DE/dx MEASUREMENTS WITH ARGUS

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Summary

The use of pure heavy hydrocarbons like propane or isobutane has some advantages for drift chambers that measure the specific ionisation for particle identification. With a prototype of the ARGUS drift chamber various gases were tested with a 3 GeV/c electron beam. We found a dE/dx resolution for propane of Fwhm = 10.4% and for isobutane Fwhm = 9.9%, by a factor of ≈ 1.6 better than that for argon-methane (92:8) mixture with Fwhm = 16.4%.

This improvement corresponds to an increase in effective gas length by a factor of 4 compared to pure argon. In isobutane and propane we found a broadening of the 55Fe-pulseheight spectrum with increasing gas amplification, showing in isobutane a clear two peak structure for gas amplifications above ~3 · 10^4. However, neither gas showed a broadening of the truncated Landau distribution for electrons.

Introduction

For the DORIS storage ring at DESY a new universal magnetic detector named ARGUS[1] is now under construction and will be installed in the beam in the middle of this year. The central detector of ARGUS is a drift chamber 2 meters long and 1.7 m in diameter, which will serve for coordinate measurement of charged tracks and particle identification by dE/dx measurement. So far mainly argon gas mixtures have been used for detectors which are designed to measure the specific ionisation loss.

We report here on measurements with isobutane and propane which show that these gases are advantageous for some applications.

Compared with these heavy hydrocarbons, argon has a larger relativistic rise of ionisation loss, which simplifies the control of systematic measurement errors. It can be used also under pressure to increase the effective gas length, but the short radiation length then tends to spoil the momentum resolution of the chamber. It also has a broad Landau distribution and hence poor dE/dx resolution. Isobutane and propane have a long radiation length, an extremely narrow Landau distribution, and low diffusion. They seem to be ideal for use in a detector like ARGUS, designed to achieve very good mass and dE/dx resolution for the low momentum particles most abundant at DORIS energies.

We will give some estimates of dE/dx resolution which can be obtained with the ARGUS chamber. Amplification saturation effects and polymerisation in isobutane and propane will be discussed.

The ARGUS Drift Chamber

This chamber has 5940 identical drift cells of nearly square cross section in 36 concentric layers, filling the whole chamber volume without dead space. The structure of the chamber is shown in Fig. 1.

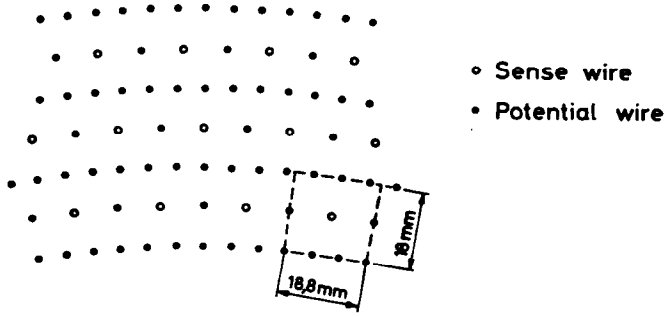

Fig. 1 : Cross section of the drift chamber showing a typical cell

The use of identical drift cells minimizes corrections, simplifies pattern recognition, and gives good granularity. There is thus no need to use electronics with multi hit features, where the extremely short gate length required for double track resolution can cause deterioration of dE/dx resolution for neighbouring tracks.

The isochrones calculated for a magnetic field of 0.8 Tesla parallel to the sense wires, are shown in Fig.2. They are nearly perfect circles in 80% of the cell, so that in this region no angular corrections will be necessary.

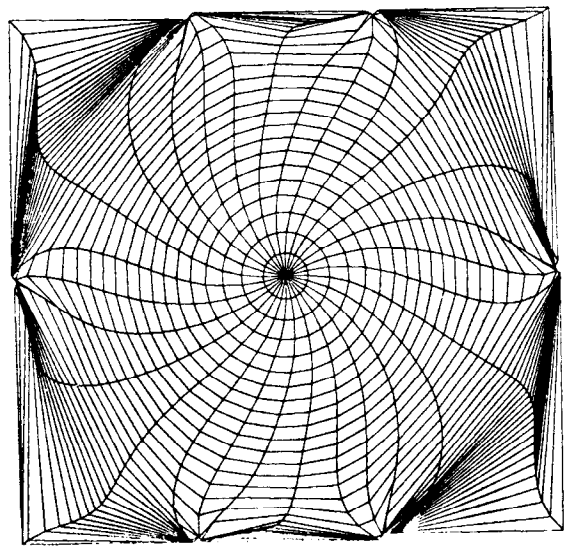

Fig. 2 : Calculated isochrones and field lines in the ARGUS drift cell.

The ARGUS chamber determines z-coordinates by a small angle stereo wire arrangement, the sequence of stereo orientation within the 36 layers being 0,+,0,-,0 ... .

In a cylindrical geometry, the stereo wires form hyperboloids. The maximal saggital displacement of all sense wires in the chamber has a constant value of 1mm. This is achieved by varying the stereo angle from 40 mrad in the innermost layer, to 80 mrad in the outermost; and by further giving the shielding wires between all layers a stereo angle which gives such a shielding wire half the saggital displacement of the neighbouring stereo sense wire. In this wire arrangement the maximum amplification variations along the sense wires do not exceed 10% and can be corrected for. The chamber has 5940 30μ tungsten sense wires and 24588 potential wires of 75μ Cu-Be.

Fig. 3 shows a picture of the ARGUS chamber during construction. The light reflections indicate adjacent layers of wires with different stereo angles. At the time of writing all wires are strung and the chamber is nearly completed.

With an expected accuracy of 150 μm for coordinate measurement and a magnetic field of 0.8 T a momentum resolution of $\Delta p/p = 1\%$ at 1 GeV/c is expected from Monte Carlo simulation.

Fig. 4 shows a reconstructed Monte Carlo event in the r-ϕ plane of the ARGUS chamber.

Each sense wire has a preamplifier mounted directly on the chamber and a main amplifier-discriminator after 30 meter of 50 Ohm coaxial cable. The main amplifier-discriminator gives a stop signal for the LeCroy TDC-system 4290 and a delayed analog signal for the LeCroy ADC-system 2280. The minimum signal for a TDC

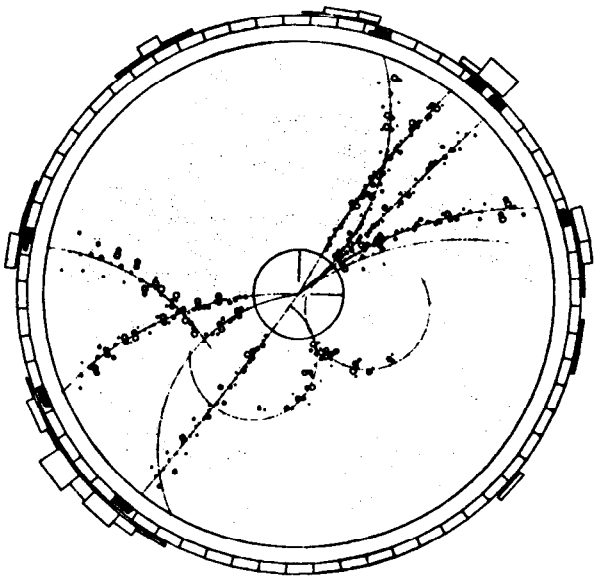

Fig. 4 : Reconstructed Monte Carlo event in the r-ϕ plane of the chamber.
The circles indicate the measured drift time.

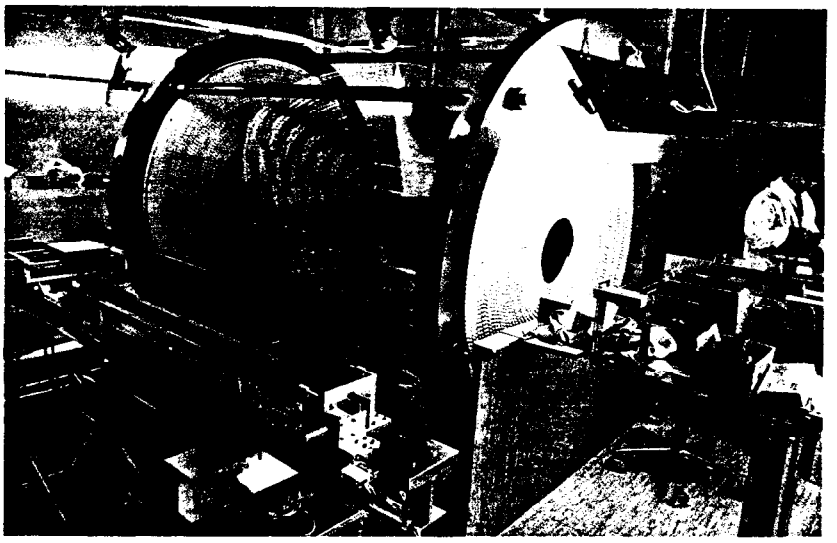

Fig. 3 : ARGUS - chamber during construction

start is 25 μV on 50 Ohms at the input of the preamplifier. This allows for gas amplifications below 10^4 with 99% cell efficiency. The electronics have a dynamic range of 50 dB which is sufficient to measure the variation of dE/dx with angle and momentum of different particles, including the large fluctuations of the Landau distribution.

Test measurements were made with three different chambers : a small tube with the ARGUS cell geometry, a full length prototype chamber with 16 sense wires with the ARGUS wire arrangement, and a chamber with 36 adjacent ARGUS drift cells.

Test Measurements

Using a 55Fe X-ray source, pulse height spectra were taken in pure propane and isobutane and in the argon-methane (92:8) mixture. For low gas amplifications of $5 \cdot 10^3$ we found a line width of Fwhm = 17% in both argon-methane and propane, and an increased width of 24% in pure isobutane. For higher gas amplifications of $5 \cdot 10^4$ we found a broadening of the line width in propane and a distinct two peak structure of the line in isobutane. Such a complicated mechanism leading to a double peak structure of the amplitude distribution has also been observed in argon-isobutane-freon mixtures and has been attributed to the appearance of secondary photon avalanches[2].

For different sense wires (20 μ , 30μ, and 37μ) we found the same behaviour.

For 3 GeV/c electrons we did not see any increase in the width of the Landau distribution. We found Fwhm ≃ 45% for propane and isobutane and Fwhm ≃~70% for argon-methane mixture for gas amplifications from $3 \cdot 10^3$ to 10^5.

Fig. 5 shows the collected charge vs. sense wire voltage for a 55Fe source and 3 GeV/c electrons with different angles to the sense wire. Data for electrons are normalized to 18 mm tracklength. Two points at the same voltage for 55Fe indicate the double peak structure of the spectrum.

Space charge saturation leads to a deviation from exponential behaviour and to different slopes for electrons perpendicular and inclined to the sense wire. This effect seems to be small in argon due to its larger diffusion. In isobutane even 55Fe shows space charge saturation.

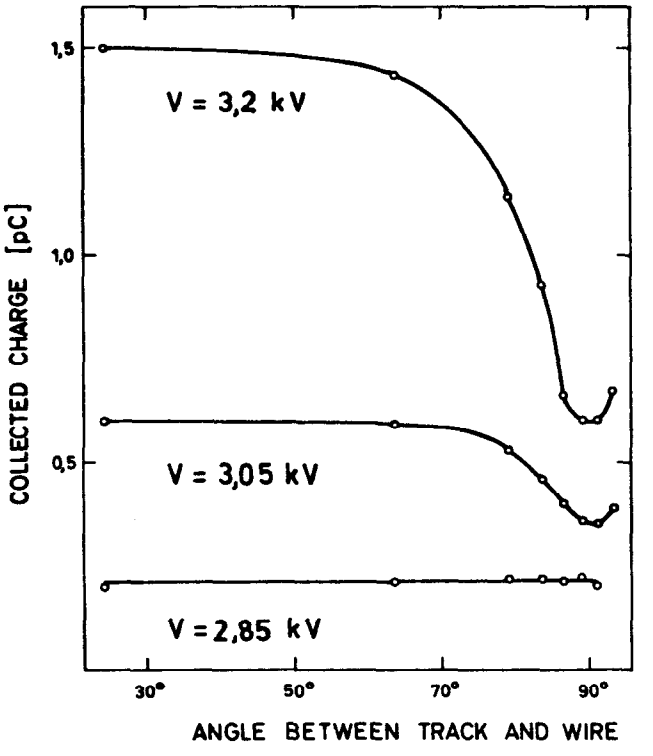

Fig. 6 : Dependence between entrance angle and collected charge for 3 GeV/c electrons for different voltages at the sense wire in isobutane. The track length is normalized to 18 mm gas length.

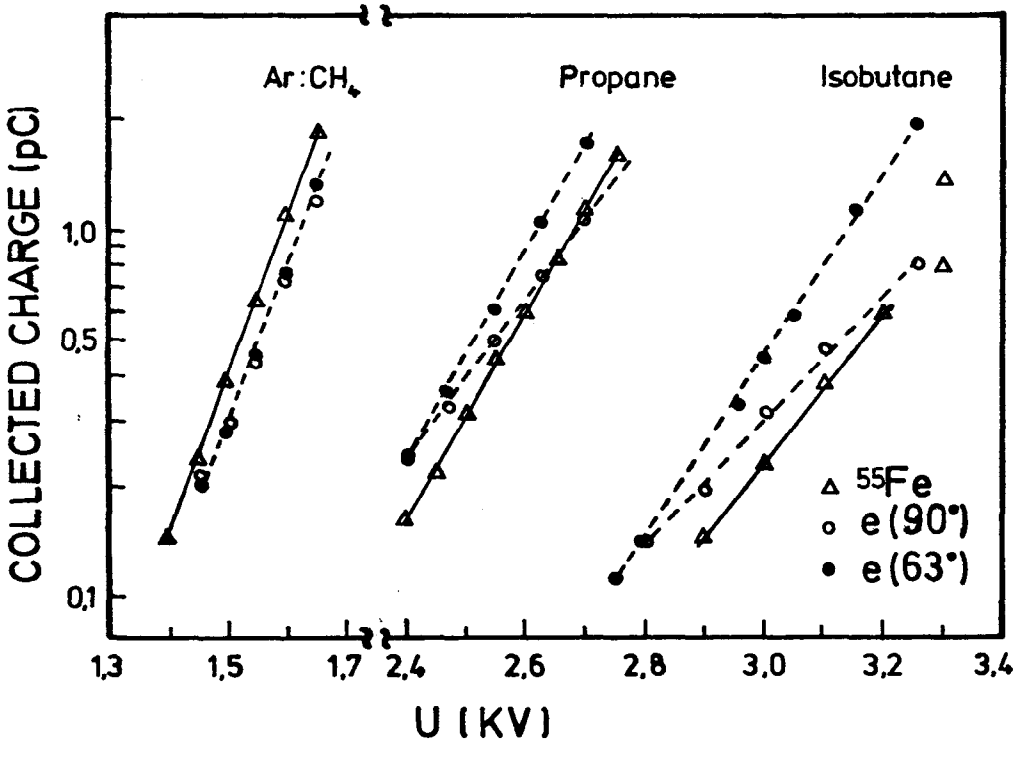

Fig. 5 : Collected charge vs. sense wire voltage for a 55Fe X-ray source and electrons inclined and perpendicular to the sense wire.
Data for electrons are normalized to 18 mm gas length.
Straight lines are to guide the eye.

Fig. 6 shows the dependence between entrance angle and normalized collected charge for different gas amplifications in isobutane.

For dE/dx measurement these saturation effects have to be corrected for with an accuracy better than the dE/dx resolution, i.e. on a 1-2% level. This seems to be only possible for gas amplifications below 10^4.

The dE/dx resolution for the 36 layers of the ARGUS chamber was estimated by applying the well known truncation method[3], using the corresponding number of signals from a single cell. These results were compared with those obtained from the 36 cell test chamber. We found good agreement showing that correlations between adjacent cells and systematic errors are small. The relative standard deviation of the truncated average distribution was taken as the dE/dx resolution. The distribution of the truncated average (mean of the smallest 60% of each 36 cell sample) shows an approximate Gaussian form. The truncated mean approximately coincides with the maximum of the Landau distribution.

For 3 GeV/c electrons we found a ratio between the truncated means of argon-methane (92:8) mixture, propane and isobutane of 1 : 1.8 : 2.1. For this measurement the gas amplification was normalized with a 55Fe-source.

The resolution dependence on the fraction of the signals used for averaging (truncation factor) is shown in Fig. 7. This indicates that, for isobutane and the ARGUS geometry, a truncation factor of about .6 - .7 is optimum.

Fig. 8 shows the dE/dx resolution obtained with different gas mixtures and different numbers of 18 mm long drift cells. Indicated is a measurement in argon-CO_2 (80:20) mixture from Ref. 4 which shows good agreement with our measurement.

To give some predictions we compared our results in terms of the scaling variable ζ/I which describes the variation of ionisation loss for different gases. We used the formula given by Allison et al.[5] which is an approximation based on Monte Carlo calculations.

$$\sigma_{rel} = 34.5 \quad n^{-.46} \quad (\zeta/I)^{-.32}$$

where n = number of layers,

I = mean ionisation potential,

$\zeta = 0.135\ (Z/A)\ \rho t$ (MeV for ρt in g/cm^2).

The solid lines in Fig. 8 were calculated using this formula. They include fluctuations in energy loss, but not measurement errors.

From this our measurement error can be estimated to be ~ 13% for the single cell measurement in propane and slightly higher in isobutane (possibly correlated with the increased width of the 55Fe line in isobutane).

We can conclude that we have obtained 50% better dE/dx resolution in heavy hydrocarbons than in argon under the same conditions.

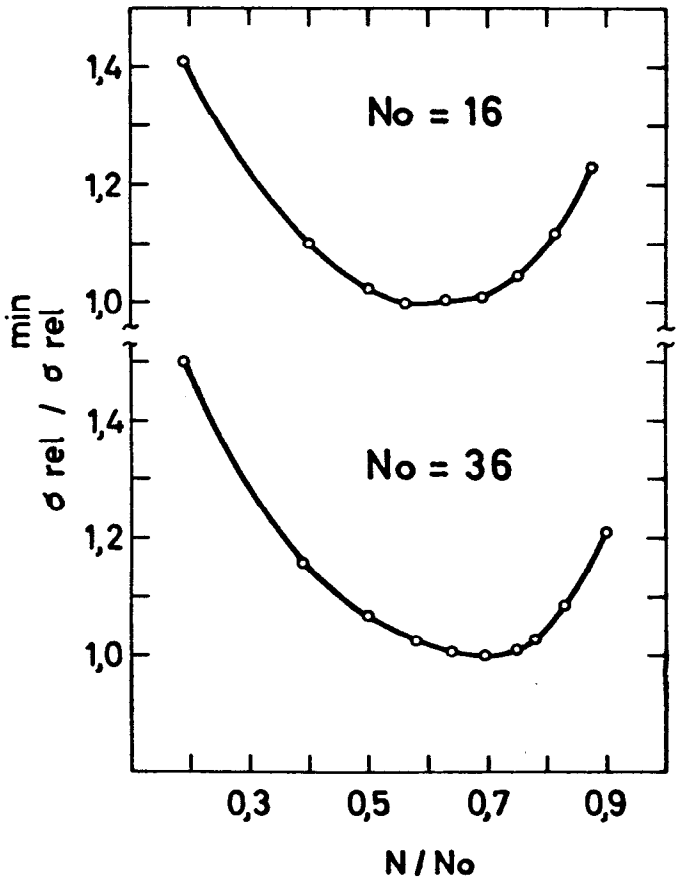

Fig. 7 : The dependence of dE/dx resolution in isobutane on the fraction of signals used for truncation.

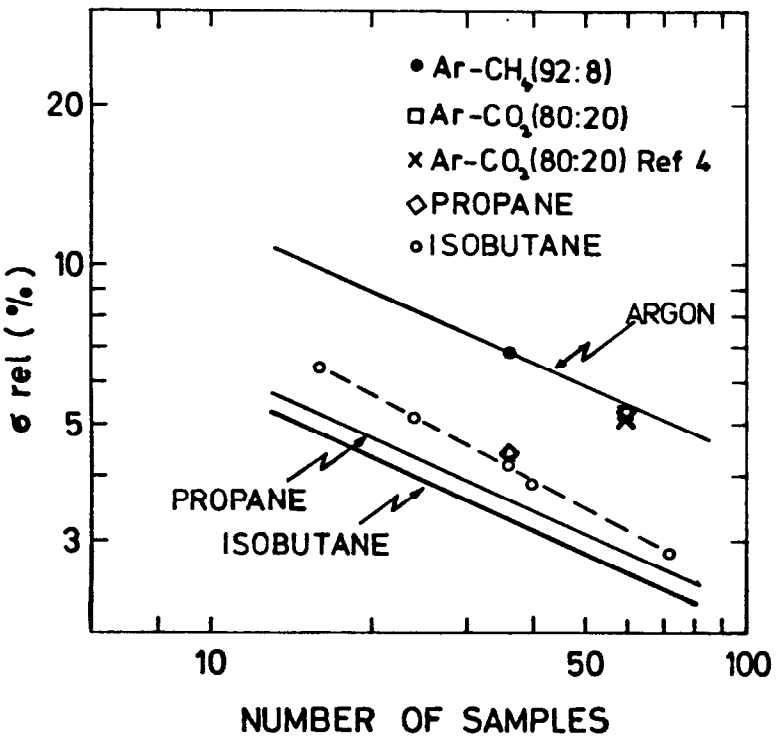

Fig. 8 : Relative dE/dx resolution in different gases vs. the number of 18 mm long drift cells used for ionisation loss measurement The solid lines were calculated according to Ref. 5.

The expected dE/dx resolution for several detectors which use argon is shown in Fig. 9 taken from Ref. 6. We have added a point to this figure to indicate the expected resolution for ARGUS. It shows that the sample size in ARGUS is near the optimum and dE/dx resolution would not be increased appreciably by increasing the number of layers at fixed gas length.

It also shows that we win a factor of four in gas length compared to the use of pure argon.

The use of heavy hydrocarbons will provide better separation of non-relativistic particles. However, the relativistic rise of ionisation loss in propane is less pronounced than in argon[7]. In the momentum range above 3 GeV/c only a slightly better particle separation can be expected for heavy hydrocarbons and this only if systematic errors can be kept small.

Polymerisation in heavy hydrocarbons can ruin a drift chamber due to a polymer sheath on the sense wires[8]. To estimate the polymerisation for the ARGUS chamber we irradiated a sense wire with a 106Ru source over a length of a few millimeters.

In an isobutane methylal (95:5) mixture we found no effect after a dose of $3 \cdot 10^9$ particles/mm corresponding to a collected charge of $2 \cdot 10^9$ pC/mm. In pure propane without methylal admixture we found first polymerisation effects for a dose by a factor of 10 smaller than in the isobutane methylal mixture. This was clearly indicated by a broadening of the 55Fe line and a considerable decrease of gas amplification in the irradiated part of the wire.

These effects disappeared after "training" the chamber for some time with pure argon and opposite high voltage polarity. Even assuming a background rate of 10^4 particles/wire·sec during ARGUS operation, it would take over ten years of operation until the background dose would exceed the dose used for the polymerisation test in isobutane methylal mixture. For propane we need further tests to understand the influence of methylal admixture on polymerisation.

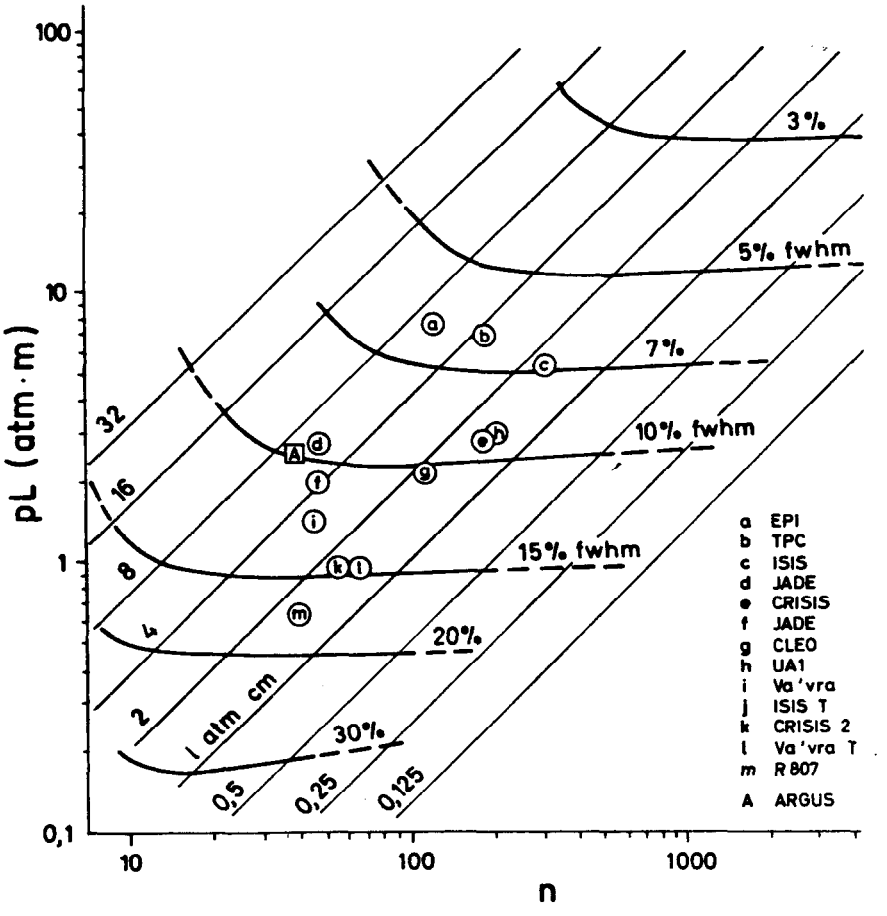

Fig. 9 : Expected dE/dx resolution in argon for different detectors taken from Ref. 5. The expected resolution for ARGUS is indicated by inserting a point A.

Conclusions

The dE/dx resolution which can be obtained over a fixed track length is about the same for propane or isobutane at atmospheric pressure and argon at a pressure of 4 atm.

The advantage of propane is an 8 times larger radiation length compared to argon, which leads to an improved momentum resolution for tracks with momenta below 1 GeV/c. Also disturbing walls of a pressure vessel are omitted. However, due to space charge saturation and polymerisation the acceptable particle rates and gas amplification are limited. For a drift chamber detector at the e^+e^- storage ring DORIS, propane seems to be the best counting gas.

References

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