PARTICLE IDENTIFICATION BY dE/dx MEASUREMENT IN JADE [+]

A. Wagner*
Physikalisches Institut der Universität
Heidelberg, Germany

Summary

The jet-chamber, used as the central track detector in the JADE experiment at PETRA, is briefly described. The present status of the dE/dx resolution, results from the measurements and the applications of particle identification in the event analysis are discussed.

The Jet-Chamber System

For the central tracking chamber of the JADE detector [1] at the e^+e^- storage ring PETRA a new type of drift chamber, the so-called jet chamber, has been developed [2-4]. This chamber is capable of recording events of high local track density (jets) with good space and double track resolution and with the possibility of particle identification within a solid angle close to 4π sterad. The concept of this chamber was developed in 1976 and data taking at PETRA has started in 1979. Details about the jet chamber and its performance have been published previously [5,6]. Before discussing particle identification the principle of the jet chamber is shortly described.

The sensitive volume of the jet chamber is a cylinder surrounding the beam pipe. The outer diameter is 1.6 m, the inner diameter 0.4 m, the length 2.4 m. The chamber is subdivided into 24 modules, two of which are shown schematically in fig. 1. Each module contains 4 cells with 16 anode wires each. A uniform drift field with equipotential planes parallel to the median plane is provided by field electrodes. The drift trajectories are up to 8 cm long. The gas gain ($\sim 4.10^4$) is adjusted through the high voltage applied to the potential wires, located between the anode wires. In the range of polar angles $34^o < \theta < 146^o$ (measured with respect to the direction of the incident positrons), 48 points are measured along each track. The track length in radial direction is 57 cm. At least 8 points on a track are obtained over a solid angle of 97% of 4π. At each point three coordinates, r, φ and z are given by the wire position, drift time and charge division measurement. The charge division method requires the measurement of the integrated charge from each hit at both ends of the anode wire. The ratio of these amplitudes determines z and the sum of both amplitudes measures the energy loss dE/dx of the particle in the chamber gas. This measurement of the total charge, determined up to 48 times along each track, is used for particle identification by multiply sampling.

The electronics [7] connected to each of the 1536 wires of the detector consists of preamplifiers on both ends of the wire, a discriminator-integrator and fast analog and time memories with a capacity of 8 hits per wire. The discriminator provides the signal for the drift time measurement and the gating signal for the charge integrators.

Different tracks within one cell do not interfere with each other provided they are separated by drift times greater than the sum of integration and dead time (20 ns). The double track resolution can be varied by adjustment of the integration time, which is currently set to 120 ns, leading to a double track resolution of 7 mm.

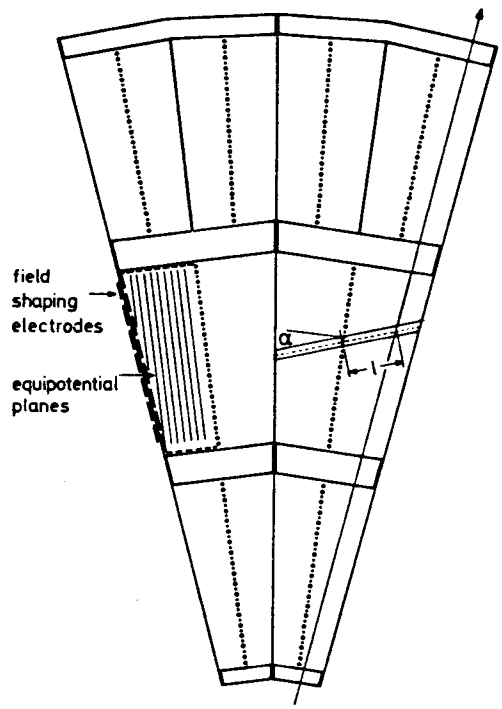

Fig.1. Cross section through two segments of the jet chamber. l is the length of the drift path, α the Lorentz angle. The position of the anode wires (small points) and of the potential wires (large points) are indicated.

A pulser system allows to inject pulses of known charge at both ends of each anode wire. This system is used to calibrate the gain factors of the electronic system. The chamber is operated with an argon-methane-isobutane mixture (0.887 : 0.085 : 0.028) at a pressure of 4 atm. This pressure is chosen for mainly two reasons: to improve the space resolution by reducing the longitudinal diffusion and to enhance the effective sample thickness in order to obtain a better dE/dx resolution. The gas temperature is kept constant to 0.5 degrees.

A solenoid provides a magnetic field of 4.8 kG parallel to the axis of the chamber. The magnetic field is orthogonal to the electric drift field and causes a rotation of the drift trajectories by a Lorentz angle of 20 degrees.

The average values of the space resolution achieved in the central detector of JADE are:

$\overline{\sigma(R,\phi)} = 160\ \mu m$, $\overline{\sigma(z)} = 13$ mm.

The average transverse momentum resolution is

$\Delta P_T/P_T = 2.2\% \cdot P_T[\mathrm{GeV/c}]$.

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*Heisenberg Foundation Fellow

Fig. 2 shows an example of a jet event as seen in the central detector and the surrounding lead glass detector.

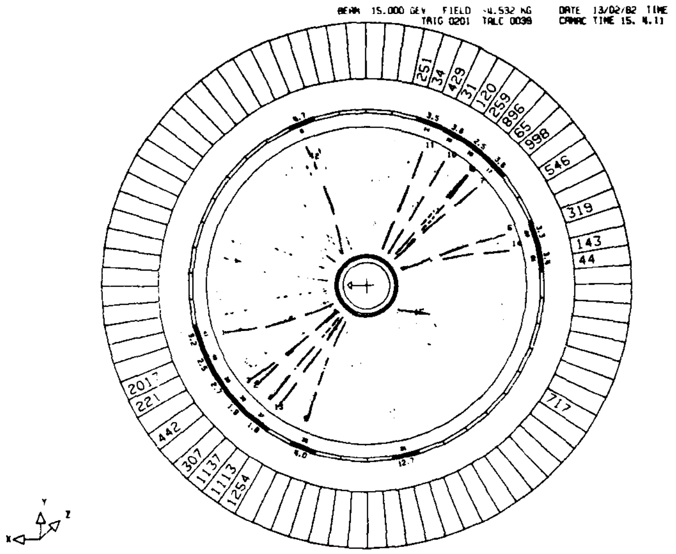

Fig. 2. Display of a typical jet event as seen looking along the e^+e^- beams.

dE/dx Evaluation

The energy loss in the chamber is calculated from the sum of the integrated charges measured at both ends of the wire. Up to 48 ionisation samples are measured per track, however for jet like events the mean number of useful samples is reduced (only 50% of all tracks have more than 30 useful samples). This reduced sample size is due to tracks which leave the chamber through the endplates and due to overlapping tracks, where hits in the region of overlap have to be rejected.

The mean energy loss for a given track is calculated by taking the average of the 60% lowest pulse heights thereby eliminating the influence of large Landau fluctuations (method of truncated means). Before taking an average, each individual integrated charge has to be corrected for several effects:

1) The ionisation is proportional to the sample thickness, which is 1 cm normal to the drift direction. The measured charge is corrected according to the track direction.
2) The gas and electronics calibration differ from wire to wire. These individual gain constants are determined by using the electronic pulser system and a large number of tracks during actual data taking. The long term stability of this calibration was found to be better than 2%.
3) A correction for cross talk between neighbouring wires is made, which improves the resolution by 10%.
4) The chamber volume is disconnected from the external gas supply during data taking periods. A pressure drop of 1% per month is observed, which causes an increase in gas amplification $\Delta A/A = -7.2\ \Delta P/P$. This change in amplification is corrected.
5) It was found that the pulse height drops with increasing drift time like exp $(-a \cdot t_{Drift})$ due to electron attachment in gas impurities, where the coefficient a depends on the time after a new gas filling. The correction reaches values of up to 30% for $t_{Drift} = 1.5\ \mu s$.
6) Since the chamber is operated at a gas gain of $4 \cdot 10^4$ the effective gas amplification depends strongly on the angle θ of the track with respect to the wire and on the drift time. This saturation effect is biggest for tracks orthogonal to the wire and for short drifttimes, when all electrons arrive nearly at the same time at the same point on the wire. The amount of saturation as function of θ and t_D was determined empirically from clean tracks during data taking.
7) A correction which depends on the angle between track and drift direction is presently under investigation.

The entire calibration relies on tracks collected during data taking. No radioactive sources or other external calibration tools are available at present.

dE/dx Resolution

The dE/dx resolution is limited by three factors:
1) Statistical fluctuations in the energy loss,
2) statistical fluctuations in the gas amplification,
3) systematic errors. The choice of gas and pressure determines the contributions from 1) and 2). The dE/dx resolution expected in the jet chamber is $\sigma/E = 4.5\%$ or (10-11)% FWHM, with a relativistic rise of 1.45 [8,9]. The observed relativistic rise is 1.48, the resolution for electrons from Bhabha scattering is $\sigma/E = 5.7\%$ or (13-14)% FWHM [fig.3].

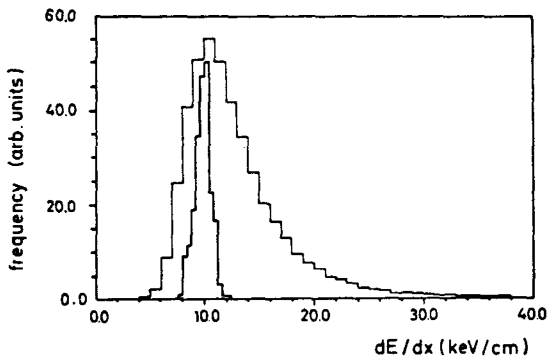

Fig. 3. Landau distribution and truncated mean for electrons from Bhabha scattering.

The resolution obtained in high multiplicity events is worse however, $\sigma/E=9.4\%$ or 22% FWHM. This deterioration is partly due to shorter effective track length and partly due to the fact that the majority of tracks in jets is of low momentum with large track inclination with respect to the wire plane. As mentioned above the inclination correction is not yet properly taken into account.

Even in the case of high momentum electrons the expected resolution was not reached. This discrepancy is due to remaining systematic errors mainly caused by saturation corrections. If one calculates for individual Bhabha events $R = (dE(e^-) - dE(e^+))/\sqrt{2}$, one obtains a resolution which is $\sim$ 20% better than the value quoted above and close to expectation. This can be understood since by calculating R in this way a number of systematic errors cancel.

Test Measurements

When the JADE experiment started no experimental information was available about dE/dx resolution in gases at elevated pressure. For this reason and in order to study sources of systematic errors, a series of test measurements was performed. The test chamber is shown in fig. 4a.

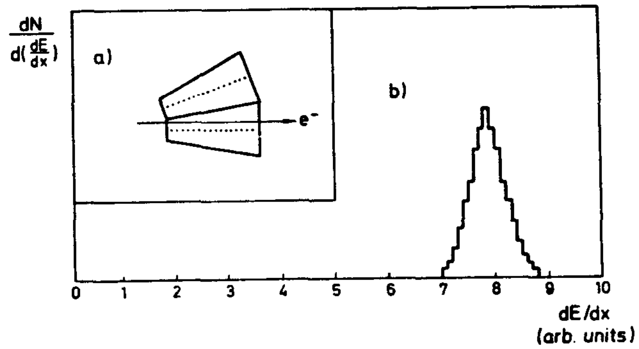

Fig. 4a. Cross section through test chamber
4b. *Distribution of the mean energy loss* (truncated mean) as obtained by adding three tracks.

It consists of two jet chamber cells, cut out of two completed segments and read out with the same electronics as used in the JADE experiment. Gas and voltage settings were also the same. The test chamber was scanned with an electron pencil beam. Three tracks were added in order to create tracks with 48 samples. In the test setup it was possible to map the dE/dx correction factors for each wire as function of the track angle θ and drift time with an accuracy of < 1%. Using these correction factors a resolution of σ/E = 4.6% or 10.8% FWHM was obtained for a large variety of track directions and drift distances (fig. 4b), in excellent agreement with the expected resolution.

The test measurements therefore have shown two things:
1) The theoretically predicted improvement of dE/dx with pressure is correct. 2) An accurate determination of the correction factors can largely reduce the *contribution of systematic* errors to the resolution. Encouraged by this result we presently use the high statistics data from fall 1981 to redo the entire calibration of the JADE jet chamber.

Application of Particle Identification

Although the dE/dx resolution of the JADE jet chamber has presently not reached the theoretically possible performance, the identification of all particles in an event is a very useful feature of the experiment. Fig. 5 shows the dE/dx information for all tracks of the event shown in fig. 2. One high momentum track (13) is strongly ionizing. A detailed analysis shows that this kind of track can be explained as complete overlap of two tracks with small azimuthal separation [10]. Particle identification by dE/dx has been used to separate π, K and P in the non relativistic region (where in jet events the TOF information is deteriorated by frequent double occupancy of the counters), for quark search [10] (fig. 6), for the identification of baryons [11], and for the determination of the $\pi/(K + P)$ ratio [12] in the region of the relativistic rise. Here the particle identification was done on a statistical basis rather than on an event to event identification, due to the limited resolution ($\sim 2\sigma$ separation). The dE/dx information was used to separate low momentum pions from electrons in the analysis of the reaction $e^+e^- \rightarrow e^+e^-\eta'$ [13]. Further applications are in progress.

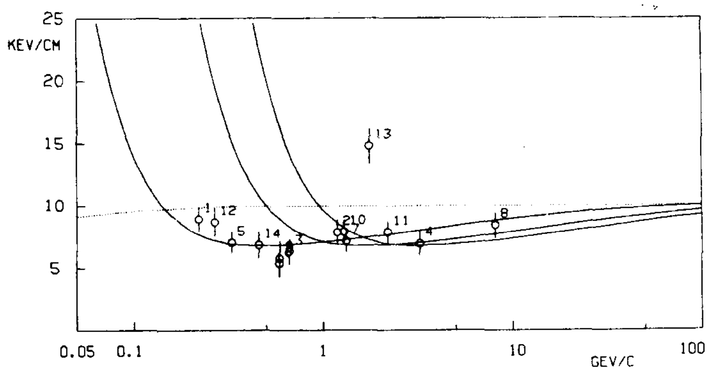

Fig. 5. dE/dx information of the event shown in fig. 2. For each track the truncated mean *energy loss is plotted versus the momentum.* The curves show the expectation for e, π, K and P.

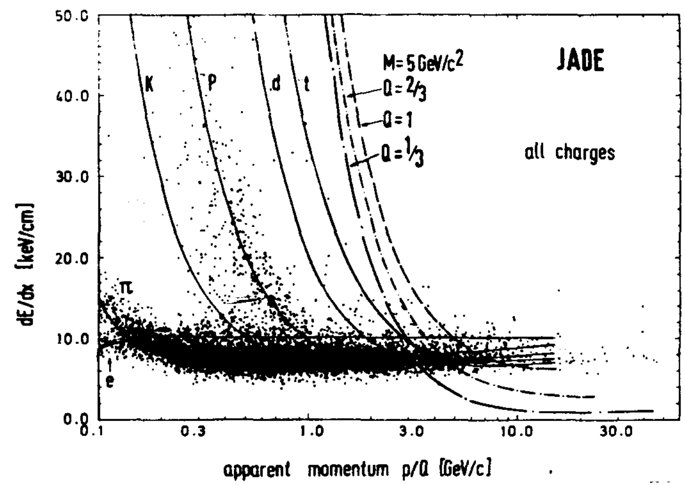

Fig. 6. Mean energy loss as function of the apparent momentum P/Q, where Q is the particle charge.

Integration Time and Gas Gain

In order to combine a good tracking quality of the jet chamber with a good dE/dx resolution, certain compromises had to be made in JADE:
1) Integration time: In order to avoid large fluctuations in charge collection one would like to work with a long integration time (> 200 ns). Good double track resolution on the other hand requires short integration times (< 100 ns). The 120 ns chosen in the present electronics is a compromise between both extremes. Recently the development of a new electronics

system has been started [14] in which this problem will be eliminated.

2) Gas gain: The accuracy of the z measurement using charge division is determined by the signal to noise ratio. Good z accuracy therefore requires high gas gain ($\sim 10^5$). In order to avoid large systematic corrections due to saturation effects in the gas amplification one would however like to operate the chamber at low gas gain ($< 10^4$). Two possible solutions exist to avoid this problem: One is to run the chamber at low gas gain, and to measure two accurate z points in separate chambers at the inner and outer radius of the main chamber. The second solution might be the use of thicker anode wires where the saturation effect seems to be smaller [15].

Conclusion

The combination of tracking information and particle identification has been very useful in the analysis of the events produced in e^+e^- annihilations even though the resolution presently achieved is a factor 1.2 - 1.8 (depending on the multiplicity) worse than expectation. Measurements with a test chamber in an electron beam have shown that in a situation, where an accurate calibration is possible, the expected resolution can be achieved. The observed difference between the measured and expected resolution is therefore attributed to the fact that the present calibration accuracy, due to low event rates, is insufficient to reach the intrinsic resolution. We try at present to make use of our recent high statistics data in order to further improve the resolution.

Acknowledgement

I would like to thank all members of the JADE Collaboration, who have helped to achieve the present performance of the central detector. The results presented here are the fruits of their combined efforts.

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