Diboson Polarization Fraction measurement and Radiation Amplitude Zero (RAZ) effect in WZ production at ATLAS

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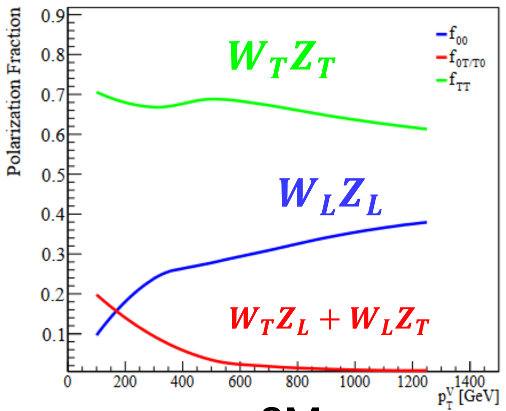
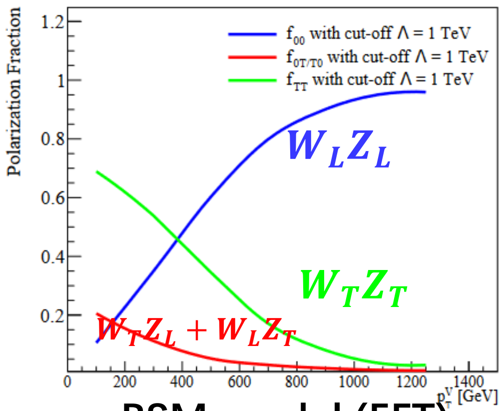
Motivation

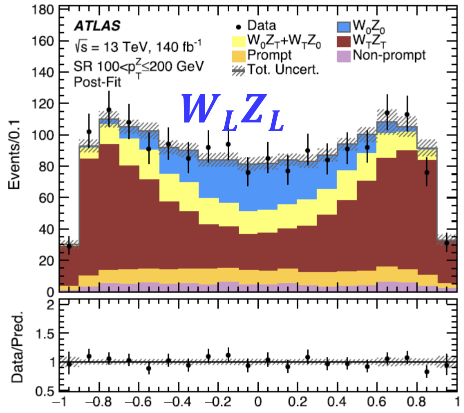
- **Polarization of the vector boson: an important target in SM&BSM research**
  - Closely linked to Electroweak Symmetry Breaking
  - Longitudinal (L) polarization playing a particularly significant role
- **Our analysis: dedicated on the High PT WZ analysis**
  - For high PT region, the measurement is more sensitive to the BSM effects
  - Aiming to increase the LL fraction and improve the discrimination of LL polarization



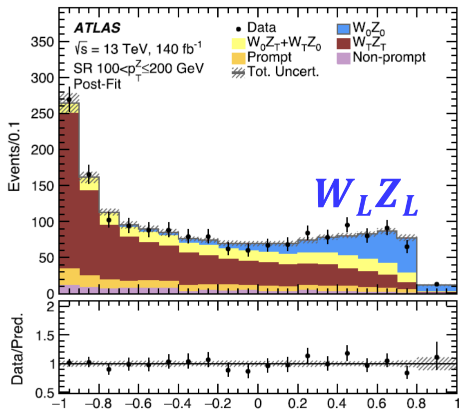
SM



BSM model (EFT)



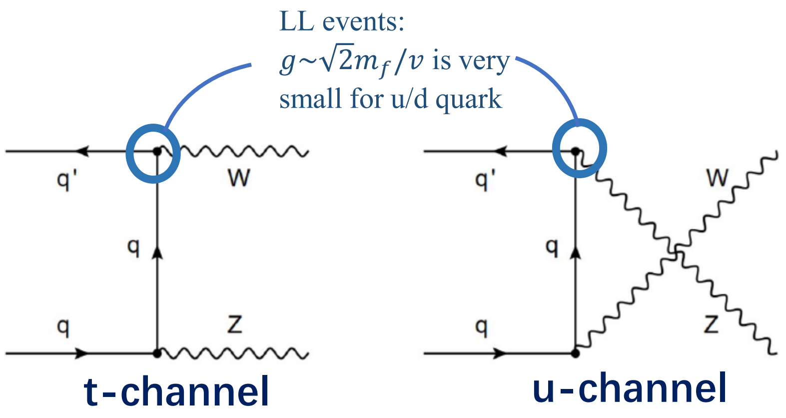
$\cos\theta_V$

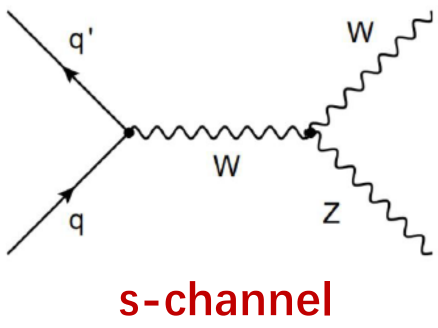


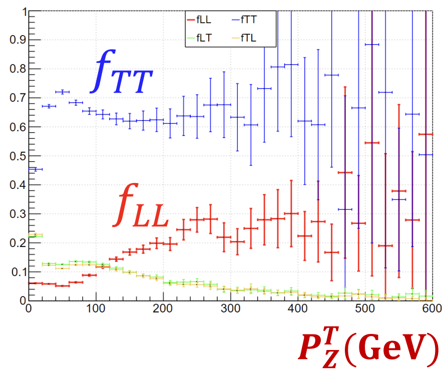
BDT Score

Longitudinal boson: physical characteristic

- **The Goldstone Boson Equivalence Theorem**
  - Longitudinal polarized boson ~ goldstone particle at high mass approximation, the (Yukawa) couplings is proportional to fermion mass m_f
  - Therefore, the t-channel and u-channel is suppressed
- **LL events are mostly from s-channel**
  - $\left|\mathcal{M}_{WZ}^{LL}\right|^2 \sim \sin^2\theta_V$, so LL events tend to have larger PT
  - TGC vertex in the s-channel provides sensitivity to potential new physics signatures





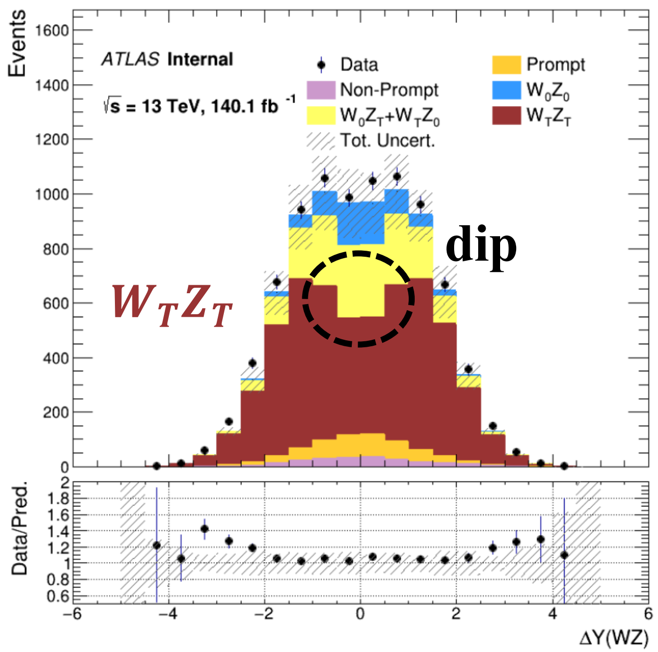


$\left|\mathcal{M}_{WZ}^{LL}\right|^2 \sim \sin^2\theta_V$

(Sherpa3 simulated)

Radiation Amplitude Zero (RAZ) effect

- **Consider LO contribution for TT polarization**
  - W^+Z^- and W^-Z^+ contribution in s-channel is forbidden by angular momentum conservation
  - TT polarization is mainly from t- and u- channel
- **RAZ effect**
  - For t- and u- channel, RAZ effect suppress the TT contribution at the LO
  - In our fiducial region, we require P_T^{WZ} to be small, to enhance the RAZ effect
- **Observation on the RAZ effect**
  - When $\cos\theta_V = 0$, $\left|\mathcal{M}_{WZ}^{TT}\right|^2 \sim 0$, this can be reflect in the ΔY_{WZ} distribution
  - A depth observable is used to quantify the magnitude of the dip



ΔY_{WZ} spectrum with $P_{WZ}^T < 20\text{GeV}$

Related analysis

- **Previous measurements**
  - Polarization fraction measurement for the WZ process at the inclusive region *Phys. Lett. B* 843 (2023) 137895
  - Polarization measurement for ZZ production *JHEP* 2312 (2023) 107
  - RAZ measurement for Wγ process Phys. Rev. Lett. 100 (2008) 241805
- **Particularity and difficulties in this analysis**
  - Polarization fraction measurement – dedicated on the high PT region
    - Raise the LL events purity
    - Show more sensitivity to the BSM effects
  - Hard to observe the RAZ effect before due to the large contamination of LL events
    - The accumulated luminosity, and the development of the MC simulator, allows to make this observation for the first time

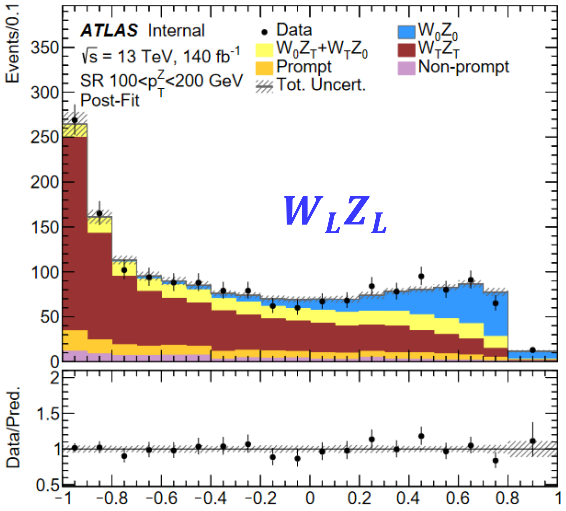
PRL published: [Phys. Rev. Lett. 133, 101802]

Measurements with full-Run2 data

- **Data and process:**
  - Full run2 13TeV 140fb^{-1} data: $pp -> WZ \rightarrow \ell\ell\ell\nu \ (\ell = e/\mu)$
- **Aiming for: f_{LL} measurement**
  - $P_{WZ}^{T} < 70$GeV, HighPT region with 2 P_T^Z bins
  - Use BDT to make measurement
    - **Low PT bin observation with 5.3σ**
    - **High PT bin limited by statistics**

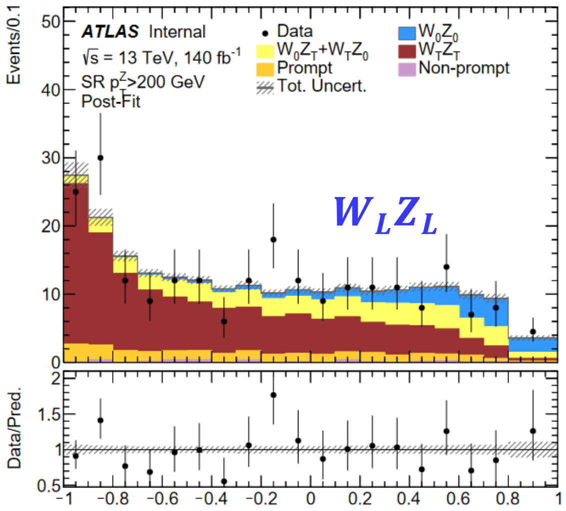
P_T^{WZ}	P_T^Z (GeV)	f_{LL}	Significance
< 70GeV	$[100, 200)$	$0.174 \pm^{0.024}_{0.025}$	5.3σ
	$[200, +\infty)$	$0.16 \pm^{0.06}_{0.06}$	1.6σ

$100\text{GeV} < P_Z^T < 200\text{GeV}$



BDT score

$P_Z^T > 200\text{GeV}$



BDT score

PRL published: [Phys. Rev. Lett. 133, 101802](#)

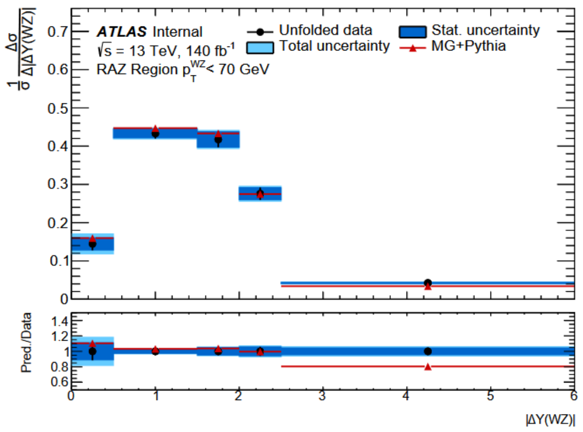
Measurements with full-Run2 data

- **Aiming for: RAZ effect observation**
  - Require $P_{WZ}^{T} < 70, 40, 20\text{GeV}$, and without P_{Z}^{T} cut
  - Depth observable (For TT events):

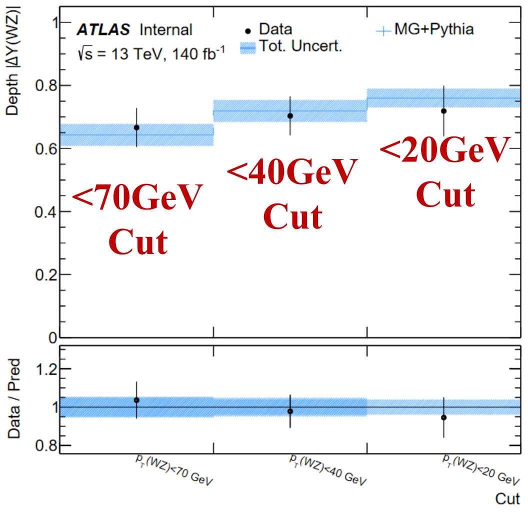
$$D = 1 - \frac{N\big(|\Delta Y| \in [0,0.5)\big)/0.5}{N(|\Delta Y| \in [0.5, 1.5))}$$

  - A first observation on the WZ RAZ effect, but with a limited statistics
  - Run3: more detailed analysis & construct other observables

Unfolded $|\Delta Y_{WZ}|$ spectrum



Measurement of *D*

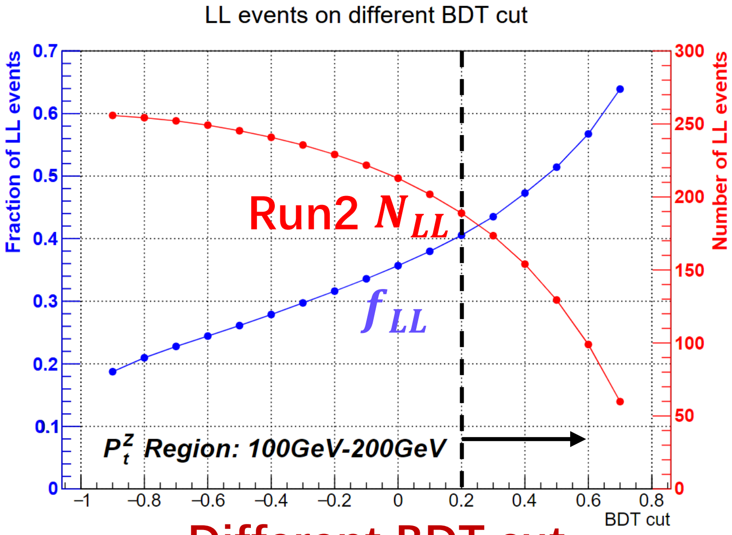


Run3 proposal

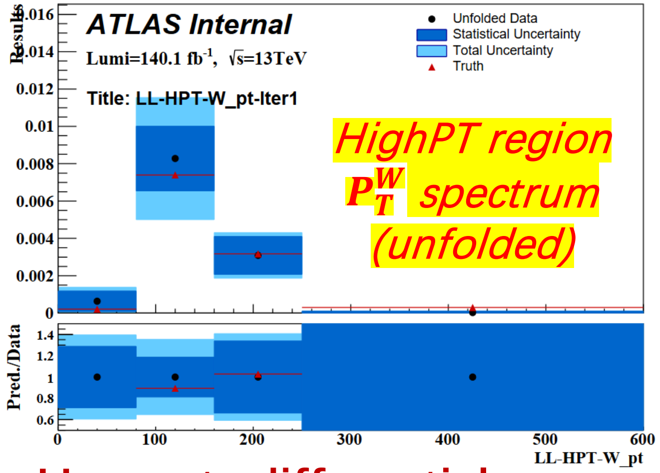
Thanks for your attention!

Run2 analysis	
Measurement of f_{LL} with $5.3\sigma(1.6\sigma)$	Rough binning on P_T^Z
	Limited statistics
First observation on WZ RAZ effect	Very preliminary study

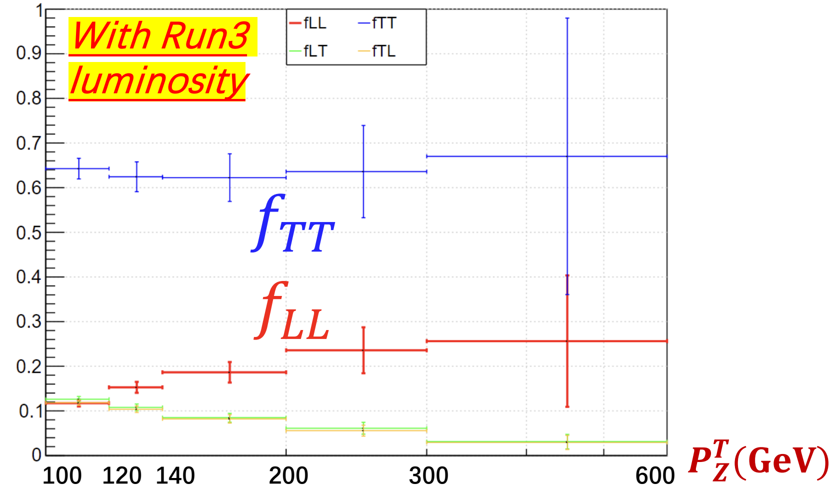
Run3 prospect
f_{LL} measurement with finer binning (spectrum measurement)
Higher precision measurement at very High PT region
Invest detailed RAZ measurement
LL events differential xsec measurement



Different BDT cut



LL events differential xsec measurement with Run2 statistics

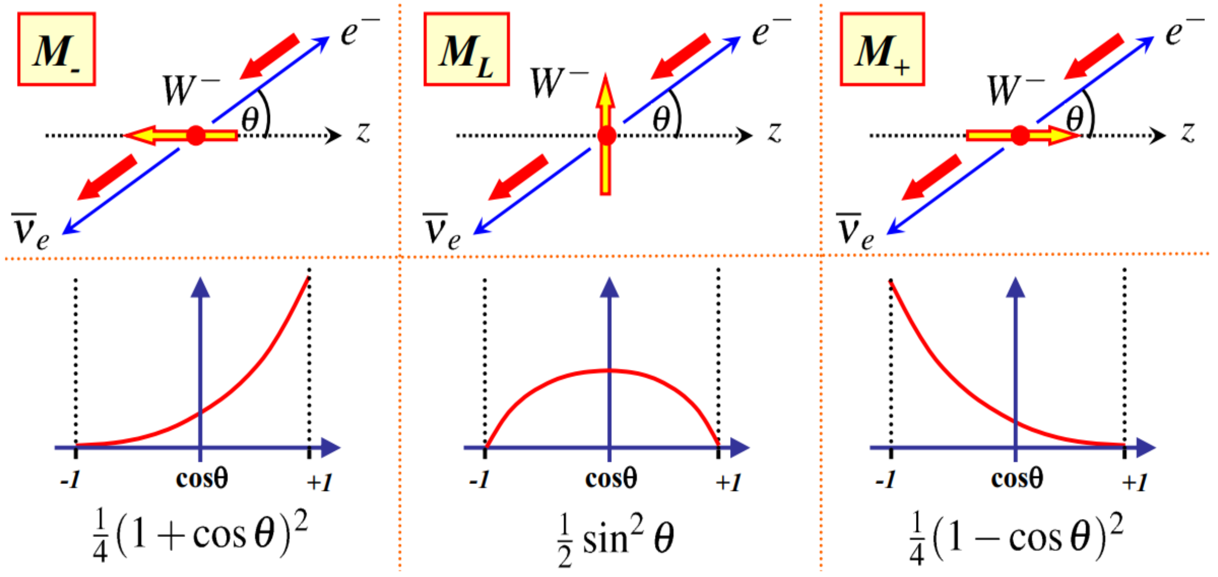


(Sherpa3 simulated, with $P_{WZ}^T < 70$GeV)

backups

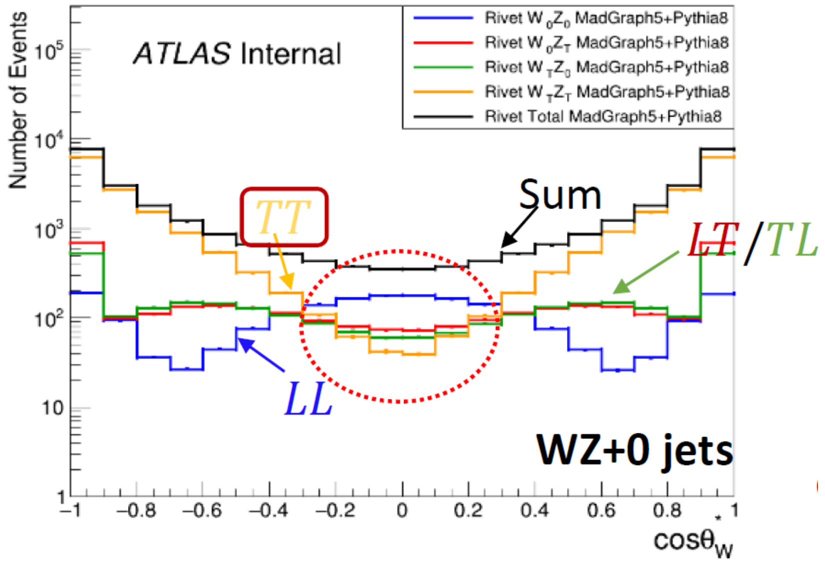
Angular distribution in different polarization state

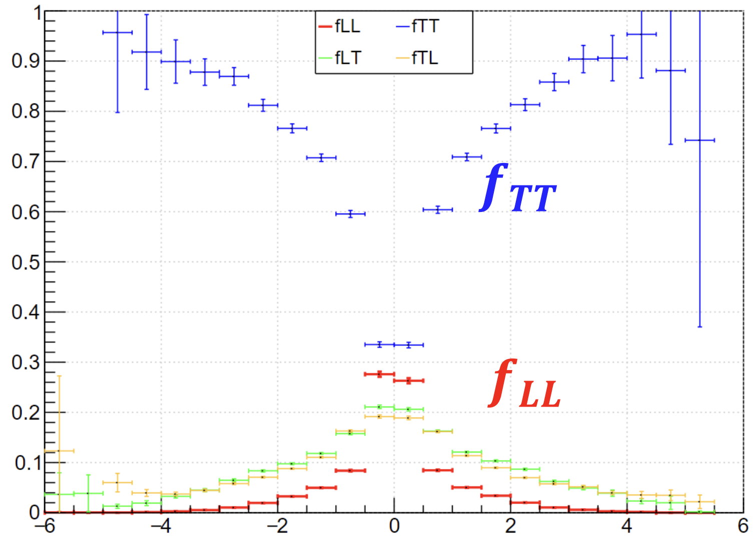
- **0: longitudinally polarized (*L*)**
- **±1: transversely polarized (*T*)**



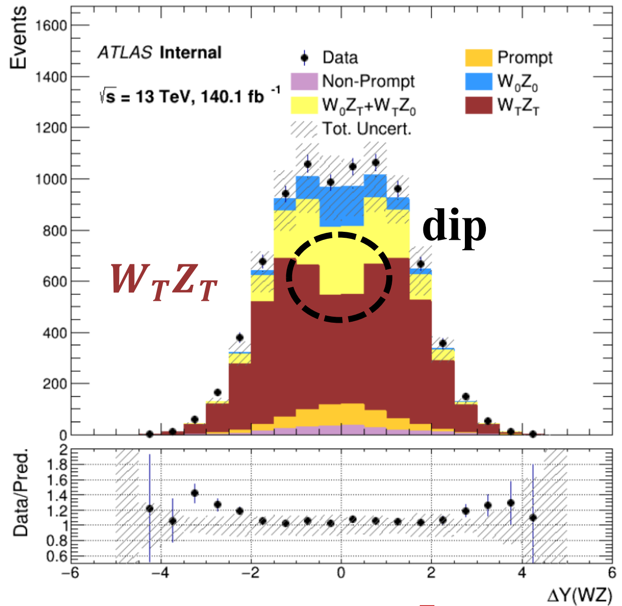
Radiation Amplitude Zero (RAZ) effect

- **When $cos\,\theta_V = 0, |\mathcal{M}_{WZ}^{TT}|^2 \sim 0$**
- **However, we do not use cos θ to observe**
  - The costheta spectrum is diluted, and the dip is filled, it is hard to measure
  - Instead of reconstructing a precise WZ frame, the DeltaY spectrum can be measured in the lab frame
- **Use the ΔY_{WZ} distribution instead**





$P_{WZ}^T < 30$GeV



ΔY_{WZ} spectrum with $P_{WZ}^T < 20$GeV

Background estimation

Irreducible (prompt): MC estimation
Reducible (non-prompt): data-driven estimation

➢ Irreducible background (~10%)

- VBS-WZ, ZZ, Tri-boson, $t\bar{t}V$

➢ Reducible background (~5%) (non-Prompt)

Measure the Tight selection cut efficiency for fake leptons in data:

Fake rate: $\frac{\text{Pass Tight efficiency}}{\text{Unpass Tight efficiency}}$

- $Z + \text{jet} \rightarrow ll + \text{jet}(l)$ fake W decay lepton
- $Z + \gamma \rightarrow ll + \gamma(l)$ fake W decay lepton

} γ/light flavor jet fake leptons, measured in $Z + \text{jet}/Z\gamma$ CR

- $t\bar{t} \rightarrow WbWb \rightarrow l\nu + b + l\nu + b(l)$ fake Z decay lepton } Heavy flavor jet fake leptons, measured in $t\bar{t}$ CR

➢ Matrix Method

$$\begin{pmatrix} N_{TTT} \\ N_{TTL} \\ N_{TLT} \\ N_{LTT} \\ N_{TLL} \\ N_{LTL} \\ N_{LLT} \end{pmatrix} = \begin{pmatrix} e_1e_2e_3 & e_1e_2f_3 & e_1f_2e_3 & f_1e_2e_3 & e_1f_2f_3 & f_1e_2f_3 & f_1f_2e_3 \\ e_1e_2\bar{e}_3 & e_1e_2\bar{f}_3 & e_1f_2\bar{e}_3 & f_1e_2\bar{e}_3 & e_1f_2\bar{f}_3 & f_1e_2\bar{f}_3 & f_1f_2\bar{e}_3 \\ e_1\bar{e}_2e_3 & e_1\bar{e}_2f_3 & e_1\bar{f}_2e_3 & f_1\bar{e}_2e_3 & e_1\bar{f}_2f_3 & f_1\bar{e}_2f_3 & f_1\bar{f}_2e_3 \\ \bar{e}_1e_2e_3 & \bar{e}_1e_2f_3 & \bar{e}_1f_2e_3 & \bar{f}_1e_2e_3 & \bar{e}_1f_2f_3 & \bar{f}_1e_2f_3 & \bar{f}_1f_2e_3 \\ e_1\bar{e}_2\bar{e}_3 & e_1\bar{e}_2\bar{f}_3 & e_1\bar{f}_2\bar{e}_3 & f_1\bar{e}_2\bar{e}_3 & e_1\bar{f}_2\bar{f}_3 & f_1\bar{e}_2\bar{f}_3 & f_1\bar{f}_2\bar{e}_3 \\ \bar{e}_1e_2\bar{e}_3 & \bar{e}_1e_2\bar{f}_3 & \bar{e}_1f_2\bar{e}_3 & \bar{f}_1e_2\bar{e}_3 & \bar{e}_1f_2\bar{f}_3 & \bar{f}_1e_2\bar{f}_3 & \bar{f}_1f_2\bar{e}_3 \\ \bar{e}_1\bar{e}_2e_3 & \bar{e}_1\bar{e}_2f_3 & \bar{e}_1\bar{f}_2e_3 & \bar{f}_1\bar{e}_2e_3 & \bar{e}_1\bar{f}_2f_3 & \bar{f}_1\bar{e}_2f_3 & \bar{f}_1\bar{f}_2e_3 \end{pmatrix} \begin{pmatrix} N_{RRR} \\ N_{RRF} \\ N_{RFR} \\ N_{FRR} \\ N_{RFF} \\ N_{FRF} \\ N_{FFR} \end{pmatrix}.$$

$$N_{fake} = N_{TTT} - e_1e_2e_3N_{RRR} = [N_{TTL} - N_{TTL}^{irr}]\frac{f_3}{\bar{f}_3} + [N_{TLT} - N_{TLT}^{irr}]\frac{f_2}{\bar{f}_2} + [N_{LTT} - N_{LTT}^{irr}]\frac{f_1}{\bar{f}_1}$$

$$-[N_{TLL} - N_{TLL}^{irr}]\frac{f_2}{\bar{f}_2}\frac{f_3}{\bar{f}_3} - [N_{LTL} - N_{LTL}^{irr}]\frac{f_1}{\bar{f}_1}\frac{f_3}{\bar{f}_3} - [N_{LLT} - N_{LLT}^{irr}]\frac{f_1}{\bar{f}_1}\frac{f_2}{\bar{f}_2}$$

Fake rate: $F_i = \frac{f_i}{\bar{f}_i}$