"Production of heavy vector boson pairs at 13 TeV with the CMS experiment at LHC"

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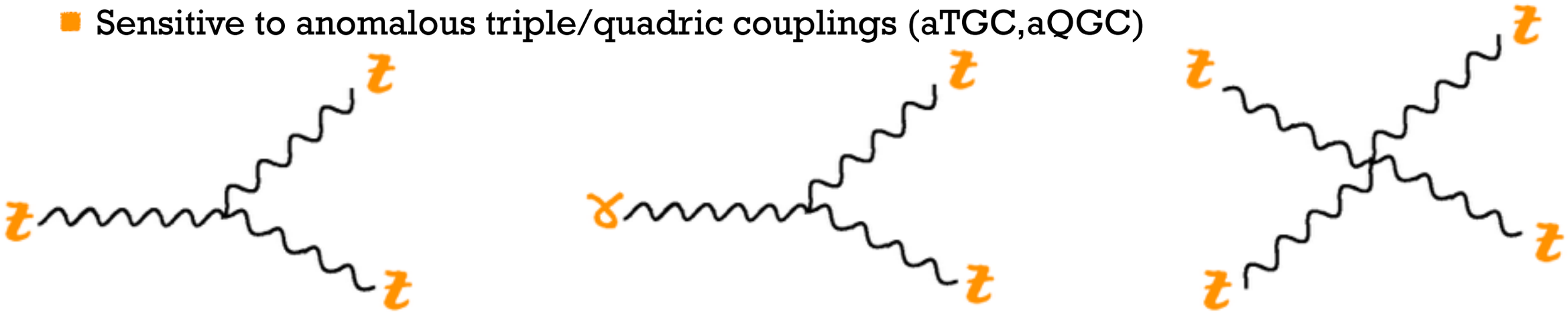
Introduction

- First measurement of WZ and ZZ cross-section at 13 TeV with the CMS experiment.
  - Leptonic decay modes.
- Others VV analysis are in progress (WW, ZZ/Zq, ZZjj, etc..)
- Data sample corresponding to an integrated luminosity of 1.3 fb^{-1} with 25 ns of bunch spaces.
- WZ and ZZ previously measured at the LHC by the CMS experiment at 7 and 8 TeV.

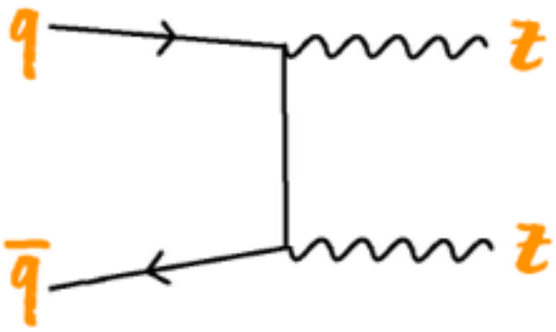
Physic Motivation

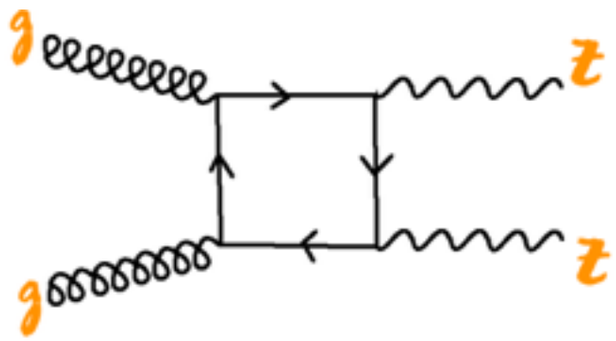
- Test of electroweak sector of SM.
  - Sensitive to the interaction between gauge bosons via triple/ quadric gauge couplings (TGC,QGC).
  - Fundamental to establish if Higgs boson really can preserve unitarity in the VV scattering amplitude at all energies.
  - QCD initiated processes have larger cross section than pure EW processes.
- Sensitive to anomalous triple/quadric couplings (aTGC,aQGC)

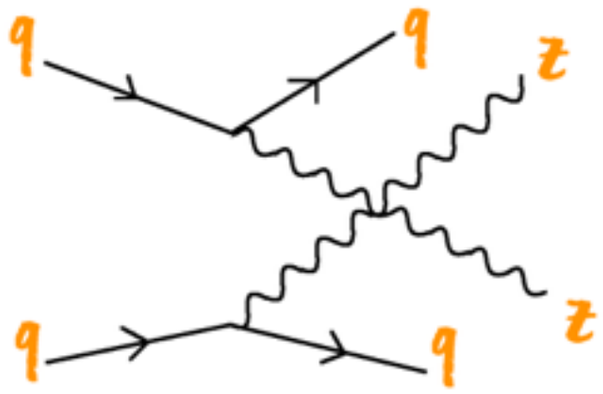


  - Modelled through effective field theory, effective Lagrangian, etc..
- Important background to Higgs and beyond-SM searches

ZZ







- Signals: $qg/q\bar{q} \to ZZ,\ gg \to ZZ,\ qg/qq \to ZZjj$
  - 3 channels: 2e2μ,4e,4μ
- Background:

ZZ➡ℓ+ℓ-ℓ'+ℓ'-

(ℓ,ℓ'=e,μ)

- Irreducible background: processes which contain 4 prompt leptons from non-signal processes (ttZ , WWZ, ttWW), very small. (negligible with this statistic).

- Reducible background: processes which contain one or more non-prompt leptons in the four-lepton final state (DY, tt, WZ, WWW).
  - Not well represented by MC samples. ➡ data driven method.

ZZ Selection

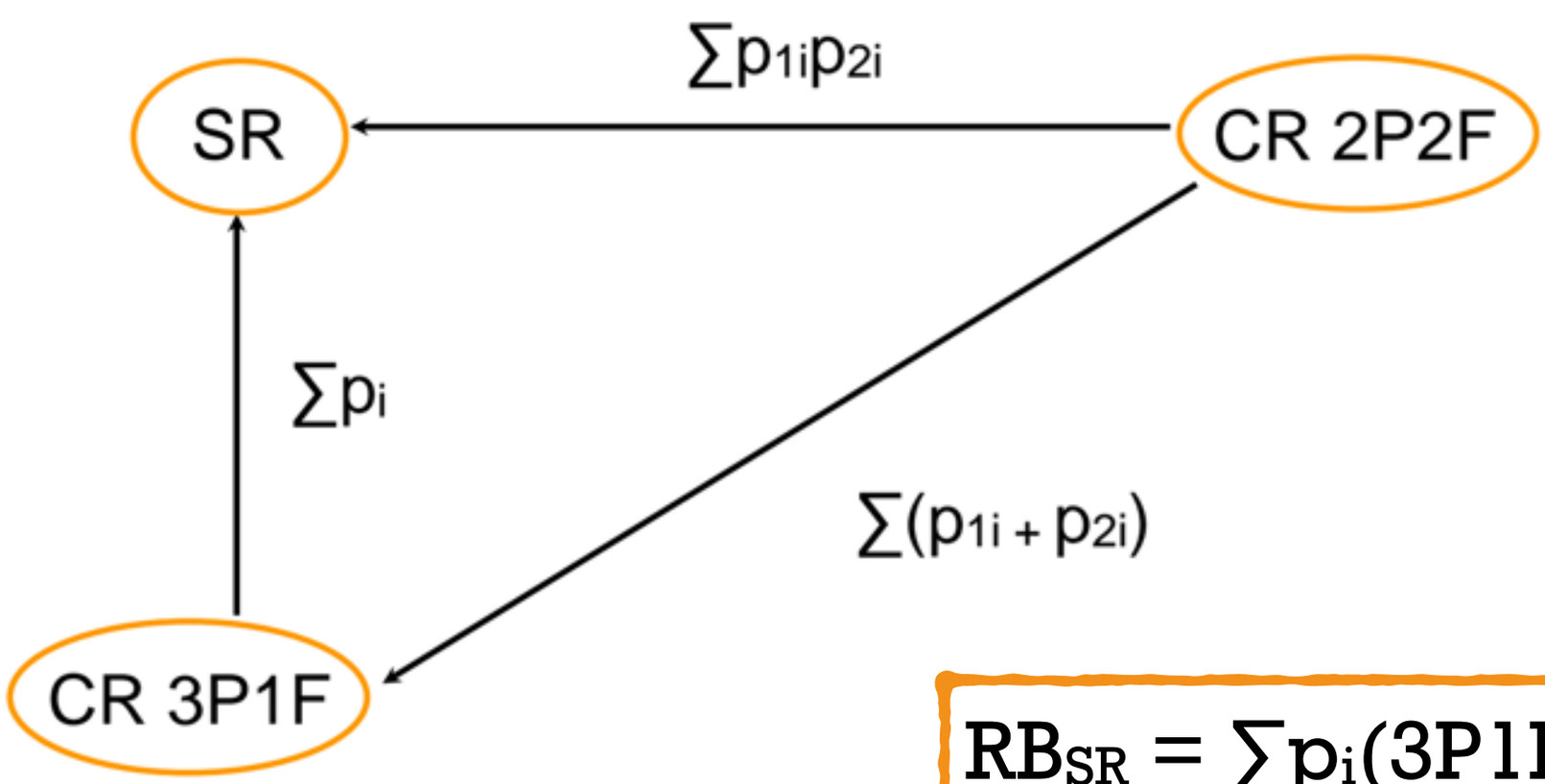
- p_T^{ℓ}>10 GeV 1 lepton p_T^{ℓ}>20 GeV On shell Z 60 GeV<$M_{2\ell}$< 120 GeV
- Leptons from interaction point SIP= $|IP/\sigma_{IP}| < 4$
- Isolated tracks in a cone $\Delta R < 0.4$ $R_{iso}^{e} < 0.5$ $R_{iso}^{\mu} < 0.4$
- Leptons in detector acceptance $|\eta_e| < 2.5$, $|\eta_\mu| < 2.4$
- QCD suppression $m_{\ell\ell'} > 4$ GeV

Decay channel	N_{exp} ZZ	Background	Total expected	Observed
4μ	10.53 ± 0.08 ± 0.31	0.04 ± 0.09 ± 0.02	10.57 ± 0.12 ± 0.31	15
2e2μ	17.83 ± 0.10 ± 0.48	0±0.11±0.10	17.83 ± 0.15 ± 0.48	16
4e	7.81 ± 0.07 ± 0.20	0.09 ± 0.12 ± 0.04	7.90 ± 0.14 ± 0.21	5
Total	36.18 ± 0.15 ± 0.61	0.10 ± 0.19 ± 0.11	36.28 ± 0.24 ± 0.61	36

ZZ Reducible Background

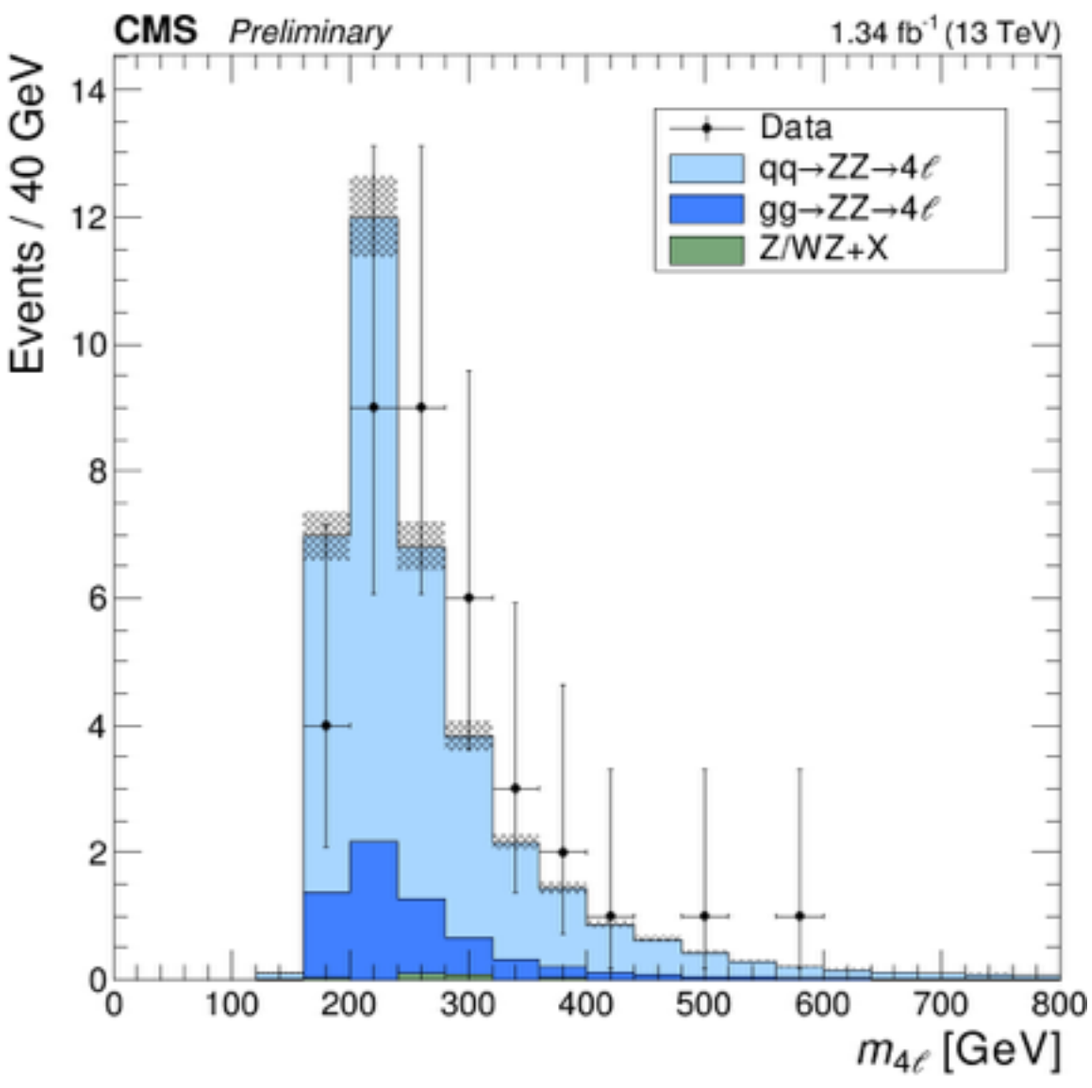
- f_i = the probability for fake electrons and fake muons which do pass predefined loose selection criteria, to also pass the final selection criteria.
  - Measured with a data driven method.

- P = lepton passing the final selection criteria (Z1)
- F = lepton not passing the final ID and ISO criteria
- $p_i = f_i / (1 - f_i)$

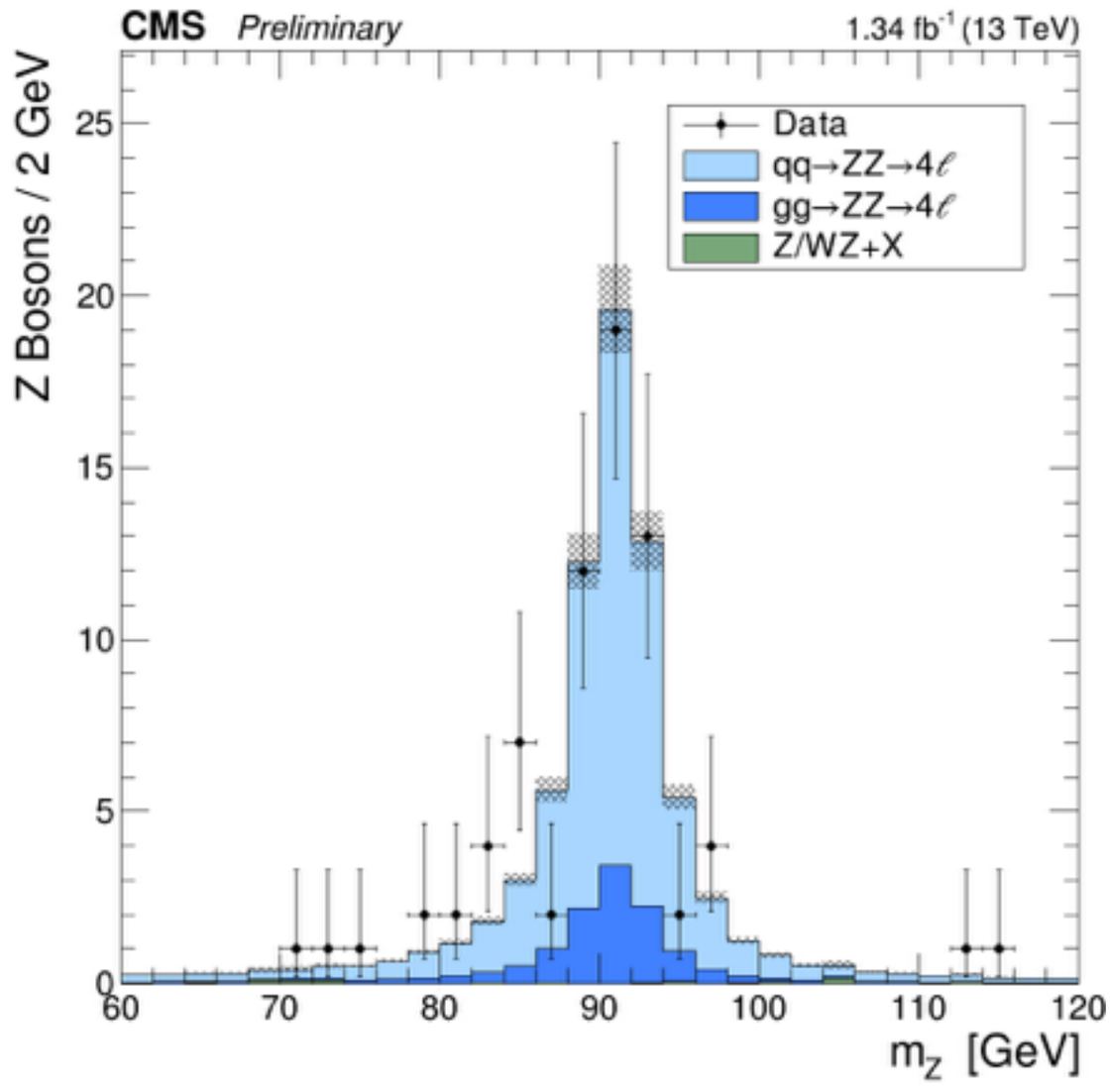


$$RB_{SR} = \sum p_i(3P1F) - \sum p_{1i}\, p_{2i}(2P2F)$$

ZZ Plots



$M_{4\ell}$



$M_{\ell\ell}$

ZZ Fiducial Cross-Section

- Fiducial Region
  - 60 GeV<$M_{2\ell}$< 120 GeV , $m\ell\ell'$>4 GeV
  - p_T^{ℓ}>20,10,10,10 GeV
  - $|\eta_\ell| < 2.5$

- Efficiency calculated from MC.
- The signal strength is derived from a combined fit to the number of observed events in all final states.

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

ZZ Total Cross-Section

The fiducial cross-section is then corrected for the acceptance, estimated form simulation and BR ZZ ➡4ℓ (ℓ = μ,e)

Fiducial Region ➡ 60 GeV<$M_{2\ell}$< 120 GeV

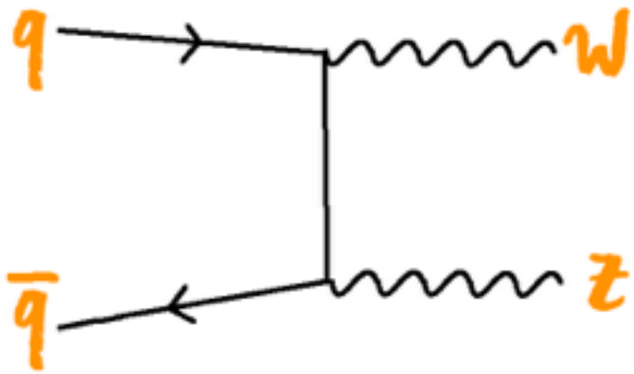
Total Cross Section

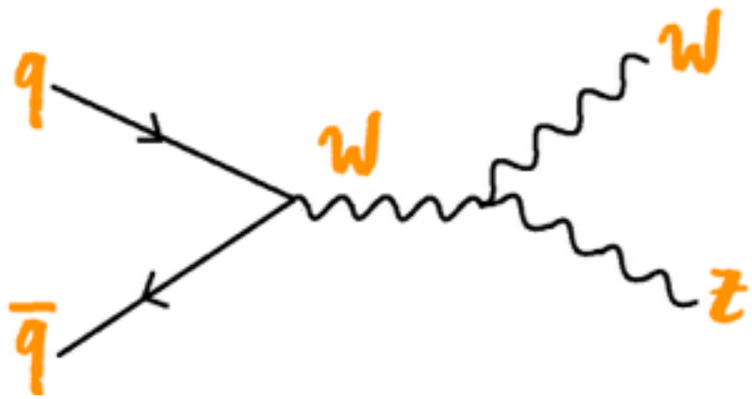
$\sigma(pp \rightarrow ZZ) = 16.7^{+2.9}_{-2.6}\,(stat)^{+0.7}_{-0.5}\,(syst) \pm 0.3\,(theo) \pm 0.8\,(lum)$ pb.

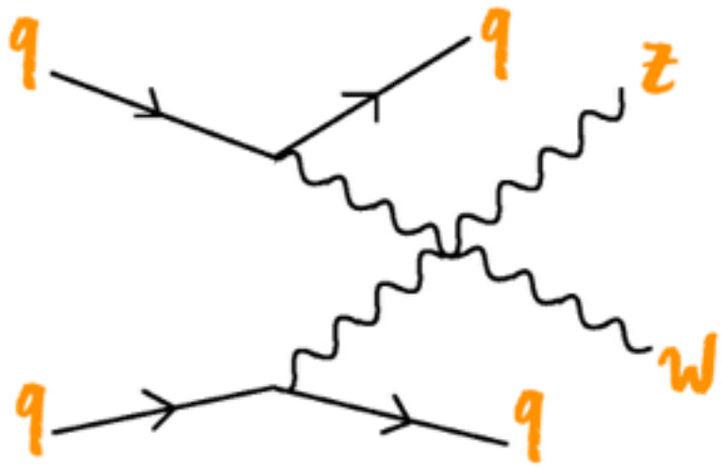
MCFM NLO Theoretical value:
$16.5^{+0.7}_{-0.5}$ pb

SMP-15-005 PAS:
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SMP-15-005/index.html

WZ







- **Signal process:** $q\bar{q}/qg \to WZ,\ q\bar{q}/qg \to WZ(TGC),\ q\bar{q}/qg \to WZ(QGC),\ q\bar{q}/qg \to WZjj$
  - Channels: (eeμ, eee, μμμ, μμe) + Missing energy MET

WZ➡$\ell_+\ell_-\ell'\nu$

(ℓ,ℓ'=e,μ)

- Background:
  - Irreducible background: processes which contain 3 prompt leptons from non-signal processes (ZZ , tZ,Zγ,VVV). Estimated from simulation
  - Reducible background: processes which contain one or more non-prompt leptons in the three-lepton final state.
    - DY, ttbar,QCD multijets
      - Not well represented by MC samples. ➡ data driven method similar to ZZ.

WZ Selection

- Leptons from interaction point $d_{xy} < 0.2$ cm, $d_z < 0.5$ cm
- Isolated tracks in a cone $\Delta R < 0.4$
  - $R_{iso}^{e} < 0.0766$ (0.0678) for barrel(endcap)
  - $R_{iso}^{\mu} < 0.12$
  - Leptons in detector acceptance $|\eta_e| < 2.5$, $|\eta_\mu| < 2.4$
- QCD suppression $m_{\ell\ell'} > 4$ GeV
- $Z\gamma$ suppression $m3\ell > 100$ GeV

Z

$p_T^{\ell} > 10$ GeV

$p_T^{\ell Z} > 20$ GeV

60 GeV $< M_{2\ell} <$ 120 GeV

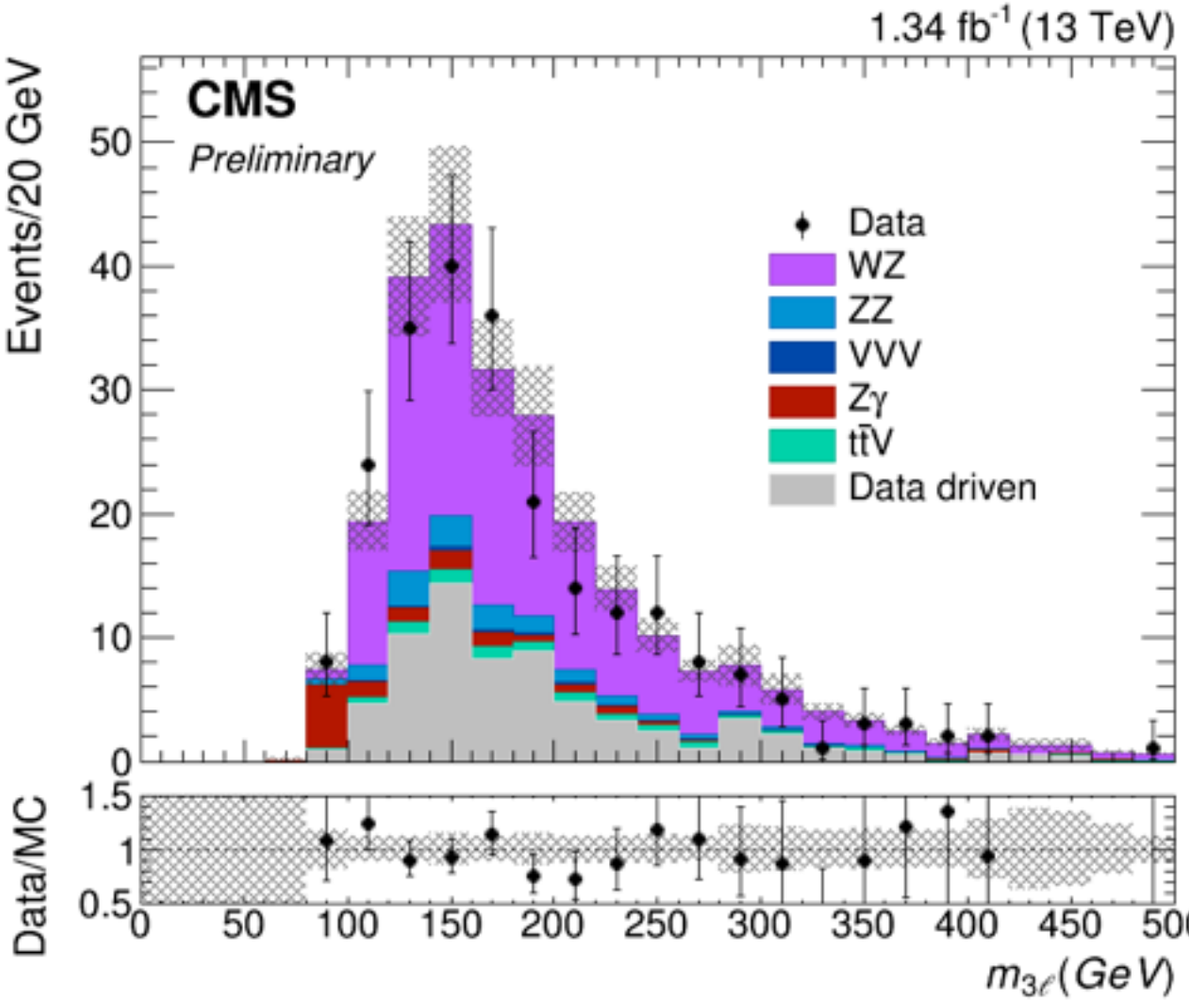
W

$p_T^{\ell W} > 20$ GeV

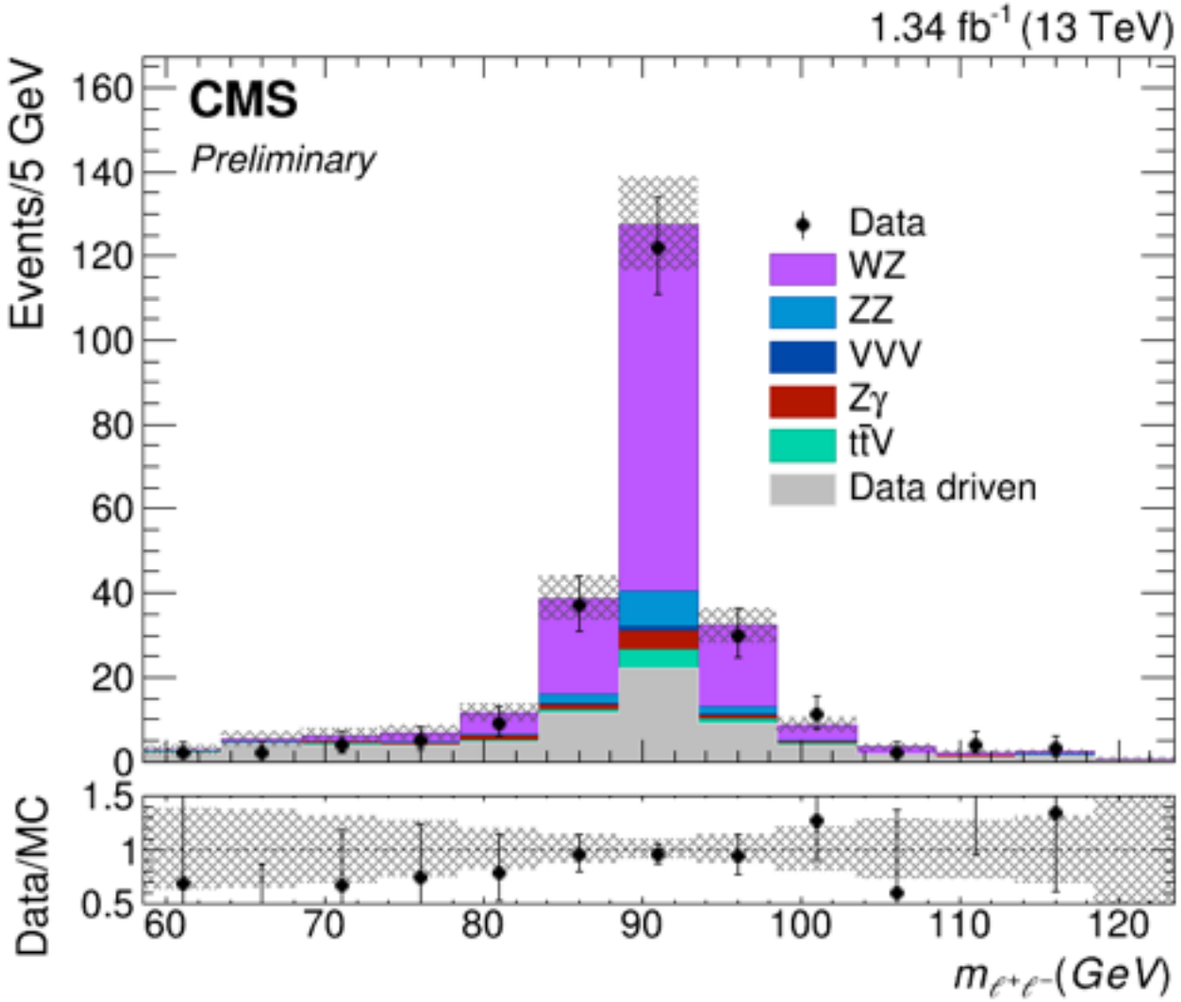
$E^{Miss} > 30$GeV

Decay channel	N^{exp} WZ	Background Datadriven	Background Monte Carlo	Total expected	Observed
eee	28.4 ± 0.5	14.1 ± 2.3	7.9 ± 0.9	50.4 ± 2.5	39
eeμ	32.5 ± 0.5	13.7 ± 1.9	6.3 ± 0.3	52.5 ± 2.0	49
μμe	39.1 ± 0.5	22.3 ± 2.5	10.3 ± 0.9	71.7 ± 2.7	74
μμμ	46.7 ± 0.9	18.8 ± 1.9	8.1 ± 0.3	73.6 ± 2.0	69
Total	146.6 ± 1.0	69.0 ± 4.4	32.6 ± 1.3	248.2 ± 4.7	231

WZ Plots



$M_{lll'}$



$M_{l^+l^-}$

WZ Fiducial Cross-Section

Fiducial Region

- 60 GeV<$M_{4\ell}$< 120 GeV
- p_T^{ℓ}>10 GeV + $p_T^{\ell Z}$>20 GeV + $p_T^{\ell W}$>20 GeV
- $|\eta_{\ell}| < 2.5$

- Efficiency calculated from MC.
- The signal strength is derived from a combined fit to the number of observed events in all final states.

σ_{fid} ($pp \rightarrow WZ \rightarrow \ell\nu\ell'\ell'$) = 239±29(stat) $^{+52}_{-40}$(syst) ± 11 (lum) fb.

MCFM NLO Theoretical value: 274^{+13}_{-8} fb

WZ Total Cross-Section

The fiducial cross-section is then corrected for the acceptance, estimated form simulation and BR for ZW ➡3ℓ (ℓ = μ,e).

- Fiducial Region ➡ 60 GeV<$M_{2\ell}$< 120 GeV

- Acceptance = (45.0 ± 0.4)%.

Total Cross Section

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

MCFM NLO Theoretical value: $42.7^{+1.6}_{-0.8}$ pb

SMP-15-006 PAS:
http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SMP-15-006/index.html

Conclusions

- First measurement of WZ and ZZ cross-section at 13 TeV with the CMS experiment.
- Results are in good agreement with the theory prediction.

Back-Up slides

Miscellaneous

- Particle Flow: event-reconstruction algorithm identifying and reconstructing individually each particle by combining the information from all the sub-detectors.

- Isolation:

  - $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.4$

  - $R^{\ell}_{ISO} = (\sum(p_T^{charged} + MAX[0, \sum(p_T^{neutral} + \sum p_T^{gamma} - p_T^{PU}(\ell)])/p^{\ell}_T$