Prospects for drift chamber calibration using a nitrogen laser

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R. A. Miskimen and K. Wang
University of Massachusetts, Amherst, MA 01003

I. Introduction

Ultraviolet lasers have proven to be of great utility in the calibration of drift chambers. Compared to calibration techniques that use cosmic rays, radioactive sources, or particle beams from accelerators, there are many advantages to laser calibration: 1) the light beam is not bent by a magnetic field, 2) multiple scattering is not a consideration, and 3) two-track resolution studies can be performed using a beam splitter. The ALEPH and OPAL groups at LEP have made extensive use of laser calibration for the testing of their detectors [Am85,Fi89]. In this note we investigate the possibility of using a nitrogen laser for drift chamber calibration in the CLAS.

There are two areas where lasers might play a role in the calibration of the CLAS drift chambers. The first, calibration of the main drift chambers, will probably require incorporation of UV transparent windows and remote-controlled internal mirrors into the design of the region I, II, and III chambers so the laser beam can be transmitted into the interior of the detector and then reflected to different regions. At present, the consensus of the CLAS technical staff is not to pursue this option but rather to use cosmic rays and electron beam to calibrate the drift chambers. The second area where laser calibration might play a role is in the small test chamber that will be constructed to monitor drift velocities. For a small, stand-alone system such as the test chamber, it will be much easier to implement laser calibration.

The two types of laser system most commonly used for drift chamber calibration are the nitrogen laser, with 337 nm wavelength, and the frequency-quadrupoled Nd-Yag laser, with 226 nm wavelength. Laser power varies with manufacturer and model, but nitrogen lasers typically have $\approx 100\mu$J per pulse while Nd-Yag lasers can have considerably more. Pulse widths for nitrogen and Nd-Yag lasers are typically 0.5 ns and 4 ns, respectively.

Although the Nd-Yag laser has the advantage of higher power and shorter wavelength, and can therefore produce a higher ion density in a drift chamber gas, the nitrogen laser is more commonly used because it is cheaper and less complicated.

Laser power is of great importance for drift chamber calibration. The reason for this is UV laser photon energies are low compared to the ionization potentials for typical drift chamber gases. For example, the nitrogen laser photon energy is 3.68 eV, compared with ionization potentials of 15.7 eV for argon and 11.6 eV for isobutane. Therefore, in order to ionize the gas, three-photon or four-photon absorption is necessary. Since three- or four-photon absorption is greatly suppressed relative to one- or two-photon processes, a signal in the chamber is small or completely absent. One way around this problem is to dope the chamber gas with an additive that has an ionization potential smaller than twice the UV photon energy and a large two-photon absorption cross section. With the additive, two-photon ionization can occur and the produced ion density is approximately proportional to the square of the incident energy density. Significant effort has gone into identifying suitable chamber gas additives that have sufficiently low ionization potentials and large two-photon cross sections [Hi86]. In practice it is generally not necessary to dope the chamber gas because laser-induced ionization is usually observed without it, provided the incident energy density is sufficiently high. Impurities in the chamber gas or outgassing from the chamber walls may be responsible for the ionization.

In this note the Laser Photonics model LN120C nitrogen laser is evaluated for use in drift chamber calibration. In some ways this laser is not well suited for this purpose. The laser has relatively low power, 70 μJ per pulse; a large spot size, 2 mm $\times$ 3 mm; and significant divergence, 3 mr $\times$ 7 mr at half-angle. The low power combined with the large spot size and beam divergence makes it difficult to achieve the high energy densities needed for two-photon ionization. Nevertheless, several other groups have reported the successful use of low-power nitrogen lasers ($< 100\mu$J/pulse) for drift chamber tests [Gu82,Hi86]. On the positive side, the short pulse width of the laser, 300 ps, makes it ideal for timing measurements. Furthermore, the possible use of this laser is an attractive prospect because the laser is inexpensive (less than \$5000) and quite durable. The laser can also be adapted to other purposes, such as the calibration of time-of-flight counters and shower counters.

II. Test setup

To achieve incident energy densities high enough to ionize chamber gas, it was necessary to focus the laser light to a much smaller spot size. A quartz lens serving as a demagnifier was used. The usual expression for magnification is

$$m = -\frac{s'}{s}$$

where s is the object distance and s′ is the image distance. The relationship between s and s′ is given by

$$\frac{1}{s} + \frac{1}{s'} = \frac{1}{f}$$

where f is the focal length of the lens. To ionize the chamber gas, the magnification should be as small as possible. In practice, this requires making either the image distance small or the object distance large. The approach taken here was to use a lens with a short focal length, giving a small image distance. Placing the laser at a large object distance would have required the use of a large-diameter lens because of the divergence of the laser beam. The lens used was a 2.54 cm diameter quartz lens with a focal length of 28 cm; the object distance was 127 cm, and the image distance was 36 cm. This gave a magnification of 0.28 and a laser spot size at the image point of 0.6 mm $\times$ 0.8 mm. The peak laser power per unit area at the image point was 0.49 MW/mm^2.

The emission process in the laser is triggered by a spark gap that sets up an LC oscillation in the excitation circuit. One difficulty in using the laser is that the spark gap produces a large burst of radio frequency (RF) noise which was picked up by the chamber, rendering it unusable for the duration of the RF pulse. Measurements at CEBAF showed that an unshielded laser at a distance of 3 meters from the CLAS protype chamber induced an oscillating pulse in the signal wires of approximately 500 mV amplitude and 125 Mhz frequency that lasted for about 150 ns. Since minimum-ionizing particles produce pulses on the order of a few mV in size, the noise burst from the laser was clearly too large. Furthermore, since the frequency of the noise was in the 100 Mhz range, filtering technques cannot be applied to suppress the noise without also suppressing real events.

To reduce the RF noise pickup in the drift chamber, the laser was shielded using standard RF shielding techniques [Ot88]. The basic criteron that must be followed in the construction of an RF shield is to make it as tight as possible. For example, wrapping the laser in copper mesh with a mesh spacing of 1/16" proved to be insufficient and reduced the

RF pickup in the chamber by only 50%. This is despite the fact that the RF wavelength, 2.4 m, is much larger than the mesh spacing. The laser was shielded by placing it in a box constructed of 1/4" thick aluminum, with the bottom and side seams in the box welded to prevent RF leakage. The lid, also constructed from 1/4" thick aluminum, was bolted onto the top of box to seal it. An RF gasket was placed between the lid and box to prevent RF leakage through the narrow crack between the lid and top. The gasket was located inside of the thru holes for the lid fasteners. To allow laser light to exit the box, a 3/8" hole was drilled in one end of the box and a 4" long, straight aluminum tube was attached to the outside of the box. The tube allowed laser light to escape but acted as an attenuating waveguide, prohibiting the escape of RF. The nitrogen gas line for the operation of the laser was coupled to a brass bulkhead connector in the wall of the box, which was then connected to 12" of copper line in the interior of the box. From the end of the copper line a gas connection was made to the laser. The purpose of the copper line was to attenuate and prevent RF leakage out of the gas port. AC power for the laser was obtained from an isolation transformer built into the wall of the box.

A diagram of the drift cell used for the laser tests is shown in Figure 1. The chamber's construction is similar to an early design by Charpak's group [Br74]. The anode voltage, +2300 V, was unusually high for a drift cell of this size and geometry, but this was necessary because the chamber pulses produced by the laser proved to be quite small. To minimize UV absorption, 1/4 mil thick mylar was used as a chamber window. The optics were adjusted so that the laser light was focused to a point inside of the drift cell; Figure 1 shows its approximate direction relative to the cell. The drift chamber gas was a 50:50 mixture of argon and isobutane with no impurities added to the gas.

Using transparent entrance and exit windows, the laser beam was transmitted completely through the chamber. Downstream of the drift chamber a UV-sensitive diode was used to detect the laser pulse. The pulse from the diode was used for triggering CAMAC electronics and as an oscilloscope trigger when observing laser-induced pulses in the drift chamber. To measure chamber pulse heights, the diode pulse was used to trigger a 200 ns gate to an LRS 2249A CAMAC ADC. The gate was sufficiently wide that drift chamber pulses would always arrive within this gate. To measure drift times, the diode pulse was used to start an LRS 2228A CAMAC TDC in common start mode. A PC-AT computer controlled and recorded data acquisition. The adjacent drift cell in the chamber (not shown in Figure 1) was out of the laser's line of fire and was used to measure accidental contributions to the ADC and TDC spectra.

III. Results

Tests showed that the laser shield nearly eliminated RF pickup in the drift chamber. From 0 to 1 μs after the laser pulse there was no observable coincident noise in the drift chamber. After 1 μs and extending for a few hundred nanoseconds, the noise was approximately 1/2 mV in amplitude. Since chamber pulses should arrive within a few hundred nanoseconds of the laser pulse, this late noise did not cause any problems.

Most laser pulses passed through the drift cell without producing a single photoelectron; one chamber pulse was observed for approximately every 400 laser firings. Furthermore, the laser-induced chamber pulses observed were quite small, typically 1/2 mV or less. This is roughly the expected pulse height corresponding to a single photoelectron. Using the measured pulse frequency and the cell height of 0.8 cm, the ionization density was estimated to be 0.003 electrons/cm. In contrast, minimum-ionizing particles produce more than 100 electrons/cm. Figure 2 shows the pulse height spectrum for the laser-induced chamber pulses. Accidentals have already been subtracted from the spectrum and the horizontal scale is 0.0025 pC per division. The distance-versus-time relationship in the drift cell was studied by moving the laser beam to different parts of the cell and measuring drift spectra. These studies failed because threshold discrimination in the chamber electronics could not be set low enough. Nevertheless, the correct time-distance relationship was verified roughly by observing with an oscilloscope the time lag between the diode pulse and the chamber pulse.

In the course of sweeping across the cell, the laser beam would sometimes strike a cathode wire, which was a 100 μm silver-plated BeCu wire. When this occurred, chamber pulses were produced with the same frequency as the laser and with approximately 20 mV amplitude. The reason for such a strong chamber response is that the work function of silver, 4.73 eV, is only slightly higher than the UV photon energy and, therefore, ionization can proceed through two-photon absorption. Only slight movement of the chamber would make these pulses disappear, confirming that the laser was indeed striking a wire. It is interesting to note that the time delay between the laser pulse and the chamber pulse was close to the maximum drift time of 350 ns in the cell, even though the laser was aimed in the vicinity of the signal wire. Presumably the drift electrons, produced at the edge of the cell, are taking a long drift path out of the cell before returning to the signal wire. Calculations with GARFIELD have confirmed the presence of these long drift paths at the cell edge.

IV. Summary and conclusions

A nitrogen laser such as the Laser Photonics LN120C may have some application for drift chamber calibration with the CLAS. By constructing a tight metal box it was possible to shield the drift chamber from the laser's RF pulse. Unfortunately, the chamber response was quite weak; the observed ionization density was very low, approximately 0.003 electron/cm. The chamber pulses were 1/2 mV in amplitude and the pulse frequency was only 1/400 that of the laser.

This result is not inconsistent with other studies that have successfully used nitrogen lasers. Using a 40 μJ/pulse nitrogen laser Guo *et al.* [Guo82] were able to achieve ionization densities of 5×10^4 electrons/cm by focusing the laser to a spot size of approximately $10\mu m \times 10\mu m$, giving a power per unit area of 40 MW/mm^2. This power density is nearly two orders of magnitude higher than what was achieved here. Using the power law deduced by that group,

$$N_e \sim I^{\,2.3}$$

where N_e is the number of photoelectrons and I is the laser intensity, their data predicts an ionization density of 2 electrons/cm at the power density of this measurement. The remaining discrepancy between the two measurements may be due to an incorrect extrapolation from high to low laser energy densities or to the presence of unknown impurities in the gases, which will complicate the comparison.

Clearly, there are two approaches that can be taken to improve the nitrogen laser as a calibration tool. The first approach is to make the spot size at the image point smaller, on the order of a few tens of microns. This will require a quartz lens with approximately 10 cm size and 1/4 m focal length and placement of the laser 10 or more meters from the chamber. The other approach is through the addition of impurities with low ionization potential to the chamber gas. For example, one part per million of benzene will produce 7×10^3 electrons/cm at an incident energy density of 1 $\mu J/mm^2$ [Hi86]. To achieve gas ionization over a significant track length in order to fire several cells simultaneously, it is also better to use a large quartz lens with long focal length and to place the laser at a long object distance.

A strong response from the chamber was observed when the laser struck a cathode wire. The chamber pulses, caused by two-photon absorption on the surface of the cathode wire, had the same frequency as the laser and an amplitude of 20 mV. It may be possible to take advantage of this in the construction of a test chamber for monitoring drift velocity. A drift cell could be constructed with a wire cathode or foil at a known distance from the signal wire, and the cathode could then be illuminated by a UV laser. The drift time over a known distance would provide a measure of the drift velocity. This might work particularly well for the hexagonal drift cell to be used in the region II and III chambers, since the cathode wires are at the greatest distance from the signal wire and will determine the drift time over a well-defined path to the signal wire.

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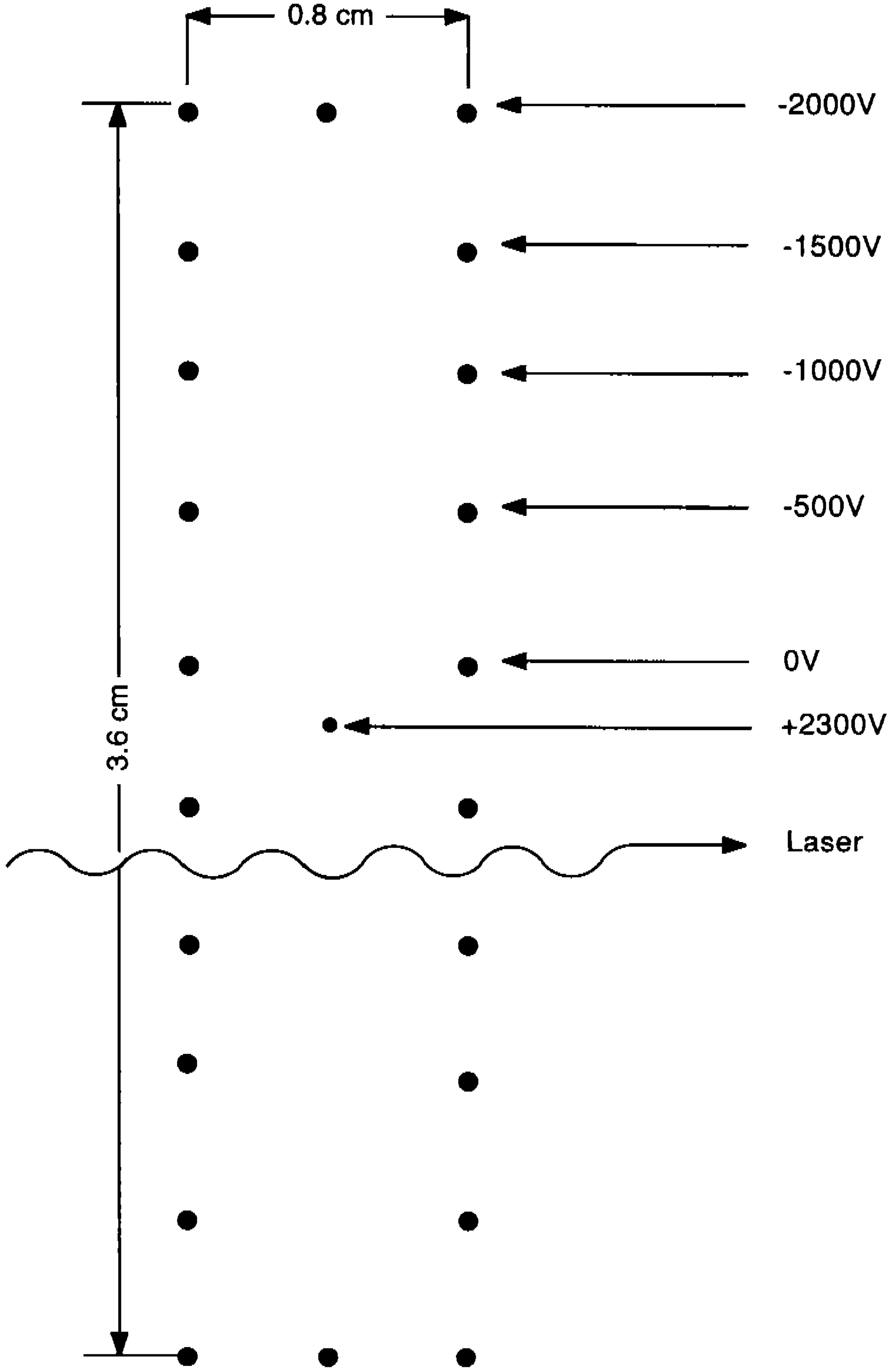
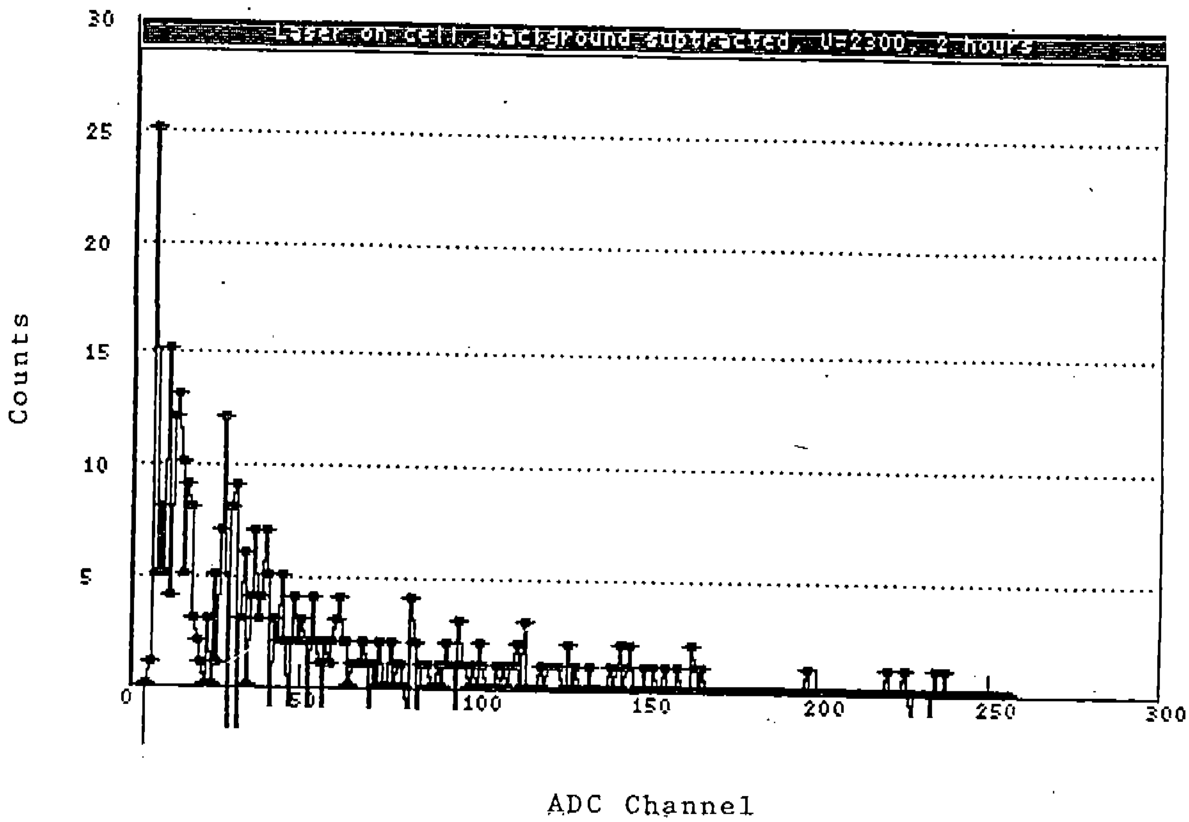
Drift Cell





Laser on cell, background subtracted, U=2300, 2 hours
Counts
30
25
20
15
10
5
0
50
100
150
200
250
300
ADC Channel