Measurement of the Charge Asymmetry in Top Quark Pair Production in *pp* Collisions at 7 Tev using the CMS Detector

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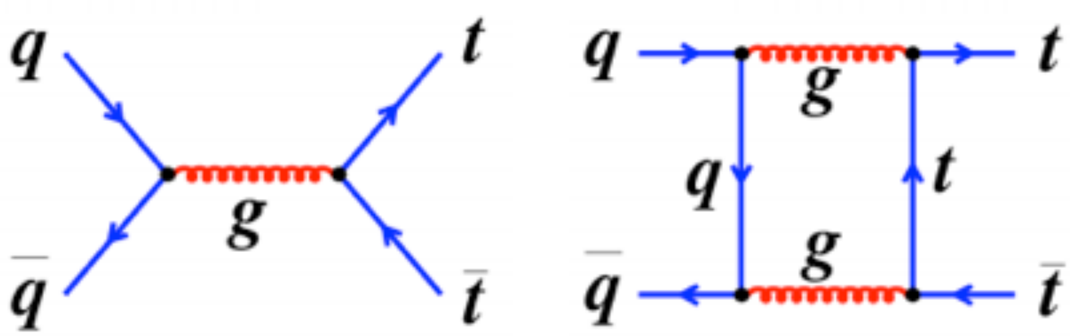
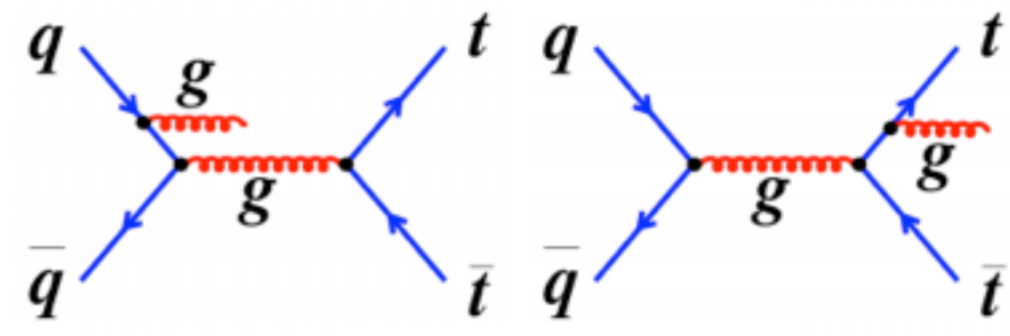
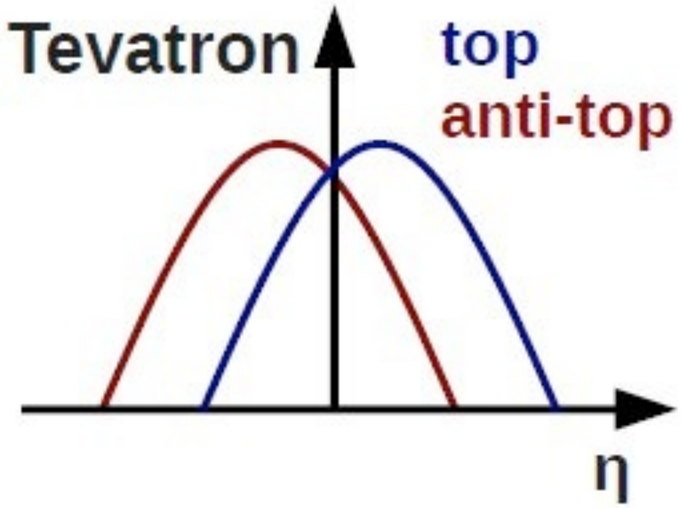
Looking for new physics with ttbar

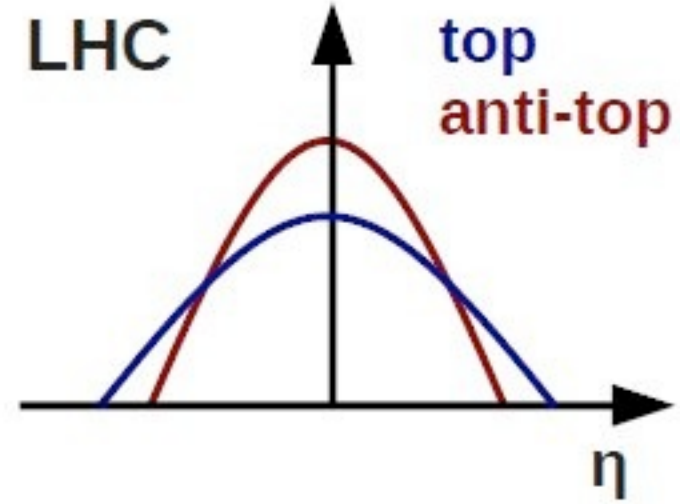




- Standard Model: Interference of leading order and box diagram (left) and initial and final state radiation diagrams (right) lead to small charge asymmetry in quark-antiquark annihilation mode
- Beyond standard model: axigluons, Z', W', Kaluza Klein
  - New resonances *s*-channel production in M(tt) not necessarily visible
  - Different couplings might lead to changes in their angular distributions
  - ★ Charge asymmetry would be sensitive to *t*- and *u*-channel exchange

Charge asymmetry in ttbar events





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

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

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

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

Asymmetric initial state

top in direction of proton(quark)

anti-top in direction of antiproton

- SM Theory: ~5% [Kühn, Rodrigo]
- CDF measures $A_C(y)$ 2σ larger than SM pred.

☆ +3.4σ for M_{tt} > 450 GeV/c^2

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Symmetric initial state

quark is usually valence (higher p)

anti-quark is usually a sea quark

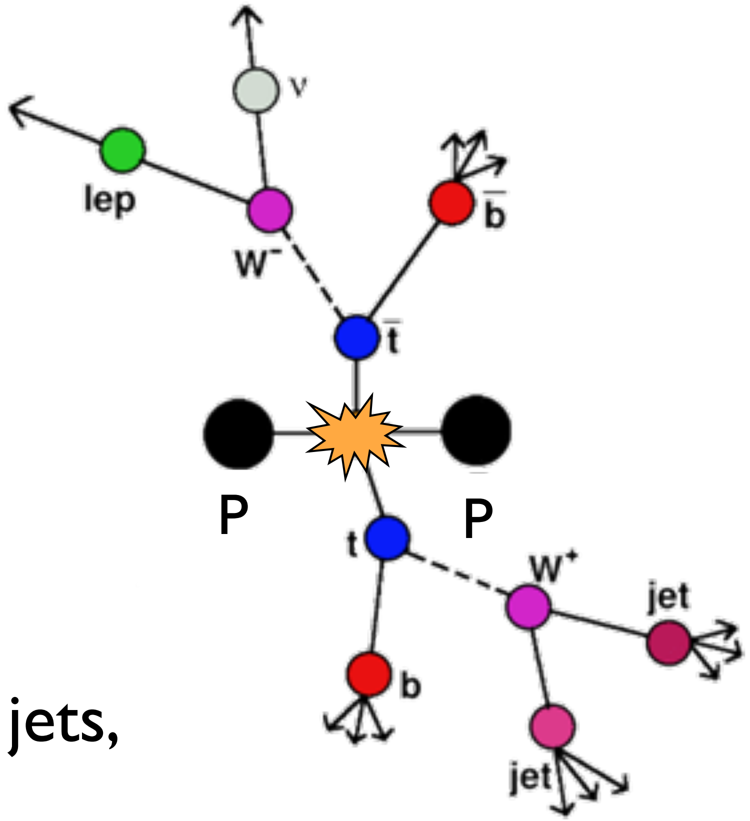
- SM Theory: 1.3% (η) and 1.1% (y) [Kühn, Rodrigo]
- CMS 36 pb^{-1}: CMS-PAS-10-010

$A_C(\eta)$ = 0.060 ± 0.134 (stat) ± 0.026 (syst)

- Today: Update to 1.09 fb^{-1}

Reconstructing ttbar decays

- Event signature: one leptonic decay, one hadronic decay
  - Require 1 high p_T e or μ, $\geq$ 4 jets, and $\geq$ one b-tag
  - Additional loose lepton veto, conversion rejection
- Important to fully and correctly reconstruct the 4 momentum of the top quarks
- For the neutrino
  - $p_x(\nu)$ and $p_y(\nu)$ from missing E_T
  - constrain W mass to 80.4 GeV
- Want to pick the best possible assignment of jets (with 4 jets, there are 12 combinations to consider)
  - Simulation: define "best possible" as best angular match for W_{had}, W_{lep}, t_{had}, and t_{lep}
  - Data: rank the hypotheses according to a likelihood *(testing method on simulation)*

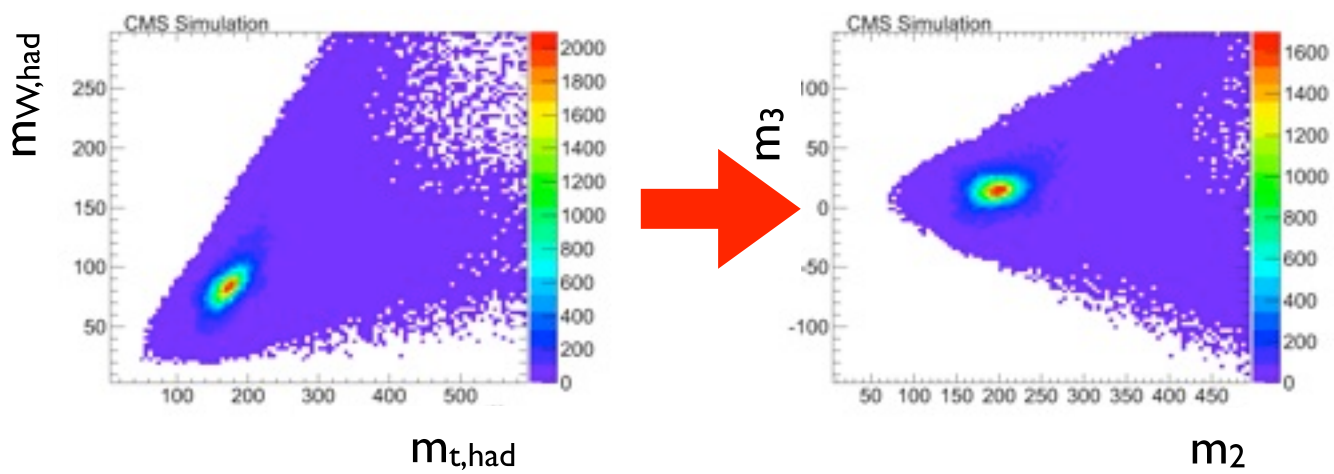


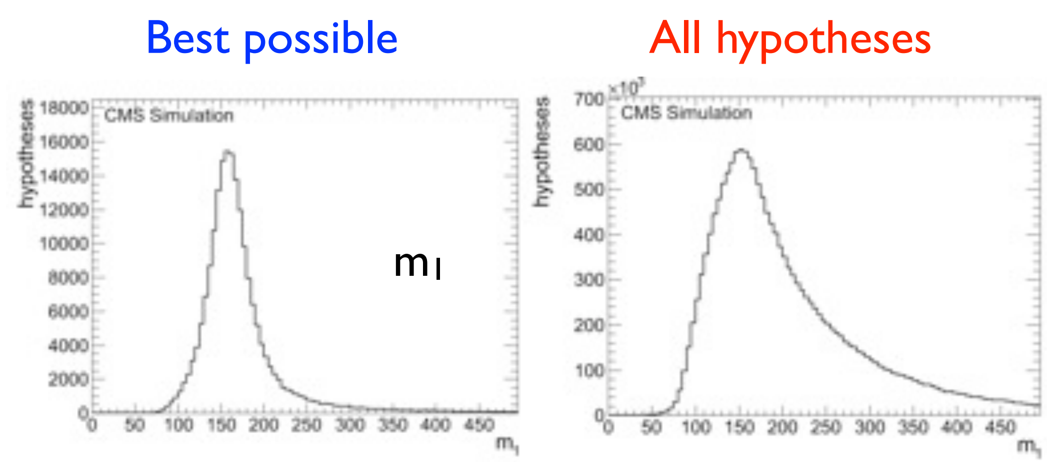
Hypothesis Selection

Choose hypothesis with maximum

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

- Consider the masses of the hadronic W and both tops
  - $m_{W,had}$ and $m_{t,had}$ are highly correlated
  - $m_{t,lep}$, $m_{W,had}$, and $m_{t,had}$ $\rightarrow m_1$, m_2, and m_3





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

- B tagging output is used to improve jet assignment
- Performance in MC
  - finds best possible hypothesis in 29% of all events
  - when all 4 final state jets are present, it's 51%

Background Estimation (1)

- The main background in lepton+jets ttbar sample

  W+jets, Z+Jets, Single Top, QCD

- Divide the data into 8 samples for simultaneous fit

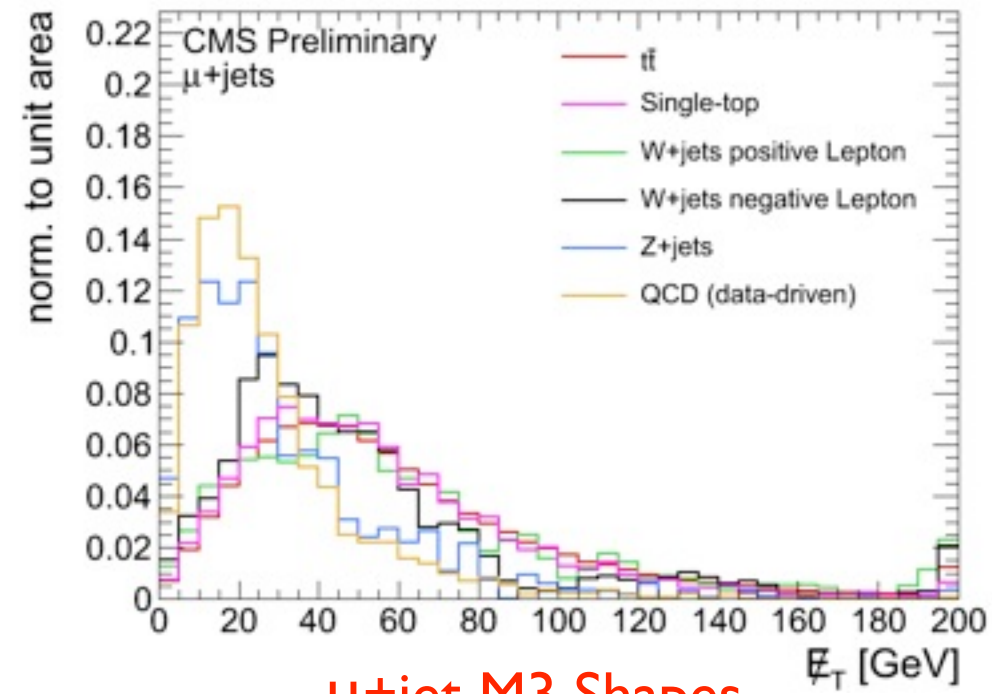
  leptons and charge: μ^+, μ^-, e^+, e^-

  missing E_T: MET<40 GeV , MET>40 GeV

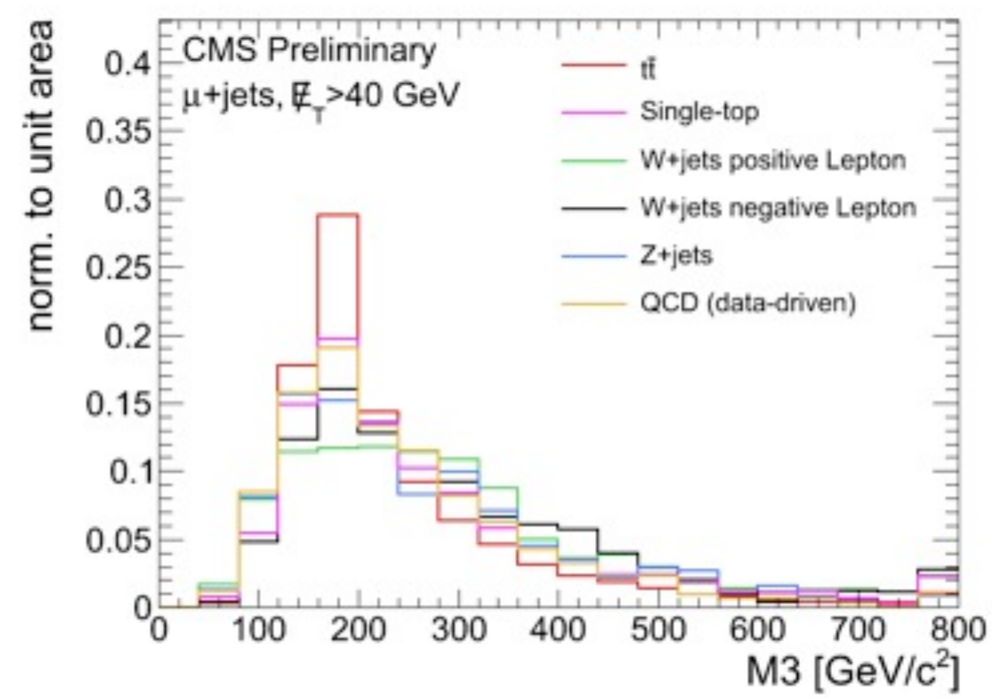
- For MET<40 GeV samples, fit MET
- For MET>40 GeV samples, fit invariant mass of three jets with largest vectoral Σp_T (M3)

- MC templates for all channels except QCD
  - QCD: data with non-isolated lepton

μ+jet Missing E_T Shapes

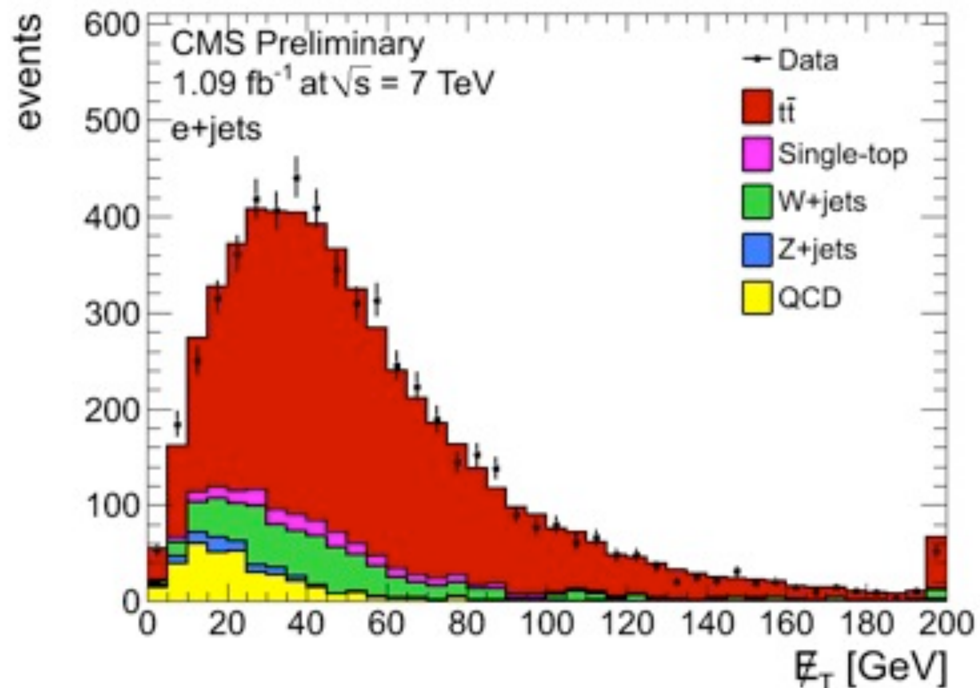


μ+jet M3 Shapes

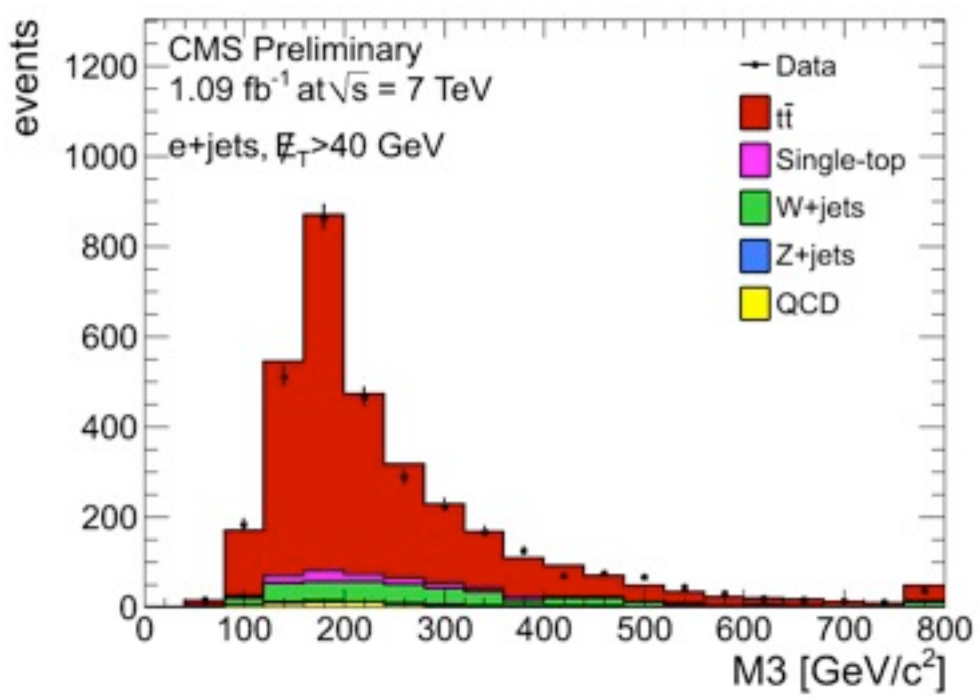


Background Estimation (2)

e+jet Missing E_T Fit Result



e+jet M3 Fit Result



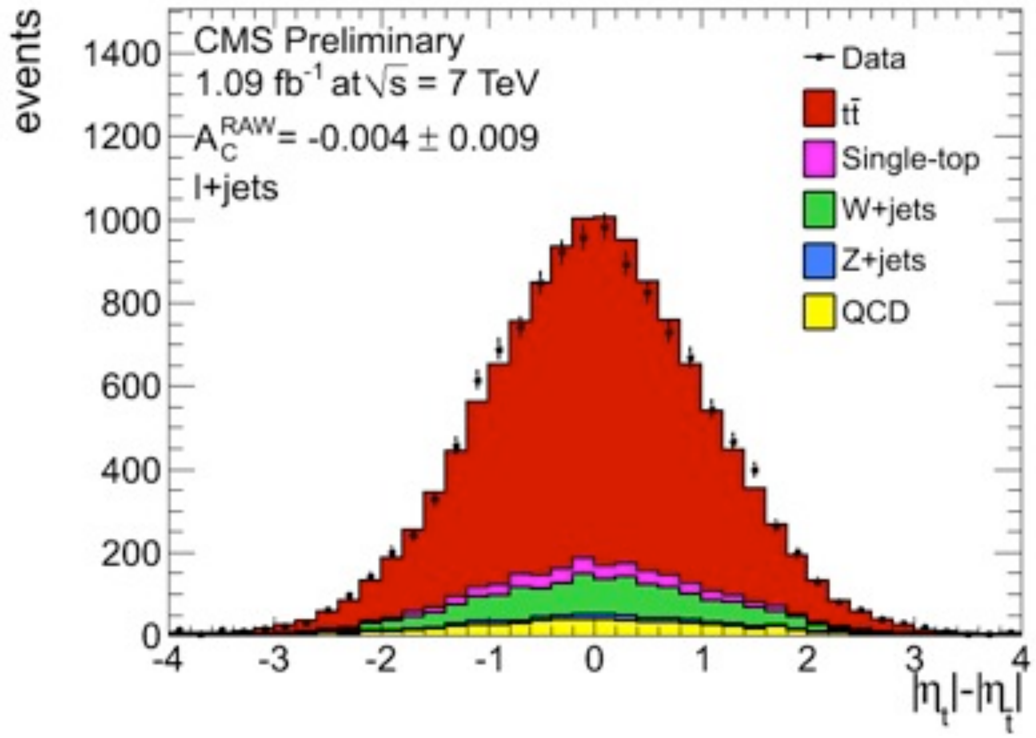
Event Yields

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

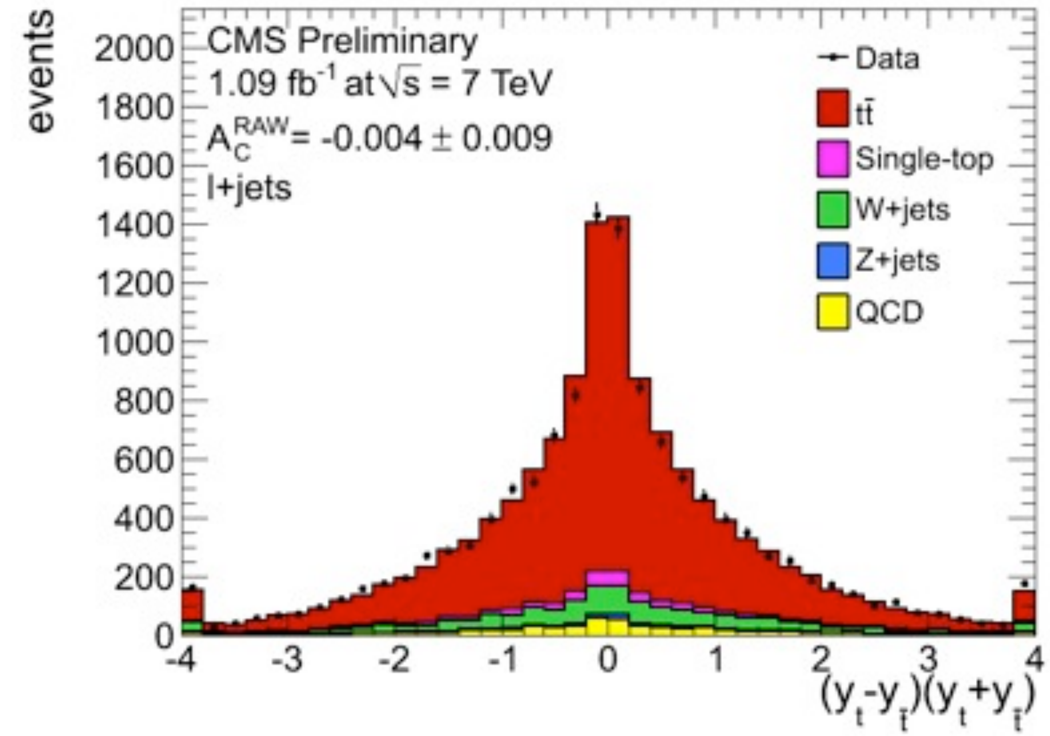
- Excellent agreement between fit and data
- Largest background is W+jets
- Background estimation
  - → background subtractions

Raw Asymmetry

Δη for lepton+jets



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

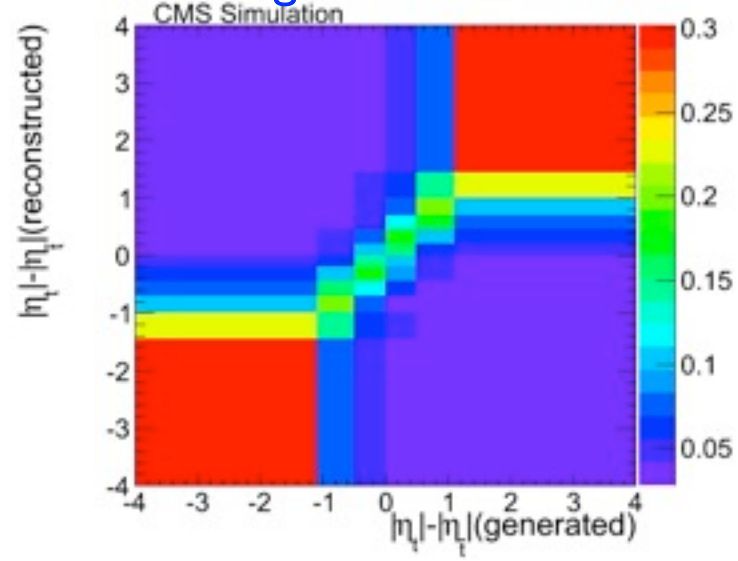


- Raw asymmetry for both variables <1%
- Effects between true asymmetry and raw asymmetry
  - selection efficiency (true ttbar → true selected ttbar)
  - imperfect reconstruction (true selected → reconstructed ttbar)
  - background contribution (ttbar → all data)
- Need to **unfold** the distributions to compare with theory

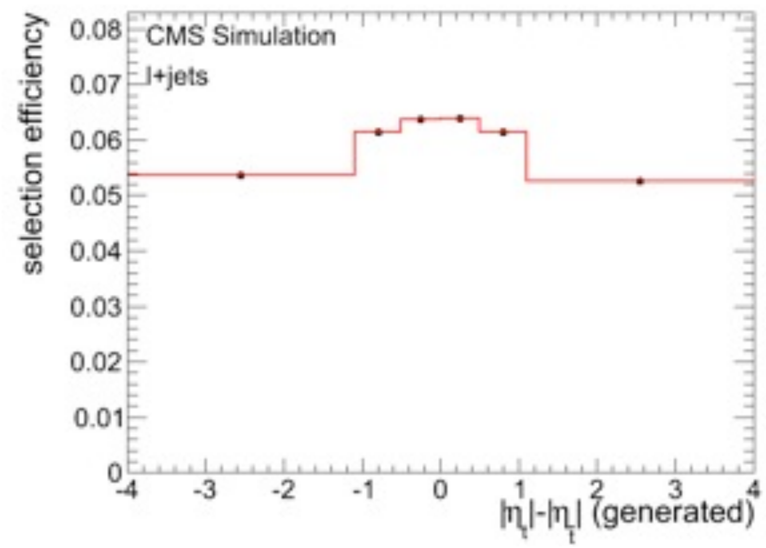
Unfolding the raw asymmetry

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

Migration effects



Selection efficiency

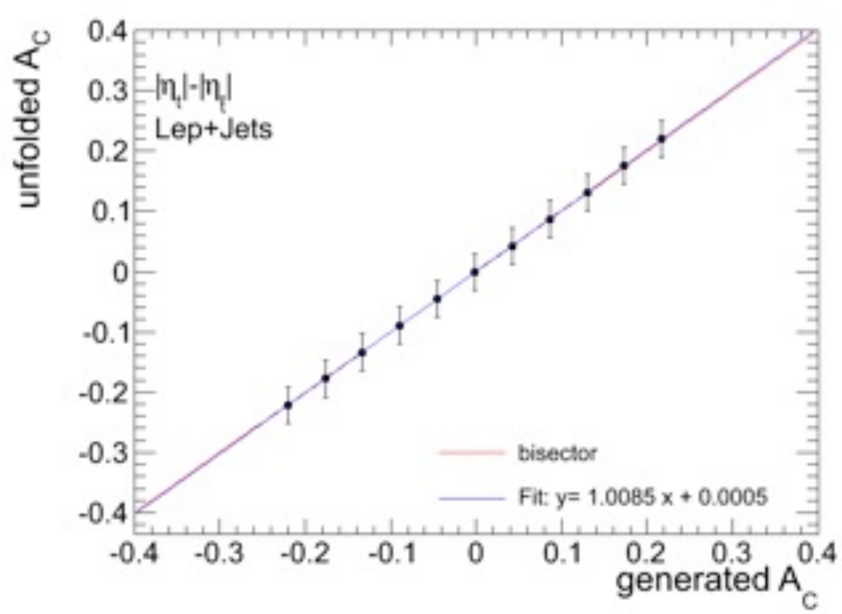


- Smearing matrix A translates true spectrum *x* into measured spectrum *w*
- A is factorizable:
  - Migration effects due to imperfect reconstruction
    - non perfect jet-parton assignment
    - detector resolution
  - Selection effects
    - selection efficiency not flat as a function of η and y
    - Ex: our 4 jet selection enriches ISR/FSR → changes asymmetry
- Solve the equation using regularized unfolding technique

Unfolding consistency check

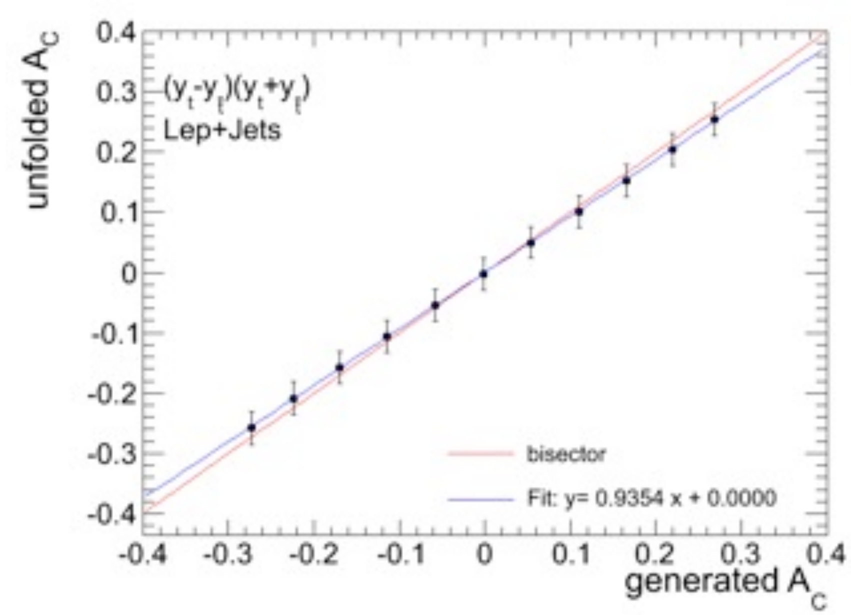
- We use pseudo experiments (PEs) to test the performance of the unfolding algorithm.
  - The "data" for a single PE is drawn from the ttbar and background templates and then unfolded.
  - 50,000 PEs per study
- A_C pull distribution are gaussian and centered: no bias in unfolding
- Linearity check: test if large values of A_C would be unfolded correctly

$$k \cdot (|\eta_t| - |\eta_{\bar{t}}|) + 1$$



Δ|η| agreement is very good.

$$k \cdot (y_t - y_{\bar{t}})\,(y_t + y_{\bar{t}}) + 1$$



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

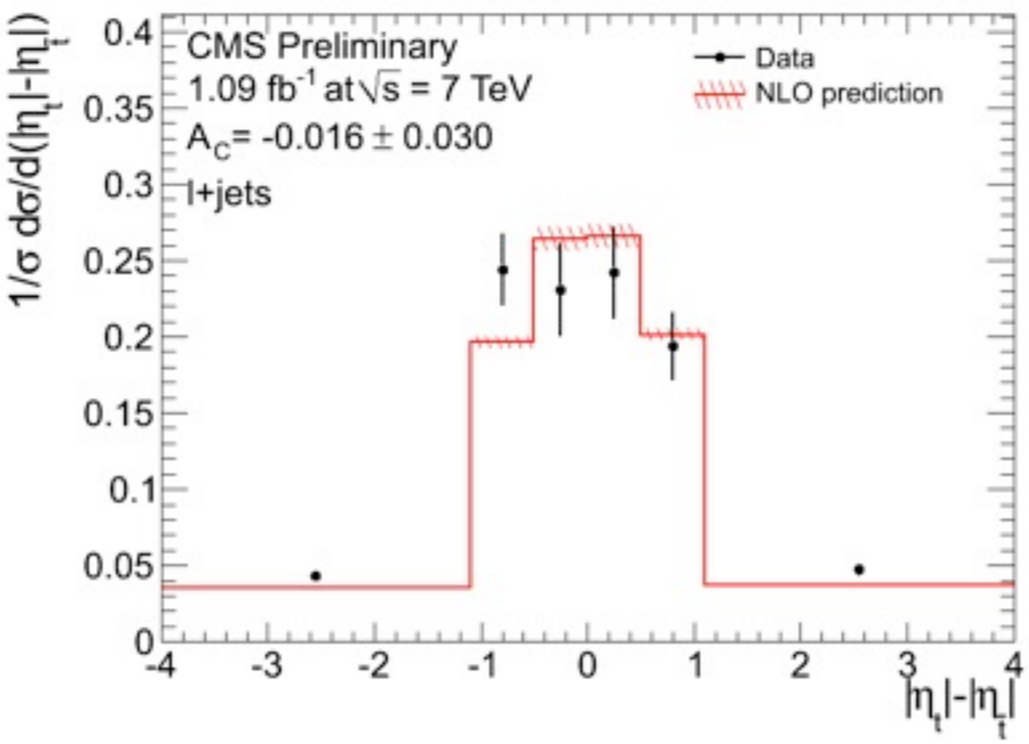
Systematic uncertainties

- 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 source that could generate relative uncertainties
  - create pseudo data from systematically shifted distributions

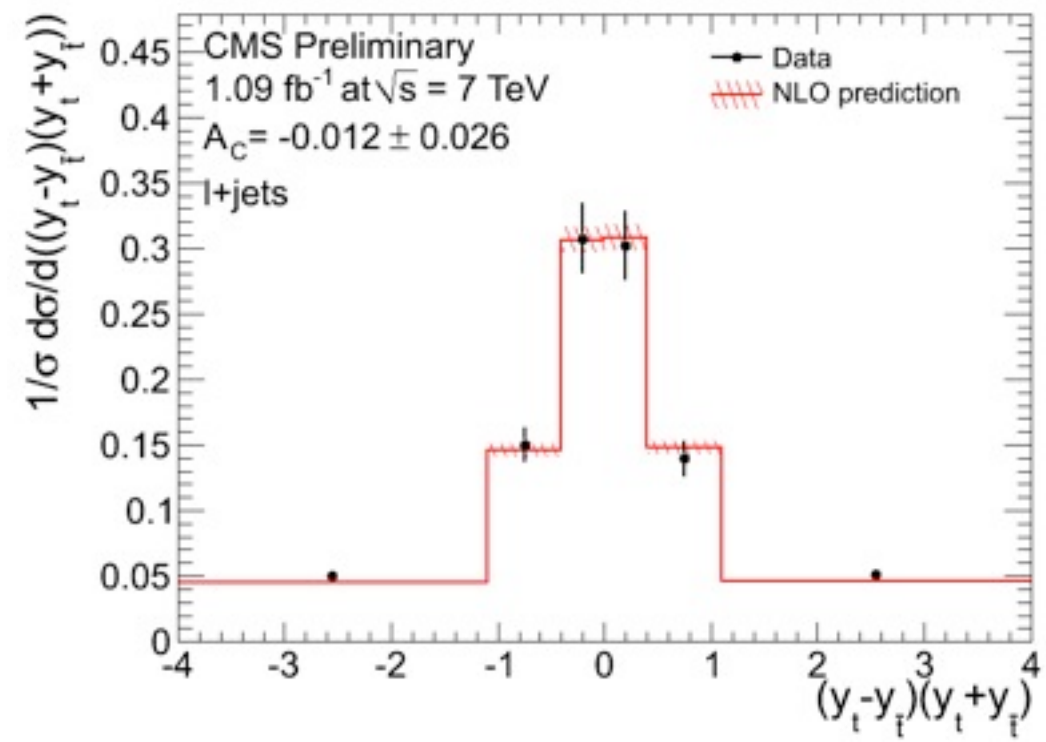
	A_C^{η}		A_C^{y}	
Source of Systematic	− Variation	+ Variation	− Variation	+ Variation
JES	−0.003	0.000	−0.007	0.000
JER	−0.002	0.000	−0.001	0.001
Q^2 scale	−0.014	0.000	−0.013	+0.003
ISR/FSR	−0.006	+0.003	0.000	+0.024
Matching threshold	−0.006	0.000	−0.013	+0.006
PDF	−0.001	+0.001	−0.001	+0.001
b tagging	−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

Unfolded Δ|η|



Unfolded Δ(y^2)

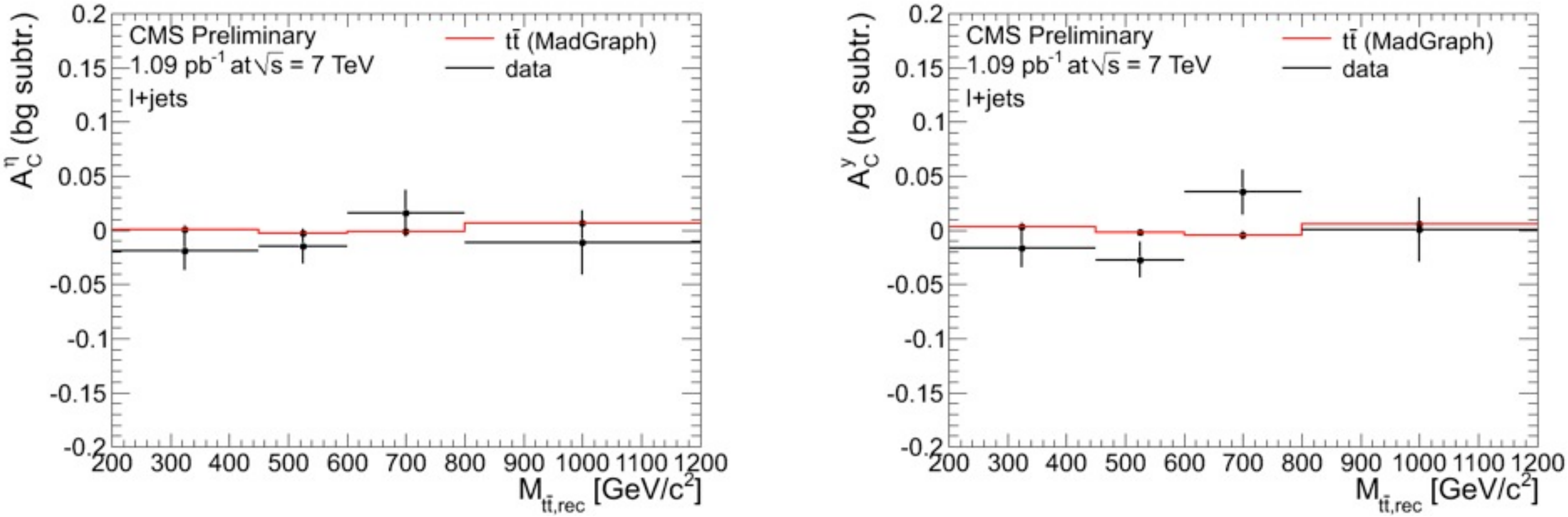


process	Raw	BG-subtracted	Unfolded (and corrected)
$\Delta\|\eta\|$	-0.004 ± 0.009	-0.009 ± 0.010	$-0.016 \pm 0.030^{+0.010}_{-0.019}$
$\Delta(y^2)$	-0.004 ± 0.009	-0.007 ± 0.010	$-0.013 \pm 0.026^{+0.025}_{-0.020}$

Both unfolded measurements are in agreement with theory predictions

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

No hint yet of M(tt) dependence



- Background subtracted (but not unfolded) A_C as a function of M(tt)
- Results so far are consistent with standard model expectations
- Next step: 2D unfolding in $\Delta|\eta|$ or $\Delta(y^2)$ and M(tt) to get unfolded A_C as a function of M(tt)

Summary

- Charge asymmetry in ttbar production can provide a window into new physics at electroweak scale
- CMS has updated the A_C measurement with 1.09 fb^{-1} of data using two different variables
- Both (slightly) negative asymmetries are compatible with the standard model predictions of ~1%
- Also compatible with Tevatron positive asymmetry measurements
  - Still room for new physics!
- Looking forward to future A_C measurements
  - with smaller statistical uncertainties
  - and mapping M(tt) dependence

Back-up slides

Analysis cuts

Muon Definition

- $p_T > 20$ GeV
- $|\eta| < 2.1$
- χ^2 global fit < 10
- $N_{trk\text{-}hits} > 10$
- IP < 0.02 cm
- $|z(\mu)-z(PV)| < 1$ cm
- PF relIso < 0.125

Electron Definition

- 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

Jet Definition

- anti KT PF jets
- $p_T > 30$ GeV
- $|\eta| < 2.4$
- Particle Flow Jet ID

Loose Muon

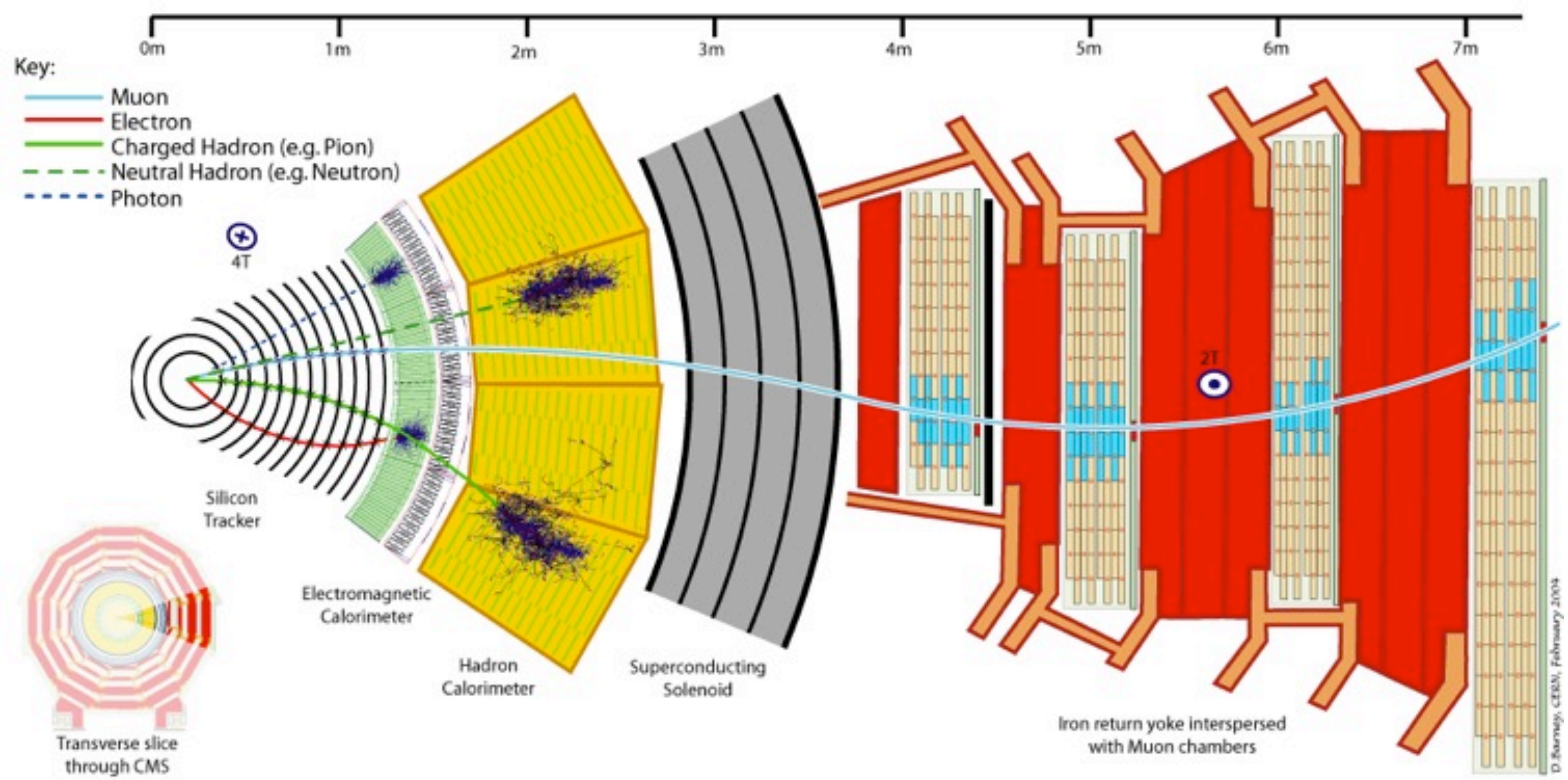
- $p_T > 10$ GeV
- $|\eta| < 2.5$
- PF relIso <0.25

Loose Electron

- $p_T > 15$ GeV
- PF relIso <0.25

CMS: The Compact Muon Solenoid

- For reconstruction, we use particle flow
  - global perspective on reconstruction
  - sub-dectector object → CMS wide object
  - effectively handles overlap (double counting) in muon/electron/jet collections



Statistical Uncertainty

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

The statistical uncertainty can be calculated from the output of the unfolding procedure as follows:

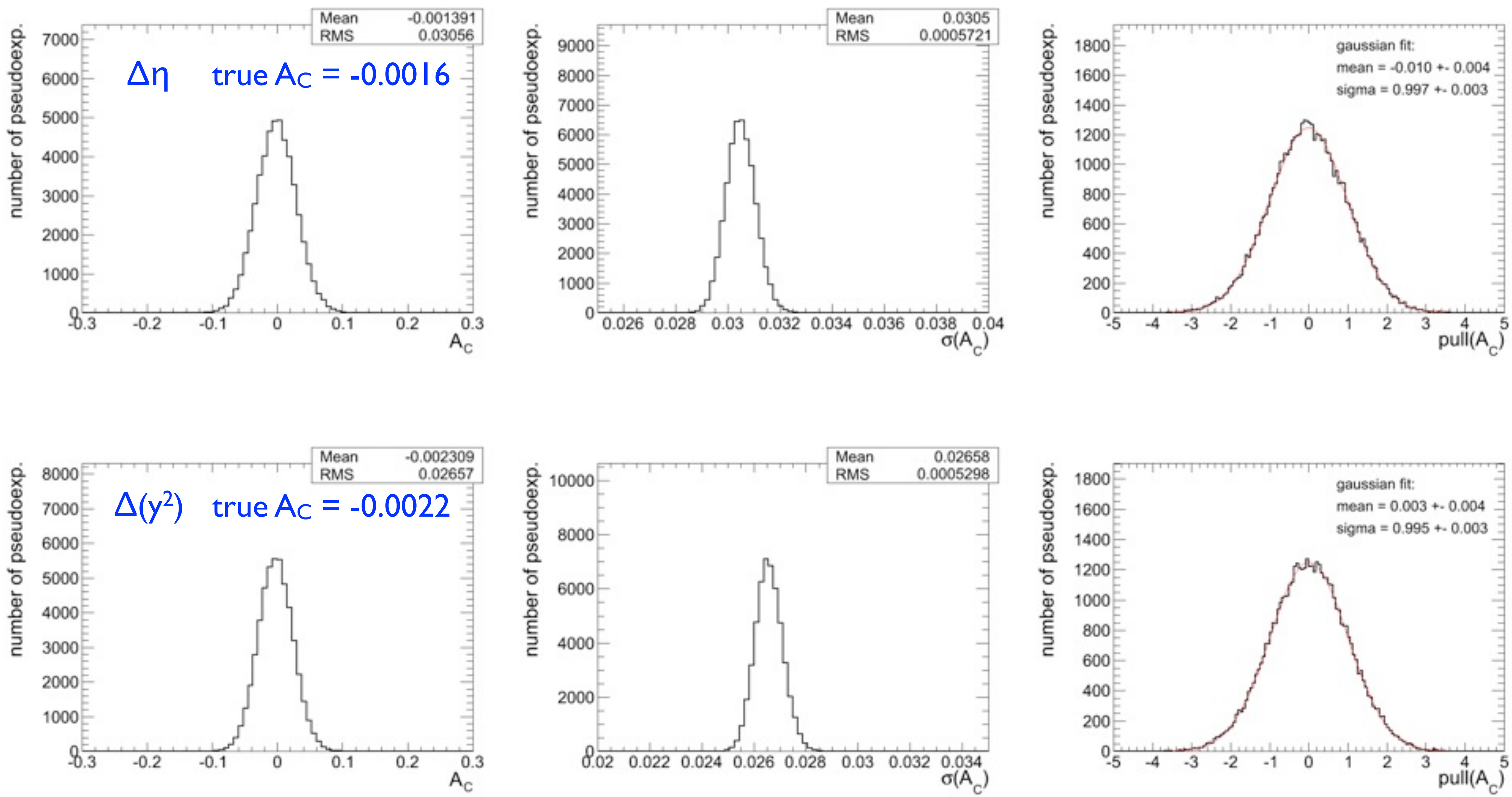
$$\sigma^2_{A_{C/DC}} = \left(\frac{\partial A_{C/DC}}{\partial N_1} \cdots \frac{\partial A_{C/DC}}{\partial N_6} \right) V_x \begin{pmatrix} \frac{\partial A_{C/DC}}{\partial N_1} \\ \vdots \\ \frac{\partial A_{C/DC}}{\partial N_6} \end{pmatrix}$$

where the partial derivatives are given by

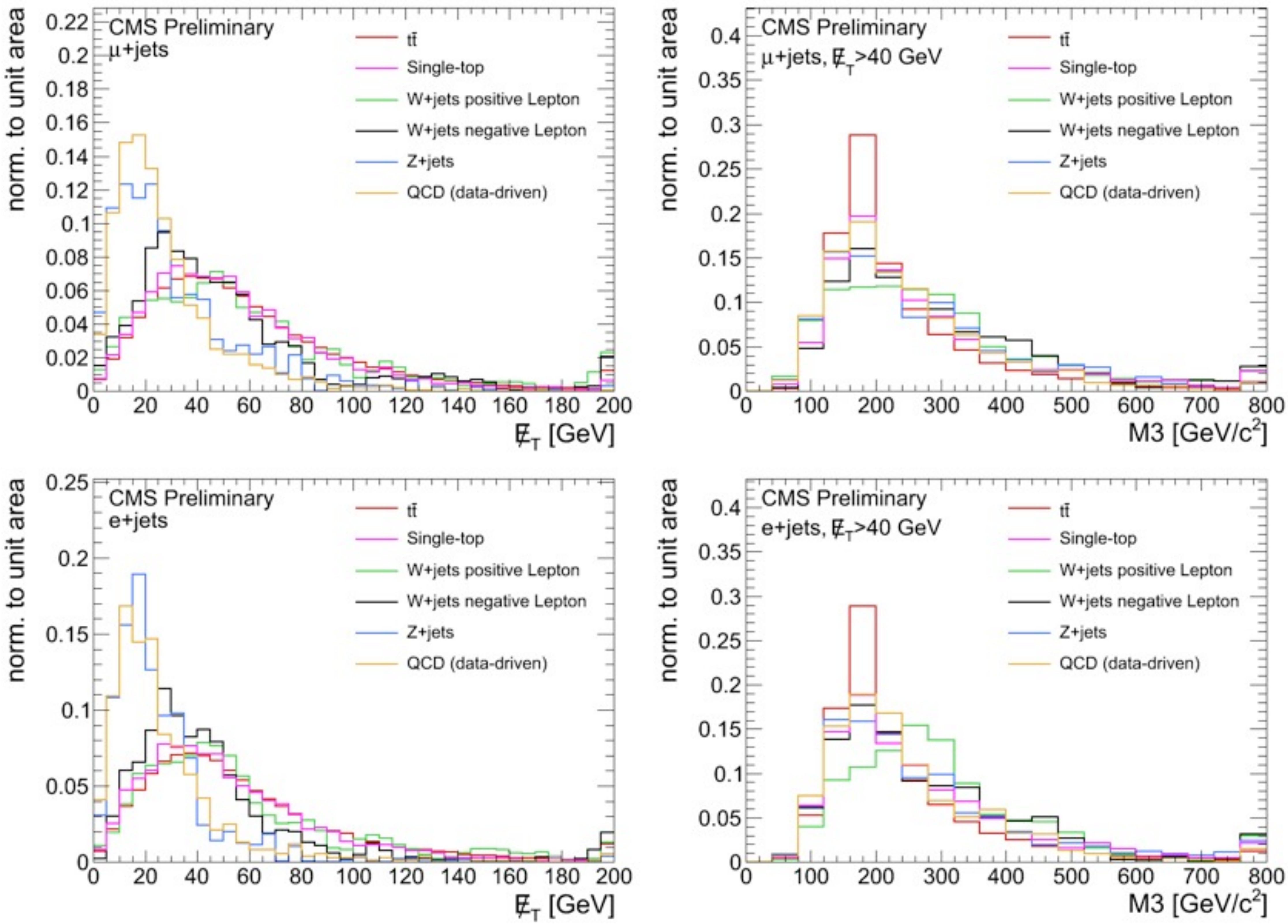
$$\frac{\partial A_{C/DC}}{\partial N_i} = \frac{-2N^+}{(N^+ + N^-)^2} \quad \text{for i} = 1 \ldots 3$$

$$\frac{\partial A_{C/DC}}{\partial N_i} = \frac{2N^-}{(N^+ + N^-)^2} \quad \text{for i} = 4 \ldots 6$$

Pull distributions for AC



Template Shapes



Extra information: hypothesis selection

$$\begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix} = \begin{pmatrix} 1.00 & -0.07 & -0.01 \\ 0.07 & 0.93 & 0.36 \\ -0.02 & -0.36 & 0.93 \end{pmatrix} \begin{pmatrix} m_{t,lep} \\ m_{t,had} \\ m_{W,had} \end{pmatrix}$$

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