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Particle Identification by Ionization Measurements
in the LEP-JET Detector

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Introduction

At present the most promising method for particle identification in a storage ring detector seems to be the measurement of the energy loss of the individual particles in the gas of the central tracking device, together with the determination of particle trajectories and momenta. It requires a high resolution measurement of the ionization. This technique has already successfully been studied in the External Particle Identifier at CERN¹⁾ and in the ISIS-detector²⁾. Two storage ring experiments (TPC at PEP and JADE at PETRA) are going to use this method in the near future. The purpose of this note is to study in which range of momenta particles can be identified by ionization measurement in the LEP-JET detector³⁾.

Energy Loss Difference and Resolution

Two quantities determine whether the mass m of a particle with measured momentum p and energy loss δ_E can be uniquely identified: 1) the difference in energy loss (ΔE_{12}) between particles of masses m_1 and m_2 at the momentum p and 2) the accuracy σ_E with which the energy loss can be measured.

The quality of particle separation is then given by $\Delta E_{12}/\sigma_E$, which should be bigger than 3 in order to reach a level of misidentification $< 5\%$ in the case of equal occurrence of m_1 and m_2 .

The difference in energy loss in the region of relativistic rise (where $dE/dx \approx 2n\gamma$) is generally rather small, i.e. $\sim 17\%$ between K 's and π 's in the case of argon, from $p/mc \sim 4$ up to momenta where due to the density effect the rise reaches the Fermi plateau and dE/dx is no more dependent on p/mc .

The fluctuations of the ionization losses on the other hand are very big (100% in 2 cm argon at NTP). Although the width of the energy loss distribution decreases with increasing sample thickness it does not become smaller than $\sim 20\%$ even in very thick samples. The resolution can however be improved by measuring the ionization in many independent samples along each track.

This was studied in detail in connection with the development of the EPI-detector¹⁾. Figure 1 shows a summary of the findings. The result is that a sampling length of ~ 3 cm at NTP yields the highest possible resolution for a given total track length, but that a change in the sampling length by a factor 2 decreases the resolution by less than 0.5%. Figure 1, which is valid for argon, can be used to derive the dependence of the resolution σ_E on the total tracklength L (in m) and the gas pressure P (in atmospheres):

$$\sigma_E = 5.65 (L.P)^{-0.45} \% \quad (1)$$

for 3 cm sampling length. The factor in front of the bracket depends on the gas, the number of samplings and the method for determining the mean energy loss.

The resolutions quoted in this note are determined by the method of truncated means: given N independent ionization measurements along a track, only the lowest 60% of the pulse heights are used to determine the mean energy loss. This method is very fast and only slightly worse than a maximum likelihood fit of a Landau distribution to the measured pulse height spectrum. It is important to note that the distribution of the truncated means is itself a gaussian distribution with tails not exceeding 2 - 3 standard deviations.

If the total track length L is limited by external constraints as the radius of a solenoid, one can improve the resolution by increasing the pressure. Going from 1 atm. to 4 atm. reduces according to formula (1) σ_E by a factor of ~ 2 .

Going to higher gas pressure changes also the dependence of ΔE on p/mc . The main feature is that with increasing pressure the density effect sets in at lower momenta, thus limiting the particle separation at high momenta.

Since few measurements of dE/dx as function of p at higher gas pressures are presently available a Monte Carlo program had to be used to study this behaviour. The program was developed by Cobb et al.⁴⁾. The results from this program for A-CH₄ at 1 atm. were compared with recent measurements of the EPI Group¹⁾ and found to be in very good agreement. Figure 2 shows the mean energy loss in 1 cm A-CH₄ at P = 4 atm. for e, π , k and p.

Particle Identification in the LEP-JET Detector

Using the energy loss curves of Figure 2 the particle identification in the LEP-JET detector was studied. The inner radius of the track chamber is 10 cm, the outer radius 180 cm, the total track length as seen under $\theta = 90^\circ$ is 170 cm. The energy loss is measured radially in 1 cm samples. If the detector is pressurized at 4 atm. this corresponds to the optimum sampling thickness of 4 cm at NTP.

In the case of multibody final states, especially jets, not the full track length can be used for particle identification, since tracks will cross each other. A jet model based on quark fragmentation⁵⁾ was therefore used in order to determine the effective track length. The result is that this length lies between 130 cm and 160 cm depending on momentum. (The shortest track length corresponds to momenta where the energy separation is biggest.) The resulting energy resolution is therefore

$$\sigma_E = (2.5 - 2.7) \% \quad (2)$$

Figure 3 shows the corresponding particle separation $\Delta E_{12}/\sigma_E$ as function of momentum. At the 3σ level pions and electrons can be separated below 30 GeV/c, pions and kaons between 1.5 and 45 GeV while a kaon-proton separation is only possible at a 2σ level above 4 GeV/c. No straightforward particle separation by ionization measurement can be done in the momentum regions where the energy loss curves cross each other.

From past experience one can hope to reach the quoted separation even in a large experiment. Effects like gas gain variation as function of θ can be corrected for without loss of resolution

Further Studies

As a next step towards an improved particle identification one has to optimize $\Delta E_{12}/\sigma$ by variation of the gas pressure and by studying other gases. First results from calculations for propane and xenon however indicate that no significant improvement in particle separation can be expected.

Test measurements at higher pressures are needed to verify the calculations and to check if unexpected saturation effects set in.

A recent analysis of test measurements by the TPC group⁷⁾ has indicated two possibilities for improvement of the resolution:

- by cutting not only on the truncated mean of the pulse height but on the mean as function of the width of the pulse height distribution, one can achieve a better particle separation;

- in the region of the crossover points one can use the fact that although the mean energy loss of particles with masses m_1 and m_2 is the same, the shape of the Landau distributions differs slightly.

Through appropriate fits one can therefore improve the probability to identify the particles correctly.

Conclusion

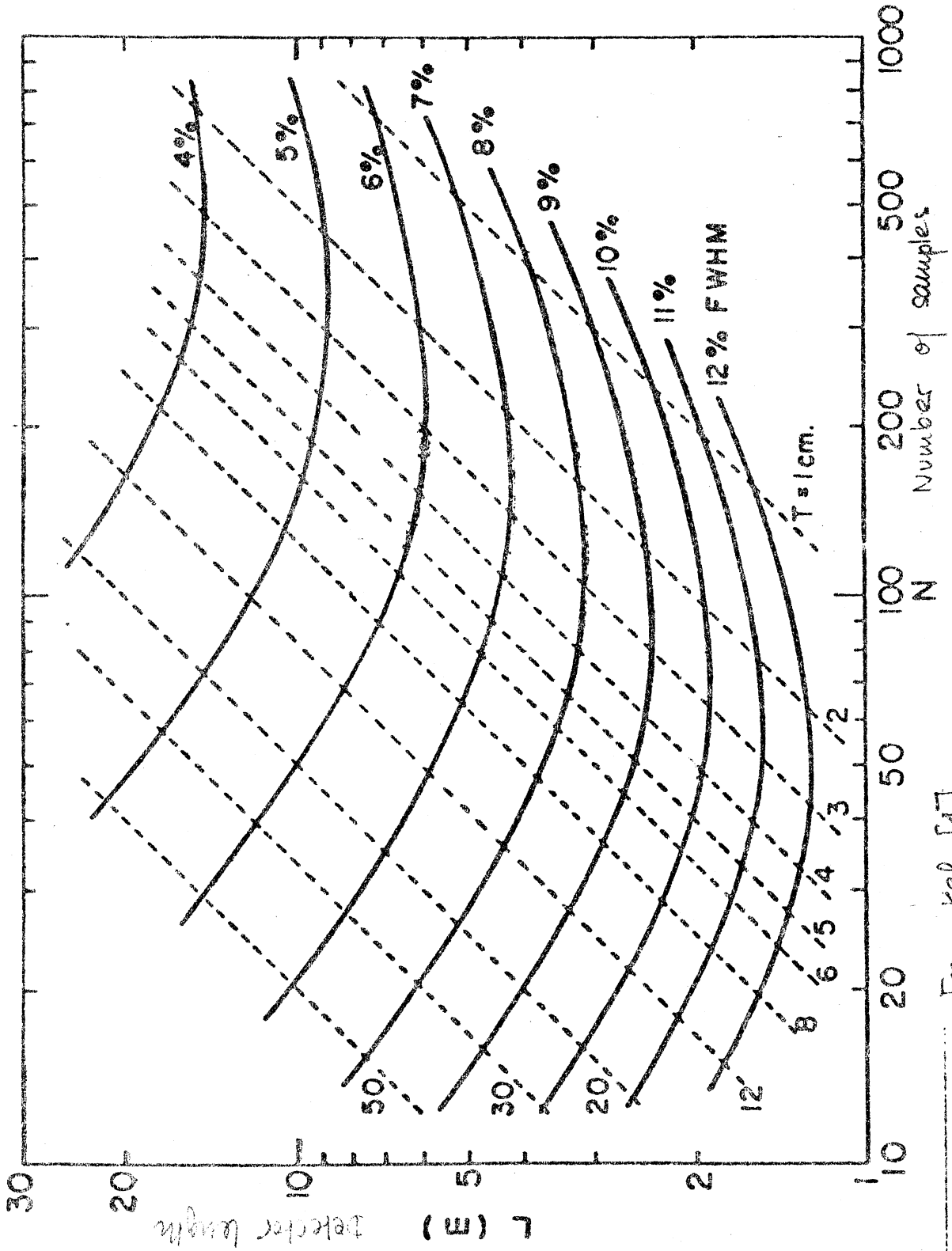
Particles can be identified over a wide momentum range, even in the unfavourable case of jets, through a high resolution ionization measurement. This requires however a central detector with a diameter of 3 - 4 m. At low momenta where different particles have the same ionization loss, a time-of-flight measurement might be used for particle identification. The present design is a first attempt and should be optimized.

Acknowledgements

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References

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From ref [1].

Figure 1 : Resolution as function of detector length and number of samples

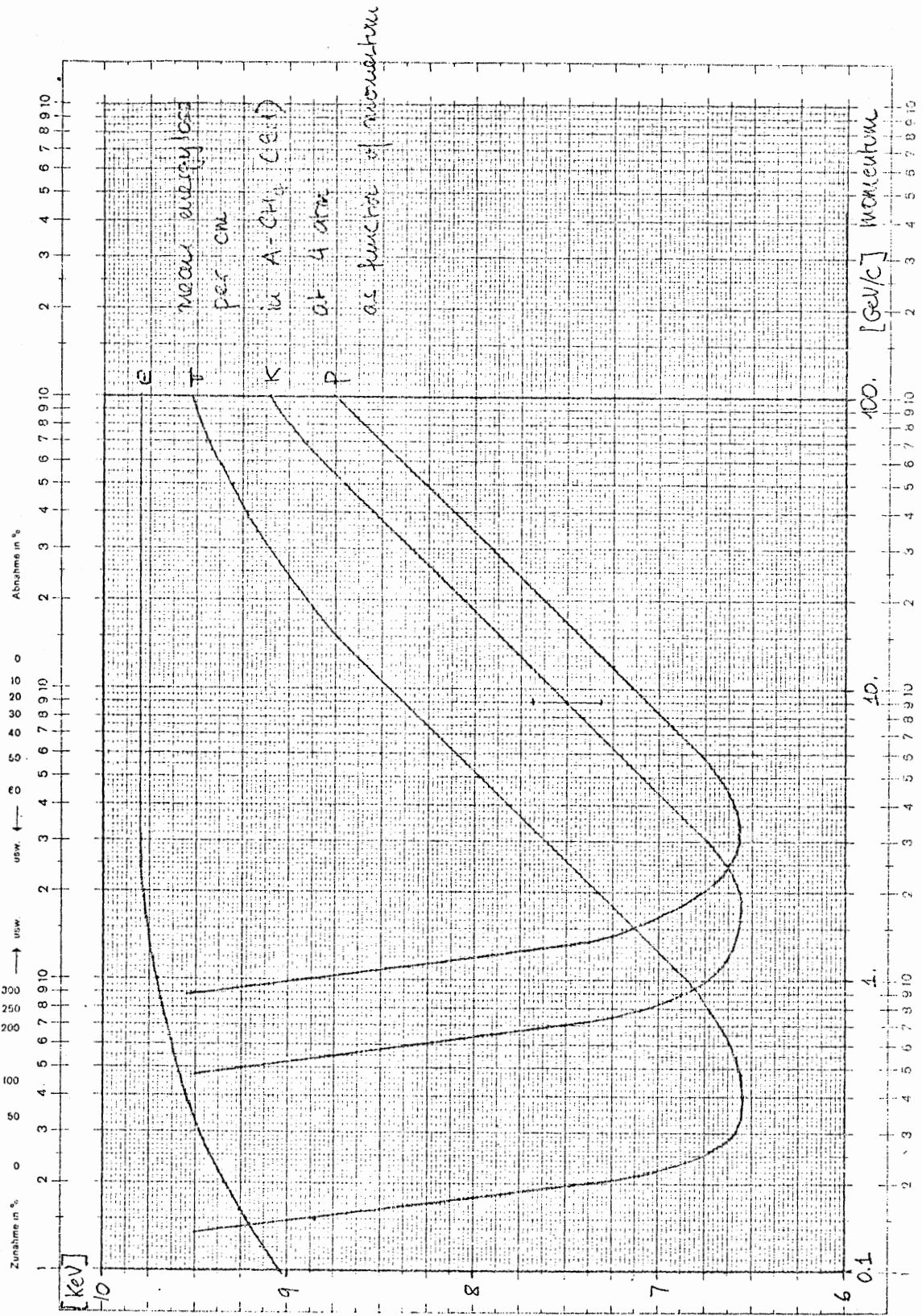


Figure 2

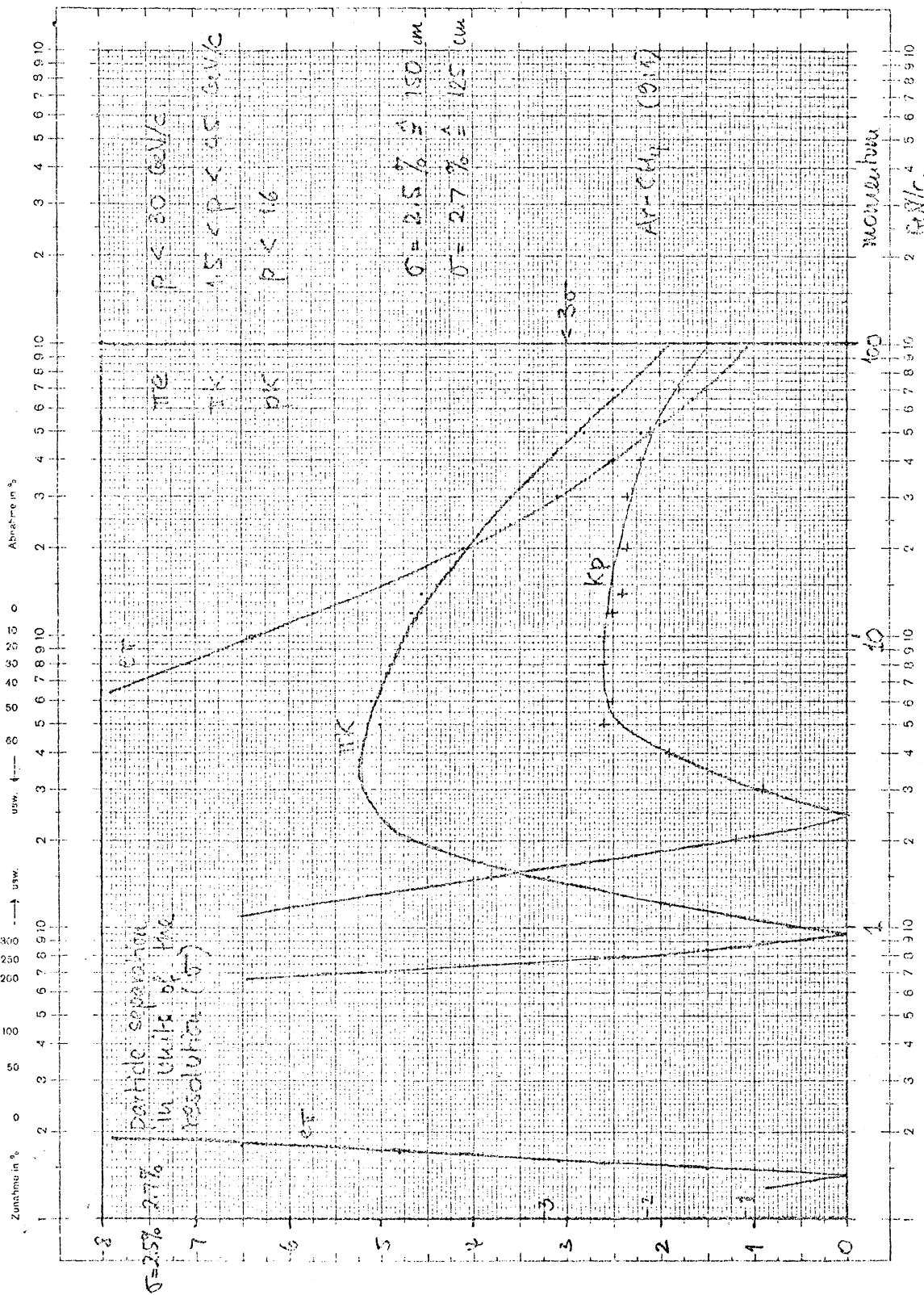


Figure 3