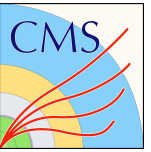


Differential measurement of top quark cross sections in association with a Z boson in CMS

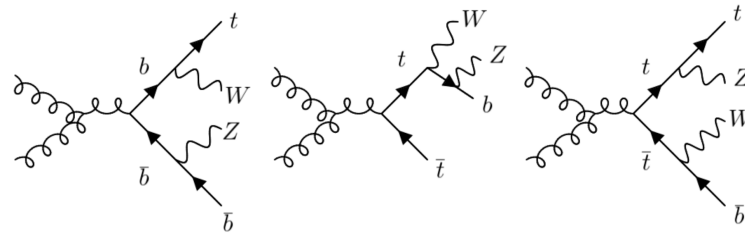
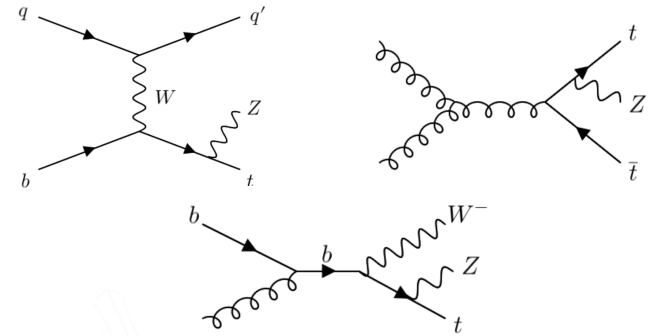
Federica C. Colombina on behalf of the CMS Collaboration



CMS-PAS-TOP-23-004: overview



- Differential measurements of tZq and $t\bar{t}Z$ with Run-2
 - both ATLAS and CMS
- Evidence for tWZ reported by CMS
- Simultaneous measurement:
 - less dependent on signal modeling assumptions
 - enhance sensitivity to deviation from SM across signals \rightarrow t-Z and W-b-t couplings
- tWZ modeling at NLO: overlap with $t\bar{t}Z$ and $t\bar{t}$, difficult to distinguish



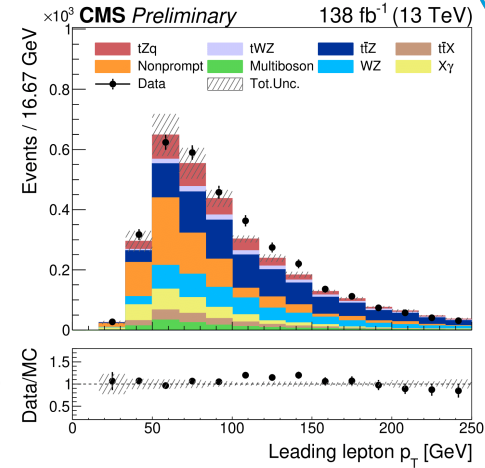
\rightarrow $t\bar{t}Z$ and tWZ treated as one signal

Event selection

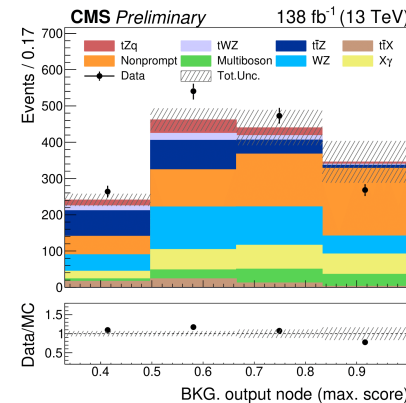
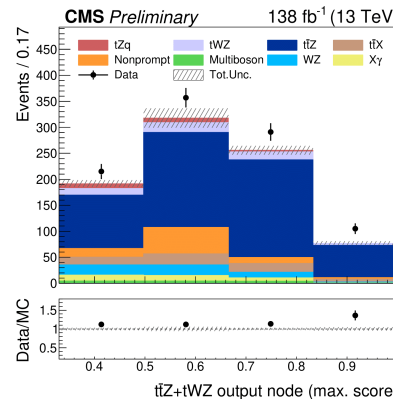
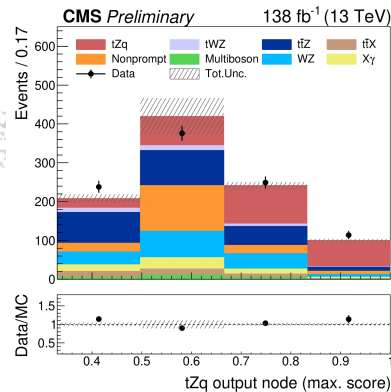
- Select $t\bar{t}Z$, tWZ and tZq in the same region
- Focus on final states with **three leptons** (e^\pm or μ^\pm)
- Nonprompt contribution estimated from data

Signal-to-background discrimination

- **Multiclass classifier** with 3 output nodes
 - tZq , $t\bar{t}Z+tWZ$, backgrounds



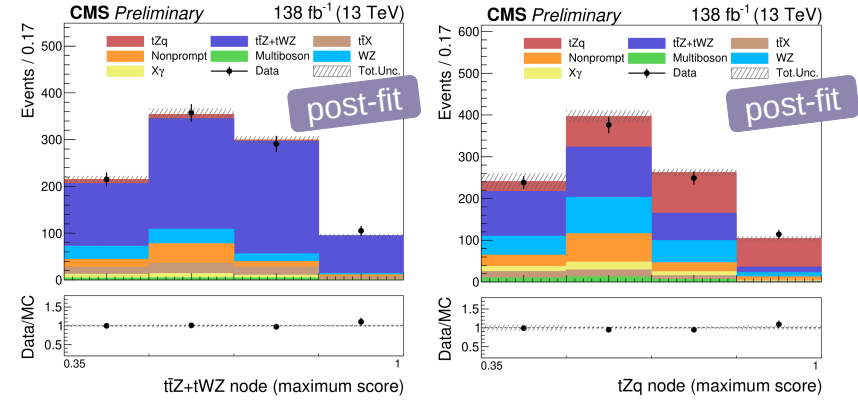
maximum-score splitting to build fit categories



Inclusive cross sections

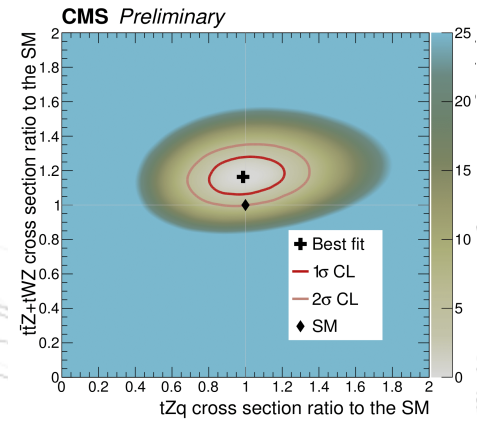


- Events with no b-jets and four leptons included for the inclusive measurement
- Profile likelihood-ratio scan for σ_{tZq} and $\sigma_{t\bar{t}Z+tWZ}$
- Statistically limited
 - main syst: background modeling, (b-)jets
- Good agreement with SM for tZq , small excess for $t\bar{t}Z+tWZ$



$$\sigma_{t\bar{t}Z+tWZ} = 1.14 \pm 0.07 \text{ pb}$$

$$\sigma_{tZq} = 0.81 \pm 0.10 \text{ pb}$$



Differential measurements

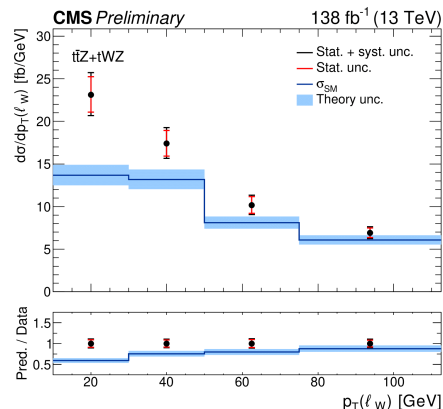
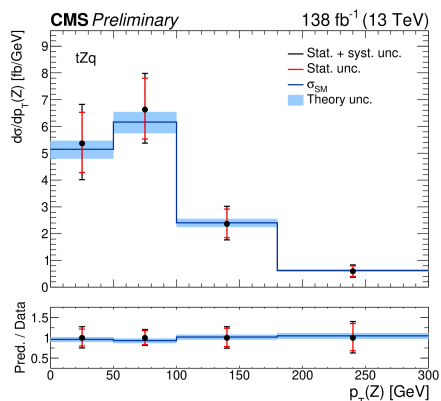
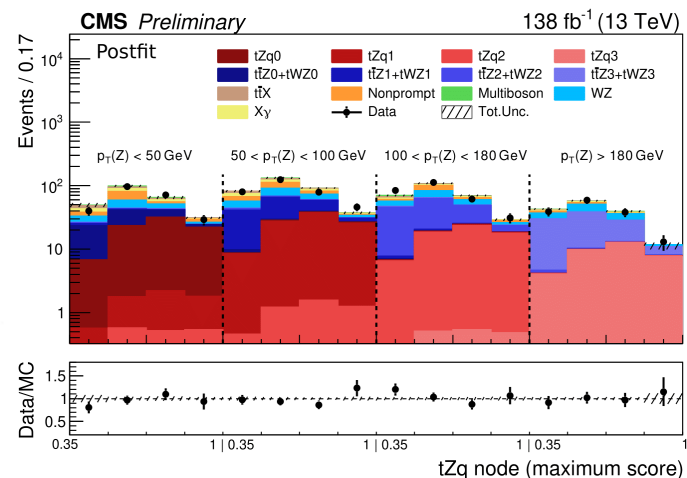


- Cross sections measured as function of

- $p_T(Z)$
- $p_T(\ell_w)$
- $\Delta R(Z, \ell_w)$
- $\Delta\phi(\ell, \ell')$
- $\cos(\theta^*)$

Likelihood-profile method to perform unfolding

- Excess at low lepton p_T for $t\bar{t}Z+tWZ$
→ more plots in backup



similar to what observed in $t\bar{t}$ analyses



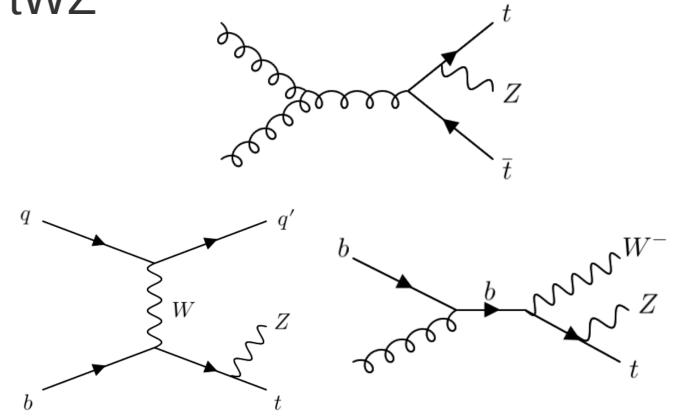
Summary



- First simultaneous differential measurement of tZq , $t\bar{t}Z$ and tWZ
 - σ_{tZq} and $\sigma_{t\bar{t}Z+tWZ}$ and correlations measured as function of five variables
- Excess for $t\bar{t}Z+tWZ$, tZq in agreement with SM

Outlook

- Results can be used for theory and EFT interpretations
- Run-3 to reduce statistical uncertainties



Thank you!

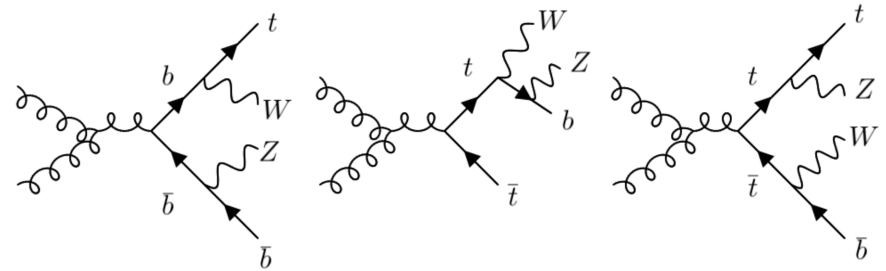
Backup



tWZ modeling



- tWZ modeling at NLO: intermediate top becomes resonant, overlap with $t\bar{t}Z$ and $t\bar{t}$
 - amplitude \mathcal{M} divided into $\mathcal{M}^{(\text{res})}$ and $\mathcal{M}^{(\text{non-res})}$
 - DR1, removes $\mathcal{M}^{(\text{res})}$ in \mathcal{M}
 - DR2, removes $|\mathcal{M}^{(\text{res})}|^2$ in $|\mathcal{M}|^2$
 - DS, subtraction term
- DR1 for nominal, DR2 for uncertainty
- DS lies between DR1 and DR2



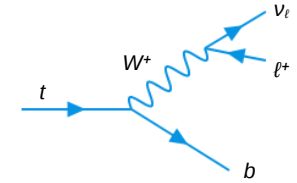
Top quark reconstruction



- Three different cases are considered:
 - 2 jets, 1 b-tag: only leptonic top is reconstructed
 - 3 jets, ≥ 1 b-tag: both hadronic and leptonic top reconstructed separate lowest χ^2 is kept

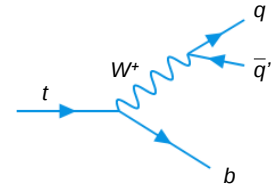
$$\chi_{t,lep}^2 = \left(\frac{m_{l\nu b} - m_t}{\sigma_{t,lep}} \right)^2$$

$$\chi_{t,had}^2 = \left(\frac{m_{bjj} - m_t}{\sigma_{t,had}} \right)^2$$



- ≥ 4 jets, ≥ 1 b-tag: both hadronic and leptonic top are reconstructed

$$\chi_t^2 = \left(\frac{m_{l\nu b} - m_t}{\sigma_{t,lep}} \right)^2 + \left(\frac{m_{bjj} - m_t}{\sigma_{t,had}} \right)^2$$



when reconstruction is not possible, unphysical value given to the related variables



Nonprompt estimation



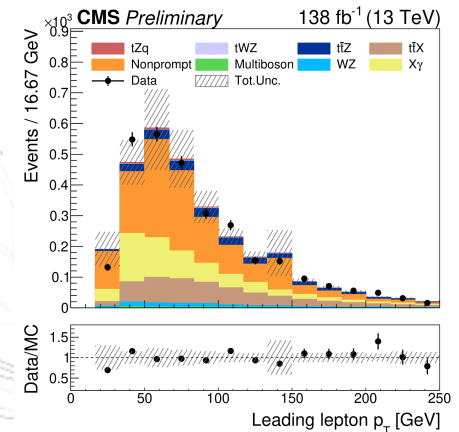
- Measurement region
 - QCD multijet samples
 - exactly one fakeable lepton
 - at least one jet with $\Delta R_{\ell j} > 0.7$
 - per-lepton FF:
- Application region (AR): same selection as SR, but fakeable leptons
- Leptons divided into prompt and nonprompt
- Weight in this region:

$$(-1)^{n-1} \prod_{i=1}^3 \frac{f_i}{1-f_i}$$

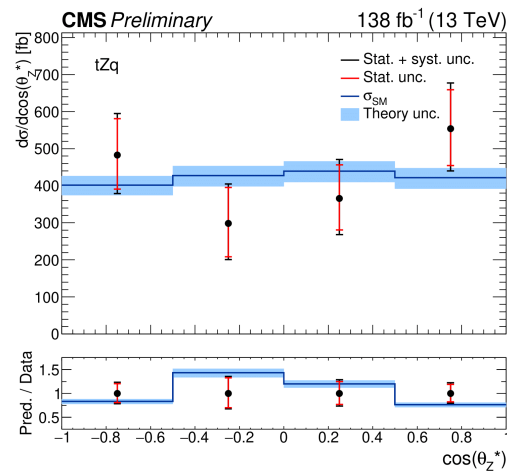
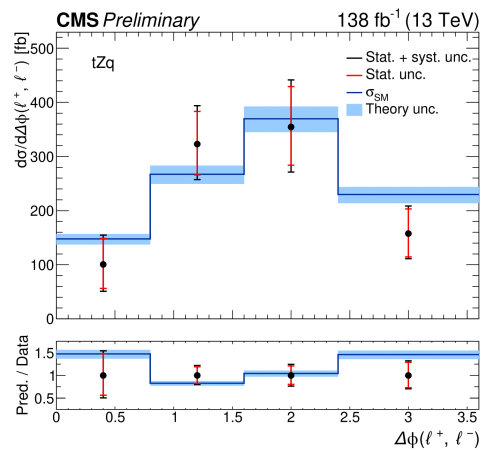
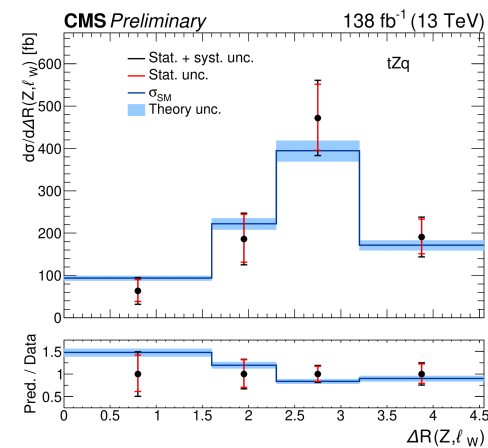
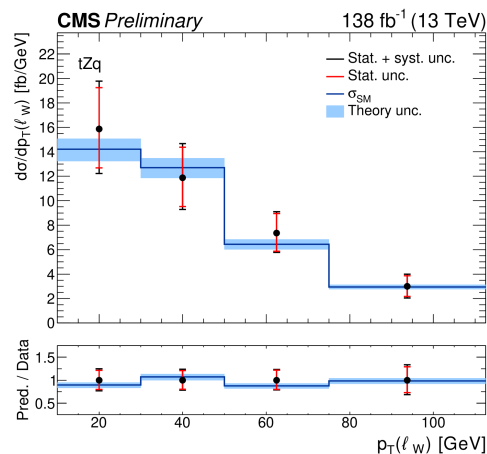
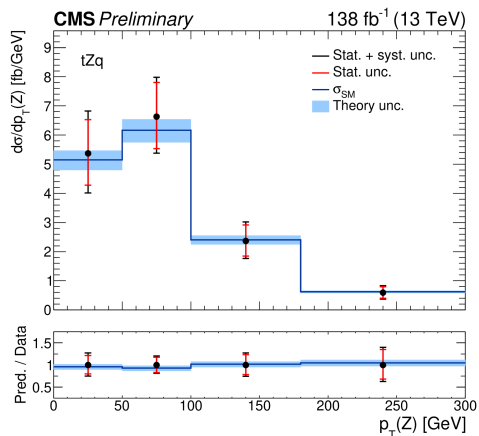
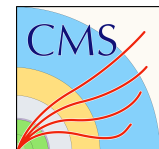
n: fakeable leptons not tight

$$f_i = \frac{N_{tight}}{N_{tight} + N_{fakeable}}$$

contribution in SR: estimated from data in the AR, subtracting events with only prompt lepton



Unfolded distributions: tZq



Unfolded distributions: $t\bar{t}Z+tWZ$

