Using unitarity to perform precision top measurements

Strong tW scattering at the LHC

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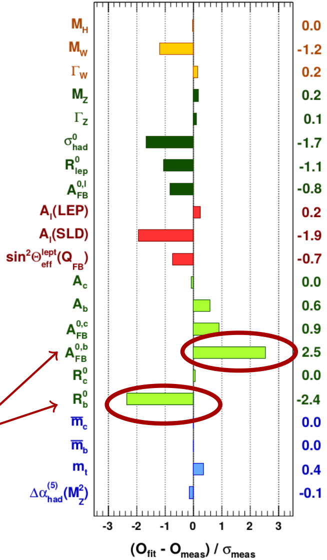
- The Standard Model has been thoroughly tested by previous expts
- LHC can have big impact on parameters relating t, h
- If no new particles found at LHC, measuring SM parameters is our future
- Excellent way to probe SM consistency
- Interestingly, outliers in the 3rd generation



Gfitter, 1209.2716

- If SM parameters deviate from theory $\Rightarrow$ amplitudes grow with energy (think $WW \to WW$)
- Such processes can be searched for at LHC
- Can use this feature to put constraints on SM couplings

  $\to$ Idea used to measure y_t **1211.3736: Farina, Grojean, Maltoni, Salvioni, Thamm** **1211.0499: Biswas, Gabrielli, Mele**

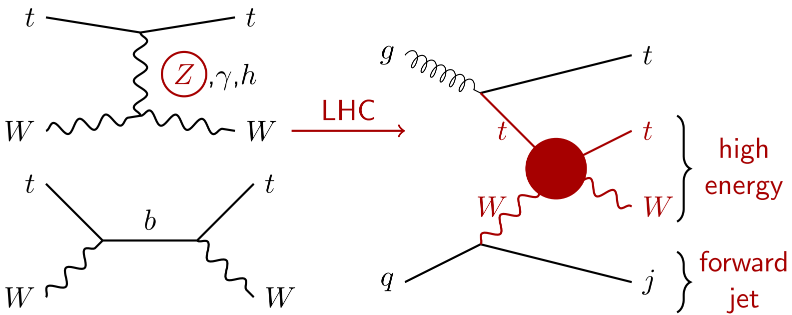
- Case study: $tW \to tW$ to probe Zt_Lt_L,Zt_Rt_R couplings
  - Currently measured through $t\bar{t}Z$
  - 8TeV 95% direct limits ($\Delta_i \equiv (g_{Zt_it_i} - g^{SM}_{Zt_it_i})/g^{SM}_{Zt_it_i}$):

$$\underbrace{-3 \lesssim \Delta_L \lesssim 1 \qquad\qquad -6 \lesssim \Delta_R \lesssim 4}_{\text{Weak bounds!}}$$

- Stronger indirect limits but can be avoided depending on model details

$tW \to tW$ at LHC

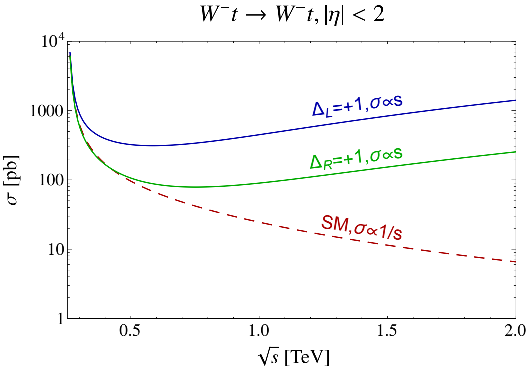
- $tW \to tW$ scattering (electroweak (EW) process):



- Sensitive to $g_{Zt_Rt_R}$, $g_{Zt_Lt_L}$, g_{Wtb}, g_{WWZ}, ...

Poorly constrained

- Quick calculation $\rightarrow$ $\mathcal{M} \sim s$ for $g_{Zt_Rt_R}, g_{Zt_Lt_L} \neq$ SM values.

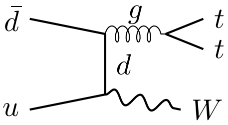


$$\Delta_i \equiv (g_{Zt_it_i} - g^{SM}_{Zt_it_i})/g^{SM}_{Zt_it_i}$$

Existing $t\bar{t}W$ search

Same-sign ℓ

- CMS performed a search for $t\bar{t}W$ CMS, 1406.7830
- Only included $\mathcal{O}(g_s^{2+n} g_w)$ contributions (σ_{QCD}) in $t\bar{t}W$ estimations, e.g.,

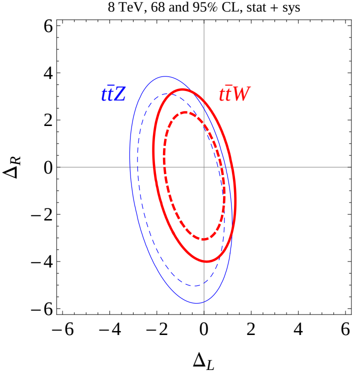


- EW process contributes at $\mathcal{O}(g_s g_w^3)$
  - Small in SM but can be large if $\Delta_L, \Delta_R \neq 0$
- Expected$=$39.7, Observed$=$36
- Can put limit on size of σ_{EW} and hence (Δ_L, Δ_R)

- Simulate EW signal as function of coupling deviations (applying CMS cuts). Find,

$$\sigma_{EW}(\Delta_L, \Delta_R)$$

- Madgraph, Pythia, PGS
- Right: compare new $t\bar{t}W$ limits with traditional $t\bar{t}Z$ search at 8TeV
- Significantly better limits even without dedicated search!



$$-4 \lesssim \Delta_R \lesssim 3$$

- At 8 TeV existing search happened to be sensitive to signal
- Would like to have dedicated search
- Unitarity effects become more pronounced at higher energies
- Goal:
  1. Simulate backgrounds and signal
  2. Find optimal cuts for $\mathcal{L} = 300\text{fb}^{-1}$, 13TeV.
  3. Produce projected limits

$$8\text{TeV} \longrightarrow 13\text{TeV}$$

(not to scale)

- Simulate all bkg at 8TeV
  - Matched at LO
  - Rescale to NLO values
- Compare distributions to those found by CMS
- Use the CMS search to calibrate monte carlo for 13TeV (important for tricky backgrounds such as misIDℓ, misIDQ)
- Dominant bkgs:

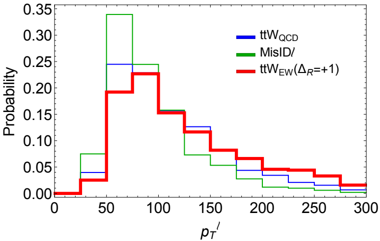
$(t\bar{t}W)_{QCD}$, $t\bar{t}Z$, misIDQ, $t\bar{t}h$, $(W^{\pm}W^{\pm}j^{n})$, misIDℓ

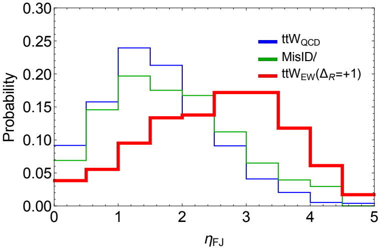
misIDQ: electron given η - dependent misidentified charge prob

misIDℓ: Simulated prob. of misID b as ℓ with smeared p_T

Curtin, Galloway, Wacker, 1306.5695

- Dominant backgrounds ($(t\bar{t}W)_{QCD}$ and $MisID\ell$) are reducible!



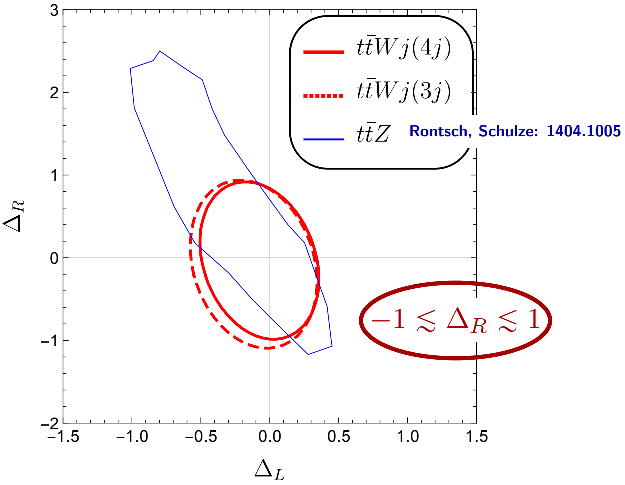


- Best cuts: CMS $t\bar{t}W$ cuts $+$

$$p_T^{\ell_1} > 100\text{GeV},\ \not{E}_T > 50\text{GeV},\ m_{\ell\ell} > 125\text{GeV}$$

$$|\eta_{FJ}| > 1.75\ ,\ d\eta_{FJ_1,FJ_2} > 2$$

- Assuming $N_{obs} = N_{bkg}$ we can get 13TeV projected limits
- Used likelihood and assumed 50% systematic on misIDℓ



Higher Dimensional Operators (HDO)

- Above SM couplings, what about HDO?

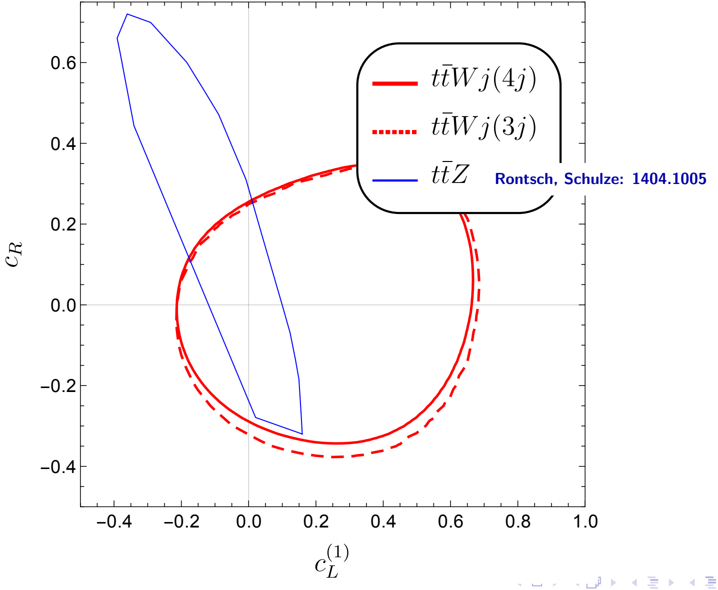
$$\mathcal{L} \supset \frac{ic_L^{(1)}}{\Lambda^2} H^\dagger D_\mu H \bar{q}_L \gamma^\mu q_L + \frac{ic_L^{(3)}}{\Lambda^2} H^\dagger \sigma^i D_\mu H \bar{q}_L \gamma^\mu \sigma^i q_L$$
$$+ \frac{ic_R}{\Lambda^2} H^\dagger D_\mu H \bar{t}_R \gamma^\mu t_R$$

where $\epsilon \equiv i\sigma^2$.

$$\frac{\delta g_{Zt_Lt_L}}{g^{SM}_{Zt_Lt_L}} = \frac{c_L^{(3)} - c_L^{(1)}}{\left(1 - \frac{4}{3}s_W^2\right)} \frac{v^2}{\Lambda^2}, \quad \frac{\delta g_{Zb_Lb_L}}{g^{SM}_{Zb_Lb_L}} = \cancel{\frac{c_L^{(1)} + c_L^{(3)}}{\left(1 - \frac{2}{3}s_W^2\right)}} \frac{v^2}{\Lambda^2}$$

$$\frac{\delta g_{Wt_Lb_L}}{g^{SM}_{Wt_Lb_L}} = c_L^{(3)} \frac{v^2}{\Lambda^2}, \quad \frac{\delta g_{Zt_Rt_R}}{g^{SM}_{Zt_Rt_R}} = \frac{c_R}{\frac{4}{3}s_W^2} \frac{v^2}{\Lambda^2}$$

HDO limits



0.6
0.4
0.2
0.0
−0.2
−0.4
c_R
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
$c_L^{(1)}$
$t\bar{t}Wj(4j)$
$t\bar{t}Wj(3j)$
$t\bar{t}Z$
Rontsch, Schulze: 1404.1005

What else you got?

- $bW \to tZ$
  - Probed in tZj
  - $\sigma \sim s$
  - Mainly sensitive to $\Delta_L(c_L^{(1)})$
- $bW \to th$
  - Probed in thj
  - $\sigma \sim s$
  - Already used to measure y_t
- $tZ \to th$.
  - Probed in $t\bar{t}hj$
  - $\sigma \sim \sqrt{s}$
  - Sensitive to Δ_L, Δ_R, y_t
- ...

Many opportunities for future study

Conclusions

- We can use unitary to measure parameters in the SM
- Considered $tW \to tW$ as a case study
- Improved measurement at 8TeV
- Significant improvements on measurement can be made for 13TeV analysis
  - NLO analysis? Better optimization? Combining channels?
- How far we can push this idea?
- Let's see whats out there!