CDF/ANA/TOP/CDFR/2419

January 13, 1994

revised March 1994

Version 2.1

ANOMALIES IN CDF TOP CANDIDATE EVENTS - DO THEY INDICATE NEW PHYSICS ?

Krzysztof Sliwa

Tufts University
Department of Physics and Astronomy
Medford, Massachusetts 02155 USA

ABSTRACT

A simple analysis of some invariant kinematical properties of CDF top candidate events in W+jets final state indicates the presence of anomalous events. Fully aware of the need to be cautious because of very limited statistics, and realizing that my conclusion is quite speculative, I am suggesting that the combined 1988+1992 sample of top candidates indicates the presence of two production mechanisms, namely, that of $t\bar{t}$ pair production as expected in the Standard Model; and production of a new, heavy, object (resonance), whose decay gives rise to anomalous events. With this interpretation of the data, the mass of the top quark is about M_t=140-150 GeV and the mass of the new heavy object is about M_{NEW} ≈500 GeV.

i. INTRODUCTION

I have been looking at the W+jets data for almost two years now, using an analysis technique which allows complete kinematical reconstruction of an event, and which verifies a hypothesis that the event is an example of $t\bar{t}$ production and decay. How well the hypothesis is satisfied can be quantified by a suitably defined likelihood (probability) which takes into account not only the kinematical constraints but, also, in a *Bayesian* way, selected characteristics of production and decay of $t\bar{t}$ quarks. Although my technique[1] has been evolving over the past year or so (I have abandoned using weighted distributions which were the basis of CDF1751,CDF1993 ver.1.0, and I am using now simple M_t distributions with unit weights, one entry per event with the best likelihood-CDF1993 ver 2.0) - my conclusions have not changed. In my analysis I have been, consistently, finding an excess of events which were clustering in a fairly narrow group about M_t=140 GeV. The number of those candidate events were consistent with the cross sections predicted for this value of the top quark. Taking into account systematic mass shifts observed in Monte Carlo simulations I find the mass of the new quark, M_t=147±10 GeV (see CDF1993, ver.2.0).

Although my findings were, by and large, ignored by the Collaboration, I would like to note that in the last few months **almost all** other CDF analyses have converged to results which are in a very good agreement with my measurement. The number of tagged events points to $M_t \approx$150 GeV[2]. Kinematical fits to the di-lepton events[3] point to the range 152-162$\pm^{16}_{14}$ GeV. The cross section was a little lower than that found in the b-tag analyses, however, a new $e\mu$ candidate which was found with only about 1 pb^{-1} of data taken in the present run will increase the di-lepton cross section to the level of a very good agreement with my results. Kinematical fits[3] find this event consistent with $t\bar{t}$ hypothesis for M_t=149$\pm^{20}_{15}$ GeV.

It was a puzzle for me for quite some time (since late spring 1993, when b-tags became available) why events selected as $t\bar{t}$ candidates with reasonably large values of the likelihood, using my kinematical technique, were clustering about 140-150 GeV; while similar analysis for b-tagged events was, by and large, yielding fits to higher mass values, but with *very small* likelihoods. I realize that the paper is quite speculative, however, I think that all of you should know what I think the explanation to the puzzle is, or at least what it seems to me when I look at the CDF data.

ii. THE TECHNIQUE

The technique used in this analysis is a refined version of the method developed by Goldstein, Sliwa and Dalitz[1]. It was presented in the form close to its present form in CDF1993, and at numerous CDF and Top Group Meetings.

In essence, the technique verifies a hypothesis that, in a given event, two objects of the same mass, were produced with limited transverse momentum and subsequently decayed in the *semileptonic* mode. In this analysis, it is assumed that the two objects are the t and $\bar{t}$ quarks. The kinematic constraints are applied in a geometric rather than albegraic way. The result can be presented as a probability of this hypothesis as a function of top quark mass M_t. Kuni Kondo independently has been advocating using a technique similar in its general concept (DLM), but differently realized[4], in his search for the top quark.

The definition of likelihood

For every jet, there is a factor, G, downgrading *guesses* far removed from the measured jet energy, I assume that the measured jet energy is correct. Each solution is assigned a probability according to the transverse momentum distribution[5] of a $t\bar{t}$ quark pair, $P(X_{t\bar{t}})$, generated by

Kuni Kondo using ISAJET; and to my fit using HERWIG Monte Carlo for $t\bar{t}$ pair production. The variable

$$X_{t\bar{t}} = \frac{P_T(t\bar{t})}{M_t}$$

scales with M_t, the top quark mass.

For every solution the momentum of the top quark (and the momentum of the neutrino is known) and the event kinematics is known completely. The production mechanism depends on the Bjorken x values for the initial state partons, that is the structure functions $F_1(x_1)$ and $F_2(x_2)$, and the parton subprocess center-of-mass energy and momentum transfer through the cross section. The relative probability for producing any kinematical configuration is given by

$$P_{x_1,x_2} = \frac{\sum_{i=qq,gg} F_i(x_1)F_i(x_2)\frac{d\sigma}{d\hat{t}}(\hat{s},\hat{t})_i}{\sum_{i=qq,gg} \frac{d\sigma}{d\hat{t}}(\hat{s},\hat{t})_i}$$

where the relevant variables are obtained from the energies and momenta of the top quarks in the $p\bar{p}$ lab frame,

$$x_{1,2} = (E_t - E_{\bar{t}} \pm (t_L + \bar{t}_L))/2P$$

$$\hat{s} = x_1 x_2 s$$

$$\hat{t} = M_t^2 - x_1\sqrt{(s)}(E_t - t_L)$$

with P the proton momentum, s the square of the $p\bar{p}$ center-of-mass energy, and t_L the top longitudinal momentum.

The leptonic decay probability (V-A calculation), depends on the top mass and the lepton and b-jet 4-momenta, l and b, through the relation

$$P_l(b,l) = \frac{2(2b\cdot l + M_W^2)(m_t^2 - m_b^2 - M_W^2 - 2b\cdot l)}{(m_t^2 - m_b^2)^2 + M_W^2(m_t^2 + M_b^2) - 2M_W^4}.$$

(Since we cannot at present assign flavours to the three quarks, we will simply take P_h=1 for the corresponding factor for the hadronic t decay).

Factors $P(X_{t\bar{t}})$,P_{x_1,x_2},P_l and P_h are the *à priori* probabilities in the Bayesian sense.

Finally, there is a Gaussian probability factor, $G_{\not{E}_t} = G^x_{\not{E}^x_t} \times G^y_{\not{E}^y_t}$, which downgrades solutions in which the $\not{E}_t$ is in poor agreement with the transverse momentum of the neutrino found as a result of this kinematical analysis. Although, I believe, $\not{E}_t$ is not adequate enough to be used as a measurement of the neutrino transverse momentum (when checking the transverse momentum balance between t and $\bar{t}$ momenta), it does carry information about its general direction and magnitude.

A complete probability for any given match is thus defined

$$L_i = G_b \times G_{\bar{b}} \times G_{j1} \times G_{j2} \times P(X_{t\bar{t}}) \times P_{x_1,x_2} \times P_l \times P_h \times G_{\not{E}_t}$$

where $j1$ and $j2$ are the W mass constrained jets from a hadronic W decay.

L_i is incorporating, via Bayes's theorem, all experimental information and it represents a measure of the probability of the hypothesis that the event kinematics corresponds to that of a $t\bar{t}$ event. It is the magnitude of L which quantifies how likely it is that a given combination of lepton and four jets may have originated from the production and decay of the t and $\bar{t}$ quarks, as expected in the Standard Model.

The relative probability for each combination is a meaningful quantity, since each kinematic configuration is treated uniformly with the same parameterization. The procedure is simply a numerical integration over the available phase space. Because the entire volume of parameter space is scanned, it is very unlikely to reach what would correspond to a local minimum in, say, a least squares fitting technique. Also, no assumptions are made about the minimized function.

This method has been shown to yield almost identical results to those of fits performed with other minimization techniques (MINUIT, SQUAW, Kuni's DLM), obtained for identical input four vectors[6]

iii. CANDIDATE DATA SETS

The inclusive W samples created by David Saltzberg (W→ $e\nu$) and Mark Krasberg[7] (W→ $\mu\nu$) were used as a starting point in this analysis, when no requirement of the presence of a b-tag was imposed. A sample of high P_t W candidates (HPTAPE), selected by Brian Winer, was used in the inclusive analysis of electron data.

The b-tag candidates were provided by Claudio Campagnari (soft lepton tags) and Weiming Yao (SVX tags), CLAU*.PAD and WEIM*.PAD.

One event (45610_139604) comes from a file of b-tag candidates generated by Liz Buckley.

The "official" (as of January 1994) sample of 7 b-tag candidate events was used in this analysis.

iv. ANALYSIS CUTS

The lepton and jets' parameters used in this analysis were extracted from the common blocks filled with EWUNPK[8] bank unpacking package. The jet clustering cone size of ΔR=0.7 was used, and jet energy scale correction only was applied using a standard routine QDJSCO. No out-of-cone and underlying event corrections were used. Including those two may result in a small, +0.7 to +2.0%, mass shift. Jet clustering with the cone size of 0.7 was used, because jet corrections are smaller for cone size 0.7 than 0.4. (This is because larger fraction of jet energy is contained in the cone of ΔR=0.7.)

All four jets were required to have $|\eta_{jet}| < 2.4$. Three sets of jet transverse energy cuts used are used in this analysis, namely: (32015) four jets $P_T > 15$ GeV, three jets $P_T > 20$ GeV; (31515) four jets $P_T > 15$ GeV; and (32010) four jets $P_T > 10$ GeV, three jets $P_T > 20$ GeV; The W+4jets QCD background, which is comparable to the $t\bar{t}$ signal (for the mass of the top quark in the range 130-160 GeV) is further reduced in the inclusive analysis with the help of tight jet cuts (32015,31515 or 32010). Also The missing transverse energy was required to be $\not{E}_t > 25$ GeV, and the lepton transverse energy was required to be $E_T > 20$ GeV.

v. RESULTS

The kinematical technique used in this analysis relies on the fact that there are sufficient kinematical constraints to be able to solve for the unobserved neutrino from the leptonic W decay, and assign a likelihood to the hypothesis that the event is a $t\bar{t}$ event, as expected in the Standard Model.

After the solution was found, all four momenta *including that of a neutrino* are known. It is thus possible, for example, to calculate the invariant mass of the $t\bar{t}$ system; plot the tranverse momentum of top quark, or that of a W. The mass of the $t\bar{t}$ system is a variable which *directly* measures the energy scale of the sub-parton interacton. If a heavy object exists and decays into the final state involving leptons and jets (which we hypothesize come from the production and decay of $t\bar{t}$ quarks) the mass of $t\bar{t}$ system can *directly* measure the mass of such an object. Comparison of the distributions of the transverse momenta of the fitted top quark and W, obtained from leptonic and hadronic channels, may also provide an important check. The hadronic t and W do not involve the neutrino, which is derived by requiring the kinematic constraints of a $t\bar{t}$ production and decay to be satisfied. However, the transverse momentum distribution are not expected to be as sensitive as the $t\bar{t}$ mass spectrum, after all $t\bar{t}$ mass is a Lorentz invariant.

The difference between the analyses of the b-tagged and inclusive (without using the tagging information) samples is due mainly to the reduced number of 4-jet combinations which may accompany the lepton. In the analysis of b-tagged sample I have assumed *blindly* that the verdict of the SVX (or SLT) algorithm, regarding which jet(s) is a b-jet, is correct. Only combinations with *correct* b-jet assignment were considered. If more than one combination of jets gave a solution, the best (the one with the largest likelihood) solution was taken. One should bear in mind that the assumption about the absolute correctness of b-tagging algorithm may not be true.

In the analysis of the inclusive sample all jet configurations passing the jet cuts were considered, without regard to b-tagging information, and a combination with the largest likelihood was chosen.

Let's take the sample of 7 b-tagged events. In Figure 1 the mass of $t\bar{t}$ system is plotted in black, superimposed on $t\bar{t}$ mass distributions expected for $t\bar{t}$ pairs at M_t=140 GeV on the parton level (including radiation) simulation (HERWIG). In Figure 1b, the transverse momentum distributions for top quarks and W, in both leptonic and hadronic decay modes, are shown, superimposed on M_t=140 GeV Monte Carlo. Figures 2 and 2b show the same 7 b-tagged events, this time compared with M_t=160 GeV Monte Carlo.

Data seem to show a high mass tail, if not a cluster of (three out of seven) events, well beyond the values expected for the standard $t\bar{t}$ production. Two events (40758_44414 and 43096_47223; the convention used here to indicate the run and event numbers is RUN_EVENT) are electron W candidates; and (43351_266423) is a muon W candidate. The transverse momenta distributions also seem to show enhanced high P_t tails. Masses of top quark, $t\bar{t}$ system and values of P_t for 7 b-tagged events are listed below.

Table I. **$t\bar{t}$ mass and transverse momenta of W and top quark for the "official" 7 b-tagged events. Jet and lepton four-momenta as in comparison of fitting methods (CDF2401). Masses and tranverse momenta in GeV.**

run	event	L	M_t	$M_{t\bar{t}}$	$P_t(e\nu b)$	$P_t(e\nu)$	$P_t(udb)$	$P_t(ud)$
40758	44414	.12e-1	173	500	178	132	181	120
43096	47223	.26e-4	166	500	125	33	107	84
43351	266423	.74e-2	148	471	131	60	166	180
45610	139604	.51e-6	189	382	32	67	10	72
45705	54765	.37e-2	170	362	93	114	93	113
45879	123158	.34e-4	164	377	46	41	76	22
45880	31838	.66e-3	124	355	94	63	94	79

The analogous distribution for *inclusive* electron 1988 and 1992 data, compared to M_t=140 GeV Monte Carlo are presented in Figures 3, 3b; and compared with M_t=160 GeV in Figure 4, 4b. Jet energies found with cone of ΔR=0.7 and corrected with QDJSCO were used here. The differences between parameters obtained for b-tagged events here provides a measure of a systematic error due to different clustering algorithm. In events 45705_54765 and 45880_31838 a different combination was selected (based on the value of likelihood) in the inclusive analysis as compared to b-tagged analysis. In events 40758_44414 and 43096_47223 the same jets are selected as b-jets in the inclusive analysis and b-tagged analysis.

In Figure 5,5B and 5C the scatterplots of $M_{t\bar{t}}$ vs M_t for the inclusive electron data sample, together with their projections, are presented for cuts 32015,31515 and 32010, respectively. On the left side, no cut on the value of the likelihood (probability) that an event is a $t\bar{t}$ event was made; while on the right side a modest cut, L>0.10, was made. Events with large L, according to the kinematical analysis used here, are more likely to be $t\bar{t}$ events than events with low L.

Fully realizing that the statistics is very small (and that all this can be a fluctuation), one may speculate, however, that there are two clusters of events in the upper-left scatterplot in Figure 5: events with large $M_{t\bar{t}}$ >400 GeV, high M_t and small L; and another group of events with larger L. The latter events do not have large $M_{t\bar{t}}$, and seem to cluster at M_t of around 140 GeV. This is the top mass value seen with this kinematical analysis of all W+jet events for quite some time (CDF1751,CDF1993,CDF2256). The true top quark mass is actually a little higher than what is observed as 140 GeV. A study of the mass shifts, due to selecting the solution with largest likelihood and, also, inconsistencies in simulations, indicates that the mass shifts are within +5 GeV to +10 GeV range, and are very unlikely to exceed +15 GeV. (In other words the top quark mass is very unlikely to exceed 155 GeV). Although more work is being done in the area of understanding the systematics of mass shifts, the results are very suggestive of the observation of a new quark (most likely it is a top quark) of the mass M_t=147±10 GeV (see CDF1993 ver.2.0).

In the sample of 17 electron events, selected with cuts (32015), there are four events in the high mass tail of the $t\bar{t}$ mass distribution; they fall in the same region as the three b-tagged events. Two out of four events are the two b-tagged high $t\bar{t}$ mass events; but there are additional two, one of which is un-taggable by SVX (41301_45902). The four electron events with low L and high $M_{t\bar{t}}$ ≈500 GeV (which together with the tagged muon candidate constitute a sample of at least 5 *anomalous* events), may be an indication of a heavy object decaying into a pair of $t\bar{t}$ quarks.

If indeed these events are coming from such a new source, the likelihood that such events are $t\bar{t}$ would be smaller than for *genuine* $t\bar{t}$ bar events, produced in the way expected within the framework of the Standard Model. Small values of likelihood would also result if in the decay products of the hypothesized new state there was only one top quark and multiple b jets. The kinematical procedure would have to pull the jets' energies more than in the "genuine" $t\bar{t}$ event to satisfy the constraint that the mass of t quark and $\bar{t}$ anti-quark are the same, which would lead to a lower likelihood. Imagine a final state with t+3b jets, after t quark decays there will be a leptonic W and 4 (!) b jets, which would make such events much easier to tag that genuine $t\bar{t}$ events.

Masses of top quark, $t\bar{t}$ system and values of P_t for 17 inclusive electron events are listed in Table II.

Table II. **$t\bar{t}$ mass and transverse momenta of W and top quark for 17 electron events selected with inclusive analysis and (32015) jet energy cuts. Masses and tranverse momenta in GeV.**

run	event	L	M_t	$M_{t\bar{t}}$	$P_t(e\nu b)$	$P_t(e\nu)$	$P_t(udb)$	$P_t(ud)$
18170	10786	7.32	134	303	51	53	48	42
40758	44414	.82e-3	168	485	177	180	176	112
41301	45902	.35e-2	180	460	82	7	96	12
42669	20656	.90e-3	106	203	8	18	12	13
43001	95154	.12e-17	150	350	71	83	64	51
43096	47223	.78e-5	157	473	117	27	99	67
43096	188919	3.54	108	234	28	44	30	24
43170	35577	.15e-6	136	460	18	3	19	37
45705	54765	.92e-2	145	385	90	104	109	115
45753	241138	.85e-2	141	293	43	66	41	56
45779	6523	.96e-2	137	327	95	112	97	97

45880	31838	.11	143	360	89	66	93	117
45902	240098	.12	141	323	82	79	65	77
46271	105198	.51e-3	117	241	58	76	48	63
46312	30210	18.9	105	206	13	9	7	21
46893	1985	.48	135	307	27	30	30	28
47586	73483	.47	143	292	32	36	21	40

I realize that my suggestion of the existence of a new, heavy, object giving rise to anomalous events in CDF sample of $t\bar{t}$ is quite speculative, on the other hand, I think one should not forget how suggestive the data look like (for both b-tagged and inclusive electron data). In the tagged sample there are three events which hardly look like $t\bar{t}$ events as expected in the Standard Model. If one extends the search to the inclusive electron sample, two additonal events are found. The fact that this events are *assumed* to be $t\bar{t}$ events leads, I think, to the estimates of the mass of the top quark higher than found with this kinematical analysis of inclusive W+jet events, by either mass fits to the b-tagged events, or by kinematics studies by Cobal, Grassman, Binkley, Westhusing[9] and others. (If you look at Figure 42 on page 109 of the January draft of the PRD paper, the data actually look more like Monte Carlo for M_t=140 GeV than for M_t=170 GeV, except for two events high in the tails of E_{T3} versus E_{T2} distributions. Not surprisingly, these two events are a subset of the four electron events with large $M_{t\bar{t}}$, 40758_44414 and 43096_47223.) and are the same as two electron tagged events. Morris Binkley also notes in his CDF2418[10] that these two events are unlikely to be $t\bar{t}$.

A kinematical analysis of the di-lepton events does not offer nearly as good mass resolution as the analysis in W+4 jets events. This is because with both neutrinos missing there are not enough constraints to do a fit, analysis finds only mass which is *most compatible* with a $t\bar{t}$ hypothesis. However, I should like to point out that event 47122_38382, which gives a high value for the most likely M_t ($\approx$170 GeV) also has very high $M_{t\bar{t}}$ >420 GeV. This could mean that this event may have also originated from the decay of the new heavy object possibly seen in the W+jets electron data. More details on the kinematical analysis of the di-lepton top candidates can be found in CDF2420.

The scatterplots of $M_{t\bar{t}}$ vs M_t for the VECBOS[10] W+4jets electron simulated data sets are presented in Figures 6 and 7; for 203 pb^{-1} sample simulated with SETPRT and HERPRT, respectively. The full CDF detector simulation QFL was used, and the data was reconstructed with the same analysis program as real data. The convention is the same as in Figure 5. It is clear that VECBOS has difficulty predicting the high mass tail in CDF W+4jet events, and certainly not their observed abundance.

In Figure 8, the scatterplots of $M_{t\bar{t}}$ vs M_t for the HERWIG+QFL generated sample of $t\bar{t}$ events, with M_t=140 GeV, are presented. The high $M_{t\bar{t}}$ tails are not as pronounced as in the data.

In Figure 9 and 9C the scatterplots of $M_{t\bar{t}}$ vs M_t for the HERWIG+QFL generated sample of $t\bar{t}$ events, with M_t=175 GeV, are presented for jet transverse energy cuts 32015 and 32010, respectively. Even here, the high $M_{t\bar{t}}$ tails are not as pronounced as in the data. Also, the scatterplots $M_{t\bar{t}}$ versus M_t in Figures 9 look very much different than those for inclusive CDF data (Figs. 5, 5B and 5C). The data match much better the Monte Carlo simulated data with M_t=140 GeV.

I have been worried for quite some time about the fact that the width of the signal in HERWIG Monte Carlo was larger that what can be seen in the data (assuming that what we see in the data can be interpreted as a signal due to $t\bar{t}$ production, which I think the data is quite suggestive of). There is some indication of inadequacies in the way the jet energies are degraded. It is a very difficult problem, at times it seems to me that only with a large sample of $t\bar{t}$ events one should be able to tune the fragmentation models. This analysis depends as none so far on how well the real transition from a parton to a jet is reproduced in "somebody's Fortran code"[11]. More details, and some thoughts about reaching a solution to this problem, can be found in the revised CDF1993 (ver. 2.0).

vi. IS IT POSSIBLE ?

Chris Hill and Stephen Parke have, without the benefit of knowledge of the CDF data, have explored in their recent paper[12] the theoretical possibility of significant distortions of the $t\bar{t}$ cross section and the distributions of variables studied in this paper ($M_{t\bar{t}}$, transverse momenta of top quark and W) due to the presence of new resonances or gauge bosons which couple strongly to top quark[13]. The existence of such objects is expected in models in which the electroweak symmetry is broken dynamically. They present several possible models. The main point of their paper is that it is *quite possible* to see very dramatic effects. In their paper they present distributions for a particular selection of M_t=160 and several M_{NEW} in the range 600-1000 GeV. The $M_{t\bar{t}}$ distribution generated for M_t=145 GeV, M_{NEW}=500 GeV for a U(1) gauge boson (model A in their paper) and with $z_1 z_2$=0.14 which is rougly electroweak strength, is shown in Figure 10[14]. Notice the logarithmic scale! The $M_{t\bar{t}}$ distribution looks remarkably similar to the analogous data plots for both b-tagged and inclusive analyses, shown in Figs.5,5B and 5C (plots 8701, in the middle on the left side).

vii. CONCLUSIONS

Of course, the statistics is very limited, and it is wonderful that we'll have (hopefully) 4-5 times more data soon. However, I think we should be very careful, having in mind the anomalies in the top candidates which I have tried to bring your attention to in this note, how we describe the excess of events (b-tagged or above VECBOS in the inclusive sample) which CDF seem to observe. We may be seeing a much more complex picture than the Standard Model $t\bar{t}$ production. It may also be a much more exciting one.

I think the mass of the top mass is M_t=147±10 GeV. This value has been consistently pointed at by my analysis, and it is also consistent now with all other top searches, except for fits to the 7 b-tagged events which indicate a higher mass value. However, I think that it is because of a few anomalous events which pull the fitted M_t distribution high in our, very small, sample of 7 tagged events. The only consistent explanation I have found for the two apparent clusters in the scatterplots of $M_{t\bar{t}}$ versus M_t, is a hypothesis of two production mechanisms, namely, that of $t\bar{t}$ pair production as expected in the Standard Model; and production of a new, heavy, object (resonance), whose decay gives rise to anomalous events. With this interpretation of the data, the mass of a top quark is about M_t=140-150 GeV (as seen in my analysis all along) and the mass of the new heavy object is about $M_{NEW} \approx$500 GeV.

REFERENCES

1. K. Sliwa, CDF/ANA/TOP/1751, CDF/ANA/TOP/1993 version 1.0, 2.0; Gary R. Goldstein, K. Sliwa and R.H. Dalitz, Phys. Rev.**D47**, 967 (1993).
2. CDF/TOPSECRET/PRD draft.
3. K. Sliwa, CDF/ANA/TOP/2420.
4. K. Kondo, S. Kim, CDF/TOP/ANA/****.
5. K. Kondo *et al.* J. Phys. Soc. Japn.**62** (1993) 1177.
6. T. Chikamatsu and S.H.Kim and K. Kondo, CDF/ANA/HEAVYFLAVOR/CDFR/1427.

7. I am deeply indebted to David Saltzberg and Mark Krasberg for sending me tapes with the electron and muon data, the inclusive analysis would be impossible without their help.

8. EWUNPK has been developed by the University of Chicago CDF Group, and is maintained by C. Campagnari.

9. several notes in USR$ROOT32:[CAROL.POT] area

10. F.A. Berends, H. Kuijf, B. Tausk, W.T. Giele, Nucl.Phys.**B357**, 32 (1991).

11. "somebody's Fortran code" is a mild version of a Steve Behrends saying.

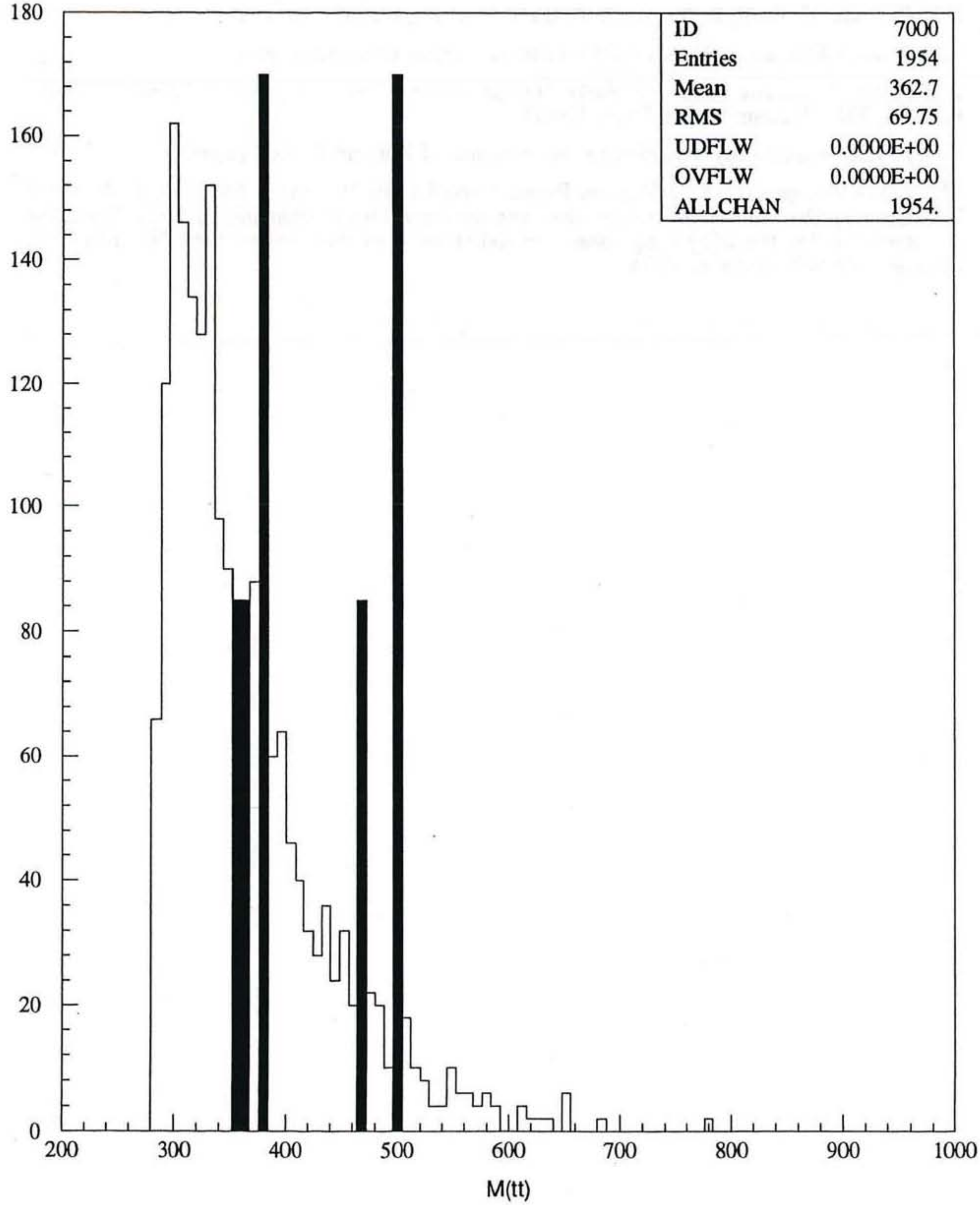
12. Christopher T. Hill and Stephen J. Parke "Top production: Sensitivity to New Physics" (FNAL-PUB-93/397-T); submitted to Phys. Rev.**D** .

13. Henry Frisch brought my attention to the existence of Hill and Parke's paper.

14. This figure was generated by Stephen Parke, I asked Chris Hill about how their plots would look like for other choices of masses than the results shown in their paper. Solid line is for $t\bar{t}$, dashed is for the U(1) gauge boson model (type A in their paper) with M_t=145 GeV, M_{NEW}=500 GeV and $z_1 z_2$=0.14.

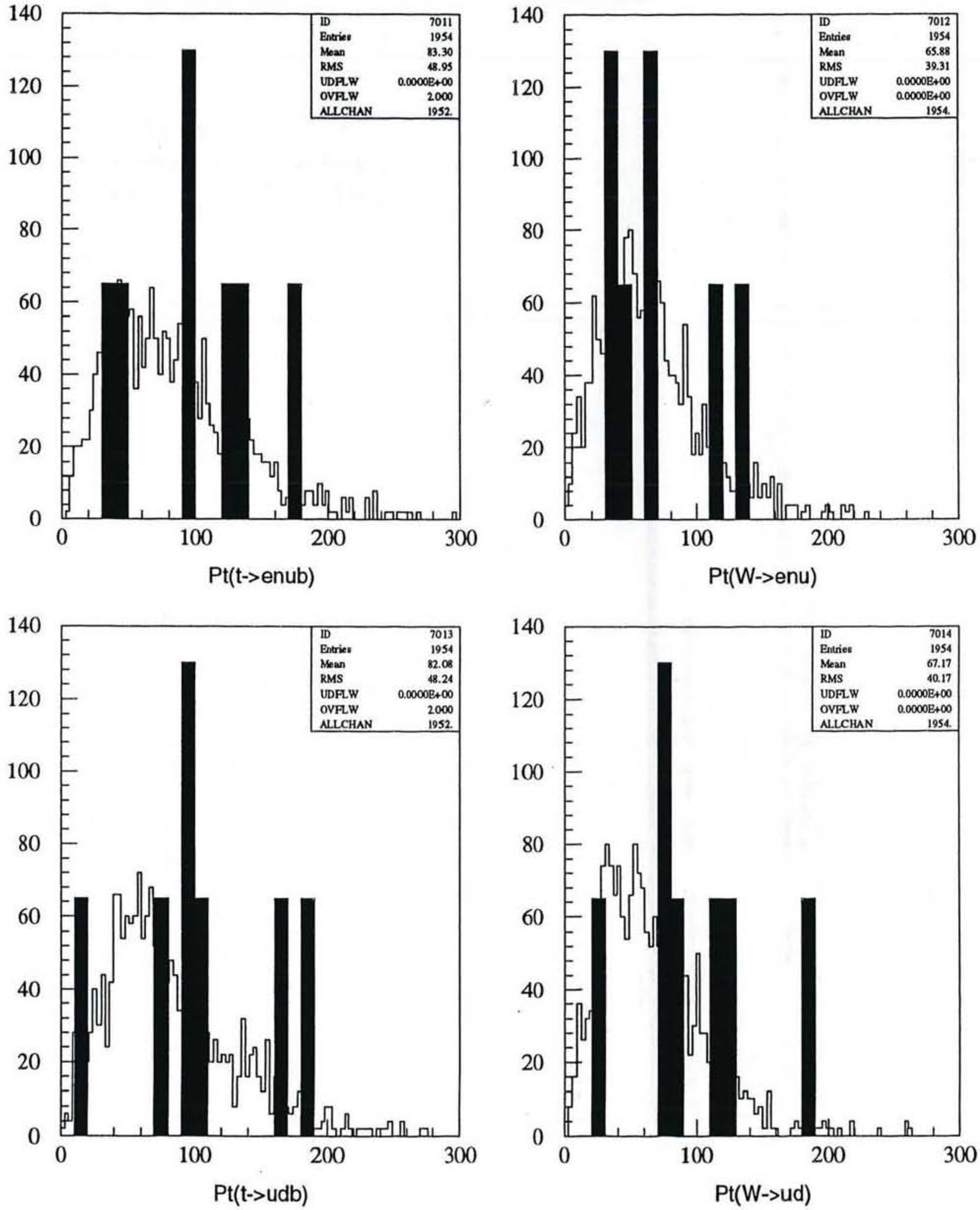
19/01/94 12.19

Figure 1. M(tt) for 7 tagged events and MC Mt=140 GeV



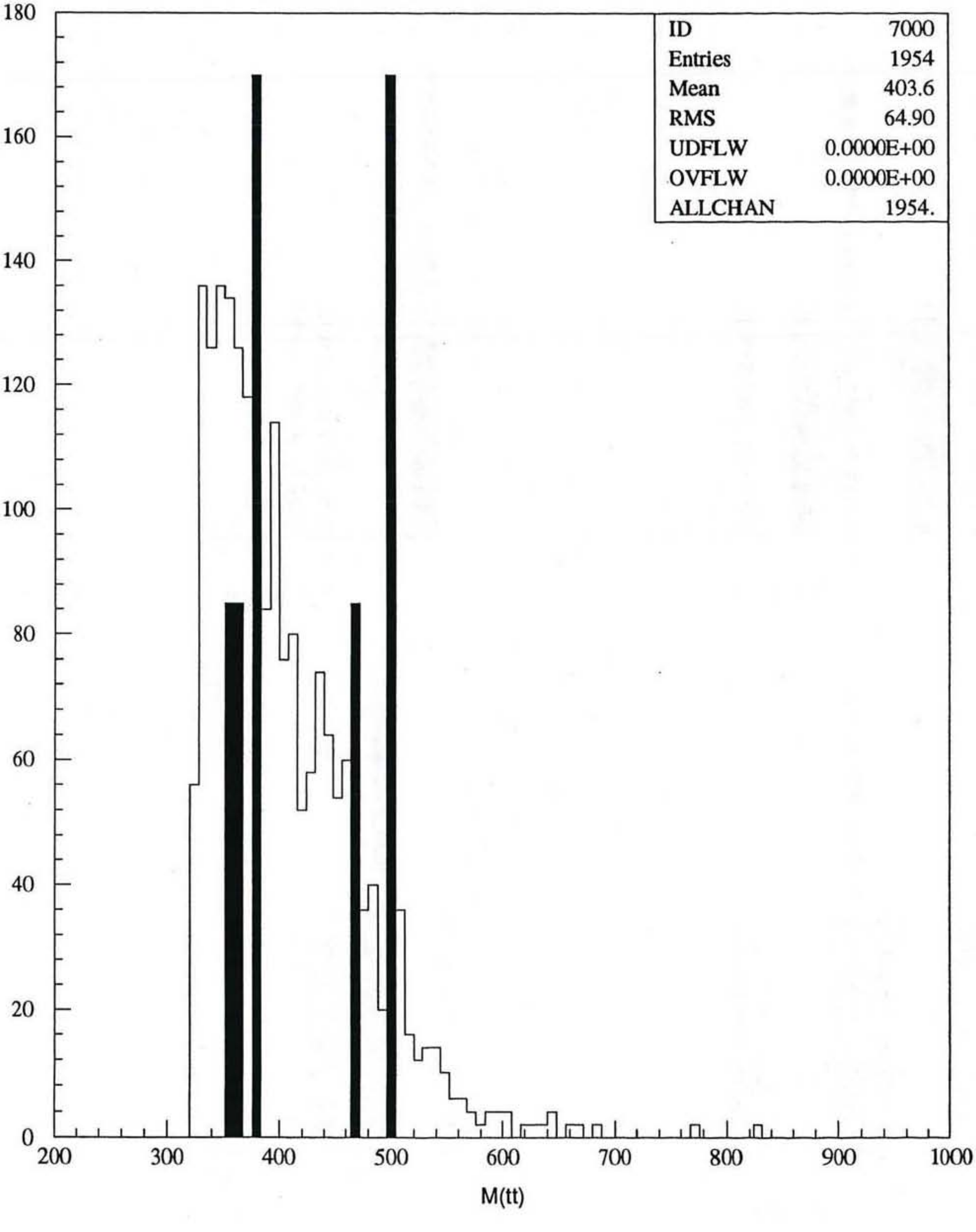
19/01/94 12.19

Figure 1b. Pt(t) and Pt(W) for 7 tagged events and MC Mt=140 GeV



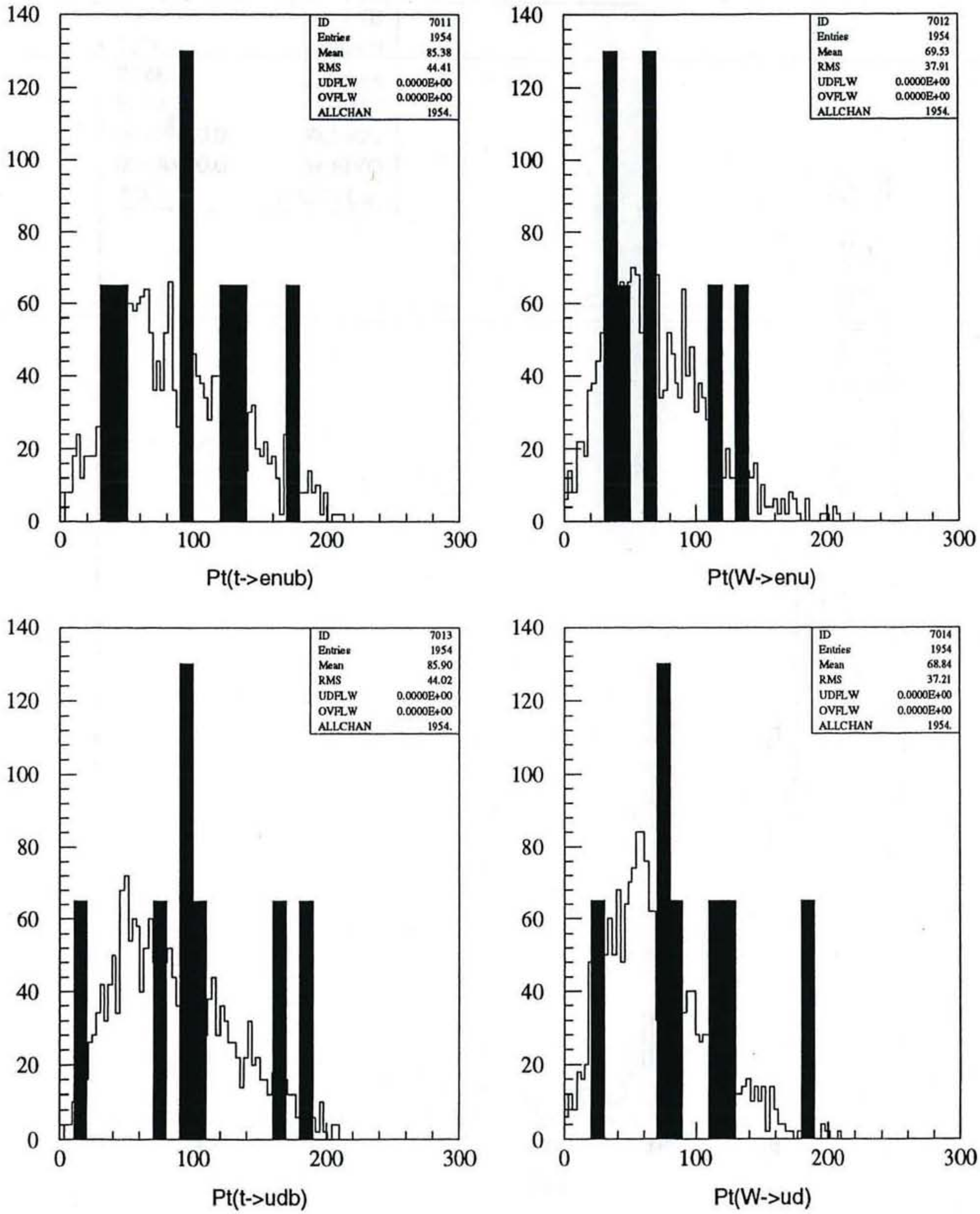
19/01/94 12.20

Figure 2. M(tt) for 7 tagged events and MC Mt=160 GeV



19/01/94 12.20

Figure 2b. Pt(t) and Pt(W) for 7 tagged events and MC Mt=160 GeV



19/01/94 11.48

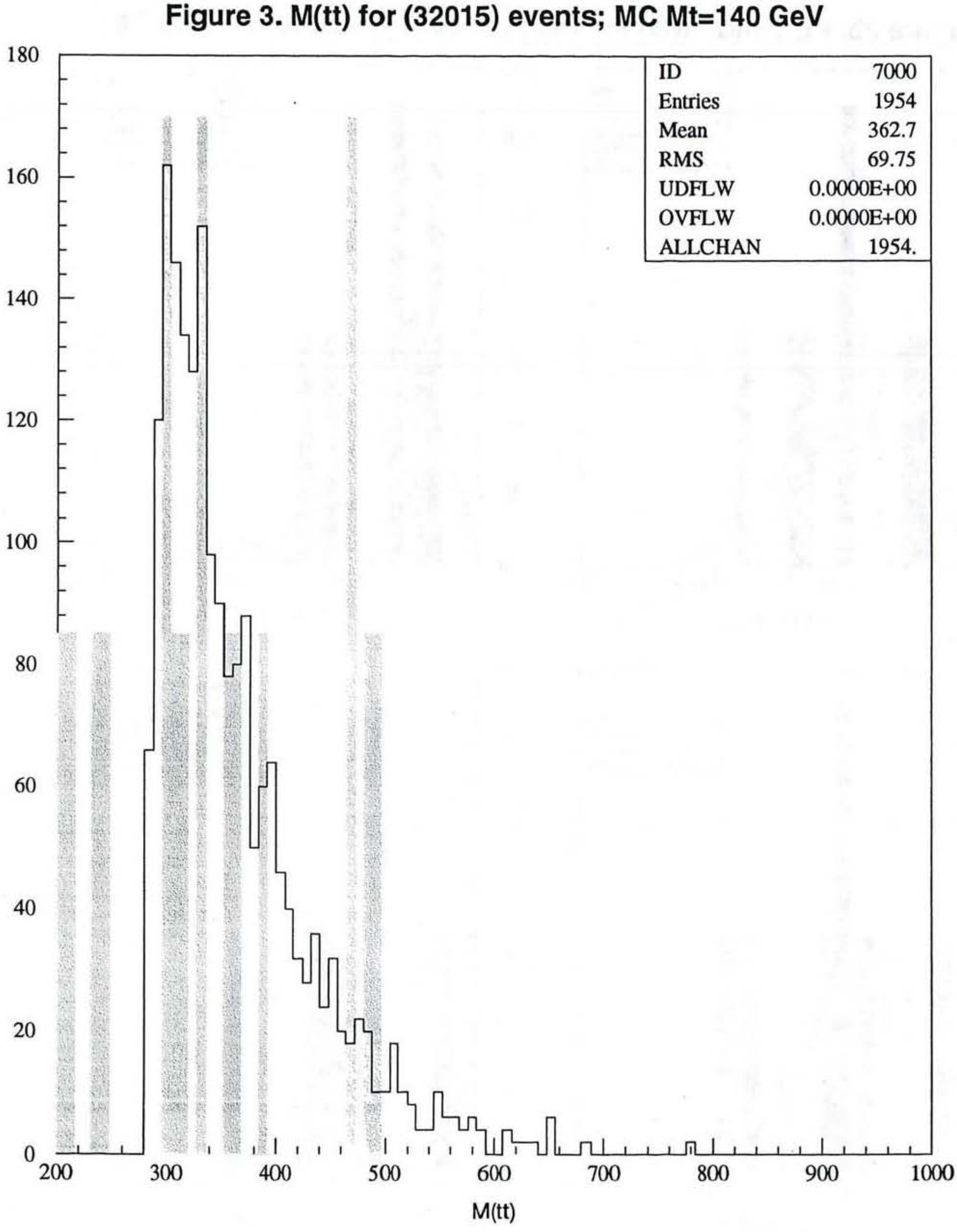
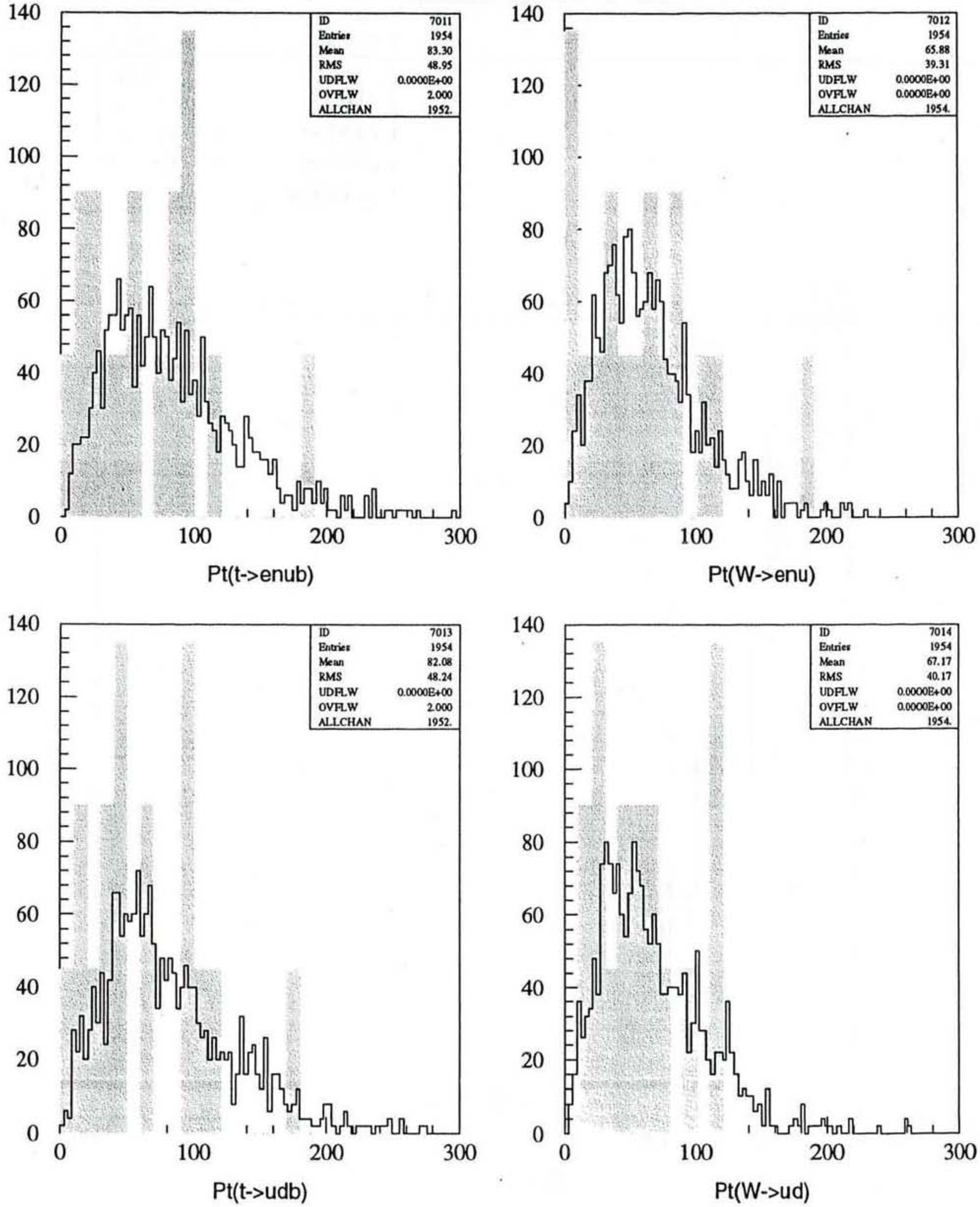


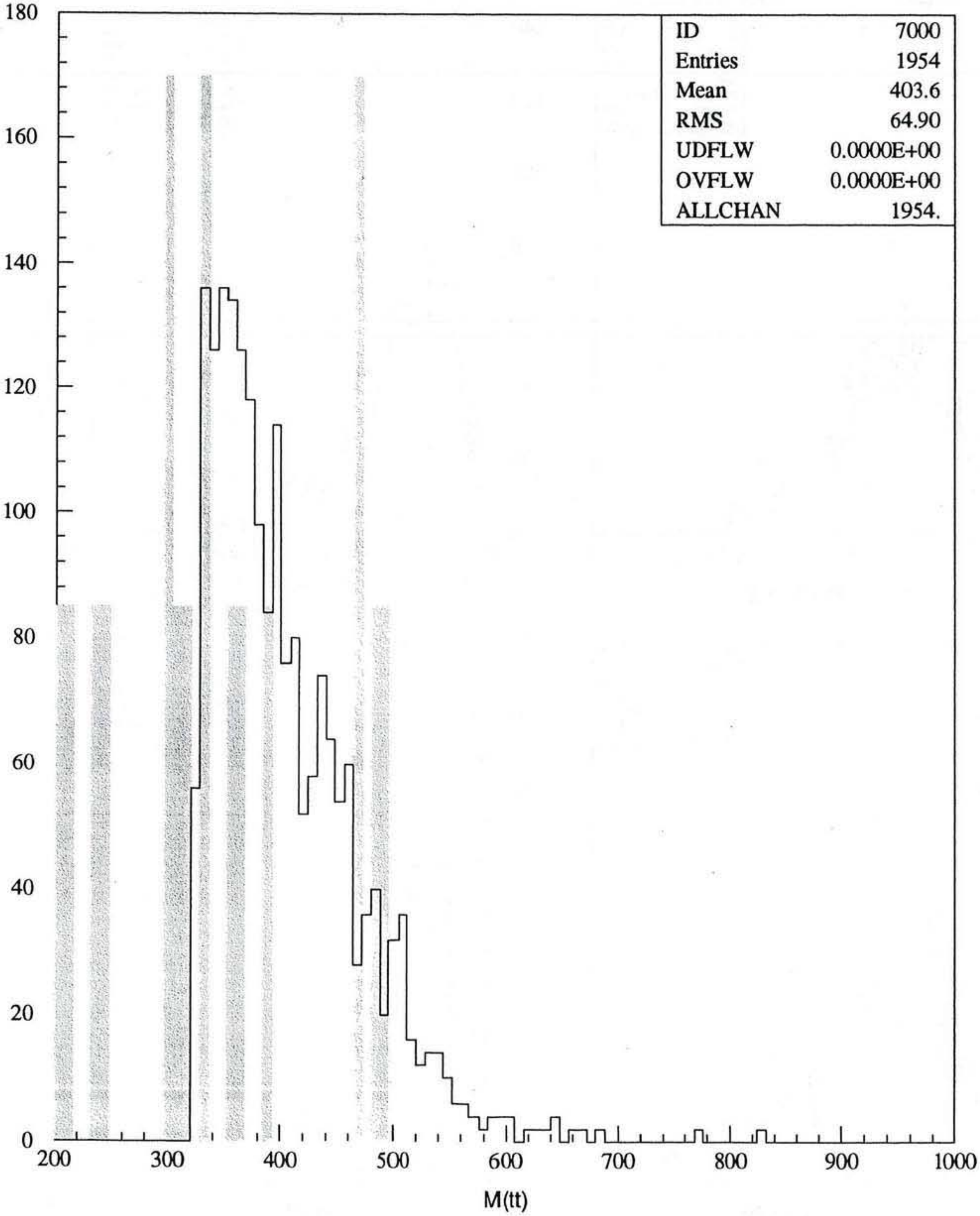
Figure 3. M(tt) for (32015) events; MC Mt=140 GeV
ID 7000
Entries 1954
Mean 362.7
RMS 69.75
UDFLW 0.0000E+00
OVFLW 0.0000E+00
ALLCHAN 1954.
180
160
140
120
100
80
60
40
20
0
200
300
400
500
600
700
800
900
1000
M(tt)

Figure 3b. Pt(t) and Pt(W) for (32015) events; MC Mt=140 GeV



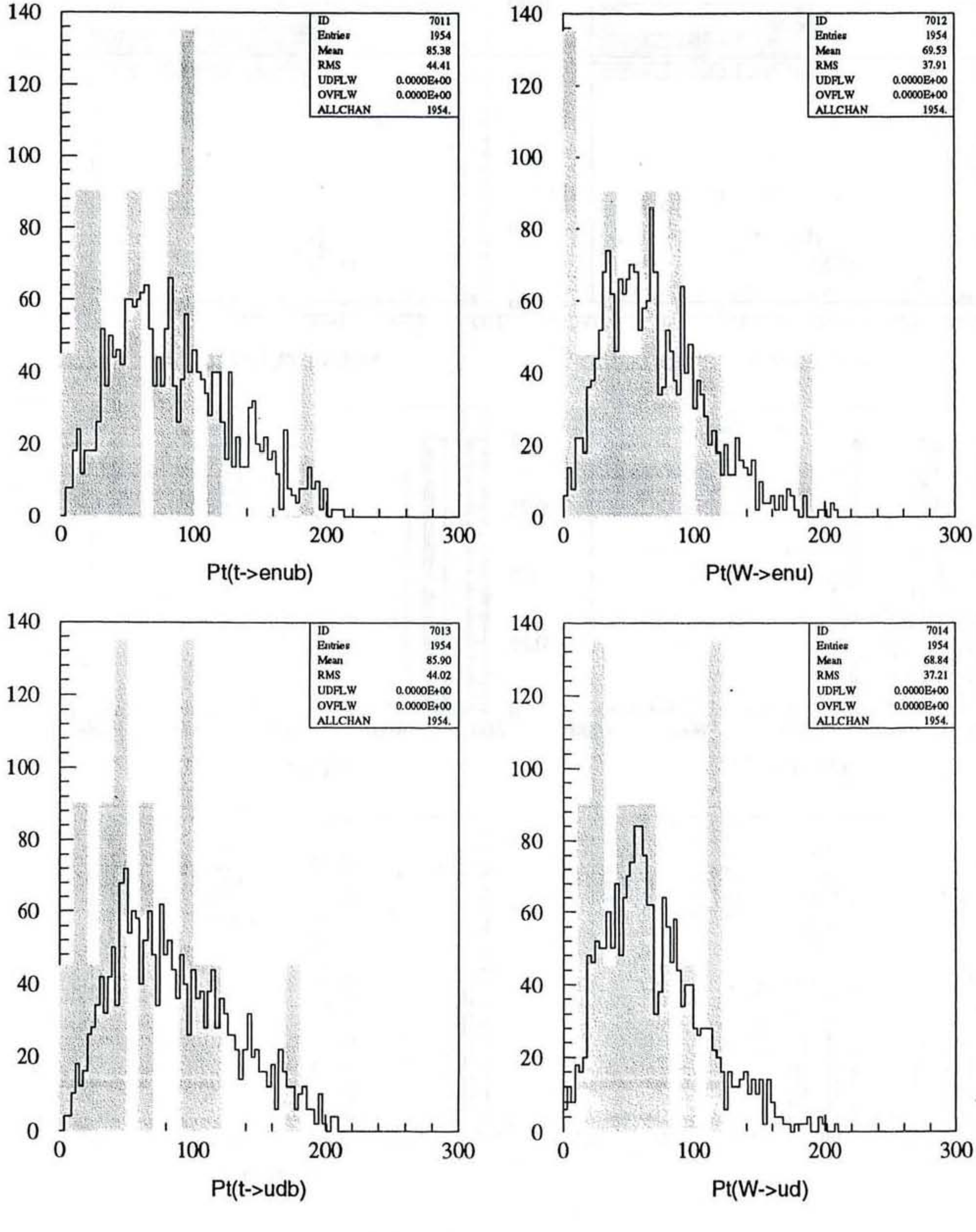
19/01/94 12.14

Figure 4. M(tt) for (32015) events; MC Mt=160 GeV



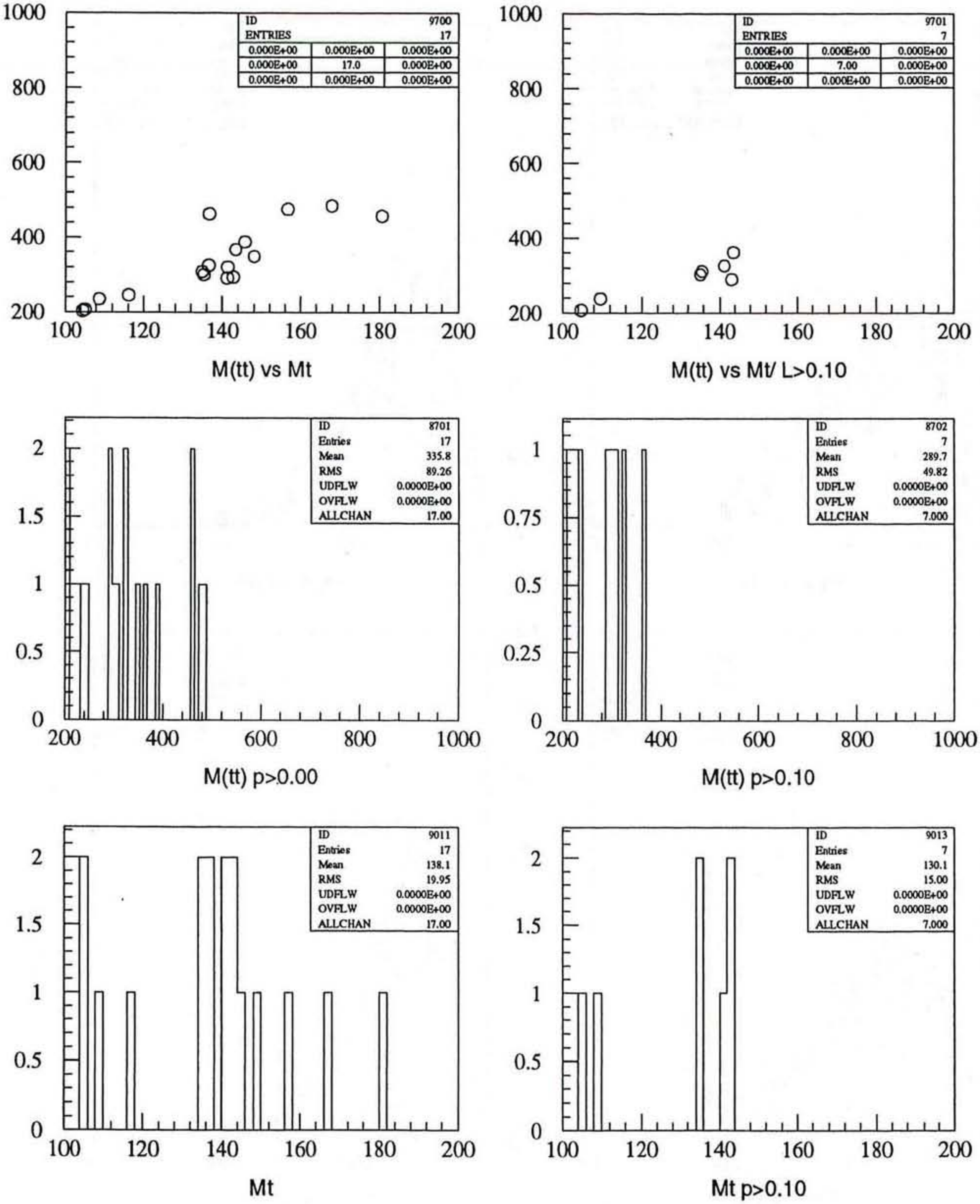
19/01/94 12.14

Figure 4b. Pt(t) and Pt(W) for (32015) events; MC Mt=160 GeV



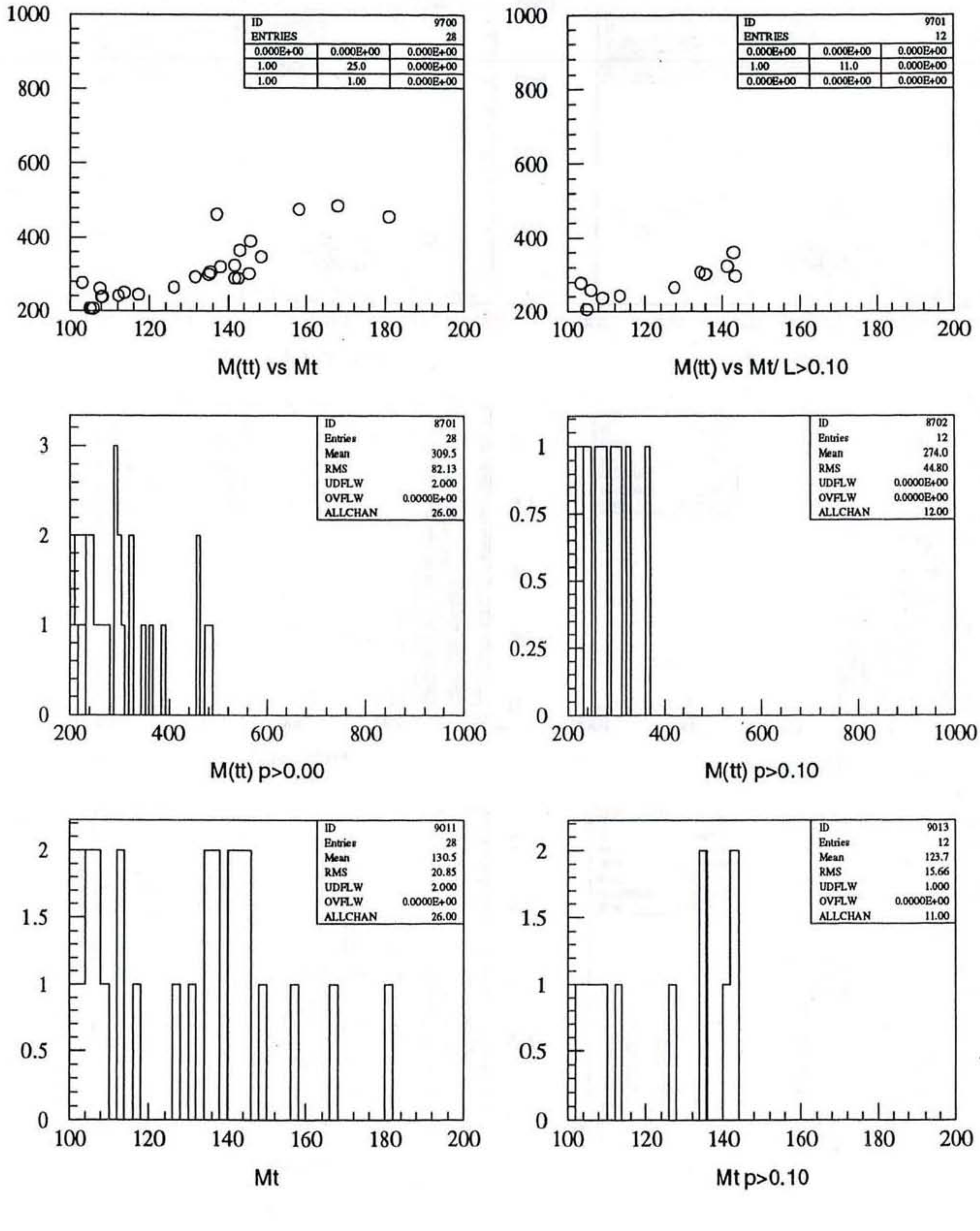
19/01/94 12.51

Figure 5. M(tt) vs M(t)/projections/88+93 W->enu (32015)



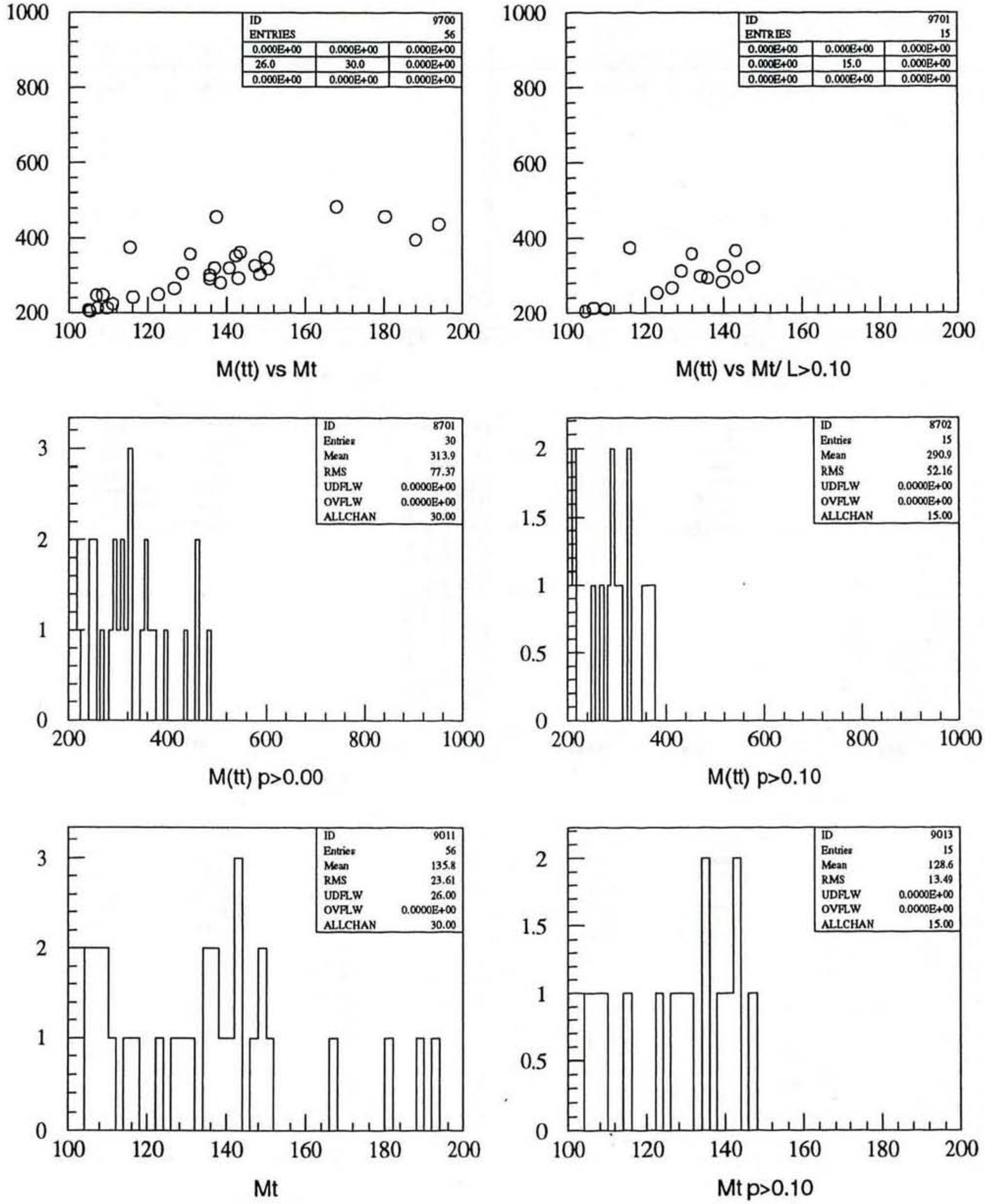
22/03/94 17.08

Figure 5b. M(tt) vs M(t)/projections/88+93 W->enu (31515)



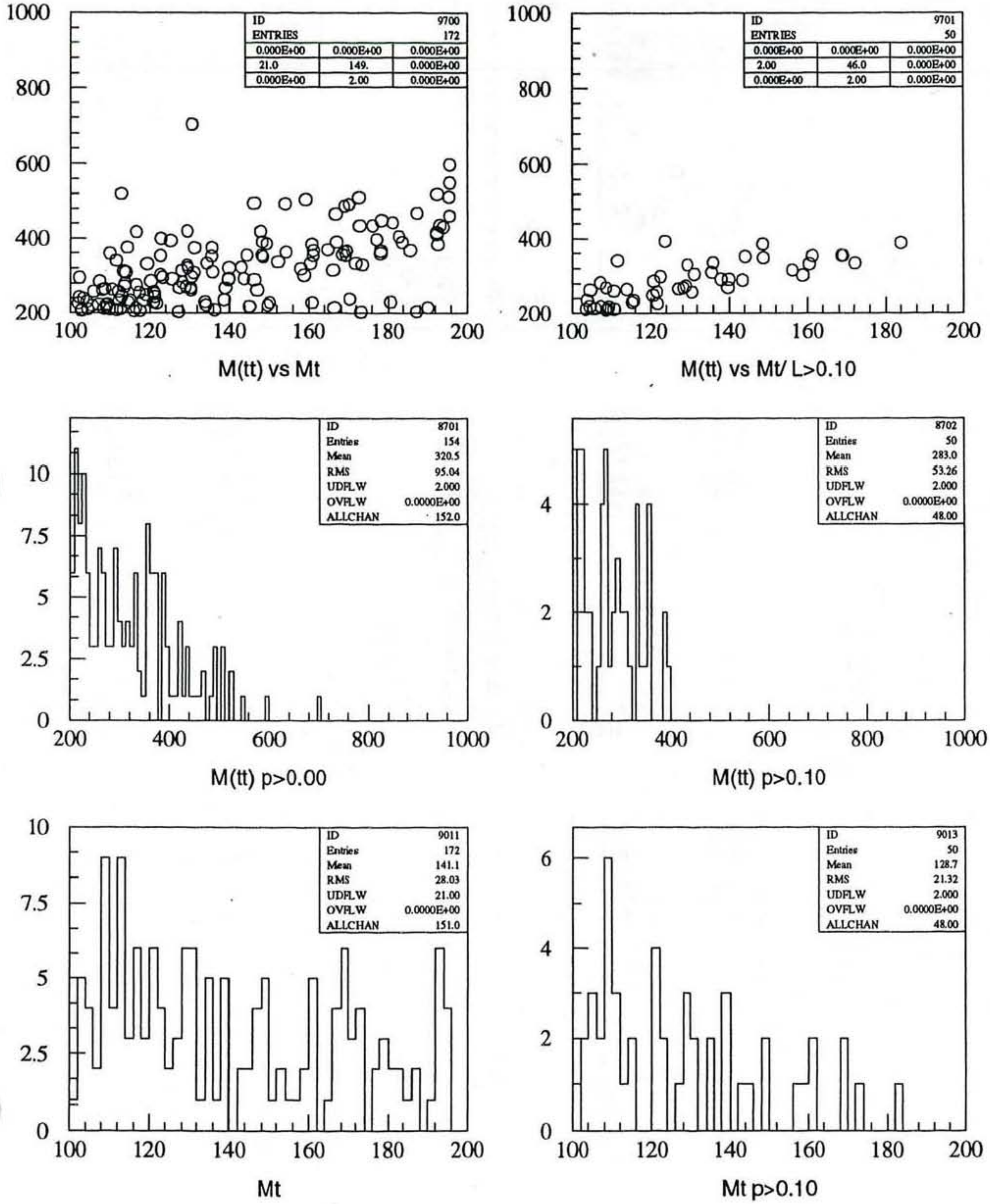
22/03/94 17.19

Figure 5c. M(tt) vs M(t)/projections/88+93 W->enu (32010)



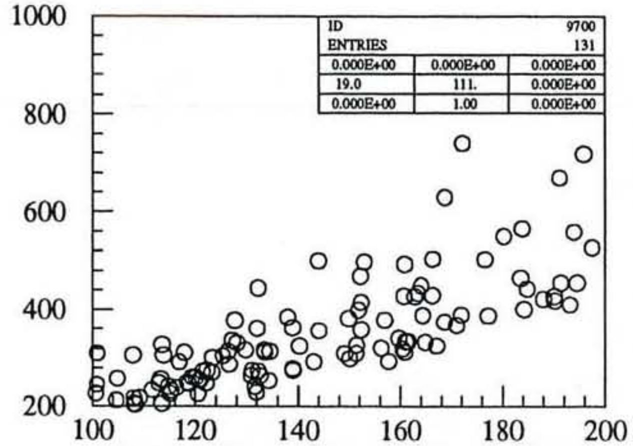
23/03/94 16.22

Figure 6. M(tt) vs M(t)/projections/203 pb-1 VECBOS+SETPRT (32015)

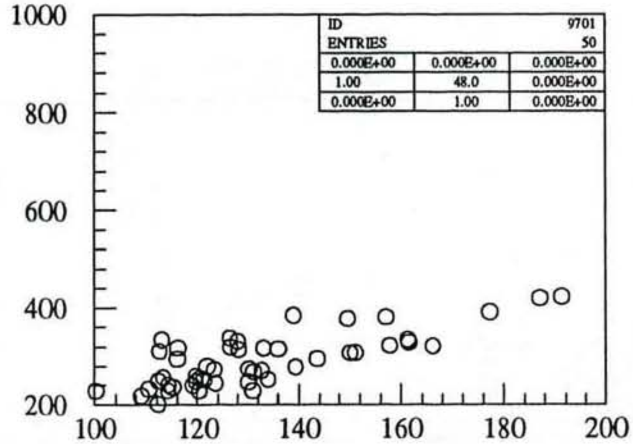


23/03/94 12.58

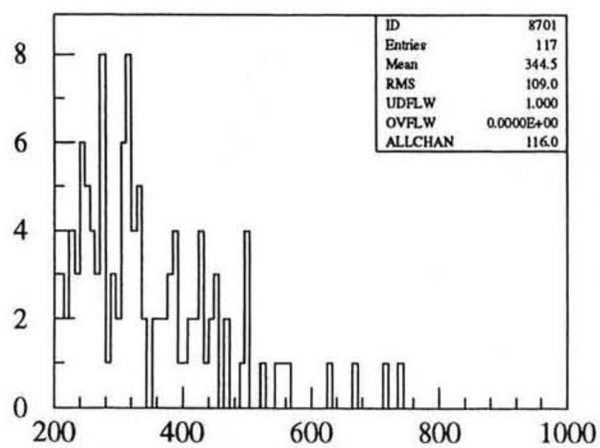
Figure 7. M(tt) vs M(t)/projections/203 pb-1 VECBOS+HERPRT (32015)



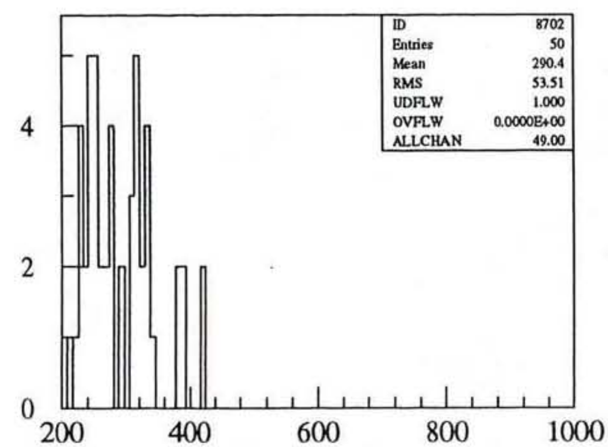
M(tt) vs Mt



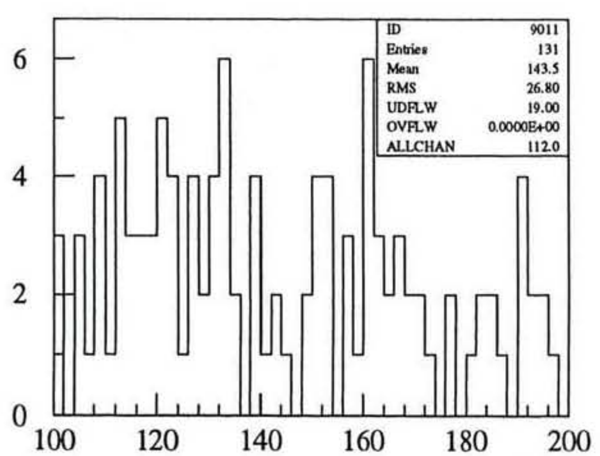
M(tt) vs Mt/ L>0.10



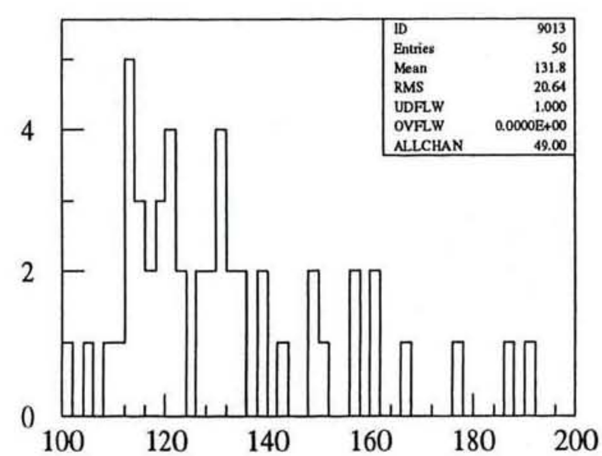
M(tt) p>0.00



M(tt) p>0.10



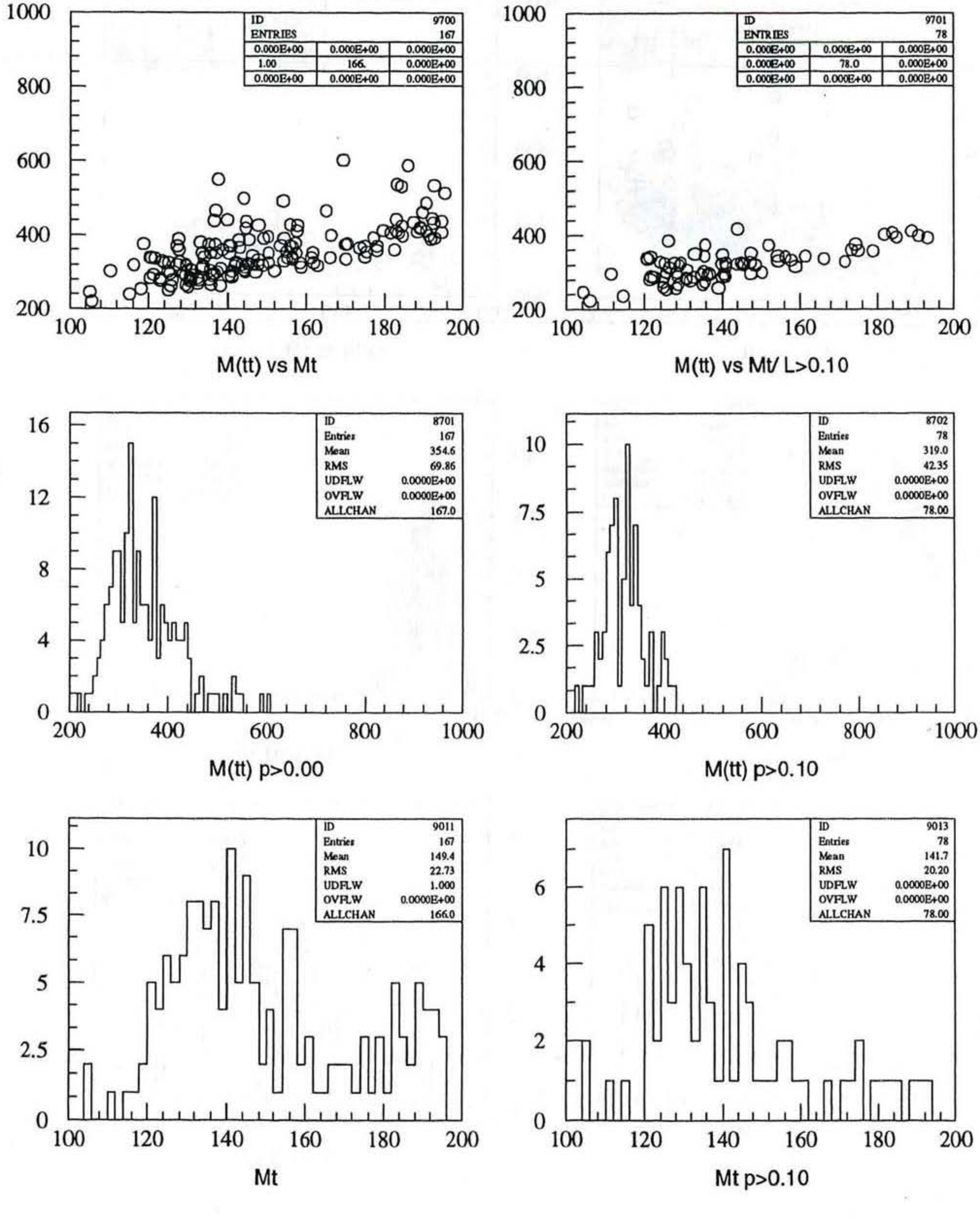
Mt



Mt p>0.10

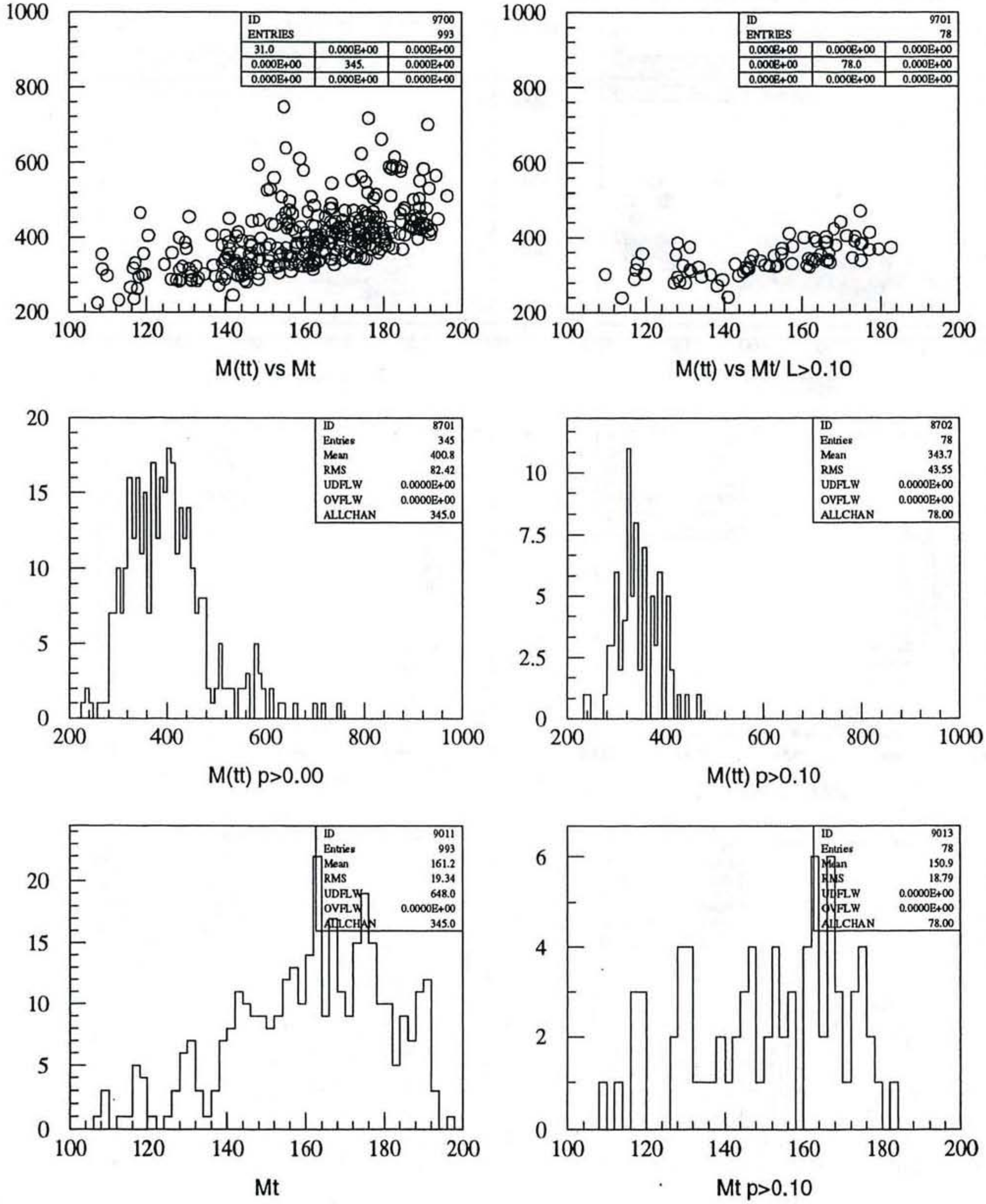
19/01/94 13.46

Figure 8. M(tt)/M(t)/projections/ HERWIG Mt=140 GeV (32015)



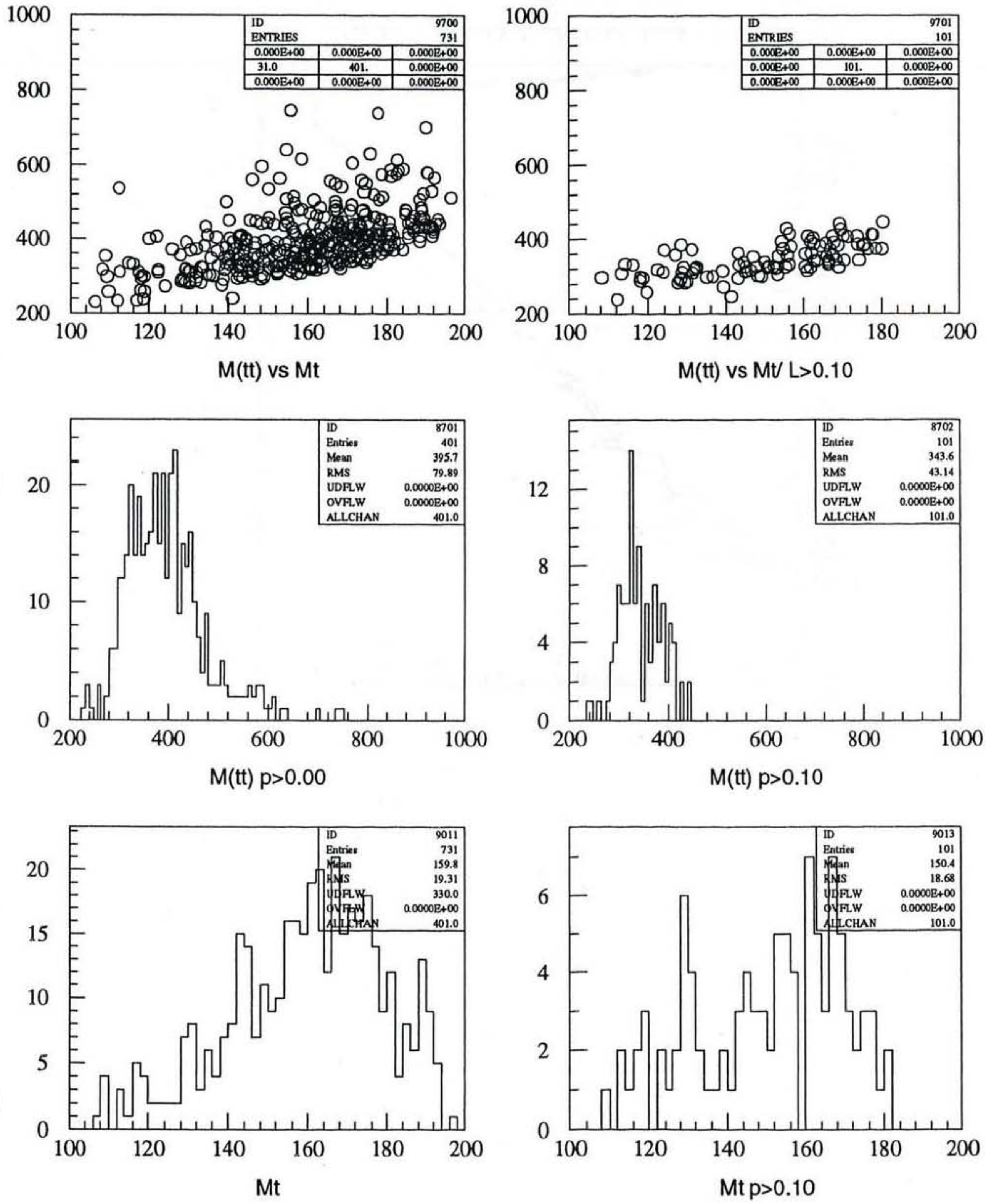
11/04/94 11.21

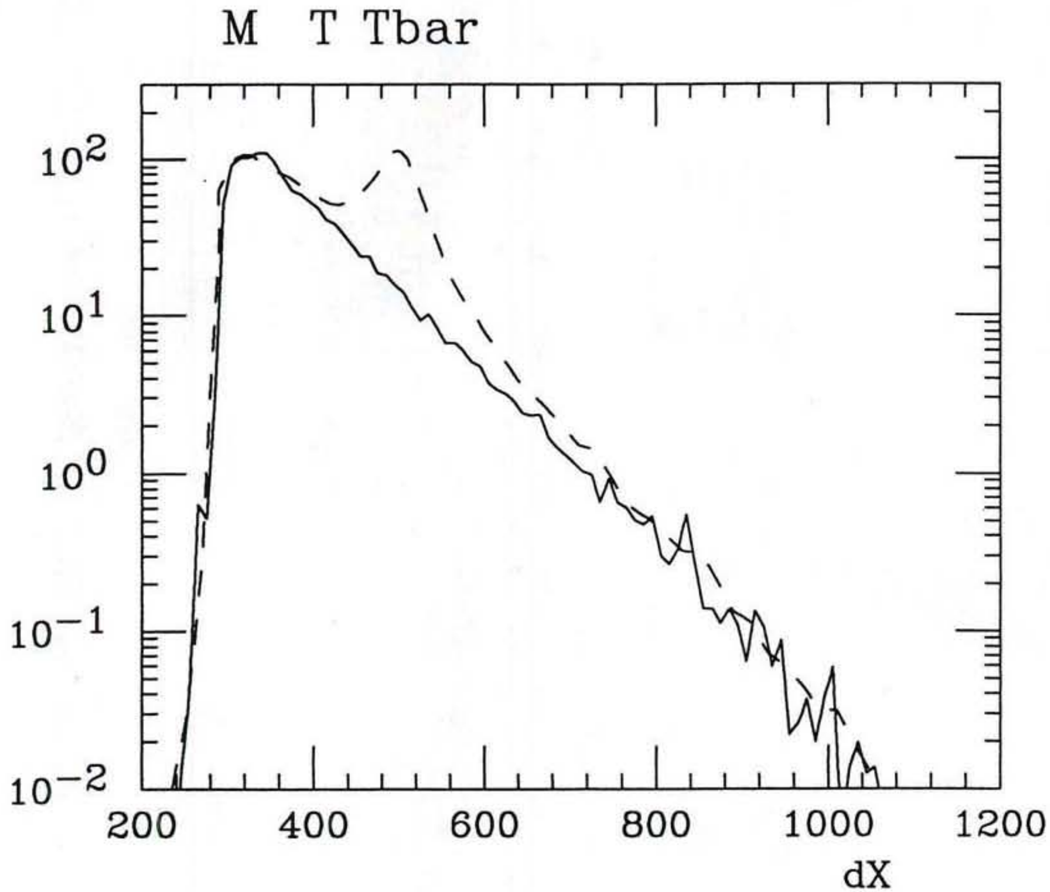
Figure 9. M(tt)/M(t)/projections/ HERWIG Mt=175 GeV (32015)



11/04/94 11.25

Figure 9C. M(tt)/M(t)/projections/ HERWIG Mt=175 GeV (32010)




M T Tbar
D SIG /D dX (fb/GeV)
10^2
10^1
10^0
10^{-1}
10^{-2}
200
400
600
800
1000
1200
dX