Indirect Search in the ttbar final state

(polarization, spin, asymmetries, differential distributions)

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W polarization

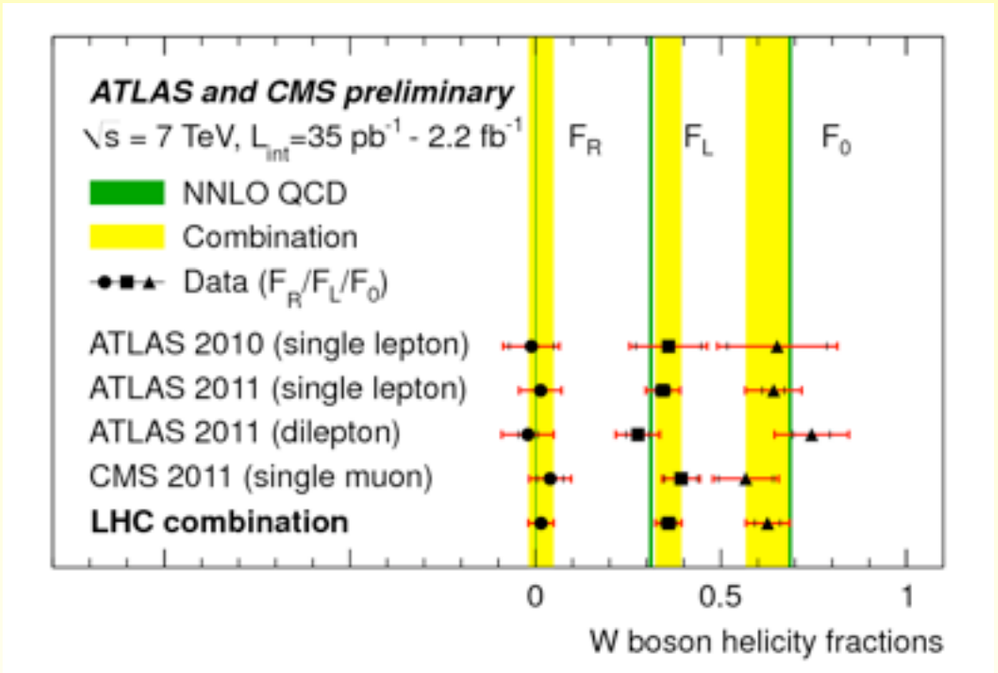
$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta^*} = \frac{3}{8}(1+\cos\theta^*)^2 F_R + \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{4}\left(1-\cos^2\theta^*\right) F_0$$

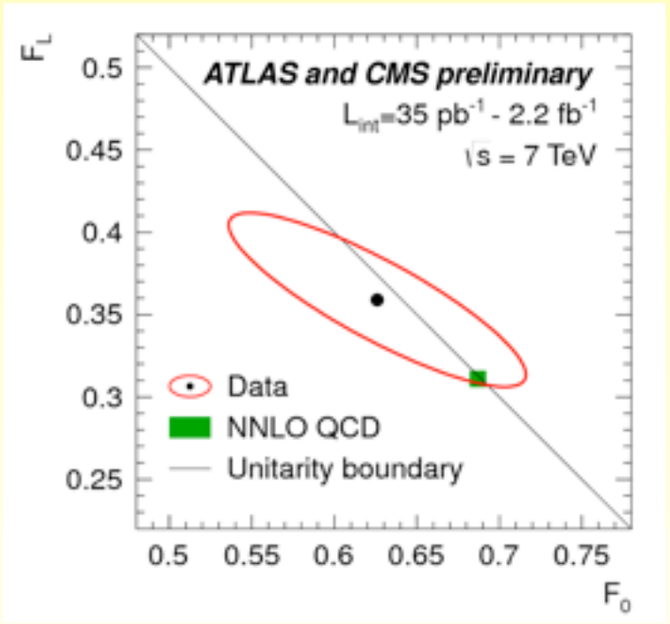
- ATLAS and CMS 7 TeV measurements combined with BLUE
  - ➔ ATLAS lepton+jets 35 pb^{-1}, lepton+jets, dilepton 1.0 fb^{-1}
  - ➔ CMS single muon channel 2.2 fb^{-1}
- in agreement with the NNLO predictions

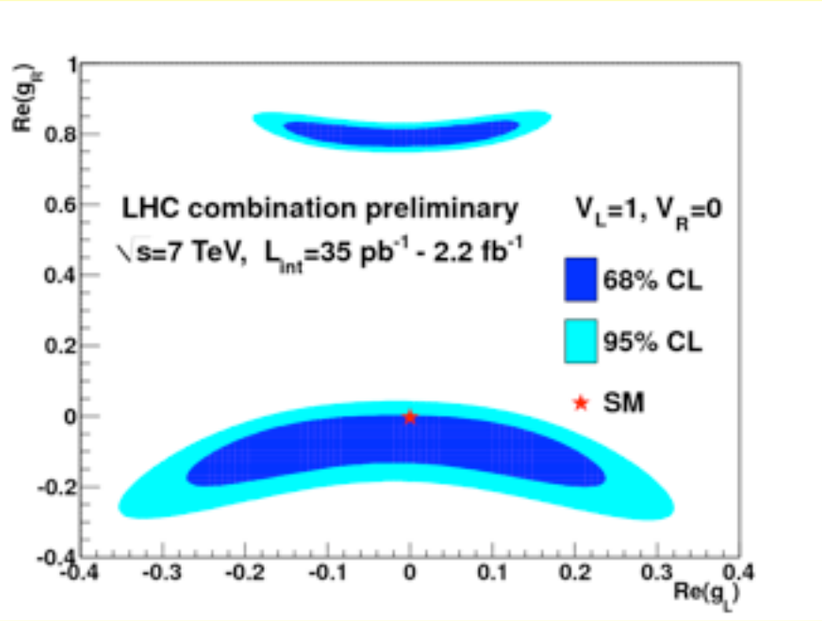
results:

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

Measurement	Coefficient [%] w_{F_0}	w_{F_L}
F_0 ATLAS 2010 (single lepton)	12.2	7.4
F_L ATLAS 2010 (single lepton)	19.0	11.6
F_0 ATLAS 2011 (single lepton)	39.5	- 8.4
F_L ATLAS 2011 (single lepton)	-16.0	35.4
F_0 ATLAS 2011 (dilepton)	13.0	2.8
F_L ATLAS 2011 (dilepton)	4.9	15.2
F_0 CMS 2011 (single lepton)	35.4	- 1.8
F_L CMS 2011 (single lepton)	- 7.9	37.8
Total weight:	100.0	100.0





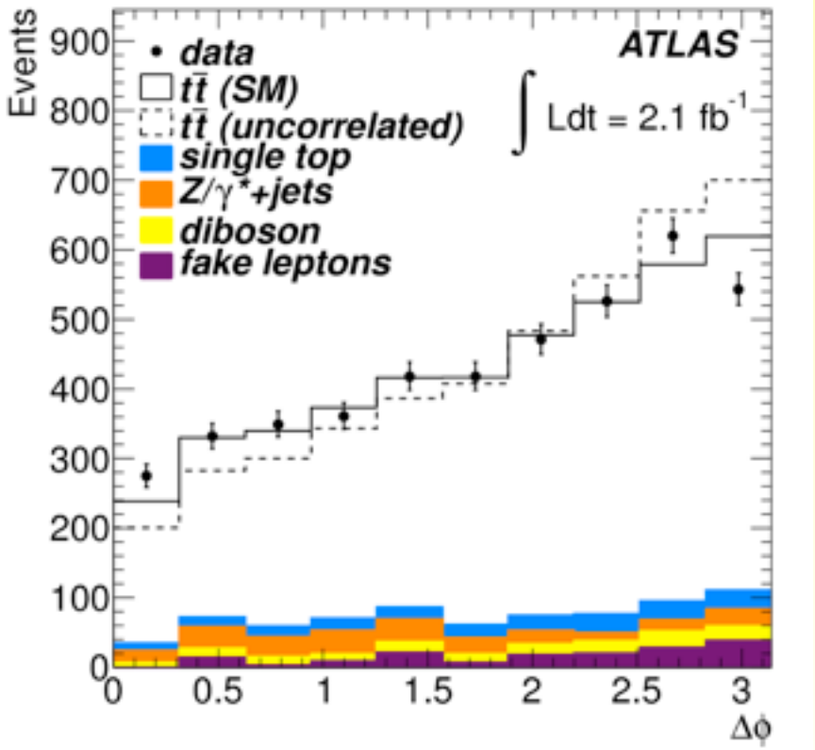


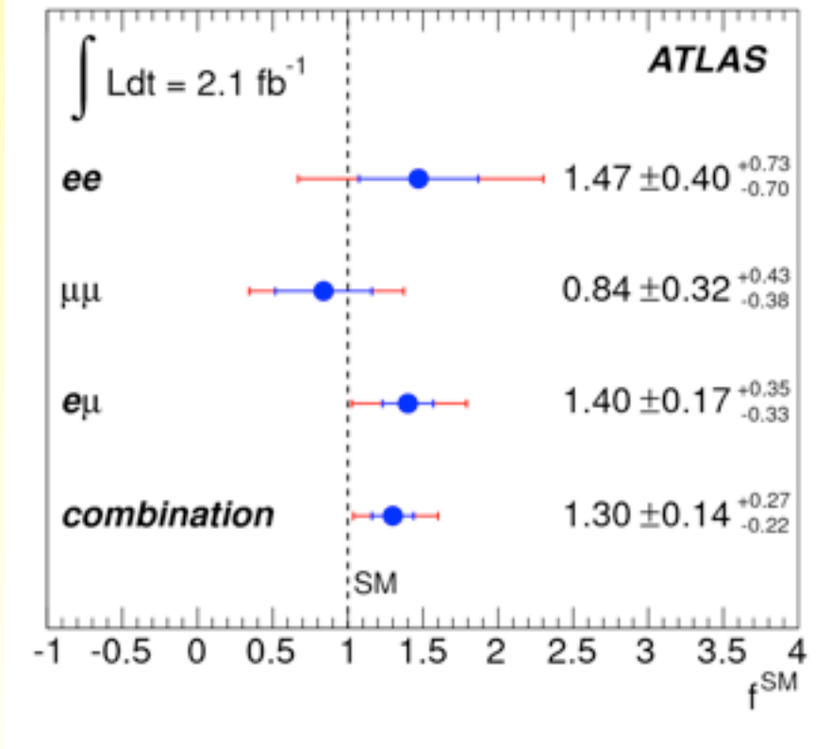
- next steps ?
  - ➔ combination with Tevatron

Spin correlation measurement in ATLAS

- top-antitop spins are produced correlated
- top decays before hadronizing
  - ➔ the angles of its decay products carry informations about the top quark spin
  - ➔ degree of correlation: $A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)}$ $A^{SM}_{hel} = 0.31$
  - ➔ can be extracted from $\Delta\Phi(l^+,l^-)$ in the lab frame with a choice of basis

result: fraction of SM = $1.30 \pm 0.14\ (\text{stat})\ ^{+0.27}_{-0.22}\ (\text{syst})$



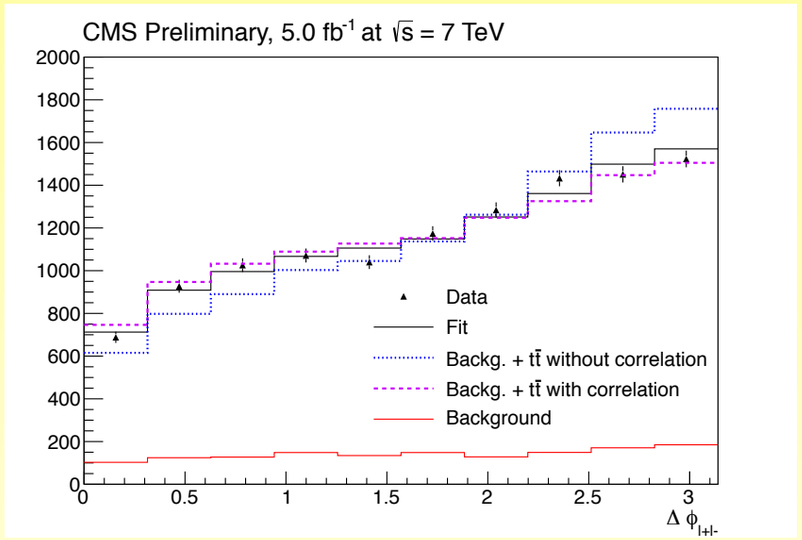


Uncertainty source	Δf^{SM}
Data statistics	±0.14
MC simulation template statistics	±0.09
Luminosity	±0.01
Lepton	±0.01
Jet energy scale, resolution and efficiency	±0.12
NLO generator	±0.08
Parton shower and fragmentation	±0.08
ISR/FSR	±0.07
PDF uncertainty	±0.07
Top quark mass	±0.01
Fake leptons	+0.16/−0.07
Calorimeter readout	±0.01
All systematics	+0.27/−0.22
Statistical + Systematic	+0.30/−0.26

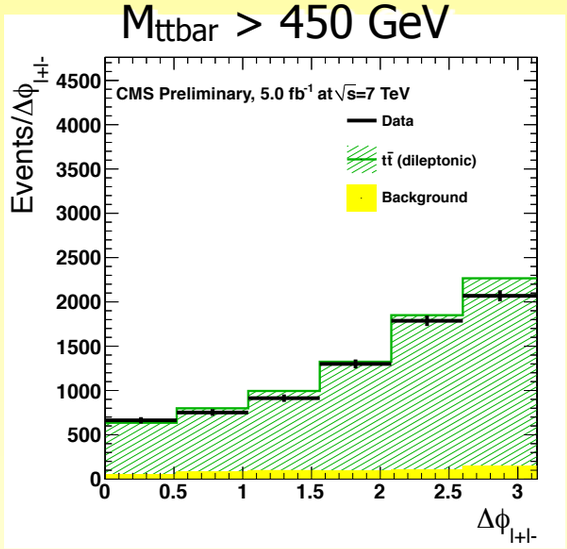
Spin correlation measurement in CMS

- CMS 5 fb^{-1} dilepton result (7 TeV)
  - ➔ result in agreement with SM predictions: $f_{SM} = 0.74 \pm 0.08(\text{stat.}) \pm 0.24(\text{syst.})$.
  - ➔ include measurements of some related asymmetry variables at high M_{ttbar}

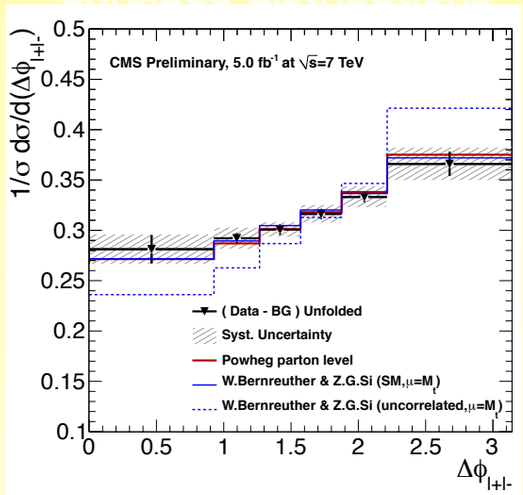
uncertainty Δf	absolute	relative (%)
statistic uncertainty	0.08	11%
MC stat uncertainty	0.07	9%
	experimental	
Lepton selection	0.01	1%
Lepton energy scale	0.01	1%
JES/JER	0.02	3%
all backgrounds	0.07	9%
PU	0.02	3%
b-tagging	0.01	1%
	$t\bar{t}$ modelling	
FastSim vs FullSim	0.06	8%
Fact. and renorm. scales	0.15	20%
τ decay	0.12	16%
top mass	0.02	3%
PDF	0.07	9%

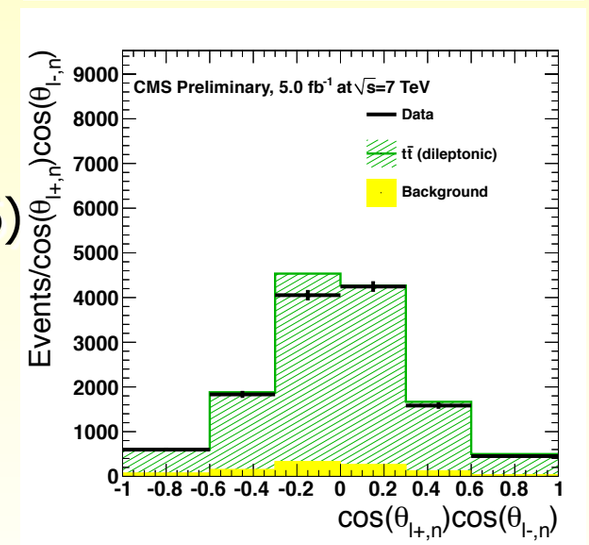


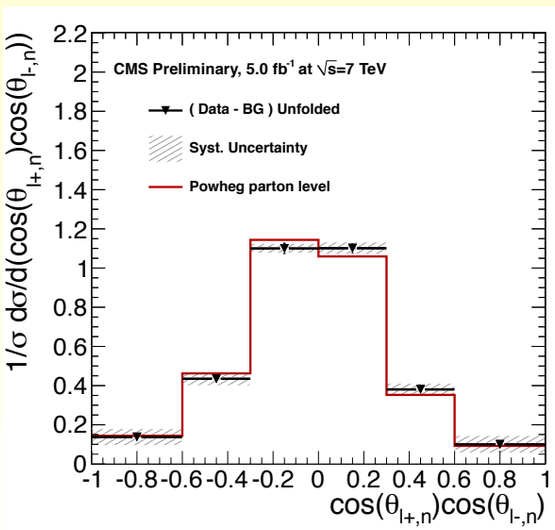
M_{ttbar} > 450 GeV



unfolded distributions







- next steps ?
  - ➔ differential measurements (arXiv: 1003.3926)
  - ➔ other observables (arXiv: 1212.4888)

Polarization in ATLAS

- In QCD, the top quark in ttbar production are produced unpolarized
- Polarization can be measured through the angular distributions of the top decay products
- ATLAS 4.7 fb^{-1} result (7 TeV) in the lepton+jets channel

➔ using the lepton angle in the helicity basis

$$W(\cos\theta_i) \propto 1 + \alpha_i p \cos\theta_i,$$

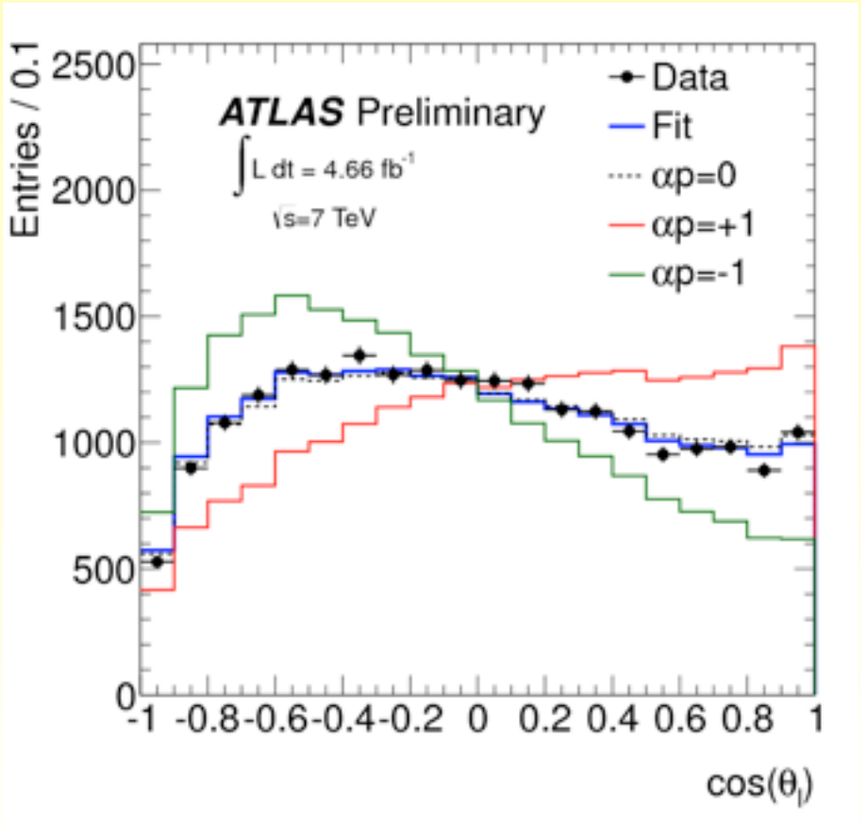
$$f = \frac{1}{2} + \frac{N(\cos\theta_l > 0) - N(\cos\theta_l < 0)}{N(\cos\theta_l > 0) + N(\cos\theta_l < 0)}$$

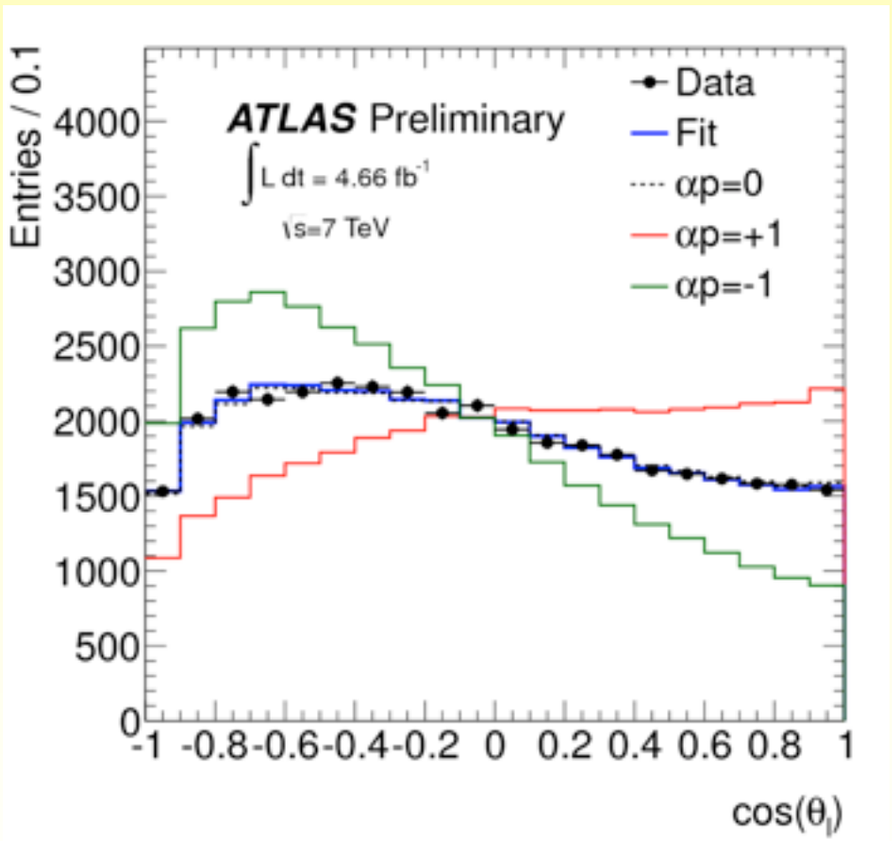
$$\alpha_\ell p = 2f - 1.$$

α_l: spin analysis power

$$\alpha_\ell p = -0.060 \pm 0.018(\text{stat})^{+0.046}_{-0.064}(\text{syst}).$$

compatible with the expectation of p=0, f=0.5

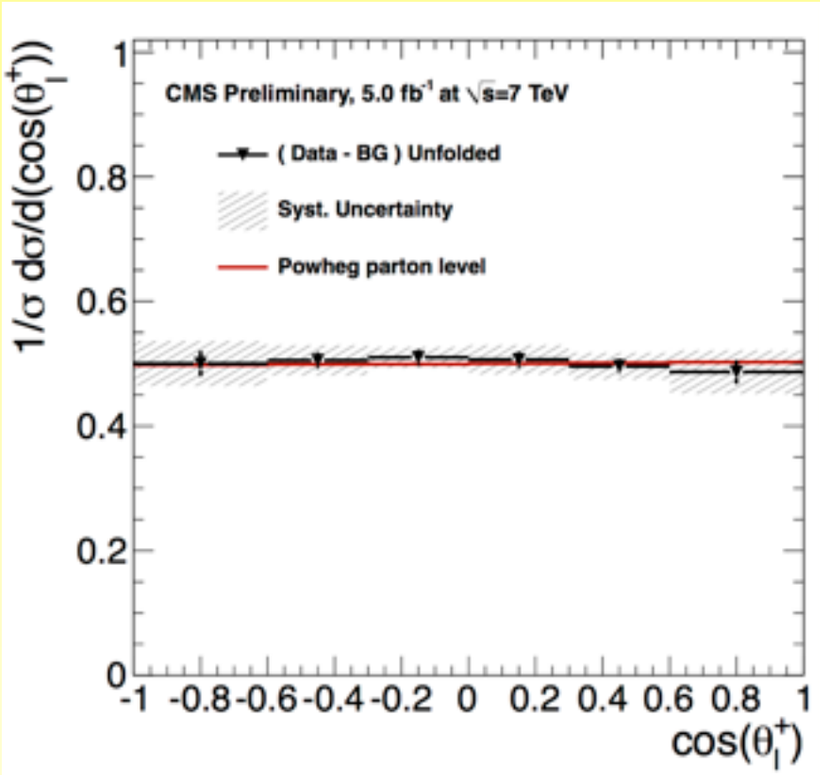




Polarization in CMS

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

  ➔ using the lepton angle in the helicity basis



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

unfolded:

$$P_n = -0.009 \pm 0.029 \pm 0.041$$

compatible with the expectation of Pn=0

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	0.005	0.002	0.041

- next steps ?

  ➔ more statistics

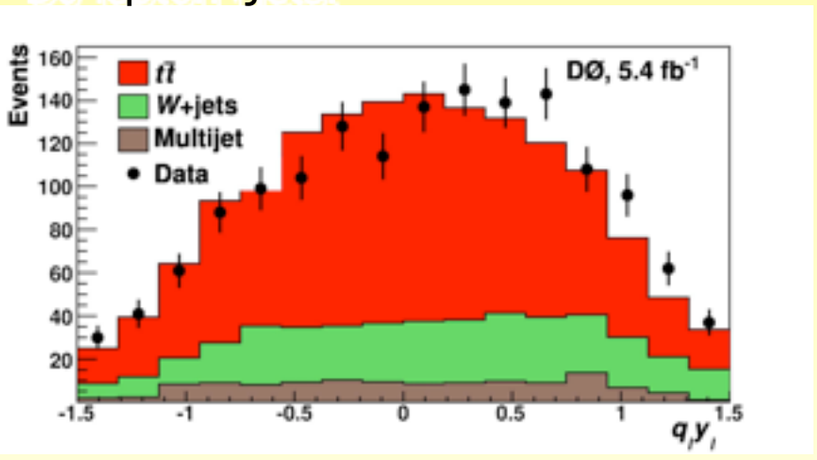
  ➔ BSM model exclusion

  ➔ ...

ttbar asymmetry at the Tevatron

- forward-backward asymmetry (dominated by qqbar -> ttbar)
  - ➔ top based or lepton based: $A_{\rm FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$
- some excess compared to SM predictions
  - ➔ D0 lepton+jets, 5.4 fb^{-1}: ~ 3σ in the lepton based asymmetry, no mass dependence
  - ➔ D0 dilepton, 5.4 fb^{-1}: $A^{\ell}_{\rm FB} = (5.8 \pm 5.1({\rm stat}) \pm 1.3({\rm syst}))\%$, $A^{\ell}_{\rm FB}({\rm predicted}) = (4.7 \pm 0.1)\%$
  - ➔ CDF lepton+jets, 9.4 fb^{-1}: ~ 3σ excess at large M_{ttbar} invariant mass

D0 lepton+jets:



ttbar-based (unfolded):

A_{FB}= $(19.6 \pm 6.5)\%$,

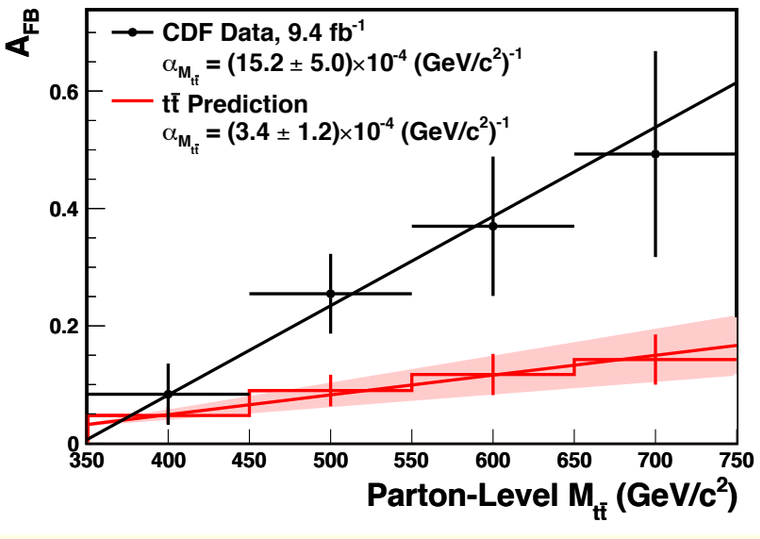
A_{FB} (MC@NLO)= $(5.0 \pm 0.1)\%$.

lepton-based (unfolded):

$A^{l}_{\rm FB} = (15.2 \pm 4.0)\%$

A^{l}_{FB} (MC@NLO)= $(2.1 \pm 0.1)\%$.

CDF lepton+jets ttbar-based



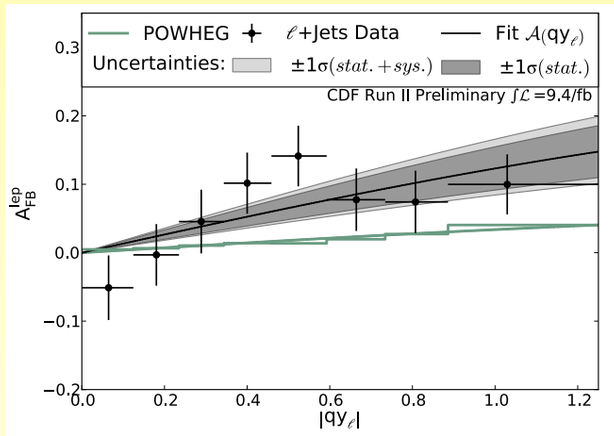
inclusive, unfolded:

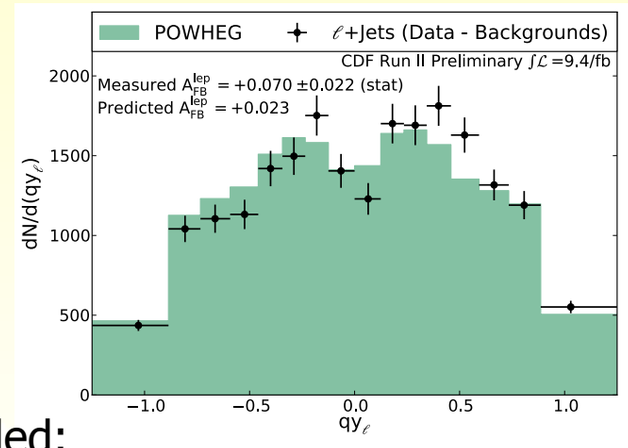
A_{FB}= 0.164 ± 0.045 (stat+syst)

A_{FB} (SM)= 0.066 ± 0.020

CDF lepton+jets lepton-based

$A^{lep}_{\rm FB} = \frac{N(qy_l > 0) - N(qy_l < 0)}{N(qy_l > 0) + N(qy_l < 0)}$





unfolded:

$A^{l}_{FB} = 0.094^{+0.032}_{-0.029}$ $A^{lep}_{\rm FB} = 0.036$. (SM)

Charge asymmetry in the lepton+jets channel in ATLAS

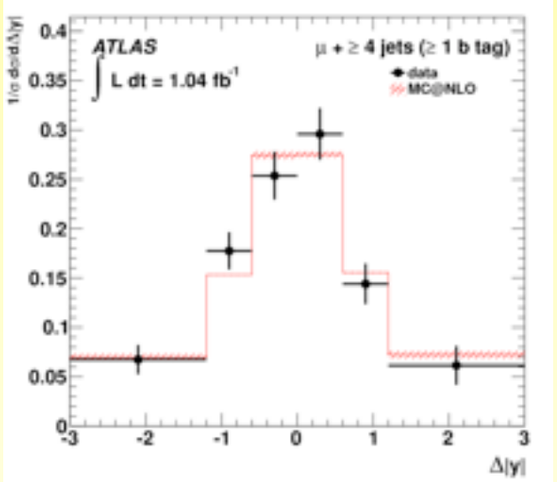
- the dominant gg->ttbar production at LHC is symmetric
  - ➔ smaller expected asymmetry than at the Tevatron
  - ➔ is enhanced at large M_{ttbar}

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

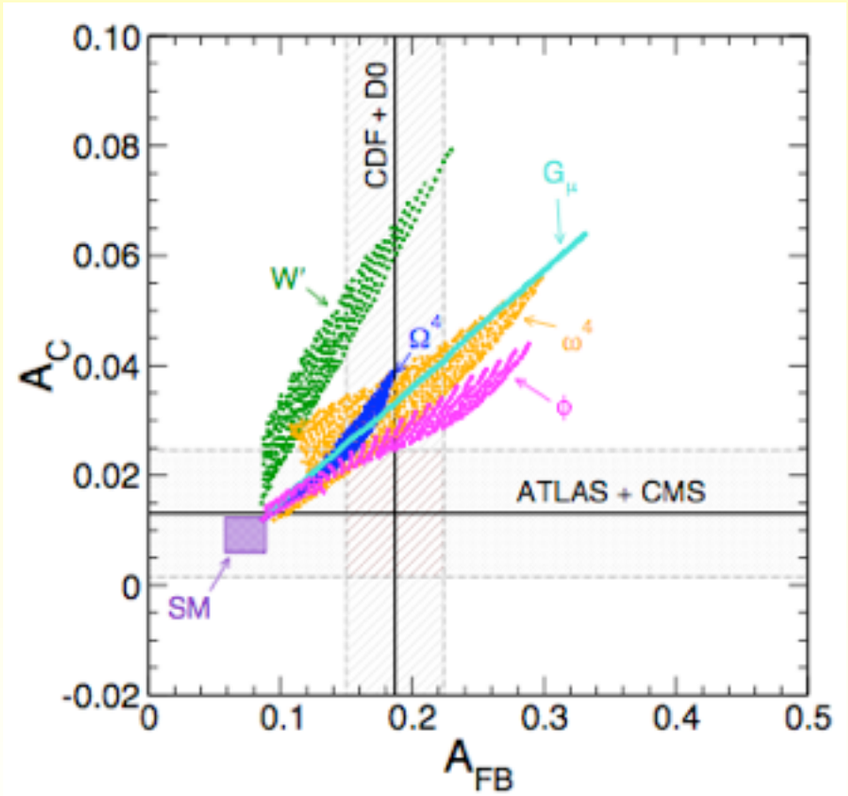
- ATLAS result in lepton+jets: 1 fb^{-1} (7 TeV)

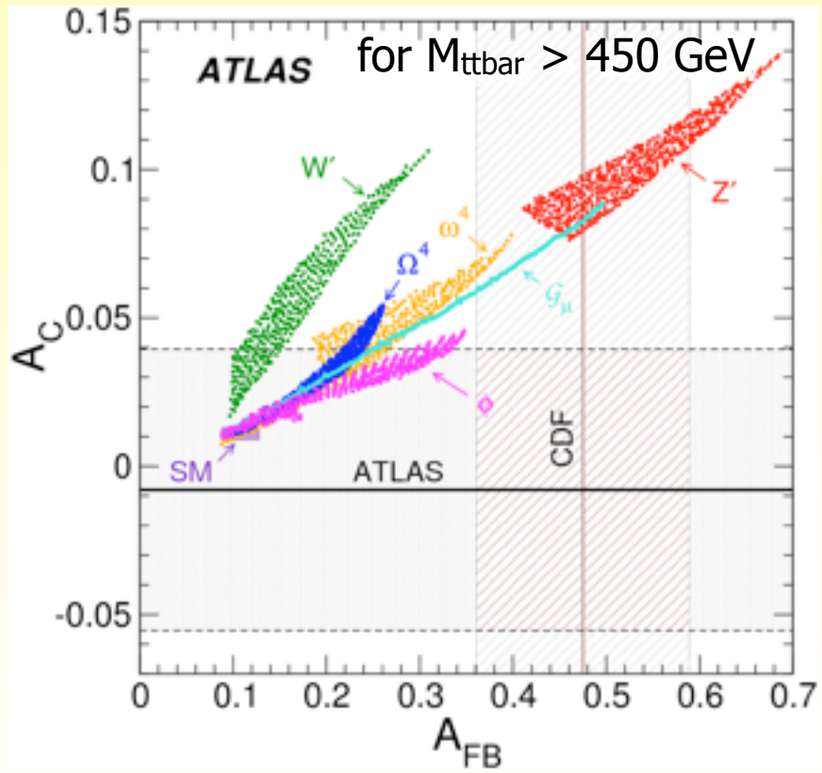
inclusive, unfolded: $A_C = -0.019 \pm 0.028\ (\text{stat.}) \pm 0.024\ (\text{syst.})$

Source of systematic uncertainty on A_C	Electron channel	Muon channel
Detector modelling		
Jet energy scale	0.012	0.006
Jet efficiency and resolution	0.001	0.007
Muon efficiency and resolution	<0.001	0.001
Electron efficiency and resolution	0.003	0.001
b-tag scale factors	0.004	0.002
Calorimeter readout	0.001	0.004
Charge mis-ID	<0.001	<0.001
b-tag charge	0.001	0.001
Signal and background modelling		
Parton shower/fragmentation	0.010	0.010
Top mass	0.007	0.007
$t\bar{t}$ modelling	0.011	0.011
ISR and FSR	0.010	0.010
PDF	<0.001	<0.001
W+jets normalization and shape	0.008	0.005
Z+jets normalization and shape	0.005	0.001
Multijet background	0.011	0.001
Single top	<0.001	<0.001
Diboson	<0.001	<0.001
MC Statistics	0.006	0.005
Unfolding convergence	0.005	0.007
Unfolding bias	0.004	<0.001
Luminosity	0.001	0.001
Total systematic uncertainty	0.028	0.024



constraints on BSM models



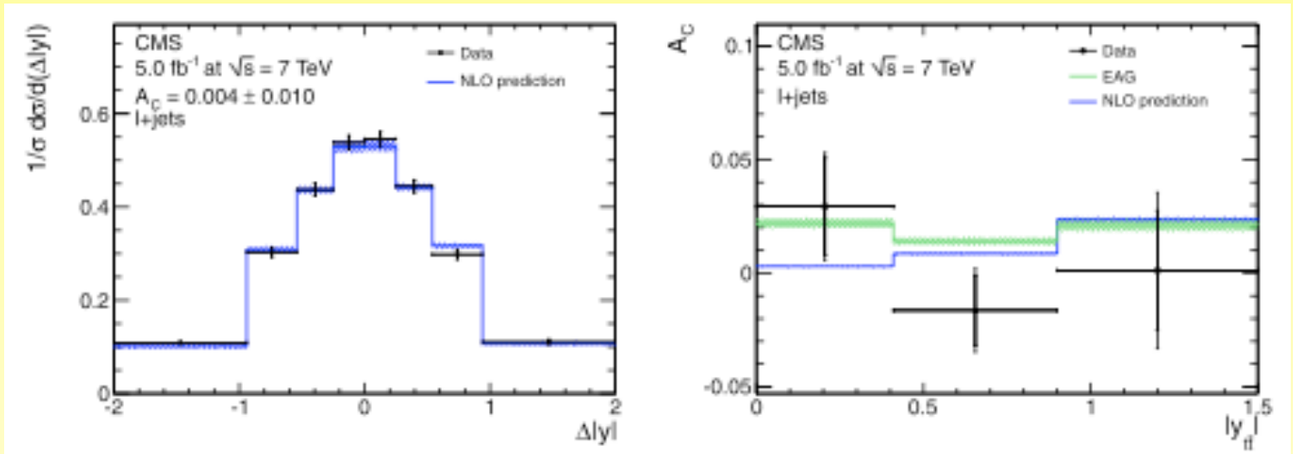


Charge asymmetry in the lepton+jets channel in CMS

- result with 5 fb^{-1} (7 TeV)
- additional differential measurements

  ➔ vs M(ttbar), y(ttbar), pt(ttbar)

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



Systematic uncertainty	Shift (±) in inclusive A_C
JES	0.003
JER	0.002
Lepton ID/sel. efficiency	0.006
Generator	0.001
Hadronization	0.001
Q^2 scale	0.002
PDF	0.002
Pileup	< 0.001
W + jets	0.004
Multijet	0.001
Migration matrix	0.002
Model dependence	0.007
Total	0.011

- next steps ?

  ➔ more statistics at large Mttbar, measurement in space space with enhanced SM prediction

  ➔ goal: to get sensitive to the SM prediction (the prediction for 13 TeV will be even smaller ...)

  ➔ collider independant observable (arXiv:1205.1898)

Charge asymmetry in the dilepton channel in ATLAS

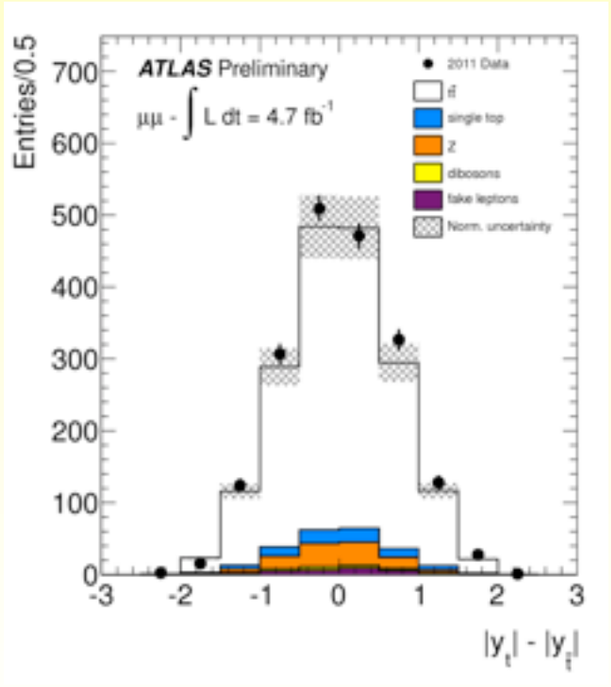
- Complementary to the measurement in the lepton+jets channel:
  - ➔ also sensitive to polarization effects
- Drawbacks
  - ➔ more difficult to reconstruct the ttbar final state
- ATLAS 4.7 fb^{-1} result (7 TeV)
  - ➔ ttbar-based and lepton-based inclusive and unfolded

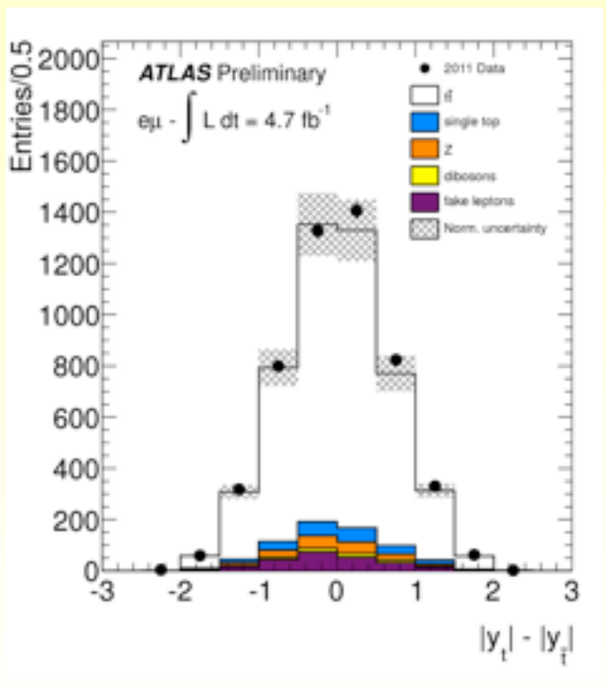
$$A_C^{\ell\ell} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)},$$

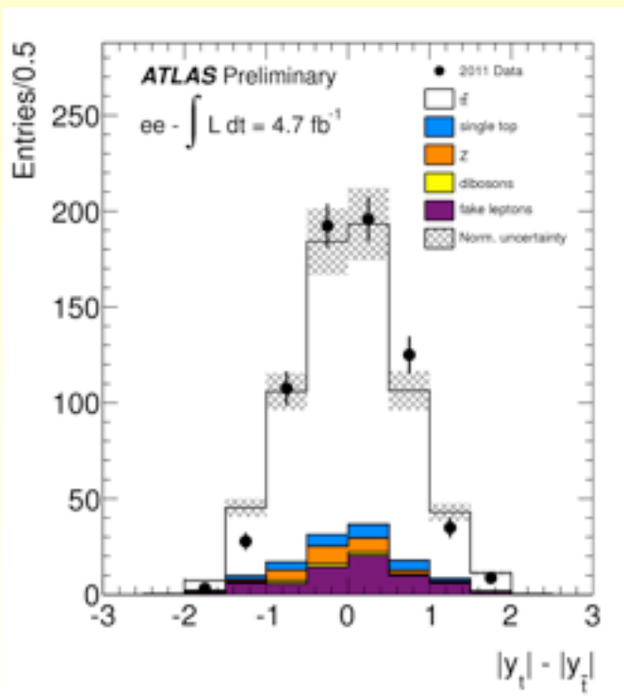
$$A_C^{\ell\ell} = 0.023 \pm 0.012\,(\text{stat.}) \pm 0.008\,(\text{syst.}),$$

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

	ee	*eμ*	*μμ*
Signal and background modeling			
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
Z+jets	0.001	0.006	0.002
Diboson	<0.001	<0.001	<0.001
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

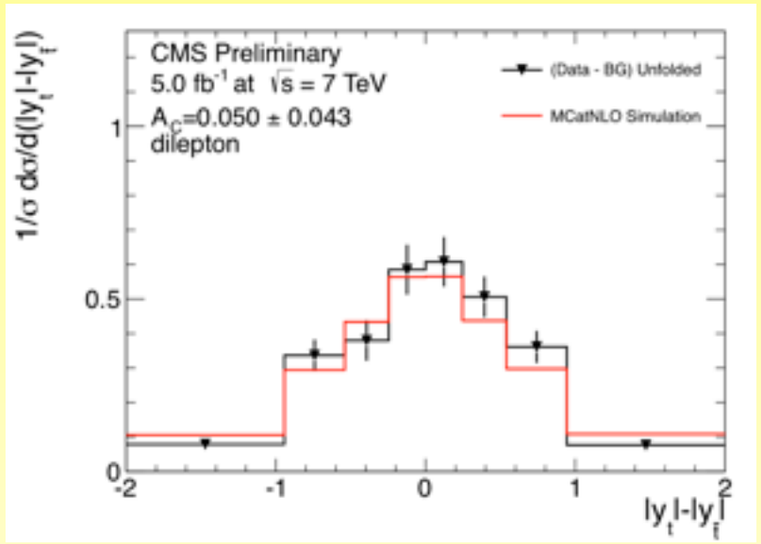


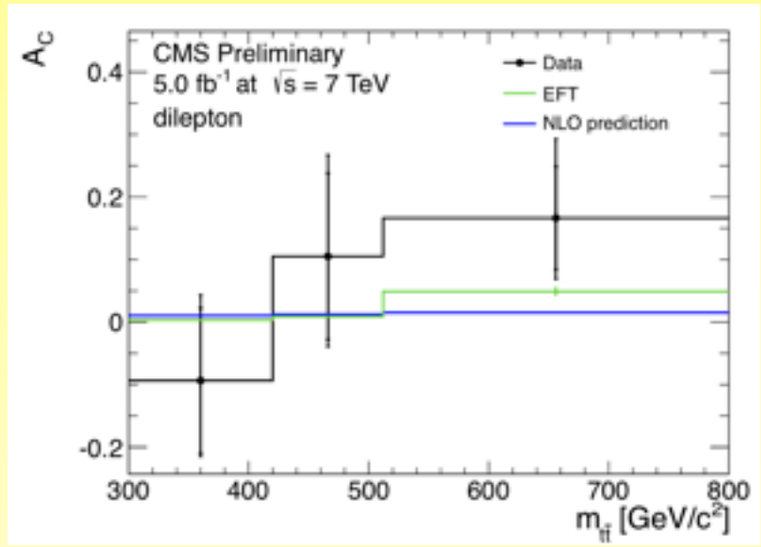


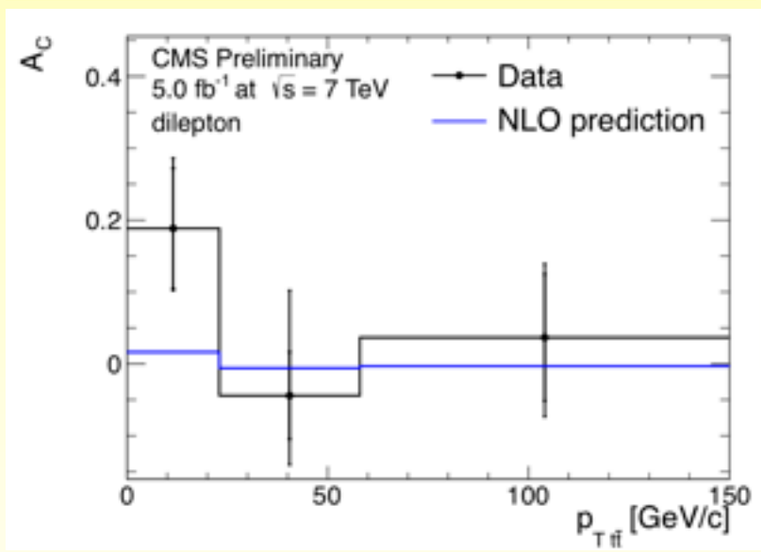


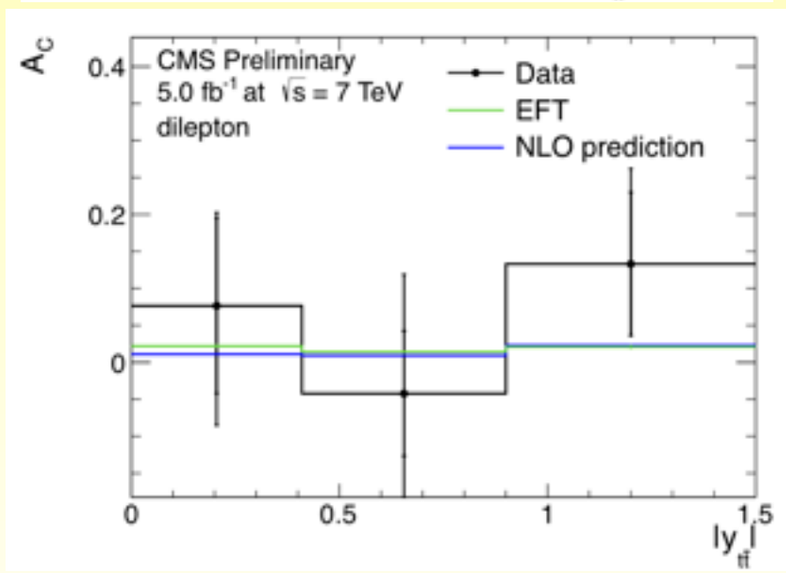
Charge asymmetry in the dilepton channel in CMS

- result with 5 fb^{-1} (7 TeV)
  - ➔ inclusive (unfolded): $A_C = 0.050 \pm 0.043(\text{stat})^{+0.010}_{-0.039}(\text{syst})$
  - ➔ differential measurements: vs M(ttbar), y(ttbar), pt(ttbar)





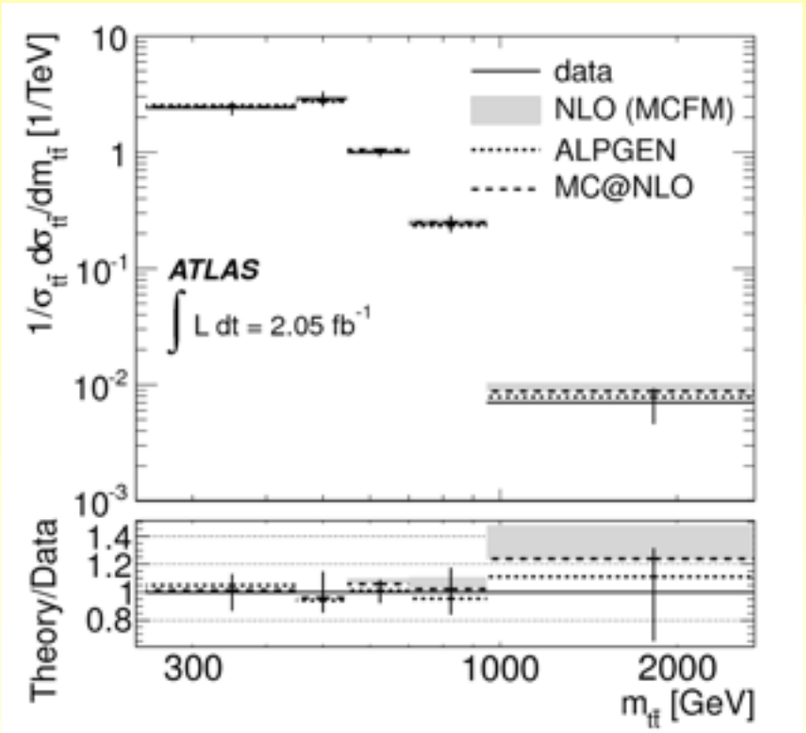


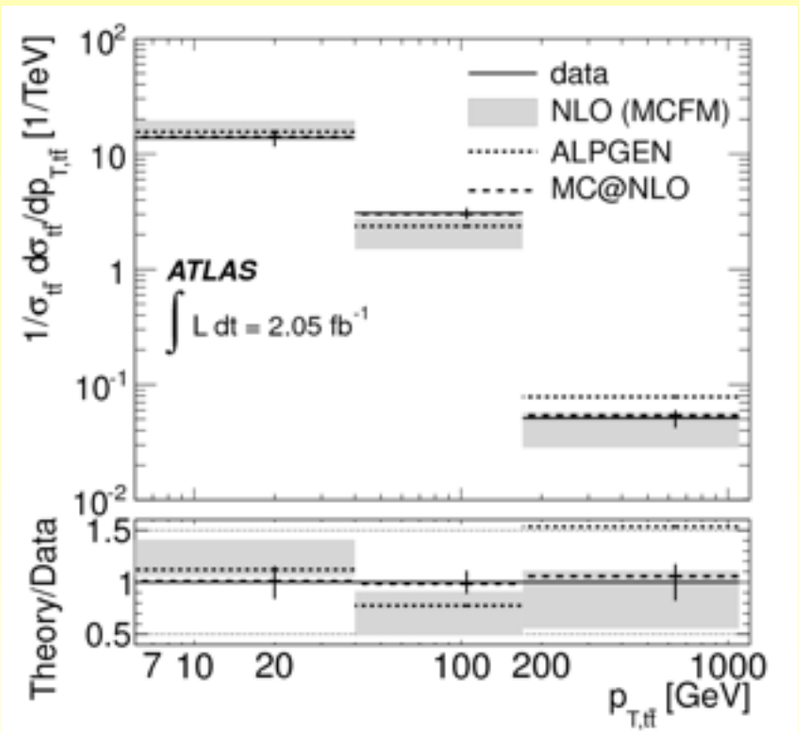


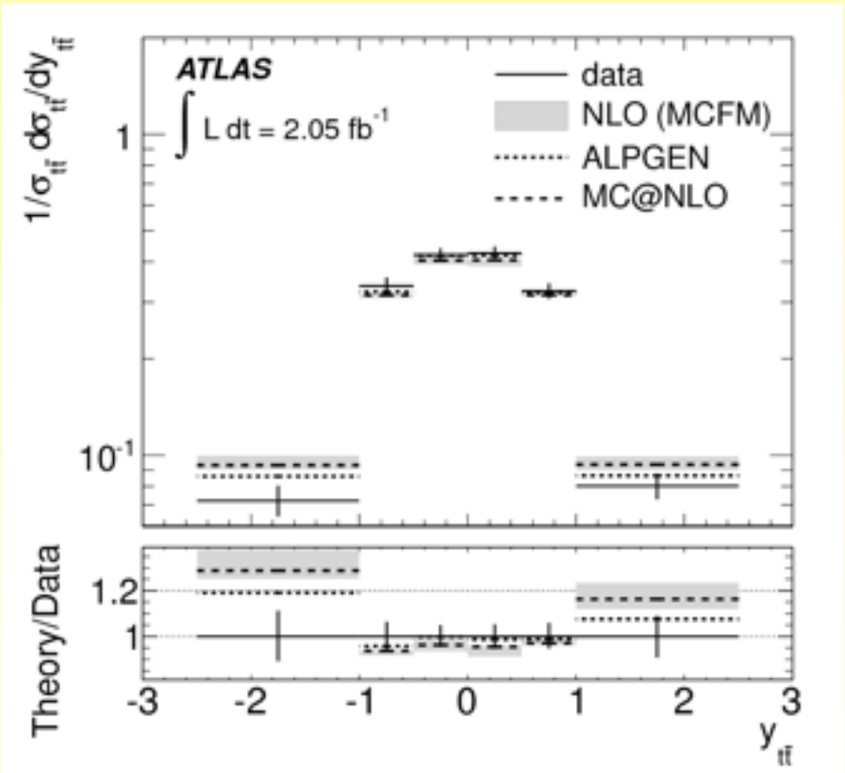
- next steps ?
  - ➔ more statistics inclusive and differentially
  - ➔ 2D ttbar vs lepton based
  - ➔ dependency vs lepton pt (arXiv:1212.4003)

Differential measurements in ATLAS

- Differential measurements important to:
  - ➔ tune MC
  - ➔ search for BSM physics (resonant or non resonant)
- ATLAS 2 fb^{-1} result in the lepton+jets channel (7 TeV)



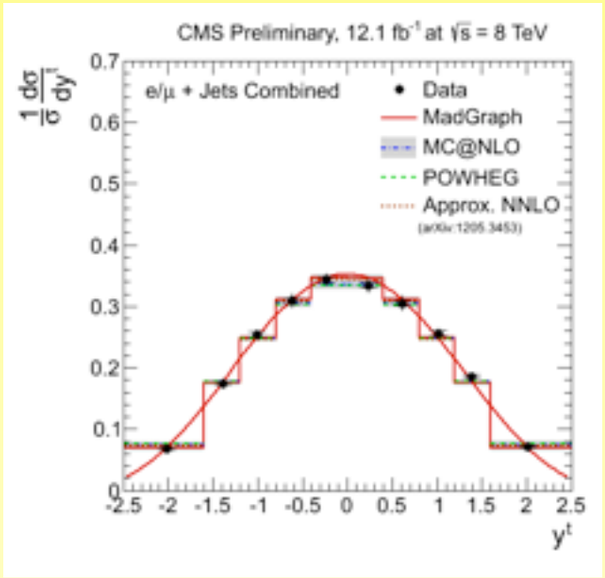


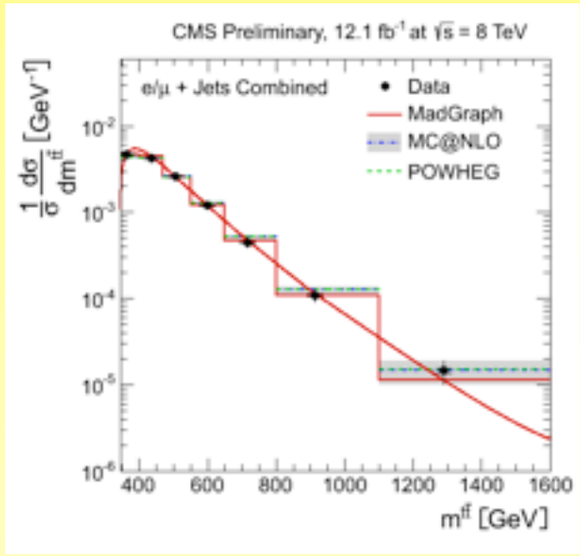


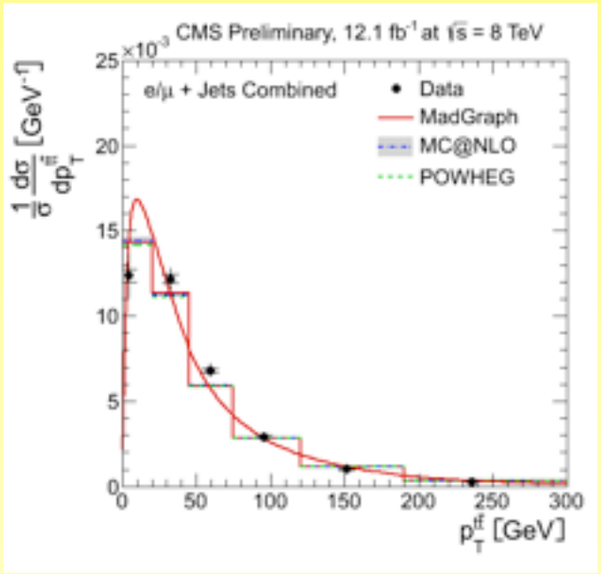
Differential measurements in CMS

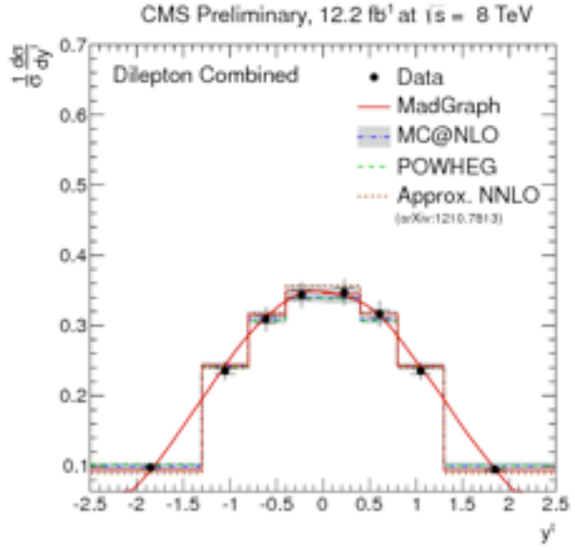
- CMS results with 12 fb^{-1} (lepton+jets and dilepton 8 TeV)

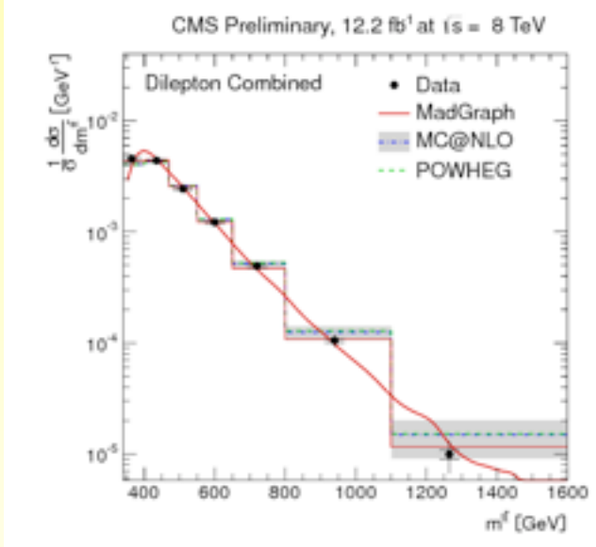
  ➔ unfolded measurements in good agreement with predictions

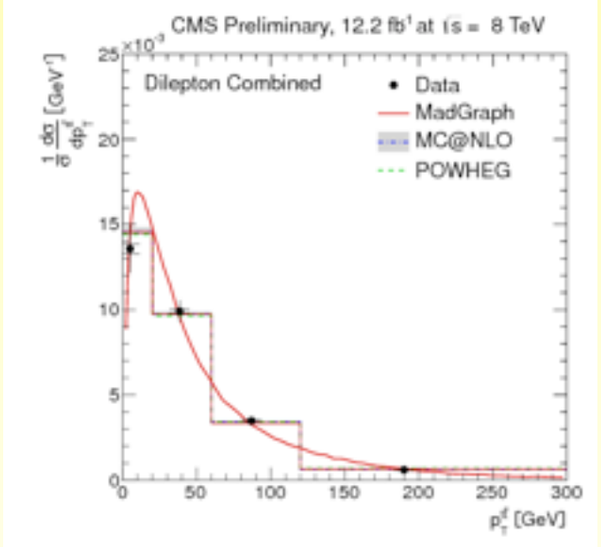












- next steps ?

  ➔ include in MC tuning

  ➔ measurements in visible phase space

  ➔ BSM model exclusion

Discussion