Comparative Analysis of Uncertainties in Top Quark Event Characteristics at HL-LHC and FCC Particle Detectors

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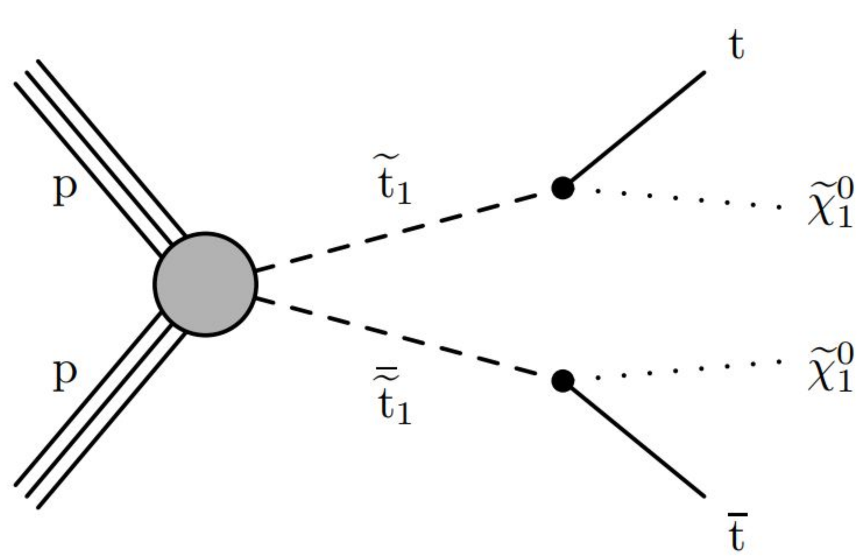
PURDUE SCIENCE

Introduction

By employing a fast detector response simulation (Delphes), we investigate the impact of different experimental conditions on the uncertainties of reconstructed top quark events using the Standard Model (SM), setting limits of the mass difference between top scalar quark and neutralino and refining Supersymmetry (SUSY) discovery potentials.



★★★ Feynman diagram for the production of (anti-)top squark pairs decaying into (anti-)top quarks and neutralinos.

Motivation and Effective Field Theory (EFT) Interpretation

Both the ATLAS and CMS group collected the distribution of indirect measurements of Δϕ for the final state leptons with unfolded data (Figure 1), they observed a discrepancy of ~1.5σ between the data and Next-to-Leading-Order (NLO) simulations. The discrepancy remains even in the fiducial phase space of the detector. Although reduced, the discrepancy is still substantial, when comparing to NNLO predictions. Now we proceed to direct measurement with spin correlation coefficients measured by even more powerful machines, in order to reduce the systematic uncertainties in the future.

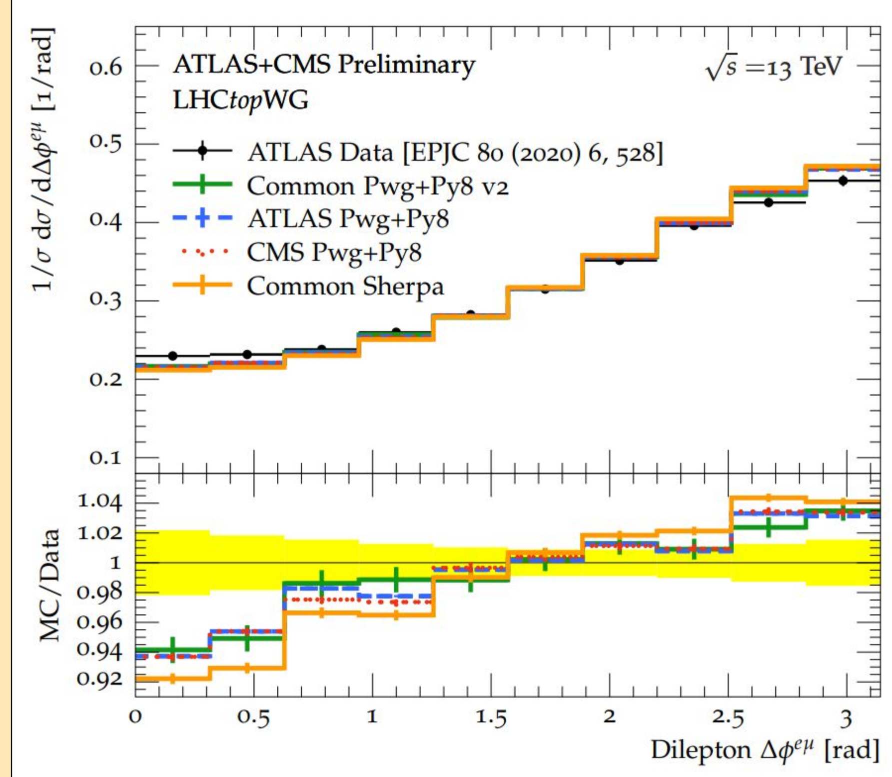
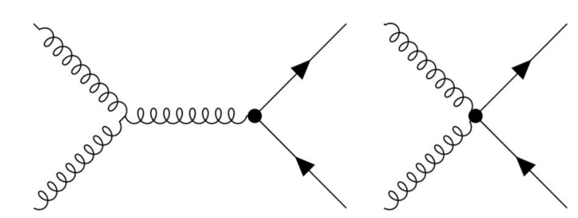
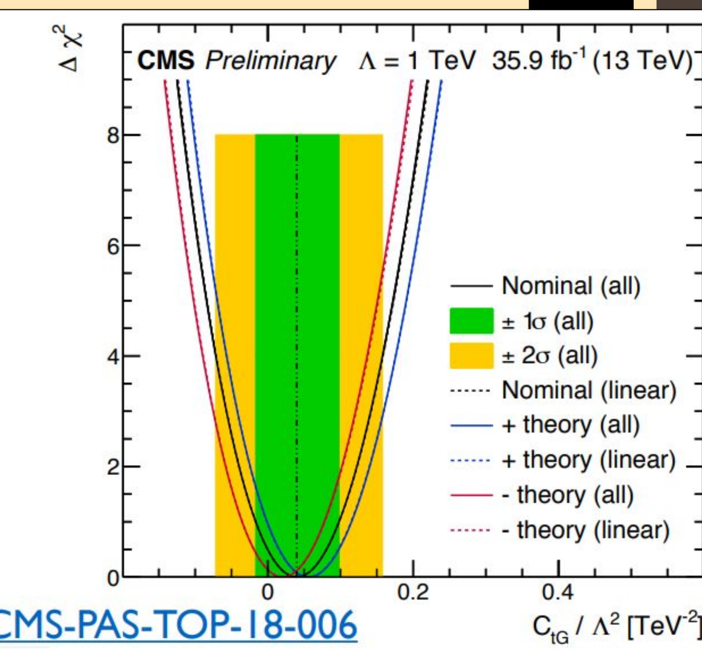


Figure 1. $\Delta\phi^{e\mu}$ distribution in data at parton level, fiducial phase space. [ATL-PHYS-PUB-2023-016]





CMS-PAS-TOP-18-006

Figure 2. $\Delta\chi^2$ values from the fit to the data are shown in the plot as a function of C_{tG}/Λ^2. The green area indicates 1σ CL, the orange indicates the 2σ CL. [Phys. Rev. D 100, 072002 (2019)]

A maximum likelihood fit is done using the chi-squared method on the fully correlated matrix (Figure 2). It gives the strongest direct constraint to date of $-0.07 < C_{tG}/\Lambda^2 < 0.16$ TeV^{-2} at 95% CL. Although the focus of the measurement (CMS Collaboration. Phys. Rev. D 100, 072002 (2019)) is to study the anomalous chromomagnetic dipole moment, it provides additional foresight for our study.

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda}\sum_i c_i \mathcal{O}_i + \frac{1}{\Lambda^2}\sum_j c_j \mathcal{O}_j + \cdots$$

Expansion Study on the Future Detectors

Professor Jung's research group at Purdue University carry on performing conservative evaluations for each possible systematic variation that contribute to the expected uncertainties. For instance, the comparison among jet energy correction (JEC) variations shown in Figure 3.

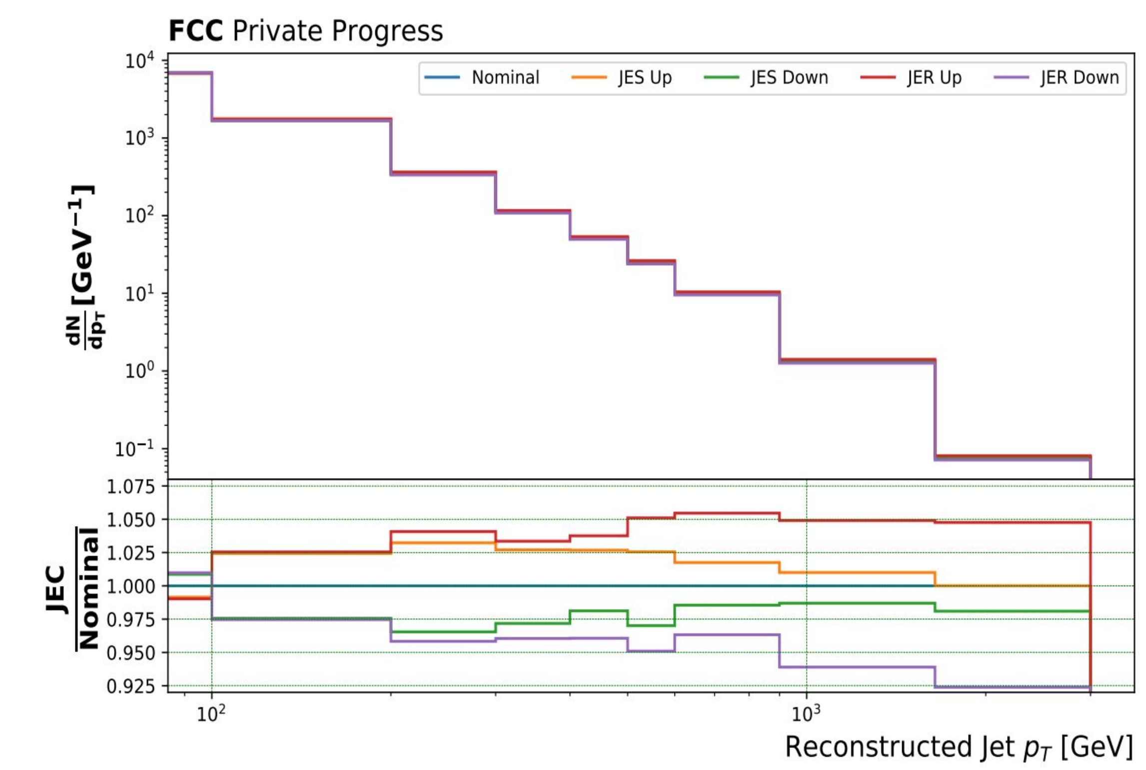


Figure 5. Histograms of jet energy correction scale variations of jet p_T at the detector level of FCC-hh Delphes samples.

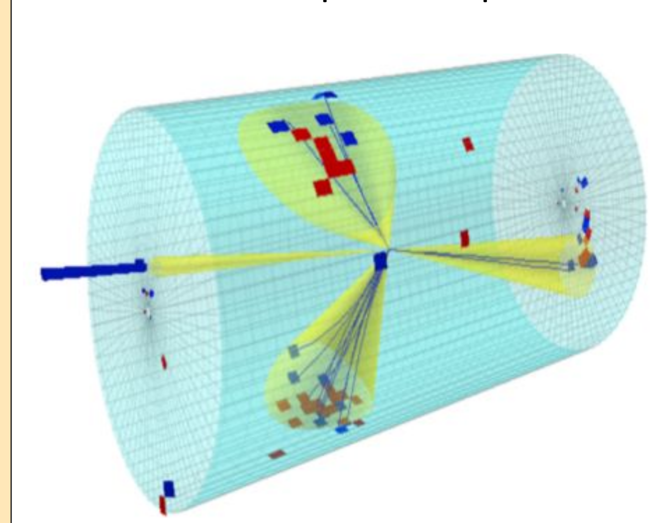


Figure 6. Artistic illustration of Future Circular Collider Delphes simulation. [FCC workshop at BNL - 25/04/2023]

The FCC project intends to build a multi-purpose collider that perform not only pp collisions, but also eē, ep and $\mu^+\mu^-$ collisions. Thus, the entanglement observable D and f_{sm} projections can be converted into a multi-dimensional comparison among the HL-LHC, FCC-hh, FCC-ee, FCC-he and other detectors which may introduce tighter constraints.

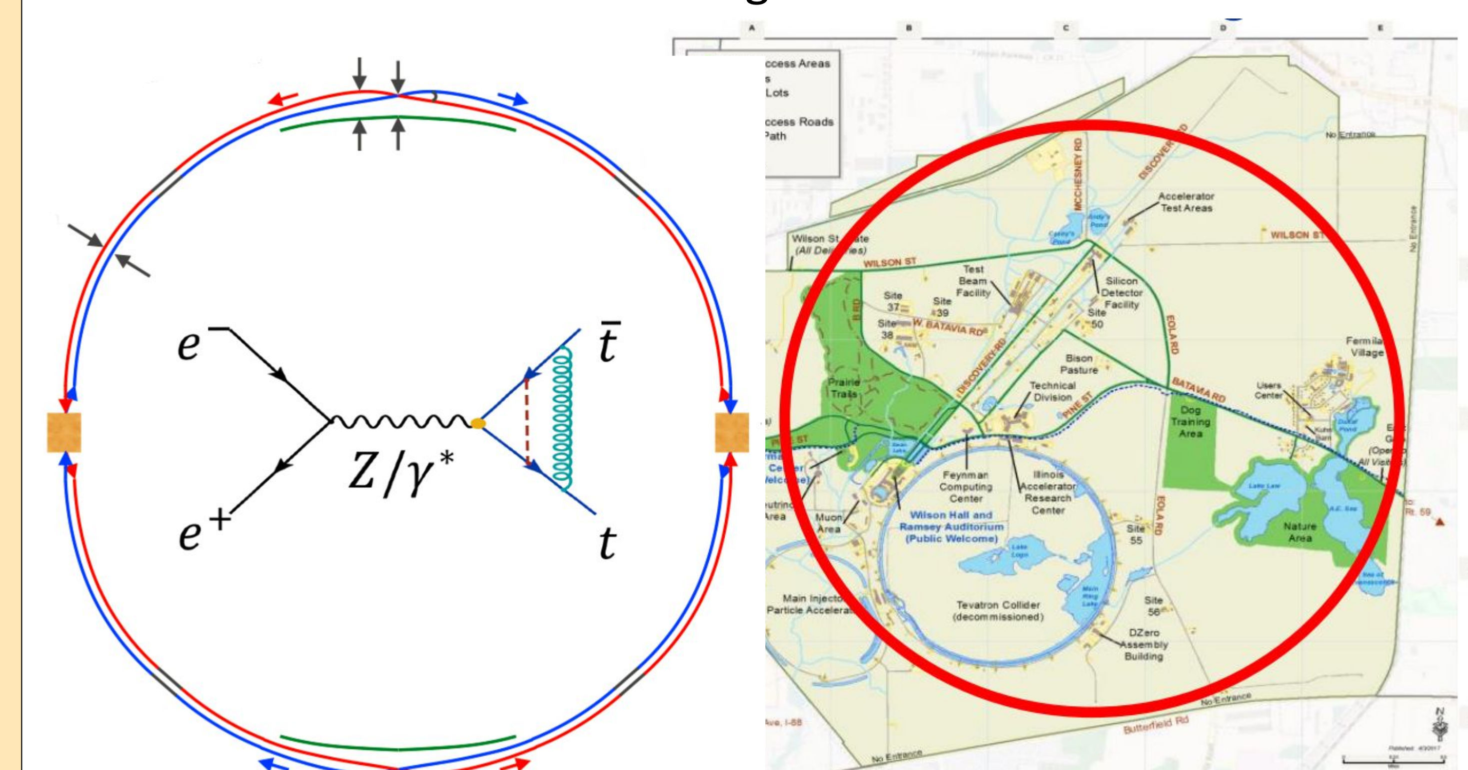


Figure 7. FCC e^+e^- detector concepts (left) and a construction blueprint of Muon Collider at Fermilab (right).

Top Quark Physics at the Precision Frontier

The most precise measurement for probing fraction of the SM prediction (f_{sm}) is done through direct measurement of differential cross-section with respect to the opening angle between outgoing leptons after $t\bar{t}$ decay in the transverse plane in the parent top rest frame (cosϕ). It has a maximal sensitivity (5% uncertainty) to the degree of alignment of the top quark spins. (Phys. Rev. D 100, 072002 (2019))

$$\cos\varphi = \hat{\ell}^{+} \cdot \hat{\ell}^{-}$$

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\varphi} = \frac{1}{2}\left(1 - D\cos\varphi\right)$$

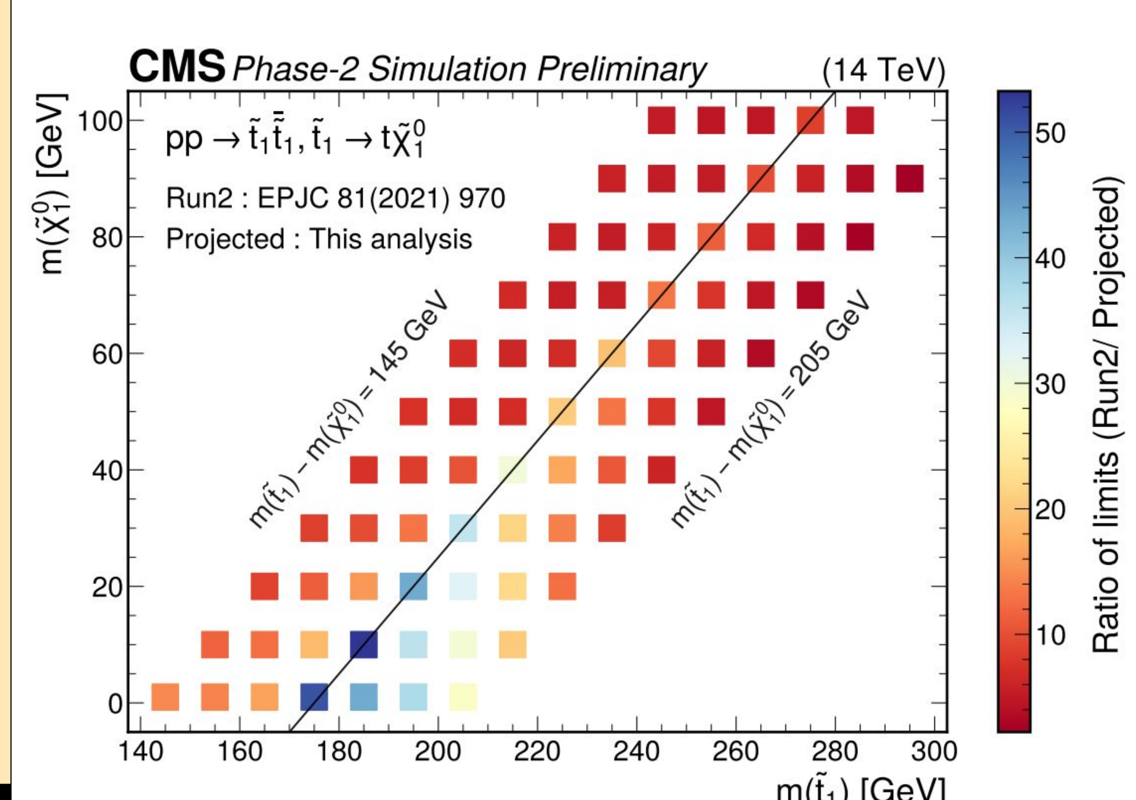
$$D = -(C_{kk} + C_{rr} + C_{nn})/3$$

The asymmetry in cosϕ, D, can be further used to obtain f_{sm} with the following expression:

$$f_{SM} = \frac{D_{measured} - D_{theory,uncorrelated}}{D_{theory,correlated} - D_{theory,uncorrelated}}$$

Systematic Variations and SUSY Sensitivity

- ➢ Shape-Based
  - Top P_T Reweighting (33% of Run2)
  - PDF Variations
  - Renormalization & Factorization (50% of Run2)
  - Jet Energy Scale
  - Jet Energy Resolution
- ➢ Flat
  - b-Tagging
  - Luminosity
  - Lepton ID
  - Theoretical σ



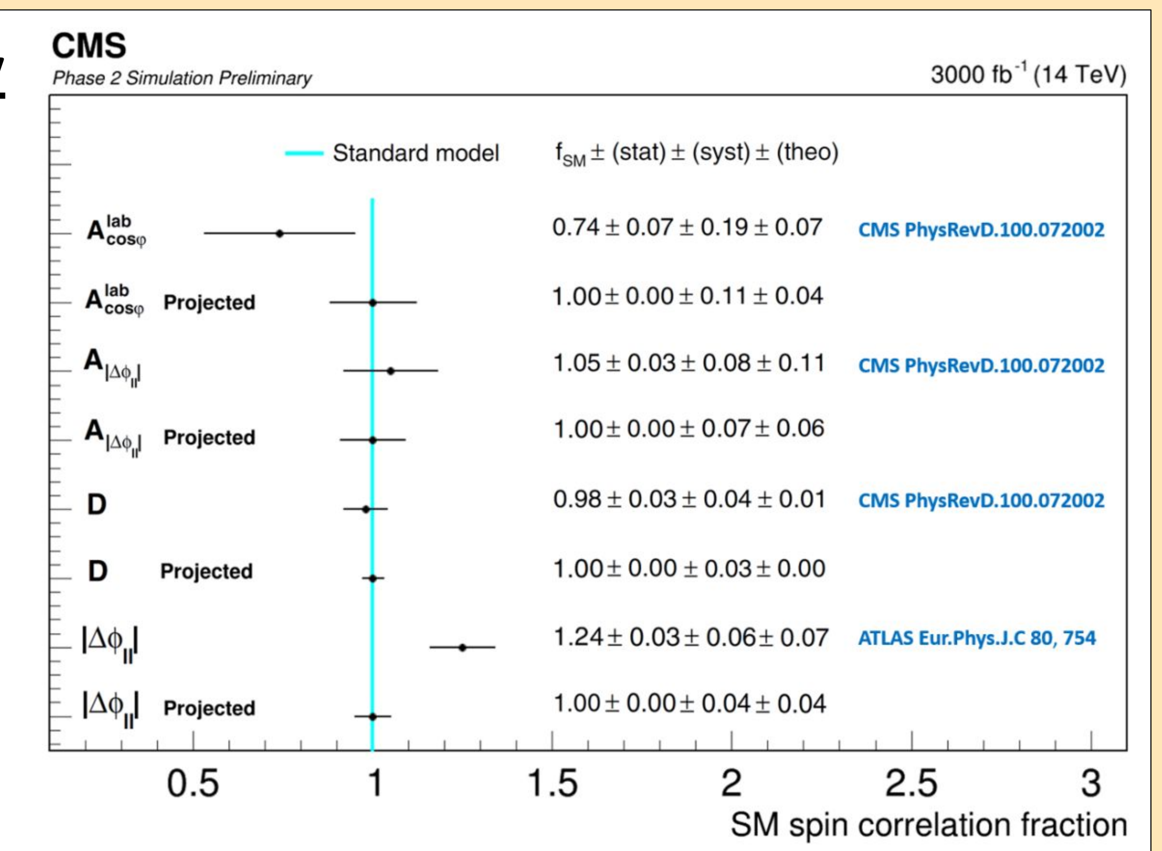


Figure 3. Extracted values of f_{SM} from lab-frame spin correlation variables by CMS and ATLAS at 13 TeV and projected values at 14 TeV. [CMS-PAS-FTR-18-034]

A significant improvement between 2-50 in sensitivity and exclusion limits of the high-lumi data set to hypothetical top quark partner particles. (Figure 4)

Figure 4. Ratio of expected 95% CL upper limits of the combined search for top squarks from CMS Run2 to the ones derived in the context of this search for the low top squark-neutralino mass plane. [CMS-PAS-FTR-18-034]

ACKNOWLEDGEMENTS

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