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CERN/EF 80-1
17 July 1980

CM-P00061309

PRIMARY IONIZATION MEASUREMENT IN A LARGE AVALANCHE CHAMBER
FOR FREE QUARK DETECTION

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Presented at the International Conference on Experimentation at LEP
Uppsala, Sweden, 16-20 June 1980

ABSTRACT

The WA44 experiment is a search for free quarks ($1/3$, $2/3$) produced in high energy ν interactions. High detection efficiency for quarks is achieved by measurement of primary ionization in a triggered large avalanche chamber which, moreover, provides the high spatial resolution required for high multiplicity jet-type events. The chamber is $2.35 \times 1.25 \times 0.6 \text{ m}^3$ and is flushed with a mixture of pure He-Ne (80-20%). The chamber is photographed with 3 cameras using image intensifiers giving 1.4 mm resolution in space. The optical gain is such that the chamber can be operated well below the streamer threshold. In order to obtain precise primary ionization measurements and high rejection coefficient for quark detection against charge 1 particles, a good high voltage pulse stability ($< 1\%$ FWHM) and a long memory time (at least 100 μs) are essential and have been achieved. Data taking is in progress. Preliminary results show that the avalanche chamber is an excellent triggerable detector for combining good spatial multitrack resolution and accurate primary ionization measurement.

1. INTRODUCTION

A search for free fractionally charged quarks produced in high energy neutrino interactions is in progress at CERN (WA44 experiment [1]). If quarks are liberated, the experiment is able to detect them with high spatial resolution, high efficiency and good accuracy by measuring the specific primary ionization of the charged particles produced in the interaction. Neutrino interactions take place in a 23-ton lead target installed in the CERN ν beam [2].

The basic detector of this experiment is a large streamer chamber ($2.35 \times 1.25 \times 0.6 \text{ m}^3$) working in the avalanche mode [3] and called the "Avalanche Chamber AC-235". When the high voltage applied to a streamer chamber is set well below the threshold value at which the space charge limit occurs in the avalanche (amplification $< 10^9$), streamers are not developed. This allows the primary specific ionization to be measured by recording, with high spatial resolution, the position of single avalanches created by primary collisions. The diameter of the avalanches due to single electron when reconstructed in space from a photograph is typically 1.4 mm. The efficiency for detecting quarks with charges $1/3$ and $2/3$ of the electron charge is 100% and with one metre track length the rejection against charge 1 particles is extremely high. The chamber is triggered by a series of scintillation counter hodoscopes (fig. 1). A system of wire chambers register both the position and the time at which particles cross the system in order to allow track reconstruction and rejection of background particles from earlier interactions. A system of iron absorbers and scintillation counters is used to trigger the avalanche chamber on muons of known energy to calibrate the primary ionization measurements at various γ values.

In this paper we present some measurements of the primary ionization of high energy muons obtained with the AC-235 chamber during the quark search experiment.

2. PRIMARY IONIZATION AND AVALANCHE COUNTING

An important feature of the avalanche chamber is that the primary specific ionization can be measured. When a charged particle passes through a gas, it creates a trail of ion-electron pairs. The density n_1 of primary pairs per centimetre is given by [4,5]

$$n_1 = 0.1536 z^2 \frac{Z}{A} \frac{\rho}{\beta^2} f(\beta^2, \text{gas})$$

where z and β are the charge (in units of the electron charge) and velocity (in units of speed of light) of the particle and Z , A and ρ are the atomic number, mass (in g) and density (in g/cm³) of the gas. n_1 has been calculated as a function of γ [5] in various gases and the values for He and Ne are shown in fig. 2. At a delay time T after the passage of the charged particle through the gas, a high electrical field E is applied to the chamber for a very short time τ (typical values are $T = 1 \mu\text{s}$, $E = 20 \text{ kV/cm}$, $\tau = 10 \text{ ns}$). As a consequence, an avalanche builds up from every individual electron created in the gas. The size and position of the avalanches are governed by many physical processes which are subject to statistical fluctuations. Primary ionization can be measured when a primary electron together with its secondaries creates only a single avalanche. This is the case if all the electrons from the primary collision have not diffused further than the avalanche size during the time T . If the primary electron has a high kinetic energy (a few keV), a short track (δ ray) starting from the trajectory of the particle is observed and can be counted as one single primary collision. In He-Ne mixtures, diffusion coefficients vary from $D = 256 \text{ cm}^2\text{s}^{-1}$ (He, 1 atm, 20°C) to $D = 2860 \text{ cm}^2\text{s}^{-1}$ (Ne, 1 atm, 20°C) [6]. The delay T must then be less than $r^2/2D$ ($\sqrt{2DT}$ is the root mean square displacement of the primary electrons and r is the average radius of the avalanche) [7]. For $r = 0.5 \text{ mm}$ T must be less than $4.9 \mu\text{s}$ in He and $0.44 \mu\text{s}$ in Ne. Low neon content is consequently more suited to primary ionization measurement. It also will be seen that low neon content is necessary to avoid saturation effects due to the finite optical resolution.

The real advantage of measuring primary ionization and not dE/dx lies in the very important fact that the statistical fluctuations of primary ionization are much lower because they are Poisson and neither Landau nor Blunke-Leisegang distributed [8]. If all primaries could be counted in an avalanche chamber filled with 80/20% He/Ne mixture, a 1 m track of charged particle at minimum ionization would give a σ of 4.6%.

However, not all primaries give rise to a detectable avalanche because of the statistical behaviour of avalanche growth (Furry-Legler statistics) [9,10].

For low amplification ($< 10^7$), the probability that a single primary electron produces an avalanche containing a total of n electrons is given by [9]

$$P(n) = \frac{1}{\bar{n}} \left(1 - \frac{1}{\bar{n}}\right)^{n-1} \rightarrow \frac{1}{\bar{n}} e^{-n/\bar{n}} \text{ for large } n$$

$$P(n)_{\max} = \frac{1}{\bar{n}} \text{ for } n = 1 \quad \sigma(n) = \bar{n}$$

where $\bar{n}$ is the average number of electrons per avalanche.

For a given gas mixture $\bar{n}$ depends only on E , the amplitude of the electric field, τ the duration of the electric field and p the gas pressure

$$\bar{n} = e^{\alpha w_- \tau}$$

α Townsend's first ionization coefficient,

w_- drift velocity of the electrons,

αw_- is proportional to E^3/p^2 in the range of E/p used in the avalanche chamber. Consequently the average luminosity of avalanches is kept constant provided $E^3\tau/p^2$ is constant.

The proportion of detected avalanches is given by $e^{-n_{\min}/\bar{n}}$ where $n_{\min}$ is the minimum number of electrons which are necessary for an avalanche to be detected on the film (the number of emitted photons is proportional to n). Furry statistics shows that 63% of the avalanches contain less than n electrons. Thus if $\bar{n}$ is close to $n_{\min}$ many

avalanches will not be detected even if the optical resolution is perfect. If $\bar{n}$ is large compared to $n_{\min}$ the proportion of avalanches above the detection threshold increases but, due to the finite resolution of the optical system and the Poisson distribution of the distance between primaries, avalanches will be lost. Therefore there exists an optimum value of $\bar{n}$ and consequently of E (for τ and p constant) which maximizes the number of detected avalanches. At high amplification ($\sim 10^8$) the proportion of small avalanches decrease and $P(n)_{\max}$ occurs at a value of n closer to $\bar{n}$. The distribution peaks around $\bar{n}$ as described by Legler's statistics [10]. $\sigma(n)$ decreases with increasing E and thus higher E and shorter τ values give more homogeneous tracks and improve the accuracy of ionization measurement and the resolution in space.

3. DESCRIPTION OF THE AVALANCHE CHAMBER SYSTEM

3.1 The avalanche chamber

The chamber AC-235 was designed and built at CERN in 1978 for the WA44 experiment. Its visible volume is $60 \times 125 \times 235 \text{ cm}^3$. External dimensions are $77 \times 242 \times 350 \text{ cm}^3$. The chamber is installed vertically (fig. 3). It has a 25Ω wave impedance and it is terminated by 8, nominally 200Ω , carbon resistances (Silohm RS0 from Le Carbone Loraine). The chamber walls are made of a sandwich of 2 mm plexiglass sheet glued to a 40 mm Rohacell plate (plexiglass foam). The high voltage plane and the two ground planes are made from $50 \mu\text{m}$ stainless steel wire mesh (from Gantois Loraine). The window facing the cameras is made from $150 \mu\text{m}$ stretched mylar foil and the back plate is covered by 24 fiducial marks made with electroluminescent panels. The chamber is flushed with He-Ne (80/20%) at a rate of 3 l/mn. The gas is continuously controlled by a mass spectrometer and by a radioactive ionization chamber. The chamber is surrounded by dry N_2 with a small quantity of freon 114 in order to avoid corona discharges. Rigidity is given to the chamber by two large plates of honeycomb sandwich (from Hexel, 75 mm thick, glued between two 3 mm aluminium plates).

3.2 The high voltage

The high voltage pulse (~ 600 kV, 10 ns) is applied to the chamber by a conventional Marx and Blumlein system. However, special care has been taken to reduce field gradients in the Marx tank and in the Blumlein line in order to increase the reliability and stability of the high voltage system. The Marx generator is a 2 MV, 10 stage, 20 nF/stage, double polarity ($U_0 = \pm 100$ kV maximum) voltage multiplication device. It is the generator described earlier [11] with double the capacitance per stage and consequent increased energy. The coefficient of transmission from the Marx to a 10 ns Blumlein line is ~ 0.75 . The output matching self inductance connecting the Marx to the Blumlein is 26 μ H and the Blumlein load is 1200 pF. The measured intrinsic equivalent Marx parameters are $C_0 = 980$ pF, $L_0 = 12$ μ H and $R_0 = 30$ Ω (see also [10]). With these conditions ± 36.5 kV/stage is necessary to obtain good tracks in the chamber. The Blumlein line is a tri-coaxial line insulated with oil (fig. 4). It has a conical spark gap geometry [12], The spark gap is pressurized with SF_6 and the gap width is monitored to within 10 μ m. Running conditions are 5400 mb and 12.7 mm gap. The stability of the peak amplitude of the high voltage can be kept within 1% FWHM (fig. 5). The total delay T is ~ 900 ns and varies by less than 10 ns. There is a linear dependence between the value of the Marx voltage and the peak amplitude of the pulse on the chamber (fig. 6). It is consequently essential to have high stability charging power supplies for the Marx; Heinzinger 100 kV with a stability of 10^{-4} are used. For each value of the charging voltage and Blumlein spark gap pressure, there is an optimum gap width at which the maximum stability is obtained. A typical curve is shown in fig. 7. The high voltage peak amplitude on the chamber is recorded in three different positions along the transmission line and on the avalanche chamber. Gold plated mylar capacitive dividers are used and a special electronic fast peak detector has been built for measuring the amplitude with 1% resolution [13]. A fast transient digitizer (TEK R7912 AD) is also used to record the full pulse time curve for each event on magnetic tape with a 0.5% resolution.

3.3 The optics

The chamber is photographed by three cameras, whose positions relative to the chamber are shown in fig. 8. Camera 2 views the entire fiducial volume. Cameras 1 and 3 view rather more than half the chamber so that all

the fiducial volume is covered by at least two cameras to enable track reconstruction in space. The higher resolution cameras, 1 and 3, enable an accurate count of the number of avalanches along a track to be made.

The design and characteristics of the optical system have been described in detail elsewhere [14] and only the salient points are described here. Each camera is based around a 50 mm diameter, 4-stage, electromagnetically focussed EMI type 9912 image intensifier. The chamber is viewed with an objective mounted in front of each intensifier. A Zeiss 50 mm F/4 S-orthoplanar lens is used with camera 2 and Zeiss 80 mm F/5.6 Componon lenses with cameras 1 and 3. The output phosphor is projected with a magnification of 1 onto 50 mm film using a Nikon 170 mm F/1.4 Repro-Nikkor lens. The film is transported in the cameras from the CERN 2m bubble chamber which have been modified for the smaller picture size obtained. The overall demagnification is 55 for camera 2 and 35 for cameras 1 and 3 in the central plane of the chamber.

It is important that the cameras give uniform photographs over the whole fiducial volume with the same optical gain and the best resolution possible. Using good quality objectives implies that the uniformity is essentially determined by the intensifier and the depth of focus of the lenses in front of the intensifier, the optical gain is governed by the objective apertures and the intensifier, and the resolution is limited by the intensifier and film. Thus the intensifiers have been selected for excellent uniformity with the best possible gain and resolution. A good resolution high speed film, SX502 from 3M, has been used. The film has a high gamma (3.5 to 4) which gives excellent contrast on the photographs but necessitates a very accurate control of the optical gains of the cameras and the intensity of the avalanches.

To obtain a sufficient depth of focus, the objectives in front of the intensifiers are used at F/8. The limiting resolution obtained in real space is 0.7 lp/mm for cameras 1 and 3 and 0.45 lp/mm for camera 2. If the modulation transfer function is assumed to be Gaussian in form, the diameter 2σ of a point object, when reconstructed in space, is given

approximately by the inverse of the limiting resolution. The overall optical gain is about 2×10^3 for each camera. The gains are equalized by operating the intensifiers at their maximum voltage (40 kV) and adjusting the aperture of the 1 : 1 projection lenses (F/5.6 to F/8).

A 5 cm pitch grid of thread coated with fluorescent paint is mounted directly in front of the mylar window of the chamber. When illuminated with a U.V. lamp, the grid provides fiducial marks in front of the chamber and allows the distortions of the optical system to be measured. These are primarily due to the spiral distortion and non-linearity of the intensifier tube.

3.4 Control and monitoring

Ionization measurements are very sensitive to the gas composition, to the high voltage pulse and to the optical parameters. These parameters are themselves dependent on the temperature and on atmospheric conditions. Therefore the whole chamber has been installed in an air conditioned room, constructed so that it also serves as a dark room and as a Faraday cage to shield other detectors against the high frequency noise from the high voltage chamber pulse. All these precautions are essential to maintain stable conditions during the experiment. Thirty six chamber parameters are controlled by a NORD 10 computer and are recorded on magnetic tape for every event. Very high stability is required for most of them. With all these precautions more than 99.9% of triggers where particles pass through the chamber result in satisfactory photographs during running of the experiment.

3.5 The gas system

The chamber is flushed with a He-Ne mixture, which is prepared in a clean stainless steel tank, evacuated to $< 10^{-5}$ Torr before mixing. Only very pure gases are used: He 45 (99.995%) and Ne 40 (99.99%). The main impurities are N_2 , H_2O , O_2 and H_2 in decreasing proportion. The memory of the chamber can be controlled by mixing a few ppm of freon 114. However, for this quark experiment it was decided to work with the longest memory possible in order that old tracks would not be mistaken for quarks. The size of the preparation tank is 5800 l and it can be pressurized up to 7 bar. The flushing rate is ~ 3 l/mn which allows

the same, very stable, gas mixture to be used for a week. The reproducibility in the gas composition is better than 1% and the impurities are checked daily at the input and at the output of the chamber. All impurities at the output are below 0.1% and the most abundant is N_2 . The gas is thermalized to 21°C before entering the chamber which is kept at $21 \pm .5^\circ\text{C}$ and 1.5 mb above atmospheric pressure.

3.6 The muon range trigger

The muon range trigger, shown on fig. 9, allows one of the three ranges (table 1) in the relativistic rise to be selected for the chamber trigger. It was designed to check ionization measurements performed with the avalanche chamber. The muon beam used is a broad spectrum of muons from external targets in the 240 GeV proton beam from the CERN SPS. The calibrations are made frequently during the experiment to check the stability of the chamber in three aspects:

- (a) Homogeneity of the ionization measurements within the volume of the chamber. This is obtained by triggering uniformly over the chamber using low energy muons around $\gamma = 10$ and using the 4 S counters placed in front of the chamber to define the beam.
- (b) Sensitivity of the ionization measurements. This is measured by triggering the chamber on muons passing through the central part of the chamber and having one of the three γ values defined by the muon range trigger.
- (c) Memory of the gas. This is measured by triggering the chamber with increasing delay and measuring the ionization and diffusion for a constant γ value.

The contamination for $\gamma = 10$ and $\gamma = 68$ has been estimated from the measured inefficiency of the various counters and measurement of the muon flux. The muon flux during the calibration was a few 10^5 per burst during the 1 s hadron spill from SPS. As the memory of the chamber is quite long, the calibrated muon is always accompanied by old tracks which can be clearly identified by their diffusion. For $\gamma = 10$ and $\gamma = 68$ the contamination from the high energy muons is estimated to be only a few percent.

4. FILM ANALYSIS

The photographs are measured in three different laboratories. Three different measuring machines are used: a Bessymatic [16] equipped with photodiodes at CERN, a FSD [17] of CNAF in Bologna and a PEPR [18,19] at Frascati. The Bessymatic in CERN is essentially used for chamber performance control during data taking.

Most of the results presented here have been obtained from manual measurements on the Bessymatic table. A link up with a PDP-10 computer allows the measurements to be stored for analysis and the photodiodes to be used for fiducial mark measurement [20]. More refined measurements are in progress in Frascati and Bologna and will be presented in a subsequent paper.

4.1 Data handling

The distortions introduced by the image intensifier tubes are corrected by measuring the calibration grid and fitting a fifth order polynomial correction. For this purpose pictures of the grid are taken on the beginning of each roll of film and the coordinates of about 120 well defined points in space are measured on the film in each view. The fifth order fit requires the determination of 21 independent coefficients and gives a r.m.s. setting error of the reconstructed point of less than 5 μm on the film (less than 180 μm in real space). To take into account the effect of small variations of the distortions due to small changes of the intensifier conditions (temperature and power supply fluctuations) a second third order polynomial correction is necessary. This second fit, which needs nine coefficients, is obtained by measuring the fiducial marks in each photograph before the measurement of the track. With the two corrections it is possible to reconstruct the points in space with an error of about 100 μm .

The tracks are seen on film as a succession of blobs along a trajectory (fig. 10) which is a straight line after these corrections. Using the Bessymatic with manual centring on each blob, a least square fit gives a r.m.s. dispersion of the order of 500 μm in space due to the combined effects of manual measurement precision, distortions, spatial reconstruction errors and diffusion of the primary electrons.

Each blob is reconstructed in space and the apparent ionization is obtained by counting the number of blobs per centimetre along the track. Furthermore, the distribution of the distances between two successive blobs is analyzed to obtain the true primary ionization. All the blobs are measured in view 1 or 3 and a few blobs are measured in view 2 to allow spatial reconstruction of the track.

4.2 Primary ionization measurement

The distribution of the distance x between successive primary ionizing collisions for a track of length L is given by

$$g(x; \mu) = \mu^2 L e^{-\mu x} , \quad (1)$$

where μ is the primary ionization per unit length (μL is the total number of primary collisions).

In order to fit the experimental distribution, this formula must be modified to take into account that blobs close together may not be individually resolved because of the finite resolution of the optical system and the size of the avalanches. These losses also cause an enlargement of all inter-blob distances because of the uncertainty in determining the centre of a blob resulting from two or more unresolved overlapping avalanches. The experimental distribution can be closely fitted with a two-parameter formula

$$g'(x; \mu, r) = \mu^2 L e^{-\mu x'} \left(1 - e^{-\frac{x'}{r}} \left(1 - \frac{x'}{r} \right) \right) \quad (2)$$

with

$$x' = x - \frac{\mu r^2 (\mu r + 3)}{(\mu r + 1)} , \quad (3)$$

where r is a second parameter related to the average radius of the blobs as seen by the operator on the projection table.

This formula is derived assuming an exponential variation of the blob sizes. The size seen by the operator is related to the density of the blobs on film. The measured distribution of the density (given by a standard KODAK grey scale) of each blob multiplied by its size (FWHM) shows an exponential behaviour (fig. 11). Formula (3) allows the enlargement in x for contiguous confusion zones to be taken into account.

For large x (x greater than 3 mm in space) the fit is sensitive only to μ since r acts only as a normalization parameter through (3). It is interesting to note that the same r gives the correct normalization for large values of x and the correct description of the experimental points for small values of x where the losses are important.

The so-called blob count I is related to μ and r by

$$I = \frac{\mu}{(\mu r + 1)^2} \quad . \quad (4)$$

4.3 Measurement of the size of blobs along a track

Preliminary results of the measurement of the avalanches as seen on the film have been made using the PEPR machine. Fig. 12 gives an idea of how the machine displays a digitized image of the avalanches to the operator. Fig. 13 shows the distribution of the peak density (given by a standard Kodak grey scale) of the blobs measured on four tracks (~ 1000 blobs). Above the saturation level, which occurs at ~ 3 on the grey scale, the peak amplitude was estimated by fitting a parabola to the truncated top of the density profile of the blob (fig. 14). Fig. 15 shows the distribution of the FWHM of the blobs of the corresponding four tracks, and thus is not the distribution of the size of blobs due to single avalanches only.

The results indicate that about 10% of the avalanche images reach the film saturation level and about the same fraction is at the background level. The most frequent density is correctly situated in the middle of the range.

4.4 Track diffusion and chamber memory

Pictures have been taken with different trigger delays in order to measure the diffusion coefficient D and the memory of the gas mixture. Fig. 16 shows the plot of σ^2 versus time. The value of σ^2 is related to the measurement dispersion (ϵ) and to the true track diffusion by

$$\sigma^2 = \epsilon^2 + 2Dt. \quad (5)$$

From the value of σ^2 at $t = 0$, ϵ is found to be $\sim 500 \mu\text{m}$. The slope of the curve gives a value of $390 \text{ cm}^2/\text{s}$ for D in He-Ne 80/20%.

The memory of the gas can be estimated by counting the number of avalanches along the diffused track. The memory is defined as the time during which the count has decreased by a factor e . As the purity of the gas is high, the memory of the chamber is so long that it is not possible to measure it correctly. The track on which the delayed trigger is made is always accompanied by other muon tracks and cannot be identified if the delay time is longer than about $100 \mu\text{s}$. The increase in the blob count due to the diffusion of the secondaries from primary collisions is clearly visible for time delays up to $50 \mu\text{s}$. These secondaries are low energy delta rays ($< \sim 6 \text{ KeV}$) and are seen at the minimum trigger delay ($\sim 0.9 \mu\text{s}$) as an individual avalanche cluster. The memory of the gas is about $350 \mu\text{s}$. Tests with a mixture of He-Ne and freon 114 have been made and show that the memory can be adjusted to any lower value.

4.5 Chamber uniformity

If the chamber is not terminated correctly with its wave impedance, the electric field is inhomogeneous along the chamber length. Measurements for different value of the termination have been made and the results are shown in fig. 17. A termination resistance of 30.5Ω (measured at DC) gives good homogeneity.

4.6 High voltage stability

Pictures of muons were taken whilst the high voltage was raised in steps of 1% with the γ (128) trigger. It is possible to see from the results (fig. 18) a saturation effect in blob count around three per centimetre as expected by formula (4) for r of about 0.8 mm (fig. 19). This r value is compatible with the measured optical resolution. Fig. 20 shows that the μ value obtained using the two-parameter fit does not show a saturation at the same electric field. If the chamber is operated below the onset of the plateau a 1% variation in the electric field gives a variation of about 12% in the primary ionization. Thus it is very important to have a very high stability, and a precise measurement, of the electric field, picture by picture during data taking.

4.7 Relativistic rise

Data have been collected for the three muon range γ triggers: $\gamma(10)$, $\gamma(68)$ and $\gamma(128)$. Fig. 21 shows the experimental results and the theoretical primary ionization as a function of γ for the gas mixture used. The accompanying table shows, for each γ value, the primary ionization obtained by the two parameter fit and the expected value. The dispersion in the measured ionization is $\sim 13\%$ for a track length of 125 cm (fig. 22). This dispersion is due to the Poisson statistics of the primary ionization ($\sim 5\%$), to the trigger inefficiency and to the manual measurement accuracy ($\sim 10\%$).

5. CONCLUSIONS

The avalanche chamber is a detector which is particularly well suited for a quark search experiment. The ionization measurements presented in this paper are in agreement with the theoretical predictions [5] of the primary ionization in He-Ne (80/20%) at the three γ values used (10, 68 and 128). The expected relativistic rise of the primary ionization is clearly observed. The dispersion of the measurements is greater than that expected from the Poisson statistics of the primary ionization, because of the large dispersion due to the manual measurements (and the γ trigger inefficiency). It is expected that automatic measurements with PEPR and FSD will result in a much smaller dispersion in the ionization measurements.

The results have shown that an avalanche chamber used for primary ionization measurements must be operated with a very high degree of stability in the high voltage pulse amplitude ($< 1\%$) and delay, the gas composition and the performance of the optical system. The apparatus used in this experiment has been shown to fulfill all these requirements. The resolution and the gain of the optical system are the present limiting factors in the quality of the photographs. Holography and electronography are two potential ways to improve the optics in order to make the avalanche chamber a more powerful detector.

An avalanche chamber can provide high precision ionization measurement and accurate track reconstruction for particle identification. The practically unlimited multitrack efficiency and the very good two track resolution combined with triggerability and short time resolution make the Avalanche Chamber an ideal detector for LEP.

Acknowledgements

The authors are particularly indebted to the following people, who have installed the WA44 experiment and have assisted in the run of the experiment F. Beauvais, Mme N. Boimond, Mme Y. Cholley, J. Gallay, J. Garavel, J. Leroy, A. Magouriotis, G. Trouiller and G. Zanolin. We wish to thank J. Dolet, P. Pfahl and P. Guerin for their assistance. We also would like to acknowledge help given by the following CERN groups: the Instrumentation group in EF Division, the EP Design Office, the Gargamelle group, the SB services section and the EF typing pool. We also wish to thank all the people in the EF film processing service.

We are particularly grateful to H. Itoh who has participated in the running of the experiment. We wish to acknowledge P. Lecoq and the "Groupe de chambre à bulles du L.A.L. Orsay" for helpful discussions and work during the early stage of the experiment.

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TABLE 1

Calculated for He-Ne 80-20% [5,15]

Trigger	γ	γ nominal	Relativistic rise in %	Primary ionization at 957 mb ^(*) and 21°C, cm ⁻¹
Beam C $\bar{V}_2\bar{V}_2'$	9.4 - 11.8	10	7.1 - 9.7	4.78 - 4.89
Beam C $R_1R_2\bar{V}_3\bar{V}_3'$	65.1 - 70.7	68	33.3 - 34.5	5.94 - 6.00
Beam C $R_1R_2V_3R_3$	> 128.3	128	42.7 to 50.7 (plateau)	6.36 - 6.71

Minimum ionization (1 atm, 20°C) - 4.72 cm⁻¹

Plateau ionization (1 atm, 20°C) - 7.11 cm⁻¹

(*) 957 mb was the working pressure of the avalanche chamber when the results reported in this paper were obtained.

FIGURE CAPTIONS

- Fig. 1 Experiment WA44: Search for quarks in high-energy neutrino interactions.
- Fig. 2 Primary ionization as a function of γ according to 5.
- Fig. 3 25 Ω AC-235 avalanche chamber.
- Fig. 4 AC-235 avalanche chamber - -25 Ω conical Blumlein line
- Fig. 5 Peak high voltage histogram (1% per channel) taken for 1191 pulses during data taking.
- Fig. 6 Peak high voltage as a function of the Marx charging voltage with fixed Blumlein spark gap pressure and width.
- Fig. 7 Peak high voltage and stability σ with fixed Marx voltage and Blumlein spark gap pressure as a function of the spark gap width.
- Fig. 8 AC-235 optics.
- Fig. 9 Muon range trigger (all dimensions are in cm).
- Fig. 10 Typical muon tracks in the AC-235 avalanche chamber.
- Fig. 11 Measured distribution of the density of each blob multiplied by its size (statistics from 4 tracks).
- Fig. 12 Density contours of blobs as seen with PEPR.
- Fig. 13 Peak density distribution of blobs.
- Fig. 14 Density profile of successive blobs seen with PEPR.
- Fig. 15 FWHM of the blobs.
- Fig. 16 Track diffusion.

FIGURE CAPTIONS(Cont'd)

Fig. 17 Chamber uniformity with various terminations.

Fig. 18 Blob count as a function of peak voltage V.

Fig. 19 Blob count as a function of μ and r according to (4).

Fig. 20 Primary ionization as a function of peak voltage V.

Fig. 21 Measured primary ionization for the three γ triggers.

Fig. 22 Distributions of the measured primary ionization for the three γ triggers.

Fig. 1

Minimum primary ionization at 1 atm-20°C

Gaz	He	H ₂	Ne
$\mu_{\min} [\text{cm}^{-1}]$	3.25	4.74	10.60
$\gamma_{\min}$	3.80	3.90	3.70
$\mu_{\text{PL}}/\mu_{\min}$	1.487	1.361	1.587
γ_{PL}	200	123	209

μ_{PL} is μ at the Fermi plateau

γ_{PL} is such that $\mu(\gamma_{\text{PL}}) = \mu_{\min} + 0.9(\mu_{\text{PL}} - \mu_{\min})$

Fig. 2

Fig. 4

TIME=16:10:15.

DATE=31/ 5/80.

CHNL	COUNTS	
1	0	I
2	0	I
3	0	I
4	0	I
5	44	I**
6	984	I*****
7	127	I*****
8	25	I*
9	11	I
10	0	I
11	0	I
12	0	I

ENTRIES= 1191 UNFL= 0 OVFL= 0

MEAN= 6.14 ST. DEV.= 0.53 MAX= 984

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Muon RANGE TRIGGER

Old muon
54 μ s delay

Trigger muon

delta ray

Typical muon tracks in the AC 235 avalanche chamber

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19

Fig. 20

Trigger	γ -range	Average μ from 5)	μ this experiment
$\gamma(10)$	9.4 - 11.8	4.84	4.73 ± 0.12
$\gamma(68)$	65 - 70	5.97	5.80 ± 0.11
$\gamma(128)$	> 128	6.54	6.59 ± 0.12

Fig. 21

Fig. 22