ARGON PURITY MEASUREMENT OF THE D0 CALORIMETER

A. BESSON, G. SAJOT

Institut des Sciences Nucléaire
53 avenue des Martyrs, 38000 GRENOBLE, FRANCE
E-mail: abesson@in2p3.fr, sajot@in2p3.fr

The D0 Argon purity Test Cell (ATC) measures the O_2-equivalent pollution of a liquid argon sample extracted from the calorimeters. The cell consists in two radioactive sources, α (^{241}Am) and β (^{106}Ru), immersed in liquid argon which produce ionizations. Then, the created charges are drifted by an adjustable electric field. Due to absorption of e^- by electronegative impurities, the total collected charge depends on the O_2 pollution. The device is an upgraded version of Run I D0 ATC. Its present sensitivity is estimated to be better than $\pm$ 0.15 ppm.
A pulser with adjustable frequency is used to calibrate the electronics. The electric field is ramped step by step between 5 kV cm^{-1} and 15 kV cm^{-1}. Furthermore, for calibration purpose, the ATC is equipped with a system to pollute a pure Argon sample, with a given amount of O_2.
The setup and method of analysis of α and β measurements will be described. Measurements of the purity of the gas Argon from the three calorimeters (Central, North and South End Cap) will be presented.

1. Introduction

The signal of drifting electrons in liquid argon is highly affected by recombination with O_2 (or other electronegative molecules)[1], so that the Argon purity needs to be precisely monitored before filling the D0 calorimeters. Pollution above 1 ppm would deteriorate the signal significantly[2].

The principle of the measurement is the following : two radioactive sources (α ^{241} Am and β ^{106} Ru) produce ionizations in the liquid Argon between two electrodes where an electric field can be adjusted (fig. 1). The collected charge depends both on the electric field and on the O_2 pollution.

1.1. *The ATC and the modifications for Run II*

The ATC developed, built and operated for Run I[3,4] has been upgraded[5,6] and tested at Grenoble from January to June 2000. Main modifications concern :

(1) the electronics which is based on NIM modules (developed for the AT-

LAS experiment[7]). A pulser with adjustable frequency and with the same shape as the signal (width 1.5 μs, amplitude 50 mV) is used for calibration purposes,

(2) the possibility to pollute at a given level a pure Argon sample, to calibrate the system,

(3) the data acquisition interface card (National Instrument AT MIO 16E10) and the acquisition program written in LabWindows/CVI ®.

The cell (fig. 1) contains two sources : an α source (^{241}Am, 5.4 MeV, activity $\sim$ 2 kBq which has already been used for Run I) and a β source (^{106}Ru, 3.5 MeV, with an activity of 40 kBq). These sources have been manufactured by Isotope Products in Burbank (USA) by electro-deposition on a 2.5 cm diameter stainless steel electrode. The gap between cathode and anode is 2.15 mm. In addition for the β source, a second gap of the same width is used as a trigger. The HV is varied between $\sim$5 and 15 kV/cm for the α and between $\sim$1 and 15 kV/cm for the β. The field in the trigger gap is set at 10kV/cm.

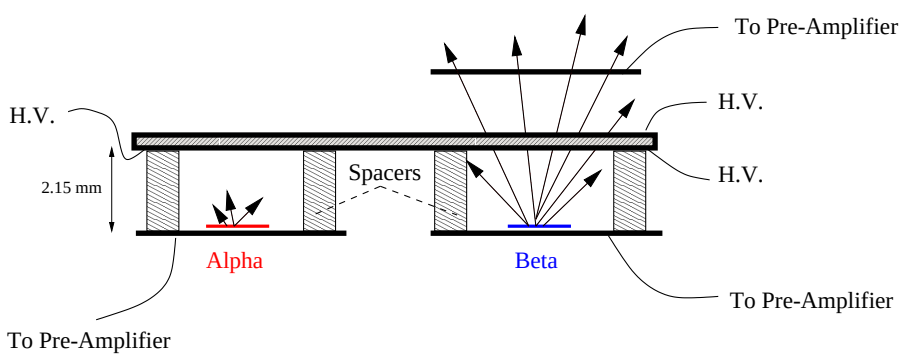

Figure 1. Alpha and Beta sources layout

1.2. *Cooling procedure*

Argon is filled in gaseous phase by "cryogenic pumping" It is cooled down by liquid Nitrogen. By adjusting the Nitrogen pressure, one can get a stable pressure of Argon at $\sim 5 \pm 1$ PSI. For cross-checking purposes, three temperature probes (Pt100) are placed close to the cell and show that temperature (T=89.0 $\pm$ 0.5 K) is stable with variations below 1 K. This is consistent with the Pressure-Temperature phase diagram[2]. The 10 liters of liquid Argon, which are necessary for the measurements, are usually obtained in 3 hours.

1.3. *Electronics and Data acquisition*

The signal goes through the following electronic chain:

(1) a preamplifier (designed at ISN), which is placed outside of the cryostat as close as possible to the cell, in order to minimize noise,
(2) a shaper, a constant fraction discriminator (CFD), a Charge Voltage Convertor,
(3) a data acquisition card (National Instrument) to allow data analysis on a PC, using LabWindows/CVI.®.

In addition to the source signal, the calibration pulser signal and the pedestal are also measured on line (with typically 40000 events in total for each high voltage value). For a given LAr sample and for twenty values of the electric field, the acquisition time is around 1 hour. The pedestal, the pulser and the α signals are fitted with a Gaussian distribution while the β signal is fitted by a Moyal fit[8]. The mean values are used to compute the pollution.

2. Measurements with α source

2.1. *Absorption factor*

α particles deposit almost all their energy over $10 - 20\mu$m. This induces a constant current over a period of time equal to the drift time t_d between the electrodes[9].

For a sample with pollution p and for each value of the electric field E, a normalized ratio $X(E,p)$ is defined as:

$$X(E,p) = \frac{< signal(E,p) > - < pedestal >}{< calibration > - < pedestal >} \tag{1}$$

Where $< signal(E,p) >$ is the mean value of the signal produced by the source, $< calibration >$ and $< pedestal >$ are the mean values of the calibration signal and of the pedestal. In this ratio possible fluctuations of the gain of the electronic chain cancel.

Collected charge $Q(E,p)$ and absorption $Abs(E,p)$ are related by[10]:

$$Q(E,p) = Q_0 \frac{1}{\xi} \ln(1+\xi) \times Abs(E,p) \tag{2}$$

where Q_0 is the total charge produced, $\frac{1}{\xi}\ln(1+\xi)$ describes initial recombination of electron-pairs, and $Abs(E,p)$ is the absorption factor. Since no theoretical model provides a satisfactory description of this recombination, a parameterized formula obtained by the ISN-ATLAS group[7] is used :

$$\xi E = a(1 - c \times e^{-bE}) \tag{3}$$

with $a = 474 \pm 1.4$ kV/cm, $b = 0.143 \pm 0.006$ cm/kV and $c = 0.403 \pm 0.010$[11]
Furthermore, the absorption factor is:

$$Abs(E,p) = \frac{\lambda(E,p)}{d}(1 - e^{-d/\lambda(E,p)}) \tag{4}$$

with:

$$\lambda(E,p) = \alpha \times E/p \tag{5}$$

where $\lambda(E,p)$ is the absorption length, d is the gap between the electrodes, and $\alpha = 14.2 \pm 1.4$ mm^2 ppm/kV([12]).
Eventually, assuming that $X(E,p)$ is proportional to $Q(E,p)$, one gets:

$$\frac{X(E,p)}{\frac{1}{\xi}\ln(1+\xi) \times C_{norm}} = \frac{\alpha E}{pd} \times (1 - e^{\frac{-pd}{\alpha E}}) \tag{6}$$

C_{norm} is a normalization term that, in particular, takes into account charge to voltage conversion factor. The equation 6 is fitted as a function of E, where p and C_{norm} are the parameters. The pollution p affects mostly the curvature of $Abs(E,p)$ vs E.

2.2. *Calibration and errors*

2.2.1. *Main sources of uncertainties on p measurement*

The main sources of errors on the O_2-equivalent pollution are due to the :

(1) fit error and statistical error on the peak determination for signal, pulser and pedestal : ± 0.07 ppm.
(2) error on the gap measurement : 2.5 %
(3) precision of the high voltage settings : 2 %
(4) error on parameters a, b, c and on trapping constant α.

Other systematic errors (electronic fluctuations, non linear response of the preamplifiers...) are more difficult to evaluate and can be estimated with a calibration, as explained below.

2.2.2. *Calibration*

Equation 6 shows that p is an absolute measurement. However, to cross-check the validity of the fit, the possibility of doing calibrated pollutions has been added. First, the cryostat is filled with high purity Argon (for example certified with less than 0.1 ppm O_2). Then, a given volume of pure O_2 is added, followed by an Argon gas flow (coming from the cylinder) during 30 minutes, so that 100% of the O_2 is transfered into the cryostat. From the quantity of

O_2 and LAr in the cryostat, a nominal (i.e. *expected*) value for the pollution is derived. Experimentally, one has found that measurements get stable and are consistent with the nominal pollution after one hour. The relative uncertainty of the nominal pollution is $\sim$ 10 %. Figure 2(a) shows different calibration measurements. The standard deviation of measurements varies from 0.05 to 0.1 ppm depending on the pollution range. We choose to set it at 0.1 ppm for all measured values to be conservative.

To cross check the consistency of the measurements, one can compare nominal and measured pollutions. A linear fit is then realized ($p_{nominal} = a \times p_{measured} + b$), giving the following results:

(1) $a = 0.95 \pm 0.05$
(2) $b = 0.03 \pm 0.04$

Where a and b are the fit parameters, $p_{nominal}$ is the nominal pollution and $p_{measured}$ is the measured pollution.

Nominal and measured pollutions are in very good agreement within a large range (from 0.1 to 5 ppm). So the calibration validates the procedure and provides an estimation of the systematic errors by adding quadratically the error on a and on $p_{measured}$. Figure 3 shows the total error of the measurements: for low pollution measurements ($p < 1$ ppm), uncertainties are lower than 0.15 ppm.

3. Measurements with a β source

3.1. *Properties of the β source*

β are minimum ionizing particles so that most of them cross the gap depositing energy along their path producing a linear decreasing current[9]. The signal of the second gap is used as a trigger to provide a good rejection of the electronic noise. Because of this minimum ionizing behavior, concentration of ion-electron pairs along the track is small, so that recombination effects are much lower than for α particles.

3.2. *Calibration*

As for α measurement, a linear fit is performed and the estimation of the systematic errors is obtained with the same method (fig. 3). The large error at high pollution is due to a lack of calibration data taken in this domain.

For each calibration sample an empirical fit is done using the following expression:

$$\frac{< signal(E,p) > - < pedestal >}{< pulser > - < pedestal >} = a + (d + c \times E + g \times E^2) \times e^{(-b*E)} \quad (7)$$

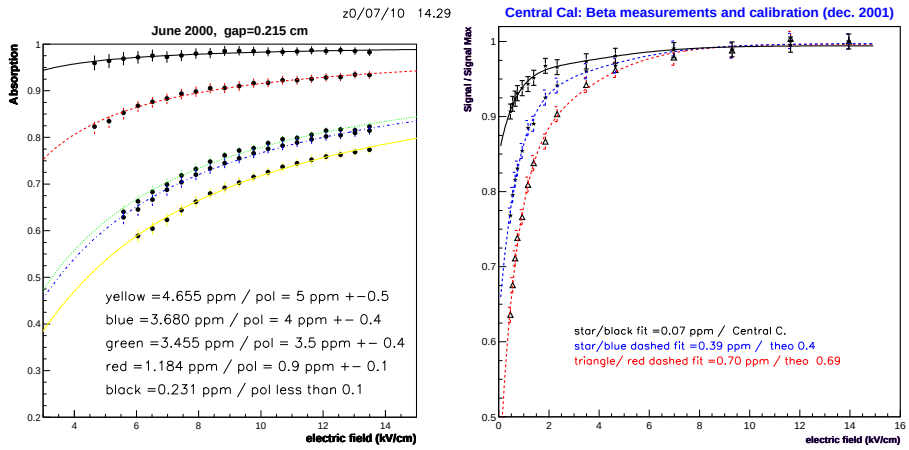

Figure 2. (a) α: Absorption measurement of samples with known pollution vs electric field. (notation measured/nominal is used for the results on the figure. (b) β: Central Calorimeter measurement (Dec.2001).

Where the same conventions as for equation 1 are used. a, b, c, d and g are the parameters of the fit. More precisely, the fitted quantity is the expression on the left hand side of the previous equation divided by its asymptotic value reached for high electric fields (E > 12 kV/cm).
The calibration has shown that d is a linear function of the pollution p. Figure 2(b) shows a measurement of the Central Calorimeter compared with two calibration samples.

3.3. *Results*

Figure 3 shows that for low pollution, β source measurements are slightly better than α source measurements. During the years 2000-2001, several campaigns of measurements have been performed. Results are summarized in table 1. It clearly appears that the purity of all the three calorimeters are far better than 0.5 ppm. This is very satisfactory after 5 years of storage in the Dewar, proving that the Argon cryogenic system has no leak. So we conclude that the Ar purity of the dewar has not been degraded and can be used for Run II wihout any correction. The analysis of the first data of the D0 calorimeter are in good agreement with expectation and confirmed *a posteriori* this result[13].

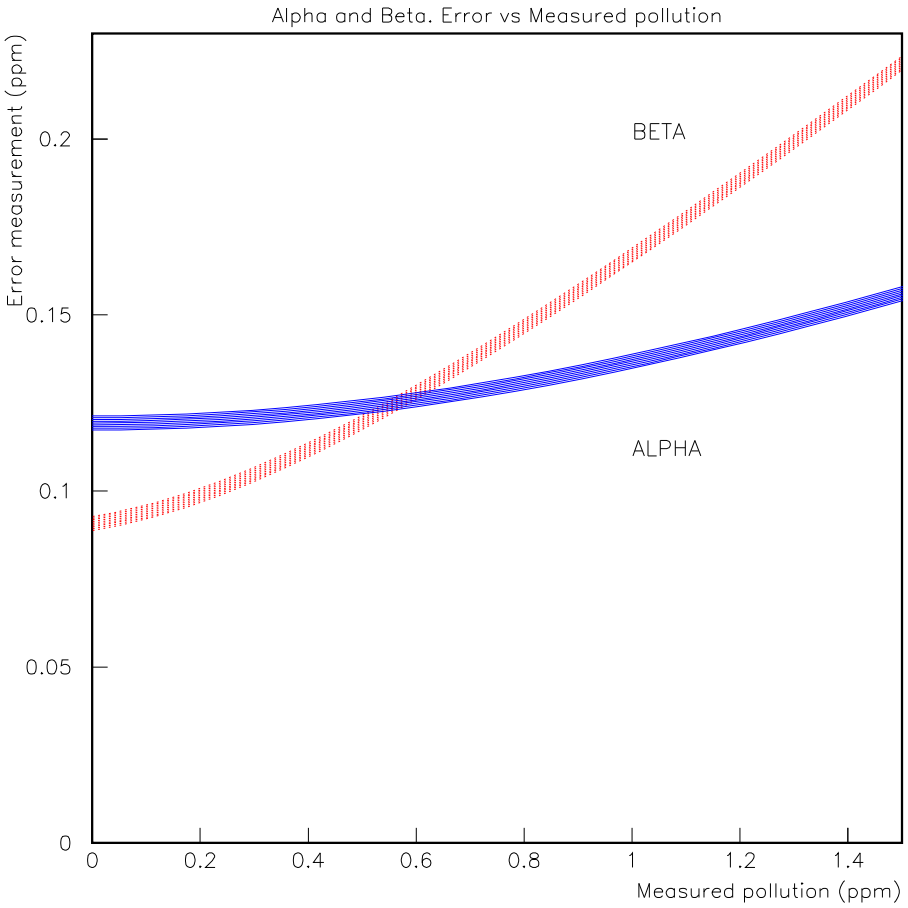

Figure 3. Errors on α and β measurement as a function of the pollution.

Acknowledgments

We are particularly grateful to Yves Carcagno and Gabriel Mondin for their great work on the ATC, and to Philippe Martin (ISN-ATLAS group) for his help during the tests of the ATC in Grenoble. Many thanks to John Kotcher for his support of the project, to Gerald Blazey, Christian Zeitnitz and Bob Hiroski for their advices, and to Dan Markley for his help during installation and data taking, and for the numerous discussions we had with him during measurements. Germain Bosson and Robert Foglio have realized the preamplifiers and electronic modules. Solveig Albrand provided the initial version of

Table 1. Summary of all the measurement performed with α and β sources.

Sample	Extracted Phase	ALPHA	BETA	date
dewar	gas	0.34 ± 0.12	-	July 2000
dewar	liquid	0.33 ± 0.12	-	July 2000
dewar	gas	0.25 ± 0.12	0.18 ± 0.10	October 2000
dewar	liquid	0.37 ± 0.12	0.19 ± 0.10	October 2000
C.C.	gas	0.49 ± 0.12	0.38 ± 0.11	December 2000
N.E.C.	gas	0.16 ± 0.12	0.21 ± 0.10	December 2000
C.C.	gas	0.07 ± 0.12	0.10 ± 0.10	December 2001
N.E.C.	gas	0.11 ± 0.12	0.09 ± 0.10	December 2001
S.E.C.	gas	0.17 ± 0.12	0.14 ± 0.10	December 2001

the Acquisition soft.

References

1. C. Brassard, Liquid ionization detectors, *NIM* **162**, 29 (1979).
2. ATLAS Technical Design Report, p.76, (December 15th 1996)
   Gas encyclopedia. Elsevier Scientific Publishing Company (1976).
3. G. Blazey for the D0 collaboration, *Monitoring liquid argon purity at DZERO*, Proceedings of the first Conference on Calorimetry in high energy physics, World Scientific October 29th - November 1st 1990.
4. G. Blazey, *D0 Liquid Argon Monitoring Hardware*, D0 Note 000940, 3/1/91.
5. Hardware details and pictures of the ATC can be found at: *http://isnwww.in2p3.fr/d0/cryostat.html*
6. A. Besson and G. Sajot, d0 internal notes 003799 and 003827, (December 2000).
7. M.L. Andrieux et al, *Response of an α source mounted in a liquid argon ionization cell and read out in full charge collection mode*, NIM **A 427**, 568 (1999).
8. J.E. Moyal, *Theory of Ionization fluctuations*, Phil. Mag **46**, 263 (1955)
9. W.J. Willis and V. Radeka *Liquid-Argon ionization chambers as total absorption detectors* NIM **120**,221 (1974)
10. J. Thomas and D.A. Imel, *Phys. Rev.* **A 36**, 614 (1987).
11. Parameters fitted by P.Martin ATLAS group ISN Grenoble (private communication)
12. W.Hofmann et al., *Production and transport of conduction electrons in a liquid argon ionization chamber*, NIM **135**, 151 (1976).
13. A. Juste, *D0 Status and first results from Run II*, Moriond, (March 2002).