Multiboson production measurements at the CMS experiment

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On behalf of the **CMS** Collaborations

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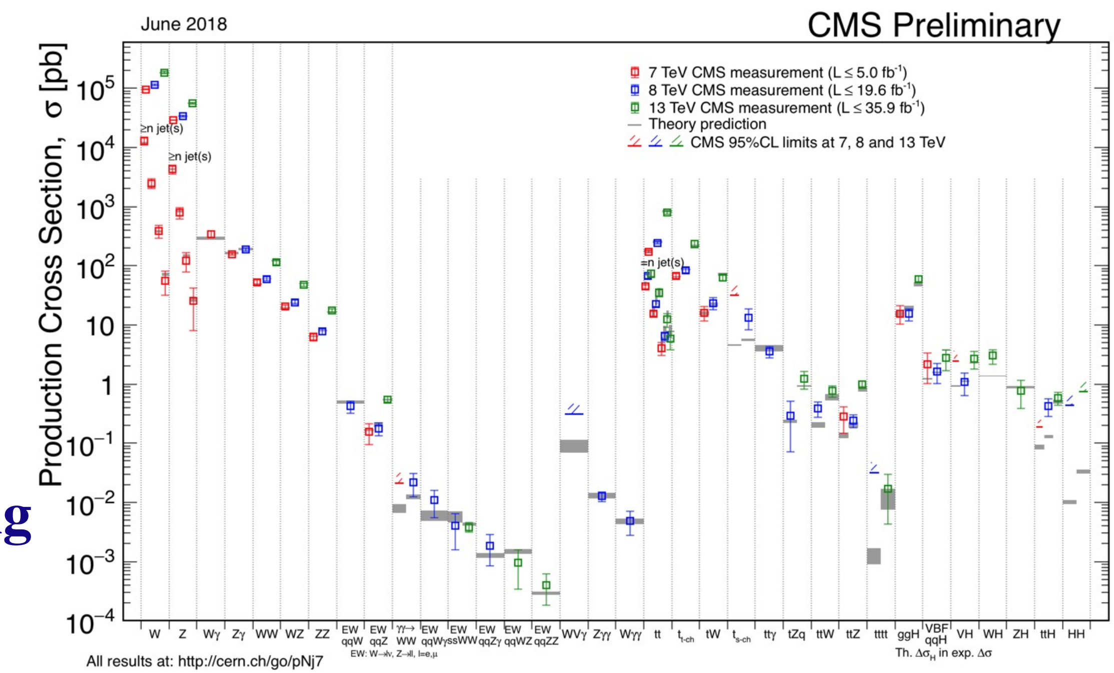
Top and electroweak physics session

Stairway to Heaven or Highway to Hell?

- Standard Model cross sections successfully tested over **9 orders of magnitude**
- We **discovered a Higgs boson**
- ***Still*** we have to understand **in detail the Electroweak Symmetry Breaking Mechanism** (*and if there is new physics beyond the SM*)

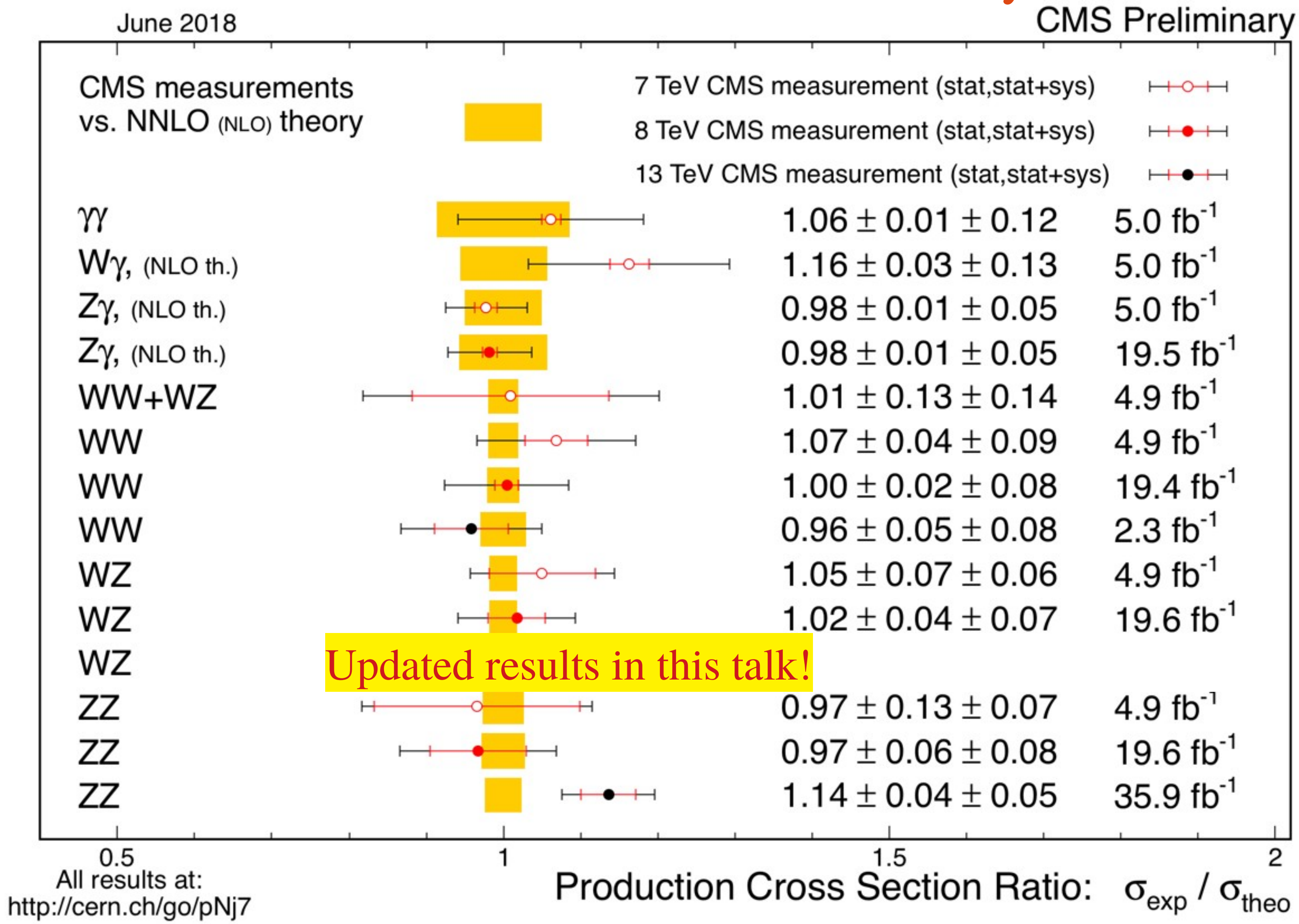


It is crucial to deeply understand the final states **mediated by heavy gauge boson pair production**: do we ***master*** them, using our N^{n}LO computations?

Measure with **high precision the differential cross sections**	Measure exclusive multi boson production mechanisms, such as **VV scattering** and **QGC mediated**	Investigate the **high VV mass region**

Multiboson production study at CMS

- Full plethora of results available in the CMS Standard Model public page: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP



Multiboson production study at CMS

- Full plethora of results available in the CMS Standard Model public page: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP
- Today, focus on most recent multiboson results:
  - $pp \rightarrow ZZ$ (+jets) $\rightarrow 4\ell$ (@13 TeV, with $\mathscr{L}$ = 35.9 fb^{-1})
    - EPJ C 78 (2018) 165 and CMS-PAS-SMP-17-005 (arXiv: 1806.11073 sub PLB)
  - $pp \rightarrow WZ \rightarrow 3\ell\nu$ (@13 TeV, with $\mathscr{L}$ = 35.9 fb^{-1})
    - CMS-PAS-18-002
  - $pp \rightarrow W\gamma\gamma \rightarrow \ell\nu\gamma\gamma$ and $pp \rightarrow Z\gamma\gamma \rightarrow \ell\ell\gamma\gamma$ (@8 TeV, with $\mathscr{L}$ = 19.4 fb^{-1})
    - JHEP 10 (2017) 072
  - $pp \rightarrow W\ W/Z \rightarrow \ell\nu qq'$ (@13 TeV, with $\mathscr{L}$ = 2.3 fb^{-1})
    - CMS-PAS-16-012

$pp \rightarrow ZZ \rightarrow 4\ell$

EPJ C 78 (2018) 165 and CMS-PAS-SMP-17-005

Search for two **on-shell** (**60 < $m_{\ell\ell}$ < 120 GeV**) **Z** bosons decaying into **electrons** or **muons** pairs, consider jets if their p_T is > 30 GeV

- Final state can be **fully reconstructed**

  → **all kinematic variables are accessible**

- **Very clean** final state
  - Irreducible background from genuine 4 lepton processes (ttZ, WWZ, ttWW) estimated with **MC** → they are pretty rare.
  - Reducible background from jets faking leptons estimated from **data**. Main sources of this kind are: DY, ttbar, WZ.

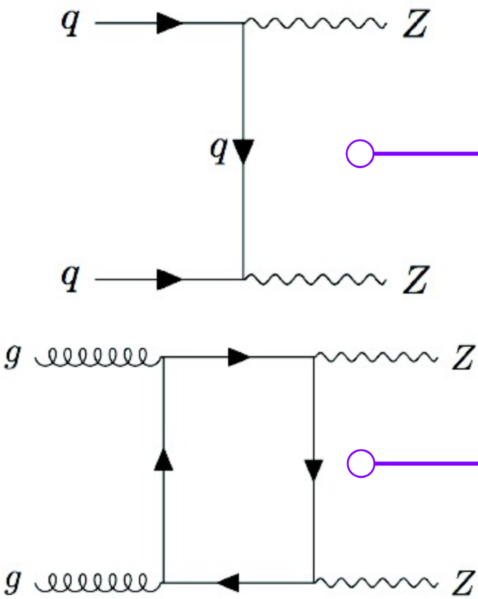
  → **low (though dominant) background from misreconstructed particles**

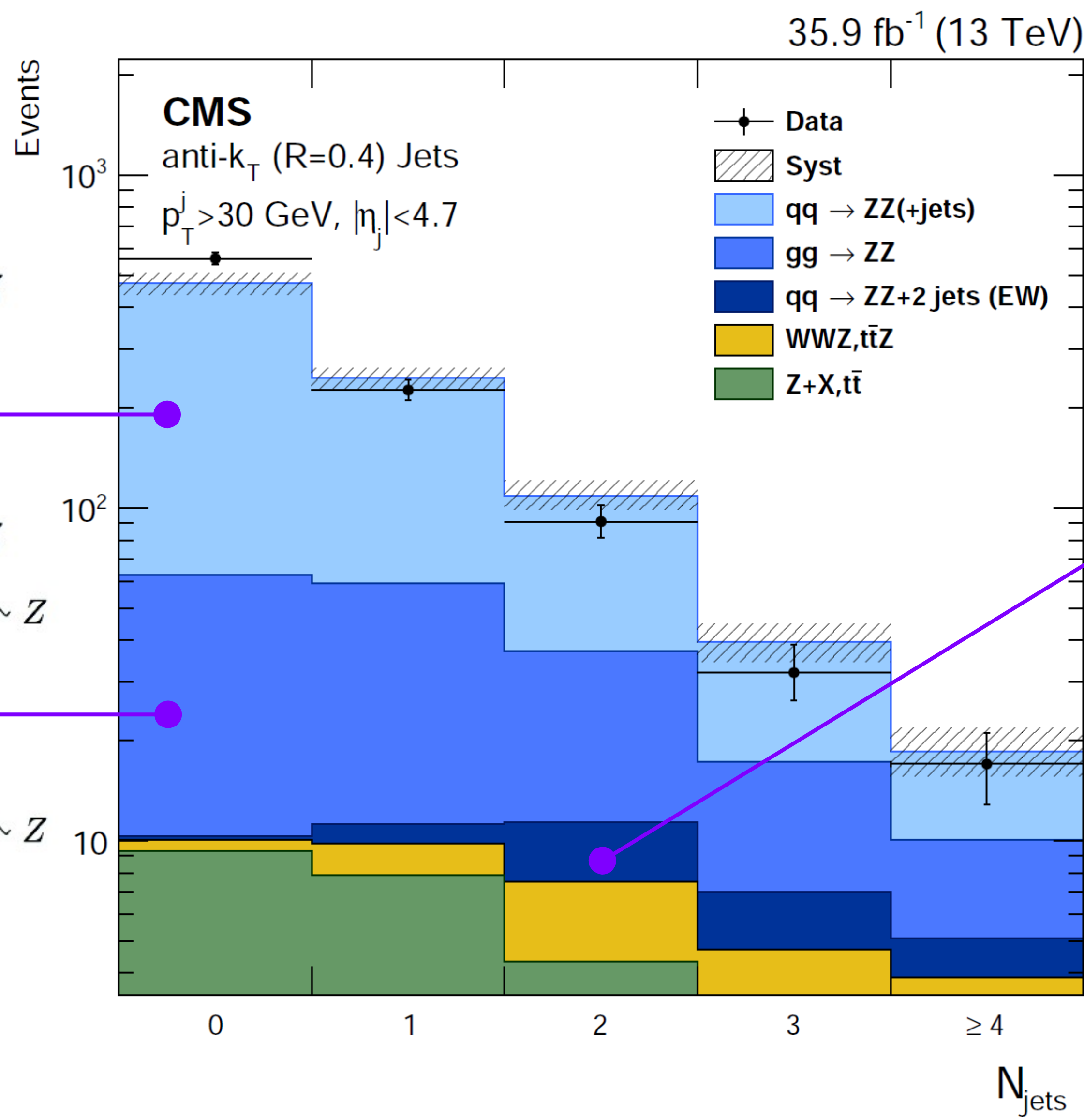
- **Low σxBR** compared to other channels

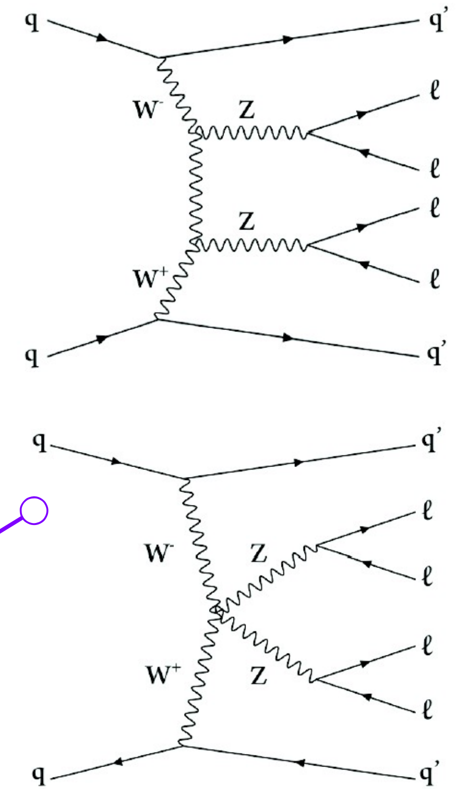
  → **maximize the selection efficiency** (minimal cuts on lepton mainly driven by trigger thresholds, detector acceptance)

$pp \to ZZ \to 4\ell$ Search region composition

CMS-PAS-SMP-17-005





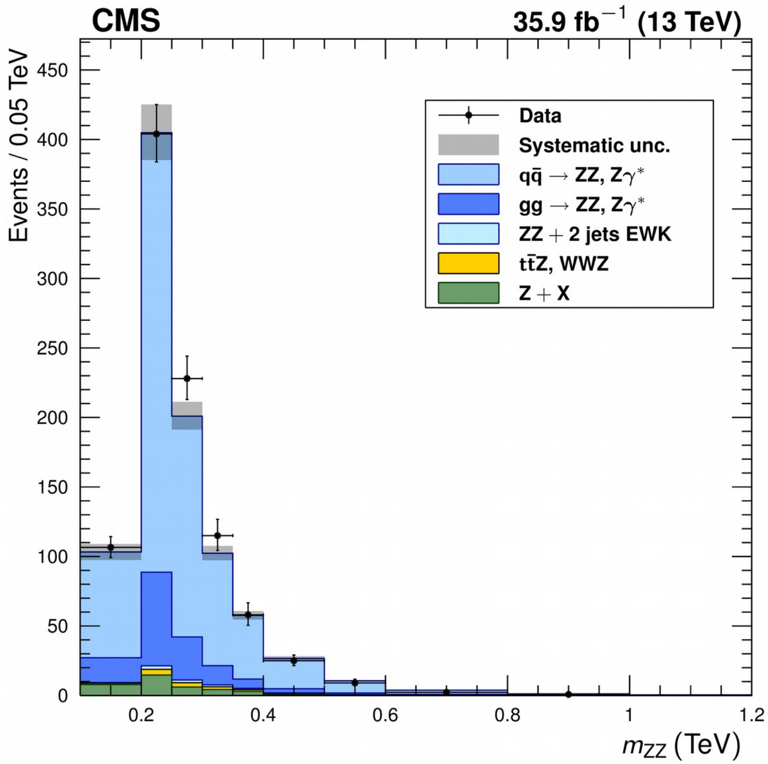


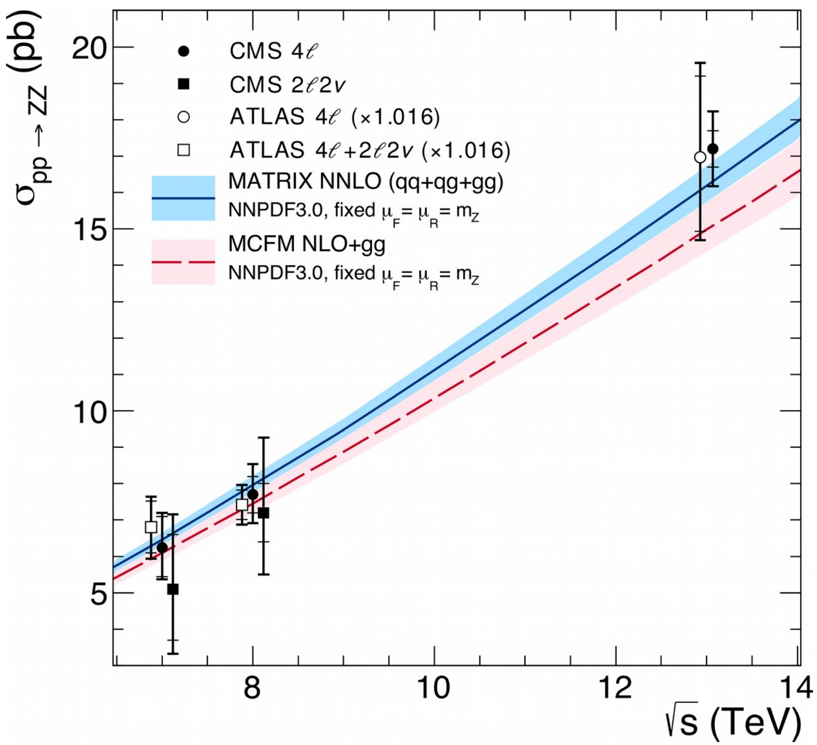
+

non-VBS diagrams, with (α_{EW}^6) at tree level

pp → ZZ → 4ℓ Inclusive cross section

EPJ C 78 (2018) 165





- Hit the regime where the measurements are **sensitive to NNLO corrections**
- Latest total cross section measurement is **systematic uncertainty limited**

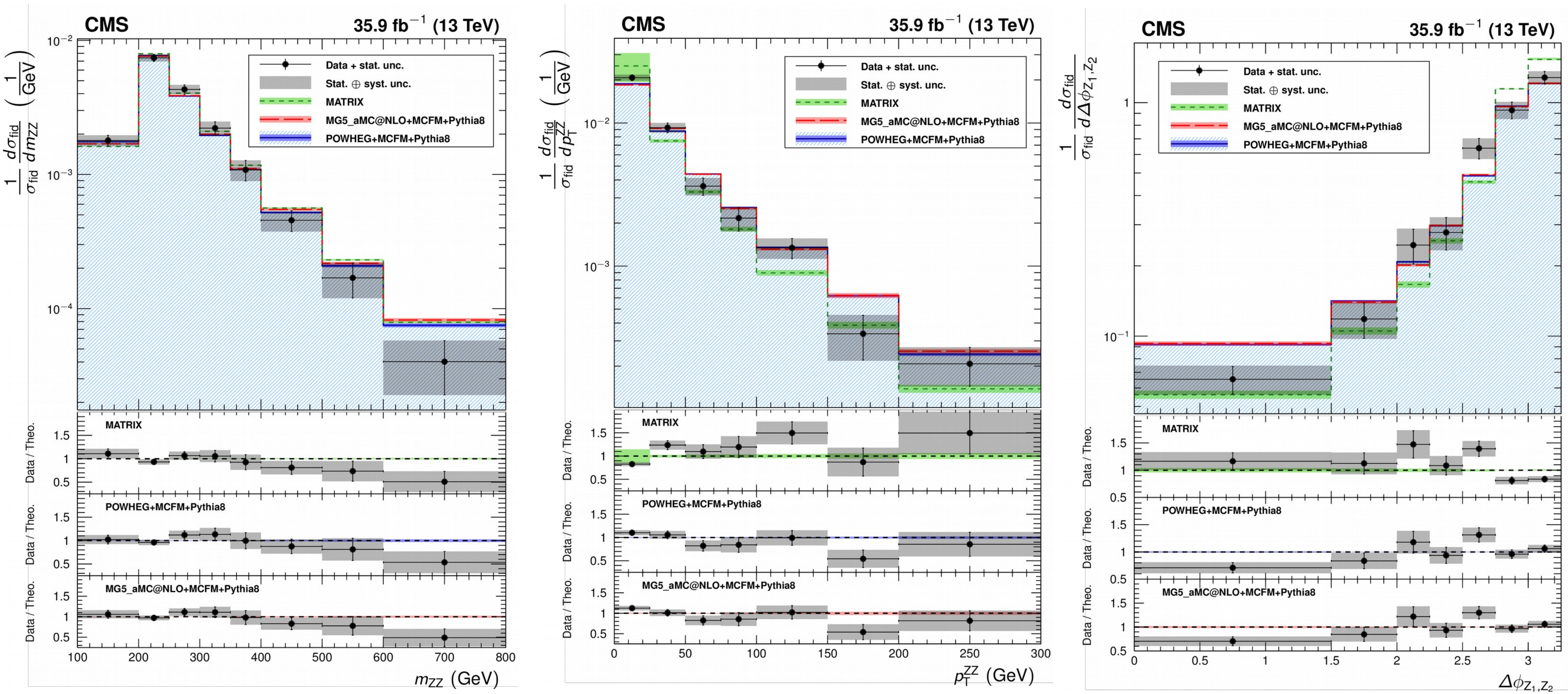
$$\sigma_{tot}(pp \rightarrow ZZ) = 17.2 \pm 0.5(stat) \pm 0.7(sys) \pm 0.4(theo) \pm 0.4(lumi)\, pb$$

To be compared with NNLO prediction from MATRIX MC $\sigma_{NNLO} = 16.2^{+0.6}_{-0.4}$

$pp \to ZZ \to 4\ell$ Differential cross sections

EPJ C 78 (2018) 165

Measured differential cross section as a function of **lepton-related variable**, such as m_{ZZ}, p_T^{ZZ}, p_T^{Z}, diboson angular separations, leptons' p_T.



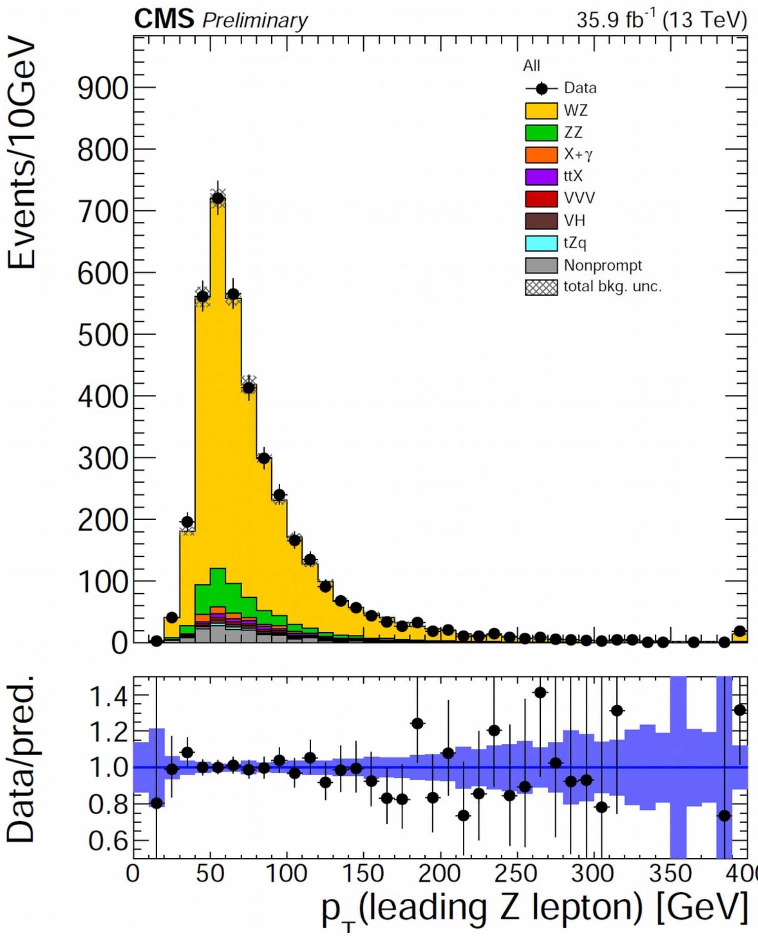
$pp \to WZ \to 3\ell 1\nu$

- Select charged leptons to pair into **one on-shell Z**, w/ $|m_{ll} - m_Z| < 15$ GeV, plus an additional isolated high-p_T lepton. Require missing $E_T > 30$ GeV and trilepton-system invariant mass > 100 GeV.

- **Background from at least 3 prompt leptons processes**, such as ZZ → 4 leptons, $t\bar{t}Z$, and tZq, is **estimated** with **simulation** and **validated** in dedicated **data control regions**.

- **Background from photon conversions** (in Z+γ process) is **estimated** with **simulation** and **validated** in a dedicated **data control region**.

- **Background from jets faking leptons** are **estimated** from **data**. The main sources of this kind are DY and ttbar.



$pp \rightarrow WZ \rightarrow 3\ell 1\nu$

CMS-PAS-SMP-18-002

- Select charged leptons to pair into **one on-shell Z**, w/ $|m_{ll} - m_Z| < 15$ GeV, plus an additional isolated high-p_T lepton. Require missing $E_T > 30$ GeV and trilepton-system invariant mass > 100 GeV.

- **Background from at least 3 prompt leptons processes**, such as ZZ → 4 leptons, $t\bar{t}Z$, and tZq, is **estimated** with **simulation** and **validated** in dedicated **data control regions**.

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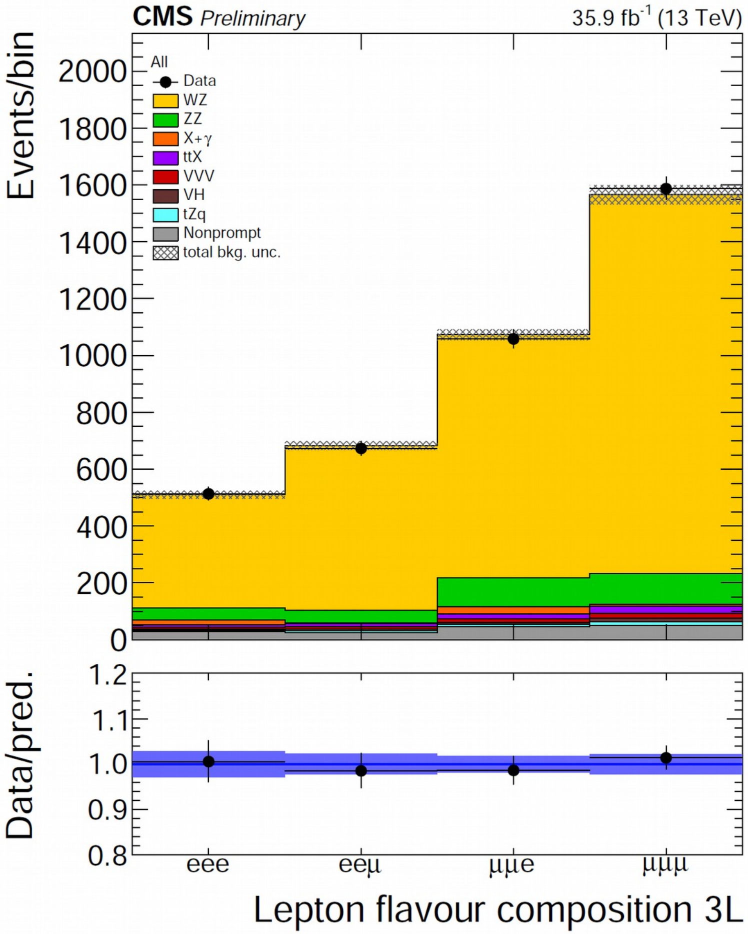


WZ → 3ℓ1ν Inclusive cross sections

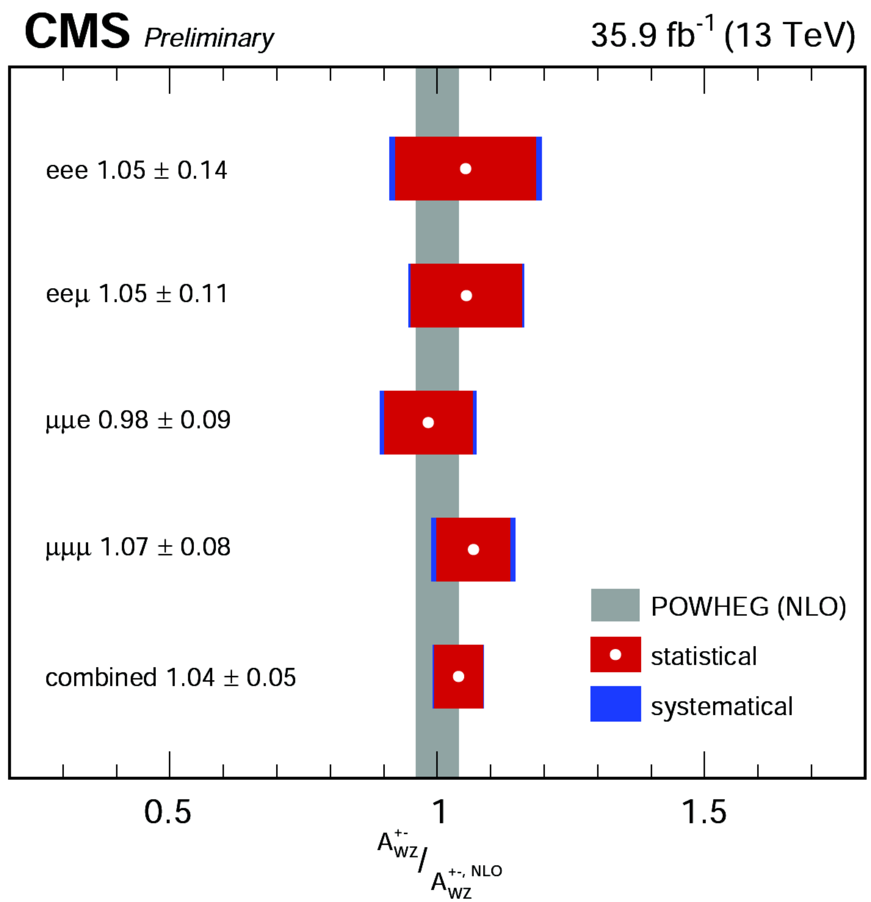
CMS-PAS-SMP-18-002

$$\sigma_{tot}(pp \rightarrow WZ) = 48.09^{+1.00}_{-0.96}(stat)^{+2.39}_{-2.17}(sys)^{+0.44}_{-0.37}(theo) \pm 1.45(lumi)\,pb$$

To be compared with NNLO prediction from MATRIX MC $\sigma_{NNLO} = 49.98^{+2.2\%}_{-2.0\%}$

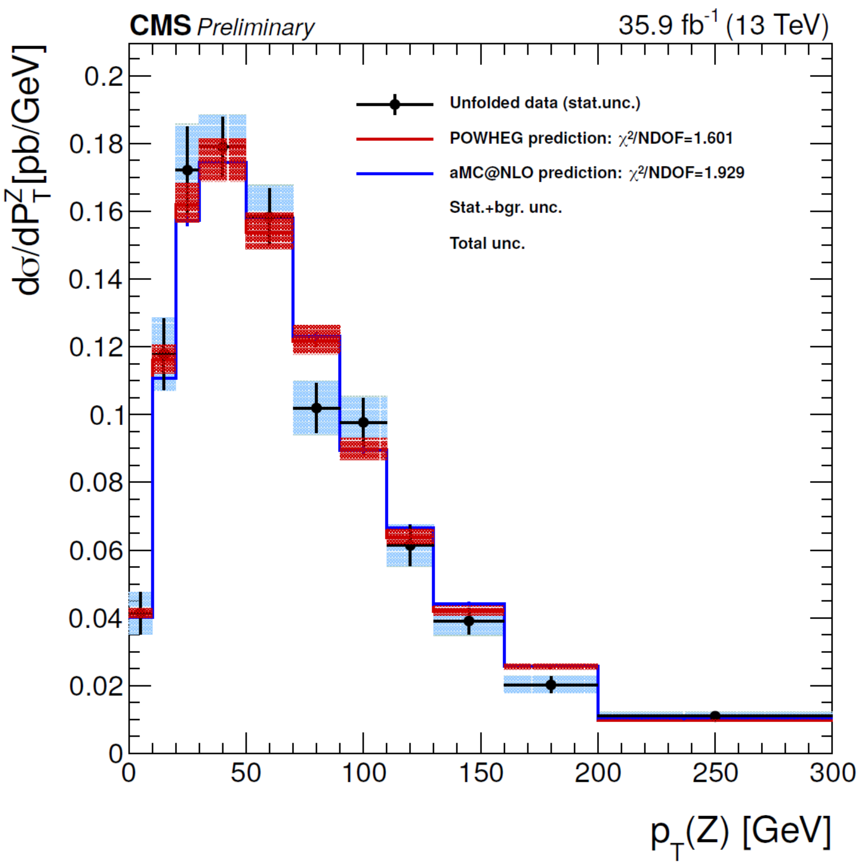
Measured WZ charge asymmetry ⇨ $$\frac{\sigma(pp \rightarrow W^+Z)}{\sigma(pp \rightarrow W^-Z)} = 1.48 \pm 0.06(stat) \pm 0.02(syst) \pm 0.01(theo)$$

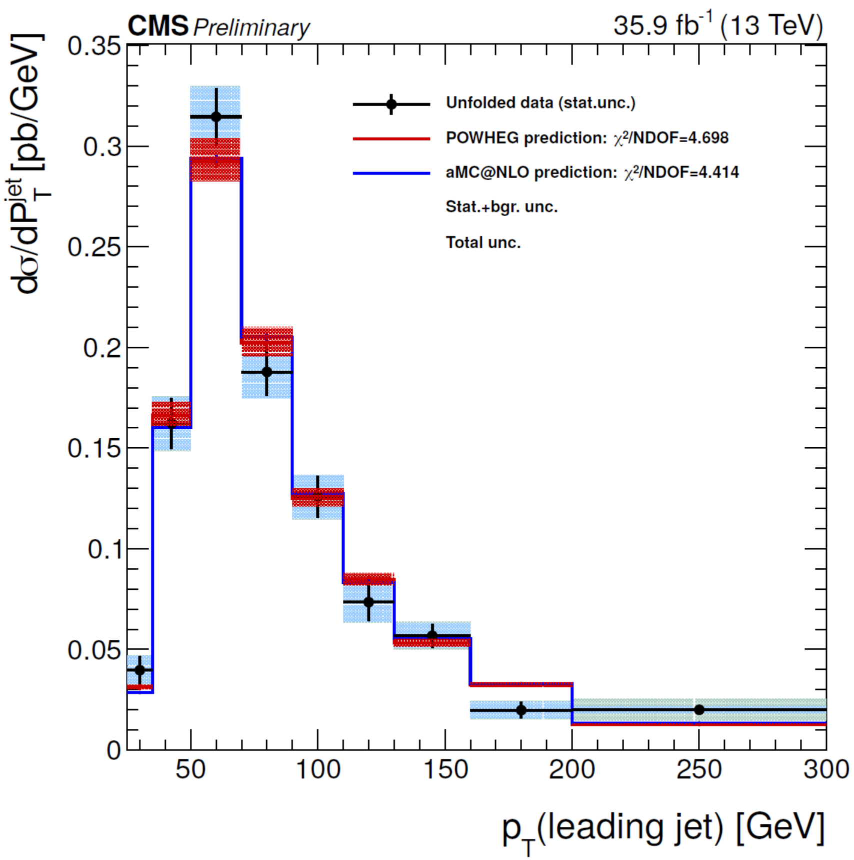
- WZ charge asymmetry **conistent** with the SM predicted value of $1.43^{+0.06}_{-0.05}$ from Powheg + Pythia.
- Among the two cross section measurements, **statistical uncertainty treated as completely uncorrelated**, while **systematical are considered fully correlated** (large cancellation occours in the ratio)



WZ → 3ℓ1ν Differential cross sections

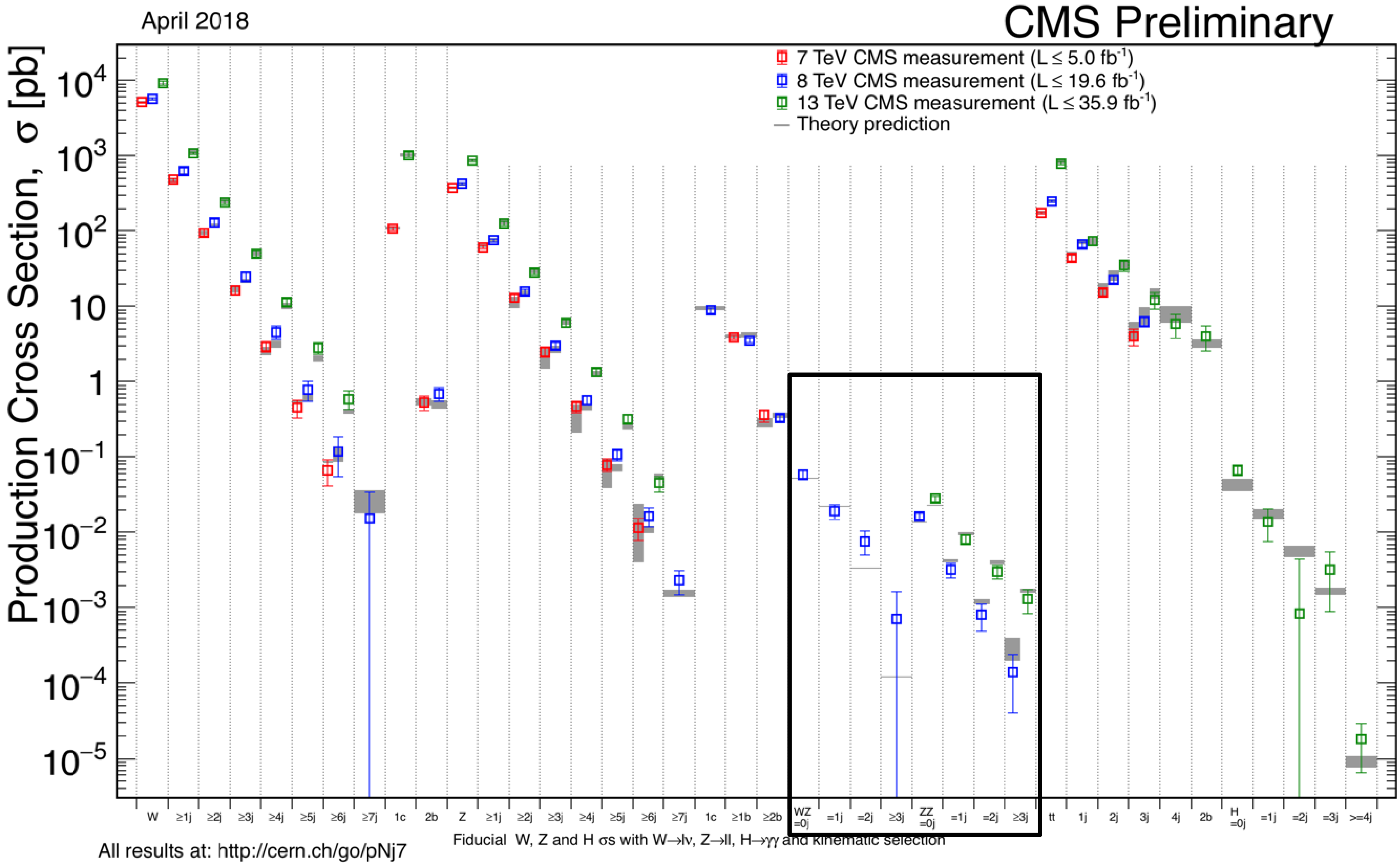
CMS-PAS-SMP-18-002





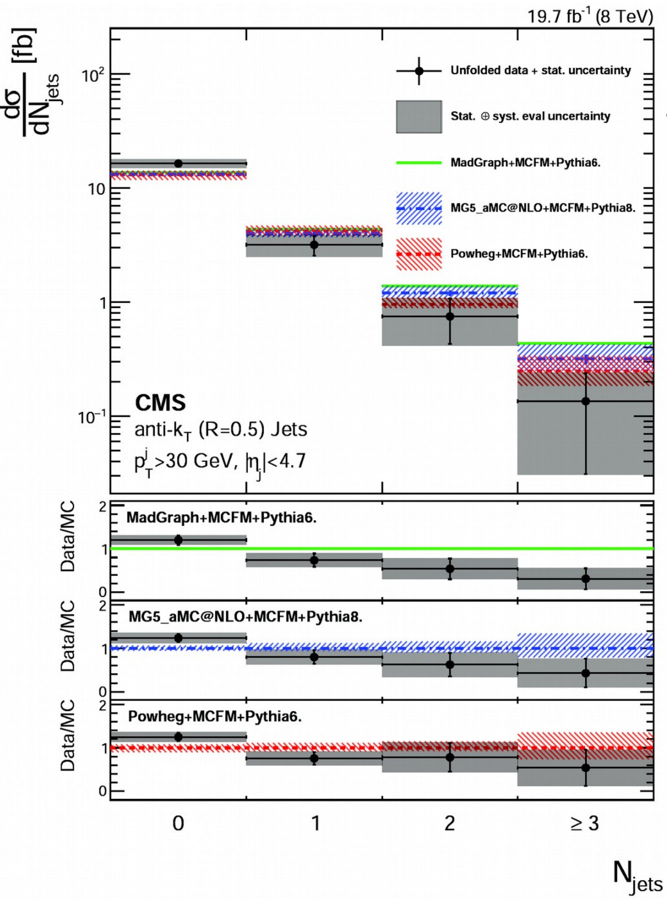
- Measurements and prediction in very good agreement.
- We also measured the W^+ and W^- differential cross sections separately, founding everything consistent with theory.

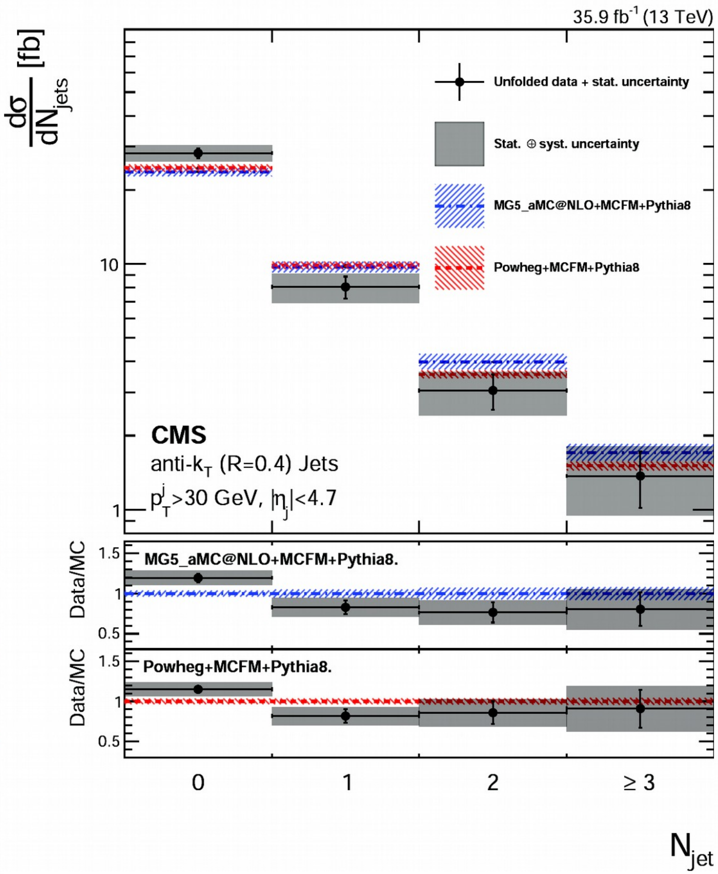
We are entering a new Era: VV+jets

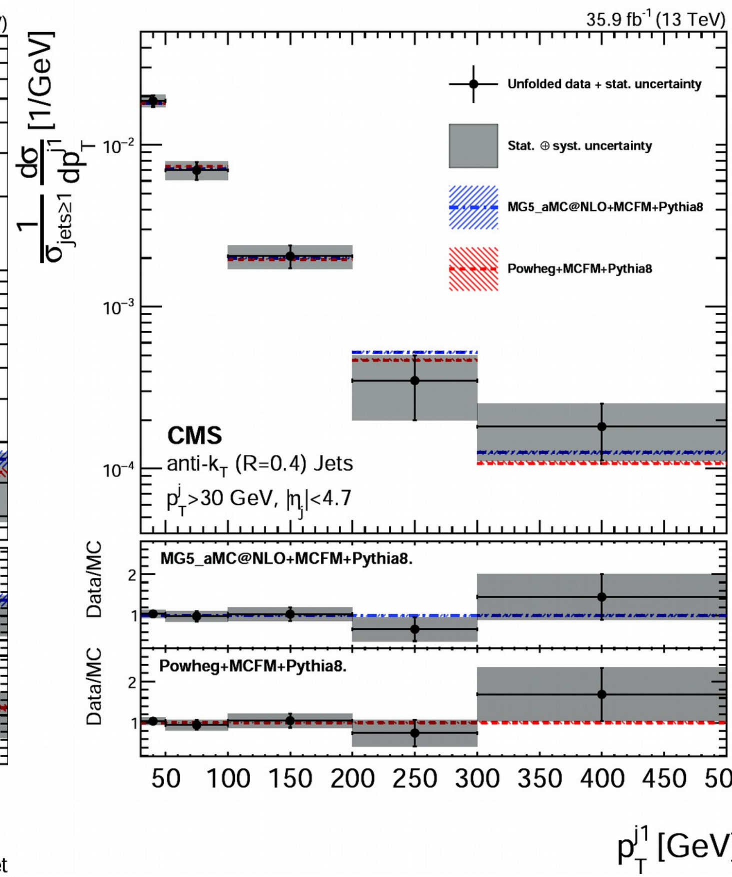


$pp \to ZZ\ (4\ell)$ +jets Differential cross sections

SMP-17-005 (arXiv: 1806.11073 sub PLB)



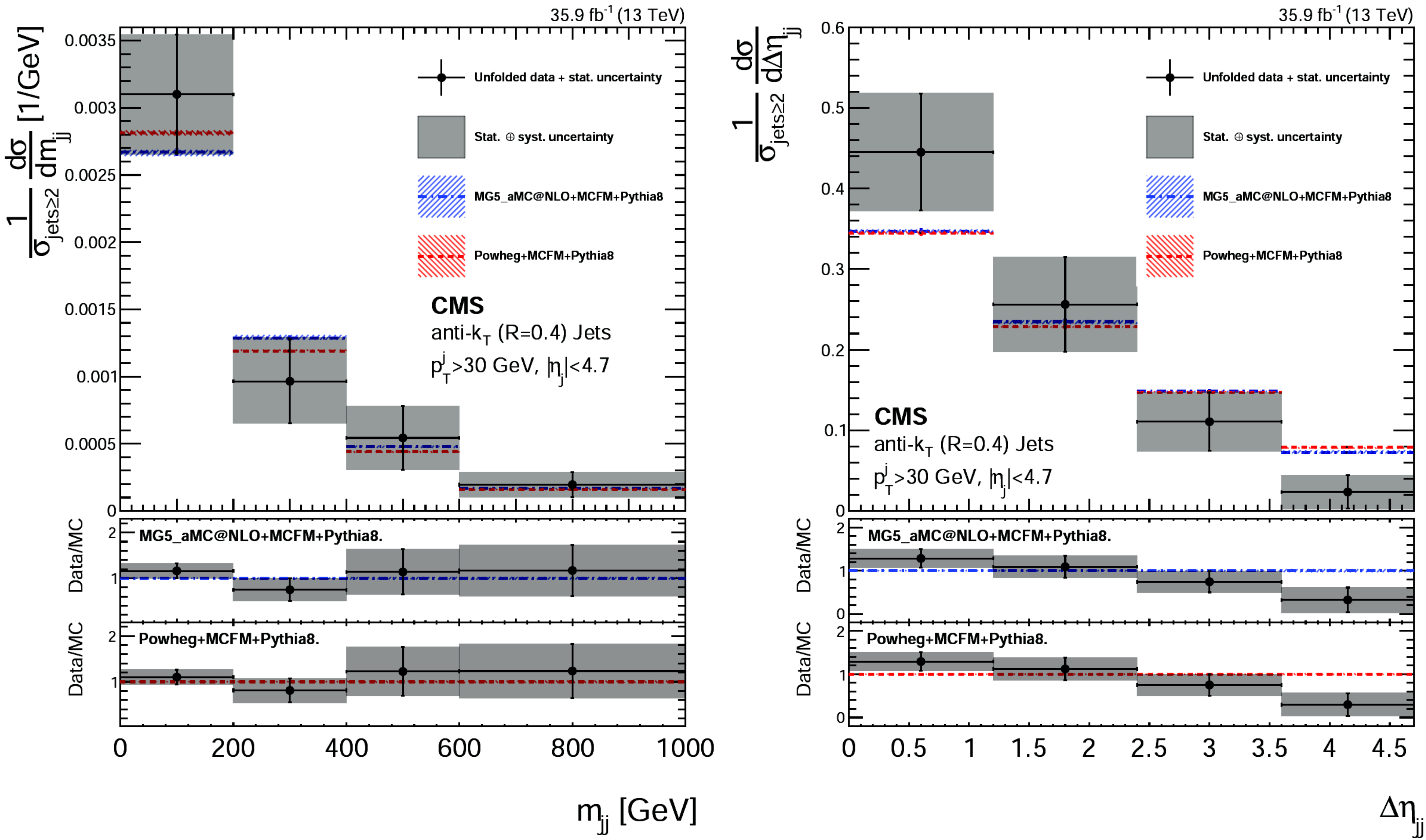




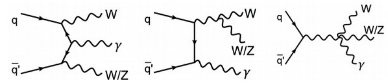
Number of jets ($|\eta_j| < 4.7$)	Cross section [fb] 13 TeV	Theoretical cross section [fb]
0	$28.3 \pm 1.3\,(\text{stat})^{+1.7}_{-1.6}\,(\text{syst}) \pm 0.7\,(\text{lumi})$	$23.6^{+0.8}_{-0.9}$
1	$8.1 \pm 0.8\,(\text{stat})^{+0.8}_{-0.8}\,(\text{syst}) \pm 0.2\,(\text{lumi})$	$9.7^{+0.4}_{-0.4}$
2	$3.0 \pm 0.5\,(\text{stat})^{+0.3}_{-0.4}\,(\text{syst}) \pm 0.1\,(\text{lumi})$	$4.0^{+0.3}_{-0.2}$
$\geq$3	$1.3 \pm 0.4\,(\text{stat})^{+0.3}_{-0.2}\,(\text{syst})$	$1.7^{+0.1}_{-0.1}$

$pp \to ZZ\ (4\ell)$ +jets Differential cross sections

SMP-17-005 (arXiv: 1806.11073 sub PLB)



pp → Wγγ and Zγγ Fiducial cross sections

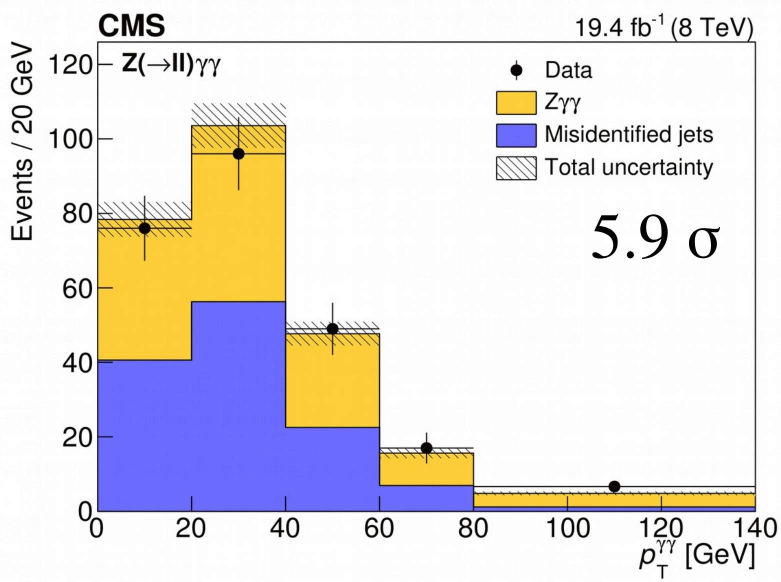


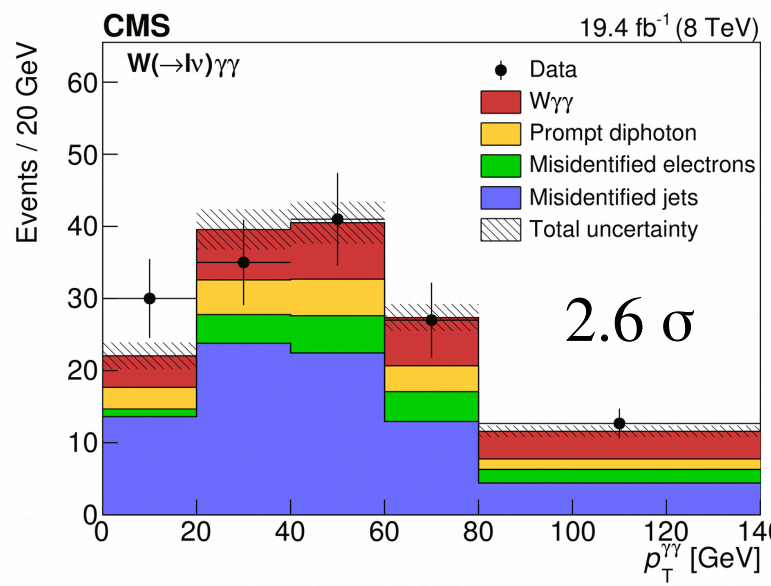
Definition of the $W\gamma\gamma$ fiducial region
$p_T^\gamma > 25\,\text{GeV}$, $\vert\eta^\gamma\vert < 2.5$
$p_T^\ell > 25\,\text{GeV}$, $\vert\eta^\ell\vert < 2.4$
One candidate lepton and two candidate photons
$m_T > 40\,\text{GeV}$
$\Delta R(\gamma,\gamma) > 0.4$ and $\Delta R(\gamma,\ell) > 0.4$
Definition of the $Z\gamma\gamma$ fiducial region
$p_T^\gamma > 15\,\text{GeV}$, $\vert\eta^\gamma\vert < 2.5$
$p_T^\ell > 10\,\text{GeV}$, $\vert\eta^\ell\vert < 2.4$
Two oppositely charged candidate leptons and two candidate photons
leading $p_T^\ell > 20\,\text{GeV}$
$m_{\ell\ell} > 40\,\text{GeV}$
$\Delta R(\gamma,\gamma) > 0.4$, $\Delta R(\gamma,\ell) > 0.4$, and $\Delta R(\ell,\ell) > 0.4$

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

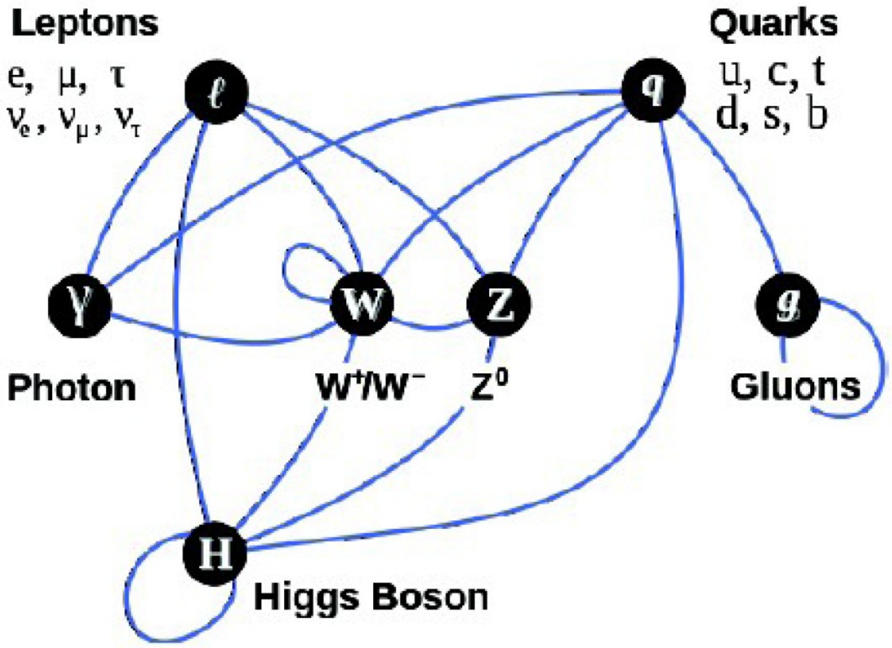
Channel	Prediction
$W\gamma\gamma \to \ell^\pm\nu\gamma\gamma$	4.8 ± 0.5 fb
$Z\gamma\gamma \to \ell^+\ell^-\gamma\gamma$	13.0 ± 1.5 fb

- Statistical and systematical uncertainty are **comparable**.
- **Observation of Zγγ** (5.9 σ)

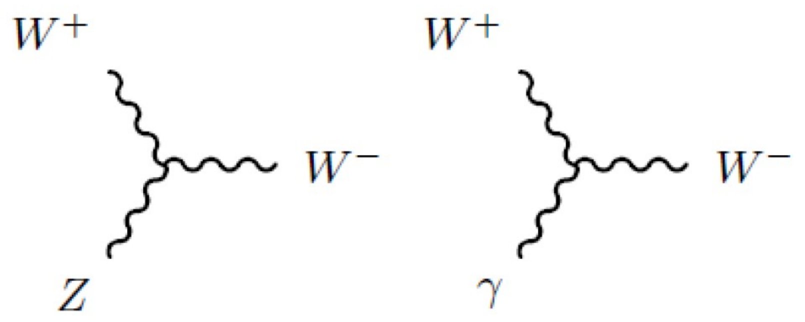




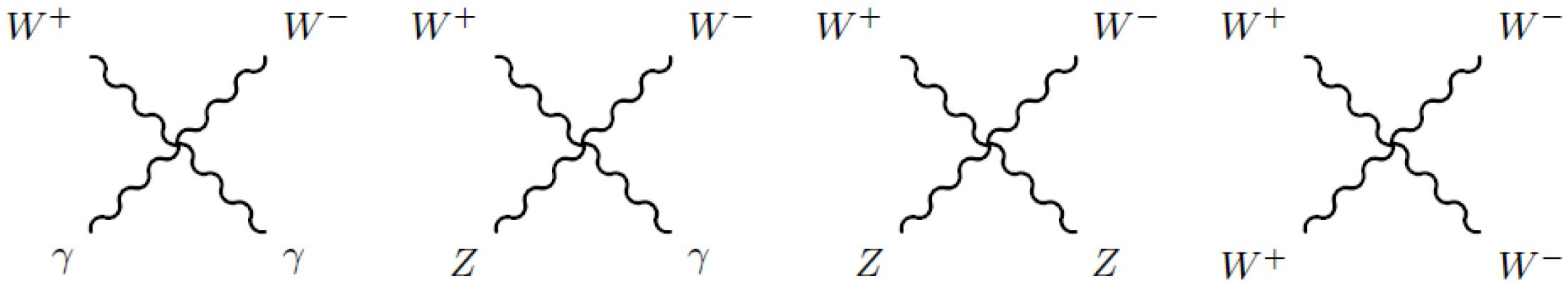
What interesting EW features can the VV production probe?



- **Triple gauge couplings (TGC)**



- **Quartic gauge couplings (QGC)**



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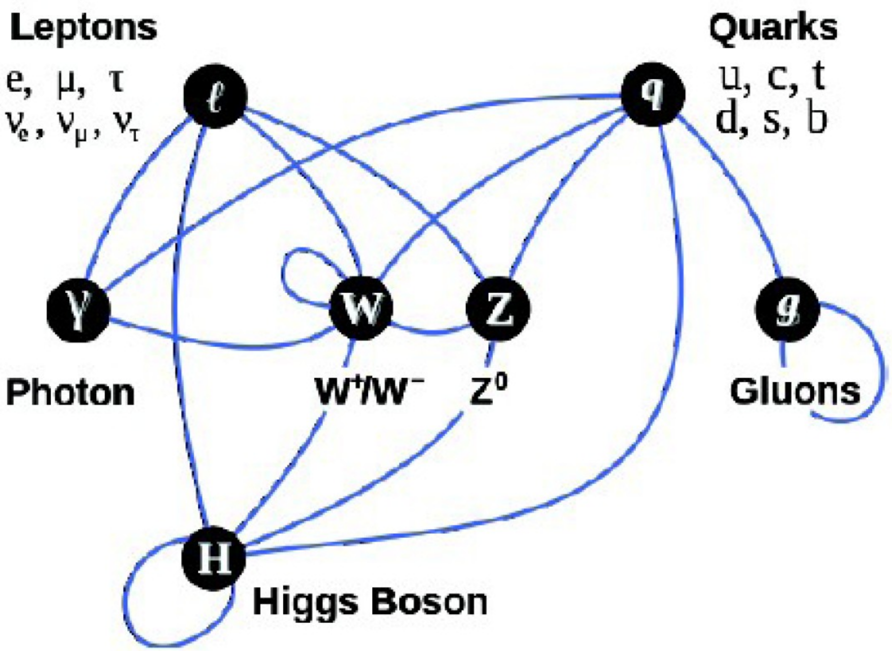
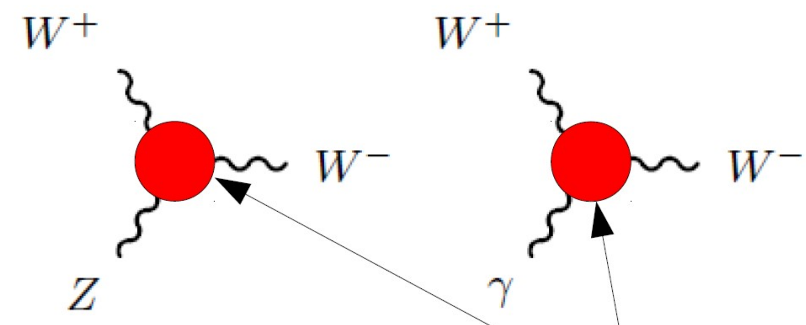
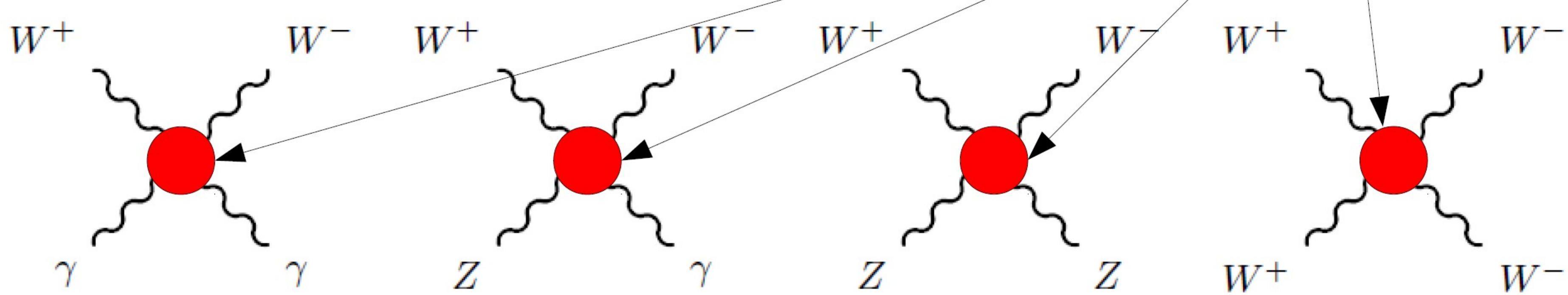


- **Triple gauge couplings (TGC)**



Anomalous couplings
+ what forbidden in SM

- **Quartic gauge couplings (QGC)**

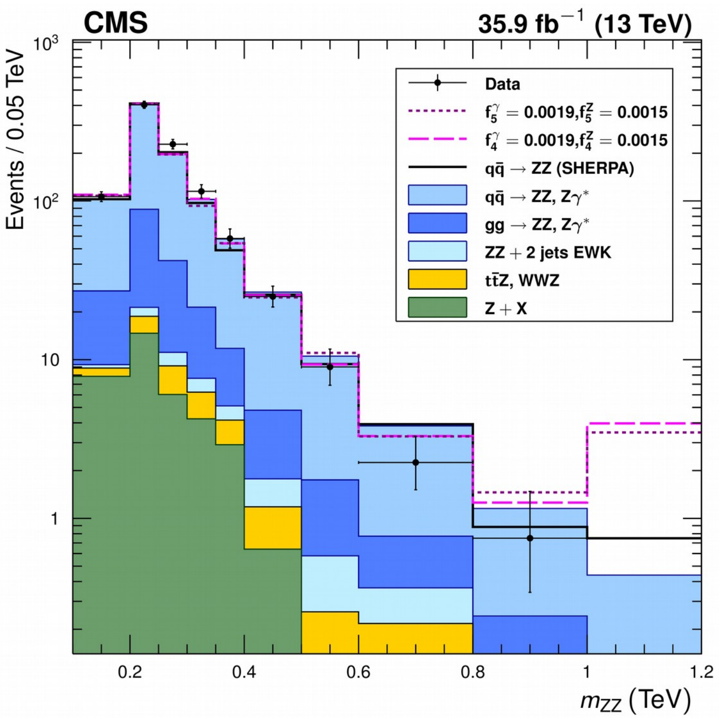


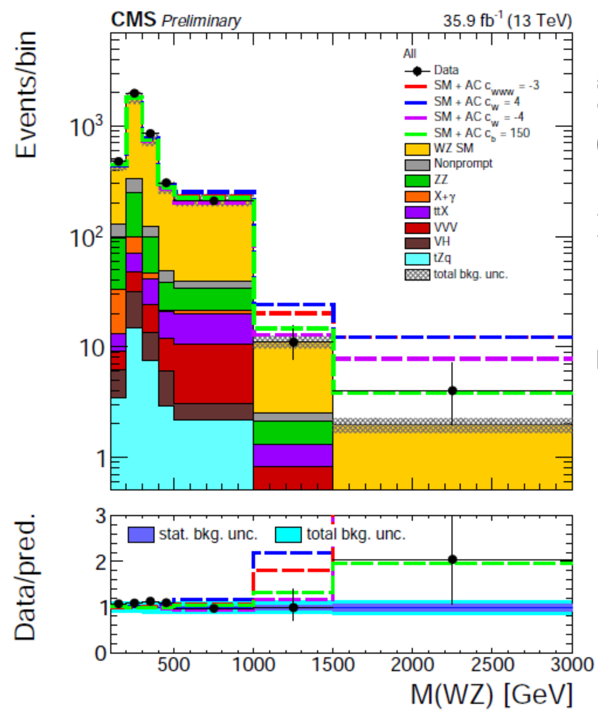
Anomalous Vector Boson Couplings

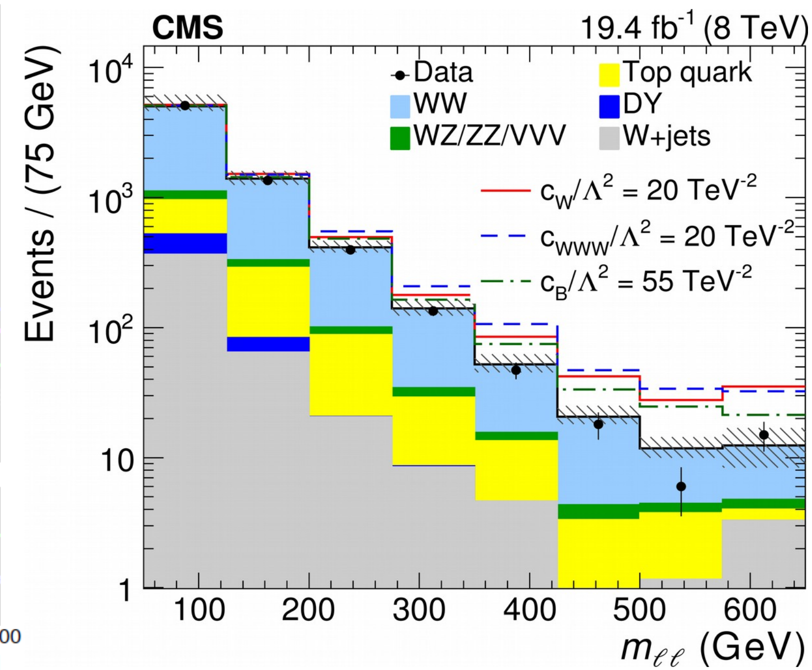
- Search for **new physics** *while doing* **EW measurements**
- Look for deviations from SM in tail of distributions ($\mathbf{m_{VV}}$, $\mathbf{m_{ll}}$, $\mathbf{m_{jj}}$, $\mathbf{p_{T,V}}$, …)
- Parametrize the new physics **adding terms to the SM lagrangian**
- **Several possibilities**:
  - **Effective vertex approach** [Nucl.Phys.B282(1987)253] → used in **ZZ** analysis.
  - **Effective lagrangian approach** [Phys.Rev.D41(1990)2113] → used in **WV** analyses.
  - **Effective field theory approach** [Phys.Rev.D48(1993)2182] → used in **WW**, **VBS** and triboson analyses.
- Parameters are usually varied ***one-by-one*** or at most ***two-by-two***, as there is **little correlation among them**.

Testing Anomalous Triple Couplings

EPJ C 78 (2018) 165, CMS-PAS-SMP-18-002, EPJ C 76 (2016) 401

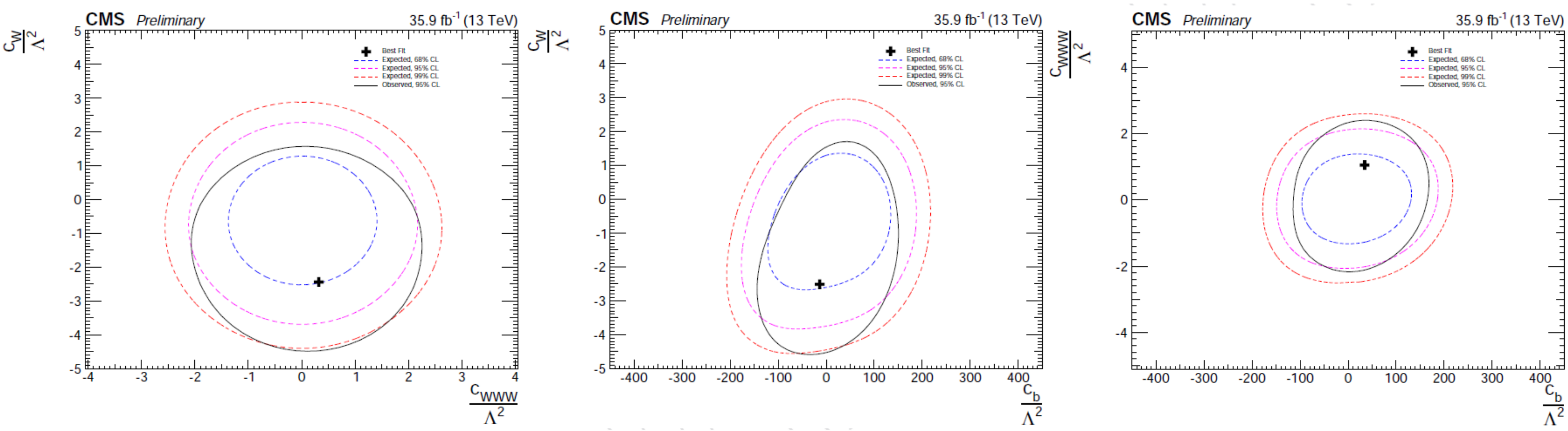






- **No** significant **deviation** w.r.t. SM are observed
- Couplings are measured (or limits are set) by performing **binned fit in single sensitive observable**
  - **Limiting factors**: observed **statistics** in the tail (primary) and systematic and statistical uncertainty on the **signal model** (secondary)

Limits from $WZ \to 3\ell 1\nu$



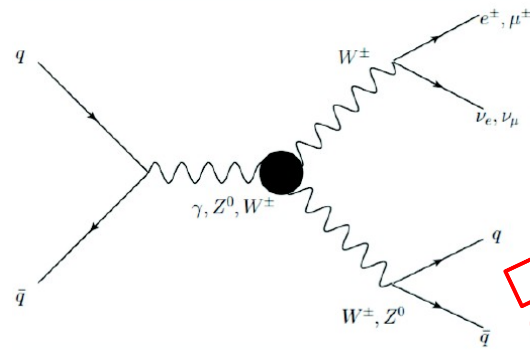
Most stringent limits up to day on C_W an C_{WWW}

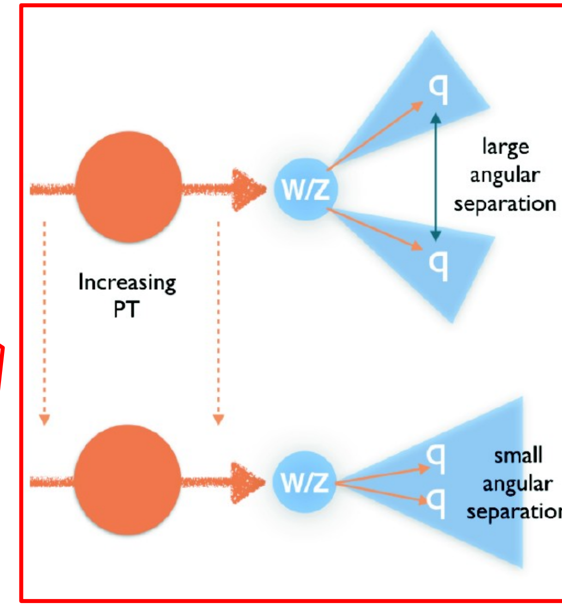
$pp \to W\,W/Z \to \ell\nu qq'$

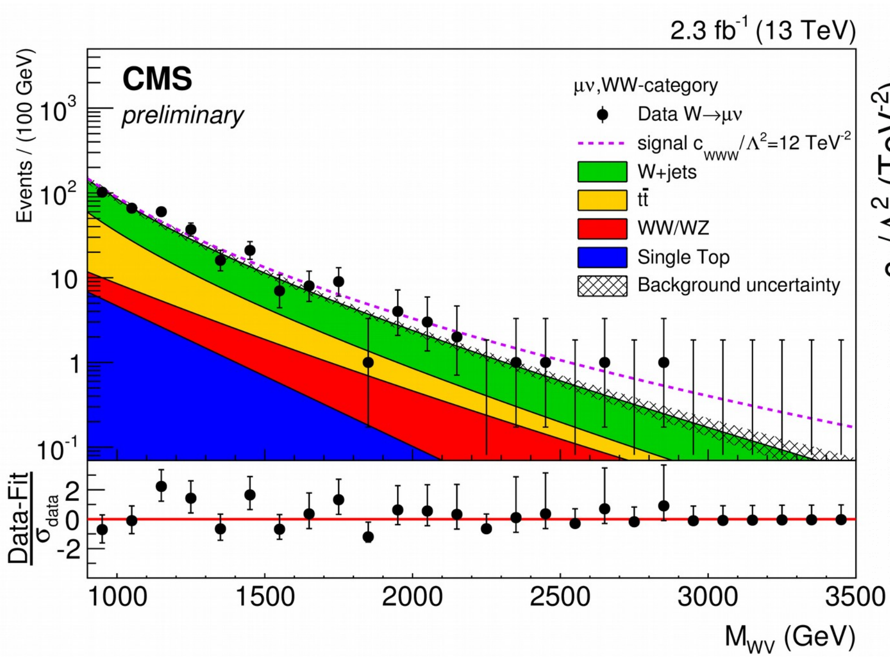
CMS-PAS-SMP-16-012

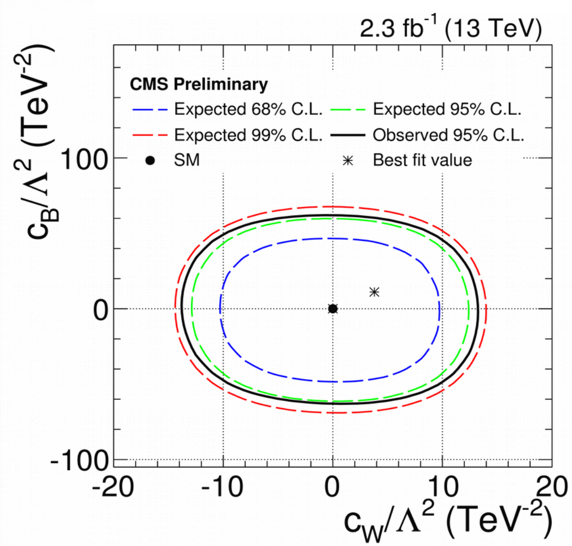
Designed to **maximize sensitivity** to anomalous TGC

Identify leptonically decaying W boson while other W or Z boson decays to jets select **dijet events** and **boosted** events such that the decay jets merge into a **single jet**





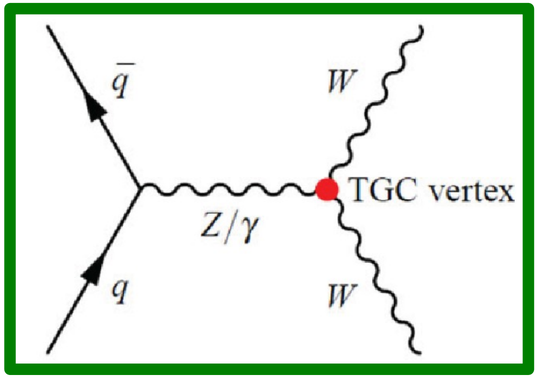


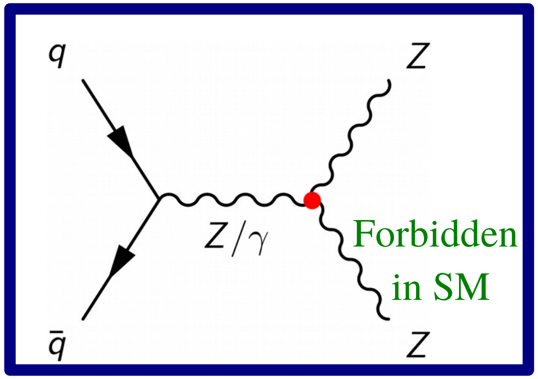


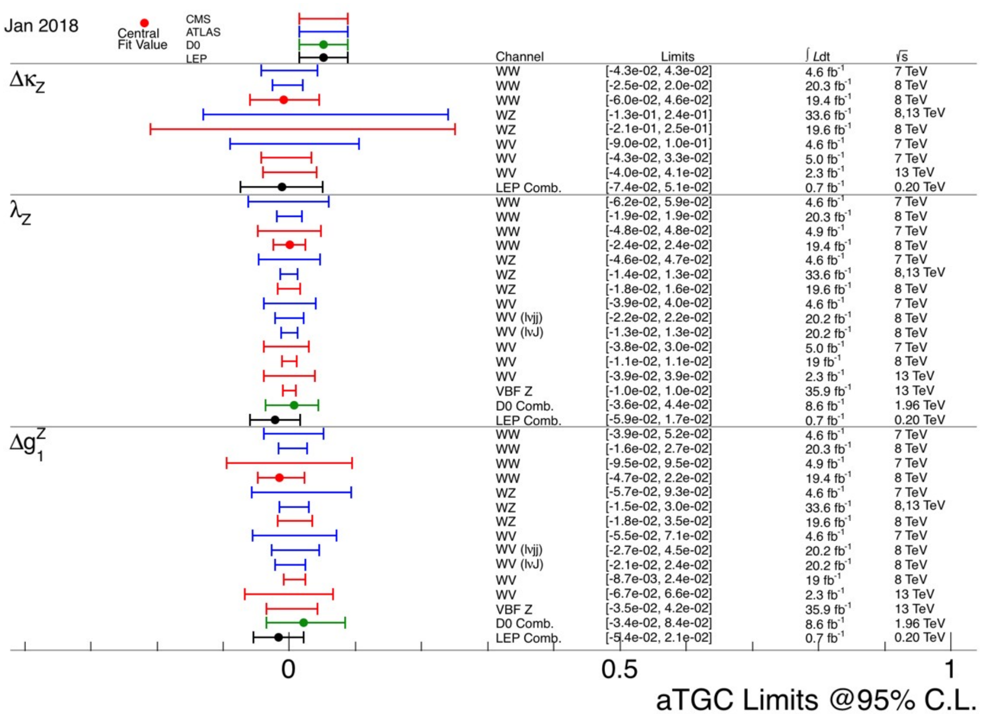
	aTGC	expected limit	observed limit
EFT param.	$\frac{c_{WWW}}{\Lambda^2}$ (TeV^{-2})	[-8.73 , 8.70]	[-9.46 , 9.42]
	$\frac{c_W}{\Lambda^2}$ (TeV^{-2})	[-11.7 , 11.1]	[-12.6 , 12.0]
	$\frac{c_B}{\Lambda^2}$ (TeV^{-2})	[-54.9 , 53.3]	[-56.1 , 55.4]
Vertex param.	λ	[-0.036 , 0.036]	[-0.039 , 0.039]
	Δg_1^Z	[-0.066 , 0.064]	[-0.067 , 0.066]
	$\Delta\kappa_Z$	[-0.038 , 0.040]	[-0.040 , 0.041]

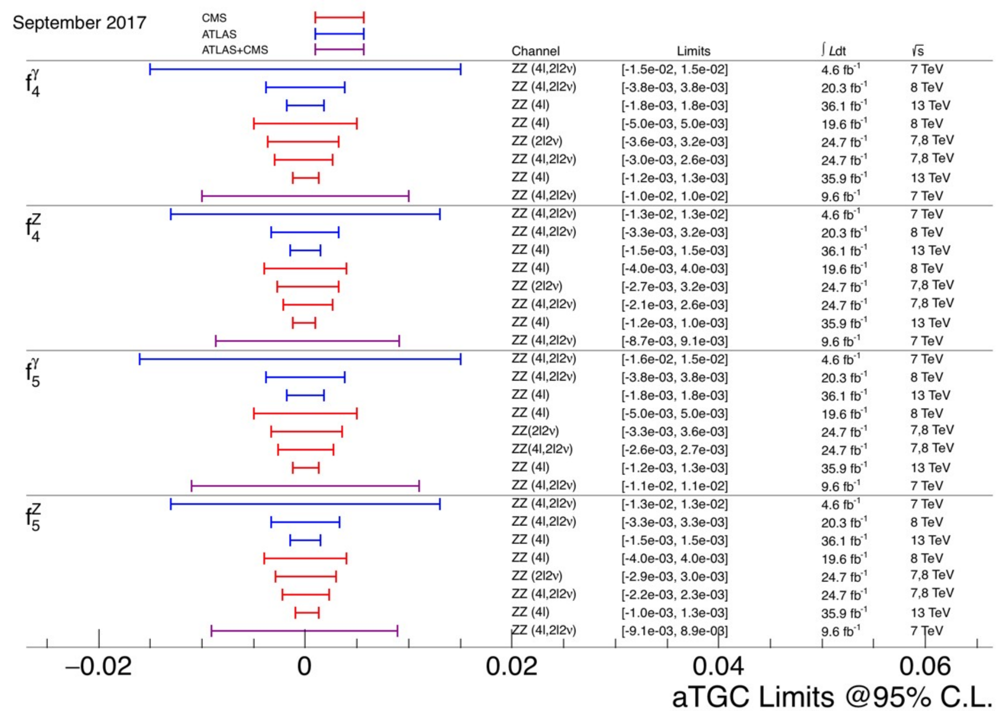
8 TeV data analysis [Eur.Phys.J. C73 (2013) 2283] still provides better limits.

Anomalous Triple Couplings Summary



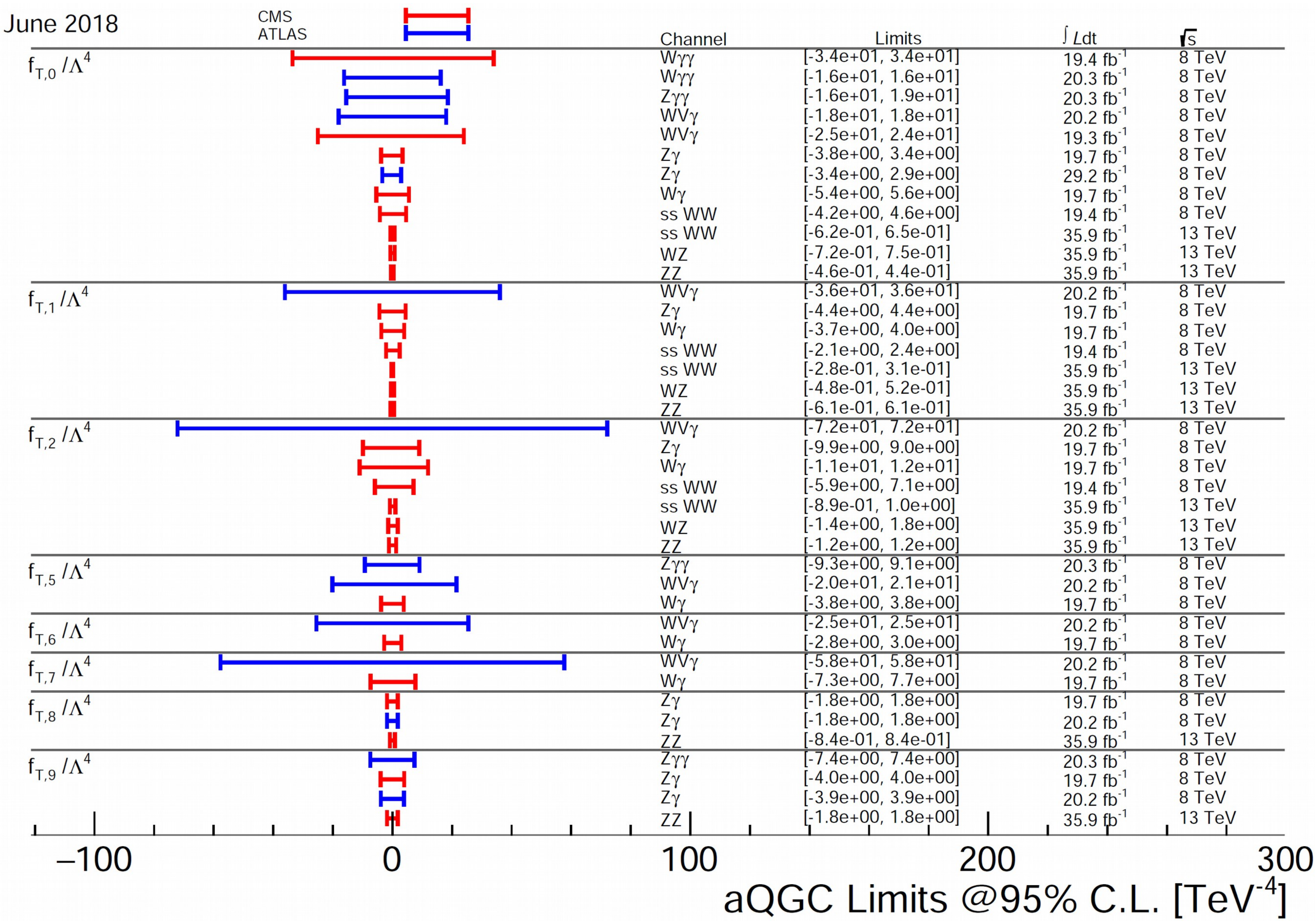






Anomalous Quartic Couplings Summary

(dim-8 transverse parameters)



Conclusions

- We discovered a Higgs boson, yet **the comprehension of the Electroweak Symmetry Breaking <u>is not completed</u>**

  → Understanding the multiboson production is now the key point for the comprehension of the Standard Model!

- **Limits on anomalous couplings more stringent than previous collider experiments**

Time of multiboson production is now, the New Frontier will be:

VV + jets, Vector Boson Scattering and triboson production

→ these are among the hot topics of LHC Run II (and more)!

Details on results can be found in the public pages of the CMS experiment:
http://cms-results.web.cern.ch/cms-results/public-results/publications/SMP/index.html

More Material

ZZ Complete Cut List

Fiducial region (baseline)

$p_T^e > 5$ GeV, $|\eta^e| < 2.5$
$p_T^\mu > 5$ GeV, $|\eta^\mu| < 2.5$
$p_T^{\ell_{3,4}} > 5$ GeV
$p_T^{\ell_1} > 20$ GeV , $p_T^{\ell_2} > 10$ GeV
$m_{\ell^+\ell^-} > 4$ GeV (any opposite-sign same-flavor pair)
$60 < m_{Z_1}, m_{Z_2} < 120$ GeV

Fiducial region (VBS)

+ $m_{jj} > 100$ GeV

Search region (baseline)

- $|\eta_e| < 2.5$ $p_T^e > 7$ GeV, $|\eta_\mu| < 2.4$ $p_T^\mu > 5$ GeV, relative isolation < 0.35 in a cone of $\Delta R = 0.3$, CMS tight ID and SIP= $|IP/\sigma_{IP}| < 4$
- At least a lepton with $p_T > 20$ GeV and a μ(e) with $p_T > 10(12)$ GeV
- $60 < m_Z < 120$ GeV (On shell), $m_{ll\text{ crossed(Opposite sign same flavour)}} > 4$ GeV
- Loosely ID jets, reco with anti-k_T 0.4; $|\eta_{jet}| < 4.7$ and $p_T > 30$ GeV

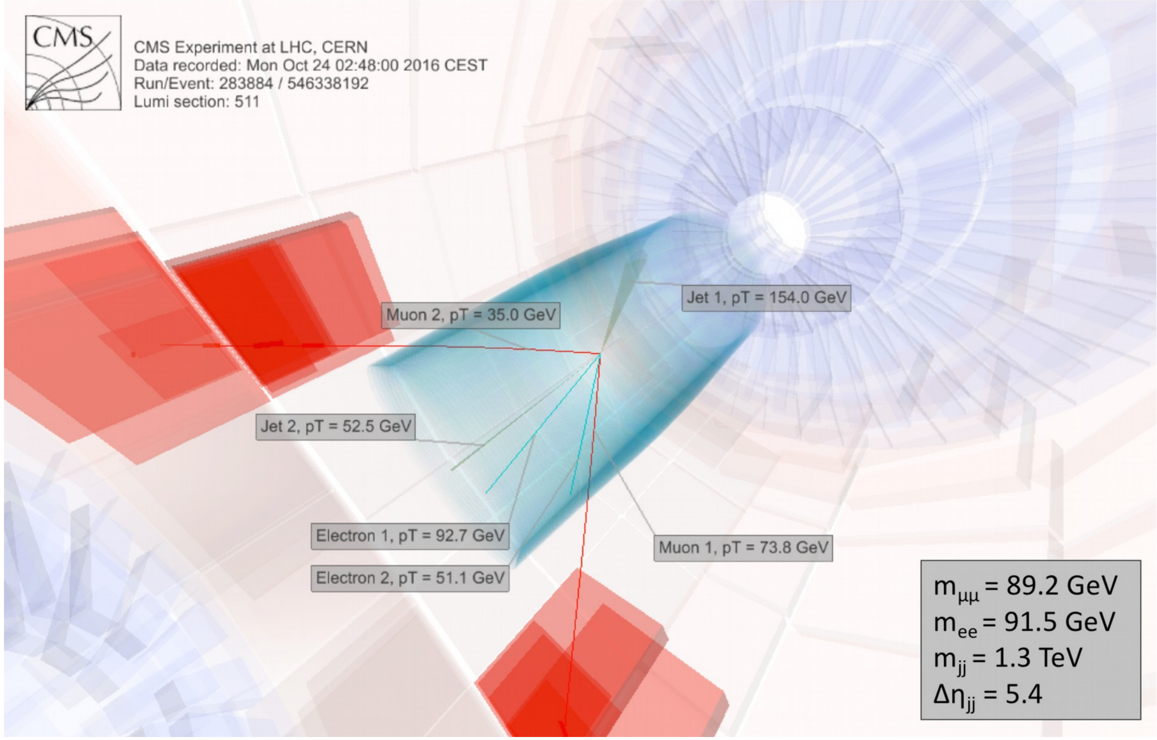
Search region (VBS)

+ $m_{jj} > 100$ GeV

ZZ+jets systematic uncertainties

Systematic source	8 TeV data Absolute (%)	8 TeV data Normalized (%)	13 TeV data Absolute (%)	13 TeV data Normalized (%)
Trigger	1.5	—	2.0	—
Lepton reconstruction and selection	0.9–4.4	$\leq$0.1	3.7–4.5	0.1–0.8
Jet energy scale	1.5–9.2	1.5–9.1	4.6–17.6	4.6–17.6
Jet energy resolution	0.2–1.7	0.2–1.7	2.1–8.4	2.1–8.4
Background yields	0.7–7.2	0.7–5.4	0.5–2.9	0.4–2.1
Pileup	1.8	1.8	0.3–1.9	0.6–1.8
Luminosity	2.6	—	2.5	—
Choice of Monte Carlo generators	0.2–3.7	0.2–3.7	0.5–5.1	0.8–4.8
qq/gg cross section	0.1–0.8	0.1–0.8	$<$ 0.1–0.3	0.1–0.2
PDF	1.0	—	$<$ 0.1–0.2	$<$ 0.1–0.2
α_S	$<$0.1	$<$0.1	$\leq$0.1	$\leq$0.1

ZZ+jets: Event Display

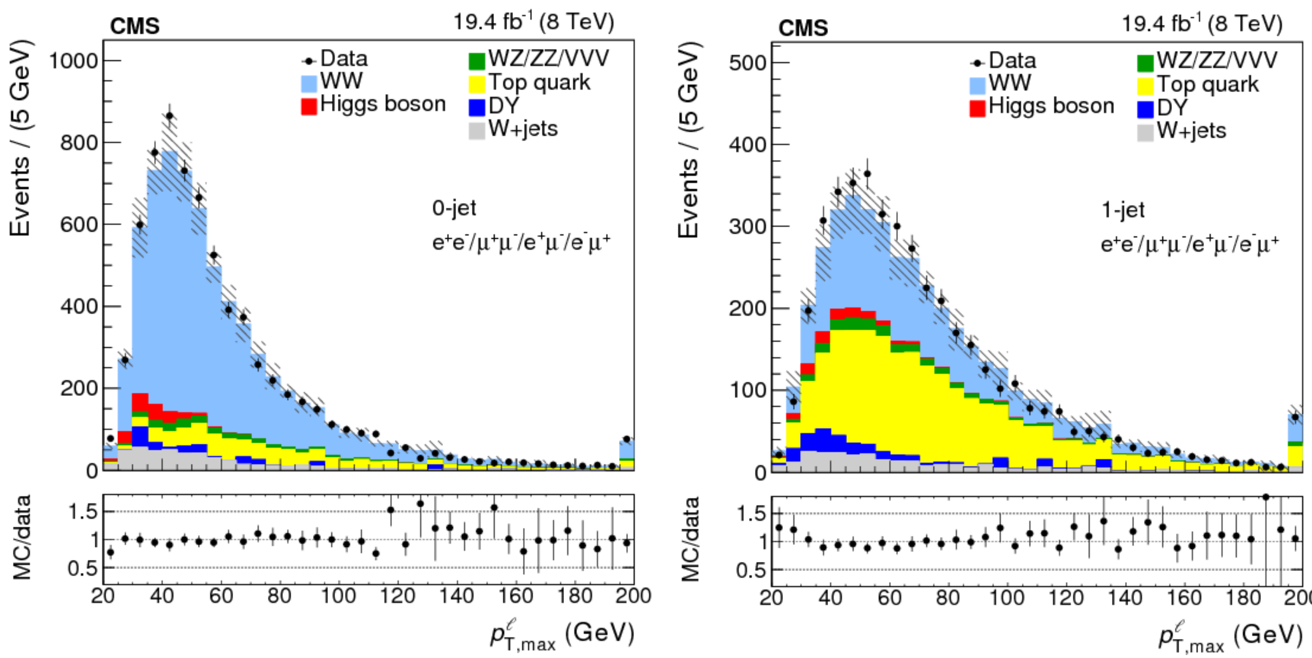


$m_{4\ell}$ [GeV]	m_{Z1} [GeV]	m_{Z2} [GeV]	m_{jj} [GeV]	$\lvert\Delta\eta_{jj}\rvert$	$\eta^\star_{Z_1}$	$\eta^\star_{Z_2}$	BDT score
365.8	91.4	101.1	844.1	3.4	-0.7	0.0	0.97
325.1	93.1	96.3	1332.9	5.2	0.0	-1.8	0.98
263.8	91.9	88.0	829.7	2.2	-0.5	1.1	0.94
562.8	93.7	88.0	947.3	2.8	0.6	0.6	0.93
248.8	91.5	89.2	1340.9	5.4	-0.5	0.2	0.98
375.2	89.4	98.5	1052.5	3.8	0.7	-0.2	0.96
482.1	95.0	95.6	1543.1	4.8	-1.6	2.5	0.99

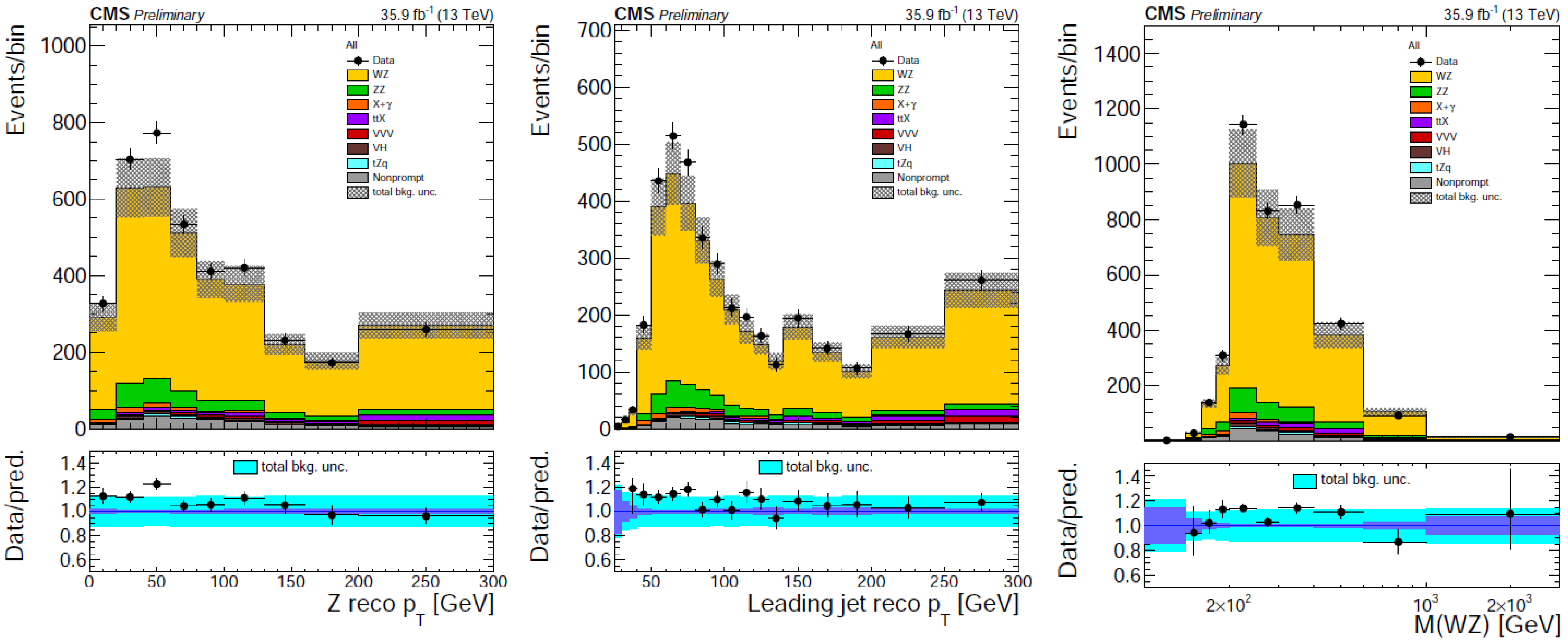
$pp \rightarrow WW \rightarrow 2\ell2\nu$

CMS: arXiv.1507.03268

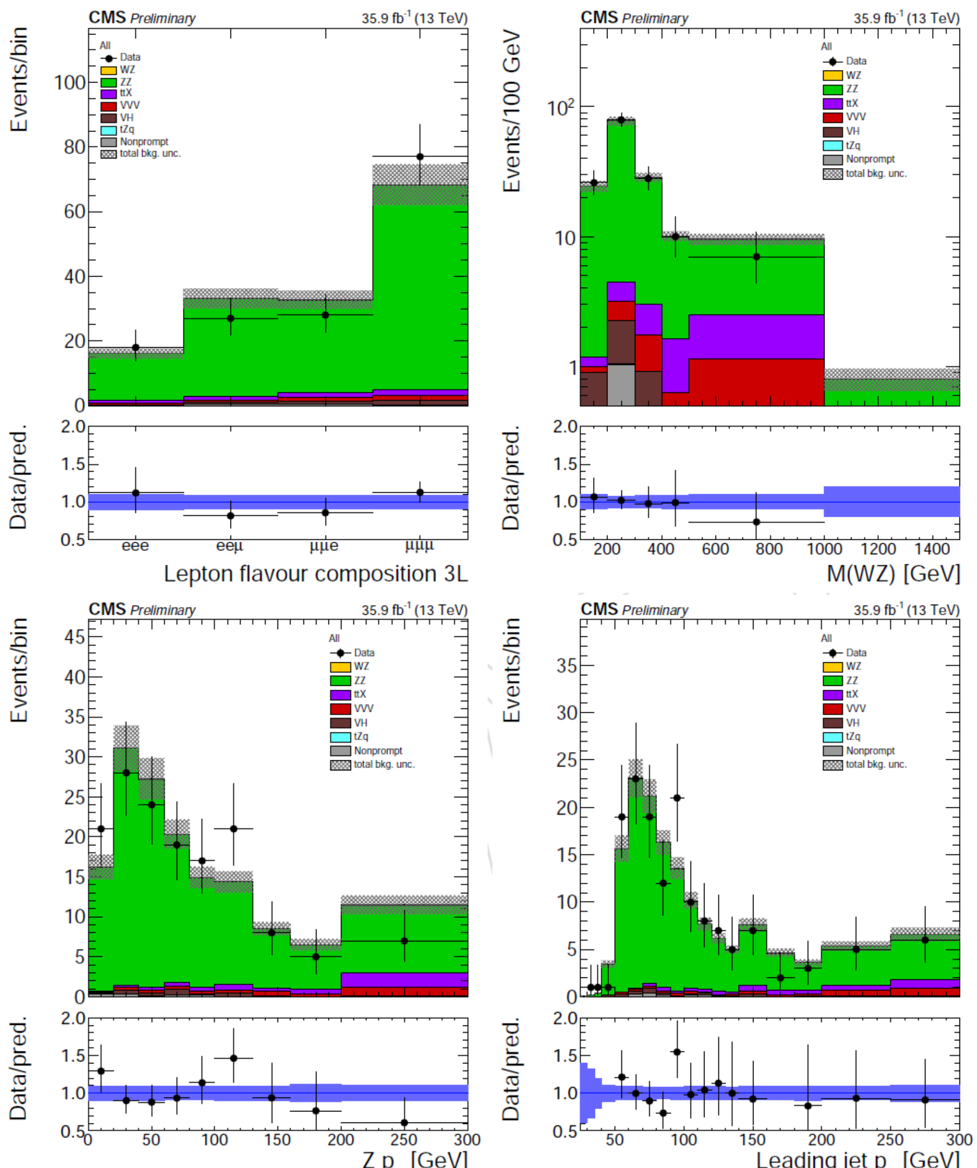
- Require 2 isolate high-p_T leptons of **opposite charge** (outside the m_Z mass window, if of same flavour). Veto additional leptons, cut on quantities such as p_T^{ll}, m_{ll}, *missing* E_T (or its projection), missing track p_T, jet b-tagging, … . **Either jet veto or 0-1 jet categorization**.
- Background from **ttbar** and **W+jets** is measured with **data**, **DY** with **MC normalized to data**, while **Wγ ,Wγ*, WZ, ZZ** and **VVV** are estimated from **simulation**.



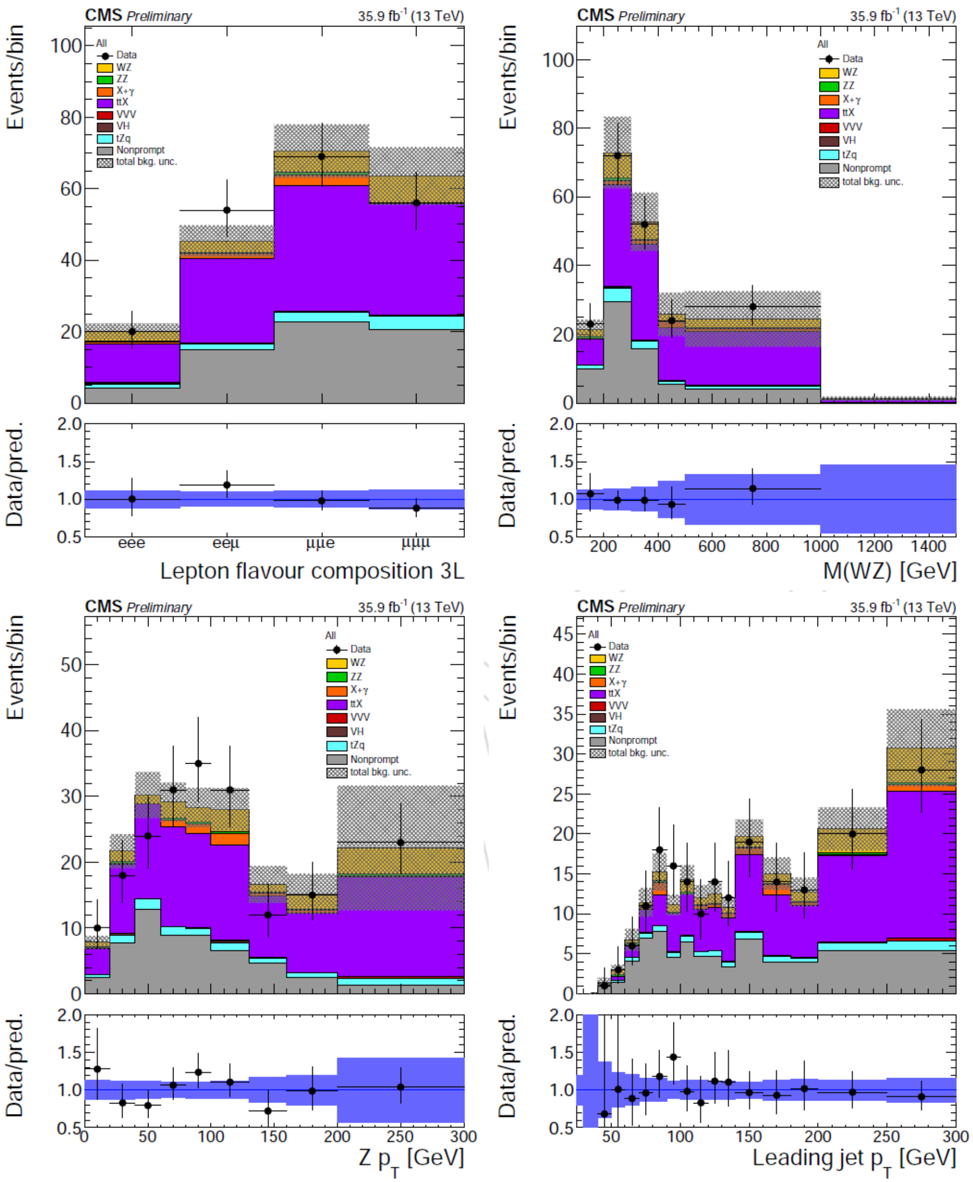
WZ, SR


CMS Preliminary
35.9 fb-1 (13 TeV)
All
Data
WZ
ZZ
X+γ
ttX
VVV
VH
tZq
Nonprompt
total bkg. unc.
Events/bin
Data/pred.
Z reco pT [GeV]
Leading jet reco pT [GeV]
M(WZ) [GeV]

WZ, ZZ CR

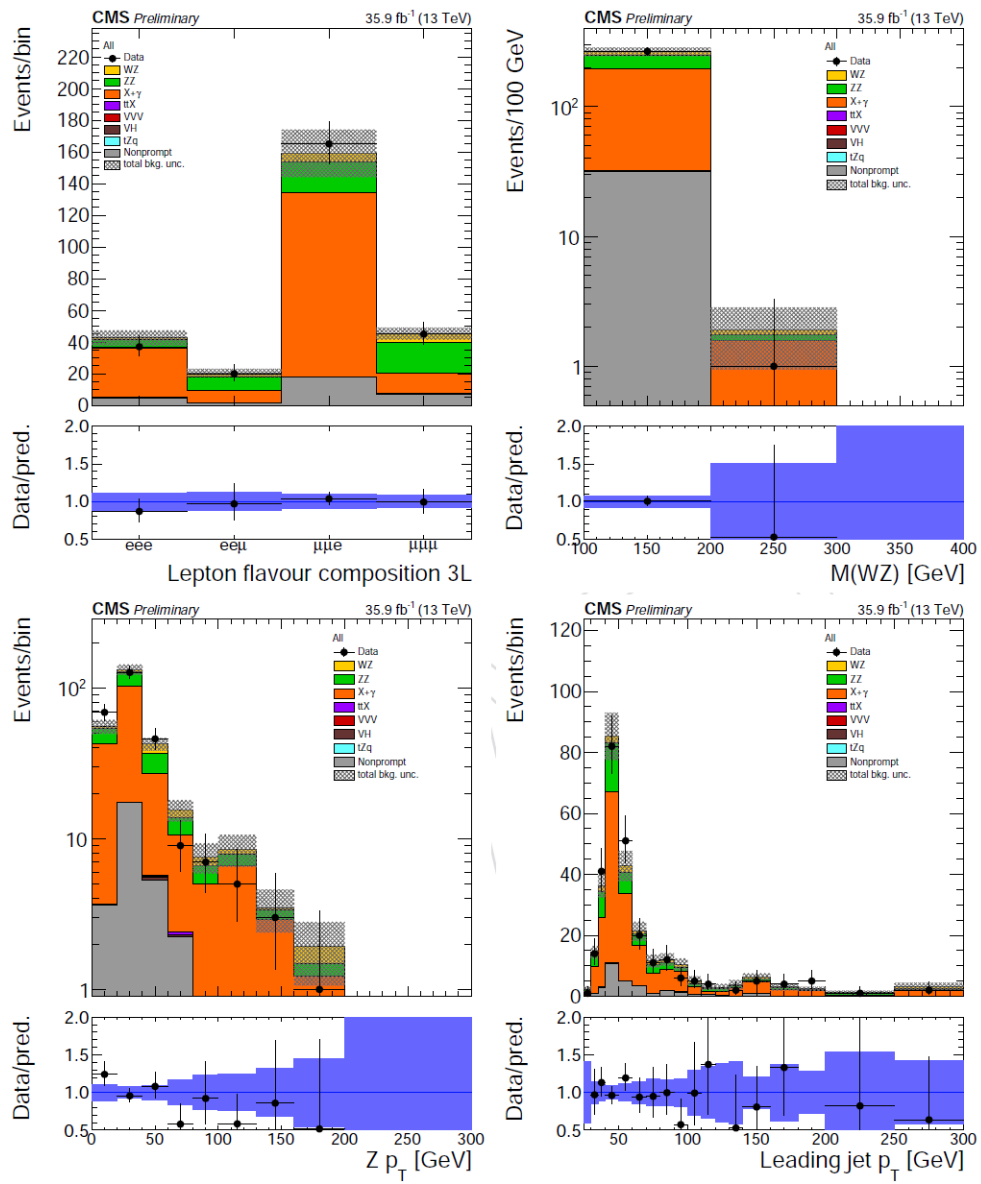

CMS Preliminary
35.9 fb^{-1} (13 TeV)
All
Data
WZ
ZZ
ttX
VVV
VH
tZq
Nonprompt
total bkg. unc.
Events/bin
Data/pred.
eee
eeμ
μμe
μμμ
Lepton flavour composition 3L
Events/100 GeV
M(WZ) [GeV]
Z p_T [GeV]
Leading jet p_T [GeV]

WZ, top CR



CMS Preliminary
35.9 fb-1 (13 TeV)
Events/bin
Data/pred.
All
Data
WZ
ZZ
X+γ
ttX
VVV
VH
tZq
Nonprompt
total bkg. unc.
eee
eeμ
μμe
μμμ
Lepton flavour composition 3L
M(WZ) [GeV]
Z pT [GeV]
Leading jet pT [GeV]

WZ, conversion CR



Anomalous Quartic Gauge Couplings Modelling

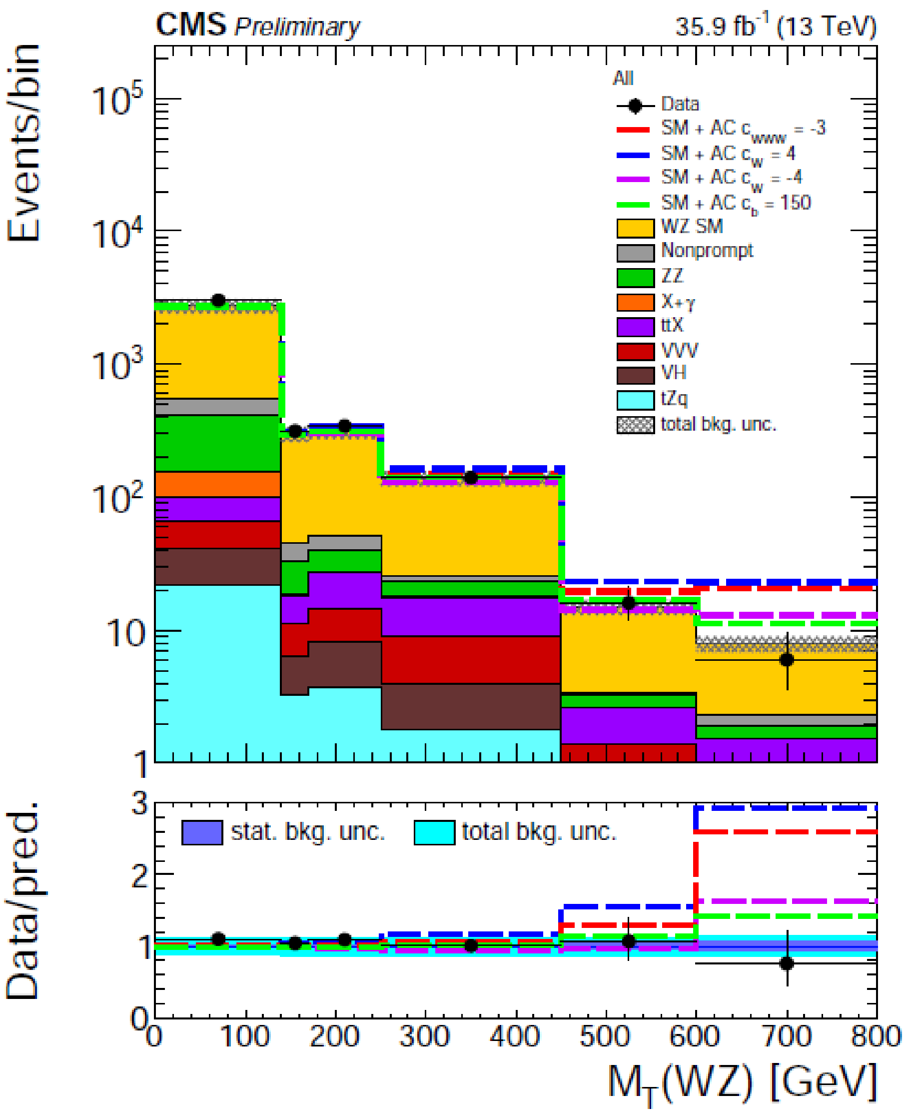
- Extension of the SM Lagrangian by introducing additional **dimension-8 (or 6) operators**:

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i + \dots$$

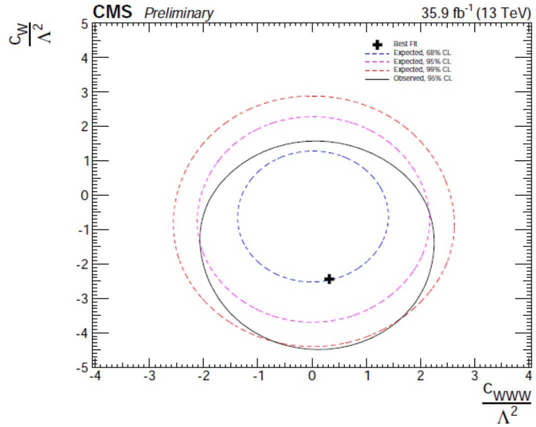
desideratum: Λ ~ 1-2 TeV

- **Effective field theory** is useful as a methodology for studying possible new physics effects from massive particles that are **not directly detectable**.
  - Underlying assumption: scale **Λ is large compared with the experimentally-accessible energy**
  - These operators have **coefficients of inverse powers of mass** (Λ), and hence are suppressed if this mass is large compared with the experimentally-accessible energy
  - **Limit**: Λ so large that the effect is comparable to missing higher order corrections from SM
  - An effective field theory is the **low-energy approximation of the new physics**
- coefficients in **dimension-6** (i.e. c_i/Λ^2) (e.g., hep-ph/9908254), **may affects 3 boson vertices too**:
  - **$C_{\varphi W}/\Lambda^2$ (VBFNLO), a_0^W/Λ^2, a_C^W/Λ^2 (CALCHEP)…**
- coefficients in **dimension-8** (i.e. c_i/Λ^4) (e.g., hep-ph/0606118), **modifies 4 boson vertices only**:
  - **$f_{S,0}/\Lambda^4$, $f_{T,0}/\Lambda^4$…**

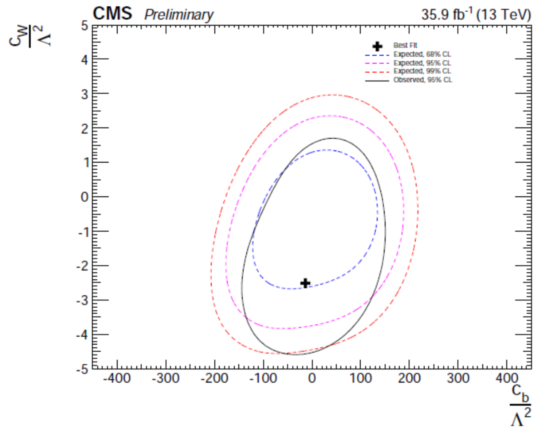
WZ aTGC



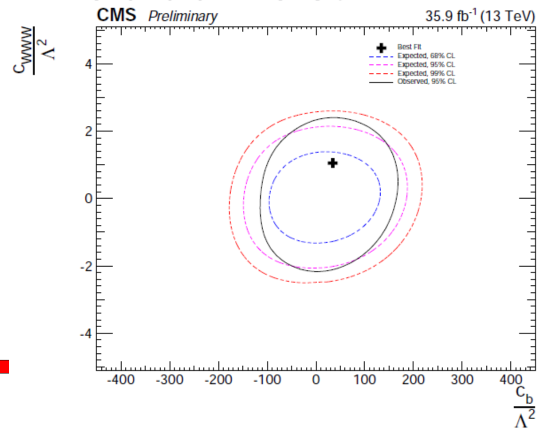
CMS Preliminary
35.9 fb^{-1} (13 TeV)
All
Data
SM + AC c_{www} = -3
SM + AC c_W = 4
SM + AC c_W = -4
SM + AC c_b = 150
WZ SM
Nonprompt
ZZ
X+γ
ttX
VVV
VH
tZq
total bkg. unc.
Events/bin
stat. bkg. unc.
total bkg. unc.
Data/pred.
$M_T(WZ)$ [GeV]



CMS Preliminary
35.9 fb^{-1} (13 TeV)
$\frac{c_W}{\Lambda^2}$
$\frac{c_{WWW}}{\Lambda^2}$

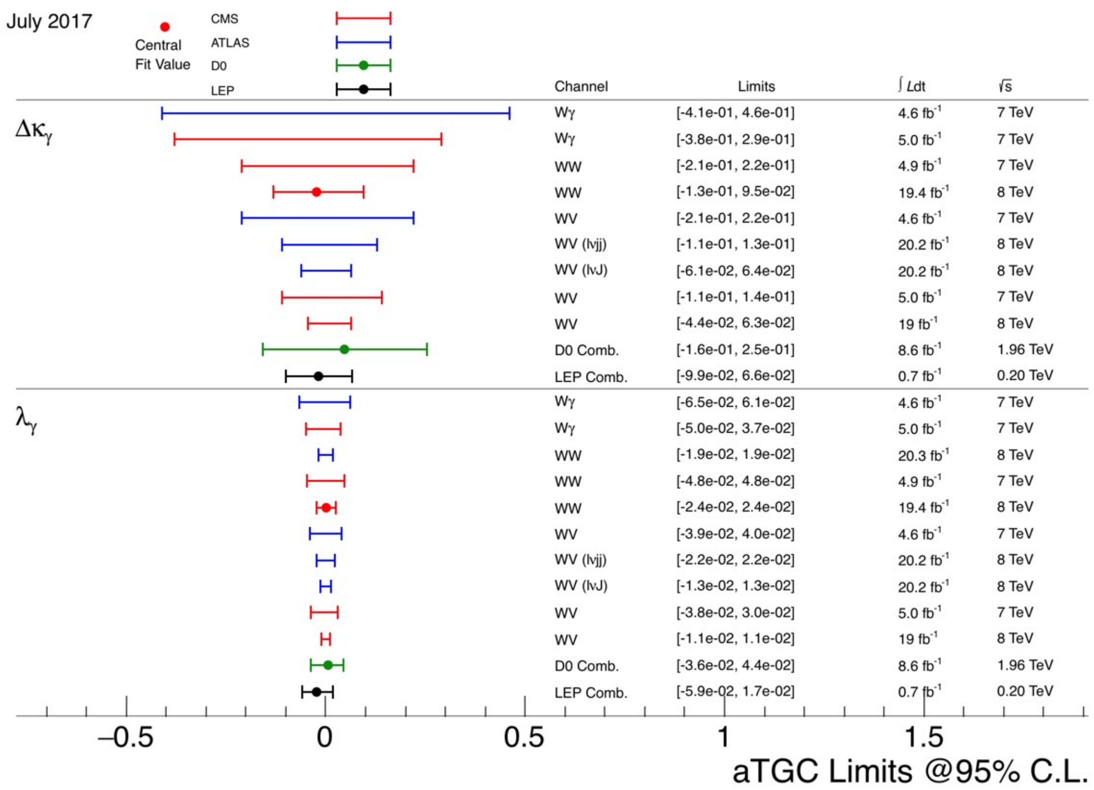


CMS Preliminary
35.9 fb^{-1} (13 TeV)
$\frac{c_W}{\Lambda^2}$
$\frac{c_b}{\Lambda^2}$



CMS Preliminary
35.9 fb^{-1} (13 TeV)
$\frac{c_{WWW}}{\Lambda^2}$
$\frac{c_b}{\Lambda^2}$

aTGC


July 2017
Central Fit Value
CMS
ATLAS
D0
LEP
Channel
Limits
∫ Ldt
√s
Δκ_γ
Wγ [-4.1e-01, 4.6e-01] 4.6 fb⁻¹ 7 TeV
Wγ [-3.8e-01, 2.9e-01] 5.0 fb⁻¹ 7 TeV
WW [-2.1e-01, 2.2e-01] 4.9 fb⁻¹ 7 TeV
WW [-1.3e-01, 9.5e-02] 19.4 fb⁻¹ 8 TeV
WV [-2.1e-01, 2.2e-01] 4.6 fb⁻¹ 7 TeV
WV (lνjj) [-1.1e-01, 1.3e-01] 20.2 fb⁻¹ 8 TeV
WV (lνJ) [-6.1e-02, 6.4e-02] 20.2 fb⁻¹ 8 TeV
WV [-1.1e-01, 1.4e-01] 5.0 fb⁻¹ 7 TeV
WV [-4.4e-02, 6.3e-02] 19 fb⁻¹ 8 TeV
D0 Comb. [-1.6e-01, 2.5e-01] 8.6 fb⁻¹ 1.96 TeV
LEP Comb. [-9.9e-02, 6.6e-02] 0.7 fb⁻¹ 0.20 TeV
λ_γ
Wγ [-6.5e-02, 6.1e-02] 4.6 fb⁻¹ 7 TeV
Wγ [-5.0e-02, 3.7e-02] 5.0 fb⁻¹ 7 TeV
WW [-1.9e-02, 1.9e-02] 20.3 fb⁻¹ 8 TeV
WW [-4.8e-02, 4.8e-02] 4.9 fb⁻¹ 7 TeV
WW [-2.4e-02, 2.4e-02] 19.4 fb⁻¹ 8 TeV
WV [-3.9e-02, 4.0e-02] 4.6 fb⁻¹ 7 TeV
WV (lνjj) [-2.2e-02, 2.2e-02] 20.2 fb⁻¹ 8 TeV
WV (lνJ) [-1.3e-02, 1.3e-02] 20.2 fb⁻¹ 8 TeV
WV [-3.8e-02, 3.0e-02] 5.0 fb⁻¹ 7 TeV
WV [-1.1e-02, 1.1e-02] 19 fb⁻¹ 8 TeV
D0 Comb. [-3.6e-02, 4.4e-02] 8.6 fb⁻¹ 1.96 TeV
LEP Comb. [-5.9e-02, 1.7e-02] 0.7 fb⁻¹ 0.20 TeV
–0.5
0
0.5
1
1.5
aTGC Limits @95% C.L.