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Search for the Standard Model Higgs Boson Production in Association with $W^{\pm}$ Boson using $\int \mathcal{L}dt = 2.7\ \mathrm{fb}^{-1}$

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Abstract

We present a search for Standard Model Higgs boson production in association with a $W^{\pm}$ boson. This search uses data through period 17, corresponding to an integrated luminosity of 2.7fb^{-1}. We select W candidate events that have 2 jets, large $\not\!\!E_T$, and isolated track lepton candidate. Discrimination between the Higgs signal and the large backgrounds in the $W + 2$ jet bin is increased through the use of an artificial neural net. We see no evidence for a Higgs signal, so we set a 95% confidence level upper limit on the WH cross section times the branching ratio of the Higgs to decay to a $b\bar{b}$ pair by fitting the neural network output distribution:

$$\sigma(p\bar{p} \to W^{\pm}H) \times BR(H \to b\bar{b})|_{M(H)=115} < 6.4 \times \mathrm{SM}$$

We set limits across a range of Higgs masses. The limts range from $\sigma(p\bar{p} \to W^{\pm}H) \times BR(H \to b\bar{b}) < 5.6$ to 48.1 times the standard model for Higgs masses from 110 GeV/c^2 to 150 GeV/c^2.

1 Introduction

This note describes the search for $p\bar{p} \to WH \to \ell\nu b\bar{b}$ in events that have at least one SECVTX b-tagged jet. The signature for this process is a W-boson, decaying to a high-p_T charged lepton and neutrino, and two jets containing b-quarks (see Figure 1). This signature is primarily sensitive for low Higgs masses where the $H \to b\bar{b}$ branching fraction is large, as shown in Figure 2. The main backgrounds for this process include $W+2$ jet production (where the jets contain either tagged heavy flavor or mistagged light flavor), $t\bar{t}$ production, and QCD multijet production, where one jet fakes a lepton. These background processes are essentially the same as the backgrounds for the $t\bar{t}$ search in the $W+\geq 3$ jet bin, although in the case of $t\bar{t}$ the ratio of signal to background is much higher. This search uses data collected up to April 2008, which corresponds to a total integrated luminosity of 2.7fb^{-1}. The previous WH search [1, 2] was performed with approximately 2fb^{-1}of integrated luminosity.

This analysis makes use of data collected using either one of the high-p_T lepton triggers (CEM, CMUP, CMX, or MET_PEM) or the $\not\!\!E_T$ + jets trigger. **(Please note: as of the posting of this note, technical difficulties have prevented us from updating the MET_PEM triggered sample to use the full luminosity. We hope to correct that soon.)**. This data is the divided into three exclusive samples:

- The "central lepton" samples is made up of data with an identified CEM, CMUP, or CMX lepton. Such events are required to pass the appropriate tight lepton trigger.
- The "PHX" sample is composed of events containing a forward, high-p_T lepton reconstructed using the Phoenix electron algorithm. These events are required to pass the MET_PEM trigger.
- Events that don't pass the central or PHX selection, but that contain an isolated track make up the "isolated track" sample. These events are required to pass the $\not\!\!E_T$ + jets trigger.

All events analyzed by this analysis are required to contain at least one SECVTX secondary vertex tag. These tagged events are further subdivided as follows:

- Events with at least two SECVTX make up the SECVTX double tag (ST+ST) category.
- Events with only a single SECVTX tag but at least one Jet Probability tag make up the SECVTX + JetProb (ST+JP) category.
- Events that have only a single SECVTX tag with no additional SECVTX or JetProb) tags make up the single tag (EQ1ST) tag category.

Applying both the lepton and the tagging categories to the data yields nine exclusive samples. We currently analyze these nine samples separately and combine limits at the end. In the future, some of these samples with similar background levels may be combined together.

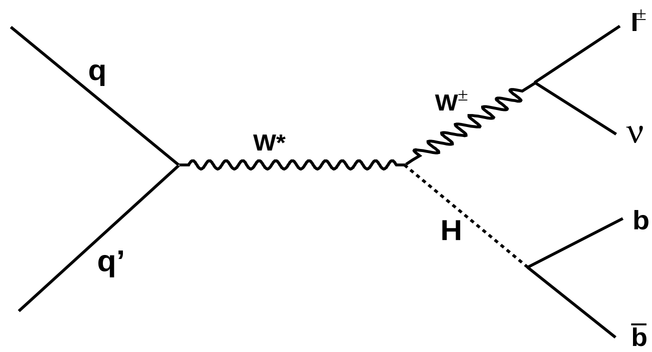

Figure 1: Feynman diagram of WH production.

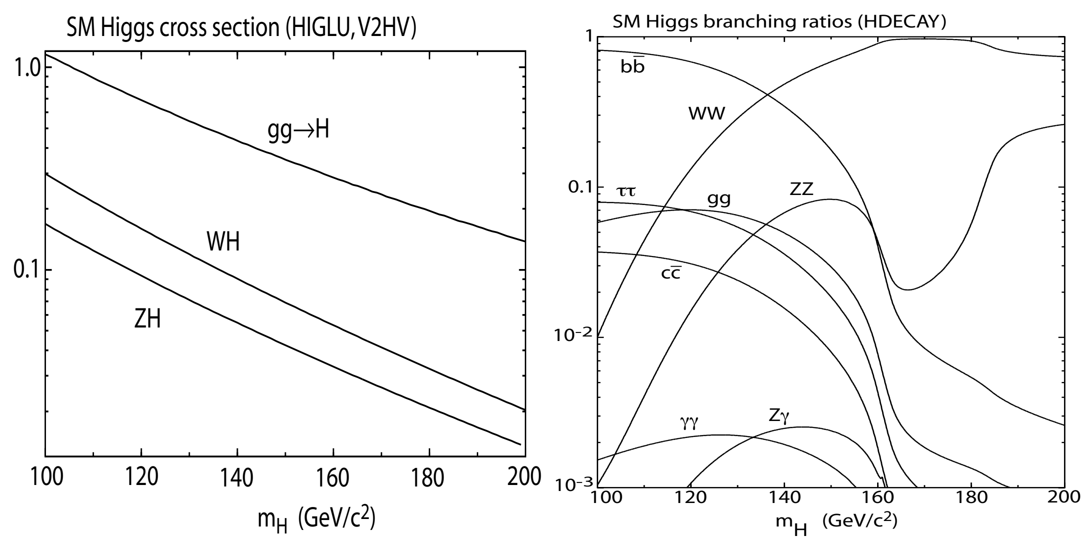

Figure 2: Standard model Higgs boson production cross section at the Tevatron and the branching ratio of Higgs boson.

2 Data Samples and Event Selection

The data used for this analysis come from the high p_T electron dataset (`bhel`), the high p_T muon dataset (`bhmu`), the high p_T plug electron dataset (`bpel`), and the $\not\!\!E_T$ + jets dataset (`emet`), collected through April 2008. We select events from these datasets that contain an energetic ($p_T > 20$ GeV) lepton identified with one of the following selection and trigger requirements:

- Tight central electrons (CEM) are required to pass the ELECTRON_CENTRAL_18 trigger.
- Tight central muons (CMUP and CMX) are required to pass the appropriate

high-p_T muon trigger (MUON_CMUP18 or MUON_CMX18). Due to trigger bandwidth limitations at high luminosity, several versions of the muon trigger: a luminosity-enabled version, which disables the CMUP or CMX trigger until a certain luminosity is reached, a "JET10" version, which adds an additional jet requirement, and at the highest luminosities, one that combines the luminosity enable and jet requirement. The luminosity lost to the luminosity enabled CMX triggers is accounted for when the sample luminosity is calculated.

- Plug electrons (PHX) are identified with the Phoenix algorithm and are required to pass the MET_PEM trigger.

- Events that don't pass one of the above lepton selections are identified as isolated tracks and are required to pass one of the following $\not\!\!E_T$ + jets triggers:

  - MET35_&_TWO_JETS
  - MET35_&_CJET_&_JET
  - MET35_&_CJET_&_JET_LUMI_190
  - MET35_&_CJET_&_JET_DPS

These samples are clustered into three broad lepton categories: tight central leptons (CEM, CMUP, CMX), phoenix electrons (PHX), and isolated tracks.

Our Higgs signal model comes from the official Higgs Discovery Group Higgs Monte Carlo (MC) samples generated with PYTHIA using the standard MC procedure outlined in CDF software version 6.1.4. These Higgs samples were generated for a range of Higgs masses from 110 GeV to 150 GeV. Our background models are composed of a number of components. The W and Z plus light flavor and heavy flavor jet processes are modeled using ALPGEN version 2.10 showered with PYTHIA. Likewise, the single-top contribution is modeled using parton-level events generated by MadEvent and showered through PYTHIA. The rest of the background processes, including the $t\bar{t}$, WW, WZ, and ZZ processes were generated with PYTHIA. For backgrounds involving a top quark, the top mass was set to 175 GeV/c^2.

2.1 Luminosity

We use the standard luminosity calculation provided by the top group including corrections for trigger prescales on a run-section by run-section basis. This calculation uses version 23 of the DQM silicon good run list (bits [1,1,4,1]) for data through period 17. The luminosity for the CEM and CMUP triggered events is 2.67fb^{-1}. Because the CMX trigger was not active for part of period 0, events taken on that trigger have a reduced integrated luminosity (2.61fb^{-1}).

2.2 Event Selection

For each lepton category, we select events consistent with a W-boson decay plus two energetic b-quark jets. The W-boson events are selected by requiring a single, isolated lepton with $p_T > 20$ GeV, and $\not\!\!E_T > 20$ GeV. The $\not\!\!E_T$ is corrected for the presence of muons (including muon-like isolated tracks) and JES. The jets are identified using the JetClu algorithm with a cone of 0.4 and are required to be central ($|\eta_{Det.}| < 2.0$) with $E_T > 20$ GeV, corrected for level-5 jet corrections. We discuss the details of the event selection specific to each lepton category below.

2.2.1 Tight Central Leptons

We use the same event selection criteria as in the SECVTX $t\bar{t}$ cross section measurement [3]. To control the non-W background, we apply the standard single-top style QCD veto to the pretag and single-tagged events. Specifically, we place the following cuts to reduce non-W contamination in the tight central lepton sample:

- CEM:
  - $m_T^W > 20$ GeV
  - $MET_{sig} \geq -0.05 m_T^W + 3.5$
  - $MET_{sig} \geq 2.5 - 3.125 * \Delta\phi_{\not E_T, jet2}$
- CMUP,CMX:
  - $m_T^W > 10$ GeV

Here MET_{sig} is defined as follows:

$$MET_{sig} := \frac{\not\!\!E_T}{\sqrt{\sum_{jets} C_{JES}^2 \cos^2(\Delta\phi_{jet,MET}) + \cos^2(\Delta\phi_{vtx,corr})}}, \tag{1}$$

where C_{JES} is the level 5 jet energy correction factor; $\Delta\phi_{vtx,corr}$ is the azimuthal angle between corrected and uncorrected missing transverse energy.

2.2.2 Phoenix Electrons

We require an electron triggered with the MET_PEM trigger and a Phoenix track (at least 3 r-ϕ hits in the silicon and no z or stereo signal). In addition, because of the high non-W contamination in the PHX sample, we require $\not\!\!E_T$ >25 GeV in addition to the single-top style QCD veto:

- $MET_{sig} > 2.0$
- For the first two leading jets $\not\!\!E_T > 45 - 30 \cdot |\Delta\phi|$, where $\Delta\phi$ is the azimuthal angle between $\vec{\not\!\!E}_T$ and the respective jet.

Also, because the MET_PEM trigger is not fully efficient for the event selection defined here, all Monte Carlo events, as well as events used to model the non-W from the jet sample, have to be weighted with a trigger turn-on curve that is a function of the $\not\!\!E_T$ and the lepton p_T . The turn on curve we used is fully detailed in Section 10.1 of the CDF note for the 1.9fb^{-1}result [2].

2.2.3 Isolated Tracks

We select high quality, high-p_T isolated tracks using the selection criteria outline in Table 1. Our selection is based on the top lepton+track cross section measurement [4].

We define the proximity of our tracks to other activity in the event using track isolation. Track isolation uses only track information and no calorimeter information. It is defined as,

$$\text{TrkIsol} = \frac{p_T(candiate)}{p_T(candiate) + \sum p_T(trk)} \tag{2}$$

where $\sum p_T(trk)$ is the sum of the p_T of tracks that meet the following requirements:

- $p_T > 0.5$ GeV
- ΔR(trk, candidate) < 0.4
- ΔZ(trk, candidate) < 5 cm
- Number of COT axial hits > 20
- Number of COT stereo hits > 10

Using this definition, a track with no surrounding activity has a isolation of 1.0. We require track isolation > 0.9, or 90% of the local track p_T .

We use a variety of vetos that ensure that isolated tracks events are from W events and that they do not overlap other lepton identifications.

- **Tight Jet Veto**: We veto isolated tracks with an angular separation $\Delta R < 0.4$ from any tight jet in the event.
- **Two Track Veto**: We count the number of isolated tracks in the event before applying the tight jet veto. If there are two or more isolated tracks, we veto the event.
- **Tight Lepton Veto**: We check to see if any any CEM, CMUP, or CMX leptons in the event. If any tight isolated leptons are found we do not allow the event to pass isotrk selection.

In addition, to suppress the non-W background, we require $m_T^W > 10$ GeV.

Variable	Cut
p_T	> 20 GeV
$\|z_0\|$	< 60 cm
$\|d_0\|corr$	< 0.2
$\|d_0\|corr$ (w/SI)	< 0.02
track isolation	> 0.9
Axial COT hits	≥ 24
Stereo Hits	≥ 20
χ^2 probability (data only)	$> 10^{-8}$
Num Si Hits (data only, only if num expect ≥ 3)	≥ 3

Table 1: Isolated track selection cuts

Jets Trigger Requirements The $\not\!\!E_T$ plus jets trigger has been used extensively in the $VH \rightarrow \not\!\!E_T + b\bar{b}$ Higgs search [5] [6], and also in the Single Top search, [7]. Those studies have shown that the trigger's jet requirements are fully efficient after the following cuts:

- Two Tight Jets with $E_T > 25$ GeV
- $\Delta R < 1.0$
- One central jet with $|\eta| < 1.0$

We apply these additional jet cuts after identifying the tight jets in the event. For jet bins ≥ 3, we require that the two lead jets in the event satisfy these requirements.

Missing Et Trigger Parameterization We parameterize the $\not\!\!E_T$ trigger turn-on as a function of vertex $\not\!\!E_T$ as shown in figure 3. We choose vertex $\not\!\!E_T$, which is corrected for the primary vertex position but not muons or jet energy scale, because this quantity is closely related to trigger-level $\not\!\!E_T$. We measure the $\not\!\!E_T$ plus jets trigger turn-on following the proceedure outlined in [7] using events recorded with the CMUP trigger. We define the the trigger efficiency as the number of CMUP events passing the trigger jet requirements that fired the $\not\!\!E_T$ plus jets trigger.

We account for the effects of the trigger turn-on by weighting each event that passes our other selection criteria by its probablity to pass the $\not\!\!E_T$ trigger.

2.3 b-Tagging

Because the sample of events with both jets b-tagged is much more pure, we adopt a b-tagging strategy that maximumizes the number of events with two or more b-tags by making use of both the SECVTX and jet probability taggers. Within our strategy, every event with at least one SECVTX b-tag falls into one of three exclusive tag categories.

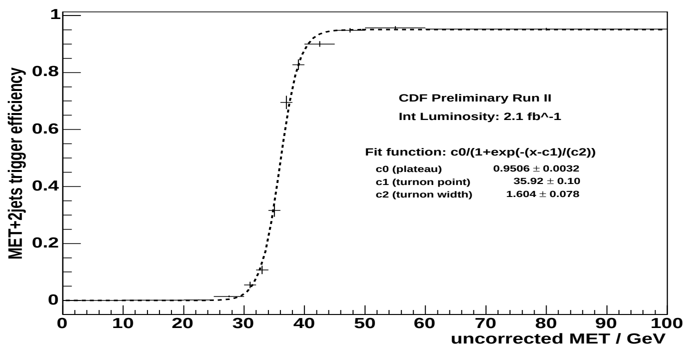

Figure 3: $\not\!\!E_T$ plus jets trigger turn-on curve parameterized as a function of vertex $\not\!\!E_T$.

SECVTX tight + SECVTX tight (ST+ST): Events in this category are required to have both jets tagged by the tight operating point of SECVTX.

SECVTX tight + Jet Probability (ST+JP): Events in this category are required to have one jet tagged by the tight operating point of SECVTX and one jet to be tagged by the jet probability algorithm. To be tagged, a jet must have a jet probability of less than 5%.

SECVTX tight: Events in this category are required to have exact one SECVTX tight tagged jet and with no additional SECVTX or jet probability tags.

3 Background Estimate

We use the same methodology of background estimation as the lepton-triggered analysis, which is closely related to the background estimate used in the $t\bar{t}$ cross section measurement [3]. The estimate is generally called "Method II". The version of the background estimate used in this analysis is documented in detail in the CDF note "Method II For You" [8].

In the W+jets sample, the following background sources are considered:

Non-W QCD: A W signature is generated when one jet fakes a high p_T lepton and $\not\!\!E_T$ is generated through jet energy mismeasurement.

W + Mistags: This background occurs when one or more light flavor jets produced in association with a W boson are mistakenly identified as a heavy flavor jet by the b-tagging algorithms. Mistags are generated because of the finite resolution of the tracking, because of material interactions, or because of long-lived light flavor hadrons (Λ and K_s) that produce displaced vertices.

W+ Heavy Flavor: These processes ($W + b\bar{b}$, $W + c\bar{c}$ and $W + c$) involve the production of actual heavy flavor quarks in association with a W boson.

Top Quark Backgrounds: This background comes both from single top quark production and top quark pair production.

Other EWK Backgrounds: Additional small background contributions come from Z + jets production and diboson (WW, WZ, and ZZ) production.

Follwing the same approach as the "Method II for You" code and the single top analysis, we determine the amount of non-w by fitting the $\not\!\!E_T$ distribution of the pretag, one secvtx tag, and double secvtx tagged samples. We estimate the W + Mistag background by applying the mistag matrix to the pretag $W+$ jets data after subtracting the non-W, top, diboson, Z+jets and W+HF contributions. We model the W + Mistag kinematics using $W+$ light flavor Monte Carlo events. The W + Heavy Flavor background is also estimated from the pretag data using ALPGEN + PYTHIA MC to set the relative normalization of light to heavy flavor events as well as the b-tagging efficiency for W + Heavy Flavor events (see below). The top quark and other EWK backgrounds are normalized directly to their theoretical cross sections, calculated at next-to-leading order. We expand upon the details of be background in the sections that follow. Additional information can be found in "Method II For You" [8].

3.1 NonW (QCD fake) background

We estimate the non-W fraction in the pretag and tag samples by fitting the data $\not\!\!E_T$ distribution with a non-W template and a MC signal template. The non-W template is obtained from non-isolated (iso > 0.1) loose muon events in the $\not\!\!E_T$ plus jets trigger. The MC signal tempalte contains events from Z+jet, W+LF, top, and EWK backgrounds. We use the same uncertainty as "Method II For You" [8], which was determined by performing fits with a variety of binings and fit ranges. The relative uncertainty on the non-W normalization is 40%. Figures 4 through 11 show the results fitting the $\not\!\!E_T$ distribution in the pretag and tag regions. The fits in the double tagged region suffers from low statistics. The uncertainty of 40% accomodates the low statistics

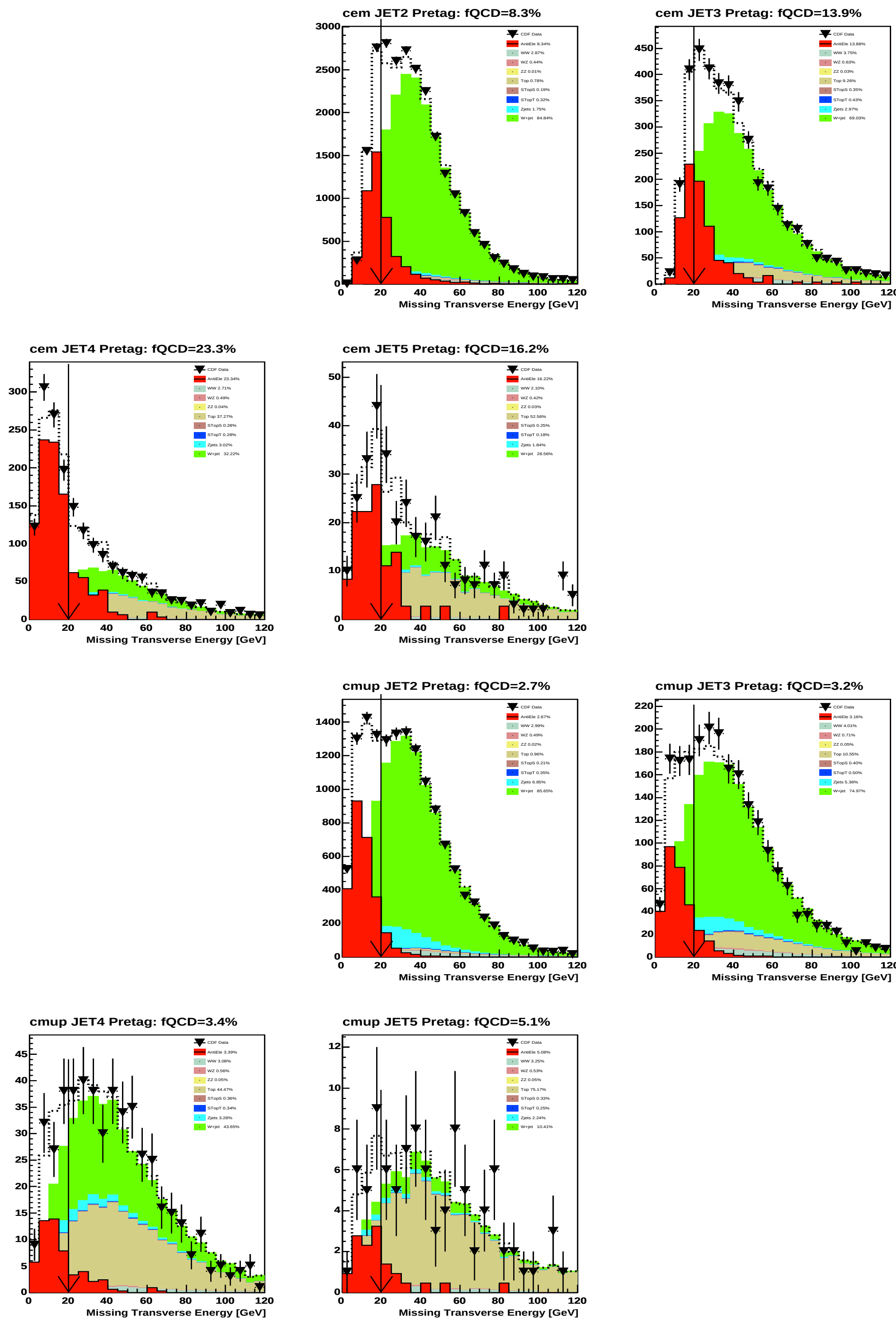

Figure 4: QCD fraction estimate for pretag CEM, CMUP, events

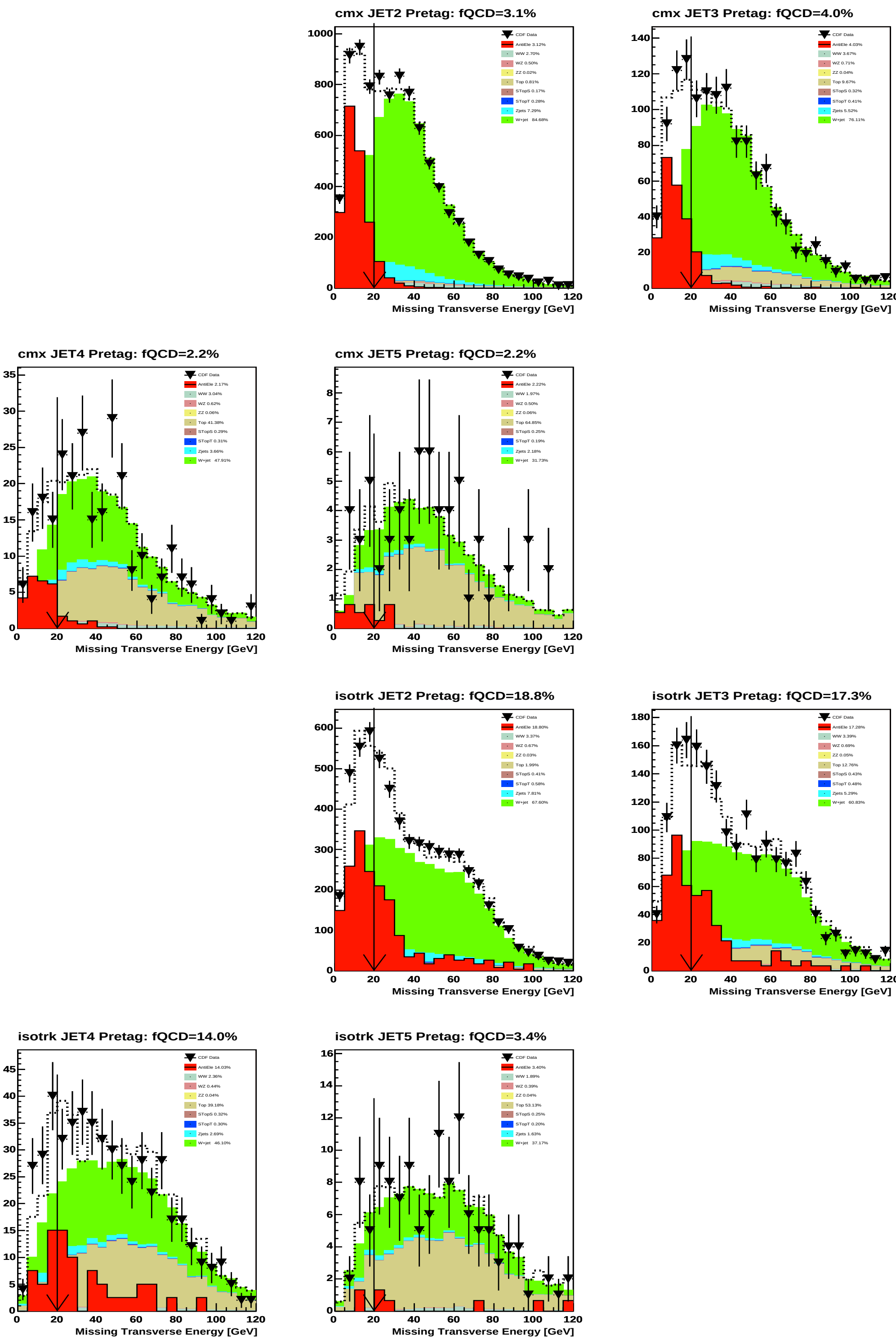

Figure 5: QCD fraction estimate for pretag CMX, ISOTRK events

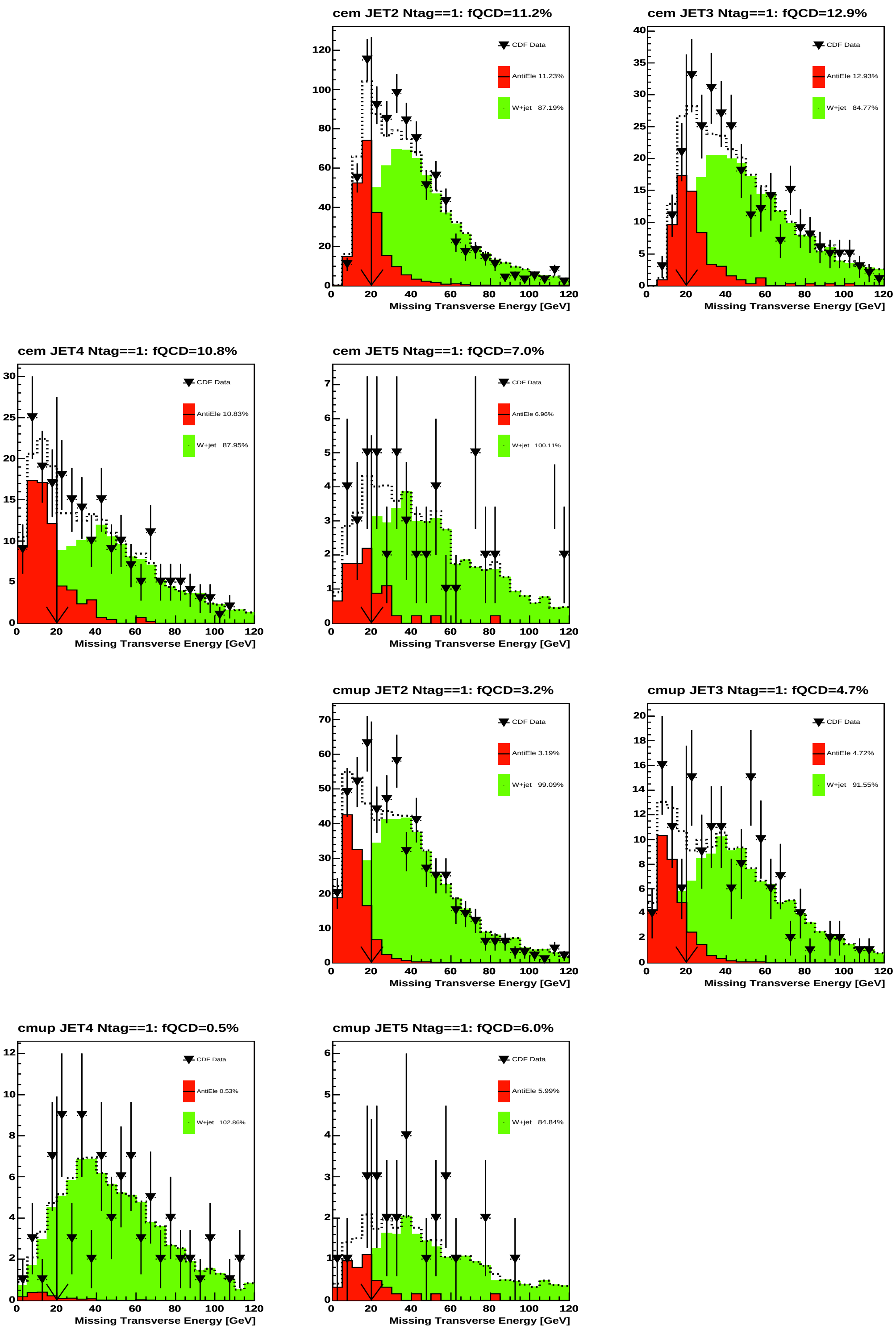

Figure 6: QCD fraction estimate for one tag CEM, CMUP, events

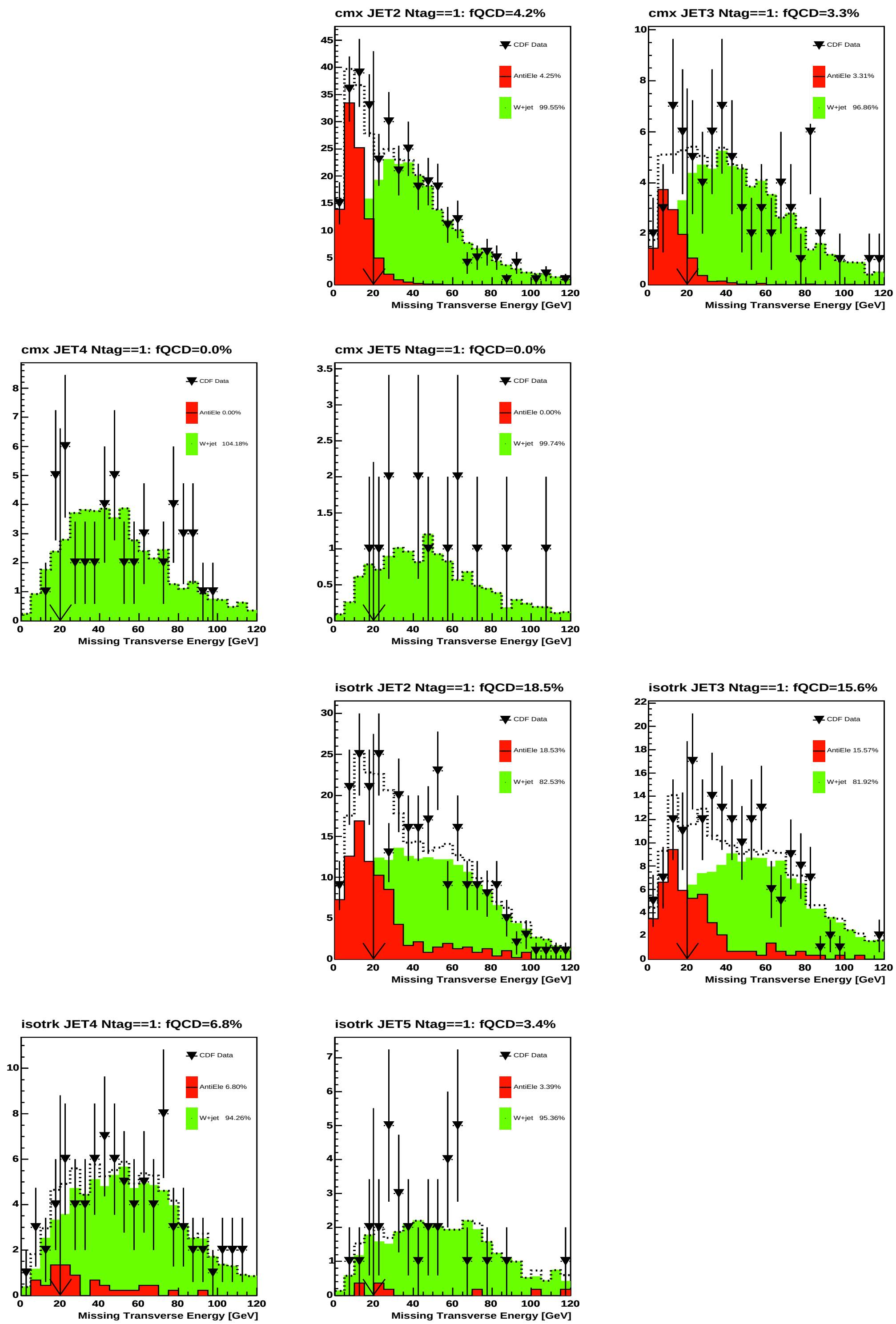

Figure 7: QCD fraction estimate for one tag CMX, ISOTRK events

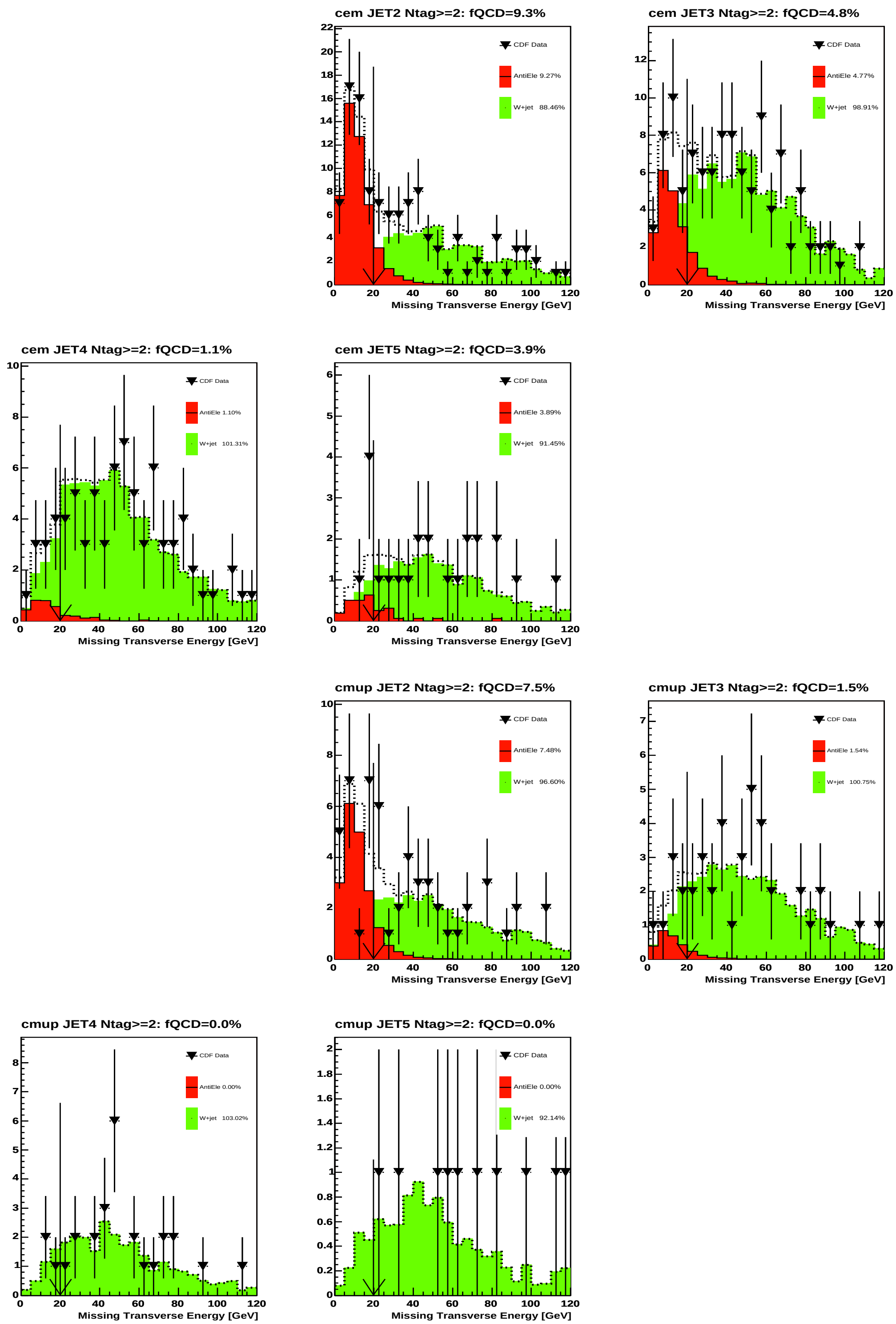

Figure 8: QCD fraction estimate for two secvtx tag CEM, CMUP, events

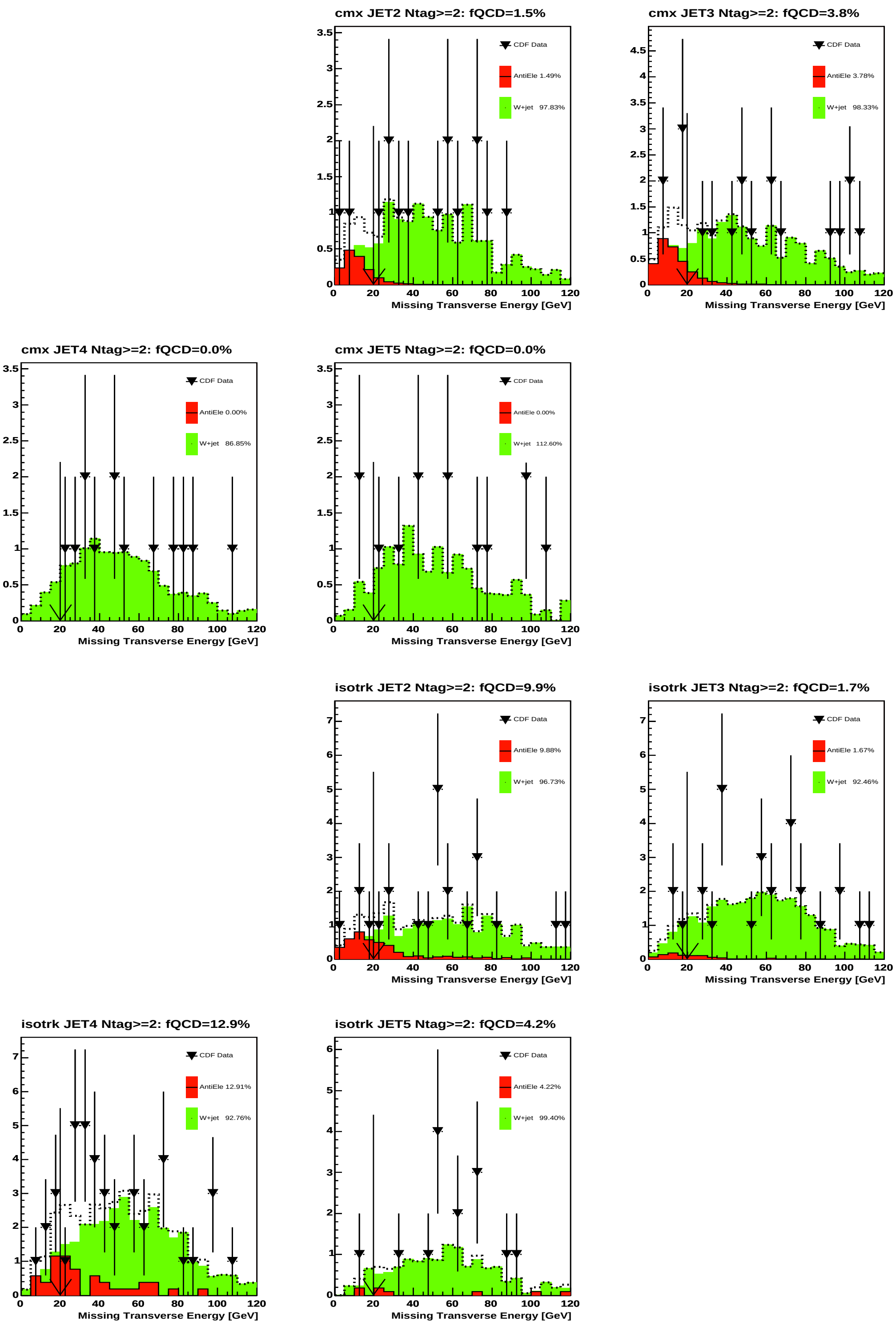

Figure 9: QCD fraction estimate for two secvtx tag CMX, ISOTRK events

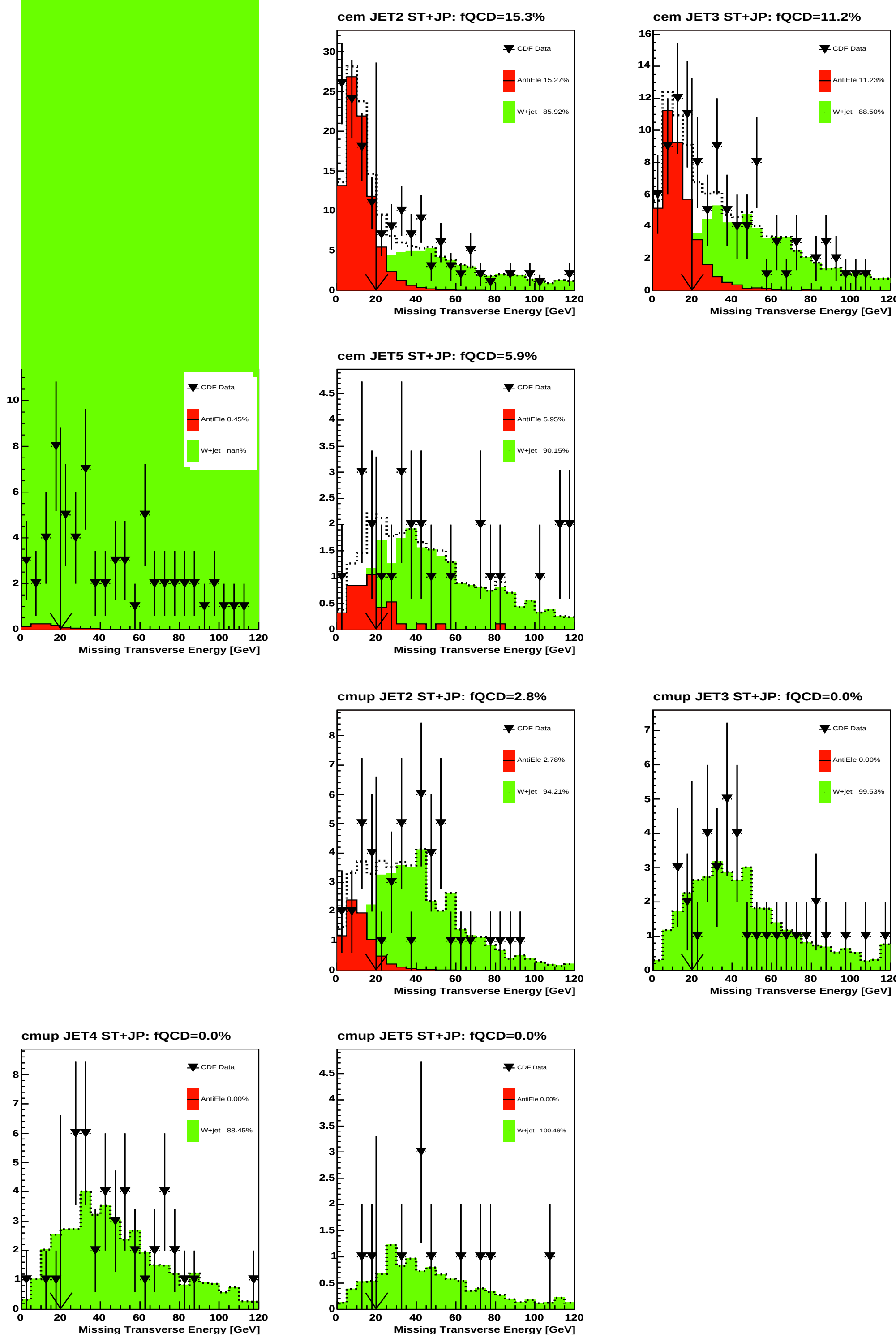

Figure 10: QCD fraction estimate for secvtx+jetprob tag CEM, CMUP, events

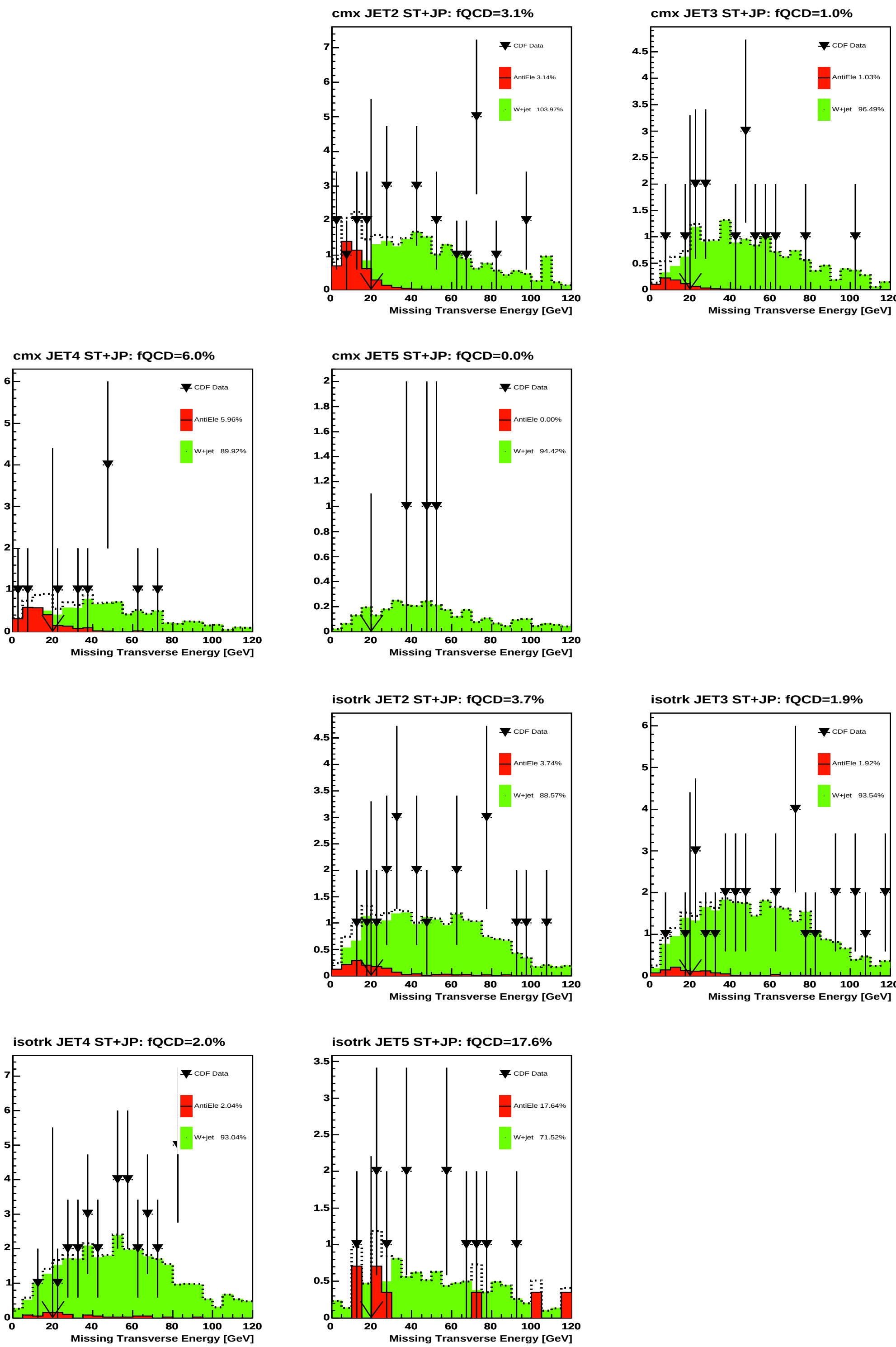

Figure 11: QCD fraction estimate for secvtx+jetprob tag CMX, ISOTRK events

3.2 W + Heavy Flavor

The $Wb\bar{b}$ and $Wc\bar{c}$ states are major sources of background events with real b-tags in the W+jets channel. They are estimated primarily from the Monte Carlo, but their overall rates are normalized to data. The contribution from true heavy flavor production in W+jet events is determined from measurements of the heavy flavor event fraction in W+jet events and the tagging efficiency for those events.

These heavy flavor fractions and a scaling factor for these fractions (k-factor) have been studied extensively elsewhere [3, 9] using ALPGEN v2 + PYTHIA Monte Carlo. Heavy flavor fractions measured in ALPGEN have been calibrated using a sample of $W+1$ jet events, and it is found that a k-factor of 1.4 ± 0.4 is necessary to make the heavy flavor production in Monte Carlo match the production in data. We have calculated the tagging rates and heavy flavor fraction for events passing our selection using the "Method II For you" framework [8]. We estimate the number of W + heavy flavor events in our tag sample according to

$$N_{W+HF} = f_{HF} \cdot \epsilon_{\mathrm{tag}} \cdot [N_{\mathrm{pretag}} \cdot (1 - f_{\mathrm{non-}W}) - N_{\mathrm{EWK}}] \,, \tag{3}$$

where f_{HF} is heavy fraction, ϵ_{tag} is tagging efficiency and N_{EWK} is the expected number of $t\bar{t}$, single top, $Z+$ jets, and diboson events.

3.3 Mistag

The rate of W + mistag, or falsely tagged, jets is derived from a sample of events collected with a jet-based trigger with no heavy flavor requirement. The mistag rate is obtained using negative tags, which are tags that appear to come from behind the primary vertex. The mistag rate obtained from negative tags is parameterized in bins of η, jet E_T, track multiplicity within a jet, $\sum E_T$ of the event, number of z vertices, and the z vertex position [10]. The mistag rate derived from negative tags is corrected for the effects of heavy flavor in the jet sample, long-lived light flavor vertices, and vertices caused by material interactions in the silicon detector. This correction is parameterized as a function of E_T to reduce its systematic uncertainty [11].

The total mistag rate is estimated from the pretag data. For each pretag event, the mistag probability for each jet is calculated as described above. These probabilities are then used to calculate the probability for that event to be singly or doubly tagged. The sum of the single-tag or double-tag probabilities for all pretag events provides the total mistag estimate. This estimate is then corrected for the fraction of the pretag sample estimated to come from other processes (non-W, top, $Z+$ jets, or dibosons).

The uncertainty on the mistag estimate includes the statistical errors from the matrix itself, accounting for correlations between jets which fall in the same bin of the mistag matrices, and an additional 5.9% error from all systematic uncertainties [10]. Although the mistag matrix was derived using the $1.12\mathrm{fb}^{-1}$sample, it has been shown that it is acceptable to apply this at least through period 13 data as long as the systematic uncertainties are increased by 1.8% to cover possible discrepancies.

Theoretical Cross Sections	
WW	12.4 ± 0.25 pb
WZ	3.96 ± 0.06 pb
ZZ	1.58 ± 0.05 pb
Single Top s-channel	0.88 ± 0.05 pb
Single Top t-channel	1.98 ± 0.08 pb
$Z+$ jets	787.4 ± 50.0 pb
$t\bar{t}$	6.7 ± 0.08 pb

Table 2: Theoretical cross sections and errors for the electroweak and single top backgrounds, along with the theoretical cross section for $t\bar{t}$ at ($m_t = 175$GeV/c^2).

3.4 MC derived background

The normalization of the diboson, $t\bar{t}$ and single top backgrounds are based on the theoretical cross sections (listed in Table 2), the measured luminosity and the acceptance and b-tagging efficiency derived from MC. The MC acceptance is corrected for lepton identification, trigger efficiencies and z vertex cut. The tagging efficiency is always scaled by the MC/data scale factor of 0.95± 0.05 for SECVTX tags. The expected number of events is obtained by the equation

$$N = \int \mathcal{L}dt \times \epsilon_{pretag} \times \epsilon_{tag} \times \sigma, \tag{4}$$

where ϵ_{pretag} is the total pretag detection efficiency corrected by all of the scale factors. The tagging efficiency ϵ_{tag} is calculated by summing over the probability to tag each jet in a pretag event. Heavy flavor jets have a tag probability equal to the SECVTX scale factor. Light flavor jets have a probability determined by the mistag matrix. The uncertainties on the normalizations are dervied from measuring the change in acceptance when the tag probabilities are shifted by ± 1 σ.

3.5 Background Summary

We have described the contributions of individual background sources to the final background estimate. The summary table of the background estimates are shown in Tables 3-8. Note: The tables for the PHX sample are not show because they have not yet been updated. In general, the number of expected events and the number of observed events are in good agreement.

4 Signal Acceptance

To calculate the expected number of signal $N_{WH\rightarrow l\nu b\bar{b}}$, the following equation is used:

Process	2jets	3jets	4jets	5jets
All Pretag Candidates	36054.000 ± 0.000	5928.000 ± 0.000	1566.000 ± 0.000	354.000 ± 0.000
Pretag (before MET cut) ww	1123.989 ± 73.043	241.315 ± 15.675	48.887 ± 3.172	9.118 ± 0.588
Pretag (before MET cut) wz	186.453 ± 11.955	43.826 ± 2.803	10.367 ± 0.659	1.978 ± 0.126
Pretag (before MET cut) zz	9.157 ± 0.658	3.250 ± 0.229	1.445 ± 0.100	0.274 ± 0.019
Pretag (before MET cut) top	306.943 ± 41.263	621.298 ± 83.524	664.659 ± 89.313	224.210 ± 30.117
Pretag (before MET cut) stops	74.319 ± 6.869	22.399 ± 2.070	5.143 ± 0.475	1.032 ± 0.095
Pretag (before MET cut) stopt	124.593 ± 12.516	28.043 ± 2.817	5.233 ± 0.525	0.766 ± 0.077
Pretag (before MET cut) zlf	2291.501 ± 207.619	371.331 ± 33.242	97.075 ± 8.554	12.361 ± 1.089
Total Pretag MC (before MET cut)	4116.957 ± 190.965	1331.462 ± 72.693	832.809 ± 61.687	249.739 ± 20.156
Pretag QCD	2127.986 ± 682.244	555.438 ± 188.074	236.243 ± 87.195	41.430 ± 14.573
Pretag (after MET cut) ww	1024.614 ± 66.578	219.747 ± 14.355	42.687 ± 2.871	7.913 ± 0.605
Pretag (after MET cut) wz	165.884 ± 10.641	38.678 ± 2.500	8.127 ± 0.550	1.564 ± 0.128
Pretag (after MET cut) zz	5.442 ± 0.401	1.988 ± 0.150	0.693 ± 0.059	0.144 ± 0.019
Pretag (after MET cut) top	291.393 ± 39.287	581.484 ± 78.279	594.405 ± 80.009	199.991 ± 26.991
Pretag (after MET cut) stops	68.795 ± 6.360	20.803 ± 1.926	4.586 ± 0.429	0.933 ± 0.091
Pretag (after MET cut) stopt	115.401 ± 11.595	26.104 ± 2.628	4.630 ± 0.472	0.687 ± 0.076
Pretag (after MET cut) zlf	1421.899 ± 129.489	236.369 ± 21.207	49.233 ± 4.407	6.924 ± 0.630
Total Pretag MC (after MET cut)	3093.429 ± 139.400	1125.173 ± 64.471	704.360 ± 54.243	218.156 ± 18.108
Total Pretag HF	5127.266 ± 1031.631	1051.465 ± 207.741	197.990 ± 49.150	35.978 ± 11.479
Total Pretag Corrected	30832.585 ± 696.340	4247.389 ± 198.817	625.397 ± 102.690	94.414 ± 23.244
Total LF Pretag Corrected	25705.319 ± 1244.649	3195.924 ± 287.549	427.406 ± 113.846	58.436 ± 25.924
Tagged ww	41.883 ± 4.611	12.664 ± 1.383	3.332 ± 0.351	0.871 ± 0.089
Tagged wz	16.296 ± 1.232	4.162 ± 0.322	1.115 ± 0.091	0.256 ± 0.022
Tagged zz	0.557 ± 0.047	0.231 ± 0.019	0.102 ± 0.009	0.029 ± 0.003
Tagged top	121.797 ± 16.690	252.088 ± 34.256	263.157 ± 35.509	89.432 ± 12.047
Tagged stops	30.493 ± 2.872	9.258 ± 0.868	2.041 ± 0.191	0.410 ± 0.038
Tagged stopt	44.594 ± 4.800	10.825 ± 1.132	2.080 ± 0.214	0.292 ± 0.030
Tagged zlf	29.513 ± 3.675	8.889 ± 1.075	2.842 ± 0.340	0.565 ± 0.067
Raw Mis-tags(info)	413.629 ± 50.793	142.425 ± 16.886	59.961 ± 6.882	18.959 ± 2.141
Tagged Wbb	384.991 ± 146.859	98.420 ± 37.748	21.032 ± 8.735	4.258 ± 1.923
Tagged Wcc/Wc	354.456 ± 137.193	81.077 ± 31.475	17.197 ± 7.198	3.490 ± 1.588
Tagged Total HF	739.447 ± 283.330	179.497 ± 68.877	38.228 ± 15.281	7.749 ± 3.248
Tagged Total MC	285.132 ± 26.454	298.117 ± 36.098	274.670 ± 35.903	91.854 ± 12.128
Tagged Mistags	294.895 ± 38.954	76.664 ± 11.505	16.356 ± 4.737	3.157 ± 1.423
Tagged Non-W	101.496 ± 40.598	42.723 ± 17.089	16.311 ± 13.733	4.565 ± 4.551
Total Prediction	1420.970 ± 290.071	597.001 ± 80.446	345.564 ± 41.636	107.326 ± 13.430
Observed	1306.000 ± 0.000	448.000 ± 0.000	265.000 ± 0.000	77.000 ± 0.000

Table 3: tlep eq1tag

$$N_{WH\to l\nu b\bar{b}} = \epsilon_{WH\to l\nu b\bar{b}} \cdot \mathcal{L} \cdot \sigma(p\bar{p} \to WH) \cdot Br(H \to b\bar{b}), \tag{5}$$

where, $\epsilon_{H\to l\nu b\bar{b}}$ is the detection efficiency for signal, $\mathcal{L}$ is the integrated luminosity, $\sigma(p\bar{p} \to WH)$ is WH production cross section in proton antiproton collisions and $BR(H \to b\bar{b})$ is branching ratio for Higgs decaying to $b\bar{b}$. The detection efficiency for signal events is defined as:

$$\epsilon_{WH\to l\nu b\bar{b}} = \epsilon_{Z0} \cdot \epsilon_{trig} \cdot \epsilon_{leptonid} \cdot \epsilon^{MC}_{WH\to l\nu b\bar{b}} \cdot \left(\sum_{l=e,\mu,\tau} BR(W \to l\nu) \right), \tag{6}$$

where $\epsilon^{MC}_{WH\to l\nu b\bar{b}}$ is the fraction of signal events (with $|z_0| < 60$cm) which pass the kinematic and b-tagging requirements. We correct the number of tagged events in the Monte Carlo by multiplying by the b-tagging scale factor. The quantity ϵ_{Z0} is the efficiency for the $|z_0| < 60$ cm cut. The trigger efficiency, ϵ_{trig}, is measured in the data. For triggers like the MET_PEM or $\not{E}_T$ + jets, it is parameterized as a function of the relevant kinematic variables, like vertex $\not{E}_T$. We apply a lepton reconstruction scale factor to match the efficiency for the various types of lepton reconstruction to what we measure in $Z \to \ell^+\ell^-$ data (more discucssion for isolated tracks is in section 4.1. Finally, $Br(W \to l\nu)$ is the branching ratio for leptonic W decay. Each of these factors and their systematic errors are treated separately for each data period and the

Process	2jets	3jets	4jets	5jets
All Pretag Candidates	44728.000 ± 0.000	7585.000 ± 0.000	1679.000 ± 0.000	382.000 ± 0.000
Pretag (before MET cut) ww	1217.058 ± 78.924	265.804 ± 17.225	48.887 ± 3.172	9.118 ± 0.588
Pretag (before MET cut) wz	211.729 ± 13.512	54.604 ± 3.468	10.367 ± 0.659	1.978 ± 0.126
Pretag (before MET cut) zz	15.297 ± 1.070	6.602 ± 0.455	1.445 ± 0.100	0.274 ± 0.019
Pretag (before MET cut) top	336.057 ± 45.156	692.689 ± 93.069	664.659 ± 89.313	224.210 ± 30.117
Pretag (before MET cut) stops	81.497 ± 7.525	24.838 ± 2.293	5.143 ± 0.475	1.032 ± 0.095
Pretag (before MET cut) stopt	134.845 ± 13.537	30.647 ± 3.076	5.233 ± 0.525	0.766 ± 0.077
Pretag (before MET cut) zlf	4579.685 ± 405.091	833.735 ± 73.477	98.067 ± 8.643	12.585 ± 1.109
Total Pretag MC (before MET cut)	6576.168 ± 336.282	1908.918 ± 103.838	833.801 ± 61.705	249.963 ± 20.160
Pretag QCD	8690.661 ± 3059.190	1642.212 ± 584.669	253.236 ± 93.715	48.301 ± 17.384
Pretag (after MET cut) ww	1066.126 ± 69.219	232.781 ± 15.185	42.687 ± 2.871	7.913 ± 0.605
Pretag (after MET cut) wz	176.237 ± 11.285	43.165 ± 2.780	8.127 ± 0.550	1.564 ± 0.128
Pretag (after MET cut) zz	6.703 ± 0.486	2.962 ± 0.217	0.693 ± 0.059	0.144 ± 0.019
Pretag (after MET cut) top	310.807 ± 41.887	626.469 ± 84.300	594.405 ± 80.009	199.991 ± 26.991
Pretag (after MET cut) stops	72.710 ± 6.719	22.132 ± 2.048	4.586 ± 0.429	0.933 ± 0.091
Pretag (after MET cut) stopt	120.366 ± 12.090	27.438 ± 2.761	4.630 ± 0.472	0.687 ± 0.076
Pretag (after MET cut) zlf	1782.632 ± 160.611	362.565 ± 32.242	49.898 ± 4.467	7.079 ± 0.644
Total Pretag MC (after MET cut)	3535.581 ± 160.213	1317.512 ± 74.161	705.025 ± 54.255	218.310 ± 18.111
Total Pretag HF	5398.314 ± 1176.855	1144.536 ± 262.331	228.371 ± 54.919	44.038 ± 12.873
Total Pretag Corrected	32501.759 ± 3063.383	4625.276 ± 589.353	720.738 ± 108.287	115.388 ± 25.104
Total LF Pretag Corrected	27103.444 ± 3281.661	3480.740 ± 645.101	492.368 ± 121.418	71.351 ± 28.212
Tagged ww	0.300 ± 0.059	0.292 ± 0.051	0.168 ± 0.027	0.076 ± 0.012
Tagged wz	3.327 ± 0.367	0.939 ± 0.107	0.187 ± 0.024	0.039 ± 0.005
Tagged zz	0.098 ± 0.011	0.073 ± 0.008	0.019 ± 0.002	0.005 ± 0.001
Tagged top	25.935 ± 4.179	76.928 ± 12.417	101.482 ± 16.360	36.225 ± 5.869
Tagged stops	9.572 ± 1.211	3.258 ± 0.414	0.723 ± 0.092	0.153 ± 0.020
Tagged stopt	2.160 ± 0.301	1.907 ± 0.259	0.533 ± 0.072	0.103 ± 0.014
Tagged zlf	1.407 ± 0.195	0.953 ± 0.133	0.261 ± 0.038	0.085 ± 0.013
Raw Mis-tags(info)	2.275 ± 0.575	2.052 ± 0.512	1.167 ± 0.286	0.553 ± 0.137
Tagged Wbb	55.064 ± 22.001	18.063 ± 7.404	4.867 ± 2.031	1.232 ± 0.548
Tagged Wcc/Wc	4.868 ± 2.014	2.350 ± 0.997	0.937 ± 0.401	0.248 ± 0.115
Tagged Total HF	59.931 ± 23.906	20.413 ± 8.307	5.804 ± 2.389	1.479 ± 0.640
Tagged Total MC	42.800 ± 5.646	84.349 ± 12.999	103.374 ± 16.511	36.688 ± 5.907
Tagged Mistags	1.376 ± 0.387	0.928 ± 0.297	0.345 ± 0.117	0.105 ± 0.047
Tagged Non-W	8.964 ± 4.008	5.015 ± 2.006	0.737 ± 1.590	0.231 ± 1.500
Total Prediction	113.071 ± 24.892	110.706 ± 15.560	110.260 ± 16.758	38.503 ± 6.128
Observed	114.000 ± 0.000	132.000 ± 0.000	105.000 ± 0.000	42.000 ± 0.000

Table 4: tlep gr2tag

results are combined weighted by the luminosity of each data period. For the later data periods, where numbers may not have been finalized, preliminary results have been taken from the slides of talks given in the Joint Physics meeting [12].

Samples of PYTHIA $WH \to l\nu b\bar{b}$ Monte Carlo with Higgs boson masses between 110 GeV and 150 GeV are used to estimate $\epsilon^{MC}_{WH\to l\nu b\bar{b}}$. The MC samples were generated using a run range up to period 8.

Table 9 shows the WH production cross section times branching ratio to $b\bar{b}$. The cross sections in Table 9 are combined with the integrated luminosity of 2.7 fb^{-1}and the overall event detection efficiencies to produce the number of expected WH isolated track events shown in Table **??** .

4.1 Isotrk Reconstruction Scale factor

The scale factors are derived analogous to the CMUP scale factors [13] using $Z \to \mu\mu$ events. We select events with one tight CMUP or CMX muon as a tag leg and a high p_T track as a probe leg. We apply the following cuts:

- $81 < m_{ll} < 101$
- $|\Delta z_{ll}| < 4$
- opposite charge

Process	2jets	3jets	4jets	5jets
All Pretag Candidates	44728.000 ± 0.000	7585.000 ± 0.000	1679.000 ± 0.000	382.000 ± 0.000
Pretag (before MET cut) ww	1217.058 ± 78.924	265.804 ± 17.225	48.887 ± 3.172	9.118 ± 0.588
Pretag (before MET cut) wz	211.729 ± 13.512	54.604 ± 3.468	10.367 ± 0.659	1.978 ± 0.126
Pretag (before MET cut) zz	15.297 ± 1.070	6.602 ± 0.455	1.445 ± 0.100	0.274 ± 0.019
Pretag (before MET cut) top	336.057 ± 45.156	692.689 ± 93.069	664.659 ± 89.313	224.210 ± 30.117
Pretag (before MET cut) stops	81.497 ± 7.525	24.838 ± 2.293	5.143 ± 0.475	1.032 ± 0.095
Pretag (before MET cut) stopt	134.845 ± 13.537	30.647 ± 3.076	5.233 ± 0.525	0.766 ± 0.077
Pretag (before MET cut) zlf	4579.685 ± 405.091	833.735 ± 73.477	98.067 ± 8.643	12.585 ± 1.109
Total Pretag MC (before MET cut)	6576.168 ± 336.282	1908.918 ± 103.838	833.801 ± 61.705	249.963 ± 20.160
Pretag QCD	8690.661 ± 3059.190	1642.212 ± 584.669	253.236 ± 93.715	48.301 ± 17.384
Pretag (after MET cut) ww	1066.126 ± 69.219	232.781 ± 15.185	42.687 ± 2.871	7.913 ± 0.605
Pretag (after MET cut) wz	176.237 ± 11.285	43.165 ± 2.780	8.127 ± 0.550	1.564 ± 0.128
Pretag (after MET cut) zz	6.703 ± 0.486	2.962 ± 0.217	0.693 ± 0.059	0.144 ± 0.019
Pretag (after MET cut) top	310.807 ± 41.887	626.469 ± 84.300	594.405 ± 80.009	199.991 ± 26.991
Pretag (after MET cut) stops	72.710 ± 6.719	22.132 ± 2.048	4.586 ± 0.429	0.933 ± 0.091
Pretag (after MET cut) stopt	120.366 ± 12.090	27.438 ± 2.761	4.630 ± 0.472	0.687 ± 0.076
Pretag (after MET cut) zlf	1782.632 ± 160.611	362.565 ± 32.242	49.898 ± 4.467	7.079 ± 0.644
Total Pretag MC (after MET cut)	3535.581 ± 160.213	1317.512 ± 74.161	705.025 ± 54.255	218.310 ± 18.111
Total Pretag HF	5398.314 ± 1176.855	1144.536 ± 262.331	228.371 ± 54.919	44.038 ± 12.873
Total Pretag Corrected	32501.759 ± 3063.383	4625.276 ± 589.353	720.738 ± 108.287	115.388 ± 25.104
Total LF Pretag Corrected	27103.444 ± 3281.661	3480.740 ± 645.101	492.368 ± 121.418	71.351 ± 28.212
Tagged ww	1.241 ± 0.528	0.857 ± 0.313	0.399 ± 0.135	0.164 ± 0.047
Tagged wz	2.517 ± 0.426	0.784 ± 0.159	0.181 ± 0.043	0.052 ± 0.013
Tagged zz	0.098 ± 0.016	0.053 ± 0.009	0.021 ± 0.004	0.005 ± 0.001
Tagged top	20.400 ± 4.162	63.966 ± 13.429	79.471 ± 16.155	29.933 ± 6.089
Tagged stops	7.004 ± 1.122	2.456 ± 0.417	0.574 ± 0.104	0.133 ± 0.024
Tagged stopt	2.107 ± 0.642	1.677 ± 0.357	0.458 ± 0.091	0.076 ± 0.015
Tagged zlf	1.791 ± 0.532	1.167 ± 0.353	0.337 ± 0.120	0.097 ± 0.032
Raw Mis-tags(info)	9.641 ± 9.903	6.581 ± 7.300	3.385 ± 3.470	1.527 ± 1.850
Tagged Wbb	49.093 ± 20.111	17.079 ± 7.221	4.886 ± 2.119	1.275 ± 0.593
Tagged Wcc/Wc	17.967 ± 8.315	7.885 ± 3.716	2.568 ± 1.236	0.670 ± 0.343
Tagged Total HF	67.060 ± 27.934	24.964 ± 10.668	7.454 ± 3.250	1.945 ± 0.887
Tagged Total MC	35.158 ± 6.932	70.961 ± 14.712	81.442 ± 16.539	30.460 ± 6.192
Tagged Mistags	5.841 ± 6.029	3.007 ± 3.374	0.997 ± 1.050	0.288 ± 0.370
Tagged Non-W	12.375 ± 4.950	7.330 ± 3.874	0.758 ± 1.429	0.283 ± 1.500
Total Prediction	120.434 ± 29.820	106.261 ± 18.885	90.650 ± 16.949	32.976 ± 6.443
Observed	124.000 ± 0.000	109.000 ± 0.000	101.000 ± 0.000	36.000 ± 0.000

Table 5: tlep stjp

- the tag leg fired the muon trigger (data only)
- the event passed the cosmic veto
- the probe leg satisfies $p_T > 20$
- the probe leg has a muon stub attached

For the events that pass these cuts we calculate the efficiency for passing the track and jet isolation cuts. The ratio of these efficiencies for data and Z Monte Carlo is defined to be the IsoTrack scale factor. Figures 12 to 14 show the isotrk scale factor as function of ϕ, η, and p_T .

4.2 Other Systematic Uncertainties on Acceptance

The systematic uncertainties on the acceptance include uncertainties on the jet energy scale, initial and final state radiation, and the b-tagging scale factor. For each source of systematics, we use the same uncertainties as measured by the lepton triggered analysis, using the values for secvtx tag + NN tag for our events with one secvtx tag (there is a 90% overlap of events with one secvtx tag and events with secvtx+NN tag).

1. To obtain the systematic uncertainty from jet energy scale, we use the Higgs sample for a mass of 120 GeV. The jet energies in the WH MC samples are

Process	2jets	3jets	4jets	5jets
All Pretag Candidates	4269.000 ± 0.000	1386.000 ± 0.000	430.000 ± 0.000	117.000 ± 0.000
Pretag (before MET cut) ww	159.225 ± 10.224	50.488 ± 3.242	10.709 ± 0.688	2.275 ± 0.146
Pretag (before MET cut) wz	32.947 ± 2.070	10.927 ± 0.686	2.196 ± 0.138	0.495 ± 0.031
Pretag (before MET cut) zz	2.262 ± 0.155	1.023 ± 0.070	0.242 ± 0.017	0.067 ± 0.005
Pretag (before MET cut) top	83.850 ± 11.241	190.873 ± 25.590	191.774 ± 25.710	65.865 ± 8.830
Pretag (before MET cut) stops	18.895 ± 1.739	6.374 ± 0.587	1.460 ± 0.134	0.302 ± 0.028
Pretag (before MET cut) stopt	26.828 ± 2.685	7.103 ± 0.711	1.348 ± 0.135	0.247 ± 0.025
Pretag (before MET cut) zlf	530.184 ± 46.671	114.375 ± 10.068	16.625 ± 1.463	2.650 ± 0.233
Total Pretag MC (before MET cut)	854.192 ± 62.947	381.163 ± 33.373	224.354 ± 26.695	71.901 ± 9.005
Pretag QCD	802.464 ± 320.985	239.533 ± 95.813	60.319 ± 24.128	3.974 ± 1.590
Pretag (after MET cut) ww	140.558 ± 9.138	45.218 ± 3.015	9.724 ± 0.729	2.035 ± 0.216
Pretag (after MET cut) wz	28.234 ± 1.809	9.347 ± 0.622	1.851 ± 0.148	0.440 ± 0.053
Pretag (after MET cut) zz	1.459 ± 0.113	0.678 ± 0.058	0.160 ± 0.020	0.052 ± 0.010
Pretag (after MET cut) top	78.484 ± 10.662	175.575 ± 23.679	176.357 ± 23.784	59.623 ± 8.133
Pretag (after MET cut) stops	17.290 ± 1.597	5.847 ± 0.544	1.334 ± 0.128	0.276 ± 0.031
Pretag (after MET cut) stopt	24.431 ± 2.453	6.502 ± 0.659	1.254 ± 0.133	0.232 ± 0.030
Pretag (after MET cut) zlf	328.948 ± 29.032	71.928 ± 6.370	11.338 ± 1.020	1.891 ± 0.184
Total Pretag MC (after MET cut)	619.405 ± 44.419	315.096 ± 28.957	202.018 ± 24.547	64.550 ± 8.275
Total Pretag HF	484.633 ± 158.037	210.110 ± 67.599	54.398 ± 19.398	18.136 ± 6.081
Total Pretag Corrected	2847.132 ± 324.044	831.371 ± 100.093	167.663 ± 34.419	48.476 ± 8.427
Total LF Pretag Corrected	2362.499 ± 360.528	621.261 ± 120.782	113.264 ± 39.509	30.340 ± 10.392
Tagged ww	6.717 ± 0.734	3.115 ± 0.328	0.856 ± 0.089	0.268 ± 0.026
Tagged wz	2.966 ± 0.223	1.127 ± 0.086	0.230 ± 0.019	0.077 ± 0.007
Tagged zz	0.156 ± 0.013	0.070 ± 0.005	0.011 ± 0.001	0.008 ± 0.001
Tagged top	34.836 ± 4.753	78.760 ± 10.680	78.430 ± 10.556	25.806 ± 3.470
Tagged stops	8.080 ± 0.755	2.664 ± 0.249	0.626 ± 0.059	0.123 ± 0.011
Tagged stopt	10.812 ± 1.158	2.861 ± 0.297	0.542 ± 0.055	0.093 ± 0.009
Tagged zlf	9.575 ± 1.165	3.401 ± 0.407	0.696 ± 0.087	0.154 ± 0.019
Raw Mis-tags(info)	77.862 ± 8.806	39.166 ± 4.475	17.859 ± 2.001	6.842 ± 0.772
Tagged Wbb	45.446 ± 18.063	21.820 ± 8.713	6.496 ± 2.809	2.454 ± 1.027
Tagged Wcc/Wc	38.638 ± 15.563	17.798 ± 7.185	5.267 ± 2.297	1.832 ± 0.773
Tagged Total HF	84.084 ± 32.890	39.618 ± 15.521	11.763 ± 4.811	4.286 ± 1.721
Tagged Total MC	73.142 ± 6.881	91.997 ± 11.197	81.392 ± 10.655	26.530 ± 3.494
Tagged Mistags	43.090 ± 8.185	17.556 ± 3.959	4.704 ± 1.723	1.774 ± 0.640
Tagged Non-W	39.093 ± 15.637	23.362 ± 9.345	5.369 ± 4.295	2.175 ± 1.740
Total Prediction	239.409 ± 37.956	172.534 ± 21.662	103.227 ± 12.573	34.765 ± 4.313
Observed	211.000 ± 0.000	150.000 ± 0.000	79.000 ± 0.000	32.000 ± 0.000

Table 6: isotrk one tag

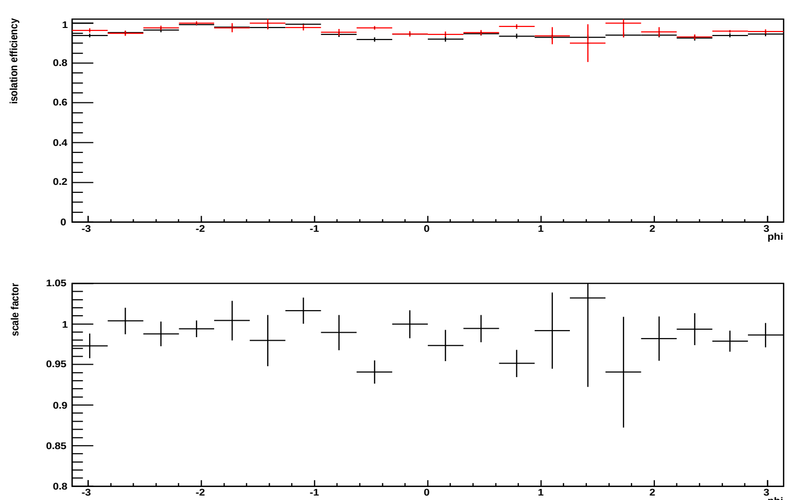

Figure 12: Isolated track reconstruction scale factor vs. lepton ϕ

shifted by $\pm 1\sigma$ and the difference from the nominal acceptance is taken as the systematic uncertainty.

Process	2jets	3jets	4jets	5jets
All Pretag Candidates	4269.000 ± 0.000	1386.000 ± 0.000	430.000 ± 0.000	117.000 ± 0.000
Pretag (before MET cut) ww	159.225 ± 10.224	50.488 ± 3.242	10.709 ± 0.688	2.275 ± 0.146
Pretag (before MET cut) wz	32.947 ± 2.070	10.927 ± 0.686	2.196 ± 0.138	0.495 ± 0.031
Pretag (before MET cut) zz	2.262 ± 0.155	1.023 ± 0.070	0.242 ± 0.017	0.067 ± 0.005
Pretag (before MET cut) top	83.850 ± 11.241	190.873 ± 25.590	191.774 ± 25.710	65.865 ± 8.830
Pretag (before MET cut) stops	18.895 ± 1.739	6.374 ± 0.587	1.460 ± 0.134	0.302 ± 0.028
Pretag (before MET cut) stopt	26.828 ± 2.685	7.103 ± 0.711	1.348 ± 0.135	0.247 ± 0.025
Pretag (before MET cut) zlf	530.184 ± 46.671	114.375 ± 10.068	16.625 ± 1.463	2.650 ± 0.233
Total Pretag MC (before MET cut)	854.192 ± 62.947	381.163 ± 33.373	224.354 ± 26.695	71.901 ± 9.005
Pretag QCD	802.464 ± 320.985	239.533 ± 95.813	60.319 ± 24.128	3.974 ± 1.590
Pretag (after MET cut) ww	140.558 ± 9.138	45.218 ± 3.015	9.724 ± 0.729	2.035 ± 0.216
Pretag (after MET cut) wz	28.234 ± 1.809	9.347 ± 0.622	1.851 ± 0.148	0.440 ± 0.053
Pretag (after MET cut) zz	1.459 ± 0.113	0.678 ± 0.058	0.160 ± 0.020	0.052 ± 0.010
Pretag (after MET cut) top	78.484 ± 10.662	175.575 ± 23.679	176.357 ± 23.784	59.623 ± 8.133
Pretag (after MET cut) stops	17.290 ± 1.597	5.847 ± 0.544	1.334 ± 0.128	0.276 ± 0.031
Pretag (after MET cut) stopt	24.431 ± 2.453	6.502 ± 0.659	1.254 ± 0.133	0.232 ± 0.030
Pretag (after MET cut) zlf	328.948 ± 29.032	71.928 ± 6.370	11.338 ± 1.020	1.891 ± 0.184
Total Pretag MC (after MET cut)	619.405 ± 44.419	315.096 ± 28.957	202.018 ± 24.547	64.550 ± 8.275
Total Pretag HF	484.633 ± 158.037	210.110 ± 67.599	54.398 ± 19.398	18.136 ± 6.081
Total Pretag Corrected	2847.132 ± 324.044	831.371 ± 100.093	167.663 ± 34.419	48.476 ± 8.427
Total LF Pretag Corrected	2362.499 ± 360.528	621.261 ± 120.782	113.264 ± 39.509	30.340 ± 10.392
Tagged ww	0.034 ± 0.008	0.129 ± 0.021	0.068 ± 0.012	0.019 ± 0.003
Tagged wz	0.621 ± 0.069	0.247 ± 0.028	0.029 ± 0.003	0.010 ± 0.001
Tagged zz	0.034 ± 0.004	0.021 ± 0.002	0.003 ± 0.000	0.002 ± 0.000
Tagged top	7.450 ± 1.196	22.076 ± 3.569	30.765 ± 4.943	10.818 ± 1.739
Tagged stops	2.601 ± 0.328	0.888 ± 0.113	0.200 ± 0.026	0.044 ± 0.006
Tagged stopt	0.576 ± 0.080	0.549 ± 0.074	0.177 ± 0.024	0.034 ± 0.004
Tagged zlf	0.448 ± 0.061	0.238 ± 0.034	0.040 ± 0.007	0.010 ± 0.002
Raw Mis-tags(info)	0.482 ± 0.115	0.470 ± 0.114	0.340 ± 0.082	0.200 ± 0.049
Tagged Wbb	7.190 ± 2.912	3.732 ± 1.517	1.314 ± 0.577	0.536 ± 0.228
Tagged Wcc/Wc	0.657 ± 0.275	0.588 ± 0.248	0.248 ± 0.112	0.113 ± 0.050
Tagged Total HF	7.847 ± 3.166	4.320 ± 1.745	1.562 ± 0.669	0.648 ± 0.271
Tagged Total MC	11.764 ± 1.563	24.148 ± 3.732	31.283 ± 4.985	10.937 ± 1.749
Tagged Mistags	0.267 ± 0.075	0.210 ± 0.065	0.090 ± 0.038	0.052 ± 0.022
Tagged Non-W	1.876 ± 0.751	0.467 ± 0.500	4.648 ± 3.718	1.678 ± 1.343
Total Prediction	21.754 ± 3.610	29.145 ± 4.151	37.582 ± 6.255	13.315 ± 2.221
Observed	19.000 ± 0.000	28.000 ± 0.000	36.000 ± 0.000	13.000 ± 0.000

Table 7: istrok ST+ST

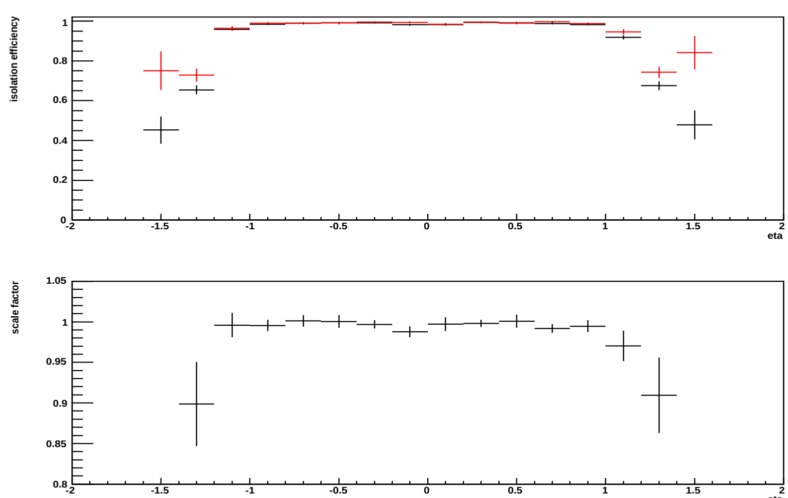

Figure 13: Isolated track reconstruction scale factor vs. η

2. ISR and FSR systematic uncertainty are estimated by changing the parameters related to ISR and FSR from default values to half and double. Half of difference between the two samples is taken as the systematic uncertainly.

Process	2jets	3jets	4jets	5jets
All Pretag Candidates	4269.000 ± 0.000	1386.000 ± 0.000	430.000 ± 0.000	117.000 ± 0.000
Pretag (before MET cut) ww	159.225 ± 10.224	50.488 ± 3.242	10.709 ± 0.688	2.275 ± 0.146
Pretag (before MET cut) wz	32.947 ± 2.070	10.927 ± 0.686	2.196 ± 0.138	0.495 ± 0.031
Pretag (before MET cut) zz	2.262 ± 0.155	1.023 ± 0.070	0.242 ± 0.017	0.067 ± 0.005
Pretag (before MET cut) top	83.850 ± 11.241	190.873 ± 25.590	191.774 ± 25.710	65.865 ± 8.830
Pretag (before MET cut) stops	18.895 ± 1.739	6.374 ± 0.587	1.460 ± 0.134	0.302 ± 0.028
Pretag (before MET cut) stopt	26.828 ± 2.685	7.103 ± 0.711	1.348 ± 0.135	0.247 ± 0.025
Pretag (before MET cut) zlf	530.184 ± 46.671	114.375 ± 10.068	16.625 ± 1.463	2.650 ± 0.233
Total Pretag MC (before MET cut)	854.192 ± 62.947	381.163 ± 33.373	224.354 ± 26.695	71.901 ± 9.005
Pretag QCD	802.464 ± 320.985	239.533 ± 95.813	60.319 ± 24.128	3.974 ± 1.590
Pretag (after MET cut) ww	140.558 ± 9.138	45.218 ± 3.015	9.724 ± 0.729	2.035 ± 0.216
Pretag (after MET cut) wz	28.234 ± 1.809	9.347 ± 0.622	1.851 ± 0.148	0.440 ± 0.053
Pretag (after MET cut) zz	1.459 ± 0.113	0.678 ± 0.058	0.160 ± 0.020	0.052 ± 0.010
Pretag (after MET cut) top	78.484 ± 10.662	175.575 ± 23.679	176.357 ± 23.784	59.623 ± 8.133
Pretag (after MET cut) stops	17.290 ± 1.597	5.847 ± 0.544	1.334 ± 0.128	0.276 ± 0.031
Pretag (after MET cut) stopt	24.431 ± 2.453	6.502 ± 0.659	1.254 ± 0.133	0.232 ± 0.030
Pretag (after MET cut) zlf	328.948 ± 29.032	71.928 ± 6.370	11.338 ± 1.020	1.891 ± 0.184
Total Pretag MC (after MET cut)	619.405 ± 44.419	315.096 ± 28.957	202.018 ± 24.547	64.550 ± 8.275
Total Pretag HF	484.633 ± 158.037	210.110 ± 67.599	54.398 ± 19.398	18.136 ± 6.081
Total Pretag Corrected	2847.132 ± 324.044	831.371 ± 100.093	167.663 ± 34.419	48.476 ± 8.427
Total LF Pretag Corrected	2362.499 ± 360.528	621.261 ± 120.782	113.264 ± 39.509	30.340 ± 10.392
Tagged ww	0.191 ± 0.088	0.235 ± 0.090	0.090 ± 0.028	0.030 ± 0.010
Tagged wz	0.509 ± 0.088	0.189 ± 0.039	0.037 ± 0.008	0.013 ± 0.003
Tagged zz	0.027 ± 0.005	0.017 ± 0.004	0.004 ± 0.001	0.002 ± 0.000
Tagged top	6.265 ± 1.285	19.290 ± 4.003	23.945 ± 4.726	8.709 ± 1.776
Tagged stops	1.878 ± 0.301	0.719 ± 0.121	0.186 ± 0.033	0.044 ± 0.009
Tagged stopt	0.522 ± 0.159	0.493 ± 0.102	0.120 ± 0.025	0.024 ± 0.004
Tagged zlf	0.535 ± 0.173	0.311 ± 0.099	0.075 ± 0.029	0.022 ± 0.009
Raw Mis-tags(info)	1.435 ± 2.125	1.386 ± 1.776	1.001 ± 1.076	0.506 ± 0.616
Tagged Wbb	5.688 ± 2.407	3.522 ± 1.497	1.269 ± 0.588	0.591 ± 0.260
Tagged Wcc/Wc	2.048 ± 0.968	1.660 ± 0.801	0.709 ± 0.359	0.340 ± 0.167
Tagged Total HF	7.736 ± 3.313	5.183 ± 2.245	1.978 ± 0.902	0.931 ± 0.410
Tagged Total MC	9.926 ± 1.968	21.254 ± 4.364	24.457 ± 4.819	8.842 ± 1.805
Tagged Mistags	0.794 ± 1.182	0.621 ± 0.805	0.264 ± 0.298	0.131 ± 0.166
Tagged Non-W	0.673 ± 0.269	0.520 ± 0.208	0.634 ± 0.507	0.245 ± 0.500
Total Prediction	19.129 ± 4.040	27.578 ± 4.978	27.332 ± 4.938	10.150 ± 1.924
Observed	18.000 ± 0.000	27.000 ± 0.000	31.000 ± 0.000	12.000 ± 0.000

Table 8: isotrk ST+JP

M(H)	$\sigma \times BR(H \to bb)$
110	0.169 pb
115	0.136 pb
120	0.104 pb
130	0.063 pb
140	0.030 pb
150	0.012 pb

Table 9: Theoretical cross section (σ) times branching ratio to $b\bar{b}$ for a variety of higgs masses.

3. PDFs uncertainties are evaluated using the standard re-weighting method recommended by Joint Physics [12].

4. The b-tagging scale factor uncertainty comes from the High p_T b-tagging group. We propagate $\pm 1\sigma$ variation of the scale factor through our acceptance calculation and use the relative variation in acceptance as our uncertainty.

5. Luminosity uncertainties are also included in calculating Higgs signal events. This uncertainty assign 6%.

CDF Run II Preliminary 2.7 fb^{-1} Number of Expected WH (M(H) = 120) Events	
Detector	Expected Number of WH events
One Tag	
cem	1.46011
cmup	0.795069
cmx	0.387908
isotrk	0.504427
ST+ST Tag	
cem	0.669306
cmup	0.362131
cmx	0.164965
isotrk	0.269368
ST+JP Tag	
cem	0.492957
cmup	0.250304
cmx	0.126863
isotrk	0.172753

Table 10: Expected number of WH events at a M(H)=120, shown broken down for tag categories and lepton types

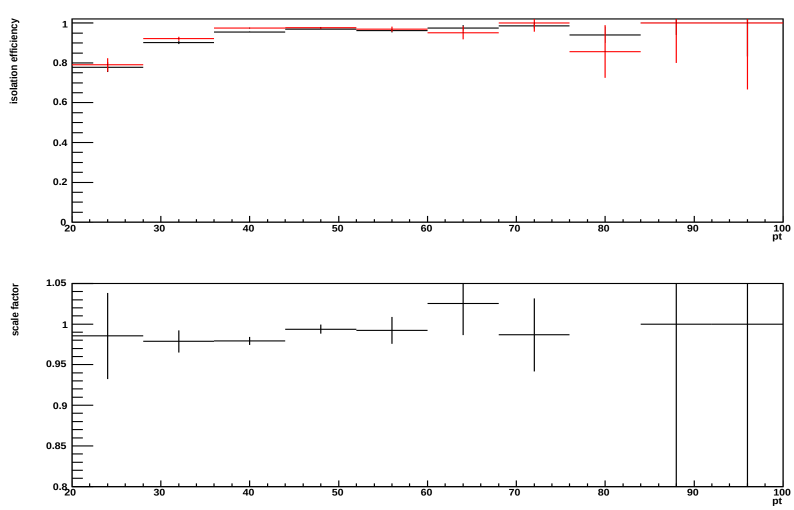

Figure 14: Isolated track reconstruction scale factor vs. p_T

6. **Z+jet Scale Factor Uncertainties:** CDF note 8696 found a change of 4% for the isotrk scale factor mesaured in the Z+2jet sample compared to the Z+0jet

b-tagging category	Isotrk Reco	Trigger	ISR/FSR	JES	PDF	b-tagging	Total
One tag	8.85%	2%	2.9%	2.3%	1.2%	3.5%	10.06%
ST + ST	8.85%	2%	5.2%	2.5%	2.1%	8.4%	13.8%

Table 11: Systematic uncertainties for each tagging category

sample. To be conservative, we increase our uncertainty on the scale factor from 1% to 6% to accomadate a change in the scale factor that is 1.5 times greater than that observed for the lepton + track search.

7. **Electron/Tau Scale Factor Uncertainties:** Both electrons and single-prong tau decays can be reconstructed as isotrks. Both lepton types make up approximately 15% of the signal composition. To account for this potential difference in the scale factor, we give assign an uncertainty of 25% to the ele+tau piece of the acceptance. This uncertainty would accomodate a variation of the scale factor that is greater than the difference between scale factors used for other lepton types. The extra 25% uncertainty on the 15% of isotrk acceptance increases our total isotrk scale factor uncertainty from 6% to 8.85%.

Total systematic uncertainties are listed in Table.11 for each b-tagging category.

5 Neural Network Discriminant

To further improve signal to background discrimination after event selection, we employ an artificial Neural Network (NN) trained on a variety of kinematic variables to distinguish WH from backgrounds. Details of the neural network optimization and training are given in the documentation for the triggered lepton analysis [2]. Recall that this network, which is optimized separately for each Higgs mass, has six input variables (listed below), eleven hidden nodes in a single hidden layer, and one output node. The input variables are listed below:

M_{jj+}**:** This variable is the invariant mass calculated from the two tight jets using Level-5 jet corrections. Furthermore, if there are additional loose jets present ($E_{T,L5} < 12$ GeV and $|\eta| < 2.4$), the loose jet that is closest to one of the two tight jets is included in this invariant mass calculation, if the separation between that loose jet and one of the tight jets is $\Delta R < 0.9$.

$\sum E_T$**(Loose Jets):** This variable is the scalar sum of the loose jet transverse energy (with Level-5 corrections).

p_T **Imbalance:** This variable expresses the difference between the scalar sum of the transverse momenta of all measured objects and the $\not\!\!E_T$. Specifically, it is calculated as $P_T(jet_1) + P_T(jet_2) + P_T(lep) - \not\!\!E_T$.

Kinematic Region	Section
Pretag Plots	9
One Tag Plots	10
ST+ST Plots	11
ST+JP Plots	12

Table 12: List of where to find kinematic plots

$M_{l\nu j}^{min}$**:** This is the invariant mass of the lepton, $\not\!\!E_T$, and one of the two jets, where the jet is chosen to give the minimum invariant mass. For this quantity, the p_z of the neutrino is ignored.

ΔR**(lepton-**ν_{max}**):** This is the ΔR separation between the lepton and the neutrino, where the p_z of the neutrino is taken from by choosing the solutions from the quadratic equations for the W mass constraint with the largest $|p_z|$.

$P_T(W+H)$**:** This is the total transverse momentum of the W plus two jets system, $P_T(\vec{lep} + \vec{\nu} + \vec{jet}_1 + \vec{jet}_2)$.

6 Kinematic Distributions

We check the kinematics each tagging category to see that the background compositions and modeling are well understood. We include a number of kinematic plots in the final sections of the note. Table 12 lists where to find the plots.

7 Results

We search for evidence for an excess of WH signal events over the background prediction in the Neural Network output distributions for the three tag categories (1-tag, ST+ST, ST+JP) in each of the three lepton categories (tight central, PHX, and isolated tracks). Figure 15 shows the NN output distributions for the search regions. We find no evidence for and excess of signal, so set a 95% confidence level upper limit on the production cross section times branching ratio. We check out limits in the individual tag channels, then perform a simultaneous search across both channels for optimal sensitivity.

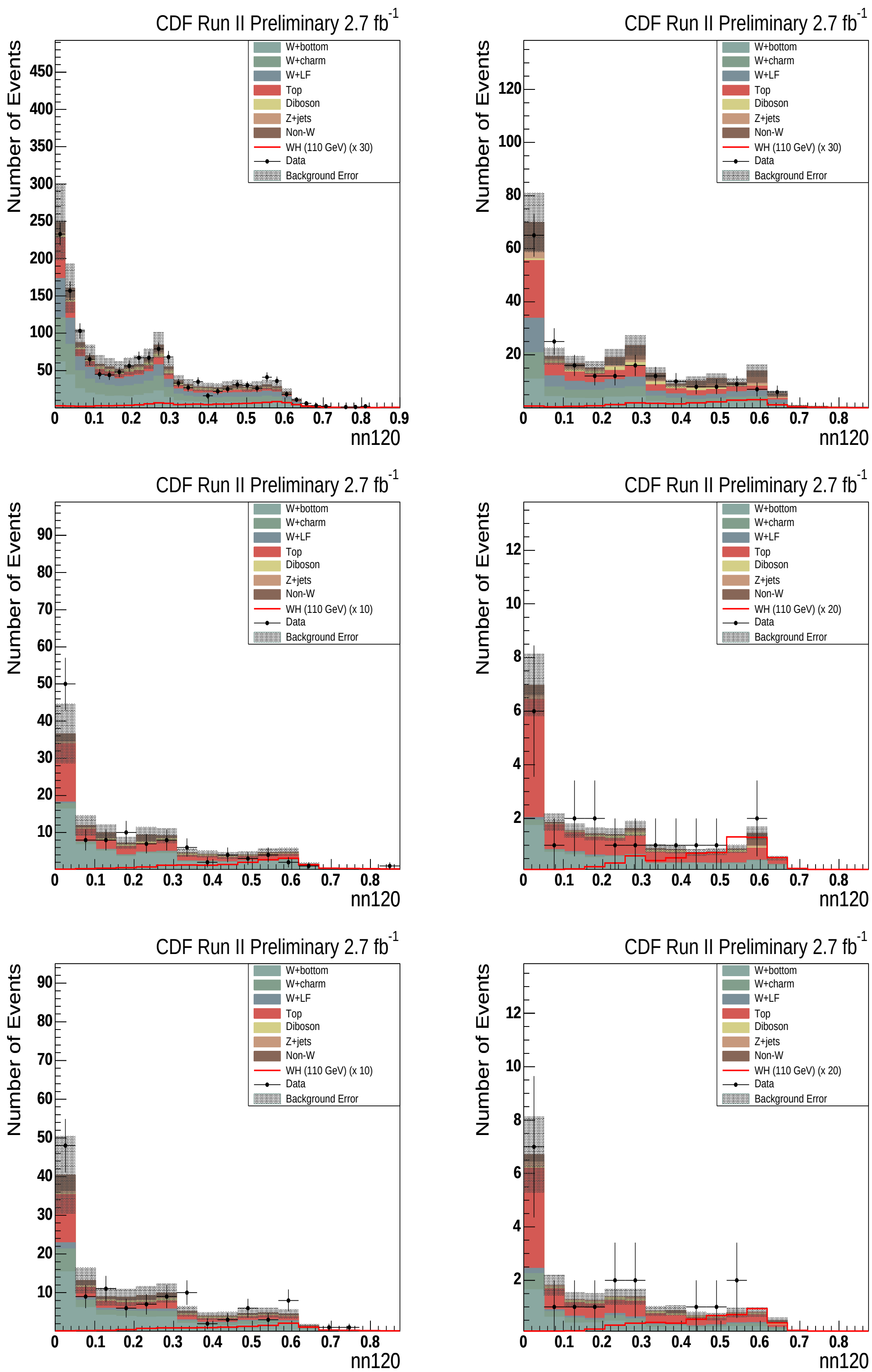

Figure 15: Comparison of NN output for signal ($M_H = 120$ GeV), expected backgrounds, and observed data. Left column is Tight Leptons, right hand column is isolated tracks. The first row is one tag, second is ST+ST, third is ST+JP.

CDF Run II Preliminary 2.7 fb^{-1} Limits for Combined Lepton and Tag Categories		
M(H)	Observed Limit	Expected Limit
110	5.10	5.59
115	6.91	6.43
120	7.18	7.49
130	12.31	11.62
140	27.50	21.46
150	64.1	48.081

Table 13: Expected and observed limits as a function of Higgs mass for the combined search of Tight Lepton and Isotrk events, including all tag categories.

We use `mclimit` [14] to extract the 95% confidence limit on WH production. To match the CDF + DØ Higgs combination, we use the Bayesian version of `mclimit` code. In this version of the code, the nuisance parameters (systematic uncertainties) in the likelihood are handled through marginalization. The expected limit is calculated from pseudo-experiments that incorporate both Poisson and systematic fluctuations of the signal and background templates. The limit setting procedure used by `mclimit` has been cross-checked against the binned likelihood technique used in previous versions of this analysis and for the CDF combination. The two procedures obtain comparable results.

Table 16 details the expected and observed limits at the various Higgs mass points for the combined search across lepton types and tag categories. Figures **??** through 16 display the limits and the with 66% and 95% psuedo experiment bands.

8 Conclusions

We have presented the results of a search for the Standard Model Higgs boson via associated WH production and decay to $b\bar{b}$. We find that for the dataset corresponding to integrated luminosity of 2.7fb^{-1}, the observed data for each tagged events agrees with the SM background predictions within the systematic uncertainties. Therefore we set upper limit on the Higgs production cross section: $\sigma(p\bar{p} \to W^{\pm}H) \times BR(H \to b\bar{b})$ ranging from 5.6 × SM (for $m_h = 110$ GeV/c^2) to 48.1 × SM (for $m_h = 150$ GeV/c^2) at 95% confidence level.

References

[1] J. Slaunwhite *et al.*, “Search for Higgs Boson Production in Asociation with a W Boson using Isolated Tracks,” CDF Note 9299.

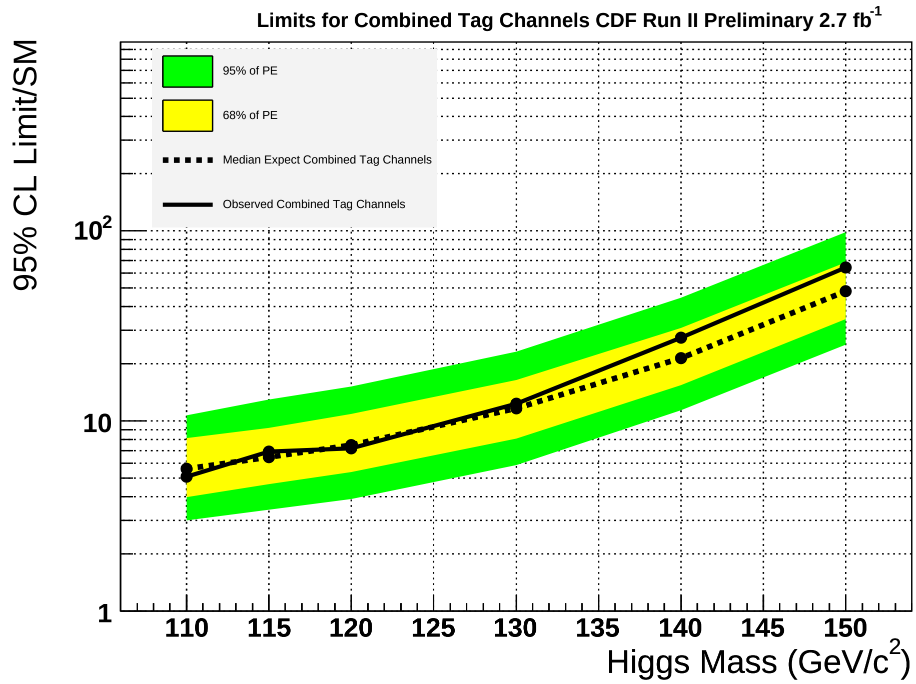

Figure 16: Expected and observed limts for a combined search in all lepton and tag categories.

[2] T. Masubuchi *et al.*, "Search for Higgs Boson Production in Association with W Boson with 1.7fb^{-1}," CDF Note 9136.

[3] Frankli, Grinstein, Guimaraes da Costa, Lannon, Schwarz, Sherman and Taffard, "Method 2 Backgrounds for 1.12/fb Lepton+Jets Analysis," CDF Note 8766

[4] J. Incandela, C. Mills, et al., "A Measurement of the ttbar Dilepton Cross-section in the 1.1 fb-1 Lepton + Isolated Track Sample" CDF Note 8696

[5] B. Parks et al, "Low Mass Higgs Serach in Met Plus Jets Data Sample" CDF Note 8678

[6] A. Apresyan et al, "Search for the Standard Model Higgs boson in the Missing Et and b-jet Signature" CDF Note 8911

[7] B. Casal, C. Group, et al "Increasing Muon Acceptance with the MET Plus Jet Triggers", CDF Note 9105

[8] J. Adelman, T. Schwarz, J. Slaunwhite, et al. "Method II For You", CDF Note 9185

[9] C. Cully, *et al.* “Calibration of Heavy-Flavor Production in W + 1 Jet Data,” CDF Note 9187.

[10] S. Grinstein, D. Sherman, “SecVtx Scale Factors and Mistag Matrices for the 2007 Summer Conferences”, CDF Note 8910

[11] Grintein, Guimaraes da Costa, Shrman, “SecVtx Mistag Asymmetry for Winter 2007”, CDF Note 8626

[12] http://www-cdf.fnal.gov/internal/physics/joint_physics/index.html

[13] Grundler, Lovas, Taffard, “High-Pt muons recommended cuts and efficiencies for Winter 2007”, CDF Note 8618

[14] T. Junk, “Sensitivity, Exclusion, and Discovery with Small Signals, Large Backgrounds, and Large Systematics” CDF Note 8128

9 Pretag Plots

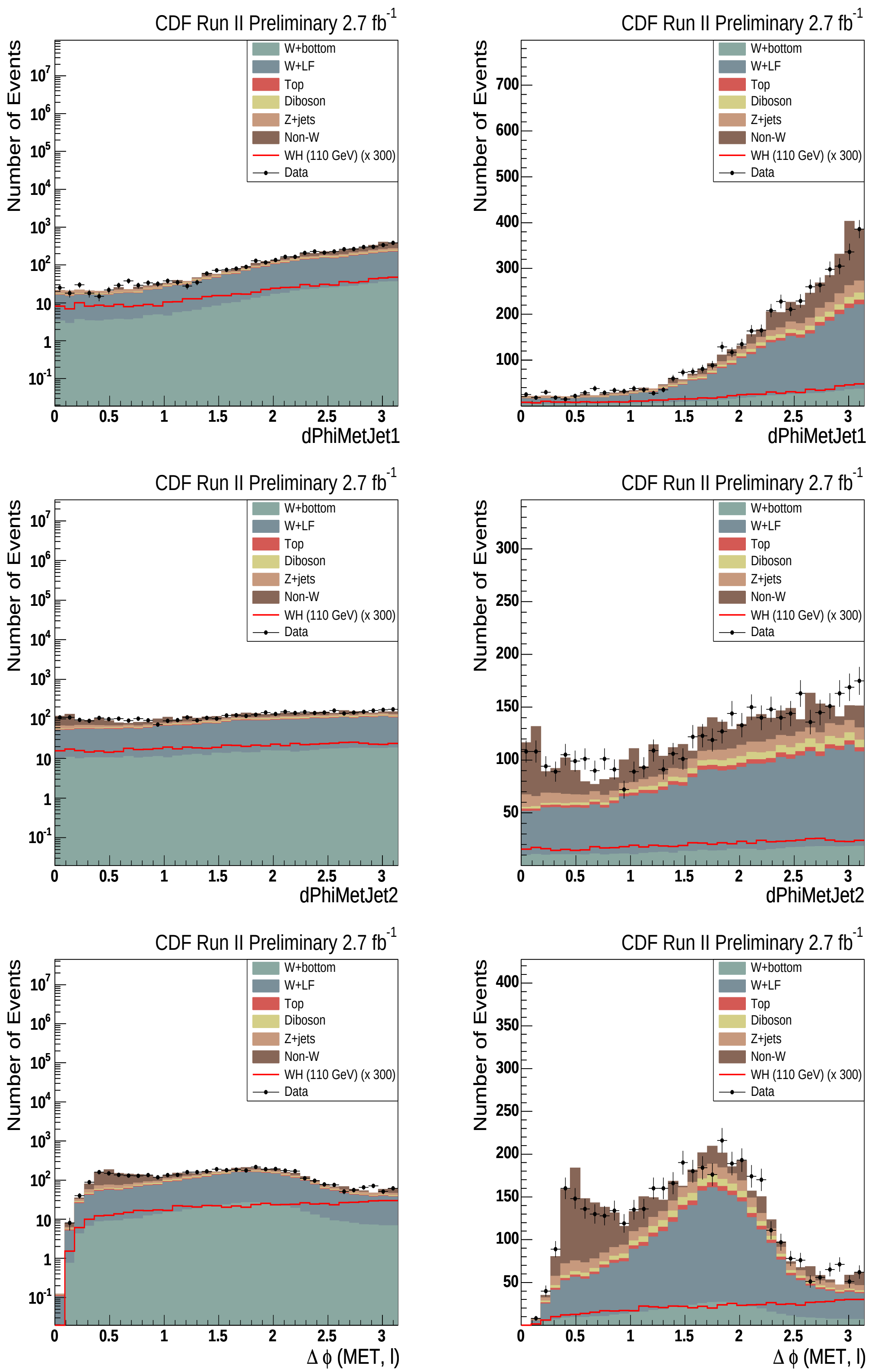

Figure 17: Isolated Track Pretag Kinematics

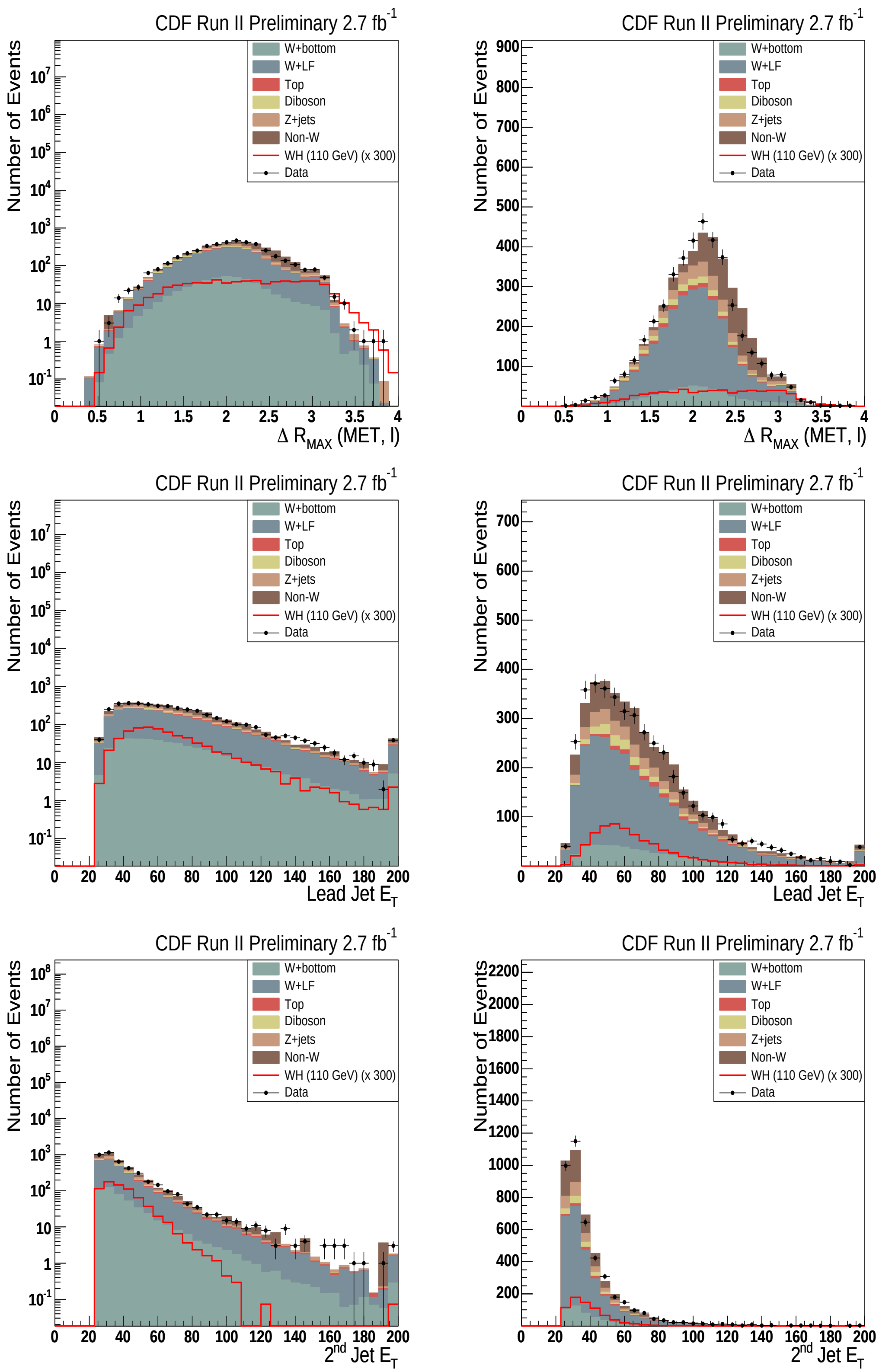

Figure 18: Isolated Track Pretag Kinematics

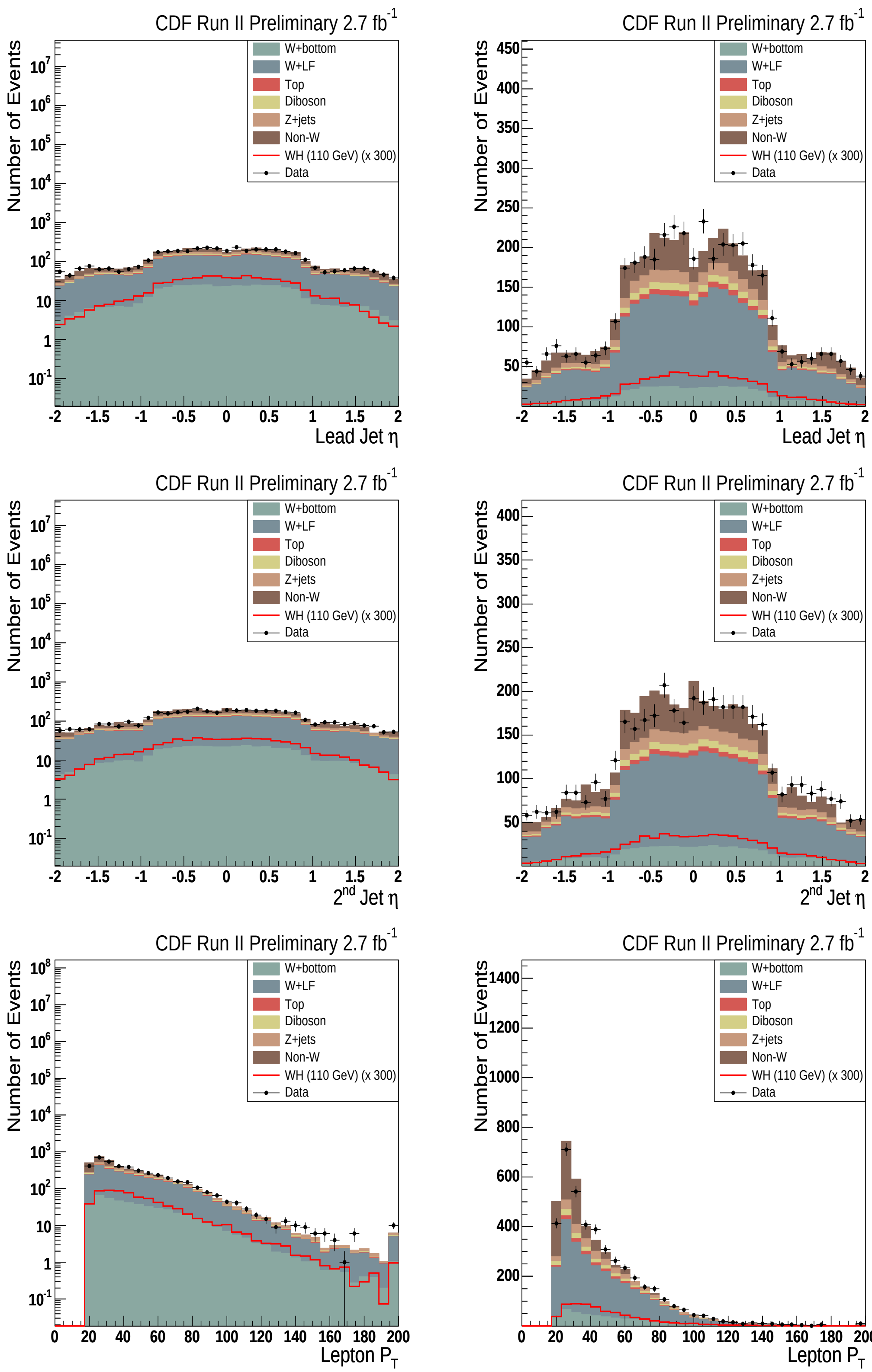

Figure 19: Isolated Track Pretag Kinematics

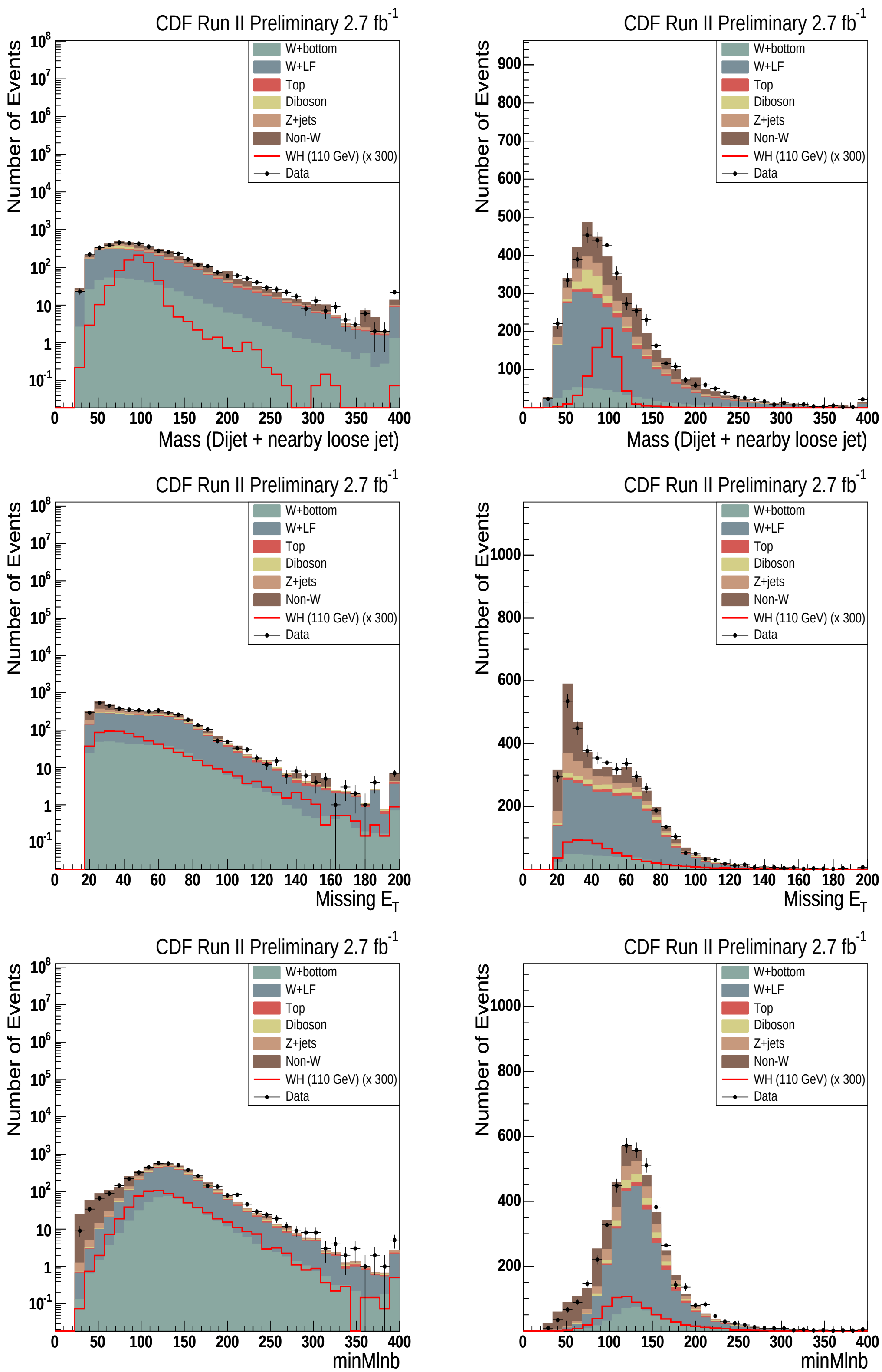

Figure 20: Isolated Track Pretag Kinematics

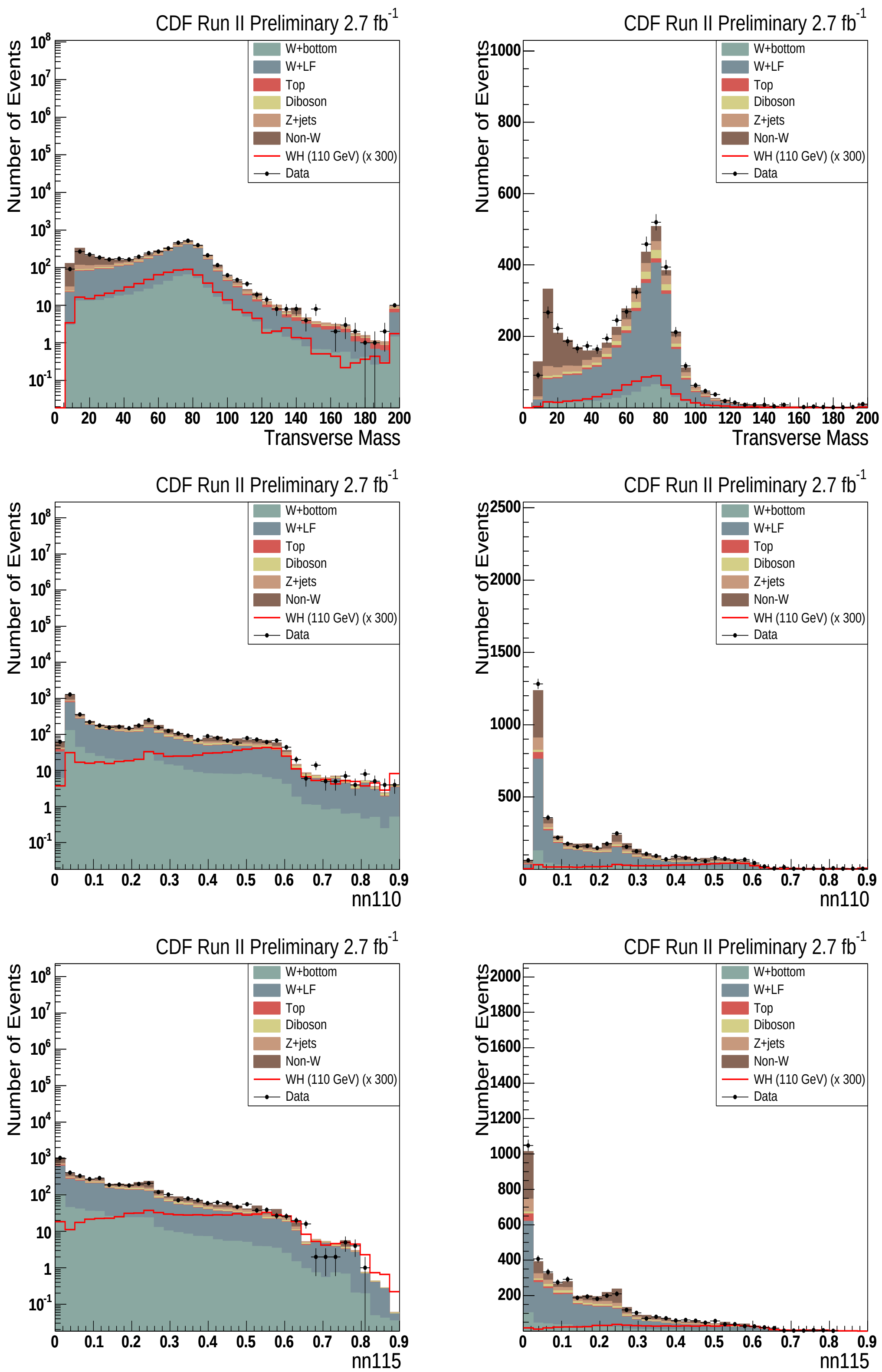

Figure 21: Isolated Track Pretag Kinematics

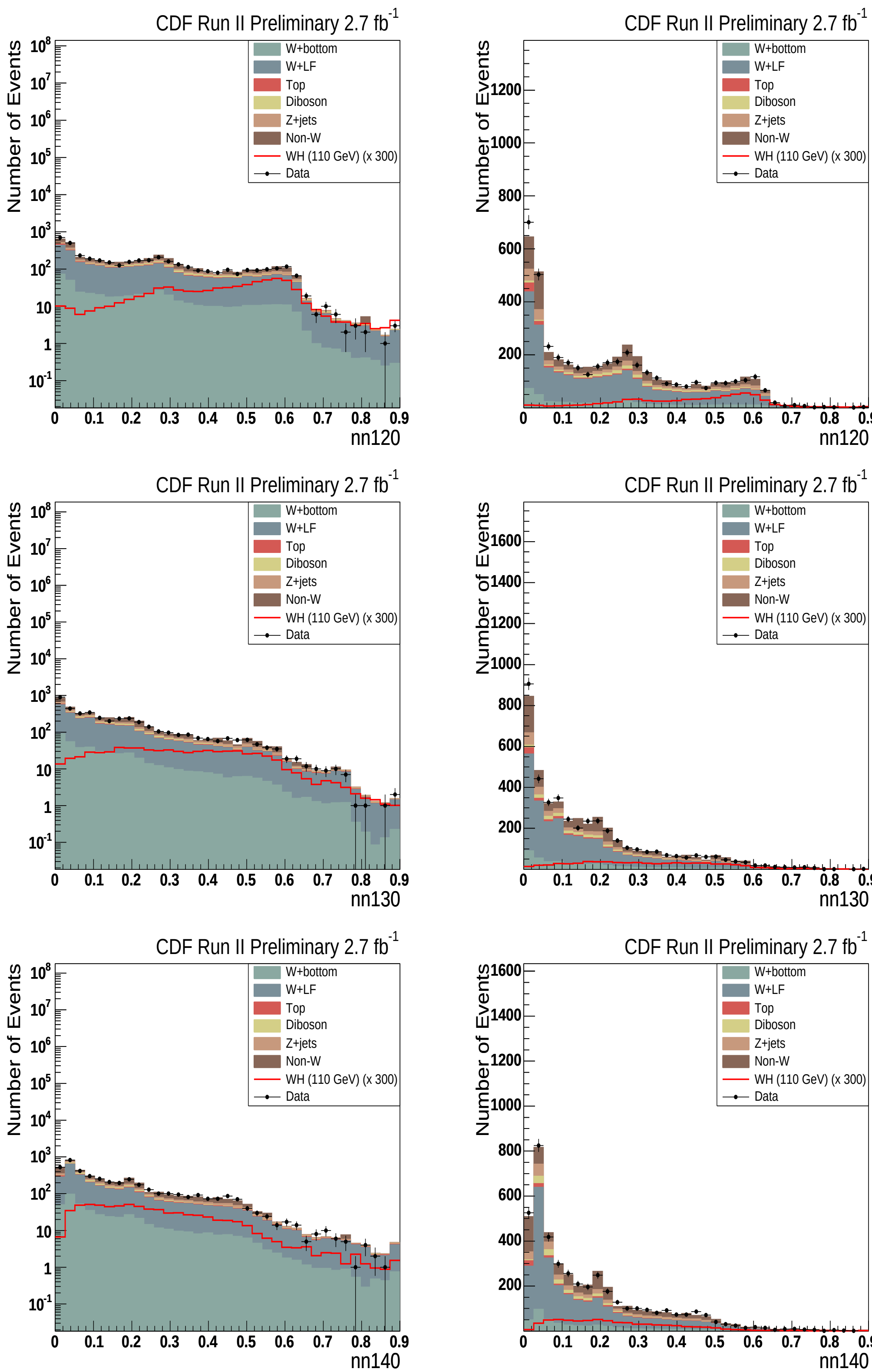

Figure 22: Isolated Track Pretag Kinematics

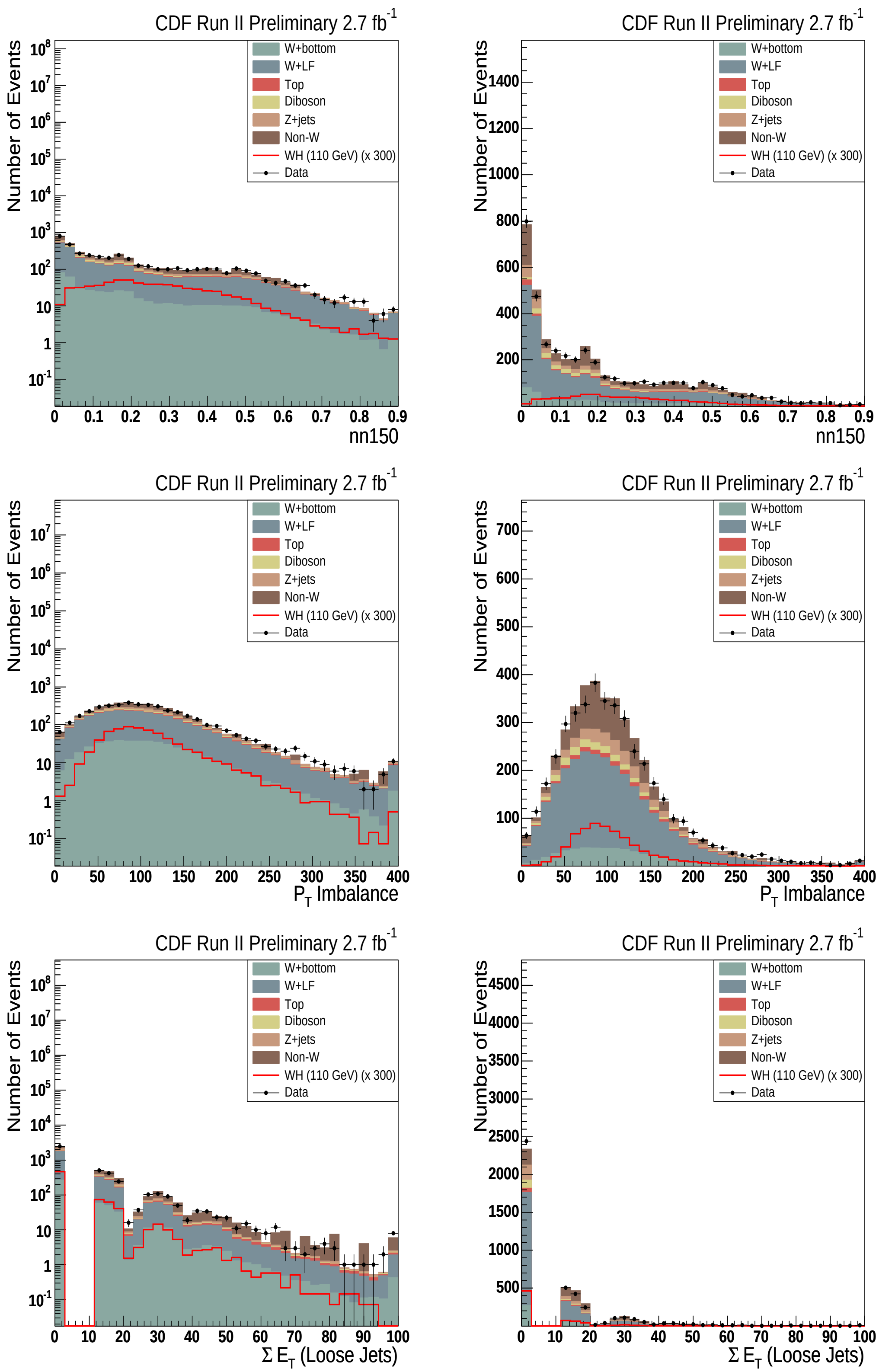

Figure 23: Isolated Track Pretag Kinematics

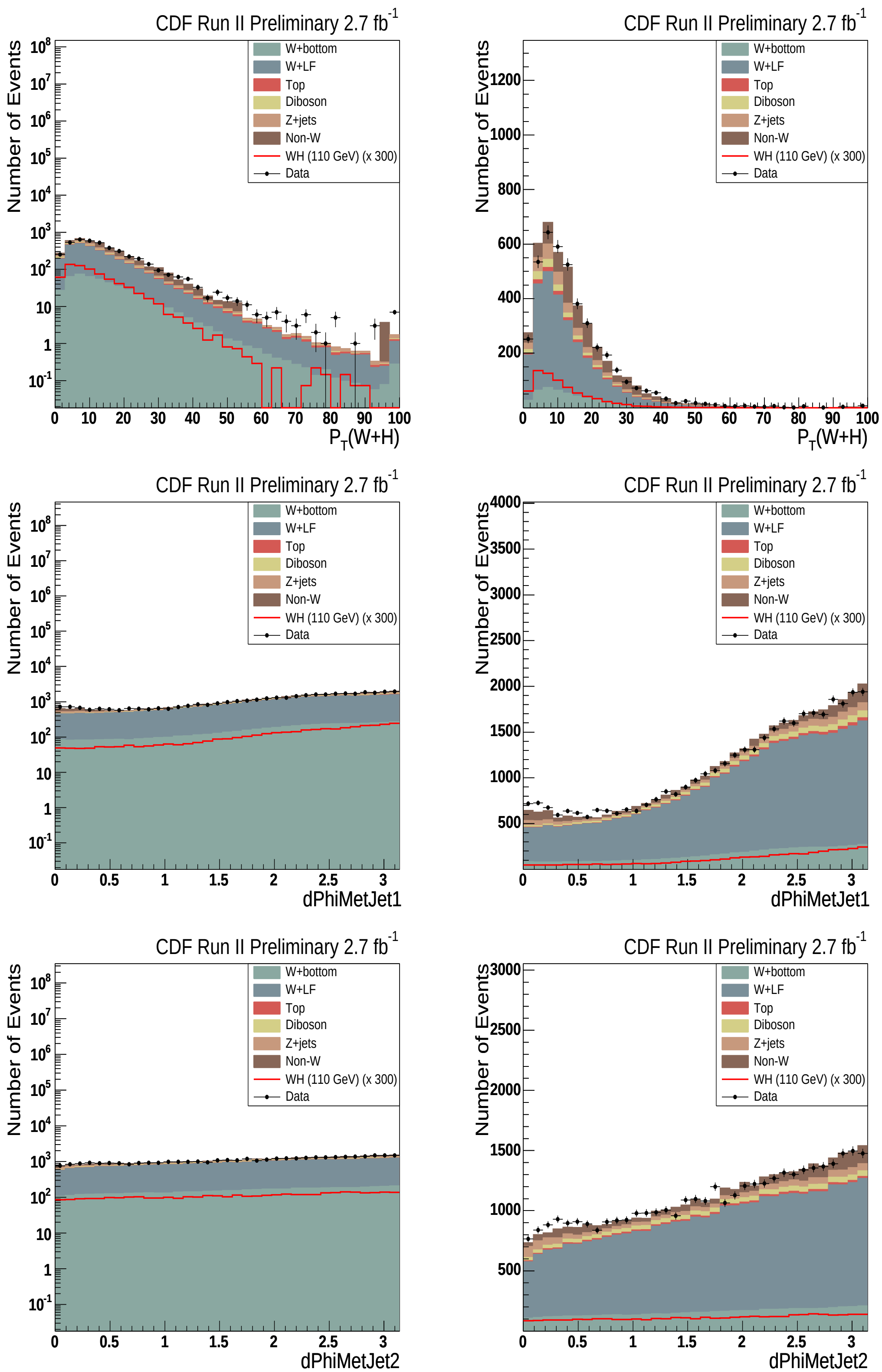

Figure 24: Isolated Track Pretag Kinematics

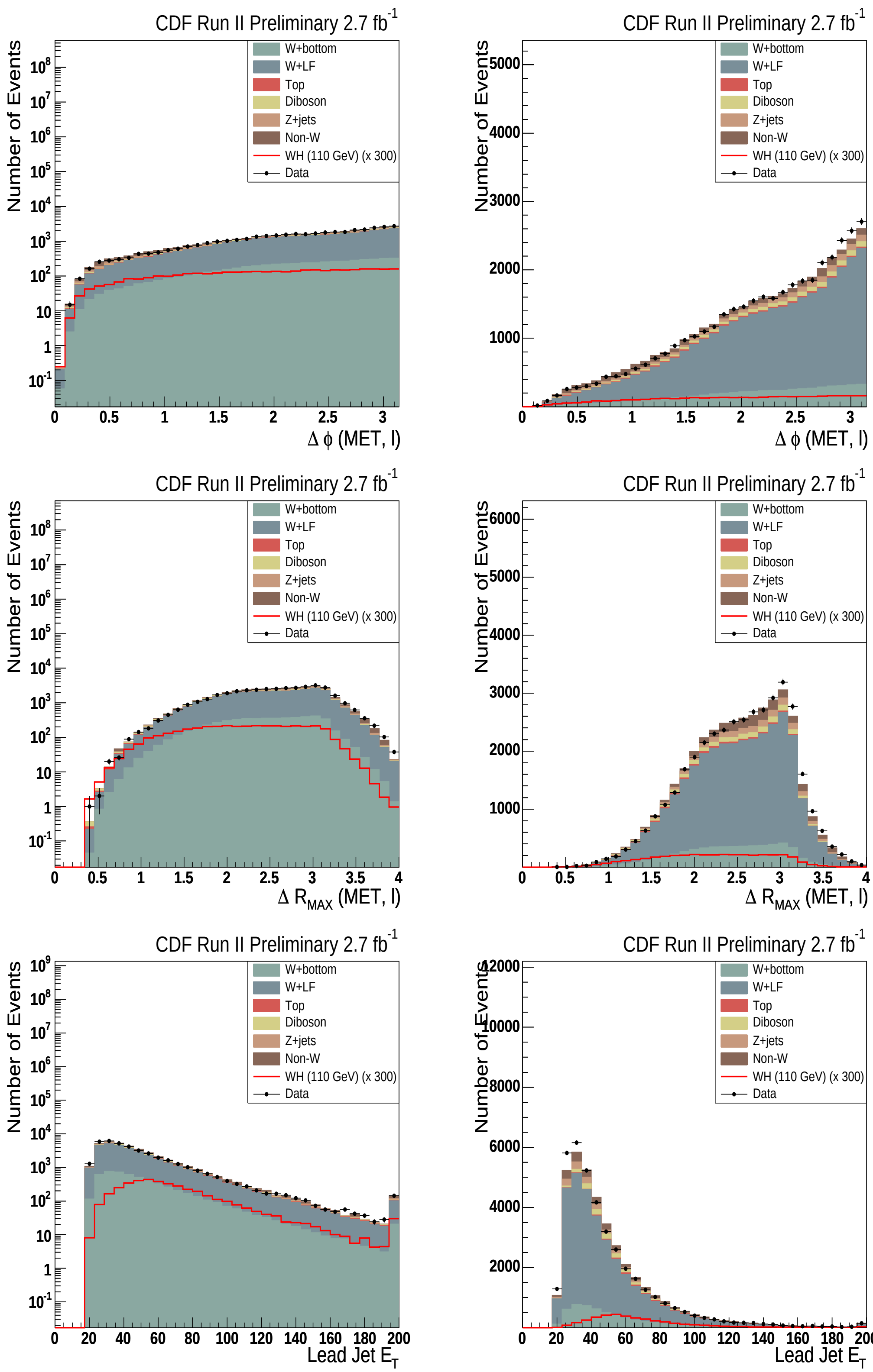

Figure 25: Tight Lepton Pretag Kinematics

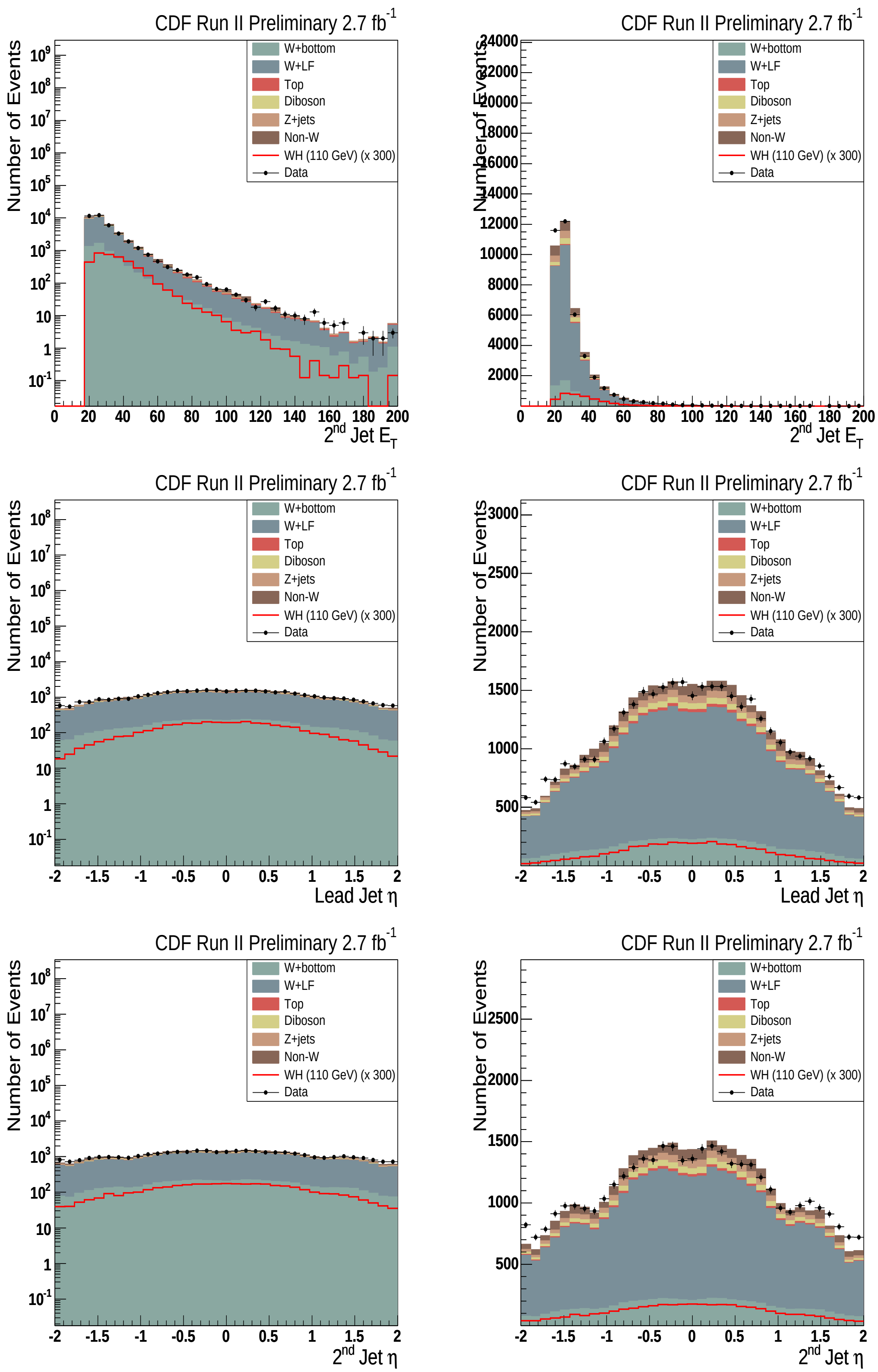

Figure 26: Tight Lepton Pretag Kinematics

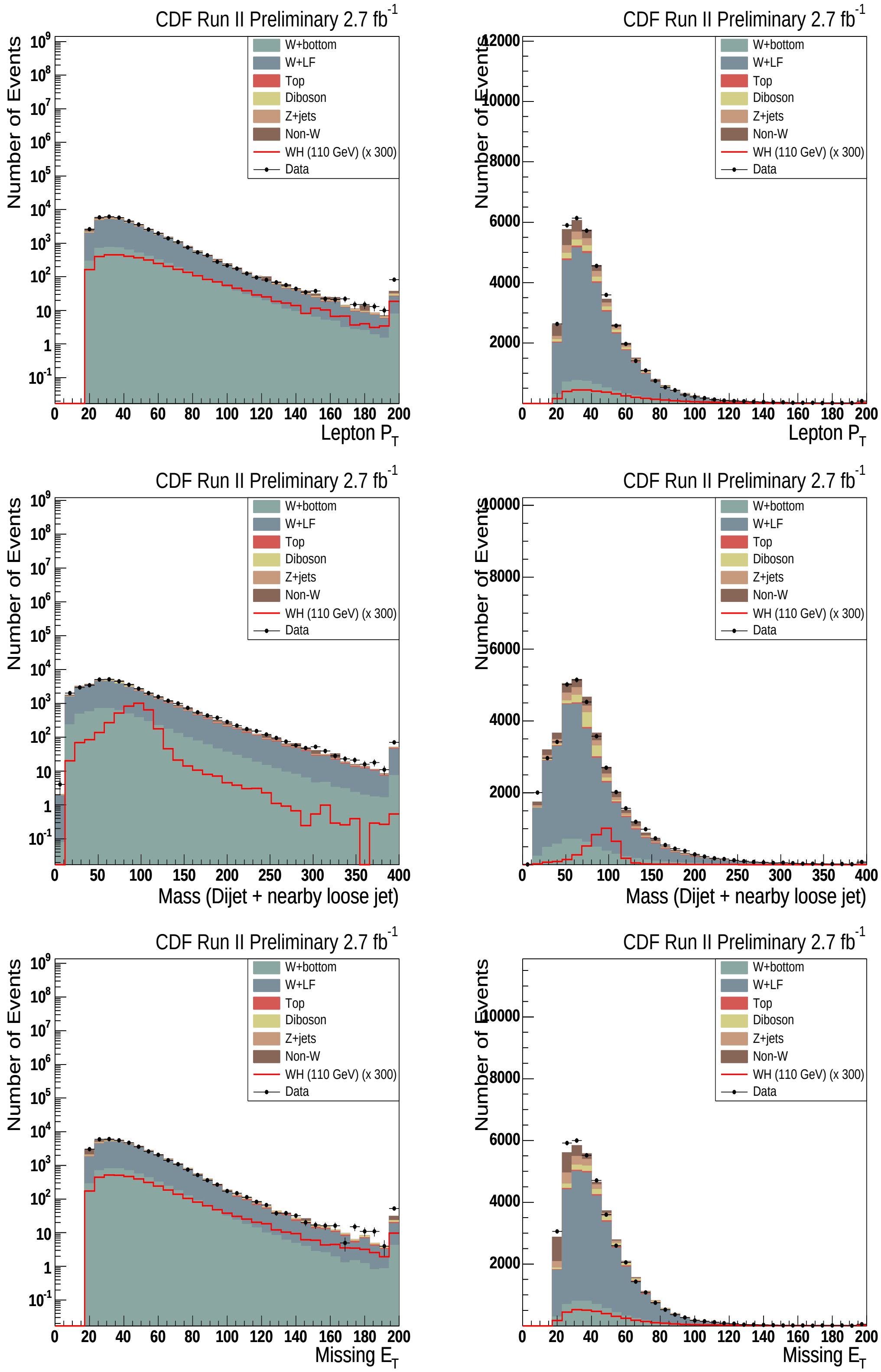

Figure 27: Tight Lepton Pretag Kinematics

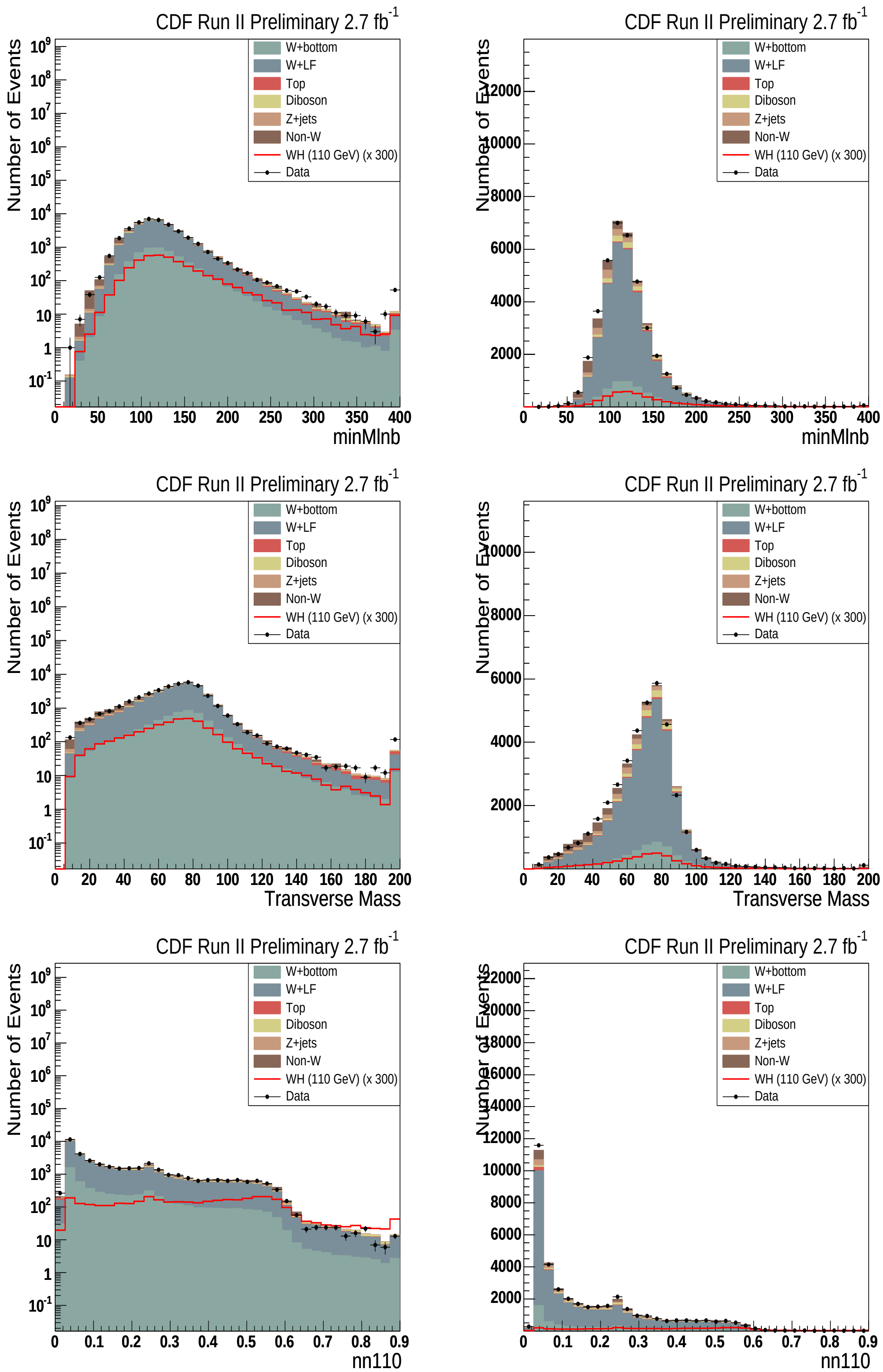

Figure 28: Tight Lepton Pretag Kinematics

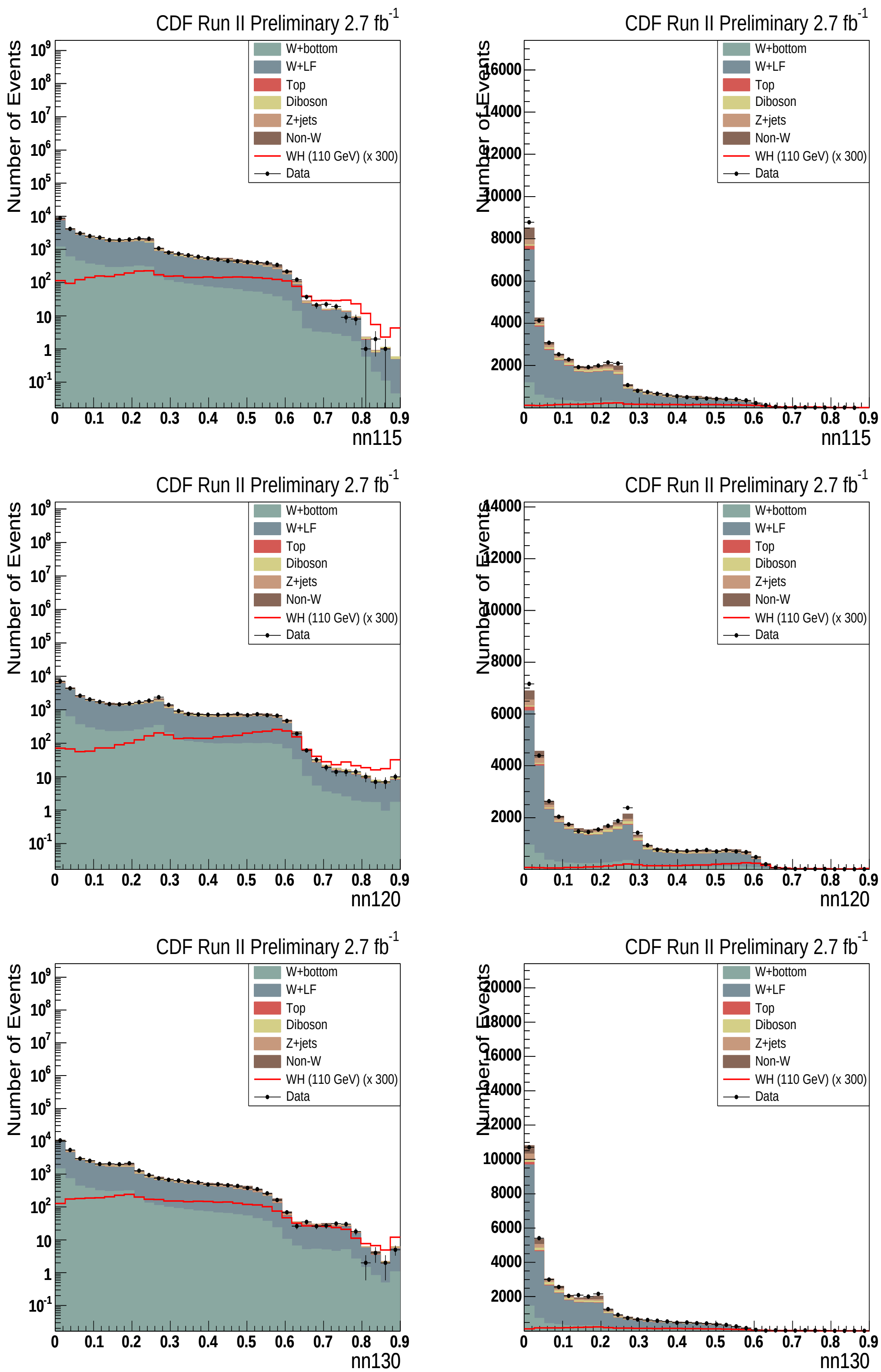

Figure 29: Tight Lepton Pretag Kinematics

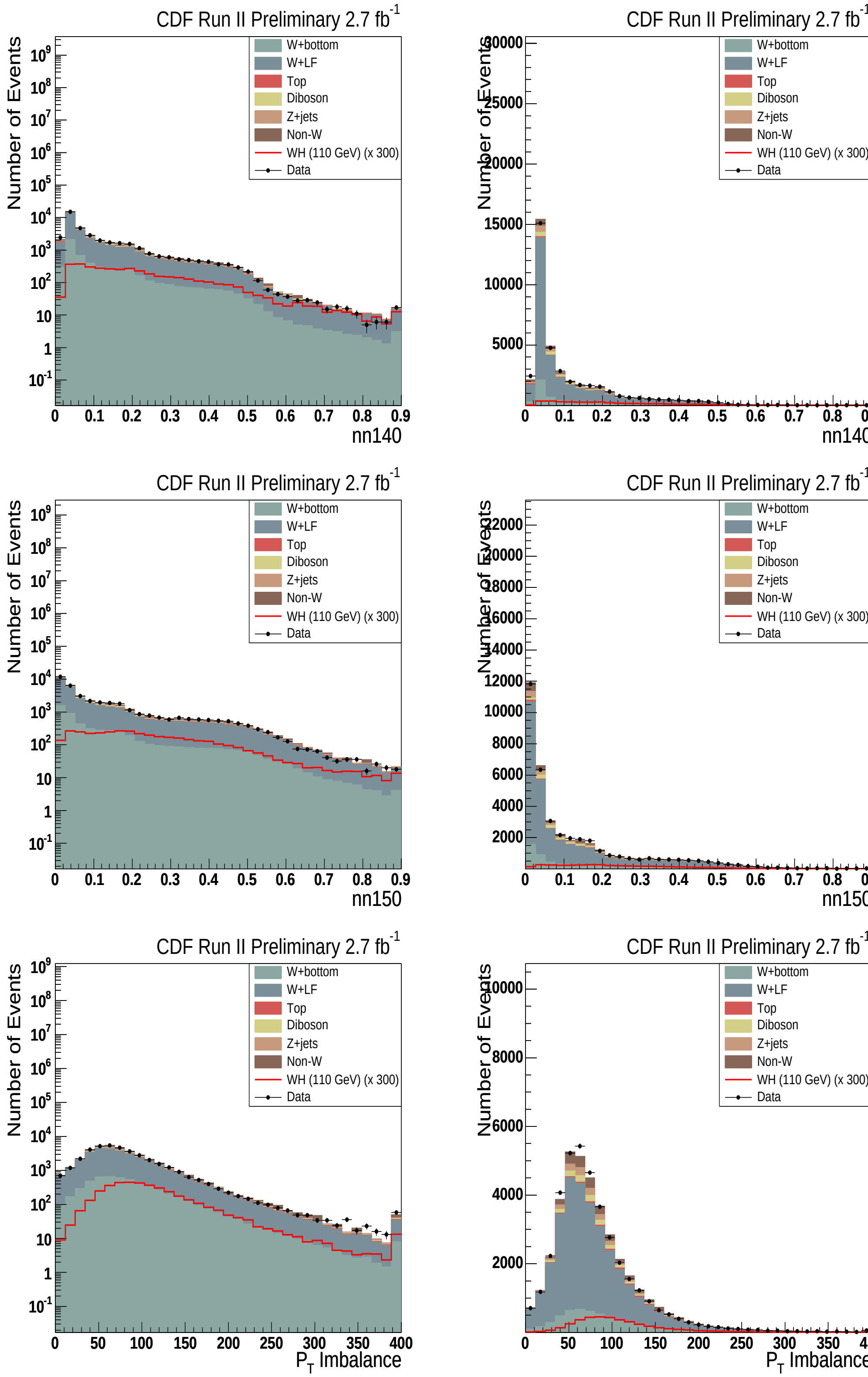

Figure 30: Tight Lepton Pretag Kinematics

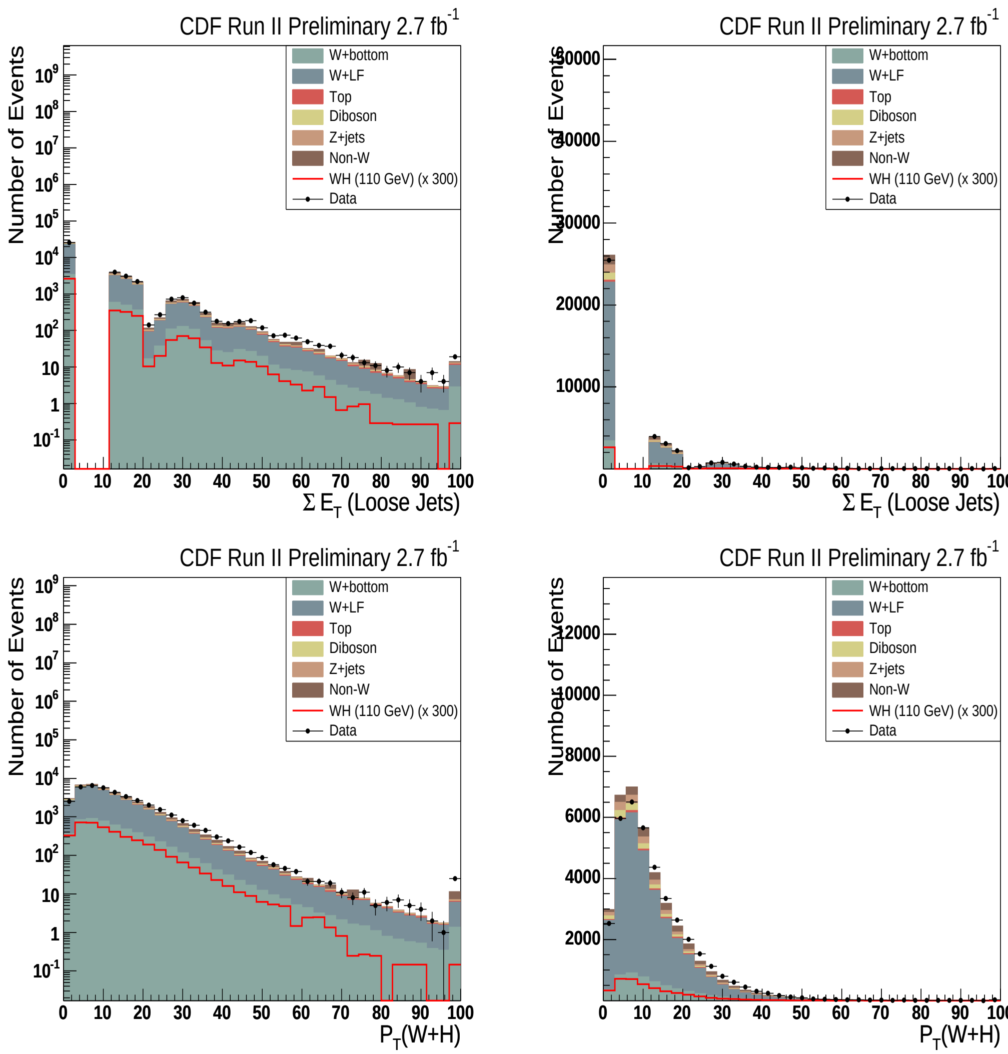

Figure 31: Tight Lepton Pretag Kinematics

10 One Tag Plots

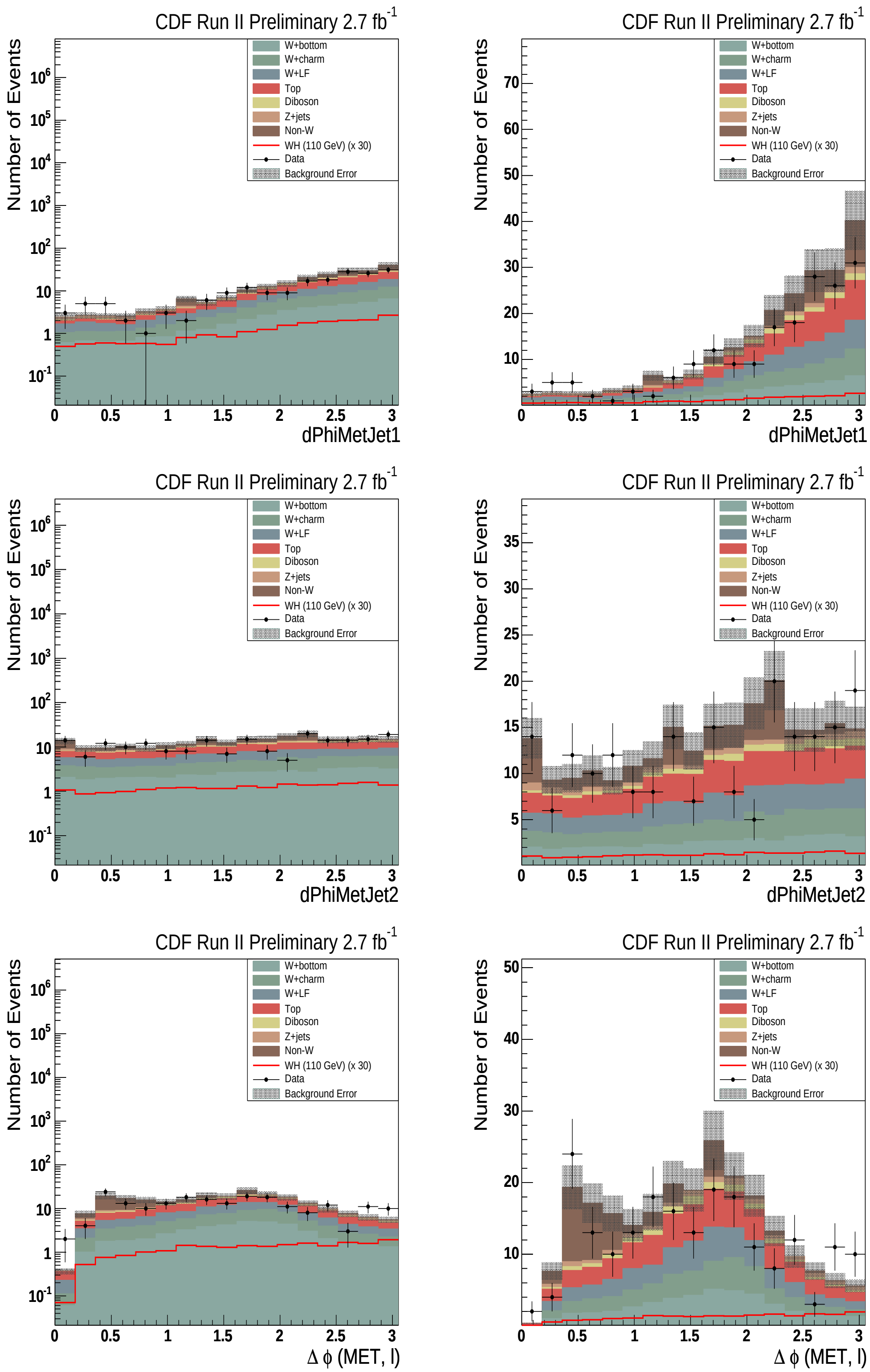

Figure 32: Isotrk One Tag Kinematics

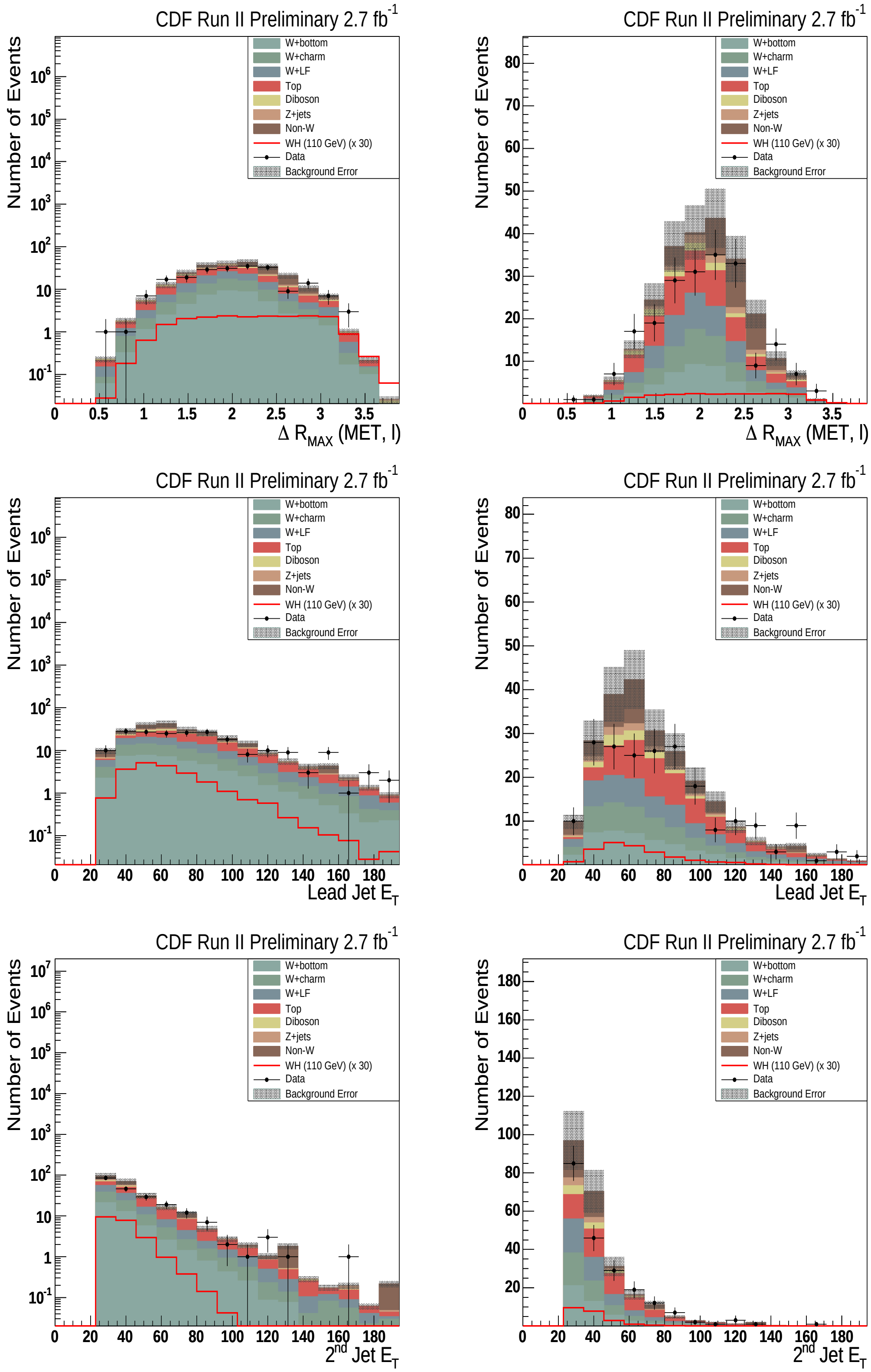

Figure 33: Isotrk One Tag Kinematics

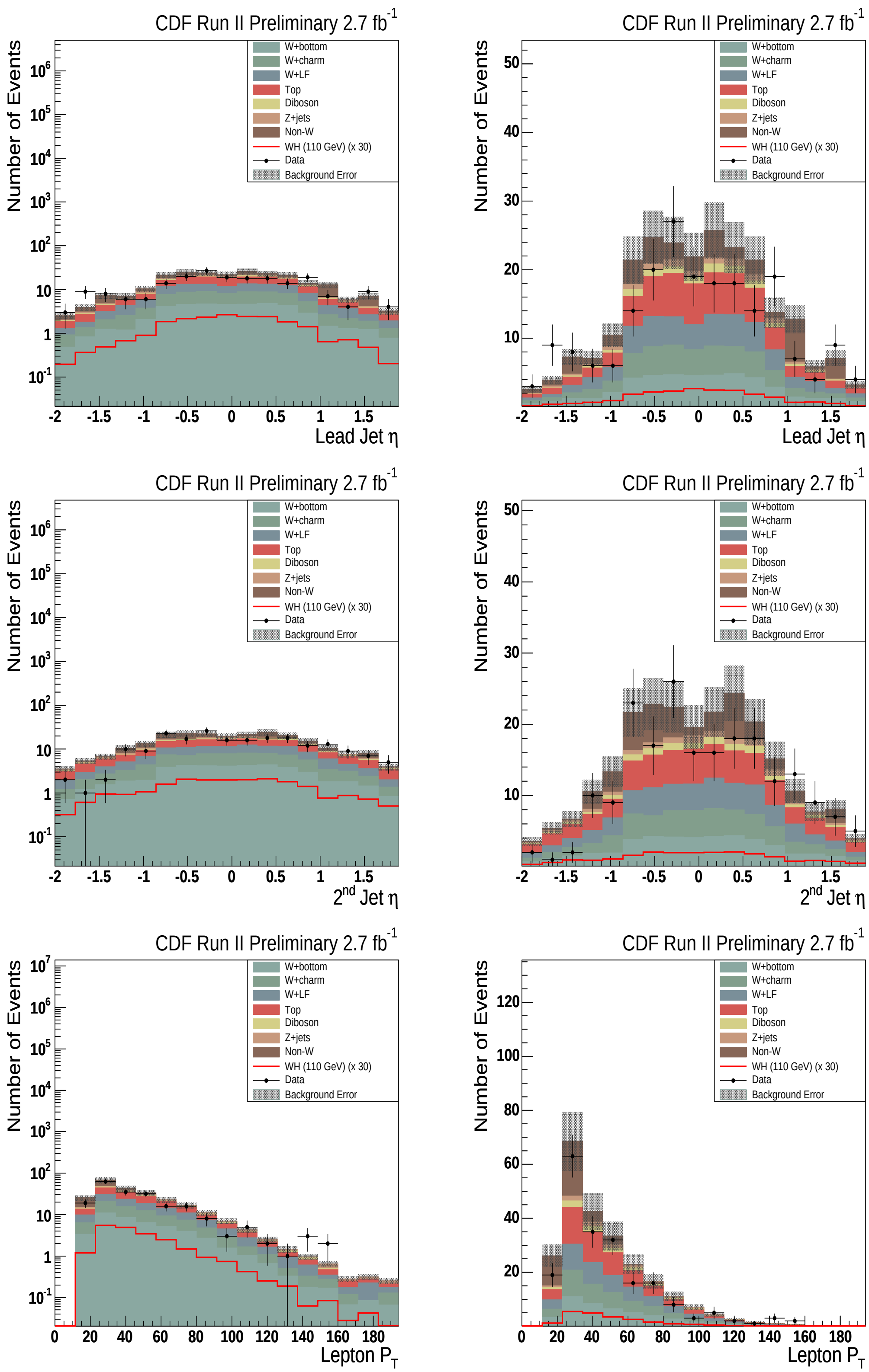

Figure 34: Isotrk One Tag Kinematics

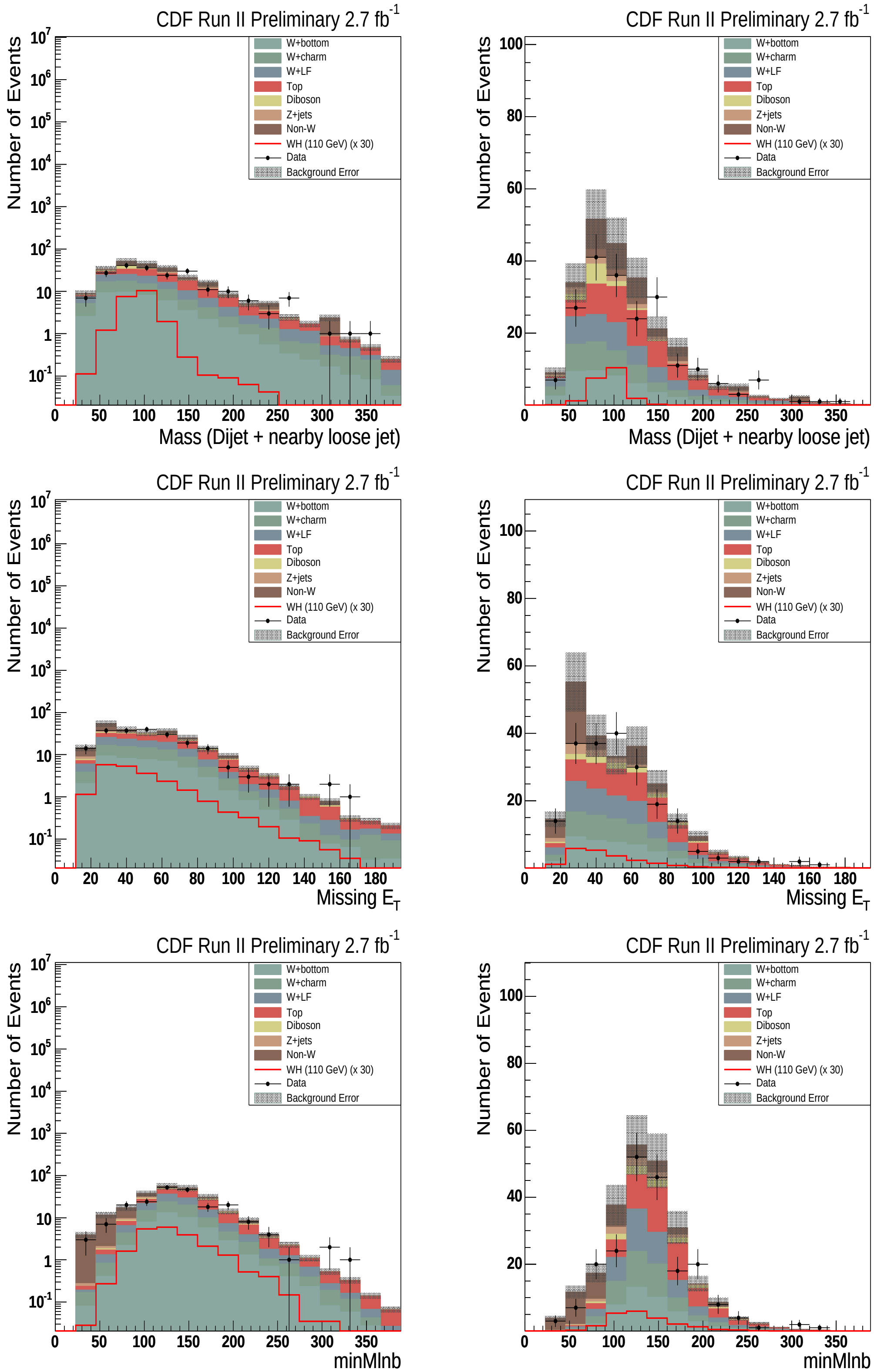

Figure 35: Isotrk One Tag Kinematics

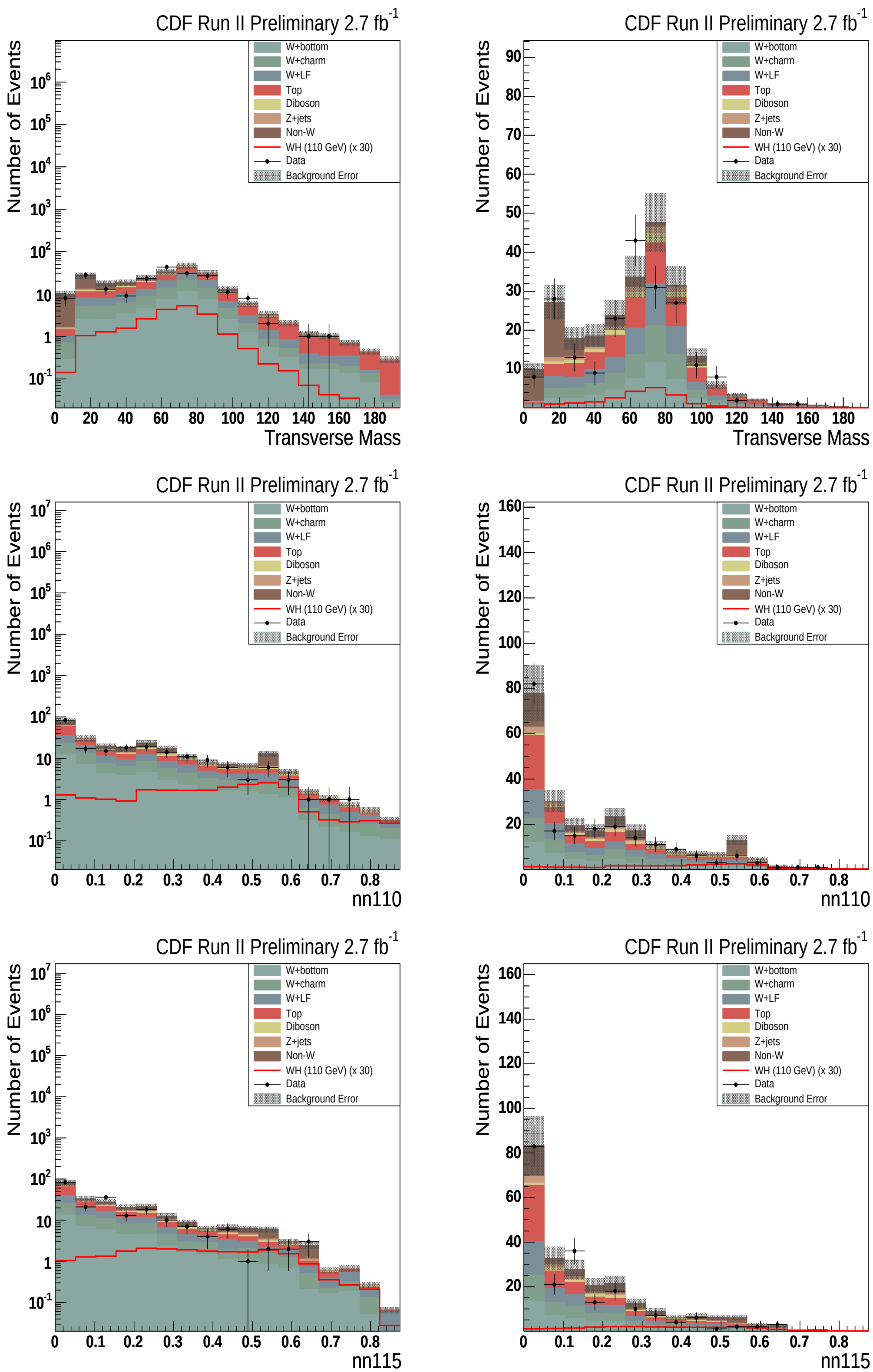

Figure 36: Isotrk One Tag Kinematics

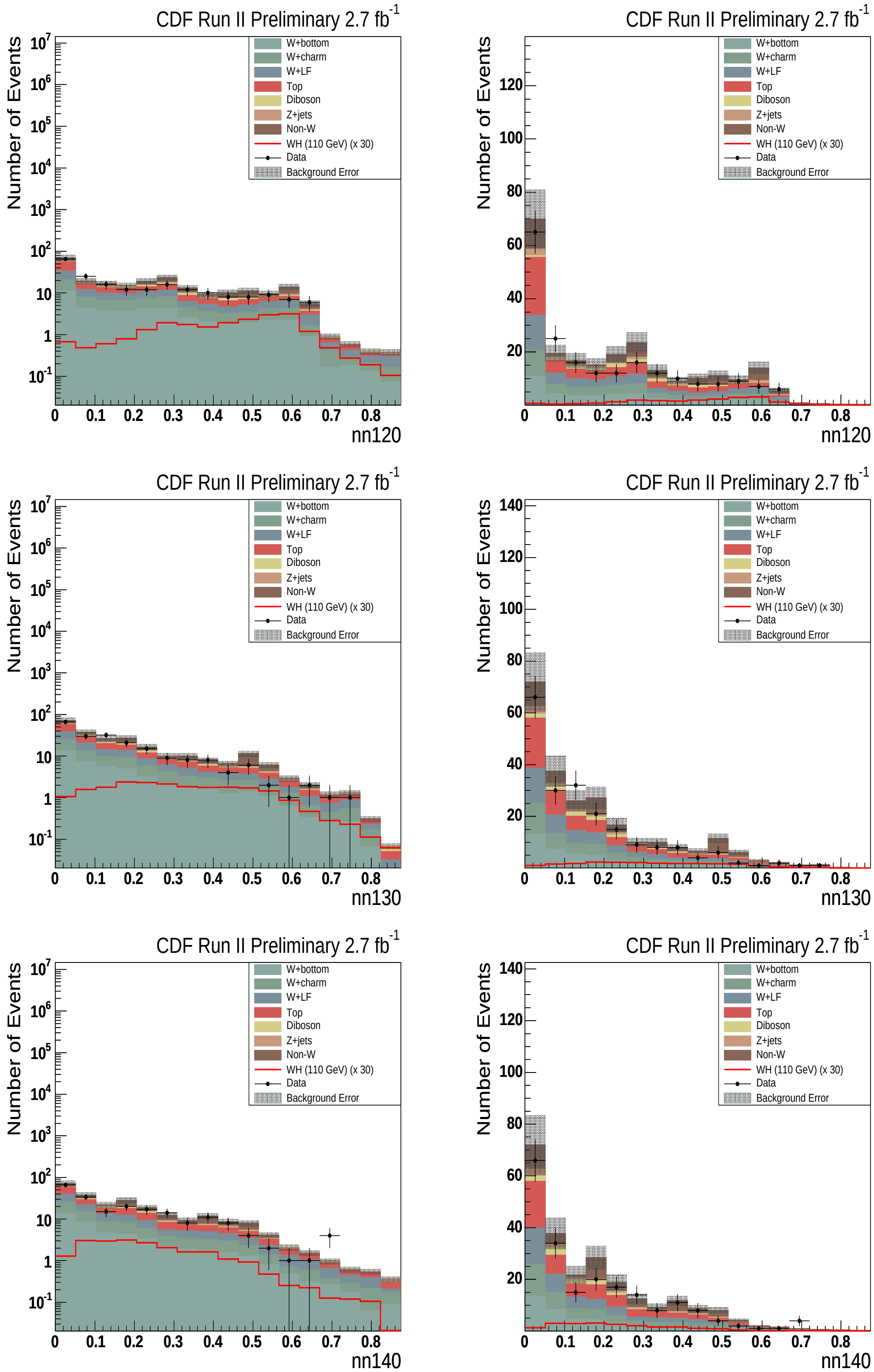

Figure 37: Isotrk One Tag Kinematics

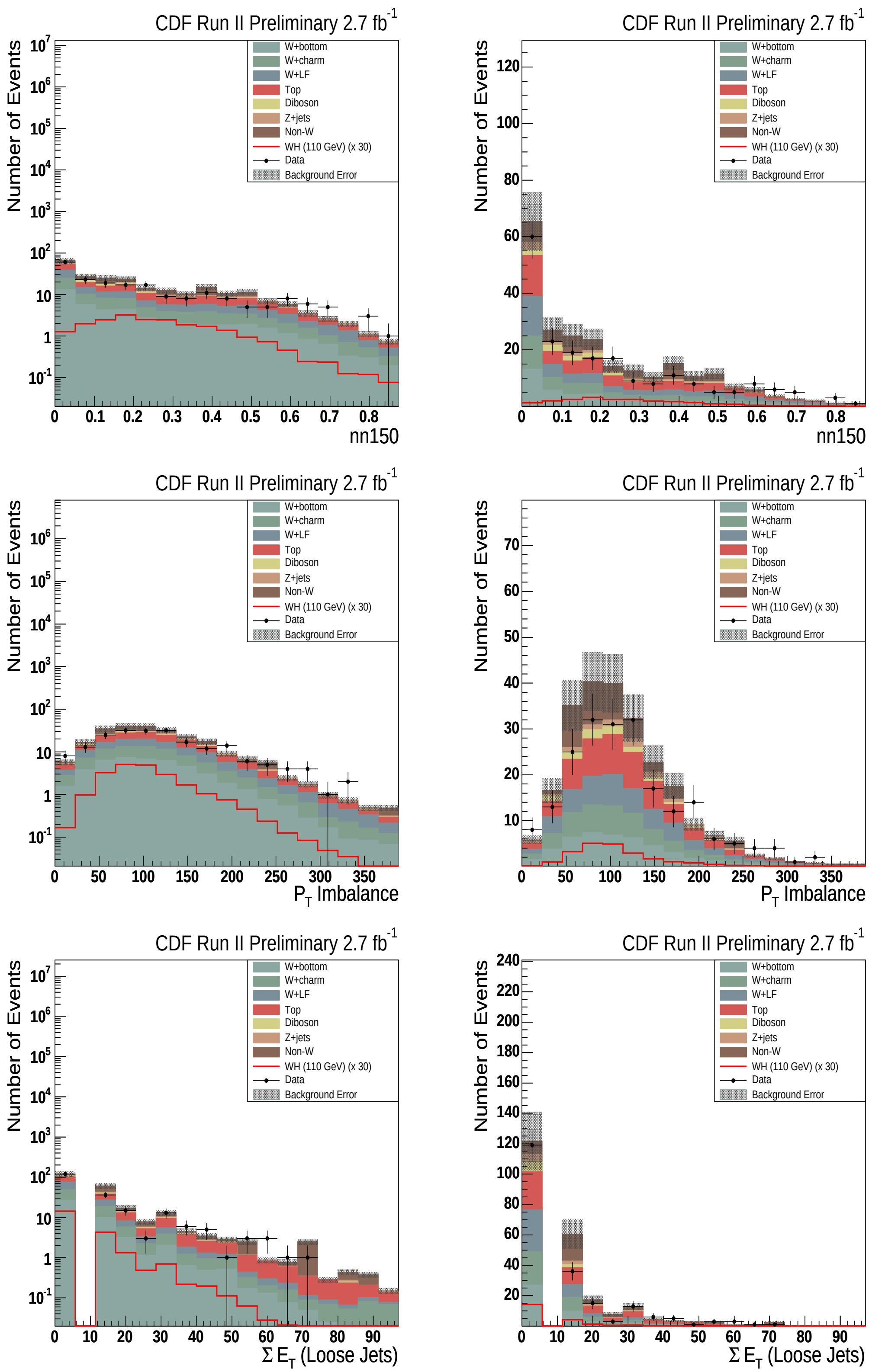

Figure 38: Isotrk One Tag Kinematics

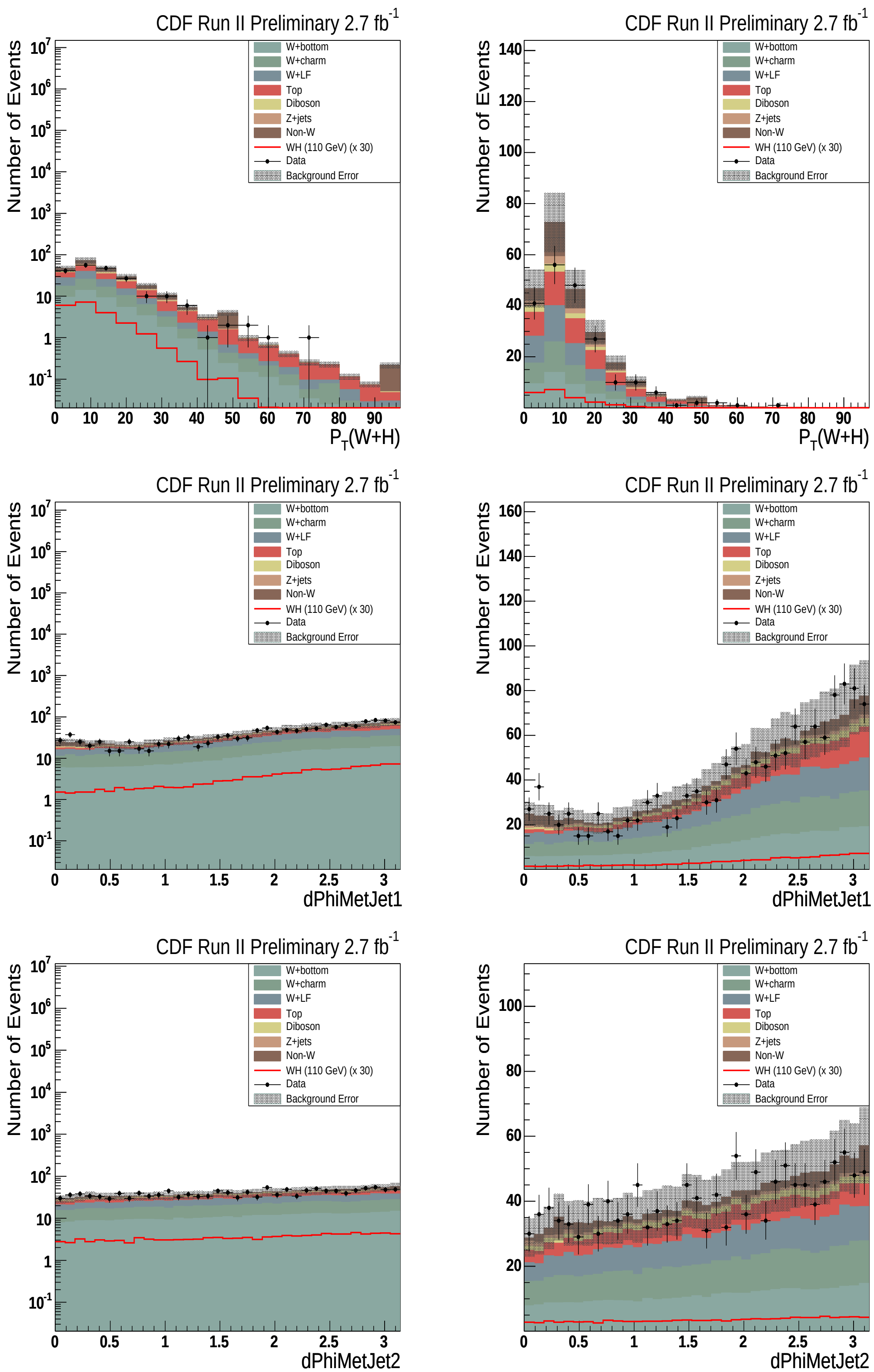

Figure 39: Tight Lepton One Tag Kinematics

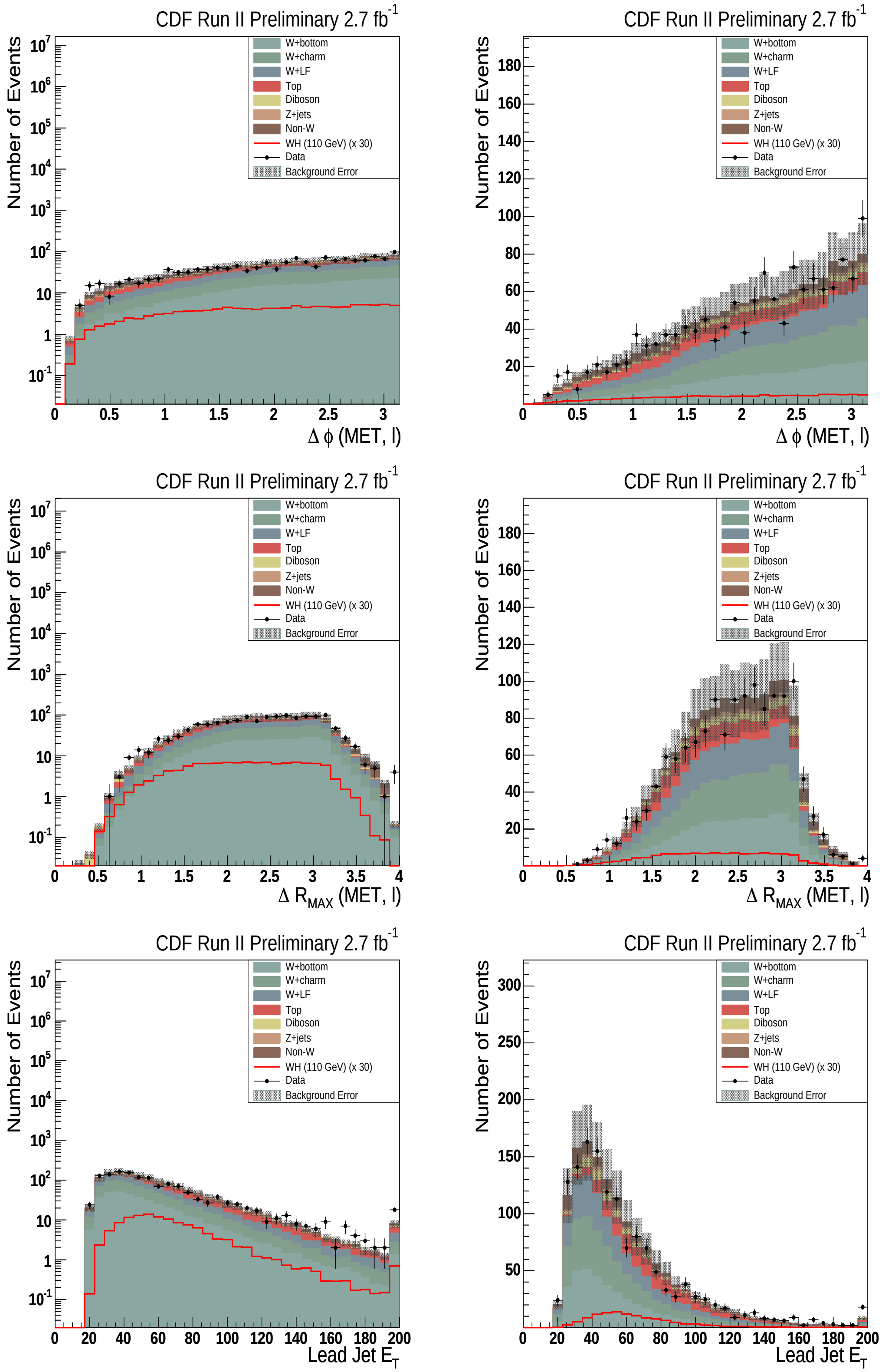

Figure 40: Tight Lepton One Tag Kinematics

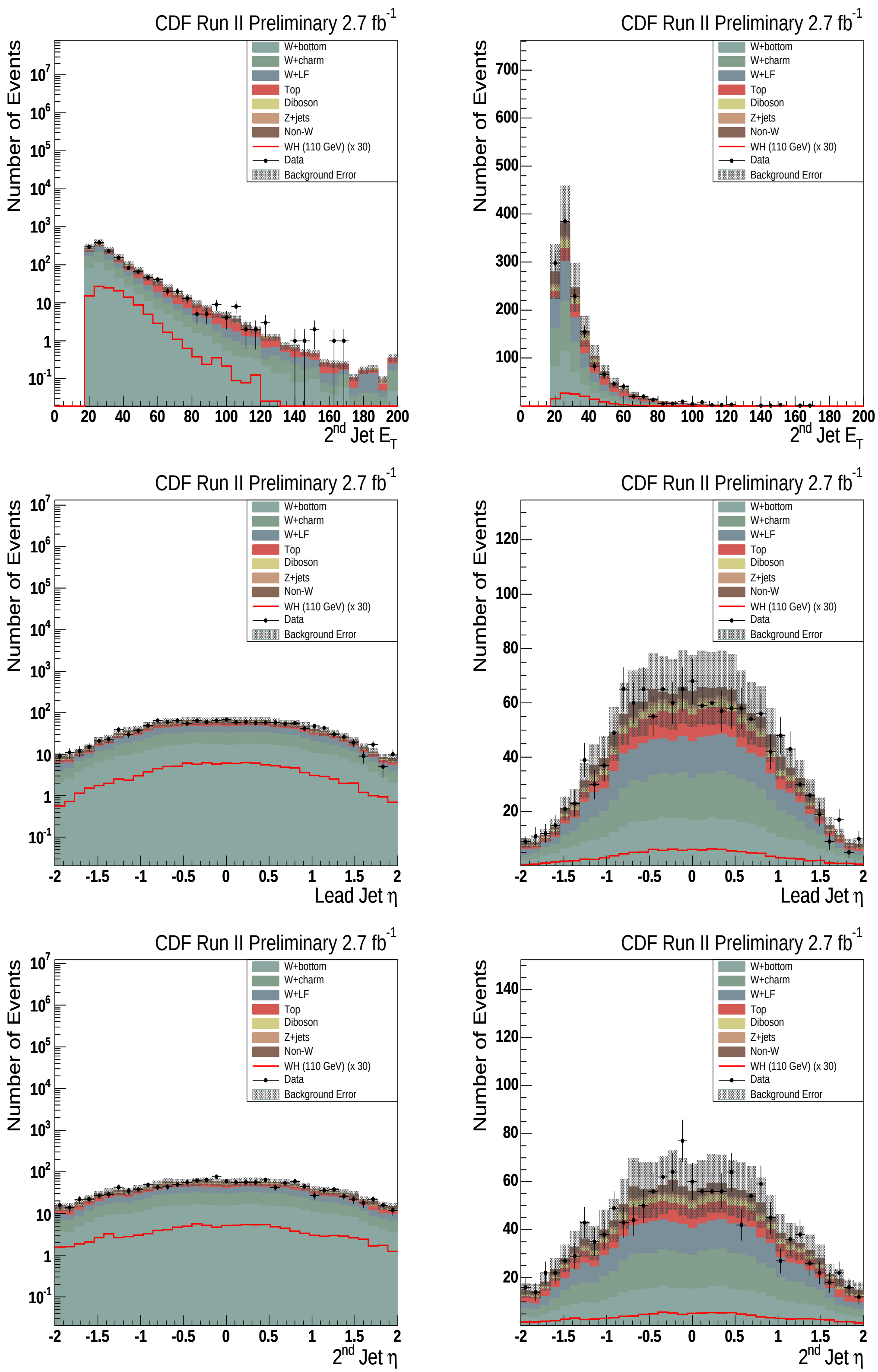

Figure 41: Tight Lepton One Tag Kinematics

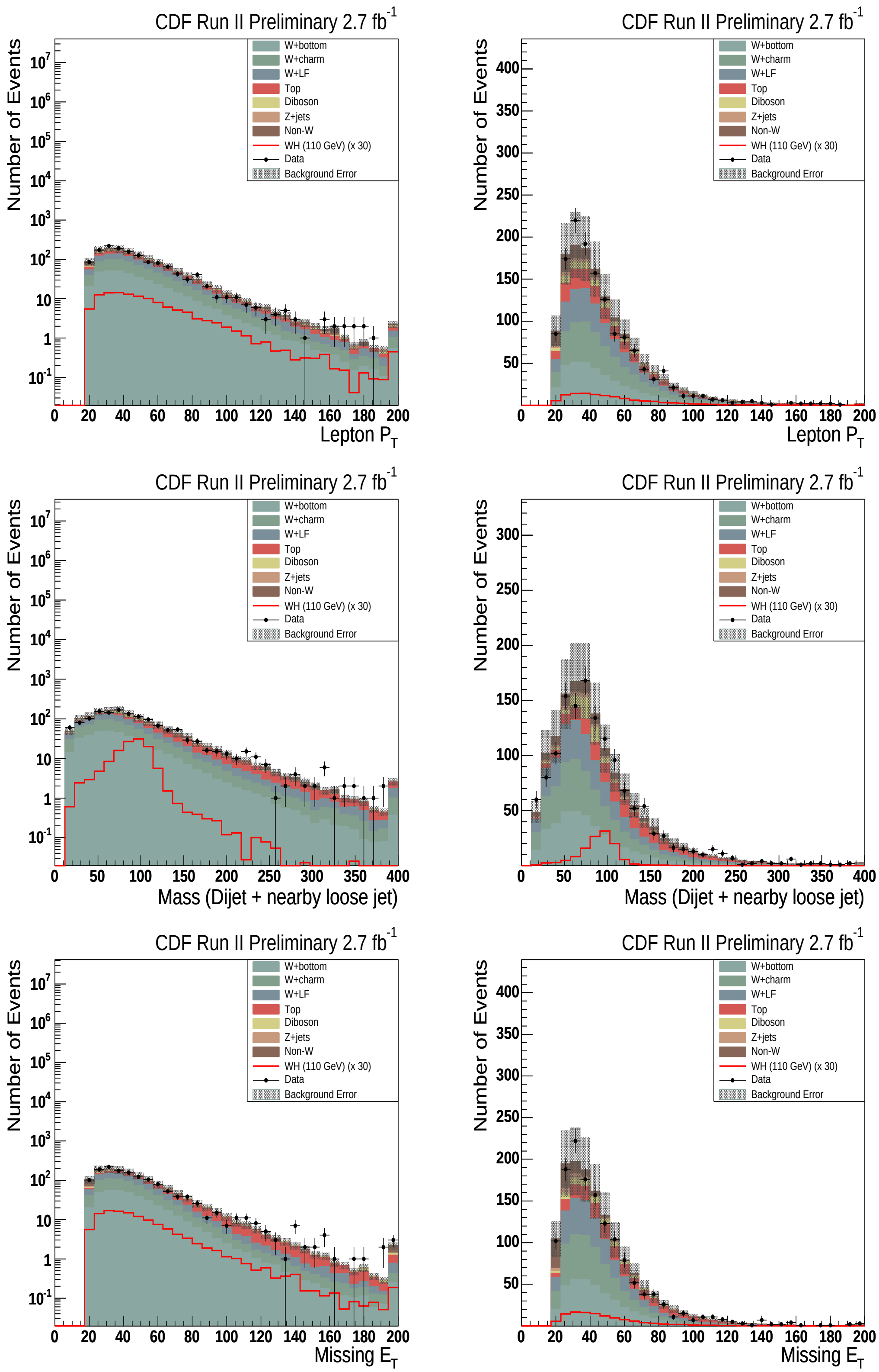

Figure 42: Tight Lepton One Tag Kinematics

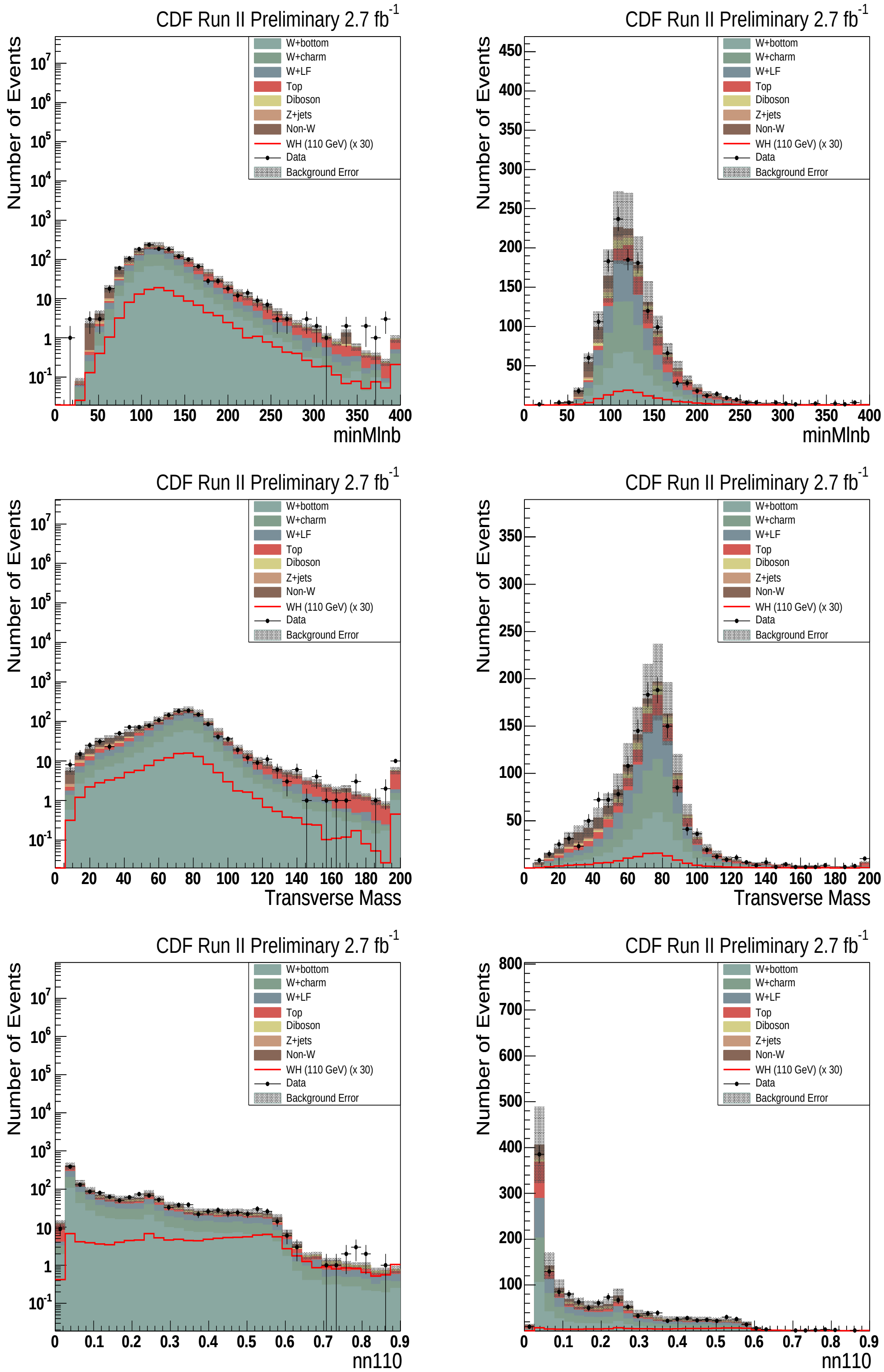

Figure 43: Tight Lepton One Tag Kinematics

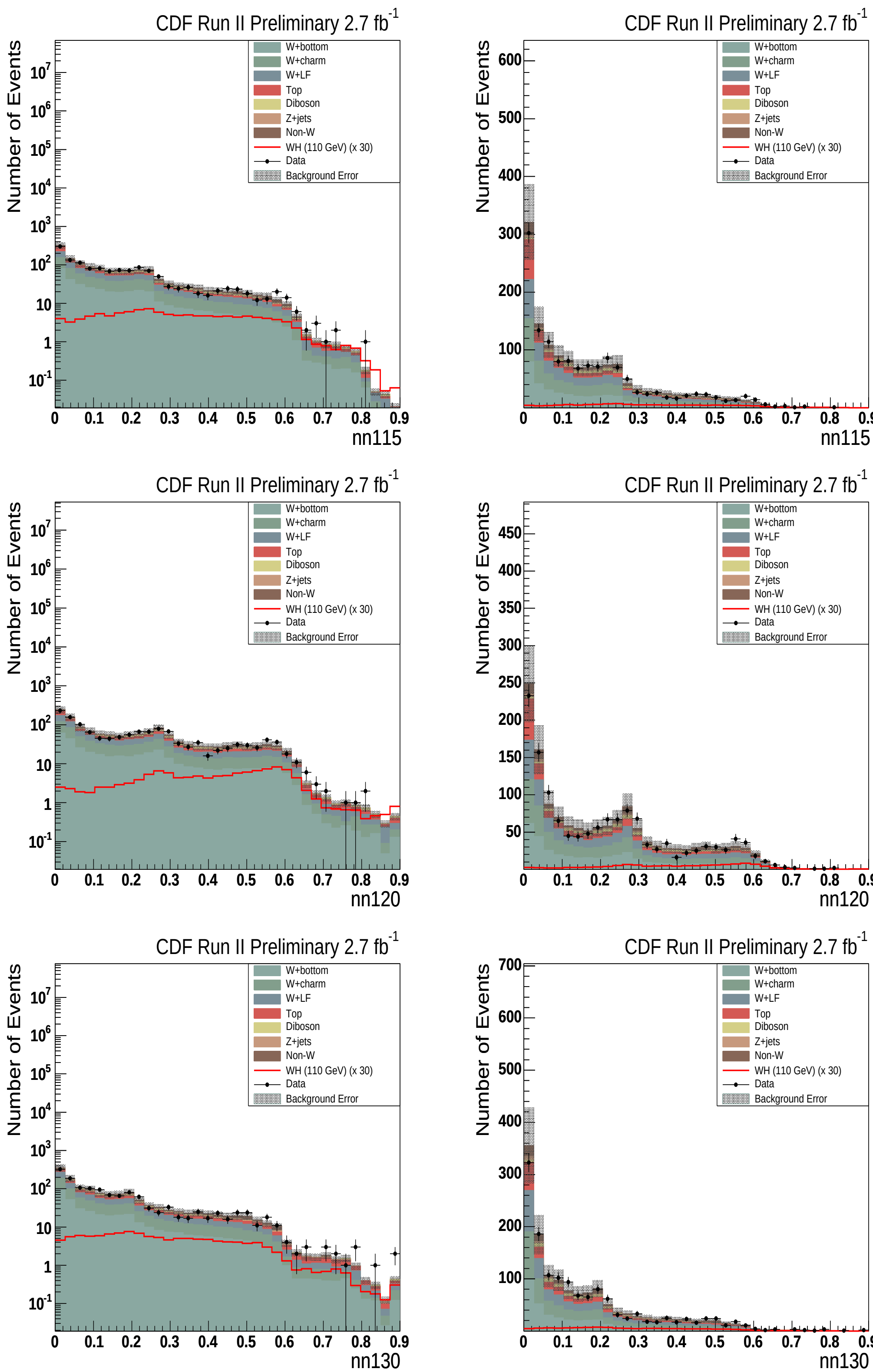

Figure 44: Tight Lepton One Tag Kinematics

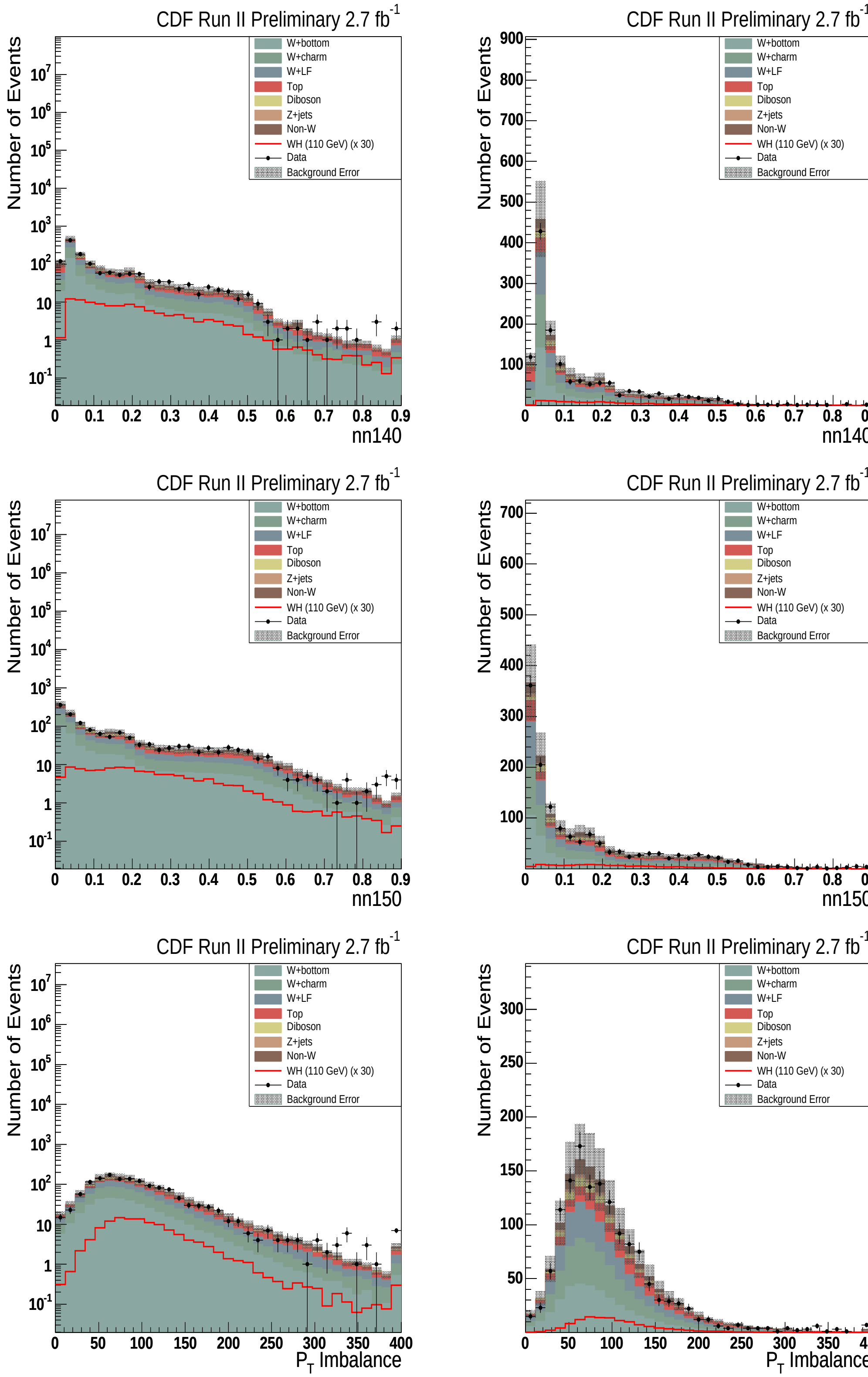

Figure 45: Tight Lepton One Tag Kinematics

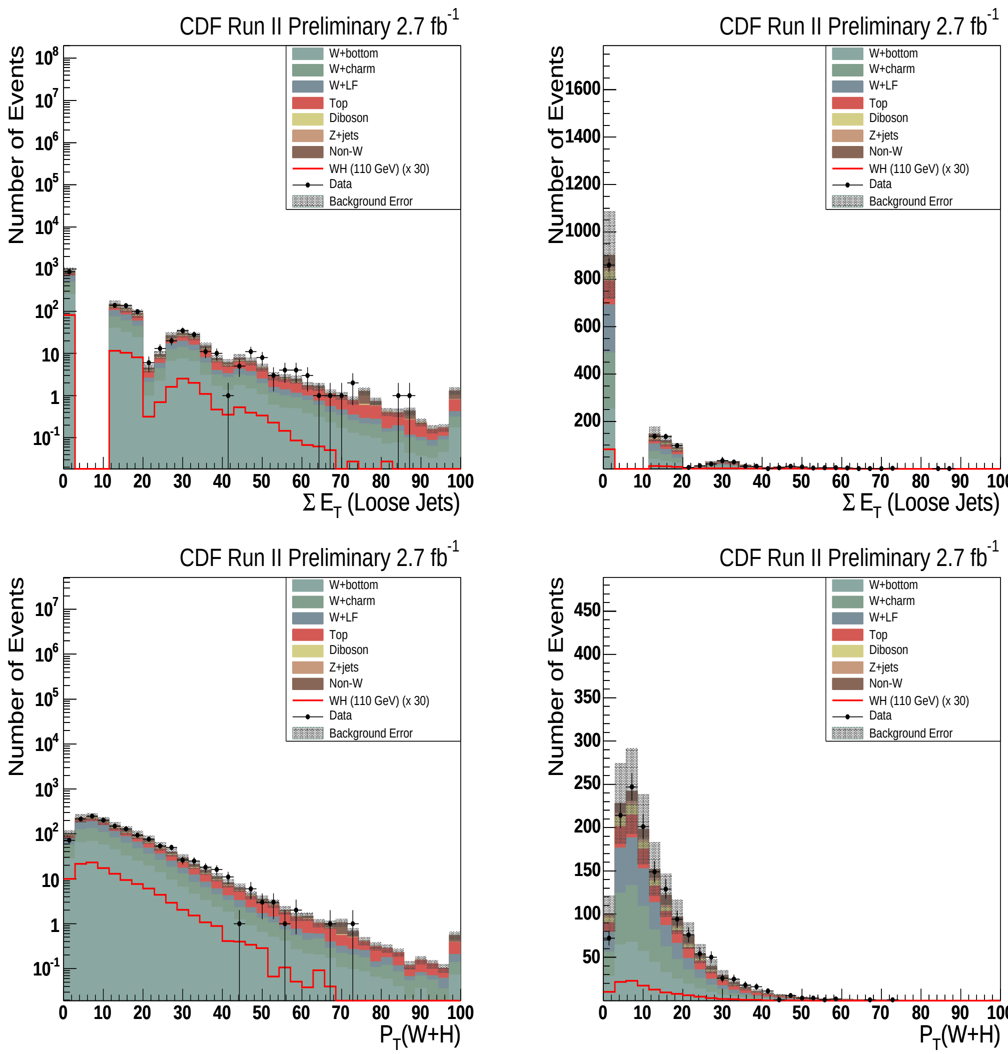

Figure 46: Tight Lepton One Tag Kinematics

11 Two Secvtx Tag Plots

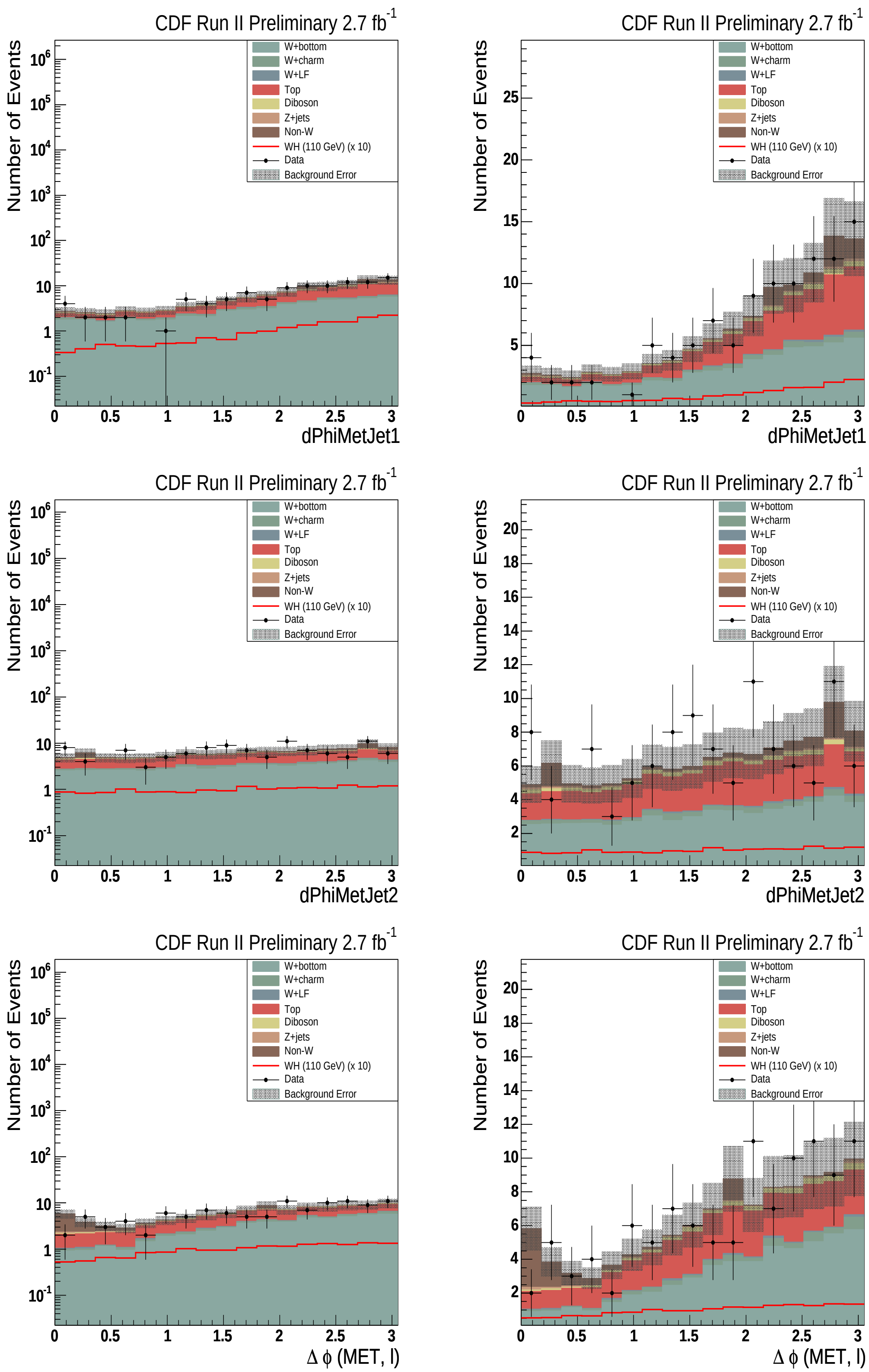

Figure 47: Tight Lepton Two Secvtx Tag Kinematics

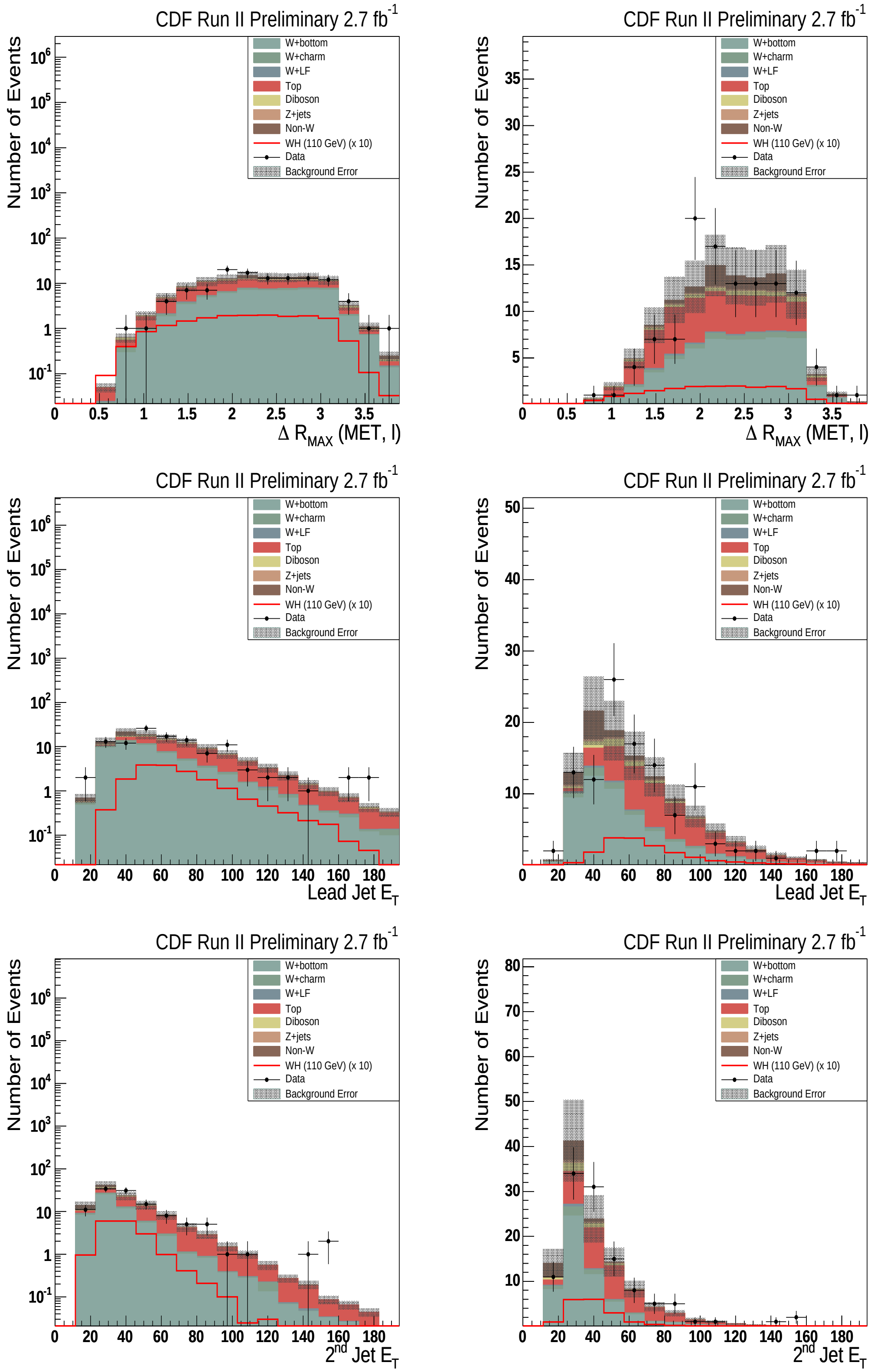

Figure 48: Tight Lepton Two Secvtx Tag Kinematics

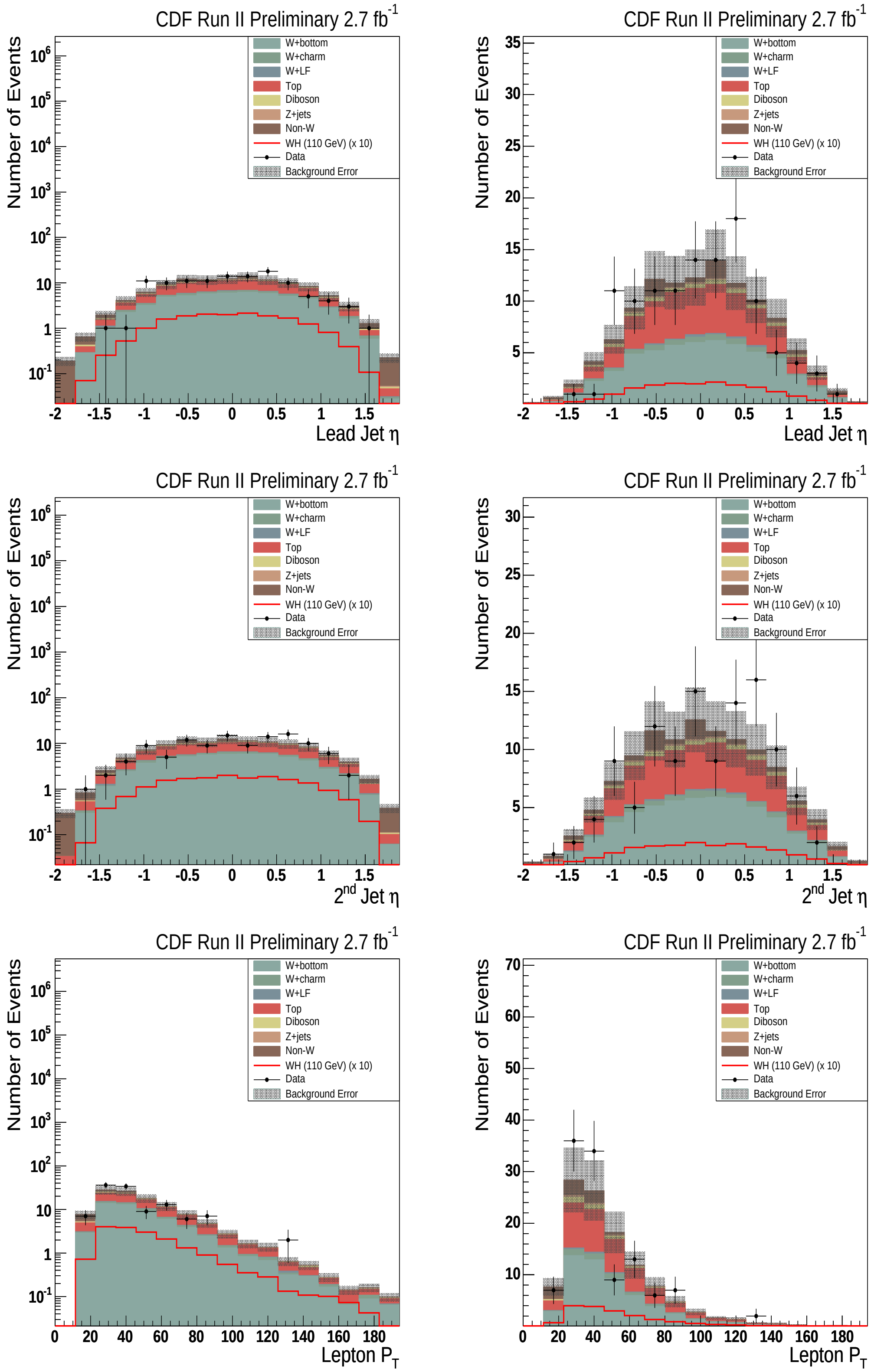

Figure 49: Tight Lepton Two Secvtx Tag Kinematics

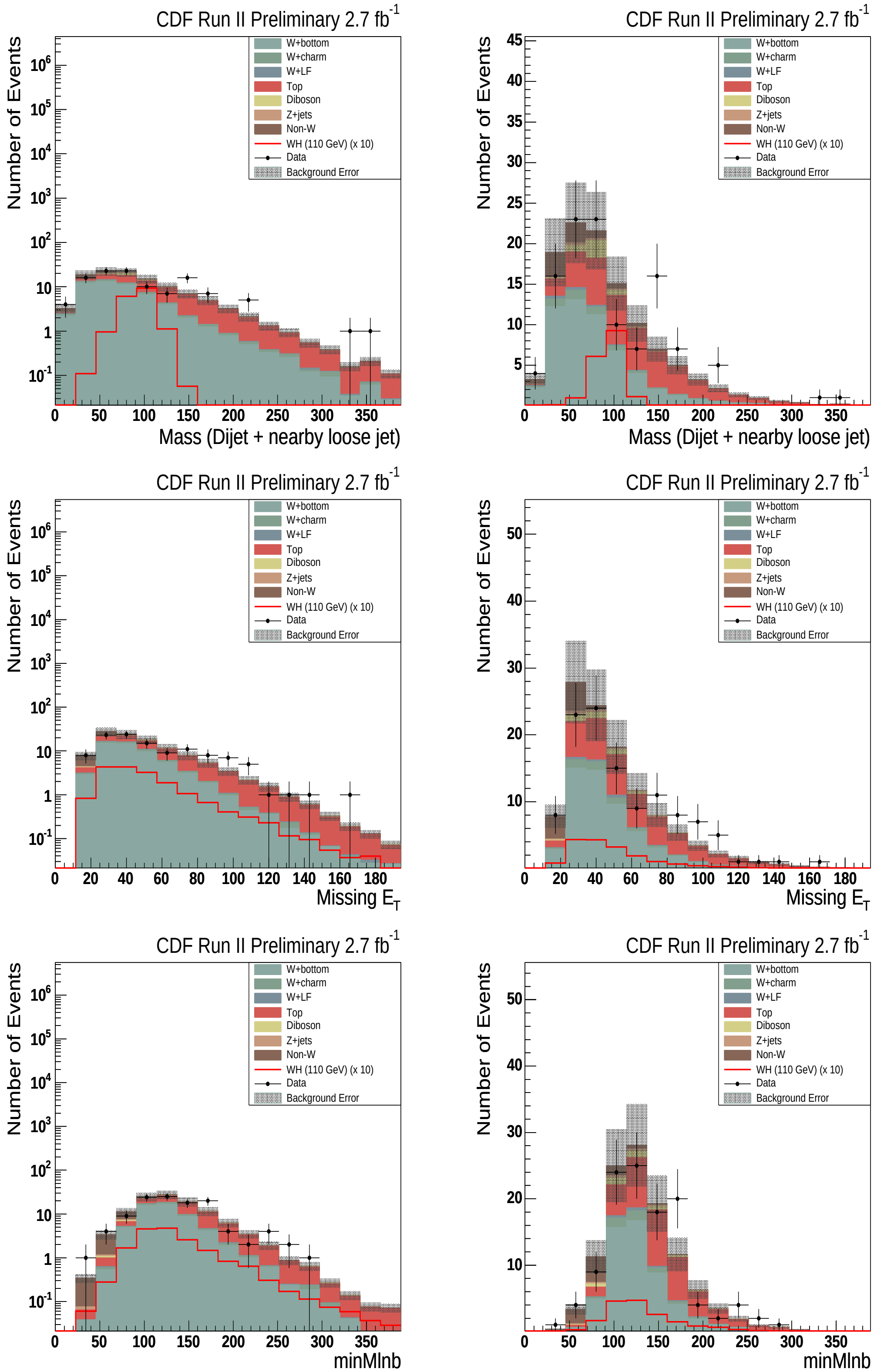

Figure 50: Tight Lepton Two Secvtx Tag Kinematics

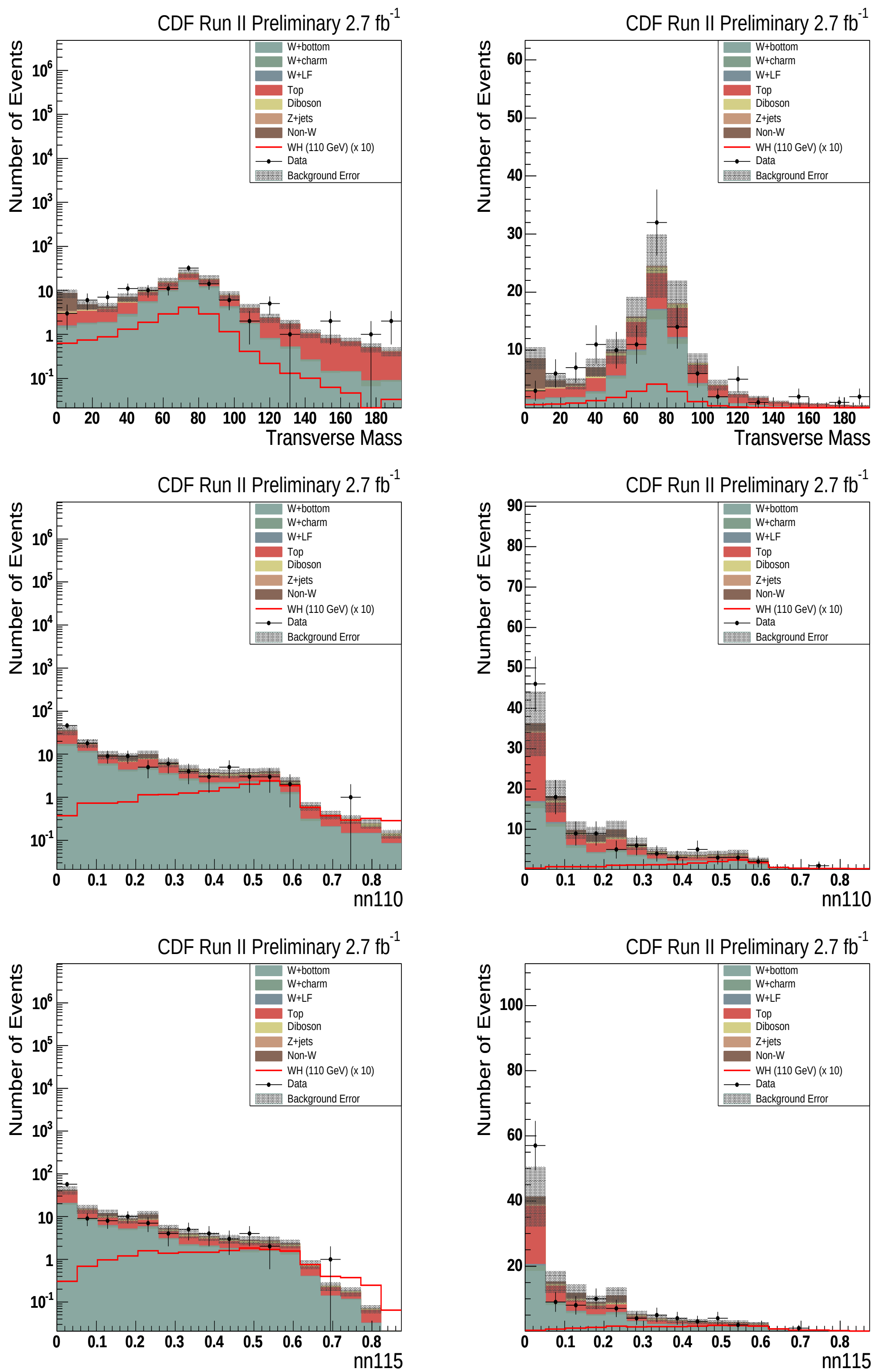

Figure 51: Tight Lepton Two Secvtx Tag Kinematics

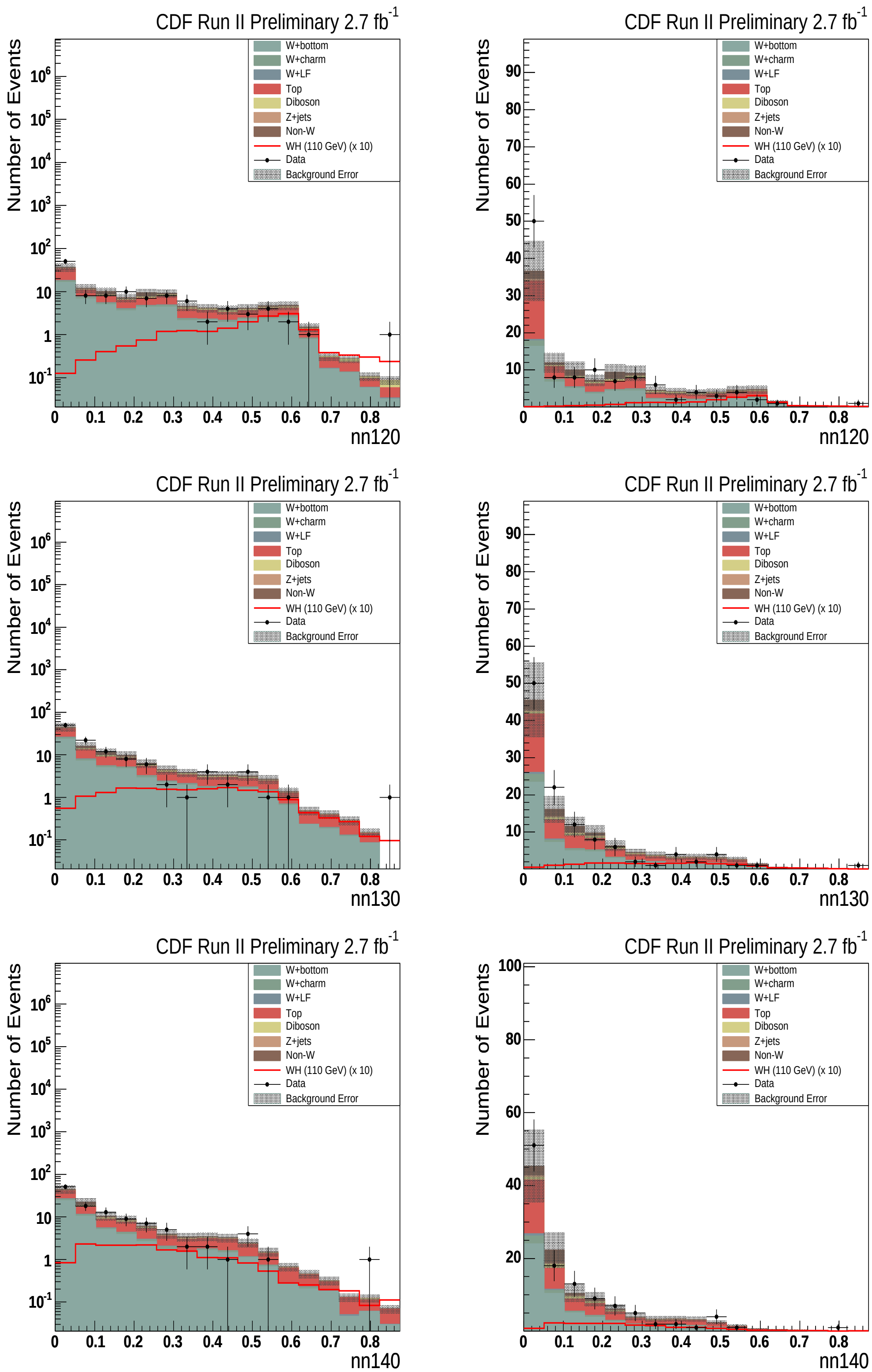

Figure 52: Tight Lepton Two Secvtx Tag Kinematics

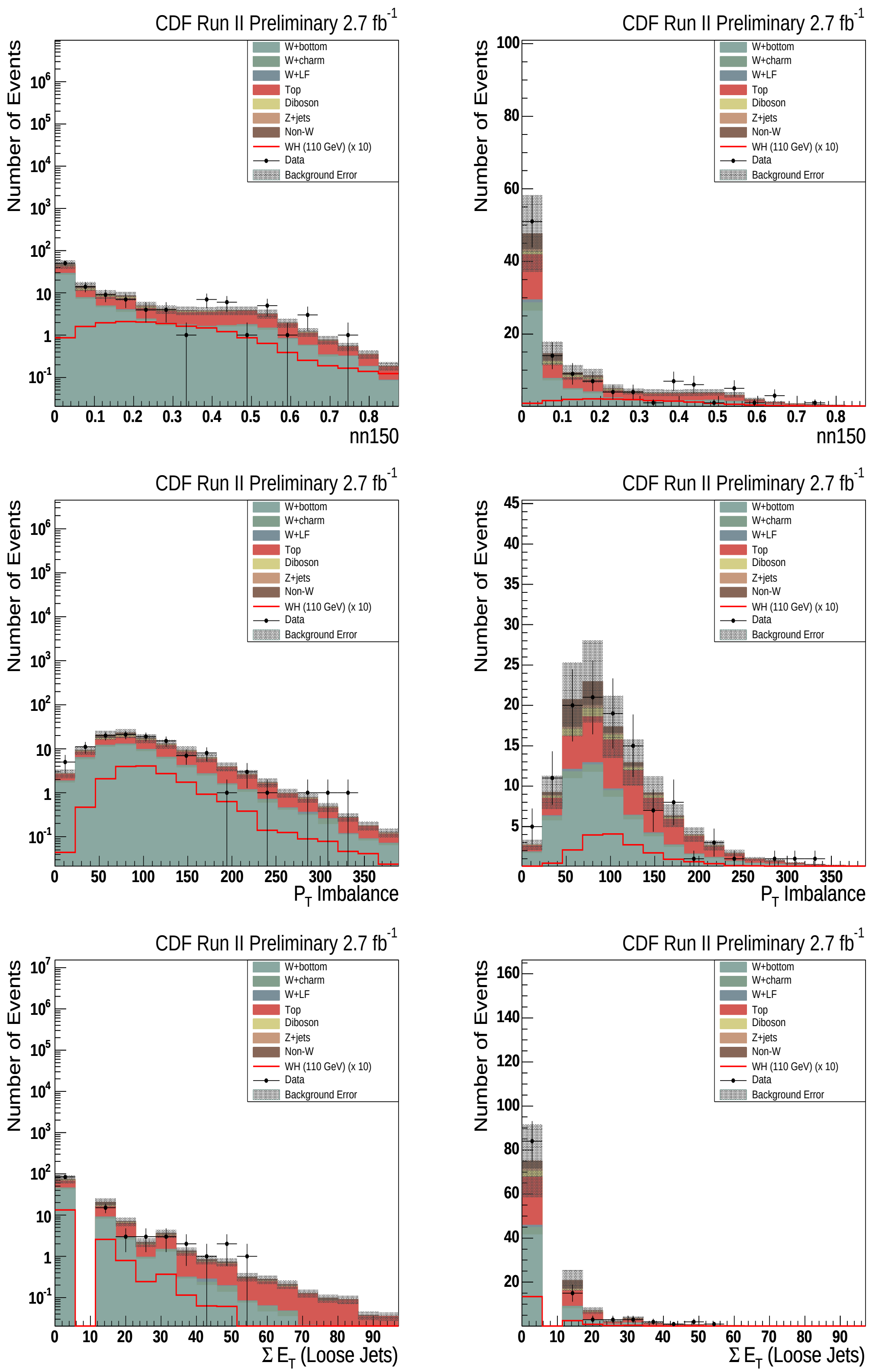

Figure 53: Tight Lepton Two Secvtx Tag Kinematics

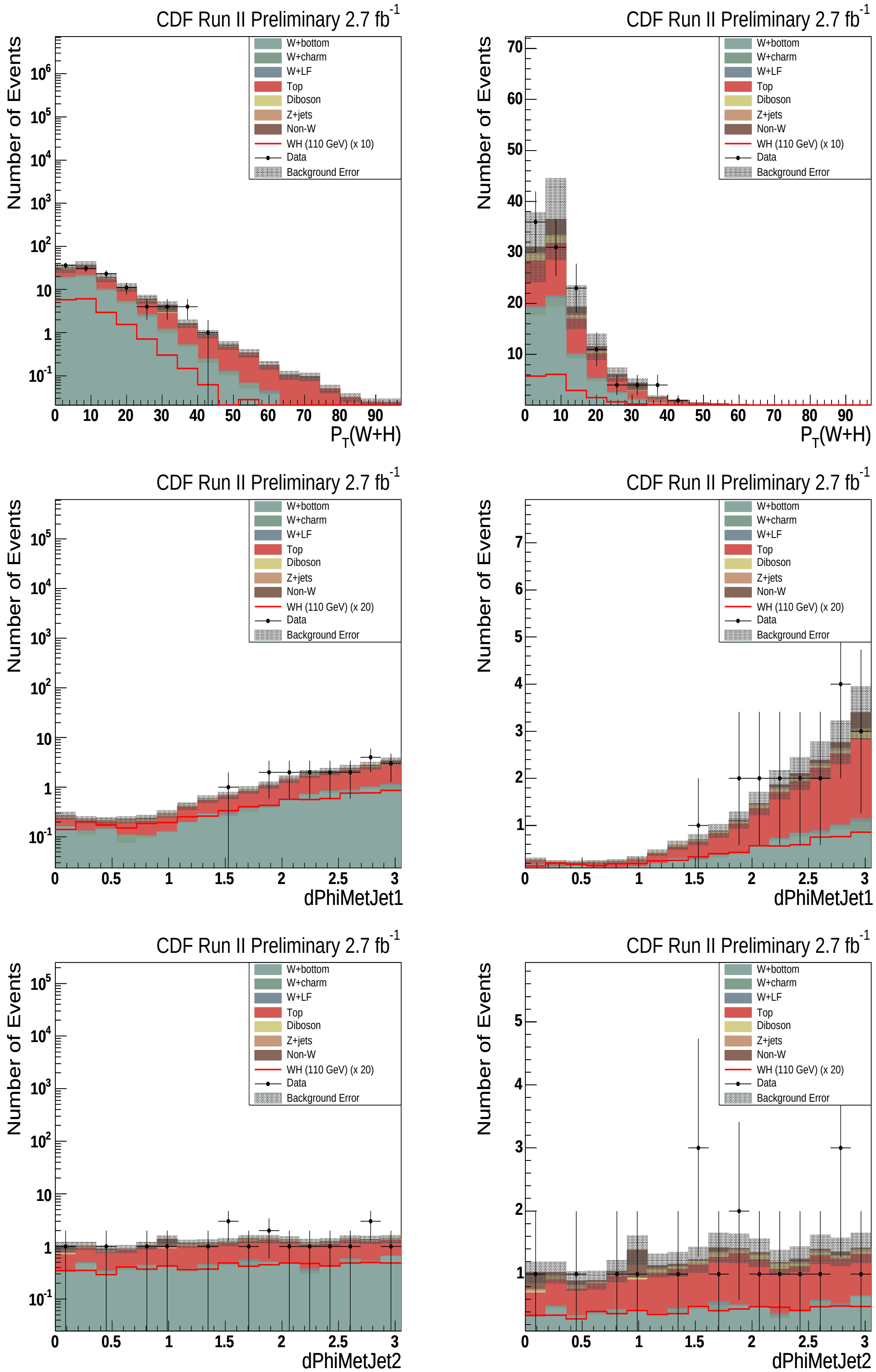

Figure 54: Isotrk Two Secvtx Tag Kinematics

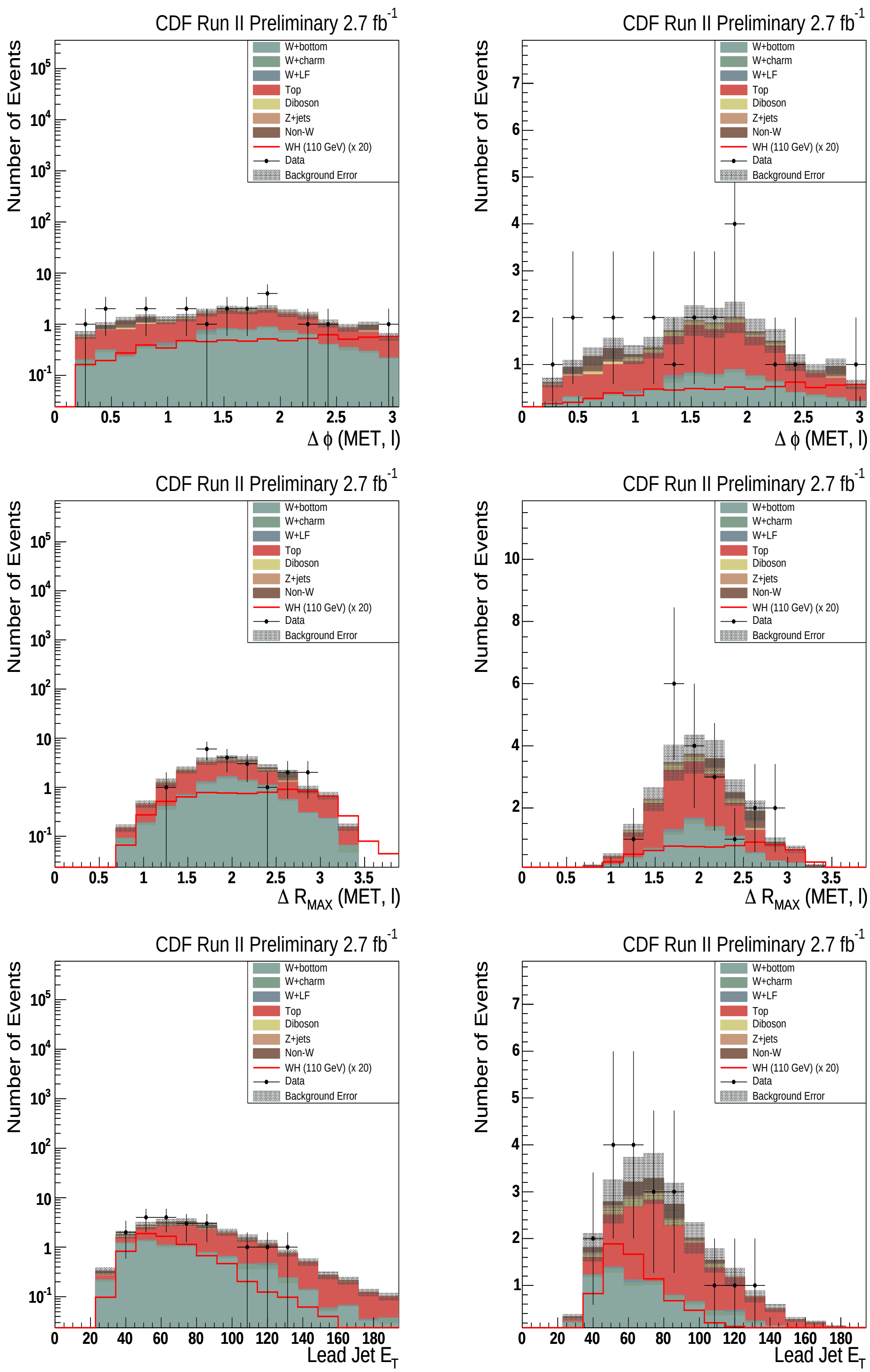

Figure 55: Isotrk Two Secvtx Tag Kinematics

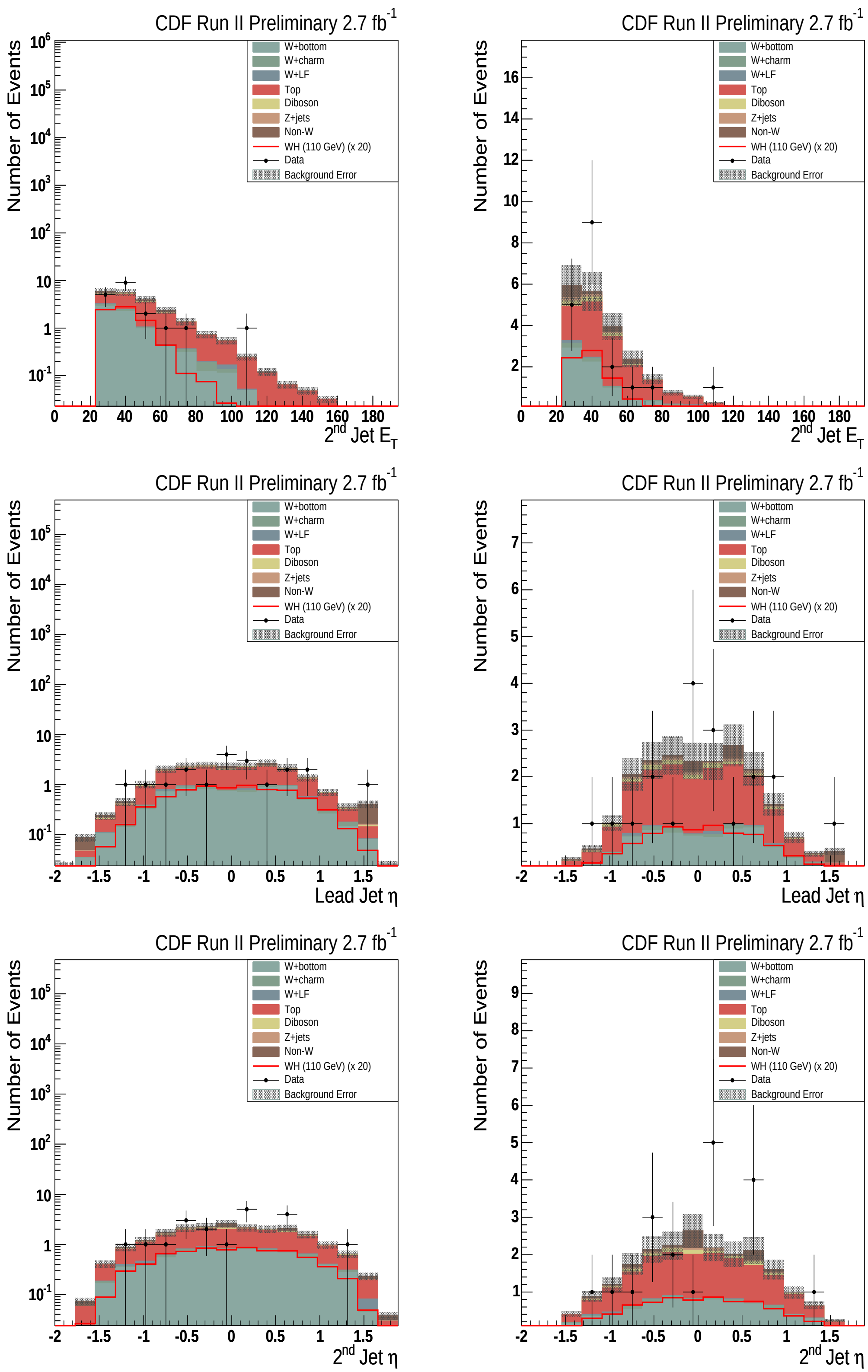

Figure 56: Isotrk Two Secvtx Tag Kinematics

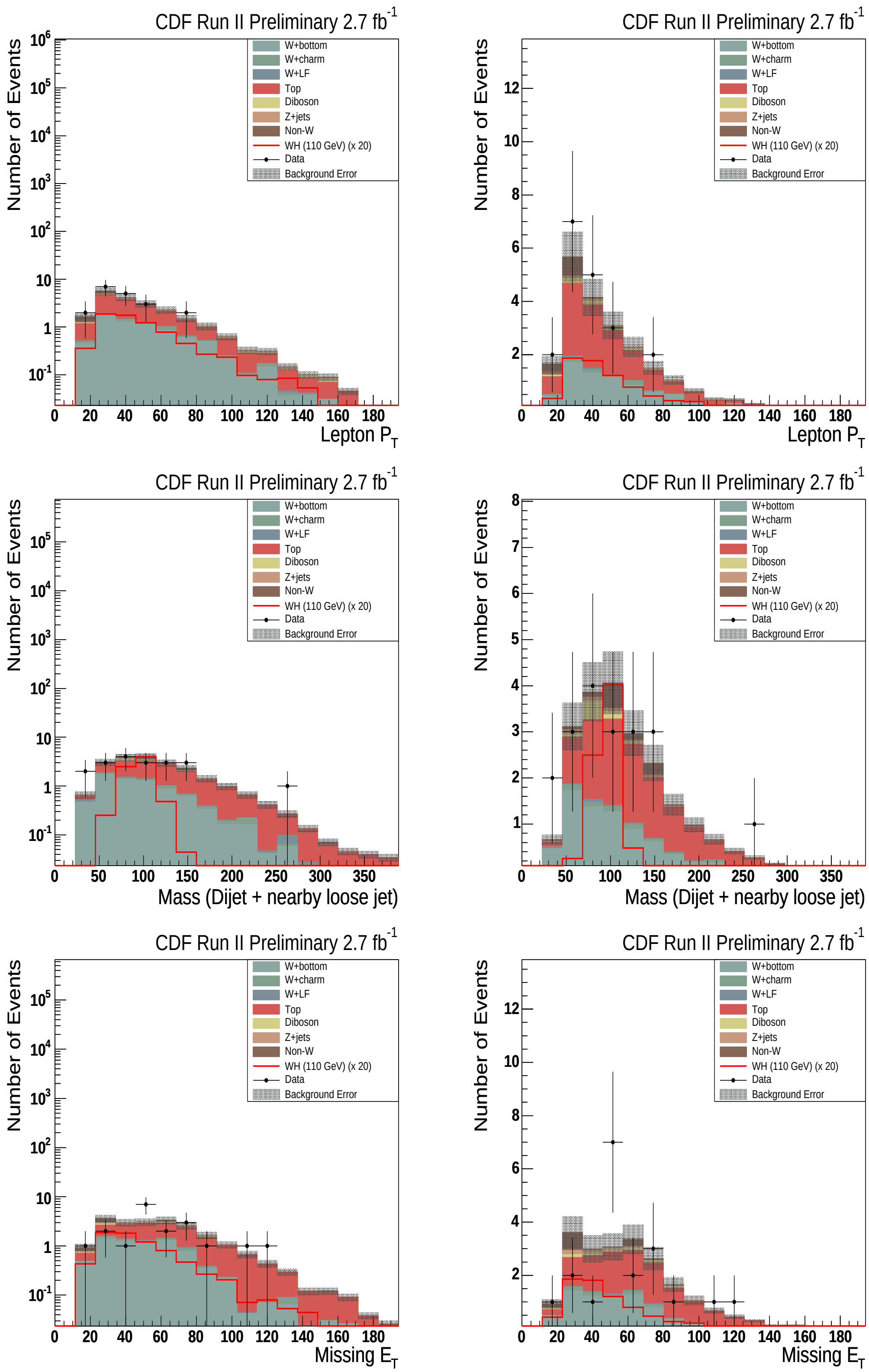

Figure 57: Isotrk Two Secvtx Tag Kinematics

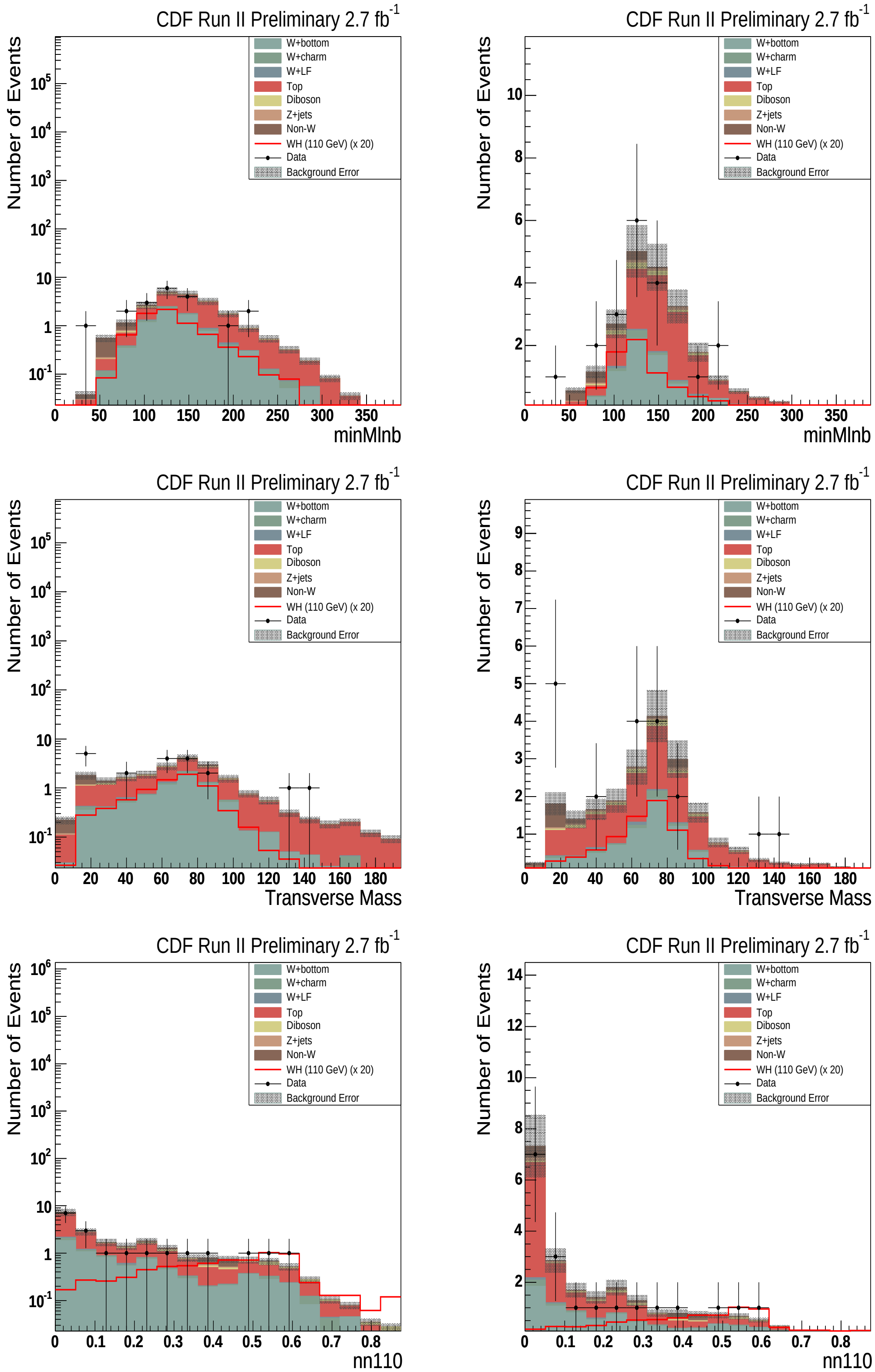

Figure 58: Isotrk Two Secvtx Tag Kinematics

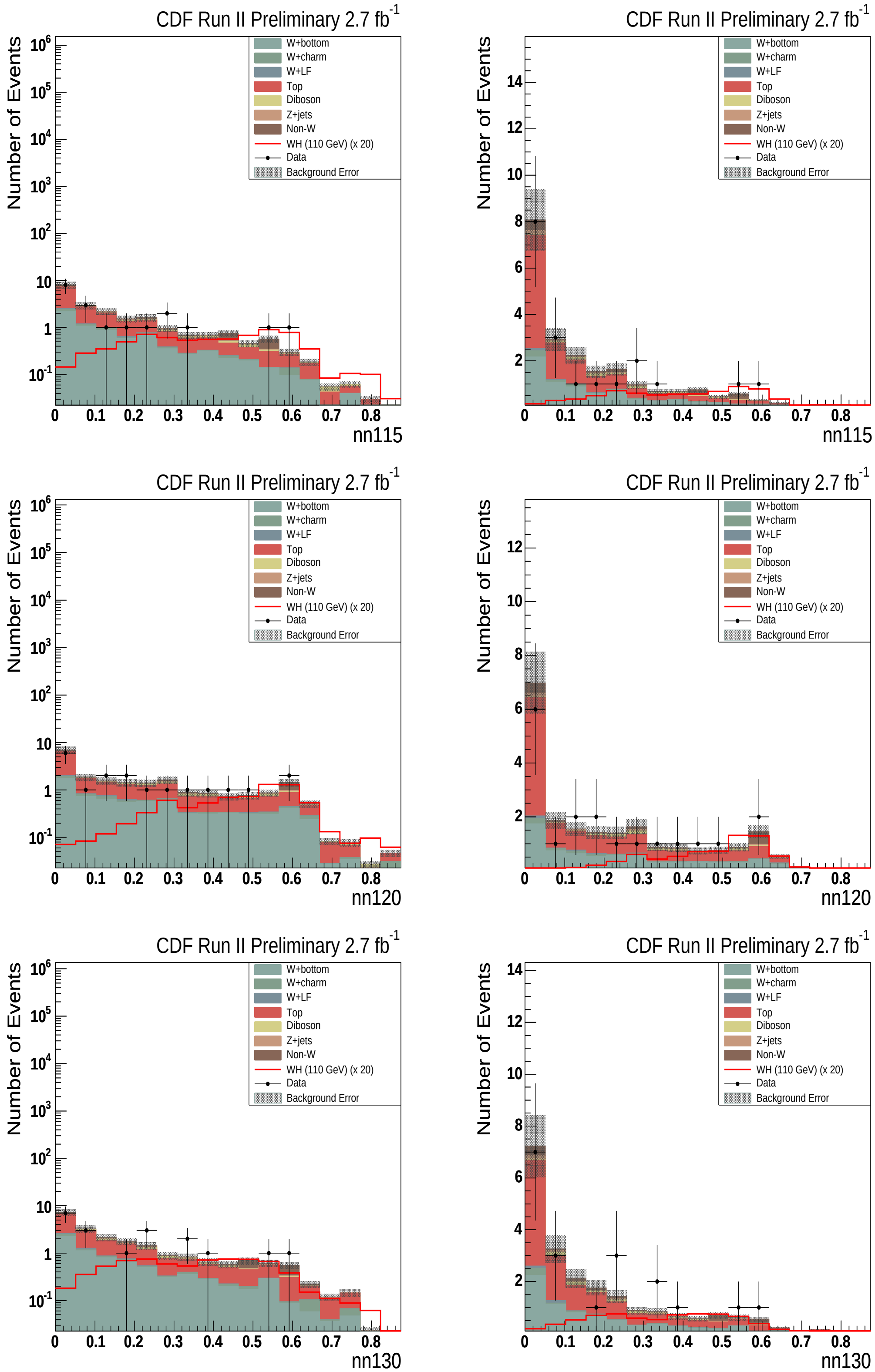

Figure 59: Isotrk Two Secvtx Tag Kinematics

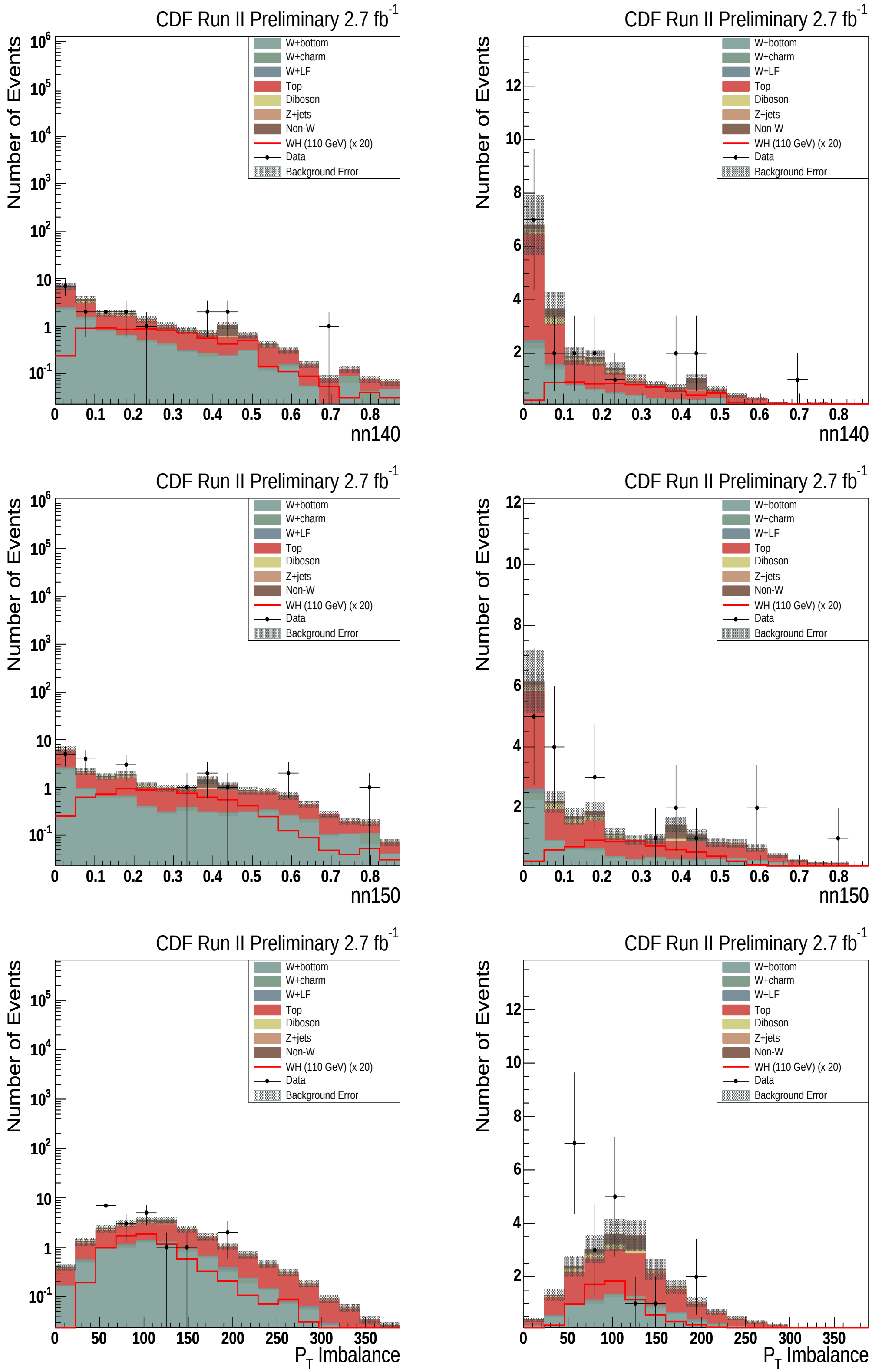

Figure 60: Isotrk Two Secvtx Tag Kinematics

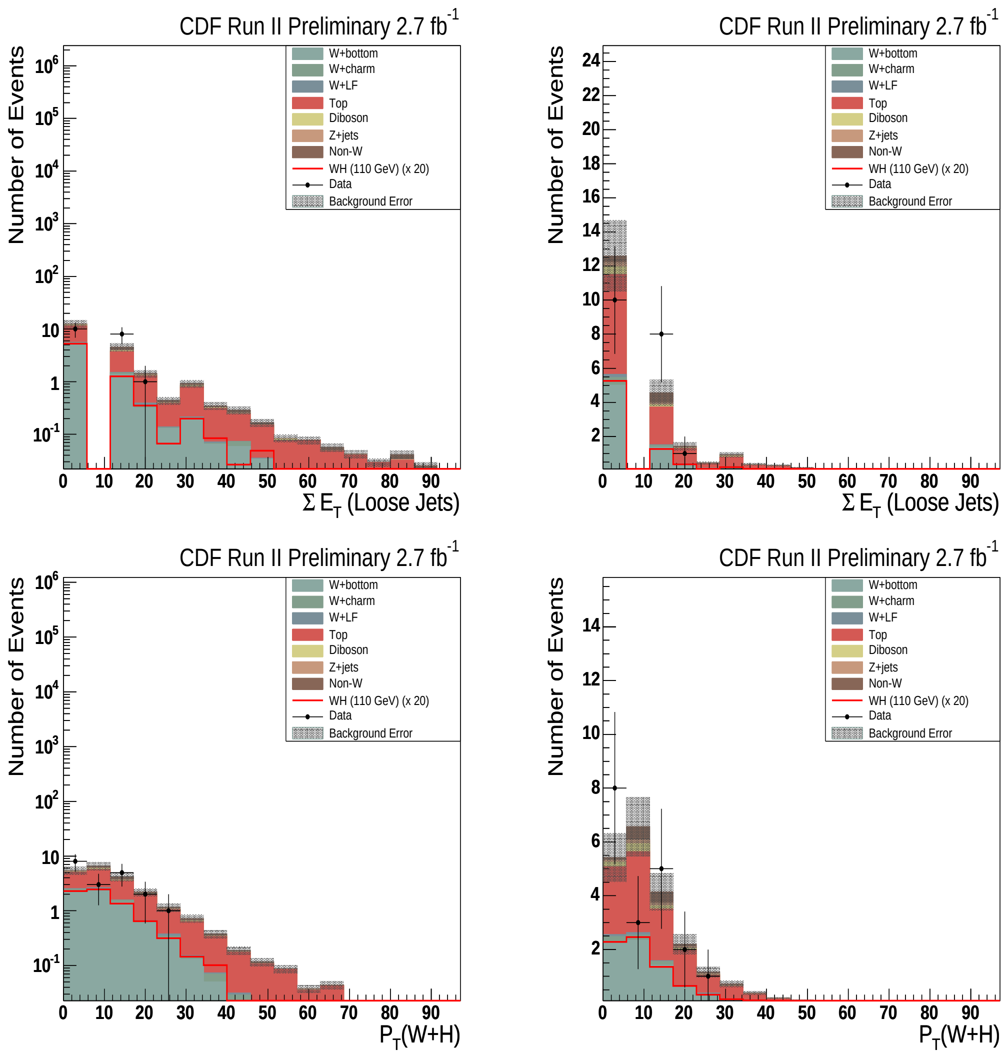

Figure 61: Isotrk Two Secvtx Tag Kinematics

12 One Secvtx Tag, One JetProb Tag Plots

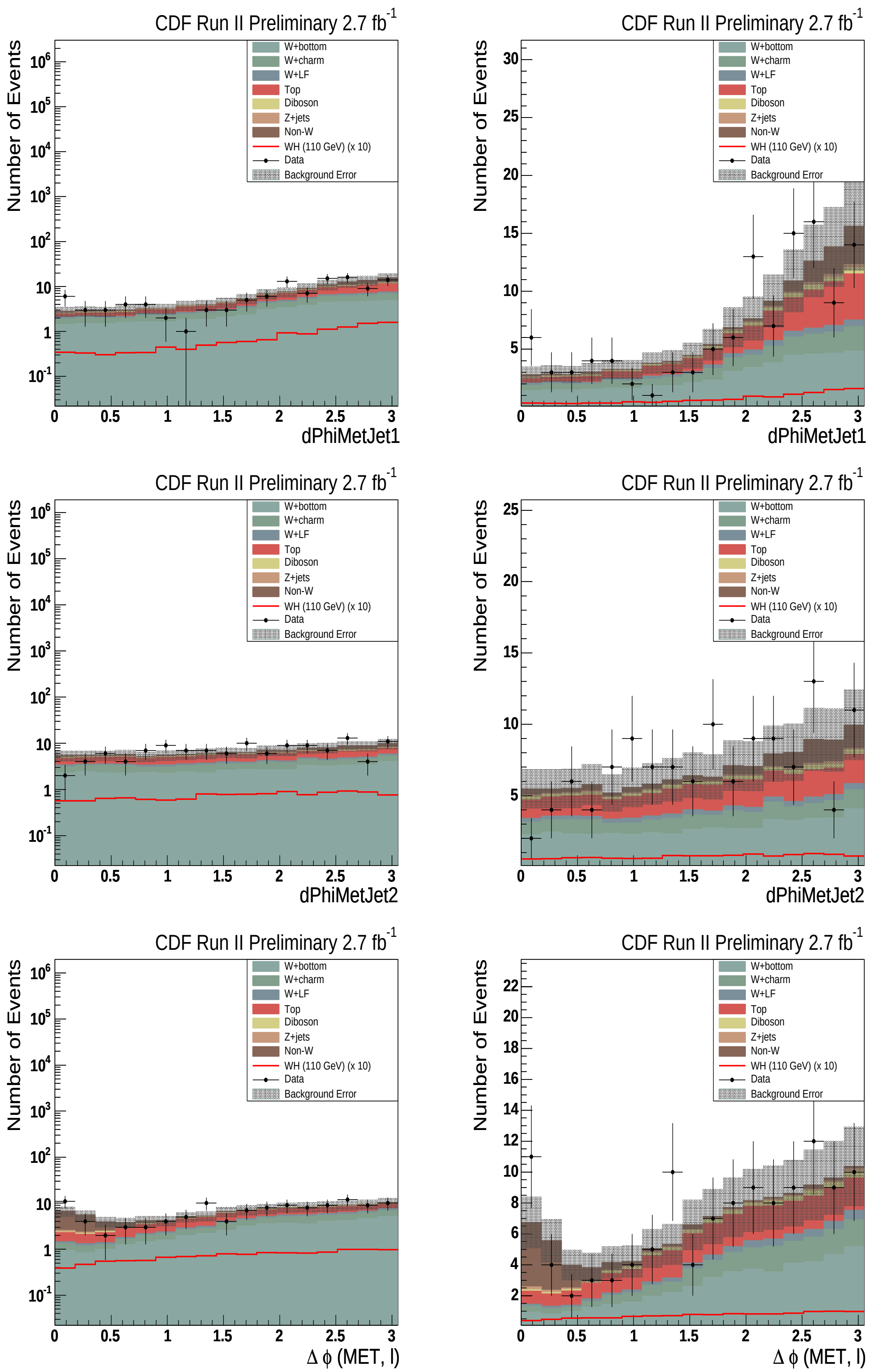

Figure 62: Tight Lepton One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

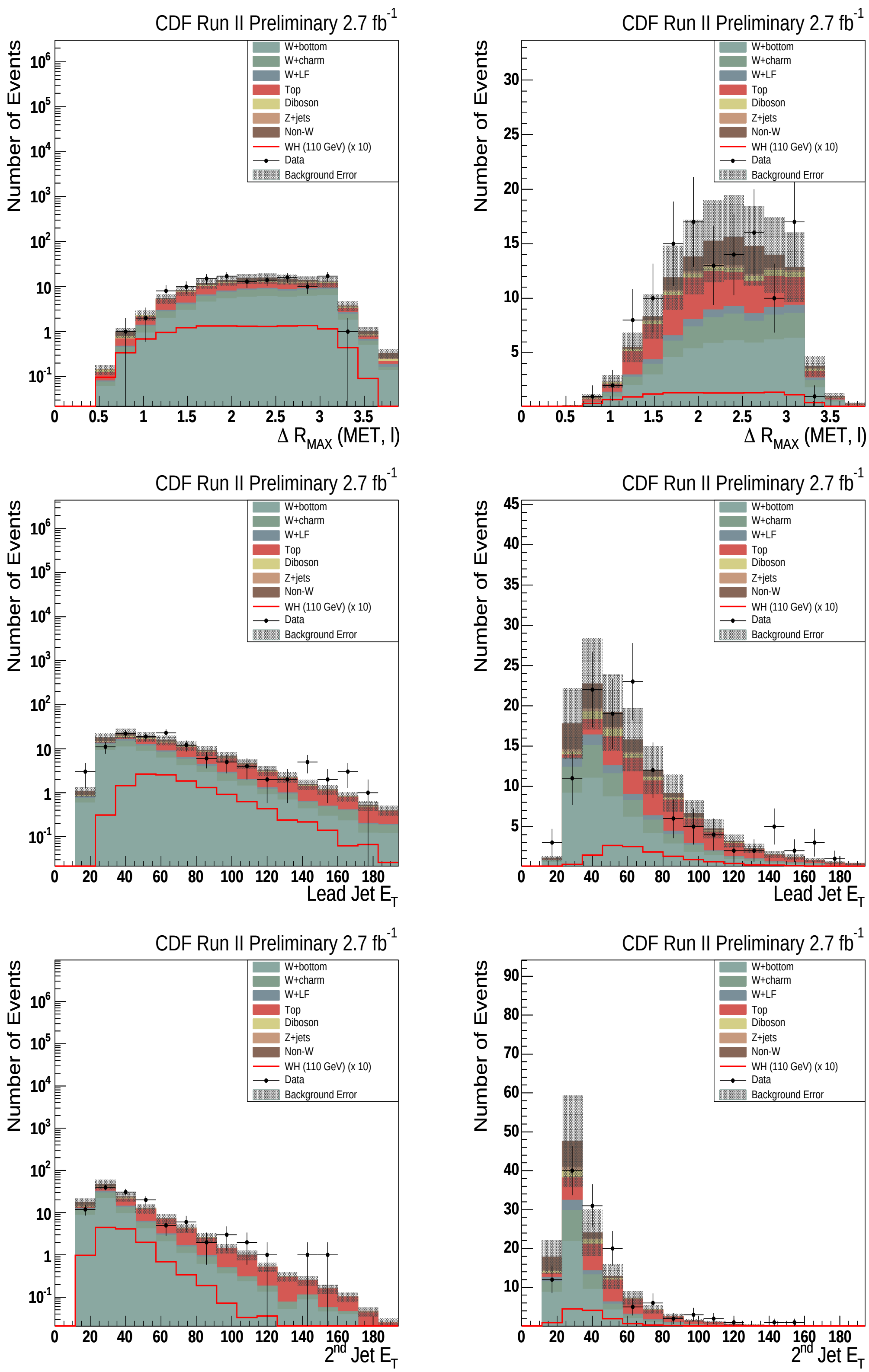

Figure 63: Tight Lepton One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

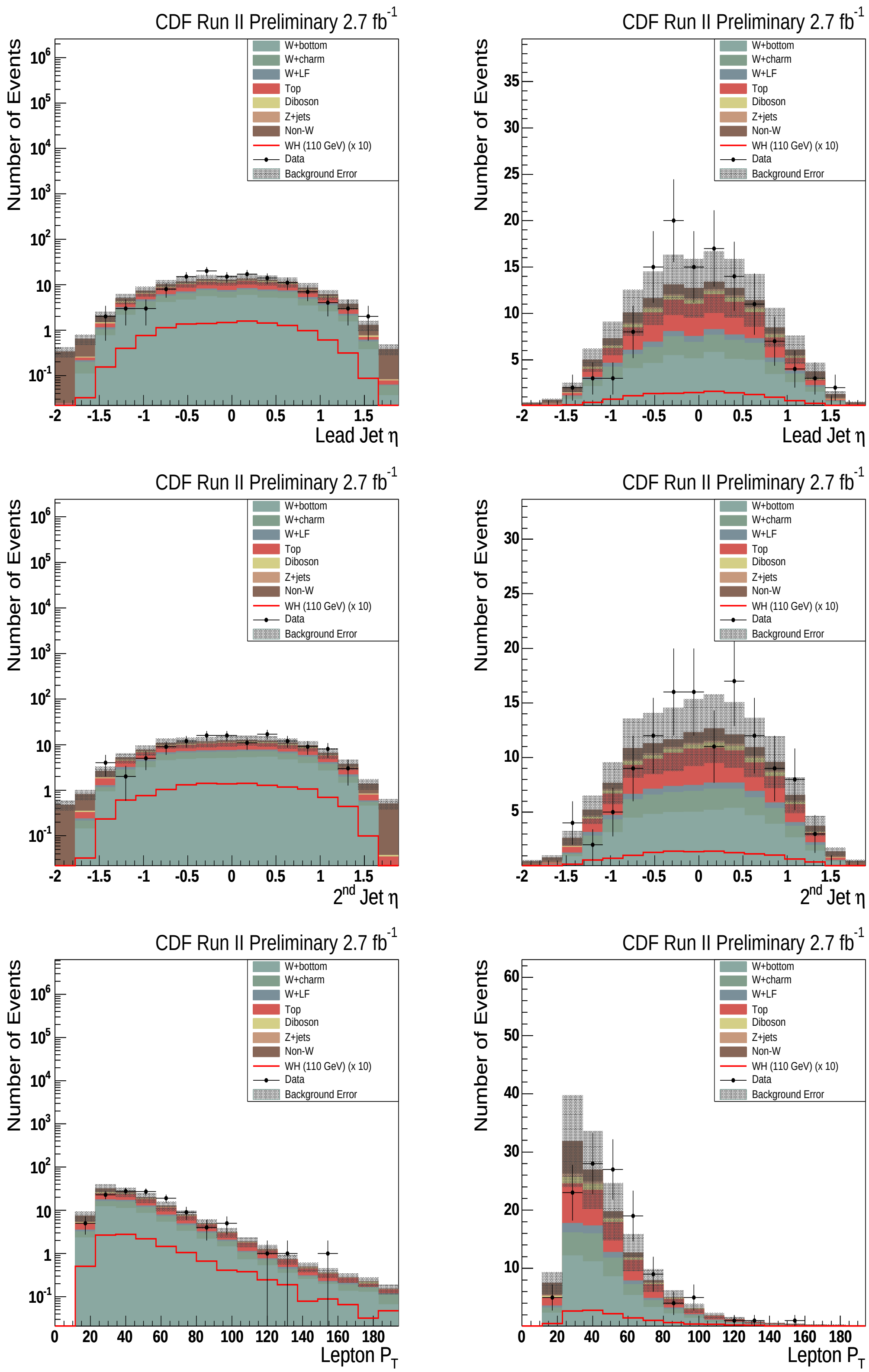

Figure 64: Tight Lepton One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

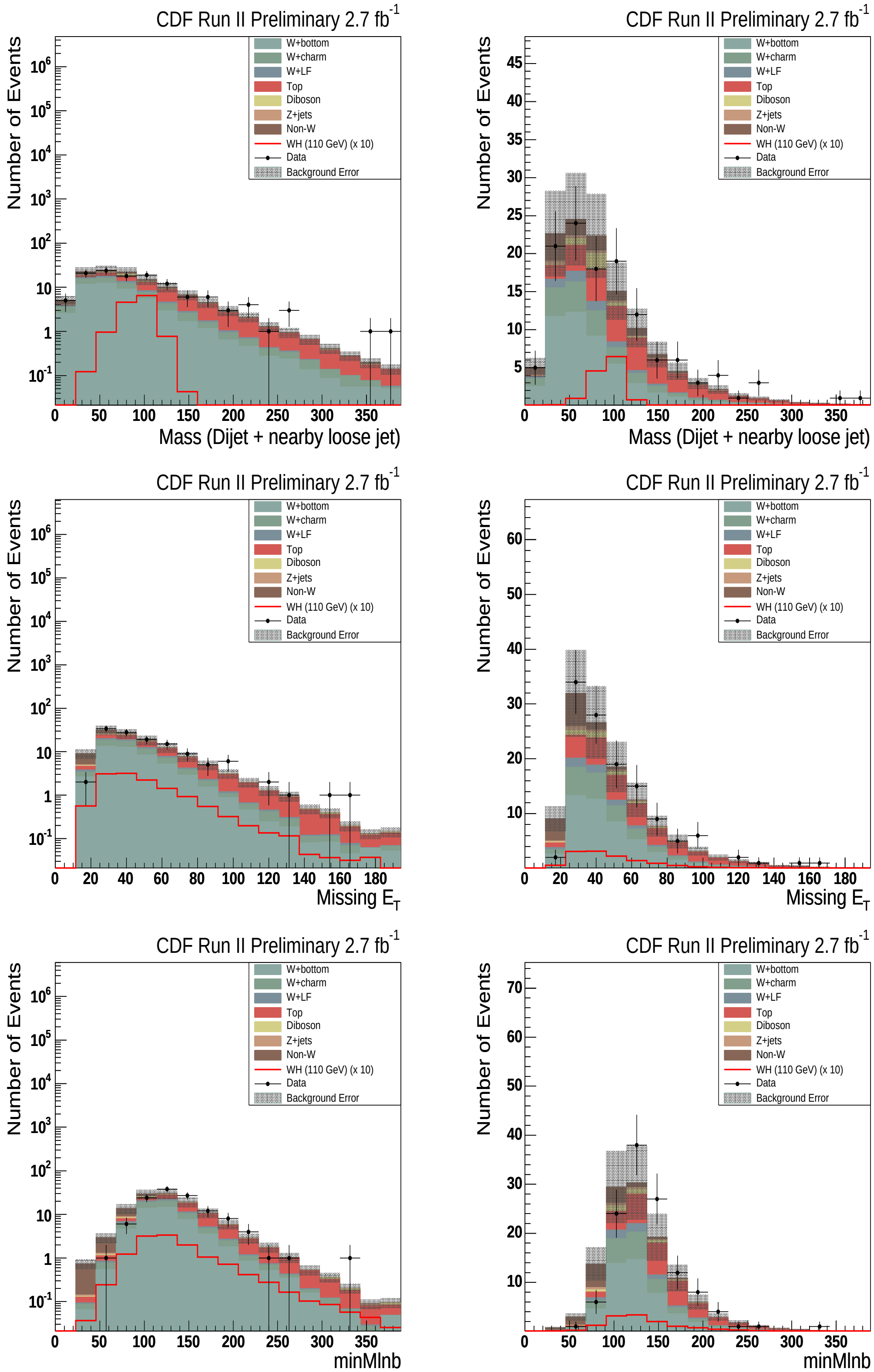

Figure 65: Tight Lepton One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

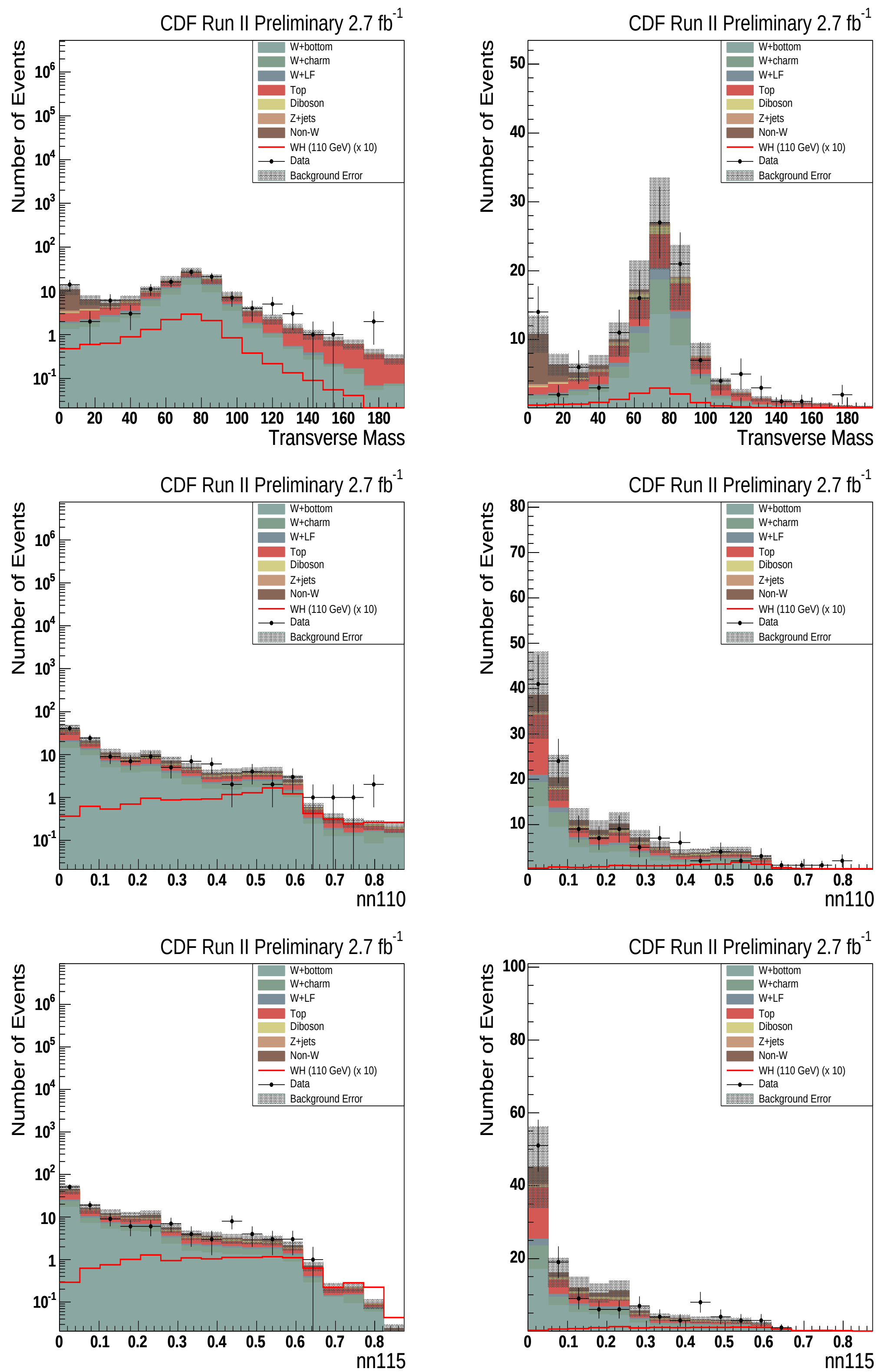

Figure 66: Tight Lepton One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

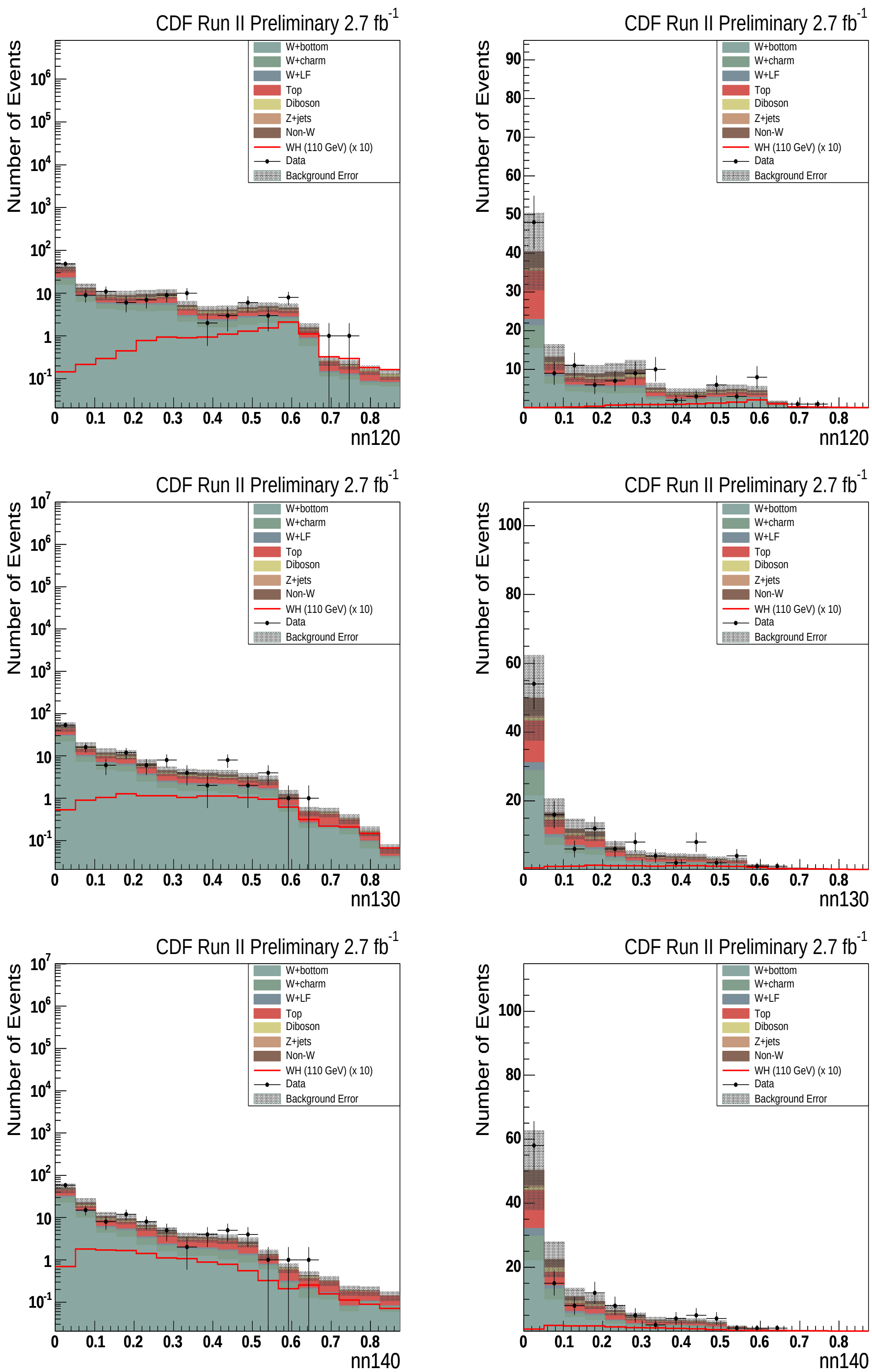

Figure 67: Tight Lepton One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

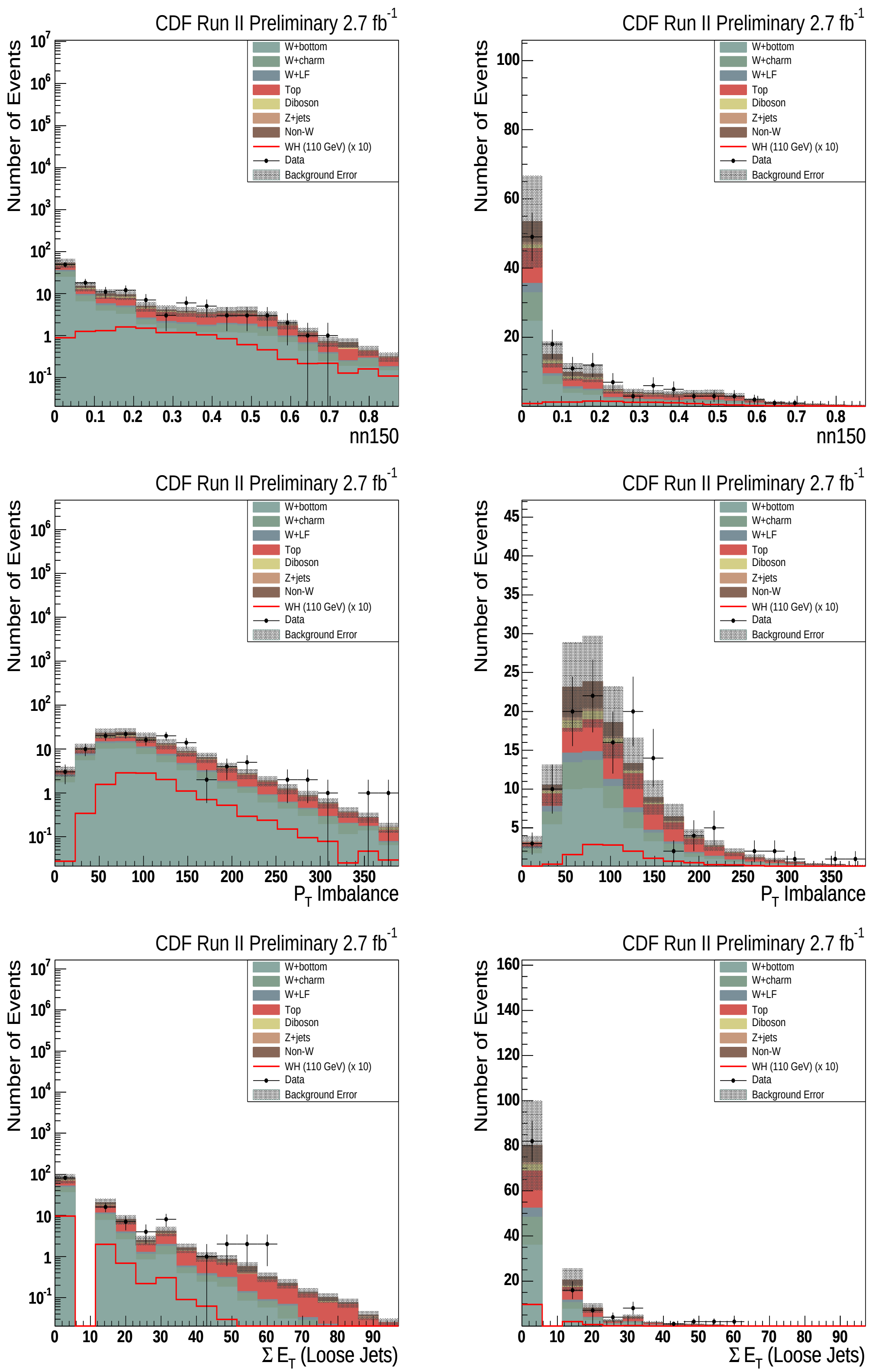

Figure 68: Tight Lepton One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

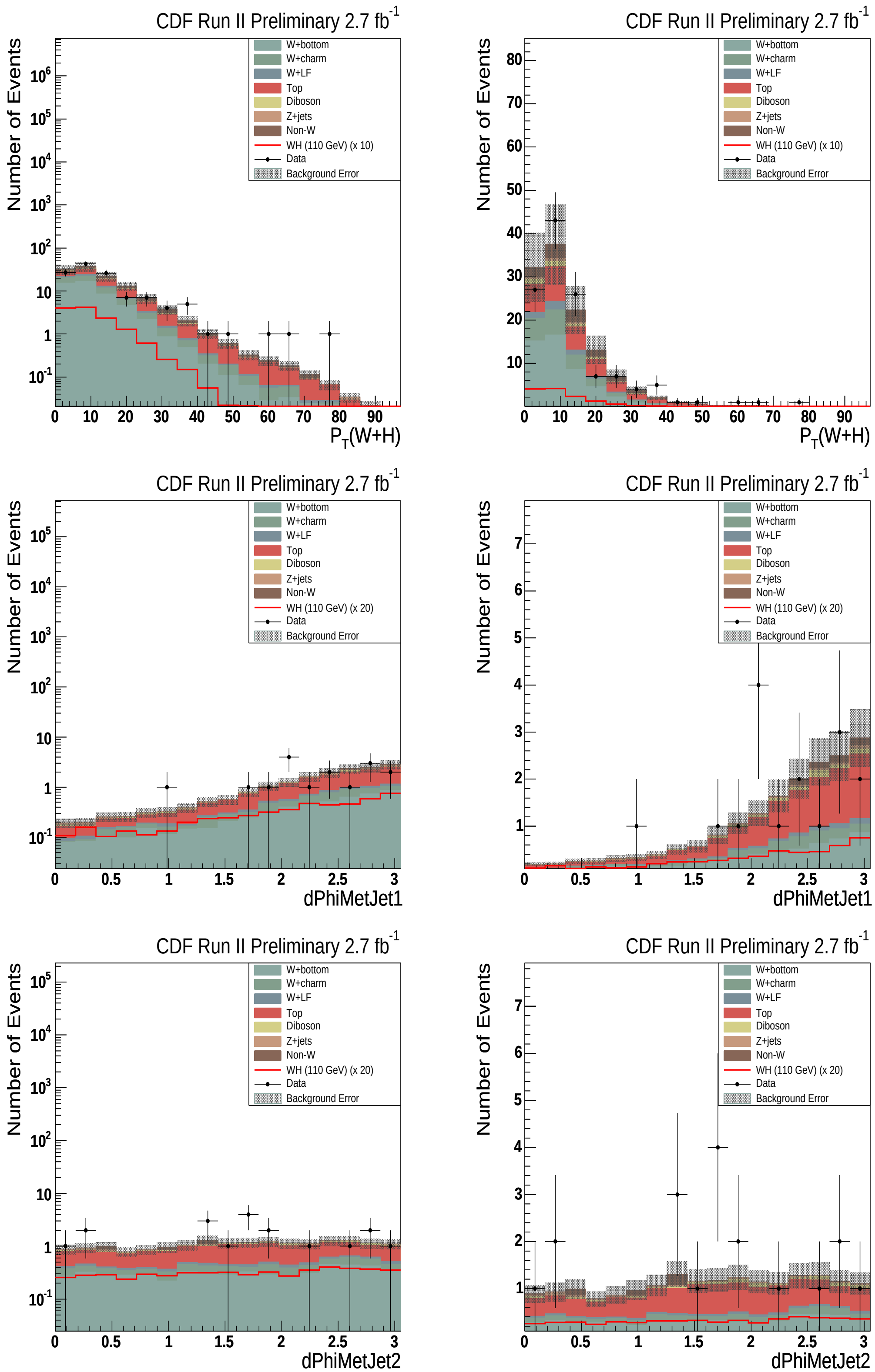

Figure 69: Isolated Track One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

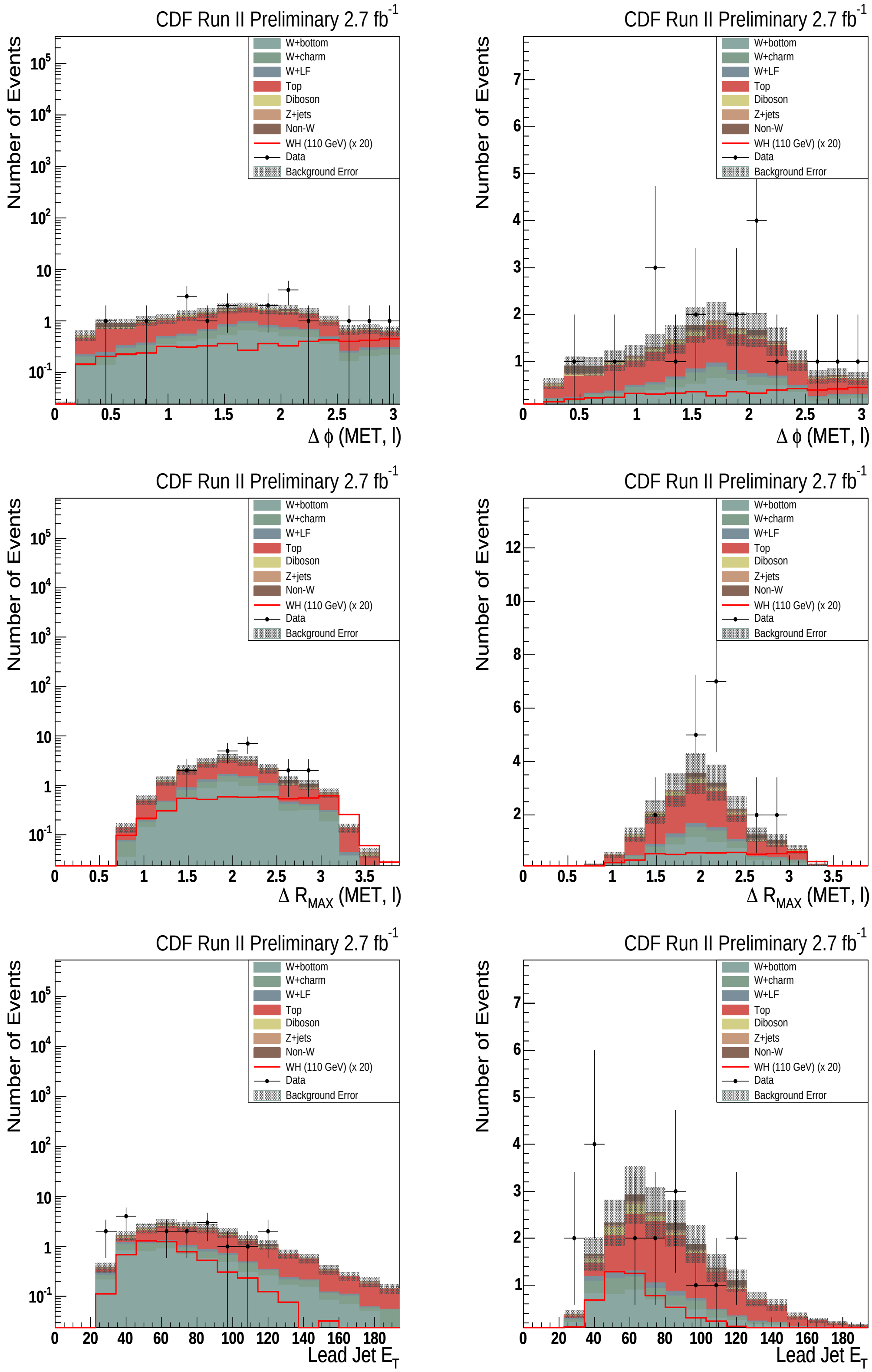

Figure 70: Isolated Track One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

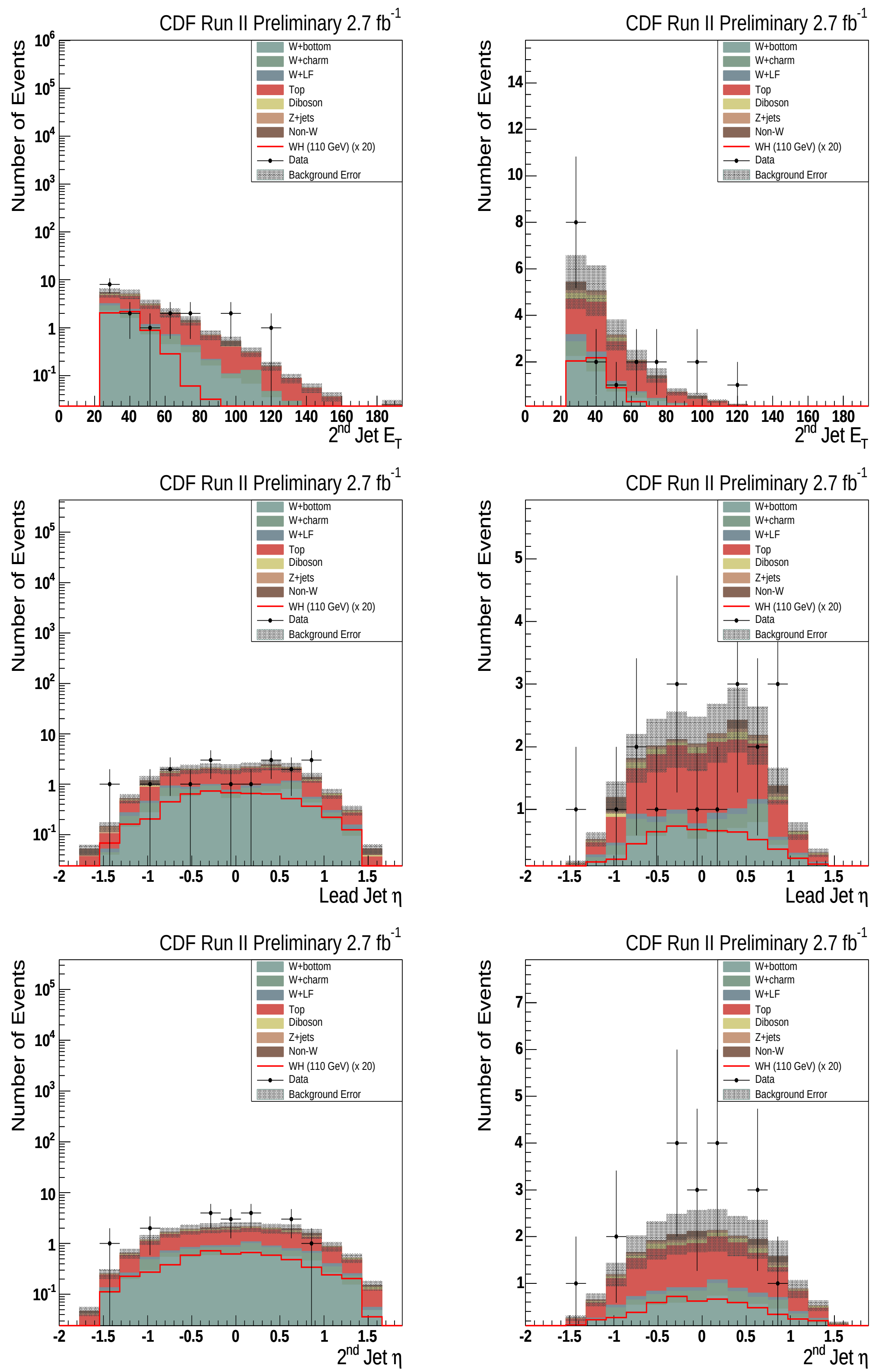

Figure 71: Isolated Track One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

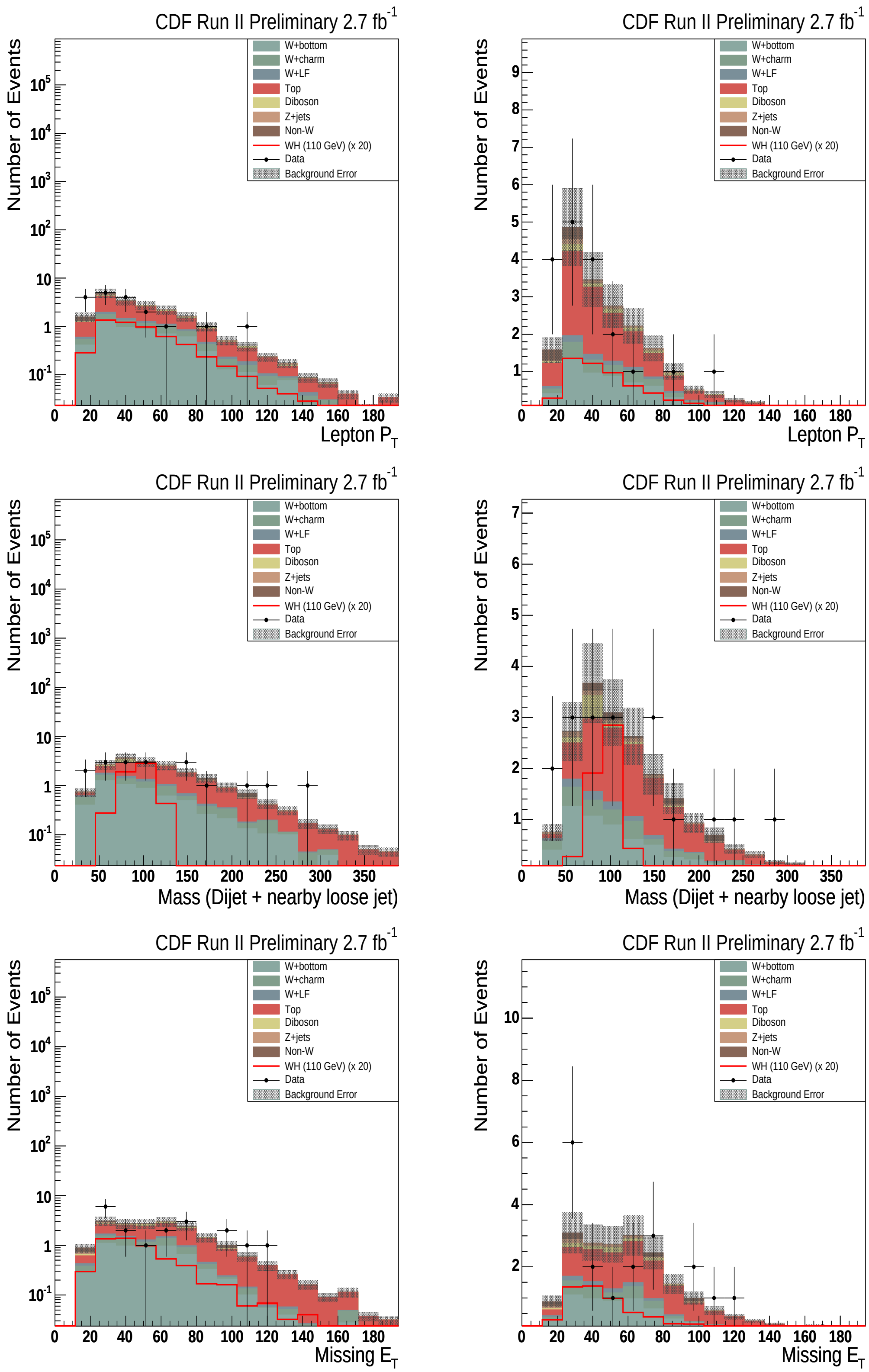

Figure 72: Isolated Track One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

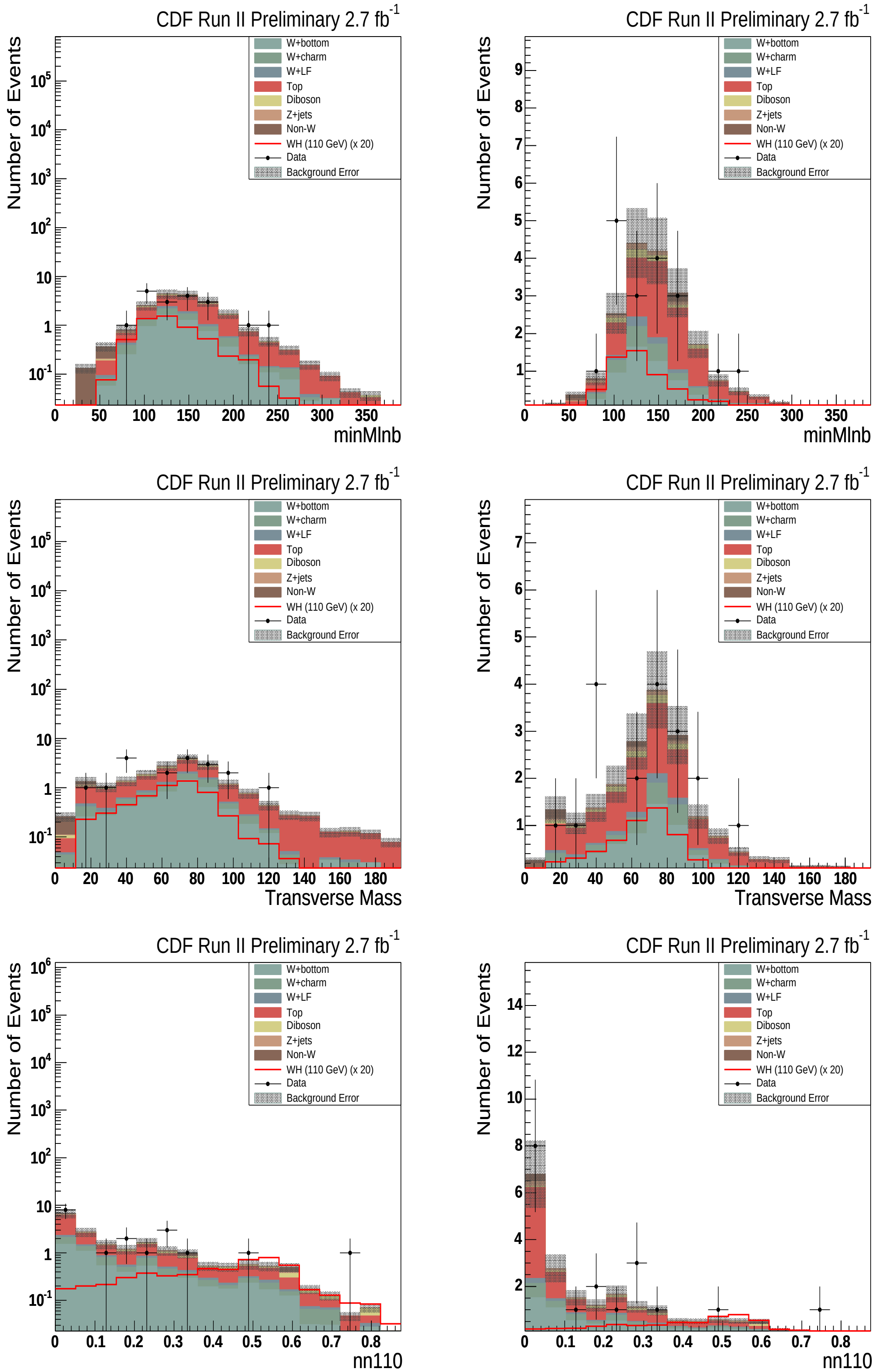

Figure 73: Isolated Track One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

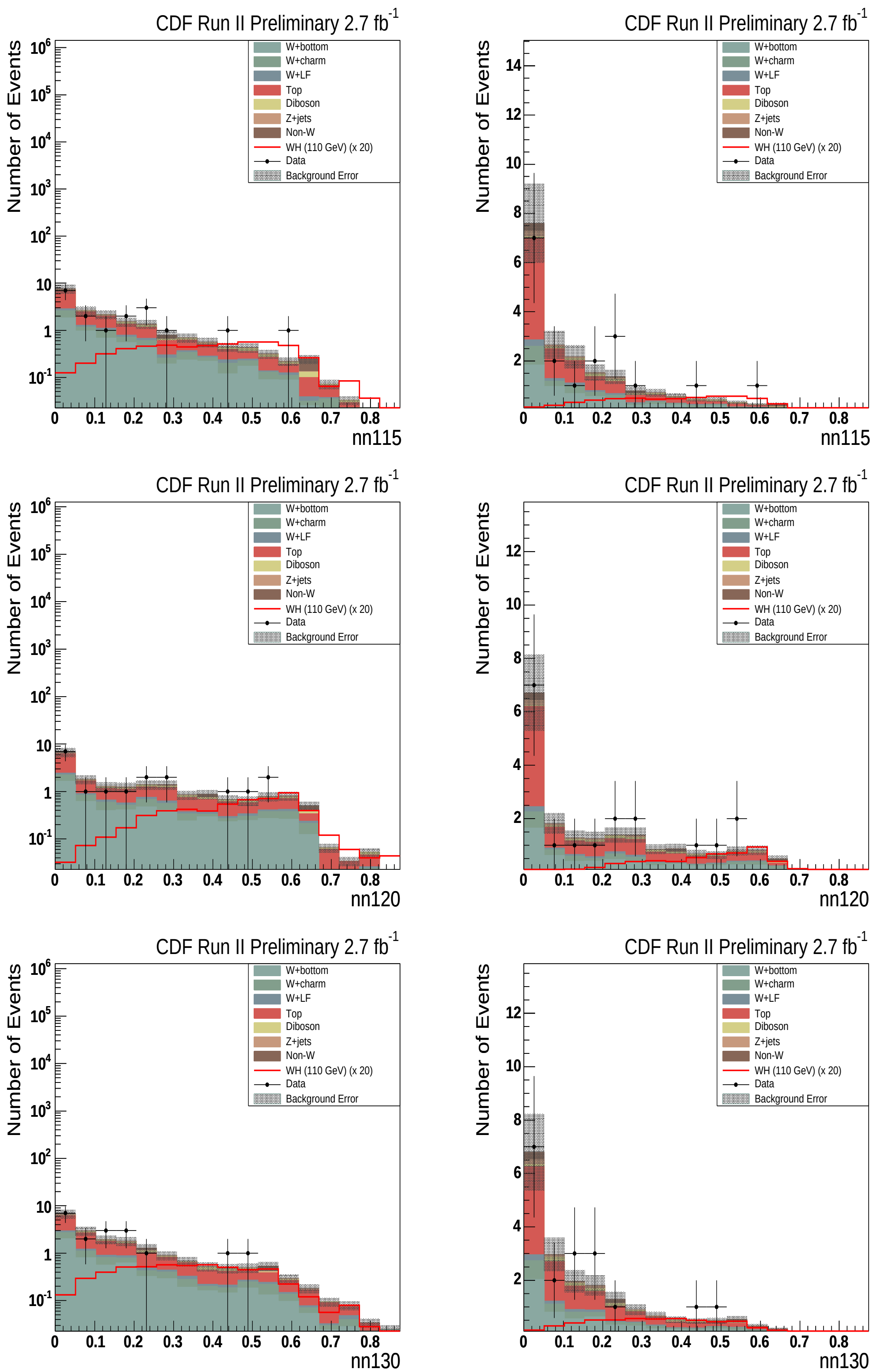

Figure 74: Isolated Track One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

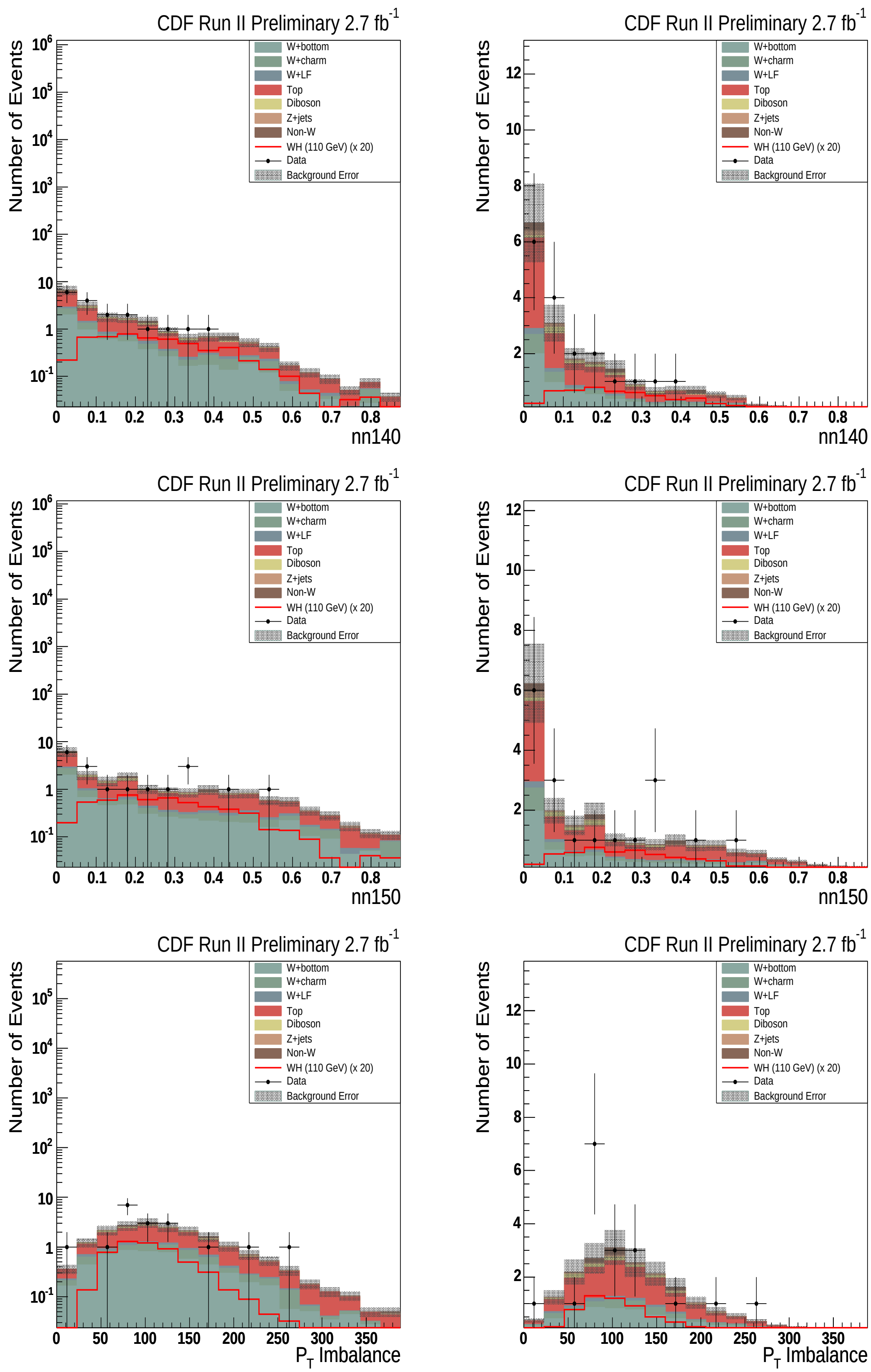

Figure 75: Isolated Track One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics

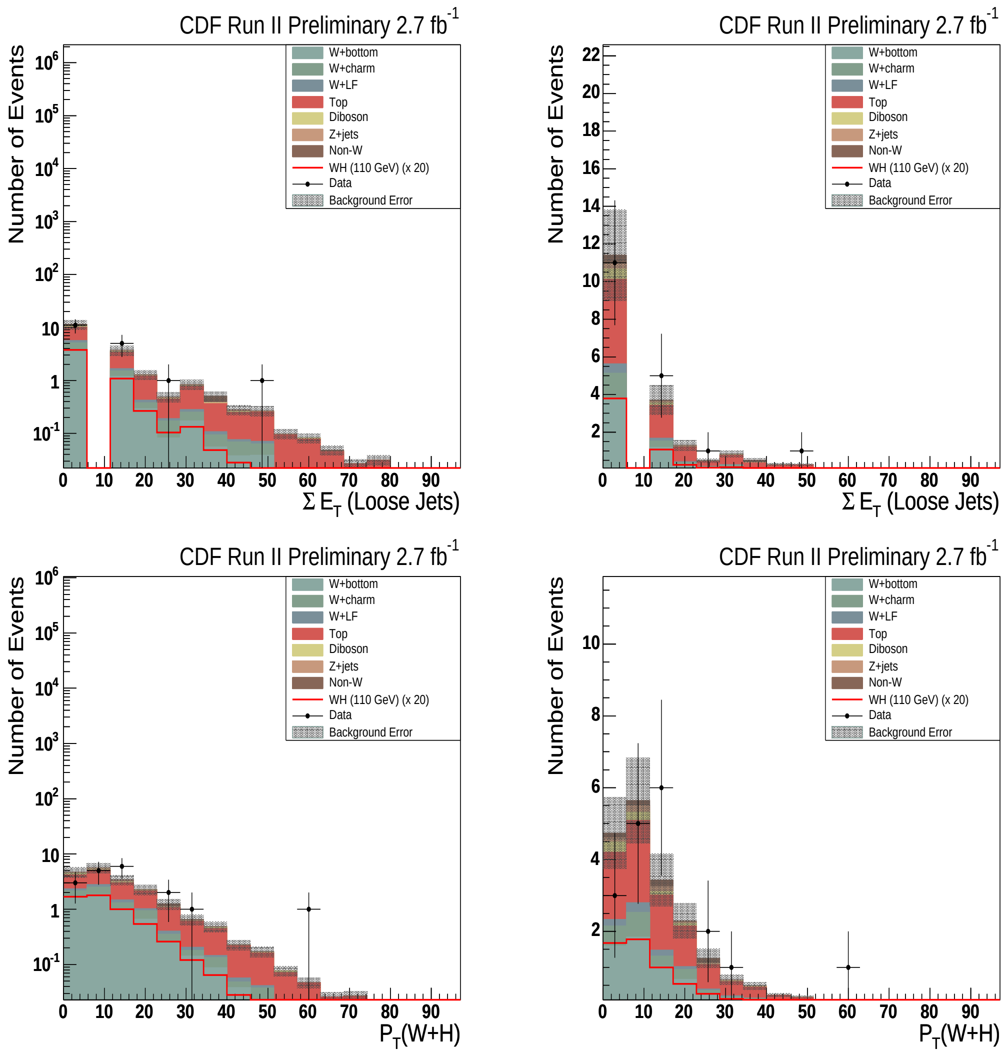

Figure 76: Isolated Track One Secvtx Tag, One Jetprob Tag (ST+JP) Kinematics