Electroweak Physics with the CMS Detector at the LHC

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for the CMS Collaboration

The Section of Nuclear Physics of the Physical Sciences Division of the Russian Academy of Sciences

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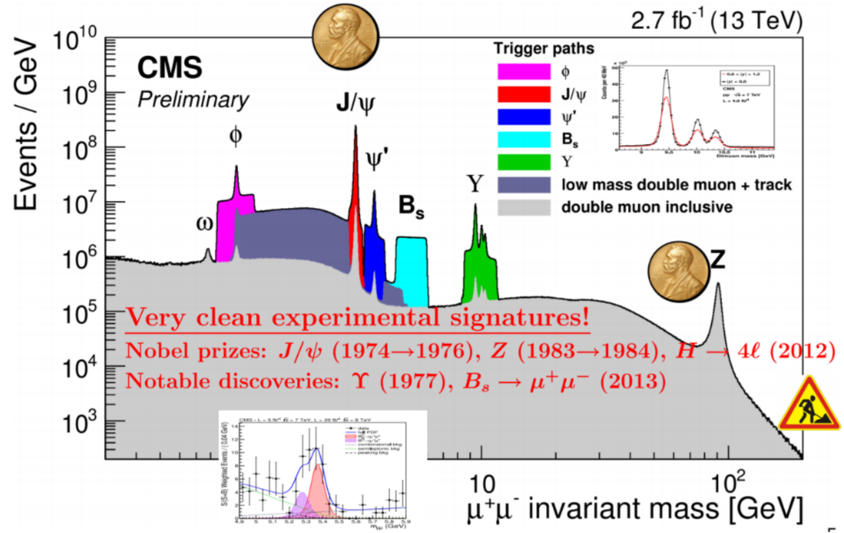
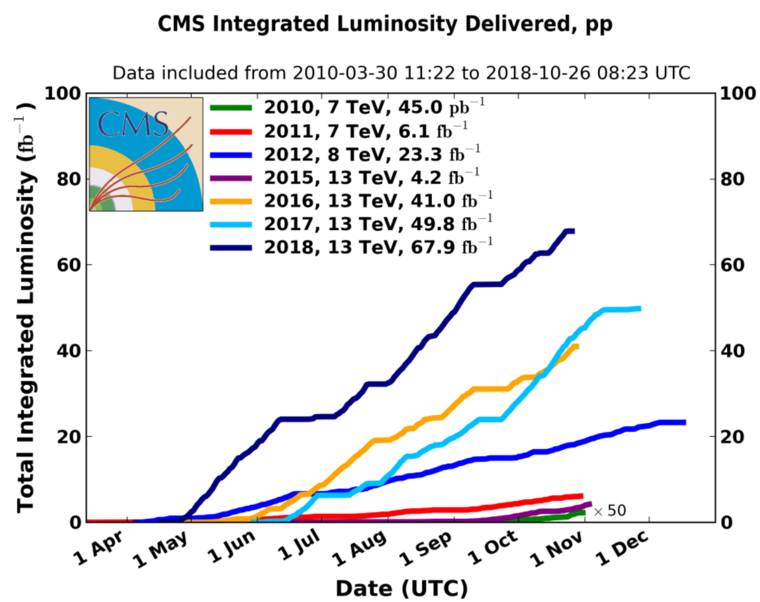
Outline

- ❑ Z/W production, Drell-Yan
  - ✓ total cross sections
  - ✓ differential cross sections
- ❑ Asymmetries
  - ✓ charged asymmetry in W production
  - ✓ forward-backward asymmetry and angular coefficients for Drell-Yan
  - ✓ weak mixing angle
- ❑ Multi-boson production
- ❑ Anomalous Triple Gouge Couplings
- ❑ Vtb measurements,Rare decays



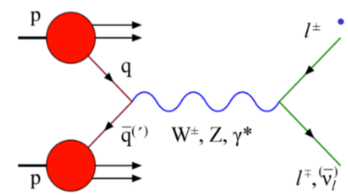
CMS Standard Models Physics Results
https://cms-results.web.cern.ch/cms-results/public-results/publications/SMP/index.html



CMS B Physics and Quarkonia Physics Results
https://cms-results.web.cern.ch/cms-results/public-results/publications/BPH/index.html

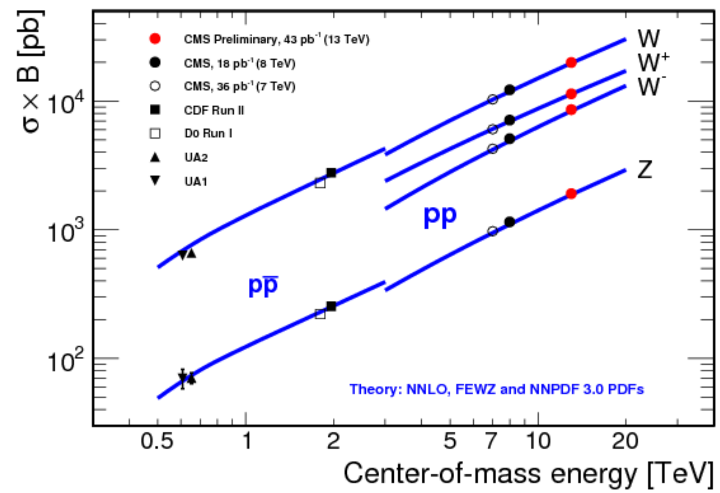
CMS Top Quark Physics Results
https://cms-results.web.cern.ch/cms-results/public-results/publications/PhysicsResultsTOP/index.html

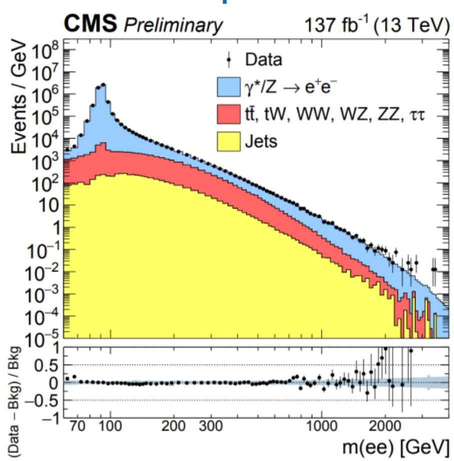
EWK Gauge Bosons: Z and W production



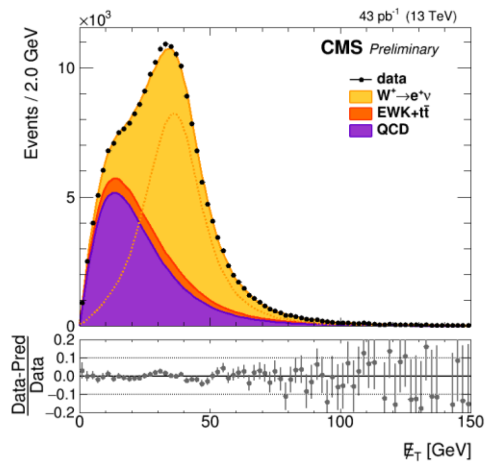
High rate at the LHC

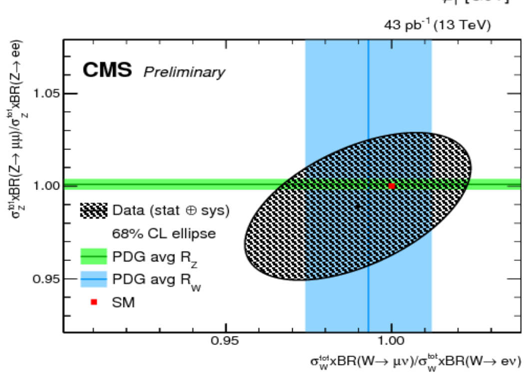
- ✓ Provides statistic to study inclusive and differential distributions
- ✓ Good understanding of the detectors allow for precision measurements
- ✓ Test p-QCD and PDF in different regimes
- ✓ Developments and testing of new MC generators and techniques

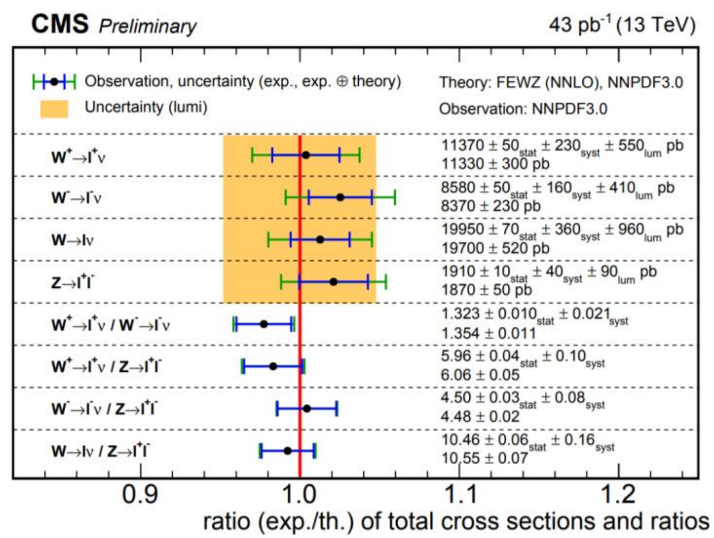




CMS-PAS-EXO-19-019





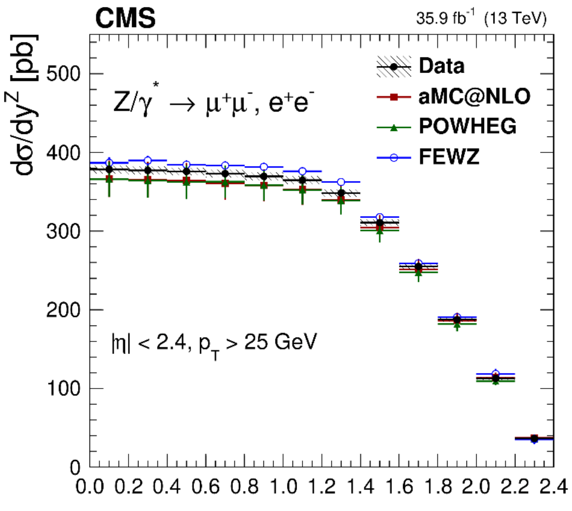


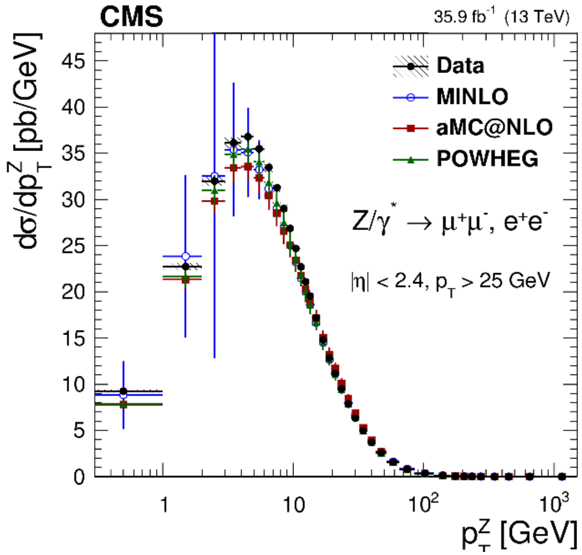
Good agreement with NNLO SM predictions

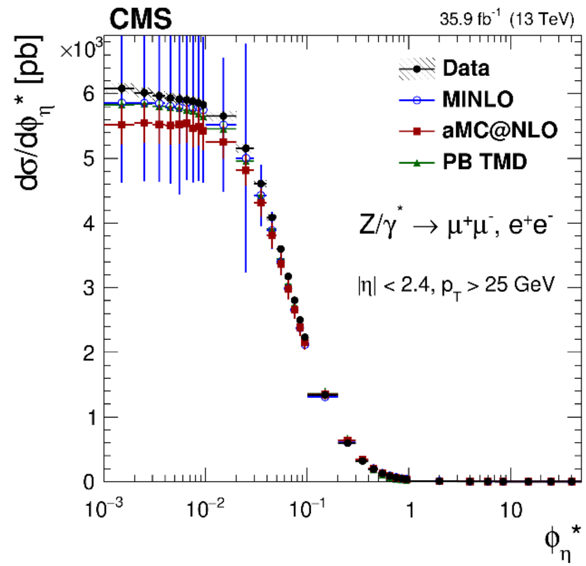
CMS-PAS-SMP-15-004

Z Differential Cross Section

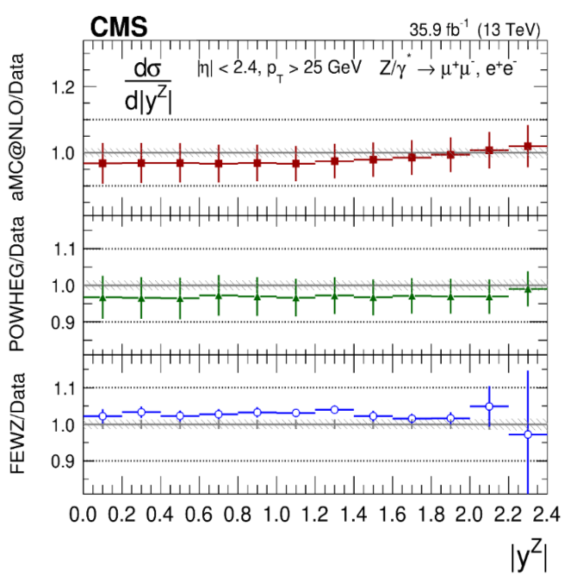
Differential cross sections of the transverse momentum p_T, the optimized angular variable φ^*, η, and the rapidity of lepton pairs are measured

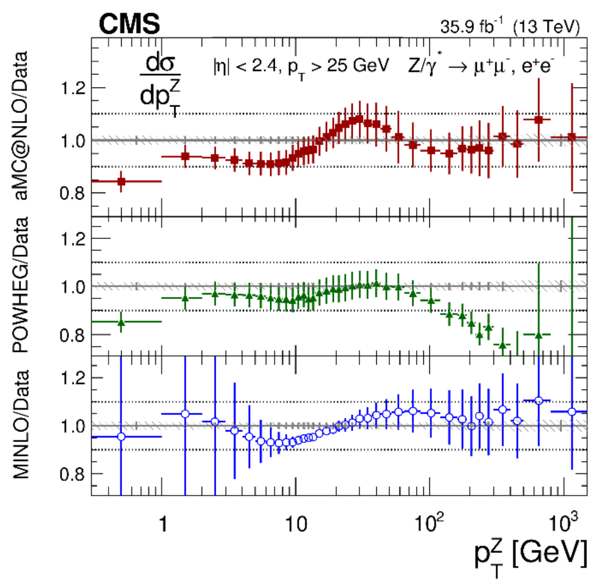


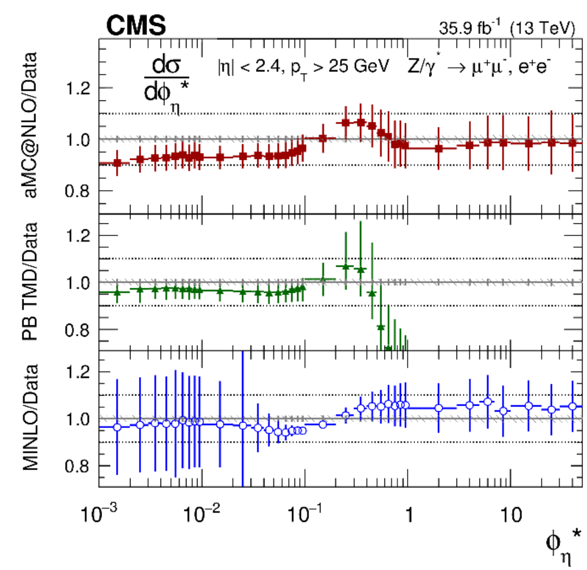




JHEP 12 (2019) 061

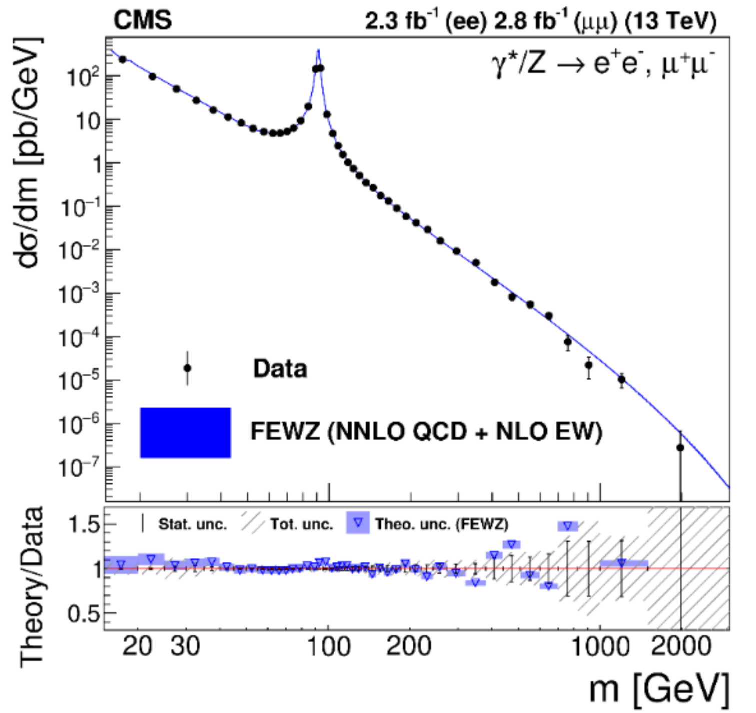




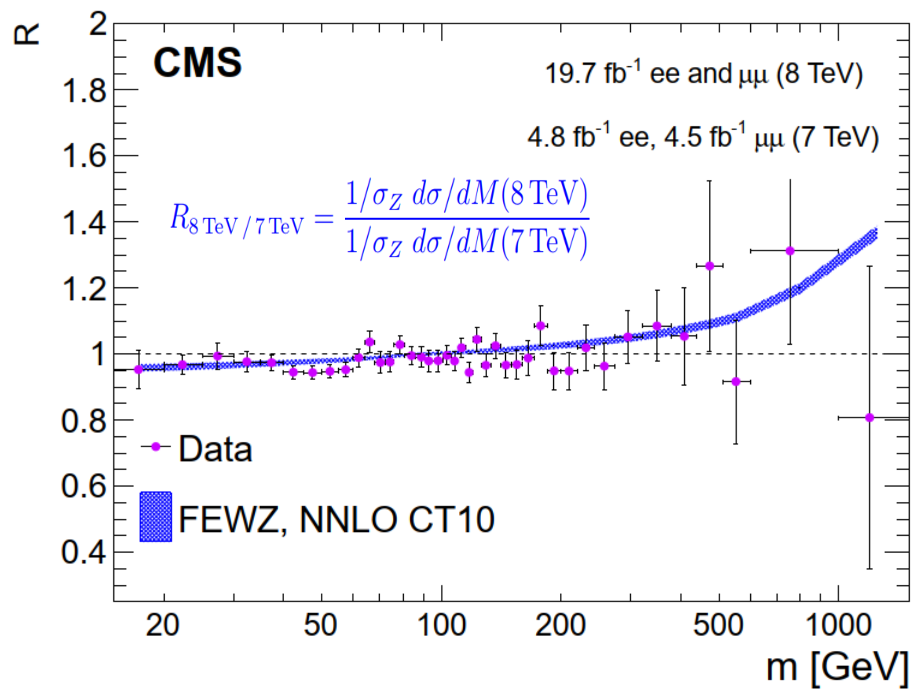


Drell-Yan Differential Cross Section

JHEP 12 (2019) 059



EPJ C 75 (2015) 147, arXiv:1412.1115



$3 \times 10^{-4} < x < 1.0$ and $6 \times 10^2 < Q^2 < 3 \times 10^6$ GeV^2

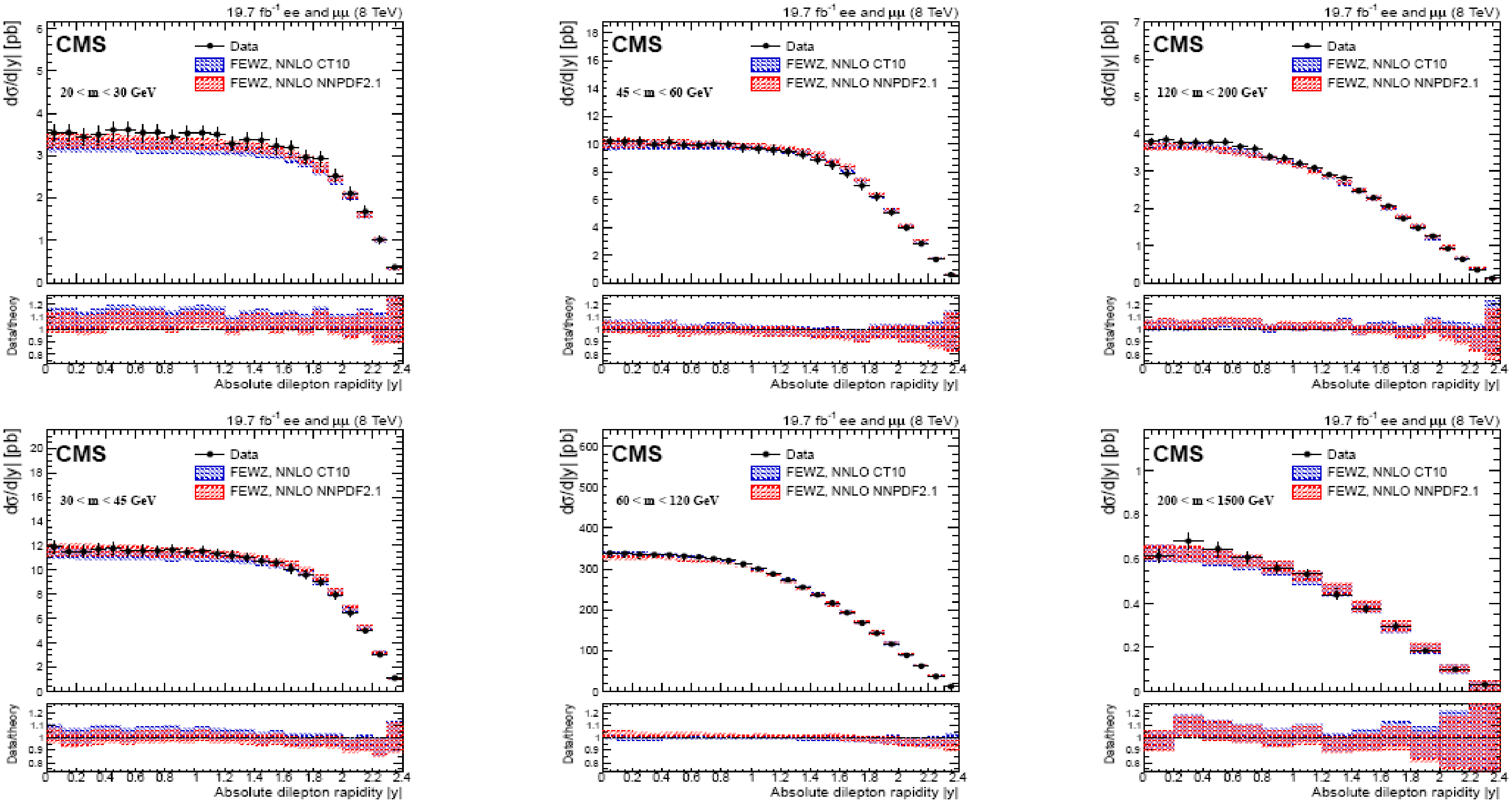
✓ The total cross section measurements are presented as a function of dilepton invariant mass in the range 15 to 3000 GeV

✓ The measured differential cross sections are in good agreement with the theoretical calculations (NNLO QCD + NLO EWK)

✓ The shape of the distribution is defined entirely by the √s and the Bjorken x dependencies of the PDFs, since the dependence on the hard scattering cross section is canceled out. In the Z peak region, the expected double ratio is close to 1 by definition

Drell-Yan Differential Cross Section vs Rapidity

EPJ C 75 (2015) 147, arXiv:1412.1115

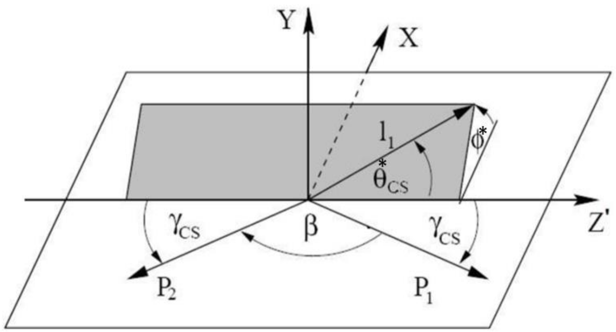


✓ We observe agreement of the cross section and double ratio measurement with the CT10 NNLO PDF theoretical prediction within uncertainties.

✓ The DY double-differential cross section and double ratio measurements presented here can be used to impose constraints on the quark and antiquark PDFs in a wide range of x.

Drell-Yan Angular Coefficients and Weak Mixing Angle

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



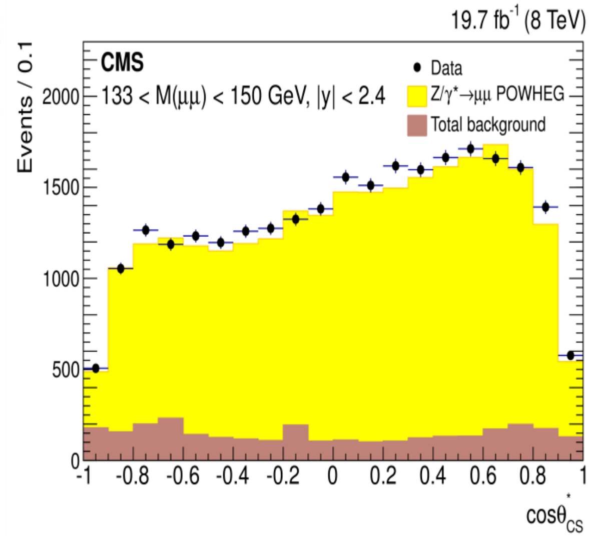
Integrated cross section by φ^*

$$\frac{d^2\sigma}{d\cos\theta^*} = 1 + A_4\cos\theta^* + \cos^2\theta^*$$

and

$$A_{FB} = \frac{3}{8}A_4 = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B},$$

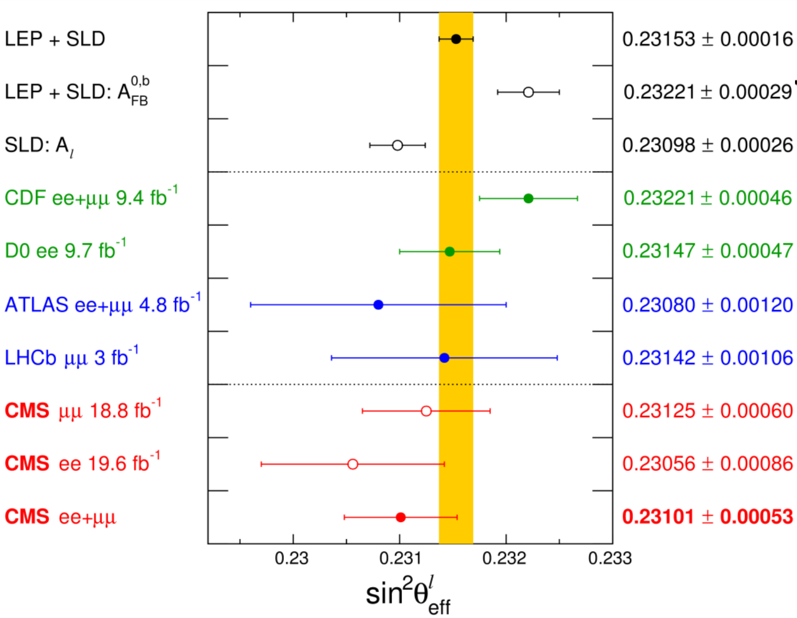
Lam-Tung Relation: $A_0 = A_2$

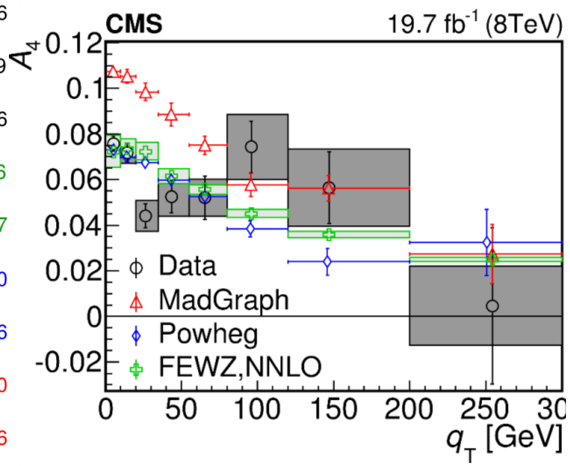


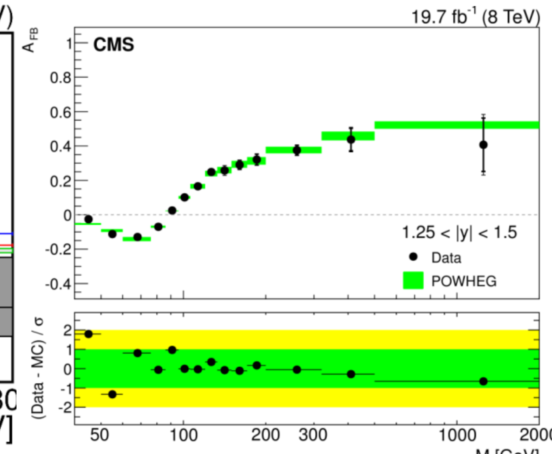
EPJ C 78 (2018) 701

PLB 750 (2015) 154

EPJ C 76 (2016) 325

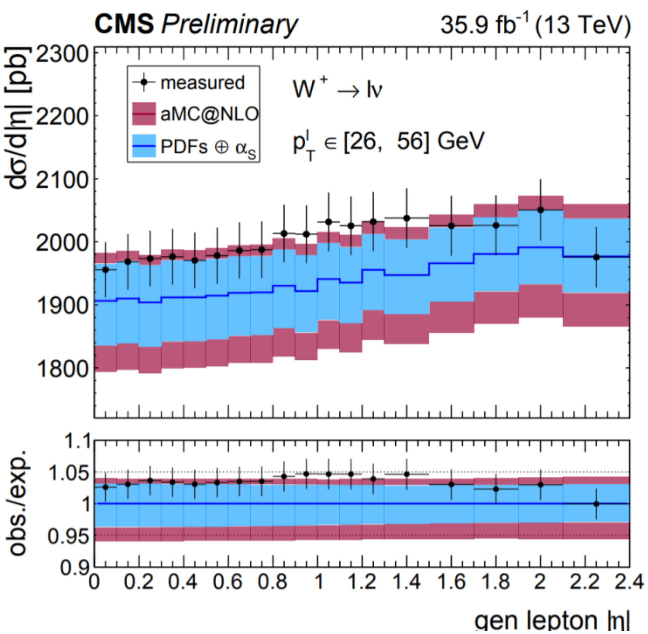


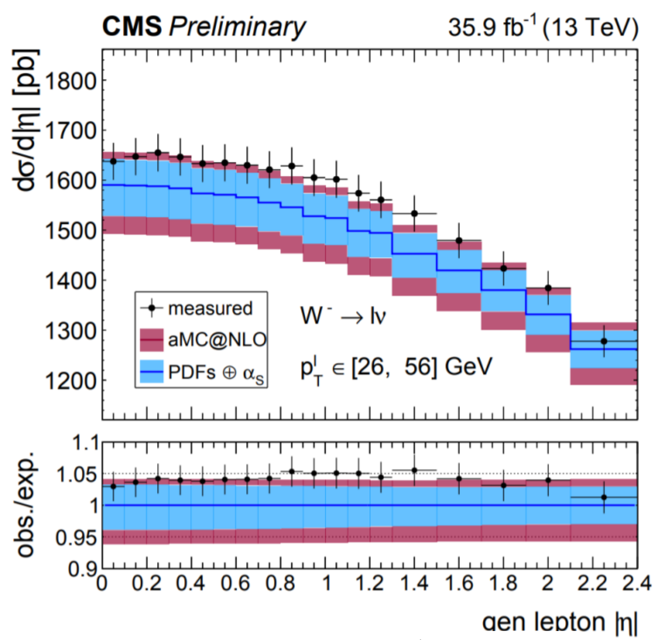




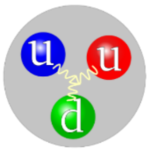
$$\sin^2\theta^{\ell}_{\text{eff}} = 0.23101 \pm 0.00053.$$

W Differential Cross Section and Charge Asymmetry



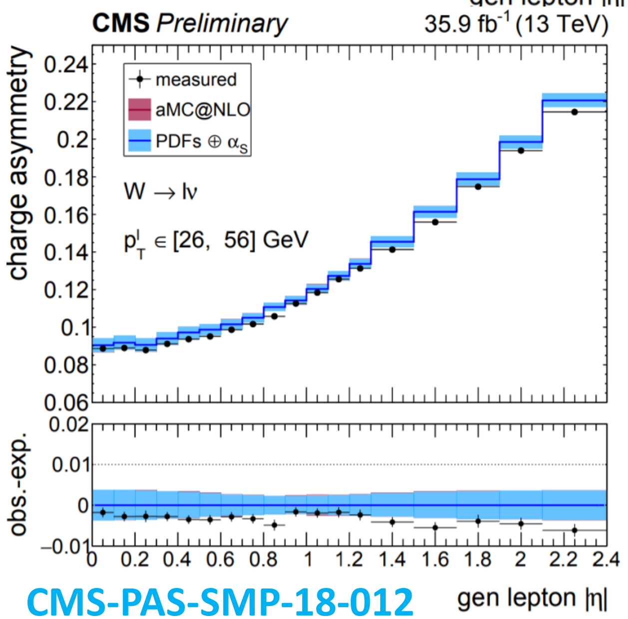


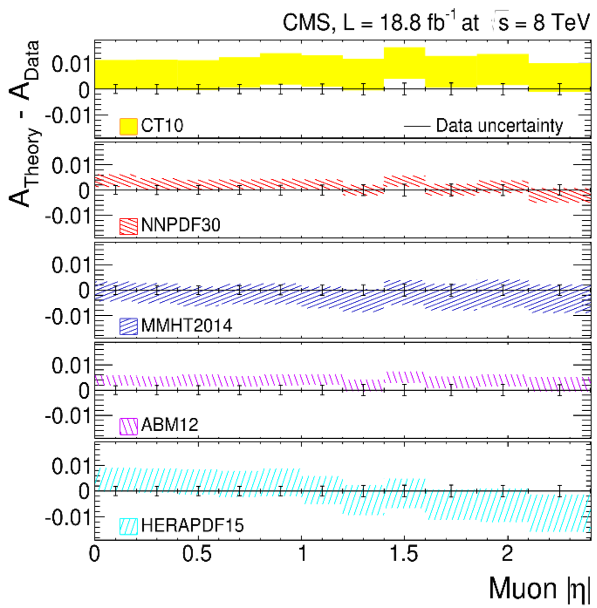
$$u\bar{d} \to W^+$$
$$d\bar{u} \to W^-$$

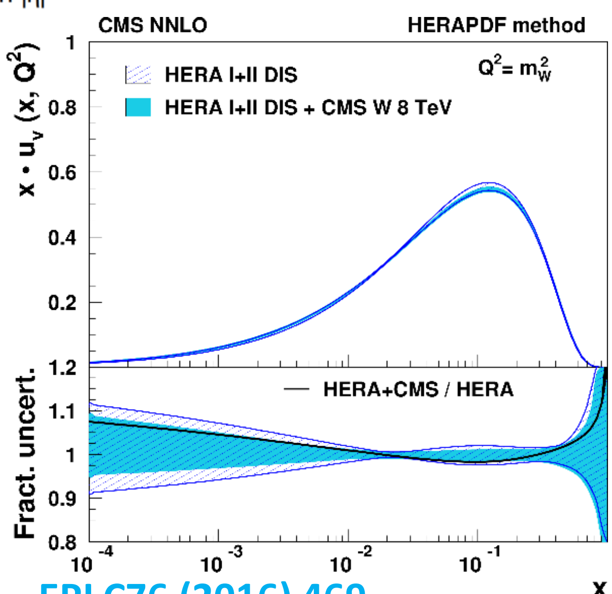


$$\mathcal{A}(\eta) = \frac{\sigma_\eta^+ - \sigma_\eta^-}{\sigma_\eta^+ + \sigma_\eta^-}$$

- ✓ Gives important constraints on the ratio of u and d quark distributions in the proton
- ✓ $sin^2\,\theta_W$ measurements



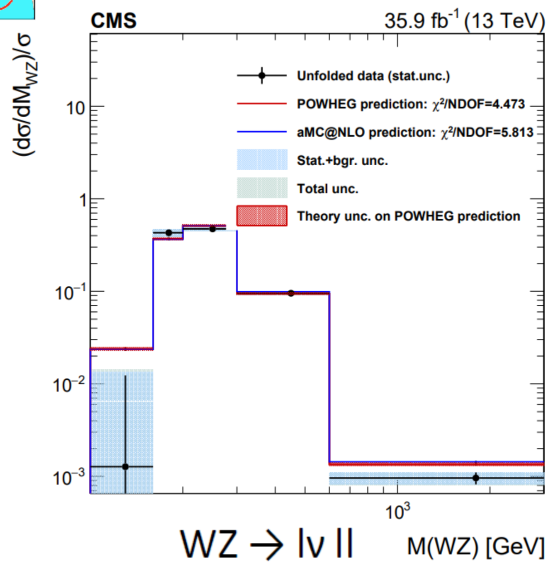




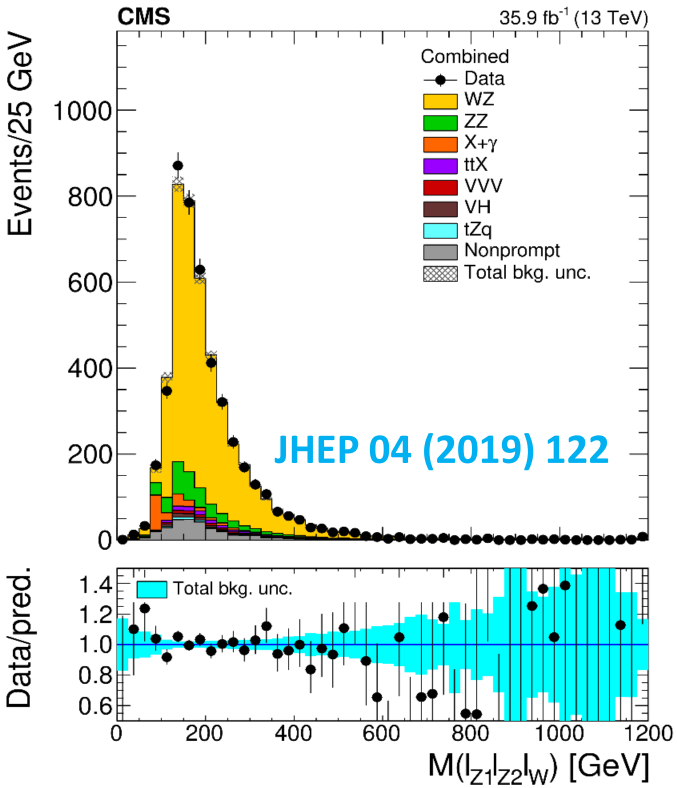
CMS-PAS-SMP-18-012

EPJ C76 (2016) 469

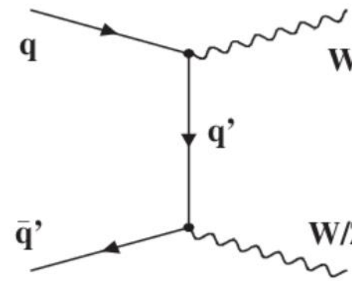
Multi-boson production



WZ → lν ll

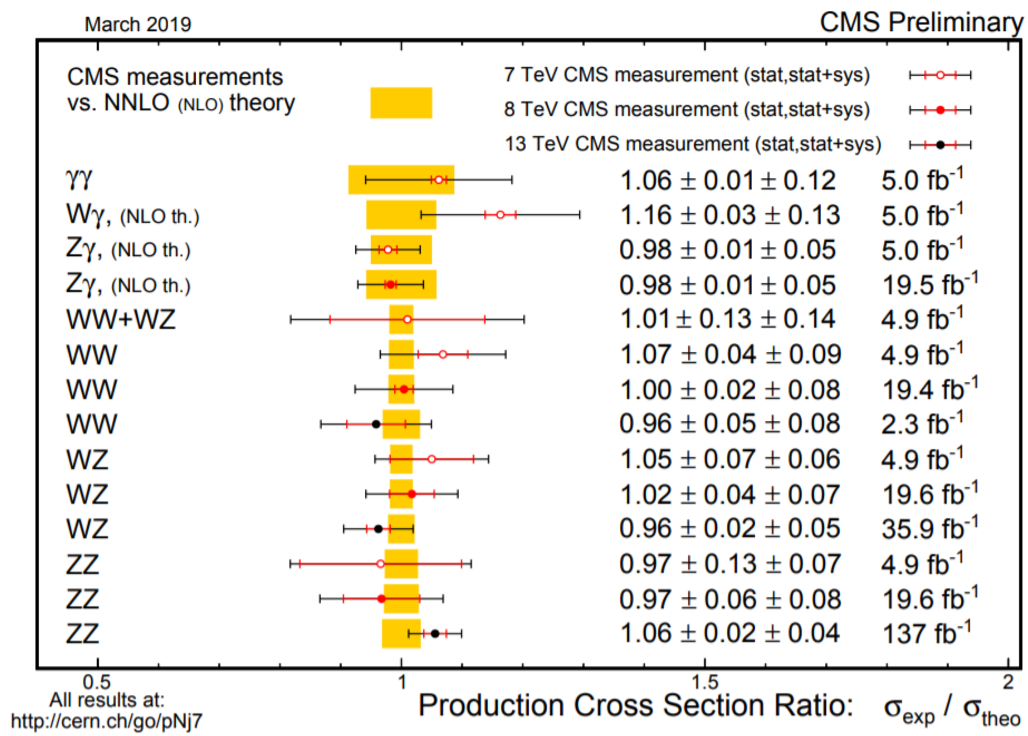


JHEP 04 (2019) 122



- Challenging analysis, benchmark for H→WW search
- Limits to anomalous WWγ and WWZ couplings set

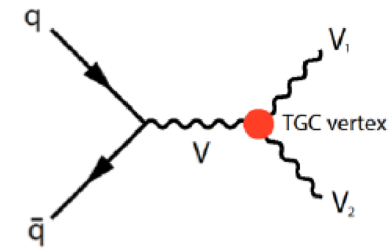
Category	$\sigma_{tot}(pp \to WZ)$ [pb]
eee	$47.11^{+5.01}_{-4.63}\,(\text{total}) = 47.11^{+2.88}_{-2.79}\,(\text{stat})^{+0.46}_{-0.41}\,(\text{theo})^{+3.89}_{-3.47}\,(\text{syst}) \pm 1.41\,(\text{lumi})$
eeμ	$47.16^{+3.87}_{-3.61}\,(\text{total}) = 47.16^{+2.31}_{-2.29}\,(\text{stat})^{+0.45}_{-0.38}\,(\text{theo})^{+2.83}_{-2.52}\,(\text{syst}) \pm 1.33\,(\text{lumi})$
e$\mu\mu$	$47.70^{+3.58}_{-3.55}\,(\text{total}) = 47.70^{+2.00}_{-1.96}\,(\text{stat})^{+0.45}_{-0.39}\,(\text{theo})^{+2.66}_{-2.61}\,(\text{syst}) \pm 1.42\,(\text{lumi})$
$\mu\mu\mu$	$49.00^{+3.18}_{-3.03}\,(\text{total}) = 49.00^{+1.57}_{-1.53}\,(\text{stat})^{+0.41}_{-0.35}\,(\text{theo})^{+2.42}_{-2.22}\,(\text{syst}) \pm 1.39\,(\text{lumi})$

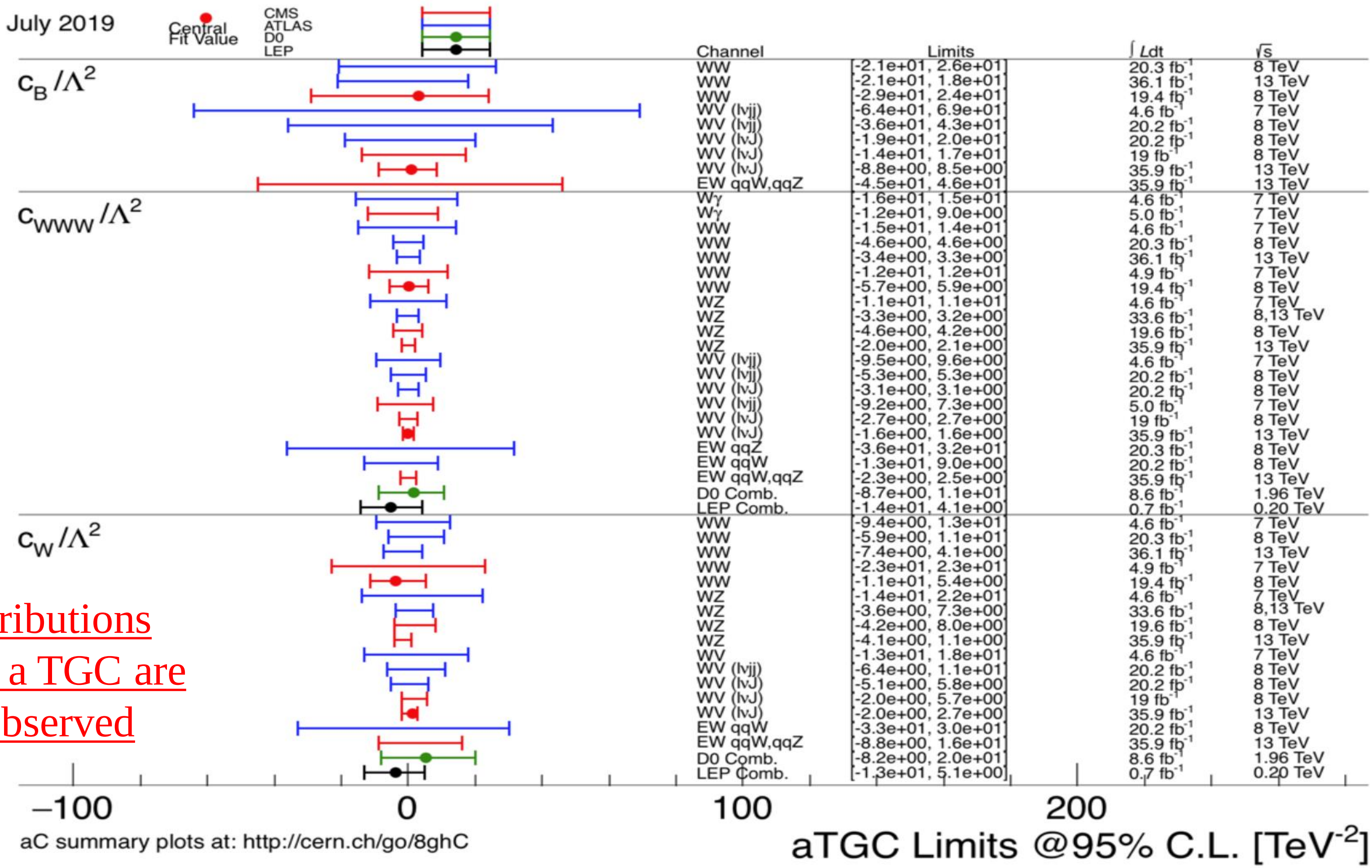


Anomalous Triple Gauge Couplings

Standard model predictions: $c_W = c_{WWW} = c_b = 0$

Non-zero c-coefficients could indicate a new physics!



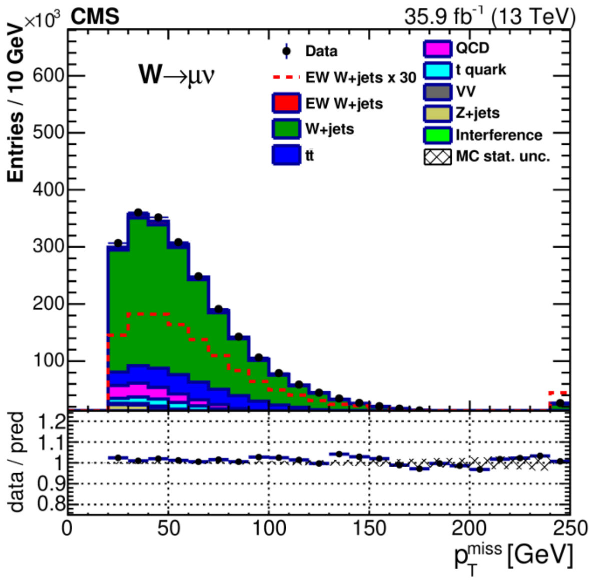


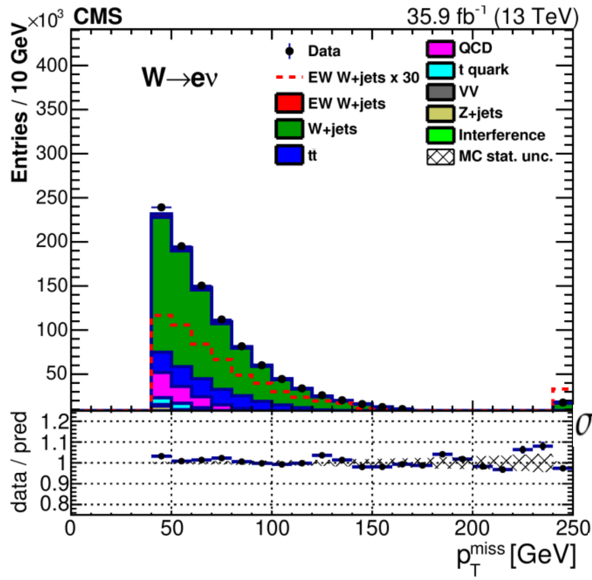
Contributions from a TGC are not observed

https://cms-results.web.cern.ch/cms-results/public-results/publications/SMP/index.html

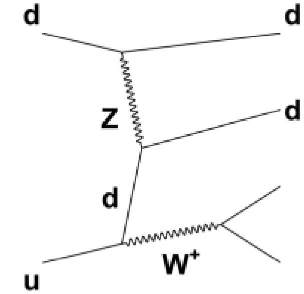
NLO pQCD Stringent Tests: V + jets, VV+jets

EPJ C 80 (2020) 43



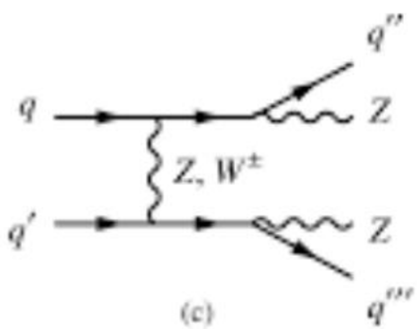


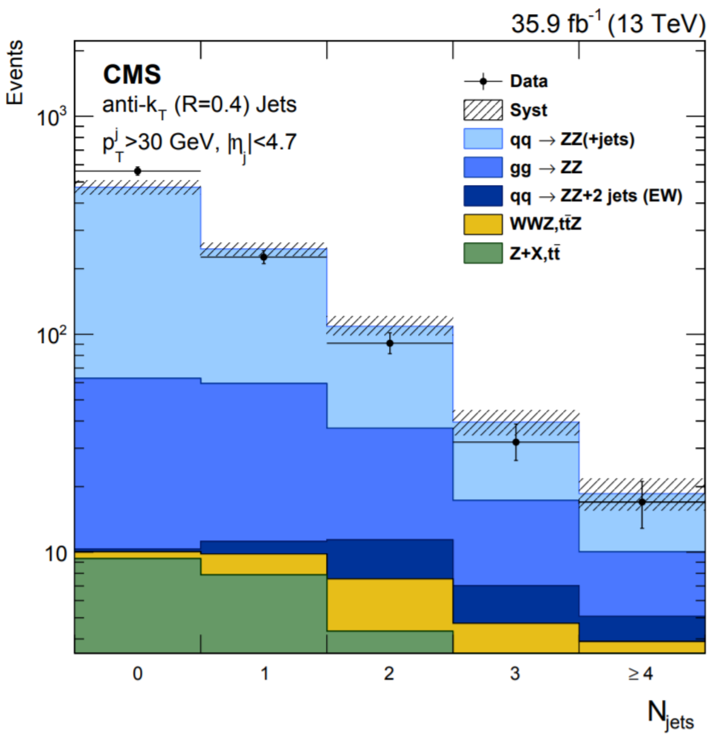
W + 2iets

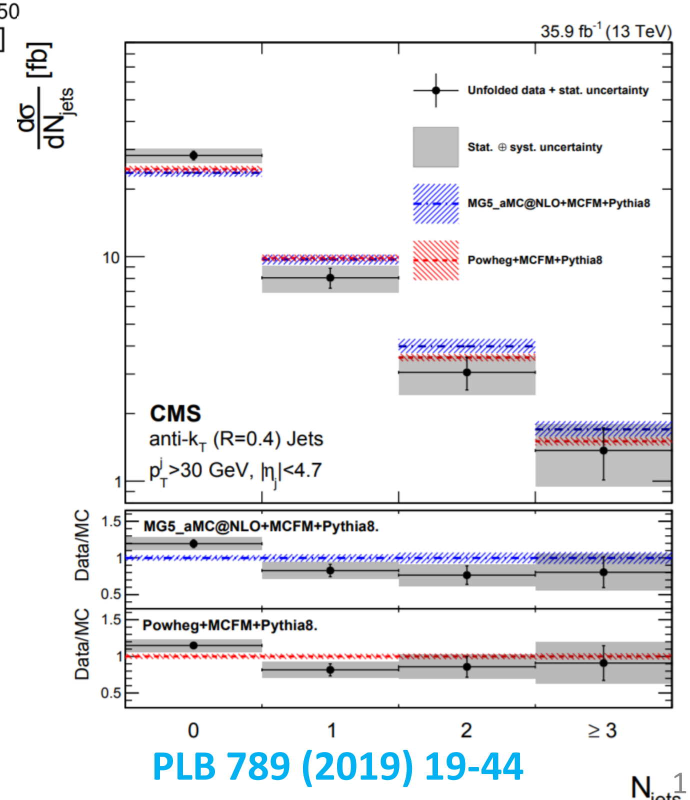


$$\sigma_{\mathrm{EW}}(\mathrm{Wjj}) = 6.23 \pm 0.12\,(\mathrm{stat}) \pm 0.61\,(\mathrm{syst})$$

ZZ + jets



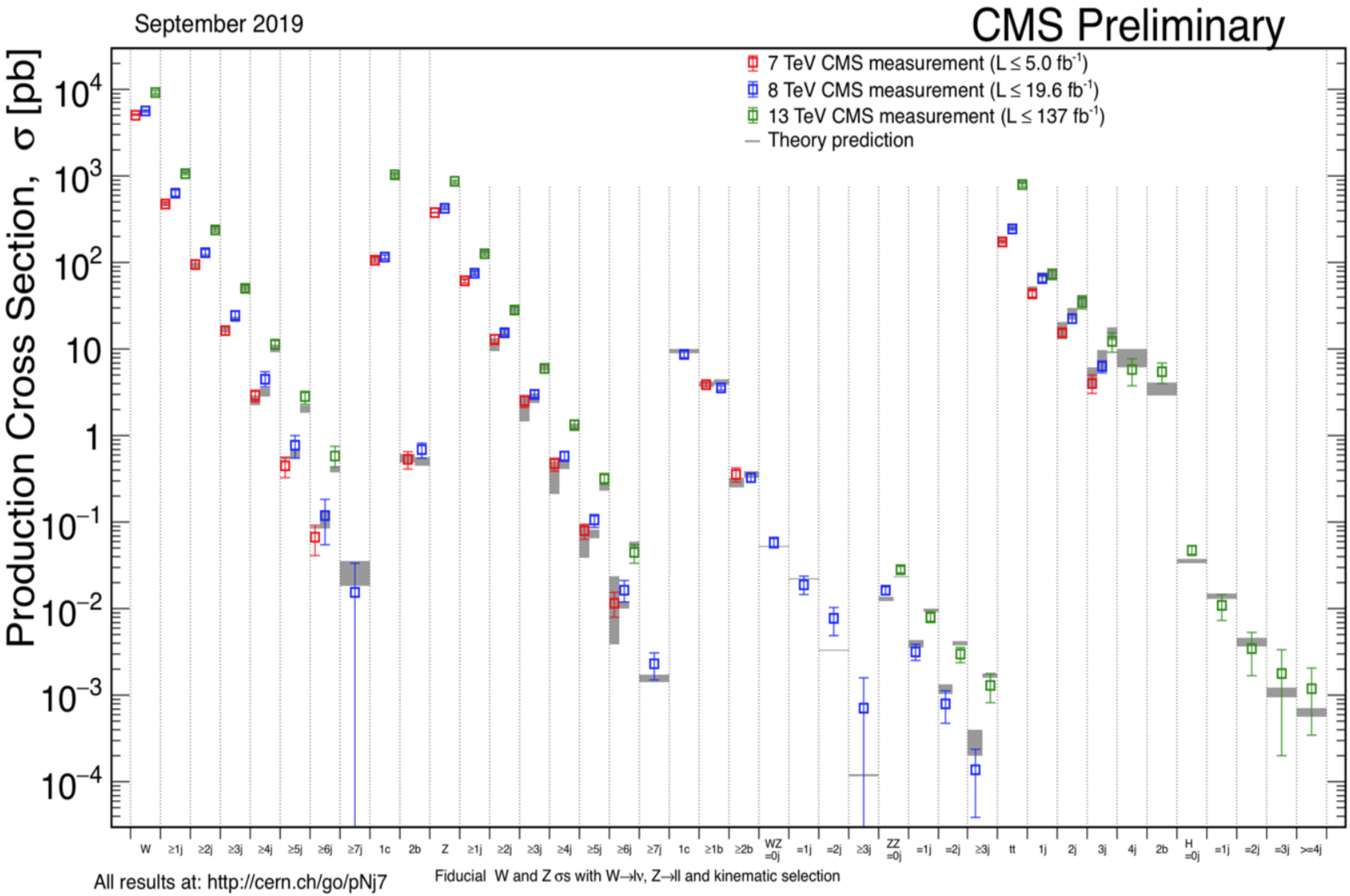




Agrees with the leading order standard model prediction!

PLB 789 (2019) 19-44

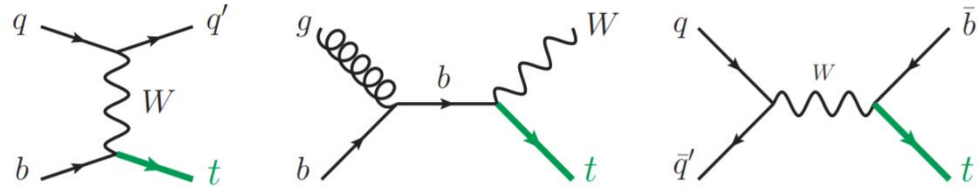
NLO pQCD Stringent Tests: V+ jets



https://cms-results.web.cern.ch/cms-results/public-results/publications/SMP/index.html

t – physics. Vtb Measurements

$$|f_{LV}\cdot V_{tb}| = \sqrt{\frac{\sigma^{meas.}_{t-chan.}}{\sigma^{theo.}_{t-chan.}}}, with |V_{td}|, |V_{ts}| \ll V_{tb}$$



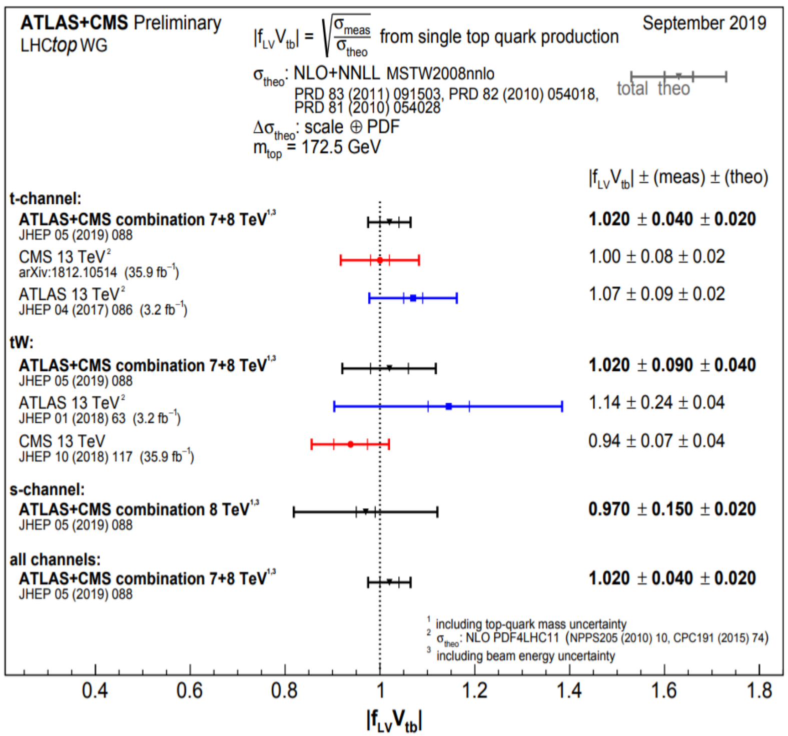
https://cms-results.web.cern.ch/cms-results/public-results/publications/PhysicsResultsTOP/index.html

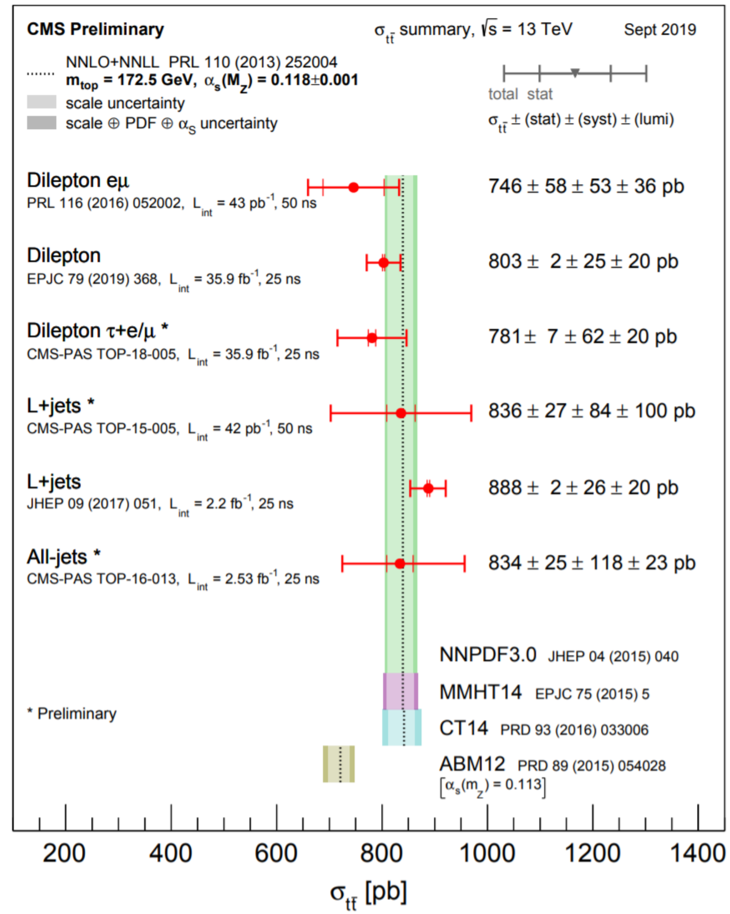
Single top quark productions has direct access to V_{tb} ($\sigma \sim V_{tb}^2$)

V_{tb} has been constrained in all t-channel and Wt-channel measurements

Assumptions:

- $BR(t \rightarrow Wb) \approx 1$
- $|V_{tb}| >> |V_{td}|, |V_{ts}|$
- $f_{LV} = 1$ for the SM





Rare decays: $B_S/B^0 \rightarrow \mu\mu$

SM predictions:

Br($B_S \rightarrow \mu\mu$): $(3.57\pm0.30)\times10^{-9}$

Br($B^0 \rightarrow \mu\mu$): $(1.07\pm0.10)\times10^{-10}$

$$\tau_{B^0_S} = 1.509 \pm 0.004\,\text{ps}$$

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = \frac{N_S}{N^{B^+}_{\rm obs}} \frac{f_u}{f_s} \frac{\varepsilon^{B^+}_{\rm tot}}{\varepsilon_{\rm tot}} \mathcal{B}(B^+)$$

$$f_s/f_u = 0.256 \pm 0.020$$

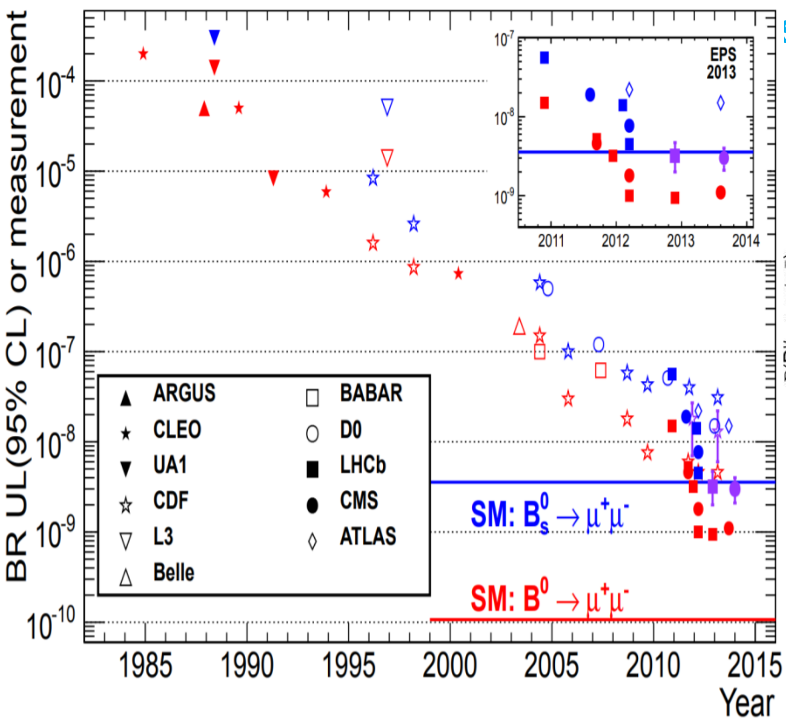
Measurements:

Br($B_S \rightarrow \mu\mu$): $(2.9\pm0.27)\times10^{-9}$

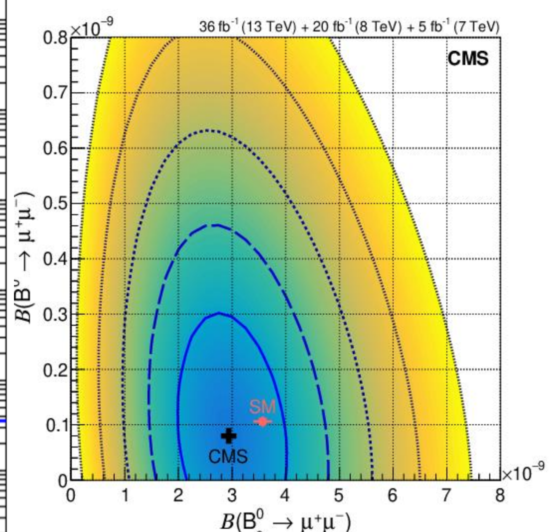
Br($B^0 \rightarrow \mu\mu$) < 3.6×10^{-10}

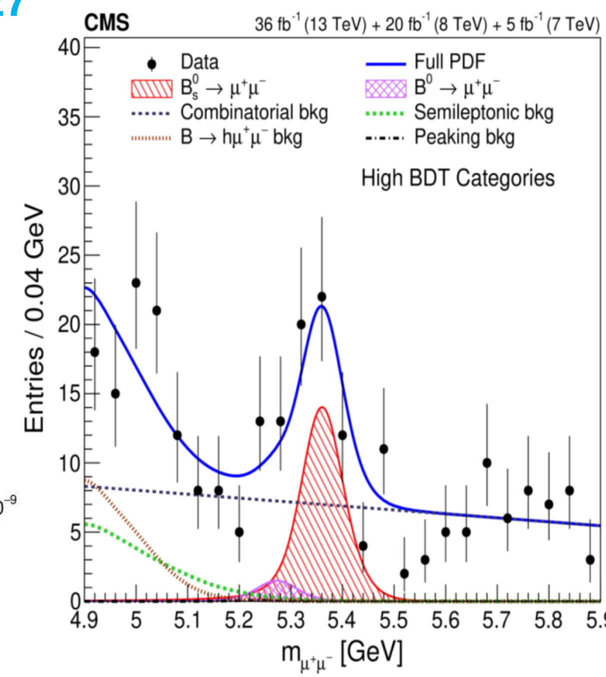
$$\tau_{\mu^+\mu^-} = 1.70\,^{+0.61}_{-0.44}\,\text{ps}$$

No significant excess from SM predictions are observed!



s.t. JHEP, arXiv:1910.12127

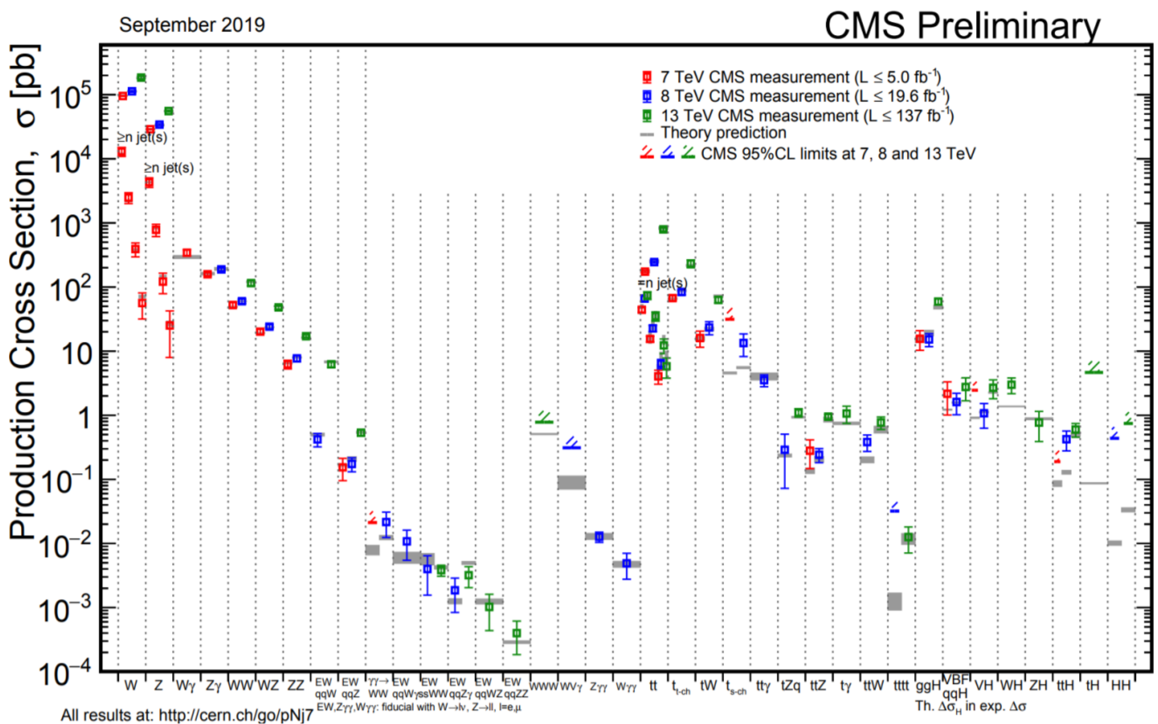




https://cms-results.web.cern.ch/cms-results/public-results/publications/BPH/index.html

Conclusions

- ✓ CMS shows a excellent performance to detect different signals and produced many EWK measurements at 7, 8 and 13 TeV
- ✓ Precision measurements of inclusive W and Z and di-boson production cross section with large statistic
- ✓ Detailed studies of differential cross sections and many observables, like asymmetries and angular coefficients
- ✓ W and Z production associated to jets, including Z plus b-jets, studied W polarization in W+jets
- ✓ All measurements are so far in agreement with theoretical predictions from the Standard model and results of another experiments. No new physic is observed

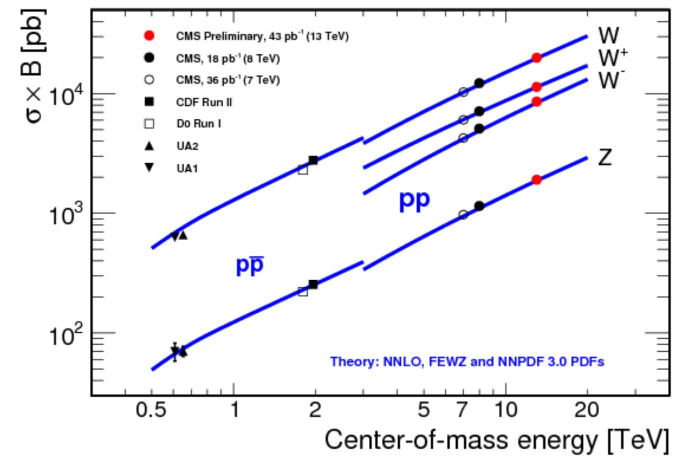


Thanks for your attention!

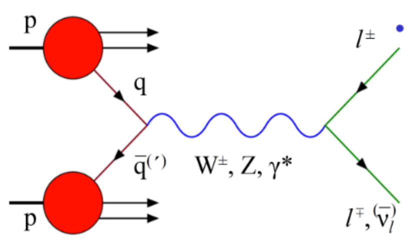
EWK Gauge Bosons: Z and W production

High rate at the LHC

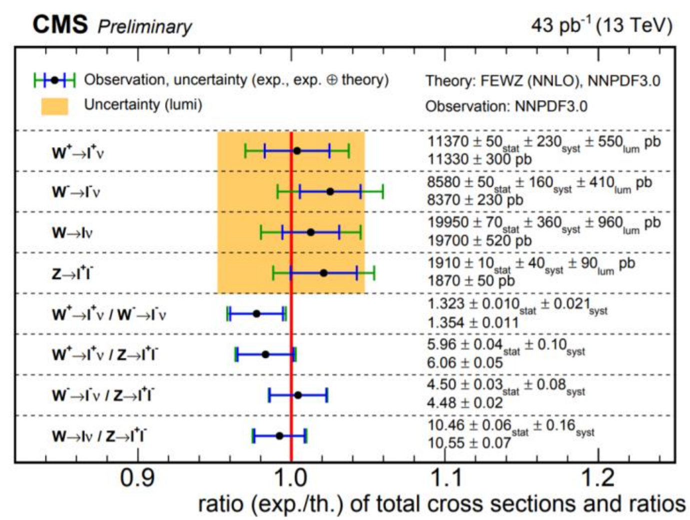
- ✓ Provides statistic to study inclusive and differential distributions
- ✓ Good understanding of the detectors allow for precision measurements
- ✓ Test p-QCD and PDF in different regimes
- ✓ Developments and testing of new MC generators and techniques



Channel	$\sigma \times \mathcal{B}$ [pb] (total)
e^+e^-	$1920 \pm 20\,(\text{stat}) \pm 60\,(\text{syst}) \pm 90\,(\text{lumi})$
$\mu^+\mu^-$	$1900 \pm 10\,(\text{stat}) \pm 50\,(\text{syst}) \pm 90\,(\text{lumi})$
$\ell^+\ell^-$	$1910 \pm 10\,(\text{stat}) \pm 40\,(\text{syst}) \pm 90\,(\text{lumi})$



W^+	$e^+\nu$	$11390 \pm 90\,(\text{stat}) \pm 340\,(\text{syst}) \pm 550\,(\text{lumi})$
	$\mu^+\nu$	$11350 \pm 60\,(\text{stat}) \pm 320\,(\text{syst}) \pm 550\,(\text{lumi})$
	$\ell^+\nu$	$11370 \pm 50\,(\text{stat}) \pm 230\,(\text{syst}) \pm 550\,(\text{lumi})$
W^-	$e^-\nu$	$8680 \pm 80\,(\text{stat}) \pm 250\,(\text{syst}) \pm 420\,(\text{lumi})$
	$\mu^-\nu$	$8510 \pm 60\,(\text{stat}) \pm 210\,(\text{syst}) \pm 410\,(\text{lumi})$
	$\ell^-\nu$	$8580 \pm 50\,(\text{stat}) \pm 160\,(\text{syst}) \pm 410\,(\text{lumi})$
W	$e\nu$	$20070 \pm 120\,(\text{stat}) \pm 570\,(\text{syst}) \pm 960\,(\text{lumi})$
	$\mu\nu$	$19870 \pm 80\,(\text{stat}) \pm 460\,(\text{syst}) \pm 950\,(\text{lumi})$
	$\ell\nu$	$19950 \pm 70\,(\text{stat}) \pm 360\,(\text{syst}) \pm 960\,(\text{lumi})$



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