Measurement of the tt Spin correlations and top polarization in dileptonic final states at $\sqrt{s} = 13$ TeV using the CMS detector

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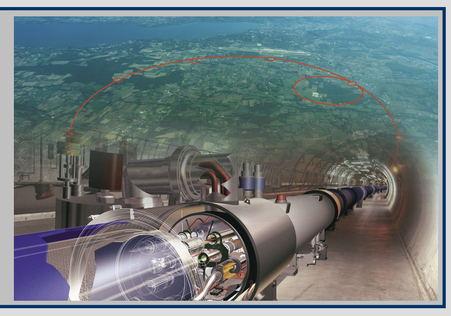
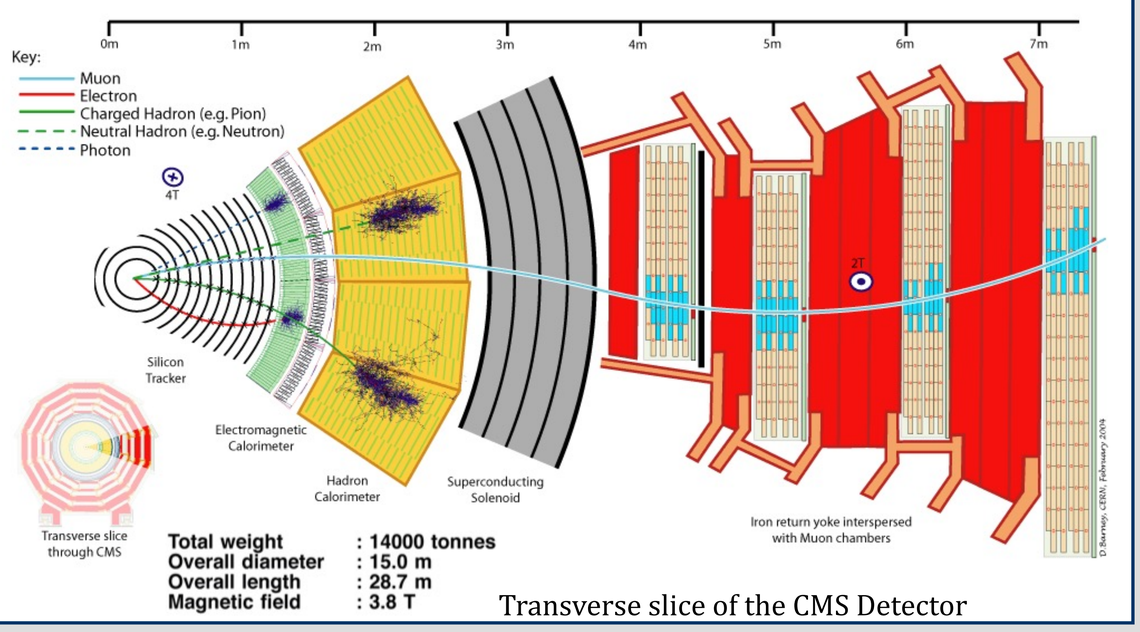


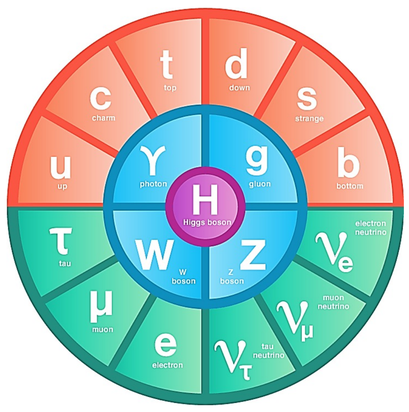
The Compact Muon Solenoid Detector



Transverse slice of the CMS Detector

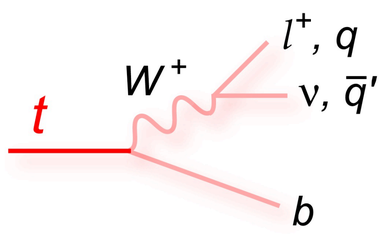
The top quark

The top quark (t) is the heaviest fundamental particle discovered, and with a remarkedly tiny lifetime, it is the only quark that decays before hadronizing. The decay time is so much faster than the characteristic time scale for the quark to spin-flip, so **the spin information of the top quark is transferred to its decay products** and is observable through their angular distributions and reconstruction.



Standard Model of Elementary Particles

$$\underbrace{\frac{1}{m_t}}_{\text{production } 10^{-27}\text{ s}} < \underbrace{\frac{1}{\Gamma_t}}_{\text{lifetime } 10^{-25}\text{ s}} < \underbrace{\frac{1}{\Lambda_{QCD}}}_{\text{hadronization } 10^{-24}\text{ s}} < \underbrace{\frac{m_t}{\Lambda^2}}_{\text{spin-flip } 10^{-21}\text{ s}}$$



In the dileptonic decay mode of the $t\bar{t}$ pair, the W daughters from both tops decay into lepton and neutrino. This mode has a 14% branching ratio, but the large $t\bar{t}$ production rate at the LHC (~ 1 $t\bar{t}$ pair per second) give this mode a clean signature, the best purity after event selection, and enough statistics that measurements are systematically limited. Furthermore, the decay leptons are a perfect spin analyzer.

Top Polarizations and $t\bar{t}$ Spin Correlations

Top quarks at the LHC are mostly produced in $t\bar{t}$ pairs. The gluons and quarks of the initial protons are unpolarized, so the pair produced top quarks of the final state are unpolarized except for tiny contributions of weak and QCD absorptive corrections. However, the spins of pair produced top quark and antiquark at the LHC are correlated with a strength that comes from the asymmetry in the QCD productions processed, and also on the choice of spin quantization axis.

The polar angle double differential distributions for a choice of reference axes $\hat{a}$ and $\hat{b}$:

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1}{4}(1 + B_1\cos\theta_+ + B_2\cos\theta_- - C(a,b)\cos\theta_+\cos\theta_-)$$

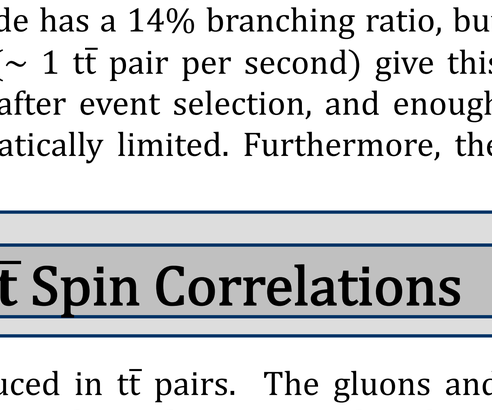
$$B_1(\hat{a}) = \kappa_l P(\hat{a}) \qquad B_2(\hat{b}) = -\kappa_l \bar{P}(\hat{b}) \qquad C(a,b) = A\kappa_l^2 \qquad A = \frac{\sigma(\uparrow\uparrow)+\sigma(\downarrow\downarrow)-\sigma(\uparrow\downarrow)-\sigma(\downarrow\uparrow)}{\sigma(\uparrow\uparrow)+\sigma(\downarrow\downarrow)+\sigma(\uparrow\downarrow)+\sigma(\downarrow\uparrow)}$$

κ_l is the top-spin analyzing power of the of the charged lepton from top decay ($\kappa_l = 0.998$)

Observables probing $t\bar{t}$ production density matrix:

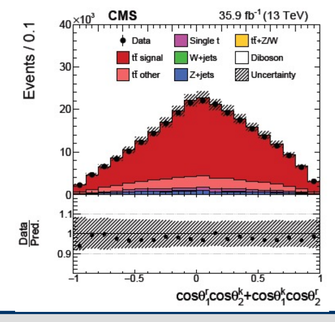
- 6 top quark and antiquark polarization
- 3 diagonal coefficients of each axis
- 6 cross correlations correlations
- 3 angles between leptons:

$$\cos\phi = \vec{l}_1 \cdot \vec{l}_2,\ \cos\phi_{lab} = \vec{l}_1^{lab} \cdot \vec{l}_2^{lab},$$
$$|\Delta\phi_{ll}| = \left|\left||\phi_{l_1} - \phi_{l_2}| - \pi\right| - \pi\right|$$



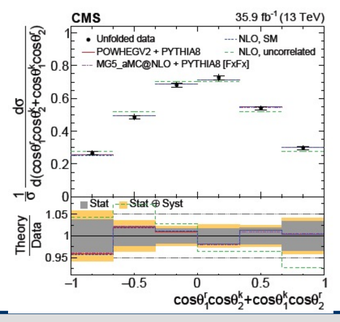
Unfolding Reconstructed Distributions

A distribution unfolded to parton level is obtained from the reconstructed distribution by applying a χ^2 minimization technique (Tunfold). A per-bin correction factor is applied in the process such that the regularization cannot introduce a bias in the unfolded distribution.



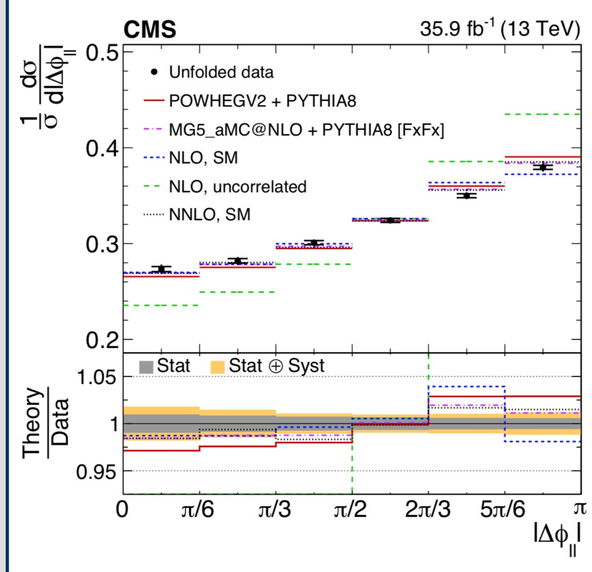
Unfolding

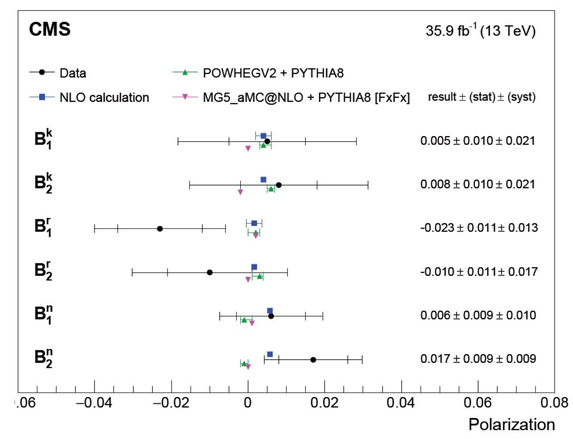
Normalization & Extrapolation to Full Phase Space



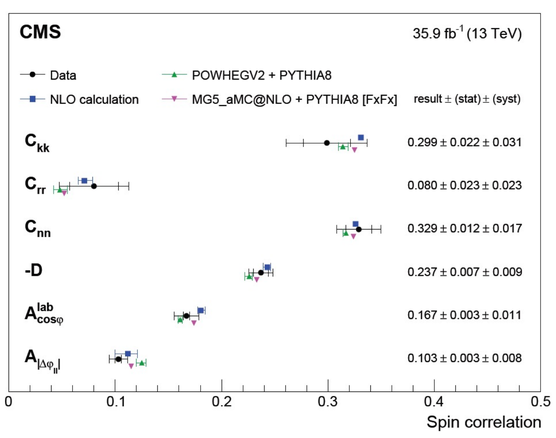
Results

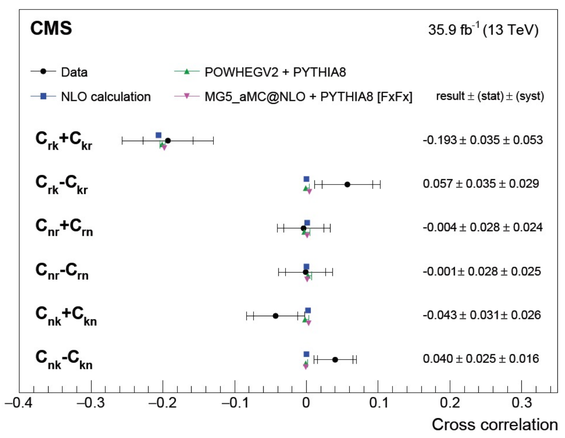
The $t\bar{t}$ spin correlation and top polarization coefficients, probing all the coefficients of the top quark spin-dependent parts of the $t\bar{t}$ production density matrix, were extracted from normalized differential cross-section distributions unfolded to parton level and extrapolated to the full phase space. When taking into account experimental and theoretical uncertainties all observables on the inclusive and differential level are found to be described. In particular, the $|\Delta\phi_{ll}|$ distribution is found to be consistent with NNLO SM prediction at the 1 SD level.





Measured polarization, spin correlation and asymmetry coefficients in comparison to various SM calculations.

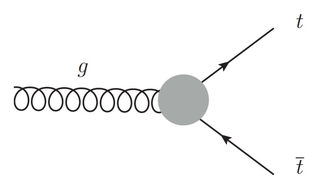


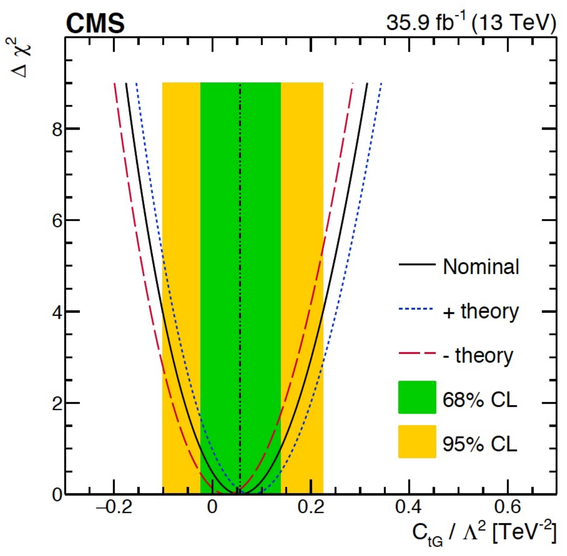


Interpretation

Measured coefficients probe most of the lowest-order EFT operators, focus on top quark anomalous chromo-magnetic dipole moment (CMDM), which induces top chirality flip. Set 95% CL limits on CMDM operator from simultaneous fit to measured differential cross sections.

$$O_{tG} = y_t g_s (\bar{Q}\sigma^{\mu\nu}T^a t)\tilde{\phi}G^a_{\mu\nu}$$





Strong direct constraint:

$$-0.07 < \frac{C_{tG}}{\Lambda^2} < 0.16\ \text{TeV}^{-2}$$

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