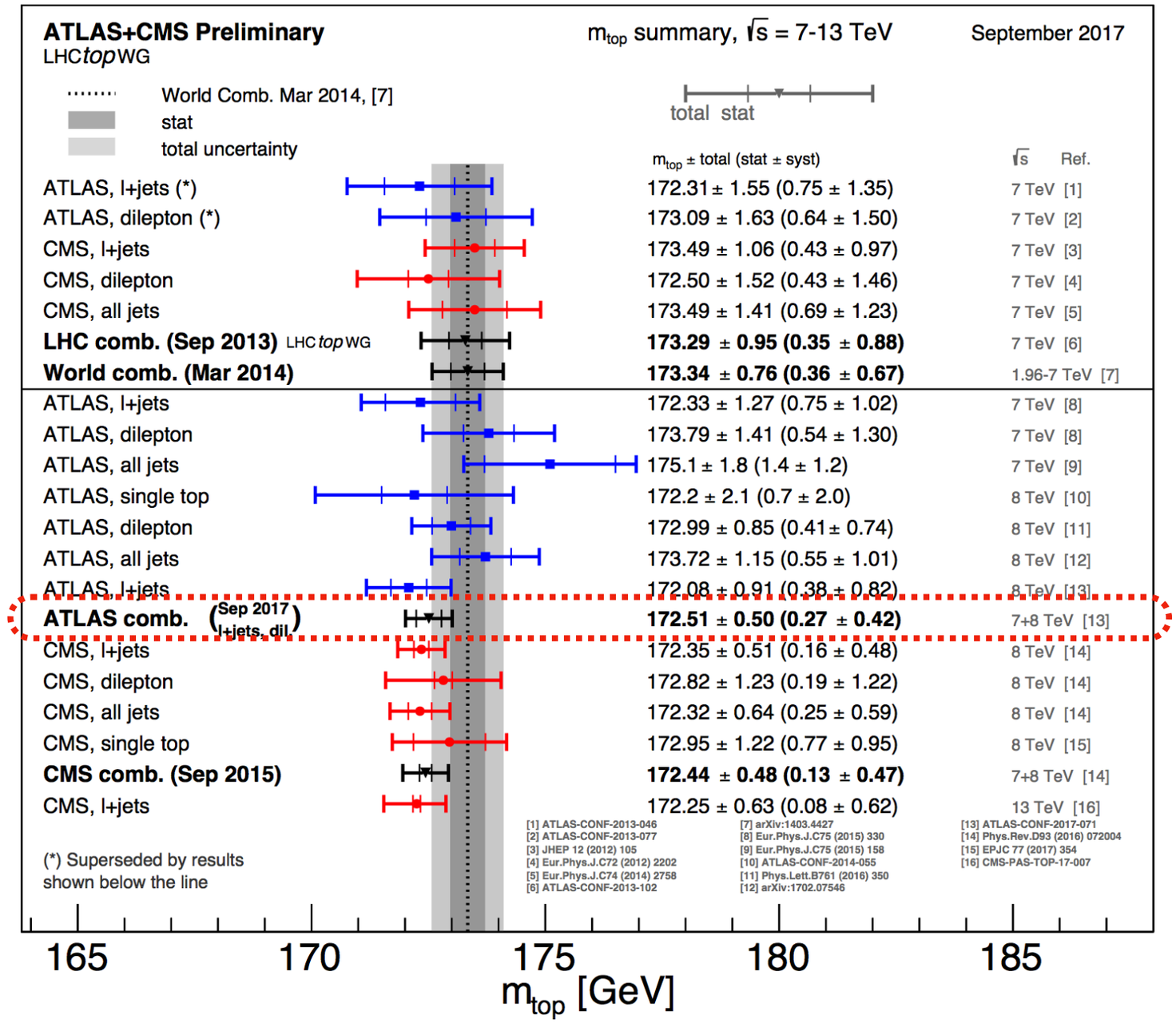
Top Quark

Why so heavy? $M_t \sim M_H$ ("natural")

Why are all the others so much lighter?



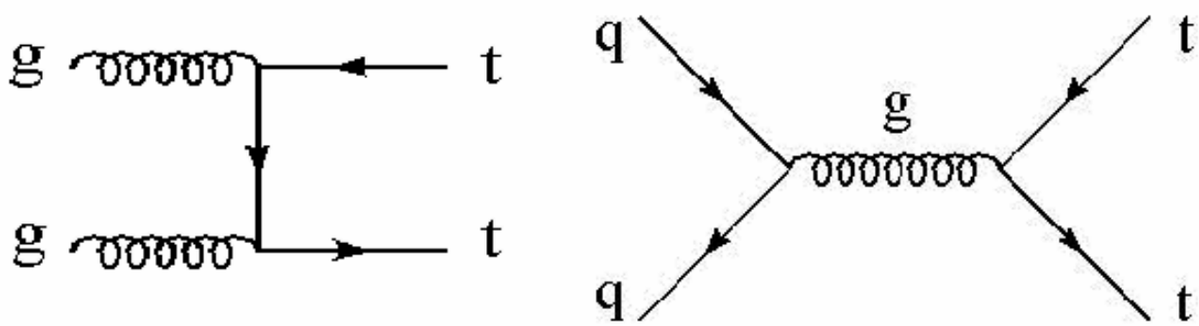




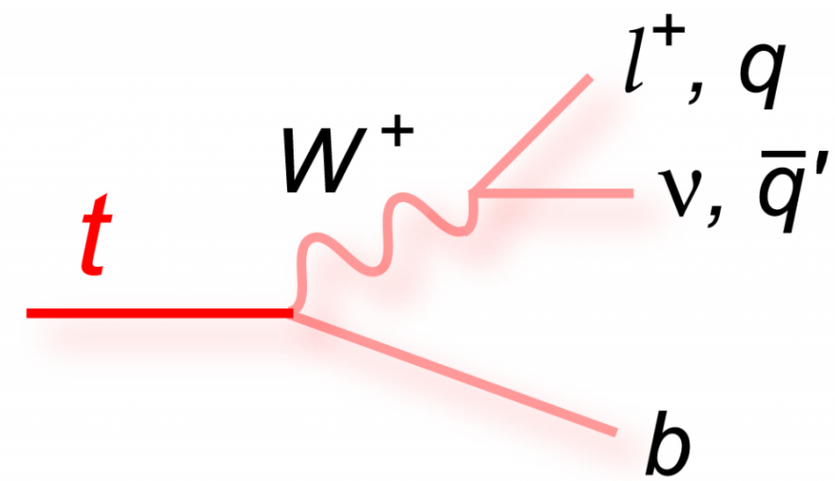
$$m_t = 172.51 \pm 0.50\,\mathrm{GeV}$$

Top Quark Cross-Section

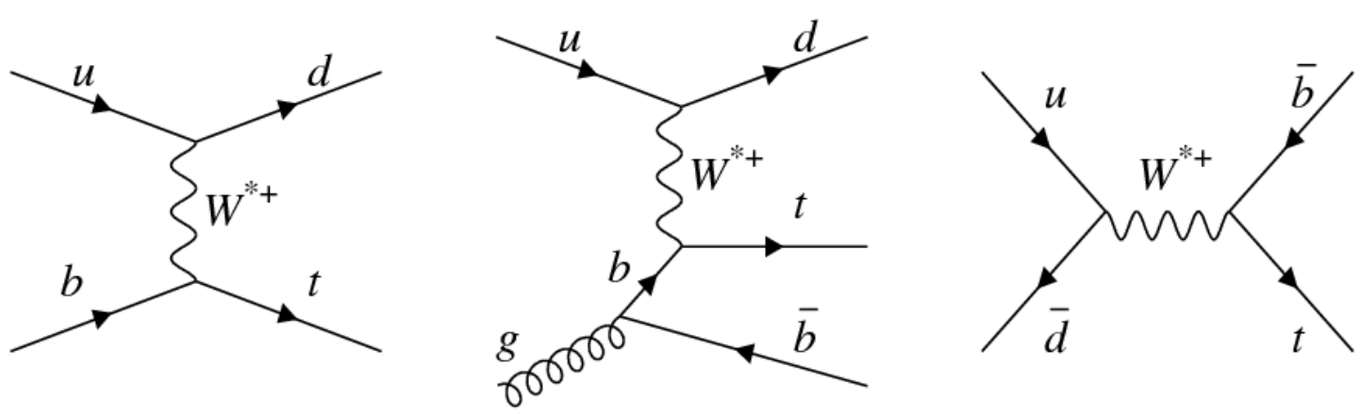
QCD production ($t\bar{t}$)



...EW decay



EW production (single top)

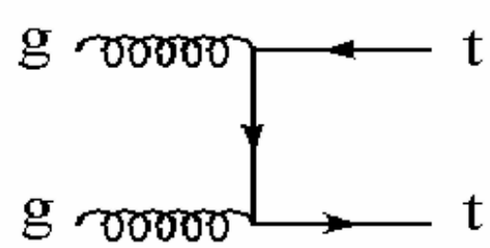


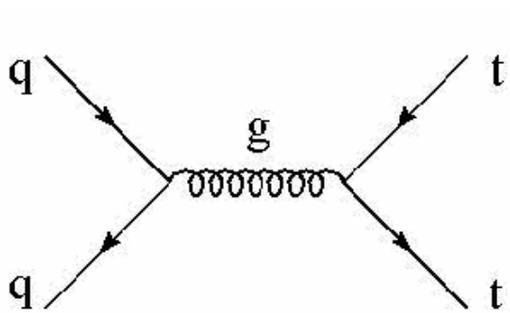
Three-body final state gives rise to a very rich phenomenology

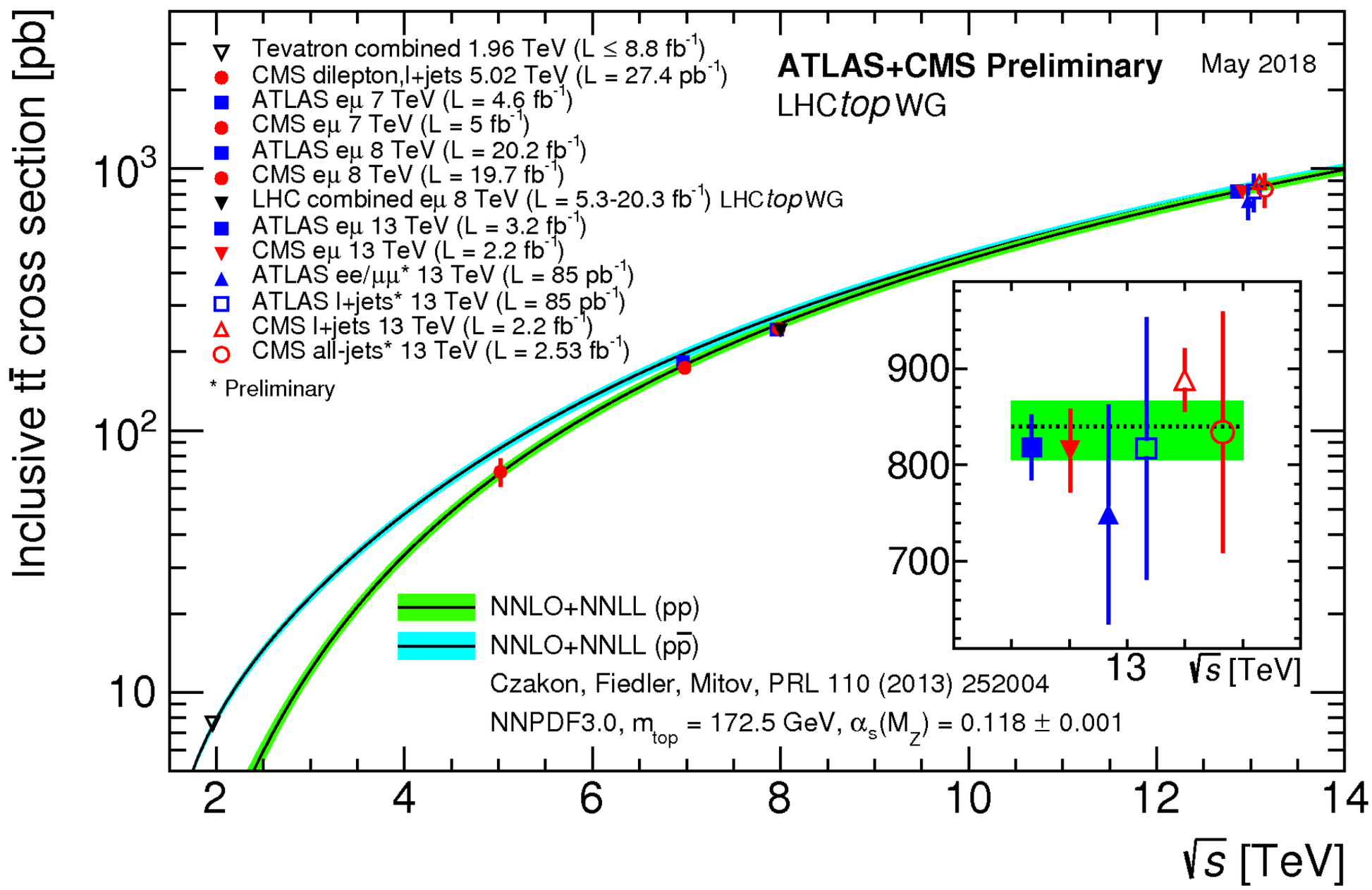
$t\bar{t}$ Cross-Section

QCD production ($t\bar{t}$)

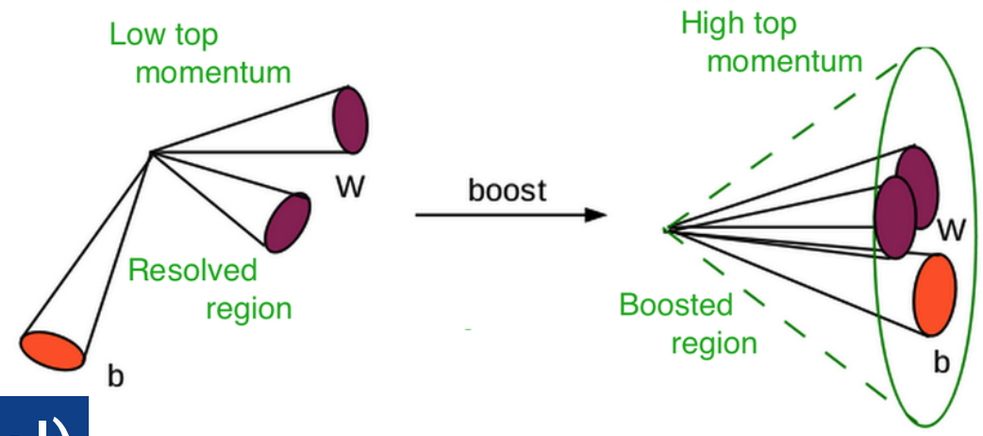
Precision exp ~ th (few %)





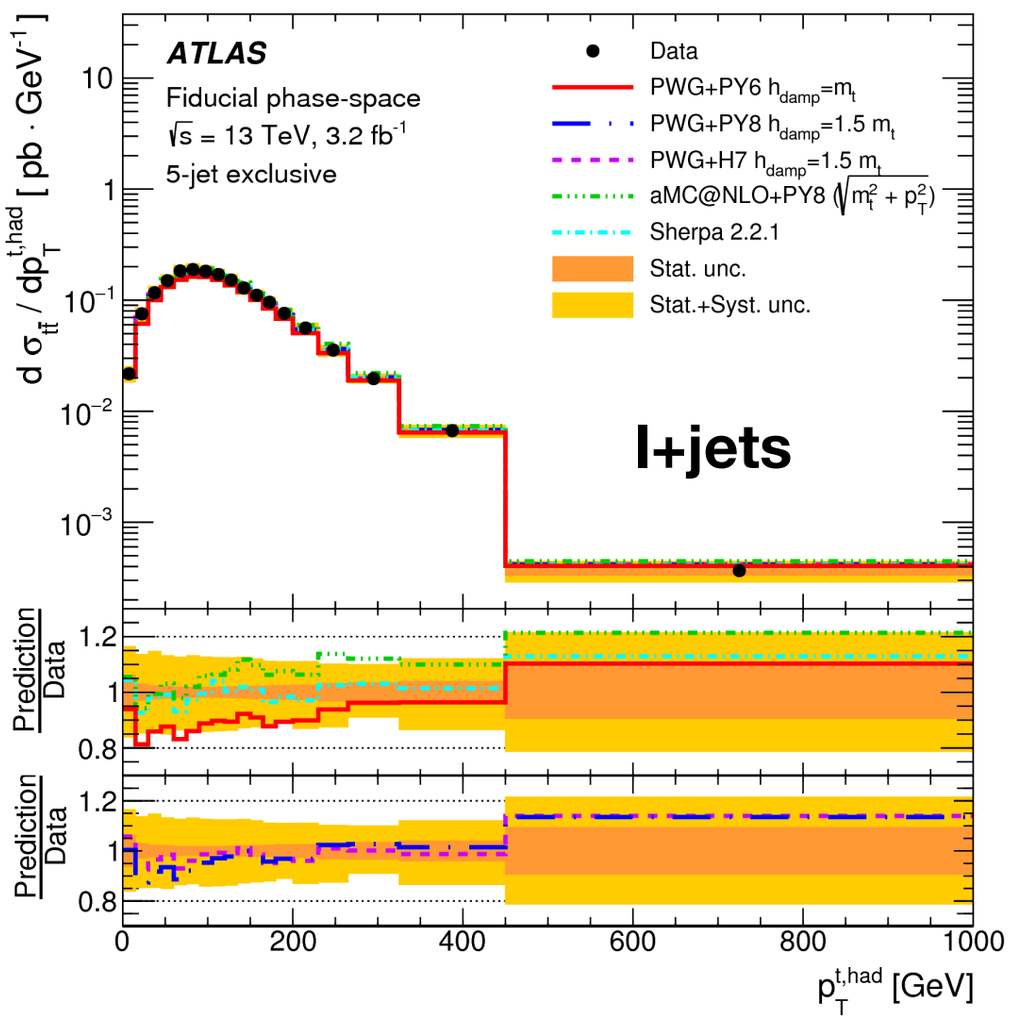


$t\bar{t}$ Cross-Section



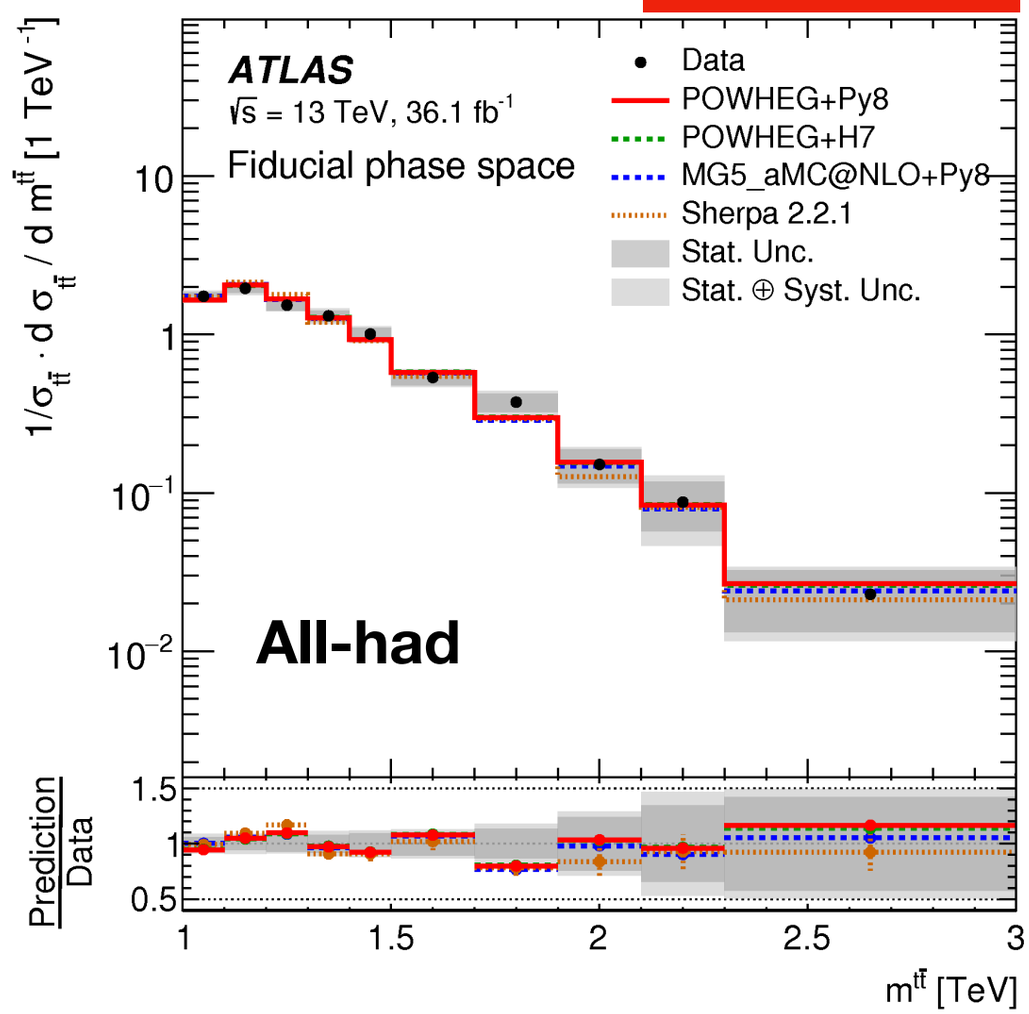
Resolved (N_{jets} excl)

arXiv:1802.06572

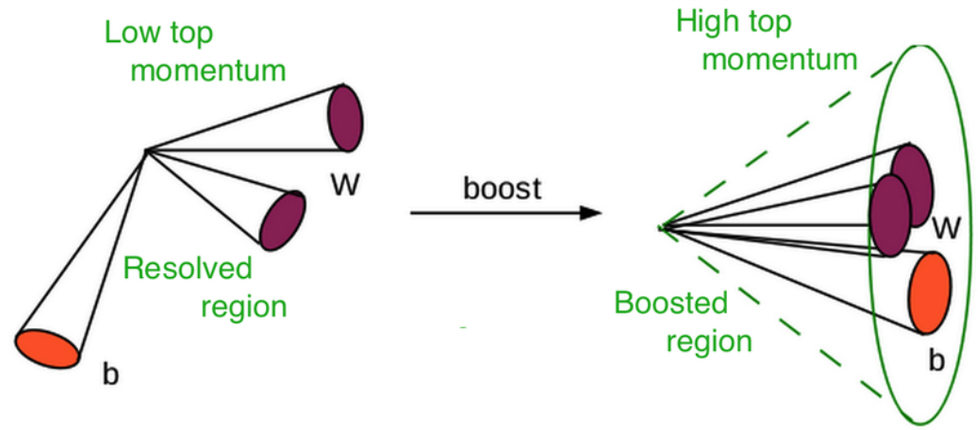


Boosted

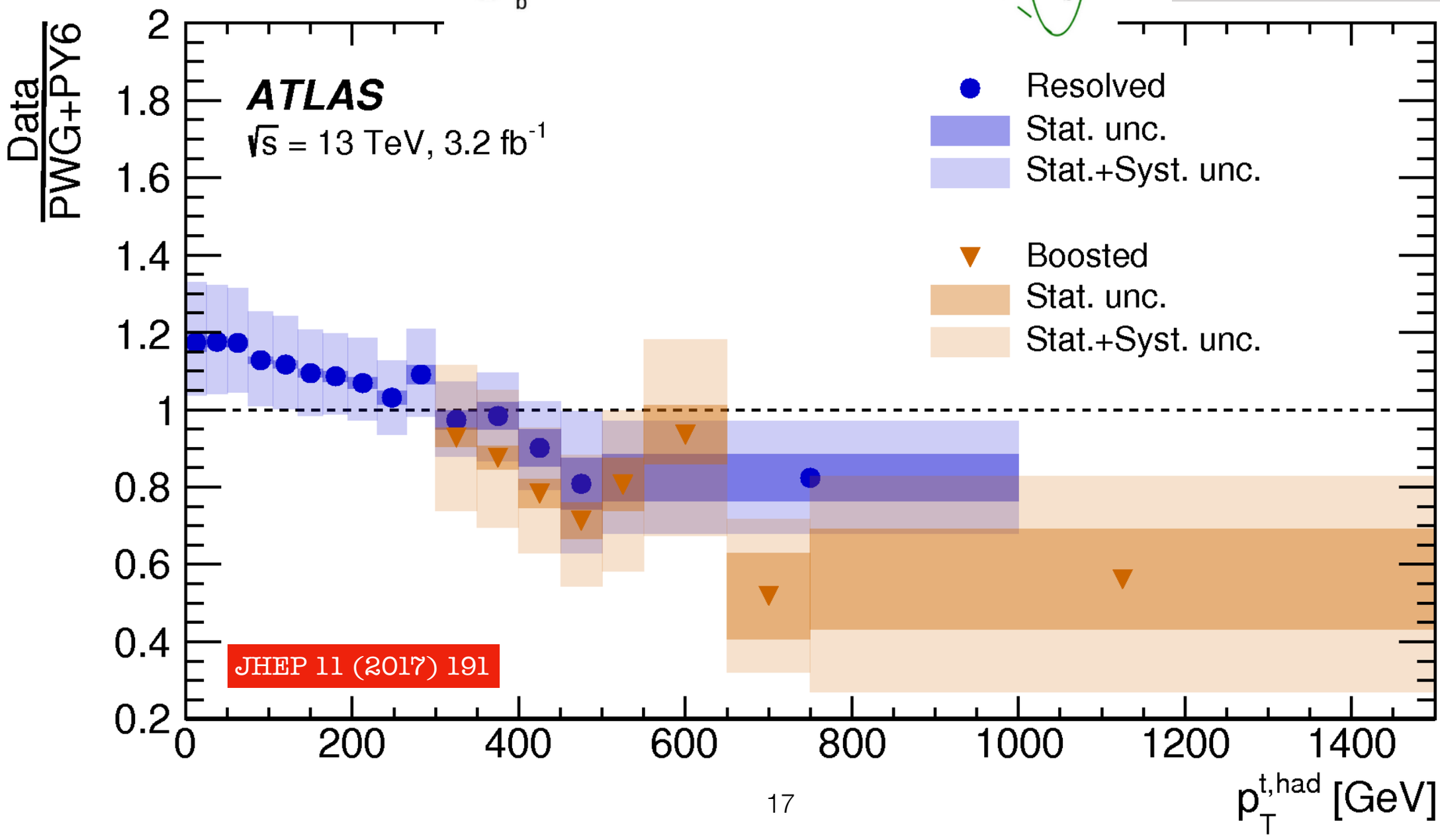
arXiv:1801.02052



$t\bar{t}$ Cross-Section

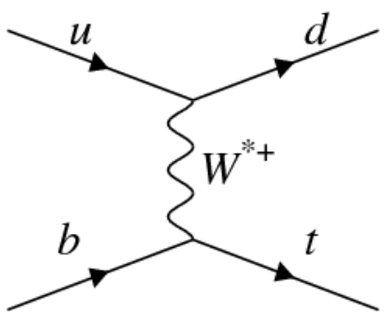


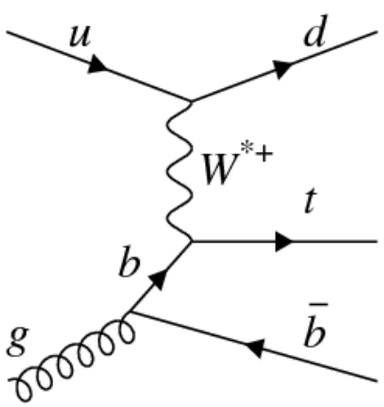
Confirmed by CMS
One of the few outstanding tensions with SM

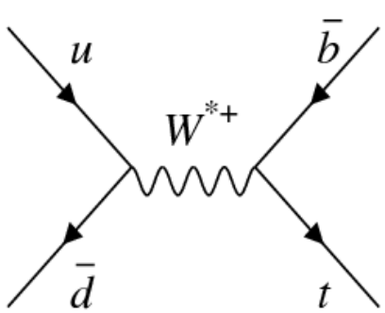


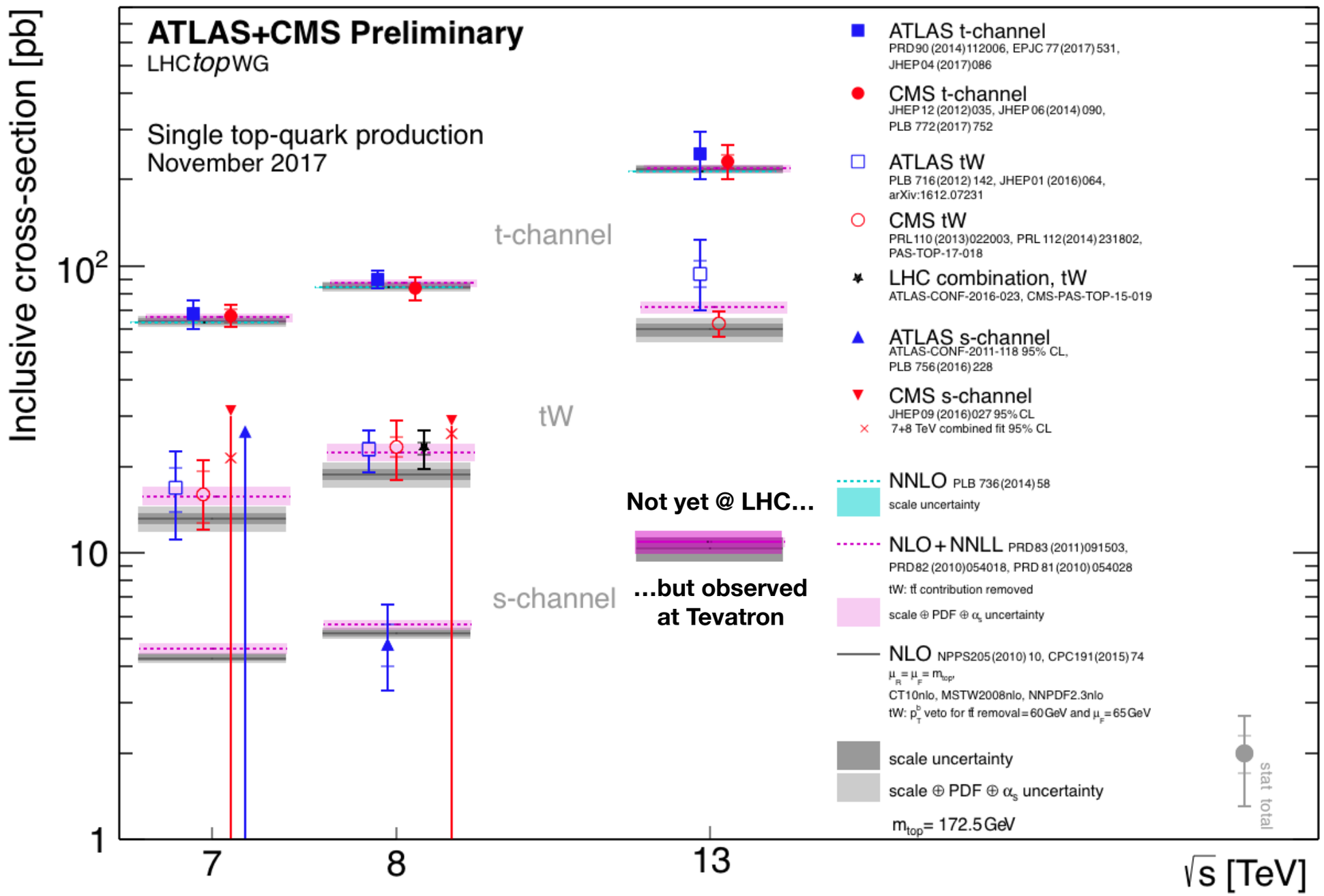
Single Top Cross-Section

EW production (single top)









Single Top Cross-Section

t channel

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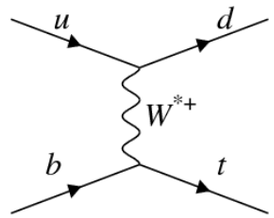
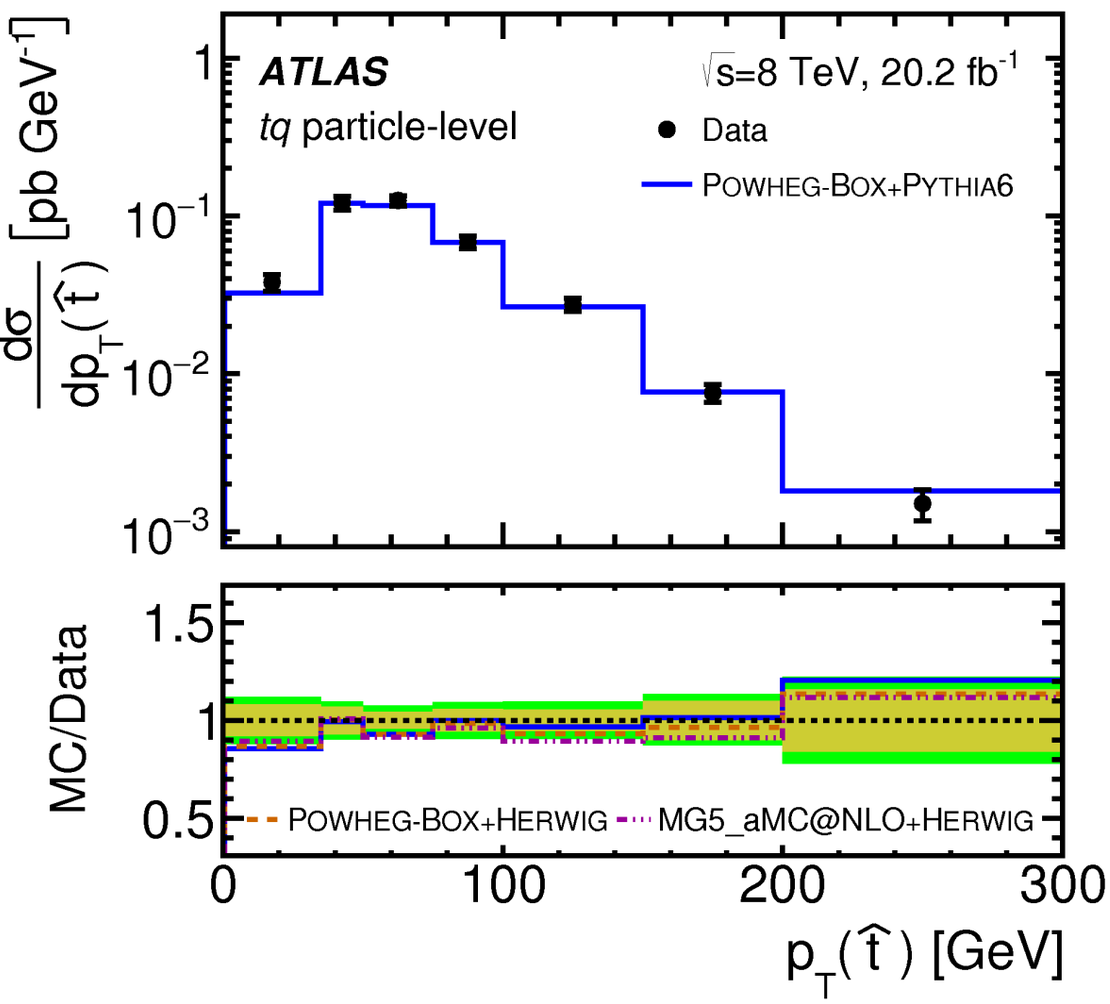
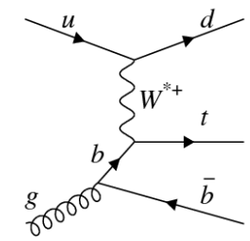
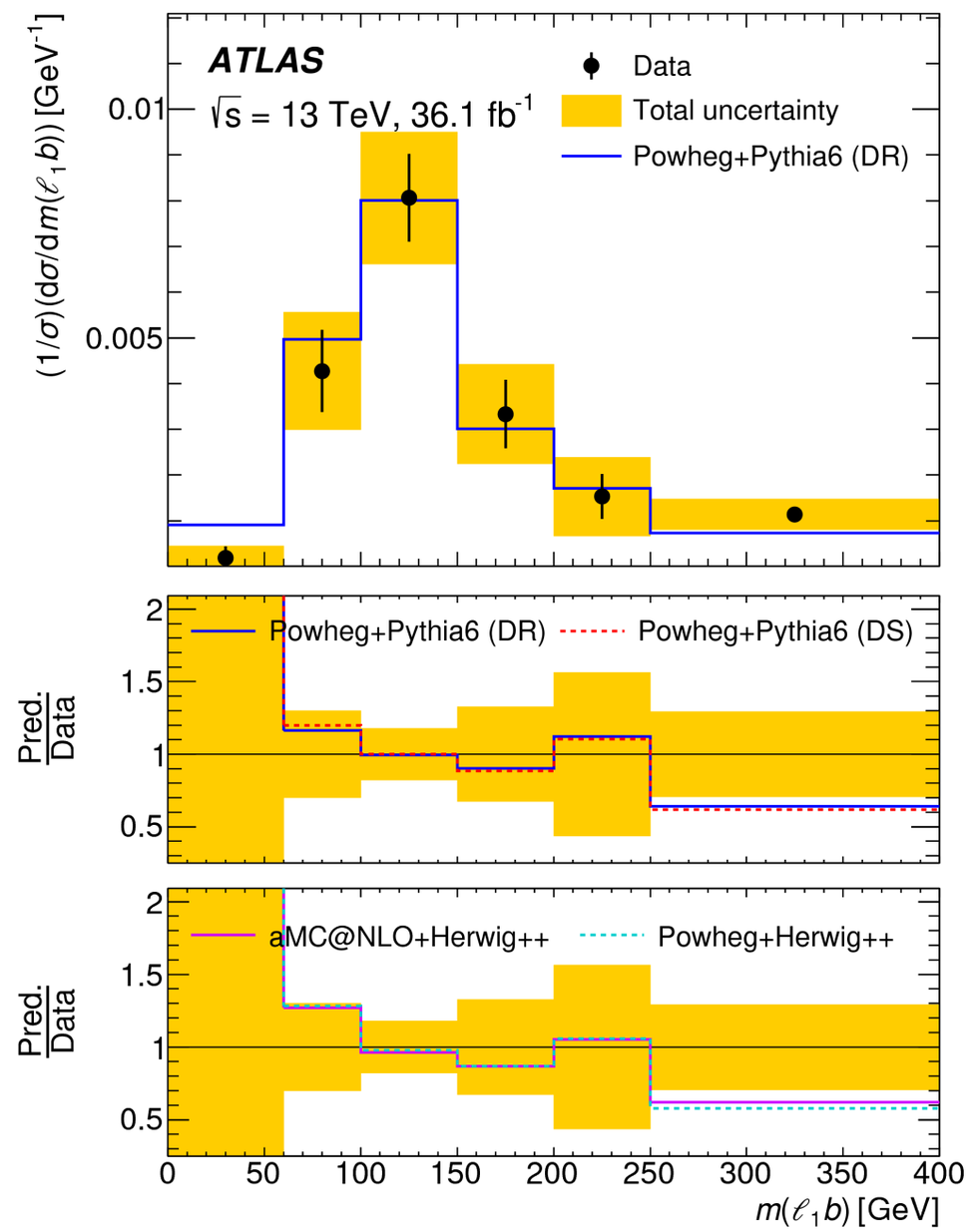




Wt channel

Eur. Phys. J. C 78 (2018) 186

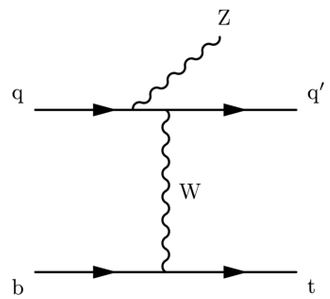




Top + W/Z Bosons

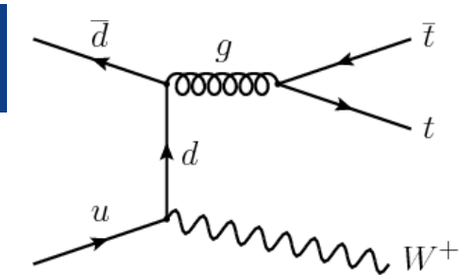
tqZ channel

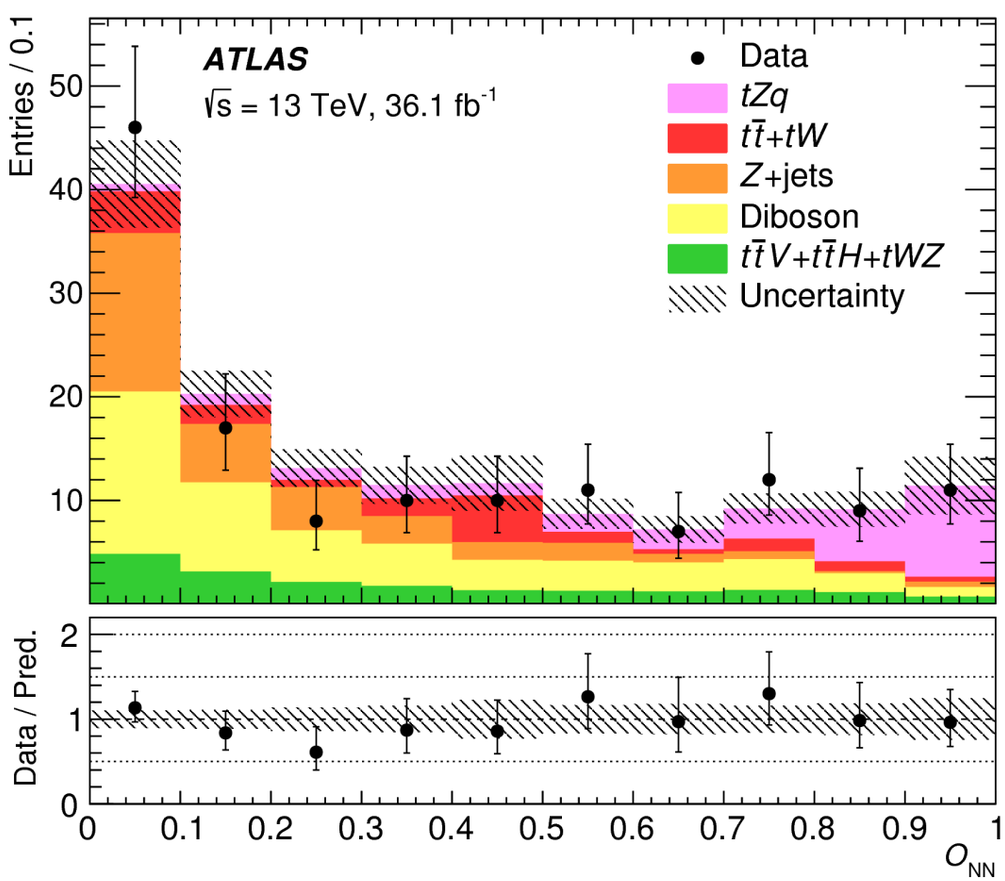
Phys. Lett. B 780 (2018) 557

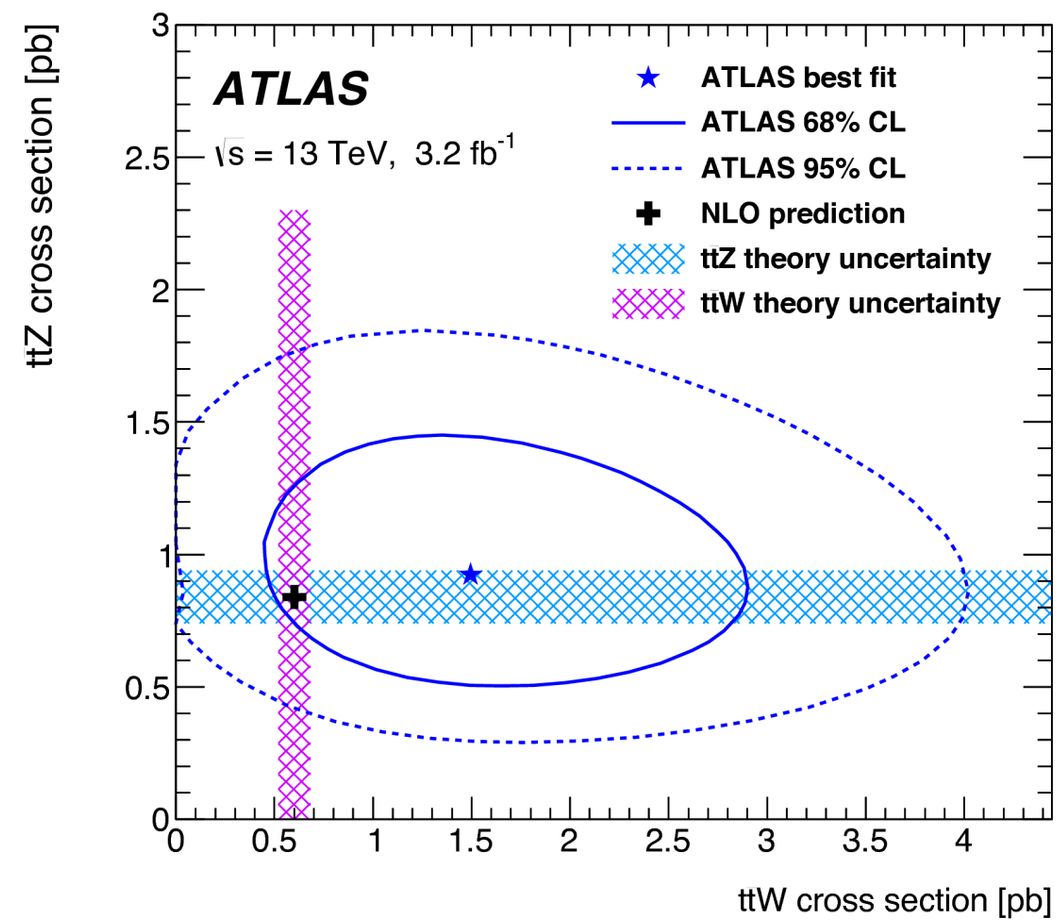


ttW / ttZ channel

Eur. Phys. J. C77 (2017) 40







Very sensitive to BSM physics (e.g. FCNC tqZ)

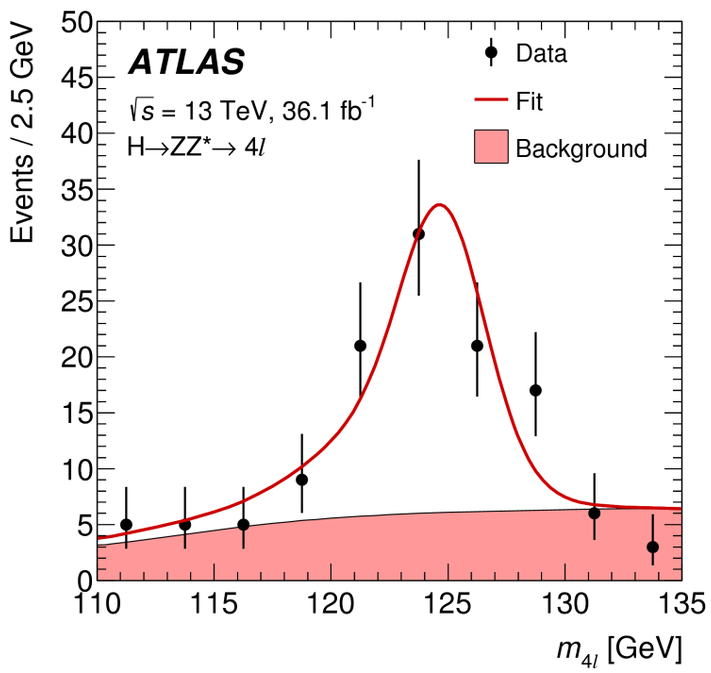
arXiv:1806.00242

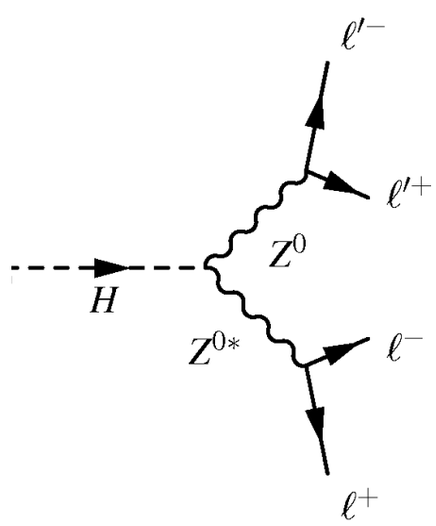
ATLAS-CONF-2018-004

Higgs(*) Boson

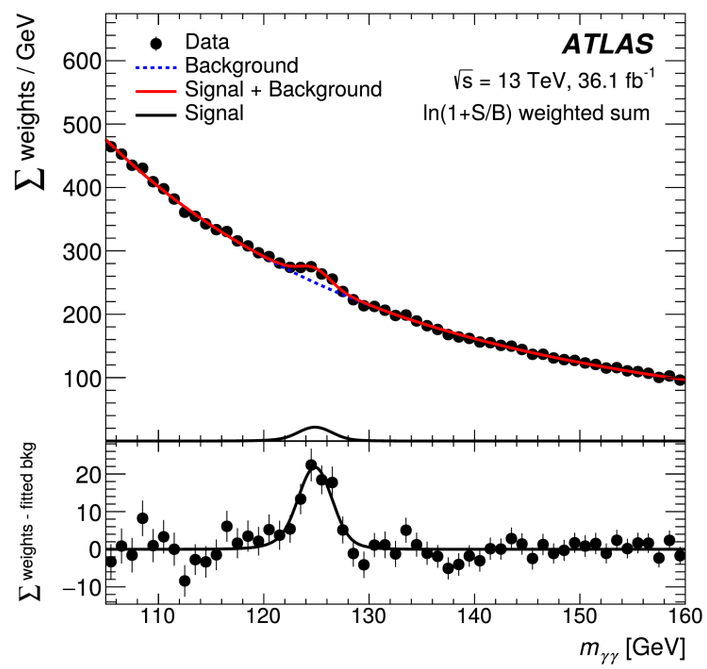
Only scalar field of the SM. Why this "intermediate" mass?
Consistent measurements in final states involving bosons

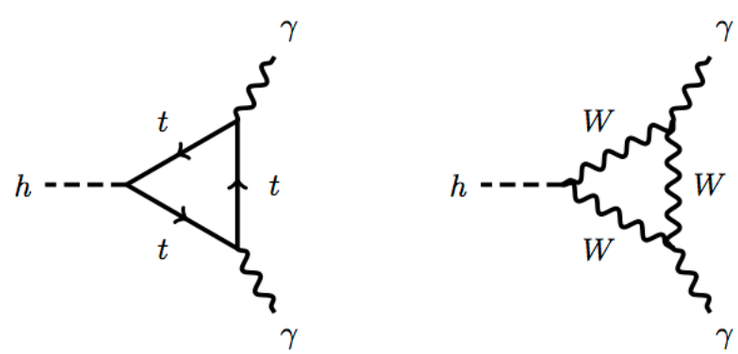
H→ZZ*→4ℓ



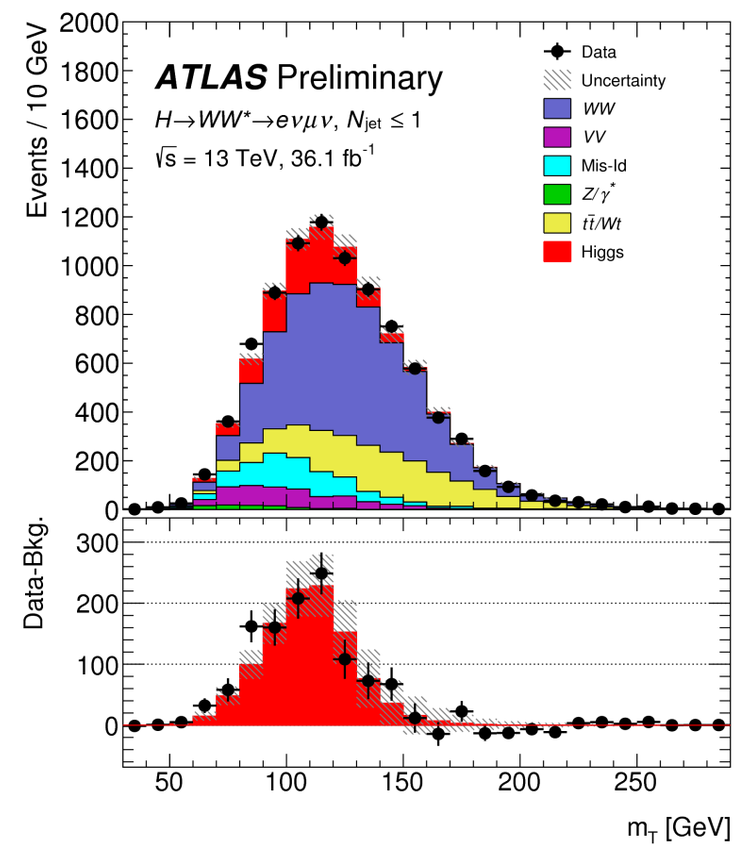


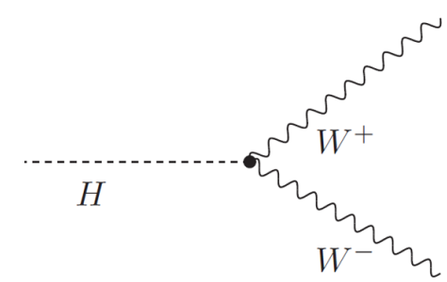
H→γγ





H→WW*





(*)Also known as Brout-Englert-Higgs (BEH) boson

arXiv:1806.00242

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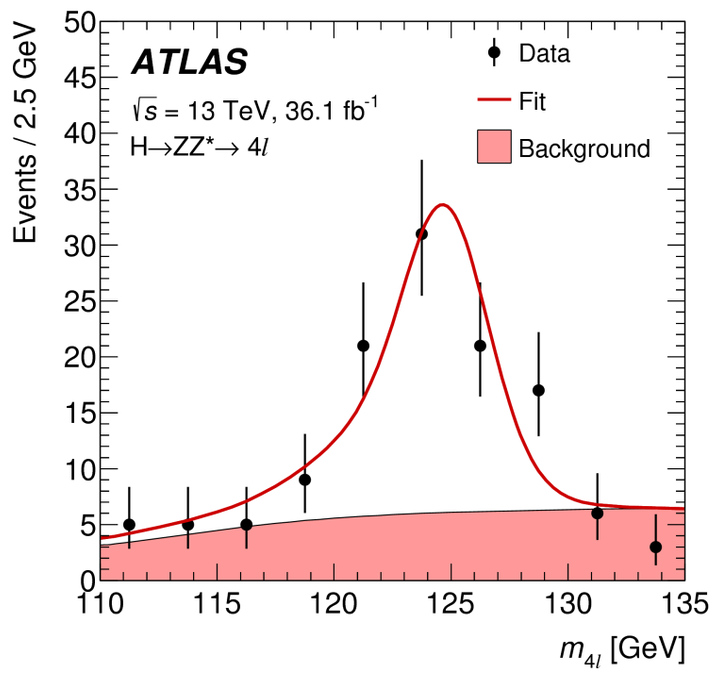
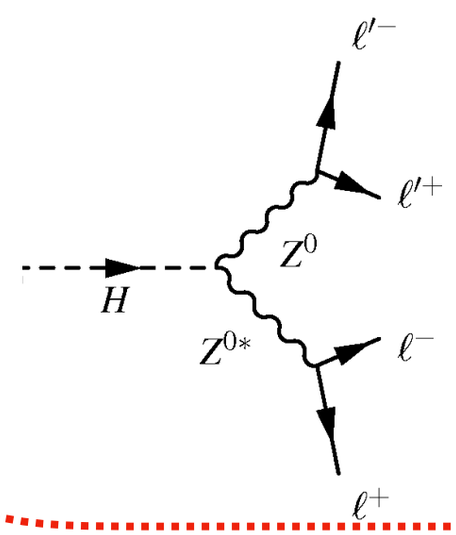
Higgs(*) Boson

Only scalar field of the SM. Why this "intermediate" mass?
Consistent measurements in final states involving bosons

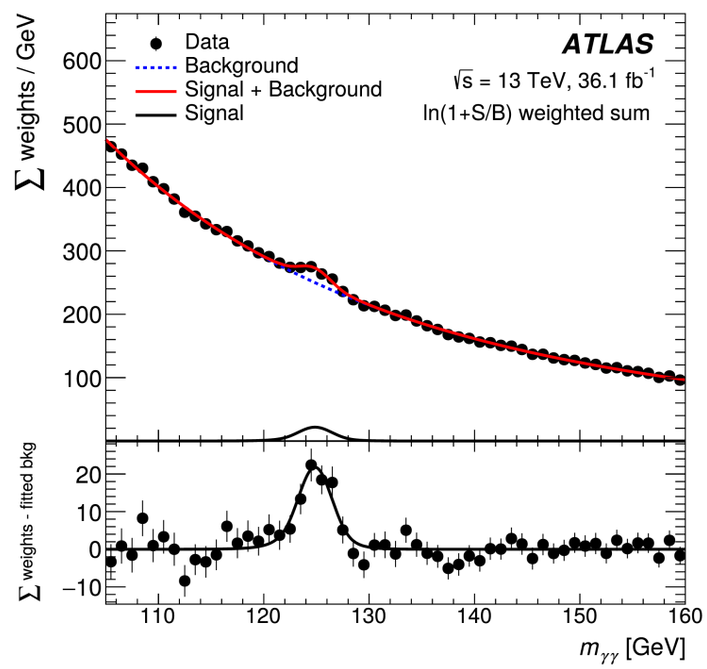
More precise measurements

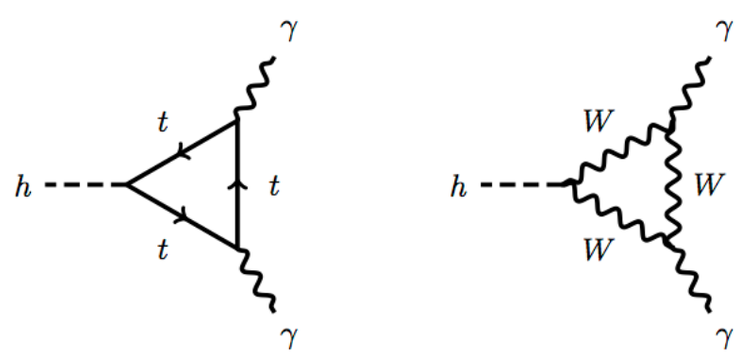
H→ZZ*→4ℓ



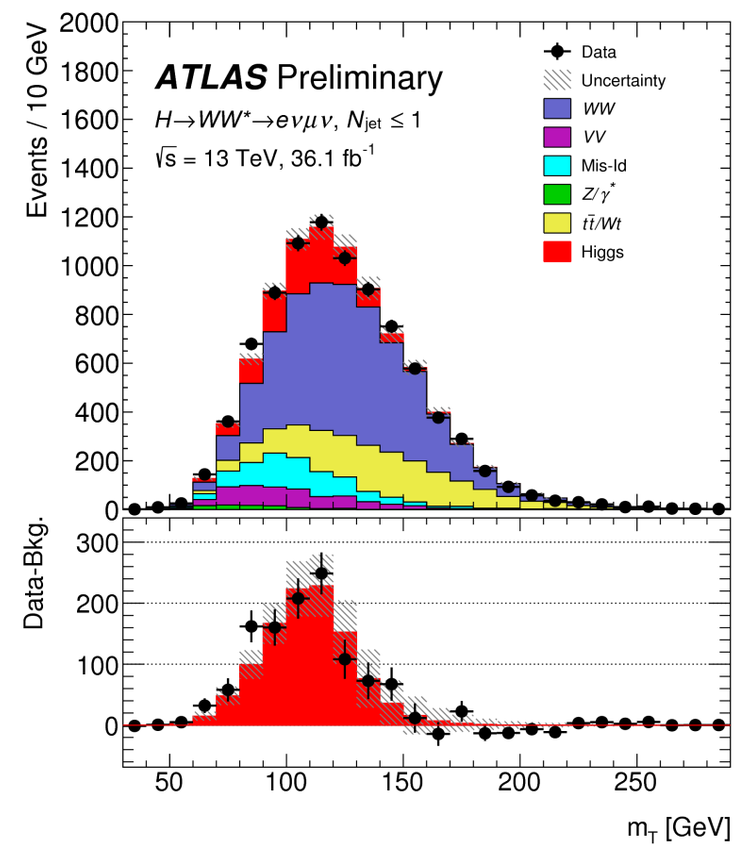


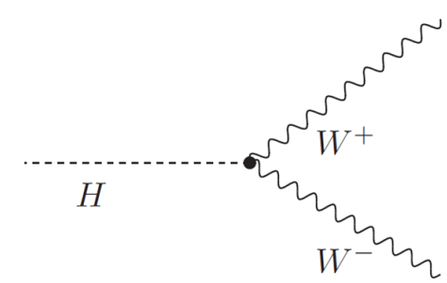
H→γγ





H→WW*



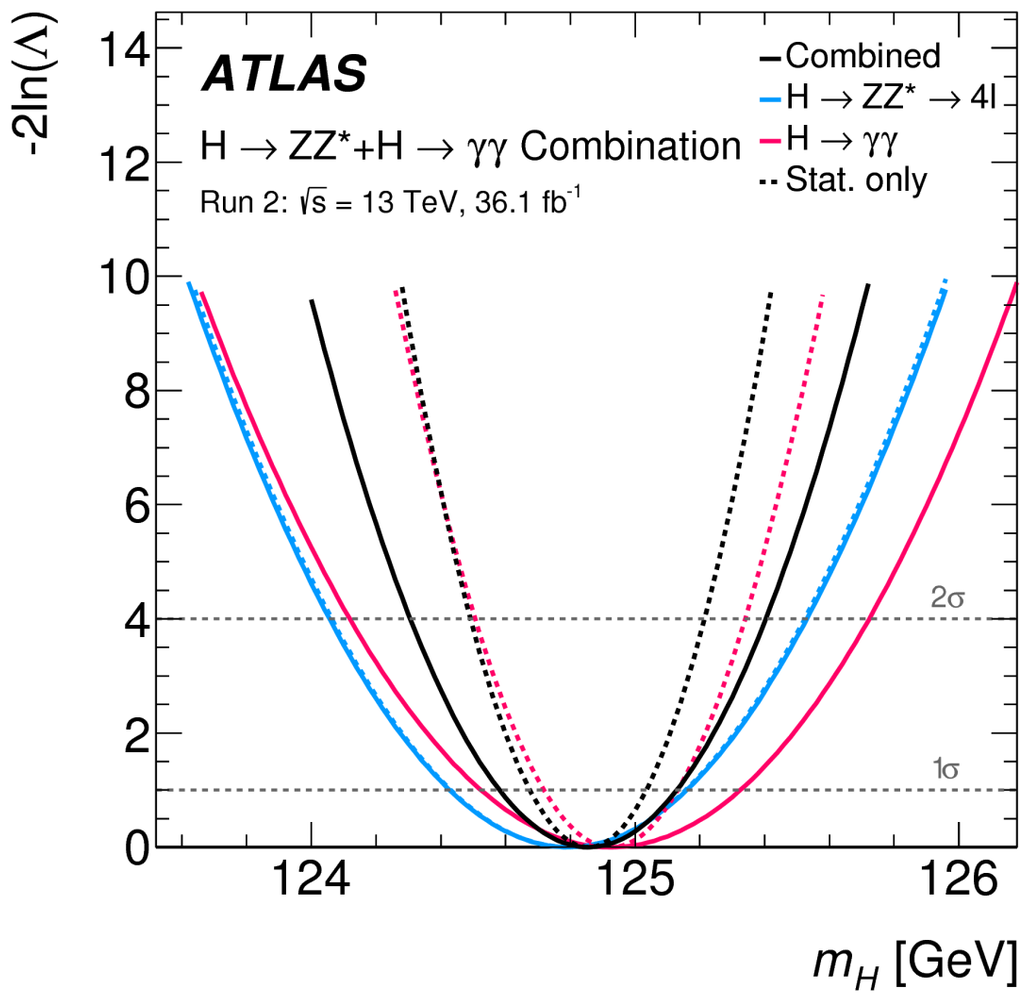


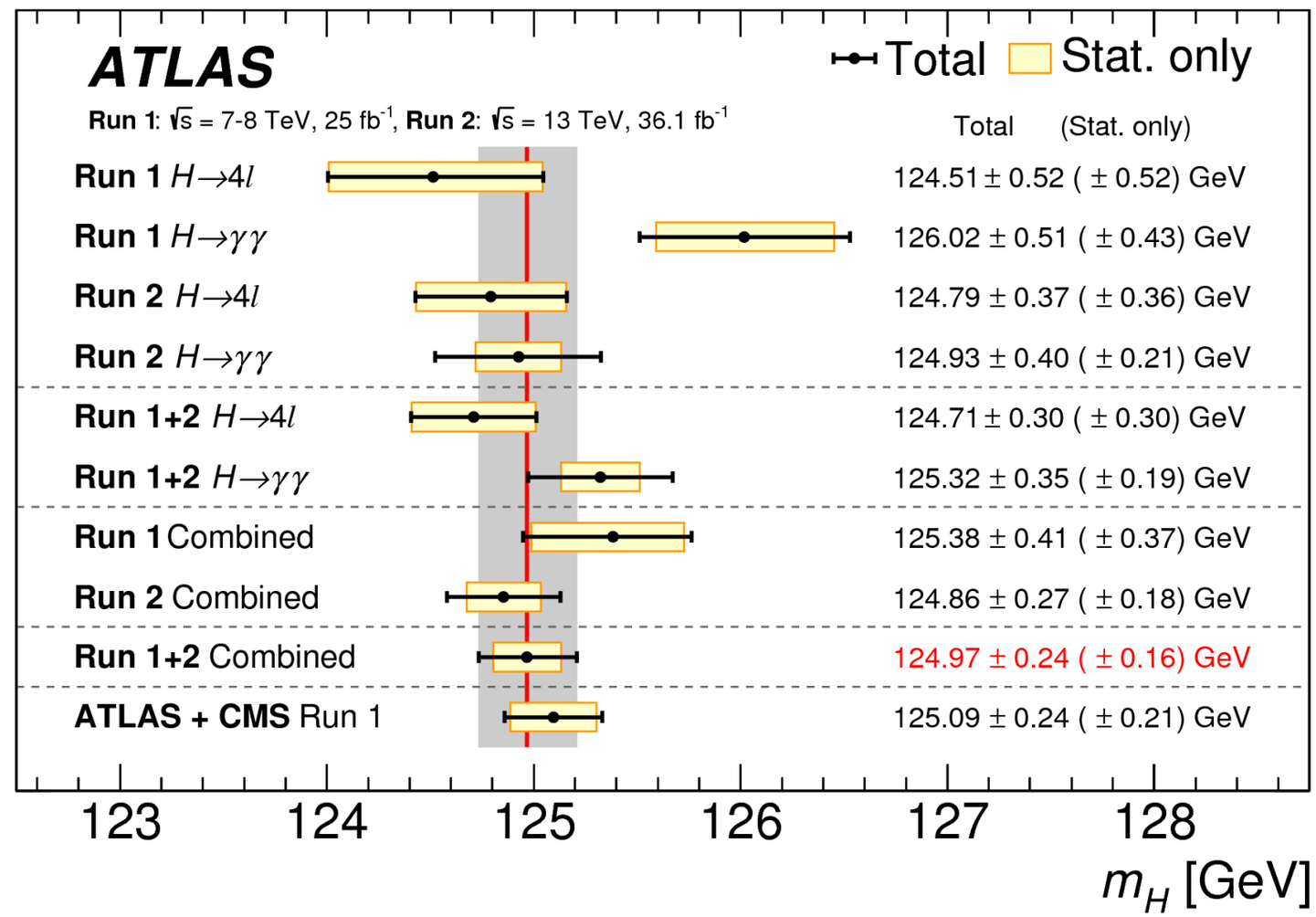
(*)Also known as Brout-Englert-Higgs (BEH) boson

arXiv:1806.00242

Higgs Mass

Only scalar field of the SM. Why this "intermediate" mass?
Consistent measurements in several final states



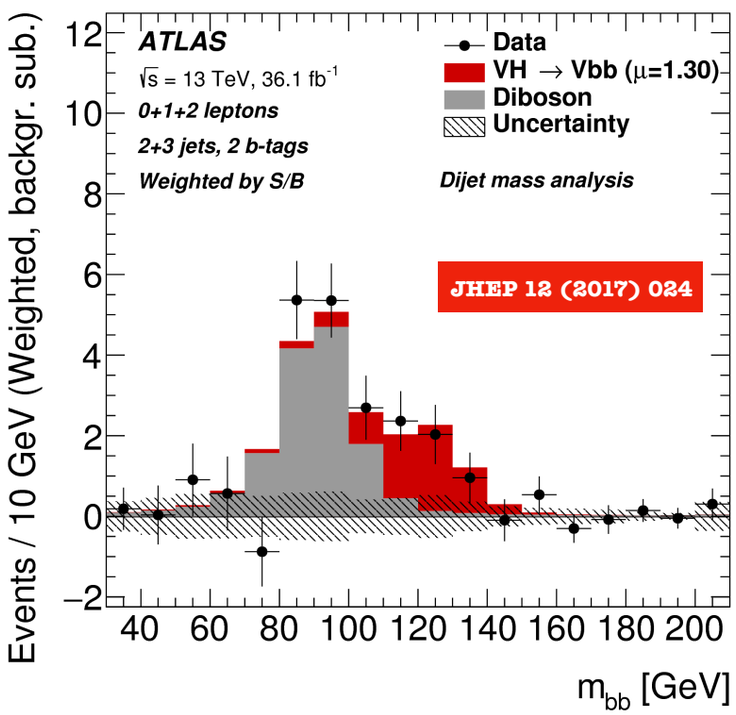


$$m_H = 124.97 \pm 0.24\,\mathrm{GeV}$$

Fermion Couplings

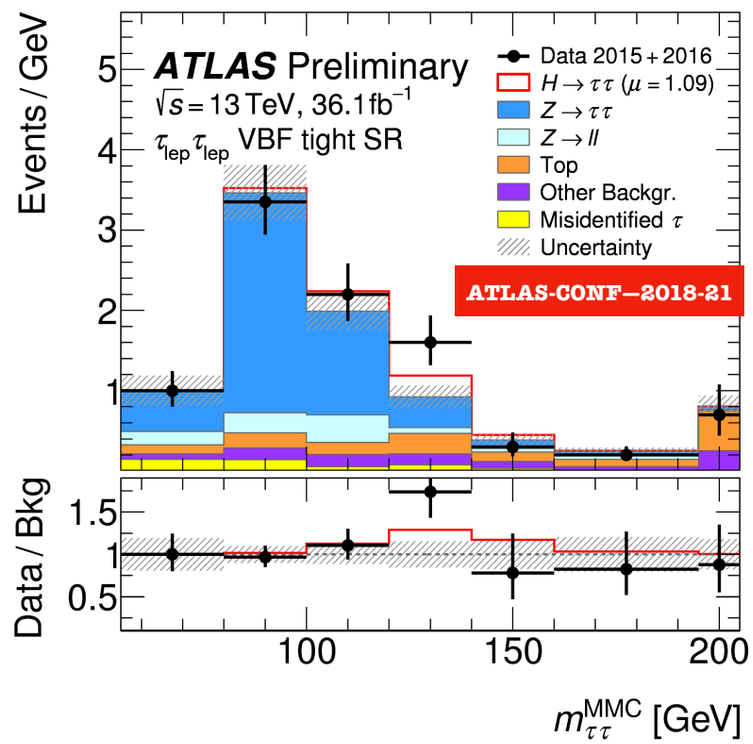
Fermion masses from Yukawa couplings with the Higgs boson, unconstrained from theory
Couplings scale with fermions generations (u/d/e << c/s/μ << b/t/τ)
Higgs to di-muon not observed yet Phys. Rev. Lett. 119 (2017) 051802

Bottom Quark



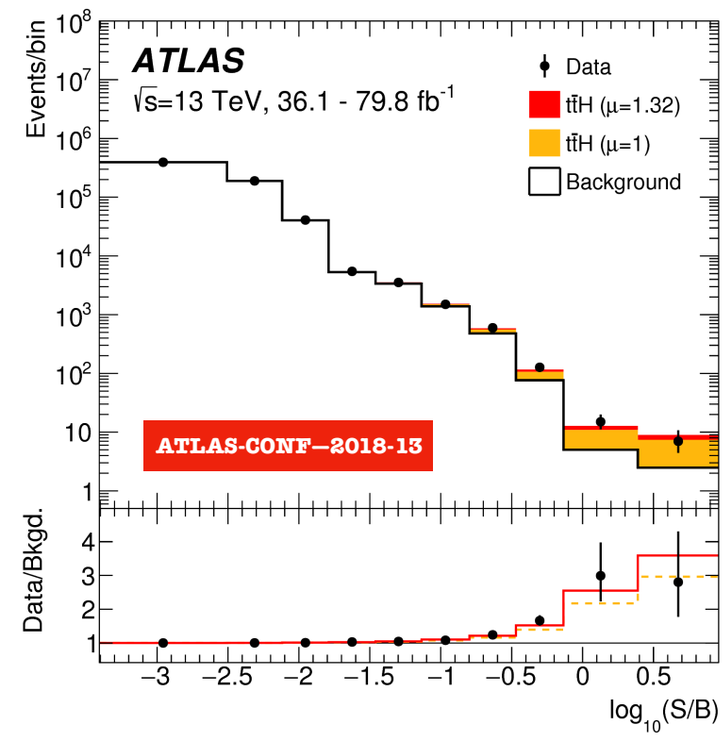
3.6σ (obs)
4.0σ (exp)

Tau Lepton



6.4σ (obs)
5.4σ (exp)

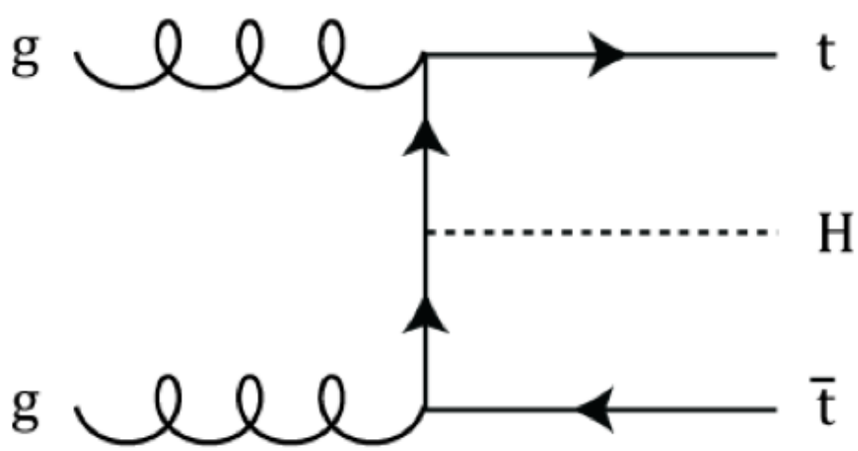
Top Quark

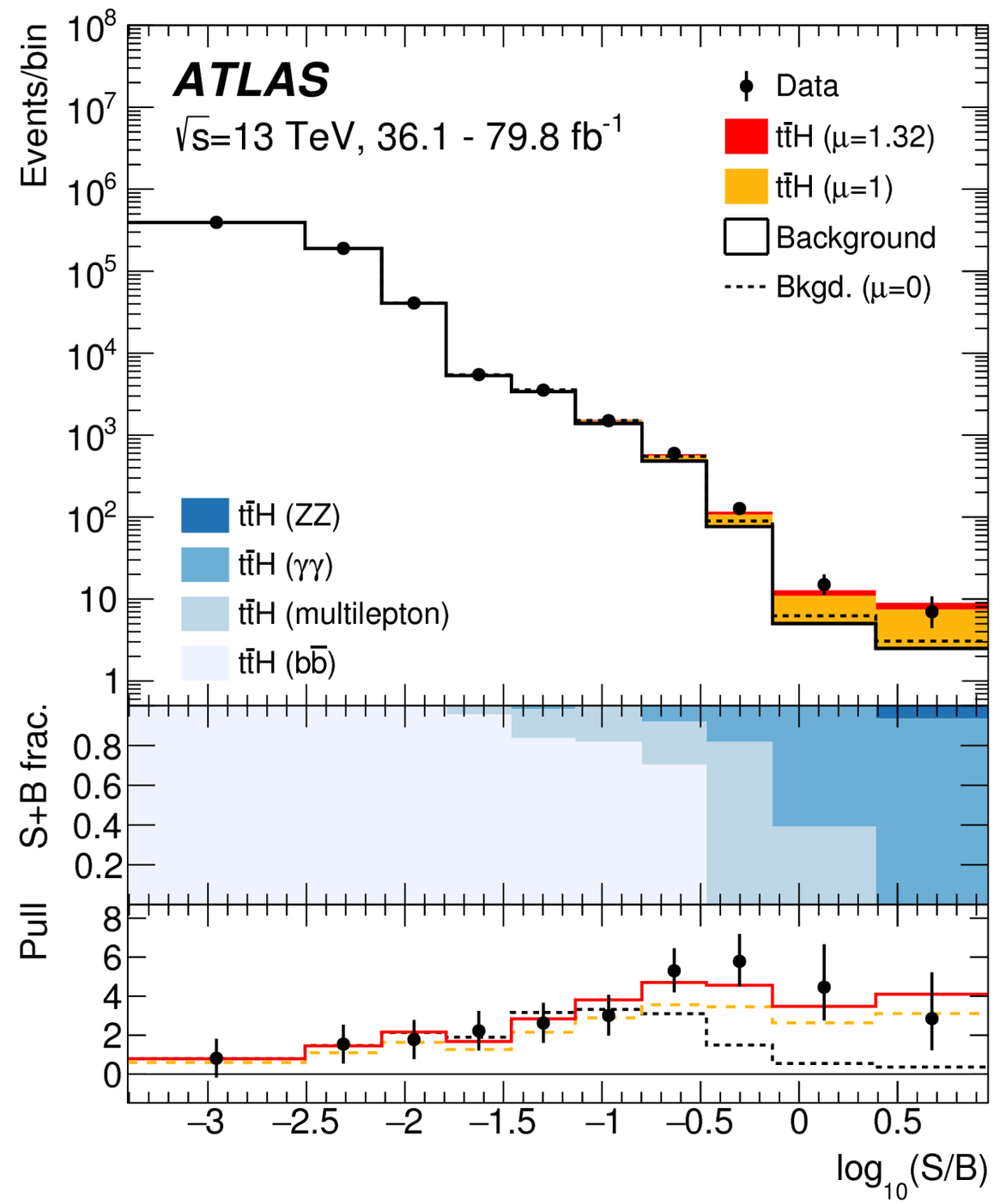


6.3σ (obs)
5.1σ (exp)

ttH

Associated production of top-quark pair with a Higgs boson





Rich combination of final states depending on the decay of top quarks and Higgs bosons

Typically classified in H(bb), H(γγ) and H(leptons) signatures

ttH(γγ)

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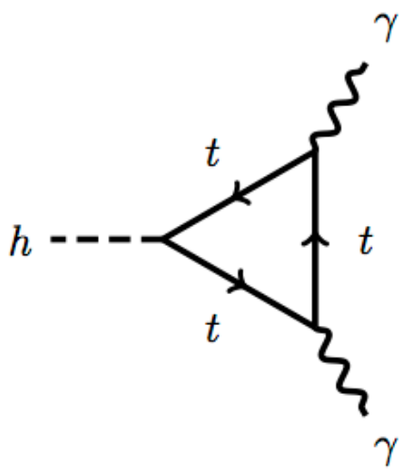
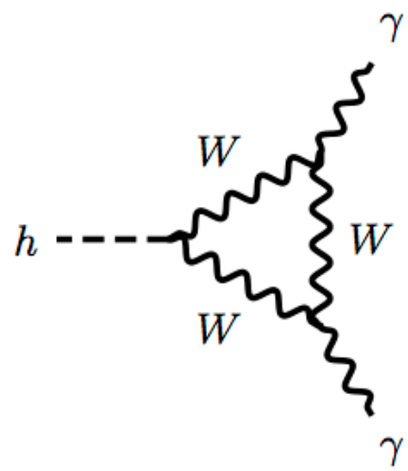
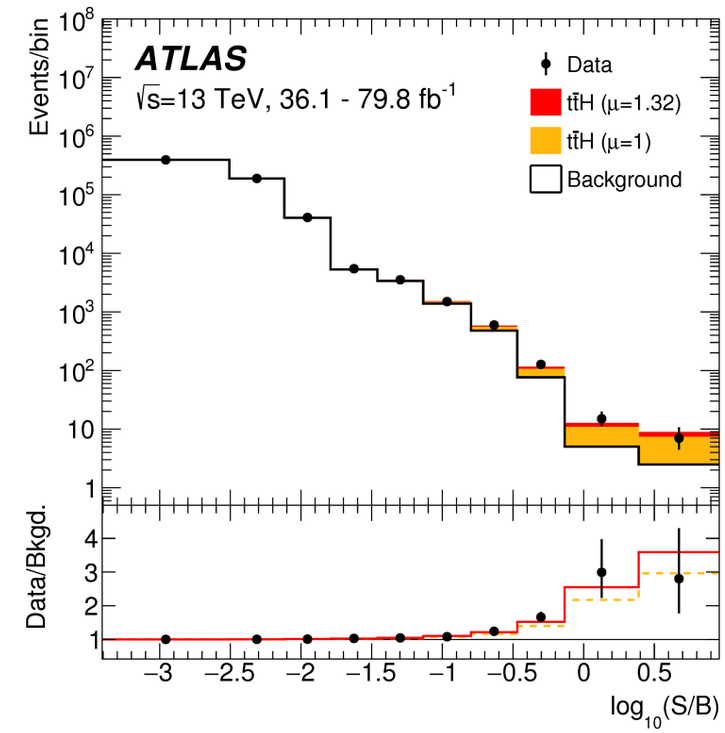
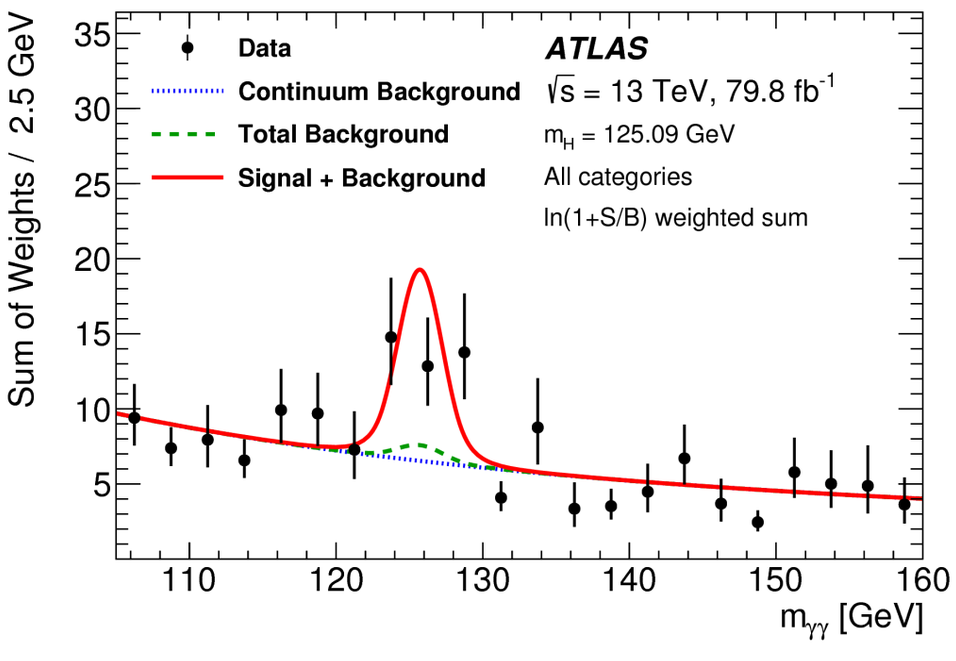
Small BR, but very clean channel. Higgs kinematics completely reconstructed



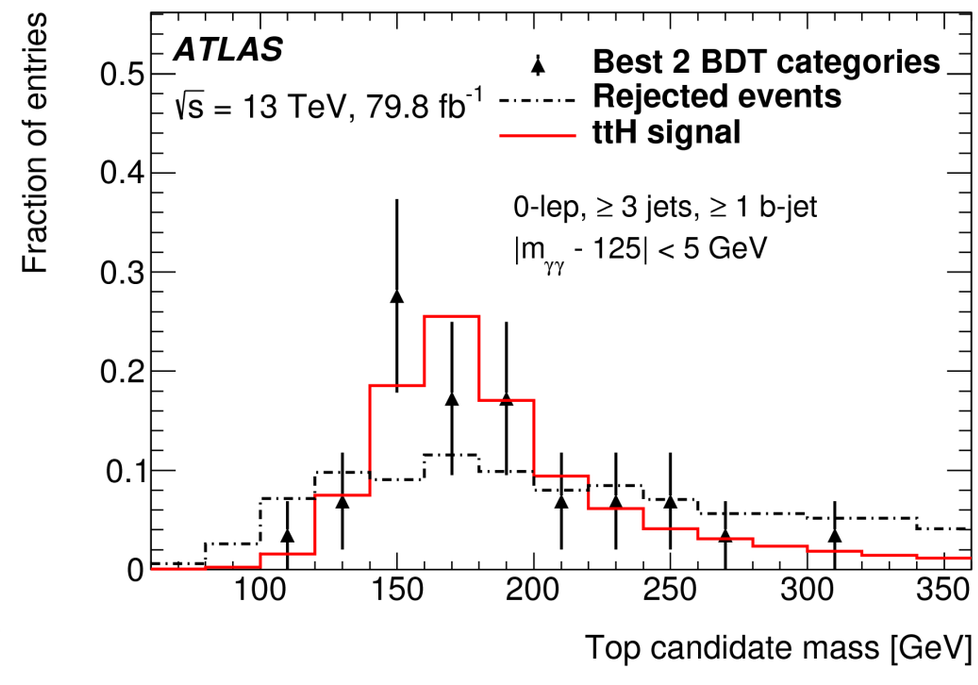




Higgs boson mass peak



Top quark mass peak



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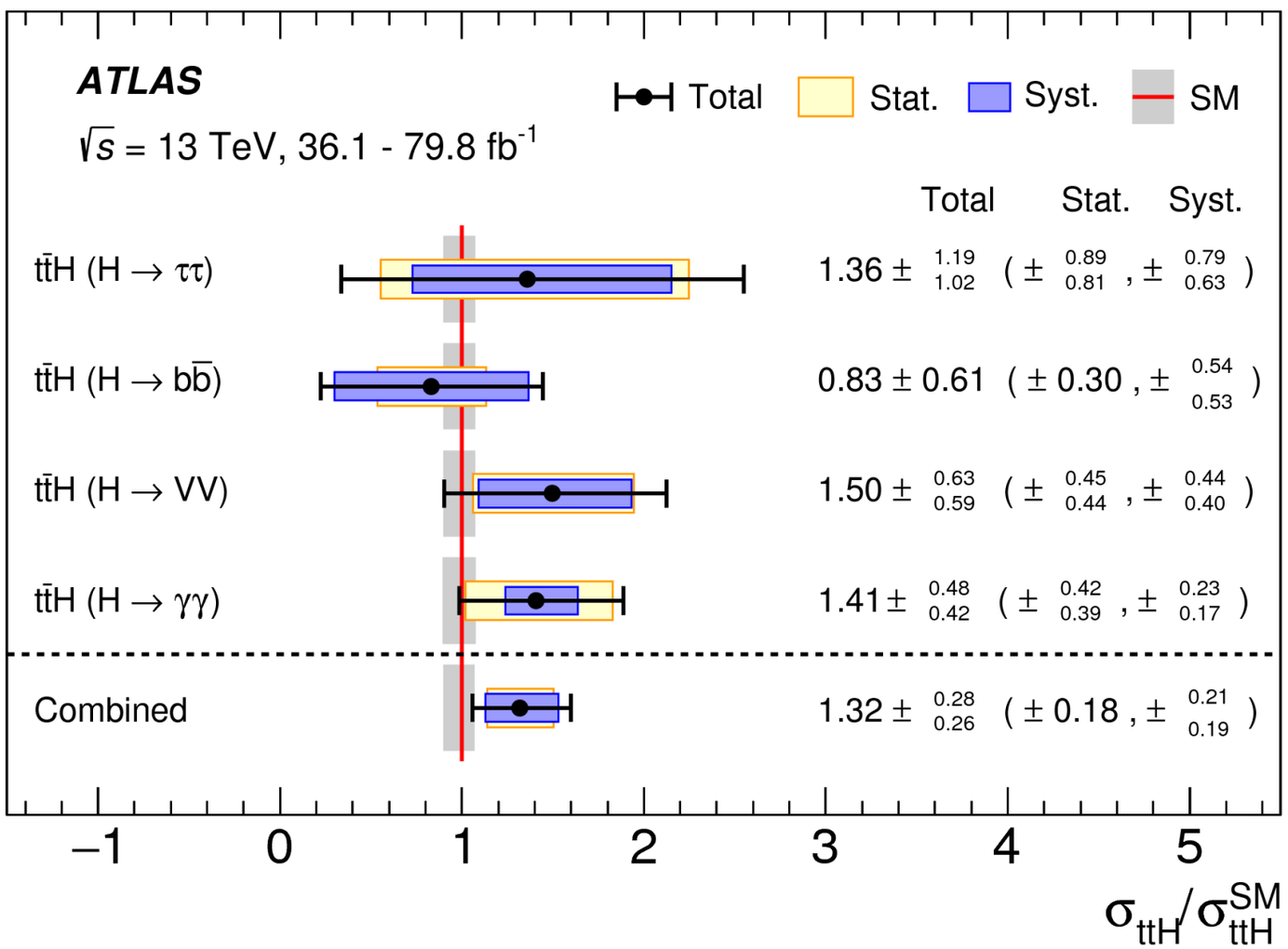
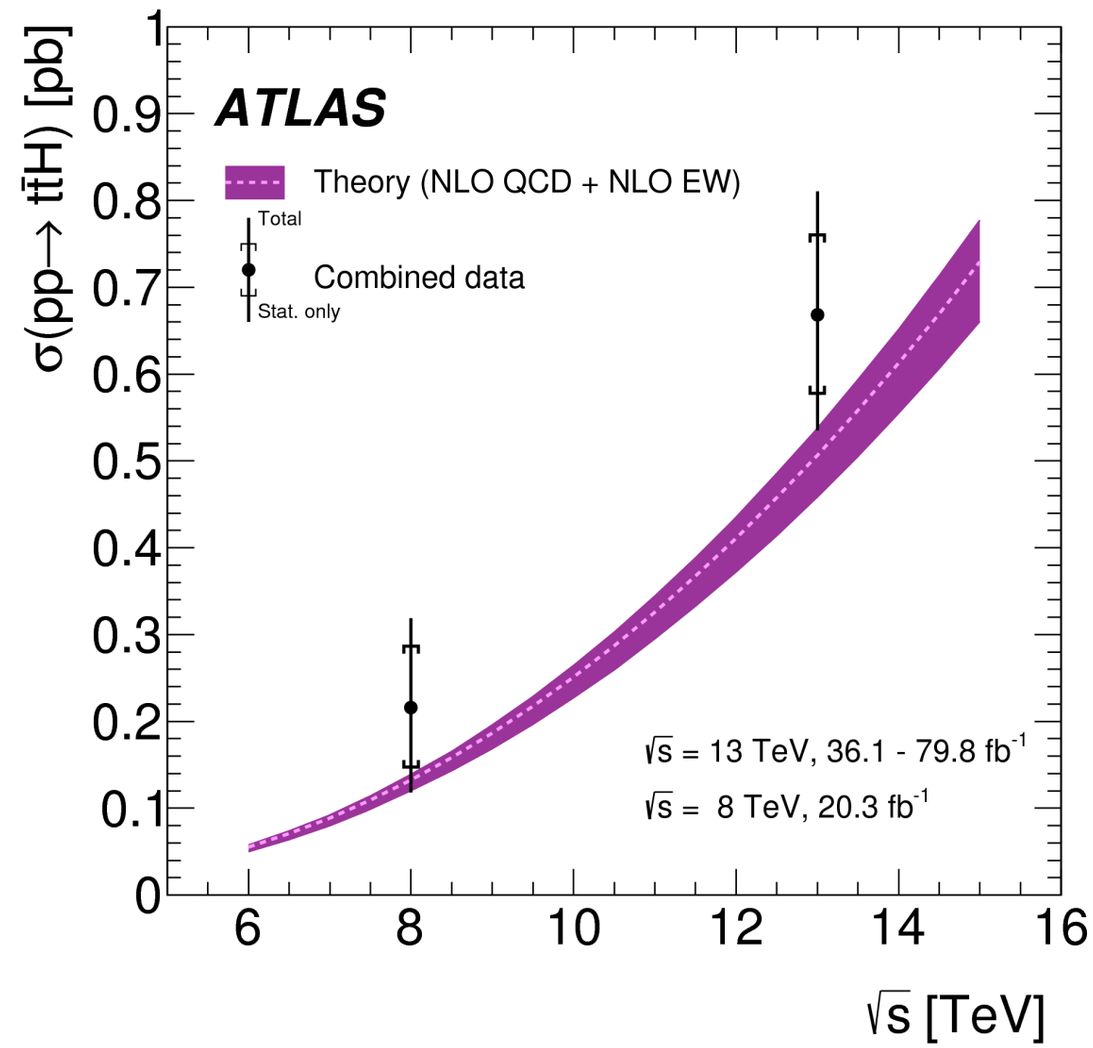
ttH Cross-Section

Combination includes Higgs boson decays into $b\bar{b}$, WW*, ττ, γγ, and ZZ*



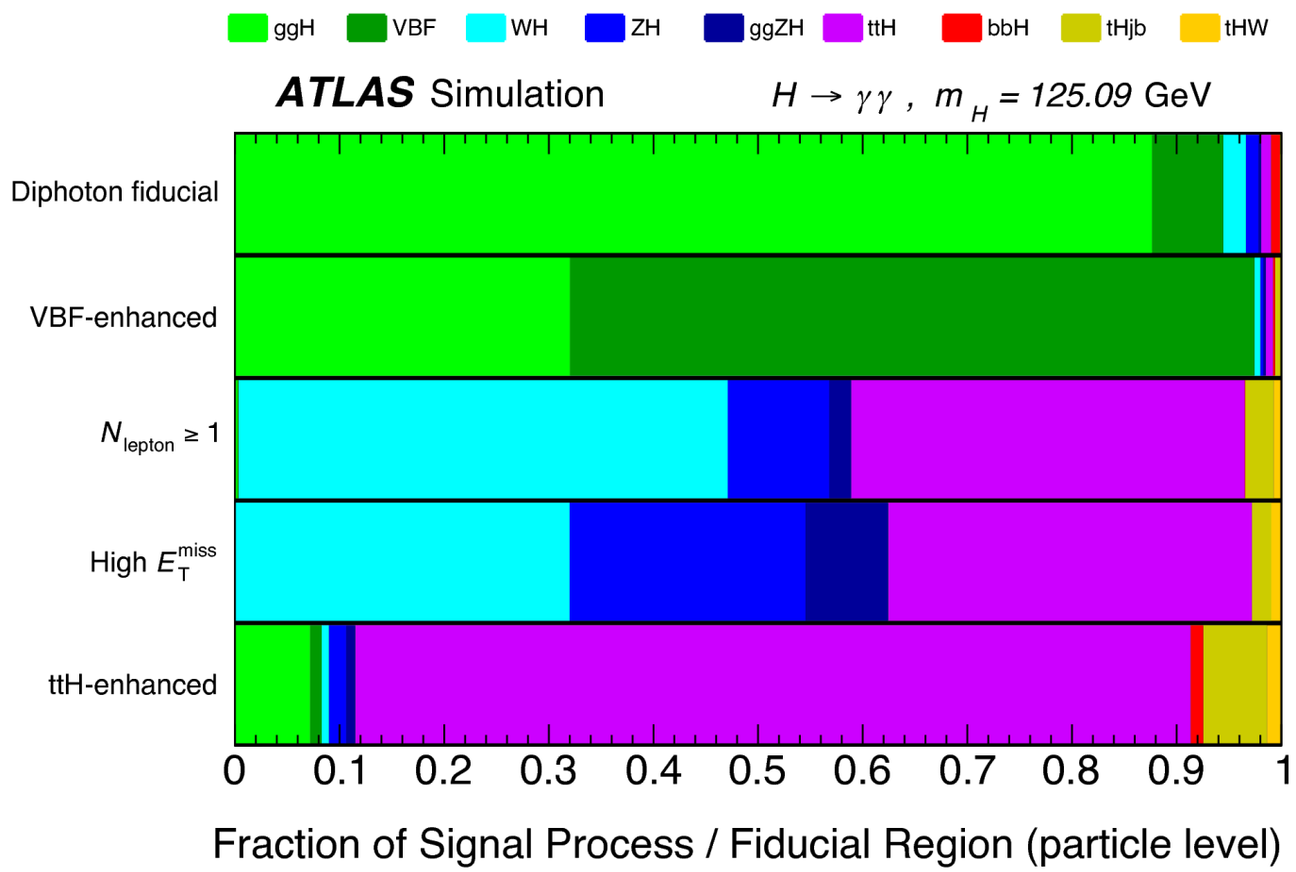
Measured cross-section (670 ± 20% fb) larger but still compatible with SM



ATLAS joined CMS in claiming experimental observation (ATLAS: 6.3σ, CMS: 5.2σ) CMS-HIG-17-035

arXiv:1802.04146

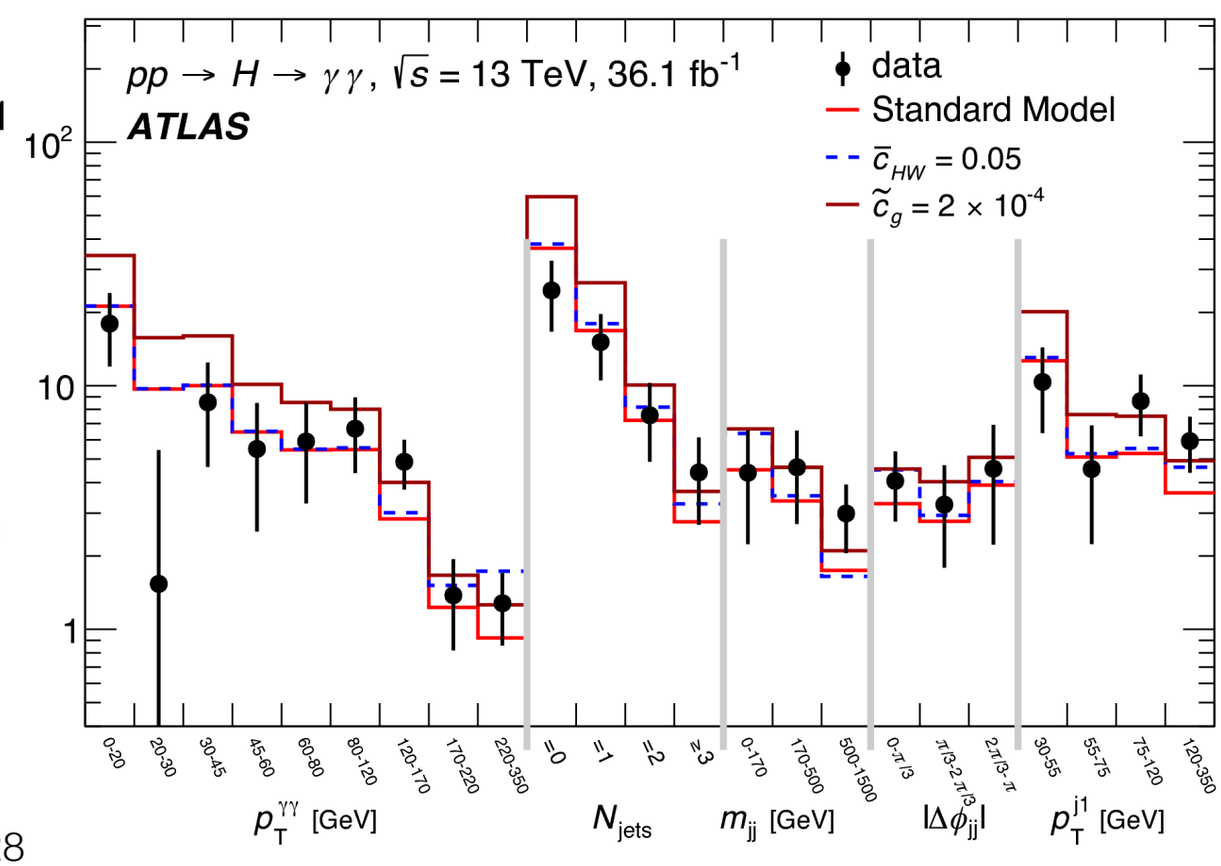
Higgs(γγ) Cross-Sections



Different production channels contribute to the same H→γγ final state

Different selections more sensitive to certain processes

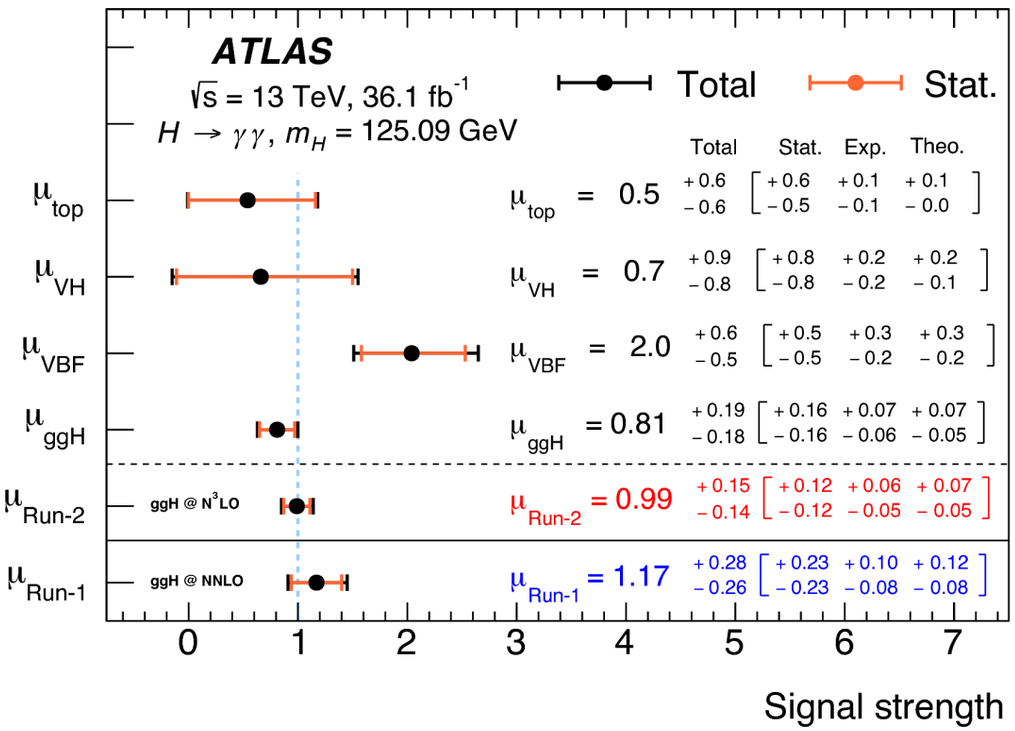
Differential cross-section show overall good agreement with theory predictions at NNLO

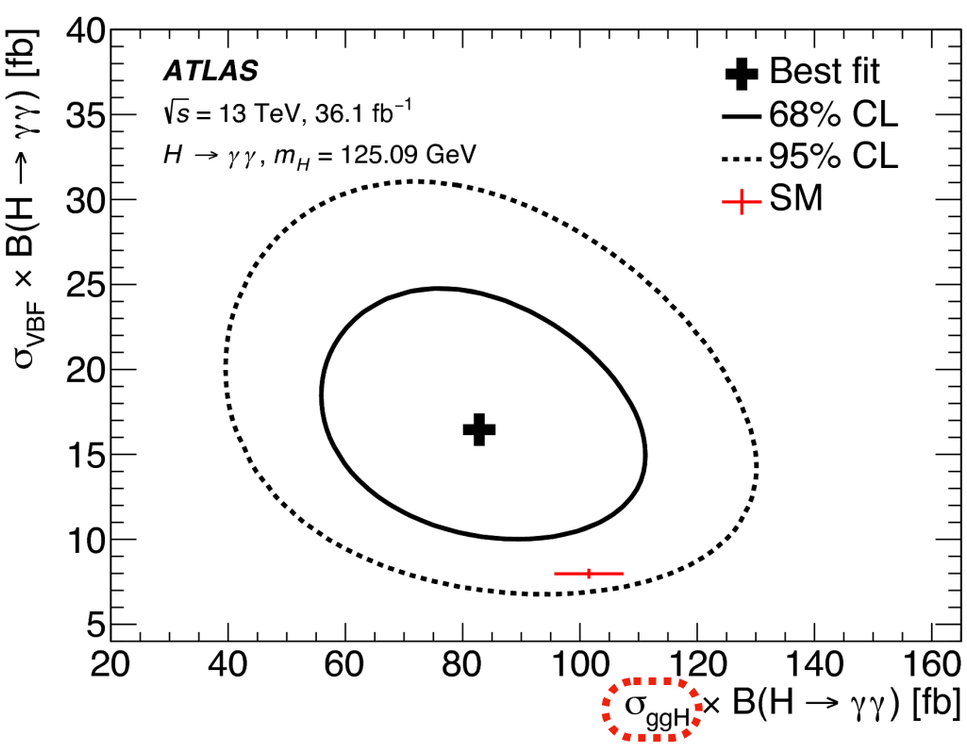


Higgs Couplings

H→γγ channel

arXiv:1802.04146





H→4ℓ channel

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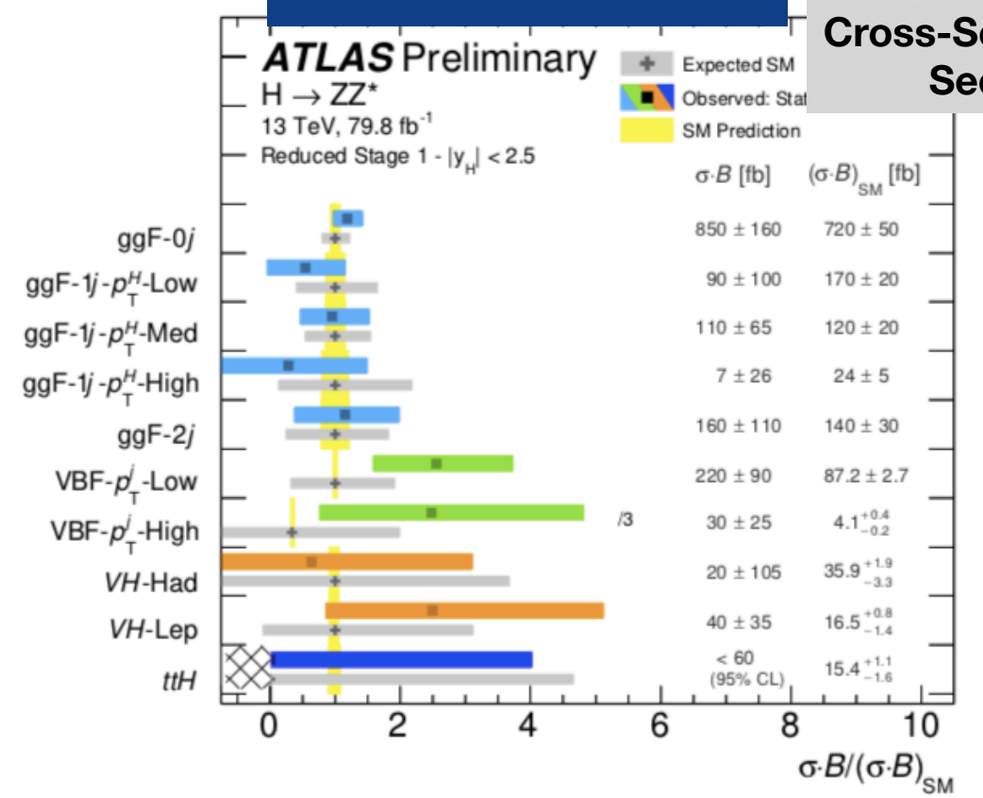
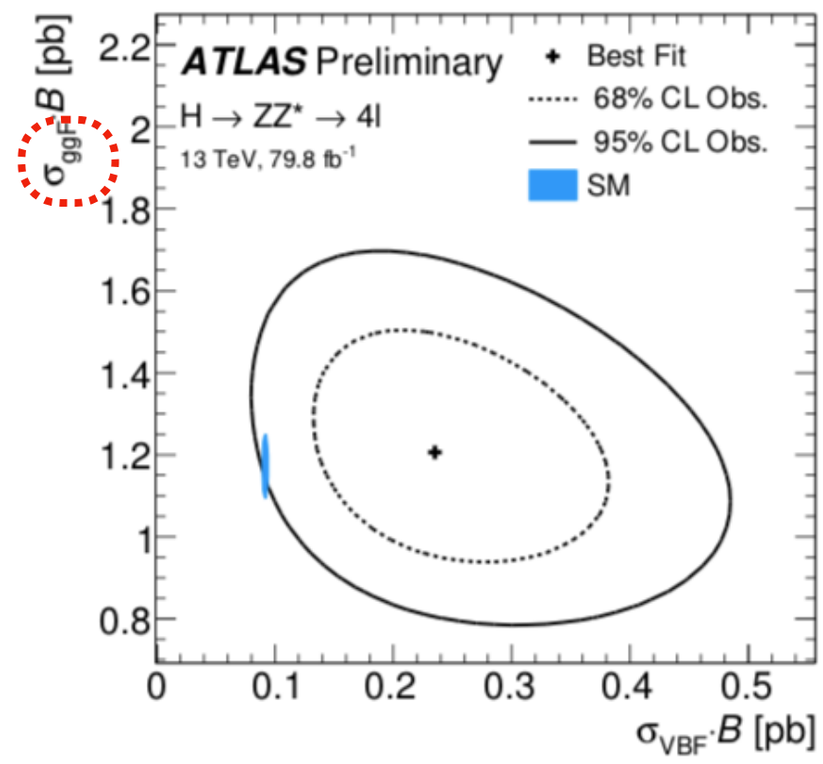
Standard Template Cross-Sections (STXS)
See backup



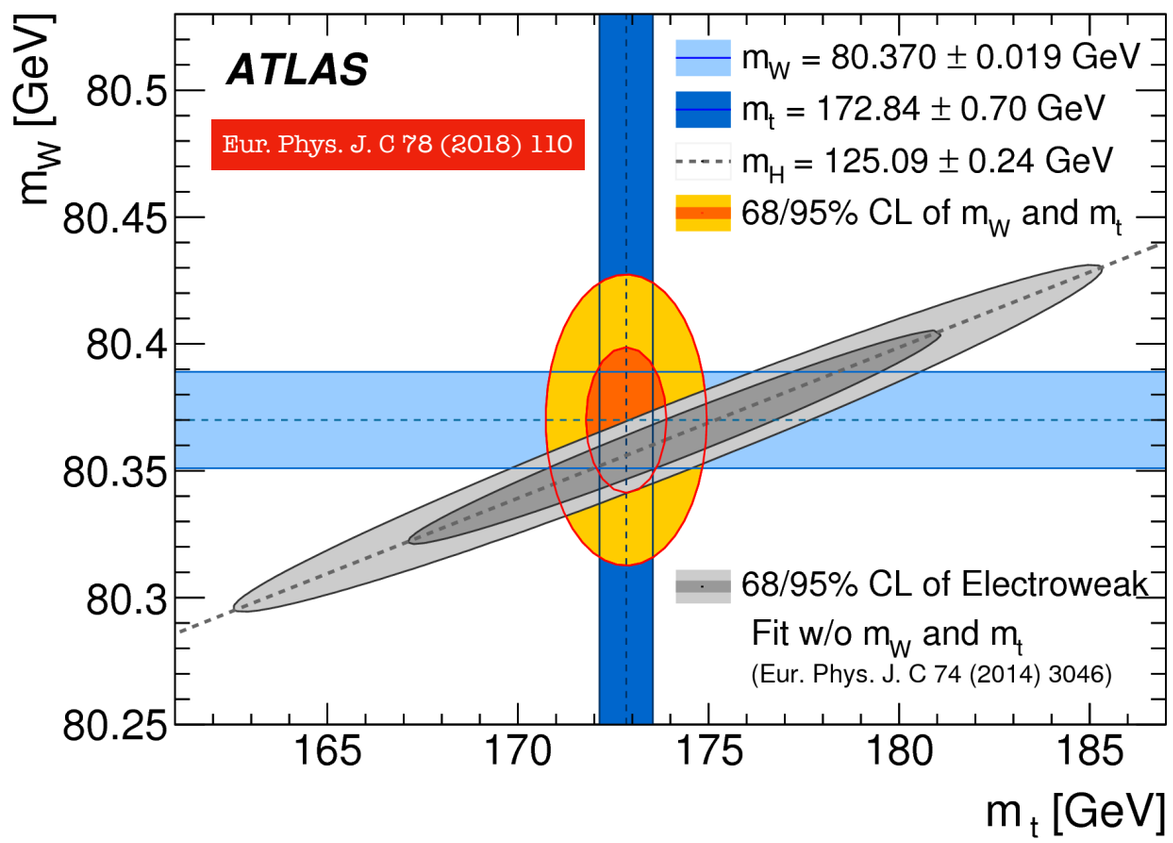


Conclusions

Standard Model measurements are at the core of the physics programme of the ATLAS Collaboration

W/Z bosons
- Standard candles
- *W* mass known with
- astonishing precision
- W/Z+jets production
- background to searches and precision measurements

$$m_W = 80370 \pm 19\,\mathrm{MeV}$$



Higgs boson
- Only known fundamental scalar particle
- Couplings and xs compatible with SM
- Interplay with top quarks

$$m_H = 124.97 \pm 0.24\,\mathrm{GeV}$$

Top quark
- Heaviest known quark, mass measurement challenging
- Important tool for searches

$$m_t = 172.51 \pm 0.50\,\mathrm{GeV}$$

Backup

Higgs Simplified Template Cross-Sections (STXS)

ATLAS preliminary