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SEARCH FOR $t\bar{t}$ EVENTS IN THE LEPTON AND FOUR JETS FINAL STATE

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PROLOGUE

I hope that my collegues, finally, will be able to find time and read my paper and learn about my analysis and my results. Hopefully before we send out our PRD. This is my 10-th, perhaps, attempt to get my collegues within CDF interested and cognizant of an analysis of CDF data that I am continuously (for the last two years) trying to present to the Collaboration and solicit comments and, so far without success, cooperation. What is the most disturbing is that a group of people called the Godparents for top analyses, whose single purpose should be to review various top analyses pursued within the Collaboration has failed to contact me even once to make any substantive comments about my work, despite my urging them to do so. I have to conclude that the presently appointed Godparents have either no time, no interest, insufficient physics expertise, or a pathological intolerance of dissenting views to perform their duties as it should be required of them. Therefore I request the appointment of a new set of Godparents for my analysis.

ABSTRACT

A preliminary result of a search for events with characteristics expected of the production and decay of a pair of new heavy quarks is presented. Throughout the paper it is assumed that the heavy quarks searched for are the top and anti-top ($t\bar{t}$) quarks, however, the analysis would be identical if one searched for a pair of, say, fourth generation $b'\bar{b}'$ quarks. The analysis is based on all available data recorded during the 1988-1989 and 1992-1993 runs with Collider Detector at Fermilab (CDF), and corresponding to an integrated luminosity of about 25 pb^{-1}. The $t\bar{t}$ events are identified by means of reconstructing the event kinematics. Several $t\bar{t}$ candidates were found. It is argued that it is unlikely that those events may have originated from QCD W+jets process. The probability that the analyzed sample of CDF events is consistent with kinematics and, via Bayes's theorem, with selected production and decay characteristics of a $t\bar{t}$ pair of quarks points to the mass of the top quark M_t=147$\pm$10 GeV, which value has been corrected for the mass shifts observed in Monte Carlo simulations. The cross section is found to be consistent with being in the range 15-20 pb.

i. INTRODUCTION

At Fermilab Tevatron energy, $\sqrt{s} = 1.8$ TeV, the dominant production mechanism of top quarks is the $t\bar{t}$ pair production from a quark-antiquark or gluon-gluon initial state via the strong interaction.

If one of the top quarks decays leptonically, into $t \to bl^+\nu_l$, and the other hadronically, $\bar{t} \to \bar{b}q\bar{q}$, the final state will be that of a lepton+multijet+$\not{E}_t$ event. The branching fraction for this decay mode (we shall call it a *semileptonic* mode) is 6 times the branching fraction for the leptonic mode, $t \to l^+\nu_l b$ and $\bar{t} \to l^-\bar{\nu}_l\bar{b}$, where l is either an electron or a muon. However, the backgrounds to the possible $t\bar{t}$ signal coming from the W+jets process of QCD, which were feared to be much larger than a signal itself, have to be addressed.

With the results of analytic calculations[1] of QCD matrix elements for a vector boson decaying into n partons (n≤6) available (which by appropriately crossing partons can be used to describe the production of a W and jets), it became clear that in a wide range of top quark mass above $M_t \approx 120$ GeV, the signal in the *semileptonic* W+4jet mode may actually be (depending on jet E_T cuts used) comparable to the QCD W+4jet backgrounds.

The transverse energy, E_T, of b-quark jets depends on the mass of the top quark. For heavy top quarks, $M_t \geq$ 110-120 GeV, most of events will have four jets of sizable transverse energy (E_T), two from $W \to q\bar{q}$ decay and two b-quark jets, a single very energetic lepton and large missing transverse energy, $\not{E}_t$.

ii. THE TECHNIQUE

The technique used in this analysis is a modification of a method developed by Dalitz, Goldstein and Sliwa, published in Physical Review D[2] in its version as of the summer 1992. Here the basic points of the method are sketched, in an attempt to simplify the presentation. Several modifications, made since, are also described.

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. The result can be presented as a probability of this hypothesis as a function of M_t.

In this analysis, it is *assumed* that the two objects are the t and $\bar{t}$ quarks. However, a pair of b' and $\bar{b}'$ quarks, decaying into charm quarks rather than b quarks (b'→Wc) would be reconstructed identically to a pair of t and $\bar{t}$ quarks[3].

If a neutrino, a partner to a lepton in the leptonic W decay, could be detected and if the energies and directions of the four jets would correspond exactly to those of the quarks they originated from, then the kinematics of the $t\bar{t}$ event would be known completely. One would simply measure the four-momenta of both the t and $\bar{t}$ quarks. The only complication could stem from combinatorics, however, it would be easy to resolve the possible assignment ambiguity owing to the fact that both t and $\bar{t}$ quarks have the same mass.

In reality, the four-momentum of the three jets coming from the top quark decaying *hadronically* will only approximate that of the parent quark, and a neutrino escapes detection altogether. In CDF, it is the lepton that is the best measured parton out of $t\bar{t}$ decay products, while the jets only approximate, much less accurately, the remaining partons (quarks). Missing transverse energy provides some information about the transverse energy of a neutrino, however, the precision of such a measurement is poor. This is a direct consequence of the way $\not{E}_t$ is defined, as a complement of the total observed transverse energy. Uncertainty with which $\not{E}_t$ is known is a convolution of not only the errors on the four jets originating from $t\bar{t}$ decay but errors on all other jets in the event as well. The correlation between the transverse momentum of a neutrino from a W decay and $\not{E}_t$ is deteriorating rapidly with increasing number of jets in W+jets events.

The technique used in this analysis takes the best information available (lepton) and a necessary minimum information from the remaining partons (jets) which are not measured as well as the lepton. Whenever possible, kinematical constraints are employed to minimize the distortions in the measurements of $t\bar{t}$ four-momenta. Most importantly, one can ignore the neutrino completely.

The ellipse

Let's consider the decay $t \rightarrow Wb$ followed by $W \rightarrow l^+\nu_l$. Assuming that the decay occured in the *semileptonic* mode, knowledge of the (measured) lepton and b-quark jet four-momenta and the (assumed) top quark mass is sufficient information to find a complete set of the possible top quark four-momenta. The solution is reached in a geometric rather than an algebraic way, following an elegant construction[4], sketched in Figure 1. There are two kinematical constraints which apply:

$$(l+\nu)^2 = M_W^2$$
$$(t-l-b)^2 = M_\nu = 0$$

where t, l, b, ν are the t-quark,lepton,b-quark and neutrino four-momenta. Relations between the *momenta* follow straightforwardly

$$(\vec{t}-\vec{b})^2 = (E_t - E_b)^2 - M_W^2 = R_W^2$$
$$(\vec{t}-\vec{b}-\vec{l})^2 = (E_t - E_b - E_l)^2 = R_\nu^2$$

The set of possible top momentum vectors is defined by a circle of intersection of those two spheres in the momentum space, with radii R_W and R_ν and whose centers are separated by $\vec{l}$. If the two spheres do not intersect there is no solution. This may occur, for example, if a *wrong* jet is taken for a b-jet coming from the $t \rightarrow Wb$ decay. The radius of this circle of constant E_t is

$$r^2 = \frac{M_W^2}{|\vec{l}\,|}(E_t - E_o)$$

where the constant E_o

$$E_o = E_b - E_l + \frac{M_W^2}{4E_l}.$$

is the lowest energy for which any top quark can be found consistent with given lepton and b-jet momenta. A complete set of circles, obtained with increasing E_t, defines (neglecting the lepton mass) the surface of a paraboloid. For any given circle the top quark mass will vary around the circle. Points of *constant* M_t will lie on a plane section of the paraboloid - an ellipse. Projection of this ellipse on the transverse momentum plane will also be an ellipse, defining a set of all possible transverse momenta of the t-quark consistent with the lepton and b-jet momenta and the assumed top quark mass.

Taking measurement errors into account

In an ideal case, the measured jet energies would correspond to the true parton energies. The three jets from *hadronic* decay of the t quark would add exactly to the top quark energy-momentum four-vector. Its length is the mass of the top quark, $t^2 = M_t^2$. Taking M_t (calculated from the three jets from *hadronic* decay) for the mass of the $\bar{t}$ quark, together with four-momenta of the lepton and b-jet from its leptonic decay allows to find the ellipse of possible momenta of $\bar{t}$ quark. (In this way the requirement that the masses of the t and $\bar{t}$ quarks are equal is implemented.) If the t and $\bar{t}$ quarks had been produced with zero transverse momentum, the projections of their momenta onto the transverse momentum plane would be equal and back-to-back. Negative of transverse momentum of the t quark, $-\vec{t}$, would match exactly a point on the ellipse in the transverse momentum plane.

In CDF's reality the jet direction is measured well, but its energy with only a limited precision. Existing parametrizations of jet energy error as a function of jet transverse energy offer information about *average* degree of jet energy mismeasurement. For any given jet, however, it is impossible to know how bad or how good the measurement is. We shall assume here that the lepton energy and direction, and the jet directions are measured perfectly. We also assume that, *on average*, the jet energies correspond to the parton energies. To account for errors in jet energy determination, we shall vary jet energy in the range of $\pm 3\sigma$ around the measured value, in a number of discrete intervals, creating a set of *guesses* for the jet energy.

Varying the energy of a b-jet from $\bar{t}$ leptonic decay will lead to a family of ellipses, corresponding to the same M_t and lepton momentum but different *guesses* about b-jet energy. In an ideal case, the $-\vec{t}$ will match best the ellipse obtained using the central value for the b-jet energy. Matches with other ellipses may be close, but nor as good. The non-zero transverse momentum of the $t\bar{t}$ system, which is the case in most of $t\bar{t}$ events, would also disturb the closeness of the *match*.

Varying the three jets from the *hadronic* decay of the t quark would give another family of values for M_t, multiplying the number of possible ellipses.

Two of the three jets come from the W decay. We constrain the masses of the two jets to M_W. Because it is not possible, at present, to tell which two out of three jets have originated from the W decay, all three possibilities are investigated. (B-quark tagging may become a viable way to improve the present approach, and the information about which jet is a b-jet in can be easily incorporated in this method.) Because we consider the jet directions perfectly measured, constraining the two jets to M_W defines a hyperbola in the $C_1 \times C_2$ plane, where C_1 and C_2 are the re-scaling factors for the two jets' energies. Restricting the variation in jet energies within $\pm 3\sigma$ around the measured values limits the allowed values for C_1 and C_2 to a section of a hyperbola. Dividing this section into a discrete number of intervals defines a set of pairs (C_1,C_2) which, in turn, lead to the pairs of jet energies constrained to M_W, while varied in the chosen range.

The third jet from the *hadronic* decay, a b-jet, is varied as the b-jet from the *leptonic* decay.

By varying jet energies within $\pm 3\sigma$, it is possible to recover matches even if the jets are mismeasured to some degree.

The definition of probability

In an ideal case, with perfect measurements of all partons, without varying jet energies and with zero transverse momentum of $t\bar{t}$ system there would be one, perfect, match in the transverse momentum plane. Going around the ellipse of $\bar{t}$ transverse momenta would necessarily lead to a single point where it matches the transverse momentum of a t quark. In the real case, applying the method will result in numerous families of t quark momenta, $\vec{t}$, their masses M_t^* and the corresponding ellipses. Going around the numerous ellipses may produce more than one match, those obtained only after varying the jet energies away from the central values not as likely as those obtained with the central values. Probability of a match is defined as a product of several factors.

For every jet, there is a factor, G, downgrading *guesses* far removed from the measured jet energy, considered less likely. (With Naor Wainer's gaussian[5] parametrization of jet energy errors it was trivial to assign such a factor, however, the technique could be easily modified to incorporate any other parametrization of jet energy errors.)

In a version of the method published in Physical Review D[2], a step function of width $0.1 \times M_t$ was taken as a criterion for matching in transverse momentum plane, for simplicity. This analysis assigns each match a probability according to the transverse momentum distribution of a $t\bar{t}$ quark pair, $P(X_{t\bar{t}})$, generated using HERWIG or ISAJET[6]. The variable

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

scales with M_t, top quark mass. The distribution of $P(X_{t\bar{t}})$ is shown in Figure 3; it is clear that this modification has increased the efficiency of the technique.

For every match 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 then 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 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, $G_{\not{E}_t} = G^x_{\not{E}_t^x} \times G^y_{\not{E}_t^y}$, 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 $G_{\not{E}_t} = G^x_{\not{E}_t^x} \times G^y_{\not{E}_t^y}$ factors are applied presently *à posteriori* , after the solution has been reached without using the information about missing transverse energy. They affect only the overall value of the likelihood without altering relative probabilities assigned to different points in the grid spanned in parameter space, as described in the next section.

The fitting procedure

The first step is to choose a combination of lepton and jets, with a set of E_T, $\not{E}_T$ and pseudo-rapidity, η, cuts. A single *combination*, of which there may be several in a single event, is characterized by a set of lepton and jet 4-momenta. The three jets, with 4-momenta p_1, p_2, p_3, form the tentative top (or anti-top) momentum $\vec{t}=\vec{p}_1+\vec{p}_2+\vec{p}_3$, with top mass estimate $(M_t^*)^2=t^2$. The lepton and remaining b-jet 4-momenta, along with the mass M_t^* just determined, define an ellipse of possible 3-momenta for the $\bar{t}$ quark.

The combination of the existence of an ellipse for M_t^* and a near cancellation of transverse momenta consitutes the kinematic fitting criteria. Varying the jet energies leads to a large family of ellipses and $\vec{t}$. For each b-jet the $\pm 3\sigma$ energy range is divided into N=17 equal intervals. The segment of hyperbola in the plane of the energy re-scaling factors for the two jets from a hadronic W decay is divided into M=21 intervals. Each ellipse is scanned in K=73 discrete points. For every *combination* the four dimensional parameter space is thus divided into a grid of $N^2 \times M \times K$ uniformly distributed points. (The values of N,M,K were chosen as a result of a Monte Carlo study, and represent a compromise between the desire for a very fine structure of the grid and the finite amount of computer time available.)

Each point (representing a different kinematical configuration) is assigned a probability equal to L_i, in case when there is a match; or zero when no solution was found. The probabilities L_i are projected for all points onto the M_t axis to form a *combination* probability, L_{comb}. If there are several combinations in an event, the best solution i.e. the combination with the largest L_{comb} becomes an *event* probability, L_{event}. The peak in this distribution points to the most likely mass, its width information about the error on the most likely mass, while the integrated value of the probability carries the information about how likely, relative to other combinations, the solution is.

À priori, for every combination the volume of the parameter space may be different. Spanning a uniform grid in this parameter space, with always the same *number of points* , elliminates the possible phase space effects.

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.

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[7]

To keep the systematics as simple as possible and to avoid issues which appear whenever one uses weighted distributions for a small number of events, each events is represented by a single entry in a M_t distribution corresponding to the most likely M_t value in L_{event}, with unit weight. This distribution provides the means to separate $t\bar{t}$ events from background events, as will be shown. By varying the jet transverse energy cuts and the likelihood(probability) cuts one may generate a family of distributions with different background to signal ratio and different systematics, which the can be compared with Monte Carlo simulations for signal and background.

iii. SIMULATED MONTE CARLO DATA SETS

Background

A full calculation of W+(n)jets QCD matrix element at tree level (with $n \leq 4$) by Berends, Giele, Kuijf and Tausk4[1], has been implemented in VECBOS event generator. Several Monte Carlo samples were used to study W+jets QCD background.

The samples used were made by Jose Benlloch; and by Jose, Alessandra Caner and Teresa Rodrigo. The common generator level cut was the jet rapidity range $|\eta_{jet}| < 2.5$. The jet multiplicity N_{jets} (at the generator level), the lepton transverse energy cut P^l_T, lepton rapidity range $|\eta^l|$, jet transverse energy (P_T), clustering cone size (ΔR), Q^2 scale, total cross section and the corresponding luminosity are listed in Table I.

TABLE I.

sample	N_{jets}	P^l_T	$\|\eta^l\|$	P_T	Δ R	Q^2	σ(pb)	L(pb^{-1})
W3S3	3	>10	<1.2	>10	>0.6	M^2_W	26.7±0.1	128.0
W4S1	4	>10	<1.2	>10	>0.6	M^2_W	5.11±0.0	112.0
WE4PM	4	>12	<2.5	> 8	>0.4	$< P^2_T >$	80	124.8
WE4PM	4	>12	<1.5	> 8	>0.4	$< P^2_T >$	65	78.4

Partons in all Monte Carlo samples were subjected to fragmentation according to the ISAJET model (SETPRT). The 203 pb^{-1} WE4PM sample was also fragmented using the HERWIG model (HERPRT). The two, differently hadronized, samples of 203 pb^{-1} W+4 jets events will be referred in this paper as WE4PM_SQ and WE4PM_HQ. All samples of Monte Carlo generated events were subjected to the CDF full detector simulation QFL and reconstructed with CDF full offline reconstruction.

Signal

Several samples of $t\bar{t}$ events generated with HERWIG were used to study the acceptances and efficiencies of the analysis technique for the signal events. Two small samples were generated with the top quark masses of M_t=120 GeV and M_t=150 GeV.

Large samples of $t\bar{t}$ events (2000 events each) were generated by Alessandra Caner for several values of the top quark mass, using HERWIG and HERPRT. I have used HER_TBENU_140.Q and HER_TENU_140.Q (generated in August 1993), HER_TBENU_160.Q and HER_TENU_160.Q (generated December 1993-January 1994) and HER_TBENU_175.Q and HER_TENU_175.Q (generated January 1994).

All samples of Monte Carlo generated $t\bar{t}$ events were subjected to the CDF full detector simulation QFL and, subsequently, to the complete CDF offline reconstruction.

iv. W$\to e\nu$ AND W$\to \mu\nu$ DATA SETS

The analysis presented in this paper is based on all available data from 1988/89 and 1992/92 runs. The total integrated luminosity of the set of data used for this version of the paper is about 25 pb^{-1}.

The standard electron and muon W candidates samples, CENTRAL_ELEC_W.EVT and CENTRAL_MUO_W.PH7, which have been described in detail in CDF-1166 and CDF-1349[8] have been used for 1988/89 run. FIDELE, BADRUN, BADTOW and PEM VTPC occupancy cuts were applied to the electron sample, Z candidates were removed from both electron and muon samples. The resulting event samples consist of 2627 W$\to e\nu$ candidates and 1428 W$\to \mu\nu$ candidates. These data sets correspond to the luminosities of 4.05$\pm$0.28 pb^{-1} and 3.54$\pm$0.24 pb^{-1}, respectively.

For the present 1992/93 run the standard files created by David Saltzberg and Mark Krasberg, based on Express Production, CENT_WMASS_ELE_6PT*.* and INCL_MUON*.*, have been the starting point for this analysis. The selection criteria are described in detail in CDF$EWK1_DATA and CDF$EWK2_DATA areas. The electron W candidates sample, HPTAPE, which is a subset of the inclusive central electron sample selected by Brian Winer, has been used in analysis of the electron data. The W_EVENTS_PART*.PAD files, where * stands for A,B,C,D and E, created by Mark Krasberg were used in analysis of the muon W candidates.

FIDELE and BADRUN cuts were applied to the electron and muon samples. The data sets from 1992-1993 run correspond to the integrated luminosity of about 21 pb^{-1}.

v. ANALYSIS CUTS

The standard electron and muon selection cuts were used in my analysis[9].

The input lepton and jets' parameters were extracted from the common blocks filled with EWUNPK[10] 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 (the "out of cone correction" and "underlying event" corrections were not applied). All four jets were required to have $|\eta_{jet}| < 2.4$. Four sets of the jet transverse energy cuts were used:

"31510"	four jets $P_T > 10$ GeV, three jets $P_T > 15$ GeV
"32010"	four jets $P_T > 10$ GeV, three jets $P_T > 20$ GeV
"31515"	four jets $P_T > 15$ GeV
"32015"	four jets $P_T > 15$ GeV, three jets $P_T > 20$ GeV

The uncorrected missing transverse energy, MET, was required to be larger than 25 GeV.

vi. HOW DOES THE METHOD WORK ?

To look into the details of how various factors in L_{comb} contribute to the final probability Monte Carlo $t\bar{t}$ events at the generator level, *before* the detector effects were included, were studied. Jets' and lepton four-momenta were extracted from GENP banks and subjected to the kinematical analysis. Internal radiation effects were taken into account, the four-momenta used were those of quarks and leptons just before fragmentation was about to take place. The relevant kinematical quatities (x_1 and x_2) and correlation between the final probability L_{comb}, and various factors contributing to L_{comb} are shown in Figure 4. It seems that the most important factor is the Bjorken x dependence. Events with both x_2 and x_2 in the moderate range 0.1-0.2 (away from the extreme large, or small, x values) give fits with high probabilities. Also, the Gaussian jet "penalty" factors influence the final likelihood in a significant way. It it not surprising, since this factor depends mainly on how far away from M_W=80.3 GeV is the mass of the two jets, which are hypothesized to have originated from a hadronic W decay.

Generator level

Let's begin from the easiest case by looking at the parton level, before the fragmentation took place, and before the detector, reconstruction programs and various corrections had a chance to even further distort the correspondence between partons and jets. To demonstrate how the analysis technique works let's look at the distributions of M_t (position of a peak in the likelihood distribution for the correct combination of partons) for three $t\bar{t}$ Monte Carlo samples, generated with M_t=120,140 and 150 GeV. They are shown in Figure 5, together with the scatterplots of the integrated likelihood (probability) L_{comb} vs M_t. No detector effects were included, four-momenta from GENP were used. It is clear that the kinematical analysis technique finds the correct mass with no difficulty. If there was no background (i.e. if one knew that all events were signal), the best measurement of the mass of the top quark would be obtained by forming a *multiplicative* probability from all L_{comb} distributions obtained for the candidate events, i.e. those with integral of L_{comb} bigger than a chosen value, L_{cut}.

It is interesting to notice that the larger the value of the probability, L_{comb}, the closer the fitted masses of the top quark are to the nominal mass of the top quark used at the generator level. The fits can be imperfect because the gluon radiation effects are incorporated in Monte Carlo generator.

One can also easily see that the value of the probability, L_{comb}, may itself vary in a wide range. A single fit with a very large L_{comb} may dominate the integrated mass distribution obtained from even a large number of events, however, the danger of this happening decreases with increase of the number of available events, or luminosity.

To provide information about the *number* of observed events we shall count *the number of events* above a chosen probability value, L_{cut}. This approach enables one to easily determine the significance of events clustering at a particular value of top quark mass.

Full detector simulation level

In Figures 6,7 and 8 we show the M_t distributions, one entry per event, for the combination with the largest likelihood, obtained for four sets of jet transverse energy cuts, 31510,32010,31515 and 32015, based on analysis of $t\bar{t}$ Monte Carlo sample generated with M_t=140,160 and 175 GeV.

Results of Monte Carlo studies, including acceptance, efficiency×acceptance, position of the peak in the reconstructed M_t distributions and their widths (from simple Gaussian fits to the histograms) are summmarized in Tables II, III and IV for M_t=140,160 and 175 GeV, respectively. Statistical errors are also listed.

TABLE II. Results of Monte Carlo studies for M_t=140 GeV. HERWIG+QFL+CDF Offline reconstruction.

jet cuts	L cuts	eff.×acc. (%)	mass (GeV)	sigma (GeV)
3151025	no	20.8±0.8	139	27
	L>0.1	10.6±0.5	134	21
	L>0.4	7.5±0.5	133	19
	L>1.0	5.2±0.4	134	16
3201025	no	19.4±0.7	140	26
	L>0.1	9.6±0.5	136	19
	L>0.4	6.9±0.4	133	17
	L>1.0	4.8±0.4	131	16
3151525	no	14.8±0.6	142	26
	L>0.1	7.3±0.4	137	19
	L>0.4	5.1±0.4	135	17
	L>1.0	3.4±0.3	132	16
3201525	no	14.3±0.6	139	26

L>0.1	6.9±0.4	134	18
L>0.4	4.9±0.4	133	17
L>1.0	3.3±0.3	134	16

For M_t=160 and M_t=175 GeV the distributions seem to have a two-component structure. The narrow part seems less shifted in mass from the nominal value, with the broader, underlying, component displaced more significantly. Positions and widths of a narrow component are listed together with the results of Gaussian fits to full distributions. It is quite possible that also for M_t=140 GeV there exist a similar two-component structure; except the narrow part is not separated from the broader part as clearly as it does for M_t=160 and M_t=175 GeV.

The mass shifts and the shapes of the signal distributions will be discussed in a separate section.

TABLE III. Results of Monte Carlo studies for M_t=160 GeV. HERWIG+QFL+CDF Offline reconstruction. Numbers in the brackets indicate the masses and widths of a narrow "core" in the reconstructed mass distributions.

jet cuts	L cuts	eff.×acc. (%)	mass (GeV)	sigma (GeV)
3151025	no	21.1±0.8	154(155)	26(14)
	L>0.1	8.9±0.5	145(154)	20(10)
	L>0.4	5.5±0.4	143(153)	18(10)
	L>1.0	3.4±0.3	137(153)	16 (7)
3201025	no	20.9±0.7	156(156)	25(14)
	L>0.1	9.6±0.6	146(153)	18(13)
	L>0.4	4.9±0.4	144(153)	17 (9)
	L>1.0	3.0±0.3	140(154)	17 (7)
3151525	no	14.2±0.6	157(156)	23(10)
	L>0.1	5.7±0.4	147(154)	18 (8)
	L>0.4	3.3±0.3	145(150)	17(11)
	L>1.0	1.9±0.2	140(150)	17 (6)
3201525	no	14.8±0.6	158(157)	22 (9)
	L>0.1	5.9±0.4	148(155)	17 (8)
	L>0.4	3.5±0.3	148(154)	17 (9)
	L>1.0	2.0±0.2	140(150)	16 (8)

TABLE IV. Results of Monte Carlo studies for M_t=175 GeV. HERWIG+QFL+CDF Offline reconstruction. Numbers in the brackets indicate the masses and the widths of a narrow "core" in the reconstructed mass distributions. This table is incomplete, less than half of the available

Monte Carlo events have been processed, so far.

jet cuts	L cuts	eff.×acc. (%)	mass (GeV)	sigma (GeV)
3151025	no		161(167)	23(15)
	L>0.1		161(163)	22 (9)
3201025	no		161(167)	21(15)
	L>0.1		(163)	(9)
3151525	no		163(168)	21(14)
	L>0.1		(165)	(9)
3201525	no		163(169)	21(14)
	L>0.1		(165)	17 (8)

In Figures 9,10,11 and 12 we present the analogous distributions for all available VECBOS+jets QCD background samples. All samples were subjected to the full CDF detector simulation, QFL, and fully reconstructed. The Monte Carlo distributions were fitted to simple polynomial forms, the results of those fits are listed in the figures.

The separation between VECBOS generated background distributions and $t\bar{t}$ signal can be clearly seen. The background almost but disappears above $M_t \approx$120-130 GeV.

If the top quarks are heavier than 120-130 GeV, and not too heavy so the $t\bar{t}$ production cross section remains high enough to be observed with the presently available integrated luminosity, the top signal should be seen in the M_t distribution for the real data.

The comparison of efficiency×acceptance for the signal and VECBOS bacground is presented in Table V, for several sets of jet energy and likelihood cuts. For M_t=140 GeV, the kinematical technique used in analysis presented in this paper enhances the signal by a factor of about 1.5-3.0 above the VECBOS background. This enhancement factor represents simply a ratio of the number of events, selected with a given set of jet energy cuts and which gave fits with likelihoods above L cut value, *without* regard whether the events form a structure in the M_t distribution, or not. (Restricting the range of M_t in which one compares the number of events in VECBOS to $t\bar{t}$ Monte Carlo to, say, M_t >120 GeV would result in an increase of the signal to background ratio.)

TABLE V. Fraction of events passing the likelihood cuts, relative to all events passing the jet energy cuts.

jet cuts	L cuts	VECBOS (%)	M_t=140 GeV (%)	M_t=160 GeV (%)
3151025	L>0.0			
	L>0.1	16±1	52±3	41±3
	L>0.4	13±1	38±2	26±2
	L>1.0	10±1	26±2	17±1

3201025	L>0.0	87±5		
	L>0.1	29±3	51±3	40±3
	L>0.4	24±3	36±2	24±2
	L>1.0	18±2	24±2	15±2
3151525	L>0.0	83±5		
	L>0.1	26±3	52±3	
	L>0.4	22±3	37±3	
	L>1.0	15±2	25±2	
3201525	L>0.0	89±7		
	L>0.1	29±4	50±3	39±3
	L>0.4	24±4	36±3	23±2
	L>1.0	16±3	24±2	13±2

Having in mind that the cross section for VECBOS W+4 jets production is comparable to that of $t\bar{t}$ production in the top quark mass range M_t ≈120-160 GeV, one may indeed hope to observe the top signal over background when one combines the jet energy cuts with the kinematical likelihood method.

vii. RESULTS FOR ELECTRON DATA

The M_t distributions for all available W+4jets electron data is shown in Figures 13 and 14, for all four sets of jet energy cuts, and for several L_{event} cuts.

The fits to the WE4PM_SQ and WE4PM_HQ datasets, normalized to the ratio of luminosities between the real data and Monte Carlo samples (25/203≈1/8), are superimposed on the data plots.

One should note here that the WE4PM_SQ and WE4PM_HQ Monte Carlo predict more W+jet events than it is observed in the data. With the "31515" jet energy cut alone, without any likelihood cuts, the number of events in VECBOS should be multiplied by a factor of about 0.8 to match the observed number of events passing those jet cuts in the data, assuming *no contribution from top quark production*. This is an indication that a choice of $Q^2=M_W^2$ gives a more appropriate description of the background for top production. (VECBOS predicts about a factor of 2 smaller cross section for W+4 events when $Q^2=M_W^2$ scale is used rather than $Q^2=< P_T^2 >$.) Careful readers of CDF notes and publications will remember that this conclusion has been hinted in CDF1873[11] (e.g. p.21 Version 2.0) by Benlloch, Caner and Rodrigo, however, it has not survived the CDF godparenting process. At the time, more than a year ago, anything that could hint the presence of a top quark in the data, especially in the lepton+jets channel was considered a heresy (for example my analysis), and the paper finally published in a journal proclaims that $Q^2=< P_T^2 >$ scale fits the data better, which surely leaves no room for top.

With tightening the jet transverse energy cuts a cluster of events around M_t=130-145 GeV becomes clearly visible in the M_t distributions. The fits to the mass distributions, with background shapes taken from the fits to VECBOS and Gaussian for the signal, point to the mass in the range 137-141 GeV, and $\sigma \approx$8-11 GeV. Examples of such fits are shown in Figures 15A and 15B, which were made with the jet transverse energy cuts 32010. The signals are not statistically significant (yet), however, their significance is at least comparable to those quoted in other CDF searches for top quark. The paramount advantage of my method is that it provides a *direct* measurement of the top quark mass, while in the same allowing standard event counting. The fitted positions of the peaks in the M_t distributions in real data (after correcting for the mass shifts listed in Tables II and III for M_t=140 and M_t=160 GeV, and taking the spread of results obtained with different jet cuts and L cuts as a systematic error) point to the mass of M_t=147$\pm$10 GeV.

To allow reader a more quantitative comparisons, the number of predicted $t\bar{t}$ events, VECBOS W+jet events (based on different samples) and the observed data events in W$\rightarrow e\nu$ channel are shown in Table VI. Events above M_t=124 GeV were counted. The luminosity was assumed to be 25 pb^{-1}. Predictions for VECBOS background were estimates in two ways, one very conservative and the other more realistic, but to some extent arbitrary. (This approach will be improved with more work on comparisons between Monte Carlo and CDF data.) The VECBOS WE4PM_SQ and WE4PM_HQ data were added, and after normalizing to the luminosity of 25 pb^{-1} multiplied by a factor of: A) 0.8 (to bring the number of events in the data and VECBOS after the jet energy cuts 31515 alone, without any L cuts, to agree; this normalization leaves no room for top with only the jet cuts 31515); and B) 0.6 (which leaves room for some $\approx$15 pb of cross section for top; this choice is stimulated by the data itself and the knowledge that chosing Q^2=M_W^2 would give a factor of two smaller cross section in VECBOS). The branching fraction of 12/81 was assumed for the $t\bar{t}$ semileptonic decay mode. To give a feeling for what values of the cross sections the observed signal is compatible with, the numbers shown in the signal column were calculated assuming the cross section of 16 pb. According to the calculations by Laenen, Smith and van Neerven[12] this corresponds to $M_t \approx$142 GeV . A 20% uncertainty in the VECBOS normalization factor has been assumed and incorporated into the error on the number of signal events observed in the data, after the background subtraction.

TABLE VI. Results of analysis of W+4jets electron data set. Number of events in each category with fitted M_t >124 GeV is listed.

jet cuts	category	L>0	L>0.1	L>0.4	L>1.0
3151025					
	data	29	16	12	8
	BKD-A	16.1$\pm$0.9	5.1$\pm$0.5	3.6$\pm$0.4	2.0$\pm$0.3
	BKD-B	12.1$\pm$0.7	3.8$\pm$0.4	2.7$\pm$0.3	1.5$\pm$0.2
	signal-A	12.9$\pm$3.7	10.9$\pm$3.7	8.5$\pm$3.2	6.0$\pm$2.6
	signal-B	16.9$\pm$4.9	12.2$\pm$4.1	9.3$\pm$0.3	6.5$\pm$2.8
	$t\bar{t}$ (16 pb)	12.3$\pm$0.5	6.3$\pm$0.4	4.4$\pm$0.4	3.1$\pm$0.2

3201025

data	21	11	8	4
BKD-A	13.2±0.8	3.9±0.4	2.9±0.4	1.6±0.3
BKD-B	9.9±0.6	2.9±0.3	2.2±0.3	1.2±0.2
signal-A	7.8±2.4	7.2±2.7	5.2±2.1	2.4±1.4
signal-B	11.1±3.4	8.1±3.0	5.8±2.3	2.8±1.6
$t\bar{t}$ (16 pb)	12.5±0.4	5.7±0.3	4.1±0.2	2.8±0.2

3151525

data	16	6	4	2
BKD-A	9.4±0.7	2.7±0.4	2.1±0.3	1.1±0.2
BKD-B	7.1±0.5	2.0±0.3	1.6±0.2	0.8±0.2
signal-A	6.6±2.2	3.3±1.6	1.9±1.0	0.9±0.7
signal-B	8.9±3.0	4.0±1.9	2.4±1.3	1.2±0.9
$t\bar{t}$ (16 pb)	8.7±0.4	4.3±0.3	2.9±0.2	2.0±0.2

3201525

data	13	5	3	1
BKD-A	8.5±0.7	3.1±0.4	1.7±0.3	0.8±0.2
BKD-B	6.5±0.5	2.3±0.3	1.4±0.2	0.6±0.2
signal-A	4.5±1.6	1.9±0.9	1.3±0.8	0.2±0.2
signal-B	6.5±2.3	2.7±1.2	1.6±1.0	0.4±0.3
$t\bar{t}$ (16 pb)	8.5±0.4	4.1±0.2	3.0±0.2	2.0±0.2

Although the numbers of events are not large, they are consistent with the expected numbers for $t\bar{t}$ production in a wide range of jet energy and likelihood cuts. The selected events satisfy all kinematic criteria for $t\bar{t}$ production and decay. The background W+jet events fall in a *different* region of phase space, they fall predominantly below M_t=120-130 GeV in the M_t distributions. Also, the expected number of W+jets events yielding good kinematical fits is smaller than the number of events giving such fits in the real data.

The cross section of the signal, depending on the cuts used, falls in the range of 15-20 pb, comfortably within expectations (maybe a little on a high side) for the mass value indicated by the cluster of events in the M_t mass distributions themselves, M_t=147±10 GeV.

The largest uncertainty comes at this time from VECBOS normalization factor. I remain confident, however, that with more work on comparing VECBOS to the data, and with exploring the effects of a different choice of Q^2 scale, one should be able to reduce this uncertainty quite significantly.

viii. RESULTS FOR MUON DATA

The M_t distributions for all available W+4jets muon data is shown in Figures 16A-16D, for all four sets of jet energy cuts, and for several L_{event} cuts. In the muon case there are no fits to

VECBOS background superimposed on the plots, the simulations for W$\rightarrow \mu\nu$ channel have not been done.

The muon data data is consistent with the electron data. Although no big enhancements in M_t distributions can be seen, it is worth noticing that a few events which pass the tight jet energy cuts and tighter L cuts cluster in the same region as in the electron channel. One expects fewer events to be reconstructed in the muon case due to the smaller efficiency and acceptance for muons. (The numbers of central muon and electron W candidates differ by about a factor of 2, one could assume a similar factor for W+jets events.)

There is another observation, worth noting. There is much more background in the muon channel compared to the electron channel. The number of events passing just the jet energy cuts, before any fits are performed, is much larger in the muon case. After imposing a modest L>0.1 requirement, this big disparity goes away. It is worth noting that the M_t plots for events passing just the jet energy cuts, before any L cut is applied, contain more events in the higher mass region, say M_t >160 GeV, than in the corresponding plots for electron W+jets events. However, almost all high M_t events disappear after L>0.1 cut is applied. This is an indication that background in the muon channel (which seems to dominate the sample) has a tendency to yield relatively high M_t values, although with very small probabilities, according to my definition of a likelihood. This opens a worrisome possibility that fits which do not take into account the "dynamical" factors could give good χ^2 fits to some of those background events, which when analysed with my technique give low likelihood values. This could lead to different conclusions of two hypothetical kinematical analyses, one with and another without the "dynamical" factors.

ix. MASS SHIFTS, OTHER CAVEATS AND POSSIBLE LOOPHOLES

The presence of mass shifts, presented in the Tables II,III and IV is, most likely, due to inadequacies in the way the jet energies are corrected. In a study[13] of jet energy corrections to jets found with the cone size of 0.4, the second order corrections (A+A) were found necessary to reconstruct the masses correctly. Based on Monte Carlo studies, for M_t=170 GeV one would find mass shifts of about -15 GeV if one did not correct jets with their A+A corrections. Similar inadequacies most likely occur in analyses using jets found with the cone size of 0.7, although in a small sample of di-lepton events, the corrected jet energies found with a cone of 0.4 and with A+A corrections were very similar to jet energies found with a cone of 0.7, corrected in the way I decided to do it, i.e. *without* the out-of-cone and underlying event corrections. A study of jet corrections for the cone size of 0.7, similar to the study already performed for the cone size of 0.4, has to be finished to gain confidence that the mass shifts are indeed due to inadequacies in correcting jet energies. Any help in this area is welcome.

However, I would like to point out some worrisome facts. The widths of the mass distributions obtained with cone size of 0.4 and A+A corrections and SQUAW fitting package, based on Monte Carlo data[14], seem larger than those listed in Tables II,III and IV, even without allowing for the two-component structure in my fits. The A+A corrections do not result in a decrease of the widths of the mass distributions obtained with the cone size of 0.4. This worries me, I would expect the corrections to help the mass resolution, the only visible effect of A+A corrections is to shift the central value closer to the nominal mass. This may mean that: a) cone of 0.7 may find jets closer to the true values than cone of 0.4 -after all a larger fraction of the jet energy is contained in a cone of 0.7 requiring *smaller* corrections to be apllied; b) A+A corrections may be nothing more than a patch to shift the mass to the nominal value *on average*, without improving our knowledge of the jet energy on jet by jet basis, which is at the heart of any kinematical analysis.

Still, it certainly seems likely that the jet correction inadequacies are responsible for the observed mass shifts in my analysis which uses jets found with a cone size of 0.7, as well. However, there exist another possibility, more difficult to correct for and potentially requiring more extensive studies. Even with all corrections, A+A including, what we are doing is to adjust the jet energies so they agree *on average* with parton energies before the hadronization takes place. Such corrections are correct as long as the fragmentation model incorporated in HERPRT is reproducing well what is happening in the real world. In none of the analyses done so far has the issue of how well the fragmentation process is modeled in a Monte Carlo program been so important as in my kinematical analysis, which attempts to reconstruct the mass of a multiparton system, using measured jets as partons. It is a new territory. Based on experience from LEP, LUND fragmentation model might be the best around, not HERPRT. Fixed cone algorithm, used in CDF, although simple, is known to have several defficiencies, which can be avoided with, for example, longitudinally invariant k_t clustering algorithms[15].

I remain confident that with additional work on jet energy corrections and studies of the fragmentation models a good agreement between Monte Carlo shapes of M_t distributions and the data will be reached, i.e. they will agree not only for the narrow part of the two-component structure seen in the reconstructed signal Monte Carlo, but that most of the entire broad component will shrink to look like the narrow part. However, if this does not happen, and the data will continue to look as it does look now with more statistics, then we are discovering a b' quark, not a top quark! Remember, it is the b quark jet four-momentum which will be distorted the most from the the original b quark four-vector. In b'$\rightarrow$ Wc decay the charm jets will undoubtedly be measured closer to the original parton than a b jet. I believe that this is only a remote possibility. It is more likely that it is the inadequacies in the simulation and fragmentation models which make the simulated $t\bar{t}$ signal broader than the enhancement in the real data. However, one should keep a possibility that we have found a b' quark rather than a top quark in memory, and look at the new data. This is where the answer is.

x. COMPARISON WITH OTHER SEARCHES FOR TOP WITHIN CDF

The number of events found in the b-tagged samples[16], both SVX and SLT point to the cross section which is consistent with M_t $\approx$150 GeV. Kinematical fits to the di-lepton events[17] point to the range 152-162$\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 was found with only about 1 pb^{-1} of data taken in the present run, which will increase the di-lepton cross section. Kinematical fits[17] find this event consistent with $t\bar{t}$ hypothesis for M_t=149$\pm^{20}_{15}$ GeV.

Kinematical fits to a sample of 7 b-tagged events were a reason of concern for me for quite some time. For most of those 7 events, if one accepted *blindly* the decission of the tagging algorithms as *correct*, the fits[18] were giving large masses (inconsistent with my results of a larger sample of events selected with jet cuts only) and very small likelihoods (unlikely for top events). Taking combinations with the best L_{event} while ignoring the tagging decision (tagging algorithms do not tag perfectly) brings in much more likely (with larger likelihood) solutions with lower M_t in several events; but in quite a few the same solutions with high M_t and low probability are found as the best ones. The only consistent explanation that I was able to find, was presented in my CDF2419[19]. When one looks more carefully at the results of the fitted four-momenta for the 7 tagged events, one discovers that three events (2 electron and 1 muon) have very high $t\bar{t}$ mass, $M_{t\bar{t}}$ $\approx$500 GeV, quite different from the remaining four events. Also, two of them have unexpectedly large transverse momenta of the reconstructed top and antitop quarks. The $M_{t\bar{t}}$ is clearly a superior discriminant, it is an invariant after all, while the transverse momenta depend on the decay angular distribution. A similar analysis of a larger sample of 17 electron events selected with the tight jet transverse energy cuts "32015" and no tagging information finds two additional events with the same characteristics. The most revealing are the scatterplots of the mass of $t\bar{t}$ system, $M_{t\bar{t}}$, versus fitted top mass, M_t. They are shown in Figures 17A, 17B and 17C for jet transverse energy cuts 32015,31515 and 32010, respectively. Here, the data points cluster in two distinct regions; one at M_t $\approx$140 GeV, fairly low $M_{t\bar{t}}$ and relatively large probabilities; and another, with $M_{t\bar{t}}$ $\approx$500 GeV, very low probabilities and M_t scattered in a wide range. Three out of four events, which fall into a well separated peak at $M_{t\bar{t}}$ $\approx$500 GeV, have large M_t as well. This looks to me suggestive of 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 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. It is those few anomalous events which pull the fitted M_t distribution high in our, very small, sample of 7 tagged events.

If a sample of 7 events indeed contains 3 events which come from a different production mechanism (which it seems to me that the data is suggestive of), then the M_t value obtained from fits which assume the Standard Model $t\bar{t}$ production may have not much relevance to the measurement of the top quark mass. In my analysis a cut on the likelihood, whose definition includes more information than a simple χ^2 does, clarifies the picture. Requiring that the top candidates must have a likelihood for a $t\bar{t}$ hypothesis L>0.1 (a very modest value) finds all anomalous events to be *incompatible* with the Standard Model $t\bar{t}$ production. Another explanation of the anomalous events would be that they are simply badly mismeasured. In such a case one should not trust the mass measurement which includes those events either.

I would like CDF to be extremely cautious about the way we phrase our conclusion in the draft of the PRD paper.

xi. CONCLUSIONS

The presently available electron data seem suggestive of the presence of $t\bar{t}$ events with the top quark mass of M_t=147±10 GeV. The cross section is in the range 15-20 pb. It is possible that the enhancement in the data may be a fluctuation, although this is very unlikely as it can be seen from the numbers in Table VI.

More work on the efficiencies in the muon channel is needed before the data is combined, however, the muon data is consistent with the conclusions from the electron sample.

As you can easily see for yourself there is plenty of work still to be done in this analysis, however, even at this moment its 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, with a significance comparable to other searches for top quark at CDF. The advantage of my method is, which point I would like to stress again, since it had been ignored by too many within CDF for too long, that it provides a *direct* measurement of the top quark mass, while in the same allowing standard event counting.

I am extending an open invitation to everyone within CDF who would like to work on this analysis, or on any aspect of studies which might help to understand the systematic issues which have to resolved.

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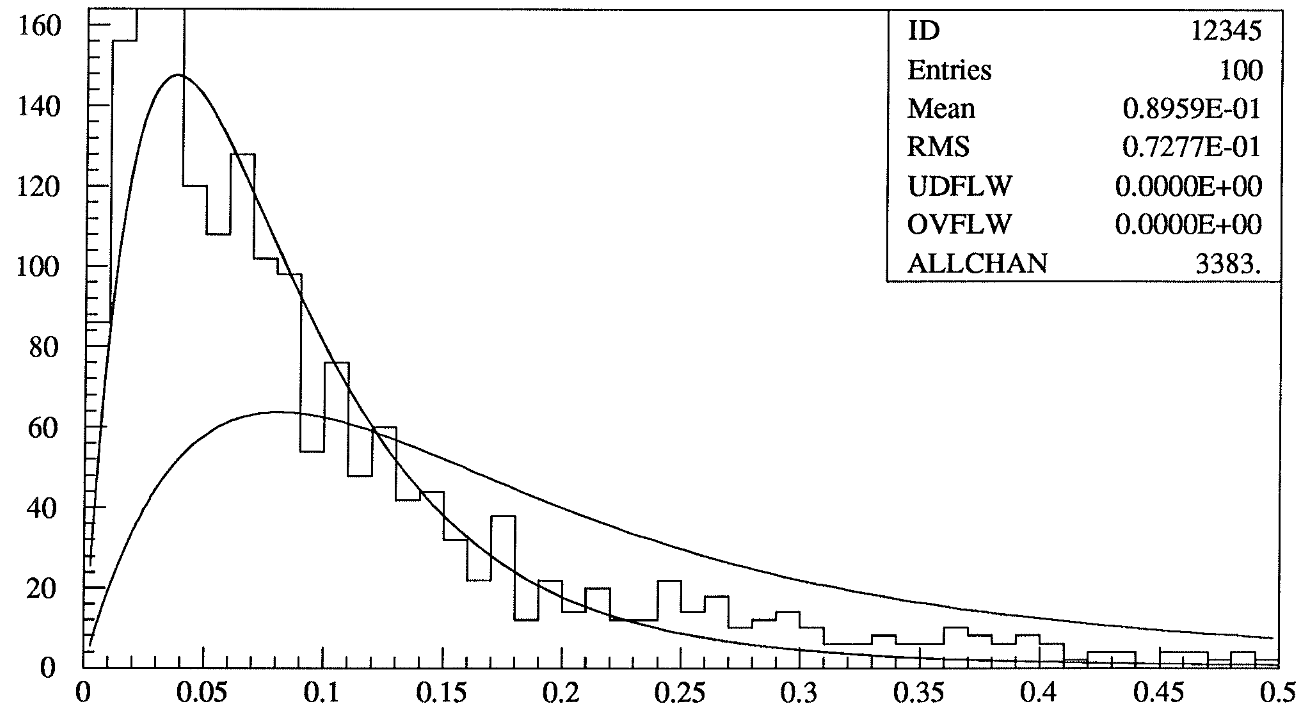
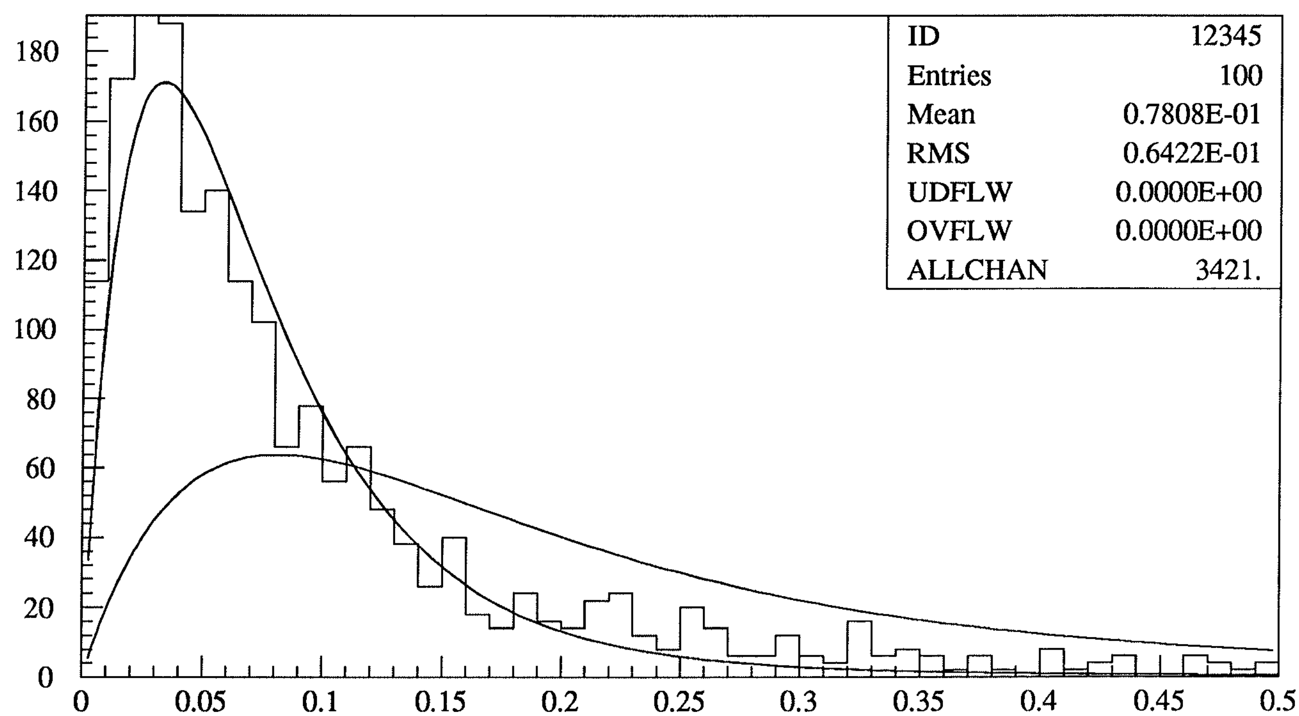
Figure 3. X=Pt(ttbar)/Mt



11013.*x*exp(20.66*x**2-28.216*x)



14510.*x*exp(25.096*x**2-32.*x)

Figure 4A. Factors contributing to the likelihood.

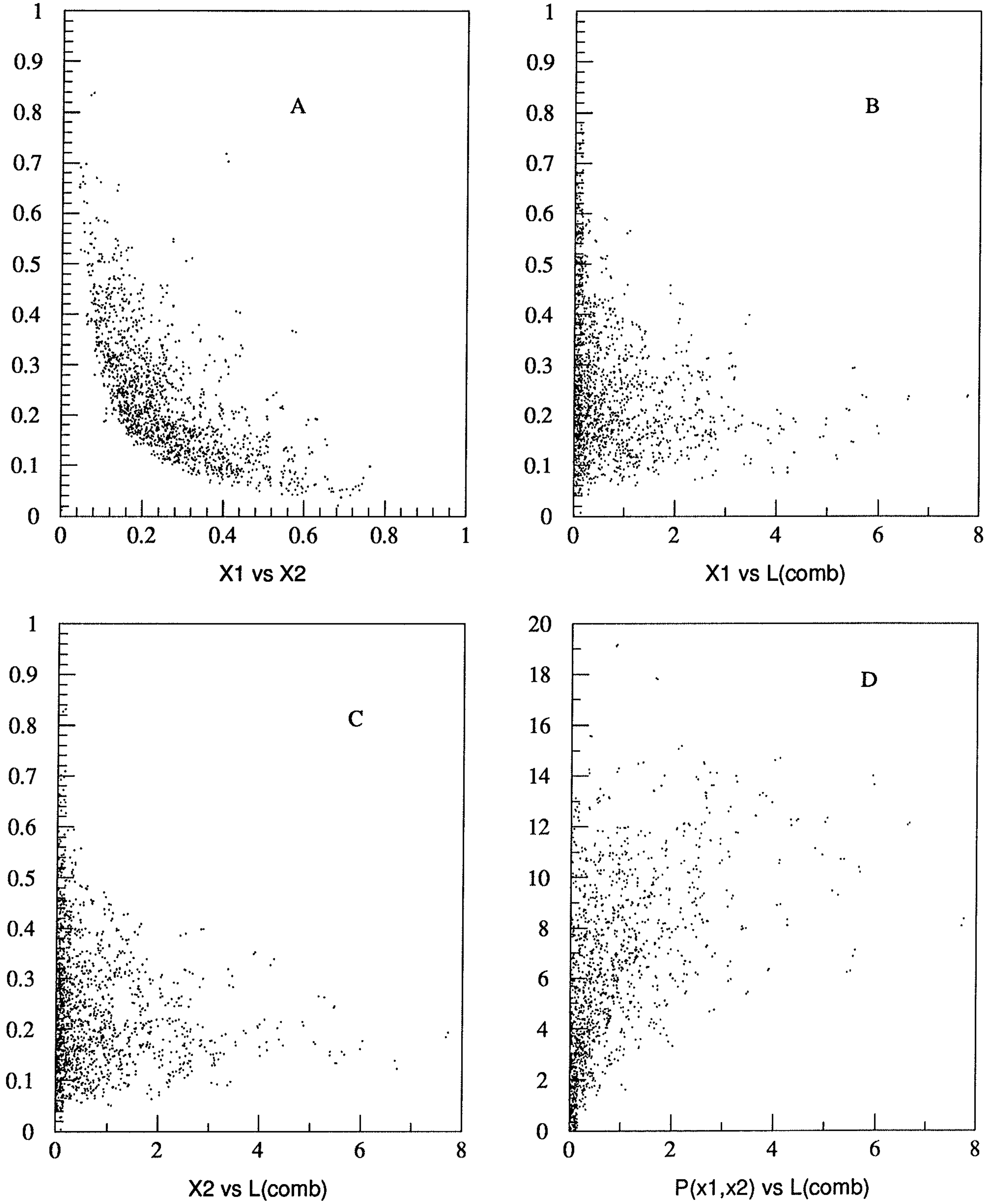


Figure 4B. Factors contributing to the likelihood.

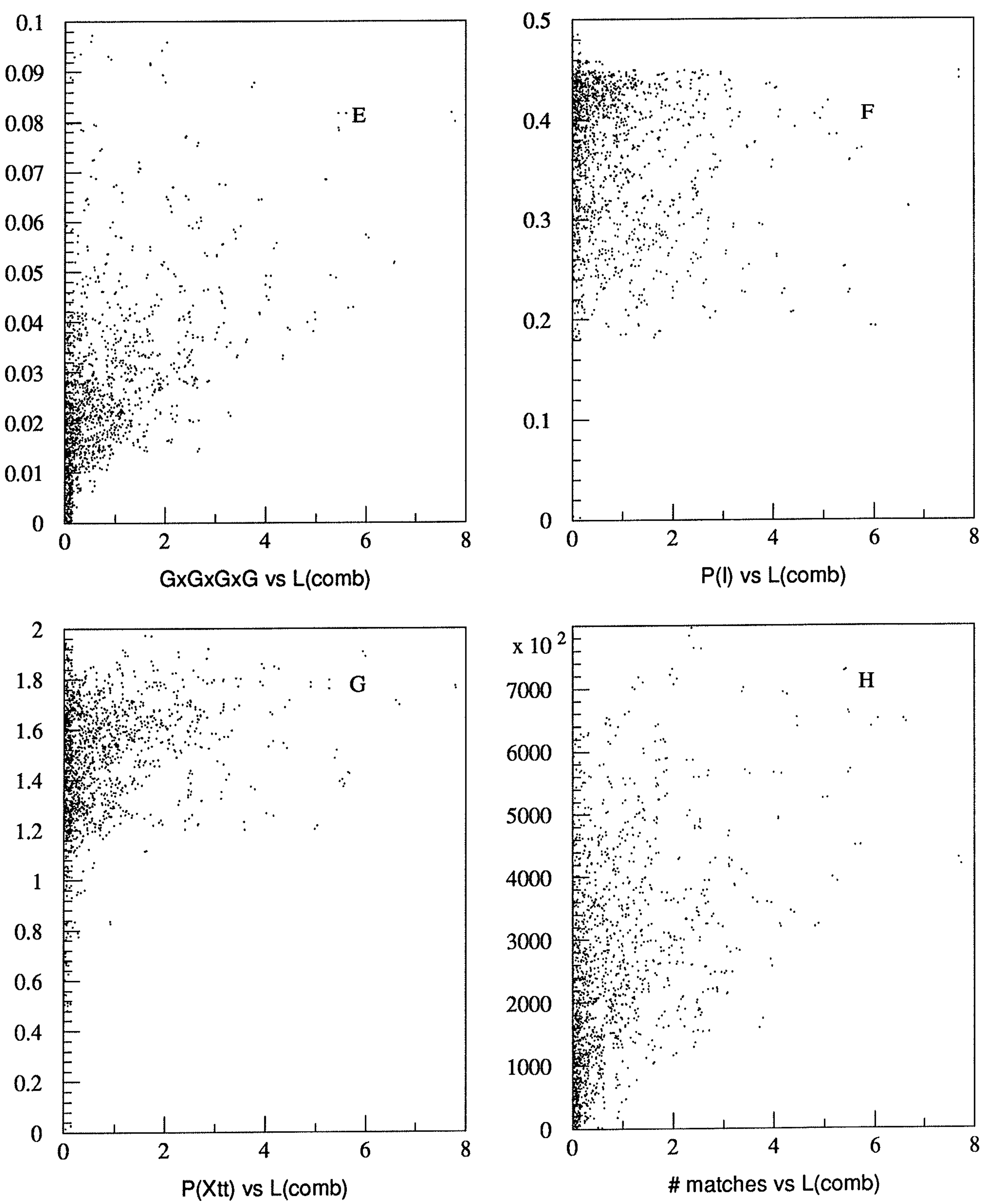
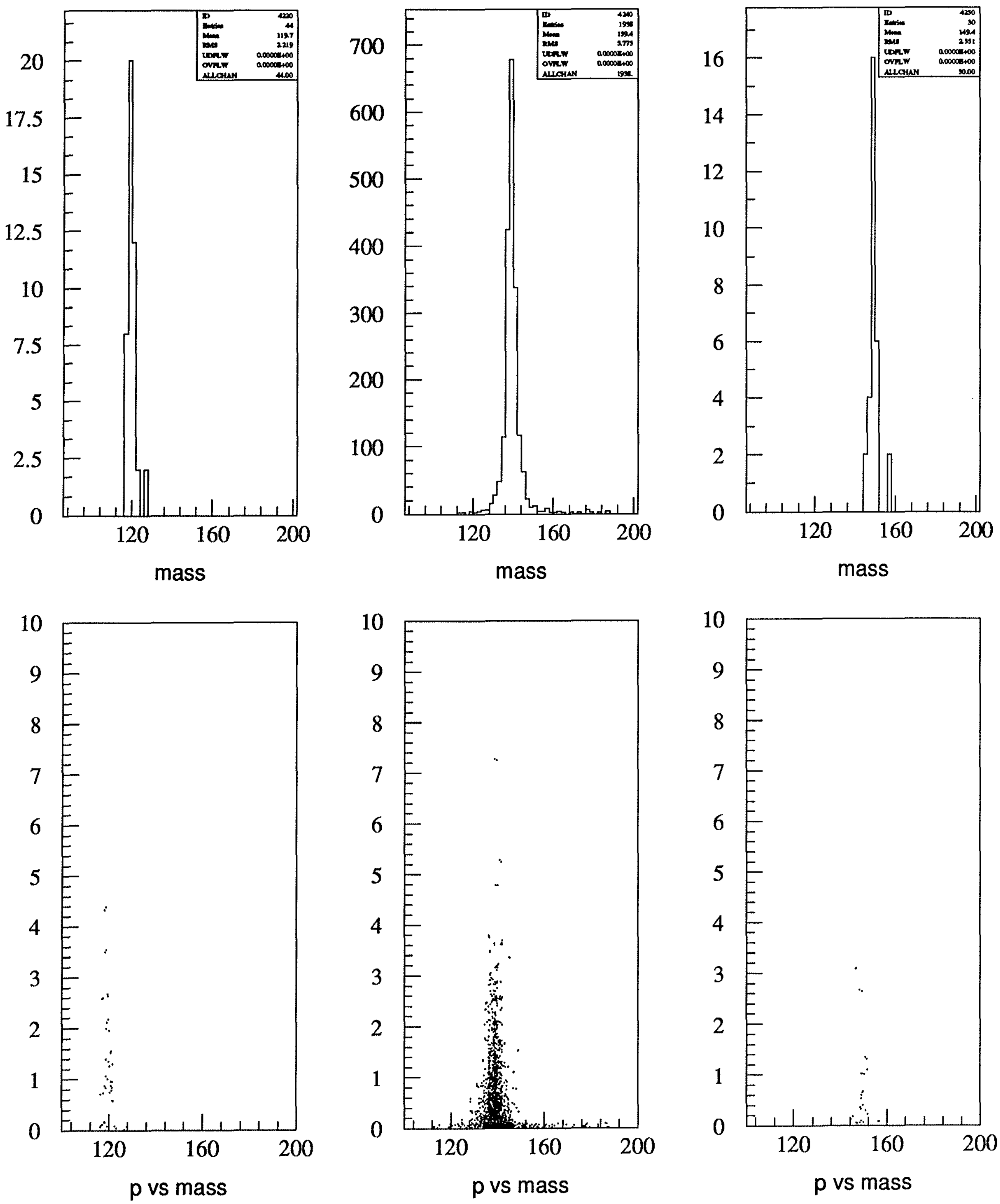
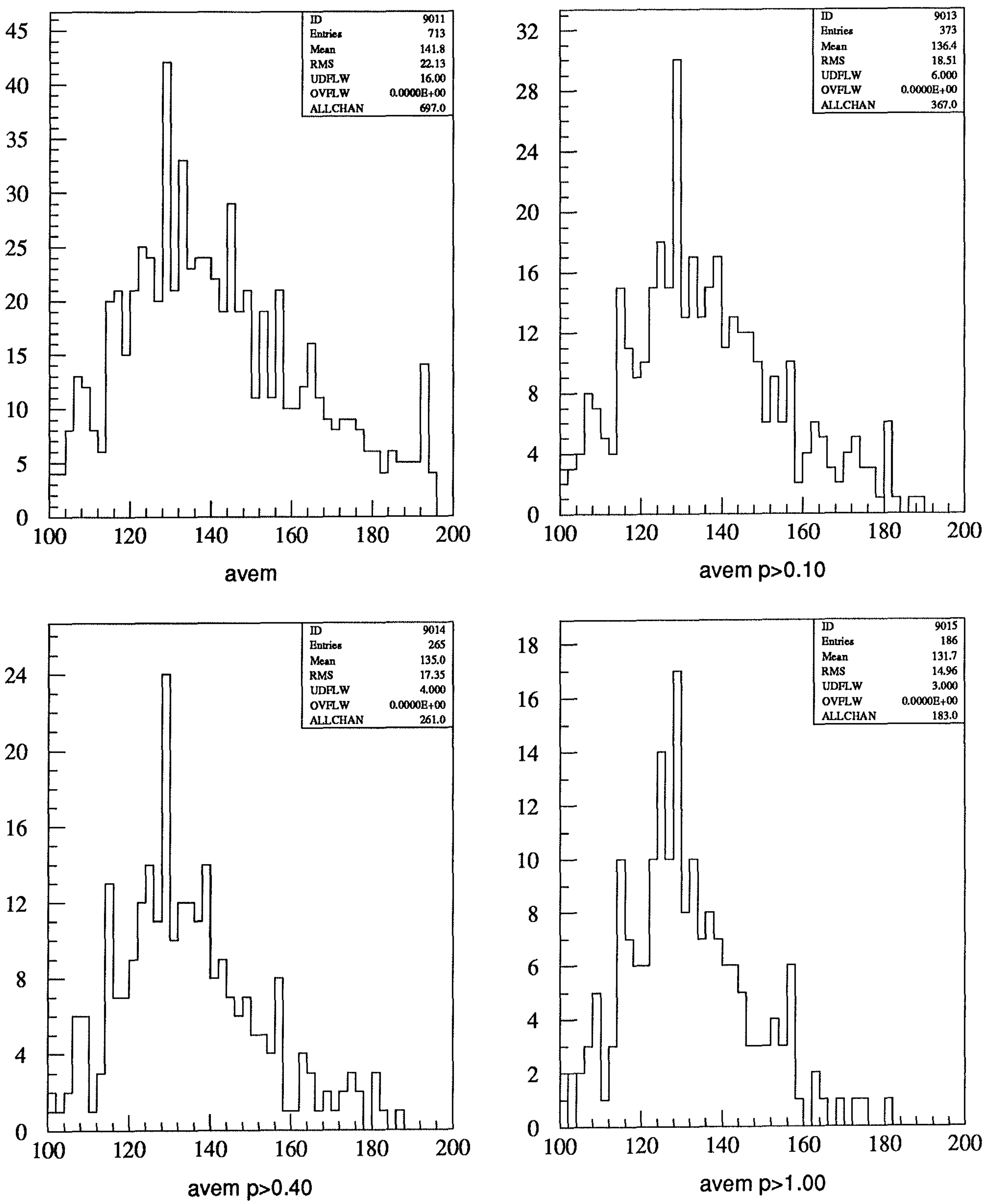


FIGURE 5.



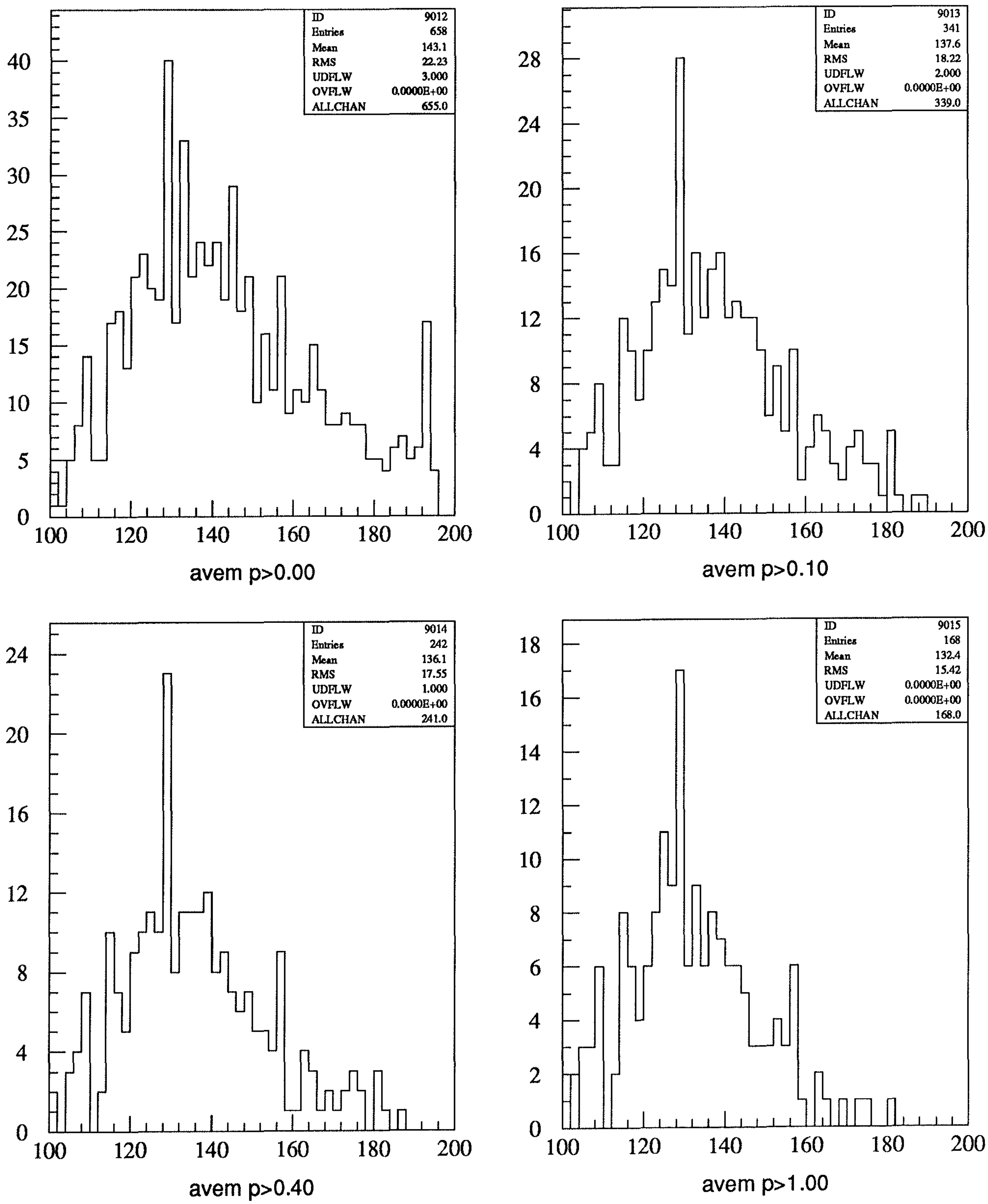
23/03/94 11.31

Figure 6B. Mt=140 GeV/ 3151025



23/03/94 10.40

Figure 6C. Mt=140 GeV/ 3201025



23/03/94 12.11

Figure 6D. Mt=140/ 3151525

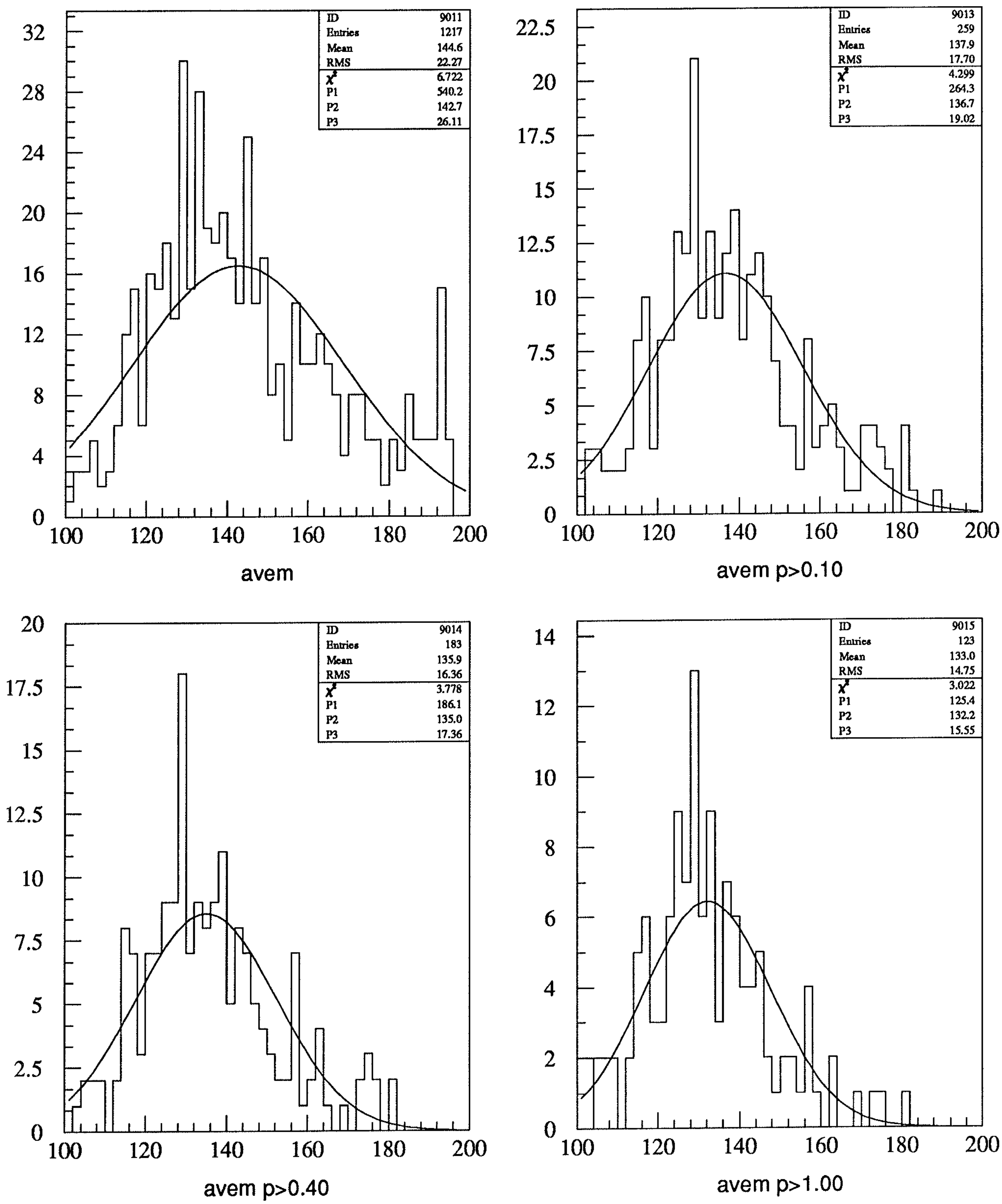
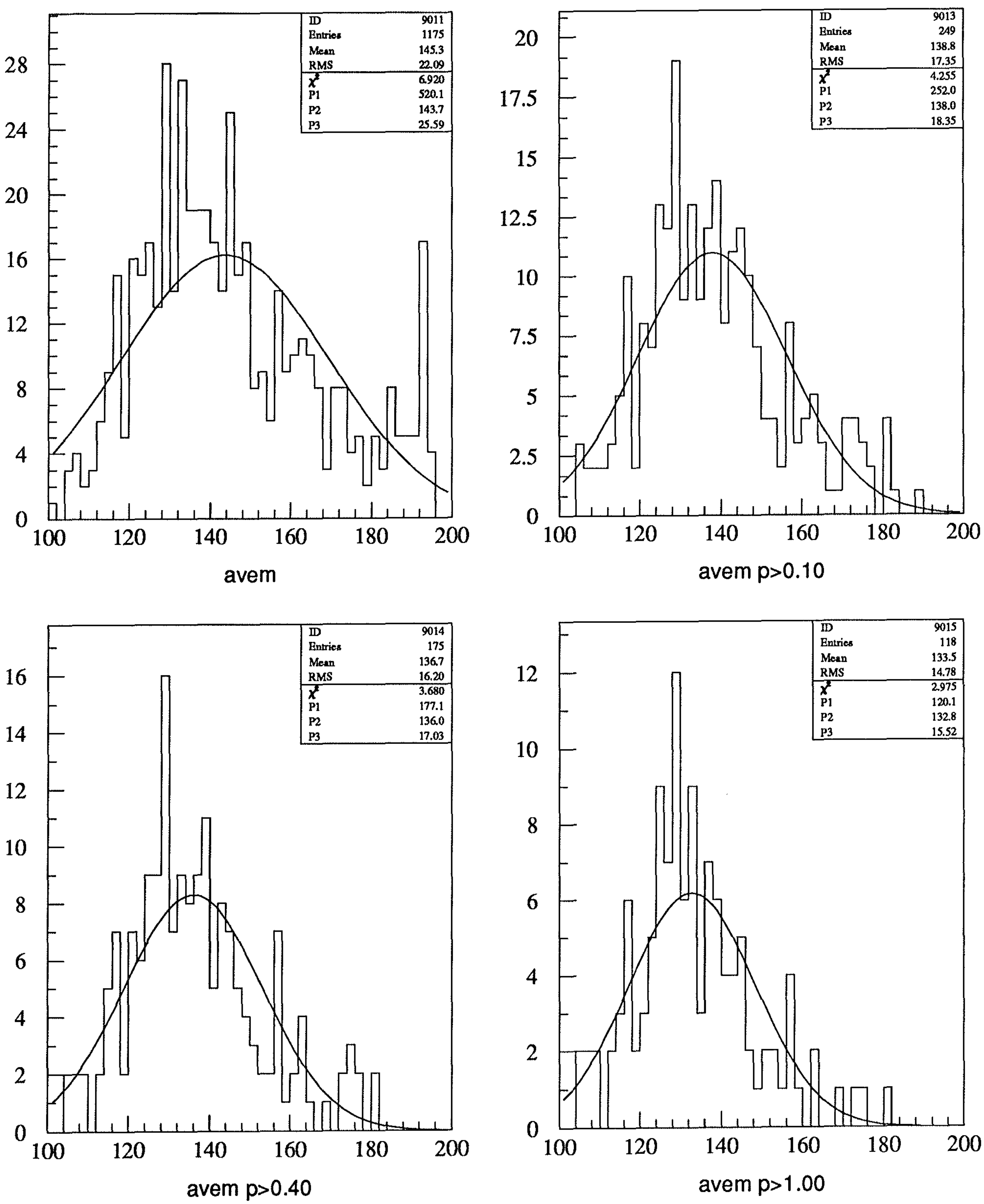
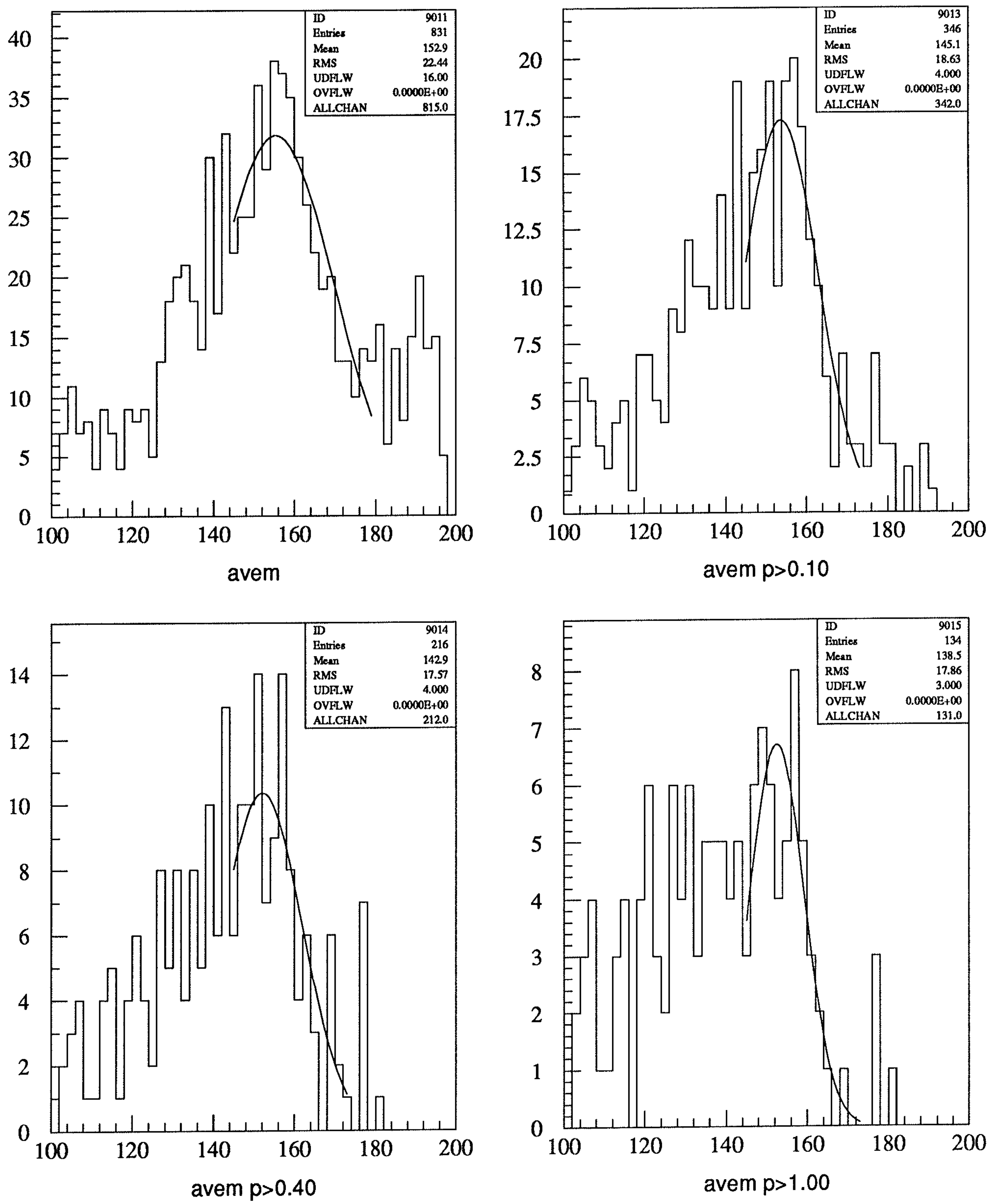


Figure 6E. Mt=140/ 3201525



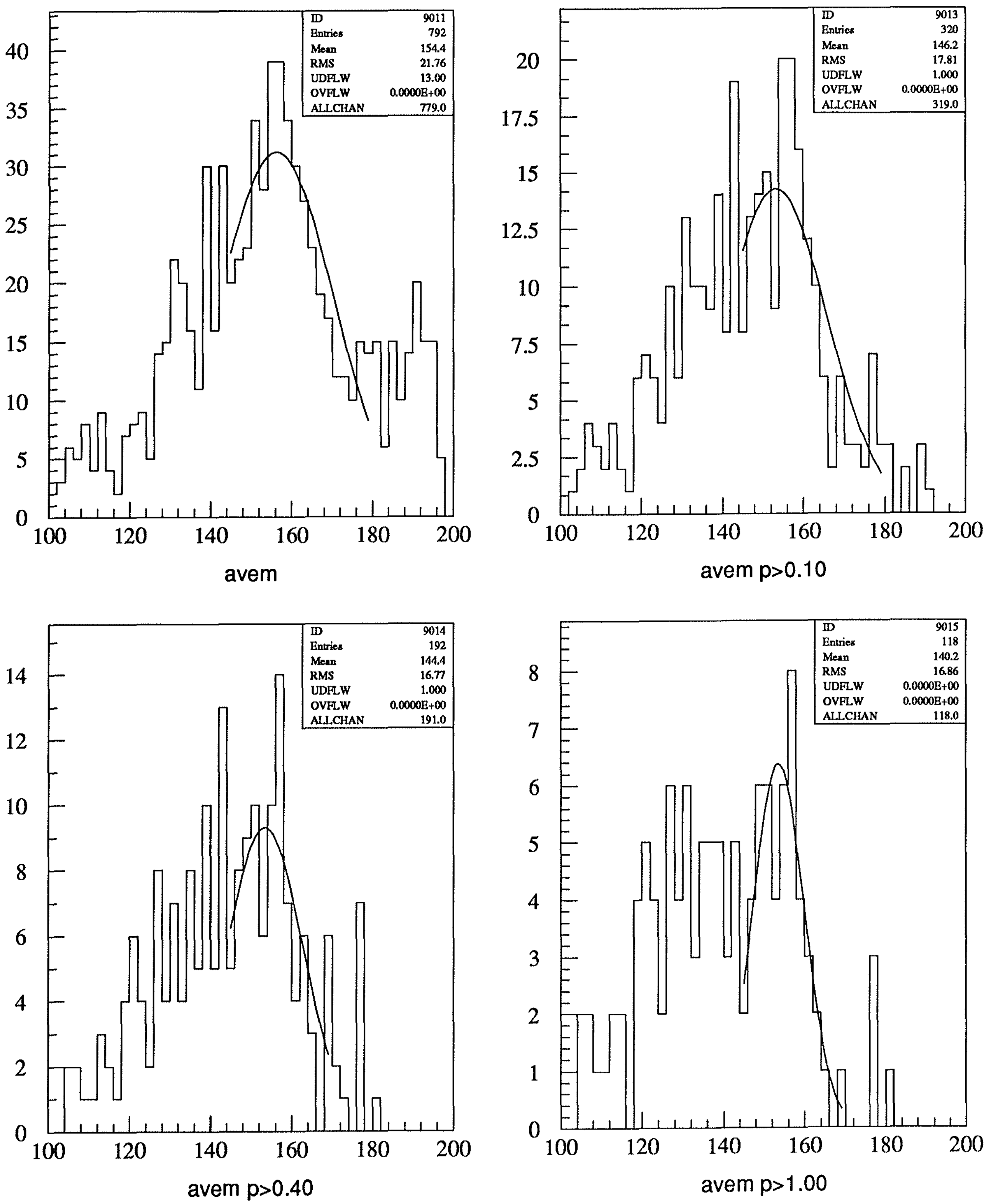
22/03/94 12.19

Figure 7B. Mt=160 GeV/ 3151025



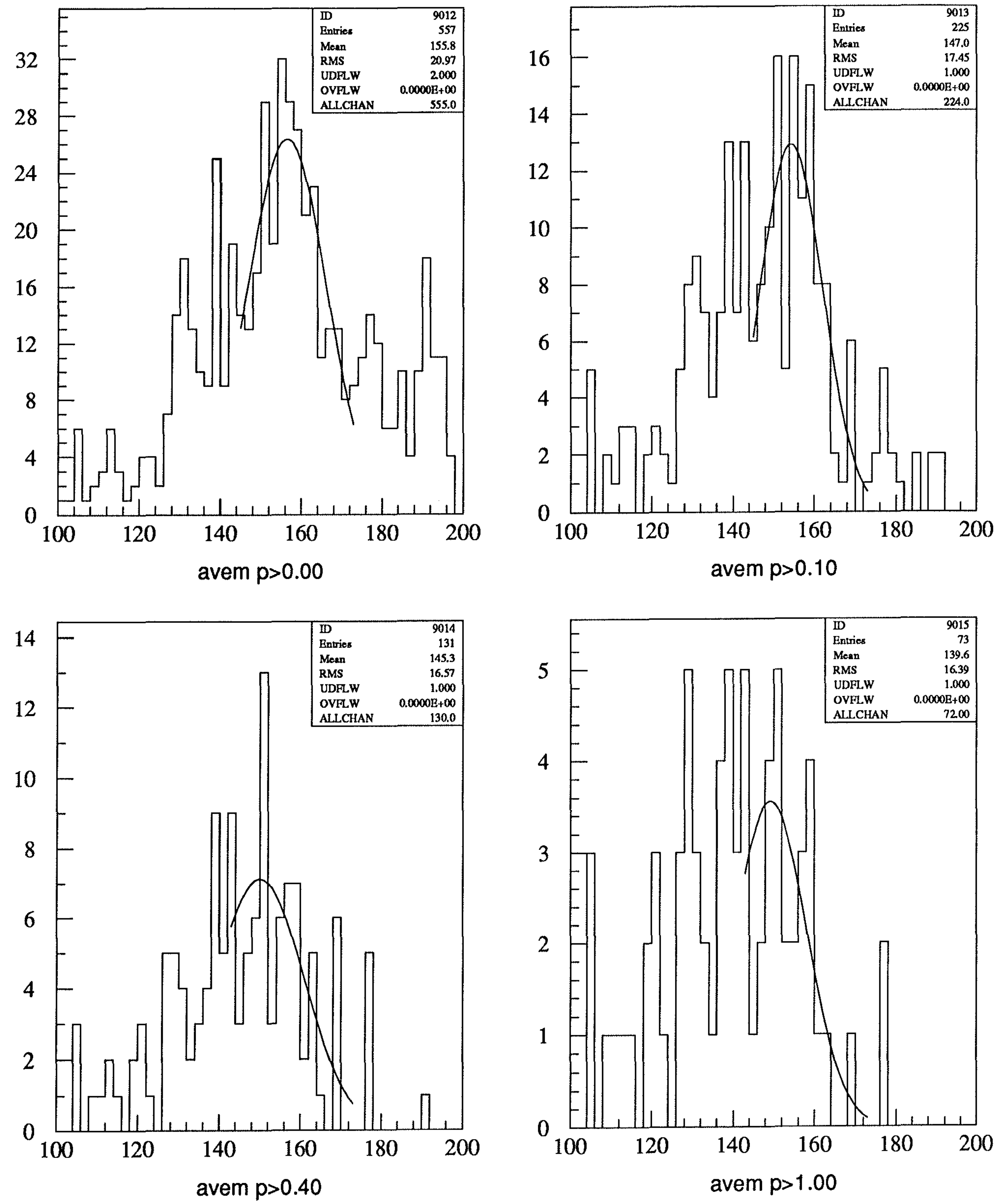
22/03/94 12.54

Figure 7c. Mt=160 GeV/ 3201025



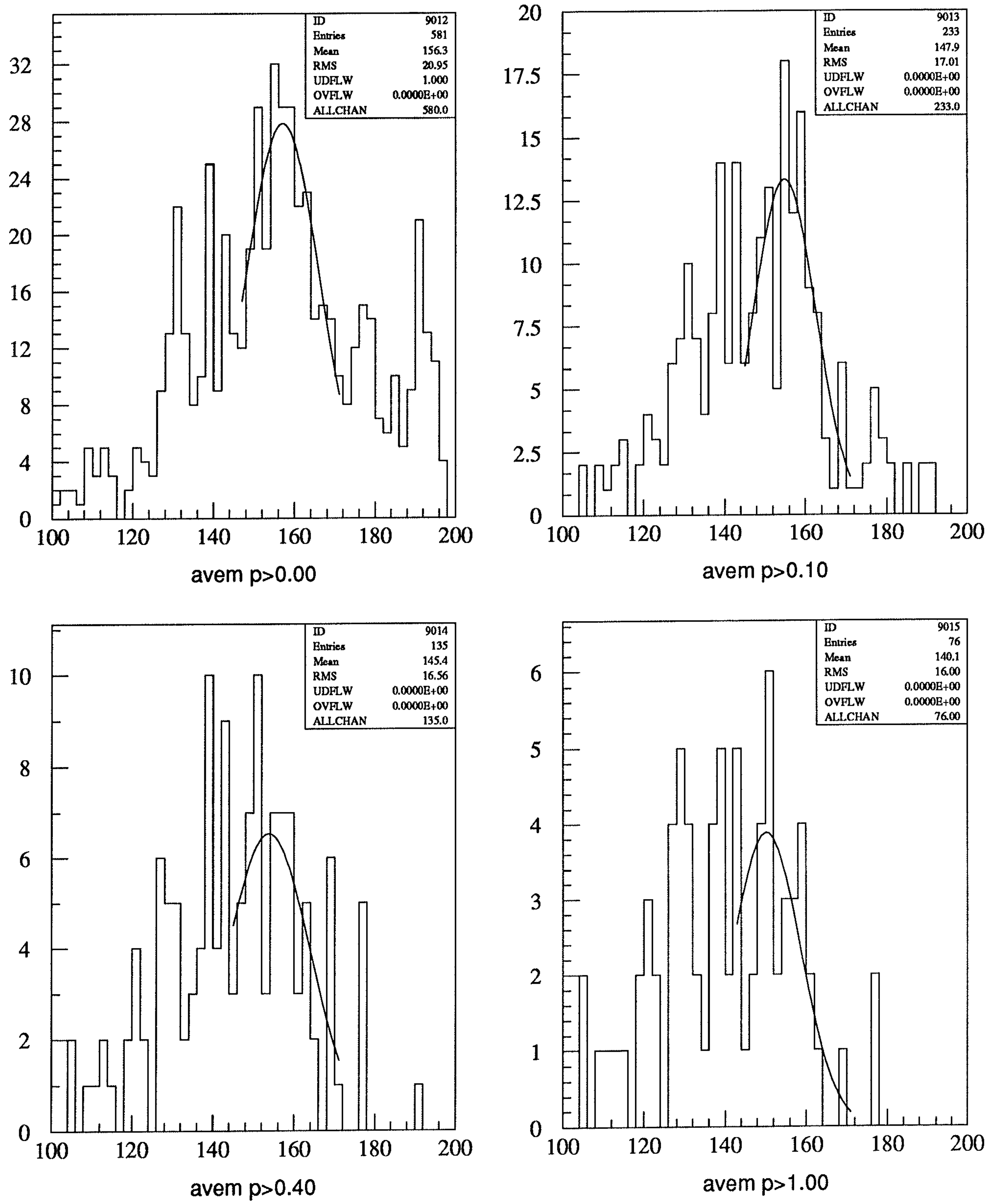
22/03/94 13.27

Figure 7D. Mt=160/ 3151525



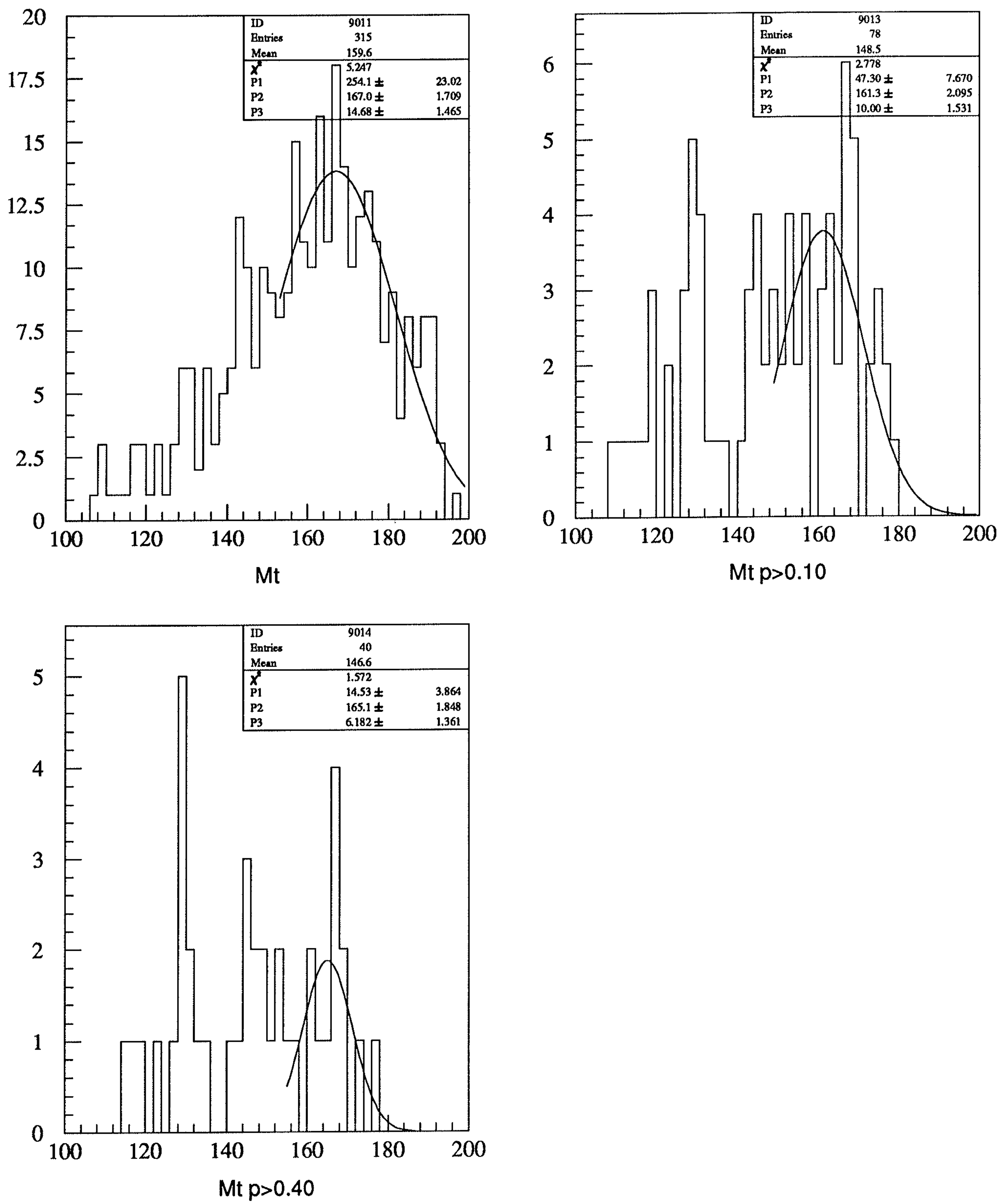
22/03/94 13.07

Figure 7E. Mt=160 GeV/ 3201525



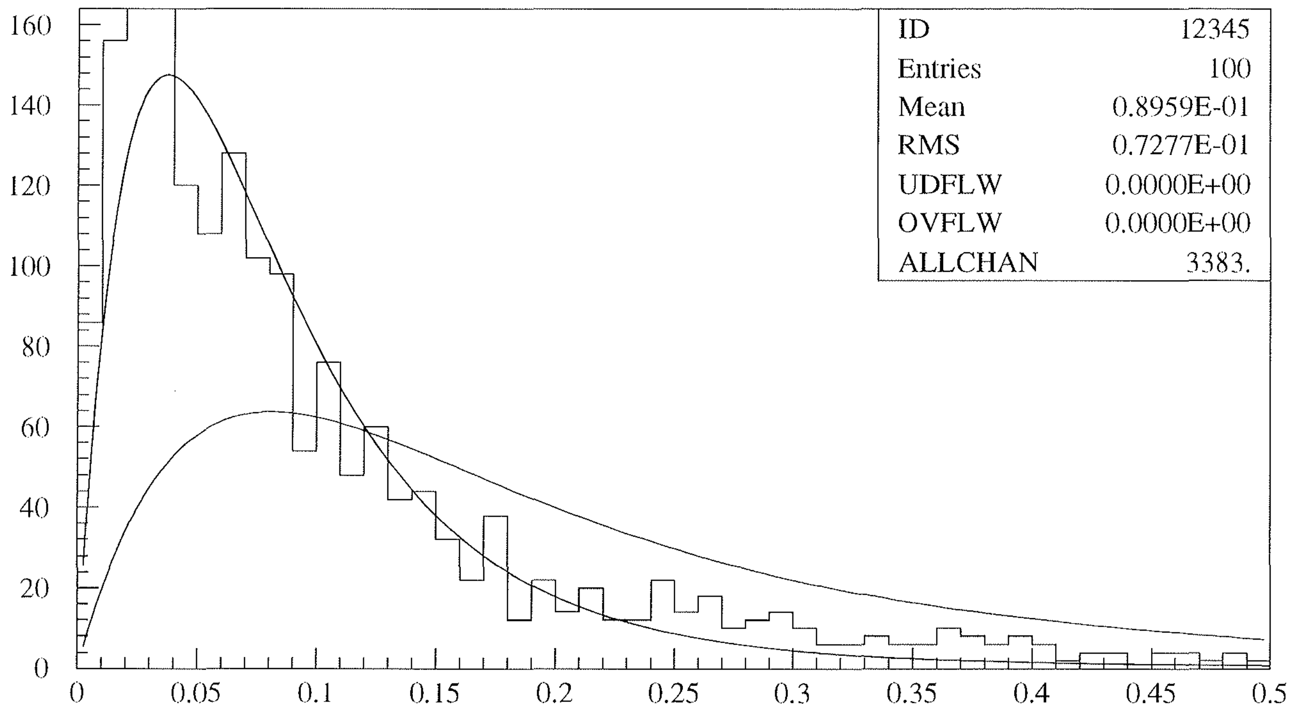
04/04/94 10.38

Figure 8B. Mt=175 GeV/3151025

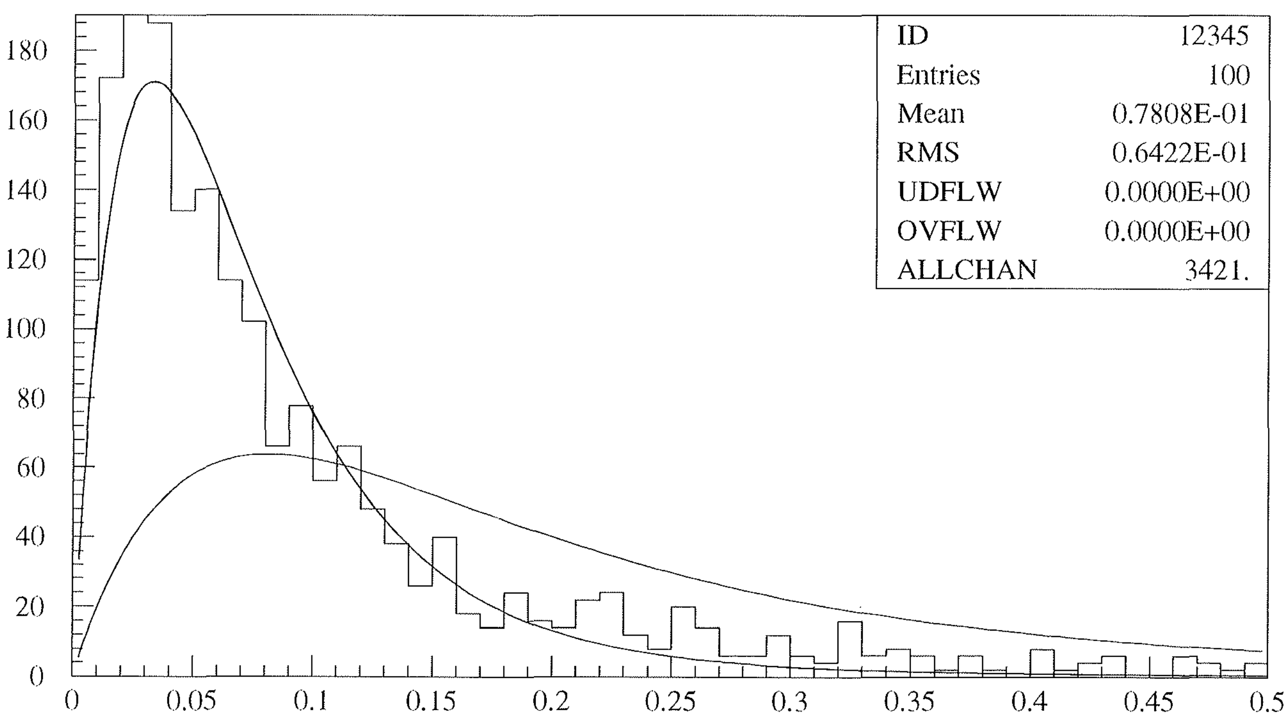


04/04/94 11.46

Figure 3. X=Pt(ttbar)/Mt



11013.*x*exp(20.66*x**2-28.216*x)



14510.*x*exp(25.096*x**2-32.*x)

Figure 4A. Factors contributing to the likelihood.

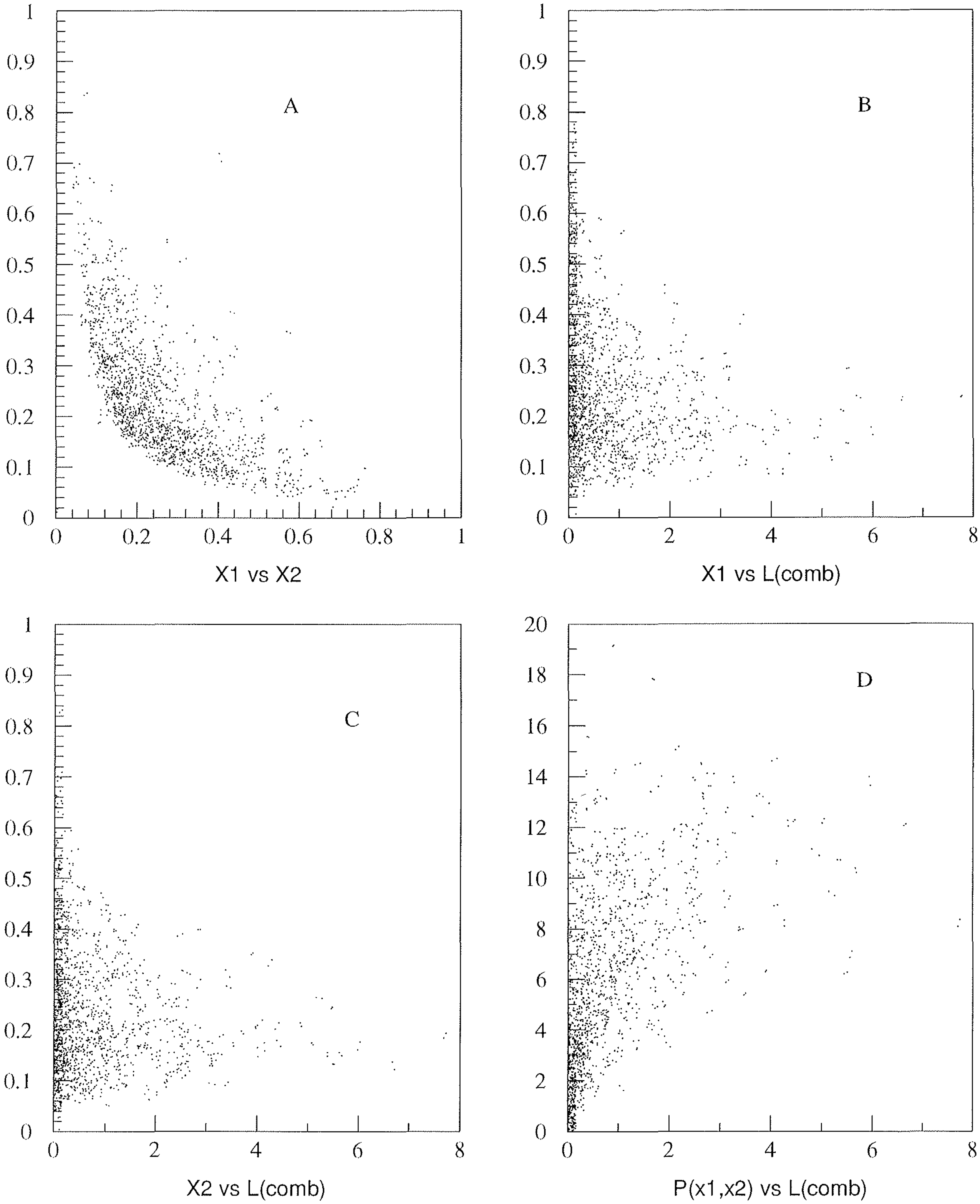


Figure 4B. Factors contributing to the likelihood.

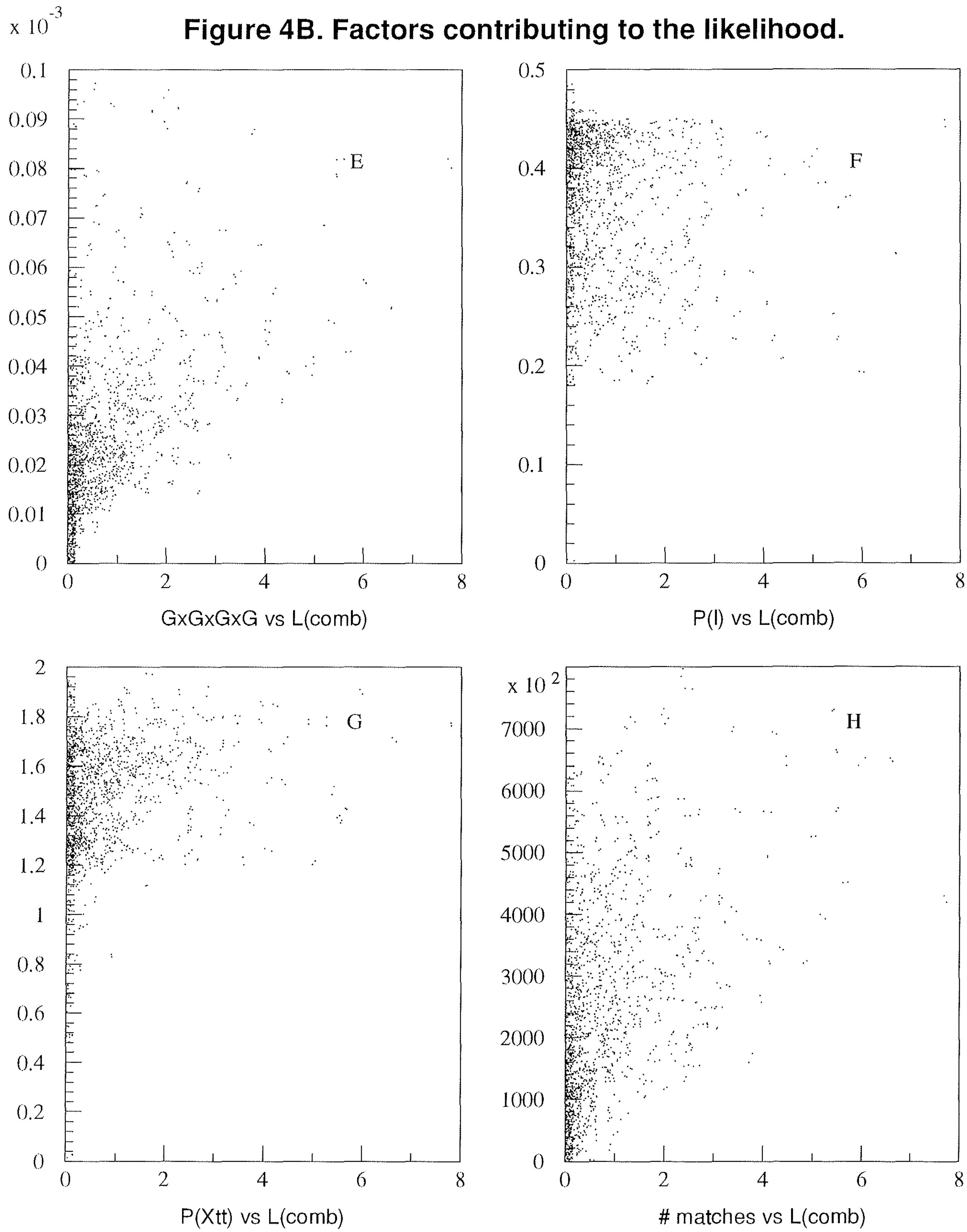
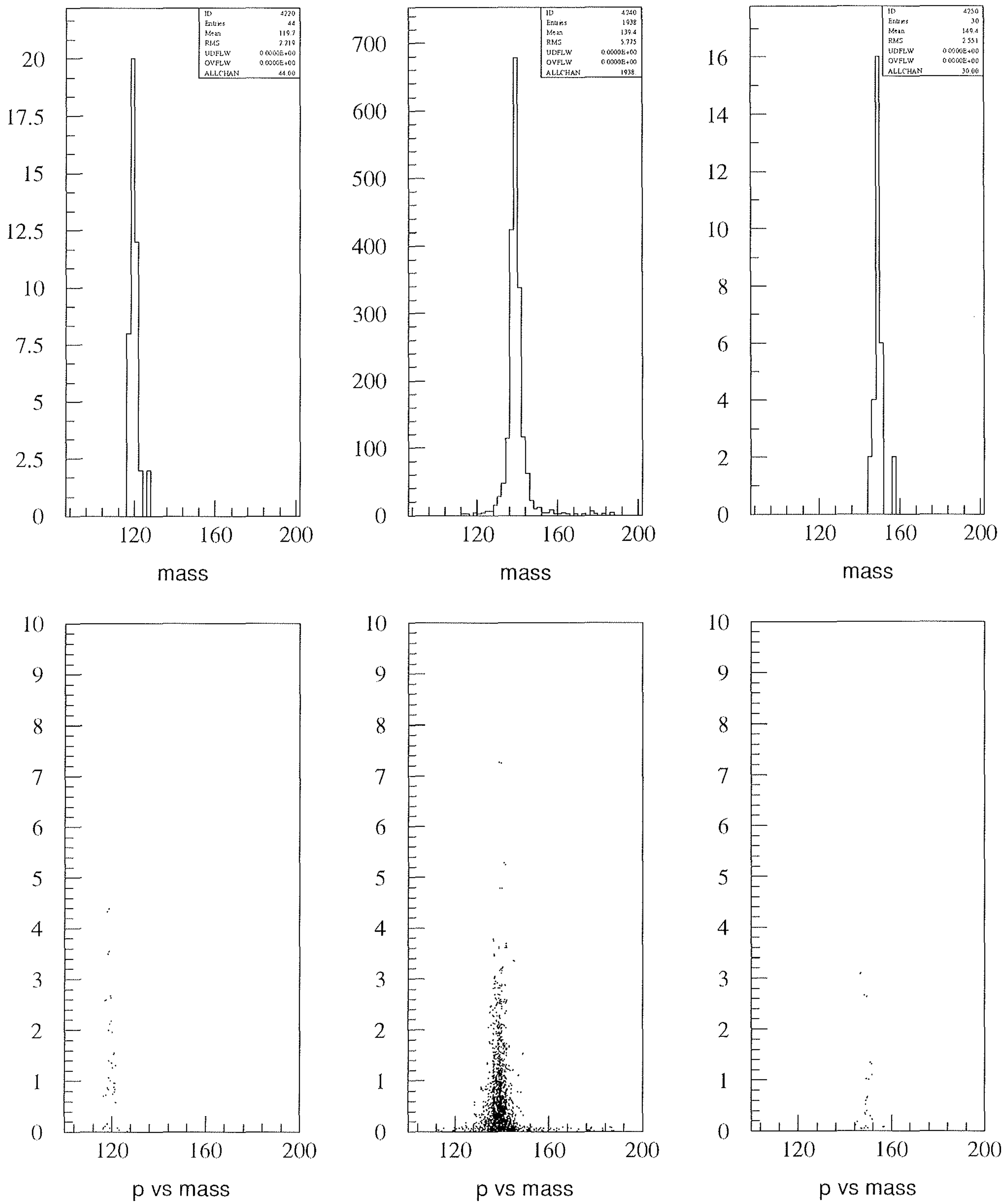


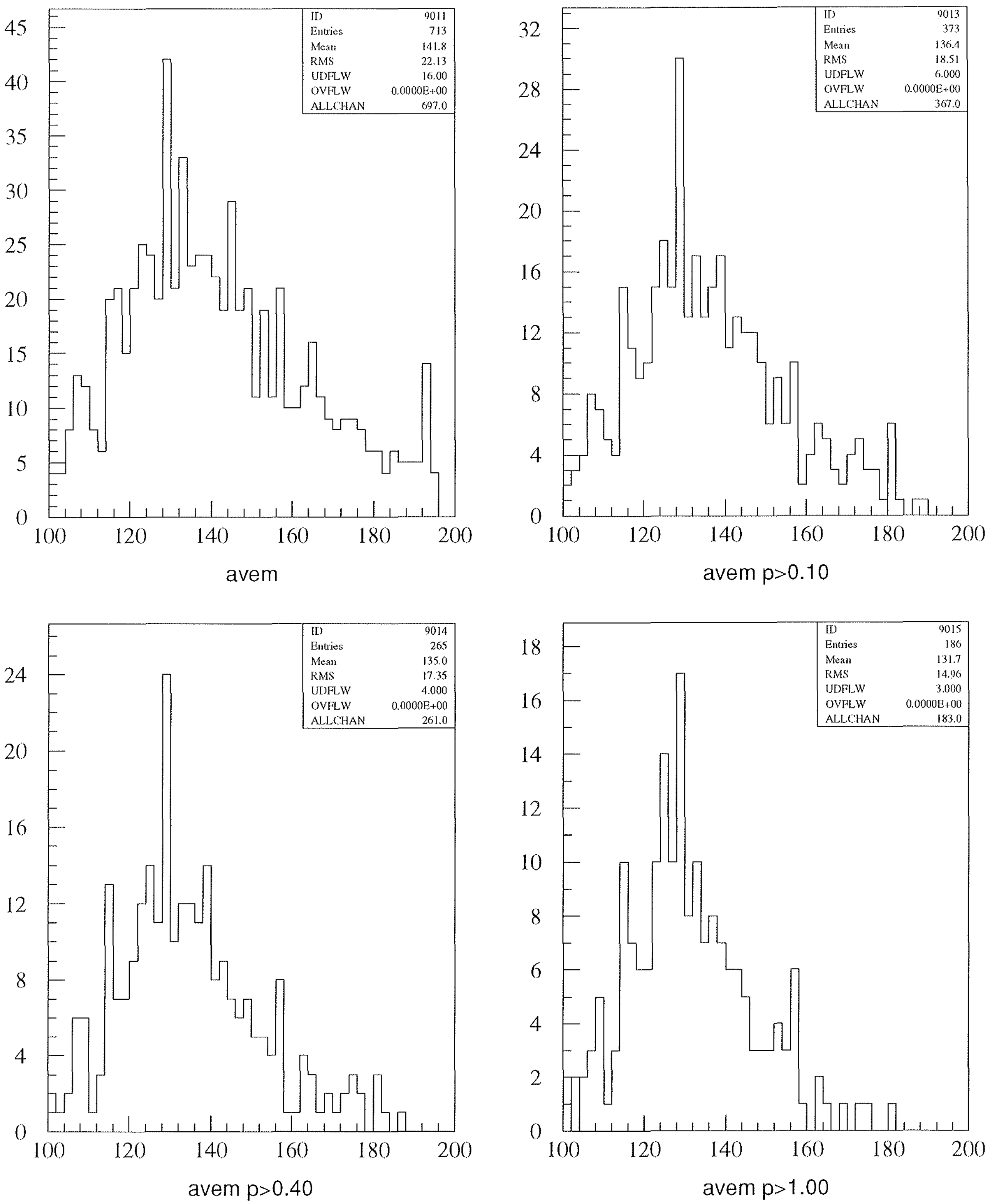
FIGURE 5.



ID 4220
Entries 44
Mean 119.7
RMS 2.219
UDFLW 0.0000E+00
OVFLW 0.0000E+00
ALLCHAN 44.00
mass
ID 4240
Entries 1938
Mean 139.4
RMS 5.775
UDFLW 0.0000E+00
OVFLW 0.0000E+00
ALLCHAN 1938
mass
ID 4250
Entries 30
Mean 149.4
RMS 2.551
UDFLW 0.0000E+00
OVFLW 0.0000E+00
ALLCHAN 30.00
mass
p vs mass
p vs mass
p vs mass

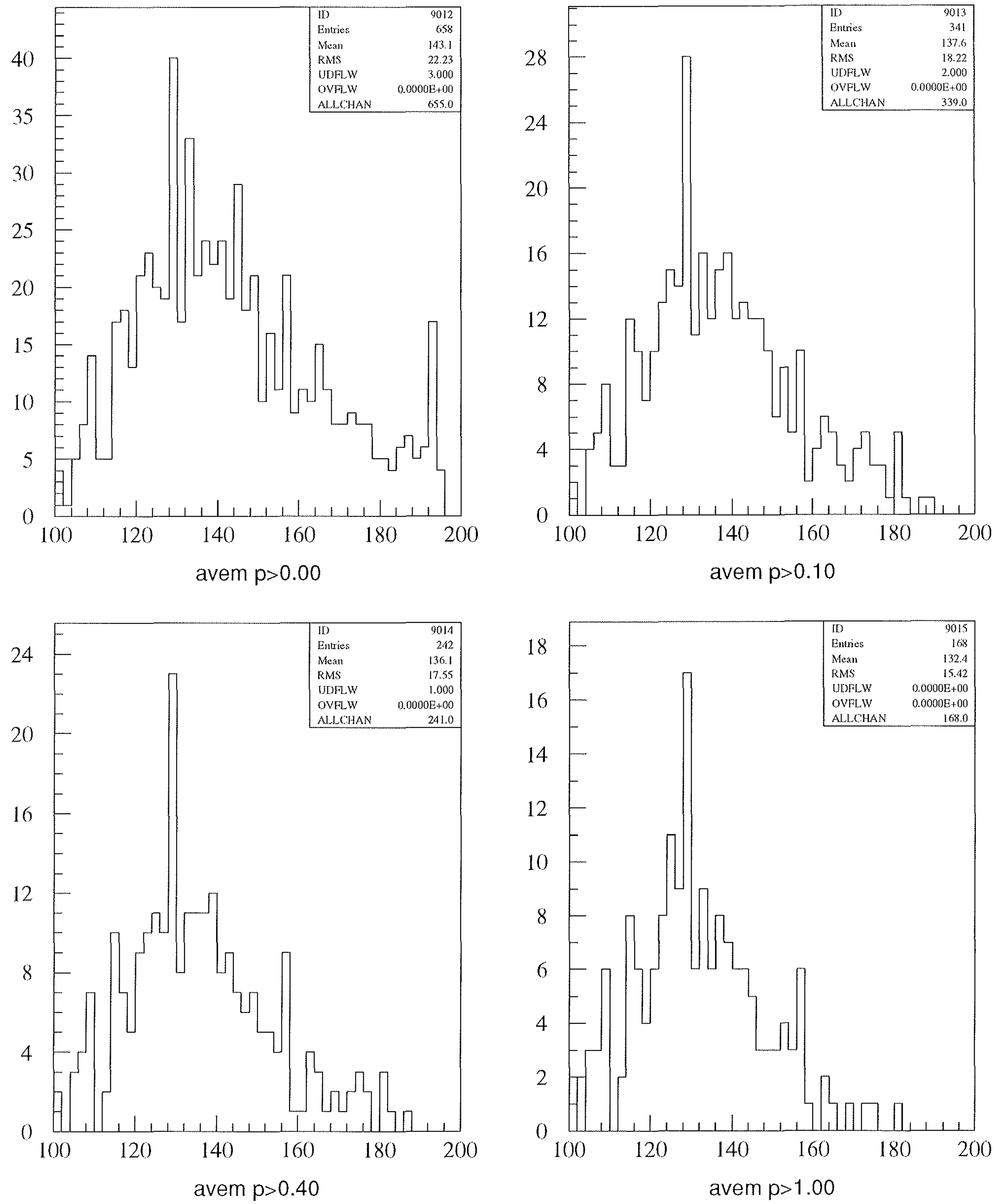
23/03/94 11.31

Figure 6B. Mt=140 GeV/ 3151025



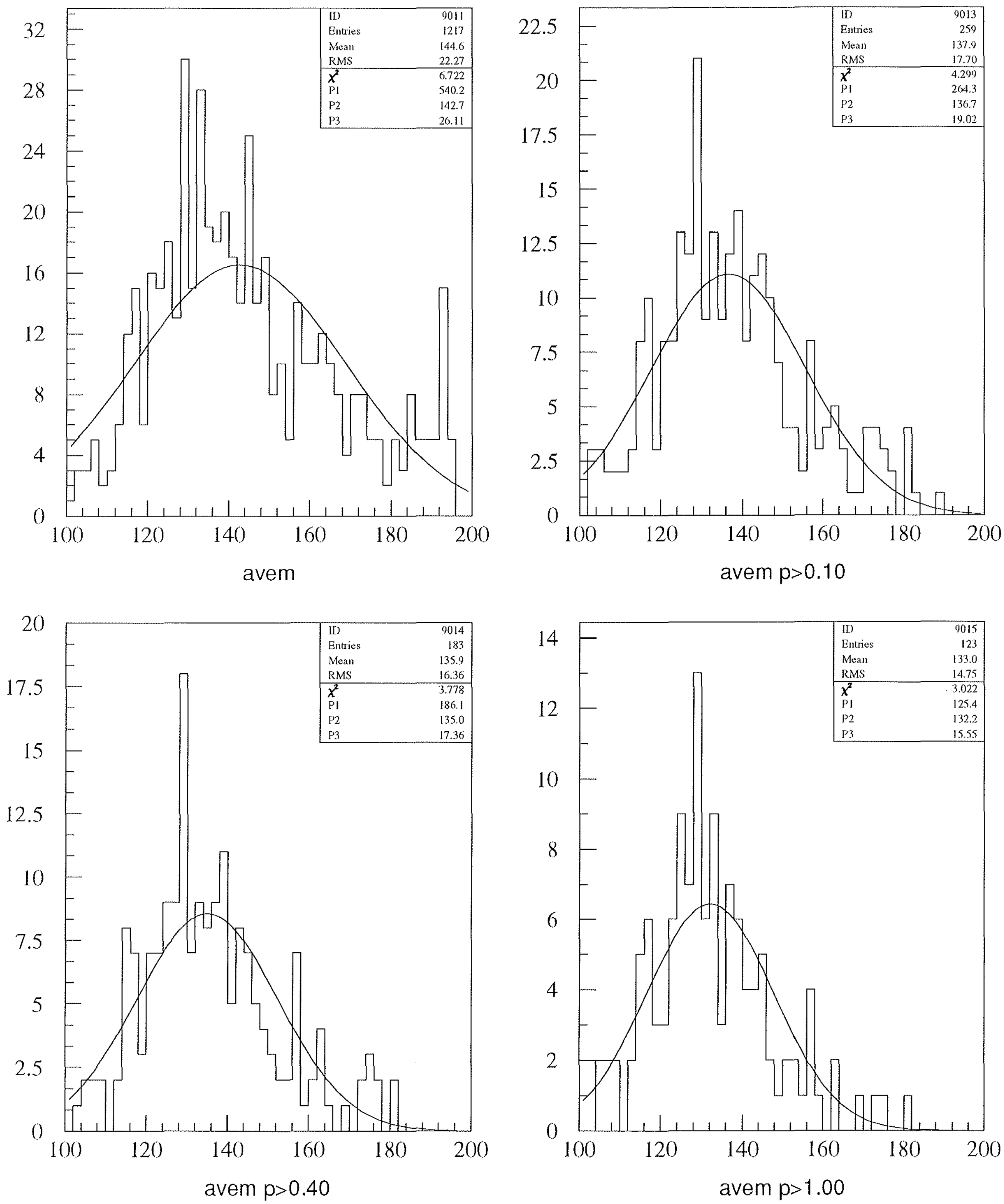
23/03/94 10.40

Figure 6C. Mt=140 GeV/ 3201025



23/03/94 12.11

Figure 6D. Mt=140/ 3151525



23/03/94 12.20

Figure 6E. Mt=140/ 3201525

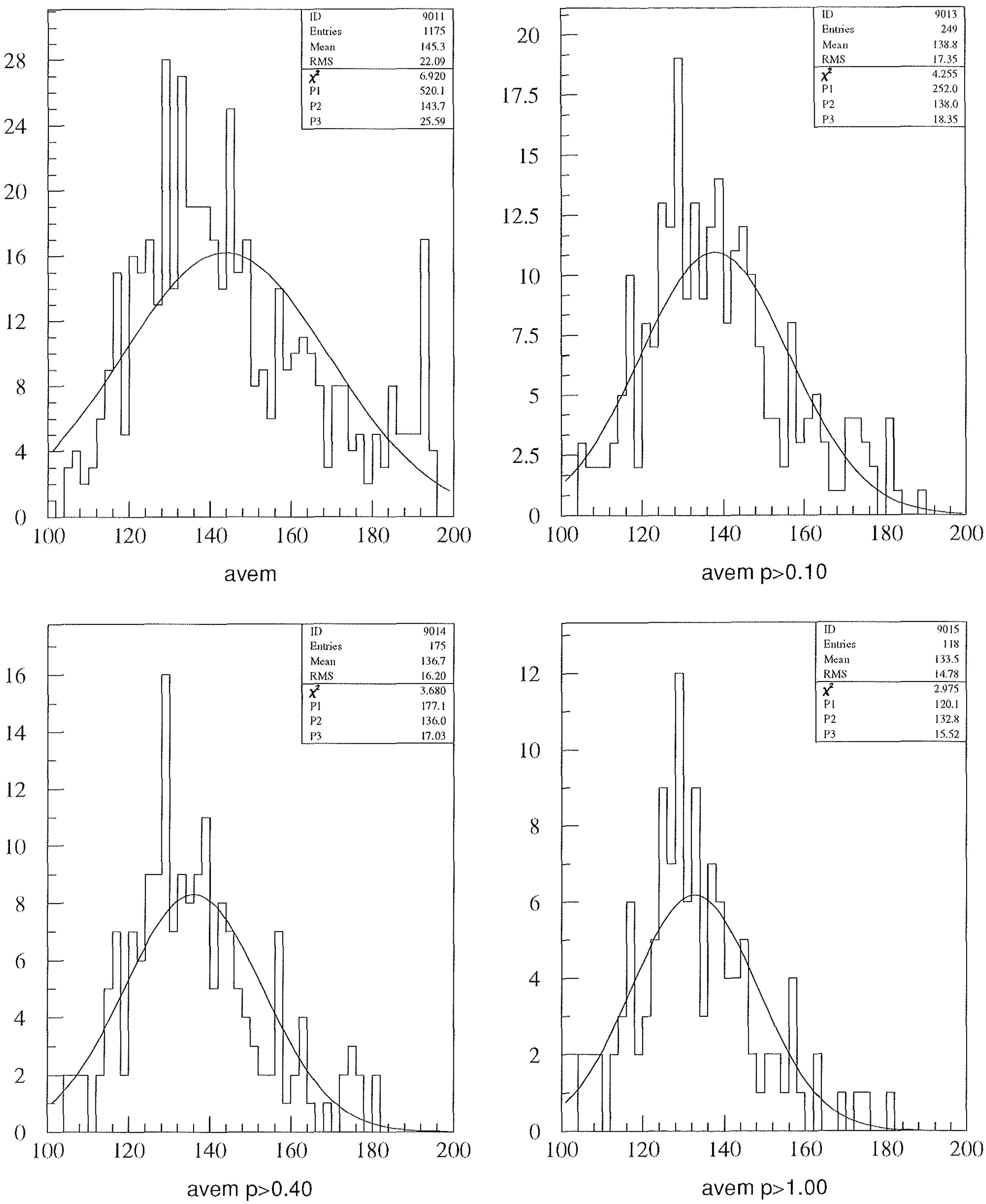
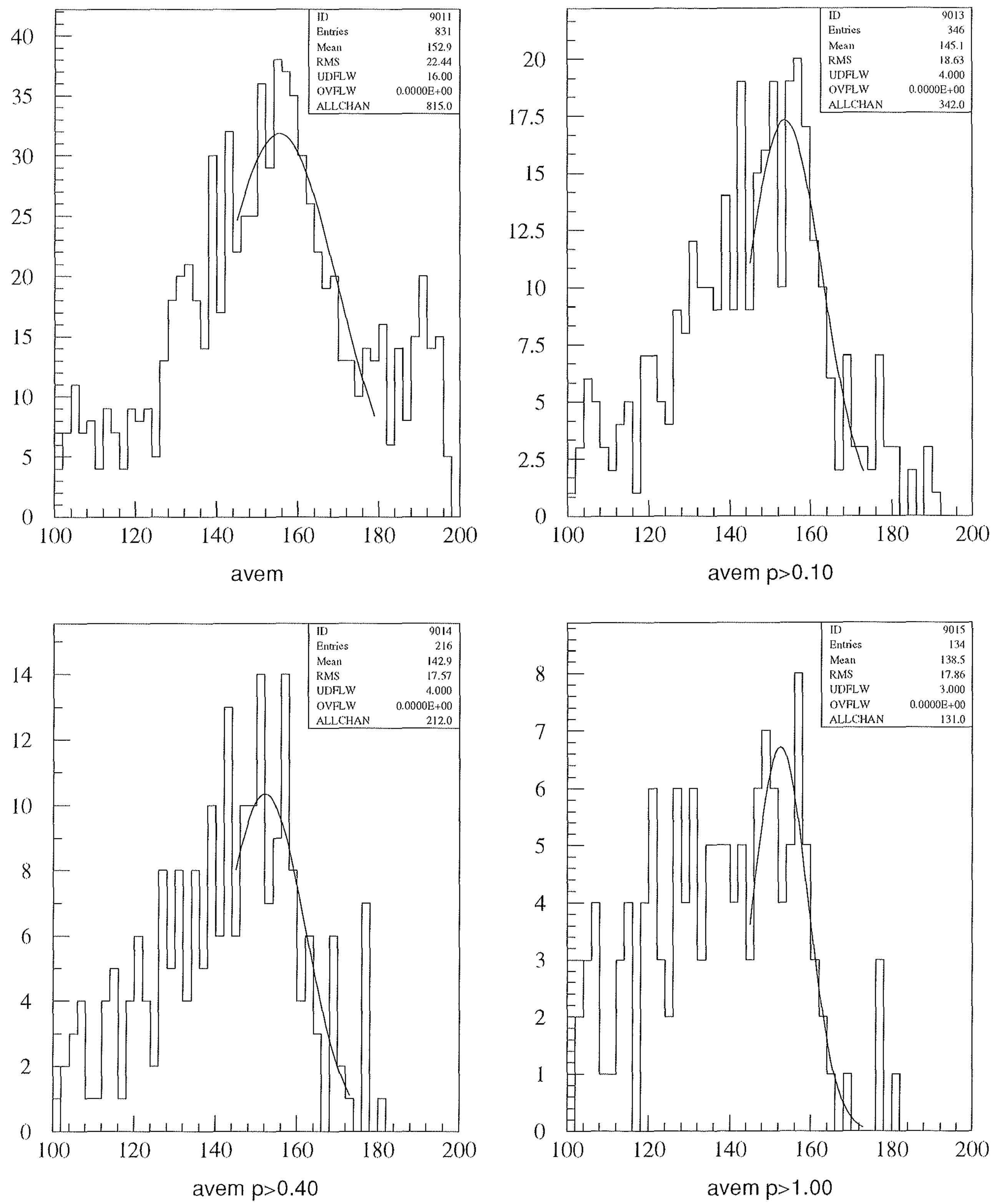
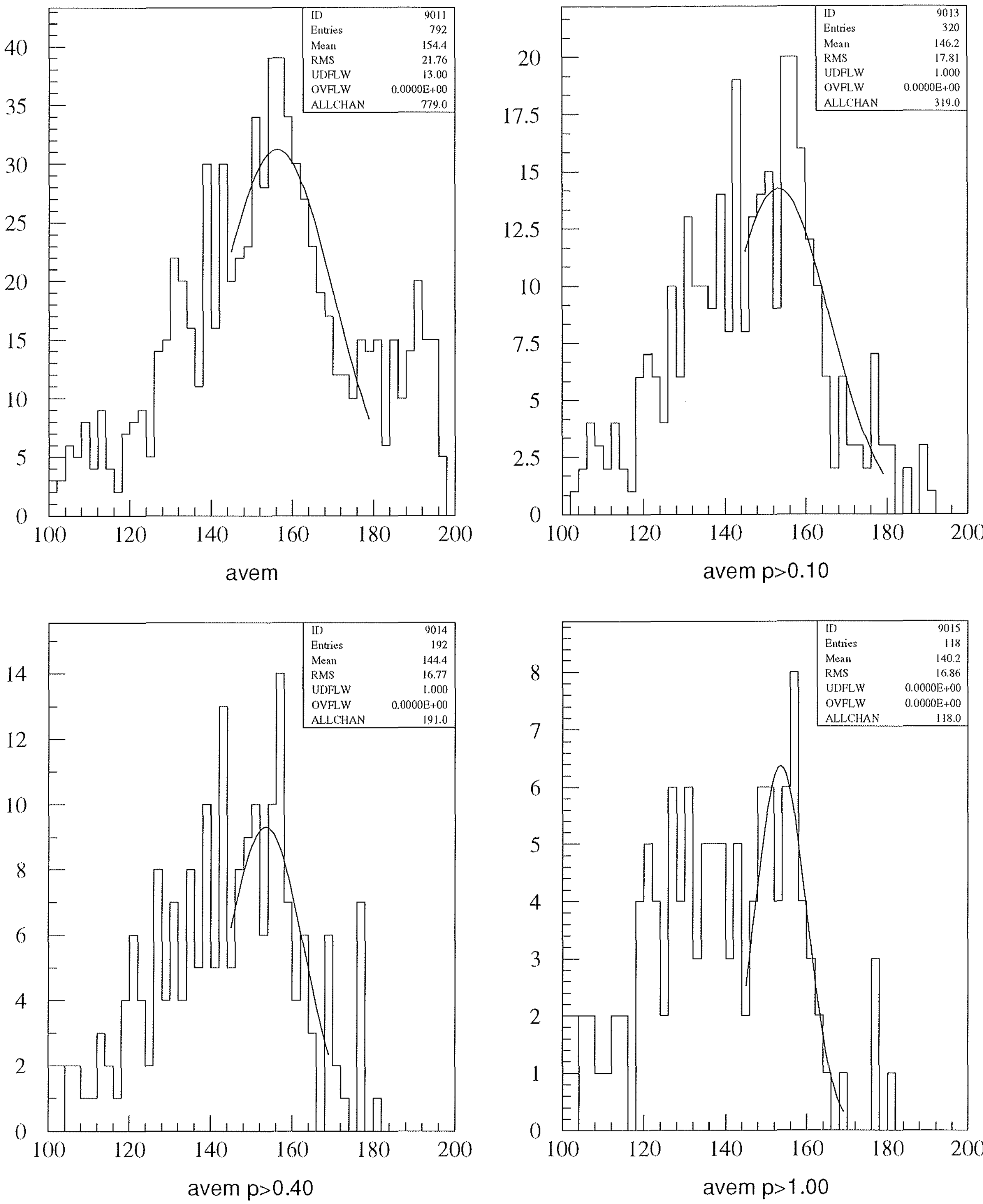


Figure 7B. Mt=160 GeV/ 3151025



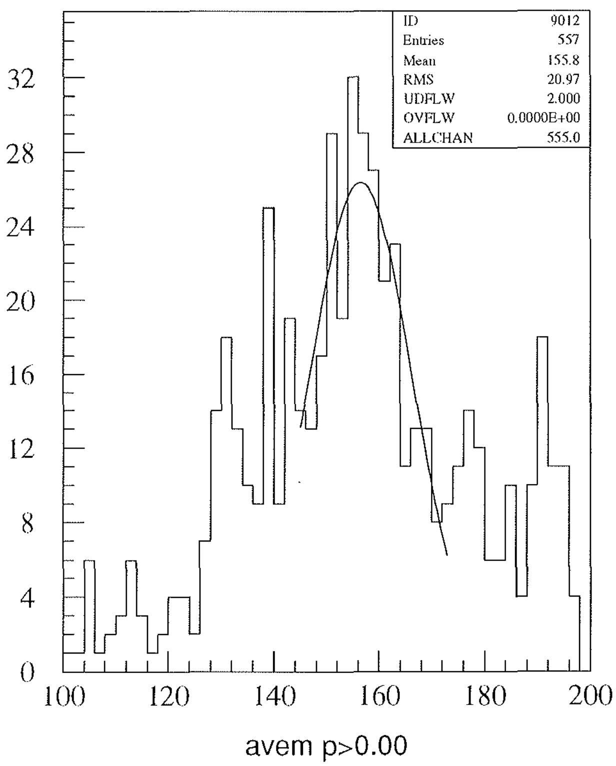
22/03/94 12.54

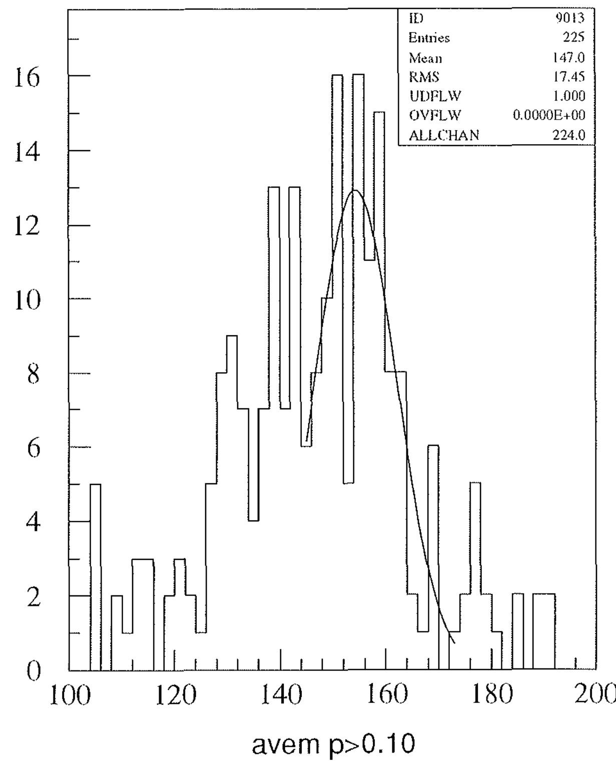
Figure 7c. Mt=160 GeV/ 3201025

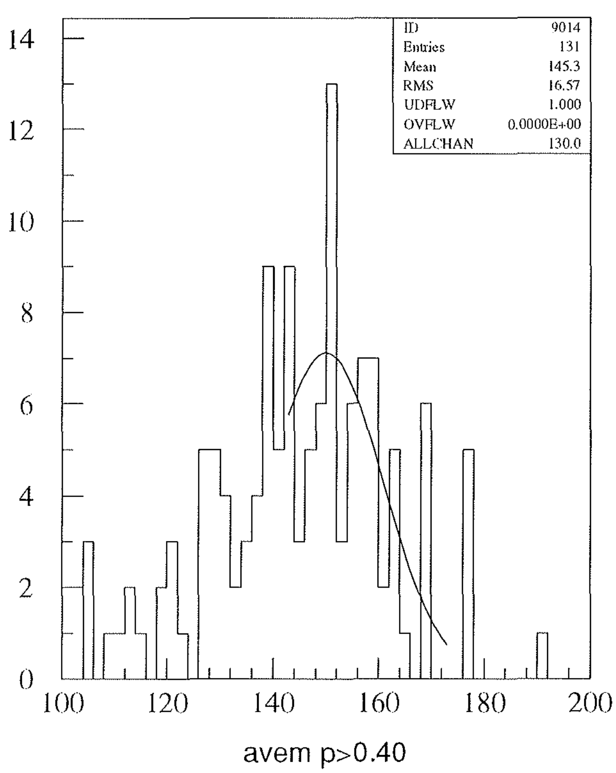


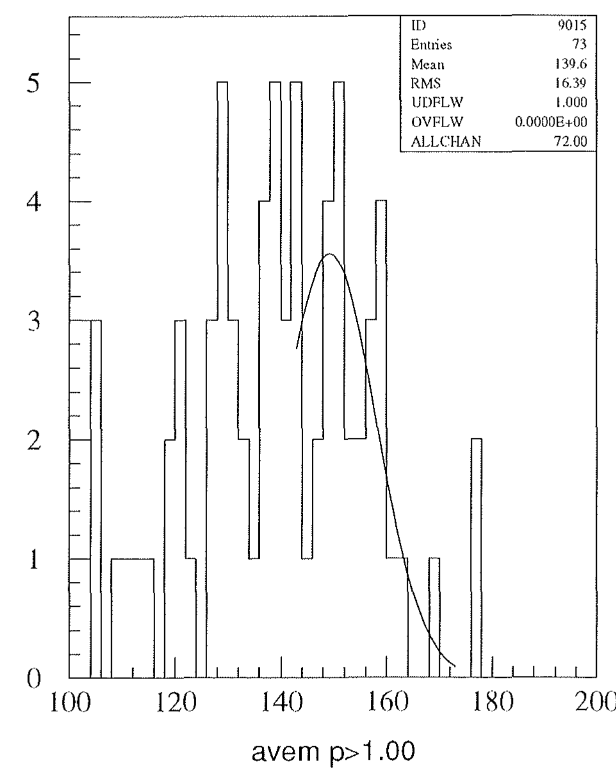
22/03/94 13.27

Figure 7D. Mt=160/ 3151525



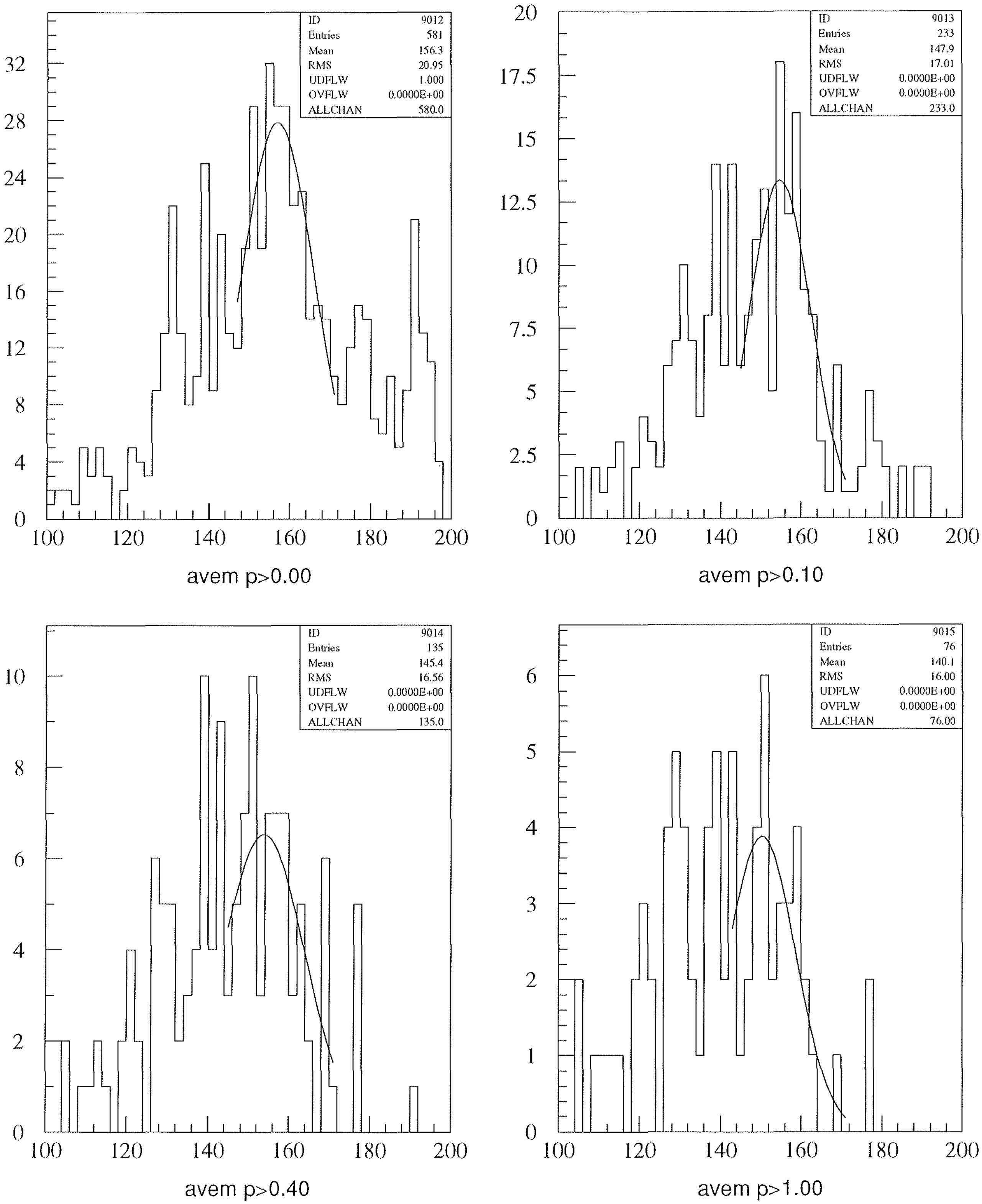






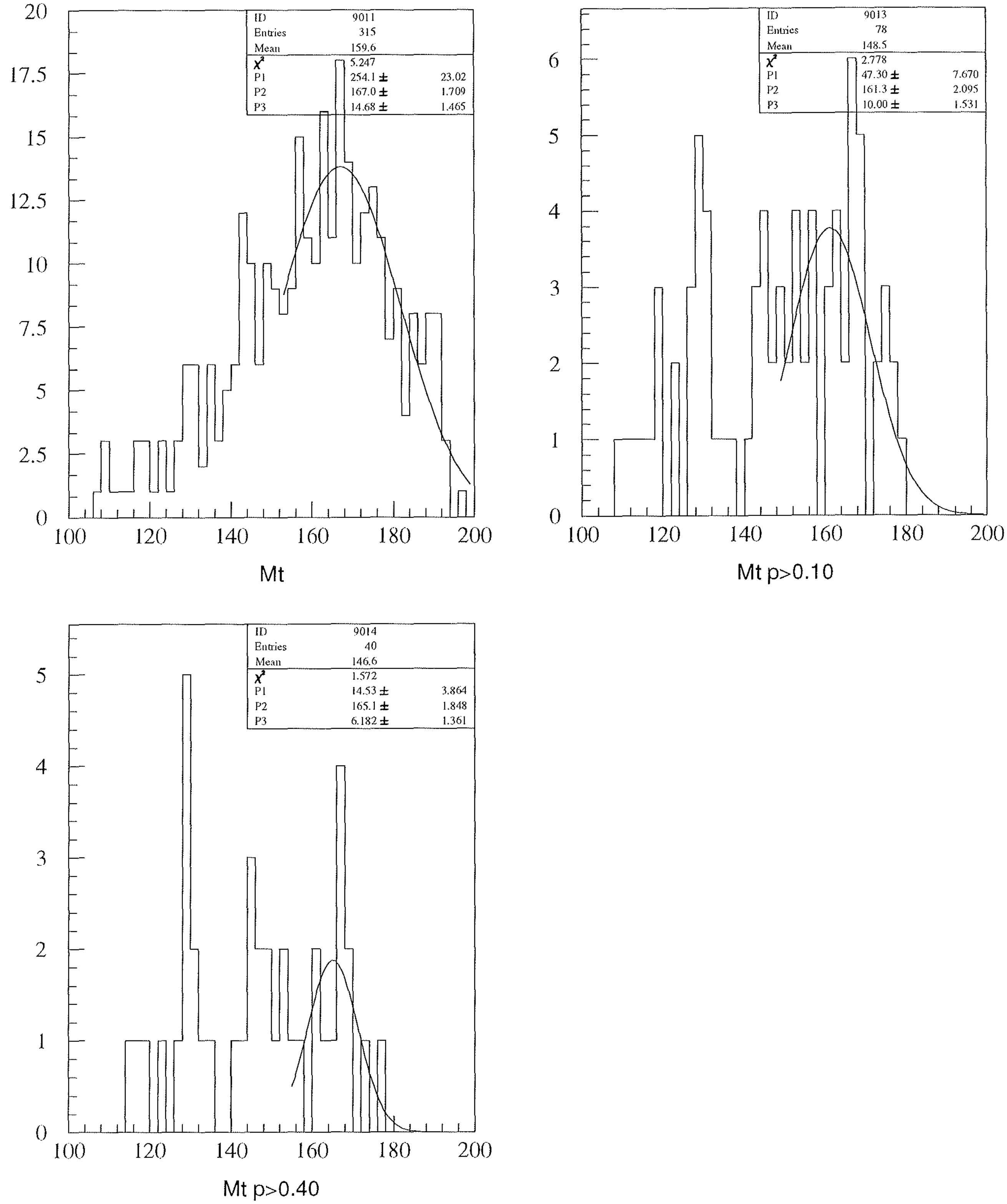
22/03/94 13.07

Figure 7E. Mt=160 GeV/ 3201525



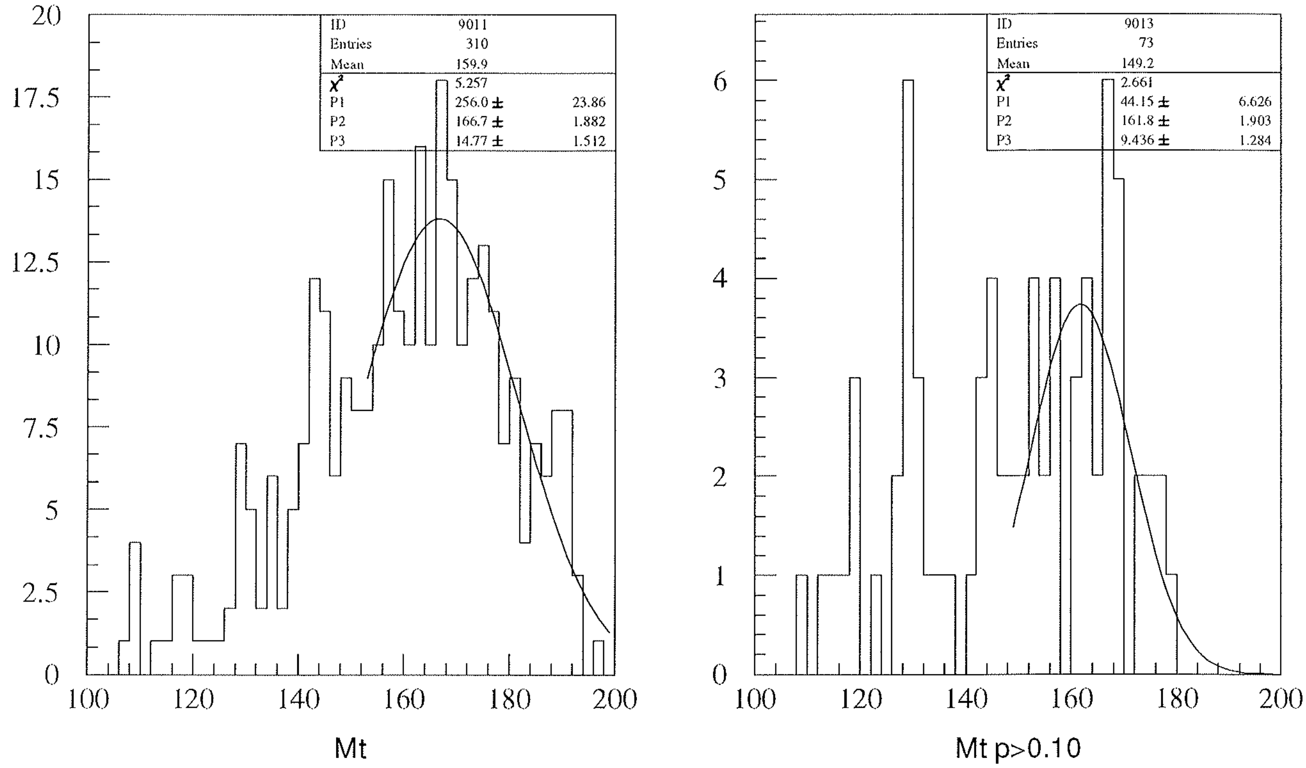
04/04/94 10.38

Figure 8B. Mt=175 GeV/3151025



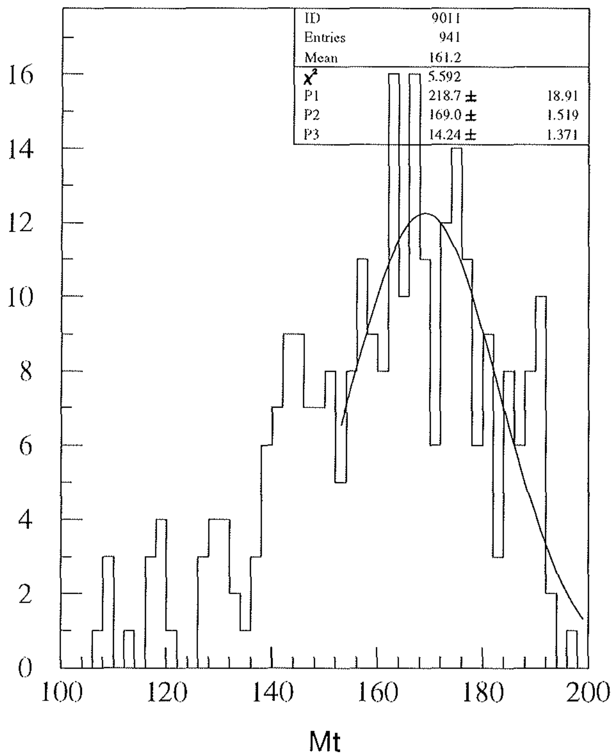
04/04/94 10.26

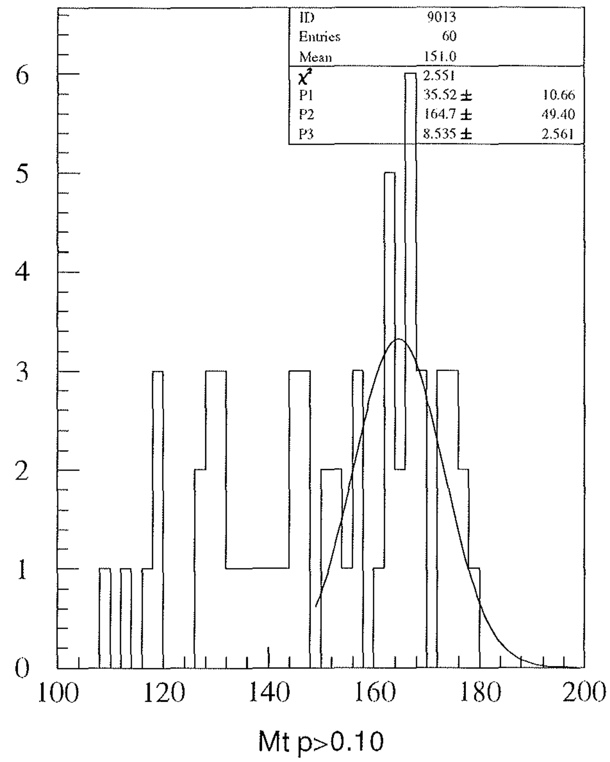
Figure 8C. Mt=175 GeV/3201025



04/04/94 16.02

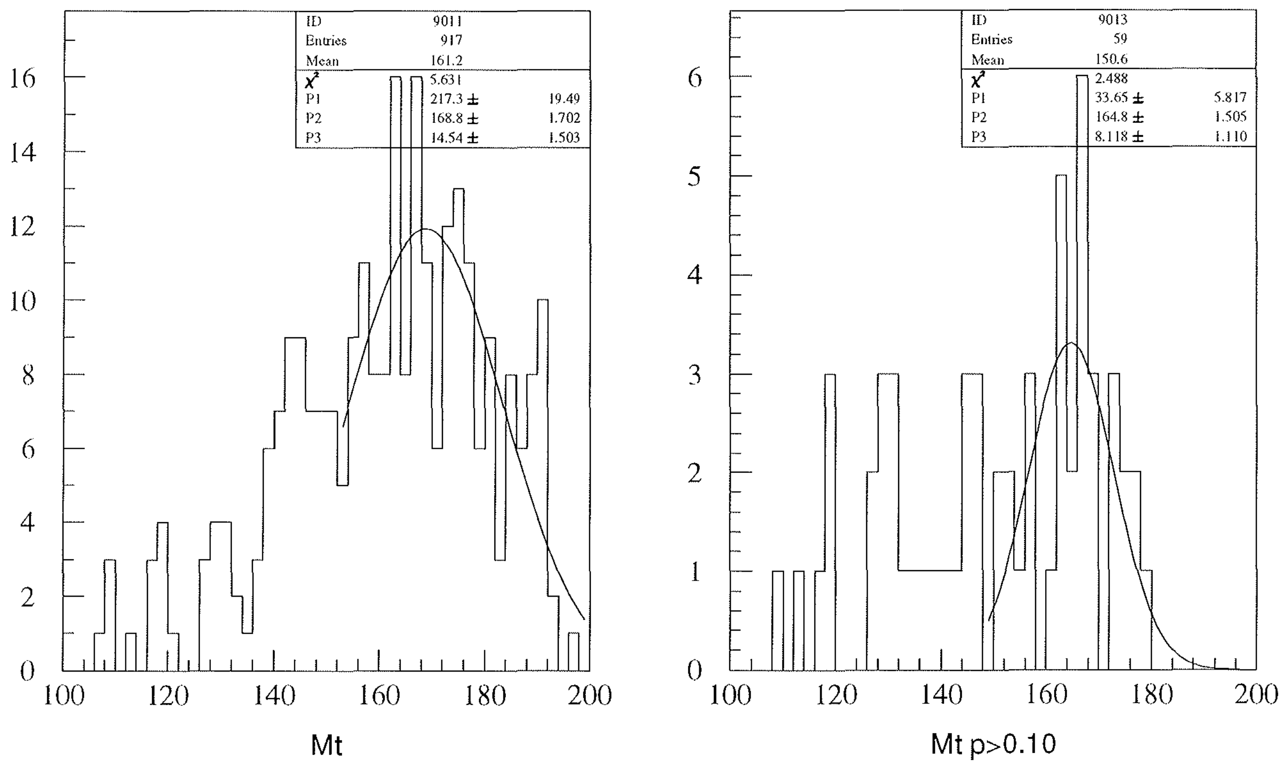
Figure 8D. Mt=175 GeV/3151525





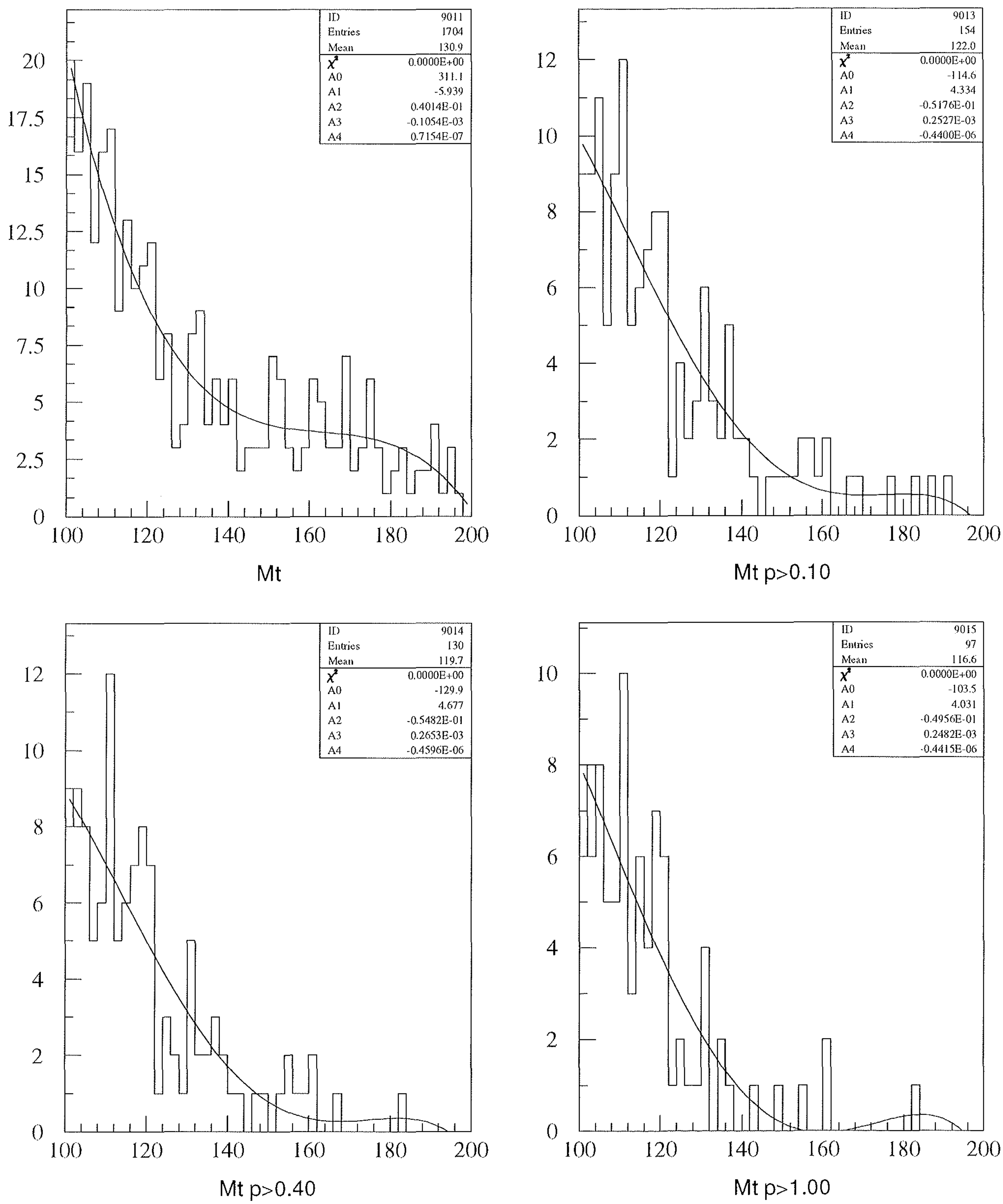
04/04/94 16.22

Figure 8E. Mt=175 GeV/3201525



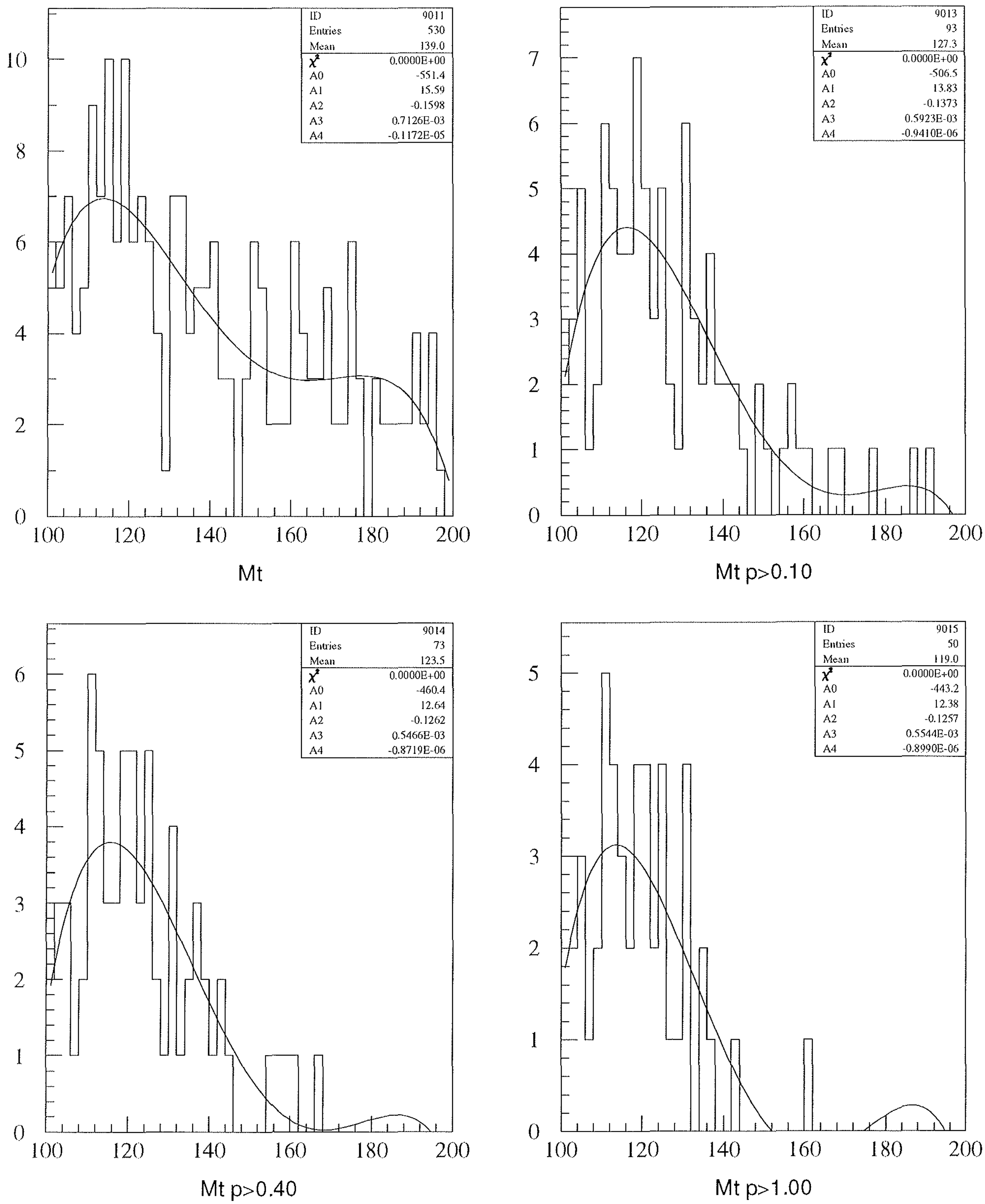
04/04/94 09.27

Figure 9A. 203 pb-1 VECBOS WE4PM_HQ/31510



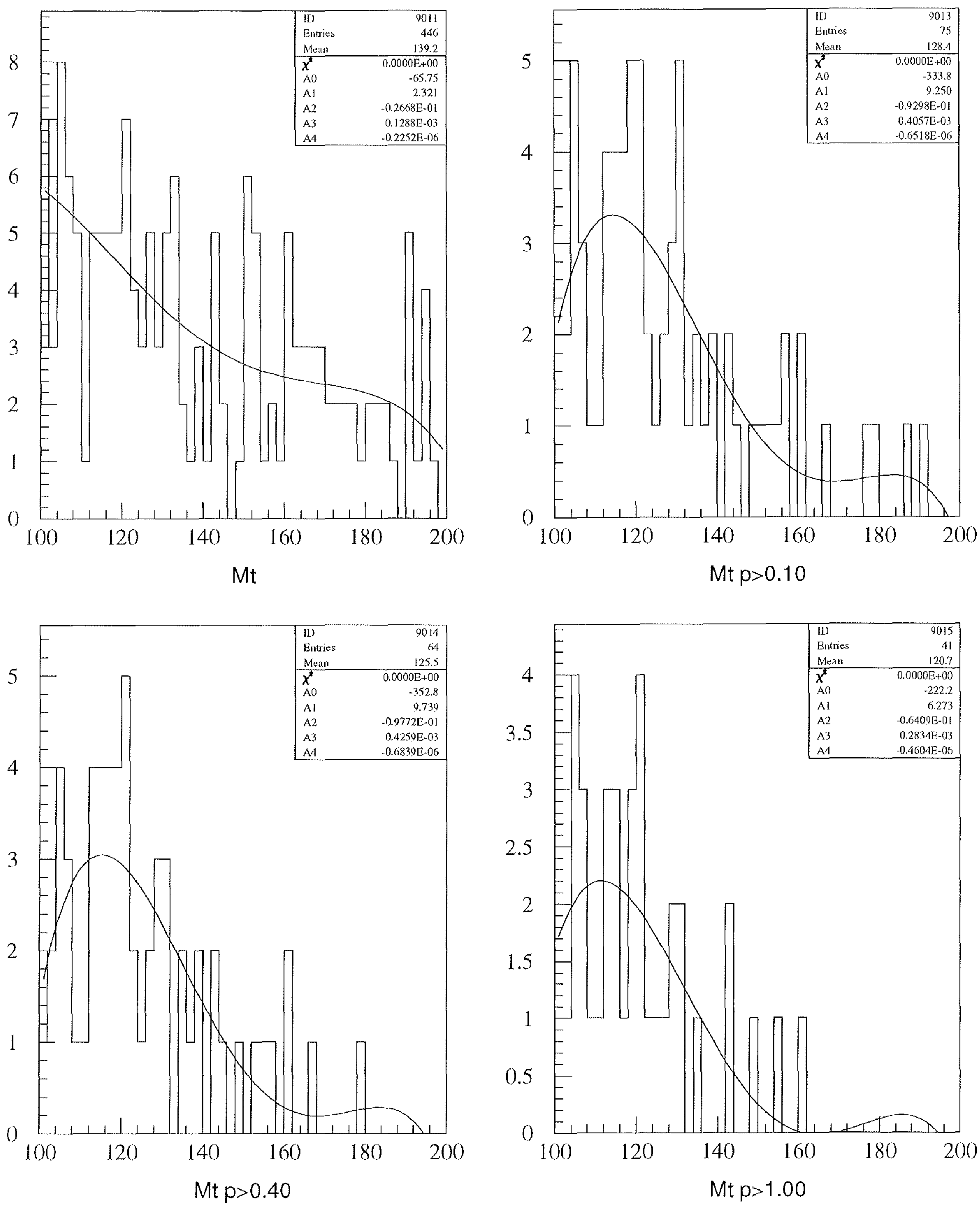
04/04/94 09.22

Figure 9B. 203 pb-1 VECBOS WE4PM_HQ/32010



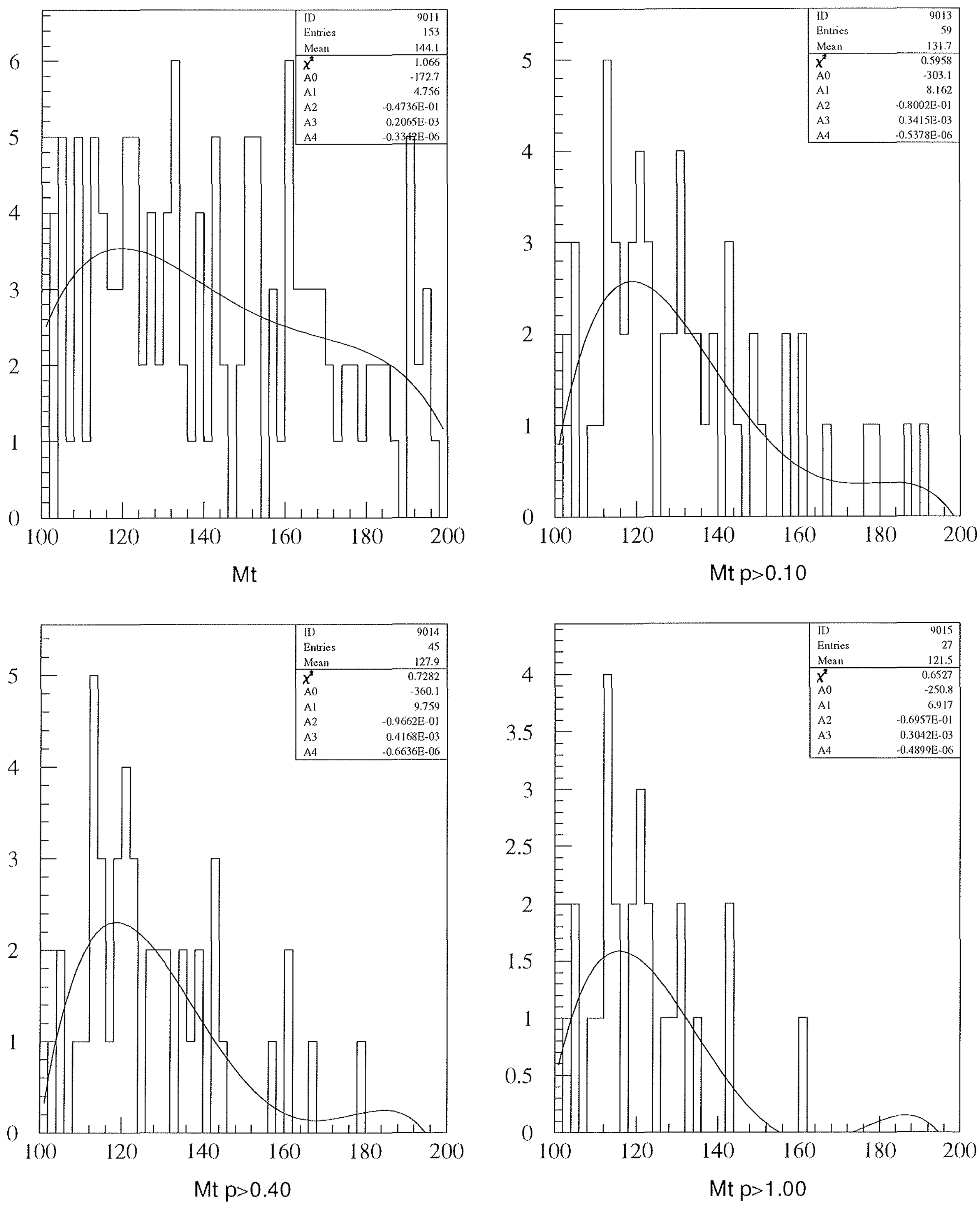
04/04/94 09.18

Figure 9C. 203 pb-1 VECBOS WE4PM_HQ/31515



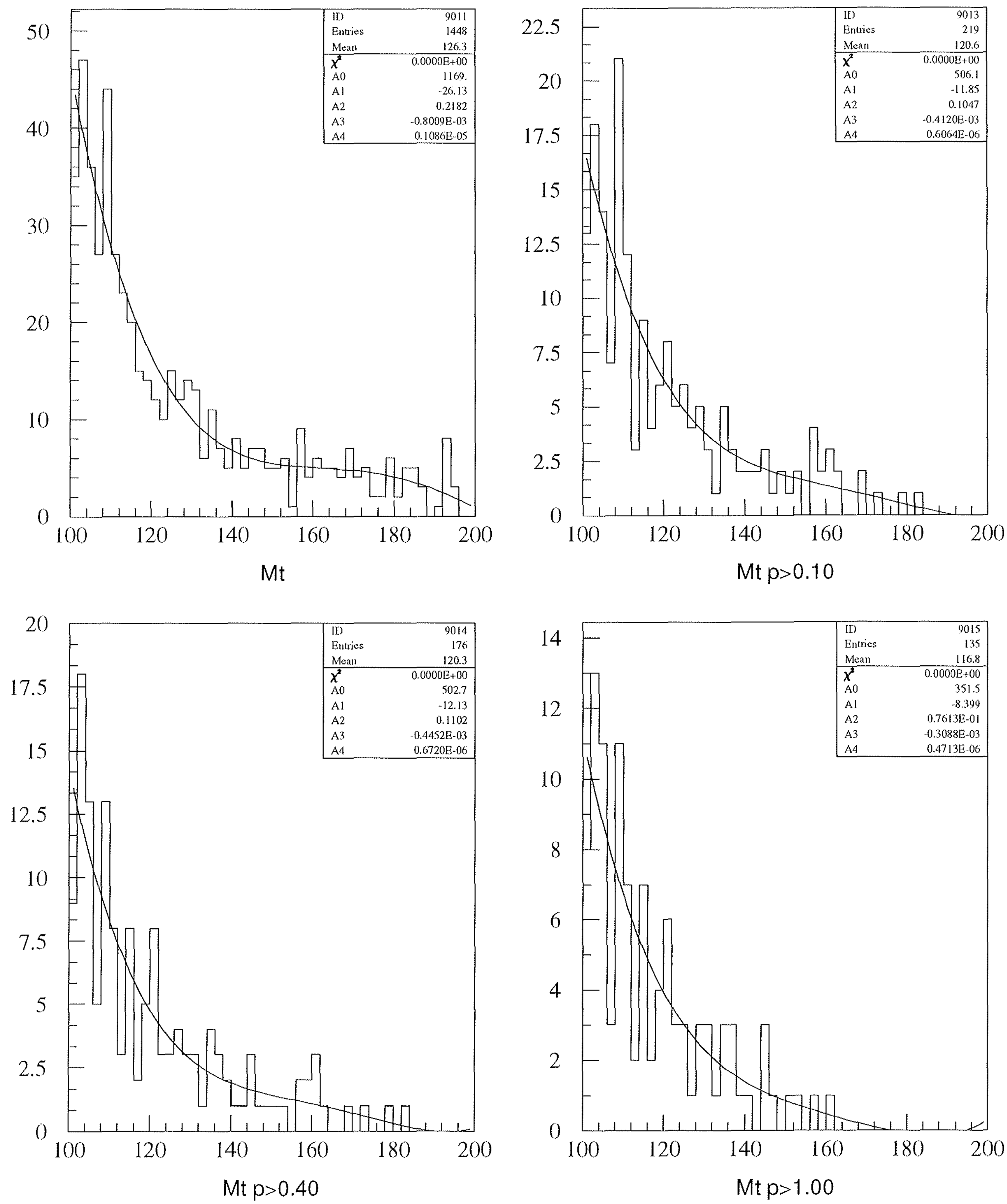
04/04/94 09.12

Figure 9D. 203 pb-1 VECBOS WE4PM_HQ/32015



04/04/94 09.32

Figure 10A. 203 pb-1 VECBOS WE4PM_SQ/31510



04/04/94 09.36

Figure 10B. 203 pb-1 VECBOS WE4PM_SQ/32010

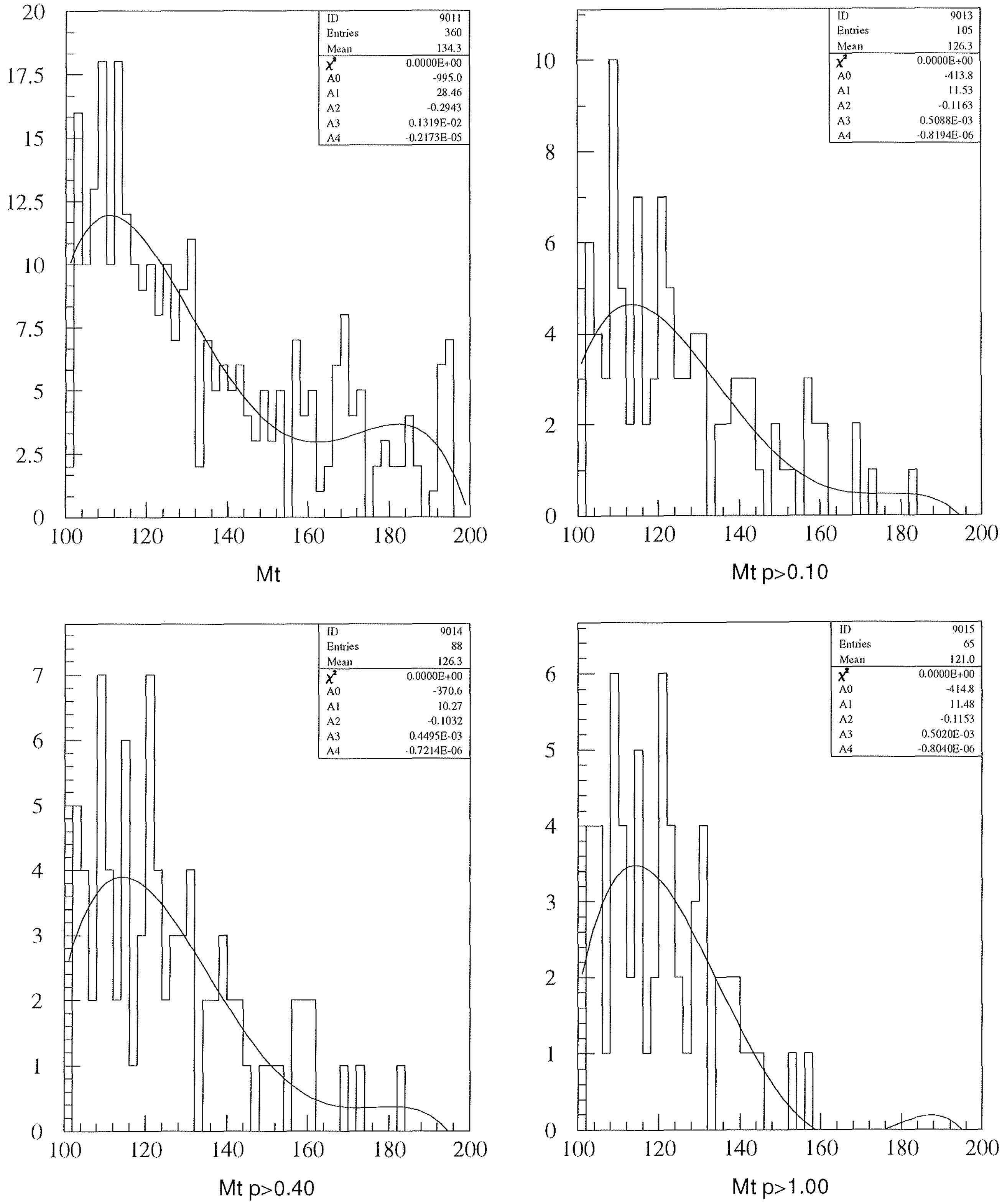


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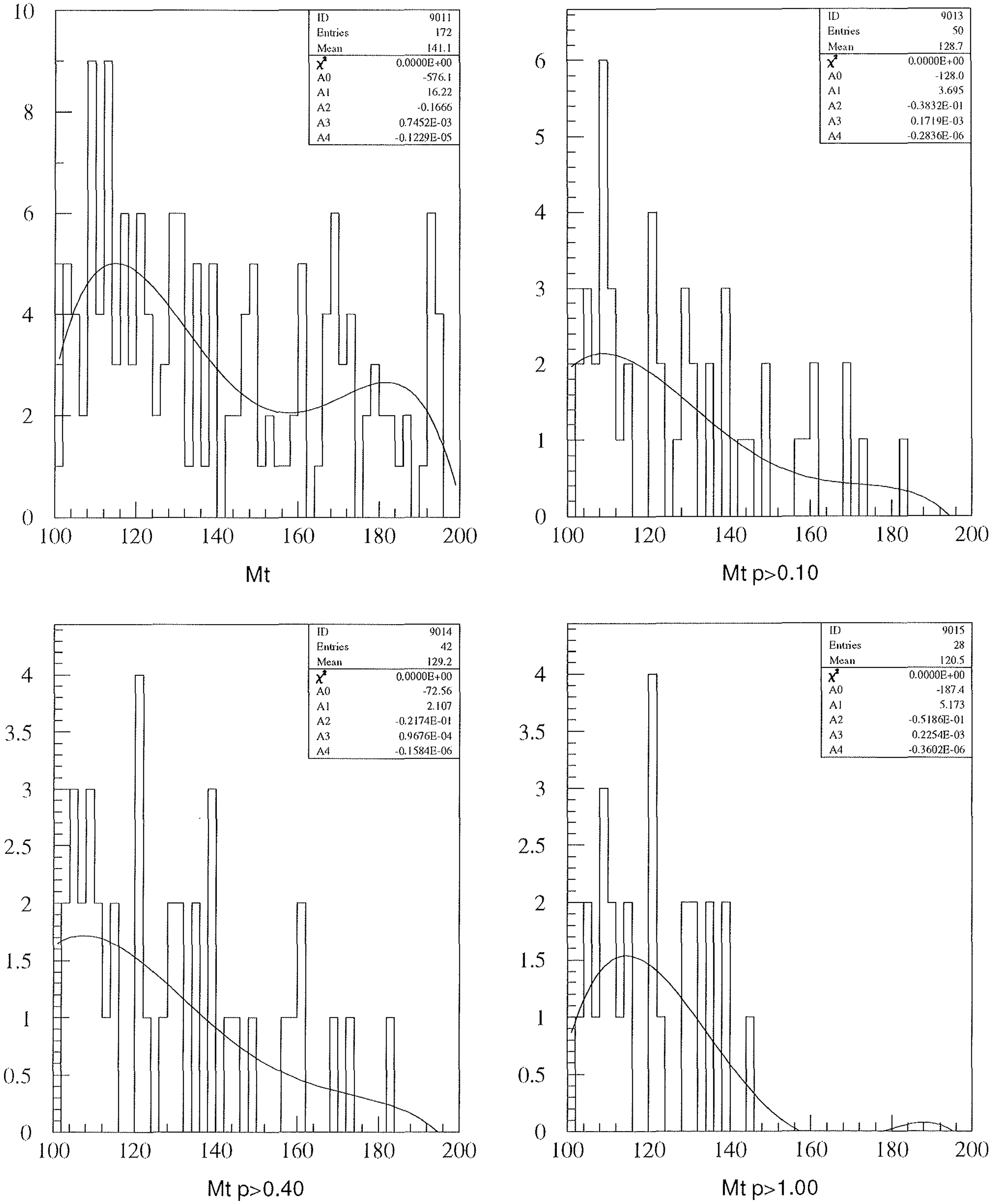
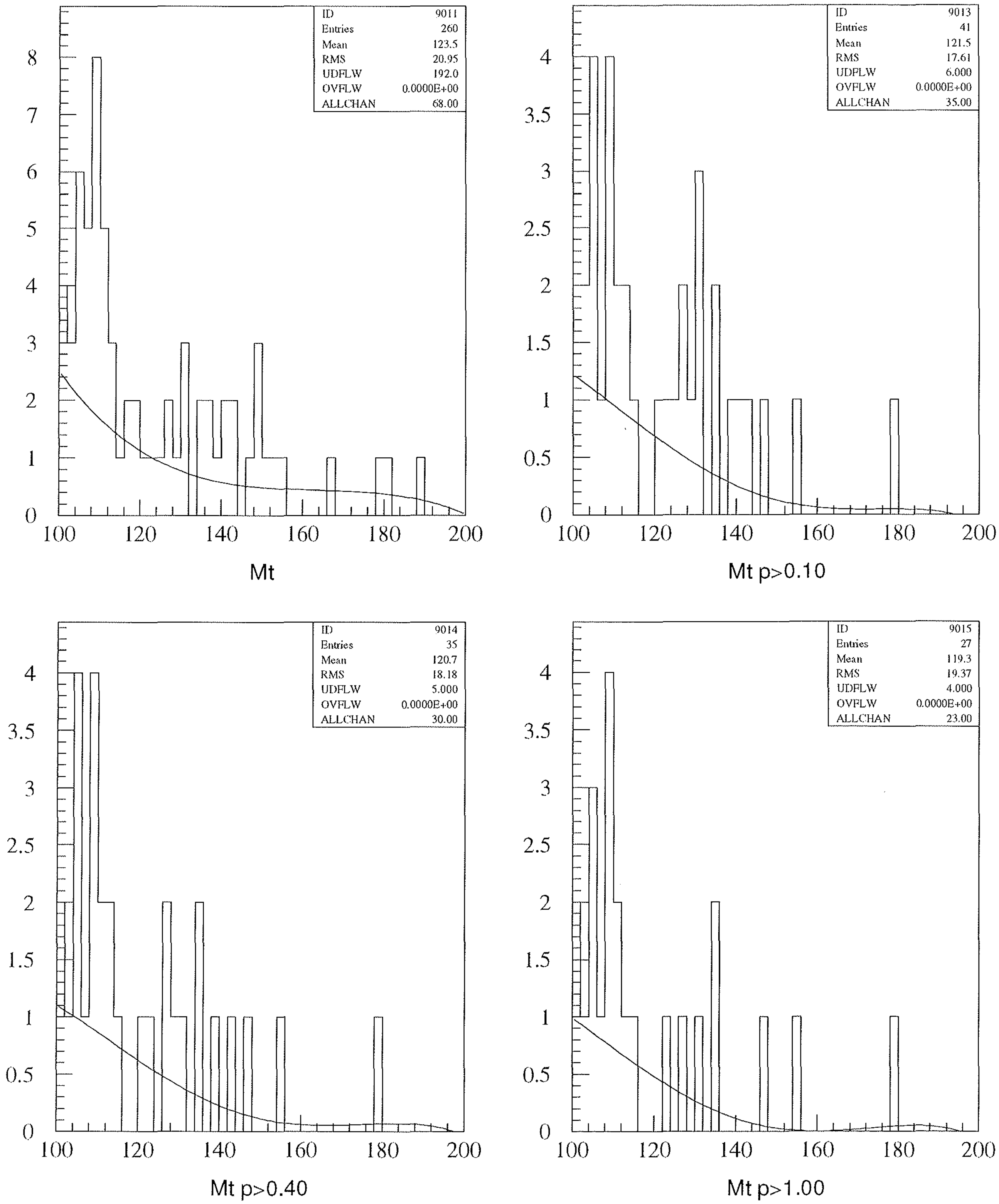
Figure 10D. 203 pb-1 VECBOS WE4PM_SQ/32015



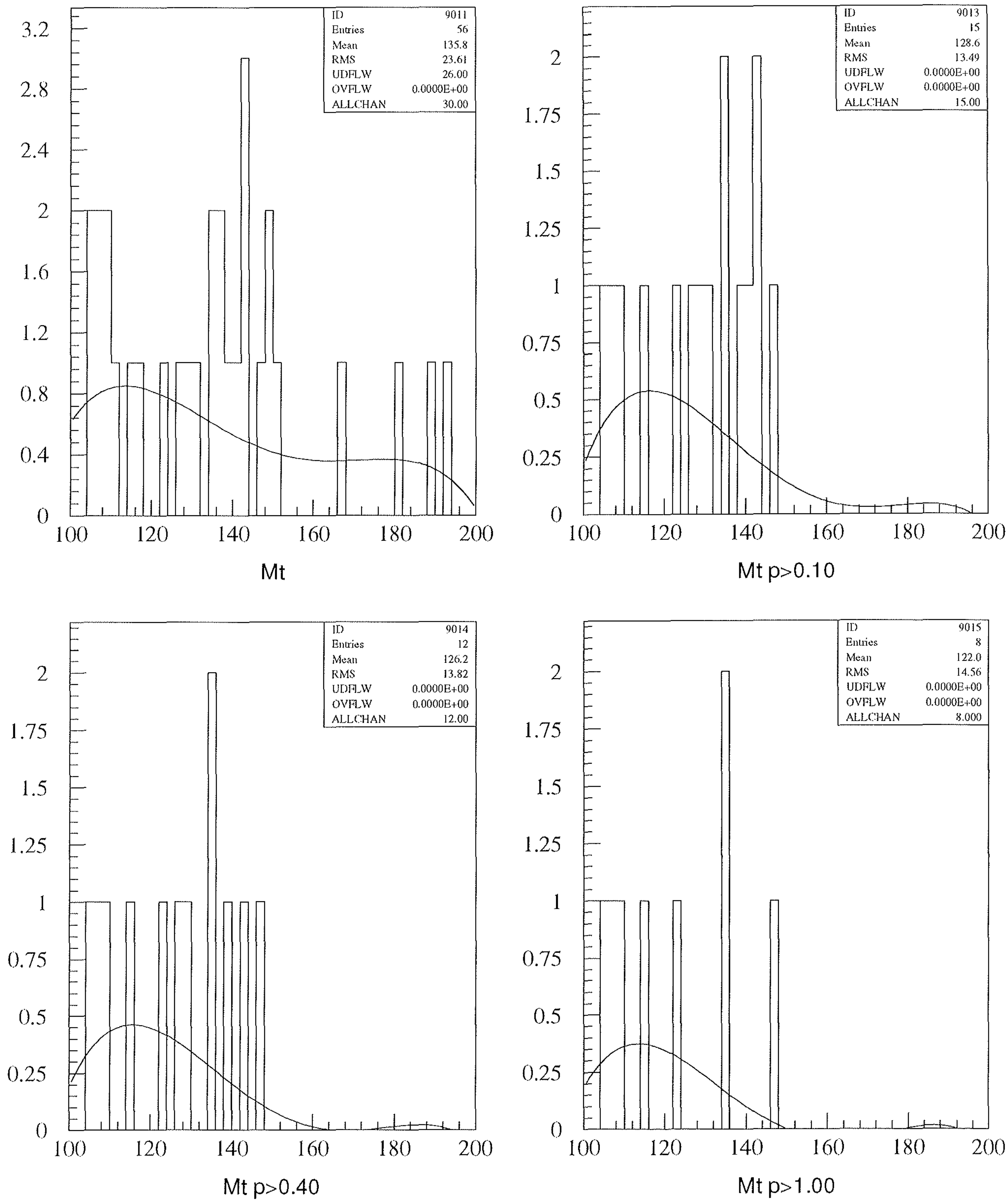
04/04/94 09.02

Figure 13A. 25 pb-1 ele/203.2 pb-1 we4pm_hq/3151025/g



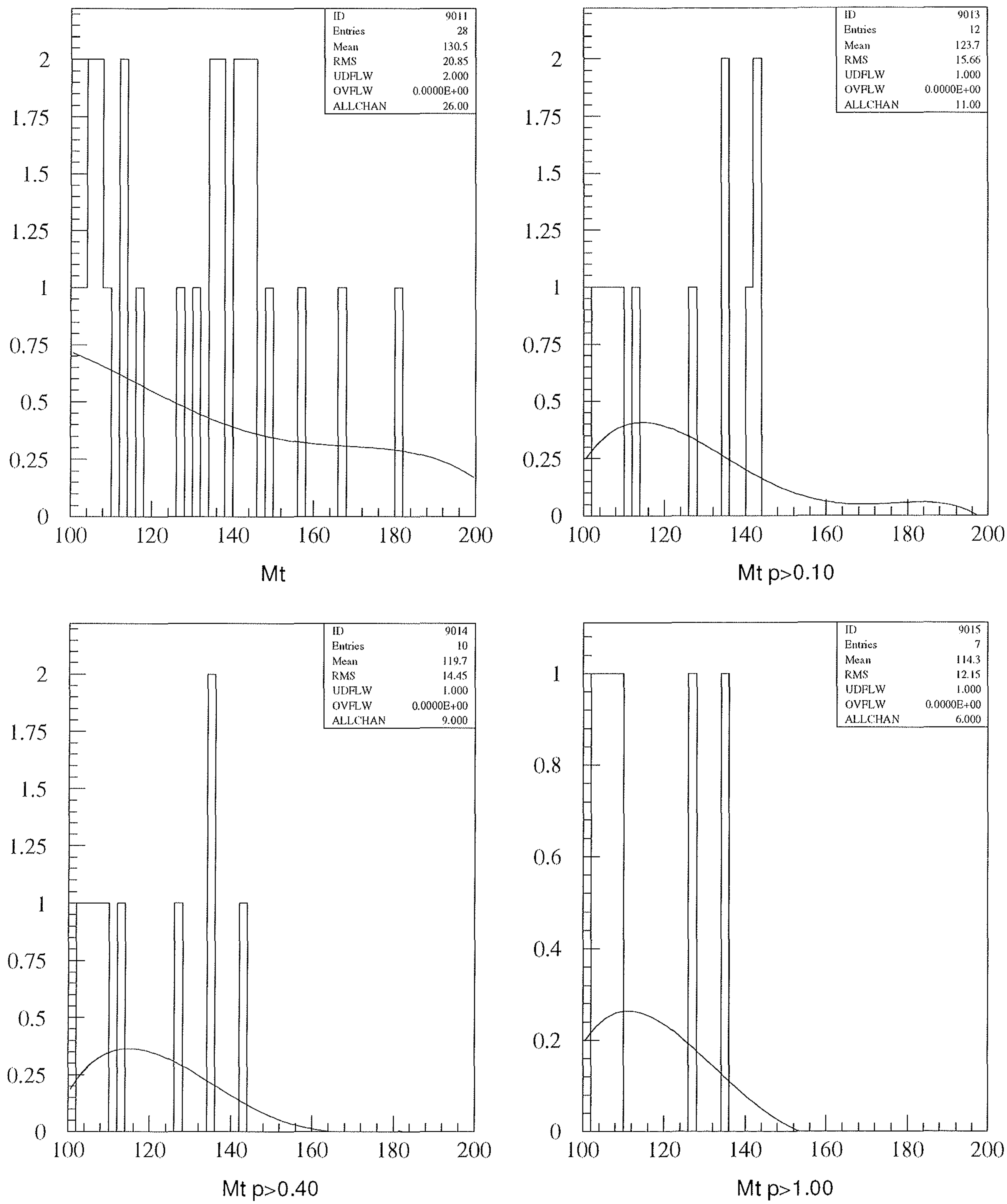
04/04/94 09.04

Figure 13B. 25 pb-1 ele/203.2 pb-1 we4pm_hq/3201025/g



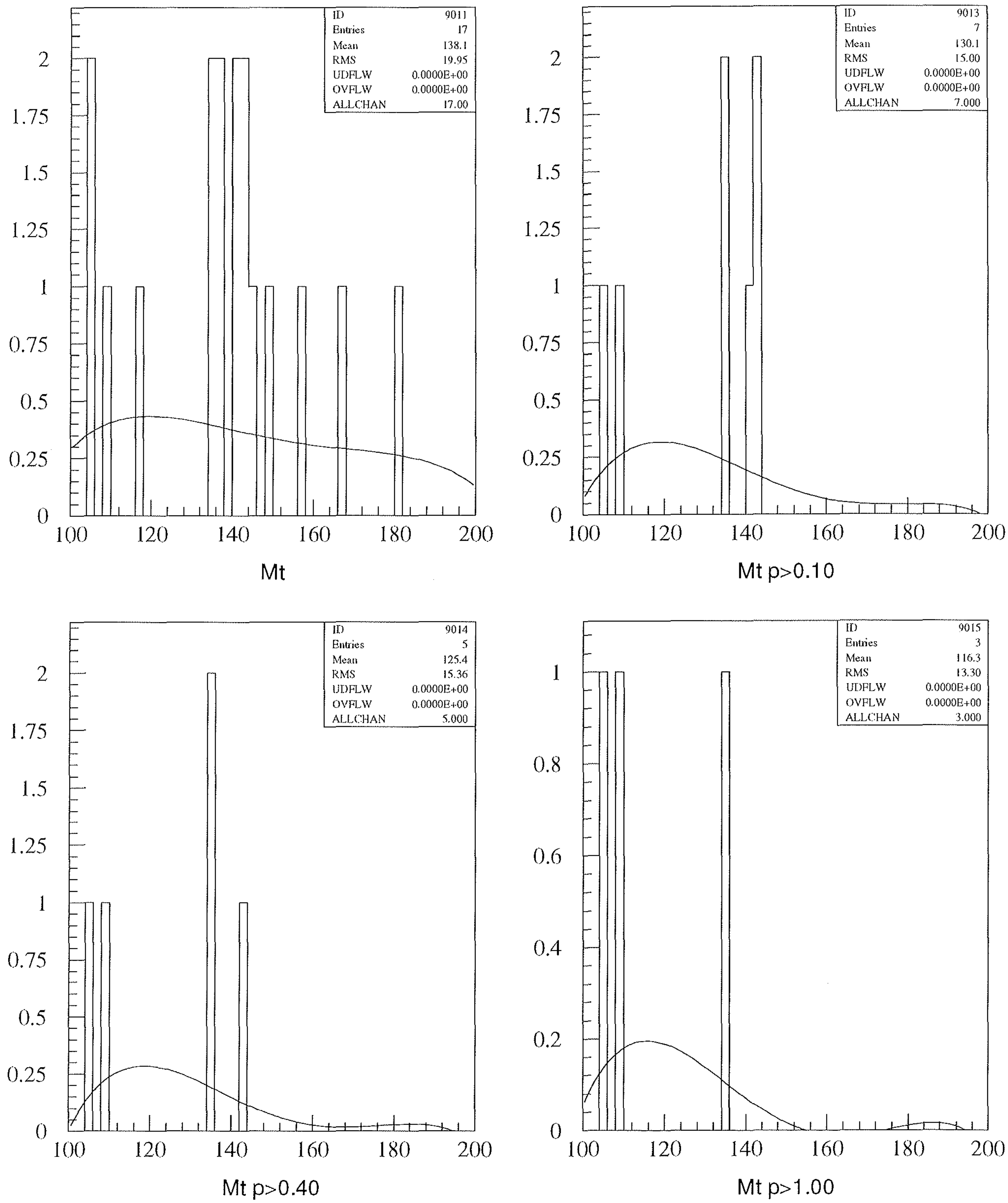
04/04/94 09.05

Figure 13C. 25 pb-1 ele/203.2 pb-1 we4pm_hq/3151525/g



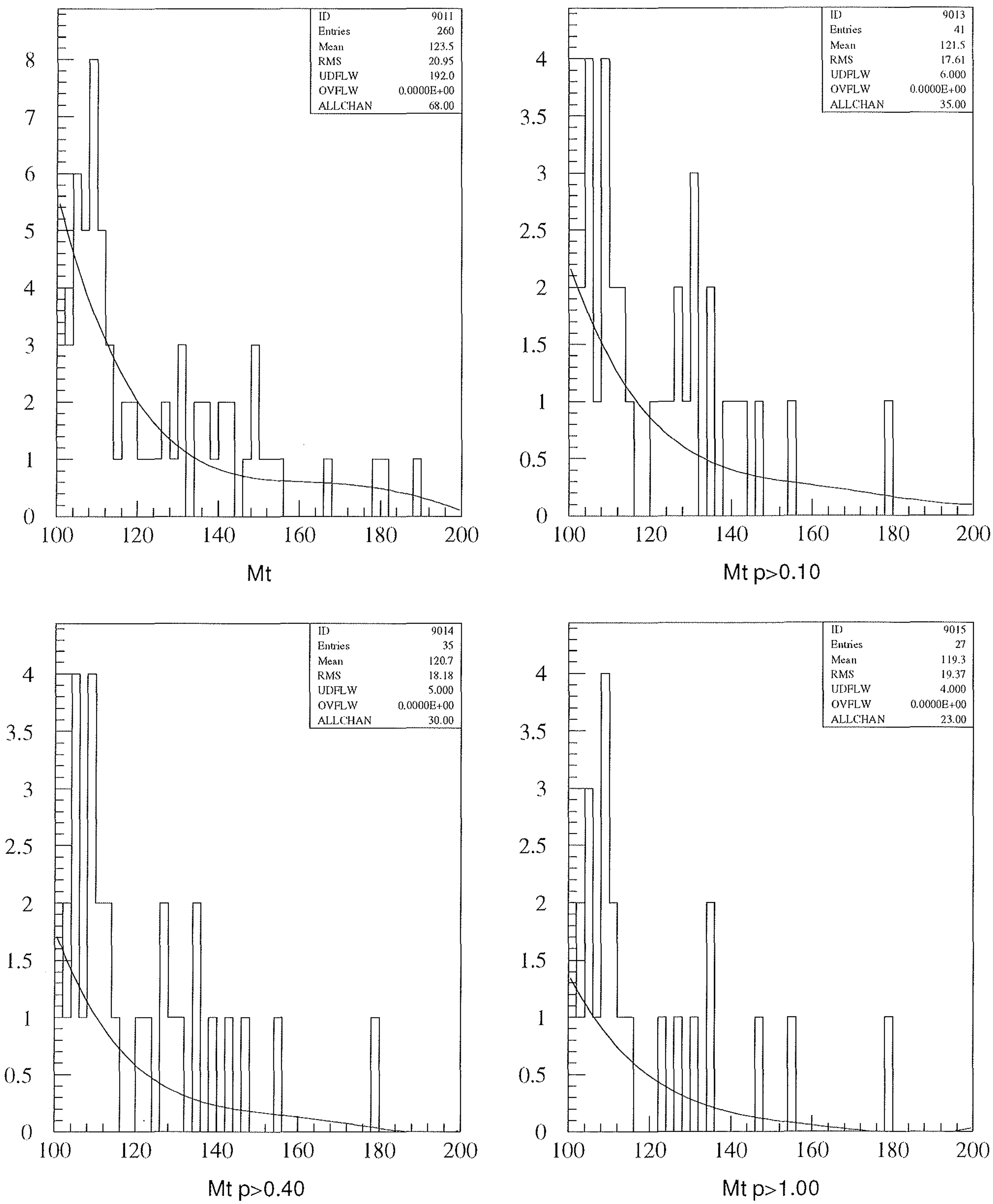
04/04/94 09.15

Figure 13D. 25 pb-1 ele/203.2 pb-1 we4pm_hq/3201525/g



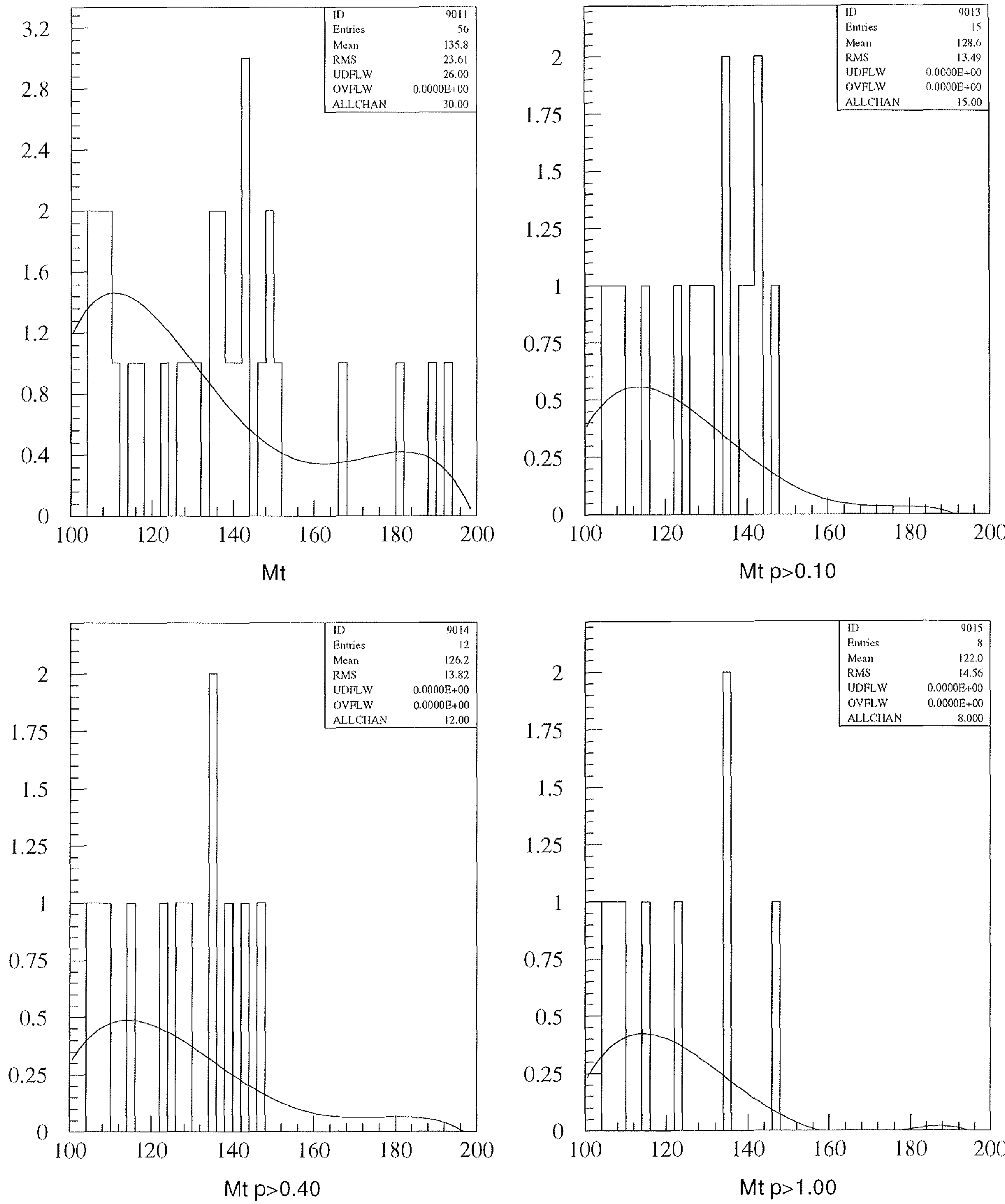
04/04/94 07.14

Figure 14A. 25 pb-1 ele/203.2 pb-1 we4pm_SQ/3151025/g



04/04/94 07.11

Figure 14B. 25 pb-1 ele/203.2 pb-1 we4pm_SQ/3201025/g



04/04/94 08.53

Figure 14C. 25 pb-1 ele/203.2 pb-1 we4pm_SQ/3151525/g

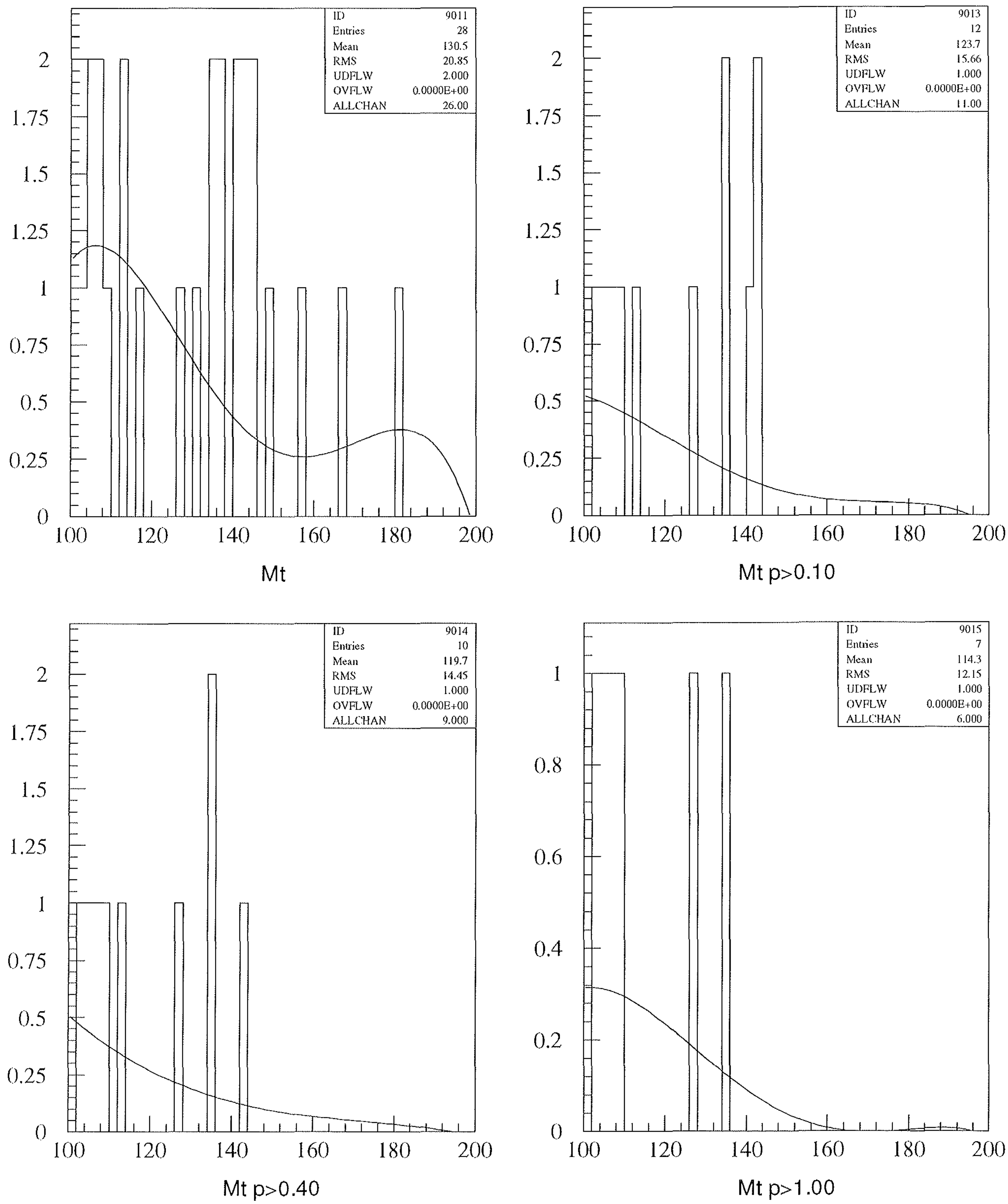


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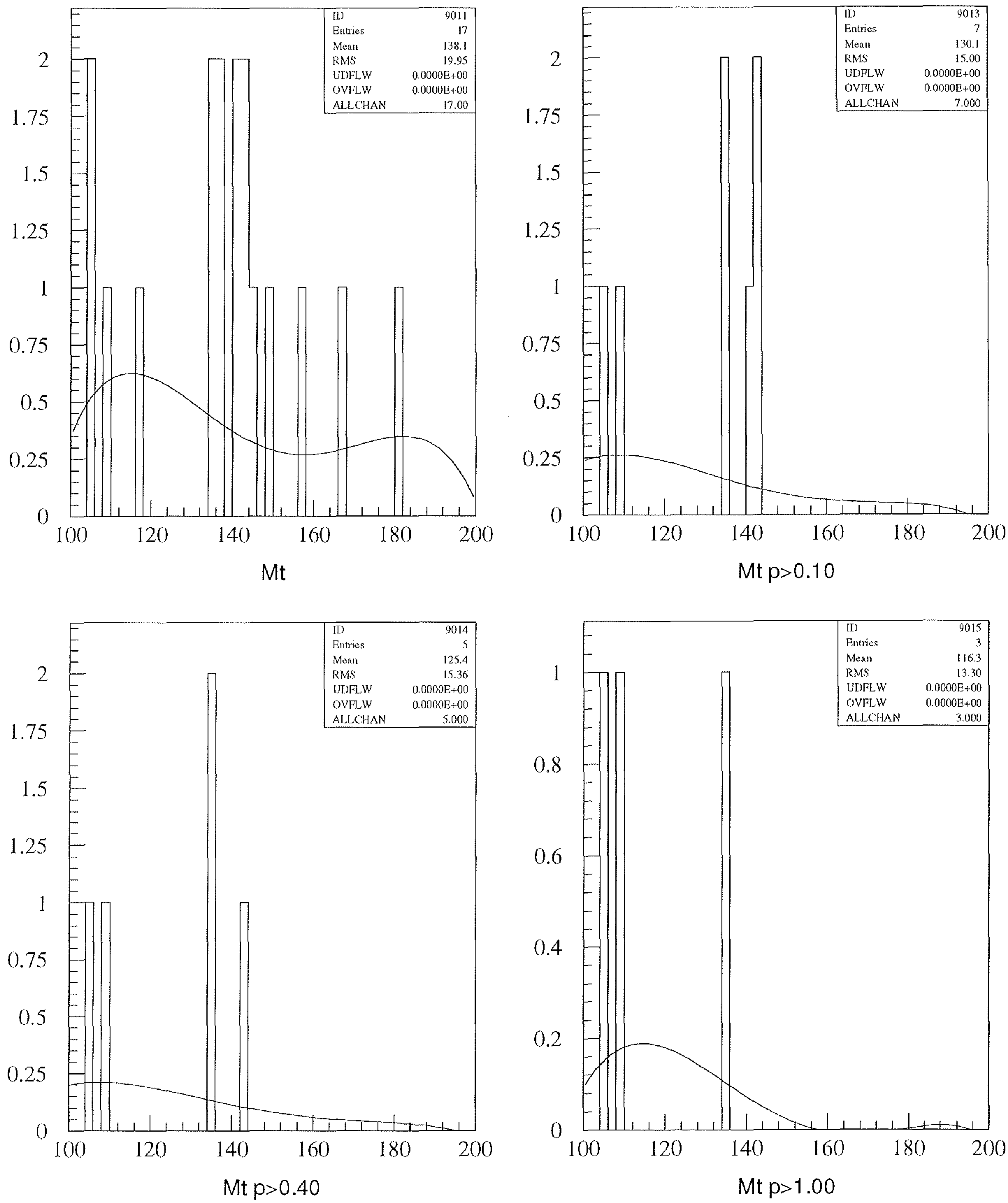
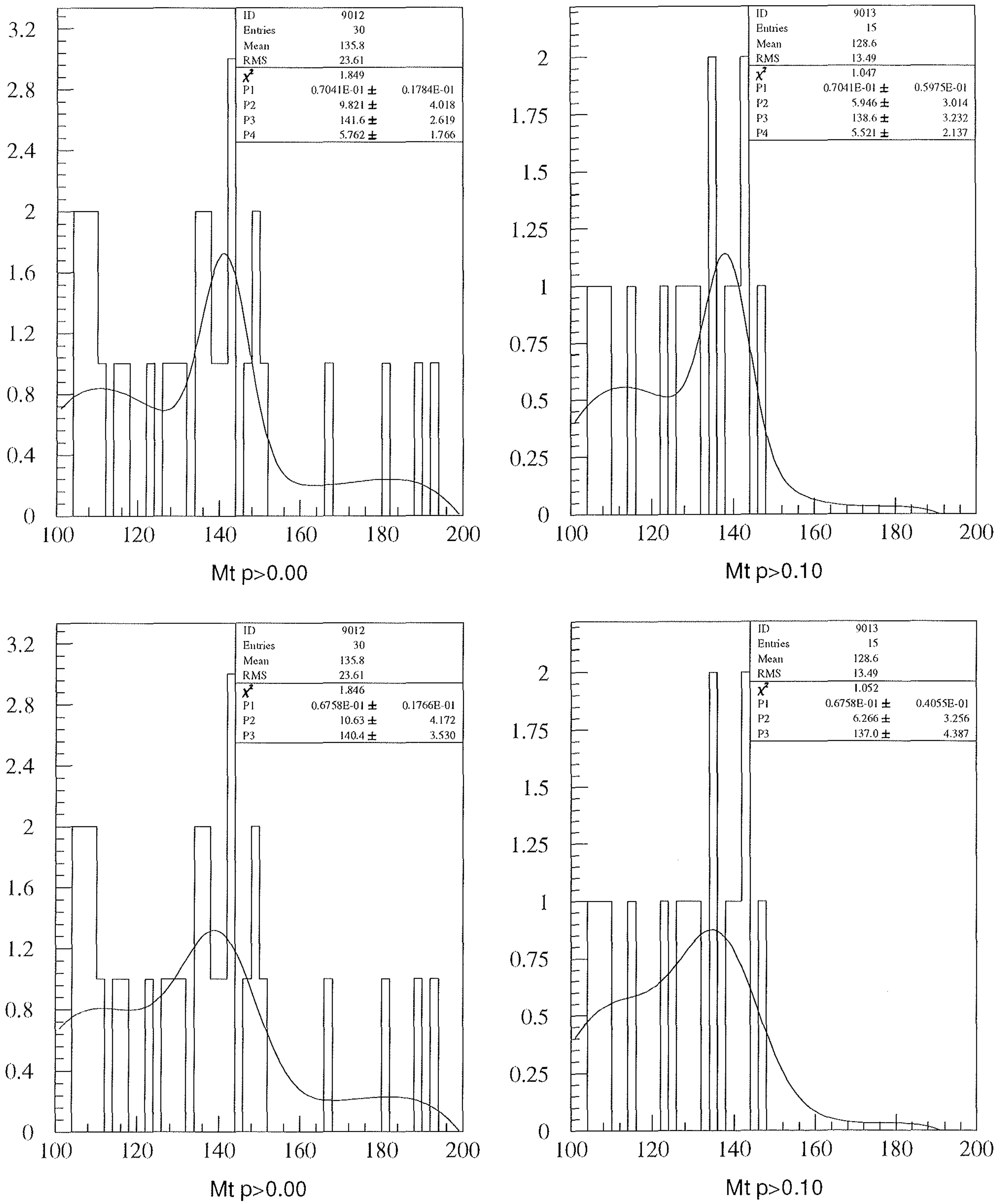
Figure 14D. 25 pb-1 ele/203.2 pb-1 we4pm_SQ/3201525/g



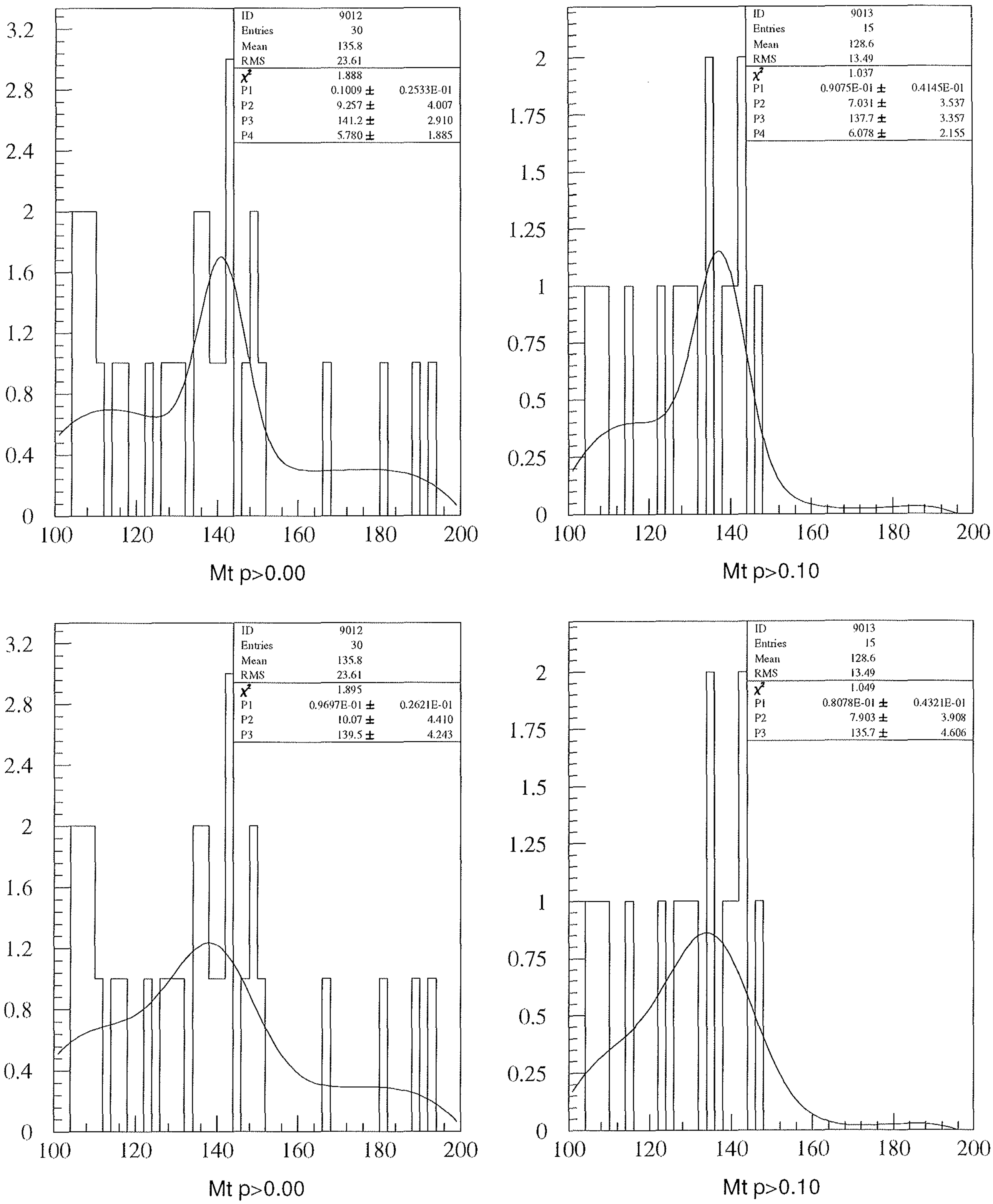
08/04/94 10.10

Figure 15. 25 pb-1 ele/ 203 pb-1 we4pm_hq/ 3201025



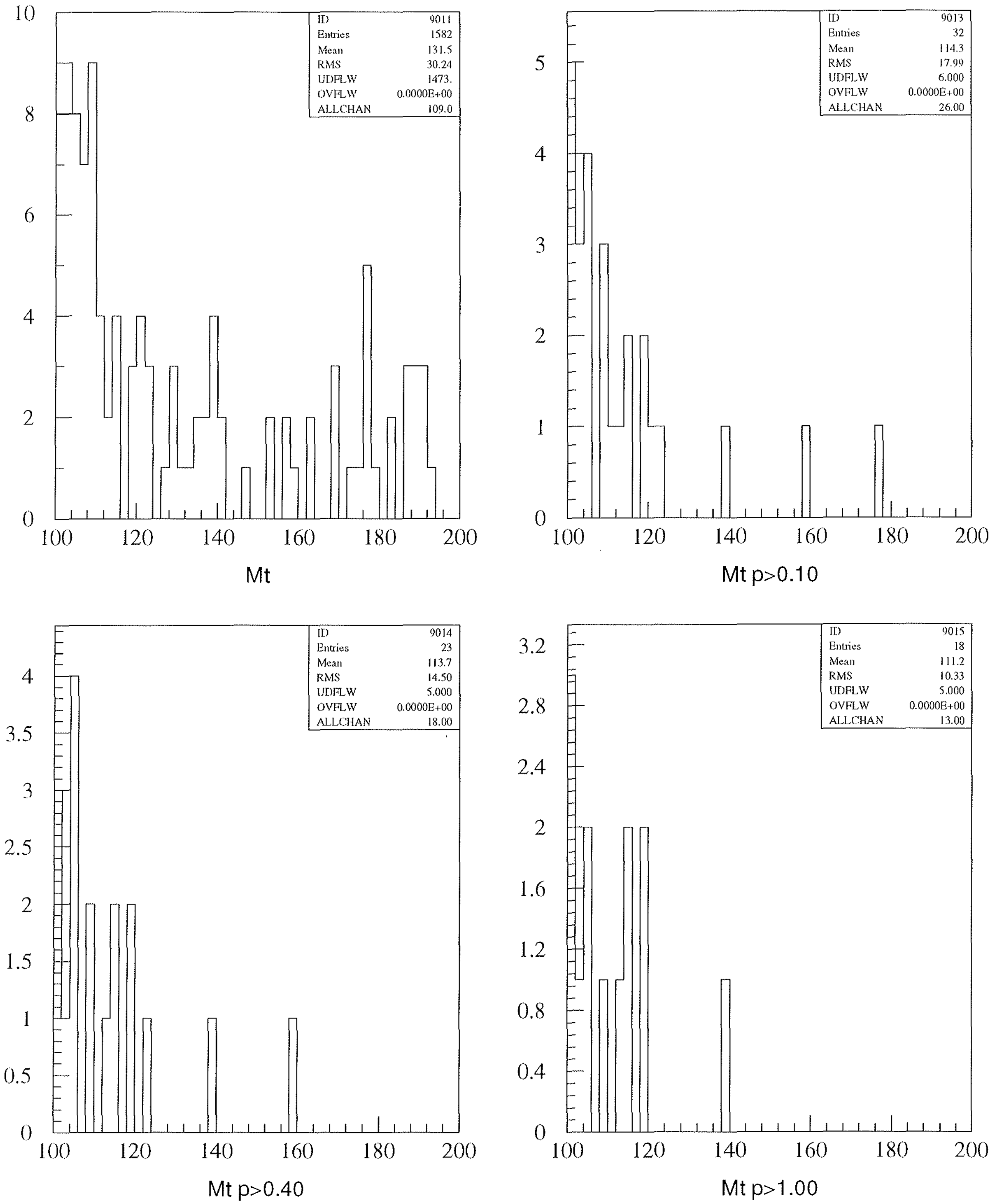
08/04/94 10.19

Figure 15B. 25 pb-1 ele/ 203 pb-1 we4pm_sq/ 3201025



08/04/94 10.04

Figure 16A. 24 pb-1 muon data/3151025



08/04/94 10.00

Figure 16B. 24 pb-1 muon data/3201025

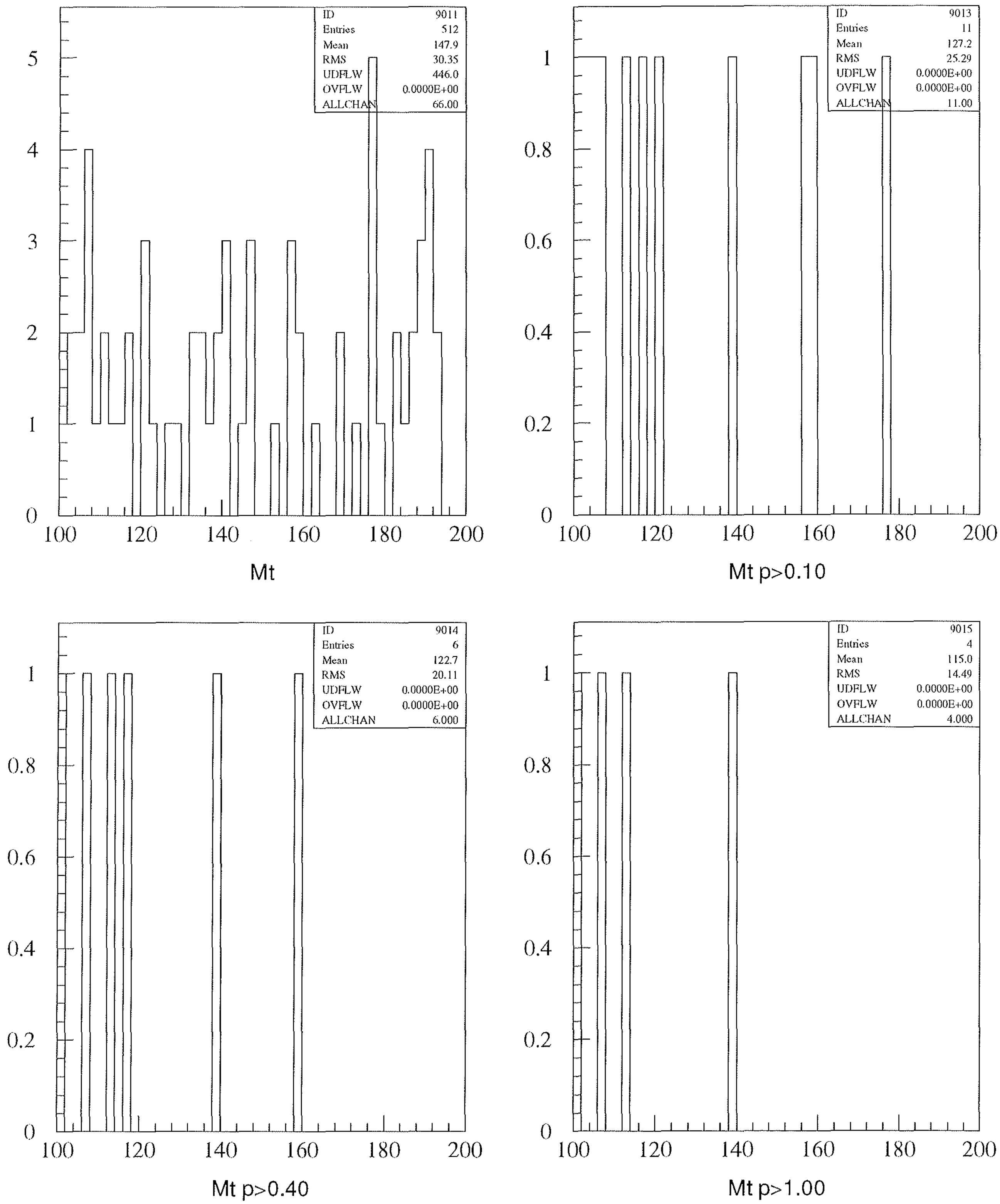
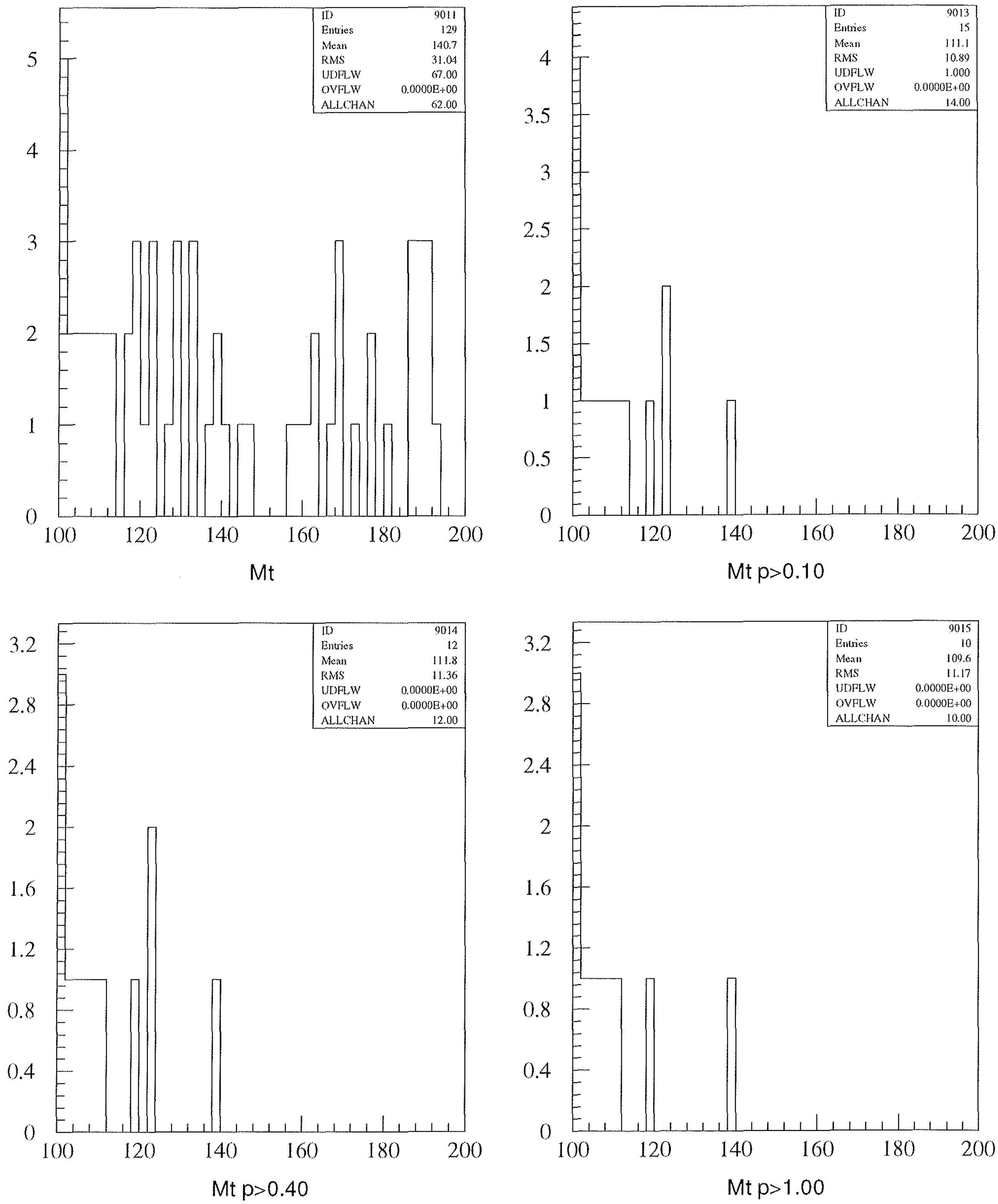
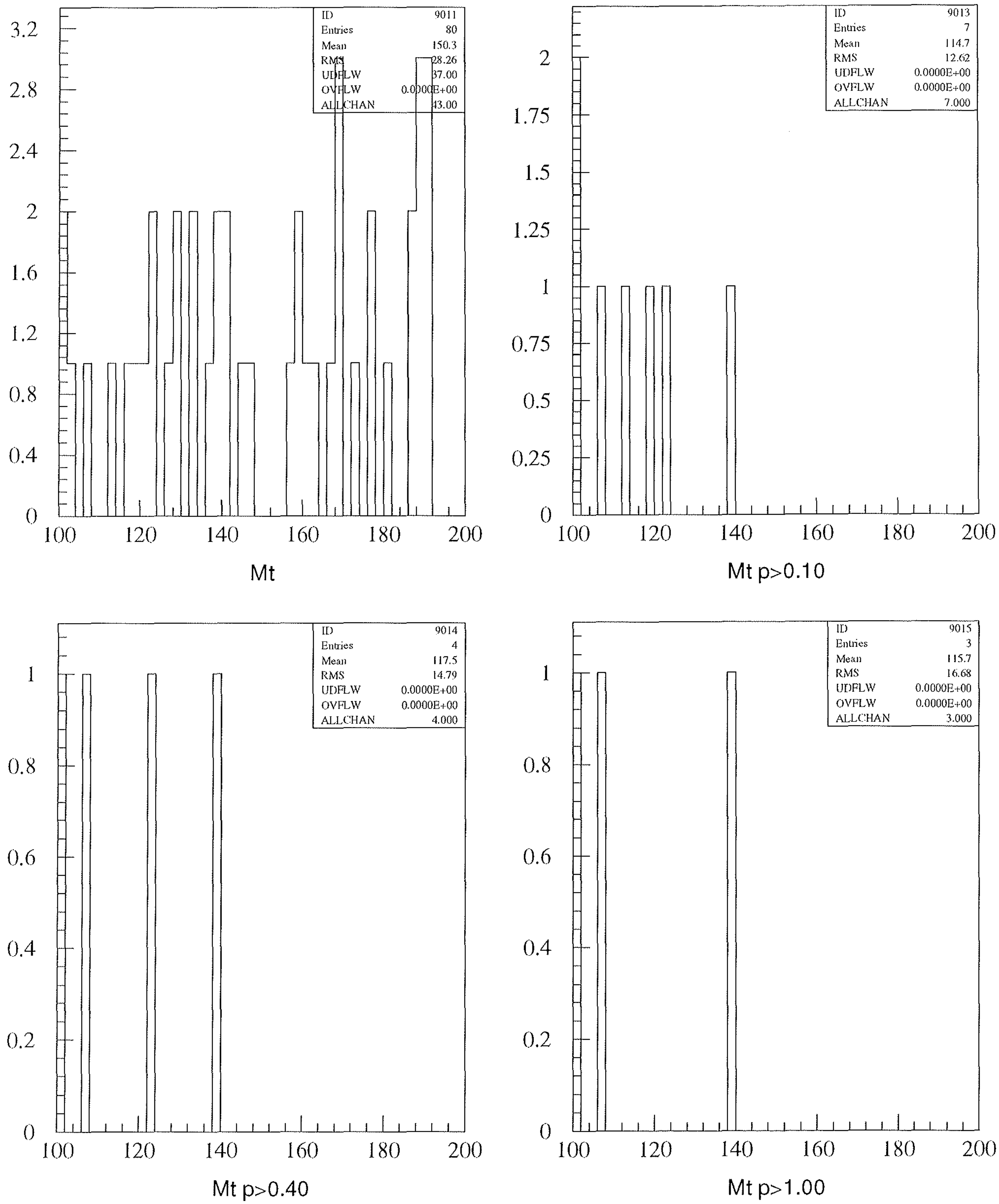


Figure 16C. 24 pb-1 muon data/3151525



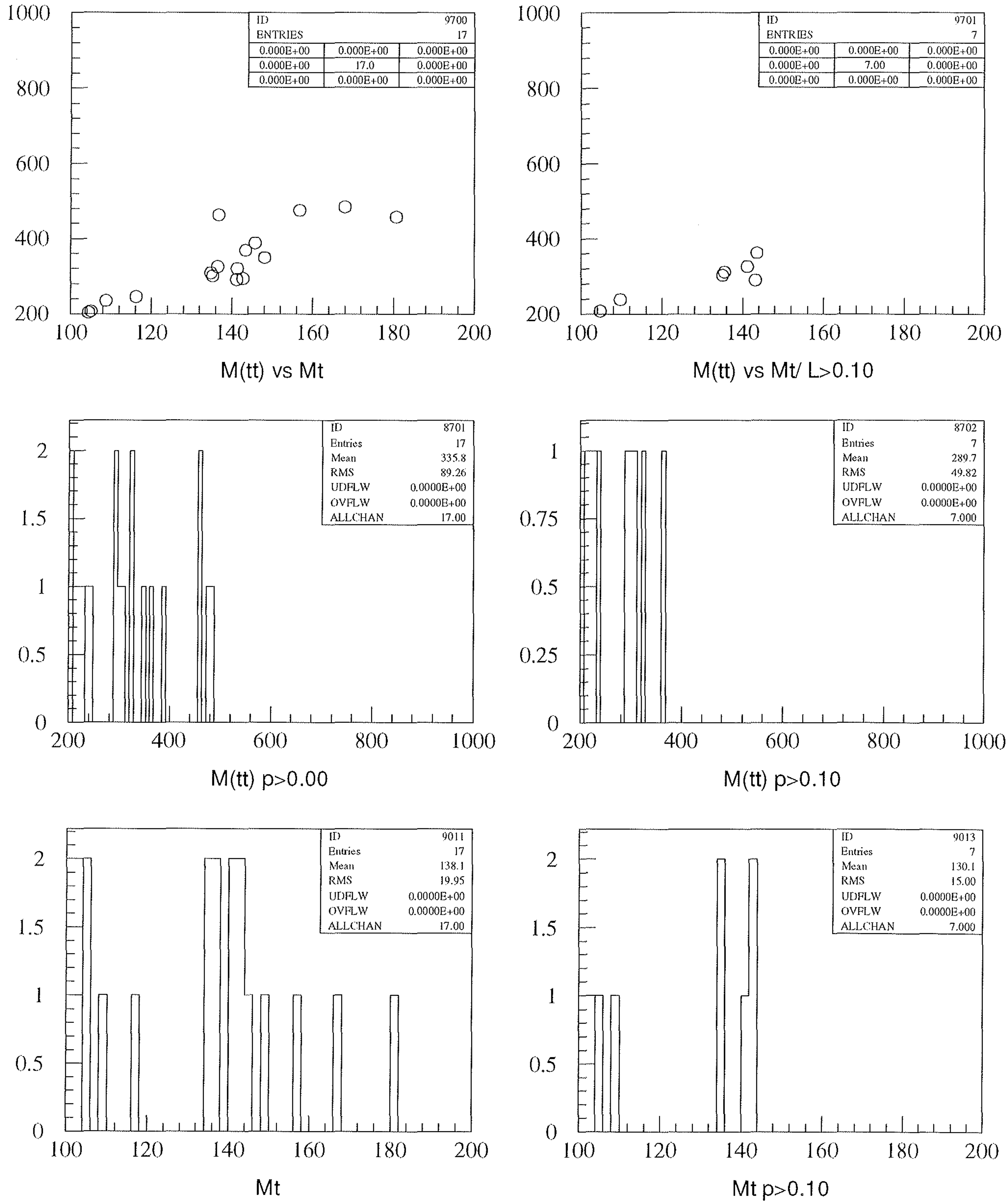
08/04/94 09.54

Figure 16D. 24 pb-1 muon data/3201525



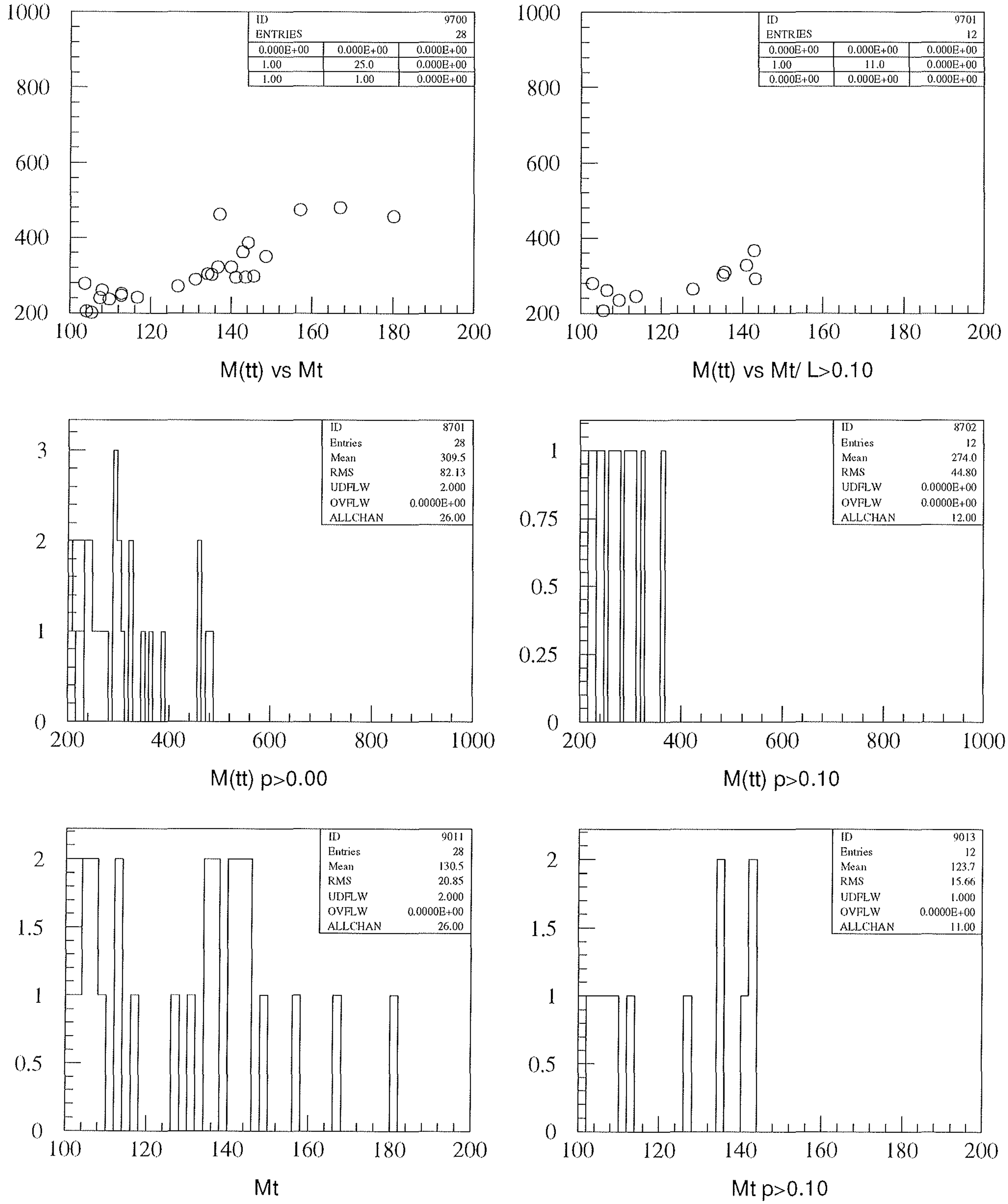
07/04/94 18.45

Figure 17A. M(tt) vs M(t)/projections/88+93 W->enu (32015)



07/04/94 18.48

Figure 17B. M(tt) vs M(t)/projections/88+93 W->enu (31515)



07/04/94 18.50

Figure 17C. M(tt) vs M(t)/projections/88+93 W->enu (32010)