# Lepton Flavor Universality in $t\bar{t}l^+l^-$ at CMS

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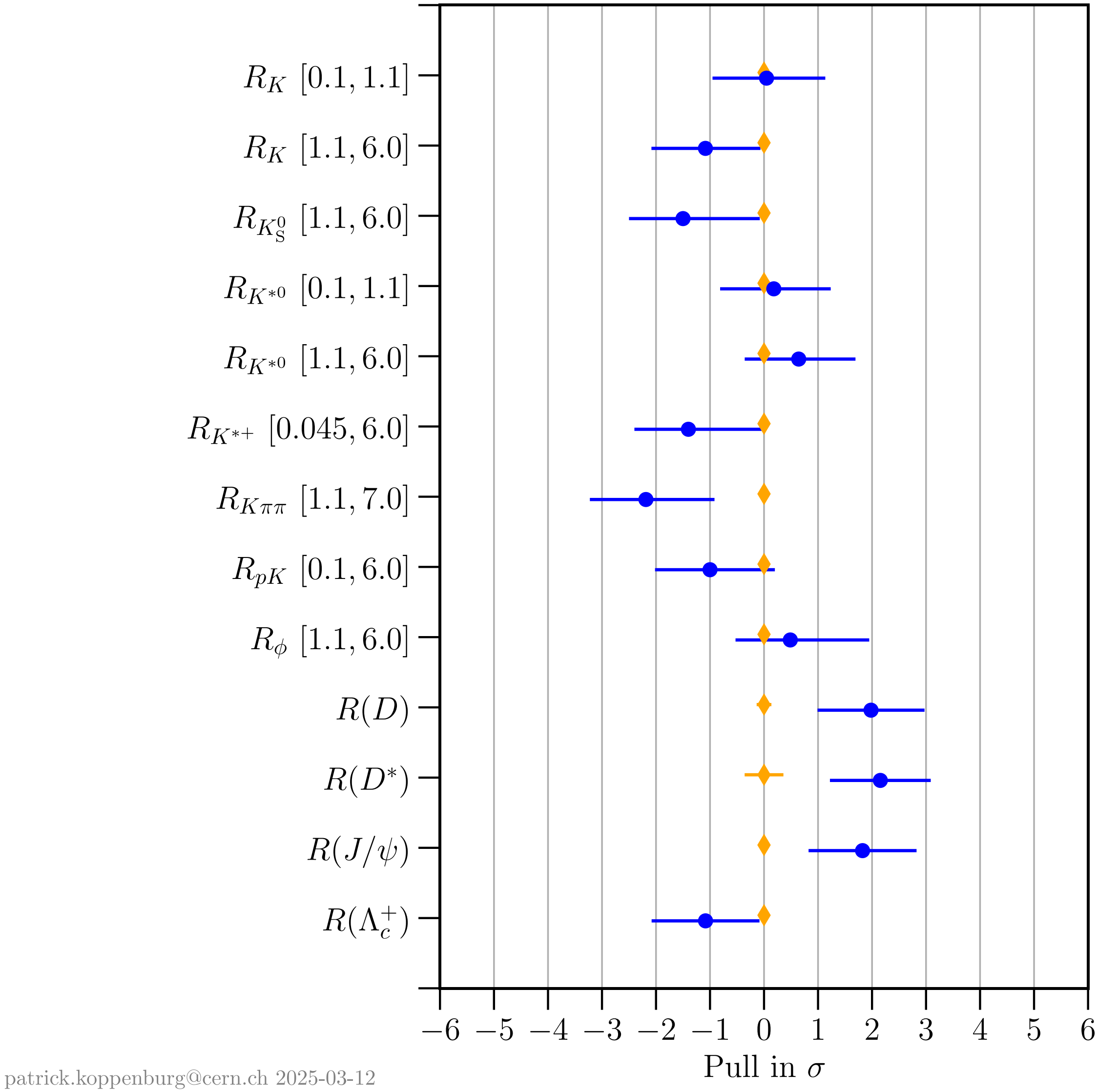
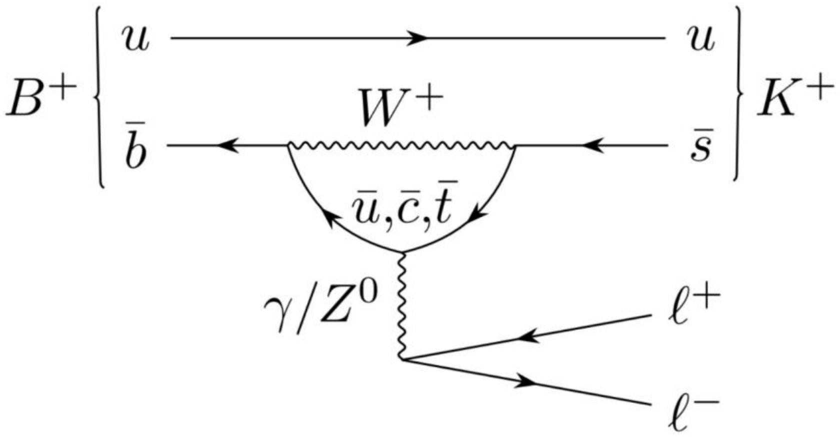
# Context : Lepton Flavor Violation




R is the ratio of branching fractions

$$R_X = \frac{\mathcal{B}(B \to X\mu^+\mu^-)}{\mathcal{B}(B \to Xe^+e^-)}$$

These deviations could be signatures of **LFV-physics.**

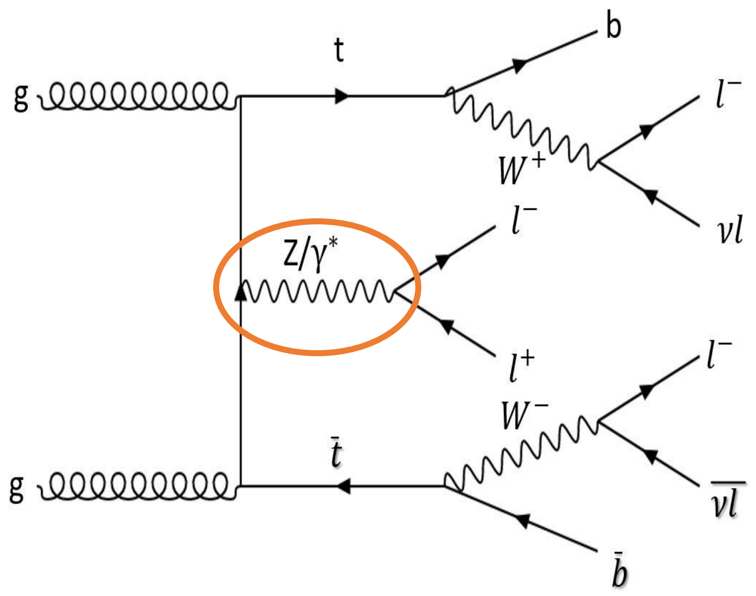



The top quark appears in loop-level diagrams.

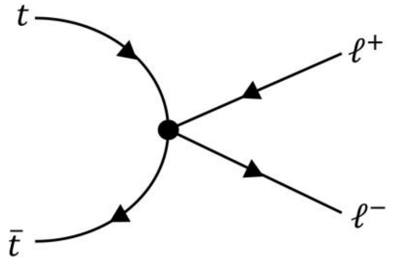
**Searching for LFU violation involving top quarks**

# LFV within Effective Field Theory

Top pair production associated with lepton pair production (signal)




The propagator can be replaced with an EFT vertex




$$\mathcal{L}_{EFT}^{(6)} = \mathcal{L}_{SM} + \sum_i \frac{c_i^{(6)}}{\Lambda_i^{(6)}} O_i^{(6)} + h.c.$$

7 operators contribute to top-lepton coupling -> 7 coefficients to measure

| Dimension 6 operators | Associated WCs | $2\sigma$ constraints |
|---|---|---|
| $\mathcal{O}_{lq}^{1(\ell)} = (\bar{\ell}\gamma^\mu \ell)(\bar{q}\gamma_\mu q)$ | $c_{Q\ell}^{-(\ell)} \equiv C_{lq}^{1(\ell)} - C_{lq}^{3(\ell)}$ | $[-1.58,\ 2.28]$ |
| $\mathcal{O}_{lq}^{3(\ell)} = (\bar{\ell}\gamma^\mu \tau^I \ell)(\bar{q}\gamma_\mu \tau^I q)$ | $c_{Q\ell}^{3(\ell)} \equiv C_{lq}^{3(\ell)}$ | $[-2.84,\ 2.55]$ |
| $\mathcal{O}_{lt}^{(\ell)} = (\bar{\ell}\gamma^\mu \ell)(\bar{t}\gamma_\mu t)$ | $c_{t\ell}^{(\ell)} \equiv C_{lt}^{(\ell)}$ | $[-1.80,\ 2.11]$ |
| $\mathcal{O}_{eq}^{(\ell)} = (\bar{e}\gamma^\mu e)(\bar{q}\gamma_\mu q)$ | $c_{Qe}^{(\ell)} \equiv C_{eq}^{(\ell)}$ | $[-1.91,\ 1.96]$ |
| $\mathcal{O}_{et}^{(\ell)} = (\bar{e}\gamma^\mu e)(\bar{t}\gamma_\mu t)$ | $c_{te}^{(\ell)} \equiv C_{et}^{(\ell)}$ | $[-1.78,\ 2.21]$ |
| $\mathcal{O}_{leqt}^{1(\ell)} = (\bar{\ell}e)(\bar{q}t)$ | $c_t^{S(\ell)} \equiv \mathrm{Re}[C_{leqt}^{1(\ell)}]$ | $[-2.60,\ 2.62]$ |
| $\mathcal{O}_{leqt}^{3(\ell)} = (\bar{\ell}\sigma^{\mu\nu} e)(\bar{q}\sigma_{\mu\nu} t)$ | $c_t^{T(\ell)} \equiv \mathrm{Re}[C_{leqt}^{3(\ell)}]$ | $[-0.37,\ 0.37]$ |

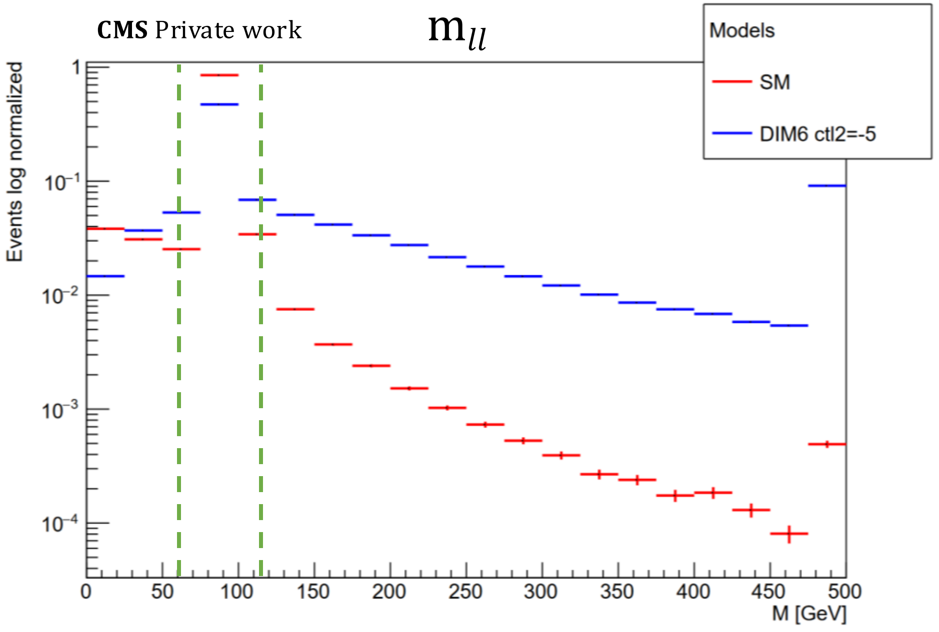
Values taken from arXiv:2307.15761v2

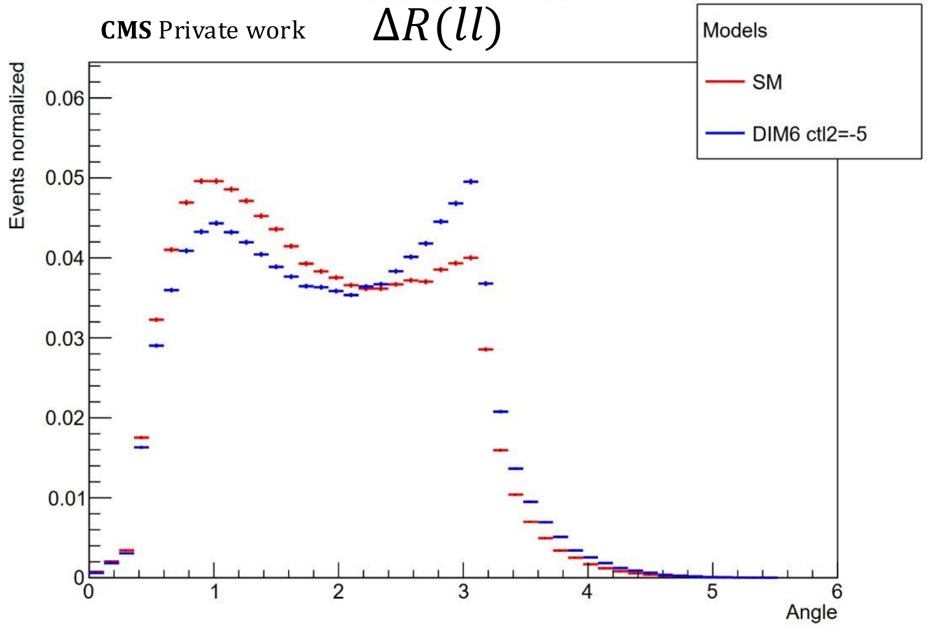
**Simulated EFT sample for each Wilson coefficient**

# EFT impact on Kinematic Variables at parton level

Kinematic variables built using the Opposite Sign Same Flavor (OSSF) pair with the largest $p_T$ vectorial sum.
Generated using MadGraph5@NLO

$$\Delta R = \sqrt{\Delta\Phi^2 + \Delta\eta^2}$$




**3 regions can be defined on/off Z-peak, with new physics primarily observed away from the Z resonance**

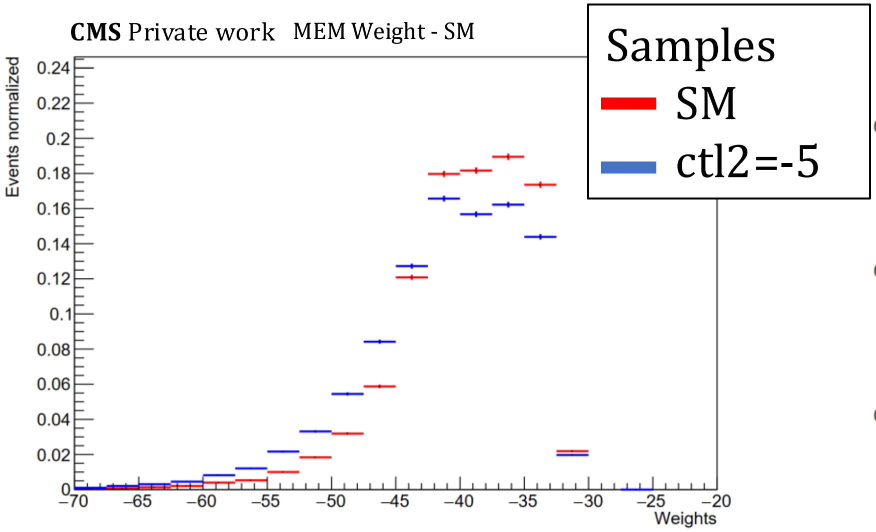
**Back-to-back emissions are slightly preferred in LFV physics.**

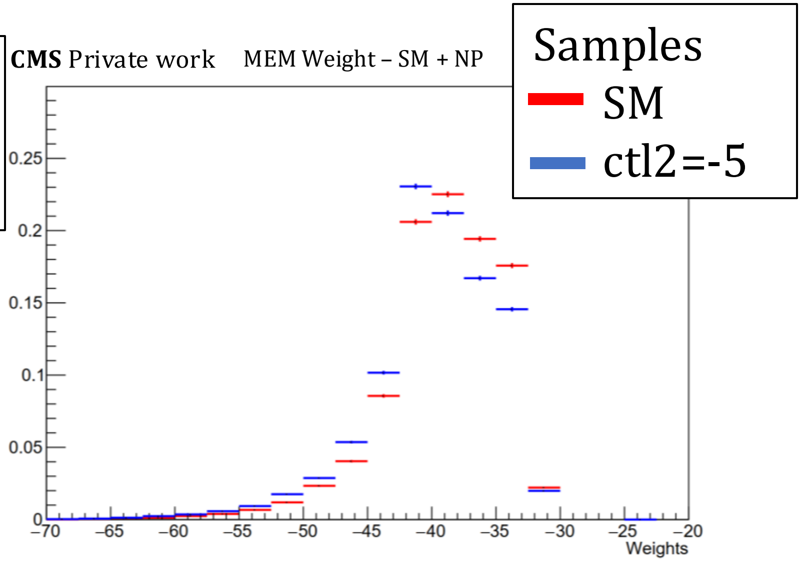
# EFT impact on Kinematic Variables at parton level

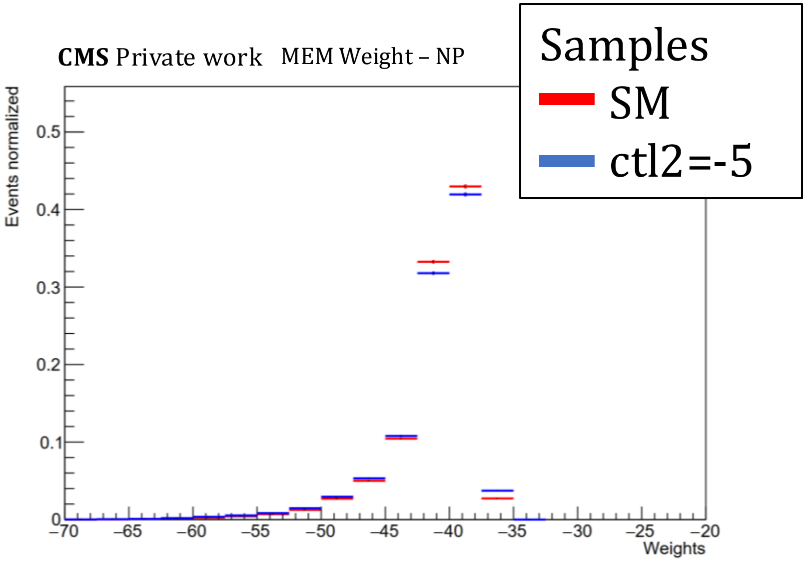
Another kinematic variable can be built using the Matrix Element Method (MEM)

Matrix Elements are taken from MadGraph5 with dim6top ufo model

$$w_{i,\alpha}(\Phi') = \frac{1}{\sigma_\alpha} \int d\Phi_\alpha \cdot \delta^4\Big(p_1^\mu + p_2^\mu - \sum_{k\geq 3} p_k^\mu\Big) \cdot \frac{f(x_1,\mu_F) f(x_2,\mu_F)}{x_1 x_2 s} \cdot \left|\mathcal{M}_\alpha(p_k^\mu)\right|^2 \cdot W(\Phi'|\Phi_\alpha)$$



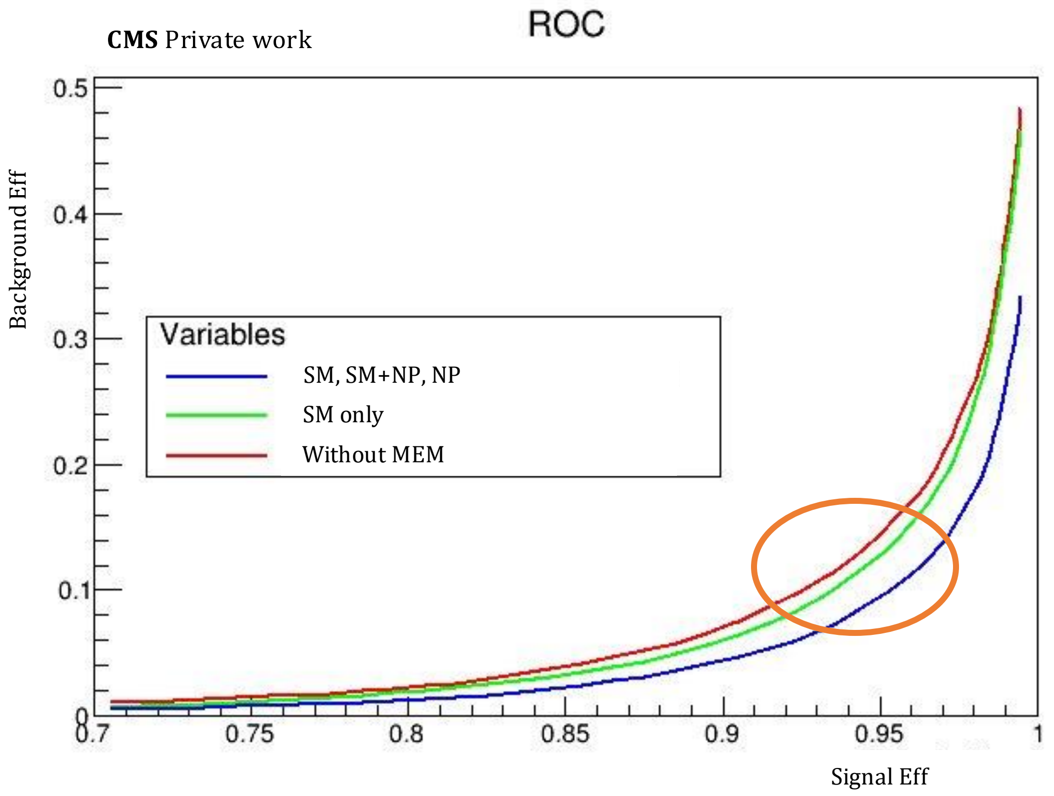
# Separation SM/EFT : BDT

Use of a Boosted Decision Tree (BDT) to distinguish:
- ○ Standard Model (SM) processes → background
- ○ Effective Field Theory (EFT) contributions → signal

Input: $\Delta R(ll)$, $m_{ll}$

Comparison of hypotheses using the Matrix Element Method (MEM):
- ○ SM-only
- ○ New Physics (NP)-only
- ○ SM + NP combined

**Relative reduction of background noise efficiency by 30%**



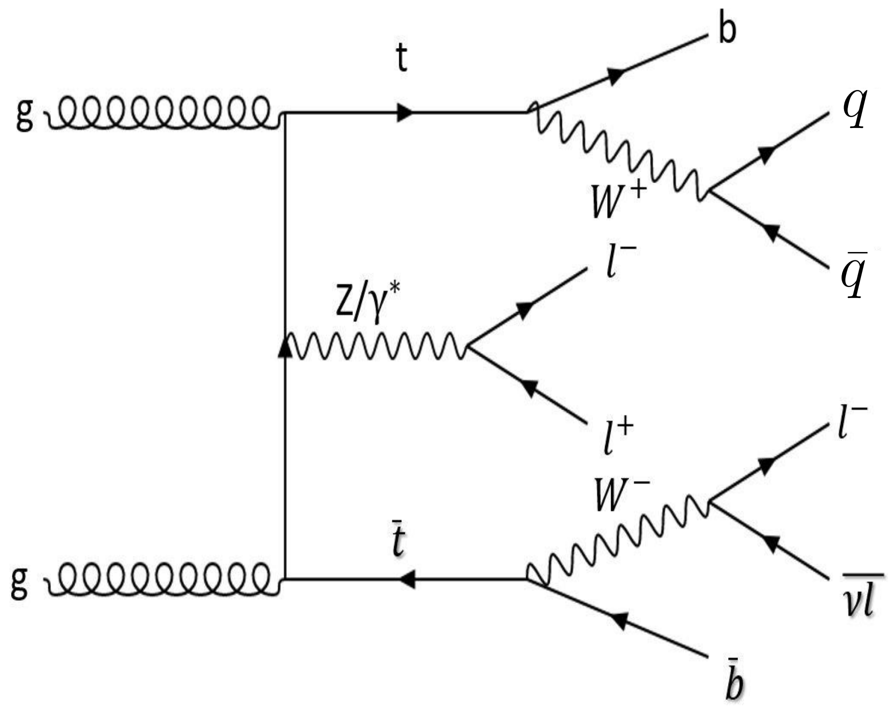
# Measurement of $t\bar{t}Z/\gamma^*$ signal strength

**Objectives :**

- Standard Model Measurement of $t\bar{t}Z/\gamma*$
- First step before EFT coefficient measurement

**Analysis setup :**

- Focus on semi hadronic decay
- Analysing full CMS Run 2 Data
- Single, double and triple isolated lepton trigger

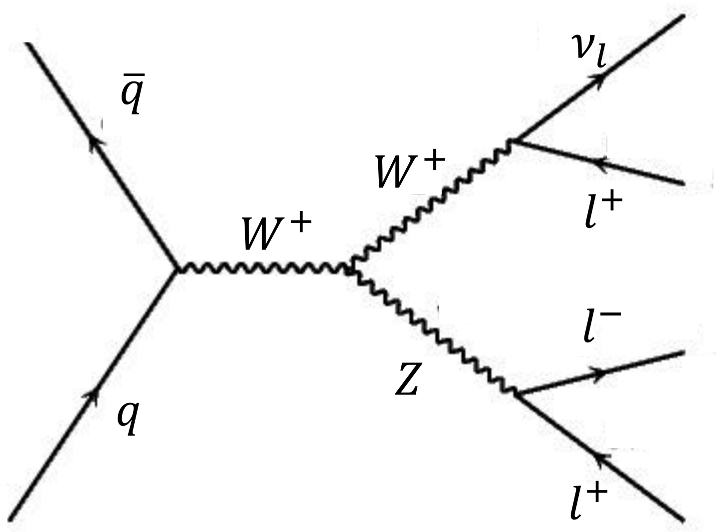


# Background processes

WZ process

$$\sigma(pp \to WZ) = 50.6 \text{ pb}$$

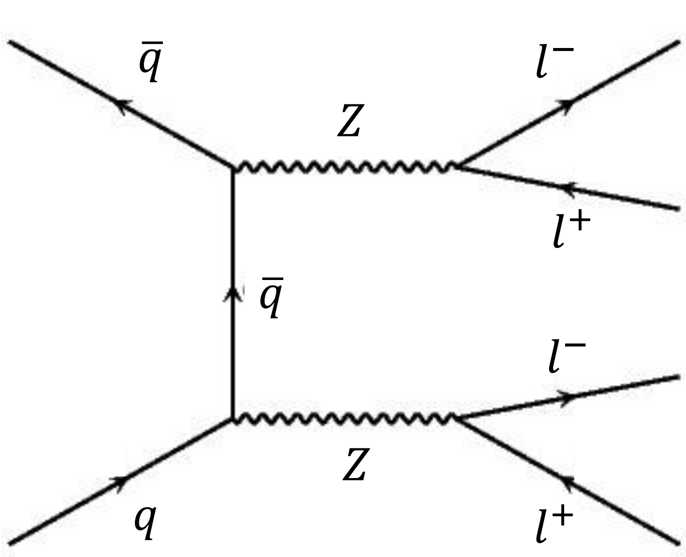
33% of the total contribution in the signal region




ZZ process

$$\sigma(pp \to ZZ) = 17.1 \text{ pb}$$

28% of the total contribution in the signal region




Other background processes:

- $t\bar{t}X$
- Nonprompt leptons from conversion

These backgrounds mimic the multilepton signature and must be carefully modeled

# SM analysis – Object selection

| **Object** | **Selection Criteria** |
|---|---|
| Electron | $p_T > 10.0$ GeV, $\|\eta\| < 2.5$, tight `TopLMVA` WP |
| Muon | $p_T > 10.0$ GeV, $\|\eta\| < 2.4$, tight `TopLMVA` WP, medium ID |
| Jet | $p_T^{\text{corr}} > 30.0$ GeV, $\|\eta\| < 2.4$, tight ID, removed if $\Delta R < 0.4$ with a lepton |
| B-Jet | Jet with tight `DeepJet` WP |

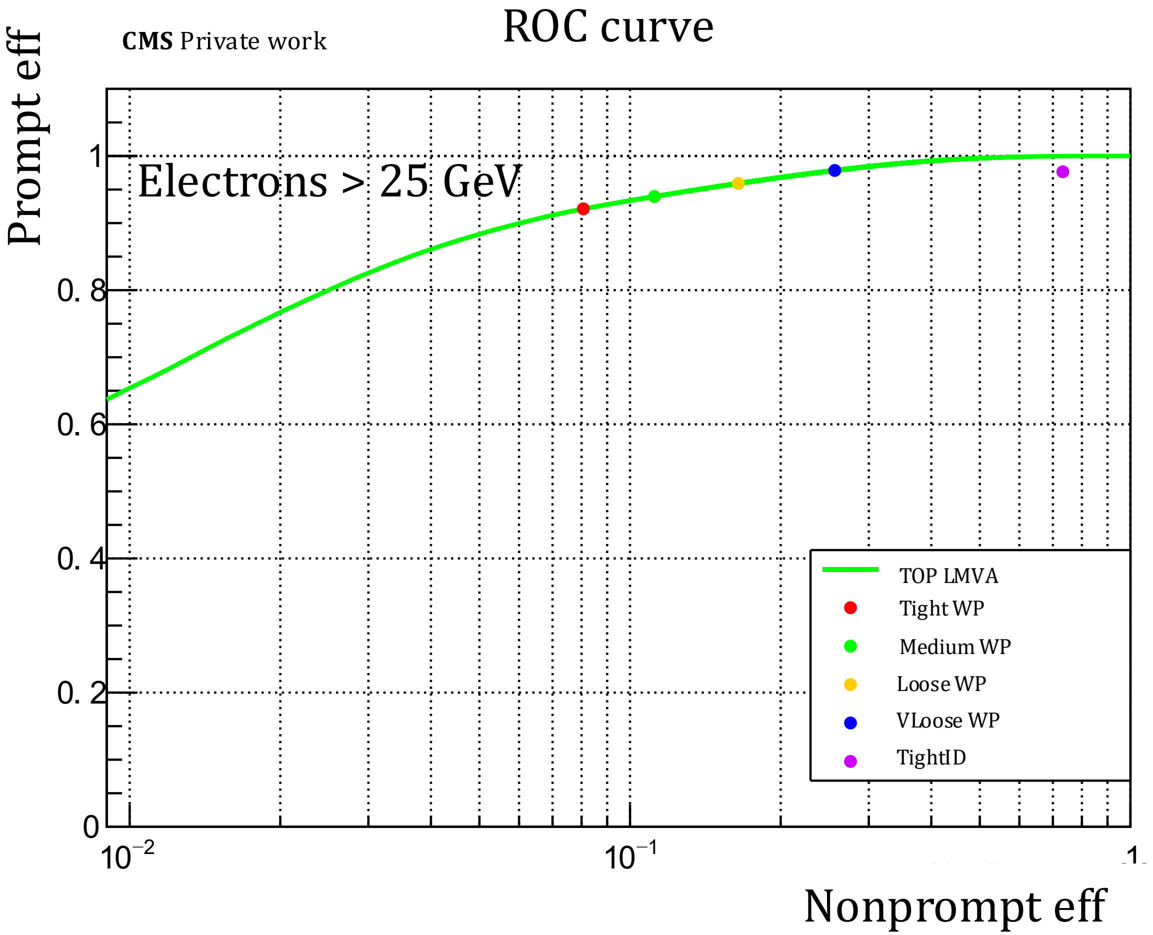
Low pT leptons

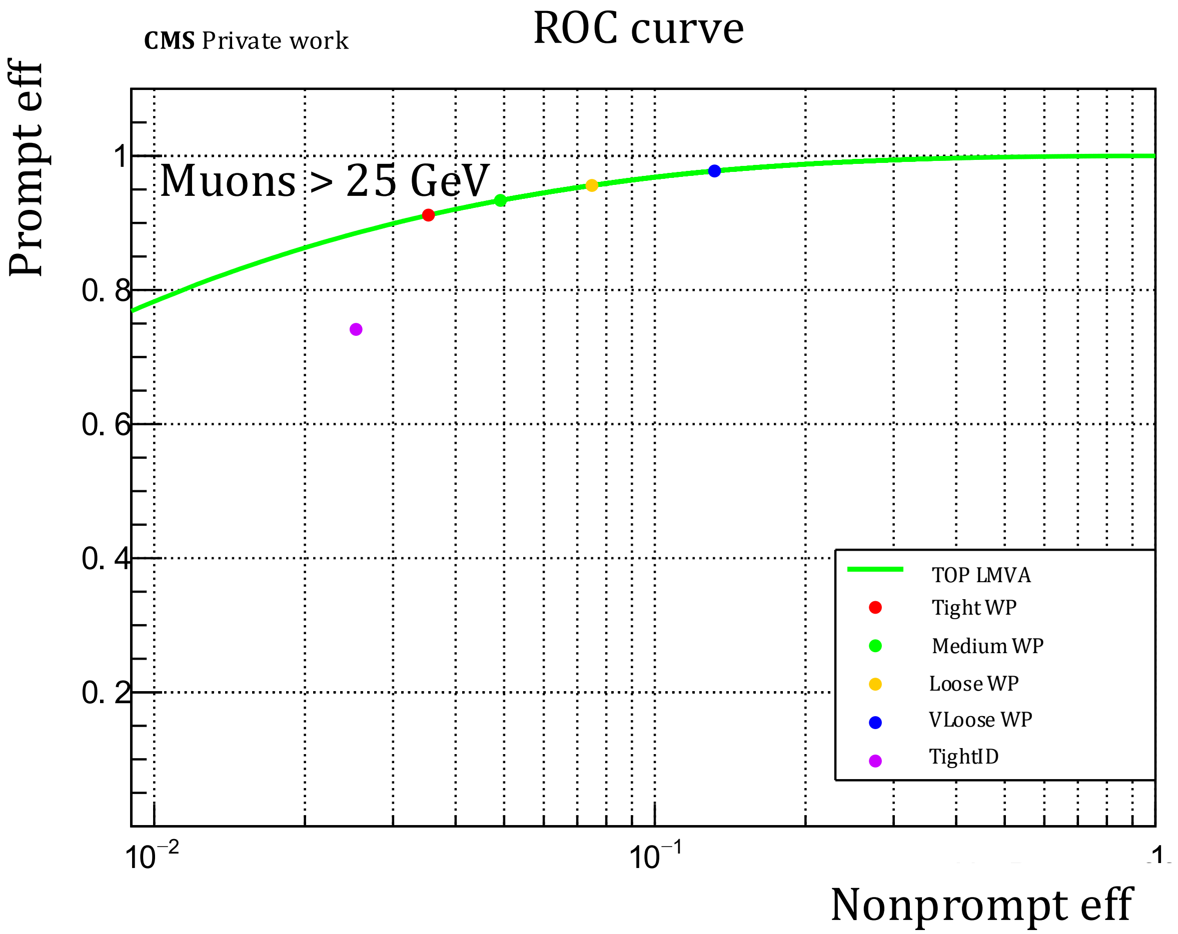
TopLMVA is a BDT trained to select prompt lepton in $t\bar{t}$ analysis

Recommended CMS corrections applied (Pileup and b-tag weights, JEC, muon and electron efficiencies).

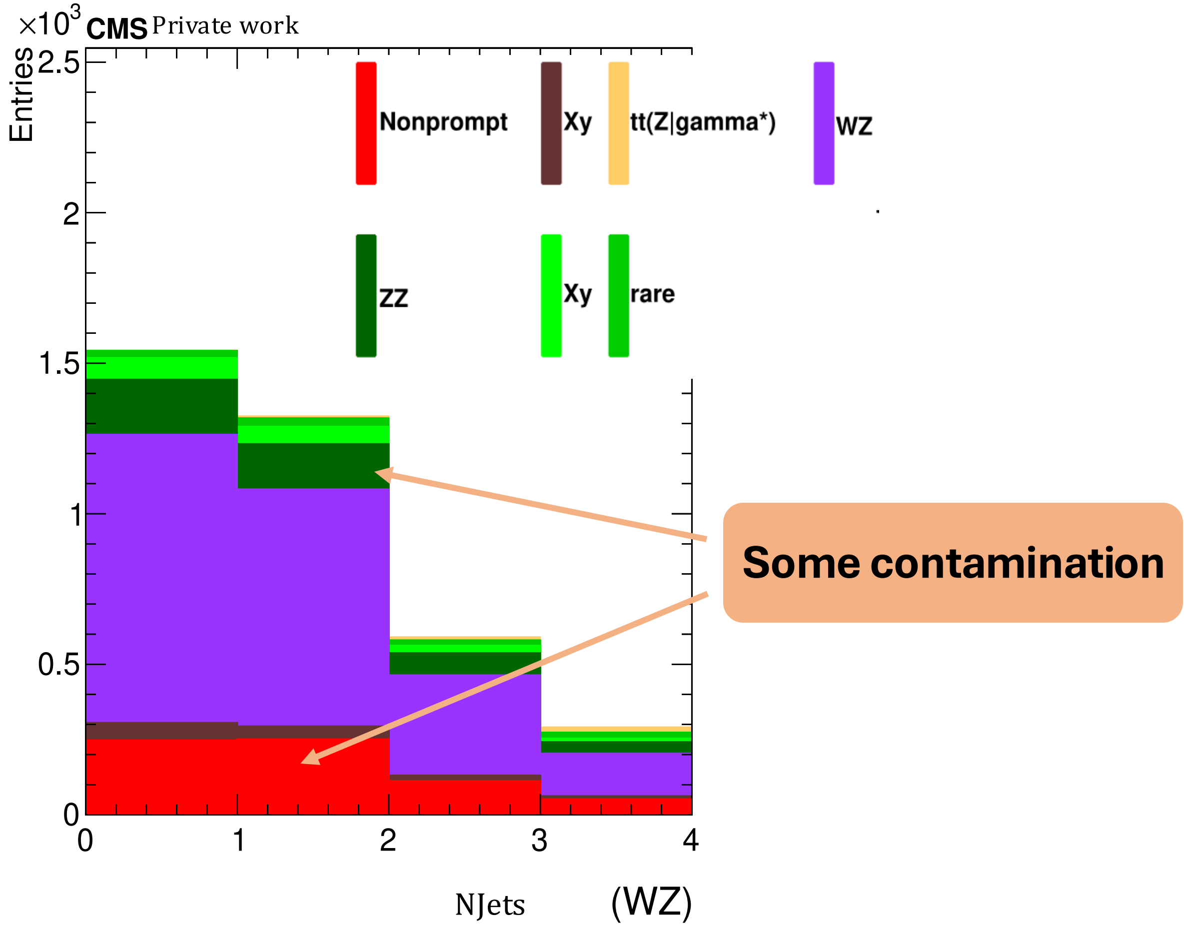
# Object selection - TopLMVA

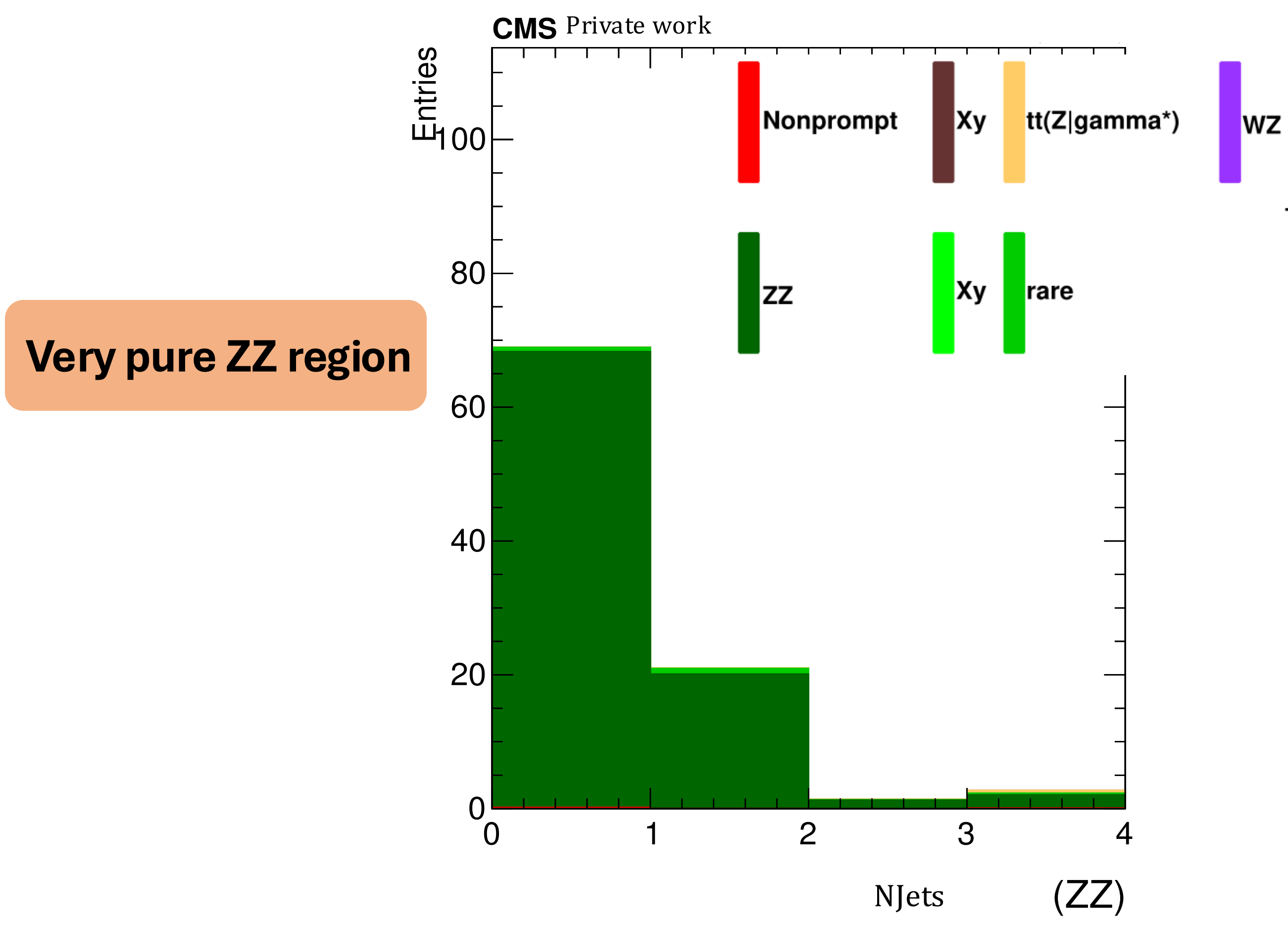
TopLMVA improve the prompt leptons selection while keeping a low nonprompt noise



# Control regions




WZ control region:
3 leptons, ≥1 OSSF pair, $p_T$ > 40, 20, 10 GeV, 0 b-jets, $|m_{OSSF} - m_Z| < 10$ GeV, MET > 50 GeV.

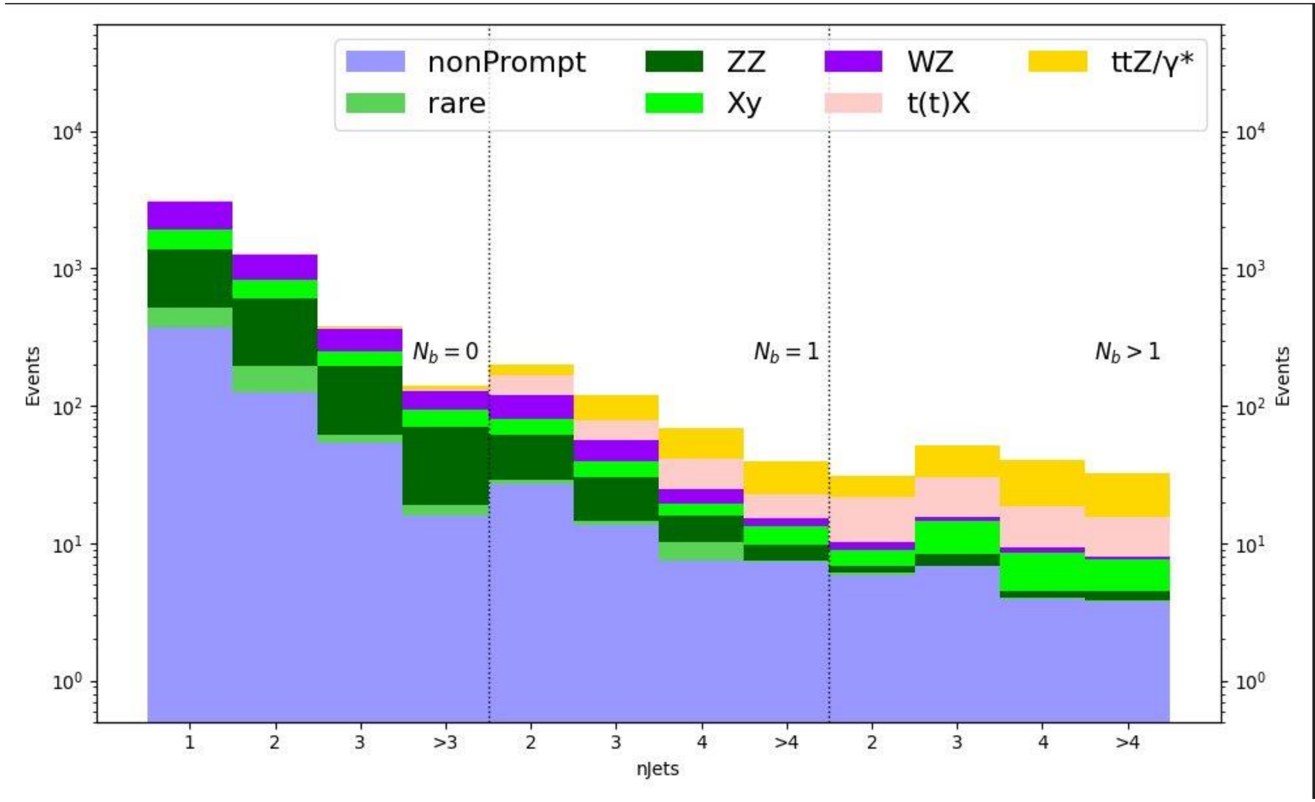
ZZ control region:
4 leptons, 2 OSSF pairs close to Z, leading $p_T$ > 40 GeV, MET < 50 GeV

# Signal region – Njets observable

**3L Signal Region:**

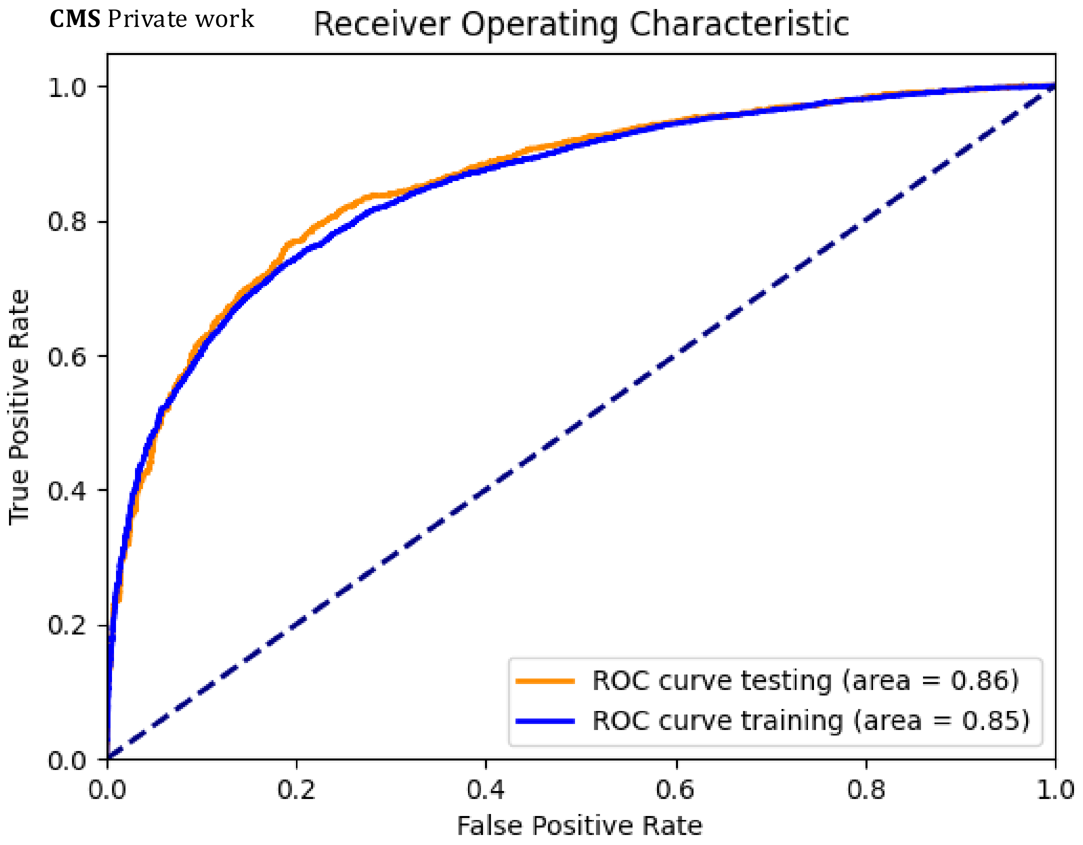
- Events with exactly **3 leptons**, including **at least one opposite-sign same-flavor (OSSF) lepton pair**.
- Lepton $\mathbf{p_T}$ > **40, 20, and 10 GeV**.
- 3 regions :
  - Nj > 1 and Nb = 0
  - Nj > 2 and Nb = 1
  - Nj > 2 and Nb > 1

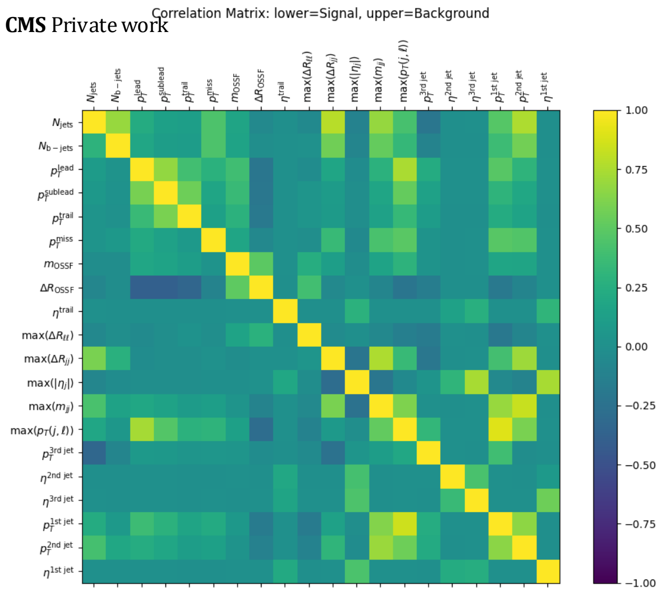
**CMS** Private work

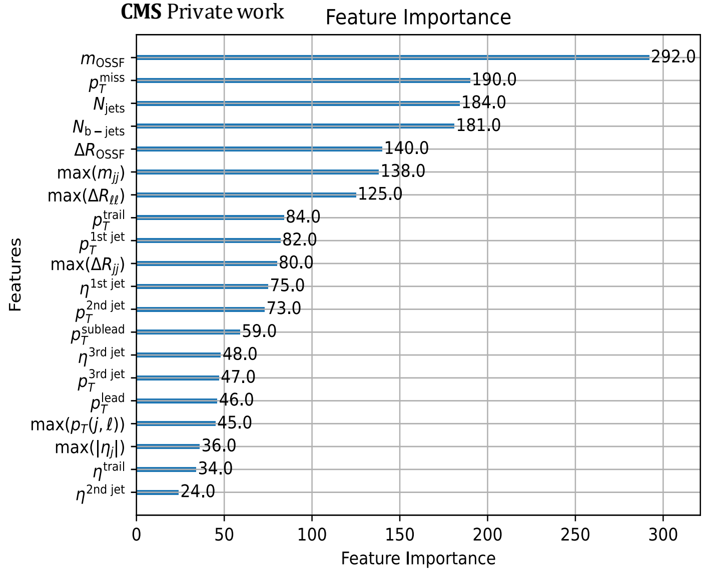


# Signal region – BDT

**The BDT is trained to separate the ttZ/γ* signal from background processes**



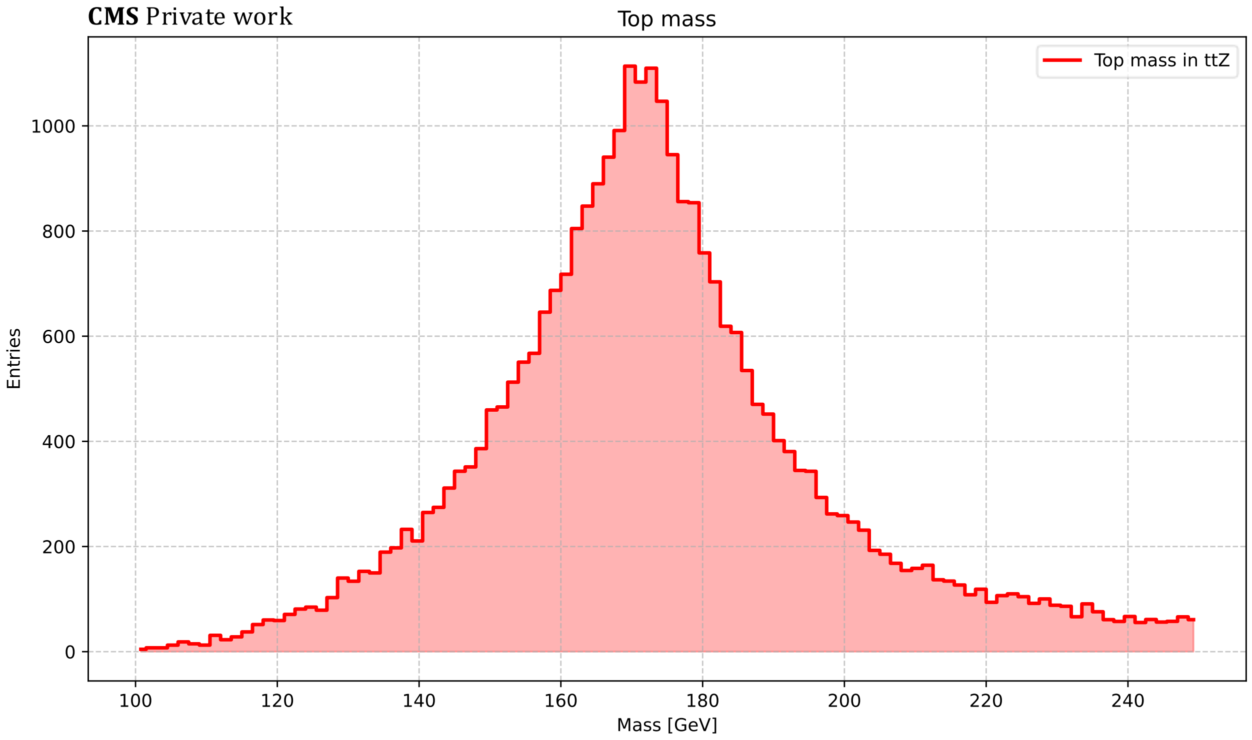



# Top reconstruction

To identify the lepton from the top quark decay, we select the lepton that yields a reconstructed top mass closest to the PDG value.

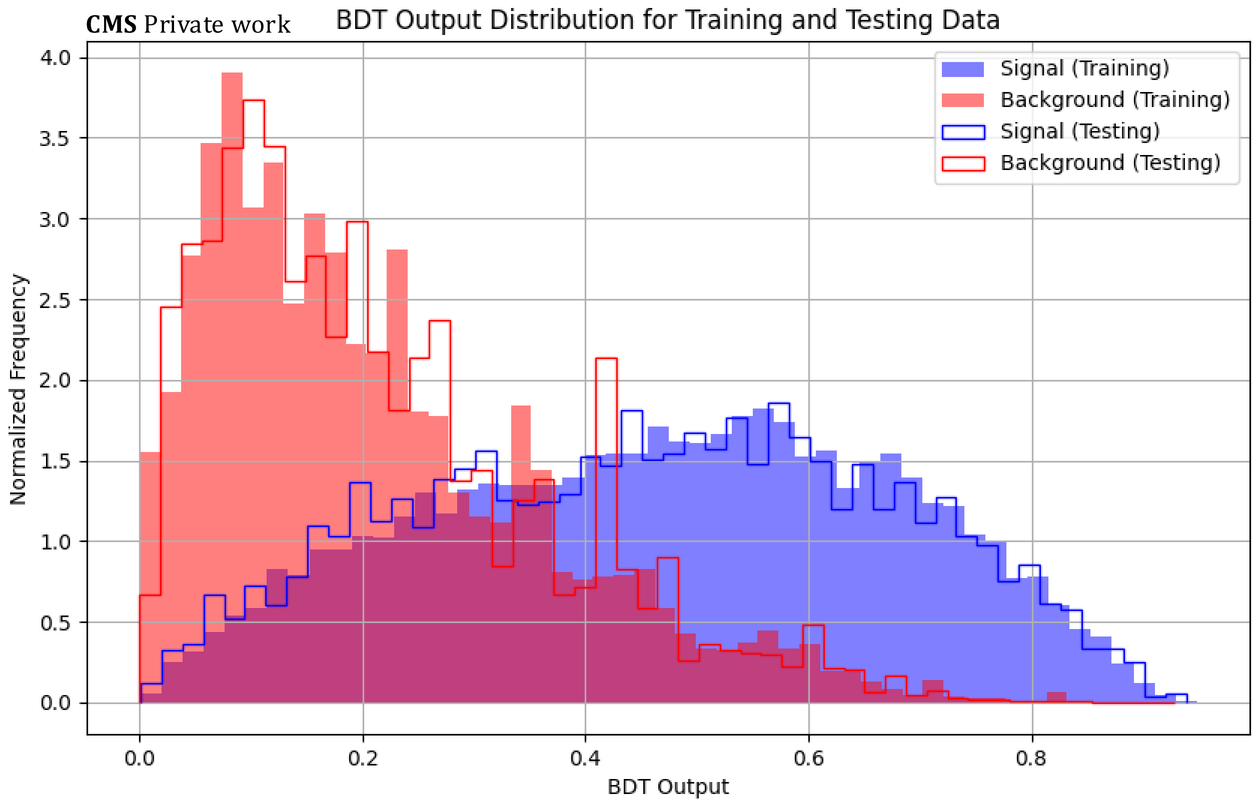
The W boson mass is constrained to its PDG value, and the missing transverse energy is assumed to correspond to the neutrino $p_T$ to solve for the neutrino $p_Z$

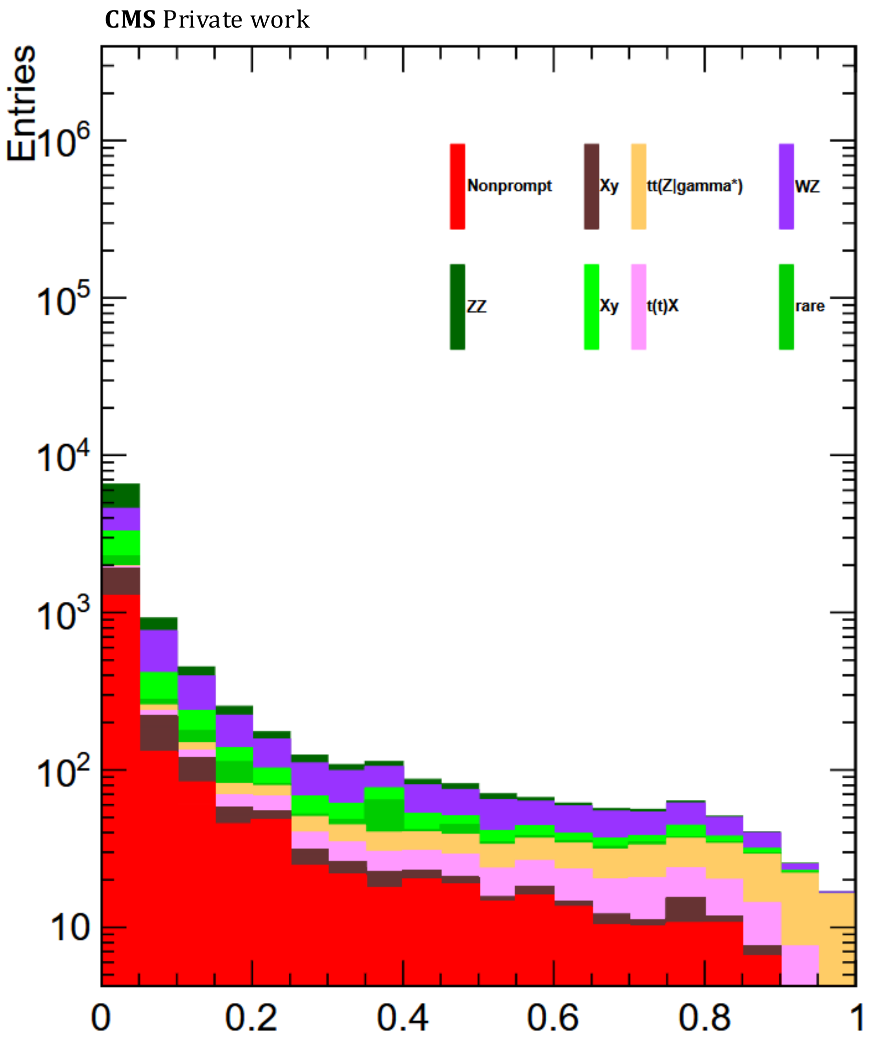
If this lead to no real solution for the neutrino $p_Z$, we modify the neutrino $p_T$ such that $m_W = m_{W,T}$



# BDT score

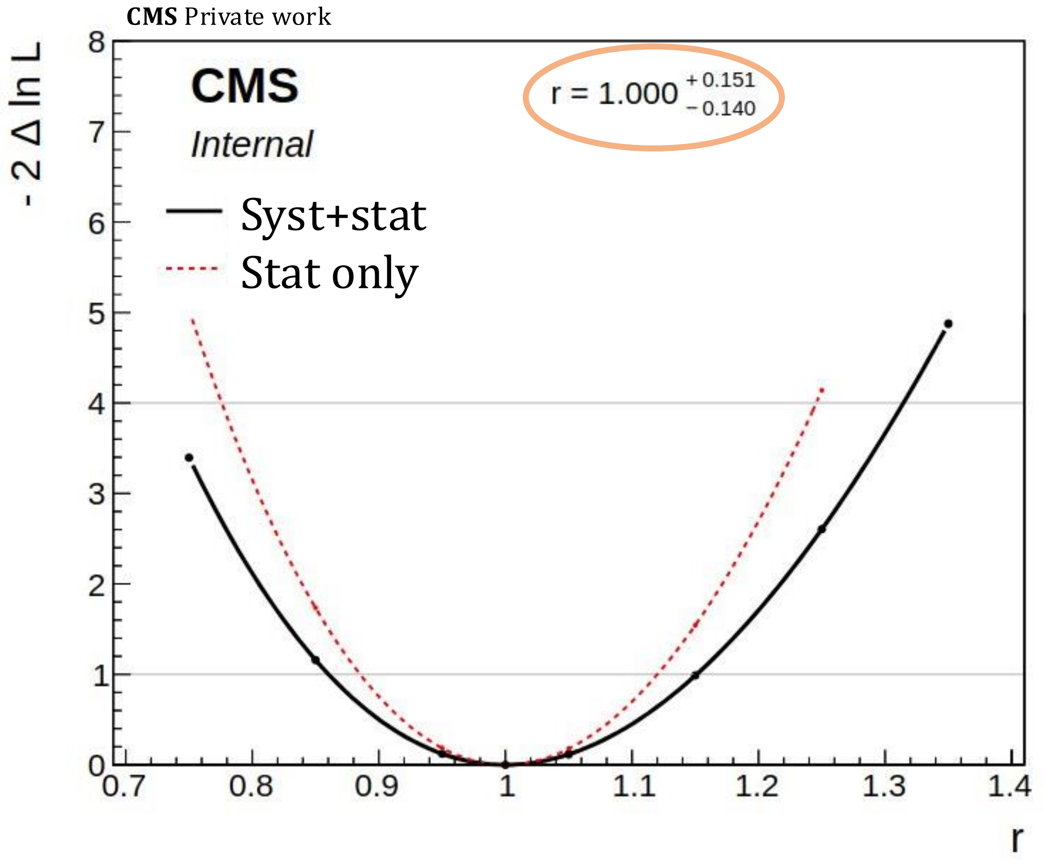
**The BDT training is still ongoing**



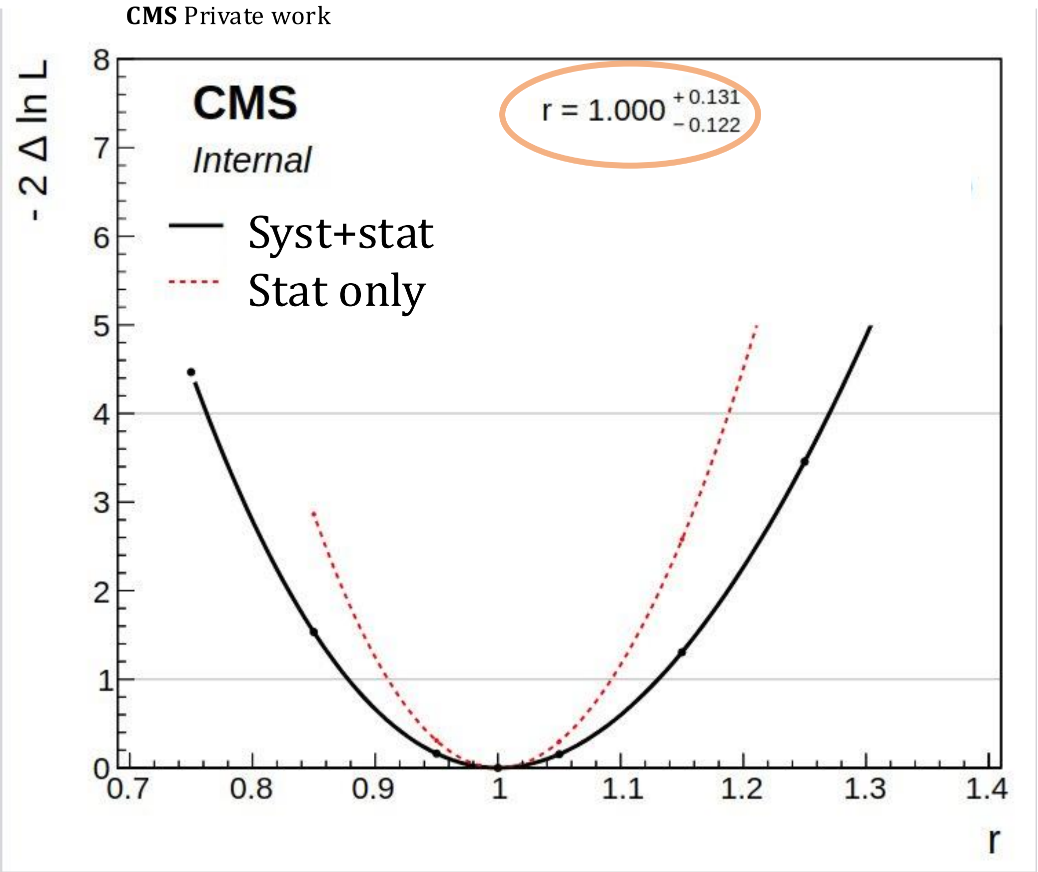



# Signal strength

Result with $N_{jets}$ observable



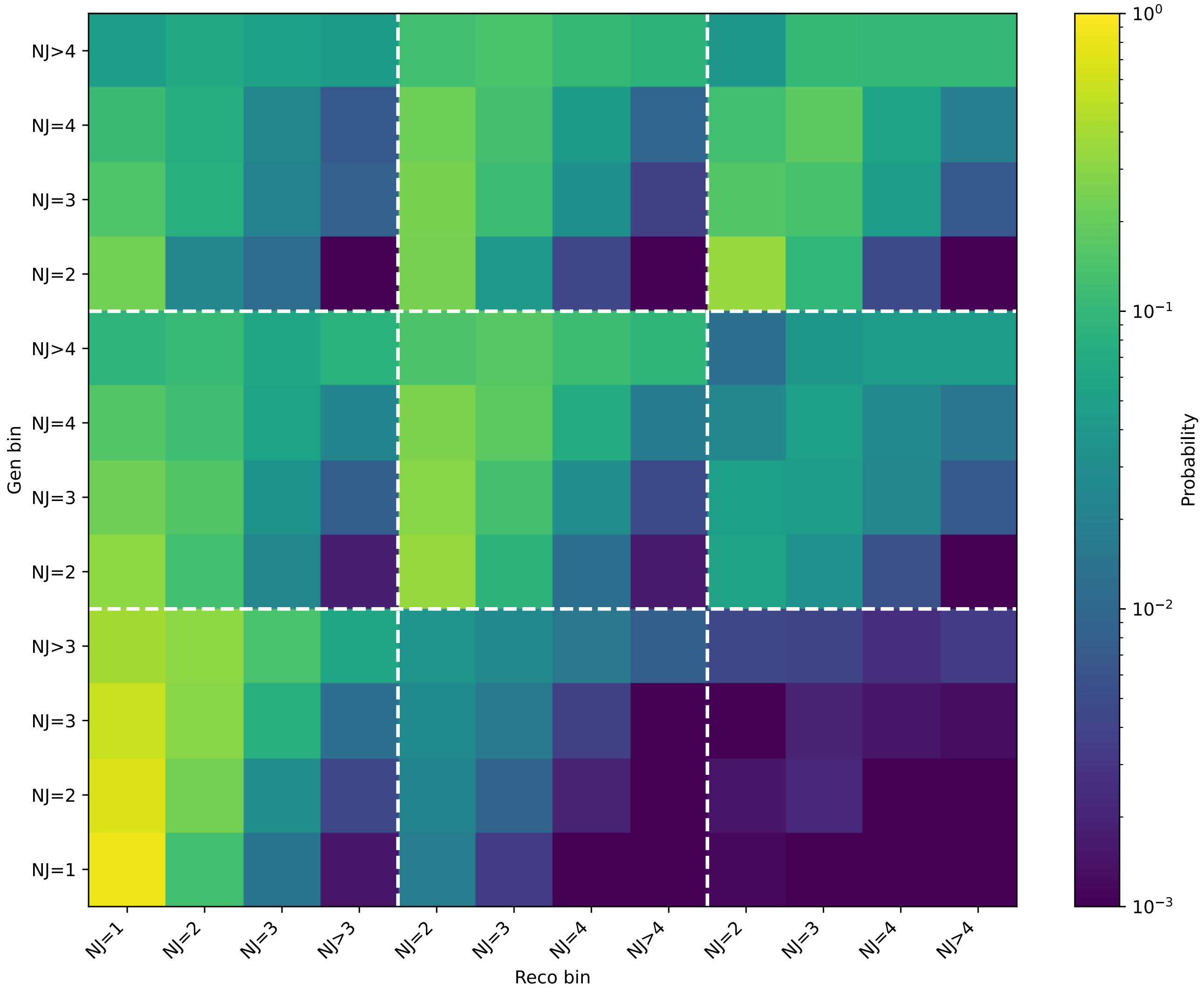

Result with BDT score




**Improvement on the signal strength uncertainty (~13%)**

# Unfolding – Response Matrix

- Correct for detector effects and recover the true distribution
- Response matrix describes the migration between true and reconstructed variables
- Input for ongoing unfolding process



# Conclusion and perspective

**Already done:**

- A framework nearly ready to do $t\bar{t}Z/\gamma^*$analysis in Run 2
- Top reconstruction algorithm to identify the dilepton pair
- Azimov signal strength mesurement
- Unfolding setup

**Next steps:**

- Separation in $ee/\mu\mu$ chanels
- Measurement of the ratio $ee/\mu\mu$
- Generation of EFT samples
- Measurement of Wilson coefficients

# Thank you