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ttbar Asymmetry
at Tevatron and LHC

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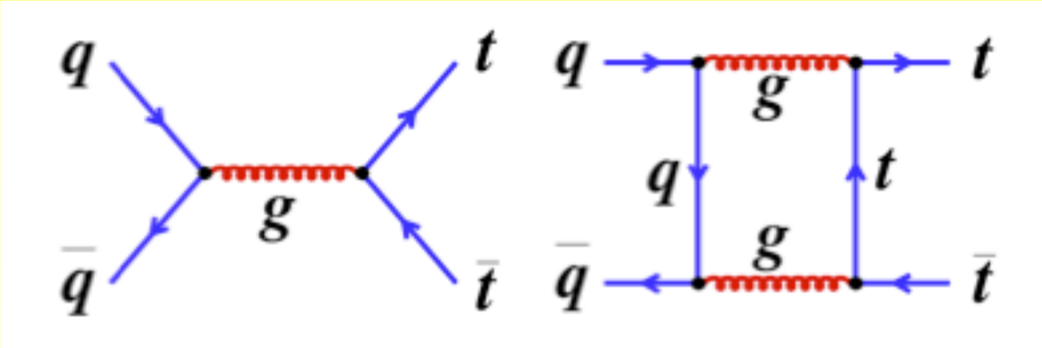
GDR Terascale, Marseille, 11-October-2011

Top-Antitop Charge Asymmetry

- At NLO, QCD predicts an asymmetry for $t\bar{t}$ produced via $q\bar{q}$ initial state
  - the top quark is predicted to be emitted preferably in the direction of the incoming quark
  - the exchange of new particles like Z' or axigluon could modify it



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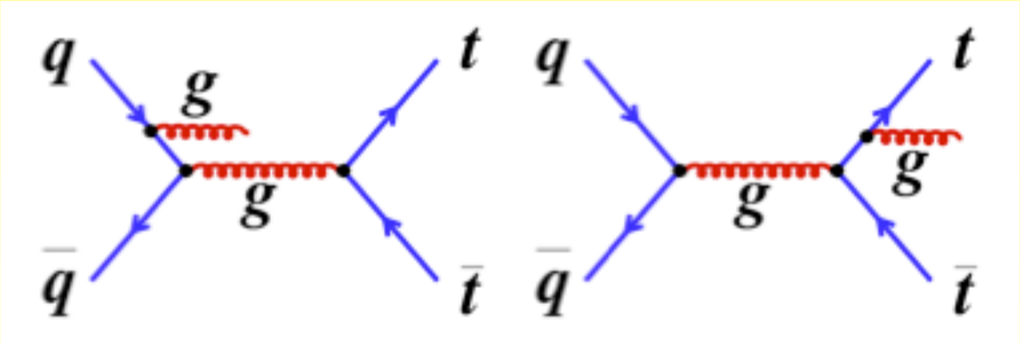
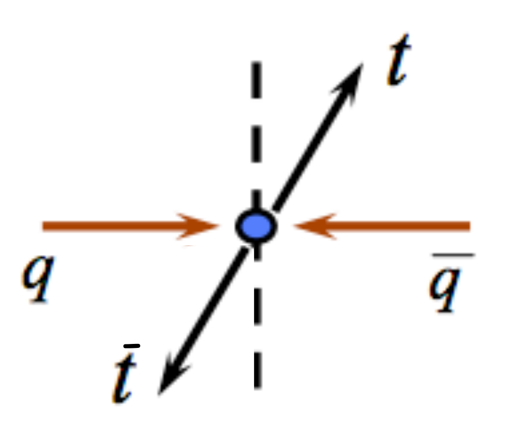


positive asymmetry negative asymmetry

(flavor excitation qg much smaller)

interference between diagrams with different C

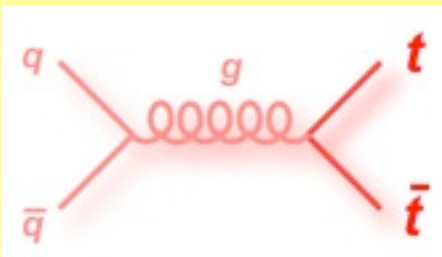


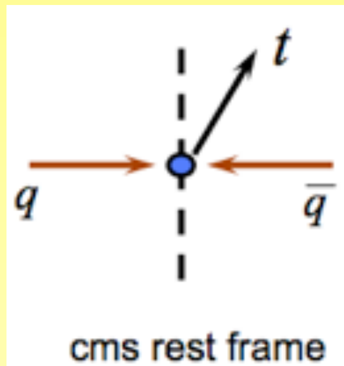
- similar phenomena in QED observed in the 80s in ee $\rightarrow$ $\mu\mu$ events
  - even without Z ($\sqrt{s}$ = 35 GeV << M_Z)

Charge Asymmetry Observables

- same process leads to different observables at the Tevatron and the LHC
  - p/pbar vs p/p collisions

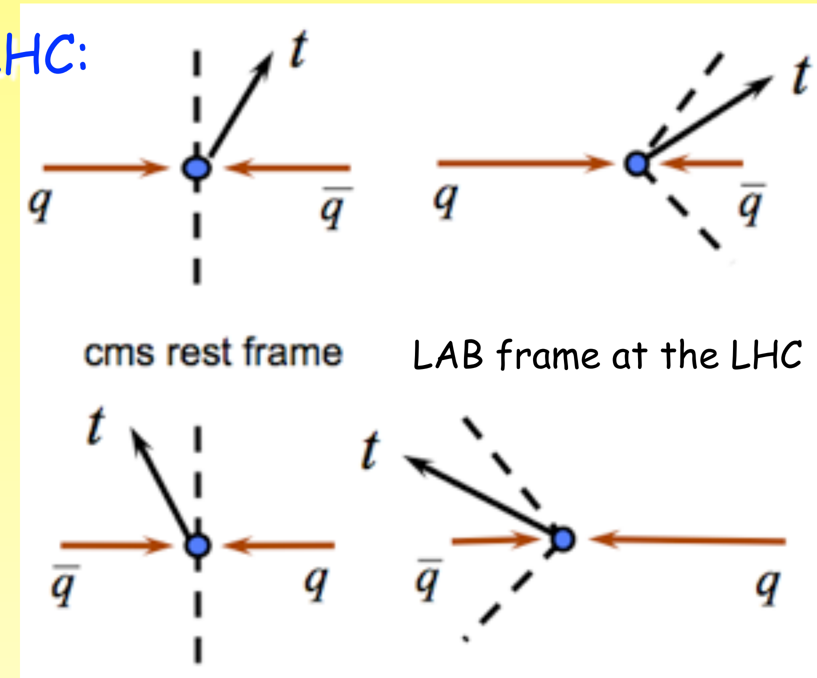
Tevatron:

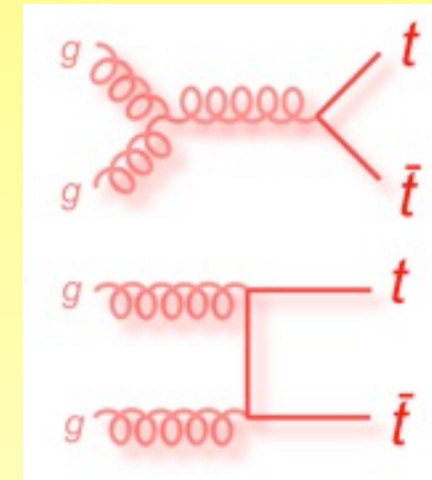


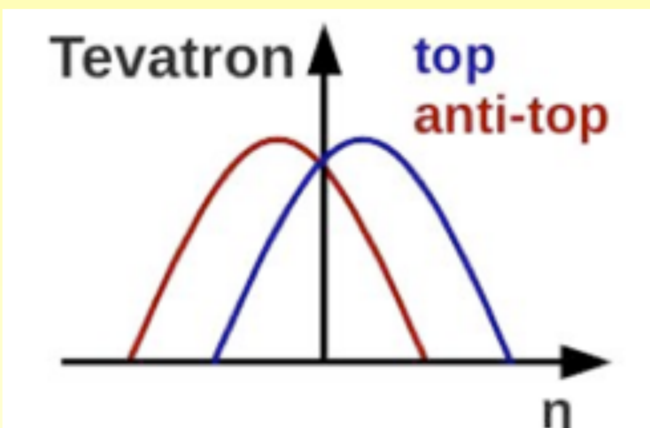


~ LAB frame at the Tevatron

LHC:







forward-backward asymmetry

$$A^i_{\mathrm{FB}} = \frac{N_t(y^i_t > 0) - N_t(y^i_t < 0)}{N_t(y^i_t > 0) + N_t(y^i_t < 0)}$$

frame i

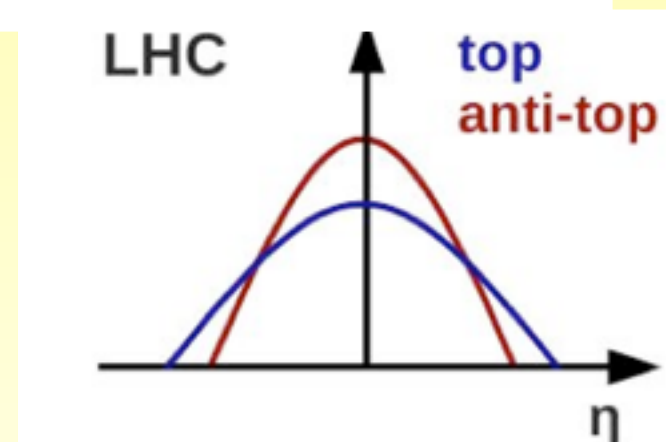
ppbar, ttbar rest frame

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

Lorentz invariant

same as A^{ttbar}_{FB}

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



central-forward asymmetry

possible observables:

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

smaller at LHC since low $q\bar{q}$ fraction

$\Delta|Y| = |Y_t| - |Y_{\bar{t}}|$ or $\Delta|\eta| = |\eta_t| - |\eta_{\bar{t}}|$

also $\Delta y^2 = y_t^2 - y_{\bar{t}}^2 = (y_t - y_{\bar{t}}) \times (y_t + y_{\bar{t}})$ ~ Tevatron variable boosted in the ttbar rest frame

SM Predictions

- in addition to the leading QCD contributions (Kuhn, Rodrigo, arXiv:hep-ph/9807420):
  - mixed QCD-EWK corrections (Bernreuther, Si, arXiv:1003.3926, Hollik, Pagani, arXiv:1107.2606) : ~ 20 %
  - higher-order QCD contributions: soft-gluon resummation : rather small
    (Ahrens et al arXiv:1003.5827, arXiv:1106.6051, Kidonakis arXiv:1105.5167)

Tevatron:

B. Pecjak, Top2011

	$A_{FB}^{t\bar{t}}$ [%]	$A_{FB}^{p\bar{p}}$ [%]
NLO	$7.32^{+0.69+0.18}_{-0.59-0.19}$	$4.81^{+0.45+0.13}_{-0.39-0.13}$
NLO+NNLL [Ahrens et. al.'11]	$7.24^{+1.04+0.20}_{-0.67-0.27}$	$4.88^{+0.20+0.17}_{-0.23-0.18}$
$NNLO_{approx}$ [Kidonakis '11]		$5.2^{+0.0}_{-0.6}$
EW'/NLO' ($\mu = m_t$) [Bernreuther, Si '10]	0.05	0.04
EW/NLO ($\mu = m_t$) [Hollik, Pagani '10]	0.22	0.22

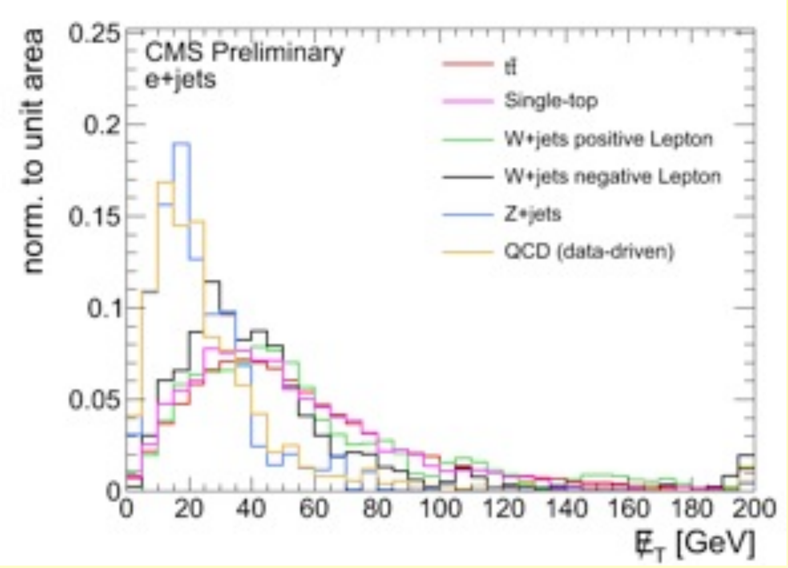
$A_{FB}^{t\bar{t}}$ [%]	$M_{t\bar{t}} < 450$ GeV	$M_{t\bar{t}} > 450$ GeV
NLO	$5.3^{+0.3+0.1}_{-0.4-0.1}$	$10.6^{+1.1+0.3}_{-0.8-0.1}$
NLO+NNLL [Ahrens et al]	$5.2^{+0.7+0.1}_{-0.5-0.0}$	$11.1^{+1.9+0.3}_{-1.0-0.0}$
EW/NLO ($\mu = m_t$) [Hollik et al]	–	0.23

LHC: A_c ~ 1 %

- small effect in QCD
  - powerful test of QCD + sensitive probe of new physics

Event Selection

- lepton+jets channel mainly
  - exactly one lepton (pt>20-30 GeV)
  - at least 4 jets (pt>20-30 GeV) $|\eta| < 2.0\text{-}2.5$, at least 1 b-tag
  - additional cuts: MET > 20-35 GeV + cut on $m_T(W)$
- CDF also in the dilepton channel
  - 2 leptons with pt > 20 GeV
  - 2 jets pt > 15 GeV, $|\eta| < 2.5$
  - MET > 20-50 GeV, Ht > 200 GeV



- background estimation in the l+jets channel
  - QCD data-driven:
    * matrix method : $N^{loose} = N^{loose}_{real} + N^{loose}_{fake}$ $\quad N^{tight} = \epsilon_{real} N^{loose}_{real} + \epsilon_{fake} N^{loose}_{fake}$
    * fit the MET distribution at low MET (+ M_{jjj})
  - W+jets: shape from MC, normalization from data:
    * fit together with asymmetry
    * from difference between positive D^+/negative D^- leptons in data (2jet pretag)
    * fit the MET distribution + M_{jjj} together with QCD

$$N_{W^+} + N_{W^-} = \frac{r_{MC}+1}{r_{MC}-1}(D^+ - D^-)$$

$$r_{\mathrm{MC}} = \frac{W^+}{W^-}$$

- l+jets yields:
  - Tevatron: CDF: 5.3 fb^{-1}, D0 5.4 fb^{-1} (published or submitted)
    ~ 1500 selected events, 22-29 % background
  - LHC: Atlas 0.7 fb^{-1}, CMS: 1.1 fb^{-1} (preliminary results for the summer 2011 conferences)
    ~ 7500-12000 selected events, ~ 20 % background

ttbar Reconstruction

- need to reconstruct the full event kinematics to compute Δy

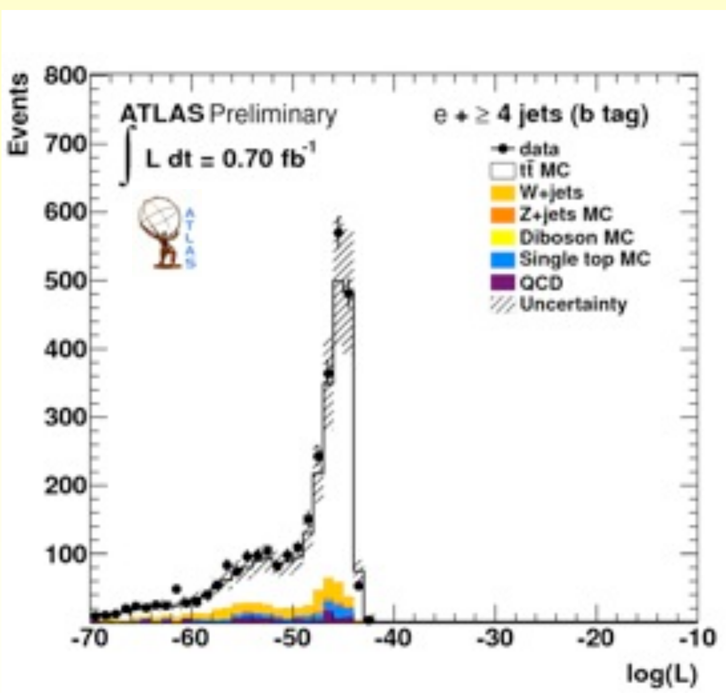
  - χ^2 test or likelihood to assign the right combination
    * accounting for experimental resolution
    * b-tag: additional constraint
    * M_W and M_t fixed to their world average values within their width

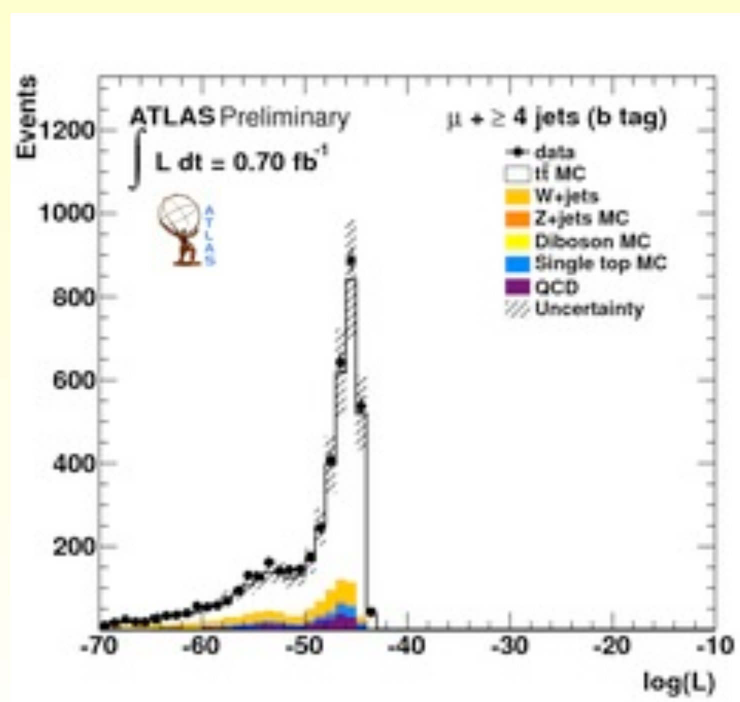
Atlas:

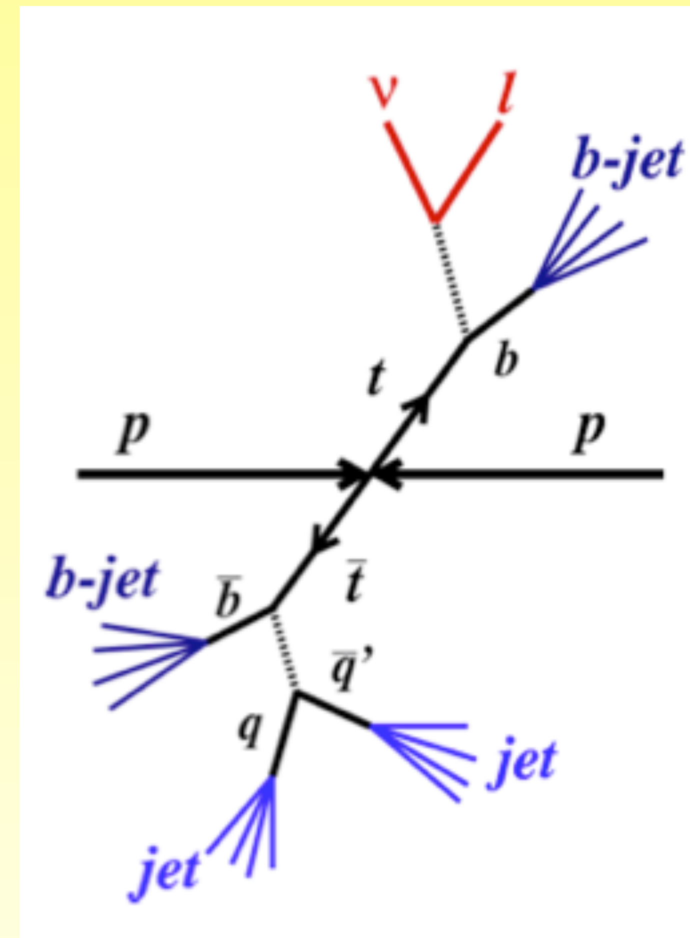
$$\begin{aligned} L = \; & \mathcal{B}(\widetilde{E}_{p,1}, \widetilde{E}_{p,2} | m_W, \Gamma_W) \cdot \mathcal{B}(\widetilde{E}_{lep}, \widetilde{E}_{\nu} | m_W, \Gamma_W) \cdot \\ & \mathcal{B}(\widetilde{E}_{p,1}, \widetilde{E}_{p,2}, \widetilde{E}_{p,3} | m_t, \Gamma_t) \cdot \mathcal{B}(\widetilde{E}_{lep}, \widetilde{E}_{\nu}, \widetilde{E}_{p,4} | m_t, \Gamma_t) \cdot \\ & \mathcal{W}(\widetilde{E}_x^{miss} | \hat{p}_{x,\nu}) \cdot \mathcal{W}(\widetilde{E}_y^{miss} | \hat{p}_{y,\nu}) \cdot \mathcal{W}(\widetilde{E}_{lep} | \hat{E}_{lep}) \cdot \\ & \prod_{i=1}^{4} \mathcal{W}(\widetilde{E}_{p,i} | \hat{E}_{jet,i}) \cdot \prod_{i=1}^{4} \mathcal{W}(\widetilde{\eta}_{p,i} | \hat{\eta}_{jet,i}) \cdot \prod_{i=1}^{4} \mathcal{W}(\widetilde{\phi}_{p,i} | \hat{\phi}_{jet,i}) \cdot \prod_{i=1}^{4} P(\text{tagged} \mid \text{parton flavour}) \end{aligned}$$

CMS:

$$\psi = L(m_1)L(m_2)L(m_3)P_b(x_{b,lep})P_b(x_{b,had})(1 - P_b(x_{q1}))(1 - P_b(x_{q2}))$$



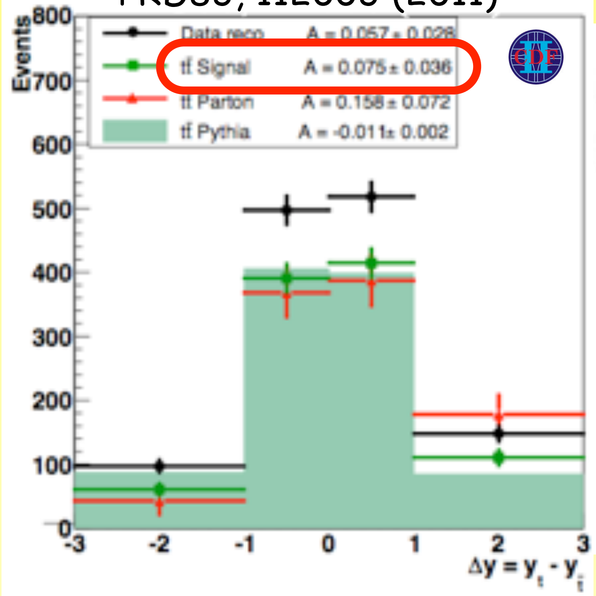




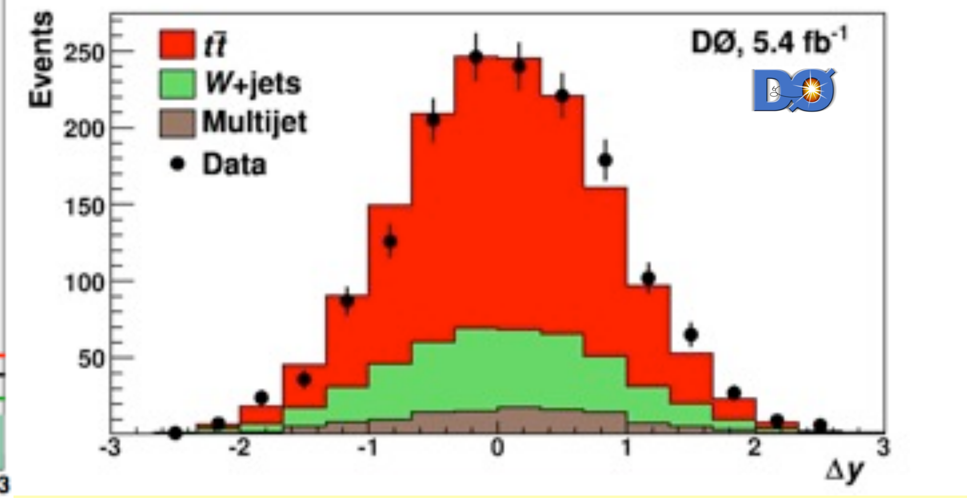
Raw (Detector Level) Asymmetry

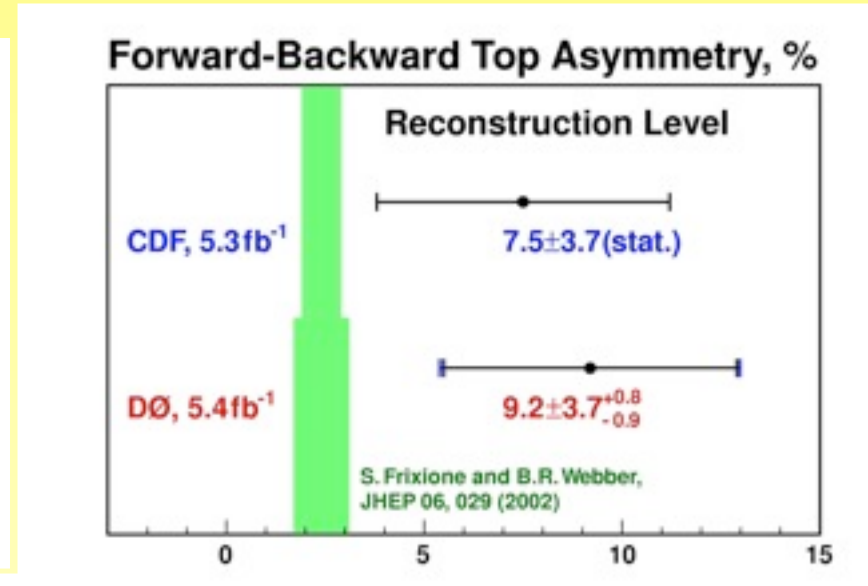
- subtract (fit) estimated background:

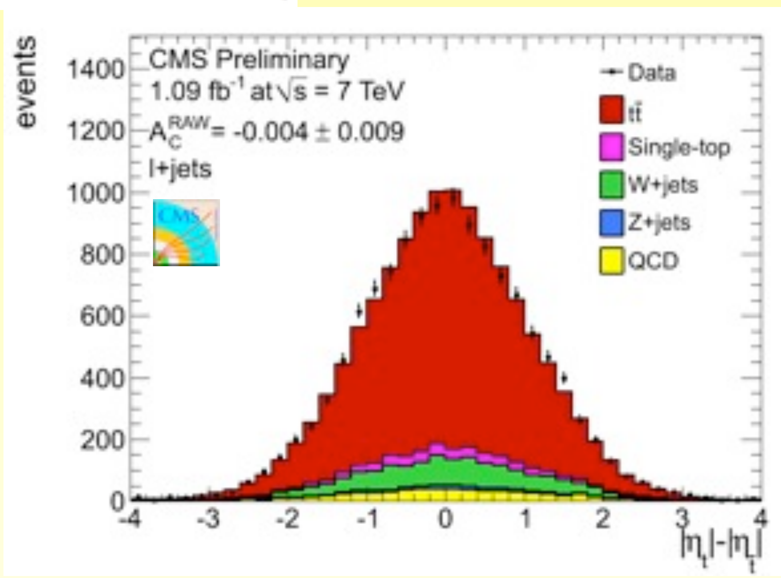
PRD83, 112003 (2011)

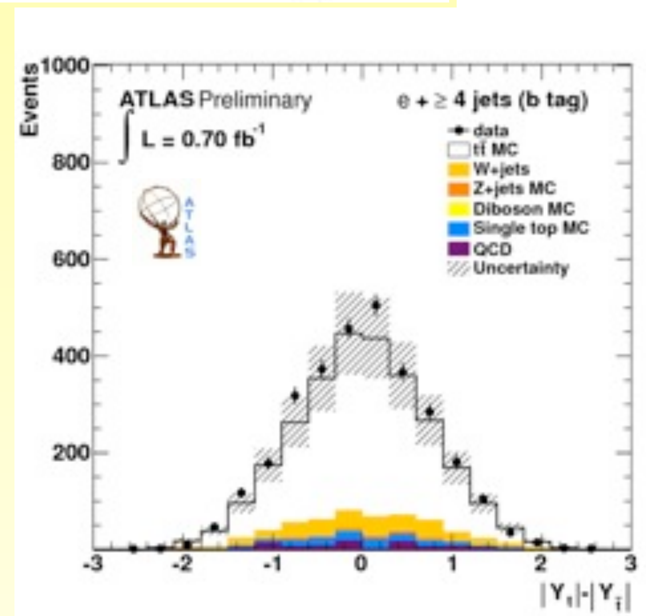


arXiv:1107.4995









	Raw Asymmetry	Predictions (MC@NLO)
CDF	$A_{FB}^{tt} = 7.5 \pm 3.7\%$	$2.4 \pm 0.5\%$
D0	$A_{FB}^{tt} = 9.2 \pm 3.7\%$	$2.4 \pm 0.7\%$
CMS	$A_{C}^{\Delta\eta} = -0.4 \pm 0.9\%$	-

difference with MC@NLO: 1.4-1.9 σ

- can't directly compare due to different acceptance cuts and detector effects

Unfolding

- Correct for acceptance and resolution effects
- different techniques:

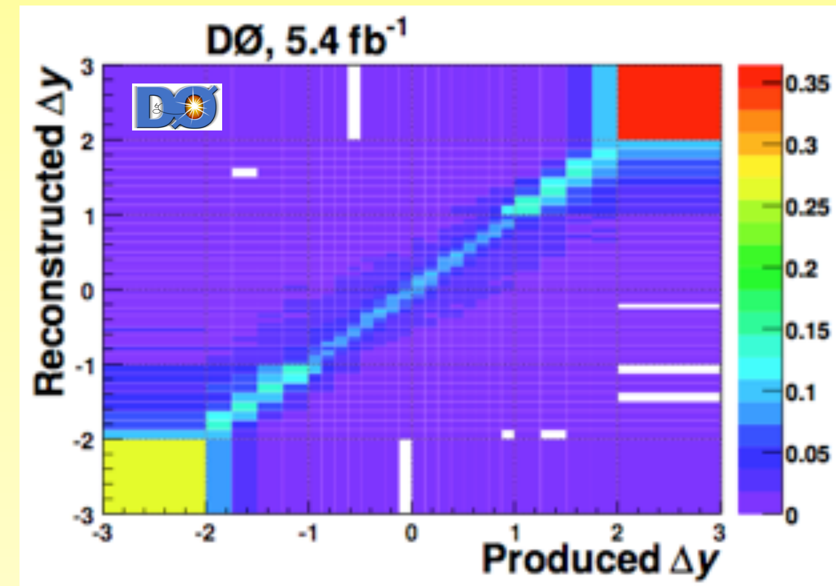
  - CDF: 4-bin unfolding
    A: acceptance matrix
    S: migration matrix

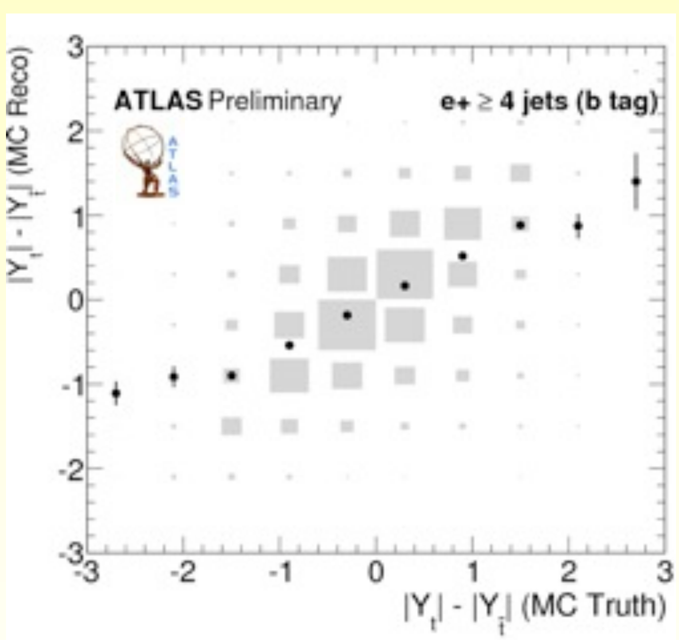
$$\vec{n}_{\mathrm{parton}} = \mathbf{A}^{-1}\mathbf{S}^{-1}(\vec{n}_{\mathrm{data}} - \vec{n}_{\mathrm{bkg}})$$

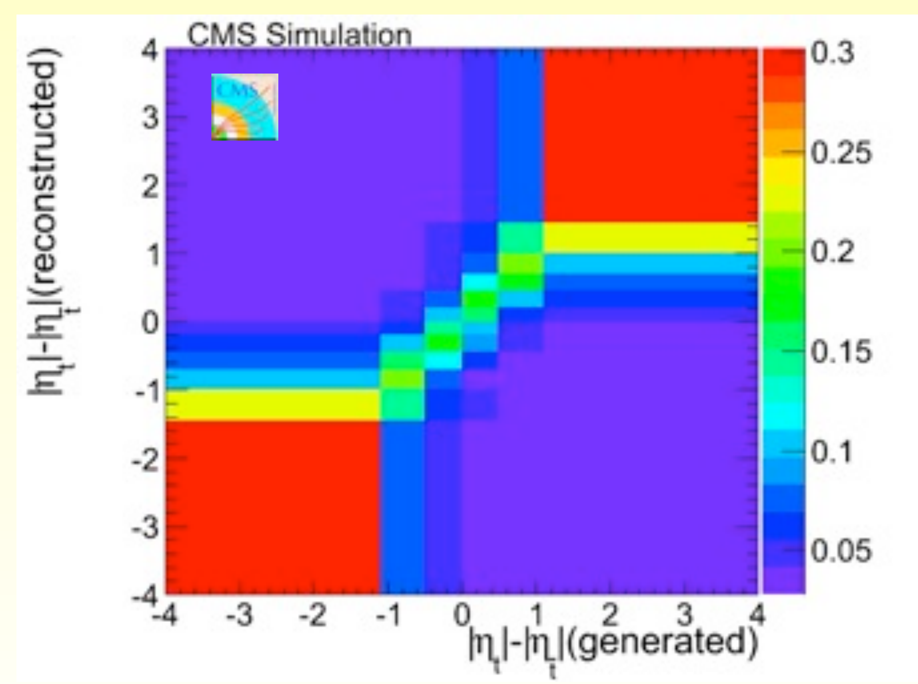
  - D0: 50-> 26 bin regularized unfolding (TUnfold)
    regularization strength evaluated using ensemble testing

  - Atlas: iterative Bayesian unfolding
    regularization through iteration
  - CMS: regularized unfolding based on generalized matrix inversion

D0 response matrix

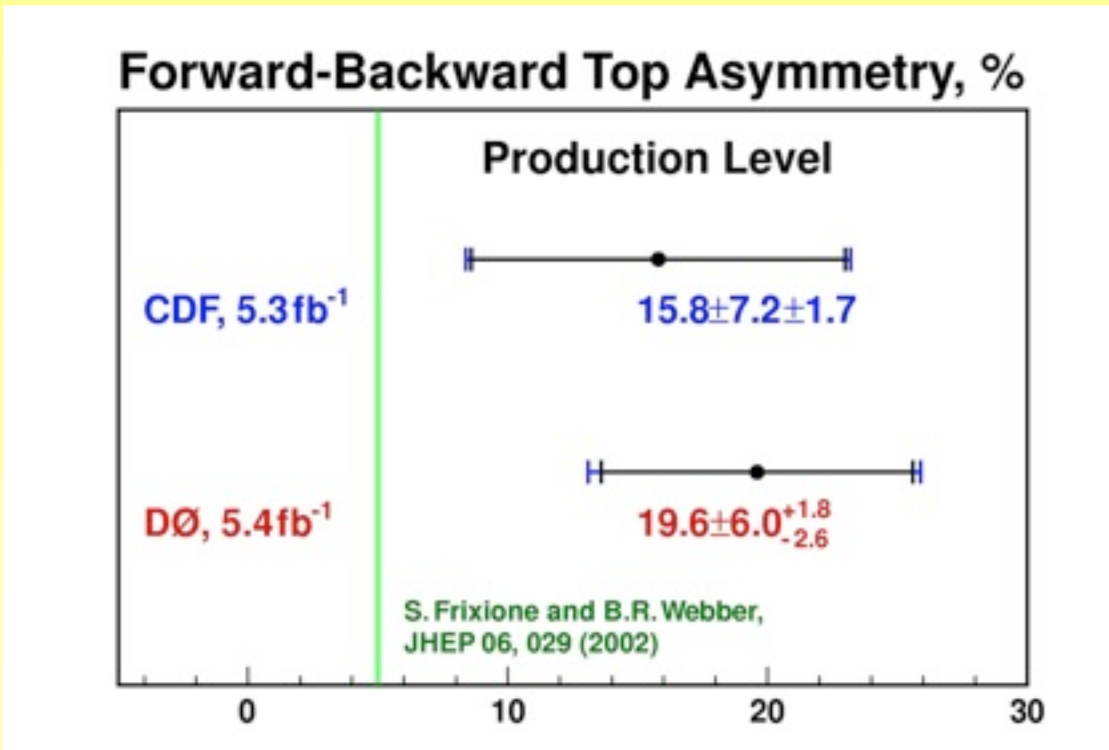


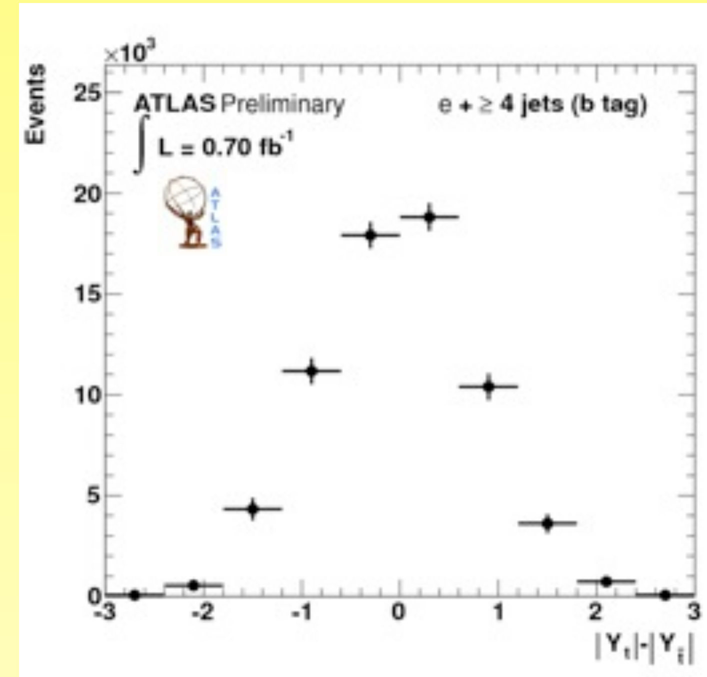


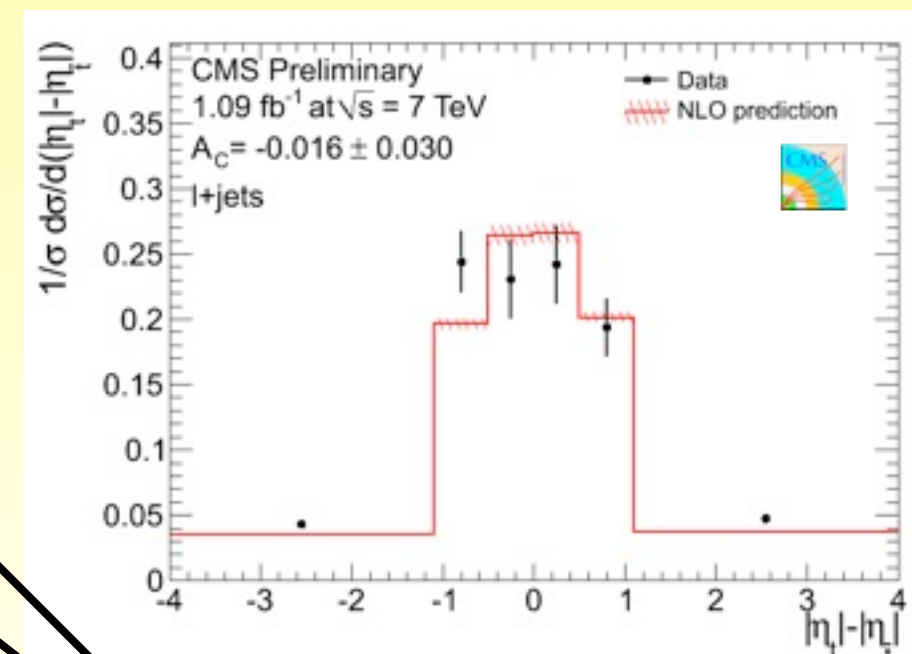


Unfolded Asymmetry

- results after unfolding







	Unfolded Asymmetry	Predictions
CDF	$A_{\text{FB}}^{tt} = 15.8 \pm 7.2(\text{stat}) \pm 1.7(\text{syst})\%$	$A_{\text{MCFM}} = 5.8 \pm 0.9\%$
D0	$A_{\text{FB}}^{tt} = 19.6 \pm 6.0(\text{stat})^{+1.8}_{-2.6}(\text{syst})\%$	$A_{\text{MC@NLO}} = 5.0 \pm 0.1\%$
Atlas	$A_C^{\Delta y} = -2.4 \pm 1.6(\text{stat}) \pm 2.3(\text{syst})\%$	$A_{\text{MC@NLO}} = 0.6\%$
CMS	$A_C^{\Delta \eta} = -1.3 \pm 2.6(\text{stat})^{+2.6}_{-2.1}(\text{syst})\%$	$A_{\text{theo}} = 1.1 \pm 0.1\%$

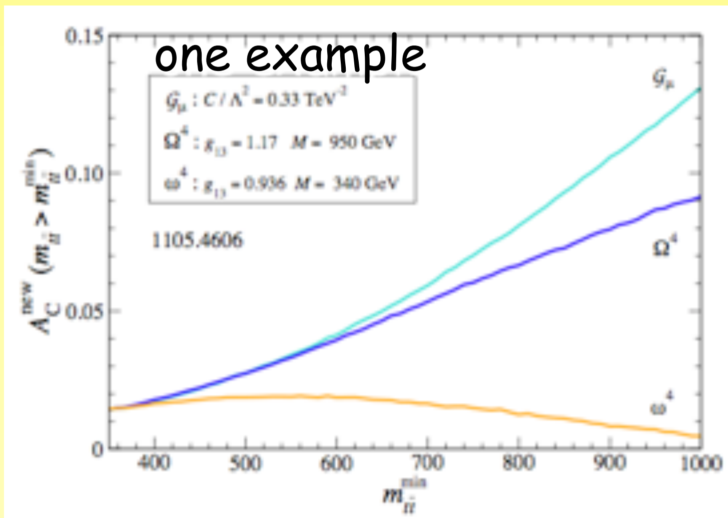
difference with MC@NLO: 1.3-2.4 σ

Statistically limited at the Tevatron

Mass Dependence

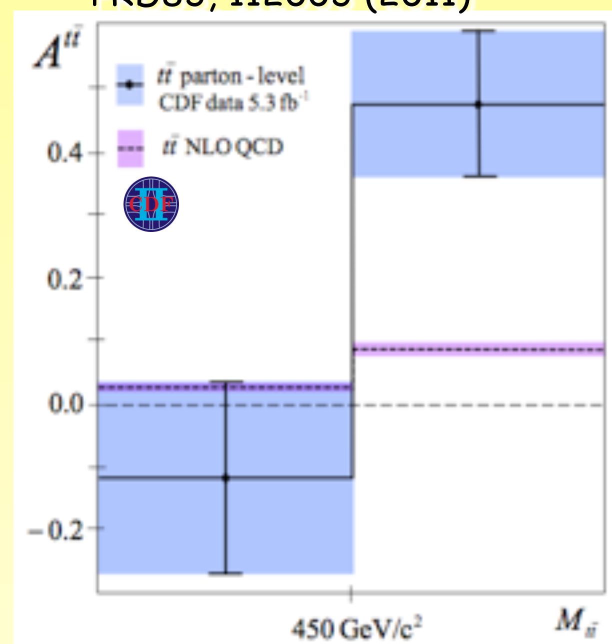
- new physics contribution would change the dependency of the asymmetry vs M_{ttbar}
(to have large effects on the asymmetry, often interference between NP and SM at tree level)

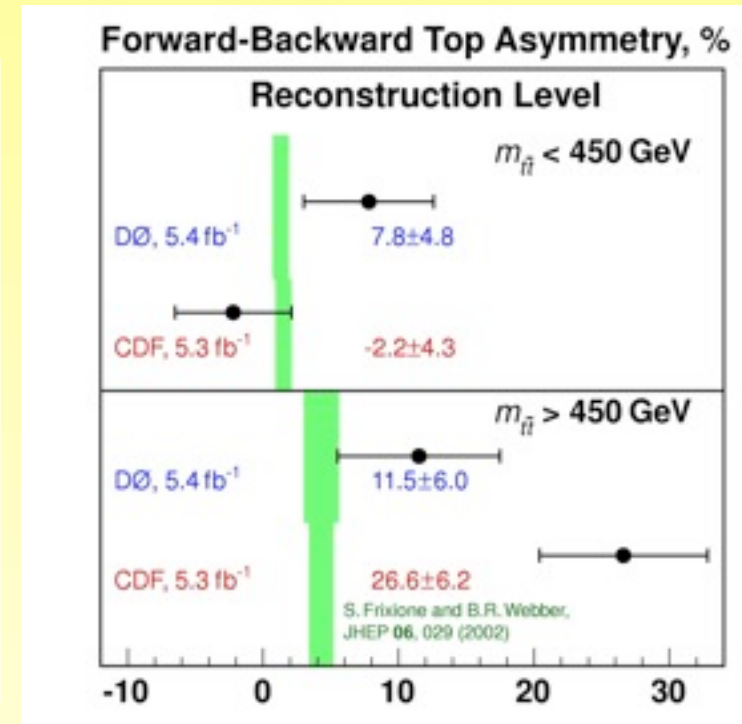
one example



- results as a function of M_{ttbar}
  - Tevatron: 2 bins (M_{ttbar} = 450 GeV)
    * reconstruction/detector level:
    CDF sees a dependency (~ 3 σ), D0 doesn't
    * CDF also unfolded vs M_{ttbar}

PRD83, 112003 (2011)

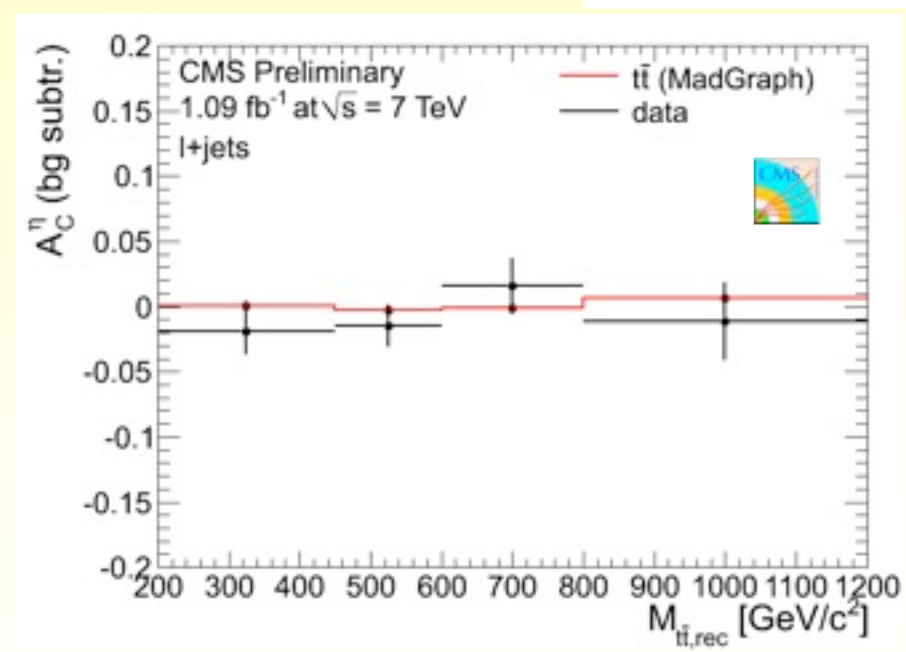




$A_{t\bar{t}}$	ljets	ljets ($M_{t\bar{t}} \geq 450$ GeV)
unfolded data	0.158 ± 0.074	0.475 ± 0.114
SM prediction (MCFM)	0.058 ± 0.009	0.088 ± 0.013

3.4 σ difference

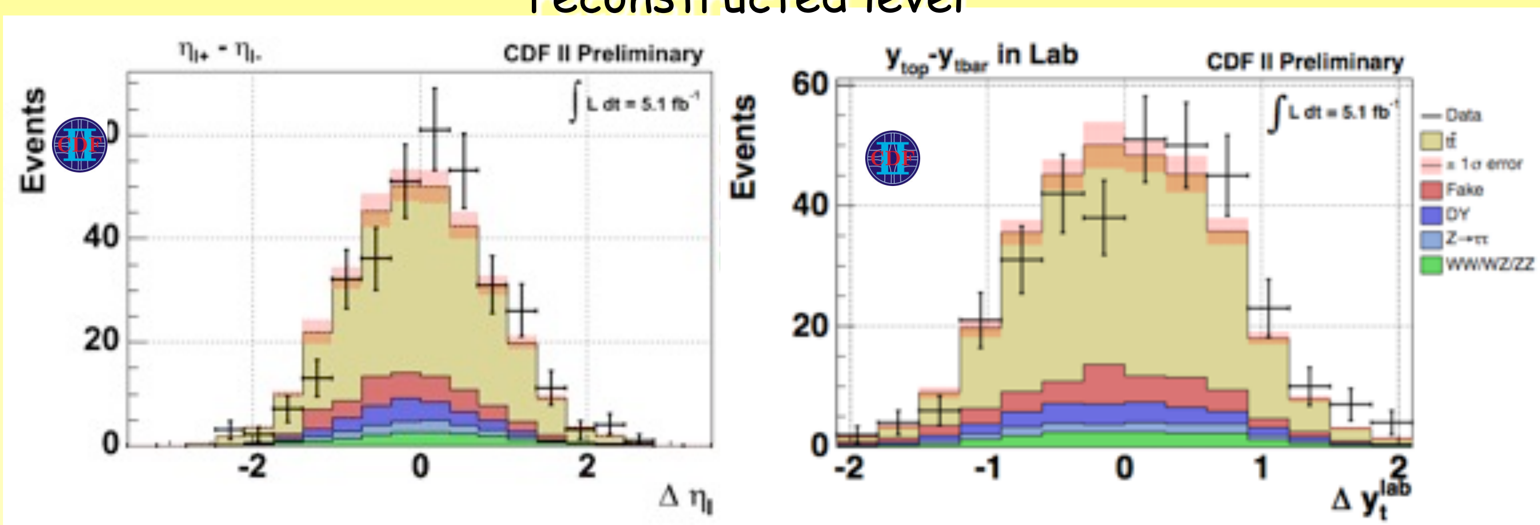
- CMS:
  * reconstruction level (not unfolded):
  agree with the SM

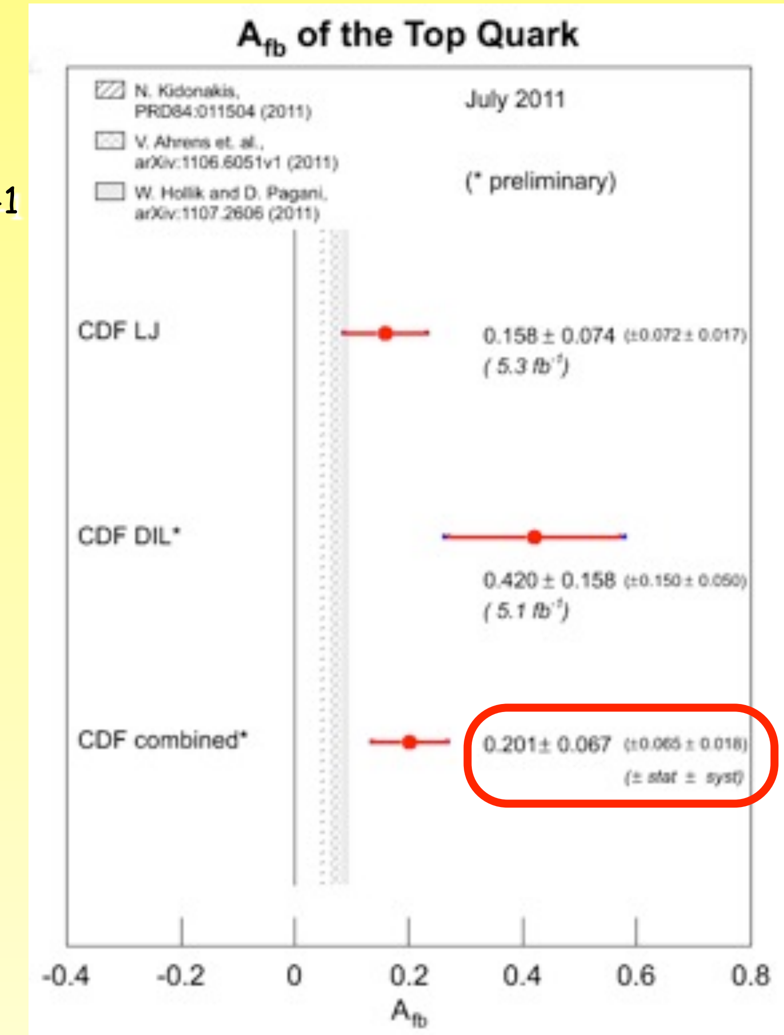


Leptonic Asymmetries

- CDF measures the asymmetry in the dilepton channel
  - dilepton final state more challenging to reconstruct
  - ttbar asymmetry using dilepton events (comparable to l+jets): 5.1 fb^{-1}

reconstructed level





Attbar: $A_{fb} = 0.42 \pm (0.15)^{stat} \pm (0.05)^{syst}$ ~ 2.3 σ from the SM

$$A_{\rm obs}^{<450\ \rm GeV} = 0.104 \pm 0.066(\rm stat.) \qquad (\rm Pred.:\ 0.003 \pm 0.031)$$
$$A_{\rm obs}^{>450\ \rm GeV} = 0.212 \pm 0.096(\rm stat.) \qquad (\rm Pred.:\ -0.040 \pm 0.055)$$

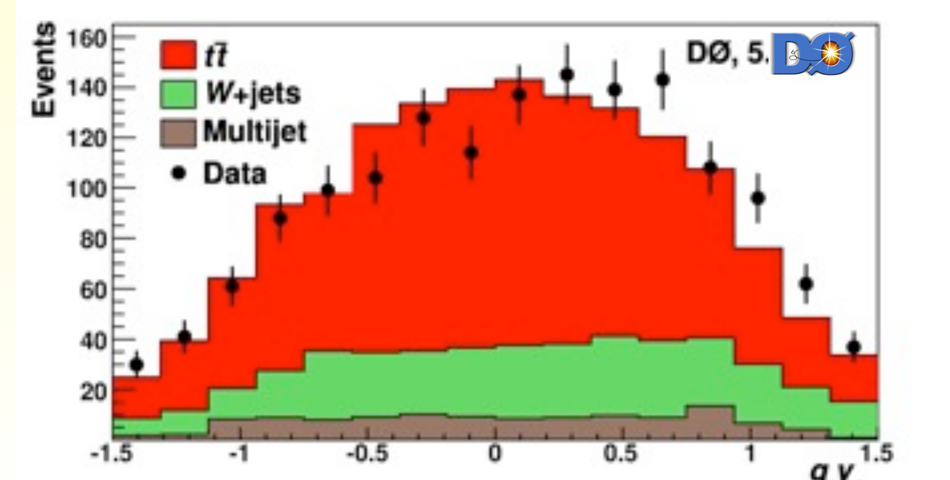
- D0 measures the lepton based asymmetry in the lepton+jets channel
  - lepton based asymmetry (diluted but less sensible to unfolding)

$$A_{\rm FB}^{l} = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

	$A^l_{\rm FB}$ (%) Reconstruction level	Production level
Data	14.2 ± 3.8	15.2 ± 4.0
MC@NLO	0.8 ± 0.6	2.1 ± 0.1

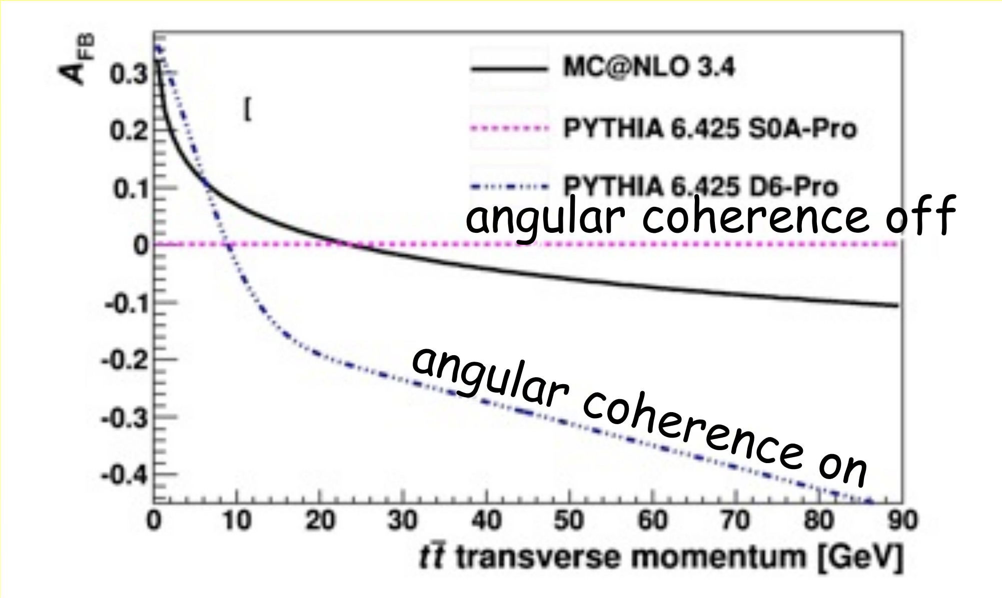
> 3 σ

arXiv:1107.4995



Modeling of the ttbar Pt

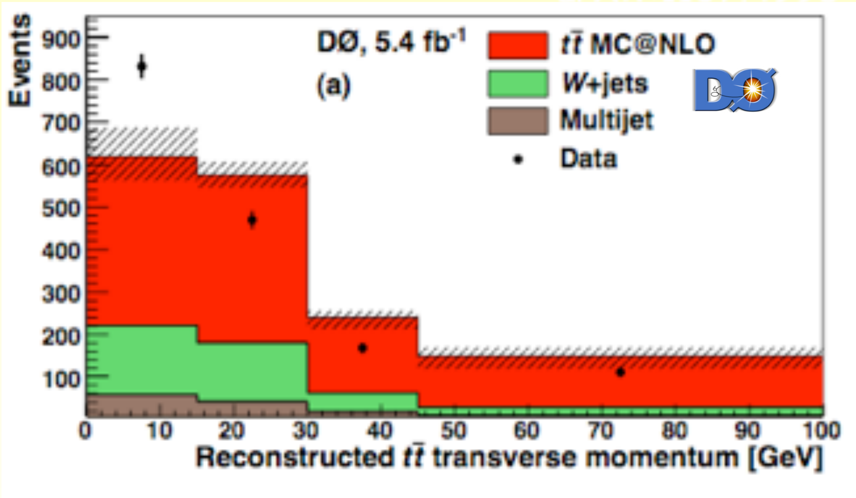
- correlation of A_{FB} with pt of the top pair
  - different predictions depending on the MC and tunes
  - systematics on the measurement conservatively estimated by turning off the dependency at D0



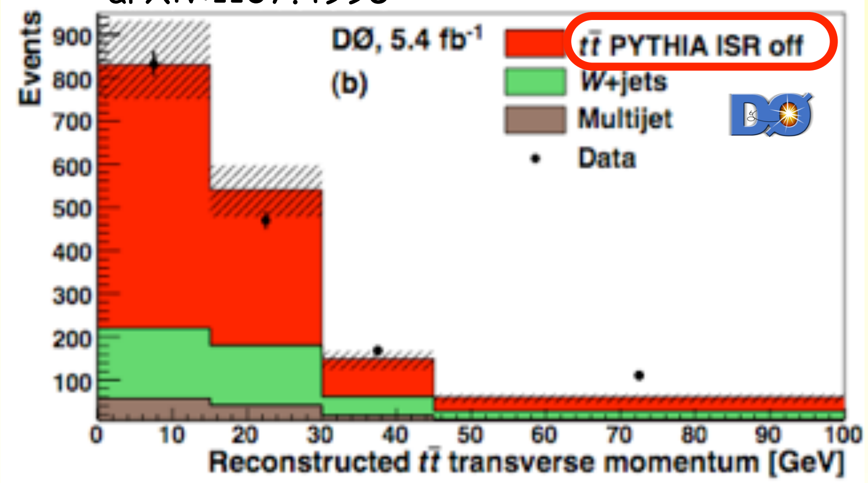
angular coherence between top and initial parton shower

- top pair pt not well modeled in data
  - check at the reconstruction level

arXiv:1107.4995

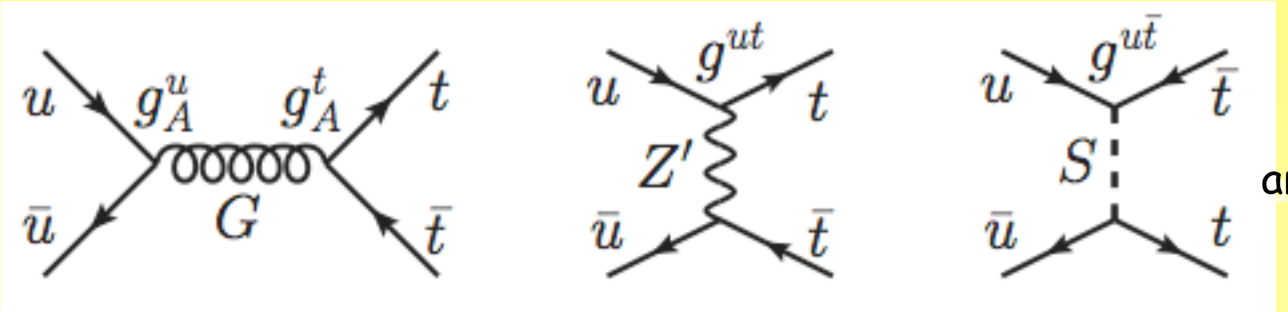


arXiv:1107.4995



Need better understanding of the predictions and dedicate measurements of the top pair pt

New Physics Scenarii



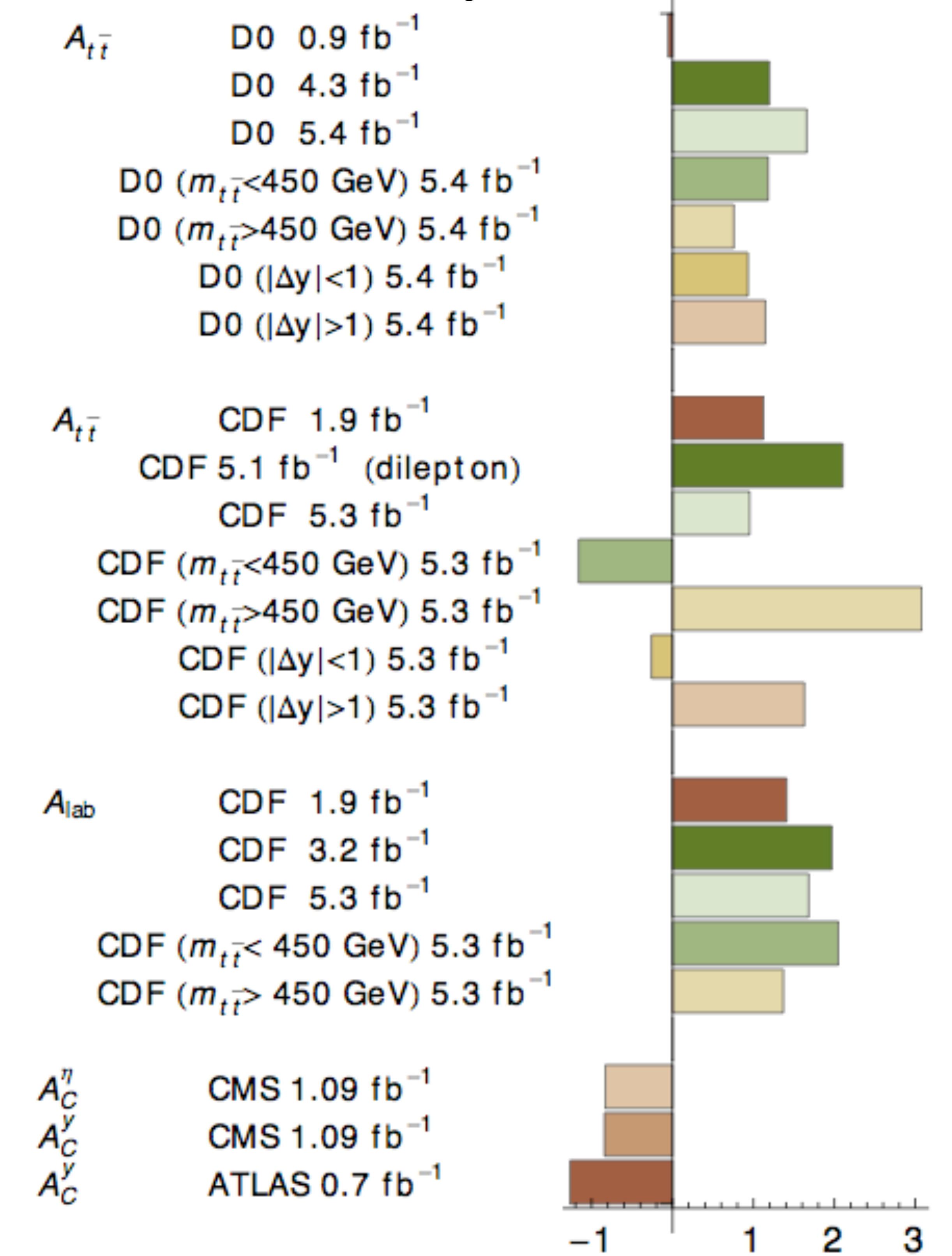
S. Westhoff, arXiv:1108.3341

- can be classified according to the channel through which the new particle interacts
  - s-channel:
    * color-octet vector (axigluons):
      constraints from FCNC, total ttbar cross section and dijet production at LHC
  - t-channel:
    * color-singlet vectors (Z', W'): large couplings to have a positive asymmetry
      constraints from total ttbar cross section, same sign top production at LHC for Z'
    * color-singlet scalar doublet (Φ)
  - u-channel:
    * color-triplet/sextet scalar (ω^4,Ω^4):
      constraints from same sign top production at LHC for Ω^4
- from experimental constraints
  - SM ttbar cross section + large asymmetry at large M_{ttbar} at the Tevatron + small asymmetry at the LHC: might favor axigluon and scalar doublet (Aguilar-Saavedra, Perez-Victoria, arXiv:1107.0841)
- but what about the constraints from the leptonic asymmetries ?
  - both CDF dilepton channel and D0 lepton+jets lepton-based asymmetries

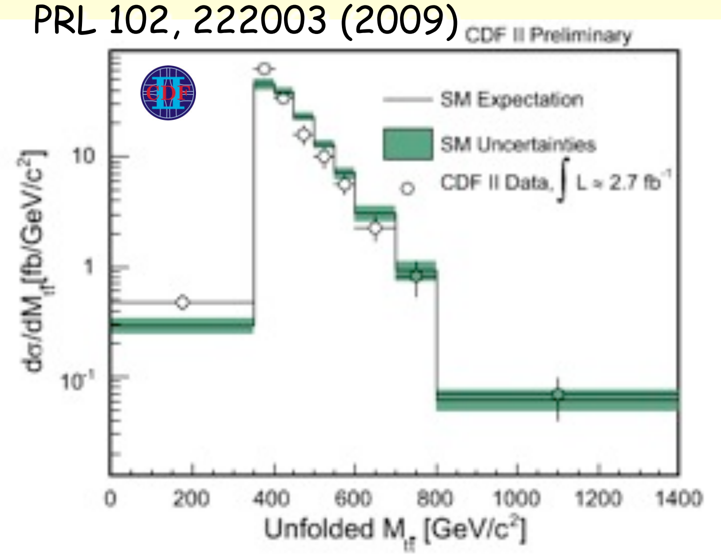
Summary

- several asymmetry has been measured
  - both at the Tevatron and the LHC
  - inclusive asymmetry ~ 2 σ from the SM at the Tevatron
- two measurements > 3 σ
  - CDF l+jets A_{ttbar} for M_{ttbar} > 450 GeV
  - D0 lepton based asymmetry on the l+jets channel
- LHC measurements not yet sensitive at a potentiel Tevatron excess
- numerous new physics scenario could play a role
  - need to be compatible with the inclusive cross section measurements
  - eager to have a measurement of the M_{ttbar} spectrum at LHC

Kuhn, Rodrigo, arXiv:1109.6830

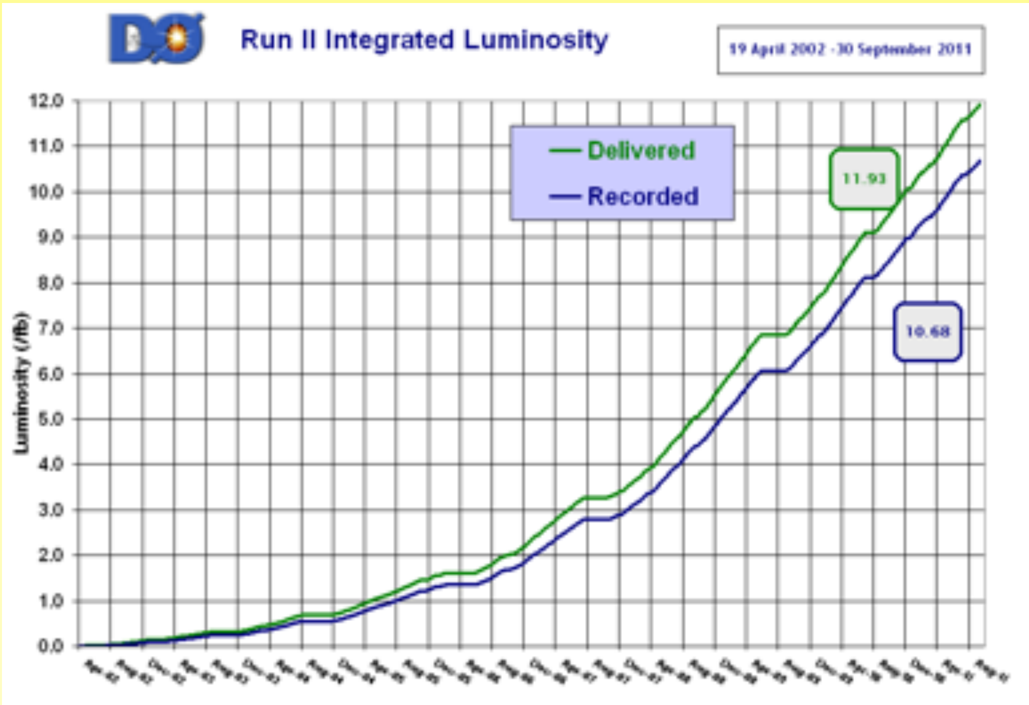


PRL 102, 222003 (2009)

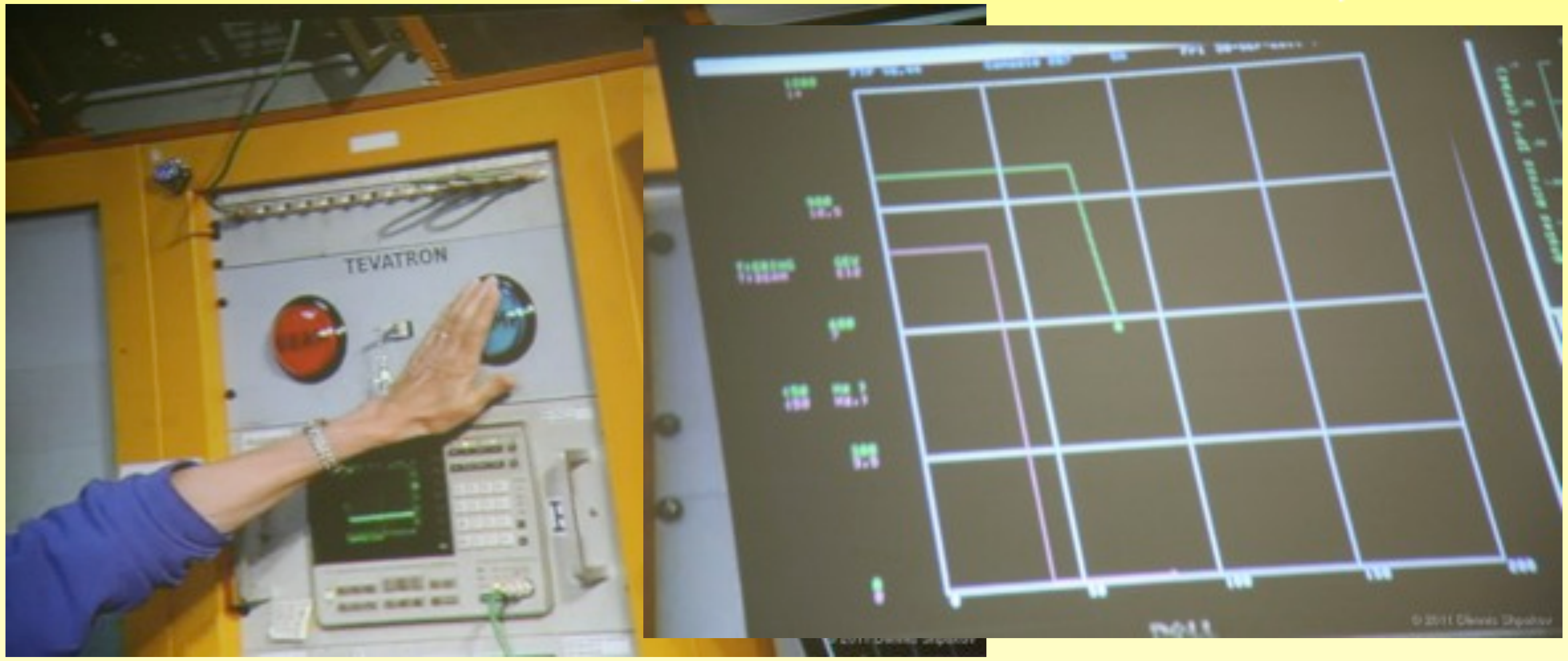


Perspectives

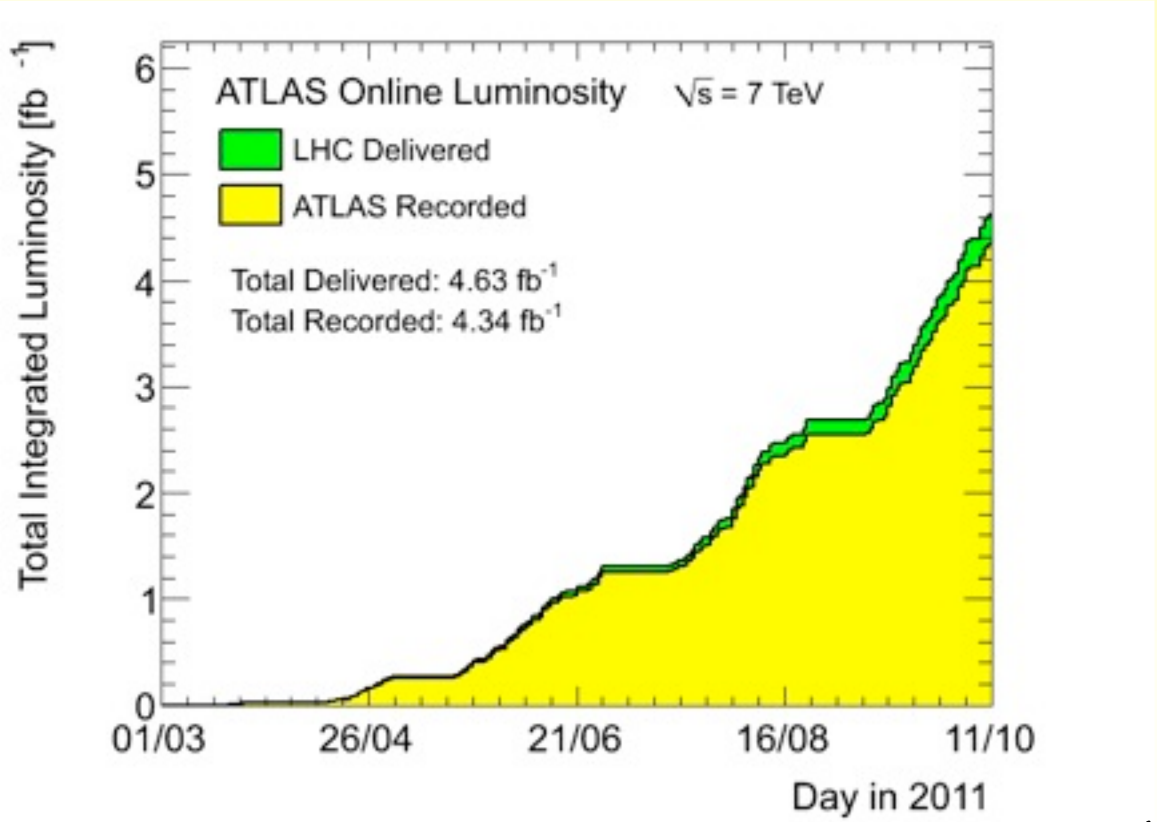
- Only half of the Tevatron data has been analyzed so far



30-SEP-11: turning off of the Tevatron after 28 years



- LHC will deliver ~ 5 fb^{-1} of data before the winter break



Stay tuned !

Backup

Systematics

CDF

effect	$\delta A^{p\bar{p}}$	$\delta A^{t\bar{t}}$
background magnitude	0.015	0.011
background shape	0.014	0.007
ISR/FSR	0.010	0.001
JES	0.003	0.007
PDF	0.005	0.005
color reconnection	0.001	0.004
LO MC generator	0.005	0.005
total	0.024	0.017

	sys.
background LJ	0.011
background DIL	0.0054
JES	0.0070
PDF	0.0047
Signal model	0.0092

D0

	Absolute uncertainty [a] (%)		
	Reconstruction level		Prod. level
Source	Prediction	Measurement	Measurement
Jet reco	±0.3	±0.5	±1.0
JES/JER	+0.5	−0.5	−1.3
Signal modeling	±0.3	±0.5	+0.3/−1.6
b tagging	-	±0.1	±0.1
Charge ID	-	+0.1	+0.2/−0.1
Bg subtraction	-	±0.1	+0.8/−0.7
Unfolding Bias	-	-	+1.1/−1.0
Total	+0.7/−0.5	+0.8/−0.9	+1.8/−2.6

Atlas

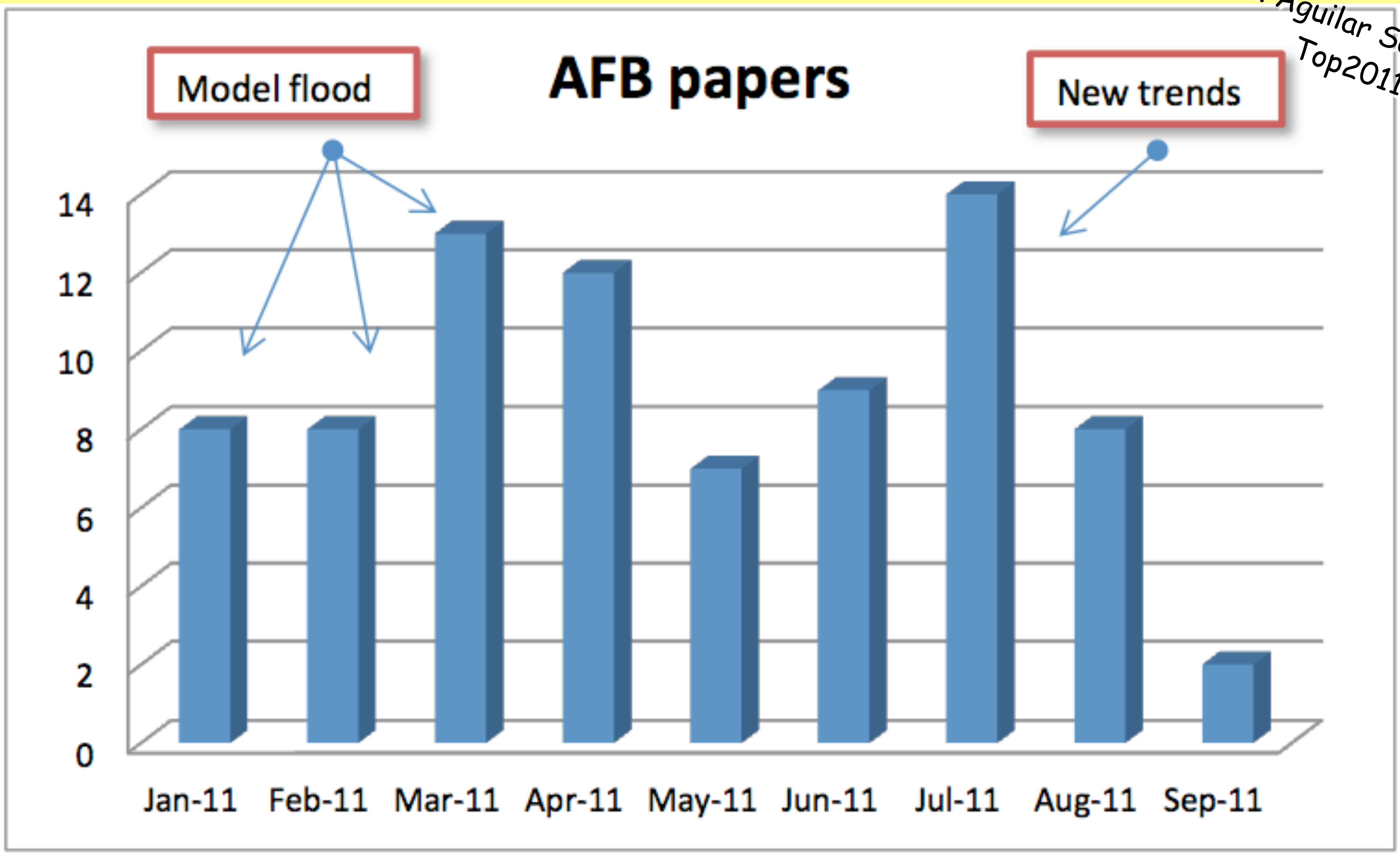
	Electron channel	Muon channel
Source of systematic uncertainty	ΔA_C	
Signal and background modelling		
$t\bar{t}$ generator	0.0243	0.0100
Parton shower/fragmentation	0.0108	0.0079
ISR/FSR	0.0074	0.0074
PDF uncertainty	0.0008	0.0008
Top mass	0.0059	0.0059
QCD normalisation	0.0062	0.0059
W+jets normalisation	0.0054	0.0097
W+jets shape	0.0043	0.0043
Z+jets normalisation	0.0002	0.0002
Z+jets shape	0.0010	0.0010
Single Top normalisation	0.0002	0.0002
Diboson normalisation	0.00001	0.00001
MC sample sizes	0.0043	0.0029
Detector modelling		
Muon efficiencies	(n.a.)	0.0002
Muon momentum scale and resolution	0.0004	0.0004
Electron efficiencies	0.0004	(n.a.)
Electron energy scale and resolution	0.0004	0.0004
Lepton charge misidentification	0.0002	0.0002
Jet energy scale	0.0041	0.0046
Jet energy resolution	0.0105	0.0040
Jet reconstruction efficiency	0.0003	0.0003
b-tagging scale factors	0.0038	0.0038
Charge asymmetry in b-tagging efficiency	0.0007	0.0007
Calorimeter readout	0.0015	0.0029
Combined uncertainty	0.032	0.022

CMS

	A_C^{η}		A_C^{y}	
Source of Systematic	− Variation	+ Variation	− Variation	+ Variation
JES	−0.003	0.000	−0.007	0.000
JER	−0.002	0.000	−0.001	0.001
Q^2 scale	−0.014	0.000	−0.013	+0.003
ISR/FSR	−0.006	+0.003	0.000	+0.024
Matching threshold	−0.006	0.000	−0.013	+0.006
PDF	−0.001	+0.001	−0.001	+0.001
b tagging	−0.001	+0.003	0.000	0.001
Lepton ID/sel. efficiency	−0.002	+0.004	−0.002	0.003
QCD model	−0.008	+0.008	−0.006	+0.006
Pileup	−0.002	+0.002	0.000	0.000
Overall	−0.019	+0.010	−0.021	+0.026

Number of New Physics Publications About the ttbar Asymmetry

J.A. Aguilar Saavedra, Top2011



~ 80 dedicated papers this year