Measurements of spin correlations and top polarization in ttbar production

(based on CMS-TOP-13-003)

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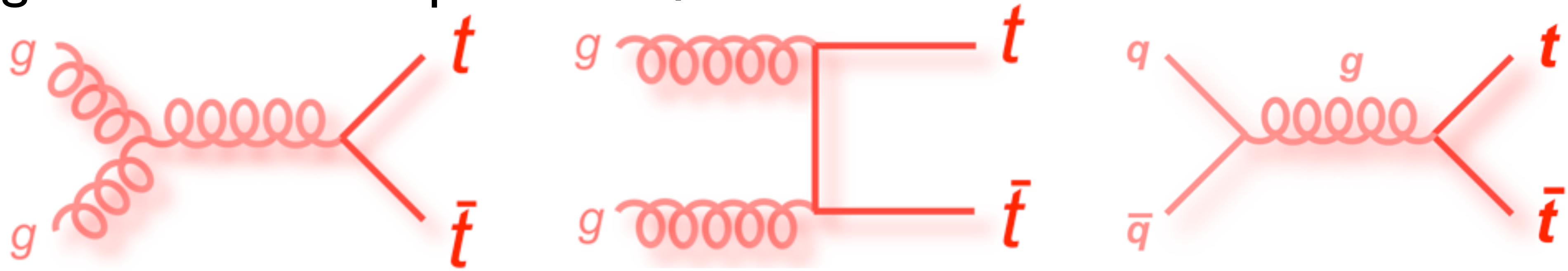
LHC: TOP Factory

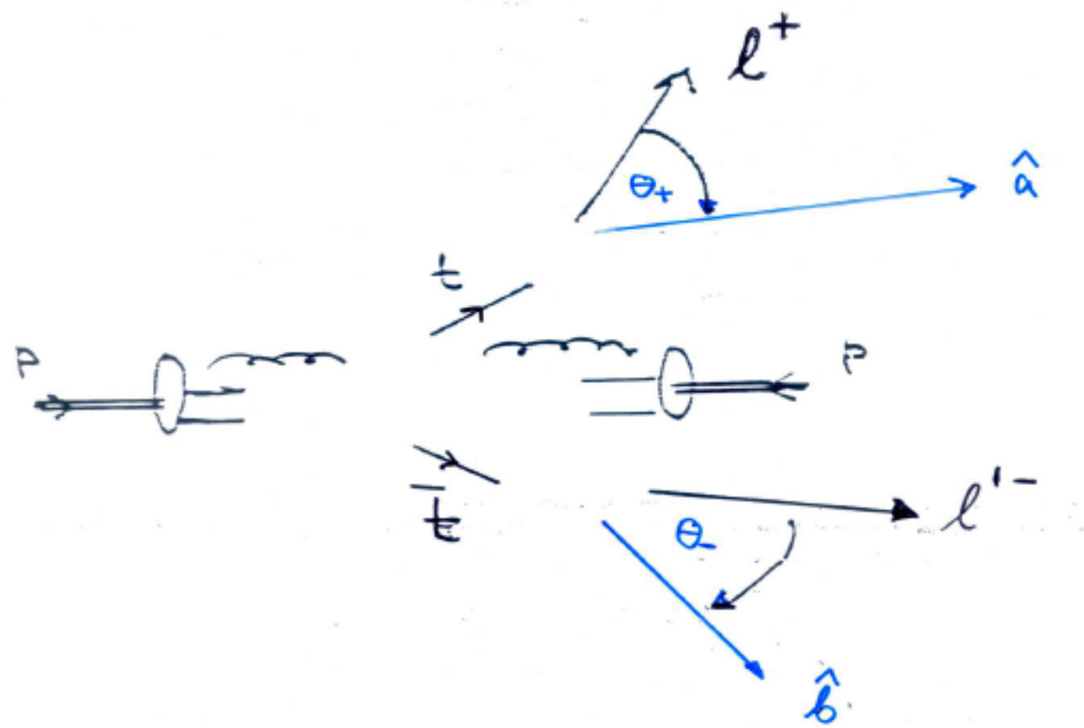
- At the LHC, $t\bar{t}$ pairs are mainly produced via strong interaction: gluon fusion and quark-antiquark annihilation



- The production cross section is orders of magnitude higher than that at Tevatron
- Top quark properties are expected to be examined with significant precision
- In addition, among the observed standard model (SM) particles, the top quark is distinguished by its mass close to the Electroweak scale. Physics beyond the SM may first manifest itself in the top quark property measurements

Introduction

- Top decays before hadronization. Polarization information is carried by its decay products
- Charged lepton from top decay is the best spin analyzer



$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{i,n}} = \frac{1}{2}(1 + \kappa_l P_n \cos\theta_{i,n}) \qquad \kappa_l = 1 \quad \text{for leptons}$$

Introduction (con't)

- We measure the top polarization and $t\bar{t}$ spin correlation in the leptonic modes
- Top polarization
  - $A_P = \frac{1}{2} P_n = \frac{N(\cos(\theta_l)>0) - N(\cos(\theta_l)<0)}{N(\cos(\theta_l)>0) + N(\cos(\theta_l)<0)}$
  - measured in the helicity basis (angle θ_l of lepton measured in parent top's rest frame, relative to direction of the top in the $t\bar{t}$ center of mass frame)
- $t\bar{t}$ spin correlation

$$A_{c_1 c_2} = \frac{N(c_1 \cdot c_2 > 0) - N(c_1 \cdot c_2 < 0)}{N(c_1 \cdot c_2 > 0) + N(c_1 \cdot c_2 < 0)}, \quad A_{\Delta\phi} = \frac{N(\Delta\phi_{l^+l^-} > \pi/2) - N(\Delta\phi_{l^+l^-} < \pi/2)}{N(\Delta\phi_{l^+l^-} > \pi/2) + N(\Delta\phi_{l^+l^-} < \pi/2)}$$

where $c_1 = \cos(\theta_{l^+})$ and $c_2 = \cos(\theta_{l^-})$

- Top is produced unpolarized and the spin of it is correlated with that of anti-top in $t\bar{t}$ production in the SM, while new physics can alter this

(D. Krohn, T. Liu, J. Shelton, L. Wang, Phys. Rev. D **84**, 074034 (2011))

Event Selections

- Two opposite sign isolated leptons: p_T > 20 GeV, |eta| < 2.5 (2.4) for e (μ)
- At least two jets with p_T > 30 GeV, |eta| < 2.5. One of them is b-tagged
- MET > 40 GeV in ee and $\mu\mu$ channels
- Z veto: $76<m_{ll}<106$ GeV veto (for SF leptons)
- $m_{ll}>20$ GeV to veto low mass resonances (SF leptons)
- After the above selections, the sample is dominated by leptonic events (92%-signal events). The background mainly consists of $t\bar{t}$ single top events

Reconstruction of Top Kinematics

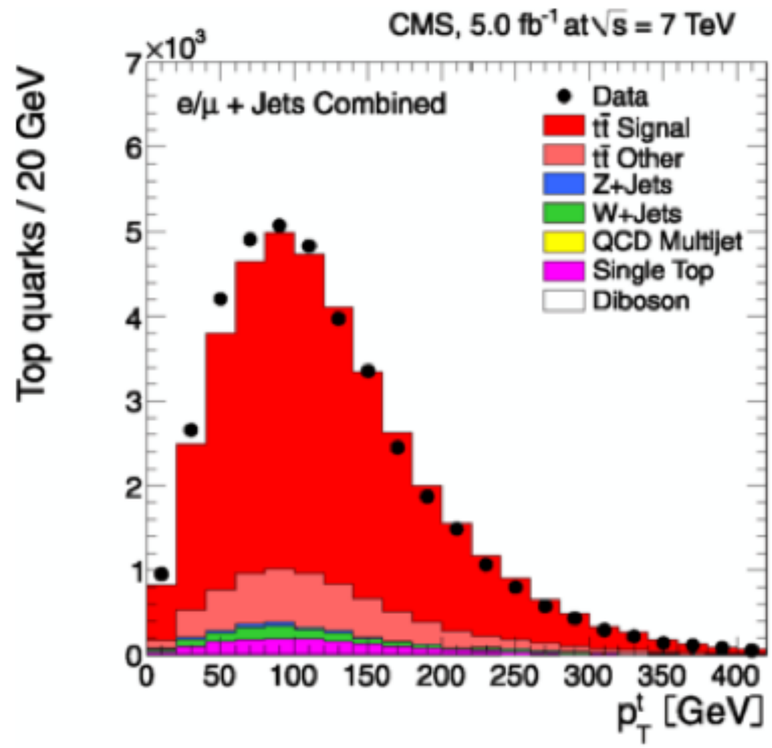
- Each $t\bar{t} \rightarrow \ell^+\ell^-$ event has two neutrinos.
- There is ambiguity in combining b-jets and leptons from same top
- We use the analytical matrix weighting technique (AMWT) described in http://arxiv.org/abs/arXiv:1105.5661
- Each events is reconstructed assuming the top-quark mass fixed
  - Each event could have multiple solutions and a weight, based on the probability of observing such a configuration, is assigned for each solution.
  - $t\bar{t}$ kinematics with the largest weight is taken
  - Events with no physical solutions are discarded for measuring A_P and A_{c1c2}

Top pT Reweighting

- CMS studies have shown that the top pT distribution in data is softer than in the (N)LO simulation, but agrees with the approx. NNLO calculation

The $t\bar{t}$ signal is simulated with madgraph in this plot, and we see a similar behavior with powheg and mc@nlo

Measurement of differential top-quark-pair production cross sections in pp collisions at 7 TeV, Eur. Phys. J. C 73 (2013) 1



- We reweight the top pT in the simulation to match the data and improve the modeling of the lepton and jet pT distributions
- 100% systematic uncertainty is applied since the origin of the effect is not yet fully understood

Unfolding

The measured distribution is distorted from the true underlying distribution by two factors: (1) bias introduced by detector acceptance and analysis cuts, and (2) effect due to the finite resolution of the measurement.

- An "unfolding" procedure is incorporated to correct the above effects and yield the parton-level distribution (truth level).
- The measured distribution b_k is related to the underlying parton-level distribution X_i by:

$$b_k = S_{kj} A_{ji} X_i \quad \Longrightarrow \quad X = A^{-1} S^{-1} b$$

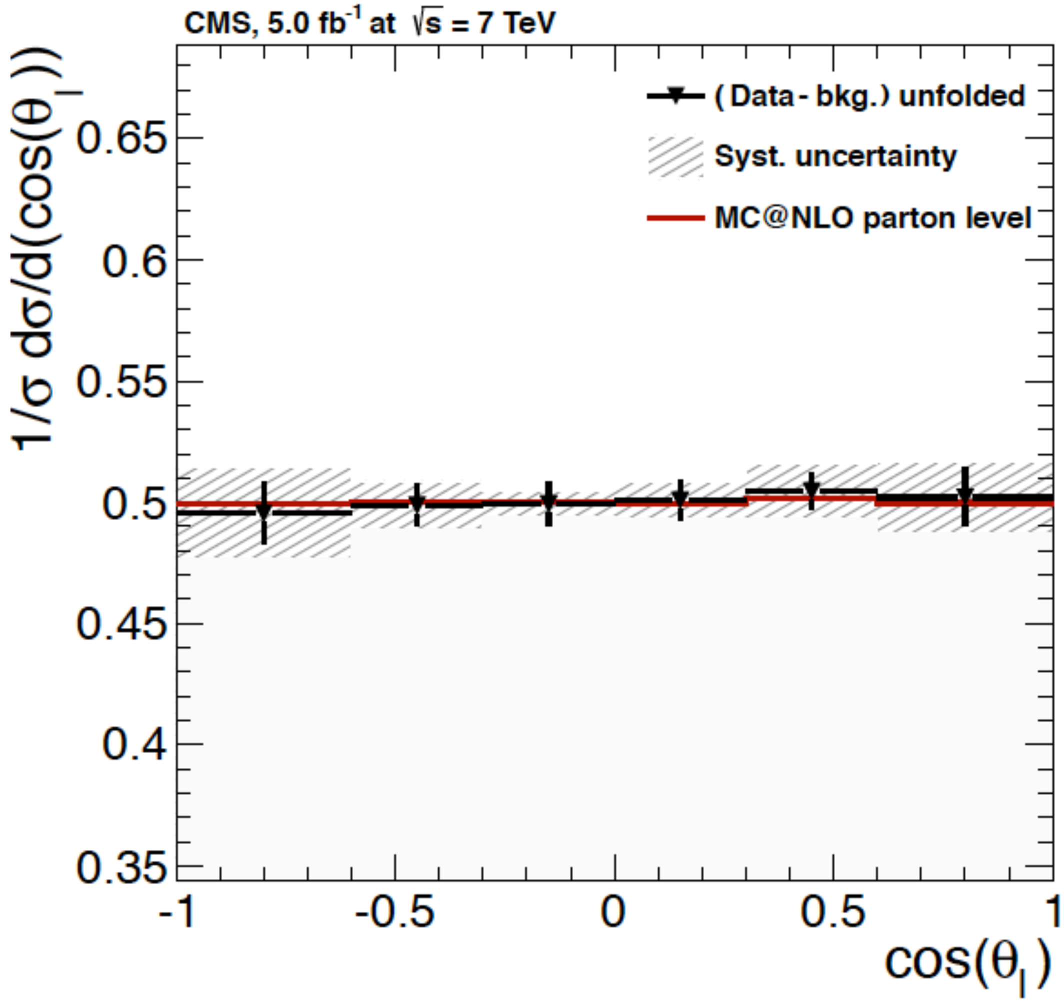
  where A is acceptance matrix and S is migration matrix. We obtain them using Monte Carlo simulation.

- Perform extensive tests using pseudo-experiments to ensure proper performance of the unfolding algorithm

Systematics

Asymmetry variable	$A_{\Delta\phi}$	$A_{c_1 c_2}$	A_P
Jet energy scale	0.002	0.012	0.009
Lepton energy scale	0.001	0.001	0.001
Background	0.003	0.001	0.006
Fact. and renorm. scales	0.001	0.010	0.004
Top-quark mass	0.002	0.009	0.016
Parton distribution functions	0.002	0.002	0.001
Jet energy resolution	< 0.001	< 0.001	< 0.001
Pileup	0.002	0.002	0.004
b-tagging scale factor	< 0.001	< 0.001	0.001
Lepton selection	< 0.001	< 0.001	< 0.001
τ decay polarization	0.001	0.002	0.001
Unfolding	0.004	0.020	0.002
Total systematic uncertainty	0.007	0.027	0.020
Top p_T reweighting uncertainty	0.012	0.010	0.008

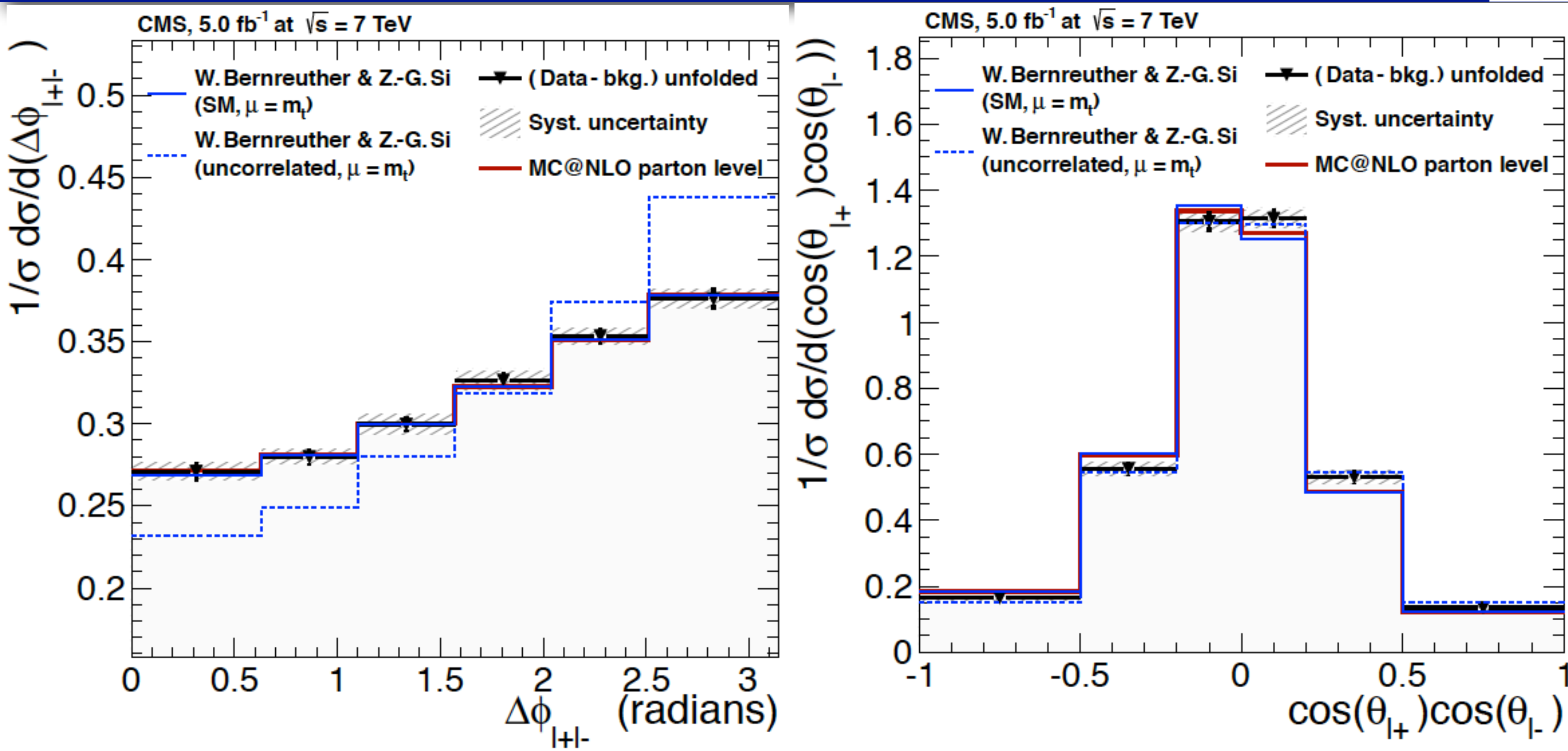
Polarization Measurement at 7 TeV



Asym.	Data (unfolded)	Simulation
A_P	$0.005 \pm 0.013 \pm 0.020 \pm 0.008$	0.000 ± 0.001

- The result is in good agreement with the SM prediction

Spin Correlation Measurement at 7 TeV



Asym.	Data (unfolded)	Simulation	NLO (corr.)	NLO (uncorr.)
$A_{\Delta\phi}$	$0.113 \pm 0.010 \pm 0.007 \pm 0.012$	0.110 ± 0.001	$0.115^{+0.014}_{-0.016}$	$0.210^{+0.013}_{-0.008}$
A_{c1c2}	$-0.021 \pm 0.023 \pm 0.027 \pm 0.010$	-0.078 ± 0.001	-0.078 ± 0.006	0

- The results agree with the SM predictions

Conclusions

- The top-quark polarization and spin correlation are measured in the $t\bar{t}$ dilepton final states with 7 TeV data. The paper is about to be submitted to the journal
  - The data are compared to the predictions of the mc@nlo Monte Carlo and to the NLO calculations
  - The results agree with the SM predictions for all three measured variables
  - The results indicate the presence of $t\bar{t}$ spin correlation, and strongly disfavors the uncorrelated case
- The 8 TeV analysis is ongoing and incorporates a number of improvements