TOP-12-004 update: Top spin correlation and polarization in the dilepton final state (7 TeV)

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Top properties meeting
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Background

- TOP-12-004 paper combines results from two groups
  - Top spin correlation and opening angle, update presented last week:
    - https://indico.cern.ch/conferenceDisplay.py?confId=246144
  - Unfolded asymmetry variables related to top spin correlation and polarization
    - this talk
- For previous results (PASes) see
  - http://cms.cern.ch/iCMS/analysisadmin/cadi?ancode=TOP-12-004
  - http://cms.cern.ch/iCMS/analysisadmin/cadi?ancode=TOP-12-016
- Selections and MC are synchronized between the two groups (see backup for details)

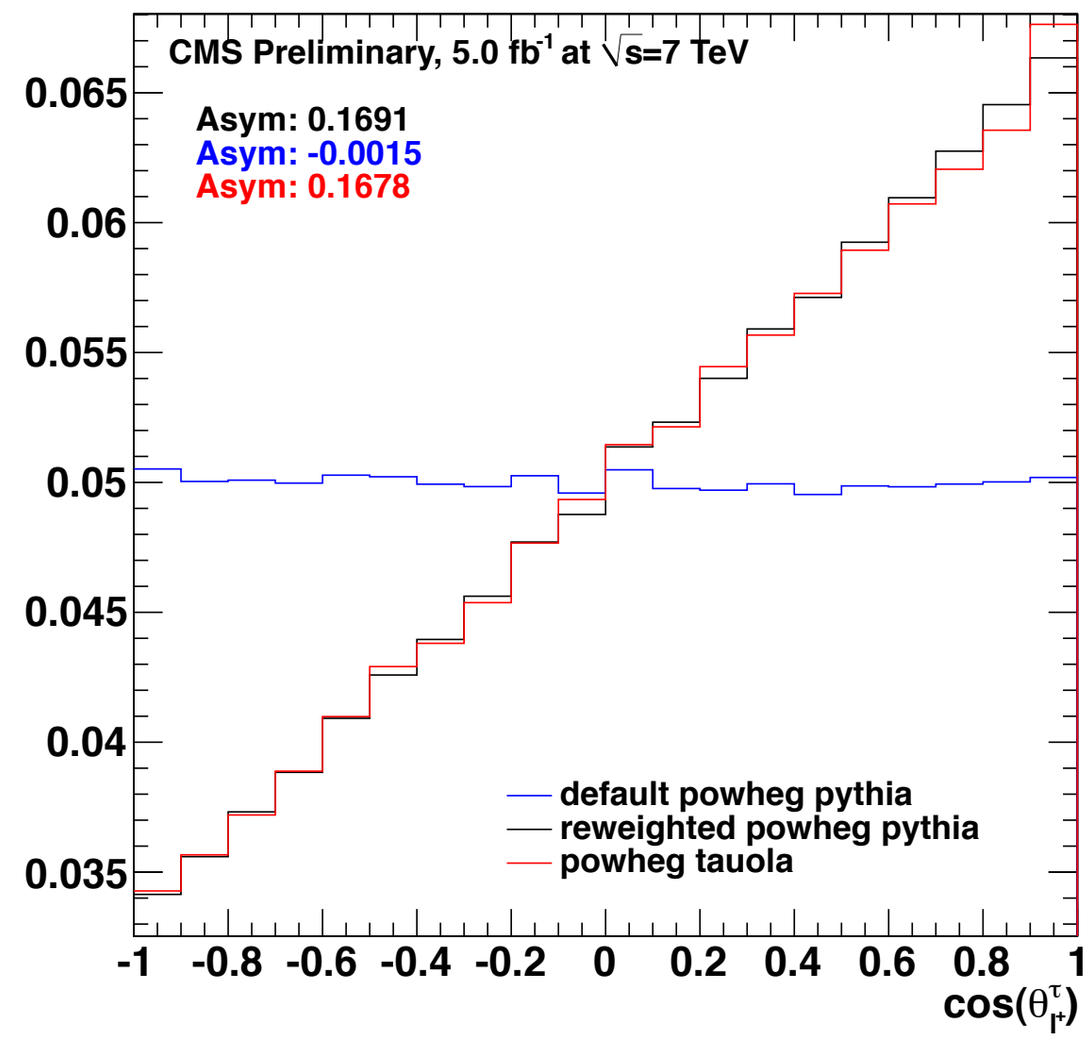
Introduction

- We measure the top polarization and variables related to the spin correlation in the dilepton final state
- top decays before hadronization can wash out polarization
  - charged lepton is best spin analyzer
- Polarization $P_n = \frac{N(\cos(\theta_l^+) > 0) - N(\cos(\theta_l^+) < 0)}{N(\cos(\theta_l^+) > 0) + N(\cos(\theta_l^+) < 0)}$
  - measured in the helicity basis (angle of lepton measured in parent top's rest frame, relative to direction of the antitop)
- Two spin correlation variables:
  - Direct (from the correlation between the + and - lepton directions)
    - $A_{c1c2} = \frac{N(\cos(\theta_l^+) \times \cos(\theta_l^-) > 0) - N(\cos(\theta_l^+) \times \cos(\theta_l^-) < 0)}{N(\cos(\theta_l^+) \times \cos(\theta_l^-) > 0) + N(\cos(\theta_l^+) \times \cos(\theta_l^-) < 0)}$
  - Indirect (lepton azimuthal asymmetry discriminates between correlated and uncorrelated $t\bar{t}$) - note, this is a purely leptonic variable (lab frame)
    - $A_{\Delta\phi} = \frac{N(\Delta\phi_{l^+l^-} < \pi/2) - N(\Delta\phi_{l^+l^-} > \pi/2)}{N(\Delta\phi_{l^+l^-} < \pi/2) + N(\Delta\phi_{l^+l^-} > \pi/2)}$

Issues addressed since PAS results

Tau decay systematic

- Tau polarization is ignored in tau decay in non-tauola MC samples
  - we thought this meant we could not use MC@NLO
    - initially we thought the systematic would be large
  - extensive investigation revealed that the true systematic as a result of this approximation is very small
- Developed method to evaluate tau decay systematic by reweighting the MC events to give the correct tau decay angular distributions
  - plot shows angle of the daughter lepton in the tau rest frame, with and without tauola, and the results of the reweighting
  - more details in backup



dilepton ttbar system reconstuction

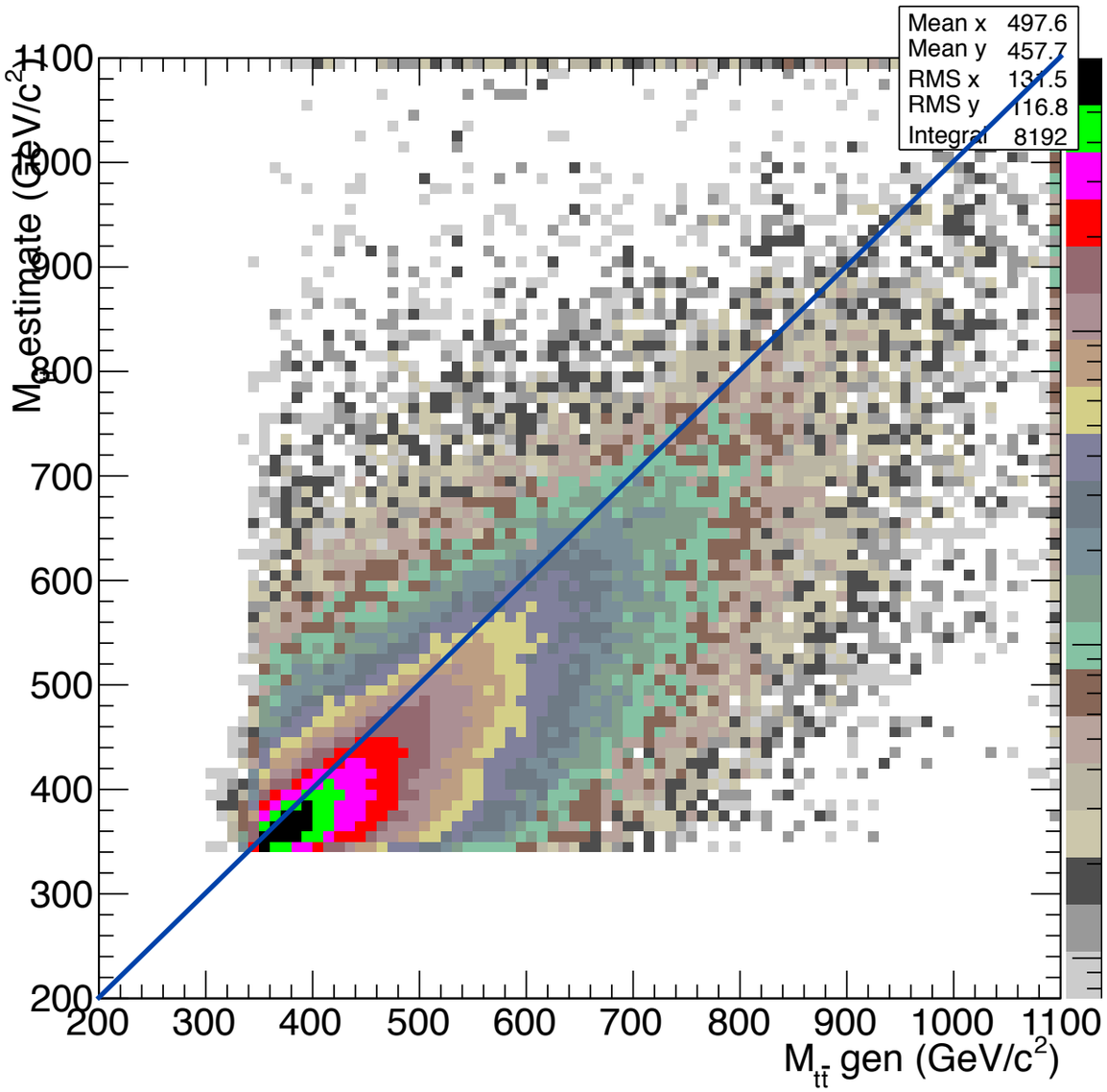
- Polarization and direct spin correlation measurements require reconstruction of the top and antitop 4-vectors
- We use the Analytic Matrix Weighting Technique (AMWT)
- Previously we used the reconstructed jet energies in the solver
  - we then scanned the top mass to compensate for jet resolution effects
- Now we smear the jets, randomly generating 100 smearing iterations for each event
  - this is done like a MC integration, with the chance of generating a given smear given by the probability density
  - decreases fraction of events with no solution (~17% to ~5%)
  - the original implementation of the jet smearing resulted in a considerable bias (next slide)

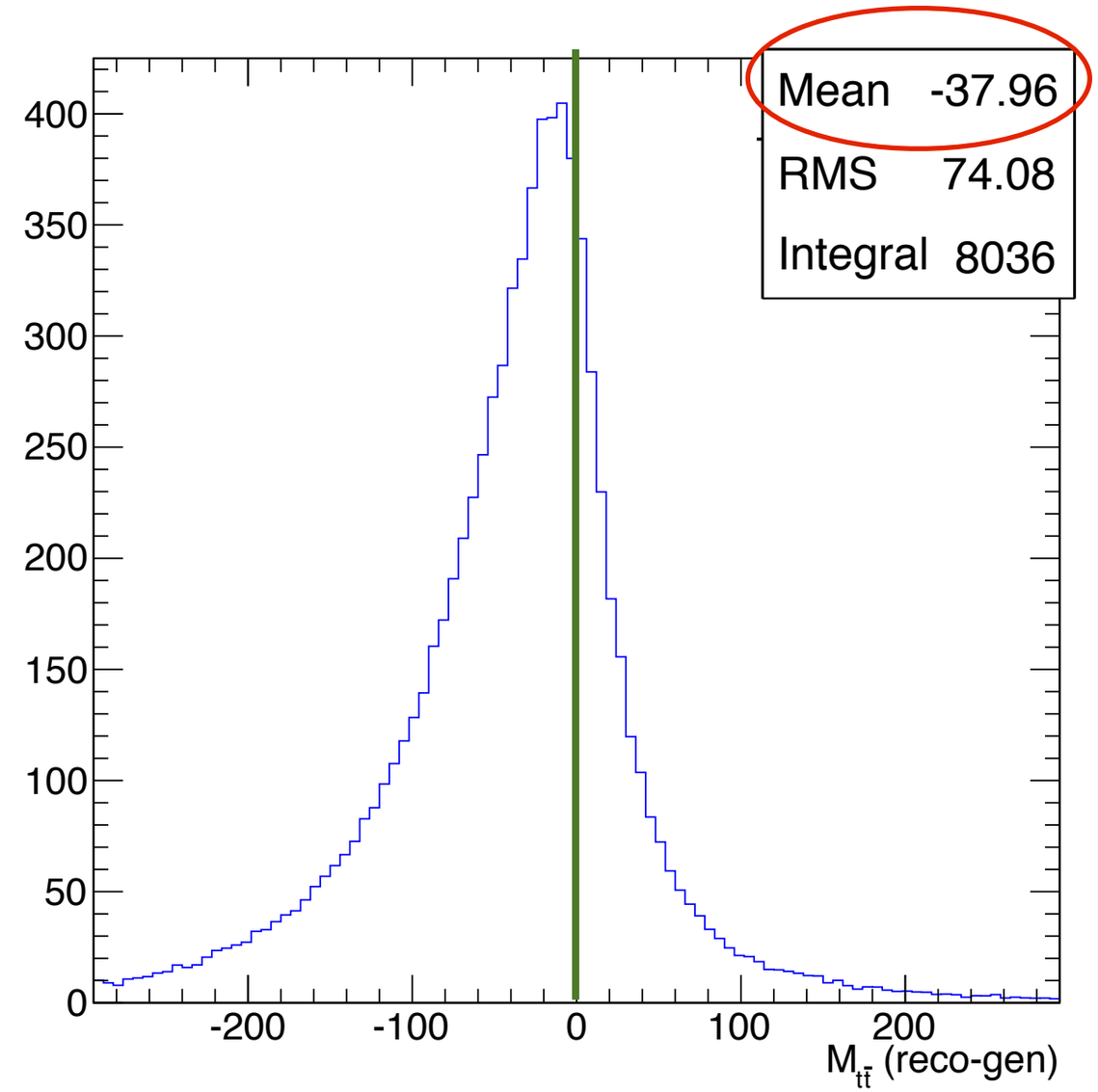
Jet smearing bias

- Original implementation: take top and antitop kinematics from the AMWT solution using the single jet smearing iteration with largest AMWT weight
  - this is incorrect because it does not disfavour the solutions with large (unlikely) smears
  - result is a bias towards the tails of the jet smearing distributions, that gets worse as the number of iterations is increased
  - we also find that, on average, the AMWT weight increases when the jet p_Ts are reduced (weight not normalised wrt input kinematics?)
    - so the bias is towards the low tail of the jet p_T smearing distribution
    - results in significant bias on reconstructed ttbar system, and variables such as top p_T and M_{ttbar} (plots on next slide)
- Note that this problem does not affect the M_{top} estimate, because this is taken from the M_{top} value with maximum sum of weights (summed over jet smearing iterations)

Jet smearing bias plots: M_{ttbar}

- Plots are for dilepton ttbar MC@NLO (after event selection)
- Left: M_{tt}(reco) vs M_{tt}(gen)
- Right: M_{tt}(reco) - M_{tt}(gen)





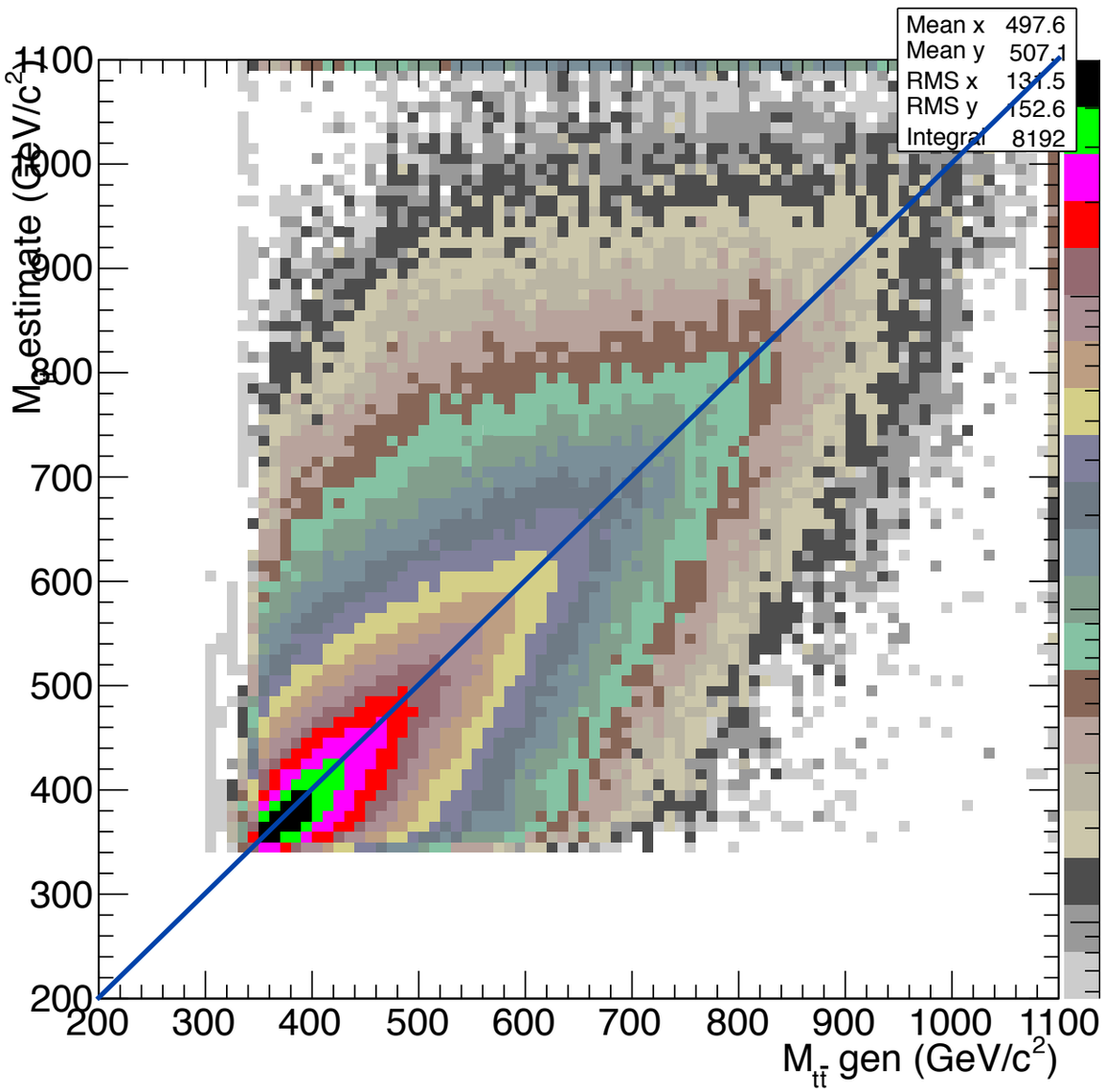
- Bias of ~40 GeV (~8%)

Fix for jet smearing bias

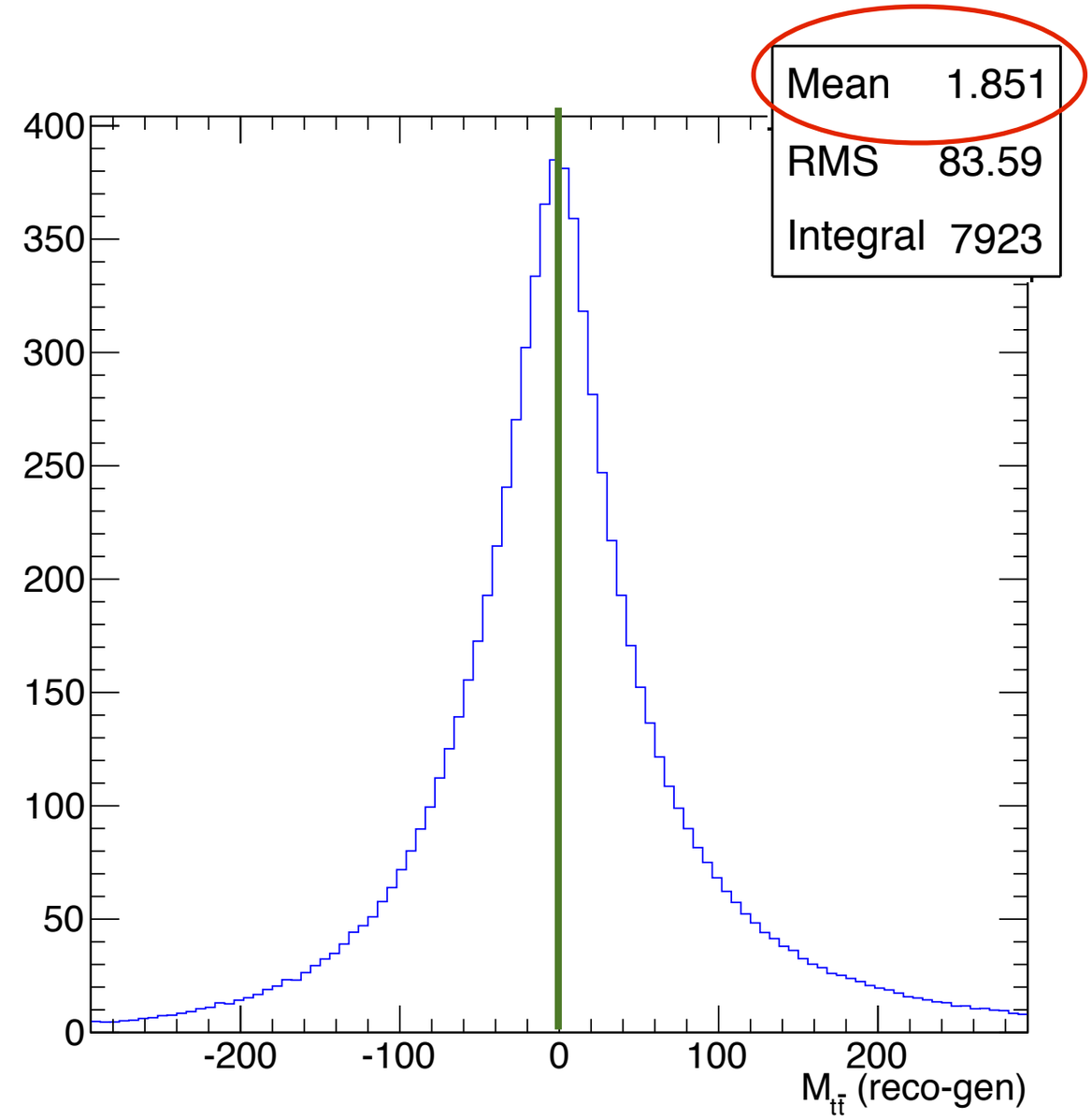
- Recall, the bias comes from selecting the solution from a single iteration of the MC integration
- Remove bias by taking instead the average from all iterations
  - use all N solutions for the ttbar kinematics, where N is the number of jet smearing iterations that have an AMWT solution
  - weight each solution by 1/N
  - propagate the uncertainties under the assumption of 100% correlation between the N solutions for each event

M_{ttbar} after jet smearing bias fixed

- Left: M_{tt}(reco) vs M_{tt}(gen)



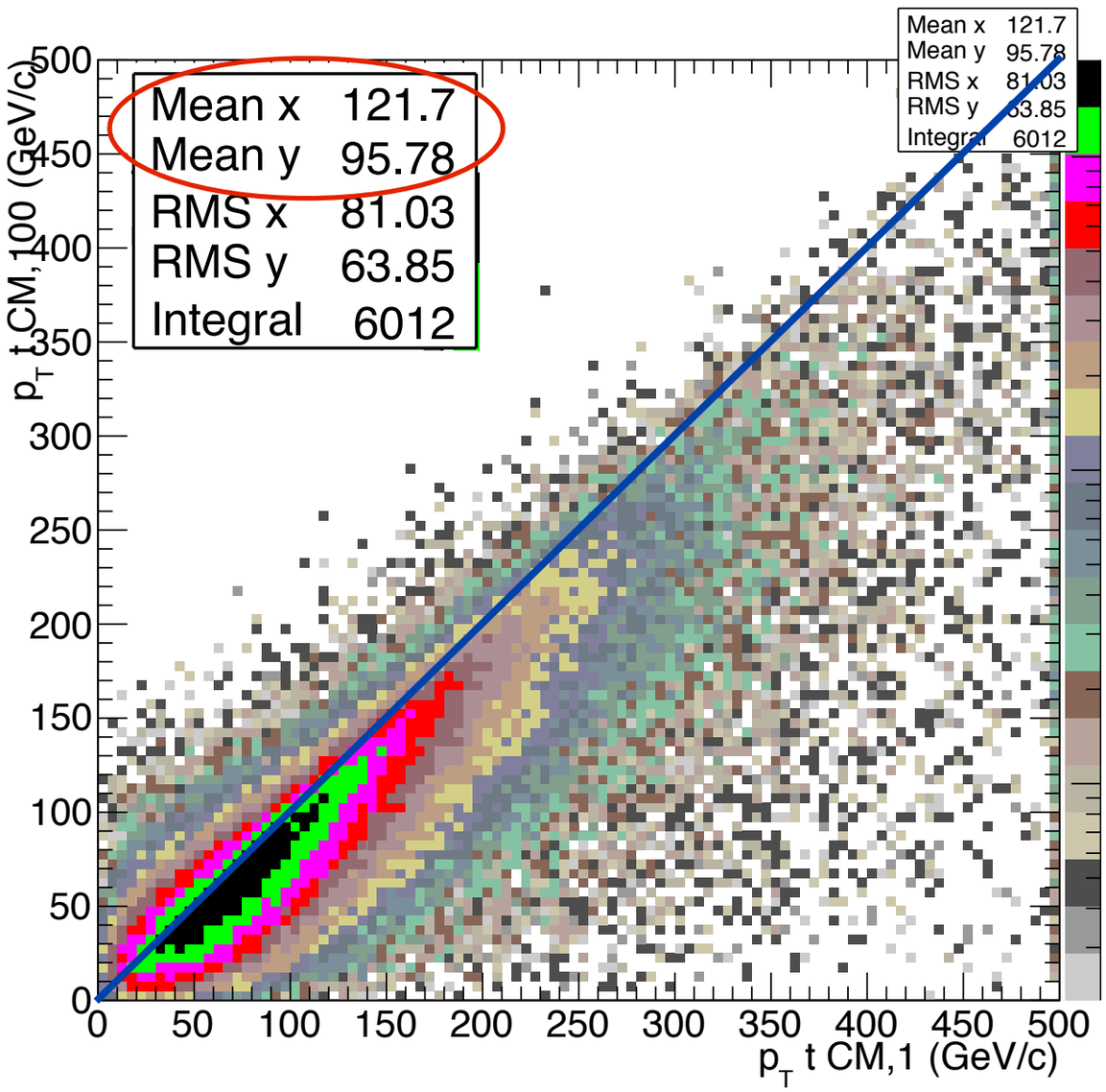
- Right: M_{tt}(reco) - M_{tt}(gen)

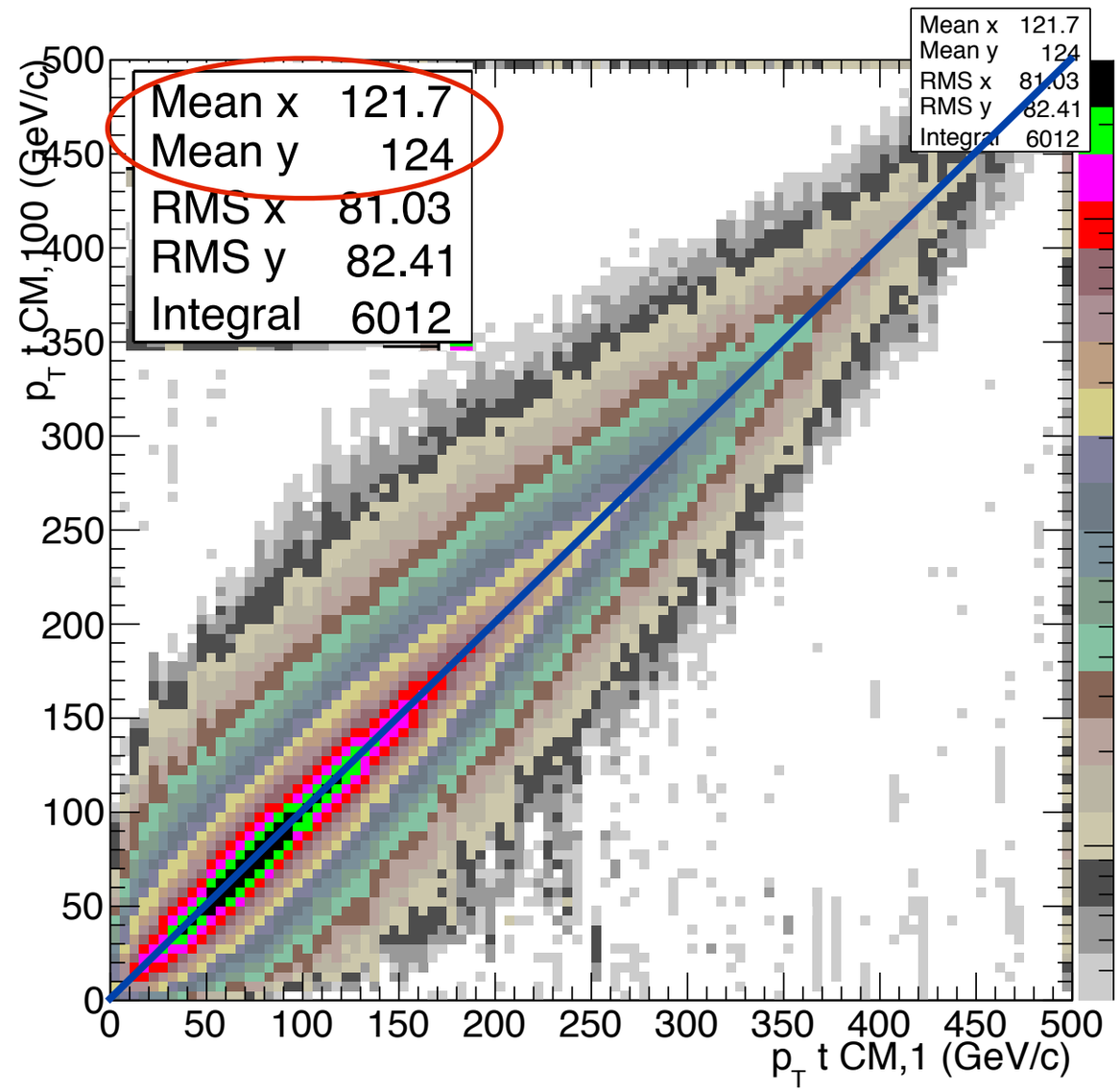


- Bias is removed

Before and after fix: top p_T (ttbar CM)

- Left: top p_T before fix
- Right: top p_T after fix





- Bias of ~25 GeV (~20%) is removed
  - Note larger bias than in M_{ttbar}, because the M_{top} value is unbiased

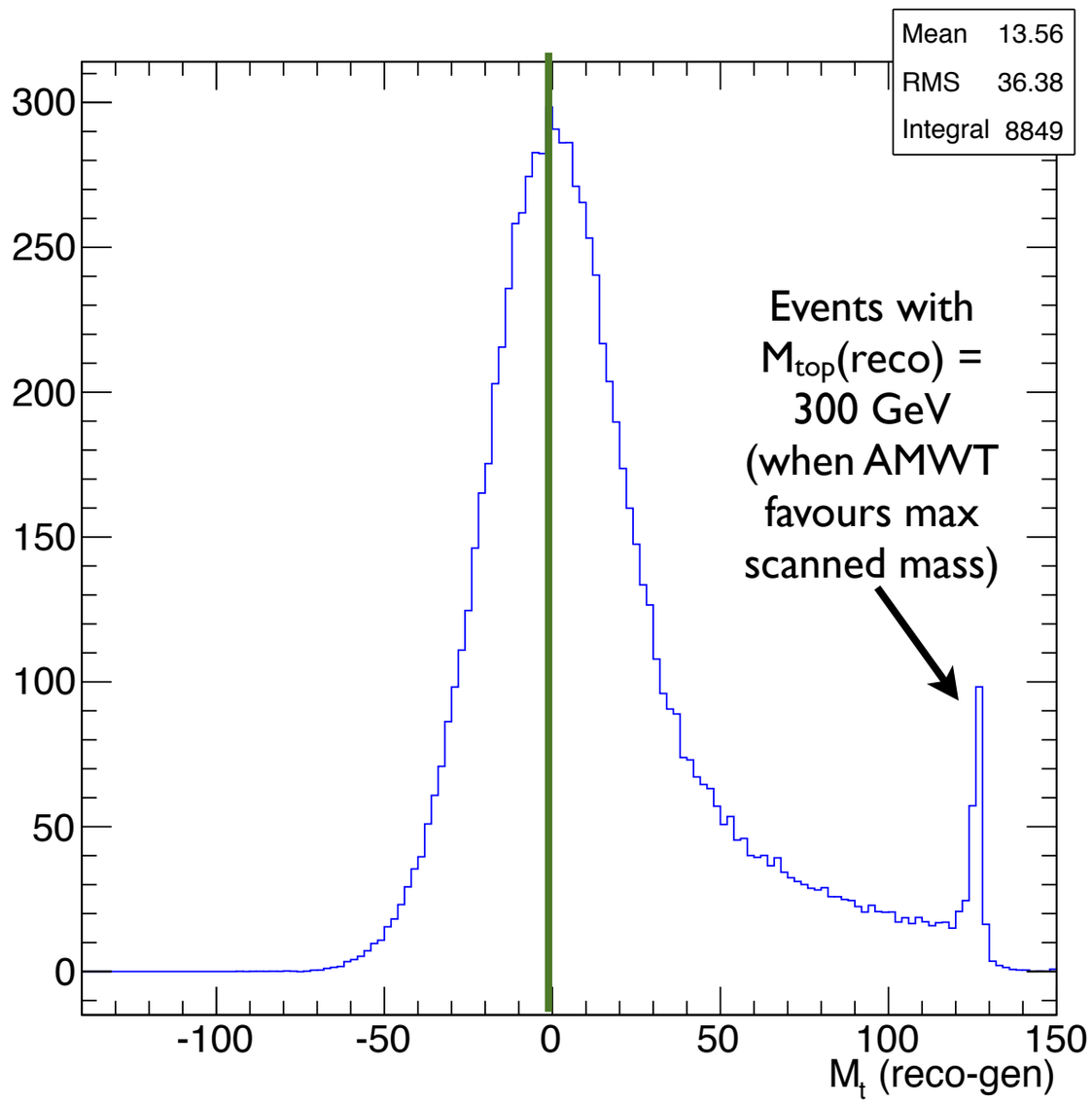
Further AMWT changes

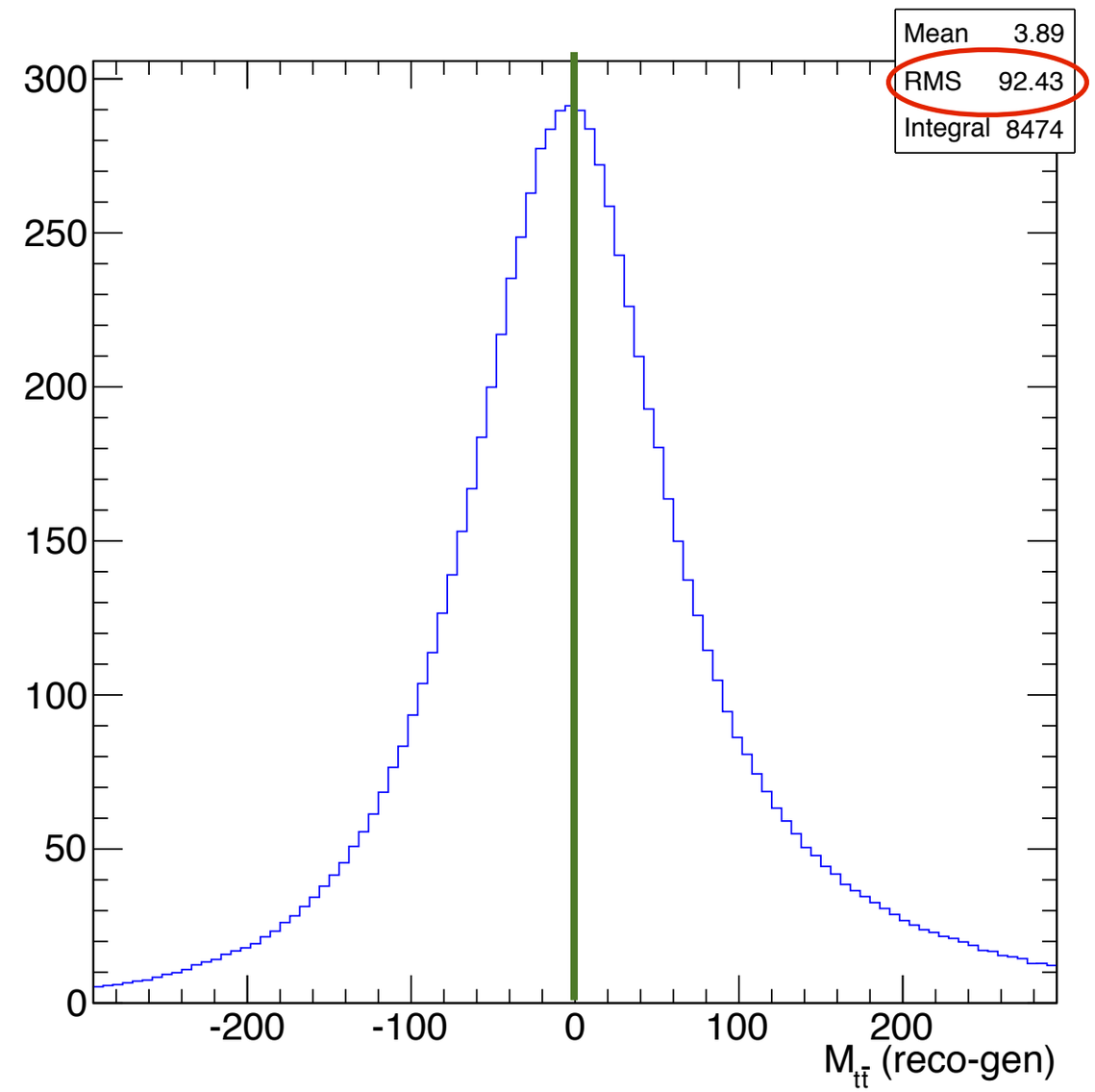
- For each event, the combination of the 2 b jets and 2 leptons is constrained to be the one with max sum of weights (so that different smearing iterations can't have different combinations)

- Mass fixed to CMS measured M_{top}
  - this improves the accuracy of the ttbar system reconstruction, since the top and antitop 4 vectors are constrained to have roughly the correct mass (not the case when scanning from 100 to 300 GeV)
  - decreases fraction of events with solution (but these can be recovered by increasing the number of smearing iterations)
  - plots on next slide
- to do: assess systematic uncertainty from choice of top mass
  - this replaces "scan range" systematic, which was quite large and difficult to define

Default scan range (100 to 300 GeV)

- Left: M_t(reco) - M_t(gen)
- Right: M_{tt}(reco) - M_{tt}(gen)

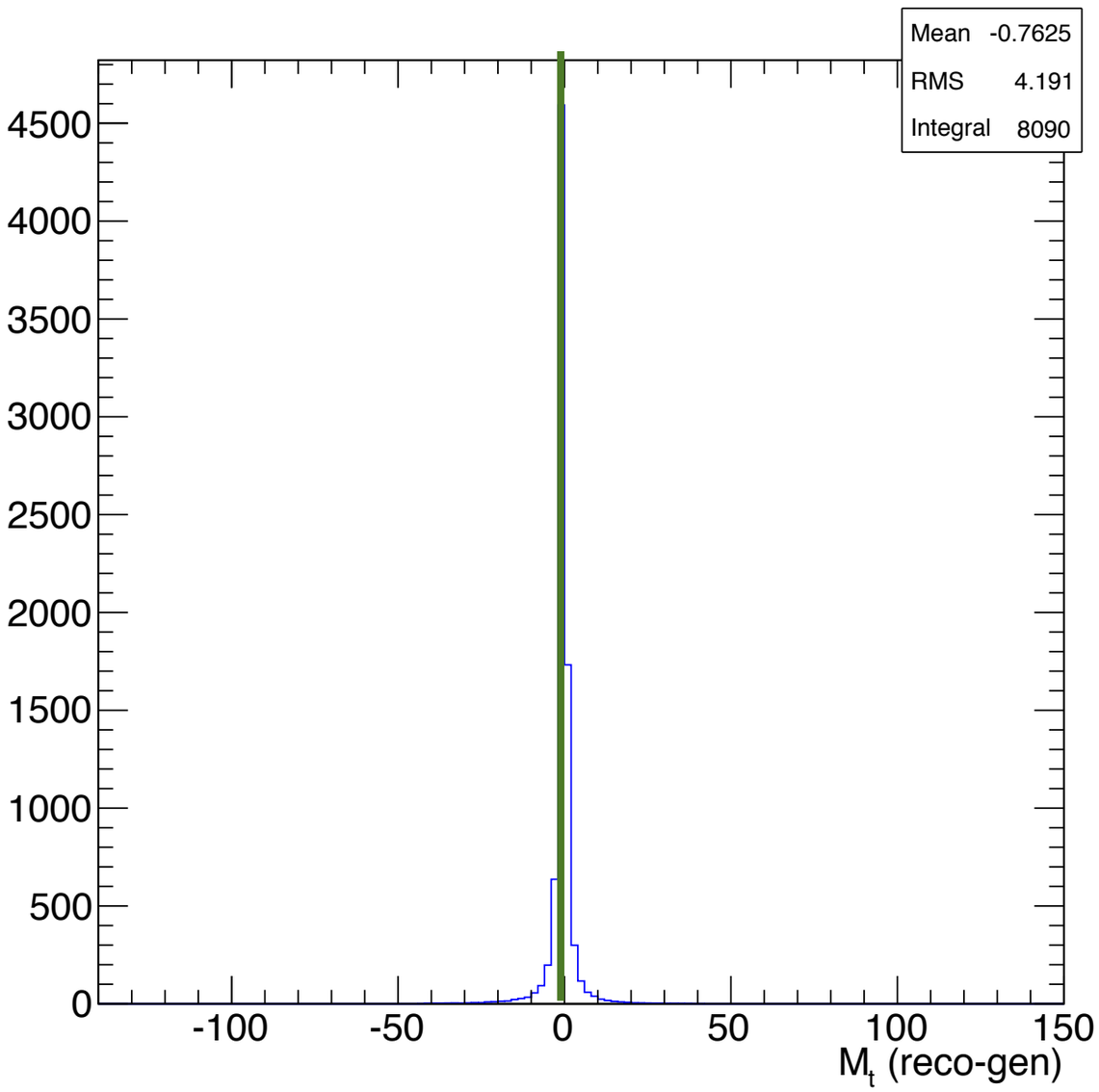


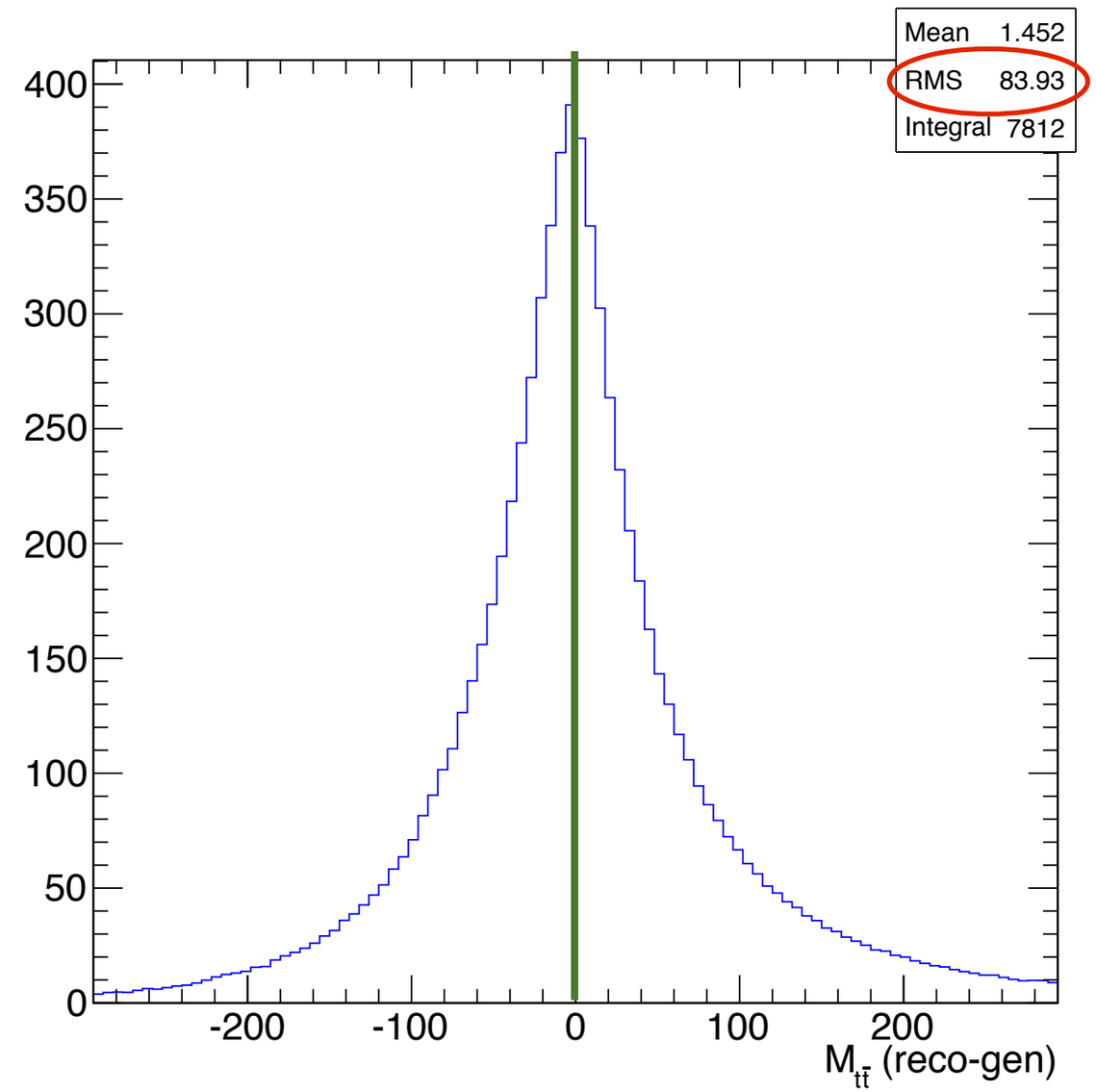


- Top mass taken from value with maximum sum of AMWT weights

Top mass fixed

- Left: M_t(reco) - M_t(gen)
- Right: M_{tt}(reco) - M_{tt}(gen)

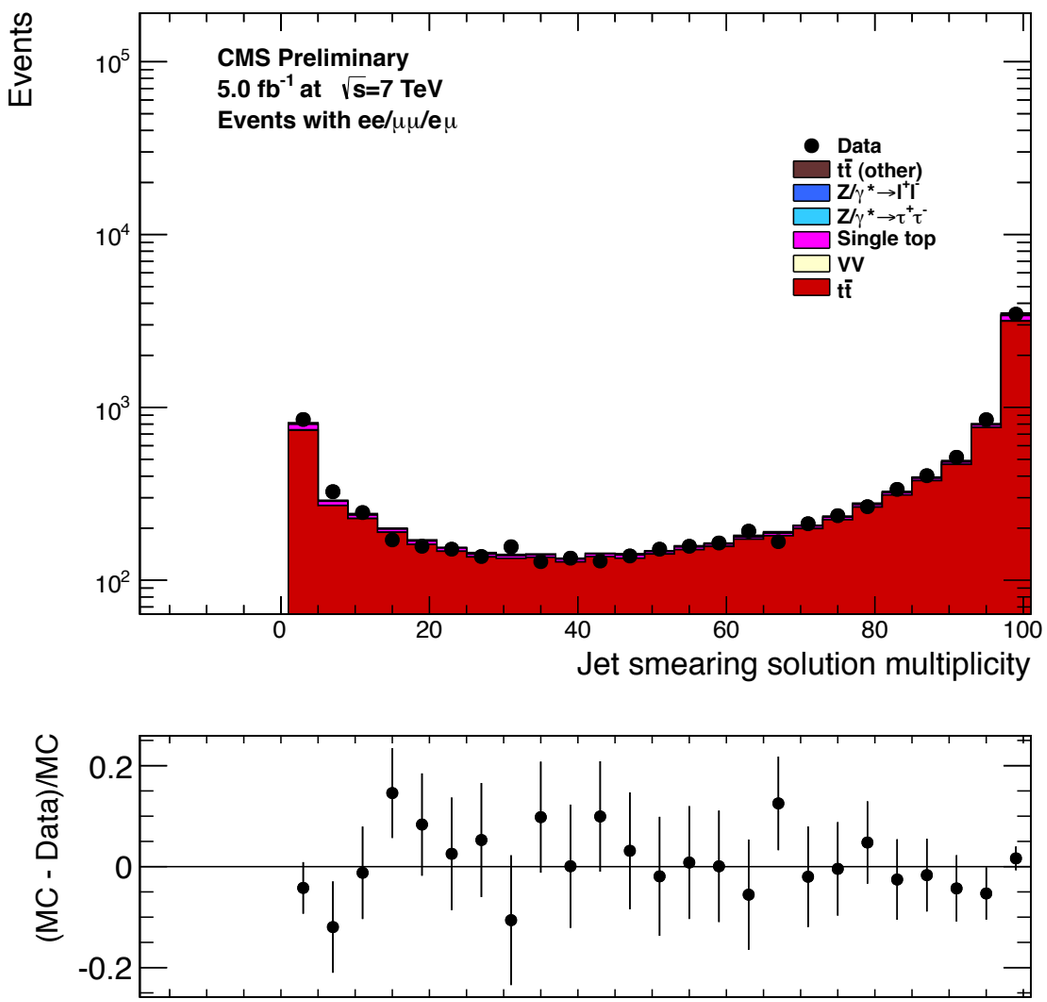


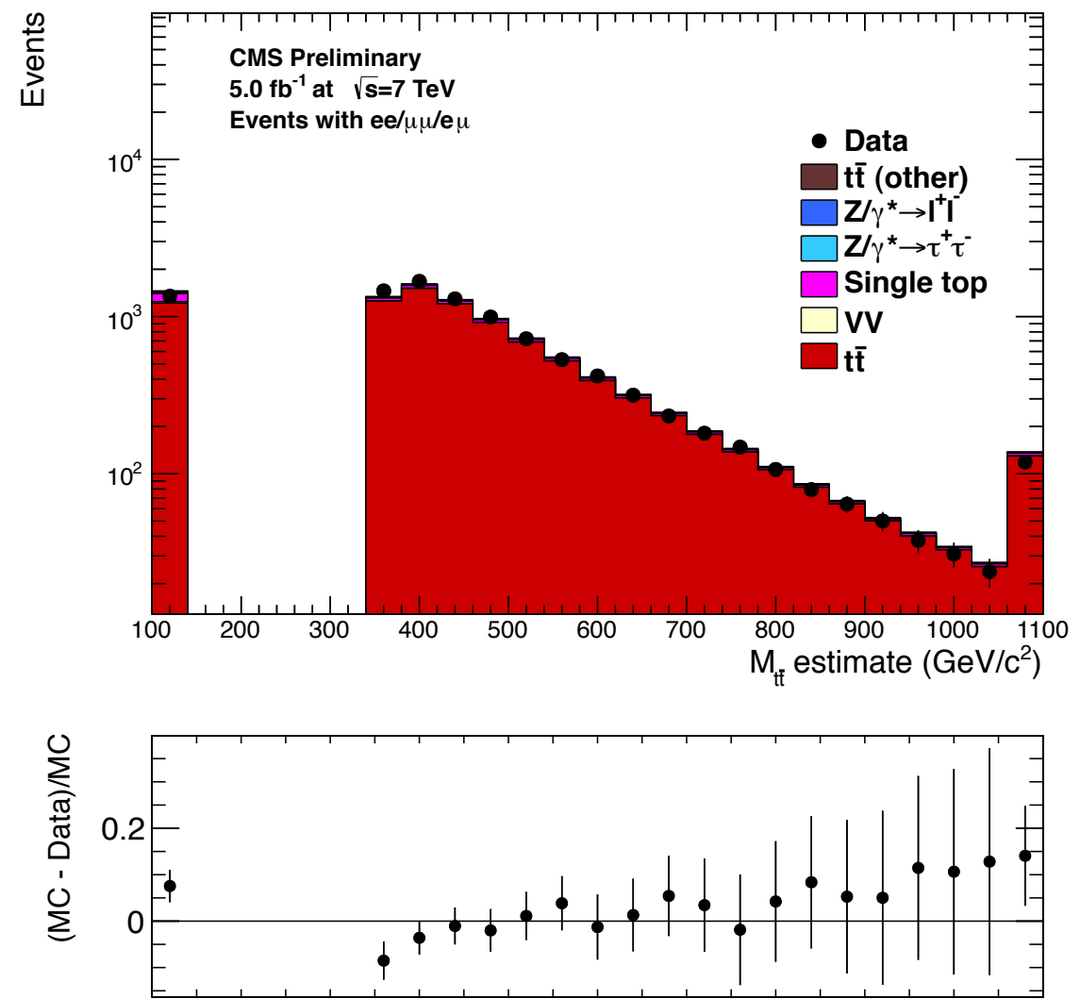


- Top mass fixed to 172.5 GeV => more accurate M_{ttbar}
  - corresponding reduction in uncertainty on unfolded results (~10%)

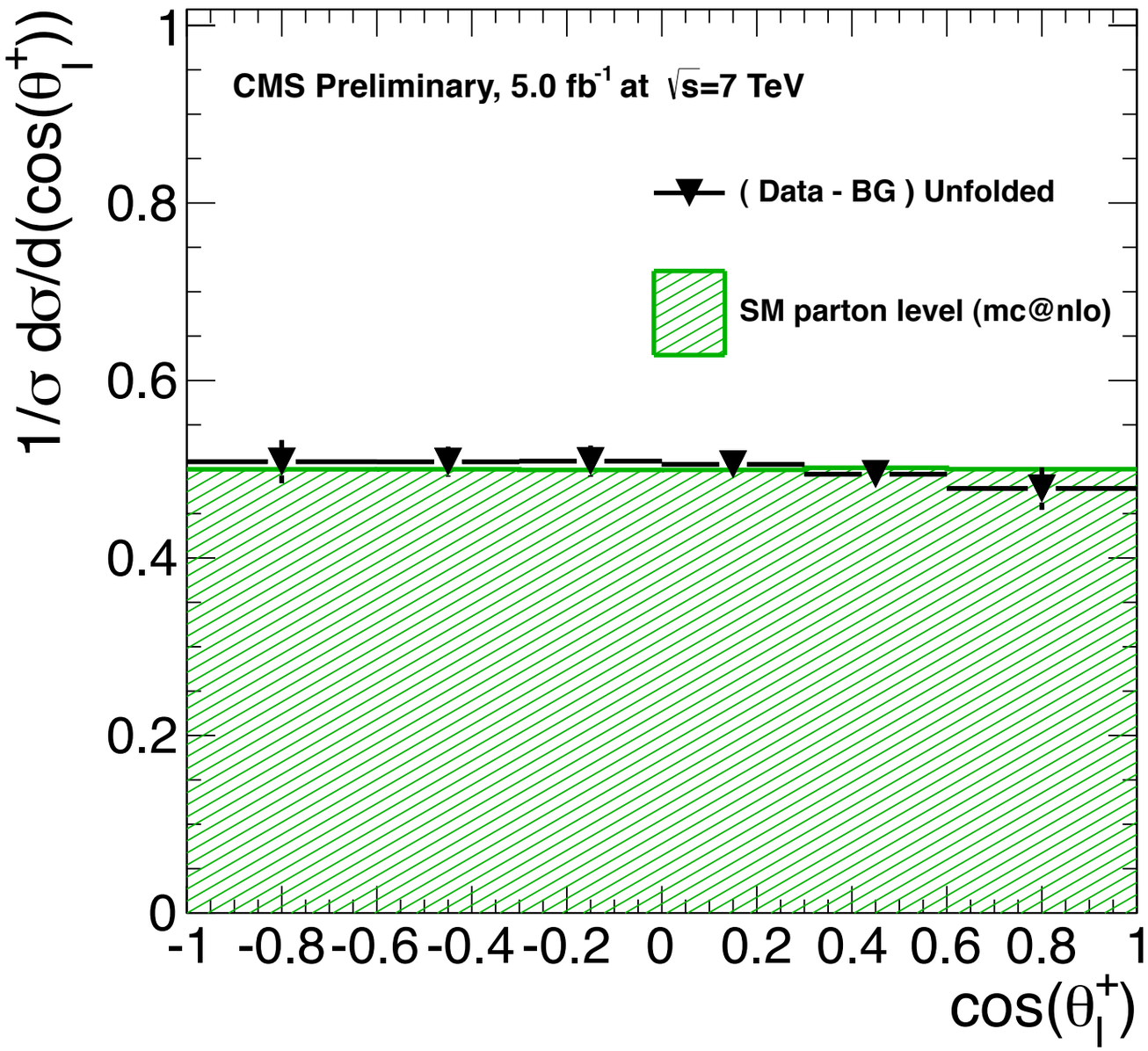
Data-MC comparison

- Vertex reweighting has been applied to MC
- Number of jet smearing iterations with a solution (left)
- M_{ttbar} (right)
- Data and MC agreement is reasonable
- more plots in backup





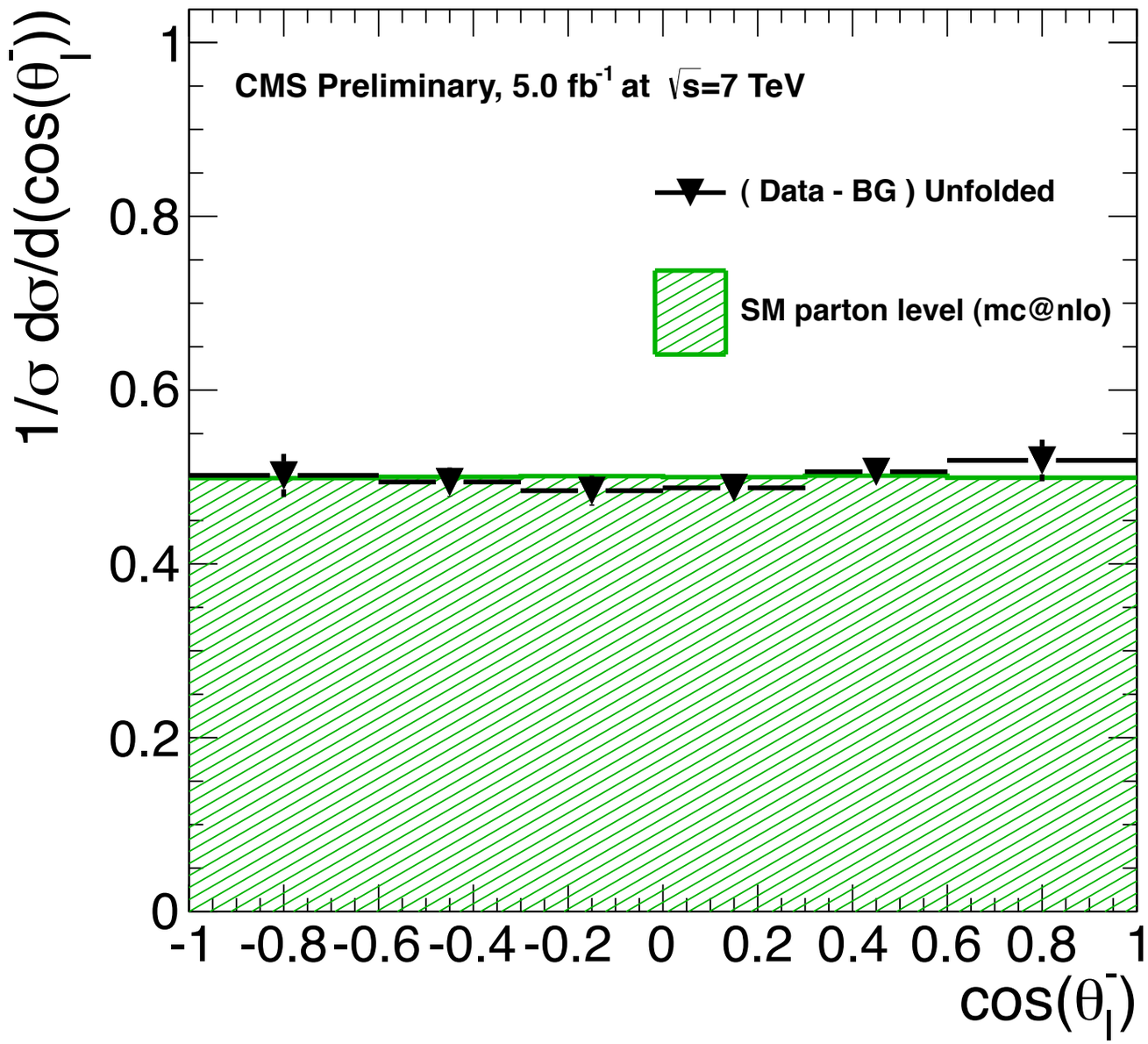
Unfolded results: polarization from l^+



preliminary
no systematics

- Plot shows unfolded parton level differential cross section compared to the SM (from MC@NLO truth level)
  - P = -0.017 ± 0.025 (stat only) in data (cf 0.009±0.029 in PAS)
  - P = 0.001 ± 0.001 in MC@NLO (parton level, no cuts)

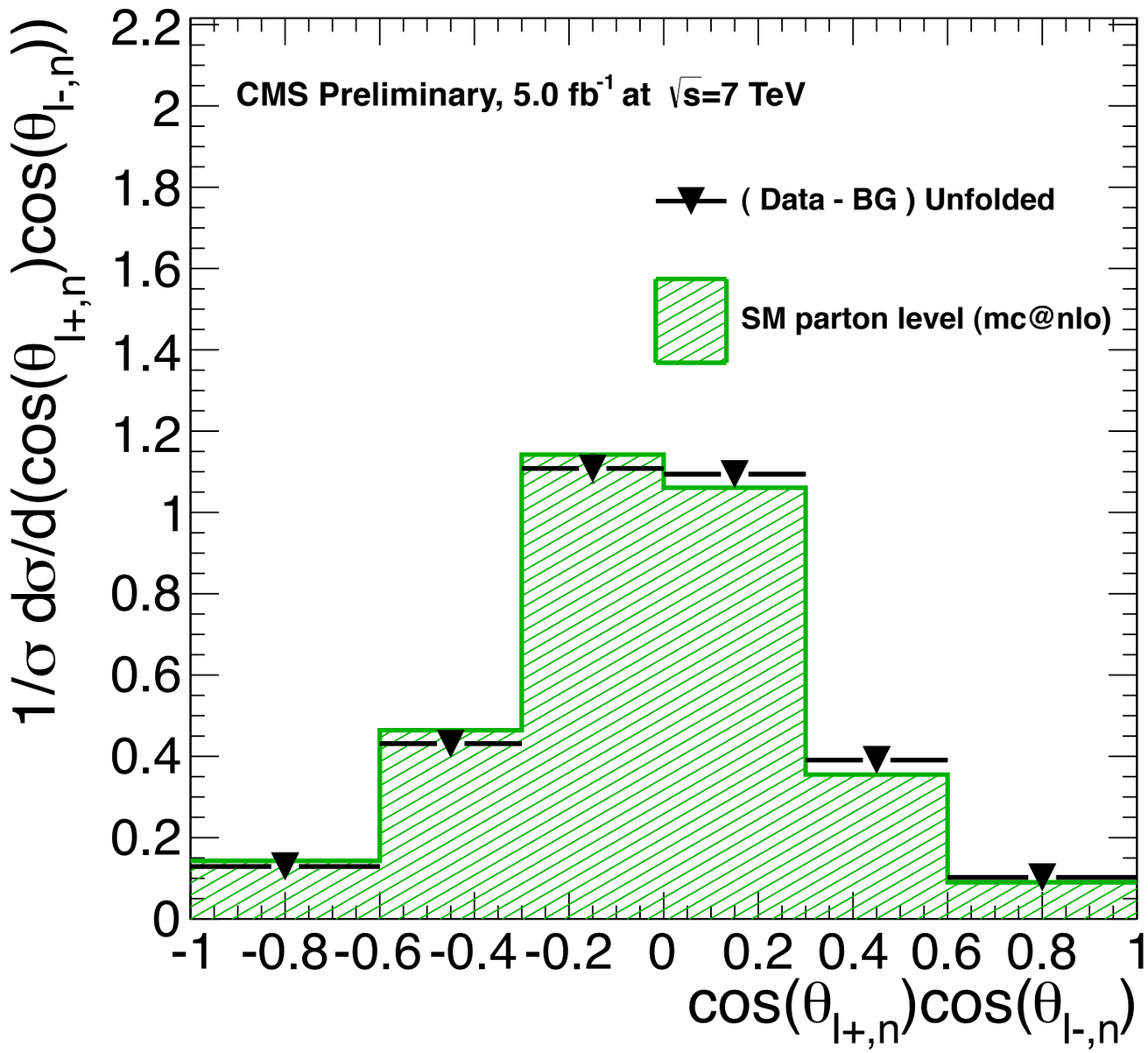
Unfolded results: polarization from l^-



preliminary
no systematics

- Plot shows unfolded parton level differential cross section compared to the SM (from MC@NLO truth level)
  - P = 0.011 ± 0.026 (stat only) in data
  - P = 0.000 ± 0.001 in MC@NLO (parton level, no cuts)

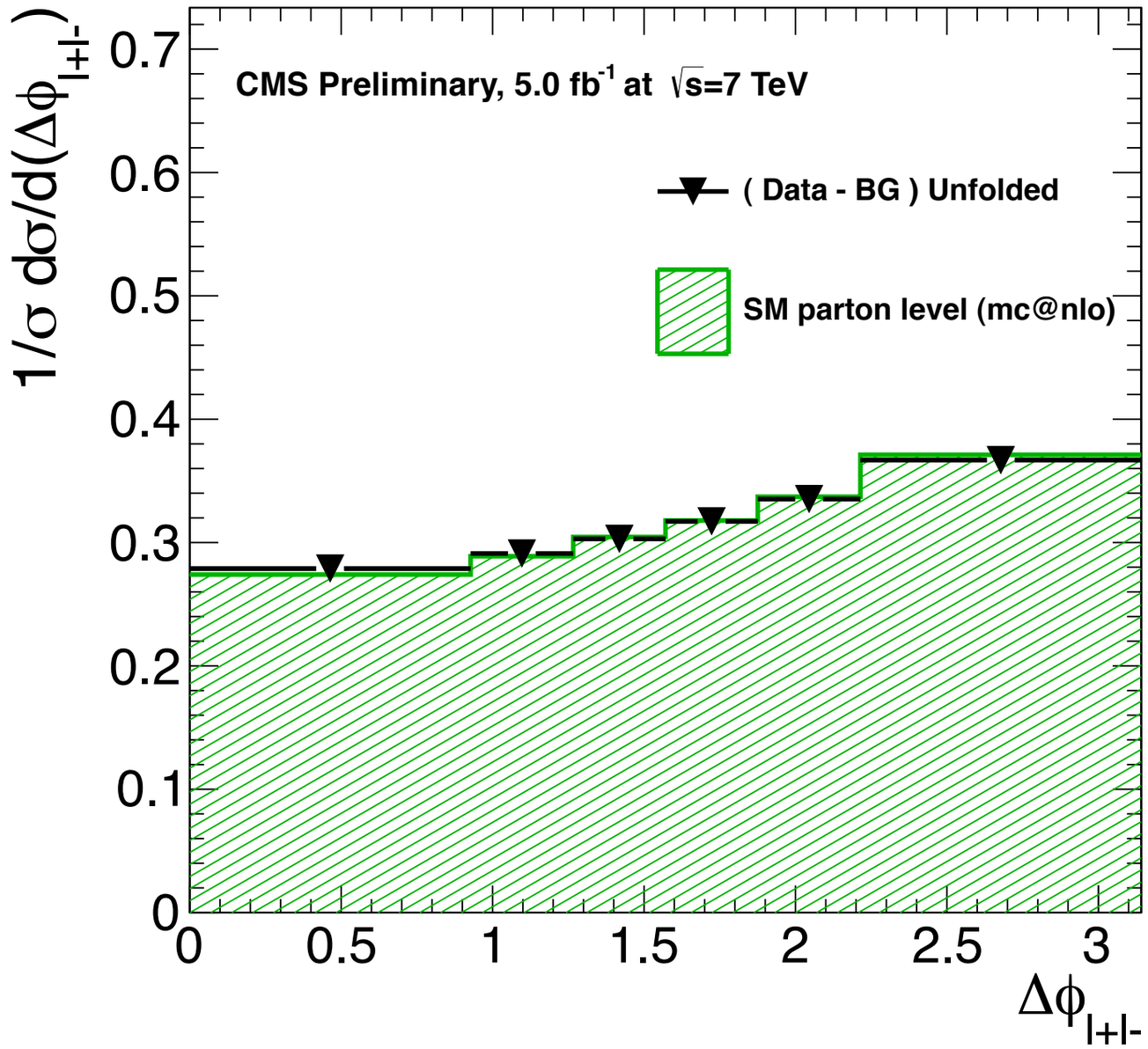
Unfolded results: direct spin correlation



preliminary
no systematics

- Plot shows unfolded parton level differential cross section compared to the SM (from MC@NLO truth level)
  - A_{c1c2} = -0.027 ± 0.032 (stat only) in data (cf -0.015 ± 0.037 in PAS)
  - A_{c1c2} = -0.078 ± 0.001 in MC@NLO (parton level, no cuts)

Unfolded results: indirect spin correlation



preliminary
no systematics

- Plot shows unfolded parton level differential cross section compared to the SM (from MC@NLO truth level)
  - $A_{\Delta phi}$ = -0.101 ± 0.014 (stat only) in data (cf -0.097 ± 0.015 in PAS)
  - $A_{\Delta phi}$ = -0.110 ± 0.001 in MC@NLO (parton level, no cuts)

Summary

- Event selection and MC samples synchronised, including systematics samples
- Developed method to evaluate tau decay systematic
- Improved AMWT
  - jet smearing with bias removed, fixed top mass
- Results all consistent with MC@NLO

- To do:
  - evaluate systematics (this is quick, methods already in place)
  - pseudoexperiment tests
  - combine + and - lepton results for polarization
  - converge on paper ASAP!

Backup

Event selection

- **Selection designed to reject events other than ttbar**
- Dilepton triggers: dimuon, dielectron or electron-muon
- 2 opposite sign isolated leptons: p_T > 20 GeV, |eta| < 2.5 (2.4) for e (μ)
- ≥2 pf jets with p_T > 30 GeV, |eta| < 2.5
  - loose pfjet ID (L1FastL2L3 corrected)
  - ΔR > 0.4 from all leptons passing analysis selection
  - ≥1b tags: CSVM
- MET > 40 GeV (ee and μμ channels only)
- Z veto: 76<m_{ll}<106 GeV veto (for SF leptons)
- m_{ll}>20 GeV to veto low mass resonances (SF leptons)

Event Samples

- TTJets_TuneZ2_7TeV-madgraph-tauola_Summer11-PU_S4_START42_V11-v1 , 154 pb
- TTTo2L2Nu2B_7TeV-powheg-pythia6_Summer11-PU_S4_START42_V11-v1 , 16.2 pb
- /TT_TuneZ2_7TeV-mcatnlo/Fall11-PU_S6_START42_V14B-v1/AODSIM , 154 pb
- T_TuneZ2_tW-channel_7TeV-madgraph_Summer11-PU_S4_START42_V11-v1 , 7.87 pb
- T_TuneZ2_t-channel_7TeV-madgraph_Summer11-PU_S4_START42_V11-v1 , 41.92 pb
- T_TuneZ2_s-channel_7TeV-madgraph_Summer11-PU_S4_START42_V11-v1 , 3.19 pb
- Tbar_TuneZ2_tW-channel_7TeV-madgraph_Summer11-PU_S4_START42_V11-v1 , 7.87 pb
- Tbar_TuneZ2_t-channel_7TeV-madgraph_Summer11-PU_S4_START42_V11-v1 , 22.65 pb
- Tbar_TuneZ2_s-channel_7TeV-madgraph_Summer11-PU_S4_START42_V11-v1 , 1.44 pb
- WJetsToLNu_TuneZ2_7TeV-madgraph-tauola_Summer11-PU_S4_START42_V11-v1 , 31314 pb
- DYJetsToLL_TuneD6T_M-50_7TeV-madgraph-tauola_Summer11-PU_S4_START42_V11-v1 , 3048 pb
- DYToEE_M-20_CT10_TuneZ2_7TeV-powheg-pythia_Summer11-PU_S4_START42_V11-v1 , 1666 pb
- DYToMuMu_M-20_CT10_TuneZ2_7TeV-powheg-pythia_Summer11-PU_S4_START42_V11-v1 , 1666 pb
- DYToTauTau_M-20_CT10_TuneZ2_7TeV-powheg-pythia-tauola_Summer11-PU_S4_START42_V11-v1 , 1666 pb
- DYToEE_M-10To20_TuneZ2_7TeV-pythia6_Summer11-PU_S4_START42_V11-v1 , 3319.61 pb
- DYToMuMu_M-10To20_TuneZ2_7TeV-pythia6_Summer11-PU_S4_START42_V11-v1 , 3319.61 pb
- DYToTauTau_M-10To20_CT10_TuneZ2_7TeV-powheg-pythia-tauola_Summer11-PU_S4_START42_V11-v2 , 3319.61 pb
- WWJetsTo2L2Nu_TuneZ2_7TeV-madgraph-tauola_ummer11-PU_S4_START42_V11-v1, 4.783 pb
- WZJetsTo2L2Q_TuneZ2_7TeV-madgraph-tauola_Summer11-PU_S4_START42_V11-v1, 1.786 pb
- WZJetsTo3LNu_TuneZ2_7TeV-madgraph-tauola_Summer11-PU_S4_START42_V11-v1, 0.856 pb
- ZZJetsTo2L2Nu_TuneZ2_7TeV-madgraph-tauola_Summer11-PU_S4_START42_V11-v1, 0.30 pb
- ZZJetsTo2L2Q_TuneZ2_7TeV-madgraph-tauola_Summer11-PU_S4_START42_V11-v1, 1.0 pb
- ZZJetsTo4L_TuneZ2_7TeV-madgraph-tauola/_Summer11-PU_S4_START42_V11-v1, 0.076 pb
- /Wprime_SM_400_Madgraph_v2/yanjuntu-Wprime_SM_400_Madgraph_v2-f3d3f52ad6235ba5a3ccb05162c152b9/USER
- /Wprime_ttbar_600_Madgraph/yanjuntu-Wprime_ttbar_600_Madgraph-f3d3f52ad6235ba5a3ccb05162c152b9/USER
- AxigluonR_2TeV_ttbar_MadGraph_sergo-AxigluonR_2TeV_ttbar_MadGraph

- Data: May10th rereco + Prompt v4 + Aug05th rereco + Prompt v6 + 2011B Data (5.0 fb^{-1})

Triggers

- Double Electron
  - HLT_Ele17_CaloIdL_CaloIsoVL_Ele8_CaloIdL_CaloIsoVL
  - HLT_Ele17_CaloIdT_TrkIdVL_CaloIsoVL_TrkIsoVL_Ele8_CaloIdT_TrkIdVL_CaloIsoVL_TrkIsoVL
  - HLT_Ele17_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL_Ele8_CaloIdT_CaloIsoVL_TrkIdVL_TrkIsoVL
- Double Muon
  - HLT_DoubleMu7
  - HLT_Mu13_Mu7
  - HLT_Mu13_Mu8
  - HLT_Mu17_Mu8
- Electron Muon
  - HLT_Mu17_Ele8_CaloIdL
  - HLT_Mu8_Ele17_CaloIdL
  - HLT_Mu17_Ele8_CaloIdT_CaloIsoVL
  - HLT_Mu8_Ele17_CaloIdT_CaloIsoVL

Trigger efficiencies

For the high p_T dilepton triggers, the efficiencies listed in Table 1, Table 2, Table 3 and Table 4 are applied to ee, $\mu\mu$ and $e\mu$ Monte Carlo Events. Details of the measurement of the trigger efficiencies are described in [12].

Table 1: The efficiency of the leading leg requirement for the double electron trigger, averaged over the full 2011 data.

Measurement	$0.0 \leq \lvert\eta\rvert < 1.5$	$1.5 \leq \lvert\eta\rvert < 2.5$
$20 \leq p_T \leq 30$	0.9849 ± 0.0003	0.9774 ± 0.0007
$p_T > 30$	0.9928 ± 0.0001	0.9938 ± 0.0001

Table 2: The efficiency of the trailing leg requirement for the double electron trigger, averaged over the full 2011 data.

Measurement	$0.0 \leq \lvert\eta\rvert < 1.5$	$1.5 \leq \lvert\eta\rvert < 2.5$
$20 \leq p_T \leq 30$	0.9923 ± 0.0002	0.9953 ± 0.0003
$p_T > 30$	0.9948 ± 0.0001	0.9956 ± 0.0001

Table 3: The efficiency of the leading leg requirement for the double muon trigger, averaged over the full 2011 data.

Measurement	$0.0 \leq \lvert\eta\rvert < 0.8$	$0.8 \leq \lvert\eta\rvert < 1.2$	$1.2 \leq \lvert\eta\rvert < 2.1$	$2.1 \leq \lvert\eta\rvert < 2.4$
$20 \leq p_T \leq 30$	0.9648 ± 0.0007	0.9516 ± 0.0013	0.9480 ± 0.0009	0.8757 ± 0.0026
$p_T > 30$	0.9666 ± 0.0003	0.9521 ± 0.0005	0.9485 ± 0.0004	0.8772 ± 0.0012

Table 4: The efficiency of the trailing leg requirement for the double muon trigger, averaged over the full 2011 data.

Measurement	$0.0 \leq \lvert\eta\rvert < 0.8$	$0.8 \leq \lvert\eta\rvert < 1.2$	$1.2 \leq \lvert\eta\rvert < 2.1$	$2.1 \leq \lvert\eta\rvert < 2.4$
$20 \leq p_T \leq 30$	0.9655 ± 0.0007	0.9535 ± 0.0013	0.9558 ± 0.0009	0.9031 ± 0.0023
$p_T > 30$	0.9670 ± 0.0003	0.9537 ± 0.0005	0.9530 ± 0.0004	0.8992 ± 0.0011

Lepton selections

Electron selection

- p_T > 20 GeV; |eta| < 2.5
- VBTF90 (cuts tightened to match CaloId+TrkIdVL HLT requirements)
- d0 (PV) < 0.04 cm, dz (PV) < 1 cm --calculated w.r.t. 1st good DA PV
- no muon ΔR < 0.1
- <=1 miss hits, |dist| < 0.02 cm and < 0.02, CMS AN-2009-159
- Veto electrons with a supercluster in the transition region (1.44 <|eta| < 1.56)
- iso/p_T < 0.15 (EB pedestal subtraction 1 GeV, no fastjet correction)
- ecaliso/p_T < 0.2

Muon selection

- p_T > 20 GeV; |eta| < 2.4
- global and tracker muon
- chi^2/ndf < 10
- nValidHits > 10 -- to be updated to frac of validHits
- valid StandAloneHits > 0
- d0 (PV) < 0.02 cm, dz (PV) < 1 cm --calculated w.r.t. 1st good DA PV
- (p_T)/p_T < 0.1
- iso/p_T < 0.15 (no fastjet correction)

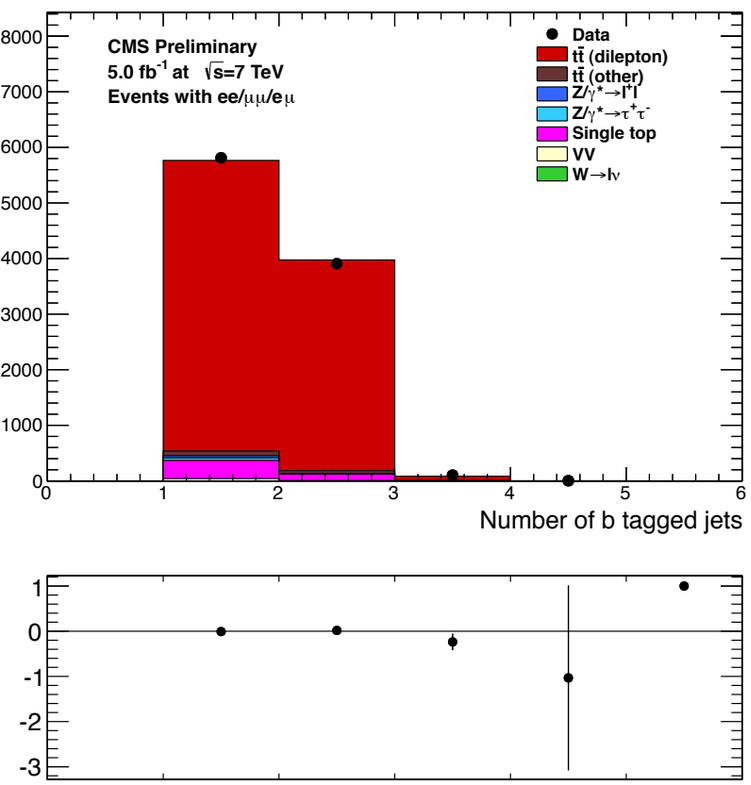
Preselection Yields (5.0 fb^{-1})

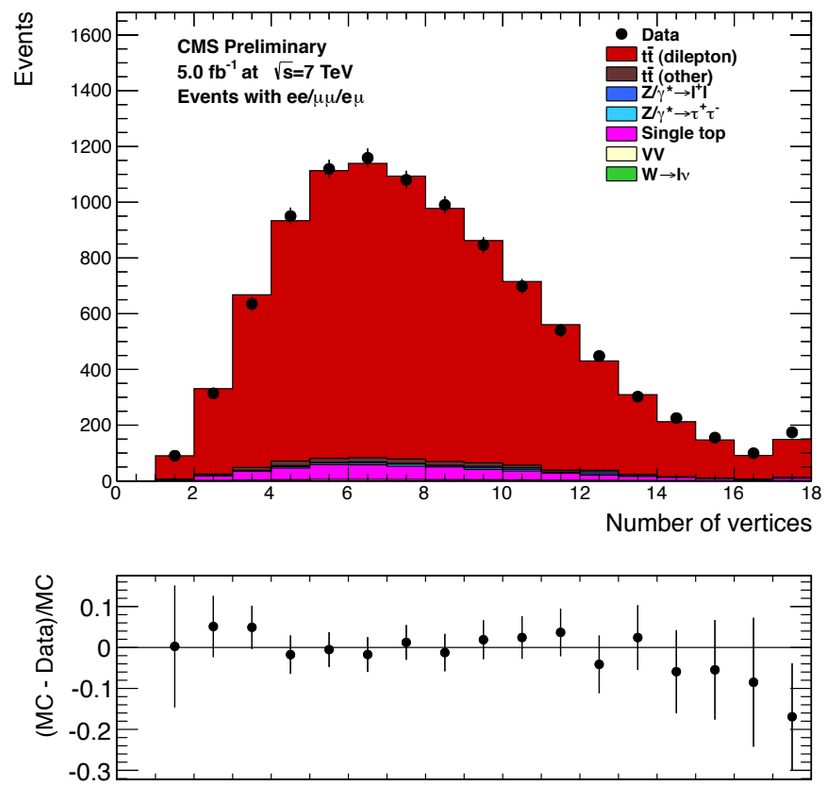
Sample	ee	$\mu\mu$	eμ	all
ttdil	1535.60 ± 9.82	1813.86 ± 10.31	5747.85 ± 18.69	9097.31 ± 23.50
ttotr	39.74 ± 1.63	4.06 ± 0.46	93.09 ± 2.41	136.88 ± 2.94
wjets	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
DYee	16.85 ± 3.28	0.00 ± 0.00	0.00 ± 0.00	16.85 ± 3.28
DYmm	0.00 ± 0.00	22.96 ± 3.66	3.80 ± 1.60	26.76 ± 3.99
DYtautau	13.35 ± 2.92	6.59 ± 1.94	31.22 ± 4.21	51.16 ± 5.48
VV	8.27 ± 0.44	10.20 ± 0.47	27.90 ± 0.81	46.37 ± 1.03
tw	72.54 ± 2.11	86.77 ± 2.23	289.37 ± 4.20	448.68 ± 5.20
Total MC	1686.35 ± 11.10	1944.43 ± 11.35	6193.23 ± 19.84	9824.00 ± 25.41
Data	1631.00 ± 40.39	1964.00 ± 44.32	6229.00 ± 78.92	9824.00 ± 99.12

Uncertainties are statistical only

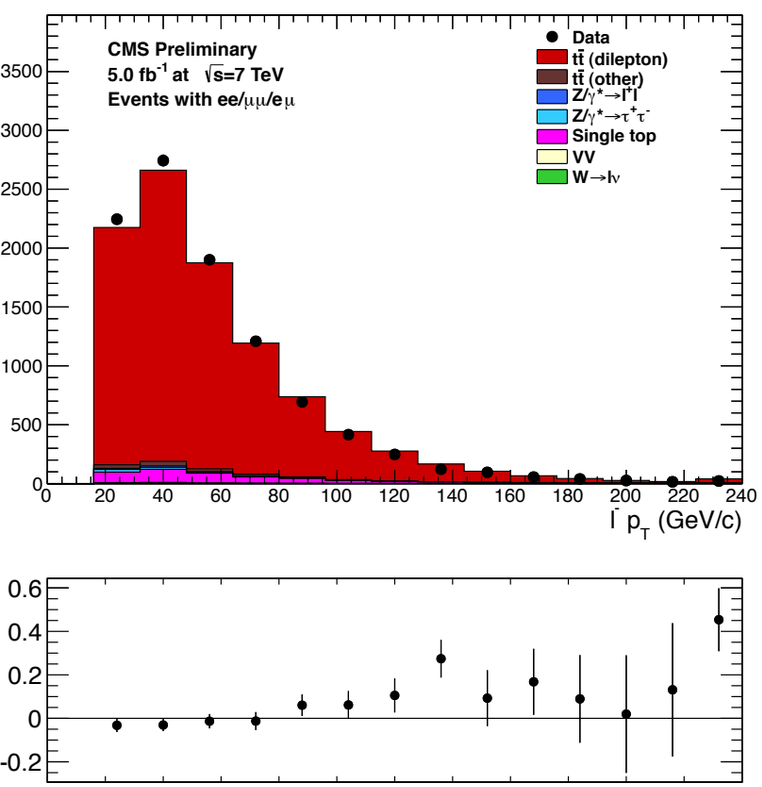
- MC events are weighted to match trigger efficiency, b tagging efficiency, and number of vertices distribution in data
- We use MC@NLO for the $t\bar{t}$ component
  - normalized so that total MC yield matches data
  - $t\bar{t} \to \ell^+\ell^-$ contributes 92% of the total yield
- Comparison plots on next slide

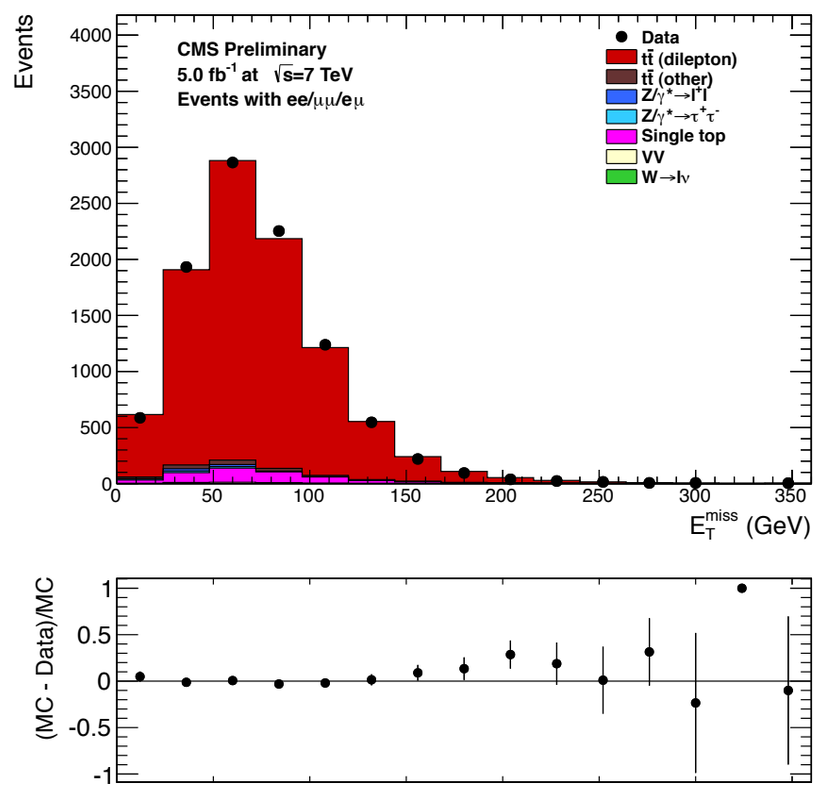
Data-MC comparison

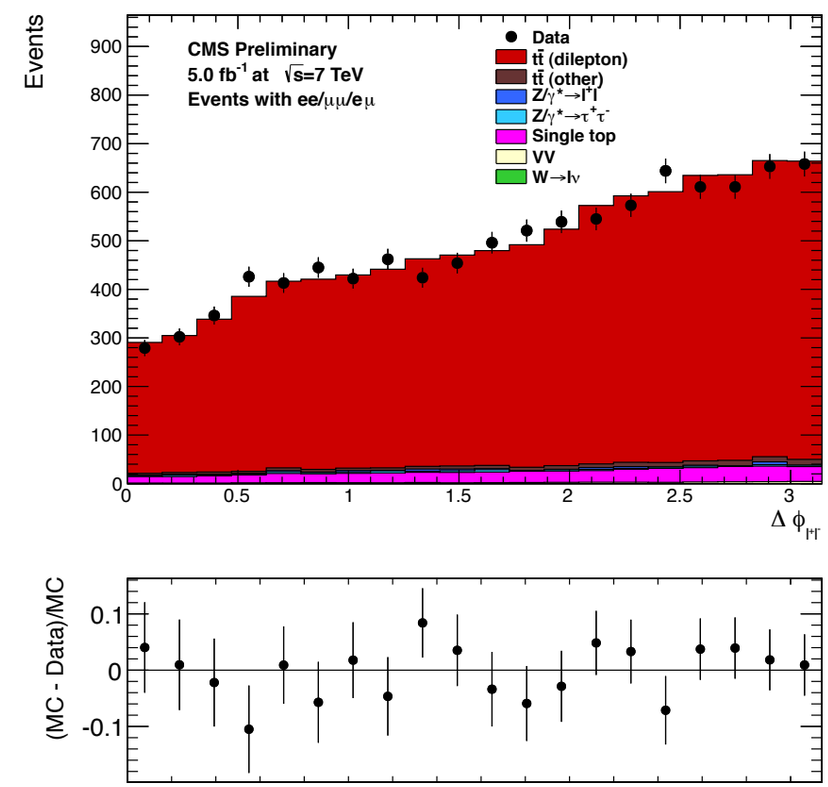




- Vertex reweighting has been applied to MC
- Selected plots: #btag jets, #vertices, MET, lepton p_T, Δphi_{ll}
- Data and MC agreement is reasonable







Background estimation

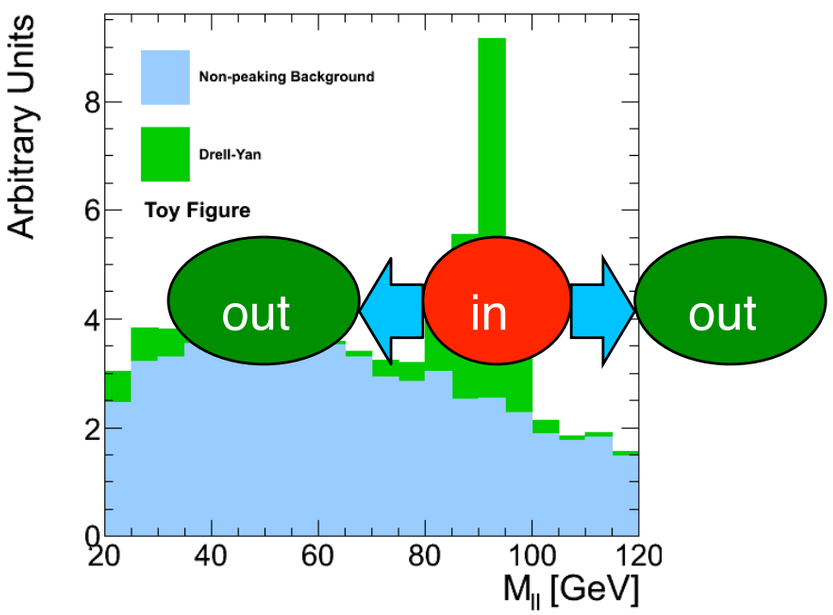
- We use the MC from the previous slides to estimate the background
- We make cross-checks for the DY and fake components using data-driven methods, and find reasonable agreement
- We then assign an appropriate background normalization systematic

Data-driven BG estimates: DY

- Estimate ee and μμ Drell-Yan using the method in CMS AN-2009-023:

  $R_{out/in}$ method

- Use data in Z peak to predict DY yields in the signal region by propagating via the MC ratio out/in-peak



$$N_{out}^{\ell\ell,exp} = R_{out/in}^{\ell\ell}(N_{in}^{\ell\ell} - N_{in}^{non-Z})$$

Z-peak to signal region ratio from MC, verified in data

opposite-flavor events in Z peak

same-flavor events in Z peak

- Estimate for pre-selection region: 142.4 ± 15.0 (stat+syst) events
  - consistent with MC prediction of 126.7 ± 8.7 events
- Estimate for Signal Region I: 47.6 ± 10.6 (stat+syst) events
  - consistent with MC prediction of 39.9 ± 4.8 events
- Estimate for Signal Region II: 10.8 ± 6.0 (stat+syst) events
  - consistent with MC prediction of 9.5 ± 2.4 events

Data-driven BG estimates: Fakes

- Estimate contribution from fake leptons using the data-driven tight-to-loose method described in CMS AN-2010/257
  - measure tight-to-loose fake rates as a function of lepton P_T and eta
  - estimate number of fakes in data based on number of fakeable object (FOs). Weight each lepton+FO event by:
  - use MC to account for signal contamination in the FO sample
  - fake background primarily from ttbar- decaying to lepton+jets

$$\varepsilon_{fake}(p_T,\eta) = \frac{N_{pass\ tight}(p_T,\eta)}{N_{loose}(p_T,\eta)}$$

$$w_i = \frac{\epsilon_{\rm fake}(p_{\rm Ti},\eta_i)}{1-\epsilon_{\rm fake}(p_{\rm Ti},\eta_i)}$$

- Estimate for pre-selection region: 138^{+281}_{-138} (stat+syst) events
  - consistent with MC prediction 100.1 ± 6.7 events
- Estimate for Signal Region I: $41.7^{+108.8}_{-41.7}$ (stat+syst) events
  - consistent with MC prediction of 47.1 ± 5.4 events
- Estimate for signal region: $6.6^{+16.4}_{-6.6}$ (stat+syst) events
  - consistent with MC prediction of 8.2 ± 2.5 events

Reconstruction of Top kinematics

- Each $t\bar{t} \to \ell^+\ell^-$ event has 2 neutrinos.
- also ambiguity in combining b-jets and leptons from same top
- It is a challenge to reconstruct top mass
- We use the analytical matrix weighting technique (AMWT) described in http://arxiv.org/abs/arXiv:1105.5661

Unfolding I

- Selection cuts and detector response are modelled by the acceptance (A) and smearing (S) matrices

- Given a true binned distribution x_i we observe b_k in our detector (after background subtraction):

$$b_k = S_{kj} A_{ji} x_i$$

Inversion:

$$x = A^{-1} S^{-1} b$$

S – migration matrix, A – acceptance matrix.

A is diagonal, S has off-diagonal elements due to migration from one bin to another

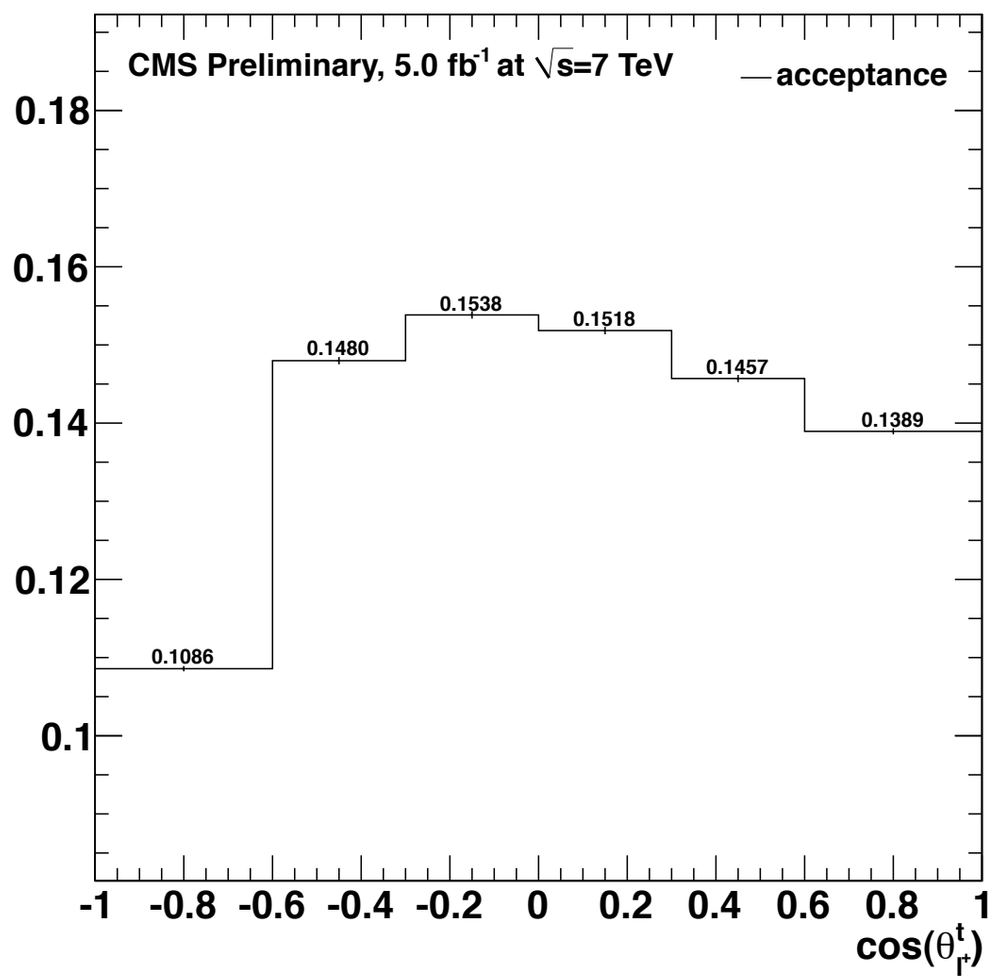
- We use regularized unfolding based on Singular Value Decomposition (SVD)
  - implemented in ROOT compatible package RooUnfold
  - SVD approach to data unfolding (Hocker and Kartvelishvili hep-ph/9509307)

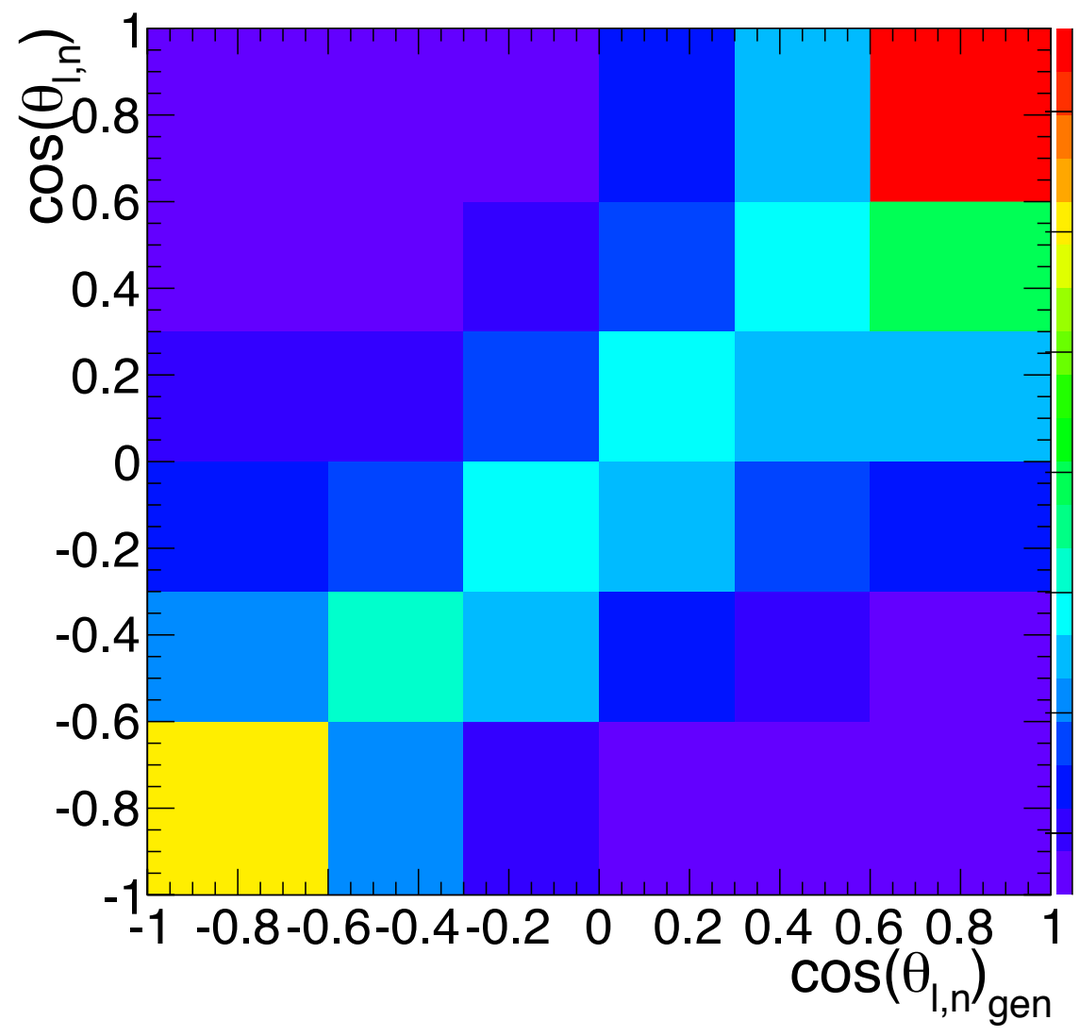
Unfolding II

- Performed extensive tests using pseudo-experiments to ensure proper performance of the unfolding algorithm
- We use 6 bins for unfolding:

B1	B2	B3	B4	B5	B6
[-1.0,-0.6]	[-0.6,-0.3]	[-0.3,-0.0]	[0.0, 0.3]	[0.3, 0.6]	[0.6, 1.0]

- Acceptance matrix and smearing matrix bins:





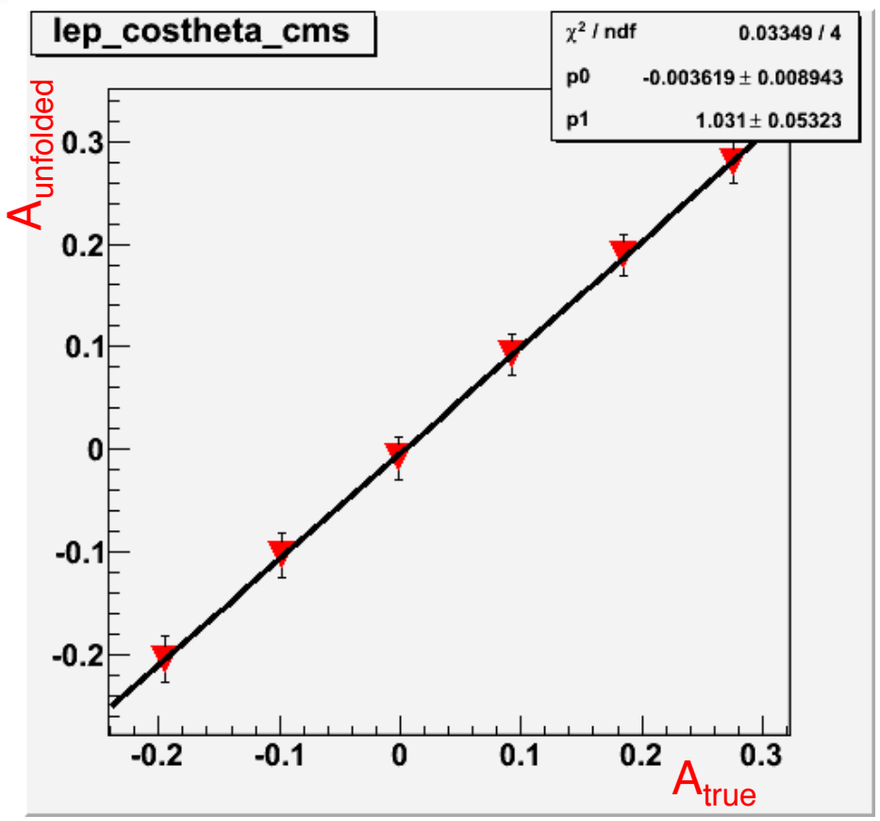
Unfolding: linearity check I

- start from ttbar in the pre-selection region
- most of our variables have no asymmetry for top
- introduce artificial asymmetry by reweighting events based on generator level quantity, for example:
  - if we are measuring Afb($|\eta_{l+}| - |\eta_{l-}|$) then reweight events as:

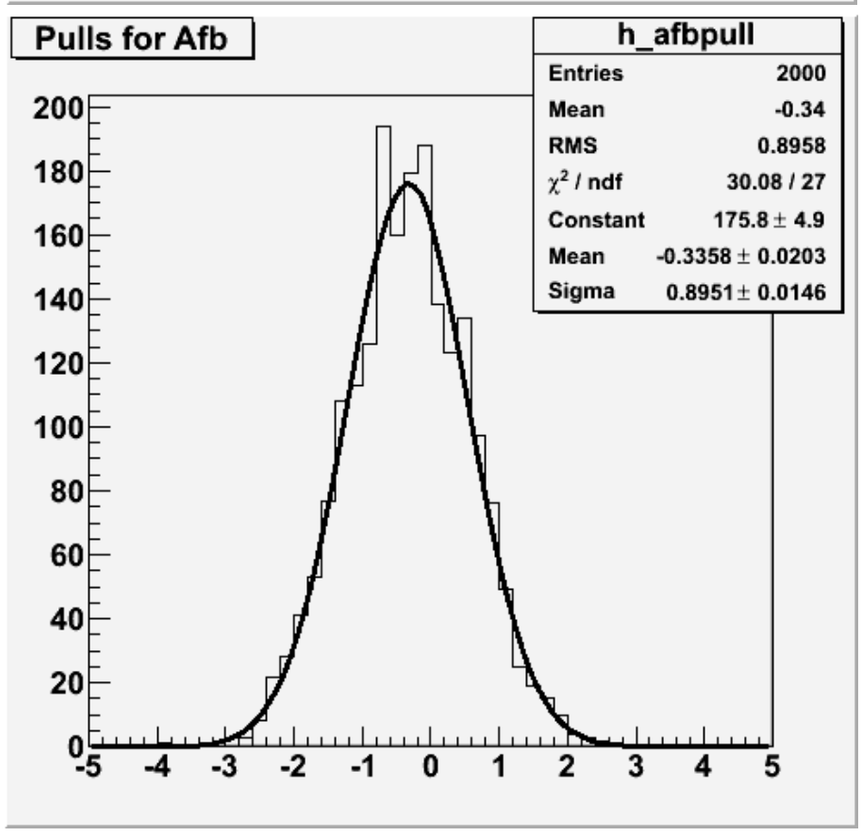
    weight=$1+K((|\eta_{l+}| - |\eta_{l-}|))$
  - vary K from -0.5 to 0.5 with 0.2 steps
  - covers much larger Afb range than expected from new physics

- Generate pseudo-experiments by fluctuating reweighted distribution, unfold every time
- 2000 pseudo-experiments
- Compare average to the true value

Unfolding: linearity check II (ICHEP)



True	Measured	Unfolded
-0.19 +-0.011	-0.036+-0.011	-0.20+-0.022
-0.097+-0.011	0.02+-0.012	-0.10+-0.021
-0.002+-0.011	0.076+-0.011	-0.008+-0.021
0.092+-0.011	0.13+-0.011	0.092+-0.021
0.18+-0.011	0.18+-0.011	0.19+-0.02
0.28+-0.011	0.24+-0.011	0.28+-0.02



- Small Bias in the mean: assign systematic uncertainty
- Slight over-estimation of the uncertainty (we don't correct this)

ICHEP Systematics

- Systematics are evaluated on the unfolded result

Table 6: Systematic uncertainties.

JES	BG	modeling	unfolding	top mass	$b-$tagging	Trigg(lep ID)	PU	Total
0.043	0.009	0.014	0.009	0.019	0.001	0.000	0.002	0.050

- JES is the dominant systematic

matching: 0.004

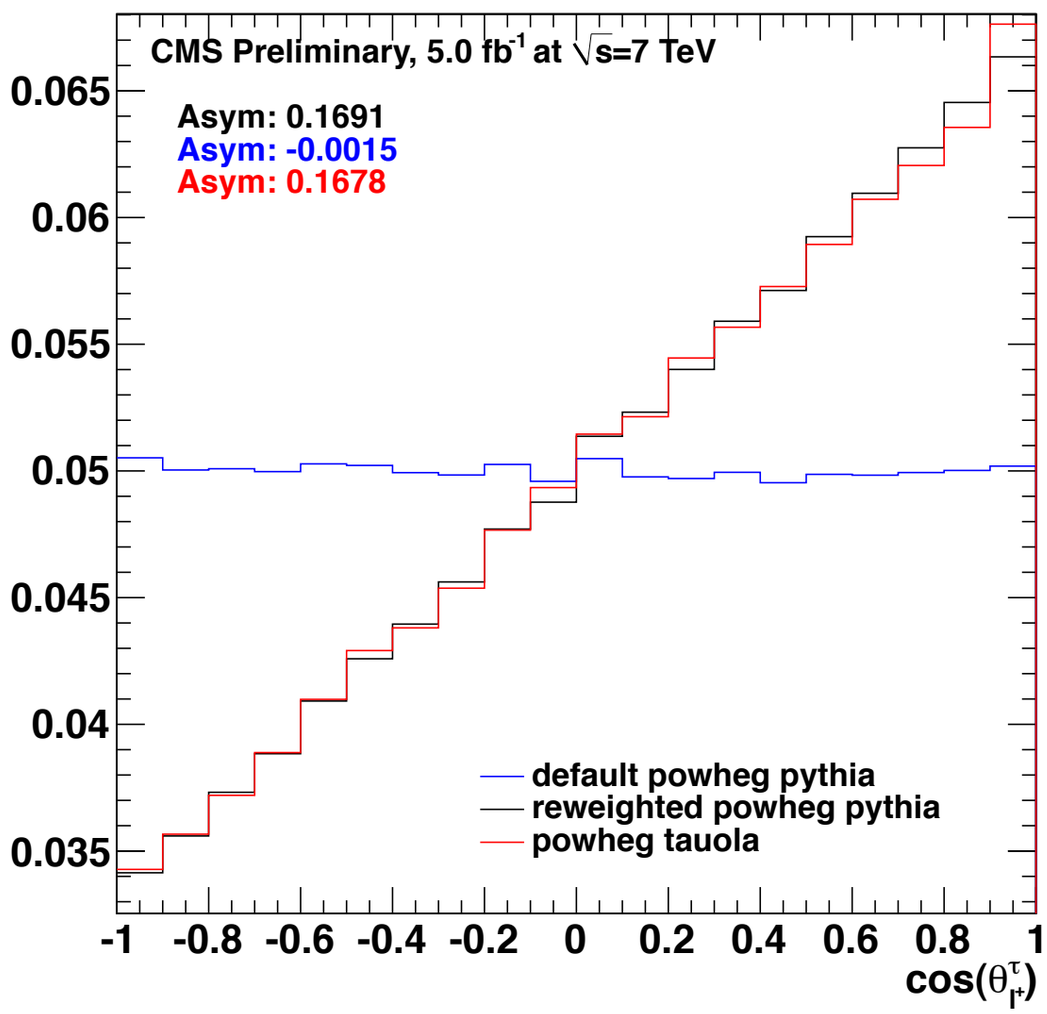
  - calculated assuming a 7.5% uncertainty on the hadronic energy scale (after L1FastL2L3 correction)
  - this directly affects the shape of the $\cos\theta_{\ell,n}$ distribution
- For BG we vary normalizations by 100% (DY and fakes) or 50% (for the single top background, which is dominant)
- Most other systematics assessed by varying the model used to calculate the unfolding (i.e. changing A and S matrices)
  - PU and b-tagging and trig/lep ID eff from reweighting powheg MC
  - modeling, matching, top mass from MC@NLO and madgraph MC
- Small unfolding bias (0.9%) also gives a systematic

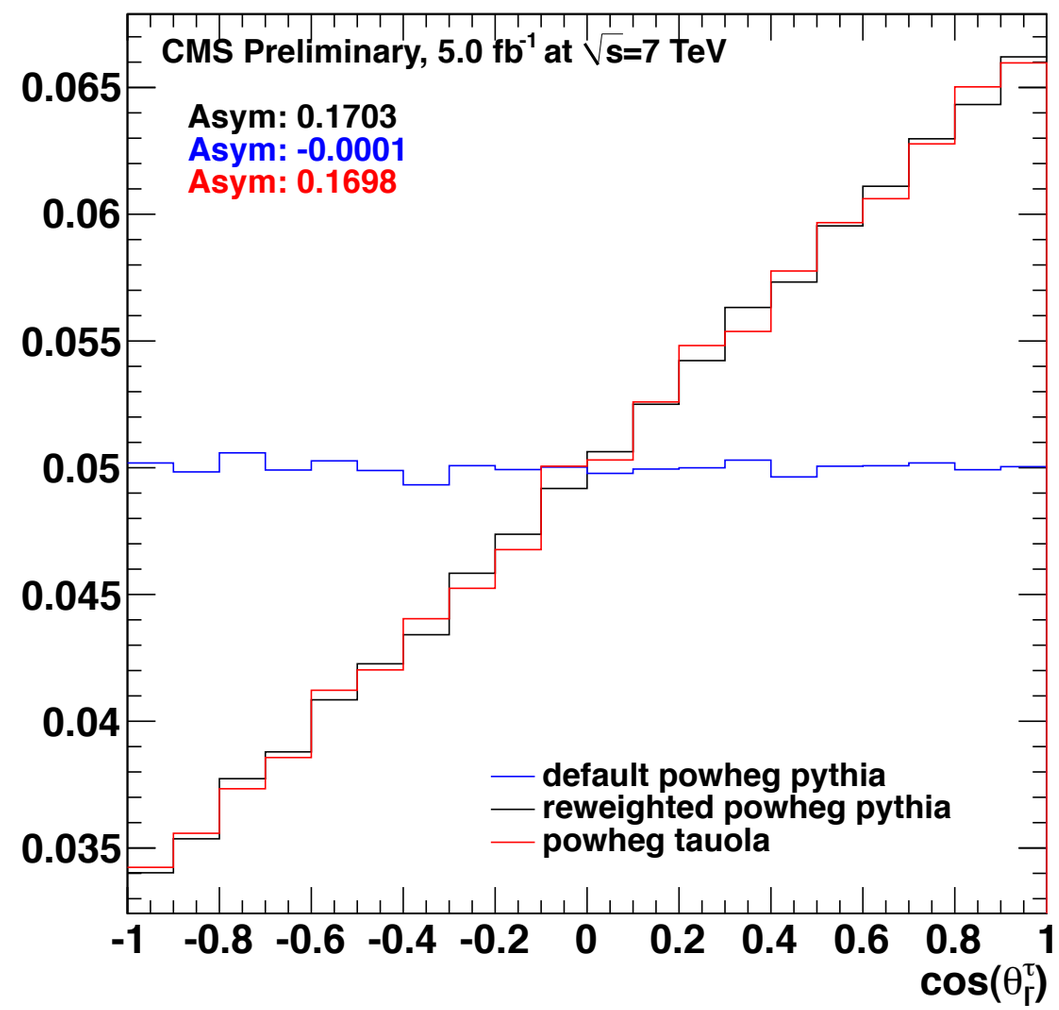
tau decay reweighting

- Try reweighting angular distribution of tau decays to reproduce tauola distribution
- Distribution is given by $\frac{d\Gamma(l^{\pm})}{d\Omega dx} = \frac{G^2 m_l^5}{192\pi^4} x^2 \{3(1-x) + \frac{2}{3}\rho(4x-3) + 6\eta \frac{m_e}{m_l}\frac{1-x}{x} \pm \xi P_l \cos\theta[1-x+\frac{2}{3}\delta(4x-3)]\}$
- Weight events by 1 + (P Cosθ (2 *x* - 1))/(3 - 2 *x*) where *x* = (lepton momentum)/(max possible lepton momentum) and θ = (angle of daughter lepton in tau rest frame)

TTTo2L2Nu2B_7TeV-powheg-pythia6

TT_TuneZ2_7TeV-powheg-tauola





- Powheg pythia distribution looks like powheg-tauola distribution after reweighting

Results (weighted vs unweighted powheg-pythia)

- Now evaluate systematic by unfolding using the reweighted powheg-pythia MC, and comparing to the default

	powheg-pythia results (same as in PAS)	**reweighted powheg-pythia results**	**difference**
$\mathcal{A}^{\ell\ell}_{\Delta\phi} = \frac{N(\cos\Delta\phi_{\ell\ell} > 0) - N(\cos\Delta\phi_{\ell\ell} < 0)}{N(\cos\Delta\phi_{\ell\ell} > 0) + N(\cos\Delta\phi_{\ell\ell} < 0)}$	-0.097	-0.097	0.0004
$\mathcal{P}^{+}_{n} = \frac{N(\cos\theta_{\ell,n} > 0) - N(\cos\theta_{\ell,n} < 0))}{N(\cos\theta_{\ell,n} > 0) + N(\cos\theta_{\ell,n} < 0))}$	-0.035	-0.033	0.0019
$\mathcal{P}^{-}_{n} = \frac{N(\cos\theta_{\ell,n} > 0) - N(\cos\theta_{\ell,n} < 0))}{N(\cos\theta_{\ell,n} > 0) + N(\cos\theta_{\ell,n} < 0))}$	0.019	0.021	0.0023
$\mathcal{A}^{\ell}_{c_1c_2} = \frac{N(c_1c_2 > 0) - N(c_1c_2 < 0))}{N(c_1c_2 > 0) + N(c_1c_2 < 0))}$	-0.015	-0.015	-0.0007
$A_{lepC} = \frac{N(\lvert\eta_{l^+}\rvert > \lvert\eta_{l^-}\rvert) - N(\lvert\eta_{l^+}\rvert < \lvert\eta_{l^-}\rvert)}{N(\lvert\eta_{l^+}\rvert > \lvert\eta_{l^-}\rvert) + N(\lvert\eta_{l^+}\rvert < \lvert\eta_{l^-}\rvert)}$	0.010	0.010	-0.0000
$A_{topFB} = \frac{N(\cos(\theta_t) > 0) - N(\cos(\theta_t) < 0)}{N(\cos(\theta_t) > 0) + N(\cos(\theta_t) < 0)}$	-0.011	-0.011	0.0000

- Results show much smaller systematic shifts than powheg-tauola vs powheg pythia (next slide)
  - the largest shift is still seen in top polarisation, and again consistent results are seen between + and - leptons
  - also tried simple reweighting (ignoring *x* dependence), just 1 + (P Cosθ)/3 , and found similar results

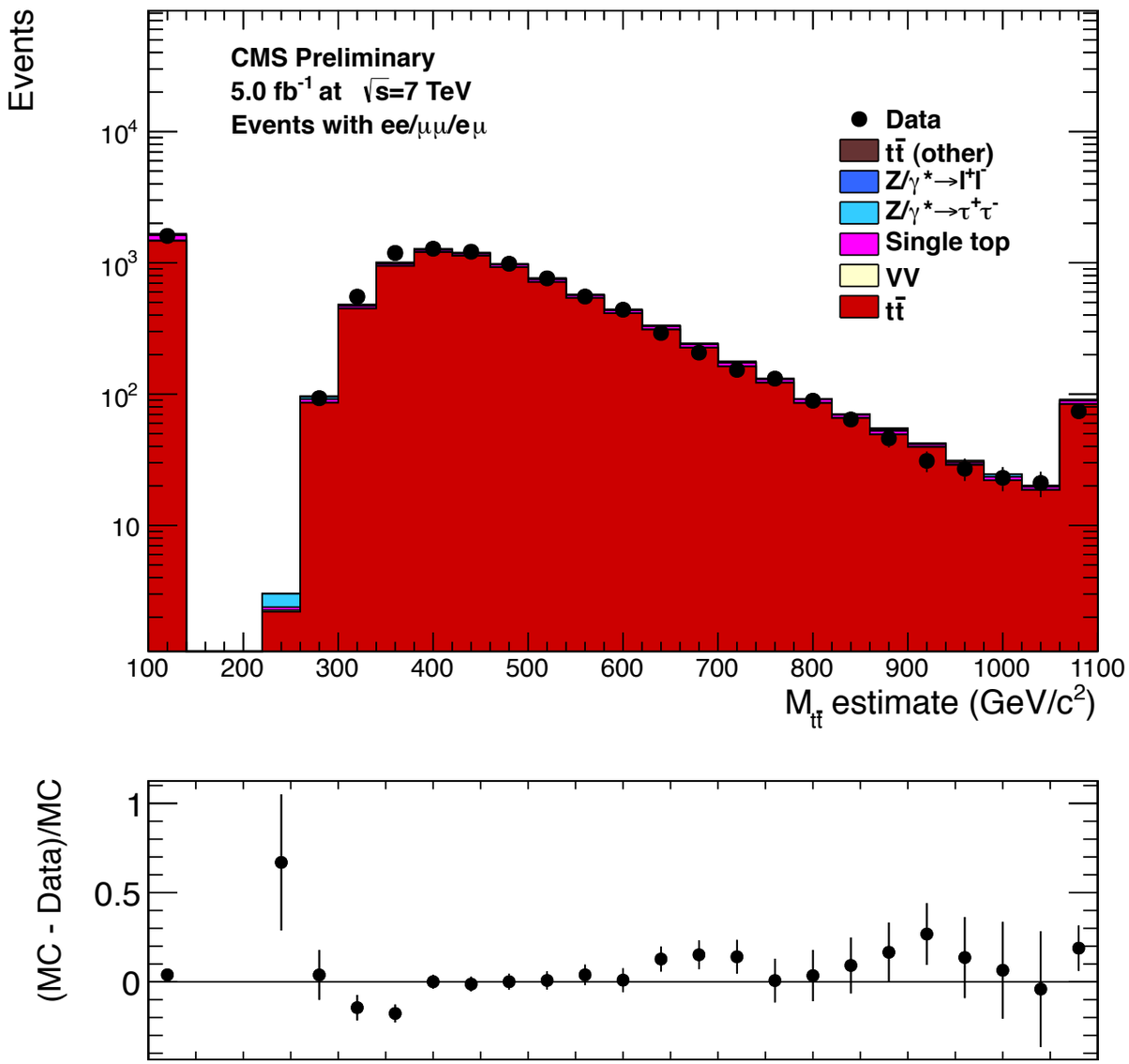
Results (powheg-tauola vs powheg-pythia)

	powheg-pythia results (same as in PAS)	powheg-tauola results	difference
$\mathcal{A}^{\ell\ell}_{\Delta\phi} = \frac{N(\cos\Delta\phi_{\ell\ell} > 0) - N(\cos\Delta\phi_{\ell\ell} < 0)}{N(\cos\Delta\phi_{\ell\ell} > 0) + N(\cos\Delta\phi_{\ell\ell} < 0)}$	-0.097	-0.094	0.0037
$\mathcal{P}^{+}_{n} = \frac{N(\cos\theta_{\ell,n} > 0) - N(\cos\theta_{\ell,n} < 0))}{N(\cos\theta_{\ell,n} > 0) + N(\cos\theta_{\ell,n} < 0))}$	-0.035	-0.024	0.0105
$\mathcal{P}^{-}_{n} = \frac{N(\cos\theta_{\ell,n} > 0) - N(\cos\theta_{\ell,n} < 0))}{N(\cos\theta_{\ell,n} > 0) + N(\cos\theta_{\ell,n} < 0))}$	0.019	0.034	0.0148
$\mathcal{A}^{\ell}_{c_1c_2} = \frac{N(c_1c_2 > 0) - N(c_1c_2 < 0))}{N(c_1c_2 > 0) + N(c_1c_2 < 0))}$	-0.015	-0.008	0.0070
$A_{lepC} = \frac{N(\lvert\eta_{l^+}\rvert > \lvert\eta_{l^-}\rvert) - N(\lvert\eta_{l^+}\rvert < \lvert\eta_{l^-}\rvert)}{N(\lvert\eta_{l^+}\rvert > \lvert\eta_{l^-}\rvert) + N(\lvert\eta_{l^+}\rvert < \lvert\eta_{l^-}\rvert)}$	0.010	0.010	0.0002
$A_{topFB} = \frac{N(\cos(\theta_t) > 0) - N(\cos(\theta_t) < 0)}{N(\cos(\theta_t) > 0) + N(\cos(\theta_t) < 0)}$	-0.011	-0.017	-0.0063

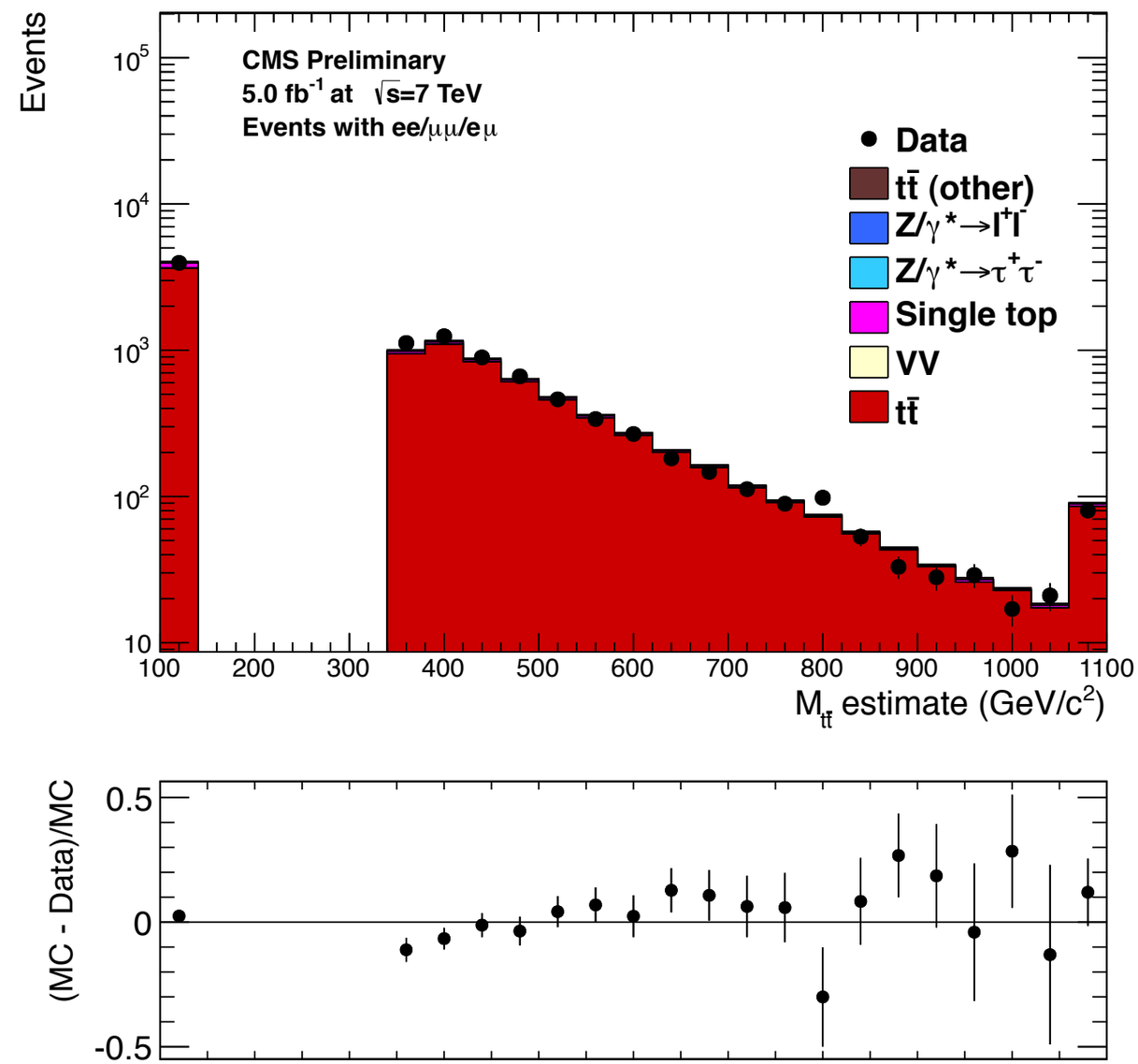
- Biggest shift seen in top polarisation
- P^+ and P^- are two independent measures of the top polarisation, using positive and negative leptons
  - consistent shifts suggests systematic = ~0.013

M_{ttbar}, no jet smearing

Original M_t scan range (100 to 300 GeV)

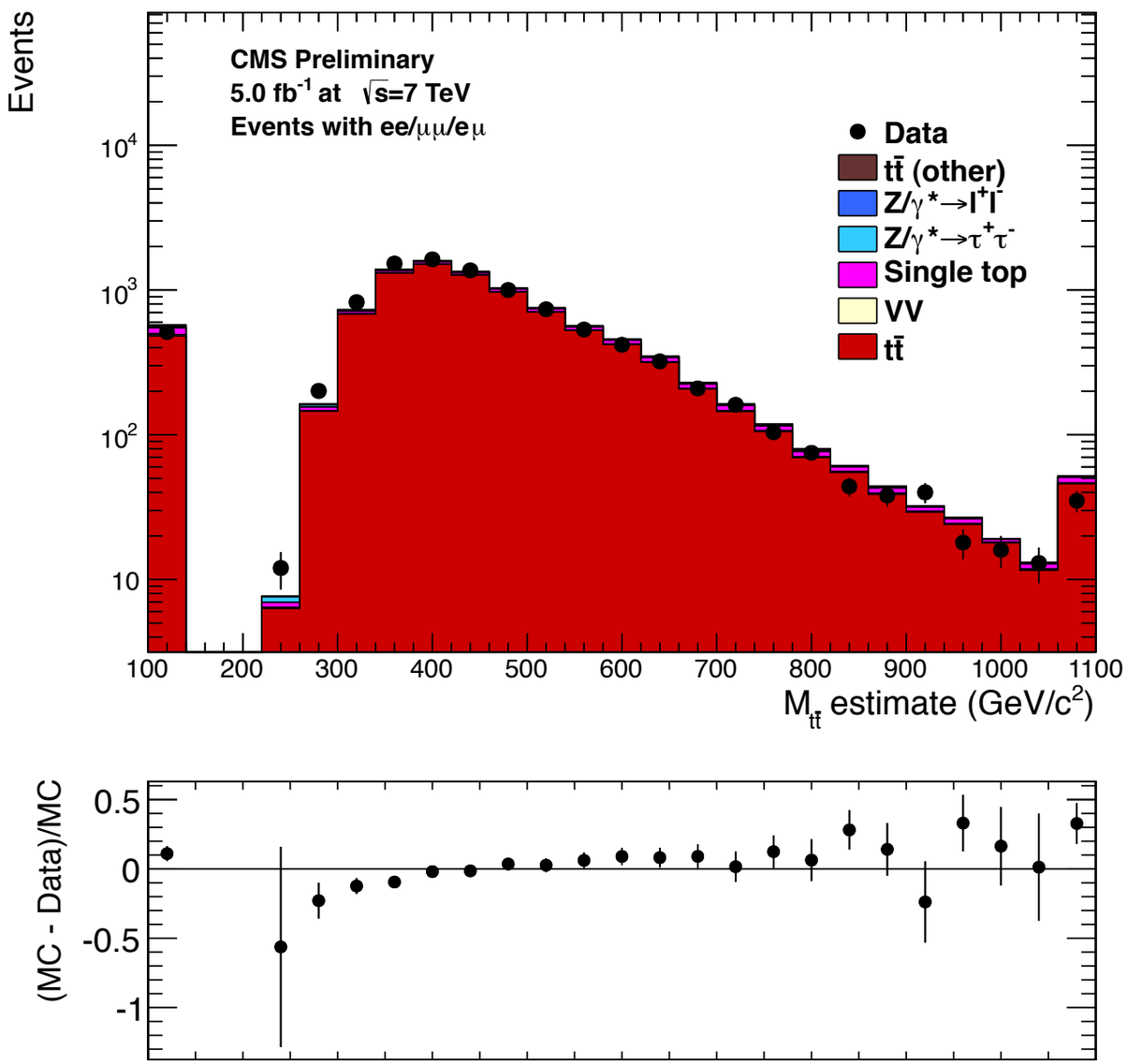


M_t fixed (172.5 GeV)

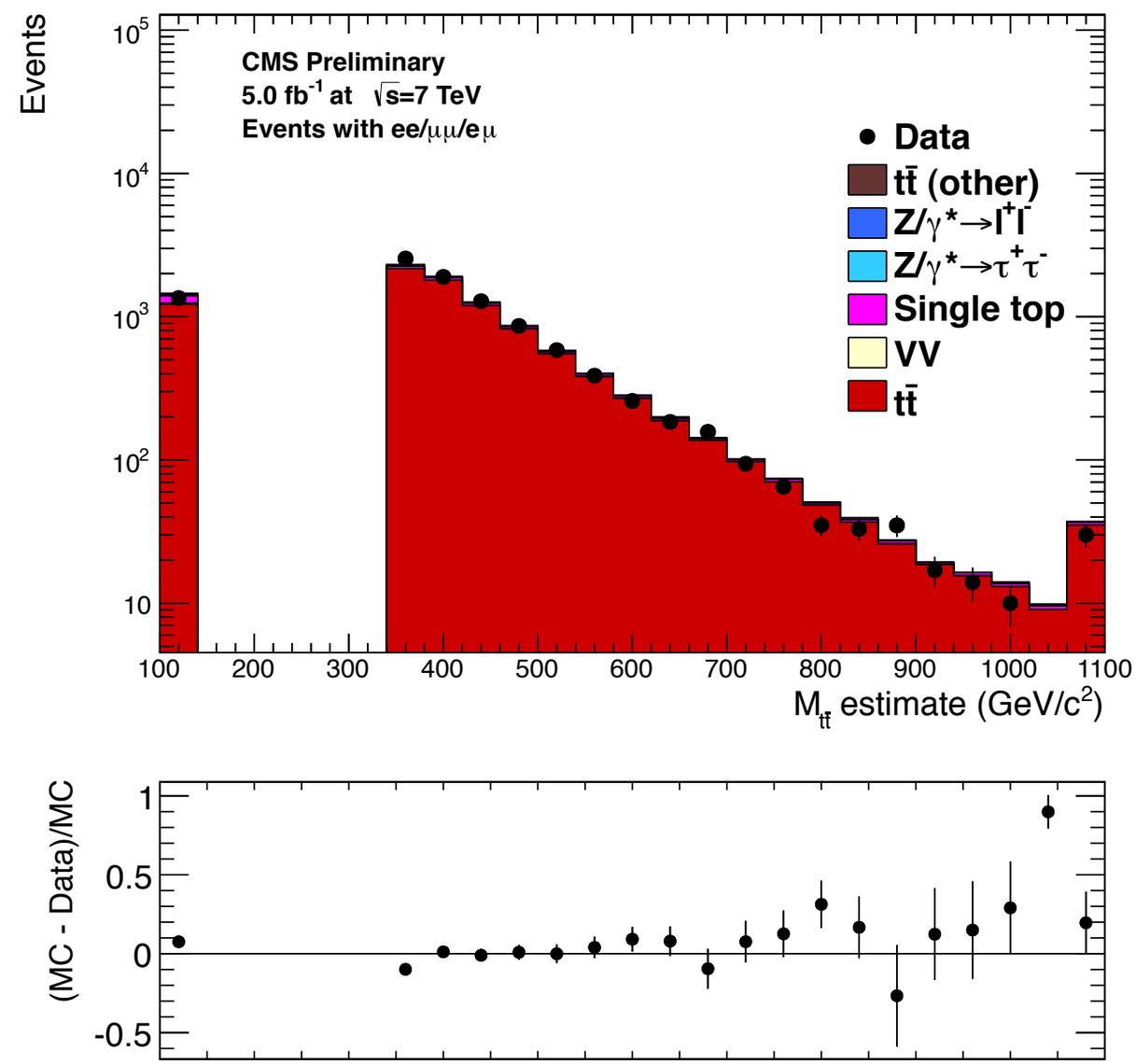


M_{ttbar}, original jet smearing

Original M_t scan range (100 to 300 GeV)

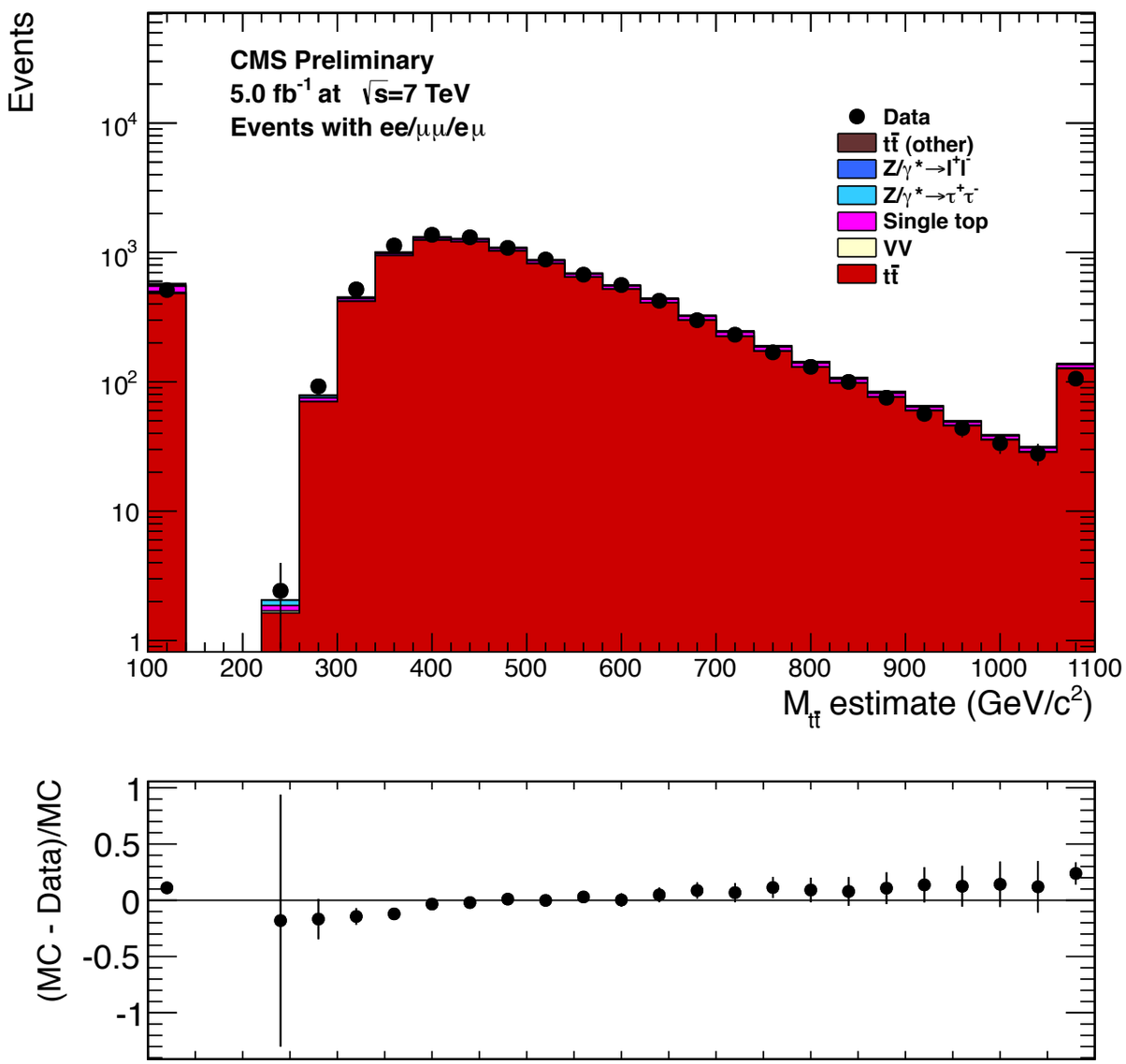


M_t fixed (172.5 GeV)

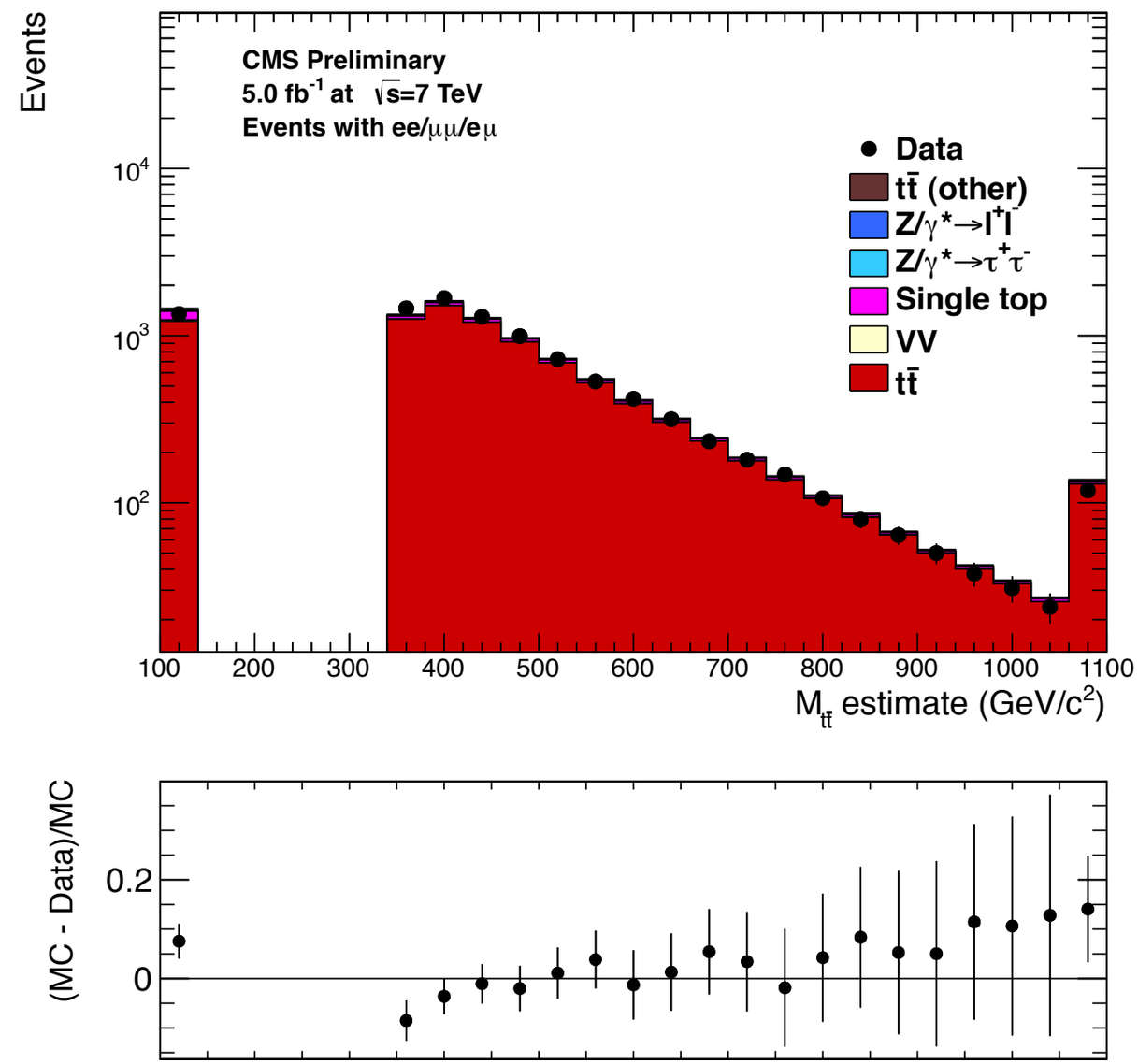


M_{ttbar}, fixed jet smearing

Original M_t scan range (100 to 300 GeV)



M_t fixed (172.5 GeV)



Previous presentations

Previous presentations by Yanjun Tu, Jacob Linacre and Sergo Jindariani in top properties group meetings:

https://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=180584

http://indico.cern.ch/getFile.py/access?contribId=8&sessionId=0&resId=0&materialId=slides&confId=180655

http://indico.cern.ch/getFile.py/access?contribId=1&resId=0&materialId=slides&confId=187624

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