Karlsruhe Institute of Technology

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

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INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK (IEKP)

Helmholtz Alliance

PHYSICS AT THE TERASCALE

5th Annual Workshop

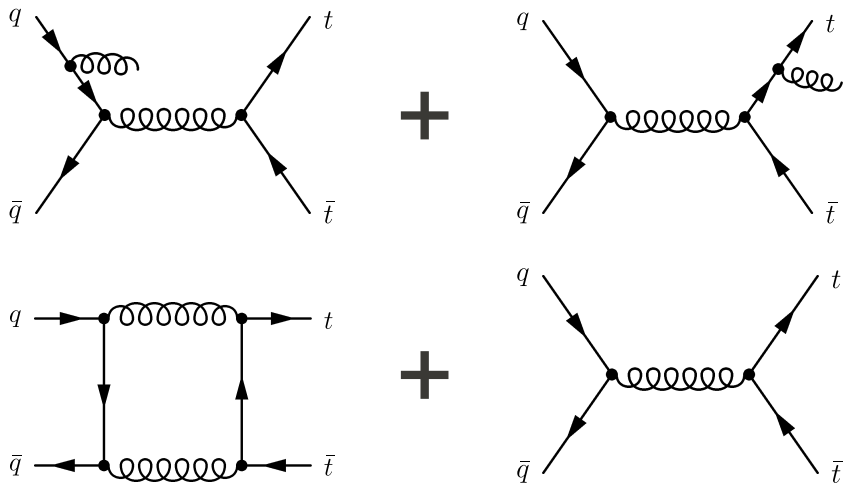
CMS Compact Muon Solenoid

PHYSICS AT THE TERA SCALE

Helmholtz Alliance

Charge asymmetry in the SM (I)

- Most dominant production mode $gg \rightarrow t\bar{t}$ is charge-symmetric
- In $t\bar{t}$ production via asymmetric initial states (eg. $q\bar{q} \rightarrow t\bar{t}$) the (anti-)top quarks are preferably produced in the direction of the incoming (anti-)quark
- Asymmetry due to interference of ISR and FSR and between box diagram and born diagram (NLO effect)

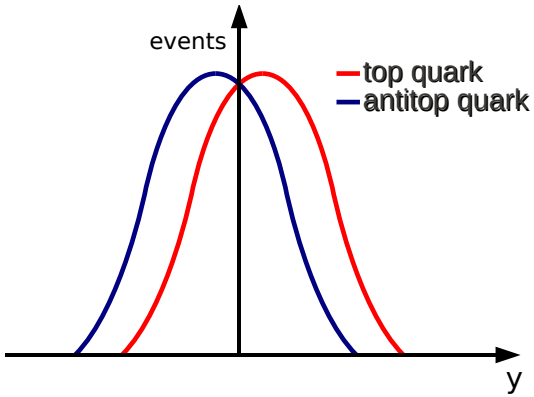


- $\Rightarrow$ excess of t vs. $\bar{t}$ in certain kinematic region, and vice versa

Charge asymmetry in the SM (II)

@ Tevatron:

- Forward-backward asymmetry:

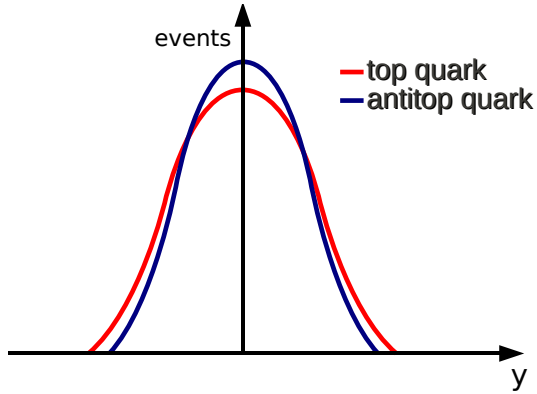


- Sensitive variable:

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

@ LHC:

- Central-peripheral asymmetry:



- Sensitive variables:

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

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

In all variables:

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

Recent results

- **@ Tevatron:**

SM prediction: $A_C^{SM,\Delta y} \approx 6\%$ [Kühn, Rodrigo]

- $A_C^{\Delta y} = 0.201 \pm 0.067$ (CDF, $5.0\,\text{fb}^{-1}$)
- $A_C^{\Delta y} = 0.196 \pm 0.065$ (DØ, $5.4\,\text{fb}^{-1}$)

  - $\approx 2\sigma$ deviation
  - CDF: $m_{t\bar{t}} > 450\,\text{GeV}$ even 3.4σ deviation!
  - Hint for new physics?

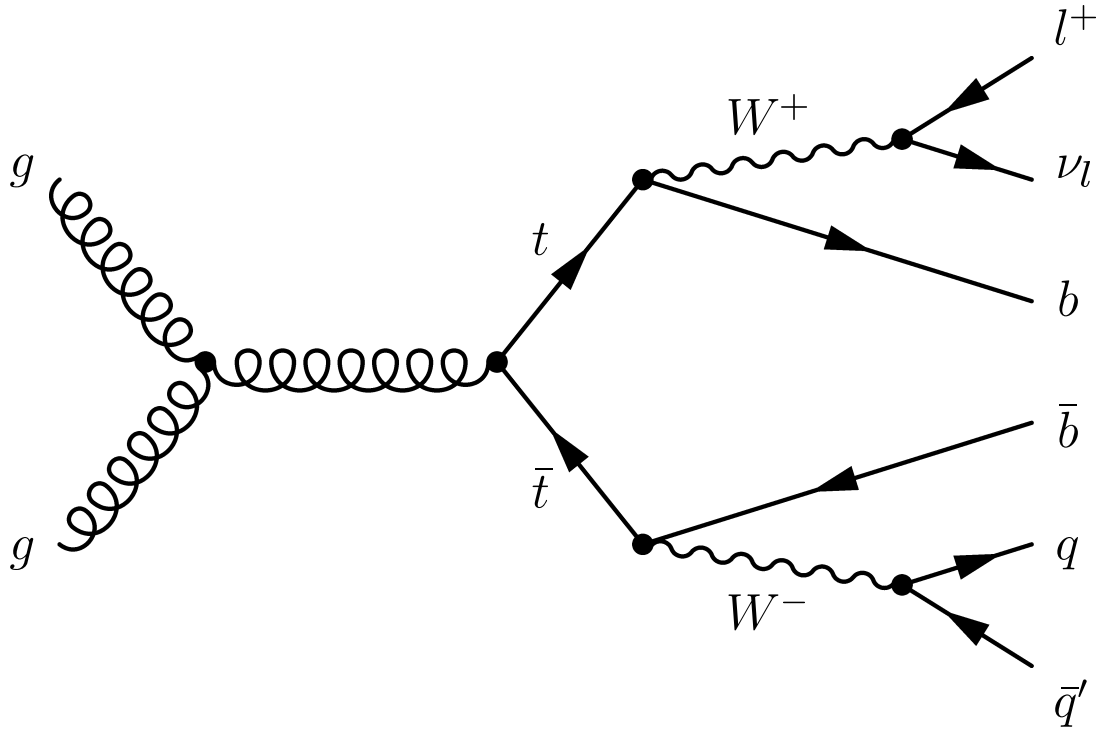
- **@ LHC:**

SM prediction: $A_C^{SM,\Delta|\eta|} = 1.3\%$, $A_C^{SM,\Delta y^2} = 1.1\%$ [Kühn, Rodrigo]

- $A_C^{\Delta|\eta|} = 0.060 \pm 0.14$ (CMS TOP-10-010, $36\,\text{pb}^{-1}$)

  - dominated by large stat. uncertainty
  - in this analysis 30 times more data

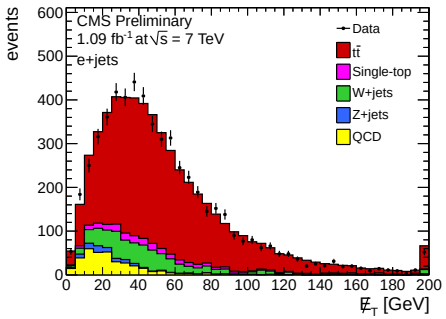
CMS-TOP-11-014: Event selection

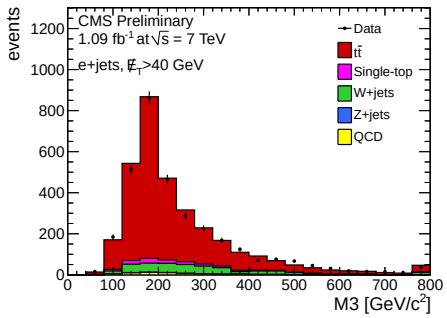


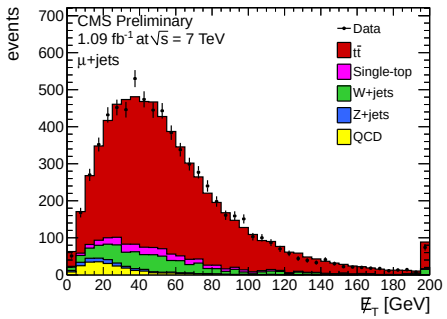
- Select events in muon+jets and electron+jets channel:
  - One isolated charged lepton (e,μ)
  - Second charged lepton veto
  - At least four jets
  - At least one of them b tagged
- Used data: $1.09\,\mathrm{fb}^{-1}$

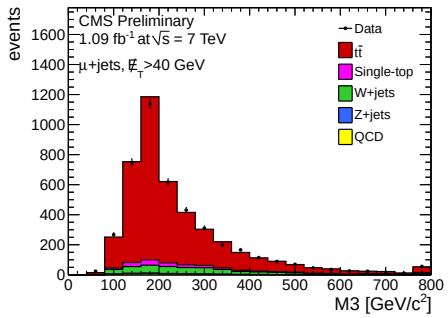
Background estimation

- Use discrimination power of MET and M3
- MC templates for all processes,
  exception: data-driven template for QCD
- Fit separately e+jets and mu+jets, subdivide each sample into MET $<$ 40 GeV (A) and MET $>$ 40 GeV (B)
- Fit simultaneous MET in (A) and M3 in (B)









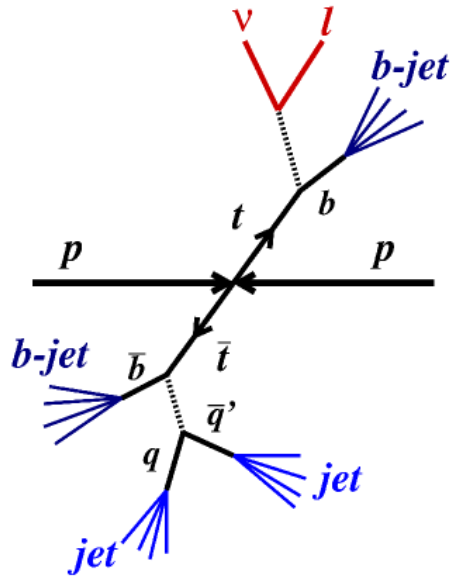
process	electron+jets	muon+jets	total
$t\bar{t}$	4401 $\pm$ 165	5835 $\pm$ 199	10236 $\pm$ 258
single top (t + tW)	213 $\pm$ 58	293 $\pm$ 81	507 $\pm$ 99
W^++jets	313 $\pm$ 84	404 $\pm$ 106	718 $\pm$ 135
W^-+jets	299 $\pm$ 90	245 $\pm$ 109	544 $\pm$ 141
Z+jets	81 $\pm$ 24	85 $\pm$ 26	165 $\pm$ 35
QCD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

Reconstruction

- Reconstruction of the four-vectors of the top quarks:
  - Reconstruct neutrino from W mass constraint (one or two solutions)
  - Assignment of selected jets to the final state quark, take all possible combinations into account
  - Best possible hypothesis from ΔR matching with MC information
- Selection of one hypothesis:
  - Use decorrelated masses and calculate Likelihood ratio for each mass:

$$\begin{pmatrix} m_{t_{lep}} \\ m_{t_{had}} \\ m_{W_{had}} \end{pmatrix} \Rightarrow \begin{pmatrix} m_1 \\ m_2 \\ m_3 \end{pmatrix}, \qquad \mathcal{L} = \frac{\text{good hypotheses}}{\text{all hypotheses}}$$

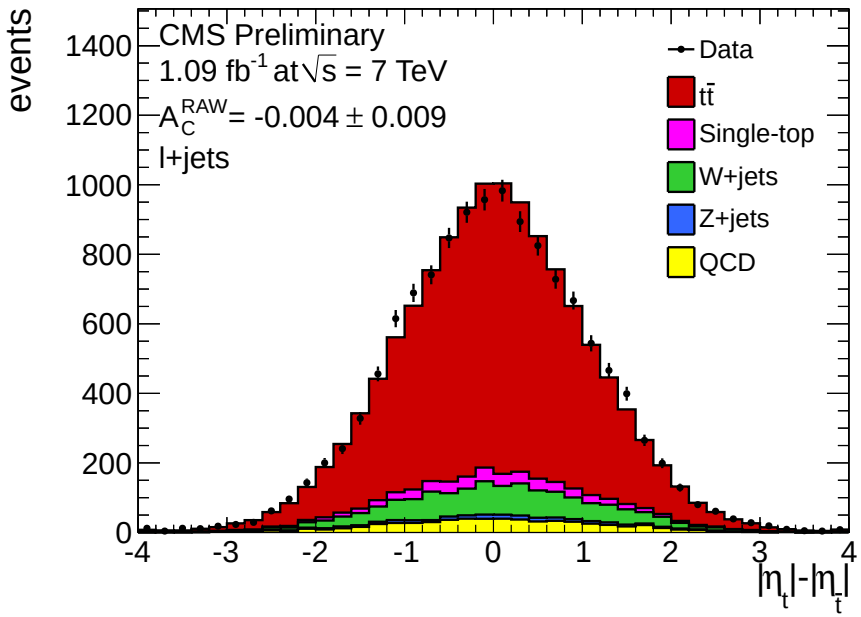
  - Use b tagger output to give probability $P_b(x)$ of jet x to be a b jet
  - Choose the hypothesis with largest value for:

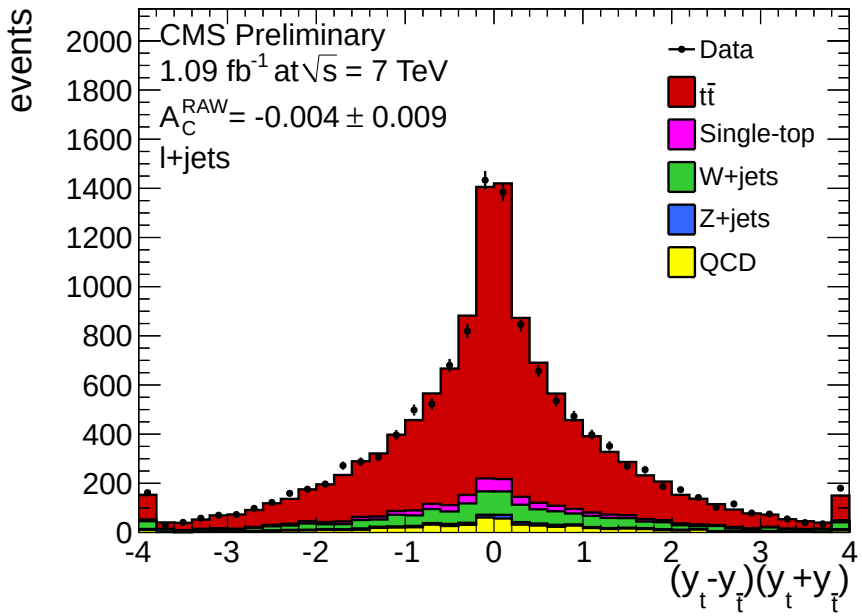


$$\psi = \mathcal{L}(m_1)\mathcal{L}(m_2)\mathcal{L}(m_3)P_b(x_{b,lep})P_b(x_{b,had})(1 - P_b(x_{q_1}))(1 - P_b(x_{q_2}))$$

Reconstructed Distributions

- Reconstruct distribution of the sensitive variables $\Delta|\eta|$ and Δy^2
- Combine e+jets and mu+jets channel



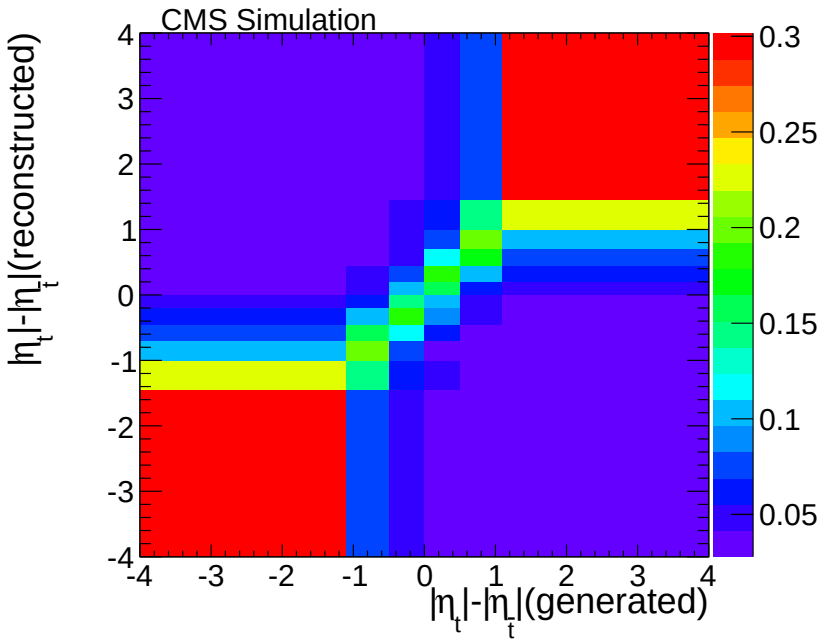


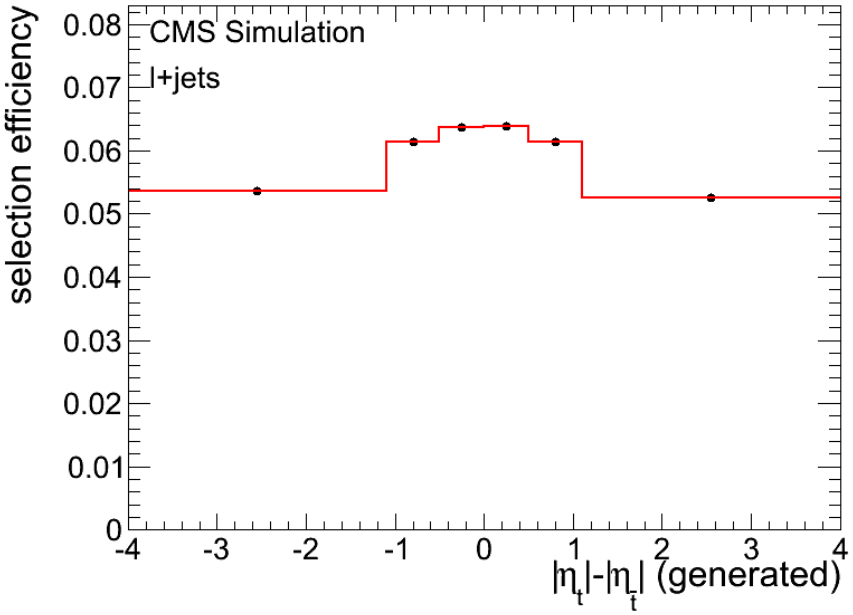
Uncorrected Asymmetry in combined channel

- $A_C^{RAW,\Delta|\eta|} = -0.004 \pm 0.009\,(\text{stat.})$
- $A_C^{RAW,\Delta y^2} = -0.004 \pm 0.009\,(\text{stat.})$

Unfolding

- Reconstructed distribution corrected for
  - Background processes
    - $\Rightarrow$ Subtraction of MC background templates normalized to prediction
  - Influences of selection efficiency and migration effects
    - $\Rightarrow$ Regularized unfolding with the ROOT TUnfold package

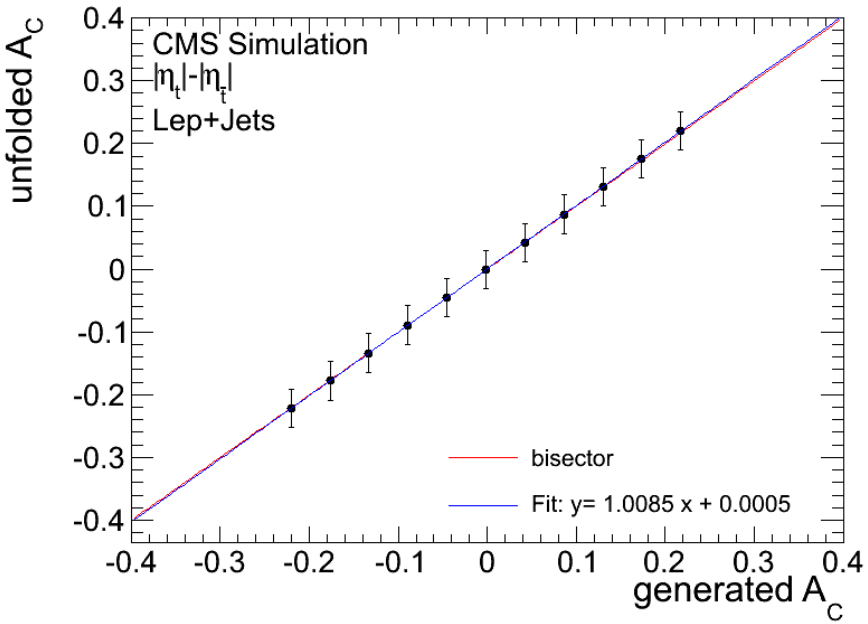


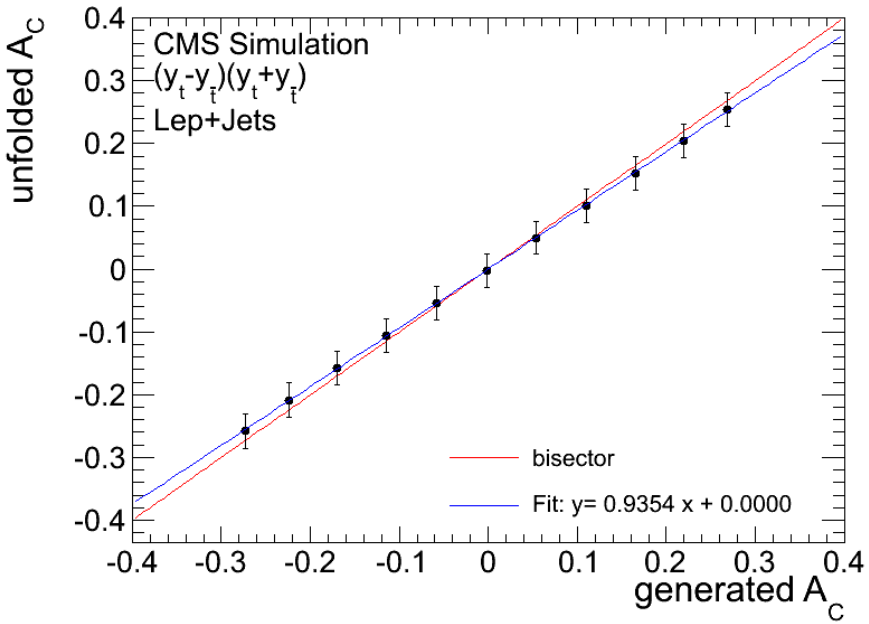


- Next step: Scrutinizing the unfolding!

Consistency checks

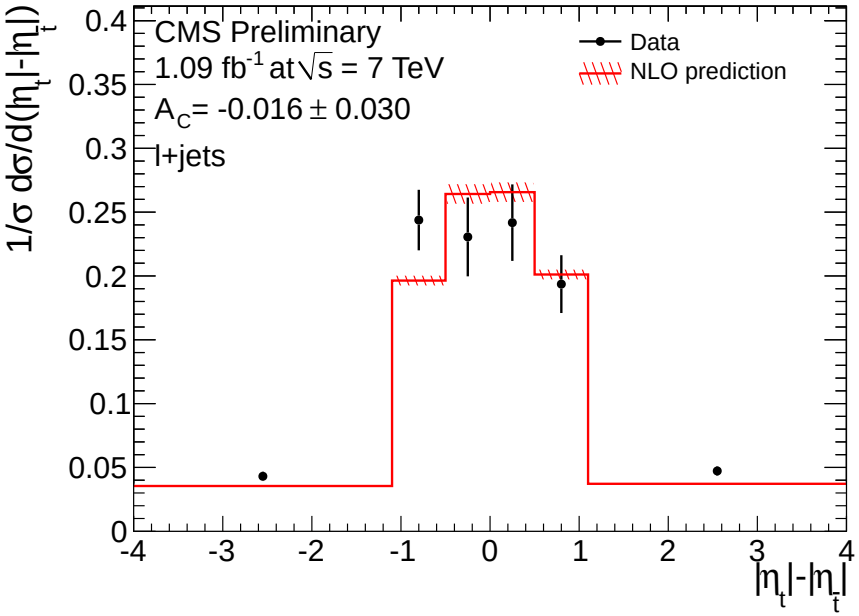
- 50,000 pseudo experiments, for each:
  - Draw signal and background events from MC-Samples according to fit
  - Subtract background and unfold the pseudo sample
  - Check relative difference of each bin with true bin content
  - Check pull distribution for each bin
  - $\Rightarrow$ Very good agreement
- Linearity checks with reweighted samples
  - $\Rightarrow$ Small correction factor for $A_C^{\Delta y^2}$

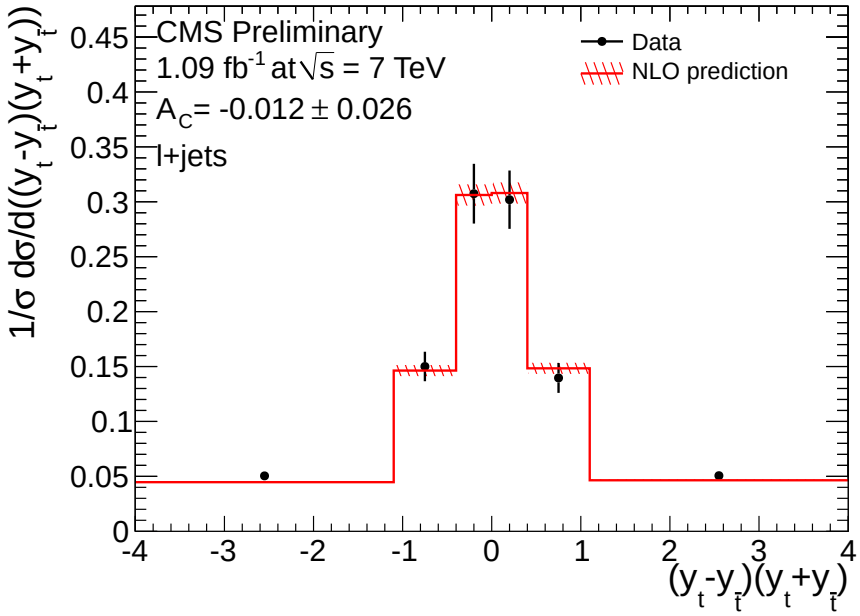




Results

- Unfolded distributions for $\Delta|\eta|$ and Δy^2:





Unfolded asymmetries

- $A_C^{\Delta|\eta|} = -0.016 \pm 0.030(\text{stat.})$
- $A_C^{\Delta y^2} = -0.013 \pm 0.026(\text{stat.})$

- Reminder: $A_C^{SM,\Delta|\eta|} = +0.013, \quad A_C^{SM,\Delta y^2} = +0.011$

Systematics

- Produce pseudo experiments from systematically shifted distributions
- Unfold with standard templates
- Measure value of unfolded asymmetry

	$A_C^{\Delta\lvert\eta\rvert}$		$A_C^{\Delta y^2}$	
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

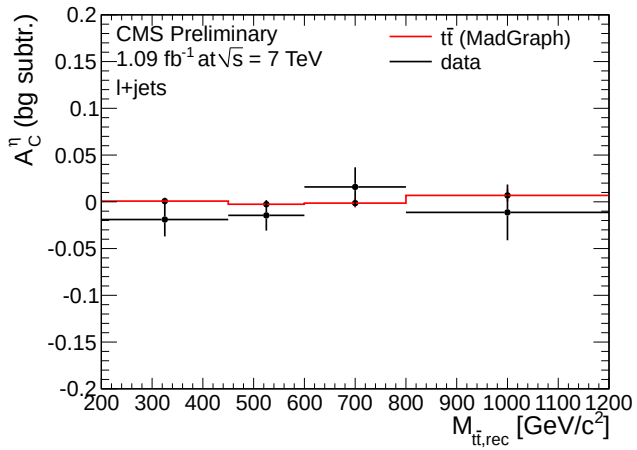
- Systematic uncertainties are of the same order as the statistical uncertainties

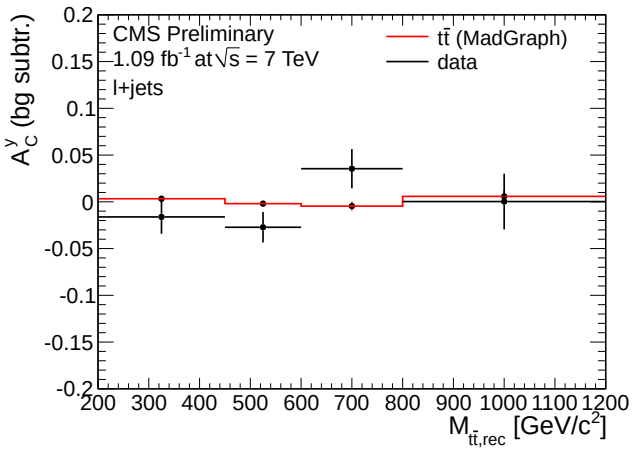
Conclusion & Outlook

Results

- $A_C^{\Delta|\eta|} = -0.016 \pm 0.030(\text{stat.})^{+0.010}_{-0.019}(\text{syst.})$
- $A_C^{\Delta y^2} = -0.013 \pm 0.026(\text{stat.})^{+0.026}_{-0.021}(\text{syst.})$

- Results are in good agreement with the Standard Model
- Background-subtracted asymmetries show no mass dependence:





- Outlook:
  - Perform 2D unfolding to get unfolded asymmetries as function of unfolded $M_{t\bar{t}}$
  - Good progress, expect results until the end of this year