Measurement of the Charge Asymmetry in Top Quark Pair Production at CMS

Michael Segala
Brown University
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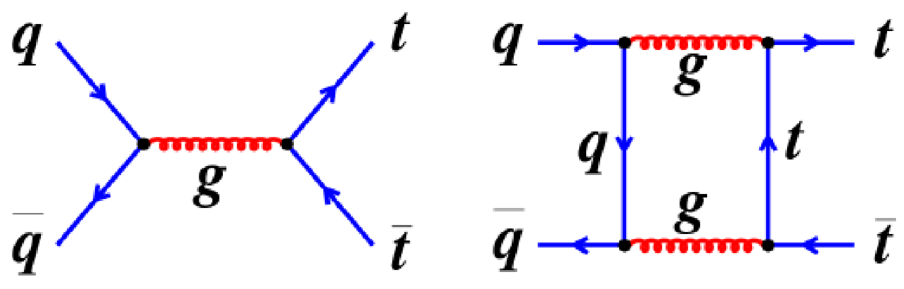
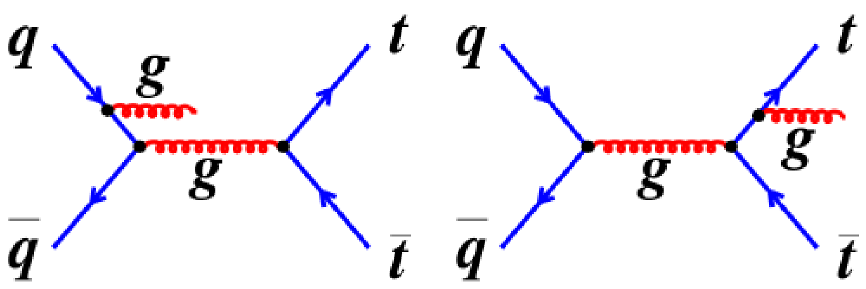
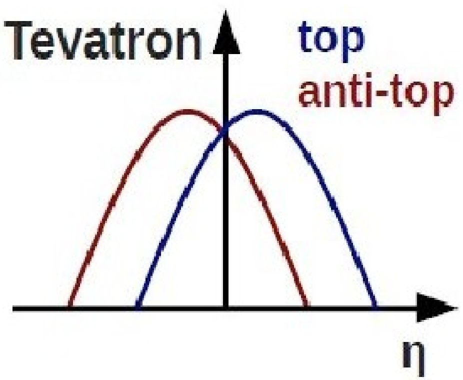
Origin of Charge Asymmetry





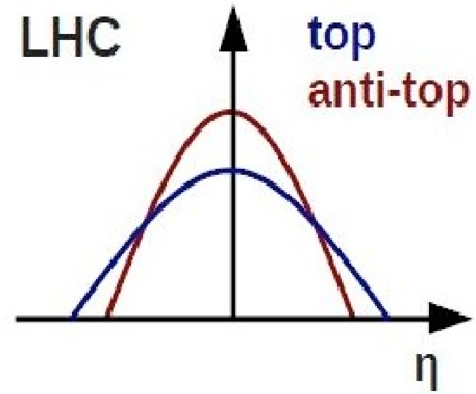
- Top quark is the only fermion with a mass on the order of the EWSB scale and therefore plays a role in many BSM theories
- Interference of leading order and box diagrams (left) and initial and final state radiation diagrams (right) lead to a small charge asymmetry in quark-antiquark annihilation mode
- BSM: axigluons, Z', W', Kaluza Klein
  - New resonances s-channel production in M(tt)
  - Charge asymmetry would be sensitive to t- and u- channel exchange

Tevatron Vs. LHC



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

$$A_C = \frac{N^+ - N^-}{N^+ + N^-}$$



$$\Delta|\eta| = |\eta_t| - |\eta_{\bar{t}}|$$

$$\Delta(y^2) = (y_t - y_{\bar{t}}) \cdot (y_t + y_{\bar{t}})$$

- Asymmetric ppbar initial state leads to FB asymmetry
  - Top in direction of quark
  - Anti-top in directon of anit-quark
- SM Theory: ~5%
- CDF measures $A_C(y)$ 2σ larger than SM predicts
- 3.4σ larger for $M_{tt} > 450$ GeV/c^2

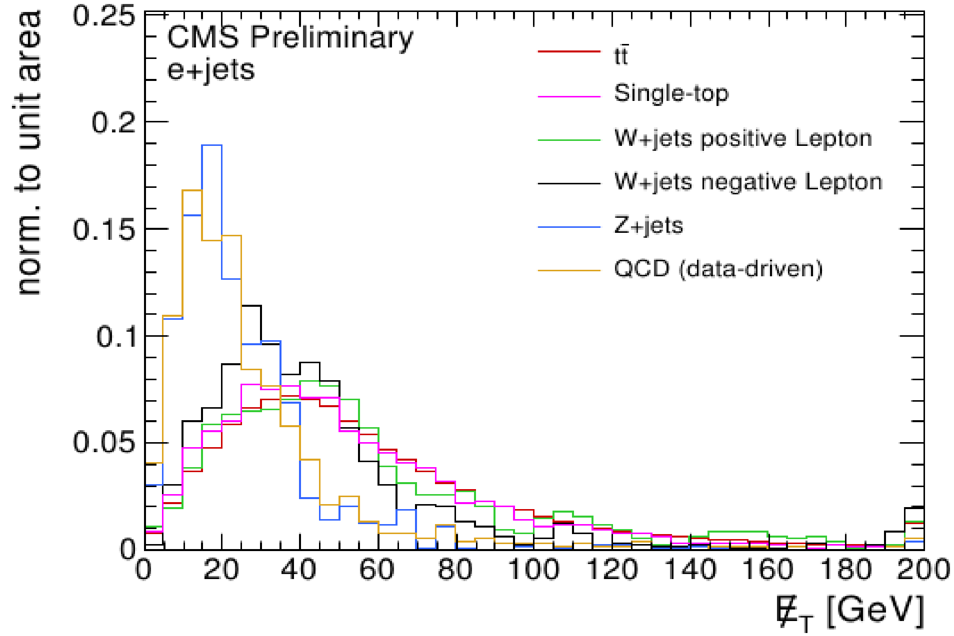
- Symmetric pp initial state
  - quark usually a valance with higher p
  - antiquark is usually a sea quark
  - Top more often found in higher η
- SM Theory: 1.3% (Δη) and 1.1% (Δy^2)

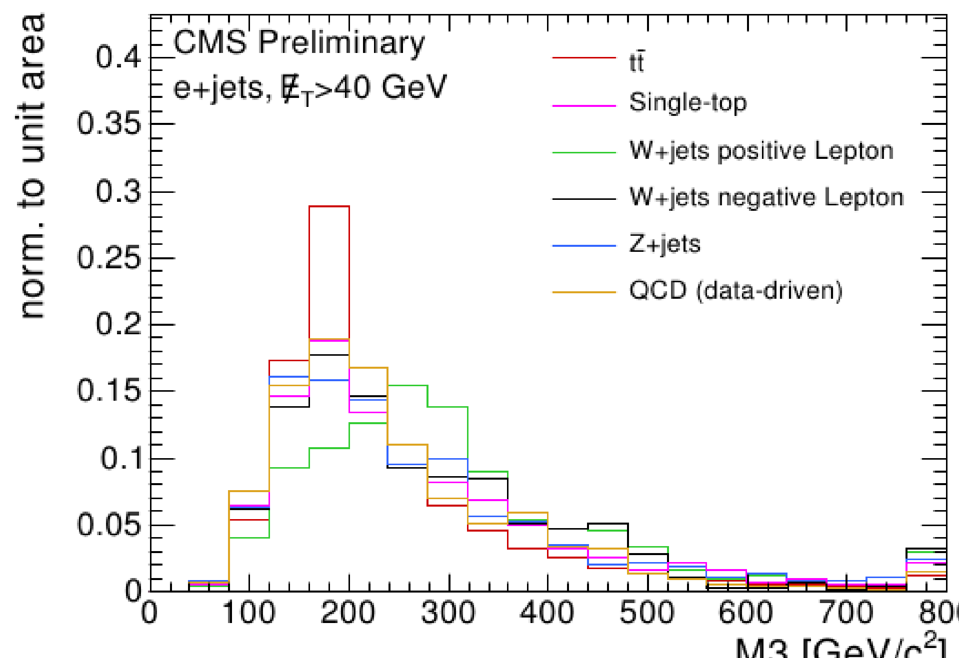
Event Selection

- Muon Definition
  - PT > 20 GeV
  - $|\eta| < 2.1$
  - X^2 global fit < 10
  - $N_{trk\text{-}hits} > 10$
  - IP < 0.02 cm
  - $|z(\mu) - z(PV)| < 1$ cm
  - PF relIso < 0.125
- Jet Definition
  - Anti KT PF jets
  - Pt > 30 GeV
  - $|\eta| < 2.4$
  - Particle Flow Jet ID
  - Require 4 jets
  - At least 1 b-tagged
- Electron Defiiniton
  - ET > 30 GeV
  - $|\eta| < 2.5 - [1.442, 1.5660]$
  - Electron ID
  - IP < 0.02 cm
  - $|z(\mu) - z(PV)| < 1$ cm
  - PF relIso < 0.125
- Loose Muons
  - PT > 10 GeV
  - $|\eta| < 2.5$
  - PF relIso < 0.25
- Loose Electrons
  - PT > 15 GeV
  - PF relIso < 0.25

Data-driven Background estimation

- Main lepton+jets background
  - W+jets, Z+jets, Single Top, and QCD
- Divide data into 8 categories for simultaneous fit
  - Leptons and charge: μ^+, μ^-, e^+, e^-
  - Missing E_T: MET < 40 GeV, MET > 40 GeV
- For MET < 40 GeV, fit MET
  - Z+jets and QCD dominate
- For MET > 40 GeV, fit invariant mass of three jets with largest vectorial sum(pT), refer to as M3
  - Distinguish between top and W+jets





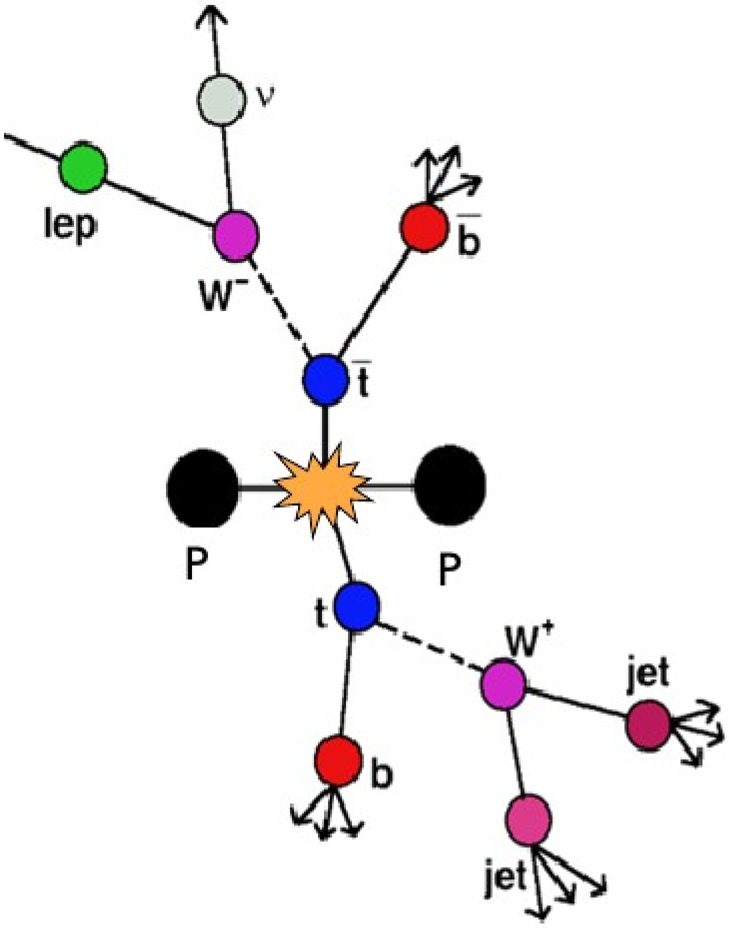
Event Yields

Luminosity = 1.09 fb^{-1}

process	electron+jets	muon+jets	total
$t\bar{t}$	4401 ± 165	5835 ± 199	10236 ± 258
single top (t + tW)	213 ± 58	293 ± 81	507 ± 99
W^++jets	313 ± 84	404 ± 106	718 ± 135
W^-+jets	299 ± 90	245 ± 109	544 ± 141
Z+jets	81 ± 24	85 ± 26	165 ± 35
QCD	355 ± 71	232 ± 79	587 ± 106
total fit result	5663 ± 226	7094 ± 276	12757 ± 357
observed data	5665	7092	12757

Reconstructing ttbar decays

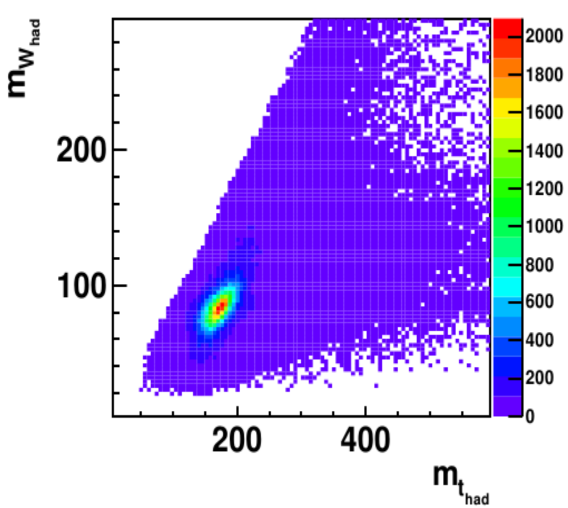
- To find η(top) or y(top) we must reconstruct the ttbar 4-vectors
- One top decays leptonically, one top decays hadronically
- During reconstruction several ambiguities arise
  - No info on z component of Missing Energy
  - jet-parton assignment
- With 4 jets there are 12 combinations for jet assignments
- For MC the best possible hypothesis is the one with the smallest

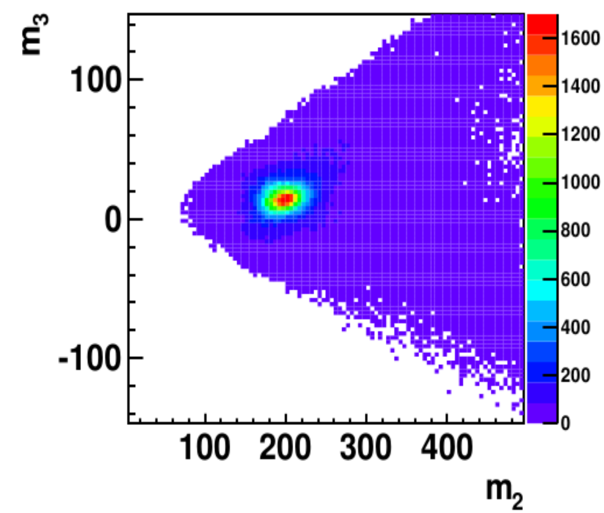


$$\sum \Delta R = \Delta R(p_{W^{rec}_{lep}}, p_{W^{gen}_{lep}}) + \Delta R(p_{W^{rec}_{had}}, p_{W^{gen}_{had}}) + \Delta R(p_{t^{rec}_{lep}}, p_{t^{gen}_{lep}}) + \Delta R(p_{t^{rec}_{had}}, p_{t^{gen}_{had}})$$

Reconstruction (2)

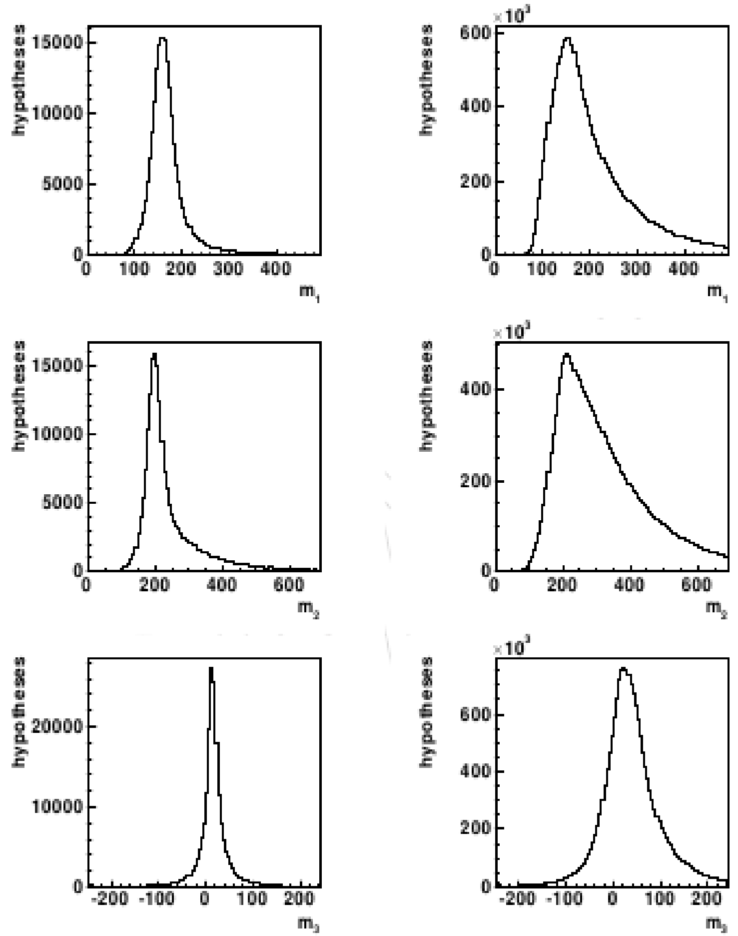
- For data only measurable quantities can be used
  - Masses of the reconstructed hadronic W and the two reconstructed tops
  - B-tagger output of the four jets assigned to the 2 light and 2 b quarks
  - $M_{W,had}$ and $M_{t,had}$ are highly correlated





Best possible

All hypotheses



$$\begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix} = \begin{pmatrix} 1.00 & -0.05 & 0.00 \\ 0.05 & 0.93 & 0.35 \\ -0.01 & -0.35 & 0.94 \end{pmatrix} \begin{pmatrix} m_{t,\mathrm{lep}} \\ m_{t,\mathrm{had}} \\ m_{W,\mathrm{had}} \end{pmatrix}$$

Build likelihood ration $L(m_i) = p_{best}(m_i) / p_{all}(m_i)$

Reconstruction (3)

- B tagger output (x_i) used to improve jet assignment

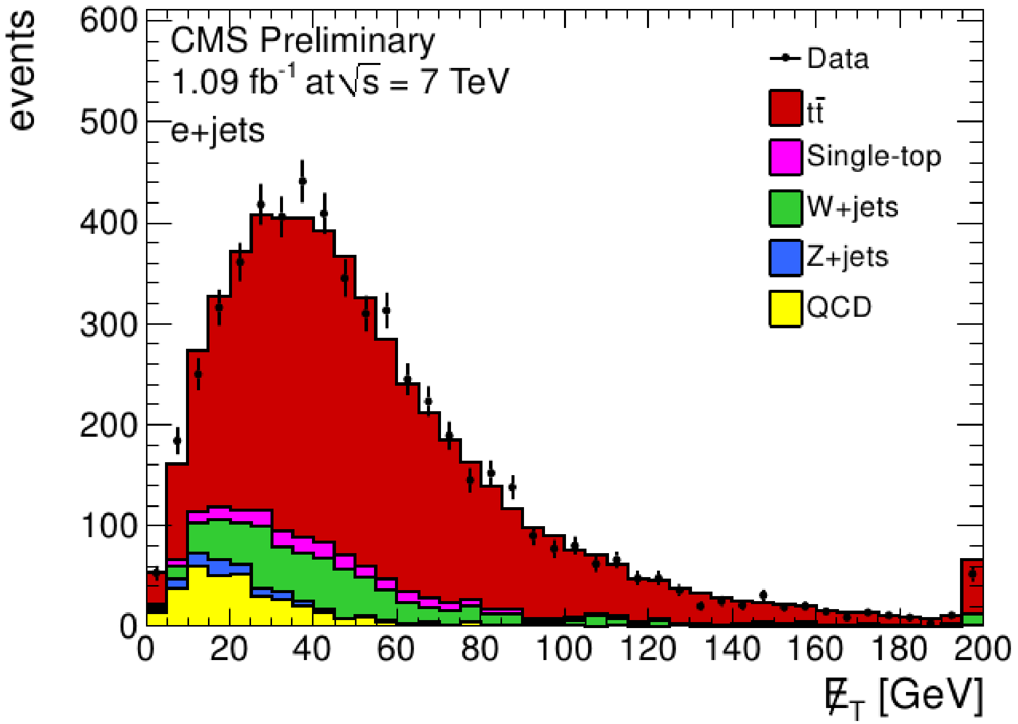
$$P_b(x_{b,had}),\ P_b(x_{b,lep}),\ P_b(x_{q1}),\ P_b(x_{q2})$$

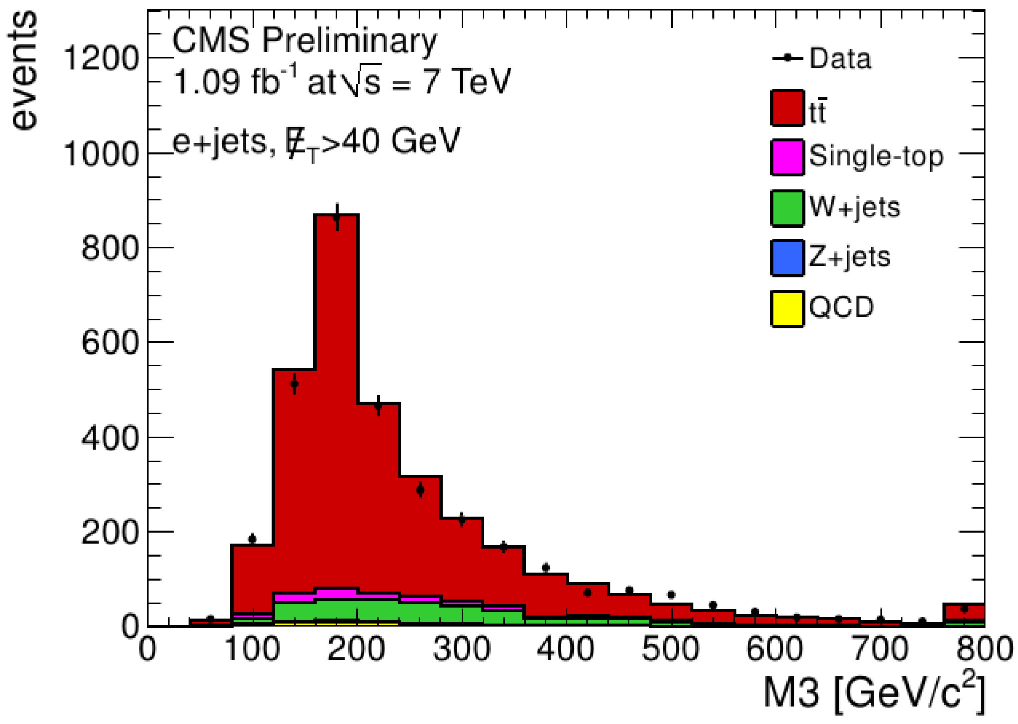
- Select the solution with maximum ψ

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

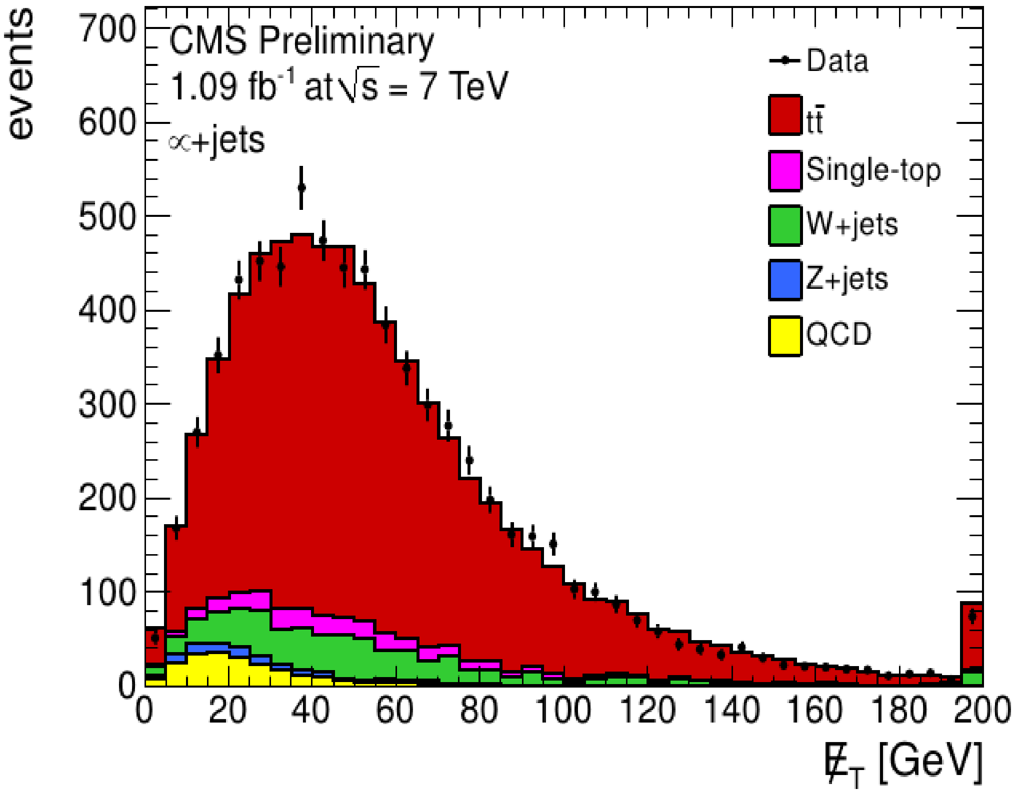
- This procedure finds best possible hypothesis
  - In 29% of all events
  - In 51% of events where all 4 final state quarks are present within detector acceptance

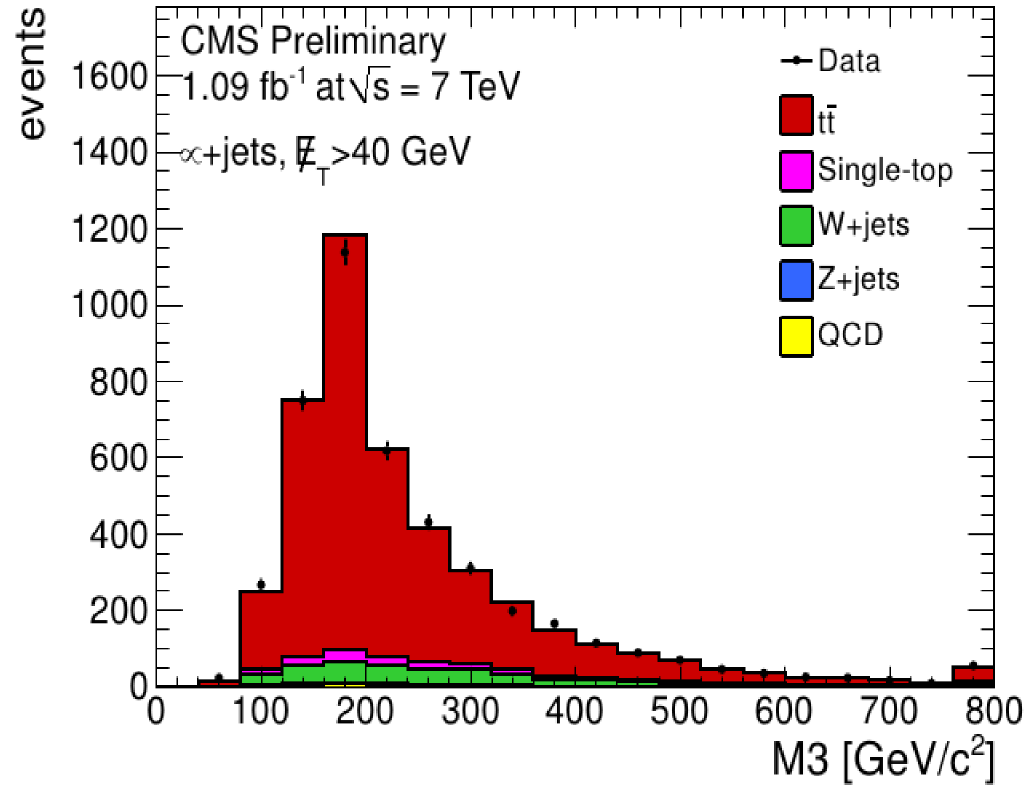
Data/MC after Reconstruction (e+jets)





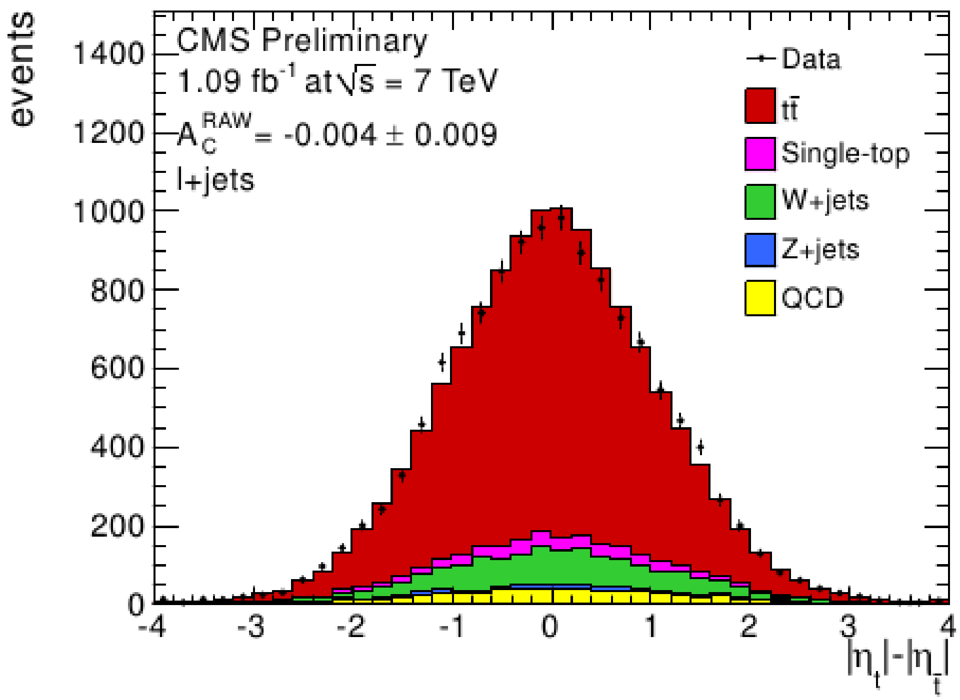
Data/MC after Reconstruction (μ+jets)



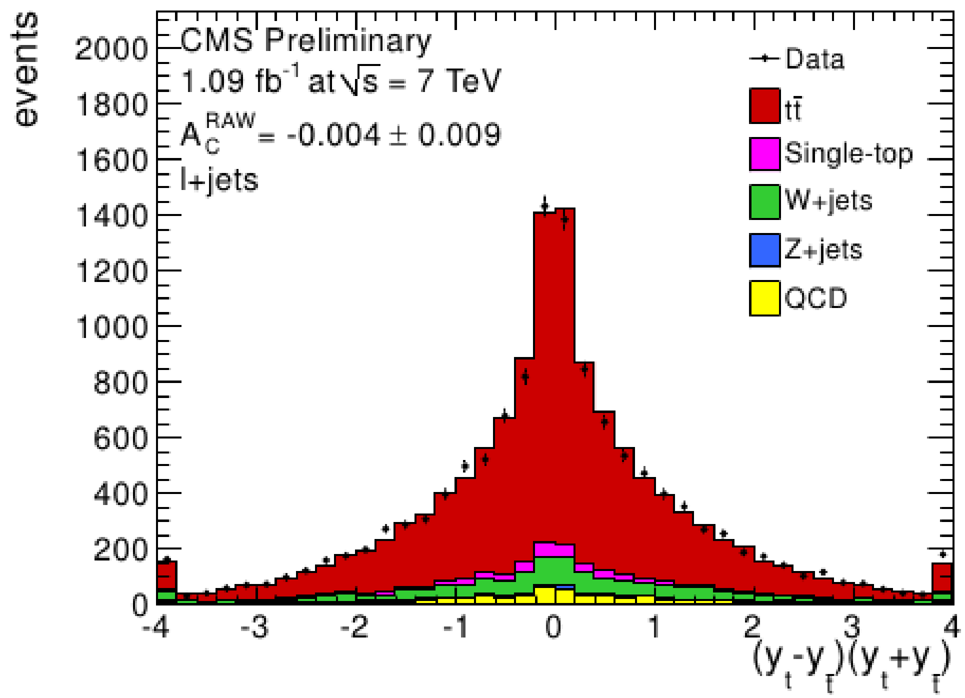


Raw asymmetry after Reconstruction

$\Delta(|\eta|)$ for lepton+jets



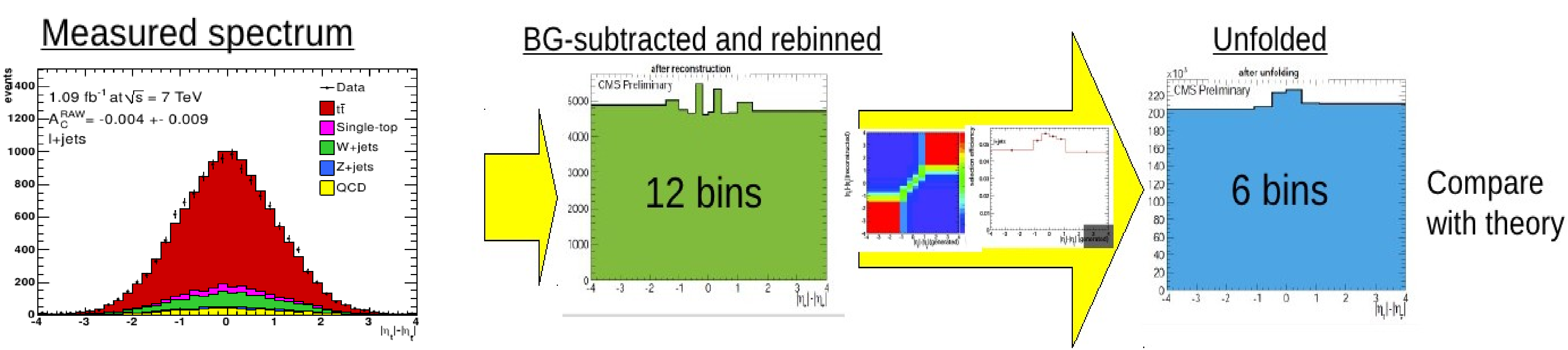
$\Delta(y^2)$ for lepton+jets



- Raw asymmetry for both variables < 1%
- Effects between true asymmetry and raw asymmetry
  - BG contribution
  - Event selection efficiency
  - Imperfect reconstruction
- Need to unfold the spectra to be able to compare to theory

Unfolding the raw asymmetry

- Subtract predicted background (all data → ttbar data)
- Unfold background subtracted distribution
  - Correct for reconstruction effects (reco hist → true selected)
    - Non perfect jet-parton assignment
    - Detector resolution
  - Correct for acceptance effects (true selected hit → true)
    - Selection efficiency not flat as a function of η and y

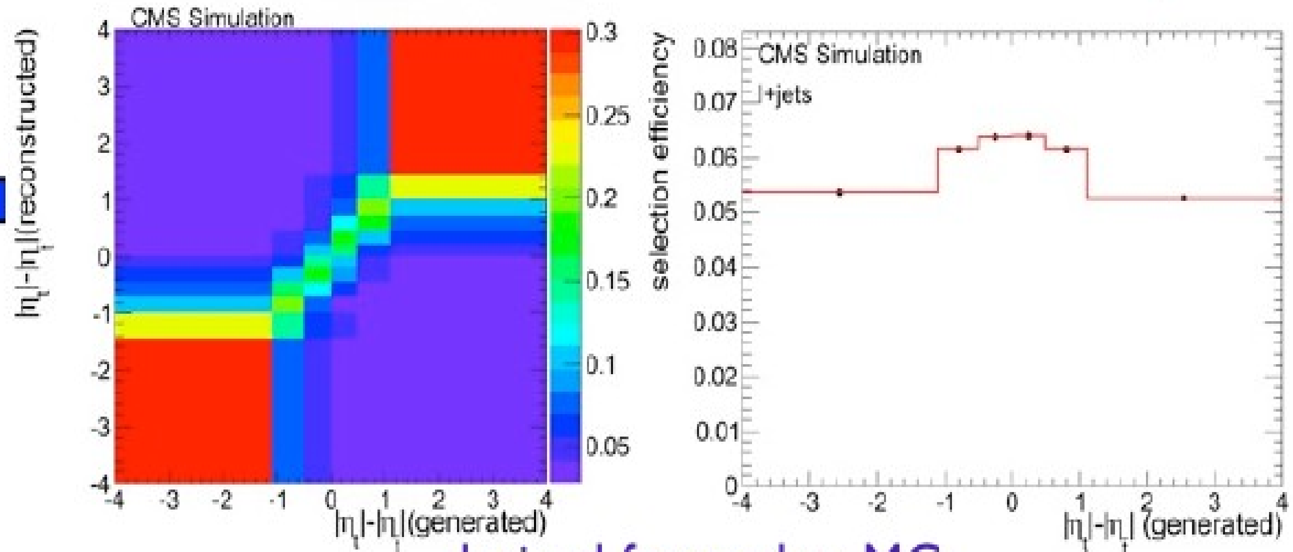


Unfolding (2)

$$\vec{w} = A\vec{x}$$

Migration effects

Selection efficiency

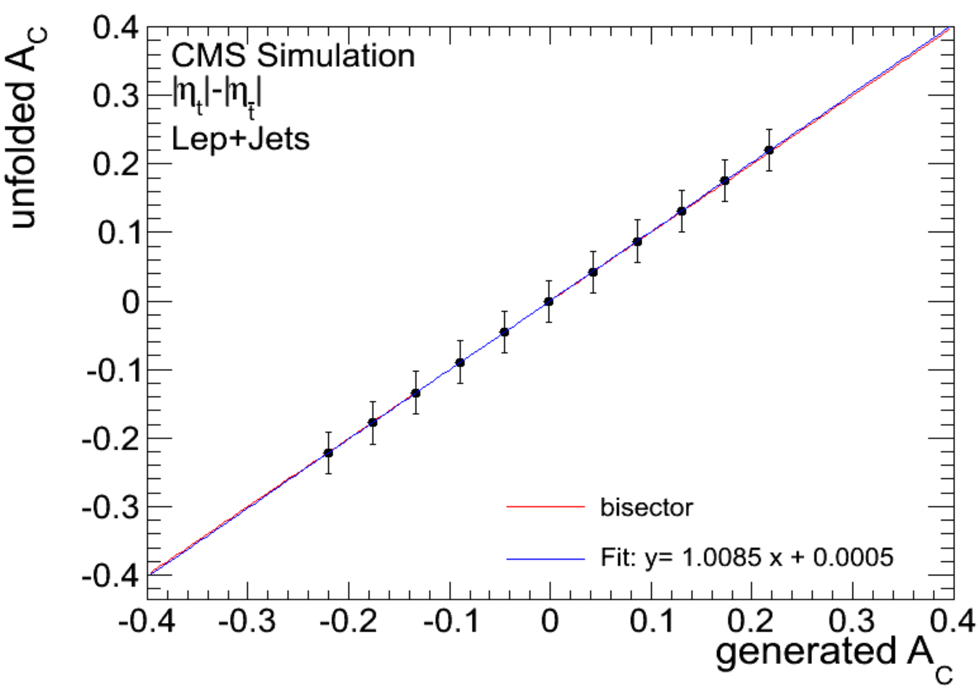


derived from ttbar MC

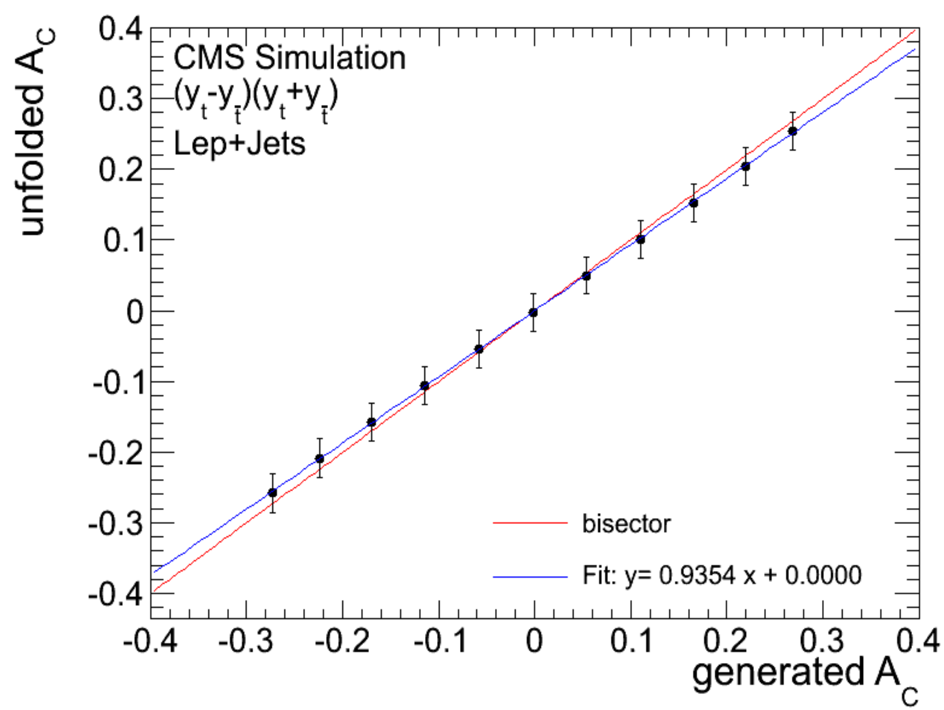
- Smearing matrix A defines translation of true spectrum x into measured spectrum w
- A is factorizable:
  - Migration effects due to imperfect reconstruction
  - Selection efficiency varying with η and y

Unfolding consistency check

- Pseudo experiments (PEs) to test the performance of the unfolding algorithm
  - The data for a single PE is drawn from the ttbar and background templates and then unfolded
  - 50,000 PEs per study
  - A_C pull distribution are Gaussian and centered: <u>**no bias in unfolding**</u>
  - Linearity check: test if large values of A_C would be unfolded correctly



Δ|η| agreement is very good



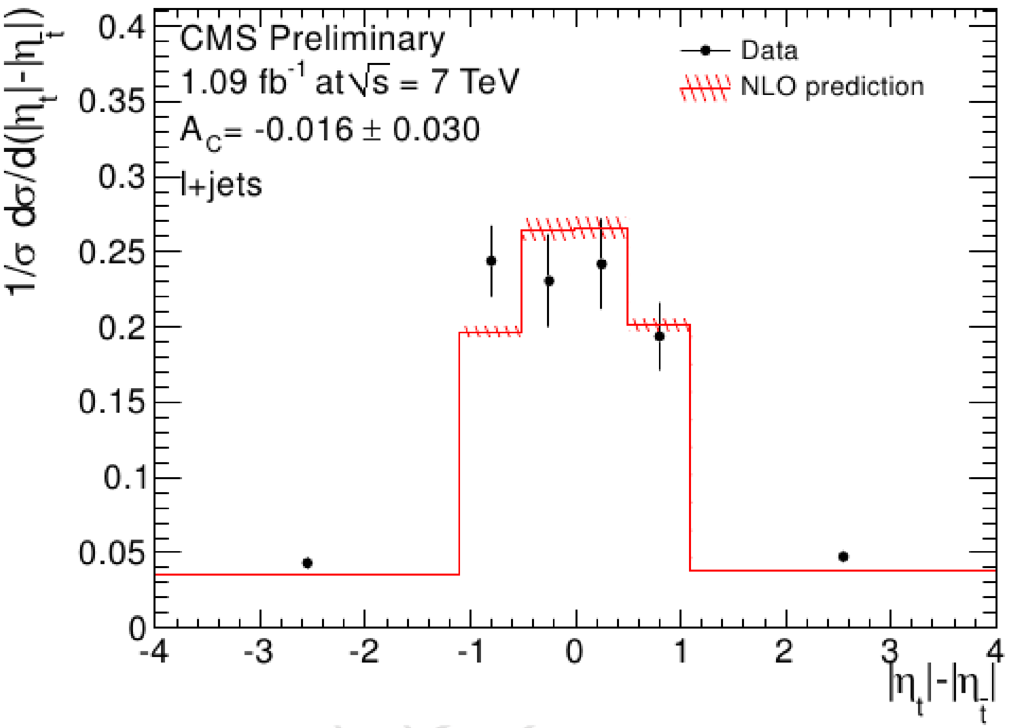
$\Delta(y^2)$ will need a slight bias correction

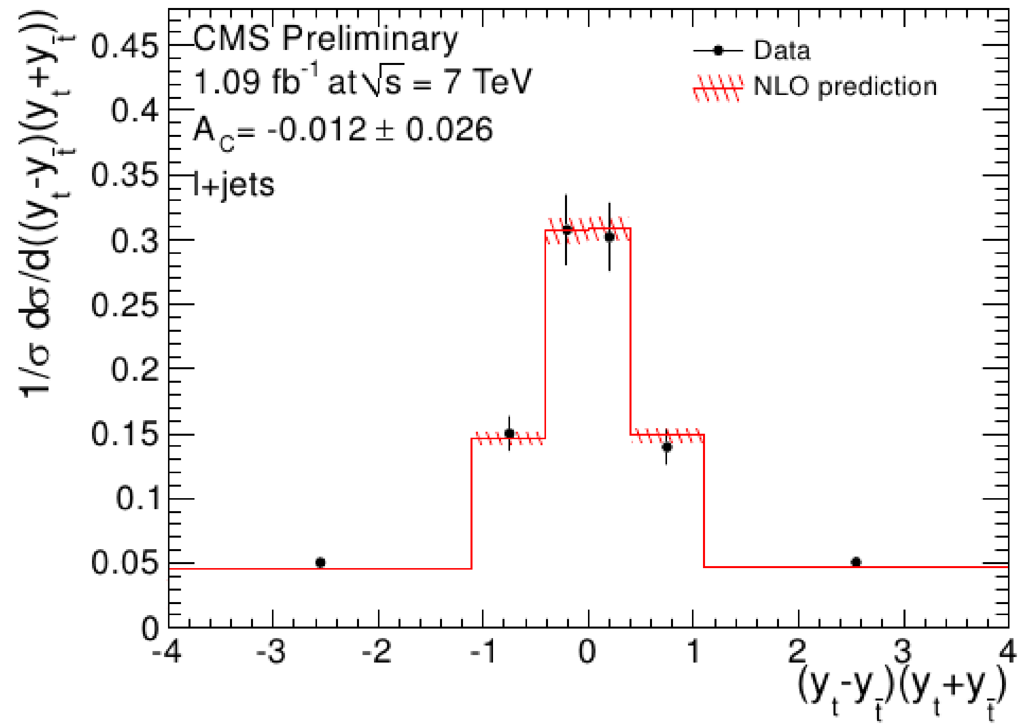
Systematic uncertainties

- A_C is insensitive to absolute normalization effects such as luminosity and overall ttbar efficiency and acceptance
- Pseudo data is also used to evaluate systematics uncertainties from sources that could generate relative uncertainties

	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

TTbar Charge Asymmetry Results



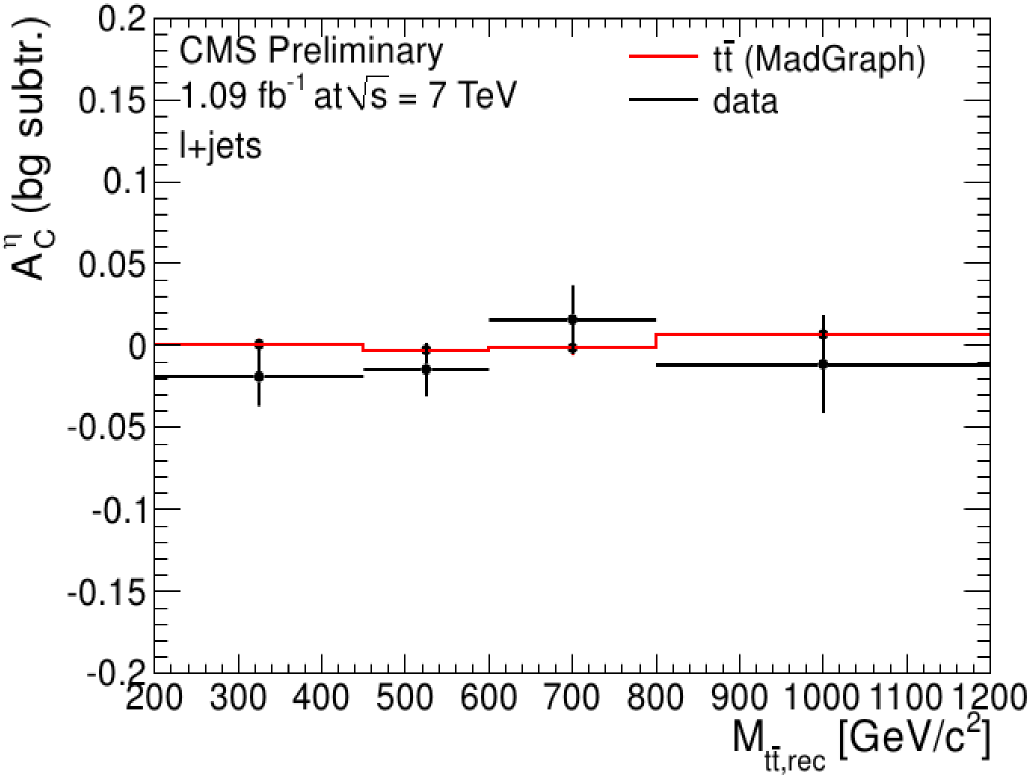


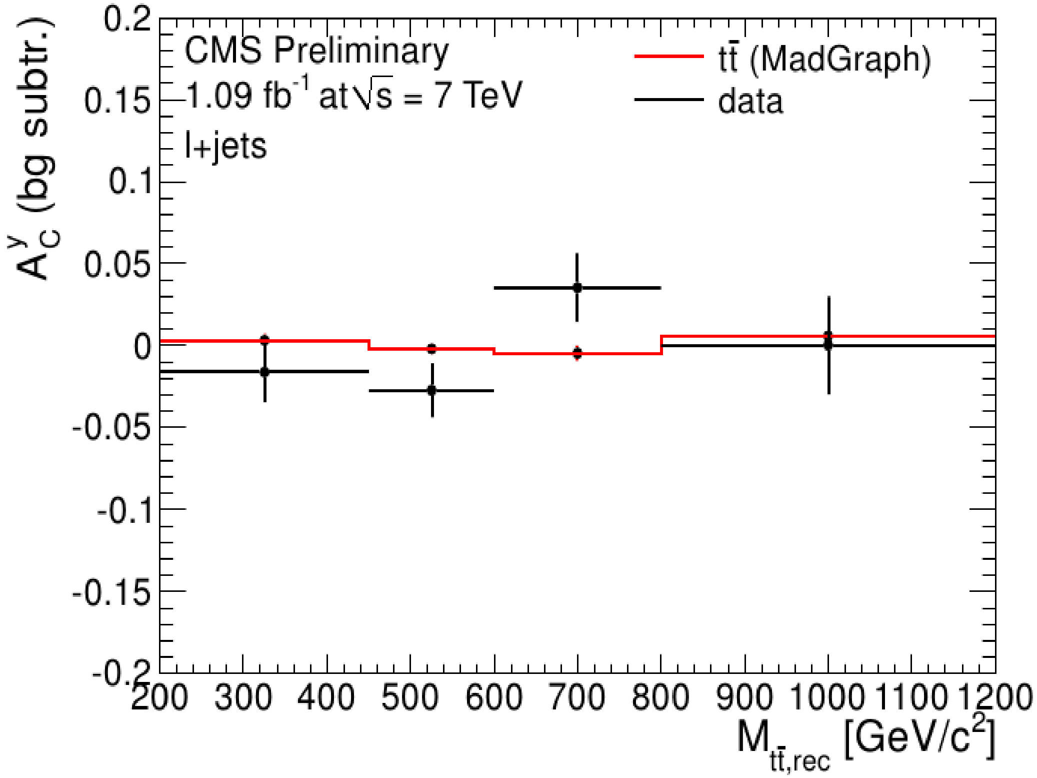
process	Raw	BG-subtracted	Unfolded (and corrected)
$\Delta\|\eta\|$	-0.004 ± 0.009	-0.009 ± 0.010	$-0.016 \pm 0.030^{+0.010}_{-0.019}$
$\Delta(y^2)$	-0.004 ± 0.009	-0.007 ± 0.010	$-0.013 \pm 0.026^{+0.026}_{-0.021}$

Both unfolded measurements are in agreement with theory predictions

$A_C^{\eta}(theory) = 0.013 \pm 0.001$ $\quad$ $A_C^{y}(theory) = 0.011 \pm 0.001$ [Rodrigo]

M(tt) dependence?





- BG subtracted (but not unfolded) A_C as a function of M(tt)
- Results so far are consistent with SM expectations
- Do not see large deviations at high mass like the Tevatron reports

Summary

- Charge asymmetry in ttbar production can provide a window into new physics at the electroweak scale
- CMS has measured the A_C with 1.09 fb^{-1} of data using two different variables
  - $A_C^{\eta} = -0.016 \pm 0.030\ (\text{stat.})^{+0.010}_{-0.019}(\text{syst.})$
  - $A_C^{y} = -0.013 \pm 0.026\ (\text{stat.})^{+0.026}_{-0.021}(\text{syst.})$
- Both slightly negative asymmetries are compatible with the SM predictions of ~1%
- Future A_C measurements:
  - Smaller statistical uncertainties
  - Unfolded and binned in M(tt)