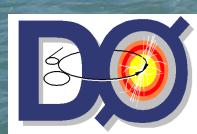


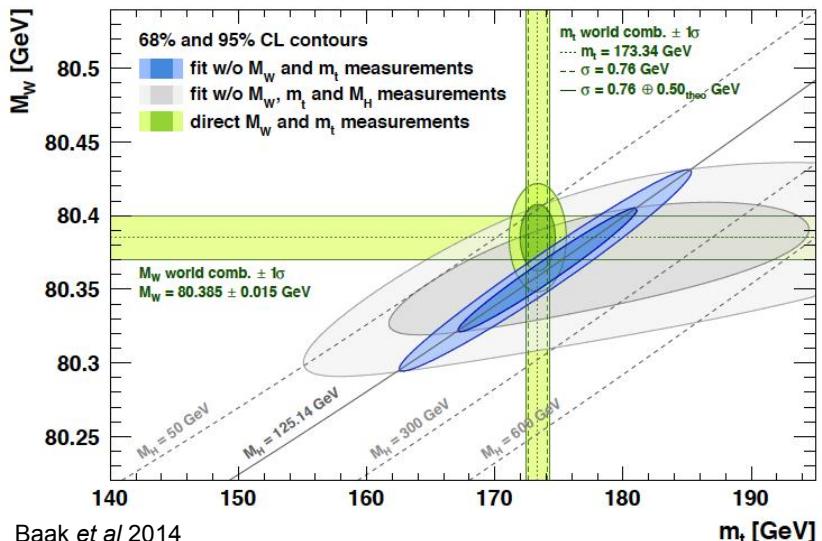
# Top and Electroweak measurements



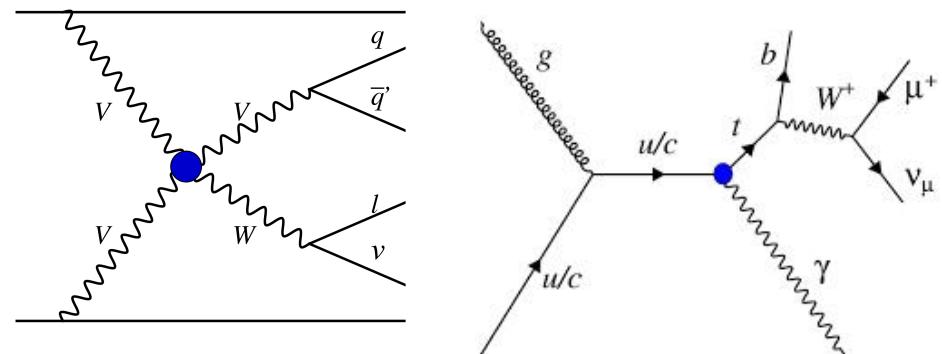
Top pair production  
Single-Top production  
Top quark properties  
Di and Triboson production  
EW precision measurements

# Top and Electroweak measurements

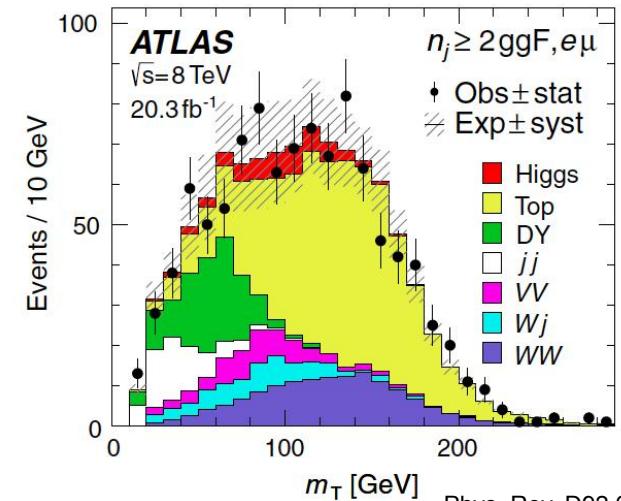
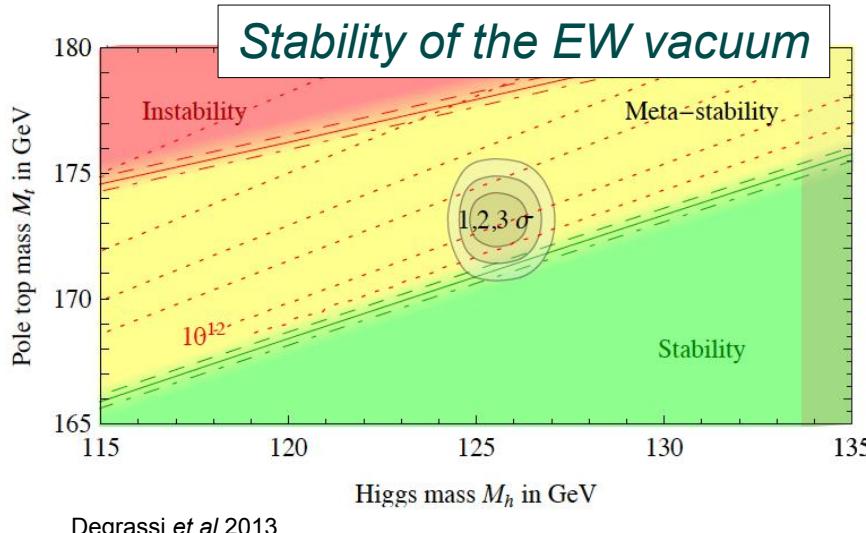
## *Self-consistency of the SM*



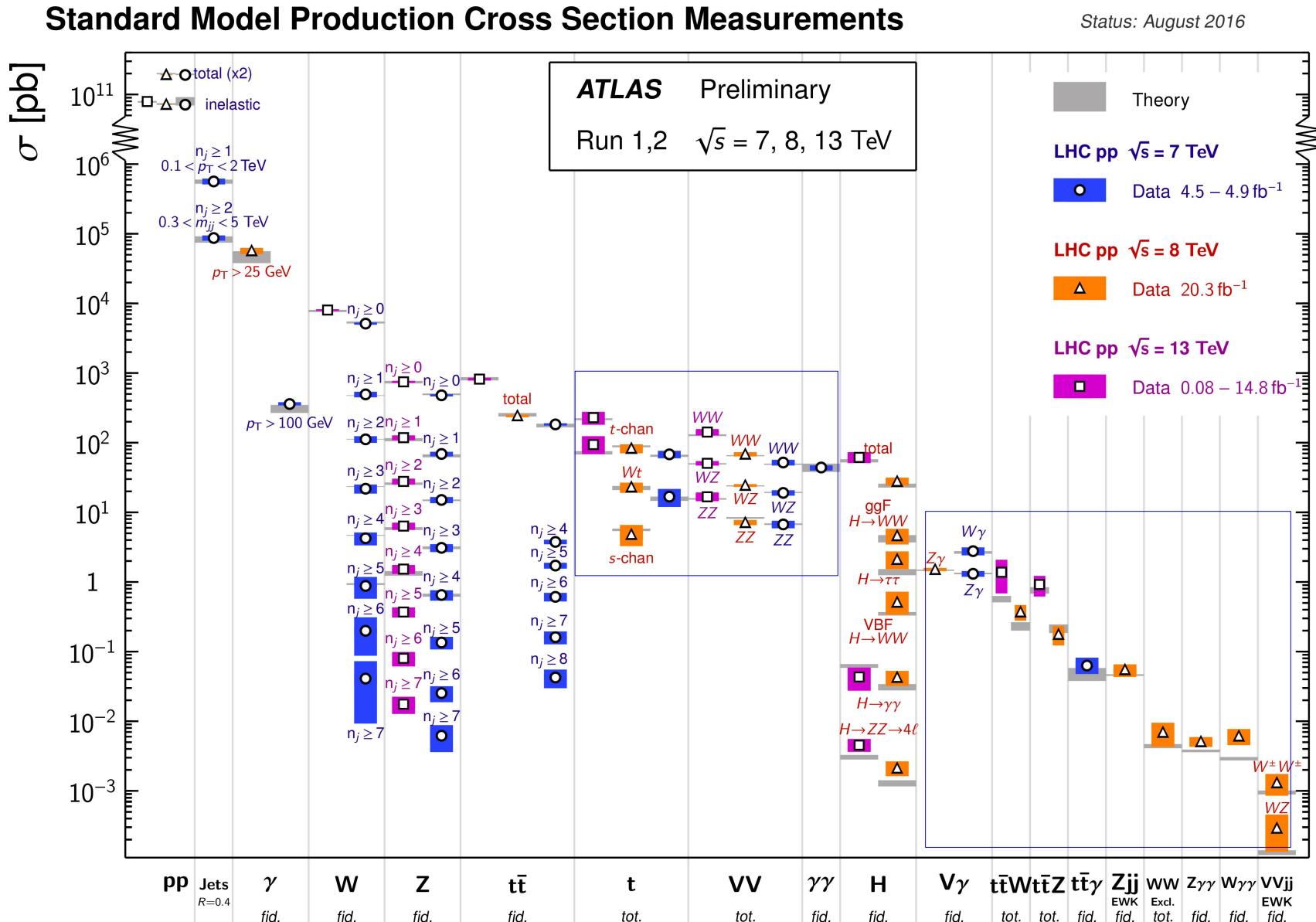
## *Test of gauge structure in the EW sector New physics in couplings?*



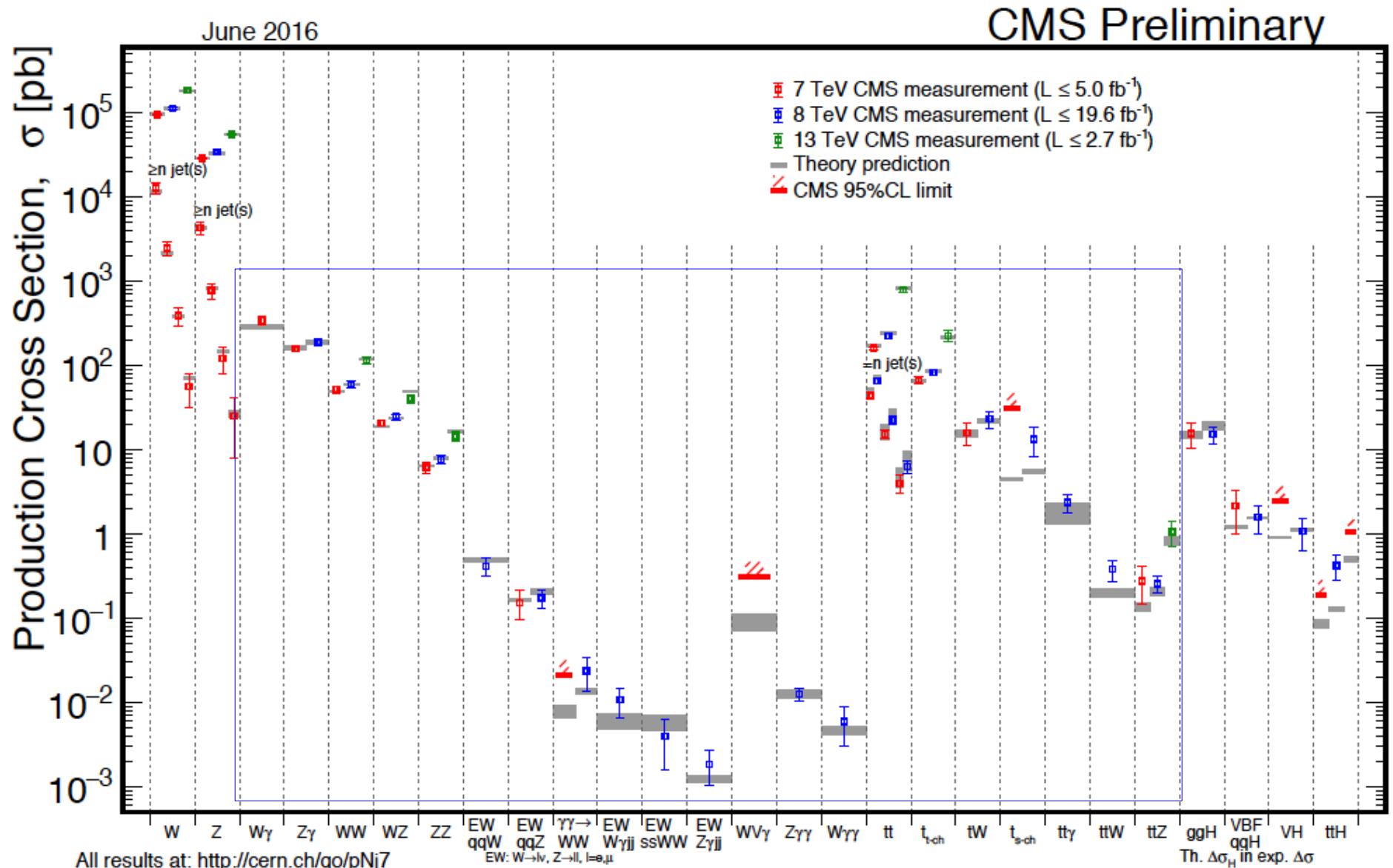
## *Background to searches*



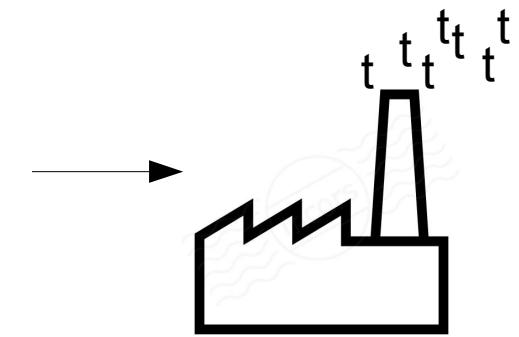
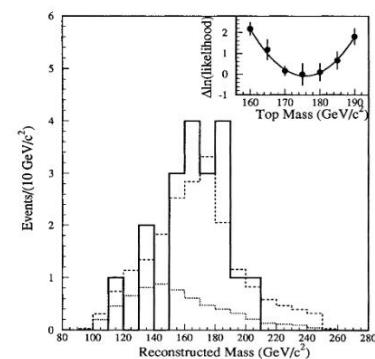
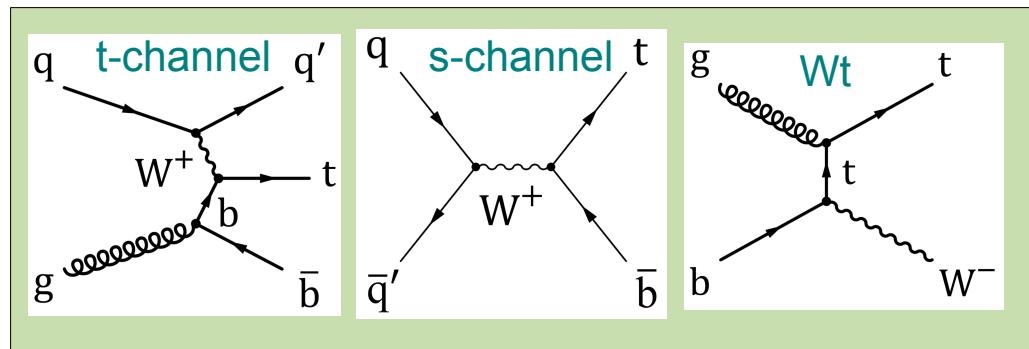
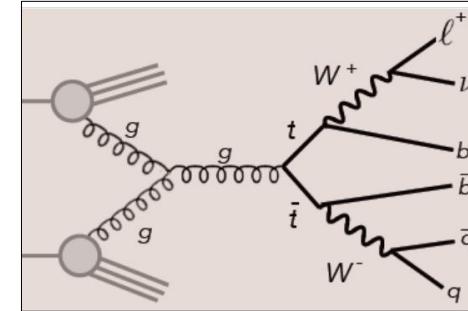
# Top and Electroweak measurements



# Top and Electroweak measurements

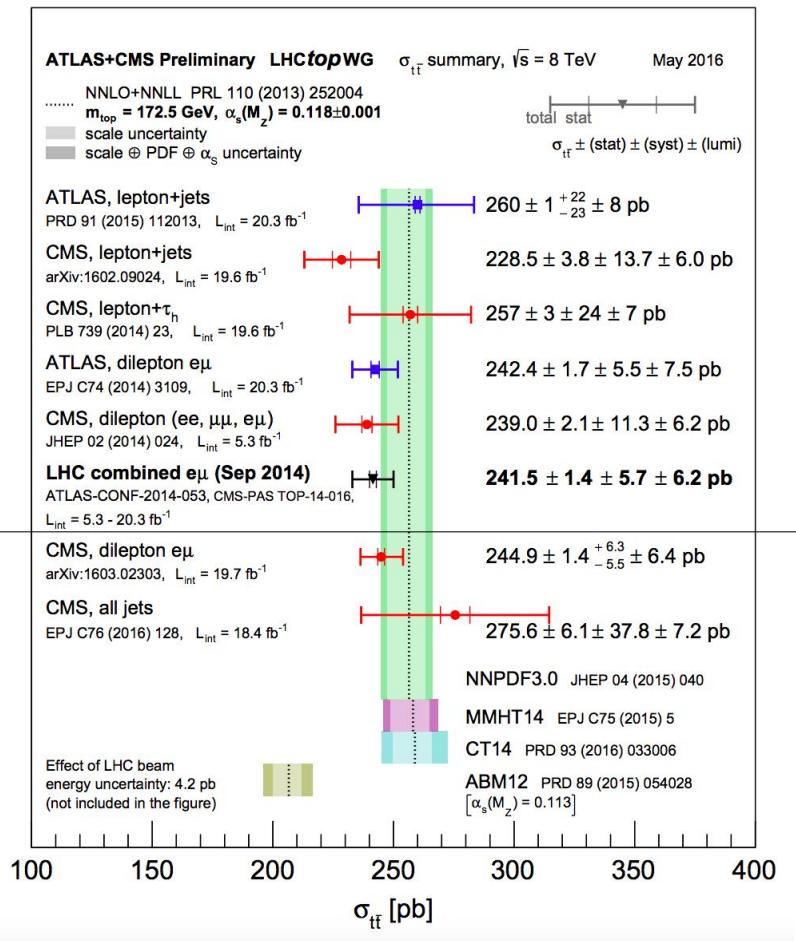


# Top physics

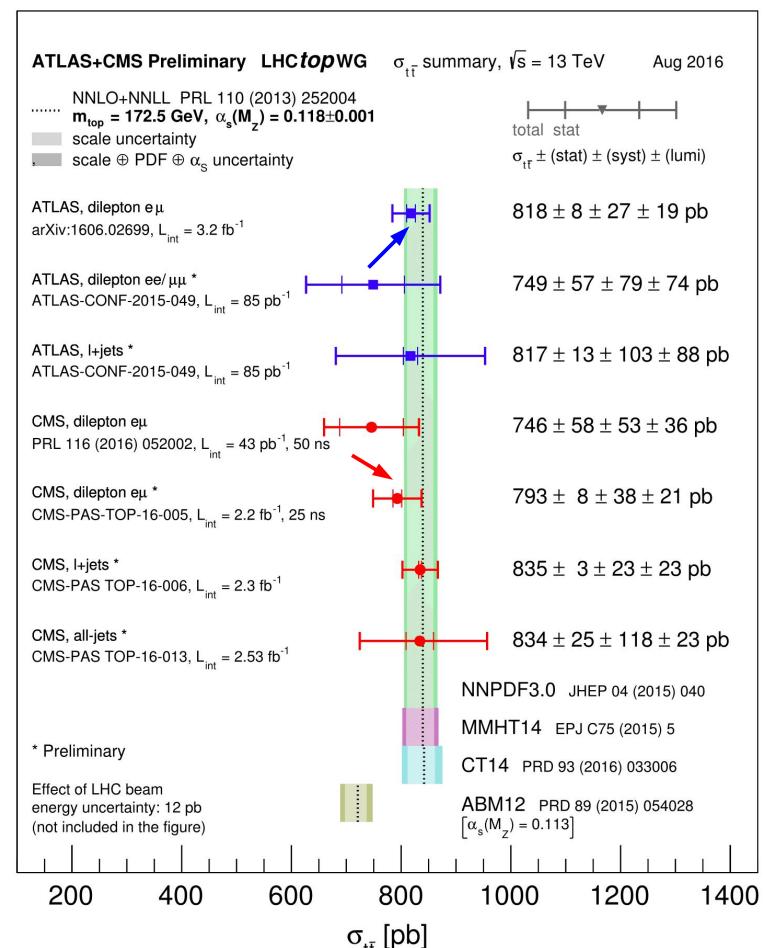


# Top pair cross section overview

ATLAS & CMS 8TeV



ATLAS & CMS 13TeV



*Precision of measurement comparable to theory precision  
LHC and Tevatron results consistent and in agreement with NNLO+NNLL*

# Top pair cross section overview

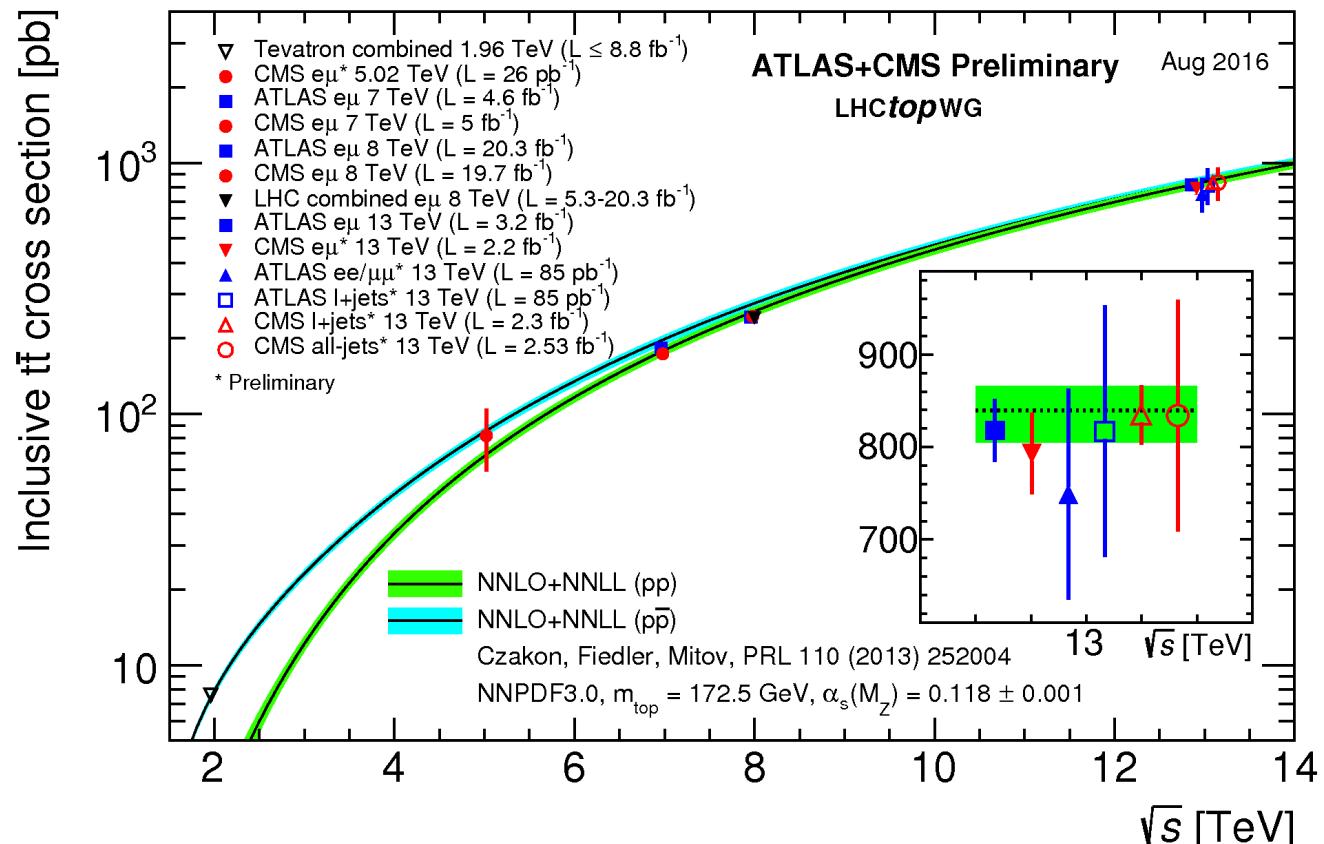
..most recent:

**ATLAS**,  $3.2\text{fb}^{-1}$ , 13TeV,  
Dilept., arXiv:1606.02699

**CMS**,  $2.3\text{fb}^{-1}$ , 13TeV, I+jets  
CMS-PAS-TOP-16-006

**CMS**,  $2.53\text{fb}^{-1}$ , 13TeV, all jets  
CMS-PAS-TOP-16-013

**CMS**,  $26\text{pb}^{-1}$ , 5TeV, dilept.  
CMS-PAS-TOP-16-015



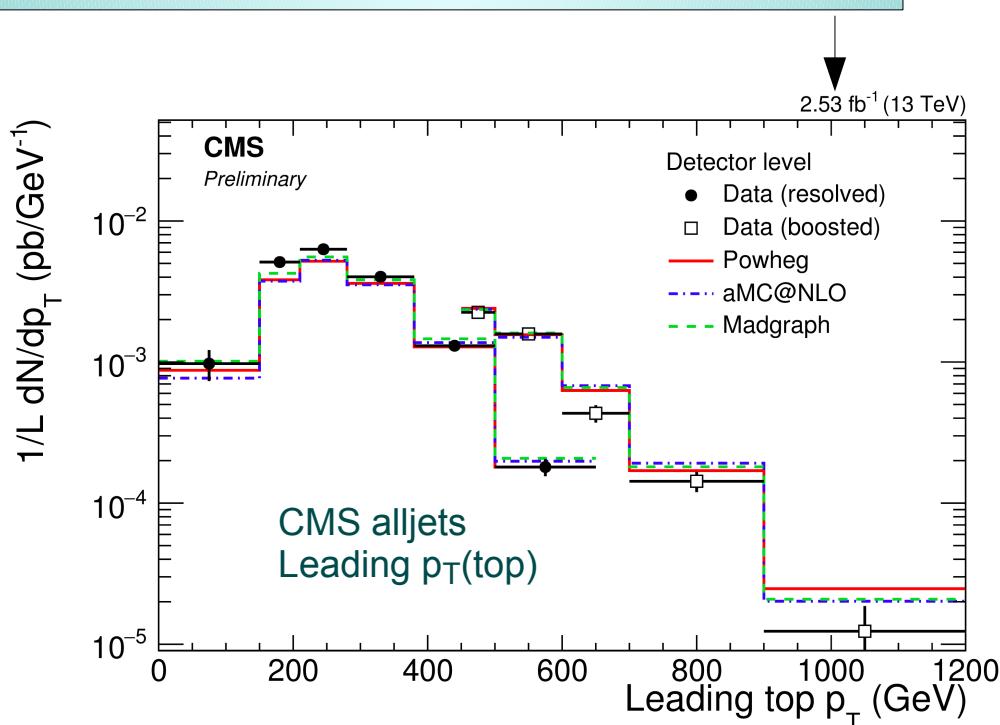
*LHC and Tevatron results consistent and in agreement with NNLO+NNLL over a large range of centre-of-mass energies*

# Top @ 13TeV: Going differential

**CMS**,  $2.5\text{fb}^{-1}$ , 13TeV, I+jets, differential  $p_T$   
CMS-PAS-TOP-16-008

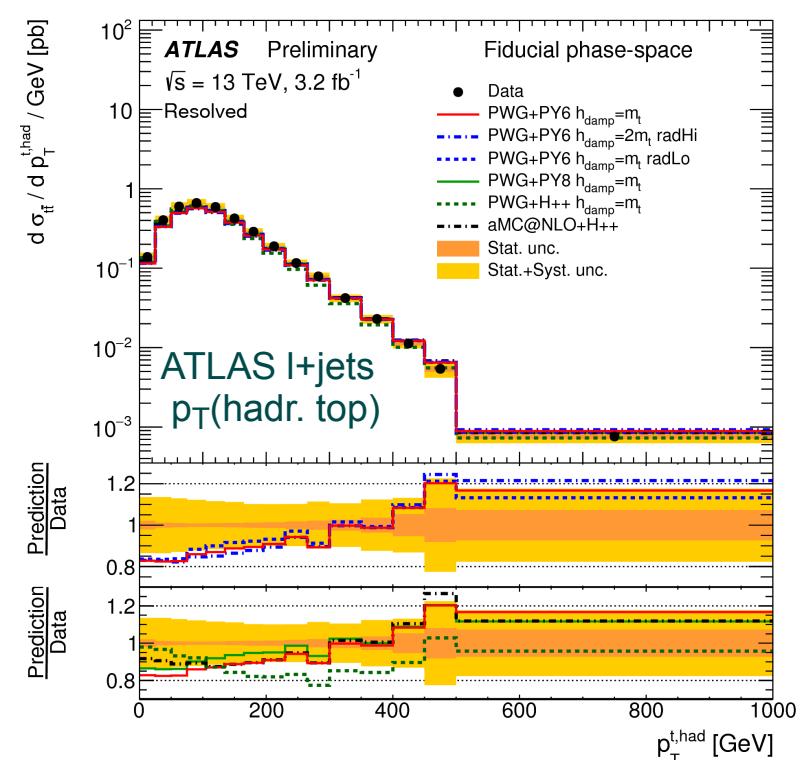
**CMS**,  $2.2\text{fb}^{-1}$ , 13TeV, dilep, differential  $p_T(t)$ ,  
 $y(t)$ ,  $y(tt)$ ,  $m(tt)$ ,  $\Delta\Phi(tt)$ , CMS-PAS-TOP-16-007

**CMS**,  $2.5\text{fb}^{-1}$ , 13TeV, all-jets, differential  $p_T$   
Resolved & boosted, CMS-PAS-TOP-16-013



**CMS**,  $2.3\text{fb}^{-1}$ , 13TeV, dilep, ttbb, ttjj  
CMS-PAS-TOP-16-010

**ATLAS**,  $3.2\text{fb}^{-1}$ , 13TeV, I+jets, differential  $p_T$   
Resolved & boosted, ATLAS-CONF-2016-040



*Similar trends as in 8TeV. Top  $p_T$  modelled too hard (improves with NNLO pQCD)*

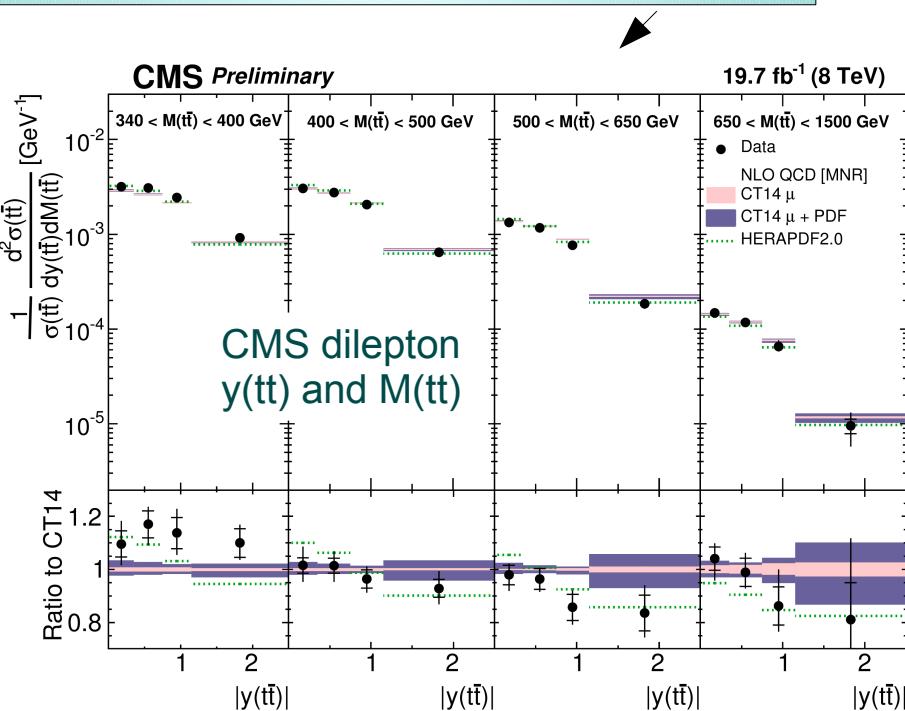
# Recent Run1 differential cross sections

**CMS**,  $19.7\text{fb}^{-1}$ , 8TeV, I+jets,  
(top  $p_T > 400$  GeV), arXiv:1605.00116

**CMS**,  $9.7\text{fb}^{-1}$ , 8TeV, I+jets, Jet multiplicity  
CMS-PAS-TOP-15-006

**CMS**,  $5.0+19.7\text{fb}^{-1}$ , 7+8TeV, I+jets,  $H_T$ ,  $S_T$ ,  
 $p_T^W$ ,  $E_T^{\text{miss}}$  arXiv:1607.00837

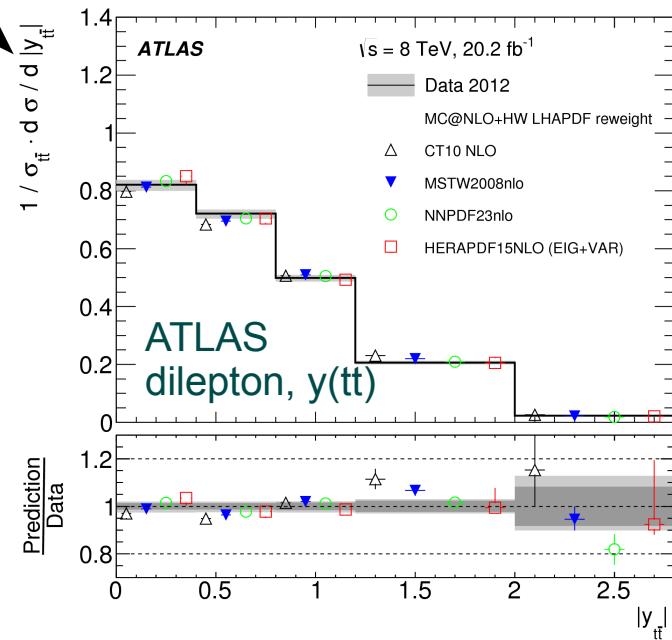
**CMS**,  $9.7\text{fb}^{-1}$ , 8TeV, dilep, double-differential,  
CMS-PAS-TOP-14-013



**LHCb**, 7+8TeV: tt and single t, forward region  
Phys. Rev. Lett. 115 (2015) 112001

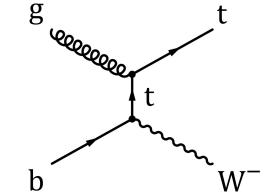
**ATLAS**,  $20.3\text{fb}^{-1}$ , 8TeV, dileptons, jet activity  
arXiv:1606.09490

**ATLAS**,  $4.6+20.2\text{fb}^{-1}$ , 7+8TeV, dilepton,  $pT(\text{tt})$ ,  
 $m(\text{tt})$ ,  $y(\text{tt})$ , arXiv:1607.07281



*LHC data modelled by subset of generators*  
 *$p_T(\text{top})$  modelled too hard*  
 *$y(\text{tt})$  &  $m(\text{tt}) \rightarrow$  constrain gluon PDF ( $x \sim 0.03-0.5$ )*

# Single-Top: recent results



Run2

**ATLAS**,  $3.2\text{fb}^{-1}$ , 13 TeV, Wt-channel  
ATLAS-CONF-2016-065

**CMS**,  $2.3\text{fb}^{-1}$ , 13 TeV, t-channel,  
Differentia, I CMS PAS TOP-16-004

Run1

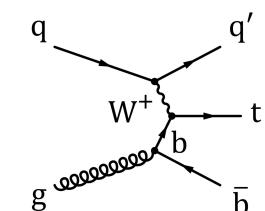
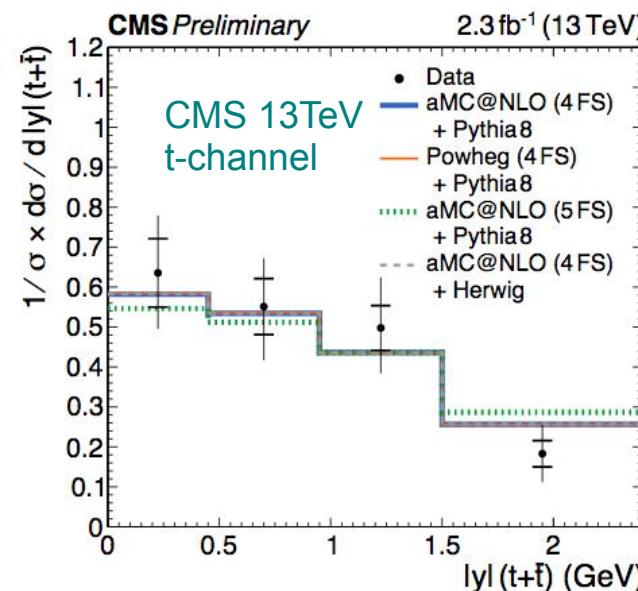
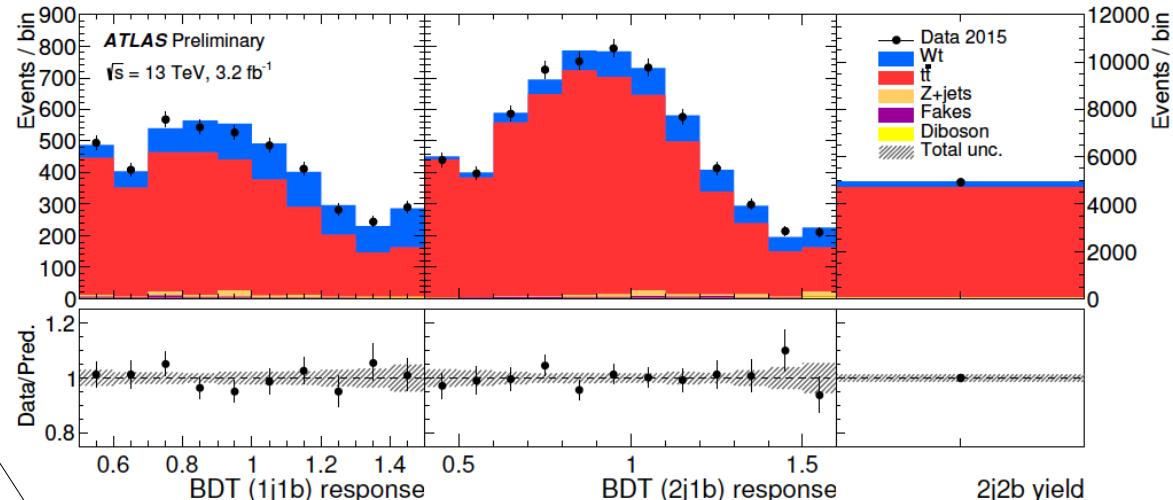
**CMS**,  $19.7\text{fb}^{-1}$ , 8 TeV, t-channel,  
Polarisation, JHEP 04 (2016) 073

**ATLAS & CMS**,  $20.3 \& 12.2 \text{ fb}^{-1}$ , 8 TeV  
 $\sigma(Wt) = 23.1 \pm 3.6 \text{ pb}$   
CMS PAS TOP-15-019

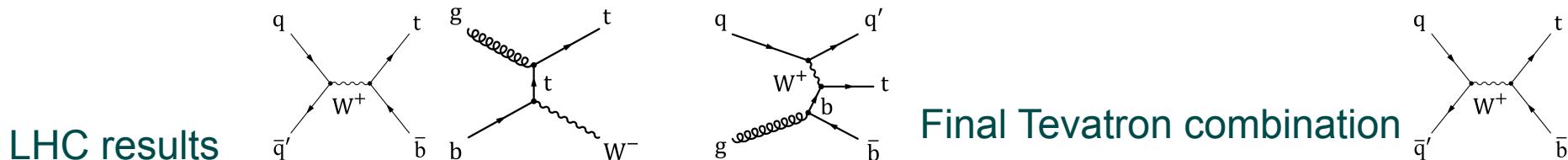
**CMS**,  $19.7\text{fb}^{-1}$ , 8 TeV, search for  $tZq$ ,  
CMS PAS TOP-12-039

ATLAS 13TeV, Wt-channel

Binned profile LLH, on BDT,  $\sigma(Wt) = 94 \pm 10+28-23 \text{ pb}$



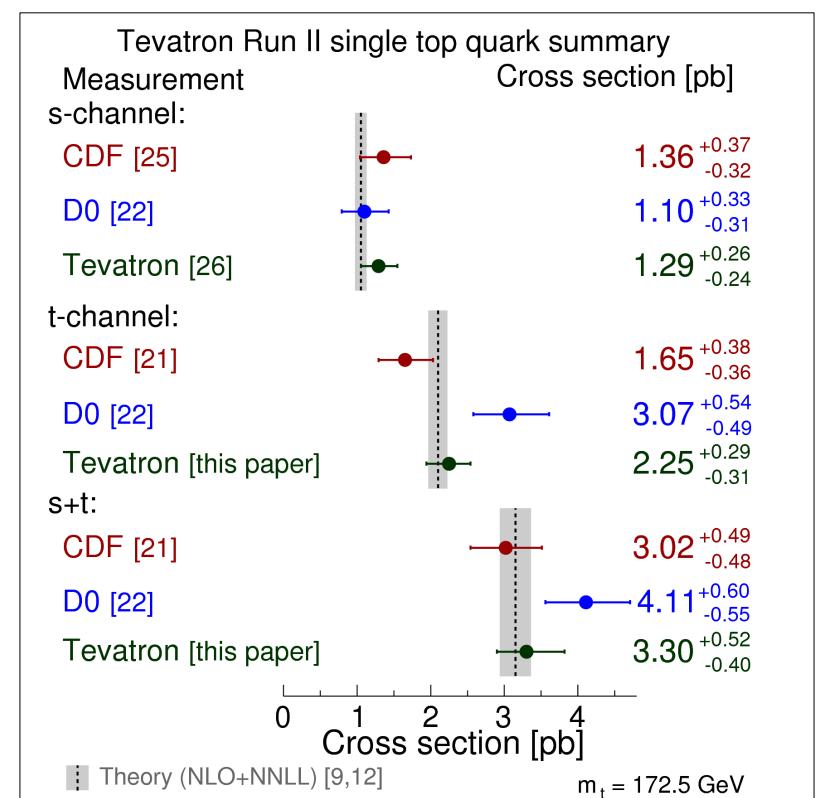
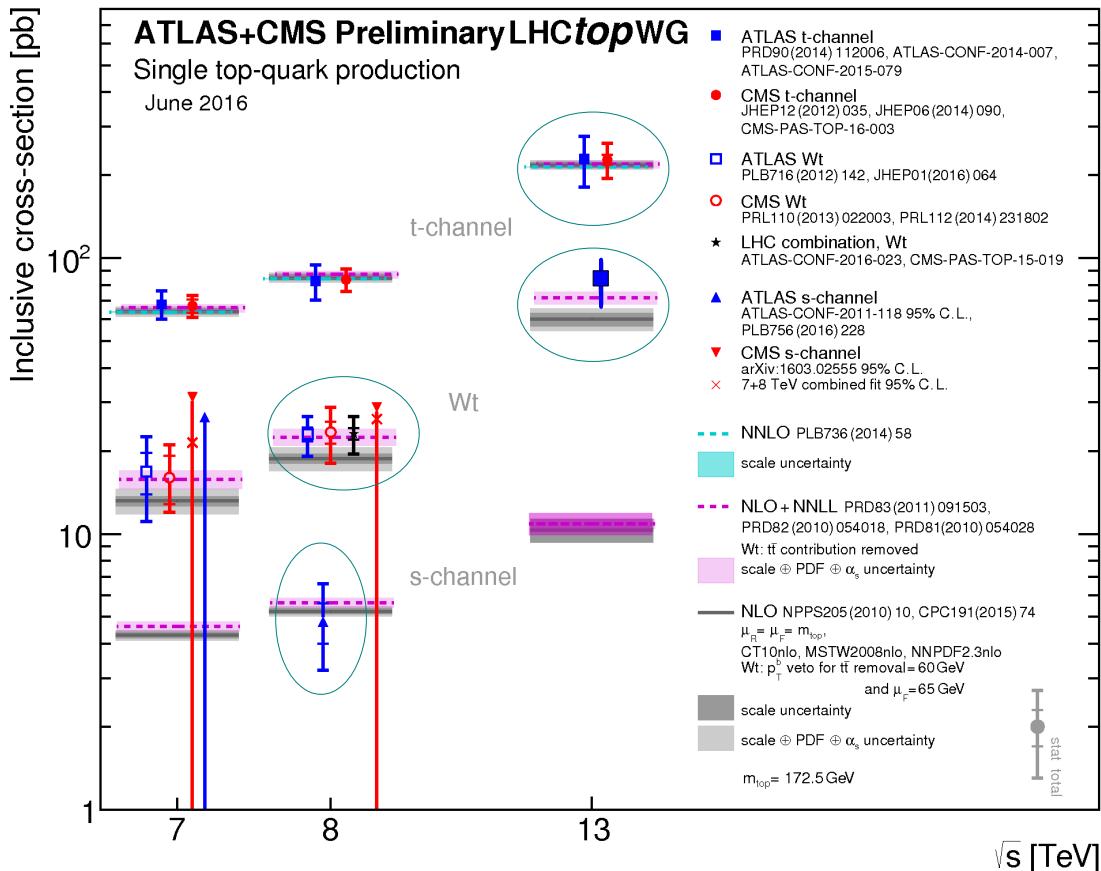
# Single-Top: summary



LHC results

Final Tevatron combination

Phys. Rev. Lett. 115, 152003 (2015)



Consistent with SM expectation  
 $|V_{tb}| > 0.92$  at 95% C.L.

# Top properties, recent results

Very active field in the past years:

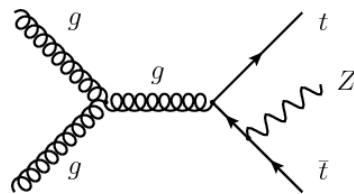
- Top polarisation
- charge asymmetry
- W helicity
- Spin correlations
- Width
- coupling to gauge bosons ...

**CMS**,  $12.9 \text{ fb}^{-1}$ , 13TeV, ttZ, ttW  
CMA-TOP-16-017

**ATLAS**,  $3.2 \text{ fb}^{-1}$ , 13TeV, tttt search  
 $\leq 21 \times \sigma_{\text{SM}}$ , ATLAS-CONF-2016-020

**CMS**,  $2.6 \text{ fb}^{-1}$ , 13TeV, tttt search  
 $\leq 10 \times \sigma_{\text{SM}}$ , CMS PAS TOP-16-016

**D0**,  $9.7 \text{ fb}^{-1}$ , Top polarisation  
l+jets, arXiv:1607.07627

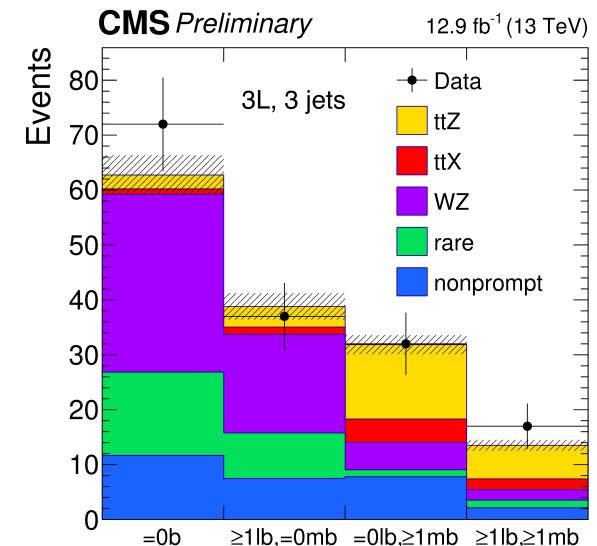


tt-Z coupling  
Important backgrounds

$$\begin{aligned}\sigma(\text{ttZ}) &= 0.70 \quad +0.16-0.15 \\ &\quad +0.14-0.12 \text{ pb} \\ \sigma(\text{ttW}) &= 0.98 \quad +0.23-0.22 \\ &\quad +0.22-0.18 \text{ pb}\end{aligned}$$

( $\rightarrow \text{ttW}: 3.9\sigma, \text{ttZ}: 4.6\sigma$ )

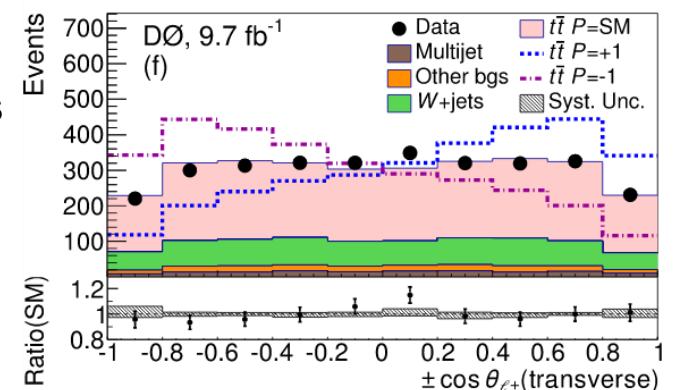
## CMS ttZ and ttW



## D0 Top polarisation

through angular distributions  
of the decay leptons  $\cos \theta_{\hat{n}}$   
 $\rightarrow$  consistent with SM

First measurement of  
transverse polarisation:  
 $0.040 \pm 0.034$  (SM: 0.011)



# Top mass: recent results

**ATLAS**,  $20.2\text{fb}^{-1}$ , all-hadronic  
 $m_{\text{top}} = 173.80 \pm 0.55 \pm 1.01 \text{ GeV}$   
 ATLAS-CONF-2016-064

**ATLAS**,  $20.2\text{fb}^{-1}$ , di-leptons, 1D fit,  $m_{lb}$   
 arXiv:1606.02179

**CMS**,  $19.7\text{fb}^{-1}$ , dileptons, 1D, 2D, hybrid,  
 $m_{bl} + m_{T2}$ , MAOS  $m_{blv} + m_{T2}$ ,  
 $M_{\text{top}} = 172.22 \pm 0.18 \pm 0.89 - 0.93$   
 CMS-PAS-TOP-15-008

**CMS**,  $19.7\text{fb}^{-1}$ , from  $t\bar{t}$ +jets inv mass  
 $M_{\text{top}} = 169.9 \pm 1.1 \pm 2.5 - 3.1 \pm 3.6 - 1.6 \text{ GeV}$   
 CMS-PAS-TOP-13-006

**D0**,  $9.7\text{fb}^{-1}$ , di-lepton, Matrix element  
 arXiv:1606.02814  
 Combination with neutrino weighting  
 $M_{\text{top}} = 173.50 \pm 1.31 \pm 0.84 \text{ GeV}$   
 D0 note 6484 conf

**D0**,  $9.7\text{fb}^{-1}$ , pole mass via cross section  
 $M_{\text{top}} = 172.8 \pm 3.4 \pm 3.2 \text{ GeV}$   
 arXiv:1605.06168

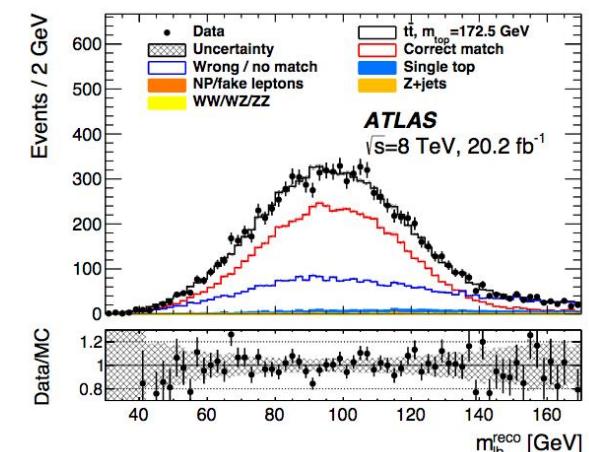
## ATLAS di-leptons

1D template fit to  $m_{lb}$

Dominant syst:

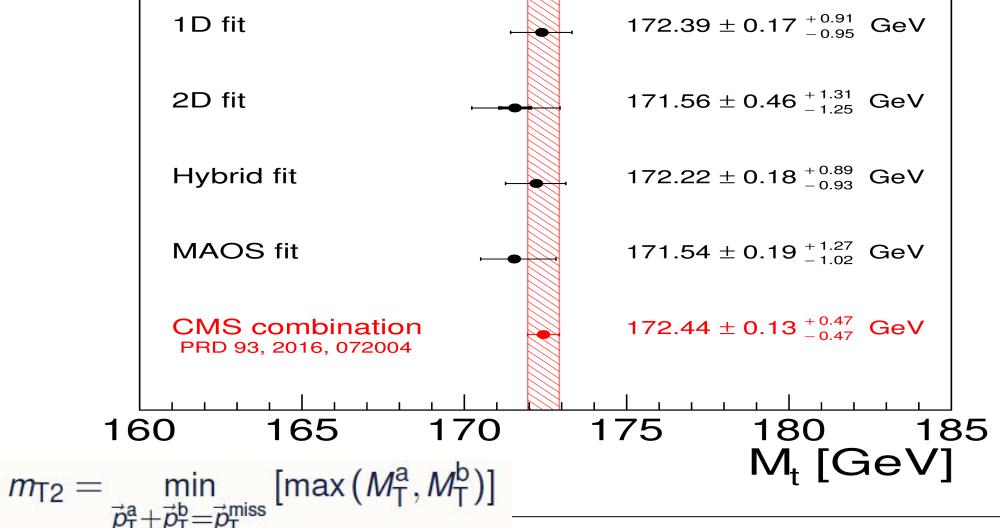
(b)JES, MC modelling

$$m_t = 172.99 \pm 0.41(\text{stat}) \pm 0.74(\text{syst}) \text{ GeV}$$



## CMS new di-leptons

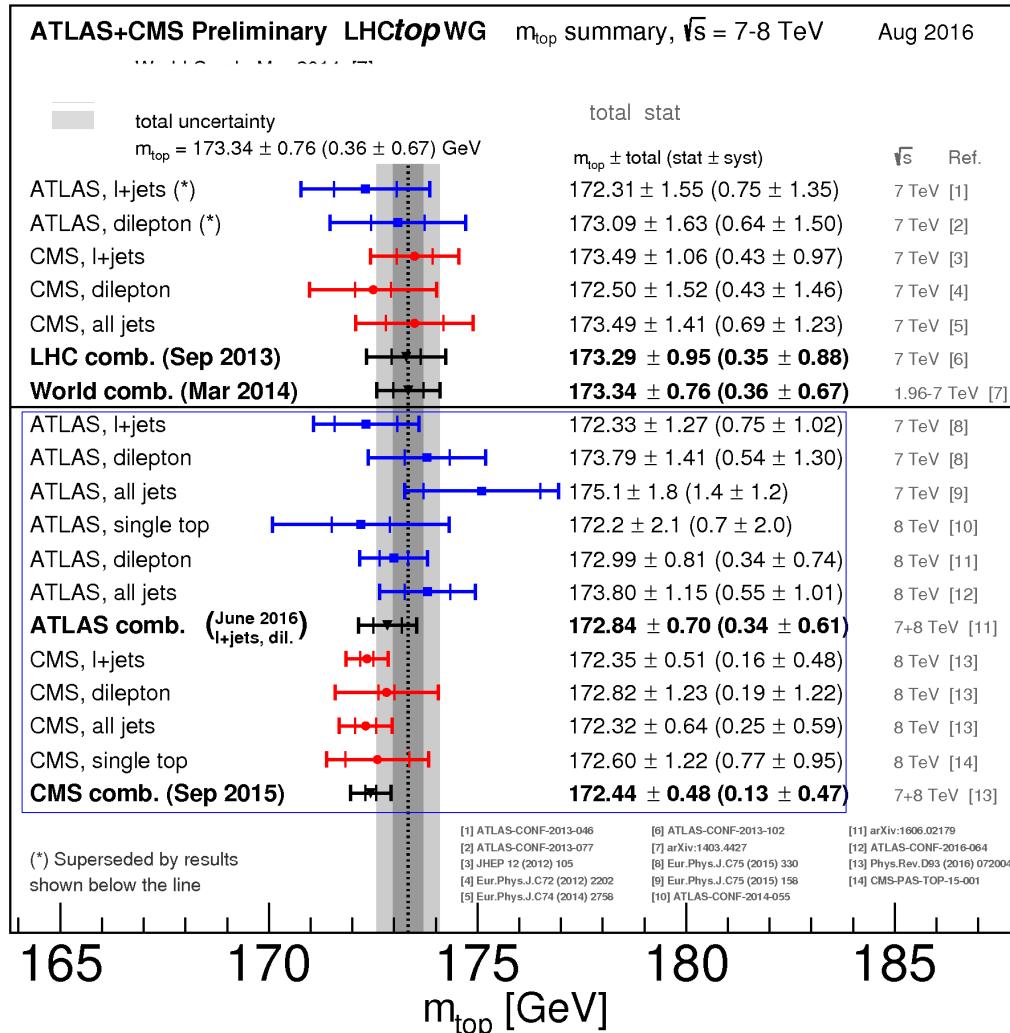
Preliminary



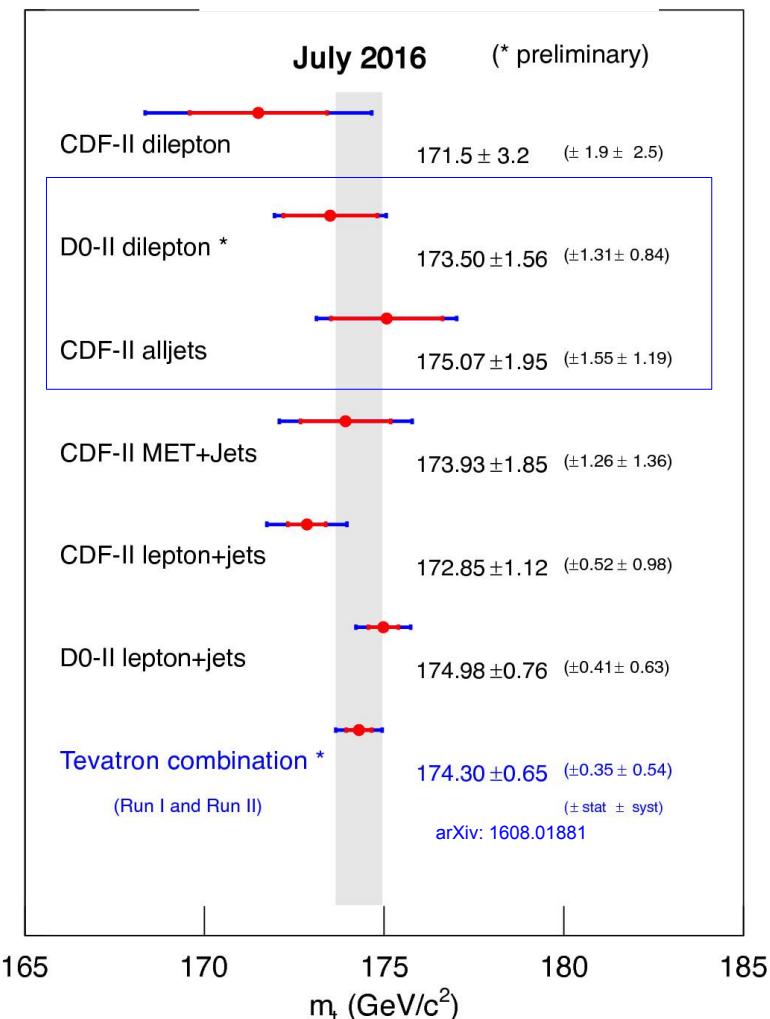
New approaches with complementary systematics can constrain combined systematics

# Direct top mass measurements

## ATLAS and CMS results



## CDF and D0 results



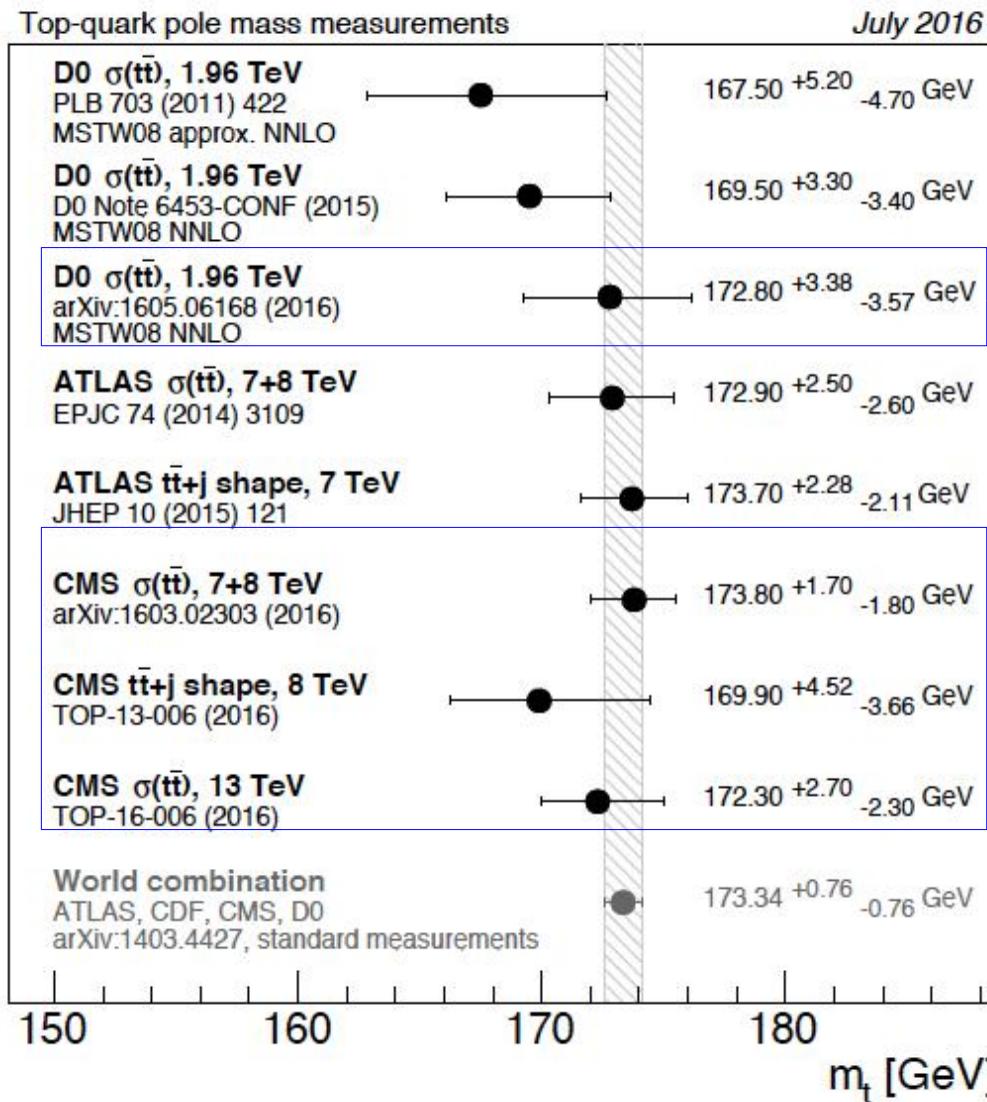
LHC and Tevatron results with nearly comparable precision of 3-4 permille (0.5 GeV)

LHC top mass systematically limited: MC modelling, (b)JES

Template/Matrix element methods → Monte Carlo top mass parameter

# Indirect top mass measurements

## Pole mass vs Monte-Carlo mass measurements



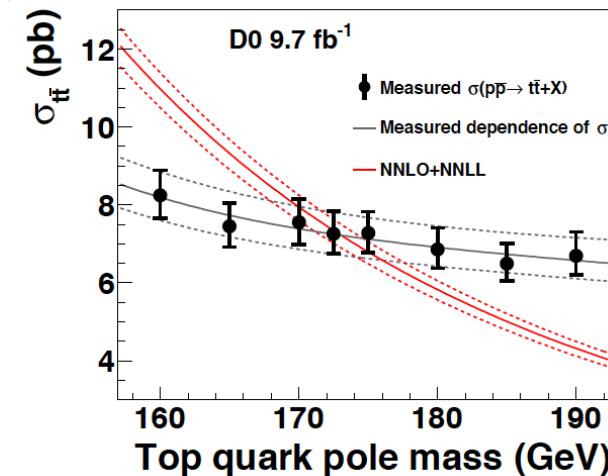
## Direct top mass measurements:

- Monte-Carlo mass  $m_t^{\text{MC}}$
- precision 0.5 GeV

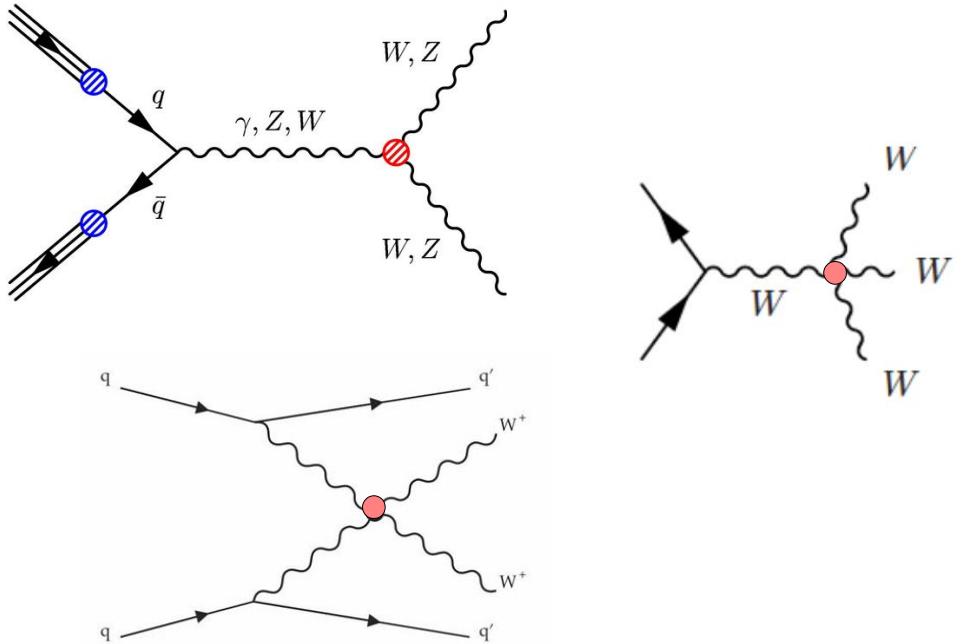
Expect  $m_t^{\text{MC}} - m_t^{\text{pole}} \sim 1$  GeV

→ Calibrate  $m_t^{\text{MC}}$

→ Indirect measurements of  $m_t^{\text{pole}}$ :  
compatible with measured  $m_t^{\text{MC}}$   
within precision of  $\pm 2$  GeV



# Diboson and multi-Boson production



$$SM: \quad \mathcal{L}^{gauge} = -\frac{1}{4} \mathbf{W}_{\mu\nu} \mathbf{W}^{\mu\nu} - \frac{1}{4} \mathbf{B}_{\mu\nu} \mathbf{B}^{\mu\nu}$$

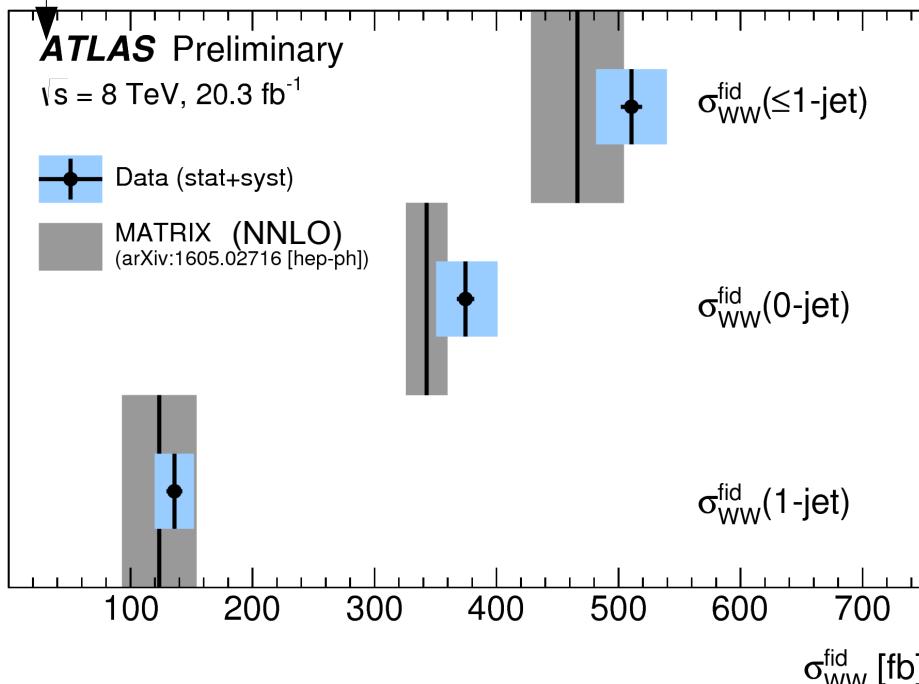
$$BSM: \quad \frac{\mathcal{L}_{WWV}}{g_{WWV}} = i \left[ g_1^V (W_{\mu\nu}^\dagger W^{\mu\nu} V^\nu - W_{\mu\nu} W^{\dagger\mu} V^\nu) + \kappa^V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2} W_{\rho\mu}^\dagger W_\nu^\mu V^{\nu\rho} \right]$$

8TeV: most precise measurements to date, many new 13TeV measurements

# Run1: precision, differential, rare processes

**CDF**,  $9.4\text{fb}^{-1}$ ,  $\text{WW}/\text{WZ} \rightarrow \text{l}\nu+\text{bb}/\text{l}\nu+\text{cc}$   
 $\sigma(\text{WW}+\text{WZ}) = 13.7 \pm 2.4 \pm 2.9 \text{ pb}$   
arXiv:1606.06823

**ATLAS**,  $20.3\text{fb}^{-1}$ , 8TeV, WW, e $\mu$ , 1 jet  
STDM-2015-24

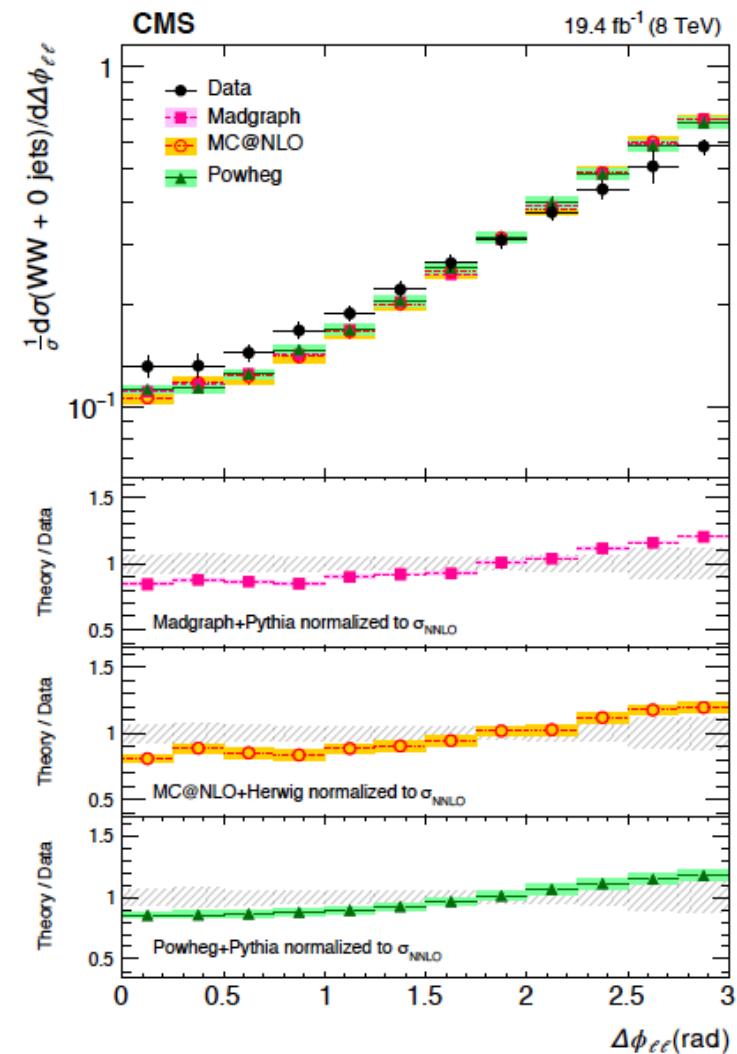


Precise diboson inclusive & differential cross sections  
(WW: 7%, WZ: 6%, Z $\gamma$ : 6%, ZZ: 11%)  
→ sensitive to higher-order pQCD effects

Precision slightly improved by loosening jet vetos

**ATLAS**,  $20.3\text{fb}^{-1}$ , 8TeV, WW, arXiv:1603.01702

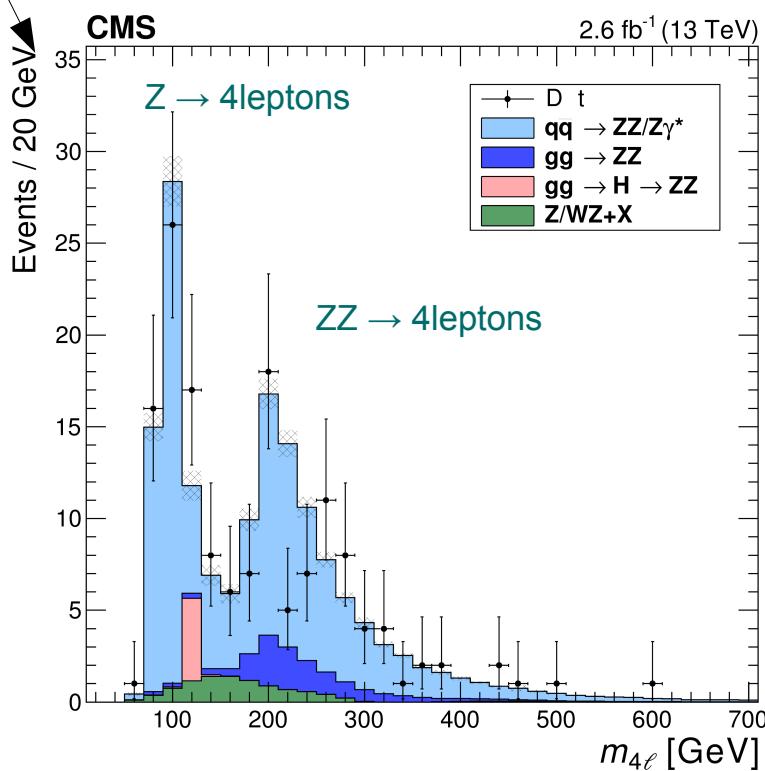
**CMS**,  $19.7\text{fb}^{-1}$ , 8TeV, WW, EPJC 76 (2016) 401



# WW and ZZ @ 13TeV: recent results

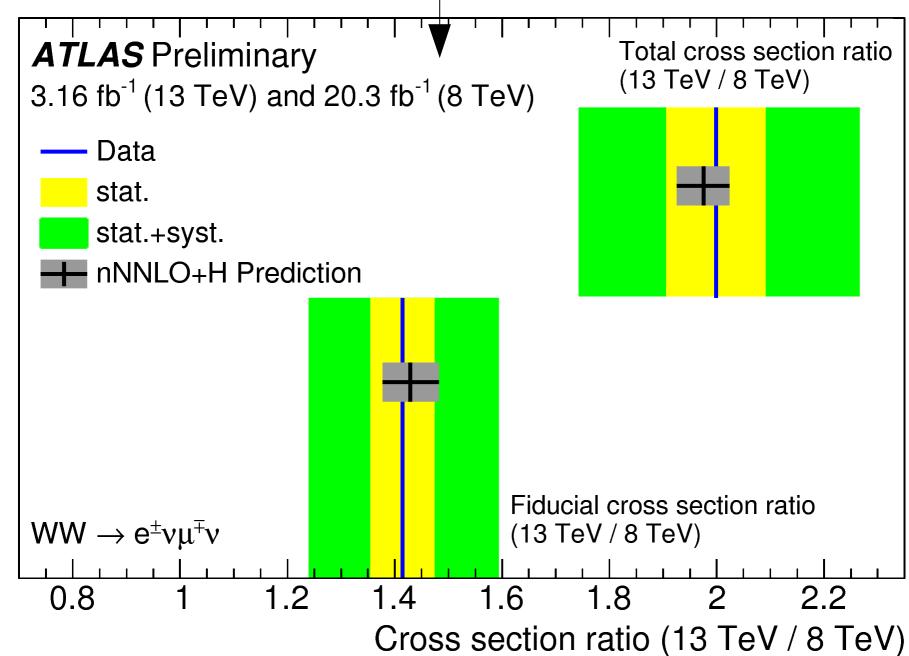
**ATLAS**,  $3.2\text{fb}^{-1}$ , 13TeV,  $\text{ZZ} \rightarrow 4\text{leptons}$   
 Phys. Rev. Lett. 116, 101801 (2016)

**CMS**,  $2.6\text{fb}^{-1}$ , 13TeV,  $\text{ZZ} \rightarrow 4\text{leptons}$   
 arXiv:1607.08834



**CMS**,  $2.3\text{fb}^{-1}$ , 13TeV, WW,  $e\mu + 0/1\text{jet}$   
 $\sigma(\text{WW}) = 115.3 \pm 10.9 \text{ pb}$  ( $\leftrightarrow \text{NNLO}: 120 \pm 3 \pm 2 \text{ pb}$ )  
 (w/o  $H \rightarrow \text{WW}$ ) CMS PAS-SMP-16-006

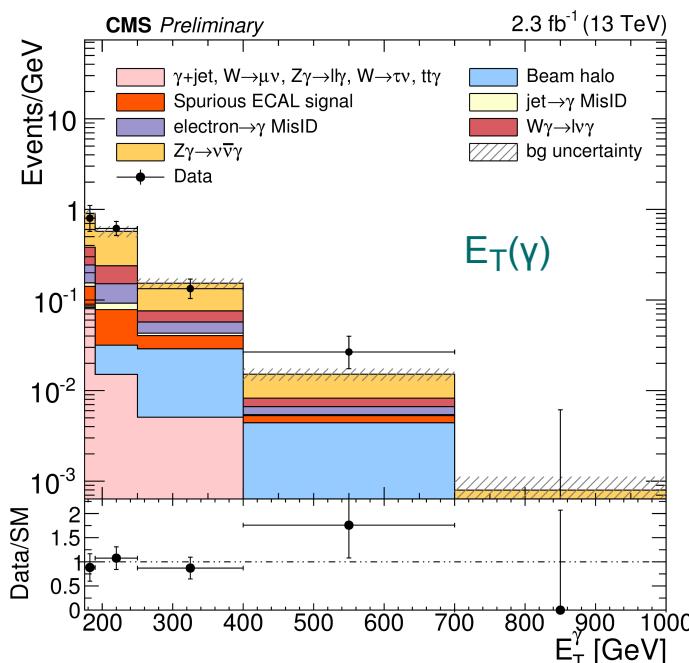
**ATLAS**,  $3.2\text{fb}^{-1}$ , 13TeV, WW,  $e\mu$ , 0 jet  
 $\sigma(\text{WW}) = 142 \pm 5 \pm 13 \pm 3 \text{ pb}$  ( $\leftrightarrow \text{NNLO}: 128 \pm 4 \text{ pb}$ )  
 ATLAS-CONF-2016-090



WW cross section with 10% precision, sys. limited, consistent with NNLO, ratios to 8TeV  
 ZZ cross section with 14% precision, statistically limited, consistent with NNLO

# Z $\gamma$ and WZ @ 13TeV: recent results

**CMS**, 2.3 fb $^{-1}$ , 13TeV, Z $\gamma \rightarrow \nu\nu\gamma$   
 $\sigma = 66.5 \pm 13.6 \pm 14.3 \pm 2.2$  (lumi) fb  
 NNLO:  $65.5 \pm 3.3$  fb, CMS-PAS-SMP-16-004



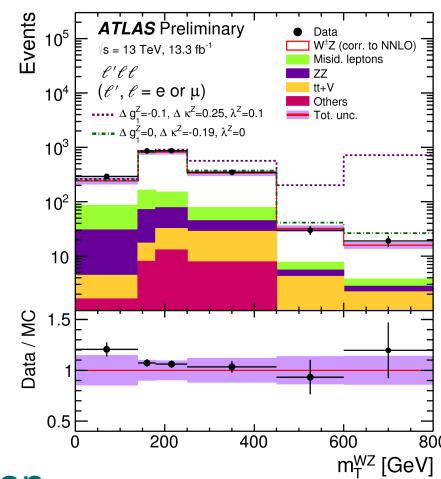
WZ cross section with 7-10% precision  
 First differential cross sections

First Z $\gamma$  cross section (vvv channel)

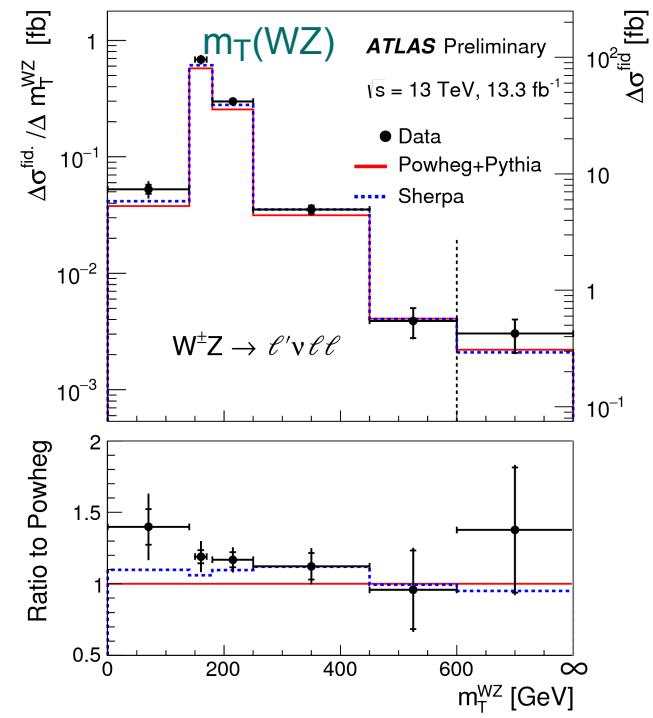
**CMS**, 2.3 fb $^{-1}$ , 13TeV, WZ leptonic,  
 $\sigma(WZ) = 39.9 \pm 3.2 \pm 2.9/-3.1 \pm 0.4$  (th)  $\pm 1.3$  (lum) pb  
 NNLO:  $50.0 \pm 1.1/-1.0$  pb, arXiv:1607.06943

**ATLAS**, 3.2 fb $^{-1}$ , 13TeV, WZ leptonic,  
 $\sigma(WZ) = 50.6 \pm 2.6 \pm 2.0 \pm 0.9$  (th.)  $\pm 1.2$  (lumi.) pb  
 NNLO:  $48.2 \pm 1.1/-1.0$  pb, arXiv:1606.04017

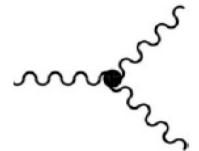
**ATLAS**, 13.3 fb $^{-1}$ , 13TeV,  
 WZ leptonic, differential  
 ATLAS-CONF-2016-043



$$m_T^{WZ} = \sqrt{\left(\sum_{\ell=1}^3 p_T^\ell + E_T^{\text{miss}}\right)^2 - \left[\left(\sum_{\ell=1}^3 p_x^\ell + E_x^{\text{miss}}\right)^2 + \left(\sum_{\ell=1}^3 p_y^\ell + E_y^{\text{miss}}\right)^2\right]}$$



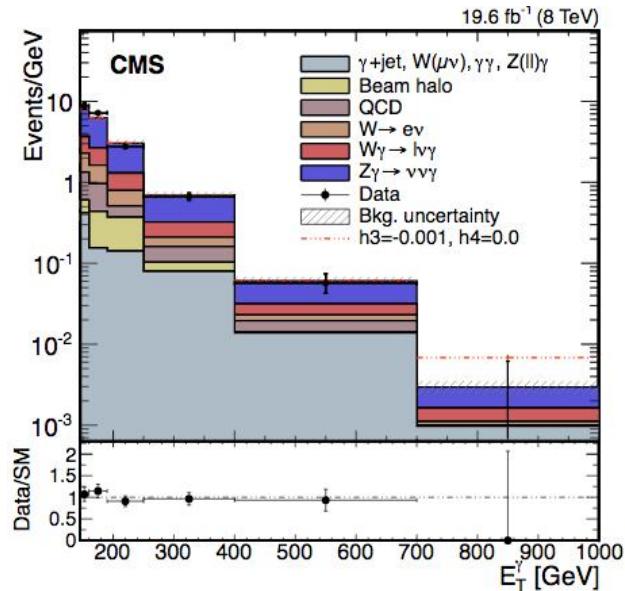
# Charged and neutral aTGC



**CMS**,  $19.6 \text{ fb}^{-1}$ , 8TeV,  $Z\gamma \rightarrow \nu\nu\gamma$ ,  
arXiv: 1602.07152v1

$$\sigma(Z\gamma) = 52.7 \pm 2.1 \pm 6.4 \pm 1.4 \text{ (lumi)} \text{ fb}$$

$$\text{Theory: } \sigma(Z\gamma) = 50.0 + 2.4 - 2.2 \text{ fb}$$



$$-1.5 \times 10^{-3} < h_3 Z < 1.6 \times 10^{-3}$$

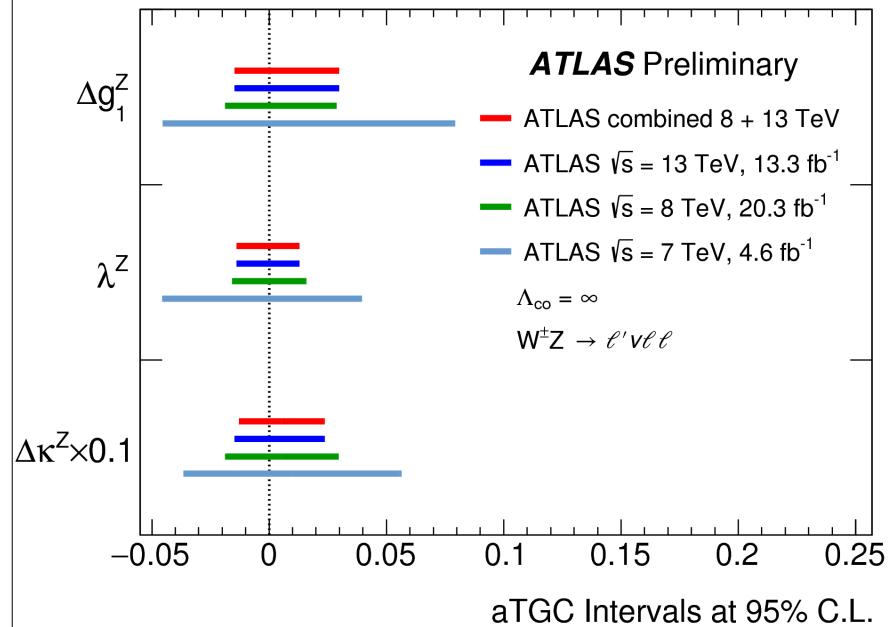
$$-3.9 \times 10^{-6} < h_4 Z < 4.5 \times 10^{-6}$$

$$-1.1 \times 10^{-3} < h_3^\gamma < 0.9 \times 10^{-3}$$

$$-3.8 \times 10^{-6} < h_4^\gamma < 4.3 \times 10^{-6}.$$

*Most stringent limits on anom. ZV $\gamma$  couplings*

**ATLAS**,  $13.3 \text{ fb}^{-1}$ , 13TeV, WZ leptonic,  
 $m_T(WZ)$ , ATLAS-CONF-2016-043



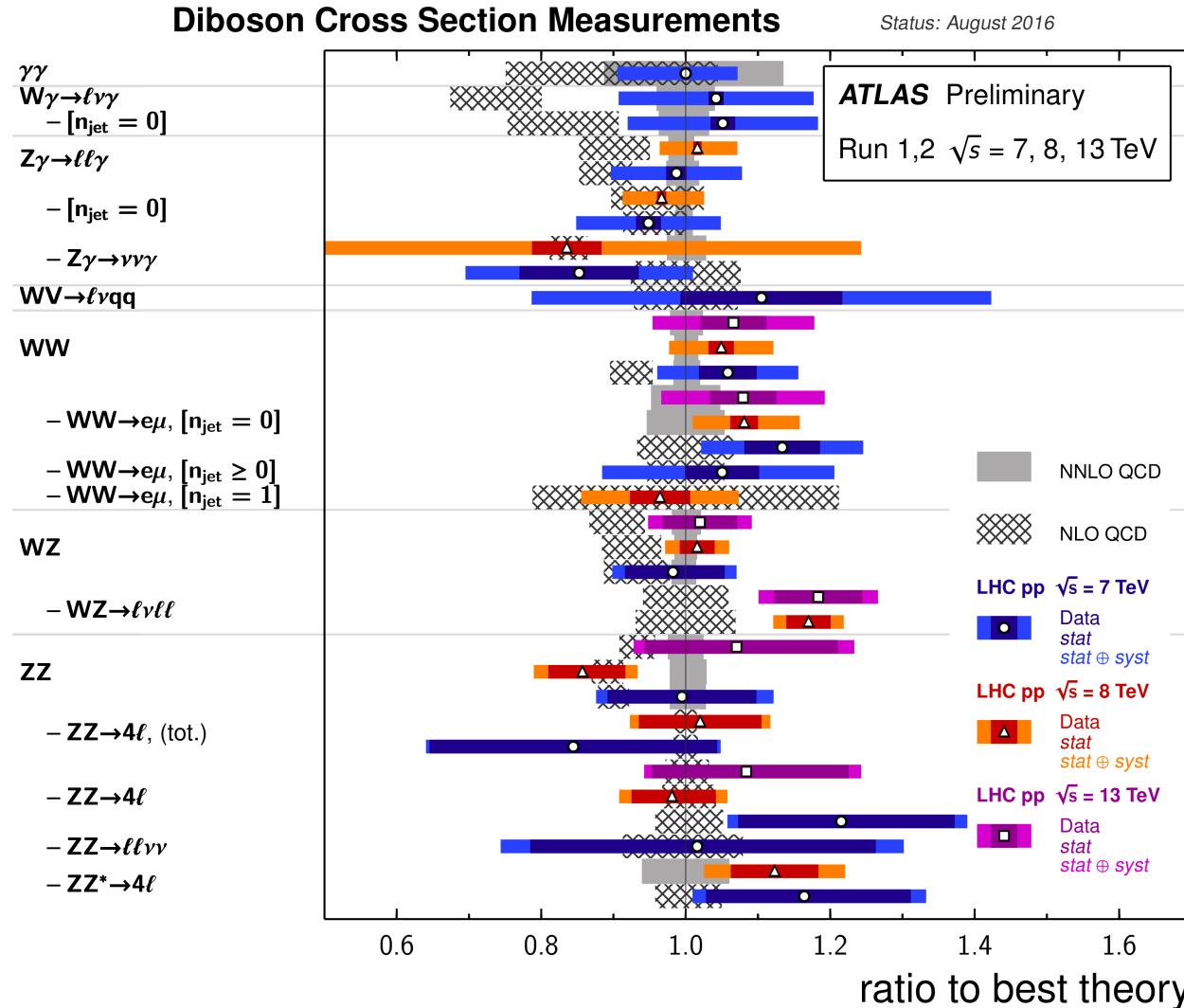
*Exceed 8TeV sensitivity  
Combination → most stringent limits  
on anomalous WWZ coupling*

# Diboson cross section summary

*Final precise 8TeV diboson cross sections, differential cross sections.*

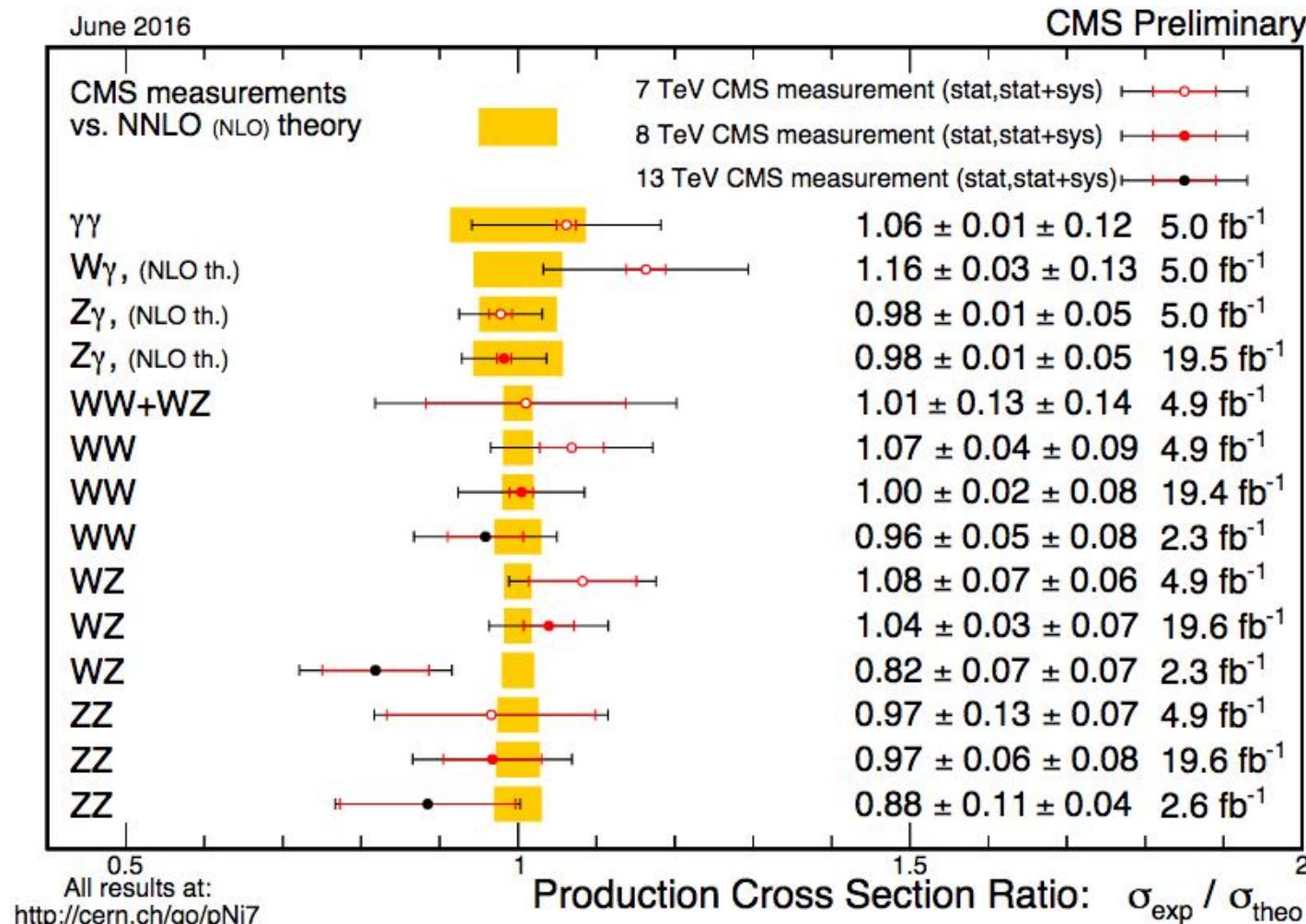
*New 13TeV cross section, starting to go differential.*

*Measurements consistent with NNLO*

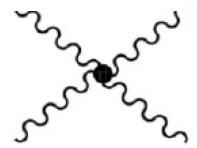


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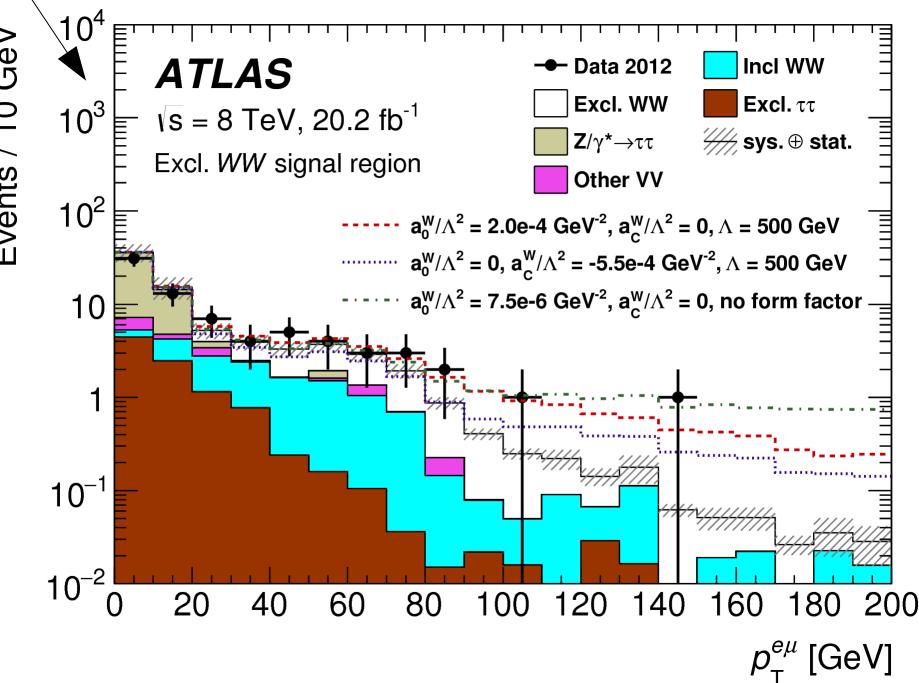


# Quartic Gauge couplings



**CMS**,  $19.7 \text{ fb}^{-1}$ , 8TeV, exclusive WW,  
 $\sigma(\gamma\gamma \rightarrow \text{WW} \rightarrow e\mu X) = 11.9 \pm 5.6 \pm 4.5 \text{ fb}$ ,  
arXiv:1604.04464

**ATLAS**,  $20.3 \text{ fb}^{-1}$ , 8TeV, exclusive WW,  
 $\sigma(\gamma\gamma \rightarrow \text{WW} \rightarrow e\mu X) = 6.9 \pm 2.2 \pm 1.4 \text{ fb}$   
arXiv:1607.03745



*Evidence:* WW scattering (WWWW), exclusive WW & Wγγ (γγWW), VBS Zγ (WWγZ/γ\*)

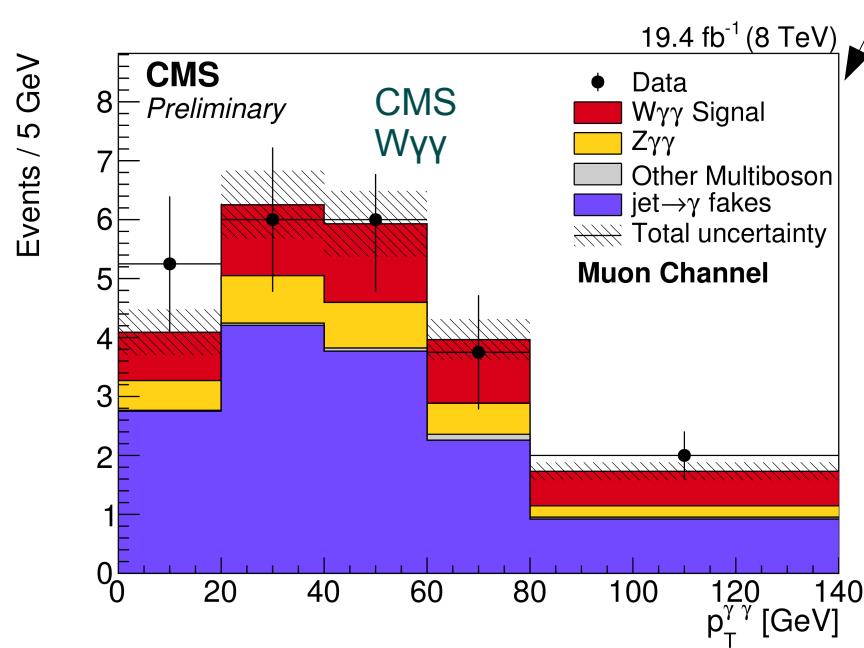
*1-2σ (SM):* WWW production (WWWW), VBS WZ leptonic (ZZWW and WWWW)

*Search:* semileptonic WV VBS, sensitive to anomalous ZZWW and WWWW couplings

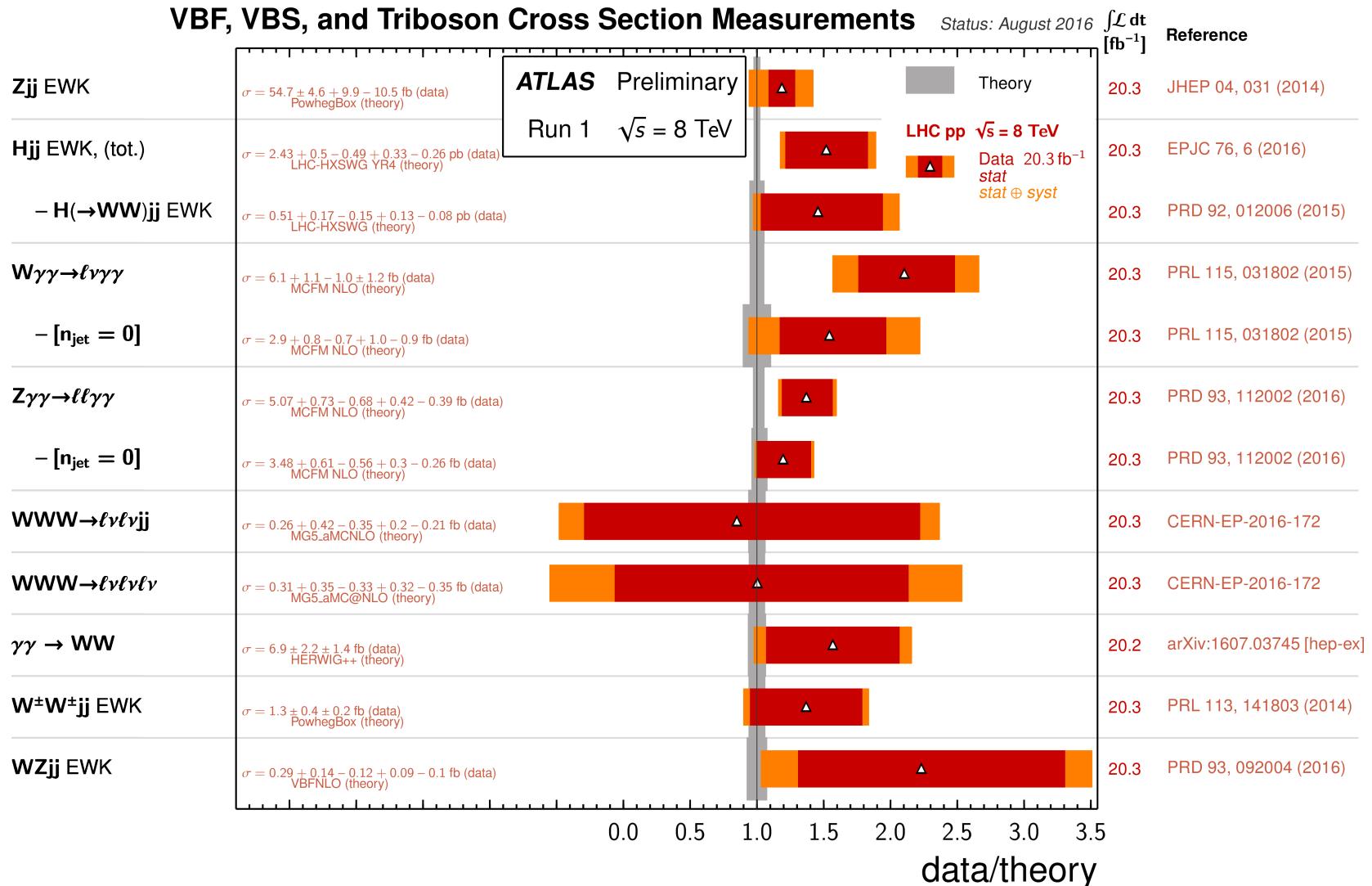
**ATLAS**,  $20.3 \text{ fb}^{-1}$ , 8TeV, WWW, production  
STDM-2015-07

**ATLAS**,  $20.3 \text{ fb}^{-1}$ , 8TeV, VBS WZ  $\rightarrow l\nu jj/ l\nu J$   
boosted and resolved, STDM-2015-09

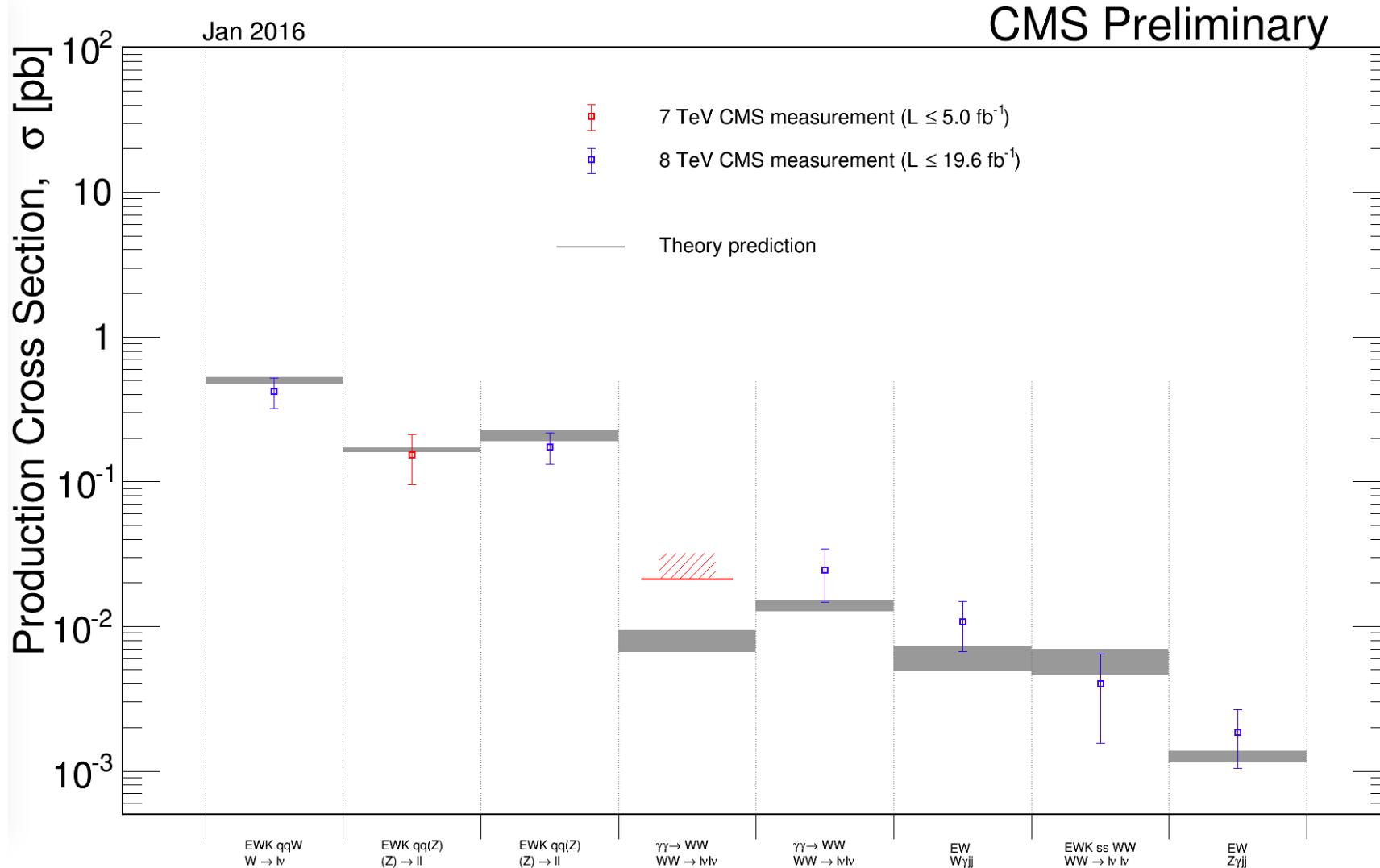
**CMS**,  $19.7 \text{ fb}^{-1}$ , 8TeV, Zγγ, Wγγ  
CMS-PAS-SMP-15-008



# VBF, VBS and Triboson summary



# VBF, VBS and Triboson summary



# EW precision measurements

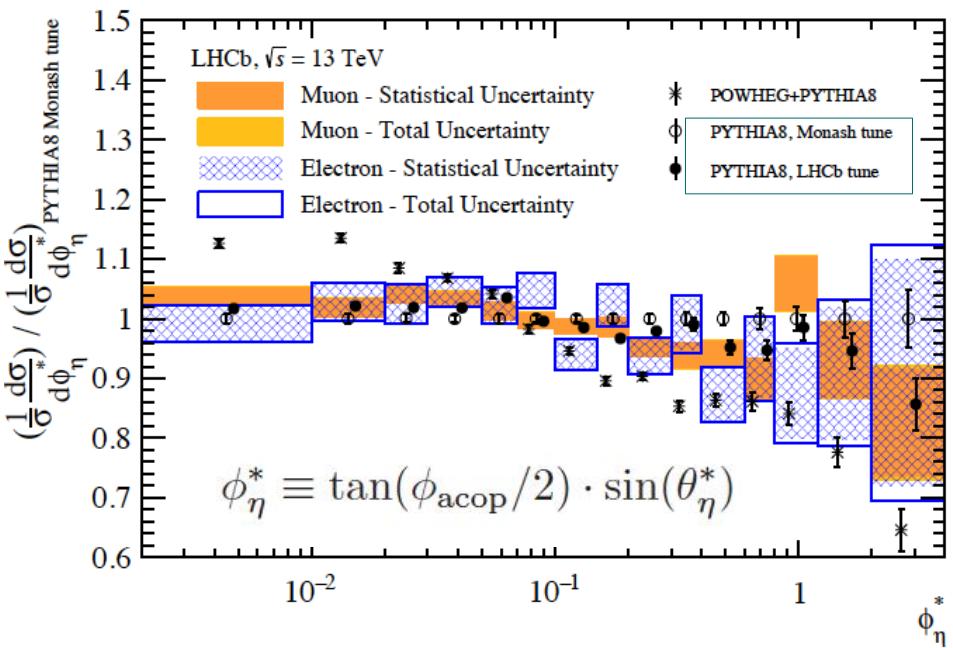
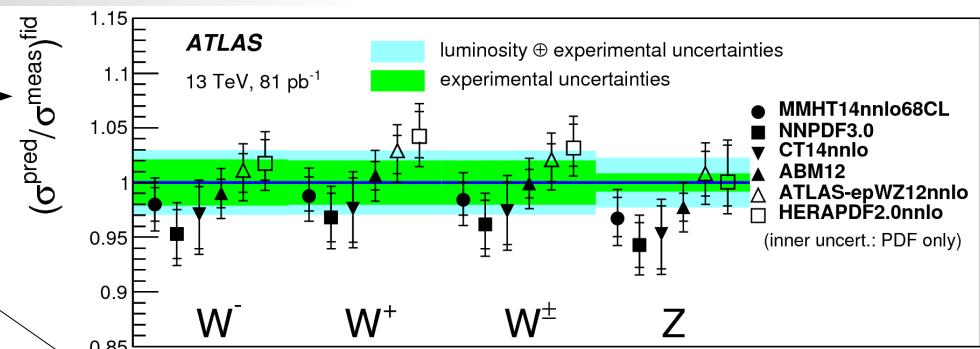
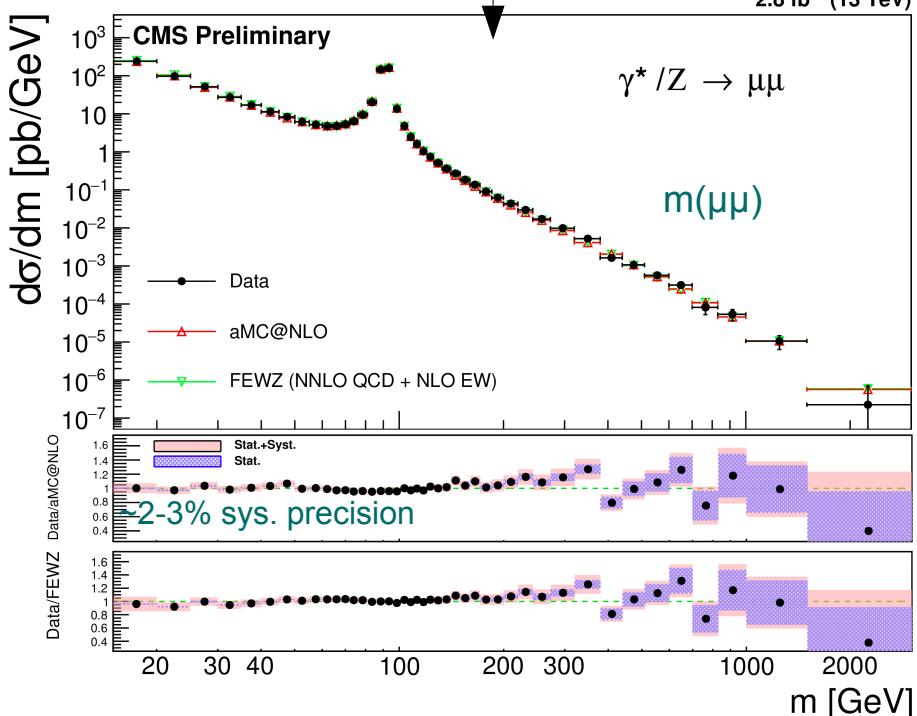


# Recent single W and Z @ 13TeV

**ATLAS**,  $81 \text{ pb}^{-1}$ , 13TeV, W, Z, W+/W-, W/Z  
Phys. Lett. B 759 (2016) 601

**LHCb**,  $294 \text{ pb}^{-1}$ , 13TeV, Forward Z  $2.0 < |\eta| < 4.5$   
 $\Phi^*$ , ZpT, y(Z) arXiv:1607.06495  
 $\sigma(Z \rightarrow ll) = 194.3 \pm 0.9 \pm 3.3 \pm 7.6 \text{ pb}$

**CMS**,  $2.8 \text{ fb}^{-1}$ , 13TeV, m(ll)  
CMS-PAS-SMP-16-009



*Inclusive (W,Z) and differential (Z) cross sections  
→ Percentage-level precision, consistent with SM  
Starting differential cross section measurements*

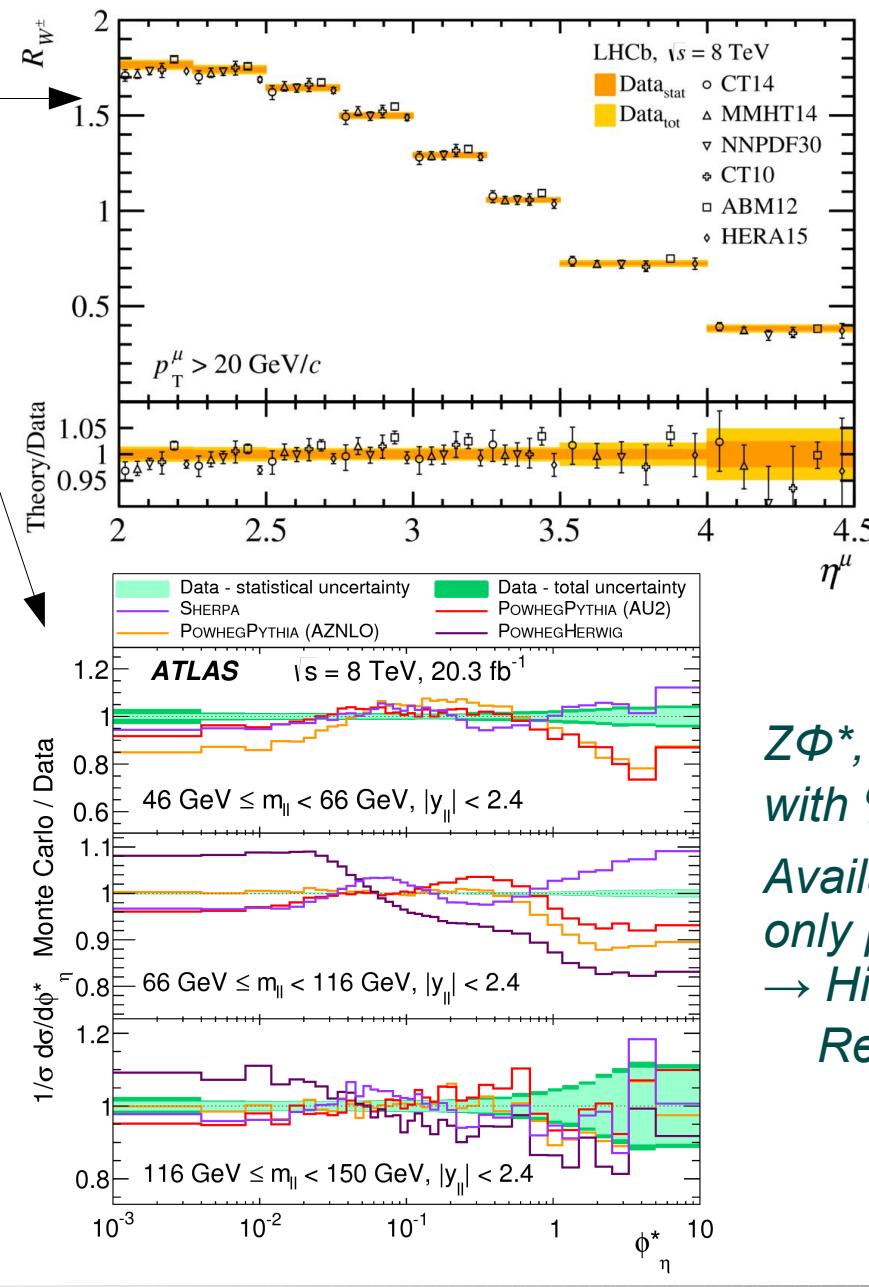
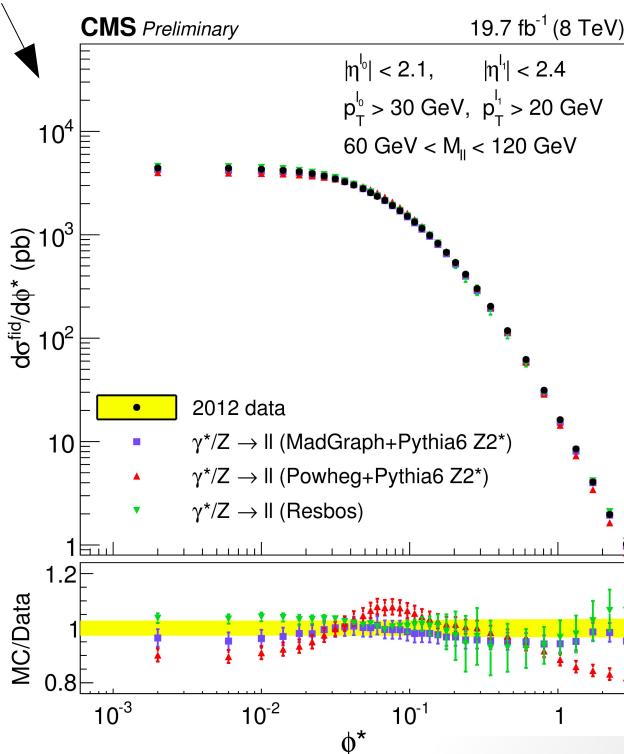
# Precision Z measurements @ 8TeV

LHCb,  $2\text{fb}^{-1}$ , 8TeV,  $W^+/W^-$ , 8/7TeV  
JHEP 01 (2016) 155

CMS ,  $18.4\text{ pb}^{-1}$ , 8TeV,  $WpT, ZpT$ ,  
arXiv:1606.05864

ATLAS,  $20.3\text{ fb}^{-1}$ , 8TeV,  $Z \Phi^*$ ,  $p_T$ ,  
EPJC 76(5), 1-61 (2016)

CMS ,  $19.7\text{ fb}^{-1}$ , 8TeV,  $Z \Phi^*$   
CMS-PAS-SMP-15-002



$W^+/W^-$  asymmetry  
7/8TeV double ratio  
→ PDF @ low- $x$ :  
complementary  
to ATLAS/CMS

$Z\Phi^*, Zp_T$  measured  
with % precision

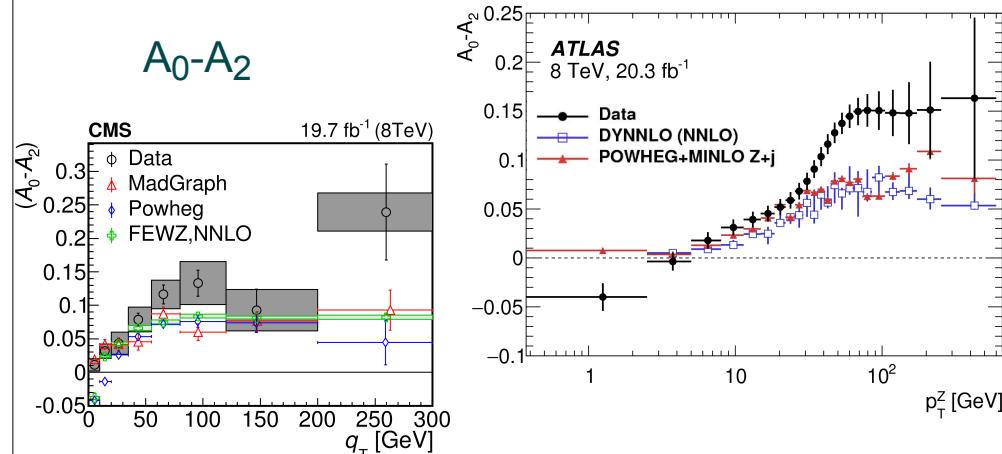
Available predictions model  
only part of the spectrum  
→ Higher  $O(\alpha_S)$  at high- $p_T$   
Resummation at low- $p_T$

# More Drell-Yan precision measurements

Z production: angular coefficients

**ATLAS, 20.3fb<sup>-1</sup>, 8TeV**  
arXiv:1606.00689

**CMS, 19.7fb<sup>-1</sup>, 8TeV, Z → μμ**  
Phys. Lett. B 750 (2015) 154



Production dynamics through spin-1 correlations

$$\frac{d^2\sigma}{d \cos \theta^* d\phi^*} \propto [(1 + \cos^2 \theta^*) + A_0 \frac{1}{2}(1 - 3 \cos^2 \theta^*) + A_1 \sin(2\theta^*) \cos \phi^* + A_2 \frac{1}{2} \sin^2 \theta^* \cos(2\phi^*) + A_3 \sin \theta^* \cos \phi^* + A_4 \cos \theta^* + A_5 \sin^2 \theta^* \sin(2\phi^*) + A_6 \sin(2\theta^*) \sin \phi^* + A_7 \sin \theta^* \sin \phi^*].$$

Discrepancies → missing higher-order pQCD effects

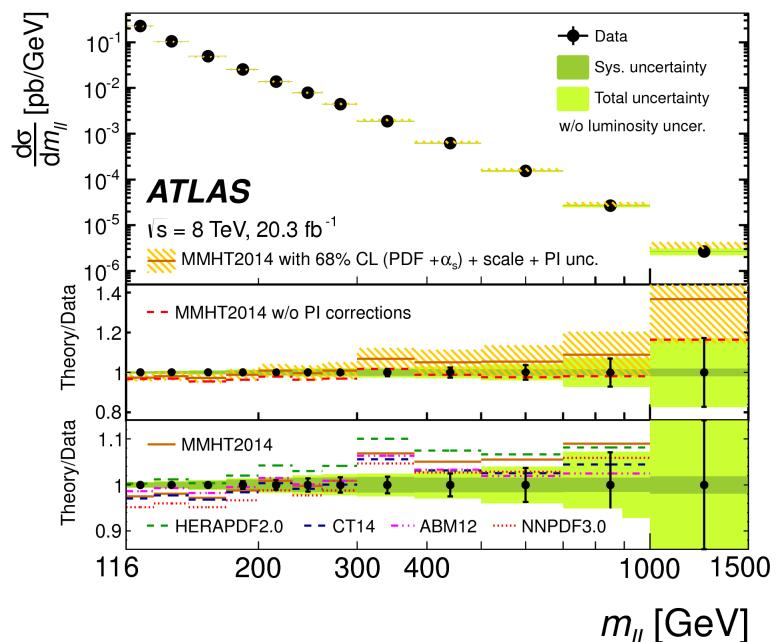
Discriminate between PS approaches

High-mass Drell-Yan, double-differential

**ATLAS, 20.3fb<sup>-1</sup>, 8TeV**  
JHEP 08 (2016) 009

Differential in m(II) and double-differential  
m(II)–y(II) and m(II) – Δη(II)

Precision up to % level.  
Comparison with NNLO pQCD+NLO EW  
→ sensitive to PDF, in particular photon PDF



# $\sin^2\Phi_W$ @ hadron colliders

$$A_{q/\mu} = \frac{2g_V^{q/\mu}/g_A^{q/\mu}}{1 + (g_V^{q/\mu}/g_A^{q/\mu})^2}$$

.....Extracted from  $A_{FB}$  measurement

$$g_V^{q/\mu}/g_A^{q/\mu} = 1 - 4|Q_{q/\mu}| \sin^2 \theta_{\text{eff}}^{q/\mu}$$

D0, 9.7 $\text{fb}^{-1}$ , AFB,  $\sin^2\Theta_{W\text{eff}}$   
PRL 115 (2015)041801

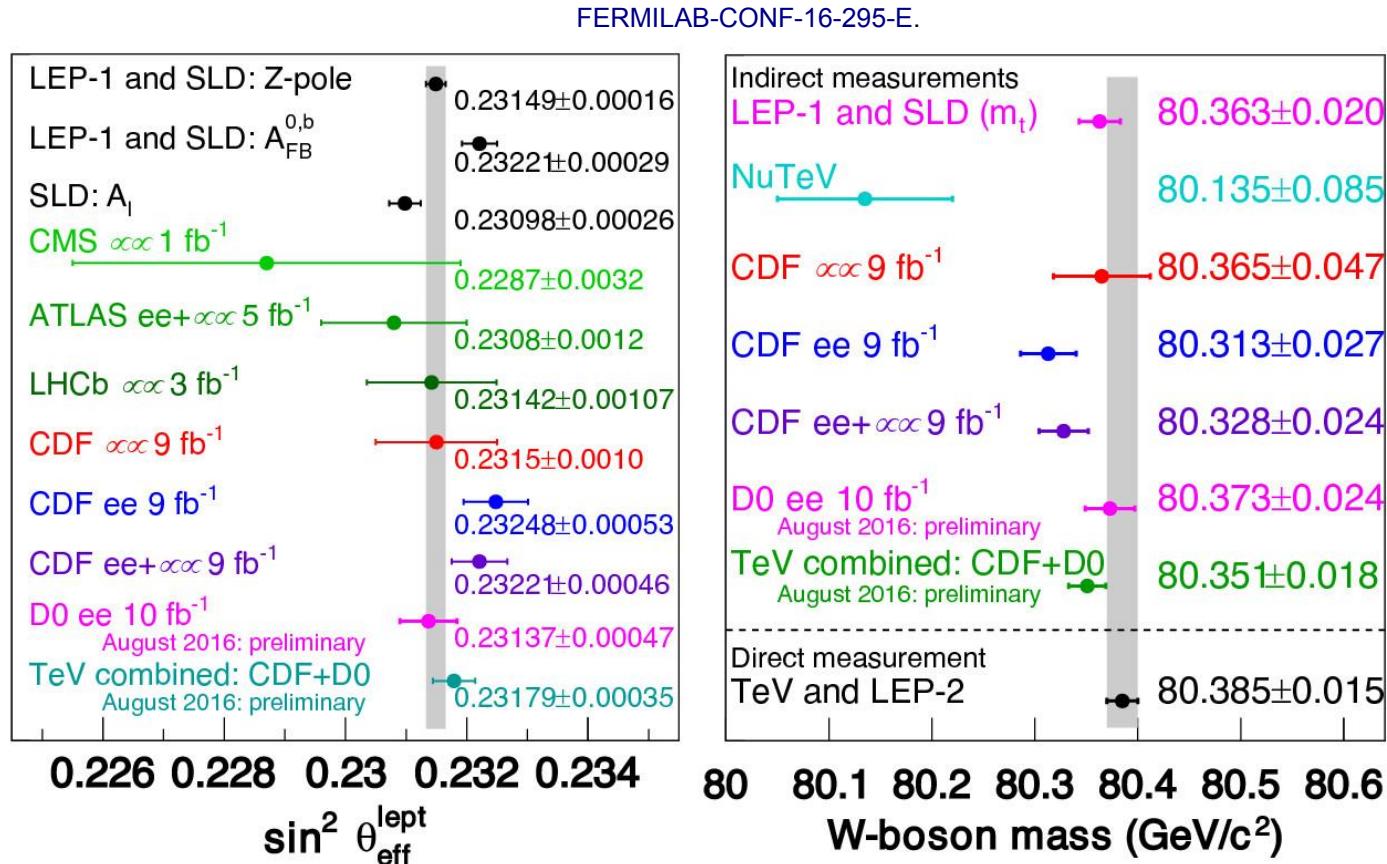
CDF, 9.4 $\text{fb}^{-1}$ , AFB,  $\sin^2\Theta_{W\text{eff}}$   
PRD 93 (2016) 112016

D0+CDF combination  $\sin^2\Theta_{W\text{eff}}$   
Fermilab-Conf-16-295-E

LHCb, 1+2 $\text{fb}^{-1}$ , 7 & 8 TeV,  
 $Z \rightarrow \mu\mu$ , JHEP 1511(2015) 190

ATLAS, 4.8 $\text{fb}^{-1}$ , 7 TeV  
JHEP09(2015)049

CMS, 1.1 $\text{fb}^{-1}$ , 7 TeV  
PRD 84 (2011) 112002



Tevatron: 1.5 permille precision, LHC at 5 permille precision

→ approaching e<sup>+</sup>e<sup>-</sup> precision, dominant unc.: LHC: PDF, Tevatron: statistical, PDF

Indirect constraint on W mass → consistency of SM

# Global Electroweak Fits

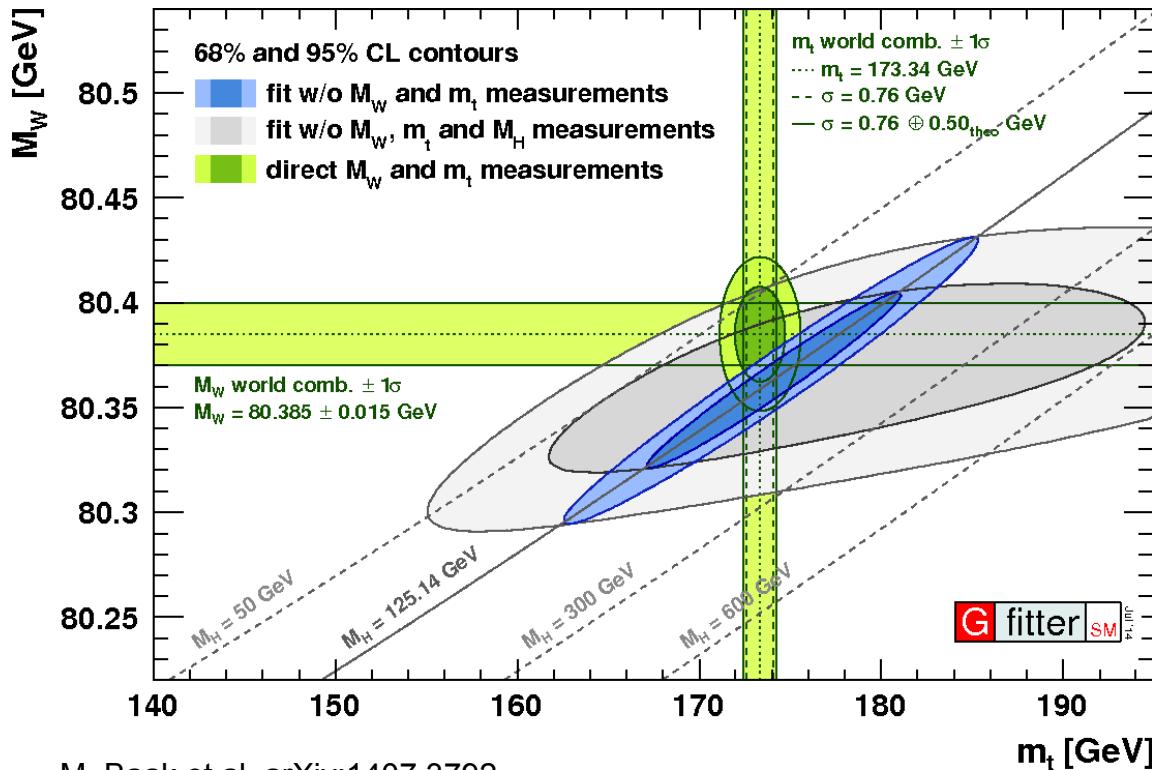
*EW parameters:  $\alpha_{EM}$ ,  $G_F$ ,  $m_W$ ,  $m_Z$ ,  $m_H$ ,  $\sin^2\Theta_W$*

*Measurements of EW precision observables  
+ accurate theoretical predictions about their relations*

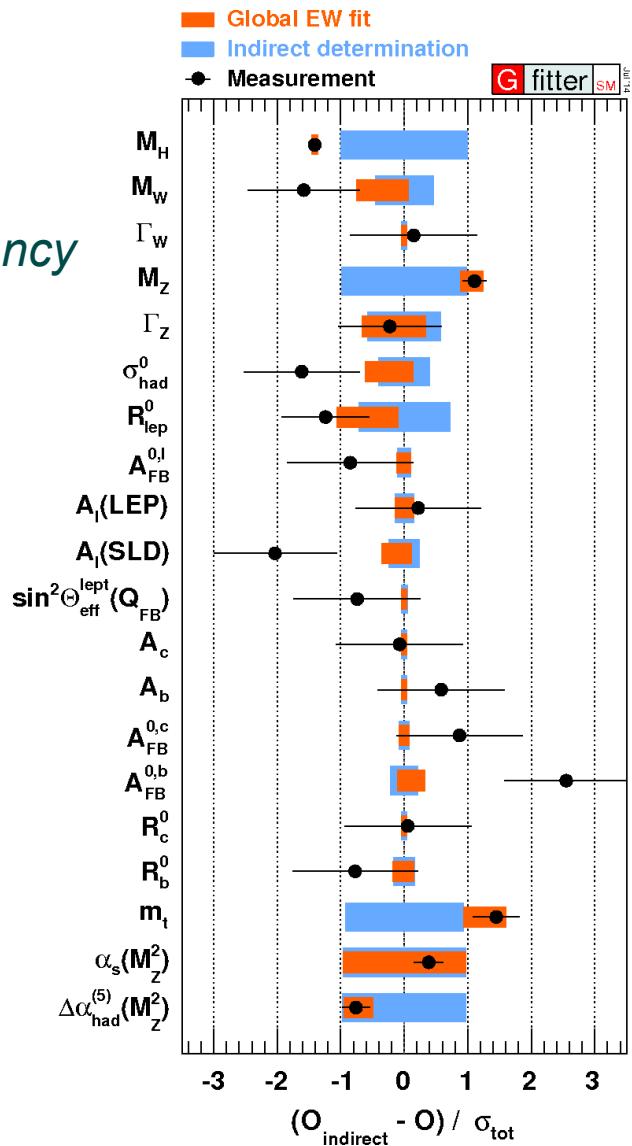
*Traditionally: predict  $m_t$ ,  $m_H$*

*Now overconstrained after Higgs discovery → check consistency*

*Direct measurement ↔ global fit ↔ indirect determination*



M. Baak et al, arXiv:1407.3792



# Electroweak Fit: HERA

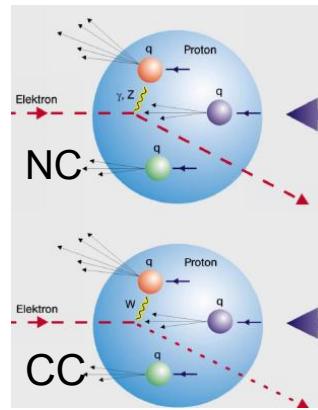
25-35% with polarized beams

Complementary test of the SM in the space-like domain.  
How well can HERA data constrain the EW parameters?

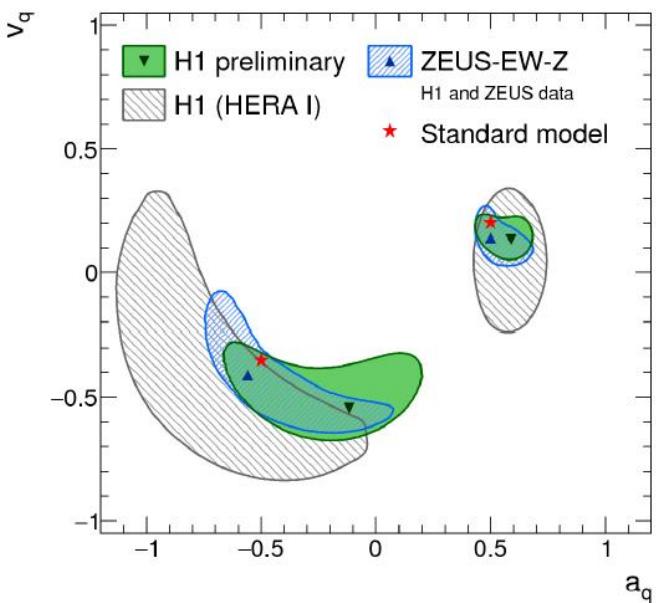
**H1 & ZEUS**, Combined QCD and EW fit  
arXiv:1604.05083

**H1 QCD and EW fit**  
H1prelim-16-041

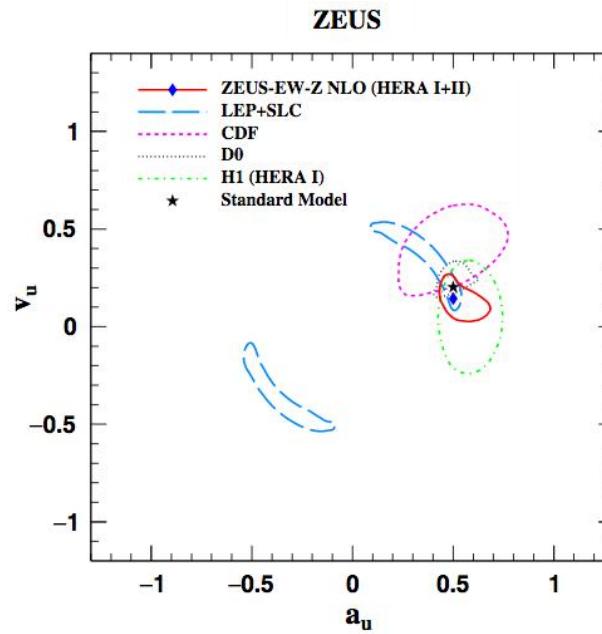
**ZEUS QCD and EW fit**  
Phys. Rev. D 93 (2016) 092002



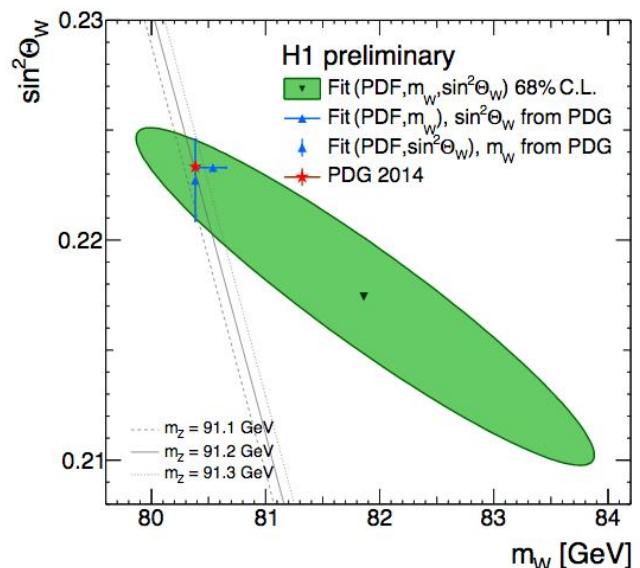
- $v_u, v_d, a_u, a_d$
- $\sin^2 \Theta_W$
- $m_W, \sin^2 \Theta_W$



Similar sensitivity and consistency of Zeus and H1



HERA very sensitive to up-type quark couplings



HERA-only and HERA+ext. input consistent with world average

Working on a combined fit → final word from HERA on the EW parameters.

# Summary

Precise Tevatron and HERA legacy measurements on full data sets

Large LHC 8TeV data set allows for high-precision measurements and to study kinematics, angular relations

→ challenging fixed-order calculations and MC generators

New 13TeV results confirm 8TeV results with already impressive precision

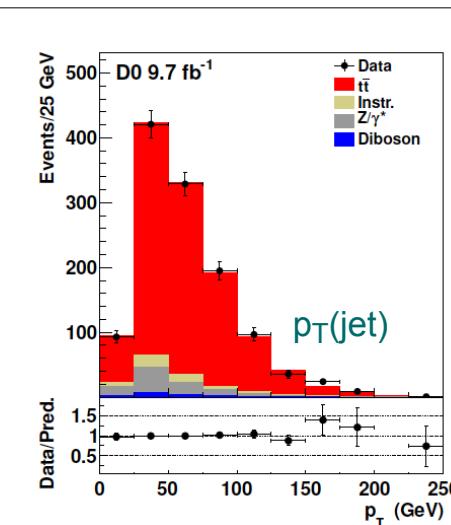
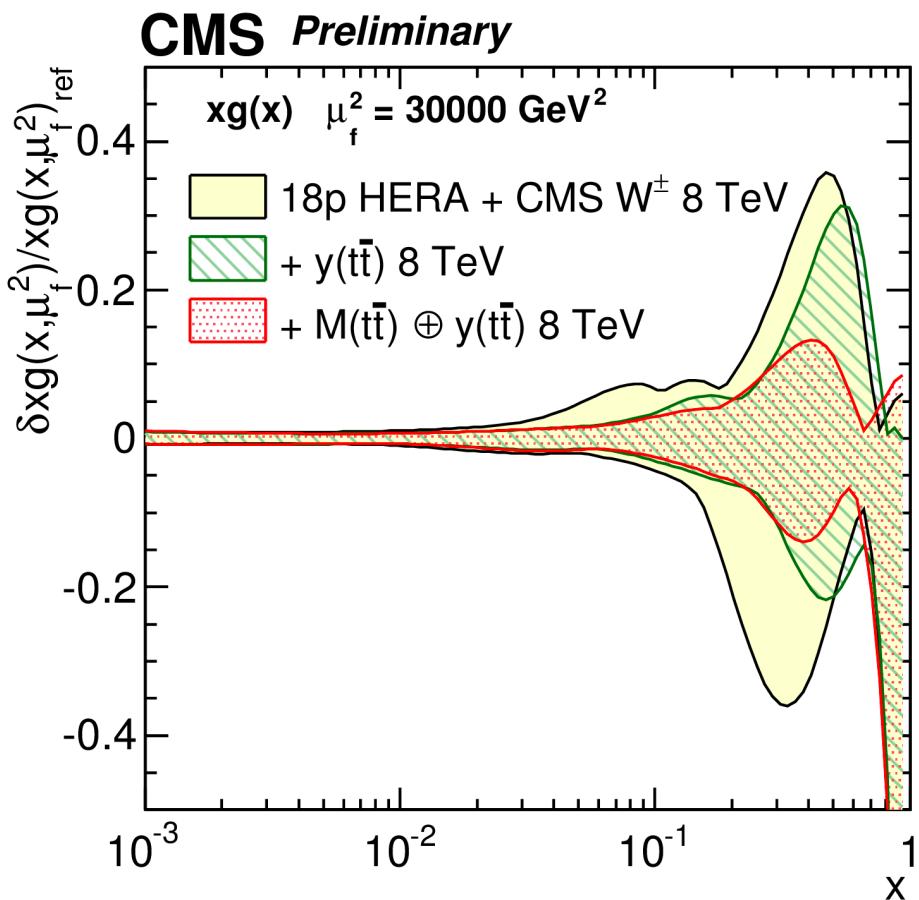
Data in general compatible with SM predictions at higher orders in pQCD.  
No hint for BSM yet.



# Appendix

# Appendix

## CMS double-differential



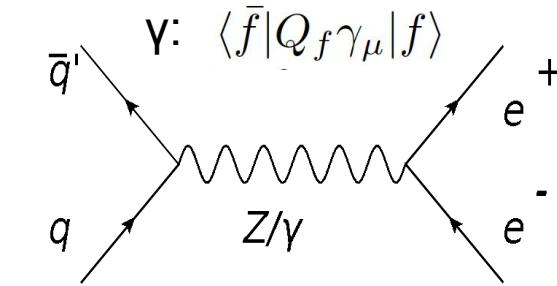
**D0 di-lepton**

Matrix element method  
JES from l+jets channel  
Stat. dominated  
Sys: JES, hadronization, UE

$$m_t = 173.93 \pm 1.84 \text{ GeV}$$

# Appendix

EW precision measurements in Drell-Yan events:  $A_{FB}$ ,  $\sin^2\Theta_W^{\text{eff}}$ , ...



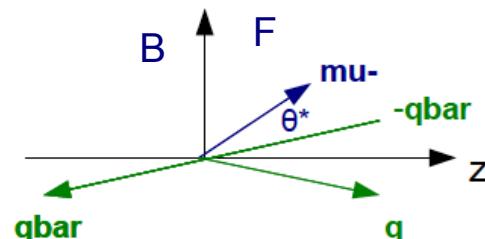
$$Z: \langle \bar{f} | g_V^f \gamma_\mu + g_A^f \gamma_\mu \gamma_5 | f \rangle$$

$A_{FB}$  : wrt quark direction:  $\cos\Theta_{CS}^*$

$$\sin^2\theta_W = 1 - M_W^2/M_Z^2$$

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

connection with  $g_V/g_A$



LHC: quark direction

estimated via Z direction

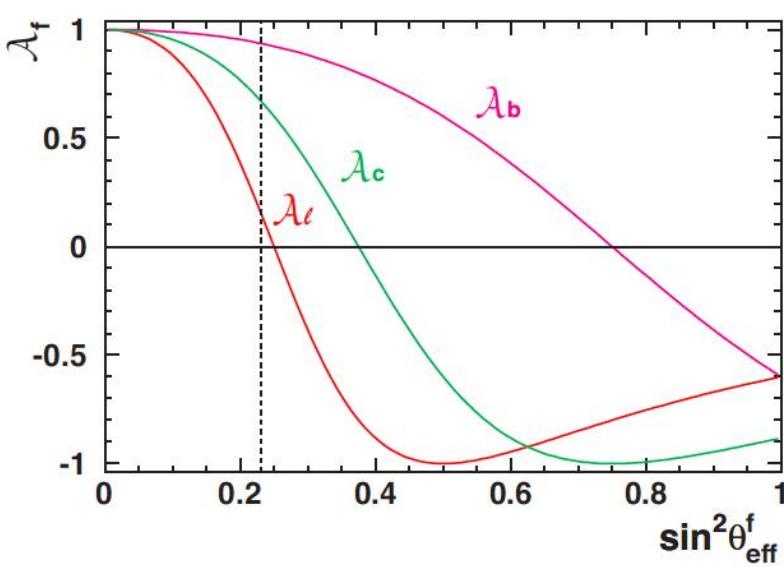
→ dilution effect

$$A_{q/\mu} = \frac{2g_V^{q/\mu}/g_A^{q/\mu}}{1 + (g_V^{q/\mu}/g_A^{q/\mu})^2}$$

$$A_{FB}^{0,\ell} = \frac{3}{4} A_q A_\ell \quad g_V^{q/\mu}/g_A^{q/\mu} = 1 - 4|Q_{q/\mu}| \sin^2 \theta_{\text{eff}}^{q/\mu}$$

→ deviations of the Z couplings to u,d ?

→ 3σ discrepancy between  $\sin^2\Theta_W$  from LEP and SLD ?



Sensitiv to  $\sin^2\Theta_W^{\text{lepeff}}$