First Running Experience With the Laser Calibration System of the UA1 Central Detector

Sean P. Beingessner¹⁾, Thomas C. Meyer²⁾, Alan Norton²⁾, Martti Pimiä³⁾, Carlo Rubbia²⁾ and
Vincent Vuillemin²⁾

Geneva, 8 May 1989

Abstract:

We report on a UA1 technical run made with four Nitrogen lasers mounted on the UA1 Central Detector during the 1987 proton - antiproton collider run. With only moderate laser power ($< 7 \mu\text{J}/\text{mm}^2$) and the help of gas seeding (1 ppb of Tetra-Methyl-Phenylene-Diamine [TMPD]) straight 2m calibration tracks can be produced. The unexpected effect of track fading under high luminosity conditions was observed. A model is presented explaining this phenomenon, which is based on the removal of neutral TMPD molecules from the drift volume via positive ion charge exchange.

International Conference on Advanced Technology and Particle Physics

Villa Olmo, June 13 - 17, 1988

Como, ITALY

¹⁾ University of Victoria, Canada

²⁾ CERN, Geneva Switzerland

³⁾ Helsinki University, Finland

1. INTRODUCTION

A laser calibration system, designed to produce straight tracks inside the UA1 central detector has previously been described [1]. The UA1 Central Detector, CD, is a large volume continuously sensitive drift chamber. There are strong arguments for introducing a laser calibration system for future physics runs under high luminosity conditions (ACOL). A downsized version of this system was installed and successfully tested during the 1987 UA1 technical run at the CERN proton-antiproton collider. Lacking substantial background conditions during this run (i.e. high luminosity, $> 10^{30} \text{ cm}^{-2}\text{sec}^{-1}$) we could not actually test the usefulness of straight laser tracks to understand and, hence, correct for the field distortions caused by excessive space charges. We therefore focused upon the technical aspects and potential problems associated with the laser calibration system, such as laser pulse height, momentum and the coordinate resolution of laser tracks, track fading and gas seeding with TMPD.

TMPD (Tetra-Methyl-Phenylene-Diamine) due to its low ionization energy is a very effective seed for producing laser ionization by two photon absorption. However in large concentrations it is known to accelerate anode wire ageing [2]. At the same time, it was shown that, if introduced at the ppb level, TMPD remained an effective laser seed, apparently helpful in controlling cathode wire ageing and in leading to a possibly tolerable level of anode wire ageing. It was therefore decided that the use of TMPD in the CD was worth pursuing but that some caution need to be taken in introducing it. Thus, during the fall 1987 run of the CERN proton-antiproton collider TMPD was introduced at the ppb level to one of the six modules of the UA1 Central Detector.

2. THE UA1 NITROGEN LASER

A detailed description of the UA1 central detector can be found in reference [2]. For future high luminosity runs, small compact nitrogen lasers ($15 \times 15 \times 2 \text{ cm}^3$) will be mounted directly on the outer shell of the detector. Owing to the specific drift cell geometry of the detector 20 such lasers are

set up to produce tracks in the central section and 16 lasers for the tracks in the forward region of the chamber. Since the forward drift gaps of the detector, (in particular those near the beam pipe), are most seriously affected by space charges [1,2], we installed four lasers as a crucial test on one forward section on the 'antiproton' side of the detector.

The lasers are equipped with an a-focal beam telescope with a total focal length of > 10 m. This compensates for the laser beam's divergence and defines optimal spot size over the entire track length in the detector (circa 2 m). The light is guided via three mirrors through a quartz window into the chamber. The angle of the laser beam (31°) has been chosen in such a way that the light will travel through the entire forward section of the chamber for a maximum track length. This defines a beam length of roughly 2 m. Hence, the laser beams traverse 6 consecutive drift gaps, from the nearest to furthest from the beam pipe. This is shown in figure 1, the MEGATEK display of a laser track. In the following we report results made with one laser only.

2.1 Gas Seeding with TMPD

In recent years the source of laser induced ionization has been the subject of much debate. But it is now a well established fact that two photon resonant absorption in low ionization potential (IP) impurities is the most plausible explanation. The UA1 gas purification system, via its catalytic action, effectively removes all residual hydrocarbons of low ionization energy. When the central detector was operated with pure gas (Argon/Ethane 40/60) the laser did not produce detectable ionization. Only with the addition of a low ionization chemical could laser tracks be produced.

Nitrogen lasers produce 337 nm wavelength light corresponding to a single photon energy of approximately 3.7 eV. Thus to ionize any molecule in two resonant steps the molecular IP must not exceed 7.4 eV. A substantial amount of research and development work has been invested in the proper seeding of the central detector drift gas. An exhaustive description of this work is given in reference 1 and 2. The choice was originally narrowed down to Di-Methyl-Aniline (DMA) or Tetra-Methyl-Phenylene-Diamine (TMPD).

Although TMPD produced more ionization than DMA, it was originally thought to be sticky and so should be treated with caution. Thus, DMA was initially favoured. However, the result of ageing tests with DMA indicated it was disastrous from the point of view of growing deposits on the anode wire. This led to more serious consideration of TMPD, which, provided it is introduced in small enough quantities, can be removed from the chamber. Thus it is only partially sticky. Ageing tests with TMPD at the ppm level showed similar results to DMA, while tests at the ppb level showed tolerable results. Therefore, for reasons of detector safety (i.e. avoiding premature wire ageing) and two photon ionization efficiency, TMPD was chosen as the most suitable doping seed for our drift chamber gas.

The seed is admitted to the normal gas flow intermittently, in order to achieve the minute concentrations of only a few ppb (parts per billion). This proved sufficient for the purpose of laser induced ionization with moderate laser power ($< 7 \mu\text{J}/\text{mm}^2$). In other words, the charge thus produced per track element is comparable to that of a minimum ionizing particle or approximately 100 electrons/cm.

3. LASER PERFORMANCE INSIDE THE UA1 CENTRAL DETECTOR

In the course of the experiment, laser tracks could be studied under basically two conditions: "with" and "without" coasting beams. Typically 1000–2000 laser events were taken and recorded on tape during test runs. The events were then analysed and some of them scanned on the MEGATEK facilities.

A typical laser track in the forward section of the central detector is illustrated in the MEGATEK display of figure 1. The hit residuals of several fitted tracks in the $x-y$ (momentum) plane are shown in figure 2. Notice the growing uncertainties along the last third of the tracks due to diminished laser beam intensity. A partial loss of laser power is also caused by laser photons directly hitting the wires in the drift volume. The R.M.S. resolution in the momentum plane for these tracks is defined as the projection of all hit residuals and is found in figure 3. The value of $280 \mu\text{m}$ is comparable to that of stiff particle tracks taken from minimum bias data. Also in terms of charge division along

the sense wires laser tracks compare closely to real particle tracks, indicating that a similar charge per segment is produced by the laser (see figure 4). Figure 5 gives the laser track momenta calculated from a measured curvature in the 0.7 Tesla magnetic field. As expected the data clusters around infinite momenta or no curvature.

On the other hand, plotting the pulse height of the laser tracks (dE/dx) in small time slices over the entire length of the laser run, produced a rather astonishing and unexpected result.

3.1 Laser Runs Without Beam

The measured pulse height remained stable during the time laser data was taken; (i.e. constant dE/dx). This is shown in figure 6, where data was taken during an accelerator shut down period. Notice the five different pulse height plateaus, each corresponding to the average pulse height in one drift gap.

Thus, the top curve describes the dE/dx measurements in the drift gap closest to the laser, and the bottom curve that in the 5th gap from the laser. The last drift gap has been suppressed from this plot, since the charge fluctuations due to loss of light intensity were considered too large for this measurement.

This shows that the TMPD seeding remained stable over the course of the test.

3.2 Laser Runs With Beam

Figure 7 gives the measured laser pulse height, dE/dx , as a function of time for a run taken at a collider luminosity of 2×10^{29} . At that time the total drift currents in the 6 gaps was approximately 10 μA . Clearly, the laser induced pulse height does not remain constant during the course of data taking as was the case without the beam. Obviously this effect must be related to the background ionization in the chamber due to proton – antiproton collisions and beam gas collisions. This ionization is amplified at the sense wires and causes background currents in the chamber. There was not sufficient time to study this effect of “track fading” in detail during the run. It is undoubtedly associated with the

specific beam conditions, as it becomes less severe with lower backgrounds, or completely absent with no backgrounds at all.

Once the laser induced pulses have faded away, they remain absent, even after the background currents have become zero (beam off). The recovery time for the laser induced charge to reappear (with no beam) is in the order of several hours, the time needed to introduce the TMPD to the pure gas. This suggests that under running conditions the ionizable traces of TMPD in the gas volume become insensitive to the two photon effect or are removed. The flow of gas seeded with TMPD, 200 l/hour could not furnish enough new TMPD into the chamber volume of 4000 l to compensate for the loss suffered.

This will have serious implications for the calibration procedure during an even higher luminosity run.

Although the absence of time prevented a more detailed study of this effect (i.e. as a function of different gap currents) a fairly consistent picture emerges on the basis of the few observations made. The TMPD is removed by a very efficient mechanism, the only one that presents itself is that the TMPD undergoes charge exchange with the positive ions produced by the charge amplification process near the sense wires, and the resulting TMPD ions are destroyed or removed while being neutralized at the cathode wires.

4. LOSS OF TMPD DUE TO CHARGE EXCHANGE

The fact that the TMPD remained constant during the laser run without the collider being on, but disappeared at a rapid rate during real running conditions implies it is removed by a rate dependent process. Since one of the main differences between the two cases is the presence of a large number of positive ions drifting through the drift gap, it is possible that they cause the TMPD to be converted to TMPD ions via a charge exchange. These ions drift to the wires where they are neutralized. This neutralization process is sometimes known to cause molecules to dissociate themselves[3]. In this way the TMPD could be destroyed.

In the gas avalanche around the anode wire, both argon and ethane ions are produced. This is a result of having the primary ionization amplified at the wire. It is generally believed that the argon ions produced in the avalanche are quickly neutralized by charge exchange with neutral ethane [3]. This is a consequence of the lower ionization energy of ethane and its presence as a significant fraction of the total gas mixture. However, the cross section for this process is not exactly known. In the same way the relatively low ionization potential of TMPD (6.75 ± 0.02 eV) compared to that of ethane suggests that it is then possible for the ethane ions to be neutralized by a charge exchange with the TMPD. This process would not be expected to be as rapid due to the much smaller concentration of TMPD, but the cross section, again unknown, could be large.

It is then possible to consider the effect of large numbers of ethane ions migrating through the drift region of the central detector on their way to the negatively charged drift wires on the concentration of TMPD. The focus is placed on the concentration or partial pressure of the TMPD, because this is directly proportional to the laser pulse height and the quantity measured.

To examine this possibility let us introduce the following variables:

P = the partial pressure of TMPD,

P_0 = the partial pressure of TMPD at $t = 0$, 1 ppb,

i = the total current, $10 \mu\text{A} = 1.6 \times 10^{19} \times 10^{-5}$ ions/sec,

V = the volume of the CD module, 4 m^3 ,

N_0 = the number of molecules of gas per m^3 , 2.5×10^{25} ,

N = the number of TMPD molecules = PN_0V ,

d = distance of the drift of positive ions, .18 m,

λ = the effective mean free path for charge exchange with TMPD,

λ_{true} = the true mean free path for charge exchange,

f = probability that the TMPD molecule is destroyed while being neutralized at the cathode wires.

The effective mean free path for charge exchange is defined as that measured along the direction of the drift. This is useful as we know the length of drift of the ions, but not the real distance traveled due to their random thermal motion. The drift velocity of the ethane ions may be only 1% to 5% of the

thermal velocity. Therefore the actual distance traveled may be 100 times the drift distance. As a consequence:

$$\lambda \approx 0.01 \times \lambda_{\text{true}}.$$

With the above definitions the probability that a positive ion (presumably ethane) would undergo charge exchange with a neutral TMPD molecule before being neutralized at the drift wires is:

$$1 - e^{-Pd/\lambda}.$$

The number of TMPD ions created in this way per second is:

$$i(1 - e^{-Pd/\lambda}).$$

Hence, the number of TMPD molecules lost due to charge exchange and then destroyed while being neutralized is given by:

$$dN = -fi(1 - e^{-Pd/\lambda})dt,$$

then using $N = PN_0V$, or $dN = N_0VdP$,

$$dP = -(fi/N_0V)(1 - e^{-Pd/\lambda})dt.$$

If Pd/λ is small, this reduces to,

$$dP = -(fi/N_0V)(d/\lambda)Pdt,$$

which integrates to:

$$P = P_0 e^{-[fid/N_0V\lambda]t}.$$

Therefore, under this model one would expect an exponential decrease in the partial pressure of TMPD in the gas volume. This would then lead to an exponential decrease in the laser pulse height as observed in figure 7. The data points of figure 7 were then fitted with a common exponential decay time of $5 \times 10^{-4} \text{ sec}^{-1}$. Assuming that this time constant is equal to $fid/N_0V\lambda$ and using the above values for i , d , N_0 and V gives:

$$\lambda/f \approx 0.001 \mu\text{m},$$

or

$$\lambda_{\text{true}}/f \approx 0.1 \mu\text{m}.$$

In order to make some empirical observations it is necessary at this point to make an assumption about λ_{true} or f , as both are unknown. If a high probability of the TMPD dissociating while being neutralized at the negative wires, f , is assumed, say $f=1$, then

$$\lambda_{\text{true}} = 0.1 \mu\text{m}.$$

Sauli [3] suggests a typical mean free path for collisions of ions and molecules as $0.1 \mu\text{m}$ and states that it takes between 100 and 1000 collisions for the ion to transfer its charge. This would imply that the TMPD is unusual in its efficiency at neutralizing the ethane ions. However, if f is much less than 1, it is necessary for the mean free path to be smaller still. Sauli also states that charge exchange is most efficient when the two kinds of molecule have ionization potentials that are close. This is not the case for TMPD and ethane.

While it seems unusual that ethane ions have a $0.1 \mu\text{m}$ mean free path for charge exchange with TMPD, and TMPD^+ has a large probability of dissociating while being neutralized at the cathode, it is difficult to come up with an alternative explanation. It will prove interesting in the future, when the collider is again active to test the above model with different values of the luminosity and gap currents. However, while the present data is still approximate and not taken under optimal conditions, it seems to point to TMPD as having a very high efficiency for charge exchange with ethane ions, a high probability of dissociating while being neutralized (or possibly in the charge exchange reaction with ethane) as well as being a very efficient laser seed.

5. CONCLUSION

Laser induced calibration tracks can be produced with excellent accuracy in a large volume drift chamber, such as the UA1 central detector. Only with the addition of a highly sensitive and efficient doping agent can pulse heights comparable to minimum ionizing particles be achieved without jeopardizing detector safety in terms of wire ageing. TMPD, a chemical with very low ionization energy satisfies the demand for high photon induced efficiency and reduced detector wire ageing.

There is strong evidence that the TMPD molecules are removed by first undergoing charge exchange with normal ions as they drift toward the cathode wires. At the cathode wires the TMPD is destroyed by the neutralization process. It is not clear what happens to the fragments of the TMPD molecule. It is known that the TMPD accelerates the formation of anode wire deposits [2]. It is not known if this is a consequence of fragments from the cathode process that catalyze the formation of

polymers at the anode, or the TMPD itself acting as a catalyst during the avalanche itself. However, this model of the process is consistent with our earlier reasoning with regard to the wire ageing phenomena, which have been observed under the influence of low ionization potential trace additives [2]. More specifically, TMPD and DMA were very efficient at inhibiting Malter currents at the cathode due to their high probability of undergoing charge exchange with ethane ions.

The fact that TMPD is removed in high luminosity situations limits its effectiveness. The impact of this effect calls for more laser power and possibly a new calibration strategy under realistic run conditions.

6. ACKNOWLEDGEMENTS

We are most grateful to the management and staff of CERN. We would also like to express our thanks to the Natural Sciences and Engineering Research Council of Canada and to Valtion luonnontieteellinen toimikunta, Finland. We are thankful to Th. Muller for many stimulating and interesting discussions. We would also like to thank D. Brozzi, A. Looten, and P. Queru and his group for their help in building the precise and complicated apparatus, and M. Bosteels and his group for the construction and modification of the UA1 gas system. The help of the UA1 people collaborating in the data taking of this run is highly appreciated as well.

Figure Captions

- Fig. 1 MEGATEK display of a typical laser event.
- Fig. 2 Plot of the residuals of individual point measurements, in the $x-y$ plane, from the fitted track. Notice the loss in accuracy as the distance from the laser increases. This correlates with the loss of pulse height shown in figures 6 and 7 as the gaps move further from the laser.
- Fig. 3 Resolution in the $x-y$ or momentum plane averaged over the total length of the laser track.
- Fig. 4 Resolution in the z coordinate, the charge division resolution with laser tracks.
- Fig. 5 Histogram of laser track momentum with $B = 0.7$ Tesla. In the presence of space charge distortion one could expect some change in curvature, simulating curvature due to a bend in the magnetic field, leading to a low or asymmetric momentum measurement. This was not observed at the luminosities at which data was taken.
- Fig. 6 Laser pulse heights or dE/dx as a function of time at zero luminosity during a collider shutdown. The five lines correspond to the average charge in each of 5 gaps. The largest pulse height corresponding to the gap closest to the laser. A minimum ionizing particle would have a dE/dx of around 50 UA1 units.
- Fig. 7 Laser pulse height or dE/dx versus time as in figure 6 but with the collider on and a luminosity of 2×10^{29} . The 5 lines are the result of a fit to 5 exponentials all with decay time set at $5 \times 10^{-4} \text{ sec}^{-1}$.

REFERENCES

- [1] Sean P. Beingessner, Thomas C. Meyer, Vincent Vuillemin, Michel Yvert, Nucl. Instr. and Meth. A263 (1988), 26.
- [2] Sean P. Beingessner, Thomas C. Meyer, Michel Yvert, Nucl. Instr. and Meth., A272 (1988), 669
- [3] Fabio Sauli, "Principles of Operation of Multiwire Proportional and Drift Chambers", CERN 77-09, (1977). (reprinted in "Experimental Techniques in High Energy Physics" ed. T. Ferbel).

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7