dE/dx MEASUREMENTS IN Ne, Ar, Kr, Xe AND PURE HYDROCARBONS

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Ionization sampling resolution and relativistic rise at 15 GeV/c were compared at different pressures in neon, argon, krypton, xenon and pure hydrocarbons, using a detector consisting of 64 samples of 4 cm and a drift space of up to 50 cm. Best results were obtained for π/p separation in neon ($>6.7\sigma$) and for e/π separation in xenon ($>4.8\sigma$). Pure ethylene and propane were comparable to argon mixtures for π/p separation, but the corresponding e/π separation suffered from a lower relativistic rise. The signal attenuation by electron attachment was more pronounced in heavier hydrocarbons. Drift velocity measurements are presented and E/p limits imposed by requirements of dE/dx resolution are discussed.

1. Introduction

In a study of optimized design parameters for a compact detector suitable for particle identification by dE/dx sampling in colliding beam experiments, a variety of gas mixtures were investigated in order to establish optimum operating conditions at reasonably low pressure. The main interest is in attaining efficient particle separation up to 10–20 GeV/c momentum range, which necessitates a dE/dx resolution below 8% fwhm. At the same time, a compromise solution must be found to contradictory demands for best possible resolution (high operating pressure, heavy gas) and preservation of the relativistic rise slope (limited pressure). For a realistic assessment of the influence of several second order effects incipiently affecting the detector performance on a first order level, it is essential to use a full scale detector segment.

The present experiment is a continuation of a detailed work which was dedicated to a study of limits of resolution and linearity of response in argon mixtures at higher pressures with up to 50 cm of drift [1].

2. Experimental set-up

The detector geometry, associated electronics, beam layout, tagging equipment and dedicated computer have been described in detail in a previous paper [1]. Here, we recall only the essential features of the device and of the method of measurement. The detector consists of 64 pairs of 2×2 cm² proportional cells, separated by a double grid from a 50 cm drift space. The proportional cells were created by stretching parallel wires with 1 cm spacing. The distance between the two separation grids

is 0.5 cm. The gas amplification factor was kept low (in the range of 10^3) to assure linear detector response. The grid transparency was adjusted each time using a method described in ref. 1 and was always above 94%. The charges collected by the individual cell pairs were integrated, amplified and processed by a set of 64 ADCs with 8-bit resolution. After application of corrections for individual cell response the data were evaluated using a truncated mean (lowest 40%) as an estimator of the energy loss.

The measurements were performed at 15 GeV/c in a tagged beam containing protons, pions and positrons with a spot size of 4 cm fwhm and momentum bite of $\pm 0.25\%$. The flux was kept low in order to avoid pile-up and background problems.

The pressure vessel housing the detector was designed for pressures up to 6 atm. The surface quality of all internal parts exposed to the gas allowed for pumping down to about 5×10^{-3} Torr, corresponding to a level of 2–5 ppm of O₂ contamination. A recirculation loop containing membrane compressor, molecular sieve and Oxisorb purifier was used when required.

The purity of the gases in the tests were as follows:

Ne > 99.99% pure, with	O ₂	≤ 1 ppm,
	N ₂	≤ 5 ppm,
	H ₂ O	≤ 2 ppm,
	He	≤ 100 ppm;
Ar > 99.995% pure, with	O ₂	≤ 5 ppm,
	N ₂	≤ 10 ppm,
	H ₂ O	≤ 5 ppm;
	He	≤ 100 ppm;
Kr > 99.99% pure, with	O ₂	≤ 1 ppm,
	N ₂	≤ 20 ppm,
	H ₂ O	≤ 2 ppm,
	Xe	≤ 50 ppm;

Xe > 99.999% pure, with

O_2	$\leq$	1 ppm,
N_2	$\leq$	1 ppm,
H_2O	$\leq$	5 ppm,
Kr	$\leq$	1 ppm.

The hydrocarbons were $\geq 99.95\%$ pure, with $O_2 \leq 10$ ppm, $N_2 \leq 50$ ppm, $H_2O \leq 5$ ppm and C_mH_n contamination ranging from ≤ 100 ppm for CH_4 to ≤ 500 ppm for iC_4H_{10} .

3. Drift velocity measurements

A small test chamber consisting of four cells of 2×2 cm² section and a drift space of 10 cm was constructed for the drift velocity (v_d) measurements. A collimated ^{106}Ru β -source was beamed across the chamber and a pair of scintillation counters in coincidence at the exit window served as a trigger for the pulse height analyser and time to amplitude converter. The two central collection cells were used for v_d and β -resolution measure-

ments and only one of these for checking the X-ray resolution. The total detector volume was only ~ 1 litre and a vacuum of 10^{-3} Torr was easily obtained prior to filling.

The results of these measurements are displayed in figs. 1–3. In fig. 1 we plot the drift velocity characteristics found in neon with various quenchers, i.e. CH_4 , C_2H_2 , C_2H_6 , C_3H_8 , iC_4H_{10} and CO_2 as well as mixtures including 45% argon. As can be seen, sufficiently fast saturated drift velocities down to very low E/p values could be achieved with several quenchers. In neon/argon mixtures a higher percentage of C_2H_6 will be required. The Ne + 10% C_2H_4 (not plotted) follows Ne + 10% CH_4 up to 0.7 kV/cm and then continues along the Ne + 10% C_2H_6 curve.

Drift velocities for argon with various quenchers are illustrated in the upper part of fig. 2. Included is the mixture (suggested in ref. 2) of Ar + 9% CO_2 + 1% CH_4 which shows little difference from Ar + 10% CO_2 . Acetylene gives a high saturated v_d and some experimentalists use this in spite of the additional safety problems. Measurements for other acetylene concentrations can be found in refs. 3–5.

Fig. 1. Drift velocity for neon and neon/argon with various quenchers.

Fig. 2. Drift velocity for argon, krypton and xenon with various quenchers.

Fig. 3. Drift velocity for pure hydrocarbons.

The middle part of fig. 2 shows drift velocities for several mixtures of krypton with methane, ethane or propane. The lower part of fig. 2 presents results for xenon. Drift velocities for higher concentrations of ethane and for 20% CO_2 can be found in refs. 6 and 7.

In fig. 3 we summarize the measurements for pure methane, ethylene, ethane, propane and isobutane. They confirm results from refs. 8–10. Measurements for mixtures of isobutane/methane, isobutane/ethane, isobutane/propane and of propane/ethylene and propane/ethane are also presented. With the exception of ethane, none of these hydrocarbons possess the desired saturated v_d characteristic.

4. dE/dx sampling

4.1. Single sample resolution

Precise experimental determination of a single proportional counter response to relativistic particles is not always straightforward. It is difficult to compare results from different publications, especially when β -sources were used (problems of collimation, scattering, energy spread, etc.). Also, the gas purity, quenching agent concentration, electronics response, noise level, signal wire quality, gas amplification factor and other parameters rarely have close values in different experiments, thus making comparison even more difficult. It should also be kept in mind that linearity of response at optimum resolution could be achieved only at low gas amplification factors in the region of several thousands. Concerning this linearity our results agree with detailed findings of ref. 11. It is evident that to maintain good

linearity and resolution necessary for ionization measurements, there is a limit to the maximum E/p values that could be used and this may conflict with the saturated v_d requirements demanded for concurrent precise coordinate measurements.

In several papers treating, theoretically and experimentally, Fano factors of various gas mixtures (refs. 5 and 12–16) it was shown that addition of acetylene leads to an increase of ionization yield in argon. A Fano factor value of 0.075 seems to be attainable. Unfortunately, any resolution improvement can be expected only at very low gas amplification factors and/or at low pressures, where the ion yield is low. At 1 atm we obtained resolution comparable to ordinary argon/methane mixture, with undetectable influence on the response to relativistic particles. Gas mixtures containing acetylene require special safety precautions and are therefore not very practical to use.

Our results for 4 cm samples obtained with pions at 15 GeV/c by using all 64 samples of the detector, corrected for individual variations, are summarized in table I. The corresponding plot is given in fig. 4, where the relative width of the Landau distribution is shown as a function of sample depth in atm·cm. Keeping in mind the above mentioned difficulties of directly comparing results from different experiments, several important factors of resolution dependence on the gas filling emerge:

(a) The results for Ar + 5% CH_4 are noticeably improved compared to our prior measurements [1]. This is due to more careful decoupling of the grid system and also to more stringent selection criteria being applied to the beam width and to the dead time definition vetoes. There is a fair agreement with data for Ar + 10% CH_4 measured by Hasebe [16] (dashed curve); the intrinsic counter resolution is included.

(b) Unexpected results were found for Ne + 10% C_2H_6 . For this mixture the resolution was slightly better than for argon. Argon/neon mixtures gave resolutions between the values for neon and for argon. For neon the disagreement with measurements of West [17] and Onuchin [18] (indicated by dotted curve) is on the level of 20%. This corresponds to more than a factor of two in the equivalent sample depth.

(c) The resolution for a mixture of Kr + 5% CH_4 + 5% C_2H_6 was worse than for Ar/ CH_4 , but this result should be taken with reserve. Unfortunately, all atmospheric krypton is now contaminated by the β -emitting ^{85}Kr isotope with half-life of 10.6 y. The resulting background is obviously worse for bigger samples and at higher gas pressures. In spite of broadening of our resolution caused by this effect, our results are still narrower by ~ 10 –12% than results from ref. 17 (dotted curve).

(d) Single sample resolution for Xe + (1–3)% C_3H_8 seems to be comparable to the Ar/ CH_4 values at atmo-

Table 1
Summary of experimental results.

Gas mixture	p [atm]	E/p [kV/cm· atm]	v_d [cm/ μ s]	Atten. Δ : 41 cm	Fwhm [%]		$\langle 40 \rangle$ e/p	D/σ_π	
					4 cm $\langle 40 \rangle$			e/π	π/p
Ne+0.1 C ₂ H ₆	0.5	0.26	3.06	1.000	70	12.3	1.464	2.53	5.72
	1.0	0.31	3.13	1.000	57	9.6	1.392	2.51	6.66
	2.0	0.32	3.17	0.980	47	8.1	1.335	2.37	6.80
	4.0	0.21	2.88	0.960	41	6.7	1.278	2.22	6.85
Ar+0.45 Ne+ 0.1 CH ₄	0.5	0.22	4.04	0.998	75	12.6	1.483	2.88	5.38
	1.0	0.21	3.93	0.990	59	9.9	1.416	2.97	6.02
	2.0	0.21	3.95	0.982	50	8.4	1.348	2.96	6.26
	4.0	0.21	3.92	0.972	39	7.0	1.297	2.93	6.59
Ar+0.45 Ne+ 0.1 C ₂ H ₆	0.5	0.30	3.52	0.997	71	12.8	1.475	2.73	5.30
	1.0	0.31	3.43	1.000	57	10.0	1.392	2.82	5.80
	2.0	0.31	3.45	0.998	46	8.4	1.337	2.79	6.05
	4.0	0.21	3.41	0.980	38	7.1	1.283	2.79	6.21
Ar+0.05 CH ₄	0.5	0.16	3.65	1.000	71	13.4	1.491	2.98	4.92
	1.0	0.18	3.61	1.000	59	11.1	1.435	3.02	5.29
	2.0	0.19	3.54	0.996	50	9.2	1.361	3.02	5.67
	5.0	0.16	3.67	0.986	39	7.1	1.290	3.01	5.98
Kr+0.05 CH ₄ + 0.05 C ₂ H ₆	0.5				78	11.8	1.548	4.14	5.64
	1.0				63	9.3	1.485	4.57	6.59
Xe+0.019 C ₃ H ₈	0.125	0.51	1.37	1.000	108	22.0	1.787	3.34	3.90
	0.25	0.44	1.32	1.000	81	15.8	1.663	3.97	4.85
	0.54	0.41	1.44	0.982	68	11.6	1.582	4.59	5.75
Xe+0.036 C ₃ H ₈	0.9	0.40	1.95	0.996	62	9.8	1.513	4.77	6.39
Xe+0.012 C ₃ H ₈	1.0	0.37	1.21	0.980	60	(11.0)	1.506	(4.19)	(5.60)
CH ₄	1.0	0.31	6.33	0.998	45	7.4	1.210	1.44	4.98
	2.0	0.32	6.47	1.000	36	6.1	1.160	1.47	4.49
C ₂ H ₄	1.0	0.34	3.02	0.970	41	6.6	1.209	1.75	5.57
C ₂ H ₆	1.0	0.36	4.02	0.970	38	6.3	1.181	1.57	4.98
	2.0	0.37	4.04	0.930	31	5.7	1.139	1.30	4.35
	3.0	0.31	3.66	0.880	29	5.7	1.120	1.14	3.86
C ₃ H ₈	1.0	0.36	2.29	0.82	34	5.3	1.163	1.65	5.49
	2.0	0.37	2.32	0.65	29	5.3	1.125	1.29	4.14
C ₃ H ₈ +0.2 C ₂ H ₆	1.0	0.35	2.50	0.86	34	6.3	1.165	1.43	4.65
	2.0	0.37	2.51	0.66	28	5.4	1.129	1.38	4.13
iC ₄ H ₁₀ +0.2 C ₂ H ₆	1.0	0.74	2.70	0.32	32	6.2	1.152	1.37	4.26

spheric pressure and improves more rapidly at lower pressures. Comparison with other data, for Xe + 10% CO₂ [18], Xe + CH₄ (Commichau [19]), Xe + 7.5% CH₄ + 5% C₃H₈ (Walenta [20]), Xe + 1.5% N₂ (Alichanian [21]), Xe + 10% C₃H₈ and Xe + 18% methylal (Fischer [22]), show considerable disagreements between various experiments. This could be explained partially by the sensitivity of xenon to impurities. The rather optimistic results of some experimenters [18] may be attributed to the method of summing-up several thin samples to obtain data for a thick sample equivalent. If used for

distribution of ionization losses this method will, under certain conditions, produce more symmetrical results with the most probable value displaced towards the mean.

(e) Pure hydrocarbons (methane, ethylene, ethane, propane, isobutane) and some hydrocarbon mixtures were measured at 1 atm and at moderately high pressures. Operation of hydrocarbon filled detectors below atmospheric pressure is to be avoided for obvious safety reasons. Best resolutions were obtained with isobutane/ethane and propane/ethane mixture. Note

Fig. 4. Single sample resolution for different gas mixtures as a function of sample depth.

that in order to obtain resolution comparable to 4 cm of C_3H_8 at atmospheric pressure, about 40 cm length or 10 atm pressure will be required in Ar/CH_4 . (At 1 cm sample thickness the "gain in length" is less by a factor of two.) This looks very attractive, certainly, but we shall see later that the greater part of this potential improvement is lost due to the consequent reduction of the relativistic rise slope and plateau and by more pronounced attachment in heavy hydrocarbons. Other data for pure CH_4 [22] and C_3H_8 [20,22] indicate a different slope for the resolution dependence on the detector depth.

In order to illustrate more clearly the surprisingly good resolution of the neon/ethane mixture, we plot in fig. 5 the resolution for a single 4 cm sample at 1 atm as a function of average molecular weight, for the noble gases and for hydrocarbons. The results for neon, argon, krypton and xenon show practically constant resolution. For comparison, corresponding results from refs. 16–18, 20 and 22 are also plotted. Their results are poorer in

Fig. 5. Single 4 cm sample resolution as a function of average molecular weight.

resolution by up to 20% in case of neon and 12% for argon. A result for pure CO_2 from ref. 18 is also shown, but this gas is difficult to handle in practical detectors.

For pure hydrocarbons the reduction of width with increasing molecular weight seems, by contrast, to be more as expected. The agreement with other data [20,22] is very good.

One hypothesis for these differences in behaviour points to similar structure and binding energies in the outer electron shell of all noble gases [23]. Also, a certain part of the energy loss may escape detection in the form of scintillation in the gas, with efficiency of light emission growing with atomic number [24].

4.2. Sixty-four samples of 4 cm

Examples of some final results of truncated mean (40% smallest values) distributions from 64×4 cm samples are shown in figs. 6–10. Corrections for individual sample response differences are included. Distributions for tagged 15 GeV/c protons, pions and positrons are plotted in the original form (no renormalization of integrals). The plots were roughly aligned on the proton peak positions to guide the eye.

Fig. 6 shows the results for Ne + 10% C_2H_6 at 1 atm (top) and 2 atm (bottom). In fig. 7 we compare Ne + 45% Ar + 10% CH_4 at 4 atm (top) with Ar + 5% CH_4 at 5 atm (bottom). In fig. 8 we have in the top part Kr + 5% CH_4 + 5% C_2H_6 at 1 atm and in the lower part Xe + 3.6% C_3H_8 at 0.9 atm. Finally, figs. 9 and 10 show atmospheric pressure data for pure CH_4 , C_2H_4 , C_2H_6 and C_3H_8 . Differences in relative population of the three particles are due to changes in ejection and targeting conditions. Note the more pronounced bremsstrahlung tail for electrons at higher pressures and for heavier gases, and the marked reduction of relativistic rise (e/π) in pure hydrocarbons.

In table 1, we summarize the operating conditions (pressure, reduced drift field, drift velocity), attenuation of signal by attachment measured over a 41 cm drift distance, resolution in percent fwhm for a single 4 cm sample and for the truncated mean of 64 samples and the relativistic rise (e/p truncated mean peak ratio). This is followed by the e/π identification efficiency expressed as the distance between the e and the π truncated mean peaks in units of the standard deviation of the π distribution. In the final column, the corresponding identification efficiency for π/p is listed. Typical errors in the individual columns of table 1 are as follows:

gas mixture:	$\pm 0.5\%$ volume,
pressure:	$\pm 0.3\%$,
drift field:	± 0.01 kV/cm · atm,
drift velocity	
(TDC resolution):	20 ns,

Fig. 6. Truncated mean of 64×4 cm samples for 15 GeV/c protons, pions and positrons. Neon at 1 and 2 atm.

Fig. 7. Truncated mean for neon/argon at 4 atm and argon at 5 atm.

attenuation in gas: 1 ADC channel,
 resolution: $\pm 1\%$ for single sample,
 $\pm 0.3\%$ (absolute) for
 truncated mean,
 resolving power D/σ_π : dominated by resolution error.

4.2.1. Resolution

The final resolution as a function of pressure for 64×4 cm samples is shown in fig. 11. At 1 atm we now

Fig. 8. Krypton at 1 atm and xenon at 0.9 atm.

Fig. 9. Pure methane and pure ethylene at 1 atm.

have resolutions for Ne, Kr and Xe all very close to 9.5% fwhm, which is coherent with the almost identical single sample resolution at a level of $\sim 59\%$ fwhm for all noble gases (fig. 5). The final resolution for argon is at $\sim 11\%$ fwhm which, from the above considerations, is broader than would be deduced from the single sample resolution. About 15% improvement in resolution for neon over the usual Ar/CH₄ mixture means, when converted into an equivalent pressure (or depth), a gain by a factor of 1.7. This advantage of neon will clearly favour its use in compact detector design, replacing much more expensive Kr and Xe. Ar/Ne mixtures give resolutions only slightly worse than Ne + 10% C₂H₆, their attractive feature being the density practically equal to air.

In contrast to the noble gases, the hydrocarbons improve strongly with increasing molecular weight for single samples and give a much better final resolution. Propane, for example, is close to 5% fwhm. Compared

Fig. 10. Pure ethane and pure propane at 1 atm.

with neon, the gain in detector depth is about tenfold. Use of pure propane for ionization sampling was suggested by Rubbia already in 1970 [25]. Unfortunately,

Fig. 11. Final resolution for 64×4 cm samples for various gases as a function of pressure.

the relativistic rise in propane is very low and so the advantage is lost.

It should be noted here that, in order to reach the best resolution in cases where the measured gas was showing strong attachment, it was necessary to use only a very narrow slice of the beam (0.5–1 cm) in the drift direction. Exceptionally, the best resolution was obtained only when measuring inside the detecting cells without any drift.

Xenon did not give satisfactory results until after several hours of recycling and purification. The deterioration of the gas without continuous purification became apparent in uncomfortably short periods. For krypton, the resolution was probably suffering from the influence of the ^{85}Kr background.

4.2.2. Relativistic rise

Particle identification efficiency depends on resolution as well as on the relativistic rise slope. Fig. 12 shows the e/p truncated mean peak ratio at 15 GeV/c as a function of gas pressure. As expected, xenon has the highest relativistic rise, followed by krypton. The difference between argon and neon is, at this energy and for atmospheric pressure, only $\sim 10\%$. For completeness, our prior argon data [1] have been added. All hydrocarbons are grouped together at considerably lower

Fig. 12. Relativistic rise given as a ratio of electron to proton peak at 15 GeV/c for various gases as a function of pressure.

values of relativistic rise, with heavier gases showing less separation. For instance, the relativistic rise in propane is only $\sim 40\%$ of that of argon. Compatible values for xenon and for propane were obtained with much reduced precision (using single sample only), ref. 20.

4.2.3. Identification efficiency

By expressing the distance between various particle peaks in terms of number of standard deviations derived from the final resolution (the familiar relationship between fwhm and σ could be used keeping in mind its application limits to our still not fully gaussian distributions of truncated means), we obtain the identification efficiency dependence on pressure.

From fig. 13 it follows that at 15 GeV/c and at 1 atm neon, krypton and xenon have practically the same merits for π/p separation ($\sim 6.5\sigma$). Neon/argon mixtures come next, whilst classical argon/methane gives separation at the 5.3σ level. The gain in resolving power with increased pressure seems to be rather marginal for neon. Note that neon at 0.5 atm (i.e. ~ 1.3 m detector depth equivalent) gives the same result as argon at 2 atm.

Pure ethylene and pure propane give results comparable to argon, but at atmospheric pressure only. That means no reduction in detector dimensions or pressure with respect to noble gas mixtures. The e/π separation is only on the 2.5 – 3.0σ level for neon and argon, while

Fig. 13. Identification efficiency (resolving power) for π/p and e/π for various gases as a function of pressure.

$\sim 4.6\sigma$ could be reached in krypton or xenon. As far as hydrocarbons are concerned, the obtained 1.5σ separation is too small to be of any practical use.

It should be remembered that fig. 13 represents the situation valid at 15 GeV/c. At lower energies there will be certain improvement, especially for e/π separation.

4.2.4. Attenuation in the gas

The analysis of relative merits of various gas mixtures must be completed by checking the signal attenuation in the gas caused by electron attachment. This is obviously very important if extensive drift distances are envisaged in any given detector. Pressure dependence of attenuation over 41 cm drift distance is plotted in fig. 14. From this figure it is immediately clear that practically all noble gases could be used at moderate pressures without problems. Xenon seems to be somewhat worse than the others, but this may be caused by not yet optimized quenching of the mixture and/or by excessive sensitivity to impurities. If it is due to the second cause, some intractable long-term stability problems may arise for this gas. Of the pure hydrocarbons, only methane is practically without attenuation at higher pressures. Ethylene and ethane are acceptable at atmospheric pressure. Propane may still be useful in rela-

Fig. 14. Attenuation over 41 cm inside the drift region for various gases as a function of pressure.

tively small samples, but isobutane seems to be excluded. It should be remembered that in order to achieve the resolutions required for operation in the relativistic rise region, any detectable difference in signal level across the sample cannot be tolerated. In the case of propane there might be some room for improvement by further purification of the gas by multiple distillation. If the attachment is caused by O_2 contamination, the effect will probably be reduced at higher values of E/p [26]. This may be prevented by contradicting requirements for low E/p needed for optimum resolution.

5. Conclusions

(1) A new gas mixture containing neon and low percentage of ethane or propane is proposed for dE/dx sampling applications in the relativistic rise region. Particle identification efficiency was found, in this mixture, to be equal to results obtained in xenon and krypton. Neon/argon mixtures have shown moderate improvement in resolution compared to argon. Their density is practically identical to the density of air, which could be attractive for atmospheric pressure detectors using thin separating foils (prevents bulging). Use of neon instead

of argon opens the possibility of efficient mass identification at atmospheric pressure in compact detectors. Also, diffusion is about the same as in argon mixtures [27] and saturated v_d is attainable down to low E/p values.

(2) Pure ethylene or propane (propane only for limited drift distances) give results comparable to argon mixtures; the resolution improvement is compensated by a reduction of the relativistic rise slope. Low diffusion in hydrocarbons could favour their use instead of argon (in spite of safety aspects) in cases where emphasis is put on the $1/\beta^2$ region below the ionization minimum, even if there is no real gain in the detector depth. Some detector lifetime problems may arise for pure hydrocarbons at high particle flux.

(3) The radiation length is 321 m in neon at atmospheric pressure, which is comparable to C_2H_4 and C_2H_6 . For argon it is 3 times, for krypton 11 times and for xenon 23 times shorter. In this respect, CH_4 is 2 times better than neon, C_3H_8 is 1.4 times worse.

(4) The economic aspects are rapidly changing and difficult to analyse in a general way independently of a particular detector design. As a rough estimation, if normalized to a unit volume cost for premixed argon/methane, the price of pure argon is $\sim 1/7$ th, neon is ~ 3.5 times more expensive and pure hydrocarbons are at (CH_4) 1.5 to (C_3H_8) 6.5 times the price level. Krypton is ~ 6 times less expensive than xenon, but unfortunately all available krypton is most probably contaminated by the ^{85}Kr isotope. The xenon price is ~ 500 argon units, which seems to be too high for its small additional merit. Furthermore, xenon was found to be excessively sensitive to impurities, so that complicated closed-loop purification is necessary. It should be underlined that Oxisorb purifiers and molecular sieves in the loop can quickly modify the quencher concentration due to differences in the adsorption coefficients of the component gases. Compensating for this by restoring the original gas percentages without spoiling the amplitude response represents a formidable technological problem. Also, losses of expensive xenon by adsorption in the purification elements may be surprisingly high.

(5) Our present results show some systematic improvements with respect to the previous measurements for argon [1]. The best resolution is now 7.1% fwhm (7.6% previously) at 5 atm. More pronounced improvements are visible in the single sample response (e.g. change from 70% fwhm to the present 59% at 1 atm). As already discussed in sect. 4.1, this is due to more efficient decoupling of the grid system and stricter selections applied to the beam, thus allowing for elimination of the greater part of the background influence. Nevertheless, our present results are not yet as good as the expected performance derived in ref. 1 from the EPI measurements [28] (about 6% fwhm was expected at 5

atm). This holds true for results including drift as well as for measurements from tracks passing directly inside the samples without drift.

Detailed analysis of parameters influencing the resolution has been made in ref. 1 and will not be repeated here. We should recall that the EPI results were obtained in a beam with virtually no background. In the present experiment the drift space was sensitive to the beam halo and to the ejection spikes, which introduced a background that was absent in the EPI. Another possible residual source of resolution broadening may be in pairing of 2 cm samples (against single 6 or 4 cm sample in the EPI and its prototype). The (variable) muon contamination of the beam was on the 5% level. The Cerenkov system tagging efficiency was above 95% for electrons; no contamination of π distributions is visible near the electron peak positions on figs. 6–10. Transparency of the grids separating the drift space from the detection part was carefully adjusted using beam particles aligned on the boundary. In the worst case, the grid transparency was 94%. Clearly, more work in optimization of the detector parameters is still required, but with neon it now seems to be possible to reach 6σ separation for π/p up to ~ 20 GeV/c in a detector depth of below 1.5 m and at atmospheric pressure.

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