Recent Electroweak Results from the LHC

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On the behalf of the ATLAS, CMS and LHCb collaborations

Outline

- Introduction
- Run1 results:
  - Multi-boson production
  - Rare processes
  - Precision measurements
- Run2 results
- Conclusions

Introduction

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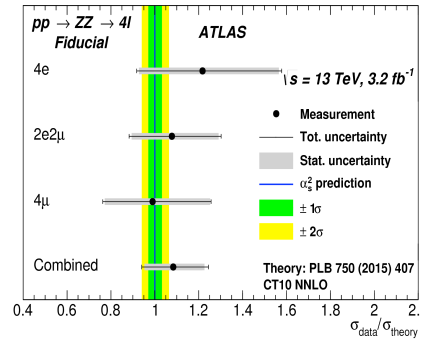
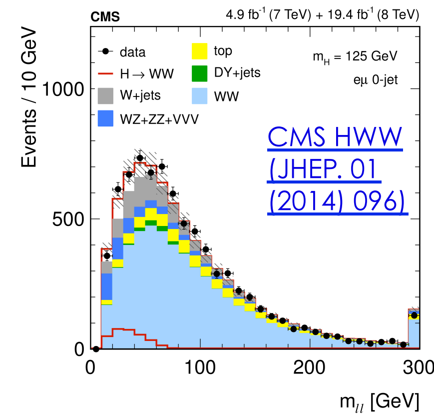
Introduction – EWK measurements

Electroweak program at the LHC is extremely important!

- Precision measurement:
  - Multi-boson production.
  - Extraction of SM parameters.
  - Comparisons to high order corrections.
    - Most analyses presented here are (very!) complex (systematic limited), run 1 still has a lot to offers!

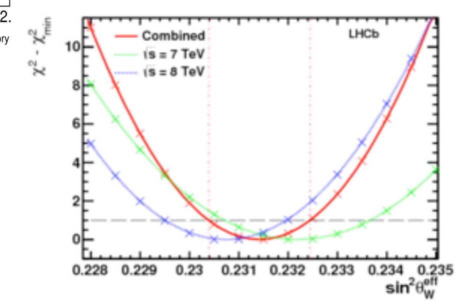
ATLAS ZZ 13TeV: 1512.05314 Submitted to PRL





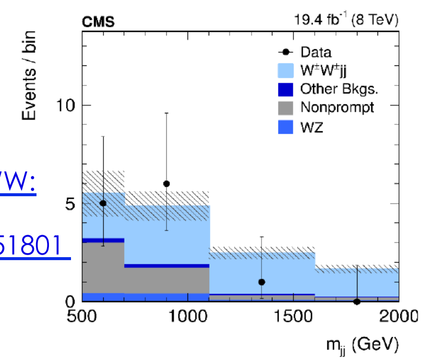
CMS HWW (JHEP. 01 (2014) 096)

LHCb ZAFB: JHEP 11 (2015) 190



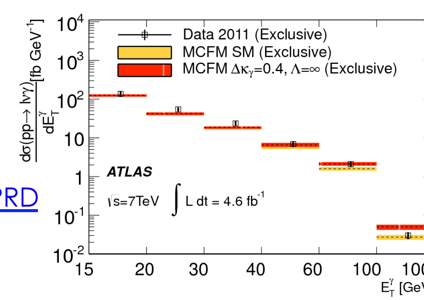
- Now sensitive to new final states never observed before!
  - Vector Boson Scattering or Fusion
  - \>2 bosons production…

CMS ssWW: PRL. 114 (2015) 051801



- Probe new physics and constrain anomalous Gauge Coupling.

ATLAS W γ (7TeV) PRD 87, 112003 (2013)



What do we provide? Cross Section measurements

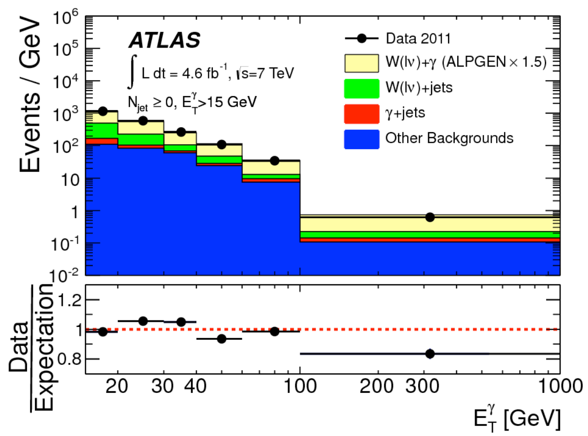
- Cross-sections are measured in a fiducial volume and are extrapolated to the total phase space:

$$\sigma_{fid} = \frac{N_{data} - N_{bkg}}{lumi \times C} \qquad \sigma_{tot} = \frac{N_{data} - N_{bkg}}{lumi \times A \times C}$$

- Where:
  - C is the efficiency correction due to the reconstruction.
  - A is signal acceptance in the fiducial volume.

- Differential measurements are performed to provide kinematic distributions of the data subtracted from backgrounds, and corrected from detector effect.

[ATLAS W γ (7TeV) PRD 87, 112003 (2013)](#)



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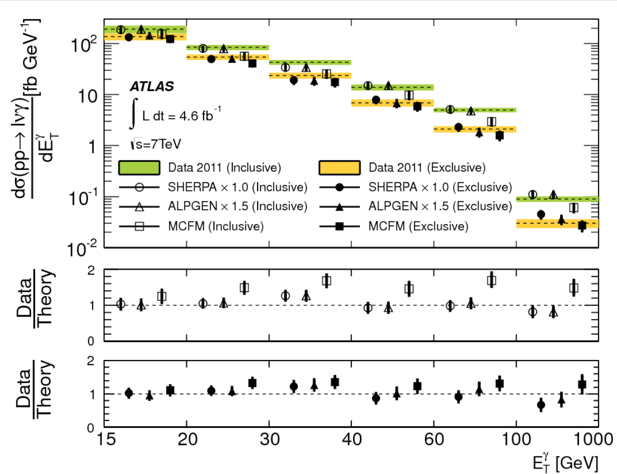
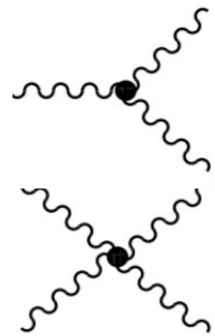


What do we provide? Interpretation on Boson Gauge Couplings

- Trilinear and Quartic Gauge boson couplings (TGC, QGC) are precisely determined by SU(2)xU(1) gauge symmetry.
  - Neutral coupling forbidden.
  - TGC:
    - VBF and VV production.
  - QGC:
    - VBS and VVV production.



aTGC operators

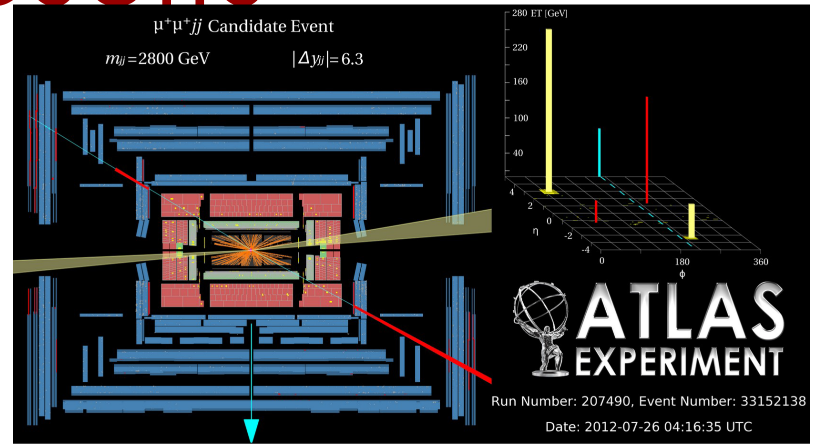
coupling	parameters	channel
$WW\gamma$	$\lambda_\gamma, \Delta k_\gamma$	$WW, W\gamma$
WWZ	$\lambda_Z, \Delta k_Z, \Delta g_1^Z$	WW, WZ
$ZZ\gamma$	h_3^Z, h_4^Z	$Z\gamma$
$Z\gamma\gamma$	h_3^γ, h_4^γ	$Z\gamma$
$Z\gamma Z$	$f_{40}^\gamma, f_{50}^\gamma$	ZZ
ZZZ	f_{40}^Z, f_{50}^Z	ZZ

- Anomalous Gauge Coupling results in large production cross-section at high energy.
  - aTGCs and aQGCs parameterized with effective theory.
  - Limits provided as functions of operators

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{O}_{S,0}, \mathcal{O}_{S,1}$	X	X	X						
$\mathcal{O}_{M,0}, \mathcal{O}_{M,1}, \mathcal{O}_{M,6}, \mathcal{O}_{M,7}$	X	X	X	X	X	X	X		
$\mathcal{O}_{M,2}, \mathcal{O}_{M,3}, \mathcal{O}_{M,4}, \mathcal{O}_{M,5}$		X	X	X	X	X	X		
$\mathcal{O}_{T,0}, \mathcal{O}_{T,1}, \mathcal{O}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{O}_{T,5}, \mathcal{O}_{T,6}, \mathcal{O}_{T,7}$		X	X	X	X	X	X	X	X
$\mathcal{O}_{T,8}, \mathcal{O}_{T,9}$			X			X	X	X	X

aQGC (dim 8) operators

Run 1 results



- Introduction
- Run1 results:
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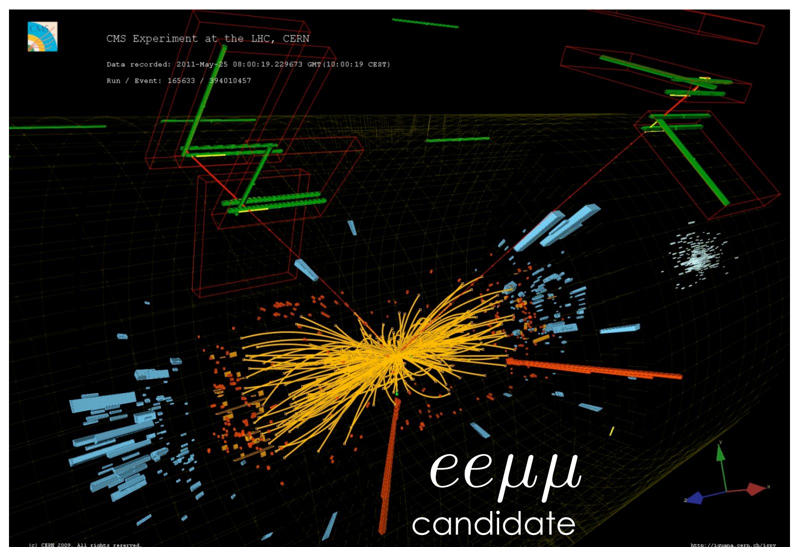
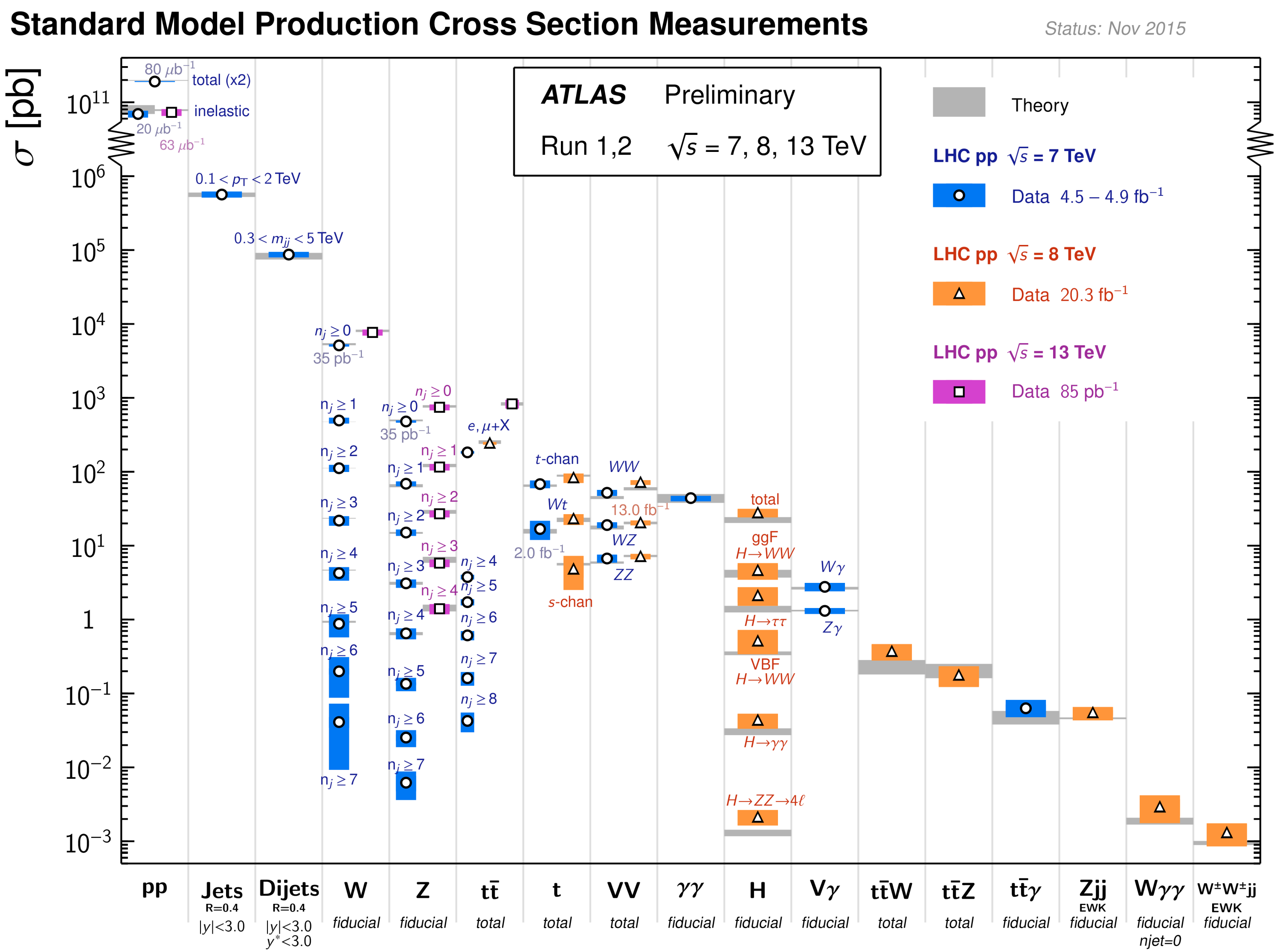
  - Rare processes
  - Precision measurements



- Run2 results
- Conclusions

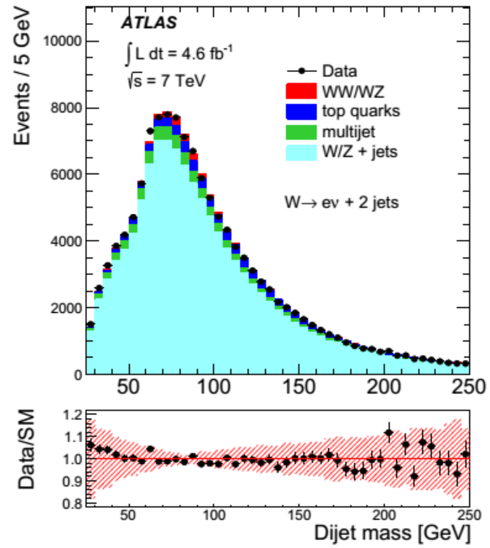
ATLAS run1 (and run2) overview



WV→ℓνqq @ 7 TeV (ℓ=e, μ)

ATLAS: JHEP01(2015)049

- Selection:
  - 1 lepton with p_T(>25 GeV).
  - E_T^{Miss}>30 GeV, m_T>40 GeV.
  - 2 Central jets (| η |<2.0) with p_T>25,30 GeV.
  - | $\Delta\Phi(E_T^{Miss}, j_1)$ |>0.8, | $\Delta\eta(j_1,j_2)$ |<1.5. | $\Delta R(j_1,j_2)$ |<0.7.

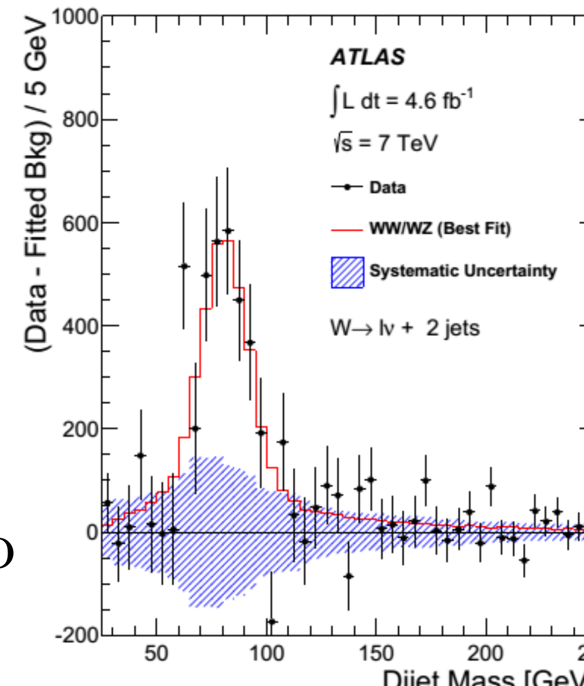


- Challenging analysis:
  - Large W+jets contamination.
  - Fit based signal extraction.

- Measurements found in good agreement with NLO predictions:

$$\sigma_{tot} = 68 \pm 7(stat) \pm 19(sys)\ \text{pb}$$

$$\sigma_{theo}^{NLO} = 61 \pm 2.2\ \text{pb}$$



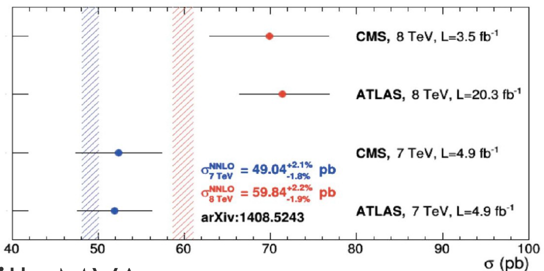
CMS WW→ℓνℓν : ArXiv 1507.03268 submitted to EPJC

CMS WW→ℓνℓν @8 TeV

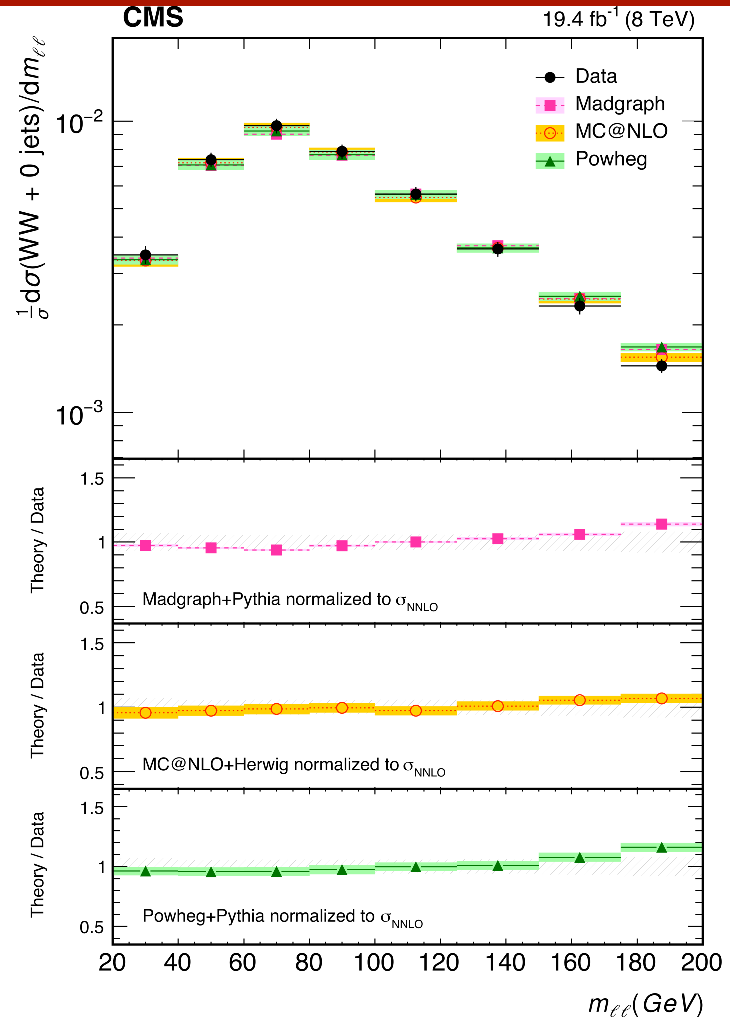
- Selection:

Variable	Different-flavor	Same-flavor
Opposite-sign charge requirement	Applied	Applied
p_T^ℓ [GeV]	>20	>20
min(proj. E_T^{miss}, proj. track E_T^{miss})[GeV]	>20	>20
DY MVA	—	>0.88 in 0-jet (>0.84 in 1-jet)
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	—	>15
$p_T^{\ell\ell}$ [GeV]	>30	>45
$m_{\ell\ell}$ [GeV]	>12	>12
Additional leptons ($p_T^\ell > 10$ GeV)	veto	veto
Top-quark veto	applied	applied
Number of reconstructed jets	<2	<2

- Disagreement with theory found in 8 TeV ATLAS and CMS(3.5 fb^{-1}).



- Challenging analysis:
  - DY contribution reduced with MVA
  - Large top and fake bkg estimated from data.
  - New compare to preliminary result:
    - H→WW is included in bkg. (8%)
    - NNLO calculations (7% higher).
    - WW p_T resummation reweighting.
    - Madgraph (LO) → Powheg (NLO)



- Measurements in good agreement with NNLO:

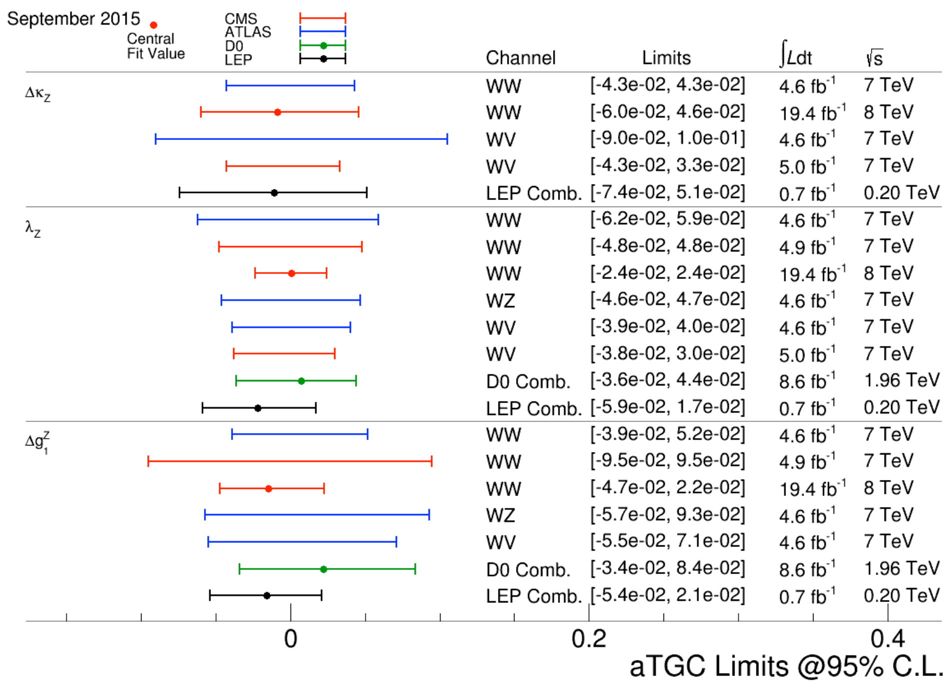
$$\sigma_{tot} = 60.1 \pm 4.8 \text{ pb}$$
$$\sigma_{NNLO} = 59.8^{+1.3}_{-1.1} \text{ pb}$$

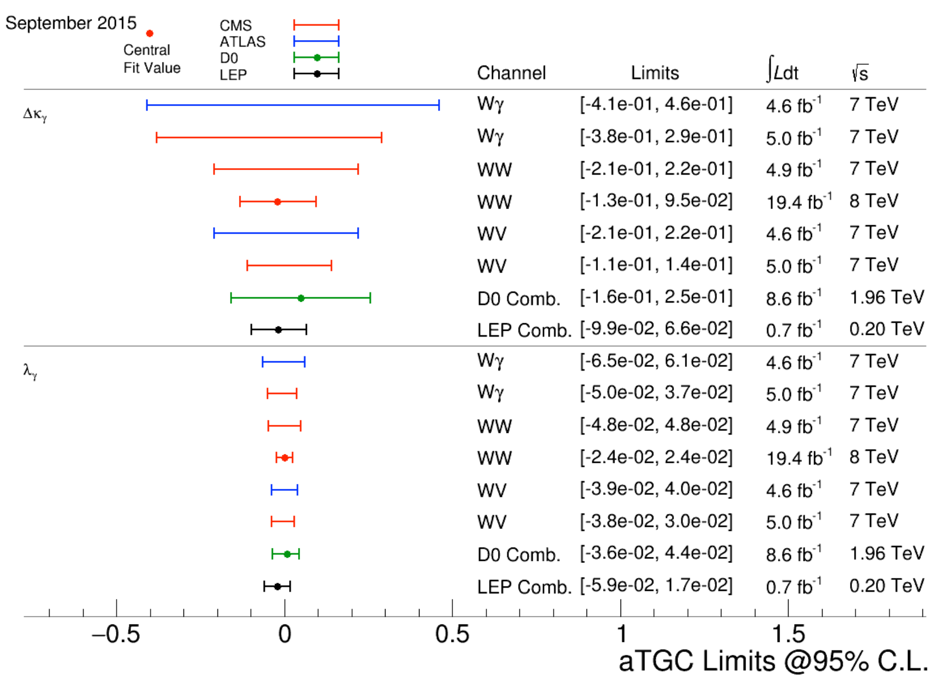
- Provided many differential measurements: $p_T^{\ell\ell}$, $\Delta|\varphi(\ell\ell)|$, $m_{\ell\ell}$, $p_T^{\ell 1}$

Limits on charged aTGCs

CMS public aQGC results

- Stringent 95% Limits are derived on charged aTGCs.
- LHC (**CMS**,**ATLAS**)Limits are compatible with Tevatron (**D0**) and start to be competitive with **LEP**.





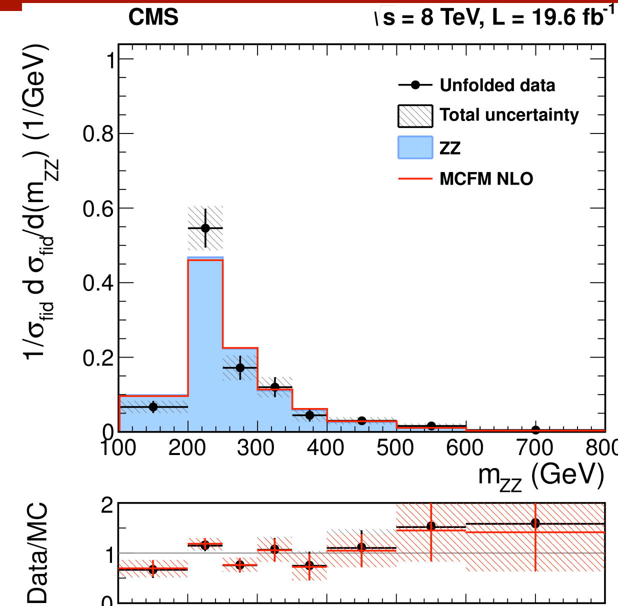
CMS ZZ-4l: PLB 740 (2015) 250

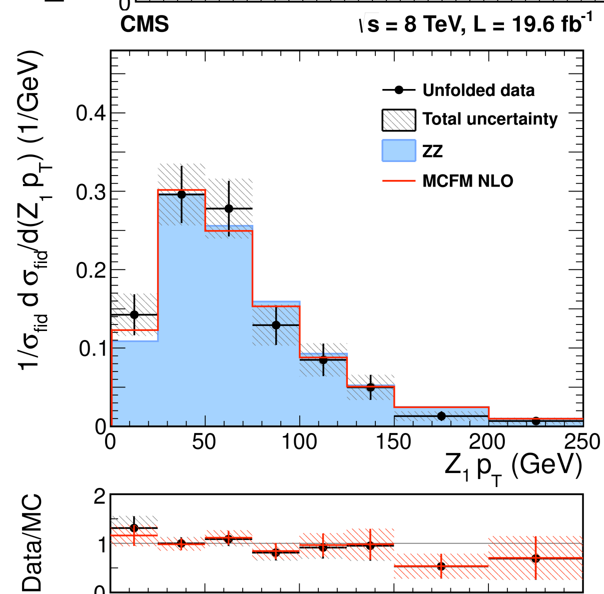
ZZ→4ℓ @ 8 TeV CMS

- ZZ→ℓℓℓ'ℓ' Selection:
  - 4 ℓ(e, μ , ℓ from τ) consistent with ZZ: (ie 2 pair SFOS).
  - $p_T^{Z\ell 1}$>20 GeV, p_T^{other}>10 GeV.
  - 60<$M_{Z1,2}$<120 GeV.
- Measurements found in good agreement with NLO qq and LO gg:

$$\sigma^{tot} = 7.7 \pm 0.5(stat) \pm 0.7(sys)\ \mathrm{pb}$$
$$\sigma^{theo}_{NLO} = 7.7 \pm 0.6\ \mathrm{pb}$$

- Provide many differential measurements: $m_{4\ell}$, $p_T^{4\ell}$, $p_T^{\ell 1}$, p_T^{Z1}, Δ Φ (ZZ), and Δ R(ZZ)

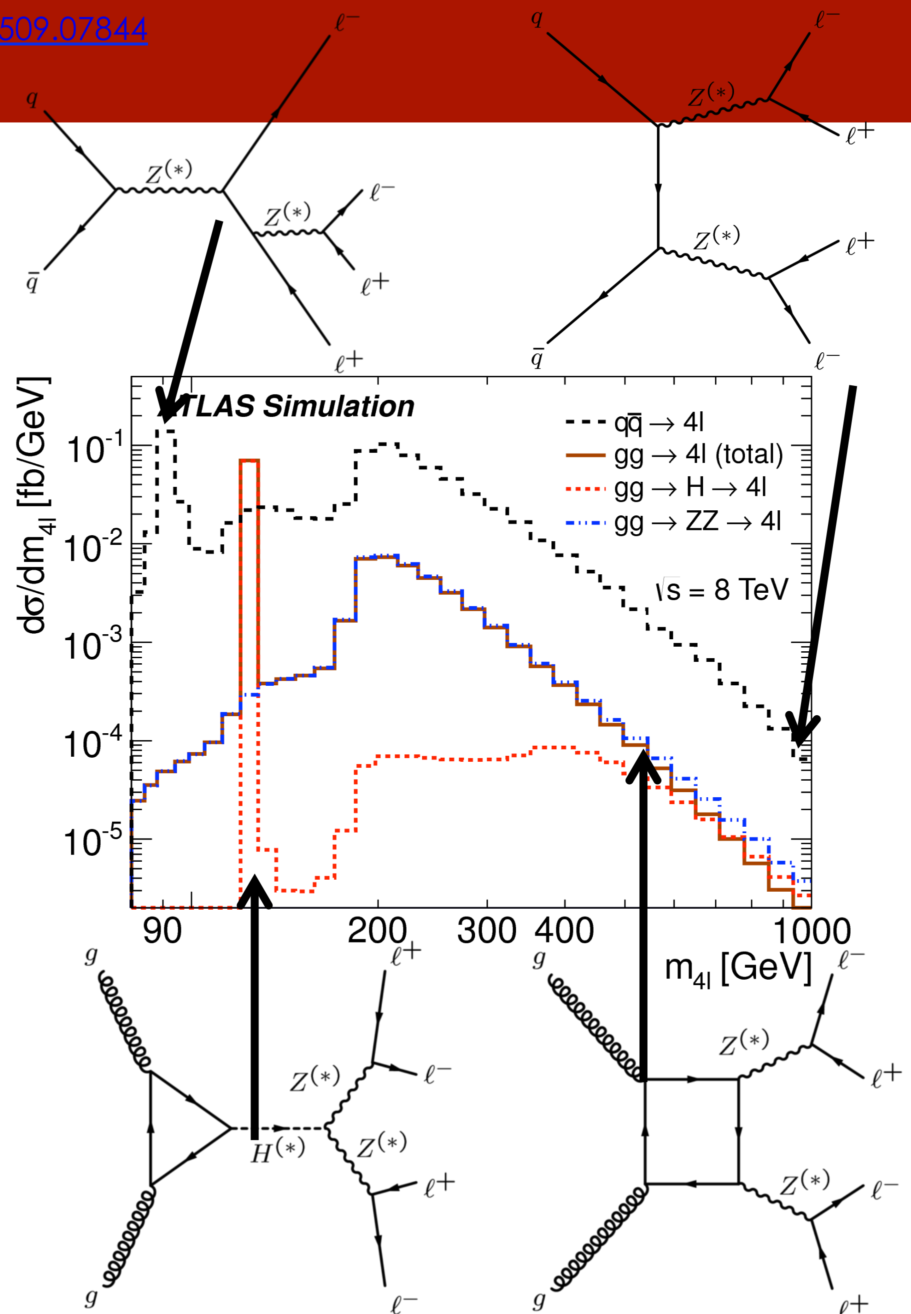




ZZ→4ℓ differential measurement @ 8 TeV ATLAS

[ATLAS ZZ4l ArXiv:1509.07844 submitted to PLB](ArXiv:1509.07844)

- ZZ→4ℓ selection:
  - 4ℓ (e, μ) compatible with 2 Zs: 2 SFOS pairs.
  - $p_T^{\ell 1}$>20 Gev, $p_T^{\ell 3}$>15 Gev, $p_T^{\ell 2}$>10 (8)Gev e(μ), $p_T^{\ell 4}$>7 (6)Gev e(μ).
  - 12<$m_{\ell\ell}$<120 GeV.
  - 80<$m_{4\ell}$<1000 GeV!
- Explore multiple production mode Z→4ℓ ,H→4ℓ , ZZ→4ℓ continuum.
- Provide unfolded $m_{4\ell}$ and $p_T^{4\ell}$.
- Measurement are compared to different level of predictions.
- About 500 candidates, expect ~5% from backgrounds

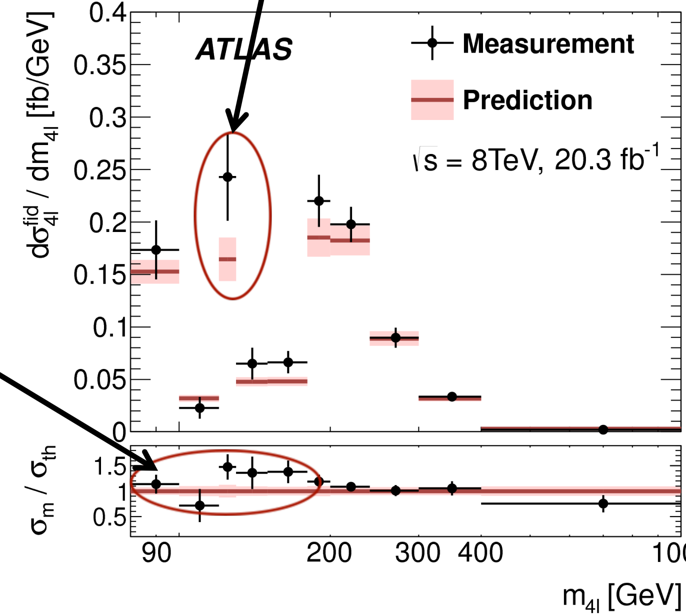


$ZZ \rightarrow 4\ell$, $m_{4\ell}$ differential measurement.

Ok with (μ ~1.4) $H \rightarrow 4\ell$

- $m_{4\ell}$ unfolded measurement:
  - LO: non resonant $gg \rightarrow 4\ell$.
  - NLO QCD: $qq \rightarrow 4\ell$.
  - NNLO QCD+NLO EW: $H \rightarrow 4\ell$ and on-shell $qq \rightarrow 4\ell$.

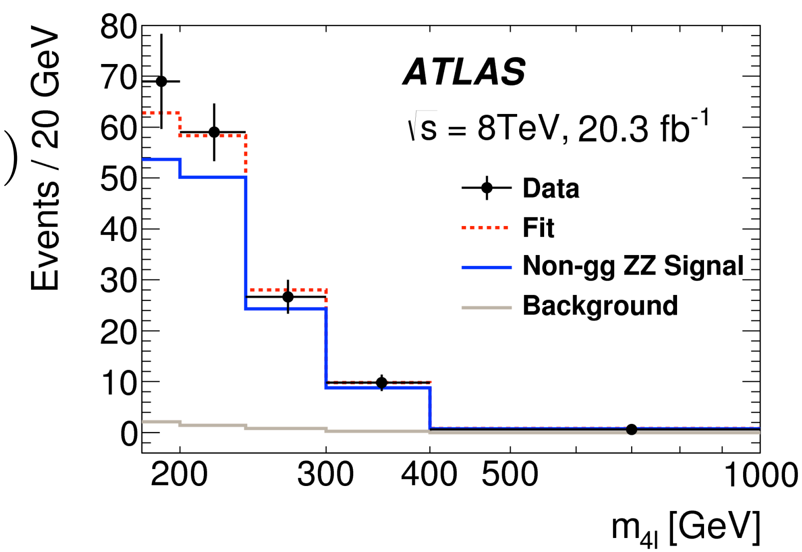
Excess in (ZZ^*)



- Extract gg component in $m_{4\ell}$>180 GeV region.
  - $gg \rightarrow 4\ell$: Off-shell Higgs, non resonant gg and interference
  - Subtract $qq \rightarrow 4\ell$ and fit signal:

$$\mu_{gg} = 2.4 \pm 1.0(stat) \pm 0.5(sys) \pm 0.8(theory)$$

  - Result compatible with the fact that predictions are LO in this region.



ZZ →ℓℓν ν @ CMS

CMS 2l2nu: EPJC 75 (2015) 511

CMS public aQGC results

- ZZ→ℓℓν ν Selection: (7 and 8 TeV!)
  - 2 ℓ(=e, μ), p_T>20 GeV,
  - p_T(ℓℓ)>45 GeV, |mℓℓ-mZ|<7.5 GeV.
  - E_T^{Miss}>65 GeV.
- Large DY contamination estimated from data, remaining contribution MC.
- Measurements found in good agreement with NLO predictions:

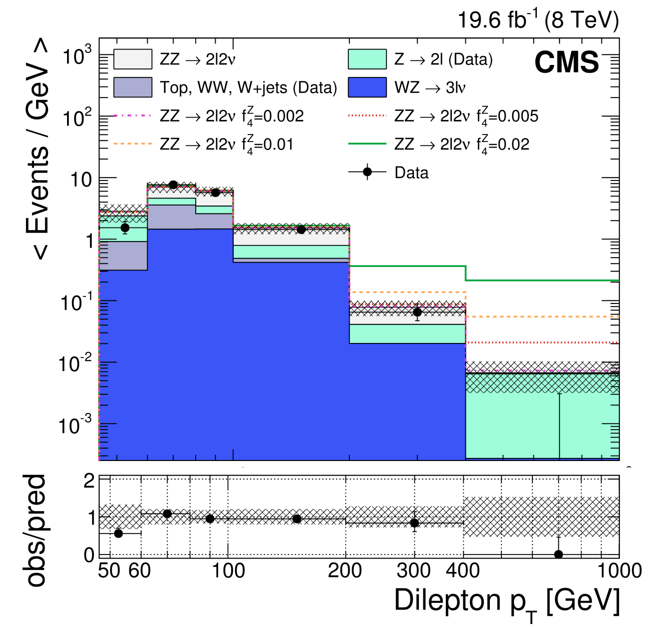
$$\sigma_{7TeV}^{tot} = 5.1^{+1.5}_{-1.4}(stat)^{1.4}_{-1.1}(syst) \pm 0.1(lumi)pb$$

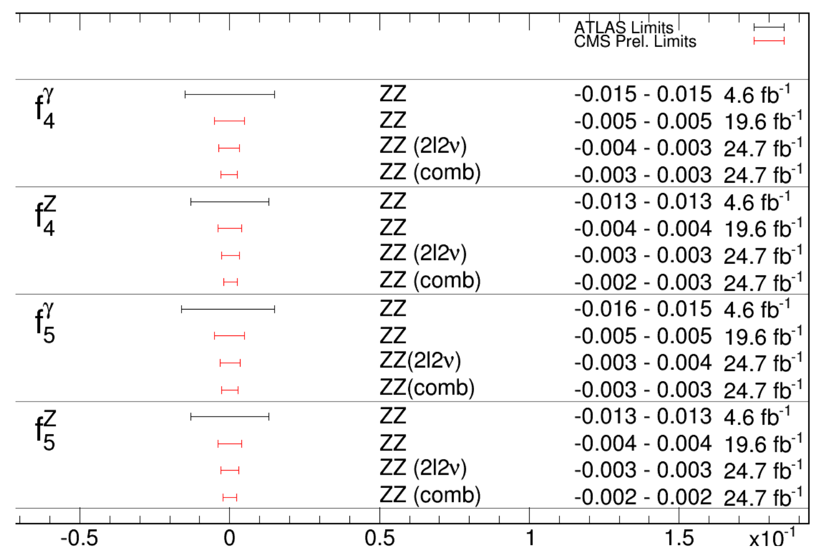
$$\sigma_{7TeV}^{NLO} = 6.2^{+0.3}_{-0.2}pb$$

$$\sigma_{8TeV}^{tot} = 7.2^{+0.8}_{-0.8}(stat)^{1.9}_{-1.5}(syst) \pm 0.2(lumi)pb$$

$$\sigma_{8TeV}^{NLO} = 7.6^{+0.4}_{-0.3}pb$$

- Best 95% CL aTGC (**CMS**,**ATLAS**) limits.





[J. High Energy Phys. 04 (2015) 164 ($\ell\ell\gamma$)]

[CMS-PAS-SMP-14-019 ($\nu\nu\gamma$)]

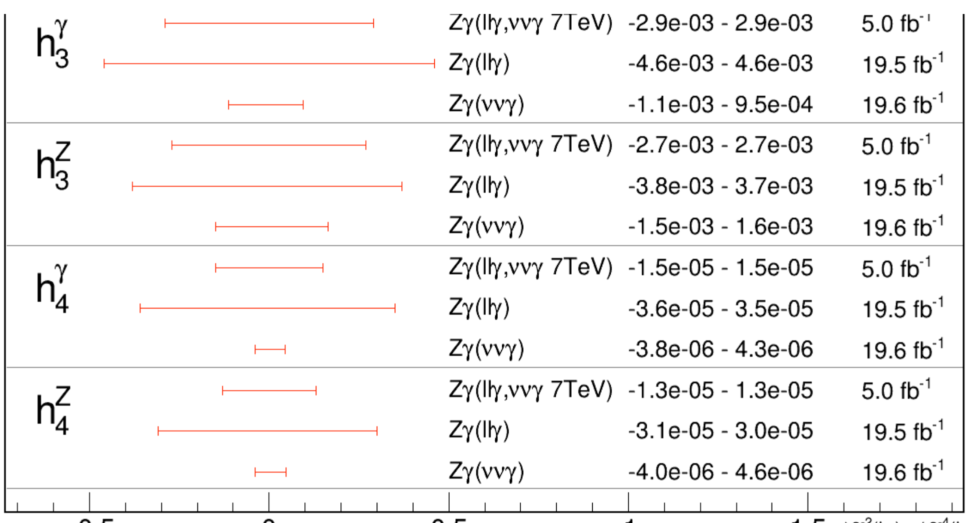
$Z\gamma$ @ 8 TeV

- $Z\gamma \rightarrow \nu\nu\gamma$ Selection:
  - 1central ($|\eta|<1.44$) high p_T(>145 GeV) photon
  - $E_T^{Miss}>140$ GeV
- Large W($\ell\nu\gamma$) bkg from MC but checked in CR.
- Measurements found in good agreement with NNLO predictions:

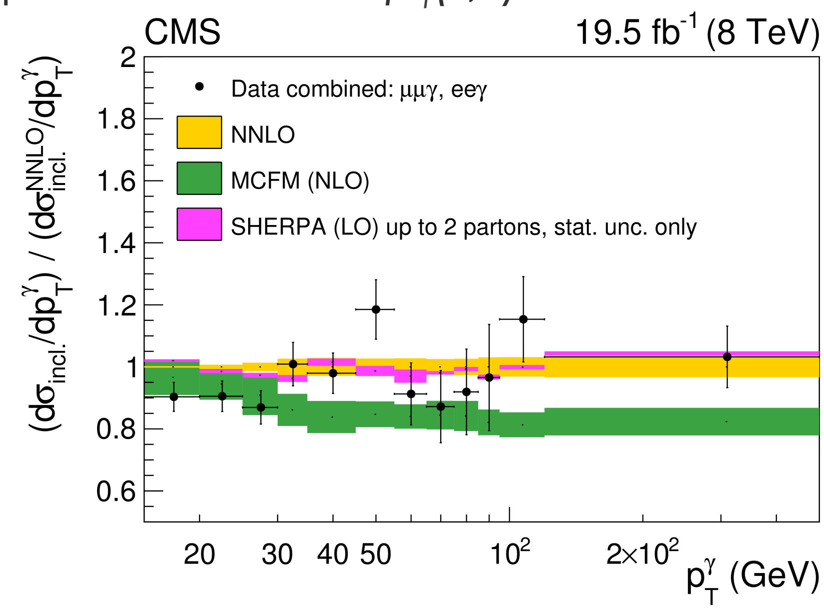
$$\sigma_{fid} = 52.7 \pm 2.1(stat) \pm 6.6(sys)\ \text{fb}$$

$$\sigma_{theo}^{NNLO} = 50. \pm 2.4\ \text{fb}$$

- Best 95% CL aTGC (**CMS**) limits.

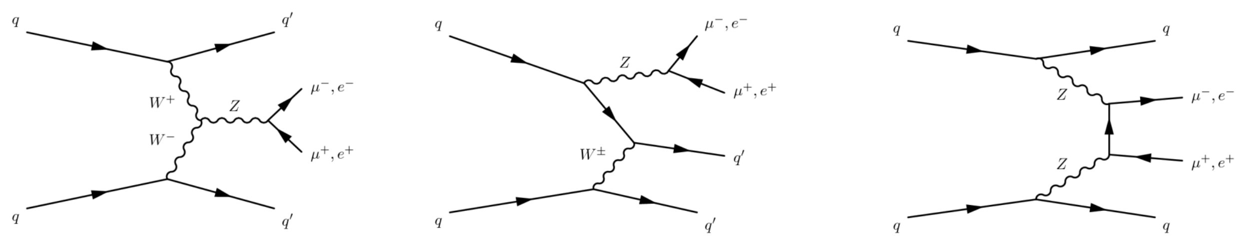


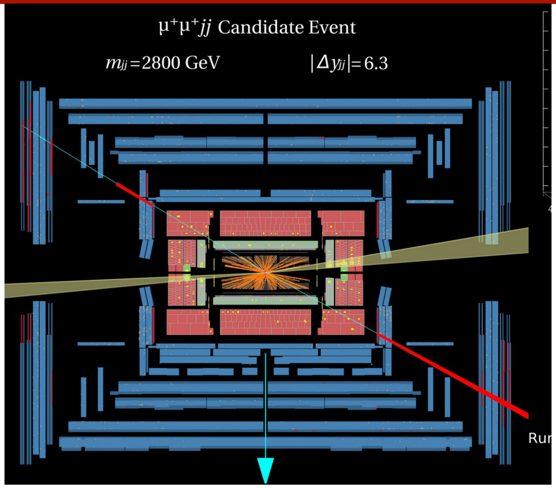
- $Z\gamma \rightarrow \ell(=e,\mu)\ell\gamma$ Selection:
  - 1($|\eta|<1.44$) with p_T(>15GeV) photon.
  - 2ℓ ($=e,\mu$) with p_T(>20GeV) .
  - $M_{\ell\ell}>50$ GeV, $|\Delta R(\ell,\gamma)|>0.7$.
- Main bkg Z+jets estimated data.
- Good agreement meas. to NNLO pred. Unfolded $p_T(\gamma)$:



Rare Processes - EWK production

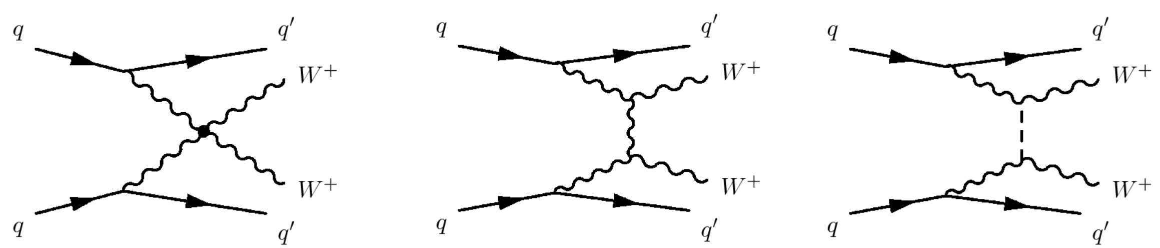
- EWK single production: ex: Z→ℓℓ+2j





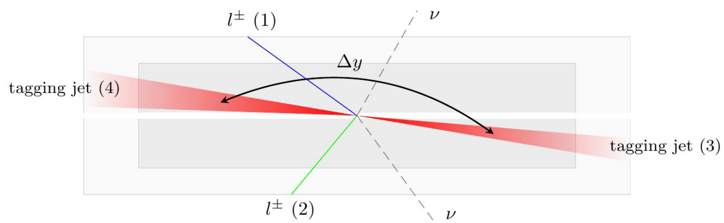
VBF : sensitive aTGC

- EWK di-boson production: ex: W±W±→ℓℓ+2j



VBS : sensitive aQGC

- EWK production is very characteristic:
  - Two high p_T well separated in rapidity
  - Suppressed hadronic activity in the gap.
  - Large mjj.



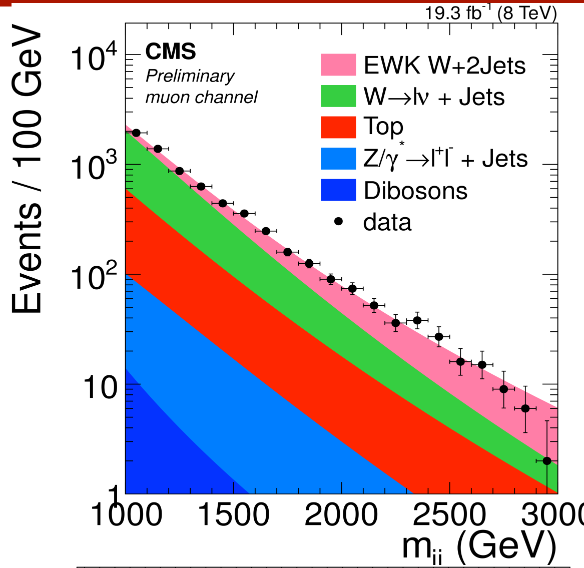
Rare Processes - Single boson EWK production @ 8 TeV

CMS-PAS-SMP-13-012 (EWK Wjj)

ATLAS: JHEP04(2014)031 (EWK Zjj)

- EWK W→ℓν +2j Selection:
  - 1 p_T(>25(μ) – 30(e) GeV) lepton.
  - E_T^{Miss}>25(μ) – 30(e) GeV.
  - 2 jets (|η|<4.7)p_T>50,60 GeV.
  - $|y^W-(y^{j1}+y^{j2})/2.0|< 1.2$, mjj>1 TeV.

QCD V+jets Estimated from CR



$$\sigma_{fid}^{Wjj} = 420 \pm 40(stat) \pm 90(sys) fb$$

$$\sigma_{theo}^{Wjj} = 500 \pm 30 fb$$

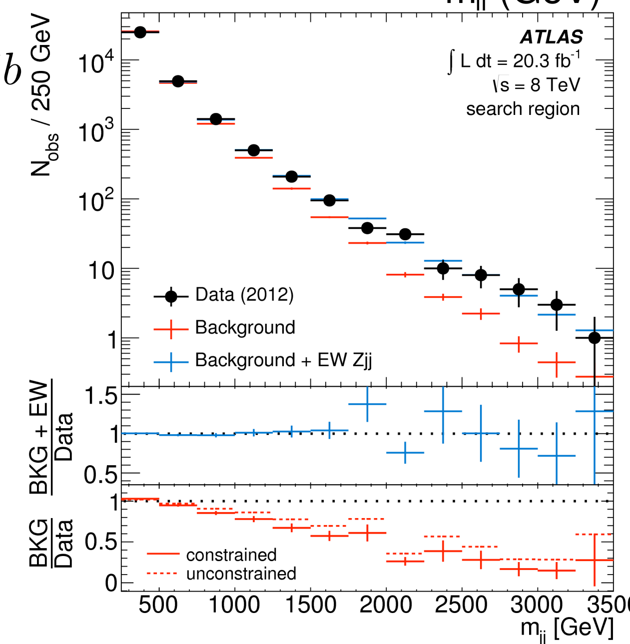
$$\sigma_{fid}^{Zjj} = 54.7 \pm 4.6(stat) \pm 10.5(sys) fb$$

$$\sigma_{theo}^{Zjj} = 46.1 \pm 1.1 fb$$

Measurements found in good agreement with predictions in two channels.

- EWK Z→ℓℓ+2j Selection:
  - 2 p_T(>25 GeV) lepton.
  - 81<$m_{\ell\ell}$<101 GeV, $p_T^{\ell\ell}$>20 GeV.
  - 2 jets (|η|<4.4)p_T>45,55 GeV.
  - p_T^{bal}< 0.15, mjj>250 GeV.

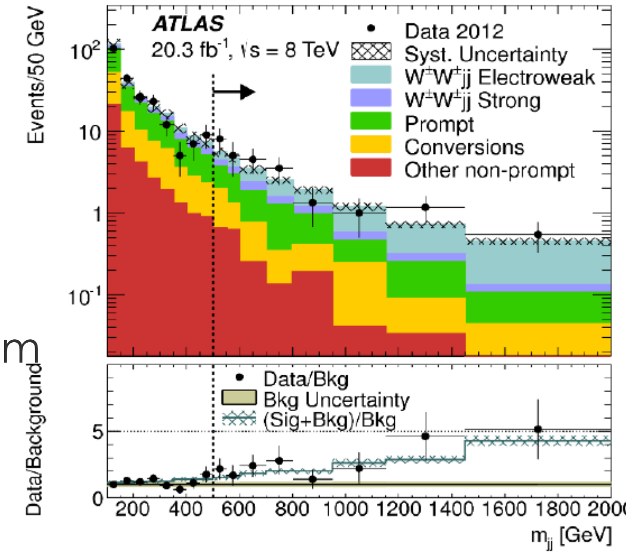
$$p_T^{\text{balance}} = \frac{\left|\vec{p}_T^{\,\ell_1} + \vec{p}_T^{\,\ell_2} + \vec{p}_T^{\,j_1} + \vec{p}_T^{\,j_2}\right|}{\left|\vec{p}_T^{\,\ell_1}\right| + \left|\vec{p}_T^{\,\ell_2}\right| + \left|\vec{p}_T^{\,j_1}\right| + \left|\vec{p}_T^{\,j_2}\right|},$$

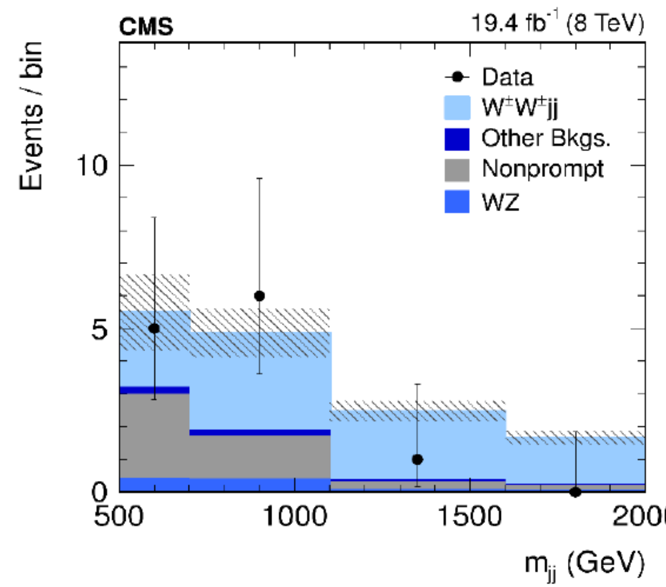


Rare Processes – Evidence of Same Sign WW production

ATLAS: PRL. 113, (2014) 141803
CMS: PRL. 114 (2015) 051801

- $W^{\pm}W^{\pm}$ channel very interesting, because QCD (gg) production is suppressed, and benefits from small background. Very good signal (EWK $W^{\pm}W^{\pm}$) over background ratio!
- $W^{\pm}W^{\pm}$ scattering essential to probe EWSB mechanism (Violate unitarity without a SM Higgs).
- Important bkg from fake and charge flip (e) estimated from data.
- ATLAS Selection:
  - 2 SS leptons (e, μ) with p_T>25 GeV.
  - $m_{\ell\ell}$>20 GeV, $\Delta R_{\ell\ell}$>0.3
  - 2 jets with pT>30 GeV, $\Delta R_{\ell j}$>0.3
  - m_{jj}>500 GeV
  - *EWK region:* $|\Delta y_{jj}|$>2.4
- CMS Selection
  - 2 SS leptons (e, μ) with p_T>10 GeV.
  - $m_{\ell\ell}$>20 GeV.
  - 2 jets with pT>20 GeV.
  - M_{jj}>300 GeV, $|\Delta \eta_{jj}|$>2.5





Rare Processes - $W^{\pm}W^{\pm}$ jj results

- Both analyses have sensitivity to first evidence: ATLAS 3.6σ (2.8σ), CMS 2.0σ (3.1σ)

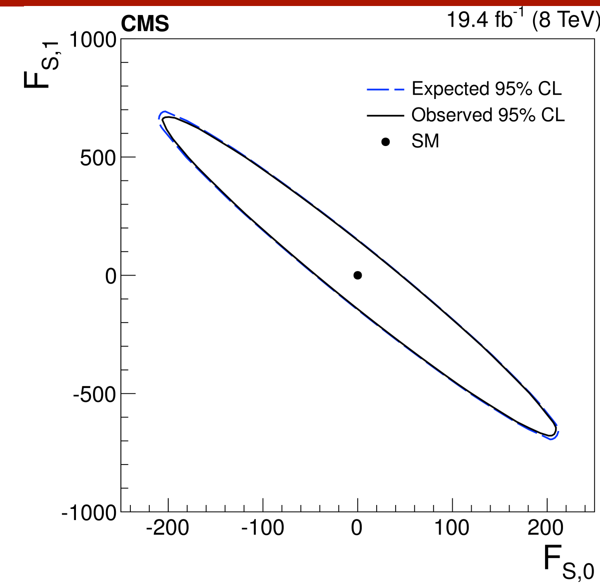
- Good agreement is found with predictions:

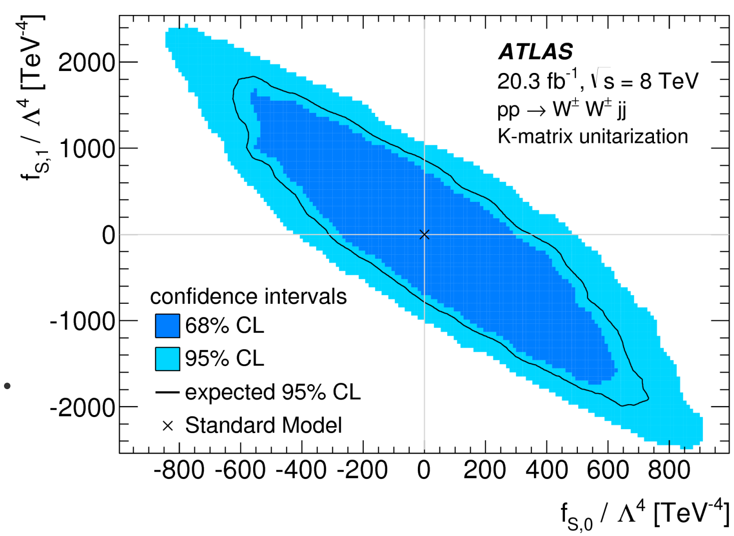
$$\sigma_{fid}^{CMS} = 4.0 \pm 2.4(stat) \pm 1.1(sys) fb$$
$$\sigma_{theo}^{CMS} = 5.8 \pm 1.2 fb$$

ATLAS:

$$\sigma_{fid}^{all} = 2.1 \pm 0.5(stat) \pm 0.3(sys) fb$$
$$\sigma_{theo}^{all} = 1.52 \pm 0.11 fb$$
$$\sigma_{fid}^{EWK} = 1.3 \pm 0.4(stat) \pm 0.2(sys) fb$$
$$\sigma_{theo}^{EWK} = 0.95 \pm 0.06 fb$$

- Limits are set on aQGC parameters F_{S0} and F_{S1} non unitarized for CMS and unitarized with Kmatrix formalism for ATLAS.

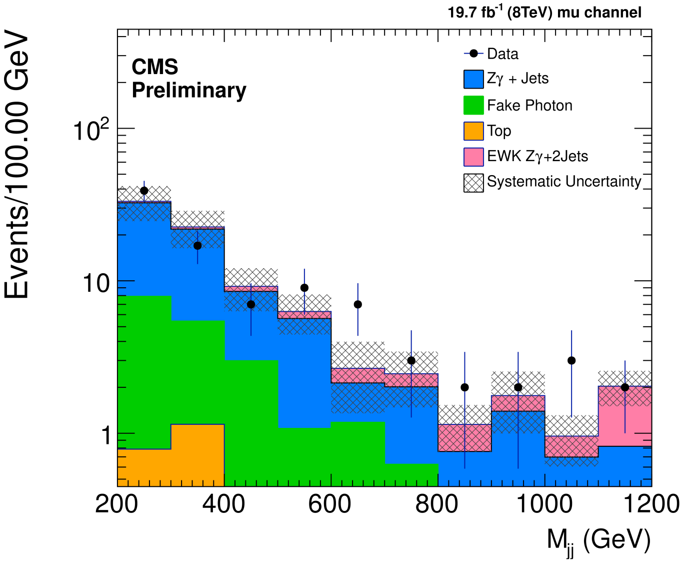




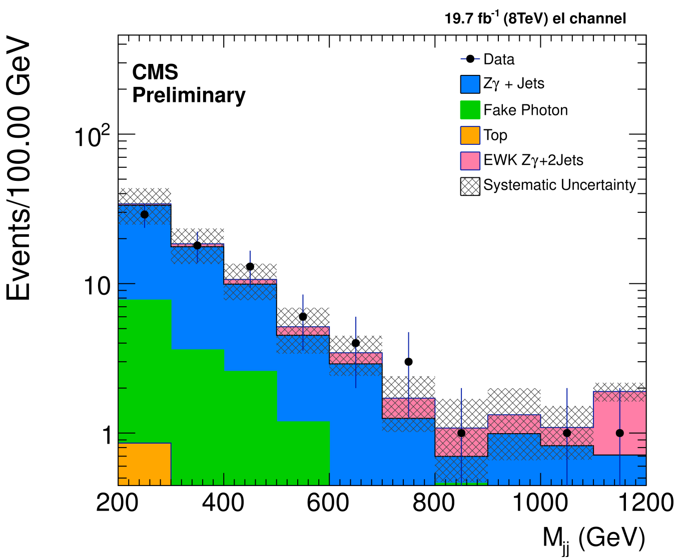
Rare Processes – First evidence of EWK Z γ production

CMS-PAS-SMP-14-018

- Z γ+jj selection:
  - Exactly *1 SFOS pair of e or μ* with p_T>20 GeV and 70< $m_{\ell\ell}$<110 GeV
  - 1 photon p_T>20 GeV and (| η | <*1.44*)
  - At least 2 jets with p_T>30 GeV, m_{jj}>400 GeV and | $\Delta\ \eta jj$ | >2.5



- Large Z γ *QCD contribution measured in CR.*



- Significance over bkg only hypothesis 3.0 σ (Exp: 2.1 σ). Good agreement with predictions:

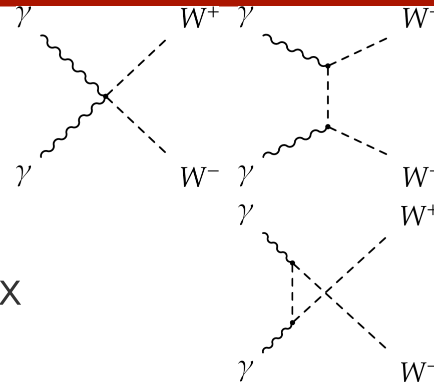
$$\sigma^{Z\gamma}_{fid} = 1.86^{+0.89}_{-0.75}(stat)^{+0.42}_{-0.27}(sys) fb$$

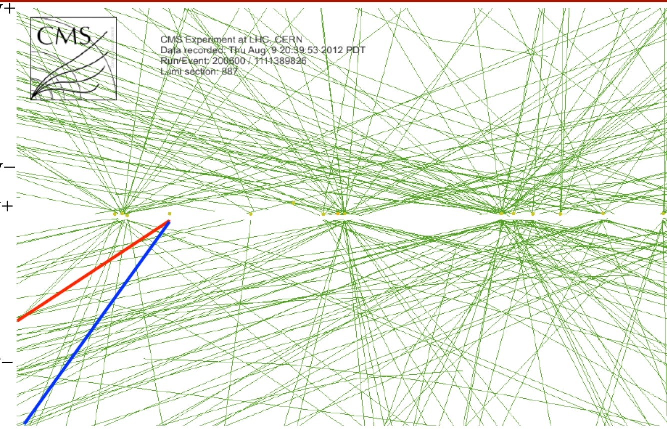
$$\sigma^{Z\gamma}_{theo} = 1.26 \pm 0.12 fb$$

Rare Processes – Exclusive *WW* production $\gamma\gamma \rightarrow WW$ @ 8 TeV

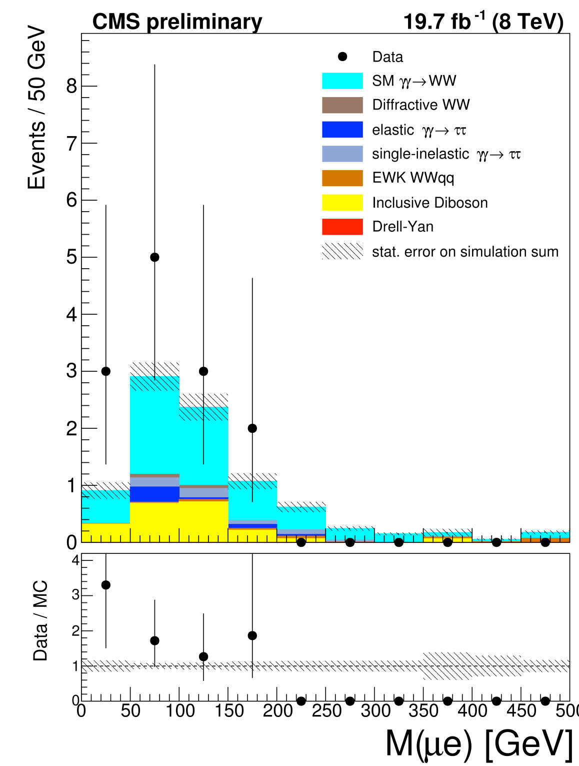
CMS-PAS-FSQ-13-008

- $\gamma\gamma \rightarrow W^+W^-$ *selection:*
  - Exactly *1 OS pair of e* and μ with p_T>20 GeV.
  - $p_T(e\mu)$>30 GeV.
  - Both originates from same vertex with no other tracks.





- Pile-up makes such an analysis very challenging.
  - Use $\gamma\gamma \rightarrow$ ee, $\mu\mu$ exclusive process as control sample at p_T (ll) ~ 0 to study charged track veto and characterize to correct for non-elastic contributions



- Significance over bkg only hypothesis 3.6σ (Exp:2.4σ). Good agreement with LO predictions

$$\sigma_{tot} = 12.3^{+5.5}_{-4.4}\ \text{fb}$$
$$\sigma_{LO} = 6.9 \pm 0.6\ \text{fb}$$

Rare Processes – Evidence for 3-boson production: W γ γ

Phys. Rev. Lett. 115, 031802 (2015)

- Fiducial definition:

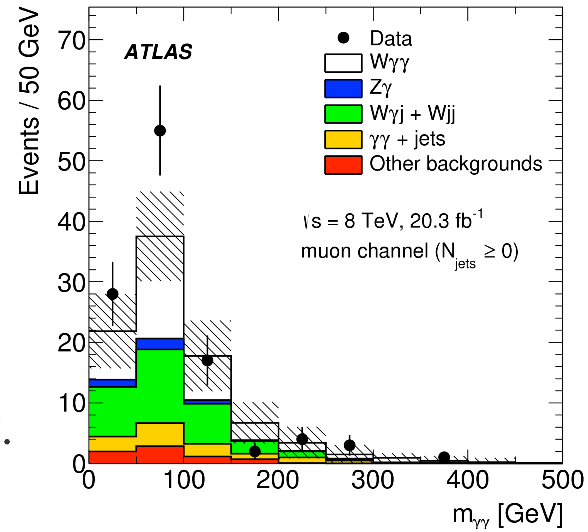
Definition of the fiducial region
$p_T^\ell > 20\,GeV$, $p_T^\nu > 25\,GeV$, $\lvert\eta_\ell\rvert < 2.5$
$m_T > 40\,GeV$
$E_T^\gamma > 20\,GeV$, $\lvert\eta^\gamma\rvert < 2.37$, iso. fraction $\epsilon_h^p < 0.5$
$\Delta R(\ell,\gamma) > 0.7$, $\Delta R(\gamma,\gamma) > 0.4$, $\Delta R(\ell/\gamma, \text{jet}) > 0.3$
Exclusive: no anti-k_t jets with $p_T^{\text{jet}} > 30\,GeV$, $\lvert\eta^{\text{jet}}\rvert < 4.4$

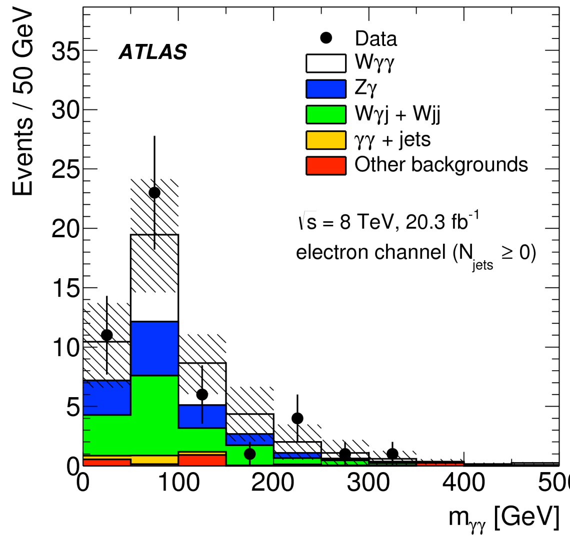
- *W γ+jet, γ γ+jet estimated from data, Z γ checked in CR.*

- First experimental evidence (>3. σ from bkg only hypo) of 3-bosons production!

- ~2. σ discrepancy with NLO prediction in inclusive measurement (1. σ exclusive).

	σ^{fid} [fb]	σ^{MCFM} [fb]
Inclusive ($N_{\text{jet}} \geq 0$)		
$\mu\nu\gamma\gamma$	$7.1\ ^{+1.3}_{-1.2}$ (stat.) ±1.5 (syst.) ±0.2 (lumi.)	2.90 ± 0.16
$e\nu\gamma\gamma$	$4.3\ ^{+1.8}_{-1.6}$ (stat.) $^{+1.9}_{-1.8}$ (syst.) ±0.2 (lumi.)	
$\ell\nu\gamma\gamma$	$6.1\ ^{+1.1}_{-1.0}$ (stat.) ±1.2 (syst.) ±0.2 (lumi.)	
Exclusive ($N_{\text{jet}} = 0$)		
$\mu\nu\gamma\gamma$	3.5 ± 0.9 (stat.) $^{+1.1}_{-1.0}$ (syst.) ±0.1 (lumi.)	1.88 ± 0.20
$e\nu\gamma\gamma$	$1.9\ ^{+1.4}_{-1.1}$ (stat.) $^{+1.1}_{-1.2}$ (syst.) ±0.1 (lumi.)	
$\ell\nu\gamma\gamma$	$2.9\ ^{+0.8}_{-0.7}$ (stat.) $^{+1.0}_{-0.9}$ (syst.) ±0.1 (lumi.)	



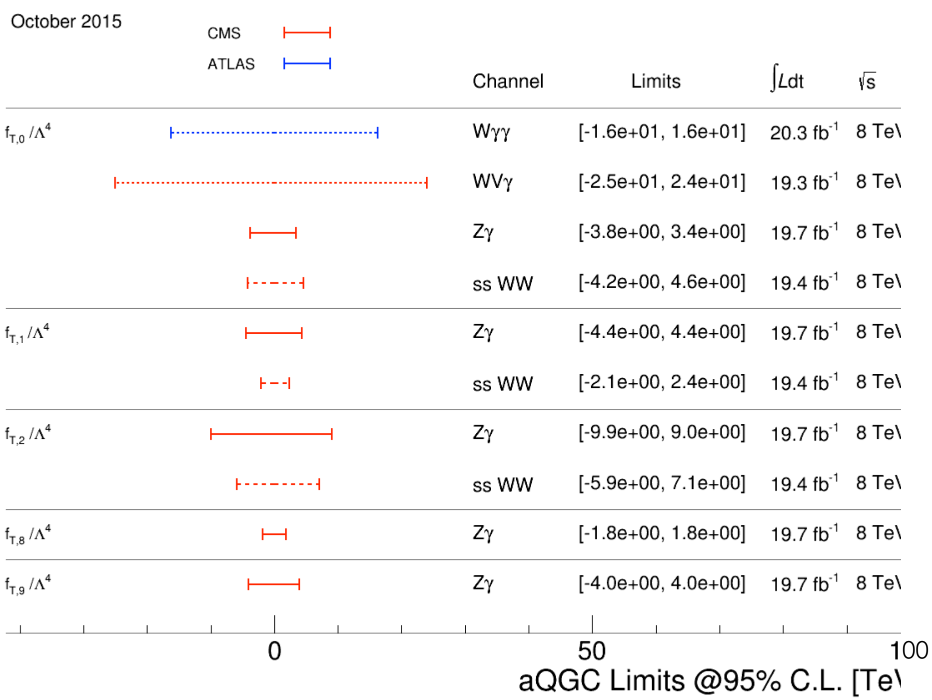


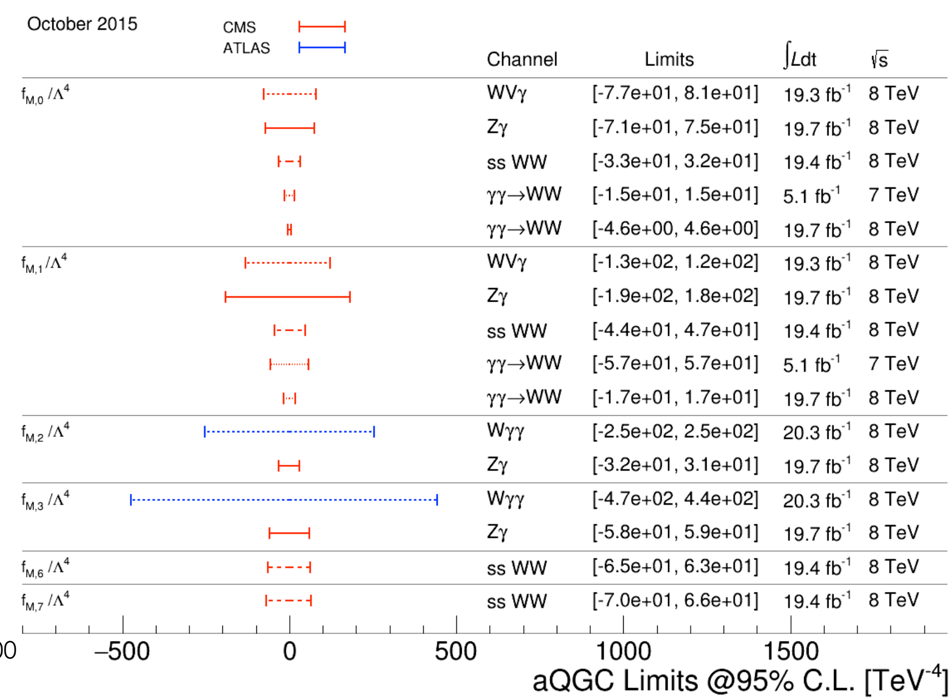
CMS public aQGC results

CMS-PAS-SMP-14-018 (EWK Z γ)

Results on aQGCs

- Using results from VBS channels: CMS-PAS-SMP-14-018 (EWK Z γ) , Phys. Rev. Lett. 114 (2015) 051801 (CMS $W^{\pm}W^{\pm}$) and tri-boson channels: Phys. Rev. Lett. 115, 031802 (2015) (ATLAS W γ γ) , Phys. Rev. D 90 (2014) 032008 (CMS WV γ) , stringent non unitarized (**CMS**,**ATLAS**) limits are set on dim 8 operators, F_M and F_T.





Precision measurements: Z forward backward Asymmetry

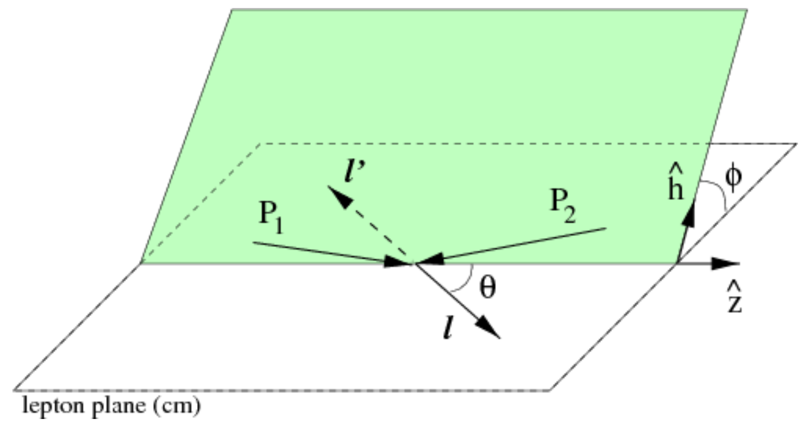
LHCb ZAFB: JHEP 11 (2015) 190

- Z Forward-Backward Asymmetry:(A_{FB})

$$A_{FB} = \frac{N_{\cos\theta^*_{CS}\geq 0} - N_{\cos\theta^*_{CS}<0}}{N_{\cos\theta^*_{CS}\geq 0} + N_{\cos\theta^*_{CS}<0}}$$

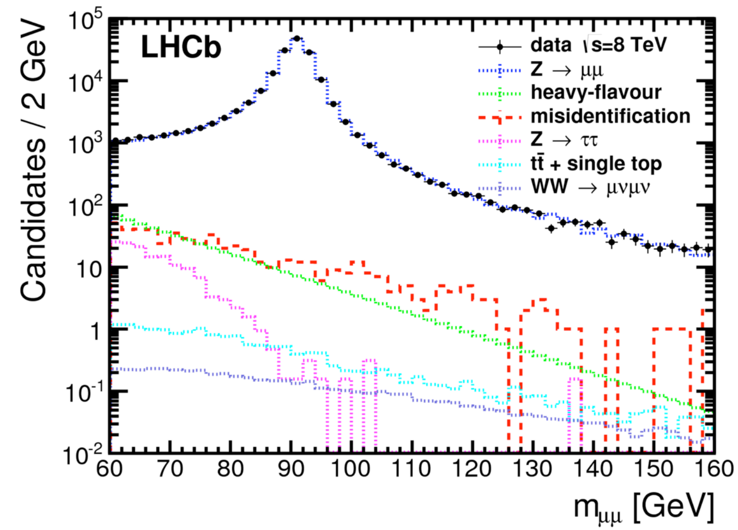
  - Z couplings differ for left- and right-handed fermions:

    → difference in ℓ+ & ℓ- angular(θ) distribution
  - Due to V-A structure of weak interaction.
  - Linked to weak mixing angle: θ_W.



Use Collins-Soper Frame: θ^*_{CS} to minimize ambiguity due to p_T of incoming quark

- Measurement in LHCb with Z→ $\mu\mu$ final state only.
  - 2 OS Muons with p_T>20 GeV and 2<| η |<4.5, 60<$m_{\mu\mu}$<160 GeV.
  - Using L=1 fb-1@ 7 TeV and L=2fb-1@8TeV.
  - Signal Powheg (99% pure sel).Fakes model with data.

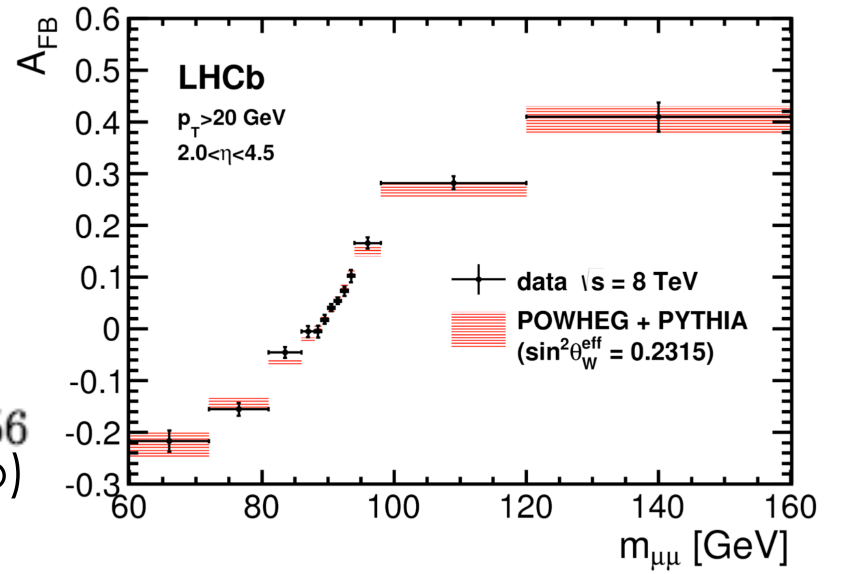


ZAFB results

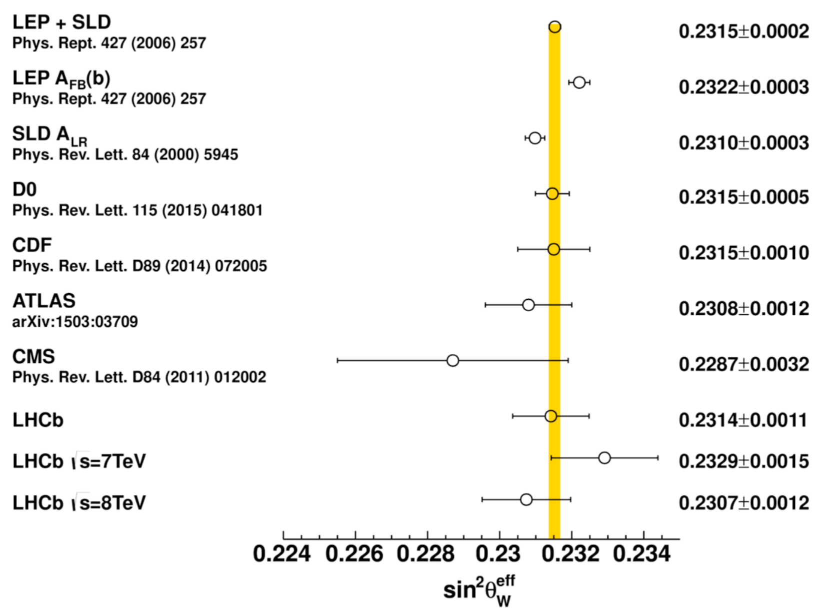
- A_{FB} measured as a function of $m_{\mu\mu}$.
  - Good agreement with generator!
  - Use template fitting to extract $\sin^2\theta^{eff}_W$.
- Measurement gives:

$$\sin^2\theta^{\rm eff}_{\rm W} = 0.23142 \pm 0.00073 \pm 0.00052 \pm 0.00056$$

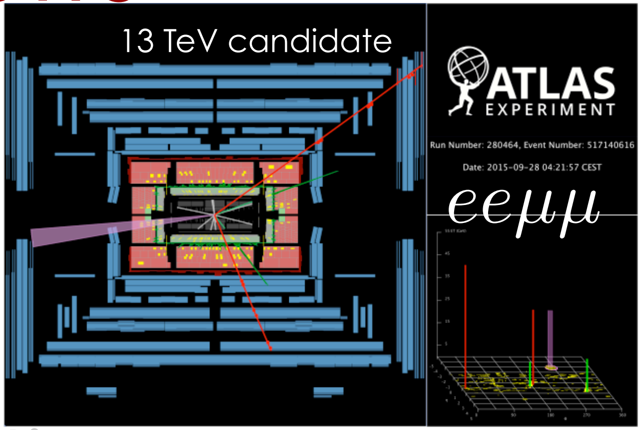
(stat) (sys) (theo)



- Both ATLAS and CMS also measured $\sin^2\theta^{eff}_W$.
  - Only 7 TeV data but with both e and μ channel.
- LEP and SLD measurement still most precise measurement, but LHC results competitive with Tevatron now!



Run 2 results



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- Run1 results:
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- Run2 results
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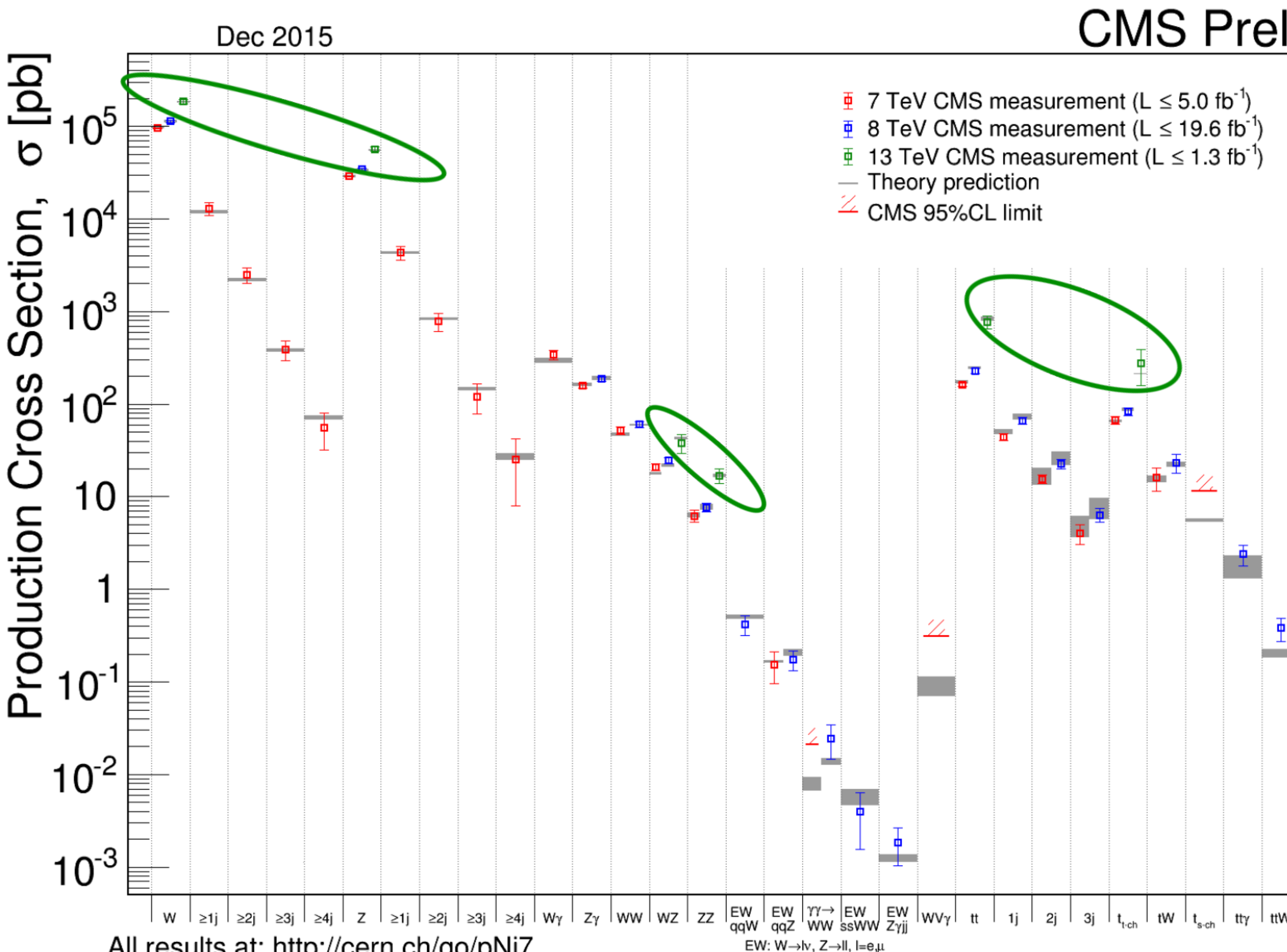
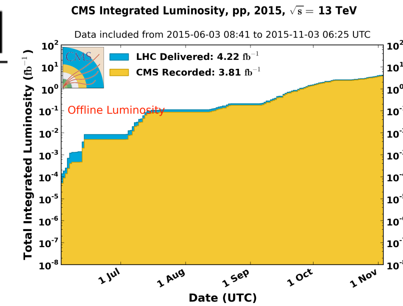
CMS run1- run2 overview





Data taking stopped 1st November!

CMS WZ run2 with L=1.3fb^{-1}@13 TeV

CMS-PAS-SMP-15-006

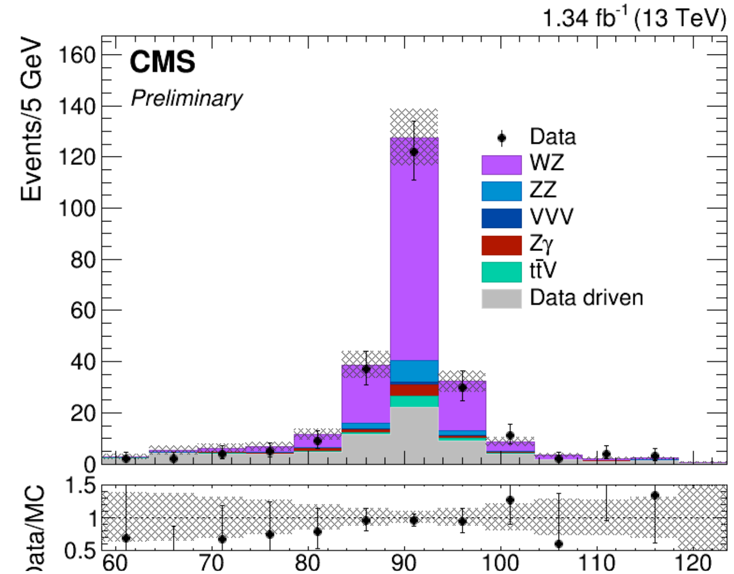
- *WZ→ℓℓℓ' ν selection:*
  - 3 lepton (e, μ) consistent with WZ: (ie 1 pair SFOS+ another lepton).
  - $p_T^{Z\ell 1}>20$ GeV, $p_T^{Z\ell 2}>10$ GeV, $p_T^{W\ell}>20$ GeV.
  - $60<M_Z<120$ GeV.
- Fake background measured from data.
- Good agreement with NLO predictions (No NNLO predictions available in this channel!).

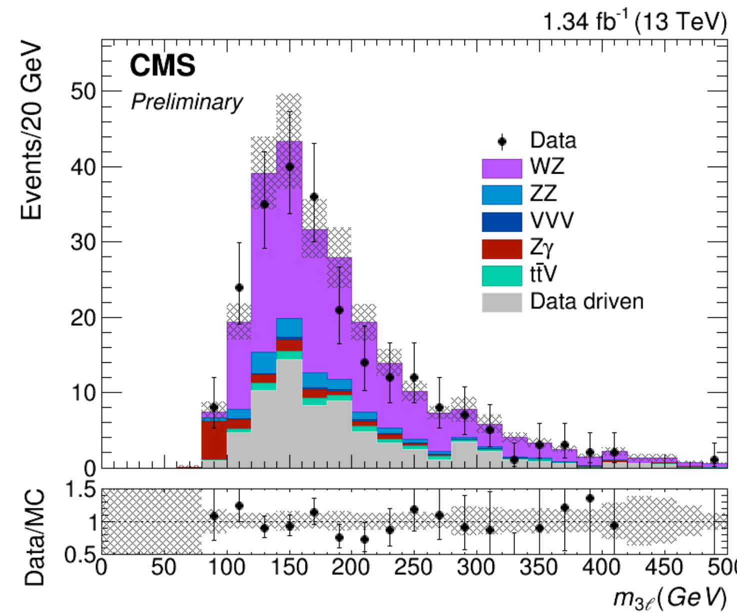
$$\sigma_{\rm fid}(pp \to WZ \to \ell\nu\ell'\ell') = 239 \pm 29\,(\rm stat)^{+52}_{-40}\,(\rm syst) \pm 11\,(\rm lum)\ fb.$$

$$\sigma^{fid}_{NLO} = 274^{+13}_{-8}\ \rm fb$$

$$\sigma(pp \to WZ) = 36.8 \pm 4.6\,(\rm stat)^{+8.1}_{-6.2}\,(\rm syst) \pm 0.6\,(\rm theo) \pm 1.7\,(\rm lum)\ pb.$$

$$\sigma^{tot}_{NLO} = 42.7^{+1.6}_{-0.8}\ \rm pb$$





CMS ZZ run2 with $L=1.3fb^{-1}$@13 TeV

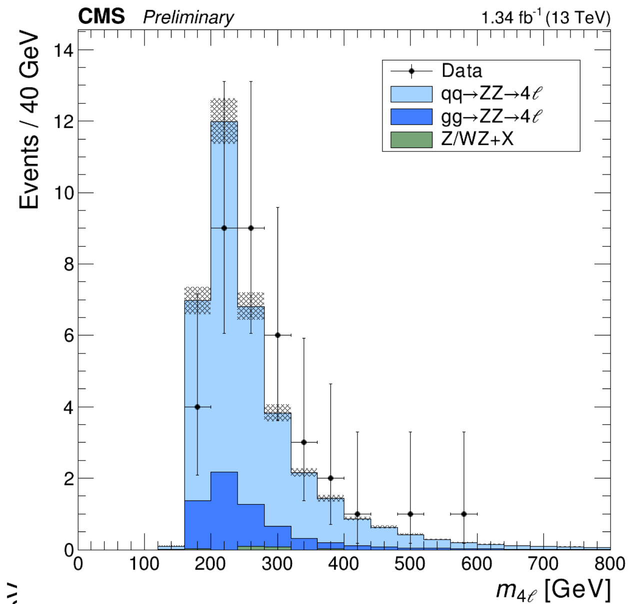
CMS-PAS-SMP-15-005

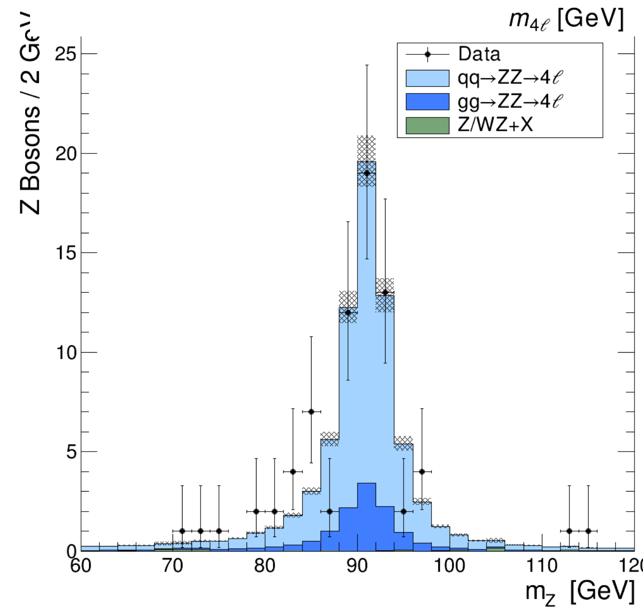
- *ZZ→ℓℓℓ'ℓ' selection:*
  - 4 lepton (e, μ) consistent with ZZ: (ie 2 pair SFOS).
  - $p_T^{Z\ell 1}$>20 GeV, p_T^{other}>10 GeV.
  - $60<M_{Z1,2}<120$ GeV.
- Fake background measured from data.
- Good agreement with NNLO predictions.

$$\sigma_{\text{fid}}(\text{pp} \rightarrow \text{ZZ} \rightarrow 4\ell) = 38.0^{+6.7}_{-6.0}\,(\text{stat})^{+1.5}_{-1.2}\,(\text{syst}) \pm 1.7\,(\text{lum})\,\text{fb}.$$

$$\sigma(\text{pp} \rightarrow \text{ZZ}) = 16.7^{+2.9}_{-2.6}\,(\text{stat})^{+0.7}_{-0.5}\,(\text{syst}) \pm 0.3\,(\text{theo}) \pm 0.8\,(\text{lum})\,\text{pb}.$$

$$\sigma^{tot}_{NNLO} = 15.4^{+0.5}_{-0.4}\ \text{pb}$$



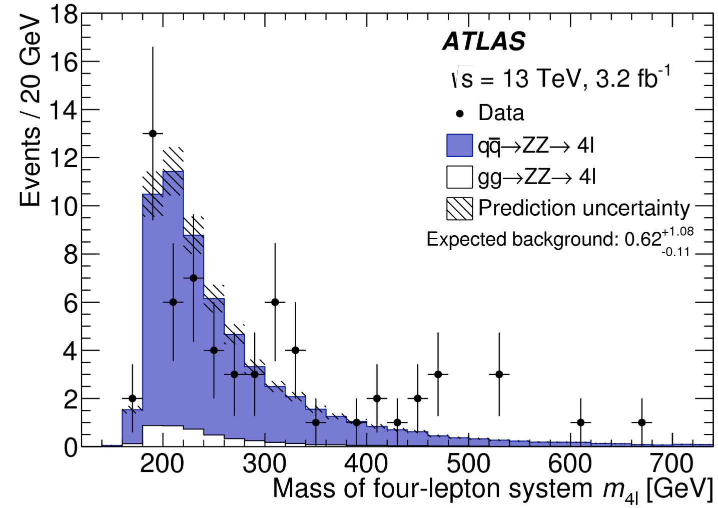


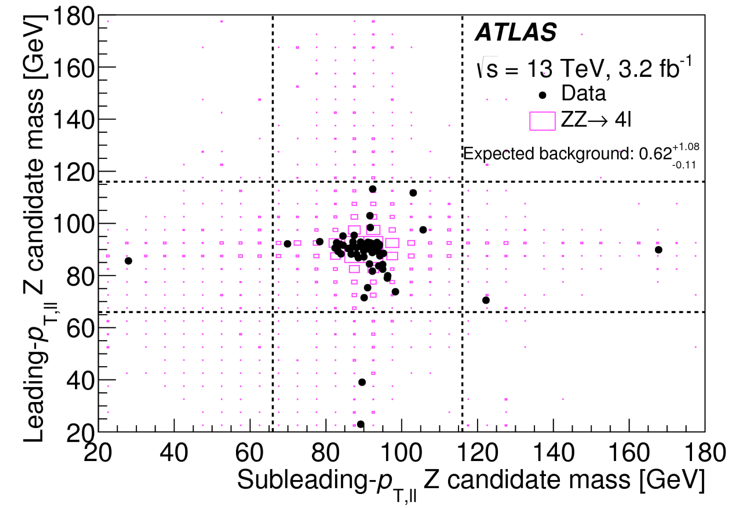
ATLAS ZZ run2 with L=3.2fb^{-1}@13 TeV

ArXiv:1512.05314 Submitted to PRL

- *ZZ→ℓℓℓ'ℓ' selection:*
  - 4 lepton (e, μ) consistent with ZZ: (ie 2 pair SFOS).
  - $p_T^{Z\ell 1}$>20 GeV.
  - 66<$M_{Z1,2}$<116 GeV.
- Fake background measured from data.
- Good agreement with NNLO predictions.

	Measurement	$O(\alpha_S^2)$ prediction
$\sigma^{fid}_{ZZ\to e^+e^-e^+e^-}$	$8.4\ ^{+2.4}_{-2.0}(stat.)\ ^{+0.4}_{-0.2}(syst.)\ ^{+0.5}_{-0.3}(lumi.)$ fb	$6.9^{+0.2}_{-0.2}$ fb
$\sigma^{fid}_{ZZ\to e^+e^-\mu^+\mu^-}$	$14.7\ ^{+2.9}_{-2.5}(stat.)\ ^{+0.6}_{-0.4}(syst.)\ ^{+0.9}_{-0.6}(lumi.)$ fb	$13.6^{+0.4}_{-0.4}$ fb
$\sigma^{fid}_{ZZ\to \mu^+\mu^-\mu^+\mu^-}$	$6.8\ ^{+1.8}_{-1.5}(stat.)\ ^{+0.3}_{-0.3}(syst.)\ ^{+0.4}_{-0.3}(lumi.)$ fb	$6.9^{+0.2}_{-0.2}$ fb
$\sigma^{fid}_{ZZ\to \ell^+\ell^-\ell'^+\ell'^-}$	$29.7\ ^{+3.9}_{-3.6}(stat.)\ ^{+1.0}_{-0.8}(syst.)\ ^{+1.7}_{-1.3}(lumi.)$ fb	$27.4^{+0.9}_{-0.8}$ fb
σ^{tot}_{ZZ}	$16.7\ ^{+2.2}_{-2.0}(stat.)\ ^{+0.9}_{-0.7}(syst.)\ ^{+1.0}_{-0.7}(lumi.)$ pb	$15.6^{+0.4}_{-0.4}$ pb





Conclusions

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  - Precision measurements
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Conclusions

- The LHC EWK recent results were presented.
  - As it can be seen no significant deviation from theoretical prediction have been observed.
    - Usually tension fixed when higher order corrections are available.
    - Start to be sensitive to NNLO correction in some channels.
  - New channels are now observed:
    - EWK (1-2)boson production, and tri-bosons.
  - Limits on aGCs are starting to be competitive with LEP results.
  - Run2 data have already been started to be analyzed although the data taking stopped 2 months ago.
    - More results (run1 and run2) will come soon! Stay tuned!