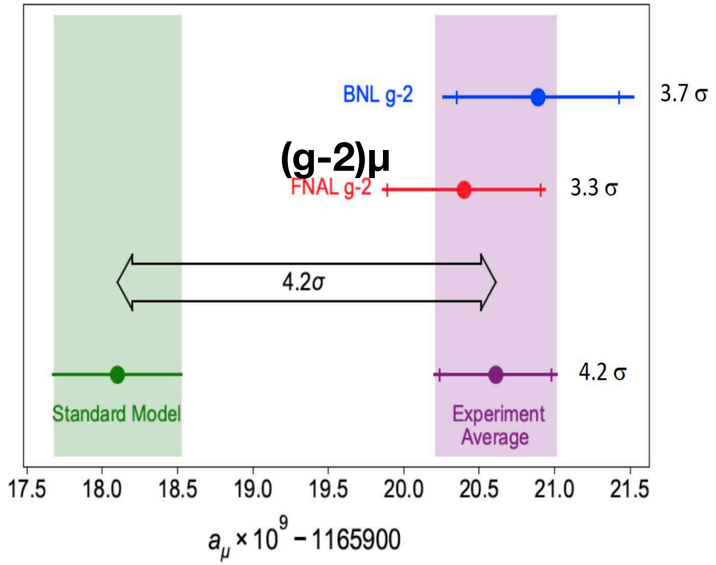
Differential measurements of WZ production in SUSY-inspired phase space

Batool Safarzadeh (University of Sussex)

15/06/2022

Differential measurements motivations

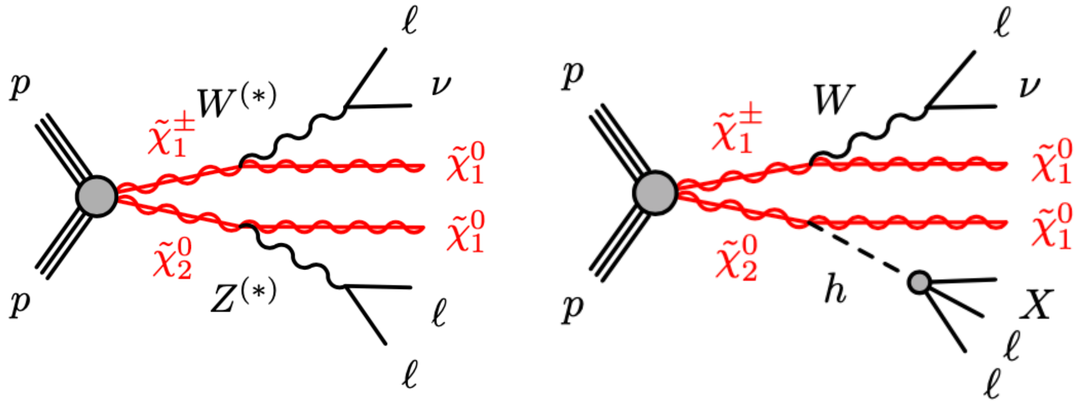
- mainly for the making search analysis re-interpretable and excluding certain models, e.g using CONTUR
- Improving the MC modelling in the extreme phase space, where the large theoretical uncertainties dominate the searches
- Why unfold three-lepton + missing transfers energy final states
- One example of re-interpretation:
  - Anomalous magnetic momentum of the muons : $a_\mu = (g-2)_\mu$
    - SUSY could explain the discrepancy between the experiment and SM (theory) results
- unfolded SUSY-motivated measurement could be used to narrow the range of possible scenarios



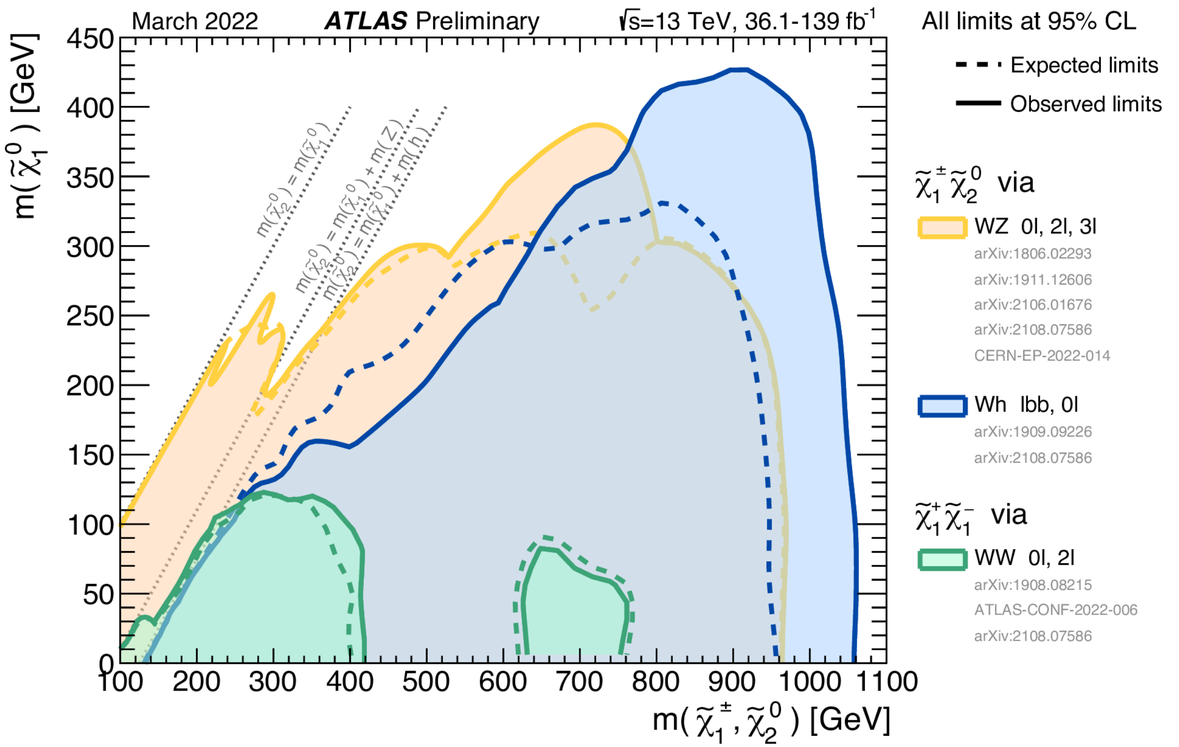
Pheno paper 1, paper 2 , Talk : Slides

3 Leptons search (RPC)

- Chargino-neutralino pair production
  - intermediate WZ or Wh (SM Higgs)
  - bino-like LSP, wino-like NSLP
- **WZ (on-shell)**
  - OSSF pair with mll ∈[75,105] GeV
  - SR binning in jet-multiplicity, HT(scalar sum of Jet pT)
    - HT > 200 GeV : at least one ISR jet, targeting the compressed scenarios
  - SR binning in m_T (W decay) & MET
- **Wh / WZ (off-shell)**
  - SFOS pair with mll∉[75,105] GeV
  - SR binning in jet-multiplicity, HT, m_T & MET
  - DFOS pair, selecting events with close-by leptons



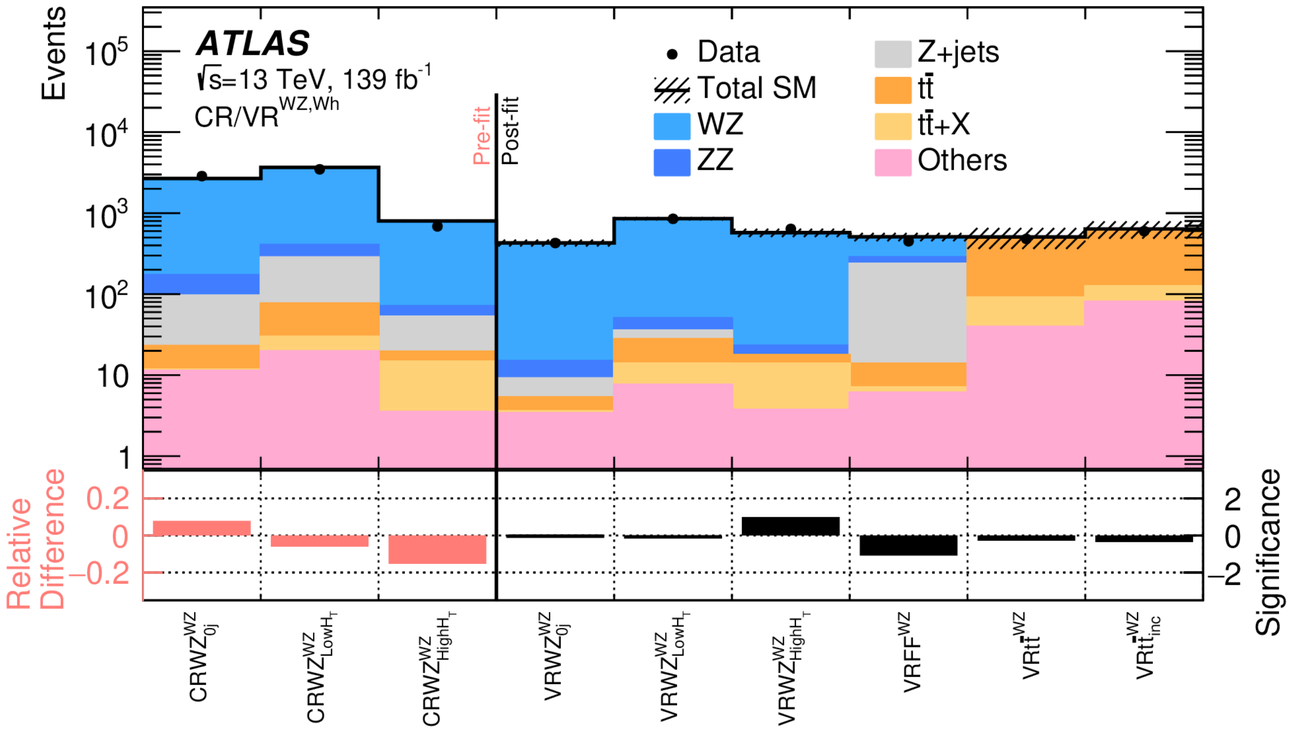
3l (e, μ) + MET final state



arxiv

3 Leptons Search (BKG Estimation)

- Diboson WZ: (Sherpa MC sample)
  - Dominant background, estimated using MC normalised to data in the CRs with purity of > 80% and signal contamination < 10%
  - Due to the jet multiplicity mis-modelling, XS NF is calculated in the given nJets/HT bin
  - 3 Validation regions (VRs) for the given *nJets*/*HT* bin to validate the measured NF from related CR
- Z/γ+jets:
  - non-prompt lepton background, estimated using data-driven method
- ttbar :
  - Non-prompt lepton background, validated in the ttbar dominated region, simulation well model top process where the heavy flavour are mainly the source of the faked lepton

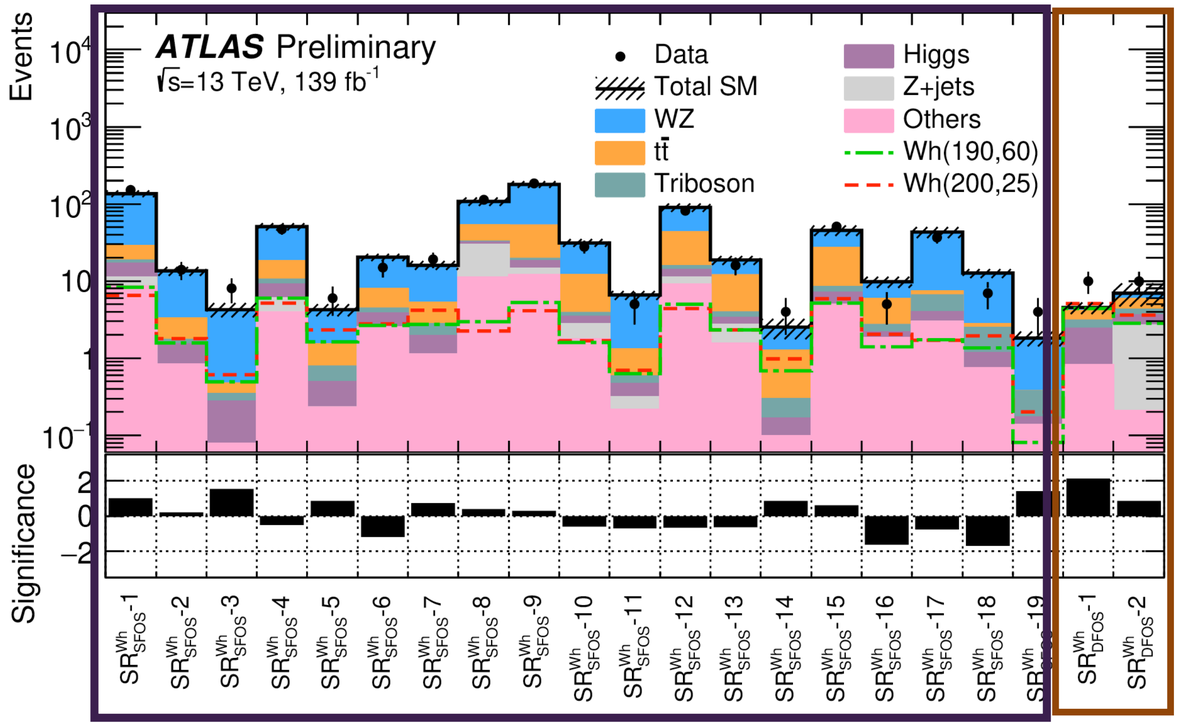


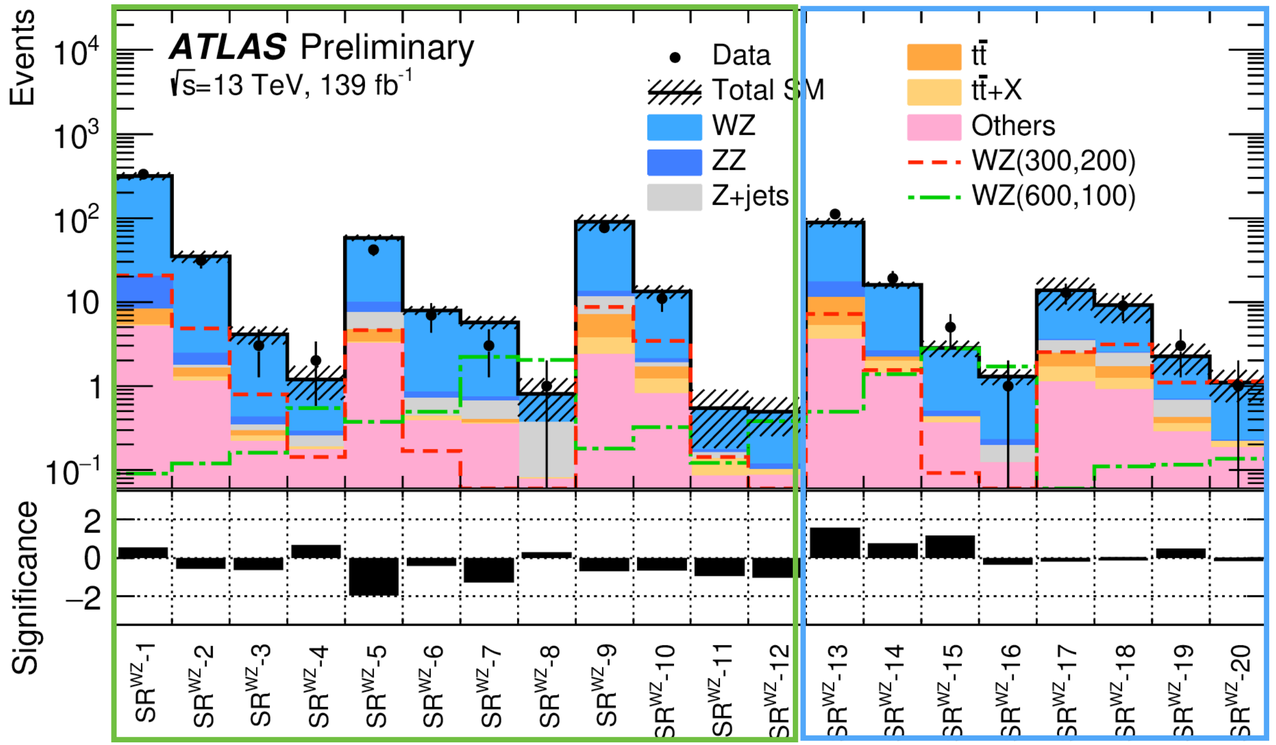
arxiv

3 Leptons Search (Results)

- SRs targeting moderate mass splittings $\Delta m > 90$ GeV
- High HT SR : highly compressed mass spectra $\Delta m \sim 90$ GeV

SFOS pair DFOS



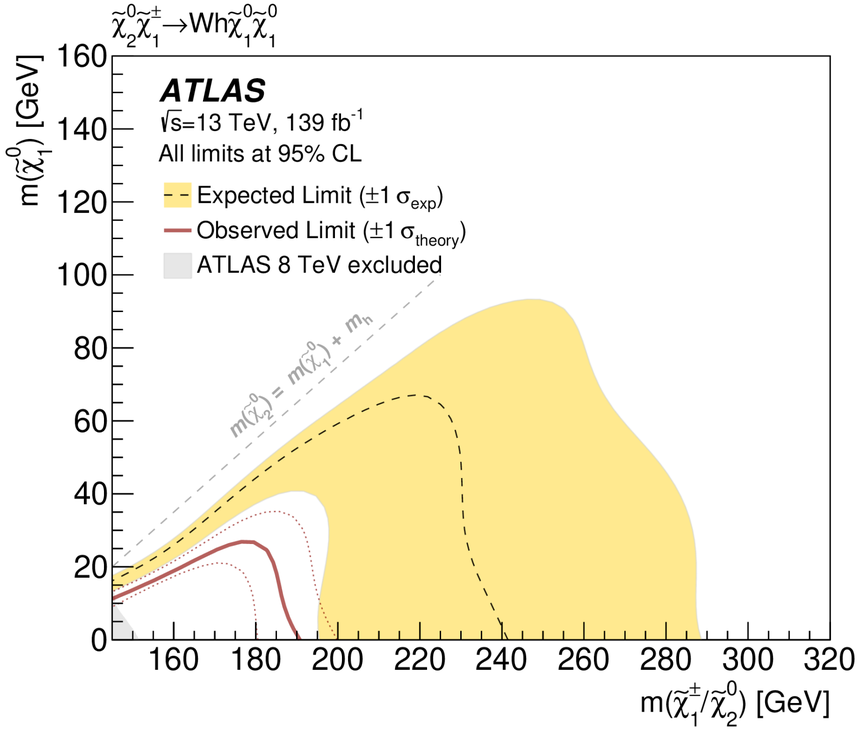


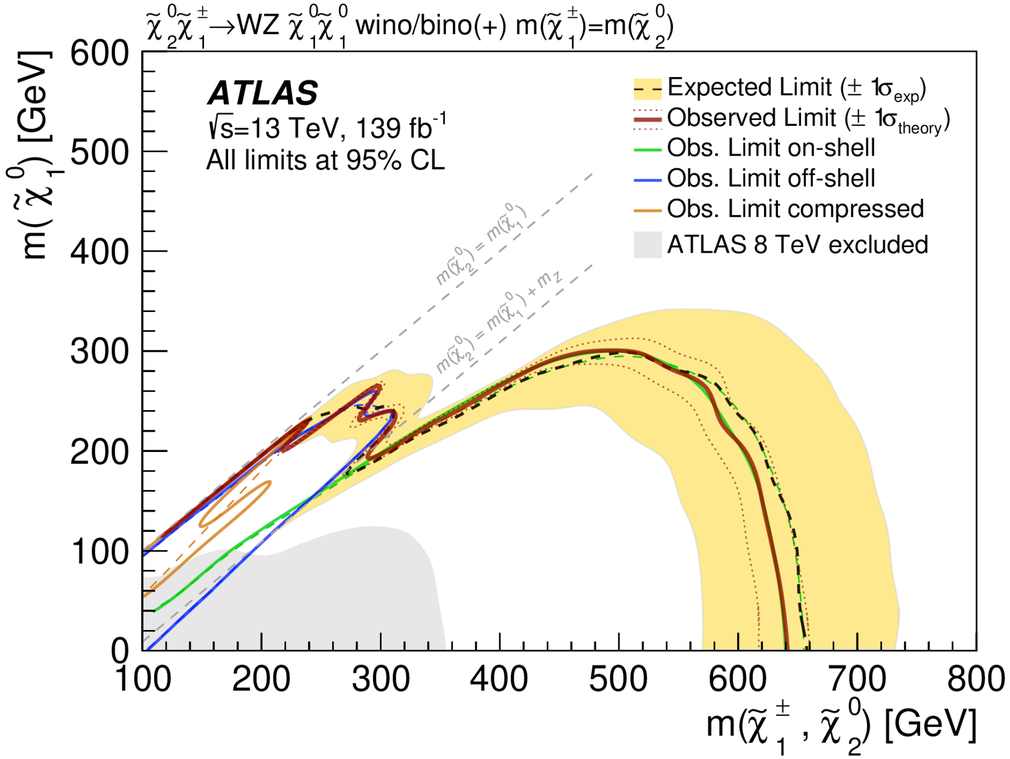
SFOS pair

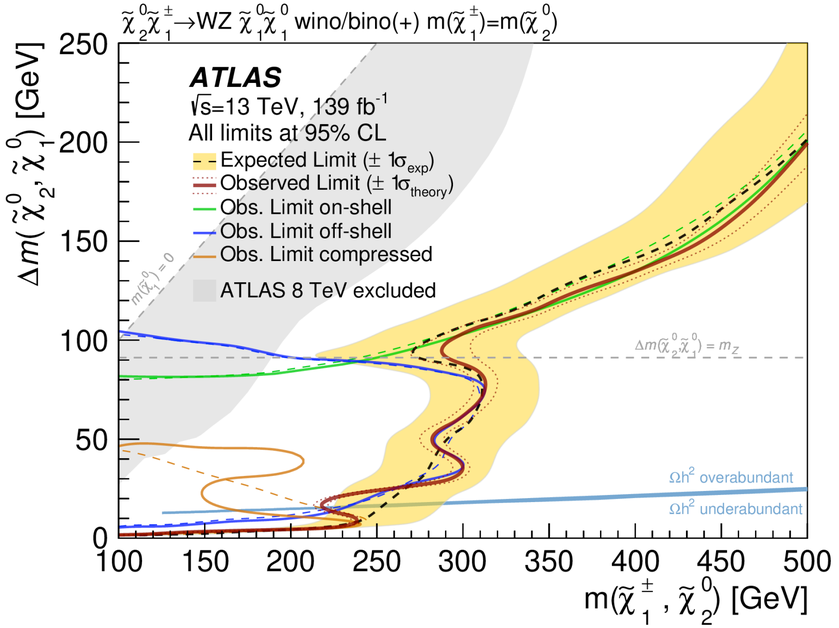
- SFOS:
  - Targeting Wh and WZ with mass splitting $\Delta m < 90$ GeV
- DFOS:
  - Strong signal sensitivity for Wh scenario, main backgrounds from tt^-, VVV, and Higgs processes
- Differential measurement of WZ production in the SFOS region

3 Leptons Search (Interpretation)

- No significant excess
  - **WZ Scenario**
    - The mass splitting range that yields a dark matter relic density equal to the observed relic density
  - **Wh Scenario**
    - weaker observed exclusion limit due to 2 σ in DFOS SR

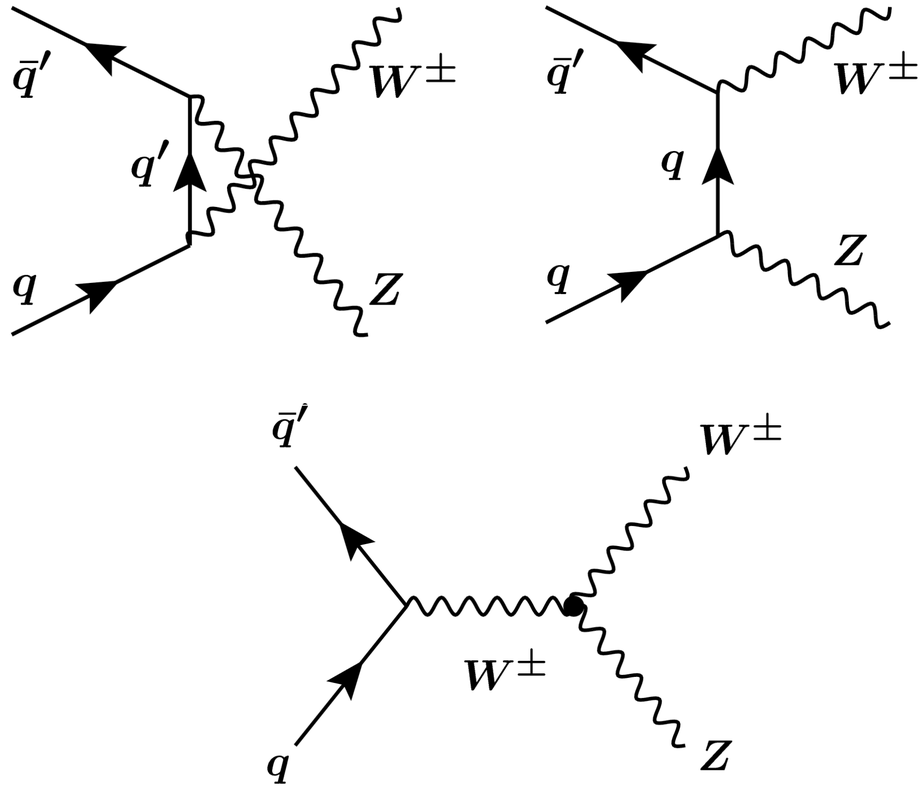






WZ SM measurements (ATLAS)

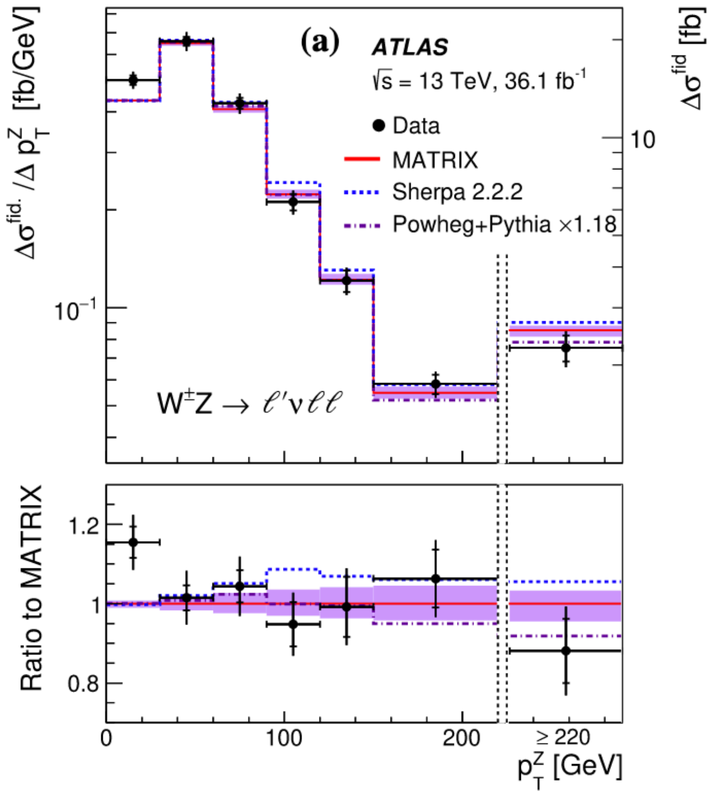
- Published (36/fb) : paper (Link) & public results (link)
  - The Powheg+Pythia MC prediction is used for the W±Z signal contribution. It is scaled by a global factor of 1.18 to match the measured inclusive W±Z cross section
  - Measurement region:
    - 3L (e, μ)
    - mT > 30 GeV to suppress non-prompt background
    - No MET requirement
    - Mll (mZ) ∈[81.2,101.2] GeV

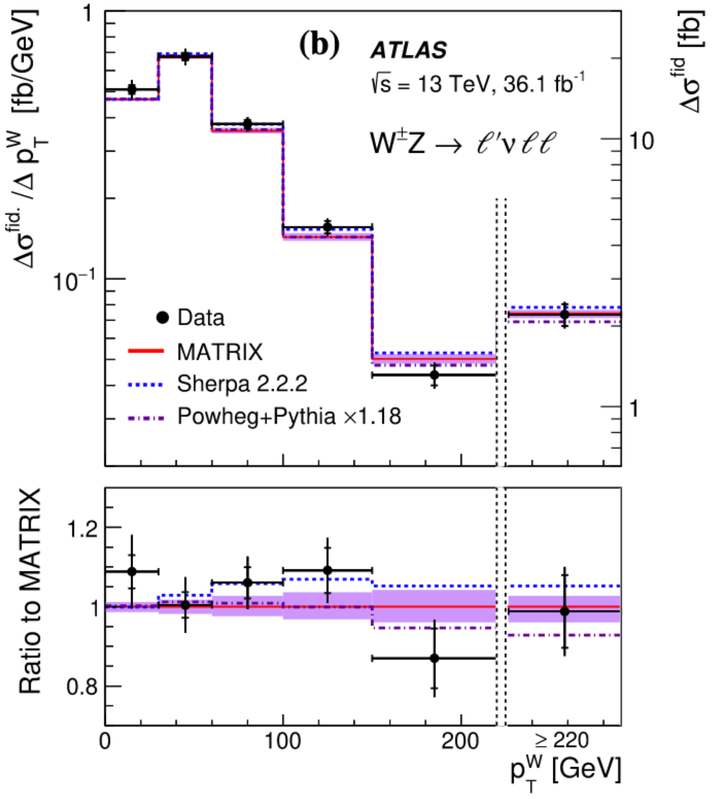


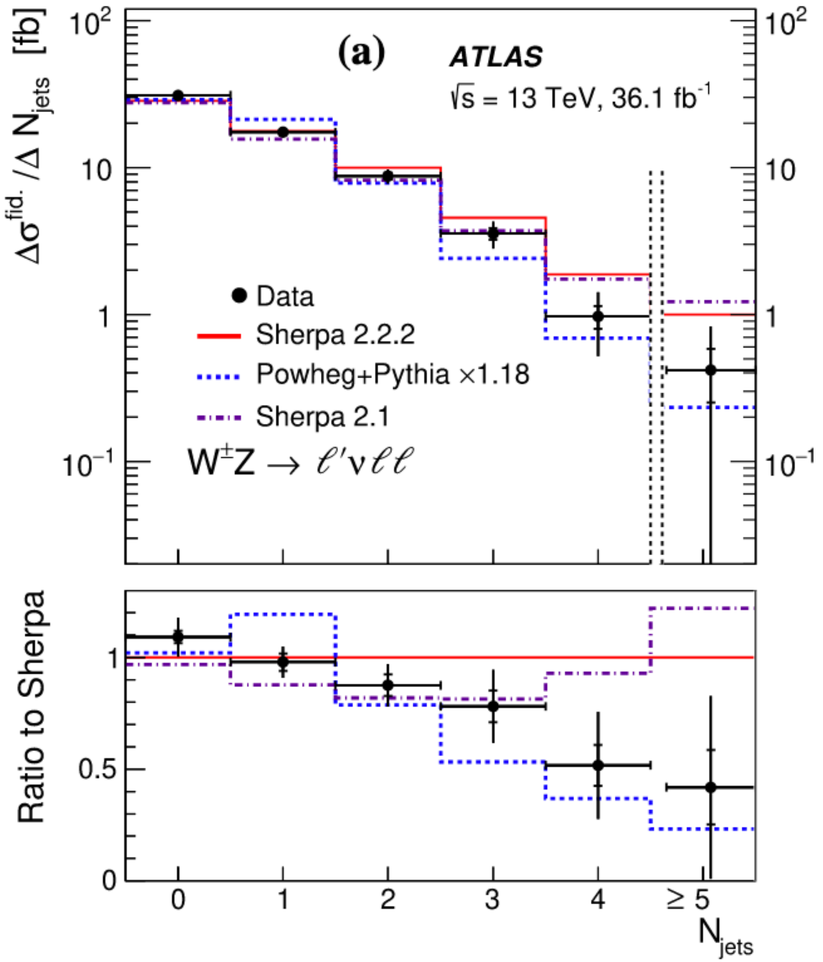
Variable	Total	Fiducial inclusive
Lepton $\lvert\eta\rvert$	—	< 2.5
p_{T} of ℓ_Z, p_{T} of ℓ_W [GeV]	—	$> 15, > 20$
m_Z range [GeV]	$66 - 116$	$\lvert m_Z - m_Z^{\mathrm{PDG}}\rvert < 10$
m_{T}^W [GeV]	—	> 30
$\Delta R(\ell_Z^-, \ell_Z^+)$, $\Delta R(\ell_Z, \ell_W)$	—	$> 0.2, > 0.3$

WZ SM measurements (ATLAS)

- Published (36/fb) : paper (Link) & public results (link)
  - Differential cross section in the fiducial phase space as a function of the exclusive jet multiplicity of jets with $p_T > 25$ GeV
  - Differential measurement as function of reconstructed bosons (W, Z) pT

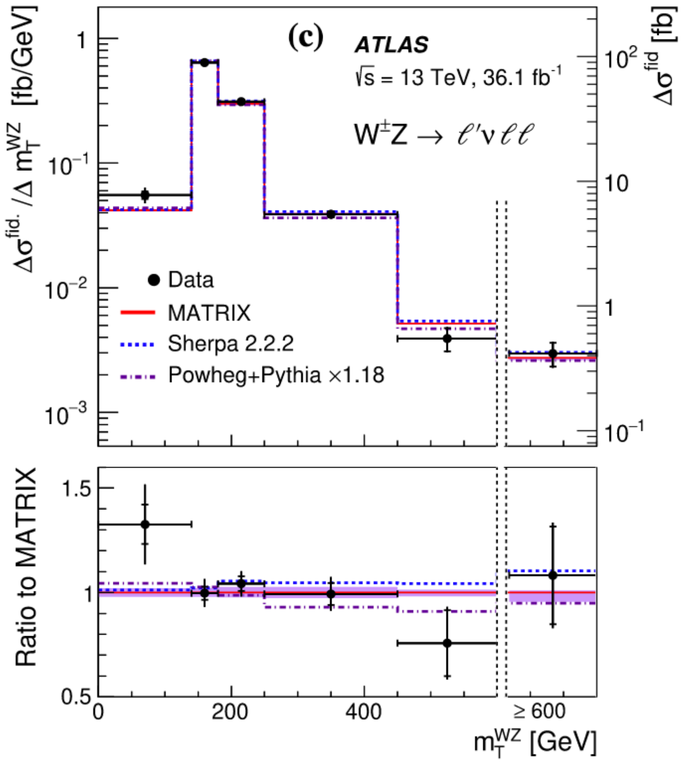


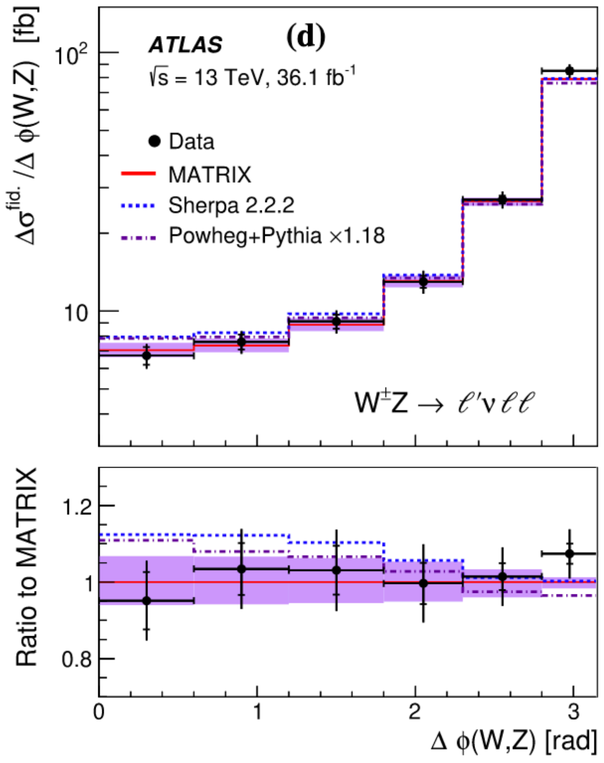


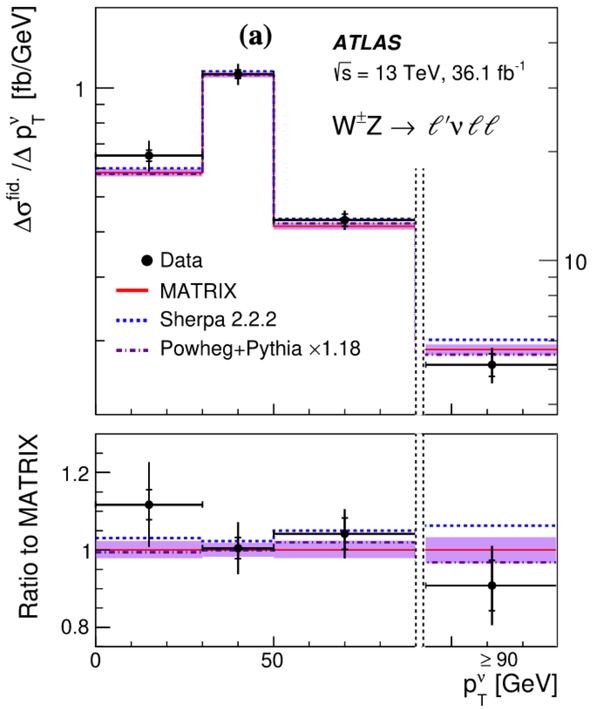


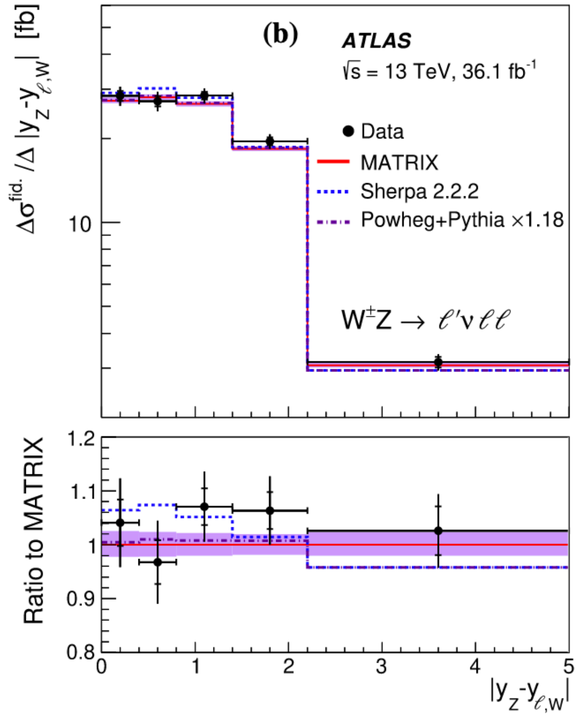
WZ SM measurements (ATLAS)

- Published (36/fb) : paper (Link) & public results (link)
  - Differential measurement as function of reconstructed bosons Δφ (W, Z), the transverse mass of the W±Z system
  - It is assumed that the whole MET of each event arises from the neutrino of the W boson decay
  - Absolute difference between the rapidities of the Z boson and the charged lepton from the decay of the W boson



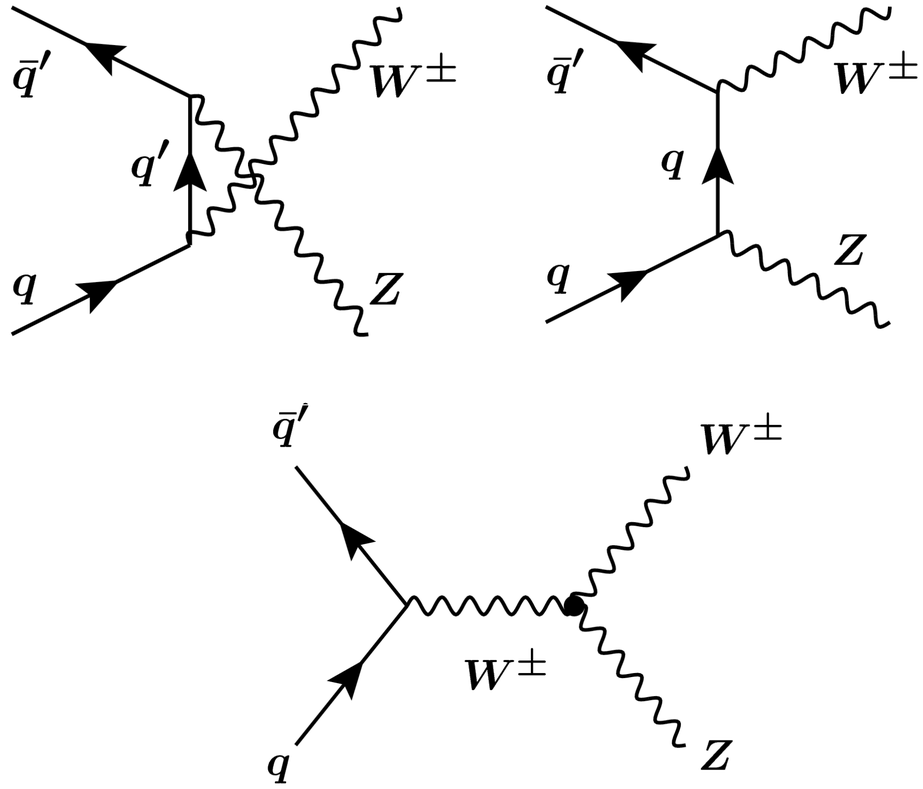






WZ SM measurements (CMS)

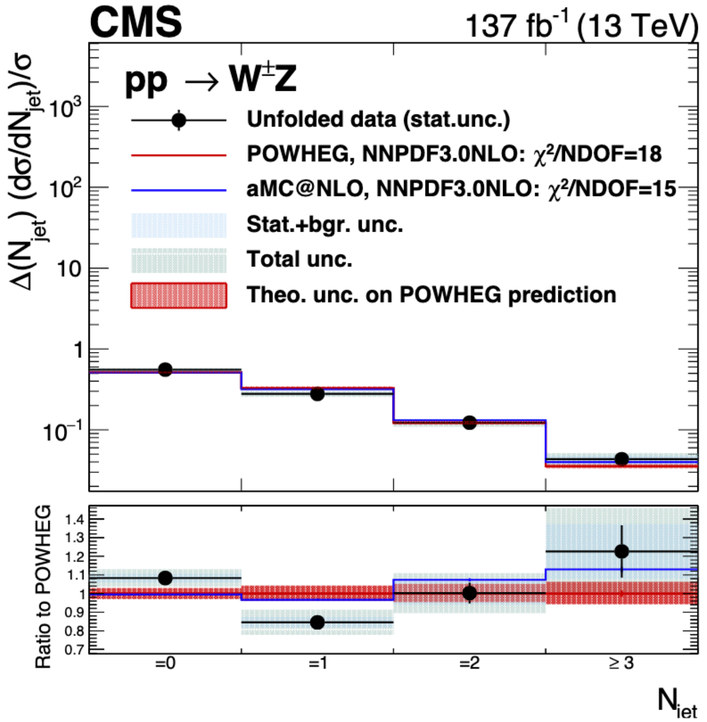
- Published (Run 2 data) : paper (Link) & public results (link)
  - The Powheg+Pythia MC prediction is used for the W±Z signal contribution.
  - Measurement region:
    - 3L (e, μ)
    - MET > 30 GeV to suppress non-prompt background
    - No MT requirement
    - Mll (mZ) ∈[76.2,106.2] GeV
    - Mlll > 100 GeV to suppress Z+ γ process

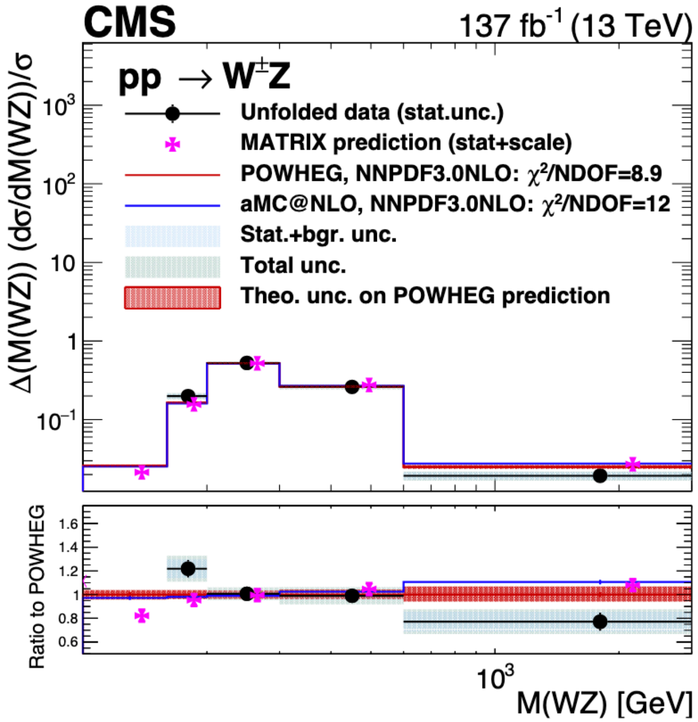


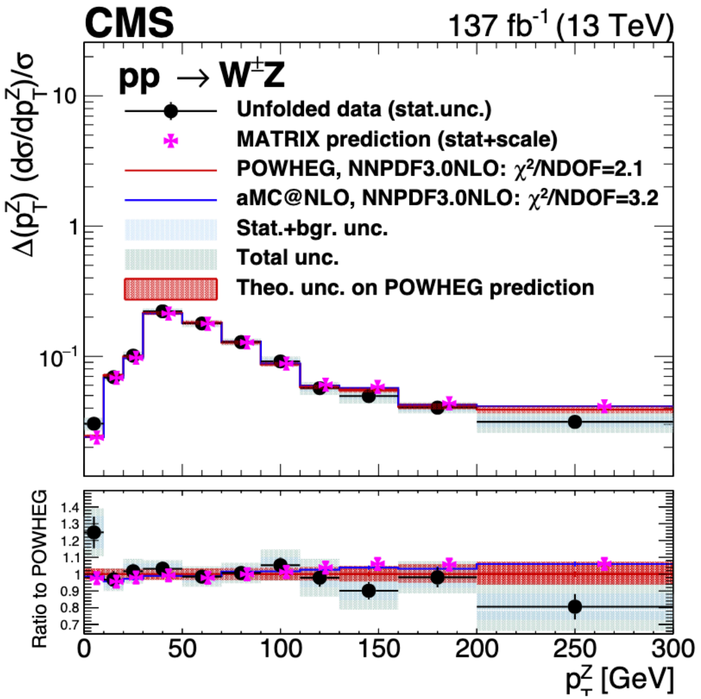
Region	N_ℓ	$p_T\{\ell_{Z1}, \ell_{Z2}, \ell_W, \ell_4\}$	N_{OSSF}	$\lvert M(\ell_{Z1}, \ell_{Z2}) - m_Z \rvert$	p_T^{miss}	$N_{b\ tag}$	$\min(M(\ell\ell'))$	$M(\ell_{Z1}, \ell_{Z2}, \ell_W)$
SR	=3	>{25, 10, 25, —} GeV	≥1	<15 GeV	>30 GeV	=0	>4 GeV	>100 GeV
CR-ZZ	=4	>{25, 10, 25, 10} GeV	≥1	<15 GeV	—	=0	>4 GeV	>100 GeV
CR-t$\bar{t}$Z	=3	>{25, 10, 25, —} GeV	≥1	<15 GeV	>30 GeV	>0	>4 GeV	>100 GeV
CR-conv	=3	>{25, 10, 25, —} GeV	≥1	—	≤30 GeV	=0	>4 GeV	<100 GeV

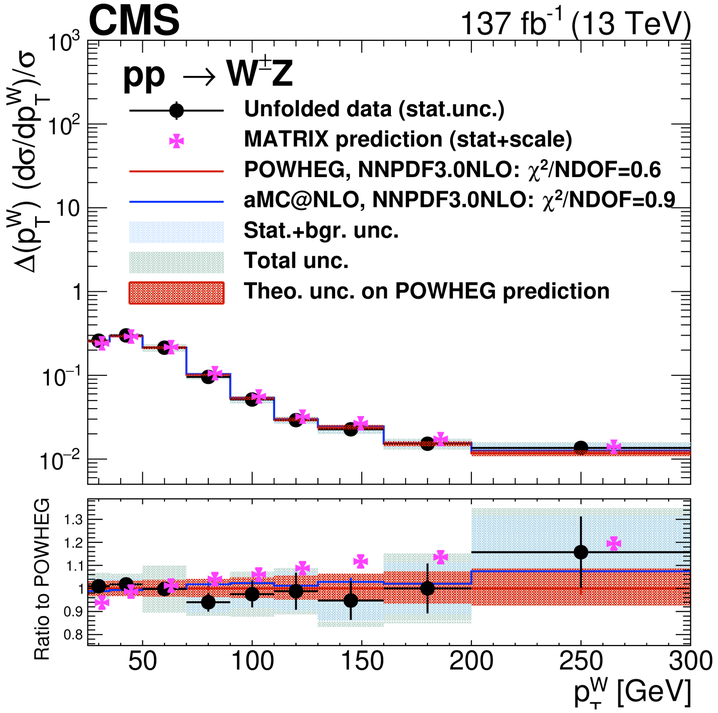
WZ SM measurements (CMS)

- Published (Run 2 data) : paper (Link) & public results (link)
  - Differential cross section in the fiducial phase space as a function of the exclusive jet multiplicity of jets with $p_T > 25$ GeV
  - Differential measurement as function of reconstructed bosons (W, Z) pT, $\Delta\varphi$ (W, Z), the transverse mass of the W±Z system
  - Almost Similar variables as ATLAS except p_Tv









WZ unfolding complementary to WZ SM measurement

- SFOS & on-shell Z boson (Mll ∈[76.2,106.2] GeV)
  - SM measurement is done in an inclusive Jet multiplicity
  - ATLAS: no MET requirement and loose MT selection
  - CMS: no MT requirement and loose MET selection
  - WZ unfolding:
    - Unfolding the high-MT (≥ M_W) and high-MET (> 100 GeV) regions where new physics may appear
    - MT > 70 GeV instead of 80 GeV
      - To reduce the bias of large event migration in/out unfolding region
    - Unfolding the BSM sensitive variables (MET, MT, …) in different nJet/HT regions
    - Unfolding HT< 200 GeV & HT > 200 GeV regions
      - High HT (> 200 GeV) with at least one high-pT ISR je
        - Targeting the challenging phase space, where the mass differences between C1 and N2 is ~Z-boson mass
    - WZ purity is more than 85%, negligible contributions from non-prompt BKG

WZ unfolding complementary to WZ SM measurement

- SFOS & off-shell Z boson (Mll ∉[76.2,106.2] GeV)
- Exclude low mass resonances
  - SM-Like region, targeting compressed region $\Delta m(C\,1, N\,1) <$ mZ or non-WZ scenarios
  - No MT requirement & MET > 50 GeV is required to suppress the BKG from fake process
    - Comparable statistics with on-shell region
  - SM measurement doesn't cover off-shell region
    - Orthogonal to SM measurement region by definition
  - WZ purity drops to 60-65% but still is the main contribution
  - 2nd dominate SM BKG is ttbar (20-25%), the rest comes from Z+jets and ZZ processes
  - Unfolding regions divided to
    - Mll < 76.2 GeV (low mll)
    - Mll > 106.2 GeV (high mll)
  - Similar nJets/HT regions as on-shell region

Differential measurements (strategy)

- On-shell region:
  - WZ is the dominate contribution in SUSY-like SR (> 85%)
  - Unfolding WZ process, subtracting non-prompt (estimated from data) and non-WZ background (from MC)
  - Unfolding variables used in the SUSY search
- Off-shell region:
  - WZ is still the dominate background but ttbar contribution isn't negligible
  - Unfolding the final state to make the results re-interpretable
  - BKG with Non-prompt Lepton
    - Subtract the contribution from Z+jets which estimated from data
    - ttbar with a non-prompt lepton was estimated using MC simulation, should/will be treated as prompt BKG?
  - Prompt BKG estimated from MC simulation, treated as a signal

Re-interpretation (Possible BSM scenarios)

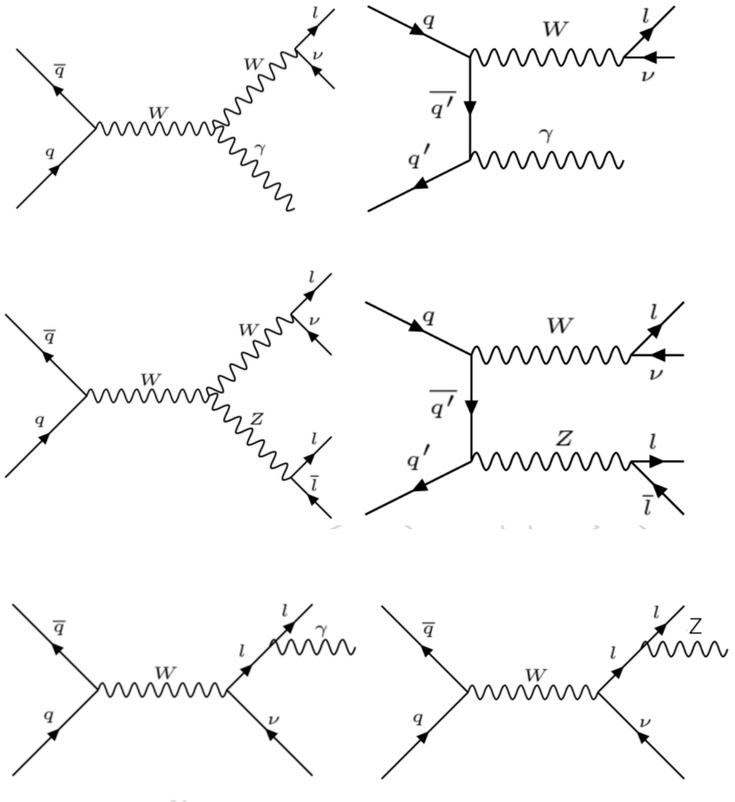
- Differential measurement in the SUSY-like phase space where the new particle may appear makes the results re-interpretable in terms of theories not considered in the original analysis publication
  - Original analysis generic search for excess on top of SM exception in several phase space
    - 5 different phase spaces to be unfolded
    - Extreme phase spaces (High HT, high MT or MET) e.g targeting boosted topologies

- Planning for BSM reinterpretations
  - CMS performed a search for anomalous values of the charged triple gauge coupling WWZ which lead to new constraints on beyond-the-standard-model contributions to the WZ triple gauge coupling
  - Different unfolded phase spaces maybe consider more than one BSM scenarios

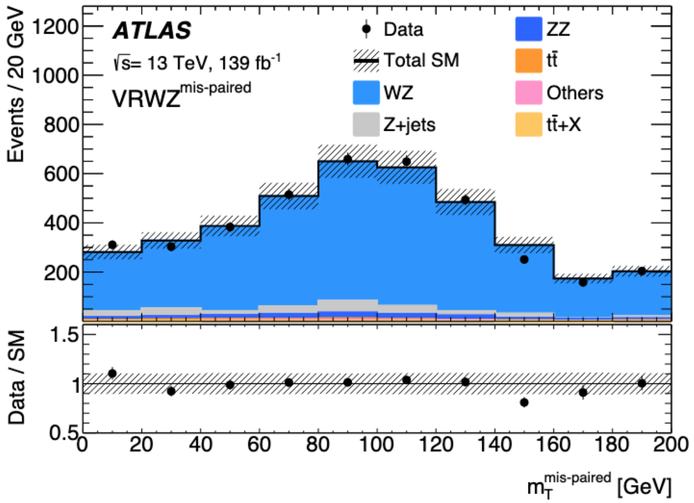
Back up

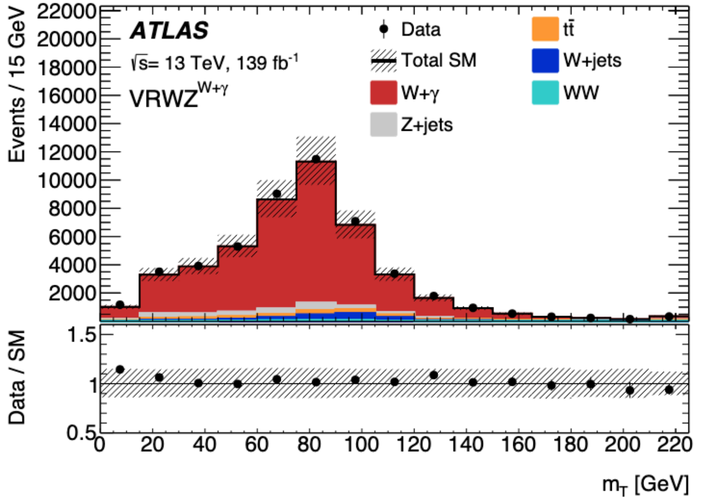
WZ Estimation (MET mis-measurement)

Using WY events, W—>lv



- The enhancement of the FSR diagram in Wγ process leads to differences in the mT shapes be tween WZ and Wγ.
- To use the Wγ mT shape to validate the WZ MC prediction the FSR contribution in the Wγ control region has to be reduced
- Applying thresholds on photon pT and the ΔR (lep, photon) in Wγ events
  - FSR photons are expected to be close to the lepton radiating them





Wγ and WZ have very similar MT shapes because their production mechanisms are similar