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PRESSURE DEPENDENCE OF THE RELATIVISTIC RISE IN NEON AND
HIGHEST ATTAINABLE IONIZATION SAMPLING RESOLUTION IN NEON, ARGON, ETHYLENE AND PROPANE

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Summary

A full-scale detector segment with 128 samples of 2 cm and a 50 cm drift space was used to measure precisely the relativistic rise of ionization from 5 to 70 GeV/c in Ne at 1, 2 and 4 atm. The pressure dependence of dE/dx resolution and of particle separation efficiency was determined at 15 GeV/c in several Ne/C_nH_m mixtures, in Ar/CH₄, pure C₂H₄ and pure C₃H₈. The results are used for optimization of parameters of a compact colliding beam detector suitable for particle identification up to the 30-50 GeV/c momentum range. The $\pi/K/p$ separation is found to be better in Ne, but extends to higher momenta in Ar. Ar is more efficient for e/π separation. The gain in resolution at higher pressures is to certain extent compensated by reduction of the relativistic rise slope, so that the separation efficiency is reduced when the detector dimensions are scaled down with pressure. At 4-5 atm. we obtained slightly better resolution than the 6.0% FWHM ($\sigma = 2.5\%$) record performance of the EPI. In pure C₃H₈ a resolution below $\sigma = 2.0\%$ was reached. Measurements of drift velocities in various Ne mixtures are presented, showing saturated behaviour already at low E/p values.

1. Introduction

The present paper reports on the extension of our previously published studies [1,2] on the optimization of efficiency of particle identification by ionization sampling in the relativistic rise region. The aim of these studies was to determine the design parameters and best gas mixtures for the most compact detector suitable for dE/dx measurements in colliding beam applications. The measurements were realized in a full-scale detector segment with up to 50 cm drift space, in which the number of samples has been doubled to 128 x 2 cm from the previously used 64 x 4 cm [2]. The experimental set-up was already described in detail elsewhere [1,2]. With a full-scale detector segment the problems related to extrapolations from small prototype tests are avoided, the higher order systematic effects affecting the resolution are clearly "visible" and the expected detector performance can be evaluated in a realistic way. It should be remembered that most of the presently operational central detectors for colliding beams (e.g. CLEO, JADE, etc.) are not adequate for full particle identification above the minimum of ionization.

We have measured the pressure dependence of the relativistic rise in Ne and Ar, the attenuation of signals across the drift space due to electron attachment in the gas, and the resolution dependence

on the gas pressure and on the number of samples. The relative merits of Ne, Ar and pure hydrocarbons are discussed with emphasis on the effects of scaling of detector dimensions with pressure.

2. Relativistic rise in neon

The pressure dependence of the relativistic rise in Ne, with an admixture of 10% C₂H₆, was measured as a function of momentum at 1, 2 and 4 atm. using tagged protons, kaons, pions and positrons in the momentum range from 5 to 70 GeV/c. The measurements were performed in an unseparated positive beam (S3 beam at the CERN SPS), tagged by two threshold Cerenkov counters. The beam momentum bite was $\pm 0.25\%$. The relativistic rise was expressed as ratios of truncated means (40% smallest values) from 128 samples of 2 cm. The results are summarized in table 1, where the I/I_0 ratios were rounded to 0.005. In addition to the systematic measurements of Ne + 10% C₂H₆, checks were made on Ne + 10% C₂H₄ at 5 GeV/c and Ar + 5% CH₄ at 5 and 15 GeV/c; results are also listed. The gas gain was identical to the corresponding values used in the previous measurements with 64 samples of 4 cm [2], e.g. about 3×10^3 for Ar + 5% CH₄ at 1 atm., to assure linear response of the detector. The errors are typically ± 0.01 , caused mainly by absolute calibration problems and to a less extent by uncertainties in determination of the individual particle peak position. At 5 GeV/c the measurements for the Ne + 10% C₂H₆ mixture were realized in a "natural" beam containing almost 98% positrons, whereas for the corresponding measurements for Ne + 10% C₂H₄ and Ar + 5% CH₄, a 5 mm Pb filter was used to remove a large fraction of the positrons so that the proton and pion intensities could be increased to yield comparable populations. The final stage of the beam line following the absorber was not sufficient to redefine the relatively broad beam and so only a 10 cm wide central part was selected using the tagging hodoscopes. As an example we show in fig. 1 the very nice particle separation at 5 GeV/c in Ne + 10% C₂H₆ at 4 atm., which is nevertheless suffering from the beam contamination (broadening of the resolution to about 8% FWHM). As a comparison, fig. 2 shows the 30 GeV/c distributions in Ne + 10% C₂H₆ at 2 atm., where the beam is clean and the resolution is $< 8\%$ FWHM at this lower pressure.

The relativistic rise curve for Ne at 1 atm. is plotted in fig. 3 together with the complete Ar relativistic rise curve from [1]. The 5 and 15 GeV/c points for 128 samples in Ar from table 1 are in reasonable agreement; there is little evidence for a 15% increase in slope suggested in [3] for twofold reduction in sample size. The relativistic rise slope is seen to be steeper in Ne than in Ar, but the

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Fermi plateau level is lower in Ne. The theoretical predictions of Sternheimer et al. [4] give, at $\beta\gamma \sim 10^2$, $I/I_0 \sim 1.50$ for both Ne and Ar (about 7% more than measured). At $\beta\gamma \sim 10^3$ the disagreement is about 10%, at $\beta\gamma \sim 10^4$ it is close to 16%. Allison [5] predicts $I/I_0 \sim 1.57$ at $\beta\gamma \sim 8 \times 10^3$ in both Ne and Ar, which is close to our plateau values of 1.59 (Ne) and 1.61 (Ar).

Figs 4 and 5 contain the relativistic rise curves for Ne at 2 and 4 atm. respectively. The dashed curves represent the combined Ar + 5% CH₄ data from this experiment and from [1] (5 atm. pressure in fig. 5). Comparison of the figures shows that for $\beta\gamma \lesssim 10^2$ the 1 atm. and the 2 atm. relativistic rise slopes for each gas are practically identical. Furthermore, the slope for Ne is always steeper than for Ar, but the plateau level is slightly lower. The pressure dependence of the plateau value, I_{pl}/I_0 , is found to go as $p^{-0.065}$ in Ar as well as in Ne. There seems to be a systematic discrepancy with the first results from the TPC measurements at 1.5, 4.0 and 8.6 atm. in Ar/CH₄ [6], where lower values of the plateau were found.

3. dE/dx sampling resolution

In our previous work using 64 samples of 4 cm we have found a significantly better resolution in Ne than in Ar [2]. In order to verify the resolution dependence on sample size and number, the present measurements were made using 128 samples of 2 cm. The gas gain was kept as for the 4 cm samples, i.e. at atmospheric pressure the gain was $\sim 3 \times 10^3$ for Ar, $\sim 6 \times 10^3$ for Ne, $\sim 4.3 \times 10^3$ for C₂H₄ and $\sim 2.7 \times 10^3$ for C₃H₈. At higher pressures the product of energy loss times gain was kept constant to avoid saturation. The loss of signal due to halving the sample size was compensated by a twofold increase in the amplifiers' gain. The corresponding increase in the noise and temperature coefficient influence remained at a still acceptable level of $\sim 2\%$ r.m.s. of the most probable ionization signal.

The measurements were performed as in [1,2] at 15 GeV/c in an unseparated tagged positive beam with $\Delta p/p \sim \pm 0.25\%$. The running conditions were practically identical. High purity gas was used with O₂ contamination < 5 ppm for Ne and Ar and ~ 10 -20 ppm for the hydrocarbons. The beam flux was limited to < 16 particles in ~ 20 ms spill, a dead-time defining gate prevented pile-up problems. The transparency of the gating grids separating the drift volume from the detecting cells was adjusted for each measurement to be > 0.94 . The asymmetry in response inside the cells was generally $< 5\%$ (this is not important, when all electrons drift always from the same side of the cells). The tagging hodoscopes were used to define 0.5 cm wide horizontal slices of the beam inside the cells and near the drift region boundary and the resolution was measured separately for each slice. In contrast to [2], this time the resolution measured inside the cells was always found to be slightly better than the one obtained in the drift region.

The results are summarized in table 2 and could be compared column by column to the results from [2]. The errors are typically ± 0.005 for the attenuation during drift (difference between 47 cm and 6 cm of drift distance), $\pm 1\%$ and $\pm 0.2\%$ for the width of the single sample and for the truncated mean distributions respectively. The e/p ratios were rounded to 0.005. For the resolving power, defined as $D/\sigma = (I_2 - I_1)/\sigma_1$, the errors in resolution are dominant.

The doubling of the number of samples seems to bring only a marginal improvement for the Ne + 10% C₂H₆ mixture. There was virtually no improvement for pure C₂H₄ and C₃H₈, but the resolution improved, on the average, by about 15% for Ar + 5% CH₄. Ne with other quenching agents (CH₄, C₂H₄, C₃H₈, iC₄H₁₀) produced results similar to the Ne + 10% C₂H₆ mixture. The differences in performance were small and, in general, an advantage in better resolution was compensated by lower relativistic rise and/or more pronounced electron attachment, so that the resolving power was practically the same. This suggests that the optimum sample thickness in Ne is above the 5 cm.atm. which is generally accepted for Ar. Nevertheless, with the exception of e/π separation, mixtures of Ne remain more efficient than Ar and have also the additional advantage of 3 x longer radiation length. Furthermore, drift velocities in Ne mixtures show conveniently flat E/p dependence starting from low E/p values. Some new measurements of drift velocities were realized, using a small test chamber with 10 cm drift space, for several concentrations of CH₄, C₂H₂, C₂H₄ and iC₄H₁₀ in Ne. They are plotted in figs 6 and 7 (see also [2] for CO₂, C₂H₆ and C₃H₈). Fig. 7 in addition contains drift velocities for some 3-component mixtures of Ne/Ar/C_nH_m which show similar "flat" v_d dependence on E/p . On the average, the saturated drift velocities in Ne mixtures are in the 3.5-4.0 cm/ μ s range. Some tendency to spurious discharges was observed in the case of Ne/iC₄H₁₀ mixtures for low quenching agent concentrations.

As a verification of the resolution dependence on the number, n , of 2 cm samples, the data for 15 GeV/c pions in Ne + 10% C₂H₆, Ar + 5% CH₄, C₂H₄ and C₃H₈ were re-analyzed, using only 112, 96, 80, 64 and 48 of the available 128 samples. The results were normalized to resolutions obtained for the full detector length and plotted for several pressures in fig. 8. The dashed lines represent the $n^{-0.45}$ dependence derived from the EPI data [7] for Ar at 1 atm. (Allison and Cobb [3] proposed $n^{-0.46}$ and Walenta [8] and Vavra et al. [9] used $n^{-0.43}$ in their semi-empirical approach). For Ar at 1 atm. the results follow the $n^{-0.45}$ dependence, but at higher pressures the deviation indicates the onset of, as yet, unsolved systematic problems. In Ne the n -dependence is steeper (close to $n^{-0.50}$) and seems to be the same for 1, 2 and 4 atm. In pure C₃H₈ the agreement with $n^{-0.45}$ is excellent, but pure C₂H₄ follows roughly an $n^{-0.30}$ dependence.

The comparison of the width of single sample distributions from [2] and table 2 shows reasonable agreement for equal sample depths expressed in cm.atm. On the other hand, there is a growing discrepancy with the $(pt)^{-0.32}$ dependence proposed for Ar in [3], for $(pt) \lesssim 2$ cm.atm.

4. "Ultimate" resolution

The best resolution values presented in the previous paragraph were still below the expected performance derived from the EPI data (realized in extremely clean conditions, without drift). In order to remove the residual systematic errors related to the background from the large volume drift region, another set of measurements was performed, at 15 GeV/c, with the drift field switched off completely. The resulting small reduction of gain was compensated by a minor adjustment of the gating grid potentials. From the 2 cm wide section of the beam (4 cm FWHM) falling within the row of detecting cells, 0.5 cm wide slices were again selected by the tagging hodoscopes and treated separately in search

for the best resolution. The response variations across the cells were found to be within the 0.94-1.02 range. In spite of this asymmetry, the resolutions obtained from both sides of the signal wires were practically identical. The beam flux was kept at the same level as in the "active drift region" case, thereby in effect reducing the mean number of ionizing tracks per spill even further. As an example of the results, fig. 9 shows the $p/\pi/e$ distributions in Ne + 10% C₂H₆ at 2 atm. with resolutions of $\lesssim 7.5\%$ FWHM. As can be seen from table 3, columns (a), the single sample resolutions remained within the errors the same as in table 2, but the truncated mean distributions improved by, on the average, about 9% for Ne + 10% C₂H₆ and by about 13% for Ar + 5% CH₄, with corresponding increase in the resolving power D/σ . In pure C₃H₈ the resolution reached the record level of $\sigma \lesssim 2.0\%$.

As a check to see if some potential improvement in resolution was still possible if the signal to noise ratio was better, this whole set of measurements was repeated with the gas gain increased by a factor of 4 (i.e. $\sim 1.2 \times 10^4$ for Ar at 1 atm., etc.) and the amplification factor reduced to $1/4^{\text{th}}$. The results are in table 3 in columns labelled (b). It should be noted here that the E/p values for the Ar + 5% CH₄ were reduced in order to run very close to the peak v_d (3.9 cm/ μ s) for this mixture. There is an evident improvement in both single sample and final resolutions for all measured gases and at all pressures, but the e/p ratios, if compared to table 2, clearly indicate the onset of non-linear response (saturation) which more than compensates the gain in resolution, so that the particle separation D/σ tends to be worse than in columns (a). This is more evident from the D/σ plots in fig. 10, where the low gain results are given by the points and the tips of the arrows indicate the variations obtained at high gain. It is also quite clear that at these rather extreme resolutions the errors in determination of the width of individual ionization loss distributions become more difficult to handle. At 15 GeV/c, about 4σ e/π separation (decreasing slowly with pressure) is possible in Ar, in Ne it is worse by about 1σ . The π/p is at about 7.5σ in Ne and worse by $\sim 0.5\sigma$ in Ar, growing slowly with pressure. The improvement in separation at higher pressures is rather modest. Note that the corresponding performance of the EPI (128 x 6 cm in Ar at 1 atm.) [10] would be about 6.6σ for e/π and close to 10σ for π/p separation. C₂H₆ and C₃H₈ are less satisfactory due to low relativistic rise, with additional problems caused by electron attachment.

The final resolution dependence on pressure is plotted separately in fig. 11, which contains also the 64 x 4 cm Ne and Ar data from [2] (taken with active drift region). The resolution in Ne and Ar is practically identical for 128 x 2 cm samples and scales roughly as $p^{-1/3}$ for both Ne and Ar. The arrows indicate the decreasing distribution width at high gas gain. The EPI resolution (plotted at the total detector depth equivalent of 7.68 m) now fits the data within the experimental errors, so that there is no longer any "missing" resolution. Nevertheless, if compared to the EPI predictions for Ar from [11], the agreement at 1 atm. is excellent, but at 2 and 5 atm. the achieved resolution is worse by about 12% and 17% respectively. The errors in determination of the measured distribution widths do not allow to verify if the doubling of the number of samples for $L = \text{const.}$ follows the pressure dependent improvement predicted in [11].

Fig. 12 shows the pressure dependence of the relativistic rise at 15 GeV/c for e/π , e/p and π/p . The more efficient π/p separation in Ne is due to the steeper slope of the relativistic rise, the lower electron separation is caused by the depressed plateau. At high gas gain (arrows) the non-linearity is affecting the response in Ne and Ar in a similar way.

5. Particle separation efficiency

The momentum dependence of particle separation expressed as D/σ for various pairs of particles in Ne + 10% C₂H₆ and Ar + 5% CH₄ was calculated using the measured relativistic rise curves for 1, 2 and 4(5) atm. For the corresponding resolutions the best values obtained without the drift field (table 3, column a) were taken. The resolution in per cent was assumed to be constant within the treated momentum range [10]. The results are plotted in figs 13-15. With the exception of e/π separation, the performance of Ne is, below 30-40 GeV/c, better by up to 0.5σ , due to the steeper relativistic rise slope. Above this momentum, Ar becomes more efficient. For the $\pi/K/p$ separation, the performance peaks more sharply into the 5-10 GeV/c range as the pressure increases. The e/π separation is practically independent of pressure. It should be kept in mind that the required level of resolving power for particle identification depends on the relative abundancies of the involved particles that enter into the probability equations [7]. In the case of a highly predominant particle, the limits of reliable separation will be imposed by tails in the distribution of ionization loss.

For a constant detector length the particle separation clearly improves with pressure, with the peak performance shifting towards lower momenta. A quite different situation arises if, in order to obtain a more compact detector, the length is reduced with corresponding increase in pressure. As an example, the total detector length of 2.56 m was scaled down to 1.28 and 0.64 m, using always 128 samples. The modified scales for σ are indicated on the right side in figs 14 and 15, separately for Ne and Ar. In table 4, we summarize the momentum ranges for which the e/π , π/K , π/p and K/p separations are above 2σ and 3σ levels. On the average, for both Ne and Ar the peak separation remains at about 4.5σ for π/K and at about 7σ for π/p . The K/p separation is too close to the 2σ limit. The upper momentum limits are considerably reduced at higher pressures and the difference between Ne and Ar becomes marginal. In general, the "compact" detector is less efficient than its atmospheric pressure version. Increasing further the number of samples will not bring any substantial improvement. An 0.5 cm sample size is already close to the limits imposed by mechanical precision tolerances, correlations caused by crosstalk, signal to noise ratio problems, primary ionization fluctuations, etc.

With respect to the relative merits of Ne versus Ar it should be noted that the 0.5σ difference near the peak of the $\pi/K/p$ separation efficiency corresponds in our case, if converted into detector depth, to a reduction by roughly 25%.

6. Conclusions

During the present measurements the best resolution was obtained when the particles were passing directly inside the detecting cells and the drift field was switched off. The observed broadening of the resolution when the drift region was active could be explained by the combined effects of background particles and noise, space charge and higher event rate. These effects were investigated separately and their influence was found in each case to be too close to the threshold of detection for clean analysis.

In general, comparisons with our results including drift indicate that a detector consisting of a matrix of many small cells would be more efficient than one with a large drift space. Relative merits of single or multi-hit electronics in connection with two track resolution will not be discussed here, but clearly the large drift approach will suffer from residual losses in the gating grid transmission as well as from correlation effects caused by diffusion and will be more sensitive to gas impurities and especially to the influence of the space charge.

From the measurements it could be deduced that decreasing the detector dimensions and proportionally increasing the pressure for a constant number of samples leads to a reduction in particle separation efficiency.

In the present conditions Ar gives best e/π separation, Ne is more efficient for $\pi/K/p$ separation. At the peak of the $\pi/K/p$ separation efficiency, use of Ne should allow about 25% saving in the detector depth in comparison to Ar.

Various Ne mixtures were compared and their performance found to be similar. All of them show saturation of the drift velocity already at low E/p values. Pure hydrocarbons are less efficient in the relativistic rise region, but their very good resolution could be attractive for use below the minimum of ionization.

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TABLE 1

Relativistic rise measurements in Ne and Ar; truncated mean
(lowest 40%) of 128 x 2 cm samples.

Gas	GeV/c	Particle	$\delta\gamma$	I/I_0			
				1 atm.	2 atm.	4 atm.	5 atm.
Ne + 0.1 C ₂ H ₆	5	p	5.3	1.005	1.005	1.015	
		π	35.8	1.285	1.275	1.245	
		e	9785	1.600	1.525	1.440	
	10	p	10.7	1.070	1.075	1.075	
		π	71.6	1.390	1.370	1.320	
		e	19570	1.590	1.530	1.445	
	15	p	16.0	1.135	1.135	1.130	
		π	107.5	1.435	1.405	1.360	
		e	29350	1.585	1.520	1.440	
	20	p	21.3	1.185	1.185	1.165	
		π	143.3	1.480	1.440	1.380	
		e	39140	1.595	1.530	1.435	
	30	p	32.0	1.255	1.260	1.235	
		π	214.9	1.520	1.480	1.410	
	50	p	53.3	1.330	1.320	1.290	
		K	101.3	1.420	1.400	1.350	
		π	358.2	1.530	1.490	1.415	
	70	p	74.6	1.385	1.380	1.325	
		K	141.8	1.490	1.450	1.385	
		π	501.4	1.555	1.505	1.425	
Ne + 0.1 C ₂ H ₆	5	p	5.3	1.005	1.005	1.010	
		π	35.8	1.295	1.280	1.260	
		e	9785	1.610	1.535	1.455	
Ar + 0.05 CH ₄	5	p	5.3	1.010	1.010		1.010
		π	35.8	1.260	1.260		1.225
		e	9785	1.610	1.540		1.450
	15	p	16.0	1.125	1.125		1.120
		π	107.5	1.410	1.370		1.330
		e	29350	1.615	1.535		1.445

TABLE 2

Results of measurements at 15 GeV/c for various gas mixtures with drift region active;
128 x 2 cm samples, low gas gain.

Gas	p [atm.]	E/p [kV/cm . atm.]	v_d [cm/us]	Atten. Δ : 41 cm	FWHM [%]		<40> e/p	D/ σ	
					2 cm	<40>		e/ π	π /p
Ne + 0.1 CH ₄	1	0.20	3.33	1.000	72	9.5	1.430	2.7	7.2
	2	0.20	3.31	0.985	63	8.0	1.365	2.6	7.5
	4	0.10	2.54	0.945	49	6.4	1.285	2.4	7.6
Ne + 0.1 C ₂ H ₆	1	0.20	3.41	0.980	75	9.4	1.415	2.8	6.8
	2	0.20	3.38	0.960	60	7.8	1.350	2.6	7.5
	4	0.20	3.37	0.850	50	6.8	1.290	2.4	7.3
Ne + 0.1 C ₂ H ₄	1	0.30	3.10	1.000	72	9.4	1.410	2.6	6.9
	2	0.31	3.12	0.970	60	7.9	1.350	2.5	7.4
	4	0.20	2.88	0.920	50	6.6	1.280	2.4	7.2
Ne + 0.1 C ₃ H ₈	1	0.22	2.93	0.985	70	8.6	1.380	2.6	7.1
	2	0.25	3.02	0.970	57	7.5	1.320	2.5	7.2
	4	0.20	2.85	0.935	48	5.7	1.265	2.6	7.7
Ne + 0.06 iC ₄ H ₁₀	1	0.25	3.04	0.995	71	8.6	1.390	2.7	7.3
	2	0.25	3.01	0.975	56	7.3	1.330	2.5	7.6
	4	0.10	1.90	0.850	46	6.1	1.280	2.3	7.9
Ar + 0.05 CH ₄	1	0.17	3.52	1.000	71	10.4	1.430	3.2	5.8
	2	0.18	3.48	1.000	58	7.6	1.365	3.6	6.7
	5	0.15	3.69	0.960	49	6.1	1.285	3.3	7.1
C ₂ H ₆	1	0.33	3.05	0.960	54	6.9	1.215	1.8	5.4
C ₃ H ₈	1	0.35	2.29	0.920	42	5.1	1.165	1.9	5.6

TABLE 3

15 GeV/c results with drift field switched off. The gas gain for columns (b) is 4 times that of columns (a).

Gas	P [atm.]	FWHM [%]				<40>	D/σ			
		2 cm		<40>		e/p	e/π		π/p	
		(a)	(b)	(a)	(b)	(b)	(a)	(b)	(a)	(b)
Ne + 0.1 C ₂ H ₆	1	73	70	8.9	8.3	1.380	2.8	2.8	7.4	7.4
	2	60	58	7.5	6.6	1.310	2.7	2.6	7.8	7.9
	4	51	47	5.7	5.2	1.245	2.7	2.5	8.3	8.2
Ar + 0.05 CH ₄	1	74	73	8.3	8.0	1.385	4.0	3.8	7.2	7.0
	2	62	56	7.3	6.7	1.325	3.8	3.8	7.2	7.0
	5	49	46	5.5	4.8	1.250	3.7	3.9	7.8	7.7
C ₂ H ₄	1	53	48	6.0	5.2	1.185	2.0	2.0	6.2	6.1
C ₃ H ₈	1	43	38	4.7	4.5	1.135	2.0	1.6	6.0	5.4

TABLE 4

Expected performance for a scaled-down detector using 128 samples

Gas	Sample [cm . atm.]	L _{tot.} [m]	Max. D/σ			Separation > 2σ (> 3σ) [GeV/c]			
			π/K	π/p	K/p	e/π	π/K	π/p	K/p
Ne + 0.1 C ₂ H ₆	2 x 1	2.56	5.0	7.5	2.7	< 20 (< 13)	1.5 - 54 (1.8 - 30)	2.0 - 110 (2.3 - 75)	5.5 - 45
	1 x 2	1.28	4.6	7.0	2.5	< 20 (< 11)	1.5 - 43 (1.7 - 25)	2.0 - 86 (2.3 - 62)	6.5 - 35
	0.5 x 4	0.64	4.3	6.3	2.2	< 20 (< 8)	1.5 - 30 (2.0 - 16)	2.0 - 70 (2.4 - 43)	7.5 - 20
Ar + 0.05 CH ₄	2 x 1	2.56	4.4	6.9	2.2	< 45 (< 23)	1.5 - 75 (1.9 - 30)	2.0 - 190 (2.3 - 115)	7.0 - 30
	1 x 2	1.28	4.5	6.8	2.2	< 37 (< 19)	1.5 - 53 (1.8 - 28)	2.0 - 135 (2.3 - 80)	8.0 - 30
	0.4 x 5	0.64	4.1	6.2	2.1	< 20 (< 12)	1.5 - 32 (2.1 - 16)	2.0 - 90 (2.5 - 46)	8.5 - 16

Fig. 1 5 GeV/c protons, pions and positrons in Ne + 10% C₂H₄ at 4 atm. High background from lead absorber.

Fig. 3 Relativistic rise at 1 atm. in Ne and in Ar.

Fig. 2 30 GeV/c protons and pions in Ne + 10% C₂H₆ at 2 atm. Clean beam.

Fig. 4 Relativistic rise at 2 atm. in Ne and in Ar.

Fig. 5 Relativistic rise in Ne at 4 atm. and in Ar at 5 atm.

Fig. 7 Drift velocities in mixtures of Ne + iC_4H_{10} and in 3-component mixtures Ne/Ar/ C_nH_m .

Fig. 6 Drift velocities in several Ne mixtures.

Fig. 8 Resolution dependence on the number of samples in Ne, Ar, C_2H_4 and C_3H_8 .

Fig. 9 Example of distributions obtained at 15 GeV/c without drift field.

Fig. 10 Resolving power at 15 GeV/c as a function of pressure in Ne, Ar, C₂H₄ and C₃H₈. The arrows indicate results obtained at high gas gain.

Fig. 11 Resolution dependence on pressure, measured at 15 GeV/c.

Fig. 12 Pressure dependence of the relativistic rise at 15 GeV/c.

Fig. 13 Expected particle separation in Ne and Ar at 1 atm. Truncated mean of 128 x 2 cm samples.

Fig. 14 Expected particle separation in Ne and Ar at 2 atm.

Fig. 15 Expected particle separation in Ne at 4 atm. and in Ar at 5 atm.