POLARIZATION STUDY USING TOP PAIR EVENTS IN ATLAS EXPERIMENT

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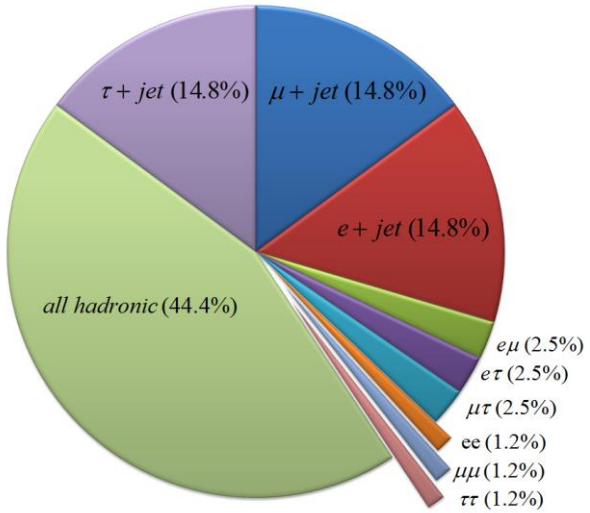
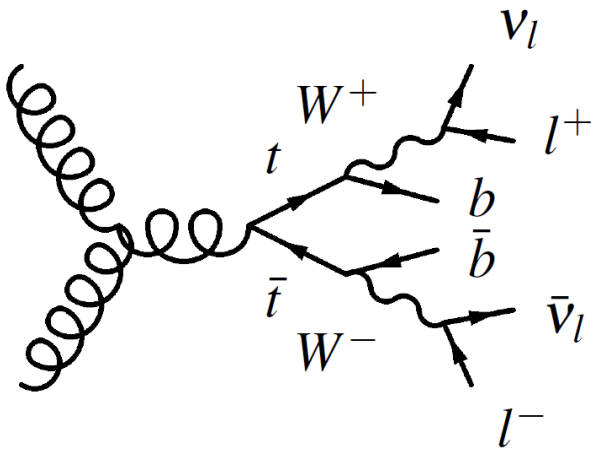
Outline

- Using top pair events
  - Top polarization of single top
  - Spin correlation between top pair
  - W-boson polarization in top decay

Motivations of the analyses

- LHC is a "top factory" (177pb@7TeV).
- As the lifetime of top quark is shorter than its de-polarization/hadronization time, it's possible to measure the effects of its spin, which makes top quark the unique quark whose spin can be accessed.
- New observable for future physics.





Motivations of the analyses

- New physics models beyond the SM (BSM) can alter the top polarization and the spin correlation strength by modifying the production mechanism of the tt pair, or the top decay, for example:
  - If tt pair is produced via a heavy Z boson [hep-ph/9911288] or via a heavy Higgs boson[PRD58, 114031 (1998)].
  - in supersymmetric models if a top quark decays into a charged Higgs boson, which then decays into a lepton and a neutrino [EPJC 66, 261 (2010)].
  - Models predicting top pair charge asymmetry introduce top polarization, as well.
  - Stop exiting will also correct the spin correlation strength by the loop corrections.

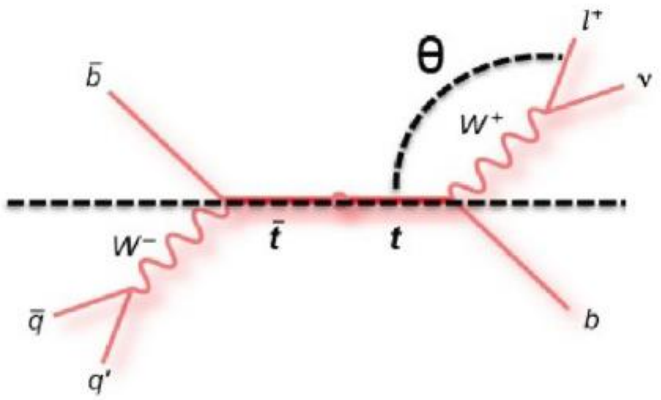
Motivations of the analyses

- The angular distribution of top decay products correlate with the top spin according to

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta} = \frac{1}{2}(1+\alpha_i \cos\theta)$$

$\alpha_{i/j}$ = Spin Analysing Power of Analyser i/j

	b	lepton	d	u
$\alpha_{i/j}$ (LO)*	-0.41	1.00	1.00	-0.31
$\alpha_{i/j}$ (NLO)*	-0.39	0.998	0.93	-0.31



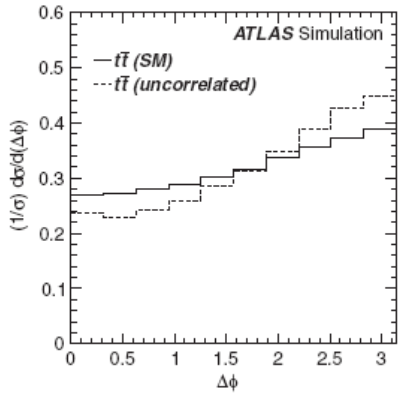
the angle defined between the top product in top rest frame and spin axis.

Strategies of the measurement in ATLAS

- The double differential scattering distribution concerning the angle defined on the top side and anti-top side summarizes the top polarization itself and spin correlation between tops by the parameters B and C, which are both predicted by SM.

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 + B_1\cos\theta_1 + B_2\cos\theta_2 - C\cos\theta_1\cos\theta_2)$$

- The correlation is also manifested in the asymmetry in the distribution of angle between the two final spin analyzers in the Lab frame.

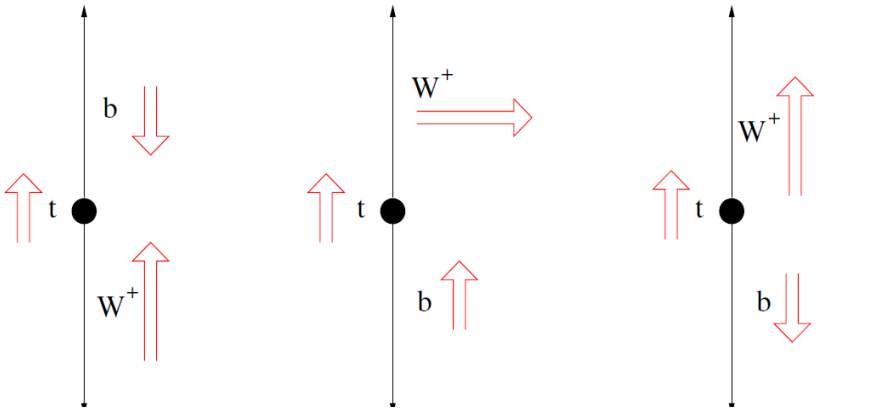


The statistic test doesn't support top polarization in Tevetron experiments

The spin correlation measurement in Tevetron suffers from the big statistic uncertainty $0.60 \pm 0{:}50$

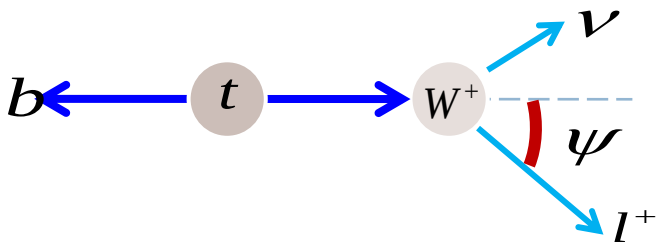
Strategies of the measurement

$$\frac{1}{N}\frac{dN}{d\cos\Psi} = \frac{3}{2}\left[F_0 \cdot \left(\frac{\sin\Psi}{\sqrt{2}}\right)^2 + F_L \cdot \left(\frac{1-\cos\Psi}{2}\right)^2 + F_R \cdot \left(\frac{1+\cos\Psi}{2}\right)^2\right]$$



$F_L = 0.304$ $F_0 = 0.695$ $F_R = 0.001$

in SM@NLO with $F_0 + F_L + F_R = 1$



Bias of F_R indicates the beyongd-SM $V+A$ theory.

Tevetron combined gives F0= 0.722 ± 0.081 and fL = −0.033 ± 0.046

Top polarization

- Once the events are reconstructed, the lepton (e or μ) and the corresponding reconstructed top are used to calculate $\cos\vartheta(l^+)$ or $\cos\vartheta(l^-)$ using the top helicity basis.
- Positive polarized (B=0.3) and negative(B=-0.3) polarized templates are used in the fit.
- The fit will return the fraction of the positive polarized template contribution by
  - $W(f)=f*P_+ +(1-f)*P_-$
- In the fit the cross section is taken as free parameter

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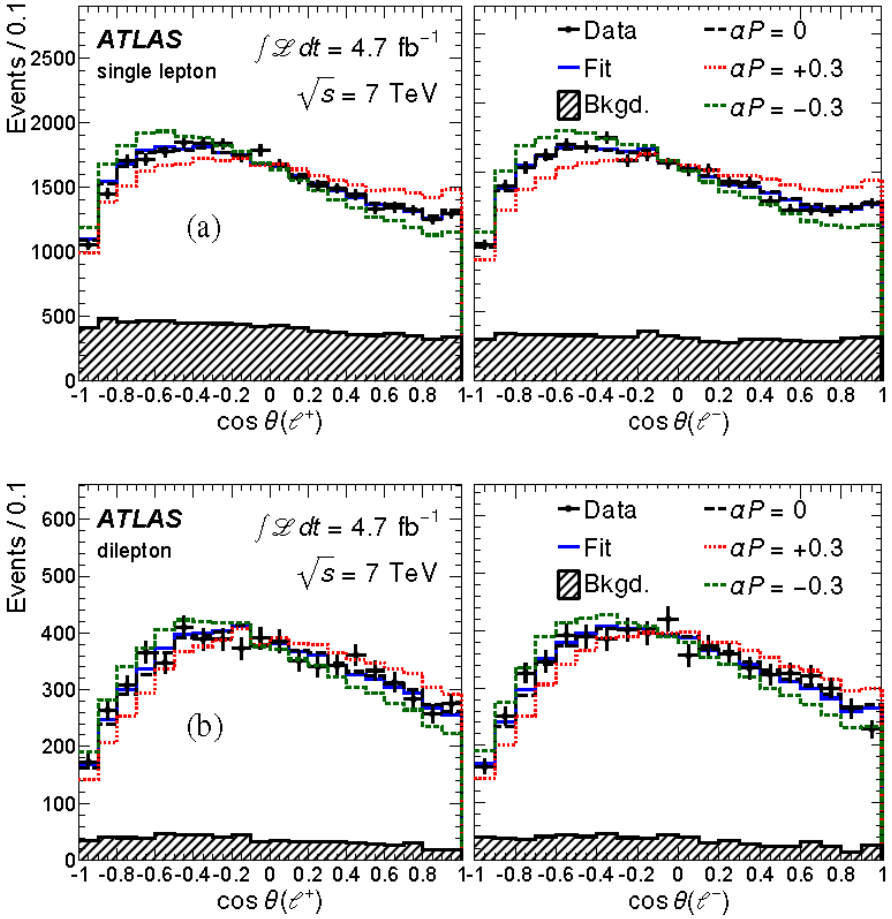
Combined $\alpha_\ell P_{\rm CPC} = -0.035 \pm 0.014(\text{stat}) \pm 0.037(\text{syst})$



- The polarization is assumed to be induced by **a CP conserving** process.
- In this case $B_1 = B_2$
- Here $\alpha_l P = B$

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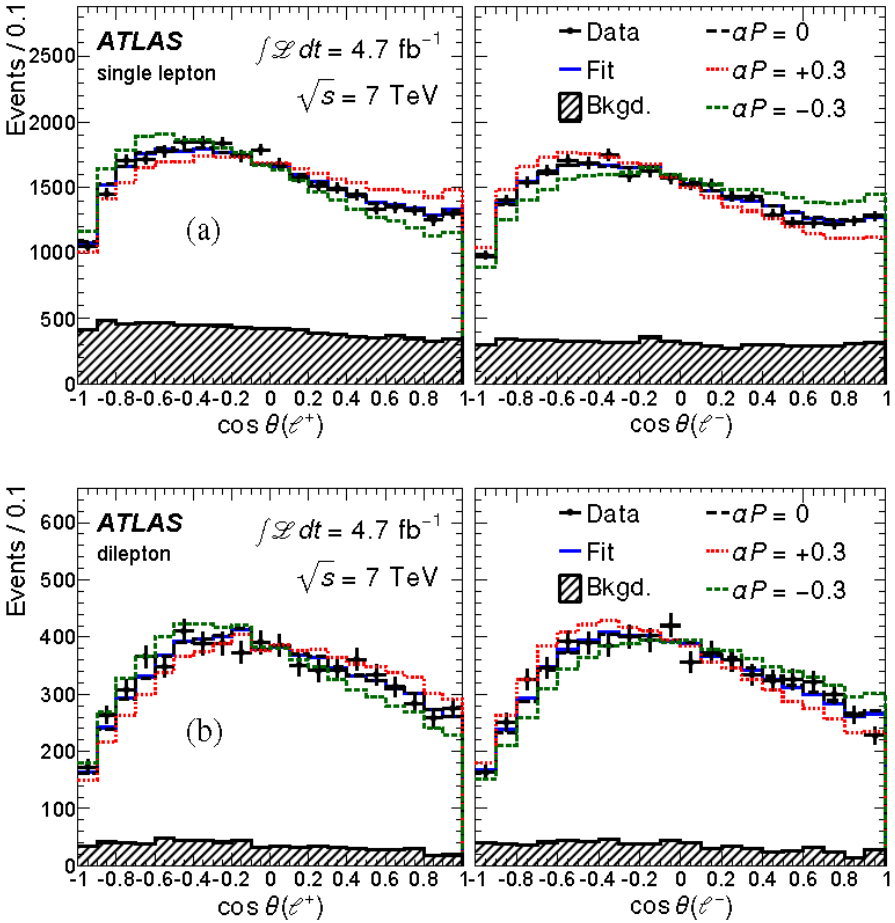
Combined $\alpha_\ell P_{\rm CPV} = 0.020 \pm 0.016({\rm stat})^{+0.013}_{-0.017}({\rm syst})$



- The polarization is assumed to be induced by **maximal CP violation** process.
- This case $B_1 = -B_2$

Top pair spin correlation

- Continue with the latter part of the equation for spin correlation, by assuming the polarization of top quark to be 0

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 + B_1\cos\theta_1 + B_2\cos\theta_2 - C\cos\theta_1\cos\theta_2)$$

Analysis strategy

- The template fit is used to extract the spin correlation strength.

$$m^i = f_{\mathrm{SM}} \times m^i_{A=\mathrm{SM}}(\sigma_{t\bar{t}}) + (1 - f_{\mathrm{SM}}) \times m^i_{A=0}(\sigma_{t\bar{t}}) + \sum_{j=1}^{N_{\mathrm{bkg}}} m^i_j$$

m^i: The predicted number of events per template bin, with f_{SM} and cross section of tt events as free parameters.

The likelihood function is constructed assuming poisson statistics of events in each bin.

$$L = \prod_{i=1}^{N} \mathcal{P}(n^i, m^i)$$

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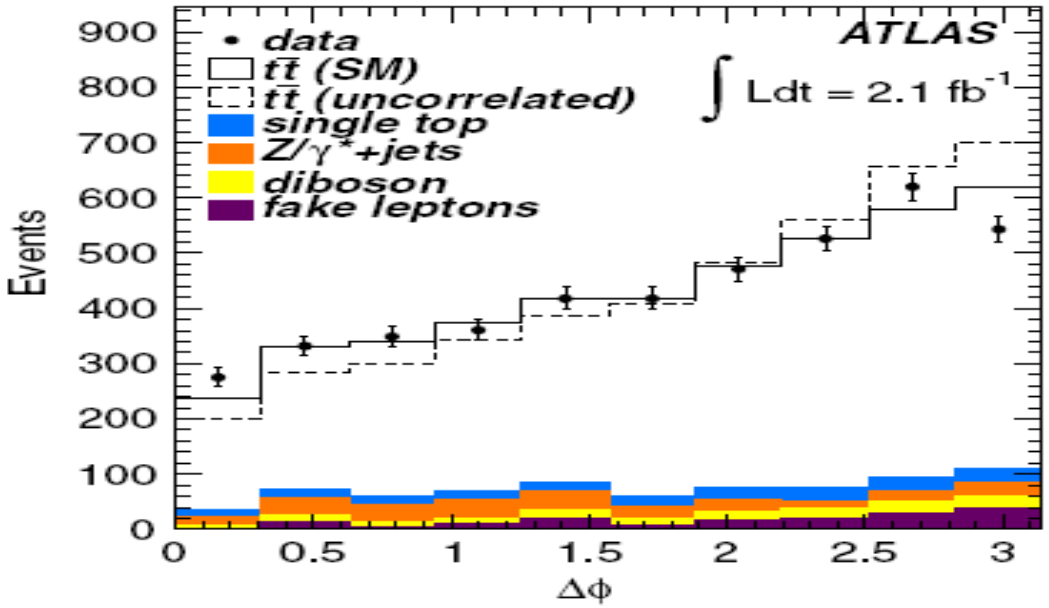
Measurements with $\Delta\phi$ (in dilepton channel)



- $A_{helicity}$ =0.40 ±0:04(stat) +0.08-0.07 (syst)

The hypothesis of zero tt spin correlation is excluded with a significance of 5.1 standard deviations.

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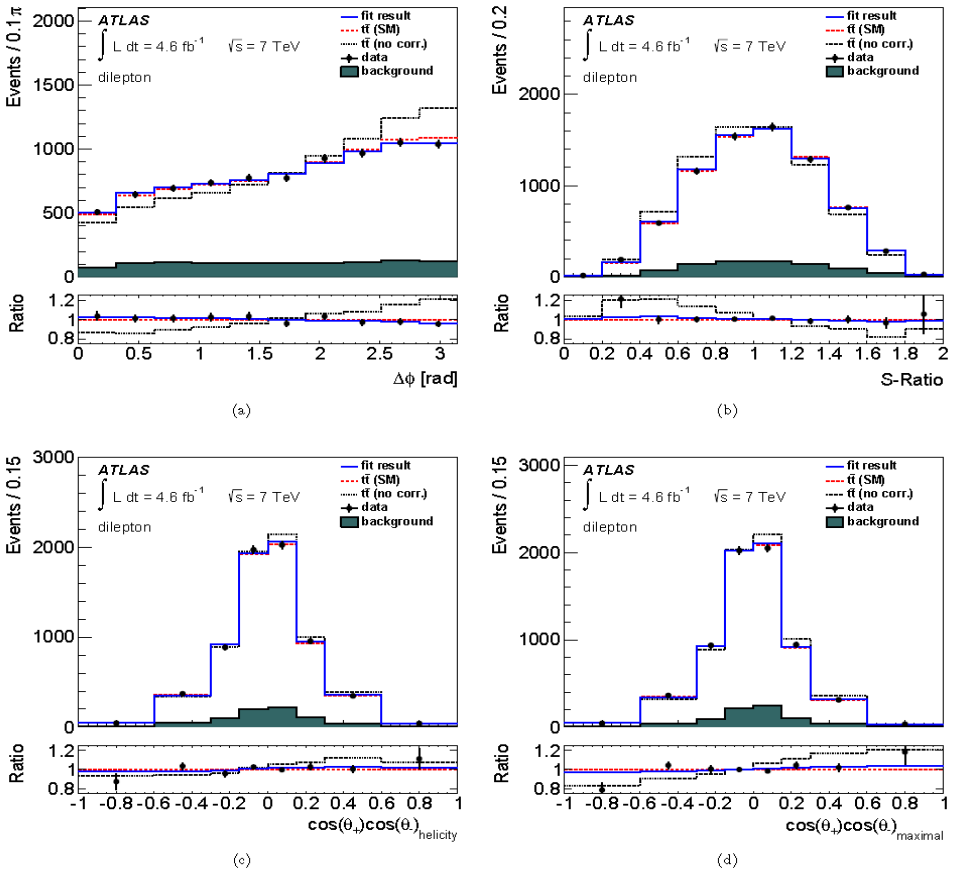
Measurements with more observables

(in dilepton channel)



- Shown the distribution of the 4 observables (black dot) and the fitting (blue line) by maximize the likelihood function.
- The SM (red dash) and 0-spin-correlation distribution(black dash) are also superimposed.

$1.19 \pm 0.09 \pm 0.18$	$0.87 \pm 0.11 \pm 0.14$	$0.75 \pm 0.19 \pm 0.23$	$0.83 \pm 0.14 \pm 0.18$

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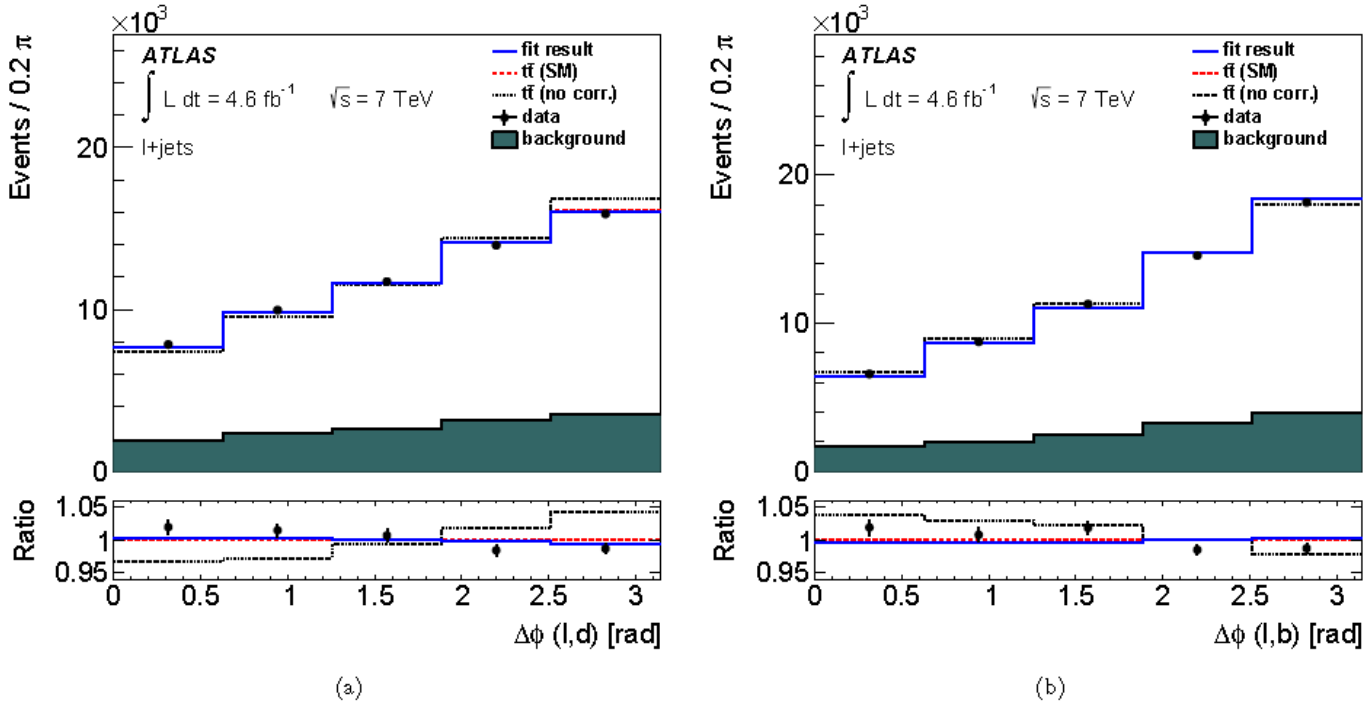
Measurement in semi-leptonic channel



Lepton used as spin analyzer in one side, d quark from W or b quark used for the other side. d- and b-quark are oppositely correlated with top spin, the combination of the two measurement cancel part of the systematic

$$f_{\mathrm{SM}} = 1.12 \pm 0.11\ (\mathrm{stat.}) \pm 0.22\ (\mathrm{syst}).$$

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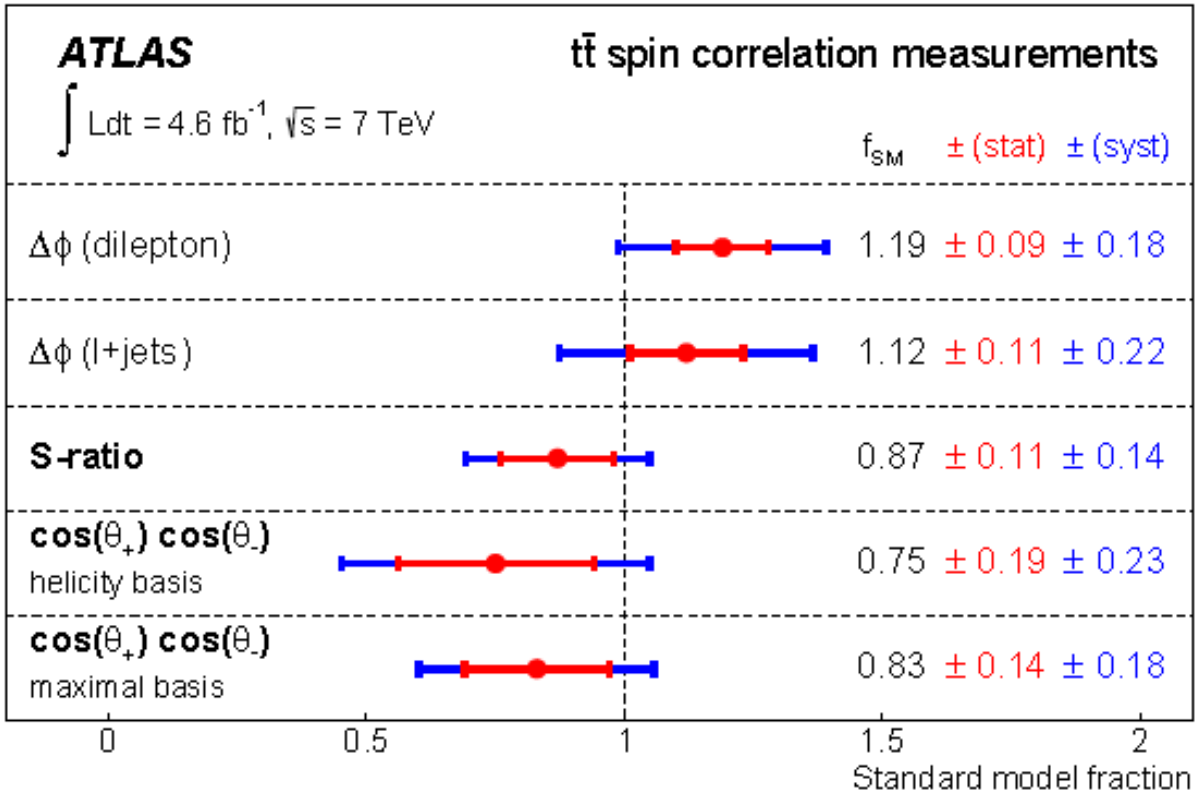
Summary of the measurements



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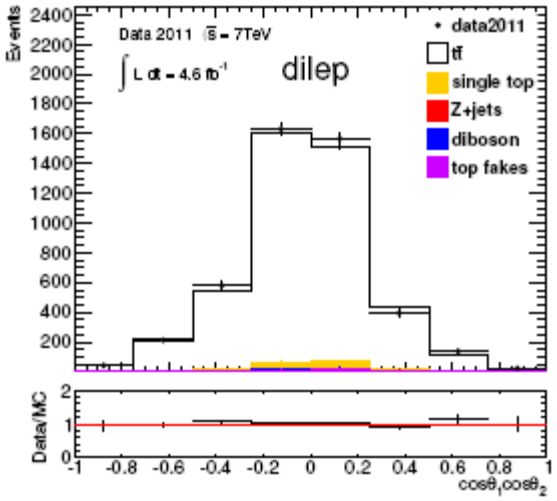
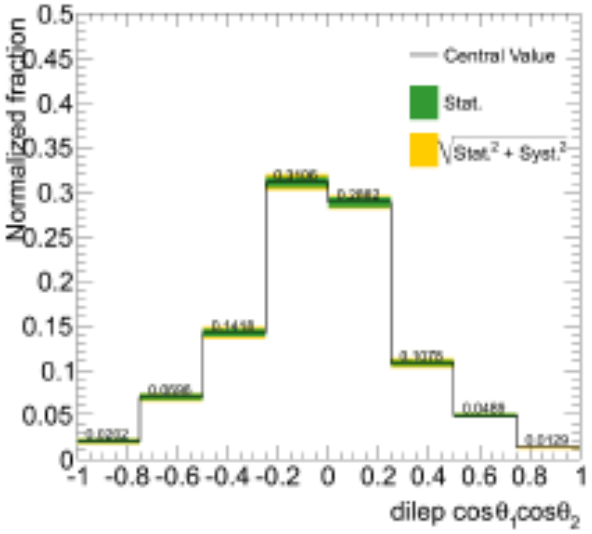
Differential analysis





- B-tagging used to highly suppress the background and unfold measured double-angle distribution to its parton level. The extracted Asymmetry agree with SM.

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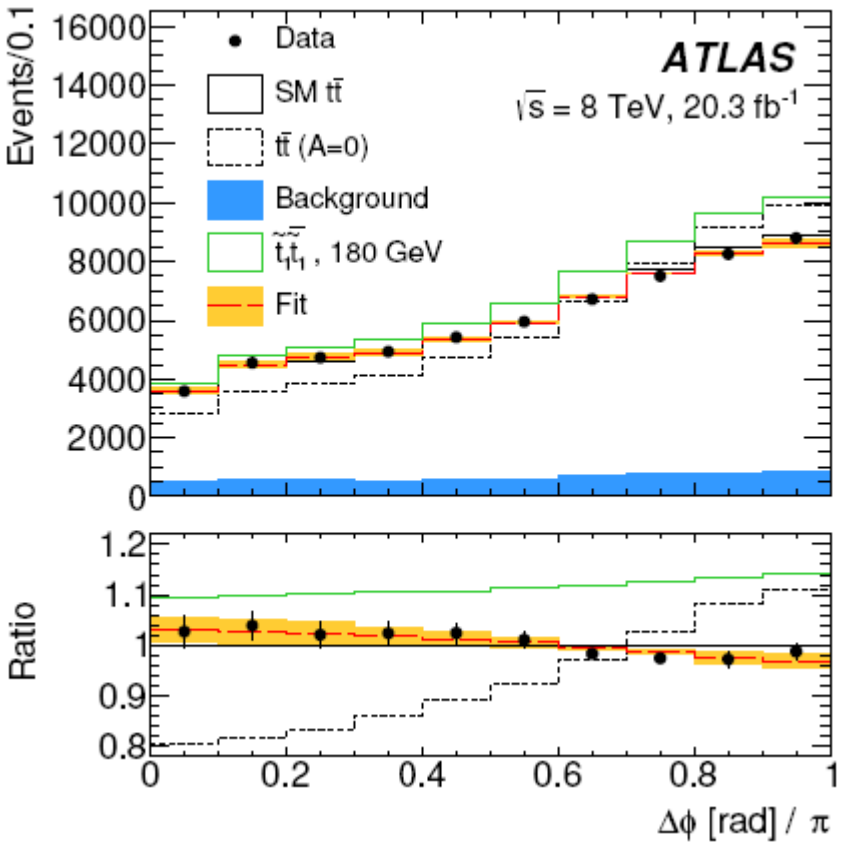
continue



- orange band represents the total systematic uncertainty on f_{SM}
- Ahelicity = 0.38±0.04, by transforming 1.20± 0.05 (stat)± 0.13(syst).

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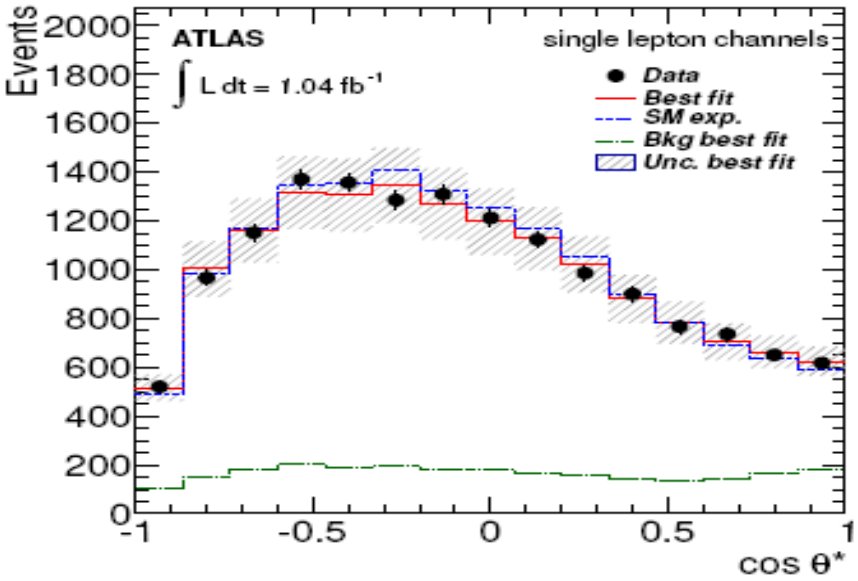
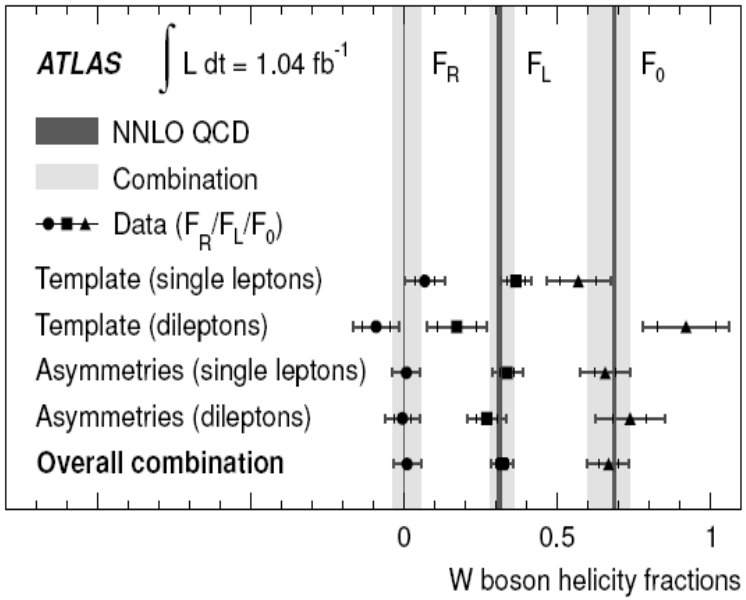
W-boson polarization





- Direct fit with 3 template samples to extract the polarization parameters.
- A little big improvement compared to Tevetron. Not public with more data.

Summary

- The results unambiguously support the naked quark theory.
- No evidence for top polarization yet, by the measurements until now.
- The spin correlation between tops, agree with the SM prediction, as well, within one standard deviation.
- With the uncertainty, V+A structure is not identified.