Top Quark Production Properties

Introduction & Motivation

Spin Correlations

Top Polarization

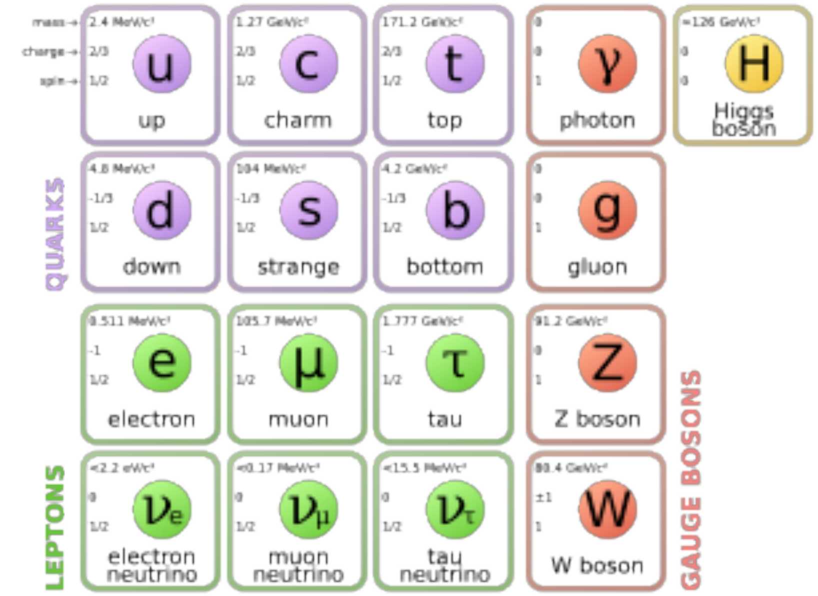
Charge Asymmetry

Conclusions

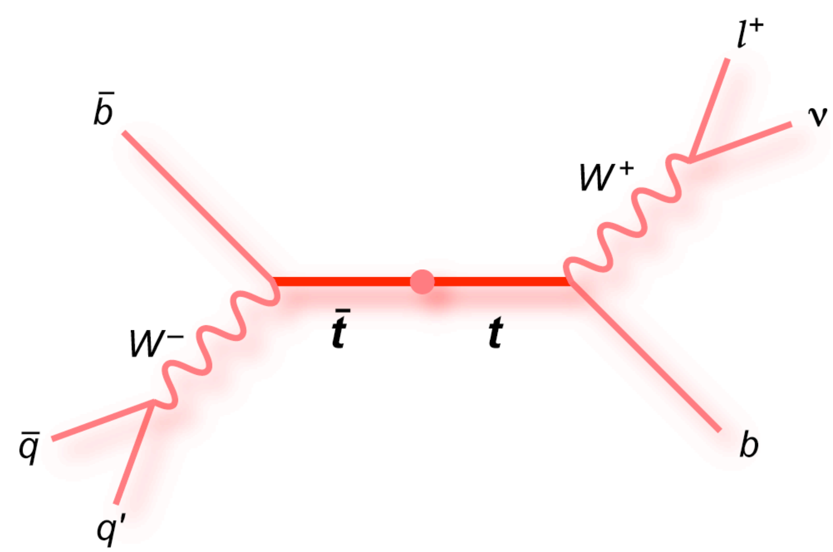
19 July 2013
European Physical Society - HEP 2013

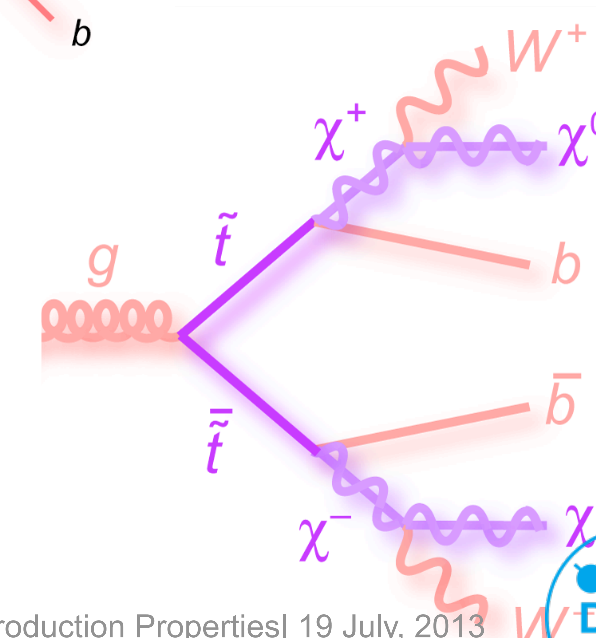
Tyler Dorland (DESY)
for the CMS collaboration

Motivation



- Unique properties of the top quark allow for measurements of fundamental quark properties
- We now have a complete standard model, but not a fully explored standard model
- Recent measurements have shown possible deviations from the standard model
- Precision results in top physics can confirm the Standard Model predictions or shed some light on new physics!



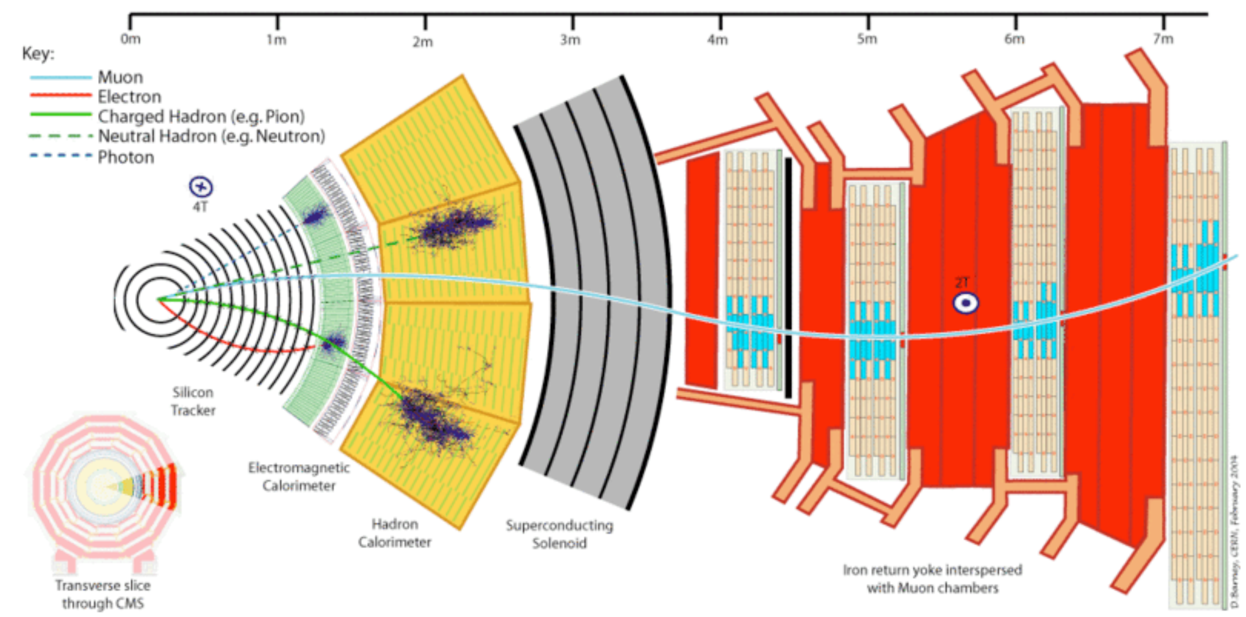


Experimental Setup

Just a few of the many impressive features important to these analyses

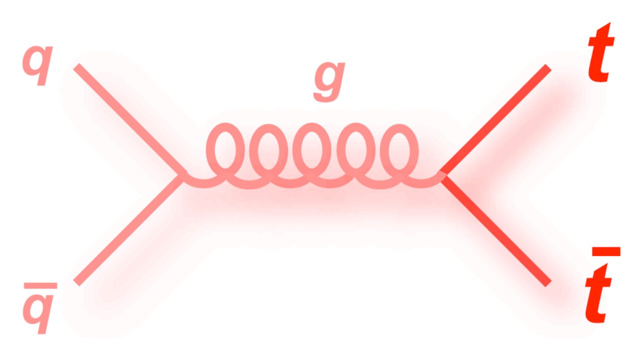
> CMS Experiment

- Very high Lepton Identification efficiencies
- Pseudorapidity coverage up to 2.5
- Basic cuts can give very pure samples
- All results here with 7TeV data
- Up to 5 fb^{-1} data

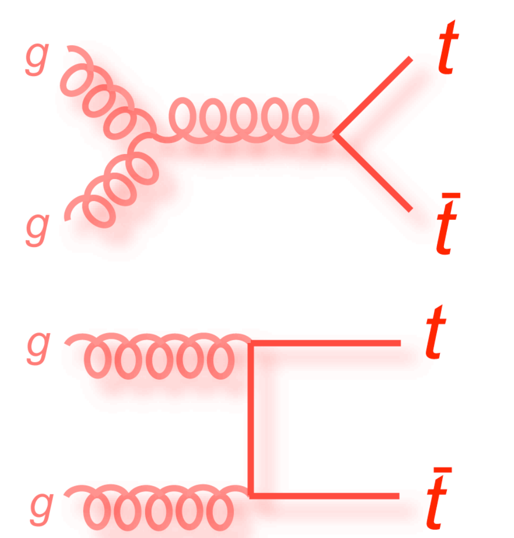


> LHC

- Proton-proton collider
- Primary production mechanism for top quarks is through gluons



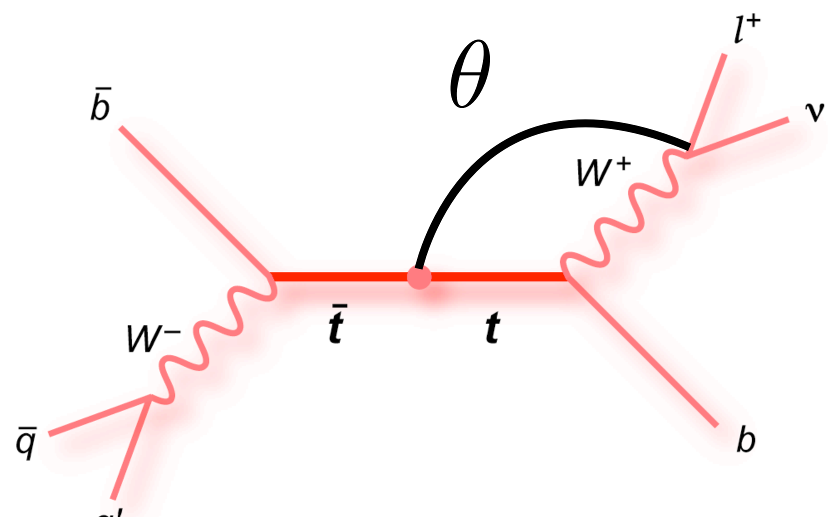
20%



80%

Top Spin Correlations - Introduction

CMS PAS TOP-12-004



tt-system CoM frame

> The decay time of the top is short so that the decay products should contain information about the spin of the top quark

> Find the variable containing the maximal amount of information from the helicity basis that is easily measurable

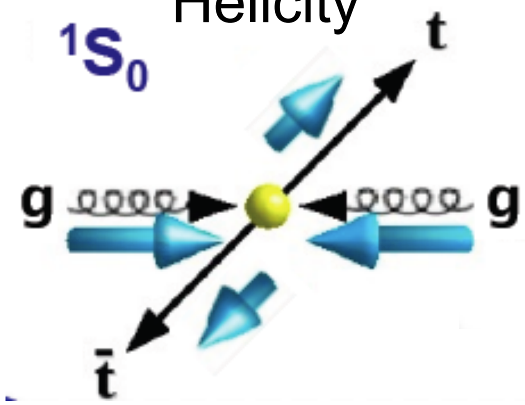
Phys. Lett. B539, 235 (2002)

spin information carried by daughter particle

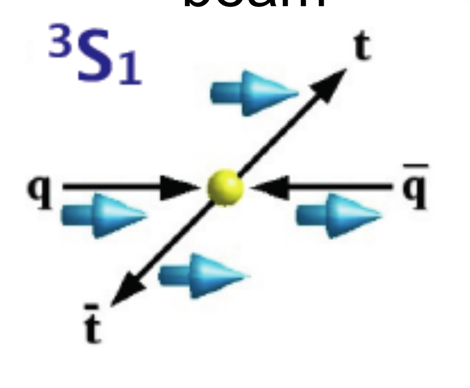
	b-quark	W^+	l^+	d/s quark	u/c quark
α(LO)	-0.41	0.41	1	1	-0.31
α(NLO)	-0.39	0.39	0.998	0.93	-0.31

choose the dilepton channel

Helicity



beam



$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\downarrow\uparrow) - N(\uparrow\downarrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\downarrow\uparrow) + N(\uparrow\downarrow)}$$

only through gluon fusion

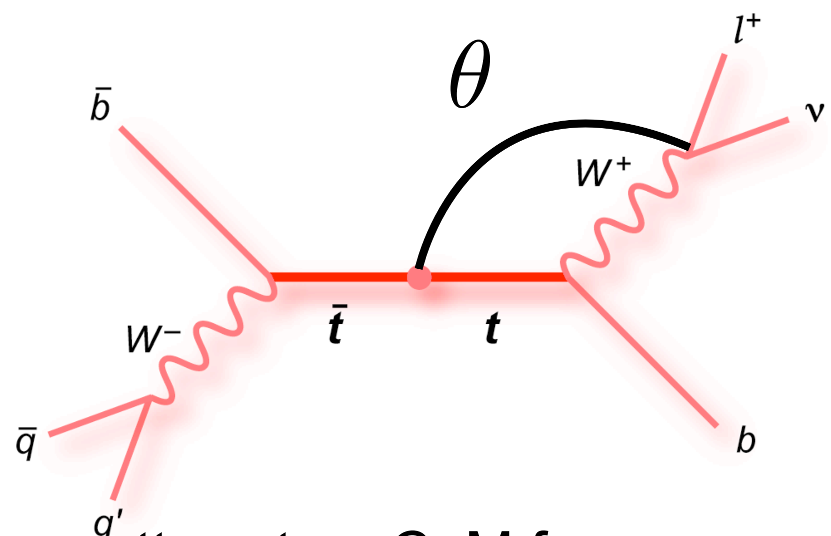
both processes

Depends on basis

$$\frac{1}{\sigma}\frac{d^2\sigma}{dcos\theta_1 dcos\theta_2} = \frac{1}{4}(1 - A\alpha_1\alpha_2 cos\theta_1 cos\theta_2)$$

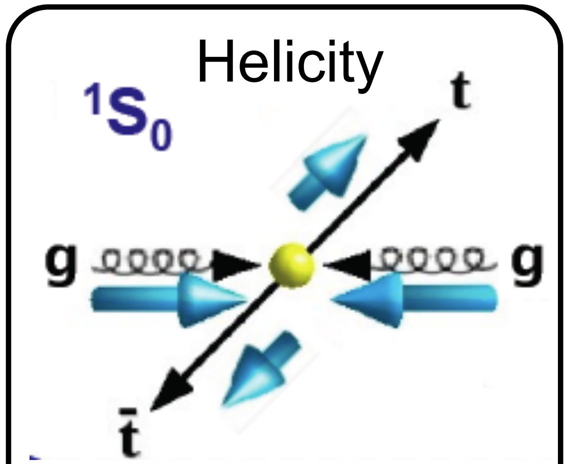
Top Spin Correlations - Introduction

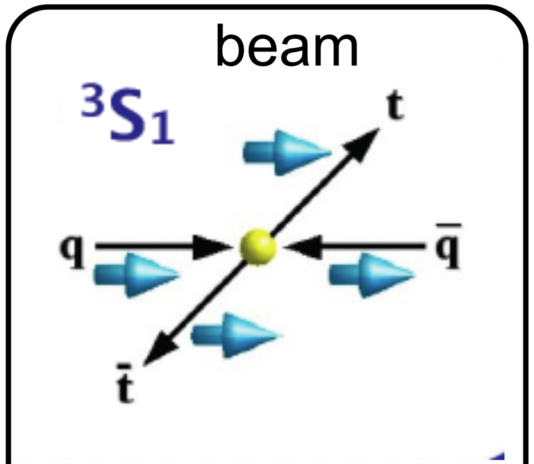
CMS PAS TOP-12-004



tt-system CoM frame

- Measuring the difference in the azimuthal angle between the leptons in the lab frame gives us information about spin correlation
- Just the lepton information is needed
  - No full reconstruction and associated error!





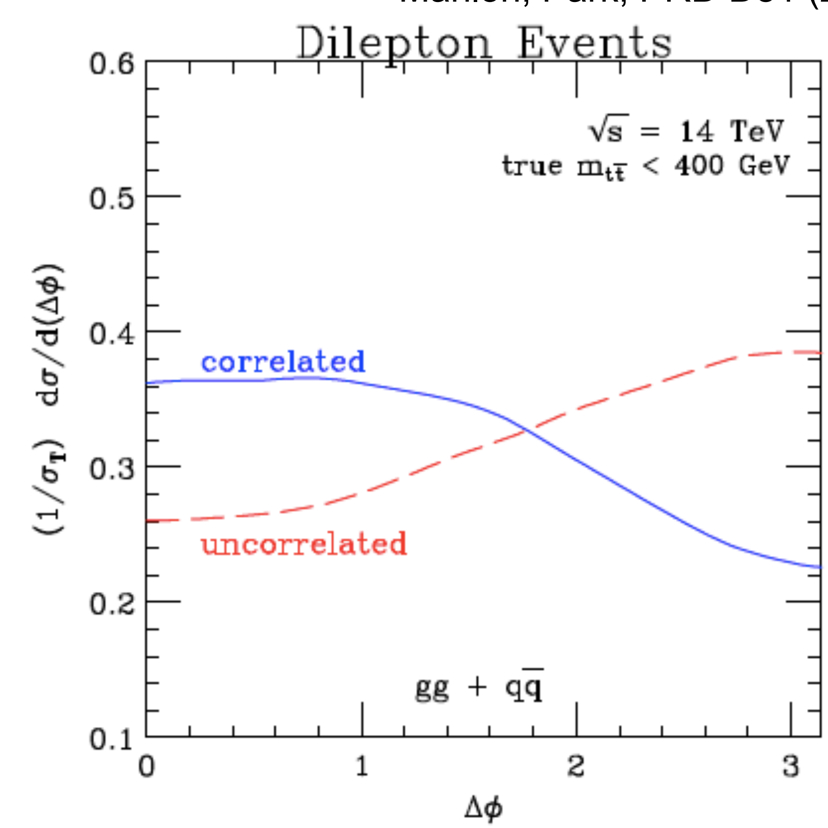
$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\downarrow\uparrow) - N(\uparrow\downarrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\downarrow\uparrow) + N(\uparrow\downarrow)}$$

only through gluon fusion

both processes

Mahlon, Park, PRD D81 (2010) 074024

boosted parallel



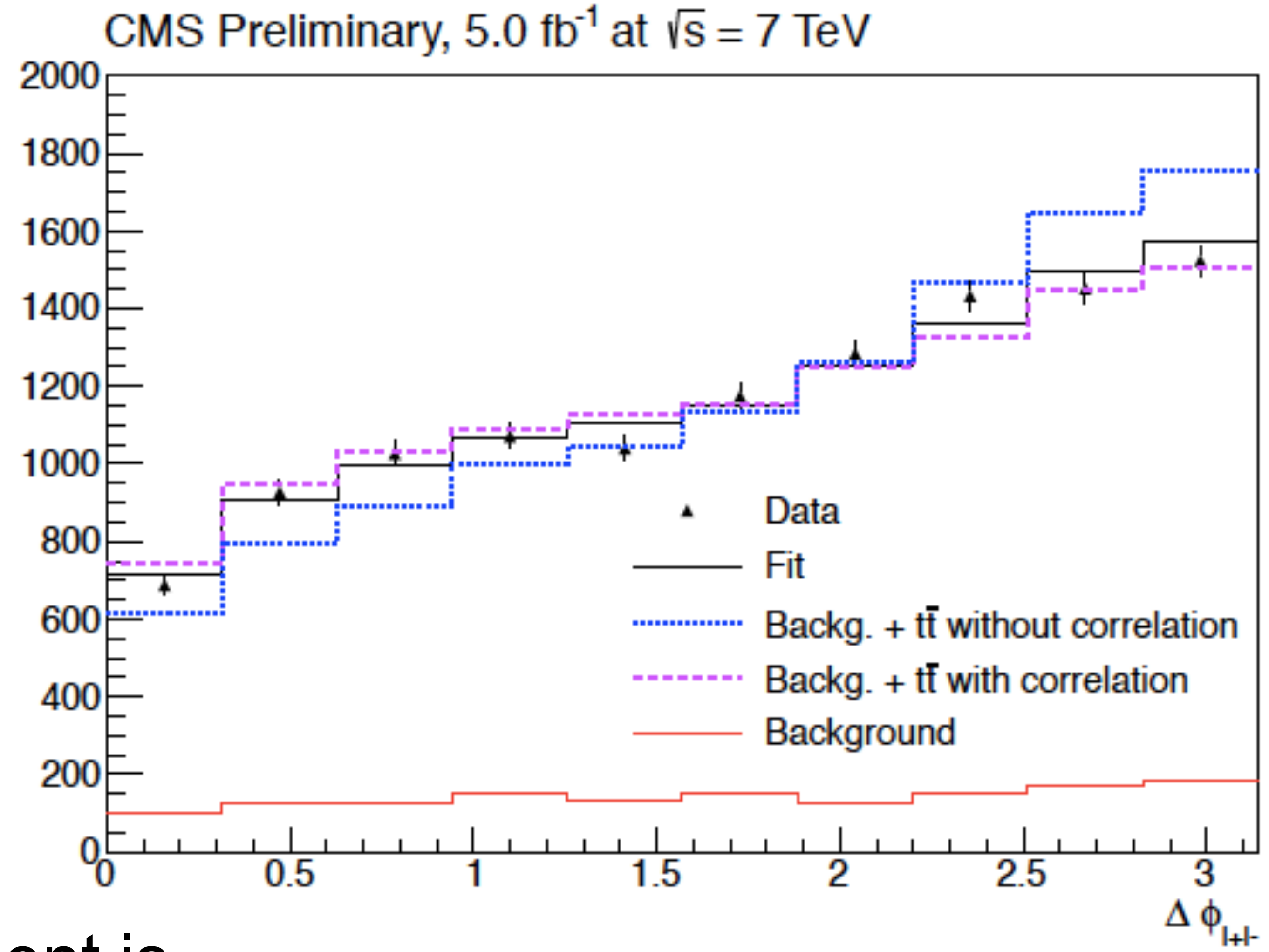
suppressed anti-parallel

$$\frac{1}{\sigma}\frac{d^2\sigma}{dcos\theta_1 dcos\theta_2} = \frac{1}{4}(1 - A\alpha_1\alpha_2 cos\theta_1 cos\theta_2)$$

Top Spin Correlation - Results

CMS PAS TOP-12-004

- Use a template fit with three different templates
  - tt with correlation
  - tt without correlation
  - background



- Determine the fraction, *f*, of correlation with respect to what is in the MC@NLO simulation, *f x A_{MC}*

$$A_{hel}^{simu} = 0.33$$

$$f = 0.74 \pm 0.08(stat.) \pm 0.24(syst.)$$

- The measured correlation coefficient is

$$A_{hel}^{meas} = 0.24 \pm 0.02(stat.) \pm 0.08(syst)$$

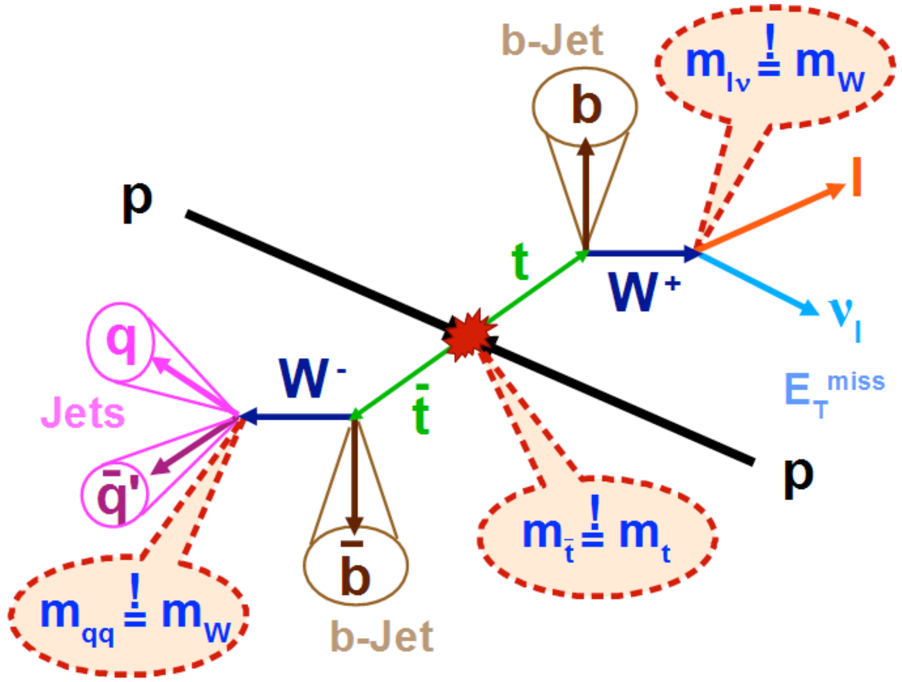
Dominant systematic uncertainties from factorization scale and tau decay

- Compared to the standard model expectation

$$A_{hel}^{SM} = 0.31$$

Nucl. Phys. B 837, 90 (2010)

Event Reconstruction



Kinematic Fit - lepton + jets

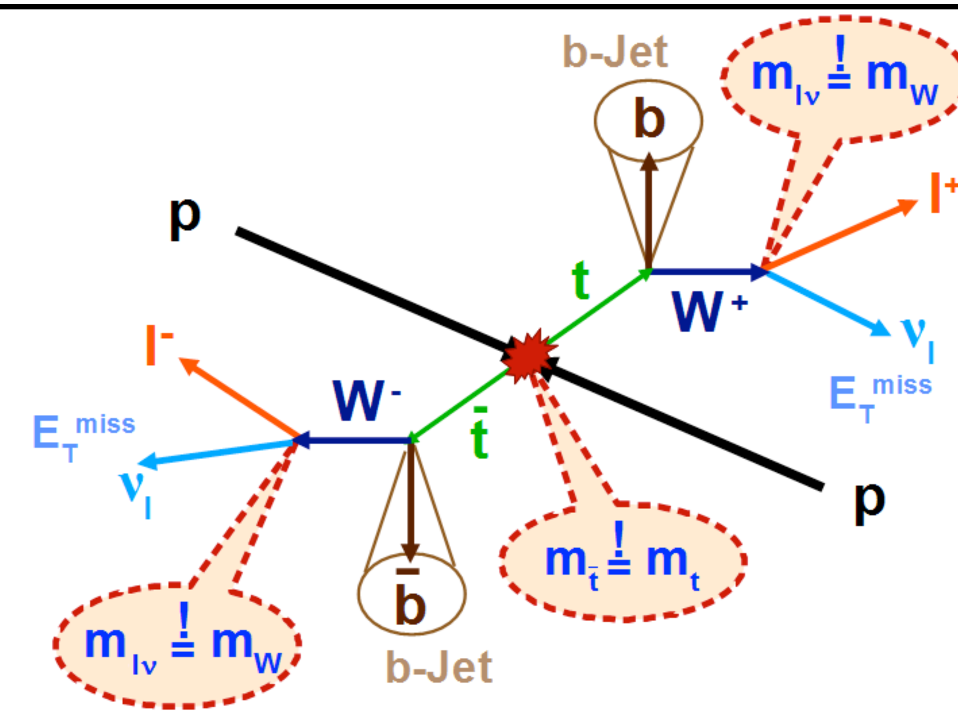
- Constrained System
- Vary measured 4-momenta of lepton, neutrino, and jets
  - Restrict m_W =80.4 GeV
  - m_t = $m_{anti\text{-}t}$

assume $p_{z,\nu}$ =0 as initial value, MET

- Apply likelihood maximization
- Consider only leading 5 jets
- Choose permutation with lowest χ^2 w.r.t. object resolution

Kinematic Reconstruction - dilepton

- Under-constrained System (2 neutrinos)
- Constraints:
  - m_W =80.4 GeV
  - m_t = $m_{anti\text{-}t}$=fixed value
  - $p_{\nu 1}(x,y) + p_{\nu 2}(x,y)$ = MET
- Vary m_t in 1 GeV steps from between two values.
- Degeneracy arsing from 4th order polynomial broken by truth information



Top Spin Asymmetry - Results

CMS PAS TOP-12-004

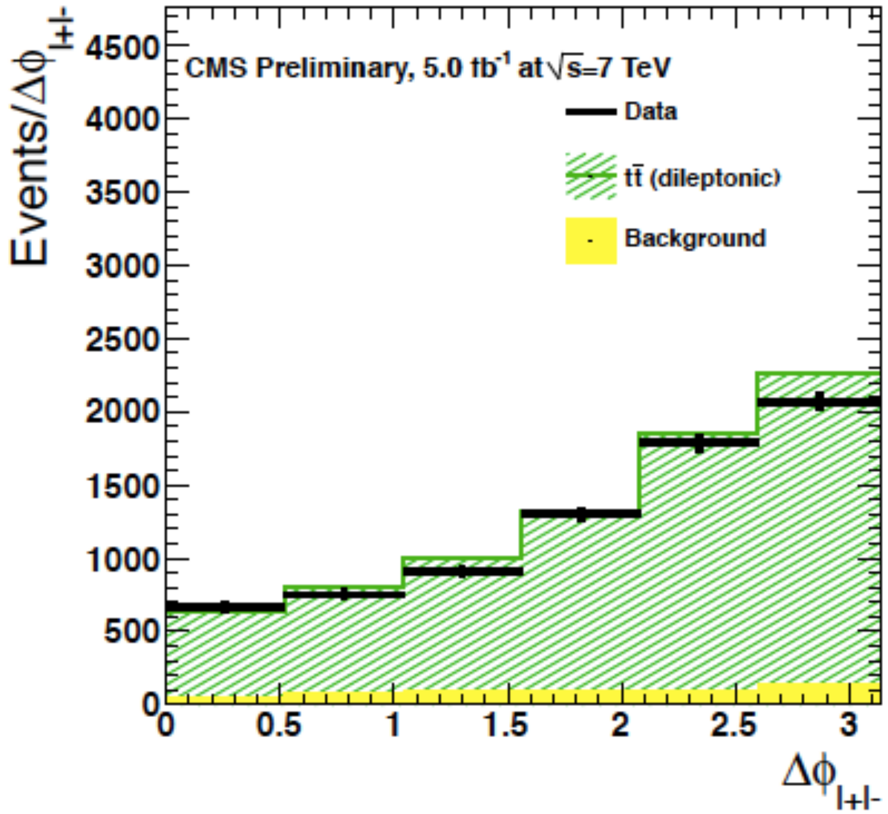
- Asymmetry variables associated to the correlation coefficient can also be measured

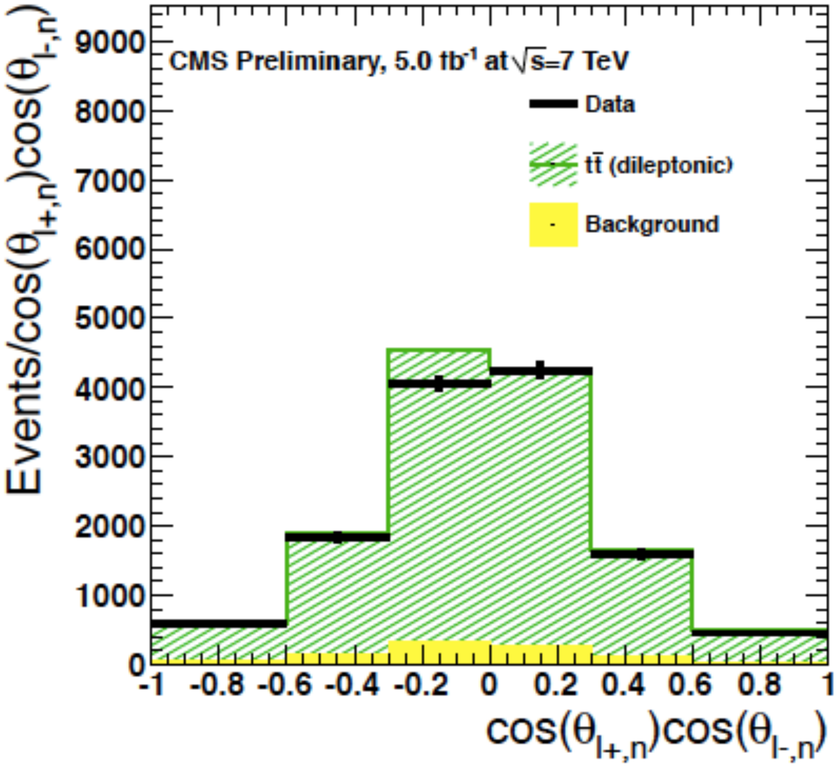
$$A_{\Delta\phi} = \frac{N(\Delta\phi_{l^+l^-} < \pi/2) - N(\Delta\phi_{l^+l^-} > \pi/2)}{N(\Delta\phi_{l^+l^-} < \pi/2) + N(\Delta\phi_{l^+l^-} > \pi/2)}$$

$$A_{c1c2} = \frac{N(\cos(\theta_l^+) \times \cos(\theta_l^-) > 0) - N(\cos(\theta_l^+) \times \cos(\theta_l^-) < 0)}{N(\cos(\theta_l^+) \times \cos(\theta_l^-) > 0) + N(\cos(\theta_l^+) \times \cos(\theta_l^-) < 0)}$$

- A_{c1c2} requires full event reconstruction
- With full kinematics make a cut on M_{tt} to look for new physics effects more prevalent at high invariant masses

Reconstructed asymmetries	Data	Simulation
$A_{\Delta\phi}$, inclusive region	-0.158 ± 0.010	-0.171 ± 0.002
A_{c1c2}, inclusive region	-0.062 ± 0.011	-0.087 ± 0.002
$A_{\Delta\phi}$, $M_{t\bar{t}} > 450$ GeV	-0.378 ± 0.019	-0.384 ± 0.003
A_{c1c2}, $M_{t\bar{t}} > 450$ GeV	-0.019 ± 0.016	-0.044 ± 0.003



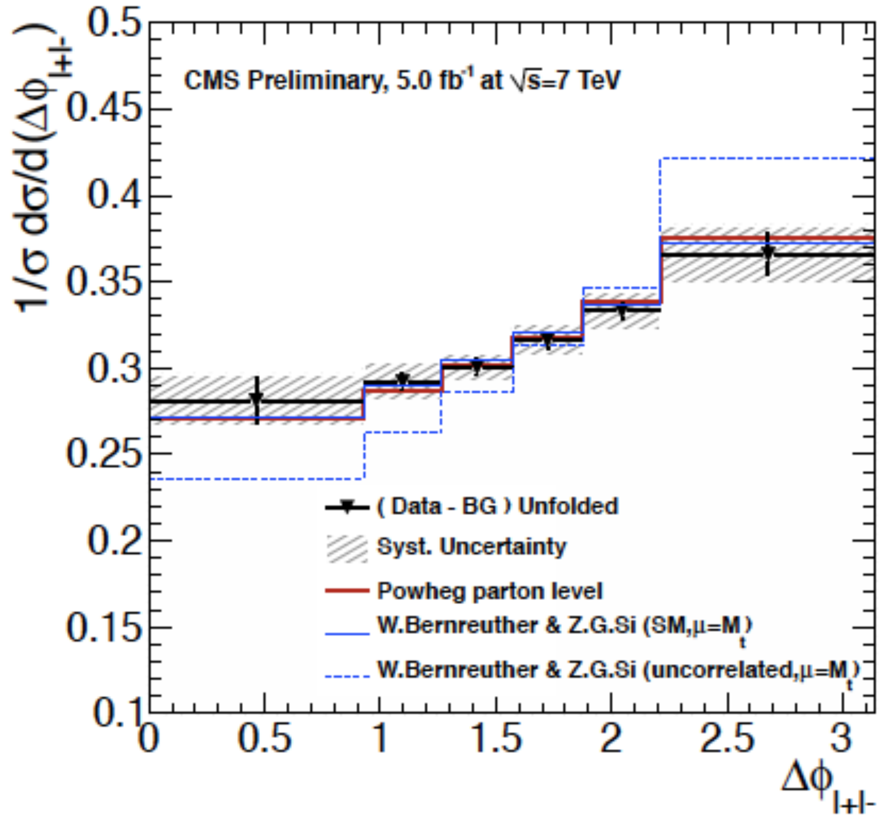


Top Spin Asymmetry - Results

CMS PAS TOP-12-004

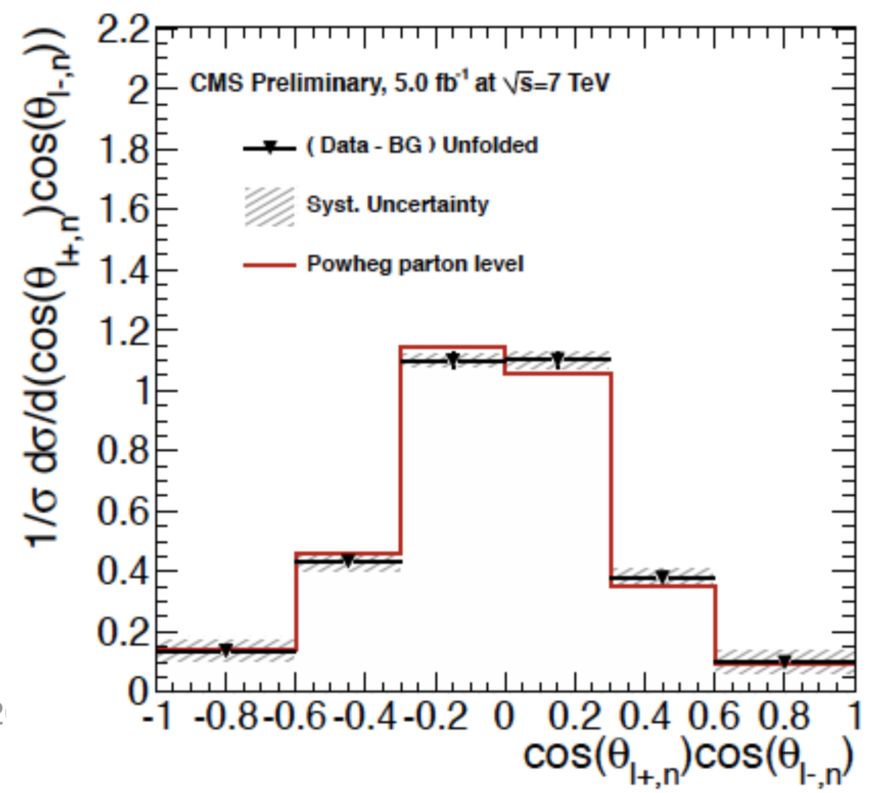
- By unfolding for detector effects we can measure the Asymmetries at parton level
- Regularized SVD unfolding applied

$$A^{meas}_{\Delta\phi} = -0.097 \pm 0.015 \pm 0.036$$
$$A^{sim}_{\Delta\phi} = -0.119 \pm 0.0004$$



- Good agreement with Powheg simulation is observed

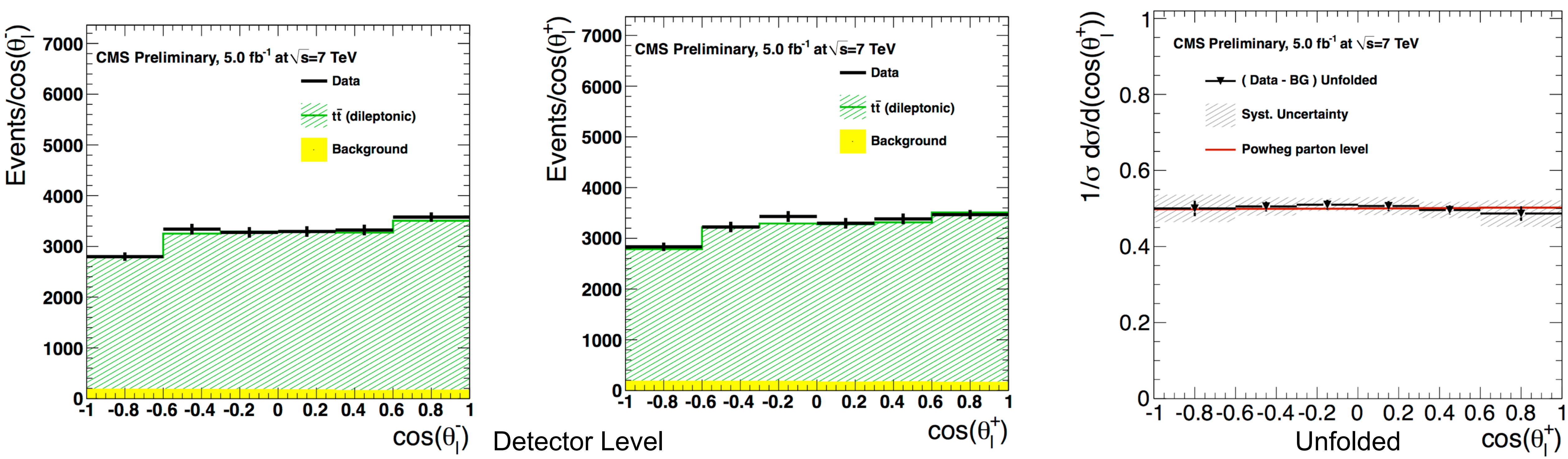
$$A^{meas}_{c1c2} = -0.015 \pm 0.037 \pm 0.055$$
$$A^{sim}_{c1c2} = -0.063 \pm 0.0004$$



CMS PAS TOP-12-016

- Similarly, the polarization of the top quark can be measured with the daughter particles $\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{l,n}} = \frac{1}{2}(1 + 2k_l P_n \cos\theta_{l,n})$
- From QCD, top pairs are unpolarized, but EWK corrections provide small polarization that is **enhanced by new physics**
- Where $\theta_{n,l}$ is the angle between the lepton in the top rest frame and the helicity axis, Experimentally:

$$P_n = \frac{N(\cos(\theta_l^+) > 0) - N(\cos(\theta_l^+) < 0)}{N(\cos(\theta_l^+) > 0) + N(\cos(\theta_l^+) < 0)}$$



$$P_n = -0.009 \pm 0.029(stat.) \pm 0.041(syst.)$$

JES	lepton energy scale	M_t scan range	background	$t\bar{t}$ modeling	matching
0.020	0.001	0.024	0.009	0.014	0.004
Q^2 scale	simulated M_t	$b-$tagging eff.	Trig eff. and lep ID	pile-up	Total
0.007	0.019	0.001	0.001	0.002	0.041

Top Charge Asymmetry - Introduction

- The two production mechanisms give very different methods to measure the asymmetry

proton-antiproton is a CP eigenstate

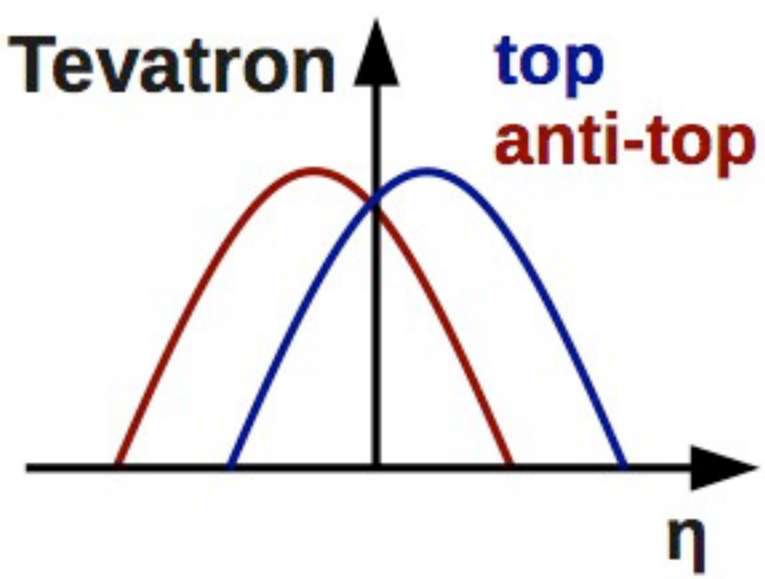
Interference terms create asymmetry

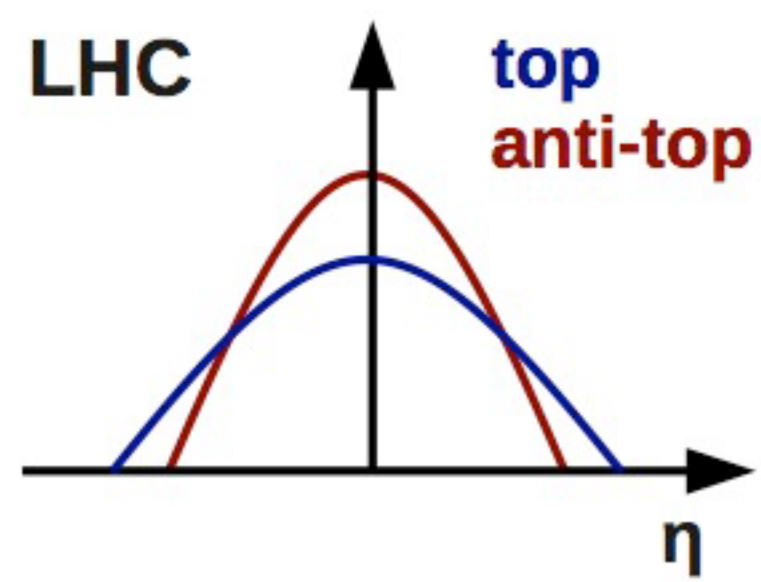
proton-proton is not a CP eigenstate

and no asymmetry comes from the gluon fusion

Instead the effect comes from the fact the quark will always be a valence quark and the anti quark comes from the sea

The average momentum fraction will be higher for the quark and will in general be more forward!





Top Charge Asymmetry - Introduction

- Considering these differences we choose variables to attempt to exploit the differences
  - At LHC we measure the charge asymmetry

$$A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

Lepton only measurement

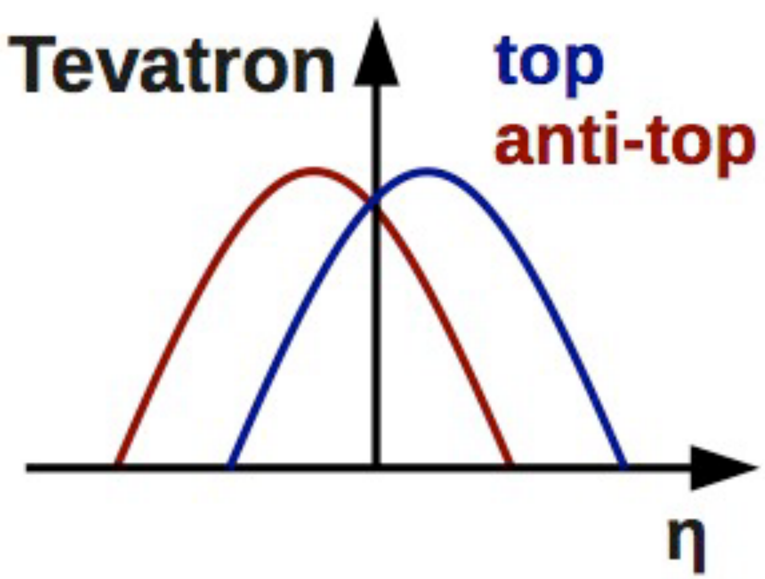
$$A_{lepC} = \frac{N(|\eta_{\ell+}| > |\eta_{\ell-}|) - N(|\eta_{\ell+}| > |\eta_{\ell-}|)}{N(|\eta_{\ell+}| > |\eta_{\ell-}|) + N(|\eta_{\ell+}| > |\eta_{\ell-}|)}$$

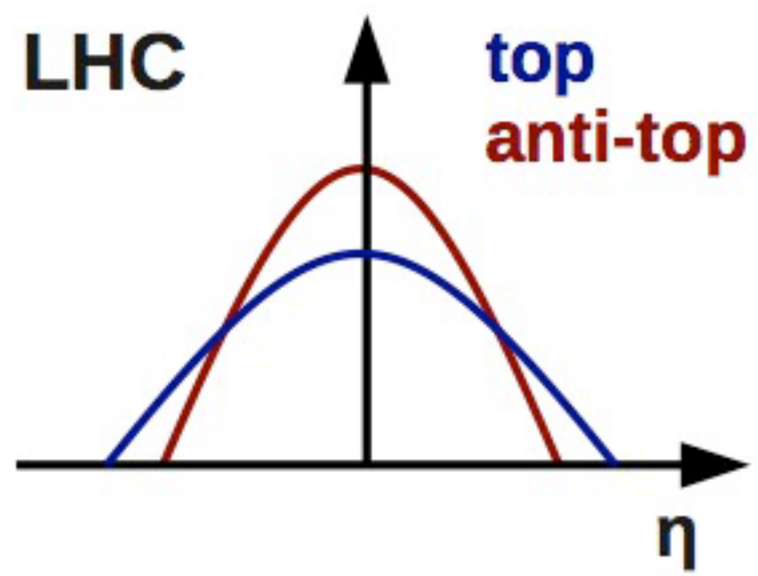
Full reconstruction needed

$$A_C = \frac{N(|y_t| > |y_{\bar{t}}|) - N(|y_t| < |y_{\bar{t}}|)}{N(|y_t| > |y_{\bar{t}}|) + N(|y_t| < |y_{\bar{t}}|)}$$

$$A_{topFB} = \frac{N(cos(\theta_t) > 0) - N(cos(\theta_t) < 0)}{N(cos(\theta_t) > 0) + N(cos(\theta_t) < 0)}$$

Krohn, Lie, Sheldon, Wang PR D84 (2011) 074034

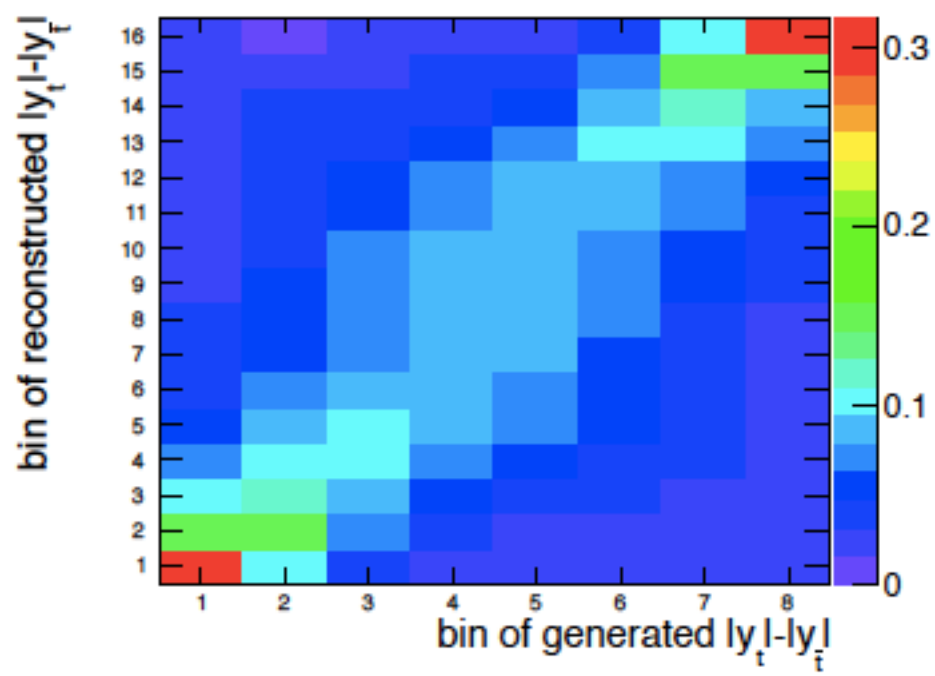


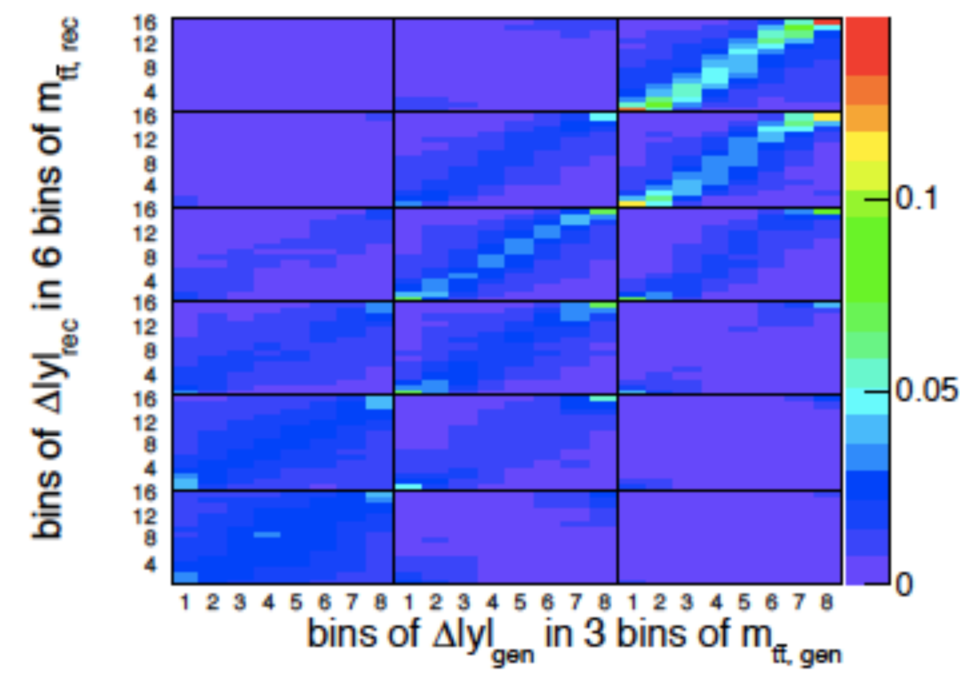


Top Charge Asymmetry - Method

CMS PAS TOP-12-004

- 2D regularized unfolding
- Chosen to have approximately the same statistics in each bin





- Background Estimation:

single lepton: fit $E_{T,miss}$ for $E_{T,miss} < 40$, M_3 for $E_{T,miss} > 40$

individual template for W^+ and W^-

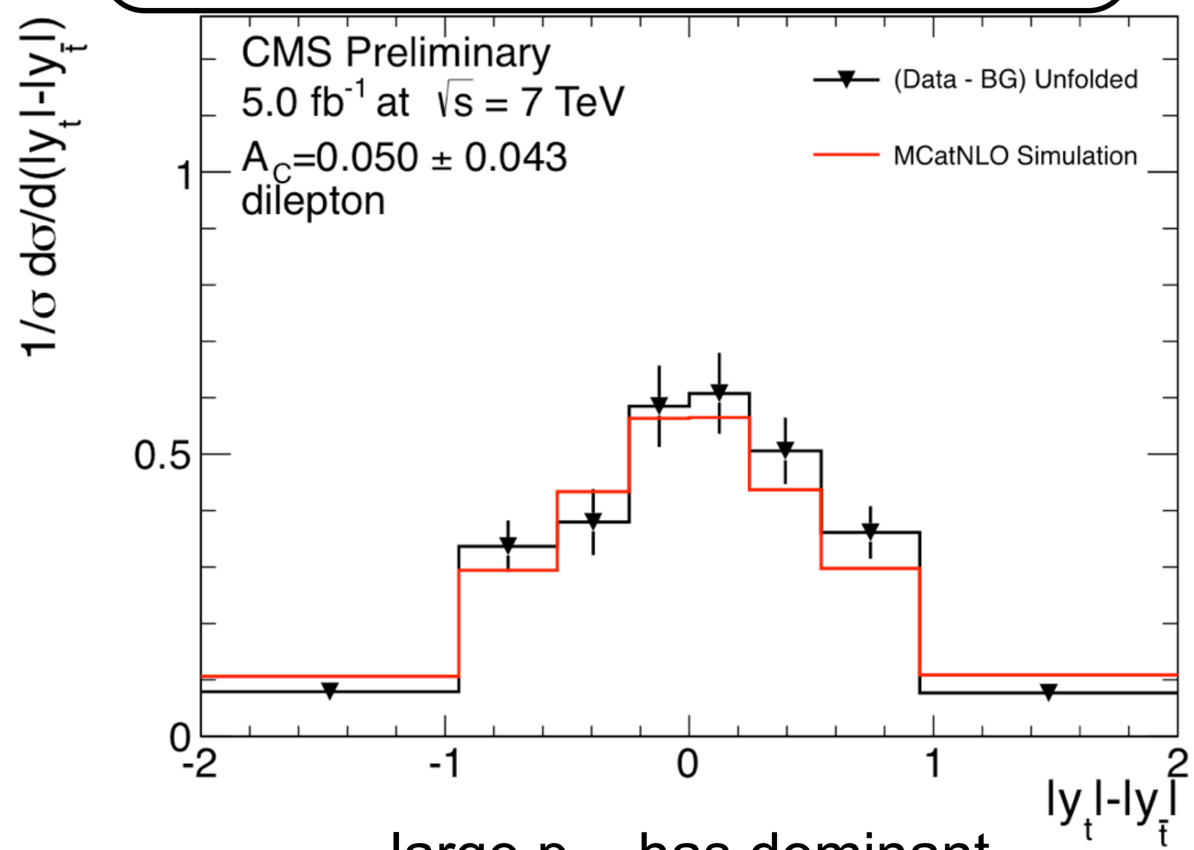
dilepton: Matrix method for QCD and W+jets

Drell-Yan normalized to prediction inside a Z-mass window

Top Charge Asymmetry - Results (dilepton)

CMS PAS TOP-12-004

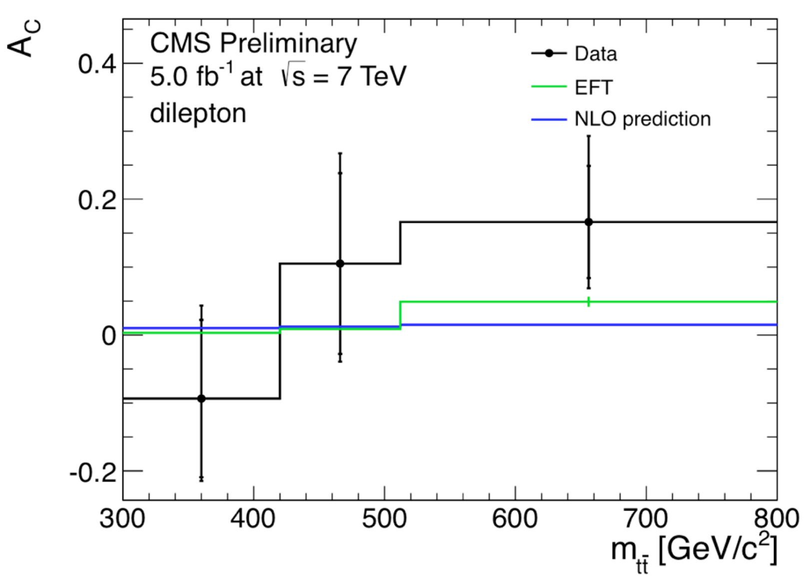
- Full unfolded result for Δ|y|
- Differential measurement of A_C provided as a function of M_{tt}, $|y_{tt}|$, $P_{T,tt}$
- Compared with EFT model with effective axial-vector coupling that could describe the M_{tt} dependence seen at the Tevatron[PRD 8 (2011) 054017]

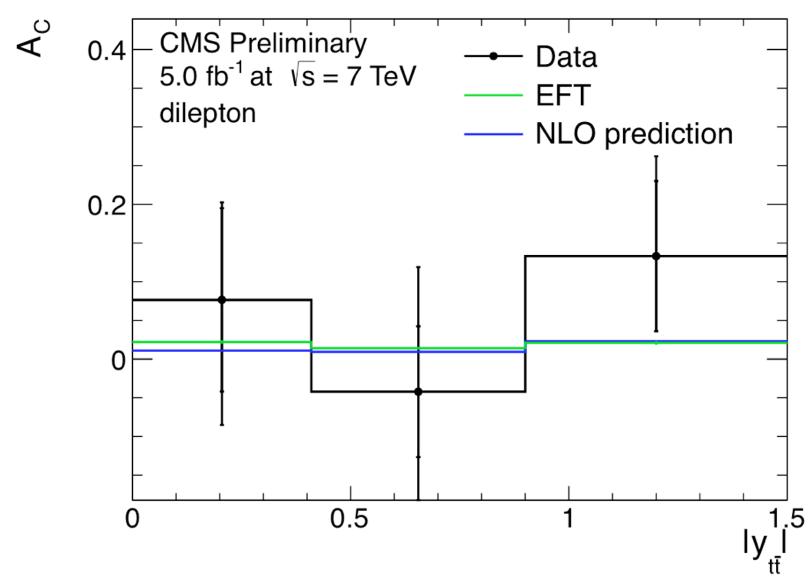


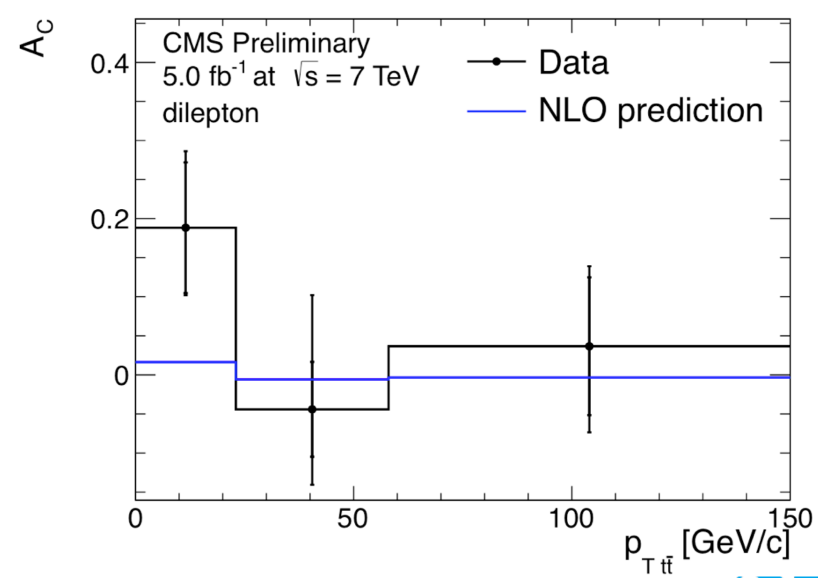
large m_{tt} has enhanced quark annihilation

gg fusion in central

large $p_{T,tt}$ has dominant contribution from ISR/FSR





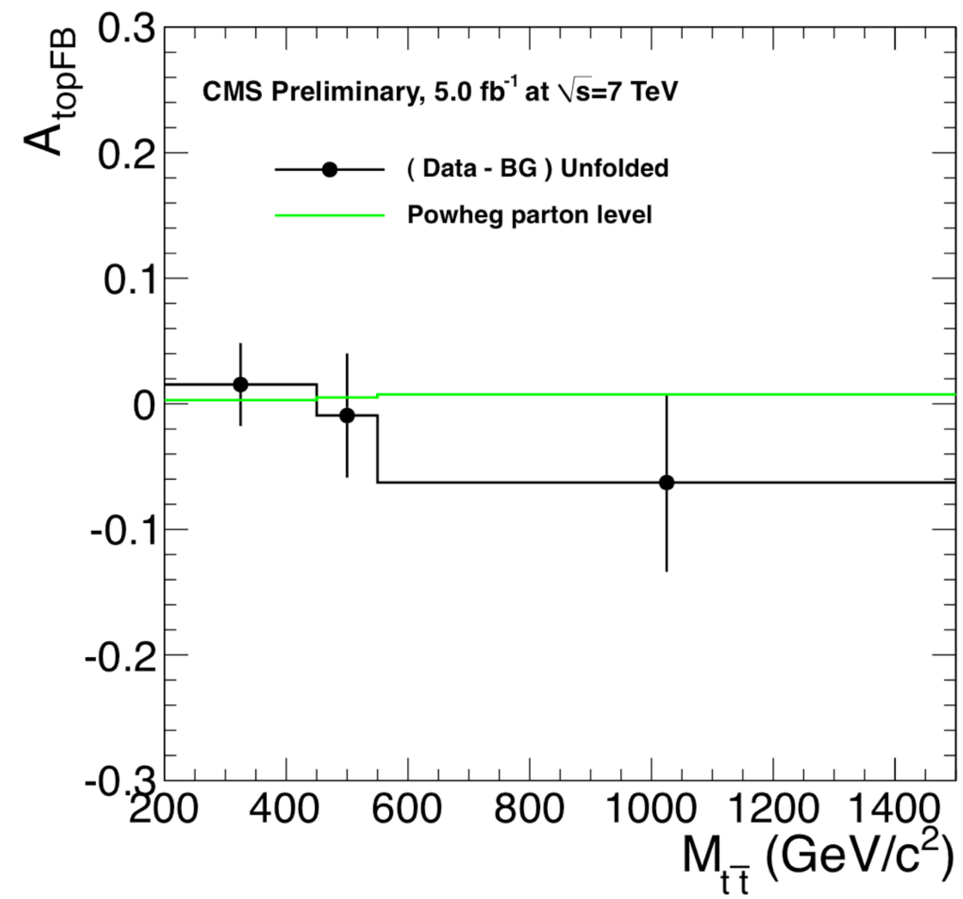


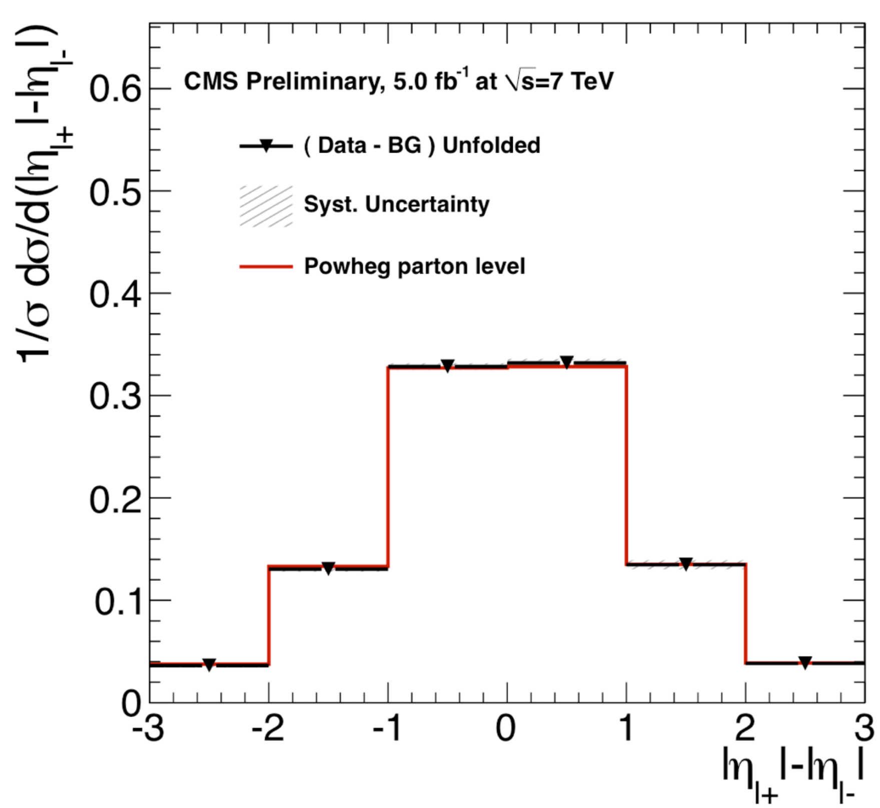
Top Charge Asymmetry - Results (dilepton)

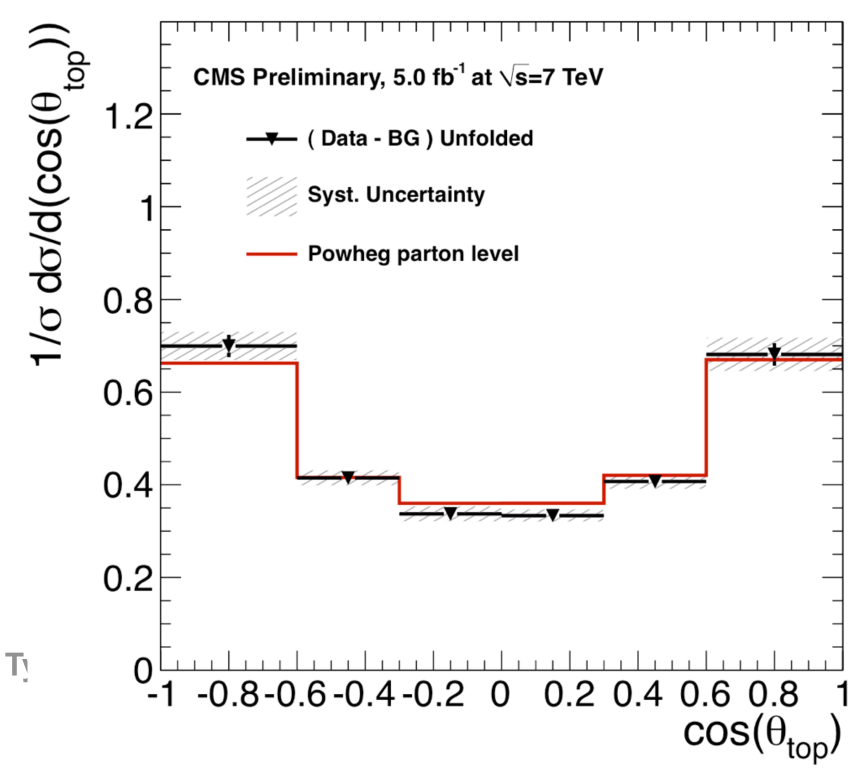
CMS PAS TOP-12-004

- Full unfolded results to parton level
- Compared with Powheg parton level
- No significant deviations from the SM

Unfolded asymmetries	Data	POWHEG
A_{lepC}	$0.010 \pm 0.015 \pm 0.006$	0.004 ± 0.0004
A_{topFB}	$-0.011 \pm 0.034 \pm 0.026$	0.005 ± 0.0004
$A_{topFB}(M_{t\bar{t}} < 450\ \text{GeV})$	$0.015 \pm 0.033 \pm 0.034$	0.003 ± 0.001
$A_{topFB}(450 \leq M_{t\bar{t}} < 550\ \text{GeV})$	$-0.009 \pm 0.050 \pm 0.055$	0.005 ± 0.001
$A_{topFB}(M_{t\bar{t}} \geq 550\ \text{GeV})$	$-0.063 \pm 0.071 \pm 0.081$	0.007 ± 0.001

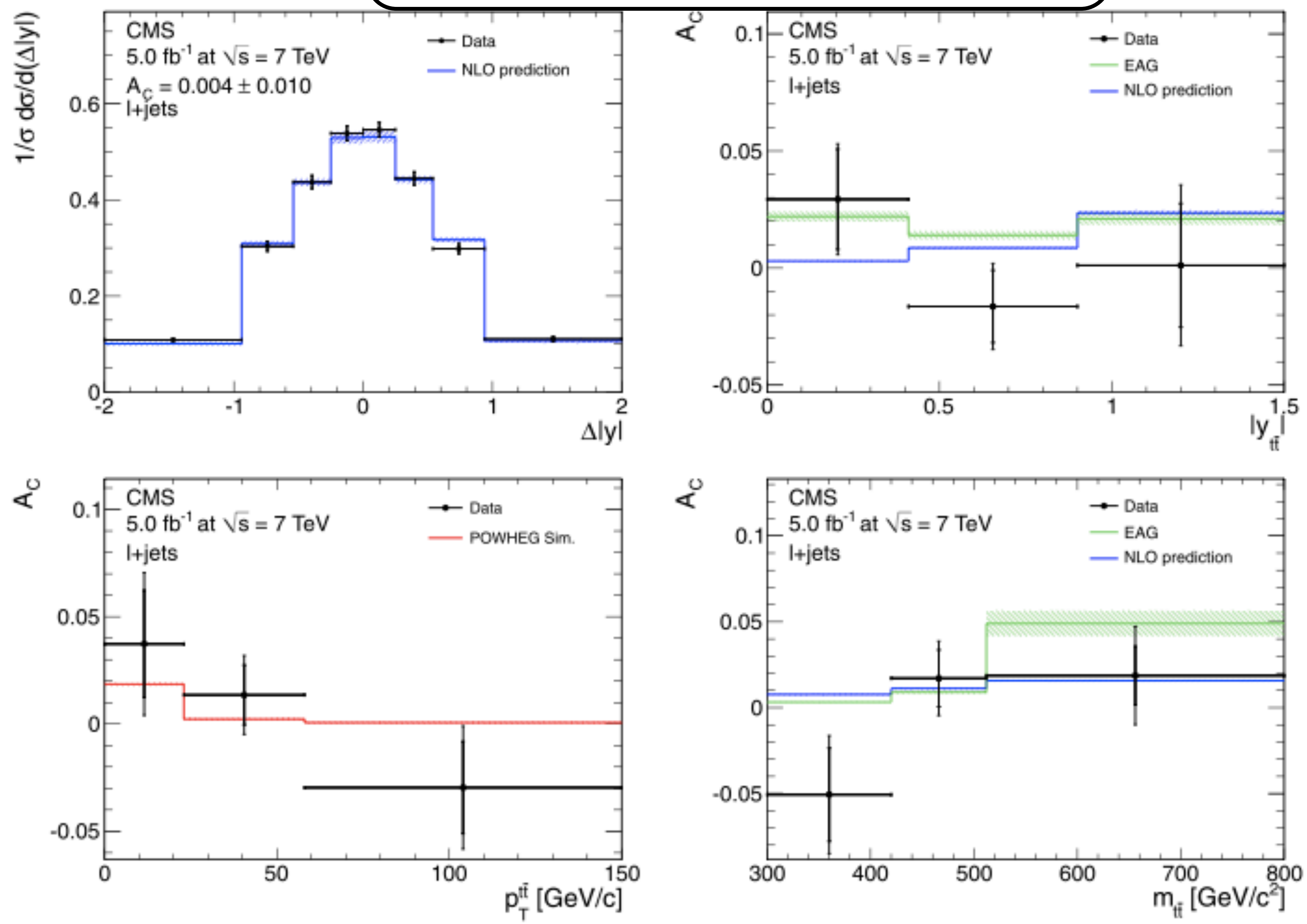






Top Charge Asymmetry - Results (single lepton)

Phys. Lett. B717 (2012) 109



- Differential and inclusive charge asymmetry
- provided as a function of M_{tt}, $|y_{tt}|$, $P_{T,tt}$
- Again no significant deviation from SM

Uncorrected	0.003 ± 0.004 (stat.)
BG-subtracted	0.002 ± 0.005 (stat.) ± 0.003 (syst.)
Final corrected	0.004 ± 0.010 (stat.) ± 0.011 (syst.)
Theoretical prediction (SM)	0.0115 ± 0.0006

Conclusion

- Measurements made of spin correlations in top-pair events and for charge asymmetry variables
  - using the full 5 fb^{-1} of pp data collected in 2011 at 7TeV
  - measurements made in dilepton and single lepton (charge asymmetry only) channels
- CMS results consistent with the Standard Model
- Thank you for listening

Backup