USE OF TPC CALIBRATIONS

P. Billoir, Ph. Charpentier, P. Delpierre, D. Delikaris, Y. Sacquin,
P. Siegrist and D. Vilanova
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P.Billoir\textsuperscript{1}, Ph.Charpentier\textsuperscript{2}, P.Delpierre\textsuperscript{1}, D.Delikaris\textsuperscript{1}, Y.Sacquin\textsuperscript{2}, P.Siegrist\textsuperscript{2} and D.Vilanova\textsuperscript{2}

Saclay, 11 February 1987

Abstract: We describe here the different measurements which have to be made on the TPC sectors before the installation in the experiment as well as during the data taking.

1. Introduction

The signals of the electrons produced by ionization in the TPC are recorded after treatment by several components: the amplification in the MWPC, the preamplifiers, the shapers and the Flash ADCs (FADC). In order to be able to achieve the desired goals, one needs to monitor the absolute calibration on the wires (for dE/dx measurements) and the relative calibration of next channels for the pads (for \( \phi \) position measurements). These calibrations are deduced from several measurements which are described in this note.

2. FADC calibration

The quantity measured by the TPC digitizers \[1\] is expressed in units of FADC counts. This number must first be converted into a "true" amplitude, i.e. a quantity which is proportional to the input signal. For this, the response curve of the FADC has to be known. Figure 1 shows the shape of this curve. It is determined by a pedestal \( P \) which corresponds to a zero input signal and two slopes \( a_1 \) and \( a_2 \). Since the input amplitude has to be known at this stage only in arbitrary units, the slope \( a_1 \) for example may be taken as equal to 1.

Whereas this curve may be measured precisely in the laboratory with a sampling clock precisely timed with respect to the input signal \[2\], such a measurement is very difficult when installed in the experiment. The procedure is therefore slightly different.

2.1 Measurement of the pedestal

The only input signal for which one is sure of its timing with respect to the sampling clock is... a null signal! This is the way the pedestal \( P \) is measured: one takes data with a random trigger. For each channel, a large number of measurements of \( P \) is made at each trigger (corresponding to the number of time slices recorded). Care has to be taken for accidental signals occurring during the digitization time.

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\textsuperscript{1} Collège de France, 75005 Paris, France

\textsuperscript{2} DPhPE, CEN-Saclay, 91191 Gif sur Yvette, France
2.2 Measurement of the slopes

A signal is applied at the input of the FADCs for example by pulsing the gating grid with a controlled voltage. The input signal is proportional to this voltage.

The maximum amplitude of each resulting signal is computed by a software interpolation. The mean value of these maximum amplitudes give the response of the FADC to the corresponding voltage. (The mean value is computed using the design value of \( a_2/a_1 \) when signals are recorded on both sides of 191).

Experimentally, the point extrapolated down to a zero amplitude from this measurement is different from the true measured pedestal. This is partly due to the software method used in computing the maximum value of the signal. However, the slopes measured with this method give a correct estimate of the ratio \( a_2/a_1 \) when using 3 points on each part of the response curve. Since it has been experimentally verified that the measured ratio \( a_2/a_1 \) is very close to the design value, no iteration of this computation is usually needed.
2.3 FADC response curve

One only needs to determine the input signal corresponding to a given FADC count in arbitrary units. One can for example fix the slope $a_1$ to be equal to 1. Then the measured values of $P$ and $a_2/a_1$ together with the constraint that the break in the curve occurs at 191 allow an unambiguous determination of the response curve of the FADCs. The absolute calibration of the FADC is incorporated into the electronics gain of the linear chain.

The first processing of any data consists in converting the FADC count number into an input signal using this curve. In all what follows, the word "amplitude" is used for this converted value.

The pedestals may be time dependent since they can depend on the electric and electronic environment of the digitizer board. They have thus to be measured very frequently (typically before any set of measurements), but this takes only a short time. The slopes should hopefully be independent of time, since they reflect the setting of the reference voltages inside the chip. Therefore, they have to be measured very carefully once for each channel. Check measurements have to be done periodically for measuring the stability.

3. Calibration of the TPC wires

The wires need the most careful calibration, since the absolute calibration of all channels has to be known precisely. The relevant quantity for $\frac{dE}{dx}$ measurements is the amount of energy deposited inside the drift volume of the TPC. It is related to the amplitude measured in the FADC by the formula:

$$A(i,x) = s \cdot M(i,x) \cdot C(T(i,x), P(i,x)) \cdot G(i)$$

where:

- $i$: is the wire number.
- $x$: is the position along the wire.
- $s$: is the energy deposited by the track above the wire. This is the quantity we finally want to extract.
- $M$: is the gain of the MWPC at a reference temperature $T_0$ and pressure $P_0$ at position (i,x) for the nominal HV on the anode wires.
- $C$: is a correction factor to this gain depending on the actual temperature $T$ and pressure $P$ at position (i,x).
- $G$: is the the electronic gain of channel $i$ when the measurement is made.

3.1 Measurement of the temperature and pressure dependence of the MWPC gain

The gain in the MWPC varies with both temperature $T$ and pressure $P$. Since it is a function of the density of gas in the amplification volume, the gain is a function of the ratio $P/T$. If we take as reference $T_0 = 20^\circ C = 293^\circ K$ and $P_0 = 1010$ hPa, we need to vary one of the parameters in a range such as to cover $\pm 3\%$ on the ratio $P/T$ and measure the MWPC gain at a fixed position. We determine in this way the correction function $C(T,P) = C(P/T)$ such that $C(P_0/T_0) = 1$.

3.2 Measurement of the electronics gain $G(i)$

The electronics gain of the linear chain (preamplifier, shaper and digitizer) may vary in time. They have thus to be measured periodically by pulsing the gating grid. If a voltage $V$ is applied on the grid, the signal induced on the wire $i$ is $V \cdot \beta(i)$ where $\beta(i)$ is the coupling between the grid and the wire. The measured amplitude is thus:

$$AP(i) = V \cdot \beta(i) \cdot G(i)$$
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If this gain does not vary to rapidly with time, periodic measurements are sufficient to know the electronics gain during the data taking. The pulse generator should however be set such as to produce signals as close as possible to the particle ones.

3.3 Measurement of the MWPC amplification gain \( M(i,x) \)

The multiplication factor of the MWPC may vary for a given chamber due to irregularities on the wire surface or variations in the gap (planarity of the cathode planes). A map of the gain on the whole area of the chamber as a function of the wire and the position \( x \) along this wire is thus needed to correct for that effect.

The procedure used for this determination is a \(^{55}\text{Fe}\) source located on a movable ruler, usually called wiper. It can be moved by small angular steps in order to scan the whole sector. All wires are irradiated by the wiper at the same time.

For each of the peaks of the \(^{55}\text{Fe}\), one measures an amplitude:

\[
A_w(i,x) = s_{Fe} \cdot M(i,x) \cdot C(T_{w,P}, P_{w}) \cdot G_w(i)
\]  

If one measures at the same time grid pulses together with the wiper signals, one obtains also amplitudes:

\[
A_w^P = V_w \cdot \beta(i) \cdot G_{w}(i)
\]

\( V_w \) is the voltage applied on the grid when the wiper measurement is made. One assumes that the grid pulse has the same shape as is normal data taking such that the coupling \( \beta(i) \) is the same as in normal operation mode. Note that since a simultaneous measurement of \( G_w \) is made, one can use for the gain map a linear chain completely different from the normal one, e.g. CAMAC shapers and a qVt instead of the Fastbus shapers and digitizers. The 5.9 keV deposited by the X-ray of the iron decay chain would induce signals outside the linear range of the shapers. Therefore, the high voltage must be decreased in order to match the signals induced by the iron with this range. However, it is assumed that the amplification \( M \) is proportional to the gain with the nominal high voltage (with a factor \( \alpha \)).

The ratio of the two measured amplitudes gives:

\[
\frac{A_w(i,x)}{A_w^P} = \frac{\alpha \cdot M(i,x)}{\beta(i)}
\]

If one wants to extract the true gain map of the chamber (i.e. the function \( M(i,x) \)), one has to make a guess on the coupling \( \beta(i) \) which in first approximation may be taken as proportional to the wire length.

3.4 Extraction of the deposited energy

However, we shall see that the relevant quantity to be measured is not the actual amplification gain \( M(i,x) \). Combining equations (1) (2) (3) and (4) give the relation:

\[
\frac{A(i,x)}{A_w(i,x)} = \frac{s_{Fe} \cdot C(T,P) \cdot A_P(i)}{C(T_{w,P}, P_w) \cdot V_w \cdot V \cdot \frac{1}{\alpha}}
\]

If we remember that the goal is to obtain \( s \), equation (6) becomes:

\[
s = K \cdot \frac{A(i,x)}{A_w(i,x)} \cdot \frac{C(T_{w,P}, P_w) \cdot A_w^P(i)}{C(T,P) \cdot A_P(i)}
\]

where:

\[
K = \alpha \cdot s_{Fe} \cdot \frac{V}{V_w}
\]
K is unfortunately a quantity which may be estimated from this expression, but may also be measured in situ for confirmation of the absolute calibration of the wires.

### 3.5 Absolute calibration of the wires

In order to extract K, one needs to use (at the nominal HV of the chamber) a source of signal whose intensity in keV is well known. The equation (7) may be then inverted to give K if an amplitude $A_c$ is measured corresponding to a known signal $s_c$.

One has two possibilities which may be complementary of each other: the use of the muons produced in the experiment and the use of the escape peak of the fixed $^{55}$Fe sources. For the later solution, each source on each wire gives an independent determination of K, whose mean value can be taken to be then applied in equation (7).

### 3.6 Quantities to be measured with the wiper

The equation (7) shows that the relevant quantity measured with the wiper is the ratio:

$$R_w(i,x) = C(T_w,P_w) \cdot A(w) / A_w(i,x)$$

A precise measurement of this ratio can be made by taking simultaneously data with the wiper and grid pulses using a single electronics channel (e.g. a peak sensing qVt) multiplexed on the wires.

A typical spectrum obtained is shown on figure 2. In order to get rid of the unknown pedestal of such a measurement, one can make use of the known value $\lambda = s_E/s_M = 0.46$. $R_w$ can be expressed as a function of the quantities directly measured on the qVt $Q_E$, $Q_M$, and $Q_P$ corresponding respectively to the escape peak of iron, the main peak of iron and the pulse peak:

$$R_w(i,x) = C(T_w,P_w) \cdot [1 + (1-\lambda) \cdot (Q_P - Q_M)/(Q_M - Q_E)]$$

With this definition, equation (7) may be rewritten as:

$$s = K \cdot R_w(i,x) \cdot A(i,x) \cdot [C(T,P) \cdot A(i)]$$

with

$$K = <K(i,X)>_{i,X}$$

$$K(i,X) = 2.7 \, \text{keV} \cdot C(T_c,P_c) \cdot A_c(i)/A_c(i,x) / R_w(i,X)$$

if one can make use of the escape peak of $^{55}$Fe for the absolute calibration.

The precision one can expect to achieve on $R_w$ may be calculated from the following formula:

$$\delta R = (1-\lambda) \cdot \sqrt{\delta Q_P^2 + \mu^2 \delta Q_E^2 + (1+\mu)^2 \delta Q_M^2} / (Q_M - Q_E)$$

with

$$\mu = (Q_P - Q_M)/(Q_M - Q_E)$$

Experimentally [3], one has $\delta Q_P << \delta Q_M << \delta Q_E$ such that one can get:

$$\delta R \approx (R-1) \cdot \delta Q_E / (Q_M - Q_E)$$

Using the values quoted in reference [3], i.e. $\delta Q_E \approx 2.6$ and $Q_M - Q_E \approx 235$, since $\mu \approx 1$ and $\lambda = 0.46$, one gets $\delta R/R \approx 0.3\%$. 


4. Calibration of the TPC pads

The problem for the pads is different since only the relative calibration of adjacent pads is important. Let us recall that the position of a hit is deduced from the quantity $\log(A_1/A_2)$ where $A_1$ and $A_2$ are the amplitudes measured on adjacent pads. When 3 pads are hit, a weighted mean of the two possible determinations is made to get the position.

Formula (1) still holds, but since the signals recorded on adjacent pads are generated by the same avalanches inside the MWPC, the term $M(i,x)\cdot C(T,P)$ is not relevant for the relative comparison. In fact, the only important calibration data is the gain of the electronic chain $G(i)$. Relation (1) can be rewritten as:

$$A(i) = \sigma_1 \cdot G(i)$$  \hspace{1cm} (12)\]

$\sigma_1$ is proportional to the signal induced on the pad number $i$ by these avalanches.
Since the pads are not calibrated using radioactive sources, one uses the grid pulsing for generating a signal on all pads. It has to be assumed that the coupling $\gamma(i)$ of equation (2) is the same for all pads in a row. In that case, the recorded signal $AP(i)$ is proportional to the gain $G(i)$:

$$AP(i) = V \cdot \gamma \cdot G(i)$$

$$\sigma_i = V \cdot \gamma \cdot A(i) / AP(i)$$

Since the absolute calibration is not needed and $V \cdot \gamma$ is constant in a row, one can take:

$$\sigma_i = A(i) / AP(i)$$

A problem remains for the few pads located at the end of a row since it is known that the coupling here is larger than for other pads, due to the presence of the power supply bus of the grid. A possible solution would be to also pulse the field wires whose power supply bus is on the opposite side of the chamber. This has however to be tested experimentally.
5. Time calibration

The diagram below shows the timing sequence in normal data taking:

\[ t = \tau + (\Delta - \Delta_c) \]

(13)

The following diagram is the timing sequence of the data acquisition when pulsing the grid.
Here, the measured time is \( t_p = \delta + \Delta_c \) where \( \delta \) is a constant. The channel dependant part of equation (13) can thus be removed by using this measured time:

\[
t = \tau + (\Delta' - \tau_p)
\]

The only remaining unknown is the constant \( \Delta' \) which corresponds to the absolute alignment of the TPC along the \( z \)-axis: if one computes the \( z \) coordinate for a given time cluster, one gets:

\[
|z| = L - t v_d = z_0 - v_d(\tau - \tau_p)
\]  

(14)

where \( z_0 \) is unknown and related to \( \Delta' \) by \( z_0 = L - \Delta' v_d \).

5.1 Alignment in \( z \)

For this alignment, only data taken with the normal timing can be used, since for the cosmics, no BCO is sent... One can use tracks which cross the MWPC, as shown below:

One extracts \( z_0 = L + v_d(\tau_s - \tau_p) \) where \( \tau_s \) is the time measured on the last hit wire and \( L \) is the length of the half TPC. If the measurement of \( \tau_p \) is made by the same process for the pads and the wires, this measurement on the wires is also valid for aligning the pads.

5.2 Drift velocity measurement

5.2.1 Using cosmic rays

If the rate is high enough, the cosmic rays which cross both the sector and the mid plane of the TPC can be used for measuring \( v_d \):

One extracts \( z_0 = L + v_d(\tau_s - \tau_p) \) where \( \tau_s \) is the time measured on the last hit wire and \( L \) is the length of the half TPC. If the measurement of \( \tau_p \) is made by the same process for the pads and the wires, this measurement on the wires is also valid for aligning the pads.
Equation (14) can be inverted to:

\[ v_d = \frac{L}{[(\tau_1 - \tau_{1p}) - (\tau_2 - \tau_{2p})]} \]

Using a large number of tracks should allow to eliminate the fluctuations due to the lack of precision on the "last" hit wire.

### 5.2.2 Using laser tracks

A much more reliable method uses a laser beam split by a prism with a precisely known angle. Each wire measures then the drift velocity \( v_d \) for each event. This method should be by far more precise than the previous one.

### 6. Conclusion

Many tedious calibration measurements have to be made and recorded with the greatest care before installing the TPC. They can be controlled permanently after installation but all measurements need not be performed as often as one often thinks.

### References

[1] Proposal for the data acquisition system of the TPC, Ph.Charpentier et al., DELPHI 85-73/DAS-20/TRACK-16.


[3] Calibration des fils, D.Delikaris, TPC Internal Note 3, 14/10/86.