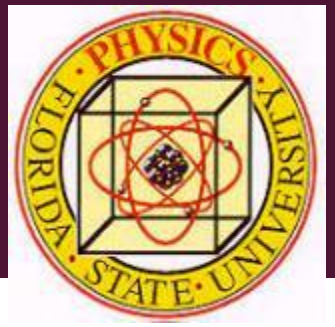
MULTIBOSON PRODUCTION AT CMS

ANDREW ASKEW

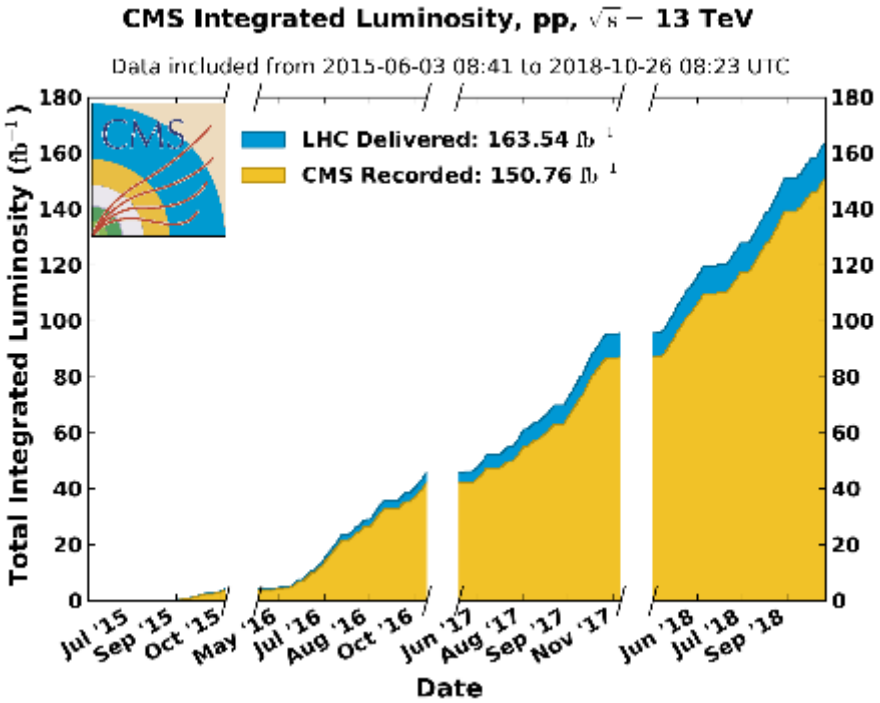
FOR THE CMS COLLABORATION

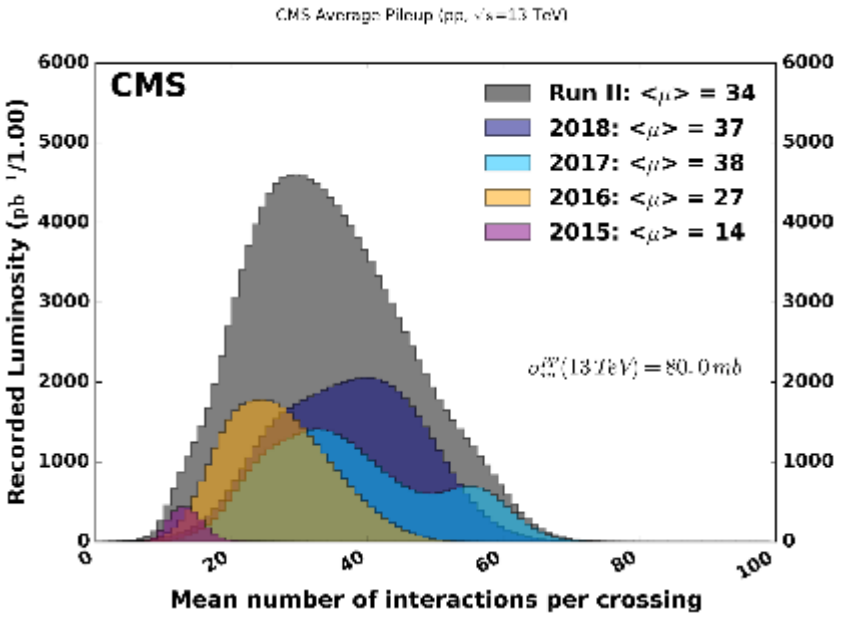


OVERVIEW

- Multiboson measurements and observations are one of the best tests of the structure of the Standard Model
- 2022 marked the beginning of Run 3. All of the results I have to show you today make use of the full Run 2 dataset.
  - I will concentrate on a couple of the most recent results, and most recent results submitted for publication.
- Where we're going:
  - There is a vast expanse of LHC data yet to be taken and explored! We're likely running RIGHT NOW.

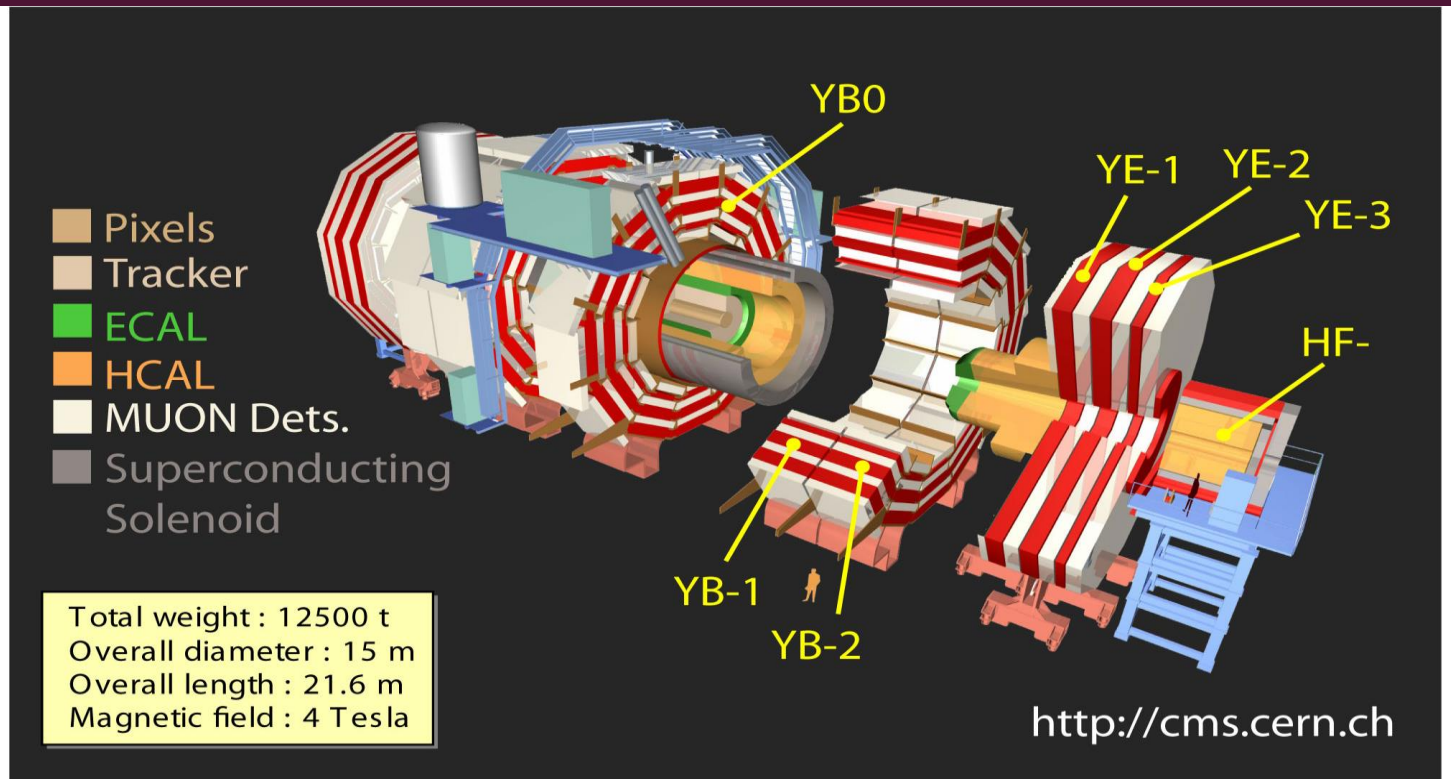
REMINDER: RUN 2





- What I will highlight today will utilize 138 fb^{-1} of data. Worth noting that there are continuing Run 2 analyses, and already analyses planned on Run 3 data (and combined Run 2+3).

NEVER COMPLETE WITHOUT:

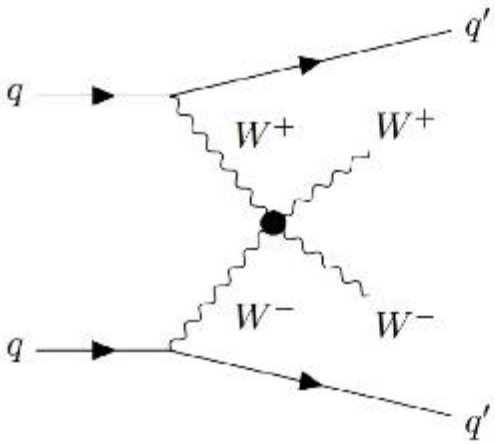


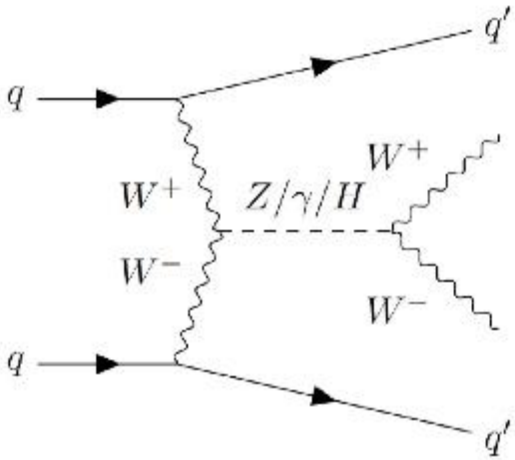
- An experimental talk is never complete without the star of our show.

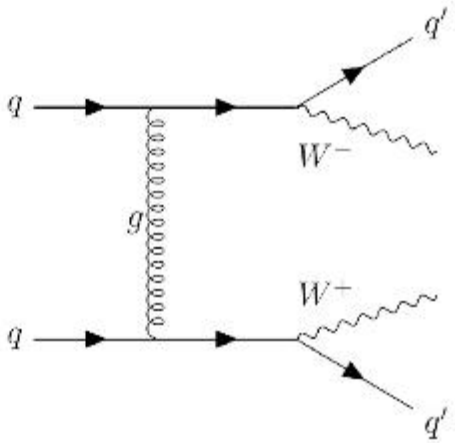
WHAT ARE WE DOING?

- You can subdivide the physics that we can do with multiboson physics (roughly) into a few categories:
  - Searches for rare though predicted SM processes.
  - Detailed examination of the kinematics in these SM processes, and inference of how these examinations constrain potential non-SM physics.
  - Precision measurement of differential cross sections.
- As you accrue more and more integrated luminosity, the first can become the second, and then the third.
- I'm going to overview a few of the most recent results, which touch on each of these.

WW PRODUCTION







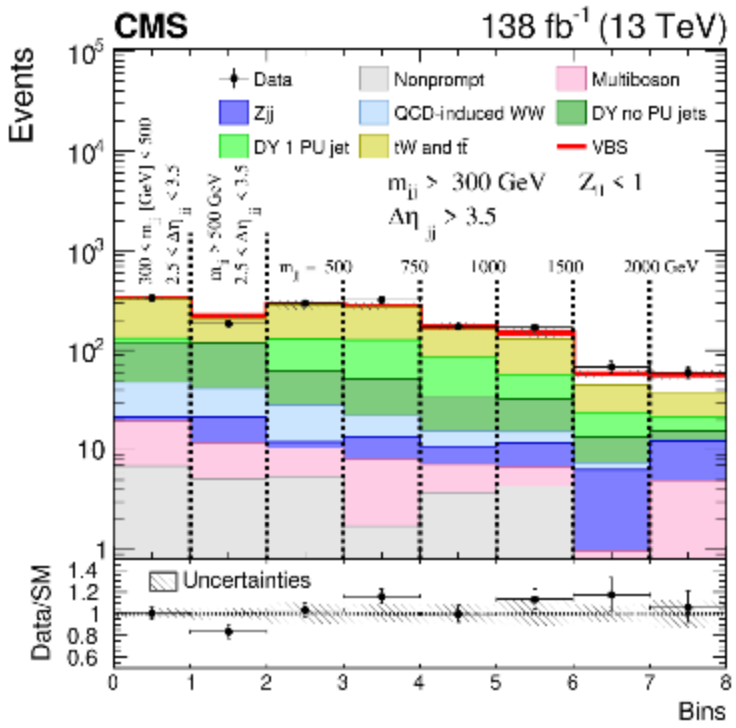
- The main processes in WW production. I'm stealing a little bit: there is a dedicated VBS talk later, but I wanted to start here.

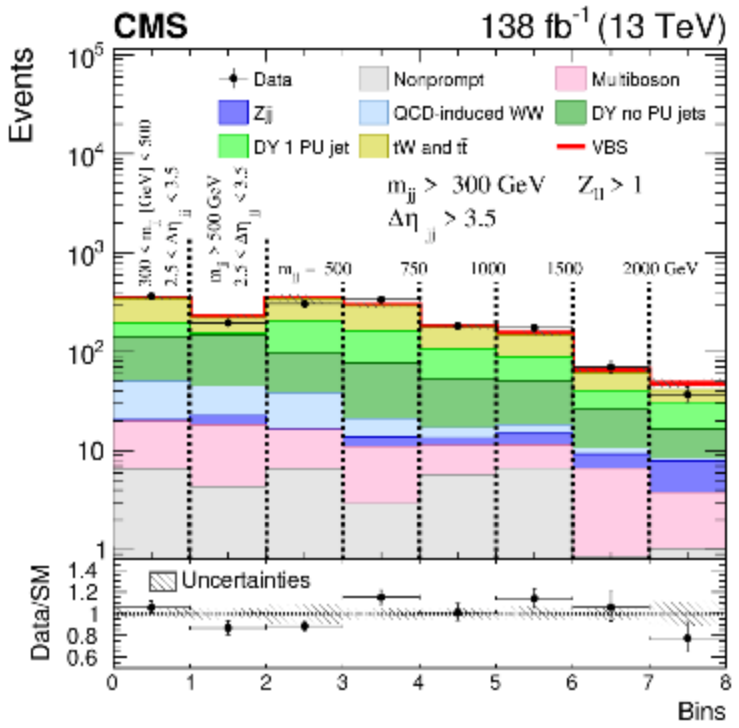
WW PARTICULARS

Process	SR eμ $Z_{\ell\ell} < 1$	SR eμ $Z_{\ell\ell} > 1$	SR ee - $\mu\mu$ $Z_{\ell\ell} < 1$	SR ee - $\mu\mu$ $Z_{\ell\ell} > 1$
DATA	2441	2192	1606	1667
Signal + background	2396.8 ± 98.5	2239.6 ± 106.0	1590.4 ± 49.4	1660.5 ± 43.6
Signal	169.1 ± 20.2	69.9 ± 8.4	98.0 ± 6.5	38.3 ± 2.5
Background	2227.7 ± 96.4	2169.7 ± 105.6	1492.4 ± 48.9	1622.1 ± 43.5
$t\bar{t} + tW$	1629.4 ± 71.4	1452.5 ± 69.5	767.8 ± 14.5	642.5 ± 13.2
WW (QCD)	327.0 ± 61.6	409.3 ± 77.3	111.1 ± 16.6	121.5 ± 17.3
Nonprompt	107.0 ± 18.4	109.9 ± 16.4	30.0 ± 4.9	32.0 ± 4.2
DY no PU jets	—	—	259.5 ± 27.3	408.3 ± 17.1
DY + 1 PU jets	—	—	222.7 ± 33.3	337.4 ± 32.9
DY$\tau^+\tau^-$	69.2 ± 4.6	102.0 ± 5.8	—	—
Multiboson	67.7 ± 6.6	75.6 ± 7.3	60.9 ± 3.8	60.1 ± 4.8
Zjj	1.0 ± 0.2	0.4 ± 0.0	40.5 ± 4.2	20.3 ± 1.3
Higgs	26.6 ± 1.5	20.1 ± 1.0	—	—

- Note the distinction being made here between signal (EWK) and background (QCD). There's no control sample that you can define that is purely dominated by WW(QCD)
- Top is, as always, a major background.

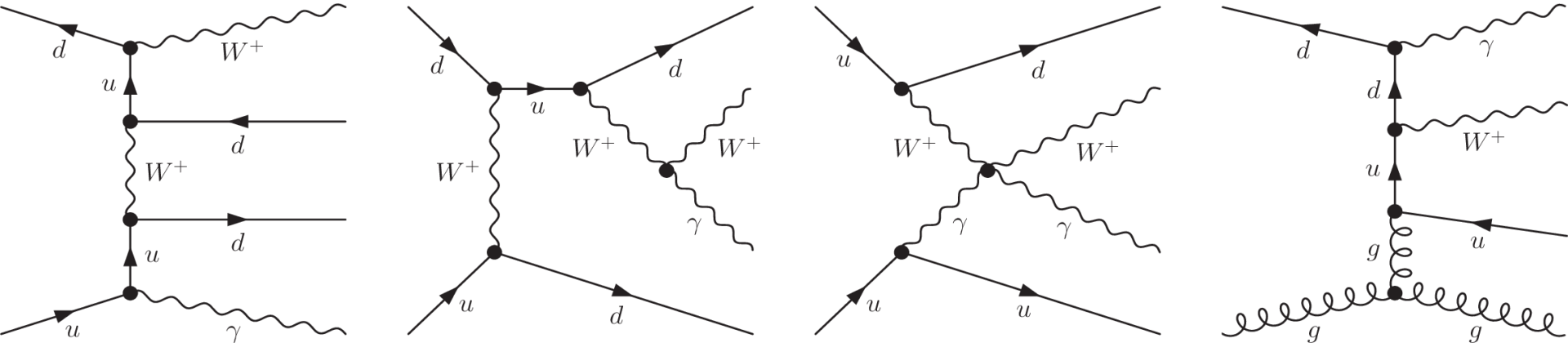
WW RESULTS





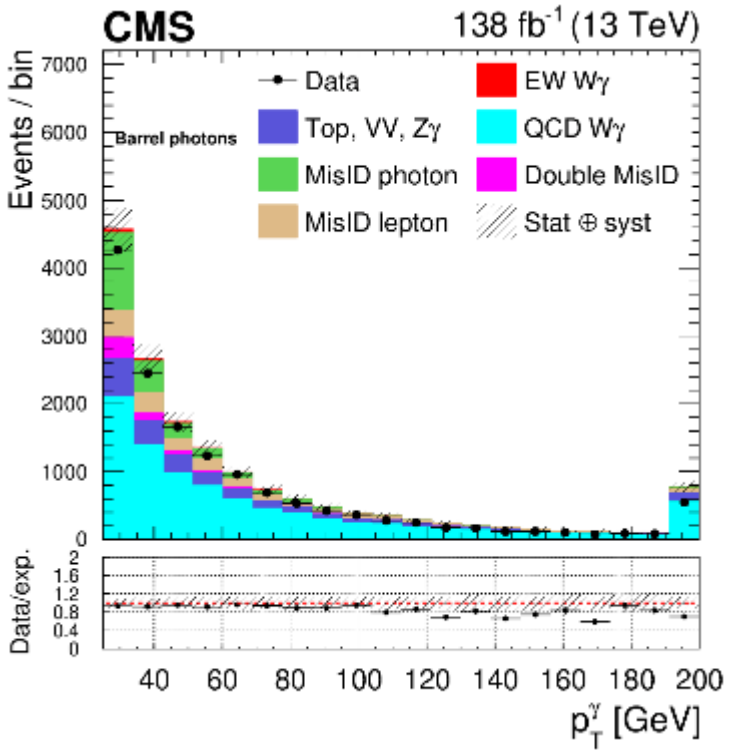
- Combined ee. μμ, separated by jet mass and Zeppenfeld variable.
- Observed significance is 5.6 (5.2) sigma for the EWK process.

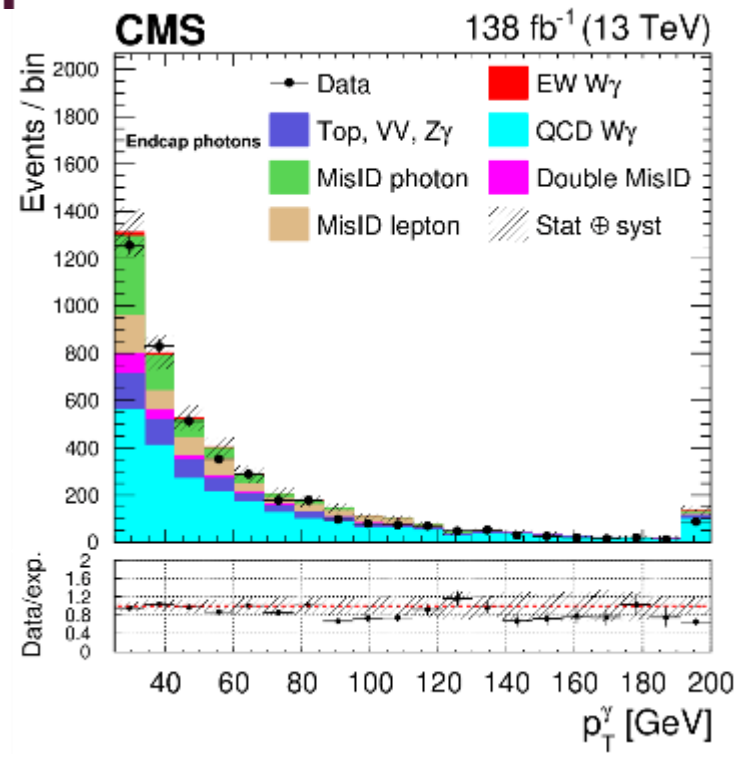
EWK Wγ PRODUCTION



- Again, stealing slightly. There is a distinction here drawn for EWK processes (the first three) and QCD initiated production of Wγ.
- Here we have the trilinear vertex in the second diagram, and the quadrilinear vertex in the third. And really, that's what is interesting here.

Wγ DETAILS





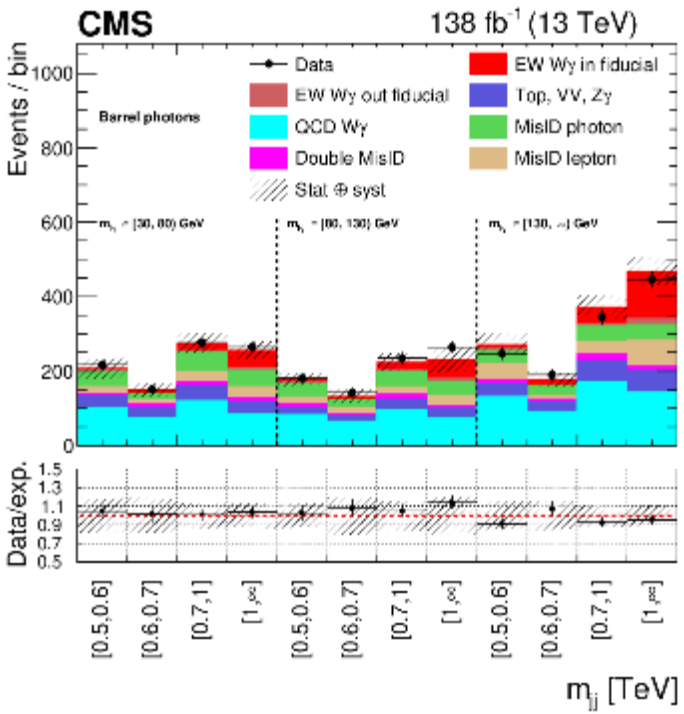
- A control region is defined adjacent to the signal region in dijet mass. As one can see (left is photon in barrel, right is endcap), there's no visible contamination from the EWK process.

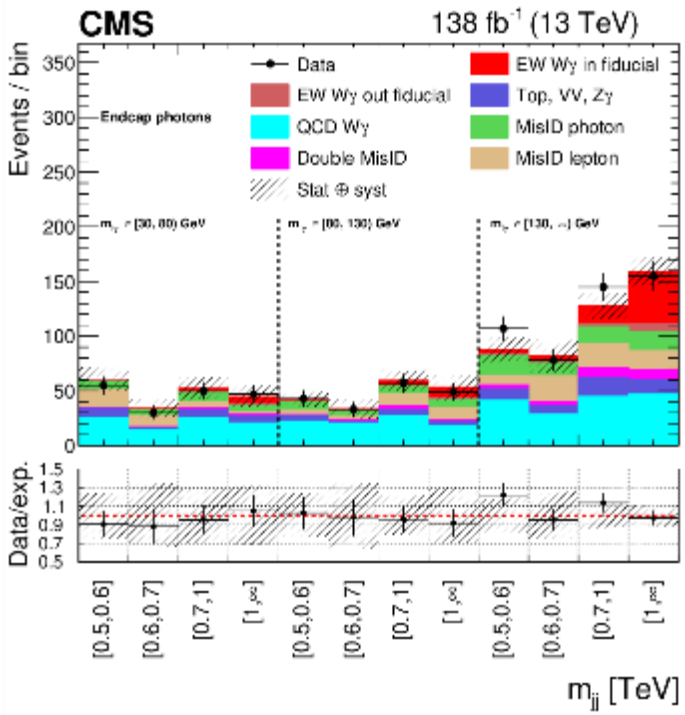
Wγ DETAILS (2)

	Barrel	Endcap
EW Wγ in fiducial region	316 ± 16	90.2 ± 5.5
EW Wγ out of fiducial region	64.7 ± 2.0	20.4 ± 1.0
QCD Wγ	1301 ± 28	362 ± 13
top, VV, Zγ	402 ± 14	93.3 ± 7.2
Nonprompt photon	434 ± 13	120.2 ± 5.7
Nonprompt muon	134 ± 27	45 ± 11
Nonprompt electron	189 ± 20	86 ± 13
Nonprompt photon, nonprompt muon	43.0 ± 7.0	14.6 ± 3.4
Nonprompt photon, nonprompt electron	75.5 ± 5.5	25.0 ± 2.0
Total prediction	2960 ± 43	856 ± 21
Data	2959 ± 57	849 ± 32

- Dealing with a very small signal on top of significant backgrounds.

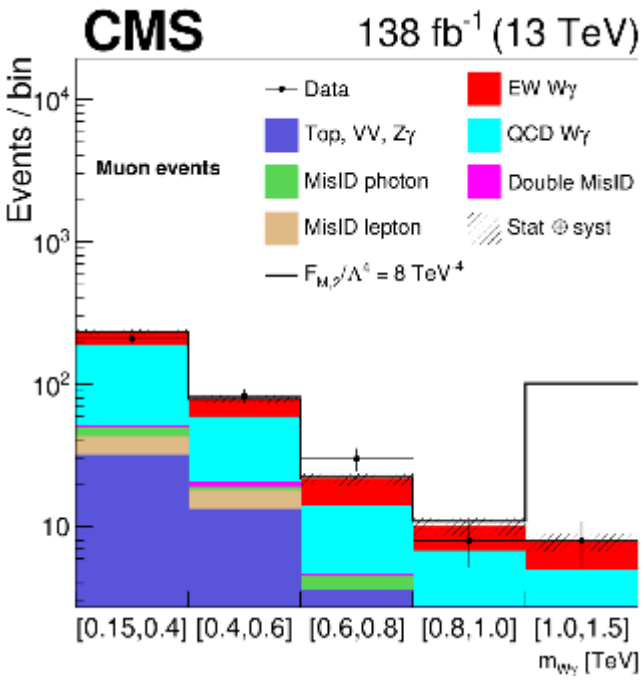
Wγ RESULTS

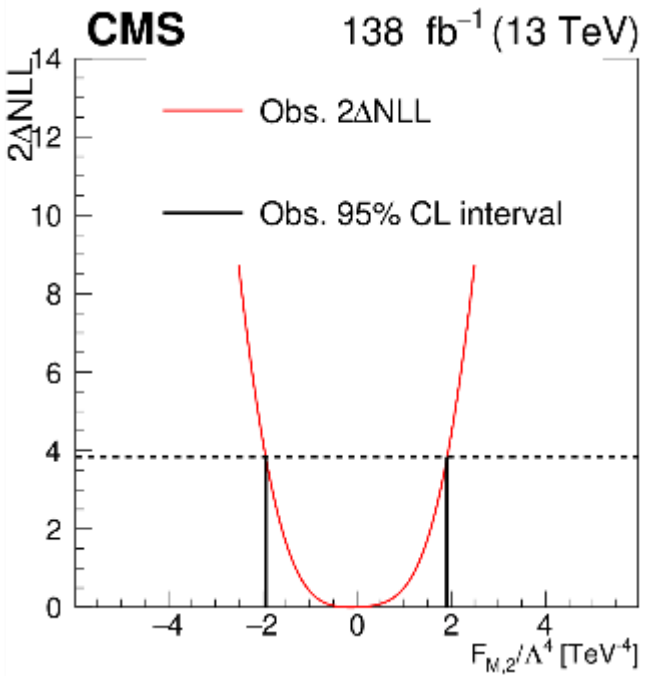




- Sensitivity enhanced, like most analyses, by binning in the sensitive variable, in this case, the jet mass and $M_{l\gamma}$. Observed significance is 6.0 (6.8).

Wγ RESULTS





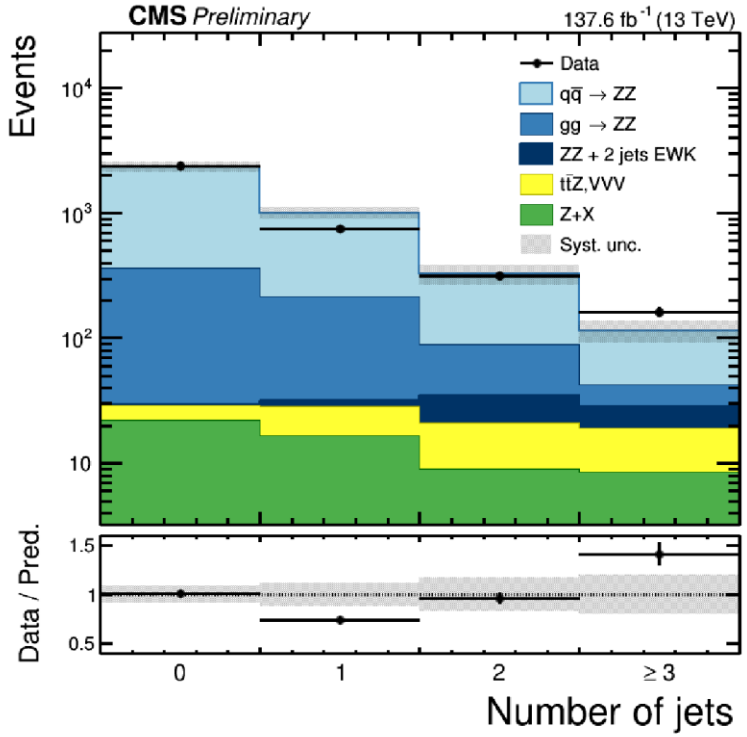
- Limits are set on the different couplings by using the Wγ mass. Here is an representative example, where the enhancement at high mass is clear.

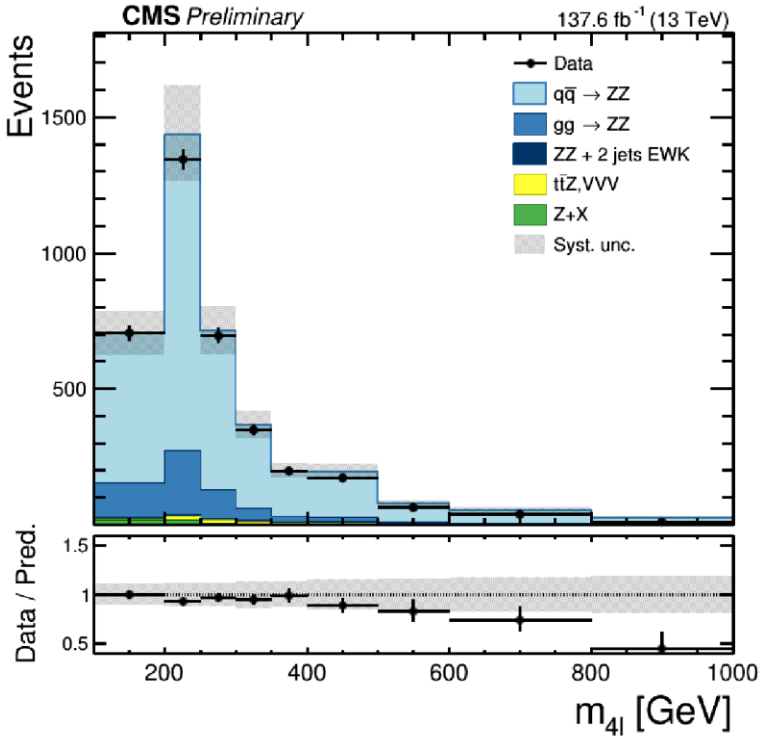
ZZ+J DIFFERENTIAL CROSS SECTION

- This is a good example of the full chain that I mentioned earlier.
  - I may be showing my age, but it wasn't THAT long ago that ZZ production in the leptonic channels wasn't established at hadron colliders (I looked it up, 2008).
  - Then a certain boson was discovered in this channel, and suddenly we're in this era of seemingly limitless statistics.
  - We now have sufficient statistics to make differential cross section measurements using the cleanest reconstructed leptons.

Process	eeee	ee$\mu\mu$	$\mu\mu\mu\mu$	$2\ell 2\ell'$
$80 < m_{4\ell} < 100 GeV$				
Background	$4.6 \pm 0.5 \pm 1.8$	$15.5 \pm 1.6 \pm 6.2$	$22.8 \pm 2.1 \pm 9.1$	$43 \pm 3 \pm 17$
Signal	$216 \pm 1\ ^{-40}_{-37}$	$731 \pm 2\ ^{+65}_{-63}$	$841 \pm 2\ ^{-60}_{-58}$	$1790 \pm 3\ ^{+260}_{-240}$
Total expected	$220 \pm 1\ ^{-40}_{-37}$	$747 \pm 3\ ^{+65}_{-63}$	$864 \pm 3\ ^{-60}_{-58}$	$1830 \pm 4\ ^{+260}_{-240}$
Data	194	698	838	1730
$60 < m_{Z_1}, m_{Z_2} < 120 GeV$				
Background	$22.9 \pm 0.9 \pm 5.7$	$46 \pm 2 \pm 10$	$28.9 \pm 1.3 \pm 6.5$	$98 \pm 2 \pm 23$
Signal	$716 \pm 2\ ^{-63}_{-61}$	$1830 \pm 3\ ^{-130}_{-130}$	$1138 \pm 3\ ^{+85}_{-82}$	$3680 \pm 5\ ^{+490}_{-470}$
Total expected	$739 \pm 2\ ^{-64}_{-61}$	$1870 \pm 4\ ^{-130}_{-130}$	$1167 \pm 3\ ^{+85}_{-83}$	$3780 \pm 5\ ^{+490}_{-470}$
Data	671	1805	1106	3582

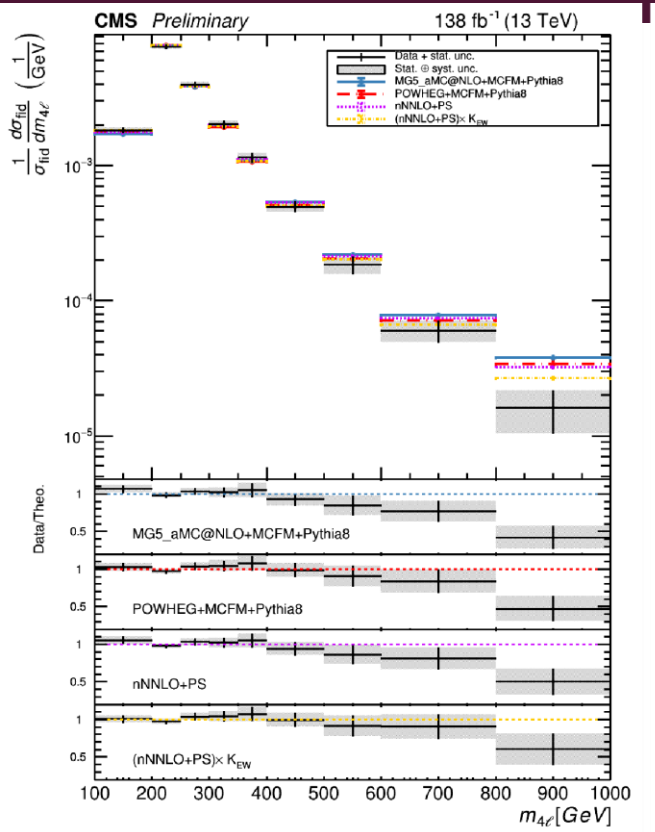
ZZ+J RESULTS (1):

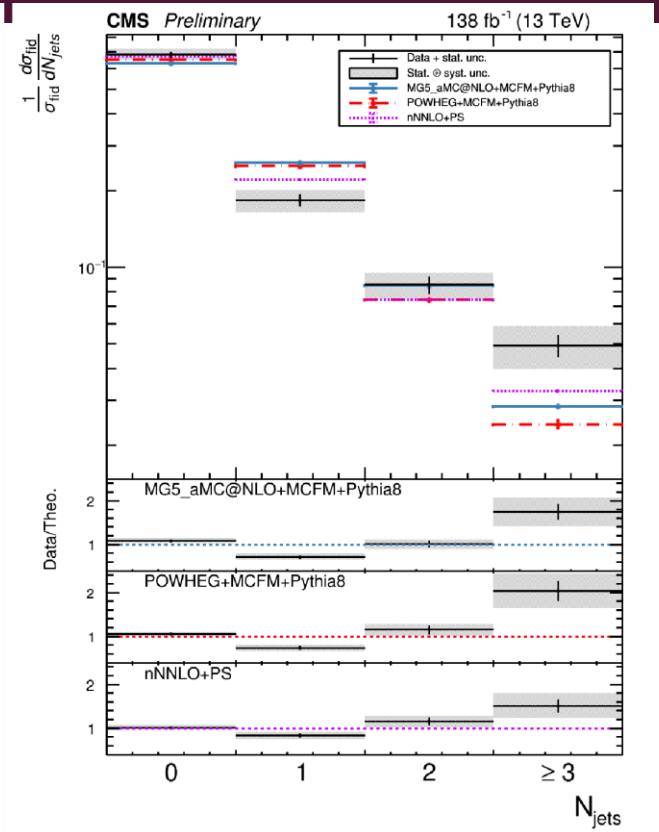




- N_{jets} and m_{4l}, for $60 < M_{Z1}, M_{Z2} < 120$

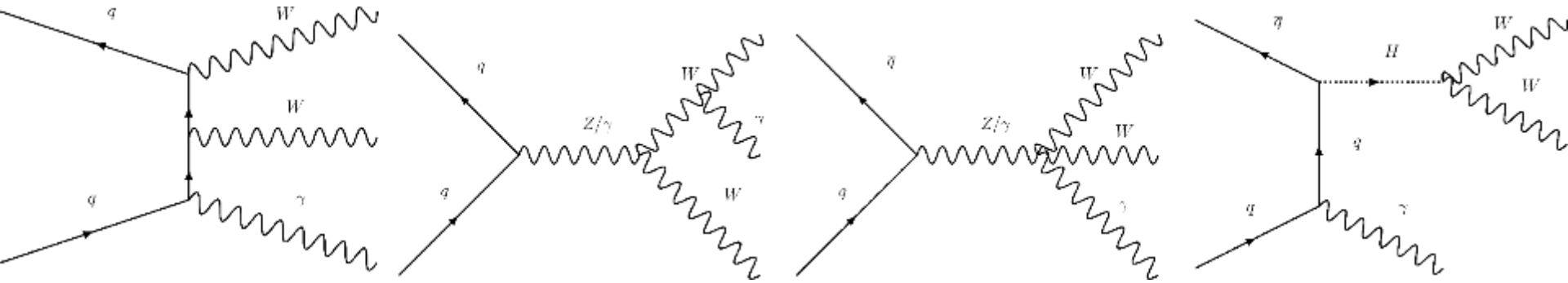
ZZ+J RESULTS





- Many different unfolded distributions are public, here I'm just showing the unfolded cross section as a function of four-lepton mass, and number of jets.

SEARCH FOR WWγ PRODUCTION:



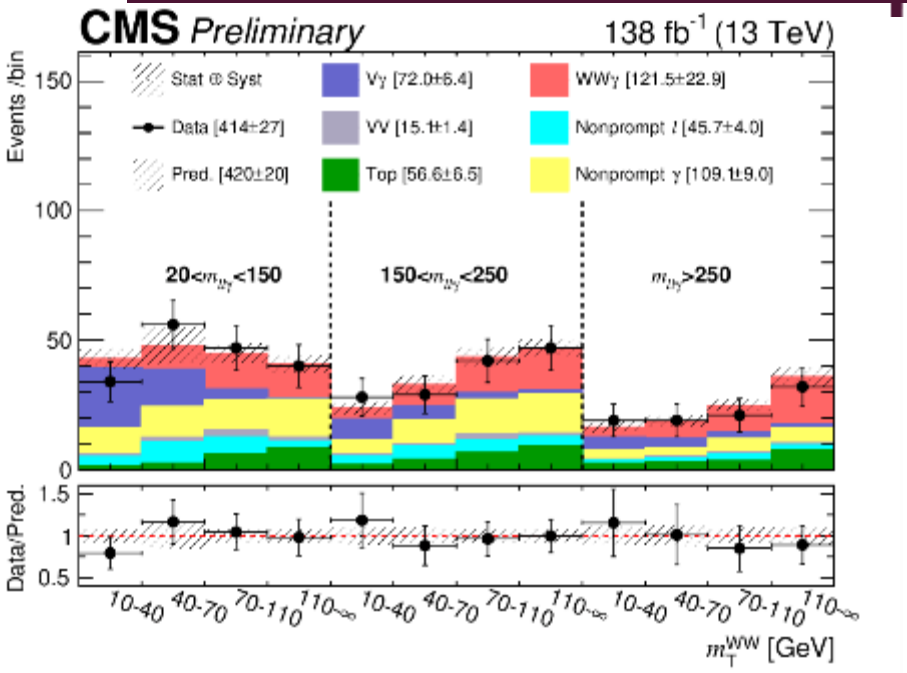
- This to me is very exciting: processes with three vector bosons in the final state, plus both trilinear and quadrilinear vertices.
- Now really into MULTI territory, three vector bosons in the final state.

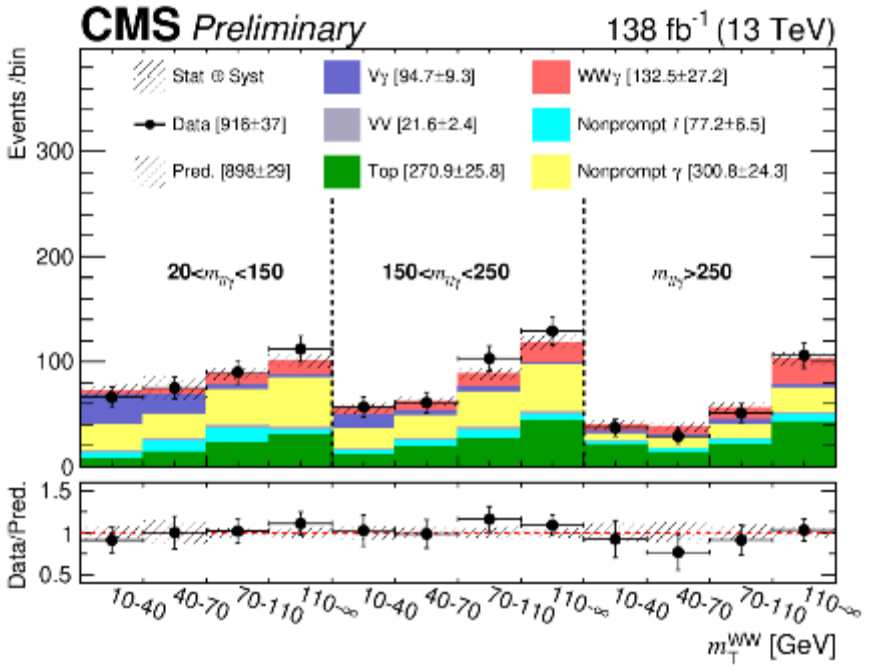
WWγ DETAILS:

- Top is an issue for everyone at the LHC.
- In this analysis a separate top control region is defined, as well as a same sign sample, in order to both check the agreement, and constrain the contributions in the simultaneous fit.
- This table is post-fit.

Process	Signal region	SSWWγ CR	Topγ CR
WWγ	254.0±47.3	1.2±0.2	12.8±2.7
QCD Vγ	166.7±13.8	12.2±2.2	12.6±1.2
VV	36.7±3.5	24.9±1.7	2.0±0.3
Top	327.5±32.2	2.4±0.6	2433.5±85.2
Nonprompt ℓ	122.9 ±9.7	196.6±13.6	39.8±10.7
Nonprompt γ	409.9 ±31.7	19.9±1.6	793.2±62.1
Expected	1318±43	257±14	3294±57
Observed	1330±46	259±20	3287±59

WWγ RESULTS:





- These are the 2D m_{TWW}-$m_{ll\gamma}$ distributions used for the significance measurement. Zero jet is on the left, one jet (or more) is on the right.
- Observed significance is 5.6 (4.7) sigma.

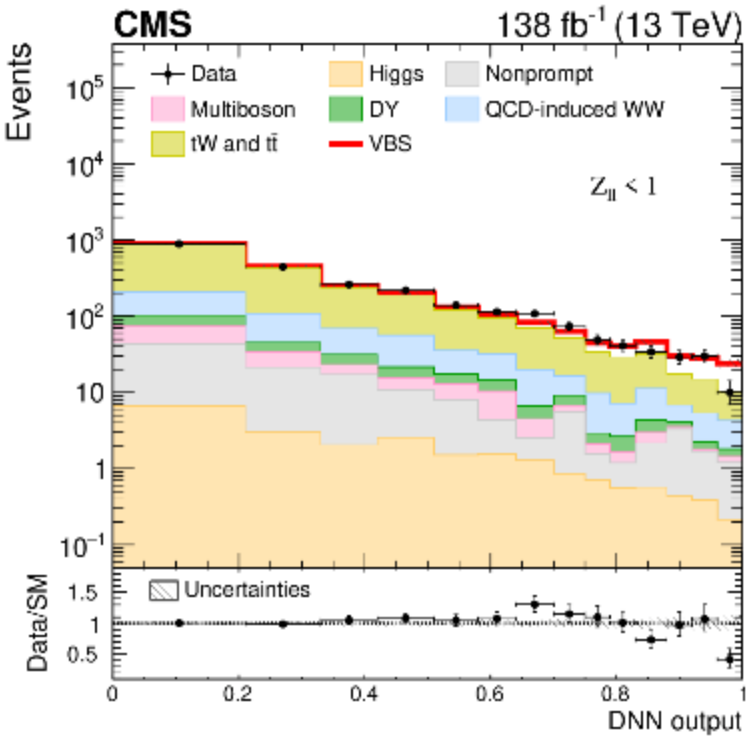
SUMMARY

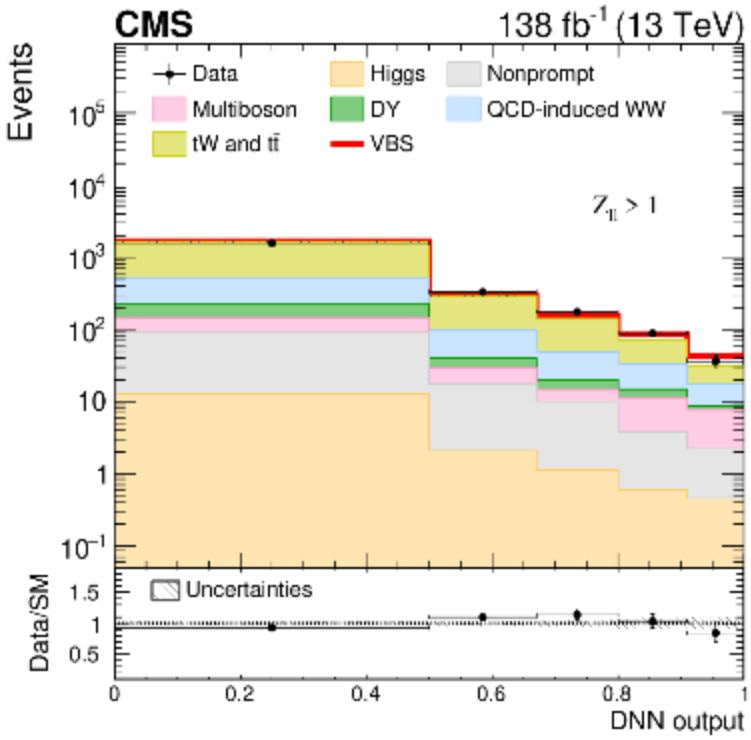
- We have done, and continue to do a very successful job widening our view into physics at the LHC.
- We've now observed some pretty novel SM phenomena. Is SUSY (or anything else) lurking in any of those places? We'll have to look hard to tell.
- You'll be hearing more soon!

- BACKUPS

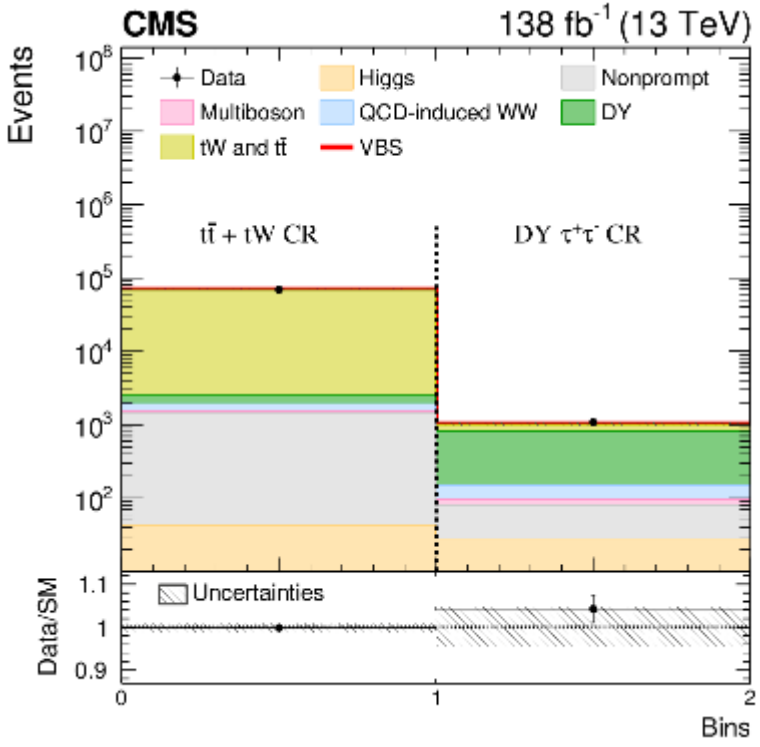
WW

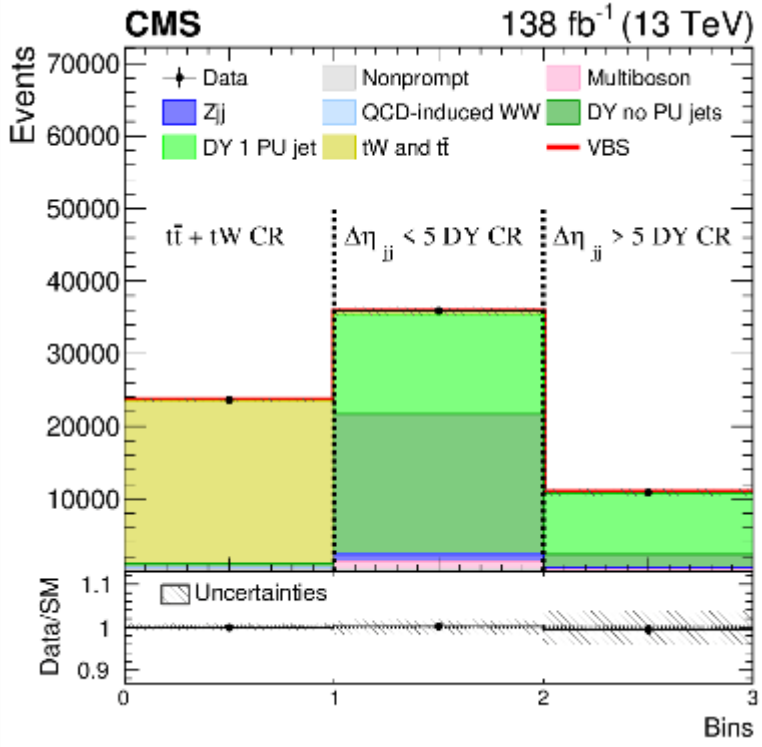
WW


CMS
138 fb^{-1} (13 TeV)
Events
Data
Multiboson
tW and tt̄
Higgs
DY
VBS
Nonprompt
QCD-induced WW
$Z_{\ell\ell} < 1$
Data/SM
Uncertainties
DNN output


CMS
138 fb^{-1} (13 TeV)
Events
Data
Multiboson
tW and tt̄
Higgs
DY
VBS
Nonprompt
QCD-induced WW
$Z_{\ell\ell} > 1$
Data/SM
Uncertainties
DNN output

WW


CMS
138 fb^{-1} (13 TeV)
Events
Data
Higgs
Nonprompt
Multiboson
QCD-induced WW
DY
tW and tt̄
VBS
tt̄ + tW CR
DY τ⁺τ⁻ CR
Uncertainties
Data/SM
Bins

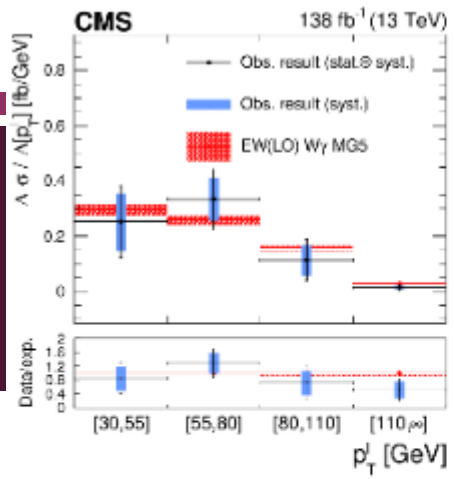

CMS
138 fb^{-1} (13 TeV)
Events
Data
Nonprompt
Multiboson
Zjj
QCD-induced WW
DY no PU jets
DY 1 PU jet
tW and tt̄
VBS
tt̄ + tW CR
Δη jj < 5 DY CR
Δη jj > 5 DY CR
Uncertainties
Data/SM
Bins

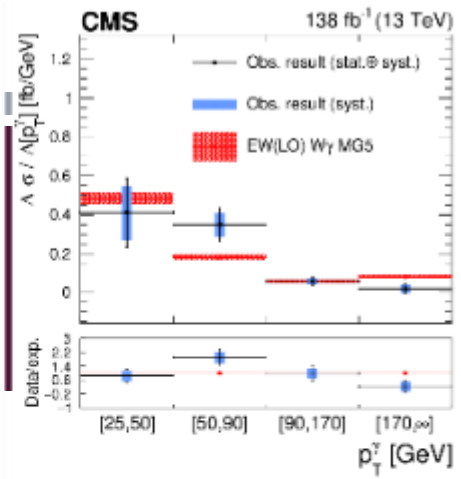
WW

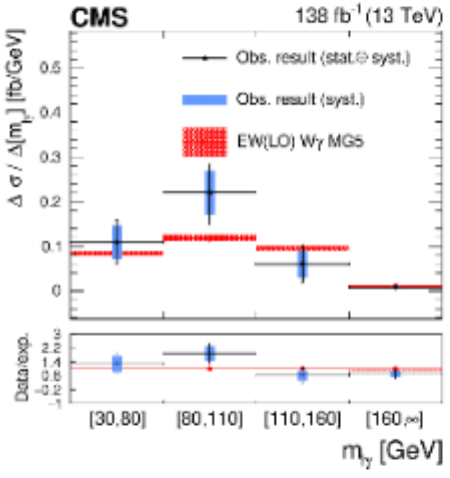
Objects	Requirements
Leptons	$e\mu$, ee, $\mu\mu$ (not from τ decay), opposite charge
	$p_{\mathrm{T}}^{\text{dressed }\ell} = p_{\mathrm{T}}^{\ell} + \sum_i p_{\mathrm{T}}^{\gamma_i}$ if $\Delta R(\ell, \gamma_i) < 0.1$
	$p_{\mathrm{T}}^{\ell_1} > 25\,\mathrm{GeV}$, $p_{\mathrm{T}}^{\ell_2} > 13\,\mathrm{GeV}$, $p_{\mathrm{T}}^{\ell_3} < 10\,\mathrm{GeV}$
	$\lvert\eta\rvert < 2.5$
	$p_{\mathrm{T}}^{\ell\ell} > 30\,\mathrm{GeV}$, $m_{\ell\ell} > 50\,\mathrm{GeV}$
Jets	$p_{\mathrm{T}}^{j} > 30\,\mathrm{GeV}$
	$\Delta R(j, \ell) > 0.4$
	At least 2 jets, no b jets
	$\lvert\eta\rvert < 4.7$
	$m_{\mathrm{jj}} > 300\,\mathrm{GeV}$, $\lvert\Delta\eta_{\mathrm{jj}}\rvert > 2.5$
$p_{\mathrm{T}}^{\mathrm{miss}}$	$p_{\mathrm{T}}^{\mathrm{miss}} > 20\,\mathrm{GeV}$

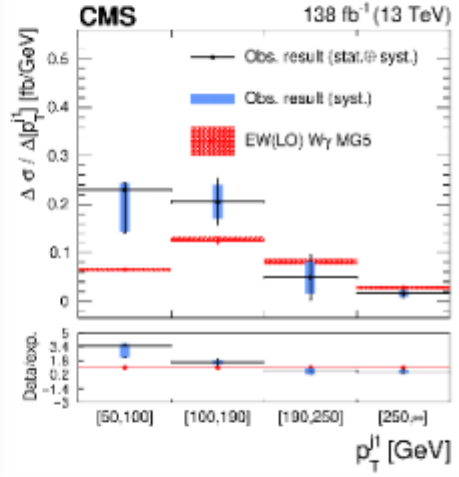
EWK Wγ

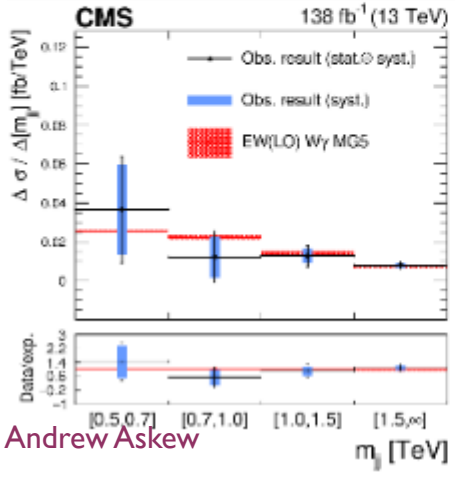
EWK Wγ

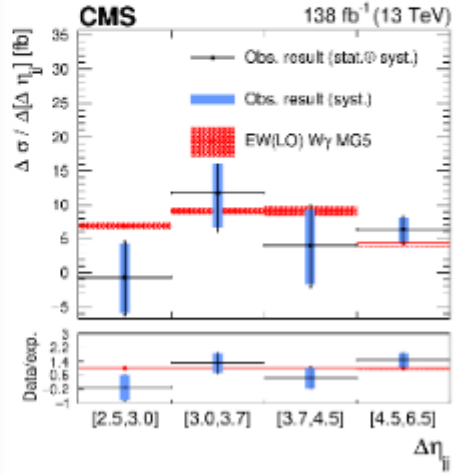

CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕ syst.)
Obs. result (syst.)
EW(LO) Wγ MG5
Data/exp.
[30,55] [55,80] [80,110] [110,∞]
p_T^l [GeV]


CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕ syst.)
Obs. result (syst.)
EW(LO) Wγ MG5
Data/exp.
[25,50] [50,90] [90,170] [170,∞]
p_T^γ [GeV]

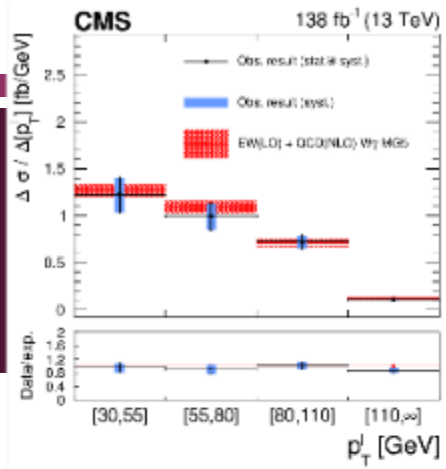

CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕ syst.)
Obs. result (syst.)
EW(LO) Wγ MG5
Data/exp.
[30,80] [80,110] [110,160] [160,∞]
$m_{l\gamma}$ [GeV]

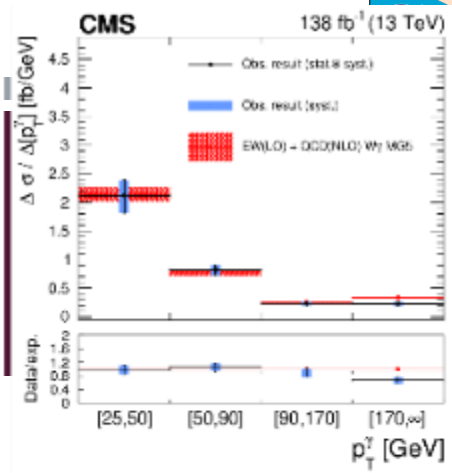

CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕ syst.)
Obs. result (syst.)
EW(LO) Wγ MG5
Data/exp.
[50,100] [100,190] [190,250] [250,∞]
p_T^{jj} [GeV]

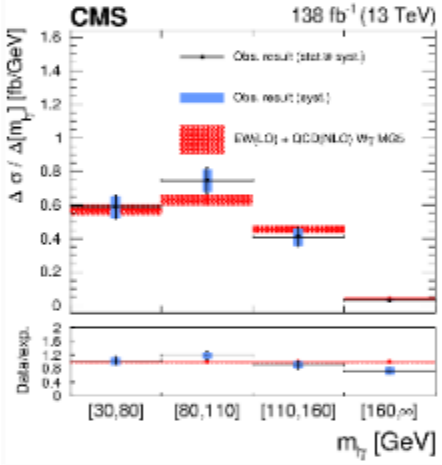

CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕ syst.)
Obs. result (syst.)
EW(LO) Wγ MG5
Data/exp.
[0.5,0.7] [0.7,1.0] [1.0,1.5] [1.5,∞]
m_{jj} [TeV]

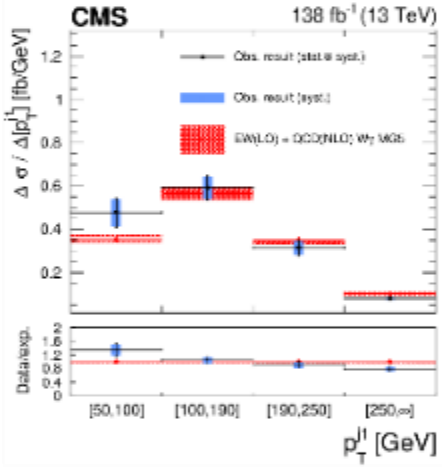

CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕ syst.)
Obs. result (syst.)
EW(LO) Wγ MG5
Data/exp.
[2.5,3.0] [3.0,3.7] [3.7,4.5] [4.5,6.5]
$\Delta\eta_{jj}$

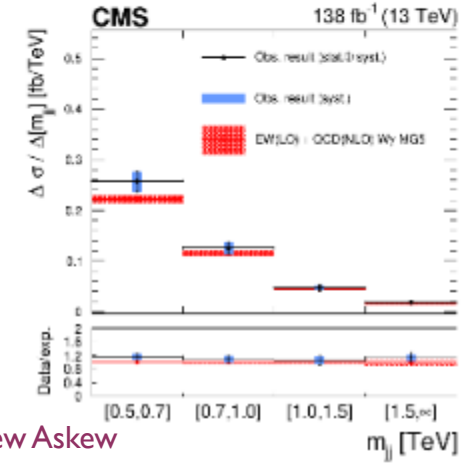
EWK Wγ

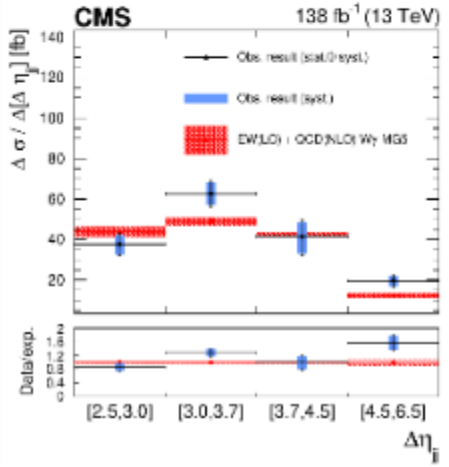

CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕syst.)
Obs. result (syst.)
EW(LO) + QCD(NLO) Wγ MG5
Δ σ / Δ[p$_T^J$] [fb/GeV]
Data/exp.
[30,55]
[55,80]
[80,110]
[110,∞]
p$_T^J$ [GeV]


CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕syst.)
Obs. result (syst.)
EW(LO) + QCD(NLO) Wγ MG5
Δ σ / Δ[p$_T^\gamma$] [fb/GeV]
Data/exp.
[25,50]
[50,90]
[90,170]
[170,∞]
p$_T^\gamma$ [GeV]


CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕syst.)
Obs. result (syst.)
EW(LO) + QCD(NLO) Wγ MG5
Δ σ / Δ[m$_{l\gamma}$] [fb/GeV]
Data/exp.
[30,80]
[80,110]
[110,160]
[160,∞]
m$_{l\gamma}$ [GeV]


CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕syst.)
Obs. result (syst.)
EW(LO) + QCD(NLO) Wγ MG5
Δ σ / Δ[p$_T^{jj}$] [fb/GeV]
Data/exp.
[50,100]
[100,190]
[190,250]
[250,∞]
p$_T^{jj}$ [GeV]


CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕syst.)
Obs. result (syst.)
EW(LO) + QCD(NLO) Wγ MG5
Δ σ / Δ[m$_{jj}$] [fb/TeV]
Data/exp.
[0.5,0.7]
[0.7,1.0]
[1.0,1.5]
[1.5,∞]
m$_{jj}$ [TeV]

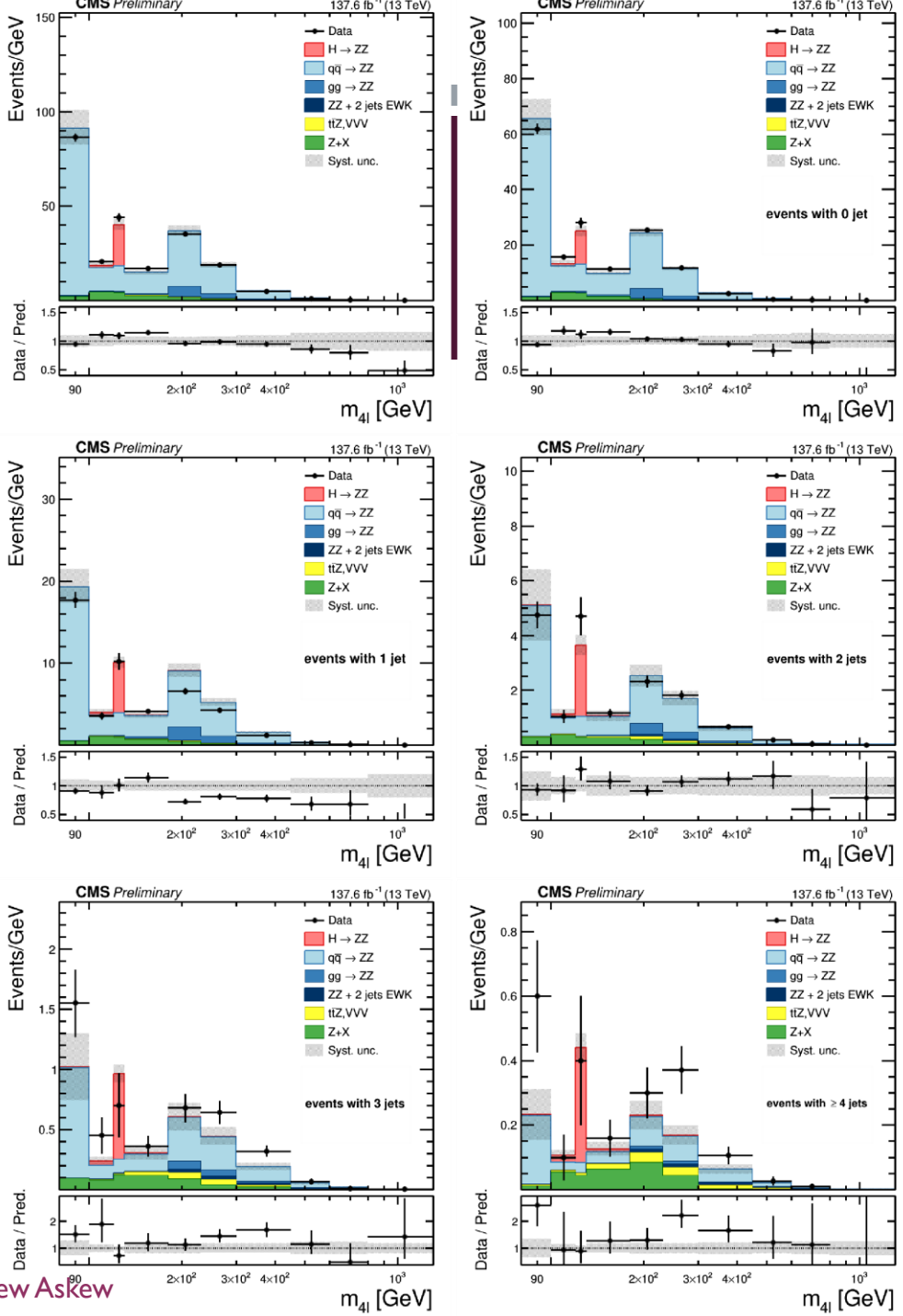

CMS
138 fb^{-1} (13 TeV)
Obs. result (stat.⊕syst.)
Obs. result (syst.)
EW(LO) + QCD(NLO) Wγ MG5
Δ σ / Δ[Δ η$_{jj}$] [fb]
Data/exp.
[2.5,3.0]
[3.0,3.7]
[3.7,4.5]
[4.5,6.5]
Δη$_{jj}$

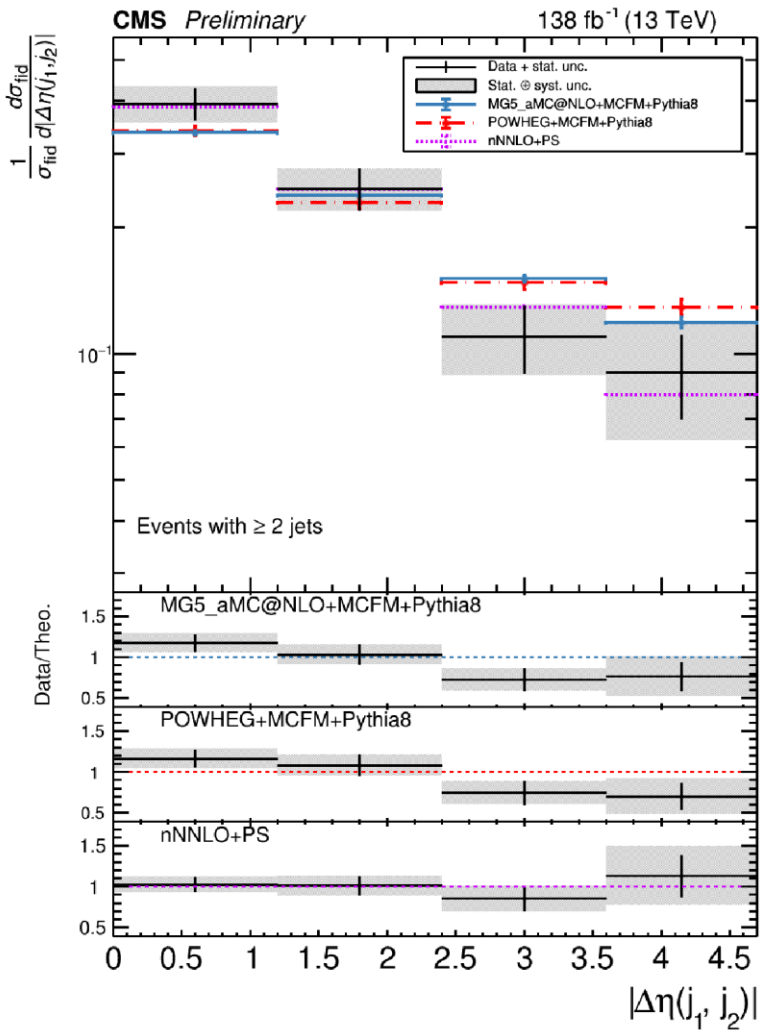
EWK Wγ

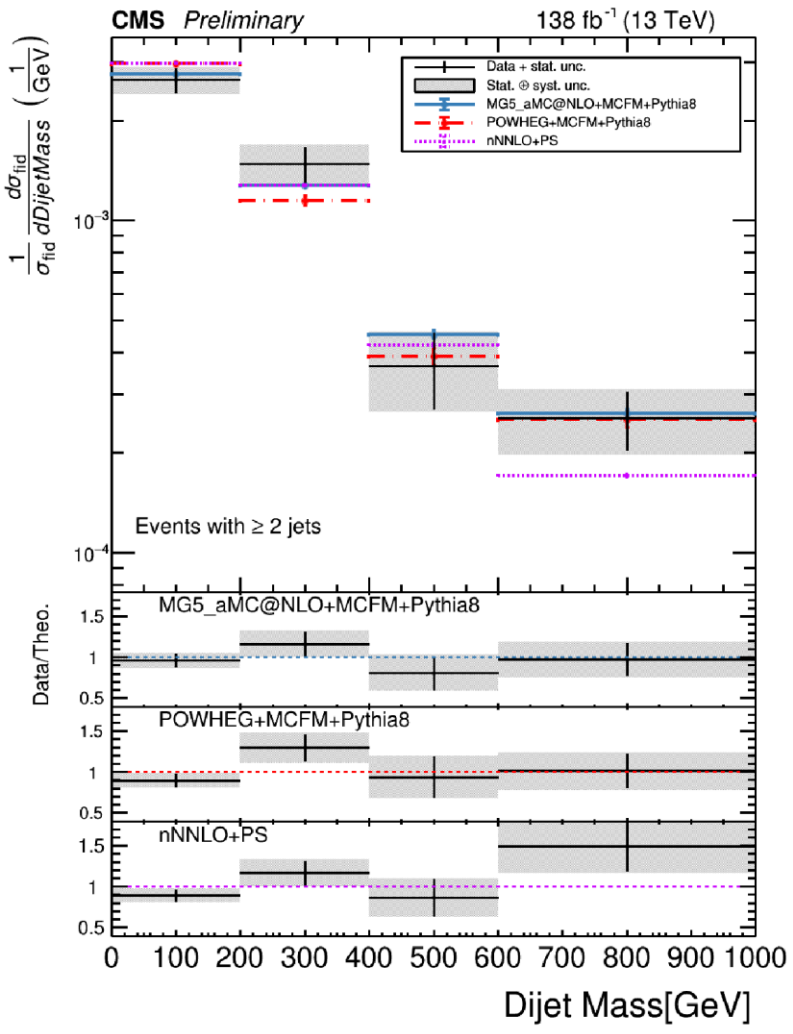
Expected limit	Observed limit	U_{bound}
$-5.1 < f_{M,0}/\Lambda^4 < 5.1$	$-5.6 < f_{M,0}/\Lambda^4 < 5.5$	1.7
$-7.1 < f_{M,1}/\Lambda^4 < 7.4$	$-7.8 < f_{M,1}/\Lambda^4 < 8.1$	2.1
$-1.8 < f_{M,2}/\Lambda^4 < 1.8$	$-1.9 < f_{M,2}/\Lambda^4 < 1.9$	2.0
$-2.5 < f_{M,3}/\Lambda^4 < 2.5$	$-2.7 < f_{M,3}/\Lambda^4 < 2.7$	2.7
$-3.3 < f_{M,4}/\Lambda^4 < 3.3$	$-3.7 < f_{M,4}/\Lambda^4 < 3.6$	2.3
$-3.4 < f_{M,5}/\Lambda^4 < 3.6$	$-3.9 < f_{M,5}/\Lambda^4 < 3.9$	2.7
$-13 < f_{M,7}/\Lambda^4 < 13$	$-14 < f_{M7}/\Lambda^4 < 14$	2.2
$-0.43 < f_{T,0}/\Lambda^4 < 0.51$	$-0.47 < f_{T,0}/\Lambda^4 < 0.51$	1.9
$-0.27 < f_{T,1}/\Lambda^4 < 0.31$	$-0.31 < f_{T,1}/\Lambda^4 < 0.34$	2.5
$-0.72 < f_{T,2}/\Lambda^4 < 0.92$	$-0.85 < f_{T,2}/\Lambda^4 < 1.0$	2.3
$-0.29 < f_{T,5}/\Lambda^4 < 0.31$	$-0.31 < f_{T,5}/\Lambda^4 < 0.33$	2.6
$-0.23 < f_{T,6}/\Lambda^4 < 0.25$	$-0.25 < f_{T,6}/\Lambda^4 < 0.27$	2.9
$-0.60 < f_{T,7}/\Lambda^4 < 0.68$	$-0.67 < f_{T,7}/\Lambda^4 < 0.73$	3.1

ZZ+JETS

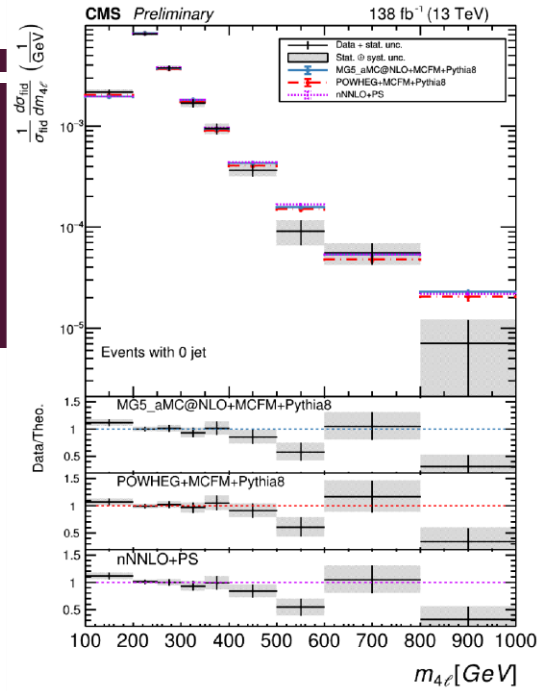
ZZ+JETS

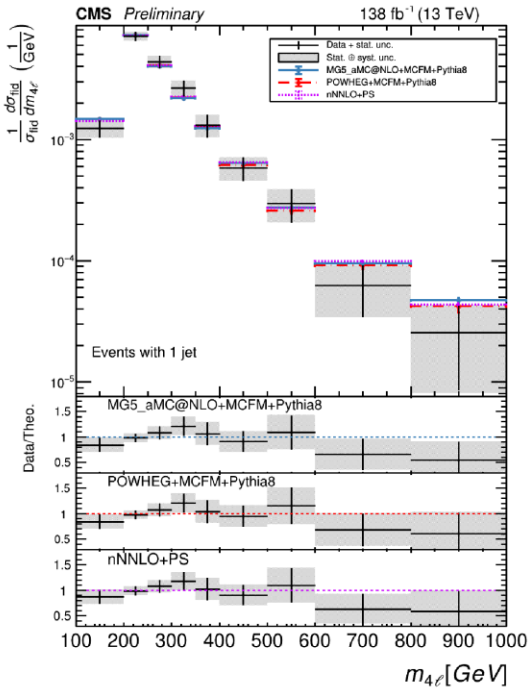

CMS Preliminary
137.6 fb^{-1} (13 TeV)
Data
H → ZZ
qq̄ → ZZ
gg → ZZ
ZZ + 2 jets EWK
ttZ,VVV
Z+X
Syst. unc.
Events/GeV
Data / Pred.
m$_{4l}$ [GeV]
events with 0 jet
events with 1 jet
events with 2 jets
events with 3 jets
events with ≥ 4 jets

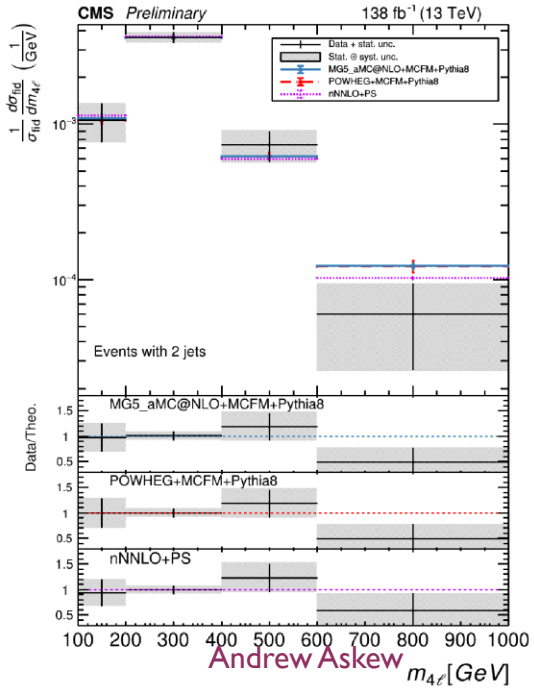

CMS Preliminary
138 fb^{-1} (13 TeV)
Data + stat. unc.
Stat. ⊕ syst. unc.
MG5_aMC@NLO+MCFM+Pythia8
POWHEG+MCFM+Pythia8
nNNLO+PS
Events with ≥ 2 jets
Data/Theo.
$\frac{1}{\sigma_{fid}}\frac{d\sigma_{fid}}{d|\Delta\eta(j_1,j_2)|}$
$|\Delta\eta(j_1, j_2)|$

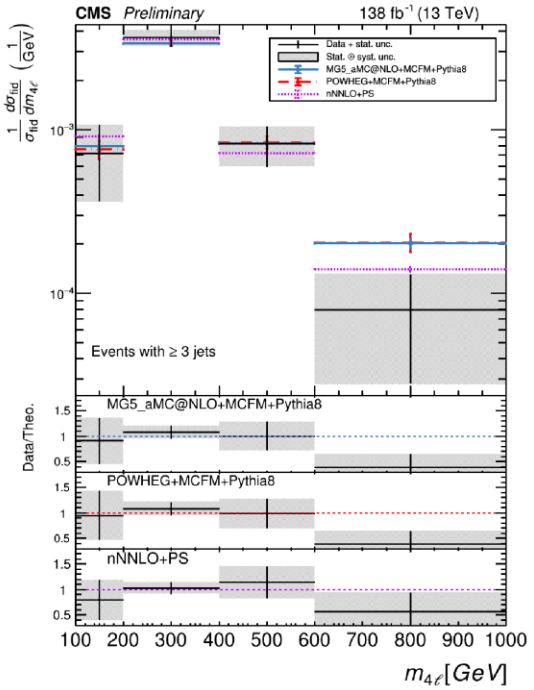

CMS Preliminary
138 fb^{-1} (13 TeV)
Data + stat. unc.
Stat. ⊕ syst. unc.
MG5_aMC@NLO+MCFM+Pythia8
POWHEG+MCFM+Pythia8
nNNLO+PS
Events with ≥ 2 jets
Data/Theo.
$\frac{1}{\sigma_{fid}}\frac{d\sigma_{fid}}{dDijetMass}\left(\frac{1}{GeV}\right)$
Dijet Mass[GeV]

ZZ+JETS


CMS Preliminary
138 fb^{-1} (13 TeV)
Data + stat. unc.
Stat. ⊕ syst. unc.
MG5_aMC@NLO+MCFM+Pythia8
POWHEG+MCFM+Pythia8
nNNLO+PS
Events with 0 jet
Data/Theo.
$m_{4\ell}$[GeV]

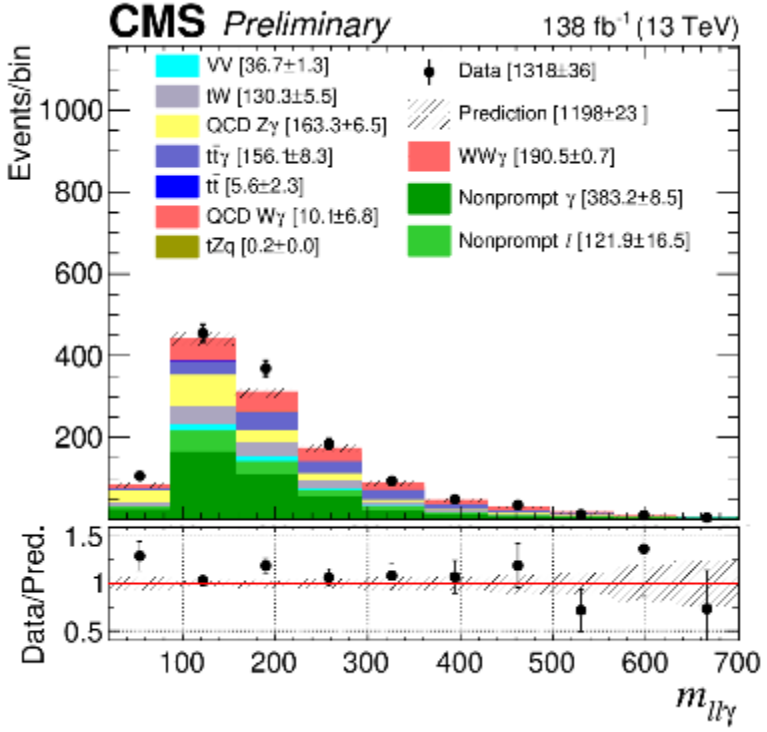

CMS Preliminary
138 fb^{-1} (13 TeV)
Data + stat. unc.
Stat. ⊕ syst. unc.
MG5_aMC@NLO+MCFM+Pythia8
POWHEG+MCFM+Pythia8
nNNLO+PS
Events with 1 jet
Data/Theo.
$m_{4\ell}$[GeV]

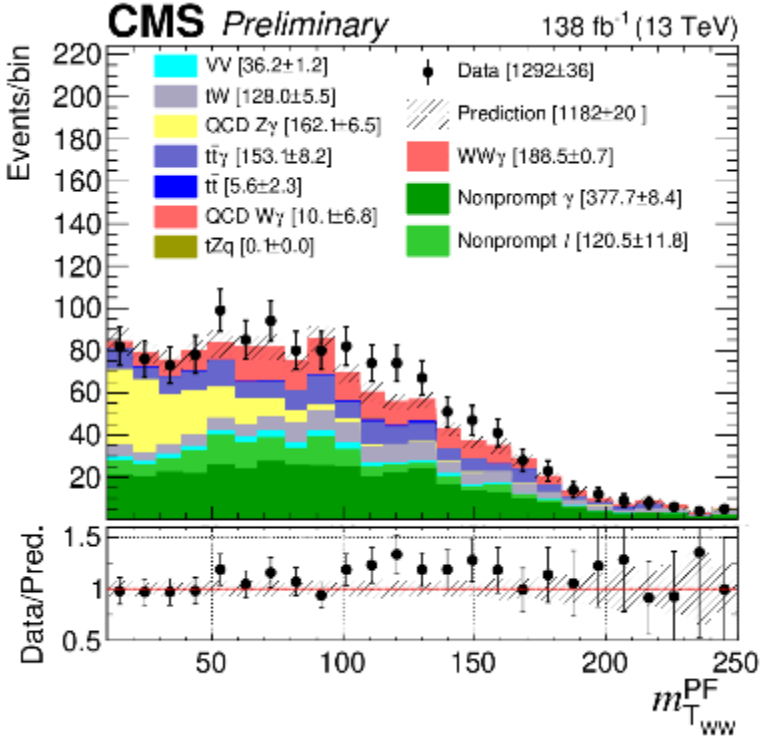

CMS Preliminary
138 fb^{-1} (13 TeV)
Data + stat. unc.
Stat. ⊕ syst. unc.
MG5_aMC@NLO+MCFM+Pythia8
POWHEG+MCFM+Pythia8
nNNLO+PS
Events with 2 jets
Data/Theo.
$m_{4\ell}$[GeV]


CMS Preliminary
138 fb^{-1} (13 TeV)
Data + stat. unc.
Stat. ⊕ syst. unc.
MG5_aMC@NLO+MCFM+Pythia8
POWHEG+MCFM+Pythia8
nNNLO+PS
Events with ≥ 3 jets
Data/Theo.
$m_{4\ell}$[GeV]

$WW\gamma$

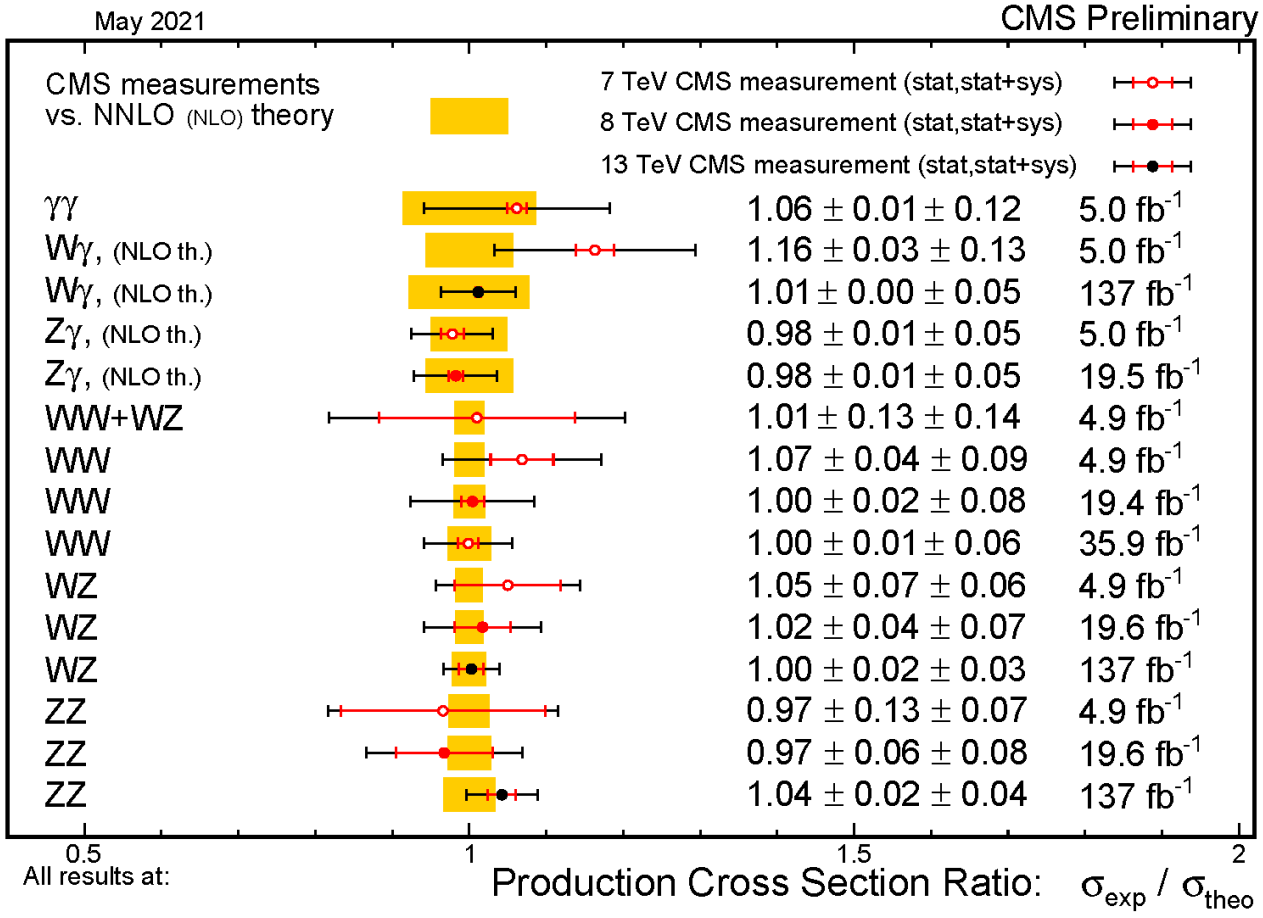
WWγ


CMS Preliminary
138 fb^{-1} (13 TeV)
VV [36.7±1.3]
tW [130.3±5.5]
QCD Zγ [163.3+6.5]
ttγ [156.1±8.3]
tt̄ [5.6±2.3]
QCD Wγ [10.1±6.8]
tZq [0.2±0.0]
Data [1318±36]
Prediction [1198+23]
WWγ [190.5±0.7]
Nonprompt γ [383.2±8.5]
Nonprompt l [121.9±16.5]
Events/bin
Data/Pred.
$m_{ll\gamma}$

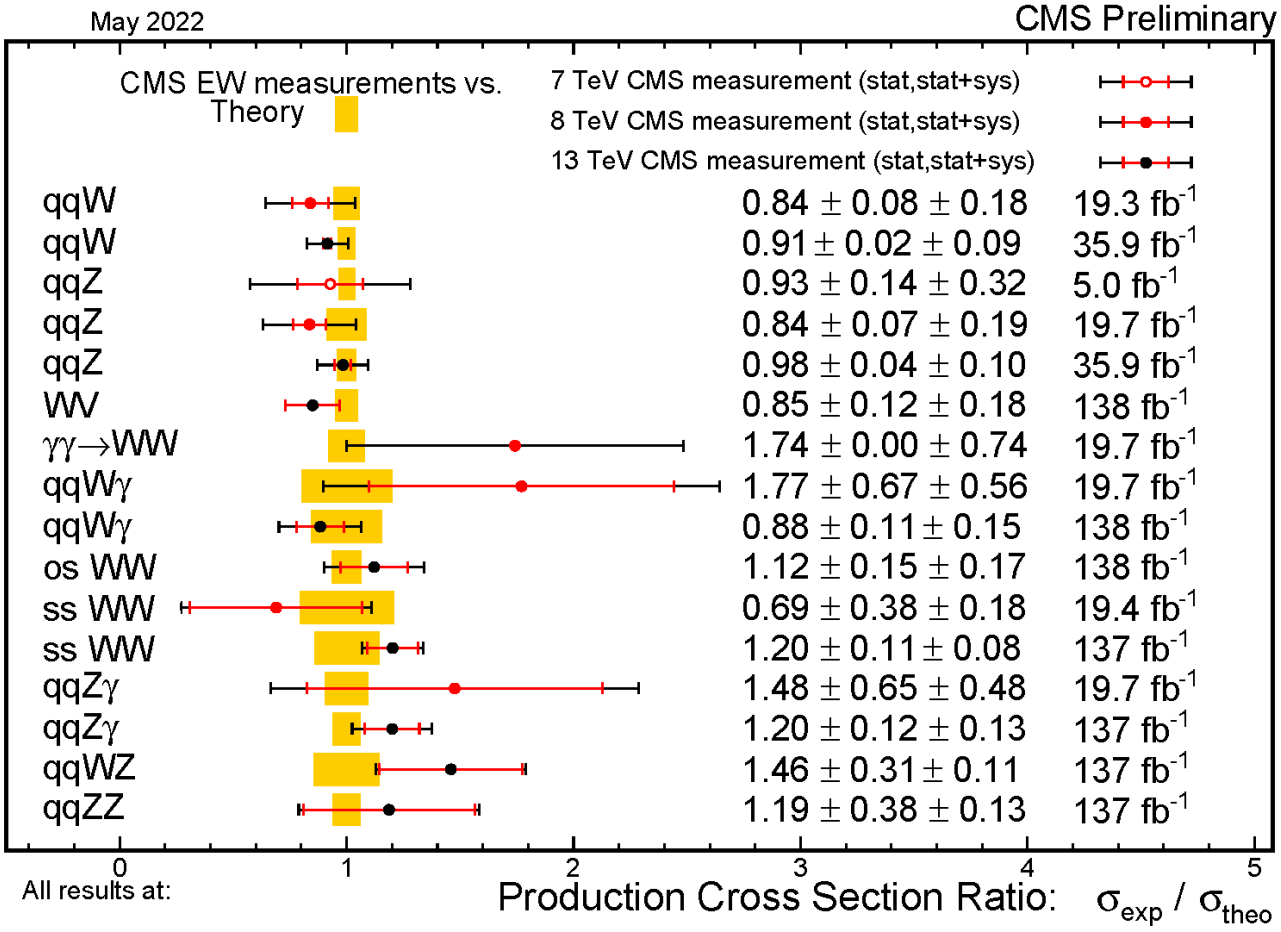

CMS Preliminary
138 fb^{-1} (13 TeV)
VV [36.2±1.2]
tW [128.0±5.5]
QCD Zγ [162.1+6.5]
ttγ [153.1±8.2]
tt̄ [5.6±2.3]
QCD Wγ [10.1±6.8]
tZq [0.1±0.0]
Data [1292±36]
Prediction [1182+20]
WWγ [188.5±0.7]
Nonprompt γ [377.7±8.4]
Nonprompt l [120.5±11.8]
Events/bin
Data/Pred.
$m_{T_{WW}}^{PF}$

SUMMARIES

WWγ


May 2021
CMS Preliminary
CMS measurements
vs. NNLO (NLO) theory
7 TeV CMS measurement (stat,stat+sys)
8 TeV CMS measurement (stat,stat+sys)
13 TeV CMS measurement (stat,stat+sys)
γγ 1.06 ± 0.01 ± 0.12 5.0 fb-1
Wγ, (NLO th.) 1.16 ± 0.03 ± 0.13 5.0 fb-1
Wγ, (NLO th.) 1.01 ± 0.00 ± 0.05 137 fb-1
Zγ, (NLO th.) 0.98 ± 0.01 ± 0.05 5.0 fb-1
Zγ, (NLO th.) 0.98 ± 0.01 ± 0.05 19.5 fb-1
WW+WZ 1.01 ± 0.13 ± 0.14 4.9 fb-1
WW 1.07 ± 0.04 ± 0.09 4.9 fb-1
WW 1.00 ± 0.02 ± 0.08 19.4 fb-1
WW 1.00 ± 0.01 ± 0.06 35.9 fb-1
WZ 1.05 ± 0.07 ± 0.06 4.9 fb-1
WZ 1.02 ± 0.04 ± 0.07 19.6 fb-1
WZ 1.00 ± 0.02 ± 0.03 137 fb-1
ZZ 0.97 ± 0.13 ± 0.07 4.9 fb-1
ZZ 0.97 ± 0.06 ± 0.08 19.6 fb-1
ZZ 1.04 ± 0.02 ± 0.04 137 fb-1
0.5
1
1.5
2
All results at:
Production Cross Section Ratio: σexp / σtheo

SUMMARIES


May 2022
CMS Preliminary
CMS EW measurements vs. Theory
7 TeV CMS measurement (stat,stat+sys)
8 TeV CMS measurement (stat,stat+sys)
13 TeV CMS measurement (stat,stat+sys)
qqW 0.84 ± 0.08 ± 0.18 19.3 fb-1
qqW 0.91 ± 0.02 ± 0.09 35.9 fb-1
qqZ 0.93 ± 0.14 ± 0.32 5.0 fb-1
qqZ 0.84 ± 0.07 ± 0.19 19.7 fb-1
qqZ 0.98 ± 0.04 ± 0.10 35.9 fb-1
WV 0.85 ± 0.12 ± 0.18 138 fb-1
γγ→WW 1.74 ± 0.00 ± 0.74 19.7 fb-1
qqWγ 1.77 ± 0.67 ± 0.56 19.7 fb-1
qqWγ 0.88 ± 0.11 ± 0.15 138 fb-1
os WW 1.12 ± 0.15 ± 0.17 138 fb-1
ss WW 0.69 ± 0.38 ± 0.18 19.4 fb-1
ss WW 1.20 ± 0.11 ± 0.08 137 fb-1
qqZγ 1.48 ± 0.65 ± 0.48 19.7 fb-1
qqZγ 1.20 ± 0.12 ± 0.13 137 fb-1
qqWZ 1.46 ± 0.31 ± 0.11 137 fb-1
qqZZ 1.19 ± 0.38 ± 0.13 137 fb-1
0
1
2
3
4
5
All results at:
Production Cross Section Ratio: σexp / σtheo