$t\bar{t}$ Asymmetry and Top Polarization at ATLAS

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Outline

- My group

- $t\bar{t}$ asymmetries

- Top polarization

- Conclusion & Outlook

My Group

- YIG "Approaching the fundaments of physics using top quarks at the LHC"

  - Started in July 2012

  - YIG Leader: Yvonne Peters

- Post-Doc: Cécile Deterre (since September 2012)

- 1st PhD Student: Ralph Schäfer (since October 2012)

- Desy Fellow joining our team: Sara Borroni
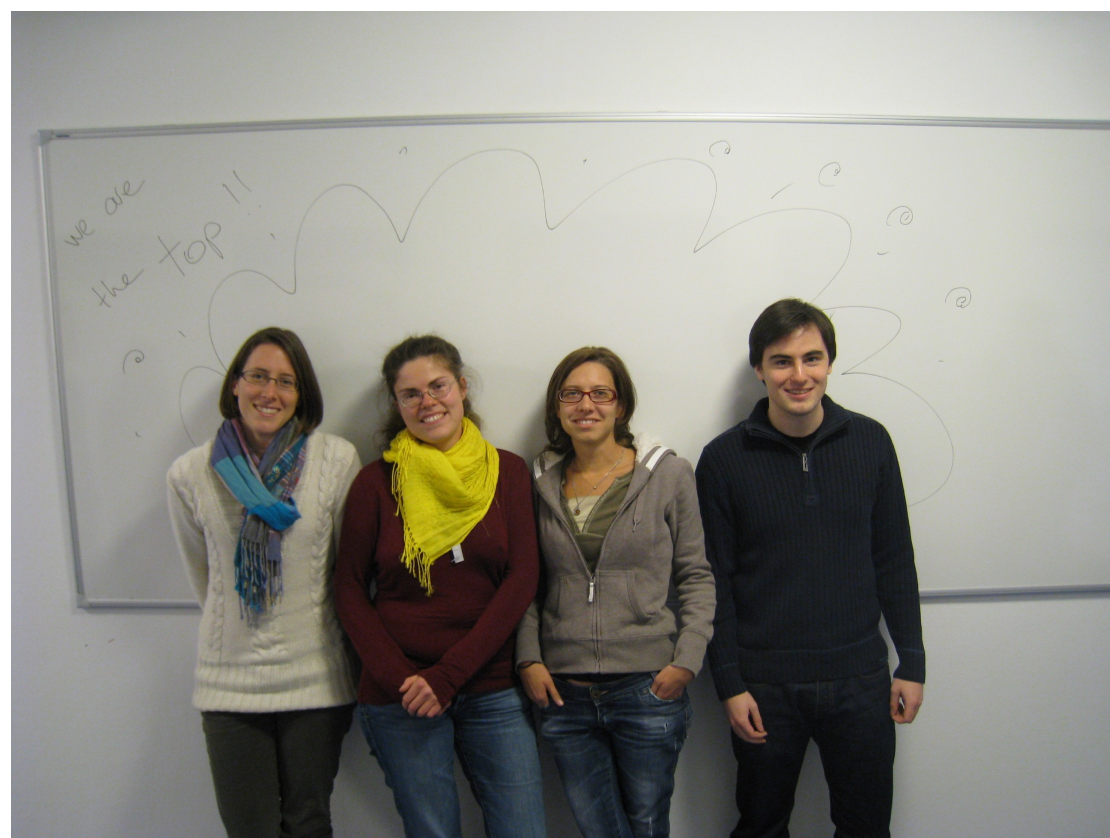
Analyses we (plan to) do

- $t\bar{t}$ spin correlation in dilepton

    - Just me → won't cover here

- $t\bar{t}$ asymmetry in dilepton

    - Cécile's thesis topic – plan to stay involved and expand

- Top quark polarization in dilepton

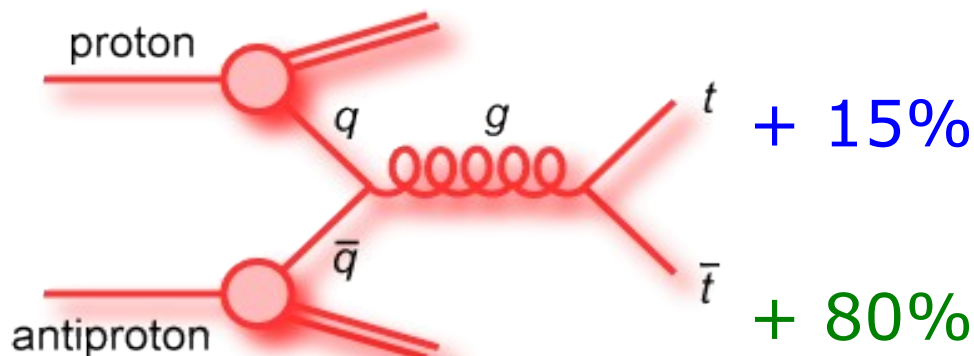   - Were involved in preliminary for Top2012 in l+jets final state

t̄t Asymmetry

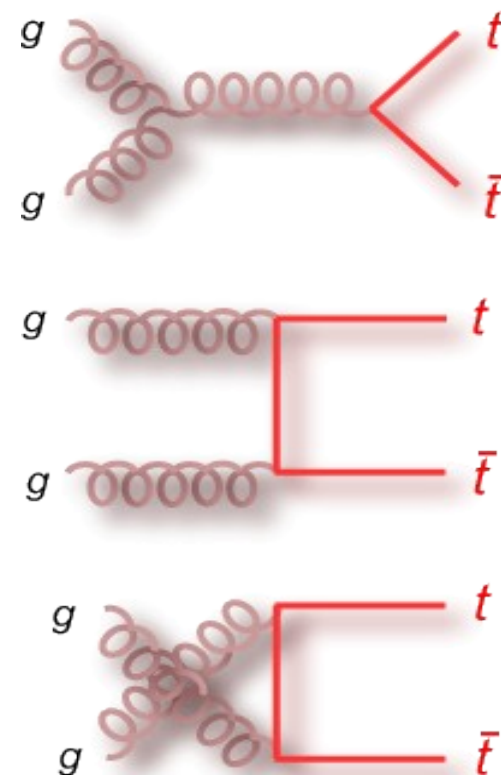# tt̄ Production at Tevatron and LHC

- tt̄ production via strong interaction

- **At Tevatron:**

      85%   + 15%

- **At LHC:**
  7 TeV: 20%   + 80%

- Production cross section (@Tevatron):
  NNLO+NNLL: $\sigma = 7.24^{+0.23}_{-0.27}\, pb$ @ $m_t = 172.5$ GeV

  Baernreuther, Cakon, Mitov, PLB 710, 612 (2012)

- **20 times higher @LHC** (7TeV):

  $$\sigma = 164.6^{+11.4}_{-15.7}\, pb$$

t$\bar{t}$ Production at Tevatron and LHC

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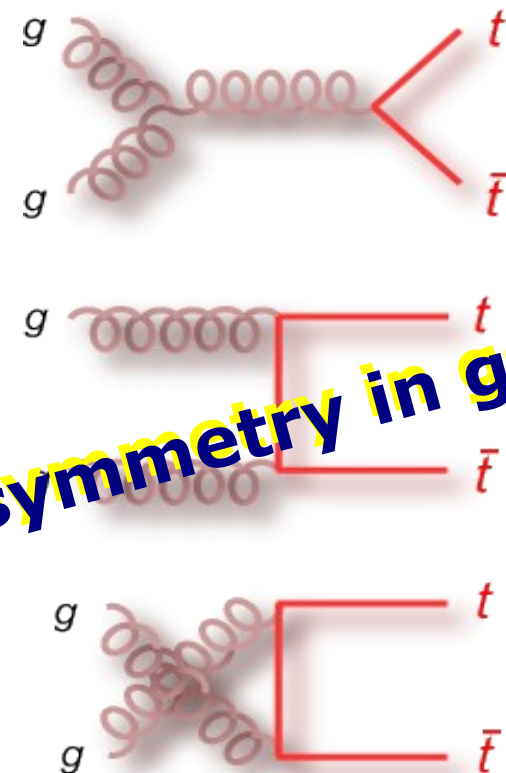 *Asymmetry in q$\bar{q}$*

  No asymmetry in gg

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Final States in tt̄

$B(t \rightarrow W^+ b) = 100\%$

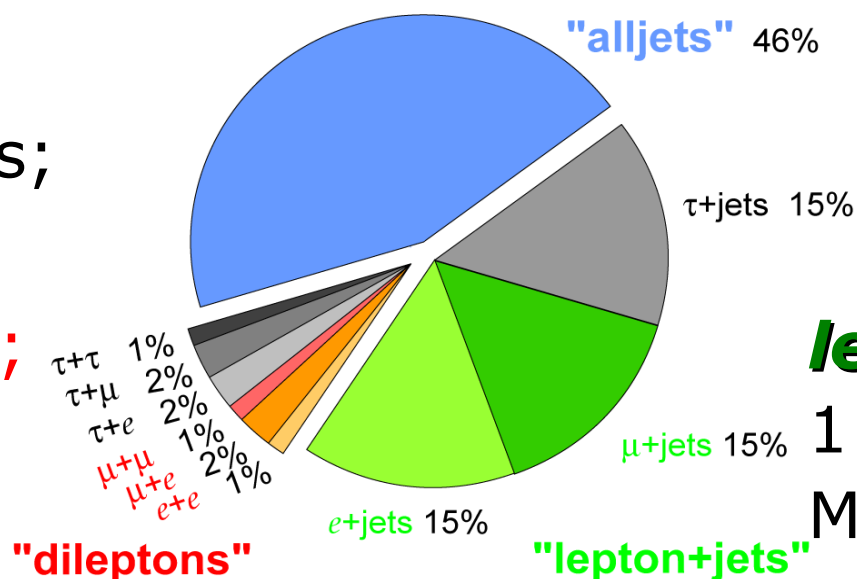$t\bar{t} \rightarrow W^+ b W^- \bar{b}$: Final states are classified according to W decay

pure hadronic:
≥6 jets (2 b-jets)

Top Pair Branching Fractions

dilepton:
2 isolated leptons;
High missing E_T

from 2 neutrinos;
2 b-jets

lepton+jets:
1 isolated lepton;
Missing E_T from neutrino;
≥4 jets (2 b-jets)

Final States in t$\bar{\text{t}}$

B(t→W⁺b)=100%

t$\bar{\text{t}}$→W⁺bW⁻$\bar{\text{b}}$: Final states are classified according to W decay

pure hadronic:
≥6 jets (2 b-jets)

Top Pair Branching Fractions

"alljets" 46%

τ+jets
μ+jets 15%
e+jets 15%
τ+τ 1%
τ+e 2%
e+e 1%

"dileptons"

"lepton+jets"

Asymmetry measurements in lepton+jets and dilepton final states

dilepton:

2 isolated leptons;
High missing E_T

from 2 neutrinos;
2 b-jets

lepton+jets:

1 isolated lepton;
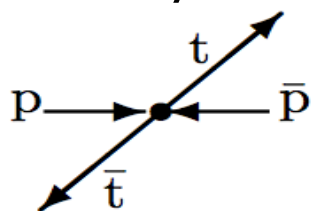Missing E_T from neutrino;
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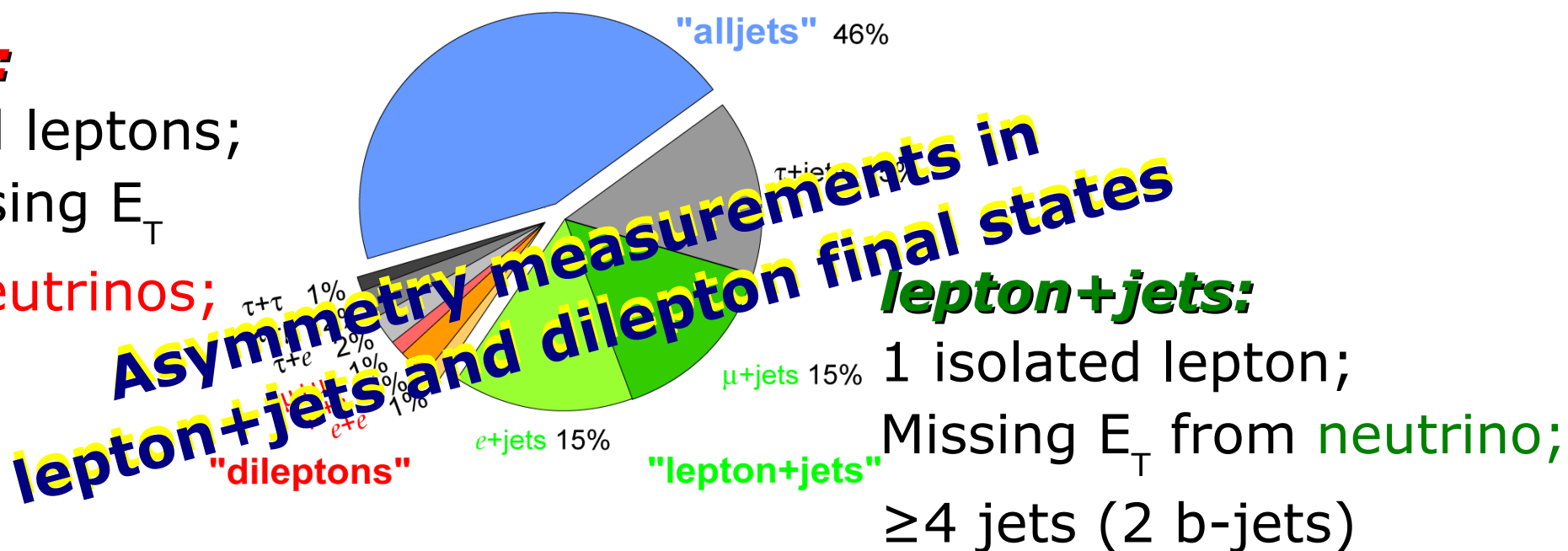
Asymmetry Idea

- LO: No charge asymmetry expected

- NLO QCD: Interference between q$\bar{\text{q}}$ diagrams

  - Asymmetry in QCD:Interference of C=1 and C=-1 amplitudes are odd under t $\leftrightarrow$ $\bar{\text{t}}$ $\rightarrow$ cause asymmetry
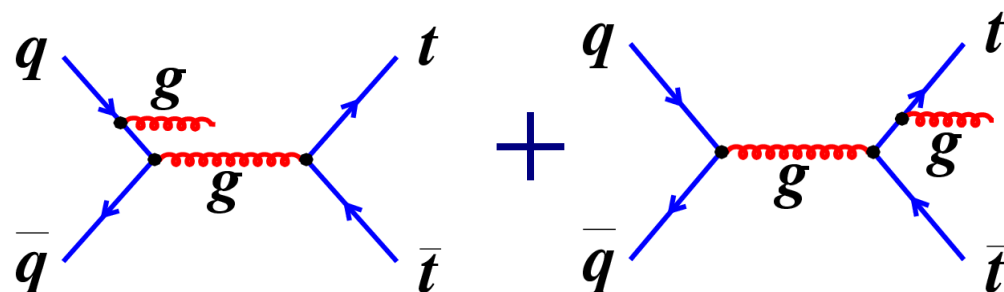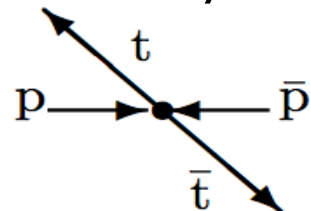
- **Tree level and box diagrams:**

  - Positive asymmetry
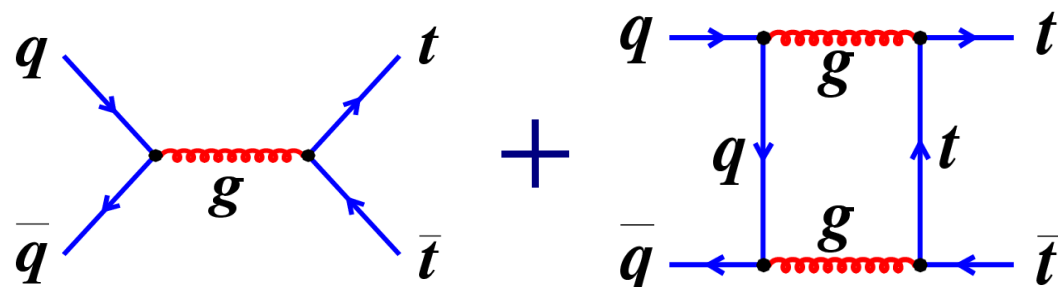
- **Initial and final state radiation:**
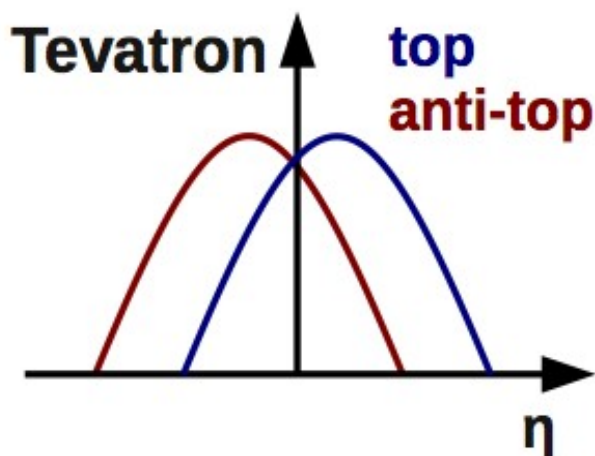
  - Negative asymmetry

- Tevatron: p$\bar{\text{p}}$ is CP eigenstate → pp (LHC) is not
  → different way to measure the effect at Tevatron and LHC

- LHC: Quarks valence quarks, antiquark always from the sea
  → antitop less boosted and more central than top in case of asymmetry

- LHC: Measure charge asymmetry

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

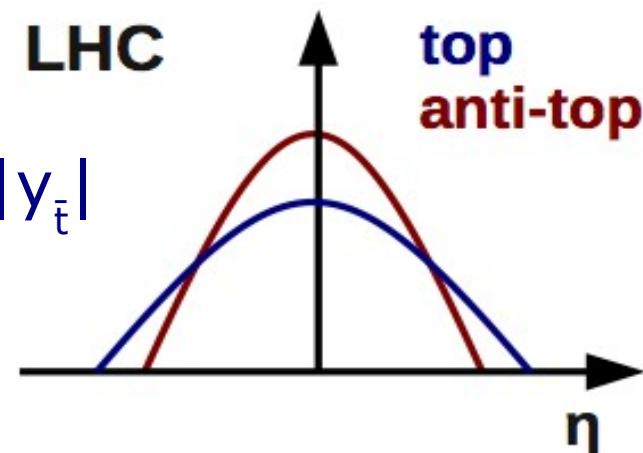$$A_C = \frac{N(\Delta |y| > 0) - N(\Delta |y| < 0)}{N(\Delta |y| > 0) + N(\Delta |y| < 0)}$$

Tevatron   LHC

$\Delta y = y_t - y_{\bar{t}}$ $\Delta |y| = |y_t| - |y_{\bar{t}}|$

$$y = \frac{1}{2} \ln\left(\frac{E + p_z}{E - p_z}\right)$$
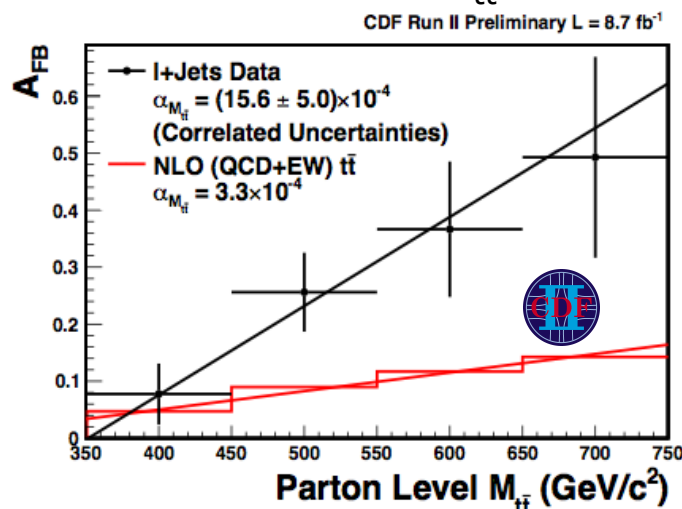
Tevatron Results

- D0 and CDF: asymmetry larger than SM prediction has been measured

    CDF: $A_{FB}^{t\bar{t}} = 16.2 \pm 4.7\%$

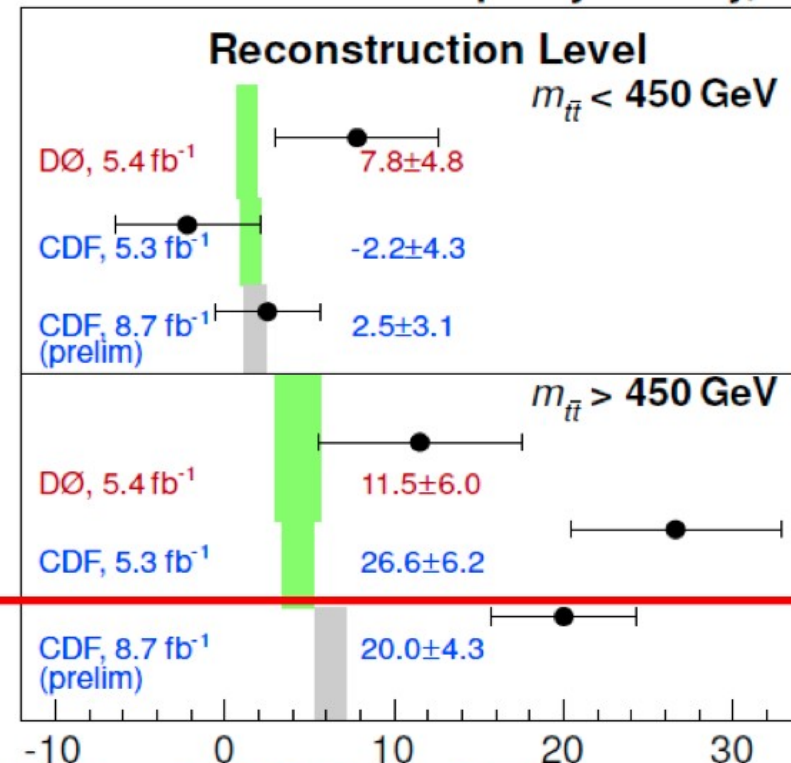   (NLO (QCD+EW) prediction: 6.6%)
    DØ: $A_{FB}^{t\bar{t}} = 19.6 \pm 6.5\%$

- CDF saw dependence on $m_{t\bar{t}}$

CDF Run II Preliminary L = 8.7 fb⁻¹

l+Jets Data
$\alpha_{M_{t\bar{t}}} = (15.6 \pm 5.0) \times 10^{-4}$
(Correlated Uncertainties)
NLO (QCD+EW) $t\bar{t}$
$\alpha_{M_{t\bar{t}}} = 3.3 \times 10^{-4}$

Parton Level $M_{t\bar{t}}$ (GeV/c²)

- Measurement performed at LHC
  → deviation?

Forward-Backward Top Asymmetry, %

Reconstruction Level $m_{t\bar{t}} < 450$ GeV

DØ, 5.4 fb⁻¹   7.8±4.8

CDF, 5.3 fb⁻¹   -2.2±4.3

CDF, 8.7 fb⁻¹   2.5±3.1
(prelim)

                                    $m_{t\bar{t}} > 450$ GeV

DØ, 5.4 fb⁻¹   11.5±6.0

CDF, 5.3 fb⁻¹   26.6±6.2

CDF, 8.7 fb⁻¹   20.0±4.3
(prelim)

~2.8 SD to NLO inc. QED corr.

LHC Results dilepton

- **Inclusive** measurements:

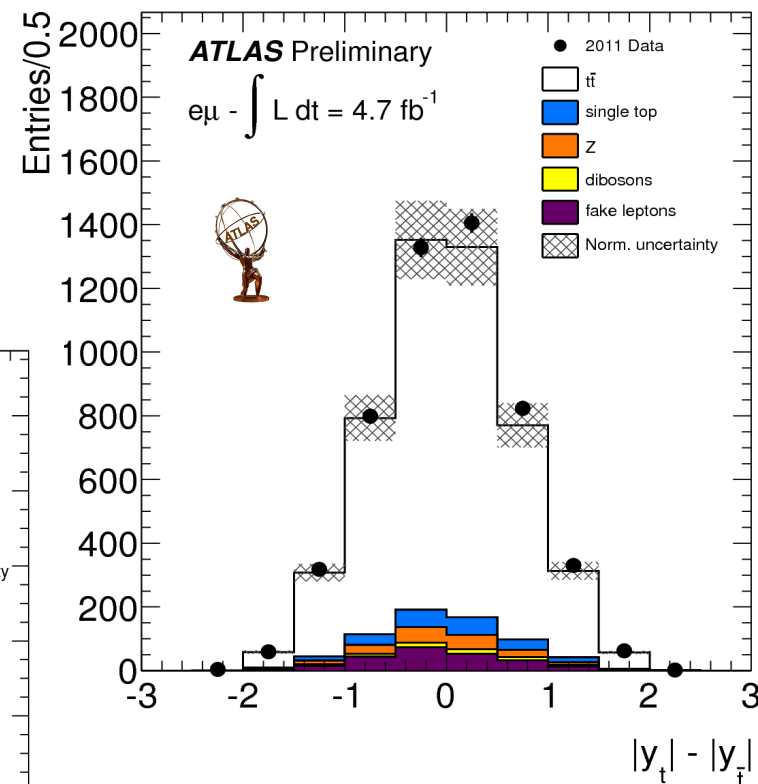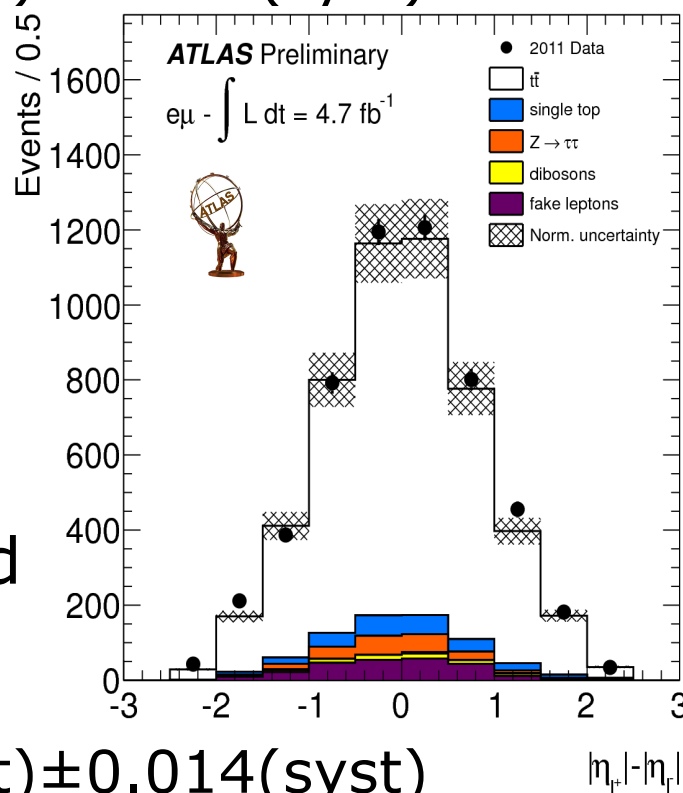 - $A_C^{ll} = 0.023 \pm 0.012 \text{(stat)} \pm 0.008 \text{(syst)}$

    - MC@NLO prediction: 0.004 ± 0.001

  - $A_C = 0.057 \pm 0.024 \text{(stat)} \pm 0.015 \text{(syst)}$

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

- **Combination** of Atlas A_C results in l+jets and dilepton final state

  - $A_C = 0.029 \pm 0.018 \text{(stat)} \pm 0.014 \text{(syst)}$

Systematics Atlas dilepton

- Main systematic uncertainties:

| Signal and background modeling	ee	eμ	μμ
Signal generator	0.011	0.003	0.002
ISR and FSR	0.004	0.004	0.006
Parton shower/fragmentation	0.001	0.004	0.003
PDF	<0.001	<0.001	<0.001
Z+jets	0.005	0.004	0.001
Diboson	<0.001	<0.001	<0.001
Single top	<0.001	<0.001	<0.001
Multijet background	0.014	0.002	<0.001
Detector modeling			
Jet efficiency and resolution	0.008	0.001	0.003
Jet energy scale	0.006	0.001	0.002
Muon efficiency and resolution	<0.001	0.001	0.002
Electron efficiency and resolution	0.005	0.003	<0.001
Calibration	0.019	0.002	0.004
Luminosity	0.002	<0.001	<0.001
Total	0.029	0.009	0.009

Table 4: List of all systematic uncertainties on the lepton-based asymmetry.

| Signal and background modeling	ee	eμ	μμ
Signal generator	0.014	0.009	0.002
ISR and FSR	0.008	0.002	0.018
Parton shower/fragmentation	0.001	0.001	0.001
PDF	0.001	<0.001	<0.001
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Single top	<0.001	<0.001	<0.001
Multijet background	0.012	0.010	0.001
Detector modeling			
Jet efficiency and resolution	0.007	0.001	0.005
Jet energy scale	0.003	0.002	0.006
Muon efficiency and resolution	0.004	0.003	0.005
Electron efficiency and resolution	0.013	0.006	0.002
Calibration	0.004	0.001	0.002
Luminosity	<0.001	0.001	<0.001
Total	0.028	0.017	0.021

Table 5: List of all systematic uncertainties on the $t\bar{t}$-based asymmetry.

LHC Results

- Results at LHC (CMS+ATLAS; l+jets and dilepton) so far compatible with SM calculation

- Preliminary result for dilepton asymmetry

  - Systematic uncertainties similar to statistical

  - Both uncertainties pretty large compared to prediction

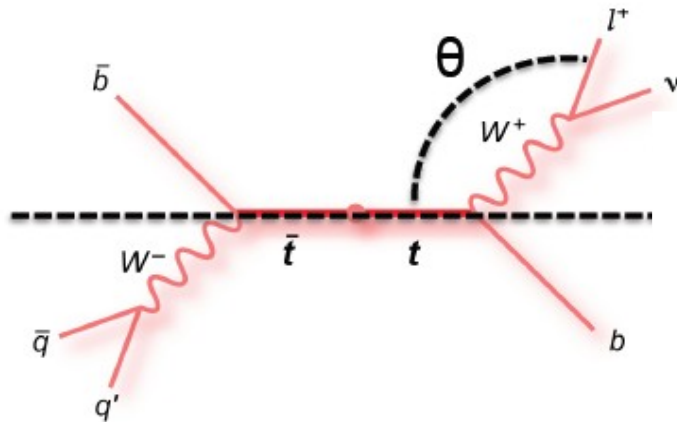- Many models predicting large asymmetry at the Tevatron, also predict top polarization !=0
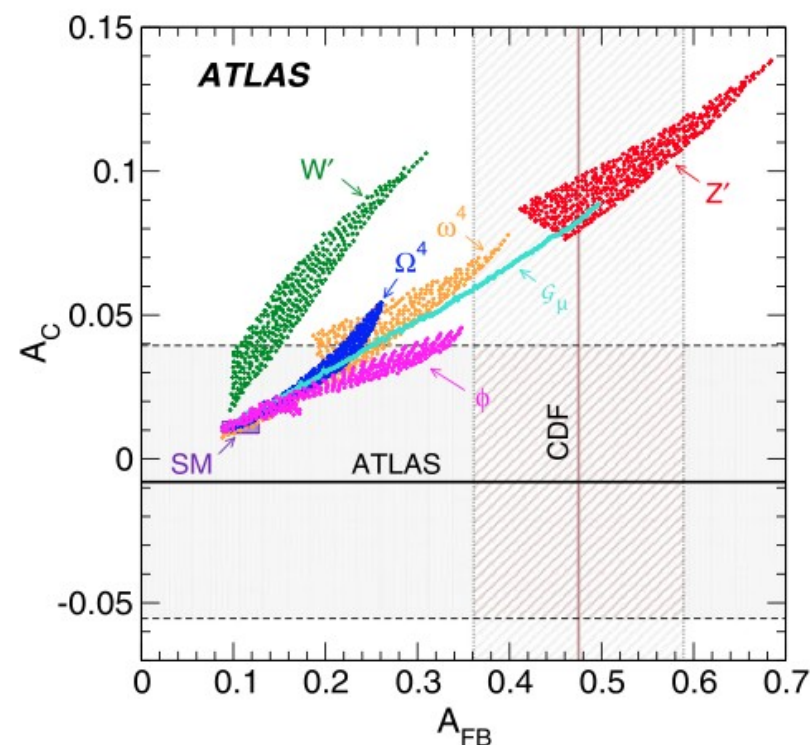
Top Polarization
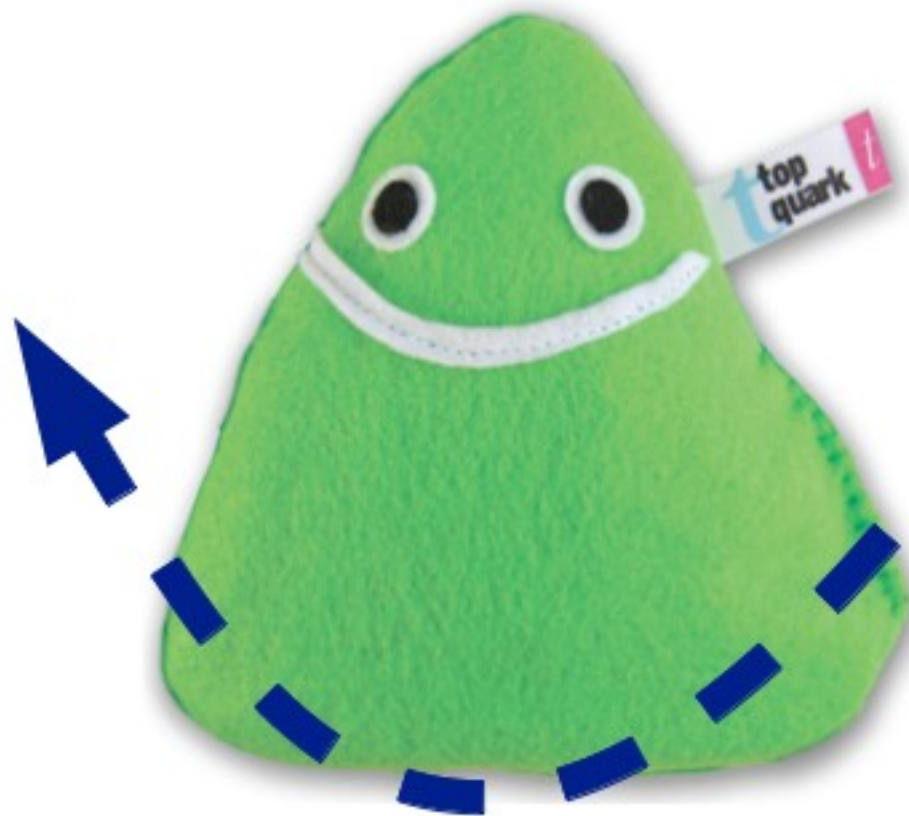
Top Polarization

- Various BSM models predicting asymmetry>SM, predict also top polarization !=0

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{i,n}} = \frac{1}{2}\left(1 + \mathcal{P}_n\kappa_i\cos\theta_{i,n}\right)$$

P_n: polarization; κ_i: spin analyzing power of decay product i;

θ_i : angle between daughter direction in top rest frame and chosen axis (e. g. helicity: top direction in $t\bar{t}$ rest frame)

Top Polarization

- First study done by DØ: good agreement with SM at reconstruction level

  - Reconstruction done with neutrino weighting

  - Plots are at Reco level
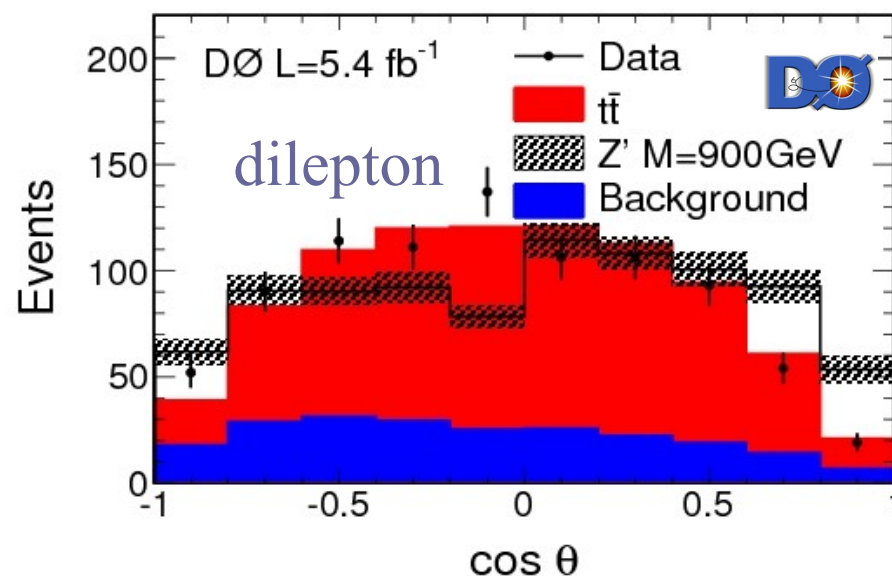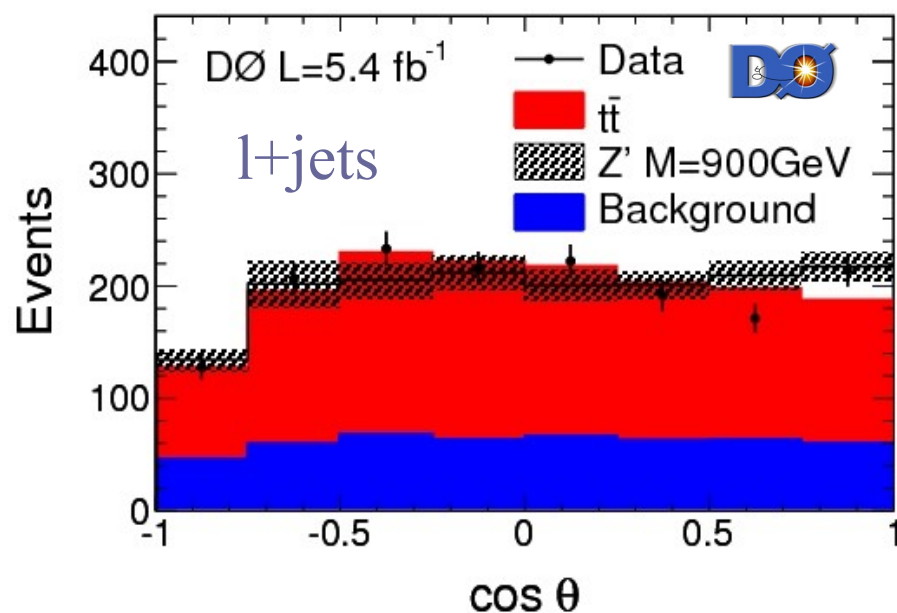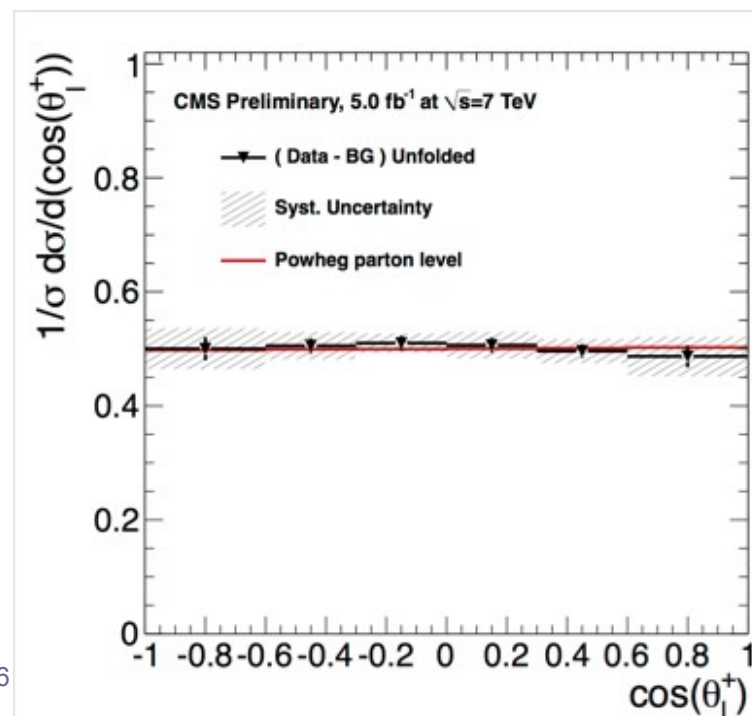

arXiv:1207.0364[hep-ex]

Top Polarization

- Atlas and CMS did first measurements of P_n

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

- CMS: dilepton final state

  - Reconstruction with matrix weighting technique

  - Extraction of P_n using unfolding technique

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

CMS Preliminary, 5.0 fb^{-1} at $\sqrt{s}$=7 TeV

(Data - BG) Unfolded
Syst. Uncertainty
Powheg parton level

CMS PAS TOP-12-016

Top Polarization

- Atlas: l+jets final state

  - $t\bar{t}$ reconstruction using kinematic fit

  - Extraction of P_n using template fit

    - Get +1 and -1 templates by reweighting at truth level

      - Fit fraction of positive polarization ($\kappa\, P_n = 1-2f$)

- $f = 0.470 \pm 0.009(\text{stat})^{+0.023}_{-0.032}(\text{syst})$

  $\rightarrow \kappa\, P_n = -0.060 \pm 0.018(\text{stat})^{+0.046}_{-0.064}(\text{syst})$

- Results systematics limited (JES, top mass)

- Both CMS and Atlas results show good agreement with SM prediction
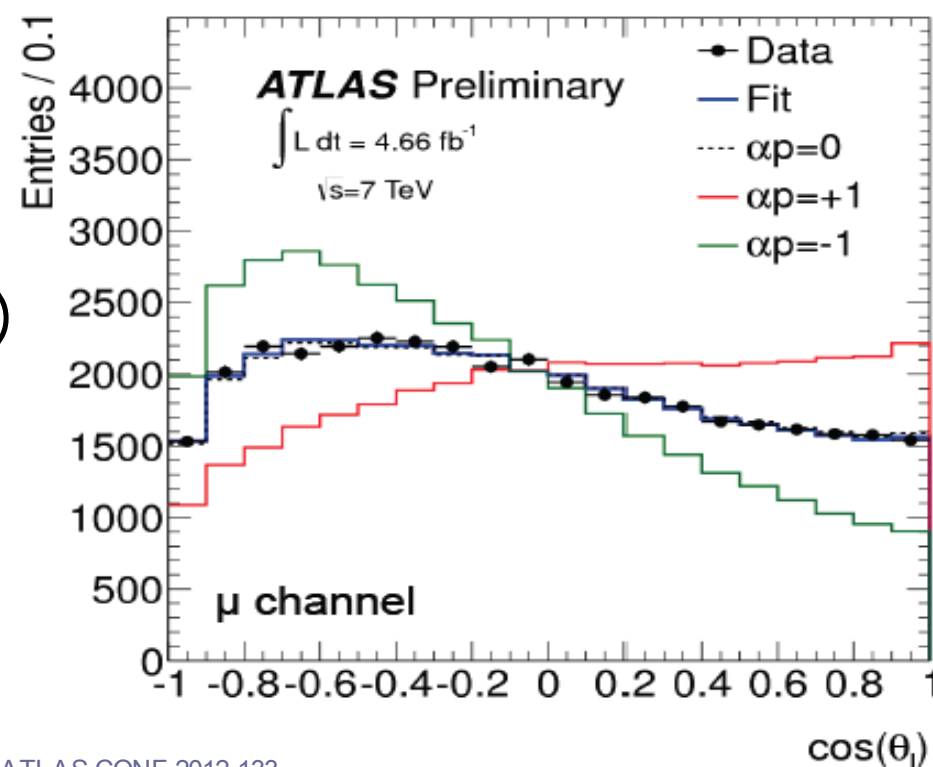
ATLAS-CONF-2012-133

Summary

- YIG just started

  - Cécile and me already having been involved in part of our analysis plans

  - Awesome team - ramping up fast 8-)

- $t\bar{t}$ asymmetry: work ongoing on 7TeV analysis

  - Work on unfolding ongoing

- Top polarization:

  - Concentrate on $t\bar{t}$ reconstruction studies right now

    - performing performance studies

  - What about MC? We would need MC with polarization information of the top quark