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Authors

Knies, Gerhard
Neuffer, David.

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DEVELOPMENT AND TEST OF A LIQUID
ARGON SHOWER DETECTOR*

Gerhard Knies[†] and David Neuffer

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

March 1974

ABSTRACT

We have designed and constructed a liquid argon shower detector, consisting of 30 sequential ionization chambers with interleaved converters. We have introduced a simple scheme to keep capacities low. The test of this detector in a $1.3 \text{ GeV/c } \pi^-$ beam was satisfactory.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[†] On leave of absence from DESY, Hamburg, Germany. Address after March 15, 1974: DESY, Hamburg, Germany

1. INTRODUCTION

Following a suggestion presented by L. Alvarez,¹⁾ Derenzo et al.²⁻⁴⁾ have made substantial progress in developing particle detectors using argon and xenon in liquid form. Their purpose has been to obtain high spatial resolution and to observe the gamma rays used in nuclear medicine. Alvarez also suggested that liquid argon could be used in a total-energy-absorbing shower detector. The detector would consist of a "barrel" of liquid argon (LA), with layers of metallic foil for charge collection. He expected that these could be produced at much lower cost than comparable NaI crystal detectors and conceivably have better energy resolution. Recently Nordberg⁵⁾ and Katsura et al.⁶⁾ have constructed shower detectors using multiwire proportional chambers. These detectors use gaseous argon to produce charges and were found to have much worse energy resolution than naively expected. This discrepancy was due to the large fluctuation in the number of δ rays produced in the gas. This phenomenon can be greatly reduced by using a solid or liquid medium for ionization. The substantially larger density of the ionizable medium in a liquid or solid increases the number of δ rays produced. The statistical fluctuation in the δ ray production can then be smaller than the fluctuation in the number of shower tracks. We have estimated that the uncertainty due to δ rays is about half the uncertainty due to track statistics when using argon gaps of a few millimeters depth.

In order to develop this new technique and to study the problems involved, we have built a test shower counter using purified LA as a medium for ionization, and exposed it to a 1.3 GeV/c π^- beam. In this report we describe details of the construction of the chamber and results from its test in a beam.

2. THE 1-GAP DETECTOR

2.1. Construction of the chamber

As a first step, we constructed a single-gap chamber (fig. 1). The purpose of this chamber was to obtain experience with the use of liquid argon in particle detection, and to see if signals were readily obtainable in the type of detector planned. This single-gap chamber was used to detect signals from a built-in α -particle source and from minimal-ionizing particles at the Bevatron, and to learn how to shield and remove the pickup of external electrical noise.

The active area of this chamber consists simply of two brass plates separated by a nylon ring as shown in fig. 1. The active area of the brass plates is a round flat area with a diameter of 3.2 cm. The edges of the nylon touching the brass plates are tapered, and contact pressure is applied by the screws so as to provide a vacuum seal. The gap between the plates is 5.4 mm. This configuration could be pumped to a vacuum of 10^{-5} Torr at both room and LA temperatures. Purified argon was condensed in the chamber by immersion in a bath of unpurified LA.

A small ^{241}Am alpha source was fixed permanently to the cathode in order to provide a permanent source of ionizing particles. This source was used to check the operation of the chamber and to provide calibration. In fig. 2a we show the signals from α particles after amplification.

2.2. Electrical signal

Positive high voltage of 1.0 to 4.0 kV was applied to one of the brass plates. The other plate was grounded. Free charge was collected at the high-voltage side and amplified by a field effect transistor (FET)—preamplifier-amplifier system. (See fig. 2.) This system was produced

by the Lawrence Berkeley Laboratory and is described elsewhere.⁷⁾ The output signal was linear in the charge sensed by the FET. The whole line of amplifiers was calibrated by test charges. We used (integration/differentiation)-time settings of (0.1/0.5) and (0.2/1.0) μ s. The rise time of the amplified signal is $\approx 0.5 \mu$ s.

2.3. The purification of argon

In order to collect charge, it was necessary to purify the LA to better than commercial standards. The purifier used was designed by Haim Zaklad and has been described before.⁸⁾ It has three active elements: First, it has a molecular sieve which removes water by absorption. The second stage contains calcium chips heated to 660°C , which are used to remove oxygen and nitrogen. The third stage is a reactor containing a copper catalyst preparation called BTS maintained at 180°C , which is used to remove oxygen, hydrogen, and carbon monoxide. In practice, the most critical impurity in electron capture is oxygen, and is most effectively removed by the calcium purifiers.

The purifier used to fill the single-gap detector has a capacity of 8 liters gaseous argon and holds pressures up to 35 psi.

2.4. Bevatron test of single-gap detector

For the Bevatron test, the detector, preamplifier, amplifier, amplifier power supply and high-voltage filter were all placed within a Faraday cage constructed from 1/4-in. copper mesh. This was to remove electrical pickup from the Bevatron area. Without the cage, the electrical interference was much larger than the signals.

The small 1-gap detector was tested at the Bevatron using a beam of $1.6 \text{ GeV}/c$ pions. A scintillator with an active area $1 \times 1 \text{ cm}^2$ was placed 8 cm upstream in front of the chamber. Pulses from the chamber were measured in coincidence with the scintillator. The intensity of

the beam was reduced to $300 \text{ particles}/\text{cm}^2$ per pulse (1 pulse lasts 1 s) to resolve individual tracks in the chamber. Figure 2a shows individual pulses from α particles on the oscilloscope, and fig. 2b a typical pulse-height spectrum from minimal-ionizing particles.

In between the scintillator and the chamber, there was about 0.1 collision length of material, mainly liquid argon from the cooling bath. If a beam particle underwent an interaction before the chamber, then, in the case of elastic scattering, it would cross the chamber gap at some angle different from the normal with a longer pathlength, thus producing more ionization inside the chamber; or, in inelastic scattering, it might produce other particles which enter the chamber. In both these cases, the electric signal would be larger. The pulse-height spectrum in fig. 2b does indeed show an asymmetric excess of $\approx 10\%$ in counts on the right side of the peak. Whether this excess was entirely due to beam interactions, or whether there was some contribution from δ -ray production (Landau fluctuation), cannot be resolved from the data we took.

2.5. Results

Table 1 shows the charge collected from minimal-ionizing tracks taken with different high voltages. There is a (common) calibration uncertainty for the charge determination of about 10% . The relative errors are less. The signal increases considerably with increasing field. This rate of increase indicates that the liquid was not perfectly clean. The signal expected in 5.4-mm LA without e^- capture is $Q_0 = 3.9 \text{ fC}$. With better purification we would expect a signal 40% larger than the one observed with $14.2 \text{ kV}/\text{cm}$.

Table 1. Signal size and width at various field strengths.

Voltage (kV)	Electric field (kV/cm)	Signal (10^{-15} C)	FWHM (%)	σ (%)
3.5	6.5	2.2	30	13
5.5	10.2	2.45	27	12
7.5	14.2	2.75	29	13

Table 2. Converting materials in one shower-counter unit.

Material	Thickness (mm)	Radiation lengths	Collision lengths
Brass Plates (2)	1	0.15	0.0085
Lead	1.6	0.28	0.0115
Argon	3	<u>0.02</u> 0.45	<u>0.0047</u> 0.0242
Total: 30 units +2 initial lead plates = 14.1 radiation lengths and 0.75 collision lengths.			

3. THE 30-GAP DETECTOR

3.1. Construction of the detector

After successfully operating the single-gap detector, we designed and built a detector consisting of 30 consecutive gaps, usable as a shower counter. Photographs of various parts of this detector are shown in fig. 4a-d. In fig. 5a we show a schematic drawing of the 30-chamber arrangement, and in more detail one conversion unit. Each unit is a square with sides 8 cm long, and consists of a brass plate, a lead plate, 2 sheets of 0.003-in. thick Kapton, and a second brass plate. The brass plates act as electrodes and provide a stable, plane surface. The Kapton is slightly oversize in order to provide secure electrical insulation between the brass plates, which are at opposite high voltages. The lead plates act as additional converters, and the entire assembly provides 14.1 radiation lengths as shown in table 2. The LA gap between units is 3 mm deep.

It was found that the FET preamplifier would not operate properly with an input capacity of greater than 100 pF. Since one gap has a capacity of $C_{CH} = 30$ pF when filled with liquid argon, we chose a connection of the gaps designed to keep the total capacity low. As can be seen from fig. 5, the gaps have been electrically split into two parallel sets of 15 gaps, where each set acts as a series of 15 plate capacitors. Also, in this particular configuration both exterior plates (#1 and #30) are grounded. This arrangement greatly decreases the stray capacity with the external detector body, and avoids microphonic effects with the external chamber body, so removing unnecessary noise. The capacity of the detector was measured to be 30 pF when filled with LA.

The external body of the detector is a stainless steel cylinder of 6-in. diameter and 10-in. length. A Varian flange provides the vacuum

seal on the removable side of the cylinder. A 2-liter gas bottle is also connected as a reservoir for vaporized argon.

The argon was purified using an enlarged version of the purifier described above. This purifier had a volume of 450 liters and could take pressures up to 60 psi. A quantity of 1.85 liters of LA was used to fill the detector.

3.2. Test of purity

An alpha source was also inserted in one of the gaps of the 30-gap detector and the charge from the gap measured. The alpha pulse heights were used to measure the purity of the argon. We made two observations: First of all, from the absolute value of these signals we determined the purity of the LA in terms of the electron capture length. The amount of charge to be observed from a ^{241}Am α source in clean LA as a function of the electric field has been measured elsewhere.⁹⁾ At a field of 12 kV/cm it is $Q_0 = 4.6 \pm 0.1 \cdot 10^{-15}$ C. If there is electron capture the charge signals will be reduced. The suppression of charge signals as a function of the capture length L is shown in fig. 6 for both cases: an alpha source at the cathode and a track crossing the gap.*

During our run, for α 's we had a ratio of $Q_m/Q_0 = 0.55$, corresponding to $L = 0.75 \cdot D = 0.225$ cm. A track signal will then be reduced to 66% of its size in pure argon.

* Since the charge produced by a track is uniformly distributed between cathode and anode, it acts in absence of capture, like half that charge being produced at the cathode. Therefore, we use Q_0 to designate one-half of the charge produced by a track. The relations shown in fig. 6 are

$$\alpha \text{ source } \frac{Q_m}{Q_0} = \frac{L}{D} \cdot (1 - e^{-D/L})$$

$$\text{track } \frac{Q_m}{Q_0} = 2 \cdot \frac{L}{D} [1 - \frac{L}{D} (1 - e^{-D/L})]$$

Secondly, we monitored the time dependence of the α signals. We found that there was no visible change ($< 1\%$) in the pulse height over a period of 24 h, indicating that the purity level of the argon in the detector (after the filling period, which took about 6 h) was stable.

3.3. Beam test

The technical performance of the 30-gap detector was tested using a beam of 1.3 GeV/c negative pions. A large fraction of the pions will cross all 30 gaps as minimal-ionizing particles and for these it is more straightforward to calculate the expected signal size than for showering particles.

As in the single-chamber case, a scintillator was placed in front of the detector, and pulses in the chambers were taken in coincidence with it. A typical spectrum is shown in fig. 7, which was taken at a high voltage of 12 kV/cm. The peak corresponds to a charge of 2.7×10^{-15} C and has a FWHM of 34% or a standard deviation of 15%. We estimate our calibration uncertainty to be $\approx \pm 10\%$. A minimal-ionizing track is expected to produce $Q_0 = 4.38 \cdot 10^{-15}$ C. After the suppression mentioned above we expect a charge signal of $Q = 2.9 \cdot 10^{-15}$ C. This is in good agreement with the observed charge.

4. RESULTS AND CONCLUSIONS

From the work we have done with the LA ionization chamber we can summarize the following results and experiences:

1) We could observe and measure an electric signal produced by a minimal-ionizing particle crossing the LA ionization chamber with standard electronic techniques. The amplified signal had a rise time of $\leq 0.5 \mu\text{s}$, and a duration of $\approx 2 \mu\text{s}$.

2) In spite of the smallness of the electric signal ($\approx 100 \mu\text{V}$) produced in the ionization chamber, there were no background problems that could not be overcome.

- (a) The electric noise pickup could be shielded away.
- (b) Acoustical noise (via microphonic effect) could be sufficiently reduced.

3) The time stability of the signal was excellent. The signal size did not vary noticeably (i. e. less than 1%) within 24 h. All the materials with which the purified LA had contact (stainless steel, nylon, Kapton, lead, brass, solder, and resistors) did not decrease the purity of the LA to the extent of affecting the stability of charge collection. There was no repurification necessary.

4) Our particular design, which avoids very large capacities by having a serial ac connection of the chambers for the signals, and by having a parallel dc connection of the chambers for keeping the (auxiliary) high voltage low, worked without problems.

5) We found for a minimal-ionizing track a ratio of signal/noise = 8. There are many ways to improve that number, e. g., by reducing the area of each element, which reduces the capacity; by increasing the width of each gap, which simultaneously reduces the capacity and increases the charge—and also the collection time; by reducing stray capacity; or by reducing the internal noise of the amplifier.

6) What are the prospects for shower energy measurements? Since the δ -ray fluctuations can be estimated to be small compared to the fluctuations in the number of observed shower tracks, we can use shower track statistics to infer the properties of shower detection.

The expected average number of observed shower tracks (N_{tr}) in a sandwich detector is given by the relation⁶⁾

$$N_{tr} = 55 E_0 / X_c,$$

with the shower energy E_0 in GeV, and the converter thickness X_c in radiation lengths per converter unit. The electric signal of one

minimal-ionizing track traversing our 30-gap detector produces 30 tracks. In our chamber ($X_c = 0.5$) this corresponds to a showering photon with energy

$$E_0 = 0.27 \text{ GeV}.$$

If we ignore the fact that the observed shower tracks are not completely independent, we find for a 30-track shower the statistical uncertainty will be 18%. This is slightly larger than the width of the noise. Since the signal size increases linearly in E_0 , the relative widths from noise and track statistics will be:

$$\sigma_{noise} = 0.15 [0.27/E_0 (\text{GeV})] = 0.04/E_0$$

$$\sigma_{track} = 0.18 [0.27/E_0 (\text{GeV})]^{\frac{1}{2}} = 0.09/E_0^{\frac{1}{2}}.$$

Therefore, for our detector we have:

$$\sigma_{noise}/\sigma_{track} \approx [0.27/E_0 (\text{GeV})]^{\frac{1}{2}}.$$

For photons with energy $E_0 \lesssim 270$ MeV, the electronic noise determines the energy resolution; for $E_0 \gtrsim 270$ MeV, track statistics are more important. The figures for σ_{noise} and σ_{track} can be reduced considerably with improved detectors. For better detection of photons with $E_0 \lesssim 250$ MeV, the electronic noise should first be reduced. Then an improvement in track statistics (by smaller converters X_c and more gaps) would be useful. For better energy determination of photons with $E_0 \gtrsim 300$ MeV, the track statistics must first be increased.

The motivation for this work originated from discussions we had with M. L. Stevenson on shower detection inside magnetic detectors like the SPEAR magnetic detector.

This work would have been impossible without the numerous enlightening discussions we had with S. Derenzo, R. G. Smits and H. Zaklad. Furthermore, without the permanent readiness for help and advice of S. Buckingham, Peter Harding, Joseph Savignano, H. Van Slyke, Garth Smith and R. G. Smits we would not have been able to complete the construction of these detectors. We thank R. G. Smits for use of the large purifier. We also appreciate the support we received from S. Buckingham and Fred Lothrop in setting up the test runs.

One of us (G. K.) is indebted to the Lawrence Berkeley Laboratory and Group A for the hospitality extended to him.

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FIGURE CAPTIONS

Fig. 1a. Schematic drawing of the one-gap detector, showing the following numbered components:

1. Active chamber volume (liquid argon)
2. Tapered nylon ring
3. Two brass pieces (they stick, like a cork in a bottle neck, from both ends into the nylon ring.)
4. Filling pipe.

Fig. 1b. Photograph of the one-gap detector.

Figs. 2. a. Oscillogram of amplified ionization signals from α particles, taken during the test at the Bevatron (beam off). High-voltage across the gap: 7.4 kV/cm. Vertical units: 0.1 V per division. Horizontal units: 2 μ s per division. Amplifier (Tranl-Amp) settings: integration time = 0.2 μ s, differentiation time = 1 μ s.

b. Pulse-height spectrum of the ionization signals from 1.6 GeV/c π^- crossing the chamber. The peak is clearly separated from the noise at the left end of the picture. Amplifier settings as above. High-voltage across the gap: 10 kV/cm.

Fig. 3. Electric connections to the one-gap detector and circuit for signal pickup. (The potential shield shown is an aluminum plate (see fig. 1b), separated from the high-voltage electrode by a plate of nylon. It is on ground potential and is at a fixed distance to the high-voltage electrode, so avoiding microphonic noise pickup.)

Fig. 4a. Photograph of the 30-gap detector. Shielding copper-mesh cage and container for the cooling bath.

Fig. 4b. Photograph of the 30-gap detector. Stainless steel tank, which contains the 30-gap array, with filling pipe, pressure release bottle, pressure gauge, safety valve and closing valve.

Fig. 4c. Photograph of the 30-gap detector. View into the opened tank, showing the front plate of the 30-gap array. Between the stainless steel cylinder and the gap array is a nylon tube for insulation. Also visible are the feed-throughs for the two signal and high-voltage leads.

Fig. 4d. Photograph of the 30-gap detector; showing the 30-gap tower in front of the stainless steel container. The flower is to add to the beauty of the colored version of this photograph.

Fig. 5a. Schema of the 30-gap detector and its electric connections. Signal from all 30 gaps appears at point A. Signal from gap #1 alone appears at point B. In gap #1 there was an α source for calibration. The capacity of the left brass plate with the right one, C_0 , as shown in the insert, is much larger than the capacity C_{CH} across the gap.

Fig. 5b. The equivalent electric circuit for the chamber.

Fig. 6. Reduction in charge signal size due to electron capture.

L = Capture length, D = Distance between cathode and anode.

Figs. 7a-b. Pulse-height spectrum from the ionization signals of a 1.3 GeV/c π^- beam traversing the 30-gap detector (labeled "1"). The narrow spikes are calibration pulses of 5 and 10×10^{-15} C, labeled "2" and "3" respectively. The spikes labeled "4" are calibration pulses at some other charge values.

- Over the full range of the pulse-height analyzer.
- Expanded scale.

XBL 743-2486

Fig. 1a.

Fig. 1b.

CBB 741-298

(a)

(b)

-18-

XBB 743-1555

Fig. 2.

Fig. 3.

XBL 743-2485

CBB 741-292

Fig. 4a.

CBB 741-296

Fig. 4b.

Fig. 4c.

CBB 741-294

Fig. 4d.

CBB 741-300

Fig. 5a.

XBL 743-2484

The capacitor C_0 provides a d-c separation of the chambers, and an a-c connection. $C_0 \gg C_{CH}$

XBL 743-2483

Fig. 5b.

XBL 743-2482

Fig. 6.

(a)

(b)

XBB 743-1556

Fig. 7.

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