$t\bar{t}$ Asymmetries

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The Top Quark

- Heaviest known elementary particle:

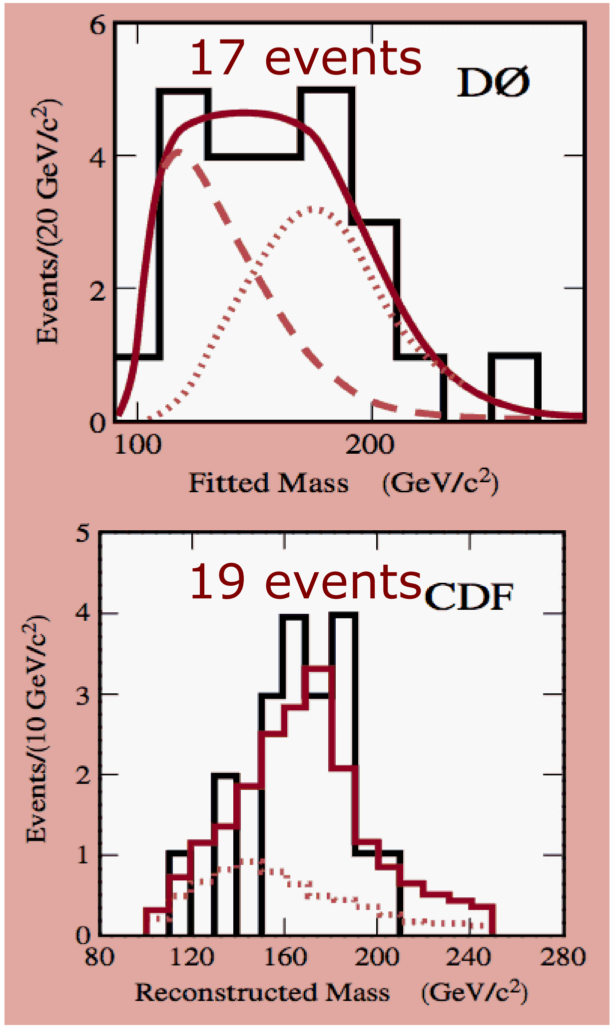
$$m_t = 173.2 \pm 0.9 \text{GeV}$$

arXiv:1107.5255

- Standard Model:
  - Single or pair production
  - Electric charge +2/3 e
  - Short lifetime 0.5×10^{-24}s
    - Bare quark - no hadronization
  - ~100% decay into Wb
  - Large coupling to SM Higgs boson

Top: The TevatrOn Particle

Discovered in 1995 by CDF and DØ at Fermilab (with few events)



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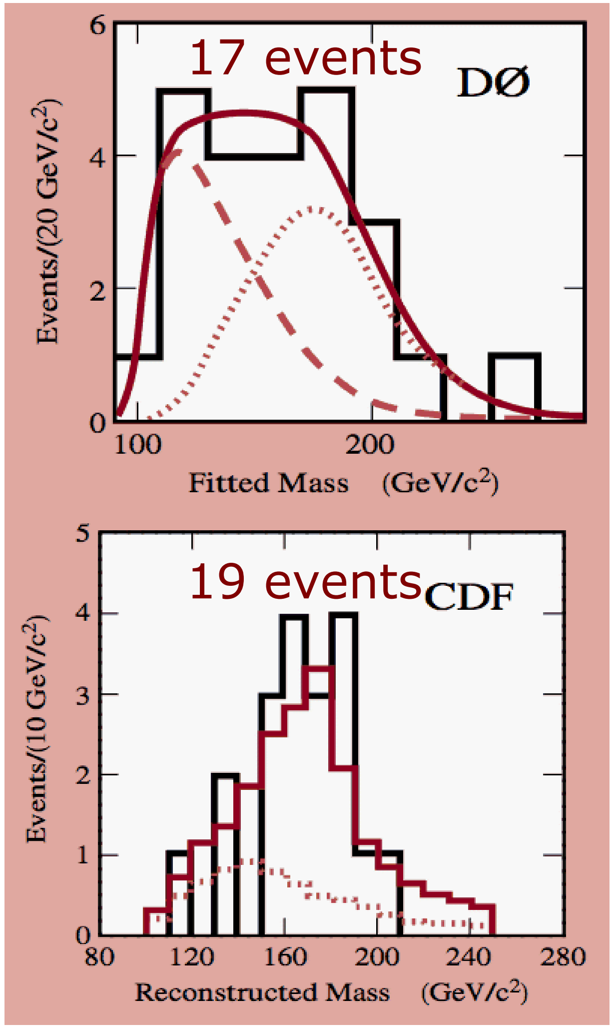
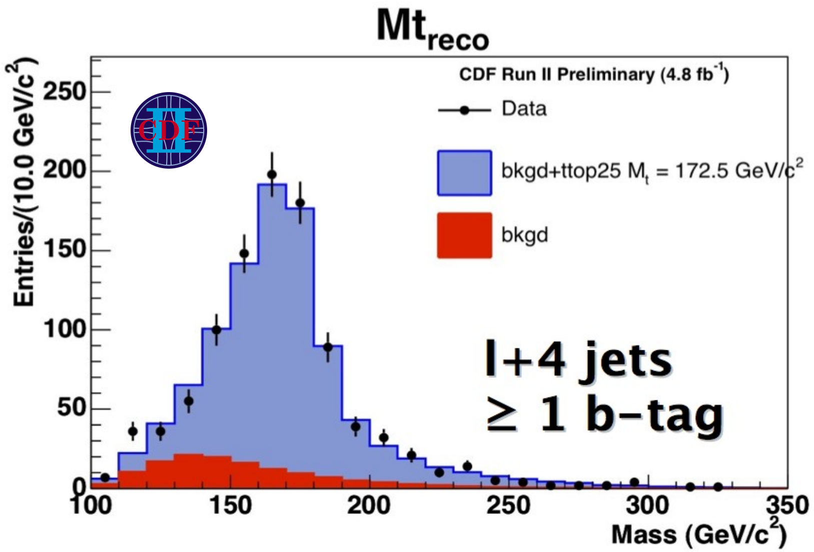
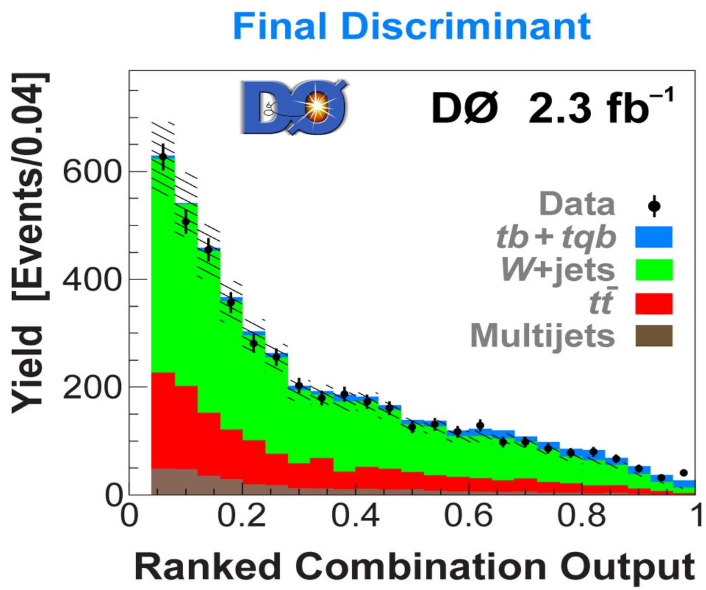


Situation today:

1000s of events!

Rediscovered in 2009 in single top production



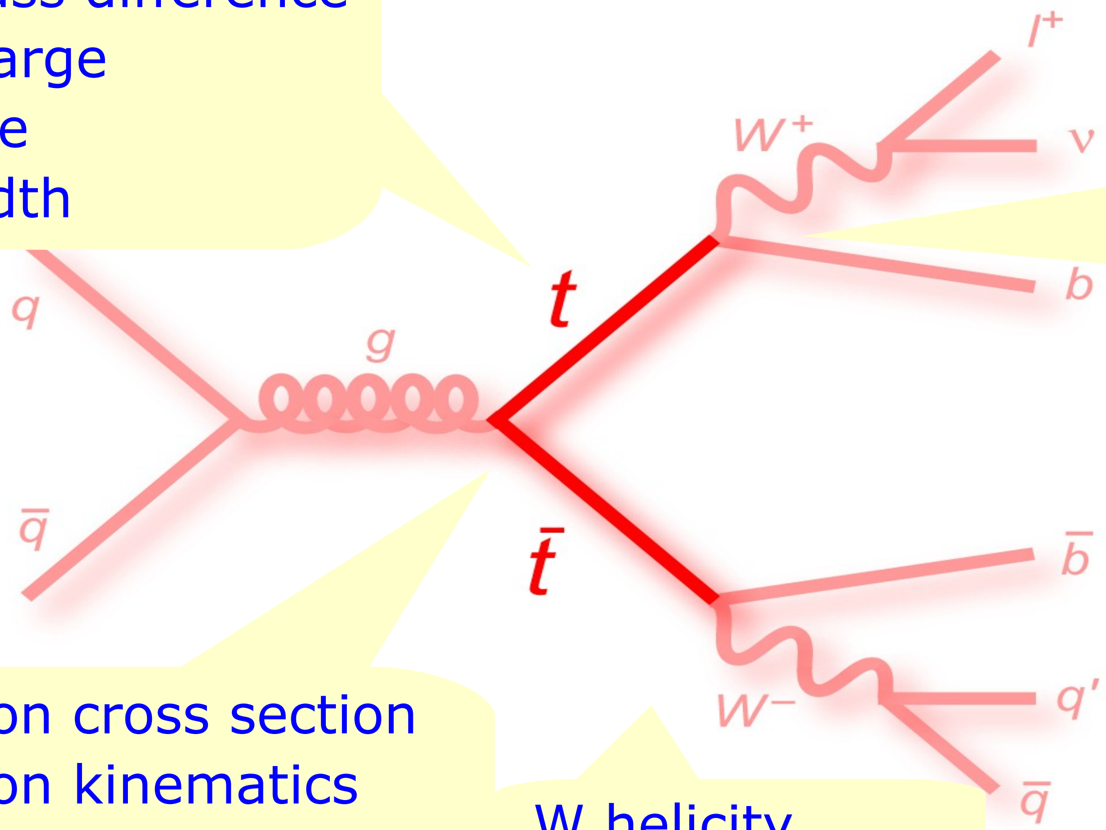


Since 2010 LHC operating → top quark factory

All we study about the Top

Top mass
Top mass difference
Top charge
Lifetime
Top width

Branching ratios
$|V_{tb}|$
Anomalous coupling
New/Rare decays



Spin correlation
Asymmetry
Color Flow

Production cross section
Production kinematics
Production via resonance
New particles

W helicity

s- & t- channel production, properties and searches in single top events

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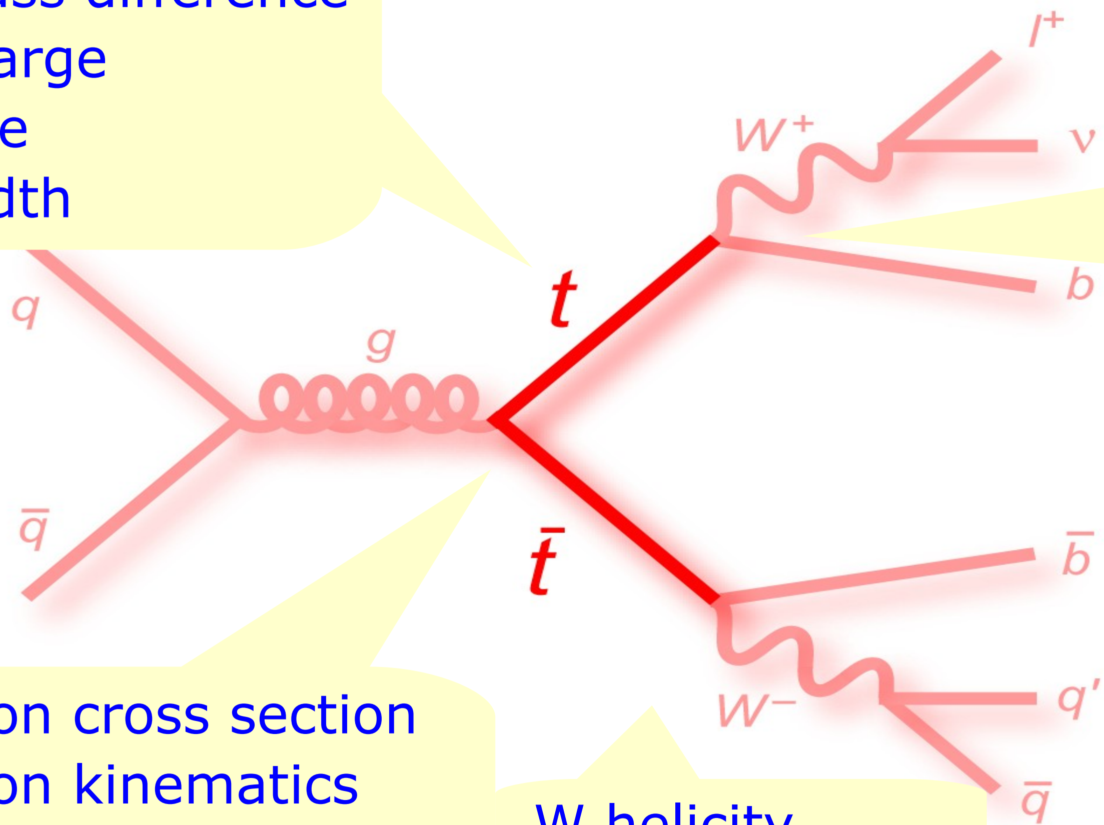

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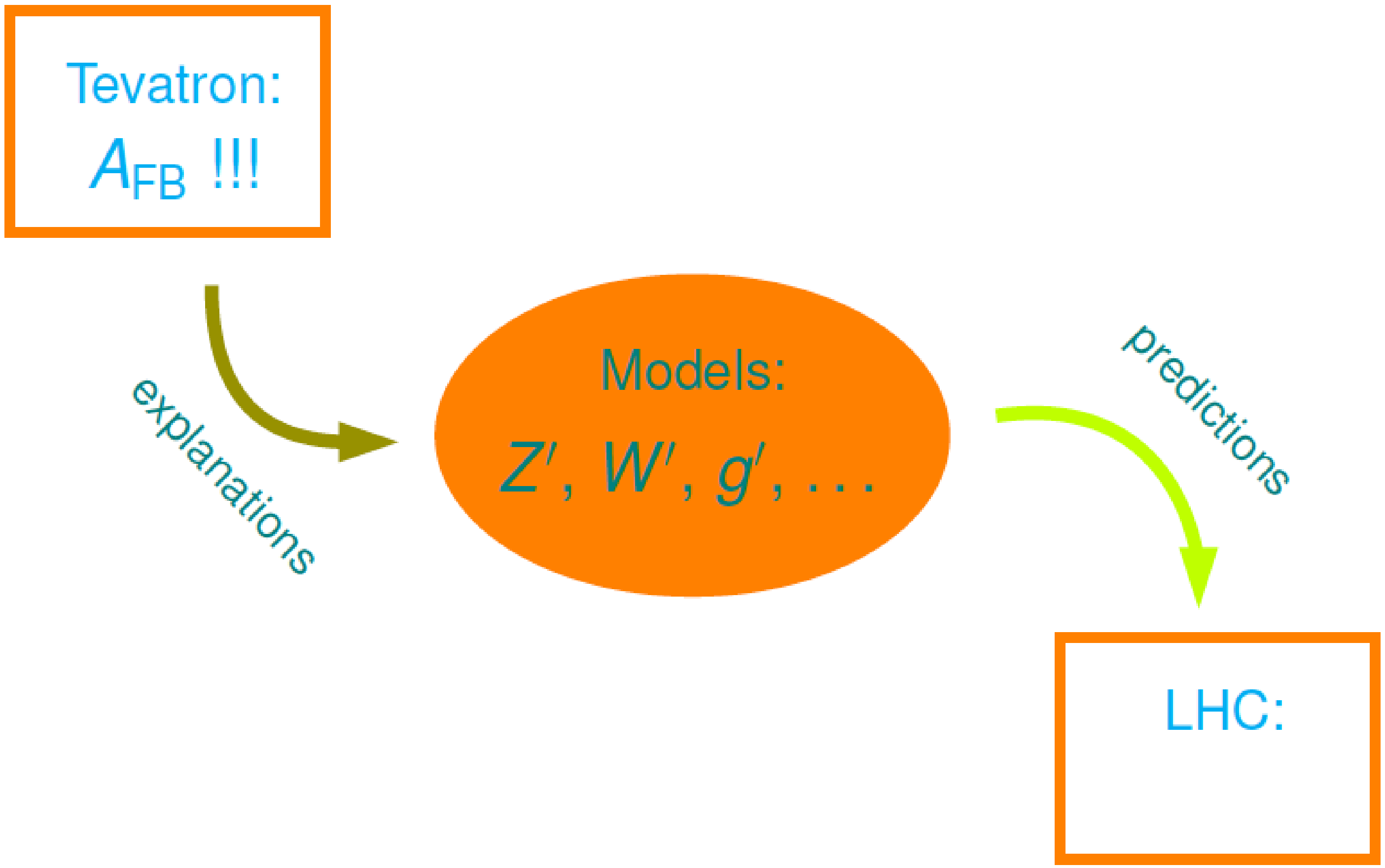
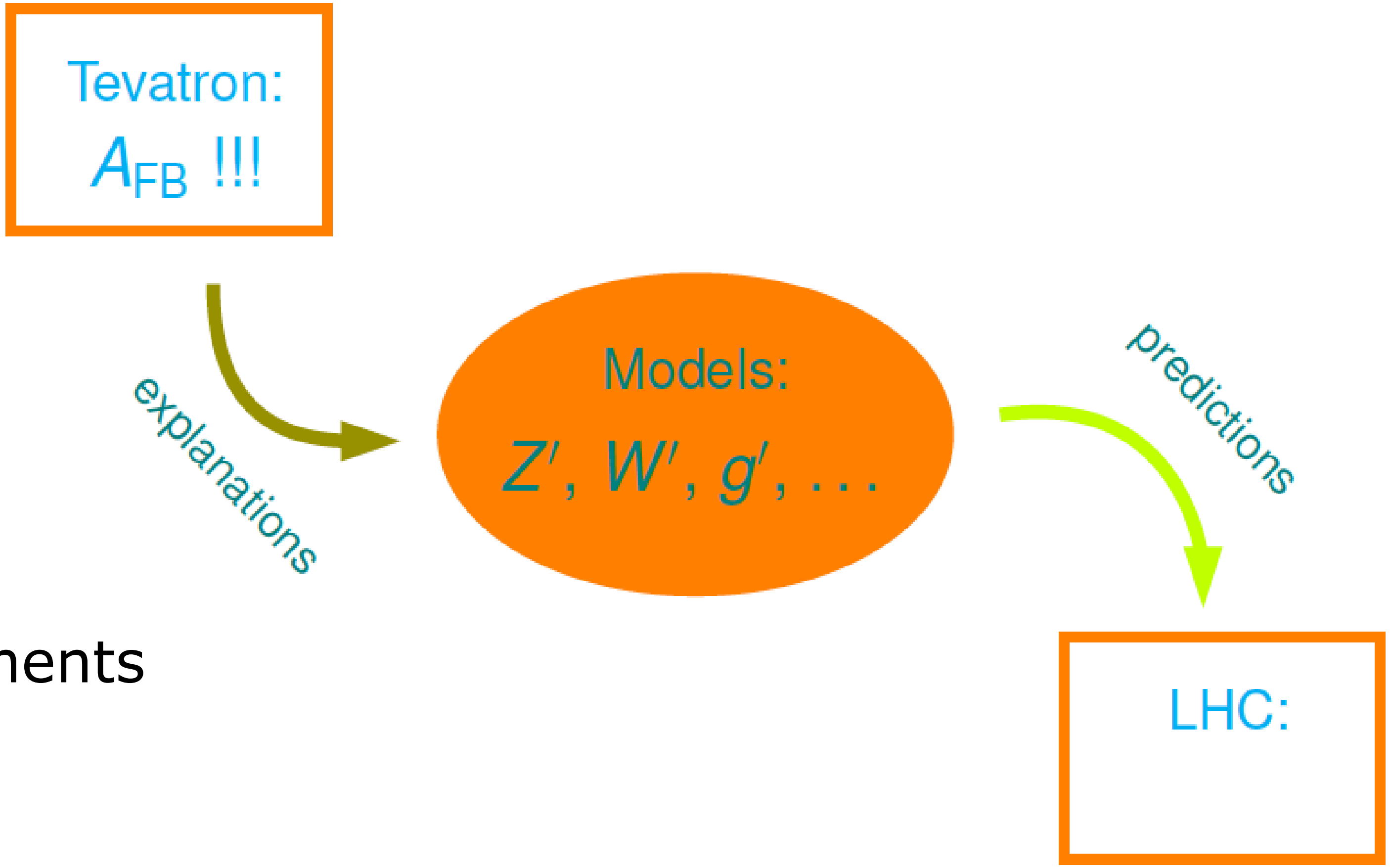
Outline



J. Aguilar Saavedra; Top2011

Outline

- Asymmetry definitions
- Asymmetry @ Tevatron
- Theory:
  - SM
  - new physics models
- Asymmetry @ LHC
- Other related measurements
- Conclusion



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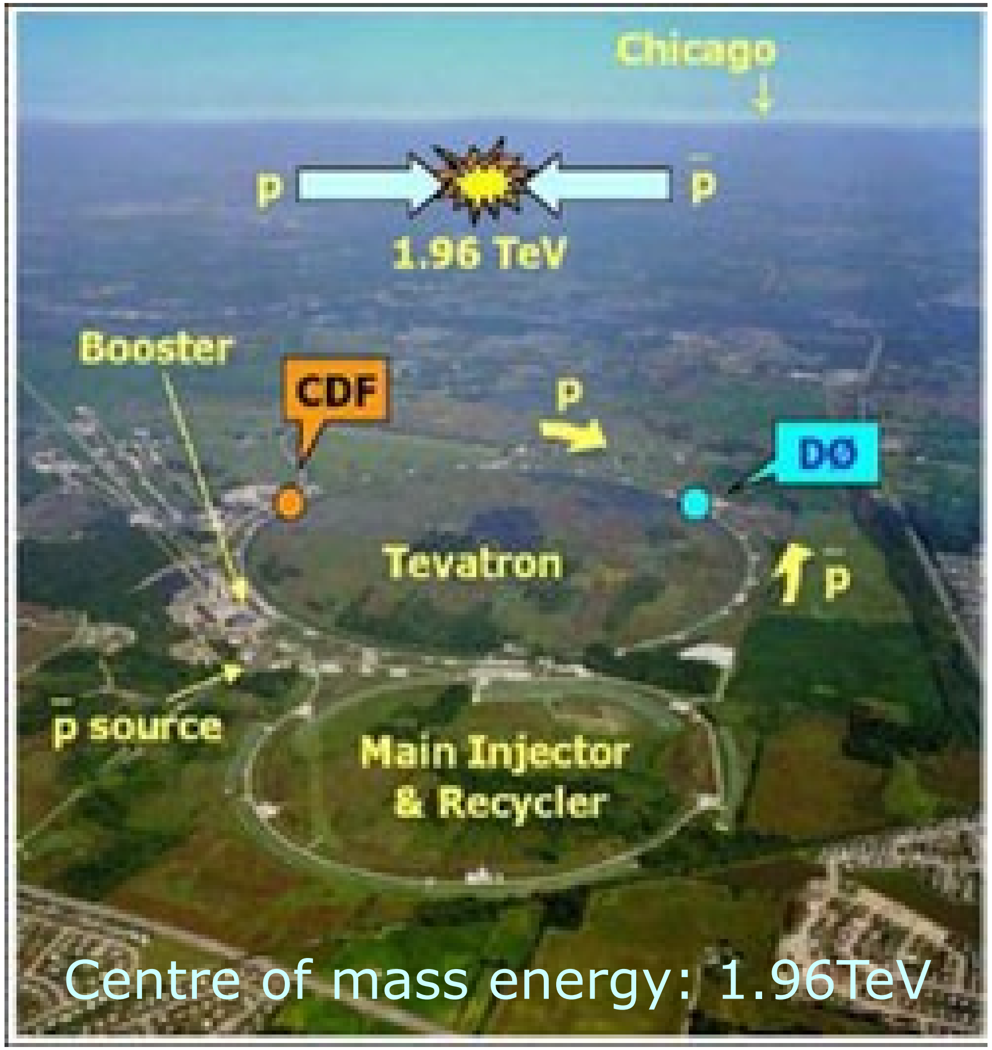
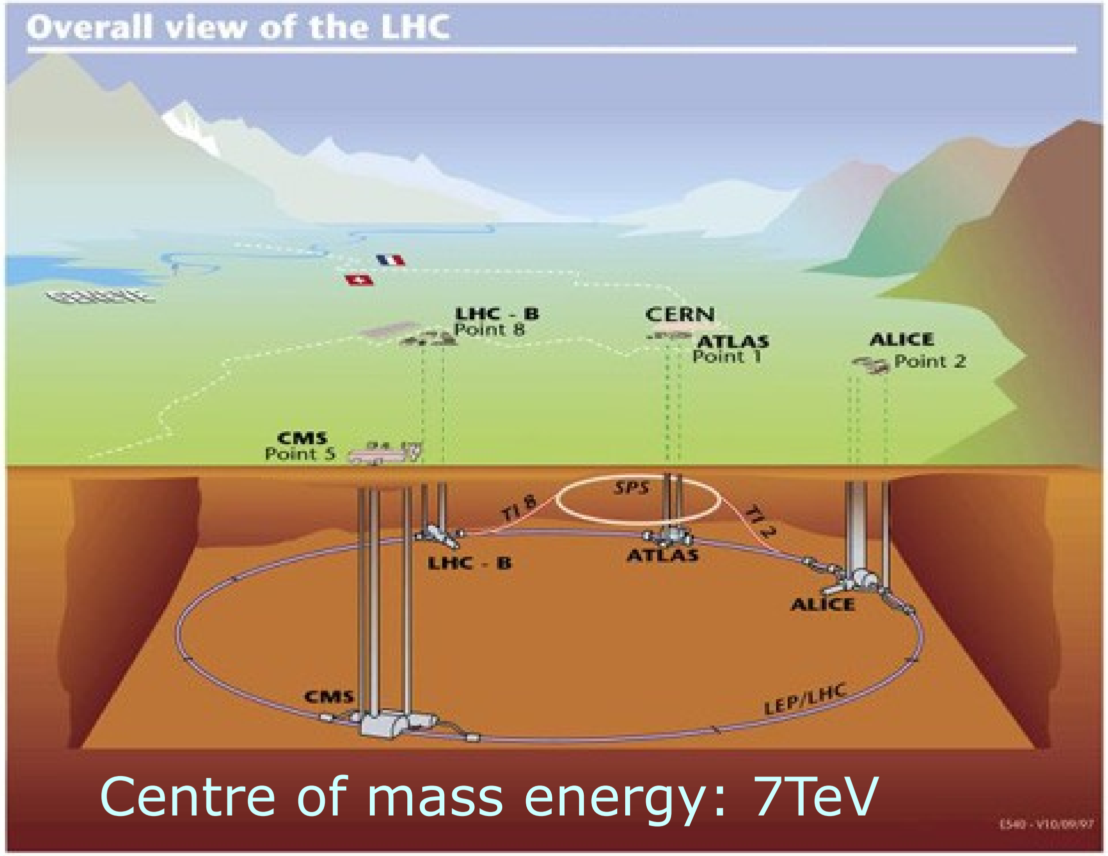
Tevatron and LHC





$p\bar{p}$ collider

pp collider

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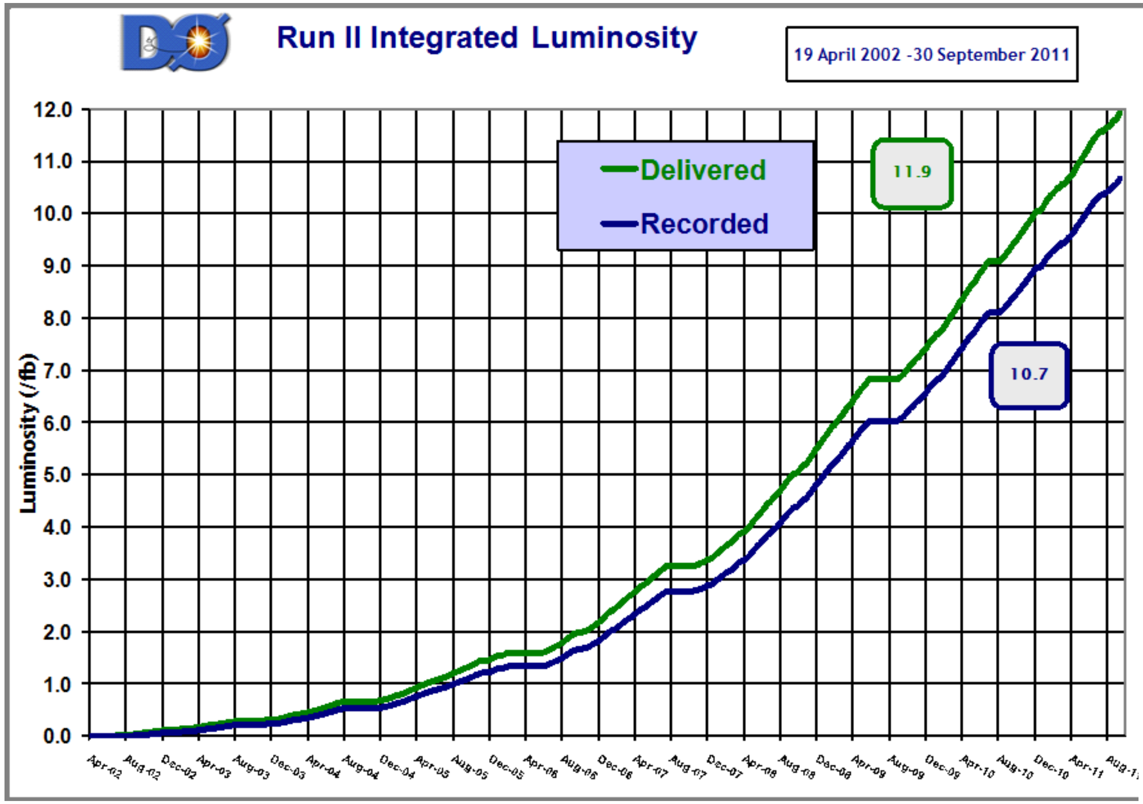
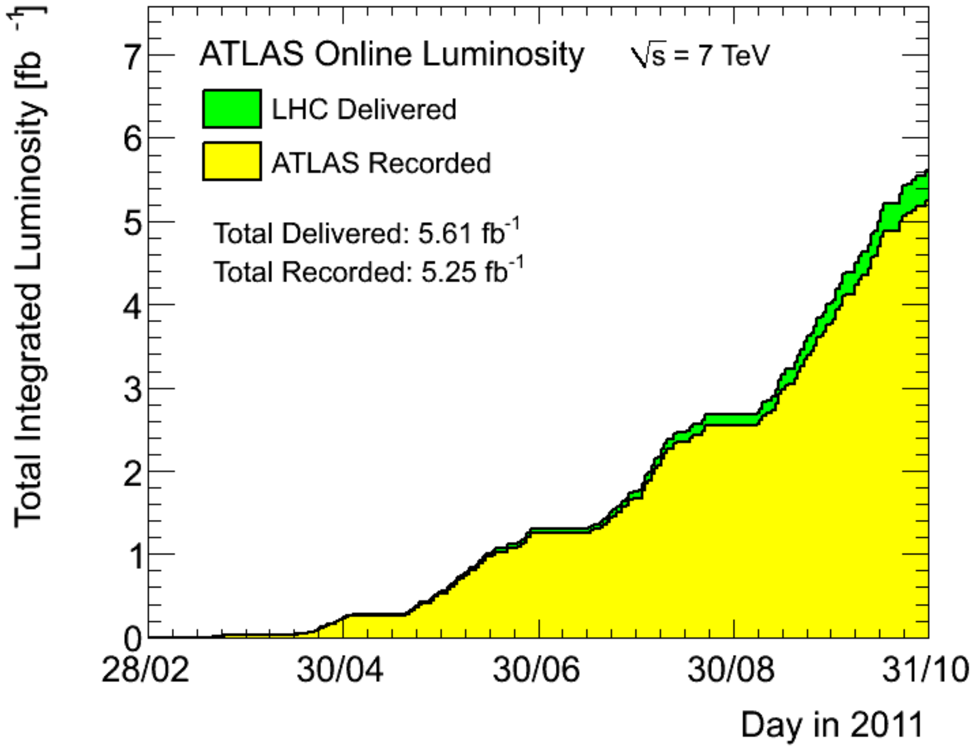
How much Data we collected





~11.5fb^{-1} delivered

>10fb^{-1} on disk per experiment

Tevatron ended operation on 30.9.2011

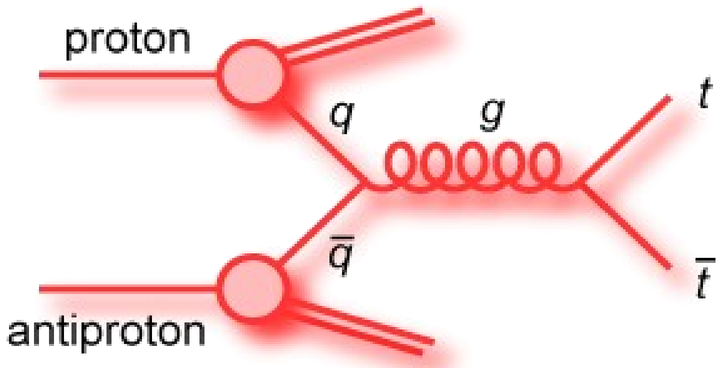
>5fb^{-1} delivered

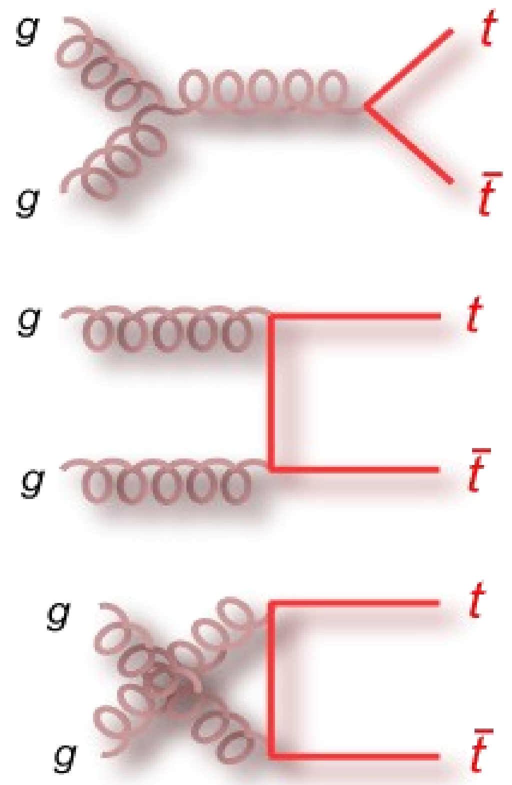
~5fb^{-1} on disk per experiment

Some $t\bar{t}$ Basics

- Most properties measured in $t\bar{t}$ events
- At Tevatron:

  85% + 15%





- At LHC:

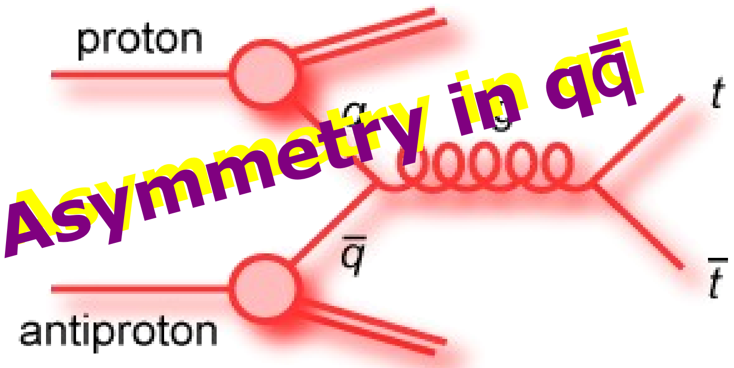
  14 TeV: 10% + 90%

  7 TeV: 15% + 85%

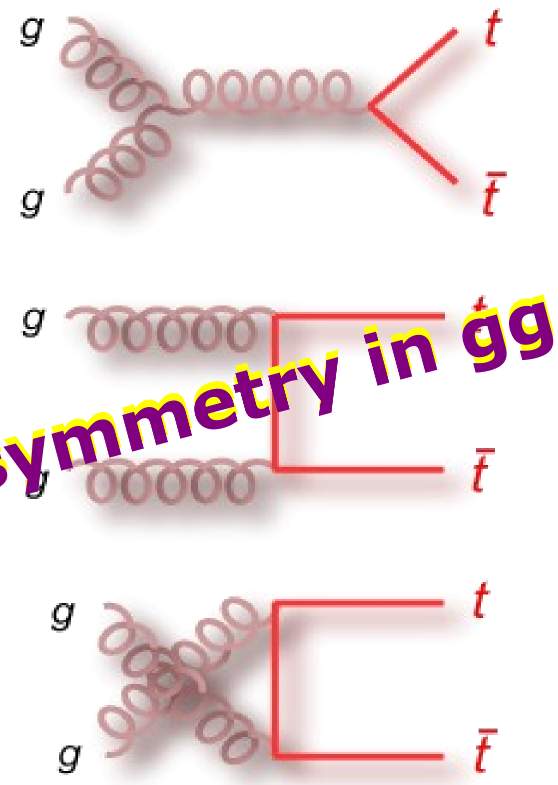
- Production cross section (@Tevatron):
  approximate NNLO: $\sigma = 7.46^{+0.48}_{-0.67}\,pb$ @ m_t=172.5GeV
  Moch, Uwer, PRD 78, 034003 (2008)
  - 20 times higher @LHC (7TeV): $\sigma = 164.6^{+11.4}_{-15.7}\,pb$

Some $t\bar{t}$ Basics

- Most properties measured in $t\bar{t}$ events
- At Tevatron: 85% + 15%
- At LHC:
  14 TeV: 10% + 90%
  7 TeV: 15% + 85%



Asymmetry in $q\bar{q}$



No asymmetry in gg

- Production cross section (@Tevatron):
  approximate NNLO: $\sigma = 7.46^{+0.48}_{-0.67}\, pb$ @ m_t=172.5GeV
  - 20 times higher @LHC (7TeV): $\sigma = 164.6^{+11.4}_{-15.7}\, pb$

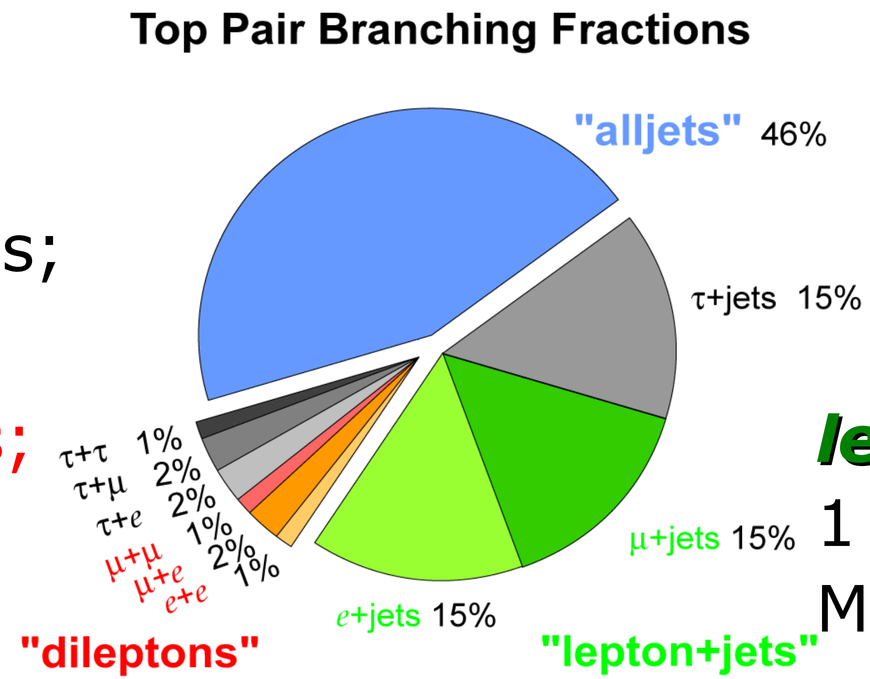
Reminder of some Basics: Final States in $t\bar{t}$

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

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

pure hadronic:
≥6 jets (2 b-jets)

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)

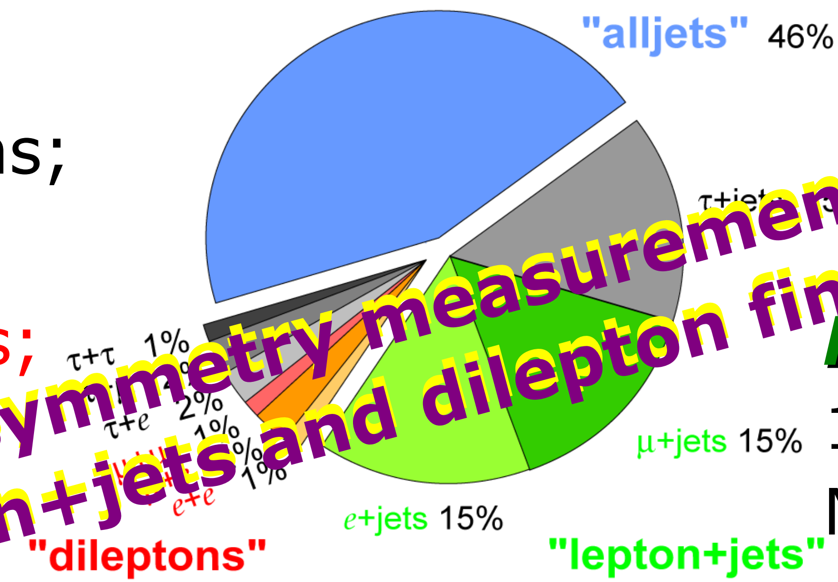
Reminder of some Basics: Final States in $t\bar{t}$

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

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

pure hadronic:
≥6 jets (2 b-jets)

Top Pair Branching Fractions



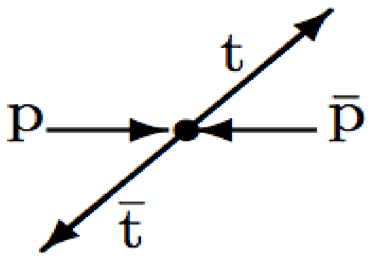
Asymmetry measurements in lepton+jets and dilepton final states

dilepton:
2 isolated leptons;
High missing E_T
from 2 neutrinos;
2 b-jets

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

Definitions and Introduction

- Do top quarks follow preferentially the initial quark or antiquark direction?

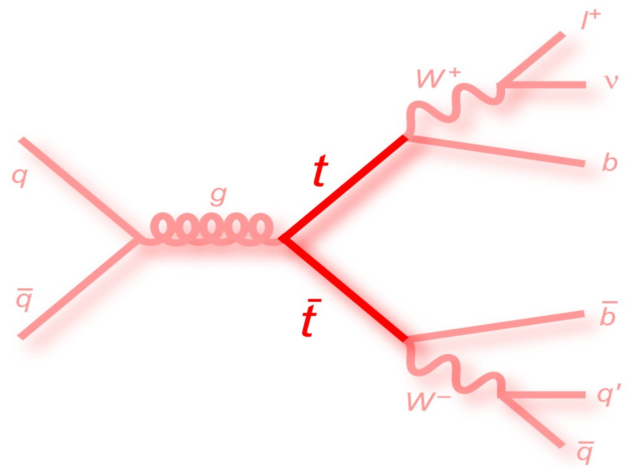


- Several asymmetry definitions can be studied
  - $t\bar{t}$ Forward backward asymmetry

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

  - Lepton based asymmetry

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

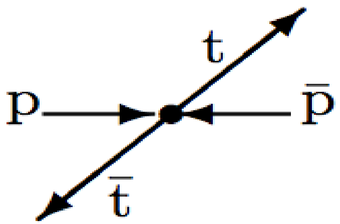


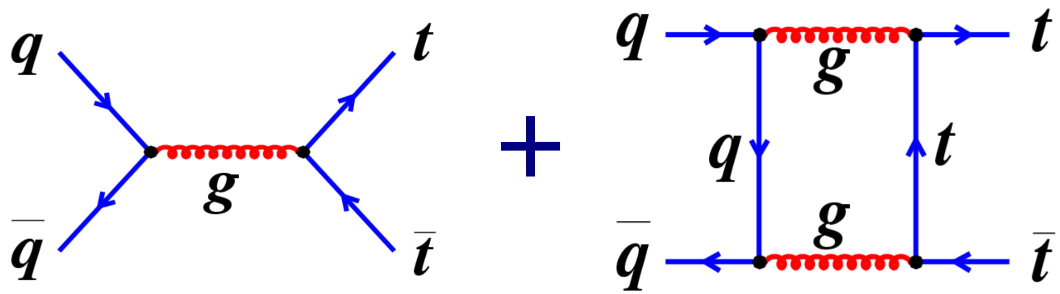
$\Delta y = y_t - y_{\bar{t}}$

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

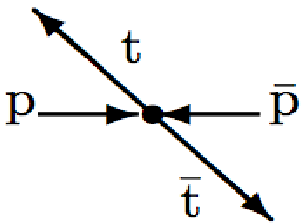
Definitions and Introduction

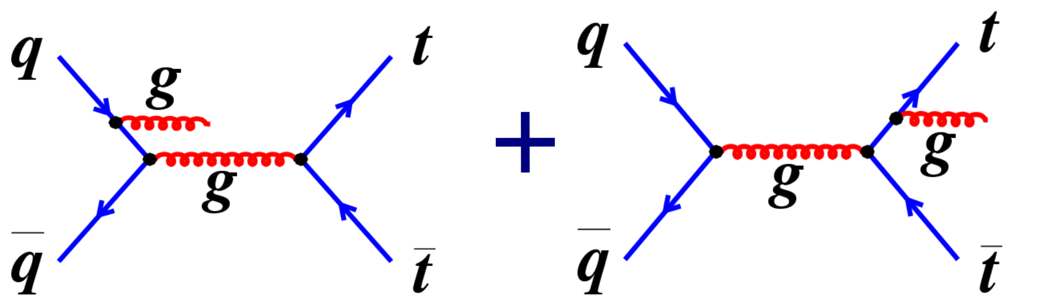
- LO: No charge asymmetry expected
- NLO QCD: Interference between $q\bar{q}$ diagrams
- Tree level and box diagrams:
  - Positive asymmetry





- Initial and final state radiation:
  - Negative asymmetry





Definitions at Tevatron and LHC

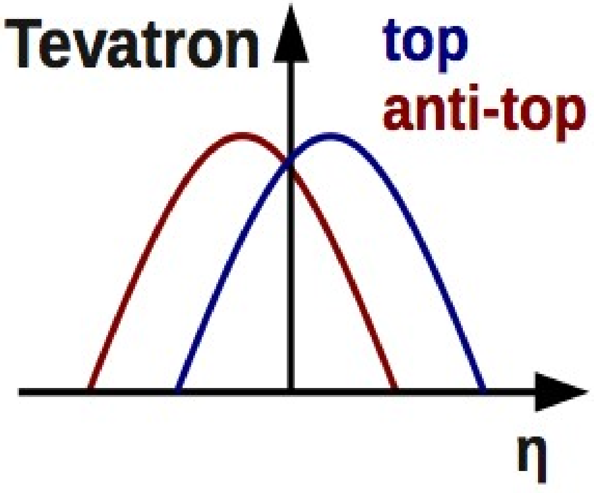
- Tevatron: $p\bar{p}$ is CP eigenstate → pp (LHC) is not
  → different way to measure the effect at Tevatron and LHC
- LHC: Charge asymmetry (other possibilities: discussed later)

Tevatron

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

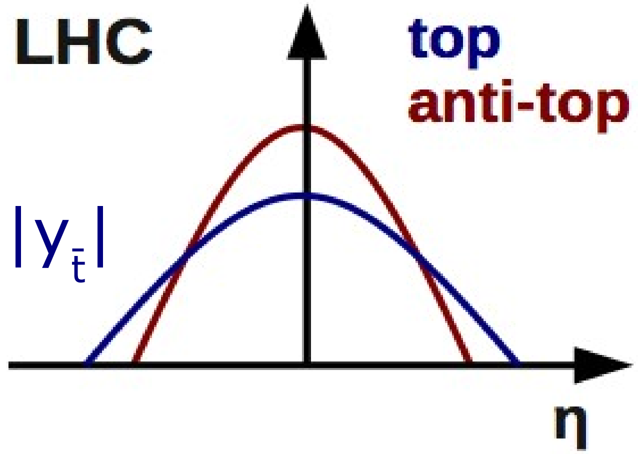
LHC

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



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

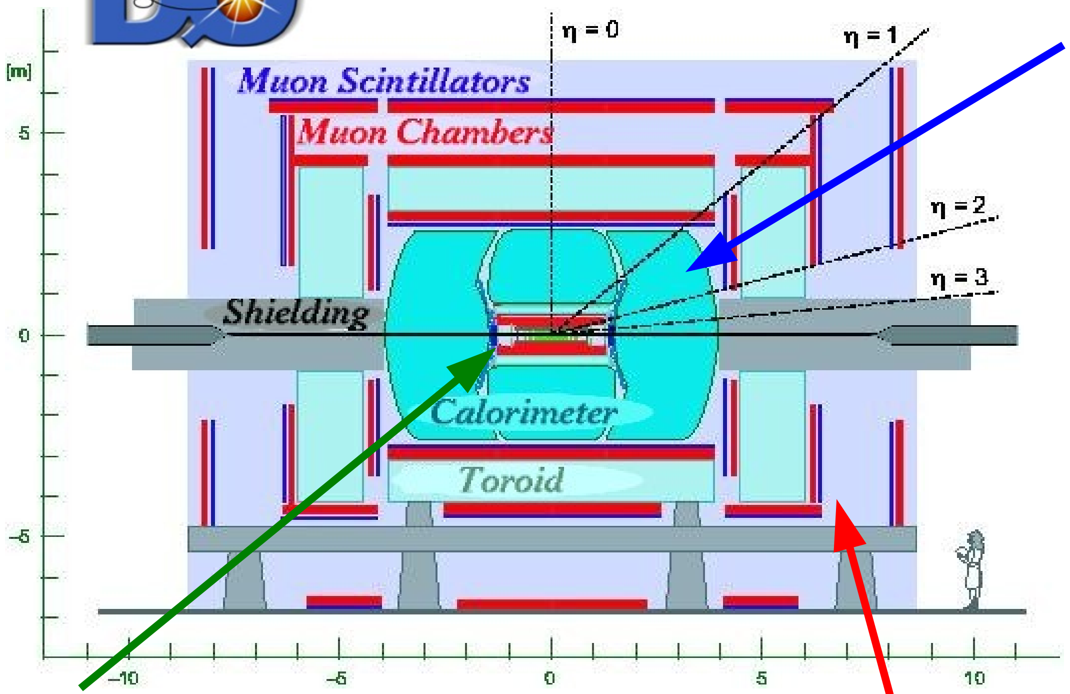
$\Delta y = y_t - y_{\bar{t}}$ $\Delta|y| = |y_t| - |y_{\bar{t}}|$



Measurements at the Tevatron

- Reconstruction
- Measurements in lepton+jets & dilepton
- Dependencies of the asymmetry
- Modeling concerns

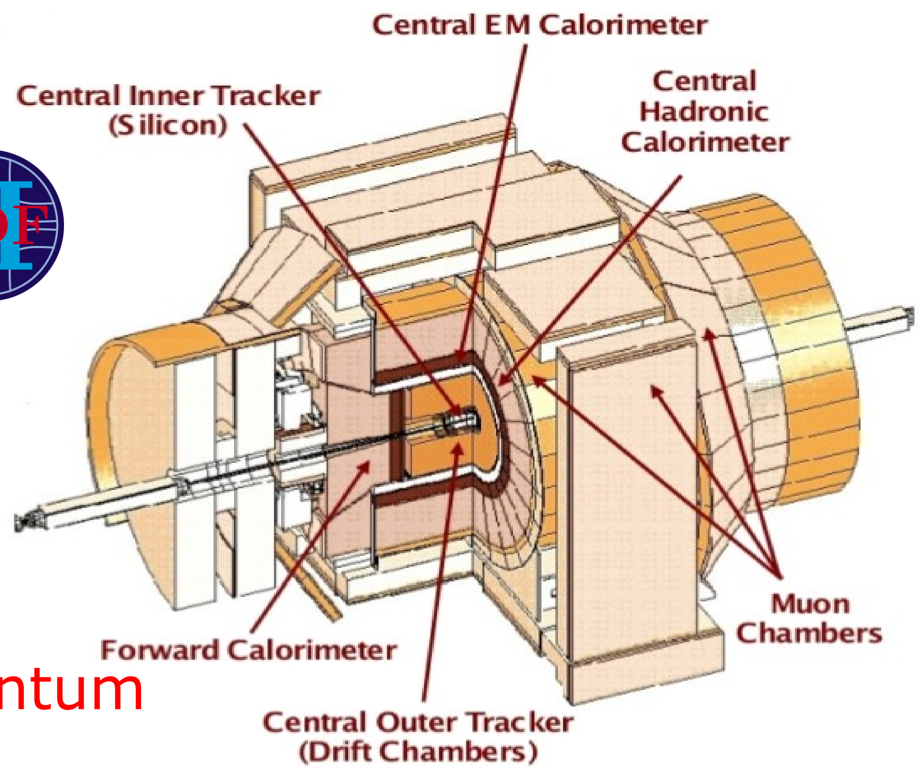
The CDF & DØ Detectors



Calorimeter: Identification and energy measurement of jets and electrons

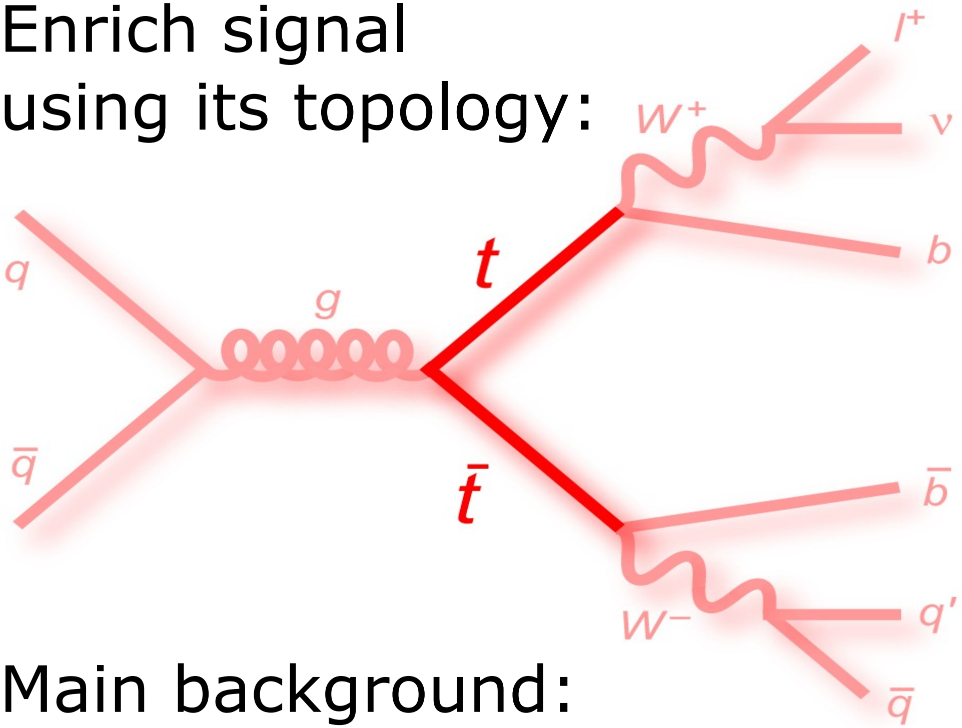
Tracker: Detection and momentum measurement for charged particles

Muon chamber: Identification and momentum measurement of muons



Event Selection l+jets

- Enrich signal using its topology:



1 lepton (e or μ) with p_T>20GeV; |η|<1.1 (DØ: $|\eta_\mu|$<2.0)

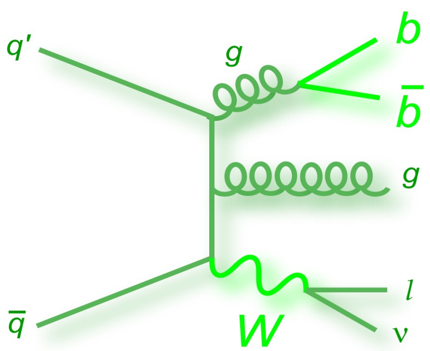
Missing p_T for neutrino ($\not{E}_T$): >20GeV

≥4 jets with p_T>20GeV;
CDF: |η|<2.0; DØ: |η|<2.5

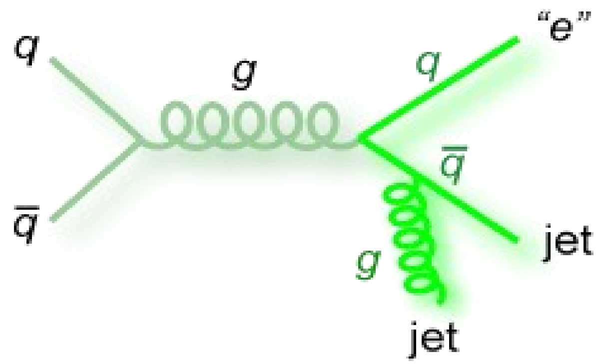
≥1 jet b-tagged

- Main background:

W+jets

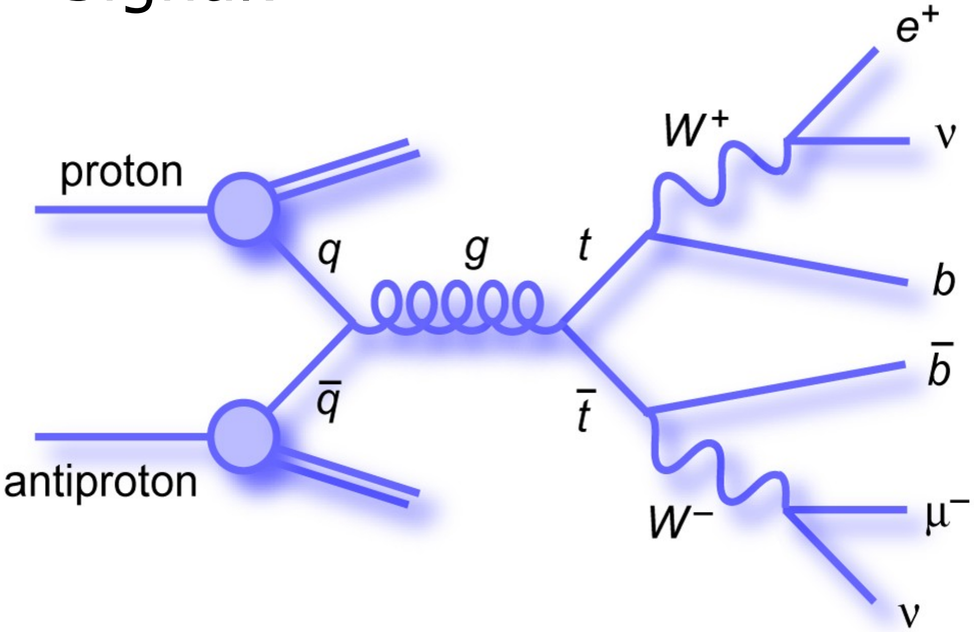


and QCD multijets



Event Selection dilepton

- Signal:



2 leptons (e or μ) with p_T>20GeV; $|\eta_e|$<1.1 or 1.2<$|\eta_e|$<2.8; $|\eta_\mu|$<1.1

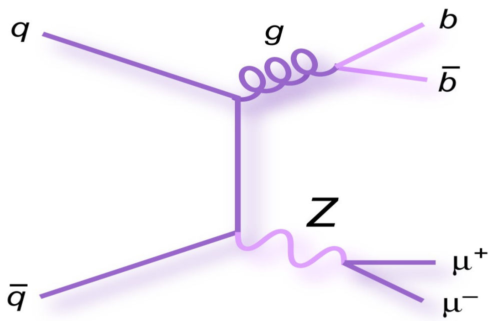
$\not{E}_T$>25 or 50GeV (depending on angle between $\not{E}_T$ direction and closest lepton or jet)

≥2 jets with p_T>15GeV and $|\eta|$<2.5

H_T (scalar sum of lepton & jet p_T & $\not{E}_T$)>200GeV

- Main background:

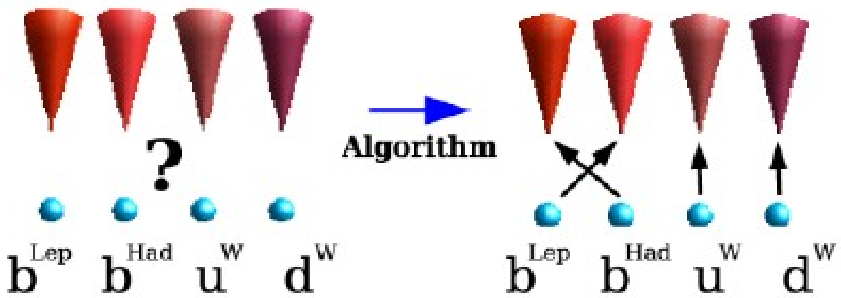
Z+jets

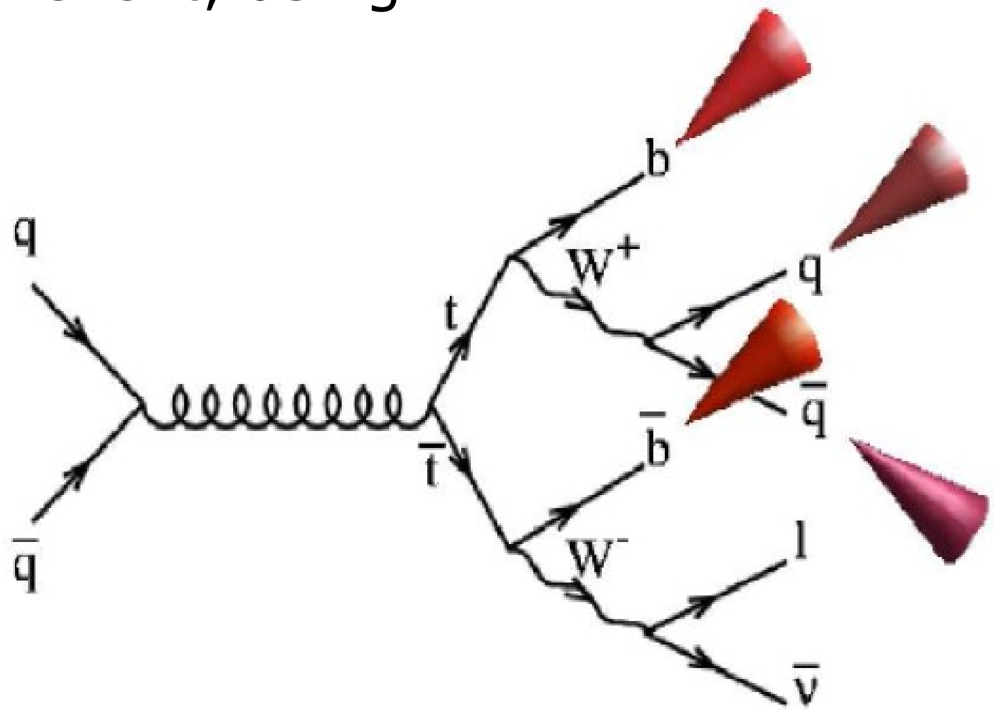


and QCD multijets

$t\bar{t}$ Reconstruction

- L+jets: kinematic fit to reconstruct full event, using
  - Fixed top mass
  - Two jets have to have $m_{jj}=m_W$
  - B-jet identification
- Experimental resolutions taken into account





- Dilepton: also kinematic fitter, but more dof (2 neutrinos) → use a priori probability distributions as input, calculate probability

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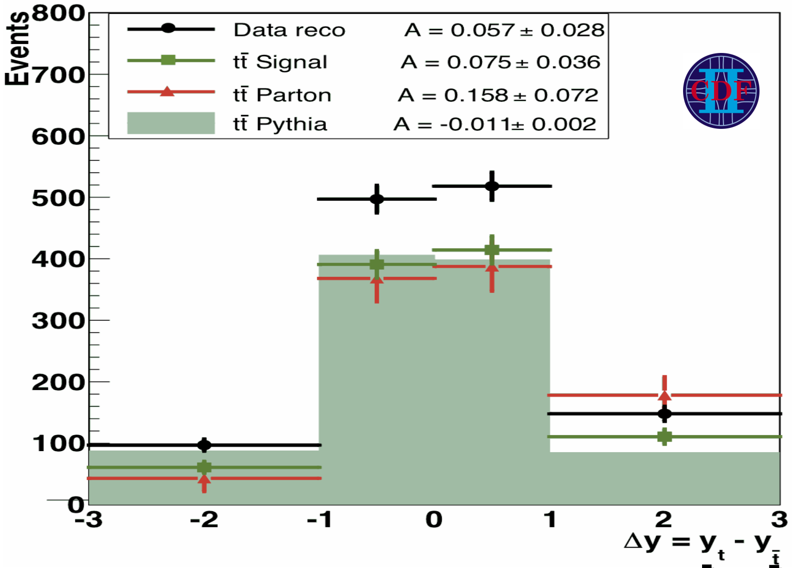
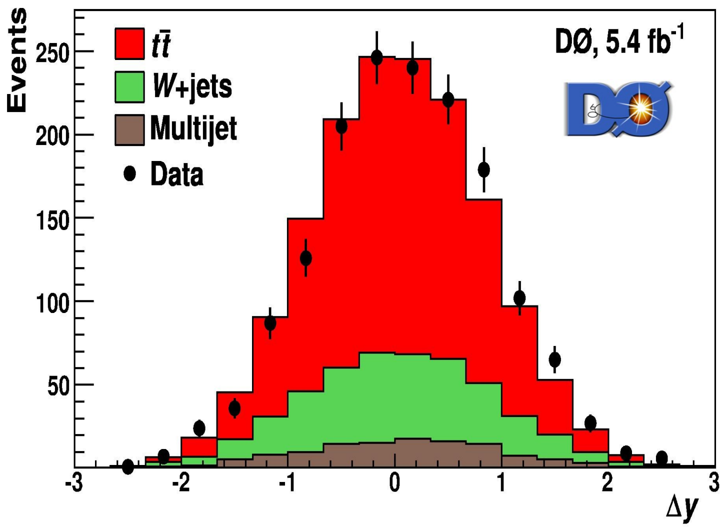
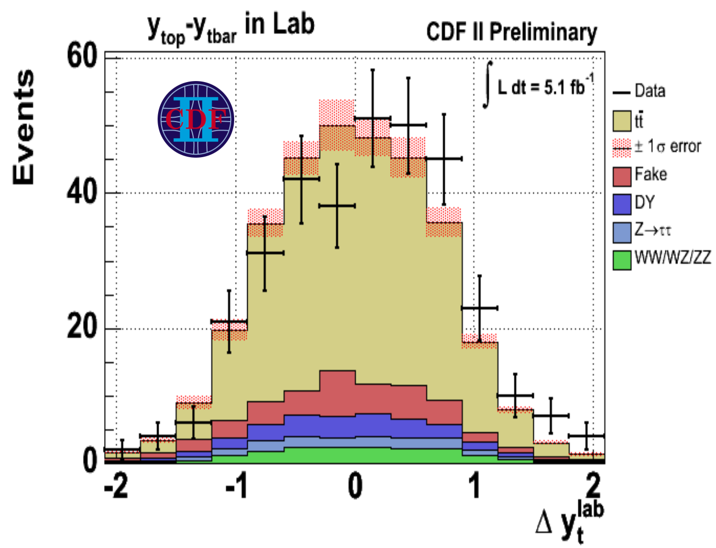
Extracting the raw Asymmetry

- Subtract background from Data
  - DØ: Background fitted with likelihood discriminant
  - CDF: Background from MC prediction







l+jets

CDF: $A_{FB}^{t\bar{t}}$=7.5±3.7% (MC@NLO prediction: 2.4±0.5%)

DØ: $A_{FB}^{t\bar{t}}$=9.2±3.7% (MC@NLO prediction: 2.4±0.7%)

dilepton

CDF: $A_{FB}^{t\bar{t}}$=21±7%

- Different acceptance cuts and detector effects → not comparable!

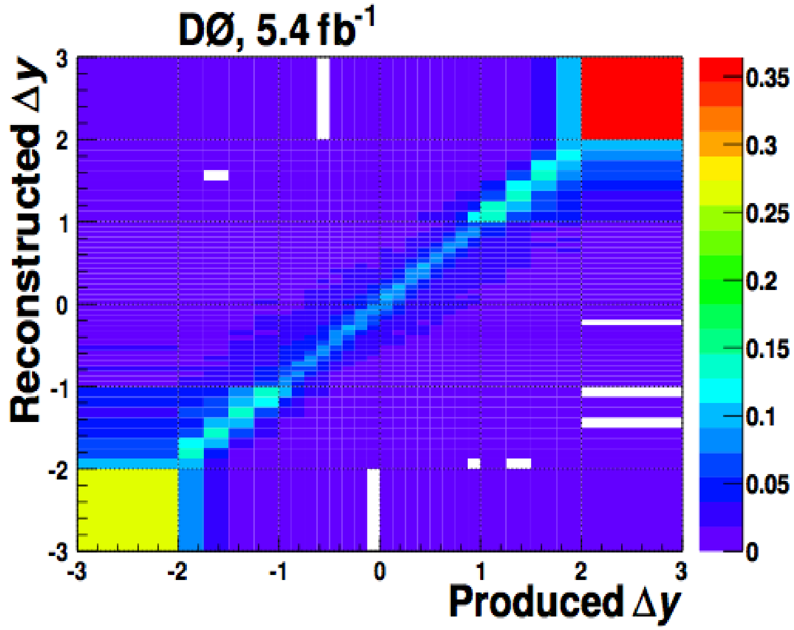
Unfolding

- Correct for acceptance & resolution effects back to production level
- Different unfolding methods used by CDF and DØ
- CDF: 4 bin matrix inversion in Δy (edges: -3, -1, 0, 1, 3)

$$\vec{n}_{production} = A^{-1} S^{-1} \vec{n}_{reco}$$

  - A: (diagonal) acceptance matrix
  - S: migration matrix

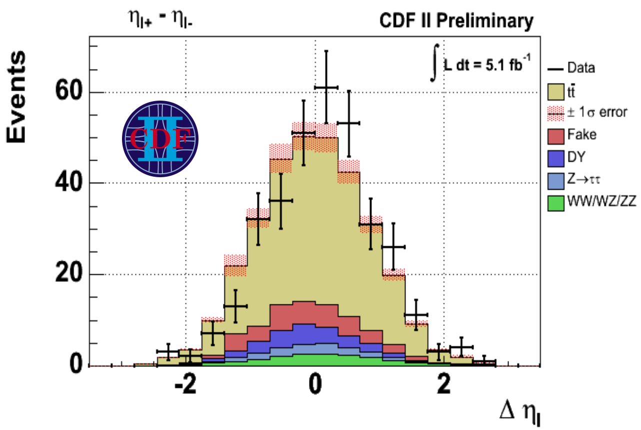
- DØ: regularized unfolding using TUnfold from ROOT (50 → 26 bins in Δy)
  - Better statistical strength than 4 bin matrix inversion

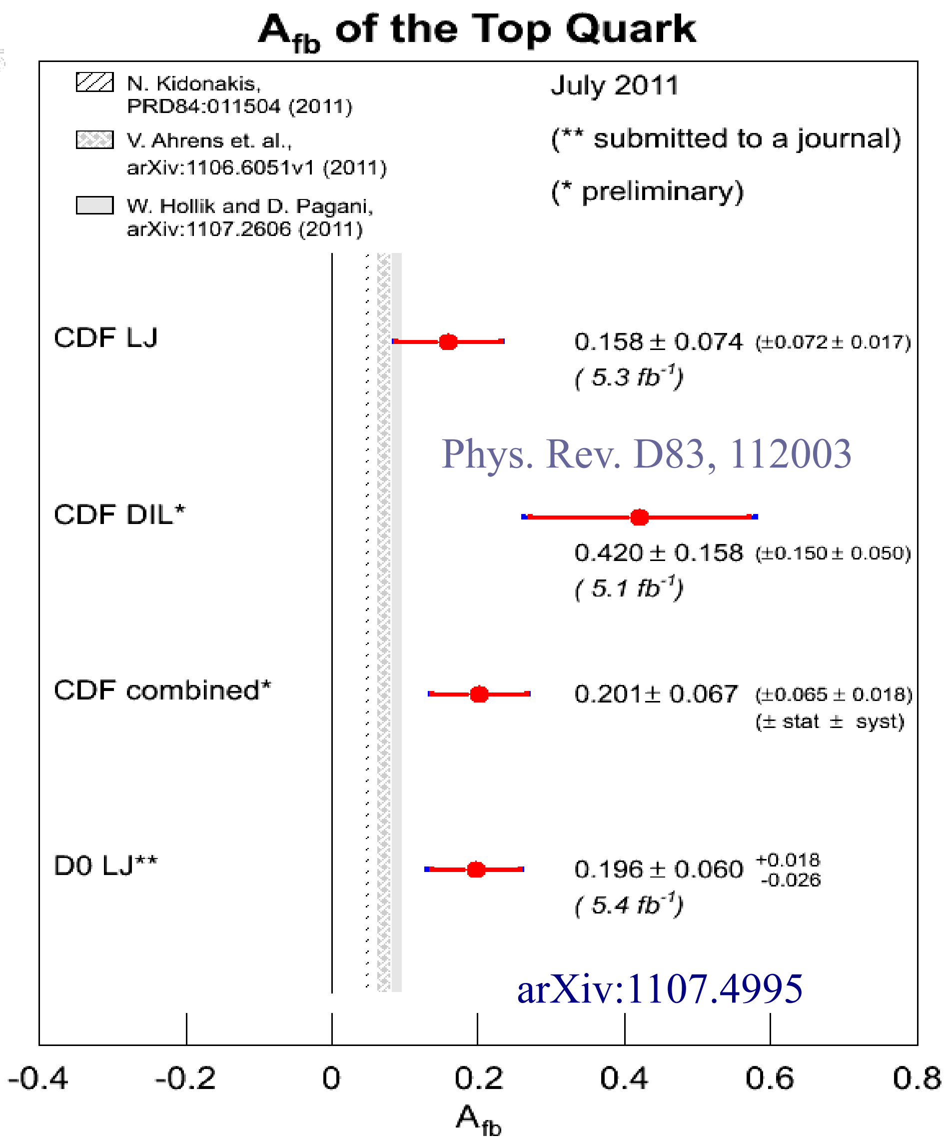


Production Level Asymmetries

- $A_{FB}^{t\bar{t}}$ after unfolding for DØ (l+jets) & CDF (l+jets and dilepton)
  → Measurements higher than prediction
- Lepton-based asymmetries:
  - Very good resolution → unfolding easy
  - DØ (l+jets): A_{FB}^{l}=14.2±3.8% (MC@NLO pred: 0.8±0.6%)

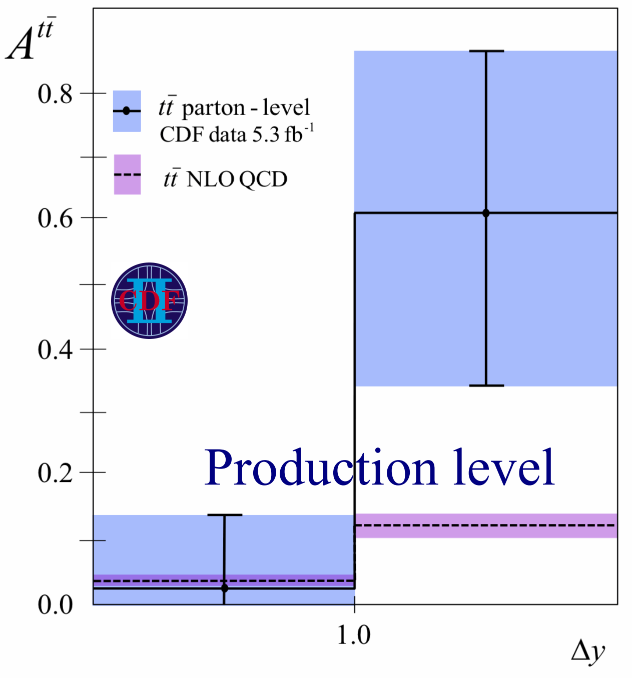
  → ~3 sigma away from prediction!
  - CDF (dilepton): $A_{FB}^{\Delta\eta(l)}$=21±7%

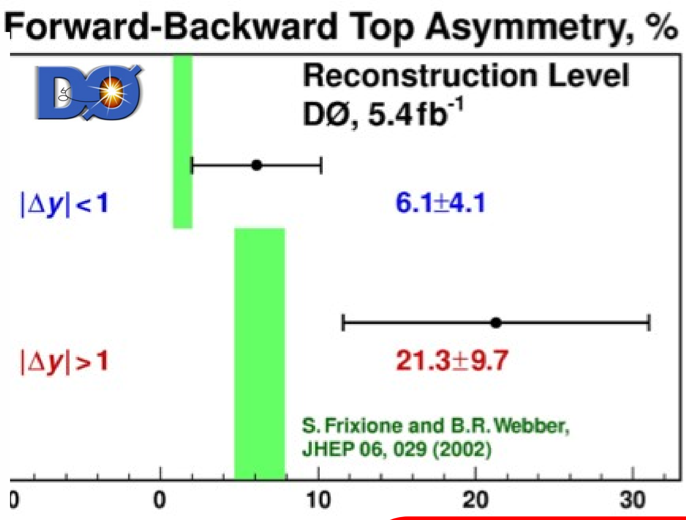


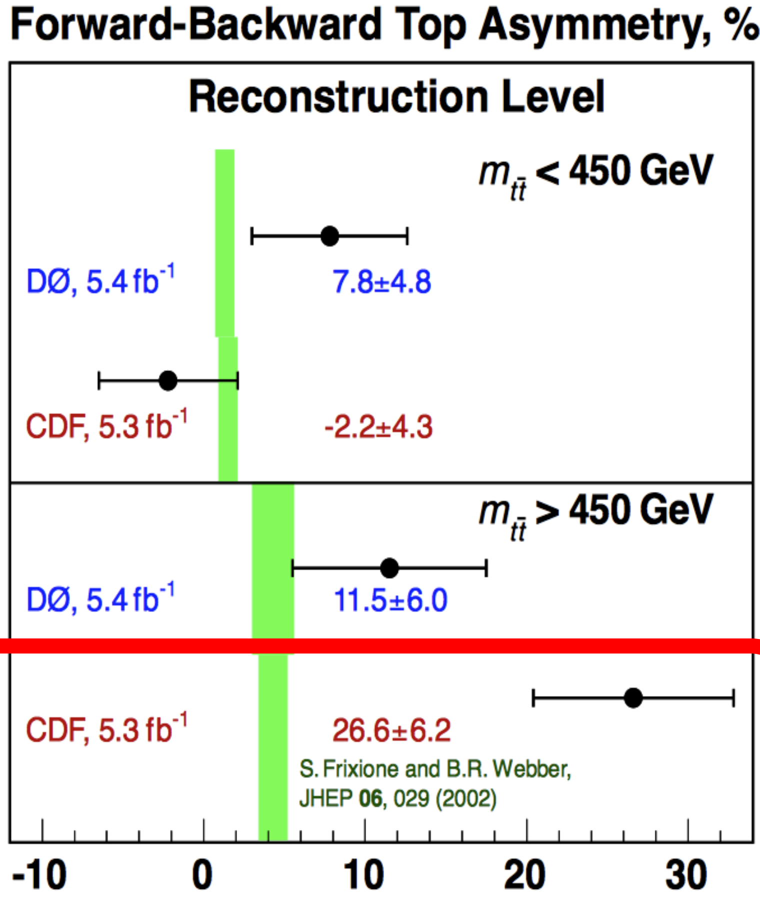


Dependencies

- Asymmetry depends on several variables ($m_{t\bar{t}}$, rapidity, etc.)
  - BSM could show a different mass dependence than in SM
- CDF & DØ: study $m_{t\bar{t}}$ & Δy dependence







~3σ away from MC@NLO prediction

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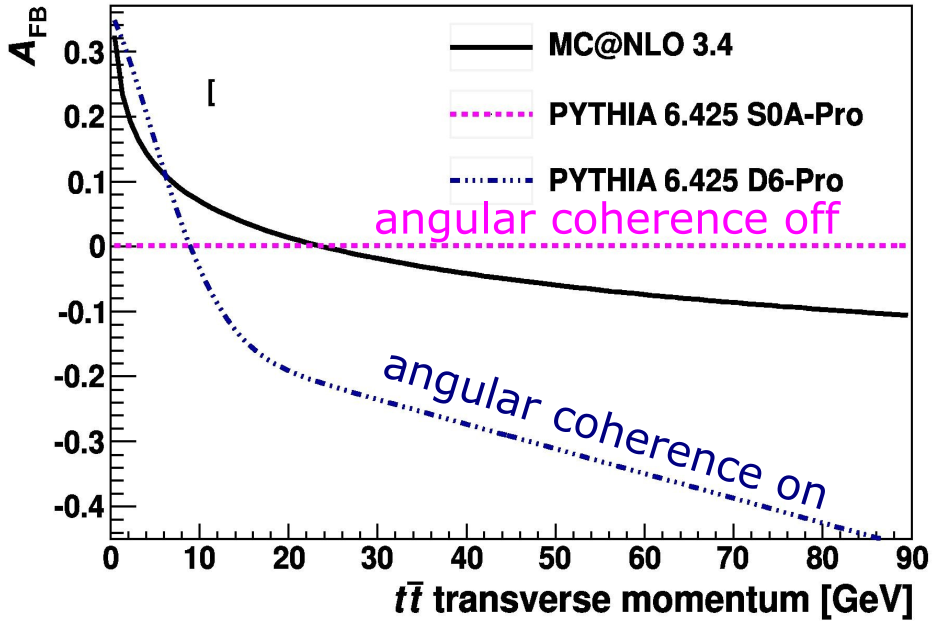
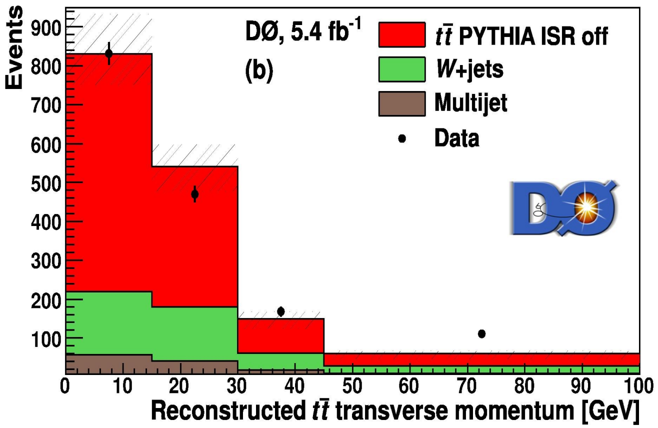
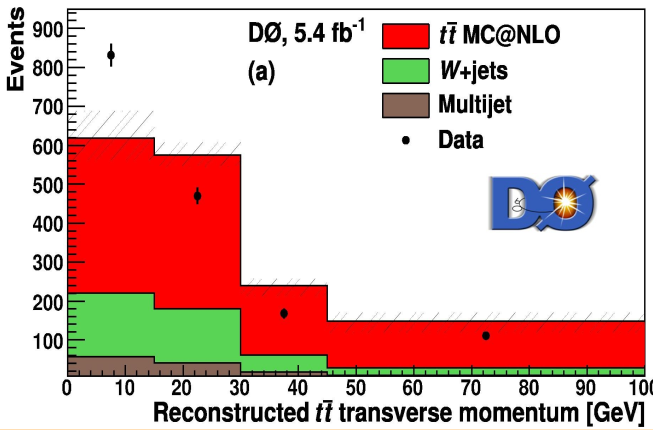
Modeling Issues

- Sensitivity of asymmetry prediction to modeling studied at DØ
- Noted a dependence on $p_T^{t\bar{t}}$
  - e. g. when switching angular coherence between top and initial parton shower on/off
  - Effect included as systematic uncertainty for now (1.6%)



- Top pair p_T difficult to model in data





→ better understanding needed (dedicated measurement)

Theory Intermezzo

- SM predictions
- New Physics models
- Constraints on the models

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SM Predictions

- Top quark asymmetry in frame i:

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

is the ratio of asymmetric (σ_A) and symmetric (σ_S) cross section

- QCD calculation:

$$\frac{\sigma_A}{\sigma_S} = \frac{\left[\int_{y_t>0} \frac{d\sigma}{dy_t} - \int_{y_t<0} \frac{d\sigma}{dy_t}\right]}{\left[\int_{y_t>0} \frac{d\sigma}{dy_t} + \int_{y_t<0} \frac{d\sigma}{dy_t}\right]} = \frac{\alpha_s^3\sigma_A^{(0)} + \alpha_s^4\sigma_A^{(1)} + \ldots}{\alpha_s^2\sigma_S^{(0)} + \alpha_s^3\alpha_s\sigma_S^{(1)} + \ldots}$$

Pecjak, Top2011

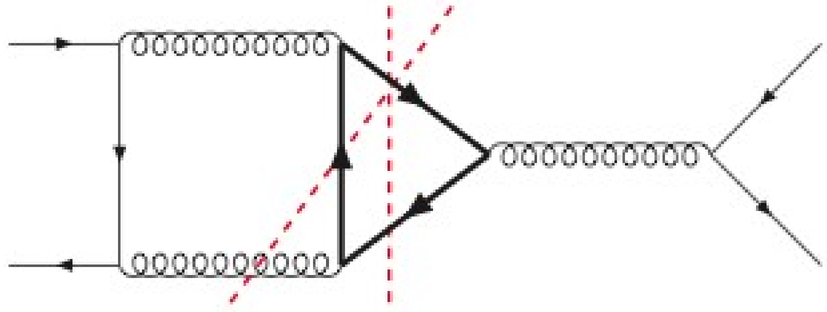
- Numerator starts at α_s^3
- NLO calculations for cross section are NOT NLO for asymmetry

SM Predictions: QCD

- Asymmetry in QCD:
  - Interference of C=1 and C=-1 amplitudes are odd under $t \leftrightarrow \bar{t}$ $\longrightarrow$ cause asymmetry

Kuhn, Rodrigo, PRL 81 (1998)

Pecjak, Top2011



- Dominant contribution from $q\bar{q}$, but also from gq channels; none from gg
- Higher order QCD contributions
  - Estimated with soft-gluon resummation
    - NLO+NNLO by Ahrens et al.; arXiv:1106.6051
    - Approximative NNLO by Kidonakis

SM Predictions: QED

- Additionally: QED contributions enhance the asymmetry

Kuhn, Rodrigo, 2011; Hollik, Pagani 2010l; Bernreuther, Si 2010

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]	$7.24^{+1.04+0.20}_{-0.67-0.27}$	$4.88^{+0.20+0.17}_{-0.23-0.18}$
$\text{NNLO}_{\text{approx}}$ [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

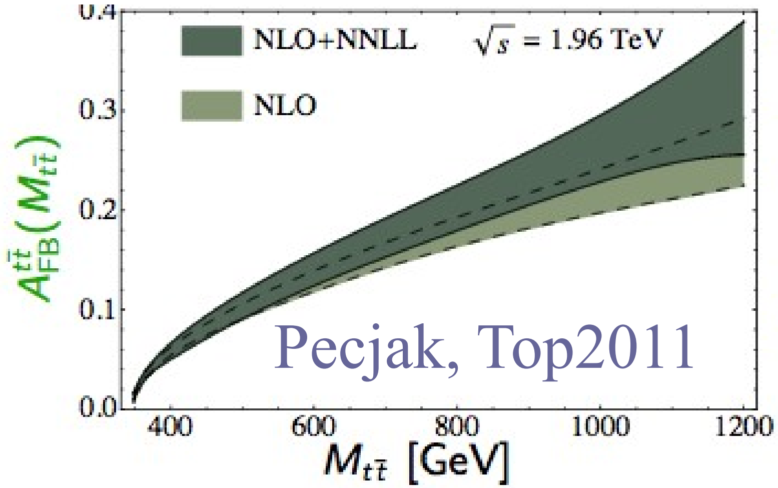
$b\bar{b} \rightarrow t\bar{t}$ included

Extra photonic corrections

- In SM: no large $m_{t\bar{t}}$ dependence seen

A_{FB}^{tt} [%]	$M_{t\bar{t}} < 450$ 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

Pecjak, Top2011



SM Predictions: $t\bar{t}j$

- Asymmetry considered so far: inclusive
  - But: prediction different for $t\bar{t}0j$ versus $t\bar{t}1j$
  - NLO calculation in $t\bar{t} \rightarrow$ LO in $t\bar{t}j$!
  - $t\bar{t}X$+jet at NLO: $A_{FB}^{p\bar{p}}=-1.8^{+0.6}_{-0.3}\%$

Dittmaier, Uwer, & Weinzierl, arXiv:hep-ph/0703120v1

Melnikov, Schulze, 2010

- Asymmetry in 4 jets (approx. $t\bar{t}0j$) and 5 jets (approx. $t\bar{t}1j$), e. g. from DØ:

	$l+\geq4$ jets	$l+4$ jets	$l+\geq5$ jets
Raw $N_{\Delta y>0}$	849	717	132
Raw $N_{\Delta y<0}$	732	597	135
$A_{FB}(\%)$	9.2±3.7	12.2±4.3	-3.0±7.9
MC@NLO A_{FB} (%)	2.4±0.7	3.9±0.8	-2.9±1.1

SM Predictions: $t\bar{t}j$ and $p_T^{t\bar{t}}$

- First calculation of $p_T^{t\bar{t}}$ at NLO & influence of parton shower on A_{FB} (for $t\bar{t}j$) $\rightarrow$ significant influence of parton shower can be seen

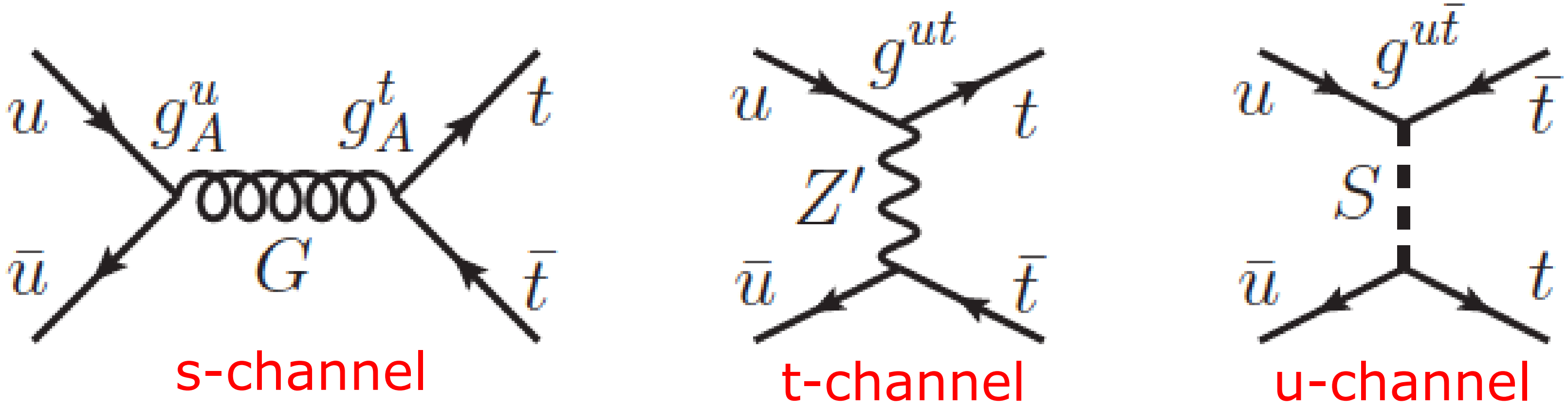
Tevatron 1.96 TeV	NLO [%]	LHEF [%]	POW+HER [%]	POW+HER+UE [%]
$A_{FB}^{t\bar{t}}$ total	-4.40 ± 0.04	-4.34 ± 0.05	-2.80 ± 0.11	-2.54 ± 0.11
$A_{FB}^{t\bar{t}}$, $\lvert\Delta y_{t\bar{t}}\rvert < 1.0$	-2.70 ± 0.04	-2.62 ± 0.05	-1.71 ± 0.11	-1.91 ± 0.11
$A_{FB}^{t\bar{t}}$, $\lvert\Delta y_{t\bar{t}}\rvert \geq 1.0$	-19.48 ± 0.18	-19.54 ± 0.22	-10.52 ± 0.52	-9.75 ± 0.51
$A_{FB}^{t\bar{t}}$, $\lvert m_{t\bar{t}}\rvert < 450$ GeV	-3.59 ± 0.06	-3.51 ± 0.06	-2.67 ± 0.14	-2.36 ± 0.13
$A_{FB}^{t\bar{t}}$, $\lvert m_{t\bar{t}}\rvert \geq 450$ GeV	-5.70 ± 0.06	-5.66 ± 0.08	-3.03 ± 0.19	-2.88 ± 0.18
$A_{FB}^{t\bar{t}}$, $p_T^{t\bar{t}} \geq 10$ GeV	-4.35 ± 0.04	-4.32 ± 0.05	-3.98 ± 0.06	-3.86 ± 0.06
$A_{FB}^{t\bar{t}}$, $p_T^{t\bar{t}} \geq 20$ GeV	-3.71 ± 0.05	-4.29 ± 0.05	-4.22 ± 0.05	-4.18 ± 0.05
$A_{FB}^{t\bar{t}}$, $p_T^{t\bar{t}} \geq 35$ GeV	-5.72 ± 0.06	-5.52 ± 0.05	-5.16 ± 0.06	-5.17 ± 0.06
$A_{FB}^{t\bar{t}}$, $p_T^{t\bar{t}} \geq 50$ GeV	-6.25 ± 0.07	-6.11 ± 0.06	-5.70 ± 0.07	-5.74 ± 0.07
$A_{FB}^{t\bar{t}}$, $p_T^{t\bar{t}} \geq 75$ GeV	-6.62 ± 0.08	-6.45 ± 0.08	-5.99 ± 0.09	-5.94 ± 0.09

Alioli, Moch, Uwer, arxiv:1110.5251 (2011)

LHEF: NLO fixed order + POWHEG after first emission

NP Models

- Within SM: higher orders calculated, show large differences in prediction
- Other possibility for deviation of measurement from prediction: New Physics!
- Several models proposed
  - That do not change total $t\bar{t}$ cross section significantly
  - New particle in s-, t- or u-channel:

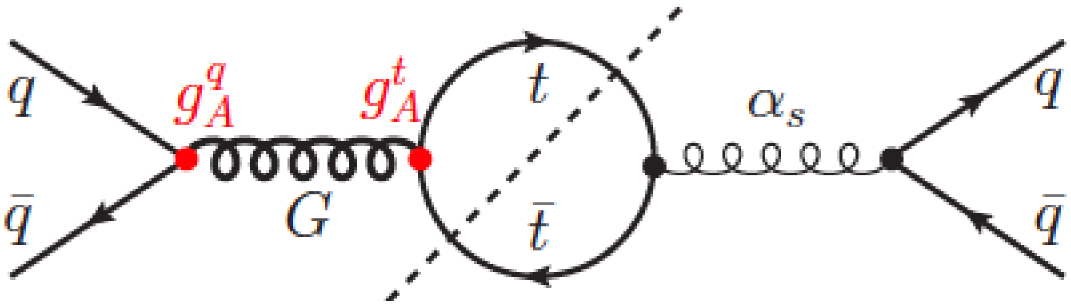


Westhoff, EPS 2011

  - More general approach if new particle heavy: "effective theory"

NP Models: s-channel

- Color-octet vector (axigluon)

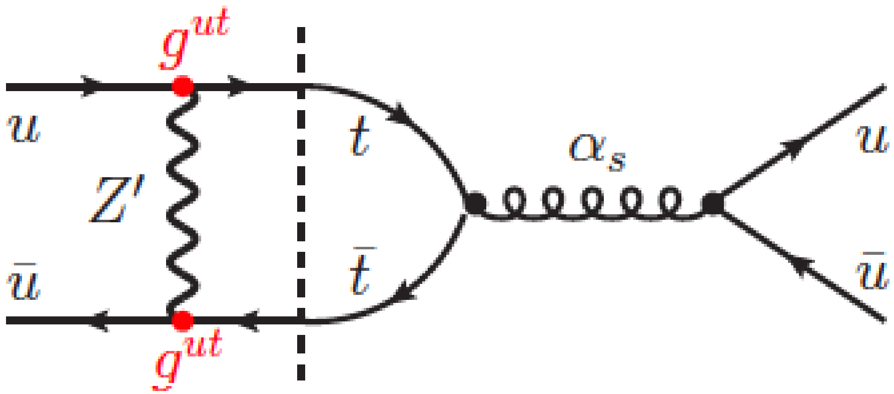


- Several requirements & problems with measurements:
  - Must have small coupling to $u\bar{u}$ and $d\bar{d}$ $\longrightarrow$ otherwise dijet production
  - Distinctive feature: bump in $m_{t\bar{t}}$ spectrum
    $\longrightarrow$ non observation: axigluon must be heavy
  - FCNC would occur at tree level

Westhoff, EPS 2011
Aguilar Saavedra, Top2011

NP Models: t-channel

- Color-singlet vectors (Z', W')

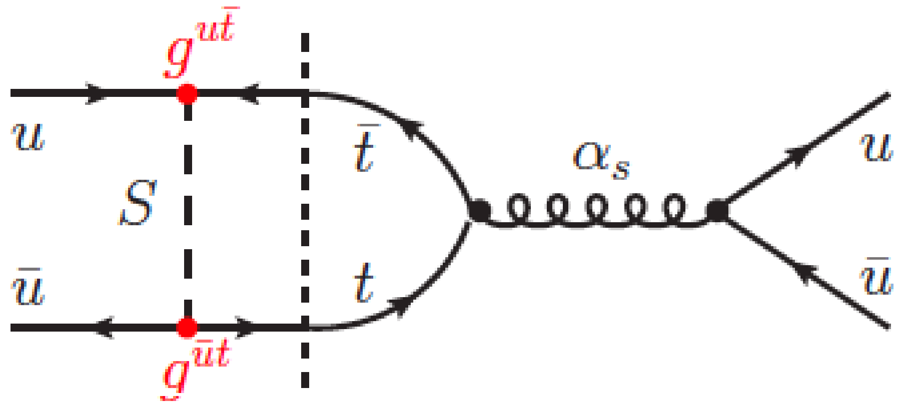


- Requirements:
  - Z': requires large coupling to get asymmetry positive
  - Z': Constraint from same sign top production

Westhoff, EPS 2011
Aguilar Saavedra, Top2011

NP Models: u-channel

- Color-triplet & color-sextet scalars:

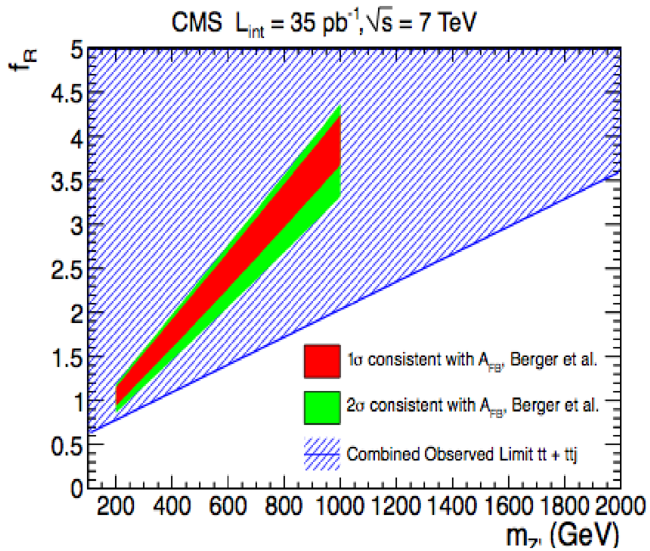


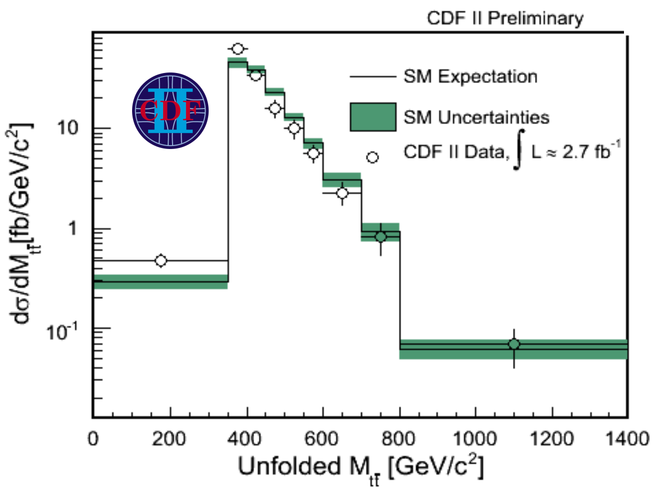
- Requirements:
  - Large mass for asymmetry to be positive
  - Color-sextet ruled out by constraints on dijet production

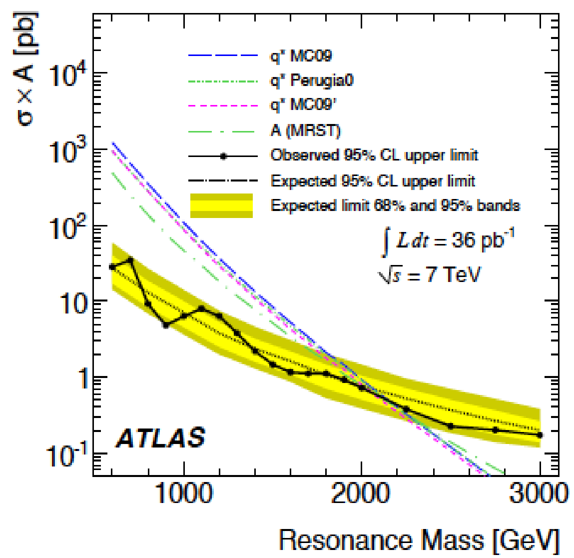
Westhoff, EPS 2011
Aguilar Saavedra, Top2011

Constraints on the Models

- Same sign top production:
  - CDF: $\sigma(\bar{t}\bar{t}+tt)<0.7$pb PRL.102:041801,2009
  - CMS: limits on $\sigma(\bar{t}\bar{t}+tt)$ excludes Z'
- Dijet: only large masses allowed for axigluon
- No bumps in $m_{t\bar{t}}$ distribution found so far
  - Several models would cause a resonance in $m_{t\bar{t}}$





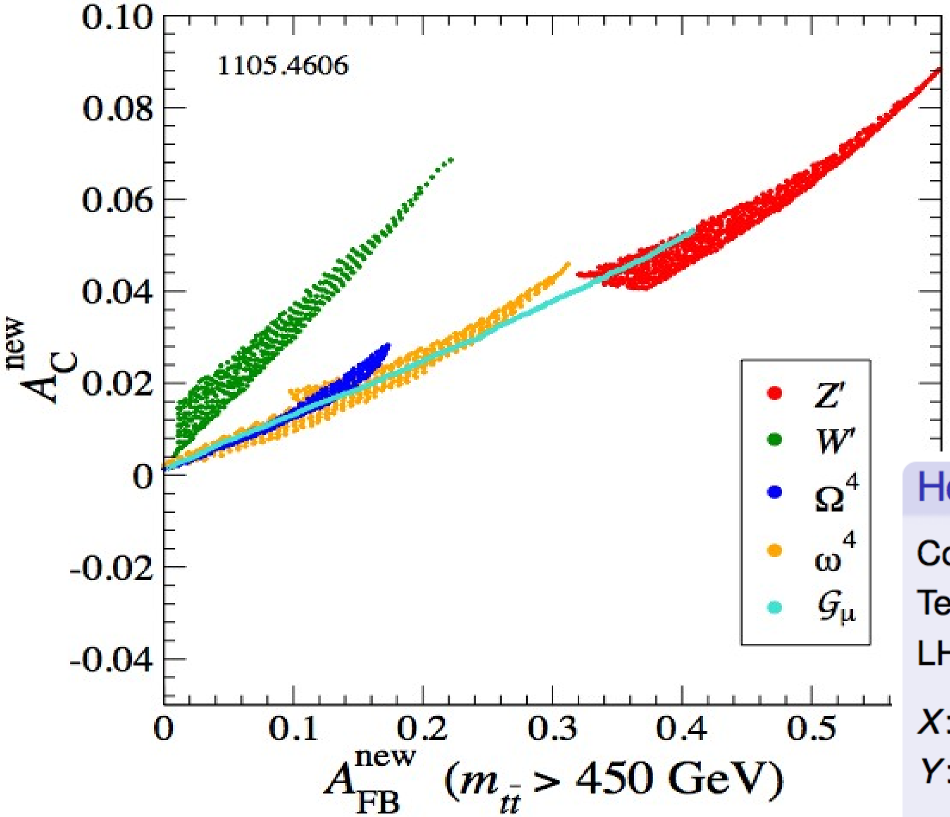


PRL 102 222003

Westhoff, EPS 2011
Aguilar Saavedra, Top2011

Constraints on the Models

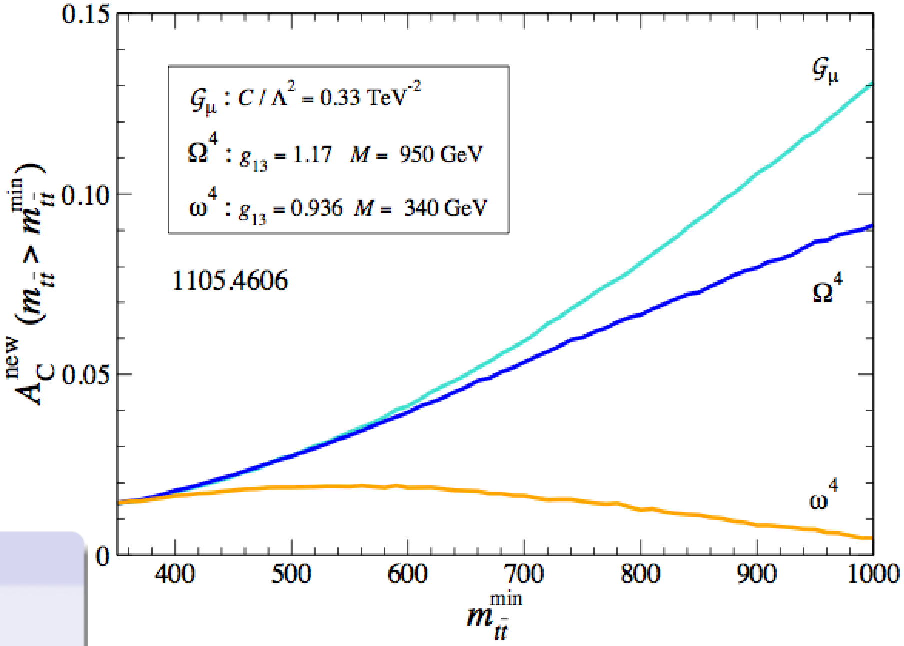
- What about LHC asymmetry measurements?
- Many models require positive A_C & enhancement with $m_{t\bar{t}}$



How to read the plot

Coloured regions:
Tevatron $t\bar{t}$ xsec within 1σ
LHC $t\bar{t}$ tail not too large

X: Tevatron high-mass A_{FB}
Y: LHC inclusive A_C
(only NP contributions)



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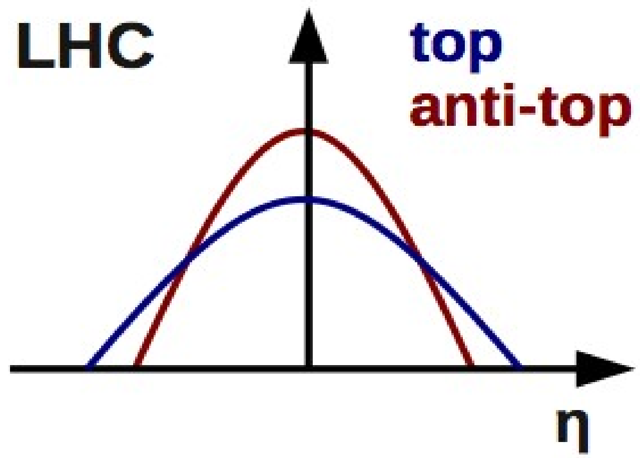
Measurements at the LHC

- Tevatron-LHC difference
- Asymmetry measurements at Atlas and CMS

Asymmetry: Tevatron versus LHC

- Asymmetry mainly in $q\bar{q}$ BUT LHC: pp collider
  - Quarks valence quarks, antiquark always from the sea $\rightarrow$ antitop less boosted and more central than top in case of asymmetry
- Define asymmetries accordingly, e. g.
  - Cut-dependent:



$$A_C = \frac{N(|y_t| > |y_{\bar{t}}|) - N(|y_t| < |y_{\bar{t}}|)}{N(|y_t| > |y_{\bar{t}}|) + N(|y_t| < |y_{\bar{t}}|)}$$

  - Use the knowledge about the boost to extract q and $\bar{q}$ direction:

$$\mathcal{A}^{t\bar{t}} = \frac{N(0 < \hat{\theta}_t < \pi/2) - N(\pi/2 < \hat{\theta}_t < \pi)}{N(0 < \hat{\theta}_t < \pi/2) + N(\pi/2 < \hat{\theta}_t < \pi)}$$

θ_t: production angle of top in $t\bar{t}$ frame wrt boost of $t\bar{t}$ system

Pecjak, Top2011

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- Asymmetry mainly in $q\bar{q}$ BUT LHC: pp collider
  - Quarks valence quarks, antiquark usually from the sea
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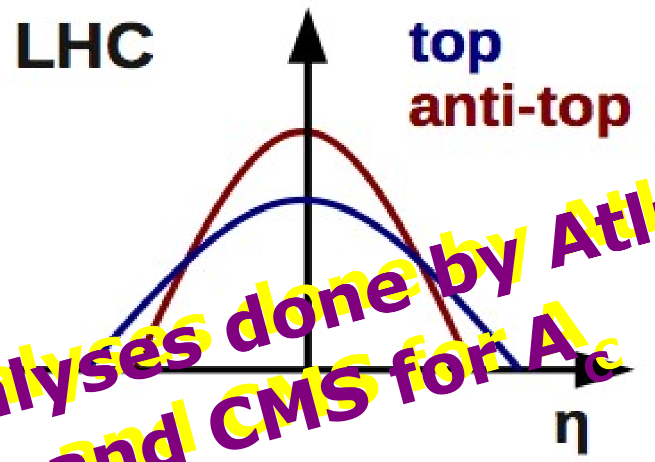

- Define asymmetries accordingly, e. g.
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Analyses done by Atlas and CMS for A_c

  - Use the knowledge about the boost to extract q and $\bar{q}$ direction:

$$\mathcal{A}^{t\bar{t}} = \frac{N(0 < \hat{\theta}_t < \pi/2) - N(\pi/2 < \hat{\theta}_t < \pi)}{N(0 < \hat{\theta}_t < \pi/2) + N(\pi/2 < \hat{\theta}_t < \pi)}$$

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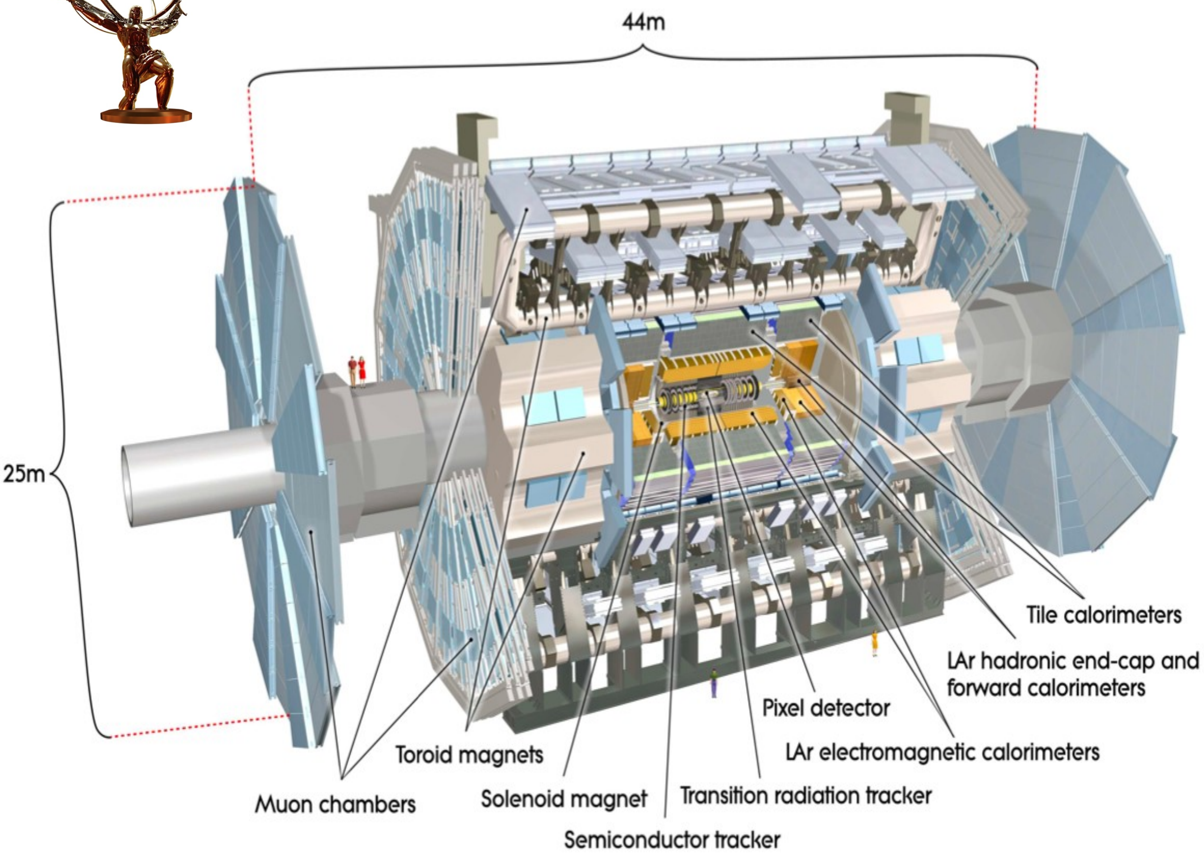
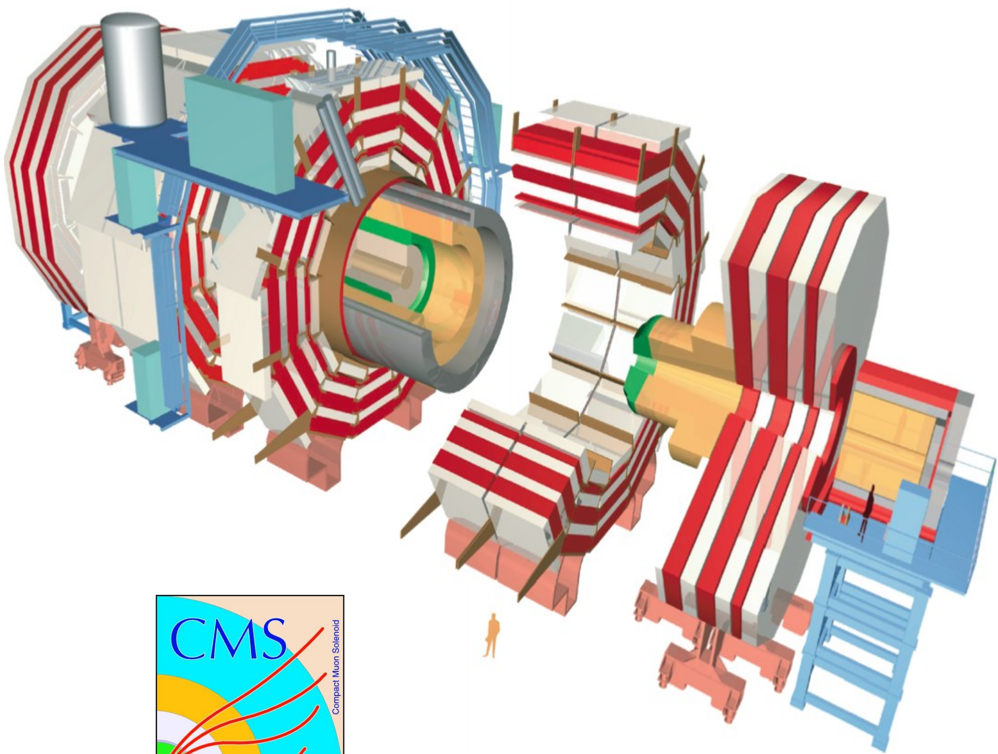
Pecjak, Top2011

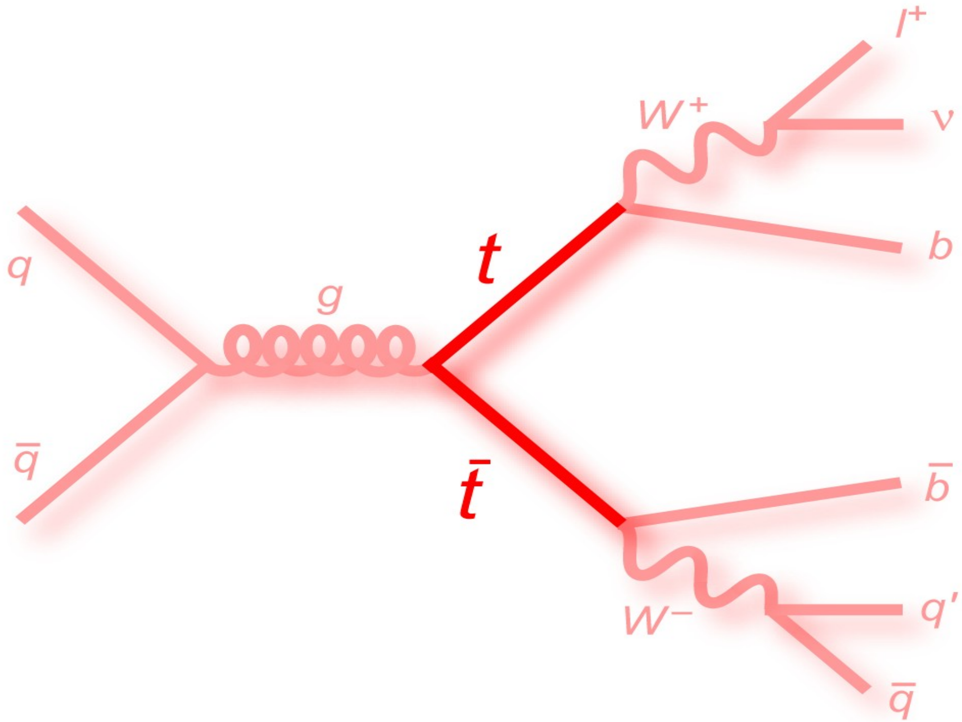
CMS & Atlas Detectors





Selection & Reconstruction

- Selection: $t\bar{t}$ l+jets selection



1 lepton (e or μ) with p_T>30GeV (Atlas: 25GeV for e, 20GeV for μ); $|\eta|$<2.5

Missing p_T for neutrino ($\not{E}_T$): no cut for CMS; Atlas: >35GeV

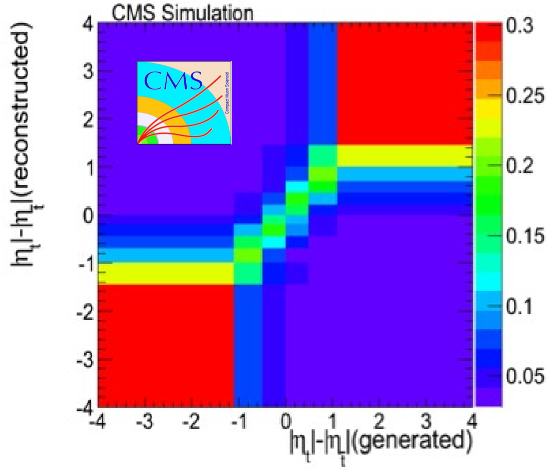
≥4 jets with p_T>30GeV (Atlas: >25GeV); CMS: $|\eta|$<2.4; Atlas: $|\eta|$<2.5

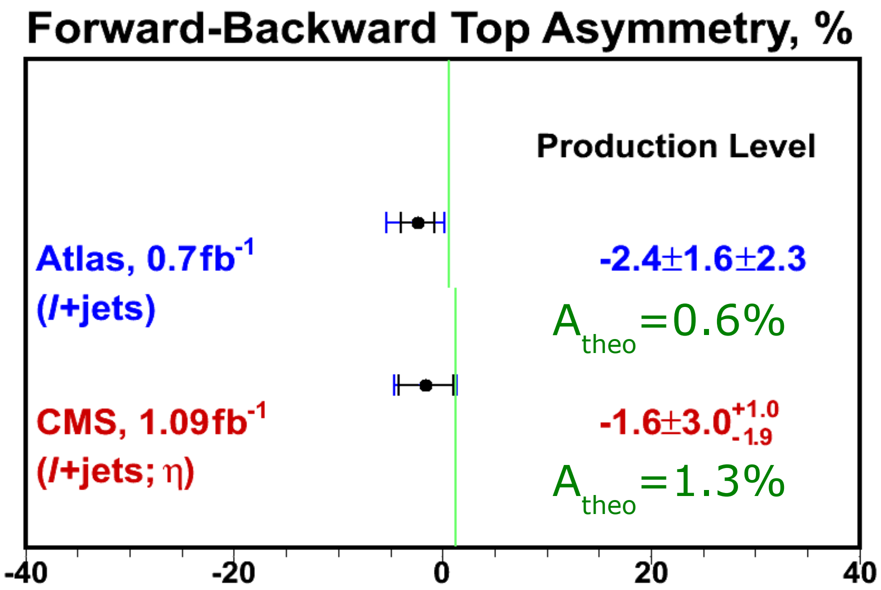
≥1 jet b-tagged

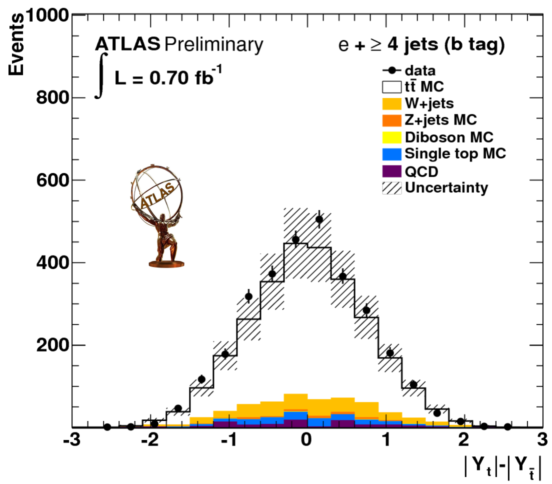
- Reconstruction of $t\bar{t}$ system:
  - Atlas: likelihood to assign the right combination
  - CMS: χ^2 test

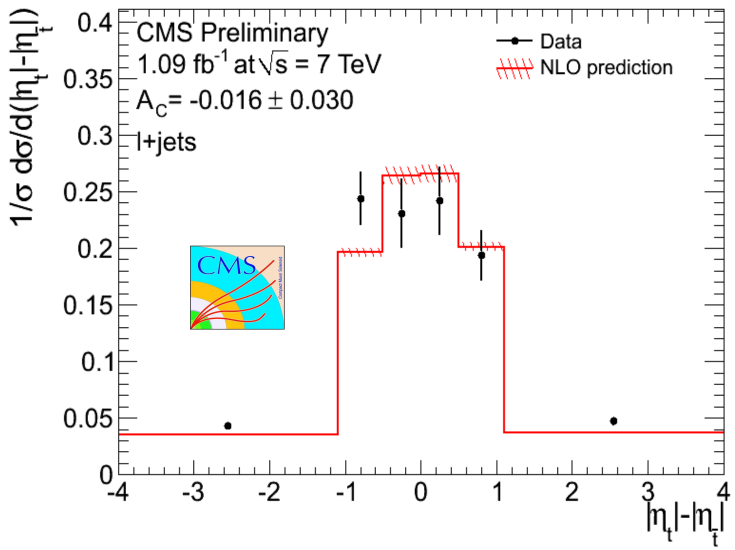
Results

- Measurements at LHC already becoming systematics limited
  - Mainly modeling of signal
- Unfolding: CMS: regularized unfolding; Atlas: iterative Bayesian
- CMS: using η instead of y







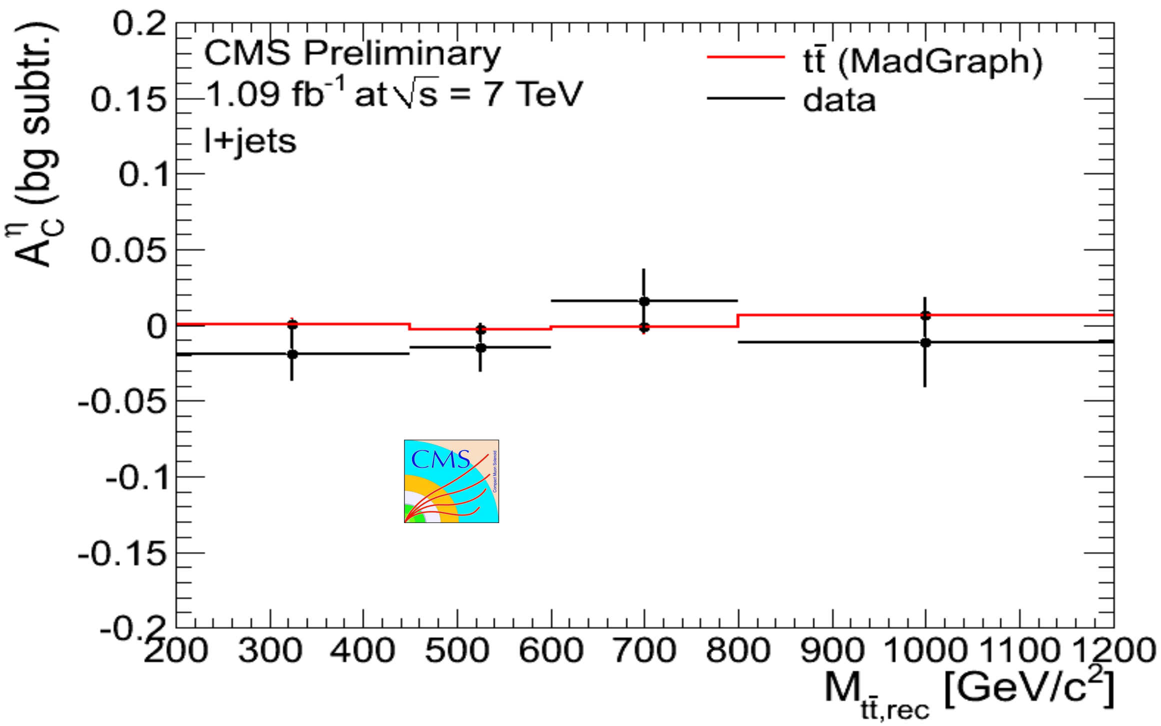


ATLAS-CONF-2011-106

CMS PAS TOP-11-014

Dependencies

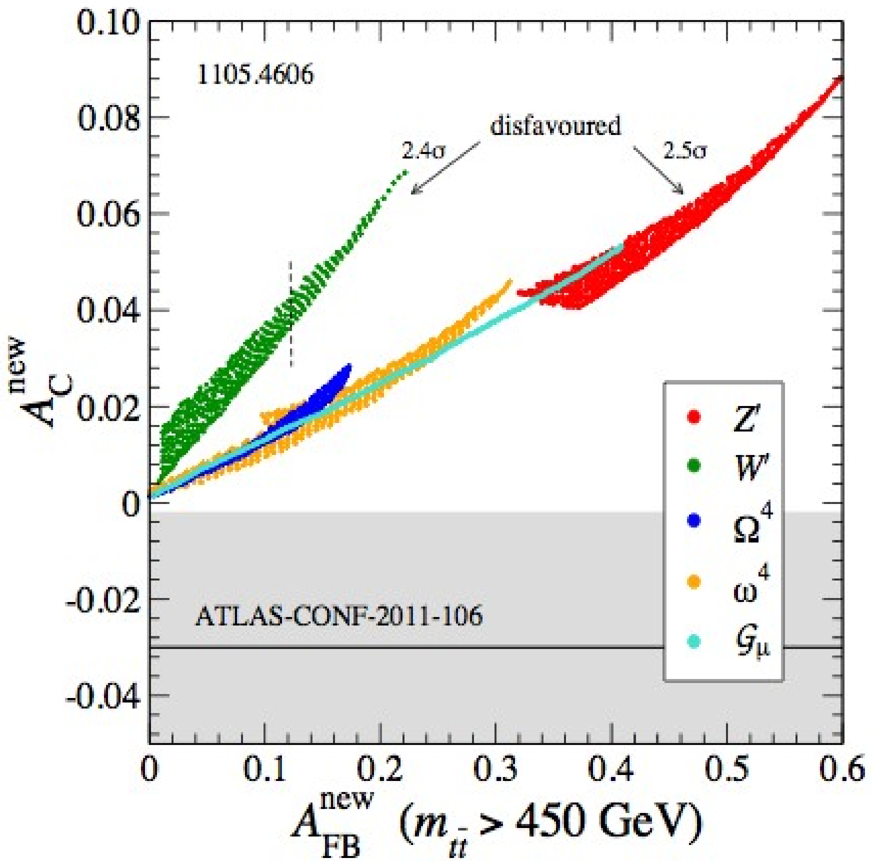
- CMS studied dependency of asymmetry on $m_{t\bar{t}}$



- No visible tendency/$m_{t\bar{t}}$ dependence

Coming back to the NP Models...

- LHC measurements disfavor several models
  - Z': outside the measurement
  - Other models: tension with CDF's mass dependence



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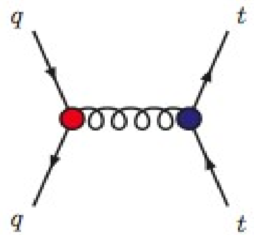
Y: LHC inclusive A_C
(only NP contributions)

Aguilar Saavedra, Top2011

Model Apocalypse

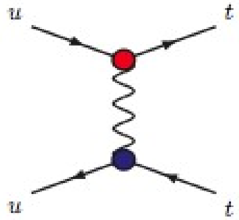
Most popular models . . . after 2011 LHC data



s channel: $t\bar{t}$ tail $\sim$ SM

$\mathcal{G}_\mu \sim (8,1)_0$

0809.3354 , 0906.0604 , 0911.2955 , 1007.0243 , 1011.6380 , 1011.6557 , 1101.2902 , 1101.5203 , 1103.0956 1104.1917 , 1105.3158 , 1105.3333 , 1106.0529 , 1106.4054 , 1107.0978 , 1107.1473 , 1107.2120 , 1107.5769 , 1109.0648



t channel: $A_C = -0.016$ (CMS), -0.024 (ATLAS)

$Z' \sim (1,1)_0$

$W' \sim (1,1)_1$

$\phi \sim (1,2)_{-\frac{1}{2}}$

09(11(11(1101 , 1106 102.(108 03.1266 1103.4835 ,

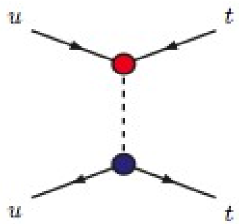
0908.258 1048 . 1003.346 .1445 , 1 , 1102.0279

1104.008 , .460

1104.4782 , 1107.084 4350 , 1108.4005

single top?

top FCNC?



u channel: $t\bar{t}$ tail $\sim$ SM

$\omega^4 \sim (3,1)_{-\frac{4}{3}}$

$\Omega^4 \sim (\bar{6},1)_{-\frac{4}{3}}$

09 4875 , (11 2757 ,

1007

.3374 ,

Aguilar Saavedra, Top2011

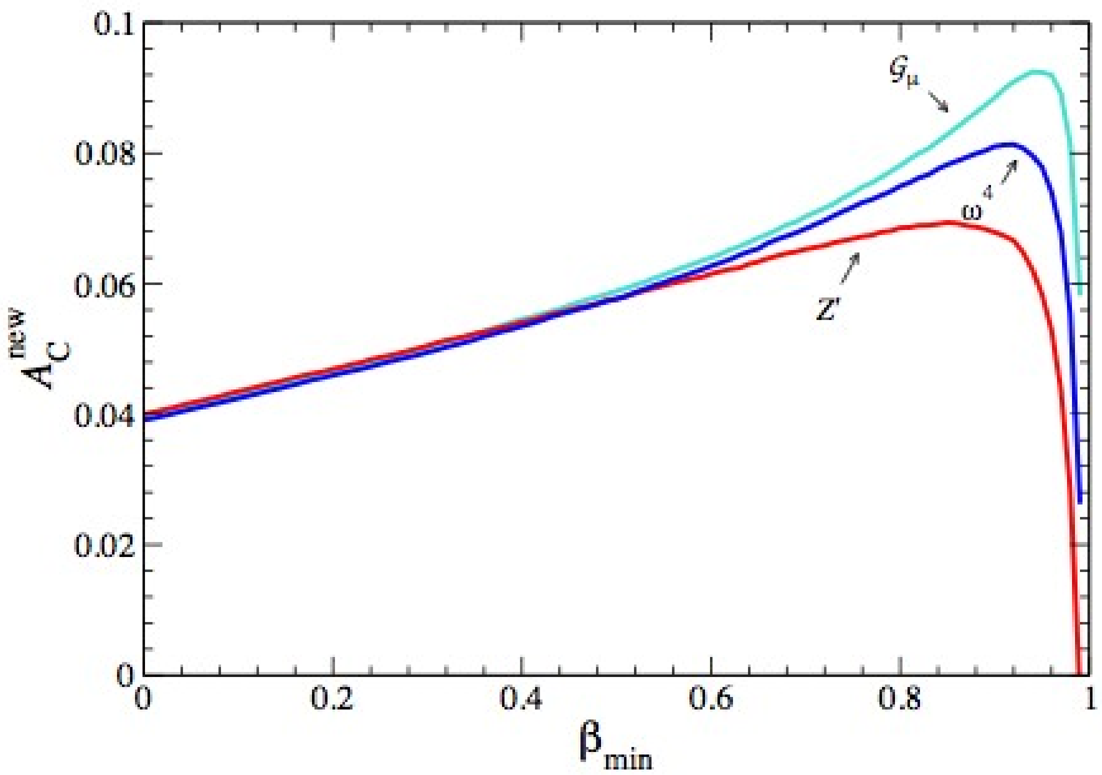
J. A. Aguilar Saavedra (Univ. Granada) | Overview of models for the $t\bar{t}$ asymmetry | TOP 2011 | 29 / 56

Measurements to be done at Tevatron and LHC

- How to further discriminate the models
  - Cuts
  - Asymmetries
  - Polarization

How to further discriminate the Models

- Several ideas float around on what measurements can be done
- Enhance the $q\bar{q}$ fraction → cut on velocity of CM in lab frame $\beta = \frac{p_t^z + p_{\bar{t}}^z}{E_t + E_{\bar{t}}}$
- For example: cut on $\beta > 0.6$ discriminates models (for A_C)



How to read the plot

Asymmetry as a function of the cut β_{min}

$\mathcal{G}_\mu$: *s*-channel

Z': *t*-channel

ω^4: *u*-channel

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How to further discriminate the Models

- Extract A^l and $t\bar{t}$ asymmetry
  → many models predict different behavior of both

Krohn et al, arxiv:1105.3743

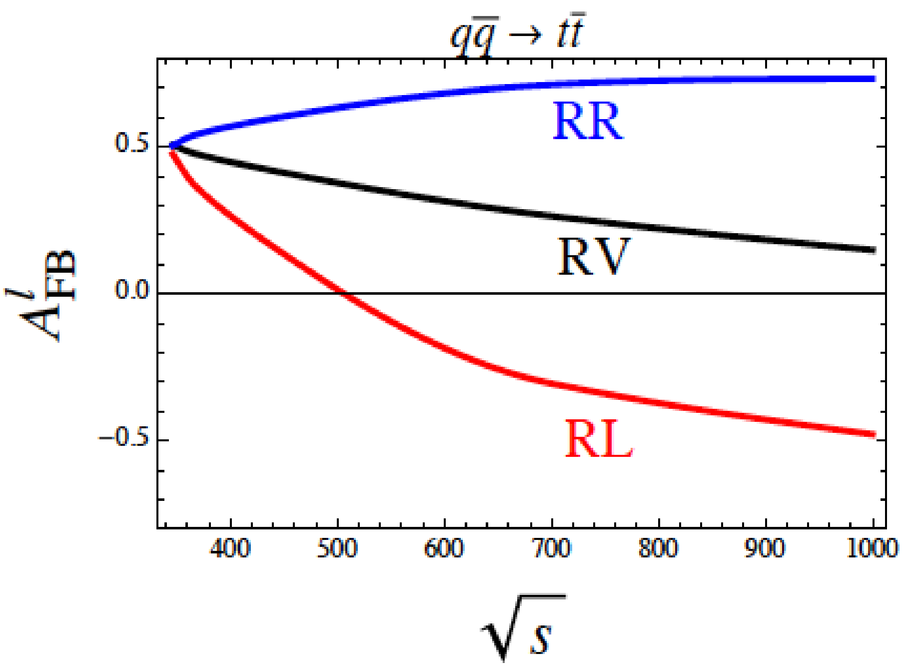
- Example: different axigluon models & W'

	frame and mass range	$t\bar{t}$ asymmetry	Lepton asymmetry	stat. sig. (5.3 fb^{-1})
G_A	lab, sel. cuts	1 %	4 %	1.1
	lab, high mass	1 %	9 %	1.9
	CM, sel. cuts	12 %	6 %	1.7
	CM, high mass	19 %	12 %	2.4
G_L	lab, sel. cuts	0 %	-3 %	0.9
	lab, high mass	1 %	-1 %	0.2
	CM, sel. cuts	13 %	-4 %	1.4
	CM, high mass	20%	-3 %	0.6
G_R	lab, sel. cuts	0 %	12 %	3.9
	lab, high mass	-1 %	18 %	5.0
	CM, sel. cuts	9 %	16 %	3.5
	CM, high mass	15 %	22 %	4.4
W'	lab, sel. cuts	0 %	13 %	3.9
	lab, high mass	1 %	22 %	4.9
	CM, sel. cuts	20 %	16 %	4.4
	CM, high mass	31 %	26 %	5.3

How to further discriminate the Models

- Measure the lepton asymmetry at threshold: measures the relative contribution of $q_L\bar{q}_L$ and $q_R\bar{q}_R$ of $t\bar{t}$ production (at threshold)
  $\rightarrow$ many models enhance one of these fractions
  - SM: $A^l_{FB}(\sqrt{s}=2mt)=+50\%$ for $q_R\bar{q}_R$ and -50% for $q_L\bar{q}_L$ $\rightarrow$ net asymmetry $A^l_{FB}(\sqrt{s}=2mt)=0$

Falkowski et al, arxiv:1110.3796



- Example: chiral gluon with purely right-handed coupling to light quarks, and left-handed (RL), right-handed (RR) or vector (RV) coupling to the top quark

  $\rightarrow$ in this model $A^l_{FB}(\sqrt{s}=2mt)=50\%$

To be done measurements

- Constraints from b quark coupling from precision flavor observables
  → many models for A_{FB} couple only to right-handed top quarks
  → predict large top polarization!

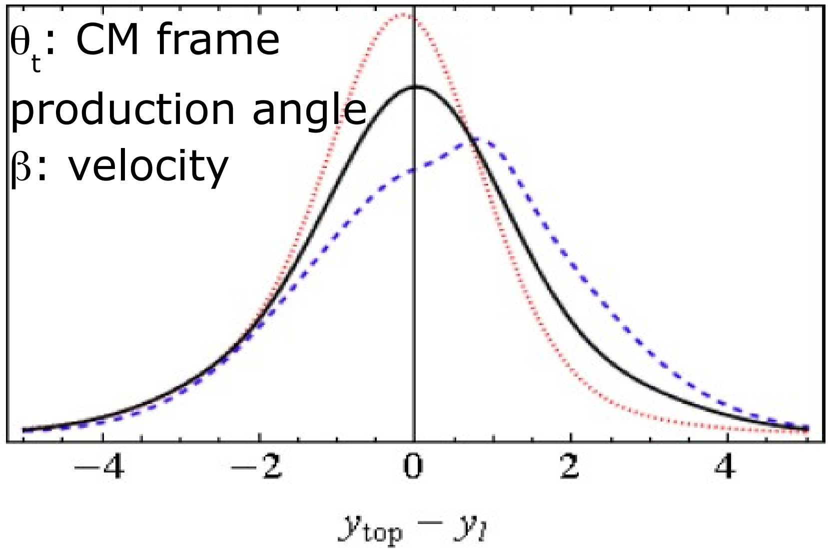
Krohn et al, arxiv:1105.3743

- Top decay in top rest frame:

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

  - P_n: polarization; κ_i: spin analyzing power of decay product i;
    θ_i: direction of daughter wrt. chosen axis

- Lepton asymmetry:
  related to top polarization

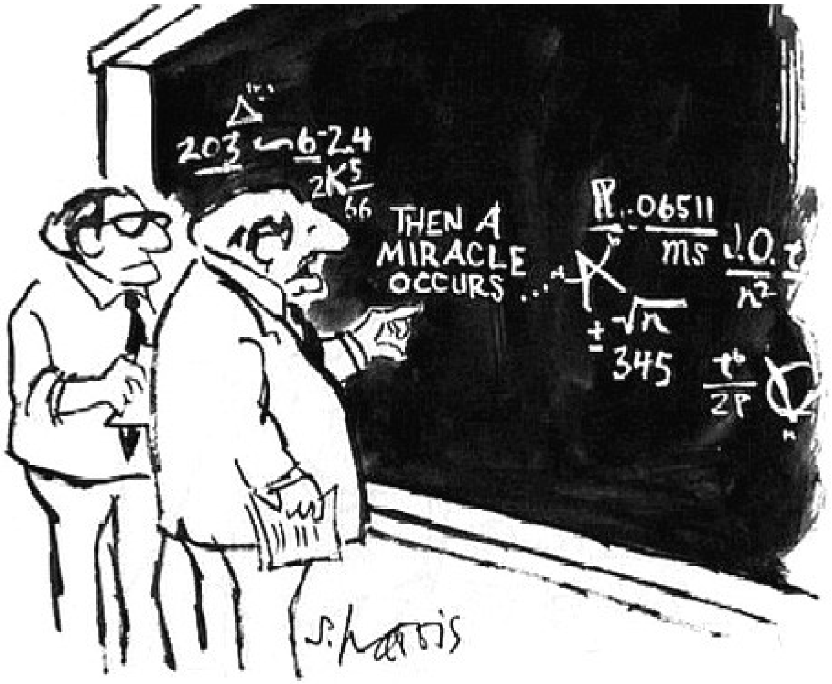


(a) $\beta_t = 0.5$, $\cos\theta_t = 0.4$

black: unpolarized top
Red: right-handed top
Blue: left-handed top

Summary and Outlook

- Asymmetry measurements larger than theory prediction at Tevatron
  → hint for new physics?
- Many attempts to understand where the difference comes from
  - Higher order SM calculations
  - Modeling
  - Potential new physics models
- First asymmetry measurements at LHC
  - No deviation from prediction
- Additional measurements needed to distinguish models and ensure proper modeling
  → $p_T^{t\bar{t}}$, polarization, Asymmetries in $b\bar{b}$
- Thanks to A. Harel for support on the talk



"I think you should be more explicit here in step two."

from *What's so Funny about Science?* by Sidney Harris (1977)

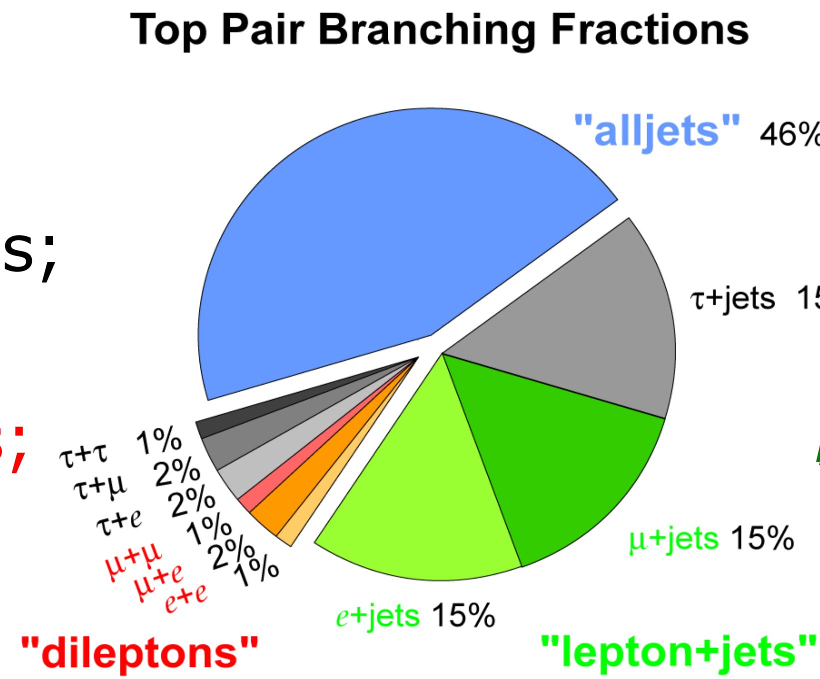
Backup

Reminder of some Basics: Final States in $t\bar{t}$

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

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

pure hadronic:
≥6 jets (2 b-jets)



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)

More on ISR

- Even though ISR off improves description of $t\bar{t}$ p_T
  $\rightarrow$ N_{jet} distribution gets worse