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Comparison of primary vertex reconstruction algorithms

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1 Introduction

Any analysis which makes used of displaced vertices in $b\bar{b}$ events needs a good determination of the primary vertex. Primary vertex finding in $b\bar{b}$ events is more difficult than in *uds* events: tracks from secondary vertices might pull the primary vertex towards the b-vertex. Several algorithms exist in the ALEPH software to find the primary vertex, some are designed especially for b-events in order to avoid problems due to the presence of secondary vertices.
In this note a comparison of three packages is presented. We used the following variables:

- *resolution in x*: This coordinate is only partially constrained by the beam size. The primary vertex finder has to determine the vertex within this constraint of about 170 μm.
- *resolution in z*: This coordinate is not constrained by the beam size.
- *resolution along the sphericity axis*: This resolution projected on the sphericity axis is the variable most sensitive to the biases from secondary vertices. This quantity is important for the determination of decay lengths.

All vertex finders use GET_BP [1] to obtain the beam spot position and its error. GET_BP calculates the beam spot position once every $\sim$ 75 hadronic events.

2 YTOPOL primary vertex finding

The YTOPOL [2] [3] primary vertex finding fits a vertex using all tracks satisfying certain quality criteria and being compatible with coming from the beam spot. Nothing special is done to reject tracks from secondary vertices. For this study YTOPOL has been used with following options (set in the YOPT card):

- VHIT: demand vertex detector hits for the initial track selection. Each track selected must have at least one VDET r-ϕ or z hit.
- BCRO: the beam spot size is used to constrain the vertex position.

The momentum cut on tracks selected for the first iteration has been lowered from the default value of 1.0 GeV/c to 0.5 GeV/c. This ensures that YTOPOL is almost 100% efficient for events within the VDET acceptance.

3 QFNDIP primary vertex finding

QFNDIP [4] is a primary interaction point algorithm that combines track, beamspot, and jet direction information. The algorithm is motivated by the physics of $Z^0 \to b\bar{b}$ events, in that most of the high-momentum tracks originate outside the primary vertex. The algorithm is designed to use all tracks, regardless of their origin, to infer the true primary vertex.

QFNDIP was called using the beam spot position and size as given by GET_BP. The jets were created using the MMCL algorithm in the Alephlib, using ENFLW energy flow objects, with $YCUT$=.02, with the total energy set to twice the beam energy. Only jets with momentum above 10 GeV were given to the algorithm.

4 QVSPVX primary vertex finding

QVSPVX is the primary vertex finder of QVSRCH [5], which has been designed to find both the primary and the two secondary vertices in b-events. QVSPVX finds the primary vertex by calculating the points at which each track intercepts the plane defined by the y of the beam, and averaging those within 3σ of each other. It requires the beam position and size as input arguments, but does not require jet directions. The x and z coordinates of the primary vertex and their errors are output as arrays, with the y coordinate and error just copied from the y beam position and size. There is an additional input argument `TSMR`, which is taken as an error to be added in quadrature to the track fit errors when calculating the vertex. Since about half of the tracks in b quark events do not actually come from the primary vertex, the track errors do not fully represent the deviations of the tracks from the true primary vertex. Most of the results shown here were found with `TSMR`=.0100, corresponding to 100 microns of extra smearing. This value of `TSMR` makes the quoted vertex errors closer to being correct for b events, and has little effect on the total RMS of the distribution, but does degrade the core resolution. (The core is due to events where the decay length is so short that the smearing due to lifetime is negligible.) For uds events, the resolution is optimal with `TSMR`=0.

5 Performance comparison

Our comparison is made using $\sim$ 50K hadronic MC events generated using the most recent versions of GALEPH (with precise VDET material modeling) and JULIA (including the Kalman filter multiple scattering improvements). The events are selected so that $|\tan\lambda| < 1$ for the sphericity axis. The sphericity axis was calculated using the ALPHA algorithm, operating on energy flow objects. With this selection, all algorithms give an efficiency of 99.9%. Figures 1, 2 and 3, show the distance between the reconstructed and the true primary vertex, projected along the x direction. Figures 4, 5 and 6, show the residuals, projected along the sphericity axis. All algorithms give identical results for the y projection of the vertex difference, being determined almost exclusively from the beamspot. These results, also along the z-axis, are summarized in table 1.

Figures 7, 8, and 9, are the distance between the reconstructed and the true primary vertex, projected along the sphericity axis, divided by the estimation of the error on the vertex reconstruction, also projected along the sphericity axis, for $Z^0 \rightarrow u\bar{u}, d\bar{d}, s\bar{s}$ and $Z^0 \rightarrow b\bar{b}$ events. These results, along with the projections along the x and z axis, are summarized in table 2.

Figures 10, 11 and 12, show the difference between the reconstructed and true vertex, projected along the sphericity axis, for $Z^0 \rightarrow b\bar{b}$ events, as a function of the distance between the two secondary b verticies, also projected along the sphericity axis. This plot is then sensitive to any systematic bias in the reconstructed primary coming from the secondary vertices. For all algorithms, this bias is seen to be of the order of a few per mille, however the sign of the bias is different for different algorithms.

algorithm	events	rms x	rms z	rms sphericity
YTOPOL	uds	52	44	55
QFNDIP	uds	60	51	64
QVSPVX TSMR=.01	uds	56	49	57
QVSPVX TSMR=.00	uds	47	42	53
YTOPOL	bb	110	115	114
QFNDIP	$b\bar{b}$	82	75	85
QVSPVX TSMR=.01	$b\bar{b}$	84	91	92
QVSPVX TSMR=.00	$b\bar{b}$	88	92	99

Table 1: rms resolution of the primary vertex (in μm) for uds and $b\bar{b}$ events

6 Timing

The average computing time was calculated using the routine TIMED. All comparisons were done on the IBM. YTOPOL needs 0.0179 sec per event, QFNDIP 0.0017 sec and QVSPVX 0.0059 sec. These are native IBM times.

algorithm	events	x	z	sphericity
YTOPOL	*uds*	0.83	0.79	0.87
QFNDIP	*uds*	1.12	1.10	1.09
QVSPVX TSMR = .01	*uds*	0.75	0.67	0.90
QVSPVX TSMR = .00	*uds*	1.24	1.09	1.52
YTOPOL	$b\bar{b}$	1.63	1.68	1.67
QFNDIP	$b\bar{b}$	1.33	1.34	1.24
QVSPVX TSMR = .01	$b\bar{b}$	1.20	1.25	1.25
QVSPVX TSMR = .00	$b\bar{b}$	2.01	1.93	2.13

Table 2: rms of residuals divided by estimated error of the primary vertex for *uds* and $b\bar{b}$ events

7 Conclusions

All algorithms give about the same rms resolution in *uds* events, although YTOPOL and QVSPVX with TSMR=0 performs slightly better . Not surprisingly all the routines have worse resolution in $b\bar{b}$ events. YTOPOL suffers most, having a rms about a factor of two larger than for *uds* events. QFNDIP and QVSPVX have a similar performance with only about 25% loss in resolution compared with *uds*. QFNDIP show the most uniform distributions of the normalized residuals. QFNDIP is the fastest routine assuming that jet clustering has already been performed.

References

[1] D. Brown, George Redlinger: *1991 Beam Spot and Beam Envelope Measurement* ALEPH 92-008, PHYSIC 92-008

[2] M. Fernandez-Bosman, J. Lauber, G. Lutz and W. Maenner: ALEPH 91-132, SOFTWR 91-005

[3] G. Lutz: *Topological Vertex Search in Collider Experiments* MPI-PhE/92-09

[4] D. Brown: *QFNDIP, a primary vertex finder* ALEPH 92-47, PHYSIC 92-42

[5] T. Mattison: *QVSRCH* ALEPH note in preparation

Figure Captions

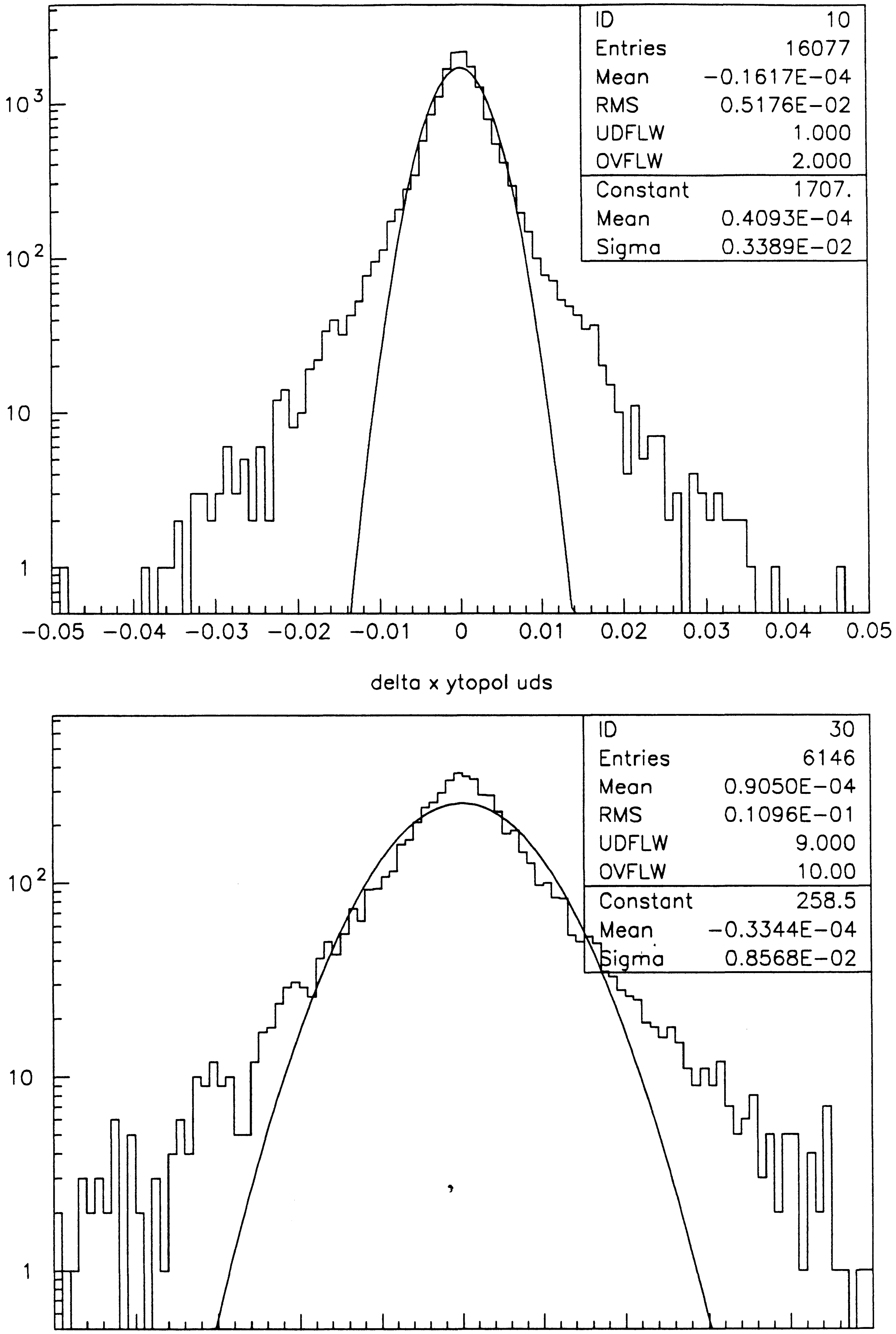


Figure 1: YTOPOL: a) difference of reconstructed and true primary vertex projected on the x axis for *uds* events b) like a) but for $b\bar{b}$ events

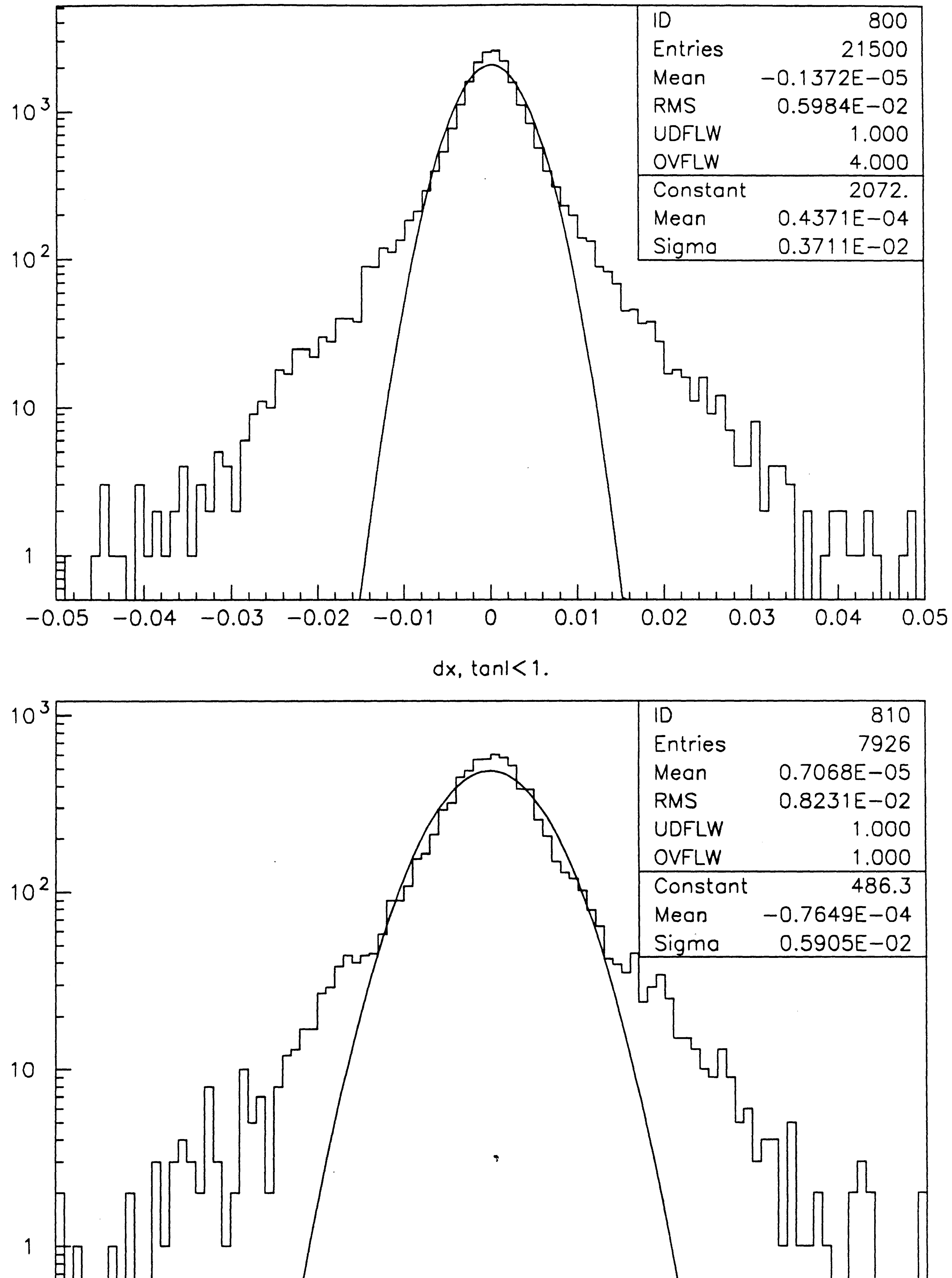


Figure 2: QFNDIP: a) difference of reconstructed and true primary vertex projected on the x axis for *uds* events b) like a) but for $b\bar{b}$ events

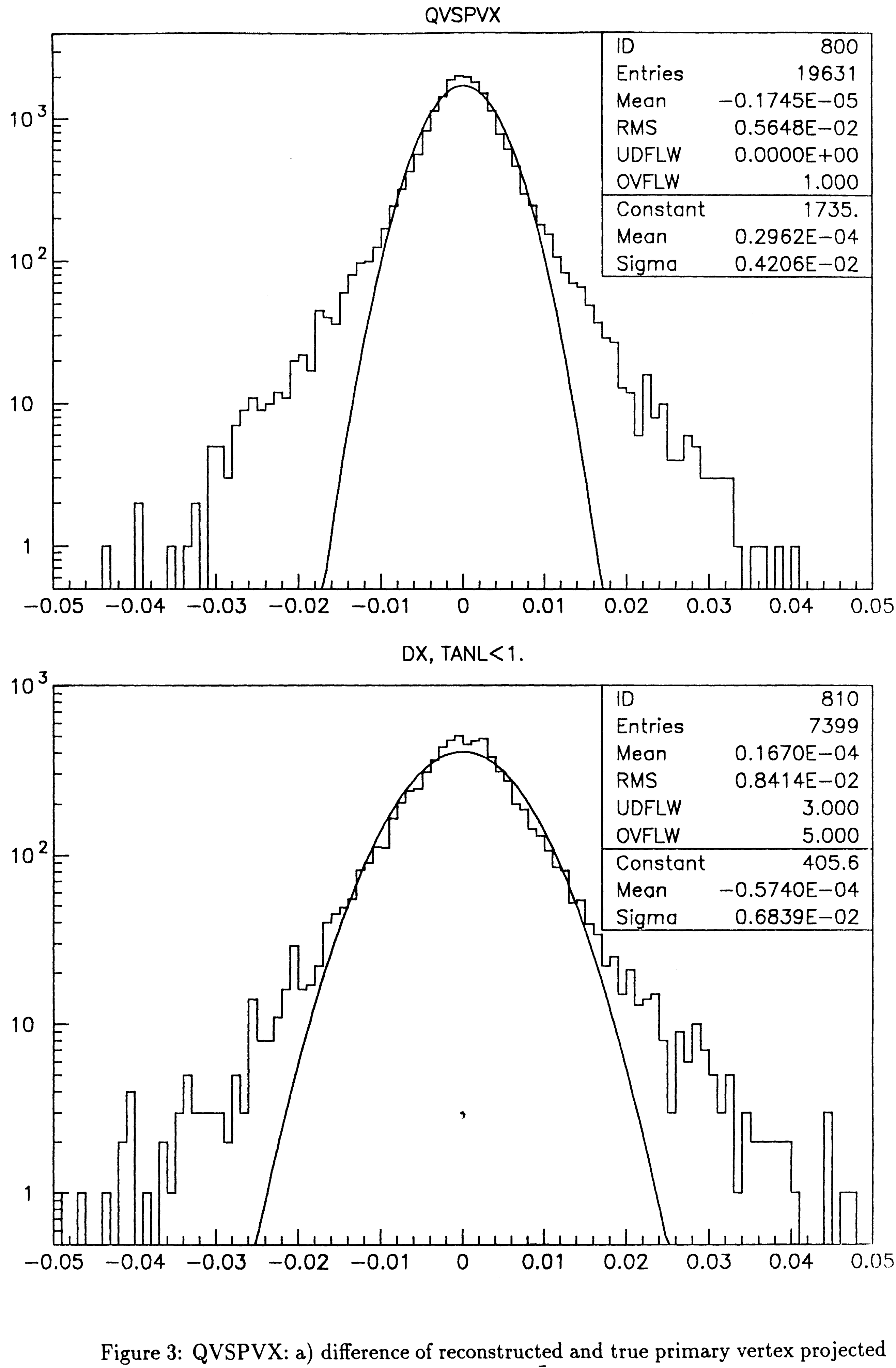


Figure 3: QVSPVX: a) difference of reconstructed and true primary vertex projected on the x axis for *uds* events b) like a) but for $b\bar{b}$ events

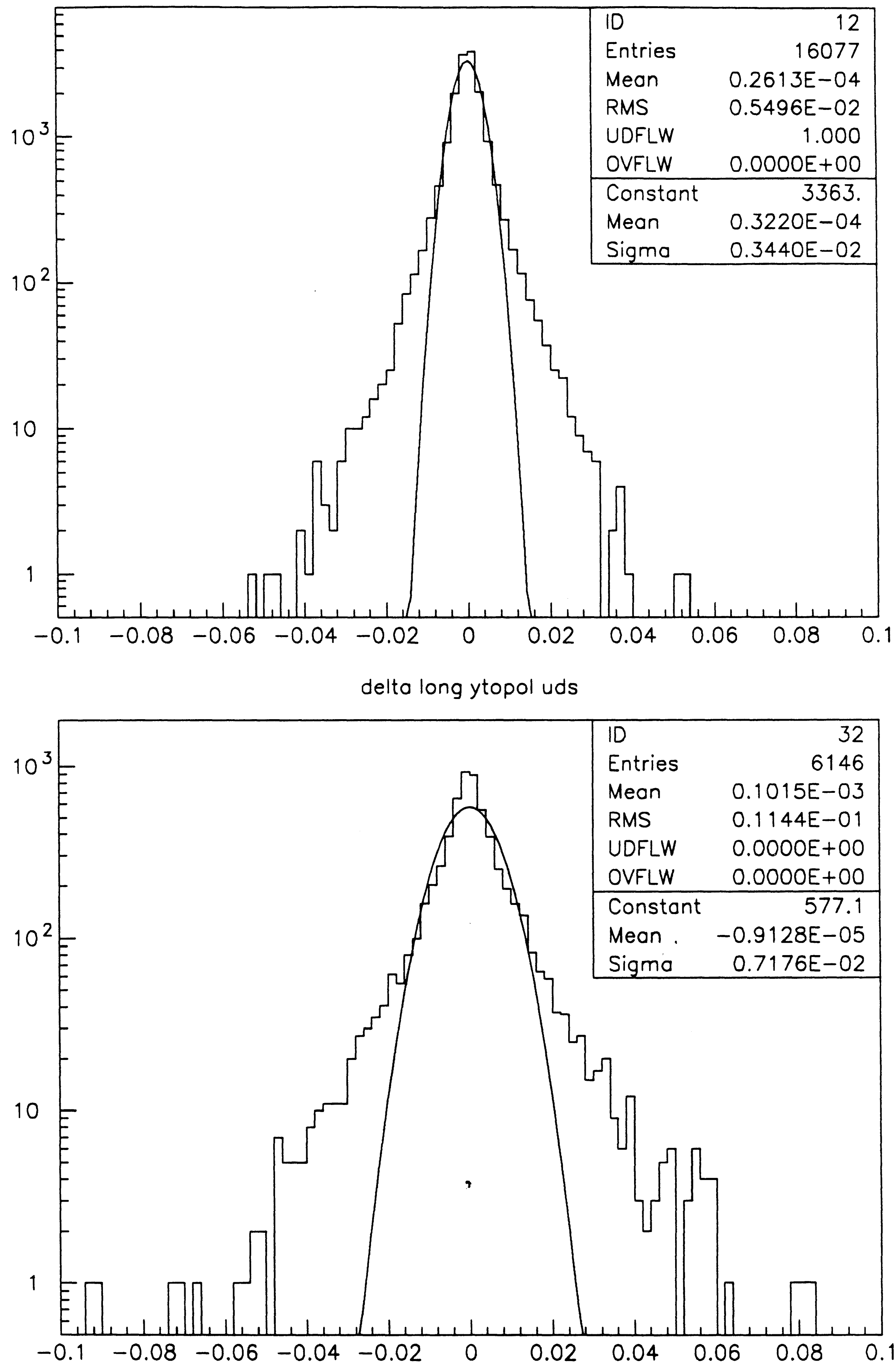


Figure 4: YTOPOL: a) difference of reconstructed and true primary vertex projected on the sphericity axis for *uds* events b) like a) but for $b\bar{b}$ events

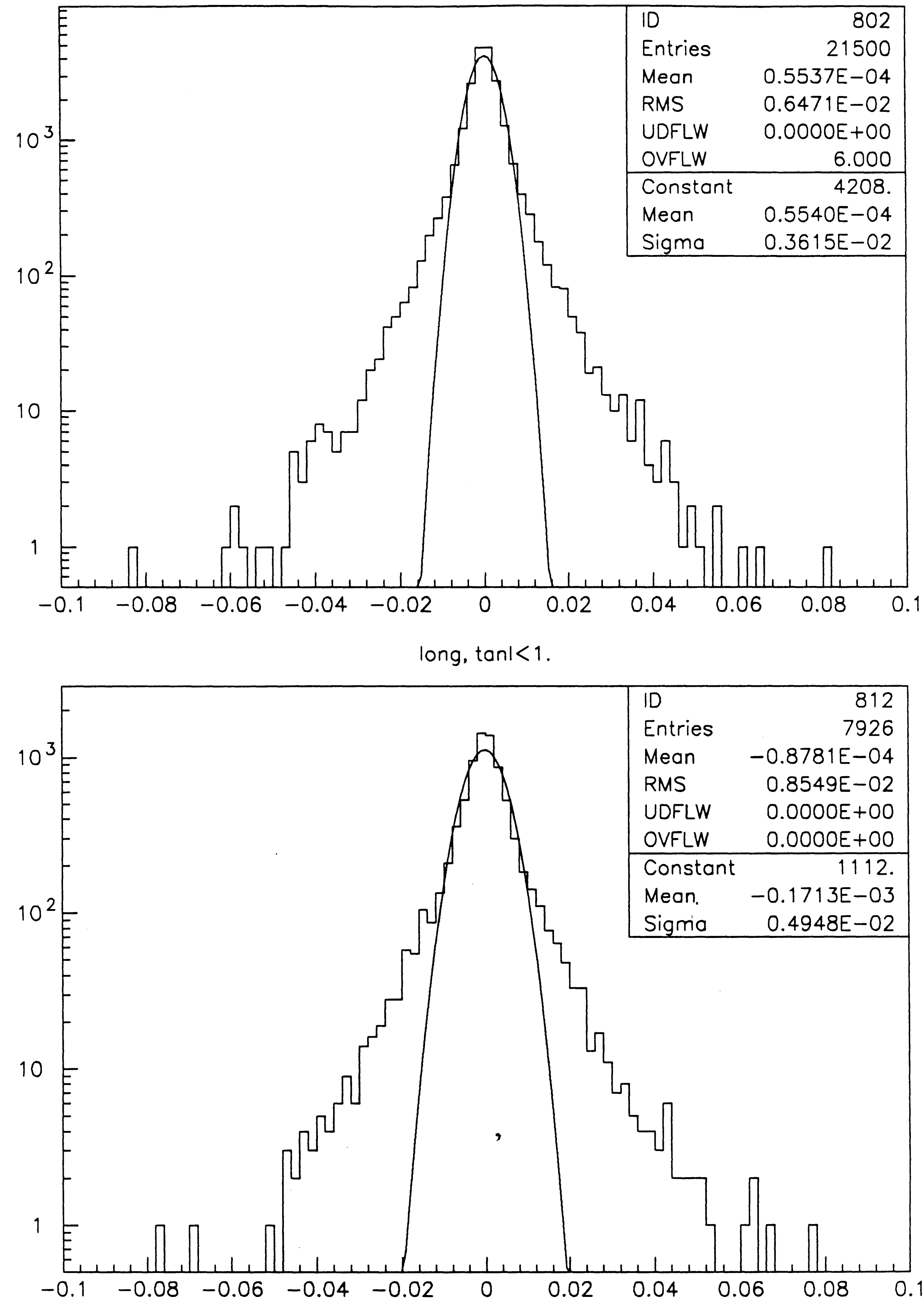


Figure 5: QFNDIP: a) difference of reconstructed and true primary vertex projected on the sphericity axis for *uds* events b) like a) but for $b\bar{b}$ events

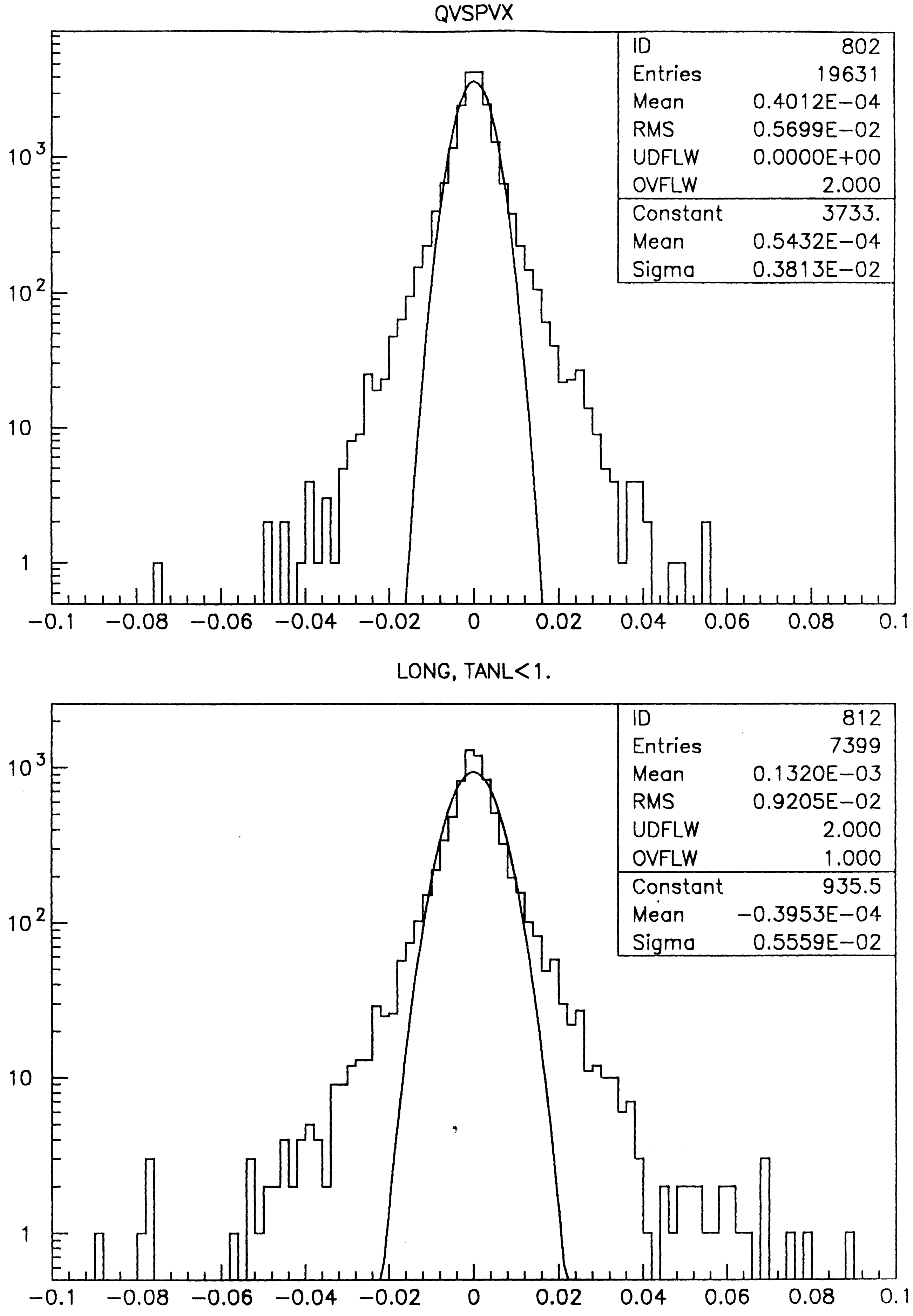


Figure 6: QVSPVX: a) difference of reconstructed and true primary vertex projected on the sphericity axis for *uds* events b) like a) but for $b\bar{b}$ events

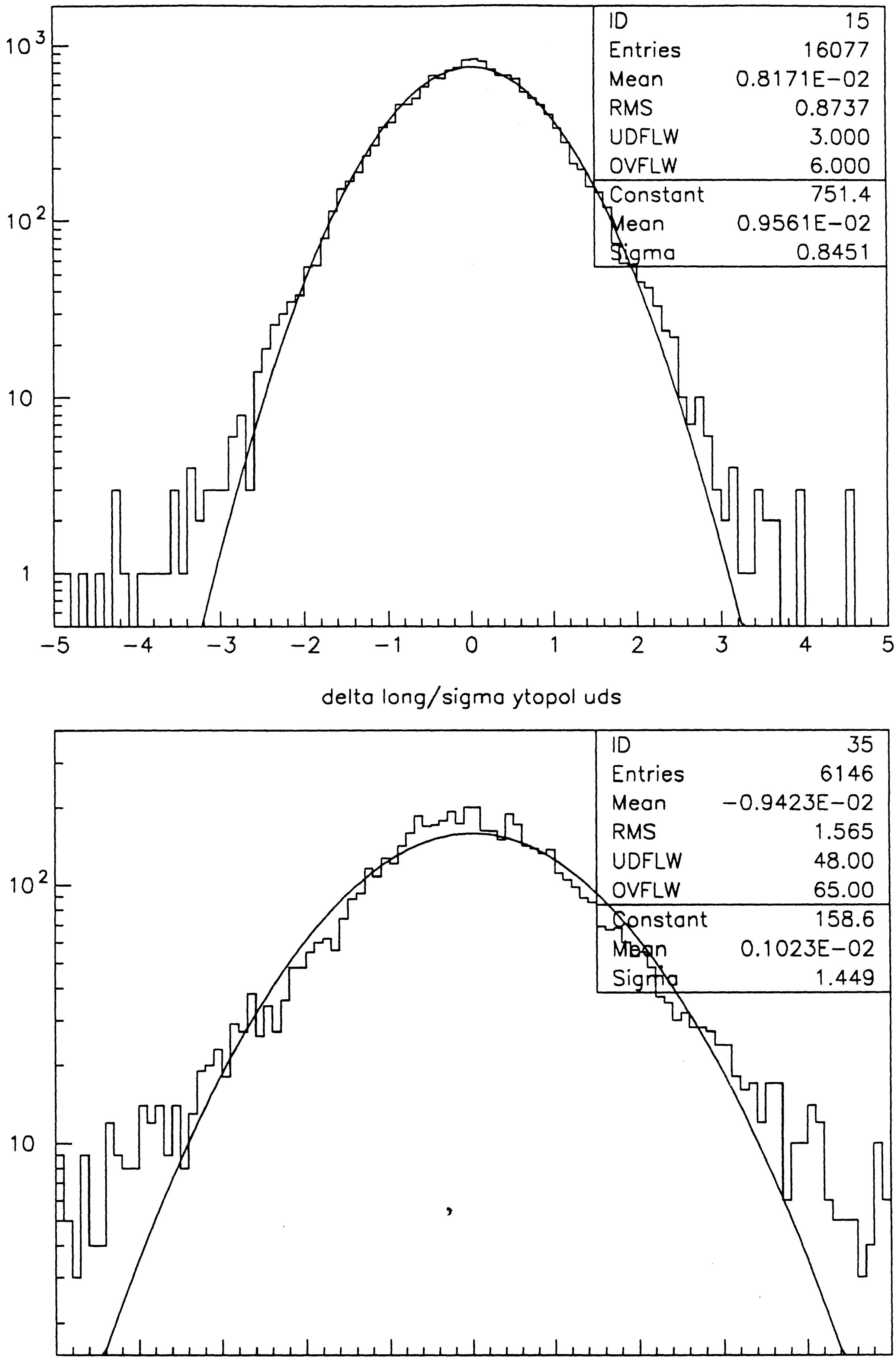


Figure 7: YTOPOL: a) difference of reconstructed and true primary vertex projected on the sphericity axis for divided by the estimated error also projected on the sphericity axis, for *uds* events, b) like a) but for $b\bar{b}$ events

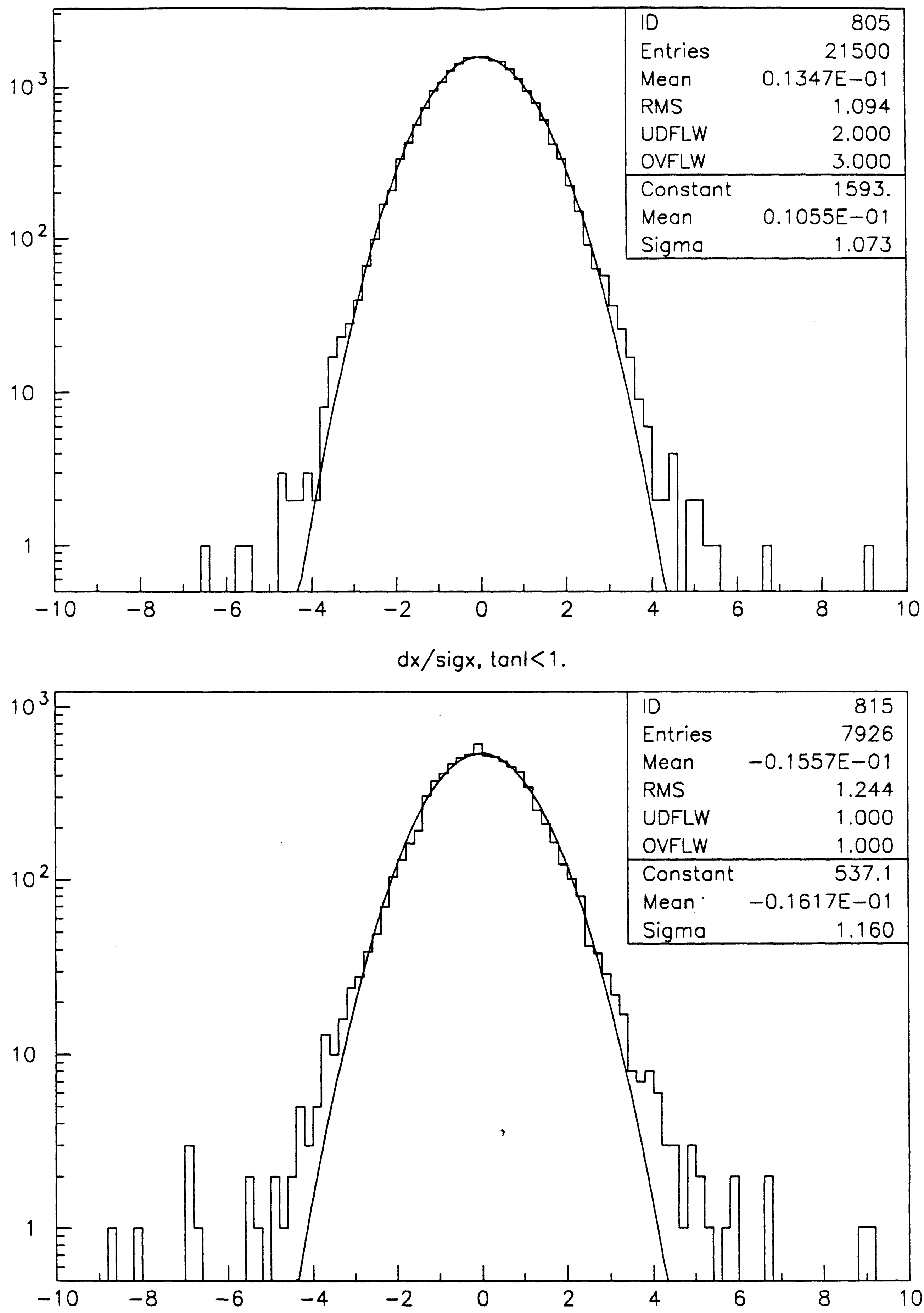


Figure 8: QFNDIP: a) difference of reconstructed and true primary vertex projected on the sphericity axis for divided by the estimated error also projected on the sphericity axis, for *uds* events, b) like a) but for $b\bar{b}$ events

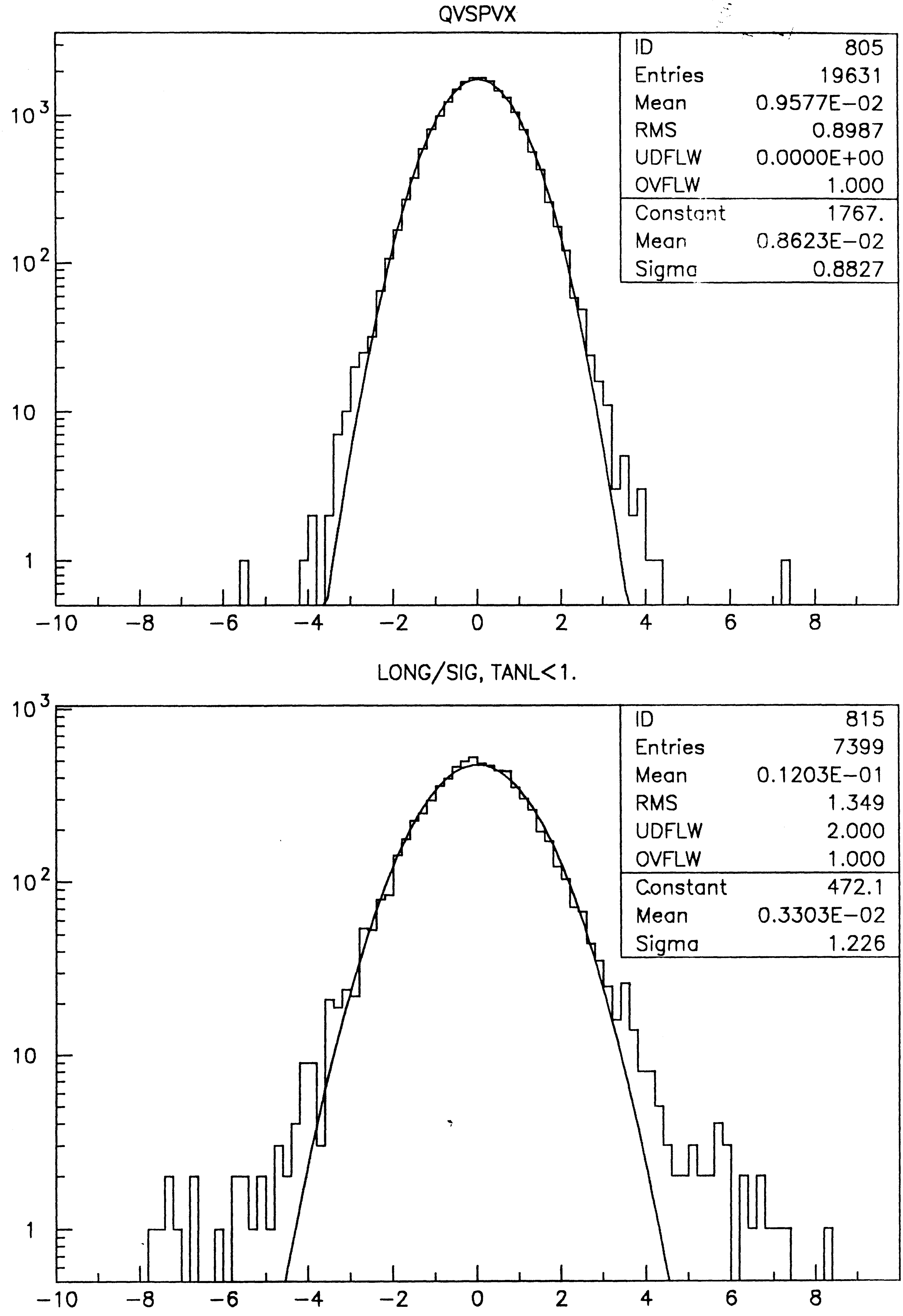


Figure 9: QVSPVX: a) difference of reconstructed and true primary vertex projected on the sphericity axis for divided by the estimated error also projected on the sphericity axis, for *uds* events, b) like a) but for $b\bar{b}$ events

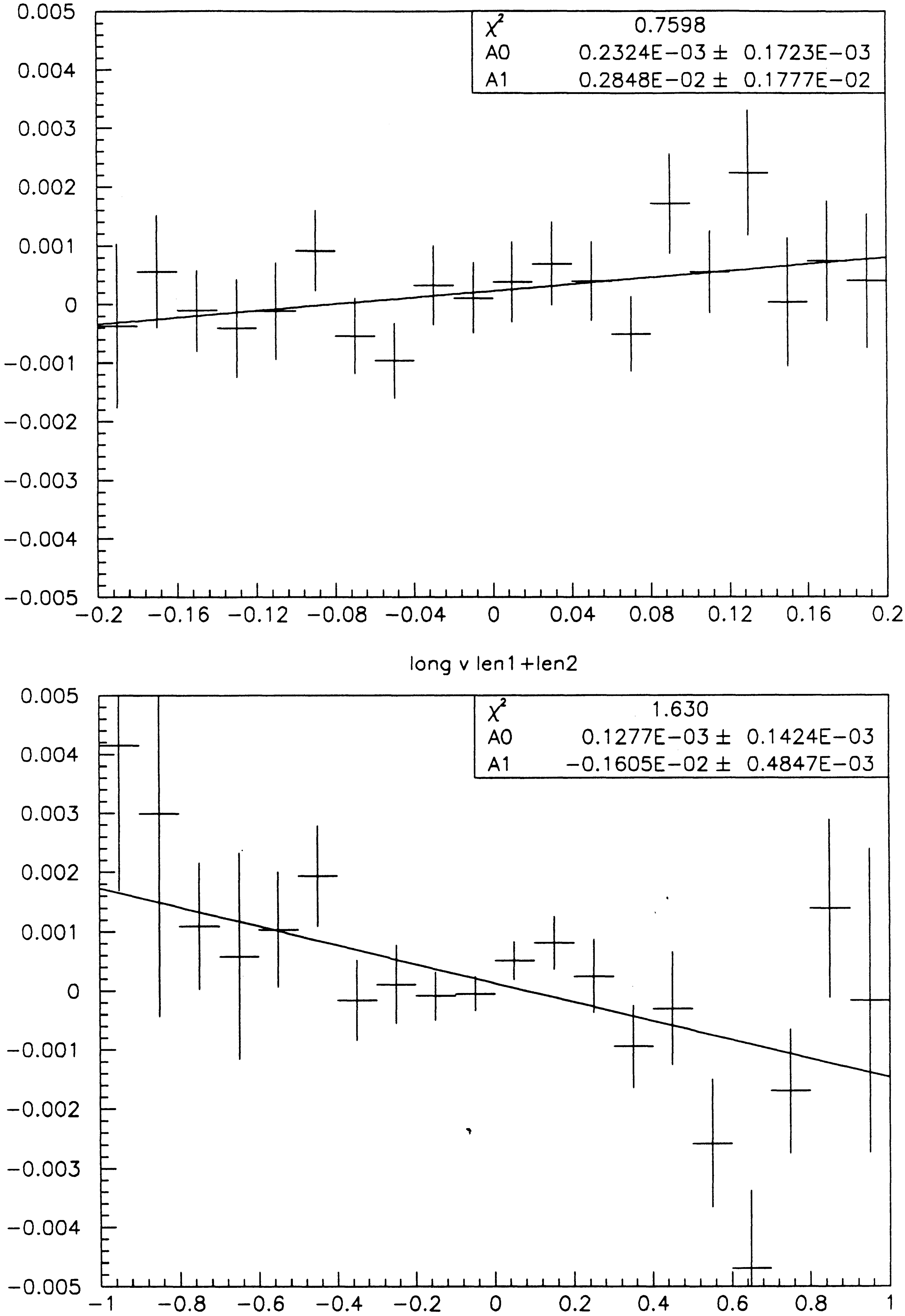


Figure 10: YTOPOL: a) difference of reconstructed and true primary vertex projected on the sphericity axis as function of the distance between the two b-vertices b) like a) but for short decaylength

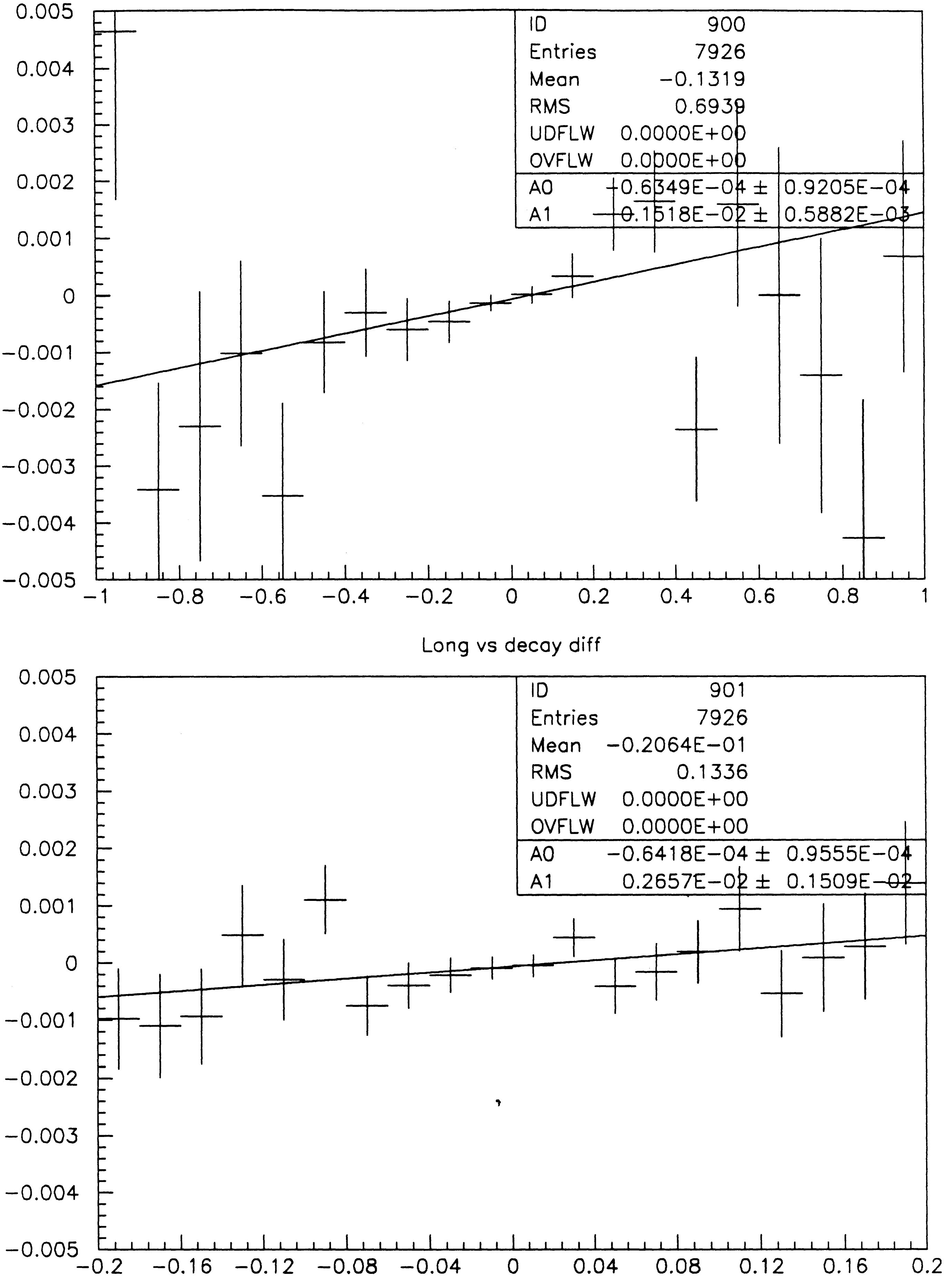
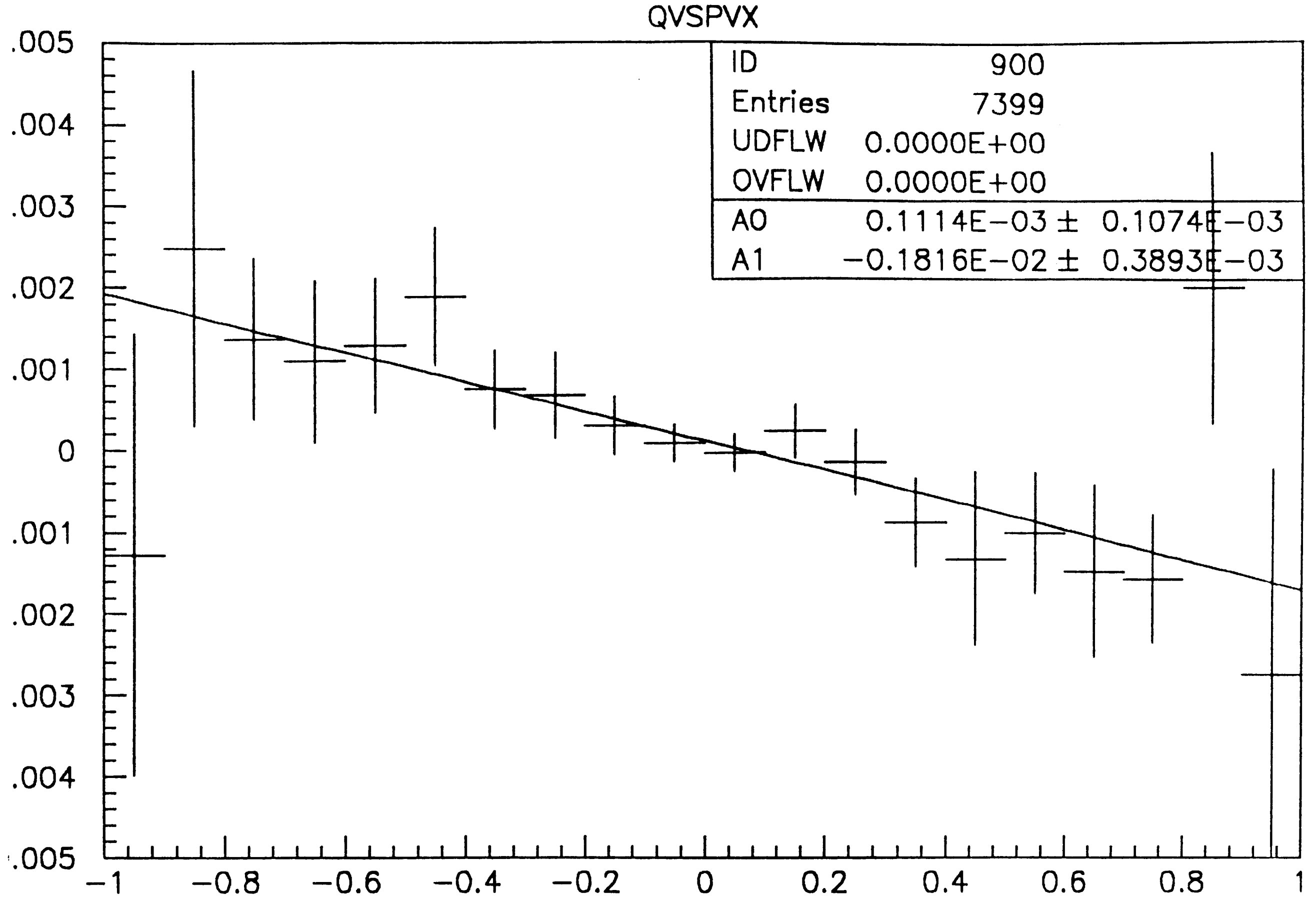


Figure 11: QFNDIP: a) difference of reconstructed and true primary vertex projected on the sphericity axis as function of the distance between the two b-vertices b) like a) but for short decaylength



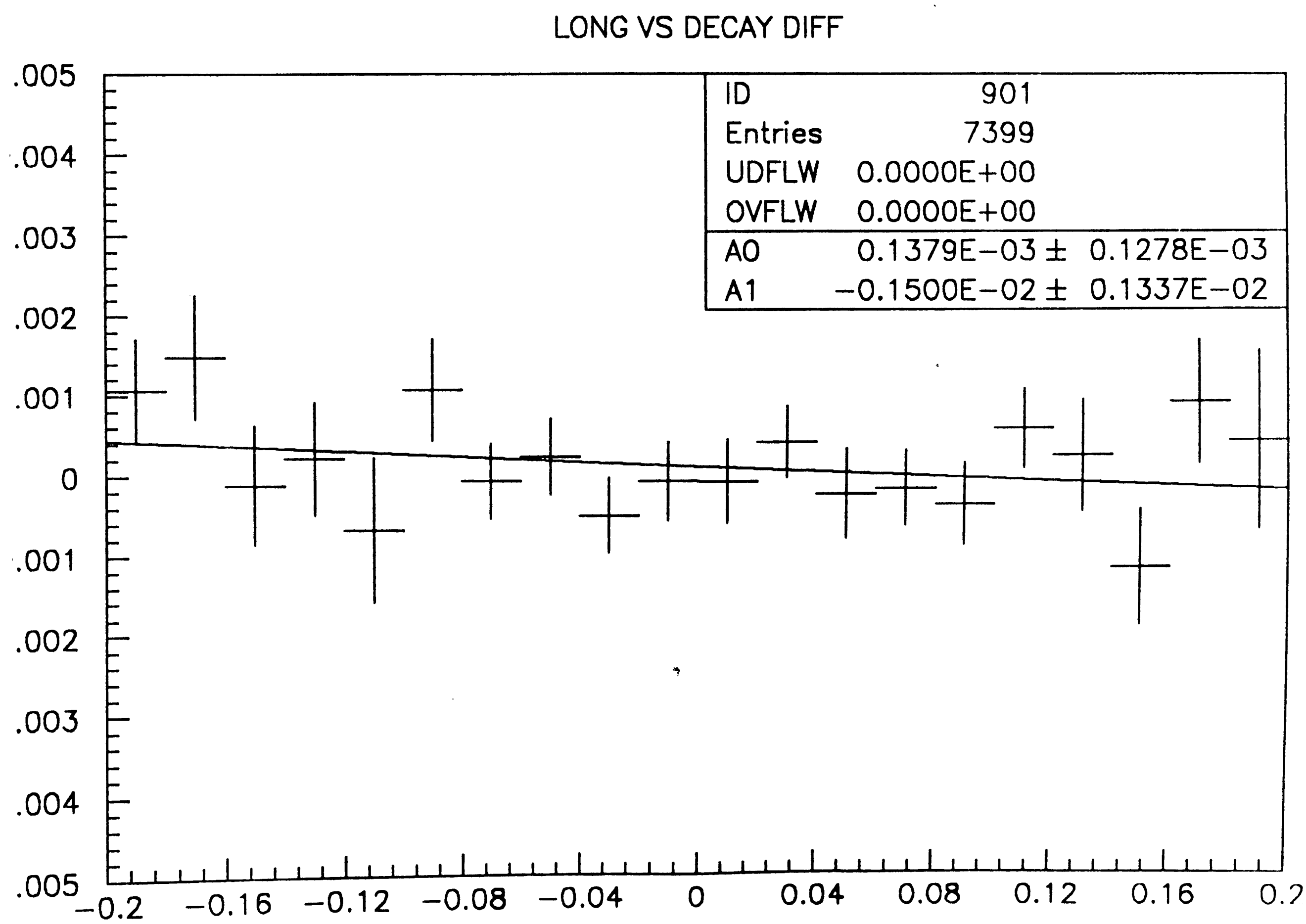


Figure 12: QVSPVX: a) difference of reconstructed and true primary vertex projected on the sphericity axis as function of the distance between the two b-vertices b) like a) but for short decaylength