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5 Since its discovery at the Fermilab TEVATRON collider in 1995, the top quark has been one of the most
 6 important topics in High Energy Physics. The study of its production rate and properties allows us to
 7 perform precision tests of standard model (SM) predictions as well as represents a chance of observing
 8 possible deviations from such predictions. Amongst all subsequent top decays, the process $t \rightarrow Wb \rightarrow \tau\nu_\tau b$
 9 represents one of the most important tools for probing beyond-SM physics. For instance, the MSSM (Minimal
 10 Supersymmetric Standard Model) [1] predicts the existence of the decay $t \rightarrow H^+ b$ if $m_{H^+} < m_t - m_b$. As
 11 the Higgs-fermion coupling is proportional to the latter's mass, the subsequent decay of a charged Higgs
 12 boson into a τ lepton is much more favored than its decays into e 's and μ 's. Therefore, for high values of \tan
 13 β (the ratio of the vacuum expectation values of the two Higgs doublets) the charged Higgs preferentially
 14 decays to $\tau\nu_\tau$, which increases the branching ratio (BR) of $t \rightarrow \tau\nu_\tau b$ relative to the SM prediction. Thus,
 15 any non-standard flavor- and mass-dependent could produce a significant effect on the τ production channel.
 16 In this respect, the work presented here represents an important test of the SM predictions as well as one
 17 step further on the investigation of non-SM processes.

18 In this analysis we study the process when the W boson from one of the top quarks decays into a τ lepton
 19 and its associated neutrino, while the other W boson decays into a quark-antiquark pair. The τ is the
 20 heaviest lepton and its prompt decay into other particles and the probability of being faked by electrons,
 21 muons and jets makes its reconstruction and identification much more difficult than other top decays.

22 Here we focus on events where the τ decays hadronically, meaning to one or three charged hadrons, zero
 23 or more neutral hadrons and a tau neutrino. This implies that our signal consists of a final state with four or
 24 more jets. Figures 1 and 2 show respectively the Feynman diagram that describes the process $t\bar{t} \rightarrow \tau + jets$
 25 and the pie chart of top decay. In Section II we discuss our signal and main backgrounds.

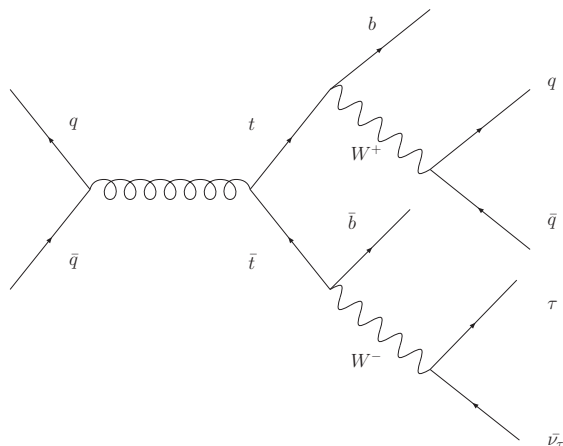


FIG. 1: Feynman diagram for $t\bar{t} \rightarrow \tau + jets$.

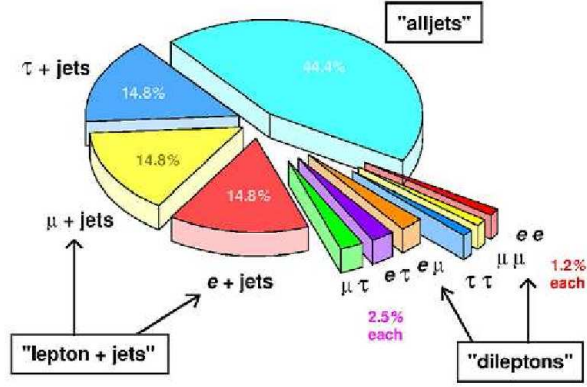


FIG. 2: Top quark decay pie chart.

26 The present work is the third measurement of the $t\bar{t}$ cross section in the $\tau + jets$ channel performed with
 27 the DØ detector. Previous results [2, 3] used using p14 RunI and p17 RunIIa Data and are summarized in
 28 Table I (only statistical uncertainties are shown).

Data set (pb^{-1})	cross section (pb)
p14 (349.0)	$5.05^{+4.31}_{-3.46}$
p17 (974.2)	$6.90^{+1.20}_{-1.20}$

TABLE I: Previous $t\bar{t}$ cross section measurements in the $\tau + jets$ channel

29 The main improvements upon previous p17 analysis are listed below:

- 30 • 5 times more data (RunIIb1, RunIIb2 and RunIIb3).
- 31 • Trigger used: we use a new set of multijet triggers that represents a gain of 10% in the final efficiency.
- 32 • Use of vertex confirmed jets.
- 33 • Tau energy scale added to the analysis.
- 34 • Improved neural net (NN) optimization.
- 35 • New set of p20 b-tag TRF's.

A. Data Sample

For this analysis the framework used was `vjets_cafe v04-00-08` (Release p21.18.00) and the data set consisted of 3JET skim produced by the common samples group [4] and recorded between August 2002 and May 2010 (runs 151817 - 258547).

- `CSG_CAF_3JET_PASS2_p21.10.00`
- `CSG_CAF_3JET_PASS4_p21.10.00_p20.12.00`
- `CSG_CAF_3JET_PASS4_p21.10.00_p20.12.01`
- `CSG_CAF_3JET_PASS4_p21.10.00_p20.12.02`
- `CSG_CAF_3JET_PASS4_p21.10.00_p20.12.04`
- `CSG_CAF_3JET_PASS4_p21.12.00_p20.12.05_allfix`
- `CSG_CAF_3JET_PASS4_p21.10.00_p20.16.07_fix`
- `CSG_CAF_3JET_PASS4_p21.12.00_p20.16.07_summer2010`

In this analysis we chose the three jets trigger `JT2_3JT15L_IP_VX`.

This particular trigger was chosen based on our needs of looking for events with multiple jets and the fact that it represents a gain of 20% efficiency on signal selection if compared to previous p17 analysis. Since the efficiencies for such trigger are not currently part of `caf_trigger` package, in this analysis we benefit from the trigger modelling provided by the `hbb` group [5] for the $\phi b \rightarrow bbb$ analysis. Trigger weight distributions for all MC samples used in the analysis as a function of the number of b-tagged jets are found in Appendix A and Table II summarizes their mean values:

Process	0 tags	1 tag	2 tags	3 or more tags
$t\bar{t} \rightarrow \tau + jets$	0.7923	0.8620	0.8953	0.9039
$t\bar{t} \rightarrow e + jets$	0.7902	0.8599	0.8933	0.9020
$t\bar{t} \rightarrow \mu + jets$	0.7942	0.8639	0.8973	0.9058
$t\bar{t} \rightarrow l + l$	0.7274	0.7915	0.8223	0.8302
$Wjj + jets \rightarrow l\nu + jj + jets$	0.5821	0.6337	0.6586	0.6652
$Wbb + jets \rightarrow l\nu + bb + jets$	0.5948	0.6475	0.6729	0.6796
$Wcc + jets \rightarrow l\nu + cc + jets$	0.5912	0.6435	0.6687	0.6754
$Zjj + jets \rightarrow ee + jj + jets$	0.6769	0.7363	0.7646	0.7719
$Zbb + jets \rightarrow ee + bb + jets$	0.4331	0.4712	0.4895	0.4943
$Zcc + jets \rightarrow ee + cc + jets$	0.6167	0.6746	0.7035	0.7127
$Zjj + jets \rightarrow \mu\mu + jj + jets$	0.6641	0.7233	0.7520	0.7598
$Zbb + jets \rightarrow \mu\mu + bb + jets$	0.6057	0.6598	0.6860	0.6931
$Zcc + jets \rightarrow \mu\mu + cc + jets$	0.5817	0.6335	0.6585	0.6653
$Zjj + jets \rightarrow \tau\tau + jj + jets$	0.5712	0.6220	0.6465	0.6530
$Zbb + jets \rightarrow \tau\tau + bb + jets$	0.6049	0.6586	0.6845	0.6914
$Zcc + jets \rightarrow \tau\tau + cc + jets$	0.5889	0.6410	0.6661	0.6727
$Zjj + jets \rightarrow \nu\nu + jj + jets$	0.5739	0.6241	0.6480	0.6541
$Zbb + jets \rightarrow \nu\nu + bb + jets$	0.6012	0.6539	0.6790	0.6854
$Zcc + jets \rightarrow \nu\nu + cc + jets$	0.6360	0.6914	0.7177	0.7242

TABLE II: Mean values of the trigger weight for all MC samples.

For this trigger we also measured the luminosity of our data sample. Table III shows the results for both v15 and v16 trigger versions.

Trigger version	Trigger name	Delivered \mathcal{L} (pb^{-1})	Recorded \mathcal{L} (pb^{-1})	Reconstructed \mathcal{L} (pb^{-1})
V15.0 - V15.99	JT2_3JT15L_IP_VX	1682.08	1544.71	1385.99
V16.0 - V16.99	JT2_3JT15L_IP_VX	4059.92	3887.95	3565.86
T O T A L		5742.00	5432.66	4951.85

TABLE III: The results of luminosity calculation for the Run2b 3JET data skim for different D0 trigger list versions

B. Backgrounds

In this analysis the largest background sources are QCD (“fake τ ”), which is estimated from data and W/Z +jets, which are simulated Monte Carlo samples. Other backgrounds that were not included in this analysis due to their small contribution are single top and diboson production. A list of backgrounds sources is found in Section III of [3]. In the following sections we describe both signal and background simulation.

C. Monte Carlo Samples

We use p20 certified MC samples as produced by CSG and cuffed with p21.11.00 (version3) [6]. All W/Z and $t\bar{t}$ were generated with ALPGEN v2.11 [7] interfaced with Pythia v6.409 [8] for production of parton-level showers and hadronization. EvtGen [9] is used to model b hadrons decays and TAUOLA [10] used to model tau leptons decays.

ALPGEN is a leading order (LL) generator. In order to correct it to match with next-to-leading order (NLO) cross sections we apply *correction factors* and then provide a correct normalization. These correction factors were taken from `vjets_cafe` framework and are described in Ref.[11]. There are two kinds of correction factors: *k-factors*, which are the result of the ratio between NLO and LL cross sections (σ_{NLO}/σ_{LL}) and *heavy flavor factors*, which are in turn the ratio between k-factors for $HF + 0lp(incl)$ and $2lp(incl)$ process from MCFM [12]. Here HF denotes $Z + bb$, $Z + cc$, $W + bb$ or $W + cc$ and lp stands for *light parton*. Heavy flavor factors are applied on the top of k-factors in order to provide the correct normalization for process where heavy quarks are present. For Z production, samples are split into $Z + light\ jets$, $Z + bb$ and $Z + cc$. $Z + light\ parton$ cross sections are multiplied by a k-factor of 1.3, while $Z + bb$ and $Z + cc$ are multiplied by additional heavy flavor factors of 1.52 and 1.67 respectively. $W + jets$ samples are also split the same way: $W + light\ jets$, $W + bb$ and $W + cc$. In $W + light\ jets$ case a k-factor of 1.3 is applied while an additional heavy flavor factor of 1.47 is applied to both $W + bb$ and $W + cc$ samples.

Table IV summarizes the correction factors applied.

Process	k-factor
W + light partons	1.3
W + bb	1.3×1.47
W + cc	1.3×1.47
Z + light partons	1.3
Z + bb	1.3×1.52
Z + cc	1.3×1.67

TABLE IV: k-factors for MC.

All MC samples used in this analysis are shown in Table V with their respective cross sections and number of events. The cross sections shown are the averages of the cross-sections of each set of MC process generated and are calculated from `/caf_mc_util/mc_sample_info/MC.list`

Sample	$\sigma(pb)$	# of Events
$t + t + 0lp - l\nu + 2b + 2lpc_excl_m172$	1.392196	793267
$t + t + 1lp - l\nu + 2b + 3lpc_excl_m172$.576927	456317
$t + t + 2lp - l\nu + 2b + 4lpc_incl_m172$.281831	277912
$W + 0lp \rightarrow l\nu + 0lp_excl$	4530.269741	47070044
$W + 1lp \rightarrow l\nu + 1lp_excl$	1283.094130	20683540
$W + 2lp \rightarrow l\nu + 2lp_excl$	306.073315	19686862
$W + 3lp \rightarrow l\nu + 3lp_excl$	73.494491	4269023
$W + 4lp \rightarrow l\nu + 4lp_excl$	16.958254	3084707
$W + 5lp \rightarrow l\nu + 5lp_incl$	5.218917	2565942
$W + 2b + 0lp \rightarrow l\nu + 2b + 0lp_excl$	9.315458	1120570
$W + 2b + 1lp \rightarrow l\nu + 2b + 1lp_excl$	4.288365	812095
$W + 2b + 2lp \rightarrow l\nu + 2b + 2lp_excl$	1.554786	563315
$W + 2b + 3lp \rightarrow l\nu + 2b + 3lp_incl$	0.716175	464475
$W + 2b + 0lp \rightarrow l\nu + 2c + 0lp_excl$	24.404153	934253
$W + 2b + 1lp \rightarrow l\nu + 2c + 1lp_excl$	13.486806	738709
$W + 2b + 2lp \rightarrow l\nu + 2c + 2lp_excl$	5.459005	554236
$W + 2b + 3lp \rightarrow l\nu + 2c + 3lp_incl$	2.526973	469900
$\gamma Z + 0lp \rightarrow ee + 0lp_excl_75_130$	132.086811	1212214
$\gamma Z + 1lp \rightarrow ee + 1lp_excl_75_130$	40.060963	599588
$\gamma Z + 2lp \rightarrow ee + 2lp_excl_75_130$	9.981935	298494
$\gamma Z + 3lp \rightarrow ee + 3lp_incl_75_130$	3.297072	150267
$\gamma Z + 2b + 0lp \rightarrow ee + 2b + 0lp_excl_75_130$	0.400826	200121
$\gamma Z + 2b + 1lp \rightarrow ee + 2b + 1lp_excl_75_130$	0.173438	97474
$\gamma Z + 2b + 2lp \rightarrow ee + 2b + 2lp_incl_75_130$	0.107248	48269
$\gamma Z + 2c + 0lp \rightarrow ee + 2c + 0lp_excl_75_130$	0.900923	182485
$\gamma Z + 2c + 1lp \rightarrow ee + 2c + 1lp_excl_75_130$	0.506337	89293
$\gamma Z + 2b + 2lp \rightarrow ee + 2b + 2lp_incl_75_130$	0.285871	47357
$\gamma Z + 0lp \rightarrow \mu\mu + 0lp_excl_75_130$	133.850906	1553222
$\gamma Z + 1lp \rightarrow \mu\mu + 1lp_excl_75_130$	41.677185	639392
$\gamma Z + 2lp \rightarrow \mu\mu + 2lp_excl_75_130$	9.822132	446737
$\gamma Z + 3lp \rightarrow \mu\mu + 3lp_incl_75_130$	3.195801	172628
$\gamma Z + 2b + 0lp \rightarrow \mu\mu + 2b + 0lp_excl_75_130$	0.424239	210139
$\gamma Z + 2b + 1lp \rightarrow \mu\mu + 2b + 1lp_excl_75_130$	0.195271	101055
$\gamma Z + 2b + 2lp \rightarrow \mu\mu + 2b + 2lp_incl_75_130$	0.099004	49600
$\gamma Z + 2c + 0lp \rightarrow \mu\mu + 2c + 0lp_excl_75_130$	0.932203	193928
$\gamma Z + 2c + 1lp \rightarrow \mu\mu + 2c + 1lp_excl_75_130$	0.548182	92744
$\gamma Z + 2b + 2lp \rightarrow \mu\mu + 2b + 2lp_incl_75_130$	0.280795	51277
$\gamma Z + 0lp \rightarrow \tau\tau + 0lp_excl_75_130$	131.564780	1556389
$\gamma Z + 1lp \rightarrow \tau\tau + 1lp_excl_75_130$	40.300291	595169
$\gamma Z + 2lp \rightarrow \tau\tau + 2lp_excl_75_130$	10.072067	305312
$\gamma Z + 3lp \rightarrow \tau\tau + 3lp_excl_75_130$	3.089442	205365
$\gamma Z + 2b + 0lp \rightarrow \tau\tau + 2b + 0lp_excl_75_130$	0.423679	196943
$\gamma Z + 2b + 1lp \rightarrow \tau\tau + 2b + 1lp_excl_75_130$	0.196527	103105
$\gamma Z + 2b + 2lp \rightarrow \tau\tau + 2b + 2lp_incl_75_130$	0.103561	48476
$\gamma Z + 2c + 0lp \rightarrow \tau\tau + 2c + 0lp_excl_75_130$	0.898135	260243
$\gamma Z + 2c + 1lp \rightarrow \tau\tau + 2c + 1lp_excl_75_130$	0.487548	100802
$\gamma Z + 2b + 2lp \rightarrow \tau\tau + 2b + 2lp_incl_75_130$	0.297808	50711
$\gamma Z + 0lp \rightarrow \nu\nu + 0lp_excl$	806.552968	2368495
$\gamma Z + 1lp \rightarrow \nu\nu + 1lp_excl$	244.651772	2591505
$\gamma Z + 2lp \rightarrow \nu\nu + 2lp_excl$	61.014112	657110
$\gamma Z + 3lp \rightarrow \nu\nu + 3lp_excl$	14.091090	194705
$\gamma Z + 4lp \rightarrow \nu\nu + 4lp_excl$	3.277295	100158
$\gamma Z + 5lp \rightarrow \nu\nu + 5lp_incl$	0.936465	49660
$\gamma Z + 2b + 0lp \rightarrow \nu\nu + 2b + 0lp_excl$	2.562976	375572
$\gamma Z + 2b + 1lp \rightarrow \nu\nu + 2b + 1lp_excl$	1.143703	180558
$\gamma Z + 2b + 2lp \rightarrow \nu\nu + 2b + 2lp_incl$	0.617265	91588
$\gamma Z + 2c + 0lp \rightarrow \nu\nu + 2c + 0lp_excl$	5.634504	376456
$\gamma Z + 2c + 1lp \rightarrow \nu\nu + 2c + 1lp_excl$	3.002712	199012
$\gamma Z + 2b + 2lp \rightarrow \nu\nu + 2b + 2lp_incl$	1.635746	96147

TABLE V: MC Samples. Here l stands for the three lepton flavor (e , μ and τ). τ decays are not restricted.

Standard $D\bar{O}$ corrections are applied to MC in order to obtain a better MC-data agreement [13].

Trigger efficiency: an additional scale factor (weight) is applied to MC to account for the trigger efficiency in data. Further details are given in Section III.

Luminosity reweighting: in order to reproduce luminosity effects from real data, simulated samples are overlaid to Zero Bias data. Due to a difference in instantaneous luminosity between the overlay and real data, the luminosity profile of all MC samples is reweighted to match the luminosity profile in data [14].

Primary vertex reweighting: z vertex distributions are different between data and MC. This difference is corrected by reweighting MC z vertex distributions using the reweight processor from the `caf_mc_util` package [15].

W and Z p_T reweighting: for both $W + \text{jets}$ and $Z + \text{jets}$, the p_T distribution from MC samples is reweighted to match the equivalent distribution in data, accordingly to the standard way [16].

b fragmentation: the systematics on the reweight of the b-fragmentation function from the default in Pythia to the value tuned to reproduce collider data was assumed to be the symmetrized difference between the AOD and SLD tunes [17].

Jet Shifting Smearing and Removing (JSSR): due to differences in energy scale, resolution, reconstruction and identification between data and MC, MC jets are shifted, smeared and possibly removed using standard JSSR processor [18]. In this analysis shifting is turned off to signal $t\bar{t}$ and on to $W/Z + \text{jets}$ samples.

Tau Energy Scale (TES): due to the analysis sensitivity to any difference between data and MC in the energy scale of taus decaying hadronically we apply a E/p correction to this energy scale as described in [19].

III. TRIGGER PARAMETRIZATION

As aforementioned the trigger used in this analysis is JT2_3JT15L_IP_VX. In both v15 and v16 trigger versions, this trigger has 4 terms at level 2. Currently, only three of these, the L2 H_T , missing E_T (\cancel{E}_T) and sphericity based branches have been modelled by the *hbb* group [5]. Therefore these are the ones used in this analysis. The missing term is the acoplanarity term, namely, L2JET(1,20,2.4) L2HT(35,6) MJT(20,10) L2ACOP(168.75), which is the same in both v15 and v15 trigger lists.

Table VI shows the L1, L2 and L3 requirements of the trigger.

In its work, the *hbb* group has parametrized the trigger in three instantaneous luminosity (10^{32}) regions: low ($L_{int} < 77$), medium ($77 \leq L_{int} < 124$) and high ($L_{int} \geq 124$). The final goal is to measure the total trigger efficiency for our events. In order to do so we take into account both the trigger probabilities and the b-tag probabilities. Thus, the trigger probabilities for 0, 1, 2 and 3 or more b-tagged jets are then multiplied by the probabilities of 0, 1, 2 and 3 or more jets being tagged, which are themselves got from TRF's, as described in section IV D.

The trigger efficiency is computed as a probability (*TrigWeight*) which we associate to each MC event with:

$$P = P_{t0} * P_{b0} + P_{t1} * P_{b1} + P_{t2} * P_{b2} + P_{t \geq 3} * P_{b \geq 3} \quad (1)$$

where P_{ti} is the trigger probability for the event if it has i b-tags and P_{bi} is in turn the probability of having i b-tags in the event offline reconstruction.

What follows is a brief description of how the trigger probabilities at each level were calculated. Single-object turn-on curves were determined using muon triggered events from the TOPJETTRIG skim. Some turn-on curves are found in Appendix B. A more complete description can be found in [5].

Level	v15
L1	CSWJT(3,8,3.2)CSWJT(2,15,2.4)CSWJT(1,30,2.4)
L2	L2JET(3,6) L2HT(75,6) SPHER(0.1) OR L2JET(1,30,2.6) L2JET(2,15,2.6) L2JET(3,8) L2HT(75,6) MJT(10,10) OR L2JET(1,30,2.6) L2JET(2,15,2.6) L2JET(3,8) L2HT(100,6)
L3	L3JET(3,15,3.6) L3JET(2,25,3.6) $ z_{PV} < 35$ cm BTAG(0.4)
Name	JT2_3JT15L_IP_VX
Level	v16
L1	CSWJT(3,8,3.2)CSWJT(2,15,2.4)CSWJT(1,30,2.4)
L2	L2JET(3,6) L2HT(75,6) SPHER(0.1) STTIP(1,5.5,3) OR L2JET(1,30,2.6) L2JET(2,15,2.6) L2JET(3,8) L2HT(75,6) MJT(20,10) OR L2JET(1,30,2.4) L2JET(2,15,2.4) L2JET(3,8,2.4) L2HT(75,6) STTIP(1,5.5,3)
L3	L3JET(3,15,3.6) JT(2,25,3.6) $ z_{PV} < 35$ cm BTAG(0.4)
Name	JT2_3JT15L_IP_VX

TABLE VI: Level-by-level description of trigger JT2_3JT15L_IP_VX. The CSWJT(x,y,z) term corresponds to x L1 jets above y GeV and within $|\eta| < z$. The JT(x,y,z) term corresponds to x jets reconstructed at L2 or L3 with $p_T > y$ GeV and $|\eta| < z$. The HT(x,y) term is used only at L2 and requires that the sum of the transverse momenta of L2 jets with $p_T > y$ GeV is above x GeV. The SPHER(0.1) term requires the event sphericity calculated from L2 jets to be greater than 0.1. The MJT(x,y) term corresponds to a missing transverse energy $> x$ GeV calculated from jets with $E_T > y$ GeV. The STTIP(1,5.5,3) term requires one L2STT track with an impact parameter significance greater than or equal to three and a $\chi^2 < 5.5$. The $|z_{PV}| < 35$ cm term requires the primary vertex reconstructed at L3 to be within 35 cm of the center of the detector and the BTAG(0.4) term is used only at L3 and corresponds to a cut of 0.4 on the probability for the event to not contain a b -quark.

127

A. Level 1

128 Level 1 consists of jet terms only: 1 jet with $E_T > 30$ GeV and $|\eta| < 2.4$, a second jet with $E_T > 15$ GeV
129 and $|\eta| < 2.4$ and a third jet with $E_T > 8$ GeV and $|\eta| < 3.2$. The total L1 probability is given by

$$\begin{aligned}
P(L1) = & [P(\geq 3\text{jets}) + P(= 2\text{jets}) * P(\geq 1\text{noise jet}) + P(= 1\text{jet}) * P(\geq 2\text{noise jets}) + P(= 0\text{jets}) * P(\geq 3\text{noise jets})] \\
& * [P(\geq 2\text{jets}) + P(= 1\text{jet}) * P(\geq 1\text{noise jet}) + P(= 0\text{jets}) * P(\geq 2\text{noise jets})] \\
& * [P(\geq 1\text{jet}) + P(= 0\text{jets}) * P(\geq 1\text{noise jet})]
\end{aligned} \tag{2}$$

130 where $P(\geq x\text{jets})$ is the probability of having x or more jets present in the event and $P(= x\text{jets})$ is
131 the probability of having exactly x jets in the event. The term *noise jets* refers to all those L1 jets
132 that didn't match to an offline jet within $\Delta R < 0.5$. In the equation above the first line corresponds
133 to the term CSWJT(3,8, $|\eta| < 3.2$), the second to the term CSWJT(2,15, $|\eta| < 2.4$) and the third to the term
134 CSWJT(1,30, $|\eta| < 2.4$). L1 jets that matched offline ones had their turn-on curves parametrized as functions
135 of offline jet p_T 's. The number of noise jets per event was parametrized as a function of offline H_T . All L1
136 turn-on curves are found in Appendix B 1.

137

B. Level 2

138 Level 2 part of this trigger consists of an OR of three terms (here classified as *top*, *hbb* and *mjt*), each with
139 a variation for v15 and v16:

140 **v15 top:** 3 jets with $p_T > 8$ GeV, 2 with $p_T > 15$ GeV, 1 with $p_T > 30$ GeV and $H_T > 100$ GeV

141 **v16 top:** 3 jets with $p_T > 8$ GeV, 2 with $p_T > 15$ GeV, 1 with $p_T > 30$ GeV, $H_T > 75$ GeV and STT IP with
142 IPSIG ≥ 3 and $\chi^2 < 5.5$.

143 **v15 hbb:** 3 jets with $p_T > 6$ GeV, $H_T > 75$ GeV and sphericity > 0.1

144 **v16 hbb:** 3 jets with $p_T > 6$ GeV, $H_T > 75$ GeV, sphericity > 0.1 and STT IP with IPSIG ≥ 3 and $\chi^2 < 5.5$.

145 **v15 mjt:** 3 jets with $p_T > 8$ GeV, 2 jets with $p_T > 15$ GeV, 1 jet with $p_T > 30$ GeV, $H_T > 75$ GeV and \cancel{E}_T
 146 > 10 GeV.

147 **v16 mjt:** 3 jets with $p_T > 8$ GeV, 2 jets with $p_T > 15$ GeV, 1 jet with $p_T > 30$ GeV, $H_T > 75$ GeV and \cancel{E}_T
 148 > 20 GeV.

149 For this level the net trigger probability is

$$\begin{aligned}
 P(L2) &= P(hbb \cup mht \cup top) \\
 &= P(top) + P(hbb) + P(mht) - P(top \cap hbb) - P(top \cap mht) - P(hbb \cap mht) + P(hbb \cap mht \cap top)
 \end{aligned}
 \tag{3}$$

150 where $P(x)$ corresponds to the probability of either L2, the mht, hbb or the top firing.

151 **Level 2 jet terms:** from Table VI we see that for v15 trigger version, L2 jets terms are actually subsets of
 152 L1. As here conditional probability is used, it means that the probability of L2 jet terms firing if L1 terms
 153 fired is unity. However in v16 the Pt requirement of jets in the first trigger term was loosened from 8 to 6
 154 GeV and η requirement on 8 GeV jets in the third trigger term was tightened from $|\eta| < 3.2$ to $|\eta| < 2.4$.
 155 As in the L1 case, all L2 jets matching offline ones had their turn-on curves parametrized as functions of
 156 offline jet p_T 's, except for noise jets, whose number in each event which paratrized as funcions of offline H_t .
 157 Turn-on curves for these cases are found in Appendix B 2.

158 **Level 2 H_T term:** this term consists of a cut of $H_T > 75$ GeV for v15 and $H_T > 100$ GeV for v16).
 159 Correspondent turn-on curves are shown in Appendix B 3.

160 **Level 2 \cancel{E}_T term:** the correspondent \cancel{E}_T cuts are > 10 GeV and > 20 GeV for v15 and v16 respectively.
 161 Their turn-on are shown in Appendix B 4.

162 **L2 Sphericity Term:** this term requires a sphericity cut of > 0.1 . Corresponding turn-on curves are shown
 163 in Appendix B 5.

164 **L2 STT:** the L2STTIP efficiency was measured for events in v16 which have passed the rest of the L1,
 165 L2 (L2top OR L2hbb) and L3 (except L3 b-tag) trigger requirements and the offline three to five jet selec-
 166 tion. The efficiency was measured versus the invariant mass of the two leading jets, separately for 0, 1, 2
 167 and 3 offline tight NN b-tagged events, in the three different luminosity regions. Appendix B 6 shows the
 168 STTIP(1,5.5,3) efficiency versus the leading invariant di-jet mass in the low, medium and high luminosity
 169 range for different number of offline b-tags.

170

C. Level 3

171 L3 consists of a jet part and a b-tag one. For the jet part of L3, turn-on curves were determined for events
 172 passing both L1 and L2 requirements. Corresponding probability is given the equation below

$$\begin{aligned}
 P(L3) &= [P(\geq 3\text{jets}) + P(= 2\text{jets}) * P(\geq 1\text{noise jet}) + P(= 1\text{jet}) * P(\geq 2\text{noise jets}) + P(= 0\text{jets}) * P(\geq 3\text{noise jets})] \\
 &\quad * [P(\geq 2\text{jets}) + P(= 1\text{jet}) * P(\geq 1\text{noise jet}) + P(= 0\text{jets}) * P(\geq 2\text{noise jets})]
 \end{aligned}
 \tag{4}$$

173 In the equation above the first line corresponds to the term JT(3,15, $|\eta| < 3.6$), the second to the term
 174 JT(2,25, $|\eta| < 3.6$). Here was applied the same treatment to L3 jets matching offline ones and to noise jets
 175 as in L1 and L2 jet terms. Corresponding turn-on curves are shown in Appendix B 1.

176 Efficiencies for the b-tag part of L3 were measured in two different ways depending whether the trigger list
 177 was v15 or v16. In the v15 case events were recorded with the JT2_4JT20 and JT2_3JT12L_MM3_V triggers,
 178 since their L1 and L2 conditions were exactly the same. Events were further required to pass the rest of L3
 179 conditions of JT2_3JT15L_IP_VX and the offline event selection. In the v16 case efficiencies were measured
 180 in a similar fashion, but using trigger JT4_3JT15L_VX (which has no L2STT or L3BTAG requirements).
 181 Events were then required to have fired one of the three L2 branches of JT2_3JT15L_IP_VX and to pass the
 182 offline three to five jet selection. All turn-on curves for both trigger lists are found in Appendix B 8.

In this section we describe the main objects used in this study: \cancel{E}_T , jets and hadronic tau candidates.

A. Taus

Taus are reconstructed in the DØ detector from energy in the calorimeter and one or more tracks. The tau reconstruction algorithm uses a cone of $\Delta R = \sqrt{\delta\eta^2 + \delta\phi^2} < 0.5$ and an inner cone of $\Delta R < 0.3$ is used to calculate tau isolation variables.

For us, the most important discriminating variables for τ -leptons are [20]:

- Profile - $\frac{E_T^1 + E_T^2}{\sum_i E_T^i}$, where E_T^i is the E_T of the i^{th} highest E_T tower in the cluster.
- Isolation, defined as $\frac{E(0.5) - E(0.3)}{E(0.3)}$, where $E(R)$ is the energy contained in a y, ϕ of radius R around the calorimeter cluster centroid.
- Track isolation, defined as scalar sum of the p'_T of non- τ tracks in a η, ϕ cone of 0.5 around the calorimeter cluster centroid divided by similar sum for tracks associated with τ .

Such variables are chosen based on the possible tau decays:

- electron or muon ($\tau \rightarrow e\nu_e\nu_\tau$ or $\tau \rightarrow \mu\nu_\mu\nu_\tau$), BR = 35% .
- single charged hadron and no neutral hadrons ($\tau \rightarrow \pi^- \nu_\tau$), BR = 12% .
- single charged hadron + ≥ 1 neutral hadron (i.e., $\tau \rightarrow \rho^- \nu_\tau \rightarrow (\pi^0 + \pi^-) \nu_\tau$), BR = 38% .
- 3 charged hadrons + ≥ 0 neutral hadrons, BR = 15% (so-called “3-prong” decays).

which leads us to classify reconstructed taus into three different types depending on the number of tracks and electromagnetic (EM) clusters [21]:

1. **Type1:** calorimeter cluster, one matched charged track and no associated EM subcluster. Mainly $\tau \rightarrow \pi^- \nu_\tau$.
2. **Type2:** calorimeter cluster, one matched charged track and one or more associated EM subclusters. Mainly $\tau \rightarrow \rho^- \nu_\tau \rightarrow \pi^0 \pi^- \nu_\tau$.
3. **Type3:** calorimeter cluster, two or more matched charged tracks and with or without EM subcluster. Mainly $\tau \rightarrow \pi^- \pi^- \pi^+ (\pi^0) \nu_\tau$.

In order to provide an optimal tau identification, three Neural Networks (NNs) are trained to identify the three types of the taus (1,2 and 3).

The output of these NNs provides a set of three variables (`nnout` = 1,2,3) to be used to select the tau in the event. The types roughly correspond to the τ lepton decay modes. High values of NN correspond to the physical taus, while low ones should indicate jets misidentified as taus (fakes).

B. Jets

Jets are identified using the RunII cone algorithm [22] with cone size of $\Delta R < 0.5$. The jet algorithm T42 [23] is run before jet reconstruction to remove isolated small energy deposits due to noise. DØ standard jet quality cuts [24] include L1 Trigger information, calorimeter electromagnetic fraction and coarse hadronic fraction.

Jets used in this analysis are required to have at least two primary vertex tracks associated to them (vertex confirmed jets). It implies that although a calorimeter cluster is still reconstructed as a jet, it will be discarded if it has less than 2 associated PV tracks. In order to correct the energies of reconstructed jets in data and MC back to parton-level energies, we apply certified jet energy scale correction (JES)[25]. Additionally, jets containing a muon with $\Delta R(\mu, jet) < 0.5$ from a b -quark decay are corrected to take into account the momentum carried away by the muon and the neutrino [26].

225 Presence of neutrinos in an event causes an imbalance of energy in the transverse plane (\cancel{E}_T). This quantity
 226 is calculated from the transverse energies of all calorimeter cells that pass the T42 algorithm, except those
 227 of the coarse hadronic layers due to high noise level. However, they are included in the case that they are
 228 clustered within a reconstructed jet. This raw \cancel{E}_T is corrected for the energies of other objects like photons,
 229 electrons, taus and jets. As muons deposit only a small portion of their energy in the calorimeter, their
 230 momenta is subtracted from the \cancel{E}_T vector.

231

D. The Neural Network b-tagging Algorithm

232 Being QCD and $W + \text{jets}$ the main sources of backgrounds in this analysis, requiring the presence of
 233 at least one jet coming from a b -quark is a very powerful method of background rejection. The b -tagging
 234 algorithm used in this measurement is a Neural Network (NN) tagging algorithm developed by the b-ID
 235 group [27], which combines 7 characteristic variables of SVT, JLIP and CSIP tagging algorithms into the
 236 NN discriminant. As in the previous analysis we have chosen the operating point TIGHT, which is equivalent
 237 to requiring the NN discriminant output to be greater than 0.775. Both the average efficiency and fake rate
 238 are comparable between this p20 version of the algorithm and the version used in p17 [28].

239 *a. b-tagging efficiency* In data we apply the b-tagging algorithm directly to jets selected in our sample.
 240 In MC such “direct tag” is not done. Instead we have to apply a certain efficiency to MC samples. This
 241 inclusive b-decay efficiency (ϵ_b) is measured in data and it is the product of the probability to tag a b-jet in
 242 an MC sample (ϵ_b^{MC}) containing inclusive decays of the b quark times a scale factor. This data/MC scale
 243 factor is given by the ratio of data semileptonic efficiency ($\epsilon_{b \rightarrow \mu}^{DATA}$) and a MC semileptonic efficiency ($\epsilon_{b \rightarrow \mu}^{MC}$).
 244 This scale factor, that measures the effect on the tagging rate caused by the differences in tracking between
 245 data and MC, is then used to properly scale the MC-derived efficiency. It is assumed that such factor could
 246 be applied to any MC tagging efficiency [27].

247 *b. c-tagging efficiency* It is assumed that the same procedure adopted in the b-jet case is also valid for
 248 c-jets, namely, a c-jet scale factor ($\epsilon_{c \rightarrow \mu}^{DATA}/(\epsilon_{c \rightarrow \mu}^{MC})$) multiplies the probability to tag a c-jet in an MC sample
 249 (ϵ_c^{MC}) to get the c-tagging efficiency.

250 *c. Light jet tagging efficiency* The b -tag fake rate from light quarks is computed by measuring the
 251 negative tag rate as defined in [29]. The method uses fits of b-, c- and light jets tagging rates to binned data
 252 combined with sample composition estimated from data. Binned NN output (NN_{out}) distributions for b, c
 253 and light jets is fitted to data distribution using b- and c-jet efficiencies provided by standard bID TRF’s.

254 *d. Taggability* b -tag algorithm can’t be applied to any jet, but only the ones that contain tracks. Such
 255 jets are called “taggable” and are defined by matching within $\Delta R < 0.5$ to a track jet, composed of at
 256 least two tracks. Just like b-tagging, taggability is different in data and MC, due to imperfect simulation of
 257 tracking system. To account for this, taggability rate functions are applied to MC events. Such functions
 258 are parametrized in terms of jet p_T , jet η and primary vertex z . They were derived on the single top loose
 259 data samples, where the isolation quality of the lepton is loose. The validity of these functions is tested
 260 by comparing observed and predicted taggability to tight samples. The results show a good agreement as
 261 described in [30].

263 Up to this point we have presented the data sample used in this analysis (Section II A) the Monte Carlo
 264 samples and corrections applied to them (Sections II C and II D), the trigger used and its simulation (Section
 265 III) and the object ID method (Section IV). Now we describe the next steps of the analysis towards the final
 266 cross section measurement:

- 267 • Preselection (section VI): at least 4 jets, at least one τ with $NN > 0.3$ and $p_T > 10$ GeV/ c , 15 GeV \leq
 268 $\cancel{E}_T \leq 500$ GeV and \cancel{E}_T significance > 4.0 .
- 269 • τ - and b-ID cuts (section VII): at least one good τ lepton candidate and at least one tight NN b-tag
 270 are required.
- 271 • Topological NN (section VIII B): a feed-forward NN's is trained in order to provide signal-background
 272 separation. The NN was optimized by testing different sets of topological variables as its inputs and
 273 by applying different \cancel{E}_T significance cuts.
- 274 • Topological Variables (section IX): section showing final analysis plots of topological variables of
 275 interest.
- 276 • Cross Section (section X) The signal fraction determination is combined with integrated luminosity
 277 measurement to calculate the cross section. Systematic uncertainties are determined by fluctuating the
 278 significant components up and down by one standard deviation one at a time, propagating it through
 279 the entire procedure.

280

VI. PRESELECTION

281 The preselection is the first step of the analysis. The cuts presented here were chosen in order to provide
 282 the best background reduction and enhance the $t\bar{t}$ content at this point. The cuts are the similar to those
 283 used in the p17 analysis [3] except that for this time we opted to optimize the value of \cancel{E}_T significance along
 284 with the sets of variables we used as inputs to NN training (Section VIII). Cuts shown below were applied
 285 to samples shown in Table V as well as to data as shown in Section II A.

- 286 • At least 4 jets with $p_T > 15$ GeV and $\eta < 2.5$, with leading (in p_T) jet $p_T > 35$ GeV and second and
 287 third jets have $p_T > 25$ GeV
- 288 • at least one τ with $NN > 0.3$ and $p_T > 10$ GeV
- 289 • 15 GeV $\leq \cancel{E}_T \leq 500$ GeV
- 290 • \cancel{E}_T significance ≥ 4.0
- 291 • No isolated electron or muon. This is done in order to ensure orthogonality with other $D\bar{O}$ measure-
 292 ments ([31] and [32]) - events that pass the lepton preselection cuts from these measurements were
 293 vetoed. Also events that pass the all-jets analysis preselection cuts (described in the alljet analysis
 294 note [33]) are rejected here.

295 Among all preselection cuts one of them requires a more detailed description at this point since it represents
 296 an improvement upon the old p17 analysis: \cancel{E}_T significance. Missing transverse energy significance is a
 297 measure of the likelihood of \cancel{E}_T arising from physical sources. It is computed from calculated resolutions
 298 of physical objects (jets, electrons, muons and unclustered energy) [3, 34]. Initially no \cancel{E}_T significance was
 299 applied neither on MC nor on data. In this analysis we decided to optimize the \cancel{E}_T significance cut along
 300 with the NN optimization itself. After finishing the \cancel{E}_T significance optimization part we went back and
 301 applied the optimized cut along with the non-optimized NNelec cut only to MC. The entire optimization
 302 procedure is described in Section VIII C.

303 In data, initially the sample contained approximately 650 million events and the number of preselected
 304 events (once again, without \cancel{E}_T significance applied) is approximately 2.8 million events.

305 Another relevant aspect of the preselection is the usage of Particle Selector (only applied to MC samples).
 306 In this step we aimed to select a particular $t\bar{t}$ final state, namely, we split W decay into $W \rightarrow e/\mu/\tau$ and
 307 tracked separate efficiencies for each of these processes. In this step we selected hadronic decays of tau, and

308 at the same events where tau decays into electrons and muons were put into $e + jets$ and $\mu + jets$ samples.
 309 As in p17, we decided to do not split the dilepton sample in different lepton flavors.

310 Before proceeding to the next step, it is important to describe the result of the preselection in terms of
 311 its efficiencies since all the rest of analysis strongly depends on the cuts applied at this level. As previously
 312 described, $t\bar{t}$ were generated by ALPGEN. In ALPGEN, different process with different numbers of partons
 313 have different cross-sections and number of events. This fact must be taken into account when calculating
 314 the efficiencies, namely, efficiencies must be properly scaled to the luminosity (4951.85 pb^{-1}) of the sample.
 315 Tables VI and III show the number beforementioned for $t\bar{t} \rightarrow \text{lepton} + jets$ and $t\bar{t} \rightarrow \text{dilepton}$ respectively.

Process	# of events	cross-section (pb)	alpgen weight
0 light parton	777068	1.4	0.00892
1 light parton	457782	0.577	0.00624
≥ 2 light partons	321166	0.267	0.00412

TABLE VII: $t\bar{t} \rightarrow \text{lepton} + jets$ ALPGEN weights.

Process	# of events	cross-section (pb)	alpgen weight
0 light parton	749642	0.352	0.00233
1 light parton	452177	0.142	0.00156
≥ 2 light partons	281453	0.068	0.00119

TABLE VIII: $t\bar{t} \rightarrow \text{dilepton}$ ALPGEN weights.

316 Tables IX, X, XI and XII show cut flows for all preselection cuts applied to different $t\bar{t}$ decays (only
 317 statistical uncertainties are shown).

Selection	Events	Relative	Cumulative
Initial	11164		
Particle selector	2412	$21.60 \pm 0.03 \%$	$21.60 \pm 0.03 \%$
Duplicate events removal	2411	$99.98 \pm 0.01 \%$	$21.60 \pm 0.03 \%$
Event quality	2315	$96.00 \pm 0.04 \%$	$20.74 \pm 0.03 \%$
Jet selection	1307	$59.45 \pm 0.09 \%$	$11.70 \pm 0.03 \%$
Vertex selection	1296	$99.18 \pm 0.02 \%$	$11.61 \pm 0.03 \%$
Electron veto	1282	$98.93 \pm 0.01 \%$	$11.49 \pm 0.03 \%$
Muon veto	1282	$99.93 \pm 0.01 \%$	$11.48 \pm 0.03 \%$
MET selection	1218	$95.05 \pm 0.05 \%$	$10.91 \pm 0.02 \%$
MET significance	772	$63.39 \pm 0.12 \%$	$6.92 \pm 0.02 \%$
NN tau cut	394	$53.51 \pm 0.15 \%$	$3.70 \pm 0.02 \%$

TABLE IX: Preselection $t\bar{t} \rightarrow \tau + jets$ cut flow

Selection	Events	Relative	Cumulative
Initial	11164		
Particle selector	4385	39.28 ± 0.04 %	39.28 ± 0.04 %
Duplicate event removal	4383	99.96 ± 0.01 %	39.26 ± 0.04 %
Event quality	4207	95.97 ± 0.03 %	37.68 ± 0.04 %
Jet selection	1923	45.71 ± 0.07 %	17.22 ± 0.03 %
Vertex selection	1907	99.20 ± 0.02 %	17.08 ± 0.03 %
Electron veto	1048	54.94 ± 0.10 %	9.39 ± 0.02 %
Muon veto	1047	99.95 ± 0.01 %	9.38 ± 0.02 %
MET selection	1002	95.64 ± 0.05 %	8.97 ± 0.02 %
MET significance	669	66.74 ± 0.13 %	5.99 ± 0.02 %
NN tau cut	395	59.12 ± 0.16 %	3.54 ± 0.02 %

TABLE X: Preselection $t\bar{t} \rightarrow e + jets$ cut flow

Selection	Events	Relative	Cumulative
Initial	11164		
Particle selector	4367	39.12 ± 0.04 %	39.12 ± 0.04 %
Duplicate event removal	4366	99.96 ± 0.04 %	39.10 ± 0.04 %
Event quality	4189	95.95 ± 0.03 %	37.52 ± 0.04 %
Jet selection	1990	47.52 ± 0.07 %	17.83 ± 0.03 %
Vertex selection	1975	99.23 ± 0.02 %	17.69 ± 0.03 %
Electron veto	1967	99.59 ± 0.01 %	17.62 ± 0.03 %
Muon veto	1170	59.48 ± 0.09 %	10.48 ± 0.02 %
MET selection	1127	96.31 ± 0.04 %	10.09 ± 0.02 %
MET significance	812	72.06 ± 0.11 %	7.27 ± 0.02 %
NN tau cut	186	22.95 ± 0.13 %	1.67 ± 0.01 %

TABLE XI: Preselection $t\bar{t} \rightarrow \mu + jets$ cut flow

Selection	Events	Relative	Cumulative
Initial	2799		
Particle selector	2799	100.00 ± 0.00 %	100.00 ± 0.00 %
Duplicate event removal	2799	100.00 ± 0.00 %	100.00 ± 0.00 %
Event quality	2685	95.92 ± 0.02 %	95.92 ± 0.02 %
Jet selection	145	5.41 ± 0.02 %	5.19 ± 0.02 %
Vertex selection	144	99.32 ± 0.03 %	5.16 ± 0.02 %
Electron veto	110	76.14 ± 0.13 %	3.93 ± 0.01 %
Muon veto	83	75.08 ± 0.16 %	2.95 ± 0.01 %
MET selection	80	96.45 ± 0.08 %	2.84 ± 0.01 %
MET significance	60	75.32 ± 0.19 %	2.14 ± 0.01 %
NN tau cut	38	63.21 ± 0.24 %	1.35 ± 0.01 %

TABLE XII: Preselection $t\bar{t} \rightarrow l + l$ cut flow

319 In the next step we applied the requirements of tight τ - and b -tagging. Table XIII shows the selection
 320 criteria that we applied to data and MC. The b -tag operating point used was TIGHT, which corresponds
 321 to $NN_{btag} > 0.775$. We chose the τ with the highest NN_τ as *the* τ candidate. At this stage of the analysis
 322 we separated the events dataset we deal with into parts, according to which type of τ the candidate with
 323 highest NN belongs. This was done primarily to separate the type 3 tau events (which are expected to
 324 have much higher fake rate and thus weaker $t\bar{t}$ cross section result) from the type 2 events. The separate
 325 measurement channels were later combined to get the final result (Section X). In principle, types 1 and 2
 326 should be separated as well but as there exists a considerable cross-migration between them [20] and type
 327 1 is a small fraction of the total (10% of type 1, 54.5% of type 2 and 35.5% of type 3), they were taken
 328 together in this analysis. The topological NN used to enhance the signal content is described in section
 329 VIII B .

330 At this point, we used these ID algorithms to define 3 mutually exclusive and exhaustive subsamples out
 331 of the original preselected data sample:

- 332 • The “non- b veto” or “signal” sample - the τ candidate has $NN_\tau > 0.90$ (NN_τ denotes the NN cut
 333 commonly applied to all taus) for taus types 1 and 2 and $NN(\tau) > 0.95$ for taus type 3, and at least
 334 one NN b -tag (as in Table XIII). These $NN(\tau)$ cuts were chosen based on previous studies involving
 335 hadronic decays of taus [19, 37]. This is the sample used to extract the cross section. Jets matched to
 336 τ candidates are not b -tagged, although they still count as jets.
- 337 • The “ τ veto sample” or “loose-tight τ sample” - Same selection, but with $0.3 < NN_\tau < 0.7$ for all
 338 taus. τ NN lower cut of 0.3 instead of 0.0 was chosen to bias their jet properties closer to those of
 339 tight tau candidates, in particular, so they have narrow showers. The upper cut is at 0.7 and not 0.95
 340 or 0.90 to reduce signal contamination. In this sample, 1400000 events were used for NN training for
 341 taus type 1 and 2 and 600000 events were used in the case of type 3 taus. In both cases, the rest of
 342 the samples served as QCD template.
- 343 • The “ b veto” sample - Require exactly 0 tight b -tags. This is the control sample used to verify the
 344 validity of the QCD modelling method. The b veto requirement implies this sample is almost purely
 345 background.

346 Along with the NN_τ cut described above, we also applied the cut $NNelec > 0.9$ only to type 2 taus since
 347 these are more likely to be faked by electrons. The cut $NNelec > 0.9$ was chosen in order to match the lowest
 348 cut of $NN_\tau > 0.9$ applied to type 2 taus (Section VII).

349 As both b and τ ID is the step immediately after the preselection, the number of events available is 2800000
 350 million events. As explained above 1400000 events were used for taus type 1 and 2 NN training and 600000
 351 for type 3 taus NN training. Thus, there are 1400000 events available in each sample for the measurement
 352 in the case of types 1 and 2 and 2200000 in the case of type 3. Details on NN training are given in Section
 353 VIII B.

354 The QCD modelling method used here is the same as used in p17 and is described in Section IXA of [3].

355 The final number of events in each channel for both signal and b veto samples is shown on Tables XIV,
 356 XV, XVI and XVII (only statistical uncertainties are shown).

357 As important as determining the subsamples to be used in this analysis, a determination as precise as
 358 possible of both signal and electroweak contamination in the “loose-tight τ sample” had be done in order
 359 to know whether this sample is totally QCD dominated or not. Numbers showing the composition of such
 360 sample are shown on Tables XVIII and XIX with their respective statistical uncertainties. From the $t\bar{t}$ content
 361 in each case we are able estimate the signal contamination in the loose-tight sample. Such contaminations
 362 are 5.4% and 3.0% for taus type 1 and 2 and type 3 respectively when a cross section of 7.46 pb is assumed
 363 (Section II C). Likewise we see that electroweak contaminations are 2.2% and 0.9%. As this is the sample
 364 used to model the QCD background both signal and electroweak contaminations were taken into account
 365 when measuring the cross section in Section X.

data	taggingMC
$\geq 1 \tau$ with $ \eta < 2.5$ and $p_T > 20$ GeV	$\geq 1 \tau$ with $ \eta < 2.5$ and $p_T > 20$ GeV
≥ 1 NN b-tag	$mcweight \cdot TrigWeight \cdot bTagProb \cdot lumiReWeight \cdot PVzReWeight \cdot bFragWeight$
	$\cdot WZPtRweight$
≥ 4 jets with $ \eta < 2.5$ and $p_T > 20$ GeV	≥ 4 jets with $ \eta < 2.5$ and $p_T > 20$ GeV

TABLE XIII: b -tagging and τ ID. In the MC, we use the b -tagging certified parameterization rather than actual b -tagging, that is, we applied the b -tagging weight. We also used the triggering weight as computed by the trigger efficiency parameterization as well as luminosity profile and PVz reweighting weights. $mcweight$ is the MC normalization factors (to luminosity), which are different for MC samples with different parton multiplicities in ALPGEN MC samples.

Sample	# events
data	386
$t\bar{t} \rightarrow \tau + jets$	48.03 ± 0.53
$t\bar{t} \rightarrow e + jets$	25.57 ± 0.36
$t\bar{t} \rightarrow \mu + jets$	3.21 ± 0.14
$t\bar{t} \rightarrow l + l$	4.01 ± 0.07
$Wbb + jets \rightarrow l\nu + bb + jets$	7.48 ± 0.30
$Wcc + jets \rightarrow l\nu + cc + jets$	4.68 ± 0.17
$Wjj + jets \rightarrow l\nu + jj + jets$	5.66 ± 0.11
$Zbb + jets \rightarrow \tau\tau + bb + jets$	0.93 ± 0.08
$Zcc + jets \rightarrow \tau\tau + cc + jets$	0.51 ± 0.04
$Zjj + jets \rightarrow \tau\tau + jj + jets$	1.07 ± 0.10
$Zbb + jets \rightarrow ee + bb + jets$	0.03 ± 0.01
$Zcc + jets \rightarrow ee + cc + jets$	0.00 ± 0.00
$Zjj + jets \rightarrow ee + jj + jets$	0.02 ± 0.01
$Zbb + jets \rightarrow \mu\mu + bb + jets$	0.07 ± 0.02
$Zcc + jets \rightarrow \mu\mu + cc + jets$	0.02 ± 0.01
$Zjj + jets \rightarrow \mu\mu + jj + jets$	0.01 ± 0.01
$Zbb + jets \rightarrow \nu\nu + bb + jets$	0.08 ± 0.03
$Zcc + jets \rightarrow \nu\nu + cc + jets$	0.00 ± 0.00
$Zjj + jets \rightarrow \nu\nu + jj + jets$	0.04 ± 0.01

TABLE XIV: Final number of events in each channel for taus types 1 and 2 τ after b -tagging, τ ID and trigger in the signal sample when the assumed cross section is 7.46 pb. An estimate of QCD background is not included.

Sample	# of events
data	459
$t\bar{t} \rightarrow \tau + jets$	25.88 ± 0.39
$t\bar{t} \rightarrow e + jets$	4.35 ± 0.16
$t\bar{t} \rightarrow \mu + jets$	3.43 ± 0.14
$t\bar{t} \rightarrow l + l$	2.80 ± 0.06
$Wbb + jets \rightarrow l\nu + bb + jets$	3.92 ± 0.17
$Wcc + jets \rightarrow l\nu + cc + jets$	3.26 ± 0.15
$Wjj + jets \rightarrow l\nu + jj + jets$	4.08 ± 0.11
$Zbb + jets \rightarrow \tau\tau + bb + jets$	0.74 ± 0.07
$Zcc + jets \rightarrow \tau\tau + cc + jets$	0.41 ± 0.03
$Zjj + jets \rightarrow \tau\tau + jj + jets$	0.80 ± 0.10
$Zbb + jets \rightarrow ee + bb + jets$	0.00 ± 0.00
$Zcc + jets \rightarrow ee + cc + jets$	0.01 ± 0.01
$Zjj + jets \rightarrow ee + jj + jets$	0.01 ± 0.01
$Zbb + jets \rightarrow \mu\mu + bb + jets$	0.04 ± 0.02
$Zcc + jets \rightarrow \mu\mu + cc + jets$	0.01 ± 0.01
$Zjj + jets \rightarrow \mu\mu + jj + jets$	0.00 ± 0.00
$Zbb + jets \rightarrow \nu\nu + bb + jets$	0.12 ± 0.04
$Zcc + jets \rightarrow \nu\nu + cc + jets$	0.19 ± 0.04
$Zjj + jets \rightarrow \nu\nu + jj + jets$	0.06 ± 0.01

TABLE XV: Final number of events in each channel for taus type 3 τ After b -tagging, τ ID and trigger in the signal sample when the assumed cross section is 7.46 pb. An estimate of QCD background is not included.

Sample	# of events
data	2494
$t\bar{t} \rightarrow \tau + jets$	33.57 ± 0.34
$t\bar{t} \rightarrow e + jets$	15.67 ± 0.23
$t\bar{t} \rightarrow \mu + jets$	2.30 ± 0.09
$t\bar{t} \rightarrow l + l$	2.69 ± 0.04
$Wbb + jets \rightarrow l\nu + bb + jets$	9.29 ± 0.27
$Wcc + jets \rightarrow l\nu + cc + jets$	31.63 ± 0.90
$Wjj + jets \rightarrow l\nu + jj + jets$	169.95 ± 2.68
$Zbb + jets \rightarrow \tau\tau + bb + jets$	1.30 ± 0.11
$Zcc + jets \rightarrow \tau\tau + cc + jets$	3.15 ± 0.20
$Zjj + jets \rightarrow \tau\tau + jj + jets$	16.86 ± 1.14
$Zbb + jets \rightarrow ee + bb + jets$	0.02 ± 0.01
$Zcc + jets \rightarrow ee + cc + jets$	0.00 ± 0.00
$Zjj + jets \rightarrow ee + jj + jets$	0.74 ± 0.33
$Zbb + jets \rightarrow \mu\mu + bb + jets$	0.08 ± 0.02
$Zcc + jets \rightarrow \mu\mu + cc + jets$	0.07 ± 0.03
$Zjj + jets \rightarrow \mu\mu + jj + jets$	0.38 ± 0.22
$Zbb + jets \rightarrow \nu\nu + bb + jets$	0.10 ± 0.03
$Zcc + jets \rightarrow \nu\nu + cc + jets$	0.00 ± 0.00
$Zjj + jets \rightarrow \nu\nu + jj + jets$	1.36 ± 0.49

TABLE XVI: b -veto data set composition for types 1 and 2 τ when the assumed cross section is 7.46 pb.

Sample	# of events
data	3688
$t\bar{t} \rightarrow \tau + jets$	19.85 ± 0.27
$t\bar{t} \rightarrow e + jets$	3.53 ± 0.13
$t\bar{t} \rightarrow \mu + jets$	2.80 ± 0.10
$t\bar{t} \rightarrow l + l$	1.81 ± 0.03
$Wbb + jets \rightarrow l\nu + bb + jets$	5.26 ± 0.19
$Wcc + jets \rightarrow l\nu + cc + jets$	22.43 ± 0.80
$Wjj + jets \rightarrow l\nu + jj + jets$	126.41 ± 2.60
$Zbb + jets \rightarrow \tau\tau + bb + jets$	0.92 ± 0.09
$Zcc + jets \rightarrow \tau\tau + cc + jets$	2.86 ± 0.20
$Zjj + jets \rightarrow \tau\tau + jj + jets$	14.53 ± 1.15
$Zbb + jets \rightarrow ee + bb + jets$	0.00 ± 0.00
$Zcc + jets \rightarrow ee + cc + jets$	0.08 ± 0.04
$Zjj + jets \rightarrow ee + jj + jets$	0.31 ± 0.18
$Zbb + jets \rightarrow \mu\mu + bb + jets$	0.04 ± 0.02
$Zcc + jets \rightarrow \mu\mu + cc + jets$	0.05 ± 0.02
$Zjj + jets \rightarrow \mu\mu + jj + jets$	0.05 ± 0.04
$Zbb + jets \rightarrow \nu\nu + bb + jets$	0.16 ± 0.05
$Zcc + jets \rightarrow \nu\nu + cc + jets$	0.83 ± 0.15
$Zjj + jets \rightarrow \nu\nu + jj + jets$	2.31 ± 0.46

TABLE XVII: b -veto data set composition for type 3 τ when the assumed cross section is 7.46 pb.

Sample	# of events
data	1217
$t\bar{t} \rightarrow \tau + jets$	32.94 ± 0.48
$t\bar{t} \rightarrow e + jets$	17.02 ± 0.34
$t\bar{t} \rightarrow \mu + jets$	14.37 ± 0.32
$t\bar{t} \rightarrow l + l$	2.43 ± 0.06
$Wbb + jets \rightarrow l\nu + bb + jets$	6.33 ± 0.23
$Wcc + jets \rightarrow l\nu + cc + jets$	4.63 ± 0.19
$Wjj + jets \rightarrow l\nu + jj + jets$	11.34 ± 0.26
$Zbb + jets \rightarrow \tau\tau + bb + jets$	0.50 ± 0.06
$Zcc + jets \rightarrow \tau\tau + cc + jets$	0.58 ± 0.06
$Zjj + jets \rightarrow \tau\tau + jj + jets$	1.10 ± 0.13
$Zbb + jets \rightarrow ee + bb + jets$	0.01 ± 0.01
$Zcc + jets \rightarrow ee + cc + jets$	0.01 ± 0.01
$Zjj + jets \rightarrow ee + jj + jets$	0.00 ± 0.00
$Zbb + jets \rightarrow \mu\mu + bb + jets$	0.03 ± 0.01
$Zcc + jets \rightarrow \mu\mu + cc + jets$	0.04 ± 0.01
$Zjj + jets \rightarrow \mu\mu + jj + jets$	0.02 ± 0.01
$Zbb + jets \rightarrow \nu\nu + bb + jets$	1.07 ± 0.17
$Zcc + jets \rightarrow \nu\nu + cc + jets$	0.57 ± 0.10
$Zjj + jets \rightarrow \nu\nu + jj + jets$	0.36 ± 0.04

TABLE XVIII: loose-tight data set composition for types 1 and 2 τ when the assumed cross section is 7.46 pb.

Sample	# of events
data	4733
$t\bar{t} \rightarrow \tau + jets$	51.16 ± 0.57
$t\bar{t} \rightarrow e + jets$	40.02 ± 0.50
$t\bar{t} \rightarrow \mu + jets$	48.00 ± 0.56
$t\bar{t} \rightarrow l + l$	2.16 ± 0.05
$Wbb + jets \rightarrow l\nu + bb + jets$	8.95 ± 0.27
$Wcc + jets \rightarrow l\nu + cc + jets$	7.80 ± 0.23
$Wjj + jets \rightarrow l\nu + jj + jets$	16.32 ± 0.30
$Zbb + jets \rightarrow \tau\tau + bb + jets$	0.52 ± 0.05
$Zcc + jets \rightarrow \tau\tau + cc + jets$	0.46 ± 0.04
$Zjj + jets \rightarrow \tau\tau + jj + jets$	1.16 ± 0.12
$Zbb + jets \rightarrow ee + bb + jets$	0.00 ± 0.00
$Zcc + jets \rightarrow ee + cc + jets$	0.00 ± 0.00
$Zjj + jets \rightarrow ee + jj + jets$	0.01 ± 0.01
$Zbb + jets \rightarrow \mu\mu + bb + jets$	0.06 ± 0.01
$Zcc + jets \rightarrow \mu\mu + cc + jets$	0.07 ± 0.01
$Zjj + jets \rightarrow \mu\mu + jj + jets$	0.11 ± 0.02
$Zbb + jets \rightarrow \nu\nu + bb + jets$	2.49 ± 0.24
$Zcc + jets \rightarrow \nu\nu + cc + jets$	1.90 ± 0.14
$Zjj + jets \rightarrow \nu\nu + jj + jets$	1.28 ± 0.08

TABLE XIX: loose-tight data set composition for type 3 τ when the assumed cross section is 7.46 pb.

A. Variables for NN training

368 Following the same procedure as in the previous analysis, we determine the content of signal and background
 369 in the preselected sample, increase signal/background rate and from this, measure the cross-section. The
 370 procedure adopted in the p17 analysis was feed a set of topological variables into an artificial neural network
 371 in order to provide the best possible separation between signal and background. As before, the criteria for
 372 choosing such variables were: power of discrimination and τ -uncorrelated variables. The set is presented
 373 below:

- 374 • H_T - the scalar sum of all jet's p_T (here and below including τ lepton candidates).
- 375 • E_T *significance* - As being the variable that provides the best signal-background separation we
 376 decided to optimize it.
- 377 • *Aplanarity* [35] - the normalized momentum tensor is defined as

$$\mathcal{M} = \frac{\sum_o p_i^o p_j^o}{\sum_o |\vec{p}^o|} \quad (5)$$

378 where \vec{p}^o is the momentum-vector of a reconstructed object o and i and j are cartesian coordinates.
 379 From the diagonalization of \mathcal{M} we find three eigenvalues $\lambda_1 \geq \lambda_2 \geq \lambda_3$ with the constraint $\lambda_1 + \lambda_2 + \lambda_3 =$
 380 1. The aplanarity \mathcal{A} is given by $\mathcal{A} = \frac{3}{2}\lambda_3$ and measures the flatness of an event. Hence, it is defined
 381 in the range $0 \leq \mathcal{M} \leq 0.5$. Large values of \mathcal{A} correspond to more spherical events, like $t\bar{t}$ events for
 382 instance, since they are typical of decays of heavy objects. On the other hand, both QCD and W + jets
 383 events are more planar since jets in these events are primarily due to initial state radiation.

- 384 • *Sphericity* [35] - being defined as $\mathcal{S} = \frac{3}{2}(\lambda_2 + \lambda_3)$, and having a range $0 \leq \mathcal{S} \leq 1.0$, sphericity is a
 385 measure of the summed p_{\perp}^2 with respect to the event axis. In this sense a 2-jets event corresponds to
 386 $\mathcal{S} \approx 0$ and an isotropic event $\mathcal{S} \approx 1$. $t\bar{t}$ events are very isotropic as they are typical of the decays of
 387 heavy objects and both QCD and W + jets events are less isotropic due to the fact that jets in these
 388 events come primarily from initial state radiation.
- 389 • *Top and W mass likelihood* - a χ^2 -like variable. $L \equiv \left(\frac{M_{3j} - m_t}{\sigma_t}\right)^2 + \left(\frac{M_{2j} - M_W}{\sigma_W}\right)^2$, where
 390 $m_t, M_W, \sigma_t, \sigma_W$ are top and W masses (172.4 GeV and 81.02 GeV respectively) and resolution val-
 391 ues (19.4 GeV and 8.28 GeV respectively). M_{3j} and M_{2j} are invariant masses composed of the jet
 392 combinations. We choose combination that minimizes L .
- 393 • *Centrality*, defined as $\frac{H_T}{H_E}$, where H_E is sum of energies of the jets.
- 394 • $\cos(\theta^*)$ - The angle between the beam axis and the highest- p_T jet in the rest frame of all the jets in
 395 the event.
- 396 • \sqrt{s} - The invariant mass of all jets and τ s in the event.

397 The chosen variables are in the end a consequence of the method employed in this analysis: use events
 398 from the QCD-enriched loose-tight sample to model QCD events in the signal-rich sample, and use a b-tag
 399 veto sample as an independent control sample to check the validity of such background modeling.

B. Topological NN

401 For training the Neural Network we used the Multilayer Perceptron algorithm, as described in [38]. As
 402 explained before in Section VII, the first 1400000 events in the “loose-tight” sample were used as background
 403 for NN training for taus types 1 and 2, and the first 600000 of the same sample for NN training for type 3
 404 taus. This means that different tau types are being treated separately in the topological NN. In both cases

405 1/3 of the Alpgen sample of $t\bar{t} \rightarrow \tau + jets$ was used for NN training and 2/3 of it for the measurement.
 406 When doing the measurement later on (Section X) we pick the tau with the highest $NN(\tau)$ in the signal
 407 sample as the tau candidate at same time that taus in the loose-tight sample are picked at random since all
 408 of them are regarded as fake taus by being below the cut $NN(\tau) = 0.7$. By doing this we expect to avoid
 409 any bias when selecting real taus for the measurement. Figures 3 and 4 show the effect of each of the chosen
 410 the topological event NN input variables on the final output.
 411 Figures 5 and 6 show the NN output as a result of the training described above. It is evident from both
 412 pictures that high values of NN correspond to the signal-enriched region.

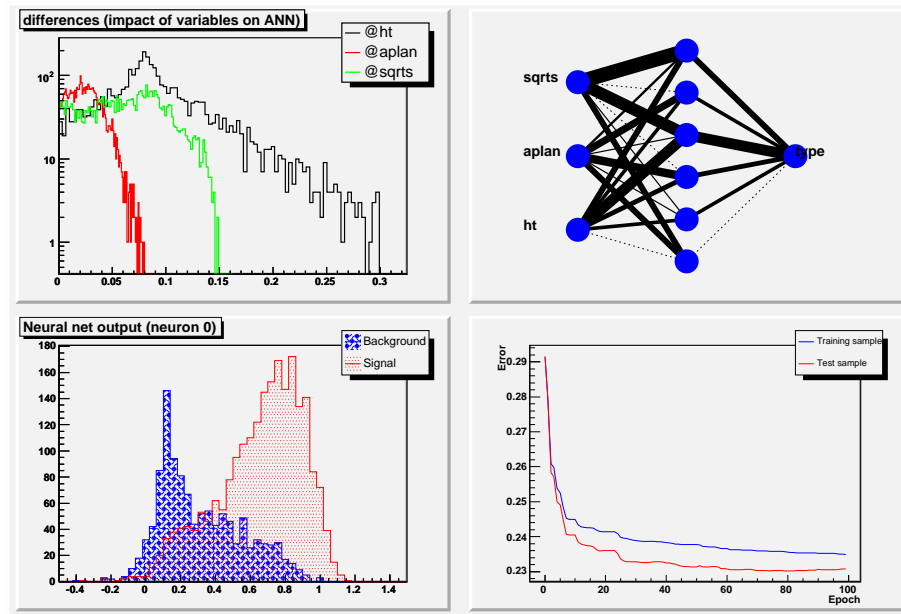


FIG. 3: Training of topological Neural Network output for type 1 and 2 τ channel. Upper left: relative impact of each of the input variables; upper right: topological structure; lower right: final signal-background separation of the method; lower left: convergence curves.

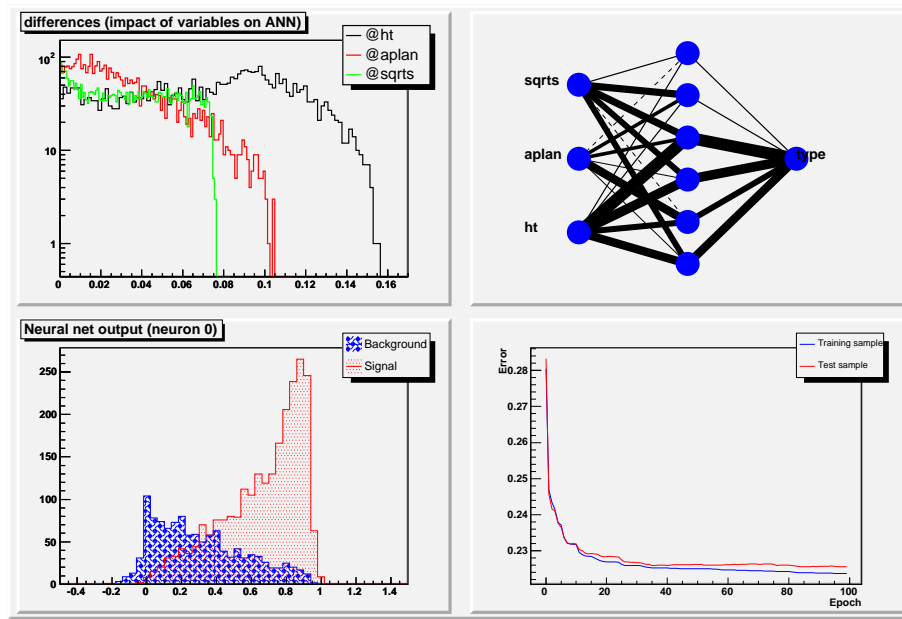


FIG. 4: Training of topological Neural Network output for type 3 τ channel. Upper left: relative impact of each of the input variables; upper right: topological structure; lower right: final signal-background separation of the method; lower left: convergence curves.

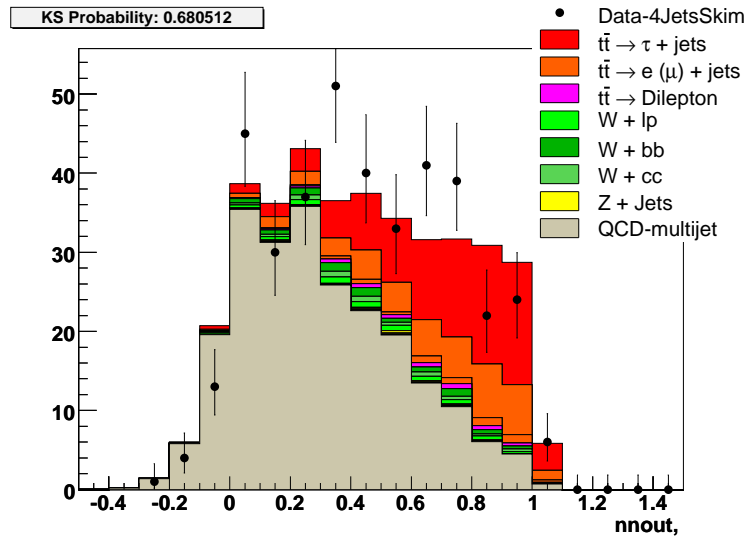


FIG. 5: The topological Neural Network output for type 1 and 2 τ channel

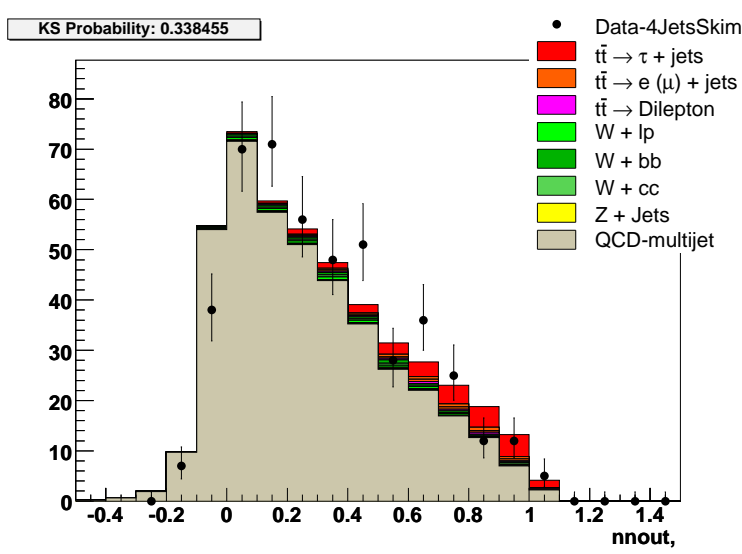


FIG. 6: The topological Neural Network output for type 3 τ channel

413

C. NN optimization

414 One difference between this present analysis and the previous p17 is that we performed a NN optimization
 415 along with a \cancel{E}_T significance optimization. Previously a cut of > 3.0 was applied to \cancel{E}_T significance at
 416 the preselection stage and then it was included as one of the variables for NN training. This time as we
 417 chose to optimize it, since it is still a good variable to provide signal-background discrimination (Figure 7).
 418 It is important to stress out that after the optimization we performed the analysis with the optimized \cancel{E}_T
 419 significance cut applied when doing both τ and b ID (Section VII), therefore after the preselection where no
 420 \cancel{E}_T significance cut was applied. We then went back and reprocessed (preselected) all MC samples with the
 421 optimized cut. Both results, with \cancel{E}_T significance applied during and after preselection were identical. We
 422 then chose to present this analysis with this cut applied at the preselection level in order to have a consistent
 423 cut flow throughout the analysis (Section VI).

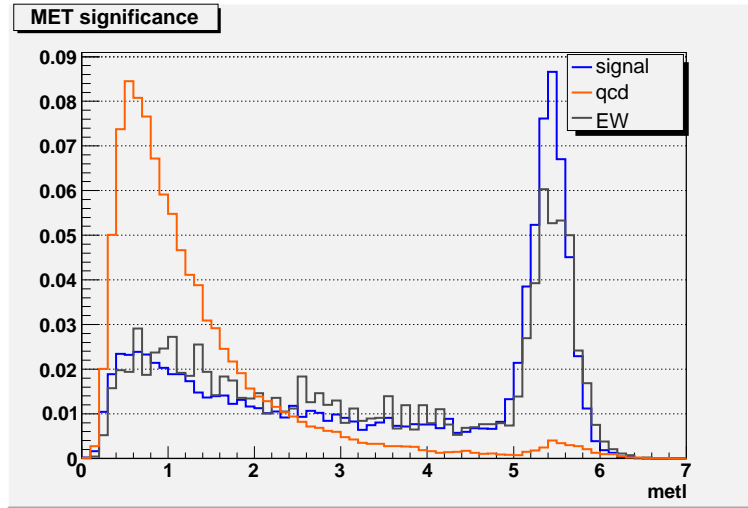


FIG. 7: \cancel{E}_T significance distribution for signal and backgrounds.

424 Below we describe how we split this part of the analysis into two parts:

425 1. **Set optimization:** We applied an arbitrary cut on E_T significance of ≥ 4.0 and varied the set of
426 variables going into NN training

427 2. E_T **significance optimization:** After choosing the best set based on the lowest RMS, we then varied
428 the E_T significance cut

429 For this part of the analysis we present the sets of variables that were taken into account to perform the
430 NN training

- 431 • **Set I** : H_T , aplan (aplanarity), sqrts (\sqrt{s})
- 432 • **Set II** : H_T , aplan, cent (centrality)
- 433 • **Set III** : H_T , aplan, spher (sphericity)
- 434 • **Set IV** : H_T , cent, spher
- 435 • **Set V** : aplan, cent, spher
- 436 • **Set VI** : H_T , aplan, sqrts, spher
- 437 • **Set VII** : H_T , aplan, sqrts, cent
- 438 • **Set VIII** : H_T , aplan, sqrts, costhetastar ($\cos(\theta^*)$)
- 439 • **Set IX** : H_T , aplan, sqrts, cent, spher
- 440 • **Set X** : H_T , aplan, sqrts, cent, costhetastar
- 441 • **Set XI** : H_T , aplan, sqrts, spher, costhetastar
- 442 • **Set XII** : metl, H_T , aplan, sqrts
- 443 • **Set XIII** : metl, H_T , aplan, cent
- 444 • **Set XIV** : metl, H_T , aplan, spher
- 445 • **Set XV** : metl, H_T , cent, spher
- 446 • **Set XVI** : metl, H_T , aplan
- 447 • **Set XVII** : metl, H_T , sqrts
- 448 • **Set XVIII** : metl, aplan, sqrts
- 449 • **Set XIX** : metl, H_T , cent
- 450 • **Set XX** : metl, H_T , aplan, sqrts, cent
- 451 • **Set XXI** : metl, H_T , aplan, cent, spher
- 452 • **Set XXII** : metl, H_T , aplan, sqrts, spher
- 453 • **Set XXIII** : metl, H_T , aplan, sqrts, costhetastar
- 454 • **Set XXIV** : metl, sqrts, cent, spher, costhetastar
- 455 • **Set XXV** : metl, H_T , cent, spher, costhetastar
- 456 • **Set XXVI** : metl, aplan, cent, spher, costhetastar
- 457 • **Set XXVII** : metl, H_T , aplan, cent, costhetastar
- 458 • **Set XXVIII** : H_T , aplan, topmassl
- 459 • **Set XXIX** : H_T , aplan, sqrts, topmassl

460 • *Set XXX* : H_T , aplan, sqrts, cent, topmassl

461 • *Set XXXI* : H_T , aplan, sqrts, costhetastar, topmassl

462 • *Set XXXII* : metl, H_T , topmassl, aplan, sqrts

463 • *Set XXXIII* : metl, spher, costhetastar, aplan, cent

464 The criteria used for making a decision on which variable should be used follow:

465 • No more than 5 variables to keep NN simple and stable. More variables leads to instabilities (different
466 result after each retraining) and require larger training samples.

467 • We do not want to use highly correlated variables in same NN.

468 • We want to use variables with high discriminating power.

469 In order to make the decision about which of these 11 choices is the optimal we created an ensemble of
470 20000 pseudo-datasets each containing events randomly (according to a Poisson distribution) picked from
471 QCD, EW and $t\bar{t}$ templates. Each of these datasets was treated like real data, meaning applying all the cuts
472 and doing the shape fit of event topological NN. QCD templates for fit were made from the same “loose-tight
473 τ sample” from which the QCD component of the “data” was drawn. The figure of merit chosen is given by
474 Equation 6 below:

$$f = \frac{(N_{fit} - N_{true})}{N_{true}} \quad (6)$$

475 where N_{fit} is the number of $t\bar{t}$ pairs given by the fit and N_{true} is the number of $t\bar{t}$ pairs from the Poisson
476 distribution. In both Set and \cancel{E}_T significance optimization, the lowest RMS was used to characterize which
477 configuration is the best in each case.

478 The plots showing results concerning the set optimizations are found in Appendix E and are summarized
479 in Table XX below, where each RMS and mean are shown. For NN training is standard to choose the number
480 of hidden nodes as being twice the number the number of variables used for the training. The parenthesis
481 after each set ID show the number of hidden nodes in NN training.

482 From Table XX we see that Set I has the lowest RMS, thus we chose it as the set to be used in \cancel{E}_T
483 significance optimization part, whose results are shown in Appendix F and then summarized in Table XXI
484 below

485 Combined results from Tables XX and XXI show that the best configuration found was Set I with \cancel{E}_T sig-
486 nificance ≥ 4.0 . Therefore, this was the configuration used to perform the cross-section measurement. Figure
487 8 shows the variation of the RMS as function of the \cancel{E}_T significance we applied.

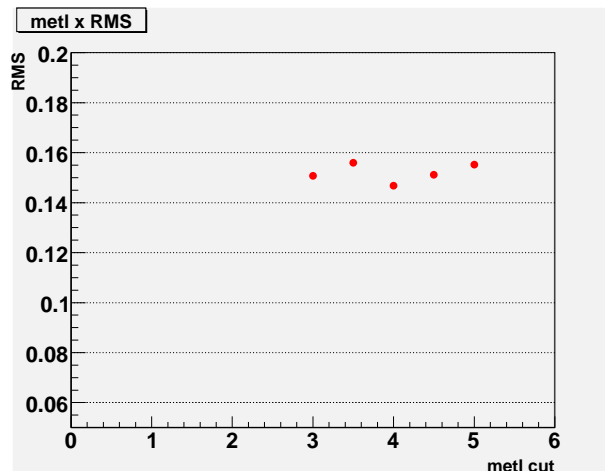


FIG. 8: Plot of RMS as a function the \cancel{E}_T significance applied

Set of variables	RMS	mean
Set1(6)	0.1642	0.0265
Set2(6)	0.1840	0.0054
Set3(6)	0.1923	0.0060
Set4(6)	0.1978	0.0175
Set5(6)	0.2385	0.0022
Set6(8)	0.1687	0.0115
Set7(8)	0.1667	0.0134
Set8(10)	0.1668	0.0162
Set9(10)	0.1721	0.0102
Set10(10)	0.1722	0.0210
Set11(10)	0.1716	0.0180
Set12(8)	0.1662	0.0039
Set13(8)	0.1819	0.0018
Set14(8)	0.1879	0.0019
Set15(8)	0.1884	-0.0004
Set16(6)	0.1912	0.0034
Set17(6)	0.1768	0.0074
Set18(6)	0.2216	-0.0030
Set19(6)	0.1921	0.0015
Set20(10)	0.1620	0.0262
Set21(10)	0.1753	0.0010
Set22(10)	0.1646	0.0086
Set23(10)	0.1683	0.0132
Set24(10)	0.2053	0.0122
Set25(10)	0.1906	0.0038
Set26(10)	0.2130	0.0028
Set27(10)	0.1859	0.0004
Set28(6)	0.1910	-0.0022
Set29(8)	0.1587	0.0214
Set30(10)	0.1546	0.0148
Set31(10)	0.1543	0.0203
Set32(10)	0.1468	0.0172
Set33(10)	0.2201	0.0081

TABLE XX: Results for set optimization part with \mathcal{E}_T significance > 4.0 applied to all sets. The number in parenthesis refers to number of hidden nodes in each case.

Set of variables	\mathcal{E}_T significance cut	RMS	mean
Set32(10)	3.0	0.1507	0.0157
Set32(10)	3.5	0.1559	0.0189
Set32(10)	4.0	0.1468	0.0172
Set32(10)	4.5	0.1511	0.0153
Set32(10)	5.0	0.1552	0.0205

TABLE XXI: Results for \mathcal{E}_T significance optimization part when varying the \mathcal{E}_T significance cut The number in parenthesis refers to number of hidden nodes in each case.

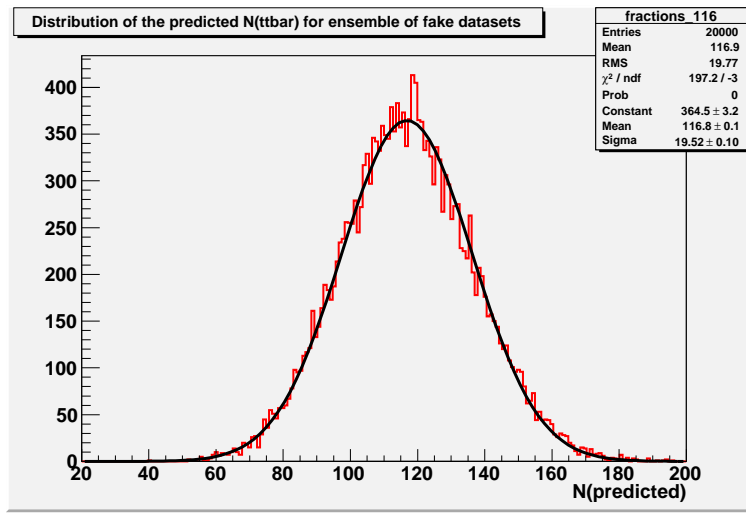


FIG. 9: Distribution of the output “measurement” for an ensemble with 116.9 $t\bar{t}$ events.

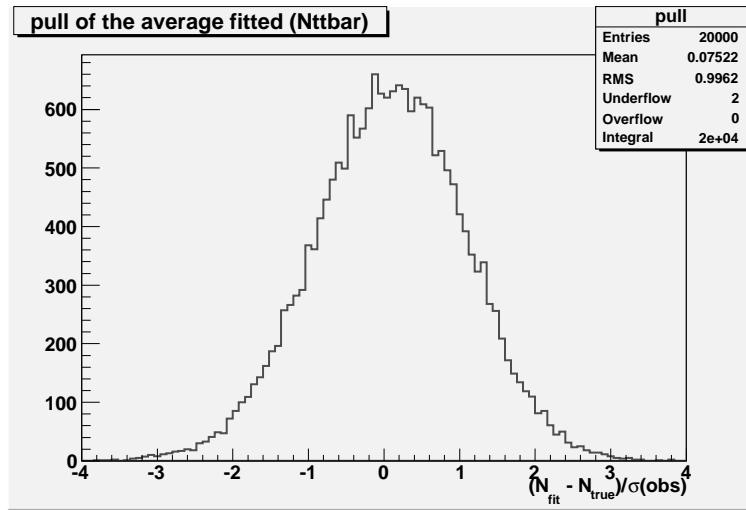


FIG. 10: The ensemble test’s pull.

488 In order to check the validity of our ensemble tests procedure, it is instructive to plot both the distribution
 489 of the predicted number of $t\bar{t}$ and what is called “pull”, defined in Equation 7 below:

$$p = \frac{(N_{fit} - N_{true})}{\sigma_{fit}} \quad (7)$$

490 where σ_{fit} is the error on the number of $t\bar{t}$ pairs given by the fit.

491 Figures 9 and 10 show both beforementioned distributions.

492 From Figure 9 we see a good agreement between the number of $t\bar{t}$ pairs initially set in the ensemble and
 493 the measured value. And Figure 10 shows a nice gaussian curve, that indicates a good behaviour of the fit
 494 uncertainties in the ensembles.

496 In this section we show plots of the topological variables used in this analysis in order to check the
 497 agreement between data and Monte Carlo in all cases. Plots are separated in two kinds: signal sample and
 498 b-veto control plots.

499

A. Signal sample plots

500 As stated in Section VII the signal sample is the one we used to perform the measurement. The cuts here
 501 consist of $NN(\tau) > 0.90$ for taus types 1 and 2, $NN(\tau) > 0.95$ for taus type 3, and at least one NN b-tag.
 502 This sample contains a good amount of $t\bar{t}$ (19.7% for types 1 and 2 and 8.6% for type 3) as shown in Tables
 503 XIV and XV. Next we show the plots of the topological variables for this sample. The error bars represent
 504 the statistical uncertainties only.

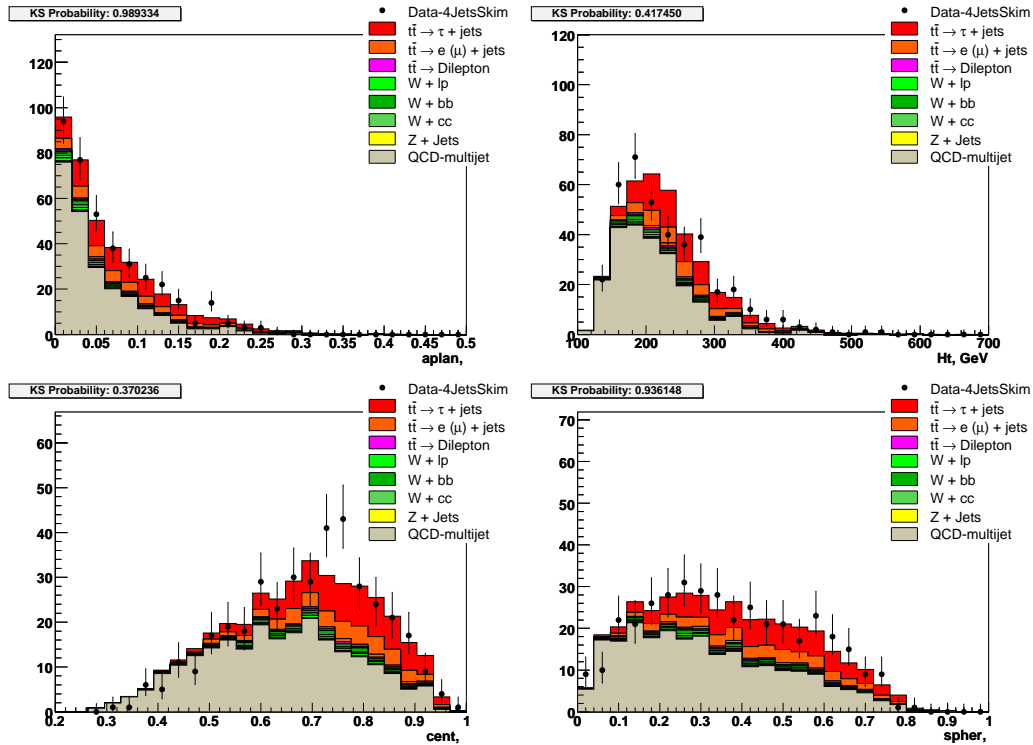


FIG. 11: The topological variables in the signal sample (τ types 1 and 2). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating the level of agreement.

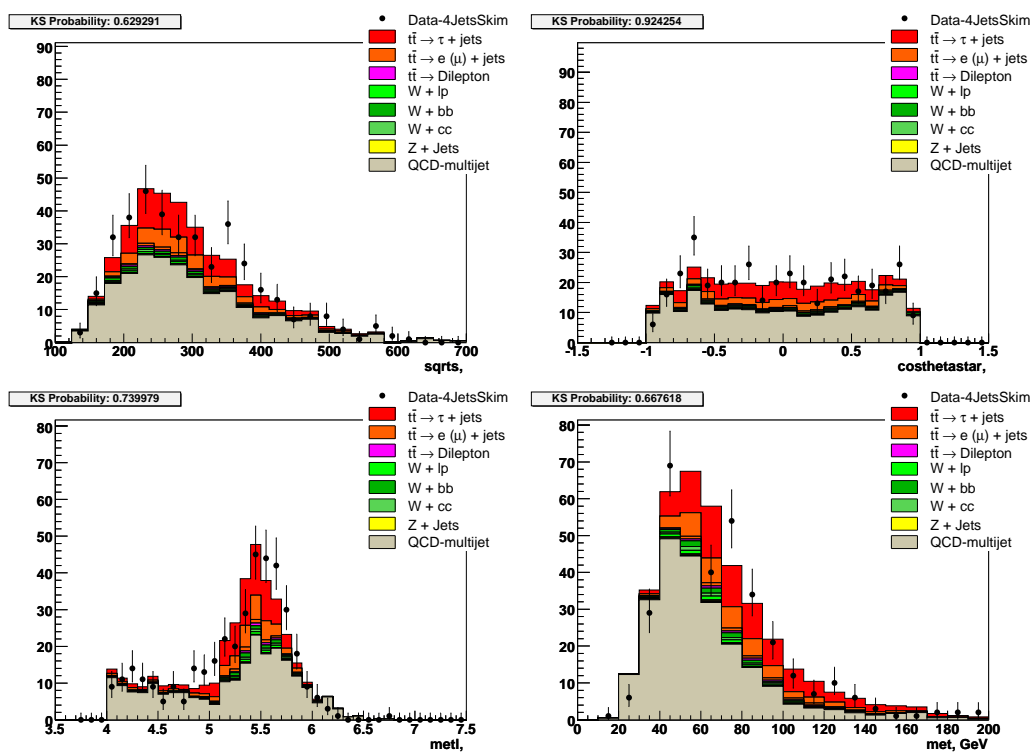


FIG. 12: The topological variables in the signal sample (τ types 1 and 2). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating the level of agreement.

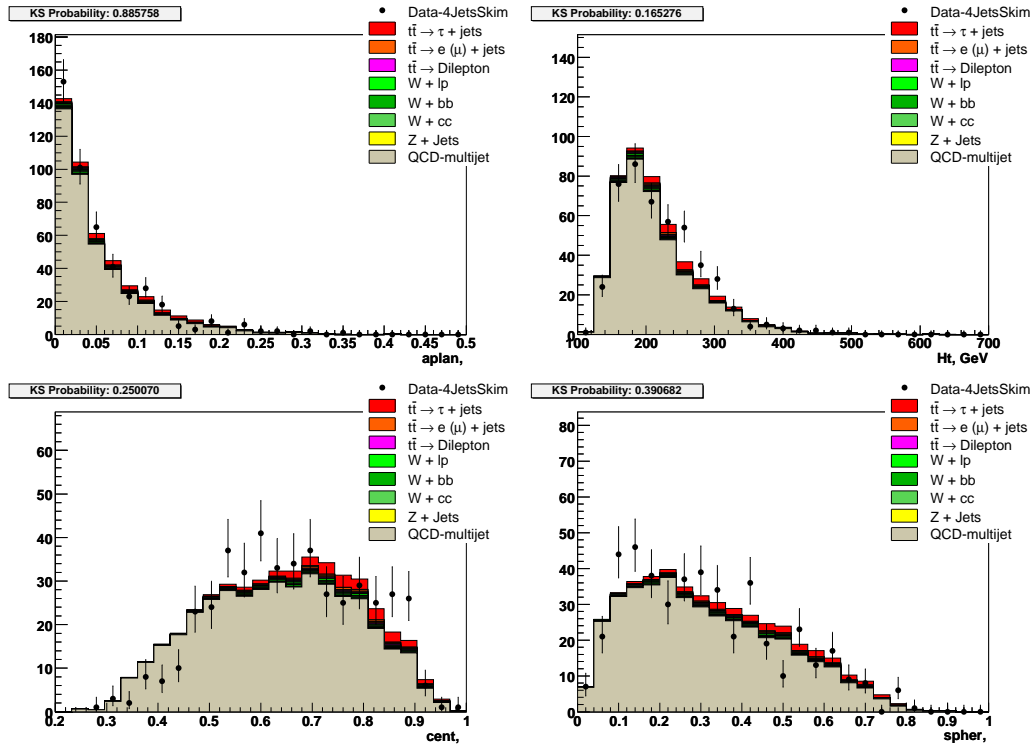


FIG. 13: The topological variables in the signal sample (τ types 3). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating the level of agreement.

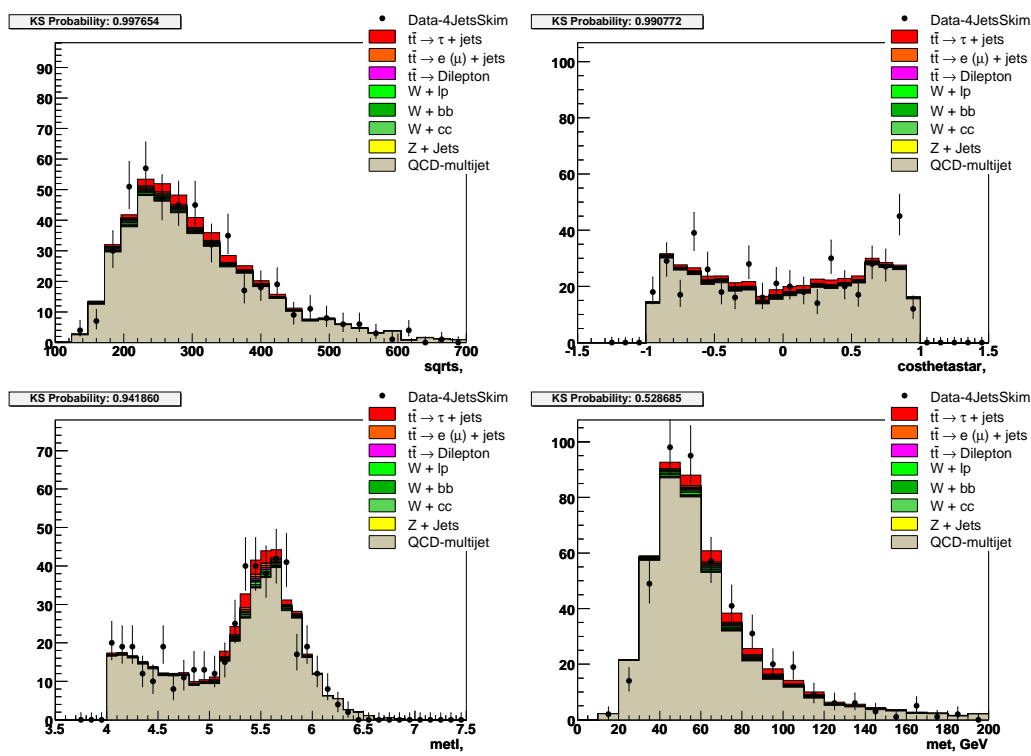


FIG. 14: The topological variables in the signal sample (τ types 3). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating the level of agreement.

506 The b-veto sample is the one used to test our QCD modelling VII. As it requires no NN b-tags it is
 507 QCD-dominated and has a tiny amount of $t\bar{t}$ (1.9% for types 1 and 2 and 0.7% for type 3) as shown in
 508 Tables XVI and XVII. It consists of an ideal sample to make sure that the QCD modelling works and can
 509 be used in the measurement. Next we show the plots of the topological variables for this sample. The error
 510 bars represent the statistical uncertainties only.

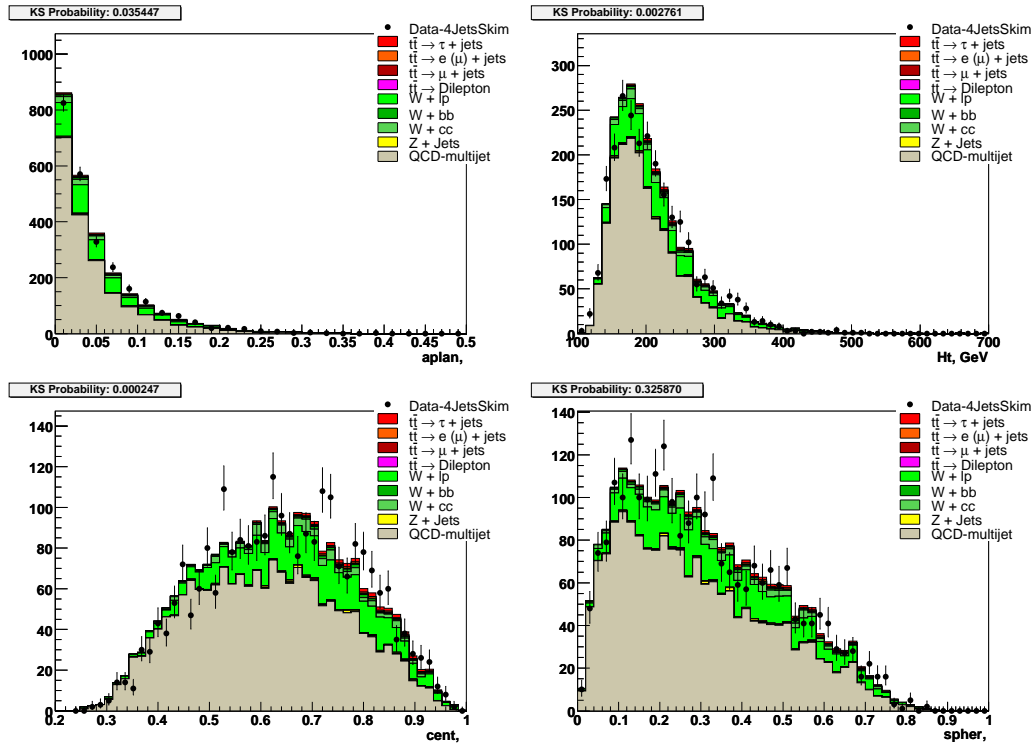


FIG. 15: The topological variables in the b-veto control sample (τ types 1 and 2). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating how good the agreement is.

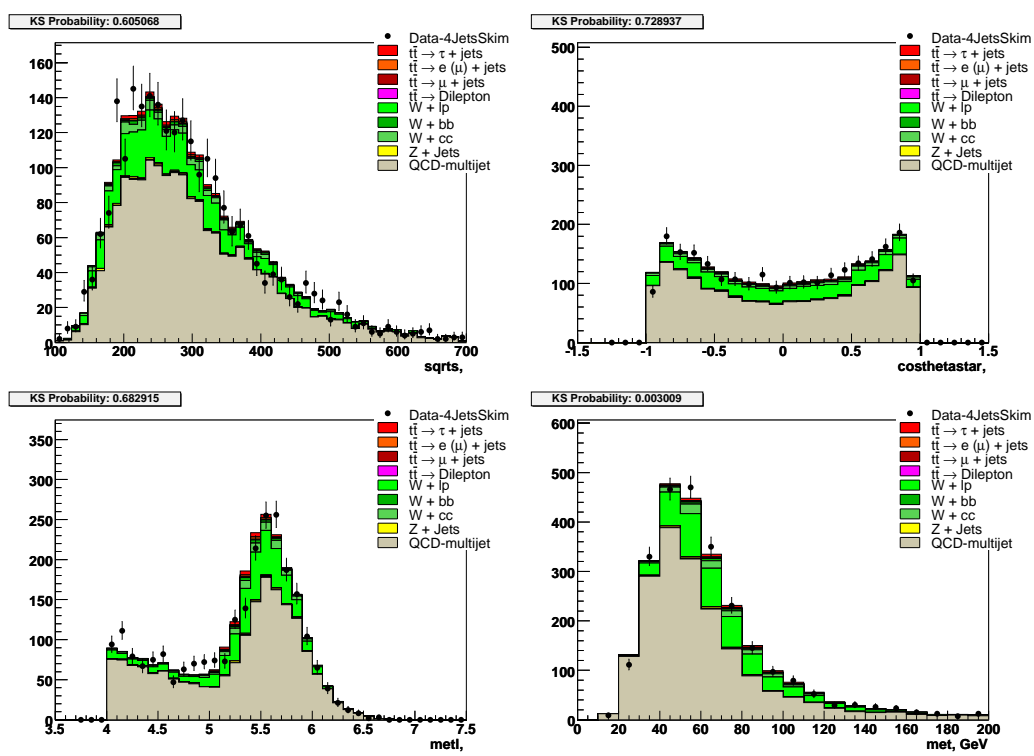


FIG. 16: The topological variables in the b-veto control sample (τ types 1 and 2). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating how good the agreement is.

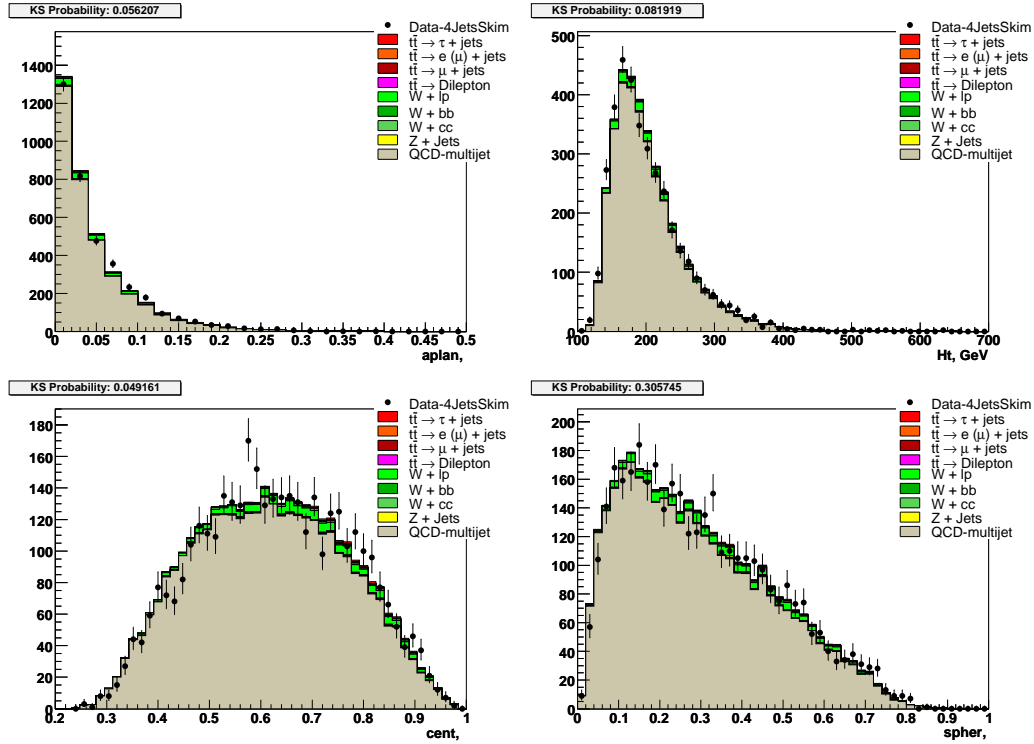


FIG. 17: The topological variables in the b-veto control sample (τ types 3). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating how good the agreement is.

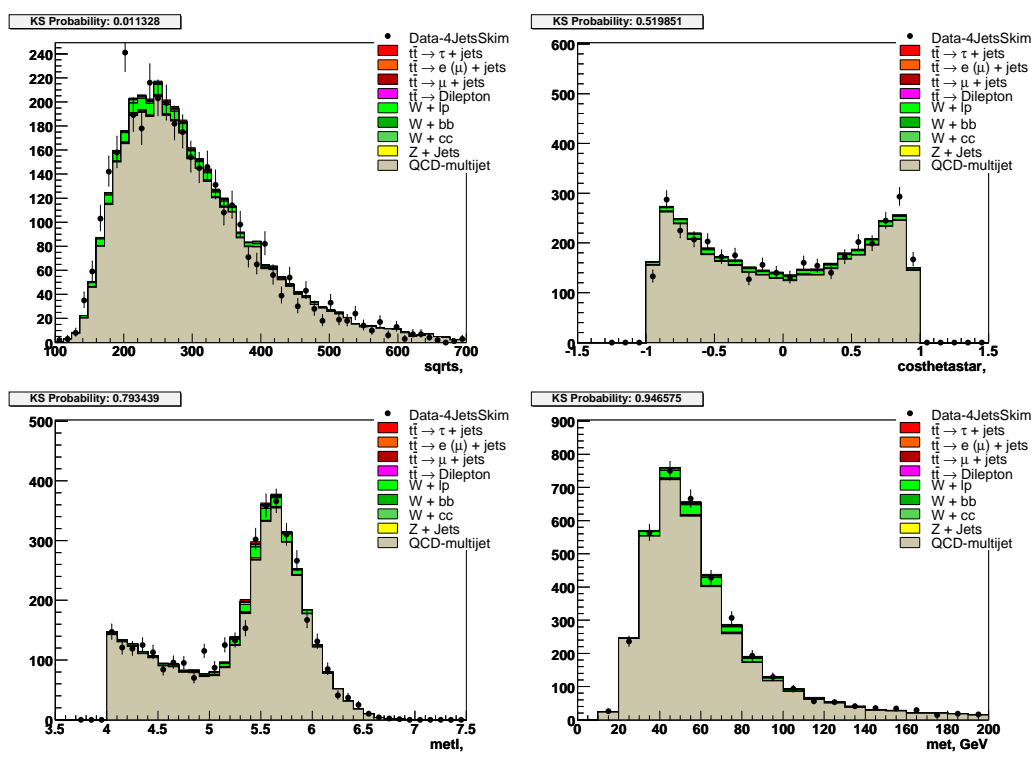


FIG. 18: The topological variables in the b-veto control sample (τ types 3). The Kolmogorov-Smirnov (KS) probabilities are shown, indicating how good the agreement is.

512 Having presented the preselection yields on Section VI we now show the results of the efficiencies for τ ID,
 513 b-tagging and trigger for all $t\bar{t}$ channels

Selection	Relative(%)	Cumulative(%)
τ ID	22.20 ± 0.24	22.20 ± 0.24
Trigger	84.54 ± 0.55	18.77 ± 0.22
b-tagging	61.82 ± 0.55	11.61 ± 0.16

TABLE XXII: $t\bar{t} \rightarrow \tau + jets$ final cut flow for taus types 1 and 2

Selection	Relative(%)	Cumulative(%)
τ ID	12.37 ± 0.21	12.37 ± 0.21
Trigger	84.79 ± 0.75	10.49 ± 0.19
b-tagging	59.63 ± 0.75	6.26 ± 0.13

TABLE XXIII: $t\bar{t} \rightarrow \tau + jets$ final cut flow for taus type 3

Selection	Relative(%)	Cumulative(%)
τ ID	10.81 ± 0.20	10.81 ± 0.20
Trigger	83.40 ± 0.81	9.02 ± 0.18
b-tagging	61.30 ± 0.82	5.52 ± 0.12

TABLE XXIV: $t\bar{t} \rightarrow e + jets$ final cut flow for taus types 1 and 2

Selection	Relative(%)	Cumulative(%)
τ ID	2.25 ± 0.11	2.25 ± 0.11
Trigger	83.62 ± 1.77	1.88 ± 0.09
b-tagging	58.26 ± 1.76	1.10 ± 0.06

TABLE XXV: $t\bar{t} \rightarrow e + jets$ final cut flow for taus type 3

Selection	Relative(%)	Cumulative(%)
τ ID	3.38 ± 0.19	3.38 ± 0.19
Trigger	84.44 ± 2.13	2.86 ± 0.17
b-tagging	61.25 ± 2.16	1.75 ± 0.11

TABLE XXVI: $t\bar{t} \rightarrow \mu + jets$ final cut flow for taus types 1 and 2.

Selection	Relative(%)	Cumulative(%)
τ ID	3.88 ± 0.21	3.88 ± 0.21
Trigger	82.79 ± 2.04	3.21 ± 0.18
b-tagging	58.11 ± 2.05	1.87 ± 0.11

TABLE XXVII: $t\bar{t} \rightarrow \mu + jets$ final cut flow for taus type 3

Selection	Relative(%)	Cumulative(%)
τ ID	21.18 ± 0.37	21.18 ± 0.37
Trigger	79.56 ± 0.90	16.85 ± 0.34
b-tagging	62.83 ± 0.92	10.59 ± 0.25

TABLE XXVIII: $t\bar{t} \rightarrow dilepton$ final cut flow for taus types 1 and 2

Selection	Relative(%)	Cumulative(%)
τ ID	14.73 ± 0.34	14.73 ± 0.34
Trigger	78.78 ± 1.08	11.60 ± 0.30
b-tagging	63.62 ± 1.11	7.38 ± 0.22

TABLE XXIX: $t\bar{t} \rightarrow$ dilepton final cut flow for taus type 3.

514 After having computed all efficiencies it is worthy to summarize all of them (in %) for the different tau
515 types:

Channel	Preselection	τ ID	Trigger	b-tag
$t\bar{t} \rightarrow \tau + jets$	3.70 ± 0.02	22.20 ± 0.24	18.77 ± 0.22	11.61 ± 0.16
$t\bar{t} \rightarrow e + jets$	3.54 ± 0.02	10.80 ± 0.20	9.02 ± 0.18	5.53 ± 0.12
$t\bar{t} \rightarrow \mu + jets$	1.67 ± 0.01	3.38 ± 0.19	2.86 ± 0.17	1.75 ± 0.11
$t\bar{t} \rightarrow dilepton$	1.36 ± 0.01	21.18 ± 0.37	16.85 ± 0.34	10.59 ± 0.25

TABLE XXX: Summary of all selections for taus type 1 & 2.

Channel	Preselection	τ ID	Trigger	b-tag
$t\bar{t} \rightarrow \tau + jets$	3.70 ± 0.02	12.37 ± 0.21	10.49 ± 0.19	6.26 ± 0.13
$t\bar{t} \rightarrow e + jets$	3.54 ± 0.02	2.25 ± 0.11	1.88 ± 0.09	1.10 ± 0.06
$t\bar{t} \rightarrow \mu + jets$	1.67 ± 0.01	3.88 ± 0.21	3.21 ± 0.18	1.87 ± 0.11
$t\bar{t} \rightarrow dilepton$	1.36 ± 0.01	14.73 ± 0.34	11.60 ± 0.30	7.38 ± 0.22

TABLE XXXI: Summary of all selections for taus type 3.

516 Table below summarizes the number of events in each channel after final selection.

TABLE XXXII: Final number of events in the two analysis channels.

	τ type I,II	τ type I,II (fitted)	τ type III	τ type III (fitted)
data	386		459	
$t\bar{t} \rightarrow \tau + jets$	72.04 ± 0.53		38.82 ± 0.39	
$t\bar{t} \rightarrow e + jets$	38.35 ± 0.36		6.52 ± 0.16	
$t\bar{t} \rightarrow \mu + jets$	4.81 ± 0.14		5.14 ± 0.14	
$t\bar{t} \rightarrow l + l$	6.02 ± 0.07		4.20 ± 0.06	
$t\bar{t}$ total MC		121.22 ± 0.43		54.68 ± 0.20
$t\bar{t}$ total fitted		133.04 ± 17.09		33.12 ± 15.04
W+jets	17.82 ± 0.33		11.26 ± 0.23	
Z+jets	2.78 ± 0.14		2.39 ± 0.12	
QCD		232.35 ± 17.09		412.22 ± 15.04
Signal significance		6.77		1.54
S/B ratio		0.52		0.08

517 The cross section was measured by minimizing the sum of the negative log-likelihood functions for each
518 bin of both the types 1 and 2 channel and the type 3 τ channel. These are functions used by MINUIT to
519 perform fits shown in Figs 5 and 6 in Section VIII B. But there L was function of $f(QCD)$ and now we want
520 to use it to measure the cross section, so we must express it in terms of $\sigma(t\bar{t})$:

$$L(\sigma, \tilde{N}_i, N_i^{obs}) \equiv -\log\left(\prod_i \frac{\tilde{N}_i^{N_i^{obs}}}{N_i^{obs}!} e^{-\tilde{N}_i}\right) \quad (8)$$

521 where $\tilde{N}_i = \sigma \times BR \times \mathcal{L} \times \epsilon(t\bar{t})_i + N_{bkg}$ is number events predicted in bin i of the data NN distribution and N_i^{obs}
522 is the actual count observed in that bin. The cross-section is then the minimum value of each function. But,
523 as stressed out in Section VII, we have to take into account both signal ($t\bar{t}$) and electroweak contamination
524 in the loose-tight sample we use to model QCD in the high NN region used for the measurement. The
525 electroweak component is small and therefore it is kept fixed during the fit and subtracted from the loose-
526 tight sample. However, as dicussed before, the numbers for signal contamination are 5.4% and 3.0% for taus
527 types 1 and 2 and type 3 respectively when we assumed a $t\bar{t}$ cross section of 7.46 pb. This means that 5.4%
528 (12.55 events) of 232.35 QCD events for taus types 1 and 2 are actually $t\bar{t}$ events and 3.0% (12.37 events)
529 of 412.22 QCD events for taus type 3 are actually $t\bar{t}$ events. 12.55 and 12.37 events represent increases of
530 9.43% and 37.35% on the number of signal events for types 1 and 2 and type 3 respectively. However this is
531 not the final measurement yet since the cross-section measurement only makes sense if the cross-section we
532 measure in the and is the same as the one we have assumed to normalize $t\bar{t}$ MC samples. This means that
533 we had to iterate back by normalizing the signal samples until we found a convergence of the cross-section.
534 Table XXIII summarizes the iteration process.

Assumed $\sigma(t\bar{t})$ (pb)	signal contamination for types 1 & 2 (%)	signal contamination for type 3 (%)	measured $\sigma(t\bar{t})$ (pb)
7.46	5.4	3.0	8.37
8.37	6.1	3.3	8.42
8.42	6.2	3.4	8.46
8.46	6.2	3.4	8.46

TABLE XXXIII: Cross-section iteration process.

535 Table above shows that when we assumed a cross-section of 8.46 pb we measured the exact same value,
536 which means that we had to take into account signal contaminations of 6.2% (14.40 events) and 3.4% (14.02
537 events) for taus types 1 and 2 and 3 respectively. This represents an increase in the number of signal events
538 of 10.82% for types 1 and 2 and 42.33% for type 3. By considering such events as part of the signal $t\bar{t}$ sample
539 we measure for the cross-sections:

τ +jets types 1 and 2 cross section:

$$\sigma(t\bar{t}) = 8.83 \begin{matrix} +1.14 \\ -1.12 \end{matrix} \text{ (stat)} \begin{matrix} +0.89 \\ -0.94 \end{matrix} \text{ (syst)} \pm 0.3 \text{ (lumi) pb,}$$

τ +jets type 3 cross section:

$$\sigma(t\bar{t}) = 6.06 \begin{matrix} +2.77 \\ -2.62 \end{matrix} \text{ (stat)} \begin{matrix} +0.94 \\ -0.99 \end{matrix} \text{ (syst)} \pm 0.3 \text{ (lumi) pb,}$$

Combined cross section:

$$\sigma(t\bar{t}) = 8.46 \begin{matrix} +1.06 \\ -1.04 \end{matrix} \text{ (stat)} \begin{matrix} +0.92 \\ -0.88 \end{matrix} \text{ (syst)} \pm 0.3 \text{ (lumi) pb.}$$

540 The correspondent likelihoods of these measurements are shown in Figures 19, 20 and 21. Figures 22, 23
541 and 24 show zoomed in graphs of the same likelihood functions described above.

542 All associated systematics concerning this measurement can be seen in Table XXXVI.

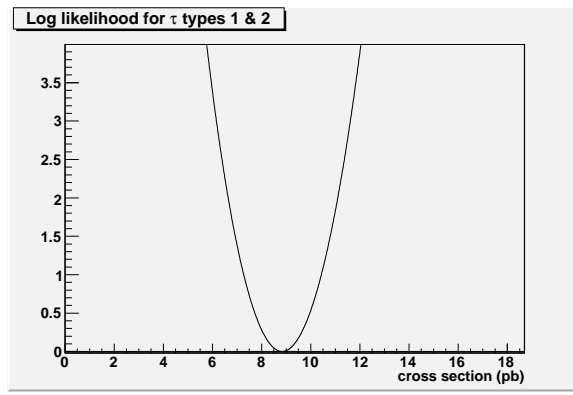


FIG. 19: The log likelihood function for type 1 and 2 τ channel

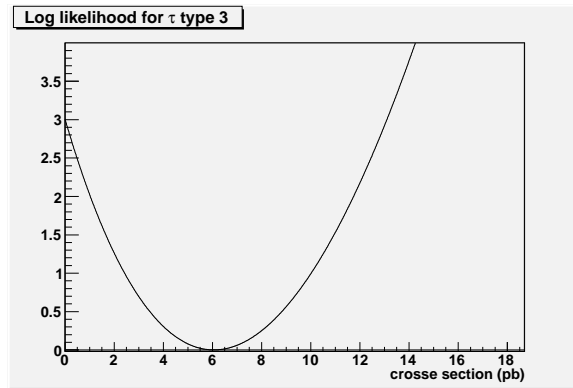


FIG. 20: The log likelihood function for type 3 τ channel

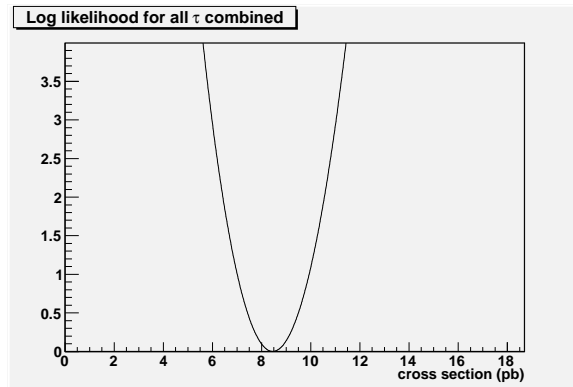


FIG. 21: The log likelihood function for all three types combined

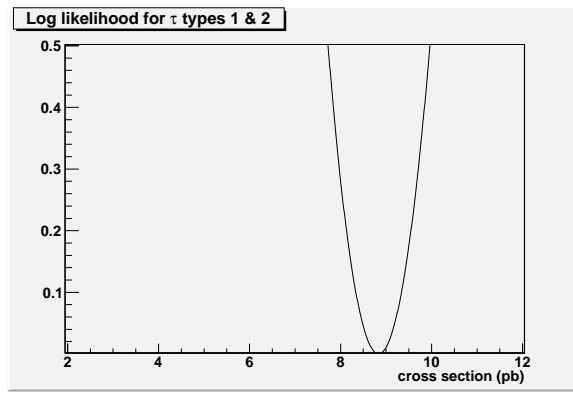


FIG. 22: Zoom in of the log likelihood function for type 1 and 2 τ channel

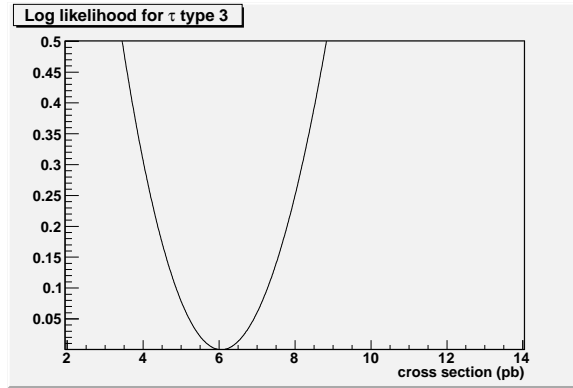


FIG. 23: Zoom in of the log likelihood function for type 3 τ channel

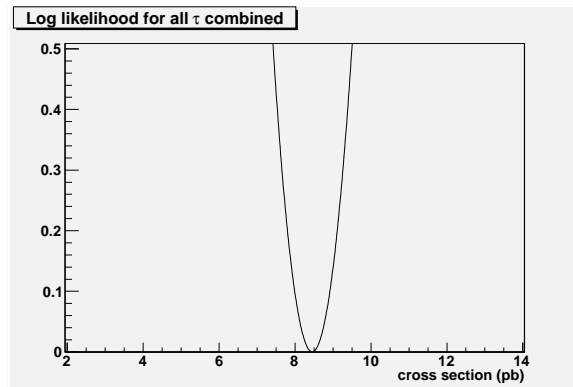


FIG. 24: Zoom in of the log likelihood function for all three types combined

543 After measuring the combined cross section we observed a significant higher statistical uncertainty value if
544 compared to the one we expected to see based on the fact that we have approximately 5 times more data than
545 in p17, where the signal contamination was not taken into account (see Appendix G). Further investigation
546 showed that the cut $N_{\text{Nelec}} > 0.9$ applied to taus type 2 only was responsible for such discrepancy. Below
547 we show the same measurement as done above but now with no N_{Nelec} cut applied.

548 Table below summarizes the number of events in each channel after final selection.

TABLE XXXIV: Final number of events in the two analysis channels.

	τ type I,II	τ type I,II (fitted)	τ type III	τ type III (fitted)
data	583		459	
$t\bar{t} \rightarrow \tau + jets$	85.46 ± 0.58		38.82 ± 0.39	
$t\bar{t} \rightarrow e + jets$	175.23 ± 0.85		6.52 ± 0.16	
$t\bar{t} \rightarrow \mu + jets$	8.98 ± 0.19		5.14 ± 0.14	
$t\bar{t} \rightarrow l + l$	12.62 ± 0.10		4.18 ± 0.06	
$t\bar{t}$ total MC		282.27 ± 1.05		54.67 ± 0.41
$t\bar{t}$ total fitted		260.71 ± 20.74		35.73 ± 15.28
W +jets	39.65 ± 0.50		11.26 ± 0.25	
Z +jets	4.56 ± 0.10		2.38 ± 0.11	
QCD		278.04 ± 20.74		409.62 ± 15.28
Signal significance		10.80		1.67
S/B ratio		0.80		0.08

549 Table below shows the iteration process in this case and and the cross section measurement follows:

Assumed $\sigma(t\bar{t})$ (pb)	signal contamination for types 1 & 2 (%)	signal contamination for type 3 (%)	measured $\sigma(t\bar{t})$ (pb)
7.46	6.0	3.0	6.84
6.84	5.4	2.7	6.91
6.91	5.5	2.8	6.92
6.92	5.5	2.8	6.92

TABLE XXXV: Cross-section iteration process.

τ +jets types 1 and 2 cross section:

$$\sigma(t\bar{t}) = 7.03^{+0.54}_{-0.56} \text{ (stat)} \quad ^{+0.65}_{-0.61} \text{ (syst)} \pm 0.3 \text{ (lumi) pb,}$$

τ +jets type 3 cross section:

$$\sigma(t\bar{t}) = 4.36^{+2.62}_{-2.50} \text{ (stat)} \quad ^{+0.62}_{-0.61} \text{ (syst)} \pm 0.3 \text{ (lumi) pb,}$$

Combined cross section:

$$\sigma(t\bar{t}) = 6.92^{+0.54}_{-0.54} \text{ (stat)} \quad ^{+0.62}_{-0.60} \text{ (syst)} \pm 0.3 \text{ (lumi) pb,}$$

550 As we can see the statistical uncertainty decreases to 0.54 pb which is in a good agreement to what we
551 would expect if compared to 1.2 pb measured in p17. Appendix G shows cross sections measurements when
552 signal contamination is not taken into account for both $N_{\text{Nelec}} > 0.9$ and no N_{Nelec} cut applied. Once again
553 we observed a discrepancy when N_{Nelec} is applied and the expected value when N_{Nelec} is not applied.

554

555 Several factors contribute to systematic uncertainties in the measurement. Here we describe such uncer-
556 tainties.

557

A. JES

558 The jet energy scale (JES) systematic is determined by shifting the jet energy scale by $\pm 1\sigma$ in all MC
559 samples.

560

B. TES

561 The tau energy scale (TES) systematic is determined by shifting the tau energy scale by its uncertainty as
562 given in [36].

563

C. Jet Energy Resolution and Jet ID

564 The jet energy resolution (JER) systematic is determined by shifting the jet energy resolution by $\pm 1\sigma$ in
565 all MC samples.

566

D. Trigger

567 Each event was corrected by the ratio of the actual and predicted trigger result as a function of H_T , which
568 was used based on the fact that the agreement varies as function of it.

569

E. b-quark fragmentation

570 This uncertainty is estimated using the standard procedure described in [17] by reweighting $t\bar{t}$ events using
571 different fragmentation functions.

572

F. b-tagging

573 b-tagging uncertainty effects are taken into account by varying the systematic and statistical errors on the
574 MC tagging weights.

575 These errors (which are computed using standard DØ b ID group tools) arise from several independent
576 sources [27]:

577

- B-jet tagging parameterization.

578

- C-jet tagging parameterization.

579

- Light jet tagging parameterization (negative tag rate).

580

- Semi-leptonic b-tagging efficiency parameterization in MC and in data (System 8).

581

- Taggability. This includes the statistical error due to finite statistic in the samples from which it had
582 been derived and systematic, reflecting the (neglected) taggability dependence on the jet multiplicity.

584 Here we include systematics associated to the NN cut (NN > 0.90 for taus types 1 and 2 and NN > 0.95 for
 585 taus type 3) applied to select hadronic taus. As recommended by the τ -ID group these systematics are 9.5%,
 586 3.5% and 5.0% for taus type 1, 2 and 3 respectively. However in this analysis we chose treat taus types 1
 587 and 2 together. This led us to combine their uncertainties in the following way

$$sys_{12} = \sqrt{\epsilon_1^2 * f_1^2 + \epsilon_2^2 * f_2^2} \quad (9)$$

588 where ϵ_1 and ϵ_2 are the τ ID efficiencies for taus types 1 and 2 respectively and f_1 and f_2 are the fractions
 589 of taus types 1 (0.16) and 2 (0.84) respectively.

590

H. QCD systematics

591 As explained in the section VIII A we use the control (b-veto) data set to validate our method of modeling
 592 the multijet background. Therefore we have to use the same sample to evaluate the associated uncertainties.
 593 The way it was done is by reweighting topological event NN for QCD template (“loose-tight” τ), so that it
 594 matches the one for “tight” τ data exactly (electroweak backgrounds were subtracted).

595

I. W and Z scale factors

596 We apply a scale factor of 1.47 to both W + bb and W + cc events with an uncertainty of 15%. At the
 597 same time a scales factors of 1.52 and 1.67 are applied to Z + bb and Z + cc events, both with an uncertainty
 598 of 20%.

599

J. Template statistics

600 When we performed the template fit to data (Section VIII) the QCD template had limited statistics (1132
 601 events for taus types 1 and 2 and 4487 events for taus type 3). We have to take the statistical uncertainty
 602 in this histogram as one of the cross section systematics. It was calculated by varying the content of each
 603 bin of the QCD template NN distribution within its uncertainty and observing how the cross section result
 604 changed.

605

K. $t\bar{t}$ contamination in the loose-tight sample

606 When measuring the cross-section we had to take into account the signal contamination in the loose-tight
 607 sample we use to model QCD in the high NN region. The systematic uncertainty in this case is calculated by
 608 varying the final assumed cross section by $\pm 1\sigma$, re-estimating the signal contamination and finally measuring
 609 the up and down values of the cross section.

610

L. PDF

611 Systematics on Parton Distribution Functions (PDF) are estimated by reweighting signal $t\bar{t}$ MC from
 612 CTEQ6L1 to CTEQ6.1m and its twenty error PDF’s. The reweighting of the PDF’s is done by using
 613 `caf.pdfreweight` package tool on Pythia $t\bar{t}$ MC. We then assigned the relative PDF uncertainty obtained
 614 with Pythia on the Alpgen $t\bar{t}$ MC.

616 Here we take the $D\bar{O}$ standard measured uncertainty on luminosity of 6.1% .

617 Tables XXXVI and XXXVII summarize all of these uncertainty sources and shows how the resulting cross
618 section shifts.

TABLE XXXVI: Systematic uncertainties on $\sigma(t\bar{t})$ (in pb) for $N_{\text{Nleec}} > 0.9$.

Channel	τ +jets types 1 and 2	τ +jets type 3	Combined
Tau Energy Scale	+0.068, -0.102	+0.340, -0.306	+0.136, -0.136
Jet Energy Scale	+0.051, -0.034	+0.051, -0.085	+0.051, -0.000
Jet Energy Resolution	+0.102, -0.051	+0.204, -0.034	+0.119, -0.052
Jet ID	+0.204, -0.204	+0.153, -0.153	+0.204, -0.204
b-tag	+0.562, -0.493	+0.493, -0.426	+0.544, -0.477
b-fragmentation	+0.102, -0.102	+0.068, -0.068	+0.085, -0.085
QCD Modeling	+0.340, -0.340	+0.221, -0.221	+0.324, -0.305
τ ID	+0.272, -0.272	+0.306, -0.306	+0.290, -0.290
Trigger	+0.256, -0.256	+0.238, -0.238	+0.256, -0.256
W Scale Factor	+0.034, -0.034	+0.034, -0.034	+0.034, -0.034
Z Scale Factor	+0.072, -0.072	+0.072, -0.072	+0.048, -0.048
Template statistics	+0.156, -0.156	+0.204, -0.204	+0.168, -0.168
Signal contamination	+0.153, -0.153	+0.255, -0.272	+0.188, -0.170
PDF	+0.097, -0.084	+0.188, -0.198	+0.092, -0.081

TABLE XXXVII: Systematic uncertainties on $\sigma(t\bar{t})$ (in pb) when no N_{Nleec} cut is applied.

Channel	τ +jets types 1 and 2	τ +jets type 3	Combined
Tau Energy Scale	+0.101, -0.002	+0.238, -0.255	+0.102, -0.017
Jet Energy Scale	+0.016, -0.001	+0.017, -0.000	+0.016, -0.000
Jet Energy Resolution	+0.084, -0.086	+0.017, -0.034	+0.068, -0.085
Jet ID	+0.169, -0.169	+0.017, -0.017	+0.153, -0.153
b-tag	+0.424, -0.375	+0.358, -0.306	+0.425, -0.375
b-fragmentation	+0.069, -0.069	+0.102, -0.102	+0.068, -0.068
QCD Modeling	+0.271, -0.273	+0.153, -0.136	+0.225, -0.256
τ ID	+0.220, -0.220	+0.204, -0.204	+0.221, -0.221
Trigger	+0.204, -0.204	+0.170, -0.170	+0.204, -0.204
W Scale Factor	+0.034, -0.034	+0.034, -0.034	+0.034, -0.034
Z Scale Factor	+0.072, -0.072	+0.072, -0.072	+0.048, -0.048
Template statistics	+0.118, -0.118	+0.170, -0.170	+0.102, -0.102
Signal contamination	+0.050, -0.052	+0.136, -0.187	+0.051, -0.051
PDF	+0.097, -0.084	+0.188, -0.198	+0.092, -0.081

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621 [3] *Measurement of $\sigma(p\bar{p} \rightarrow t\bar{t}X)$ in $\tau + jets$ channel using 1 fb^{-1} of data*, DØ Note 5765.
622 [4] Commom Sample Group, <http://www-d0.fnal.gov/Run2Physics/cs/index.html>
623 [5] *Search for neutral Higgs bosons in $\phi b \rightarrow b\bar{b}$ using RunIIb data*, DØ Note 5709
624 [6] Commom Sample Group, <http://www-d0.fnal.gov/Run2Physics/cs/MC/MC.html>
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633 [13] *Systematics Uncertainties in Top Quark Measurements*, DØ Note 6024.
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637 [17] Y. Peters, M. Begel, K. Hamacher, and D. Wicke, *Reweighting of the fragmentation function for the DØ Monte*
638 *Carlo*, DØ Note 5325.
639 [18] N. Makovec and J.F. Grivaz, *Shifting, smearing, and removing simulated jets*, DØ Note 4914.
640 [19] *Search For MSSM Higgs Boson Production in the Decay $h \rightarrow \tau_\mu \tau_{had}$ with the DØ Detector at at $\sqrt{1.96} \text{ TeV}$* , DØ
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642 [20] *DØ τ ID certification*, DØ Note 4773.
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646 *struction*, DØ Note 4335.
647 [24] A. Harel, *Jet ID Optimization*, DØ note 4919.
648 [25] *Jet Energy Scale Determination at DØ Run II*, DØ Note 5382.
649 [26] A. Harel, *Capping the JES muon corrections*, DØ Note 5563.
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651 *Tool on p20 Data*, DØ Note 5554
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653 [29] T. Scalon and S. Greder, *Measurement of the p20 Fake Rate using Binned Fits do Data*, DØ Note 6046
654 [30] *Search for Single Top Quark Production with 1.0 fb^{-1}* , DØ Note 5285
655 [31] *Measurement of the $t\bar{t}$ cross section in the lepton+jets channel with 5.3 fb^{-1}* , DØ Note 6028.
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657 [33] *Measurement of the $t\bar{t} \rightarrow all - jets$ production cross section using Secondary Vertex Tagging*, DØ Note 4830
658 [34] *E_T significance Algorithm in RunII Data*, DØ Note 4254
659 [35] *Measurement of the top-antitop quark pair production cross section in proton-antiproton collisions at $\sqrt{1.96} \text{ TeV}$*
660 *in the lepton + jets final state*, DØ Note 5262
661 [36] <http://www-d0.hef.kun.nl//fullAgenda.php?ida=a092001&fid=57>.
662 [37] *DØ Search for Neutral Higgs Bosons at high $\tan \beta$ in the final state $\tau_\mu \tau_{hb}$ with 4.3 fb^{-1} of Run2b Data* , DØ
663 Note 6077.
664 [38] <http://schwind.home.cern.ch/schwind/MLPfit.html>

666 In this appendix we present the trigger weight distributions of all MC samples for different numbers of
 667 b-tagged jets. These are the weight distributions we referred to in Sections II A and III.

668

1. Trigger Efficiencies for $\tau + jets$

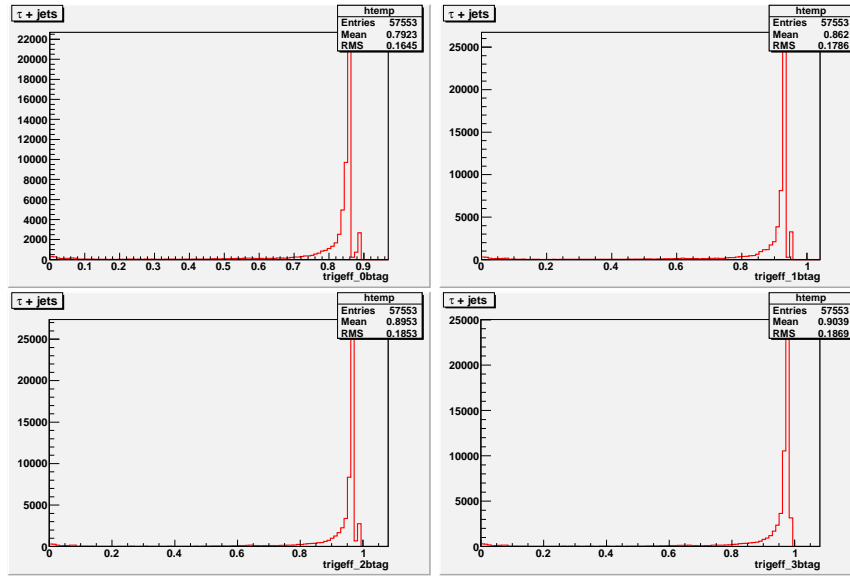


FIG. 25: Trigger Efficiencies for $\tau + jets$.

669

2. Trigger Efficiencies for $e + jets$

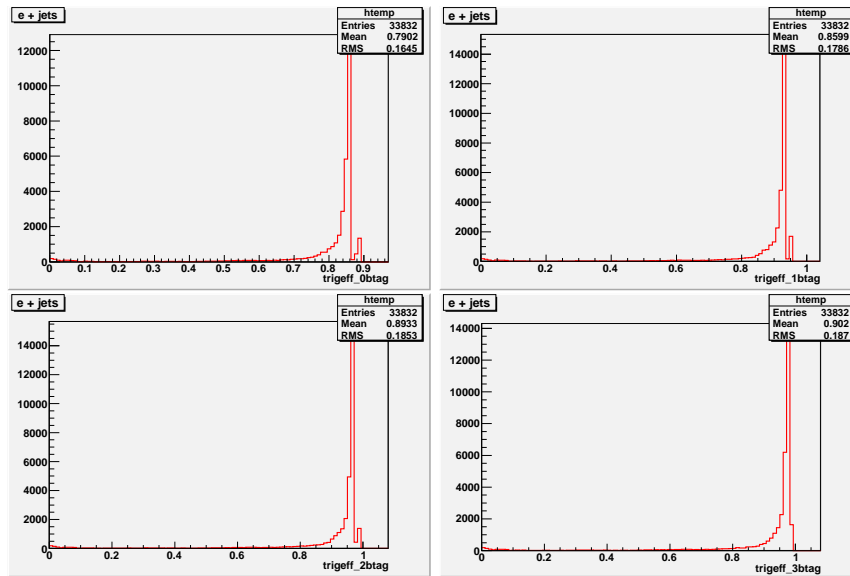
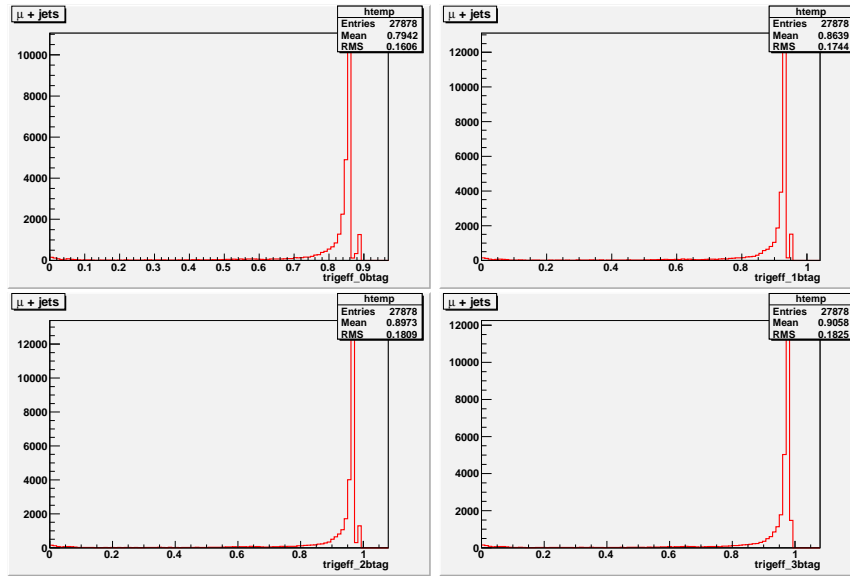
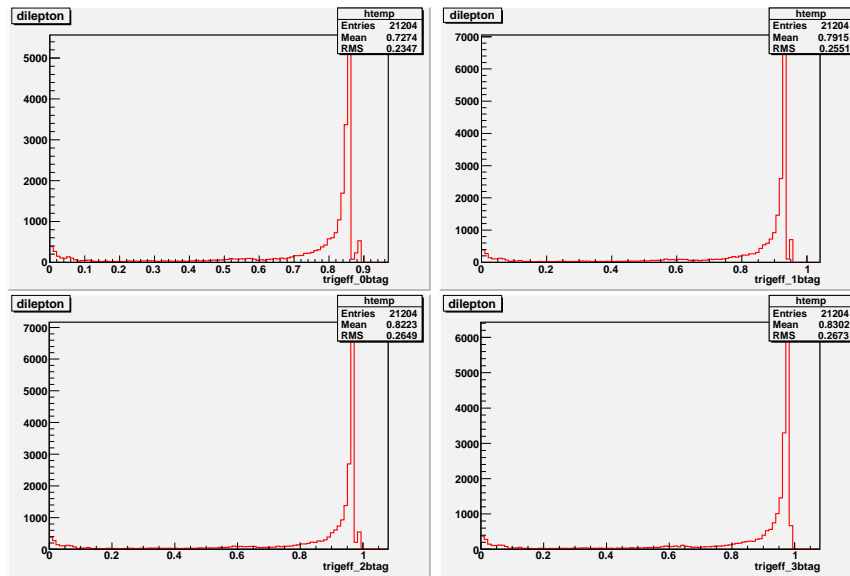
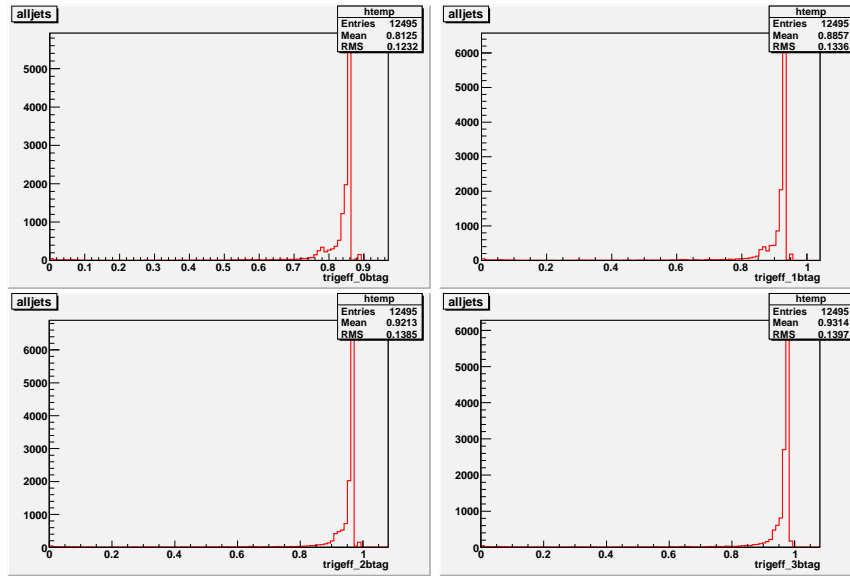
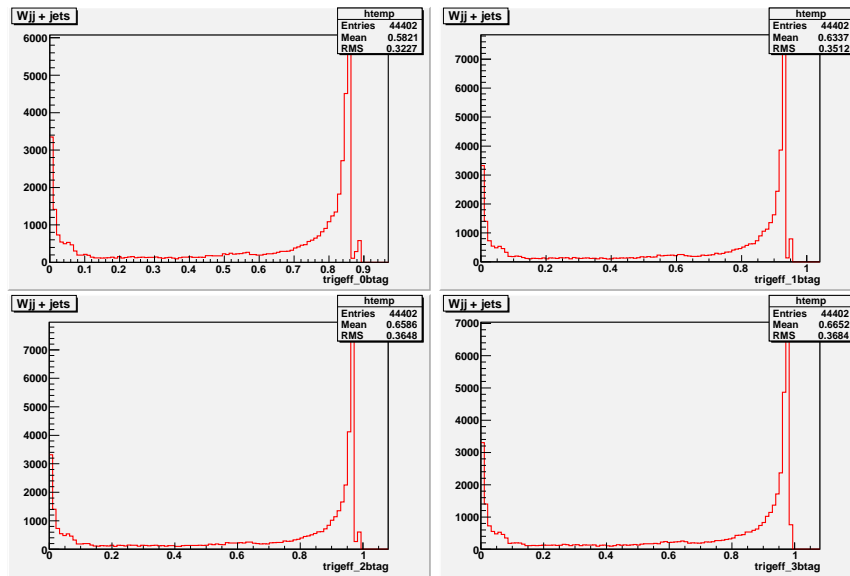
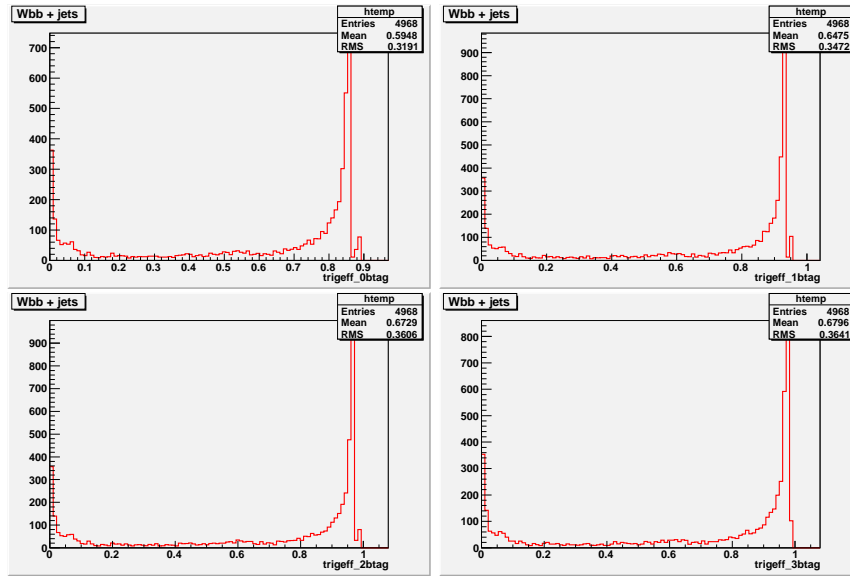
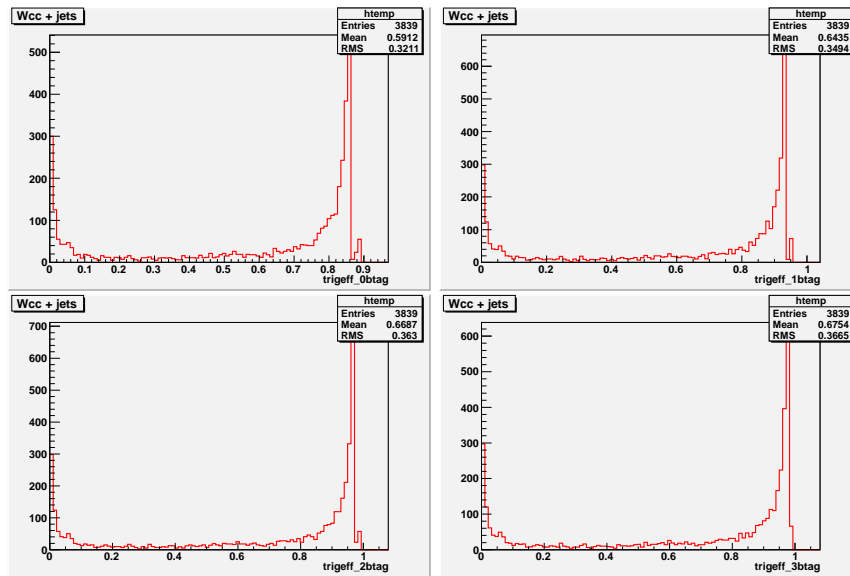
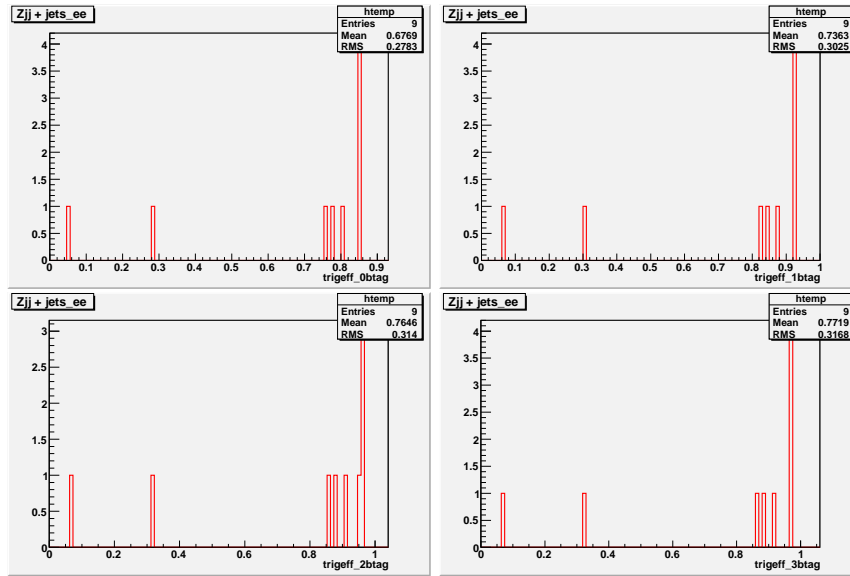
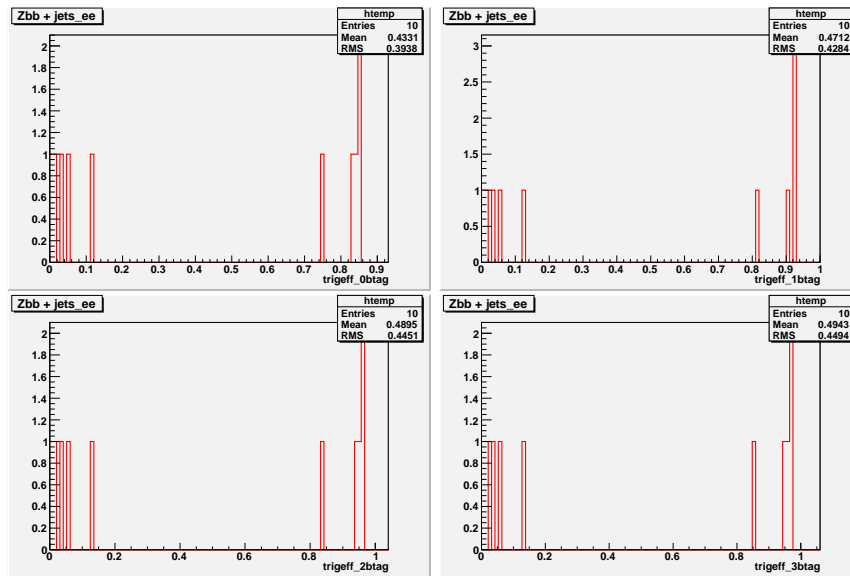


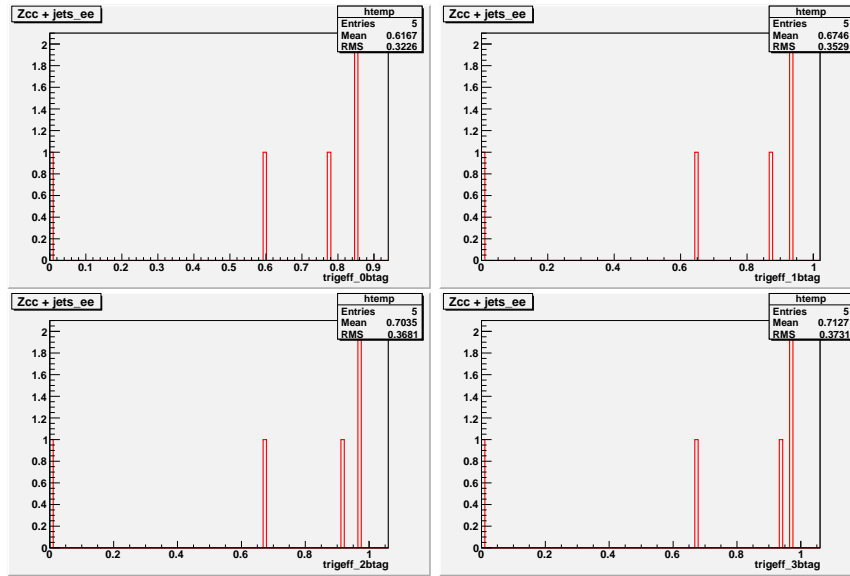
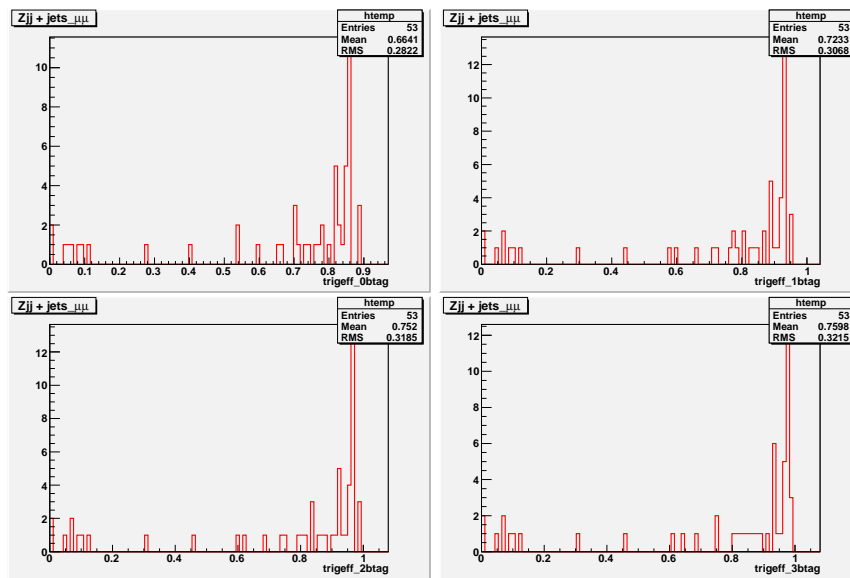
FIG. 26: Trigger Efficiencies for $e + jets$.

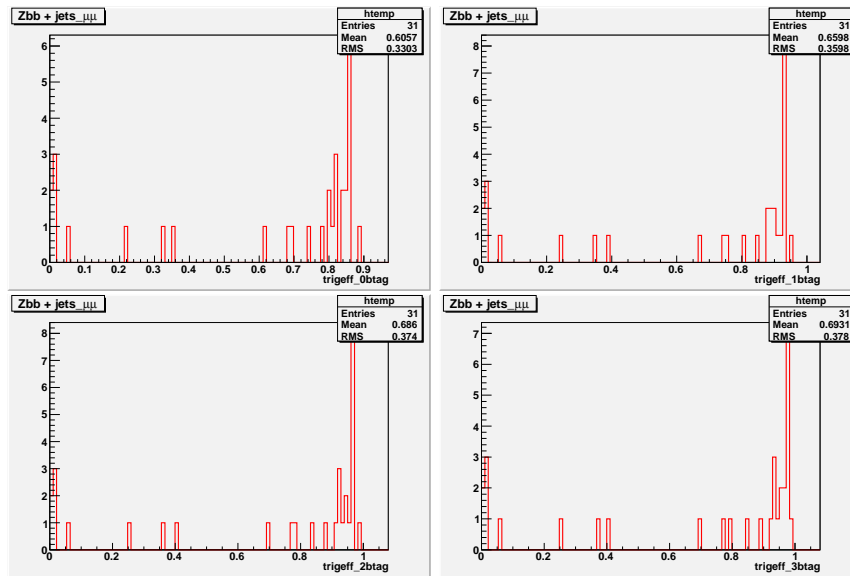
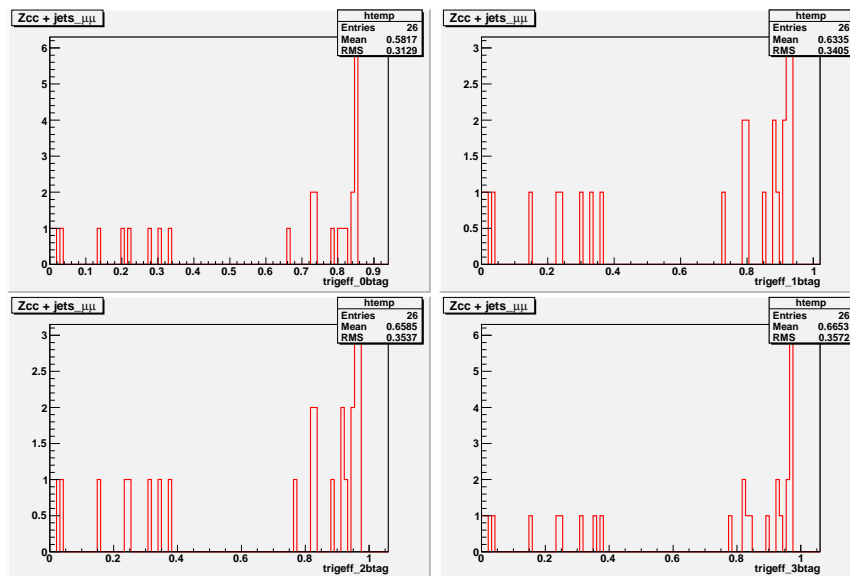
3. Trigger Efficiencies for $\mu + jets$ FIG. 27: Trigger Efficiencies for $\mu + jets$.4. Trigger Efficiencies for $dilepton$ FIG. 28: Trigger Efficiencies for $dilepton$.

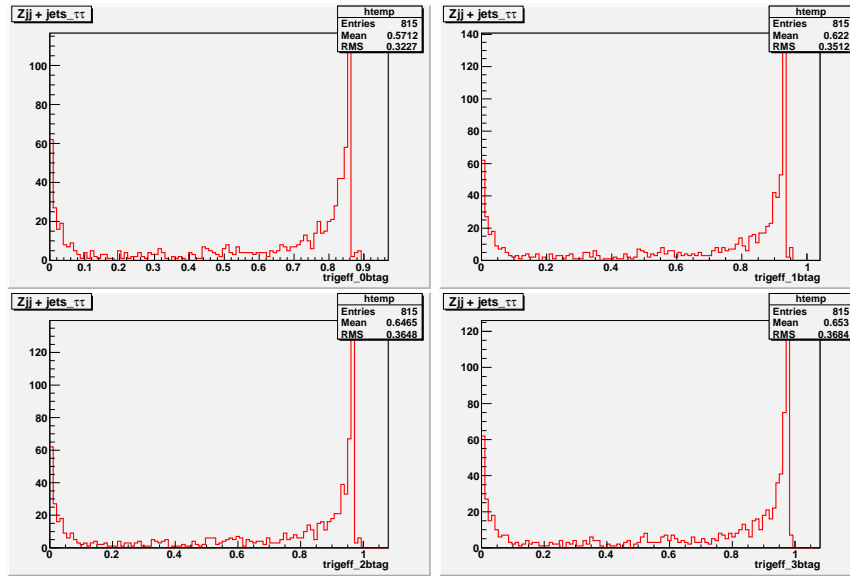
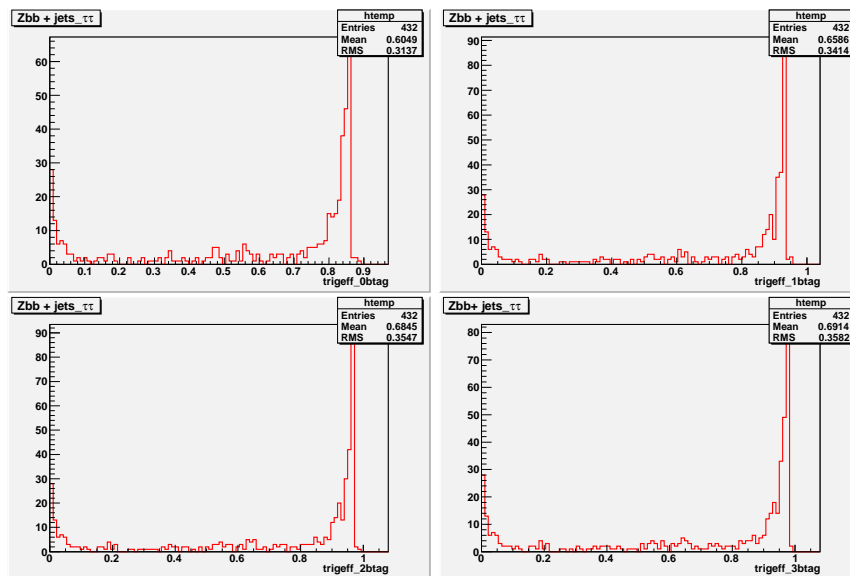
5. Trigger Efficiencies for *alljets*FIG. 29: Trigger Efficiencies for *alljets*.6. Trigger Efficiencies for *Wjj + jets*FIG. 30: Trigger Efficiencies for *Wjj + jets*.

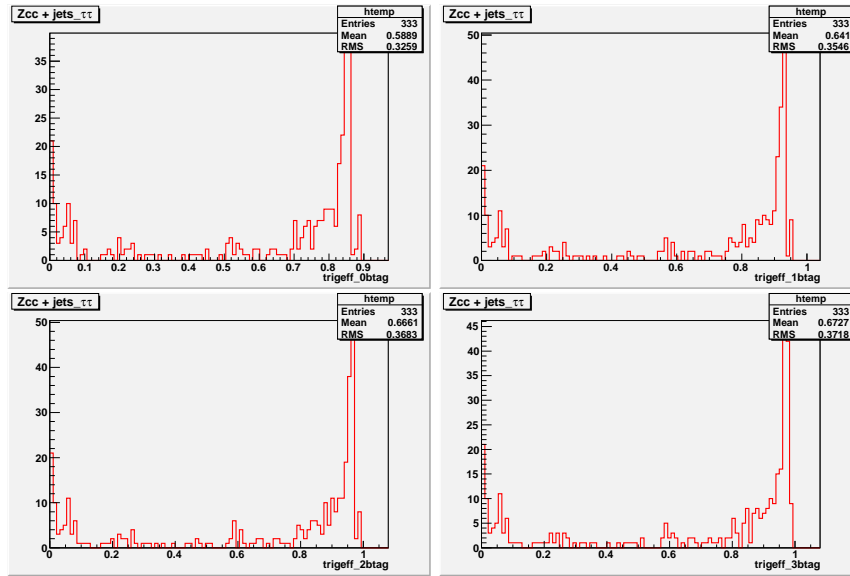
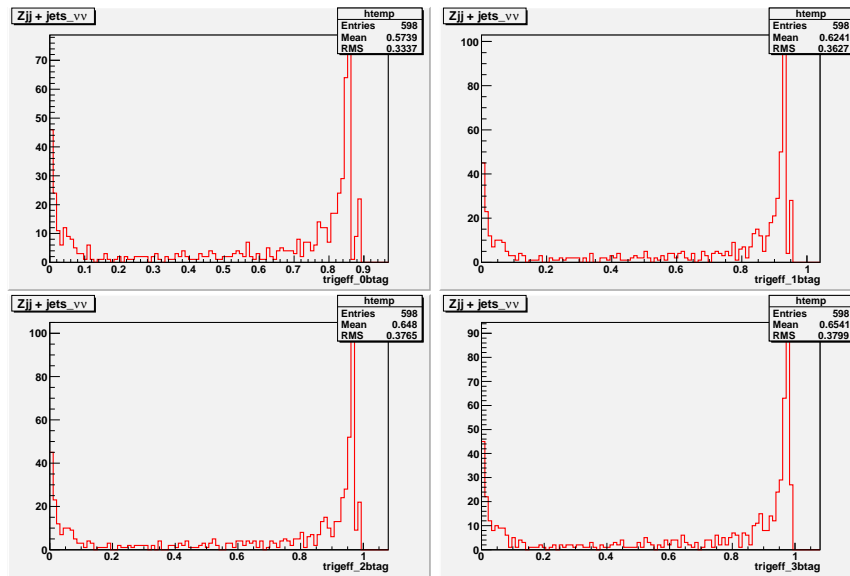
7. Trigger Efficiencies for $Wbb + jets$ FIG. 31: Trigger Efficiencies for $Wbb + jets$.8. Trigger Efficiencies for $Wcc + jets$ FIG. 32: Trigger Efficiencies for $Wcc + jets$.

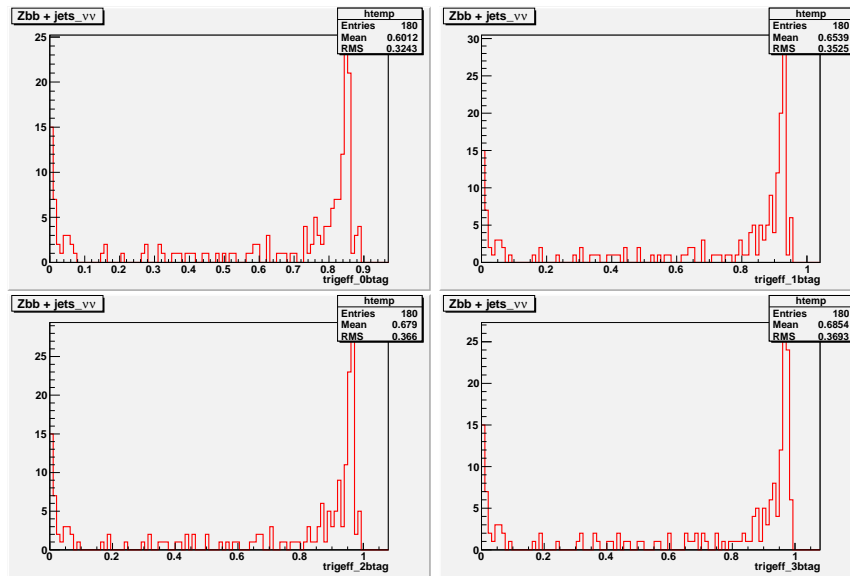
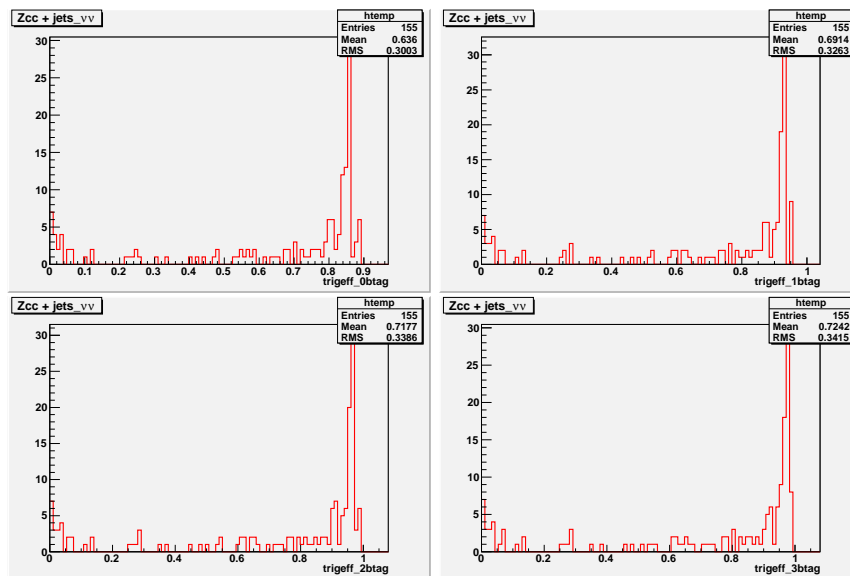
9. Trigger Efficiencies for $Zjj + jets \rightarrow ee + jj + jets$ FIG. 33: Trigger Efficiencies for $Zjj + jets \rightarrow ee + jj + jets$.10. Trigger Efficiencies for $Zbb + jets \rightarrow ee + bb + jets$ FIG. 34: Trigger Efficiencies for $Zbb + jets \rightarrow ee + bb + jets$.

11. Trigger Efficiencies for $Zcc + jets \rightarrow ee + cc + jets$ FIG. 35: Trigger Efficiencies for $Zcc + jets \rightarrow ee + cc + jets$.12. Trigger Efficiencies for $Zjj + jets \rightarrow \mu\mu + jj + jets$ FIG. 36: Trigger Efficiencies for $Zjj + jets \rightarrow \mu\mu + jj + jets$.

13. Trigger Efficiencies for $Zbb + jets \rightarrow \mu\mu + bb + jets$ FIG. 37: Trigger Efficiencies for $Zbb + jets \rightarrow \mu\mu + bb + jets$.14. Trigger Efficiencies for $Zcc + jets \rightarrow \mu\mu + cc + jets$ FIG. 38: Trigger Efficiencies for $Zcc + jets \rightarrow \mu\mu + cc + jets$.

15. Trigger Efficiencies for $Zjj + jets \rightarrow \tau\tau + jj + jets$ FIG. 39: Trigger Efficiencies for $Zjj + jets \rightarrow \tau\tau + jj + jets$.16. Trigger Efficiencies for $Zbb + jets \rightarrow \tau\tau + bb + jets$ FIG. 40: Trigger Efficiencies for $Zbb + jets \rightarrow \tau\tau + bb + jets$.

17. Trigger Efficiencies for $Zcc + jets \rightarrow \tau\tau + cc + jets$ FIG. 41: Trigger Efficiencies for $Zcc + jets \rightarrow \tau\tau + cc + jets$.18. Trigger Efficiencies for $Zjj + jets \rightarrow \nu\nu + jj + jets$ FIG. 42: Trigger Efficiencies for $Zjj + jets \rightarrow \nu\nu + jj + jets$.

19. Trigger Efficiencies for $Zbb + jets \rightarrow \nu\nu + bb + jets$ FIG. 43: Trigger Efficiencies for $Zbb + jets \rightarrow \nu\nu + bb + jets$.20. Trigger Efficiencies for $Zcc + jets \rightarrow \nu\nu + cc + jets$ FIG. 44: Trigger Efficiencies for $Zcc + jets \rightarrow \nu\nu + cc + jets$.

APPENDIX B: TURN ON CURVES FOR TRIGGER JT2_3JT15LIP_VX

689 Here it is shown all turn-on curves for all three levels of the trigger JT2_3JT15LIP_VX as described in
 690 Section III.

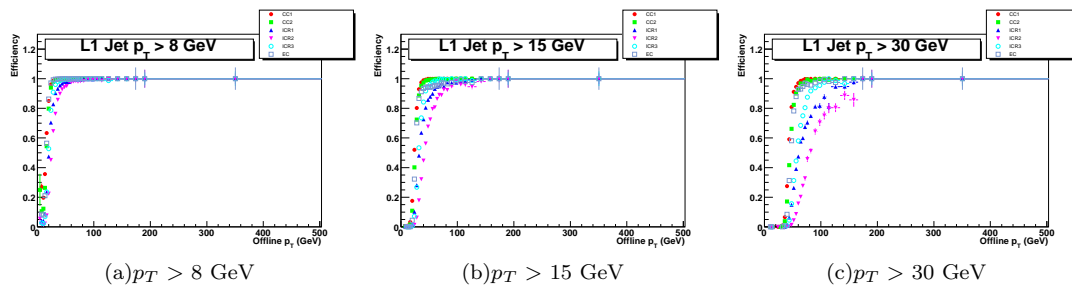


FIG. 45: Level 1 jet turn-on curves, low luminosity.

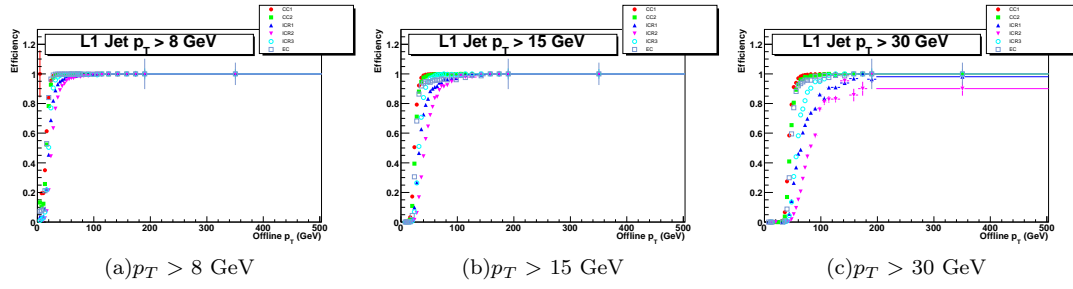


FIG. 46: Level 1 jet turn-on curves, medium luminosity.

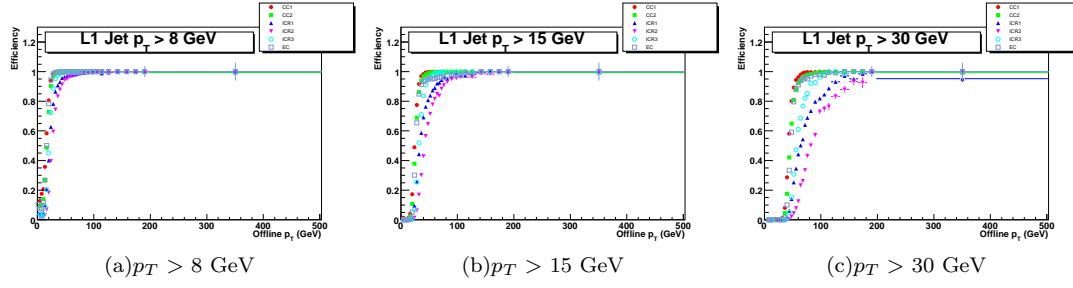


FIG. 47: Level 1 jet turn-on curves, high luminosity.

2. Level 2 jet turn on curves for trigger JT2_3JT15L_IP_VX

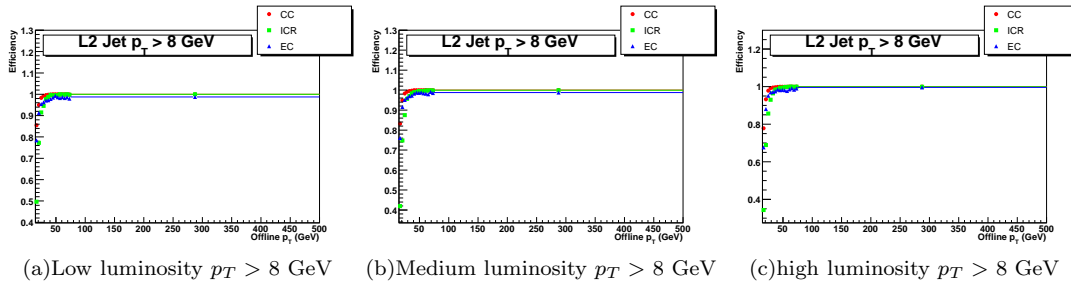


FIG. 48: Level 2 $p_T > 8$ GeV jets turn-on curves.

3. Level 2 H_T turn on curves for trigger JT2_3JT15L_IP_VX

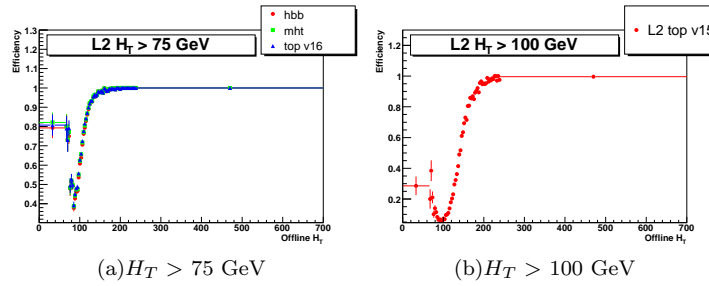


FIG. 49: L2 H_T turn-on curves, low luminosity.

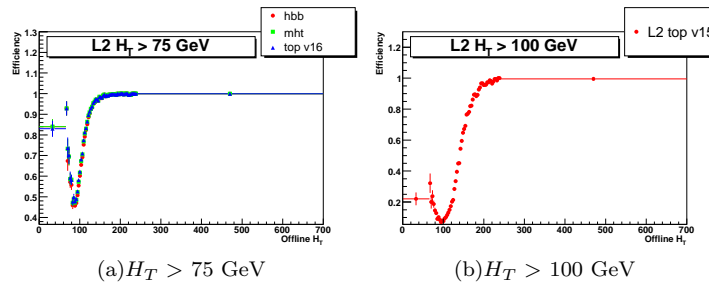


FIG. 50: L2 H_T turn-on curves, medium luminosity.

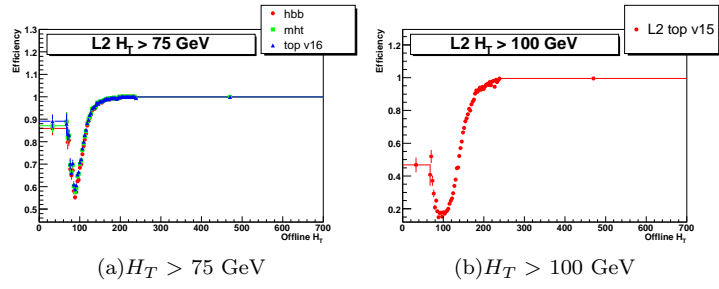


FIG. 51: L2 H_T turn-on curves, high luminosity.

4. Level 2 E_T turn on curves for trigger JT2_3JT15L_IP_VX

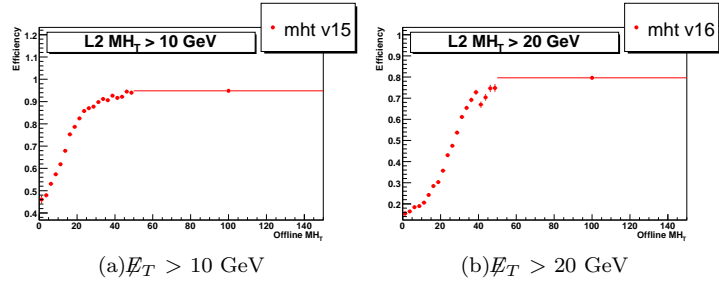


FIG. 52: L2 E_T turn-on curves, low luminosity.

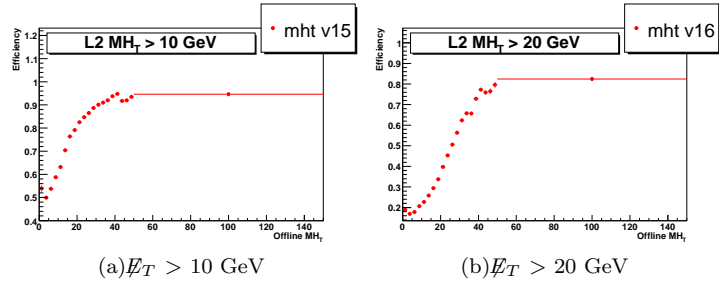


FIG. 53: L2 E_T turn-on curves, medium luminosity.

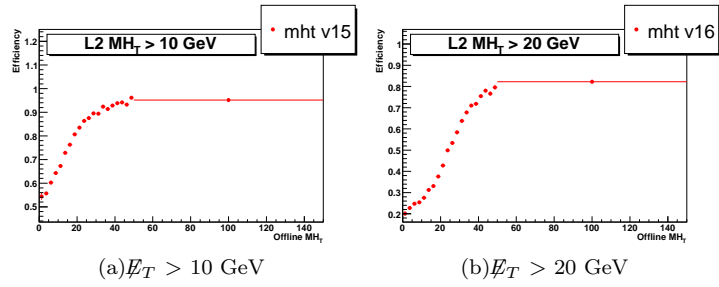


FIG. 54: L2 \cancel{E}_T turn-on curves, high luminosity.

695

5. Level 2 Sphericity turn on curves for trigger JT2_3JT15L_IP_VX

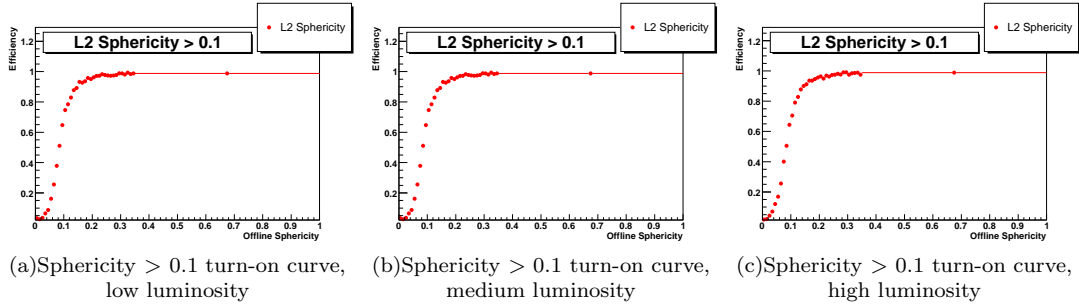


FIG. 55: L2 Sphericity turn-on curves.

696

6. Level 2 STTIP turn on curves for trigger JT2_3JT15L_IP_VX

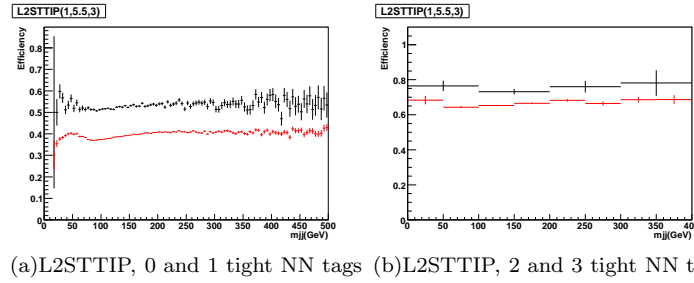
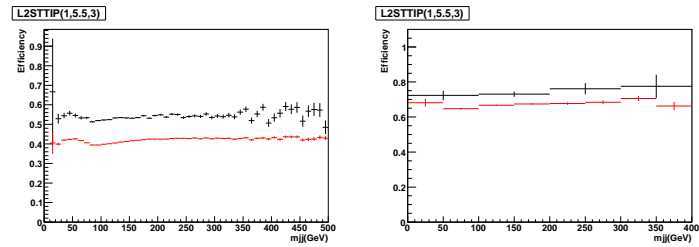
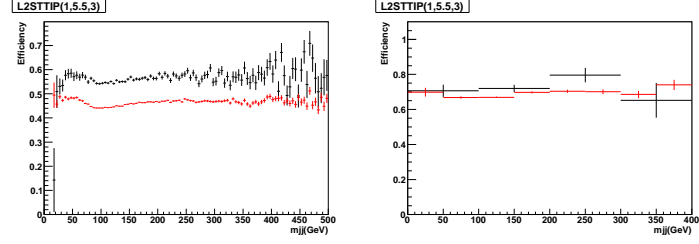


FIG. 56: L2STTIP efficiency in the low luminosity range. Left: events with 0 (red) and 1 (black) tight NN b-tags. Right: events with 2 (red) and 3 (black) tight NN b-tags.



(a)L2STTIP, 0 and 1 tight NN tags (b)L2STTIP, 2 and 3 tight NN tags

FIG. 57: L2STTIP efficiency in the medium luminosity range. Left: events with 0 (red) and 1 (black) tight NN b-tags. Right: events with 2 (red) and 3 (black) tight NN b-tags.

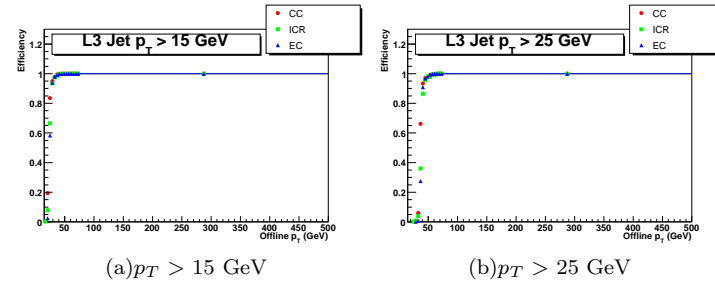


(a)L2STTIP, 0 and 1 tight NN tags (b)L2STTIP, 2 and 3 tight NN tags

FIG. 58: L2STTIP efficiency in the high luminosity range. Left: events with 0 (red) and 1 (black) tight NN b-tags. Right: events with 2 (red) and 3 (black) tight NN b-tags.

697

7. Level 3 jet turn on curves for trigger JT2_3JT15L_IP_VX



(a) $p_T > 15$ GeV

(b) $p_T > 25$ GeV

FIG. 59: L3 jet turn-on curves, low luminosity.

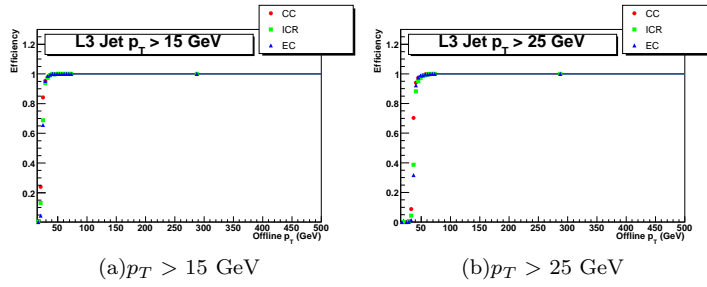


FIG. 60: L3 jet turn-on curves, medium luminosity.

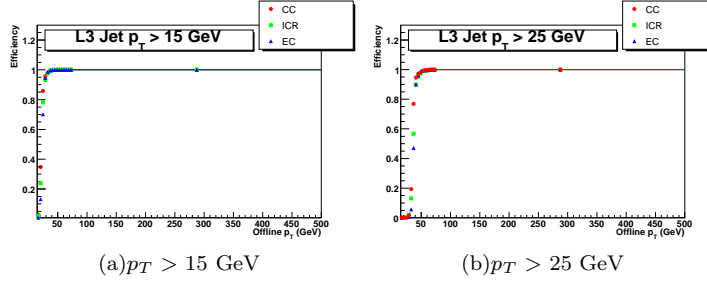


FIG. 61: L3 jet turn-on curves, high luminosity.

698

8. Level 3 b-tag on curves for trigger JT2_3JT15L_IP_VX

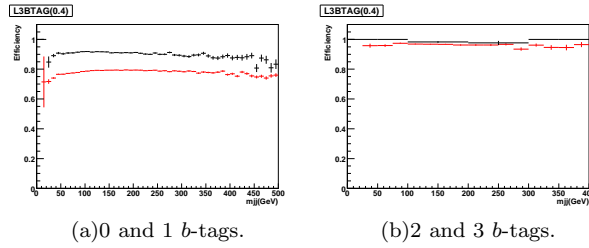


FIG. 62: (a) Efficiency of the L3 b -tag (Level3 Event b -tag < 0.4) for the low luminosity range in triggerlist v15. The selected events passed the rest of the trigger and offline event selection and had zero (red) or one (black) offline NN (TIGHT) b -tags. (b) Same for events with 2(red) and 3(black) offline NN (TIGHT) b -tags.

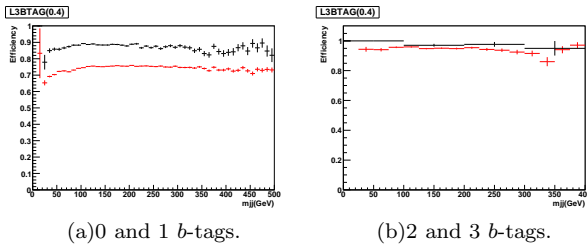


FIG. 63: (a) Efficiency of the L3 b -tag (Level3 Event b -tag < 0.4) for the medium luminosity range in triggerlist v15. The selected events passed the rest of the trigger and offline event selection and had zero (red) or one (black) offline NN (TIGHT) b -tags. (b) Same for events with 2(red) and 3(black) offline NN (TIGHT) b -tags.

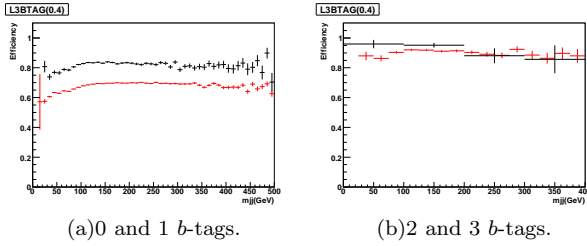


FIG. 64: (a) Efficiency of the L3 b -tag (Level3 Event b -tag < 0.4) for the high luminosity range in triggerlist v15. The selected events passed the rest of the trigger and offline event selection and had zero (red) or one (black) offline NN (TIGHT) b -tags. (b) Same for events with 2(red) and 3(black) offline NN (TIGHT) b -tags.

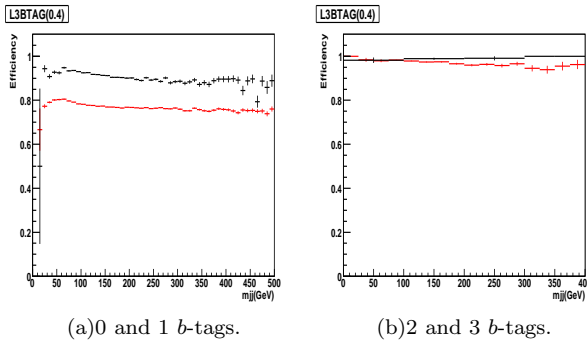


FIG. 65: (a) Efficiency of the L3 b -tag (Level3 Event b -tag < 0.4) for the low luminosity range in triggerlist v16. The selected events passed the rest of the trigger and offline event selection and had zero (red) or one (black) offline NN (TIGHT) b -tags. (b) Same for events with 2(red) and 3(black) offline NN (TIGHT) b -tags.

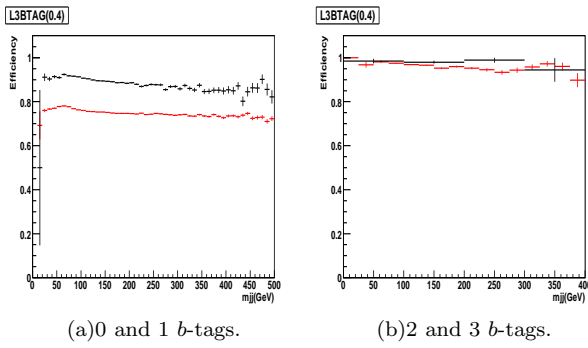


FIG. 66: (a) Efficiency of the L3 b -tag (Level3 Event b -tag < 0.4) for the medium luminosity range in triggerlist v16. The selected events passed the rest of the trigger and offline event selection and had zero (red) or one (black) offline NN (TIGHT) b -tags. (b) Same for events with 2(red) and 3(black) offline NN (TIGHT) b -tags.

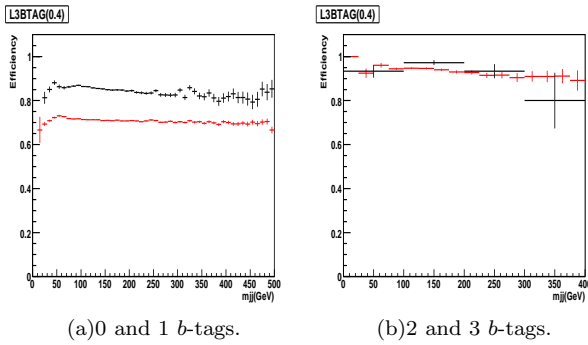


FIG. 67: (a) Efficiency of the L3 b -tag (Level3 Event b -tag < 0.4) for the high luminosity range in triggerlist v16. The selected events passed the rest of the trigger and offline event selection and had zero (red) or one (black) offline NN (TIGHT) b -tags. (b) Same for events with 2(red) and 3(black) offline NN (TIGHT) b -tags.

700 This appendix shows normalized plots of signal and background samples for all discriminant variables tested
 701 for this analysis.

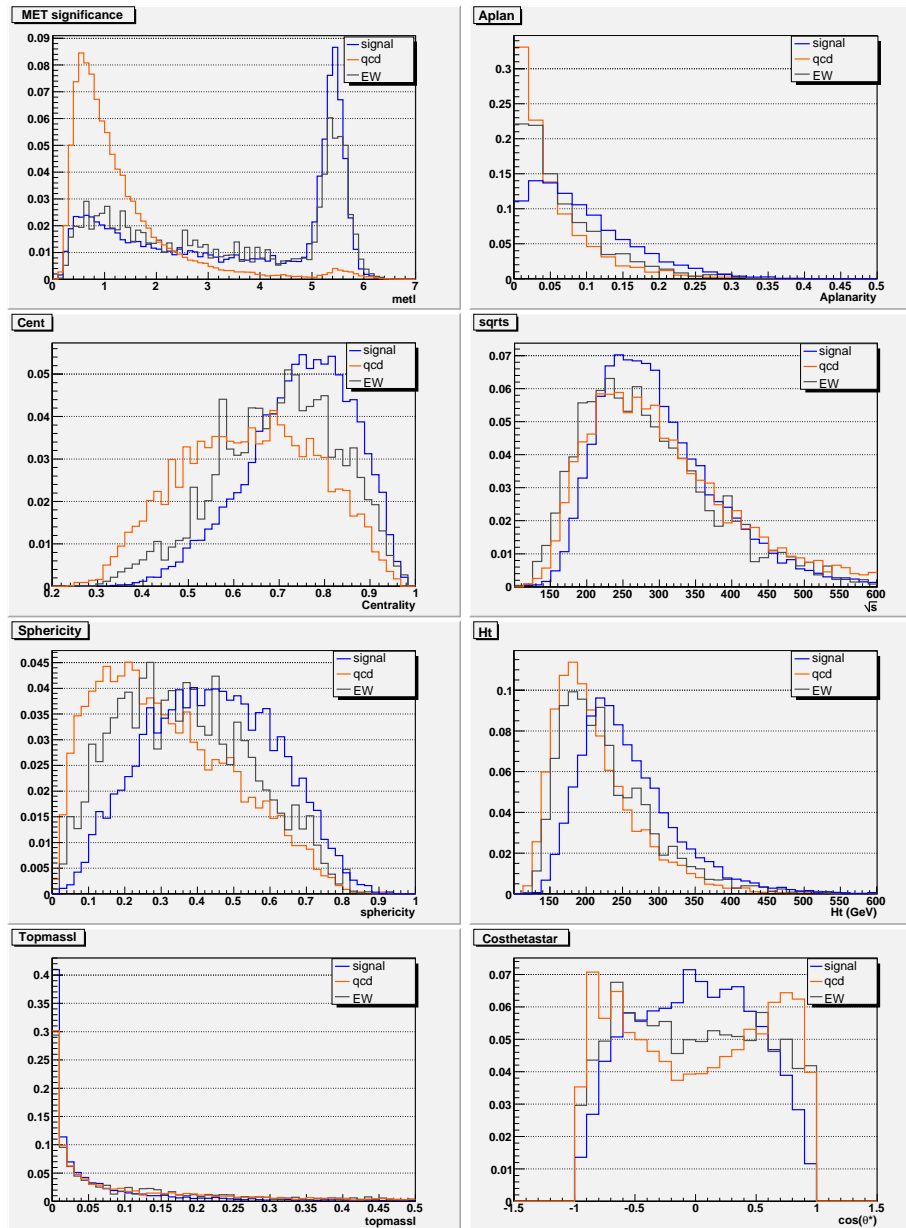


FIG. 68: Discriminant variables.

703 In this appendix it is shown plots of the figure of merit (Equation 6) used to perform the NN variables set
704 optimization as described in Section VIII C.

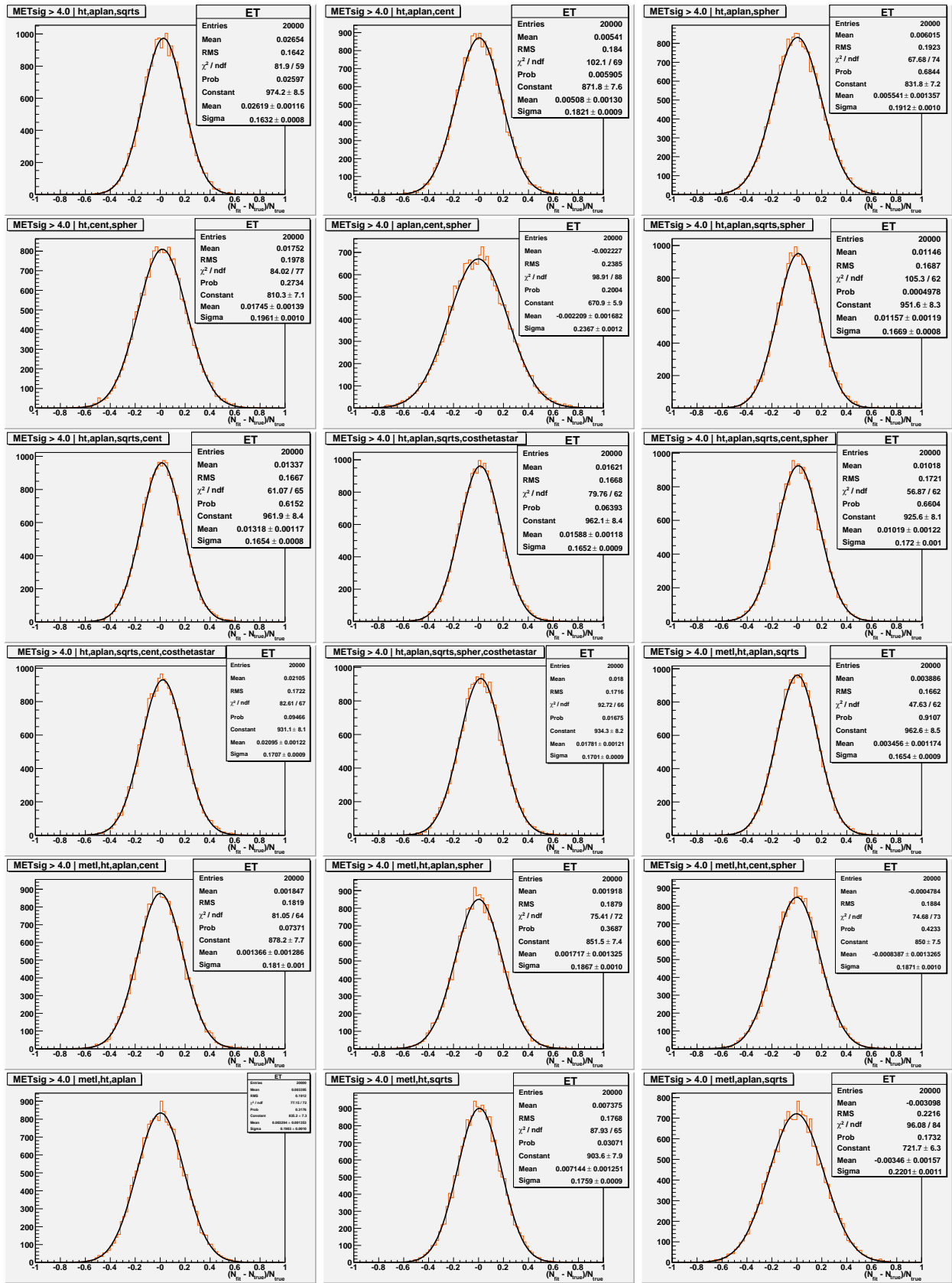


FIG. 69: Sets of NN inputs variables with \mathcal{E}_T significance > 4.0 for set optimization.

706 In this appendix it is shown plots of the figure of merit (Equation 6) used to perform the NN variables set
 707 optimization as described in Section VIII C.

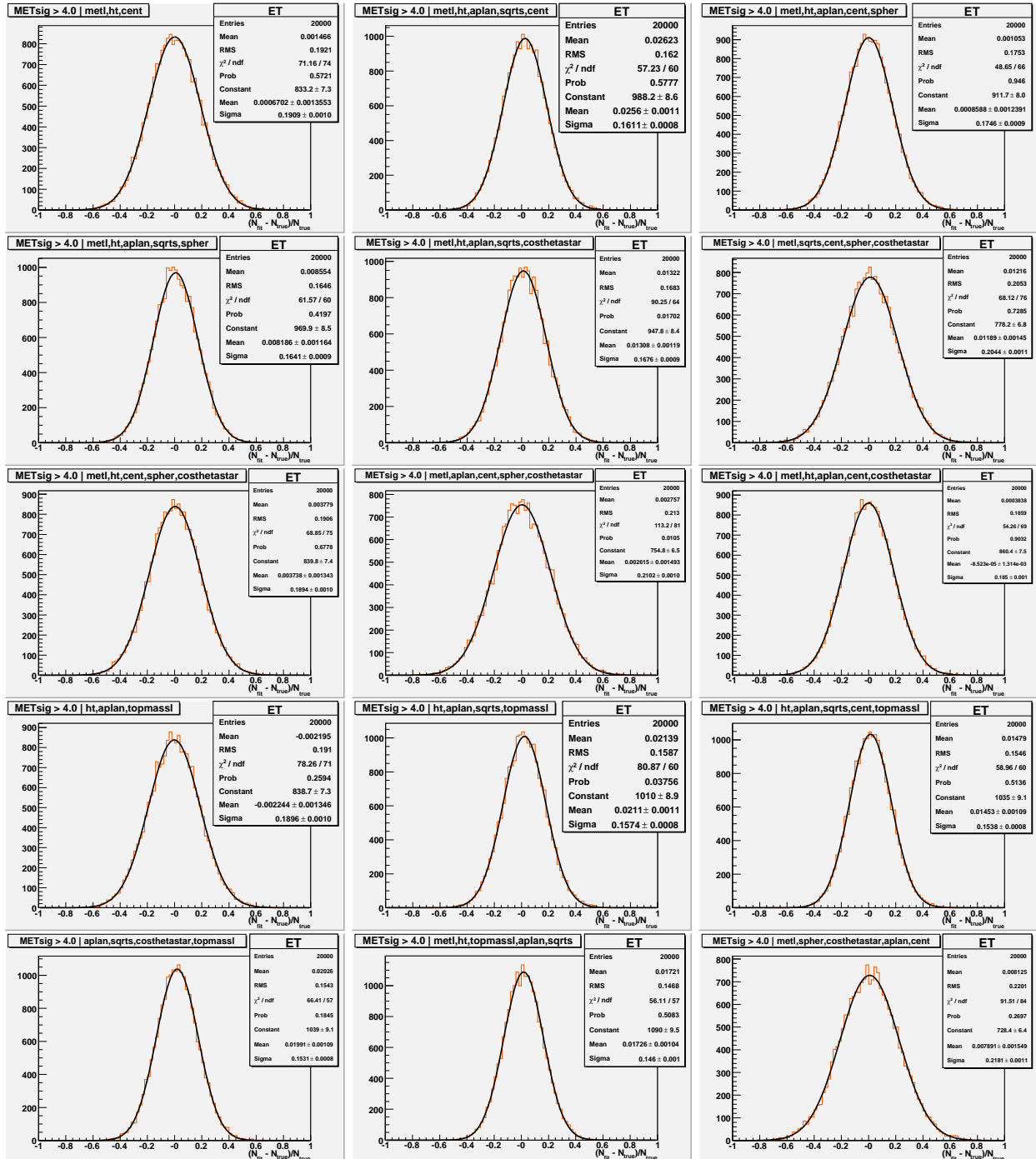


FIG. 70: Sets of NN inputs variables with \mathcal{E}_T significance > 4.0 for set optimization.

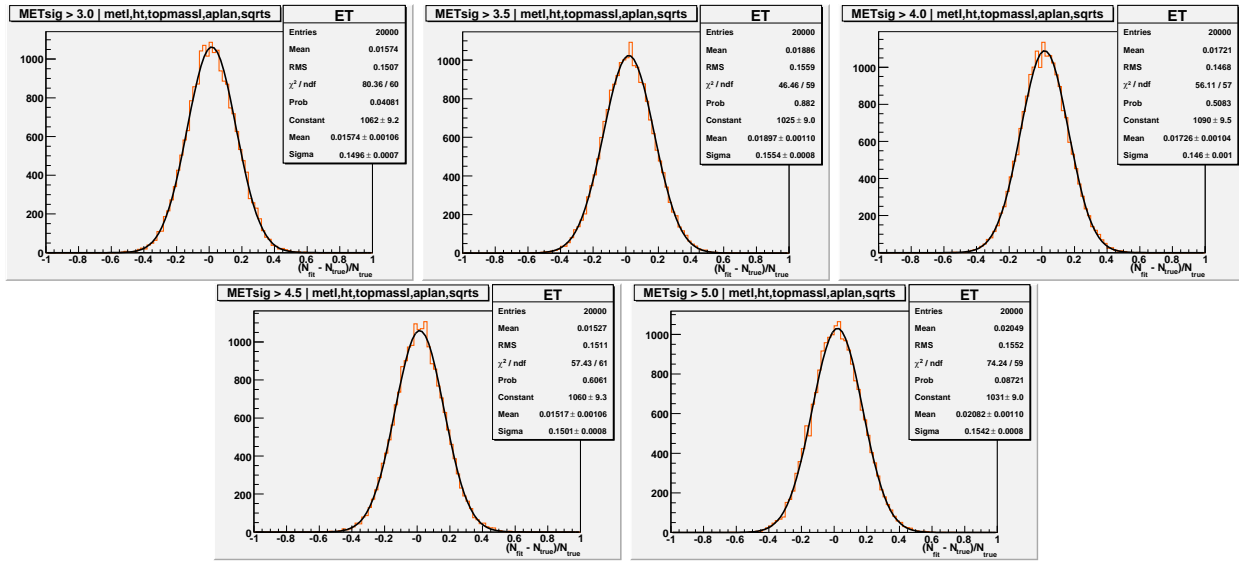


FIG. 71: Variation of \cancel{E}_T significance cut for Set XXXII = metl, H_T , topmassl, aplan, sqrts.

711 In this appendix it is shown plots of the figure of merit (Equation 6) used to perform the NN variables set
712 optimization as described in Section VIII C.

713 **1. Results for Set = metl, H_T , topmassl, aplan, sqrts, metl > 4.0, lumi = 4951.86/pb, VC jets and**
714 **NNelec > 0.9**

715 Table below summarizes the number of events in each channel after final selection.

TABLE XXXVIII: Final number of events in the two analysis channels.

	τ type I,II	τ type I,II (fitted)	τ type III	τ type III (fitted)
data	386		459	
$t\bar{t} \rightarrow \tau + jets$	72.04 ± 0.53		38.82 ± 0.39	
$t\bar{t} \rightarrow e + jets$	38.35 ± 0.36		6.52 ± 0.16	
$t\bar{t} \rightarrow \mu + jets$	4.81 ± 0.14		5.14 ± 0.14	
$t\bar{t} \rightarrow l + l$	6.02 ± 0.07		4.20 ± 0.06	
$t\bar{t}$ total MC		121.22 ± 0.43		54.68 ± 0.20
$t\bar{t}$ total fitted		133.04 ± 17.09		33.12 ± 15.04
W+jets	17.82 ± 0.33		11.26 ± 0.23	
Z+jets	2.78 ± 0.14		2.39 ± 0.12	
QCD		232.35 ± 17.09		412.22 ± 15.04
Signal significance		6.77		1.54
S/B ratio		0.52		0.08

716 Without taking into account the signal contamination the result is (only statistical uncertainties are shown)

τ +jets types 1 and 2 cross section:

$$\sigma(t\bar{t}) = 8.05^{+1.04}_{-1.02} \text{ (stat)} \pm 0.3 \text{ (lumi) pb,}$$

τ +jets type 3 cross section:

$$\sigma(t\bar{t}) = 4.24^{+1.94}_{-1.80} \text{ (stat)} \pm 0.3 \text{ (lumi) pb,}$$

Combined cross section:

$$\sigma(t\bar{t}) = 7.26^{+0.92}_{-0.92} \text{ (stat)} \pm 0.3 \text{ (lumi) pb,}$$

719 Table below summarizes the number of events in each channel after final selection.

TABLE XXXIX: Final number of events in the two analysis channels.

	τ type I,II	τ type I,II (fitted)	τ type III	τ type III (fitted)
data	583		459	
$t\bar{t} \rightarrow \tau + jets$	85.46 ± 0.58		38.82 ± 0.39	
$t\bar{t} \rightarrow e + jets$	175.23 ± 0.85		6.52 ± 0.16	
$t\bar{t} \rightarrow \mu + jets$	8.98 ± 0.19		5.14 ± 0.14	
$t\bar{t} \rightarrow l + l$	12.62 ± 0.10		4.18 ± 0.06	
$t\bar{t}$ total MC		282.27 ± 1.05		54.67 ± 0.41
$t\bar{t}$ total fitted		260.71 ± 20.74		35.73 ± 15.28
W+jets	39.65 ± 0.50		11.26 ± 0.25	
Z+jets	4.56 ± 0.10		2.38 ± 0.11	
QCD		278.04 ± 20.74		409.62 ± 15.28
Signal significance		10.80		1.67
S/B ratio		0.80		0.08

720 Without taking into account the signal contamination the result is (only statistical uncertainties are shown)

 τ +jets types 1 and 2 cross section:

$$\sigma(t\bar{t}) = 6.47^{+0.53}_{-0.53} \text{ (stat)} \pm 0.3 \text{ (lumi) pb,}$$

 τ +jets type 3 cross section:

$$\sigma(t\bar{t}) = 4.58^{+1.96}_{-1.85} \text{ (stat)} \pm 0.3 \text{ (lumi) pb,}$$

Combined cross section:

$$\sigma(t\bar{t}) = 6.35^{+0.51}_{-0.51} \text{ (stat)} \pm 0.3 \text{ (lumi) pb,}$$