Institute of High Energy Physics
Chinese Academy of Sciences

Standard Model and Electroweak Results from CMS

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(On Behalf of CMS Collaboration)

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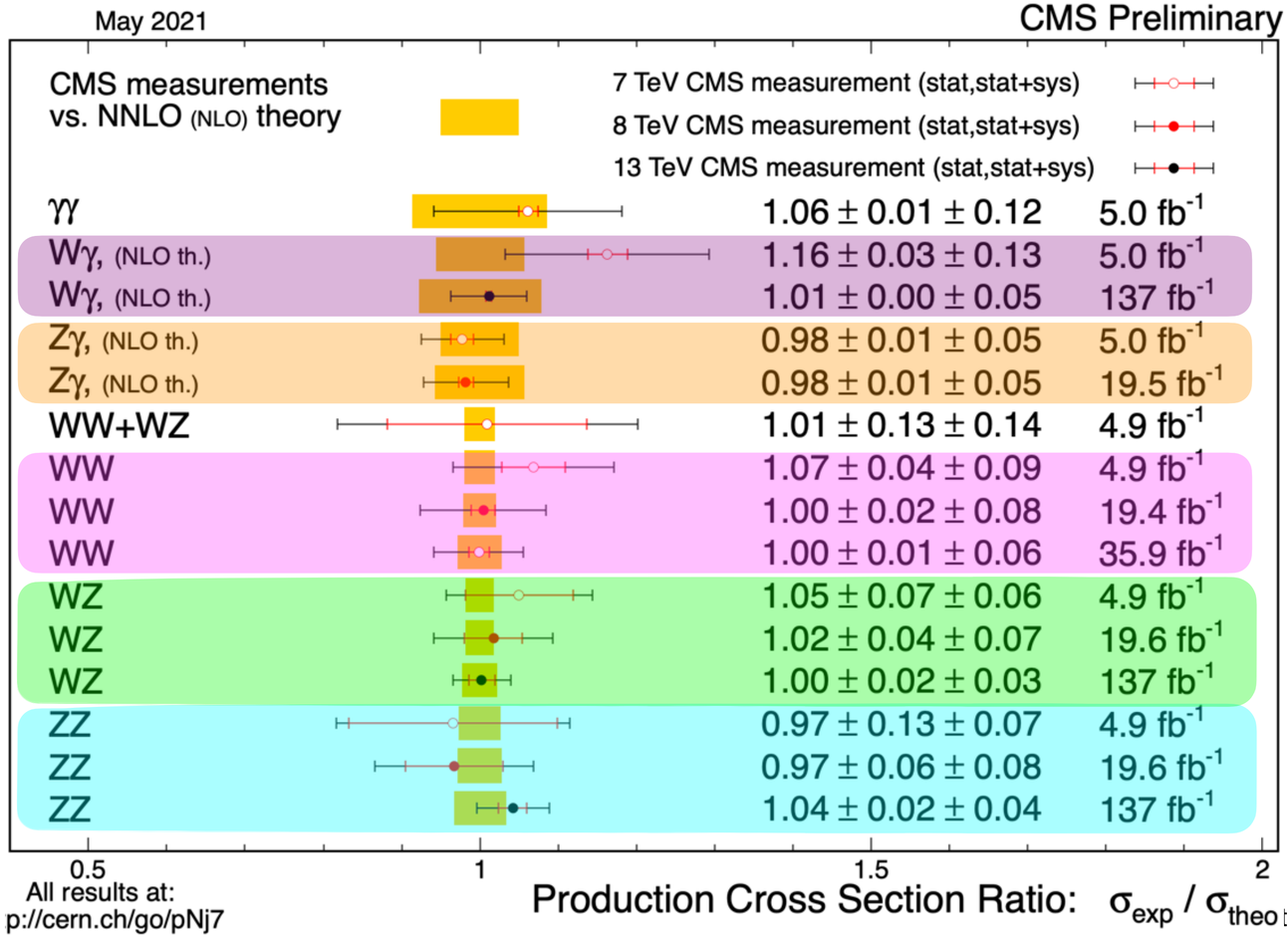
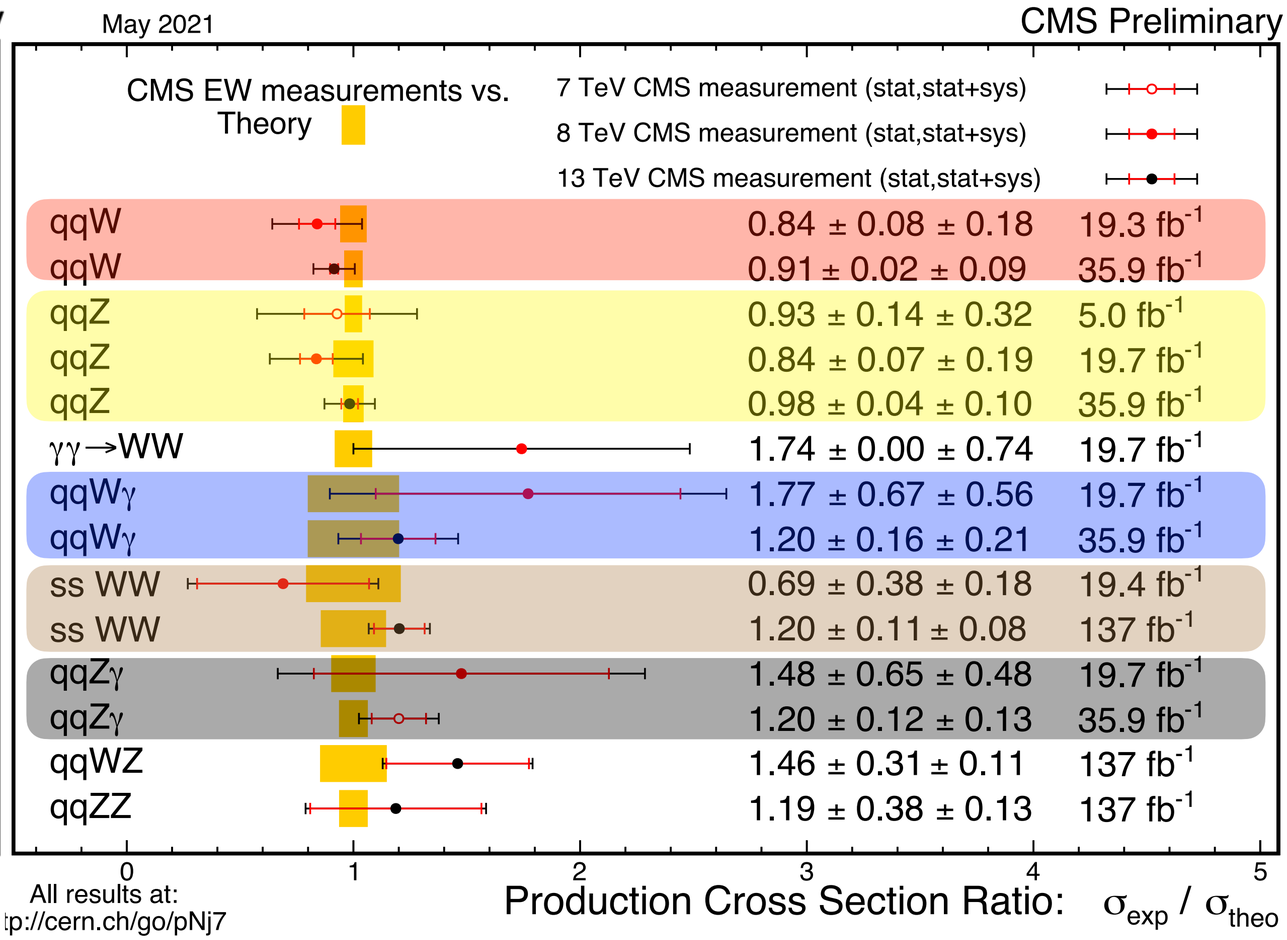
Background reference: https://www.symmetrymagazine.org/article/six-fabulous-facts-about-the-standard-model

Introduction

- Summary of recent results out of huge number of SM EW results from CMS
- EW boson (in association with jets) plays important role in testing the SM
  - Also, it contributes as background for almost all new physics searches.
- Main focus in this talk:
  - Production of EW boson cross-section measurement and EFT interpretation (some of them)
- Now, with large CMS data its great opportunity to extend and improve SM measurements and performed the remaining channels which was not explored before.

SM Electroweak boson results overview





Selection of analysis

- Measurement of the electroweak production of Zγ and two jets in proton-proton collisions at sqrt(s) = 13 TeV and constraints on anomalous quartic gauge couplings, CMS SMP-20-016
- Measurements of the pp→W±γγ and pp→Zγγ cross sections at sqrt(s) = 13 TeV and limits on anomalous quartic gauge couplings, CMS SMP-19-013
- Measurement of Wγ production cross-section in proton-proton collision at sqrt(S) = 13 TeV and constraints on effective field theory coefficients, CMS-SMP-19-002
- Measurement of the pp -> WZ inclusive and differential cross-sections, polarisation angles and search for anomalous gauge couplings at sqrt(s) = 13 TeV, CMS PAS SMP-20-014
- Measurement of the differential cross sections of the production of Z+jets and γ+jets and of Z boson emission collinear with a jet in pp collision at sqrt(s) = 13 TeV, CMS-SMP-19-010
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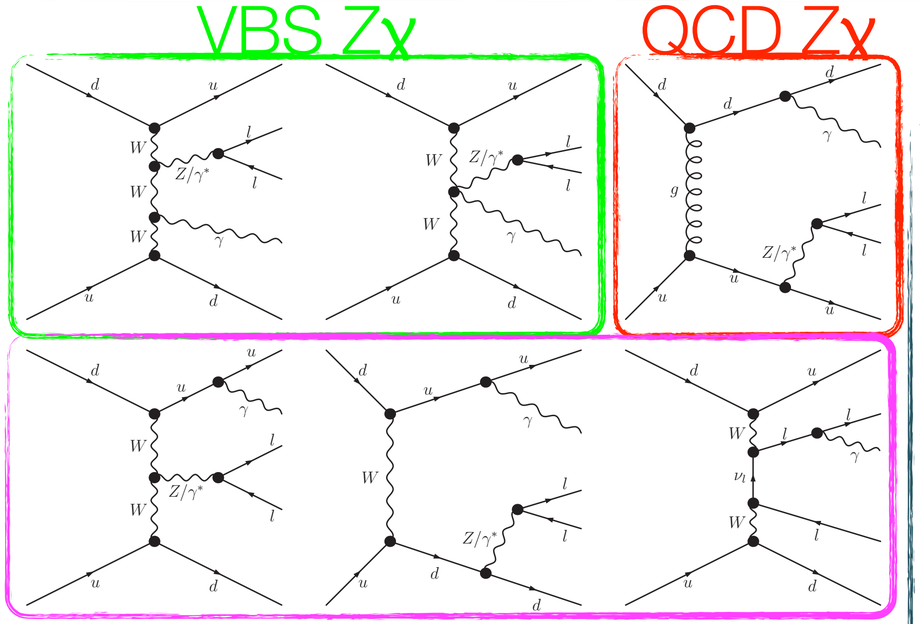
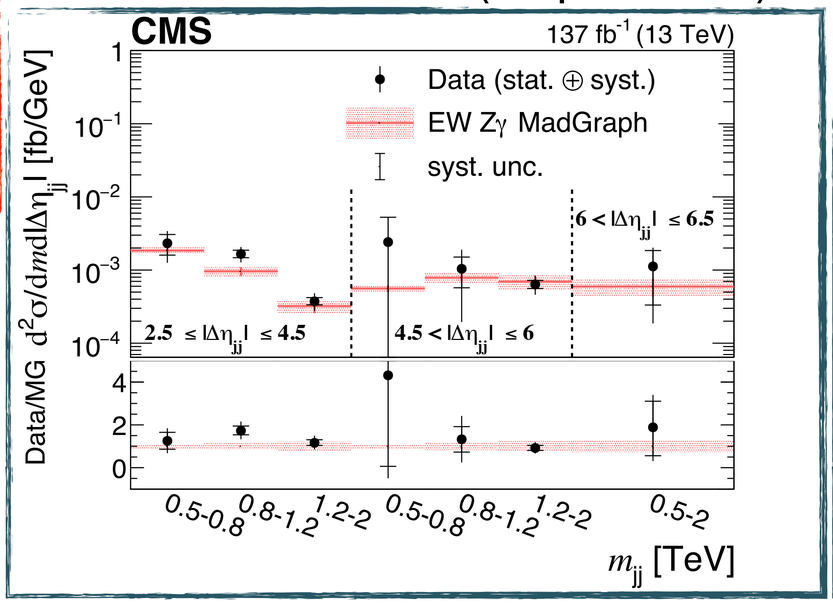
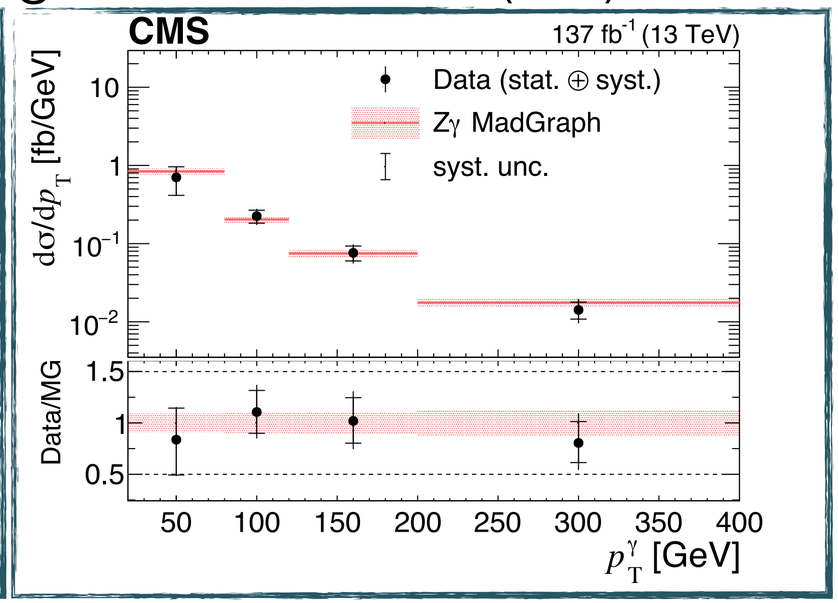
EW production of Zγ+2j (First observation & measurement)

CMS-SMP-20-016



Observed (expected) significance = 9.4 (8.5) SD





Unfolded differential cross-section for EW Zγjj

Main event selection:

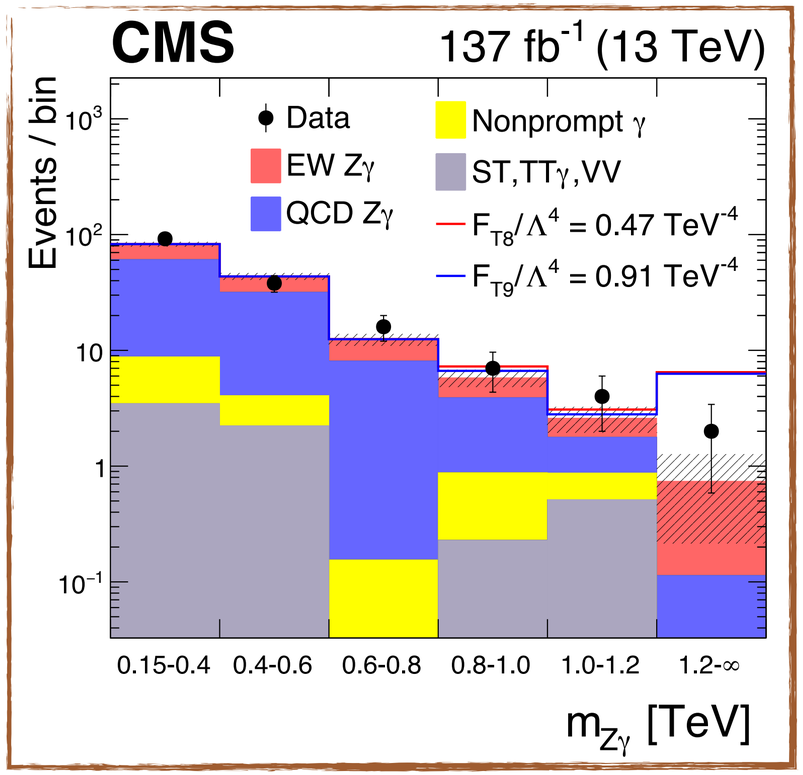
1. EW signal region: m_{jj}>500 GeV, $|\Delta\eta_{jj}|$>2.5, $\Delta\phi_{z\gamma,jj} > 1.9$, $\eta^* = |\eta_{Z\gamma} - (\eta_{j1} + \eta_{j2})/2| < 2.4$
2. Fiducial volume: m_{jj}>500 GeV, $|\Delta\eta_{jj}|$>2.5
3. aQGC region: m_{jj}>500 GeV, $|\Delta\eta_{jj}|$>2.5, $p_T^{\gamma} > 120$

EW production of Zγ+2j (First observation & measurement)

- Effective field theory (EFT) approach
- 16 independent dimension-8 operators
- Invariant mass of z-boson and photon was used to extract the limit

Coupling	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity bound
F_{M0}/Λ^4	−12.5	12.8	−15.8	16.0	1.3
F_{M1}/Λ^4	−28.1	27.0	−35.0	34.7	1.5
F_{M2}/Λ^4	−5.21	5.12	−6.55	6.49	1.5
F_{M3}/Λ^4	−10.2	10.3	−13.0	13.0	1.8
F_{M4}/Λ^4	−10.2	10.2	−13.0	12.7	1.7
F_{M5}/Λ^4	−17.6	16.8	−22.2	21.3	1.7
F_{M7}/Λ^4	−44.7	45.0	−56.6	55.9	1.6
F_{T0}/Λ^4	−0.52	0.44	−0.64	0.57	1.9
F_{T1}/Λ^4	−0.65	0.63	−0.81	0.90	2.0
F_{T2}/Λ^4	−1.36	1.21	−1.68	1.54	1.9
F_{T5}/Λ^4	−0.45	0.52	−0.58	0.64	2.2
F_{T6}/Λ^4	−1.02	1.07	−1.30	1.33	2.0
F_{T7}/Λ^4	−1.67	1.97	−2.15	2.43	2.2
F_{T8}/Λ^4	−0.36	0.36	−0.47	0.47	1.8
F_{T9}/Λ^4	−0.72	0.72	−0.91	0.91	1.9

aQGC region



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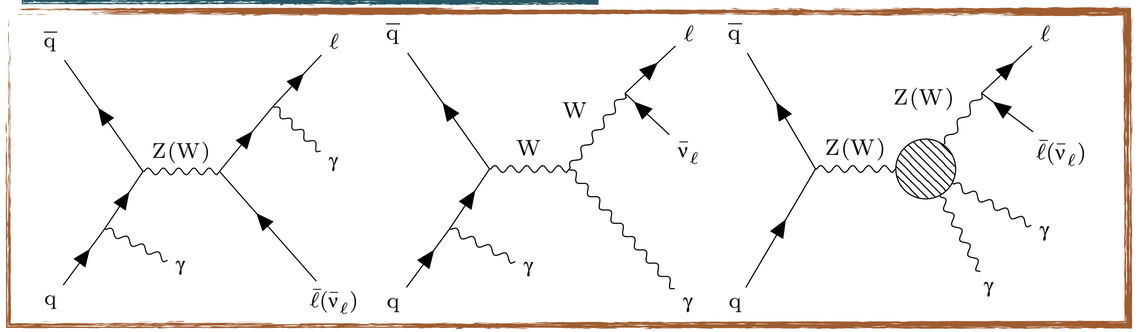
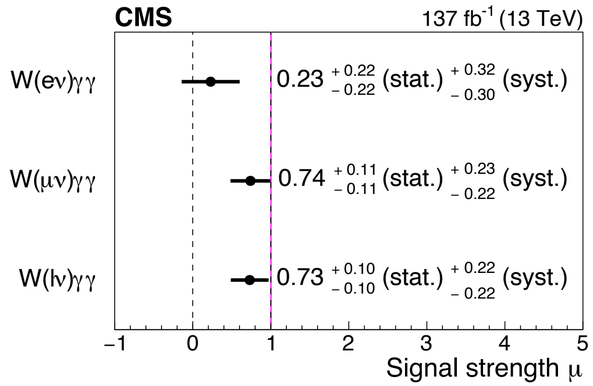
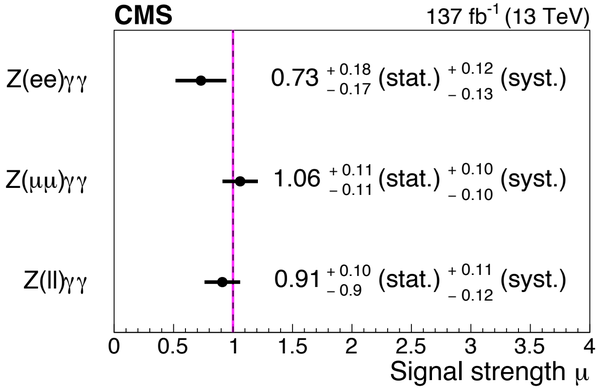
EW production of W/Zγγ (First measurement of cross-section)

CMS-SMP-19-013



Vγγ production





Parameter	Wγγ (TeV^{-4}) Expected	Wγγ (TeV^{-4}) Observed	Zγγ (TeV^{-4}) Expected	Zγγ (TeV^{-4}) Observed
f_{M2}/Λ^4	$[-57.3, 57.1]$	$[-39.9, 39.5]$	—	—
f_{M3}/Λ^4	$[-91.8, 92.6]$	$[-63.8, 65.0]$	—	—
f_{T0}/Λ^4	$[-1.86, 1.86]$	$[-1.30, 1.30]$	$[-4.86, 4.66]$	$[-5.70, 5.46]$
f_{T1}/Λ^4	$[-2.38, 2.38]$	$[-1.70, 1.66]$	$[-4.86, 4.66]$	$[-5.70, 5.46]$
f_{T2}/Λ^4	$[-5.16, 5.16]$	$[-3.64, 3.64]$	$[-9.72, 9.32]$	$[-11.4, 10.9]$
f_{T5}/Λ^4	$[-0.76, 0.84]$	$[-0.52, 0.60]$	$[-2.44, 2.52]$	$[-2.92, 2.92]$
f_{T6}/Λ^4	$[-0.92, 1.00]$	$[-0.60, 0.68]$	$[-3.24, 3.24]$	$[-3.80, 3.88]$
f_{T7}/Λ^4	$[-1.64, 1.72]$	$[-1.16, 1.16]$	$[-6.68, 6.60]$	$[-7.88, 7.72]$
f_{T8}/Λ^4	—	—	$[-0.90, 0.94]$	$[-1.06, 1.10]$
f_{T9}/Λ^4	—	—	$[-1.54, 1.54]$	$[-1.82, 1.82]$

$$\sigma(W\gamma\gamma)^{meas} = 13.6^{+1.9}_{-1.9}(stat)^{+4.0}_{-4.0}(syst) \pm 0.08(PDF + scale)\ fb$$

$$\sigma(Z\gamma\gamma)^{meas} = 5.41^{+0.58}_{-0.55}(stat)^{++0.64}_{-0.70}(syst) \pm 0.06(PDF + scale)\ fb$$

Madgraph prediction at NLO:

$$\sigma(W\gamma\gamma) = 18.70 \pm 0.03(MC\ stat) \pm 0.12(PDF + scale)\ fb$$

$$\sigma(Z\gamma\gamma) = 5.96 \pm 0.01(MC\ stat) \pm 0.06(PDF + scale)\ fb$$

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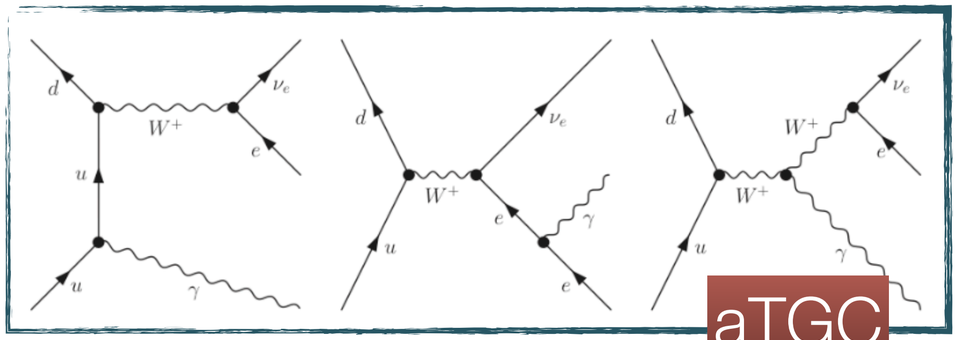
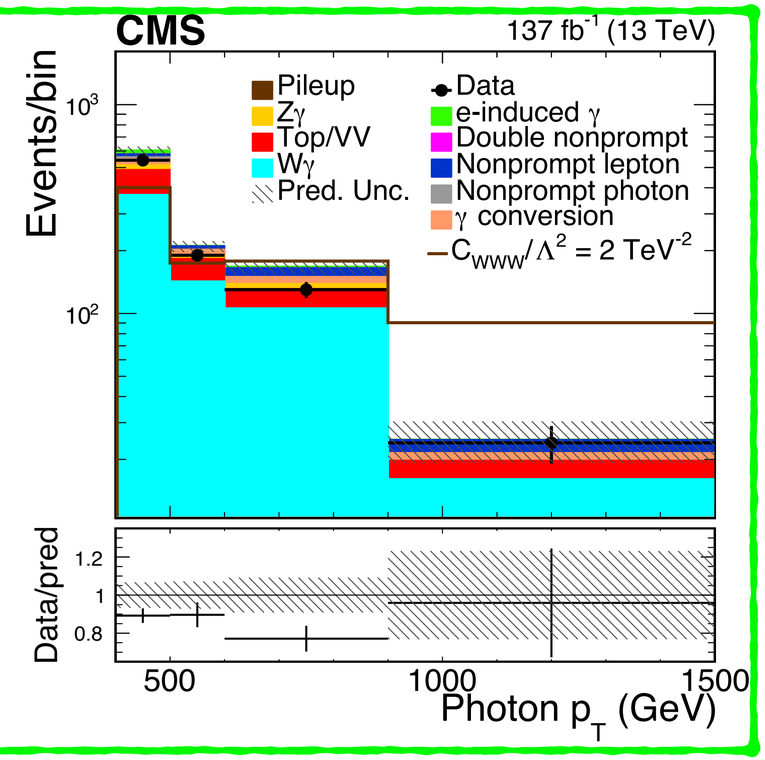
Wγ production cross-section & constraint on EFT coefficients

CMS-SMP-19-002

$pp \rightarrow l^{+}\nu_{l}\gamma$ *production*





Measured cross-section = 15.58±0.05(stat)±0.73(cyst)±0.15(Theo)pb
Cross-section from MG5 at NLO QCD = 15.4±1.2(scale)±0.1(PDF)pb
Cross-section from POWHEG at NLO QCD = 22.4±3.2(scale)±0.1(PDF)pb

Coefficient	Exp. lower	Exp. upper	Obs. lower	Obs. upper
c_{WWW}/Λ^2	−0.85	0.87	−0.90	0.91
c_B/Λ^2	−46	45	−40	41
$c_{\overline{W}WW}/\Lambda^2$	−0.43	0.43	−0.45	0.45
$c_{\overline{W}}/\Lambda^2$	−23	22	−20	20

Most stringent limit on coefficient CWWW

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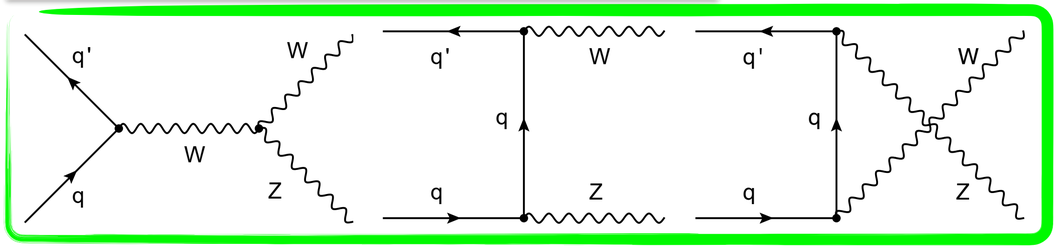
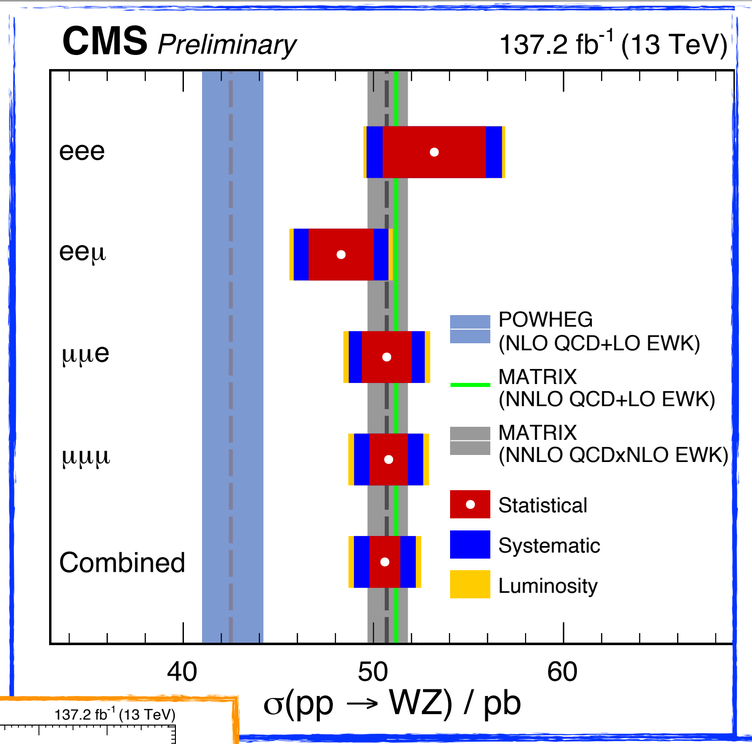
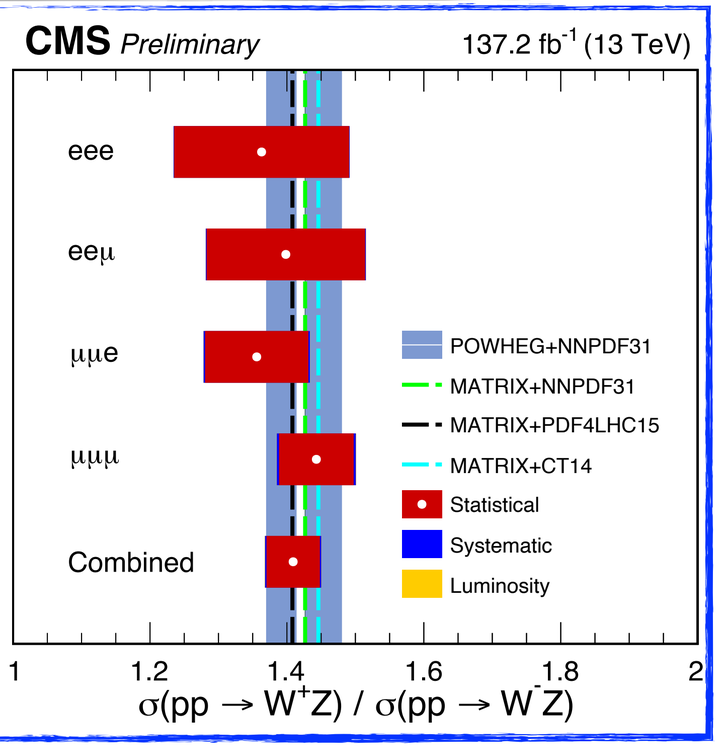
WZ inclusive and differential cross-section, polarisation angle measurement & aGC

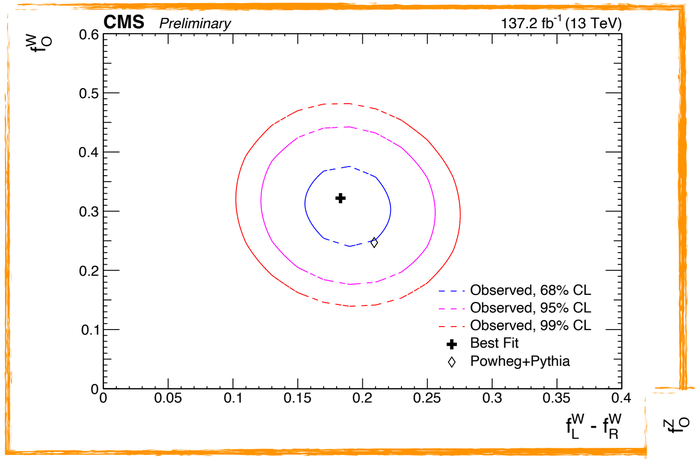
CMS PAS SMP-20-014

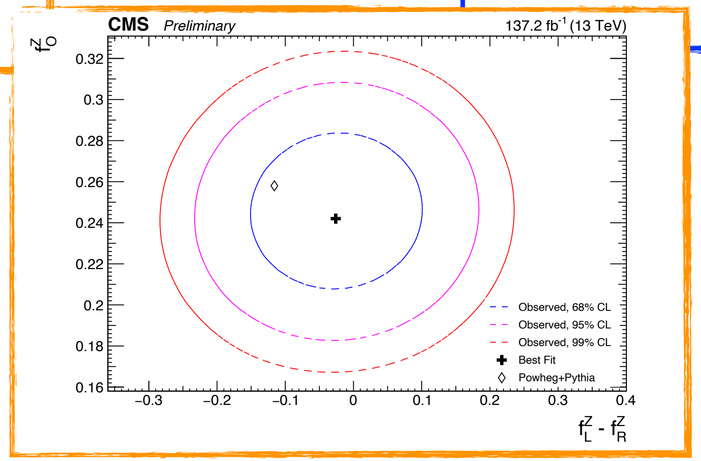
cross-section measurement











Polarisation measurement in f_{LR}-f_0 parameter plane

Parameter	95% CI, Exp. (TeV^{-2})	95% CI, Obs. (TeV^{-2})	Best fit, Obs. (TeV^{-2})
c_W/Λ^2	$[-2.05, 1.27]$	$[-2.52, 0.33]$	-1.34
c_{WWW}/Λ^2	$[-1.27, 1.33]$	$[-1.04, 1.19]$	0.15
c_b/Λ^2	$[-86.0, 125.0]$	$[-42.7, 113.0]$	43.6
$\tilde{c}_{WWW}/\Lambda^2$	$[-0.76, 0.65]$	$[-0.62, 0.53]$	-0.03
$\tilde{c}_W/\Lambda^2$	$[-46.1, 46.1]$	$[-45.9, 45.9]$	0.0

EFT parameter constraints

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Z/γ+jets differential cross section measurement

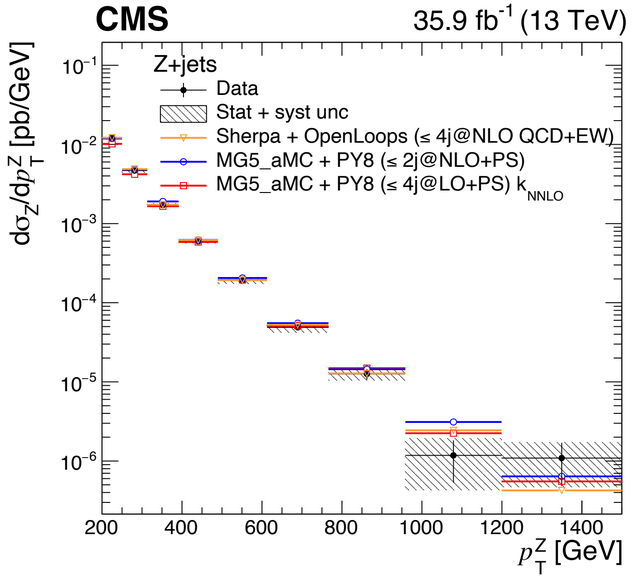
CMS-SMP-19-010

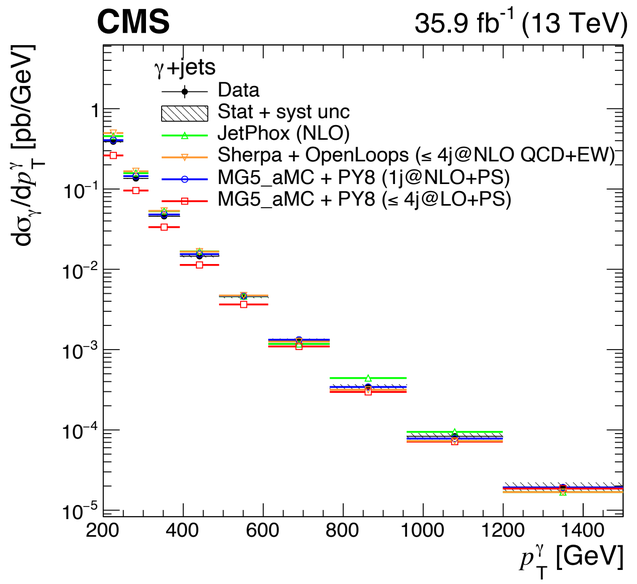
Main event selection (Z+jets):

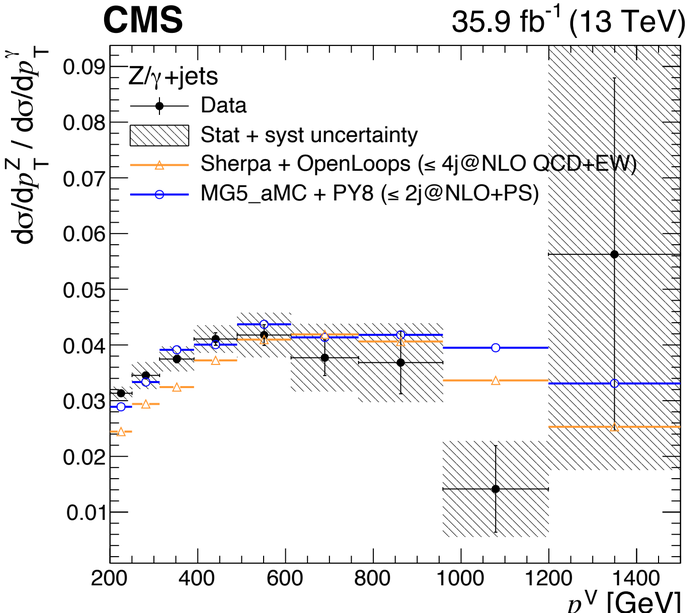
- Z boson pT > 200 GeV, |η|<2.4
- Leading jet pT > 100 GeV, |η|<2.4
- All jets pT > 40 GeV, |η|<2.4

Main event selection (γ+jets):

- >=1 tight, isolated photon with pT>200 GeV, |η| <1.4
- Leading jet pT > 100 GeV, |η|<2.4
- All jets pT > 40 GeV, |η|<2.4



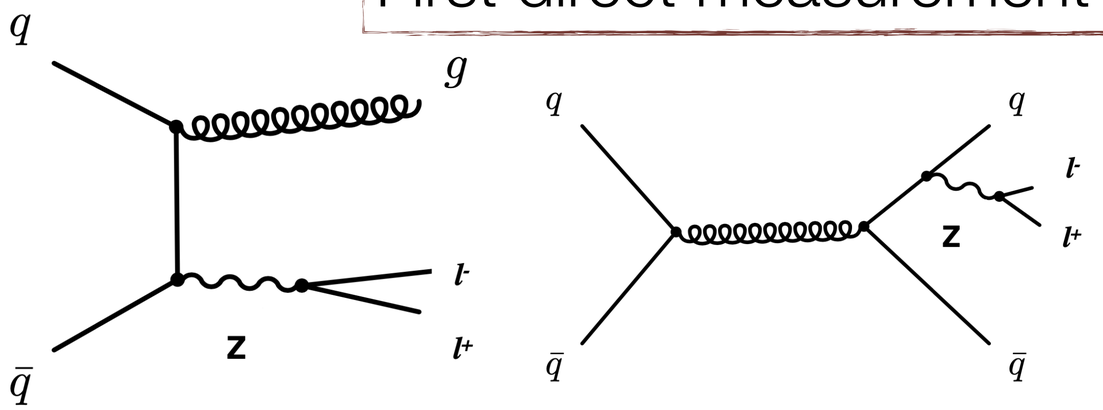




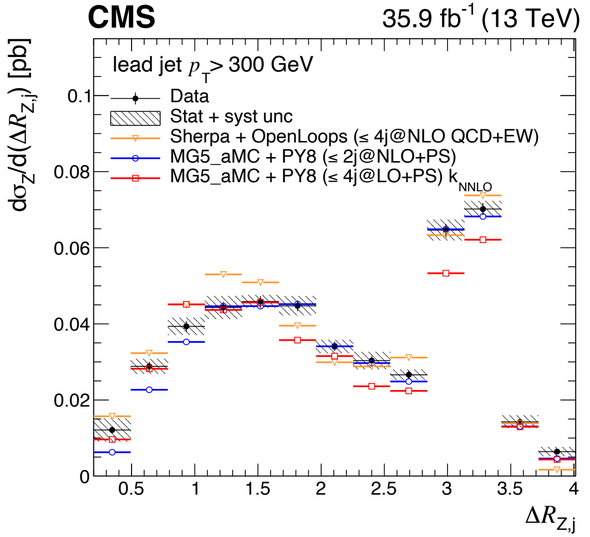
Z/γ+jets differential cross section measurement
(Z boson emission collinear with jet)

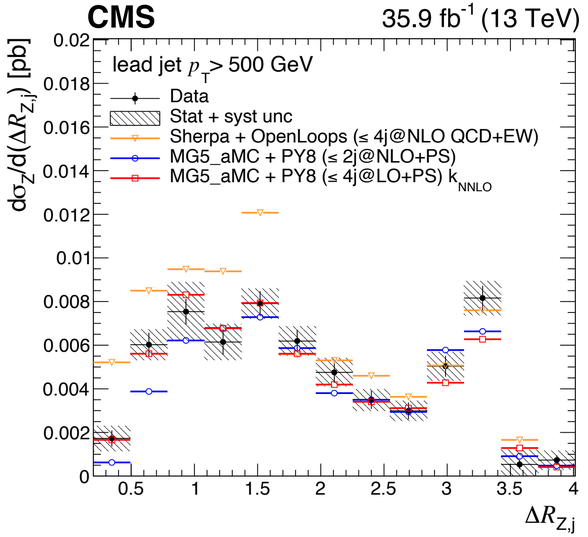
CMS-SMP-19-010

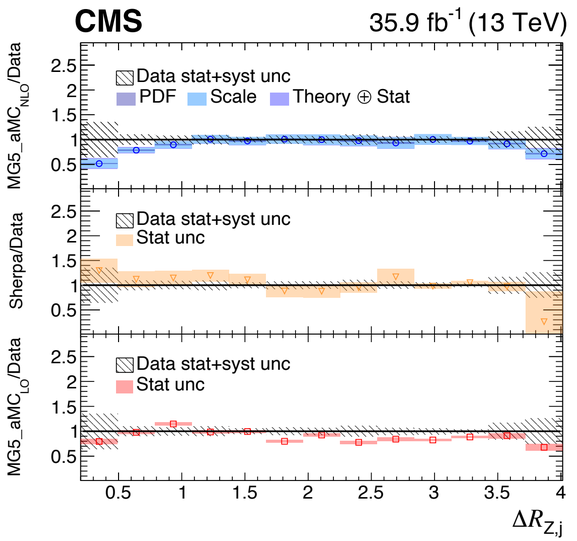
First direct measurement of Z Boson emitted colinearly with jet

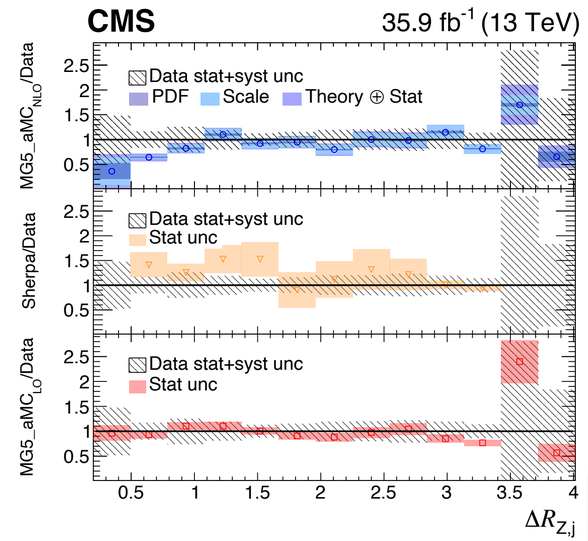


LO: Z and jet are back to back
NLO: Because of contribution from events
Where z is emitted collinear with jet, Z & jets are not back to back.









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- All jets pT > 40 GeV, |η|<2.4

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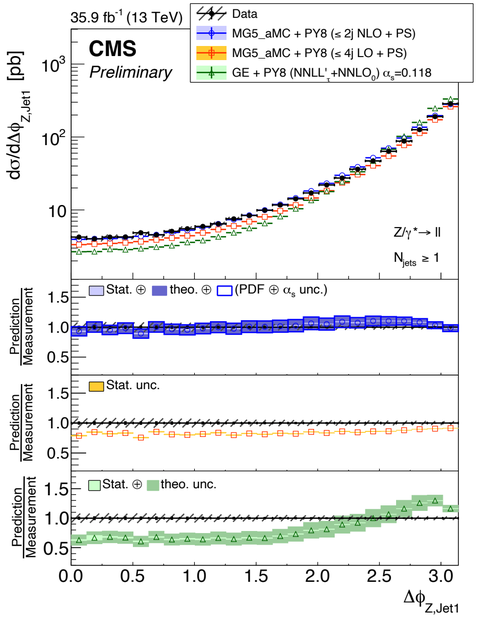
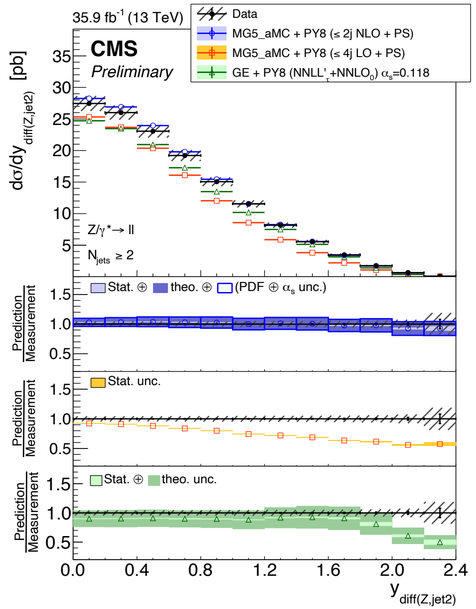
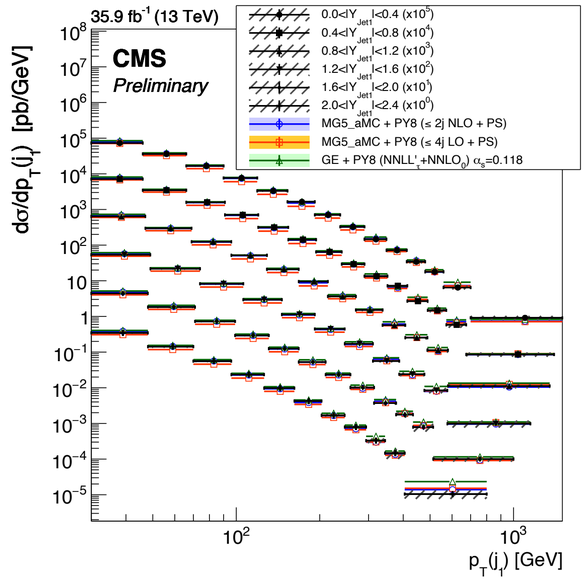
Z+jets differential cross section measurement

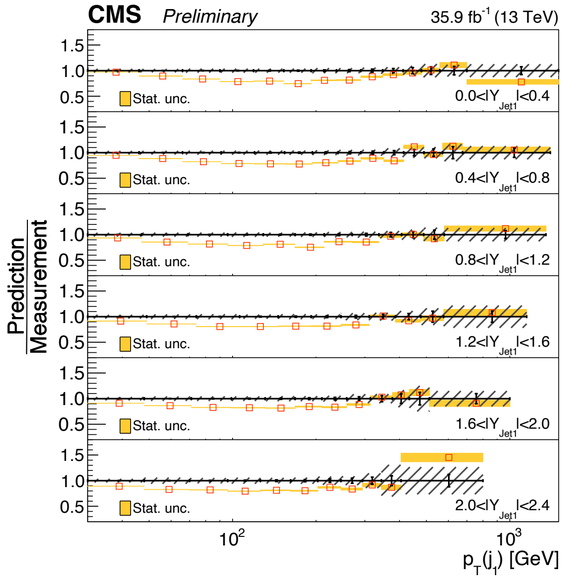
CMS-SMP-19-009

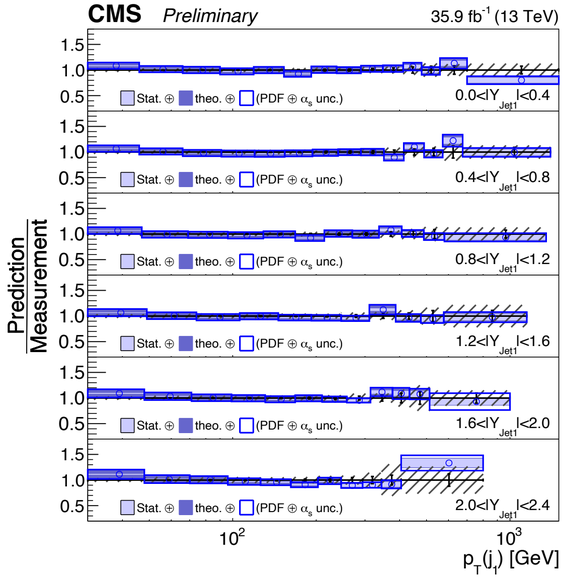
- Benchmark for many important analysis
- Accurately constrain the PDF and probe the strong coupling.
- Presents result with upto 8 jets inclusively and five jets differentially.

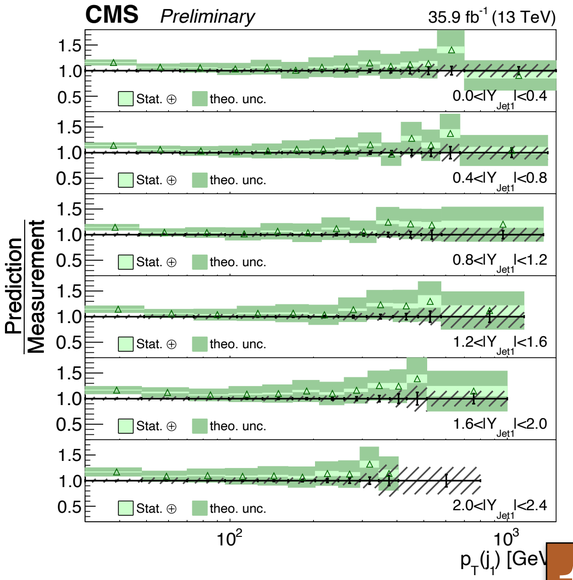






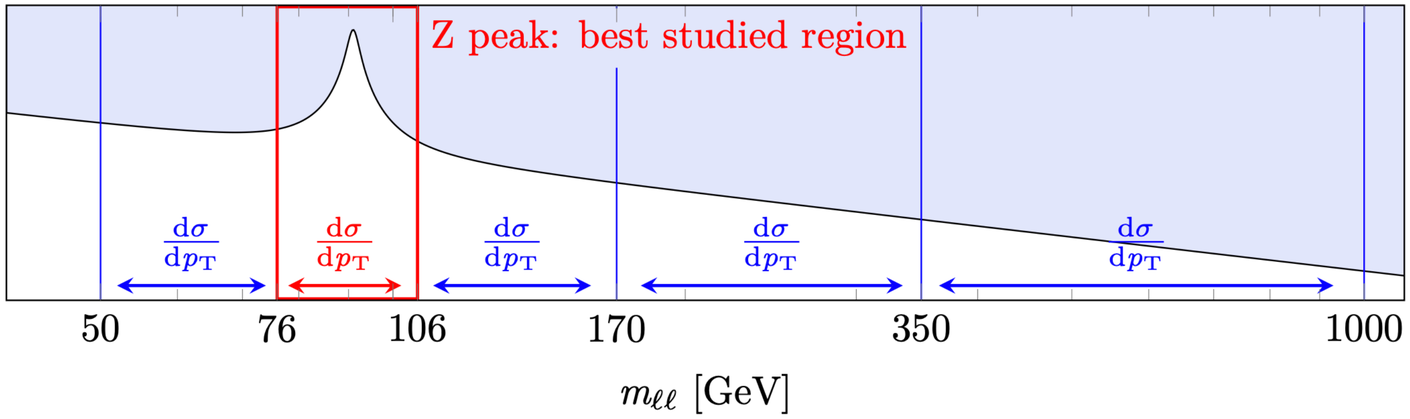




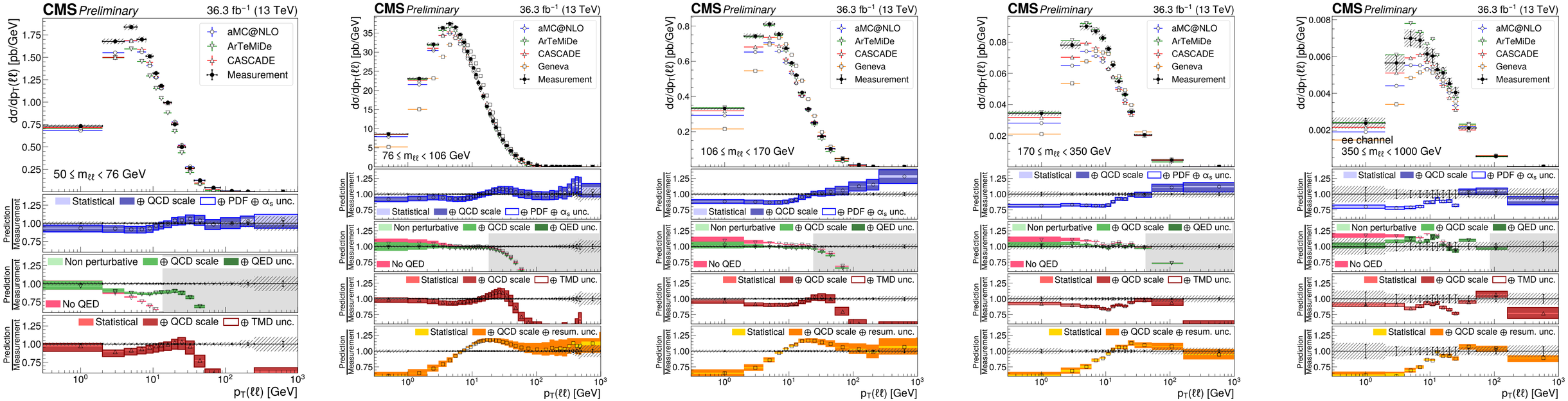


Z+jets differential cross section measurement

CMS-PAS-SMP-20-003



- Double differential cross-section of DY production as a function of m_{ll} and $p_T(ll)$.
- Z pT is crucial to prove the heavy states
  - Sensitive to resumption/TMD, pQCD (high pT) and their matching (moderate pT)



Selection of analysis

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WW, WZ and ZZ production cross-section at $\sqrt{s} = 5.02\ TeV$

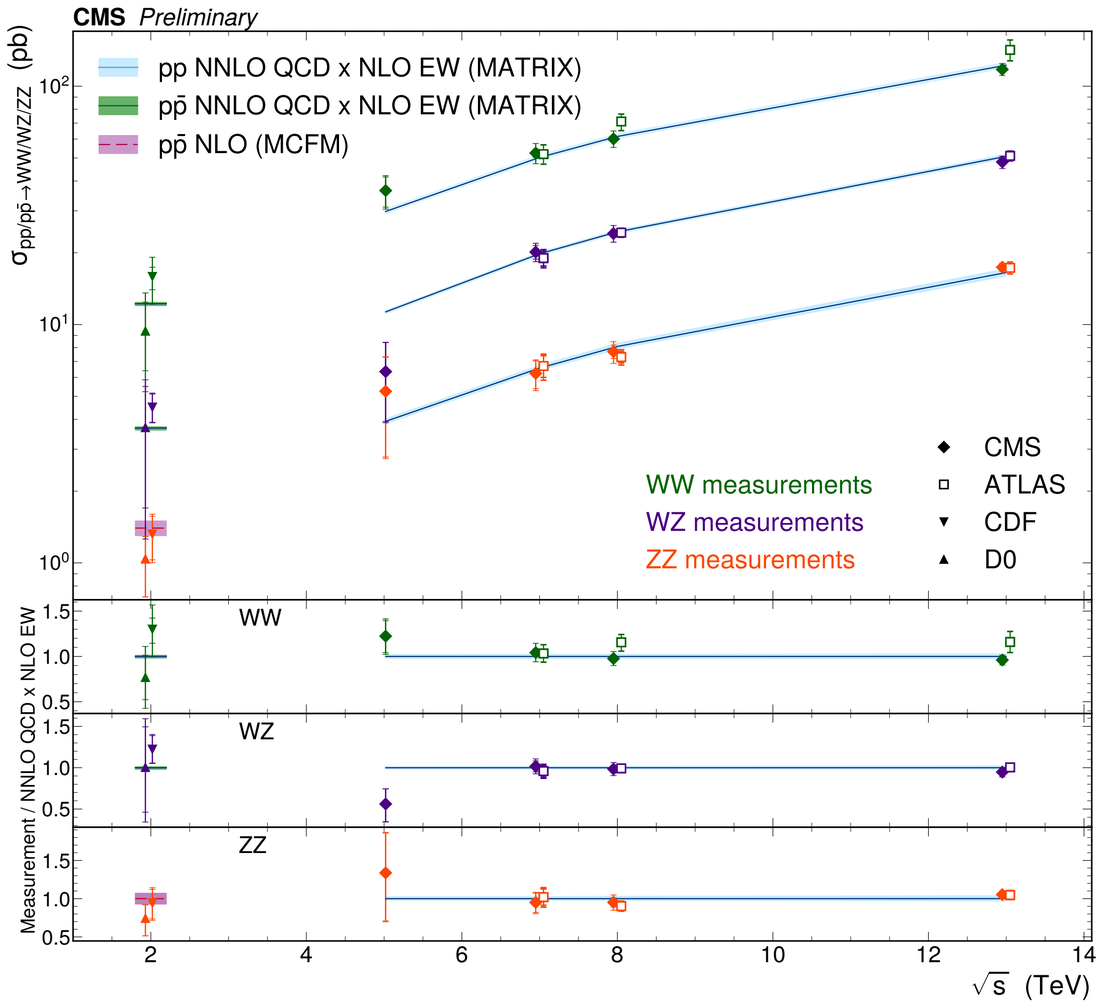
CMS-SMP-20-012

- **First measurement of weak diboson production at 5TeV.**
- Reduce the gap between the Tevatron and LHC measurement.
- Focus: Only leptonic decay of W/Z bosons.
  - $W^+W^- \rightarrow l^+\nu l^-\nu$
  - $W^\pm Z \rightarrow l^\pm\nu l^+l^-$ (also included channel, 2 muons with same charge)
  - $ZZ \rightarrow l^+l^-l^+l^-$ (also included 2l2nu)

Measured total cross-section:

- $\sigma_{WW} = 36.5^{+5.5}_{-5.1}(stat)^{+2.6}_{-2.5}(syst)\ pb$
- $\sigma_{WZ} = 6.4^{+2.4}_{-2.1}(stat)^{+0.5}_{-0.3}(syst)\ pb$
- $\sigma_{ZZ} = 5.3^{+2.5}_{-2.0}(stat)^{+0.5}_{-0.4}(syst)\ pb$

Measured values are in consistent with the NNLO QCD time NLO EW cross-sections.



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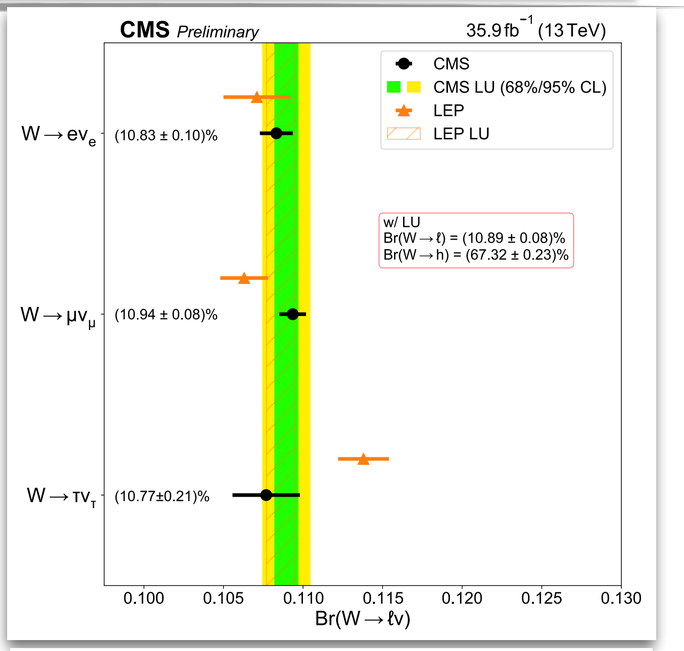
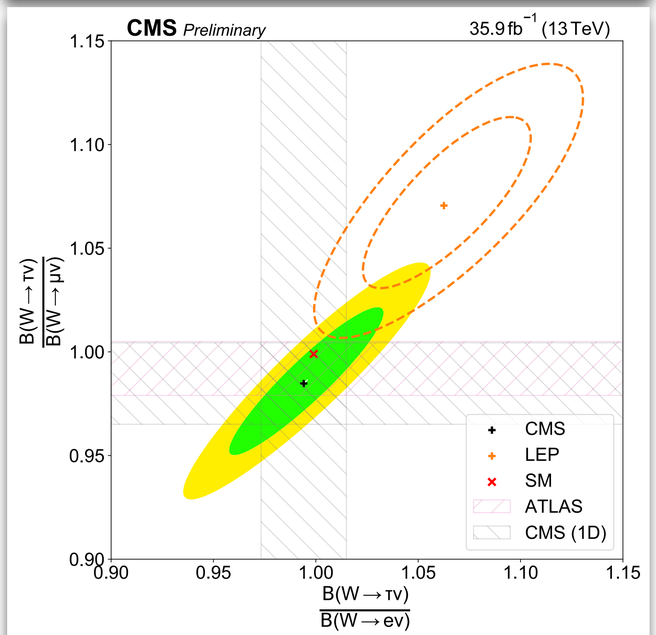
W-Boson BR precision measurement

CMS-PAS-SMP-18-011

- W-boson branching fraction measurement
  - Leptonic and inclusive hadronic
  - Cleaner channel to check the lepton universality by measuring the branching fraction of W-boson in the electron, muon and tau decay channel.
- Studied using $t\bar{t}$, tW, WW, *and* $W + jets$
- Measurement is in agreement with the SM





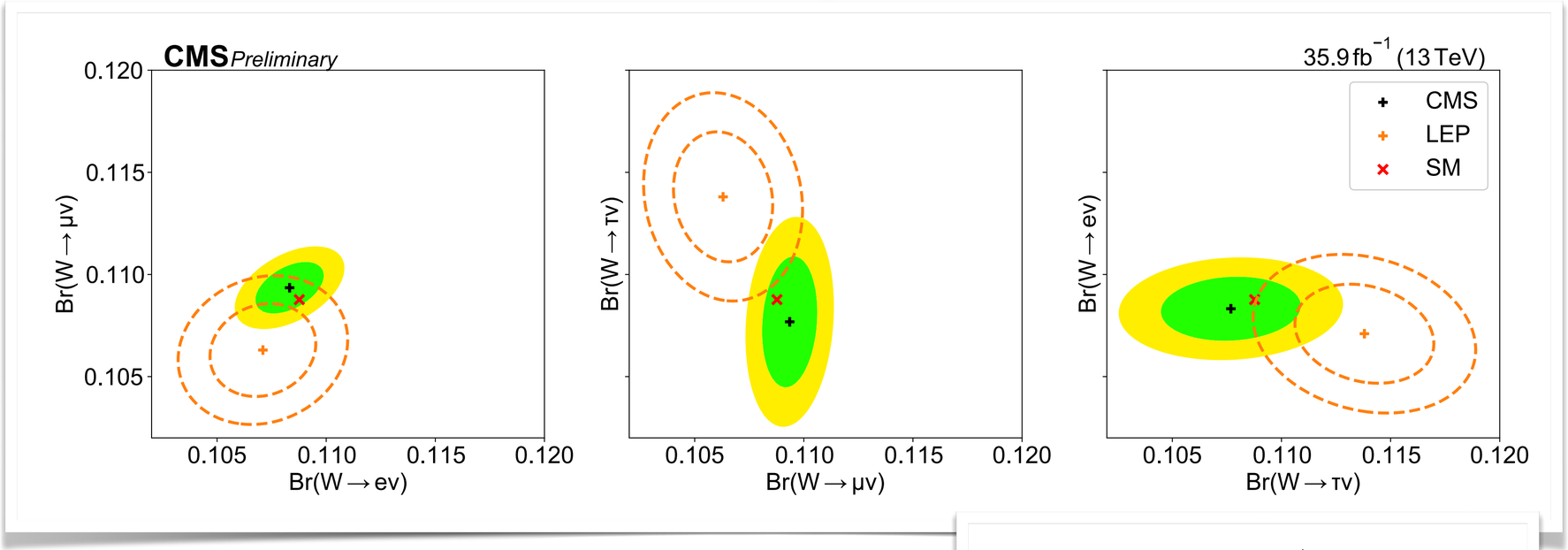
	CMS	LEP	ATLAS
$R_{\mu/e} = \mathcal{B}(W \to \mu\bar{\nu}_\mu)/\mathcal{B}(W \to e\bar{\nu}_e)$	1.009 ± 0.009	0.993 ± 0.019	–
$R_{\tau/e} = \mathcal{B}(W \to \tau\bar{\nu}_\tau)/\mathcal{B}(W \to e\bar{\nu}_e)$	0.994 ± 0.021	1.063 ± 0.027	–
$R_{\tau/\mu} = \mathcal{B}(W \to \tau\bar{\nu}_\tau)/\mathcal{B}(W \to \mu\bar{\nu}_\mu)$	0.985 ± 0.020	1.070 ± 0.026	0.992 ± 0.013
$R_{\tau/\ell}$	1.002 ± 0.019	1.066 ± 0.025	–

Summary (Some of the results from CMS… many more coming…)

- Imporved the W-boson branching ratio measurement.
- For WW, WZ and ZZ production (at 5.02 TeV):
  - Reduced the gap between Tevatraon and LHC measurement.
- Z+jets differential cross-section measurement
  - Went unto 8 inclusive jets for differential cross-section
  - Double differential w.r.t. m_{ll} and z p_T measured along with other observables.
- First measurement of the Z-boson emitted colinearly with jets

Thank you…

W-Boson BR precision measurement: CMS-PAS-SMP-18-011



	CMS	LEP
$\mathcal{B}(\mathrm{W} \to \mathrm{e}\bar{\nu}_\mathrm{e})$	$(10.83 \pm 0.01 \pm 0.10)\%$	$(10.71 \pm 0.14 \pm 0.07)\ \%$
$\mathcal{B}(\mathrm{W} \to \mu\bar{\nu}_\mu)$	$(10.94 \pm 0.01 \pm 0.08)\%$	$(10.63 \pm 0.13 \pm 0.07)\ \%$
$\mathcal{B}(\mathrm{W} \to \tau\bar{\nu}_\tau)$	$(10.77 \pm 0.05 \pm 0.21)\%$	$(11.38 \pm 0.17 \pm 0.11)\ \%$
$\mathcal{B}(\mathrm{W} \to \mathrm{h})$	$(67.46 \pm 0.04 \pm 0.28)\%$	–
with LU		
$\mathcal{B}(\mathrm{W} \to \ell\bar{\nu})$	$(10.89 \pm 0.01 \pm 0.08)\%$	$(10.86 \pm 0.06 \pm 0.09)\%$
$\mathcal{B}(\mathrm{W} \to \mathrm{h})$	$(67.32 \pm 0.02 \pm 0.23)\%$	$(67.41 \pm 0.18 \pm 0.20)\%$

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$R_{\mu/\mathrm{e}} = \mathcal{B}(\mathrm{W} \to \mu\bar{\nu}_\mu)/\mathcal{B}(\mathrm{W} \to \mathrm{e}\bar{\nu}_\mathrm{e})$	1.009 ± 0.009	0.993 ± 0.019	–
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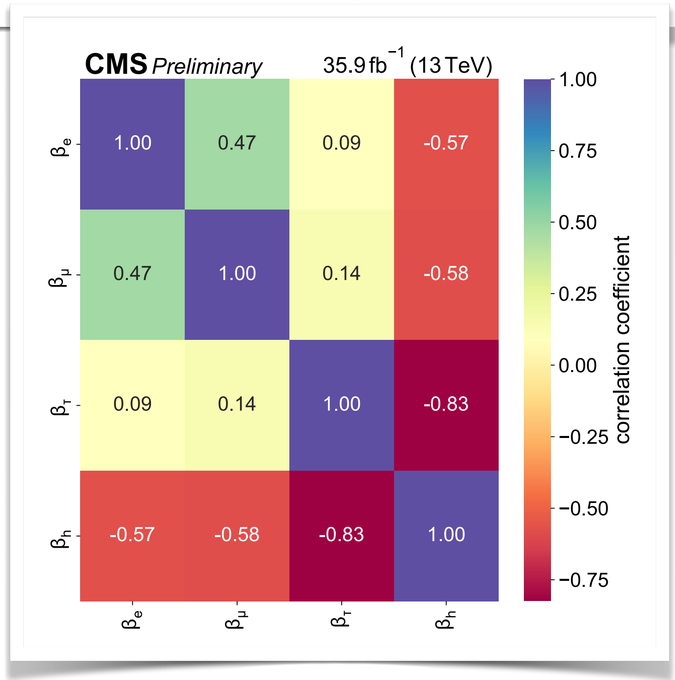
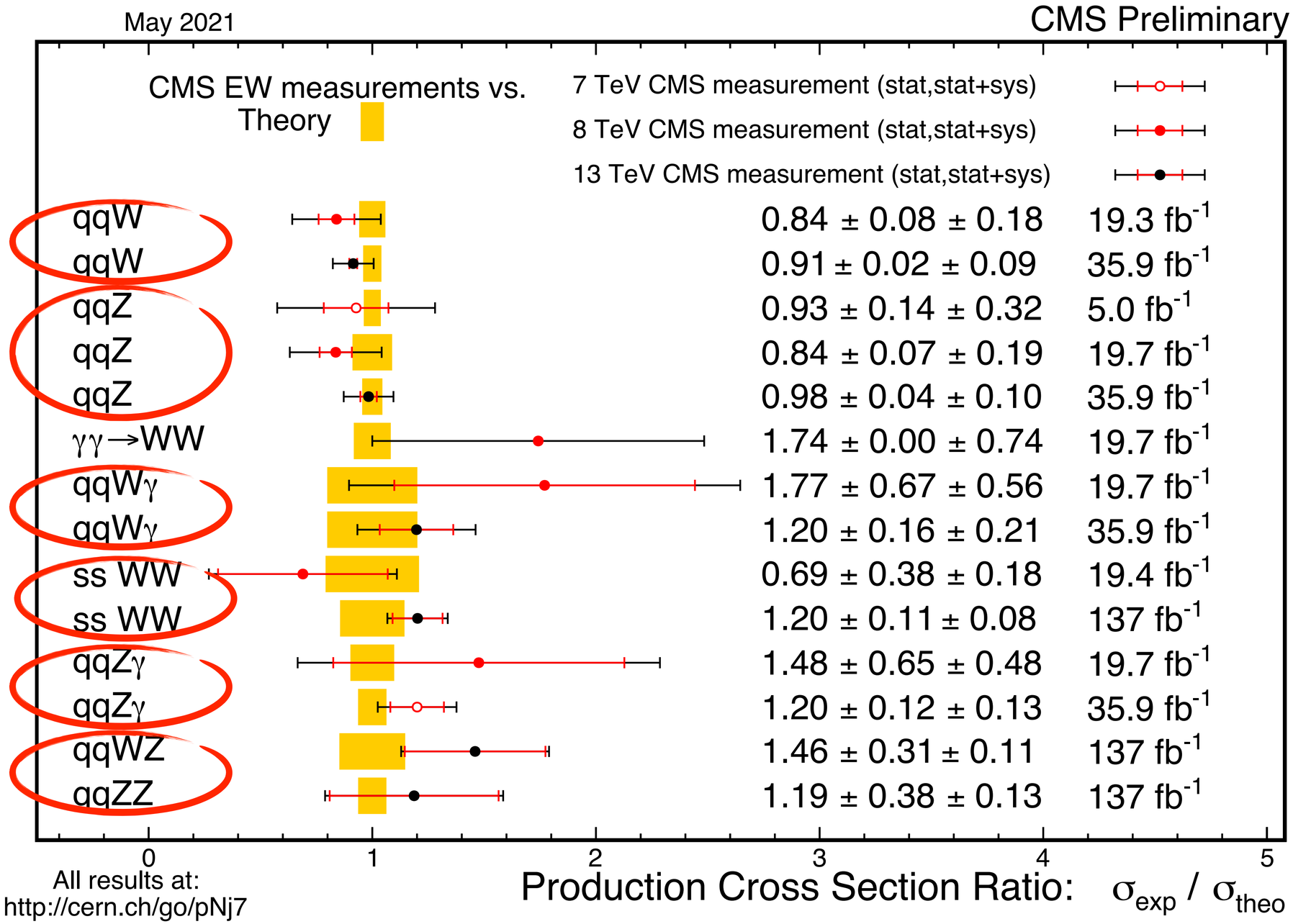


SM Electroweak boson results overview



SM Electroweak boson results overview