$t\bar{t}$ spin density matrix and constraints on new phenomena

CMS-PAS-TOP-18-006

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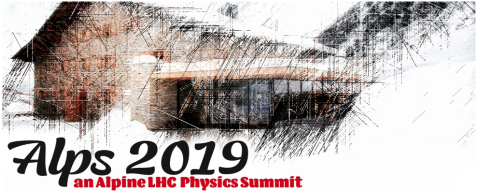
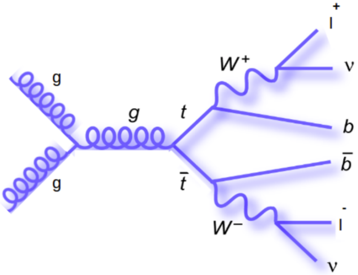
on behalf of the CMS Collaboration

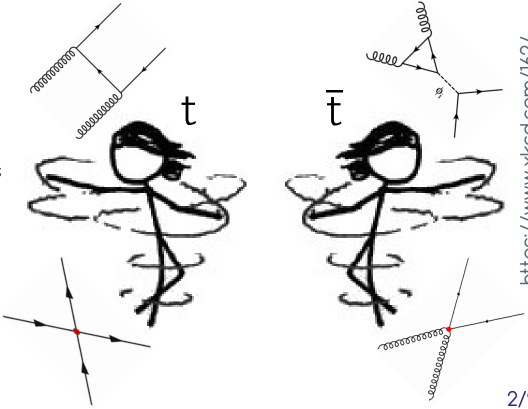
26 April 2019



Introduction



- Top is the only quark whose spin structure can be studied
  - Very short lifetime → no spin decorrelation
  - Down-type W daughter is a perfect spin analyzer
    - Follows from the V - A structure of the decay
    - It's great that we can measure THIS daughter well!
  - Analysis performed in the $\mathrm{t\bar{t}} \to 2(\mathrm{b}\ell\nu)$ channel
    - Select events with 2 hard jets and 2 isolated leptons
    - May also involve high $\not{p}_T$
- Watch the tops dance to understand their culture
  - e.g. $\mathrm{A/H} \to \mathrm{t\bar{t}}$ or EFT have different spin structures
  - Shows up in the correlations of t and $\bar{\mathrm{t}}$ spins



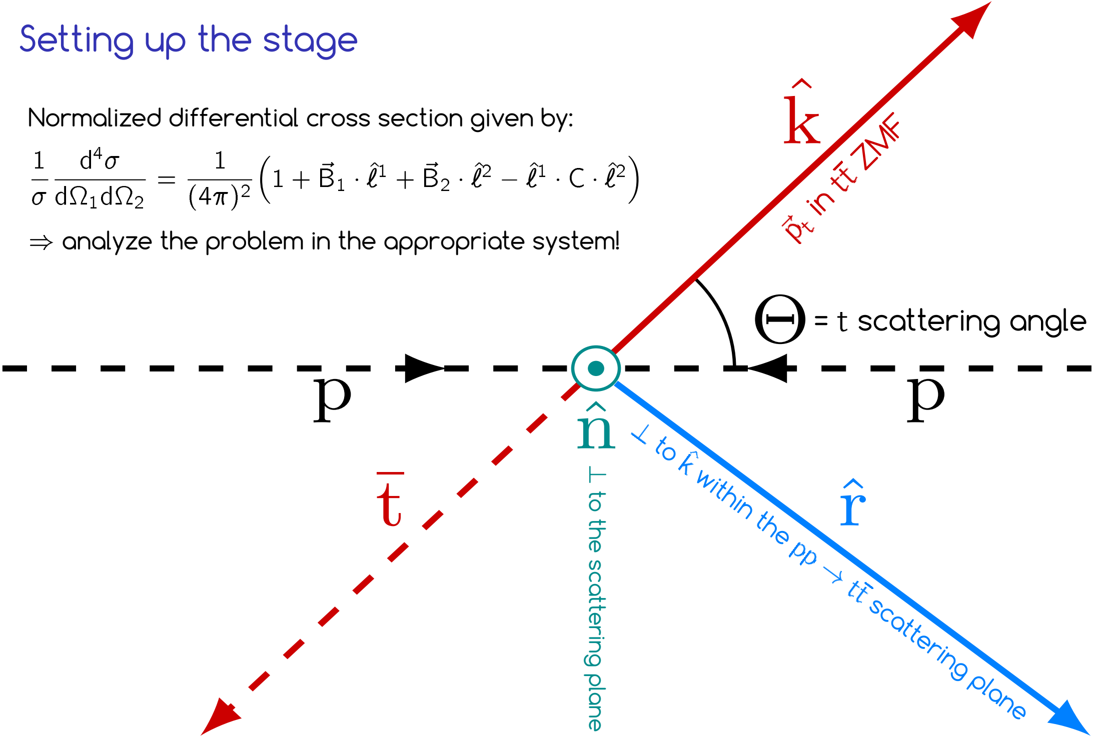
https://www.xkcd.com/162/

Setting up the stage

Normalized differential cross section given by:

$$\frac{1}{\sigma}\frac{d^4\sigma}{d\Omega_1 d\Omega_2} = \frac{1}{(4\pi)^2}\left(1 + \vec{B}_1\cdot\hat{\ell}^1 + \vec{B}_2\cdot\hat{\ell}^2 - \hat{\ell}^1\cdot C\cdot\hat{\ell}^2\right)$$

$\Rightarrow$ analyze the problem in the appropriate system!



JHEP 12 (2015) 026 [arXiv:1508.05271]

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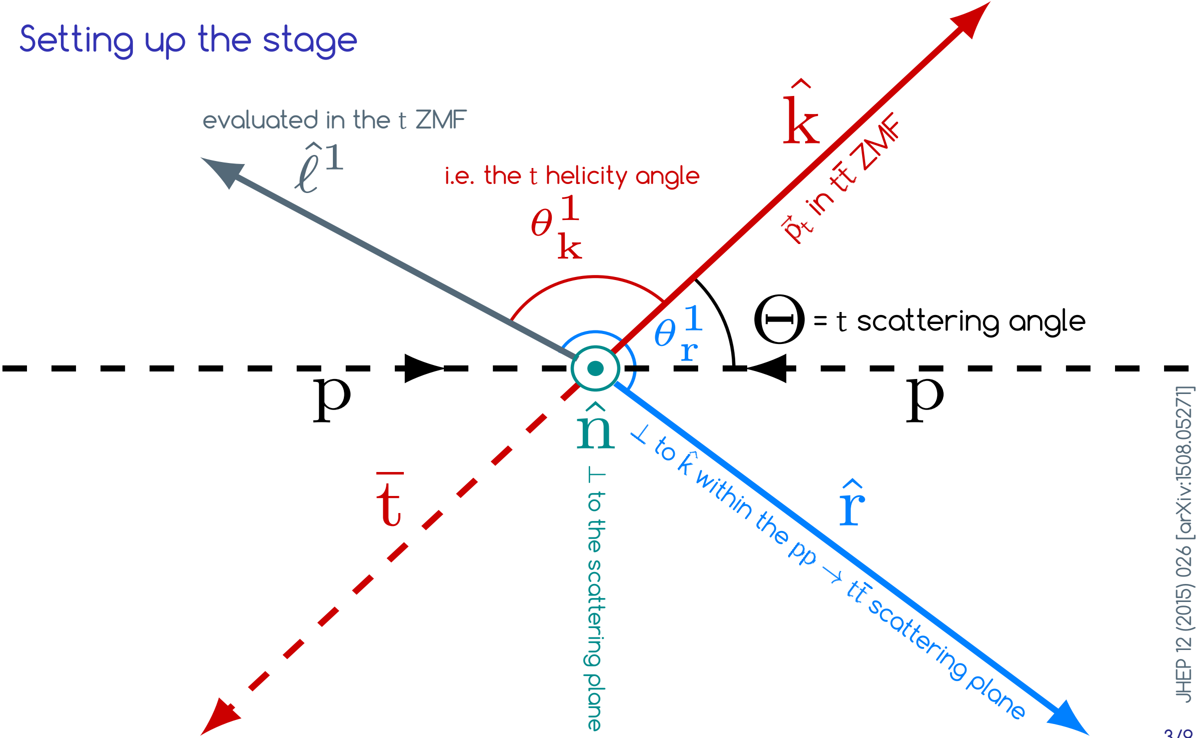

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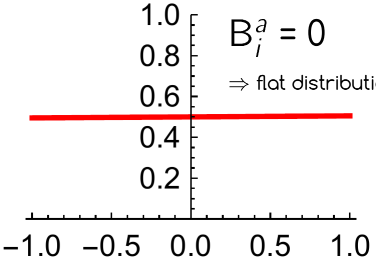
Polarization

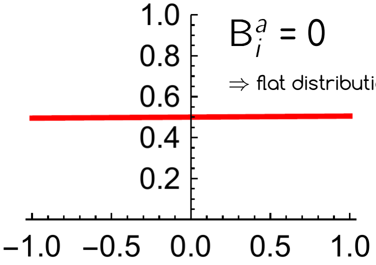


$B_i^a = 0$

$\Rightarrow$ flat distribution of $\cos\theta_i^a$

$$\frac{d^4\sigma}{d\Omega_1 d\Omega_2} \propto \boxed{\vec{B}_1 \cdot \hat{\ell}^1 + \vec{B}_2 \cdot \hat{\ell}^2} - \hat{\ell}^1 \cdot C \cdot \hat{\ell}^2$$

Polarization



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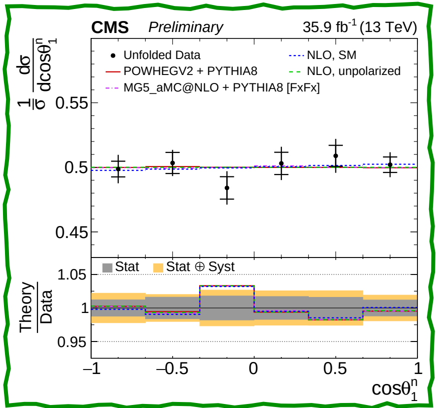
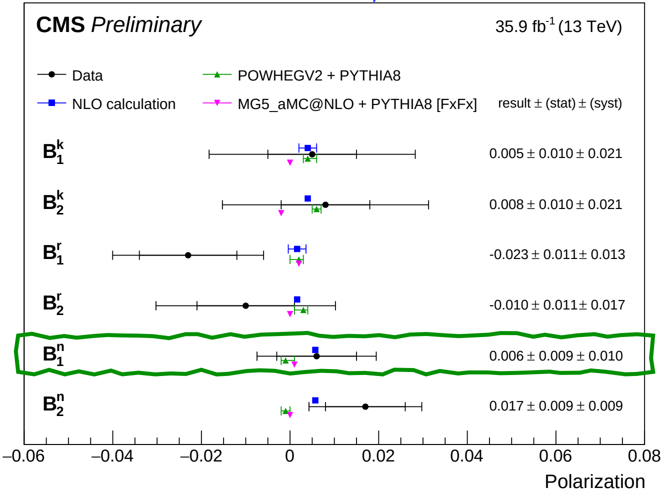
Consistent with 0

Not yet at a level to test SM

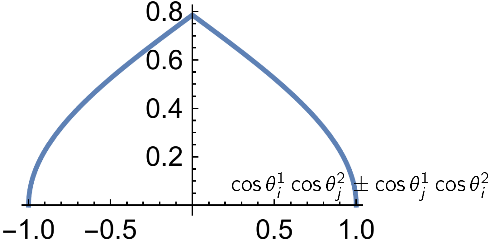




Off-diagonal correlation

$$\frac{d^4\sigma}{d\Omega_1 d\Omega_2} \propto \vec{B}_1 \cdot \hat{\ell}^1 + \vec{B}_2 \cdot \hat{\ell}^2 - \boxed{\hat{\ell}^1 \cdot C \cdot \hat{\ell}^2}$$

$$\begin{pmatrix} & X & X \\ X & & X \\ X & X & \end{pmatrix}$$



$C_{ij} \pm C_{ji} = 0 \Rightarrow$ symmetric distribution

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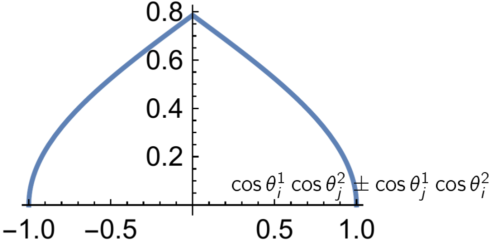

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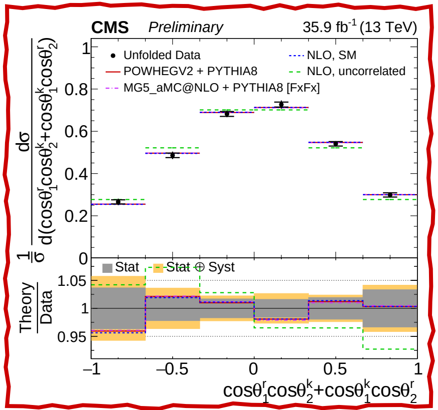
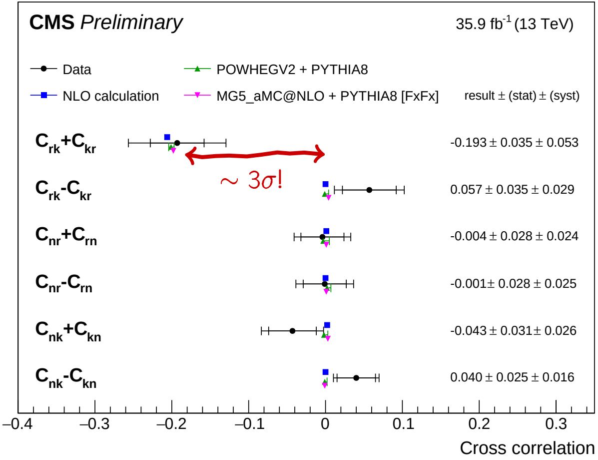
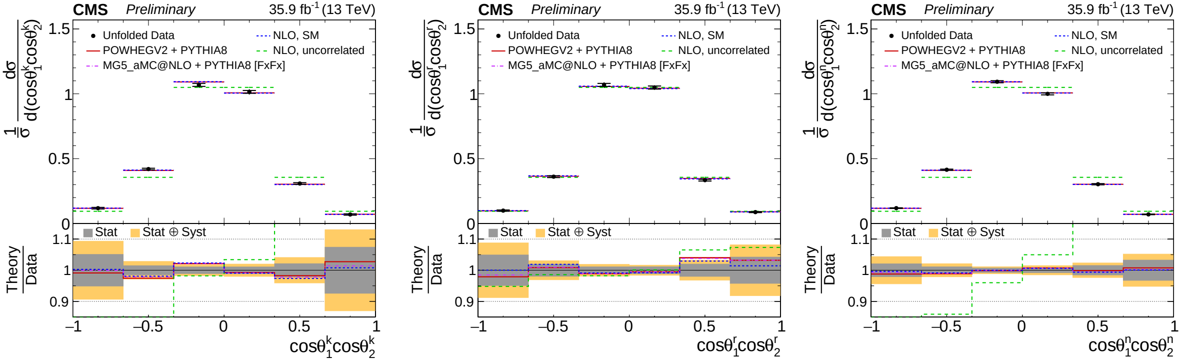


All $C_{ij} \pm C_{ji}$ consistent with SM



Diagonal correlation

$$\frac{d^4\sigma}{d\Omega_1 d\Omega_2} \propto \vec{B}_1 \cdot \hat{\ell}^1 + \vec{B}_2 \cdot \hat{\ell}^2 - \hat{\ell}^1 \cdot C \cdot \hat{\ell}^2$$



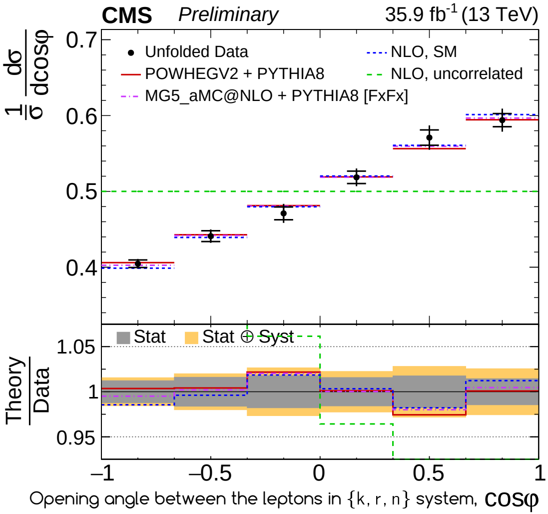
$$\begin{pmatrix} 0.30 \pm 0.04 & & \\ & 0.08 \pm 0.03 & \\ & & 0.33 \pm 0.02 \end{pmatrix}$$

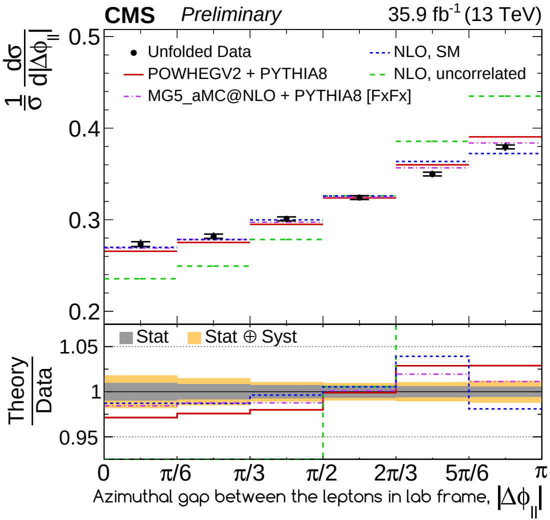
measured vs predicted

C_{ii} consistent with SM

$$\begin{pmatrix} 0.33 & & \\ & 0.07 & \\ & & 0.33 \end{pmatrix}$$

On traces and gaps





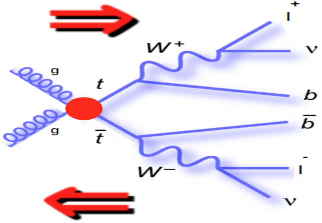
- Expresses how well t and $\bar{t}$ spins align together
- Spin coefficient $D \propto \mathrm{Tr}[C]$
- -0.24 ± 0.01 measurement consistent with SM (-0.24)

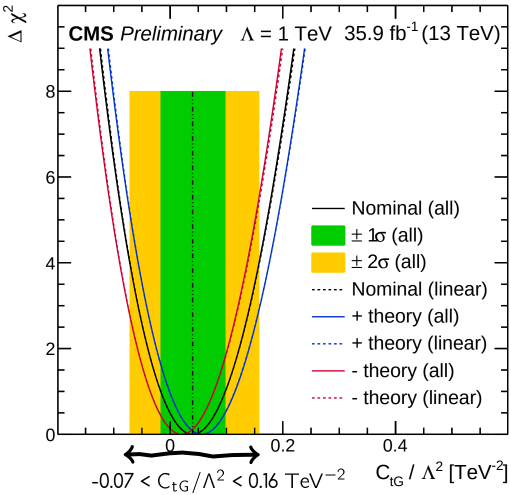
- + Experimentally very precise
- − Complex interplay of spin correlation and kinematics
- Tension between different predictions MC vs calc.
- Still consistent with SM NLO and NNLO calculations

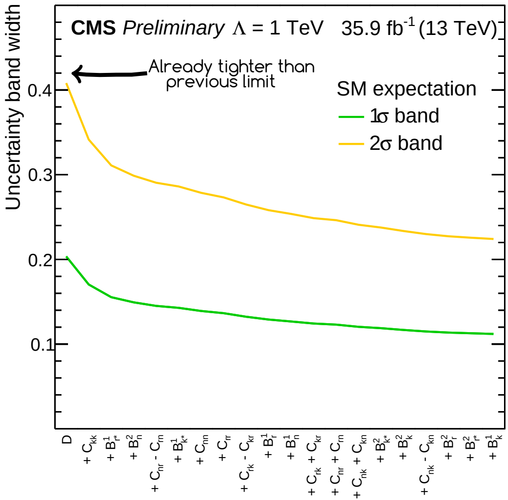
NLO from JHEP 12 (2015) 026 [arXiv:1508.05271], NNLO from [arXiv:1901.05407]

Constraining EFTs

- Measurement is sensitive to operators affecting LHC $t\bar{t}$ production
- Start by constraining the CMDM operator affecting mainly C_{ii}
  - Perform a simultaneous fit to constrain systematics
  - The strongest direct constraint thus far







Afterword

- $t\bar{t}$ spin density matrix measurement is consistent with SM predictions
  - First one that covers all the full matrix at 13 TeV
- $t\bar{t}$ spin density matrix is a powerful probe for BSM phenomena
  - Tightest single operator constraint on top CMDM thus far
  - More to come in the paper version
  - Stay tuned for more dancing tops!

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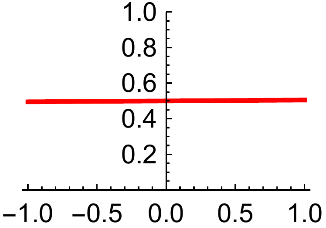
Thanks for your attention!

Backup

Observables

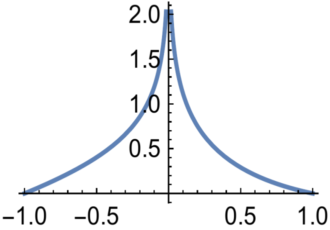


$$\frac{1}{\sigma}\frac{d\sigma}{dx} = \frac{1}{2}(1 + Cx)$$

$\Rightarrow x = \cos\theta_i^a, \quad \cos\varphi$

$\Rightarrow C = B_i^a, \quad -D$

$$i, j \in \{k, r, n\}$$



$$\frac{1}{\sigma}\frac{d\sigma}{dx} = \frac{1}{2}(1 + Cx)\ln\left(\frac{1}{|x|}\right)$$

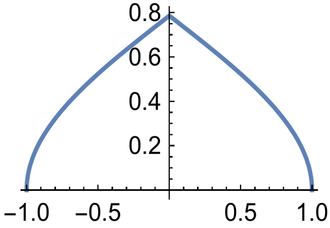
$\Rightarrow x = \cos\theta_i^1 \cos\theta_i^2$

$\Rightarrow C = -C_{ii}$

$$a \in [1, 2] \equiv [t, \bar{t}]$$

Any BSM physics can only change C

Use known shape to eliminate reg. bias



$$\frac{1}{\sigma}\frac{d\sigma}{dx} = \frac{1}{2}(1 + Cx)\cos^{-1}|x|$$

$\Rightarrow x = \cos\theta_i^1 \cos\theta_j^2 \pm \cos\theta_j^1 \cos\theta_i^2$

$$\Rightarrow C = -\frac{C_{ij} \pm C_{ji}}{2}$$

SM spin correlation fraction