EWK & QCD measurements

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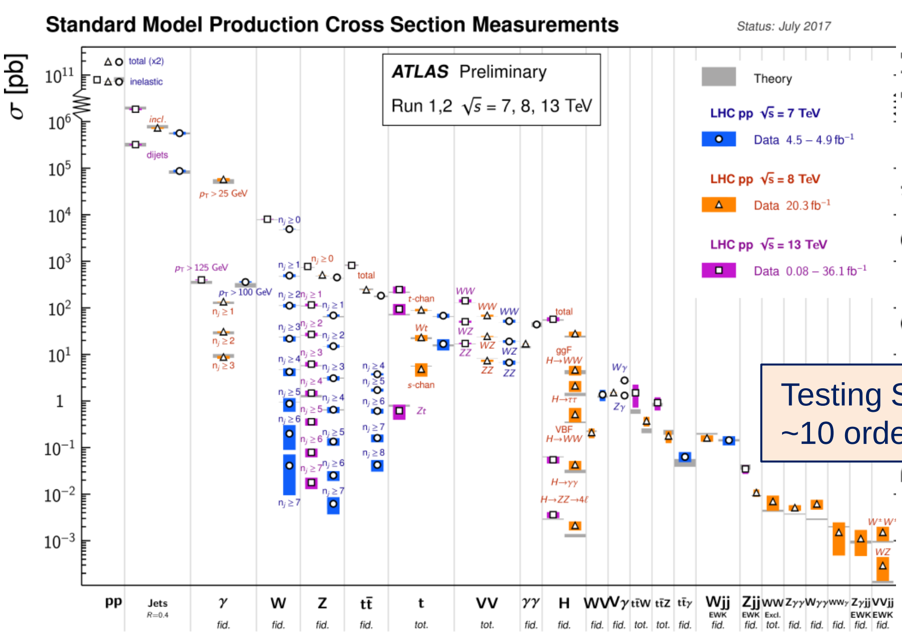
The 21st Particles & Nuclei International Confernence

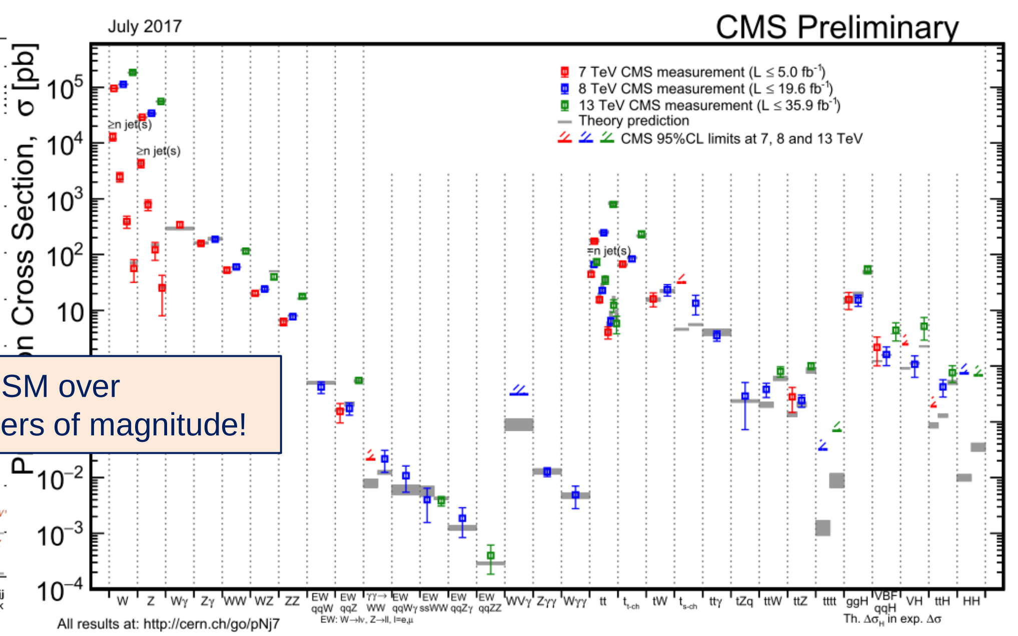
1-5 September 2017, IHEP, Beijing, China

Why EWK/QCD Physics ?

- **Lack of evidence of new physics:**
  - Not looking at the correct searching region
  - New phenomena located at larger energy scale or small production cross section

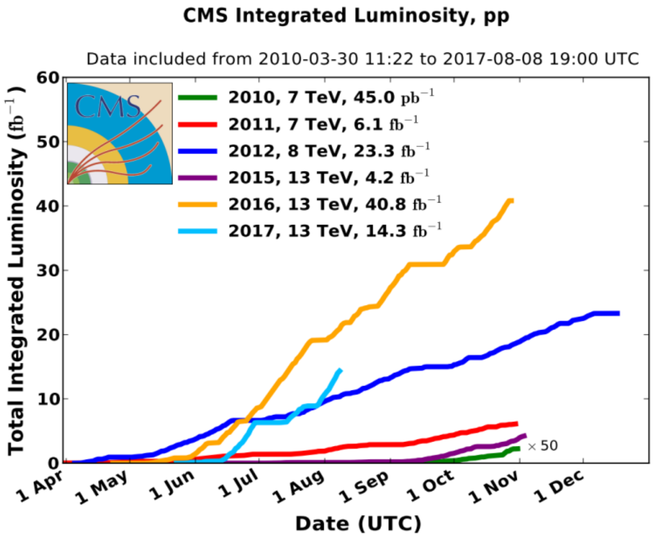
- **Precision measurements of Standard Model are crucial:**
  - Provide **precise systematics** for theoretical modellings
  - Explore **unreached phase space**
  - Improve theoretical modellings and MC generators (including PDF constraints)
  - Better control on SM background for **new physics searches**
    - Deviations from SM expectations may be a hint to new physics

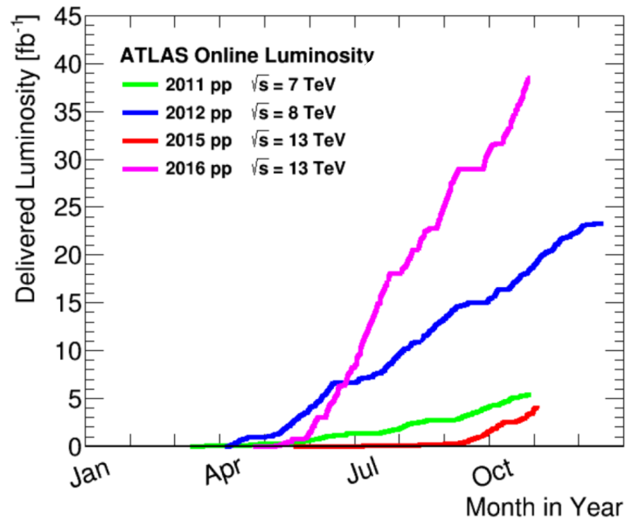


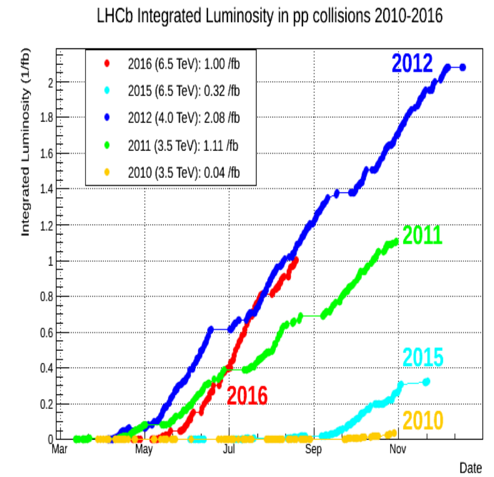


Testing SM over
~10 orders of magnitude!

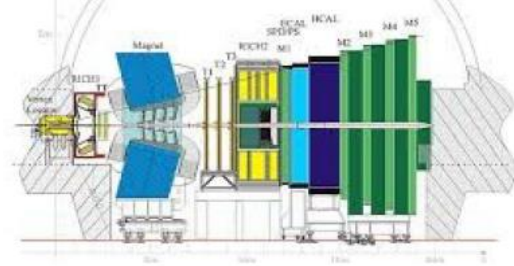
Detectors

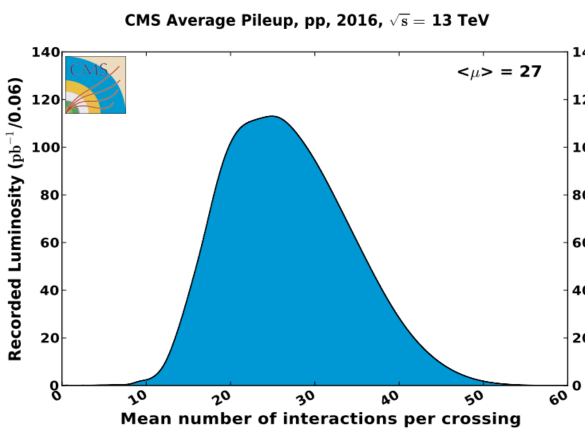


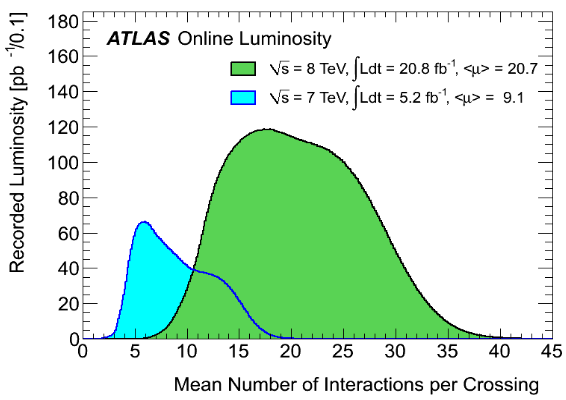


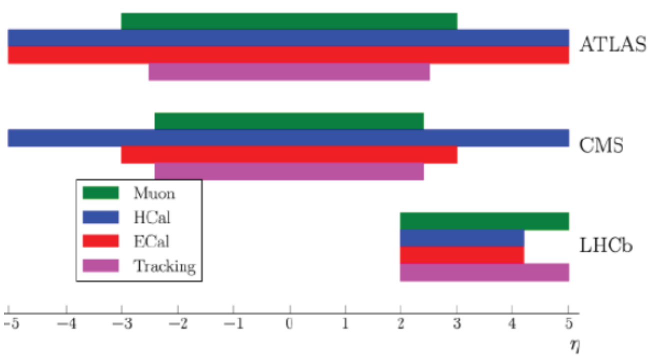


LHCb JINST 3 (2008) S08005

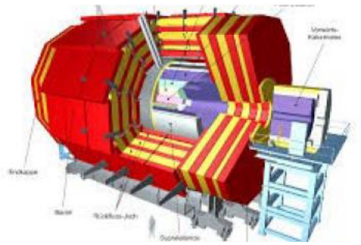




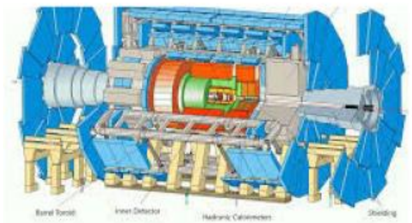




CMS JINST 3 (2008) S08004

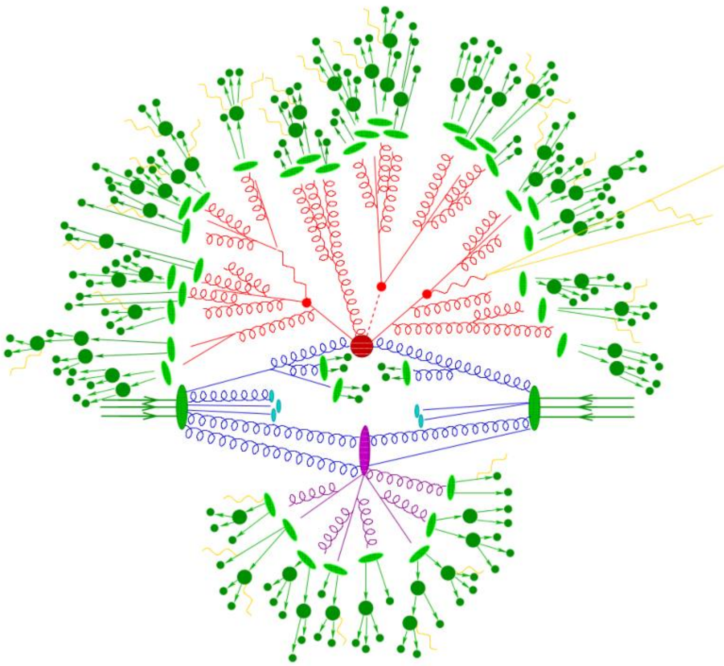


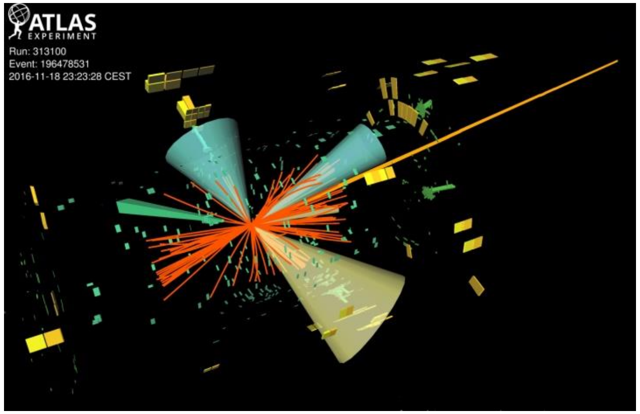
ATLAS JINST 3 (2008) S08003

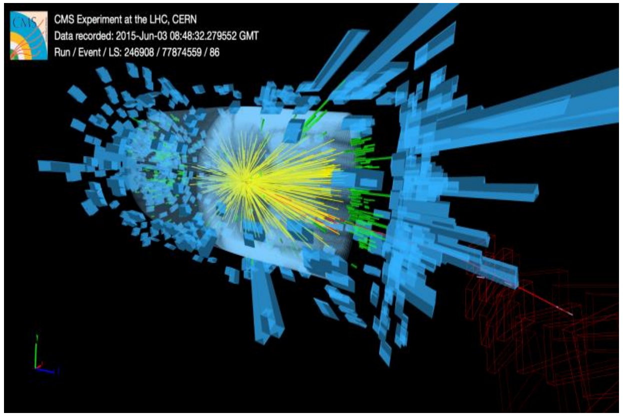


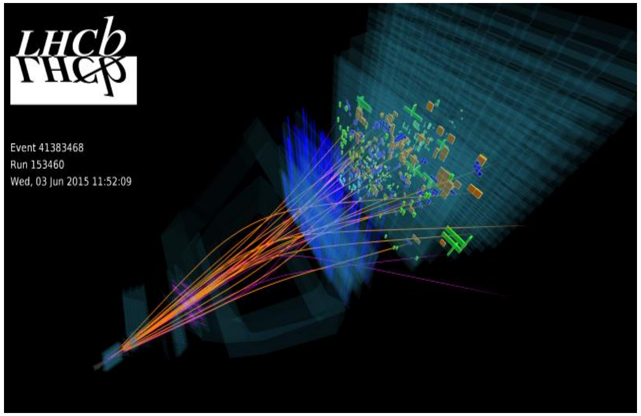
Outline

- Jet production (+jet mass, charge, angular correlation, PDF, alphas)
- W/Z/γ production (+W mass, mixing angle)
- V+jets (+VBF)
- VV
- VV+jets (+VBS)
- VVV
- Single top quark (+top mass & width)
- $t\bar{t}$
- $t\bar{t}$ V





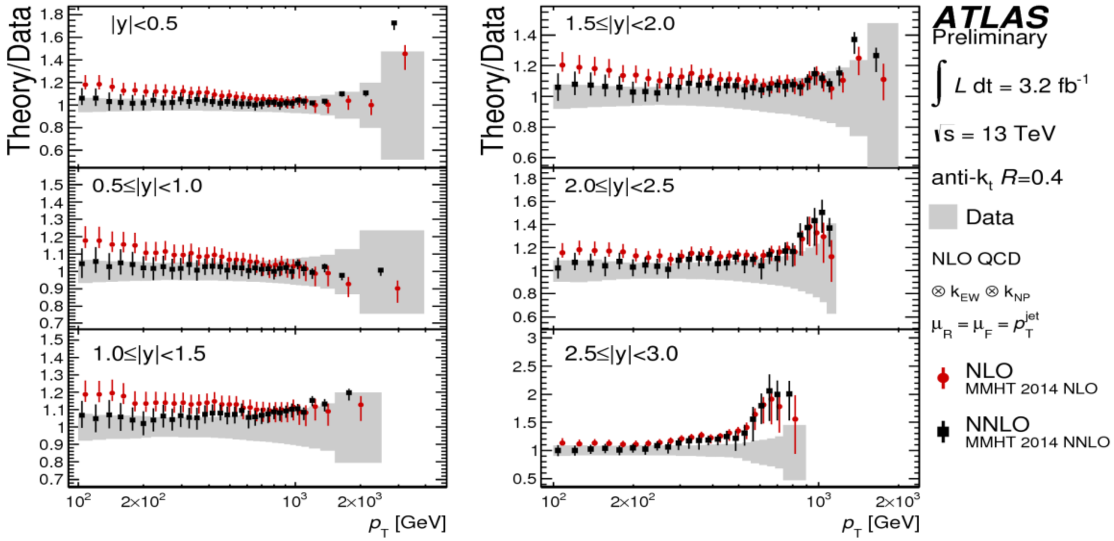


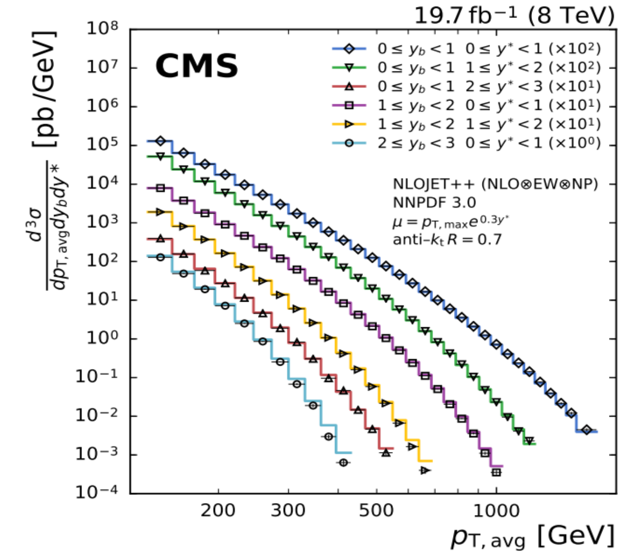


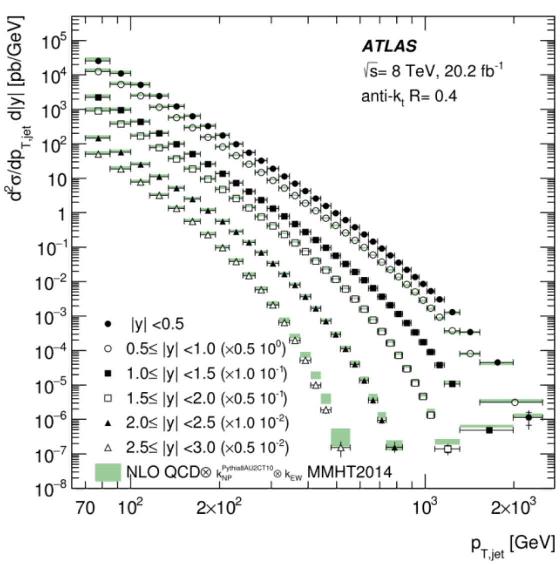
Inclusive jet production

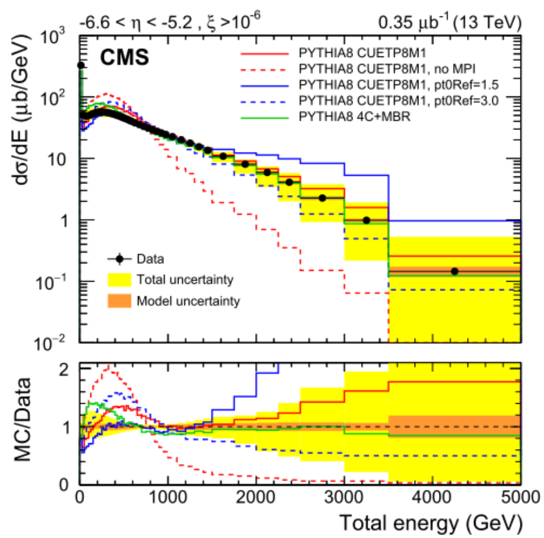
ATLAS-CONF-2017-048 JHEP 08 (2017) 046
arXiv:1706.03192 arXiv:1705.02628

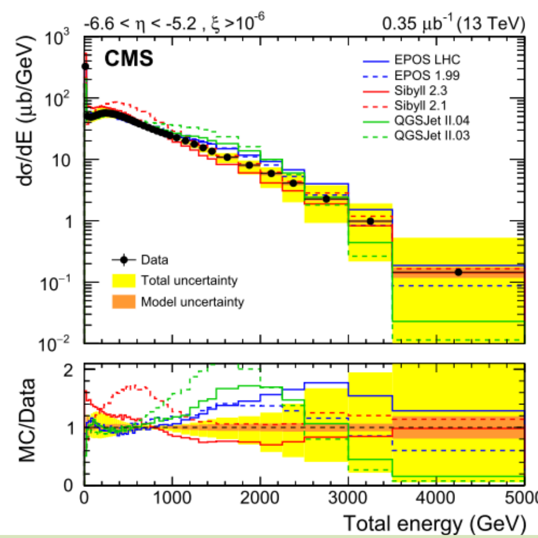
Agreements between the measurements and the theoretical predictions in NNLO/NLO accuracy!









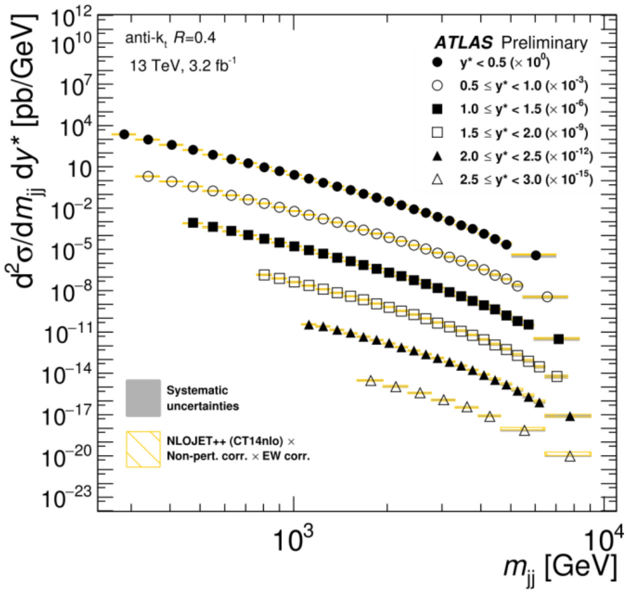


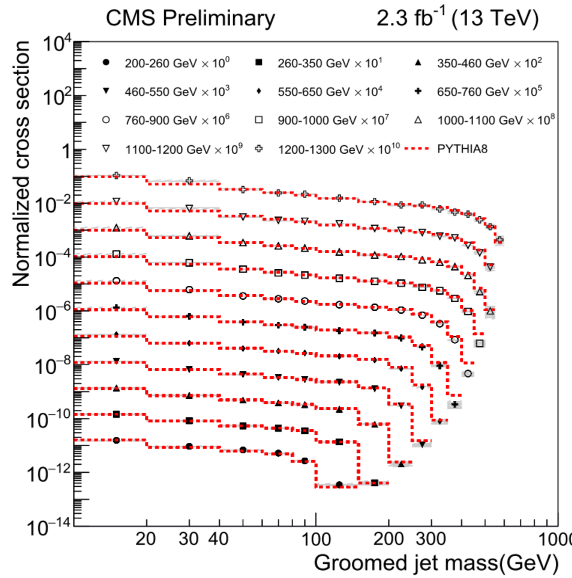
See from J. L. MERINO

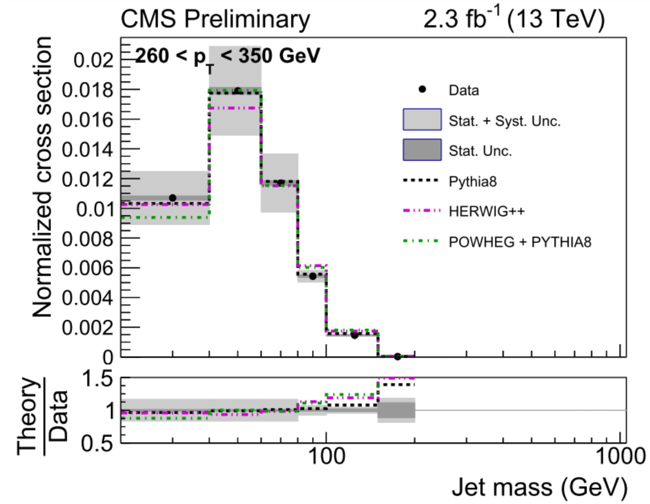
- Distribution of energy deposit (forward jet) in CASTOR :
  - Access low x where DGLAP evolution is expected to break down
  - None of the predictions manage to describe the measurement!

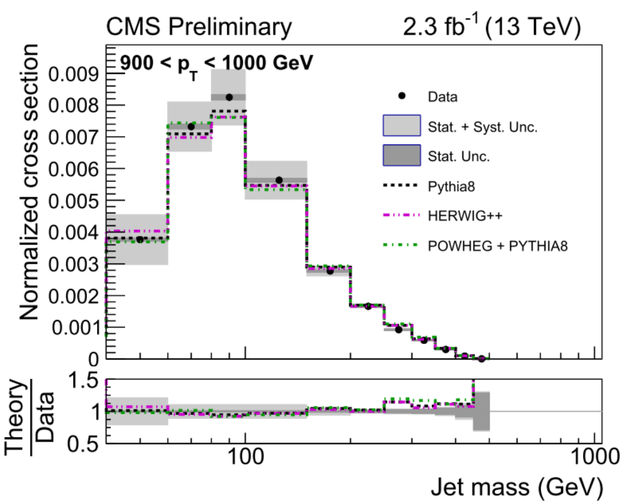
Jet mass measurement

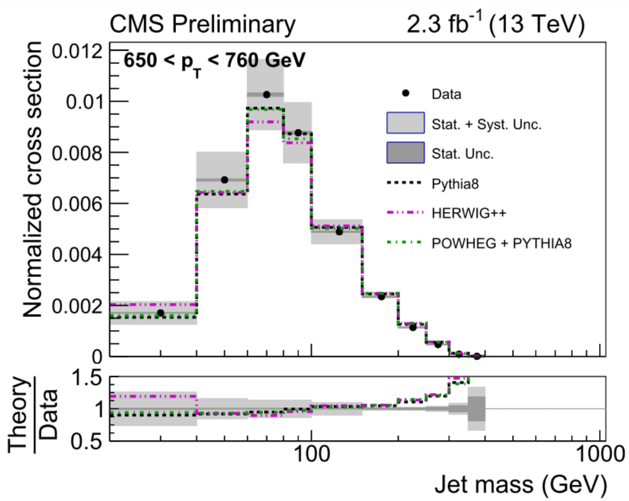
ATLAS-CONF-2017-048
CMS-PAS-SMP-16-010

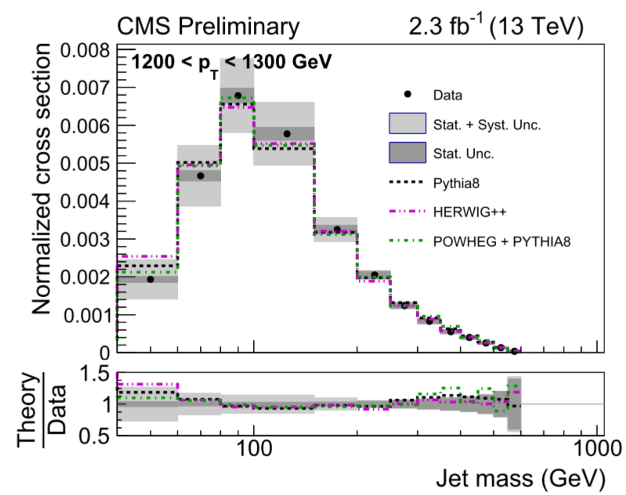








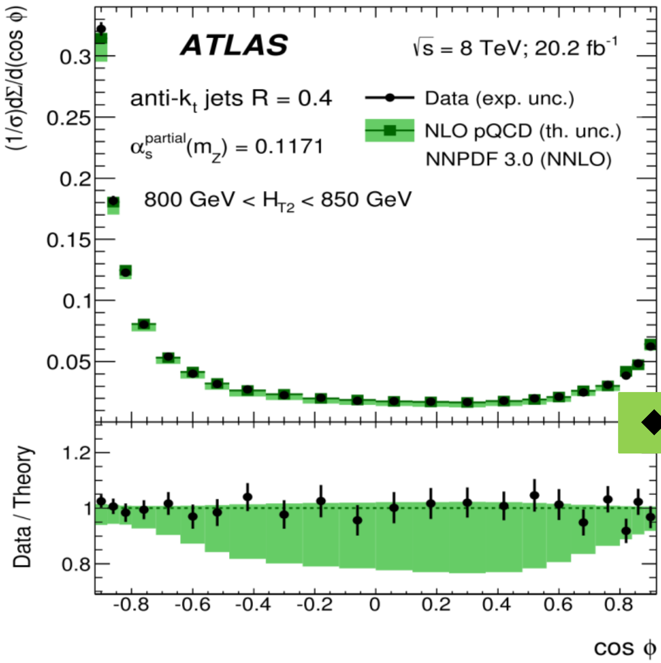


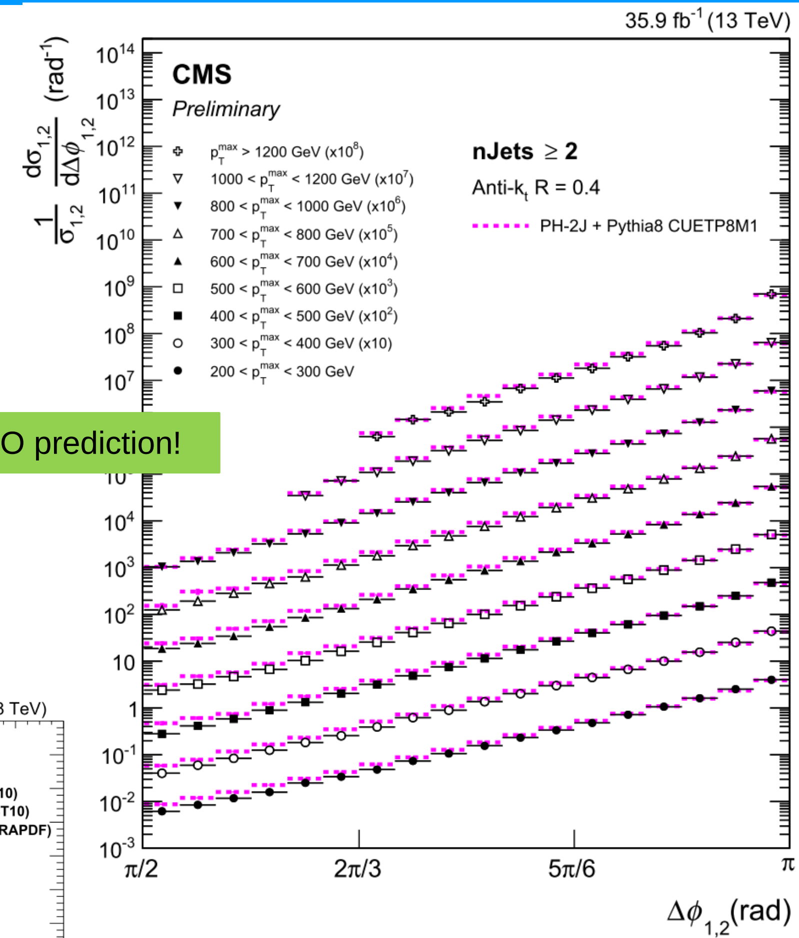


Agreements between the measurements and the theoretical predictions in NLO/LO accuracy!

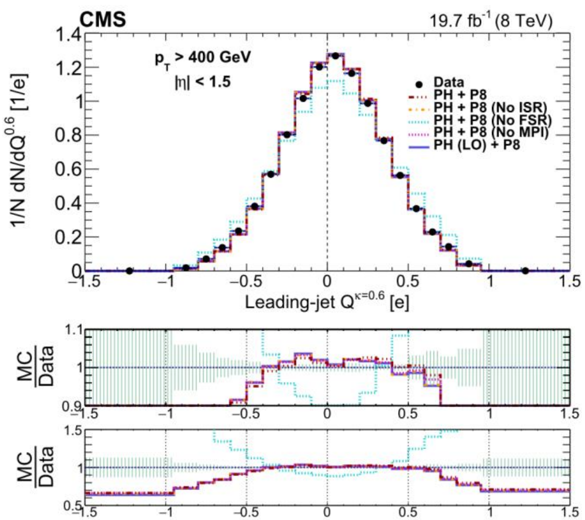
Angular correlation & charge @ Jet

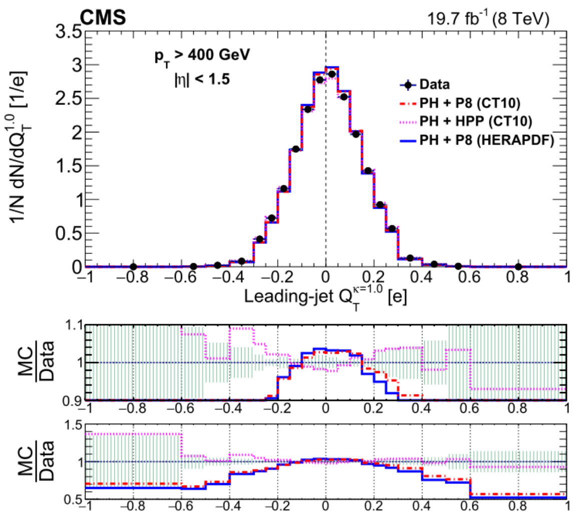
arXiv:1706.05868 arXiv:1707.02562
CMS-PAS-SMP-16-014





◆ Good agreement with NLO prediction!





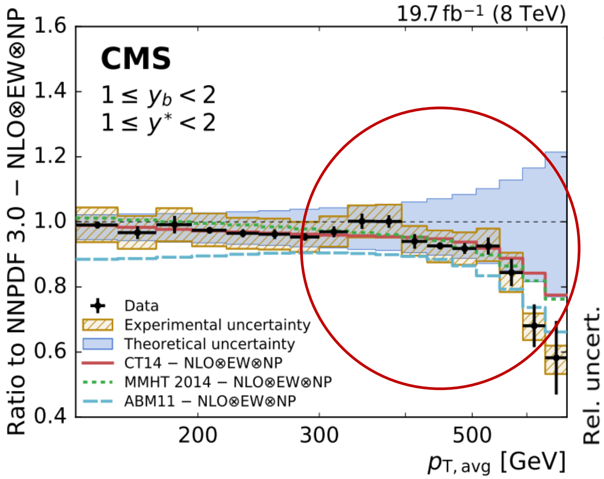
$$Q^{\kappa} = \frac{1}{(p_{\mathrm{T}}^{\mathrm{jet}})^{\kappa}} \sum_i Q_i (p_{\mathrm{T}}^i)^{\kappa}$$

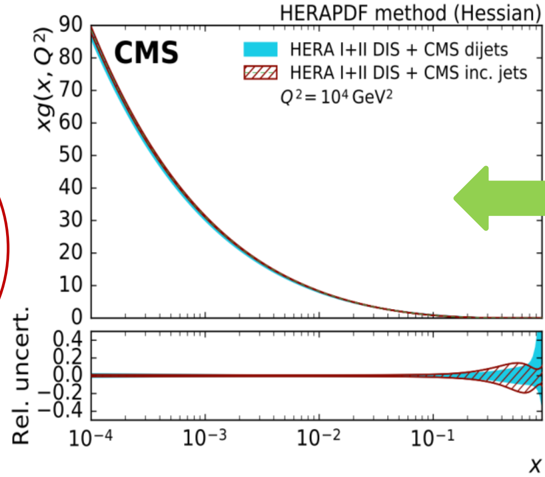
➢ The prediction for jet charge is insensitive to the NLO QCD effects, while sensitive to the modeling of final state radiation

PDF constrain & alphas @ Jet

arXiv:1705.02628

arXiv:1707.02562

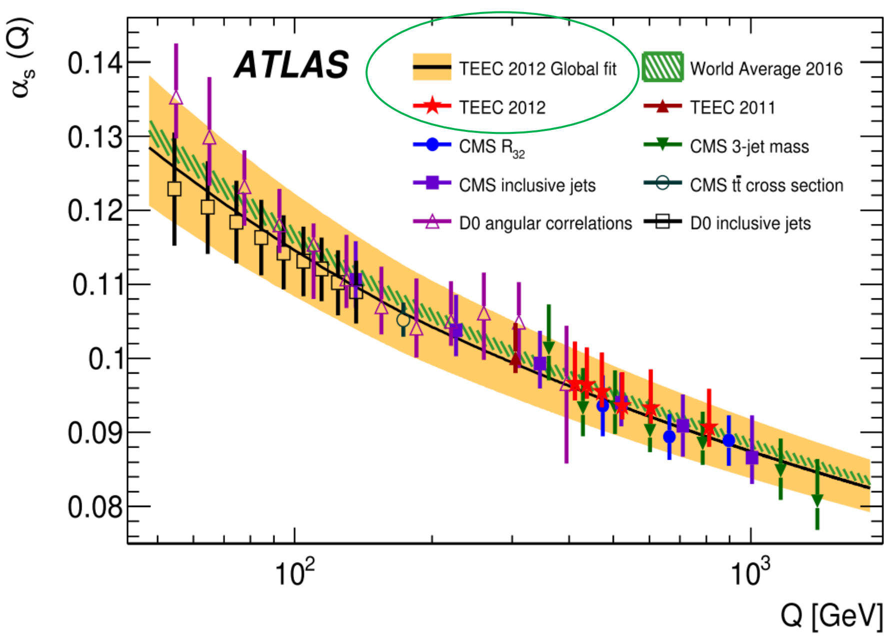


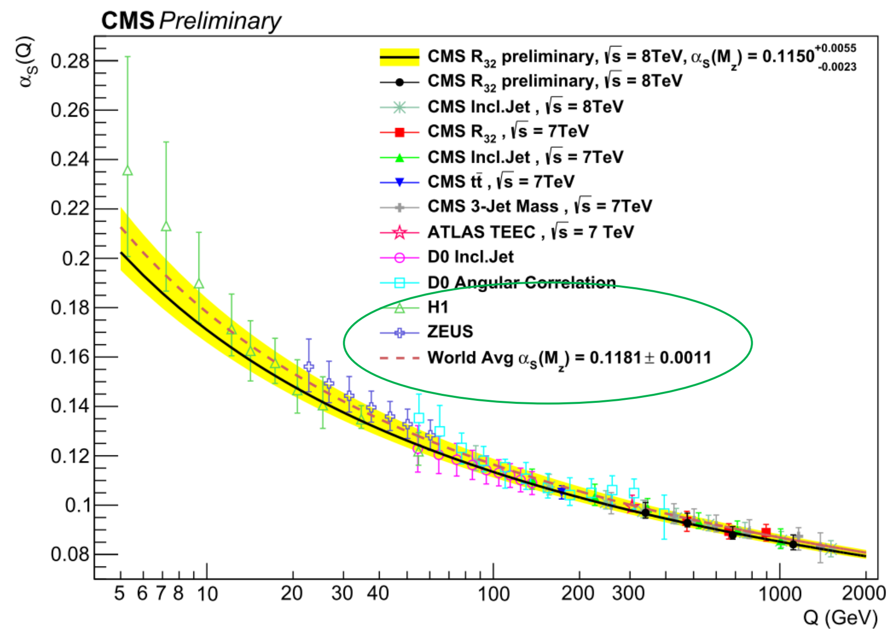


- High boosted di-jet topology:
  - High p_T access to high x
- Small experimental uncertainty:
  - Constrain PDF at high x

See from J. L. MERINO

- Estimate alphas at MZ from differential cross section measurements
- Determine alphas from a fit of theoretical predictions to data

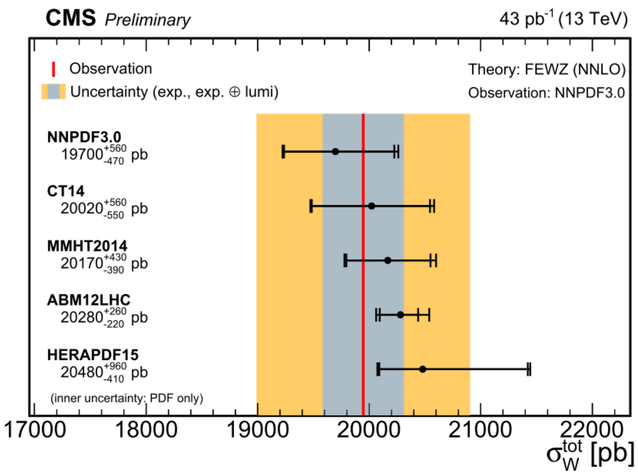


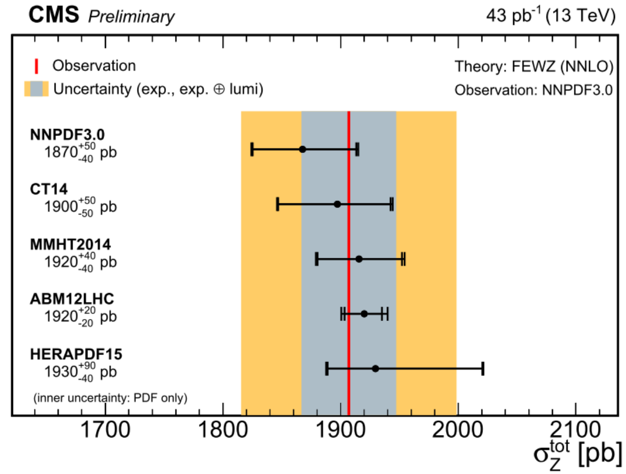


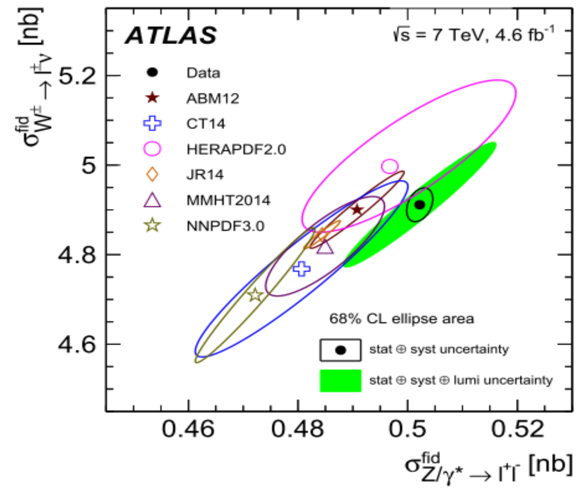
Inclusive W/Z boson

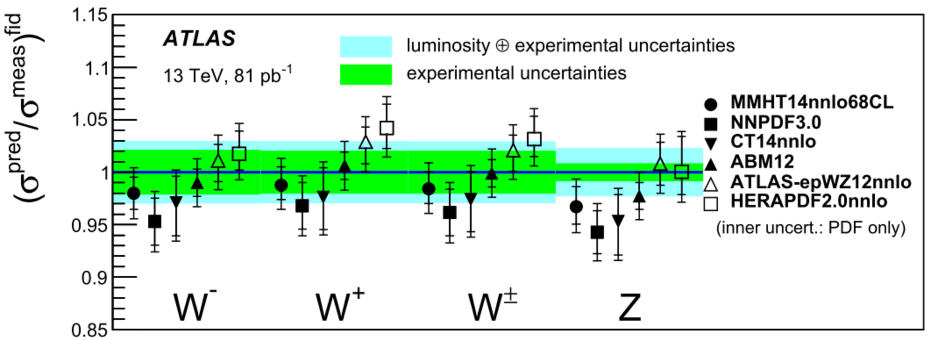
CMS-PAS-SMP-15-004 CMS-PAS-SMP-15-011

Eur. Phys. J. C 77 (2017) 367 Phys. Lett. B 759 (2016) 601

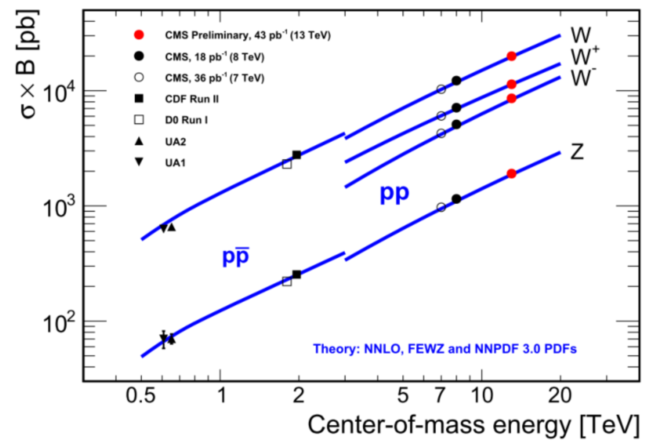


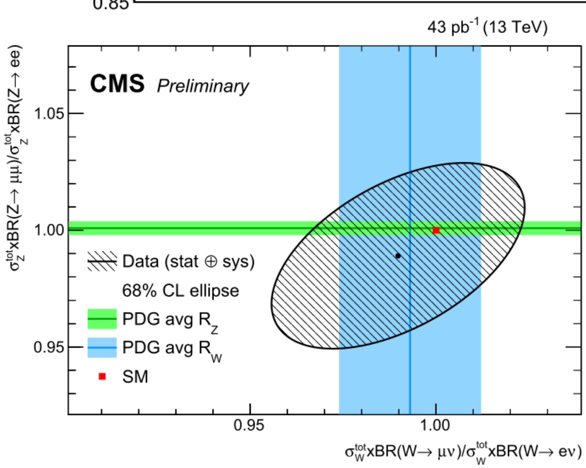


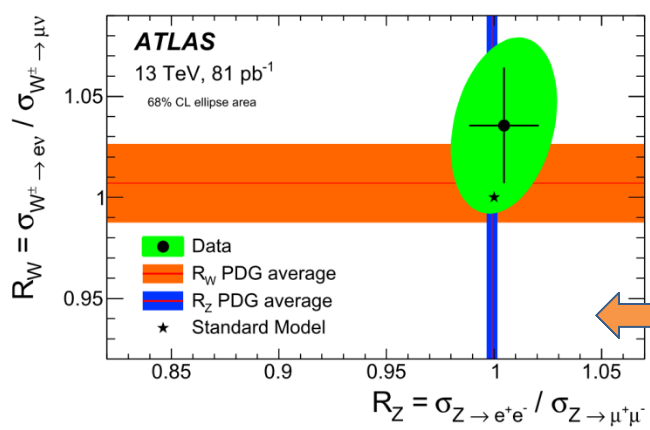




- Precision of measurements needs to be improved
- Cross section described well by NNLO predictions
- Cross section sensitive to PDF sets





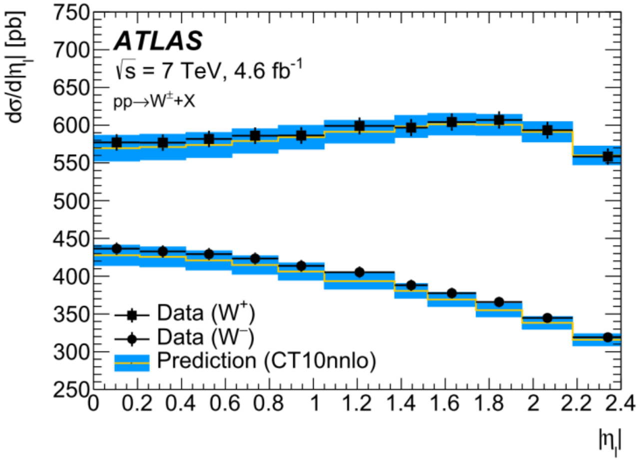


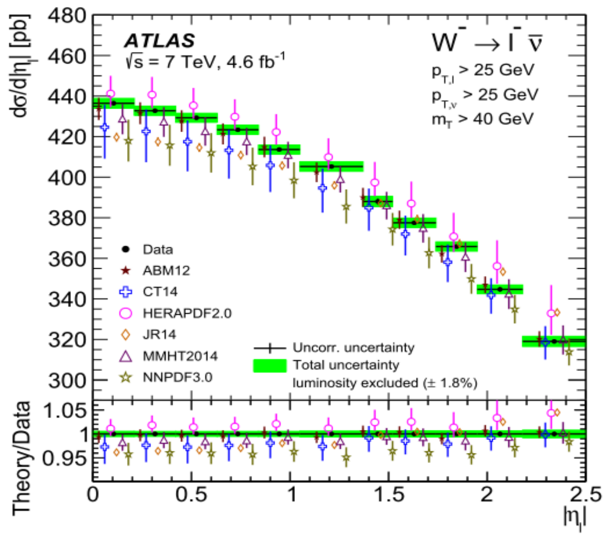
- Lepton universality validation
- Partial systematical unc. cancelled in the ratio

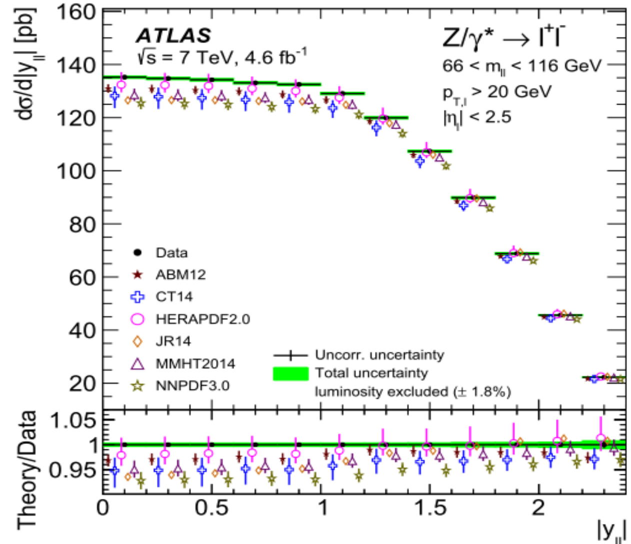
Differential cross sections @ W/Z

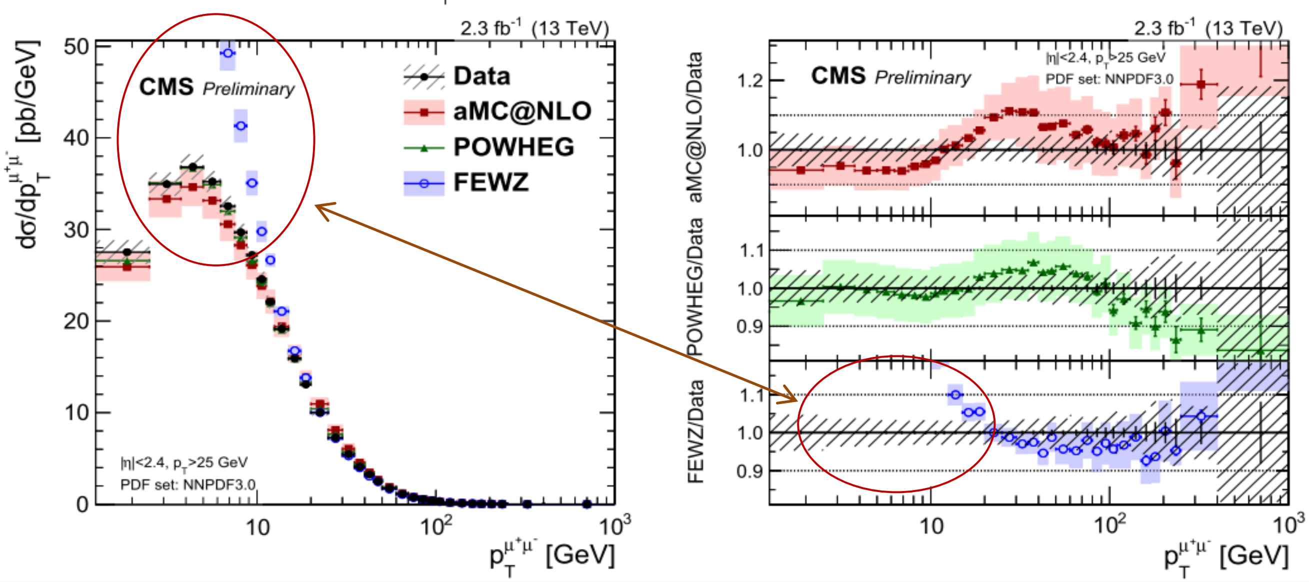
CMS-PAS-SMP-15-011
Eur. Phys. J. C 77 (2017) 367 arXiv:1701.07240

See from V. S. LANG





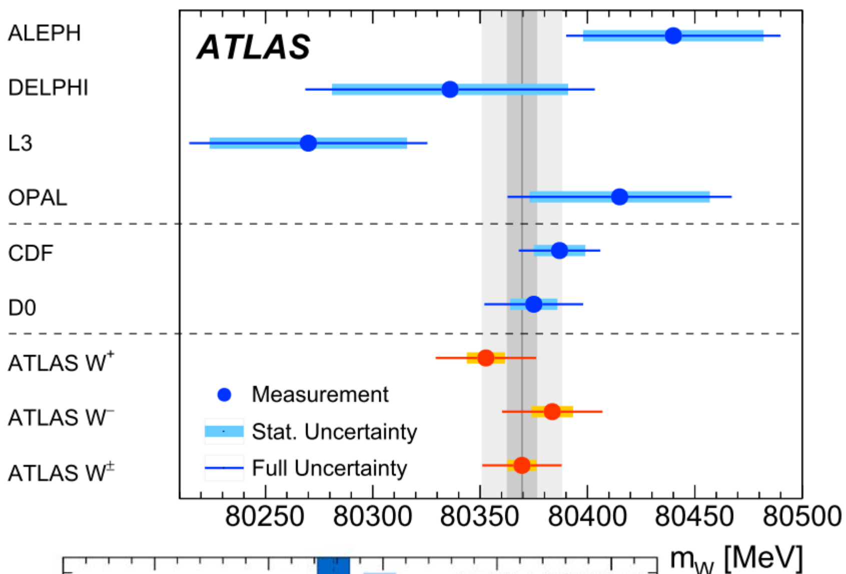


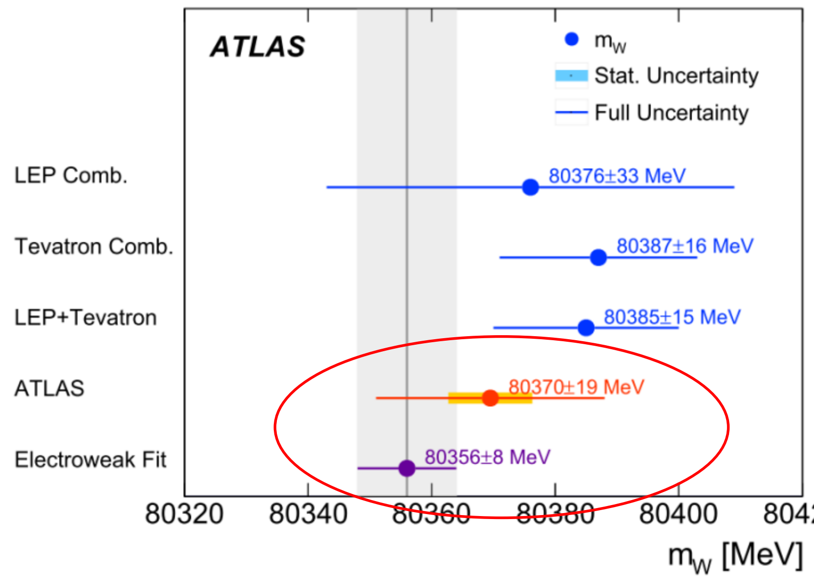


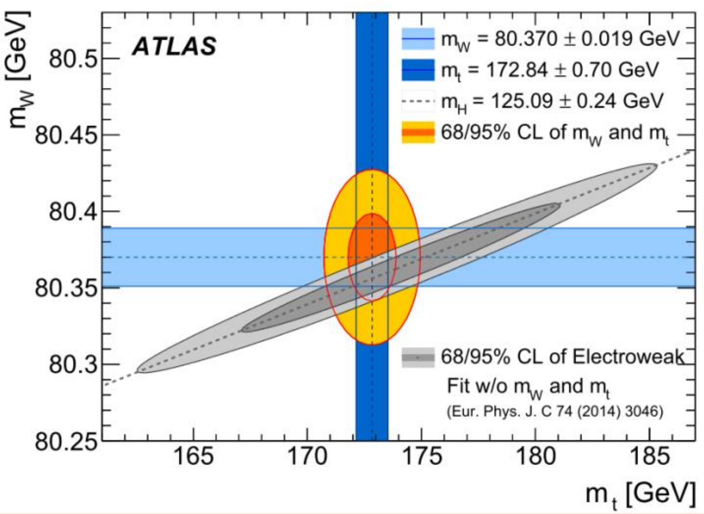
- **General agreements between measurements and predictions**
- **FEWZ fails to describe the data at low Z transverse momentum due to absence of resummation or parton shower**

W boson mass

arXiv:1701.07240







$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r)$$

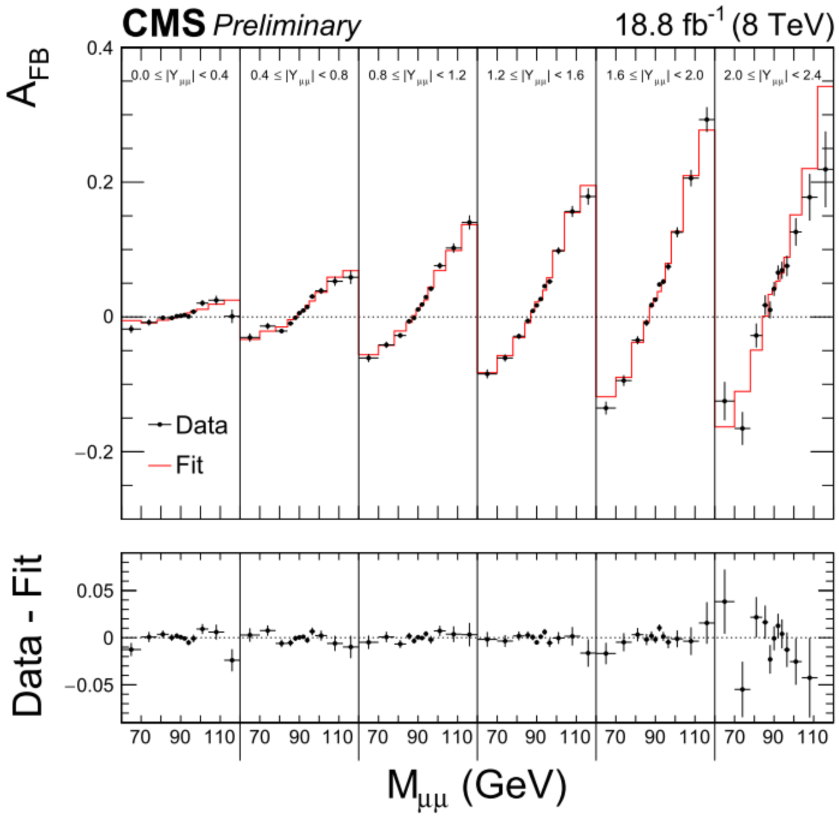
$$\begin{aligned} m_{W^+}-m_{W^-} &= -29.2 \pm 12.8\,\text{MeV(stat.)} \pm 7.0\,\text{MeV(exp. syst.)} \pm 23.9\,\text{MeV(mod. syst.)} \\ &= -29.2 \pm 28.0\,\text{MeV}, \end{aligned}$$

$$\begin{aligned} m_W &= 80370 \pm 7\,\text{(stat.)} \pm 11\,\text{(exp. syst.)} \pm 14\,\text{(mod. syst.) MeV} \\ &= 80370 \pm 19\,\text{MeV}, \end{aligned}$$

- Precision W boson mass can be used to test SM consistency
- W boson mass is determined from fits to transverse mass and to transverse momentum of charge lepton
- Modelling uncertainties dominate the overall uncertainty

Weak mixing angle

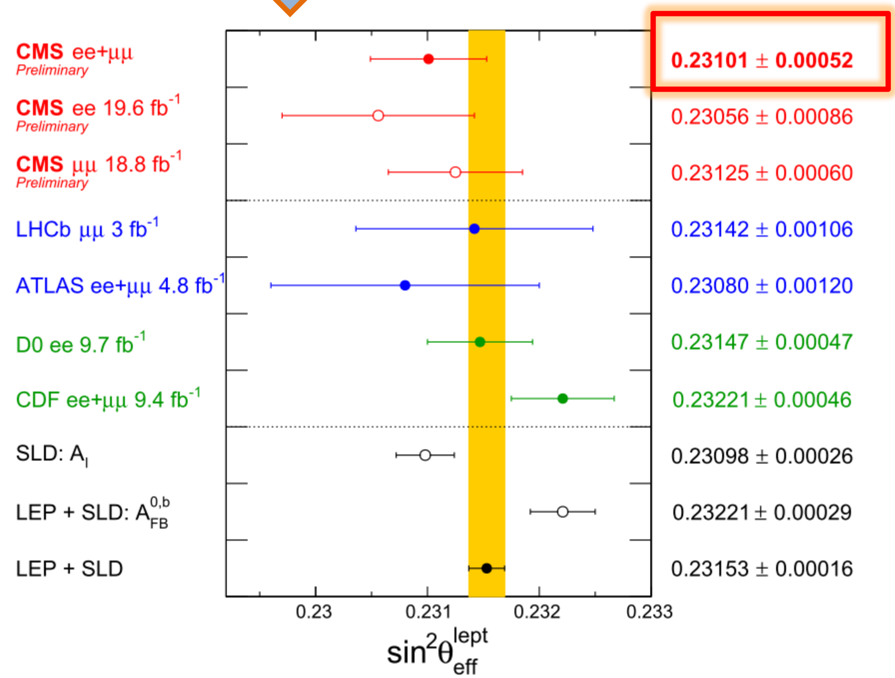
CMS-PAS-SMP-16-007



$$A_{\rm FB} = \frac{\sigma_{\rm F} - \sigma_{\rm B}}{\sigma_{\rm F} + \sigma_{\rm B}}$$

See from L. HAN

- For dilepton events, sensitive to leptonic effective weak mixing angle



$$\sin^2\theta^{\rm f}_{\rm eff} = \kappa_{\rm f}\sin^2\theta_{\rm W}$$

Determined by EWK corrections

- Extracted weak mixing angle by fits to data (the **best one from LHC**):

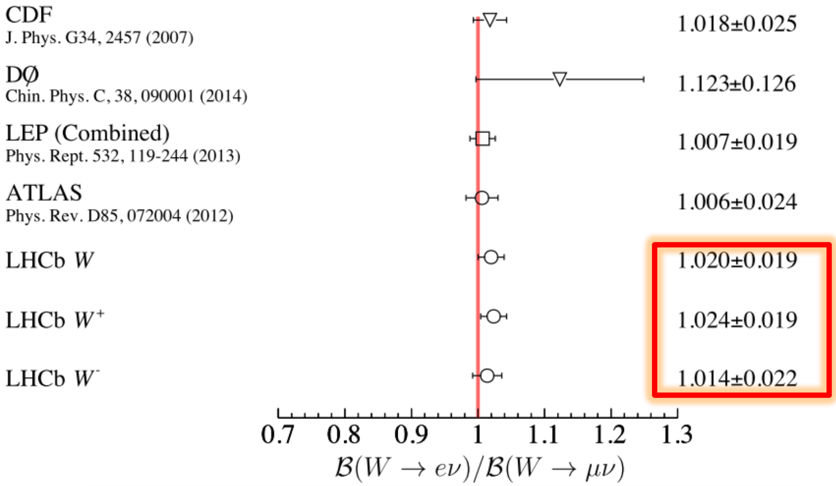
$$\sin^2\theta^{\rm lept}_{\rm eff} = 0.23101 \pm 0.00036({\rm stat}) \pm 0.00018({\rm syst}) \pm 0.00016({\rm theory}) \pm 0.00030({\rm pdf})$$

- Provide more information specially **in the context of 3σ tension between LEP and SLD**

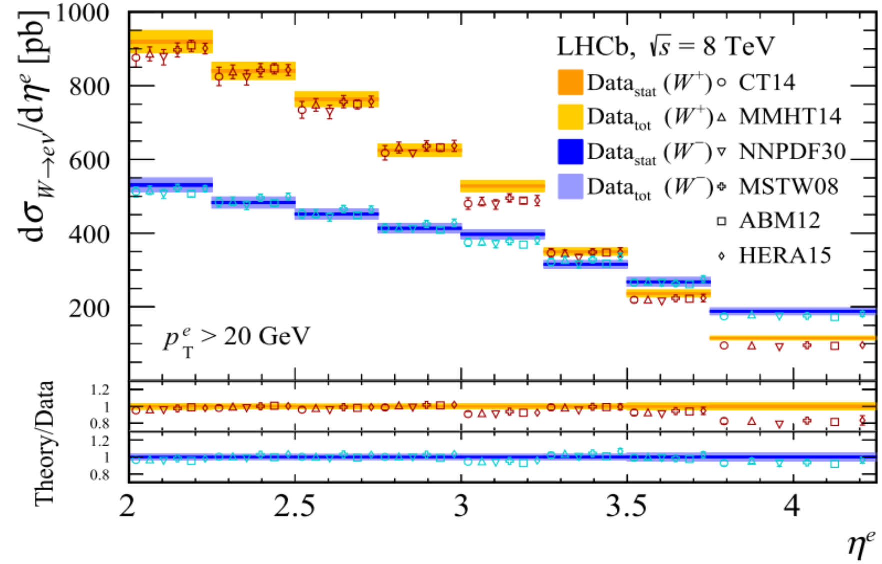
Forward W/Z boson

See from Y. HANG

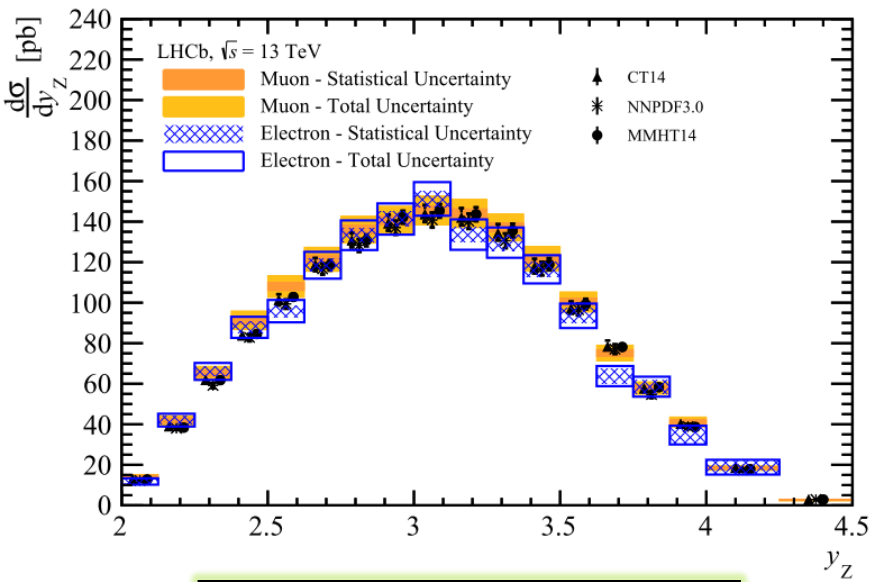
JHEP 10 (2016) 030
JHEP 09 (2016) 136



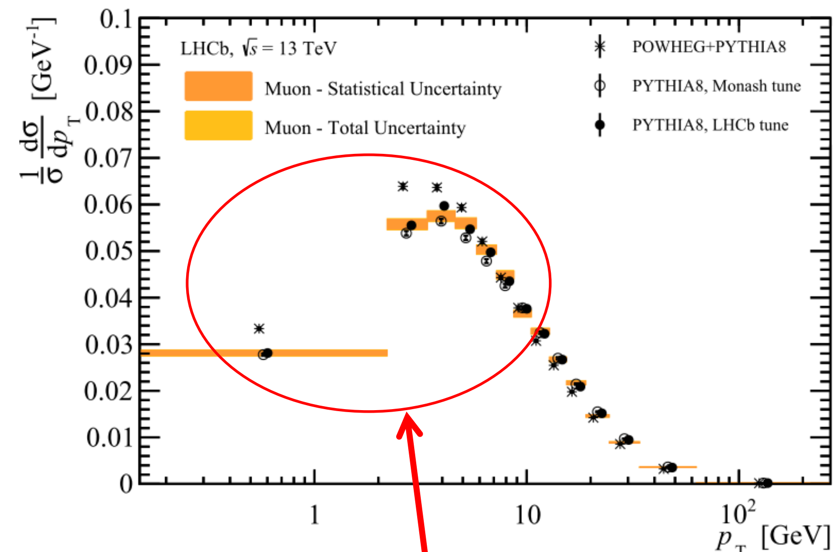
$$\sigma_{W^+\to e^+\nu_e} = 1124.4 \pm 2.1 \pm 21.5 \pm 11.2 \pm 13.0\,\text{pb}$$
$$\sigma_{W^-\to e^-\overline{\nu}_e} = 809.0 \pm 1.9 \pm 18.1 \pm 7.0 \pm 9.4\,\text{pb}$$



Good agreement with NLO/NNLO accuracy for W/Z xsec



$$\sigma_{\rm Z}^{\ell\ell} = 194.3 \pm 0.9 \pm 3.3 \pm 7.6\,\text{pb}$$

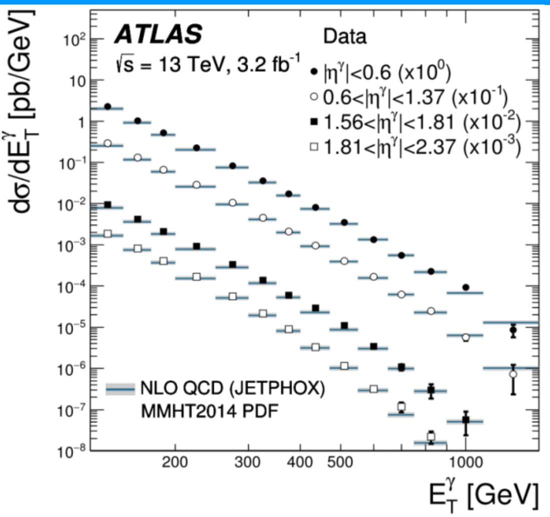


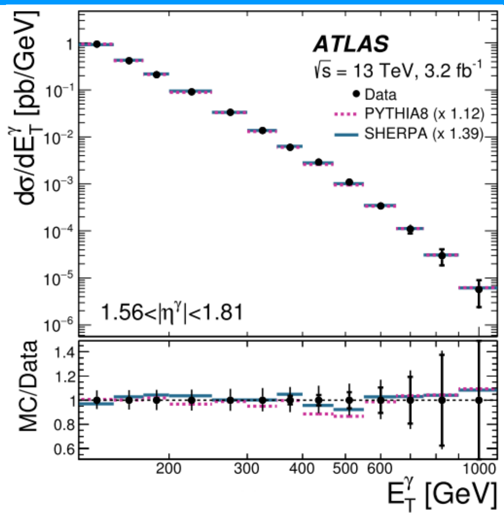
Significant pythia tuning for LO pythia

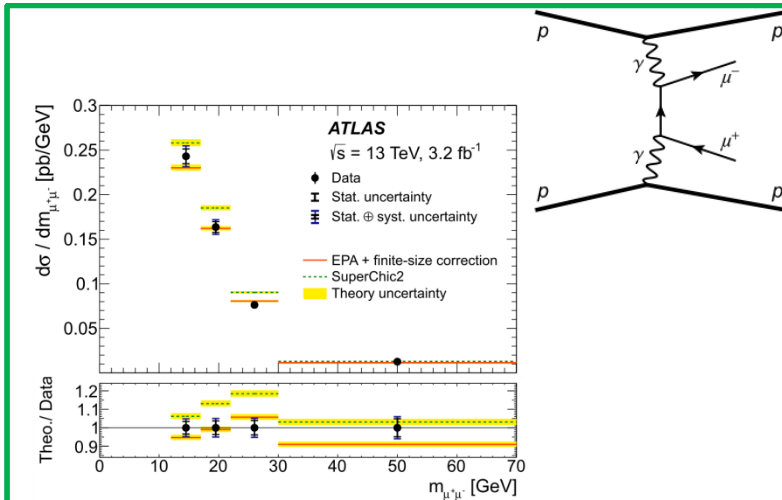
Inclusive Photon & γ pair

Phys. Lett. B 770 (2017) 473

arXiv:1708.04053   Phys. Rev. D 95 112005 (2017)

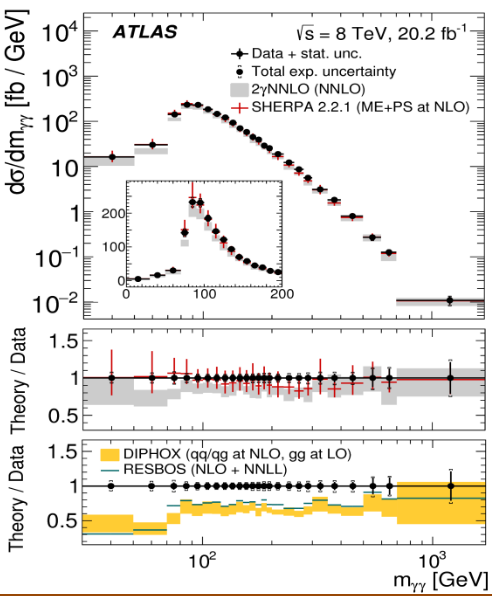


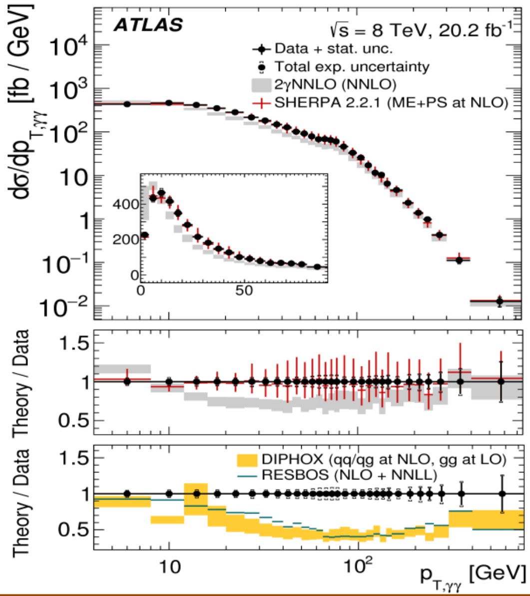


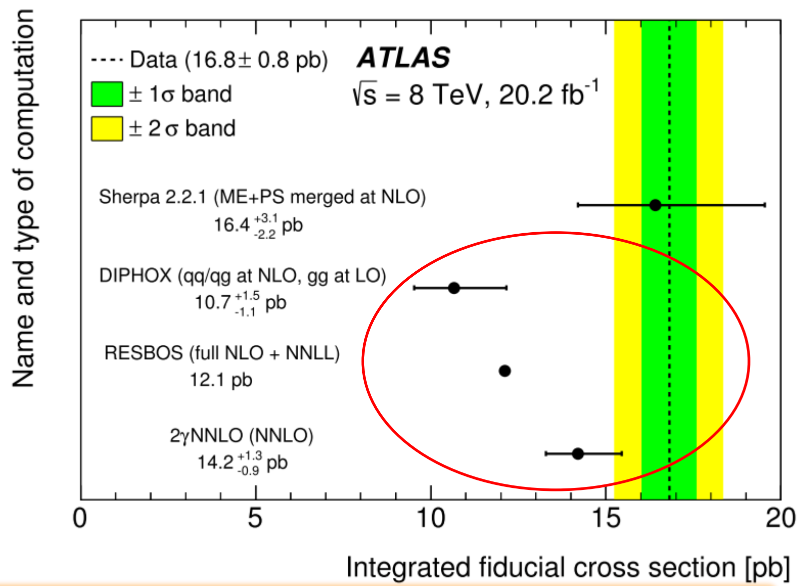


$$\sigma^{\text{excl. fid.}}_{\gamma\gamma\to\mu^+\mu^-} = 3.12 \pm 0.07\,(\text{stat.}) \pm 0.10\,(\text{syst.})\text{ pb}$$

◆ **Good agreement with inclusive photon measurement**



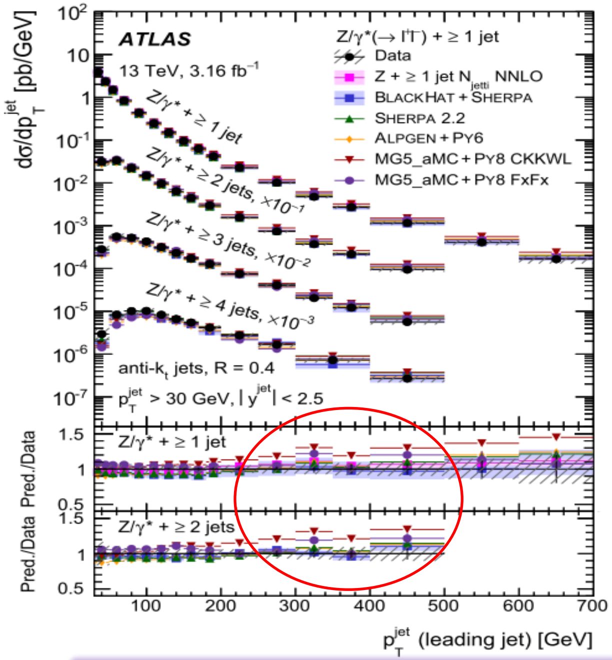


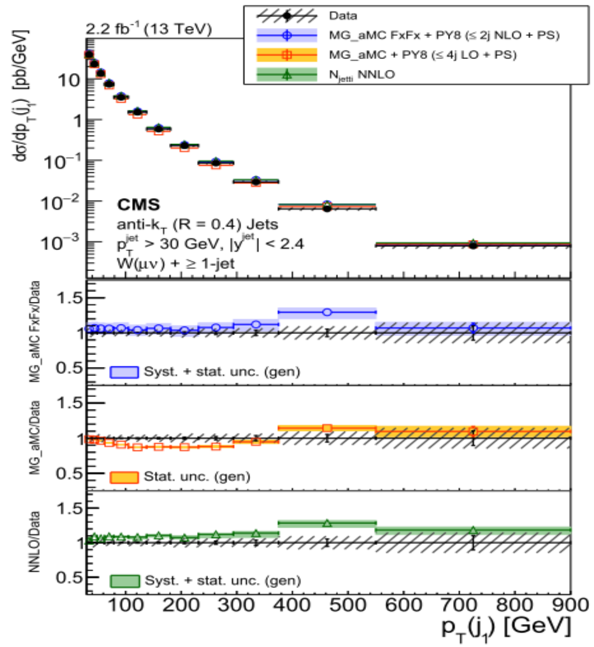


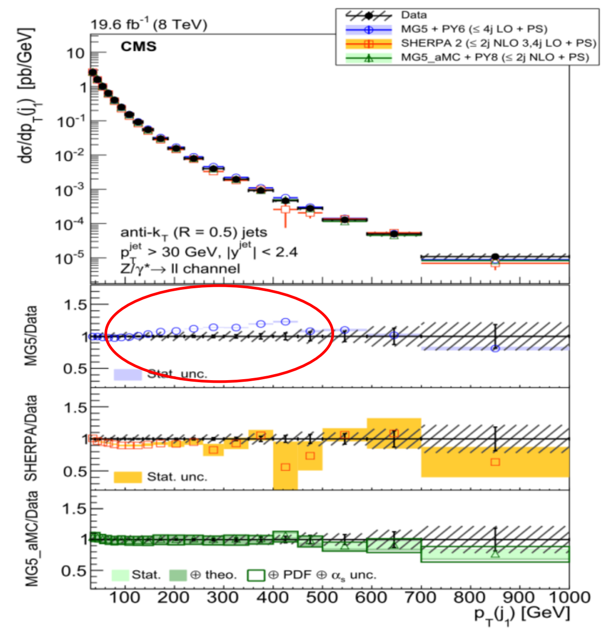
◆ The effects of infrared emissions are reproduced by the inclusion of soft gluon resummation at NNLL accuracy, however the prediction (RESBOS) cannot describe the data in most parts of the phase space

W/Z/γ + jets production

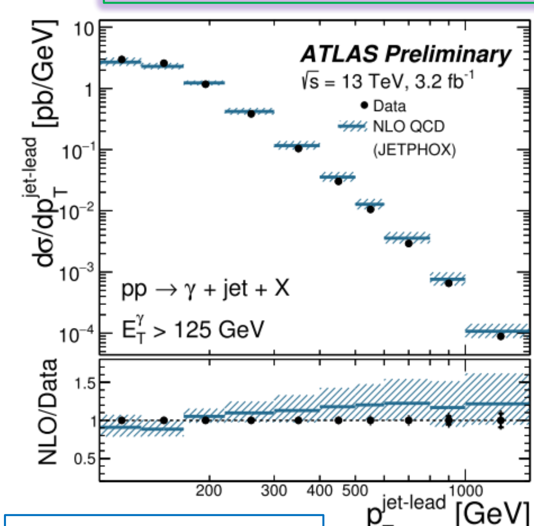
ATLAS-CONF-2017-059 Eur. Phys. J. C77 (2017) 361
arXiv:1707.05979 JHEP 04 (2017) 022

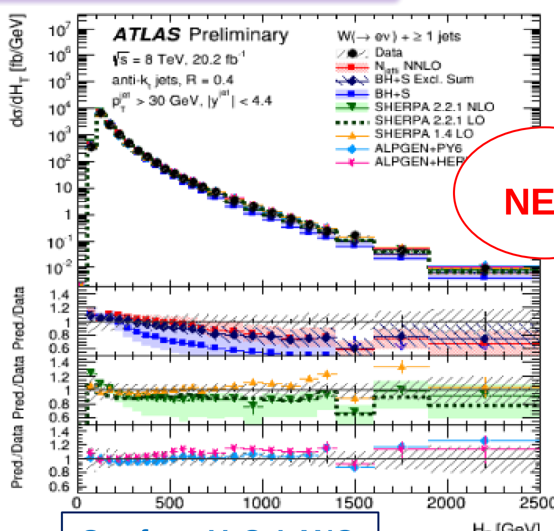


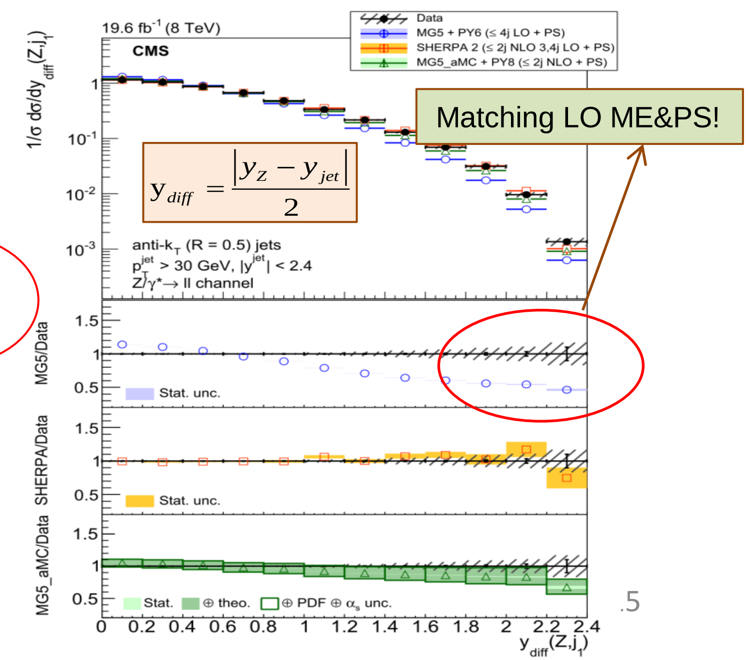




◆ Good agreement with NLO/NNLO predictions







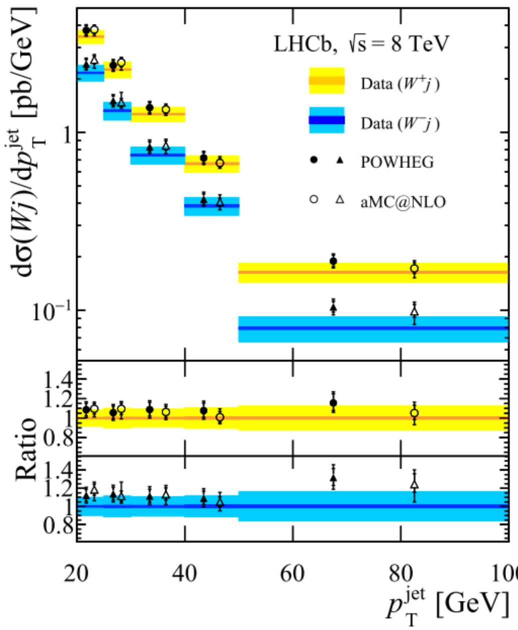
See from E. TASSI

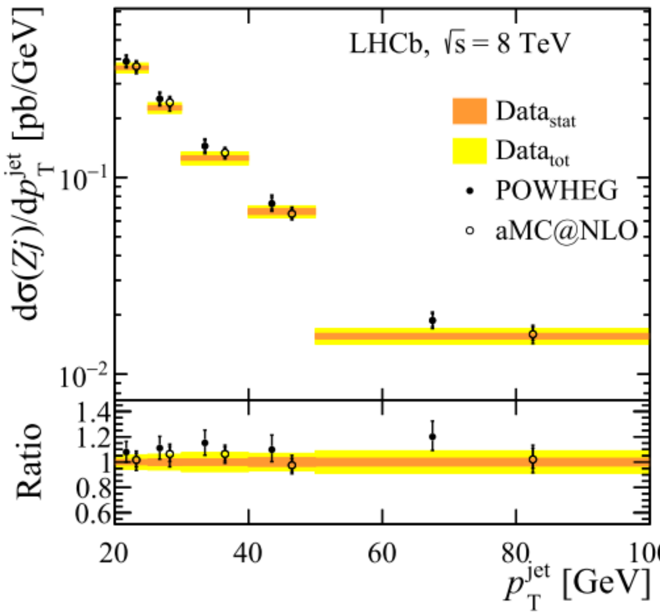
See from V. S. LANG

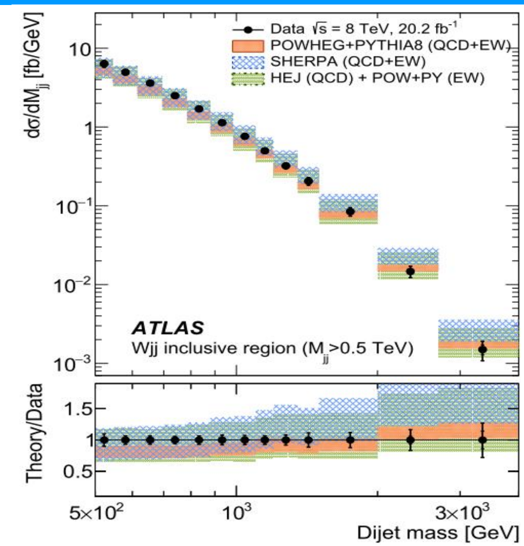
Forward W/Z + jets & VBF

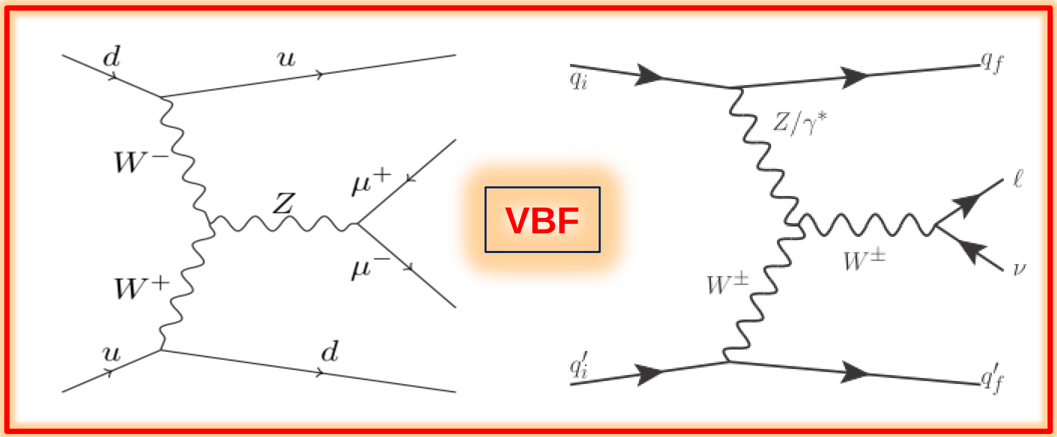
Eur. Phys. J. C 77 (2017) 474

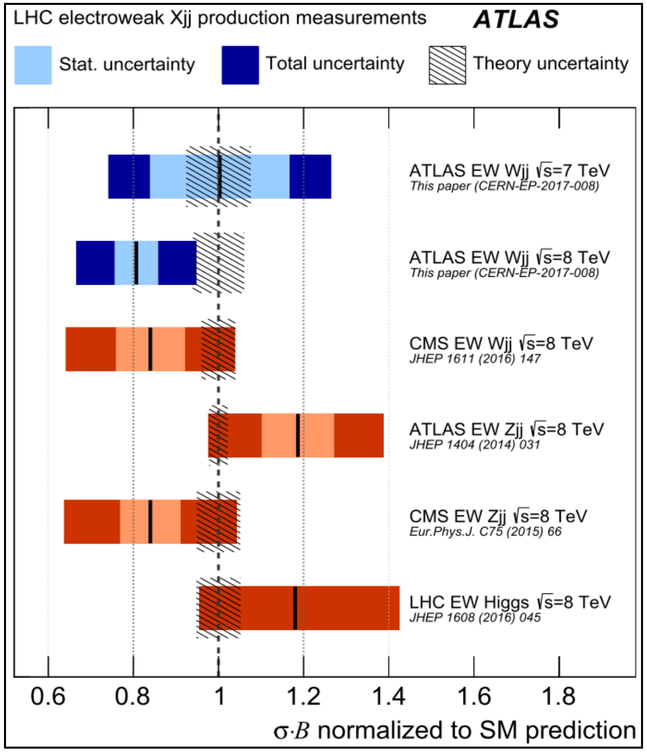
CMS-PAS-SMP-16-018 JHEP 1605 (2016) 131











EWK Wjj xsec:

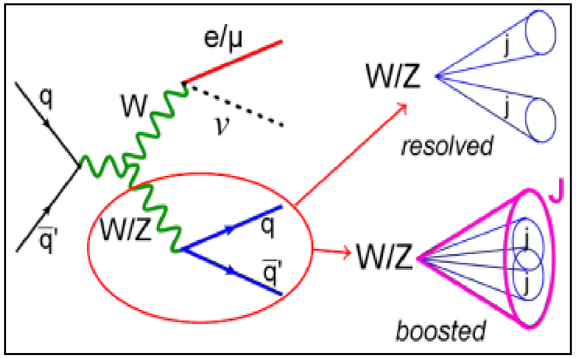
$$\sigma^{\rm fid}_{{\rm EW}\ W(\to\ell\nu)jj}\ (7\ {\rm TeV}) = 144 \pm 23\ ({\rm stat}) \pm 23\ ({\rm exp}) \pm 13\ ({\rm th})\ {\rm fb}$$

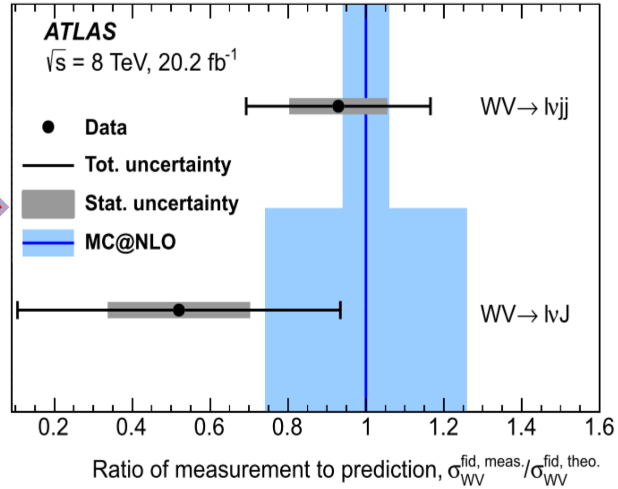
$$\sigma^{\rm fid}_{{\rm EW}\ W(\to\ell\nu)jj}\ (8\ {\rm TeV}) = 159 \pm 10\ ({\rm stat}) \pm 17\ ({\rm exp}) \pm 20\ ({\rm th})\ {\rm fb}$$

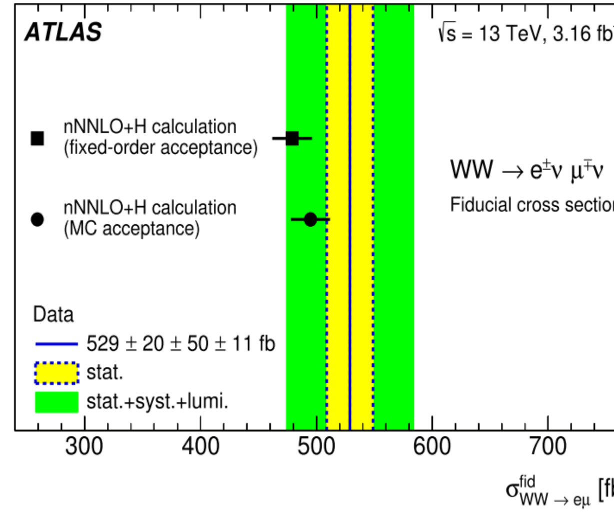
EWK Zjj xsec: $\sigma({\rm EW}\ \ell\ell{\rm jj}) = 552 \pm 19\,({\rm stat}) \pm 55\,({\rm syst})\,{\rm fb} = 552 \pm 58\,({\rm total})\,{\rm fb}$

WW/WZ production & VBS

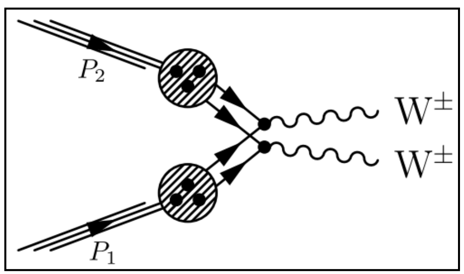
CMS-PAS-FSQ-16-009 arXiv:1706.01702
CMS-PAS-SMP-17-004 arXiv:1702.04519





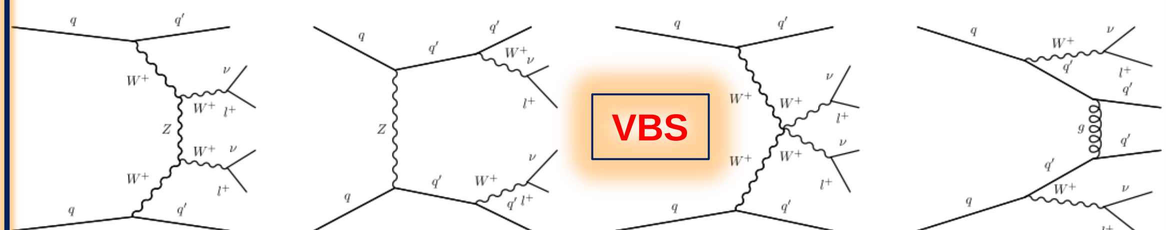


See from C. GENG

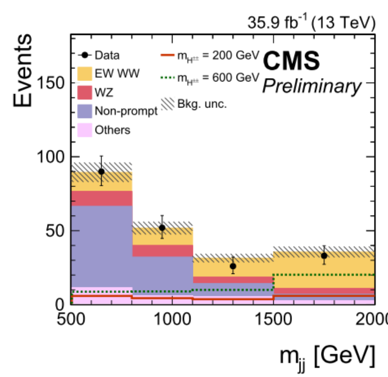


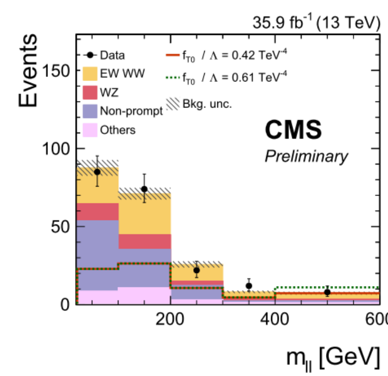
CMS

	expected	observed
$\sigma^{\text{pythia}}_{\text{DPSWW}}$	1.64 pb	$1.09^{+0.50}_{-0.49}$ pb
$\sigma^{\text{factorized}}_{\text{DPSWW}}$	0.87 pb	
significance for $\sigma^{\text{pythia}}_{\text{DPSWW}}$	3.27 σ	2.23 σ
significance for $\sigma^{\text{factorized}}_{\text{DPSWW}}$	1.81 σ	
UL in the absence of signal	< 0.97 pb	< 1.94 pb



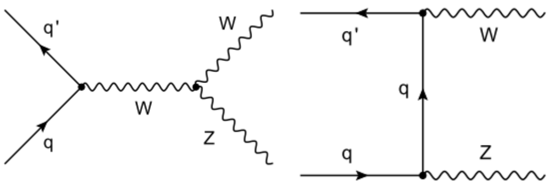
Observed 5.5σ deviation for same sign WW production!

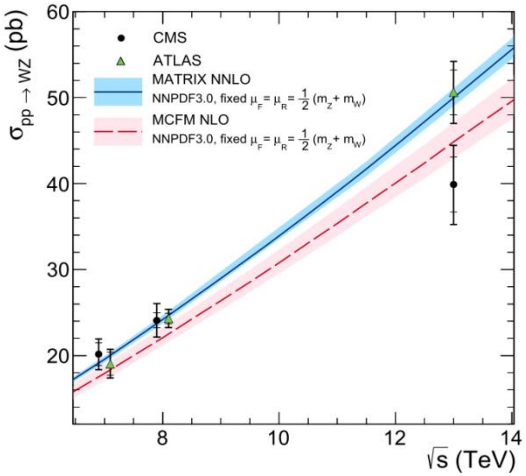


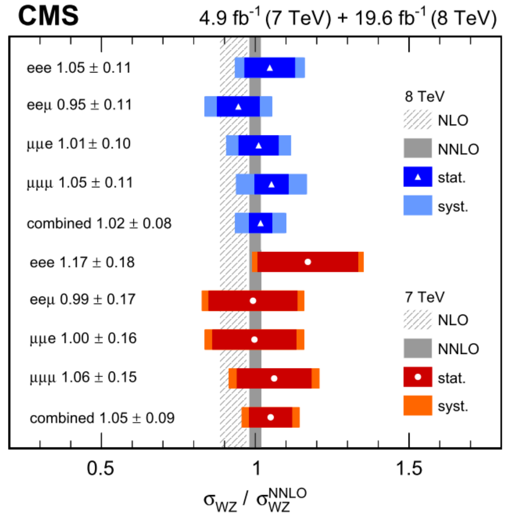


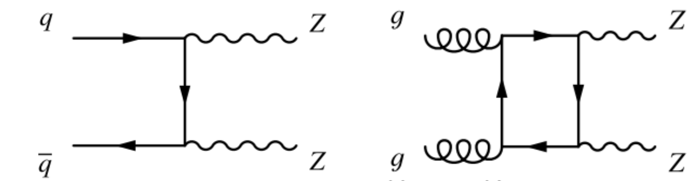
WZ/ZZ

CMS-PAS-SMP-16-017 ATLAS-CONF-2017-031 Eur. Phys. J. C 77 (2017) 236
Phys. Lett. B 763 (2016) 280 Phys. Lett. B 766 (2017) 268



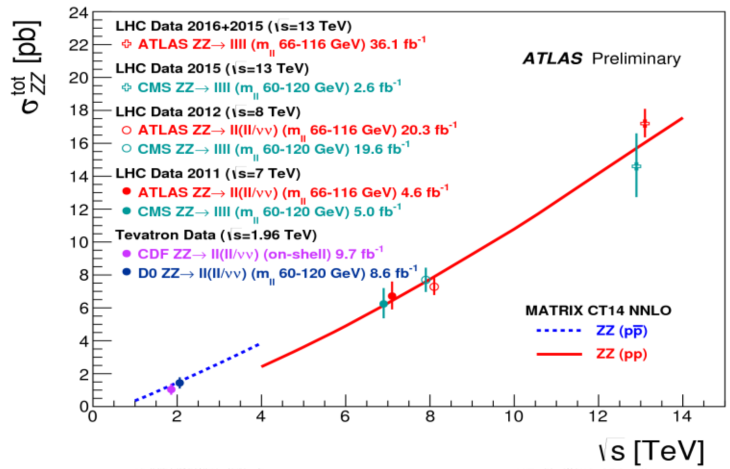


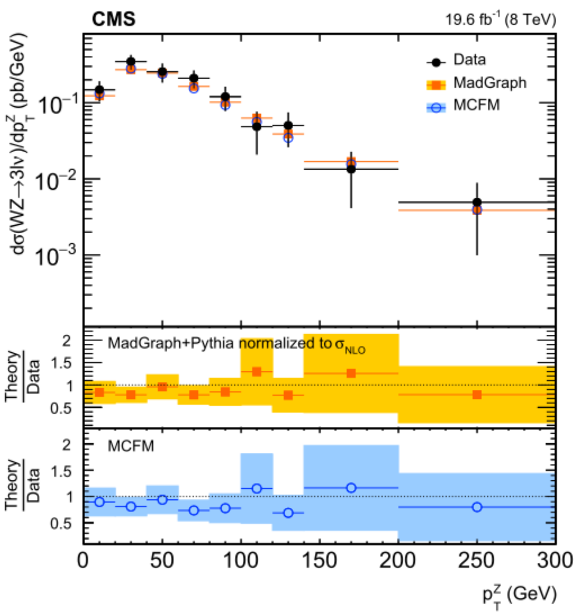


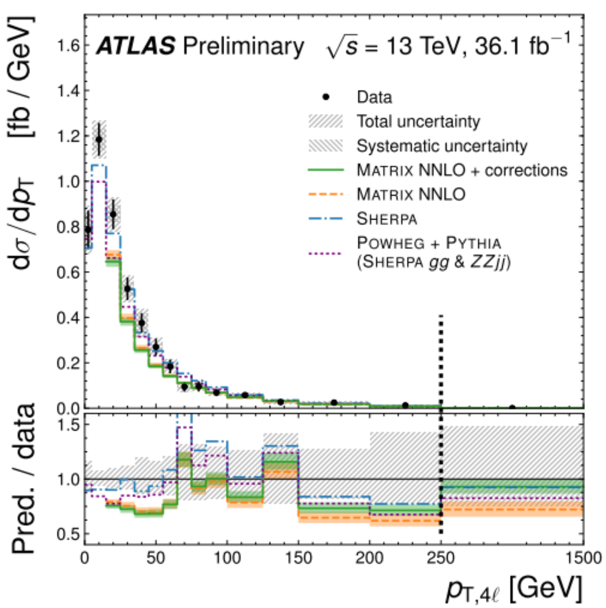


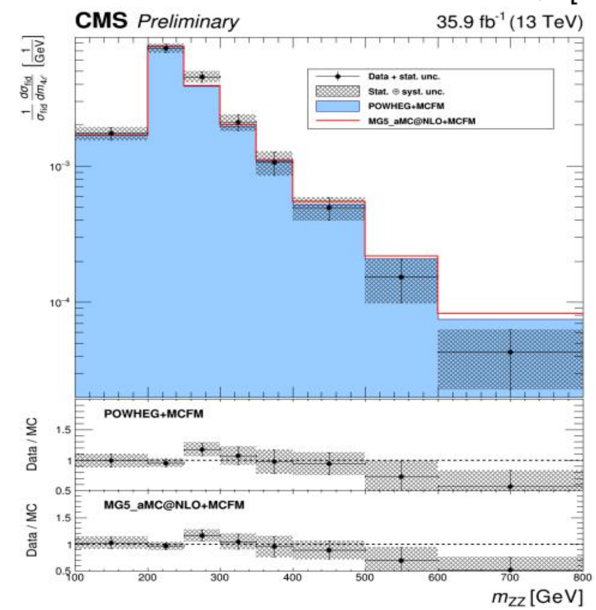
$$\mathcal{B}(Z \to \ell^+\ell^-\ell'^+\ell'^-) = 4.9^{+0.8}_{-0.7}\,(\text{stat})^{+0.3}_{-0.2}\,(\text{syst})^{+0.2}_{-0.1}\,(\text{theo}) \pm 0.1\,(\text{lumi}) \times 10^{-6}$$

◆ **Good agreement with NNLO/NLO prediction!**





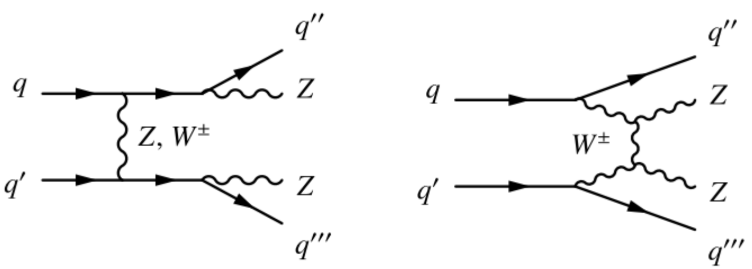


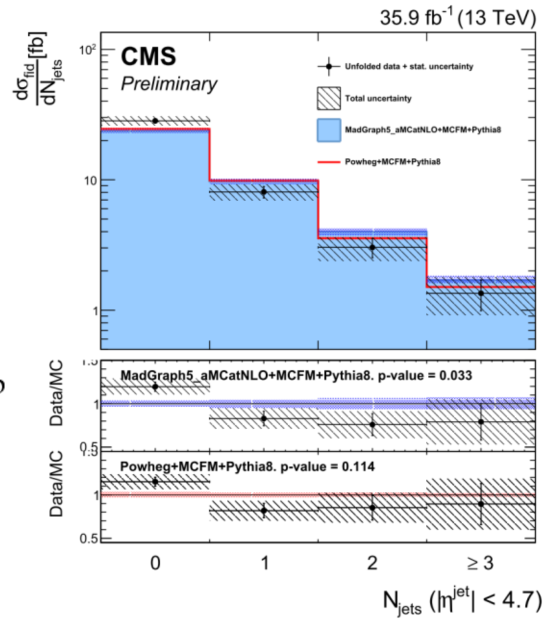


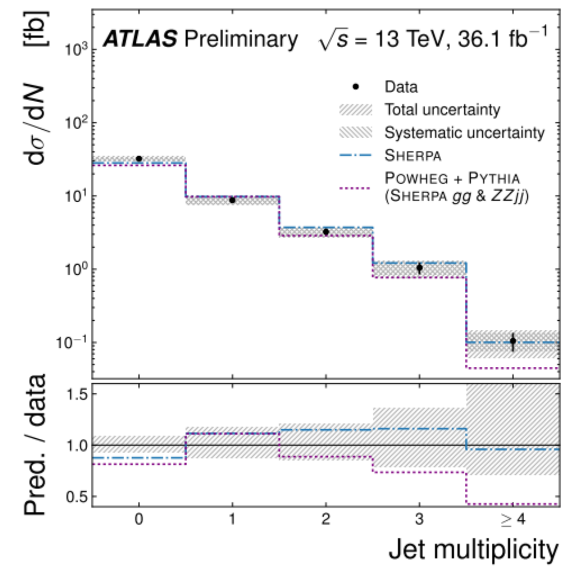
ZZ+jets & VBS

ATLAS-CONF-2017-031

arXiv:1708.02812 CMS-PAS-SMP-16-019

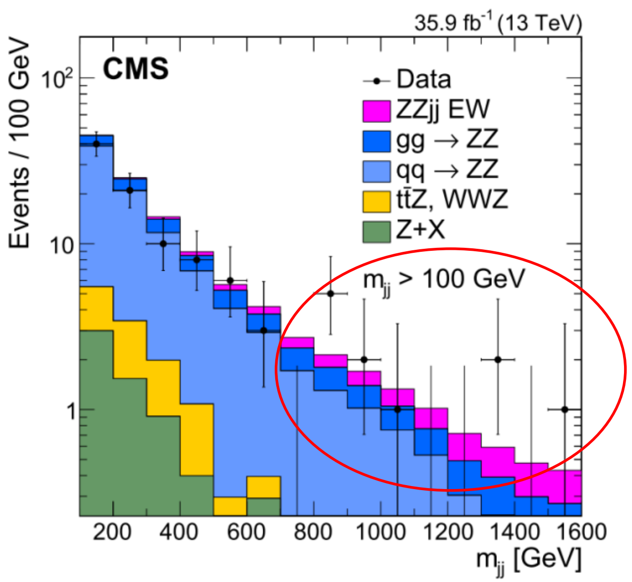


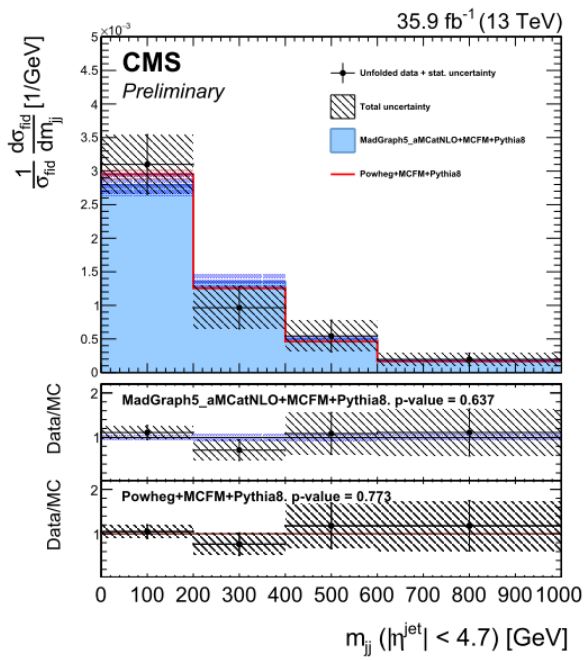


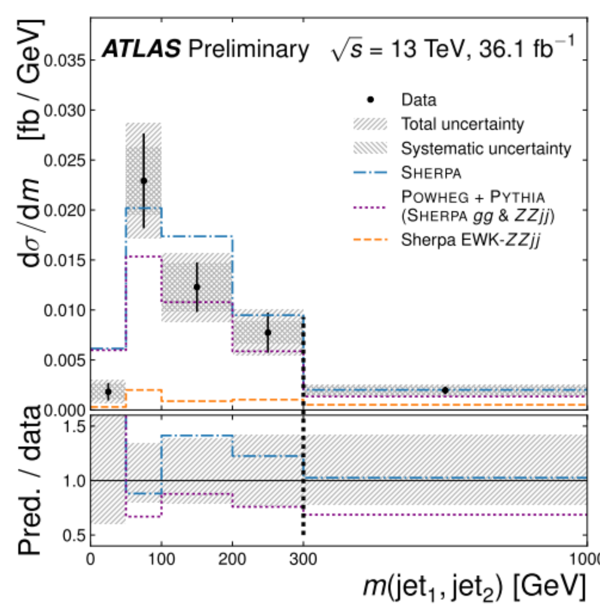


$$\sigma_{EW}(pp \to ZZjj \to \ell\ell\ell'\ell'jj) = 0.40^{+0.21}_{-0.16}\,(\text{stat})\,^{+0.13}_{-0.09}\,(\text{syst})\ \text{fb}$$

$$\mu = 1.39^{+0.72}_{-0.57}\,(\text{stat})\,^{+0.46}_{-0.31}\,(\text{syst}) = 1.39^{+0.86}_{-0.65}$$





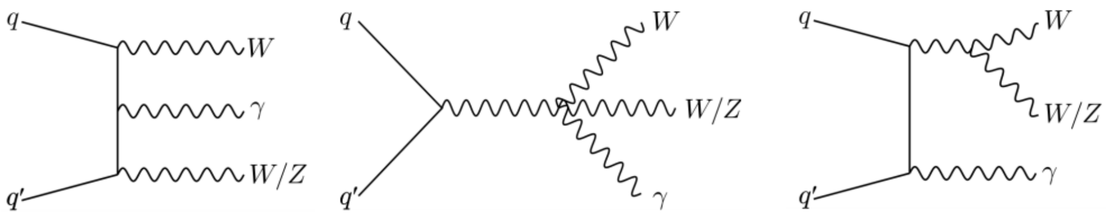


EW signal significance: 2.7 σ

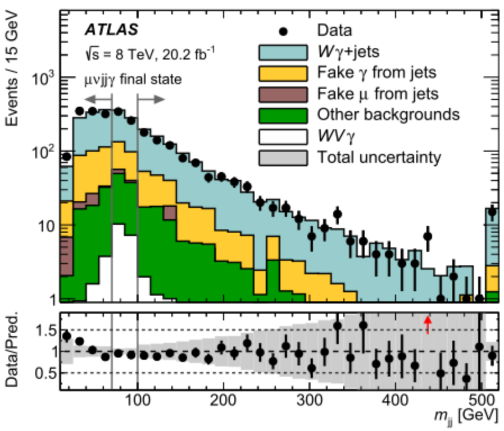
WVγ / Vγγ

arXiv:1707.05597

arXiv:1704.00366

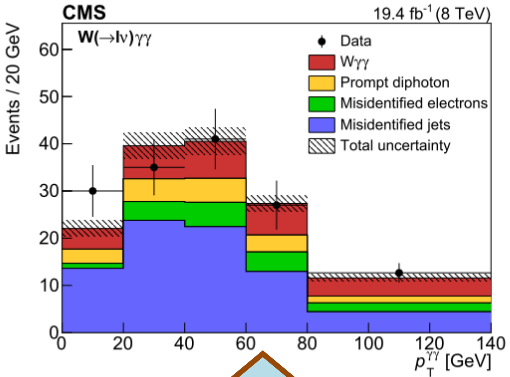


$$\sigma_{\text{fid}}^{e\nu\mu\nu\gamma} = 1.5 \pm 0.9(\text{stat.}) \pm 0.5(\text{syst.})\ \text{fb}$$



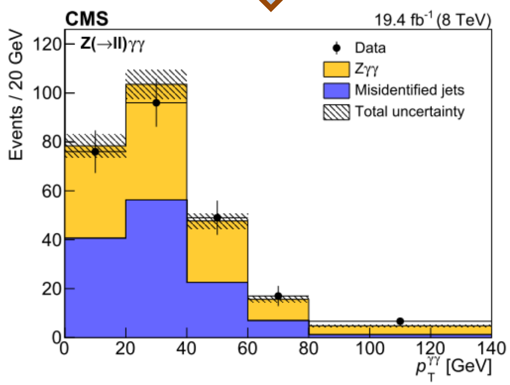
Upper limits on the cross sections determined at 95% CL using $\mathrm{CL_s}$ approach

		Observed limit [fb]	Expected limit [fb]	σ_{theo} [fb]
Fully leptonic	$e\nu\mu\nu\gamma$	3.7	$2.1^{+0.9}_{-0.6}$	2.0
Semileptonic	$e\nu jj\gamma$	10	16^{+6}_{-4}	2.4
	$\mu\nu jj\gamma$	8	10^{+4}_{-3}	2.2
	$\ell\nu jj\gamma$	6	$8.4^{+3.4}_{-2.4}$	2.3



Signal significance: 2.6σ

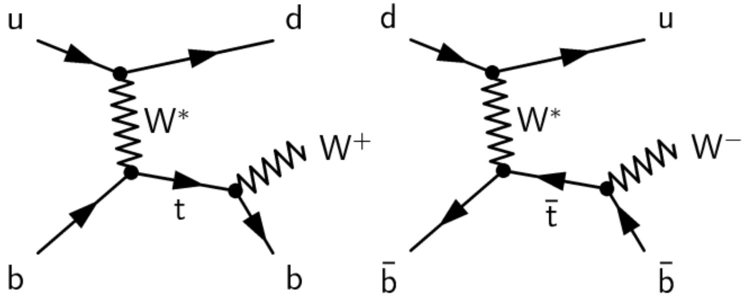
Signal significance: 5.9σ

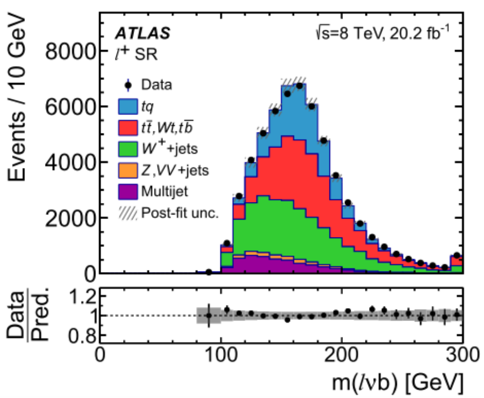


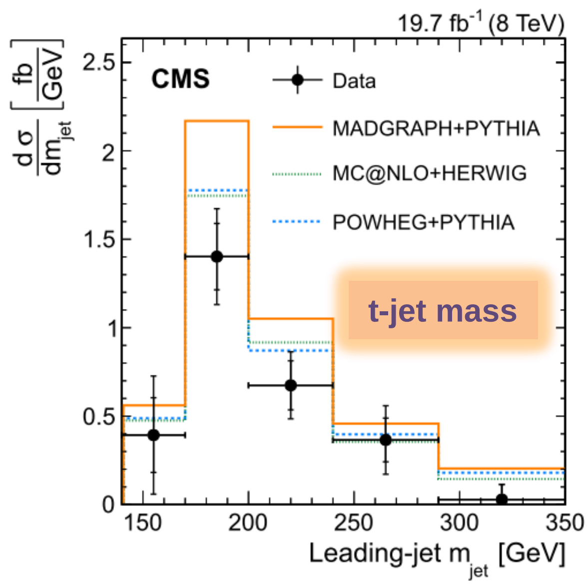
Channel	Measured fiducial cross section
$W\gamma\gamma \to e^{\pm}\nu\gamma\gamma$	$4.2 \pm 2.0\,(\text{stat}) \pm 1.6\,(\text{syst}) \pm 0.1\,(\text{lumi})$ fb
$W\gamma\gamma \to \mu^{\pm}\nu\gamma\gamma$	$6.0 \pm 1.8\,(\text{stat}) \pm 2.3\,(\text{syst}) \pm 0.2\,(\text{lumi})$ fb
$W\gamma\gamma \to \ell^{\pm}\nu\gamma\gamma$	$4.9 \pm 1.4\,(\text{stat}) \pm 1.6\,(\text{syst}) \pm 0.1\,(\text{lumi})$ fb
$Z\gamma\gamma \to e^{+}e^{-}\gamma\gamma$	$12.5 \pm 2.1\,(\text{stat}) \pm 2.1\,(\text{syst}) \pm 0.3\,(\text{lumi})$ fb
$Z\gamma\gamma \to \mu^{+}\mu^{-}\gamma\gamma$	$12.8 \pm 1.8\,(\text{stat}) \pm 1.7\,(\text{syst}) \pm 0.3\,(\text{lumi})$ fb
$Z\gamma\gamma \to \ell^{+}\ell^{-}\gamma\gamma$	$12.7 \pm 1.4\,(\text{stat}) \pm 1.8\,(\text{syst}) \pm 0.3\,(\text{lumi})$ fb
Channel	**Prediction**
$W\gamma\gamma \to \ell^{\pm}\nu\gamma\gamma$	4.8 ± 0.5 fb
$Z\gamma\gamma \to \ell^{+}\ell^{-}\gamma\gamma$	13.0 ± 1.5 fb

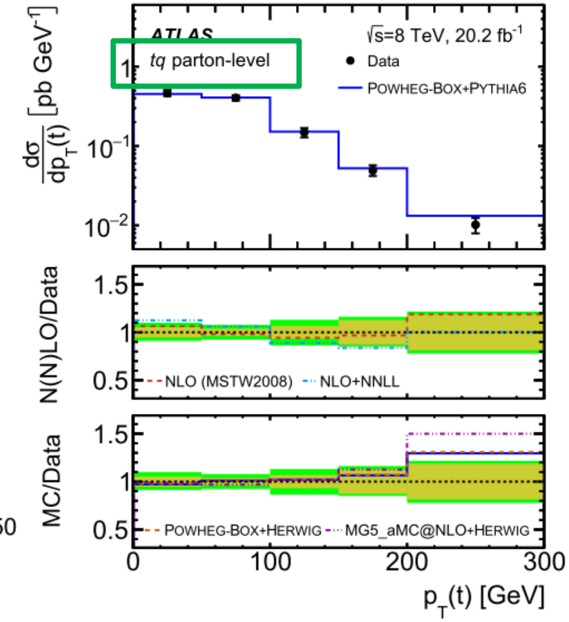
Top quark precisions

Eur. Phys. J. C 77 (2017) 467
CMS-PAS-TOP-16-018 Eur. Phys. J. C 77 (2017) 531

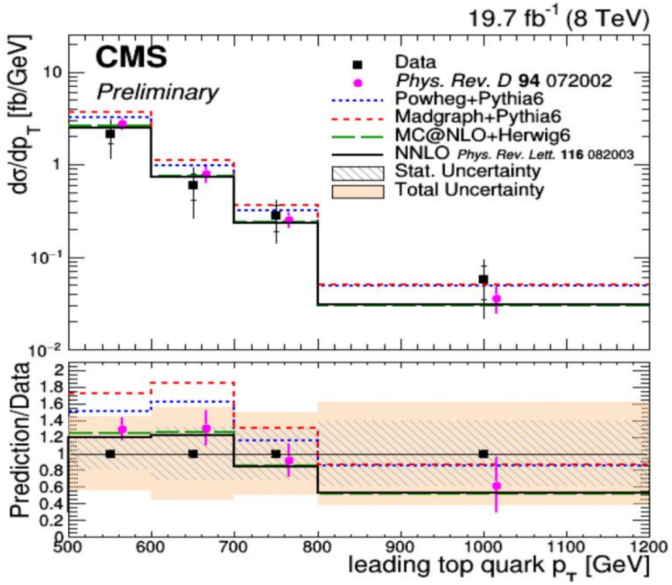


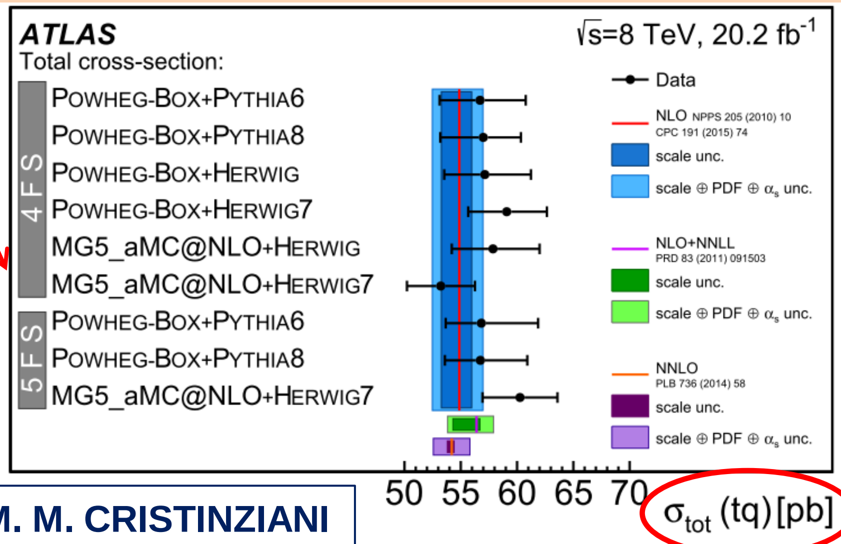






4FS: Massive heavy flavor quarks generated by gluon split
5FS: Massless heavy flavor quarks generated in initial protons

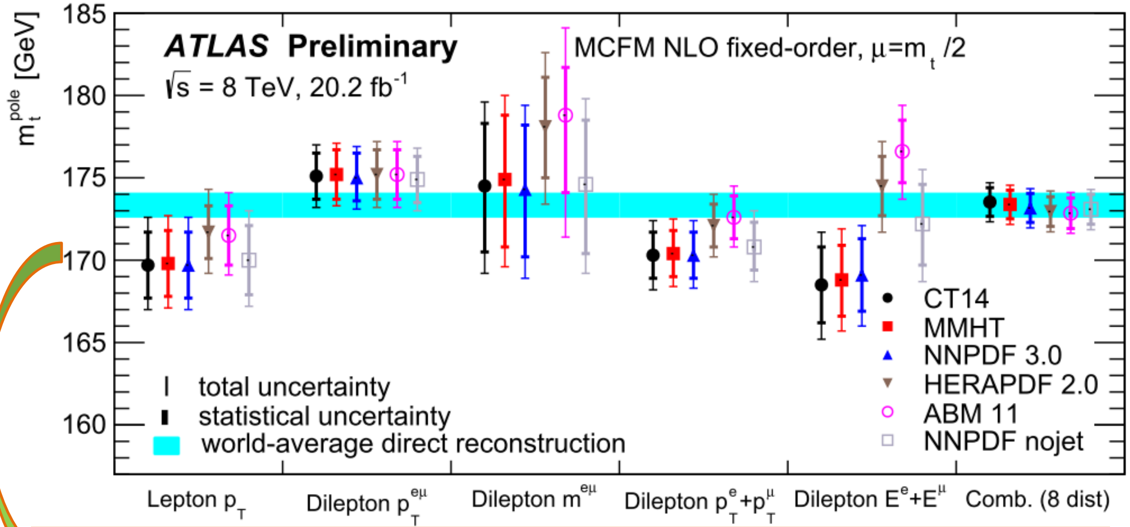


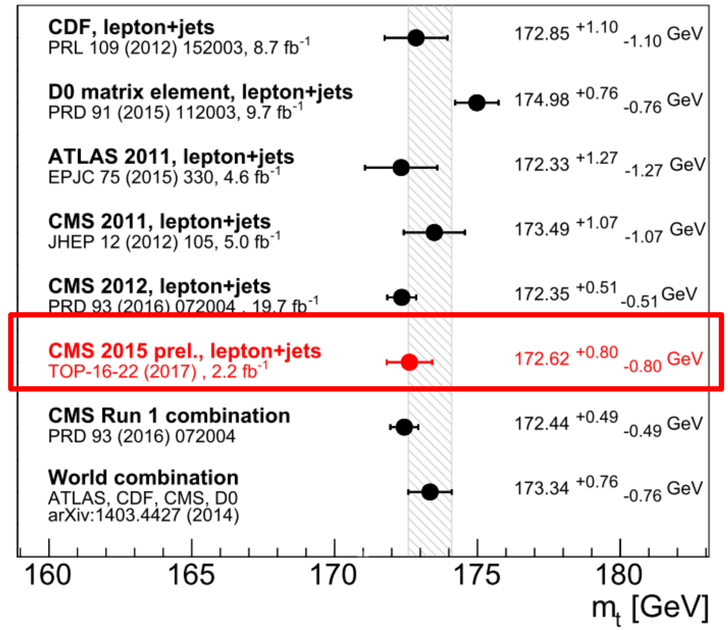


See from M. M. CRISTINZIANI

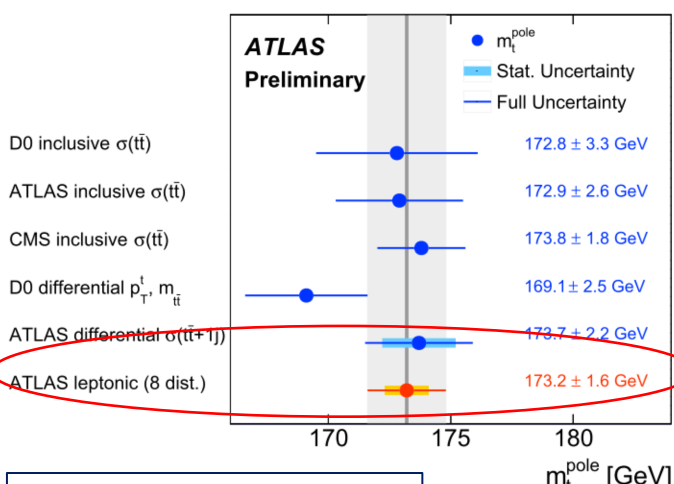
Top mass & width

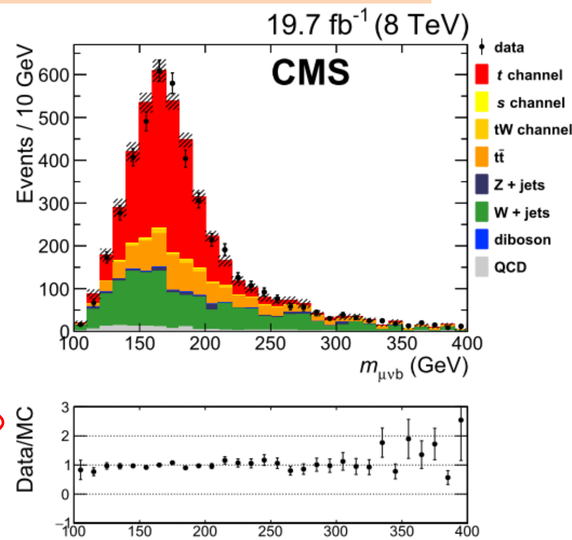
CMS-PAS-TOP-16-022 ATLAS-CONF-2017-044
ATLAS-CONF-2017-056 EPJC 77 (2017) 354

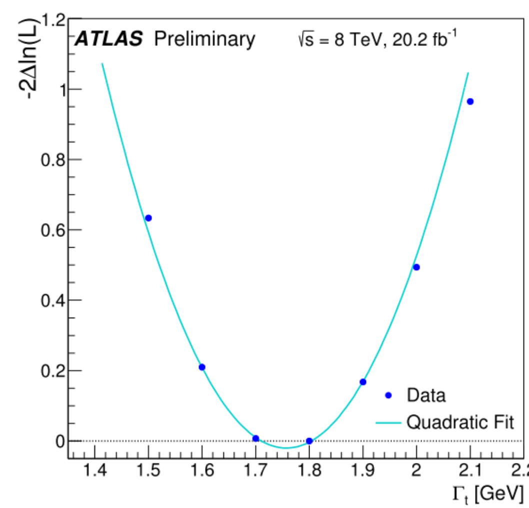




- **Various techniques for top mass extraction is explored**
- **Top mass extraction is sensitive to PDF sets**
- **Central scale of predictions is chosen to be $M_t/2$**







Likelihood template fit result:

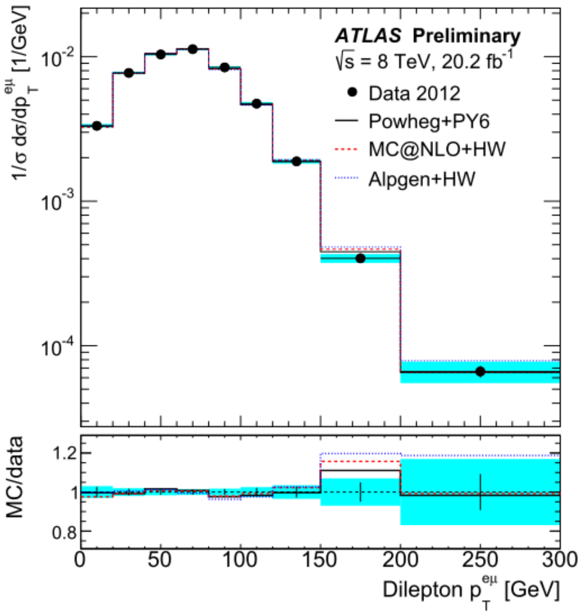
$$\Gamma_t = 1.76 \pm 0.33\ (\text{stat.})\ ^{+0.79}_{-0.68}\ (\text{syst.})\ \text{GeV} = 1.76^{+0.86}_{-0.76}\ \text{GeV}$$

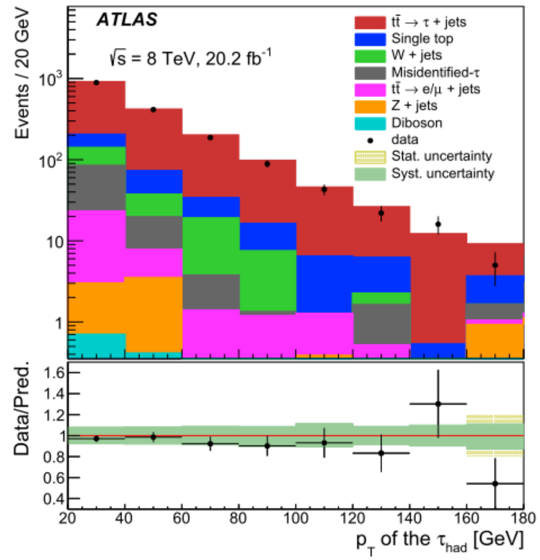
See from M. LLACER

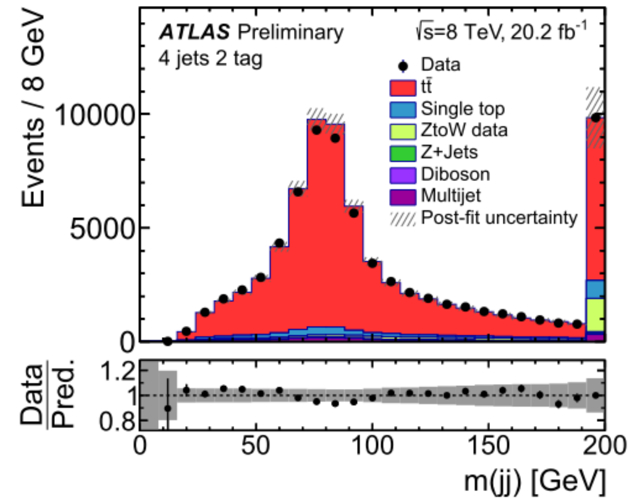
$t\bar{t}$ @ 8 TeV (RunI)

ATLAS-CONF-2017-054 ATLAS-CONF-2017-044

EPJC 77 (2017) 459 Phys. Rev. D 95, 072003 (2017)

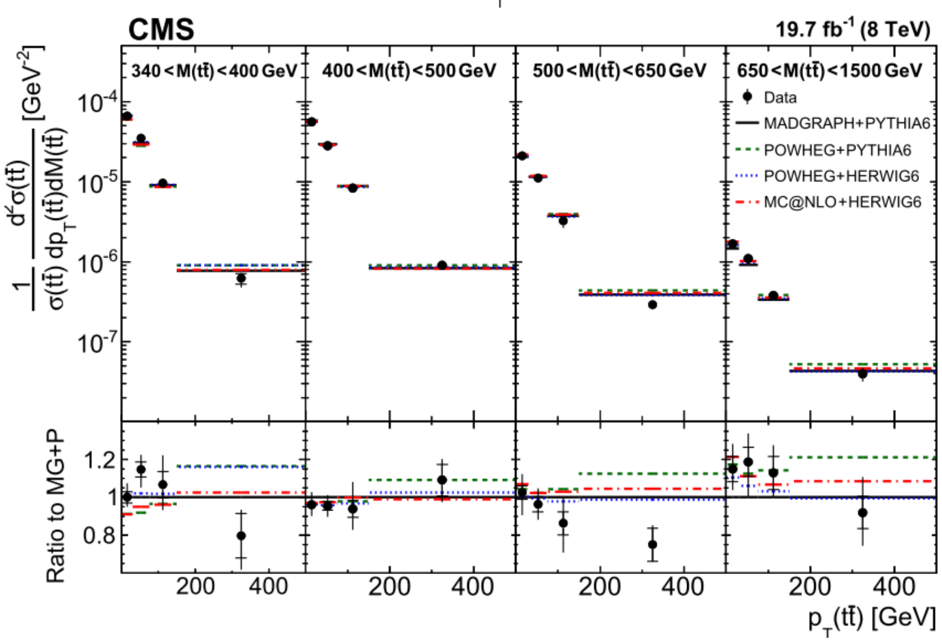


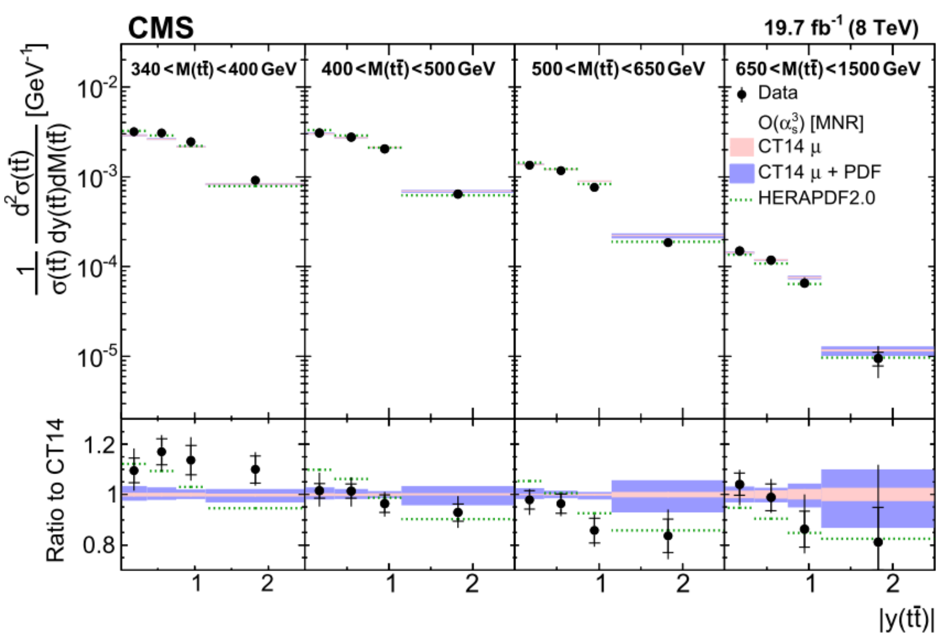




Binned maximum likelihood fit approach:

$$\sigma_{t\bar{t}} = 248.3 \pm 0.7\,(\text{stat.}) \pm 13.4\,(\text{syst.}) \pm 4.7\,(\text{lumi.})\ \text{pb}$$

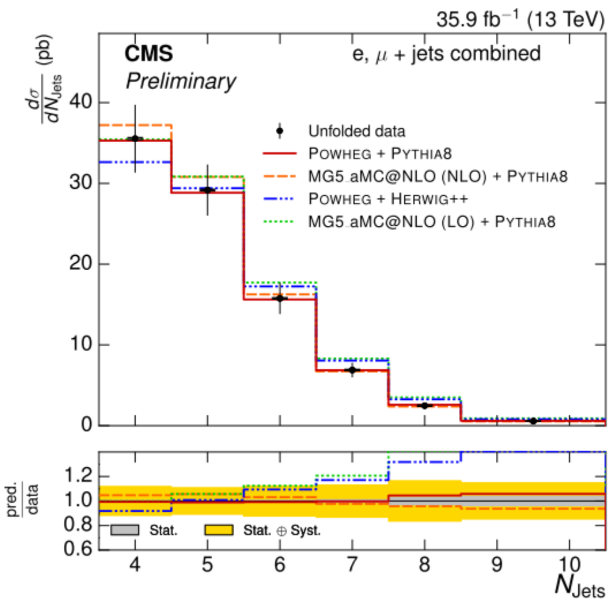


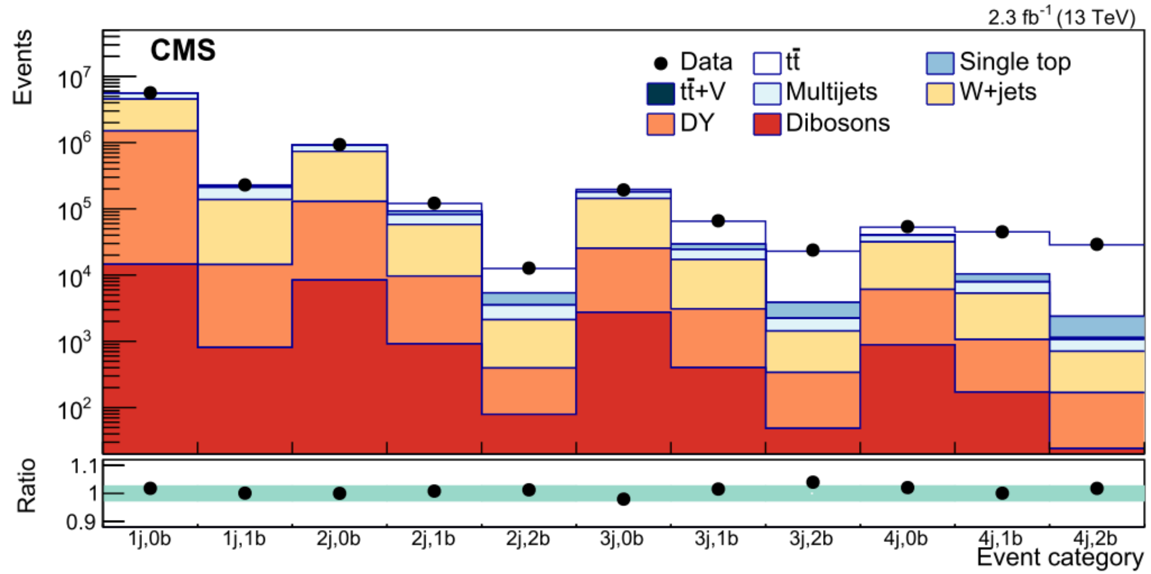


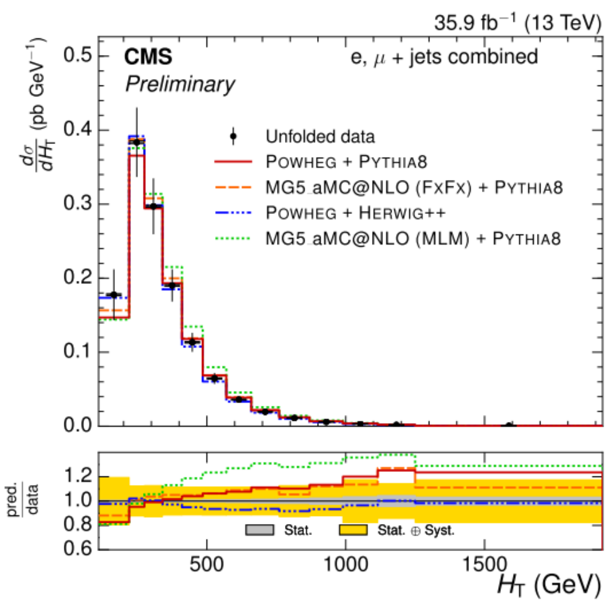
◆ Constraints in PDF are competitive with those from inclusive jet data!

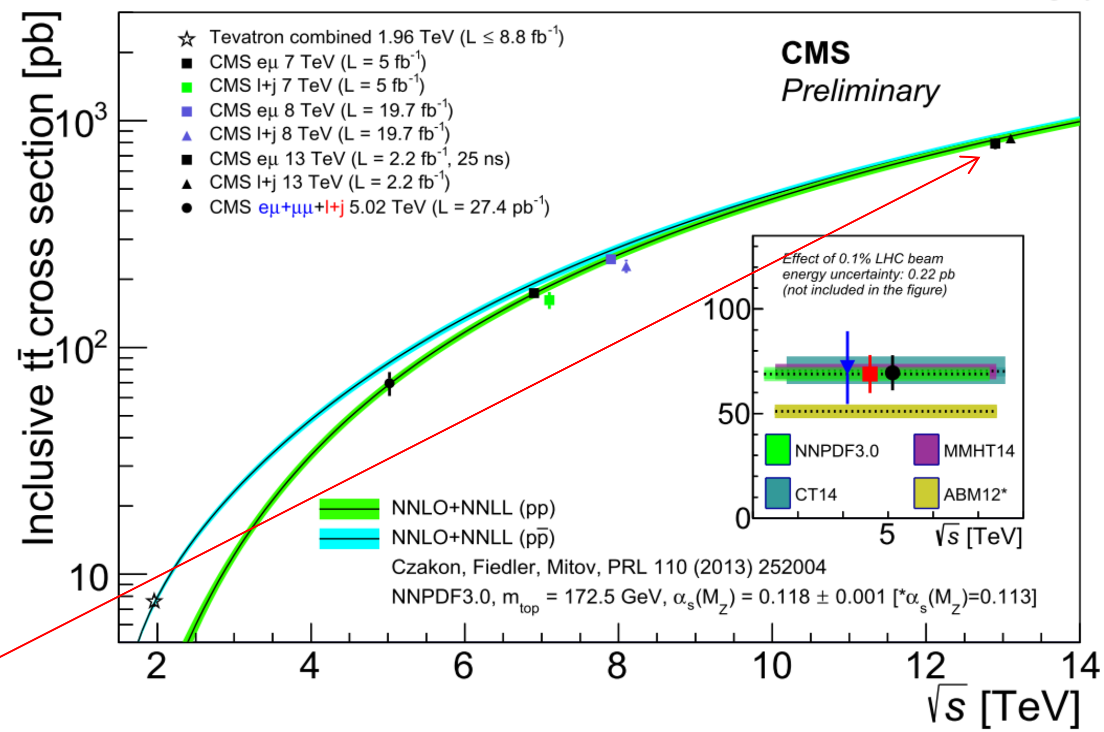
$t\bar{t}$ @ 5.02, 13 TeV (RunII)

arXiv:1701.06228 CMS-PAS-TOP-16-014 CMS-PAS-TOP-16-023





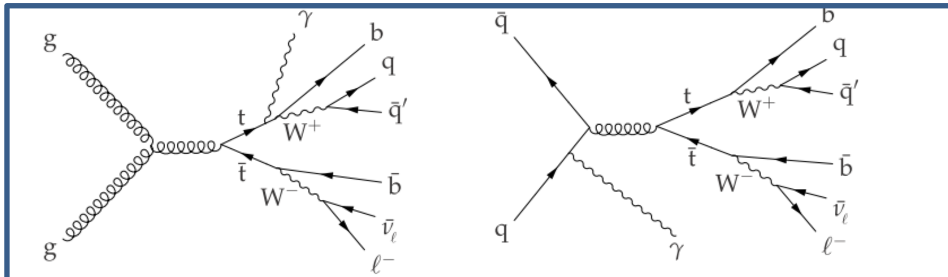




$$\sigma(t\bar{t}) = 835 \pm 3\,(\mathrm{stat}) \pm 23\,(\mathrm{syst}) \pm 23\,(\mathrm{lumi})\,\mathrm{pb}$$

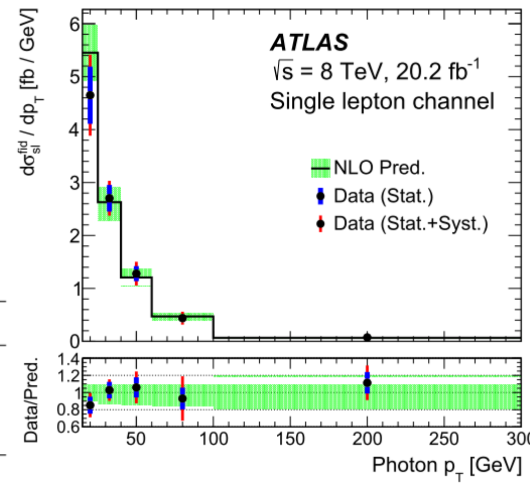
tZq & $t\bar{t}V$ production

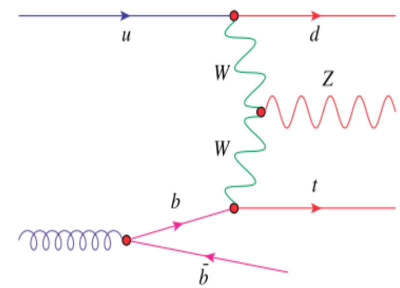
ATLAS-CONF-2017-052 arXiv:1706.03046
CMS-PAS-TOP-17-005 arXiv:1706.08128



◆ Xsec measured using maximum likelihood fit method

Category	R	$\sigma^{\rm fid}_{t\bar{t}+\gamma}$ (fb)	$\sigma_{t\bar{t}+\gamma}\mathcal{B}$ (fb)
e+jets	$(5.7 \pm 1.8) \times 10^{-4}$	138 ± 45	582 ± 187
μ+jets	$(4.7 \pm 1.3) \times 10^{-4}$	115 ± 32	453 ± 124
Combination	$(5.2 \pm 1.1) \times 10^{-4}$	127 ± 27	515 ± 108
Theory	—	—	592 ± 71 (scales) ± 30 (PDFs)



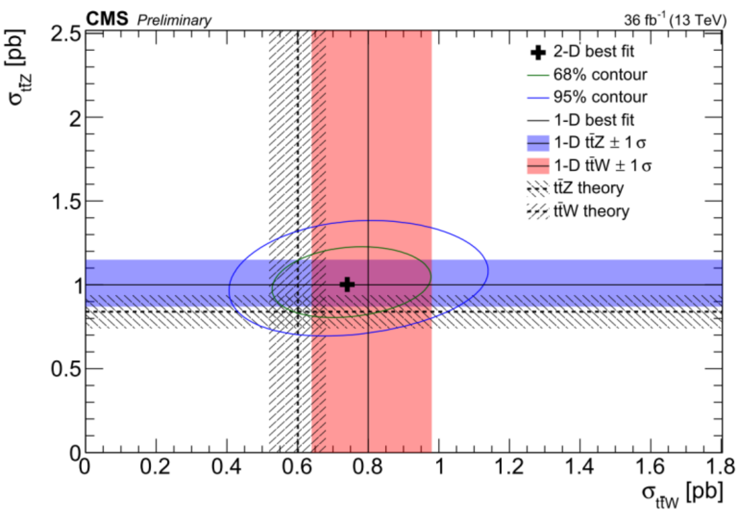


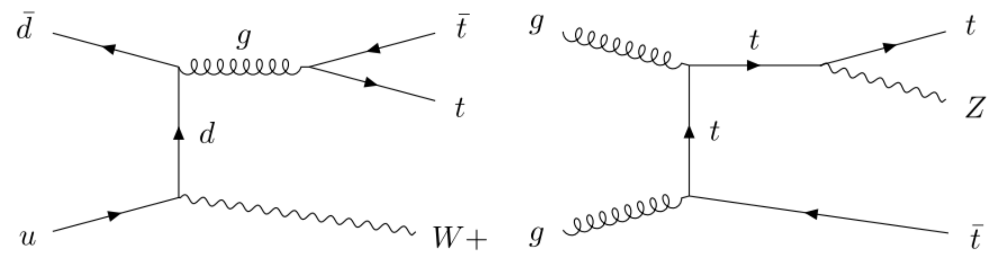
Observed significance:

4.2 σ

Measured tZq xsec:

600 ± 170 (stat.) ± 140 (syst.) fb





$$\sigma(pp \to t\bar{t}W) = 0.80\,^{+0.12}_{-0.11}(\text{stat.})\,^{+0.13}_{-0.12}(\text{sys.})\ \text{pb}$$
$$\sigma(pp \to t\bar{t}Z) = 1.00^{+0.09}_{-0.08}(\text{stat.})\,^{+0.12}_{-0.10}(\text{sys.})\ \text{pb}$$

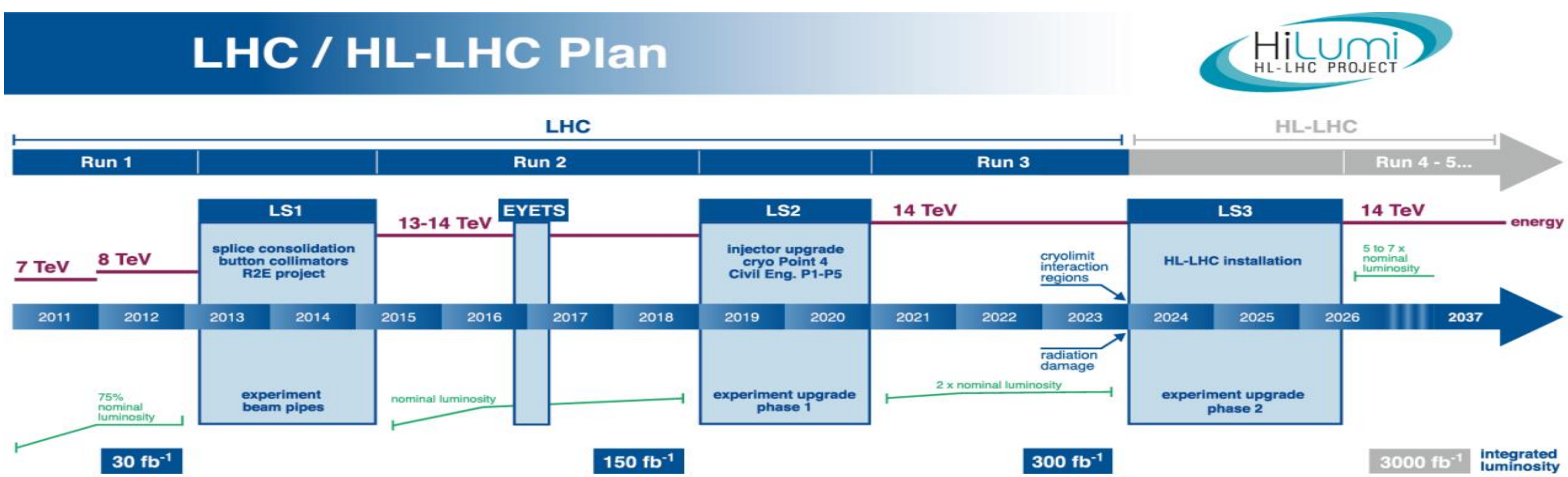
- Profile likelihood fit approach
- Higher nonprompt contribution in 2D fit than 1D case

Channel	Expected significance	Observed significance
$2\ell ss$ analysis $t\bar{t}W^-$	2.4	2.3
$2\ell ss$ analysis $t\bar{t}W^+$	4.3	5.9
$2\ell ss$ analysis ($t\bar{t}W$)	4.6	5.5
3ℓ analysis ($t\bar{t}Z$)	8.4	8.7
4ℓ analysis ($t\bar{t}Z$)	4.8	4.6
3ℓ and 4ℓ combined ($t\bar{t}Z$)	9.5	9.9

Outlook

- ➢ Substantial measurements have been done at the LHC for understanding QCD and EW with high precision from RunI to RunII:
  - ◆ Provide precise systematics for different theoretical models, better constraints on their inputs (e.g. PDFs)
  - ◆ Quantify the improvements with high order of pQCD and EW calculations on matrix elements
  - ◆ Improve the modeling of background for Higgs measurements and new physics searches
  - ◆ Extend to physical phase space unreached before with unprecedented energy and statistics
  - ◆ Give evidence for some rare processes such as triple boson production, VBS
  - ◆ Increase the sensitivity to anomalous gauge boson coupling

- ■ Remained discrepancies and large uncertainties motivate the ongoing work to improve precisions and modellings
- ■ More results will come out soon with higher energy and luminosity!



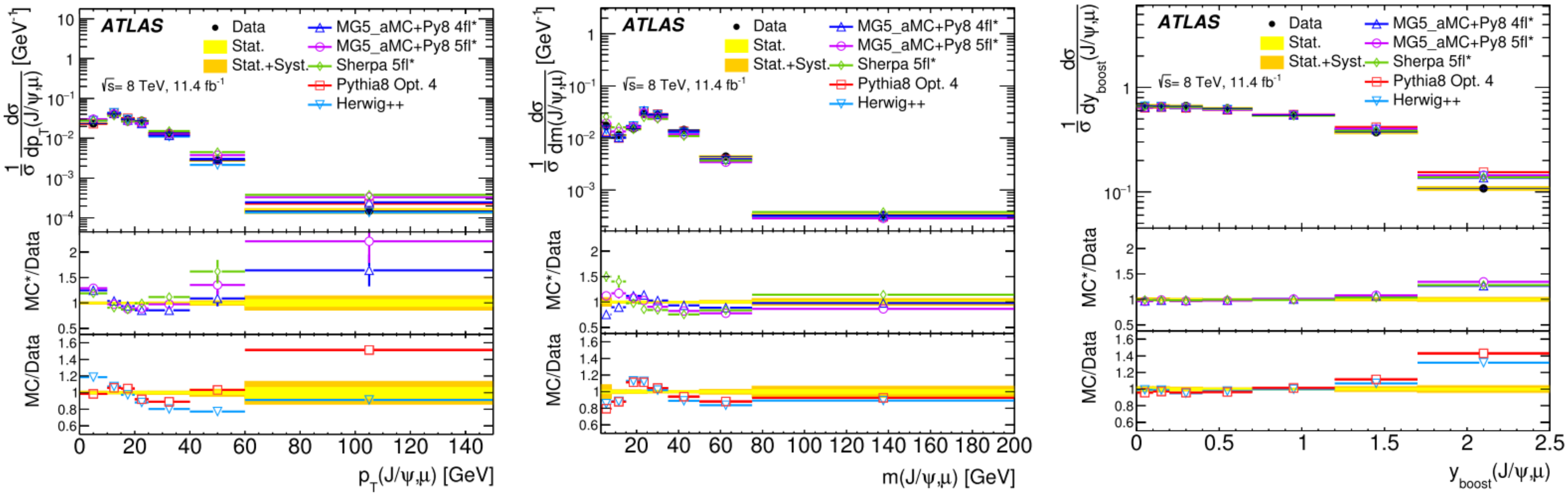
Backup

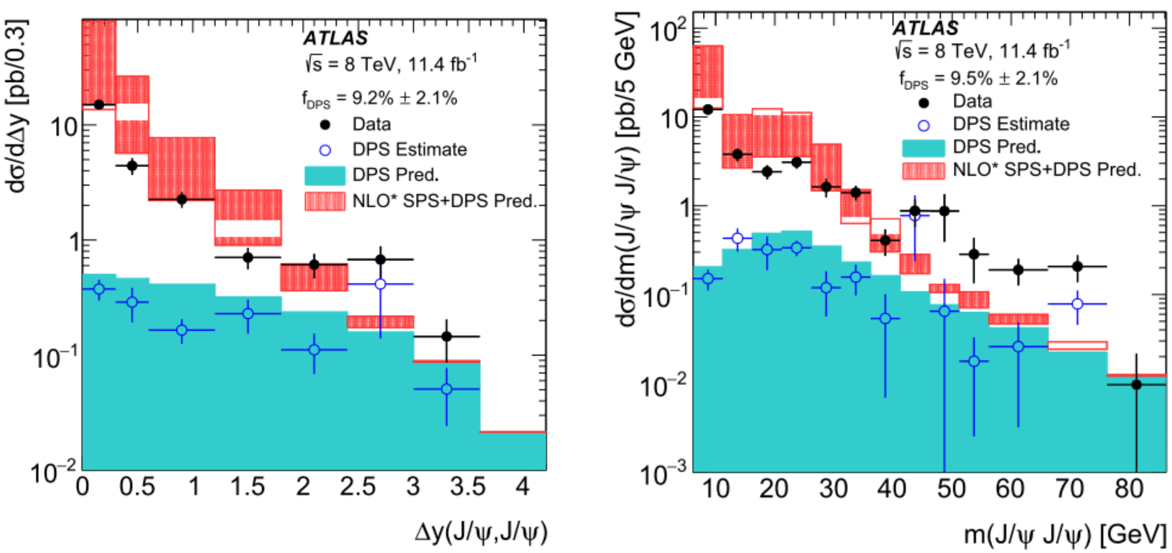
b-hadron & J/ψ production

arXiv:1705.03374 Eur. Phys. J. C (2017) 77

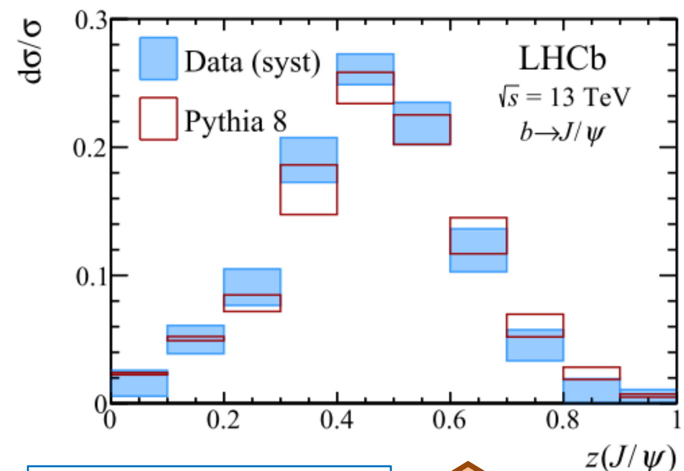
Phys. Rev. Lett. 118, 192001 (2017)

b-hadron pair -> J/ψ + μ





$$\sigma_{\rm eff} = 6.3 \pm 1.6\ ({\rm stat}) \pm 1.0\ ({\rm syst}) \pm 0.1\ ({\rm BF}) \pm 0.1\ ({\rm lumi})\ {\rm mb}$$

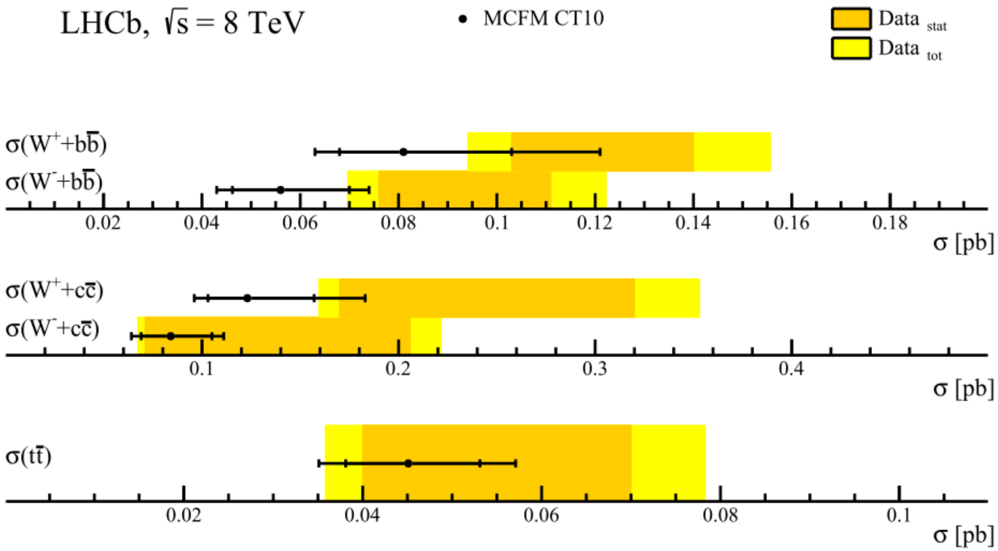


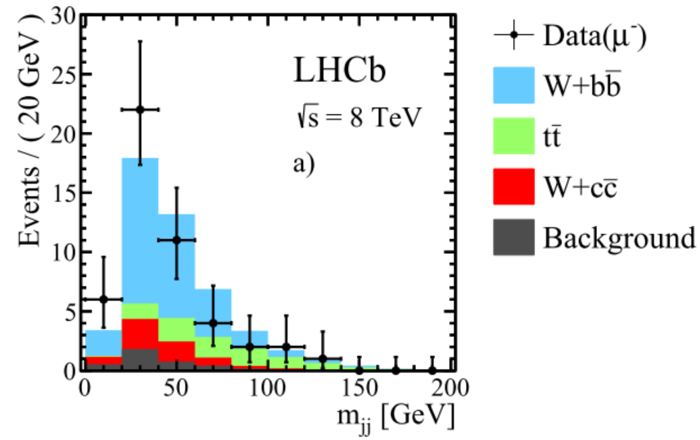
See from S. BARSUK

Frac. of jet p_T carried by J/ψ

$t\bar{t}$ (forward) & W+$b\bar{b}$/$c\bar{c}$ & Z+b jets

arXiv:1611.06507 EPJC 77 (2017) 92
Phys. Lett. B767 (2017) 110

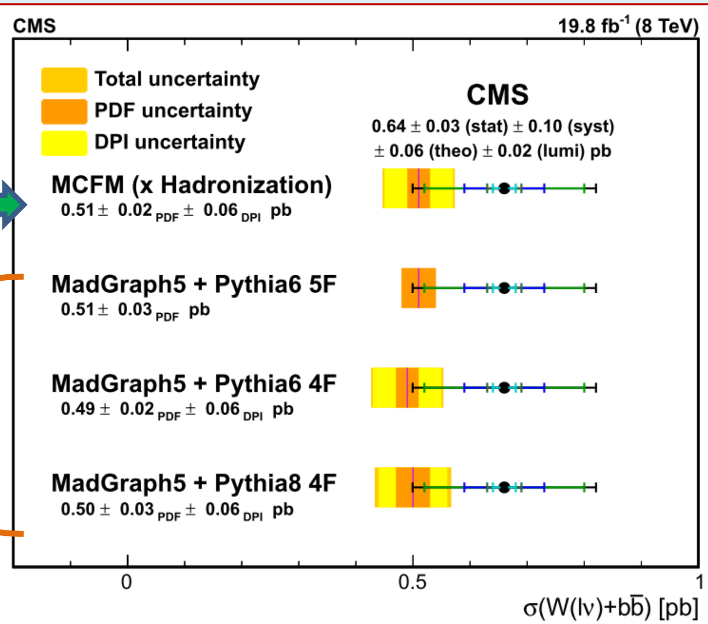


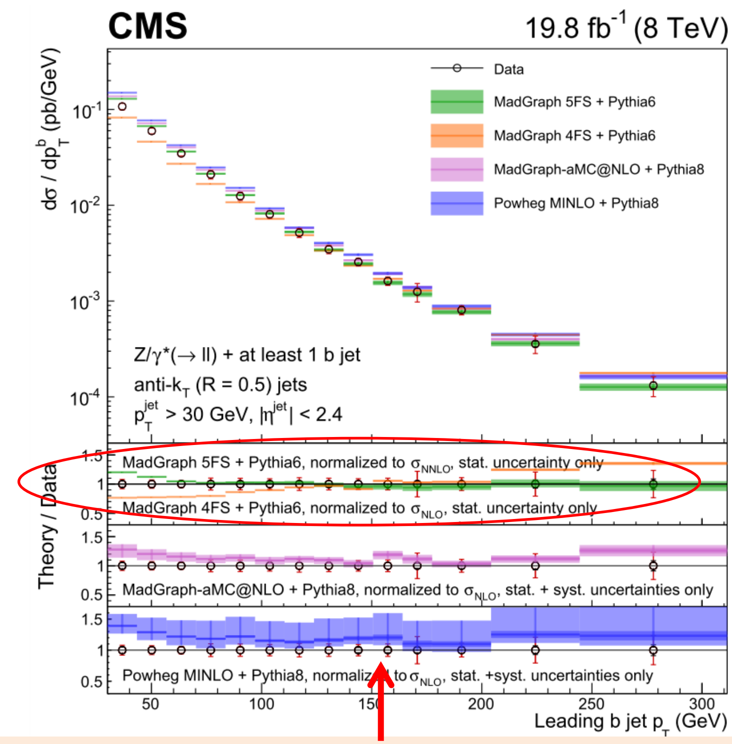


- ➢ **All the predictions agree with measured cross section within one standard deviation!**

NLO

LO

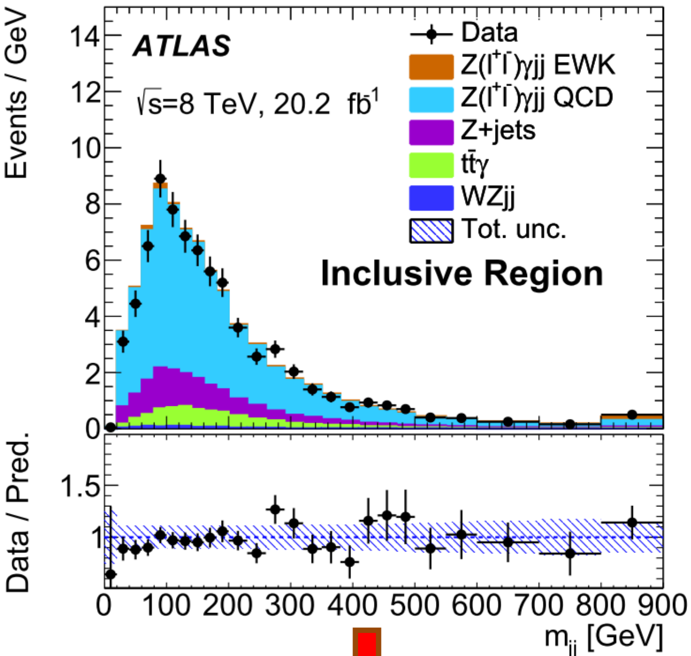


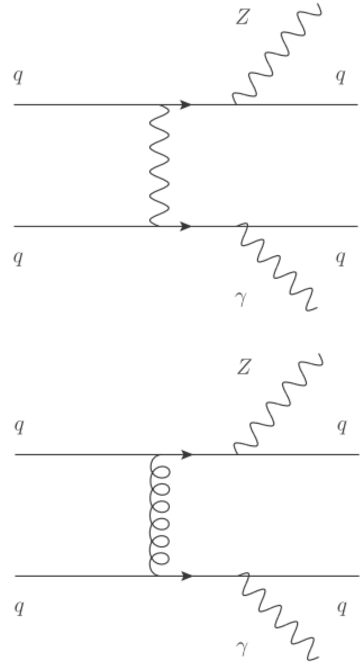


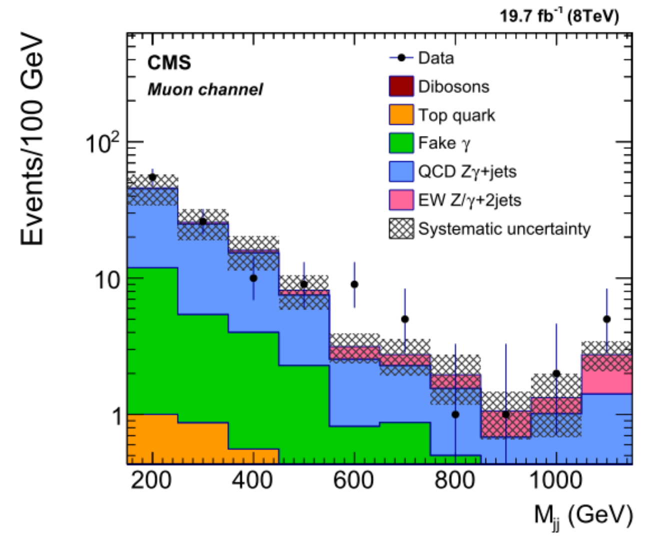
- Powheg NLO prediction implemented with "Multi-scale Improved NLO" (MINLO): 10.1007/JHEP10(2012)155

Zγjj/Wγjj production

JHEP 06 (2017) 106 JHEP 07 (2017) 107
Phys.Lett. B770 (2017) 380





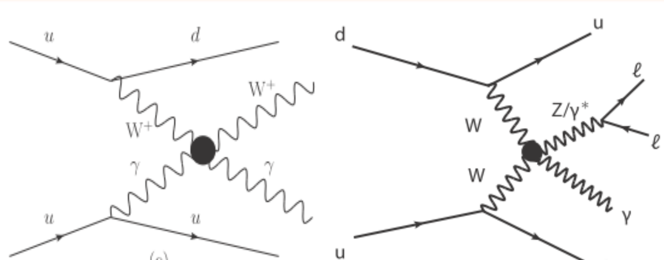


EW signal significance: 3σ

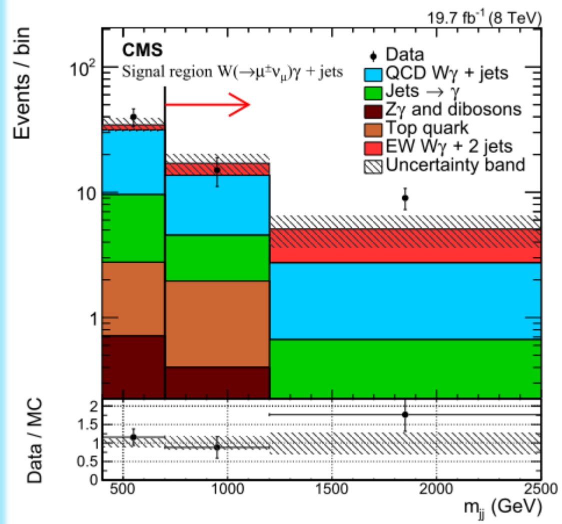
$$1.86^{+0.90}_{-0.75}\,(\text{stat})^{+0.34}_{-0.26}\,(\text{syst}) \pm 0.05\,(\text{lumi})\,\text{fb}$$

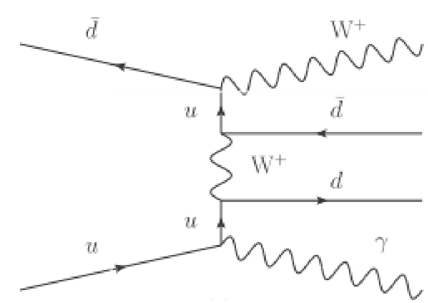
EW signal significance: 2σ

$$\sigma^{\text{EWK}}_{Z\gamma jj} = 1.1 \pm 0.5\,(\text{stat}) \pm 0.4\,(\text{syst})\,\text{fb} = 1.1 \pm 0.6\,\text{fb}$$



Quartic gauge coupling in VBS

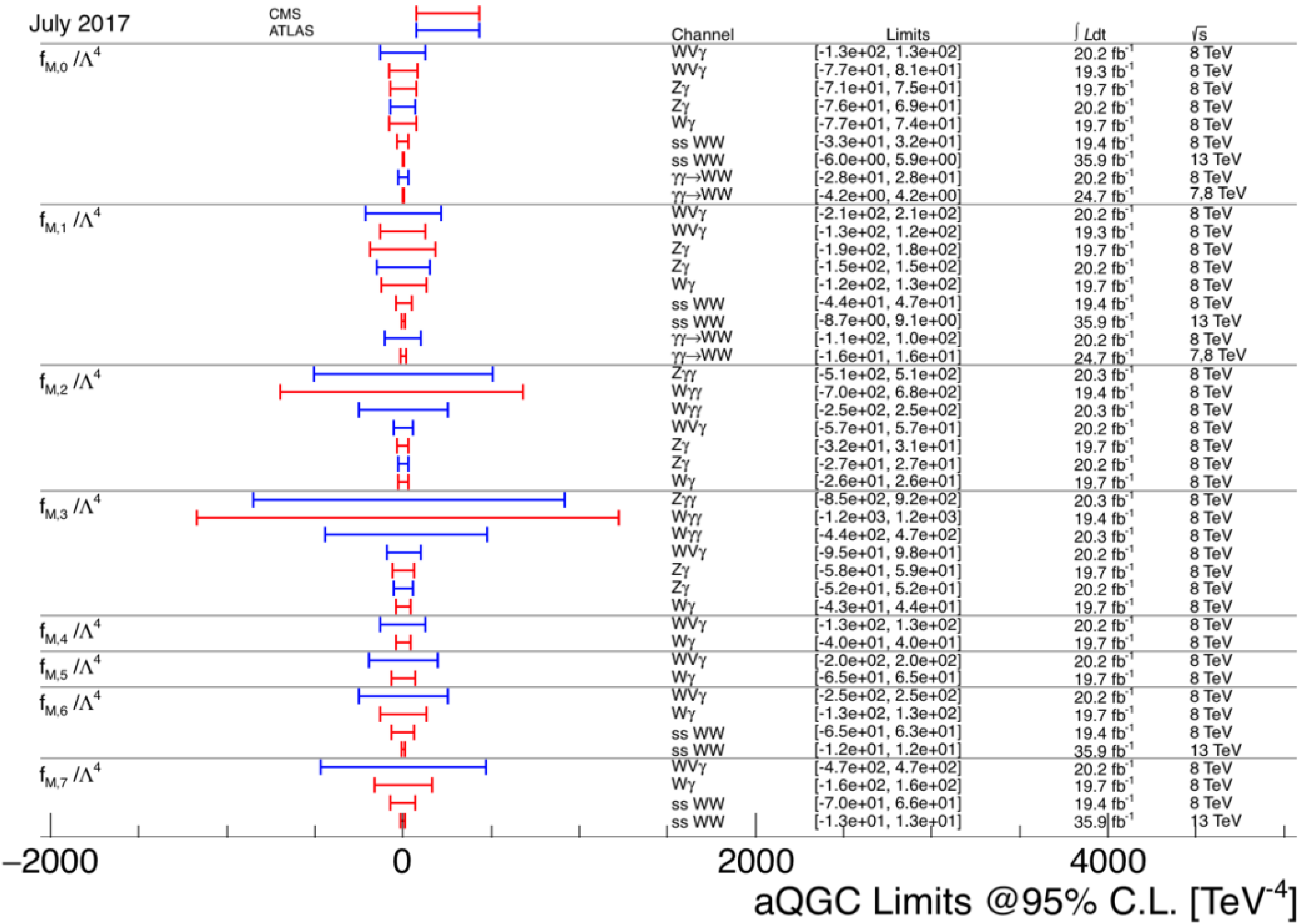




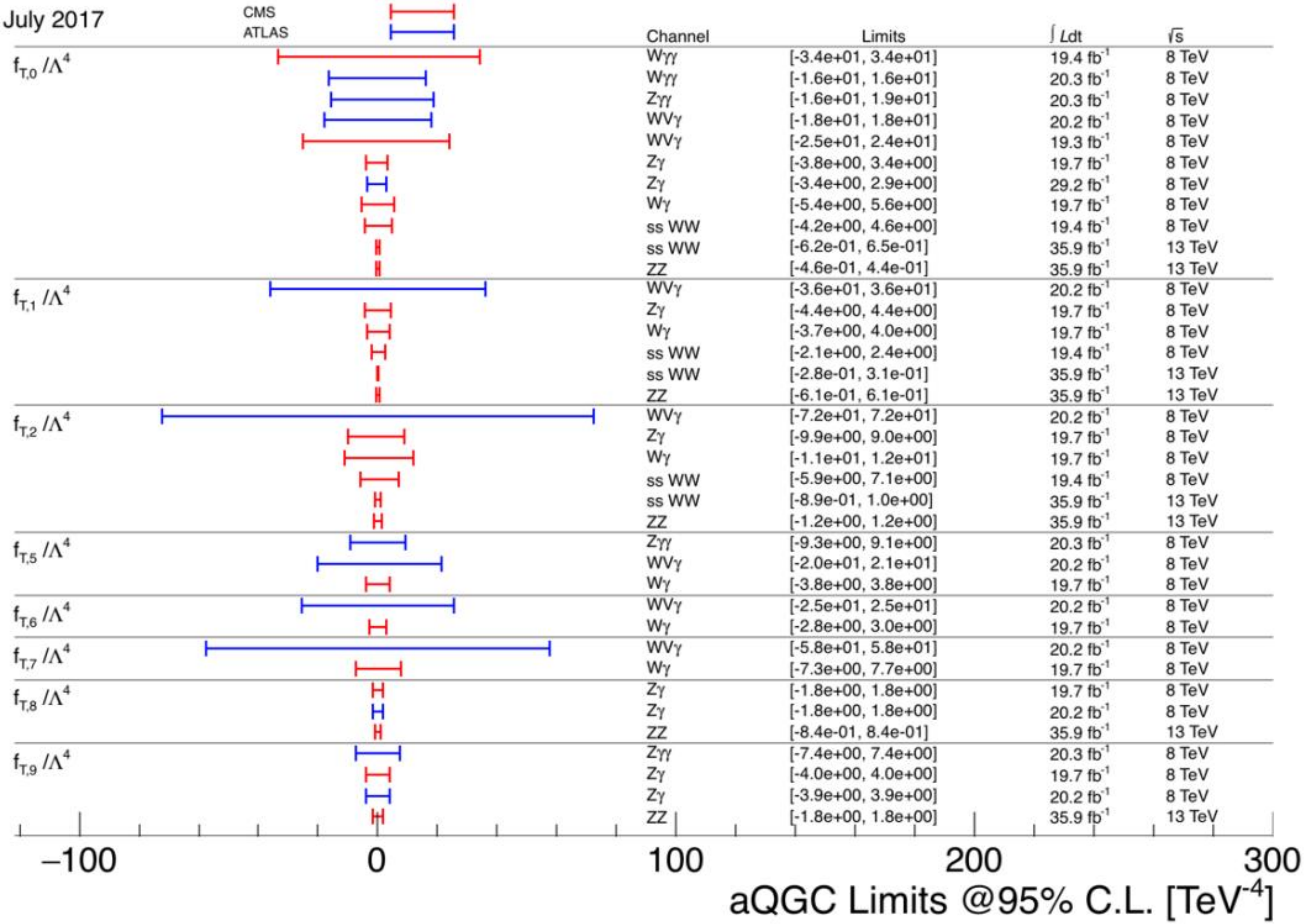
EW signal significance: 2.7σ

$$10.8 \pm 4.1\,(\text{stat}) \pm 3.4\,(\text{syst}) \pm 0.3\,(\text{lumi})\,\text{fb}$$

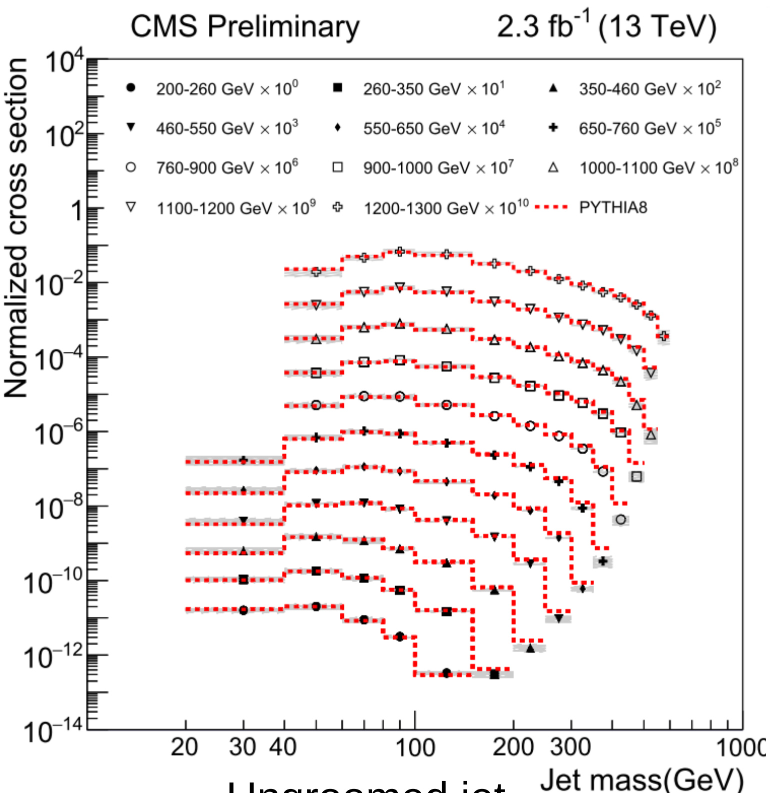
Anomalous quartic gauge coupling (AQGC)



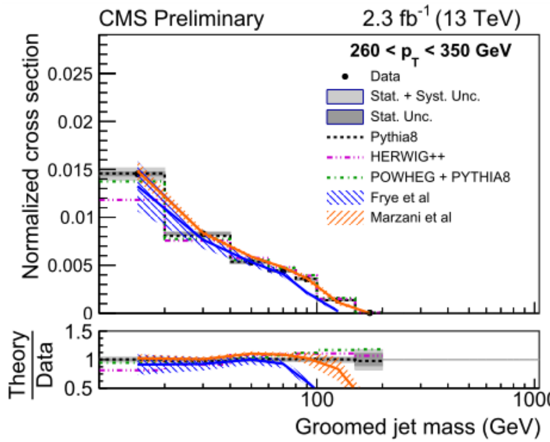
Anomalous quartic gauge coupling (AQGC)

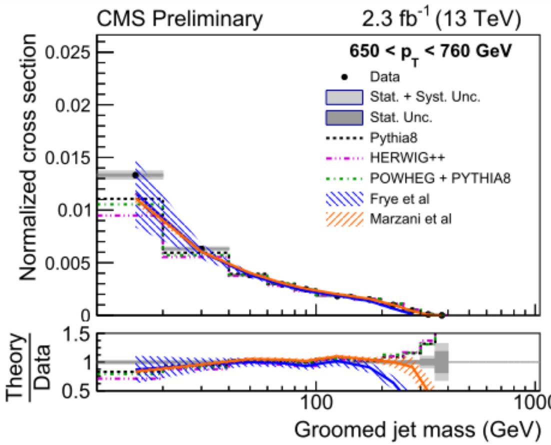


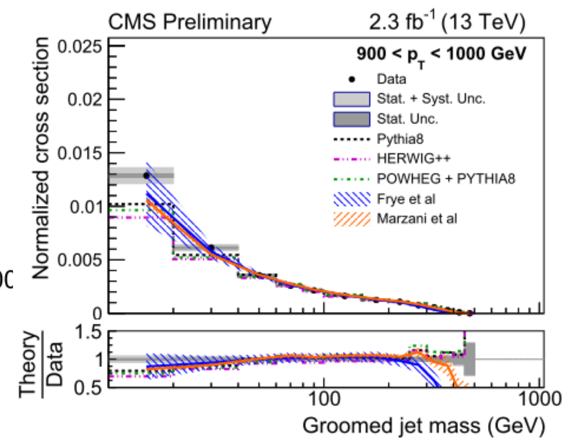
Jet mass measurement

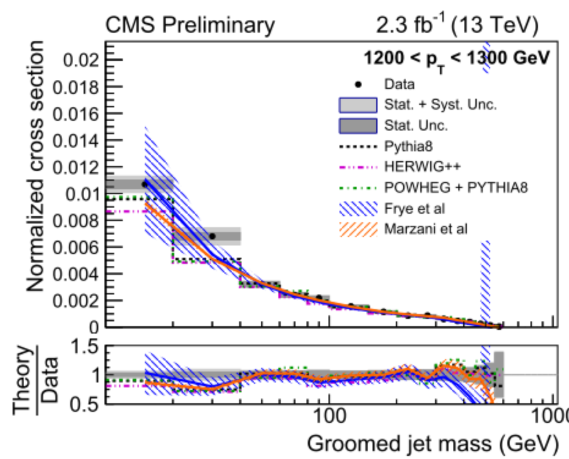


Ungroomed jet





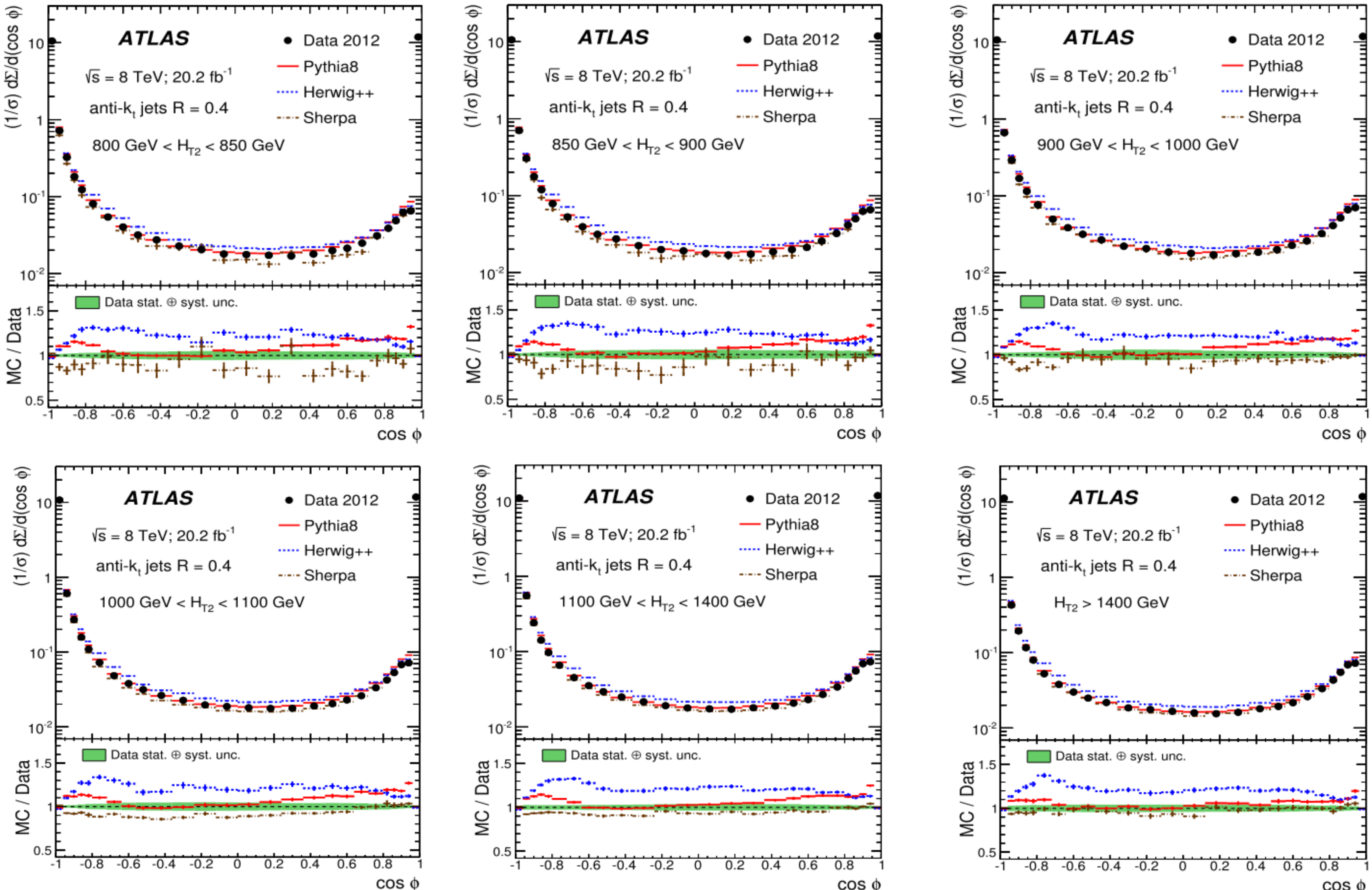




- Events extracted from dijet topology
- For groomed jets, the jet mass peak is suppressed and the precision in the low and intermediate regions improves, since the grooming algorithm removes the portions of the jet arising from soft radiation that are difficult to model

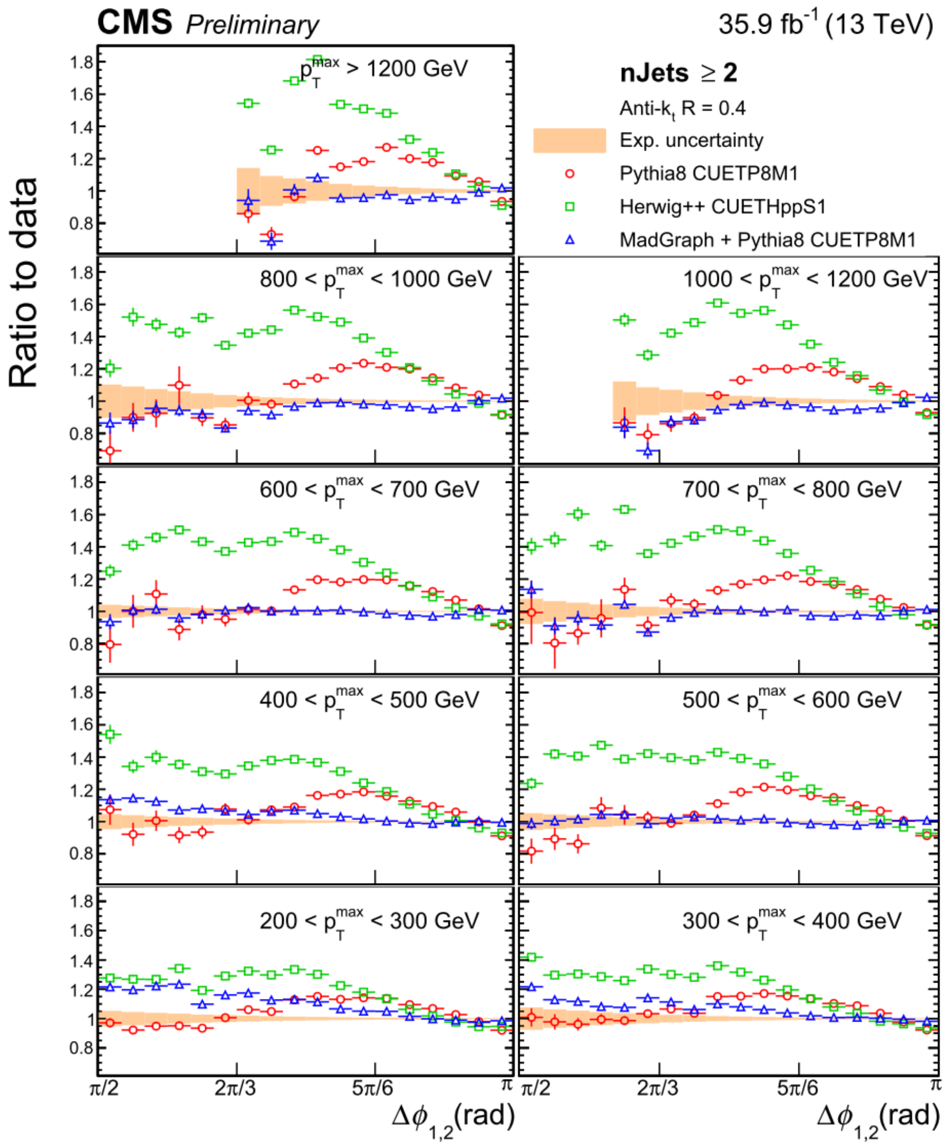
$$\frac{\min(p_{t,i}, p_{t,j})}{(p_{t,i} + p_{t,j})} > z_{cut} \left(\frac{\Delta R_{ij}}{R_0}\right)^{\beta}$$

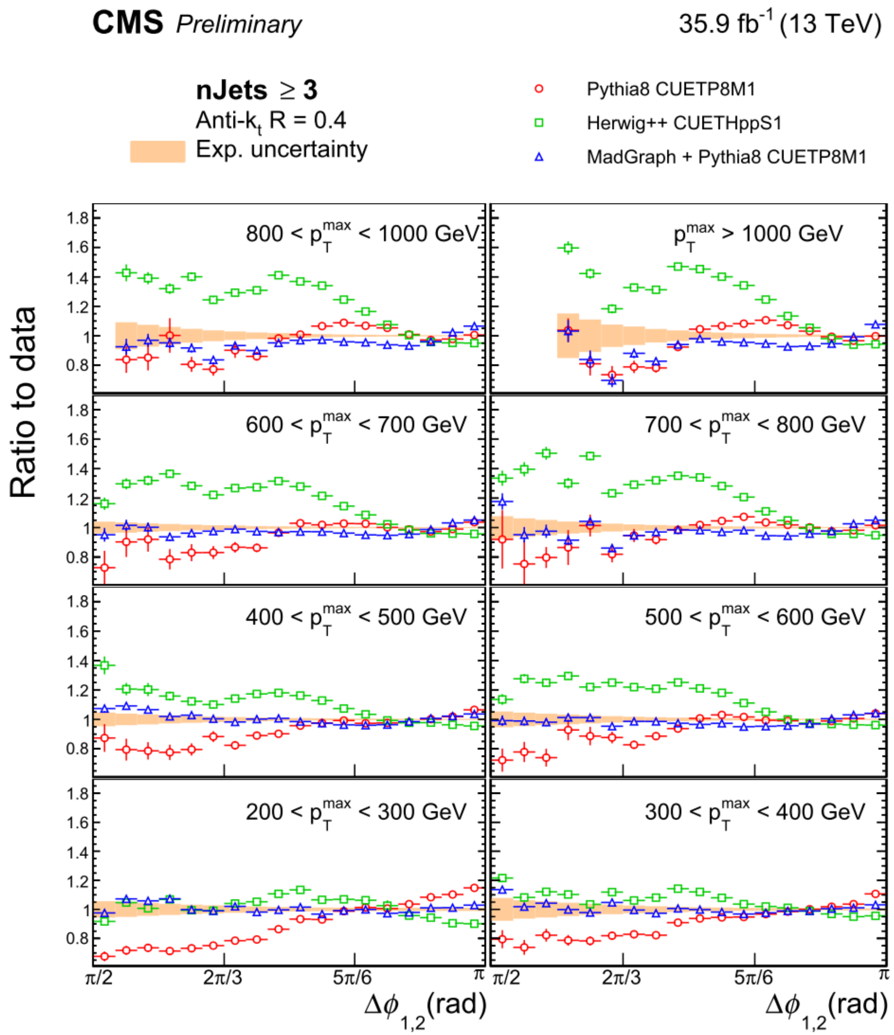
Jet angular correlation



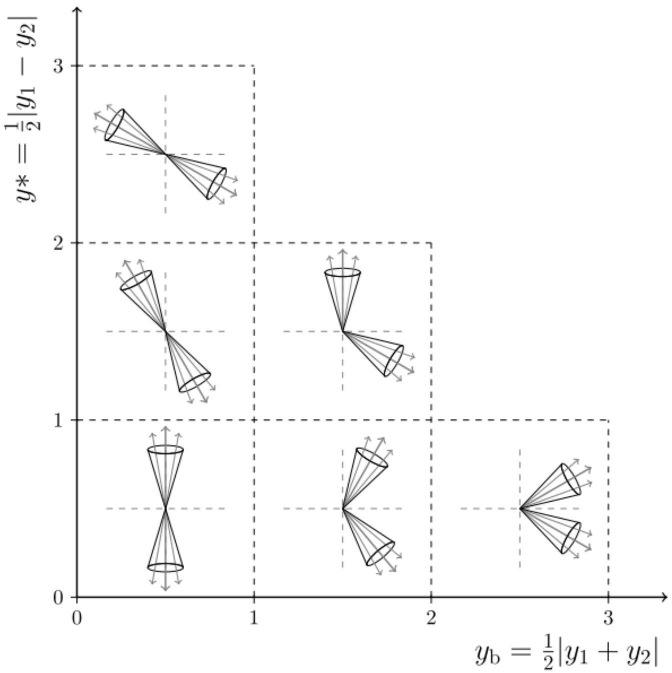
$$\mu_R = \frac{p_{T1} + p_{T2}}{2} \qquad \mu_F = \frac{p_{T1} + p_{T2}}{4}$$

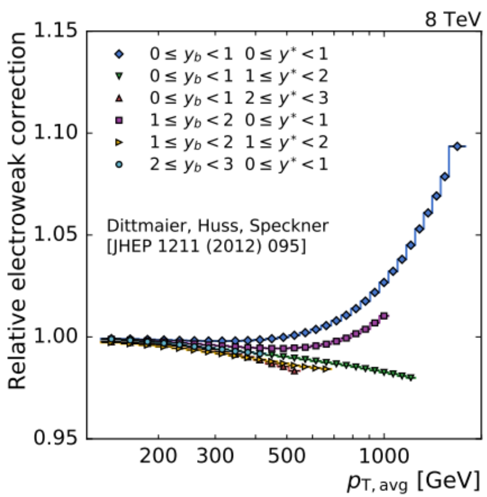
Jet angular correlation

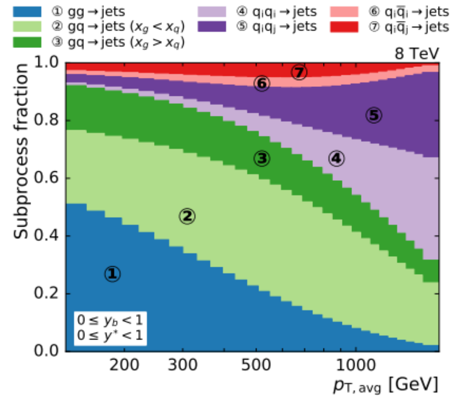


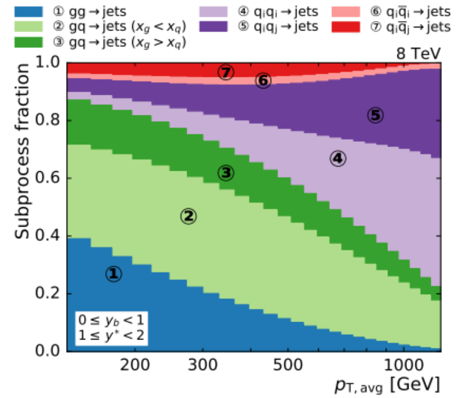


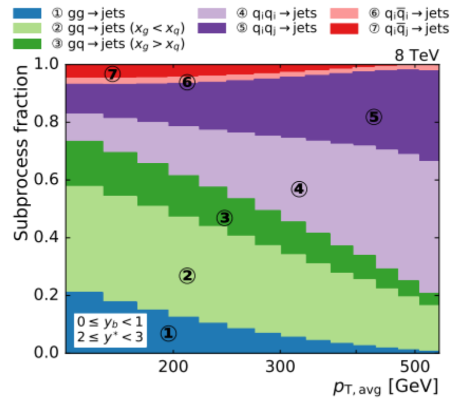
Jet angular correlation

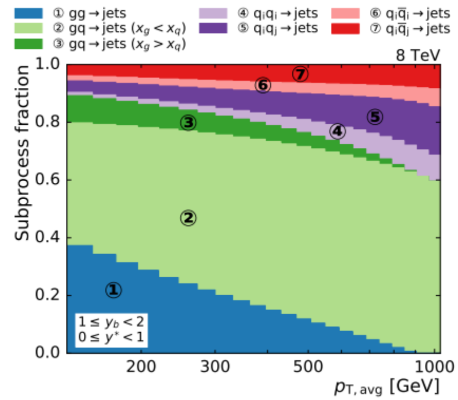


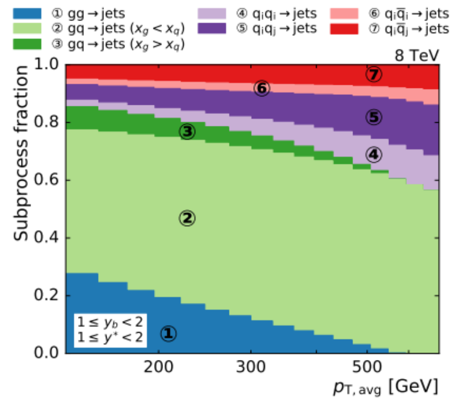


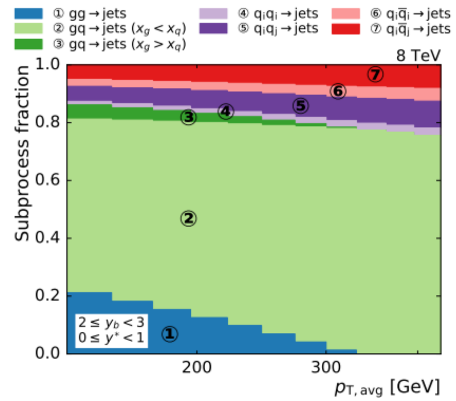




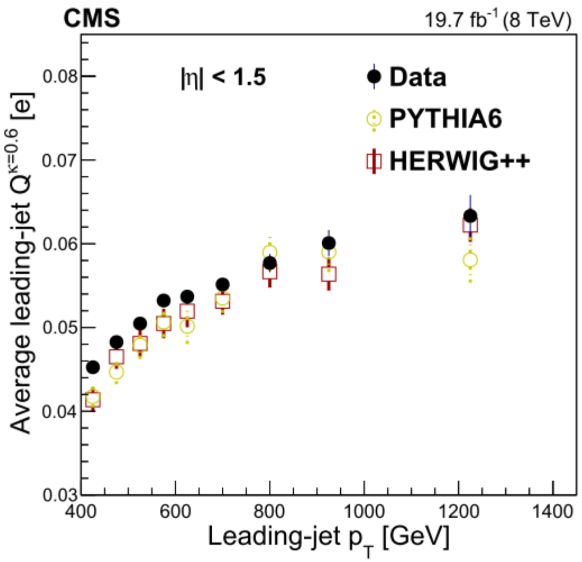




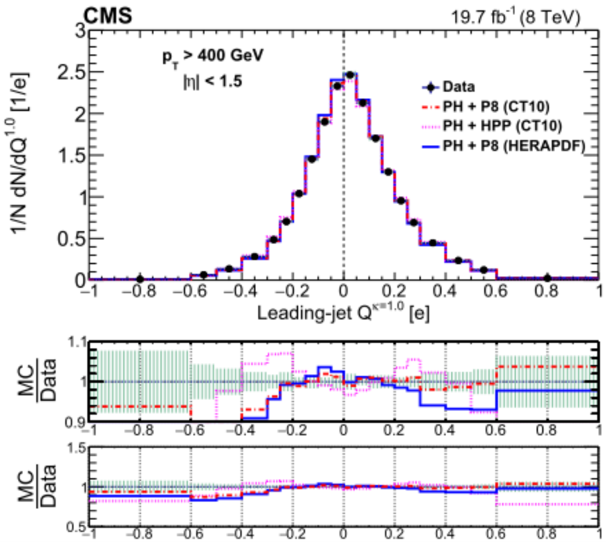




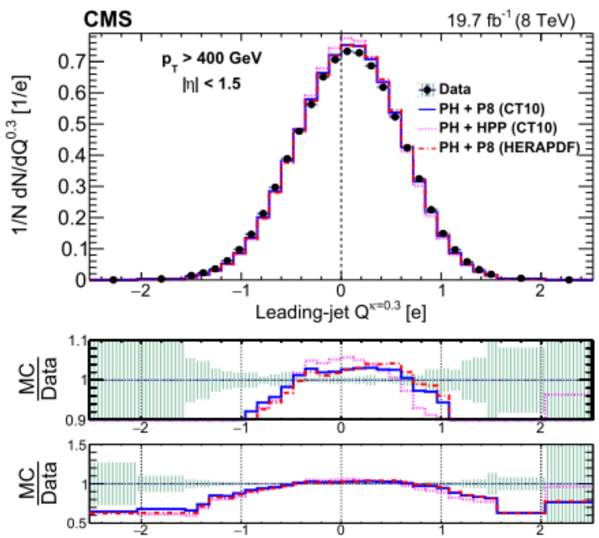
Jet charge



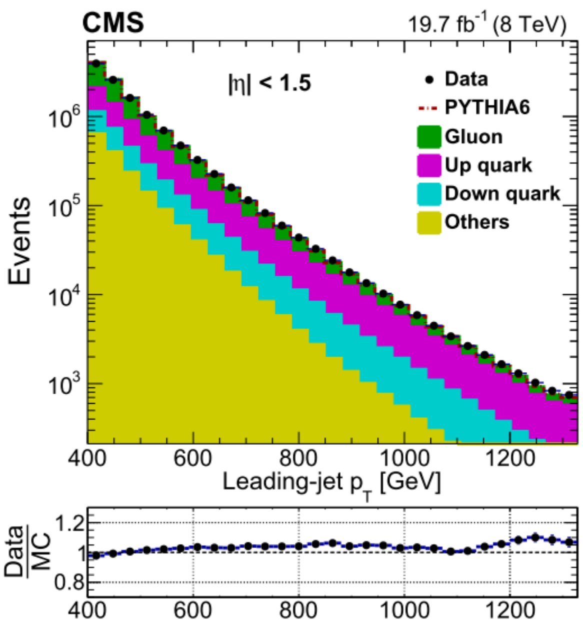
CMS
19.7 fb^{-1} (8 TeV)
|η| < 1.5
Data
PYTHIA6
HERWIG++
Average leading-jet $Q^{\kappa=0.6}$ [e]
Leading-jet p_T [GeV]



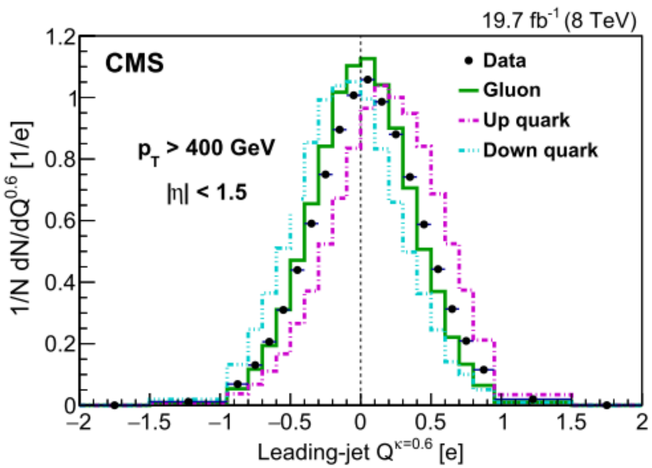
CMS
19.7 fb^{-1} (8 TeV)
p_T > 400 GeV
|η| < 1.5
Data
PH + P8 (CT10)
PH + HPP (CT10)
PH + P8 (HERAPDF)
1/N dN/d$Q^{1.0}$ [1/e]
Leading-jet $Q^{\kappa=1.0}$ [e]
MC/Data



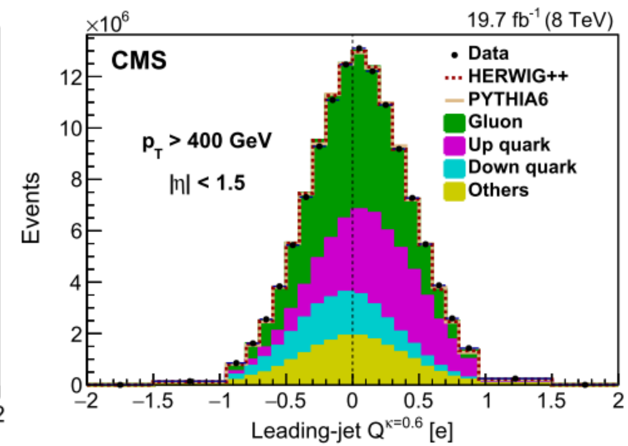
CMS
19.7 fb^{-1} (8 TeV)
p_T > 400 GeV
|η| < 1.5
Data
PH + P8 (CT10)
PH + HPP (CT10)
PH + P8 (HERAPDF)
1/N dN/d$Q^{0.3}$ [1/e]
Leading-jet $Q^{\kappa=0.3}$ [e]
MC/Data



CMS
19.7 fb^{-1} (8 TeV)
|η| < 1.5
Data
PYTHIA6
Gluon
Up quark
Down quark
Others
Events
Leading-jet p_T [GeV]
Data/MC



CMS
19.7 fb^{-1} (8 TeV)
p_T > 400 GeV
|η| < 1.5
Data
Gluon
Up quark
Down quark
1/N dN/d$Q^{0.6}$ [1/e]
Leading-jet $Q^{\kappa=0.6}$ [e]



CMS
19.7 fb^{-1} (8 TeV)
$\times 10^6$
p_T > 400 GeV
|η| < 1.5
Data
HERWIG++
PYTHIA6
Gluon
Up quark
Down quark
Others
Events
Leading-jet $Q^{\kappa=0.6}$ [e]

Inclusive W/Z boson

Channel	Measured cross section × BR($W \to \ell\nu$, $Z \to \ell\ell$) [nb] (value ± stat ± syst ± lumi) Fiducial	Total	Predicted cross section × BR($W \to \ell\nu$, $Z \to \ell\ell$) [nb] (value ± PDF ± scale ± other) Fiducial	Total
W^-	$3.50 \pm 0.01 \pm 0.07 \pm 0.07$	$8.79 \pm 0.02 \pm 0.24 \pm 0.18$	$3.40^{+0.09}_{-0.11} \pm 0.04 \pm 0.06$	$8.54^{+0.21}_{-0.24} \pm 0.11 \pm 0.12$
W^+	$4.53 \pm 0.01 \pm 0.09 \pm 0.10$	$11.83 \pm 0.02 \pm 0.32 \pm 0.25$	$4.42^{+0.13}_{-0.14} \pm 0.05 \pm 0.08$	$11.54^{+0.32}_{-0.31} \pm 0.15 \pm 0.16$
$W^\pm$	$8.03 \pm 0.01 \pm 0.16 \pm 0.17$	$20.64 \pm 0.02 \pm 0.55 \pm 0.43$	$7.82^{+0.21}_{-0.25} \pm 0.09 \pm 0.13$	$20.08^{+0.53}_{-0.54} \pm 0.26 \pm 0.28$
Z	$0.779 \pm 0.003 \pm 0.006 \pm 0.016$	$1.981 \pm 0.007 \pm 0.038 \pm 0.042$	$0.74^{+0.02}_{-0.03} \pm 0.01 \pm 0.01$	$1.89 \pm 0.05 \pm 0.03 \pm 0.03$
	Measured ratio (value ± stat ± syst)		**Predicted ratio** (value ± PDF)	
W^+/W^-	$1.295 \pm 0.003 \pm 0.010$	–	1.30 ± 0.01	–
$W^\pm/Z$	$10.31 \pm 0.04 \pm 0.20$	–	10.54 ± 0.12	–