Electroweak Multilepton Searches and Measurements

The many faces of the WZ process

Workshop Red LHC

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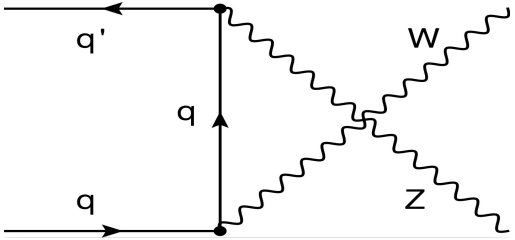
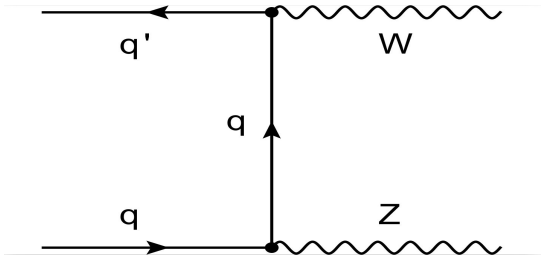
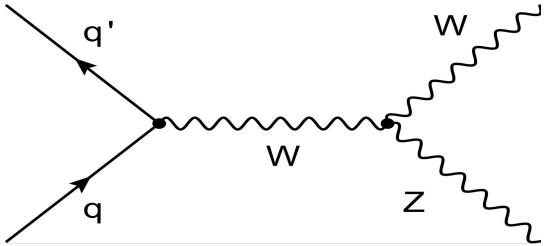
Motivations (Unique properties of WZ production)

⇢ WZ production is completely dominated by the electroweak interaction.







⇢ Offers a special channel that is not completely dominated by QCD processes.

⇢ The **WWZ charged vertex**, dominant at higher energies, can be probed directly for either SM measurements or searches for deviations from the SM.

⇢ Three leptons (3l) are a very clean final state that is highly dominated by WZ production:

- ⇢ Very pure event selection. Measurements don't need complex signal extraction procedures. Thus, SM measurements of its properties are "easier" to perform.
- ⇢ Any other process with a 3l final state will have WZ production as quite the relevant background. Thus, we need a precise measurement of its behavior to improve other BSM searches.

What can we look for? (Analysis in reach and what to expect from them)

Standard Model measurements

1) **Total cross-section**: has been already measured in the past. Improvements might be obtained with specific techniques derived for the multilepton channel.

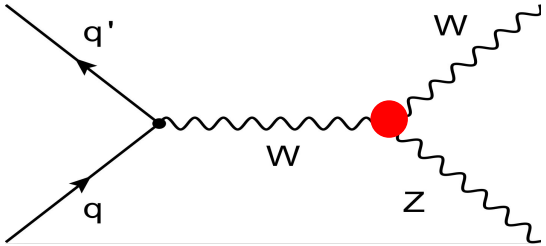
2) **Differential cross-section**: target relevant physical variables that probe either the WZ system's energy or properties of the final state particles.

3) **Charge asymmetry**: a good test of our knowledge of the SM predictions. Measure the proportion of events with a given total charge.

"Untargeted" BSM searches

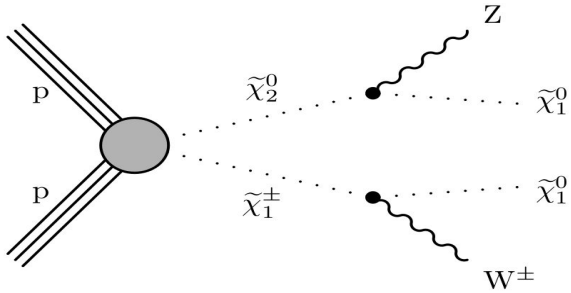
1) Any **relevant deviation in the SM measurements**. Differential cross section can be especially sensitive in the high energy regime.

2) "Model independant" approach based on the presence of generic **anomalous couplings** in the WWZ vertex. Enhanced at high energies:



Targeted BSM searches (SUSY)

1) Not strictly WZ measurements, but highly dominated by WZ production. **Electroweak SUSY** might be hidden mass degenerated with SM WZ!



$$m_{\chi_2^0} \approx m_{\chi_1^\pm} \approx m_{\chi_1^0} + m_V$$

→ Experimentally process is nearly identical to SM WZ. Need a good understanding of SM to separate.

A WZ(-like) pure selection (how to reduce non-prompt leptons)

⇢ Most multileptonic searches are highly dominated by *non-prompt* lepton presence. Typical 2l SM processes dominated by Z+jets and tt productions with additional objects identified as leptons.

⇢ The missing transverse momentum p_T^{miss} can be used as an effective Z+jets discriminant that preserves most of the WZ signal. Minimum requirements (~30 GeV) reduce it by a half.

⇢ b-jet tagging: b-jet presence is a good variable to handle (and veto) the presence of most top-enriched processes.

⇢ "On-Z peak" required the invariant mass of an OSSF pair of leptons to be in the Z peak. Further discrimination against tt background.

⇢ Additional quality criteria imposed in the lepton selection:

- ⇢ Isolation: less leptons produced in jet-enriched environments.
- ⇢ Vertexing: leptons more likely to come from the primary vertex.

Selection checklist

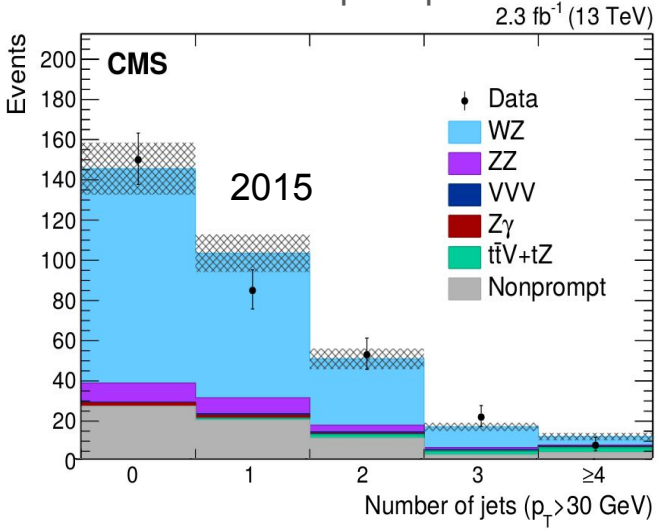
⇢ $p_T^{miss} > p_T^{miss}{}_{min}$

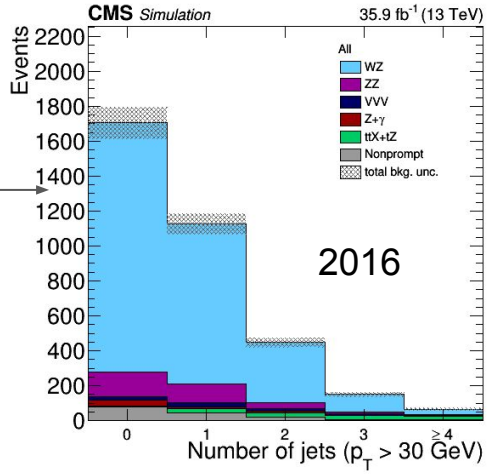
⇢ $N_{b\text{-}tag} = 0$

⇢ $|m_{ll} - m_Z| < \Delta m_{min}$

Standard Model measurements

- Already used by CMS for an early measurement with 2015 data.
- Limiting factors were the statistical power (~8% uncertainty) and the non-prompt presence (~7% uncertainty).
  - Statistical uncertainty reduced by a factor 4 with 2016 dataset.
  - Apply per-lepton requirements to have less non-prompt ones.
    - Non-prompt reduction of a factor 4-5!





- Already presented for preapproval inside the CMS collaboration.

Selection checklist

- p_T^{miss} > 30 GeV
- $N_{b\text{-}tag} = 0$
- $|m_{ll} - m_Z| < 15$ GeV

- Minimum lepton p_T requirements (mimic trigger ones).
- m_{3l} > 100 GeV (less Z + γ presence).

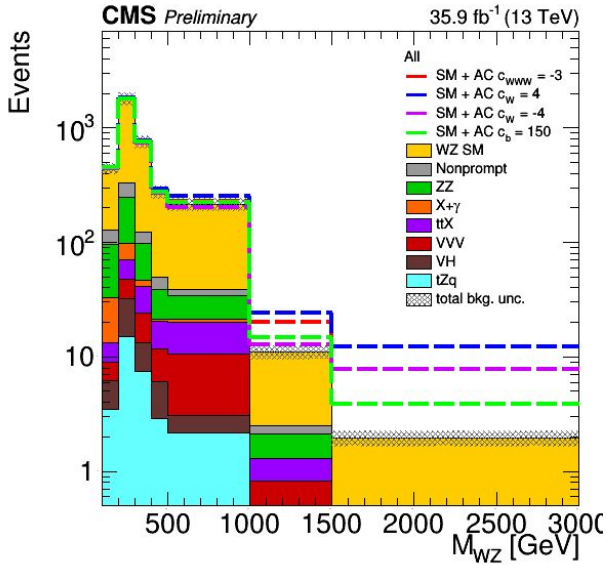
Uncertainty	2015	2016 (exp.)
Statistical	8.1%	2.1%
Non-prompt	6.7%	1.4%
Total	11.7%	5.7%

Prospects in Anomalous Couplings searches

- The high purity signal region defined in the cross-section measurement is optimal to search for BSM presence (deviations from SM seen in data are likely to be due to alterations in the WZ process).
- Approach: study all allowed independent dim. 6 operators with a possible effect in WZ production.

$$\frac{\mathcal{L}_{\mathrm{TGC}}}{g_{\mathrm{WWV}}} = i g_1^{\mathrm{V}} (W^-_{\mu\nu} W^{+\mu} V^{\nu} - W^-_{\mu} V_{\nu} W^{+\mu\nu}) + i\kappa_{\mathrm{V}} W^-_{\mu} W^+_{\nu} V^{\mu\nu} + \frac{i\lambda_{\mathrm{V}}}{M_{\mathrm{W}}^2} W^-_{\delta\mu} W^{+\mu}_{\nu} V^{\nu\delta} \longrightarrow \text{aTGC basis}$$

$$\delta\mathcal{L}_{\mathrm{AC}} = c_{\mathrm{www}} \mathrm{Tr}[W_{\mu\nu} W^{\nu\rho} W^{\mu}_{\rho}] + c_{\mathrm{w}} \left(D_{\mu} H\right)^{\dagger} W^{\mu\nu} \left(D_{\nu} H\right) + c_{\mathrm{b}} \left(D_{\mu} H\right)^{\dagger} B^{\mu\nu} \left(D_{\nu} H\right) \longrightarrow \text{EFT basis}$$



- Statistical model over the distribution of a discriminant variable: binned likelihood with parametric signal yields:

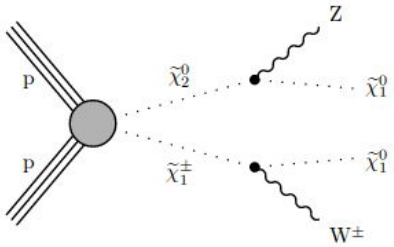
$$\mathcal{L}(c_w, c_{wwww}, c_b|\vec{\theta}) \prod_{n=1}^{N} \mathcal{P}\left(x, b(\vec{\theta}) + f_N(c_w, c_{www}, c_b, \vec{\theta})\right) \Theta(\vec{\theta})$$

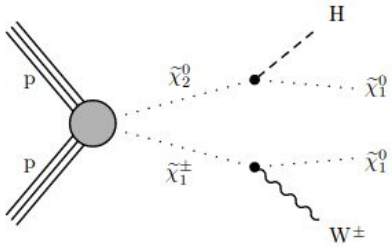
Uncertainties Data Background Signal

- Confidence intervals can be obtained assuming a χ^2 distribution.
- Expectations show improvements of a factor ~3 with respect to previous CMS analysis. Quite competitive with current best world measurements.

Supersymmetric searches (separating BSM WZ-like from SM WZ)

⇢ Electroweak SUSY production models with heavy sleptons can be dominated by “electroweakino” (gaugino/higgsino) pair production. Expect similarities to WZ production:





⇢ Typical effective models depending on few parameters:

$$m_{\chi_1^0} \quad // \quad m_{\chi_2^0} = m_{\chi_1^\pm} \quad // \quad \mathrm{Br}(\chi_2^0 \to H)$$

⇢ Assume the rest of SUSY partners are much heavier.

⇢ Can produce the same final state as SM WZ.

Selection checklist

⇢ $p_T^{miss} > 50$ GeV

⇢ $N_{b\text{-tag}} = 0$

⇢ $|m_{ll} - m_Z| < 15$ (*)

⇢ Design the search selection targeting higher p_T^{miss} regions (account for neutralino presence). Otherwise expect WZ-like selection.

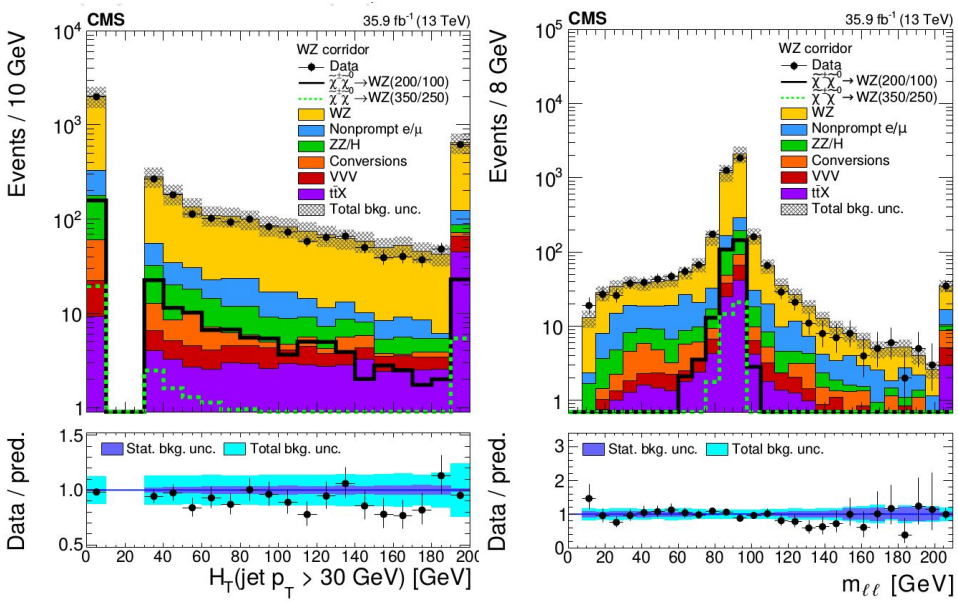
⇢ Understanding SM WZ production is now fundamental as it becomes an enormous near-irreducible background source for the process.

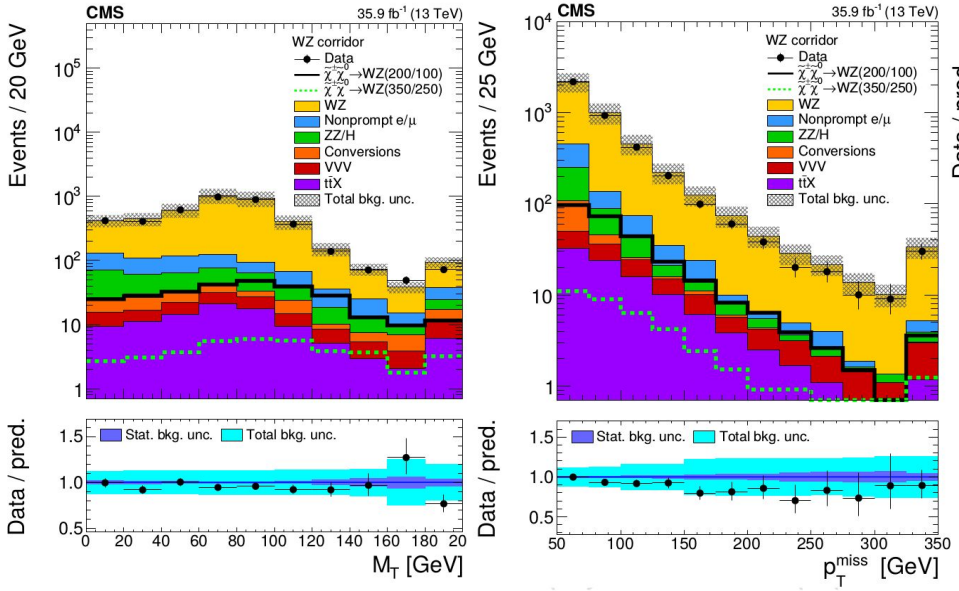
⇢ Separation from WZ becomes a complementary task to improve the discrimination power. Multiple signal regions targeting different scenarios.

⇢ Published as JHEP03(2018)166.

Supersymmetric searches (separating BSM WZ-like from SM WZ)

- H_T (transverse hadronic energy): a proxy for the boost of the total WZ system. More "compressed" signals tend to have lesser hadronic presence.
- m_{ll} (closest to Z): typical WZ selection variable. Going off the peak helps reaching higher sensitivities for off-shell Z production.



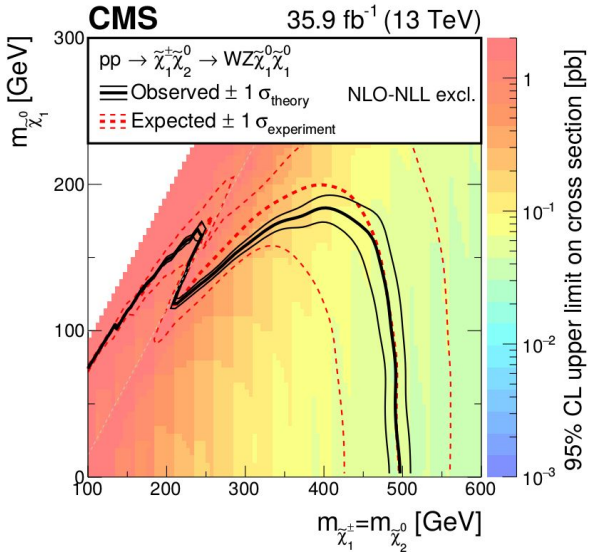


- $M_T^W(l,p_T^{miss})$: transverse mass associated to the W system. Neutralino presence (true additional p_T^{miss}) suppresses the kinematical endpoint at m_W.
- p_T^{miss}: the total transverse momentum now should include the additional neutralino contributions. Very sensitive to heavier SUSY configurations.

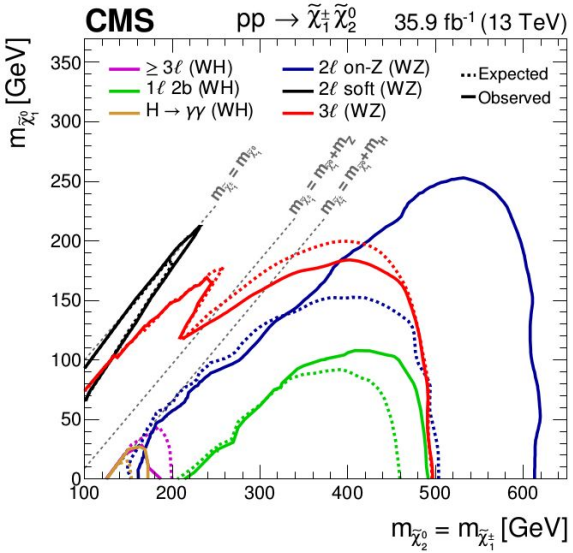
Supersymmetric searches (reach comparisons and combinations)

- 95% CL limits are obtained with the standard CL_s procedure.
- Multileptonic searches are competitive in the compressed regions, were the mass splitting of the SUSY spectra is similar to the mass of the gauge bosons. The so called WZ-corridor (still **some tension in the gaps**).
- Even after combining all results (JHEP03(2018)160): **still some tension in the compressed regions.**
- Prospects: improve the WZ-like searches (+on-Z one) to close the WZ gap and expand in the uncompressed.

Individual excluded regions



Comparison with other searches



Combination with other searches