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RESOLUTION LIMITS OF IONIZATION SAMPLING IN HIGH PRESSURE DRIFT DETECTORSI. Lehraus, R. Matthewson and W. Tejessy
CERN, Geneva, SwitzerlandABSTRACT

A systematic study of particle identification performance of full-scale dE/dx sampling detectors including large drift was realized in a device containing 64 pairs of $2 \times 2 \text{ cm}^2$ proportional cells and a 50 cm drift space. Gas, pressure and drift dependence of the relativistic rise of ionization and mass resolution were measured from 0.5 to 5.5 atm at 15 GeV/c, for mixtures of argon and CH_4 , C_2H_4 , C_2H_6 , C_3H_8 , iC_4H_{10} , CO_2 , $\text{CO}_2/\text{C}_2\text{H}_6$, Xe/CH_4 , $\text{Xe}/\text{C}_2\text{H}_6$. Multitrack resolution (linearity of dE/dx response, saturation) was measured for up to 10 quasi-simultaneous particles within a 2 cm diameter beam spot during 1 μs fast spill. The amplitude resolution was found to improve more slowly with pressure (7.5% FWHM was reached at 5.5 atm for 14 m NTP equivalent detector length) than expected from extrapolations of atmospheric pressure measurements without drift. Pressure dependence of signal attenuation in the drift space was smallest in $\text{Ar} + \text{CH}_4$ mixtures. The results confirm a marked reduction of the relativistic rise slope at higher pressures.

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1. INTRODUCTION

Particle identification by dE/dx sampling in high pressure drift detectors allows for a compact design with high granularity required for colliding beam experiments. On the basis of the present state of development and achieved or expected performance of several large-scale devices using this method, various parameters important for optimized design were precisely measured; the results are analyzed in this paper. The application limits of the ionization sampling are discussed with the main interest concentrated on the relativistic rise region and maximum attainable momentum.

In a single layer detector (proportional chamber) working at atmospheric pressure, the width of the distribution of the ionization losses is typically $\sim 60\%$ FWHM for a depth of a few centimetres and the distribution is asymmetric with a long tail. As an example, the difference in the most probable values of ionization between kaons and protons is at 40 GeV/c $\sim 6\%$; it is 16% for π/p , 9% for π/K and 5% for e/π . The dE/dx resolution required for reliable kaon identification should clearly be close to 6% FWHM, which can only be reached by evaluating many independent samples for each registered particle track. The most practical method, which eliminates efficiently the influence of the asymmetric distribution, is a "mean of lowest 40-60% of ionization values" (truncated mean).

The detector performance should be optimized in number of samples for a given overall length [1]. This leads to a minimum detector length of 5-6 m of argon and several hundred samples. Use of xenon, if economically acceptable, will allow for reduction of length by a factor of ~ 2.6 . The EPI detector (External Particle Identifier) [2], working without drift with a fixed matrix of 4096 individual samples as well as ISIS [3] and CRISIS [4] devices designed to operate with large drift spaces are typical examples of box-shaped detectors used for fixed target experiments outside magnetic fields; they demand large area thin entry and exit windows. Operation at higher pressures is practically excluded.

For colliding beam experiments where the most important factor of the detector design is limited available space, the gas pressure could be

increased. This is attractive also because of reduction of diffusion during drift, resulting in improvement of precision of track reconstruction. The TPC detector [5], the jet detector for JADE [6] and equipment envisaged for the new LEP e^+e^- machine are examples of application of cylindrical geometry and drift in high pressure gas and in magnetic field.

The scaling of detector resolution to higher gas pressures is being currently done by assuming that the product of sample thickness and gas pressure is an invariant. The present state of theory of ionization losses (predictions of the shape of distributions, relativistic rise, pressure dependence etc.) unfortunately does not yet allow for necessary level of precision in predictions of performance of big detectors. Therefore, "fairly good" agreement with theory for a given small scale prototype may not show higher order effects which can develop into first order problems in a final large device. Also, at higher pressures the relativistic rise of ionization is considerably reduced by the density effect, and the onset of the Fermi plateau occurs at lower particle momenta, offsetting the gain in resolution.

Lack of precise experimental evidence concerning the resolution and relativistic rise dependence on the drift distance, gas mixture and pressure, saturation effects, multitrack resolution etc., measured in a set-up of appropriate size, was the principal motivation of the present study.

2. EXPERIMENTAL SET-UP

2.1 The detector

The geometry of the detector was chosen with emphasis on the possible direct comparison with prior measurements with identical sample number and size without drift, using a structure of 64 x 4 cm [1] or 128 x 6 cm [2] at NTP. Higher pressures require reduced sample size, which together with other considerations led to a choice of 64 pairs of 2 x 2 cm² samples as a compromise for medium pressures, comfortably low level of crosstalk and

reduction of spread in the charge collection time across the sample. The total active detector length then is 2.56 m. The maximum working pressure was chosen to be 6 ata, with the possibility of operation below atmospheric pressure. Fig. 1 shows schematically the inner structure of the detector. The 64 pairs of $2 \times 2 \text{ cm}^2$ proportional counters with an additional pair at each edge are formed by parallel wires stretched with 1 cm spacing between Vetronite bars and crimped in copper pins. The signal wires (at ground potential) are of 25μ diameter stainless steel (Stablohm 675), tensioned to 40 g. The HT grid and field wires are of 100μ diameter stainless steel, tensioned to 100 g. The lower electrode (at a negative potential of a few kilovolts) is made of polished light alloy plate which is fixed together with the Vetronite wire supports to a rigid light alloy welded frame. Another gating grid with identical spacing is stretched 0.5 cm above the inner HT grid. The field wires are connected to the lower electrode. Separated connections to all odd and all even wires of each of the two HT grids allow for several potential distributions (even in a zig-zag pattern) to be applied there, to vary the transparency of the grid system and to gate on/off the gas amplification. In the "open" state the inner grid is connected to the lower electrode and field wires; the outer grid has higher negative potential. The gas amplification factor was kept below 4×10^3 at NTP to assure linear response.

The uniform electric field in the 50 cm of drift space is formed by a cage structure of 19 tubular stainless steel frames fixed with 2.5 cm interaxial spacing in 5 perpendicular Vetronite support frames. The tube diameter is 15 mm, the surface is polished and the corners of the frame are rounded with 3 cm radius. The beam entry and exit short frame sections have inserts of stainless steel tubes of only 0.2 mm wall thickness, to reduce the amount of matter in the particle path. The drift space is closed by a polished stainless steel HT electrode (max. potential -60 kV) with a stainless steel tube of 22 mm diameter fixed around the edge to avoid corona. Two of the insulating frame supports contain the HT distribution chain of resistors of $10 \text{ M}\Omega$ per stage, encapsulated in Araldite. Polished "elbows" of 48 mm diameter stainless steel tubes are fixed to the electrode corners to reduce the critical field gradient. The electrode system was showing no discharge problems at full HT. The "short" dimension of the frames is 29 cm between tube axes. From the 25.5 cm of

the signal wire length, the middle part of ~ 15 cm length shows response uniform to within a few per cent.

The detector assembly is suspended on insulators from a 5 cm thick steel lid which is bolted with O-ring seal to a rectangular shaped steel pressure vessel, so that the drift is taking place in the horizontal direction. The inner surfaces of the vessel are painted with an Araldite based vacuum paint. The minimum distance of the upper HT electrode from the vessel walls is 14 cm. The 60 kV connection is made via external RC filter through one of the big support insulators, sealed by O-ring. The other HT connections are made via separated vacuum-tight connectors. The signal wires are connected by short loops of cables to a row of vacuum-tight BNC coaxial connectors fixed in the lid.

Four 178 mm diameter 1 mm thick mylar windows with Al foil sandwiched between the mylar sheets allow for alignment of the beam in "small drift", "full drift" and "diagonal" positions. Two more windows at 90° to the previous set were provided in the middle of the detector to enable the investigation of the longitudinal drift along the particle trajectory. The upper electrode was made thinner in the appropriate region.

A collimated Fe^{55} source equipped with a remotely controlled shutter was attached at one edge of the signal wire plane. Another separated pair of $2 \times 2 \text{ cm}^2$ proportional counters with attached collimated Sr^{90} source was placed inside the lower electrode support frame. Both sources were used for monitoring and calibration.

Fig. 2 shows the detector assembly being lowered into the pressure vessel. The whole system was then positioned on rails fixed on a heavy turntable, so that the translation and rotation around the vertical axis permitted the beam to pass through the required parts of the drift volume.

2.2 Electronics

In a detailed study of the ionization-amplitude response of the detector for straight tracks, it is preferable to use slow electronics triggered externally. This permits measurements on quasi-simultaneous

parallel tracks avoiding the limit imposed by double pulse resolution in fast electronics. In any case, the counting rate of a large drift detector is inherently limited by space charge saturation caused by slowly moving positive ions.

Each pair of sample wires was connected to its integrating amplifier, track and hold and ramp comparison 8 bit ADC with shift register readout, as described in ref. [7]. The electronics circuitry was mounted directly on the detector. The original system was slightly modified - the pulse rise time at the hold input was 5 μ s to the crest with a differentiation time constant of 20 μ s. The pile-up problems were negligible at a flux of the order of 1 particle/ms, imposed by short spill and limited readout buffer capacity.

For strictly parallel drift of tracks with respect to the signal wire plane, the common hold trigger and start of data acquisition were derived from a fast discriminator connected to a central sample pair. The error in measured amplitudes caused by errors and jitter in hold timing with respect to the pulse crest was $\sim \pm 0.5\%$ for 1 μ s. The jitter was typically within ± 0.2 μ s and the systematic part of this error was removed by individual sample corrections in the off-line data handling. On the average the signal to noise ratio was at the most probable (peak) value $\sim 20:1$.

For "diagonal" tracks at fixed angle, the first hold trigger derived from the front edge cell started an adjustable frequency clock, which provided consecutive appropriately spaced equidistant triggers for the following samples.

A string of 64 digitized pulse amplitudes corresponding to a given particle track was strobed first into a local fast RAM buffer with capacity for 16 tracks. The dead time of the system including the ADC conversion time and readout into the buffer was ~ 500 μ s. The blocks of accumulated data were transferred between beam spills via data link to a NORD-10 computer and written onto magnetic tape.

The arrival time of the signal from each particle was measured by a 20 ns resolution TDC as a difference between a beam tagging trigger and a stop pulse generated by the hold trigger discriminator and the result was also recorded on the tape. The drift velocity was determined over a 41 cm drift distance.

2.3 Layout of the beam tests

The detector was installed near the end of the S3 beam line in the E2 Hall. Two ejections per SPS cycle were available, either of ~ 20 -30 ms duration each, or fast spills of < 1 μ s. The latter was used for the multitrack resolution studies. The systematic measurements of gas, pressure and drift dependence were performed at 15 GeV/c using a "natural" mixture of $\sim 10\%$ protons, $\sim 46\%$ pions and $\sim 44\%$ positrons. The muon contamination of the beam was negligible. The momentum bite was $\pm 0.25\%$, the beam spot size was at 15 GeV/c ~ 4 cm FWHM in the horizontal (drift) plane and a little less in the vertical plane. The beam divergency was negligible inside the 2.56 m of active detecting volume. The particle flux was kept on the average at ~ 10 per burst and a retriggerable veto gate was provided to prevent additional data acquisition triggers during drift time of any registered track. The dead time was determined by vetoes from data conversion and readout to ~ 500 μ s, causing tolerable loss of $\sim 15\%$ of data.

The detector was placed in front of the second of the beam tagging scintillation hodoscopes [8], so that the horizontal position of each particle was determined and registered with < 20 ns time resolution and within 0.5 cm in space. Two threshold Cherenkov counters identified electrons, pions and protons. Position and identification label for each particle was written onto the tape, radioactive source monitors and pressure transducer measurements were also available for recording.

Additional anti-halo large area scintillator with central hole for the beam was used for part of the run, covering most of the drift region exposed to the beam. Some of the electron showers generated near the end of the detector were eliminated this way.

2.4 Gas system and choice of mixtures

The quality of the mostly metallic surfaces exposed to the gas, the Araldite coating of the Vetronite and good quality seals allowed for pumping down to almost 5×10^{-3} Torr. This corresponds, for a detector volume of some 1850 l, to a level of 2-5 ppm of O_2 , improving with each consecutive pumping. A recirculation loop containing "Oxysorb" purifier and molecular sieve and membrane compressor was installed to be used for prolonged multiparticle resolution tests. The measured gas mixtures were filled in from premixed bottles. Heating of the inlet tubes was necessary to speed up the stabilization of temperature during fast filling. The precision of the premixing was $\pm 0.5\%$ in volume.

The gas purity for the Ar + 5% CH_4 mixture used in long runs was 99.995% for Ar with an O_2 concentration < 5 ppm and 99.95% for CH_4 with $O_2 < 30$ ppm. For other measurements the Ar purity was 99.999% with $O_2 < 2$ ppm, the CO_2 purity was similar and the organic quenching agents were 99.95% pure with $O_2 < 30$ ppm.

The gas mixtures were selected so as to have close values of the drift velocity. In fig. 3 the compilation of data from ref. [9] shows that for a 1 kV/cm field strength the "common" point is near 4 cm/ μ s at NTP and at $\sim 20\%$ concentration in argon for the majority of the quenching agents. Mixtures of argon and 20% CH_4 , C_2H_4 , C_2H_6 , C_3H_8 and CO_2 were used. For iC_4H_{10} the chosen concentration was 15%. 5% CH_4 was used for comparison with the extensive data available for this mixture at NTP. One should note here that argon and up to 9% CH_4 mixture is non-explosive (the explosive concentrations are on a few per cent level for the other organic quenchers). Measurements were also performed for 5% C_3H_8 and for two more exotic mixtures with small amounts of xenon: Ar + 2% Xe + 15% CH_4 and Ar + 5% Xe + 15% C_2H_6 . In order to improve the uncomfortably low drift velocity of CO_2 , a mixture of Ar + 10% CO_2 + 10% C_2H_6 was used for some tests.

Fig. 4 shows the field strength dependence of the drift velocity for the chosen mixtures (compiled from ref. [9]).

2.5 Measurements and data processing

Each gas mixture was measured at 0.5, 1, 2 and 3 to 5 atm. First, the beam was aligned on the gating HT grids and the grid transparency optimized for a given drift field. This has been done via on-line display, by adjustments of the grid potentials so as to merge the peaks of truncated means for tagged pions from the sense wire region and from the drift region next to it into a single peak (well positioned in the centre of the ADC dynamic range). In spite of wide range of gas amplification factors for various gas mixtures and sometimes conflicting requirements for the three correlated potential distributions, the drift/no drift peak ratios were > 0.90 . The applied drift fields were mostly in the range of 0.5 to 0.2 kV/cm $\cdot$ atm at 0.5 and 5 atm, respectively.

On the average, ~ 5000 events were then accumulated for each gas and pressure and in two parallel drift positions spaced by 41 cm, as indicated by arrows on fig. 1. Control measurements were also performed along the diagonal of the detector at an angle of $\sim 10^\circ$.

In the off-line analysis, events containing more than 15 particles per spill were rejected. Particle tracks were accepted when passing within ± 5 cm around the beam axis defined by the tagging hodoscopes. The differences of response from sample to sample (originally below $\pm 10\%$) were determined from measured most probable values of individual dE/dx distributions. The corresponding corrections were applied during the off-line analysis, so that the non-uniformity for the full detector length was below $\pm 2\%$.

The cosmic ray background producing ~ 1 -2 hits per spill was mostly vertical, influencing as a big signal only a few samples and thereby having little effect on the truncated mean. Most showers generated by electrons inside the detector were eliminated by the applied cuts. The beam was practically without halo. Protection against ejection spikes was provided by combined data acquisition veto and dead time defining gate. The data accumulation time was typically ~ 1 h for a given pressure and drift position. After temperature stabilization, the gas pressure was constant to within a few millibars at 5 atm.

3. RESULTS

3.1 Resolution

Fig. 5 shows an example of results obtained at 5 atm for a mixture of Ar + 5% CH₄ at full drift (raw data). The distributions in the top part were produced by directly plotting the 64 samples for each tagged track. In the lower part the truncated mean distributions for protons, pions and electrons indicate the reduced relativistic rise at 5 atm pressure. The resolution for uncorrected data was $\sim 8\%$ FWHM.

In fig. 6 we summarize the relative width of the distribution for a single 4 cm sample as a function of gas pressure, for various gas mixtures. The dashed curve represents the expected behaviour for Ar + 5% CH₄ extrapolated from atmospheric pressure measurements, assuming the sample size to be a product of (thickness x pressure). The expected values are in reasonable agreement with results for Ar + 10% CH₄ from ref. [10]. Most of the gas mixtures are clustered together but the resolution is worse than expected from NTP extrapolations without drift.

The pressure dependence of the final resolution of the truncated mean is plotted in fig. 7. At NTP the measured FWHM is 11-12% compared to an expected 10%. In cases where important attenuation of the signal in the drift region was observed only data for the short drift were taken into consideration, so that some of the presented results are a little optimistic.

3.2 Relativistic rise

In fig. 8 is shown the relativistic rise of ionization for $p/\pi/e$ at 15 GeV/c, measured for mixtures of Ar + CH₄. Data for 5% CH₄ are compared with measurements from ref. [2]. Data for 20 and 10% CH₄ from refs [5] and [11] are also plotted. The reduction of the relativistic rise slope and plateau values with increasing pressure is clearly marked. Part of the discrepancy visible at higher pressures could be explained by errors in the I_0 reference values and by different methods of measurement (single sample only in ref. [11]).

Relativistic rise expressed as e/p truncated-mean peak ratio at 15 GeV/c is plotted on fig. 9 as a function of pressure. The rapid decrease of relativistic rise slope with pressure increase is evident. The behaviour of the various gas mixtures is similar, but the more complex hydrocarbons seem to saturate more rapidly. Note the anomaly for the CO_2 mixture.

3.3 Resolving power

When the improvement of resolution with increasing pressure is combined with corresponding reduction of the relativistic rise, we obtain for various gas mixtures the results presented in fig. 10. There the resolving power is expressed in ratio of distance between the tagged peaks of truncated distributions to the standard deviation of the distribution for pions. The top part of the plot shows π/p separation and the bottom part the e/π separation. This plot is valid for 15 GeV/c; the situation will be better at lower and deteriorate for higher particle momenta. Clearly, for dE/dx measurements there seems to be no "magic" gas which is considerably better than the others. The general tendency indicates that with the exception of low percentages of CH_4 and C_3H_8 , the gain by increased pressure becomes marginal already above 2 atm for π/p identification. Note that the e/π identification does not surpass the 3σ level and it is slowly degrading for pressures above 2 atm. A low percentage of CH_4 or C_3H_8 looks more efficient here also. As in results presented on figs 6 and 7, the influence of signal attenuation in the drift space was not taken into account.

The decay of signal due to electron attachment over 41 cm of drift distance as a function of pressure is plotted in fig. 11, as an average ratio of truncated means for tagged pions. With the exception of CO_2 mixtures (which are anyhow too slow for any practical use in high rate drift chambers), most other gas mixtures are acceptable up to ~ 2 atm. The best results at higher pressures were obtained for CH_4 .

3.4 Multitrack resolution

Linearity of response, space charge saturation and its influence on the reliability of the amplitude measurements were investigated for

summed-up signals from quasi-simultaneous particles, The measurements were done in the full drift position using negative pions at 70 GeV/c. Up to ten particles in a fast spill of $< 1 \mu\text{s}$ were hitting a beam spot of $< 2 \text{ cm}$ in diameter. The gas mixture was Ar + 5% CH₄ at 1 atm. The drift velocity was 2.9 cm/ μs , causing a corresponding increase of the horizontal beam size in the space-time reference frame.

Fig. 12 shows the truncated mean for single, double, triple and quadruple particles. Note that the positions of the truncated mean peaks rise more rapidly than might be expected so that, for instance, the ionization of four particles produces a peak at about five times the single peak position. This is caused by the effect of the narrowing of the asymmetric Landau distribution on the truncated mean with increasing ionization deposit. For the single particles the corresponding 4 cm sample Landau distribution is also plotted in the same scale. The general background and contamination from multiple tracks is clearly negligible. Therefore, this single sample distribution has correct shape and may be used as a reference for Monte-Carlo simulation. In case of serious non-linearity caused by space charge for practically simultaneous tracks arriving closely together, the measured and simulated response will be different. In fig. 13 we plot the measured peak position ratios of truncated 40% and overall mean distributions for up to 4 and up to 10 particles. The connecting lines represent the simulated data. No detectable difference in response can be seen with respect to the measurements. More detailed studies of this subject are required, since the integrated multitrack performance is not sensitive enough to show effects on the level of a few per cent. Separation into smaller space-time intervals is needed, but an accumulation of sufficient statistics for tracks running parallel within e.g. 0.5 cm is difficult.

Care is required in the appreciation of effects due to limited ADC range. The fig. 13 clearly shows the non-linearity in the overall mean coming from a cut at < 255 , the point being that the fixed cut-off edge introduces an artificial increase in resolution. The influence of the truncation percentage on the ionization ratio was further studied using the measured Landau single particle distribution from fig. 12; the results are shown in fig. 14 for the means of lowest N% of 64 values. The ratio

clearly increases with decreasing truncation cut, but widening of the distribution excludes <20%> for effective separation. Between 40 and 70% the resolving power, given by the ratio of difference in ionization to σ forms a broad plateau, so the separation efficiency is not affected by the choice of percentage in this region. Nevertheless, it should be kept in mind that the relativistic rise slope is somewhat dependent on the chosen truncation.

Finally, in fig. 15 we compare the resolution obtained for quasi-simultaneous particles with results for Ar + 5% CH₄ from fig. 7, assuming this time that the increase of the number of particles is equivalent to increase of pressure in a given sample thickness. The resolution is apparently worse than expected, for the same number and sample size, from NTP measurements without drift.

4. CONCLUSIONS

Our measurements indicate less favourable limits of resolution attainable in high pressure dE/dx sampling drift detectors than expected from the extrapolation of measurements at atmospheric pressure without drift.

If we discard gas mixtures with marked signal attenuation in the drift space and neglect also the possible influence of diffusion of the track during drift, it seems that the scaling principle applied to the sample size does not rigorously hold, e.g. doubling the pressure is not fully equivalent to doubling the sample size. The same is valid, for instance, for pairs of 2 cm samples versus single 4 cm cells or two particles through a single cell compared to one particle traversing a double-sized sample.

Without trying to find a complete and exact explanation of the complex mechanism involved, we offer the following "rule of thumb" for realistic estimation of resolution of detectors of similar size: the experimental resolution of a detector will be roughly equal to the previously predicted resolution of a device having half its sample size. This includes a safety margin that is absolutely necessary for the design of full-size detectors, if disappointments are to be avoided.

Other scaling principles concerning optimum sample size in (cm x atm) and optimum ratio of signal wire diameter to the sample size are not likely to be affected. In that case, the detector design parameters could be determined from the updated graph in ref. [1] or using semi-empirical formulas proposed in refs [11] and [12].

As an example, let us try to evaluate the maximum attainable resolution in space limited to ~ 1.3 m which is typical of the geometry envisaged for colliding beam detectors [13]. We require resolution $< 7\%$ FWHM. For argon we will need an operating pressure of ~ 8 atm and there will be only a marginal difference in performance by going from 64 samples of 2 cm to 256 samples of 0.5 cm. Obviously, the upper limit of momentum for acceptable π/K separation will be reduced to ~ 25 GeV/c.

The same starting conditions give for xenon ~ 3.5 atm and a 40 GeV/c upper momentum limit for similar sample number and size as in the version for argon. The gain in momentum limit and in thinner pressure vessel walls when using xenon will be probably offset by economical problems (at present the price of xenon is of the order of 25 SF/ℓ).

Careful analysis of possible sources of problems (e.g. signal wire plane/drift region asymmetry, cross-talk, spread in data acquisition triggering, influence of the beam width, signal wire surface and diameter variations, drift field uniformity, rigidity of the electrode structure and precision in positioning of the wires, transparency of the gating grids, space charge effects caused by positive ions, noise and other background from continuously sensitive drift region, residual influence from uncorrected differences in response within pairs of samples, positive induced charge on the HT grid structure etc.) show that the influence of none of the individual effects mentioned above is by itself strong enough to be responsible for the observed broadening of the resolution. It is of course not excluded that some combination of those essentially second order effects might appear on a sufficiently high level to be of influence. In our case, the most important contribution, estimated to account for $\sim 1/3$ of the "missing resolution", seems to stem from positive induced charges. The problem there is to find an acceptable compromise between requirements for perfect decoupling, gate pulse rise/fall time and wire protection in case of discharge.

The gas purity was in our case found to be not too critical for O_2 concentrations of the order of 10 ppm, so that rather simple purification loop or, in case of argon, frequent refilling was sufficient. Ar/CH_4 mixtures offer the lowest signal attenuation in the drift at higher pressure.

There are still some open problems to be studied in detail, e.g. influence of magnetic field on amplitude, exact definition of dE/dx deposit per sample for strongly curved tracks, correlation effects for multiple tracks etc.

The final detector performance should be verified from measurements of a full-scale segment of required geometry. Hopefully, the new generation of faster and cheaper electronic components of the CCD or FADC type, will allow for further improvements in future detectors.

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FIGURE CAPTIONS

- Fig. 1   Layout of the electrode structure.
- Fig. 2   The detector assembly being lowered into the pressure vessel.
- Fig. 3   Drift velocity for various percentages of quenching agents in argon; 1 kV/cm field strength.
- Fig. 4   Drift velocity for chosen gas mixtures as a function of E/p .
- Fig. 5   Example of distributions obtained at 5 atm of Ar + 5% CH₄ in tagged beam at 15 GeV/c, full drift.
Top: 4 cm single sample distributions for protons and electrons.
Bottom: Truncated mean of 64 x 4 cm samples for protons, pions and electrons. Resolution (uncorrected data): $\sim 8\%$ FWHM.
- Fig. 6   Resolution of single 4 cm sample as a function of pressure, for various gas mixtures.
- Fig. 7   Final resolution (truncated mean) of 64 x 4 cm samples as a function of pressure for various gas mixtures.
- Fig. 8   Relativistic rise of ionization in Ar + CH₄ mixtures.
- Fig. 9   Truncated mean of 64 x 4 cm samples; 15 GeV/c e/p peak ratio for various gas mixtures as a function of pressure.
- Fig. 10   Pressure dependence of resolving power D/σ for various gas mixtures at 15 GeV/c. Truncated mean of 64 x 4 cm samples.
Top: π/p separation; bottom: e/π separation.
- Fig. 11   Attenuation of the signal in 41 cm of drift as a function of pressure for various gas mixtures.

FIGURE CAPTIONS (Cont'd)

- Fig. 12 Truncated mean distributions of 64 x 4 cm samples for single, double, triple and quadruple particles. 70 GeV/c pions in Ar + 5% CH₄, NTP.
- Fig. 13 Behaviour of truncated mean of 64 x 4 cm samples for multiple particles. Ar + 5% CH₄, NTP.
- Fig. 14 Truncated mean response for multiple particles with percentage taken for the truncation as a parameter.
- Fig. 15 Comparison of expected and measured resolution for truncated mean of 64 x 4 cm samples, as a function of pressure and for multiple particles at NTP. Ar + 5% CH₄ mixture; pions at 15 GeV/c.

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