Constraining new physics through the $t\bar{t}$ spin density matrix

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$t\bar{t}$ spin density matrix

- The matrix element of $t\bar{t}$ production in partonic CoM frame is:

$$|\mathcal{M}|^2 \propto A + \boldsymbol{B}^+ \cdot \boldsymbol{s}_1 + \boldsymbol{B}^- \cdot \boldsymbol{s}_2 + C_{ij} s_{1i} s_{2j} \quad (1)$$

arXiv:1508.05271

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- Determines cross section
- Spin-independent distributions
- $m_{t\bar{t}}$, p_T^t...

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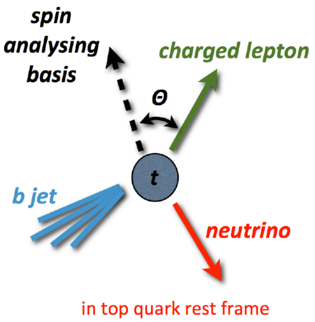
- $s_{1,2} = t(\bar{t})$ spin operators
- $B^{\pm}$ related to $t(\bar{t})$ polarization
- 0 at SM LO, small at NLO
- Deviations $\rightarrow$ P, CP violations



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- In SM: only P, CP even coefficients $\neq 0$
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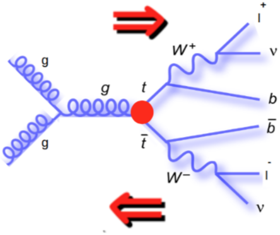

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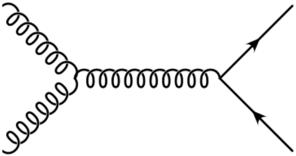
Spin effects for any model fully specified!

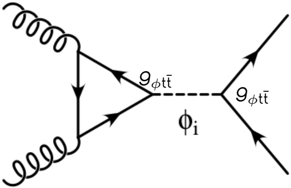
arXiv:1508.05271

A case study: $\phi \to t\bar{t}$

- Search for resonant ϕ decaying to $t\bar{t}$ pure pseudo/scalar A/H
  - Interference with SM taken into account
  - Coupling between ϕ and top quark denoted with the letter $g_{\phi t\bar{t}}$



SM $gg \to t\bar{t}$



$gg \to \phi \to t\bar{t}$

Diagrams from arXiv:1511.05584

A case study: $\phi \to t\bar{t}$

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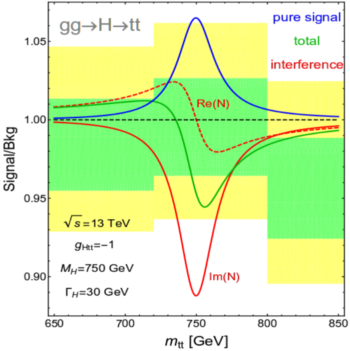
  - Interference with SM taken into account
  - Coupling between ϕ and top quark denoted with the letter $g_{\phi t\bar{t}}$
- Significant peak-dip structure in $m_{t\bar{t}}$ spectrum due to interference
  - No resonance peak in some cases
  - Exact structure depends on parity, m_ϕ and Γ_ϕ
- Search performed mainly through $m_{t\bar{t}}$ shape analysis
- Do we gain by looking also into spin correlation effects?
- Are there scenarios where we gain more from it?



Plot from arXiv:1605.00542

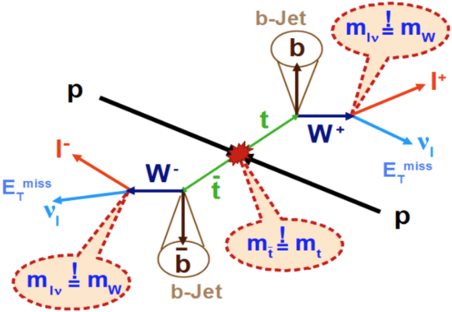
Analysis strategy and event selection

- Search performed in the dileptonic channel
  - Both W bosons in top decays decay leptonically, with ℓ = e or μ
  - Used the 2016 single and dilepton CMS data totalling 35.9 fb^{-1}
- Generated signal points:
  - In 2D [m_ϕ, Γ_ϕ] array talk focuses on 50% width case
  - $g_{\phi t\bar{t}}$ assumed to be 1
- Set limits on $g_{\phi t\bar{t}}$ through shape analysis
  - Not the conventional σ/σ_{th} due to different scaling of signal parts
- Baseline selection:
  - 2 opposite-sign isolated leptons with Z-veto in same-flavor channels
  - $\geq$2 jets, at least 1 jet is b-tagged
  - Pass the kinematic reconstruction routine
- Shape and rate-affecting systematics are taken into account:
  - Experimental: jet energy scales, lepton identification, b-tagging...
  - Theoretical: ME scales, top mass, background cross sections...

$t\bar{t}$ kinematic reconstruction

- Missing neutrinos in the event → $t\bar{t}$ system is underconstrained
- Reconstruct the $t\bar{t}$ system with an analytical routine (arXiv:hep-ph/0603011)
  - Impose constraints based on known top and W masses
  - Assume $\not{E}_T$ is entirely due to the neutrinos
  - Resulting polynomial in p_i^{ν} solvable → full $t\bar{t}$ system kinematics

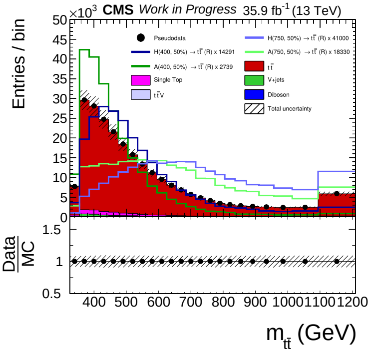
- Increase efficiency by solving for all lepton-jet combinations
- Account for detector effects by random object smearings
- Procedure described in detail in CMS-PAS-TOP-16-011



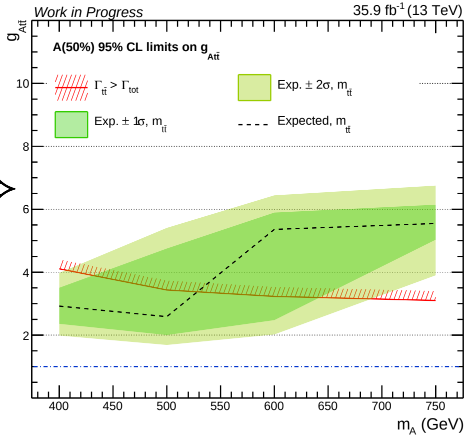
Limits on $g_{\phi t\bar{t}}$ with $m_{t\bar{t}}$

- Now let's look at the expected results, first obtained with $m_{t\bar{t}}$

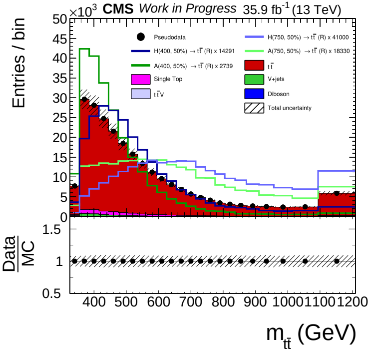
A(50%) limits on $g_{\phi t\bar{t}}$ with $m_{t\bar{t}}$



$\Rightarrow$



H(50%) limits on $g_{\phi t\bar{t}}$ with $m_{t\bar{t}}$



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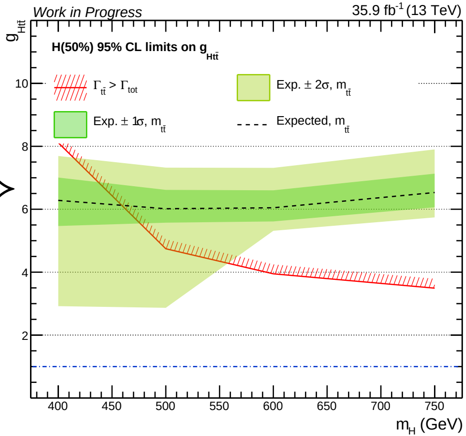
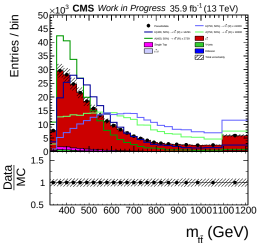


Limits on $g_{\phi t\bar{t}}$ with $m_{t\bar{t}} \times c_{hel}$

- What do we gain by adding a spin correlation observable?
- Which one to use? There are a lot of them…
- c_{hel}: opening angle between the leptons in the $t\bar{t}$ helicity frame
  - Theoretically simple: $< c_{hel} > = -\frac{1}{3}[C_{kk} + C_{rr} + C_{nn}]$
  - Experimentally tricky: kinematic reconstruction, jets, $\not{E}_T$ resolution…
- $\Delta\phi_{lab}$: azimuthal separation between the leptons in lab frame
  - Experimentally clean: leptons very well measured at high efficiency
  - Theoretically complex: interplay between A and C_{ij} highly non-trivial

A(50%) limits on $g_{\phi t\bar{t}}$ with $m_{t\bar{t}} \times c_{hel}$



Clear improvement compared to using $m_{t\bar{t}}$ alone

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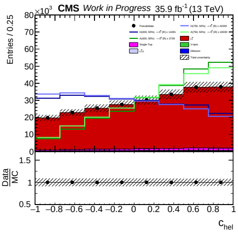

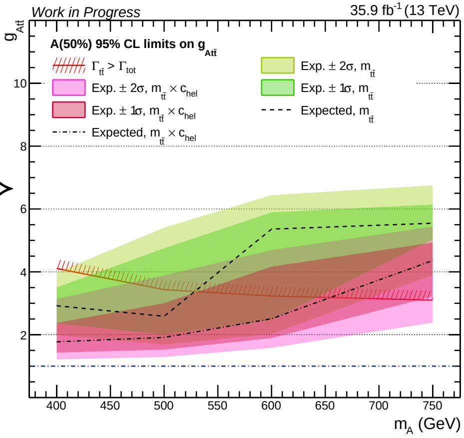

X picture from shadypenpen.deviantart.com

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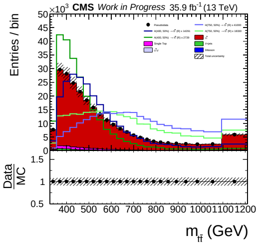
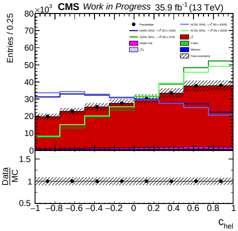
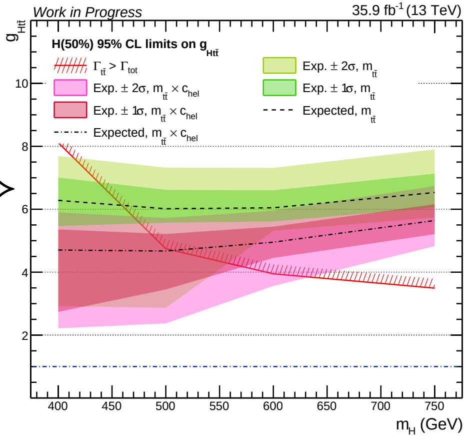




$\Longrightarrow$



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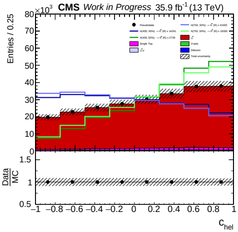
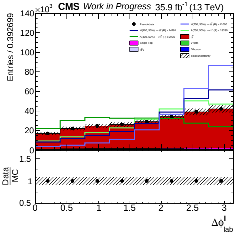
Limits on $g_{\phi t\bar{t}}$ with $c_{hel} \times \Delta\phi_{lab}$

- Are results with pure angles competitive?

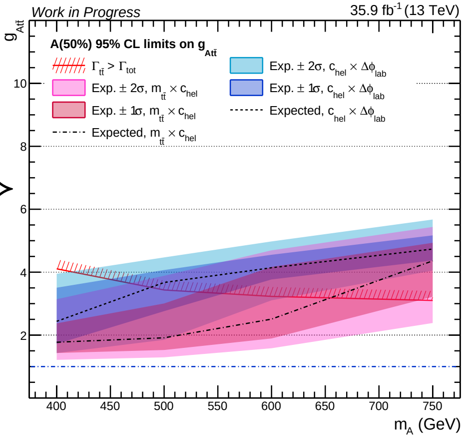
A(50%) limits on $g_{\phi t\bar{t}}$ with $c_{hel} \times \Delta\phi_{lab}$





Competitive results especially towards higher m_ϕ

$\Longrightarrow$



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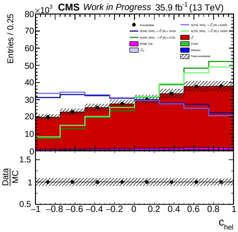

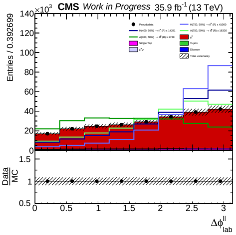

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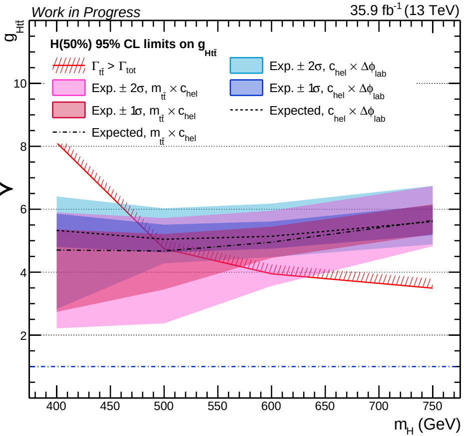

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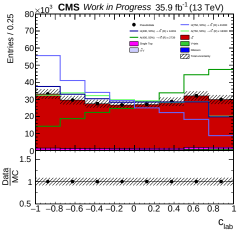
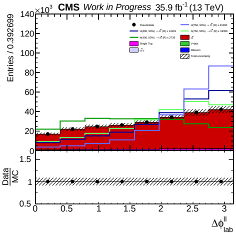
Afterword

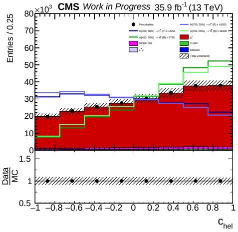
- The $t\bar{t}$ spin density matrix provides additional handles with which new physics can be constrained
- Case study showed that these can be as competitive as results obtained through A e. g. $m_{t\bar{t}}$
- Expect these to be even more powerful in constraining more subtle new physics effects:
  - i. e. cases with anomalous couplings instead of new particles
  - Commonly considered e. g. in the EFT approach to BSM extensions

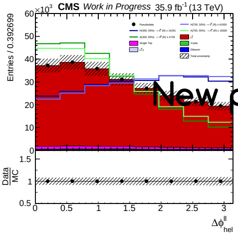
Afterword



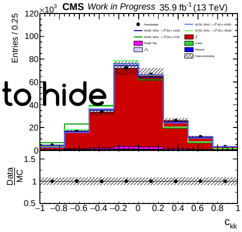
Leave no stones unturned!







New physics shall have nowhere to hide



Backup slides