ATLAS Internal Note
LARG-NO-012
29 November 1994

Measurements at cold temperature of an absorber

B.Aubert, B.Beaugiraud, C.Girard, J.C.Hiohich, G.Sauvage, J.Thion, Y.Zolnierowski

LAPP, Annecy, FRANCE

Abstract

This note summarizes the measurements done at room temperature and at liquid nitrogen temperature of the contraction of an absorber. One has observed that the angles of the accordion absorber shrinks at cold.

1 Introduction

We report here a set of measurements made to determine the thermal contraction of the different materials used in the electromagnetic barrel calorimeter of ATLAS. The results are compared to calculations performed with finite elements method of the SYSTUS software [1].

2 Measurement principles

2.1 Modifications of the 3D measuring machine for measurements at cold

We have used our 3D measuring machine NUMEREX able to measure geometrical shapes in 3 dimensions to an accuracy of a few microns. To perform measurements at cold temperature, a special vessel has been built which rests on the marble of the NUMEREX. The sample to be measured is put on the bottom of this vessel and was immerged in the liquid nitrogen. The top of the vessel is left open to allow free displacement of the measuring head of the NUMEREX. The measuring head was equipped with a sensor TP6 from RENISHAW firm : this sensor is more robust than the one usually used. The contact pressure to trigger a measurement has been adjusted to 15 grammes, instead of a few grammes for more precise sensors. At such a contact pressure the displacement of the stylus in the non totally quiet liquid nitrogen is not provoking spurious measurements. A carbon fiber stylus , 15 cm long, equipped with a rubis sphere, 6 mm in diameter is partially immerged in the liquid during the measurements. The variation of length of the stylus due to thermal contraction of the immerged part of the stylus has been estimated to be small : a typical variation of ± 2 cm of the immerged part implies a variation of length of at most ± 8 μm, if the immerged part is immediately at $-196°$C. This δz has been ignored in the results presented here. The important length of the stylus induces also some loss of accuracy. Nevertheless the accuracy is estimated around 10 μm. The TP6 sensor, the marble, the different mobile pieces of the NUMEREX have been protected from cold with foam.

2.2 Measurement principles

The NUMEREX machine is able to measure simple geometrical shapes (called elements in the NUMEREX terminology) like a plan (at least three points have to be measuered), like a straight line (at least two points projected onto a given plan) or like a point, ... and so on. The software of the NUMEREX is able to perform some simple geometrical constructions, like the intersection line between two plans,.., or some calculations, like the angle between two plans or like the distance from a point to a plan. A file containing the results of the measurements and of the calculations is written and can be transferred to other computers.

2.3 Measurement of a flat plan plate

Two squares are glued at each tip of the flat plate in order to materialize two parallel plans, perpendicular to the plate, allowing the NUMEREX to measure these two plans and their mutual distance. 2 points are measured on each square : the distance between the 2 squares is measured in a redundant way (4 independant measurements). By performing the measurements at room temperature and at cold one can determine the thermal expansion coefficient of the plate.

2.4 Measurement of an accordion absorber

Three samples, 6 cm wide, have been cut by the water jet method, in a 2 m absorber : $N1$ with 1.2 mm lead thickness, $N3$ with 1.2/1.8 mm lead thickness and $N5$ with a 1.8 mm lead thickness. All the plans of the different folds of the accordion and of the G10 bars are measured (4 points for each plan), elements 5 to 26 and element 28 in the NUMEREX program: 2 plans for each G10 bars and all zigs and zags of the absorber (see Figure 1). Furthermore 2 points are measured on each G10 bars to measure the length of the absorber. The absorbers have been measured resting on the ridges of the folds or resting on G10 bars through the use of unequal shims to have approximately the same δz between the two bars. These measurements have been performed at cold and room temperature. One can then determine the angles of the folds to be compared with their theoretical value, the sagitta due to the weight and the thermal contraction.

3 Quality of measurements

We have evaluated the quality of the measurements in several ways :

- plans planeity : As 4 points are systematically used to determine a plan, the NUMEREX software not only computes the equation of the average plan but also the maximal distance of the points to this average plan. Figure 2 shows the distribution of this distance for all the measured plans of an absorber sample : each absorber has been measured about ten times over a period of two months. The figure 3 shows the distribution plan by plan of this distance. One notices a rms of 24, 21, 13 μm for the absorbers $N1$, $N3$, $N5$, (bad measurements are not removed for the determination of the rms). A cut at 30 μm eliminates the few bad measurements.

- angle between successive plans of the folds : the reproducibilty for two consecutive measurements is good even at cold, $< \delta\alpha > = 0.02°$. Over a longer period, two months, the reproducibility is less good, but acceptable, $< \delta\alpha > = 0.06°$, $0.05°$, and $0.08°$ for the three absorbers.

- distances between one point and a plan : Here also two consecutive measurements give much better results, δd = 0.015 mm for 5 couple of measurements and only δd = 0.32, 0.30, 0.23 mm for the three absorbers over long periods of time (several months). This more important variation comes likely from different adjustments of the measuring head of the NUMEREX done during the measurement period. For the measurement of thermal contraction we have compared files with a small time difference (typically 10 to 30 minutes due to the cooling time of the samples).

4 Results

4.1 Accordion angles

Figures 4 and 5 show the difference between the nominal and measured values (at room temperature) for the successive angles of the folds of the accordion. For the samples N1 and N5 one notices a mean difference $\alpha_{nom} - \alpha_{meas}$ of about 0.2° and a drop to −0.6° for the angles close to the small radius extremity of the absorber. The absorber N3 has a more complex variation.

4.2 Absorber sagitta

To measure the sagitta of the absorber due to its own weight, we compare two measurements : one where the absorber is resting on its folds and one where it is resting on the G10 bars. If $z(A_i)$ is the z coordinate of the straight line i (Figure 1) (i goes from 1 to 18), intersection of two successive absorber plans, one defines :

$$z'(A_i) = z(A_i) - [\, z(A_1) + z(A_{18})]/2$$

and the z displacement f_i for the straight line i is given by :

$$f_i = z'(A_i)_{Abs.\ on\ folds} - z'(A_i)_{Abs.\ on\ G10\ bars}$$

The Figure 6 shows f_i as a function as the abscissa of the straight line i for the absorbers N1, N3, N5 at room temperature and N5 at cold. The maximal sagitta is close from the center of the absorber and has the following values : 1.1 mm for N1, 3 mm for N3, 1.8 mm and 1.1 mm for N5 at room temperature and at cold. The "too big" sagitta of the sample N3 is likely due to the discontinuity between the two lead thicknesses. The sagitta at cold is smaller due to bigger Young moduli at cold and a smaller relative weight of the absorber (the liquid nitrogen density is equal to 0.81).

4.3 Thermal expansion coefficients for plan plates

The table 4.3 shows the obtained results. One has also estimated the length of the plate with a second method. Due to the choice of the reference frame in the measuring sequence the 2 measured plans have as equation $x = constant$ up to the measurements errors. Therefore one can evaluate the plate length as $x_{point} - x_{plan}$ and derive from this value the thermal expansion coefficient. This method of determining the length eliminates parallelism defects between the two squares. The two values agree very well in general and in table 4.3 the two values are given only for the sandwich where the biggest difference has been observed. Table 4.3 reports two sets of measurements for the stainless steel samples.

One has noticed a strange result for the 0.2 mm stainless steel sheet, likely due to a parallelism defect of 0.3° of the squares at cold. If one tries to correct for this effect by using measurements made on thicker plates where such an effect is observed, due to a bad measurement, the values indicated in the table 4.3 become : 1.96 → 1.62 and 1.69 → 1.62 which are more reasonable values. The 2 mm stainless steel give a correct result.

The thermal expansion coefficient for a symmetric sandwich [2] is given by :

$$\alpha_{sandwich} = \Sigma\, E_i e_i \alpha_i \;/\; \Sigma\, E_i e_i$$

where E_i, e_i, α_i are the averaged Young modulus, the thickness and the averaged thermal expansion coefficient of material i. Using the following input values for the averaged parameters

material	$-196°C$[3] (Litt.)	$+25°C$[3] (Litt.)	measurements ($-196°C \rightarrow +25°C$)
stainless steel foil (0.2 mm)	0.7	1.6	1.98/1.96 1.76/1.69
stainless steel 304L (2mm)	0.7	1.6	1.39/1.26
stainless steel 316L (2mm)	0.7	1.6	1.34/1.28
lead	2.5	2.9	2.80
sandwich (1.8mm lead)			1.41 1.38

Table 1: Measured thermal expansion coefficients in 10^{-5}/ °C

:

$<\alpha_{steel}> = 1.35\ 10^{-5}$, $<\alpha_{lead}> = 2.8\ 10^{-5}$, $<\alpha_{preimp.}> = \alpha_{steel}$
$<E_{steel}> = 1.8\ 10^{11}$ Pascal , $<E_{lead}> = 2\ 10^{10}$ Pascal and $<E_{preimp}> = <E_{lead}>$ *or* $<E_{steel}>$
one gets : $\alpha_{sandwich} = 1.81\ 10^{-5}$ *or* $1.71\ 10^{-5}$ instead of $1.4\ 10^{-5}$.

4.4 Thermal contraction of the absorber

The contraction at cold of the absorber is partly due at thermal contraction of the sandwich and partly due to the closing at cold of the angles of the folds of the accordion. We have observed the following contractions :

$$\begin{aligned} N1 &: \Delta l = 3.99 \pm 0.09 \text{ mm} \\ N3 &: \Delta l = 4.33 \pm 0.11 \text{ mm} \\ N5 &: \Delta l = 4.48 \pm 0.12 \text{ mm} \end{aligned}$$

The indicated errors correspond to the rms of at least 4 independent performed measurements. Figures 7a,7b show the values of the angles of the different folds and the observed diminution of these angles at cold for the samples N1 and N5. One notices that small angles closes more than large angles. An approximate calculation of the contraction δl_{angle} due to the closing of the angles is given by :

$$\delta l_{angle} = \Sigma\ l_i sin\alpha_i/2(1 - cos\alpha_i)\ \delta\alpha_i$$

where α_i is the angle of the fold i and l_i the length of the corresponding zig-zag. The preceding formula can be approximated by :

$$\delta l_{angle} = l_{tot}/2\ sin <\alpha> /(1 - cos <\alpha>)\ \delta <\alpha> = 3.2\ mm$$

with $<\alpha> = 80°$, $\delta<\alpha> = 0.7°$ and $l_{tot} = 445\ mm$
the thermal contraction is evaluated at 1.48 mm from the plan sandwich measurement giving a total of 4.68 mm instead of 4.48 mm for the absorber N5. Figures 7a,7b give also the result of a calculation performed with SYSTUS which underestimates the closing of the angles between 20% and 30% depending on the absorber.

5 Numerical simulations

We have used the SYSTUS software [1] to compute the contractions of the plates and of the absorber. We have also calculated the sagitta of an absorber due to its weight.

To do this calculations we usually need to know only the thermal expansion coefficient and the Young modulus of each material as a function of temperature. The value of the Poisson coefficient, when needed, has been taken equal to 0.3 for the stainless steel and the preimp. and 0.42 for the lead. In a first round we have used only the measured averaged thermal expansion coefficient and the averaged Young modulus from literature (see table 5).

The contraction of the stainless steel and of the lead plates is given only by the thermal expansion coefficient. For the contraction of the sandwich, stainless steel/ lead/ stainless steel of the absorber, we need to know the averaged Young moduli of the materials.

The option "thin shell" (coque mince) has to be adapted for the accordion : the thermal expansion coefficient is modified in the circular parts of the accordion to take into account the difference of the length of the different layers. One gets the following results on the contraction :

1.8 mm lead : 4.4 mm ; 1.2 mm lead : 3.85 mm

The contraction of the sandwich is due to thermal contraction and to the closing of the angles of the folds as shown in figures 7a,7b.

	$<\alpha>$ (/°C)	$<E>$ (Pascal)
stainless steel	$1.3\ 10^{-5}$	$1.8\ 10^{11}$
lead	$2.8\ 10^{-5}$	$8\ 10^{9}$
prepreg	=stainless steel	=lead

Table 2: thermal expansion coefficient and Young modulus of some materials

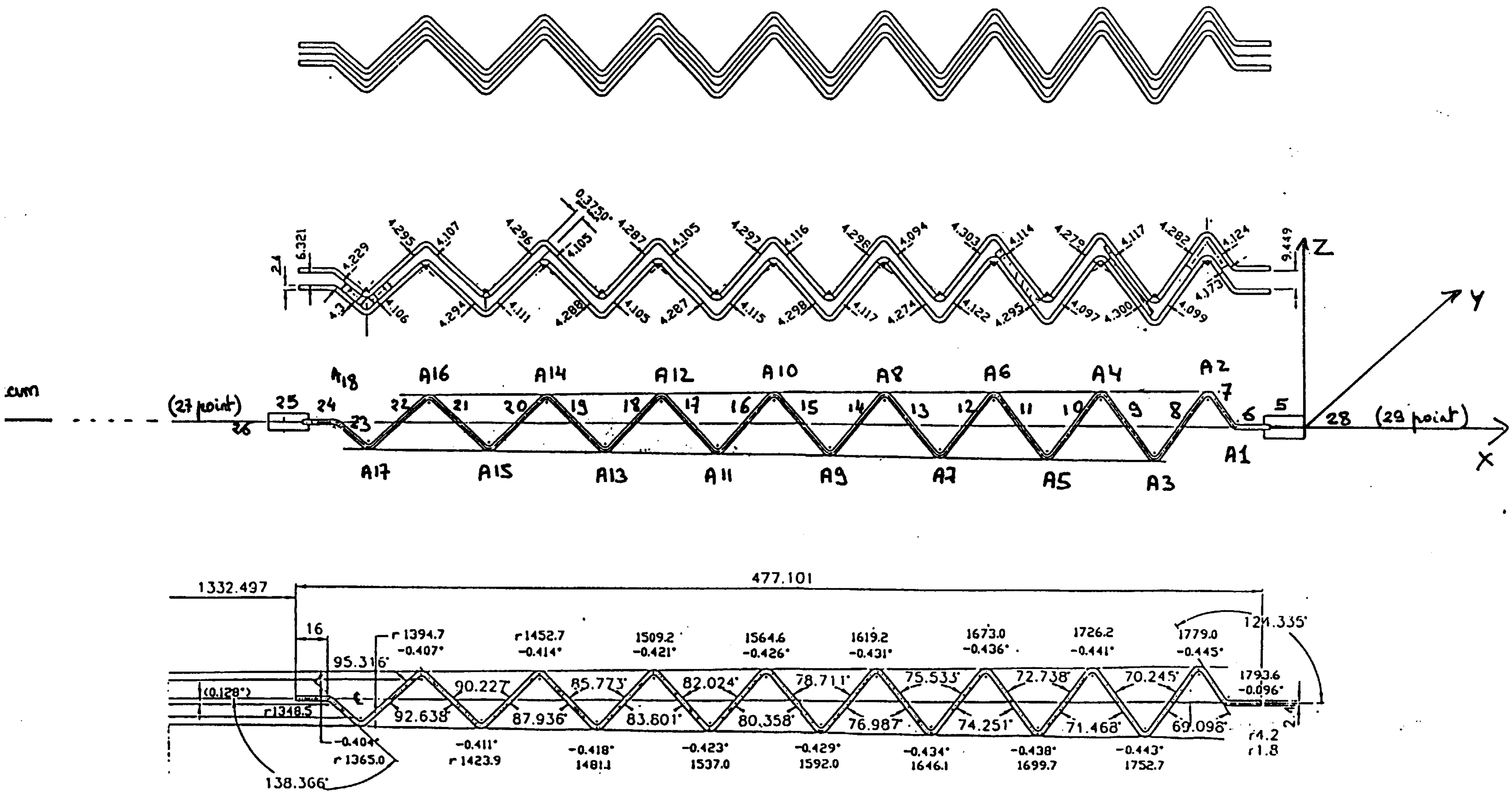
References

[1] FRAMASOFT+CSI, groupe FRAMATOME :numerical simulation by finite elements method with SYSTUS software

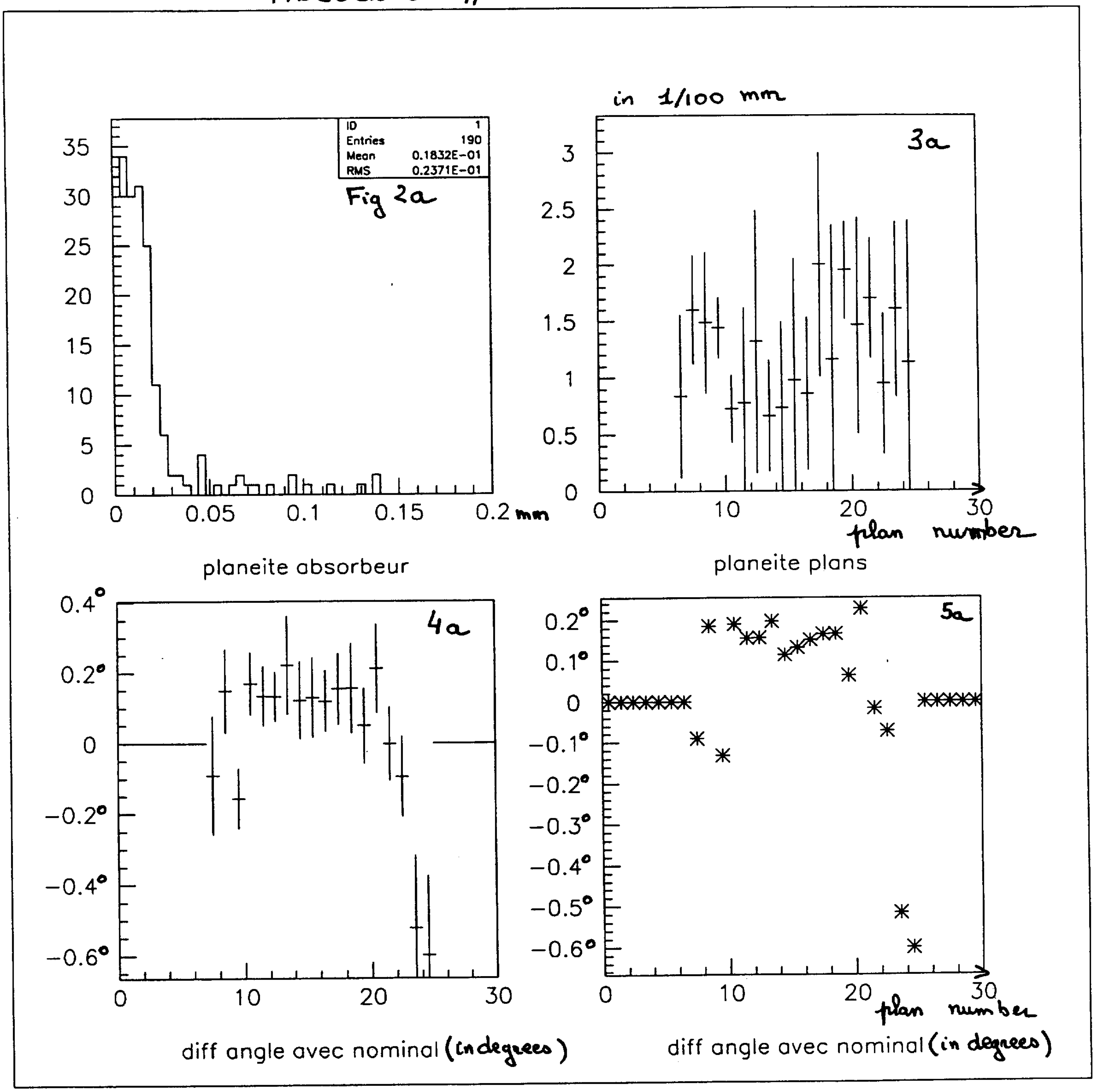
[2] D.Gay : Matériaux composites (édition Hermès)

[3] Physics handbooks and mechanics handbooks

FIGURE 1 : elements numbering given by NUMEREX

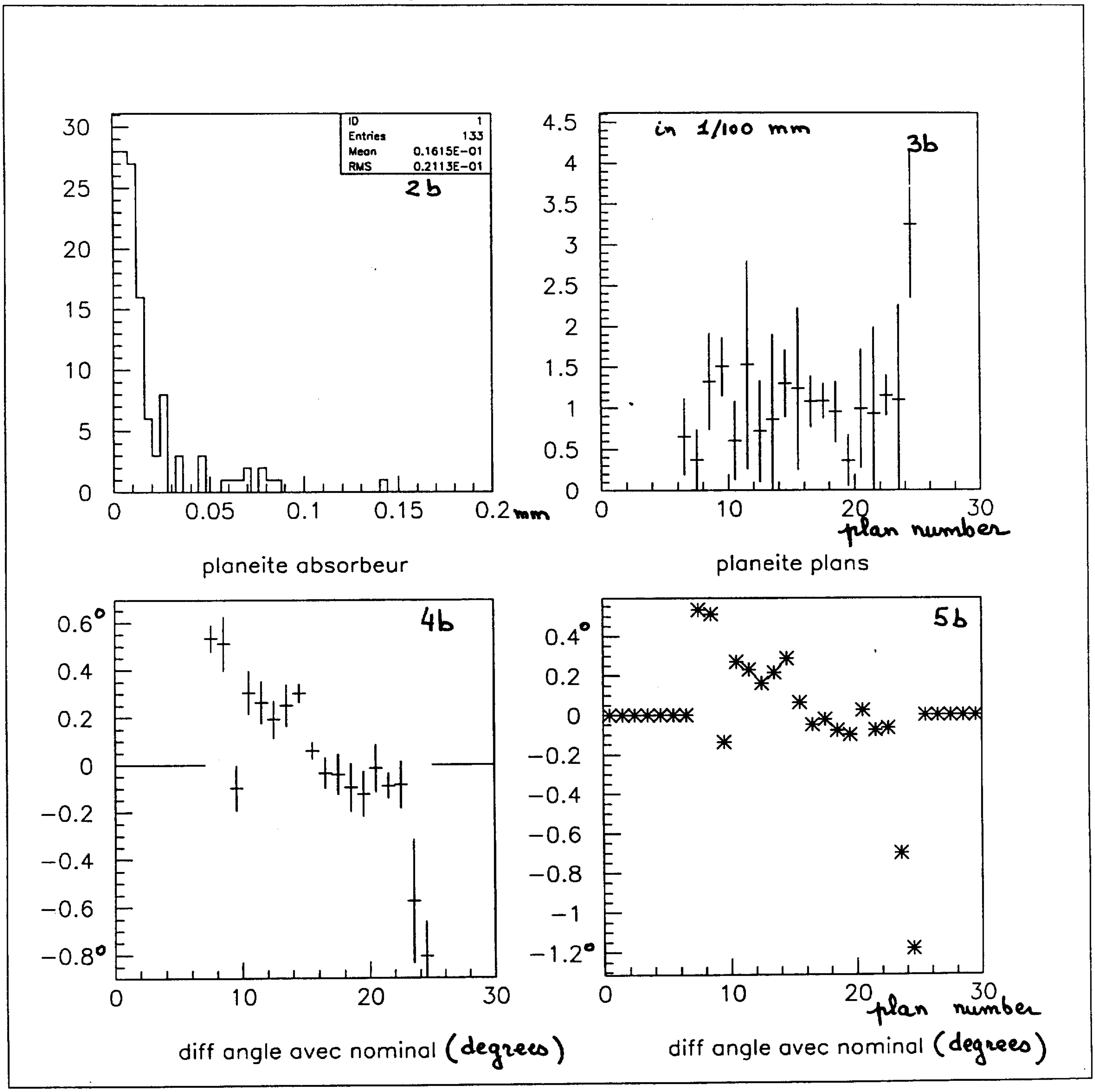


Absorber # 1



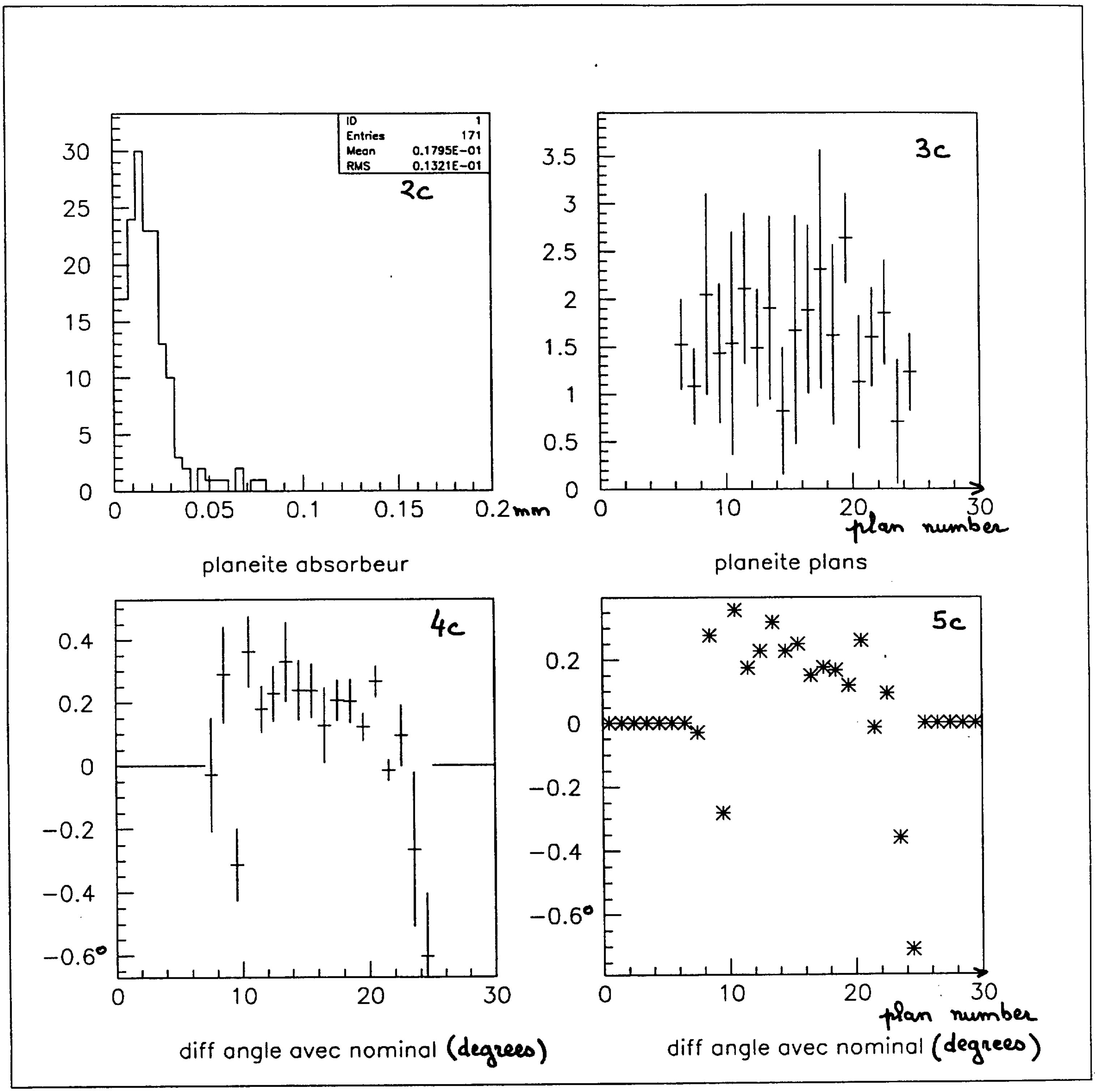
Figures 2a, 3a, 4a, 5a

Absorber # 3

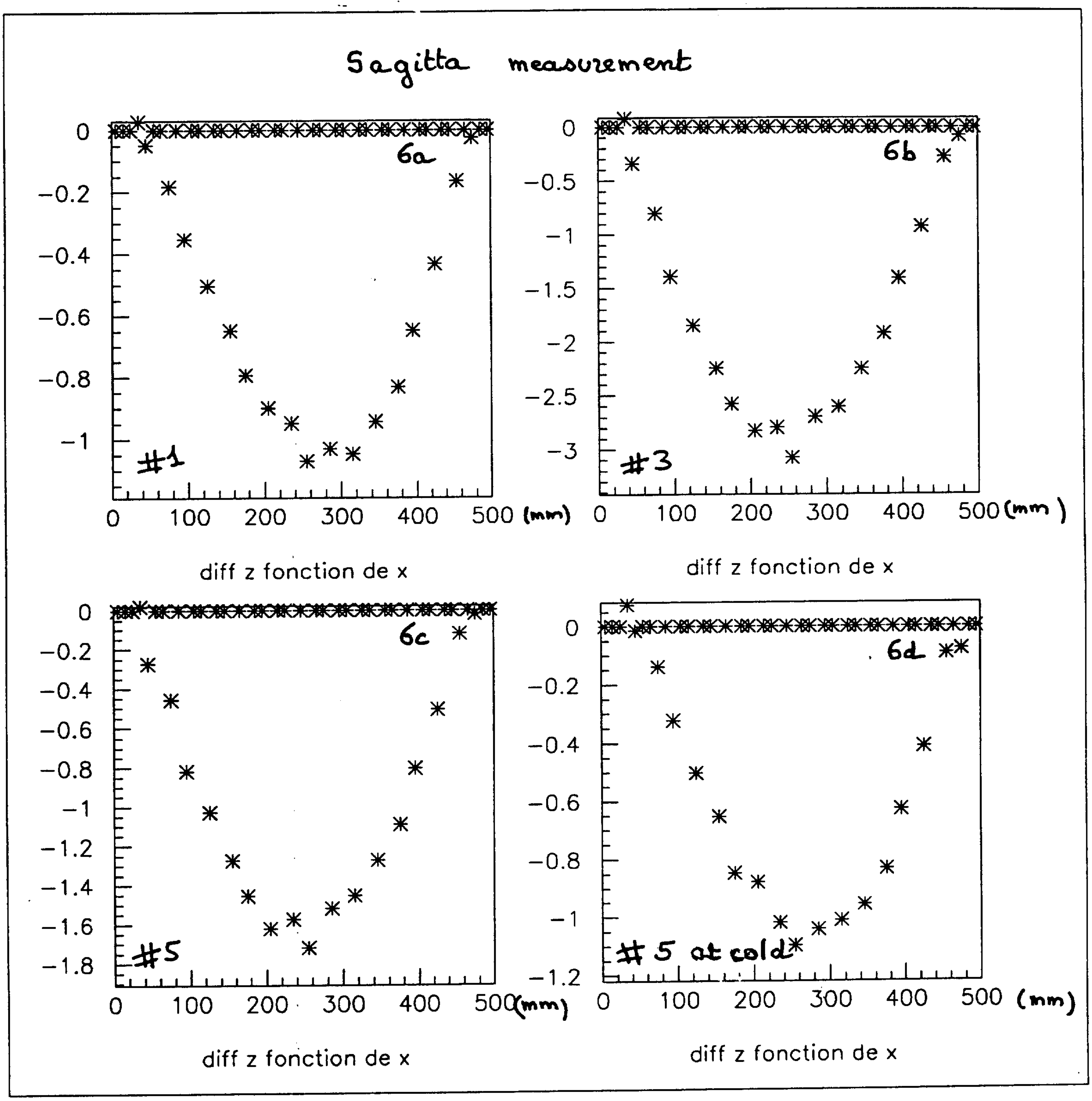


Figures 2b, 3b, 4b, 5b

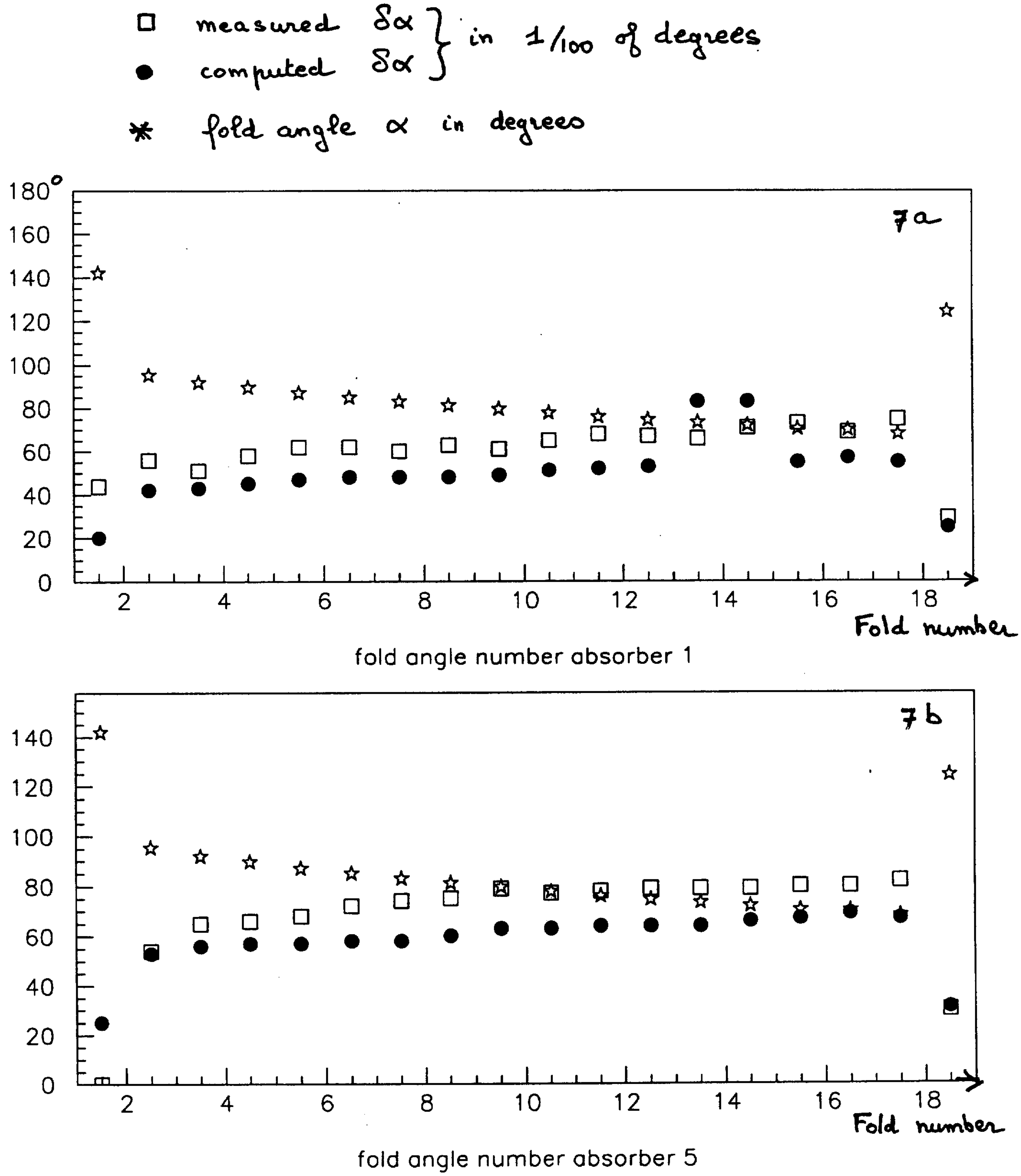
Absorber #5



Figures 2c, 3c, 4c, 5c



Figures 6a, 6b, 6c, 6d



Figures 7a - 7b