Some of the Top Quark Properties from the $t\bar{t}$ final state

(W/top polarization, asymmetries, spin correlations)

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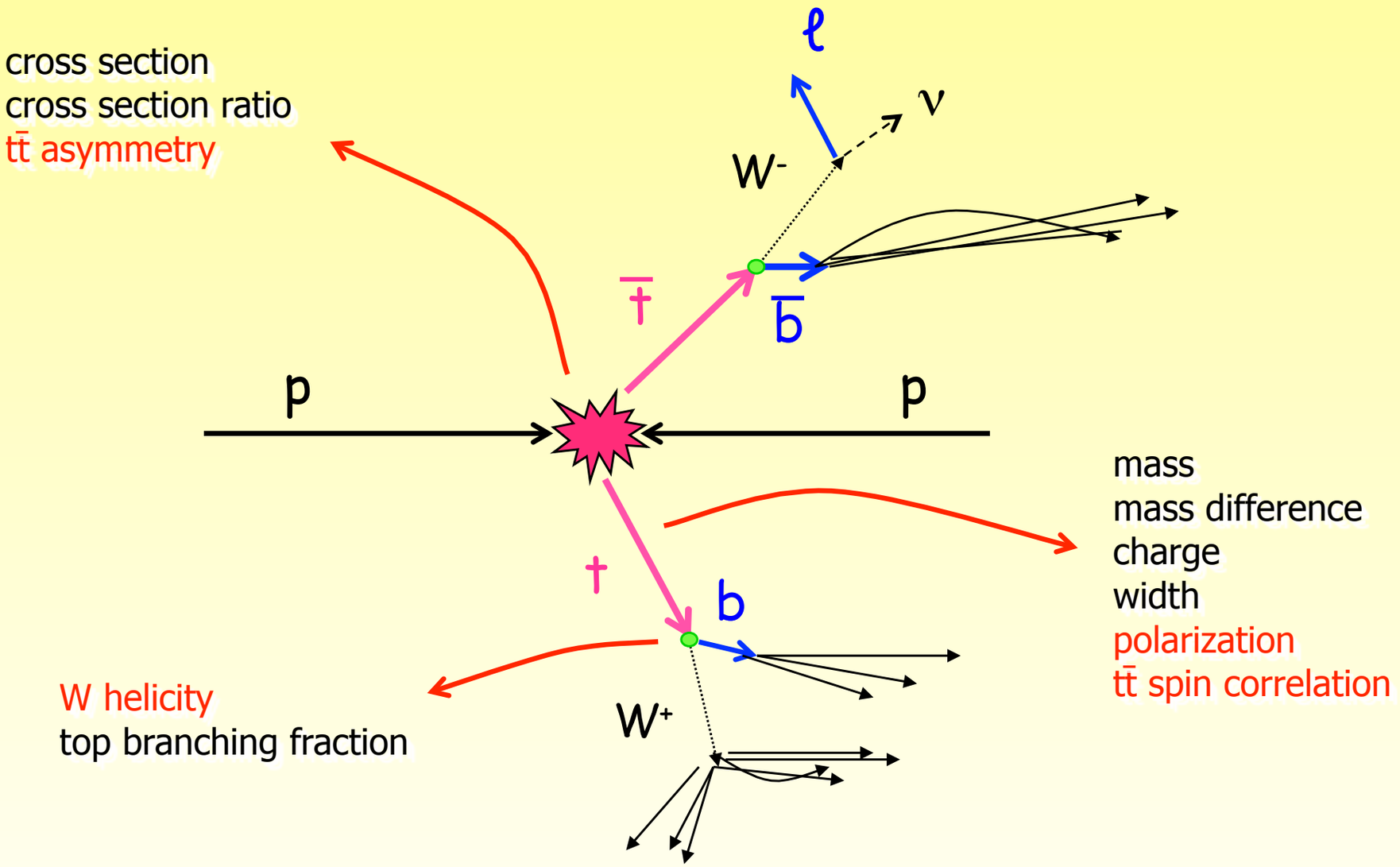
LHC-France 2013, Annecy, 4-April-2013

The properties of the top quark

- Does the heaviest elementary particle behave as a SM particle ?

  ➔ the top quark sector is a special sector to search for new physics



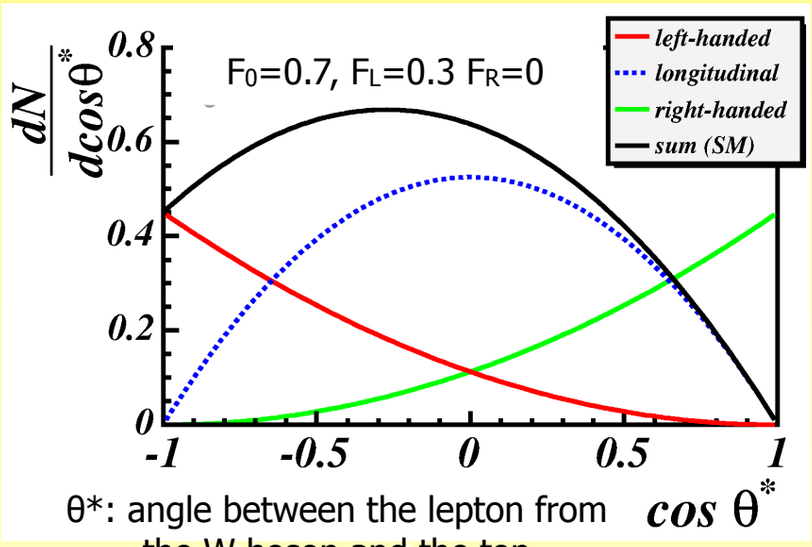
W polarization

Grenoble, Marseille

- Test of the Wtb coupling

$$\frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta^*} = \frac{3}{4}\left(1-\cos^2\theta^*\right)\,F_0 + \frac{3}{8}\left(1-\cos\theta^*\right)^2\,F_\mathrm{L} + \frac{3}{8}\left(1+\cos\theta^*\right)^2\,F_\mathrm{R}$$

- Methods based on fitting the cosθ* distribution or looking at angular asymmetries
- combination of ATLAS and CMS 7 TeV measurements
  - ➔ ATLAS lepton+jets 35 pb^{-1}, lepton+jets, dilepton 1.0 fb^{-1}
  - ➔ CMS single muon channel 2.2 fb^{-1}

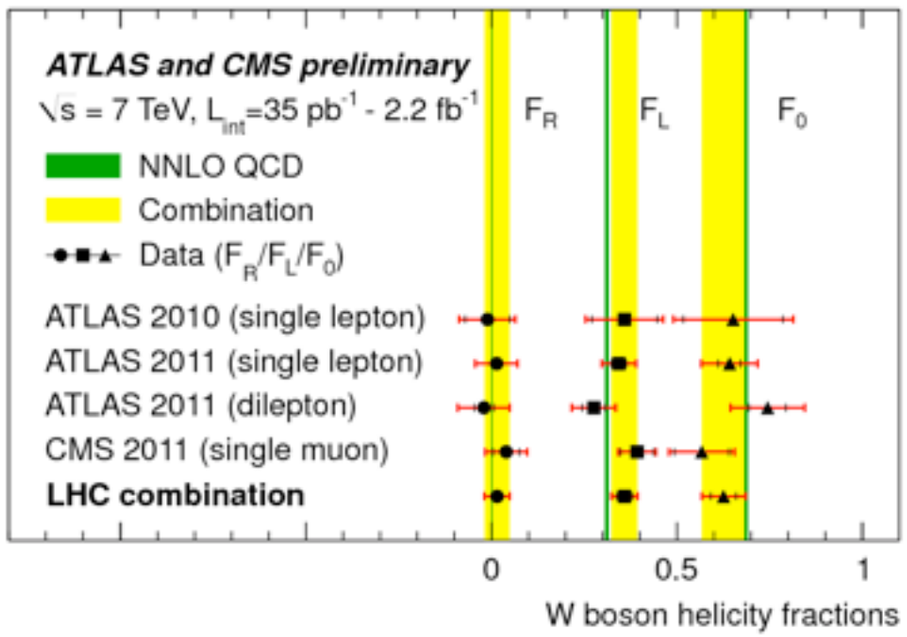


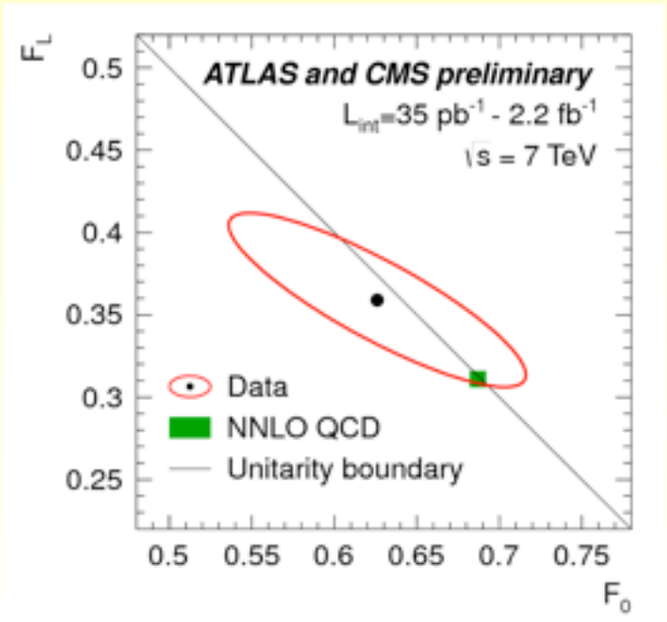
θ*: angle between the lepton from the W boson and the top direction in W boson rest frame

- results in agreement with the SM predictions

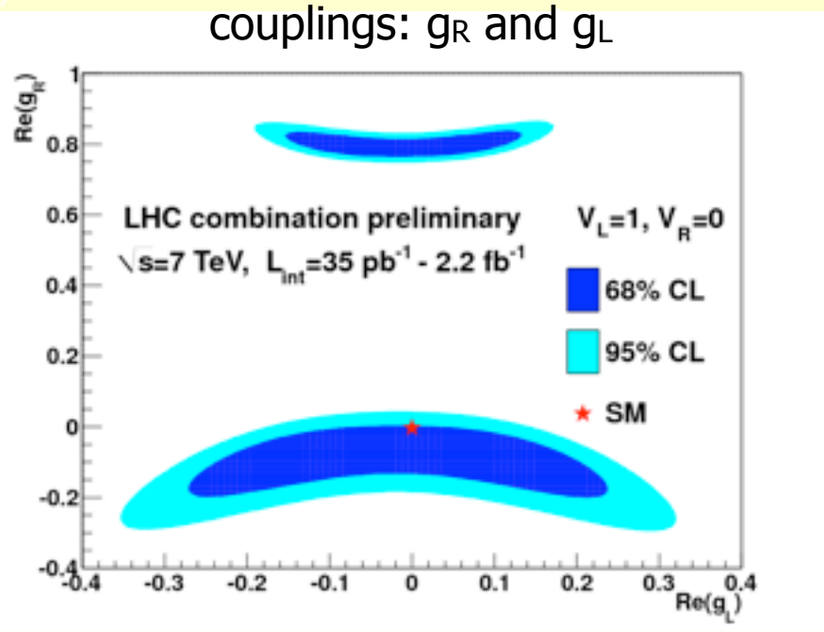
$$F_0 = 0.626 \pm 0.034\ (\mathrm{stat.}) \pm 0.048\ (\mathrm{syst.})$$
$$F_L = 0.359 \pm 0.021\ (\mathrm{stat.}) \pm 0.028\ (\mathrm{syst.})$$

ATLAS-CONF-2013-033, CMS-PAS-TOP-12-025



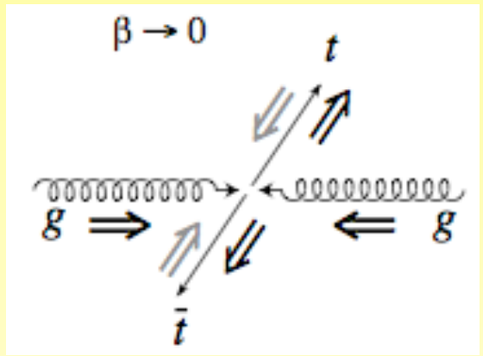


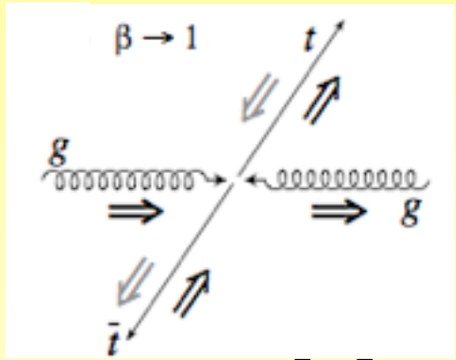
limit on Wtb anomalous couplings: g_R and g_L



$t\bar{t}$ spin correlation

- in the SM, the spin of the top and of the antitop are produced correlated
  - ➔ the top quark decays before hadronizing: correlation preserved in the decay products
  - ➔ can be affected by new physics + allow to confirm the top quark spin value
  - ➔ in the SM:





same as $q\bar{q} \to t\bar{t}$

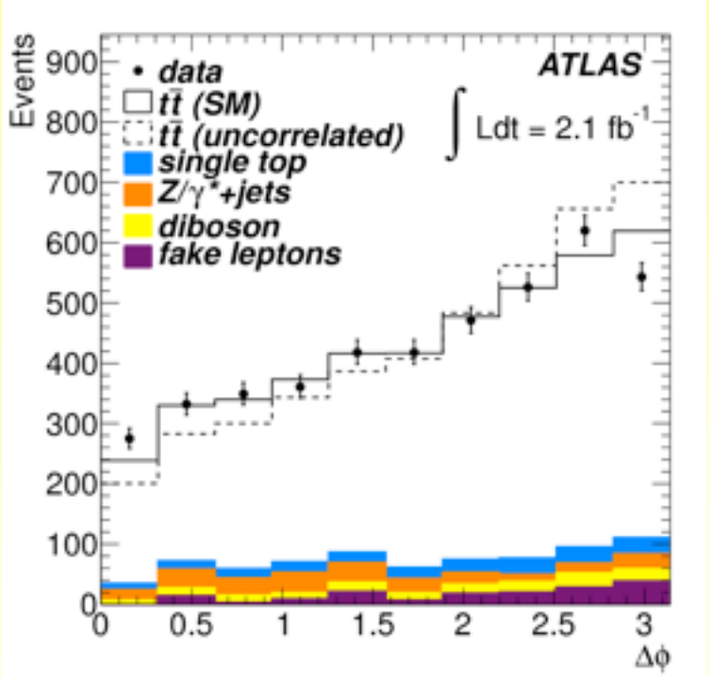
- method
  - ➔ degree of correlation: $A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$
  - ➔ can be extracted from $\Delta\Phi(l^+,l^-)$ in the lab frame with a choice of basis:

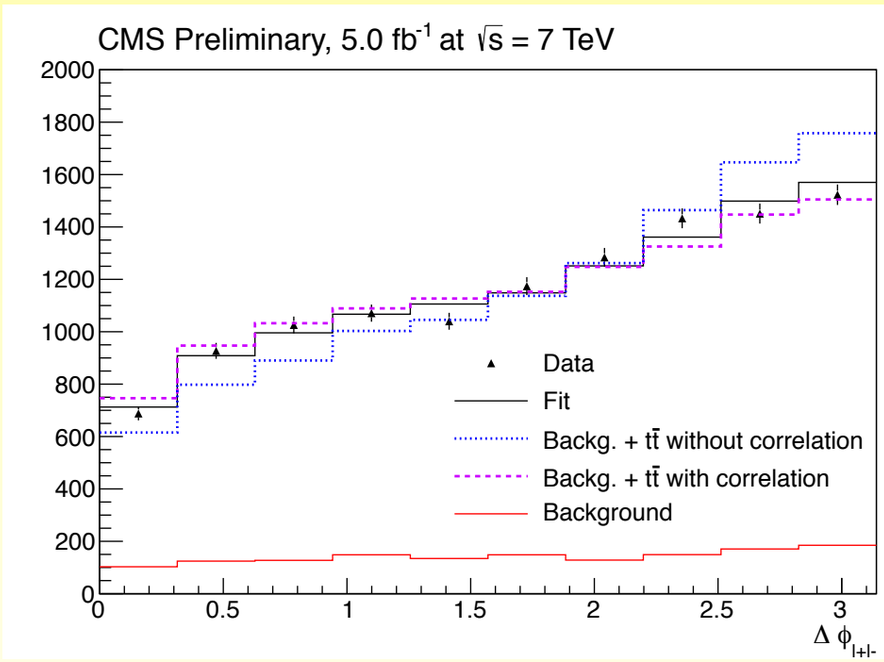
    helicity basis or maximal basis
  - ➔ SM prediction: $A^{SM}_{hel} = 0.31$

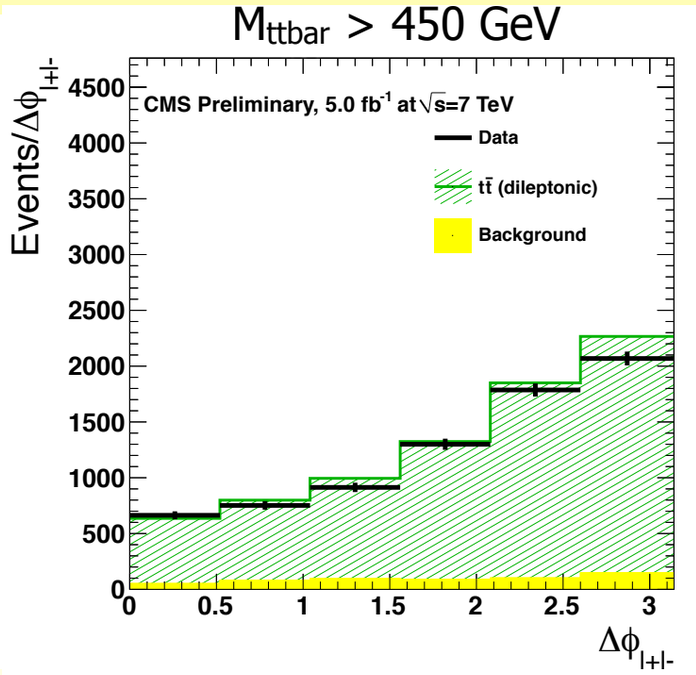
$t\bar{t}$ spin correlation results

Strasbourg

- ATLAS: 5 σ observation using 2 fb^{-1} dilepton events (7 TeV)
  - ➔ fraction of SM (w/ correlation): $f_{SM} = 1.30 \pm 0.14\ (stat)\ ^{+0.27}_{-0.22}\ (syst)$ PRL 108, 212001 (2012)
- CMS 5 fb^{-1} dilepton result (7 TeV)
  - ➔ result in agreement with SM predictions: $f_{SM} = 0.74 \pm 0.08(stat.) \pm 0.24(syst.)$ CMS-PAS-TOP-12-025
  - ➔ also measurements at high M_{ttbar}





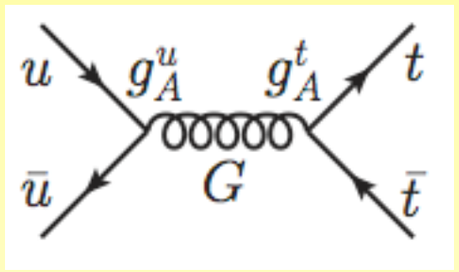


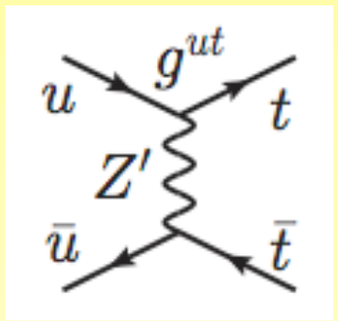
- perspectives
  - ➔ more statistics will allow to perform more differential measurements and use other observables

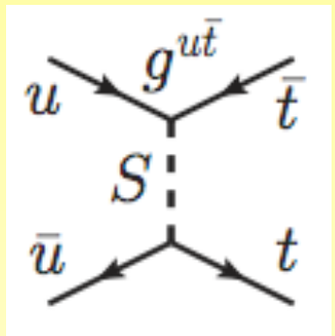
Top quark polarization

- In QCD, the top quark in $t\bar{t}$ production are produced unpolarized
- Polarization can be measured through the angular distributions of the top decay products

  ➔ in case of anomaly, polarization information can help to distinguish between BSM models







- observables

  ➔ distribution of the polar angle θ_i for the top daughter particle i: $W(\cos\theta_i) \propto 1 + \alpha_i p \cos\theta_i$

  p: degree of polarization along the chosen quantification axis n

  α_l: spin analysis power of i (=1 for leptons)

$$\mathcal{P}_n = \frac{N(\cos\theta_{\ell,n} > 0) - N(\cos\theta_{\ell,n} < 0))}{N(\cos\theta_{\ell,n} > 0) + N(\cos\theta_{\ell,n} < 0))}$$

Top quark polarization results

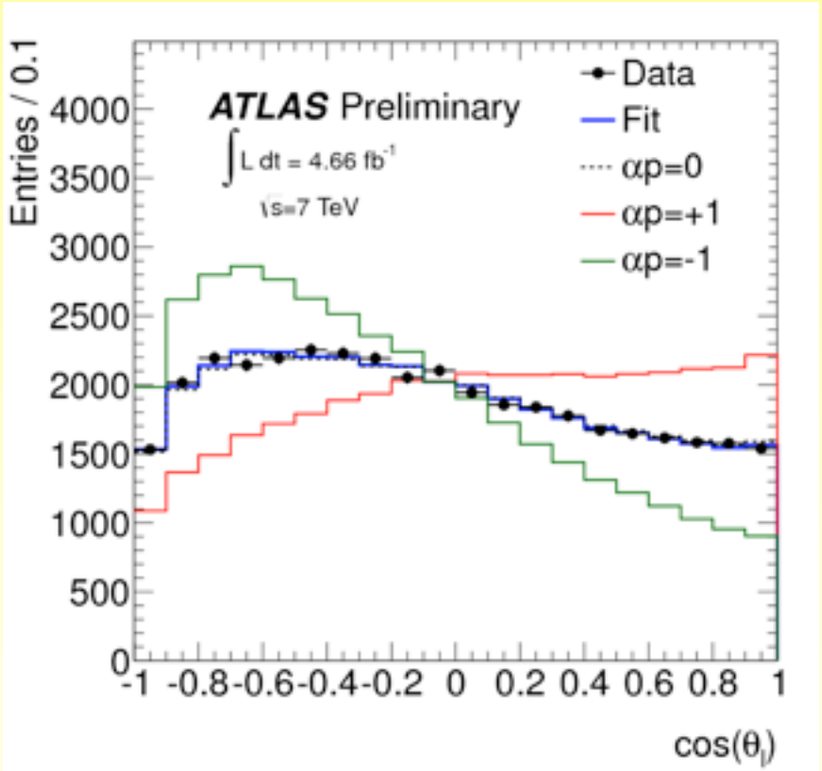
Marseille, Saclay

- ATLAS 4.7 fb^{-1} result in the lepton+jets channel (7 TeV):

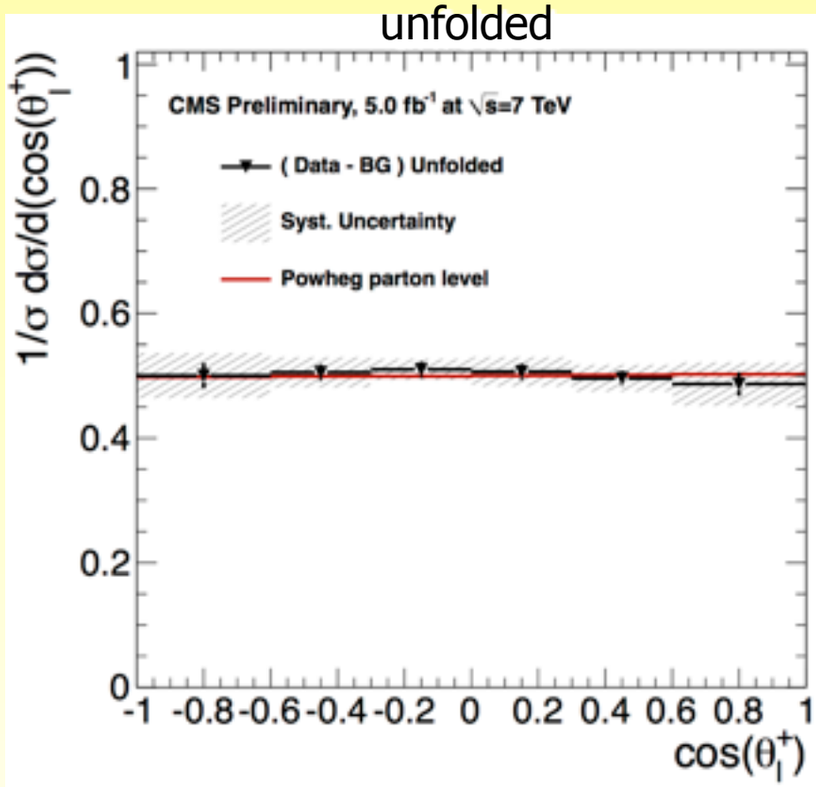
  ➔ using the lepton angle in the helicity basis $\alpha_\ell p = -0.060 \pm 0.018(\text{stat})^{+0.046}_{-0.064}(\text{syst})$. ATLAS-CONF-2012-133

- CMS 5.0 fb^{-1} result in the dilepton channel (7 TeV):

  ➔ using the lepton angle in the helicity basis $P_n = -0.009 \pm 0.029 \pm 0.041$ CMS-PAS-TOP-12-016



unfolded



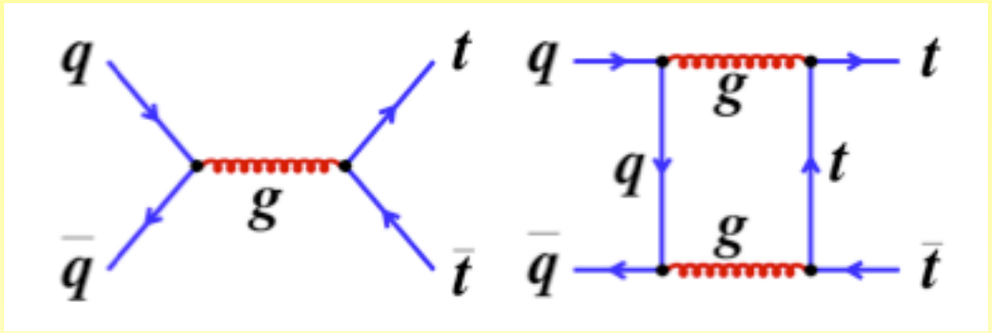
- perspectives

  ➔ more statistics

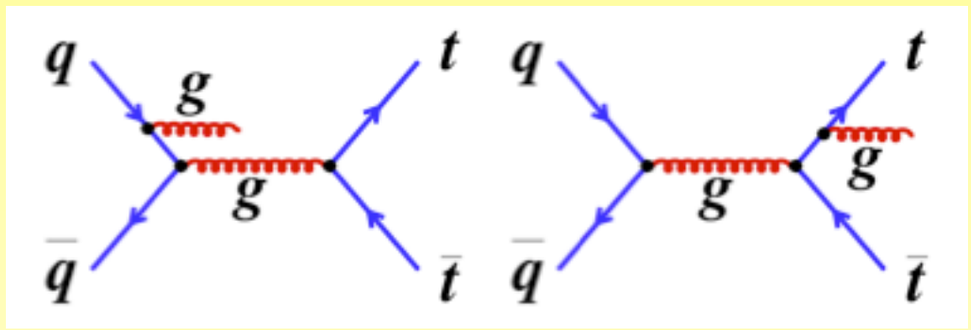
  ➔ BSM model exclusion

$t\bar{t}$ charge asymmetry

- At NLO, QCD predicts an asymmetry for $t\bar{t}$ produced via $q\bar{q}$ or qg (from interferences)
  - ➔ the top quark is predicted to be emitted preferentially in the direction of the incoming quark
  - ➔ BSM (Z', W', axigluon, ...) can modify it

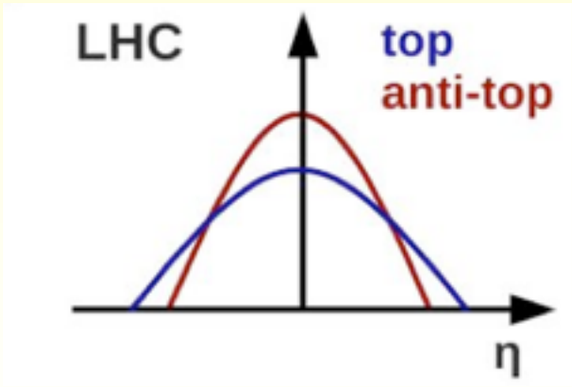


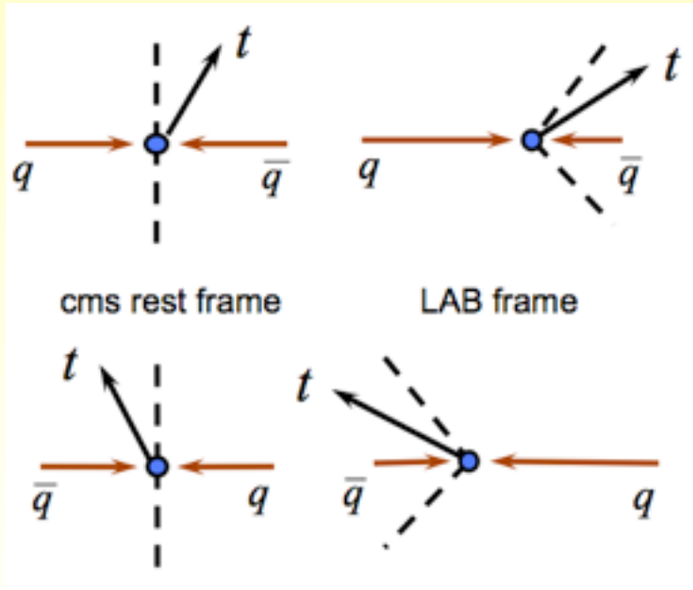
positive asymmetry



negative asymmetry

- At the LHC, the dominant $t\bar{t}$ production is via gluon fusion which is symmetric
  - ➔ smaller asymmetry than at the Tevatron
  - ➔ central-forward/backward asymmetry
  - ➔ higher predicted value at large $M_{t\bar{t}}$





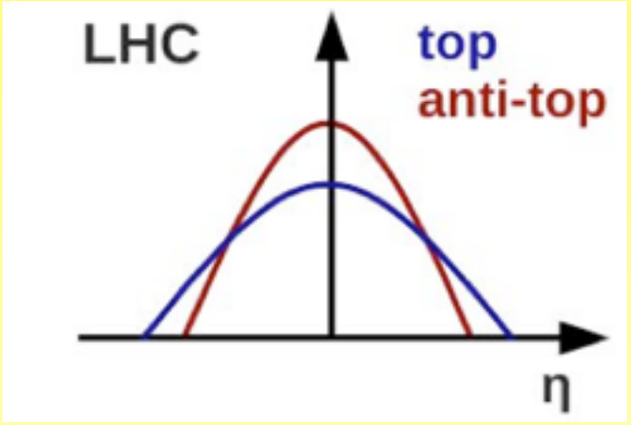
$t\bar{t}$ charge asymmetry observables

- $t\bar{t}$-based asymmetry

  ➔ SM prediction: 0.6-1%

$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

$$\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$$



- Lepton-based asymmetry

  ➔ asymmetry using the lepton from the top decays in dilepton events

  ➔ advantages: no top reconstruction need + also sensitive to polarization effects

  ➔ drawback: diluted (smaller) asymmetry

  ➔ complementary information to the $t\bar{t}$-based asymmetry

  ➔ SM prediction: ~ 0.4%

$$A^{ll} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}$$

$$\Delta|\eta| = |\eta_{l^+}| - |\eta_{l^-}|$$

- Still some excess at the Tevatron

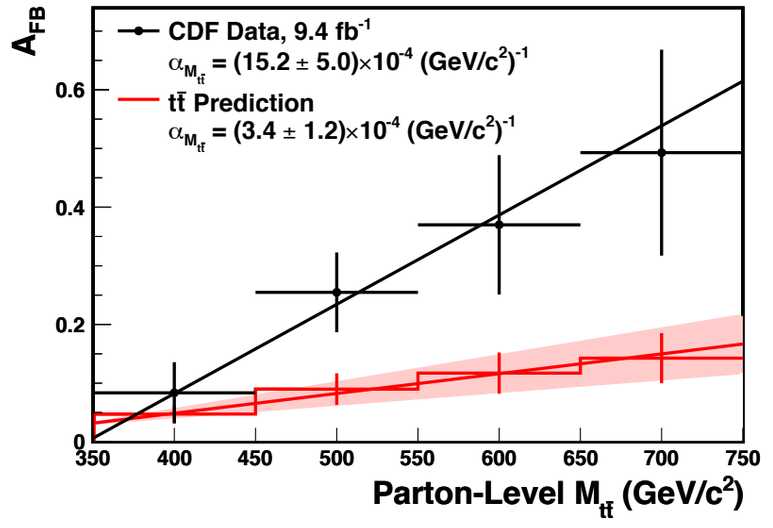
  ➔ different asymmetry ($p\bar{p}$ collider): forward-backward asymmetry

  inclusive, unfolded: A_{FB}= 0.164 ± 0.045 (stat+syst)

  A_{FB} (SM)= 0.066 ± 0.020

  arXiv:1211.1003

CDF $t\bar{t}$-based lepton+jets

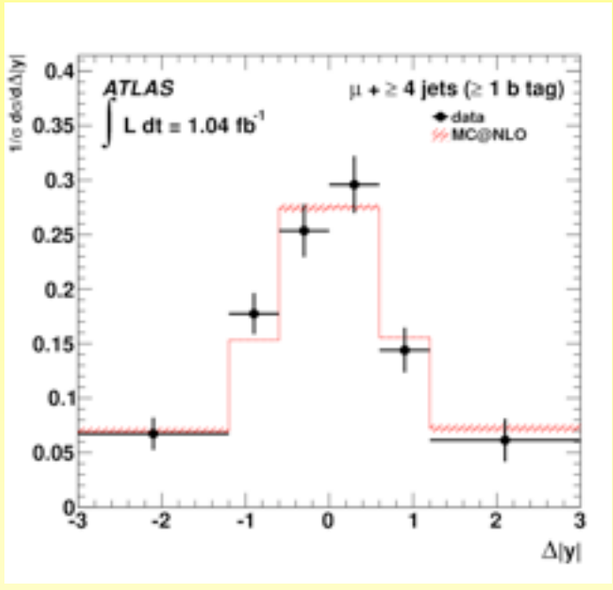


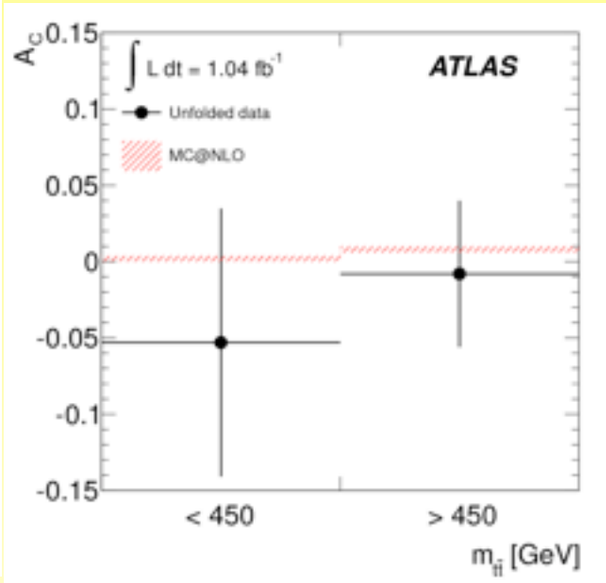
$t\bar{t}$-based asymmetry in the lepton+jets channel

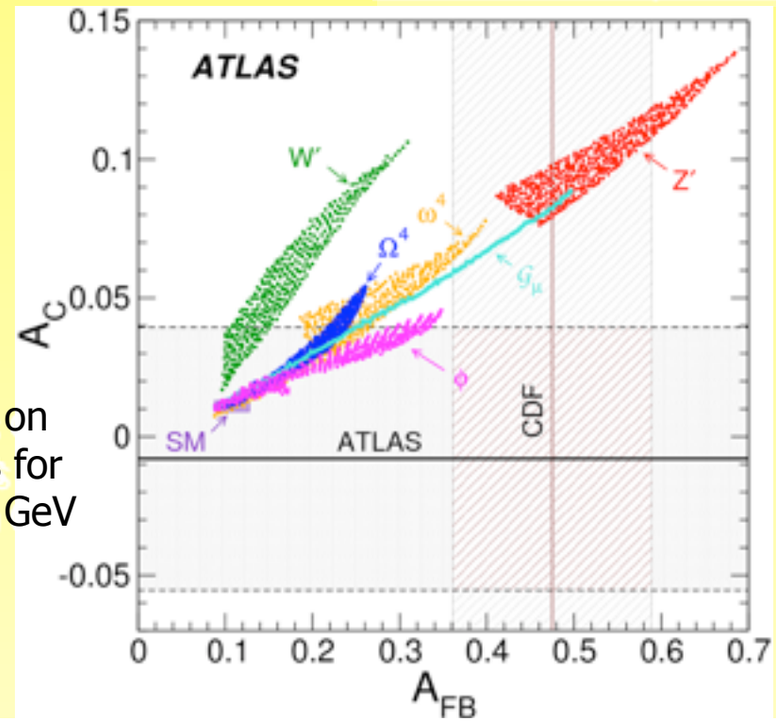
Saclay

- ATLAS result with 1 fb^{-1} (7 TeV)

inclusive, unfolded: $A_C = -0.019 \pm 0.028\ (\text{stat.}) \pm 0.024\ (\text{syst.})$ EPJ C72 (2012) 2039







constraints on BSM models for M_{ttbar} > 450 GeV

- CMS result with 5 fb^{-1} (7 TeV)

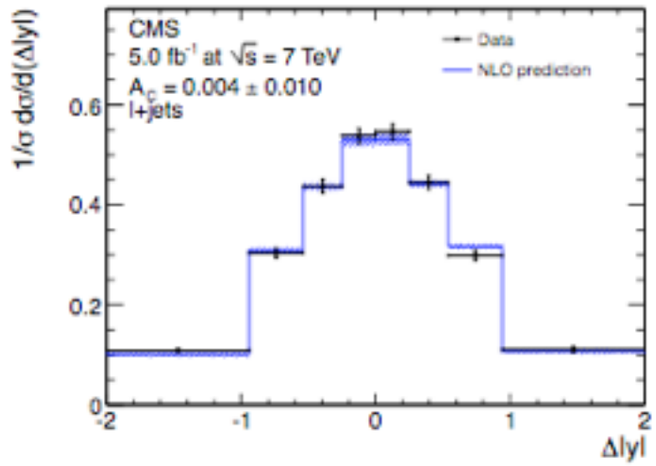
inclusive, unfolded:

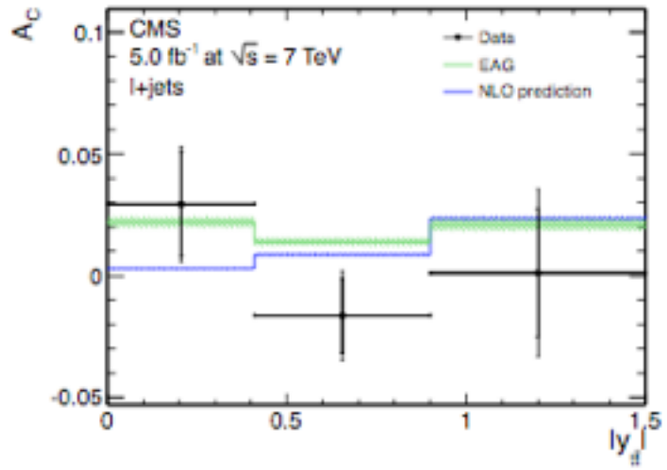
$A_C = 0.004 \pm 0.010\ (\text{stat.}) \pm 0.011\ (\text{syst.})$

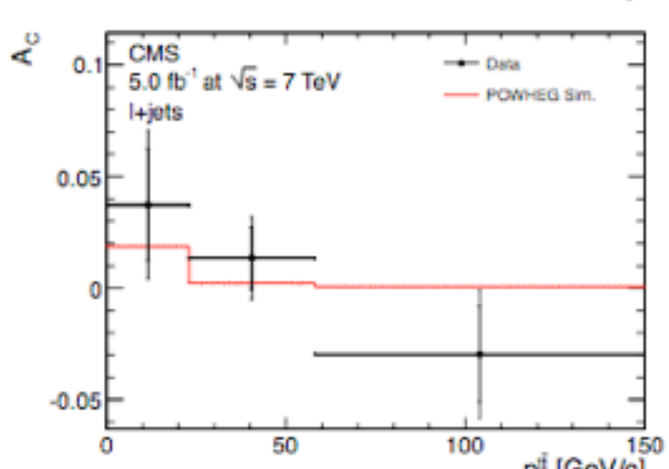
PLB 717 (2012) 129

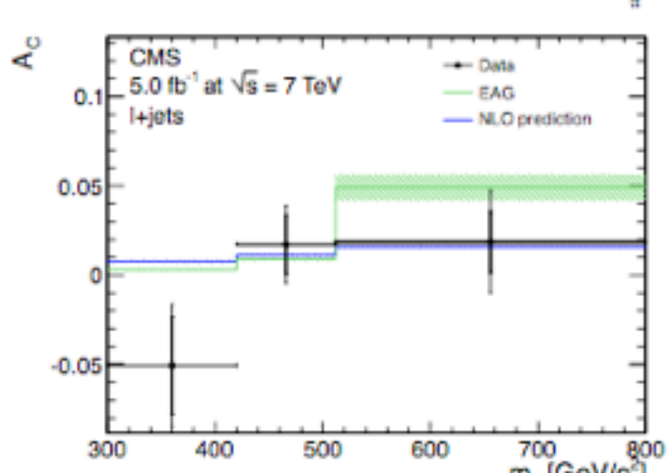
➔ addition differential measurements

vs M(ttbar), y(ttbar), pt(ttbar)









Charge asymmetry in the dilepton channel

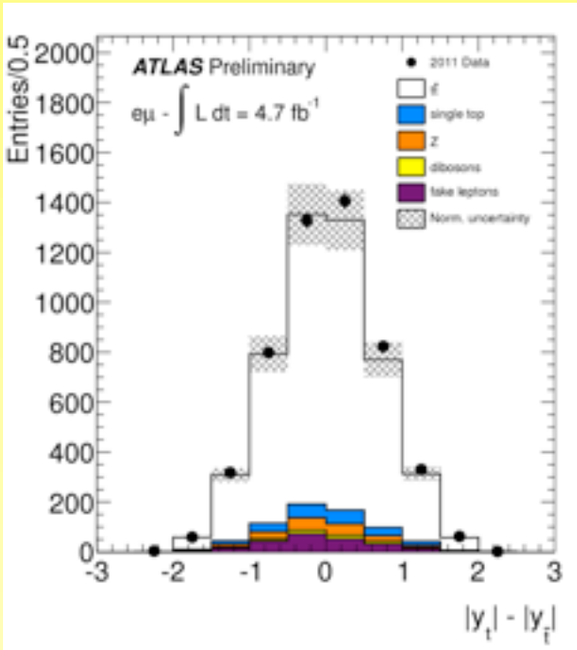
Saclay, Strasbourg

- ATLAS result with 4.7 fb^{-1} (7 TeV)

  ➔ $t\bar{t}$-based and lepton-based inclusive and unfolded

$$A_C^{t\bar{t}} = 0.057 \pm 0.024\,(\text{stat.}) \pm 0.015\,(\text{syst.})$$
$$A_C^{\ell\ell} = 0.023 \pm 0.012\,(\text{stat.}) \pm 0.008\,(\text{syst.})$$

ATLAS-CONF-2012-057



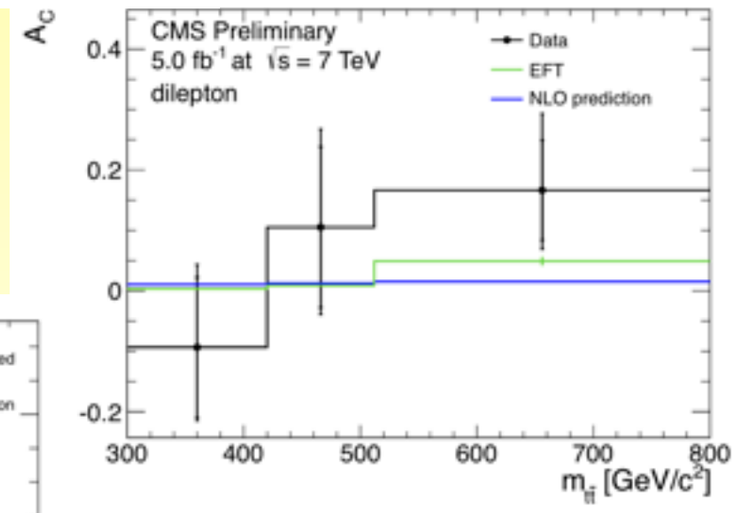
- CMS result with 5 fb^{-1} (7 TeV)

  ➔ inclusive (unfolded): $A_C^{t\bar{t}} = 0.050 \pm 0.043(\text{stat})^{+0.010}_{-0.039}(\text{syst})$

$$A_C^{\ell\ell} = 0.010 \pm 0.015(\text{stat}) \pm 0.006\ (\text{syst})$$

CMS-PAS-TOP-12-010

  ➔ differential measurements vs M($t\bar{t}$), y($t\bar{t}$), pt($t\bar{t}$)



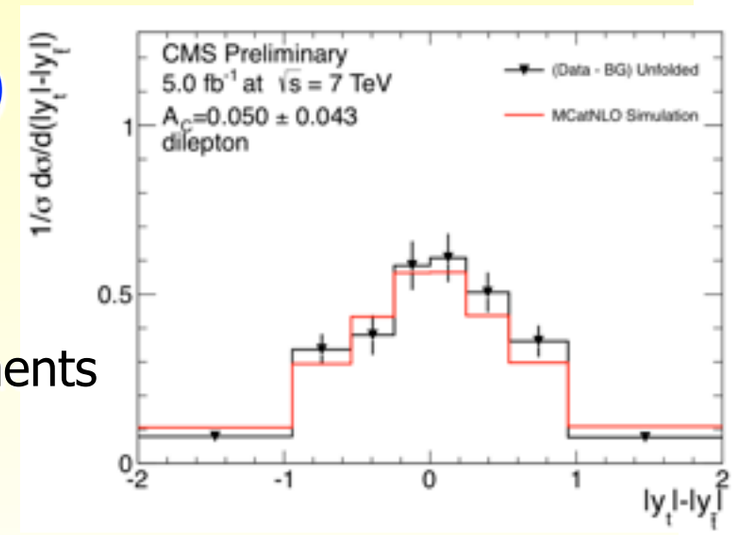
- perspectives (lepton+jets and dilepton)

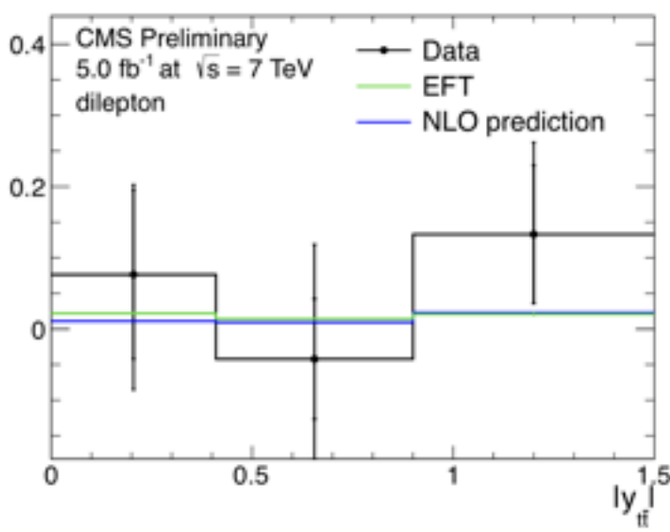
  ➔ goal: get sensitive to the SM prediction with 8 TeV data

  ➔ more statistics for differential measurements

  ➔ collider independent observable,

  2D measurements, measurements in specific phase space, ...





Conclusion

- Large implication of the french groups into top quark property measurements

  ➔ using the $t\bar{t}$ final state: W helicity, polarization, spin correlations, asymmetries

- 8 TeV property analyses on-going

  ➔ unprecedent probe of the top quark sector expected

- longer term perspectives (13 TeV)

➔ a lot of french groups are moving to direct searches in the top quark sector