$t\bar{t}$ Charge Asymmetry

with Fully Bayesian Unfolding at $\sqrt{s} = 13$ TeV in ATLAS

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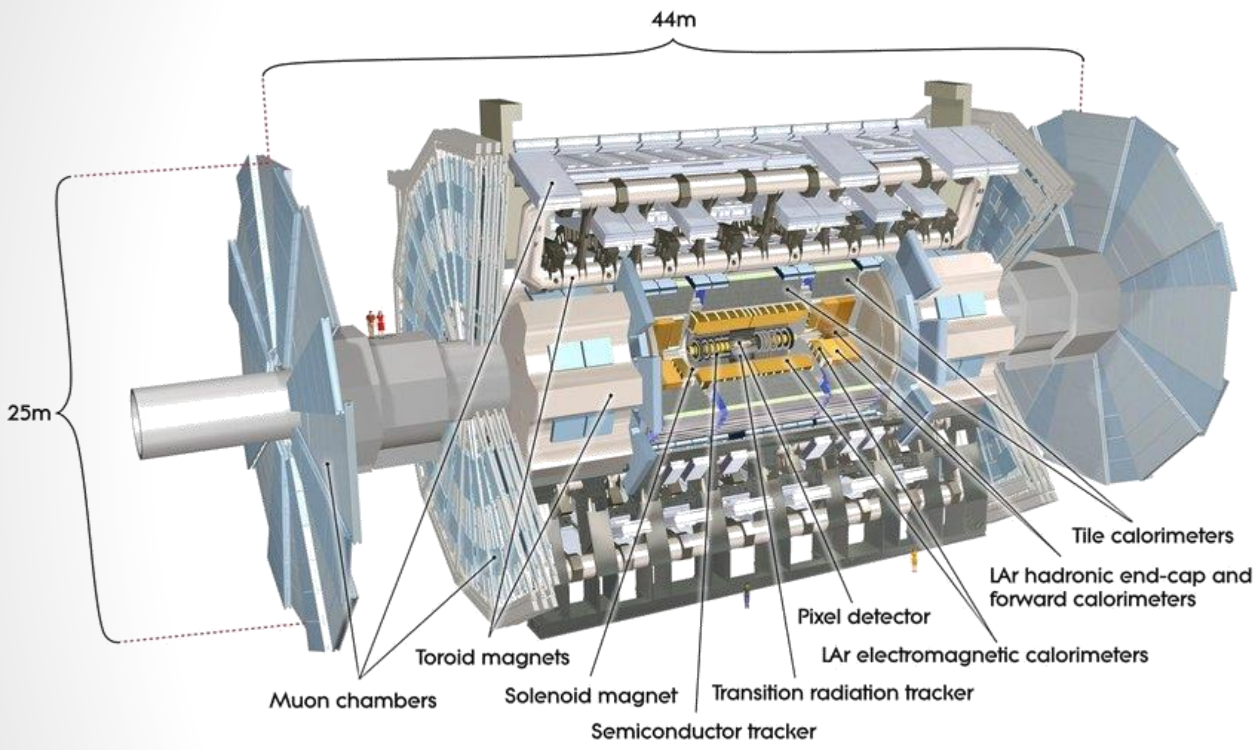
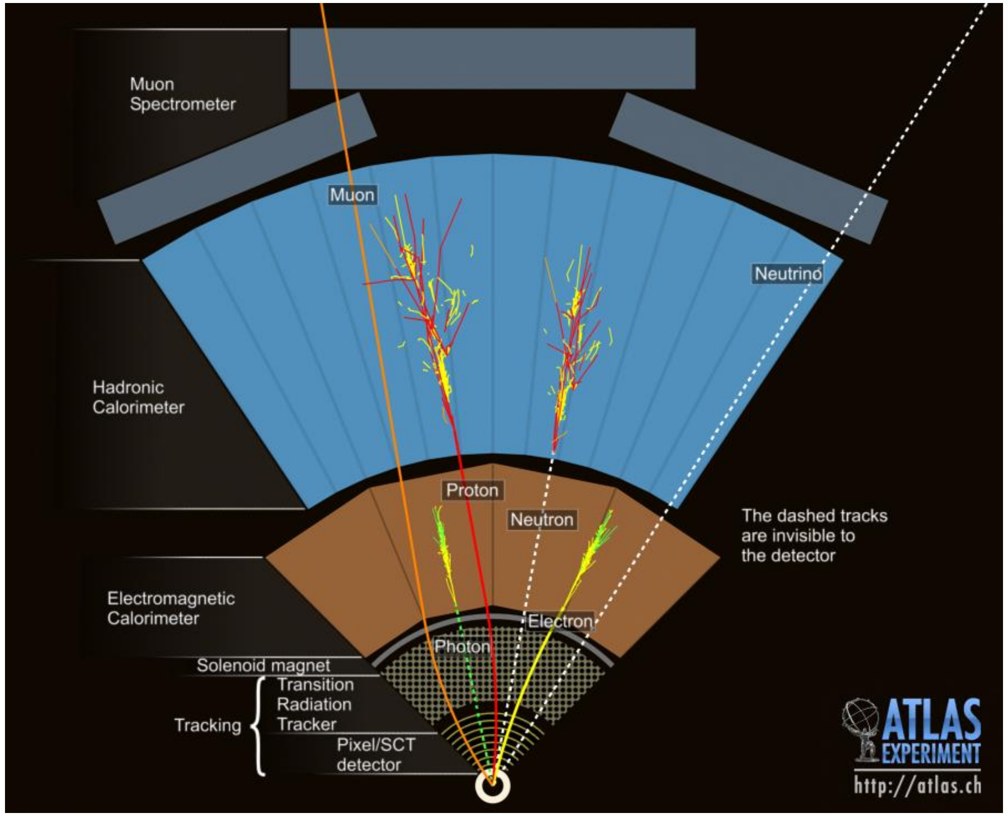
ATLAS EXPERIMENT

UNIVERSITY OF BIRMINGHAM

The ATLAS Detector

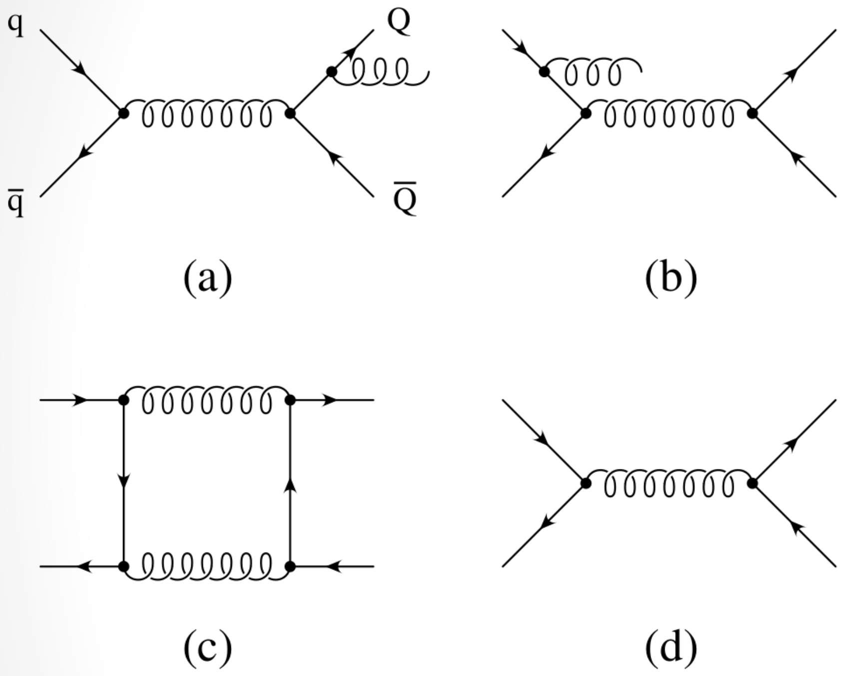


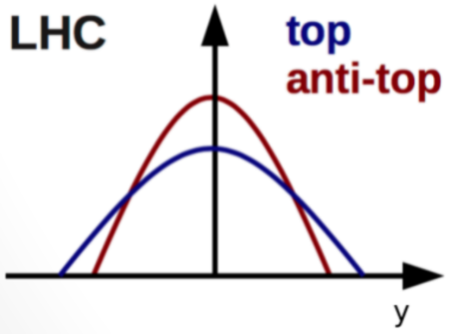


$$y = \frac{1}{2}\left(\frac{E + p_Z}{E - p_Z}\right)$$

$$\eta = -\ln \tan \frac{\theta}{2}$$

Charge Asymmetry Origin

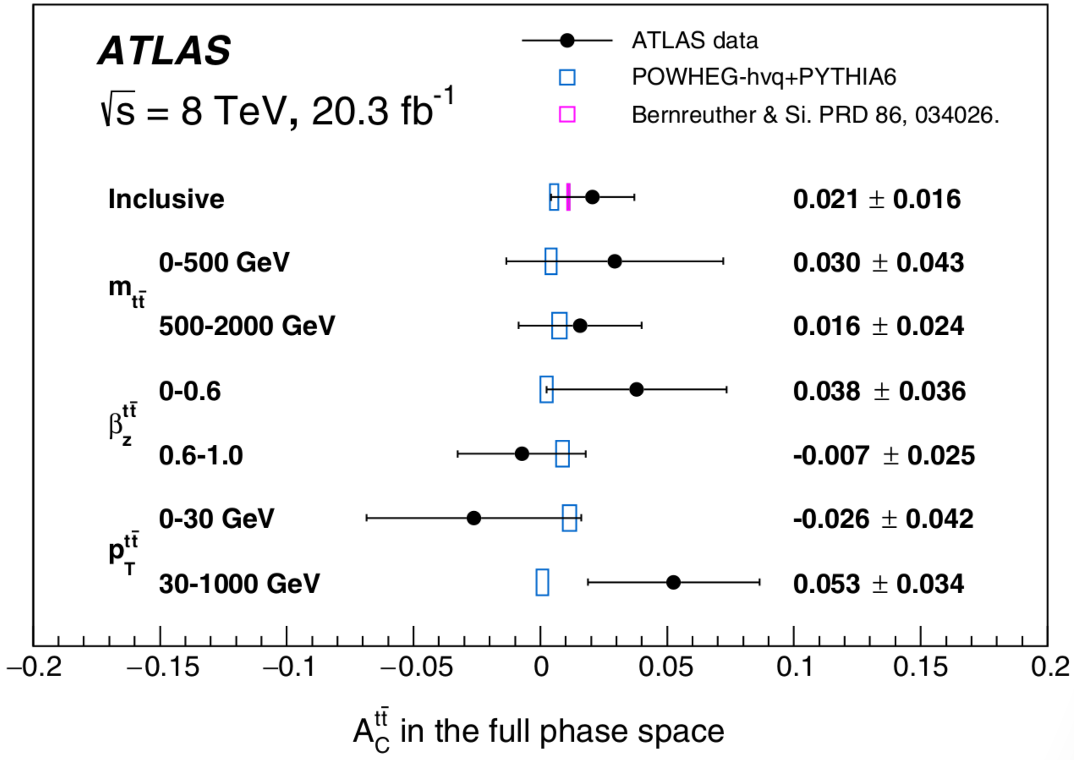




- At 13 TeV pp collisions in the LHC, 10% of $t\bar{t}$ production by $q\bar{q}$ annihilation.
- Incoming q can be valence (higher momentum fraction of proton) and incoming $\bar{q}$ must be from sea (lower momentum fraction).
- At NLO (Next-to-Leading Order) in QCD (Quantum Chromodynamics), interference between final/initial state radiation and one-loop/Born diagrams.
- Leads to top preferentially produced in q direction (with greater rapidity) and antitop produced in $\bar{q}$ direction (less rapidity).

Motivations for Study

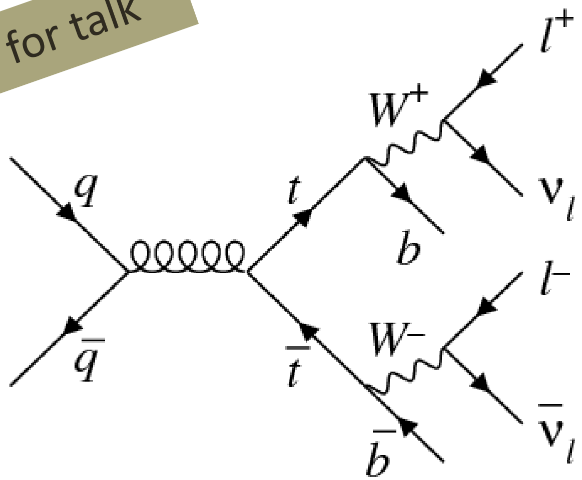
- D0 and CDF experiments at the Tevatron found small deviations of charge asymmetry from NLO QCD predictions. arXiv:1101.0034 [hep-ex], arXiv:1107.4995 [hep-ex].
- 7 and 8 TeV LHC results show no such deviations but uncertainties are statistically dominated.
- Asymmetry is sensitive to BSM (Beyond the Standard Model) theories such as axigluons, Z' particles and effective field theories.



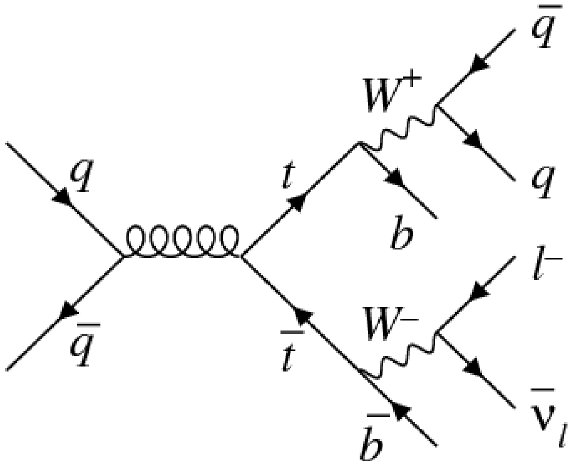
Phys. Rev. D 94, 032006

Two Channels

Focus for talk



Dilepton



Lepton+Jets

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Dataset and Event Selection

$t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow b\bar{b}l^+\nu l^-\bar{\nu}$ (Branching ratio: ≈ 11 %)

80 fb^{-1} 13 TeV ATLAS dataset from 2015-17

Exactly 2 oppositely-charged leptons ($ee/e\mu/\mu\mu$)

One lepton has p_T > 28 GeV, other has p_T > 25 GeV

At least 2 narrow jets, each with p_T > 25 GeV

1 or ≥ 2 jets to be b-tagged

Z veto in $ee/\mu\mu$ channels: $|m_{l\bar{l}} - m_Z|$ > 10 GeV

$t\bar{t}$ system reconstructed

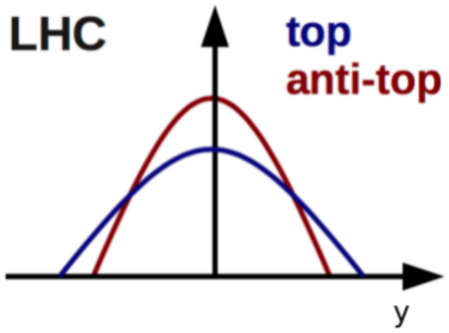
- 6 sub-channels: ($ee/e\mu/\mu\mu$) × (1 b-tag/≥ 2 b-tags) of different background contamination.
- Backgrounds of single top production, Z+jets, dibosons, fake leptons, W bosons decaying to taus, and rare processes.

Charge Asymmetry Observables

- Measuring charge asymmetry between top and antitop:

$$A_C^{t\bar{t}} = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)} \qquad \Delta|y| = |y_t| - |y_{\bar{t}}|$$

Expected to be small and positive (0.01 - 1%).



- And also between the two leptons:

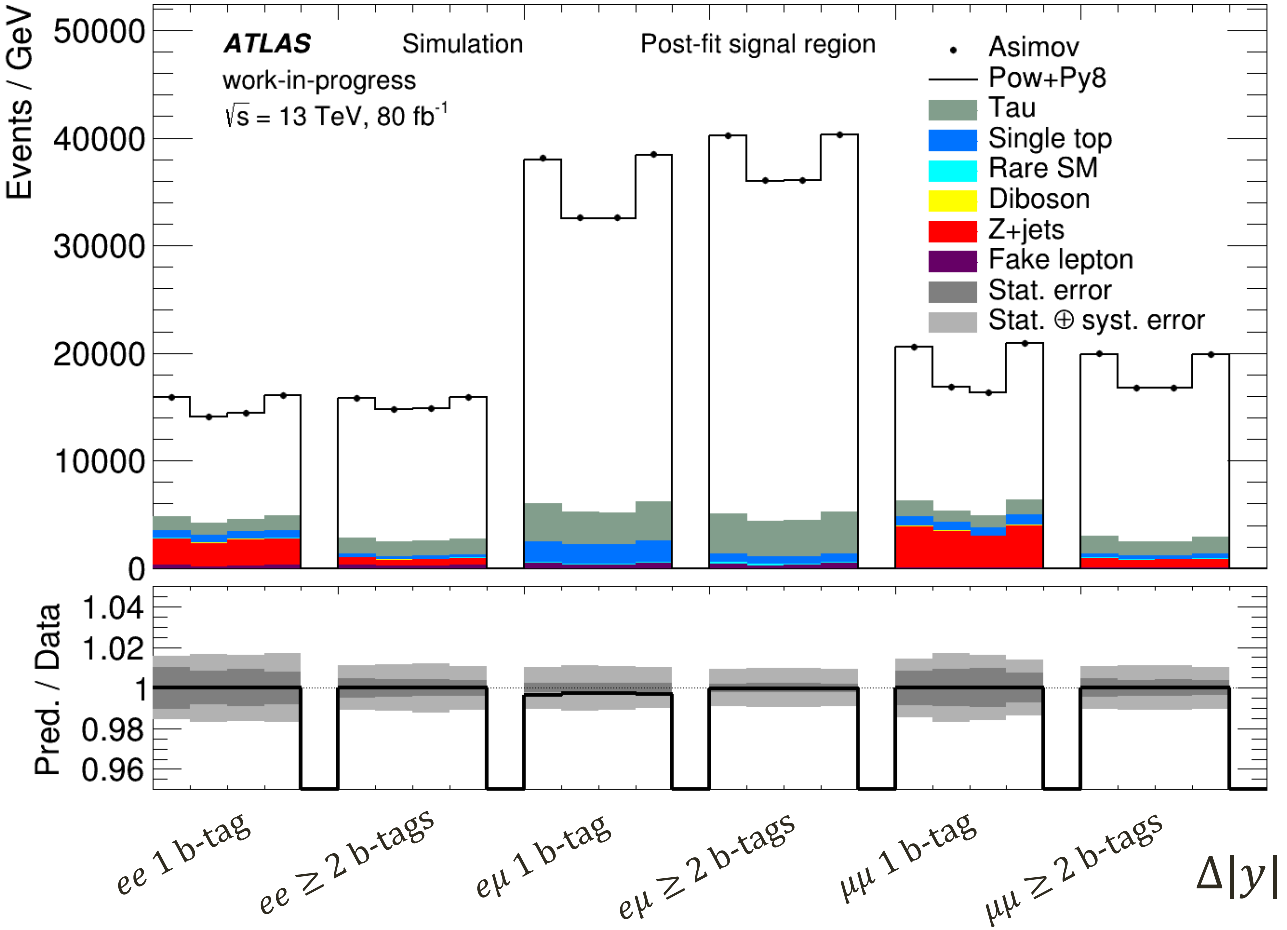
$$A_C^{l\bar{l}} = \frac{N(\Delta|\eta| > 0) - N(\Delta|\eta| < 0)}{N(\Delta|\eta| > 0) + N(\Delta|\eta| < 0)} \qquad \Delta|\eta| = |\eta_l| - |\eta_{\bar{l}}|$$

No $t\bar{t}$ reconstruction so smaller systematics.
Asymmetry expected to be even smaller than for $t\bar{t}$.

- Calculating asymmetries inclusively and in differential bins of $t\bar{t}$ mass, p_T and velocity. Work in 4 $\Delta|y|$ or $\Delta|\eta|$ bins in each case. Focussing on $t\bar{t}$ asymmetry in this talk.

Our 6 Sub-Channels

- Clean signal in dilepton channel.
- Asymmetry calculated by subtracting left two bins from right two bins in each channel.
- Just showing Asimov – total MC prediction treated like data.

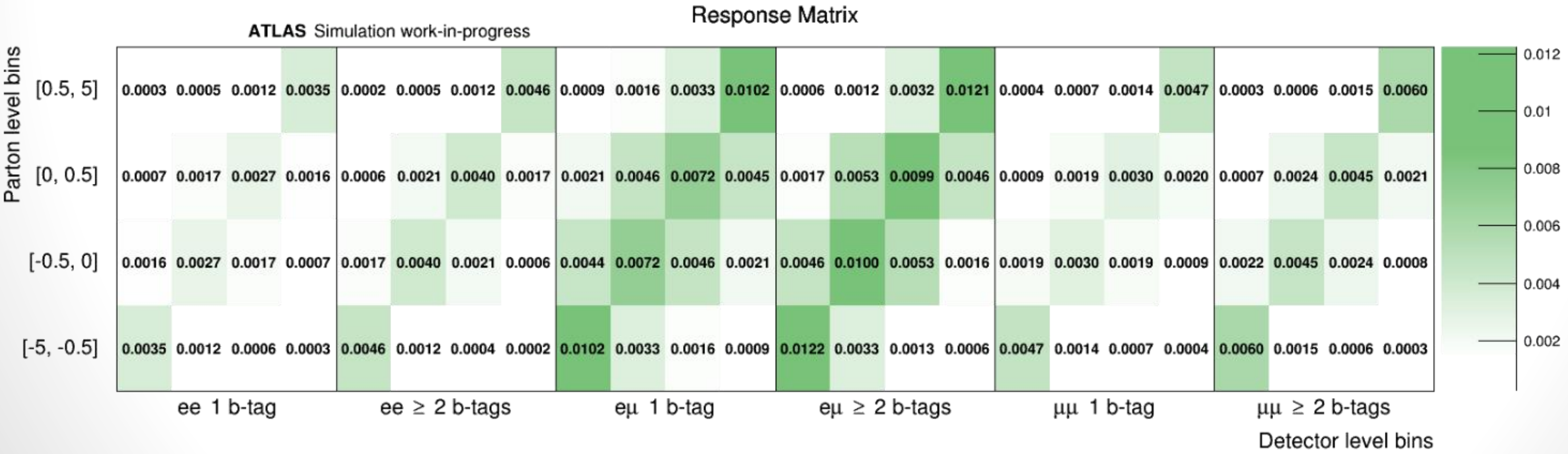


Fully Bayesian Unfolding (FBU)

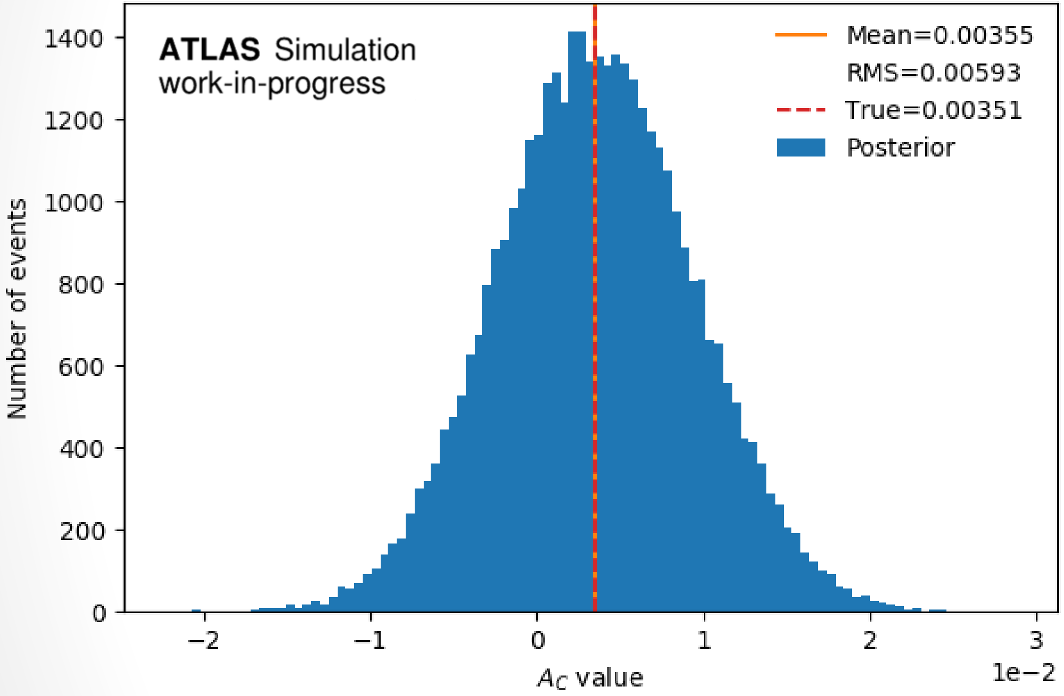
- Data is subject to smearing/resolution effects and doesn't cover the full phase space of $\bar{t}t$ production. FBU uses response matrices to map detector level events back to parton level events.

- Can then compare with other experimental results.

- Method allows our 6 sub-channels to be combined and for systematic uncertainties (including detector, modelling and background normalisation) to be constrained. This arises from sampling gaussian distributions describing each systematic.



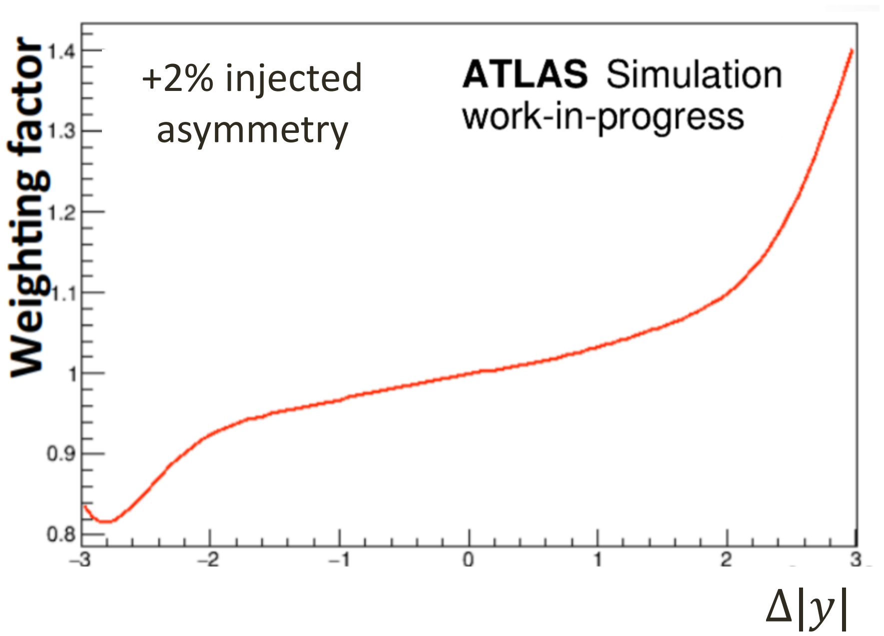
Fully Bayesian Unfolding (FBU)



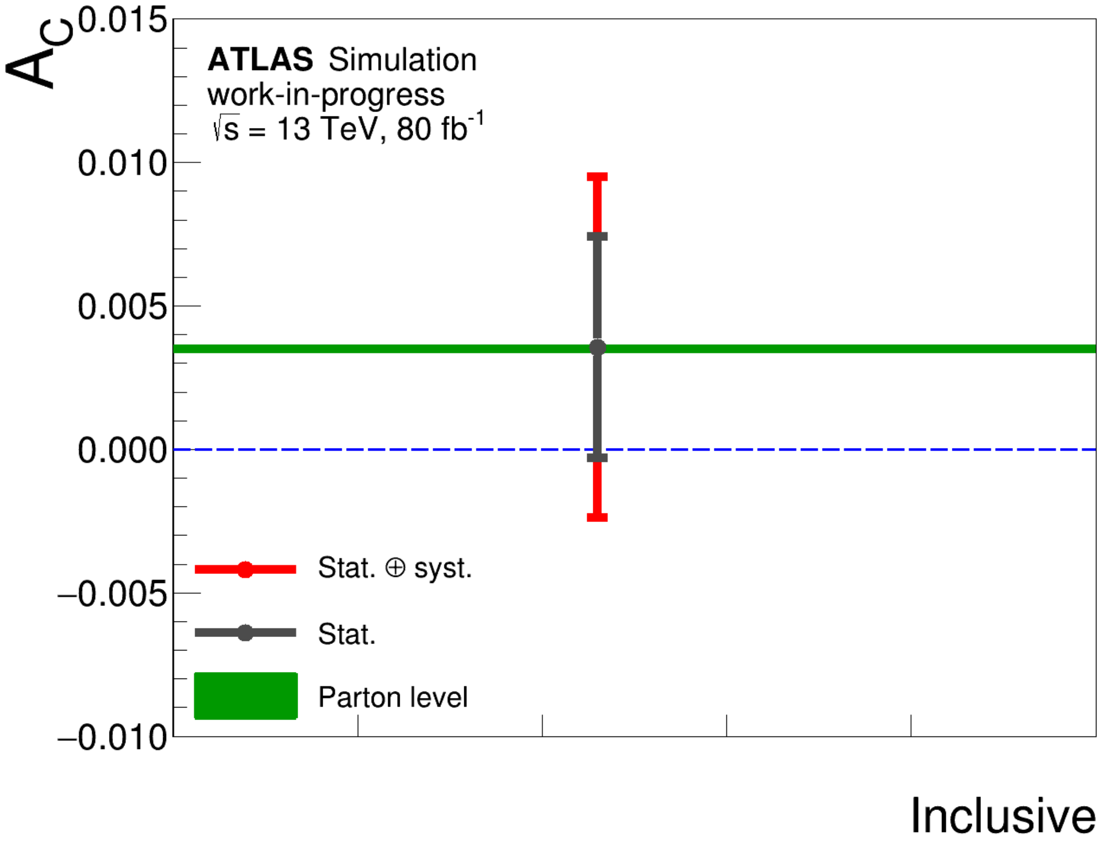
- Samples different parton level values for each $\Delta|y|$ bin, folds to detector level with response matrix and then calculates the likelihood of this with respect to expected detector level MC or data.
- Likelihood value multiplied by prior in parton level events to get a posterior value.
- The posterior values together make up a posterior distribution.

Binning Choice to Eliminate Bias

- A BSM axigluon model is used to reweight the $\Delta|y|$ MC events at parton and detector level.
- Weights are introduced to scale the simulated asymmetry by $\pm$ 1, 2, 3 and 4 % away from the Standard Model expectation.
- Select bin edges x in the 4 $\Delta|y|$ bins [-5, -x, 0, x, 5] that give best unfolded vs parton level agreement.



Expected Sensitivities

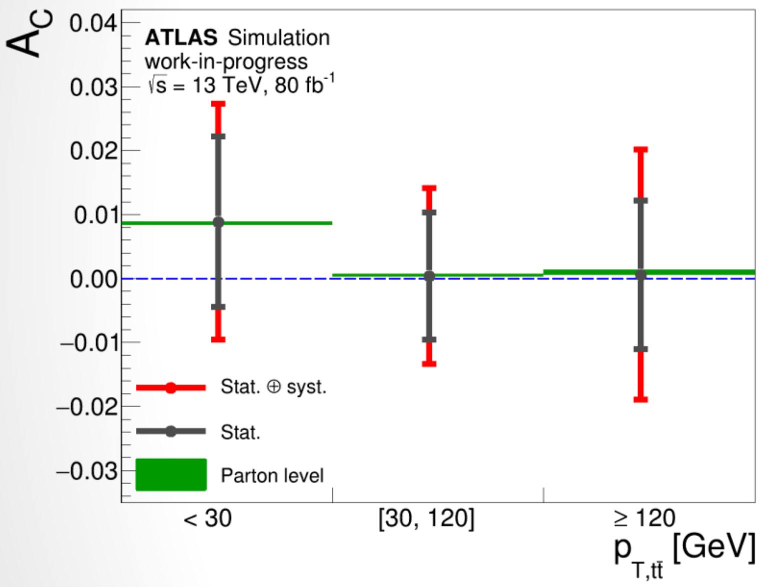


80 fb^{-1} 13 TeV ATLAS: 0.0035 ± 0.0065

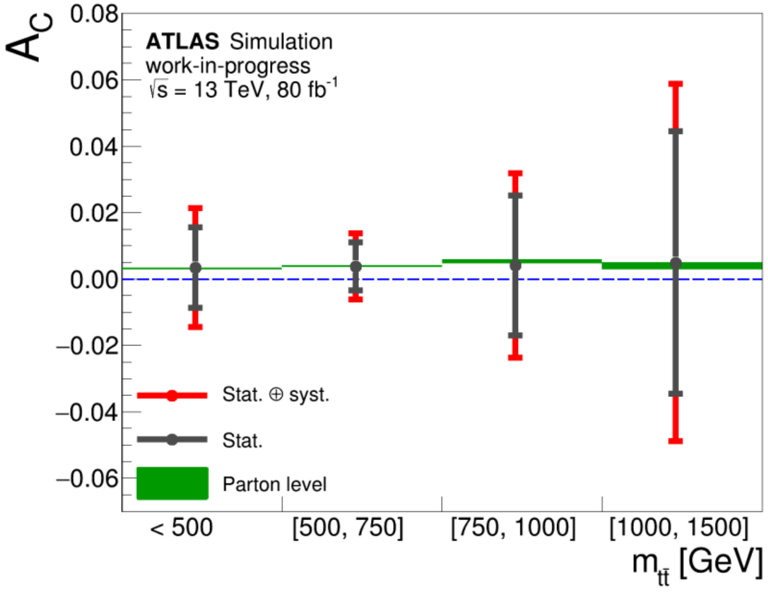
20 fb^{-1} 8 TeV ATLAS: 0.021 ± 0.016 (from 2016 paper Phys. Rev. D 94, 032006)

Expected Sensitivities

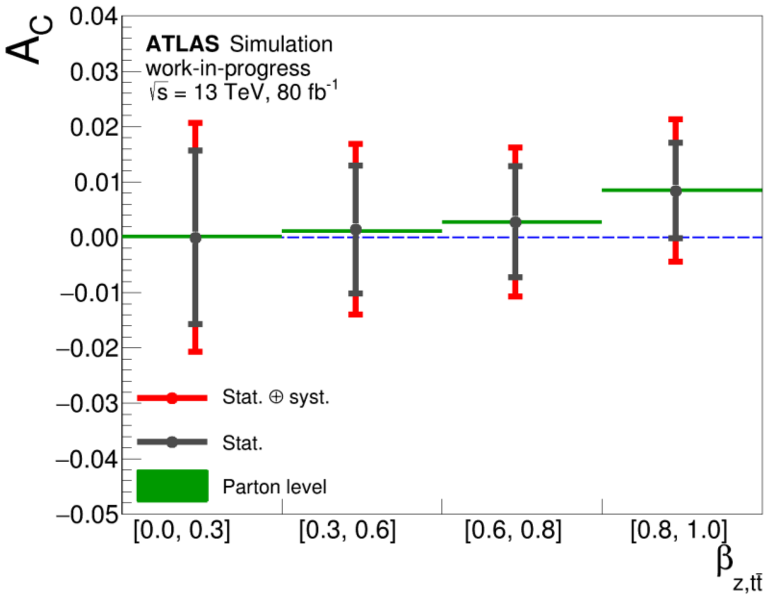
Binned by $t\bar{t}\ p_T$



Binned by $t\bar{t}\ m$



Binned by $t\bar{t}$ velocity, β_Z



Conclusions

- FBU being used to determine parton level $t\bar{t}$ charge asymmetry in two channels (as well as dilepton asymmetry in dilepton channel).
- Binning optimisation to help reduce bias.
- Showing expected sensitivities for 80 fb^{-1}. Uncertainties reduced with respect to 8 TeV analysis. More differential bins also used.
- Aim to combine dilepton and lepton+jets results in full 140 fb^{-1} dataset.

BACKUP: Fully Bayesian Unfolding (FBU)

- Calculate likelihood of data D given parton level (truth T) using expected detector level (reco R) and background B with Poisson statistics. $\mathcal{M}$ = response matrix from truth to reco.

$$\mathcal{L}(\mathrm{D}|\mathrm{T},\mathcal{M},\mathrm{B}) = \prod_{i=1}^{N_r} \frac{(r_i + b_i)^{d_i}}{d_i!} e^{-(r_i+b_i)}$$

- Flat prior $\pi_F(\mathrm{T})$ chosen and combined with likelihood to obtain a posterior probability of truth given data.

$$P(\mathrm{T}|\mathrm{D},\mathcal{M}) \propto \mathcal{L}(\mathrm{D}|\mathrm{T},\mathcal{M})\pi_F(\mathrm{T})$$

- Systematics θ (nuisance parameters) included by extending likelihood with Gaussian priors $\pi_G(\theta)$.

$$\mathcal{L}(\mathrm{D}|\mathrm{T}) = \int \mathcal{L}(\mathrm{D}|\mathrm{T},\theta)\pi_G(\theta)d\theta$$

- Allows combined unfolding of dilepton and lepton+jets channels as well as marginalising the systematics to reduce their values.

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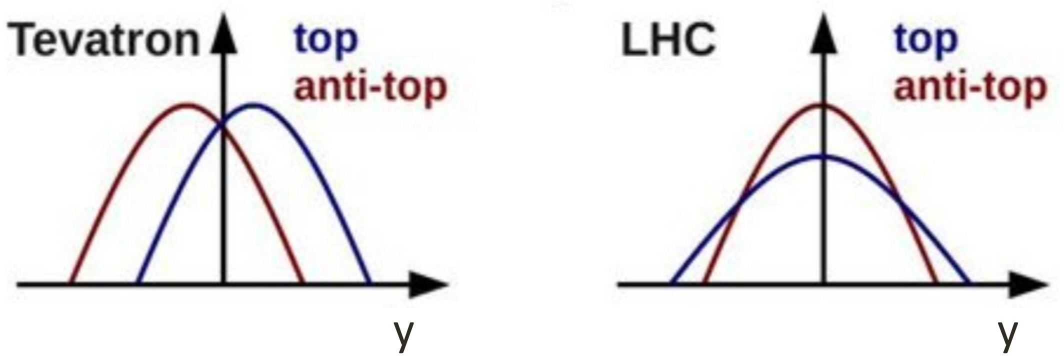
BACKUP: Charge Asymmetry at the Tevatron

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

This is a forward-backward asymmetry that considers the means of the rapidity distributions rather than the widths as at the LHC.

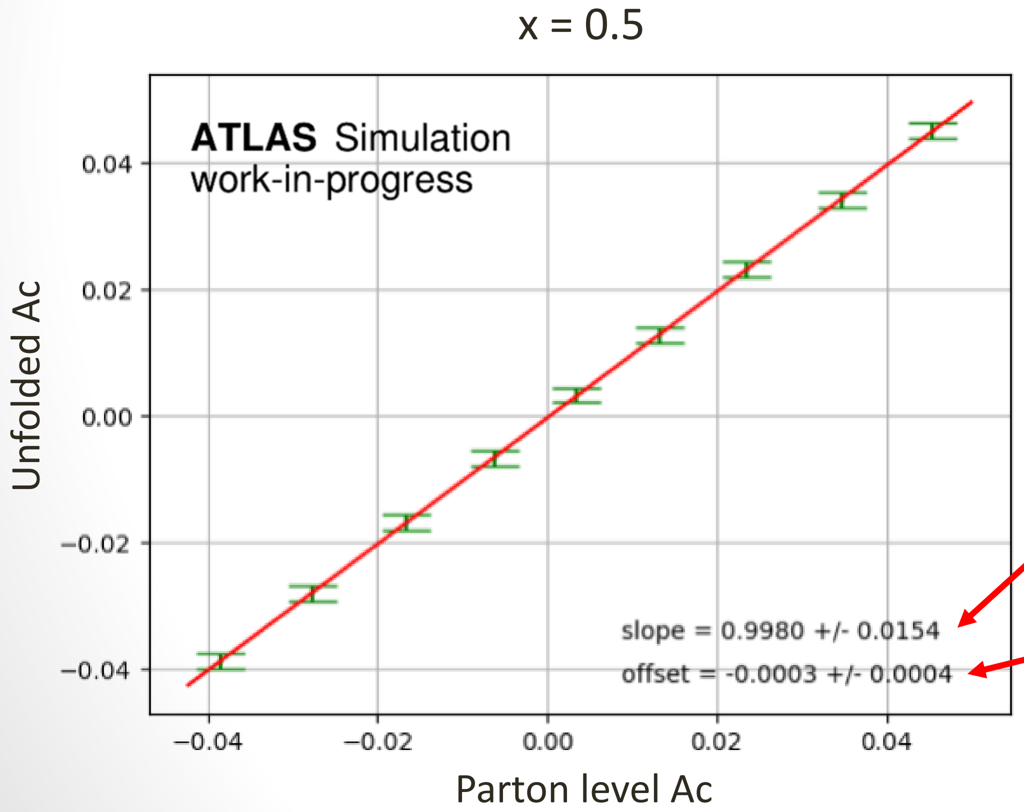


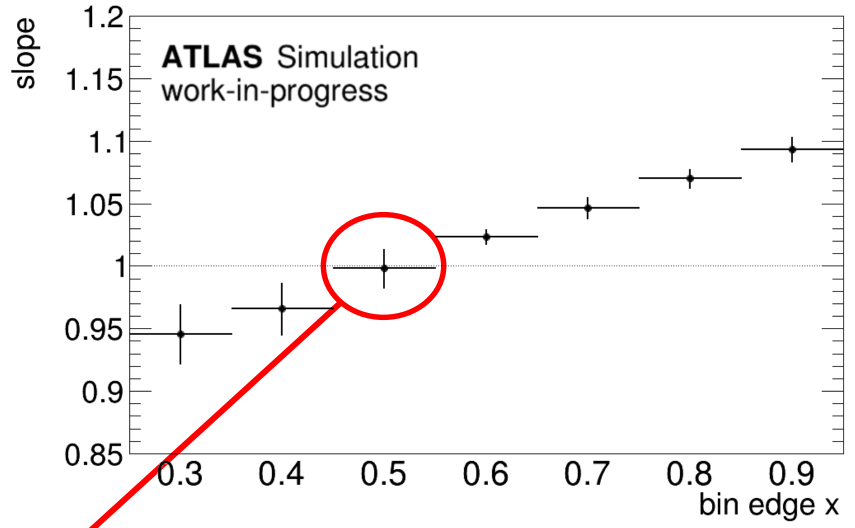
Tevatron	inclusive	$m_{t\bar{t}} < 450$ GeV	$m_{t\bar{t}} > 450$ GeV	$\lvert\Delta y\rvert < 1$	$\lvert\Delta y\rvert > 1$
SM $t\bar{t}$ rest-frame $A_{t\bar{t}}$	0.087 (10)	0.062 (4)	0.128 (11)	0.057 (4)	0.193 (15)
D0 [9]	0.196 (65)	0.078 (48)*	0.115 (60)*	0.061 (41)*	0.213 (97)*
CDF [12]	0.162 (47)	0.078 (54)	0.296 (67)	0.088 (47)	0.433 (109)

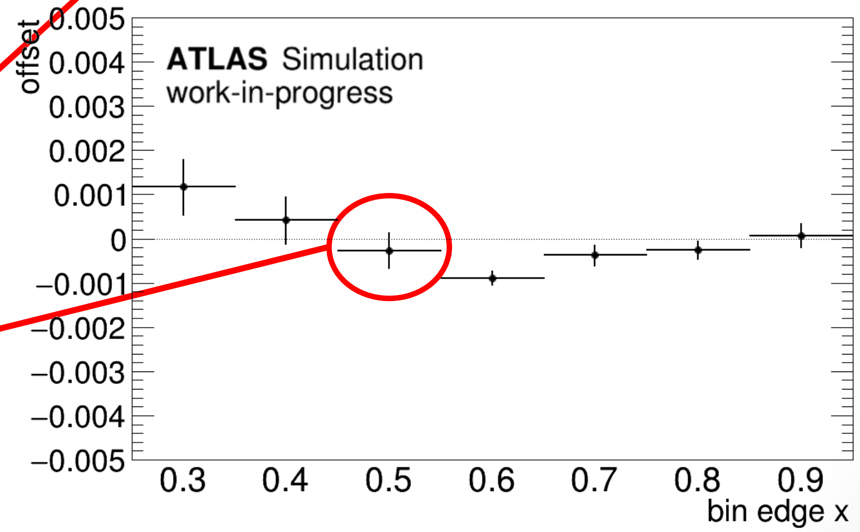
arXiv:1207.0331 [hep-ph]

BACKUP: Binning Choice to Eliminate Bias

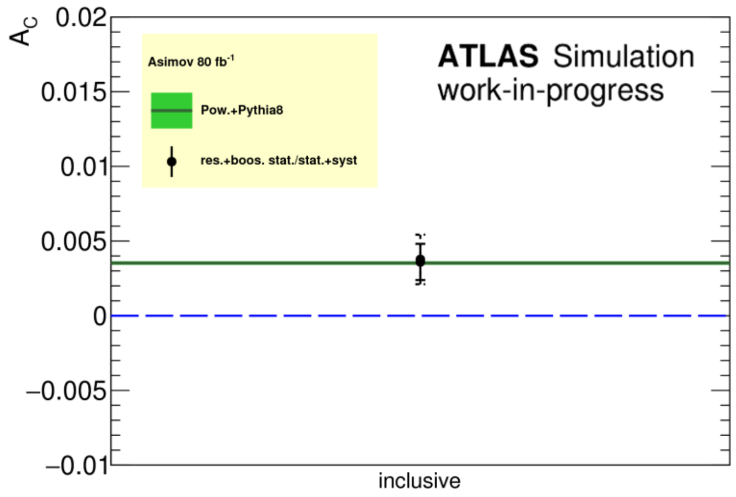
For different injected asymmetries, choose the bin x that gives a slope closest to 1 and offset 0.

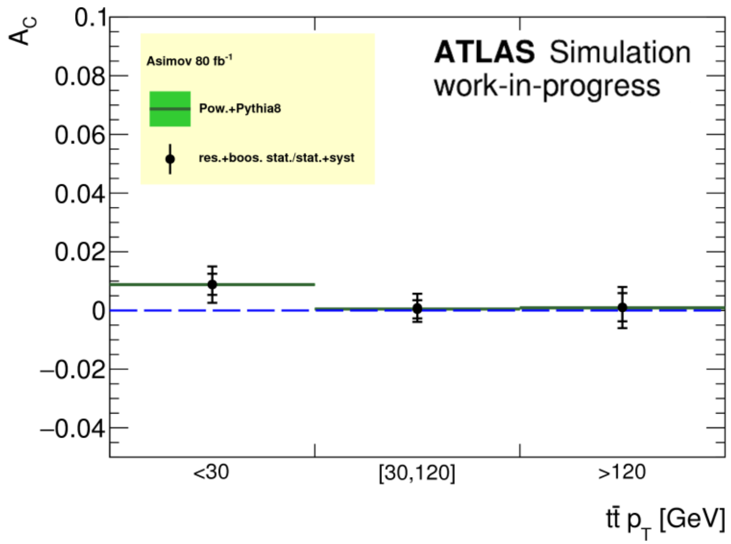


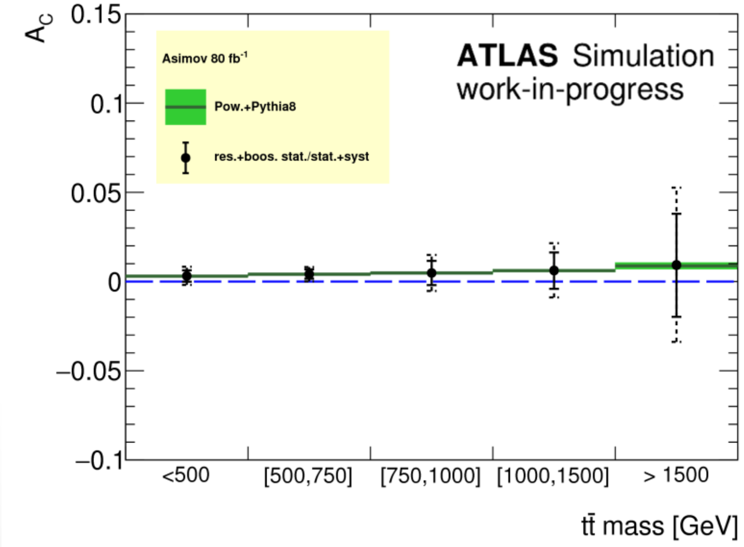


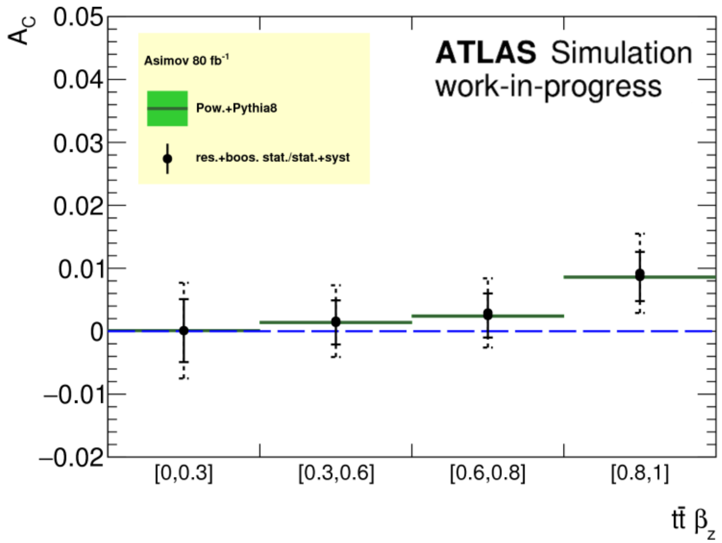


BACKUP: Expected Sensitivities (Lepton+Jets Channel)









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