Probing top quark couplings in associated top quark production

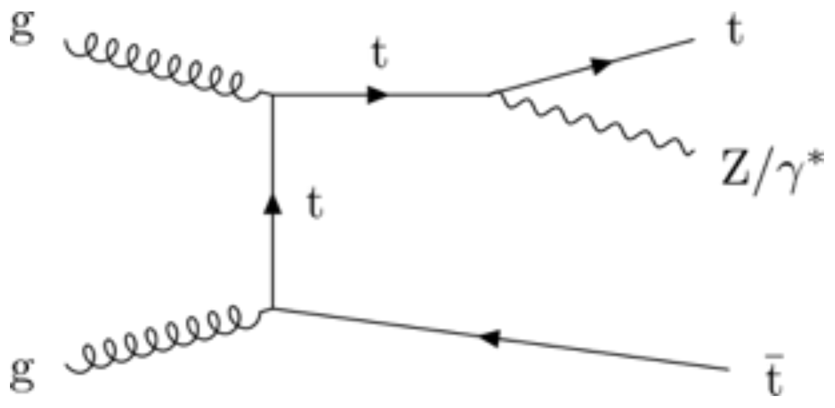
M.S.Soares on behalf of the ATLAS and CMS Collaborations
CKM2018 - Heidelberg

This talk:

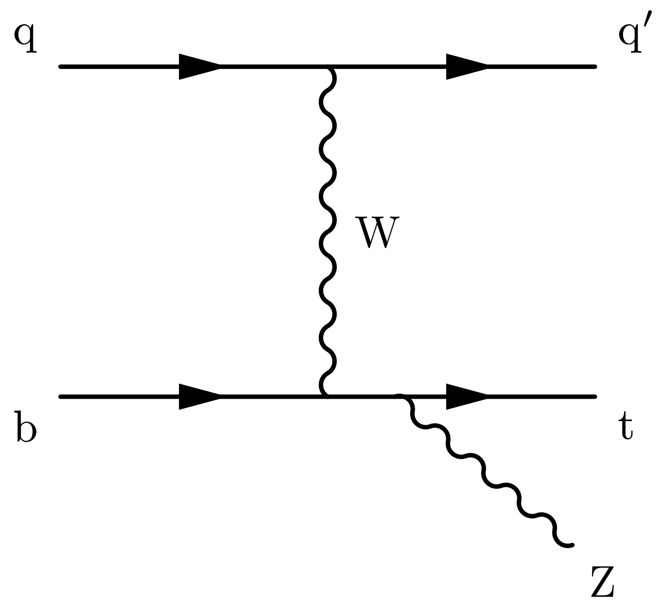
Experimental status of the following SM processes - sensitive to (rare) top couplings:

top quark coupling to Z boson:

1. ttV

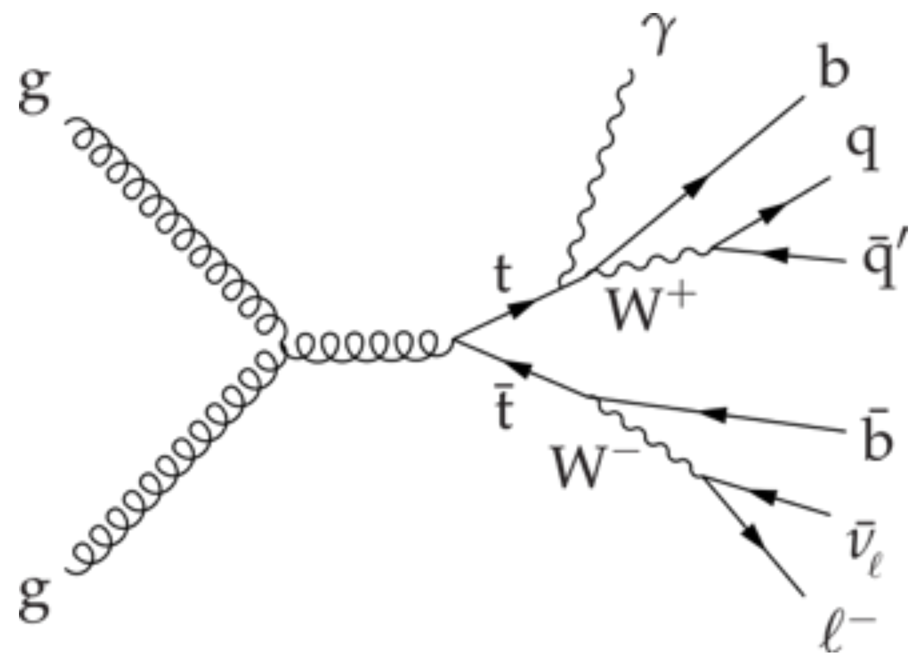


2. tZq

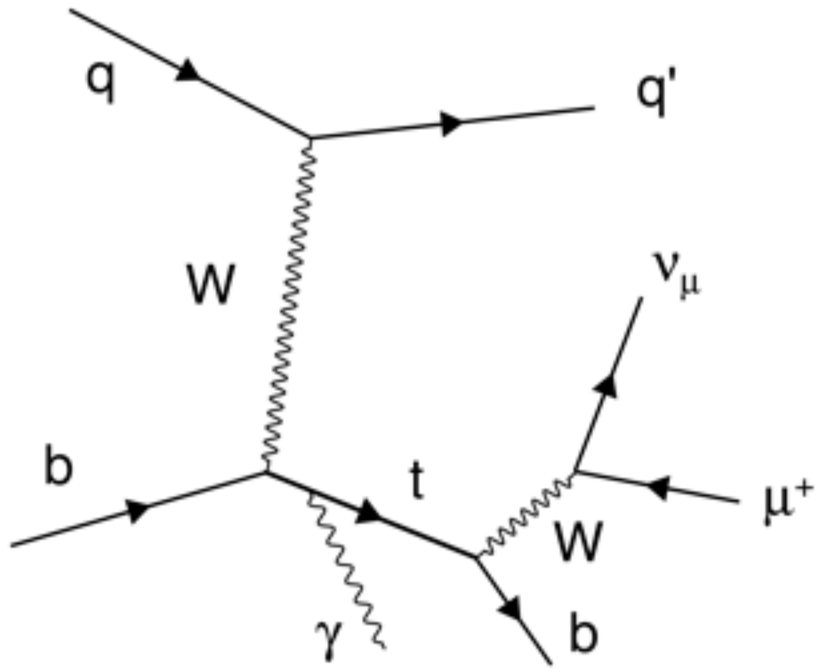


top quark coupling to photon:

3. ttγ



4. tγ



EFT in top physics

(1. ttV: reinterpretation)

5. tW & tt dilepton

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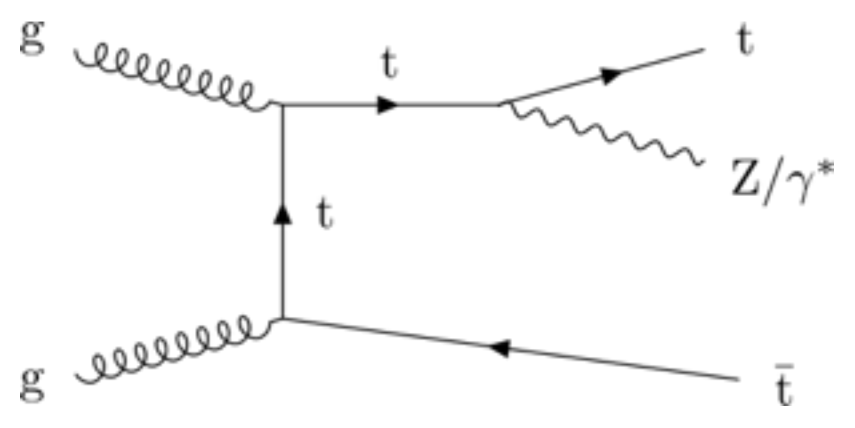

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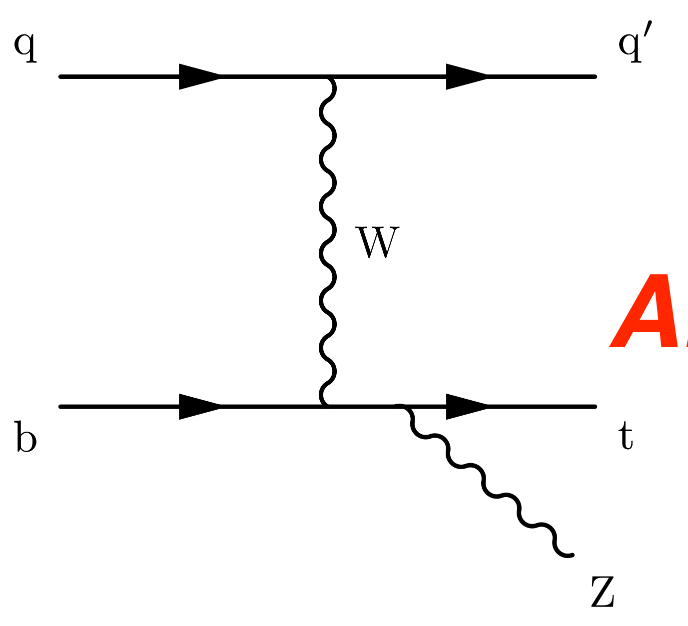

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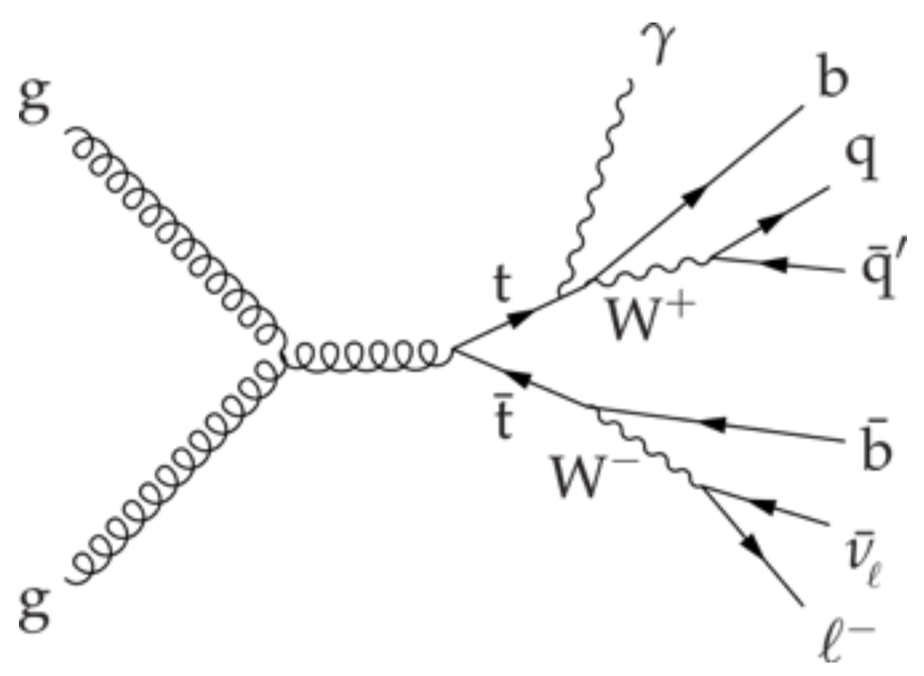

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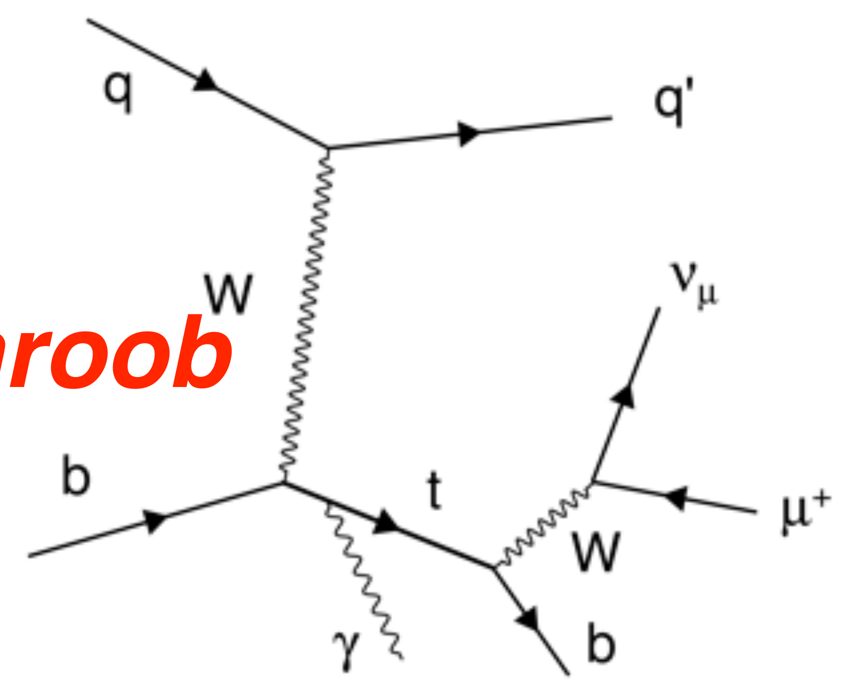

Also covered by M. Alhroob

EFT in top physics

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For further ATLAS+CMS reports on interesting processes probing top couplings : see talks by N.Faltermann (ttH and tH) and G.Mohanty (CPV and FCNC)

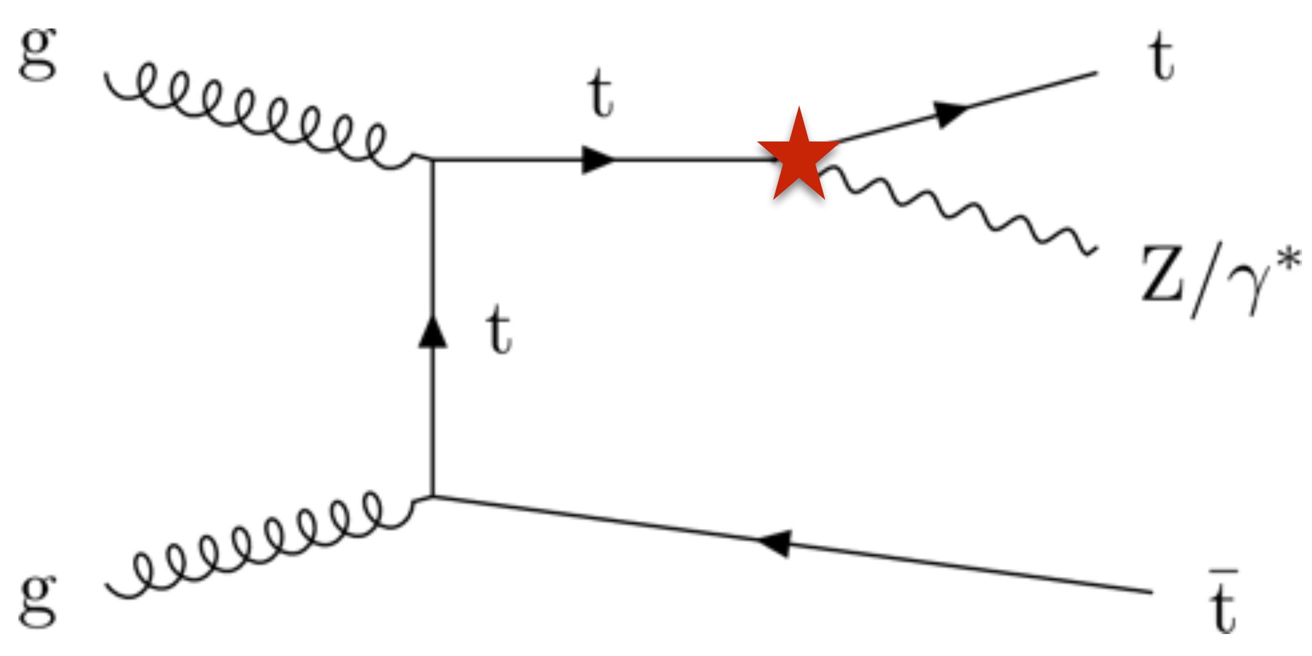
Associated production of top quark pairs and vector bosons

- ATLAS: ATL-COM-PHYS-2018-1346

NEW!

- CMS: arXiv:1711.02547

ttZ

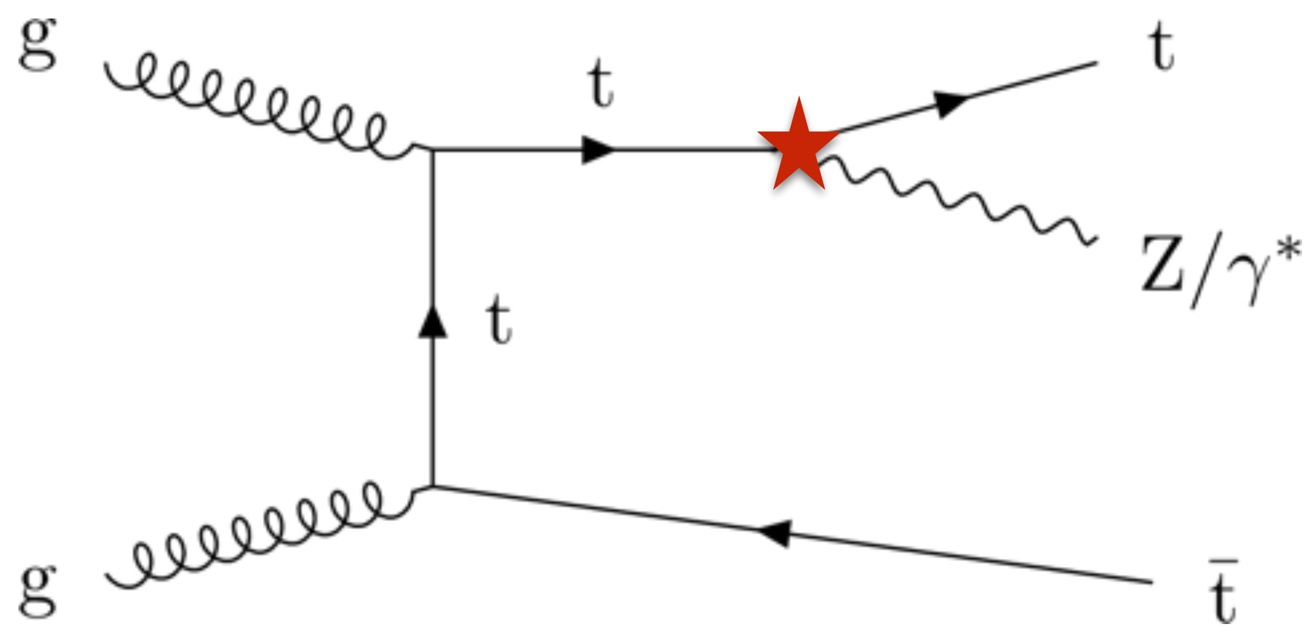


Ignoring 0 or 1 lepton final states

- t →(q+q) b or (**lepton**+v) b
- t →(q+q) b or (**lepton**+v) b
- Z →**lepton**+**lepton**

→ 2 to 4 leptons

ttZ… and ttW



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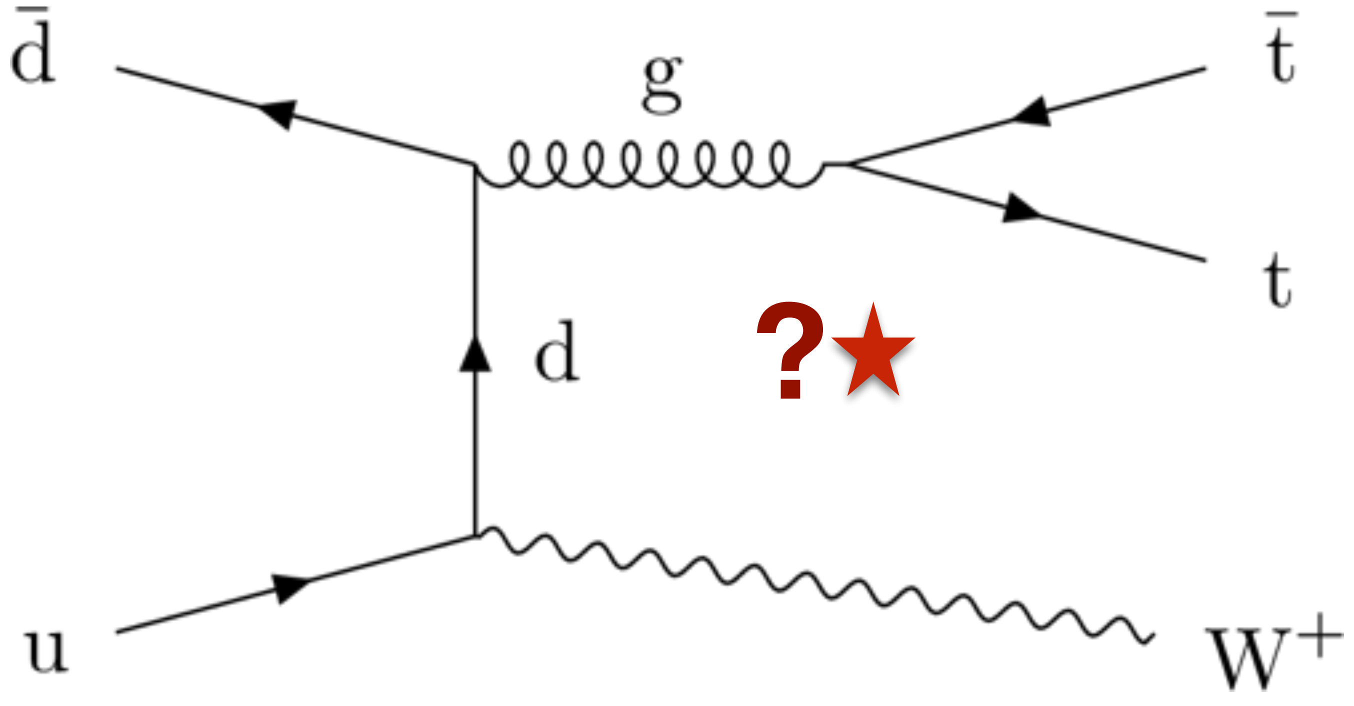


Requiring at least one top quark + W boson to decay into leptons to reduce multijet background:

- t →(q+q) b or (**lepton**+v) b
- t →(**lepton**+v) b
- W →**lepton**+v

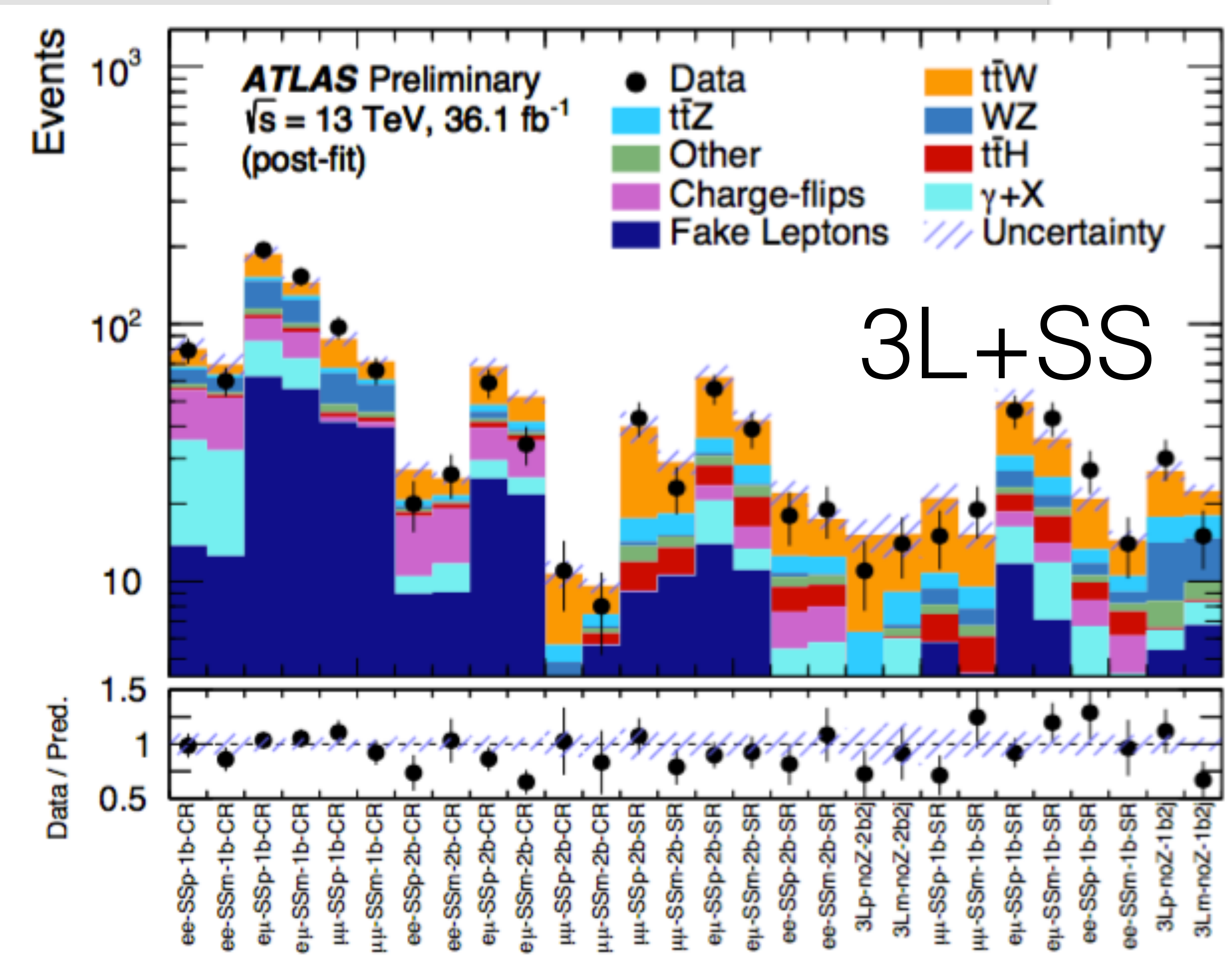
2 or 3 leptons

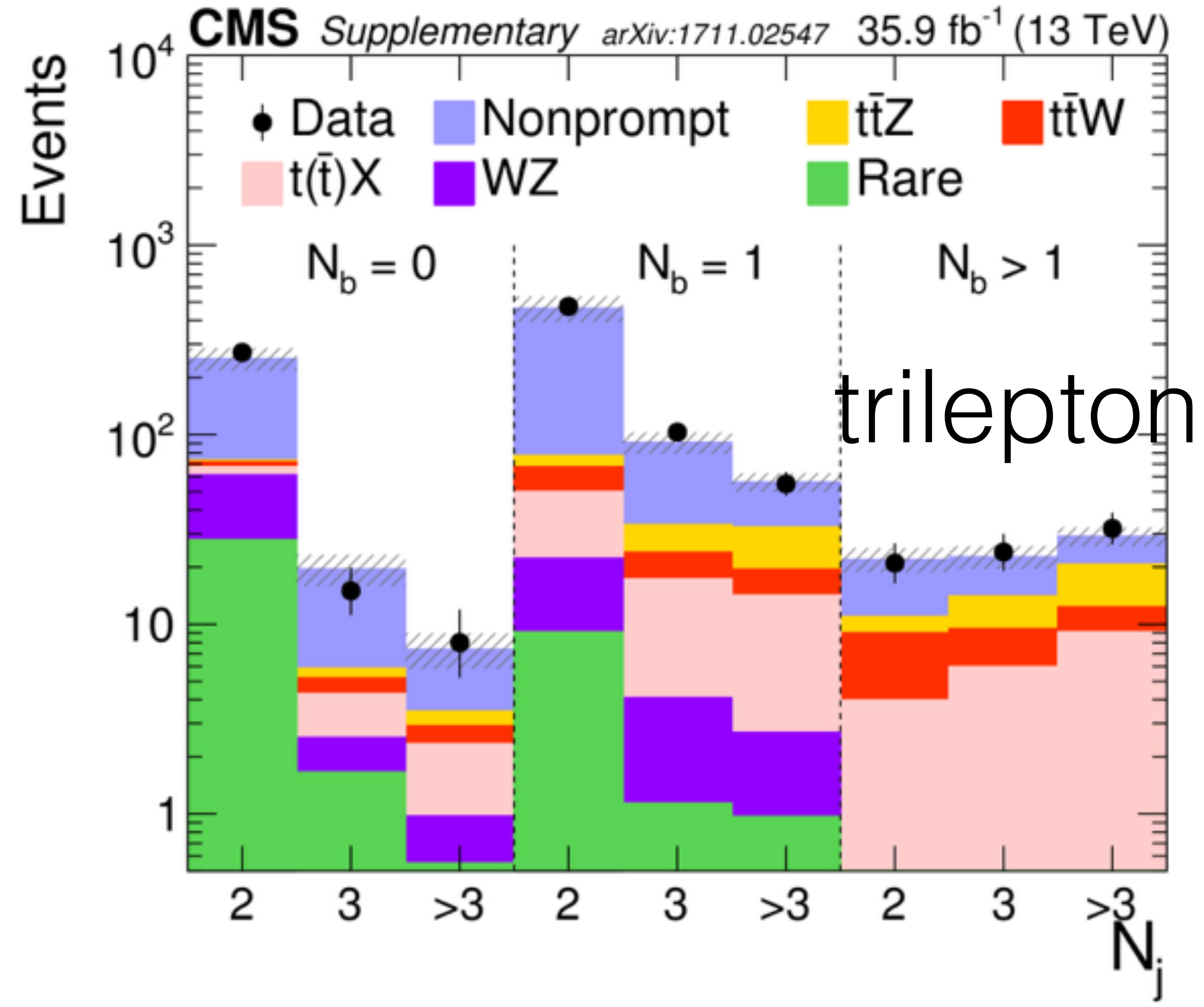
competing multi-lepton final state

- ttW may not look so interesting in terms of SM couplings *…but it is for EFT: see in 2 slides*
- Instead of treating as background:
  - add 2 leptons (same sign) region ; fit ttW contribution together

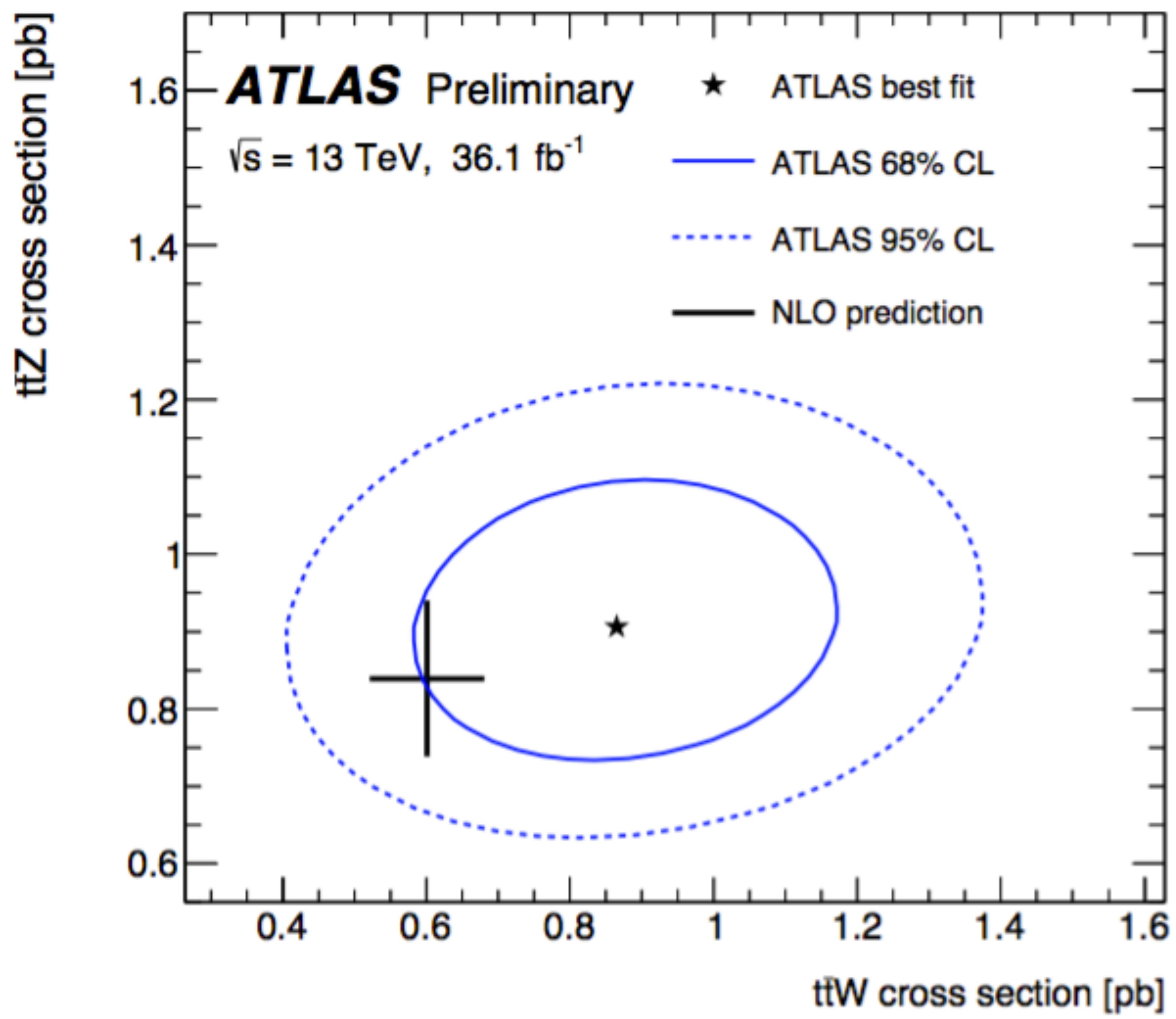
ttZ and ttW

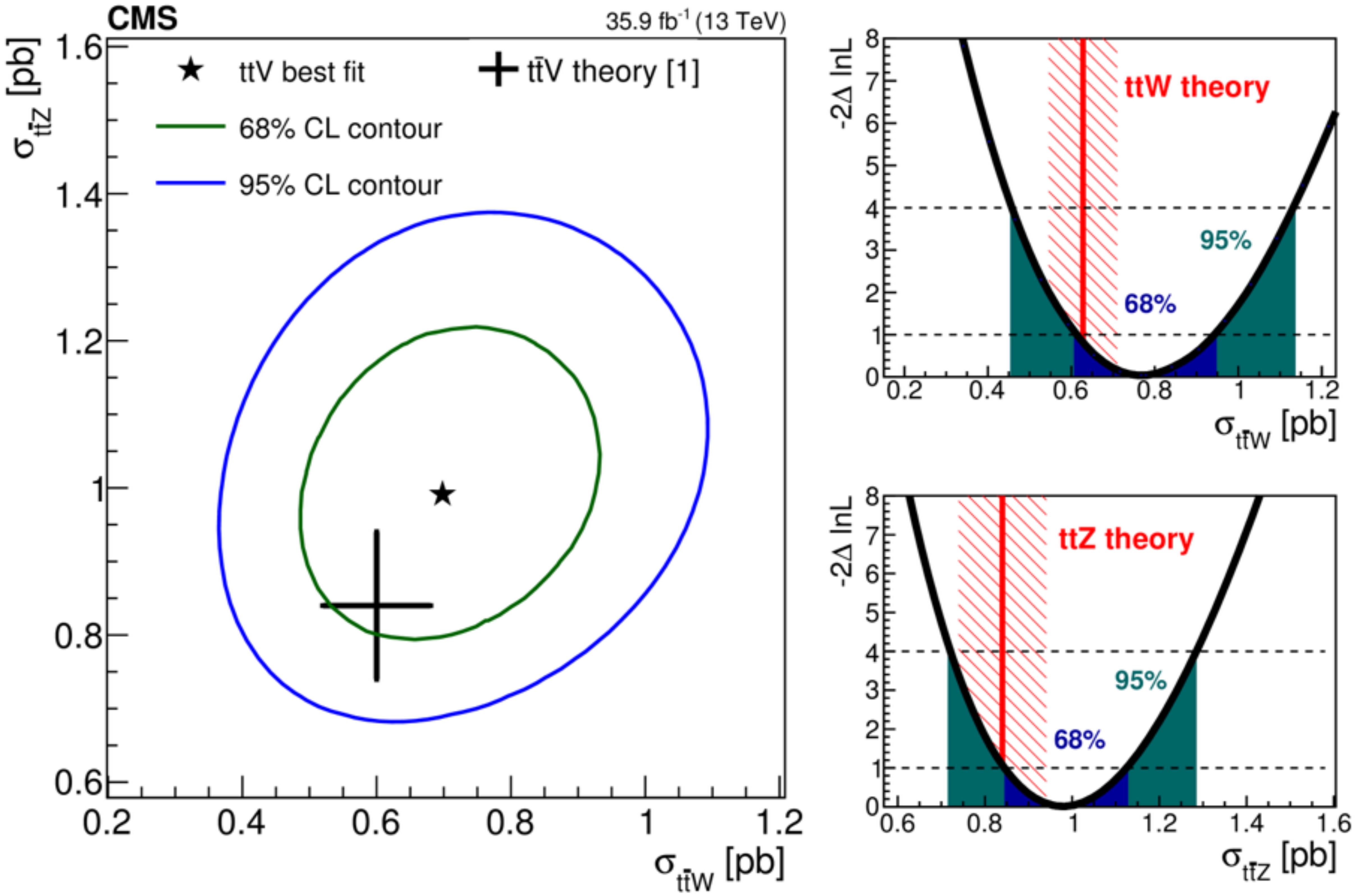
- Main backgrounds: ZZ, WZ, tt+X, t+X
- Luminosity: ~ 36 fb-1
- Signal extraction — ***more leptons, less jets***:
  - simultaneous fits to several control regions: $N_{leptons}$, N_{jets}, $N_{b\text{-}jets}$
- Boosted Decision Trees for signal to background separation in dilepton final states
  - ATLAS: for opposite sign same flavour ttZ enriched (using e.g. η of the dilepton system, p_T/E_T jet sums, global event variables)
  - CMS: for same-sign dilepton (using e.g. jet, leptons, global event variables)
- Background from control regions in data: e.g. “fake leptons” (tigh-loose ID), ttbar (opposite sign different flavour requirement)





ttZ and ttW





Observation: ***significance (obs and exp) for ttW and ttZ above 5 s.d. in both experiments***

Both ATLAS and CMS measurements compatible (slightly above) SM predictions

In terms of EFT

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2}\sum_i c_i \mathcal{O}_i + \cdots, \quad \Rightarrow \quad \sigma = \sigma_{SM} + C_i\sigma_i^{(1)} + C_i^2\sigma_i^{(2)}$$

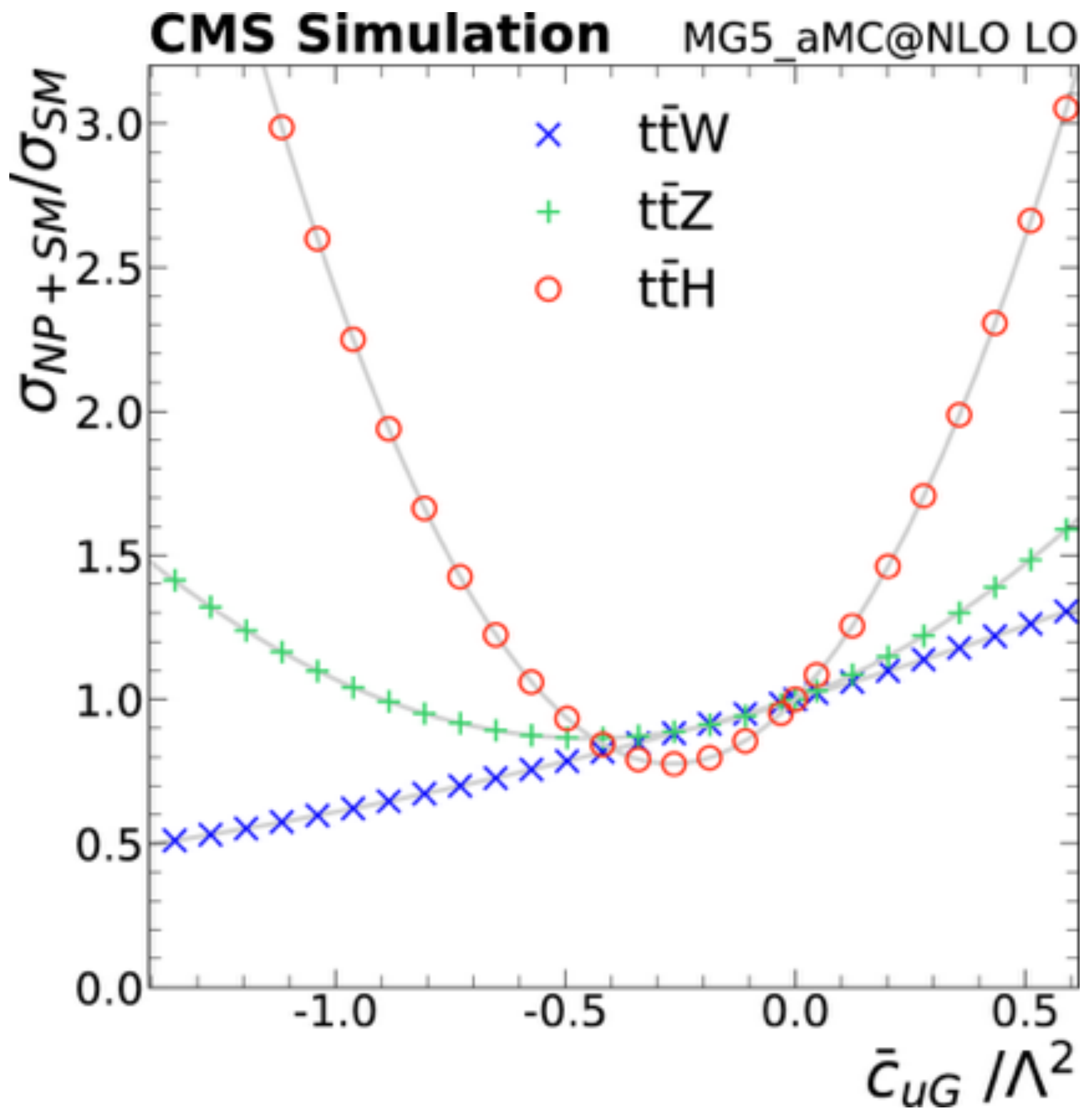
- From a large number of operators affecting ttV cross sections
    - constrains from other processes (e.g. tt cross section, properties…)
    - conservation laws (e.g. baryon and lepton numbers)
    - no new physics couplings to light quarks
    - ignore operators that affect backgrounds too much (except ttH)…
        - 8 operators left

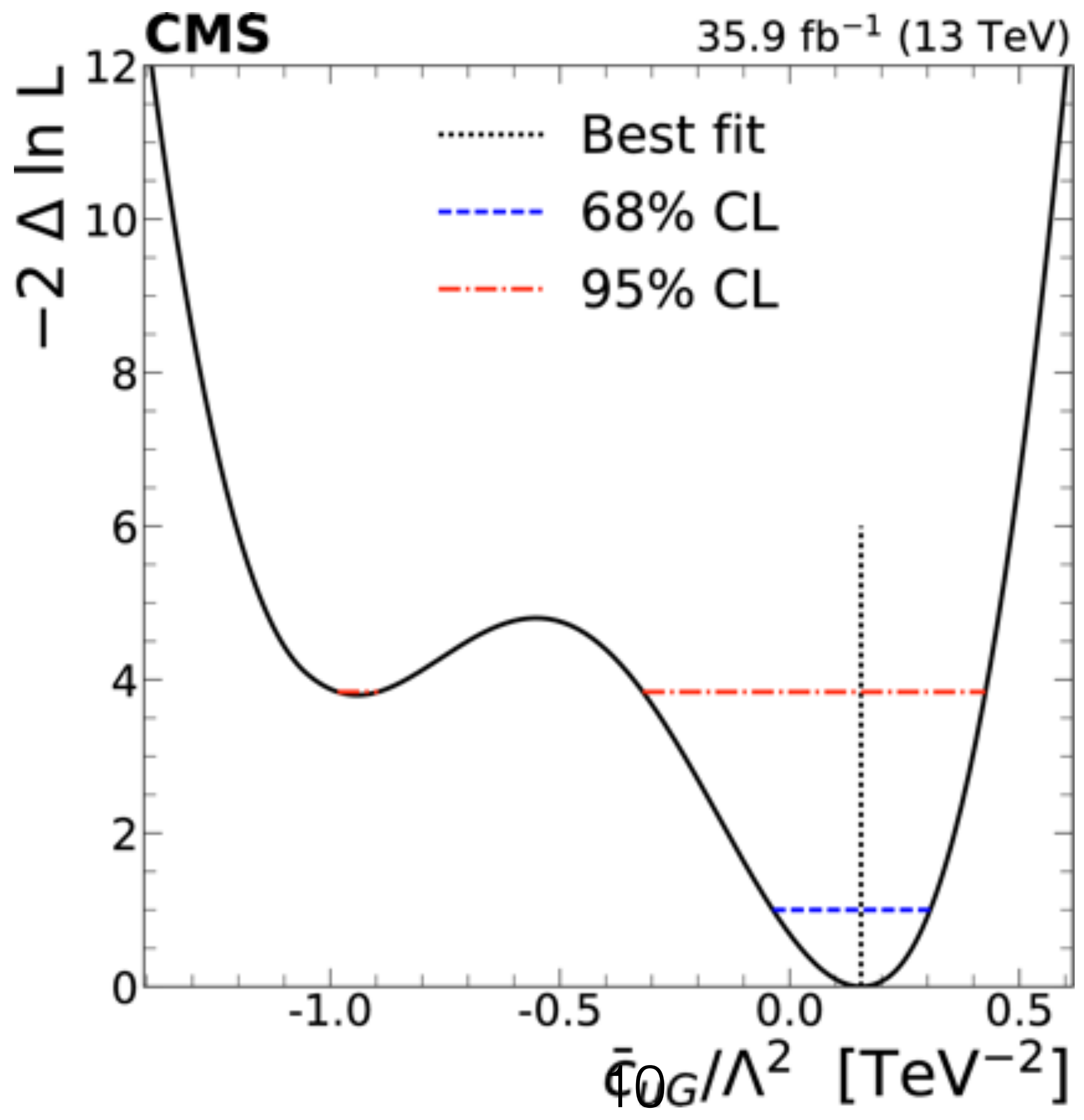
In terms of EFT

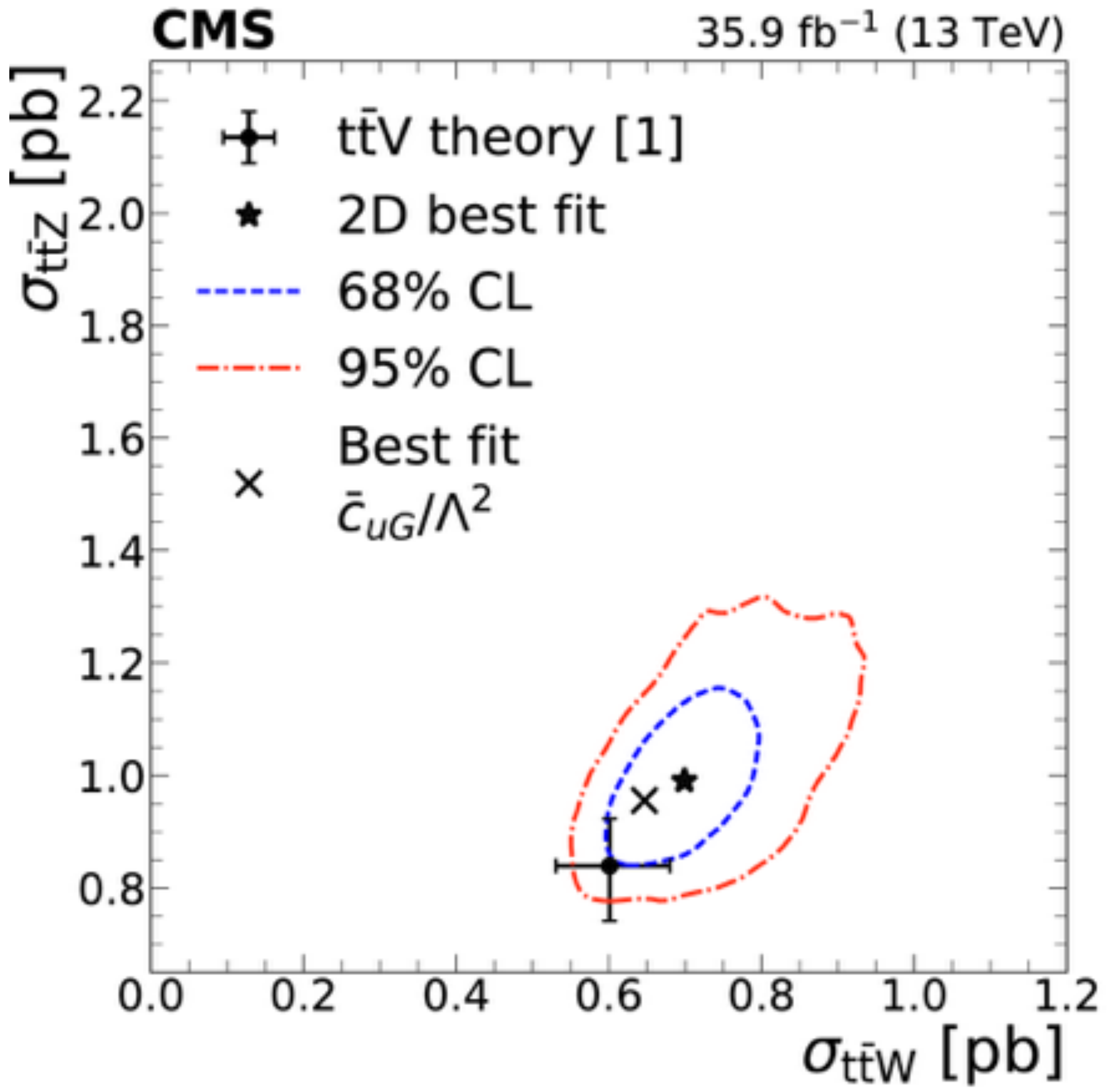
- New physics constrains:
  - considering only dim-6 operators that modify ttZ, ttW and *(as important background)* ttH
  - varying one coefficient at a time

CMS

Example:







In terms of EFT

- New physics constrains:
  - considering only dim-6 operators that modify ttZ, ttW and *(as important background)* ttH
  - varying one coefficient at a time

CMS

Results:

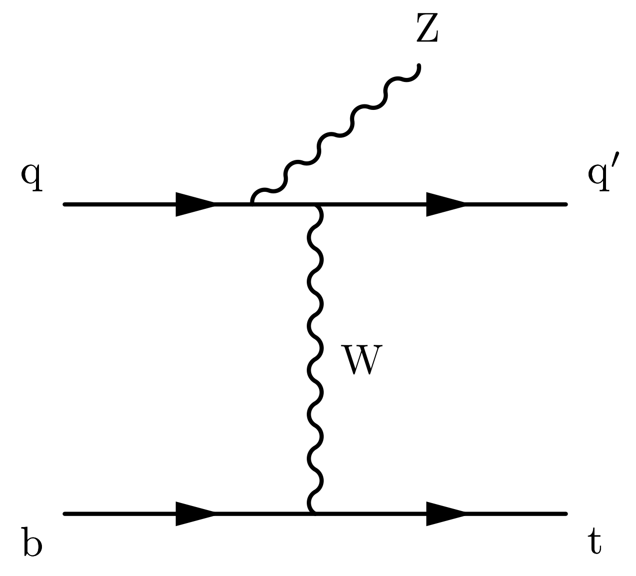
Wilson coefficient	Best fit $[\text{TeV}^{-2}]$	68% CL $[\text{TeV}^{-2}]$	95% CL $[\text{TeV}^{-2}]$
$\bar{c}_{\text{uW}}/\Lambda^2$	1.7	$[-2.4, -0.5]$ and $[0.4, 2.4]$	$[-2.9, 2.9]$
$\lvert\bar{c}_{\text{H}}/\Lambda^2 - 16.8\ \text{TeV}^{-2}\rvert$	15.6	$[0, 23.0]$	$[0, 28.5]$
$\lvert\widetilde{c}_{3\text{G}}/\Lambda^2\rvert$	0.5	$[0, 0.7]$	$[0, 0.9]$
$\bar{c}_{3\text{G}}/\Lambda^2$	-0.4	$[-0.6, 0.1]$ and $[0.4, 0.7]$	$[-0.7, 1.0]$
$\bar{c}_{\text{uG}}/\Lambda^2$	0.2	$[0, 0.3]$	$[-1.0, -0.9]$ and $[-0.3, 0.4]$
$\lvert\bar{c}_{\text{uB}}/\Lambda^2\rvert$	1.6	$[0, 2.2]$	$[0, 2.7]$
$\bar{c}_{\text{Hu}}/\Lambda^2$	-9.3	$[-10.3, -8.0]$ and $[0, 2.1]$	$[-11.1, -6.5]$ and $[-1.6, 3.0]$
$\bar{c}_{2\text{G}}/\Lambda^2$	0.4	$[-0.9, -0.3]$ and $[-0.1, 0.6]$	$[-1.1, 0.8]$

Not only top quark pairs, also single top : tZq

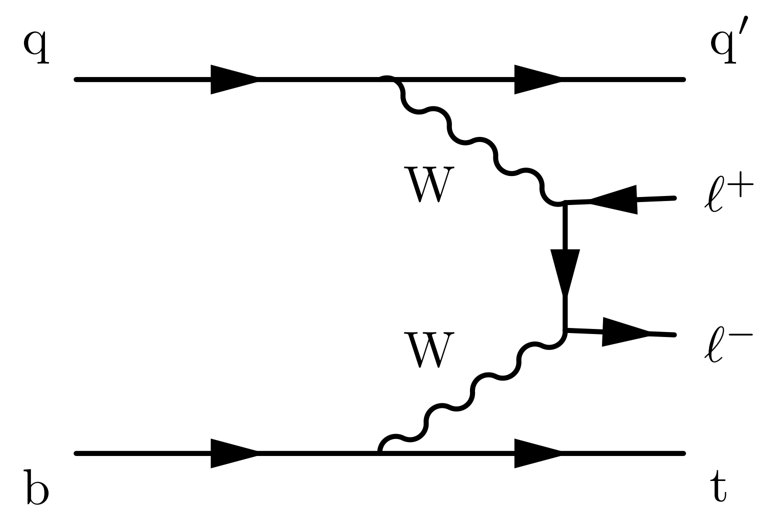
- ATLAS: PLB 780 (2018) 557
- CMS: PLB 779 (2018) 358

Single top associated to a Z boson

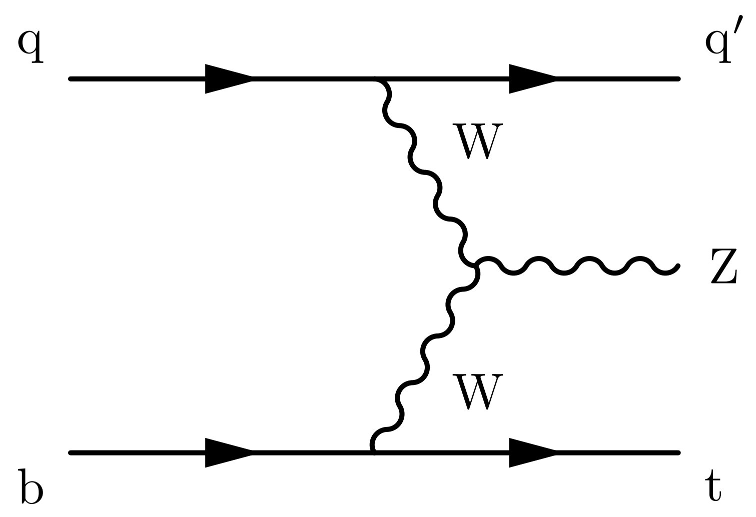
Examples:



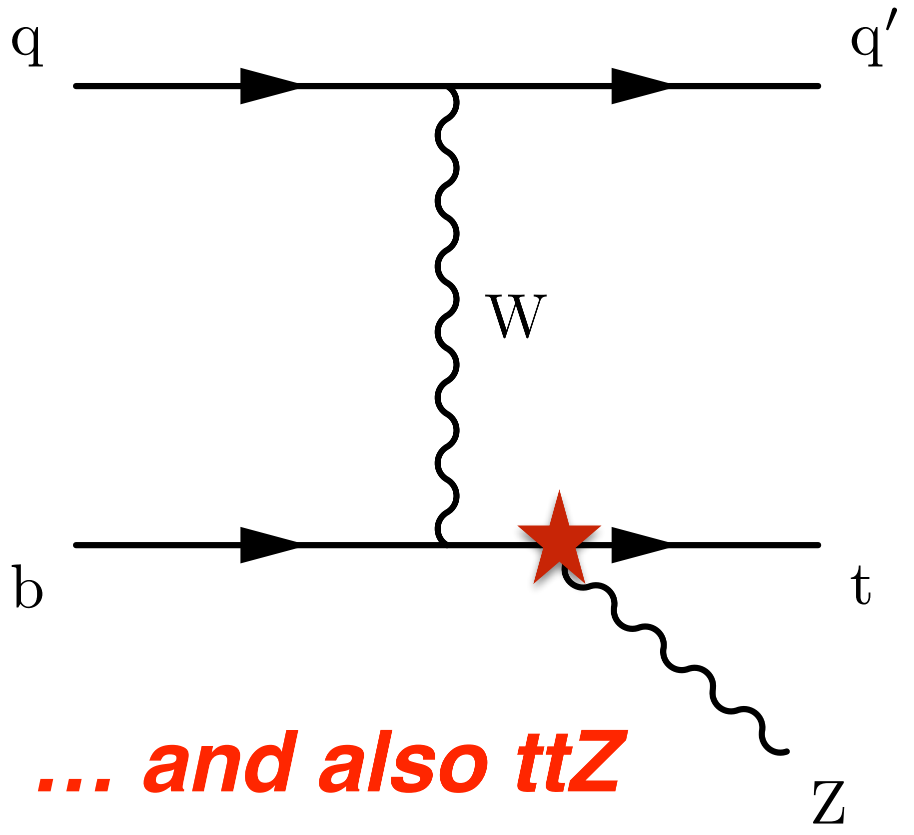
Z radiated off a light quark



non-resonant



triple-boson coupling



… and also ttZ

Single top associated to a Z boson

Also covered by M. Alhroob

- Using 3 lepton final states
- Multivariate analyses for signal to background separation
- Control regions (N_{jets}, $N_{b\text{-}jets}$) to better constrain main backgrounds:
  - ttV, WZ, fake leptons
- ATLAS
  - trains a neural network against fake leptons
  - LO MC
  - narrow Z mass requirement to M($lepton^+ lepton^-$)
- CMS
  - uses NLO MC
  - includes non-resonant contribution tllZ

Using ~36 fb-1 of data at 13 TeV

Single top associated to a Z boson

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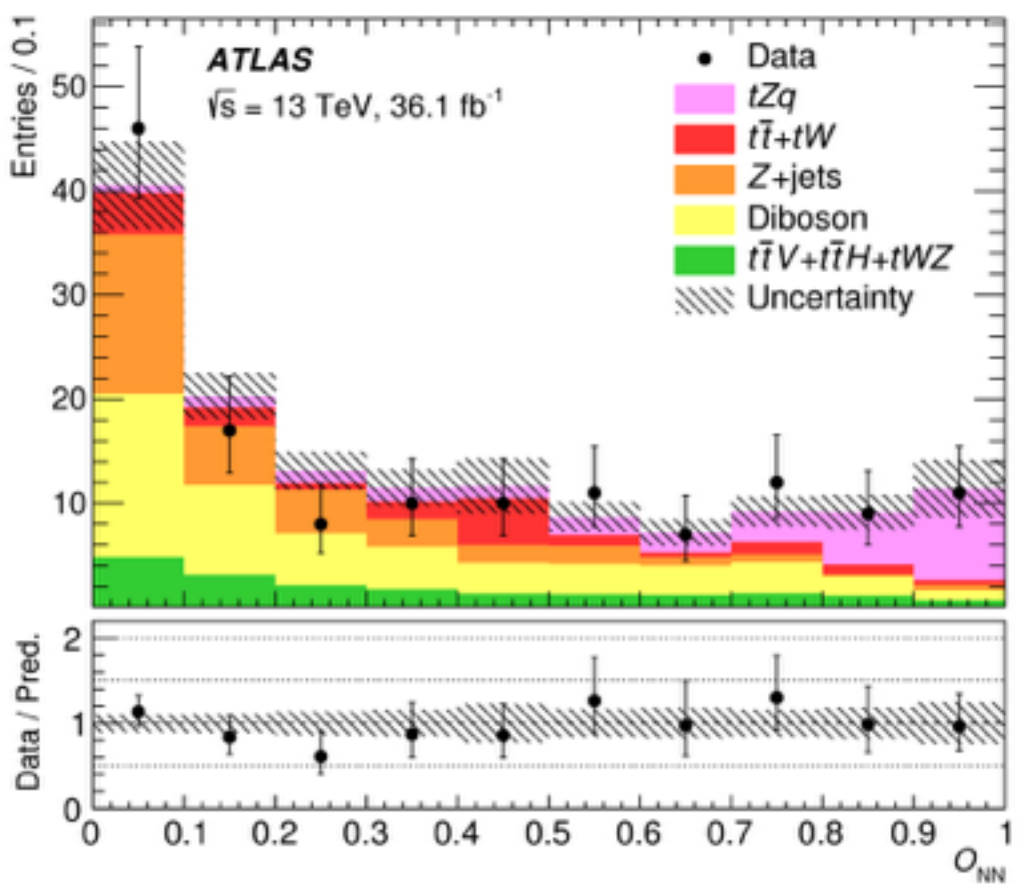
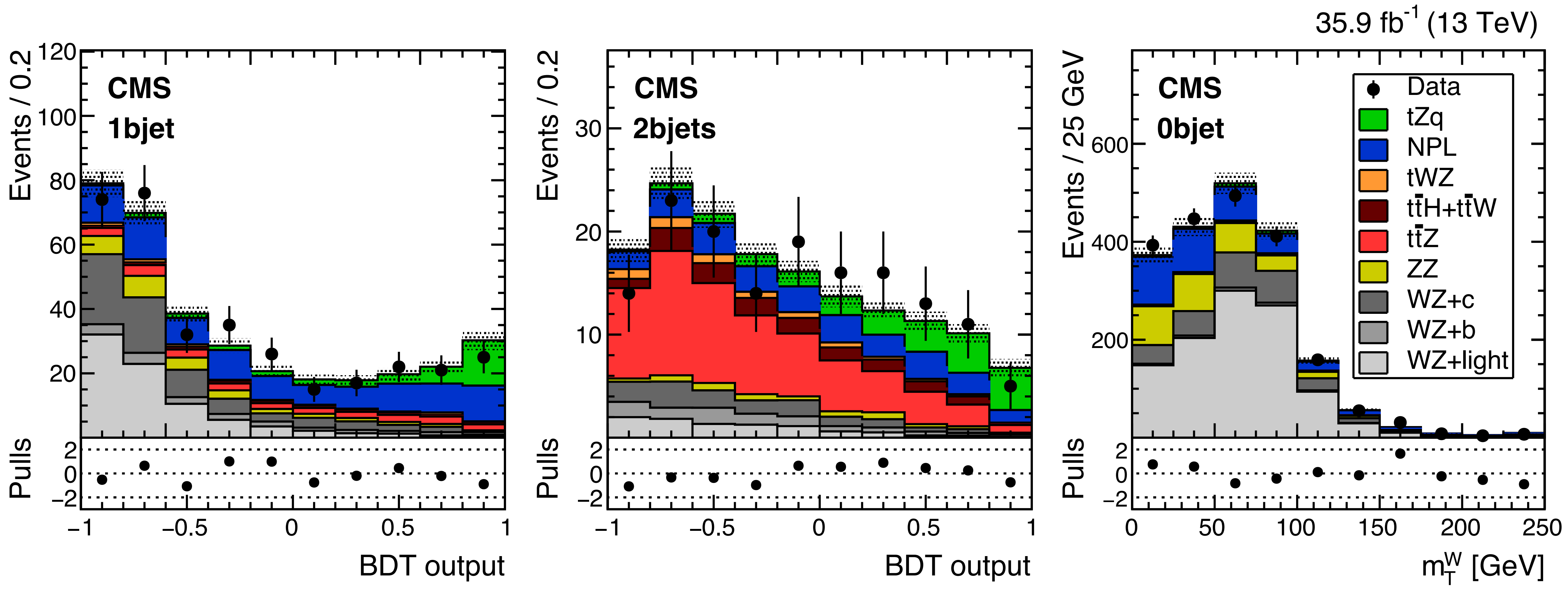




$\sigma(tZq) = 600 \pm 170$ (stat) $\pm$ 140 (sys) fb

4.2 (5.4) s.d. observed (expected) significance

NNLO prediction:

$800\ ^{+6.1}_{-7.4}$(scale) fb

Corrected for t and Z branching fractions

$\sigma(tllq) = 123^{+33}_{-31}(\text{stat})^{+29}_{-23}(\text{sys})$ fb

3.7 (3.1) s.d. obs (exp) significanc

NNLO prediction:

$94.2^{+1.9}_{-1.8}$(scale) $\pm$ 2.5 (PDF) fb

with l = e, μ, τ
corrected for t branching fraction

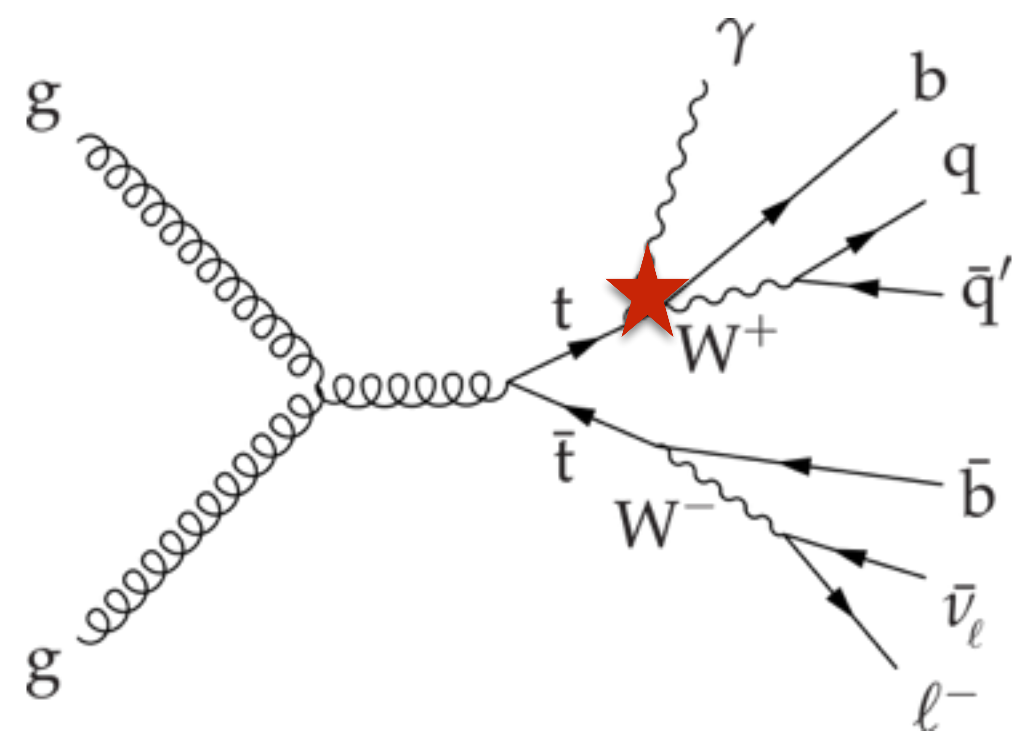
Associated production of top quark pair and a photon

- ATLAS: JHEP 11 (2017) 086
- CMS: JHEP 10 (2017) 006

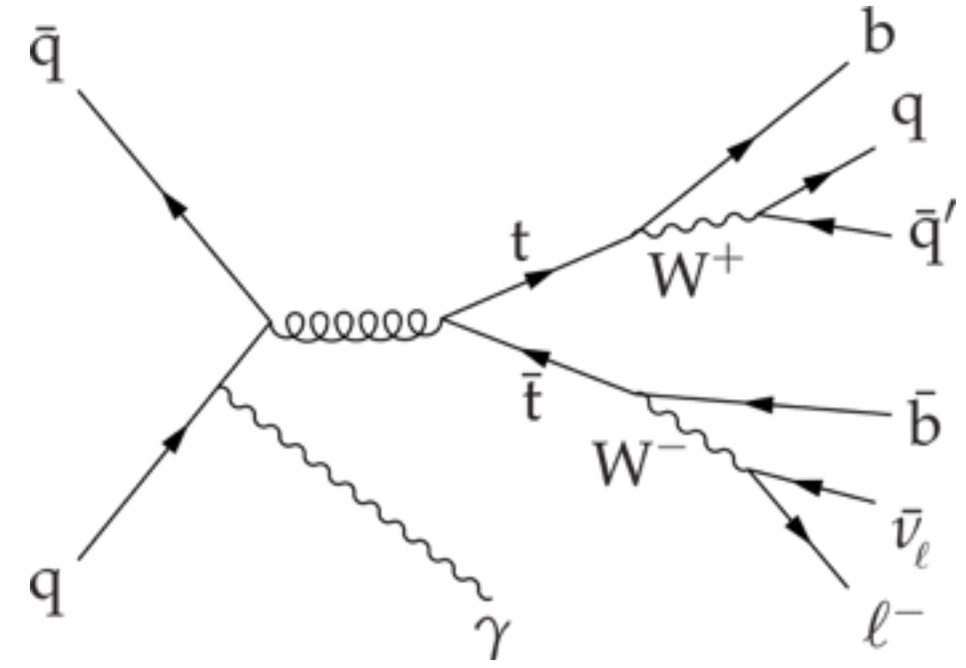
ttγ cross section using 8 TeV data

- Based on ~20 fb-1
- Semileptonic: tt → Wb+Wb → (q+q) b + (lepton+v) b
  - at least for jets, large missing E_T
- Main backgrounds:
  - tt + jet, with a jet faking (or containing) a photon
  - V + photon
  - tt or V, with a jet or an electron faking a photon
- Template fits for signal to background separation

target for coupling:



signal includes also



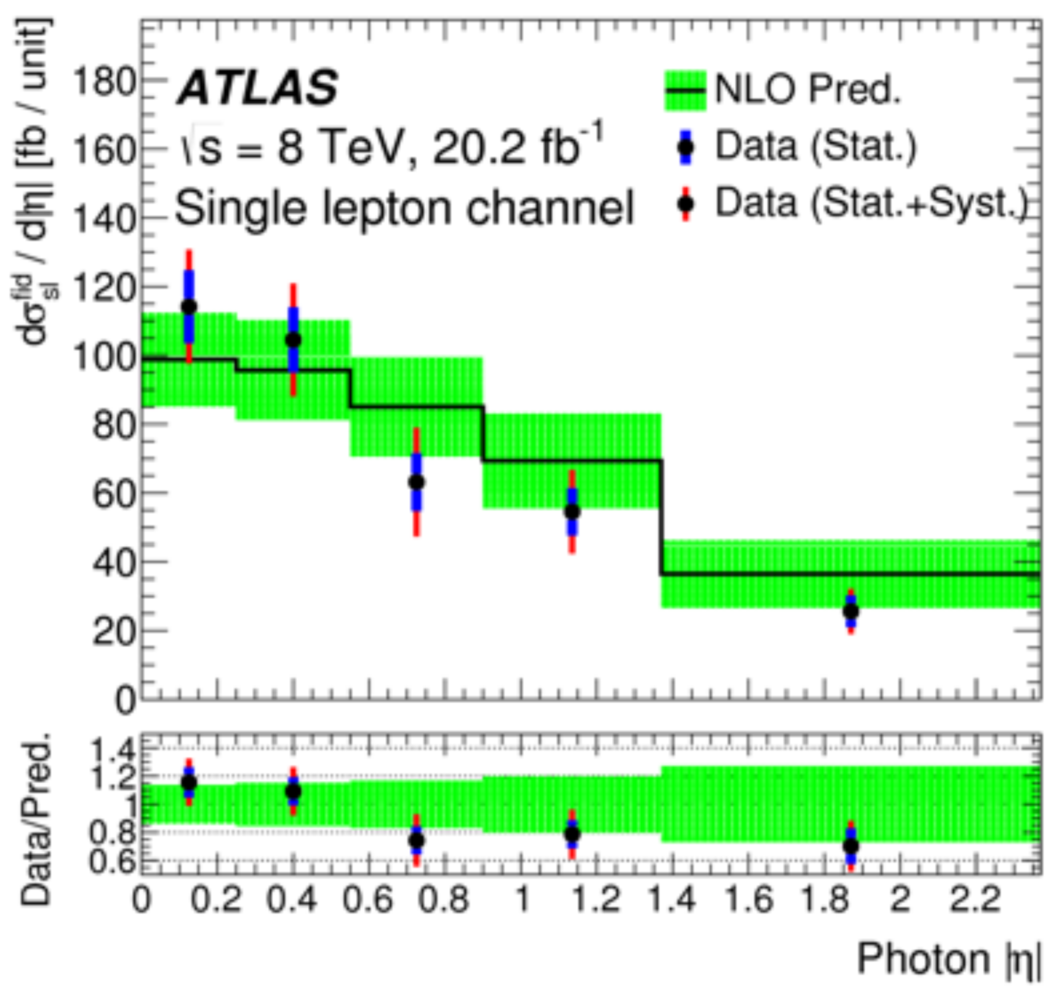
$t\bar{t}\gamma$ cross section using 8 TeV data

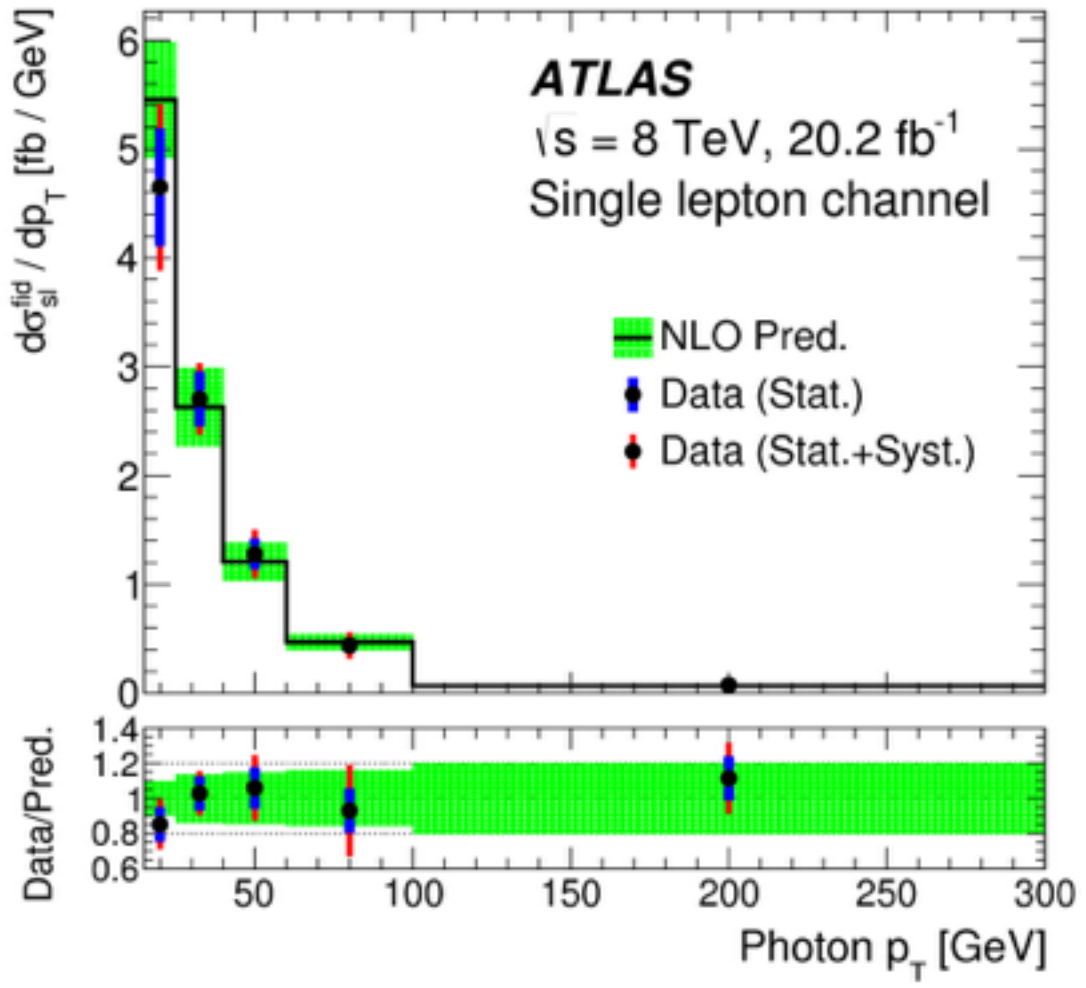
ATLAS

photon p_T > 15 GeV, $|\eta| < 2.4$

Template variable: $p_T^{iso} = \Sigma_{tracks}\, p_T$ within 0.2 rad around γ

Also differential cross section





Fiducial: **$\sigma(t\bar{t}\gamma)$ = 139±7(stat.)±17(syst.) fb**

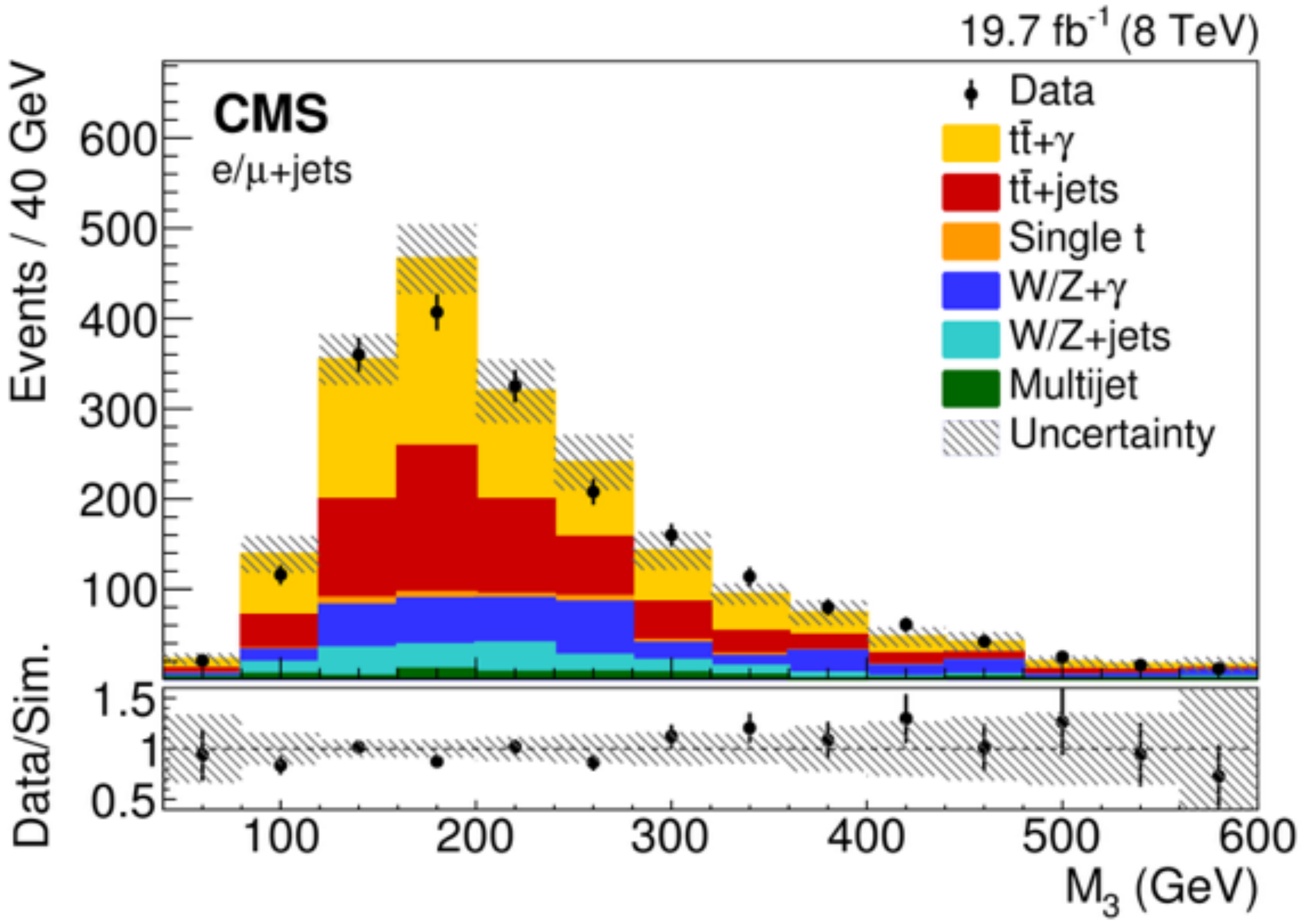
[NLO: 151±24 fb]

CMS

photon p_T > 25 GeV, $|\eta| < 1.4$

Template variables :
M_3 = invariant mass of the 3 jets giving the highest $\Sigma_{jets}\, p_T$

Charged hadron γ isolation for fake photon determination



Fiducial: **$\sigma(t\bar{t}\gamma)$ = 127±27(stat. + syst.) fb**

Total: **$\sigma(t\bar{t}\gamma)$ = 515±108 fb**

[NLO: 592±71(scale)±30(PDF) fb]

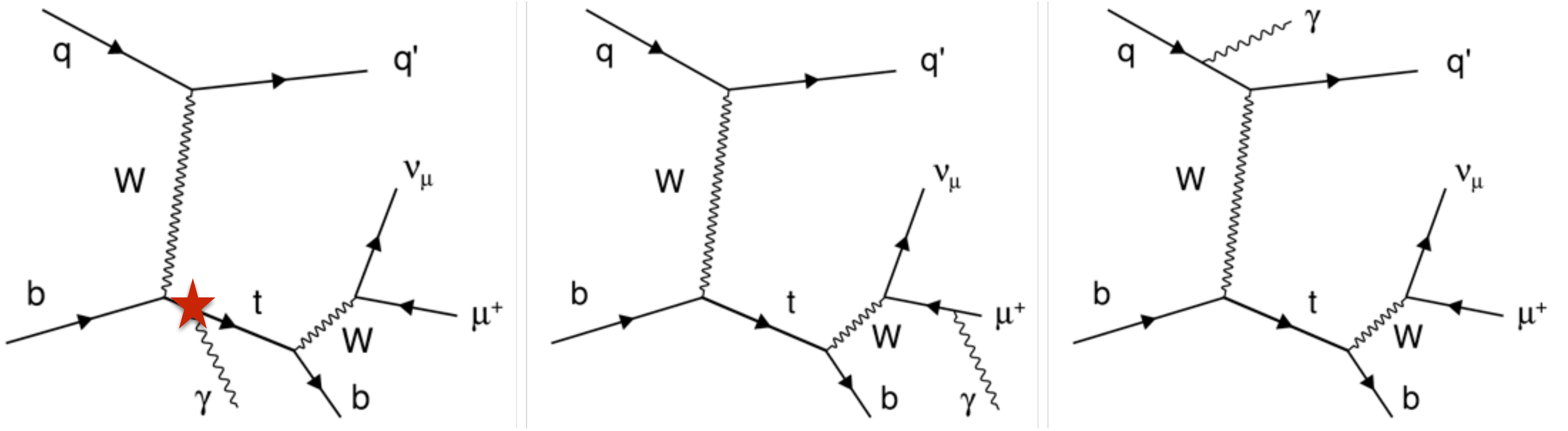
Not only top quark pairs, also single : tγq

- CMS: TOP-17-016, submitted to PRL

Single top + γ at 13 TeV

Also covered by M. Alhroob

Again, not only top-photon coupling:



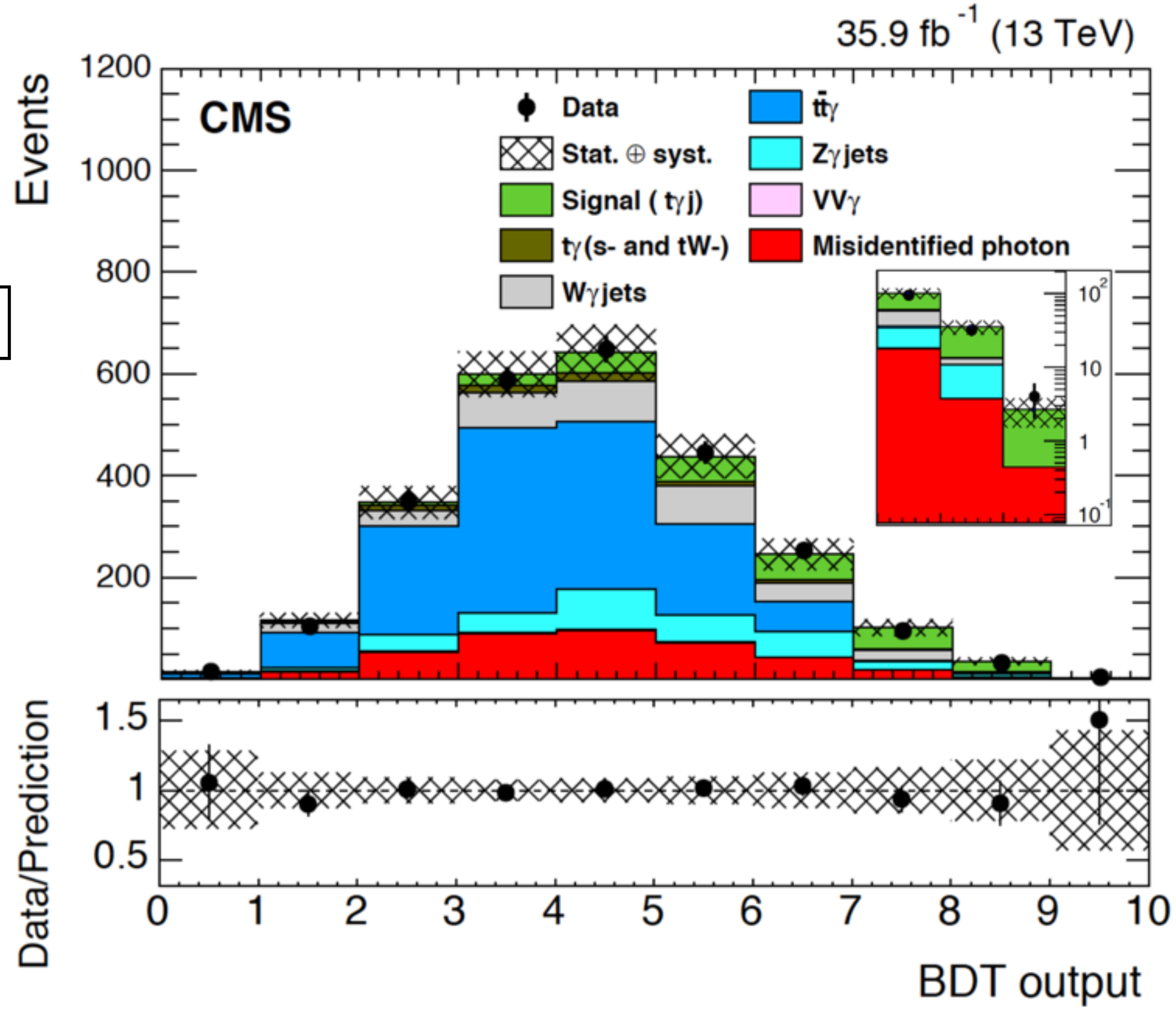
- Now ttγ becomes the main background followed by V+γ and fakes
- Statistically & systematically challenging
  - Focus on muon channel to improve signal efficiency
  - Use BDT for signal to background separation

Single top + γ at 13 TeV

Also covered by M. Alhroob

- Event selection:
- One isolated muon (p_T>26 GeV, |η|<2.4)
- At least two jets, one b-tagged
- One isolated photon (p_T>25 GeV, |η|<1.44)
  - separated from jets and muon with ΔR > 0.5
- E_T^{miss} > 30 GeV
- BDT variables e.g. jets and lepton η, angles, distance separation, reconstructed top mass…

220 signal, 1220 ttγ events



Fiducial cross section for γ p_T>25 GeV, |η|<1.44, ΔR > 0.5:

σ(tγ)xB(t→μνb) = 115±17(stat.)±30(syst.) fb

[SM: 81±74 fb]

First evidence:

4.4 (3.0) s.d. obs (exp) significance

Search for new physics in top quark production

- CMS: TOP-17-020

NEW!

Search for new physics in top quark dilepton events

- So far, LHC top quark-releated analyses have two approaches
  - (SM) measurements
    - examples: those presented in this talk → ***reinterpreted in terms of EFT***
  - Seaches for specific new physics model dependent/independent
    - examples: FCNC searches, exotic final stated including top quarks, anomalous couplings in differential distributions

Search for new physics in top quark dilepton events

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reinterpreted in terms of EFT

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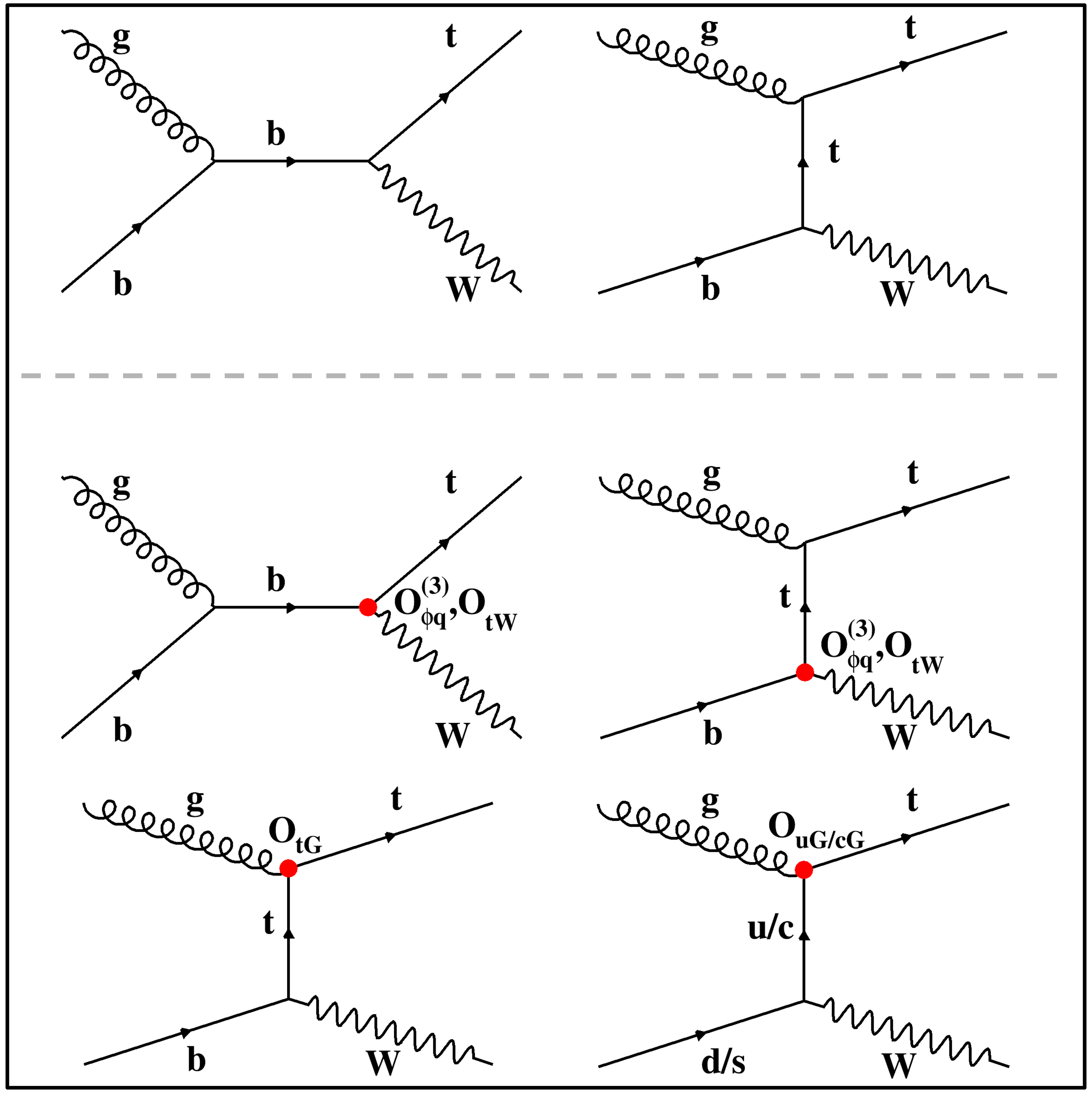
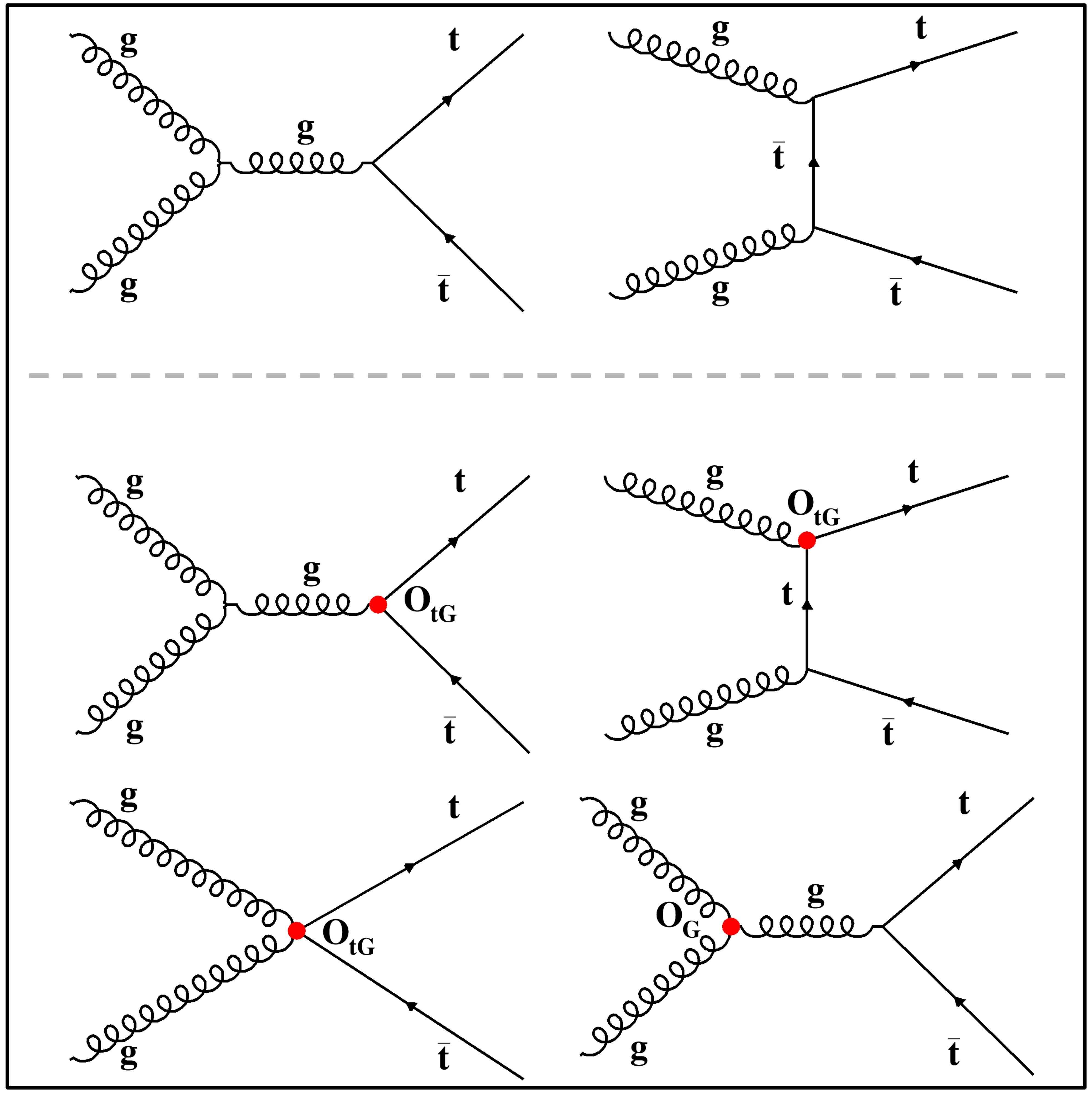
    - examples: FCNC searches, exotic final stated including top quarks, anomalous couplings in differential distributions

- ***New approach*:**
  - Event selection: 2 isolated leptons, opposite sign+b-jet: mostly tt, tW events , different N_{jet}, $N_{b\text{-}jet}$ categories as before
  - **Not one single observable: analysis fully designed to access the 6-dim operators relevant for top production**
  - ***first global analysis using tW + tt dilepton final states***

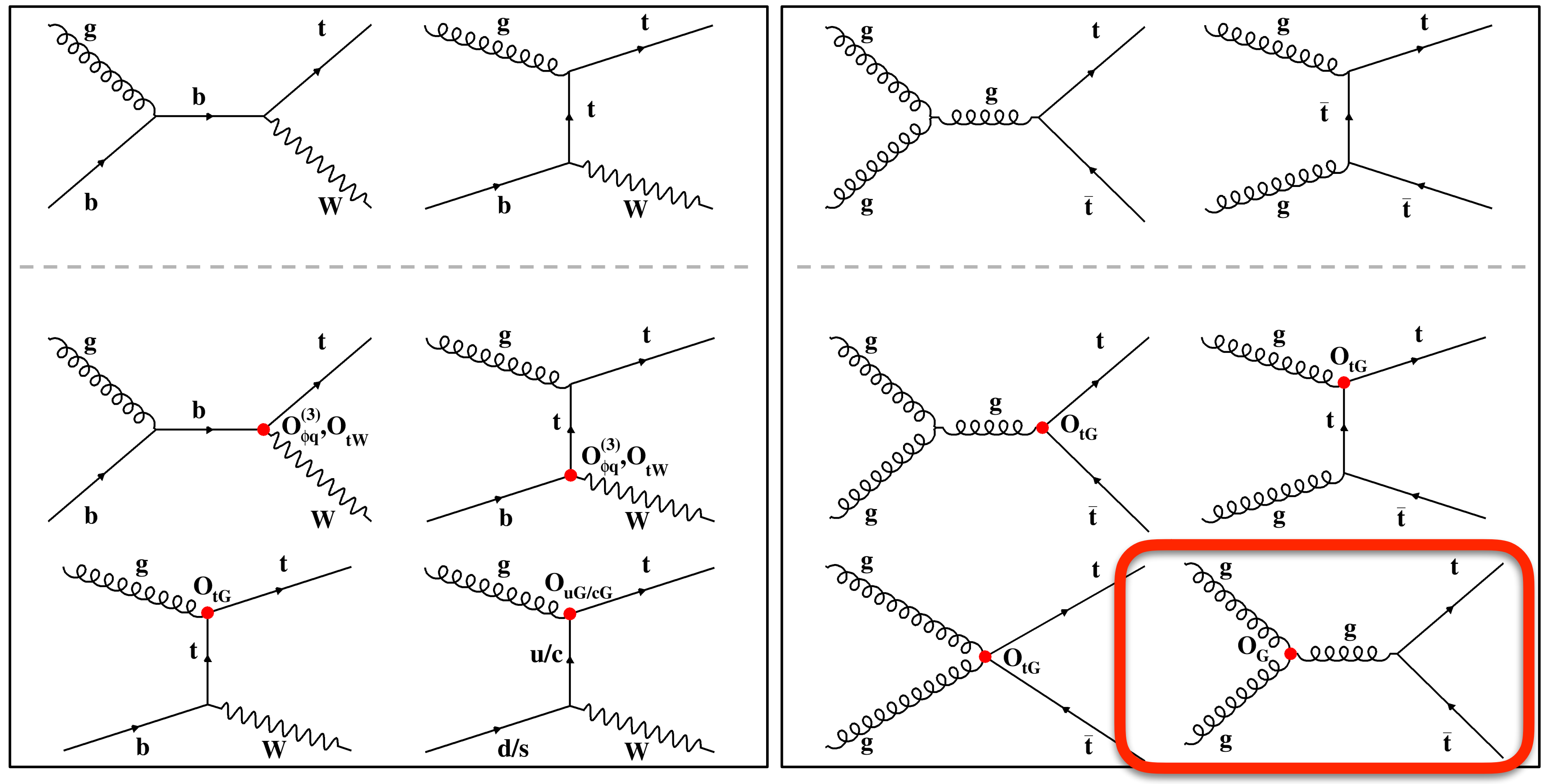
Search for new physics in top quark dilepton events





Search for new physics in top quark dilepton events

Example effects:



- O_G: doesn't affect tW; kinematic distributions not too sensitive: use yields to check for the effect of O_G in tt production

Search for new physics in top quark dilepton events

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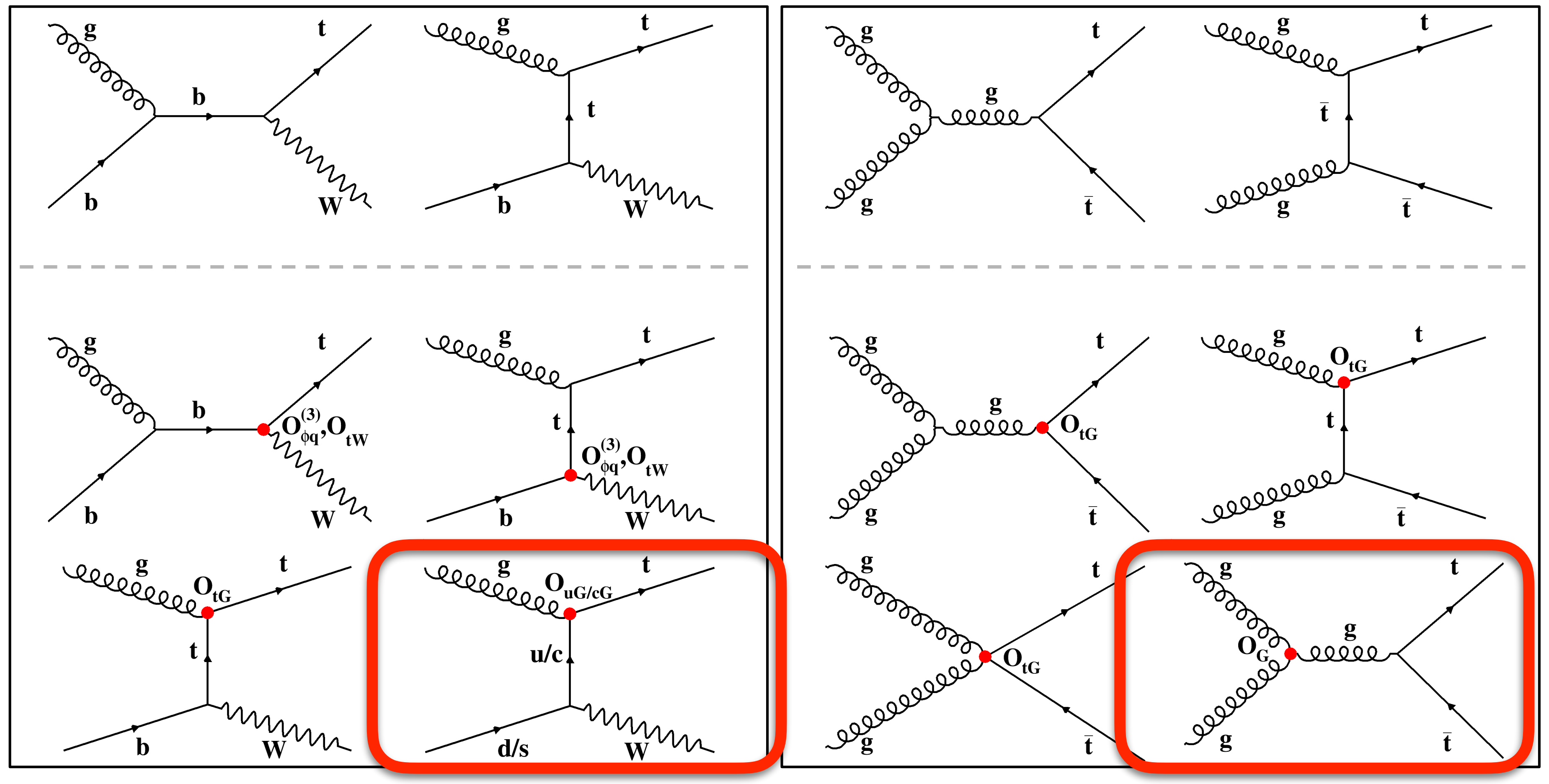

- O_G: doesn't affect tW; kinematic distributions not too sensitive: use yields to check for the effect of O_G in tt production
- $O_{uG,cG}$: affects tt & tW; kinematic distributions discriminate FCNC x SM production: neural network NN_{FCNC}

Search for new physics in top quark dilepton events

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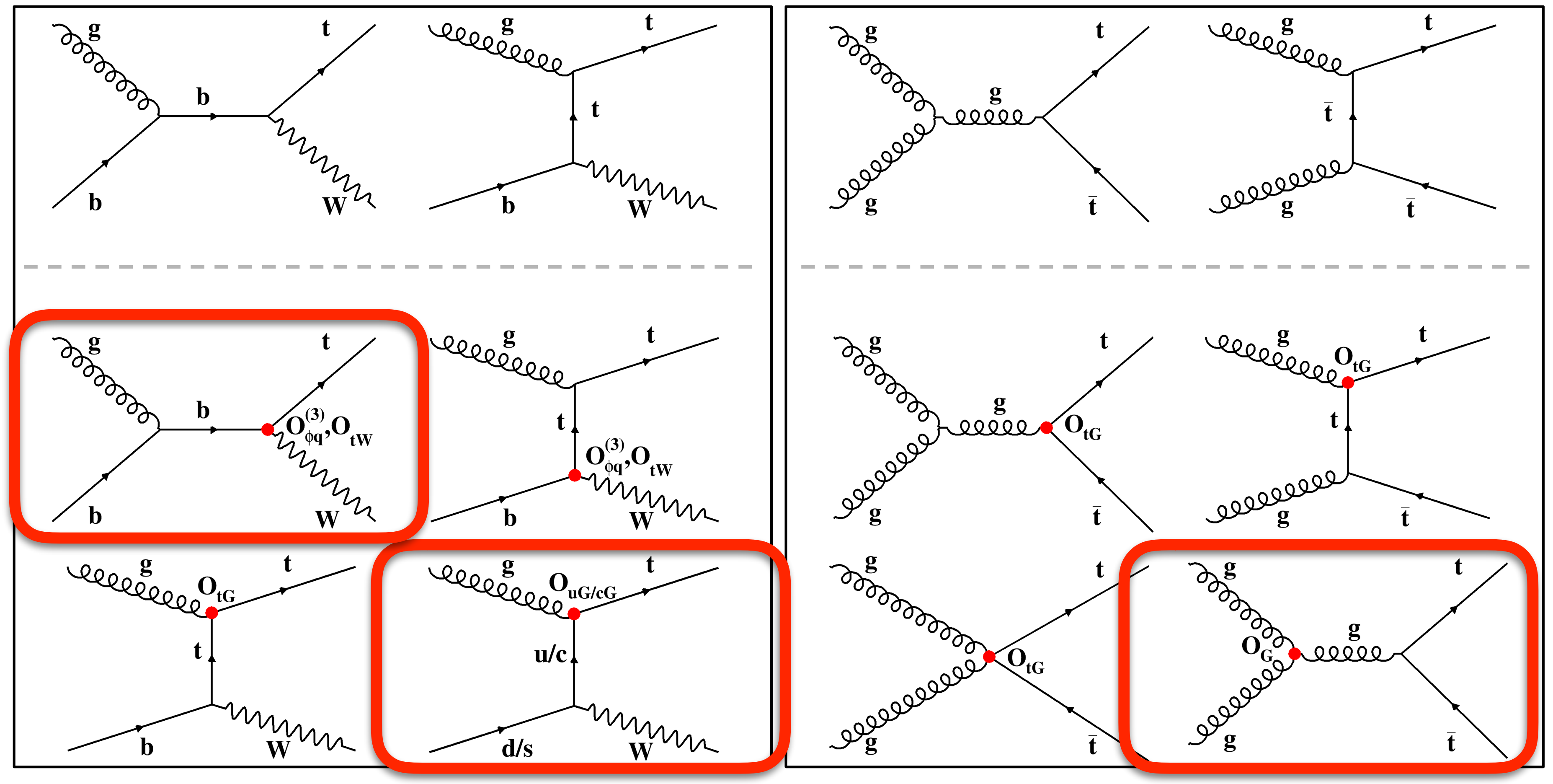

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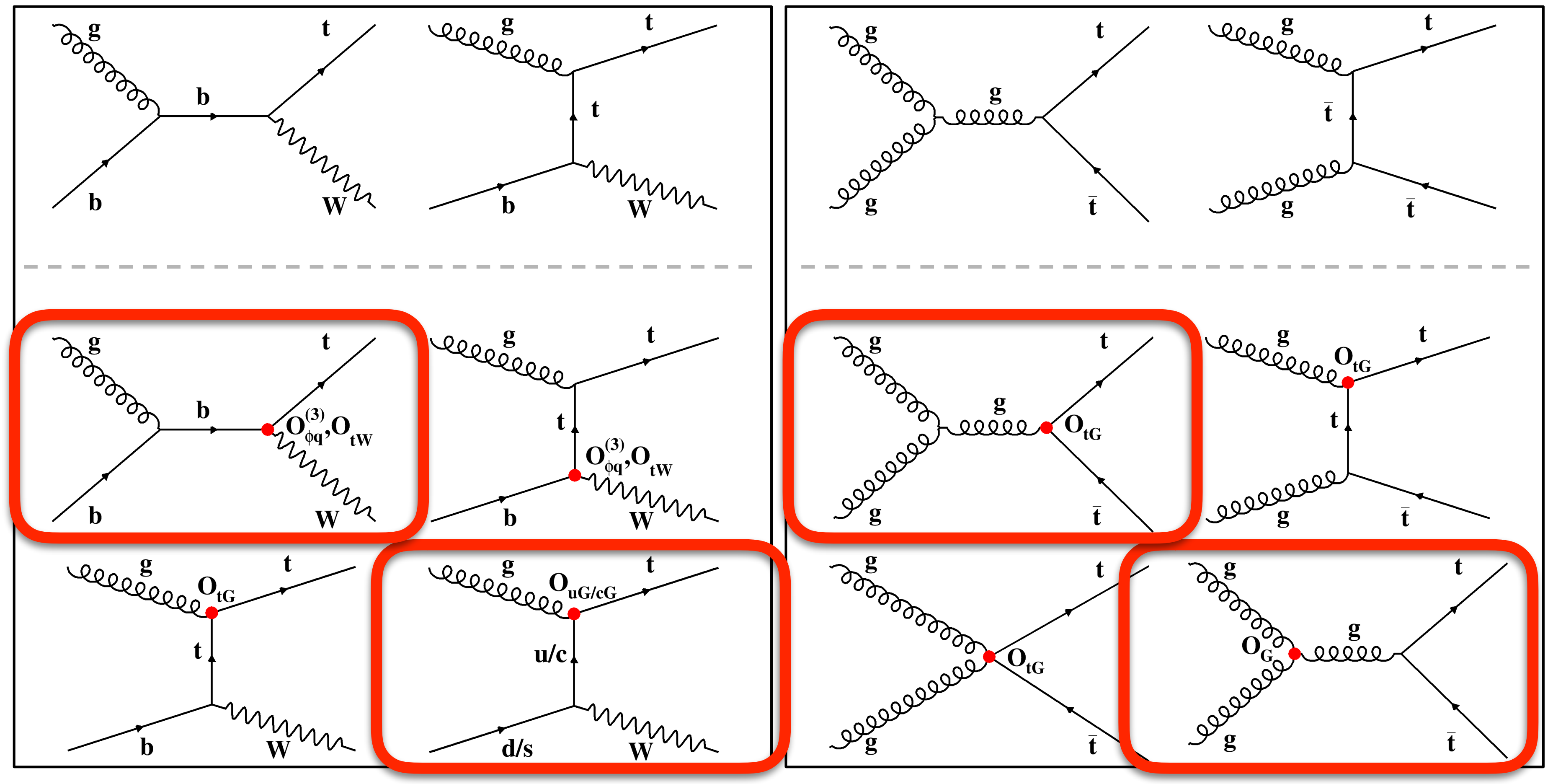
- $O_{\phi q,tW}$: affects tW kinematic distributions ; neural network $NN_{jet,b\text{-}jet}$ to discriminate (tt + DY) from tW ; discriminate SM from New Physics effects

Search for new physics in top quark dilepton events

Example effects:



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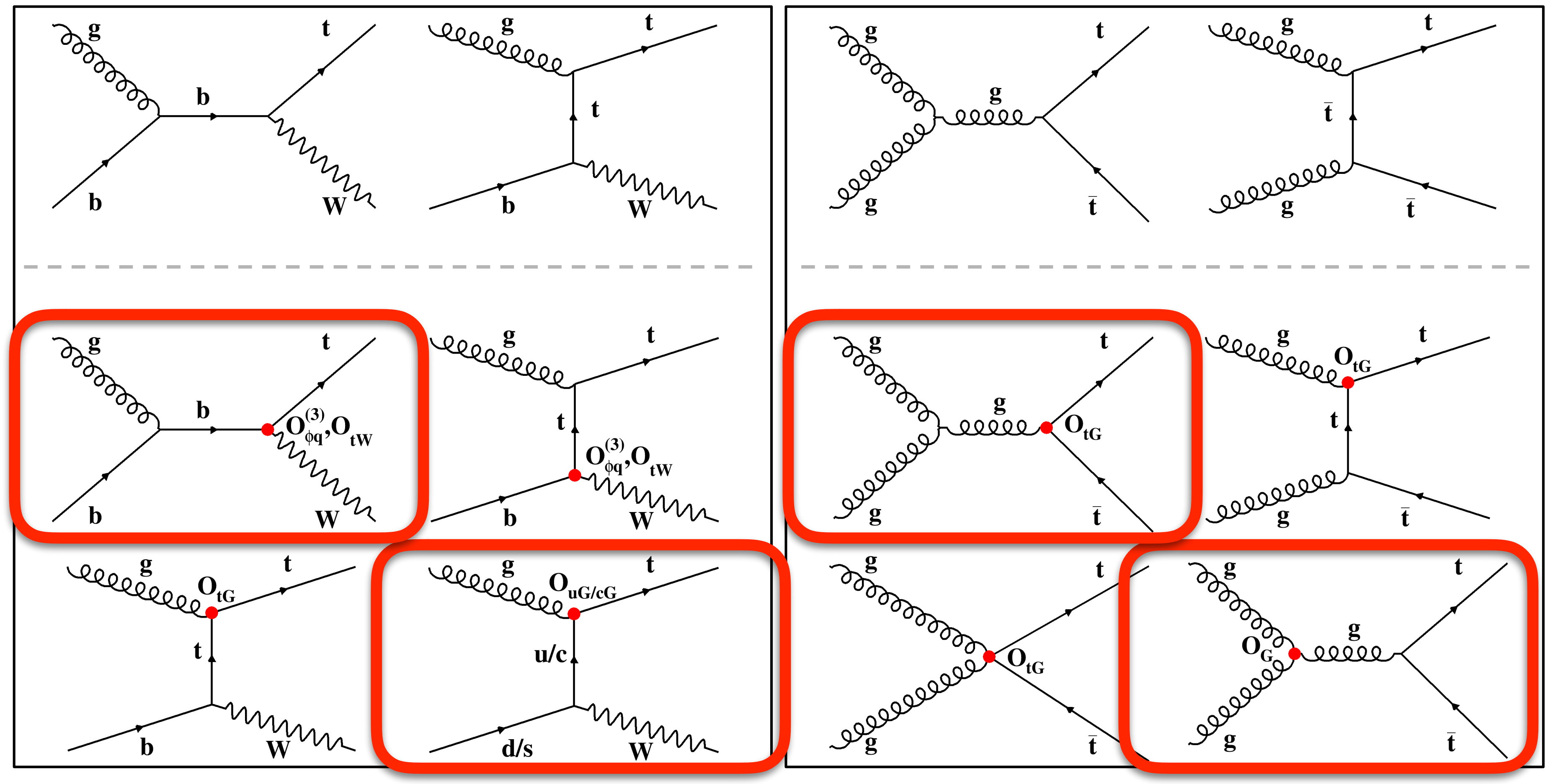
- $O_{\phi q,tW}$: affects tW kinematic distributions ; neural network $NN_{jet,b\text{-}jet}$ to discriminate (tt **'bkg'** + DY) from tW ; discriminate SM from New Physics effects
- O_{tG}: as above + affects differently tt and tW cross sections: use yields!

Multivariate analysis: SM-signal / SM-background / New Physics separation!

Search for new physics in top quark dilepton events

Some effects:



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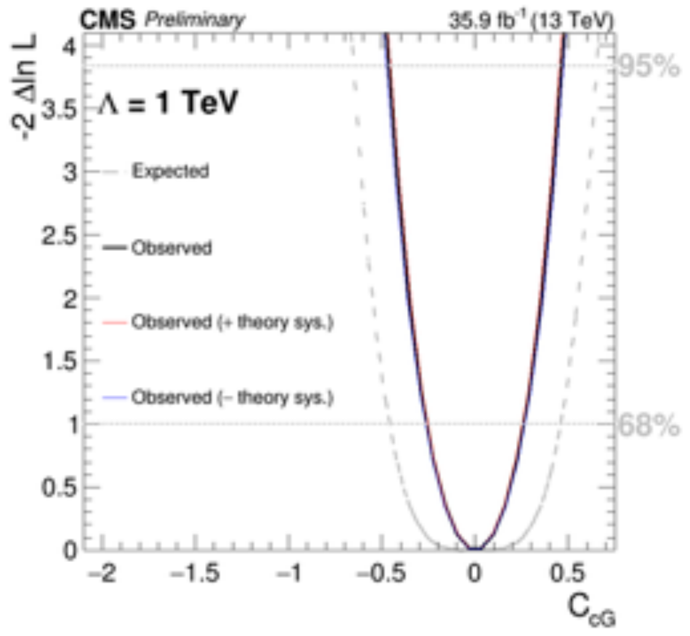
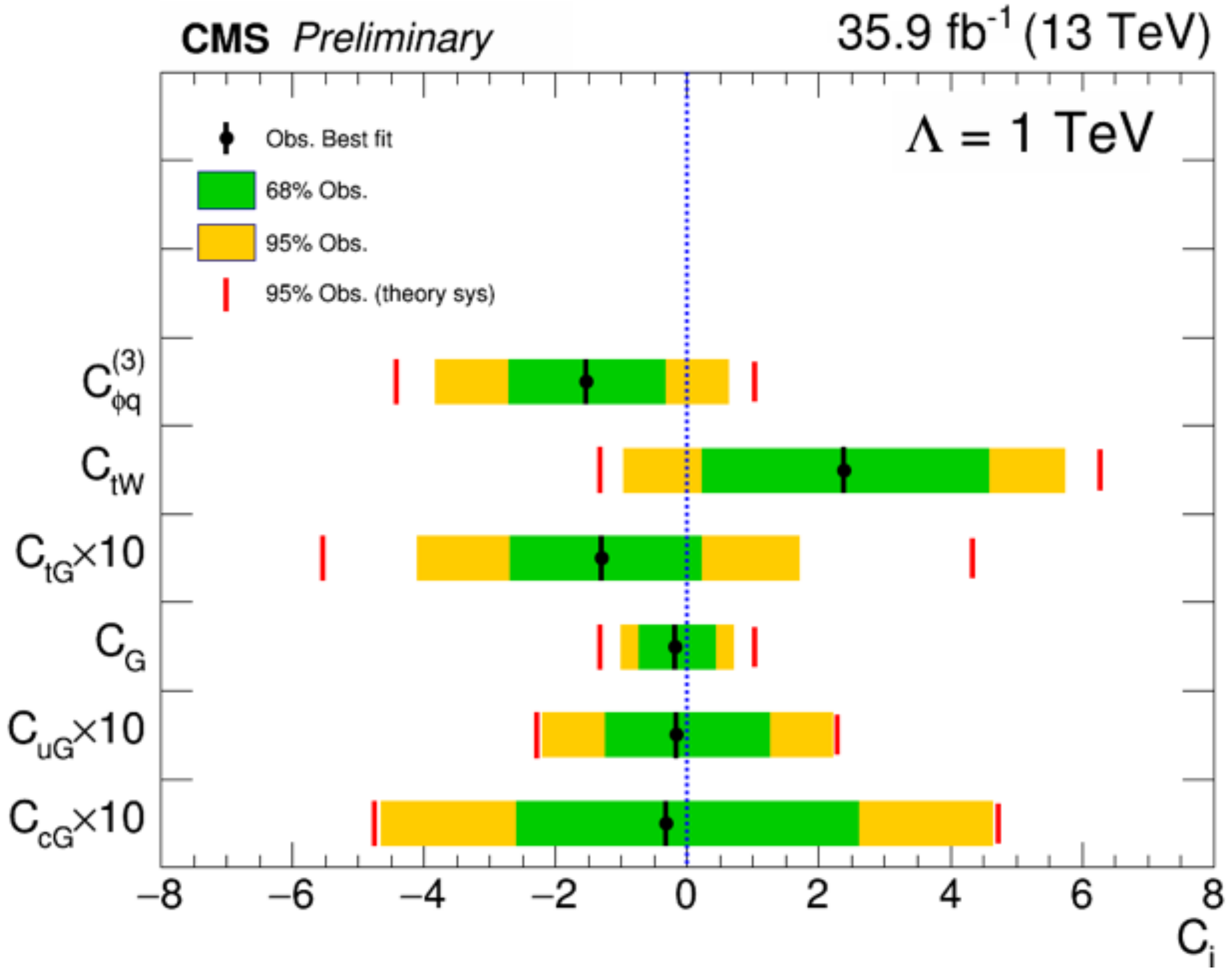
- O_{tG}: as above + affects differently tt and tW cross sections: use yields!

Example likelihood:



Results:

assuming new physics scale Λ= 1 TeV



Summary and conclusions

Conclusions

- ***Increased precision on ATLAS and CMS measurements***
  - top quark couplings accessed in rare processes, this talk:
    - top pairs and single top production in association with vector bosons
    - top pairs and single top production in association with photons
  - Some processes still statistically dominated :
    - naturally improving with current data taking
    - good prospects for more detailed measurements, e.g. differential associated production cross section
- ***Tools to interpret these measurements also improving***
  - e.g. accurate SM predictions ,
  - EFT (global) studies using multiple processes : ttW and ttZ cross sections imposing limits to 8 Wilson operators
  - also tZq already analyzed, in terms of EFT, e.g. arXiv:1804.07773
- ***New approach on the experimental side***
  - model-independent measurements : analysis designed to be more sensitive to EFT-Lagrangian terms
    - ***Improved chances of finding new physics!***