

# Search for new physics in the 2011 opposite sign dilepton sample

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## **Abstract**

We present the results of a search for new physics in the opposite-sign leptons + jets + missing energy final state based on  $204 \text{ pb}^{-1}$  of 2011 CMS data.

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# 1 Introduction

In this note we describe a search for new physics in the opposite sign isolated dilepton sample ( $ee$ ,  $e\mu$ , and  $\mu\mu$ ) based on  $204 \text{ pb}^{-1}$  of 2011 data. The main source of isolated dileptons at CMS is Drell Yan and  $t\bar{t}$ . Here we concentrate on dileptons with invariant mass inconsistent with  $Z \rightarrow ee$  and  $Z \rightarrow \mu\mu$ , thus  $t\bar{t}$  is the most important background. A separate search for new physics in the  $Z$  sample is described in a separate note [1]. This is an update of a (soon to be) published analysis performed on 2010 data [2, 3].

The search strategy is the following

- We start out with a pre-selection which is as close as possible to the published  $t\bar{t}$  dilepton analysis [4] (same lepton ID, same jet definitions, etc.). We do make a couple of substantive modifications:
  1. The top analysis requires two leptons of  $p_T > 20 \text{ GeV}$ . In this analysis we search for new physics in 2 data samples. The first data sample is collected with high  $p_T$  dilepton triggers; for this sample we require leptons with  $p_T > (20, 10) \text{ GeV}$  (leading lepton  $p_T > 20 \text{ GeV}$ , trailing lepton  $p_T > 10 \text{ GeV}$ ). The second data sample is collected with dilepton- $H_T$  cross triggers; for this sample we require leptons with  $p_T > (10, 5) \text{ GeV}$ . This is motivated by our desire to maintain sensitivity to possible SUSY signals with relatively low  $p_T$  leptons generated in the cascade decays of heavy objects.
  2. The top analysis requires at least two jets of  $p_T > 30 \text{ GeV}$  with  $E_T^{\text{miss}} > 30 \text{ GeV}$  ( $ee$  and  $e\mu$ ) or  $E_T^{\text{miss}} > 20 \text{ GeV}$  ( $e\mu$ ). We tighten the  $E_T^{\text{miss}}$  cut to  $50 \text{ GeV}$  and we also require that the scalar sum of the  $p_T$  of all jets with  $p_T > 30 \text{ GeV}$  be  $> 100 \text{ GeV}$ . These requirements considerably reduce backgrounds to the  $t\bar{t}$  sample, e.g., backgrounds from Drell Yan and  $W$ +jets.
- The pre-selection consists mostly of  $t\bar{t}$  events. We perform data – Monte Carlo comparisons of kinematical distributions. Assuming reasonable agreement for the bulk of  $t\bar{t}$  we move on to a search for new physics in the tails of the  $t\bar{t}$   $E_T^{\text{miss}}$  and  $H_T$  distributions.
- Our prejudice is that new physics would manifest itself in an excess of events with high  $E_T^{\text{miss}}$  and significant hadronic activity. We define a a-priori search regions by tightening the  $E_T^{\text{miss}}$  and hadronic activity requirements.
- We perform a counting experiment in the signal regions. We compare observed yields with expectations from Monte Carlo and with three independent data driven techniques (see Sections 9.1, 9.2 and 9.3).

## 2 Datasets, Triggers, Luminosity

We use the following datasets, and official golden json file ( $204 \text{ pb}^{-1}$ ):

Cert\_160404-163869\_7TeV\_May10ReReco\_Collisions11\_JSON.txt

We use two data samples, one collected with high  $p_T$  dilepton triggers and the other with dilepton- $H_T$  cross triggers. These samples are complementary, since the dilepton- $H_T$  trigger sample extends to lower lepton  $p_T$ , while the high  $p_T$  dilepton trigger sample does not include requirements on the hadronic activity in the event.

Currently we use data reconstructed in CMSSW 4.2.X and Spring11 MC reconstructed in CMSSW 3.11.X. We will update the MC when the Summer11 madgraph MC samples become available.

### • Datasets

#### – High $p_T$ dilepton trigger sample

- \* DoubleElectron\_Run2011A-May10ReReco-v1\_AOD
- \* DoubleMu\_Run2011A-May10ReReco-v1\_AOD
- \* MuEG\_Run2011A-May10ReReco-v1\_AOD

#### – Dilepton- $H_T$ cross trigger sample

- \* ElectronHad\_Run2011A-May10ReReco-v1\_AOD
- \* MuHad\_Run2011A-May10ReReco-v1\_AOD

### • Monte Carlo samples

```

45     - TTJets_TuneZ2_7TeV-madgraph-tauola_Spring11-PU_S1_START311_V1G1-v1
46     - DYToEE_M-10To20_TuneZ2_7TeV-pythia6_Spring11-PU_S1_START311_V1G1-v1
47     - DYToMuMu_M-10To20_TuneZ2_7TeV-pythia6_Spring11-PU_S1_START311_V1G1-v1
48     - DYToTauTau_M-10To20_CT10_TuneZ2_7TeV-powheg-pythia-tauola_Spring11-PU_S1_START311_V1G1-v2
49     - DYToEE_M-20_CT10_TuneZ2_7TeV-powheg-pythia_Spring11-PU_S1_START311_V1G1-v1
50     - DYToMuMu_M-20_CT10_TuneZ2_7TeV-powheg-pythia_Spring11-PU_S1_START311_V1G1-v1
51     - DYToTauTau_M-20_CT10_TuneZ2_7TeV-powheg-pythia-tauola_Spring11-PU_S1_START311_V1G1-v1
52     - DYJetsToLL_TuneD6T_M-50_7TeV-madgraph-tauola_Spring11-PU_S1_START311_V1G1-v1
53     - WWTo2L2Nu_TuneZ2_7TeV-pythia6_Spring11-PU_S1_START311_V1G1-v1
54     - WZtoAnything_TuneZ2_7TeV-pythia6-tauola_Spring11-PU_S1_START311_V1G1-v1
55     - ZZtoAnything_TuneZ2_7TeV-pythia6-tauola_Spring11-PU_S1_START311_V1G1-v1
56     - WJetsToLNu_TuneZ2_7TeV-madgraph-tauola_Spring11-PU_S1_START311_V1G1-v1
57     - TToBLNu_TuneZ2_s-channel_7TeV-madgraph_Spring11-PU_S1_START311_V1G1-v1
58     - TToBLNu_TuneZ2_t-channel_7TeV-madgraph_Spring11-PU_S1_START311_V1G1-v1
59     - TToBLNu_TuneZ2_tW-channel_7TeV-madgraph_Spring11-PU_S1_START311_V1G1-v1

```

### 3 Event Preselection

The purpose of the preselection is to reject backgrounds other than  $t\bar{t} \rightarrow$  dileptons. We compare the kinematical properties of this sample with expectations from  $t\bar{t}$  Monte Carlo.

The preselection is based on the  $t\bar{t}$  analysis [4]. We select events with two opposite sign, well-identified and isolated leptons ( $ee$ ,  $e\mu$ , or  $\mu\mu$ ); one of the leptons must have  $p_T > 20$  GeV, the other one must have  $p_T > 10$  GeV. Events with dilepton mass consistent with  $Z \rightarrow ee/\mu\mu$  are rejected. In case of events with more than two such leptons, we select the pair that maximizes the scalar sum of lepton  $p_T$ 's. There must be at least two pfjets of  $p_T > 30$  GeV and  $|\eta| < 3.0$ ; jets must pass loose `pfJetId` and be separated by  $\Delta R > 0.4$  from any lepton with  $p_T > 10$  GeV passing the selection. The scalar sum  $H_T$  of the  $p_T$  of all such jets must exceed 100 GeV, for the dilepton- $H_T$  sample this requirement is increased to 200 GeV since these triggers have large inefficiency below this threshold. Finally  $E_T^{\text{miss}} > 50$  GeV (we use `pfmet`). More details are given in the subsections below.

#### 3.1 Event Cleanup

- Require at least one good deterministic annealing (DA) vertex
  - not fake
  - $\text{ndof} > 4$
  - $|\rho| < 2$  cm
  - $|z| < 24$  cm.

#### 3.2 Muon Selection

Muon candidates are RECO muon objects passing the following requirements:

- $p_T > 5$  GeV and  $|\eta| < 2.4$
- Global Muon and Tracker Muon
- $\chi^2/\text{ndof}$  of global fit  $< 10$
- At least 11 hits in the tracker fit
- Impact parameter with respect to the first DA vertex  $d_0 < 200$   $\mu\text{m}$  and  $d_z < 1$  cm
- $Iso \equiv E_T^{\text{iso}}/p_T < 0.15$ ,  $E_T^{\text{iso}}$  is defined as the sum of transverse energy/momentum deposits in ecal, hcal, and tracker, in a cone of 0.3
- At least one of the hits from the standalone muon must be used in the global fit
- Require tracker  $\Delta p_T/p_T < 0.1$ . This cut was not in the original top analysis. It is motivated by the observation of poorly measured muons in data with large relative  $p_T$  uncertainty, giving significant contributions to the  $E_T^{\text{miss}}$

### 3.3 Electron Selection

Electron candidates are RECO GSF electrons passing the following requirements:

- $p_T > 10$  GeV and  $|\eta| < 2.5$ .
- Veto electrons with a supercluster in the transition region  $1.4442 < |\eta| < 1.556$ .
- VBTF90 identification[5] with requirements tightened to match the CaloIdT and TrkIdVL HLT requirements:
  - $\sigma_{i\eta i\eta} < 0.01$  (EB), 0.03 (EE)
  - $\Delta\phi < 0.15$  (EB), 0.10 (EE)
  - $\Delta\eta < 0.007$  (EB), 0.009 (EE)
  - $H/E < 0.1$  (EB), 0.075 (EE)
- Impact parameter with respect to the first DA vertex  $d_0 < 400 \mu\text{m}$  and  $d_z < 1$  cm.
- $Iso \equiv E_T^{\text{iso}}/p_T < 0.15$ .  $E_T^{\text{iso}}$  is defined as the sum of transverse energy/momentum deposits in ecal, hcal, and tracker, in a cone of 0.3. A 1 GeV pedestal is subtracted from the ecal energy deposition in the EB, however the ecal energy is never allowed to go negative.
- Electrons with a tracker or global muon within  $\Delta R$  of 0.1 are vetoed.
- The number of missing expected inner hits must be less than two [6].
- Conversion removal via partner track finding: any electron where an additional GeneralTrack is found with  $\text{dist} < 0.02$  cm and  $\Delta \cot \theta < 0.02$  is vetoed [6].

We estimate the contributions from fake leptons using the data-driven fake rate (FR) method. The requirements defining the fakeable objects are listed in App. A.

### 3.4 Invariant mass requirement

We remove  $e^+e^-$  and  $\mu^+\mu^-$  events with invariant mass between 76 and 106 GeV. We also remove events with invariant mass  $< 12$  GeV, since this kinematical region is not well reproduced in CMS Monte Carlo and to remove events with Upsilon's.

In addition, we remove  $Z \rightarrow \mu\mu\gamma$  candidates with the  $\gamma$  collinear with one of the muons. This is done as follows: if the ecal energy associated with one of the muons is greater than 6 GeV, we add this energy to the momentum of the initial muon, and we recompute the  $\mu\mu$  mass. If this mass is between 76 and 106 GeV, the event is rejected.

### 3.5 Trigger Selection

We do not make any requirements on HLT bits in the Monte Carlo. Instead, as discussed in Section 4, a trigger efficiency weight is applied to each event, based on the trigger efficiencies measured on data (see Sec. 4).

We select data events using the following triggers. An event in the  $ee$  channel is required to pass a DoubleElectron trigger, an event in the  $\mu\mu$  channel is required to pass a DoubleMu trigger, and an event in the  $e\mu$  channel is required to pass a Ele-Mu trigger.

- High  $p_T$  dilepton trigger sample
  - HLT\_Ele17\_CaloIdL\_CaloIsoVL\_Ele8\_CaloIdL\_CaloIsoVL
  - HLT\_DoubleMu7
  - HLT\_Mu13\_Mu7
  - HLT\_Mu17\_Ele8\_CaloIdL
  - HLT\_Mu8\_Ele17\_CaloIdL

- Lepton  $H_T$  cross trigger sample

- HLT\_DoubleMu3\_HT150
- HLT\_DoubleMu3\_HT160
- HLT\_Mu3\_Ele8\_CaloIdL\_TrkIdVL\_HT150
- HLT\_Mu3\_Ele8\_CaloIdT\_TrkIdVL\_HT150
- HLT\_Mu3\_Ele8\_CaloIdL\_TrkIdVL\_HT160
- HLT\_Mu3\_Ele8\_CaloIdT\_TrkIdVL\_HT160
- HLT\_DoubleEle8\_CaloIdL\_TrkIdVL\_HT150
- HLT\_DoubleEle8\_CaloIdT\_TrkIdVL\_HT150
- HLT\_DoubleEle8\_CaloIdL\_TrkIdVL\_HT160
- HLT\_DoubleEle8\_CaloIdT\_TrkIdVL\_HT160

## 4 Trigger efficiency

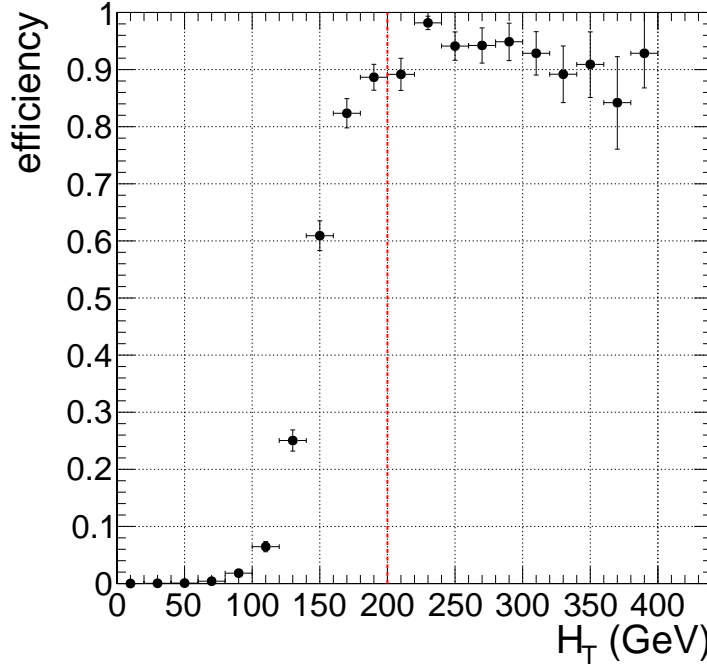


Figure 1: Efficiency for the dimuon- $H_T$  trigger HLT\_DoubleMu3\_HT150 as a function of the offline  $H_T$ . Events are selected with the high  $p_T$  dilepton trigger HLT\_DoubleMu7 and required to have 2 muons passing analysis selection. The vertical dashed line indicates the requirement  $H_T > 200$  GeV, which is used in the preselection for the dilepton- $H_T$  trigger sample.

For the high  $p_T$  dilepton triggers, the efficiencies have been measured to be approximately 100% (DoubleEle), 90% (DoubleMu), and 95% (Mu-Ele) [7]. In the following, unless otherwise specified we weight the  $ee$ ,  $\mu\mu$  and  $e\mu$  MC events by these efficiencies. We do not apply any efficiency correction for the hadronic part of the dilepton- $H_T$  triggers. We have verified that the efficiencies for these triggers with respect to an offline selection of  $H_T > 200$  GeV is high ( $\sim 90$ – $95\%$ ), as shown in Fig. 1.

## 5 Dilepton Yields

The data and MC dilepton mass distributions for events with 2 selected leptons are displayed in Fig. 2. The yields of  $Z$  events in the mass range 76–106 GeV are indicated in the figure. In data we observe a 3% excess in the  $ee$  channel and a 9% excess in the  $\mu\mu$  channel, which we attribute to uncertainties in trigger efficiency, lepton selection efficiency, and integrated luminosity. We use the ratio of  $Z \rightarrow \mu^+\mu^-$  to  $Z \rightarrow e^+e^-$  yields in data to estimate the ratio of muon to electron selection efficiencies, and find  $R_{\mu e} = \text{eff}(\mu)/\text{eff}(e) = 1.12$ .

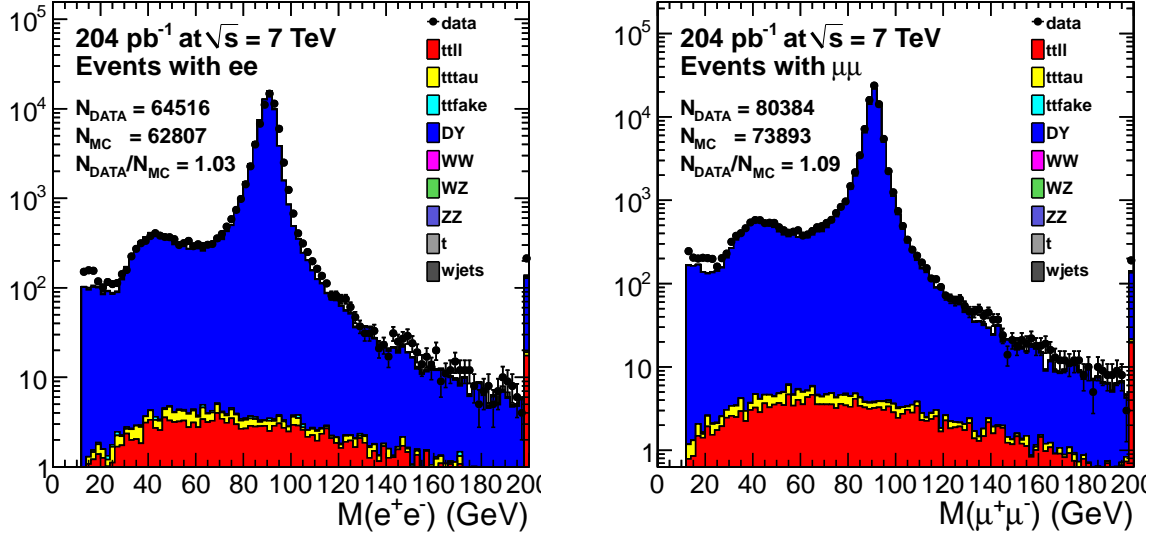


Figure 2: Distributions of dilepton mass in data and MC, in the  $ee$  channel (left) and  $\mu\mu$  channel (right). The quoted yields refer to events inside the  $Z$  mass window 76–106 GeV.

## 6 Preselection yields

The data yields and the MC predictions for the dilepton trigger sample are given in Table 1. We also look for an excess of low lepton  $p_T$  events using the dilepton- $H_T$  trigger sample, and requiring the leptons to pass lepton  $p_T > (10,5)$  GeV but not pass lepton  $p_T > (20,10)$  GeV (to remove overlap with the dilepton trigger sample), as summarized in Table 2. Finally, we verify in Table 3 that the data samples collected with high  $p_T$  dilepton triggers and lepton- $H_T$  cross triggers give consistent yields, after including the requirements  $H_T > 200$  GeV and lepton  $p_T > (20,10)$  GeV.

The MC yields are normalized to  $204 \text{ pb}^{-1}$  using the cross-sections from Reference [8]. The MC is scaled by the approximate trigger efficiency (100% for  $ee$ , 95% for  $\mu\mu$ , and 95% for  $e\mu$ ) and has been reweighted such that the distribution of reconstructed DA vertices matches that in data. Contributions for  $t\bar{t} \rightarrow \text{fake}$  and  $W + \text{jets}$  with 1 lepton not originating from  $W/Z$  decay (fake lepton) and the contributions from QCD multijet events with 2 fake leptons (single fakes and double fakes, respectively) are estimated with the data-driven fake rate method [4]. The DY contribution is dominated by  $\text{DY} \rightarrow \tau^+\tau^-$ , and we have verified with the data-driven  $R_{\text{out/in}}$  method [4] that the contributions from  $\text{DY} \rightarrow e^+e^-$  and  $\text{DY} \rightarrow \mu^+\mu^-$  are negligible. Also shown are the yields for LM1 and LM3, two of the LM points which are benchmarks for SUSY analyses at CMS. The LM yields are calculated at NLO using process-dependent k-factors computed from Prospino.

As anticipated, the MC predicts that the preselection is dominated by  $t\bar{t}$ . We observe a slight excess in data with respect to MC expectations.

## 7 Properties of data passing the preselection

A number of kinematical distributions for events passing the preselection in data are compared with MC in Appendix C. Although we observe a slight overall excess of data, in general we find that the MC does a good job of reproducing the shapes of the kinematical distributions. Therefore we turn our attention to the tails of the  $t\bar{t}$  events.

## 8 Definition of the signal region

We define signal regions to look for possible new physics contributions in the opposite sign isolated dilepton sample. The choice of signal region is driven by three observations:

1. astrophysical evidence for dark matter suggests that we concentrate on the region of high  $E_T^{\text{miss}}$ ;

Table 1: High  $p_T$  dilepton trigger data and Monte Carlo yields for the preselection ( $n_{\text{jets}} \geq 2$ ,  $H_T > 100$  GeV,  $E_T^{\text{miss}} > 50$  GeV, lepton  $p_T > (20, 10)$  GeV). For the  $t\bar{t} \rightarrow \ell^+\ell^-$  and  $t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$  samples,  $\ell = e, \mu$ . The fake lepton contributions have not been corrected for contamination from true leptons.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
Sample	$ee$	$\mu\mu$	$e\mu$	tot
$t\bar{t} \rightarrow \ell^+\ell^-$	$70.3 \pm 1.7$	$77.8 \pm 1.7$	$187.3 \pm 2.7$	$335.4 \pm 3.6$
$t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$	$16.1 \pm 0.8$	$19.5 \pm 0.9$	$42.0 \pm 1.3$	$77.7 \pm 1.8$
single fakes	$8.5 \pm 4.2$	$16.1 \pm 8.1$	$20.7 \pm 10.4$	$45.3 \pm 13.8$
double fakes	$0.0 \pm 0.0$	$0.4 \pm 0.2$	$1.0 \pm 0.5$	$1.5 \pm 0.6$
DY	$3.8 \pm 1.0$	$5.7 \pm 1.3$	$7.9 \pm 1.5$	$17.4 \pm 2.2$
$W^+W^-$	$0.8 \pm 0.1$	$0.9 \pm 0.1$	$2.0 \pm 0.1$	$3.7 \pm 0.2$
$W^\pm Z^0$	$0.2 \pm 0.0$	$0.2 \pm 0.0$	$0.4 \pm 0.0$	$0.8 \pm 0.0$
$Z^0 Z^0$	$0.1 \pm 0.0$	$0.1 \pm 0.0$	$0.1 \pm 0.0$	$0.2 \pm 0.0$
single top	$2.6 \pm 0.1$	$2.9 \pm 0.1$	$6.9 \pm 0.2$	$12.5 \pm 0.3$
tot SM MC	$102.5 \pm 4.8$	$123.6 \pm 8.4$	$268.3 \pm 10.9$	$494.4 \pm 14.6$
data	113	122	313	548
LM1	$13.1 \pm 0.3$	$14.6 \pm 0.3$	$7.5 \pm 0.3$	$35.1 \pm 0.6$
LM3	$3.0 \pm 0.1$	$3.7 \pm 0.1$	$5.3 \pm 0.1$	$12.0 \pm 0.2$

Table 2: Dilepton- $H_T$  trigger data and Monte Carlo yields for the preselection ( $n_{\text{jets}} \geq 2$ ,  $H_T > 200$  GeV,  $E_T^{\text{miss}} > 50$  GeV, lepton  $p_T > (10, 5)$  GeV and not lepton  $p_T > (20, 10)$  GeV). For the  $t\bar{t} \rightarrow \ell^+\ell^-$  and  $t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$  samples,  $\ell = e, \mu$ . The fake lepton contributions have not been corrected for contamination from true leptons.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
$t\bar{t} \rightarrow \ell^+\ell^-$	$0.3 \pm 0.1$	$2.2 \pm 0.3$	$2.4 \pm 0.3$	$4.9 \pm 0.4$
$t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$	$0.4 \pm 0.1$	$2.3 \pm 0.3$	$2.1 \pm 0.3$	$4.7 \pm 0.4$
single fakes	$0.0 \pm 0.0$	$1.7 \pm 0.9$	$3.0 \pm 1.5$	$4.8 \pm 1.7$
double fakes	$0.0 \pm 0.0$	$0.6 \pm 0.3$	$0.0 \pm 0.0$	$0.6 \pm 0.3$
DY	$0.0 \pm 0.0$	$2.2 \pm 0.8$	$0.4 \pm 0.4$	$2.6 \pm 0.9$
$W^+W^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^\pm Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$0.0 \pm 0.0$	$0.2 \pm 0.0$	$0.2 \pm 0.0$	$0.4 \pm 0.1$
tot SM MC	$0.7 \pm 0.2$	$9.1 \pm 1.3$	$8.1 \pm 1.6$	$18.0 \pm 2.1$
data	1	7	5	13
LM1	$0.3 \pm 0.1$	$2.9 \pm 0.2$	$2.3 \pm 0.1$	$5.5 \pm 0.2$
LM3	$0.0 \pm 0.0$	$0.4 \pm 0.0$	$0.3 \pm 0.0$	$0.7 \pm 0.1$

2. new physics signals should have high  $\sqrt{s}$ ;

3. observable high cross section new physics signals are likely to be produced strongly; thus, we expect significant hadronic activity in conjunction with the two leptons.

Following these observations, we define the following 3 signal regions by adding requirements of large hadronic activity and missing transverse energy to the preselection of Section 3.

- 2010 signal region:  $H_T > 300$  GeV and  $y > 8.5$  GeV $^{1/2}$ .
- high  $y$  signal region:  $H_T > 300$  GeV and  $y > 13$  GeV $^{1/2}$ .
- high  $H_T$  signal region:  $H_T > 600$  GeV and  $y > 8.5$  GeV $^{1/2}$ .

We cut on the quantity  $y \equiv E_T^{\text{miss}}/\sqrt{H_T}$  rather than  $E_T^{\text{miss}}$  because the variables  $H_T$  and  $y$  are largely uncorrelated for the dominant  $t\bar{t}$  background. This allows us to use a data-driven ABCD method to estimate the background (see Section 9.1). In the future, we plan to cut instead on  $E_T^{\text{miss}}$  and  $H_T$ , since we observe that  $E_T^{\text{miss}}$  is a better discriminant between  $t\bar{t}$  vs. SUSY. We have developed a novel technique, which is a variation of the ABCD method, to estimate the background in a signal region defined by  $E_T^{\text{miss}}$  and  $H_T$  requirements (see App. B).



Table 3: Comparison of data yields in the high- $p_T$  dilepton and dilepton- $H_T$  trigger samples, passing the selection  $n_{\text{jets}} \geq 2$ ,  $E_T^{\text{miss}} > 50$  GeV,  $H_T > 200$  GeV, lepton  $p_T > (20, 10)$  GeV.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
high- $p_T$ dilepton trigger	50	49	124	223
dilepton- $H_T$ trigger	50	48	117	215

The 2010 signal region is the same as the one used in the 2010 analysis, and was chosen to preserve about 1% of the  $t\bar{t}$  sample. The additional signal regions (high  $y$  and high  $H_T$ ) have tightened requirements on  $y$  and  $H_T$ , respectively, which reduce the expected background by roughly an order of magnitude.

For each signal region, we search in the high  $p_T$  dilepton trigger sample requiring lepton  $p_T > (20, 10)$  GeV, and separately in the dilepton- $H_T$  trigger sample requiring lepton  $p_T > (10, 5)$  GeV and not passing lepton  $p_T > (20, 10)$  GeV, to remove overlap with the high  $p_T$  dilepton trigger sample. For the high  $p_T$  dilepton sample, for which we have prior experience with the 2010 analysis, we apply the ABCD,  $p_T(\ell\ell)$ , and OF subtraction background estimates. For the dilepton- $H_T$  sample we currently apply only the OF subtraction background estimate.

We present the data and MC expected yields in the 3 signal regions in Tables 4-6 for the high  $p_T$  dilepton trigger sample and in Tables 7-9.

Table 4: High  $p_T$  dilepton trigger data and MC yields in the 2010 signal region. MC errors are statistical only.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
$t\bar{t} \rightarrow \ell^+\ell^-$	$0.9 \pm 0.2$	$1.4 \pm 0.2$	$2.6 \pm 0.3$	$5.0 \pm 0.4$
$t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$	$0.4 \pm 0.1$	$0.4 \pm 0.1$	$1.2 \pm 0.2$	$2.0 \pm 0.3$
$t\bar{t} \rightarrow \text{fake}$	$0.1 \pm 0.1$	$0.0 \pm 0.0$	$0.2 \pm 0.1$	$0.3 \pm 0.1$
DY	$0.2 \pm 0.2$	$0.4 \pm 0.4$	$0.4 \pm 0.4$	$1.0 \pm 0.6$
$W^+W^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.1 \pm 0.0$	$0.2 \pm 0.0$
$W^\pm Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.1 \pm 0.0$
$W + \text{jets}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
tot SM MC	$1.8 \pm 0.3$	$2.3 \pm 0.5$	$4.5 \pm 0.6$	$8.6 \pm 0.8$
data	4	3	7	14
LM1	$6.4 \pm 0.2$	$7.6 \pm 0.2$	$3.9 \pm 0.2$	$18.0 \pm 0.4$
LM3	$1.3 \pm 0.1$	$1.5 \pm 0.1$	$2.0 \pm 0.1$	$4.8 \pm 0.1$

Table 5: High  $p_T$  dilepton trigger data and MC yields in the high  $y$  signal region. MC errors are statistical only.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
$t\bar{t} \rightarrow \ell^+\ell^-$	$0.2 \pm 0.1$	$0.3 \pm 0.1$	$0.5 \pm 0.1$	$0.9 \pm 0.2$
$t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.1 \pm 0.1$	$0.2 \pm 0.1$
$t\bar{t} \rightarrow \text{fake}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
DY	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^+W^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.1 \pm 0.0$
$W^\pm Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W + \text{jets}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
tot SM MC	$0.2 \pm 0.1$	$0.4 \pm 0.1$	$0.7 \pm 0.2$	$1.3 \pm 0.2$
data	3	0	3	6
LM1	$2.7 \pm 0.2$	$3.2 \pm 0.2$	$1.7 \pm 0.1$	$7.6 \pm 0.3$
LM3	$0.4 \pm 0.0$	$0.5 \pm 0.0$	$0.7 \pm 0.1$	$1.7 \pm 0.1$

Table 6: High  $p_T$  dilepton trigger data and MC yields in the high  $H_T$  signal region. MC errors are statistical only.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
$t\bar{t} \rightarrow \ell^+\ell^-$	$0.1 \pm 0.1$	$0.2 \pm 0.1$	$0.2 \pm 0.1$	$0.5 \pm 0.1$
$t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$	$0.1 \pm 0.1$	$0.1 \pm 0.1$	$0.1 \pm 0.1$	$0.2 \pm 0.1$
$t\bar{t} \rightarrow \text{fake}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
DY	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.4 \pm 0.4$	$0.4 \pm 0.4$
$W^+W^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^\pm Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W + \text{jets}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
tot SM MC	$0.2 \pm 0.1$	$0.3 \pm 0.1$	$0.7 \pm 0.4$	$1.2 \pm 0.5$
data	1	0	2	3
LM1	$2.3 \pm 0.1$	$2.7 \pm 0.2$	$1.2 \pm 0.1$	$6.2 \pm 0.2$
LM3	$0.6 \pm 0.0$	$0.6 \pm 0.0$	$0.7 \pm 0.1$	$1.9 \pm 0.1$

Table 7: Dilepton- $H_T$  trigger data and MC yields in the 2010 signal region. MC errors are statistical only.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
$t\bar{t} \rightarrow \ell^+\ell^-$	$0.0 \pm 0.0$	$0.1 \pm 0.1$	$0.2 \pm 0.1$	$0.3 \pm 0.1$
$t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$	$0.0 \pm 0.0$	$0.1 \pm 0.1$	$0.0 \pm 0.0$	$0.2 \pm 0.1$
$t\bar{t} \rightarrow \text{fake}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.1 \pm 0.0$	$0.1 \pm 0.0$
DY	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^+W^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^\pm Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W + \text{jets}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
tot SM MC	$0.0 \pm 0.0$	$0.2 \pm 0.1$	$0.3 \pm 0.1$	$0.6 \pm 0.1$
data	0	1	0	1
LM1	$0.2 \pm 0.0$	$1.6 \pm 0.1$	$1.3 \pm 0.1$	$3.0 \pm 0.2$
LM3	$0.0 \pm 0.0$	$0.2 \pm 0.0$	$0.1 \pm 0.0$	$0.3 \pm 0.0$

Table 8: Dilepton- $H_T$  trigger data and MC yields in the high  $y$  signal region. MC errors are statistical only.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
$t\bar{t} \rightarrow \ell^+\ell^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$t\bar{t} \rightarrow \text{fake}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
DY	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^+W^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^\pm Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W + \text{jets}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
tot SM MC	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
data	0	0	0	0
LM1	$0.1 \pm 0.0$	$0.7 \pm 0.1$	$0.6 \pm 0.1$	$1.3 \pm 0.1$
LM3	$0.0 \pm 0.0$	$0.1 \pm 0.0$	$0.1 \pm 0.0$	$0.1 \pm 0.0$

Table 9: Dilepton- $H_T$  trigger data and MC yields in the high  $H_T$  signal region. MC errors are statistical only.

Sample	$ee$	$\mu\mu$	$e\mu$	tot
$t\bar{t} \rightarrow \ell^+\ell^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$t\bar{t} \rightarrow \ell^\pm\tau^\mp/\tau^+\tau^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$t\bar{t} \rightarrow \text{fake}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
DY	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^+W^-$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^\pm Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W + \text{jets}$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
tot SM MC	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
data	0	0	0	0
LM1	$0.1 \pm 0.0$	$0.6 \pm 0.1$	$0.4 \pm 0.1$	$1.1 \pm 0.1$
LM3	$0.0 \pm 0.0$	$0.1 \pm 0.0$	$0.0 \pm 0.0$	$0.1 \pm 0.0$

These results are summarized as:

- High  $p_T$  dilepton trigger sample
  - 2010 signal region ( $y > 8.5 \text{ GeV}^{1/2}$ ,  $H_T > 300 \text{ GeV}$ )
    - \* observed yield : 14
    - \* MC prediction :  $8.6 \pm 0.8$
  - high  $y$  signal region ( $y > 13 \text{ GeV}^{1/2}$ ,  $H_T > 300 \text{ GeV}$ )
    - \* observed yield : 6
    - \* MC prediction :  $1.3 \pm 0.2$
  - high  $H_T$  signal region ( $y > 8.5 \text{ GeV}^{1/2}$ ,  $H_T > 600 \text{ GeV}$ )
    - \* observed yield : 3
    - \* MC prediction :  $1.2 \pm 0.5$
- Dilepton- $H_T$  trigger sample
  - 2010 signal region ( $y > 8.5 \text{ GeV}^{1/2}$ ,  $H_T > 300 \text{ GeV}$ )
    - \* observed yield : 1
    - \* MC prediction :  $0.6 \pm 0.1$
  - high  $y$  signal region ( $y > 13 \text{ GeV}^{1/2}$ ,  $H_T > 300 \text{ GeV}$ )
    - \* observed yield : 0
    - \* MC prediction :  $0.0 \pm 0.0$
  - high  $H_T$  signal region ( $y > 8.5 \text{ GeV}^{1/2}$ ,  $H_T > 600 \text{ GeV}$ )
    - \* observed yield : 0
    - \* MC prediction :  $0.0 \pm 0.0$

For the high  $p_T$  dilepton trigger sample, in the 2010 signal region we observe 14 events, representing a slight excess with respect to the MC expectation. This excess is enhanced after moving to the high  $y$  signal region, where we find 6 events. In the high  $H_T$  region we observe 3 events, representing a slight excess. A data/MC comparison of the kinematic distributions of the 14 events passing the 2010 signal region selection is presented in App. D. For the dilepton- $H_T$  trigger sample we observe 1 event in the 2010 signal region, consistent with MC expectations. We observe no events in either the high  $y$  or high  $H_T$  signal regions.

For all signal regions, we observe 0 events in the  $Z$  mass window, confirming the expectation from MC that the DY background is negligible. We also confirm the MC expectation that the contribution of fake leptons is small, using the data-driven fake rate method. For the high  $p_T$  dilepton trigger sample, We find 1 lepton + fakeable object in the 2010 signal region, giving a predicted contribution from fake leptons of  $0.6 \pm 0.6$ , consistent with MC expectations. For the high  $y$  and high  $H_T$  signal regions, we do not observe any lepton + fakeable object events and our data-driven prediction for the fake contributions in these regions is zero. For the dilepton- $H_T$  trigger sample we observe 1 lepton + fakeable object event, leading to a predicted fake contribution of  $0.4 \pm 0.4$ , which falls in the high  $y$  signal region (but not in the high  $H_T$  signal region).

## 9 Data Driven Background Estimation Methods

For the high  $p_T$  dilepton trigger sample, we use 3 data-driven methods to estimate the background in the signal region. The first one exploits the fact that  $H_T$  and  $y$  are nearly uncorrelated for the  $t\bar{t}$  background. The second one is based on the fact that in  $t\bar{t}$  the  $p_T$  of the dilepton pair is on average nearly the same as the  $p_T$  of the pair of neutrinos from  $W$ -decays, which is reconstructed as  $E_T^{\text{miss}}$  in the detector. The third method exploits the fact that in  $t\bar{t}$  events the rates of same-flavor vs. opposite-flavor dilepton events are the same. For the low lepton  $p_T$  events collected by the dilepton- $H_T$  triggers, we use the opposite-flavor subtraction technique.

We study the closure of these methods using our madgraph  $t\bar{t}$  sample, as well as the powheg sample TTTo2L2Nu2B\_7TeV-powheg-pythia6\_Spring11-PU\_S1\_START311\_V1G1-v1 which has approximately 10 times more events in the dilepton channel than the madgraph sample. We use these samples to estimate correction factors and systematic uncertainties for the background predictions. However, the final choice of correction factors and uncertainties will be extracted from the Summer11  $t\bar{t}$  madgraph sample which will have 50 times as many events as the current madgraph sample. For the studies presented in this section, we do not apply trigger efficiency corrections or reweighting for number of reconstructed vertices since we are not comparing MC to data.

## 9.1 ABCD method

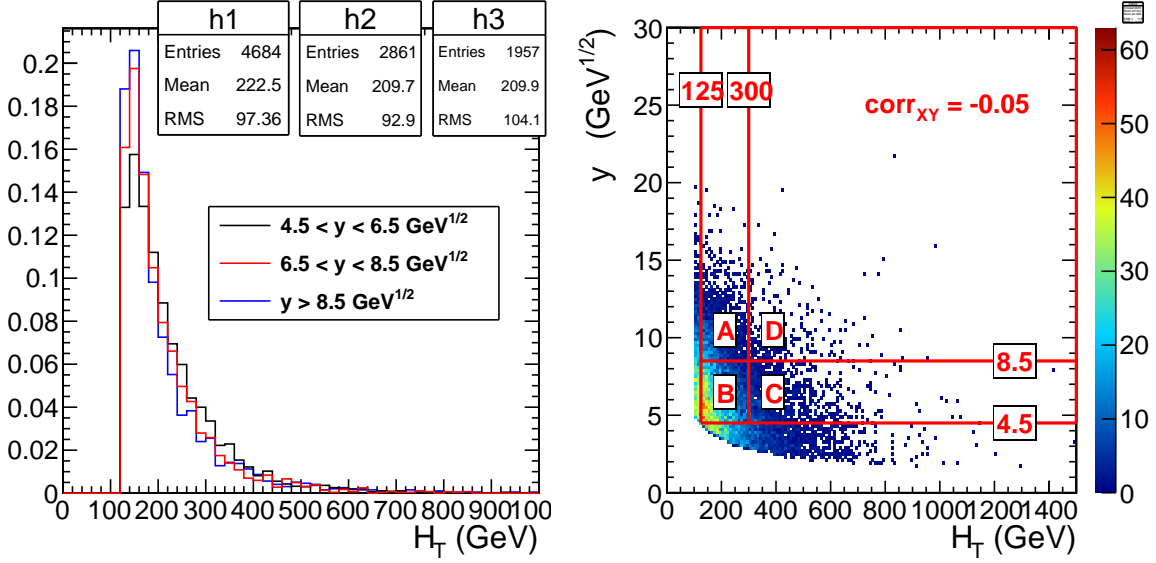


Figure 3: Left: distributions of  $H_T$  in MC  $t\bar{t}$  events for different intervals of  $y$ . h1, h2, and h3 refer to the  $y$  intervals 4.5-6.5, 6.5-8.5 and  $>8.5$ , respectively. Right: Distributions of  $y$  vs.  $H_T$  for  $t\bar{t}$  MC. Here we also show our choice of ABCD regions. The correlation coefficient  $\text{corr}_{xy}$  is computed for events falling in the ABCD regions.

We find that in  $t\bar{t}$  events  $H_T$  and  $y$  are nearly uncorrelated, as demonstrated in Fig. 3 (left). Thus, we can use an ABCD method in the  $y$  vs.  $H_T$  plane to estimate the background in a data driven way. We define 4 regions in the plane of  $y$  vs.  $H_T$ , as shown in Fig. 3 (right). The region D is the signal region, and the regions A, B and C are control regions. The predicted background in region D is given by  $N_A \times N_C / N_B$ .

In Table 10, we quote the  $t\bar{t}$  MC expected yields for  $1 \text{ fb}^{-1}$ . In general we find that the prediction agrees with the observed yield in the signal region within  $\sim 30\text{-}50\%$  for all signal regions. We also study the dependence of the ratio of observed to predicted signal yields, as a function of the  $y$  and  $H_T$  requirements used to define the signal region, shown in Fig. 4. Based on these results, we apply the scale factors and uncertainties summarized in Table 13 to the predicted background from the ABCD method.

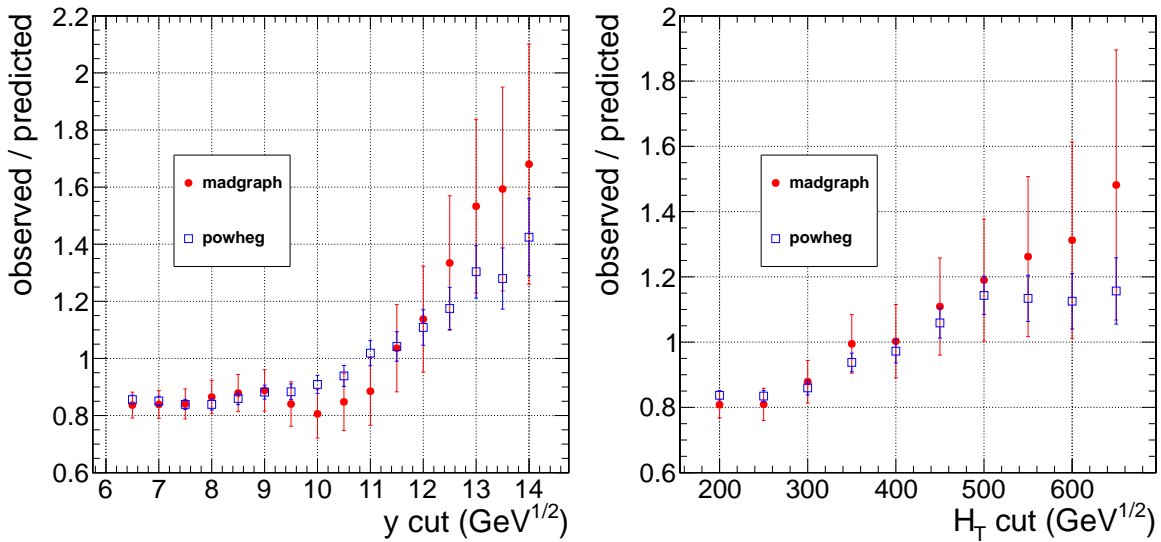


Figure 4: Variation of observed/predicted for the ABCD method as a function of the  $y$  and  $H_T$  cuts defining the signal region.

Table 10: Expected yields from  $t\bar{t}$  MC in  $1 \text{ fb}^{-1}$  in the four ABCD regions for the signal regions depicted in Figs. 7-9, as well as the predicted yield in region D given by  $N_A \times N_C/N_B$  and the ratio of the observed signal yield to the prediction. The quoted uncertainties are statistical only.

signal region	sample	A	B	C	D	$N_A \times N_C/N_B$	obs/pred
2010 signal region	madgraph	$251.3 \pm 6.1$	$951.5 \pm 11.9$	$165.2 \pm 4.9$	$38.3 \pm 2.4$	$43.6 \pm 1.8$	$0.88 \pm 0.07$
	powheg	$231.7 \pm 2.0$	$850.6 \pm 3.7$	$157.8 \pm 1.6$	$37.0 \pm 0.8$	$43.0 \pm 0.6$	$0.86 \pm 0.02$
high $y$ signal region	madgraph	$18.4 \pm 1.6$	$951.5 \pm 11.9$	$165.2 \pm 4.9$	$4.9 \pm 0.9$	$3.2 \pm 0.3$	$1.53 \pm 0.30$
	powheg	$17.3 \pm 0.5$	$850.6 \pm 3.7$	$157.8 \pm 1.6$	$4.2 \pm 0.3$	$3.2 \pm 0.1$	$1.30 \pm 0.09$
high $H_T$ signal region	madgraph	$251.3 \pm 6.1$	$951.5 \pm 11.9$	$11.1 \pm 1.3$	$3.8 \pm 0.8$	$2.9 \pm 0.3$	$1.31 \pm 0.30$
	powheg	$231.7 \pm 2.0$	$850.6 \pm 3.7$	$12.5 \pm 0.5$	$3.8 \pm 0.3$	$3.4 \pm 0.1$	$1.13 \pm 0.08$

## 9.2 Dilepton $p_T$ method

This method is based on a suggestion by V. Pavlunin [9], and was investigated by our group in 2009 [10] and in our 2010 analysis [3]. The idea is that in dilepton  $t\bar{t}$  events the lepton and neutrinos from  $W$  decays have the same  $p_T$  spectrum (modulo  $W$  polarization effects). One can then use the observed  $p_T(\ell\ell)$  distribution to model the sum of neutrino  $p_T$ 's which is identified with the  $E_T^{\text{miss}}$ .

Then, in order to predict the  $t\bar{t} \rightarrow$  dilepton contribution to a selection with  $E_T^{\text{miss}} + X$ , one applies a cut on  $p_T(\ell\ell) + X$  instead. In practice one has to rescale the result of the  $p_T(\ell\ell) + X$  selection to account for the fact that any dilepton selection must include a moderate  $E_T^{\text{miss}}$  cut in order to reduce Drell Yan backgrounds. This is discussed in Section 5.3 of Reference [10]; for a  $E_T^{\text{miss}}$  cut of 50 GeV, the rescaling factor is obtained from the MC as

$$K = \frac{\int_0^\infty \mathcal{N}(p_T(\ell\ell)) dp_T(\ell\ell)}{\int_{50}^\infty \mathcal{N}(p_T(\ell\ell)) dp_T(\ell\ell)} = 1.5.$$

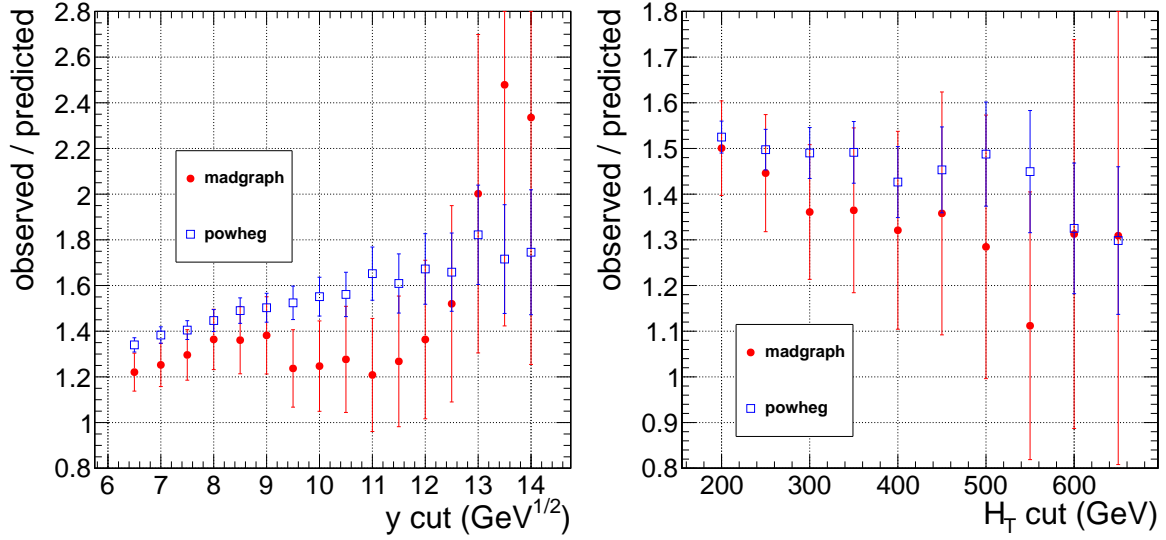


Figure 5: Variation of observed/predicted for the  $p_T(\ell\ell)$  method as a function of the  $y$  and  $H_T$  cuts defining the signal region.

We summarize the expected results of the  $p_T(\ell\ell)$  method in  $1 \text{ fb}^{-1} t\bar{t}$  MC in Table 11, and we show the dependence of observed/predicted vs. the signal region requirements in Fig. 5. Based on these results, we apply the scale factors and uncertainties summarized in Table 13 to the predicted background from the  $p_T(\ell\ell)$  method. In [2], we have studied extensively the origin of the excess of observed vs. predicted events from this method. We found that it is due mostly to the  $W$  polarization, which results in a harder  $p_T$  distribution for the  $W$  neutrinos than charged leptons.

Table 11: Expected observed and predicted yields in  $1 \text{ fb}^{-1}$  for  $t\bar{t}$  MC for the  $p_T(\ell\ell)$  method applied to the 3 signal regions, and the ratio of the observed signal yield to the prediction. The quoted uncertainties are statistical only.

signal region	sample	predicted	observed	obs/pred
2010 signal region	madgraph	$28.2 \pm 2.5$	$38.3 \pm 2.4$	$1.36 \pm 0.15$
	powheg	$24.8 \pm 0.8$	$37.0 \pm 0.8$	$1.49 \pm 0.06$
high $y$ signal region	madgraph	$2.4 \pm 0.7$	$4.9 \pm 0.9$	$2.00 \pm 0.70$
	powheg	$2.3 \pm 0.2$	$4.2 \pm 0.3$	$1.82 \pm 0.22$
high $H_T$ signal region	madgraph	$2.9 \pm 0.8$	$3.8 \pm 0.8$	$1.31 \pm 0.43$
	powheg	$2.9 \pm 0.2$	$3.8 \pm 0.3$	$1.33 \pm 0.14$

As a validation of the  $p_T(\ell\ell)$  method, we also apply the background estimate to the  $H_T$  sideband region 125–300 GeV, where we expect the events to be dominated by background and where the higher event yields allow us to test the method with higher statistical precision. The results of the  $p_T(\ell\ell)$  method applied to  $t\bar{t}$  MC in the  $H_T$  sideband region with the  $y$  requirements corresponding to the 2010 signal region ( $y > 8.5 \text{ GeV}^{1/2}$ ) and the high  $y$  region

Table 12: Expected observed and predicted yields in  $1 \text{ fb}^{-1}$  for  $t\bar{t}$  MC for the  $p_T(\ell\ell)$  method for the control regions in the  $H_T$  sideband region  $125 < H_T < 300 \text{ GeV}$ , and the ratio of the observed signal yield to the prediction. The quoted uncertainties are statistical only, assuming Gaussian errors.

control region	sample	predicted	observed	obs/pred
$125 < H_T < 300 \text{ GeV}, y > 8.5 \text{ GeV}^{1/2}$	madgraph	$35.8 \pm 1.3$	$51.3 \pm 1.2$	$1.43 \pm 0.06$
	powheg	$33.4 \pm 0.4$	$47.3 \pm 0.4$	$1.42 \pm 0.02$
$125 < H_T < 300 \text{ GeV}, y > 13 \text{ GeV}^{1/2}$	madgraph	$3.4 \pm 0.4$	$4.4 \pm 0.4$	$1.29 \pm 0.19$
	powheg	$3.3 \pm 0.1$	$4.1 \pm 0.1$	$1.23 \pm 0.06$

( $y > 13 \text{ GeV}^{1/2}$ ) are given in Table 12. Based on these results we will apply a correction factor  $K_C = 1.4 \pm 0.1$  ( $K_C = 1.2 \pm 0.1$ ) to data for the loose (tight)  $y$  requirements in the  $H_T$  sideband region.

Table 13: Summary of correction factors and systematic uncertainties for the ABCD and  $p_T(\ell\ell)$  methods in the 3 signal regions.

signal region	ABCD	$p_T(\ell\ell)$
2010 signal region	$1.0 \pm 0.2$	$1.4 \pm 0.2$
high $y$ signal region	$1.3 \pm 0.3$	$1.7 \pm 0.3$
high $H_T$ signal region	$1.2 \pm 0.2$	$1.3 \pm 0.2$

### 9.3 Opposite-Flavor Subtraction

The opposite-flavor subtraction technique exploits the fact that in  $t\bar{t}$ , the flavor of the 2 leptons from  $W$  decay are uncorrelated. Hence we expect equal rates of same-flavor (SF)  $ee$  or  $\mu\mu$  vs. opposite-flavor (OF)  $e\mu$  lepton pairs. In SUSY, the lepton flavors may be correlated, producing an excess of SF over OF events. We use the observed yield in the OF final state to predict the yields in the SF final state according to:

$$N(ee) = \frac{1}{2R_{\mu e}} N(e\mu) \text{ and } N(\mu\mu) = \frac{R_{\mu e}}{2} N(e\mu)$$

where  $R_{\mu e}$  is the ratio of muon to electron selection efficiencies. This quantity is evaluated by taking the ratio of the number of observed  $Z \rightarrow \mu^+\mu^-$  to  $Z \rightarrow e^+e^-$  events, in the mass range 76-106 GeV with no jets or  $E_T^{\text{miss}}$  requirements (see Fig. 2). Alternatively, we can quantify the excess of SF vs. OF events with the quantity:

$$\Delta = R_{\mu e} N(ee) + \frac{1}{R_{\mu e}} N(\mu\mu) - N(e\mu), \quad (1)$$

which is predicted to be 0 for processes with uncorrelated lepton flavors. In order for this technique to work, the kinematic selection applied to events in all dilepton flavor channels must be the same, which is not the case for our default selection because the  $Z$  mass veto is applied only to same-flavor channels. Therefore when applying the OF subtraction technique we also apply the  $Z$  mass veto also to the  $e\mu$  channel.

We will apply this technique to both the high  $p_T$  dilepton trigger and dilepton- $H_T$  trigger data samples. In the following, we first apply the technique to  $t\bar{t}$  MC with high  $p_T$  leptons, and then to  $t\bar{t}$  MC with low  $p_T$  leptons.

#### 9.3.1 OF subtraction: Application to high $p_T$ lepton sample

We begin by applying the OF subtraction technique to  $t\bar{t}$  MC with leptons passing  $p_T > (20,10) \text{ GeV}$ . Here we extract  $R_{e\mu}$  by taking the ratio of  $Z \rightarrow \mu^+\mu^-$  vs.  $Z \rightarrow e^+e^-$  events in the window 76–106 GeV in DY MC. For data, we have verified that the contribution from fake leptons in the high lepton  $p_T$  signal regions is small using the data-driven fake rate method, hence we do not need to correct for fake leptons here. The results are summarized in Table 14, where we find values of  $\Delta$  consistent with 0, as expected.

#### 9.3.2 OF subtraction: Application to low $p_T$ lepton sample

In this section, we apply the OF subtraction technique to  $t\bar{t}$  MC with leptons passing  $p_T > (10,5) \text{ GeV}$  but not passing  $p_T > (20,10) \text{ GeV}$  (in order to remove overlap with the high lepton  $p_T$  sample). The OF subtraction in the low lepton  $p_T$  regime is complicated by 2 factors:



Table 14: Expected yields in  $1 \text{ fb}^{-1} t\bar{t}$  MC for the OF subtraction method, and the quantity  $\Delta$ , defined in Eq. 1. The quoted systematic uncertainty refers to that of  $R_{\mu e}$ .

region	sample	$N(ee)$	$N(\mu\mu)$	$N(e\mu)$	$\Delta$
preselection region	madgraph	$431.1 \pm 8.0$	$531.3 \pm 8.9$	$945.8 \pm 11.8$	$11.8 \pm 16.8 \text{ (stat)} \pm 1.1 \text{ (syst)}$
	powheg	$383.1 \pm 2.5$	$492.9 \pm 2.9$	$876.2 \pm 3.8$	$-7.0 \pm 5.4 \text{ (stat)} \pm 0.8 \text{ (syst)}$
2010 signal region	madgraph	$7.4 \pm 1.0$	$10.7 \pm 1.3$	$14.5 \pm 1.5$	$3.3 \pm 2.2 \text{ (stat)} \pm 0.04 \text{ (syst)}$
	powheg	$7.2 \pm 0.3$	$8.6 \pm 0.4$	$16.8 \pm 0.5$	$-1.1 \pm 0.7 \text{ (stat)} \pm 0.03 \text{ (syst)}$

- The ratio of muon to electron selection efficiencies  $R_{\mu e}$  increases significantly at low  $p_T$ , due to a drop in the electron selection efficiency.
- We reconstruct muons down to  $p_T > 5 \text{ GeV}$  but electrons only to  $p_T > 10 \text{ GeV}$ .

Our strategy is the following:

- Evaluate  $R_{\mu e}$  from  $t\bar{t}$  MC.
- Parameterize  $R_{\mu e}$  as a function of lepton  $p_T$ . For now we split in 2 bins,  $10 < p_T < 20 \text{ GeV}$  and  $p_T > 20 \text{ GeV}$ .
- For data, we will apply to  $R_{\mu e}$  a trigger efficiency correction and subtract the expected contribution from fake leptons from the data-driven fake rate method (but neither correction is performed for the MC studies in this section).
- We first apply the OF subtraction to the preselection region, and then to the signal region.

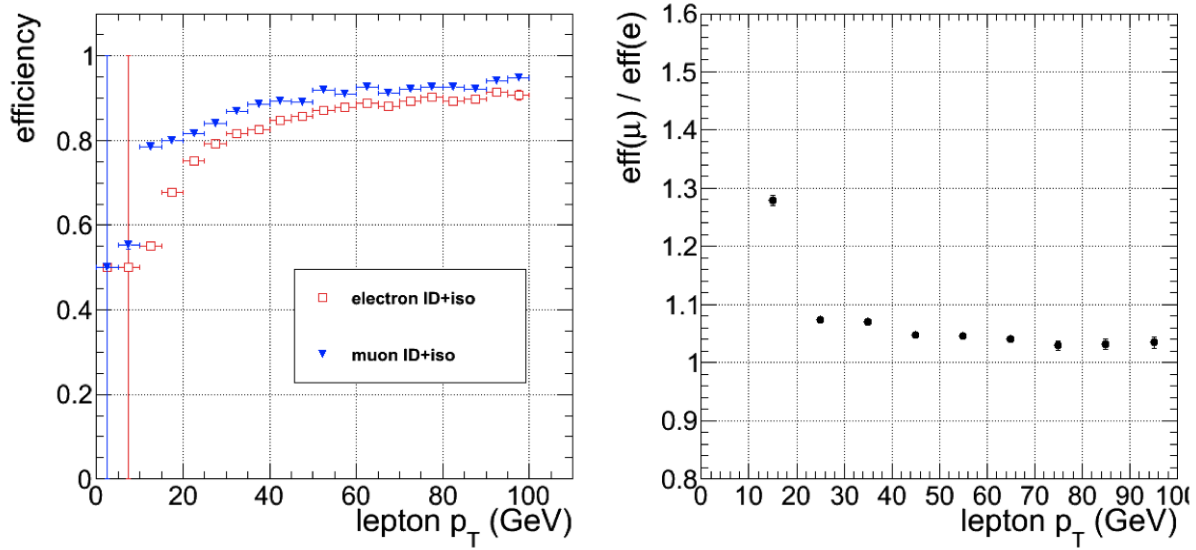


Figure 6: Left: the electron and muon selection efficiencies, as a function of lepton  $p_T$ , extracted from  $t\bar{t}$  MC. Right: the ratio  $R_{\mu e}$  of muon to electron selection efficiencies as a function of lepton  $p_T$ .

We begin by examining the dependence of  $R_{\mu e}$  on lepton  $p_T$ , as shown in Fig. 6. We find that  $R_{\mu e}$  increases in the region  $p_T$  10–20 GeV, but is roughly constant for  $p_T > 20 \text{ GeV}$ . Hence we take  $R_{\mu e}^{10-20} = 1.28$  for  $p_T$  10–20 GeV and  $R_{\mu e}^{>20} = 1.08$  for  $p_T > 20 \text{ GeV}$ , and assign a 5% systematic uncertainty.

Next, to take into account the fact the electrons and muons have a different  $p_T$  range, we split the low  $p_T$  sample into events with leptons passing  $p_T > (10,10) \text{ GeV}$ , denoted in the following as (10,10), and events with leptons passing  $p_T > (10,5) \text{ GeV}$  but not passing  $p_T > (10,10) \text{ GeV}$ , denoted in the following as (10,5). We find the following relations, expected for backgrounds with uncorrelated lepton flavors:

- $N(ee)(10, 10) = 1/(2R_{\mu e}^{10-20})N(e\mu)(10, 10)$
- $N(\mu\mu)(10, 10) = (R_{\mu e}^{10-20}/2)N(e\mu)(10, 10)$
- $N(\mu\mu)(10, 5) = R_{\mu e}^{>20}N(e\mu)(10, 5)$

Note that for (10,10) events, both leptons are in the range  $p_T$  10–20 GeV, hence the relevant efficiency ratio is  $R_{\mu e}^{10-20}$ . For (10,5) events, both  $ee$  and  $\mu\mu$  events have a muon with  $p_T$  5–10 GeV and an additional lepton with  $p_T > 10$  GeV. In most cases the leading lepton has  $p_T > 20$  GeV, hence we use  $R_{\mu e}^{>20}$  for these events.

In this case we find the following expression for  $\Delta$ , quantifying the excess of SF vs. OF yields:

$$\Delta = R_{\mu e}^{10-20}N(ee)(10, 10) + 1/R_{\mu e}^{10-20}N(\mu\mu)(10, 10) + 1/R_{\mu e}^{>20}N(\mu\mu)(10, 5) - N(e\mu)(10, 10) - N(e\mu)(10, 5) \quad (2)$$

In Table 15 we apply this technique to  $t\bar{t}$  MC. As expected, we find  $\Delta$  consistent with 0.

Table 15: Expected yields in  $1 \text{ fb}^{-1}$   $t\bar{t}$  MC for the OF subtraction method in the low lepton  $p_T$  regime, and the quantity  $\Delta$ , defined in Eq. 2. The quoted systematic uncertainty refers to that of  $R_{\mu e}$ .

region	sample	$N(ee)(10, 10)$	$N(\mu\mu)(10, 10)$	$N(e\mu)(10, 10)$	$N(\mu\mu)(10, 5)$	$N(e\mu)(10, 5)$	$\Delta$
preselection region	madgraph	$3.4 \pm 0.7$	$4.9 \pm 0.9$	$6.4 \pm 1.0$	$22.9 \pm 1.8$	$18.2 \pm 1.6$	$4.8 \pm 2.8 \text{ (stat)} \pm 1.0 \text{ (syst)}$
	powheg	$2.5 \pm 0.2$	$4.4 \pm 0.3$	$7.0 \pm 0.3$	$19.0 \pm 0.6$	$16.6 \pm 0.5$	$0.6 \pm 0.9 \text{ (stat)} \pm 0.9 \text{ (syst)}$
2010 signal region	madgraph	$0.0 \pm 0.0$	$0.4 \pm 0.3$	$0.6 \pm 0.3$	$1.0 \pm 0.4$	$0.7 \pm 0.3$	$-0.0 \pm 0.6 \text{ (stat)} \pm 0.1 \text{ (syst)}$
	powheg	$0.1 \pm 0.0$	$0.2 \pm 0.1$	$0.4 \pm 0.1$	$1.4 \pm 0.2$	$1.1 \pm 0.1$	$0.1 \pm 0.2 \text{ (stat)} \pm 0.1 \text{ (syst)}$

## 10 Results

### 10.1 Background estimate from the ABCD method

The data yields in the four regions are summarized in Tables 16-18 for the 3 signal regions. The ABCD background prediction  $N_A \times N_C/N_B$  is scaled by the correction factors determined in Sec. 9, as summarized in Table 13. The results of the ABCD predictions are summarized in Table 19.

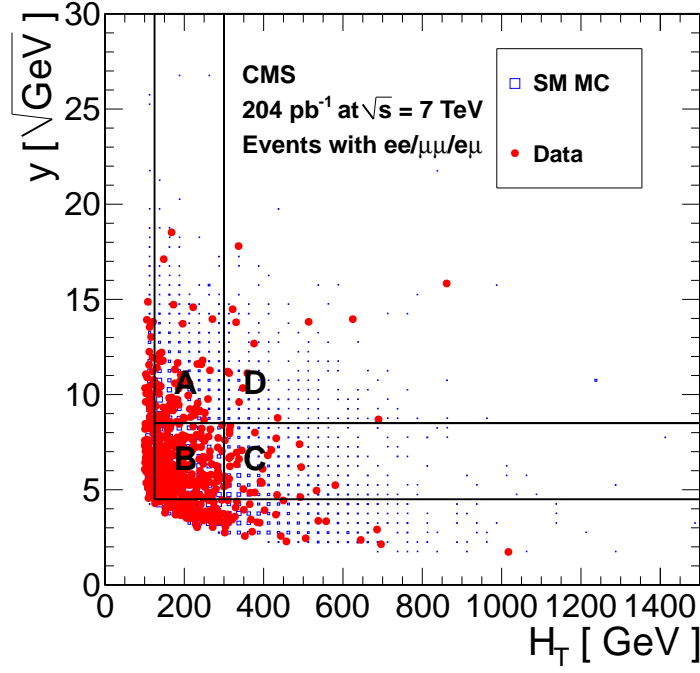


Figure 7: Distributions of  $y$  vs.  $H_T$  for SM Monte Carlo and data. The 2010 signal region boundaries are overlaid.

Table 16: Data yields in the four regions of Figure 7 for the 2010 signal region, as well as the predicted yield in region D given by  $A \times C / B$ . The quoted uncertainty on the prediction in data is statistical only, assuming Gaussian errors. We also show the SM Monte Carlo expectations with statistical errors only.

sample	A	B	C	D	$A \times B / C$
$t\bar{t}$	$48.8 \pm 1.4$	$184.1 \pm 2.7$	$31.9 \pm 1.1$	$7.3 \pm 0.5$	$8.5 \pm 0.4$
DY	$0.5 \pm 0.4$	$8.2 \pm 1.5$	$0.7 \pm 0.5$	$1.0 \pm 0.6$	$0.0 \pm 0.0$
$W^+W^-$	$0.6 \pm 0.1$	$1.6 \pm 0.1$	$0.1 \pm 0.0$	$0.2 \pm 0.0$	$0.1 \pm 0.0$
$W^\pm Z^0$	$0.1 \pm 0.0$	$0.3 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.1 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$1.9 \pm 0.1$	$5.6 \pm 0.2$	$0.2 \pm 0.0$	$0.1 \pm 0.0$	$0.1 \pm 0.0$
$W + \text{jets}$	$0.6 \pm 0.6$	$1.2 \pm 0.6$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
Total SM MC	$52.6 \pm 1.6$	$201.2 \pm 3.2$	$33.1 \pm 1.2$	$8.6 \pm 0.8$	$8.6 \pm 0.4$
data	72	238	29	14	$8.8 \pm 2.0$

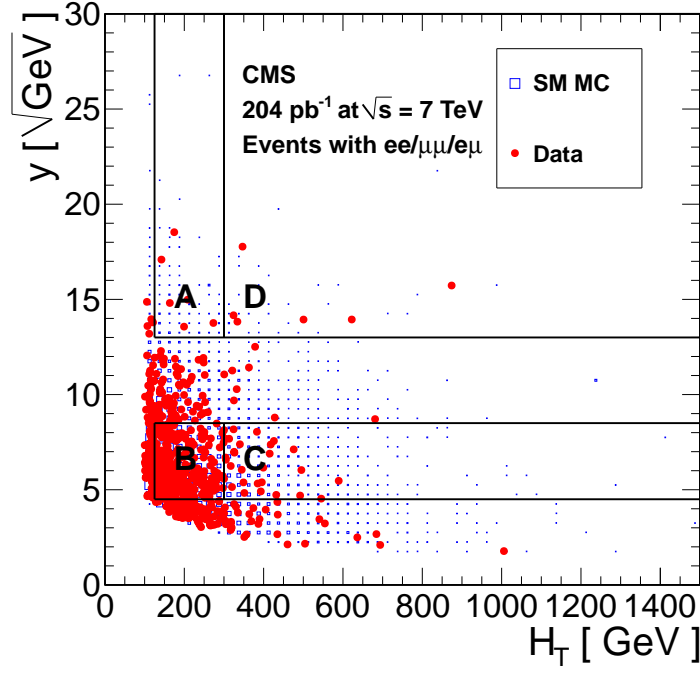


Figure 8: Distributions of  $y$  vs.  $H_T$  for SM Monte Carlo and data. The high  $y$  signal region boundaries are overlaid.

Table 17: Data yields in the four regions of Figure 8 for the high  $y$  signal region, as well as the predicted yield in region D given by  $A \times C / B$ . The quoted uncertainty on the prediction in data is statistical only, assuming Gaussian errors. We also show the SM Monte Carlo expectations with statistical uncertainties.

sample	A	B	C	D	$A \times B / C$
$t\bar{t}$	$3.6 \pm 0.4$	$184.1 \pm 2.7$	$31.9 \pm 1.1$	$1.2 \pm 0.2$	$0.6 \pm 0.1$
DY	$0.3 \pm 0.3$	$8.2 \pm 1.5$	$0.7 \pm 0.5$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W^+W^-$	$0.1 \pm 0.0$	$1.6 \pm 0.1$	$0.1 \pm 0.0$	$0.1 \pm 0.0$	$0.0 \pm 0.0$
$W^\pm Z^0$	$0.0 \pm 0.0$	$0.3 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$Z^0 Z^0$	$0.0 \pm 0.0$	$0.1 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
single top	$0.2 \pm 0.0$	$5.6 \pm 0.2$	$0.2 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
$W + \text{jets}$	$0.0 \pm 0.0$	$1.2 \pm 0.6$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
Total SM MC	$4.1 \pm 0.5$	$201.2 \pm 3.2$	$33.1 \pm 1.2$	$1.3 \pm 0.2$	$0.7 \pm 0.1$
data	6	238	29	6	$0.7 \pm 0.3$

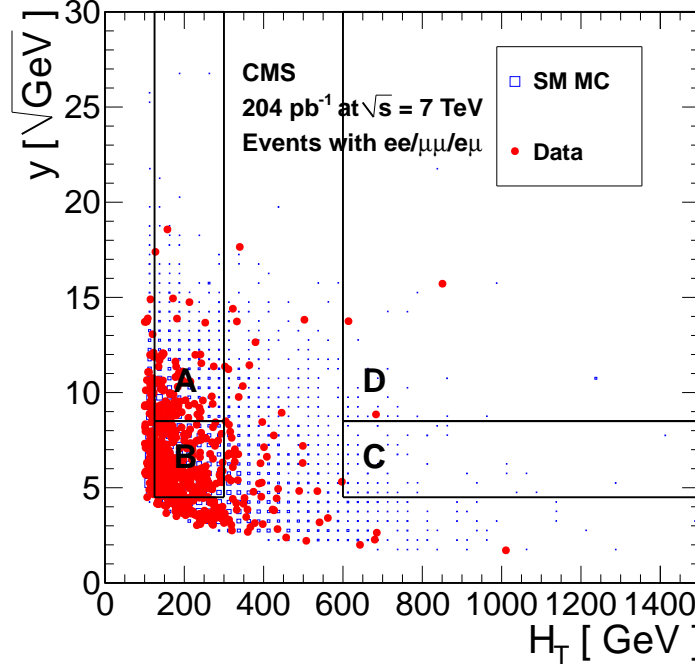


Figure 9: Distributions of  $y$  vs.  $H_T$  for SM Monte Carlo and data. The high  $H_T$  signal region boundaries are overlaid.

Table 18: Data yields in the four regions of Figure 9 for the high  $H_T$  signal region, as well as the predicted yield in region D given by  $A \times C / B$ . The quoted uncertainty on the prediction in data is statistical only, assuming Gaussian errors. Since the yield in region C is 0, we assess as the uncertainty the prediction corresponding to 1 observed event in 1. We also show the SM Monte Carlo expectations with statistical uncertainties.

sample	A	B	C	D	$A \times B / C$
ttall	$48.8 \pm 1.4$	$184.1 \pm 2.7$	$2.2 \pm 0.3$	$0.7 \pm 0.2$	$0.6 \pm 0.1$
DY	$0.5 \pm 0.4$	$8.2 \pm 1.5$	$0.0 \pm 0.0$	$0.4 \pm 0.4$	$0.0 \pm 0.0$
WW	$0.6 \pm 0.1$	$1.6 \pm 0.1$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
WZ	$0.1 \pm 0.0$	$0.3 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
ZZ	$0.0 \pm 0.0$	$0.1 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
t	$1.9 \pm 0.1$	$5.6 \pm 0.2$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
wjets	$0.6 \pm 0.6$	$1.2 \pm 0.6$	$0.0 \pm 0.0$	$0.0 \pm 0.0$	$0.0 \pm 0.0$
Total SM MC	$52.6 \pm 1.6$	$201.2 \pm 3.2$	$2.2 \pm 0.3$	$1.2 \pm 0.5$	$0.6 \pm 0.1$
data	72	238	0	3	$0.0 \pm 0.3$

Table 19: Summary of results of the ABCD method, applied to the 3 signal regions.

Signal Region	$N_A \times N_C/N_B$	correction factor	prediction
2010 signal region	$8.8 \pm 2.0$	$1.0 \pm 0.2$	$8.8 \pm 2.0$ (stat) $\pm 1.8$ (syst)
high $y$ signal region	$0.7 \pm 0.3$	$1.3 \pm 0.2$	$0.9 \pm 0.4$ (stat) $\pm 0.2$ (syst)
high $H_T$ signal region	$0.0 \pm 0.3$	$1.2 \pm 0.2$	$0.0 \pm 0.4$ (stat) $\pm 0.1$ (syst)

## 10.2 Background estimate from the $P_T(\ell\ell)$ method

Table 20: Summary of results of the dilepton  $p_T$  template method applied to the 3 signal regions. The quantities indicated in the table are discussed in the text. The quoted statistical uncertainty in the prediction  $N_P$  is due to that of  $N(D')$ , the quoted systematic uncertainty includes that of  $N(DY)$  and  $K_C$ .

Signal Region	$N(D')$	$N(DY)$	$K$	$K_C$	$N_P$
2010 signal region	3	$0.4 \pm 0.3$	1.5	$1.4 \pm 0.2$	$5.5 \pm 3.6$ (stat) $\pm 1.0$ (syst)
high $y$ signal region	2	$0.1 \pm 0.1$	1.5	$1.7 \pm 0.3$	$4.8 \pm 3.6$ (stat) $\pm 0.9$ (syst)
high $H_T$ signal region	0	$0.0 \pm 0.1$	1.3	$1.3 \pm 0.2$	$0.0 \pm 1.7$ (stat) $\pm 0.3$ (syst)

For each signal region D, we count the number of events falling in the region D', which is defined using the same requirements as D but switching the  $y$  requirement to a  $p_T(\ell\ell)/\sqrt{H_T}$  requirement. We subtract off the expected DY contribution using the data-driven  $R_{out/in}$  technique, using  $R_{out/in} = 0.13 \pm 0.07$ . We then scale this yield by 2 corrections factors:  $K$ , the  $E_T^{\text{miss}}$  acceptance correction factor, and  $K_C$ , the correction factor determined in Sec. 9. Our final prediction  $N_P$  is given by:

$$N_P = (N(D') - N(DY)) \times K \times K_C,$$

as summarized in Table 20, and displayed in Figs. 10-12. Note that we currently extract  $K$  from MC, and verify that it is consistent with the value extracted from data. We may instead use  $K$  extracted from data in the future, as the data sample increases and the statistical uncertainty in  $K$  decreases. We also perform the  $p_T(\ell\ell)$  method in the  $H_T$  sideband region 125–300 GeV, as a validation of the technique in a high statistics sample which is expected to be dominated by background. The results are summarized in Table 21. For both the loose ( $y > 8.5 \text{ GeV}^{1/2}$ ) and tight ( $y > 13 \text{ GeV}^{1/2}$ ) control regions, the observed yields are consistent with the predictions from the  $p_T(\ell\ell)$  method.

Table 21: Summary of results of the dilepton  $p_T$  template method applied to the  $H_T$  sideband control region 125–300 GeV. The quantities indicated in the table are discussed in the text. The quoted statistical uncertainty in the prediction  $N_P$  is due to that of  $N(D')$ , the quoted systematic uncertainty includes that of  $N(DY)$  and  $K_C$ . The predictions are compare with the observed yield  $N_O$ .

Control Region	$N(D')$	$N(DY)$	$K$	$K_C$	$N_P$	$N_O$
$125 < H_T < 300 \text{ GeV}, y > 8.5 \text{ GeV}^{1/2}$	32	$1.7 \pm 0.9$	1.7	$1.4 \pm 0.1$	$71 \pm 13$ (stat) $\pm 5.5$ (syst)	72
$125 < H_T < 300 \text{ GeV}, y > 13 \text{ GeV}^{1/2}$	5	$0.5 \pm 0.3$	1.7	$1.2 \pm 0.1$	$9.0 \pm 4.5$ (stat) $\pm 1.0$ (syst)	6

## 10.3 Background estimate from OF subtraction

The results of the OF subtraction technique applied to the high  $p_T$  dilepton trigger sample are summarized in Table 22. We evaluate the quantity  $\Delta = R_{\mu e} N(ee) + \frac{1}{R_{\mu e}} N(\mu\mu) - N(e\mu)$  with  $R_{\mu e} = 1.12 \pm 0.05$  extracted from the ratio of  $Z \rightarrow \mu^+\mu^-$  vs.  $Z \rightarrow e^+e^-$  events in data. We perform the OF subtraction first in the preselection region, and find  $\Delta$  consistent with 0, as expected. We then perform the OF subtraction in all 3 signal regions, and do not observe any excess of same-flavor vs. opposite-flavor events.

For the dilepton- $H_T$  trigger sample, we observe only 1 event in the 2010 signal region, consistent with MC expectations, and no events in either the high  $y$  or high  $H_T$  signal regions. In the case of an excess of events at low lepton  $p_T$ , we will perform the OF subtraction technique of Sec. 9.3.2.

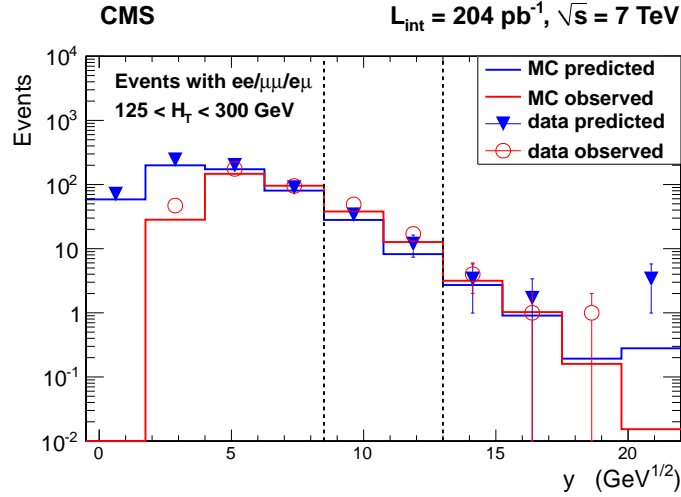


Figure 10: Distributions of  $p_T(\ell\ell)/\sqrt{H_T}$  (predicted) and  $y$  (observed) for SM MC and data, for the  $H_T$  sideband region 125–300 GeV. The vertical dashed lines indicate the loose ( $y > 8.5 \text{ GeV}^{1/2}$ ) and tight ( $y > 13 \text{ GeV}^{1/2}$ ) control regions.

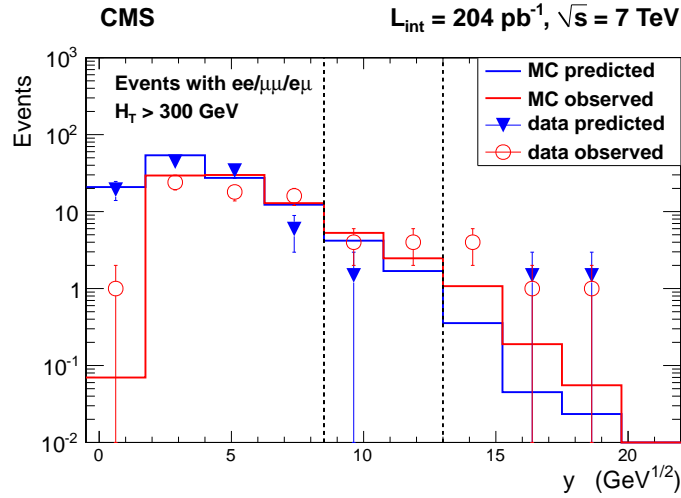


Figure 11: Distributions of  $p_T(\ell\ell)/\sqrt{H_T}$  (predicted) and  $y$  (observed) for SM MC and data, for the region  $H_T > 300 \text{ GeV}$ . The vertical dashed lines indicate the 2010 signal region ( $y > 8.5 \text{ GeV}^{1/2}$ ) and high  $y$  signal region ( $y > 13 \text{ GeV}^{1/2}$ ).

## 10.4 Summary of results

A summary of our results is presented in Table 23. We observe a slight excess of events with respect to MC and data-driven predictions in our loose 2010 signal region. The excess with respect to MC and ABCD predictions is enhanced after tightening the  $y$  requirement, but the observed yield shows no significant excess with respect to the  $p_T(\ell\ell)$  method prediction. There is also a slight excess of events with respect to MC and data-driven predictions for the high  $H_T$  signal region. We do not observe any excess of same-flavor vs. opposite-flavor events.

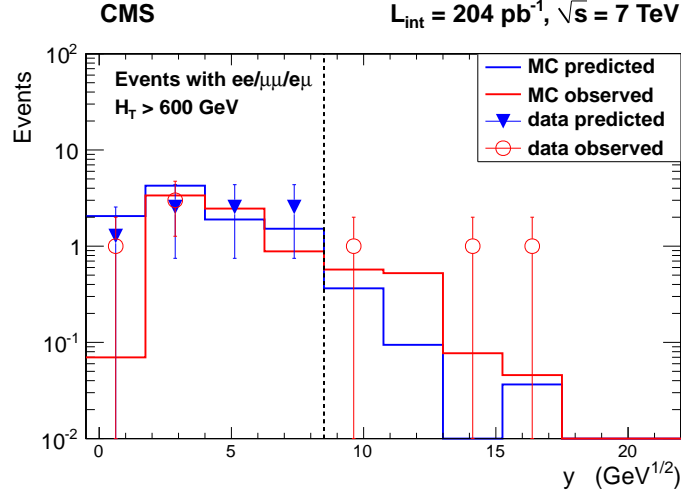


Figure 12: Distributions of  $p_T(\ell\ell)/\sqrt{H_T}$  (predicted) and  $y$  (observed) for SM MC and data, for the region  $H_T > 600$  GeV. The vertical dashed line indicates the high  $H_T$  signal region.

Table 22: Summary of results for the OF subtraction technique. The quantity  $\Delta = R_{\mu e}N(ee) + \frac{1}{R_{\mu e}}N(\mu\mu) - N(e\mu)$  is quoted with  $R_{\mu e} = 1.12 \pm 0.05$ . The quoted systematic uncertainty corresponds to that of  $R_{\mu e}$ . The  $e\mu$  yields differ from those previously quoted because the  $Z$  mass veto is included here.

region	$N(ee)$	$N(\mu\mu)$	$N(e\mu)$	$\Delta$
preselection region	113	122	258	$-22.5 \pm 22.3$ (stat) $\pm 0.8$ (syst)
2010 signal region	4	3	5	$2.2 \pm 3.5$ (stat) $\pm 0.1$ (syst)
high $y$ signal region	3	0	2	$1.4 \pm 2.4$ (stat) $\pm 0.1$ (syst)
high $H_T$ signal region	1	0	1	$0.1 \pm 1.5$ (stat) $\pm 0.0$ (syst)

Table 23: Summary of the observed and predicted yields in the 3 signal regions. MC errors are statistical only. The systematic uncertainty on the ABCD and  $p_T(\ell\ell)$  method is from the scaling factors from MC closure only. For the OF subtraction, the quantity  $\Delta = R_{\mu e}N(ee) + \frac{1}{R_{\mu e}}N(\mu\mu) - N(e\mu)$  is quoted; the systematic uncertainty here is from the ratio of muon to electron selection efficiencies.

	2010 signal region	high $y$ signal region	high $H_T$ signal region
Observed yield	14	6	3
MC prediction	$8.6 \pm 0.8$	$1.3 \pm 0.2$	$1.2 \pm 0.5$
ABCD prediction	$8.8 \pm 2.0$ (stat) $\pm 1.8$ (syst)	$0.9 \pm 0.4$ (stat) $\pm 0.2$ (syst)	$0.0 \pm 0.4$ (stat) $\pm 0.1$ (syst)
$p_T(\ell\ell)$ prediction	$5.5 \pm 3.6$ (stat) $\pm 1.0$ (syst)	$4.8 \pm 3.6$ (stat) $\pm 0.9$ (syst)	$0.0 \pm 1.7$ (stat) $\pm 0.3$ (syst)
OF subtraction ( $\Delta$ )	$2.2 \pm 3.5$ (stat) $\pm 0.1$ (syst)	$1.4 \pm 2.4$ (stat) $\pm 0.1$ (syst)	$0.1 \pm 1.5$ (stat) $\pm 0.0$ (syst)



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## Appendix A Fakeable Object Definitions

We estimate the contributions from leptons not originating from  $W/Z$  decay (fake leptons) using the data-driven fake rate method [4]. We define the following ‘fakeable object’ selections, by taking the electron and muon requirements listed in Sec. 3 and loosening the following requirements:

- electrons

- $d_0 < 0.2 \text{ cm}$

- $Iso \equiv E_T^{\text{iso}}/p_T < 0.4$ ,  $E_T^{\text{iso}}$  is defined as the sum of transverse energy/momentum deposits in ecal, hcal, and tracker, in a cone of 0.3 A 1 GeV pedestal is subtracted from the ecal energy deposition in the EB, however the ecal energy is never allowed to go negative.

- muons

- $d_0 < 0.2 \text{ cm}$

- $\chi^2/\text{ndof of global fit} < 50$

- $Iso \equiv E_T^{\text{iso}}/p_T < 0.4$ ,  $E_T^{\text{iso}}$  is defined as the sum of transverse energy/momentum deposits in ecal, hcal, and tracker, in a cone of 0.3

## Appendix B The ABCD' Technique

We have developed a novel technique, based on the ABCD technique which we perform in the plane of  $y$  vs.  $H_T$ , which allows us to estimate the background in a signal region defined in the  $E_T^{\text{miss}}$  vs.  $H_T$  plane. We refer to this as the ABCD' technique.

First, we extract the  $y$  and  $H_T$  distributions  $f(y)$  and  $g(H_T)$  from data, using events from control regions which we expect to be dominated by background. Under the assumption that  $y$  and  $H_T$  are weakly-correlated (the same assumption which allows the use of the ABCD technique), we can predict the distribution of events in the  $y$  vs.  $H_T$  plane as:

$$\frac{\partial^2 N}{\partial y \partial H_T} = f(y)g(H_T) \quad (3)$$

Once the distribution of events in the  $y$  vs.  $H_T$  plane is known, the number of events falling in any region of this plane can be deduced. In particular, we can deduce the number of events falling in a region defined by requirements on  $E_T^{\text{miss}}$  and  $H_T$ .

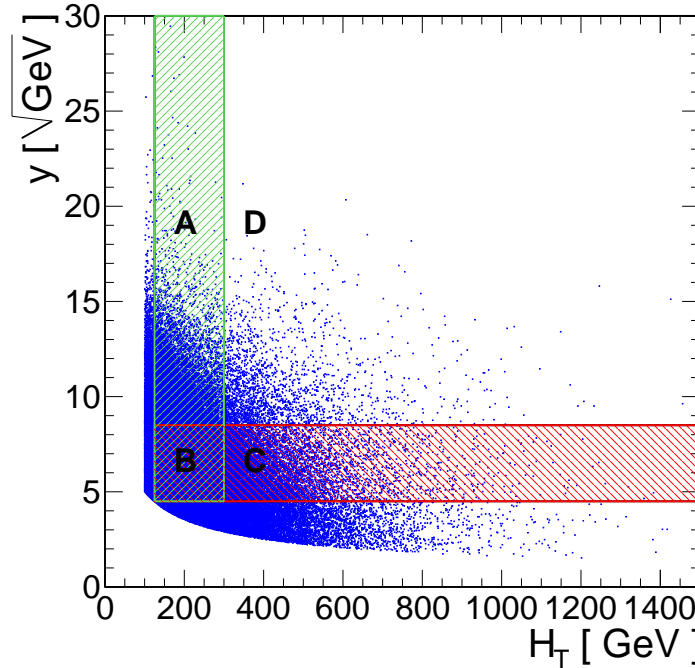


Figure 13: Distributions of  $y$  vs.  $H_T$  for  $t\bar{t}$  MC. The  $f(y)$  and  $g(H_T)$  functions are measured using events in the green and red shaded areas, respectively.

In this section, we study the ABCD' technique by applying it to  $t\bar{t}$  MC (we use the powheg sample which has 10 times the number of dilepton events as the madgraph sample). As a cross-check, we first use the ABCD' technique to estimate the background in the 2010 signal region defined as  $y > 8.5 \text{ GeV}^{1/2}$  and  $H_T > 300 \text{ GeV}$ , which may be compared to the prediction of the standard ABCD technique. We measure the  $f(y)$  and  $g(H_T)$  distributions using events in the regions indicated in Fig. 13, yielding the distributions shown in Fig. 14. Next, we randomly sample values of  $y$  and  $H_T$  from these distributions; each pair of  $y$  and  $H_T$  values is a pseudo-event. We generate 1 million pseudo-events, and find the ratio  $R_{S/C}$ , the ratio of the number of pseudo-events falling in the 2010 signal region (ie. region D) to the number of pseudo-events falling in a control region, defined as the OR of the A, B and C regions. We then multiply this ratio by the number of  $t\bar{t}$  MC events which fall in the control region to get the predicted yield, ie.  $N_{\text{pred}} = R_{S/C} \times N(\text{control})$ . The results are summarized in Table 24, which show that the prediction of the ABCD' method is consistent with that of the ABCD method within the statistical uncertainty.

We next apply the ABCD' technique to estimate the background in the regions:

- SR1:  $E_T^{\text{miss}} > 275 \text{ GeV}$ ,  $H_T > 300 \text{ GeV}$

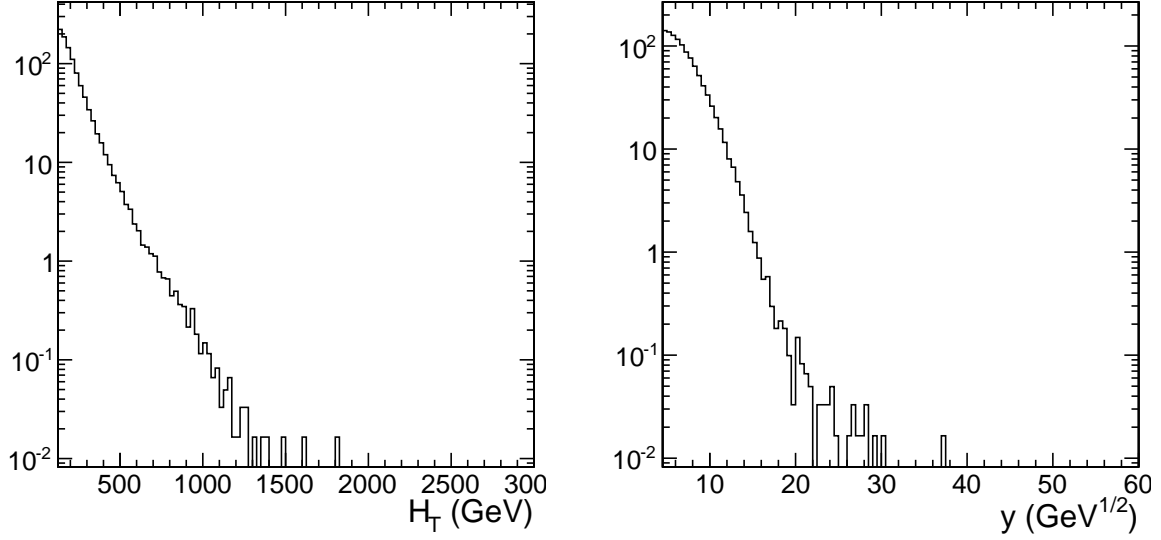


Figure 14: The distributions  $f(y)$  and  $g(H_T)$  extracted from  $t\bar{t}$  MC.

433 • SR2:  $E_T^{\text{miss}} > 200$  GeV,  $H_T > 600$  GeV.

434 Note that we are unable to predict the yield in this region using the standard ABCD technique, since  $E_T^{\text{miss}}$  and  
 435  $H_T$  are not weakly correlated. The signal regions are shown in Fig. 15. There is a sizable overlap between SR2  
 436 and region C, hence when estimating the background for this signal region we restrict the control region used to  
 437 measure  $g(H_T)$  and to determine  $N(\text{control})$  to  $4.5 < y < 6.5$   $\text{GeV}^{1/2}$ . As summarized in Table 24, we find  
 438 agreement between the observed and predicted yields in these signal regions within  $(25 \pm 8)\%$  and  $(3 \pm 5)\%$  for  
 439 SR1 and SR2, respectively.

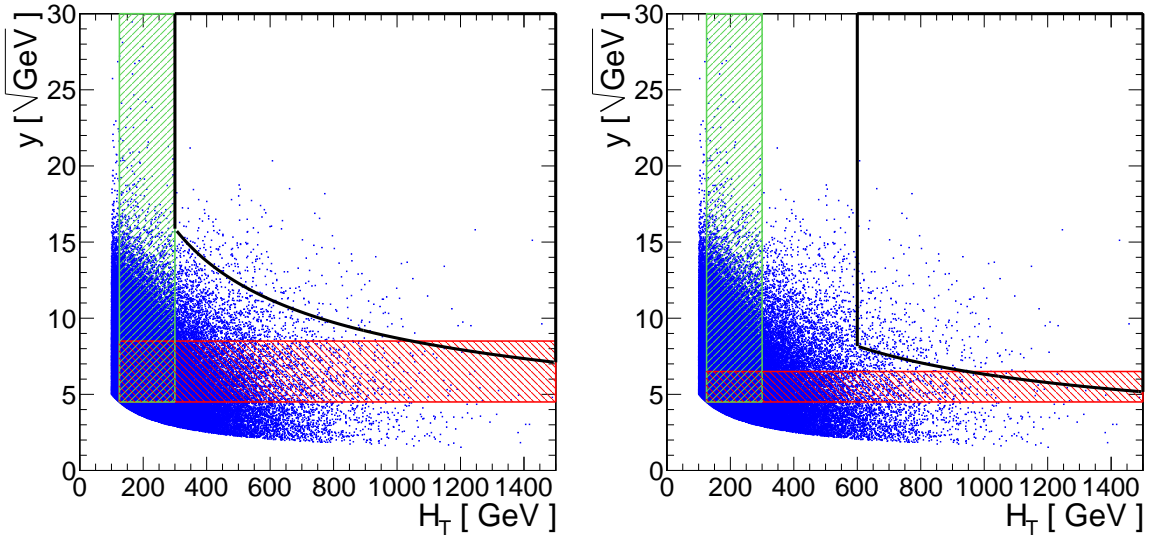


Figure 15: Distributions of  $y$  vs.  $H_T$  for  $t\bar{t}$  MC. The signal regions  $E_T^{\text{miss}} > 275$  GeV,  $H_T > 300$  GeV (left) and  $E_T^{\text{miss}} > 200$  GeV,  $H_T > 600$  GeV (right) are indicated with thick black lines. The  $f(y)$  and  $g(H_T)$  functions are measured using events in the green and red shaded areas, respectively.

Table 24: Summary of results expected results of the ABCD' method for  $1 \text{ fb}^{-1}$  using  $t\bar{t}$  MC. The quantities  $R_{S/C}$  and  $N(\text{control})$  are discussed in the text. The prediction of the ABCD' technique (ABCD' pred) is compared with the observed signal yield (observed) and where applicable, with the prediction of the ABCD technique (ABCD pred). The errors in ABCD' pred and observed/ABCD' pred include only the statistical uncertainty in the observed yield. **will update after doing stat uncertainty for prediction**

	2010 signal region	$E_T^{\text{miss}} > 275 \text{ GeV}, H_T > 300 \text{ GeV}$	$E_T^{\text{miss}} > 200 \text{ GeV}, H_T > 600 \text{ GeV}$
$R_{S/C}$	$3.5 \times 10^{-2}$	$2.9 \times 10^{-3}$	$5.1 \times 10^{-3}$
$N(\text{control})$	1239	1239	1187
ABCD' pred	43.4	3.6	6.0
observed	$37.0 \pm 0.8$	$4.5 \pm 0.3$	$6.2 \pm 0.3$
observed/ABCD' pred	$0.85 \pm 0.02$	$1.25 \pm 0.08$	$1.03 \pm 0.05$
ABCD pred	$43.0 \pm 0.6$	N/A	N/A

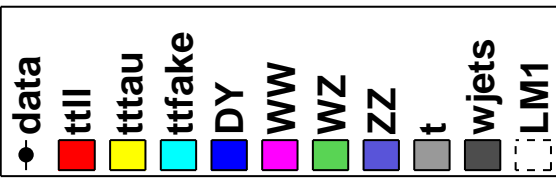
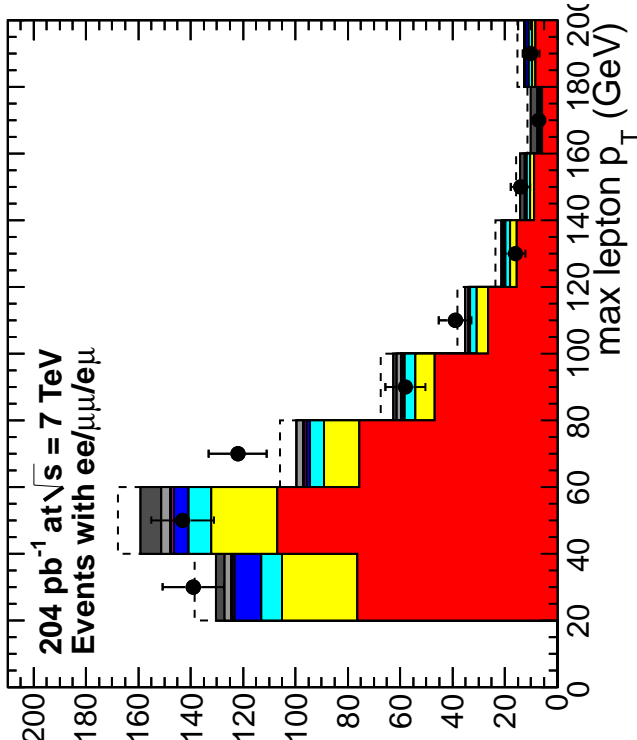
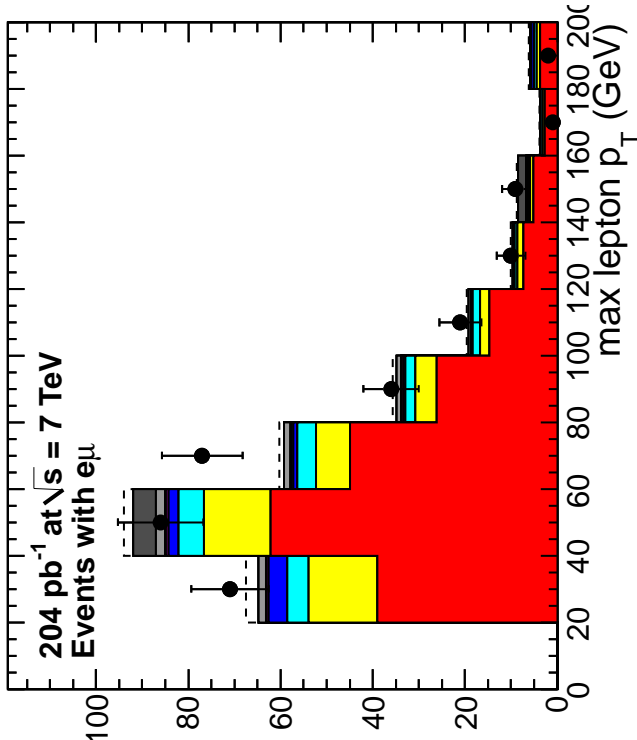
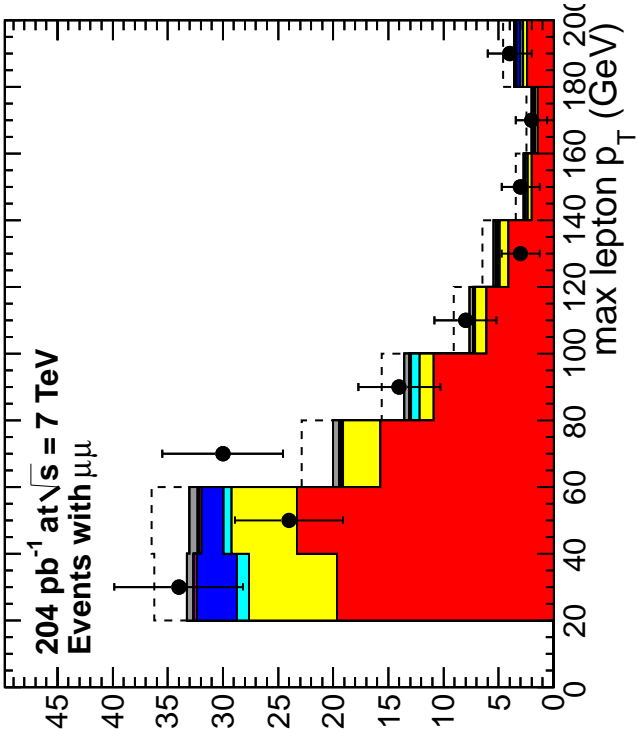
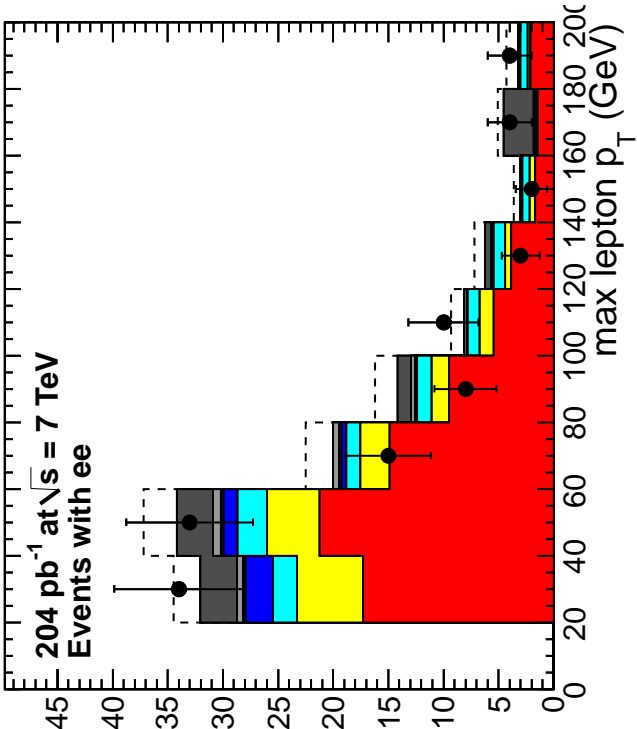
## Appendix C Data/MC Comparison: Preselection Region

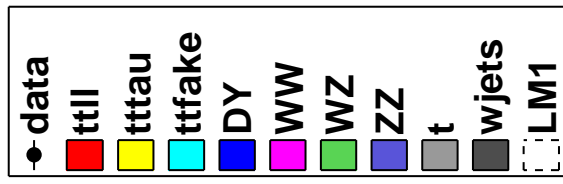
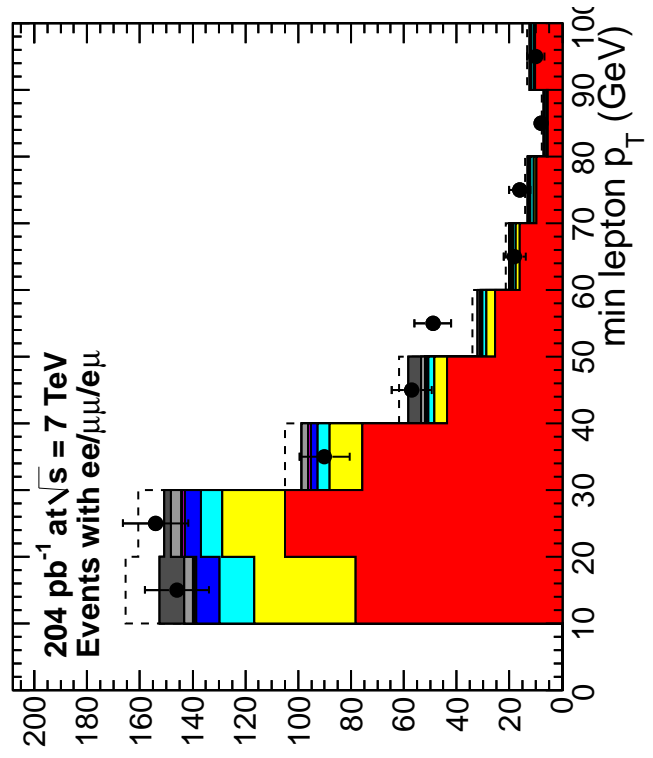
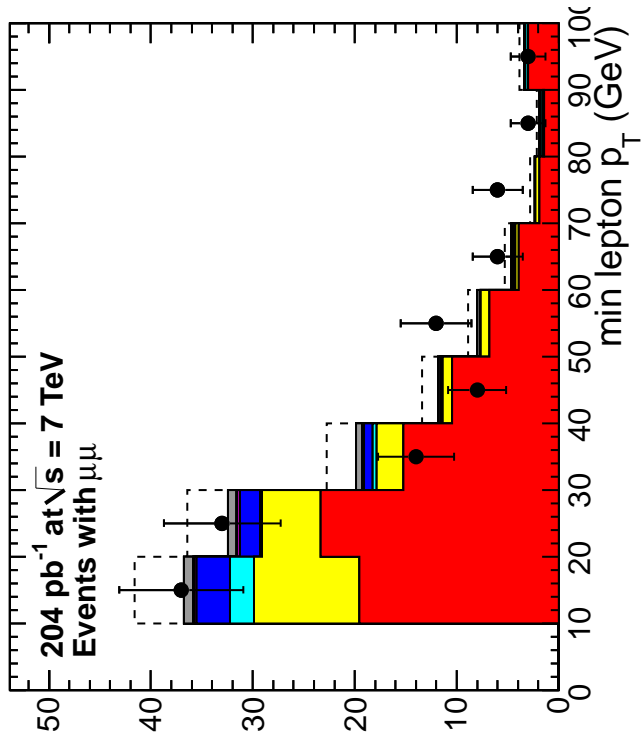
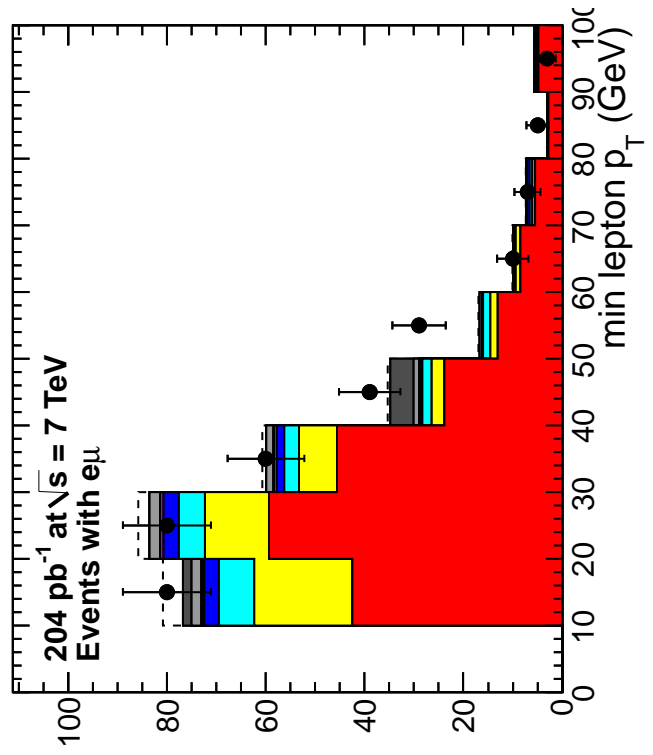
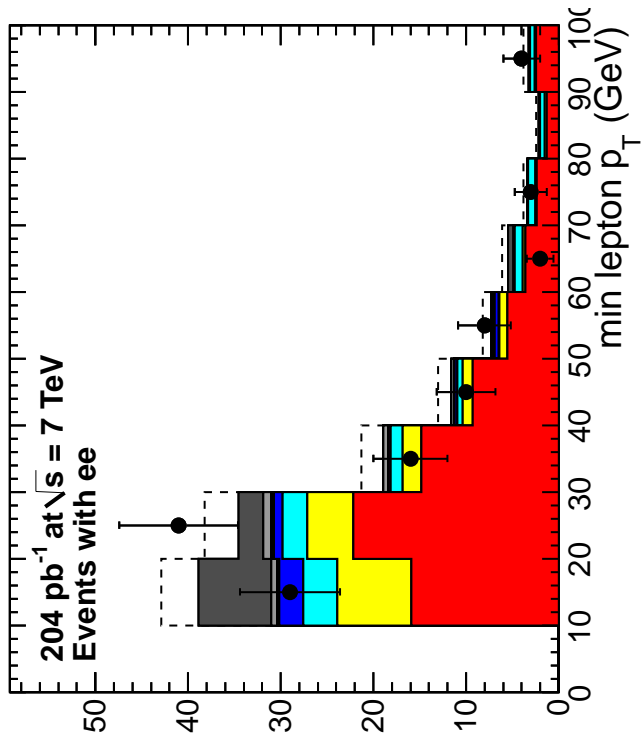
Here we compare data and MC distributions for data passing the preselection requirements. The high  $p_T$  dilepton trigger data is used.

The meaning of most of the variables plotted in the following figures should be obvious. There are some exceptions that we explain below:

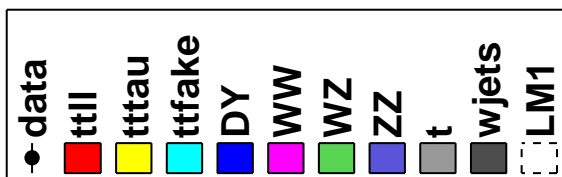
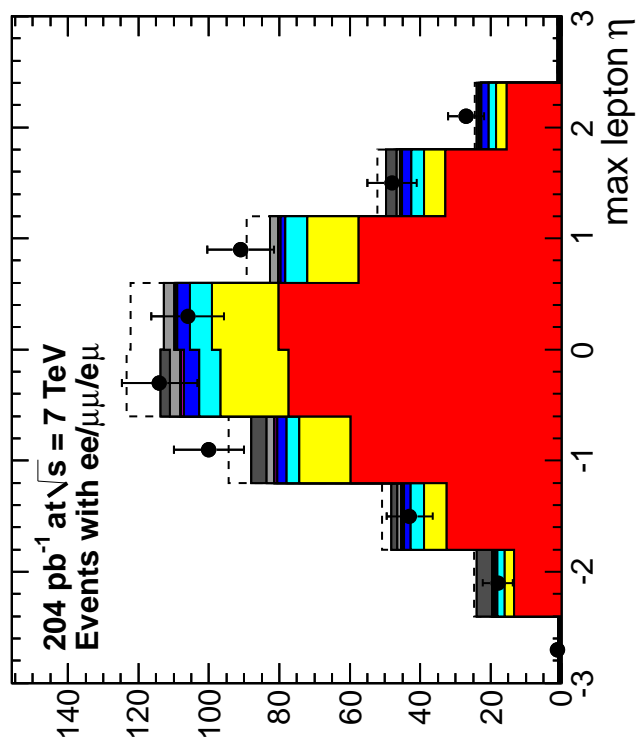
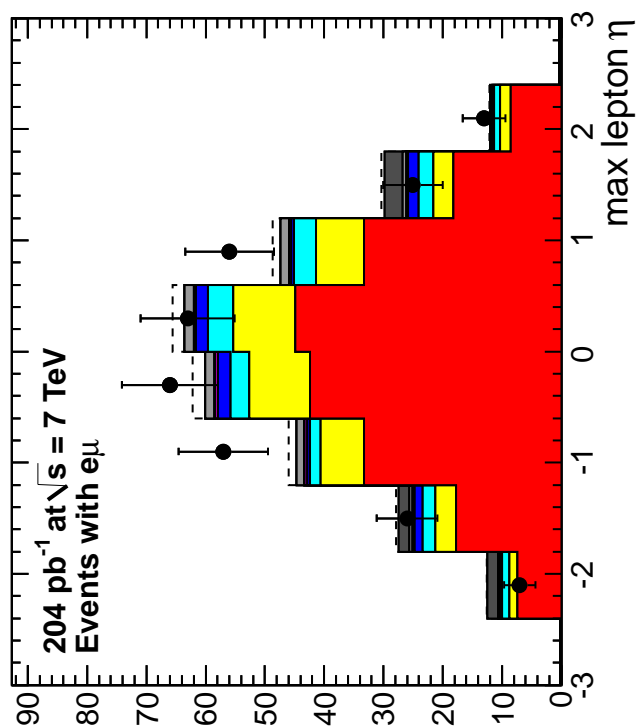
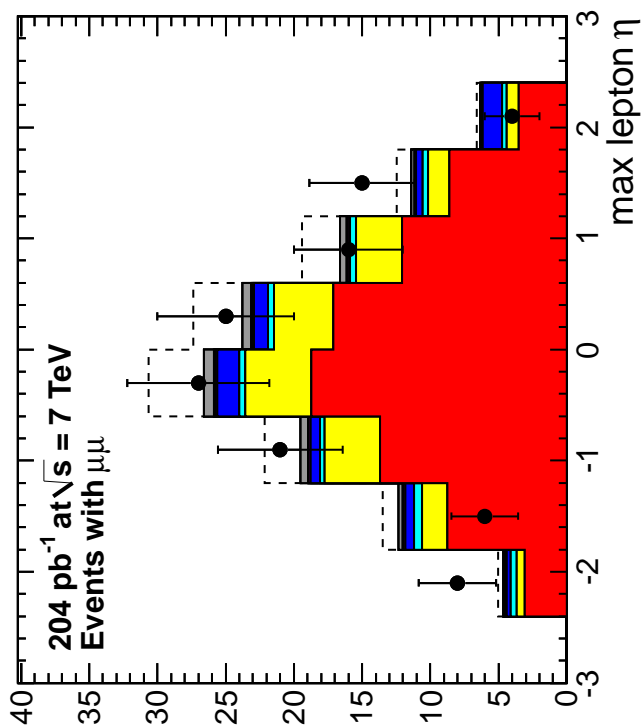
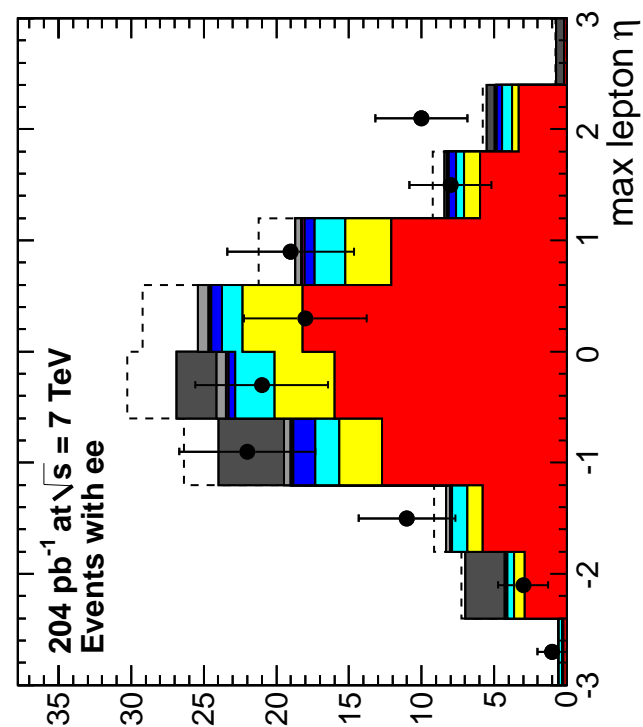
The  $t\bar{t} \rightarrow \text{fake}$  and  $W + \text{jets}$  samples are scaled here by 3.8, which is the ratio of the predicted contribution from fake leptons from the fake rate method to the MC expectation. All MC samples are scaled by an overall factor 1.10, the ratio of the observed data yield in the preselection region to the prediction from MC augmented by the data-driven fake lepton prediction. For illustration purposes, we overlay the distributions from the LM1 SUSY benchmark point.

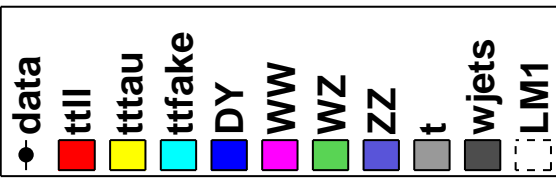
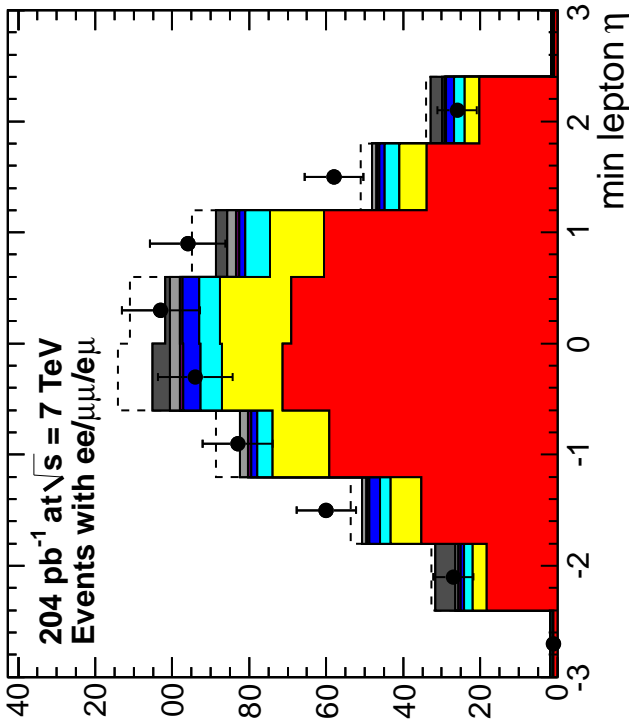
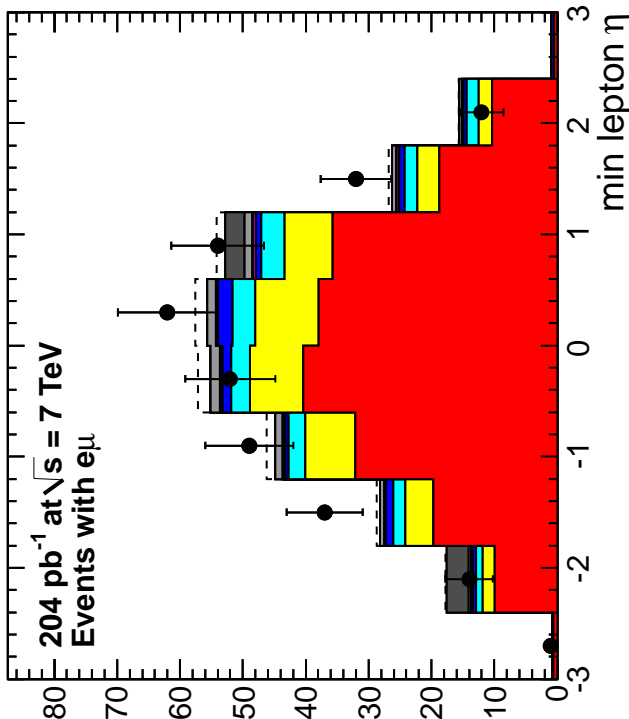
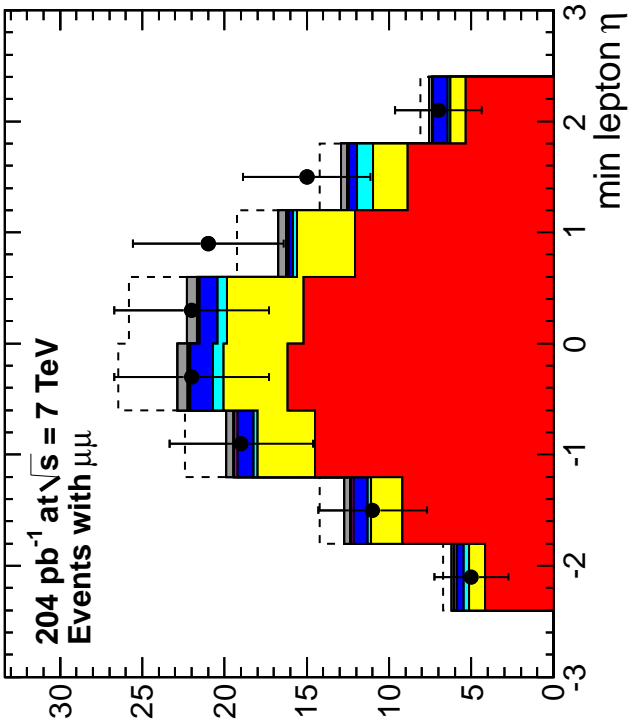
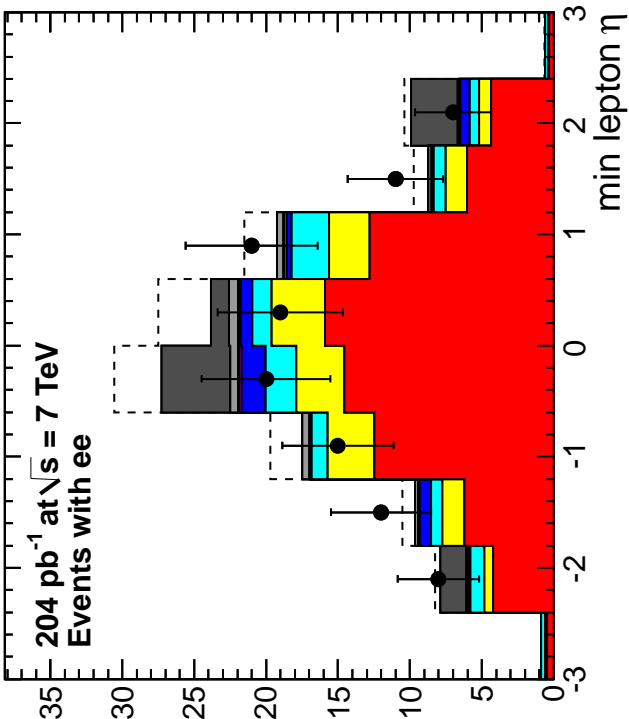
- $MT2$  is a kinematical quantity built from the two leptons and the  $E_T^{\text{miss}}$ . For events with two  $W \rightarrow \ell$  decays it should have a sharp kinematical cutoff at  $W$  mass. For more details, see Reference [22].
- $MT2J$  is very much like  $MT2$  but it is built out of the leptons, the  $E_T^{\text{miss}}$  and the two jets. For  $t\bar{t}$  events it has a kinematical cutoff at  $M_{\text{top}}$ , with tails due to the fact that occasionally one of the  $b$ -jets is not found and is replaced by a gluon jet from ISR or FSR. For more details, see Reference [23].

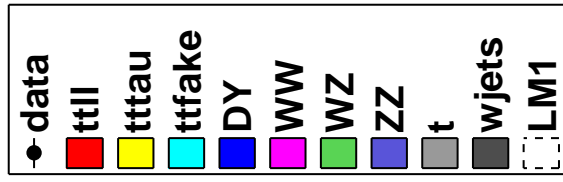
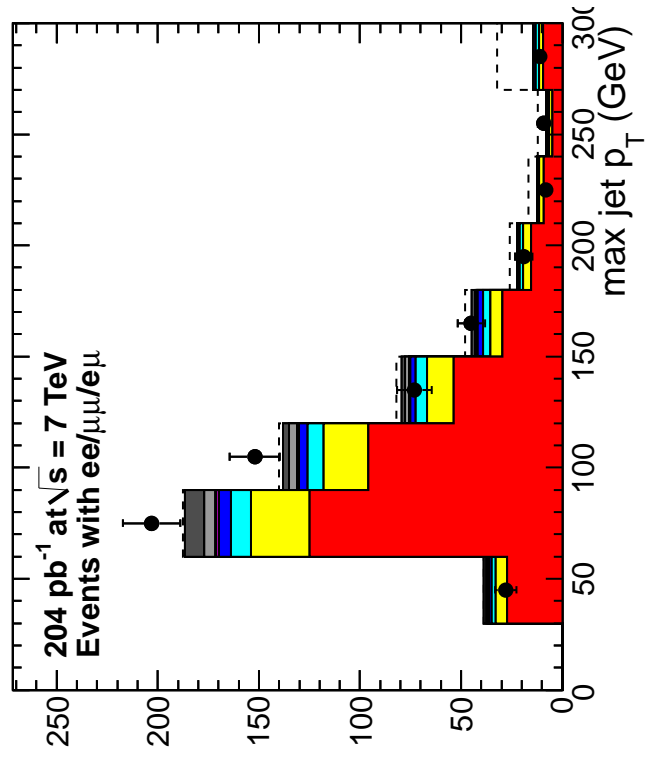
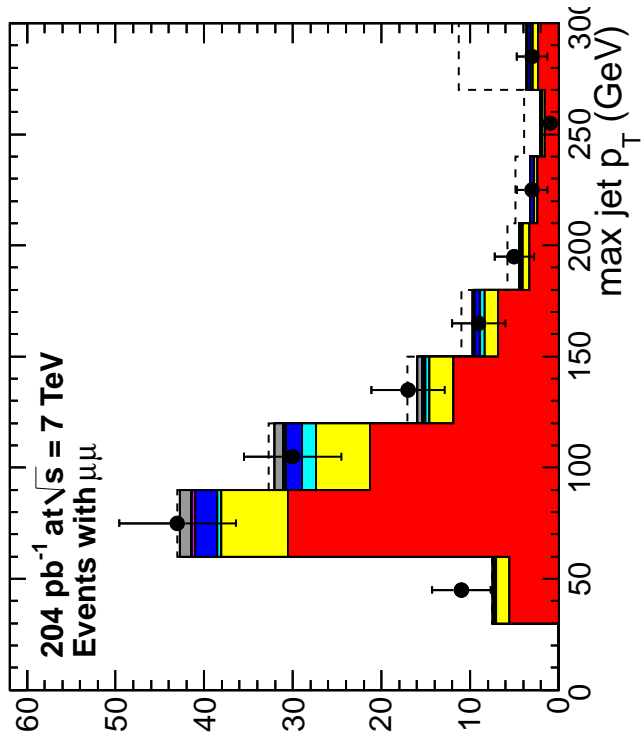
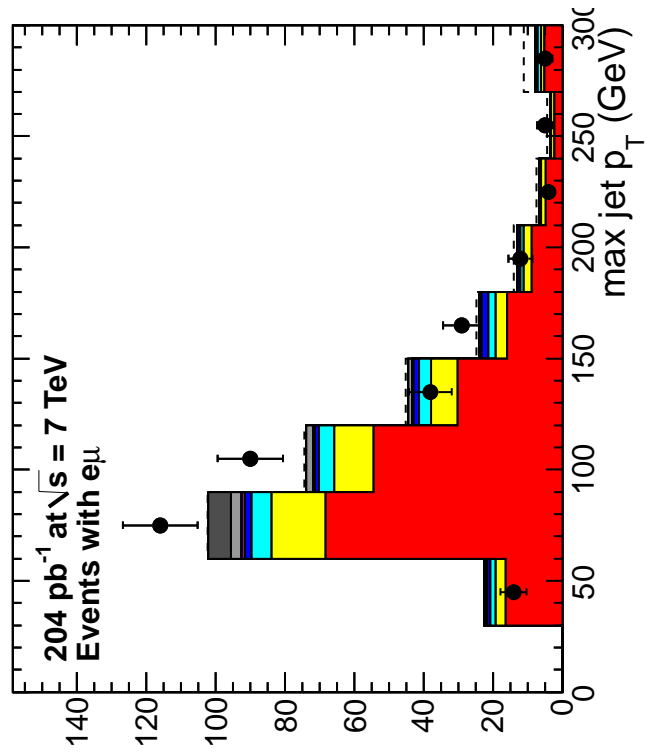
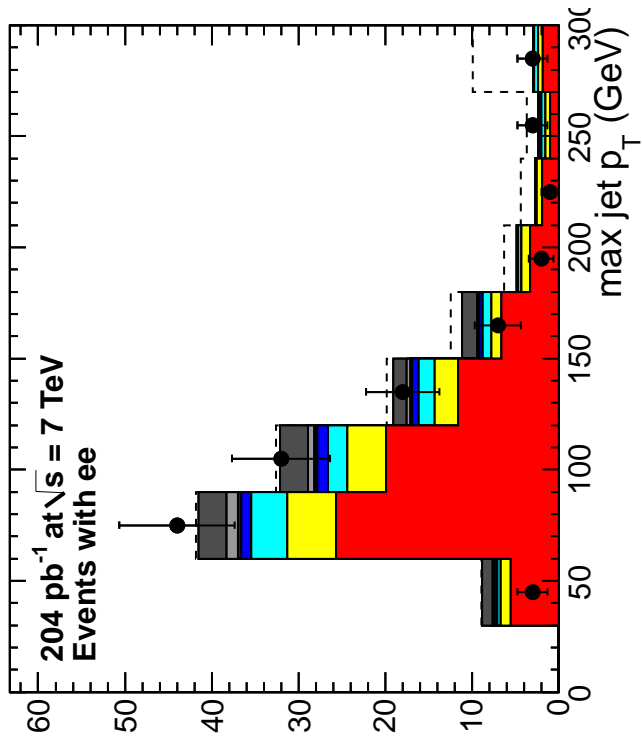


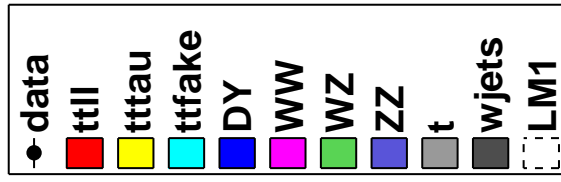
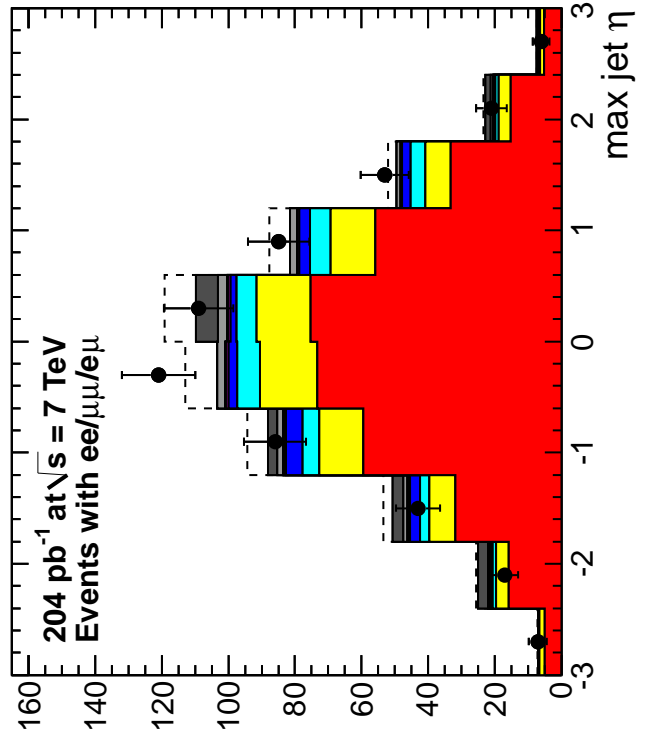
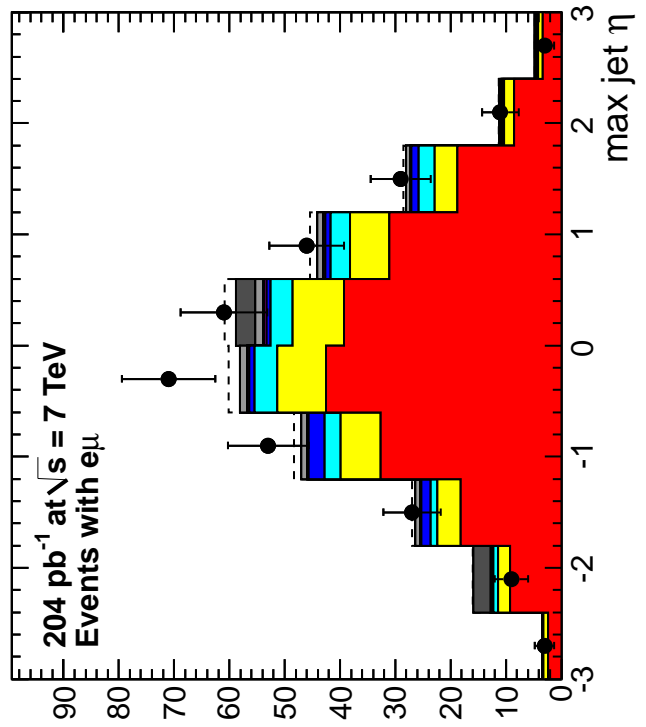
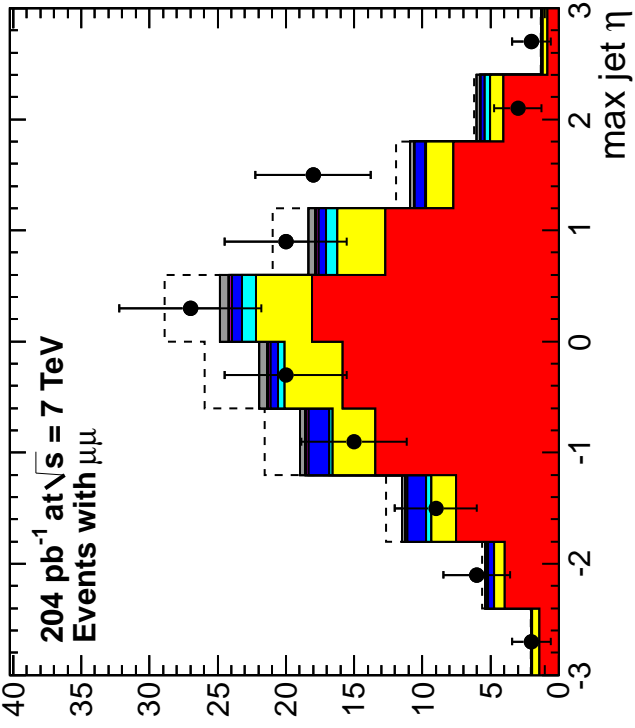
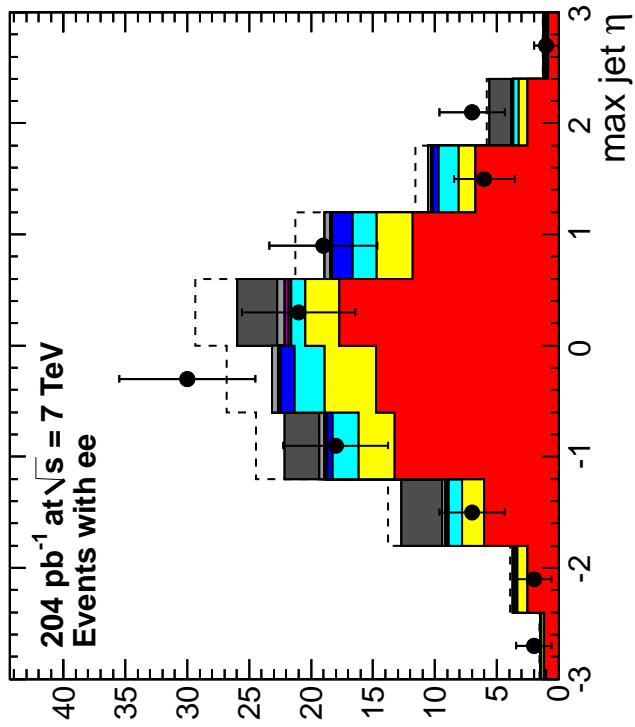


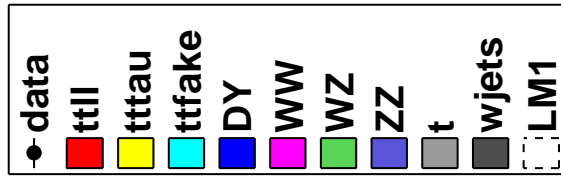
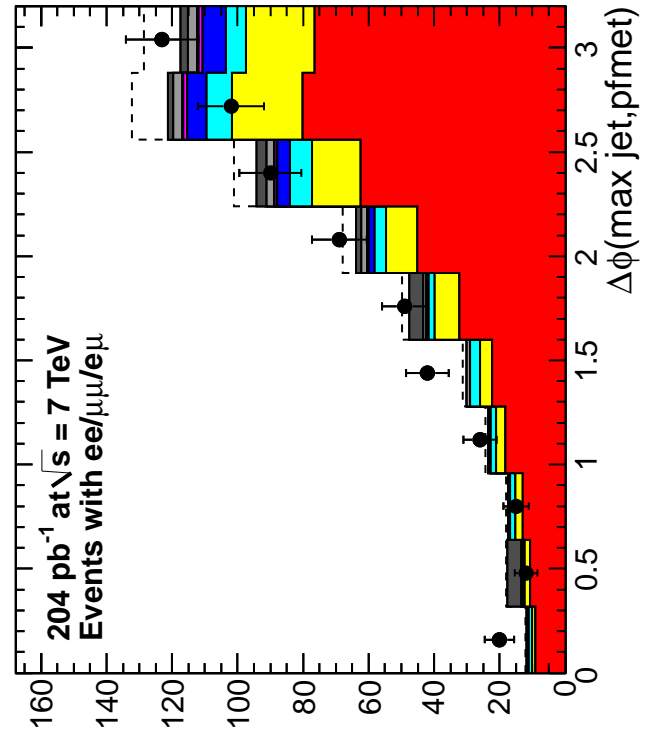
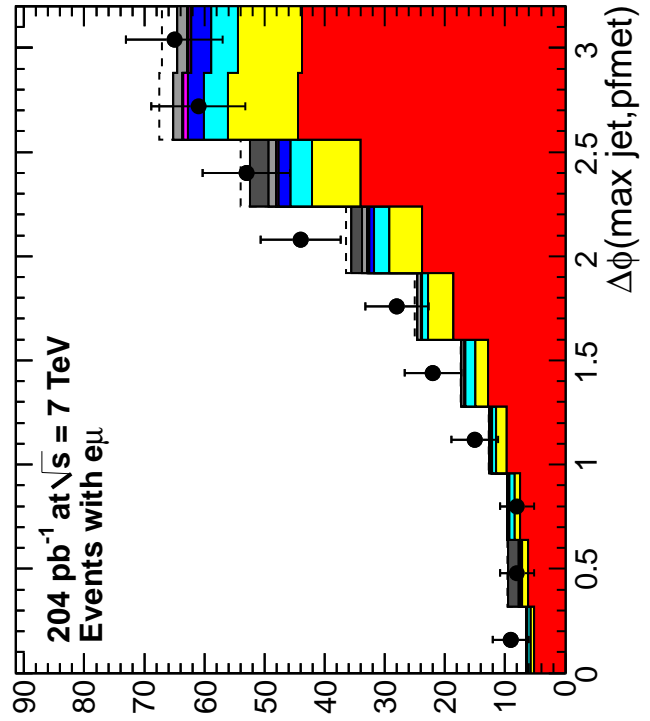
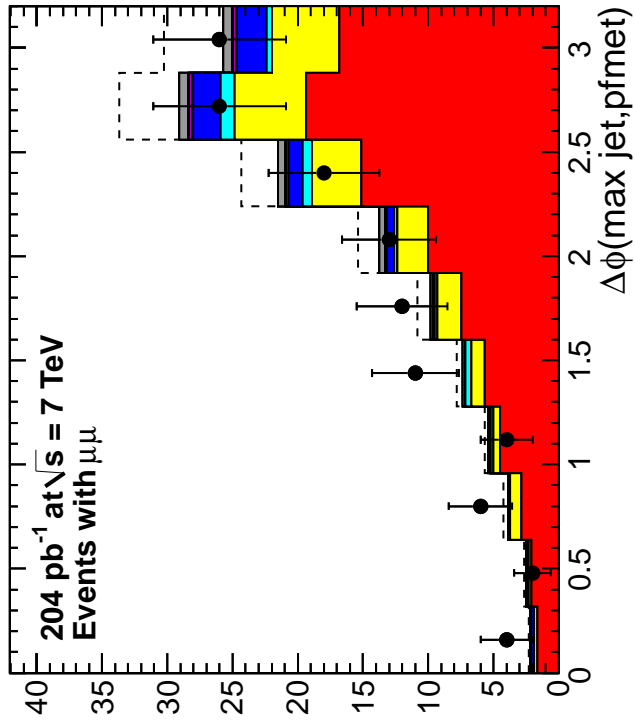
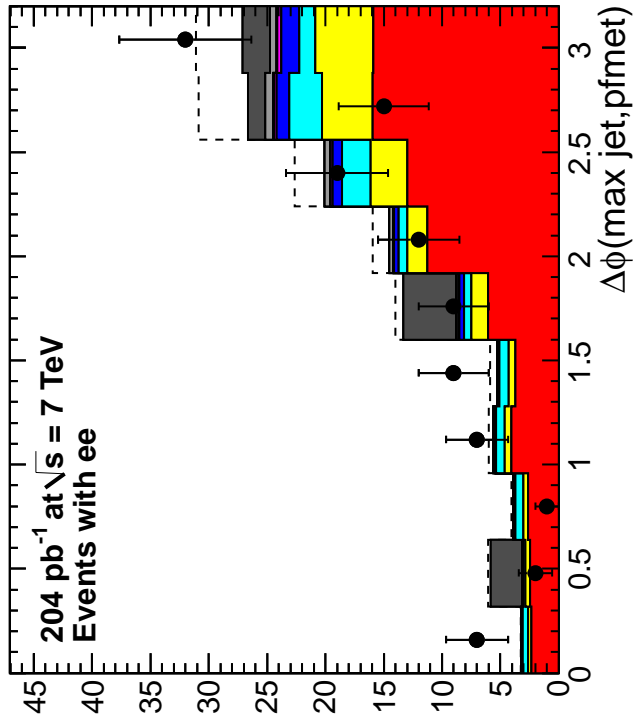


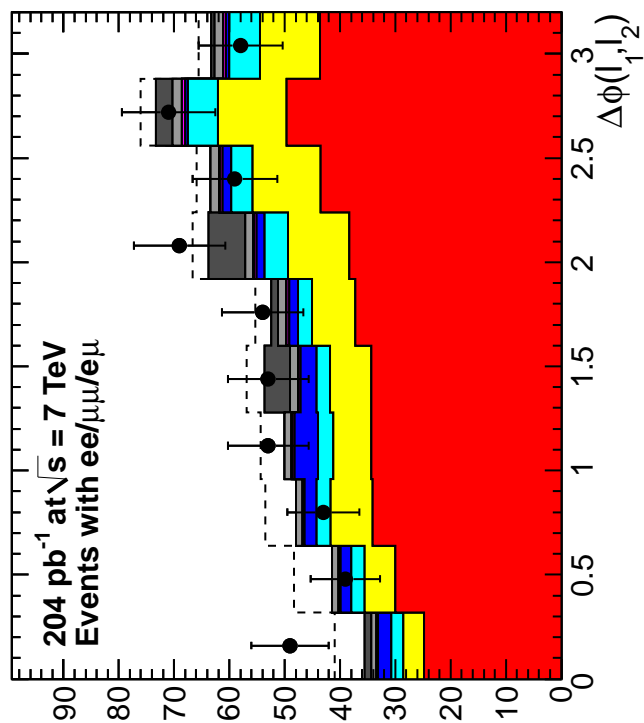
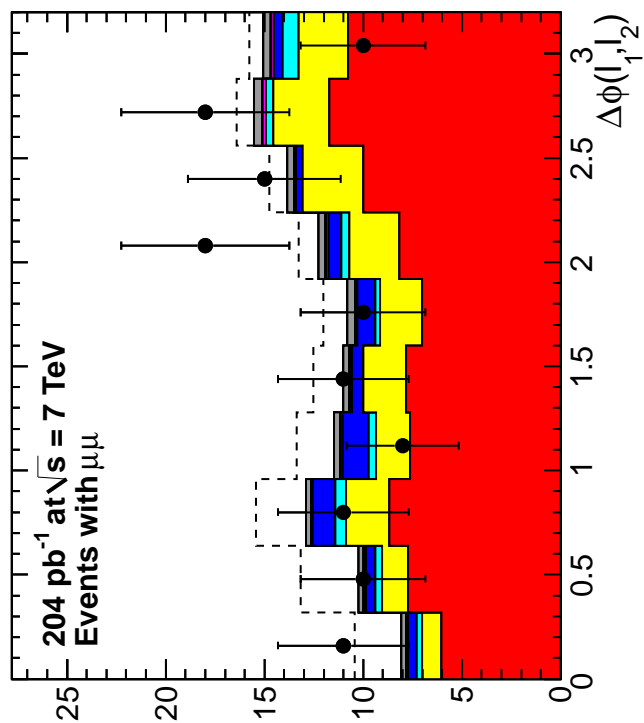
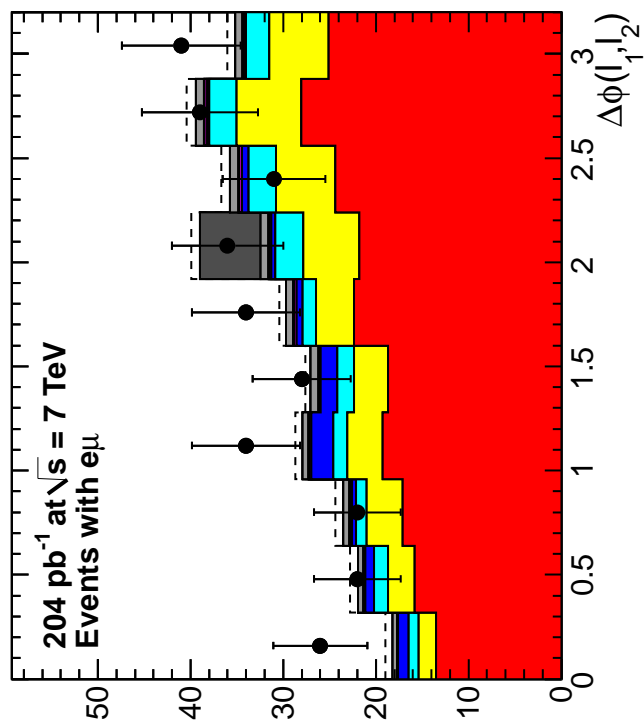
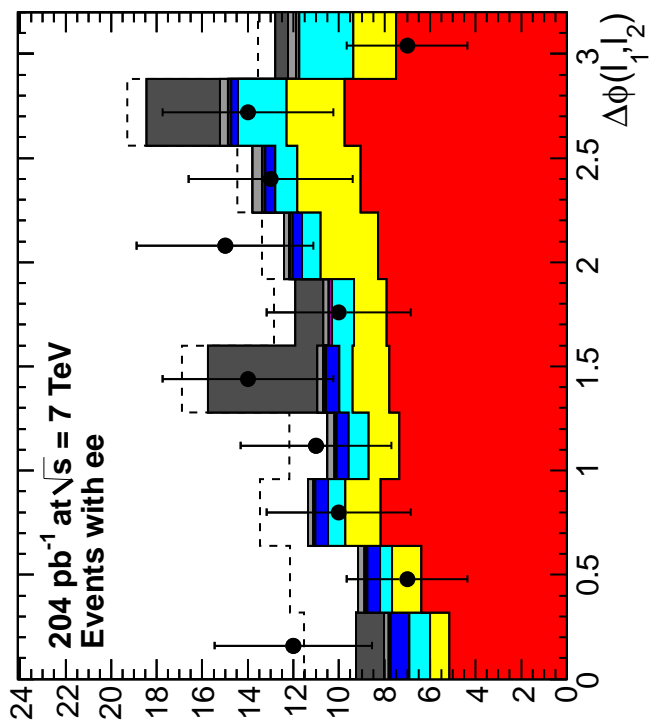


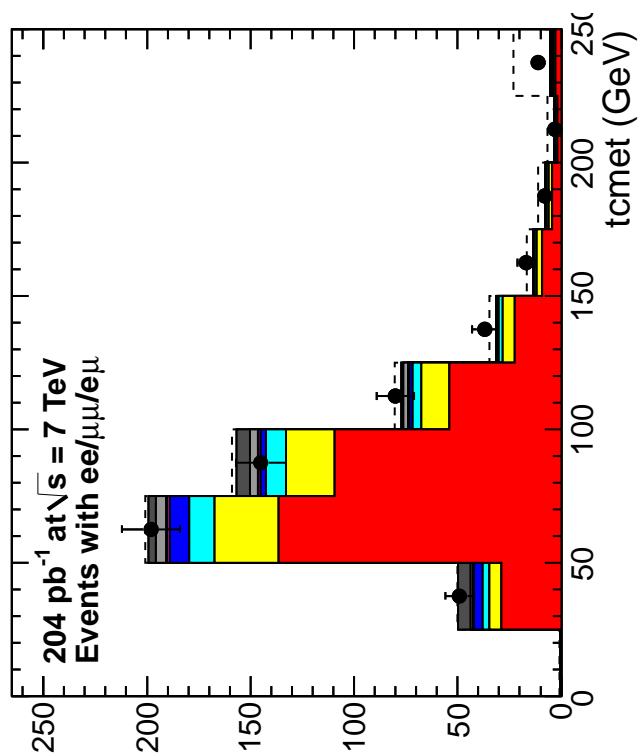
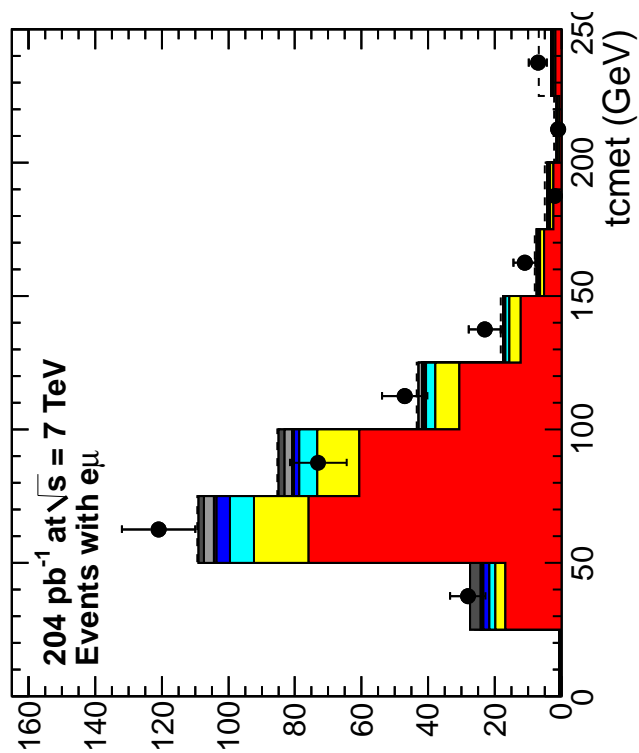
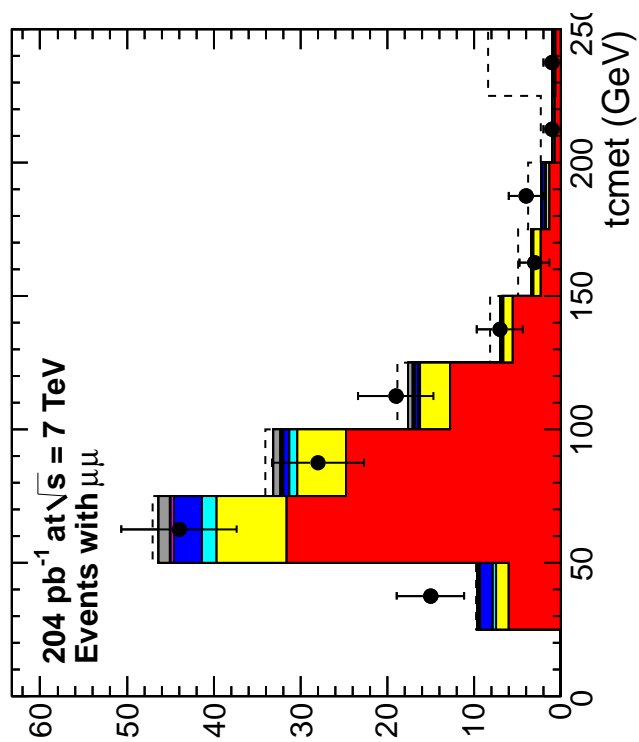
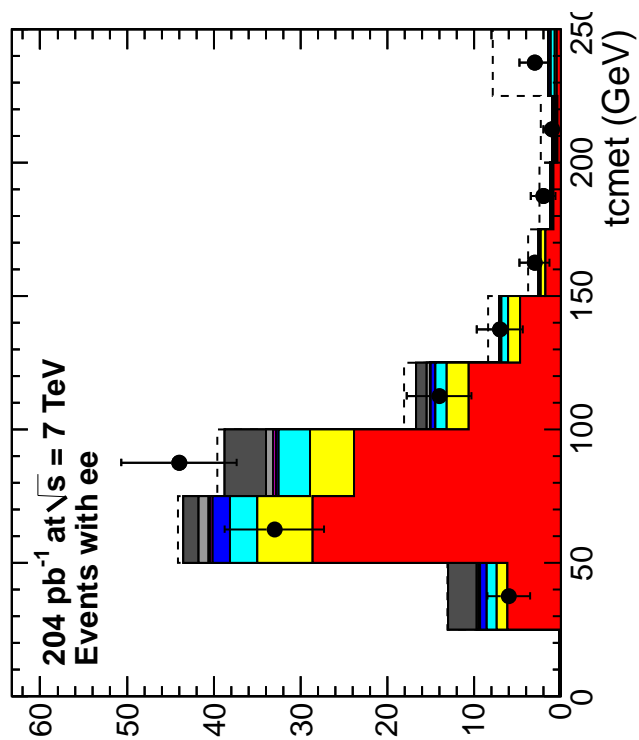


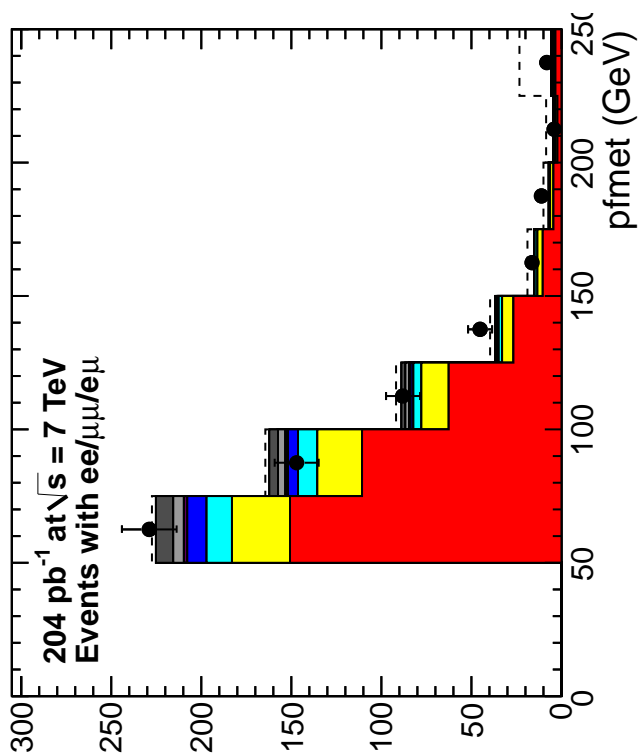
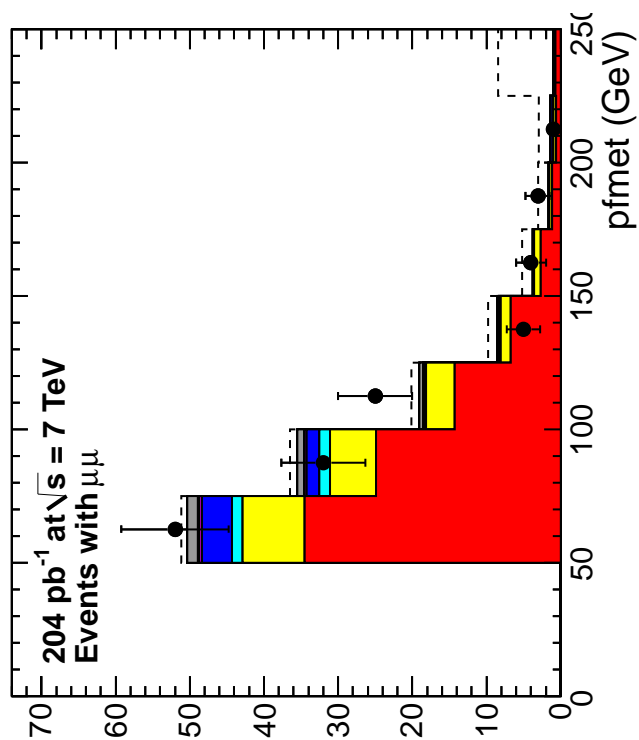
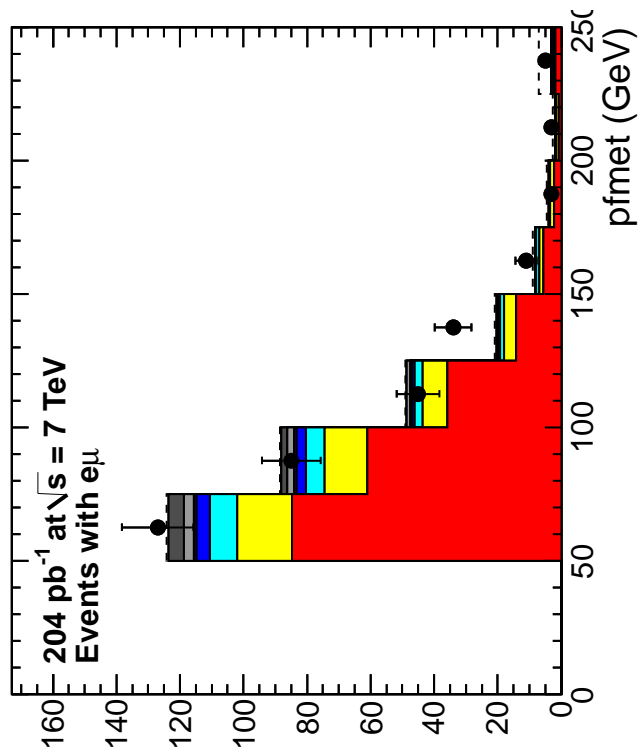
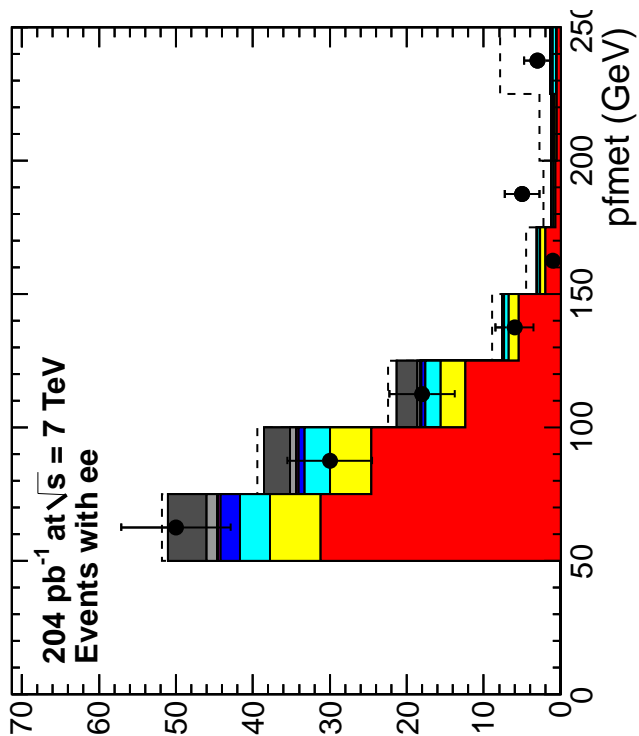




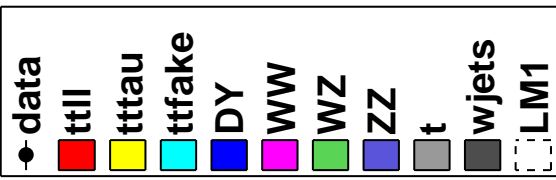
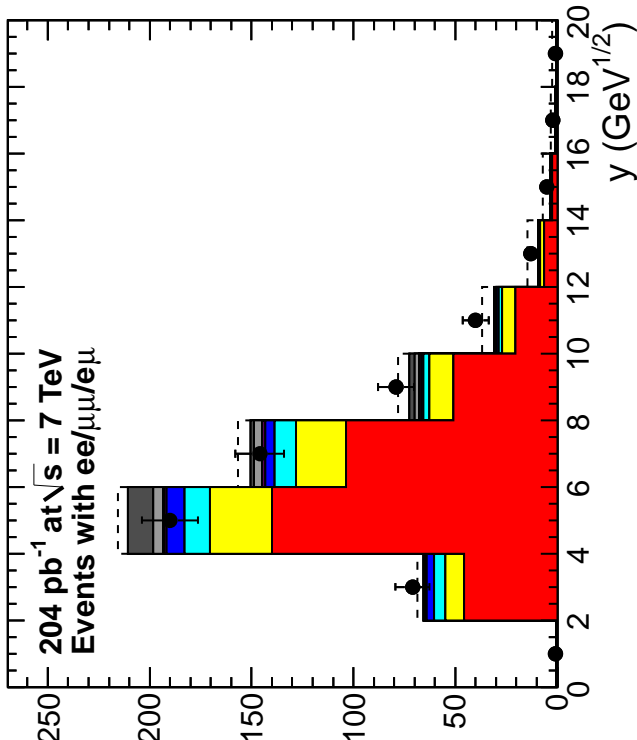
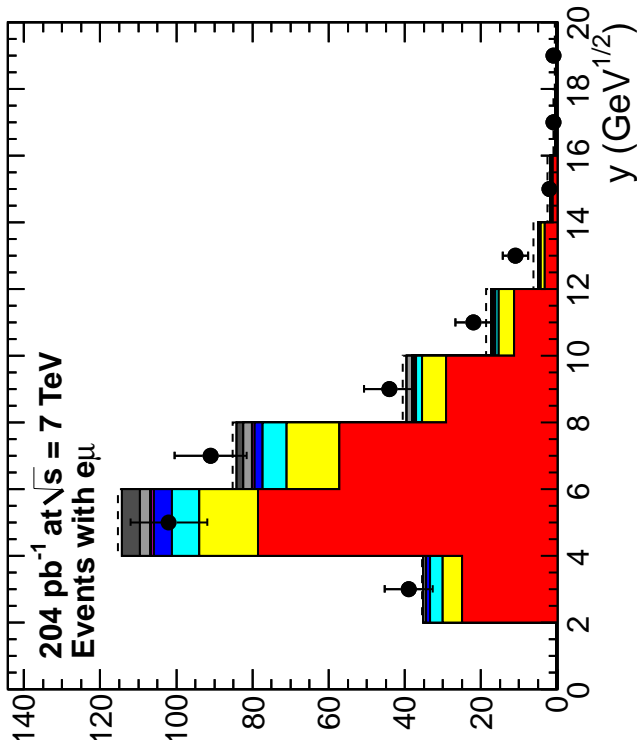
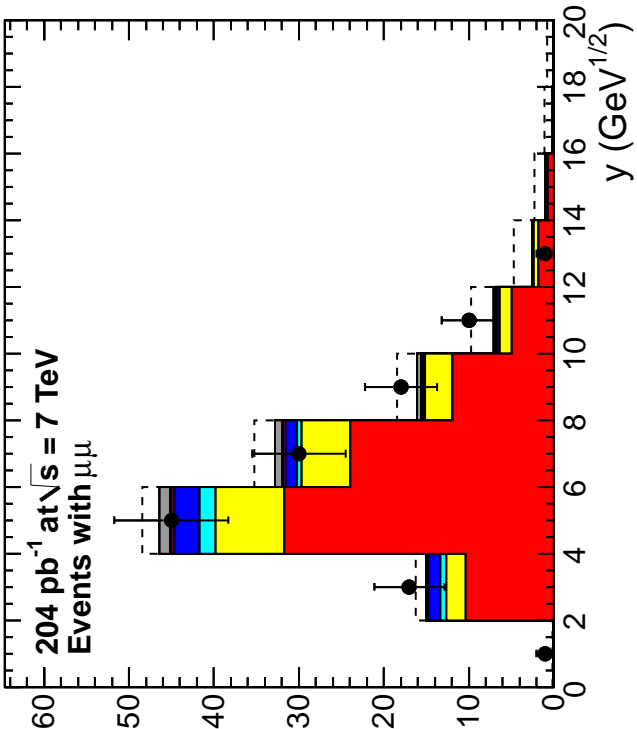
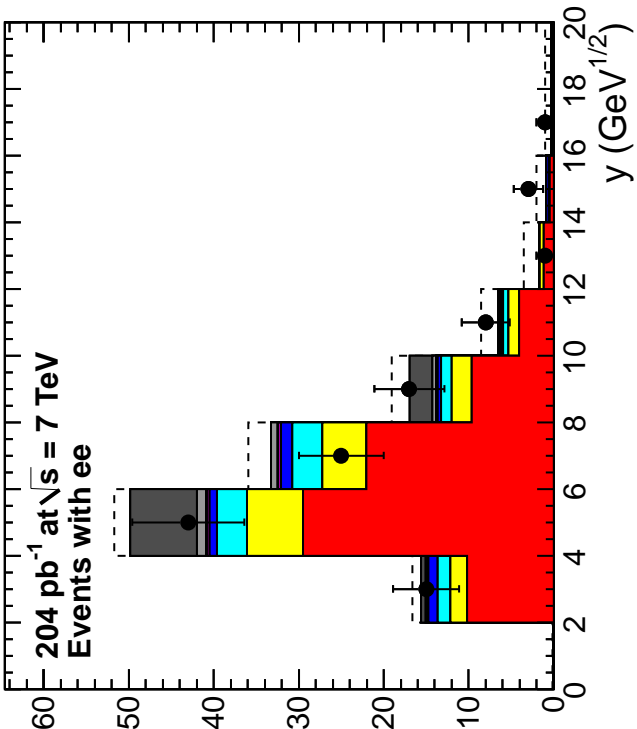


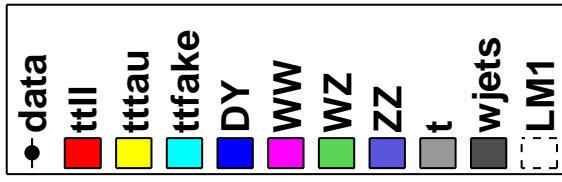
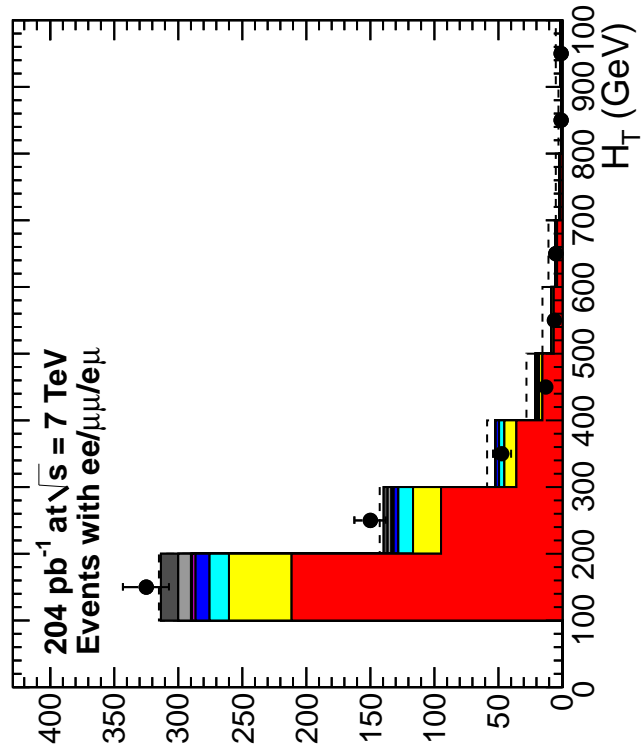
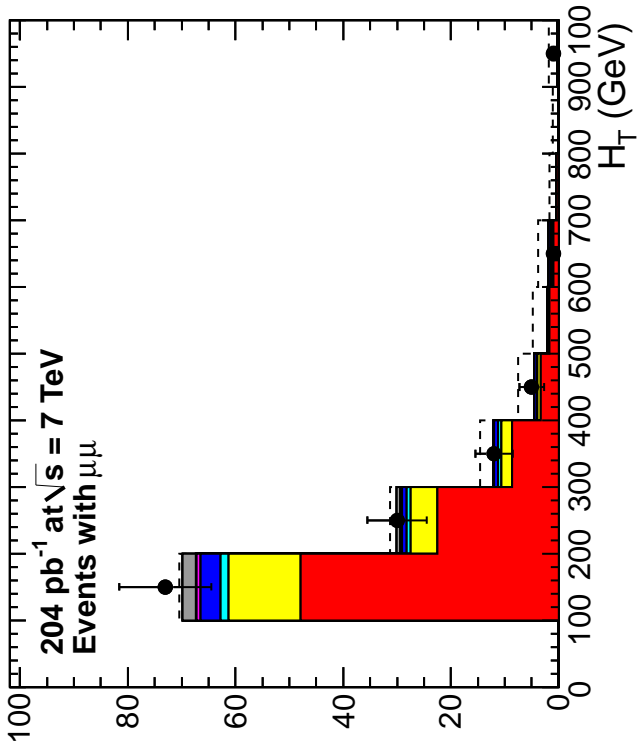
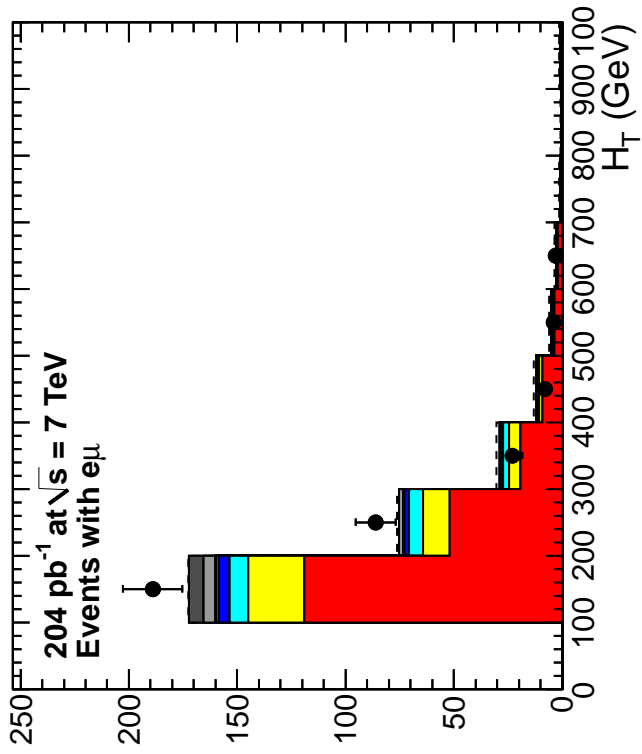
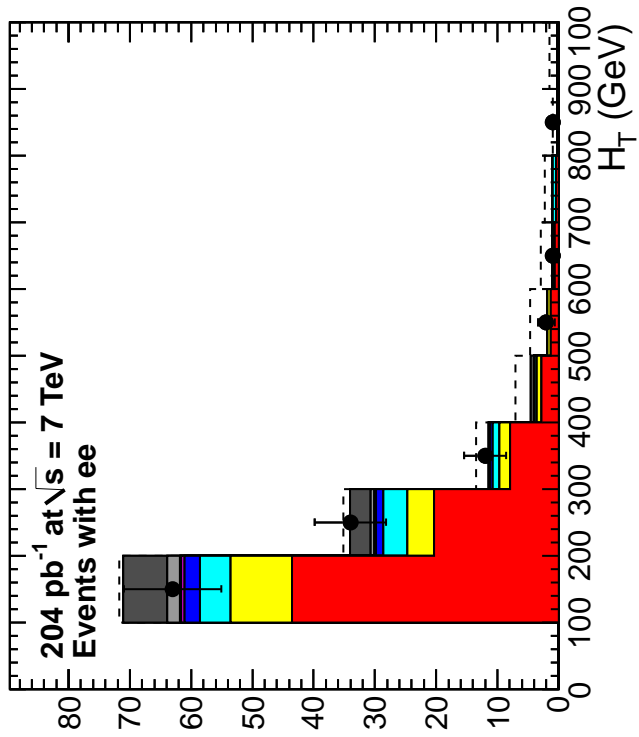


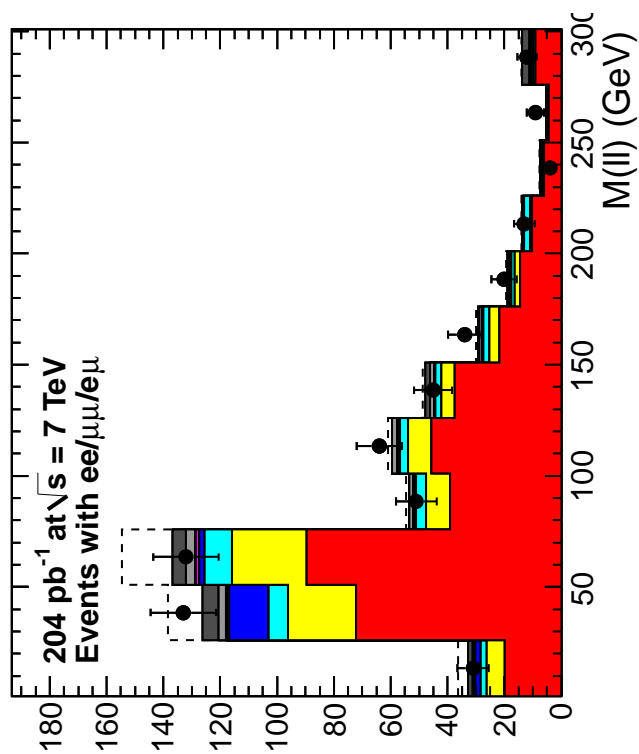
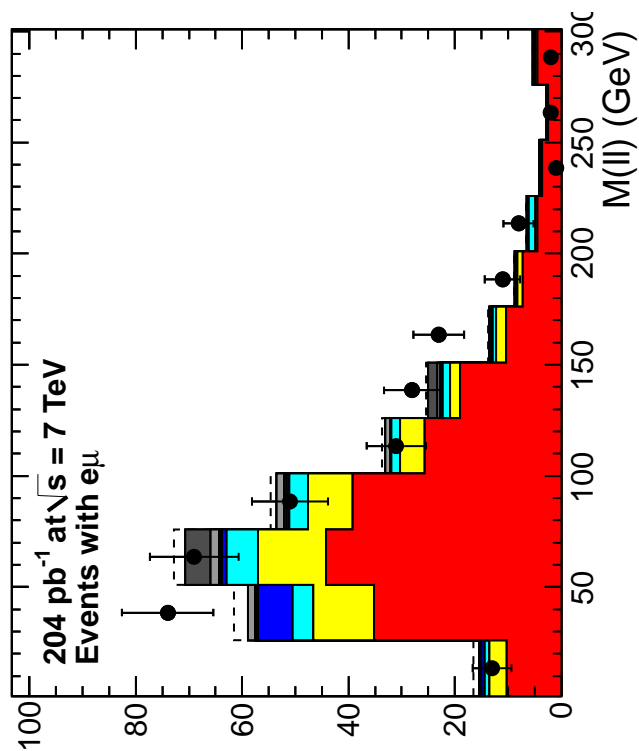
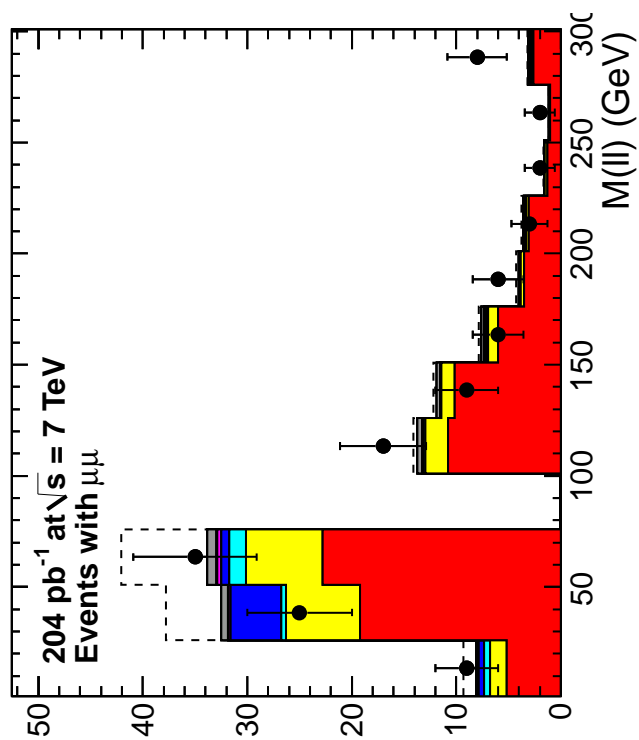
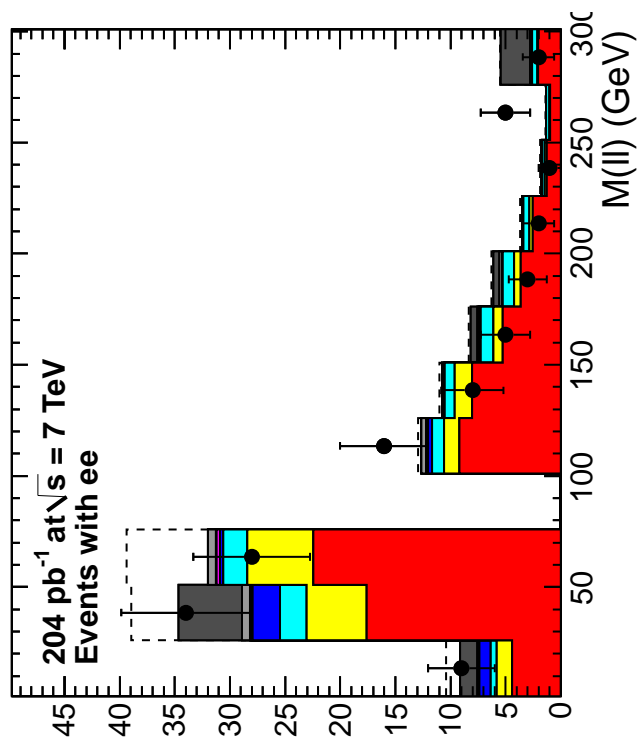


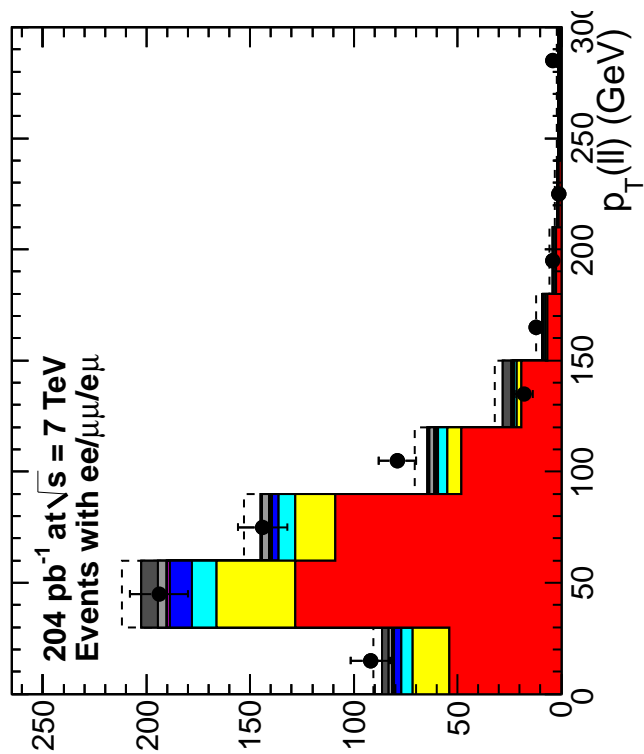
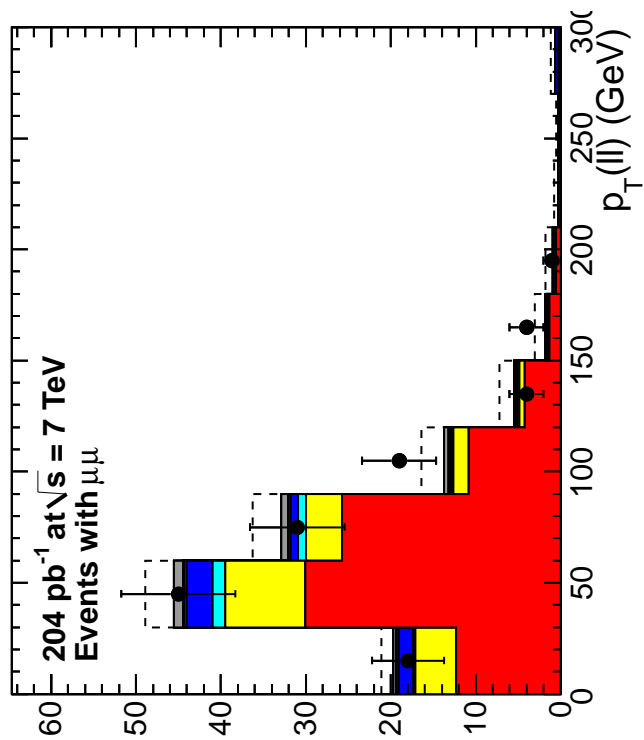
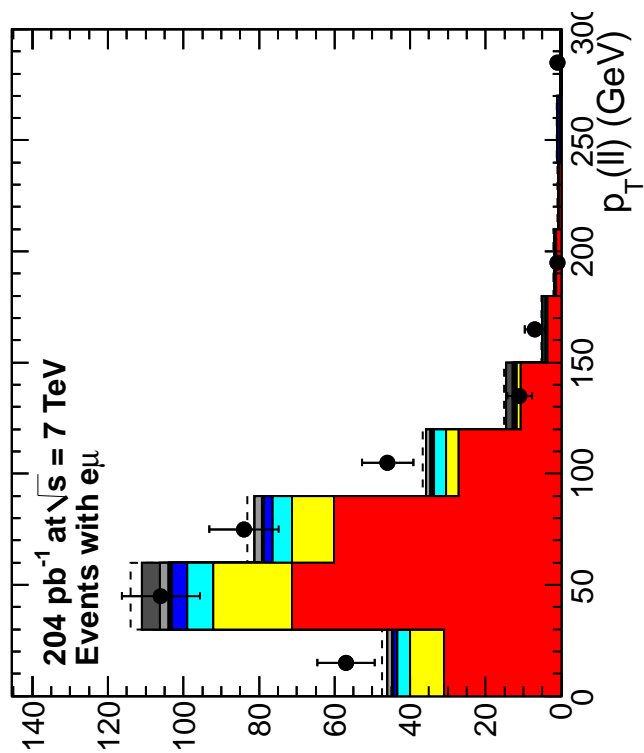
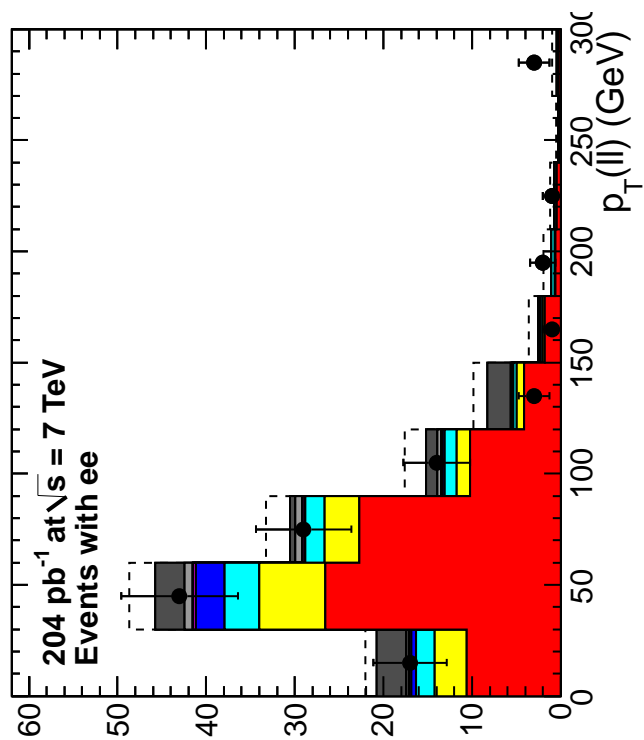


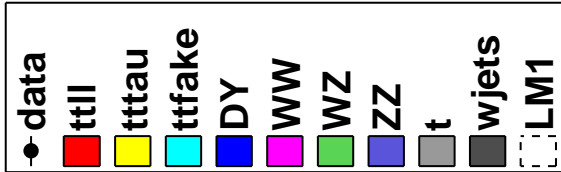
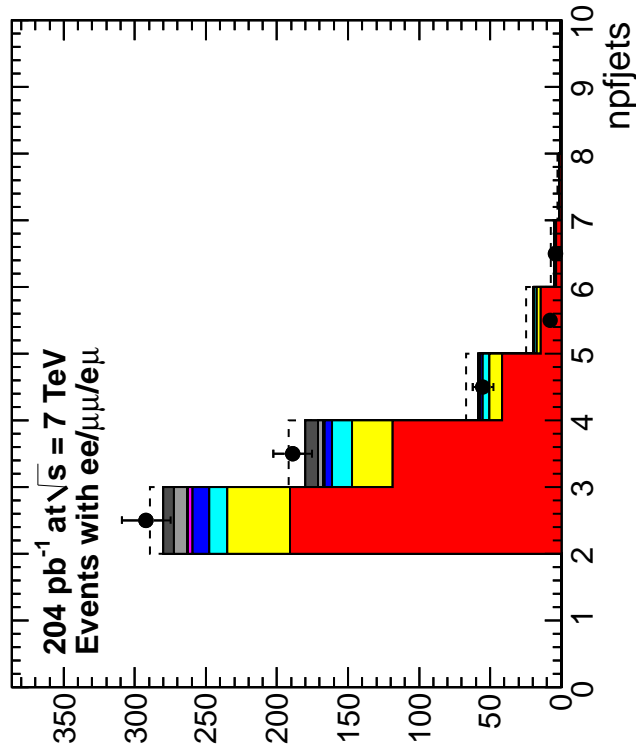
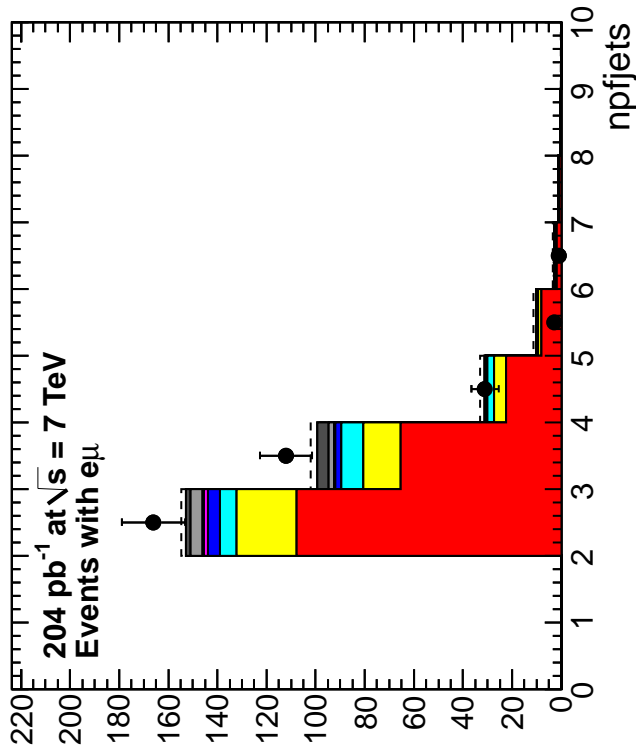
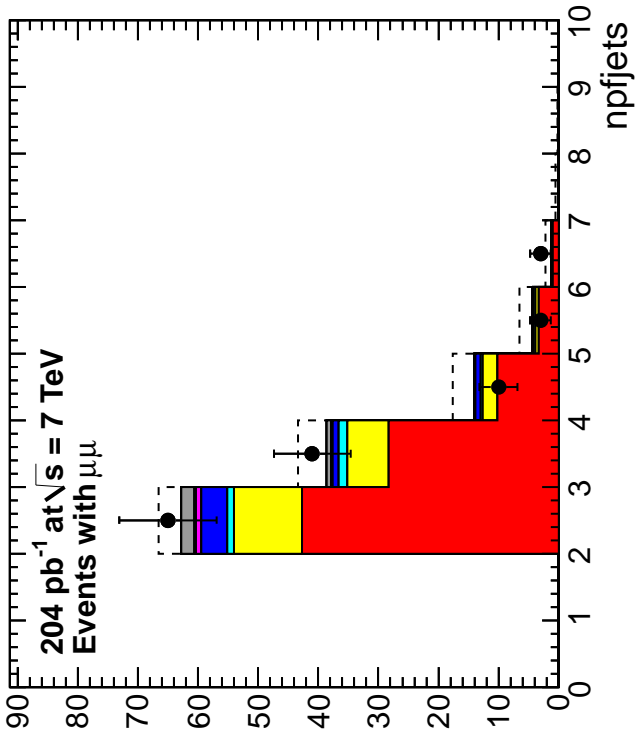
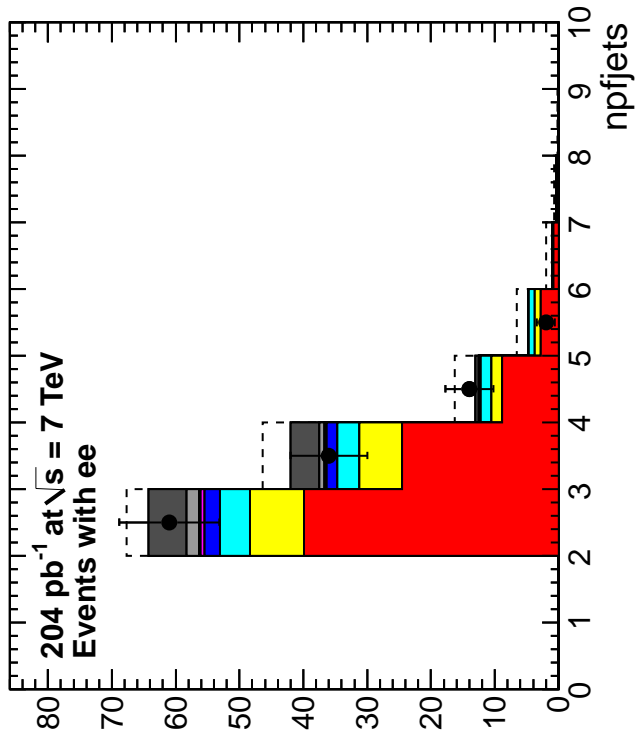


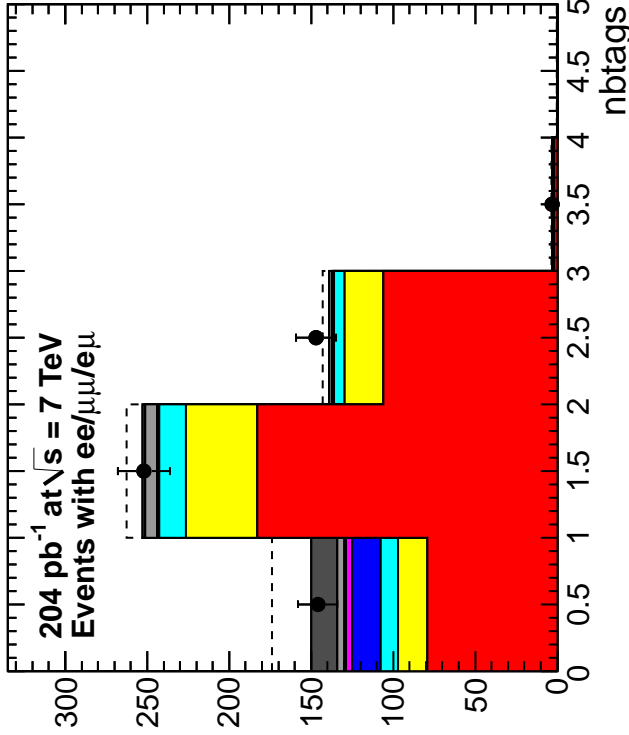
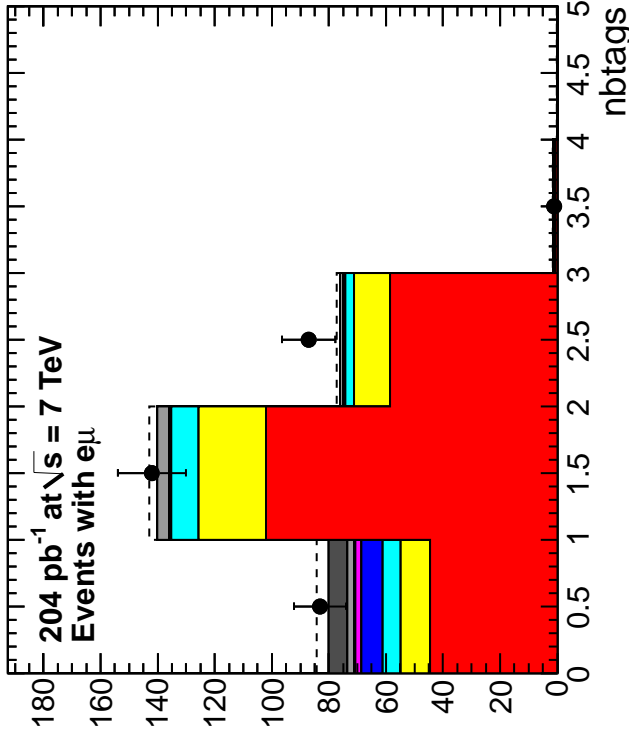
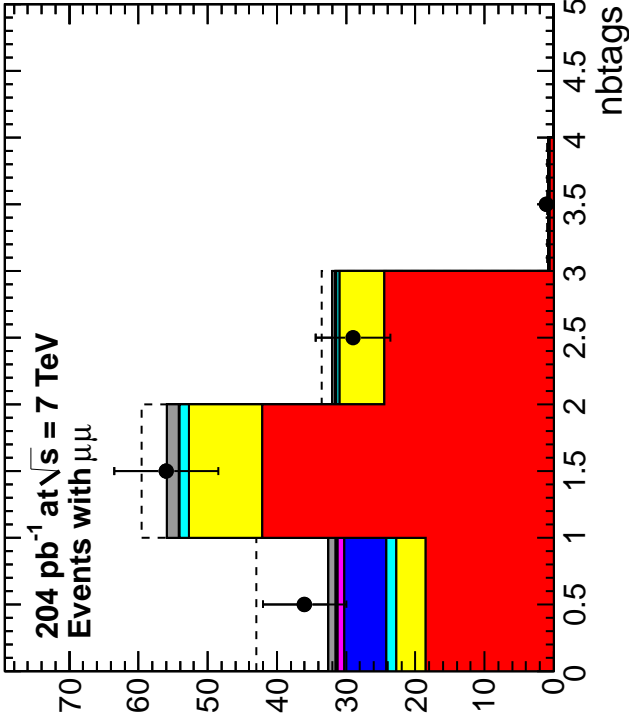
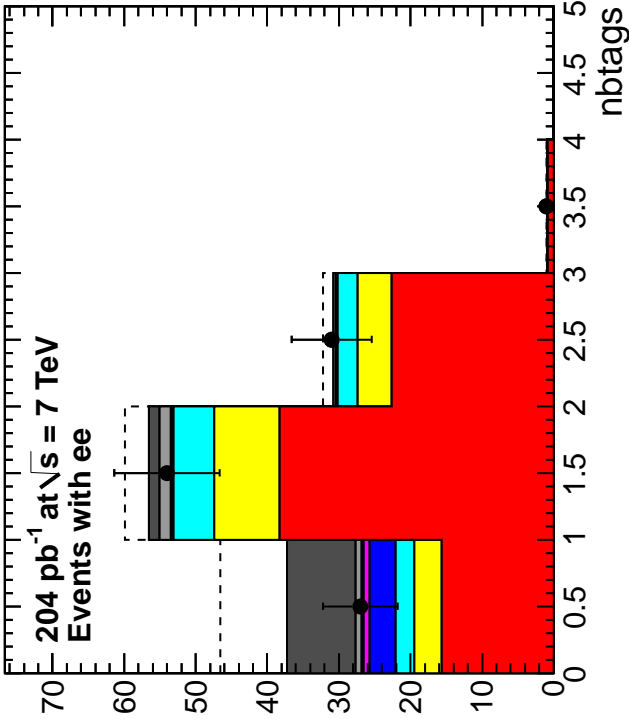


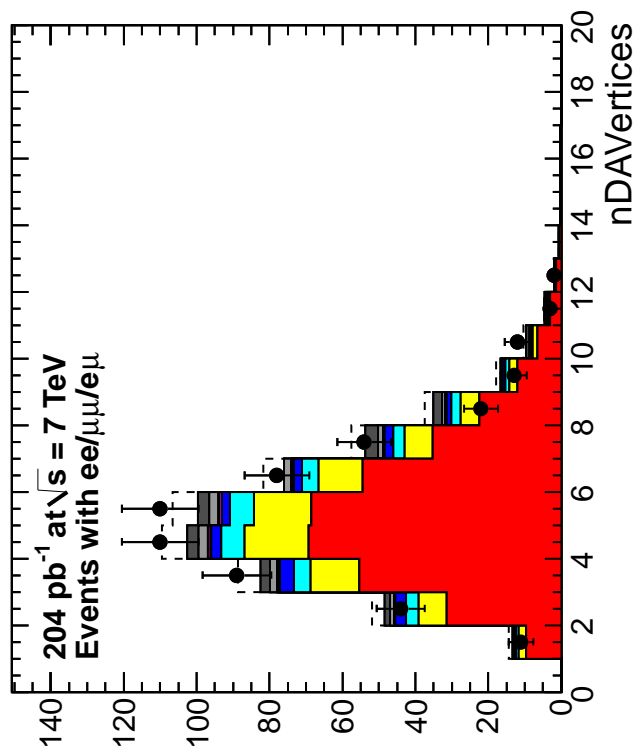
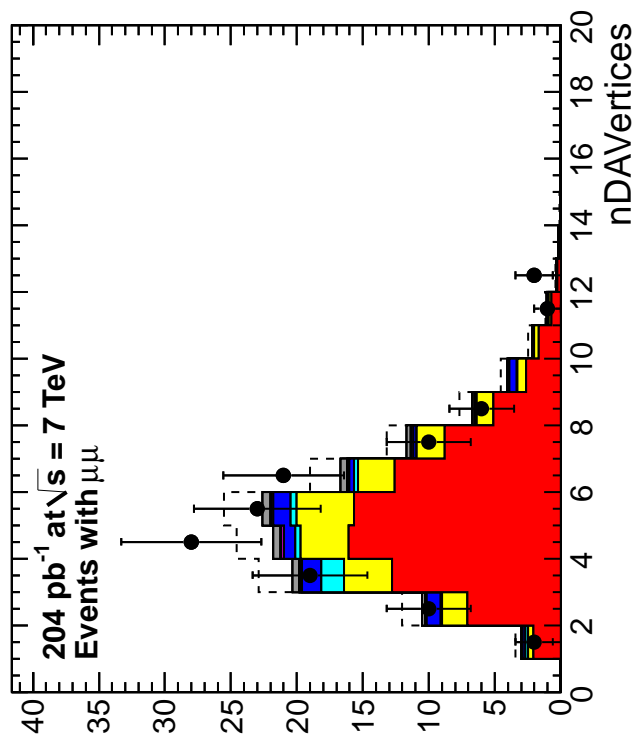
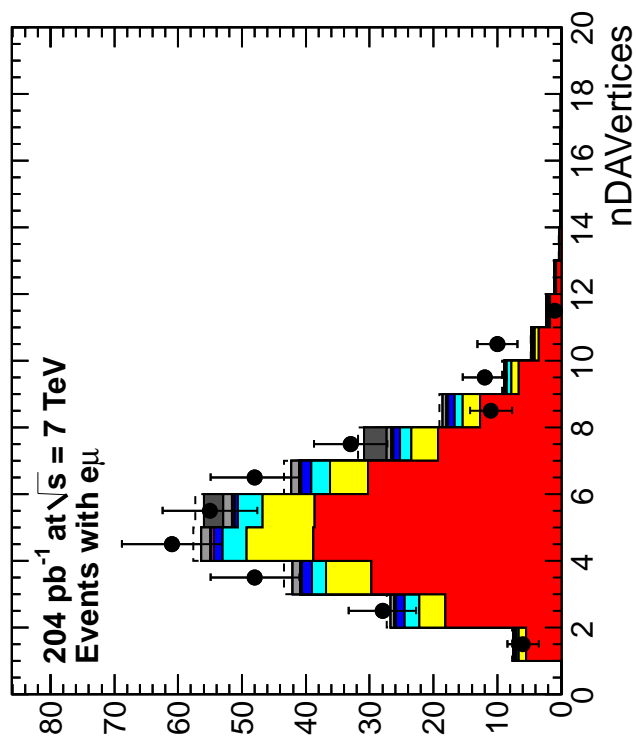
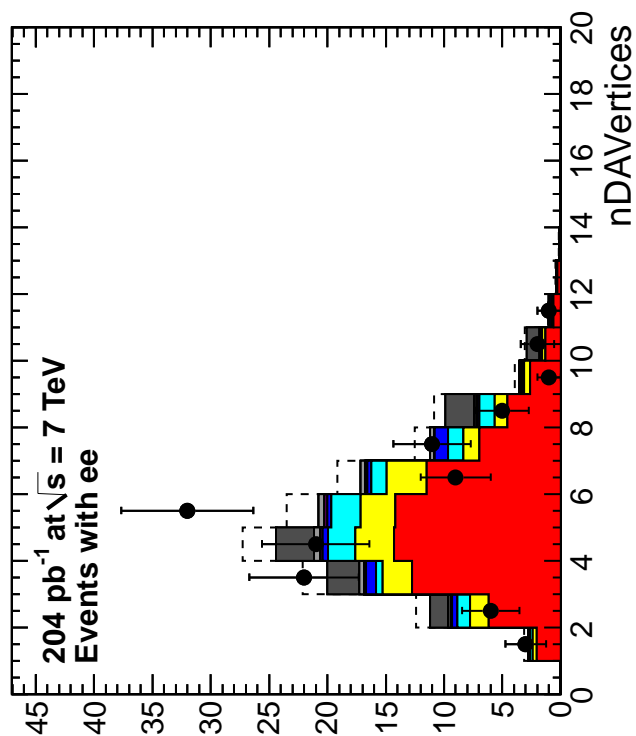


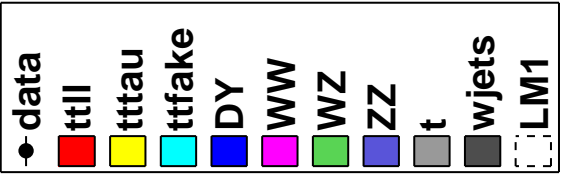
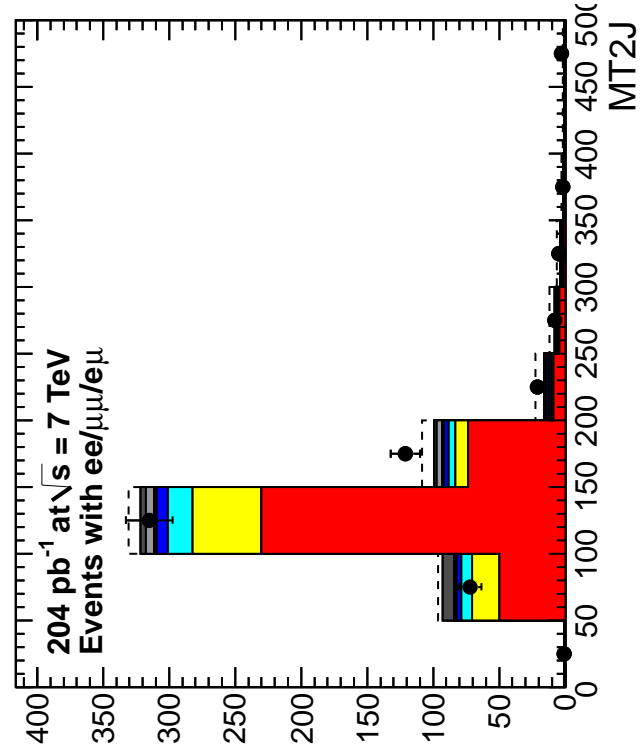
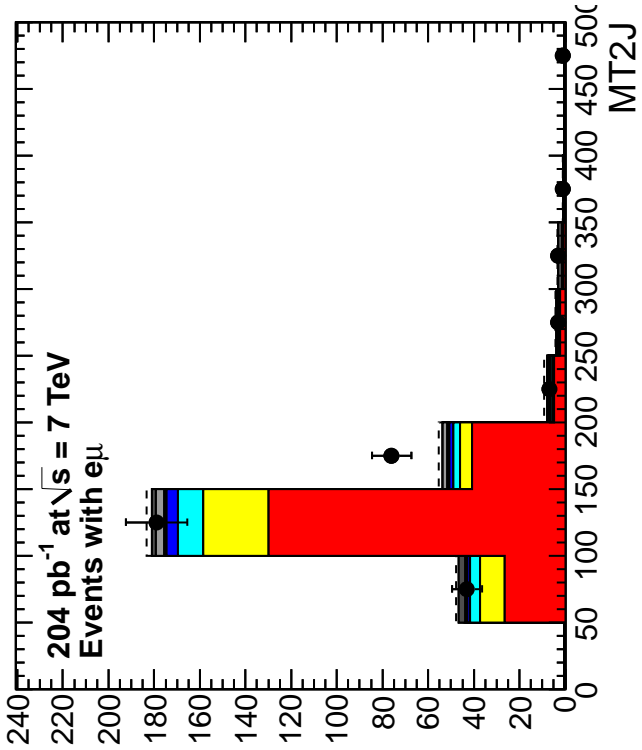
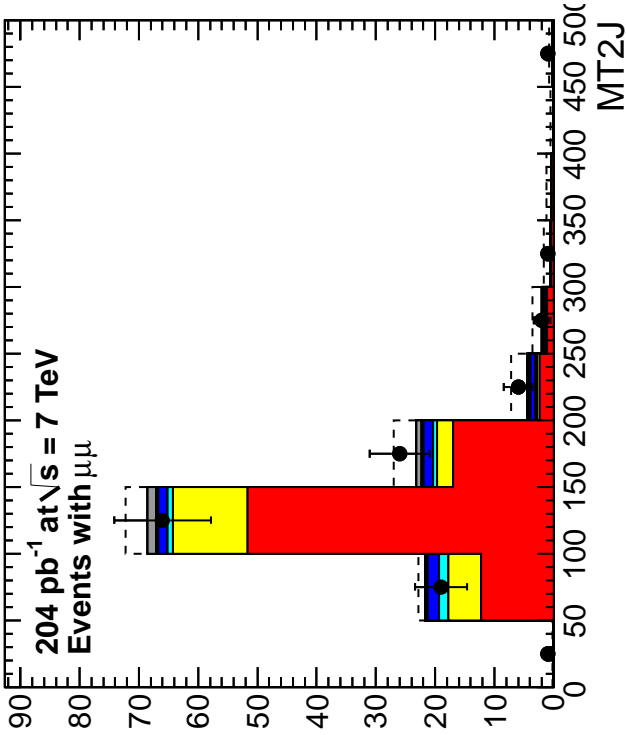
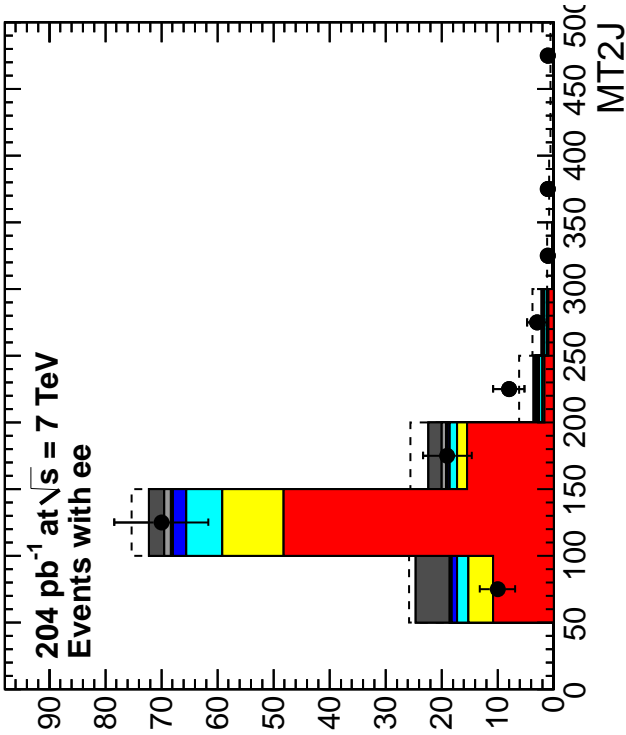




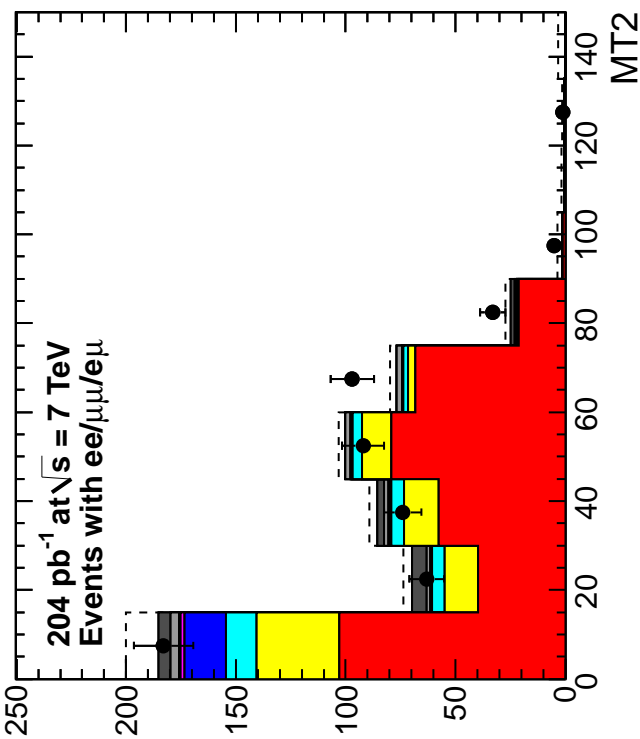
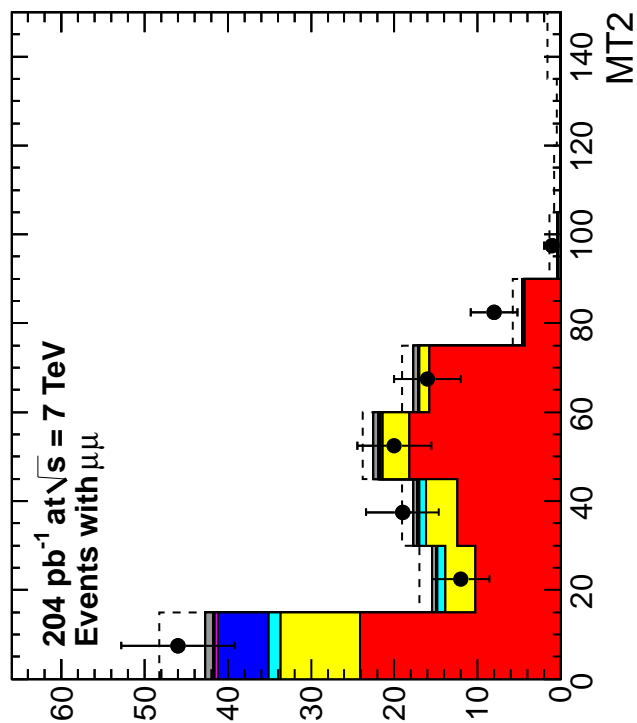
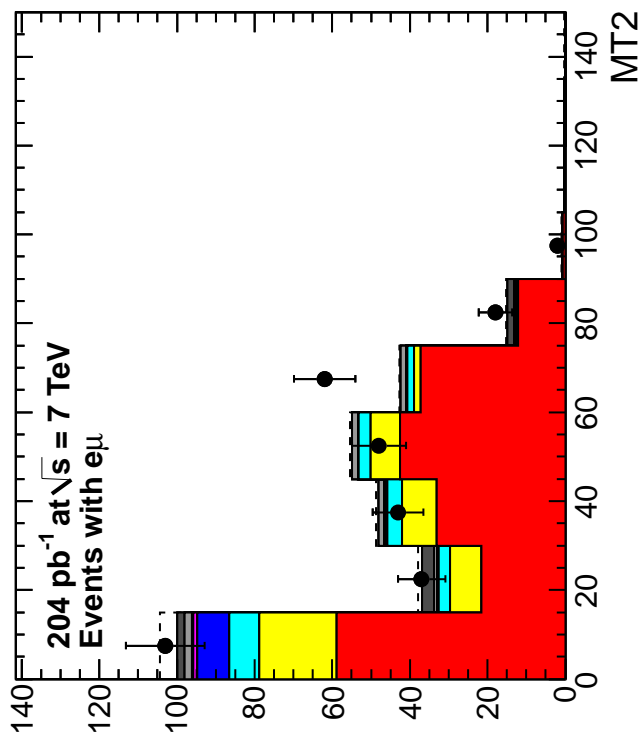
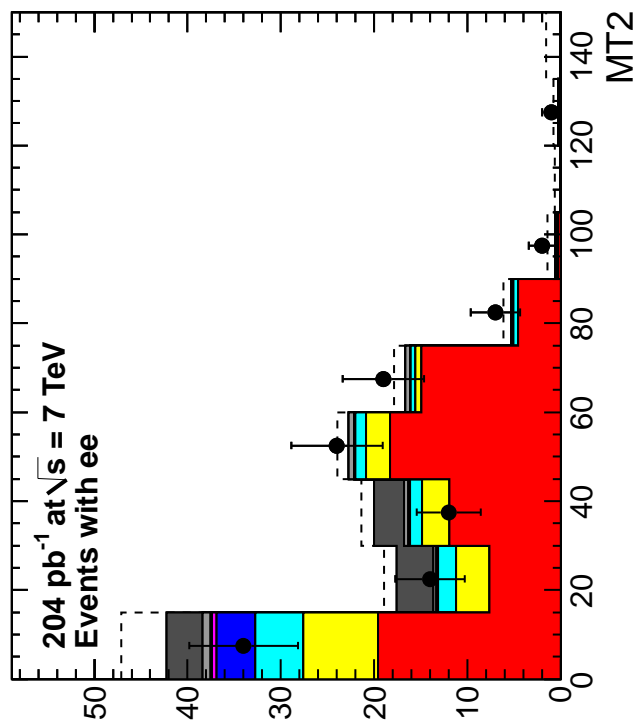


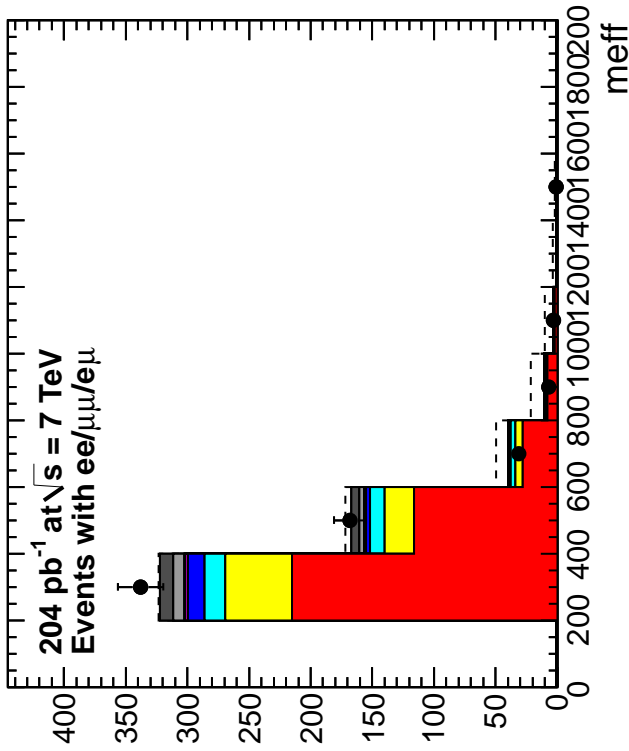
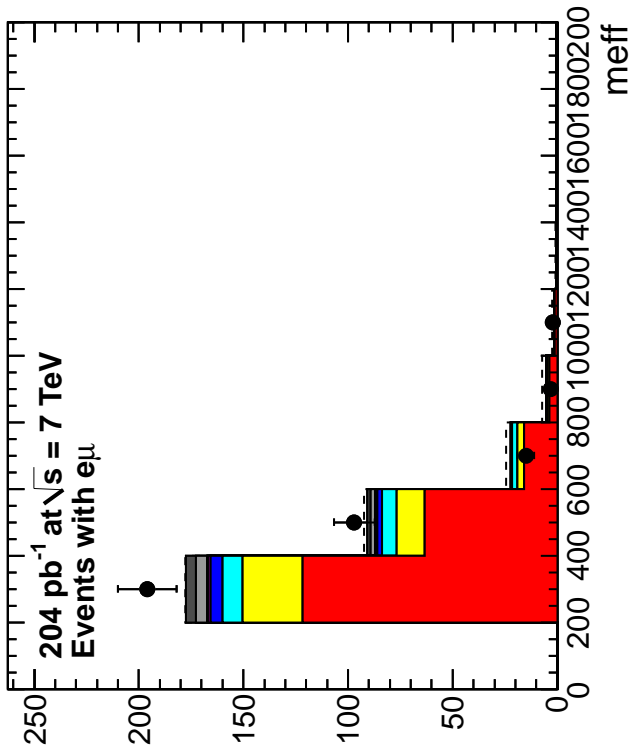
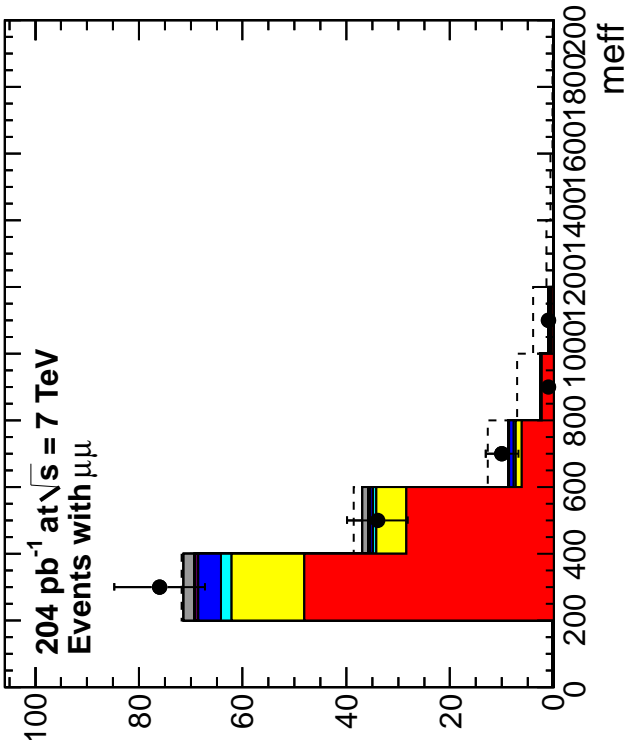
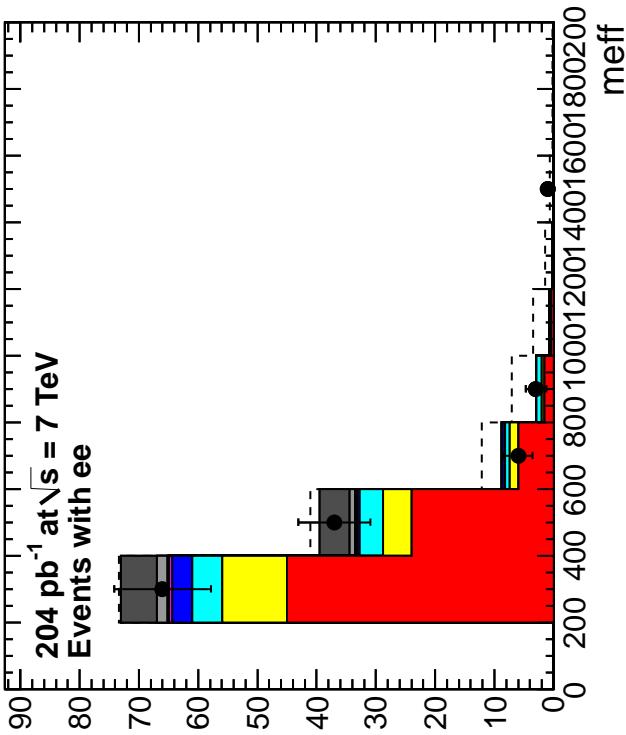












## 475 **Appendix D Data/MC Comparison: 2010 Signal Region**

476 Here we compare data and MC distributions for data passing the 2010 signal region requirements (preselection +  
477  $y > 8.5 \text{ GeV}^{1/2} + H_T > 300 \text{ GeV}$ . The high  $p_T$  dilepton trigger data is used. We observe 14 events in this region.

