RESULTS AND PROSPECTS ON AN EFT INTERPRETATION OF THE TWZ PROCESS

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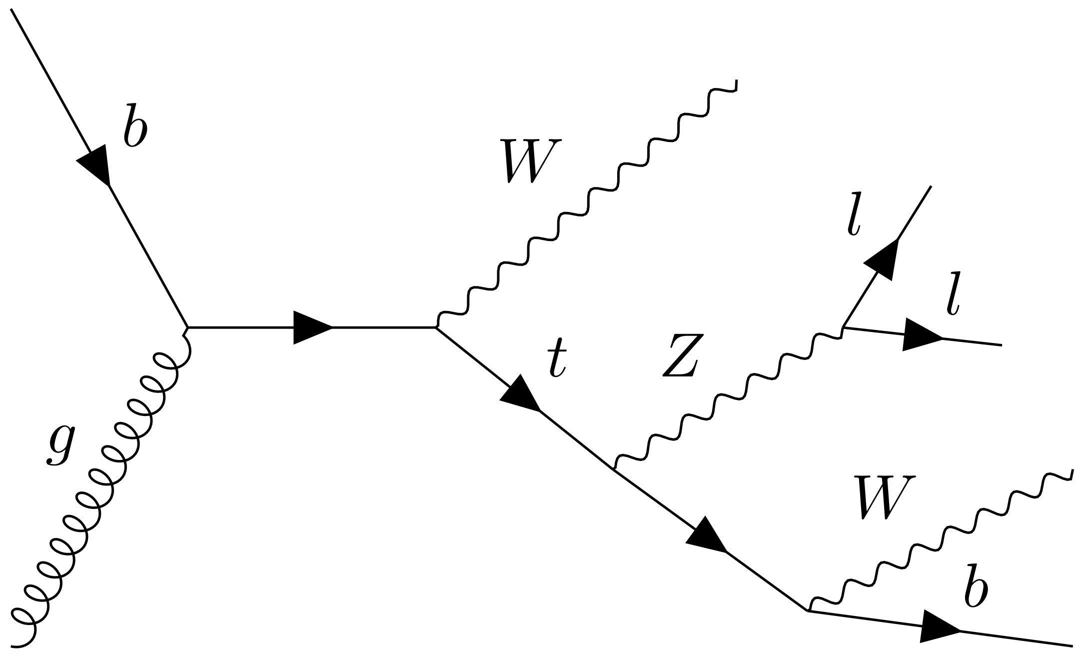
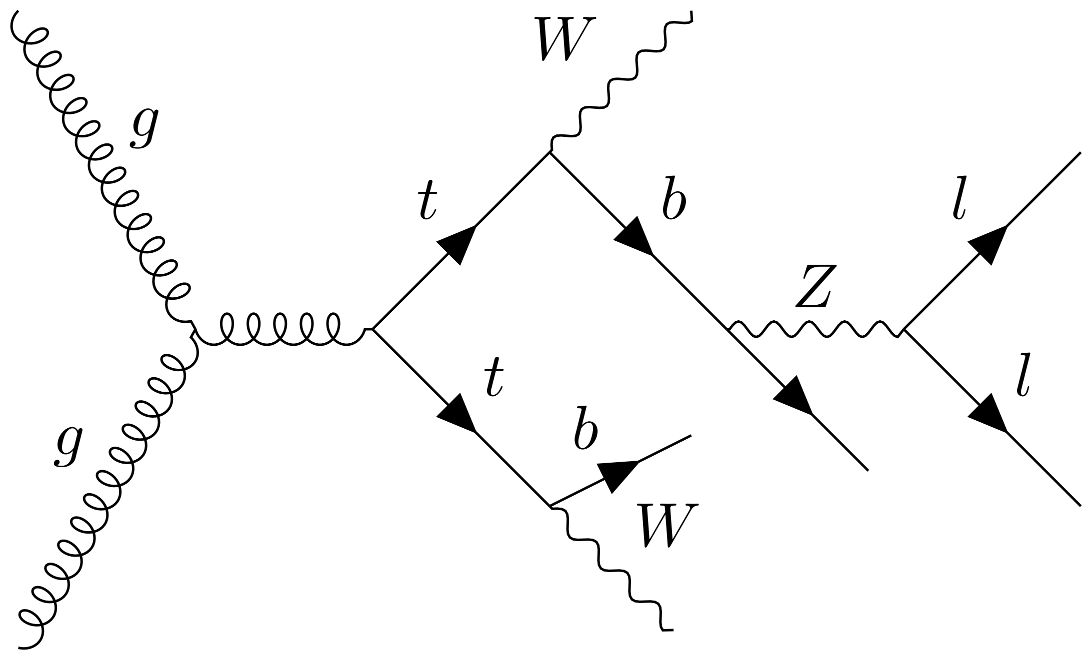
The TWZ process

- CMS has recently published the first evidence for the TWZ process.
- Very challenging process:
  - **Small** predicted **cross-section** (σ_{tWZ} = 127 fb).
  - **Large** irreducible **background** (TTZ process):





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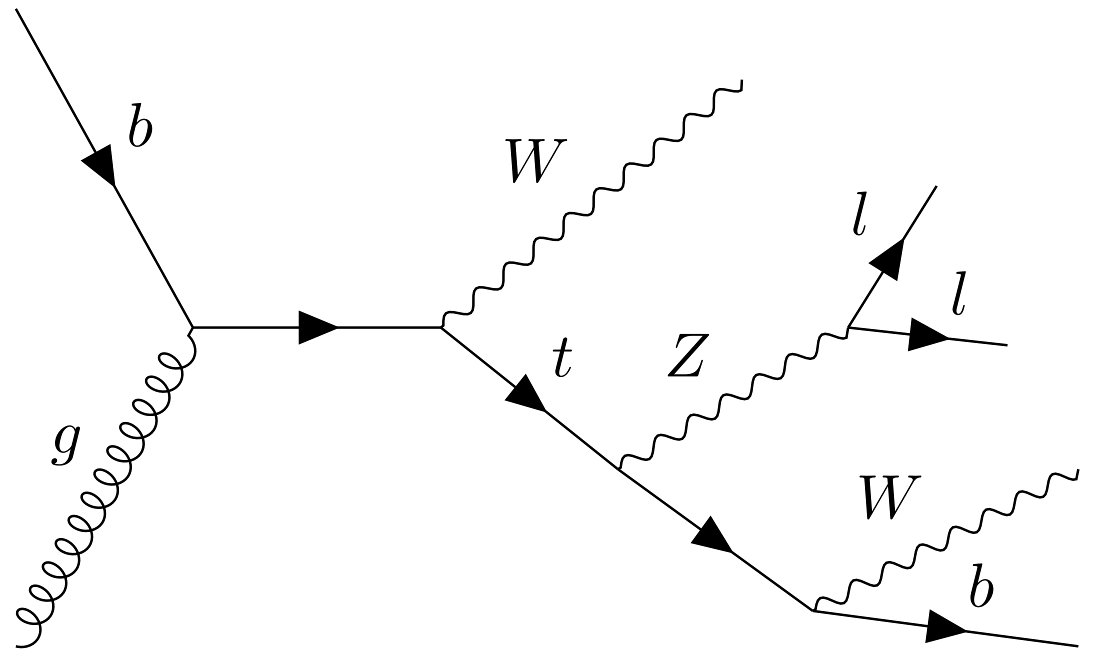
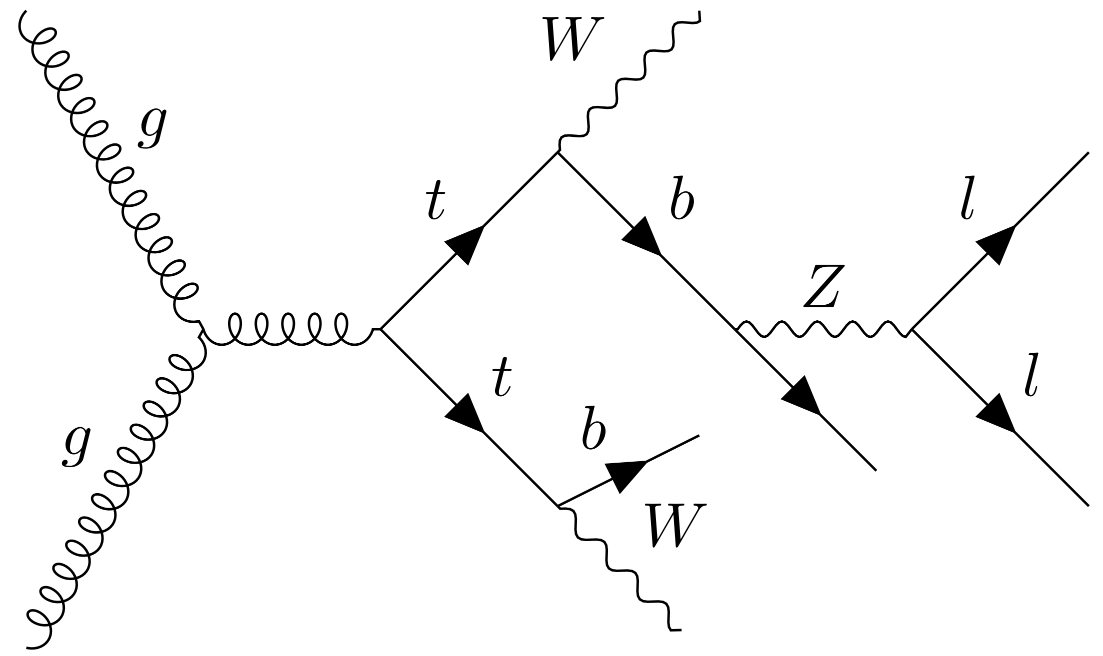
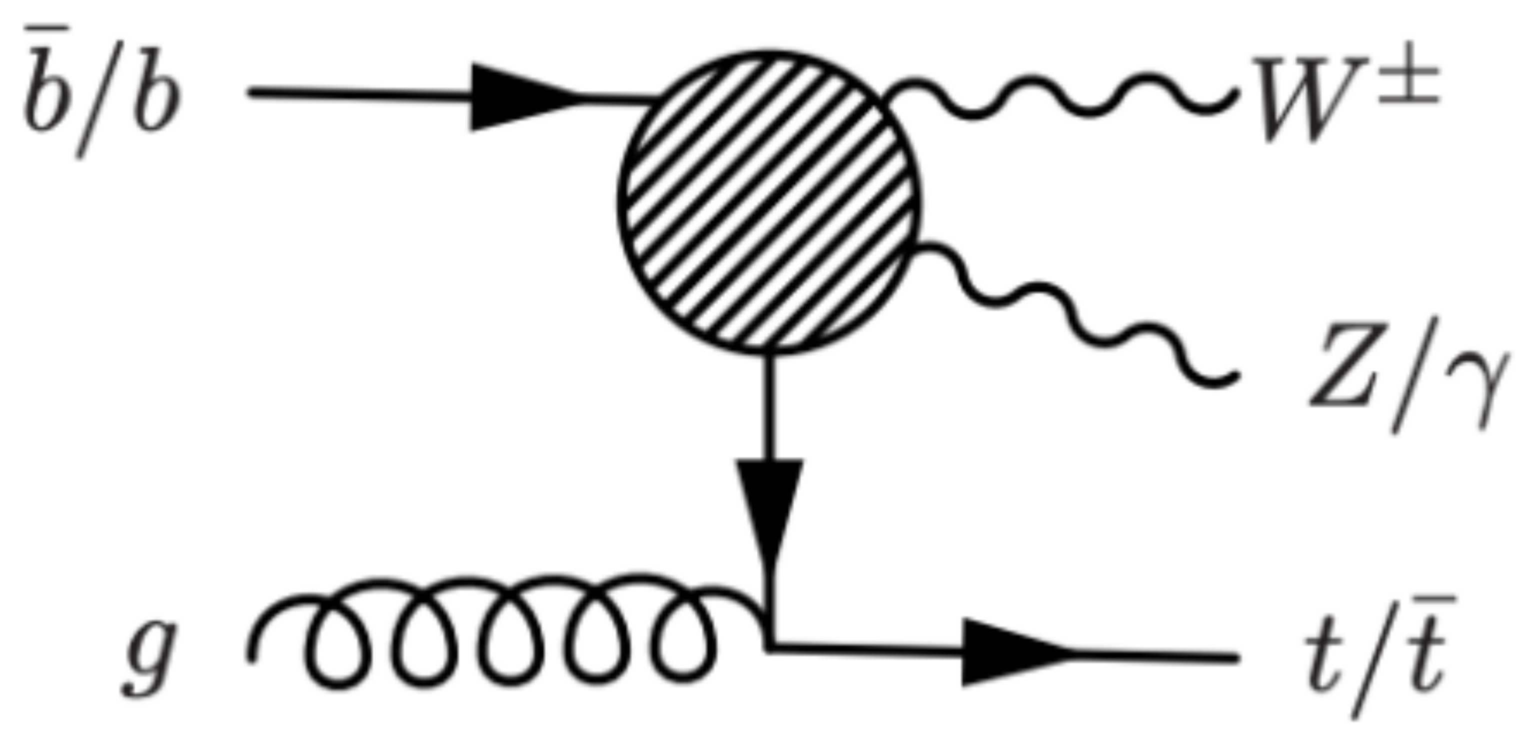




- New physics could arise from **bW→tZ** vertices leading to energy growth in specific kinematic distribution.

arXiv:1904.05637 arXiv:2111.03080



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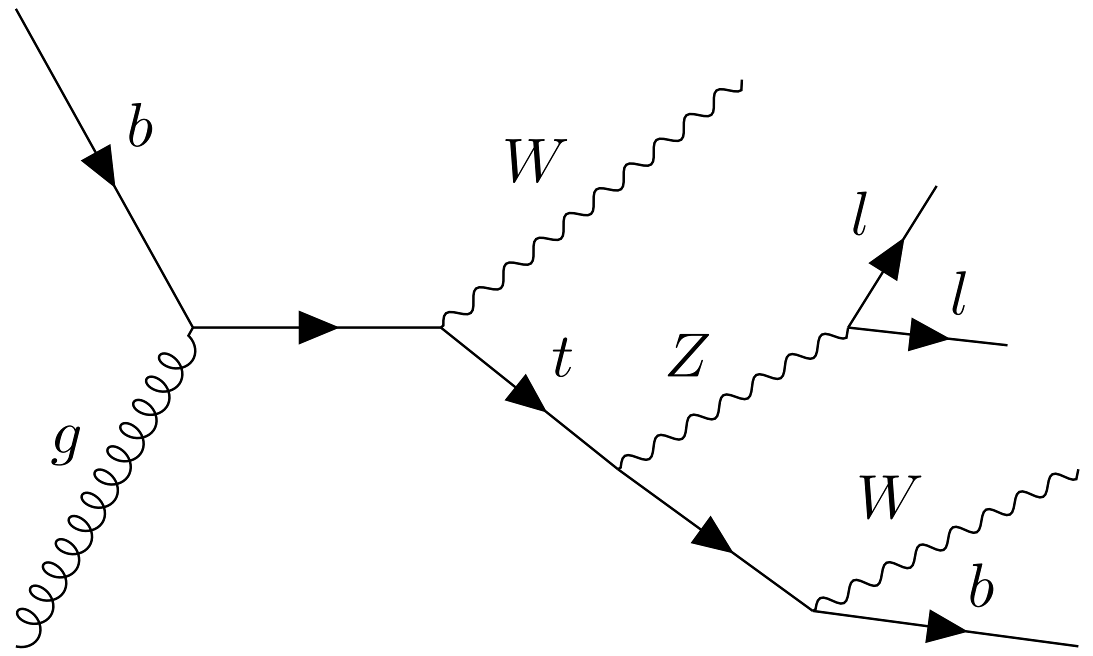

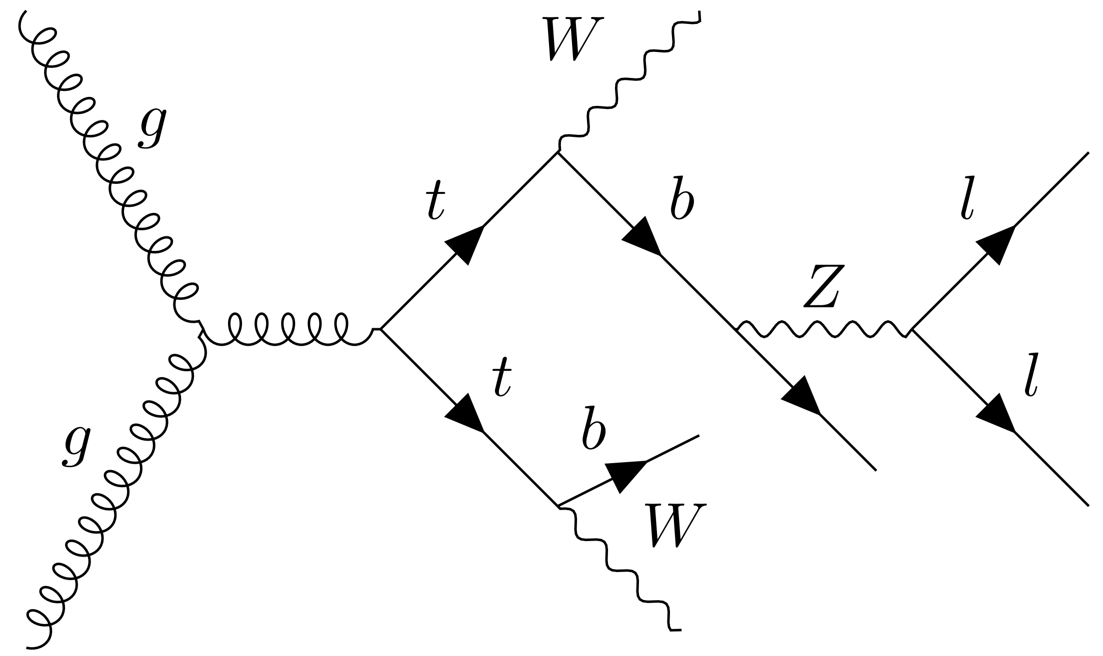

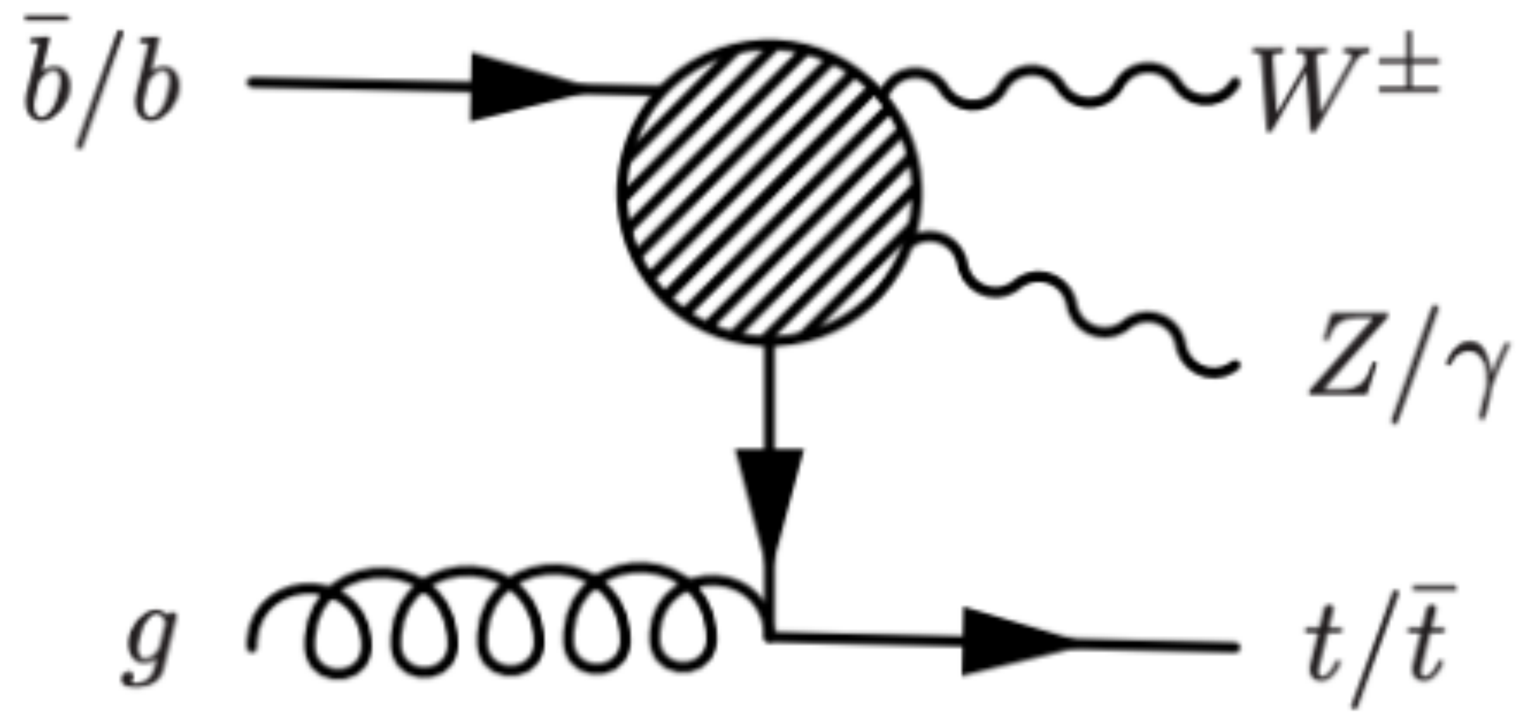

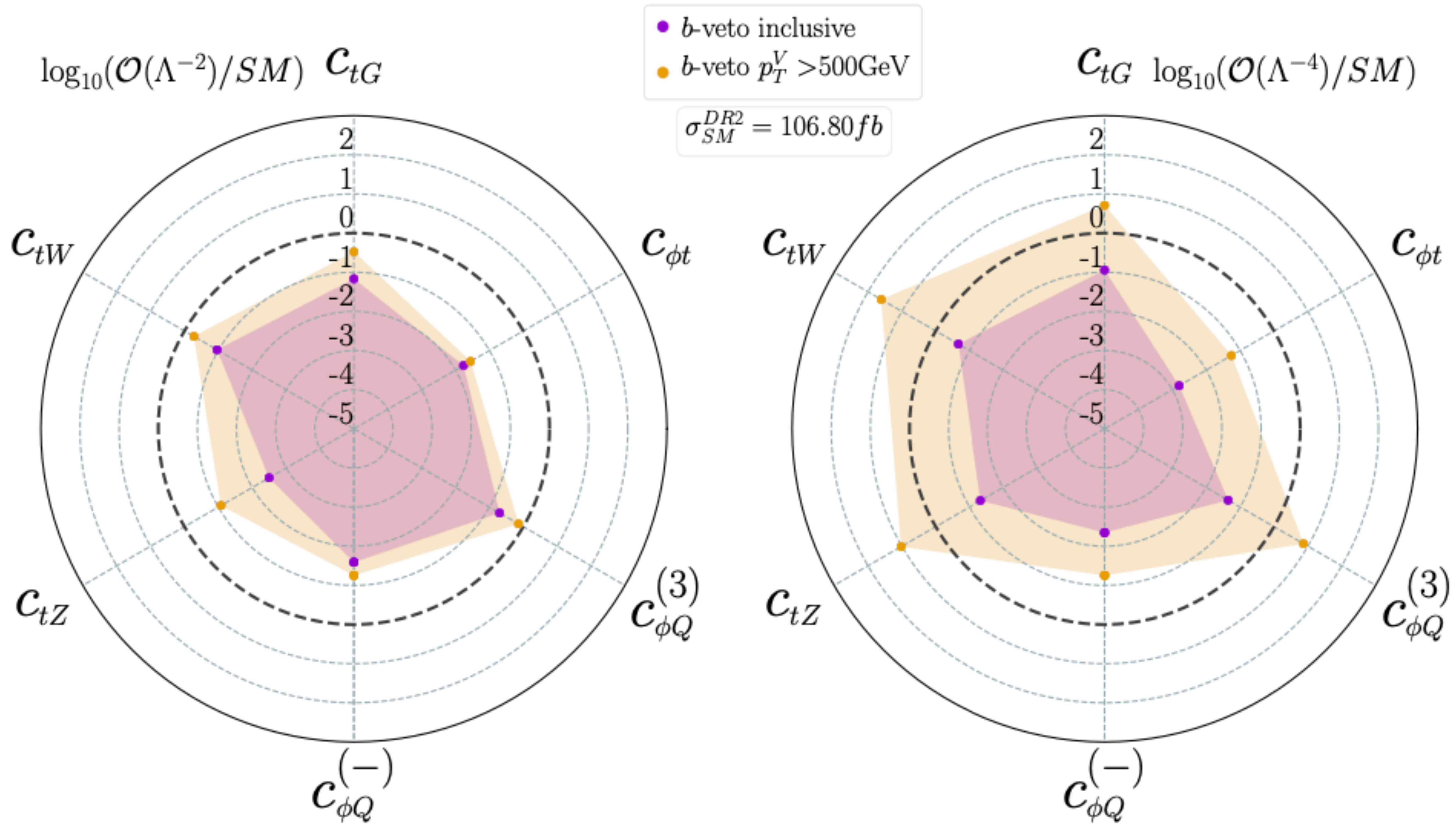

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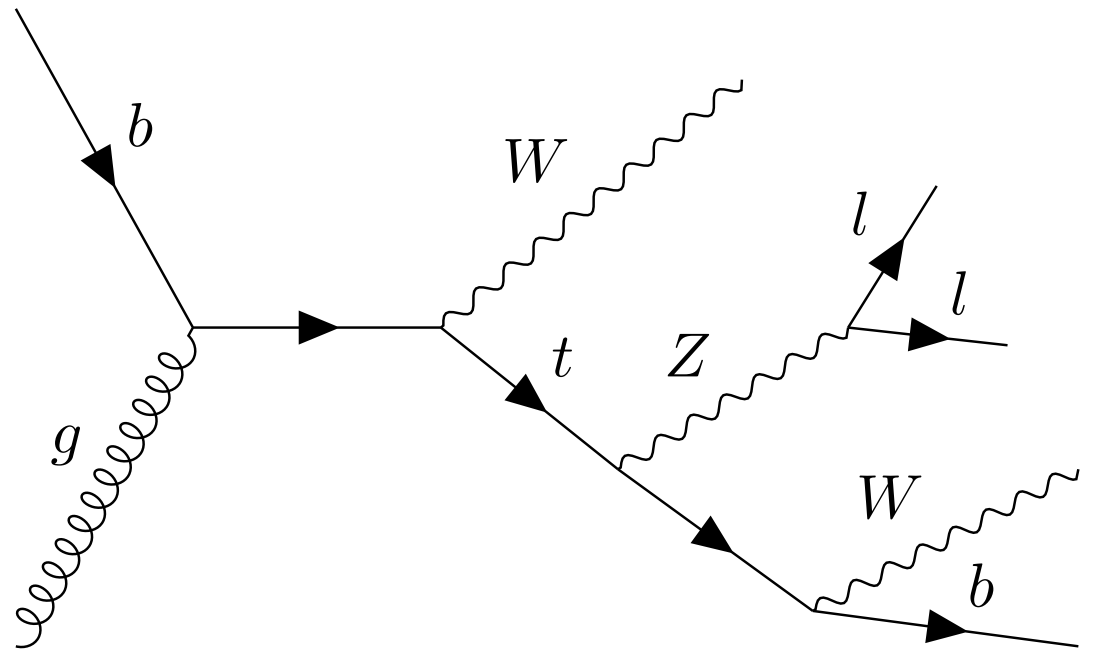

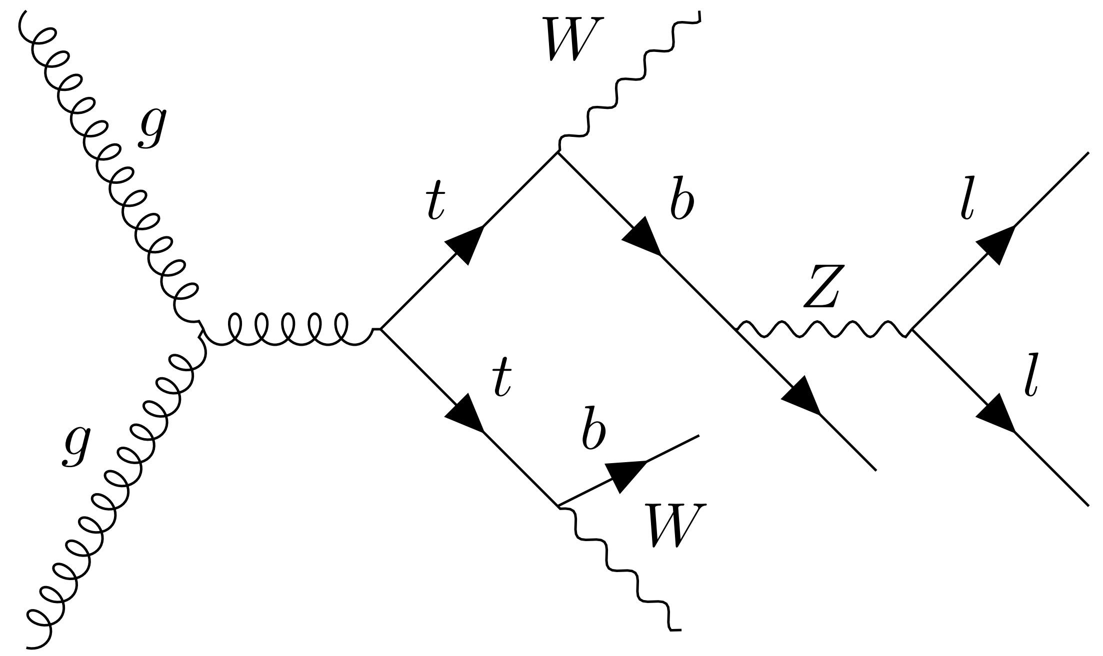

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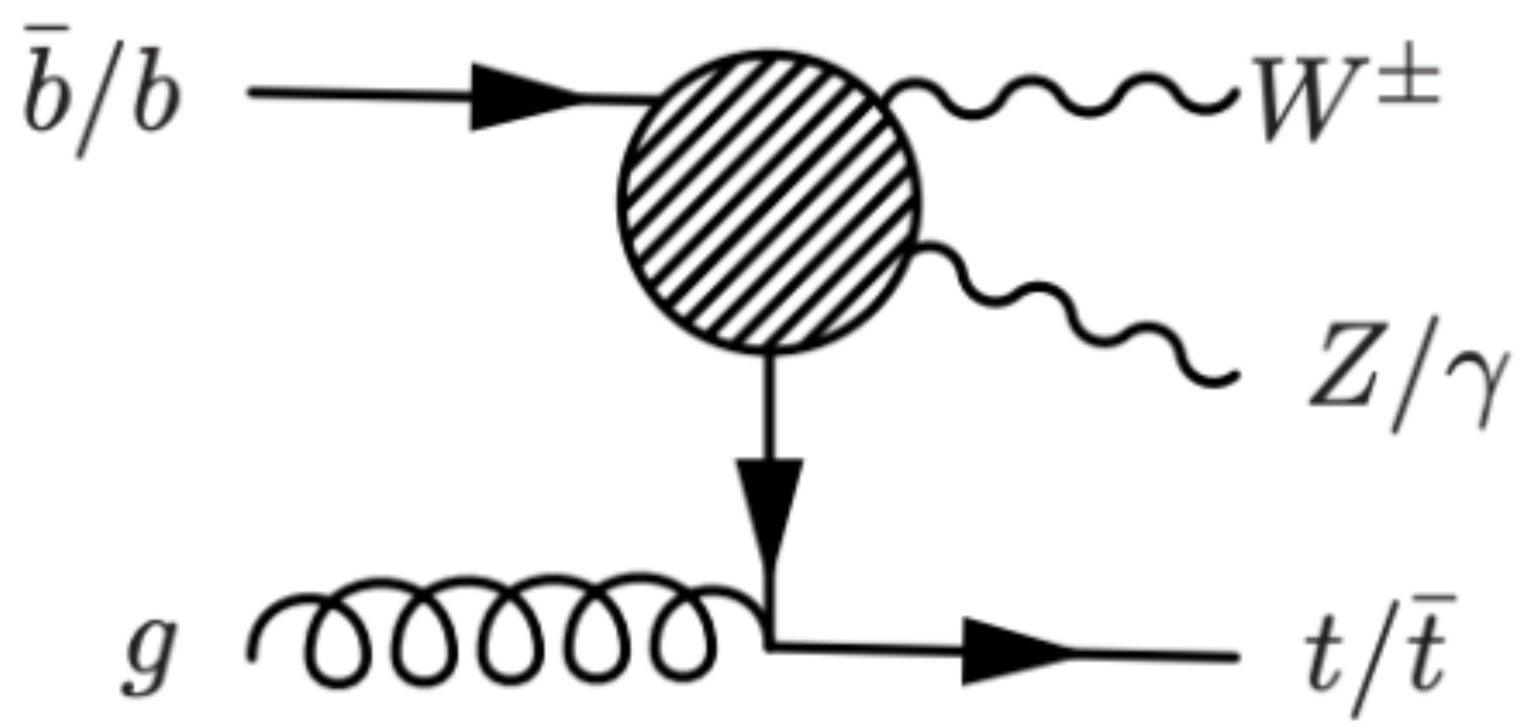
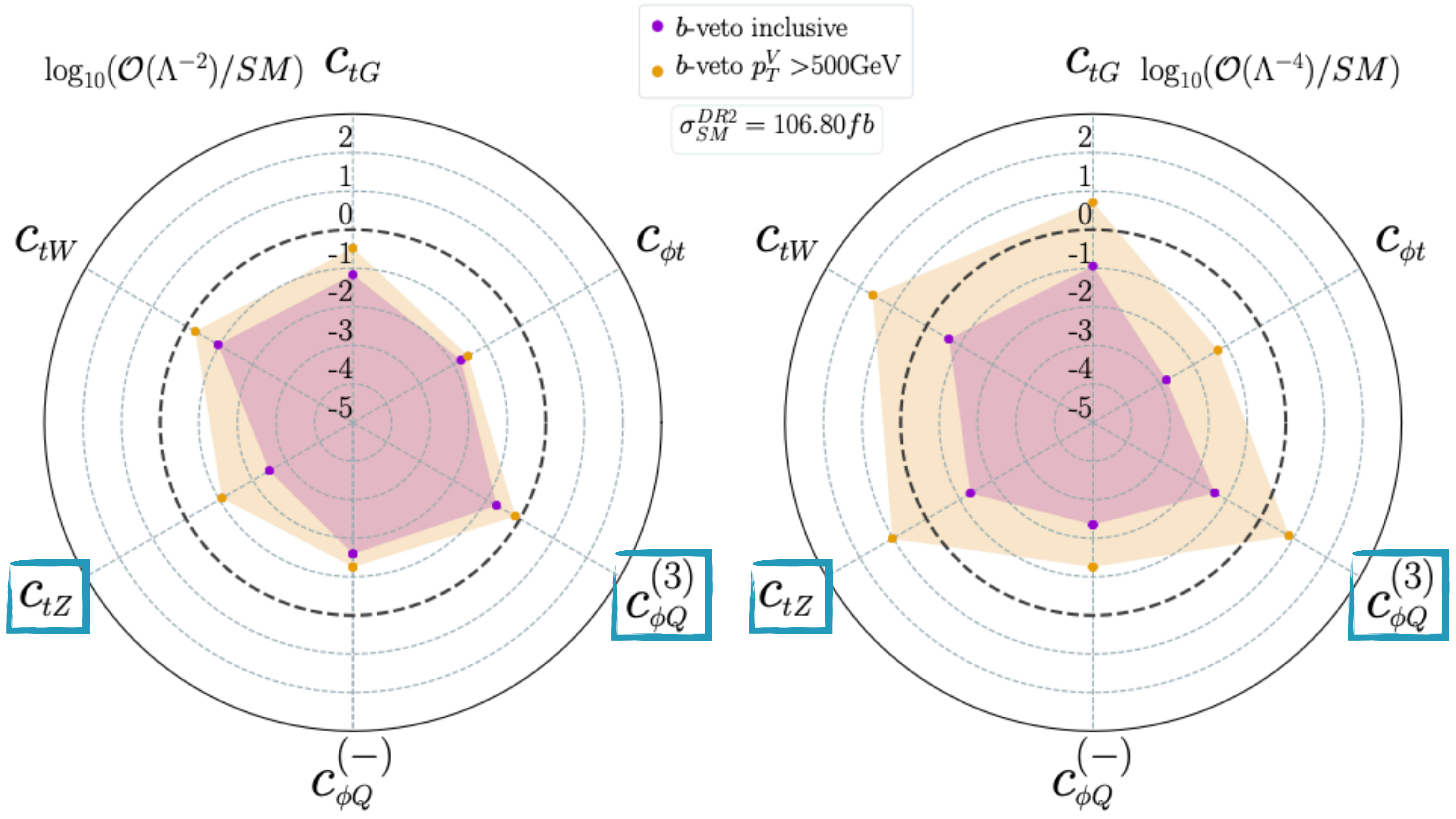




SMEFT PREDICTION GENERATION

$$\mathcal{L} = \frac{1}{\Lambda^0}\mathcal{L}_{SM}^{(d=4)} + \frac{1}{\Lambda}\mathcal{L}^{(d=5)} + \frac{1}{\Lambda^2}\mathcal{L}^{(d=6)} + \dots$$

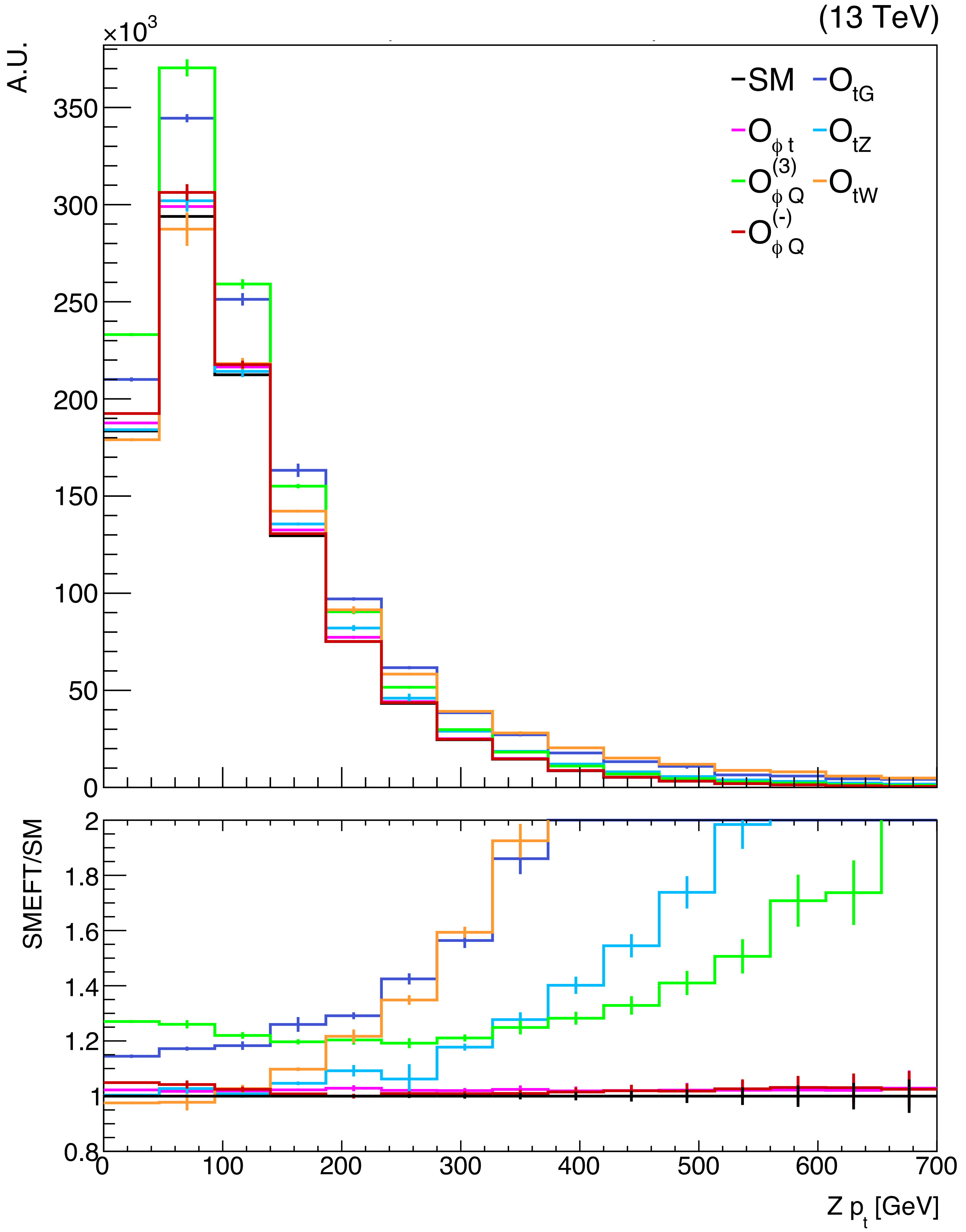
$$\sum_i \frac{c_i \mathcal{O}_i^{(6)}}{\Lambda^2}$$

- SMEFT prediction generated using **MadGraph5** (v2.6.5) and the **SMEFT@NLO** model (v1.0.3).
- Focus on the $\mathcal{O}_{tZ}$ and the $\mathcal{O}_{\phi Q}^{(3)}$ **operators**.
- **Normalisation scale** set to 1 TeV.
- Reweighting used to generate enough EFT points to perform a fit to the data where the **Wilson coefficients** are free parameters.

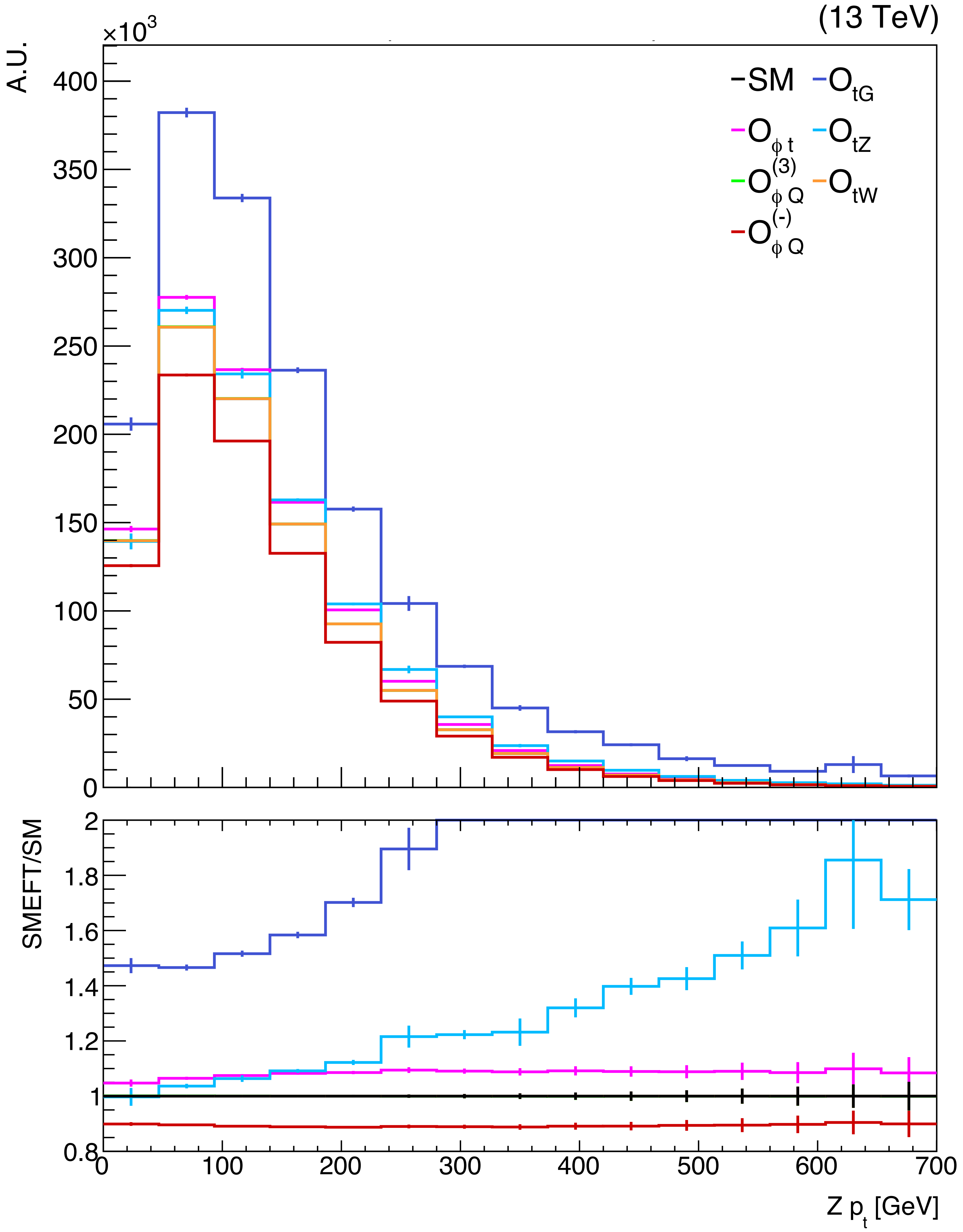
SMEFT PREDICTIONS

Comparison between SM distributions and SMEFT distributions obtained through reweighting.

TWZ



TTZ



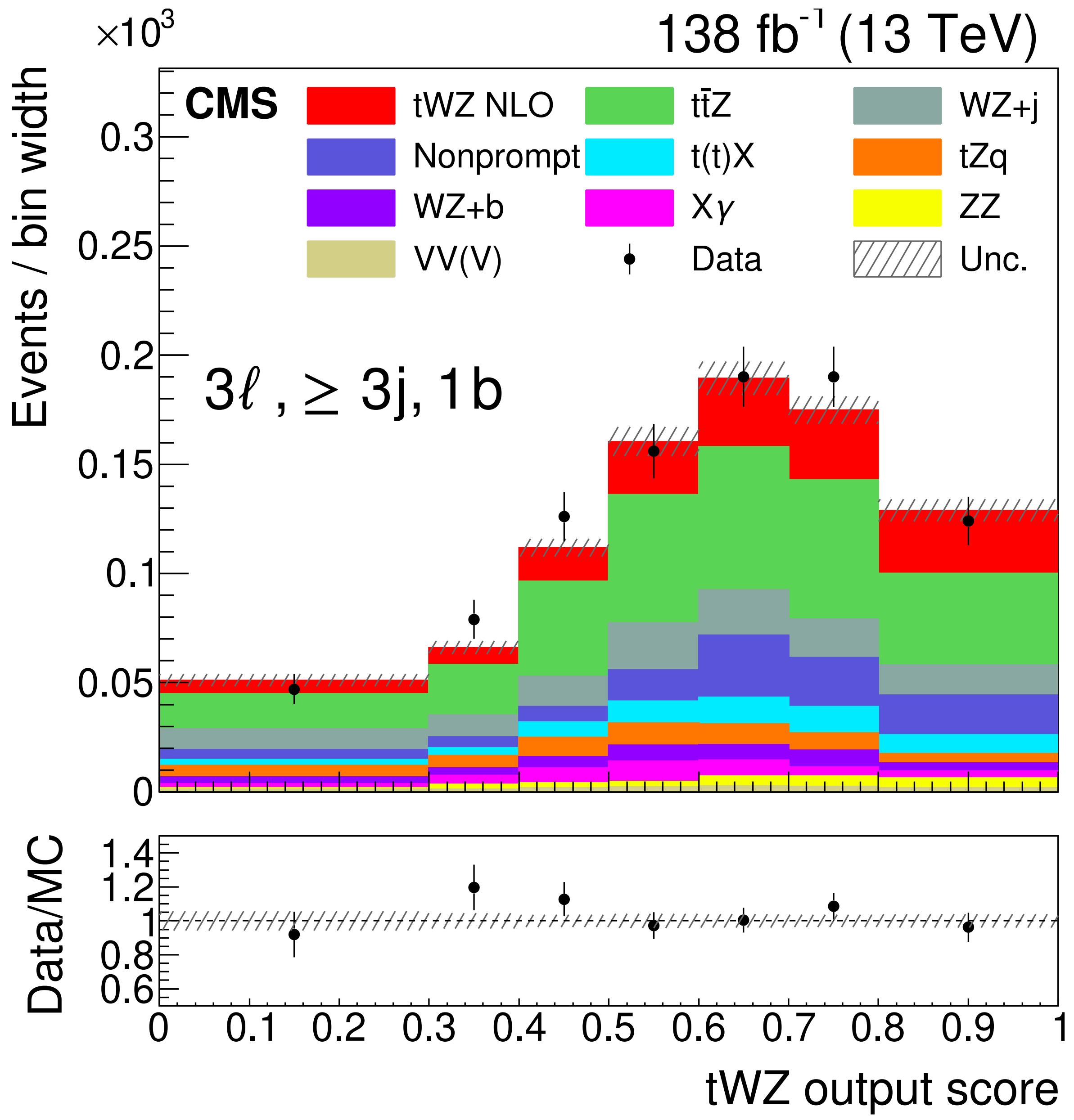
- Excess for the $\mathcal{O}_{\phi Q}^{(3)}$ operator present only for the **TWZ** process.
- The $\mathcal{O}_{tZ}$ operator shows energy growth for both **TWZ** and **TTZ**.
- **TWZ** is more sensitive than **TTZ** to most of the operators.

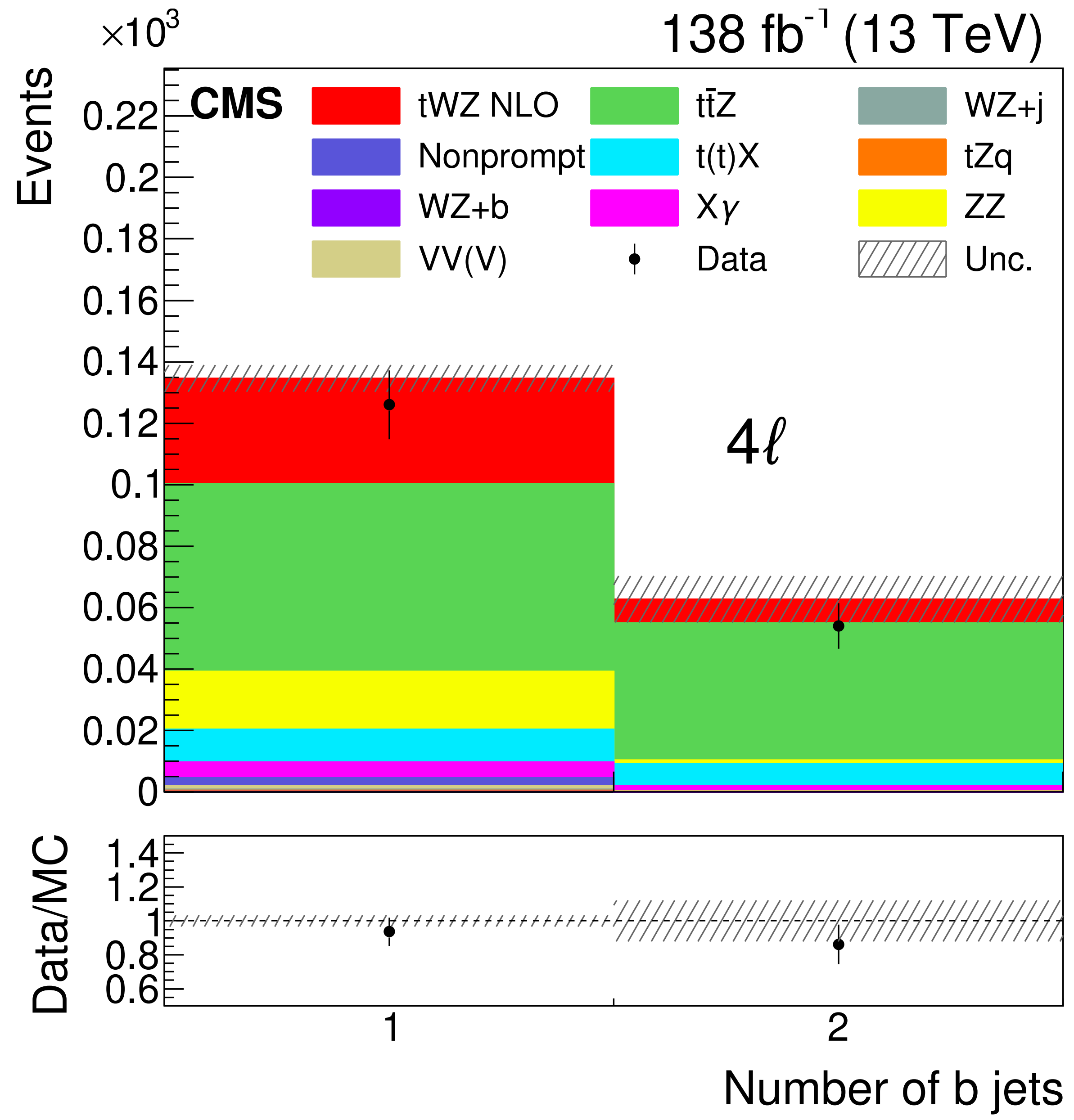
Re-Interpretation of CMS Measurement

CMS measurement

- Three and four-lepton final states.
- DNN to separate between **TWZ** and **TTZ** in 3ℓ and $N_{\text{b-jets}}$ in 4ℓ.

CMS, arXiv:2312.11668





EFT interpretation

- Simulation of **TTZ** and **TWZ** processes (σ_{ttZ} = 787 fb, σ_{tWZ} = 127 fb).
- Estimate event yields using realistic assumptions for acceptances and lepton efficiencies.
- Background yields from CMS measurement.
- Uncertainties:
  - 15% on **TTZ** and **TWZ**
  - 10% on **VV**
  - 30% on non-prompt leptons
  - 11% on other backgrounds

EVENT YIELDS AND EXPECTED SIGNAL STRENGTHS

	3ℓ	**4ℓ**
TTZ (CMS) **TTZ (this study)**	781 803 ± 120	114 101 ± 15
TWZ (CMS) **TWZ (this study)**	105.7 108 ± 16	16 13 ± 2
VV bkg	504 ± 50	22 ± 2
NP bkg	309 ± 93	1 ± 0.3
Other bkg	485 ± 53	24 ± 3
CMS observed	**2312**	**180**

- Efficiencies to separate between TWZ and TTZ:
  - SR: $\varepsilon_{tWZ} = 0.5$, $\varepsilon_{ttZ} = 0.25$
  - CR: $1 - \varepsilon_{tWZ}$ and $1 - \varepsilon_{ttZ}$

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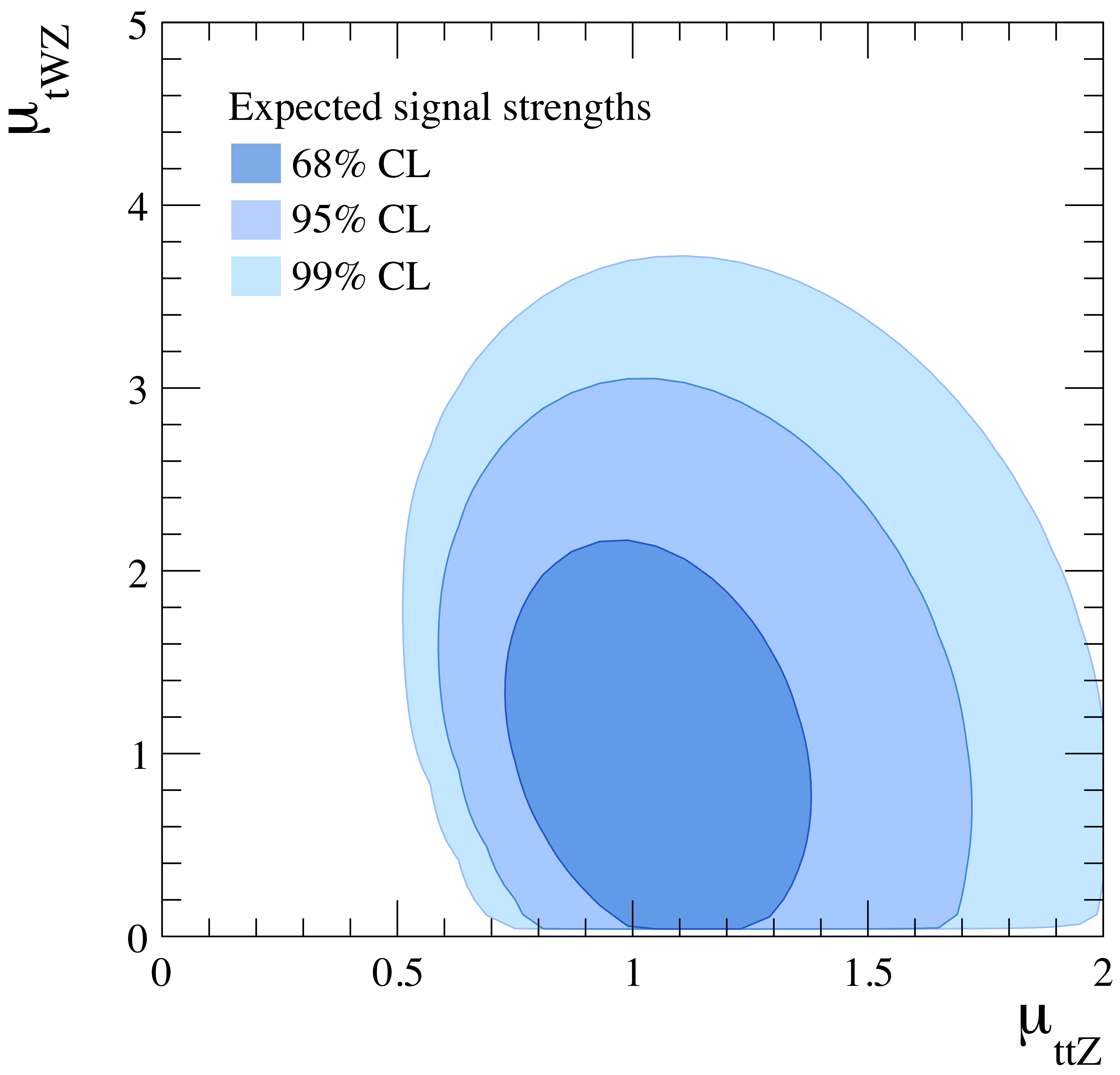

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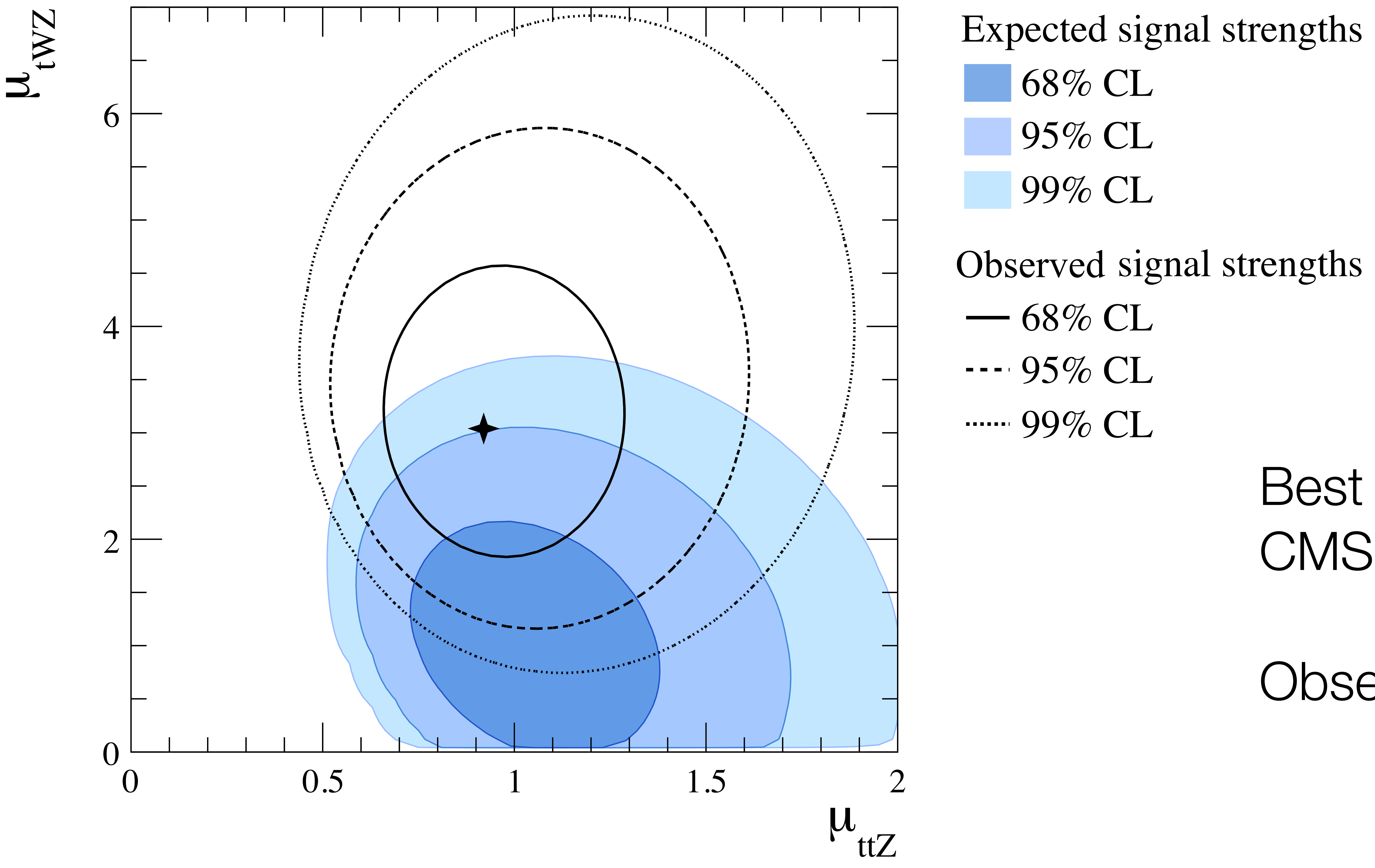
OBSERVED AND EXPECTED LIMITS

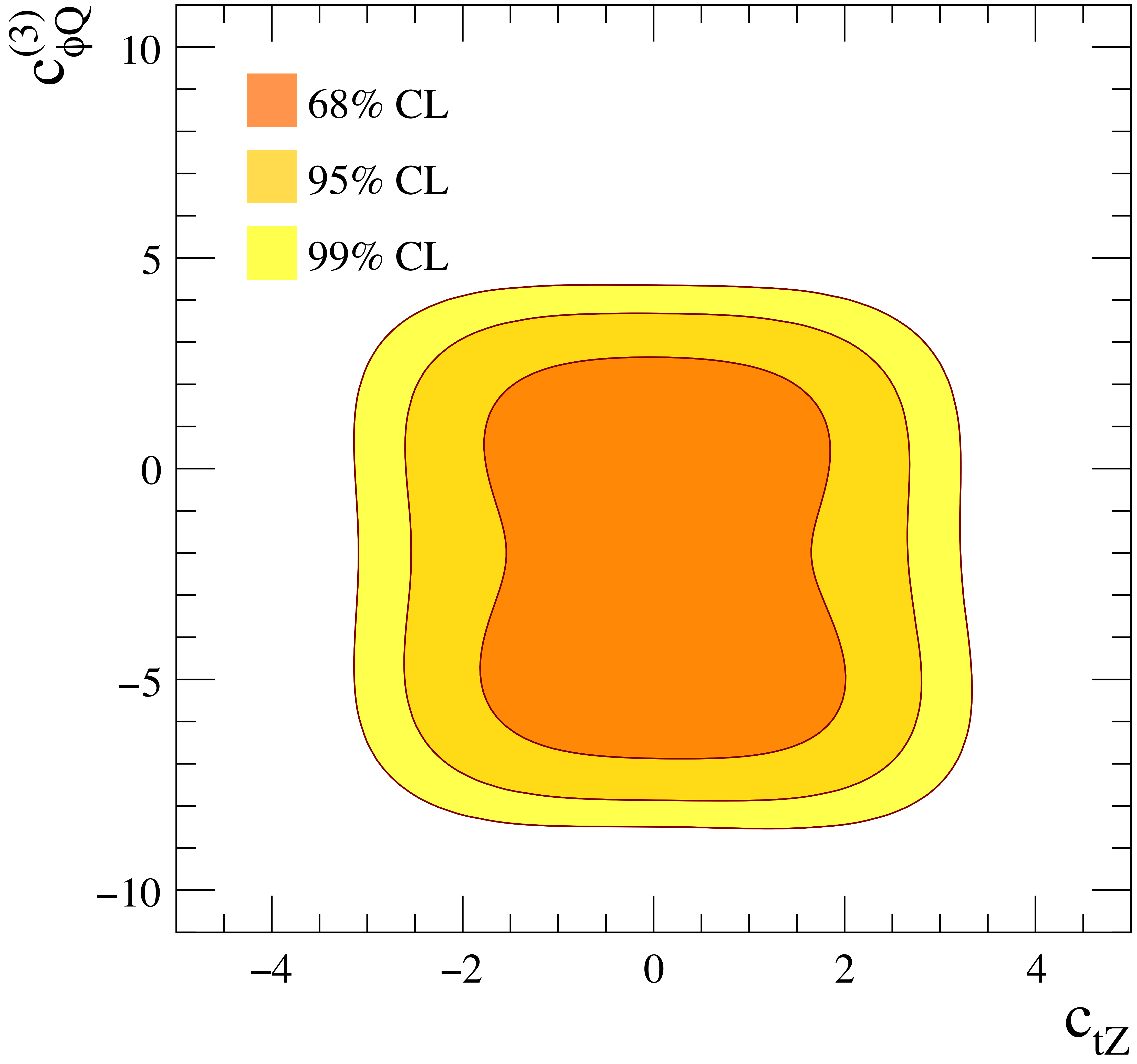


Best fit values: $\mu_{tWZ} = 3$, $\mu_{ttZ} = 0.92$

CMS values: $\mu_{tWZ} = 3.4$, $\mu_{ttZ} = 0.87$

Observed μ_{tWZ} is 2σ higher than SM.

SMEFT LIMITS FROM CMS TWZ



Bounds on the $\mathcal{O}_{tZ}$ and the $\mathcal{O}_{\phi Q}^{(3)}$ operators **compatible with SM**.

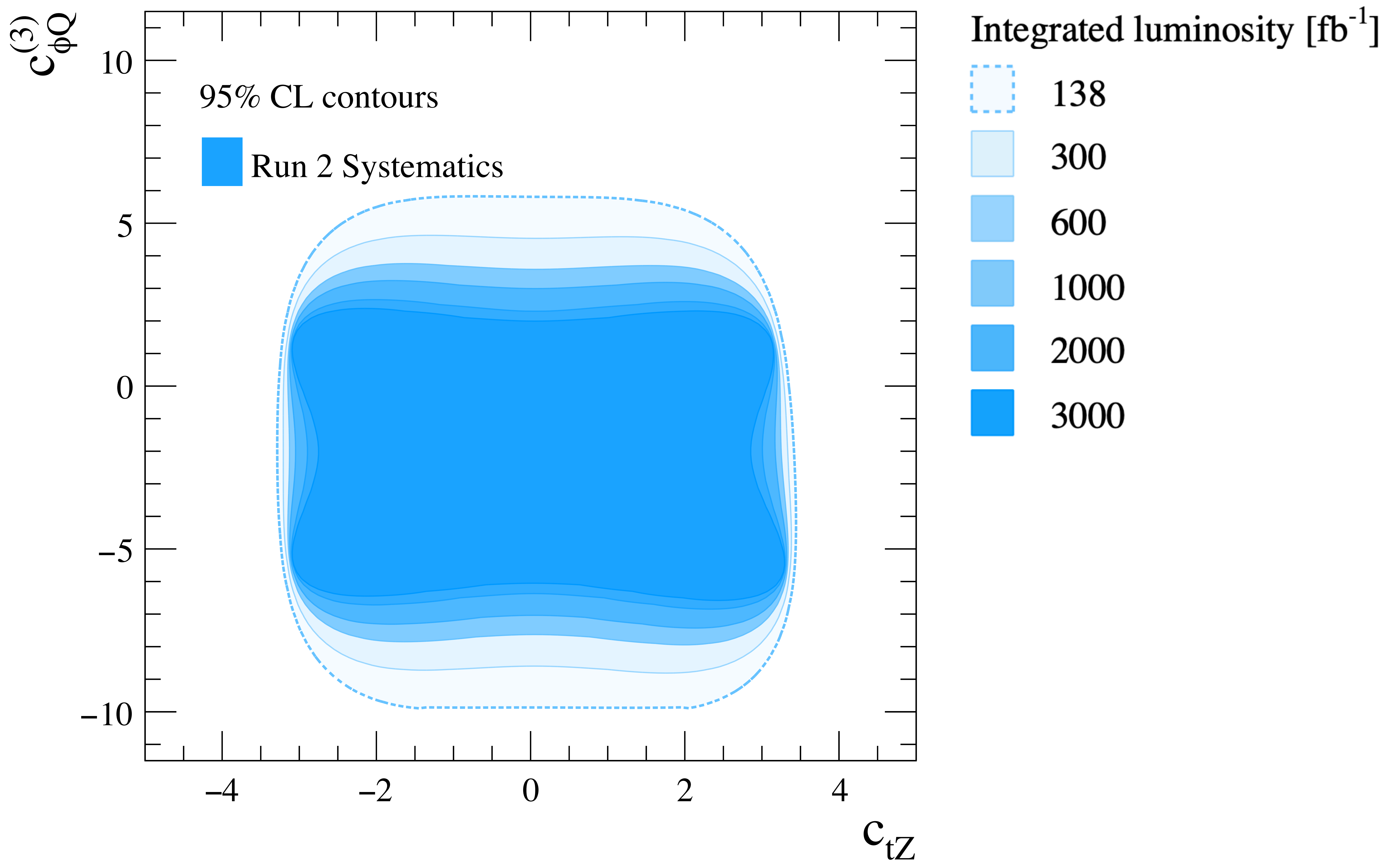
Result on $\mathcal{O}_{tZ}$ can improve global fits, where this measurement is one of the more powerful ones.

Sensitivity on $\mathcal{O}_{\phi Q}^{(3)}$ not great yet.

Future improvements will make TWZ more powerful to constrain this operator.

Prospects for SMEFT constraints from tWZ/ttZ

- Consider SM values for sensitivity estimates.
- Extrapolate measurement to HL-LHC luminosities.



Improvement in c_{tZ} marginal for 3000 fb^{-1}

Some improvement for $c^{(3)}_{\phi Q}$ but less than factor of two.

→ **Systematically limited!**

PROSPECTS FOR SMEFT CONSTRAINTS FROM TWZ/TTZ

- Improve systematics gradually to have 1/2 the size of uncertainties at 3000 fb^{-1}

- Assume improved analysis methods resulting into a better signal background separation:

  $\varepsilon_{tWZ} = 0.65$
  $\varepsilon_{ttZ} = 0.18$
  $\varepsilon_{bkg} = 0.5$

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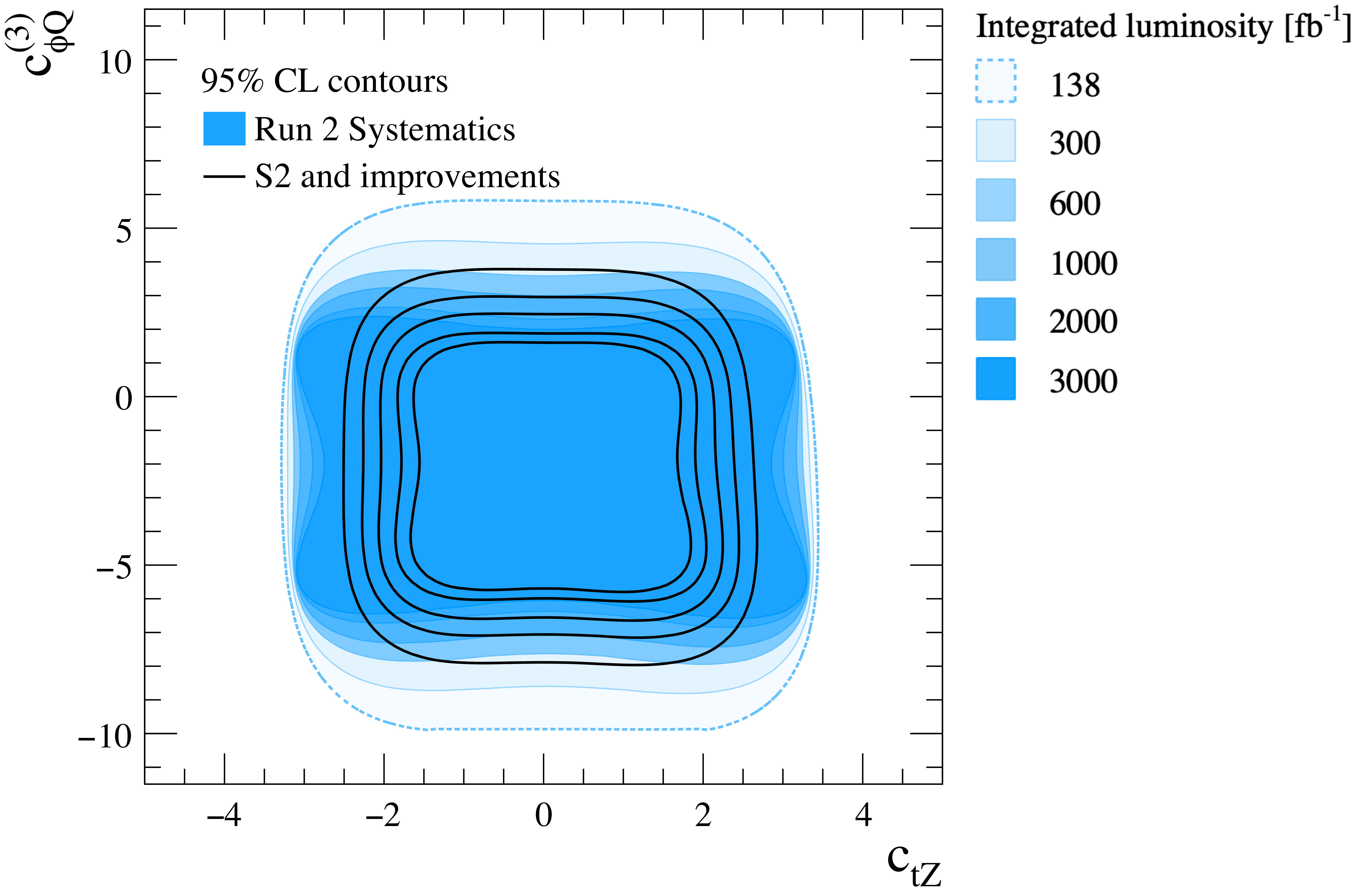
→ **Substantially better constraints**



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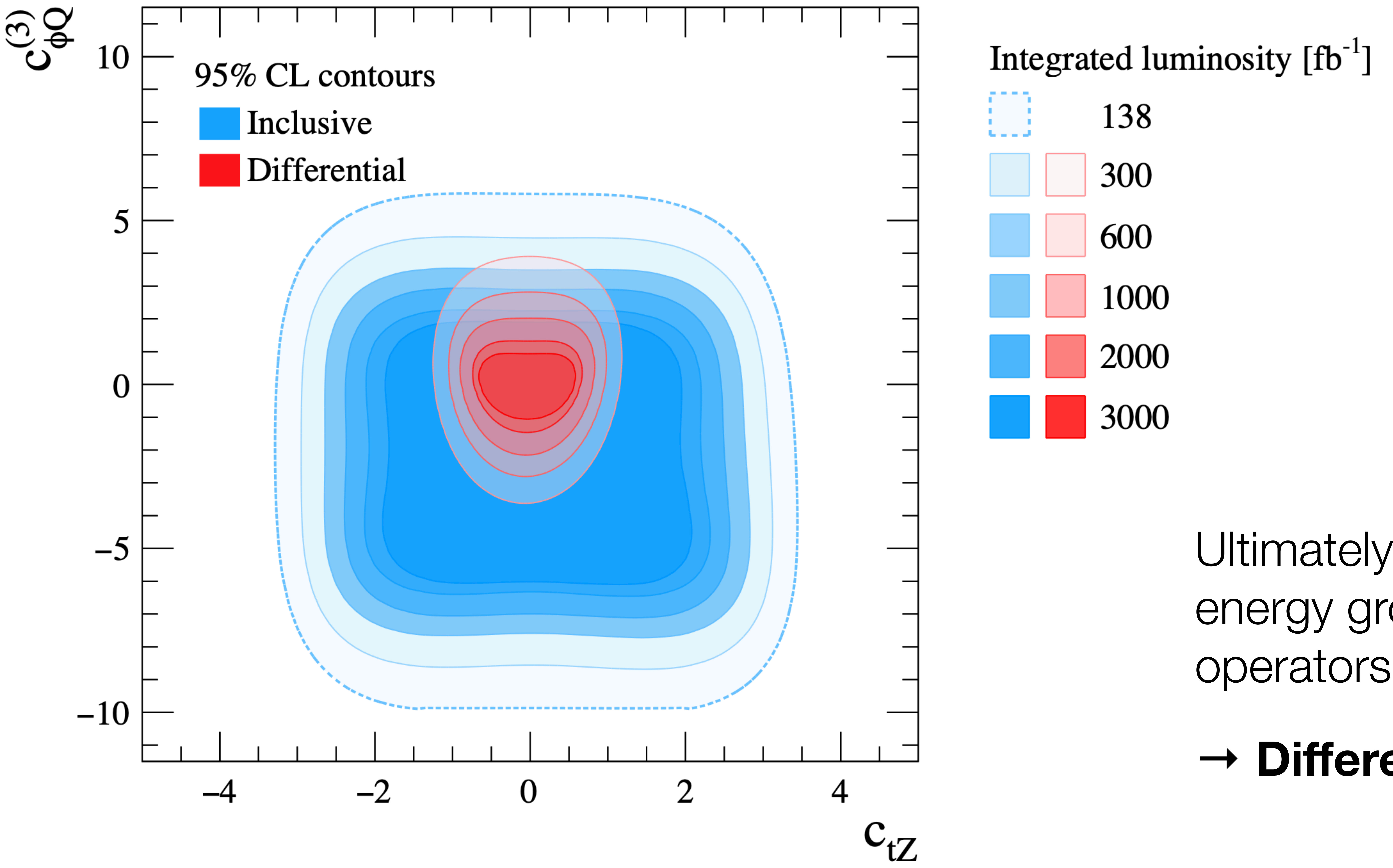

Ultimately, use the anomalous energy growth of SMEFT operators.

→ **Differential measurements**

CONCLUSIONS

The TWZ process is a very promising process for probing EFT operators that modify the top-electroweak SM interaction.

The recent CMS measurement has been leveraged to derive **limits on the Wilson coefficient** of the $\mathcal{O}_{tZ}$ and $\mathcal{O}_{\phi Q}^{(3)}$ operators and to **explore possible future analysis strategies** to enhance the sensitivity to these operators.

- A **differential measurement** in Z p_T significantly enhances the sensitivity to possible EFT effects.
- Overlap between TWZ and TTZ: **simultaneous measurement** is much more powerful than the individual unfolding of TWZ [J. Keaveney, PhysRevD.107.036021].

BACKUP SLIDES

OPERATIVE DEFINITION OF THE tWZ PROCESS

The cancellation of the overlap between tWZ and tt̄Z can be done in two ways:

- Diagram subtraction (**DS**): locally gauge-invariant subtraction term.
- Diagram removal (**DR**): resonant diagrams directly removed from computation.

$$|\mathcal{M}_{tWZ}|^2 = |\mathcal{M}_{tWZ}^{non-res}|^2 + 2\mathcal{R}(\mathcal{M}_{tWZ}^{res}\mathcal{M}_{tWZ}^{non-res}) + |\mathcal{M}_{tWZ}^{res}|^2$$

$$|\mathcal{M}_{tWZ}|^2_{DR1} \equiv |\mathcal{M}_{tWZ}^{non-res}|^2$$

$$|\mathcal{M}_{tWZ}|^2_{DR2} \equiv |\mathcal{M}_{tWZ}^{non-res}|^2 + 2\mathcal{R}(\mathcal{M}_{tWZ}^{res}\mathcal{M}_{tWZ}^{non-res})$$

The DR1 scheme is applied using the **MadSTR** tool.