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1. INTRODUCTION

The high precision vertex detector[1] at TASSO has been used extensively to determine the lifetimes of particles with heavy flavors. In recent years, TASSO has measured the τ lepton[2], the D^0 meson[3] and the average B hadron[4] lifetimes. This report describes the updates to these measurements based on the data taken during the 1986 running period. A total of 110 pb^{-1} was obtained at a center of mass energy of 35 GeV which corresponds to four times the amount of data available for the previously published results.

The method used to determine the τ lepton and D^0 meson lifetimes involved reconstructing the decaying particle so that the lifetimes could be ascertained by the measured momentum and decay length. The accurate evaluation of the production and decay vertices as well as the particle flight direction were then necessary.

At PEP and PETRA energies, the reconstruction of B hadrons has not been possible due to their high charged particle multiplicities. The determination of this lifetime has then relied upon indirect techniques based on Monte Carlo calculations. TASSO has employed several methods to obtain the average B hadron lifetime. The first method measured the decay length of the B hadron by the best three prong vertex in a jet. In this analysis, no dedicated scheme was used to separate B from non-B hadronic events. The second method measured the particle decay times by the signed impact parameter. Here, the event sample was selected on the basis of an event shape parameter.

2. THE τ LEPTON LIFETIME [5]

In the Standard Model, the τ lepton couples to the weak charged bosons, $W^{\pm}$, with the same strength as the muon. The τ lepton lifetime (τ_τ) can then be related to the μ lifetime (τ_μ) :

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$$\tau_\tau = \tau_\mu \cdot \left(\frac{m_\mu}{m_\tau} \right)^5 \cdot BR(\tau \rightarrow e\nu\bar{\nu}),$$

where m_μ and m_τ are the muon and tau lepton masses respectively. Since the branching ratio $BR(\tau \rightarrow e\nu\bar{\nu})$ has been measured to be 17.4 ± 0.4 %[6] the above relation predicts $\tau_\tau = (2.86 \pm 0.07) \times 10^{-13}$ sec. Significant deviations from this value would then cast doubt upon the concept of lepton universality.

The data sample consisted of events where a τ lepton in one hemisphere decayed into three charged particles while the other τ lepton decayed into one or three charged particles. These are referred to as 1-3 and 3-3 topologies. The criteria for selecting τ leptons has been described in previous works[7] After all cuts, a visual scan was performed to reject possible contamination from Bhabha events, obvious fakes, events with misassigned hits, and events where the τ lepton decays via the process $\tau \rightarrow K^0 \pi \nu$ which could bias the lifetime. Possible backgrounds were also investigated by Monte Carlo studies. The background from hadronic events was estimated to be 1.1 ± 0.5 % for the 1-3 topology and 8.0 ± 3.3 % for the 3-3 topology. The contribution from two photon τ pair production was found to be 3.2 ± 0.5 % and 3.4 ± 0.9 % respectively.

The τ decay vertices were found by re-fitting all tracks using information from the vertex detector and the cental drift chamber[8] and by adding the constraint that all tracks share a common production point[9] The effects of multiple scattering as well as the ability to delete bad hits to improve the χ^2 were incorporated into the fitting procedure.

A total of 683 vertices were used to determine the lifetime found by calculating the most likely decay length and transforming it into a proper time. The best estimate for the decay length was given by :

$$\ell_{2d} = \frac{x_v \sigma_{yy} t_x + y_v \sigma_{xx} t_y - \sigma_{xy}(x_v t_y + y_v t_x)}{t_x^2 \sigma_{yy} - 2\sigma_{xy} t_x t_y + \sigma_{xx} t_y^2},$$

where x_v and y_v are the differences in position between the decay vertex and the center of the beam spot, σ_{ij} are the components of the sum of the decay error matrix and error matrix from the beam spot, and t_x and t_y are the direction cosines of the decaying particle. The decay lengths were then converted to a proper time by the relation :

$$c t_\tau = \frac{\ell_{2d}}{\beta\gamma} \; ; \; \gamma = \frac{rE_{beam}}{m_\tau},$$

where β is the velocity of the τ and r is a correction factor which takes into account the effects of initial state radiation and the reduced energy of τ events which come from two photon processes[10].

The lifetime was obtained by using a maximum likelihood fit where the proper time distribution was assumed to be an exponential convoluted with Gaussian resolution functions. A two parameter fit was performed where one was the lifetime (τ_τ) and the other a common error scaling factor (k) for the Gaussian resolution function. The results of the fit were $\tau_\tau = \left(3.03 \begin{smallmatrix}+0.20\\-0.19\end{smallmatrix}\right) \times 10^{-13}$ sec. and $k = 1.07 \pm 0.04$. The fact that the scaling factor was consistent with unity showed that the errors associated with the vertex reconstruction were well understood.

Various sources of systematic biases were studied and the most significant contributions are described here. The detector resolution was varied by 10% which led to an error of $\pm 0.04 \times 10^{-13}$ sec. A change of $\pm 1\sigma$ of the relative alignment of the chambers produced an error of $\pm 0.06 \times 10^{-13}$ sec. Changing the contribution of the hadronic background and its apparent lifetime resulted in an error of $\pm 0.03 \times 10^{-13}$ sec. The analysis method was also studied by generating Monte Carlo data samples with different lifetimes and investigating whether the vertex reconstruction technique could reproduce them. The measured lifetimes were found to be consistent with the generated values, but to be conservative an error of $\pm$ 0.13×10^{-13} sec. was ascribed to the technique.

Adding all the systematic errors in quadrature, the preliminary result of $\tau_\tau = \left(3.08 \begin{smallmatrix}+0.20\\-0.19\end{smallmatrix} \pm 0.19\right) \times 10^{-13}$sec. was obtained. This result can be seen to be consistent with lepton universality.

3. THE D^0 LIFETIME [11]

The spectator diagram of heavy meson decays describes a process where the heavy quark decays independently of its partner. If this diagram is the only contributor to D meson decays, then the lifetimes of the D^+, D_s, and the D^0 should be nearly identical. The evaluation of the D^0 lifetime then provides valuable information to the understanding of the dynamics of D meson decays.

The D^0 lifetime can be determined from events identified via the decay $D^{*+} \rightarrow D^0\pi^+$ where the D^0 then decays in the modes $D^0 \rightarrow K^-\pi^+$, $D^0 \rightarrow K^-\pi^+\pi^0$, or $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$ (Here and elsewhere the charge conjugate states are implied.) Only the first two modes were looked for during the 1986 data taking period and so only these will be described in this report. The small Q value of the decay of the D^{*+} makes the spectrum of the mass difference between the reconstructed D^{*+} and D^0 quite narrow. A clean sample of primary D^0 mesons

can then be obtained by requiring that this mass difference be less than 0.150 GeV / C^2 and that the energy of the reconstructed D^{*+} satisfy the requirement that $X = \frac{E_{D^{*+}}}{E_{beam}} > 0.5$.

For the decay mode $D^0 \rightarrow K^-\pi^+$, all combinations of tracks interpreted as $K^-\pi^+$ were formed from tracks of momentum greater than 0.8 GeV. These tracks were then geometrically fitted to a common vertex, as in the τ lepton analysis, and kinematically constrained to the D^0 mass[12]. After eliminating badly reconstructed vertices, all combinations with a χ^2 less than 5 for the kinematic constraint were paired with the remaining positively charged tracks in the hemisphere with momentum greater than 0.3 GeV to form D^{*+} candidates.

For the mode $D^0 \rightarrow K^-\pi^+\pi^0$, $K^-\pi^+$ combinations were formed from all tracks greater than 1.4 GeV and then geometrically fitted to a common vertex. In this mode, the π^0 was not explicitly reconstructed. Therefore, the $K^-\pi^+$ combinations were required to lie in a satellite peak whose invariant mass fell in a region below the D^0 mass.

The mass difference plots for the two modes described above are shown in figures 1a and 1b. In the 1986 data, 29 events in the mode $D^0 \rightarrow K^-\pi^+$ and 19 events in the mode $D^0 \rightarrow K^-\pi^+\pi^0$ were found. The backgrounds for the two modes were estimated by Monte Carlo simulations to be 5% and 15% respectively (shown hatched in the figures).

The D^0 meson lifetime was found, as in the τ lepton lifetime, by measuring the most likely decay distance and converting it to a proper time. Once again, a maximum likelihood method was used to extract the value of the lifetime. The likelihood function contained four terms : D^0 mesons from primary production, cascade D^0 mesons coming from B decays (4.5% of the signal), background events with a lifetime from B decay, and background events with no finite lifetime. The fit resulted in a lifetime of : $\tau_{D^0} = \left(4.8 \begin{smallmatrix}+1.0\\-0.9\end{smallmatrix}\right) \times 10^{-13}$ sec.

Several checks were made to ensure that the lifetime was not biased and to estimate the systematic errors. The same analysis procedure was applied to selected events in the upper D^0 side bands. This event sample produced a lifetime of $\left(0.03 \pm 0.2\right) \times 10^{-13}$ sec. Changing the vertex detector resolution by 20% led to an error of $\pm 0.3 \times 10^{-13}$ sec. As a check, the lifetime and a common error scale factor were fit simultaneously as in the τ analysis. A systematic shift of -0.6×10^{-13} in the lifetime was found from this procedure. Varying the beam spot position and detector alignment gave a change in lifetime of $\pm 0.14 \times 10^{-13}$ sec. Finally, changing the background fractions in primary and cascade production of D^0 mesons resulted in a change of $\pm 0.28 \times 10^{-13}$ sec. Adding all the systematic errors in quadrature produced the final result of $\tau_{D^0} = \left(4.8^{+1.0}_{-0.9}{}^{+0.5}_{-0.7}\right) \times 10^{-13}$ sec. This number can be seen to agree well with the world average value of $\left(4.3^{+0.20}_{-0.19}\right) \times 10^{-13}$ sec. However, a comparison of this result to the world average value for the D^+ lifetime $\tau_{D^+} = \left(10.3^{+0.52}_{-0.44}\right) \times 10^{-13}$ sec. indicates that the spectator model is insufficient to completely describe the dynamics of charm decays[13].

4. THE AVERAGE B HADRON LIFETIME

The lifetime of a B hadron can be written as[14]:

$$\tau_B = \tau_\mu \cdot \left(\frac{m_\mu}{m_b}\right)^5 \cdot Br(B \rightarrow Xl\nu_l) \cdot \frac{1}{k_c|U_{cb}|^2 + k_u|U_{ub}|^2},$$

where k_c and k_u are mass and QCD corrections of order unity[15], U_{cb} and U_{ub} are Kobayashi-Maskawa matrix elements[16], and $Br(B \rightarrow Xl\nu_l)$ is a nominal semileptonic branching ratio for a B hadron. The relative size of U_{cb} and U_{ub} can be given in the following form[13]:

$$R_B = \frac{\Gamma(B \rightarrow X_u l\nu_l)}{\Gamma(B \rightarrow X_c l\nu_l)} < 3\% \text{ @ } 90\% \text{ C.L.}$$

This then implies that a measurement of the average B hadron lifetime would primarily measure U_{cb}.

The vertex method[17] utilized events whose tracks were well contained in the detector. The cosine of the angle between the sphericity axis and the beam had to be less than 0.6. The events which remained were divided into two jets and all possible three track vertices in a jet were then constructed, provided that all three tracks were not of the same charge. The tracks which formed the vertices were required to have $|P| > 0.6$ GeV, at least 5 vertex detector hits (out of 8), $|z_0| > 3.0$ cm (where z_0 is the closest approach in z to the origin), and good track χ^2 in z and r-ϕ. The best vertex per jet was chosen based on the change in total χ^2 of the tracks before and after the formation of the vertex. The vertex was kept if the confidence level of the fit was greater than 1%. Since the B hadrons were not explicitly reconstructed, the direction of flight of a B was estimated from the sphericity axis. The two dimensional most likely decay distance, ℓ_{2d}, was then calculated along this direction. The decay distance was accepted if $|\ell_{2d}| < 1.0$ cm, $|\Delta\ell_{2d}| < 0.1$ cm, and the $\chi^2 < 5.0$.

The lifetime was determined by comparing the decay length distribution from data to various decay length distributions from Monte Carlo samples generated with different lifetimes. A chi squared fit was performed to determine which Monte Carlo sample most closely resembled the data. This fit yielded $\tau_B = \left(1.39 \pm .10\right) \times 10^{-12}$sec. Figure 2 shows the decay distribution from data as the solid line histogram with the Monte Carlo distribution, which gave the best fit, overlaid.

The main systematic errors arose from the effects of B hadron decay and b quark fragmentation. The fraction of B in the Monte Carlo sample was varied by ±20% and produced a 12% change in lifetime. A 3% error was attributed to using the sphericity axis as an estimation of the B hadron flight direction. A 7% change in lifetime was associated with the uncertainties due to b quark fragmentation.

The various causes of systematic error from charm were also studied. The uncertainties attributed to charm quark fragmentation resulted in a 3% change in the B hadron lifetime. The charm hadron lifetimes[13] were also changed by 1σ to produce a 2% effect. When the charged to neutral direct charm production ratio was varied, this caused only a 2% change in lifetime. The charm fraction in the Monte Carlo data sample was also made to vary by ±20% and resulted in a change of 5%. Other sources of systematic error such as beam spot effects and the vertex detector resolution produced errors of ±.05 ps and ±.09 ps respectively. Adding all the systematic errors in quadrature gave the preliminary result of $\tau_B = \left(1.39 \pm .10\, ^{+0.25}_{-0.26}\right) \times 10^{-12}$ sec.

The second method described in this report to measure the B hadron lifetime relied on the impact parameter technique. This method employed a B enrichment scheme based on an event shape parameter. All high quality tracks in events of the enriched data sample were used to form the impact parameter distribution. Since the multiplicities of b quark events are higher than those from lighter flavored quark events, using all tracks made us more sensitive to a given B decay point. The impact parameter distribution was also made less dependent upon the position of the beam spot because the errors from these multiple tracks tended to cancel.

The B enrichment scheme was based on the fact that since a b quark has a much higher mass than lighter quarks, the average transverse momenta from these events should be correspondingly higher and therefore the B events should be more spherical. The enrichment procedure started by requiring the event to be well within the detector. The cosine of the angle between the sphericity axis and the beam was required to be less than 0.7. Since this method depended on tagging events with high sphericities, it was necessary to remove the three jet background. Therefore, the Wu-Zobernig three jet finding algorithm[18] was used to find three jet events and then eliminate them from the event sample. The events were then split into two hemispheres defined by the sphericity axis and each jet was boosted in the direction of the rest frame of a b quark by using a β value of 0.74. Finally, the sphericities of each boosted jet were taken seperately and then multiplied together to produce the enrichment parameter. The enrichment scheme is then referred to as the method of boosted sphericities or "S1xS2"[19].

Once the enriched data sample was established, the signed impact parameters for all high quality tracks were found. These tracks had to satisfy the criteria that the momentum $| P | > 1$ GeV, $z_0 < 3$ cm, the tracks must have had at least 5 hits in the vertex detector, the track must have crossed the sphericity axis, and the impact parameter for a track must have been less than 0.5 cm. All tracks meeting these requirements were then weighted by their tracking errors determined by the track refitter described in reference 9. A comparison of the mean of the distribution of the weighted impact parameters from data to those from Monte Carlo with different lifetimes resulted in a lifetime of $\tau_B = \left(1.52 \pm 0.18\right) \times 10^{-12}$ sec. Figure 3 below shows the distribution of weighted impact parameters from data as the solid line histogram. The Monte Carlo distribution whose mean coincided with that from the data is shown overlaid.

The systematic errors studied for this measurement arose mainly from the enrichment scheme and from heavy quark fragmentation. The cut used to define a B enriched region was varied and therefore changed the percentage of B events in the data sample. This resulted in an error of ± 0.14 ps. The uncertainties in the average boost of B hadrons was evaluated to produce a systematic error of ± 0.10 ps. while those from c quark fragmentation was found to be ±0.07 ps. Varying the charm lifetimes and the relative contribution of charged to neutral charm resulted in an error of ± 0.06 ps. The total contribution from the various track cuts led to a systematic error of ±0.11 ps. All detector effects such as beam spot position, relative alignment of the detectors, and the resolution was found to contribute ±0.07 ps. All the systematic errors above added in quadrature yielded the preliminary result of $\tau_B = \left(1.52 \pm 0.18 \pm 0.24\right) \times 10^{-12}$ sec.

It should also be mentioned that TASSO employs a third method, the "Dipole Method"[20] to measure the average B hadron lifetime. A result which utilizes this technique and which includes the 1986 data will be available for the later summer conferences.

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FIGURE CAPTIONS

1) a. Mass difference plot for D^0 decay mode $K^-\pi^+$. The hadronic background calculated by Monte Carlo is shown hatched.

   b. Mass difference plot for D^0 decay mode $K^-\pi^+\pi^0$. The hadronic background is again shown hatched.

2) Decay distance distribution for the Vertex Method to measure the average B hadron lifetime. The data is represented by the solid line histogram with the Monte Carlo distribution, which gave the best fit, overlaid.

3) Weighted impact parameter distribution to measure the average B hadron lifetime. The data is again represented by the solid line histogram. The Monte Carlo distribution which provided the best agreement for the means between data and simulation is shown overlaid.

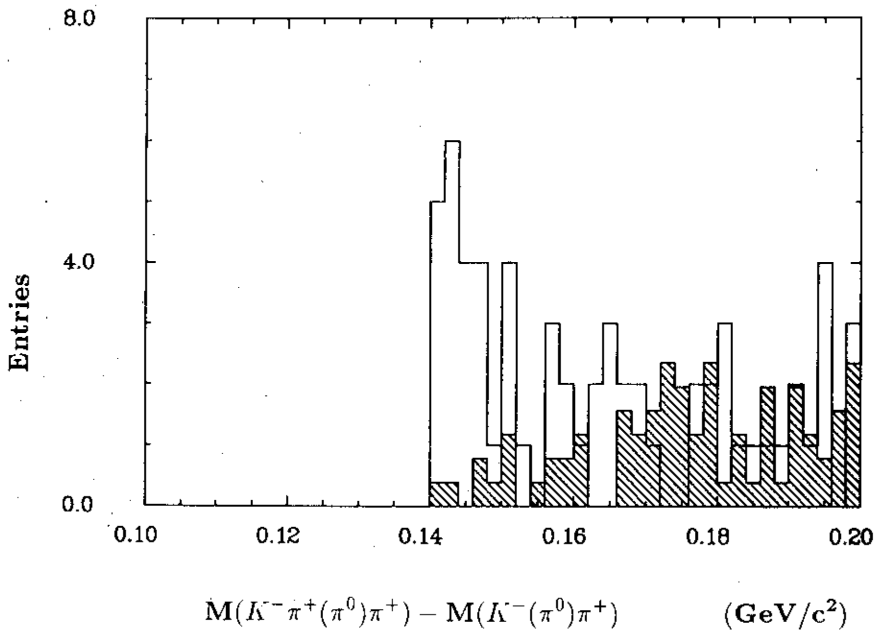

Figure 1b

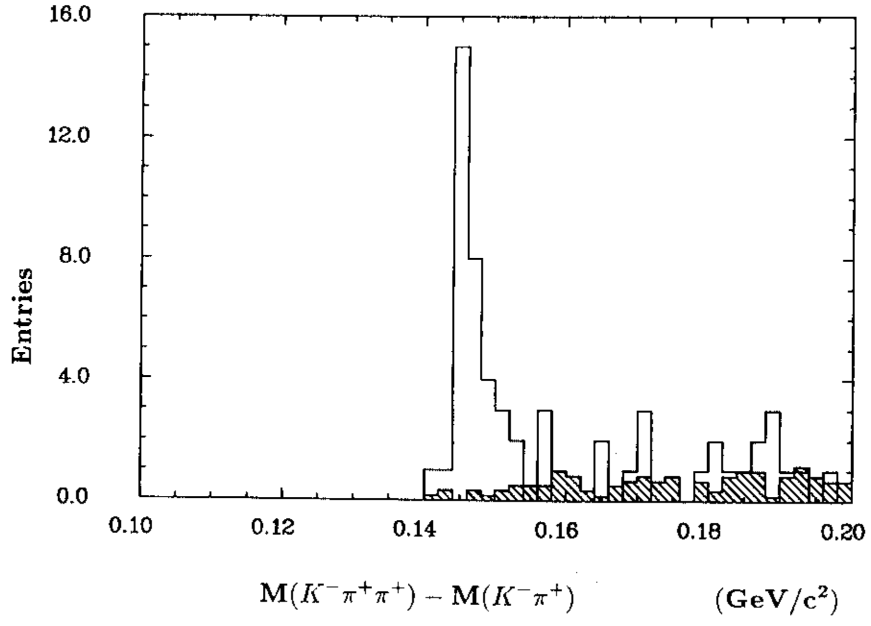

Figure 1a

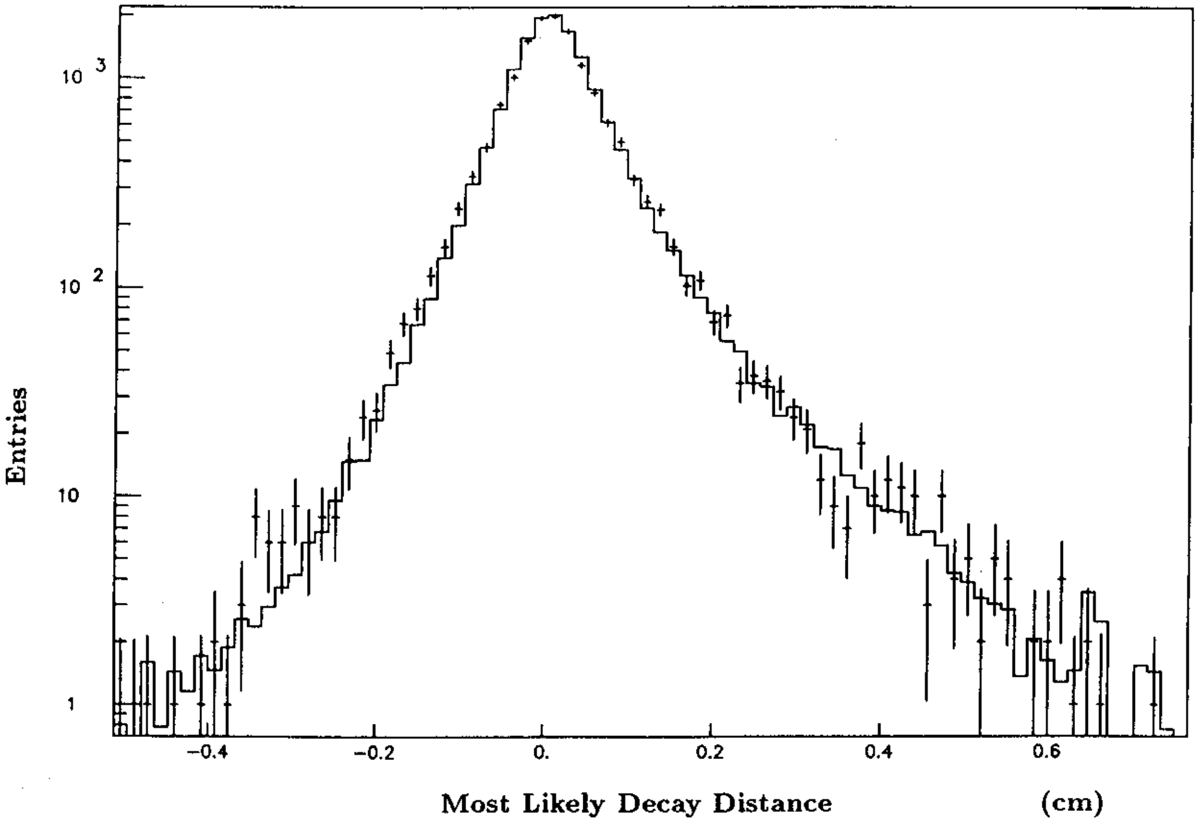

Figure 2

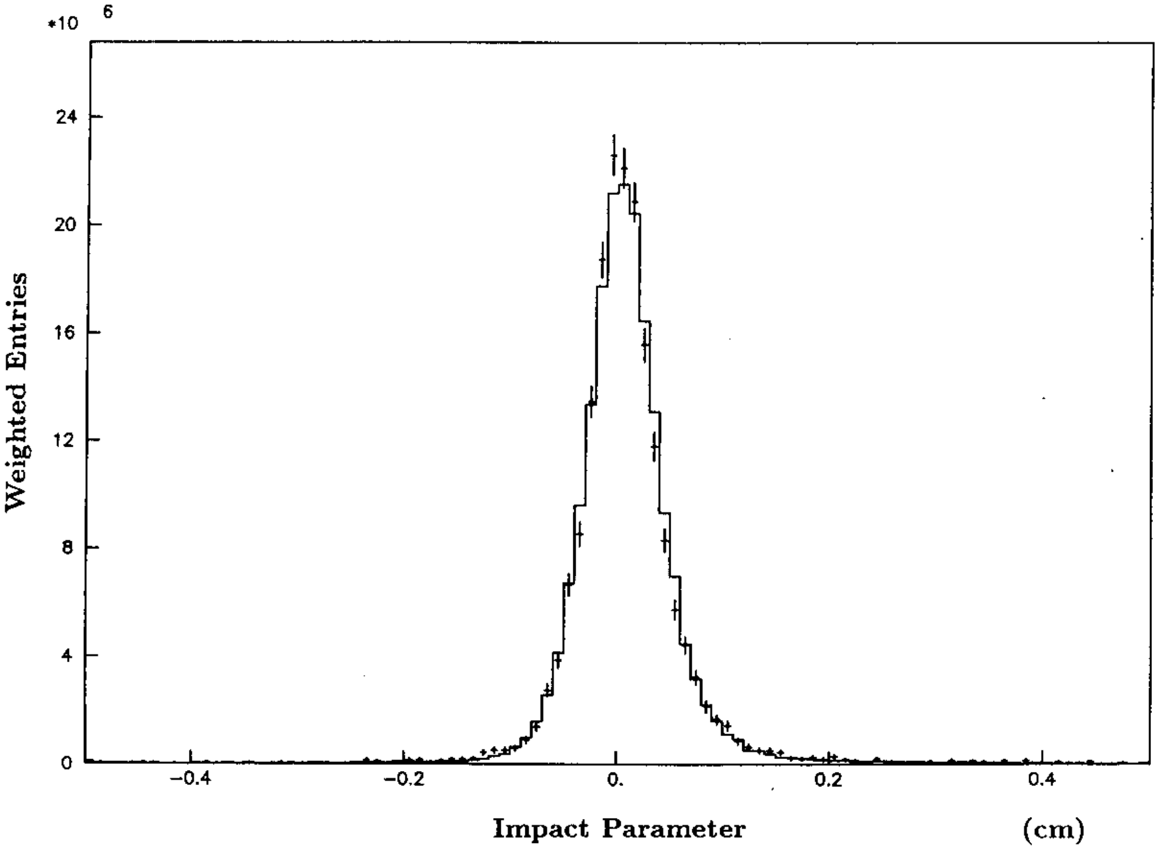

Figure 3