Measurement of MET, HT and other global distributions in top pair events

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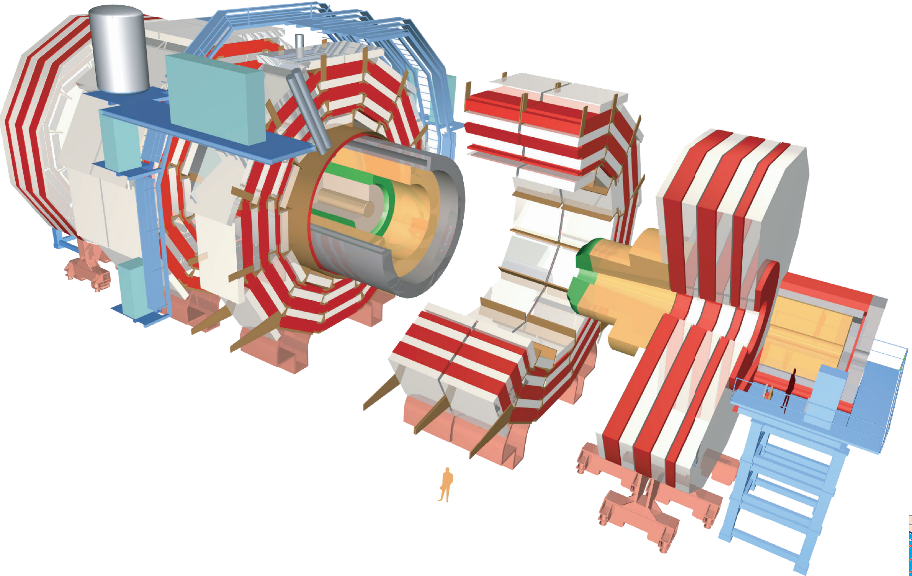
Outline

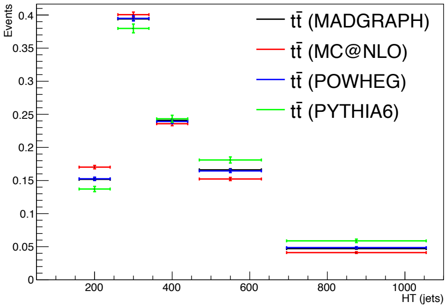
CMS detector



Motivation

- $t\bar{t}$+MET (or $E_{\mathrm{T}}^{\mathrm{miss}}$) is an important background to many BSM processes (including heavy top partner decays)
- Probing rare SM processes with *additional* $E_{\mathrm{T}}^{\mathrm{miss}}$: $t\bar{t} + Z$ and $t\bar{t} + W$
- New physics: $t\bar{t} + X$ where X is invisible

- Expanding on this to include other global variables that are also used in BSM searches
- Will look at how they discriminate between different generators
- MC studies suggest HT/ST to have better discriminating power than MET



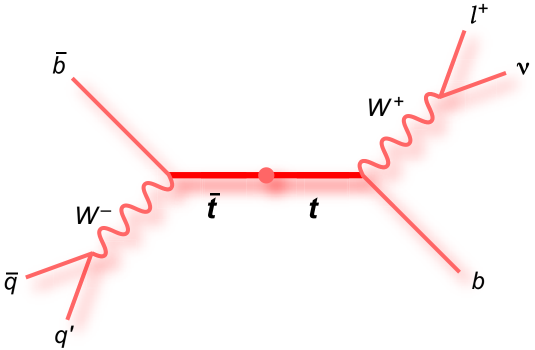
HT with different generators

Analysis Strategy

- Select *e*- and μ+jets events *based* on reference selection of $t\bar{t}$ pairs
- Divide the selected events into subsamples (bins of measured $E_{\mathrm{T}}^{\mathrm{miss}}$, HT, ST)
- Perform template fits in lepton $|\eta|$ in each subsample to estimate its composition (signal+various background processes)
- Apply bin-by-bin corrections (2011) or perform SVD unfolding (2012) to take into account detector effects
- Calculate the normalised differential cross section in each bin: $\frac{1}{\sigma_{\mathrm{t\bar{t}}}} \frac{\mathrm{d}\sigma_{\mathrm{t\bar{t}}}}{\mathrm{d}X}$

Event Signature and Selection

- We study the semi-leptonic $t\bar{t}$ decay (e+jets and μ+jets):



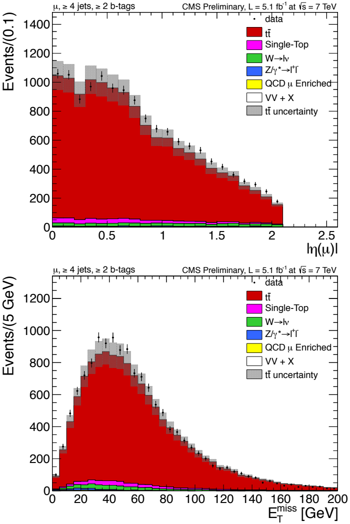
- Exactly one isolated high-pt lepton
- At least 4 energetic jets
- At least two of the jets have to be b-tagged

Backgrounds

- Most significant backgrounds
  - W+jets (MC)
  - QCD (data-driven)
- Other backgrounds estimated from MC
  - Z+jets
  - Single top
- QCD is data-driven in both channels
  - **Conversion region** is used in the electron channel
    - ⋆ full event selection with inverted conversion veto
  - **Non-isolated region** is used in the muon channel
    - ⋆ Inverted muon isolation requirement and reduced jet multiplicity

Data-MC comparison (2011)

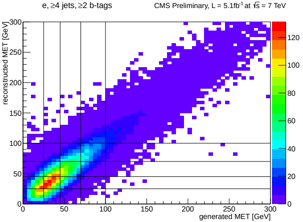
Kinematic variable distributions after all cuts



Top: lepton $|\eta_\ell|$; bottom: $E_{\mathrm{T}}^{\mathrm{miss}}$; left: μ+jets; right: e+jets

Choice of E_T^{miss} bins

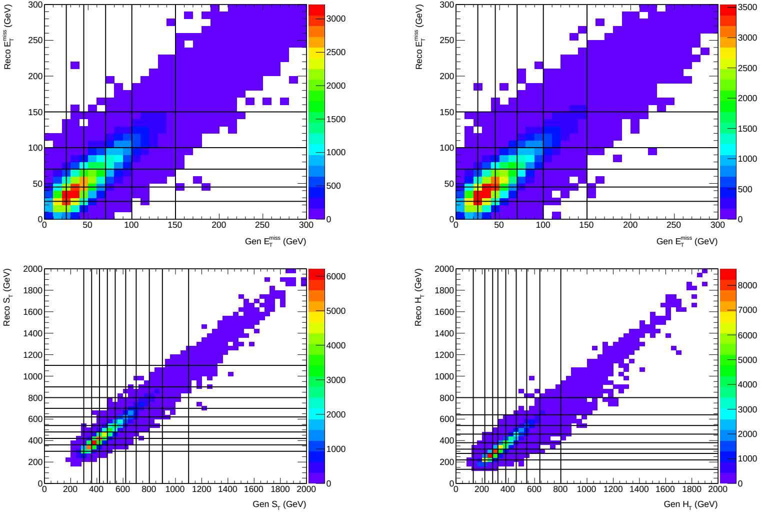
- The binning of the E_T^{miss} variable is chosen as to minimise migration between neighbouring bins and to keep reasonable statistics in each bin
- Migration is measured using bin purity (p^k) and stability (s^k):
  - $p^k = \frac{N^k_{rec\&gen}}{N^k_{rec}}$ (sensitive to migration into bin)
  - $s^k = \frac{N^k_{rec\&gen}}{N^k_{gen}}$ (sensitive to migration out of bin)



- The plot shows generated E_T^{miss} vs reconstructed E_T^{miss}(e+jets channel), used to calculate p^k and s^k
- The table lists the E_T^{miss} bins chosen and the values of p^k and s^k observed

Bin optimization											
	Bin	$0< E_T^{miss} <25$		$25\leq E_T^{miss} <45$		$45\leq E_T^{miss} <70$		$70\leq E_T^{miss} <100$		$100\leq E_T^{miss}$	
		μ	e	μ	e	μ	e	μ	e	μ	e
$\geq$ 4 jets	events	1852	2292	3343	3765	3515	3947	2029	2573	1433	2210
	purity	0.58	0.60	0.52	0.51	0.52	0.46	0.52	0.44	0.80	0.72
	stability	0.51	0.48	0.49	0.44	0.55	0.50	0.58	0.54	0.81	0.88

Binning choice in 2012



top: $E_{\mathrm{T}}^{\mathrm{miss}}$, left: e+jets, right: μ+jets;
bottom left: ST (μ+jets), right: HT (μ+jets)

Method - fit procedure

- Cross section $\frac{\mathrm{d}\sigma_{\mathrm{t\bar{t}}}}{\mathrm{d}E_{\mathrm{T}}^{\mathrm{miss}}}$ is measured by means of a binned likelihood fit of the $|\eta_\ell|$ distribution using

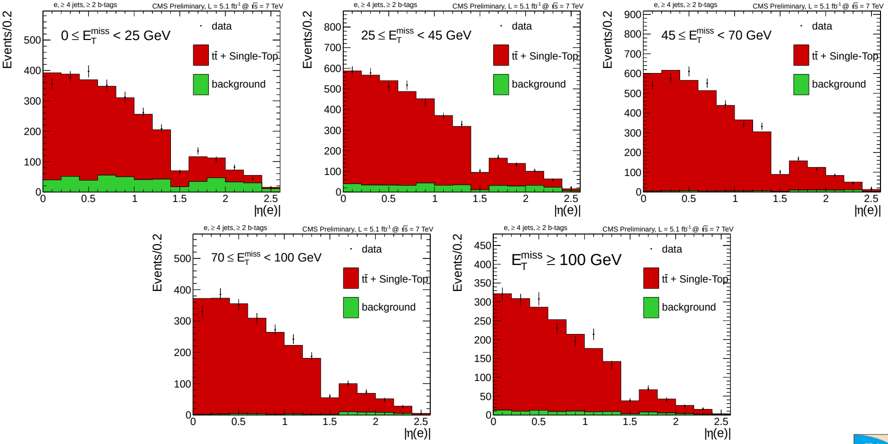
$$\mathrm{LL}(\{\lambda_i, d_i\}) = -2 \log \left(\prod_i \frac{\lambda_i^{d_i} \cdot e^{-\lambda_i}}{d_i!} \right) = -2 \sum_i \log \left(\frac{\lambda_i^{d_i} \cdot e^{-\lambda_i}}{d_i!} \right)$$

(λ_i (d_i) are the expected (observed) number of events in each bin i)

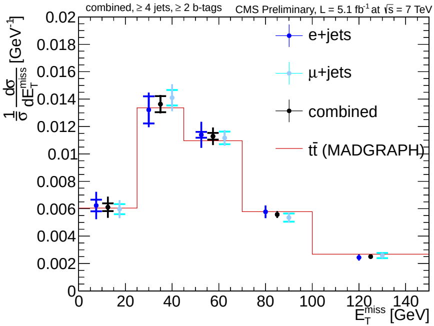
- Template fit is performed separately in each $E_{\mathrm{T}}^{\mathrm{miss}}$ bin

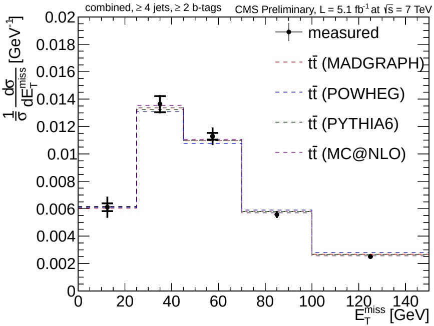
Fit results (e+jets, 2011)

Electron $|\eta|$ distributions after the template fit in order of increasing $E_{\mathrm{T}}^{\mathrm{miss}}$ bin



Combined results (2011)





- Comparison of normalised differential cross section results between two channels (left) and different generators (right) for the combination of both channels
- Good agreement is seen in all bins

Summary

- Presented the normalised $t\bar{t}$ differential cross section measurement for e+jets and μ+jets channels for 2011 data
- Combined the results from both channels
- Comparison between different Monte Carlo generators as well as different tunes was performed
- The results agree within errors with the Standard Model expectations
- 2012 data analysis is currently work in progress, including unfolding and additional variables
- Will top up to the full 2012 dataset and eventually go for a publication

Backup Slides

Event Selection

- following standard CMS $t\bar{t}$ reference selection
- Electron + jets channel
  - e+jets trigger (2011) or single electron trigger (2012)
  - electron $E_T > 30$ GeV, $|\eta| < 2.5$, ID cuts
  - Muon veto and Z veto (loose second electron veto)
  - Photon conversion rejection
  - jets: $p_T > 45/45/45/20$ GeV (2011) or $p_T > 30/30/30/30$ GeV (2012)
- Muon + jets
  - single muon trigger
  - muon $p_T > 26$ GeV
  - jets: $p_T > 30/30/30/30$ GeV
- Similar for both channels
  - b-tagging: ≥ 2 b-tagged jets
  - MET corrections include corrections for pile up, propagated jet energy corrections and systematic shift correction for phi modulation

Data and Simulation

- Collision data
  - 2011
    - ★ Using full 2011 ReReco dataset (Golden JSON)
    - ★ $\sim 5.1\ \text{fb}^{-1}$ @ $\sqrt{s} = 7$ TeV
    - ★ Iso electron ($E_T > 25$ GeV) + 3 (PF) jets ($p_T > 30$ GeV) trigger
    - ★ Iso muon ($p_T > 24$ GeV) and same trigger with $|\eta| < 2.1$
  - 2012
    - ★ Using Run A,B,C 2012 ReReco dataset (Golden JSON)
    - ★ $\sim 5.8\ \text{fb}^{-1}$ @ $\sqrt{s} = 8$ TeV
    - ★ Iso electron ($E_T > 27$ GeV) trigger, WP80 isolation
    - ★ Iso muon ($p_T > 24$ GeV) trigger with $|\eta| < 2.1$
- Monte Carlo
  - 7 TeV
    - ★ Using Fall11 MC for both channels (CMSSW 44X)
    - ★ Applying PU truth-reweighting (Fall11)
    - ★ b-tag scale factors are applied
  - 8 TeV
    - ★ Using Summer12 MC for both channels (CMSSW 53X)
    - ★ Applying PU truth-reweighting (Summer12)
    - ★ b-tag scale factors are applied

Event yields (2011)

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	Background processes							
	W+jets		Z+jets		QCD multijet		other	
	μ	e	μ	e	μ	e	μ	e
Trigger, preselection, skim	136273	115089	32947	34822	141680	728545	8702	7883
Exactly one isolated lepton	100175	99247	13499	21475	1942	75752	6551	6515
Four or more jets	19367	20869	2634	3914	*330*	*13863*	1684	1783
Two or more b tags	396$\pm$5	414$\pm$5	78$\pm$5	101$\pm$6	*27$\pm$27*	*669$\pm$145*	432$\pm$3	483$\pm$4

	Overall summary							
	$t\bar{t}$ signal Data		Background summed		MC Total		Data	
	μ	e	μ	e	μ	e	μ	e
Trigger, preselection, skim	71640	71185	183403	886339	391245	957526	448476	1121873
Exactly one isolated lepton	53481	57605	122167	202989	175614	260632	181471	253777
Four or more jets	29531	31268	24015	40459	53548	71700	53296	69669
Two or more b tags	12298$\pm$33	13426$\pm$34	933$\pm$40	1667$\pm$160	13231$\pm$44	15093$\pm$149	13816	14805

figures in italics are data-driven estimates of QCD

Data samples (2011)

Datasets used by run period with corresponding integrated luminosities (L_{int}) and run numbers:

Data set name	Run period	L_{int} / pb^{-1}	Runs
ElectronHad 08 Nov 2011 ReReco	Run2011A	2311	160404–173692
ElectronHad 19 Nov 2011	Run2011B	2739	175860–180252
SingleMu 08 Nov 2011 ReReco	Run2011A	2311	160404–173692
SingleMu 19 Nov 2011	Run2011B	2739	175860–180252

JSON file used: Cert_160404-180252_7TeV_ReRecoNov08_Collisions11_JSON.txt

Trigger requirements (2011)

- Muon triggers:
  - HLT_IsoMu24 for data taken with trigger menu upto "3e33"
  - HLT_IsoMu24_eta2p1 for "3e33" and later menus
- Electron triggers:
  - HLT_Ele25_CaloIdVT_TrkIdT_CentralTriJet30_v1 (run $\leq$ 161216)
  - HLT_Ele25_CaloIdVT_TrkIdT_CentralTriJet30_v2 (run $\leq$ 163269)
  - HLT_Ele25_CaloIdVT_TrkIdT_TriCentralJet30_v1 (run $\leq$ 165969)
  - HLT_Ele25_CaloIdVT_CaloIsoT_TrkIdT_TrkIsoT_TriCentralJet30_v1 (run $\leq$ 166967)
  - HLT_Ele25_CaloIdVT_CaloIsoT_TrkIdT_TrkIsoT_TriCentralJet30_v2 (run $\leq$ 167913)
  - HLT_Ele25_CaloIdVT_CaloIsoT_TrkIdT_TrkIsoT_TriCentralJet30_v4 (run $\leq$ 173235)
  - HLT_Ele25_CaloIdVT_CaloIsoT_TrkIdT_TrkIsoT_TriCentralJet30_v5 (run $\leq$ 178380)
  - HLT_Ele25_CaloIdVT_CaloIsoT_TrkIdT_TrkIsoT_TriCentralPFJet30_v2 (run $\leq$ 179889)
  - HLT_Ele25_CaloIdVT_CaloIsoT_TrkIdT_TrkIsoT_TriCentralPFJet30_v3 (run $\leq$ 180252)

Bin-by-bin corrections (2011)

- Naturally, not all $t\bar{t}$ events can be selected using signal selection
- Need to account for various inefficiencies (detector geometry, trigger thresholds, quality cuts), as well as for the bin migration
- The measured number of $\mathrm{t\bar{t}}$ events in each $E_{\mathrm{T}}^{\mathrm{miss}}$ bin needs to be corrected for these acceptance and migration effects
- $t\bar{t}$ contamination also needs to be taken into account:
  - Two main sources of $\mathrm{t\bar{t}}$ contamination
    - $\ell + \tau_{\mathrm{hadron}}$ with hadronic τ decay; τ_ℓ+jets where lepton comes τ
    - dilepton final states (e.g. events where 1 or 2 leptons come from τ)
  - all sources have additional neutrinos $\rightarrow$ harder $E_{\mathrm{T}}^{\mathrm{miss}}$ spectrum
  - contamination is not flat with $E_{\mathrm{T}}^{\mathrm{miss}}$ (10-30% across the bins)

Bin-by-bin corrections (2011)

- The correction factor for each $E_{\mathrm{T}}^{\mathrm{miss}}$ bin is estimated using the MC:
$$\epsilon_{\mathrm{t\bar{t}}}^{k} = \frac{N_{\mathrm{rec}}^{k}}{N_{\mathrm{gen},\ \ell+\mathrm{jets\ total}}^{k}} = \frac{A^k}{M^k}$$
- M^k is the *migration factor* $M^k = \frac{N_{\mathrm{gen}}^{k}}{N_{\mathrm{rec}}^{k}} = \frac{p^k}{s^k}$
- A^k is the *acceptance factor* $A^k = \frac{N_{\mathrm{gen}}^{k}}{N_{\mathrm{gen},\ \ell+\mathrm{jets\ total}}^{k}}$
- For normalised differential cross section, average correction is used:
$$\epsilon_{\mathrm{t\bar{t}}}^{\mathrm{average}} = \frac{\sum_k N_{\mathrm{gen}}^{k}}{\sum_k N_{\mathrm{gen},\ \ell+\mathrm{jets\ total}}^{k}}$$

Measured corrections for both channels (2011)

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$E_{\mathrm{T}}^{\mathrm{miss}}$ bin	acceptance	contamination	migration	combined correction factor
≥ 2 b-tags, electron channel				
0-25 GeV	0.128 ± 0.002	0.013 ± 0.001	1.222 ± 0.020	0.945 ± 0.018
25-45 GeV	0.112 ± 0.002	0.011 ± 0.001	1.175 ± 0.017	1.056 ± 0.017
45-70 GeV	0.085 ± 0.001	0.014 ± 0.001	0.921 ± 0.014	1.025 ± 0.018
70-100 GeV	0.067 ± 0.002	0.021 ± 0.001	0.803 ± 0.015	1.019 ± 0.021
100-inf GeV	0.069 ± 0.002	0.029 ± 0.001	0.813 ± 0.017	0.930 ± 0.023
≥ 2 b-tags, muon channel				
0-25 GeV	0.135 ± 0.002	0.011 ± 0.001	1.220 ± 0.020	0.990 ± 0.019
25-45 GeV	0.117 ± 0.002	0.012 ± 0.001	1.155 ± 0.016	1.056 ± 0.017
45-70 GeV	0.098 ± 0.001	0.014 ± 0.001	0.941 ± 0.013	1.009 ± 0.016
70-100 GeV	0.077 ± 0.002	0.022 ± 0.001	0.805 ± 0.014	0.967 ± 0.019
100-inf GeV	0.072 ± 0.002	0.031 ± 0.001	0.822 ± 0.017	0.954 ± 0.023

Method - fit procedure in detail

- Cross section $\frac{d\sigma_{t\bar{t}}}{dE_T^{miss}}$ is measured by means of a binned likelihood fit of the $|\eta_\ell|$ distribution using

$$\mathrm{LL}(\{\lambda_i, d_i\}) = -2\log\left(\prod_i \frac{\lambda_i^{d_i} \cdot e^{-\lambda_i}}{d_i!}\right) = -2\sum_i \log\left(\frac{\lambda_i^{d_i} \cdot e^{-\lambda_i}}{d_i!}\right)$$

(λ_i (d_i) are the expected (observed) number of events in each bin i)

- Template fit is performed separately in each E_T^{miss} bin
- Estimate of the cross section $\Delta\sigma_{t\bar{t}}^k$ for $t\bar{t}$ production in each E_T^{miss} bin is

$$\Delta\sigma_{t\bar{t}}^k = \frac{N_{t\bar{t}}^k}{\epsilon_{t\bar{t}}^k \mathcal{L}}$$

($\epsilon_{t\bar{t}}^k$ – total efficiency after selection, $N_{t\bar{t}}^k$ – number of $t\bar{t}$ events from the fit)

- By dividing it by the bin width $\Delta\left(E_T^{miss}\right)$, average value for the differential cross section is found:

$$\frac{d\sigma_{t\bar{t}}^k}{dE_T^{miss}} = \frac{\Delta\sigma_{t\bar{t}}^k}{\Delta\left(E_T^{miss}\right)}$$

- Then normalised differential cross section is given by

$$\frac{1}{\sigma_{t\bar{t}}}\frac{d\sigma_{t\bar{t}}^k}{dE_T^{miss}} = \frac{1}{\Delta\left(E_T^{miss}\right)} \frac{N_{t\bar{t}}^k}{\sum_k N_{t\bar{t}}^k} \frac{\epsilon_{t\bar{t}}^{average}}{\epsilon_{t\bar{t}}^k}$$

Fit results (2011)

Fit results for the e+jets channel

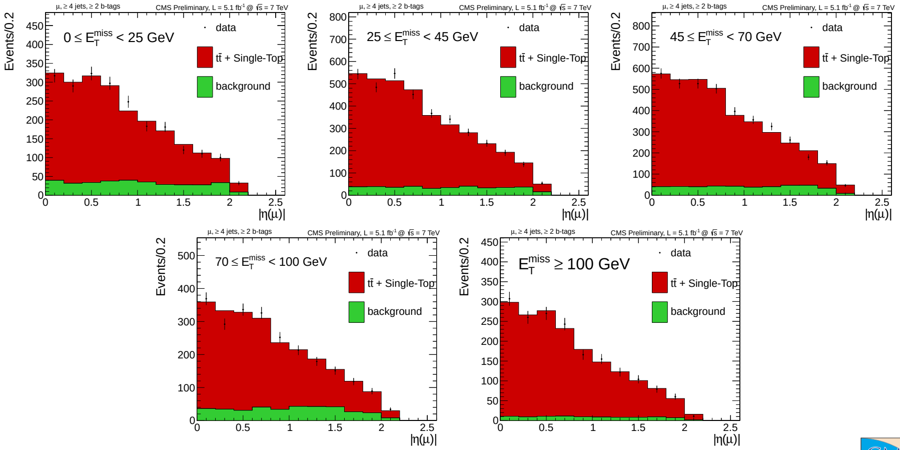
Template Fit Measurements				
MET [GeV]		$t\bar{t}$+single-t	V+Jets	qcd
$0 \leq$ MET < 25	input events	2099	127	315
	output events	2220 ± 150	362 ± 150	125 ± 66
$25 \leq$ MET < 45	input events	3443	150	259
	output events	3520 ± 263	288 ± 263	89 ± 144
$45 \leq$ MET < 70	input events	3602	120	67
	output events	3846 ± 71	0 ± 71	74 ± 37
$70 \leq$ MET < 100	input events	2284	59	80
	output events	2332 ± 55	0 ± 55	53 ± 28
MET ≥ 100	input events	1904	58	46
	output events	1798 ± 95	94 ± 95	0 ± 23

Fit results for the μ+jets channel

Template Fit Measurements				
MET [GeV]		$t\bar{t}$+single-t	V+Jets	qcd
$0 \leq$ MET < 25	input events	1871	114	27
	output events	1856 ± 114	344 ± 114	0 ± 3705
$25 \leq$ MET < 45	input events	3092	136	0
	output events	3252 ± 123	377 ± 123	0 ± 692
$45 \leq$ MET < 70	input events	3353	111	0
	output events	3450 ± 135	104 ± 135	294 ± 105
$70 \leq$ MET < 100	input events	2133	56	0
	output events	1997 ± 111	361 ± 111	0 ± 179
MET ≥ 100	input events	1749	56	0
	output events	1677 ± 108	86 ± 108	13 ± 38

Fit results (μ+jets, 2011)

Muon $|\eta|$ distributions after the template fit
in order of increasing $E_{\mathrm{T}}^{\mathrm{miss}}$ bin



Templates for e+jets, pre-tag events (2011)

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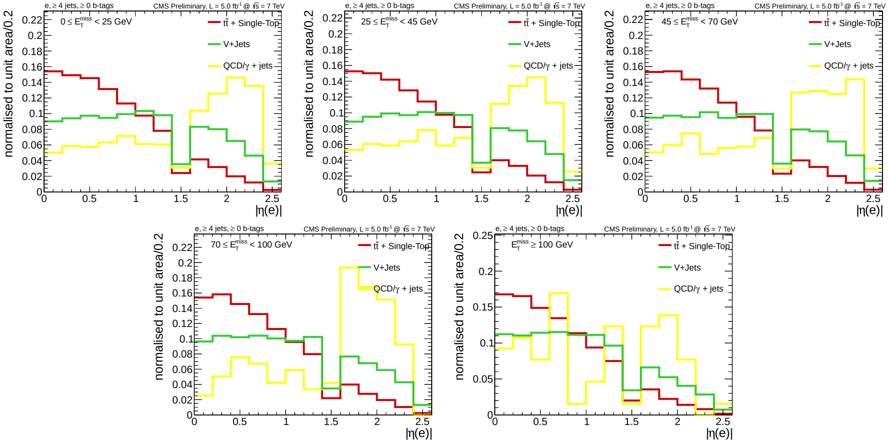

Templates for μ+jets, pre-tag events (2011)

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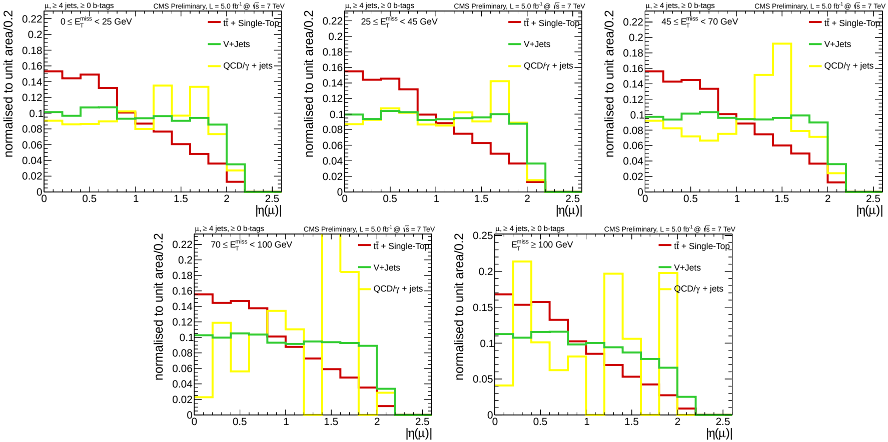
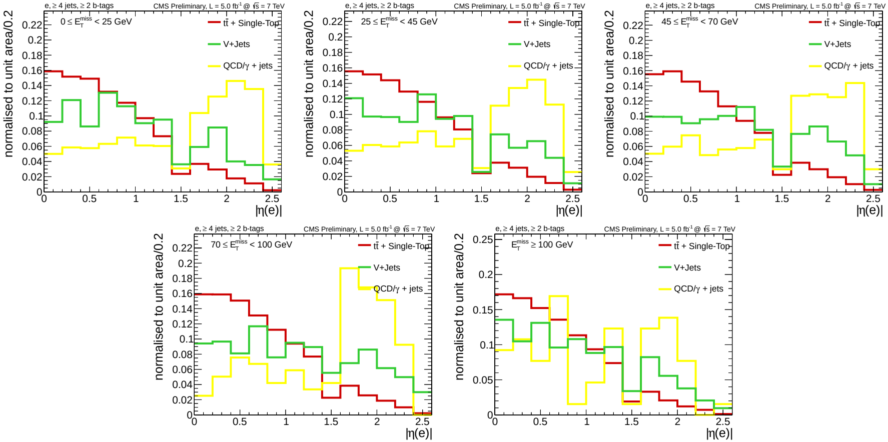


Templates for e+jets, ≥ 2 b-tag events (2011)



Templates for μ+jets, ≥ 2 b-tag events (2011)

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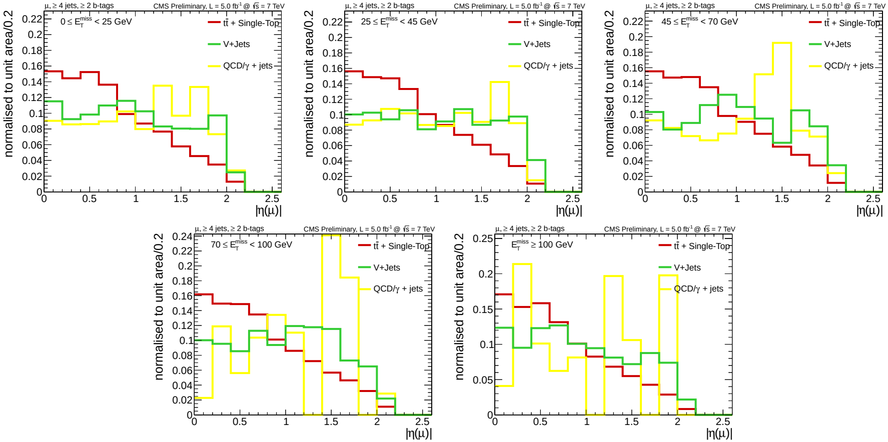
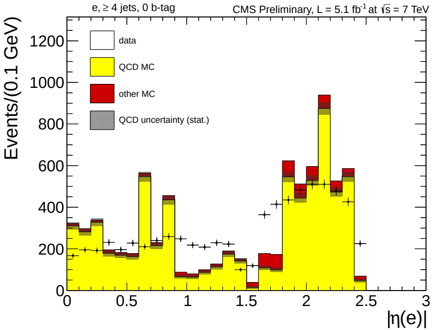


Data-driven QCD (electrons)

- **Conversion region** is used for QCD shape extraction:
  - full event selection with inverted conversion veto
- Extracting shapes from 0 b-tag regions to increase the QCD purity

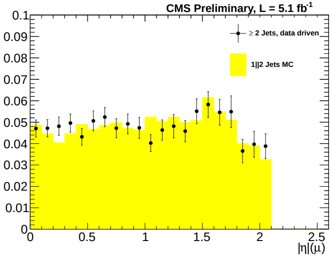


$|\eta_e|$ distribution for conversion selection

- QCD shape is not well described by the MC simulation
- Hence, using 2 b-tags requirement in the final selection to minimise QCD contamination

Data-driven QCD (muons)

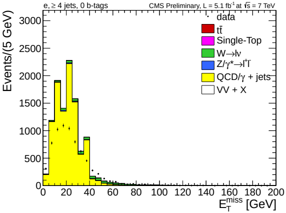
- **Non-isolated region** is used for QCD shape extraction:
  - Inverted muon isolation requirement and reduced jet multiplicity: PFRelIso > 0.3 and $N_{jet} \geq 2$
- Extracting shapes from 0 b-tag region (highest purity)
- Correcting for muon isolation efficiency (η-dependent)

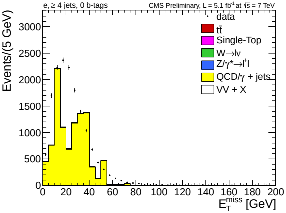


The data driven template compared with MC simulation

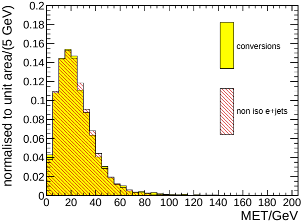
Data-driven QCD (electrons)

Non-isolated region is used for systematic uncertainty
(full selection with the isolation changed from *relIso* < 0.1 to *relIso* > 0.2)





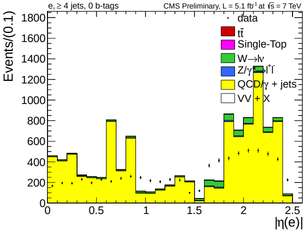
Distribution of the $E_{\mathrm{T}}^{\mathrm{miss}}$ for conversion selection (left), non-isolated electron selection (right) – both not well described by simulation

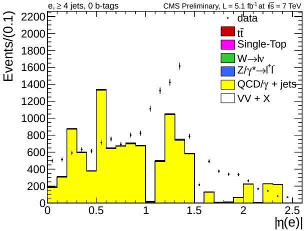


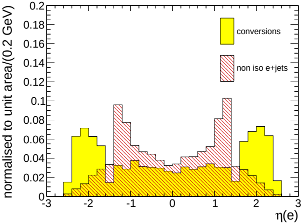
The QCD shapes from the two control regions agree well in the $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution

Data-driven QCD (electrons)

The differences are more pronounced in the electron-η distributions: conversion selection (left), non-isolated electron selection (right)



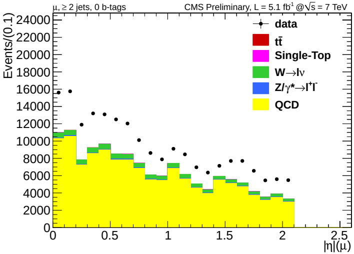


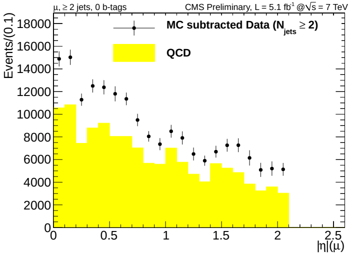


the shape comparison of QCD selections

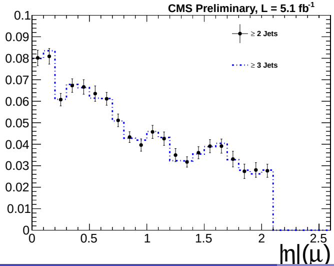
- While the shapes are very different, it has a little impact on the final result ($\geq$ 2 b-tags)
- Normalisation is not important as it's determined by the fit

Data-driven QCD (muons)



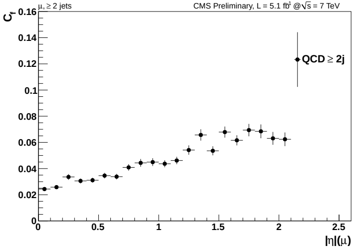


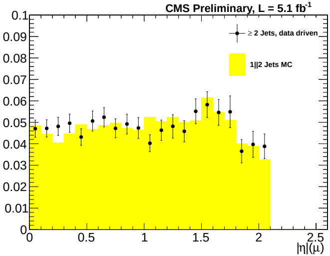
Absolute value of the rapidity (left) and background subtracted distribution (right) for $N_{\mathrm{jet}} \geq 2$ in the non-isolated control region



- Some difference between data and MC in the control region
- No difference between the shapes using different jet multiplicities (left)

Data-driven QCD (muons)





- To account for the discrepancy in QCD $|\eta|$ shapes in control and signal regions using MC, caused by a relative isolation cut efficiency as a function of $|\eta|$, the correction factors are applied (left plot):

$$C_i^f = \frac{N^{\mathrm{Events}}_{\mathrm{relIso}<0.1,i}}{N^{\mathrm{Events}}_{\mathrm{relIso}>0.3,i}}$$

- With these corrections applied, the data driven QCD template agrees well with that predicted by MC (right plot)

Event yields (detailed – from AN, 2011)

University of BRISTOL

Event yields for the e+jets selection

Selection step	$t\bar{t}$	W + Jets	Z + Jets	Single-top	Di-boson	QCD Multijet	Sum MC	Data
Skim	234844 ± 495	399219 ± 631	90447 ± 300	26762 ± 163	8419 ± 91	23184758 ± 4815	23944452 ± 4894	4977370
Event cleaning & HLT	71185 ± 272	115089 ± 339	34822 ± 186	5536 ± 74	2347 ± 48	728545 ± 853	957526 ± 980	1121873
Electron	61995 ± 254	102507 ± 320	24229 ± 155	4856 ± 69	1978 ± 44	127509 ± 357	323077 ± 570	307178
Muon Veto	59112 ± 248	102488 ± 320	24151 ± 155	4787 ± 69	1960 ± 44	127509 ± 357	320009 ± 567	304385
Electron veto	58829 ± 247	102436 ± 320	22212 ± 149	4778 ± 69	1934 ± 43	127502 ± 357	317693 ± 565	302021
Conversion veto	57605 ± 245	99247 ± 315	21475 ± 146	4677 ± 68	1874 ± 43	75752 ± 275	260632 ± 512	253777
$\geq$ 4 jets	31268 ± 180	20869 ± 144	3914 ± 62	1442 ± 37	341 ± 18	*13863 ± 2427*	71700 ± 2439	69669
$\geq$ 1 CSV b-tag	27117 ± 43	3276 ± 15	633 ± 14	1173 ± 5	73 ± 1	*3892 ± 286*	36167 ± 291	34573
$\geq$ 2 CSV b-tag	13426 ± 34	414 ± 5	101 ± 6	471 ± 4	12 ± 0	*669 ± 145*	15097 ± 149	14805

Event yields for the μ+jets selection

Selection step	$t\bar{t}$	W + Jets	Z + Jets	Single-top	Di-boson	QCD Multijet	Sum MC	Data
Skim	234844 ± 495	399219 ± 631	90447 ± 300	26762 ± 163	8419 ± 91	17672446 ± 4203	18432140 ± 4294	4231421
Event cleaning & HLT	71640 ± 273	136273 ± 369	32947 ± 181	6127 ± 78	2575 ± 50	141680 ± 376	391245 ± 627	448476
Muon	57484 ± 244	100345 ± 316	20203 ± 142	4808 ± 69	1924 ± 43	1966 ± 44	186733 ± 435	193227
Electron veto	54456 ± 238	100177 ± 316	20079 ± 141	4725 ± 68	1901 ± 43	1966 ± 44	183307 ± 430	190615
Muon Veto	53481 ± 236	100175 ± 316	13499 ± 116	4703 ± 68	1812 ± 42	1942 ± 44	175614 ± 421	181471
$\geq$ 4 jets	29531 ± 175	19367 ± 139	2634 ± 51	1347 ± 36	337 ± 18	*330 ± 19*	53548 ± 234	53296
$\geq$ 1 CSV b-tag	24896 ± 41	3045 ± 14	487 ± 13	1065 ± 5	74 ± 1	*113 ± 46*	29681 ± 65	30852
$\geq$ 2 CSV b-tag	12298 ± 33	396 ± 5	78 ± 5	418 ± 3	14 ± 0	*27 ± 27*	13234 ± 44	13816

figures in italics are data-driven estimates of QCD

Systematic uncertainties (2011)

- The list of systematics considered:
  - Luminosity (2.2%) and Pile-Up (5% inelastic cross section)
  - Lepton efficiencies (3% electron, 1% muon from tag-and-probe)
  - QCD shape uncertainty
  - Single top cross section (30%)
  - Q^2 scale and matching threshold ($t\bar{t}$, W/Z+jets)
  - JES uncertainty (p_T/η-dependent)
  - b-tagging
- MET uncertainty:
  - JER (10%) and JEC (p_T/η-dependent)
  - Unclustered energy (10%)
  - Tau energy (3%)
  - Electron & photon energy: 0.6% in EB and 1.5% in EE
  - Muon momentum (0.2%)

Systematic uncertainties (2011)

Uncertainty	0-25 GeV	25-45 GeV	45-70 GeV	70-100 GeV	$\geq$ 100 GeV
Factorisation and renormalisation scale and matching threshold					
TTJet matching	0.01%	0.00%	0.00%	0.00%	0.01%
TTJet scale	0.01%	0.00%	0.00%	0.00%	0.00%
V+Jets matching	5.32%	0.46%	3.50%	2.24%	0.58%
V+Jets scale	5.77%	1.53%	3.80%	2.58%	1.44%
$E_{\mathrm{T}}^{\mathrm{miss}}$ uncertainties					
Electron energy	0.69%	0.30%	0.30%	0.33%	0.40%
Jet energy	0.54%	0.22%	0.48%	1.08%	1.65%
Jet resolution	0.48%	0.47%	0.05%	0.57%	0.73%
Muon energy	0.46%	0.19%	0.46%	0.52%	0.51%
Tau energy	0.26%	0.28%	0.34%	0.31%	0.09%
Unclustered energy	0.49%	1.41%	0.61%	0.28%	1.21%
Rate changing uncertainties					
Electron Efficiency	0.00%	0.01%	0.00%	0.01%	0.02%
Muon Efficiency	0.01%	0.00%	0.00%	0.00%	0.01%
Luminosity	0.00%	0.00%	0.01%	0.00%	0.02%
SingleTop	0.01%	0.02%	0.07%	0.01%	0.22%

Systematic uncertainties (2011)

continued...

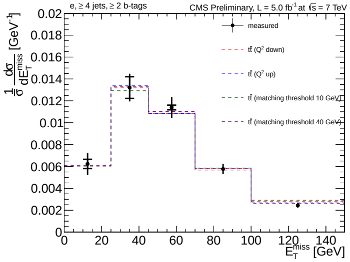
Uncertainty	0-25 GeV	25-45 GeV	45-70 GeV	70-100 GeV	$\geq$ 100 GeV
B-tagging uncertainties					
BJet	0.13%	0.08%	0.10%	0.02%	0.08%
LightJet	0.01%	0.22%	0.05%	0.20%	0.11%
Other shape changing uncertainties					
JES	0.77%	1.30%	1.06%	0.22%	0.72%
PDFWeights	0.02%	0.01%	0.01%	0.01%	0.00%
PileUp	0.07%	0.49%	0.21%	0.21%	0.22%
QCD shape	2.11%	0.64%	0.17%	1.82%	3.24%
Total					
Total $\pm$	9.35%	2.41%	6.71%	4.14%	4.42%

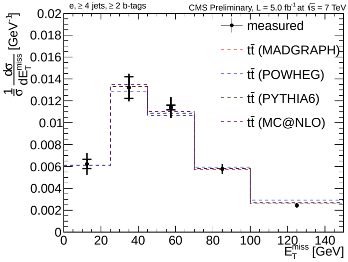
Systematics here are listed for the combined measurement of normalised differential cross section

Combination method

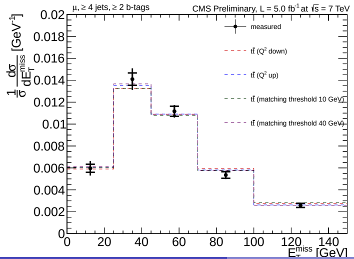
- For the final result, combination of both channels is performed
- The numbers of $t\bar{t}$ events from the template fits in both channels are corrected for acceptance, bin migration and contamination
- Then these numbers are added to calculate the combined normalised cross section
- Procedure is done for both central value and systematics, to take into account the correlations between two channels

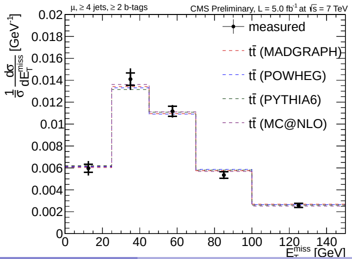
Cross section measurement (2011)



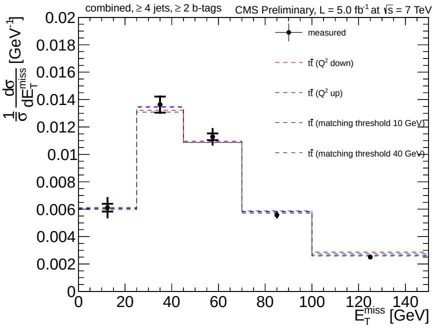


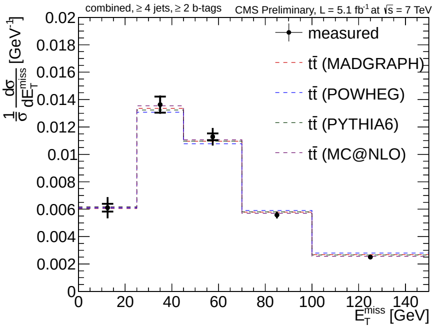
Normalised differential cross section compared to Q^2 up/down samples (left) and different generators (right) for the e+jets (top) and μ+jets (bottom) channels





Combined results (2011)





- Comparison of normalised differential cross section result to Q^2 scale up and down samples (left) and different generators (right) for the combination of both channels
- Good agreement is seen in all bins