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Protvino drift tubes for BML-98. Test results.

IHEP, Protvino, Russia

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Abstract

In this report we describe drift tube constructed in IHEP Protvino for BML-98. Tube test results are presented. Much attention is devoted to design of used end plug and its possible modifications towards mass-production.

[1] LMU is responsible for test of the tubes only

Contents

1 Introduction

The 2nd Frascati full scale 4m long prototype chamber (BML-98) is considered as a final chance for choice of the end plug option. Production sites claimed to final design of the end plug have to produce tubes for the prototype. A door was opened for Protvino end plug idea.

To show its option Protvino group has to develop design of industrially produced end plug, deliver some amount of end plugs and construct 1/6 of BML tubes. Time limits were hard, the first proposal was done in summer 1997, decision was taken on 17 November, on 15 March of 1998 58 tubes [2] were shipped to LMU, which was responsible for test of all tubes for the chamber.

2 End plug design

Writing this section we followed to requirements developed during the choice of the 1st generation of the end plugs at beginning of 1996.

2.1 Design principles

The end plug is one of the most important parts of the MDT. From functional point of view it must:

1. support wire under tension;
2. precisely locate wire in the tube;
3. provide gas tightness of the tube;
4. have reliable gas connection;
5. provide HV electrical insulation between wire and tube;
6. provide reliable signal paths both to the anode and the cathode.

The bases of Protvino end plug design are follows: end plug has precise reference surface which is used for a tube location in a comb during chamber assembling; wire location is done by 60 μm hole precisely drilled by laser with respect to the end plug reference surface; wire is fixed by crimping.

The basic principles were checked during construction of BIL prototype chamber destined for DATCHA at CERN [1,2]. The only serious problem of the chamber was gas leakage due to using of epoxy glue as a gas seal inside the end plug. We took into account the lessons of BIL and avoided any using of an epoxy glue inside end plug described here. More efforts were applied towards industrial mass-production. Conserving our basic principles we really produced new end plug design. It should be mentioned that we used idea of gas connection through the end plug central pin, initially developed by Pavia group[3],

[2] 48 tubes are 1/6 of the chamber+ 2 tubes for safety reason; 8 tubes were sent for special tests in LMU.

and adopted our end plug to Pavia's gas jumper, as it was already chosen for BML-98 prototype chamber.

2.2 End plug design, its components, production procedure

Steps of the end plug construction are shown in fig.1. Fig.2 shows an example of connection of the end plug and a tube. Fig.3 presents engineering drawing of the end plug.

Main components of the end plug are aluminium cylinder, central brass pin and noryl (with 30% of glass), filling space between the central pin and the outer aluminium cylinder. The central brass pin and outer cylinder are machined separately with moderate precision then they are placed into mould-injection form, which is filled by noryl. After injection the outer aluminium cylinder is precisely machined. At the same time groves are done, one for O-ring on noryl part of the end plug and another at the aluminium cylinder for tube fixation by crimping. The next step (step 3 in fig.1) is a creation of a hole for wire location. For this purpose brass disk 0.5 mm thick is pressed into the central pin from internal part of the end plug. The locator hole is done by laser beam in a special support which utilize precisely machined outer surface of the aluminium cylinder. And finally copper tube (ID=0.27 mm, OD=1 mm) with brass ring is pressed into the central pin.

2.3 Main functional properties

2.3.1 Tube location

Basic idea of our end plug is an utilization of the end plug precise reference surface for location of tubes during a chamber assembling. Such approach allows to overcome questions about tube tolerances. We recognize that much problem arise from a spread of internal tube diameters, which leads to several outer end plug diameters inserted into a tube.[3] We suppose that we can use only one end plug diameter. Possible inclination of end plug reference surface with respect to tube axes which gives error in wire location we are going to limit by means of much efforts to do tube axis parallel to one of the end plug during crimping. Reduction of the end plug reference surface length and reduction as much as possible length of comb grove used for tube stacking during a chamber assembling will help also for diminishing of wire location errors induced by the inclination. Now we were limited by requirements of using existing groves and sucker scheme and could not reduce length of the end plug surface less than 20 mm, but we did short 6mm cylindrical part and the tail part of the end plug reference surface was made as a cone.

[3] In MDT specification dated on 17 November 1997 it is written 4 or 7 diameters for two different solutions.

2.3.2 Wire location

Wire is located in hole of the brass disk attached to the central pin of the end plug. The hole diameter [4] is 60 μm with eccentricity less than 10 μm. End plugs which did not meet these conditions were rejected. It is important that the disk of the locator is placed under middle of the end plug reference surface for reduction of influence inclination of the end plug on wire location.

2.3.3 Wire fixation

Wire is fixed by crimping in the copper tube (OD=1mm, ID=0.27mm) by tooth-like crimper. Length of crimped tube is 6 mm. Crimp is very reliable and can withdraw wires with tension up to a break limit (e.g. 700 g for 50 μm W+5%Re wire and 5 kg for 200 μm stainless steel wire). The copper tube is fixed in hole of the end plug central pin by means of brass ring, pressed into the hole (fig.1, step 4). The ring can withdraw tension up to 10-15 kg.

2.3.4 Gas seals

We adopted tail part of the end plug and used jumper designed in Pavia with 2 O-rings and closing cap (fig.2). The closing cap was slightly modified to accept copper pipe used for crimping of the wire. Gas seal between of the end plug and tube is done also by O-ring placed in grove of noryl plug. The tube over this O-ring is crimped. Calculated compression of the O-ring is 15-20%.

2.3.5 Tube fixation

The fixation of the tube and the end plug is done by a gas crimping at 165 bar with simultaneous crimping of the tube over O-ring. 6 bar over pressure inside tube could not destroy conjunction. There is an important question about inclination of tube and end plug. Internal diameter of used tubes [5] was measured 29.160$\pm$0.01 mm. Outer diameter of the end plug part inserted into the tube is $29.130_{-0.02}$mm. During the tube crimping the efforts were applied to diminish relative inclination tube and end plug by an using of rectangular cut of the tube, in future we are considering to use another tools for alignment of tube and end plug during crimping. For several tubes we measured their profile in place of the crimping (see Appendix 1).

2.3.6 Gas path

Tubes in the chamber will be connected by Pavia gas jumpers. The central brass pin of the end plug is used also as gas pipe. Gas goes through central hole in the pin and two lateral holes.

[4] Really the hole in 0.5 mm thick brass plate looks like cone with diameters 60 μm and about of 120 μm. When we tell "wire locator hole" we suppose the smallest one faced inside tube.

[5] METALBA

2.3.7 Electrical contacts and insulation

Insulation between the end plug central pin and aluminium cylinder is provided by noryl. There is a special part of noryl plug inside of tube which surface is perpendicular to direction of an external electric field strength.

Electrical contact between wire and the central pin is provided by crimps (wire – copper tube; copper tube – brass ring; brass ring – central pin). The contact between the central pin and closing cap is done by carving. The curving is also considered for further signal connection.

Electrical contact between the tube and the end plug aluminum body is given by crimping special spring in end plug grove. For connection of the end plug with PC board a screw hole in the aluminium cylinder is considered.

3 Test results of tubes and end plug.

We produced 68 tubes with described end plug. 58 tubes were shipped to LMU, because of this site was responsible for test of all BML tubes. Of course we also performed tests of tubes, some items of our tests were same as in LMU, some ones were different. Due to time limit our tests are not so careful but we are sure that they guaranteed tube functionality. Some of our tests concern to end plug only.

3.1 Tubes

We used tubes produced by METALBA. Tubes were cut for proper length: the most of tubes were 3900 mm and small fraction - 3360 mm for creation of cutouts in BML. After the cutting tubes were cleaned mechanically with using of petrol and isopropyl alcohol.

3.2 Results of tube and end plug tests made in Protvino

3.2.1 Gas resistance of the end plug

Drop of pressure for end plug gas path is less than 0.3 mbar at gas (Ar at NTP) rate 10 l/hour (fig.4) when gas flow is directed out of a tube.

3.2.2 Wire locator hole

Diameter of the wire locator hole and its eccentricity were measured by microscope during drilling. Distributions of hole diameters and its eccentricities after the selection are given in fig.5(a,b). Mean value of the hole diameter is 58.3 ± 2.6(RMS)μm. Eccentricity is 6.2 ± 1.9(RMS)μm. From known value of the hole diameter (D) and its eccentricity (E) we can calculate maximal possible R_{offset} of a wire (R_{offset}=E+(D-50)/2). Result is shown in fig.5(c).

3.2.3 Tension of wire and resonant frequency

We used W(+5%Re) gold-plated 50 μm wire produced by Moscow MELZ. The wire was stretched in a tube by 350 grams weight with simultaneous measurement of resonant wire frequency. As recommended we conserved constant resonant wire frequency for both tube lengths. Immediately after the crimping of the wire the resonant frequency was recorded again and finally it was measured after all tube tests which we did. So we have tree measurements of the resonant wire frequency. Results are presented in fig.6(a-h). In fig.6(a,b) the frequency is plotted as function of tube number. All three measurements are superimposed. Fig.6 (a) and (b) are the same, we changed vertical scale of fig.6(a) to show one tube (number 11) with 7.6% outstanding frequency measured after all tests. Distributions of the frequency for all 3 measurements are given in fig.6(f-h). Mean value is about of 38 Hz with initial RMS about of 0.3%. After all tests RMS of the frequency distribution was about 0.6%, but we did not stabilize the temperature which varied about 3°C during this test. Remember that relative RMS of tension will be twice large as compare to frequency one.

Dependence of the used weight as a function of tube number is plotted in fig.6(c). Sometimes to have constant resonant frequency we had to increase applied weight. Distributions of used weight, split for long and short tubes, are shown in fig.6(d,e). There is a "tail" for larger weight. Possible explanation of the tail is a friction in the locator hole and in copper tube used for wire crimping. There is also uncertainty in efficient length of the wire, it can be larger than distance between locators.

Calculated value of the frequency for wire length 3906 mm,[6] tension 350 grams and wire material density 19.34 g/cm^3 is 38.5 Hz. Difference about of 0.5 Hz between measured and calculated frequency is caused by our bad knowledge of wire properties (wire material specific weight and diameter).

3.2.4 Length of tubes

We measured relative length of tubes after wiring. From gas tightness point of view lengths of tubes connected by Pavia gas jumpers must be equal. Dependence of relative tube length versus tube number and its distribution is shown in fig.7. RMS of the distribution is about of 0.16 mm. Length of several tubes outstands from mean one about of 0.5 mm. It must be taken into account during the chamber assembling and such tubes must be paired.

3.2.5 Inclination of end plug reference surface

As it was already mentioned above the inclination of end plug reference surface will deteriorate wire location precision if sizable length of the grove is utilized, we suppose that tube is located by end plug during stacking a layer. The possible sources of the inclination are imperfection of the tube cut and crooking of the tube. After tube wiring we measured inclination of 6 mm long end plug reference surface with respect to tube axis. During the measurement the tube is placed in support and rotated around its axis and gauge was

[6] Length between wire locators. For short tubes it is 3366 mm

attached to top of the end plug reference surface. Half between minimal and maximal deviations of the end plug reference surface was taken as the inclination. Dependence of the inclination versus tube number and its distribution ar shown in fig.8. Its mean value is 7 ± 4(RMS) μm for 6 mm length of the end plug reference surface. Estimated contribution of tube curvature is about 3 μm if specified value 30 μm per 30 cm is taken, but really it is larger. We tested several tubes and found the curvature up to 6 mm for 4 m long tubes.

3.2.6 HV tests

15 end plugs were tested (air, normal conditions) with 5.3 kV positive voltage applied to the central brass pin. For all end plugs except of one no current was detected at 1 nA level of sensitivity. For one of the end plugs current about 1-3 nA was measured for voltage larger than 4.8 kV. The current disappeared after additional cleaning of noryl plug surface.

High voltage test of all produced tubes was done with air at normal pressure after intensive flushing of tubes to remove of alcohol traces from tube. The tubes after cleaning were covered by plastic film with cleaning liquids vapor inside. We measured current-voltage dependence for positive voltage applied to wire. Without any treatment the current-voltage dependence has very sharp edge, it was enough about 20 V of the voltage decreasing to reduce current from 0.5 μA to 0. Voltage of appearance glow (coronal) discharge with current 0.5 μA was fixed. The voltage dependence versus tube number and its distribution is shown in fig.9. There was 2 tubes with the voltage significantly smaller, they are out of frames in fig.9 (underflow of distribution). We attributed them to possible imperfection of wire surface. It was confirmed when we opened one of these tubes and inspected the wire. A small region of wire without gold plating was found.

We think that our HV test is enough. An absence of background leakage current below beginning of the glow discharge indicates quality of the end plug insulation. Small spread (RMS=18 V !) of the voltage appearance of the glow discharge confirm quality of wire. Voltage of 3.4 kV is about of a working point for tube with 3 bar Ar-based mixtures.

Trying to restore 2 bad tubes we applied negative voltage to wire. The dependence of the negative glow discharge voltage is not so stable as compare to positive one. With the same threshold 0.5 μA the negative voltage versus tube is shown in fig.10. Lines in the fig.10 indicates a hysteresis of current – voltage dependence. It seems such behaviour is caused by tube wall surface or noryl plug one. We do not know how it will effect on tube work.

3.2.7 Resistance of tube - end plug contact

For BIL DATCHA chamber the contact between tube and end plug body was established during crimping of tube. After more than 1.5 year of the chamber operation we did not hear anything bad about this contact. For tubes which were left in Protvino after production of the BIL chamber we measured the contact resistance after 1.5 year after their production. It was 12.4 ± 13.6(RMS) mOhms (fig.11(a)).

We started production of tubes for BML-98 with such manner, but several days after tube crimping significant increasing of the resistance was seen. Starting from the 39th tube we introduced a special spring between end plug and tube. Such idea was successfully tested in drift tubes[4] of SPHINX setup at IHEP. We specially measured for those tubes of the setup, which have access, resistance between Al tube and Al end plug. After 3 years of operation it was 2.6±2.1(RMS) mOhms (fig.11(b)). Last 20 tubes for BML were done with similar spring, using existing grove. Because of the grove was already done and its shape was not optimal we have got worse result as compare to SPHINX tubes.

In fig.12 dependence of the resistance versus end plug number is shown for three sets of measurements: immediately after tube wiring, after several days and after all tube tests. The boundary when we introduced the spring between tube and end plug is clearly seen. Distributions of tube resistance for three sets of the measurements are given in fig.13 and 14 for tube without and with spring. For tubes with spring the resistance after all tests is 14.1±5.3(RMS) mOhms.

We tried to improve the situation with the resistance for tubes without the spring by additional crimping of tube at the same pressure 165 bar, but results was negative (fig.14).

3.2.8 Leakage test

There are several potential sources of a tube gas leakage: tube wall imperfections; plug noryl body and 3 places with O-ring seals: between end plug and tube, between end plug and gas jumper, between gas jumper and the closing cap (fig.2). We should like to point out that the O-ring seals are the most probable source of leakage and the jumper attachment can be tested only with whole chamber. In all schemes of tube leakage test the gas jumper is replaced by temporal closing.

The first 13 tubes were tested with He mass-spectrometer leak-tester especially for conjunction the end plug—tube. No leakage was detected. Sensitivity of the leak-tester is $5 \cdot 10^{-15}$ bar·l/s, but several order of magnitude uncertainty could be introduced by unknown composition of He-air mixture which was used.

All produced tubes with temporal Al pieces instead of the real gas jumpers were filled by Ar at 4 bar absolute pressure and tested in water bath. There were not detected leaky tubes, end plug bodies and leakage in O-ring seal between tube and end plug. We estimated the sensitivity of the method about $(1\text{-}5) \cdot 10^{-8}$ bar·l/s.

Several leaky closing caps were found. Leakage was in a cracks between curving and internal hole. We had limited number of real (as we think) gas jumpers, if they were attached to a tube for some of them we detected leakage in water bath. Microscope inspection of the jumper surface shows its imperfection.

Combined this test with our previous results for tubes of DATCHA BIL we can conclude that for METALBA tubes there is not a hole in wall for 800 m total tube length.[7]

3.2.9 X-ray test of wire location

Limited number of tubes was tested at our X-ray setup where wire profile was measured as a function of angle rotation of the tube around its axis. The method was described in [5]. An offset of the wire with respect to rotation center leads to an oscillation ∼-like

[7] For DATCHA BML one hole was found for 1200 m tubes

curve of measured wire coordinate (center of its profile from gaussian fit) versus the angle of the rotation. Fitting the oscillation curve we calculate the wire offset from parameters of the fit. Results are shown in fig.16: scatter plot in X,Y-plane, X_{offset} and Y_{offset} and radius of the offset. RMS of X_{offset} is 8.1μm, Y_{offset} - 10.9μm. Mean values of the X and Y offsets are less than 3 μm

From optical measurements of the wire locator holes we can calculate maximal possible wire offset radius and plot correlation between the optical and X-ray measurements (fig.17). Allowed region for the wire offset from the locator hole optical measurements is under the straight line (dashed area in fig.17). About half of X-ray measurements is above of the allowed region. The possible reasons can be: imperfection of the setup and influence of tube curvature, which was measured up to 6 mm for 4 m, or something else, which we do not understand.

3.2.10 Production rate

We did not try to reach the best production rate. The rate at the end of the tube manufacturing reached 15 tubes/day[8] (fig.18).

3.3 Rejected tubes

We produced 68 tubes and 58 were shipped. What are reasons of our selection?

- 2 tubes have lower voltage of beginning of glow discharge in air;
- 1 tube has 7.6% decreasing of resonant frequency;
- 1 tube with not crimped wire;
- 1 tube with imperfection of tube surface;
- 2 tubes were accidentally broken;
- 3 with the largest tilt of end plug.

3.4 Tube test results from LMU

In LMU wire tension, wire location by means X-ray, leakage rate and HV performance of tubes were tested. For the HV and leakage test we shall present results only for 28 tubes. Results of HV and leakage tests of another tubes are similar.

Limited number of tubes (8) successfully passed through special tests with wire vibration, temperature and pressure cycling. We shall not present these result here.[9]

[8] During visit of end plug committee production of 15 tubes during 2 hours was demonstrated, the rate 7.3 minutes per tube was achieved by 3 working technicians

[9] Short tubes with our end plugs passed successfully also through special HV test in BNL

3.4.1 Results of tension measurements

Tension was measured by commercial CAEN tension meter. Input data for the device were: wire length 391 or 337 cm; wire diameter - 50 μm and specific wire weight - 19.3 g/cm^3. Results are 351.6±3.1(RMS) grams and 254.7±2.8 grams for long and short tubes accordingly (fig.19). According relations of RMS to mean are 0.9 and 1.1%. It is not so bad and in agreement with our measurements of the resonant frequency. Dependence of the tension versus tube number is shown in fig.20(a). The LMU tension test is well correlated with our result for the resonant frequency.

3.4.2 X-ray test results

For X-ray wire measurement method developed in Brandeis University was used [6]. Dependences of wire Z-,Y- and R-offset as a function of end plug number (two per tube) are given in fig.20(b-d). Results of the test (fig.21) similar to X-ray test results obtained in Protvino with smaller statistics (fig.16): X_{offset} is 0.4±9.3(RMS) μm, Y_{offset} is -1.1±11.9(RMS) μm, R_{offset} is 13.3±7(RMS) μm. Corresponding results in Protvino (fig.15) are: X_{offset} – -2.7±8.1(RMS) μm, Y_{offset} – -1.9±10.9(RMS) μm and R_{offset} – 12.4±6.4(RMS) μm.

Again we see the offsets outside the hole locator limits. It can be explained additional errors arising during positioning of the tube in groves for X-ray tests. In principle we can attribute them to inclination of the end plug reference surface. Unfortunately we can not establish correspondence for tube sides of both measurements in Protvino and LMU.

3.4.3 Leakage test result

Leakage rate was tested for tubes filled by Ar+10%CH_4 gas mixture at 3 bar absolute pressure by means of method developed also in Brandeis. The small part of tube including end plug is placed in vessel volume of which is evacuated by vacuum pump during about 30-40 minutes. Then after closing of a valve between the pump and the vessel change of pressure versus time is recorded and leakage rate is calculated. For all tubes no leakage was detected with threshold $5 \cdot 10^{-9}$ bar·l/s.

3.4.4 HV test result

HV test is performed with Ar-CH_4(90-10) gas mixture at 3 bar absolute pressure in tube. Natural radiation background (cosmic) counting rate and radioactive source one were measured with L3 amplifier. Dependence of the rates versus tube number is shown in fig.22(a). Mean value of natural radiation counting rate is 42±3(RMS) 1/s (fig.22(b)). Tube counting rate with radioactive source is 2740±110(RMS) 1/s (fig.22(c)).

4 Our weakness - wire inserting

We head many critical remarks of our end plug option concerning to the need of inserting "by hand" 50 μm diameter wire into 50-60 μm diameter hole. We are not sure that the wire inserting could not be automatized, we did not think much about it. At least it can be done much easy. For the first case we developed several modifications of special tools. One of them was widely demonstrated among MDT community. It is a narrow wedge-like cut in cylinder which is faced exactly to the locator hole. The wedge is used as a conductor of wire during the inserting. Such edge wire conductor works well for pure W wire, but with hard W+5%Re[10] wire it works worse. Due to hardness of the wire it is crooked on 20 mm length of the edge conductor. To avoid this problem we produced new modification of the wire conductor to its inserting (fig.23). Idea is the same, but now the wedge of the conductor is closed by additional wedge piece to prevent the crooking of the wire.

5 Improvements of the end plug design

Of course we are thinking about improvements of the end plug design. We could not realized them now because of already established requirements of BML-98 assembling. For comparison in fig.25 two types of the end plug are shown: upper drawing corresponds to the end plug already done for BML-98, lower one presents foreseen now end plug design.

5.0.5 Outer Al cylinder

By all our forces we should like to conserve idea about location of tube in comb during gluing of a chamber by means of precise end plug reference surface. Without such idea our end plug will lose its sense. As concerning to the outer Al cylinder of the end plug our improvements are follows: reduction of its total length; the removing of conical tail; slight decreasing of precise part length; introduction of an additional 4 mm grove for spring, providing electrical contact between tube and the Al cylinder. Such spring contact already have been tested with dummy end plugs and gave resistance about several mOhms.

Logical continuation of our end plug improvements is reduction of grove length where the end plug will be seat during the chamber assembling. It contradicts existing solution for chamber assembling method when vacuum suckers are placed into the comb with groves. We propose to remove the suckers from the 1st and the last combs. Then the length the grove can be reduced significantly. There are two possible solution for pressing of tube to grove: the suckers are shifted along tube outside the end plug or instead of suckers on the 1st and last comb a spring like shown in fig.24 will be used.

We will insist seriously on reduction of the assembling comb grove length. Due to inclination of the end plug (or tube curvature) long grove can be serious source of error in wire location. Moreover there is a large problem of curving tubes in a layer for end cap chambers which will also require optimization of the grove length. The question is now under investigation. Let us remind that tubes of the largest end cap chambers must be crocked with inclination about 300 μm/m within a plane to follow a wire sag.

[10]The wire was produced by MELZ. It is more hard as compare to the wires used in another production sites. Wire used by Pavia and MPI goes well through the tool

5.0.6 Central pin

The central pin will be modified to conserve position of the locator disk under the reference surface of the outer cylinder.

5.0.7 Gas jumper

The question of gas jumper is still open and we conserved old decision. Of course it must be also improved. The 1st improvement concerns to an equality gas flow in different tubes. It can be easy done in existing jumper. The second one is more serious. The existing gas jumper requires equal lengths (within of 0.1-0.2 mm) of connected tube. We have to think about it.

5.0.8 Tube length

Length of tubes produced for BML was determinated by tube cut. Now we a thinking about tube wiring scheme where the length of a tube with end plugs with precision 0.1 mm will be determinated by adjustment of the end plug in gas crimper to allow a tolerance of cut tube length about ± 0.5 mm.

6 Conclusion

We developed industrially produced end plug with precise reference surface and wire locator made by laser. The tests of of the end plug and small batch of tubes for BML-98 chamber show promising results.

7 References

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2. A. Borisov et al. BIL chamber prototype assembly in Protvino. ATLAS MUON Note 178

3. A. Biscossa et al. The First Full-Scale Prototype of a BIL MDT Chamber for the ATLAS Muon Spectrometer. ATLAS MUON Note 136

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6. H.Wallenstein et al. The X-raying of single MDTs using films. ATLAS MUON Note 183

Tube profile near the crimp

Some people asked us about the tube profile near the crimp. We tried to perform such measurements with several tubes. For the measurement tested tube was placed on set of supports. Micrometer gauge attaching to top of the tube moved along tube (in X-direction). Zero X-coordinate corresponds to boundary between the end plug reference surface and tube end. The two nearest supports of the tube were at distance 34 and 768 mm from middle of the end plug reference surface. Relative tube top height detected by the gauge was recorded versus X. The measurements were done for 8 rotations of tube around its axis with 45^o step. Examples of such dependences are shown in fig.A1 and fig.A2, where relative height of tube top versus X is shown and all 8 measurements with rotation of the tube are superimposed. Fig.A1 corresponds to 3.9 m long tube left in Protvino after production of tubes for BML. Fig.A2 presents results for tube made during visit of end plug committee. Outer diameter of end plug part inserted into tube was $29.130_{-0.020}$ mm and 29.020 ± 0.010 mm for the 1st and the 2nd plots accordingly. Spread of curves below x=0 is caused by a tilting. From these measurements we calculated mean radius of the tube versus distance along it. Such results are given in fig.A3 and fig.A4. where the mean tube radius minus 15 mm is plotted versus X. It is seen that in range of the crimp there is not an increasing of tube diameter. The end plug with smaller diameter of inserted part as compare to tube ID (fig.A2 and fig.A4) is acceptable.

A Figures

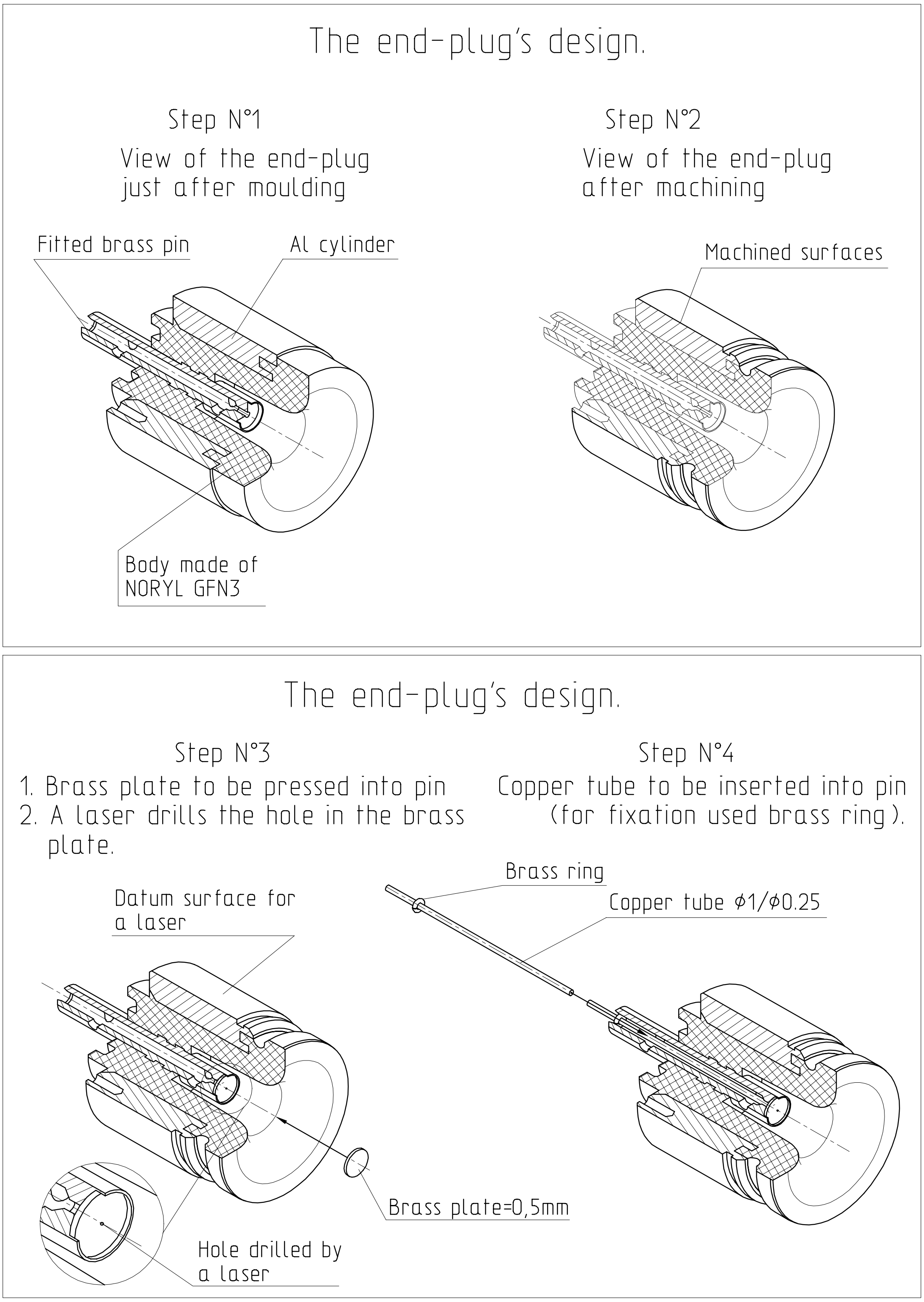

Figure 1: End plug for BML-98. Explored views.

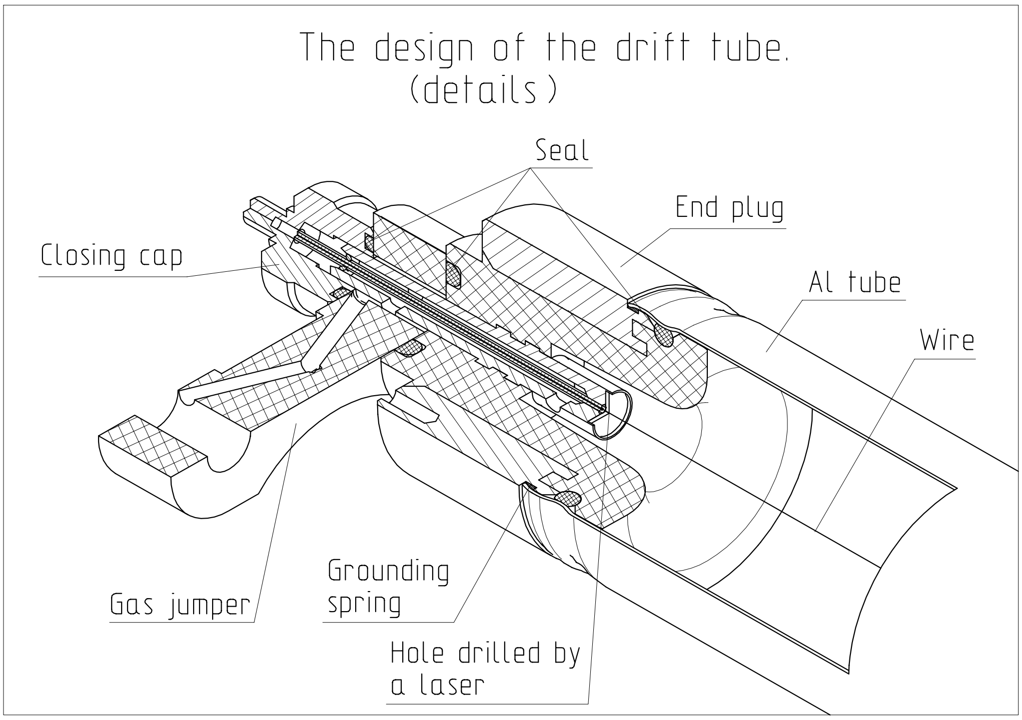

Figure 2: End plug for BML-98. Connection with tube.

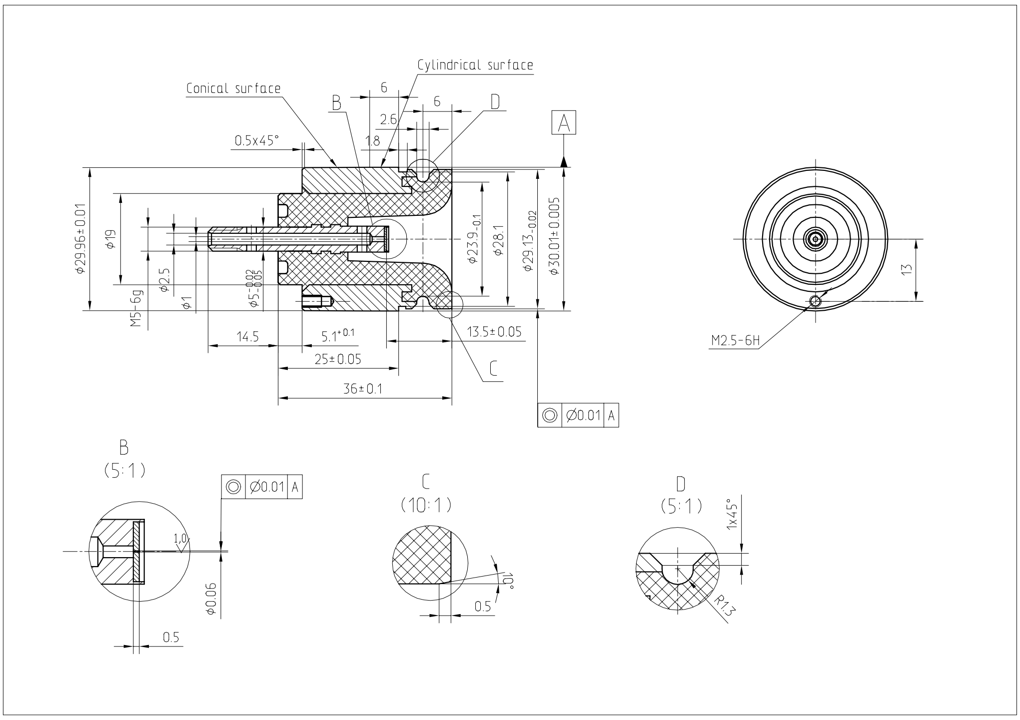

Figure 3: End plug for BML-98. Engineering drawing.

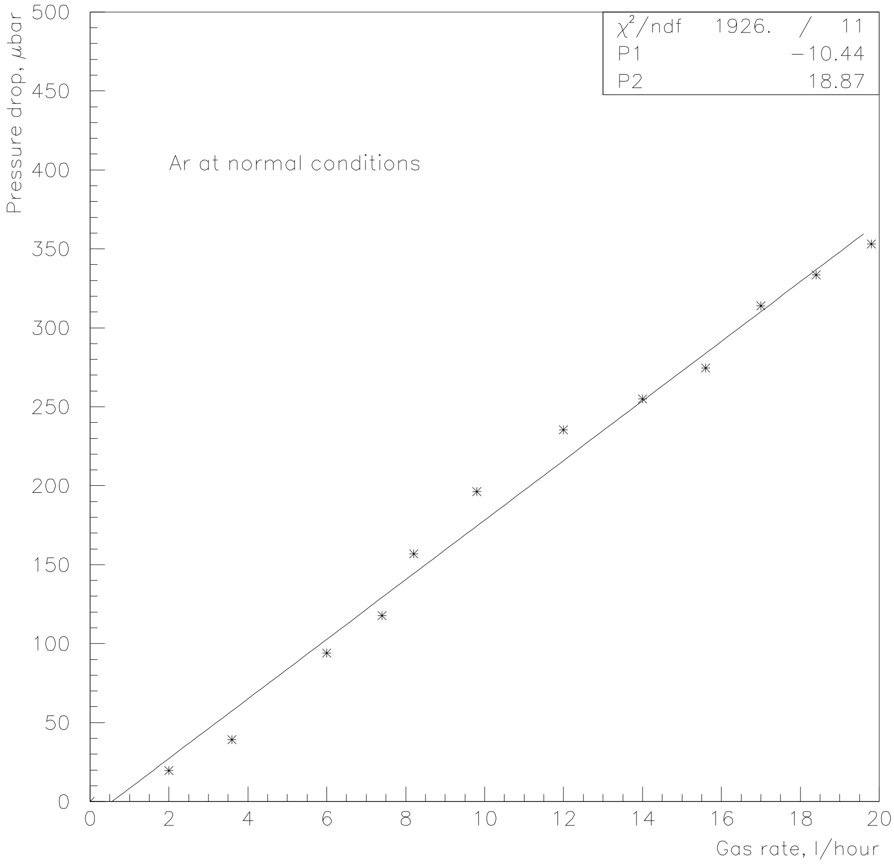

Figure 4: End plug drop of pressure vs. gas rate.

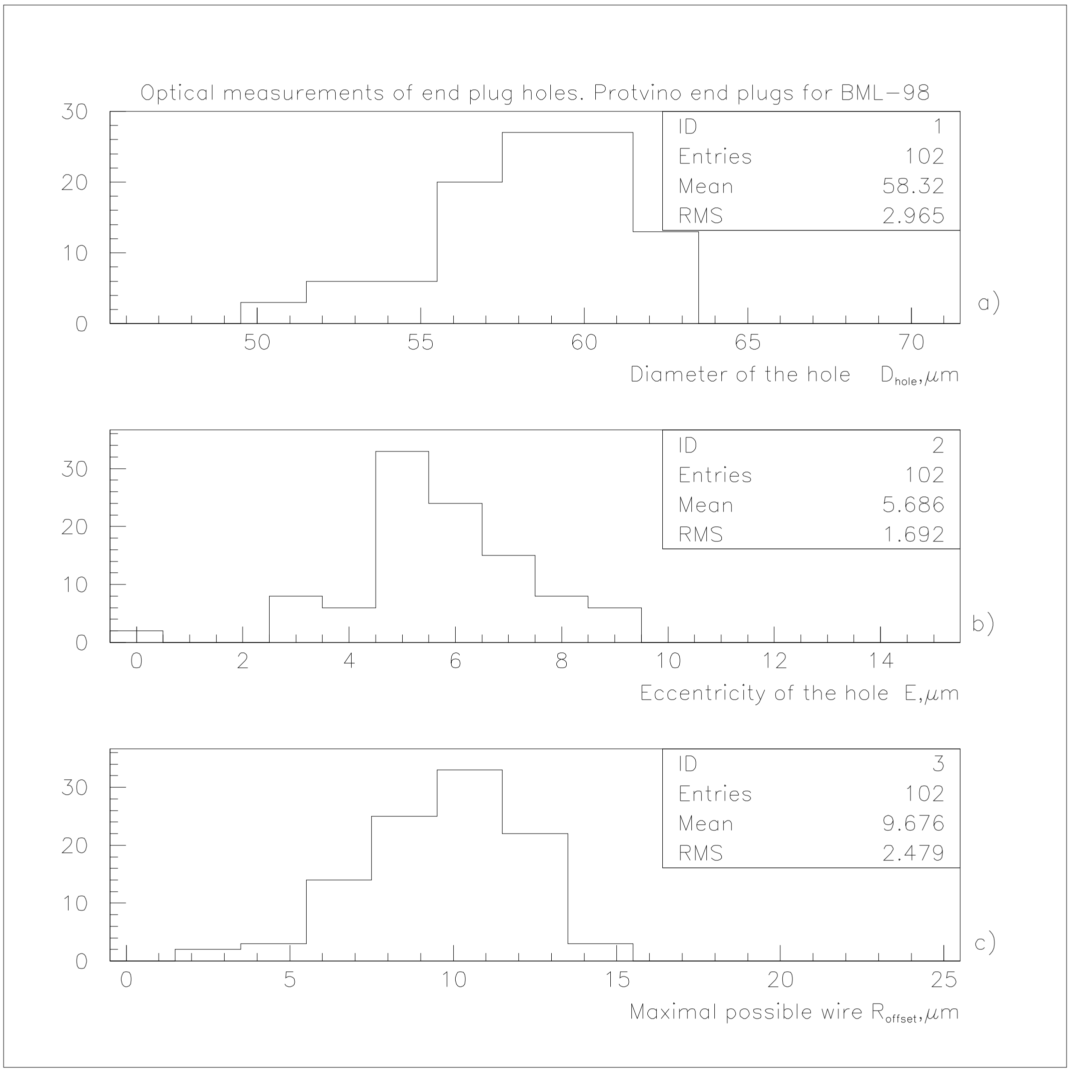

Figure 5: Optical measurements of end plug locator hole.

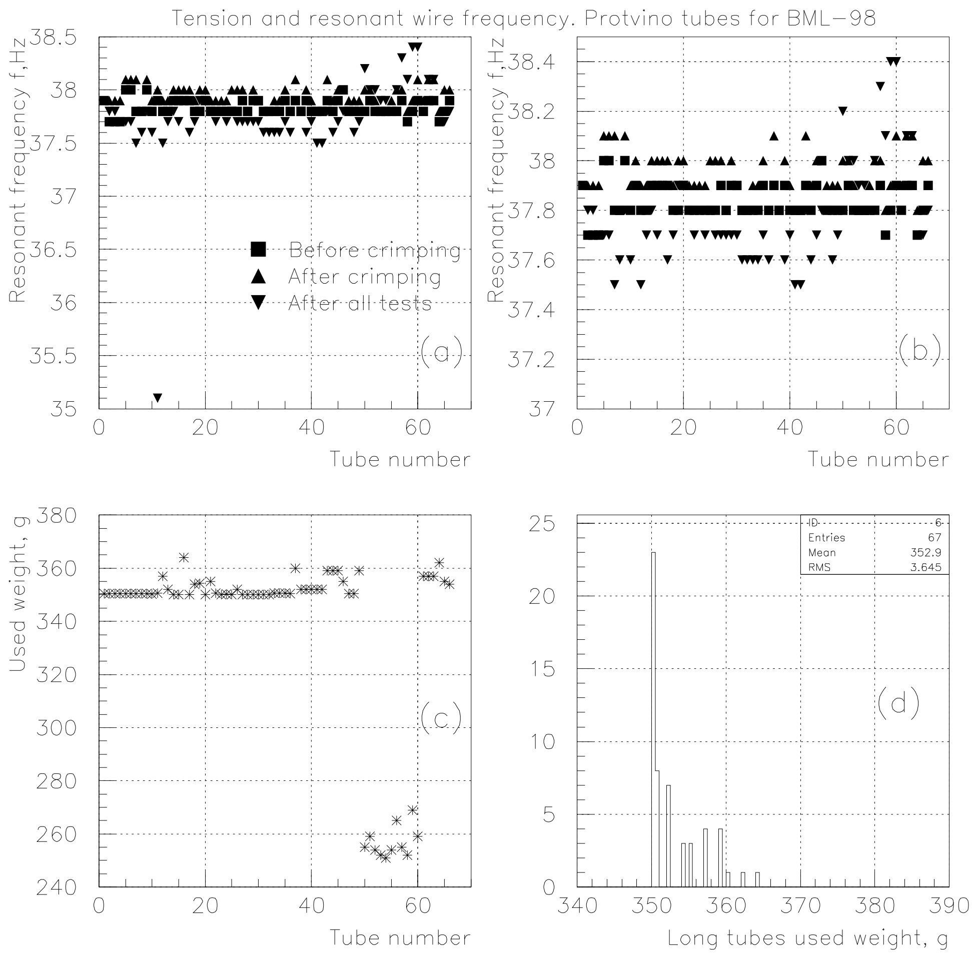

Figure 6: Resonant wire frequency and used weight.

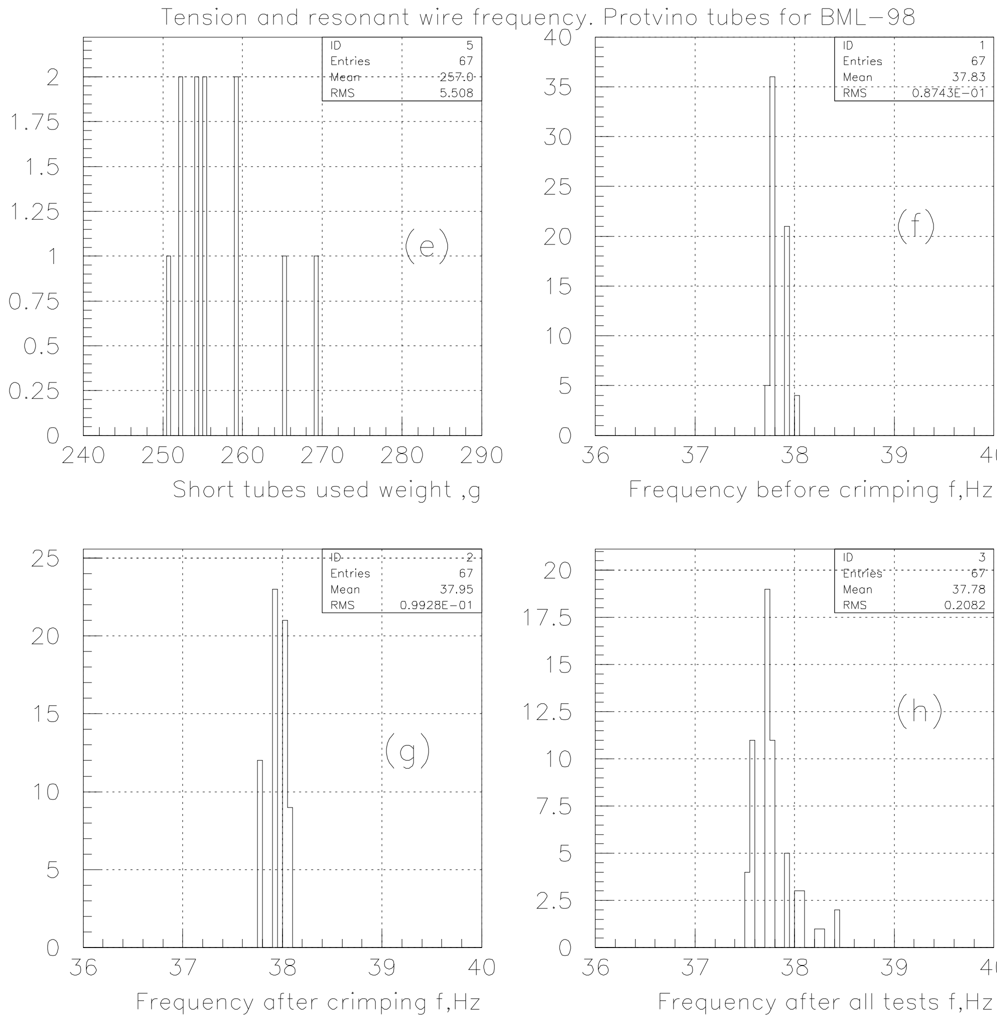

Figure 6: Resonant wire frequency and used weight.

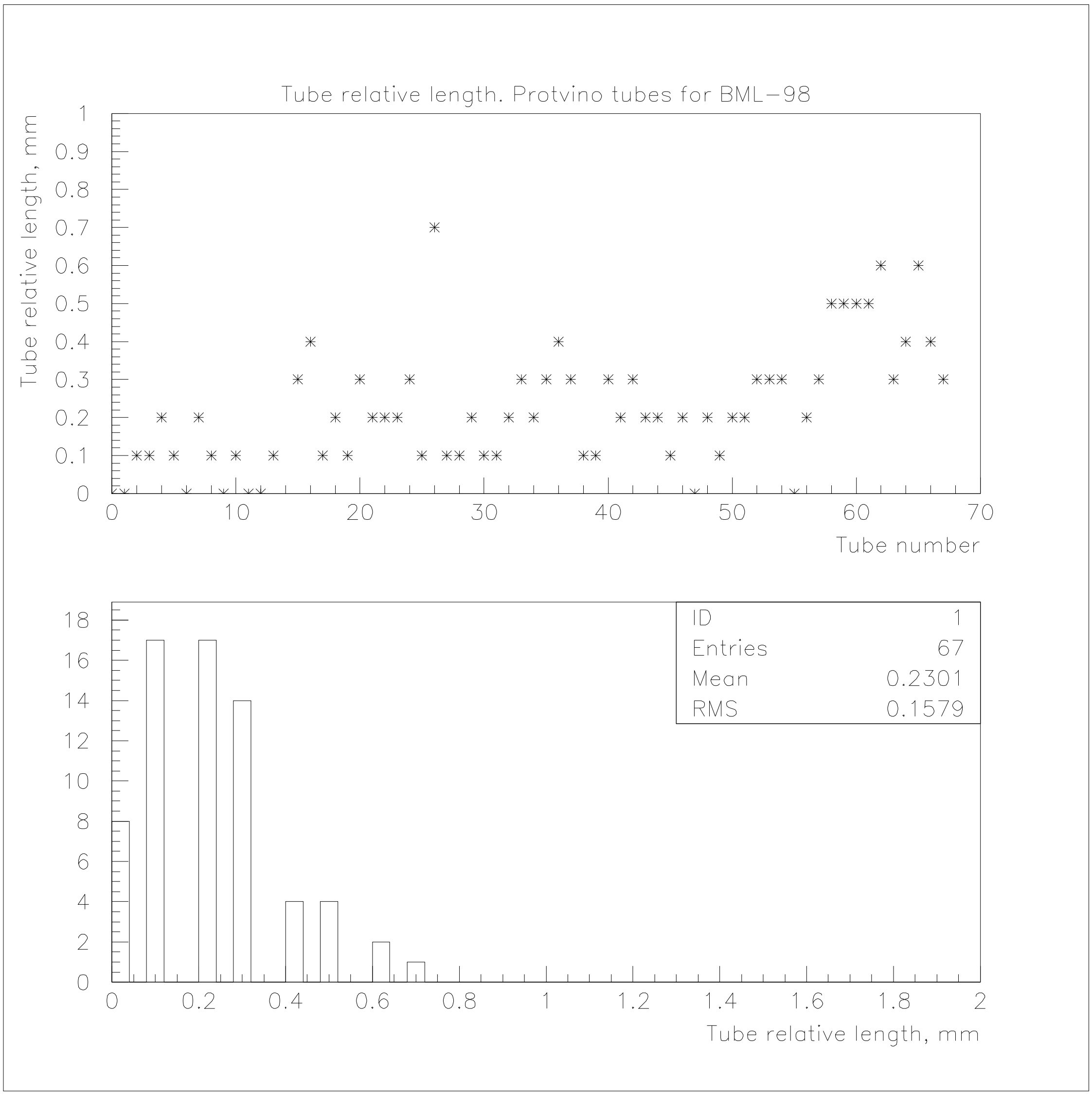

Figure 7: Relative length of tubes.

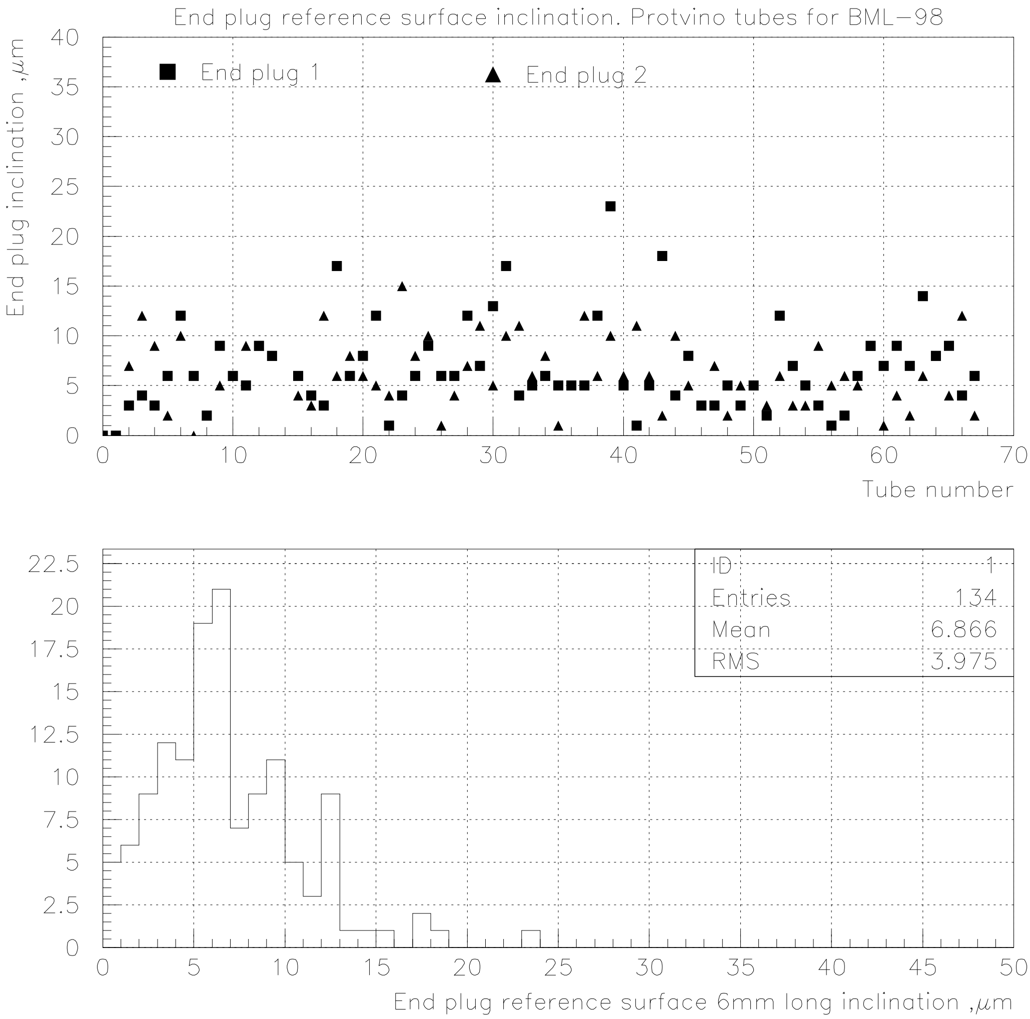

Figure 8: Inclination of end plug reference surface.

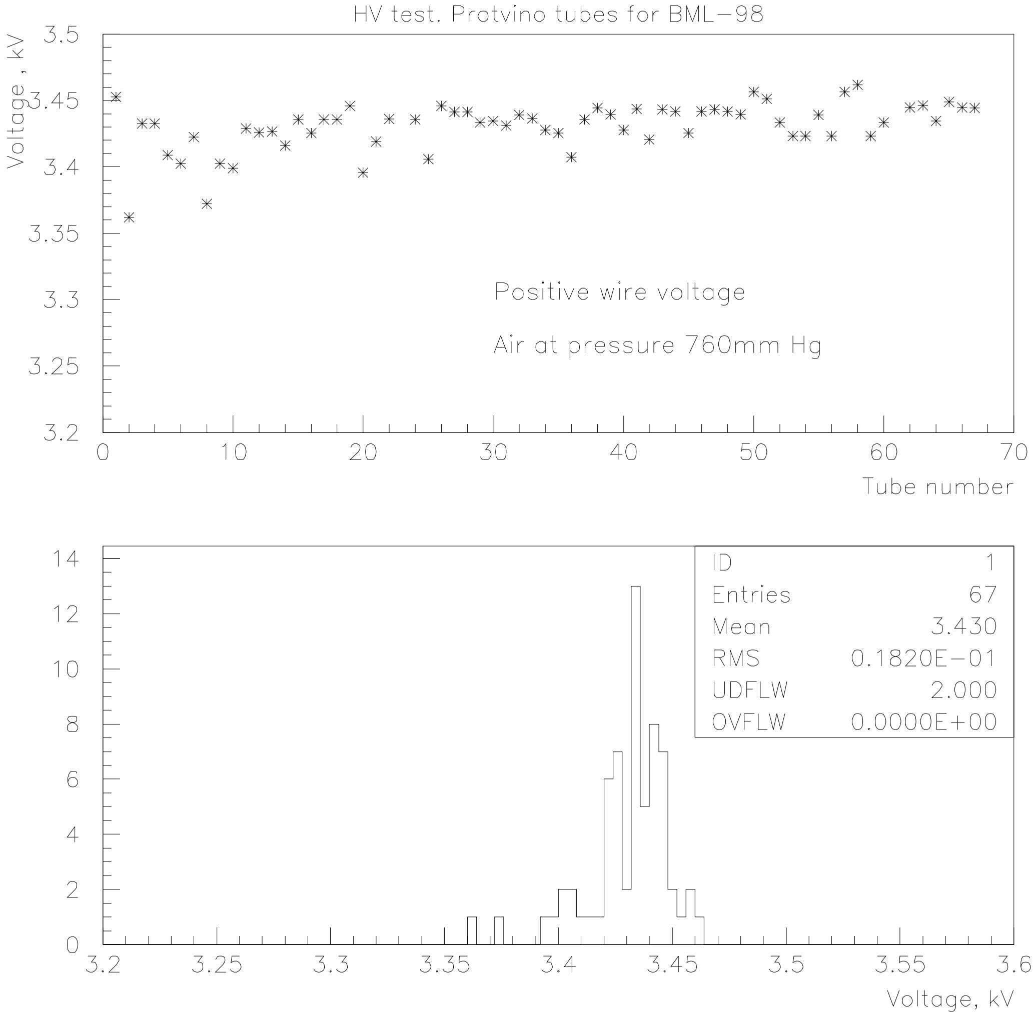

Figure 9: Positive wire HV test of tubes.

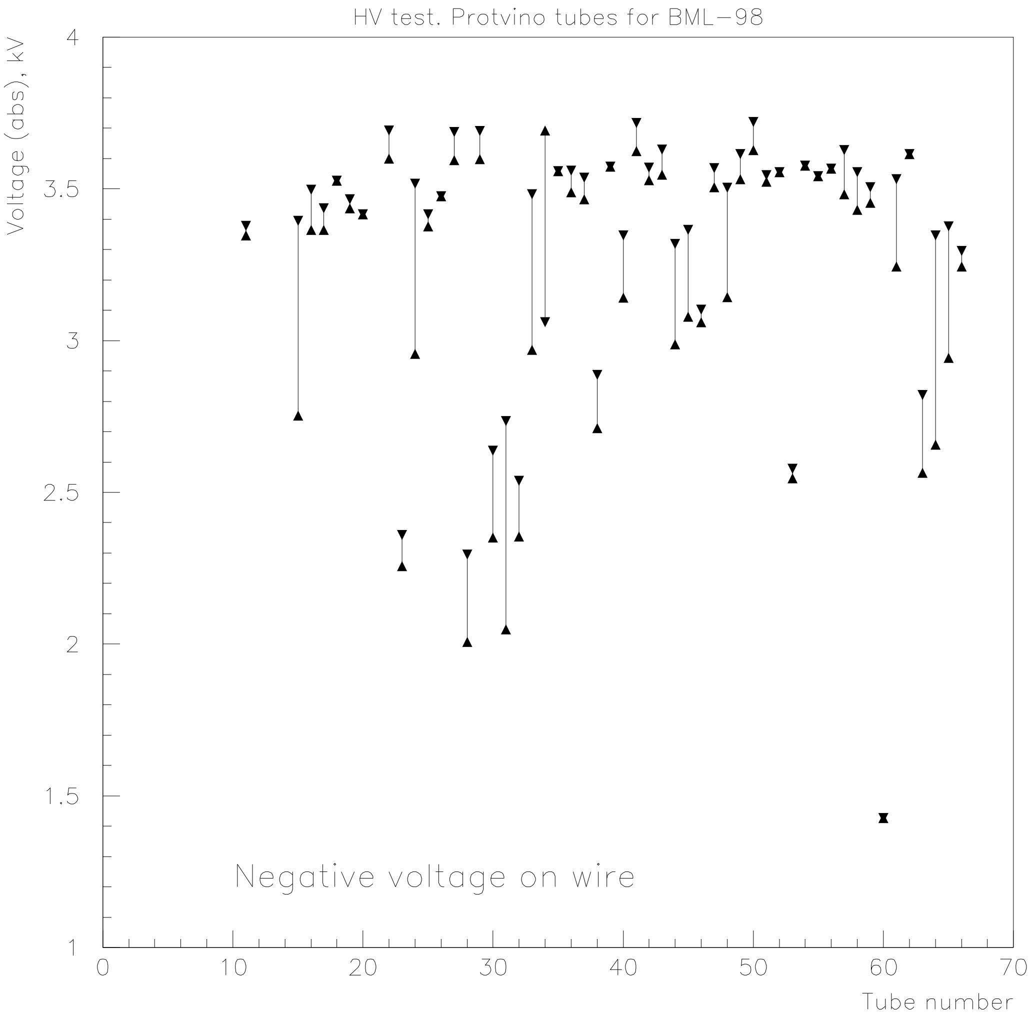

Figure 10: Negative wire HV test of tubes.

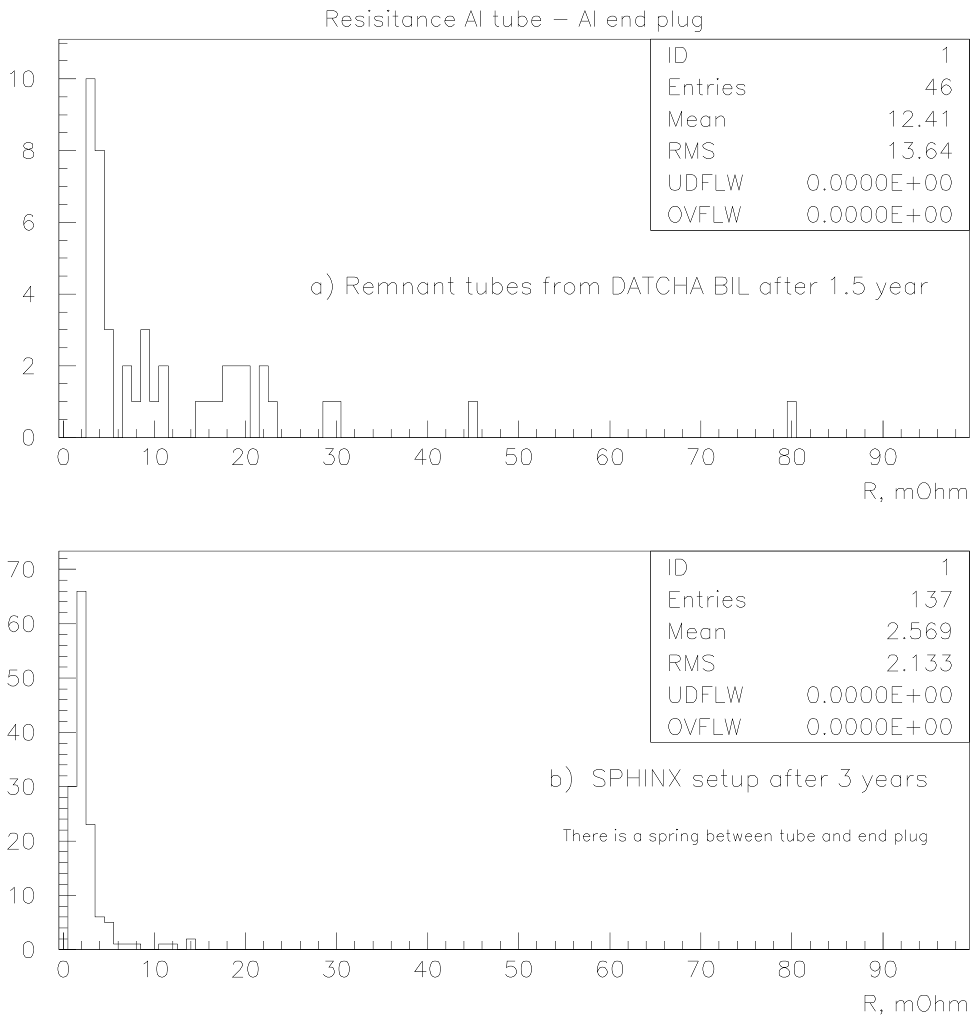

Figure 11: Resistance tube - end plug for tubes of BIL and SPHINX chambers.

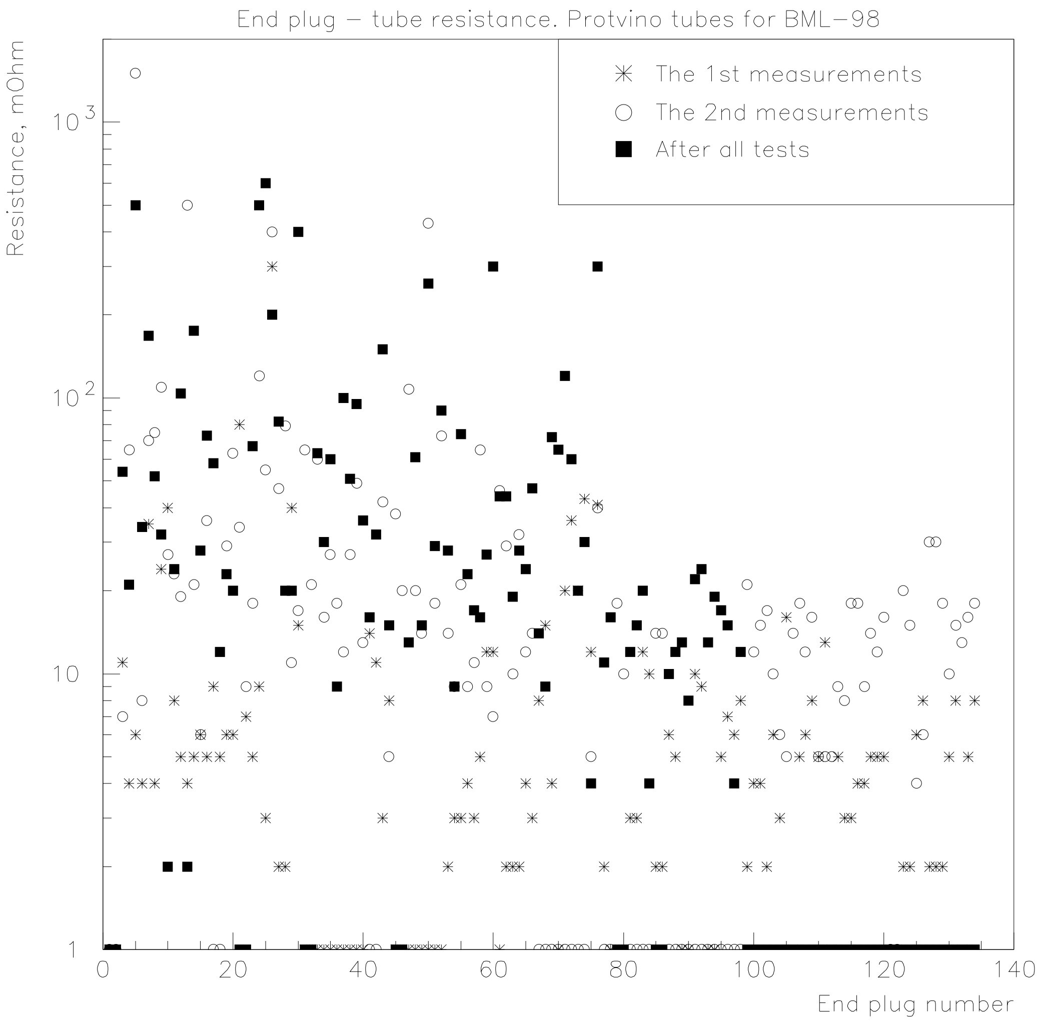

Figure 12: Resistance tube – end plug vs. tube number.

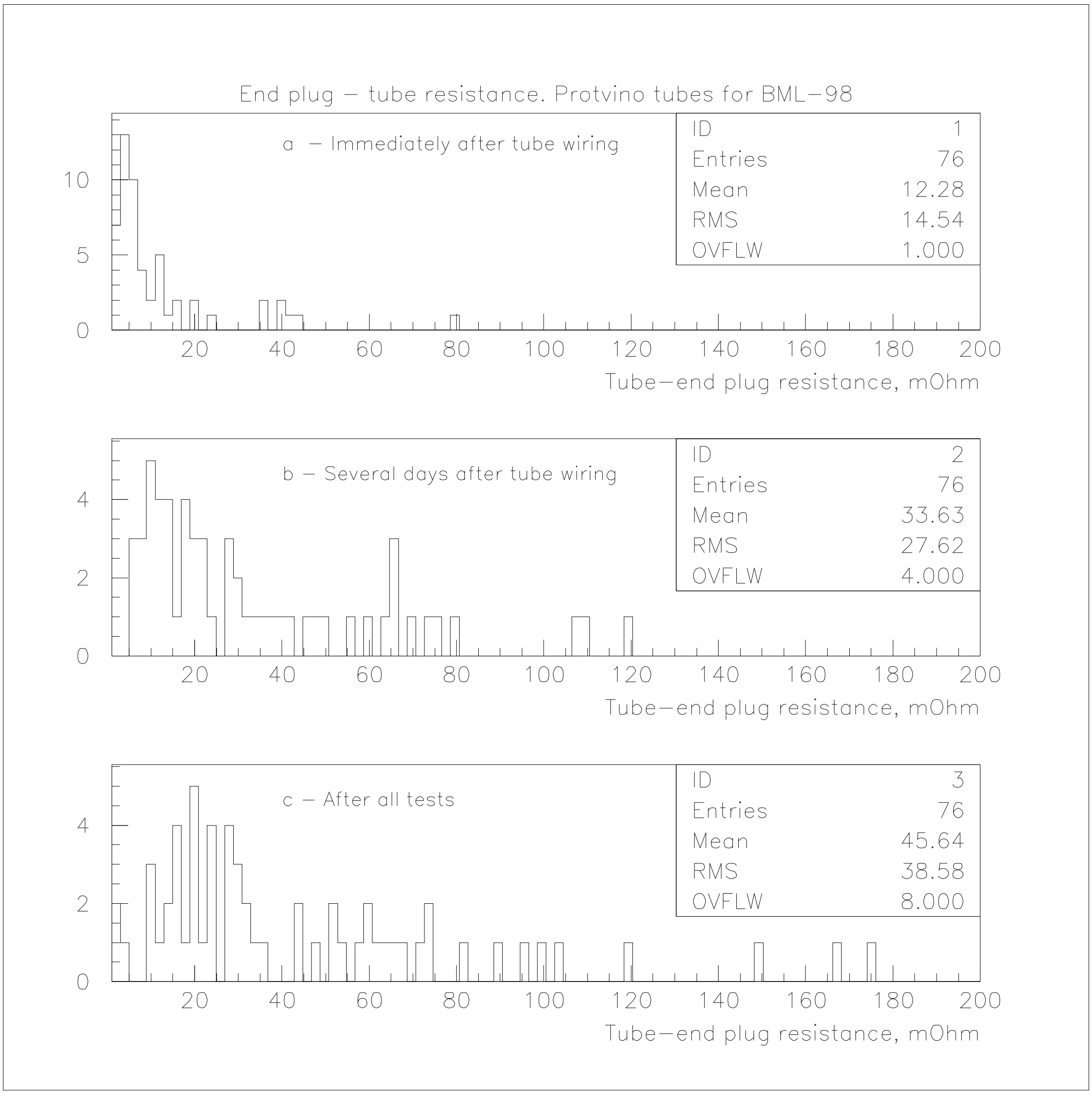

Figure 13: Resistance tube – end plug without spring.

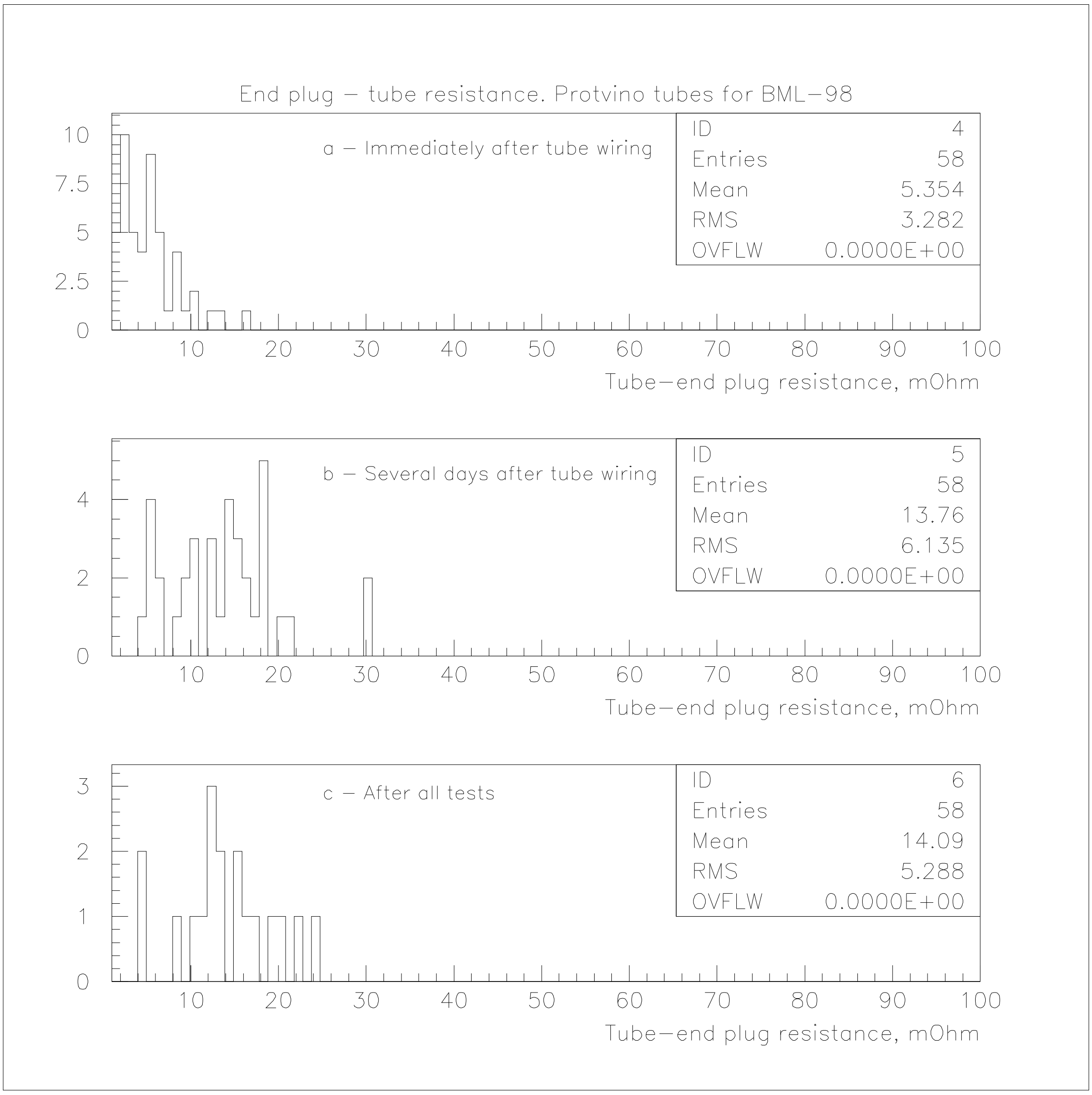

Figure 14: Resistance tube – end plug with spring.

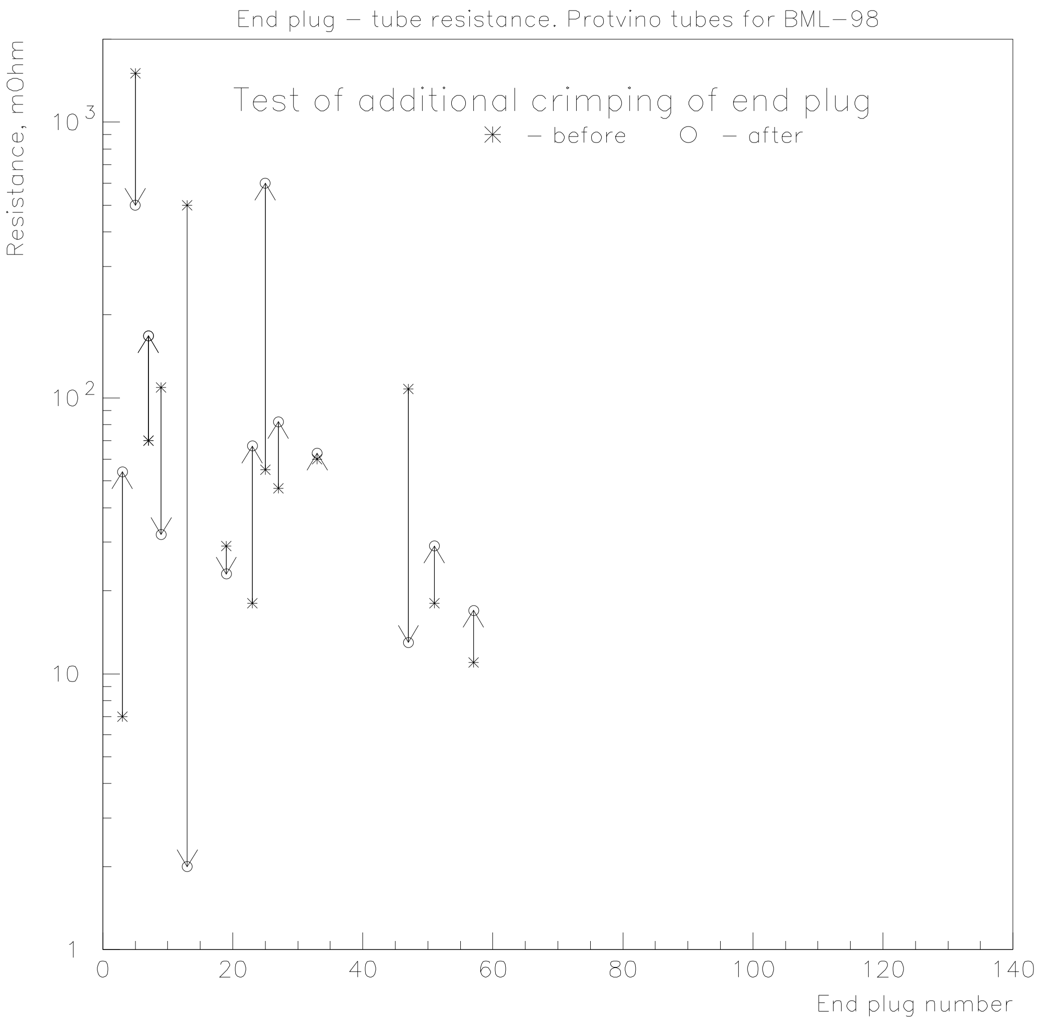

Figure 15: Resistance tube – end plug with additional crimping.

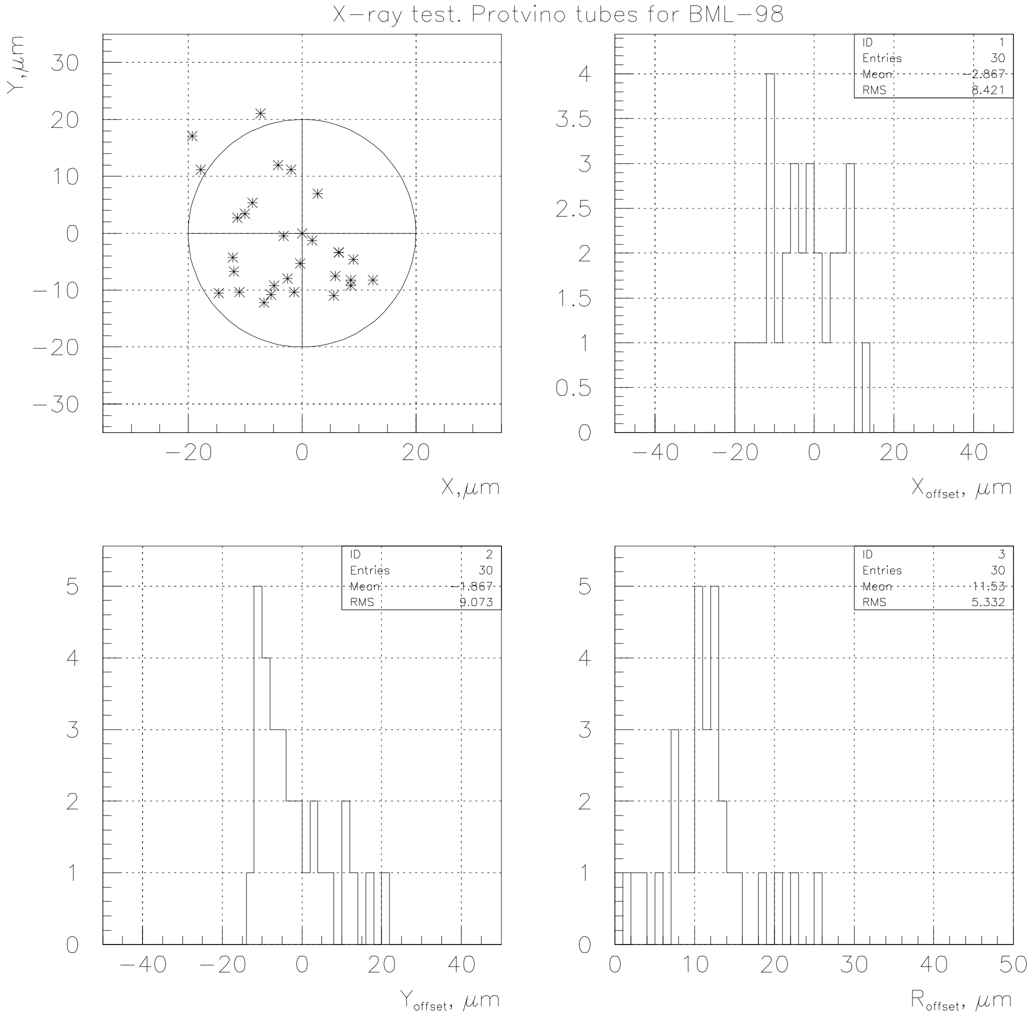

Figure 16: X-ray test of wire location in the tube.

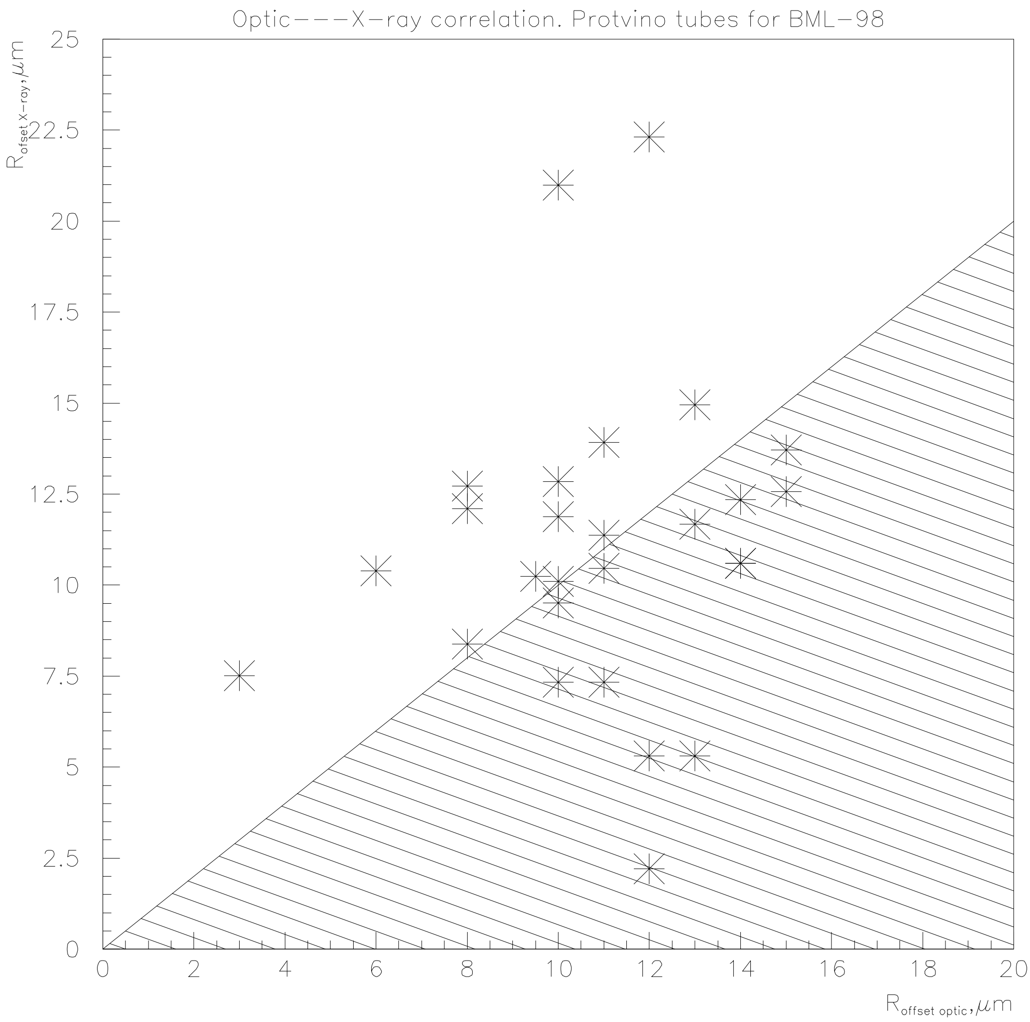

Figure 17: Optical – X-ray wire location correlation.

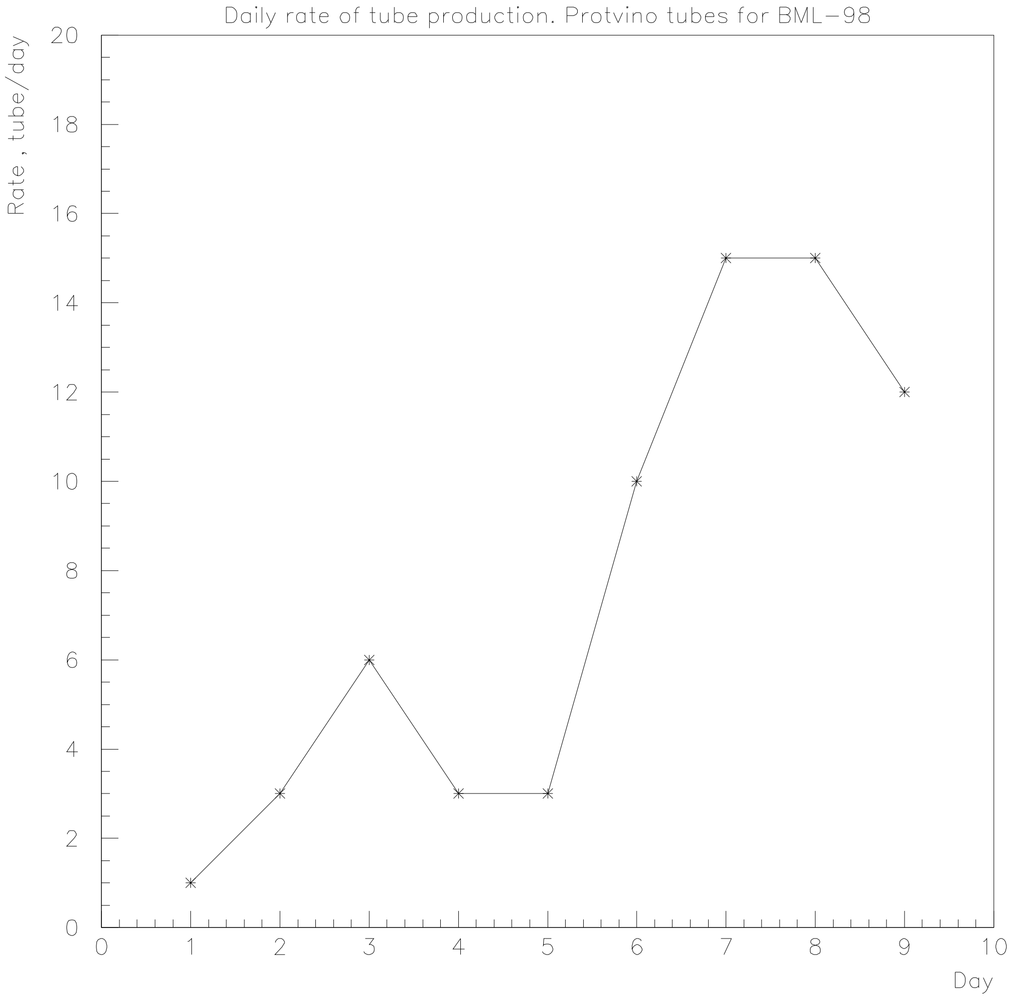

Figure 18: Tube production rate.

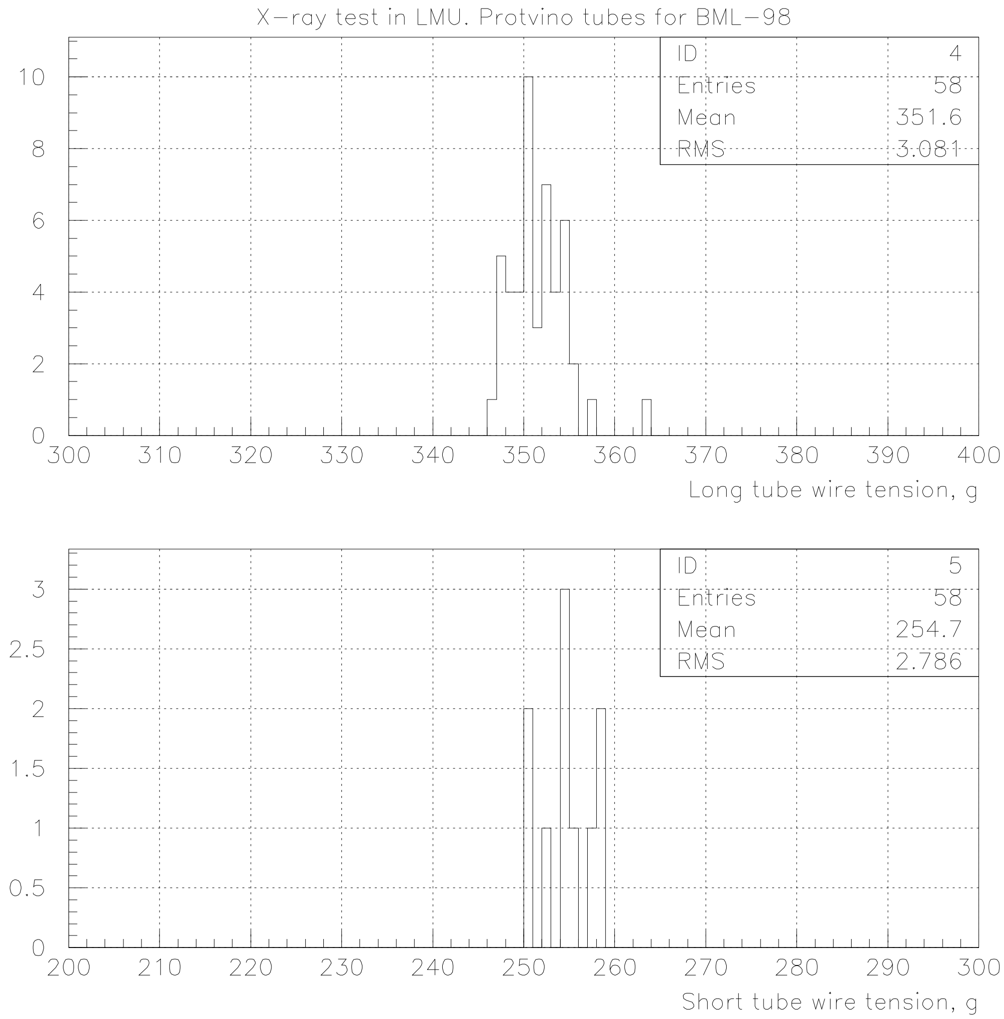

Figure 19: Wire tension test in LMU.

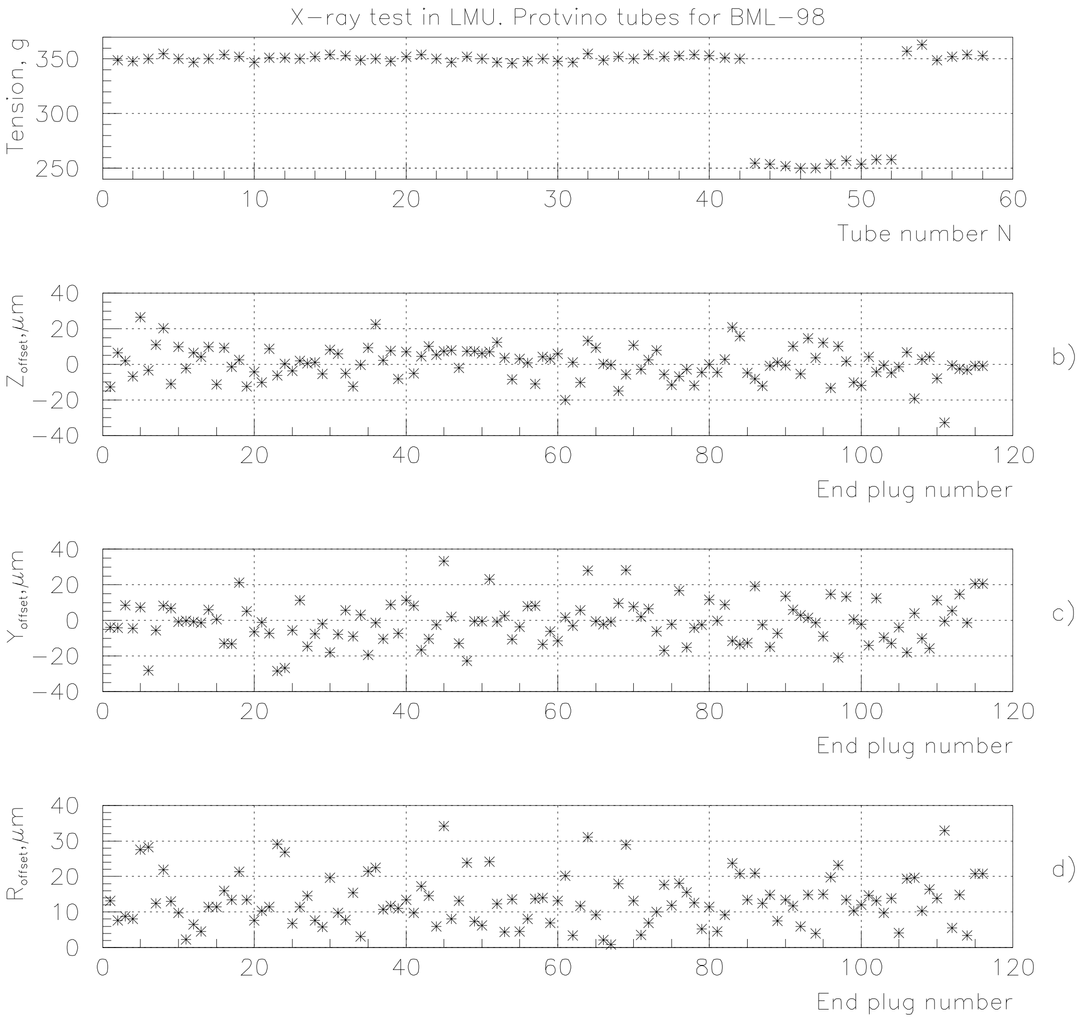

Figure 20: Tension vs. tube number and
X-ray test results vs.end plug number.

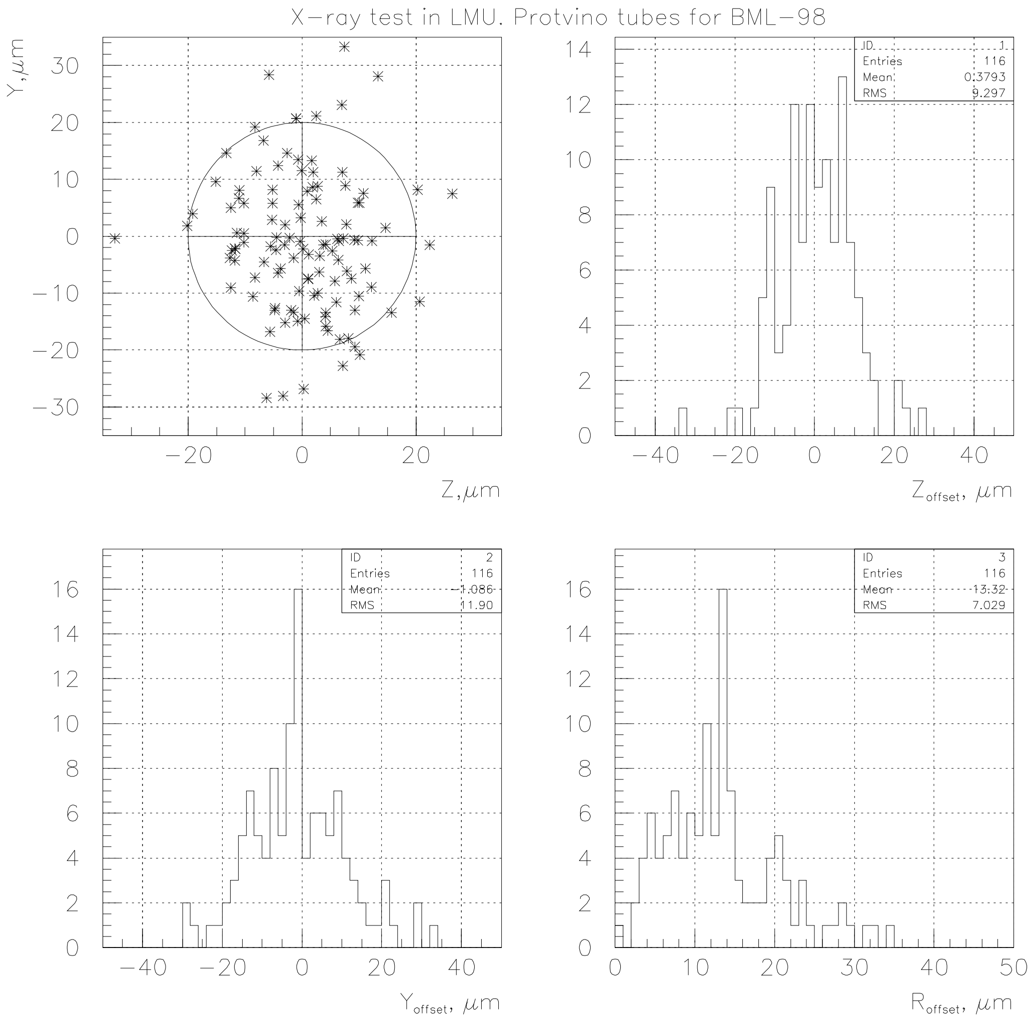

Figure 21: LMU X-ray test of wire location in tubes.

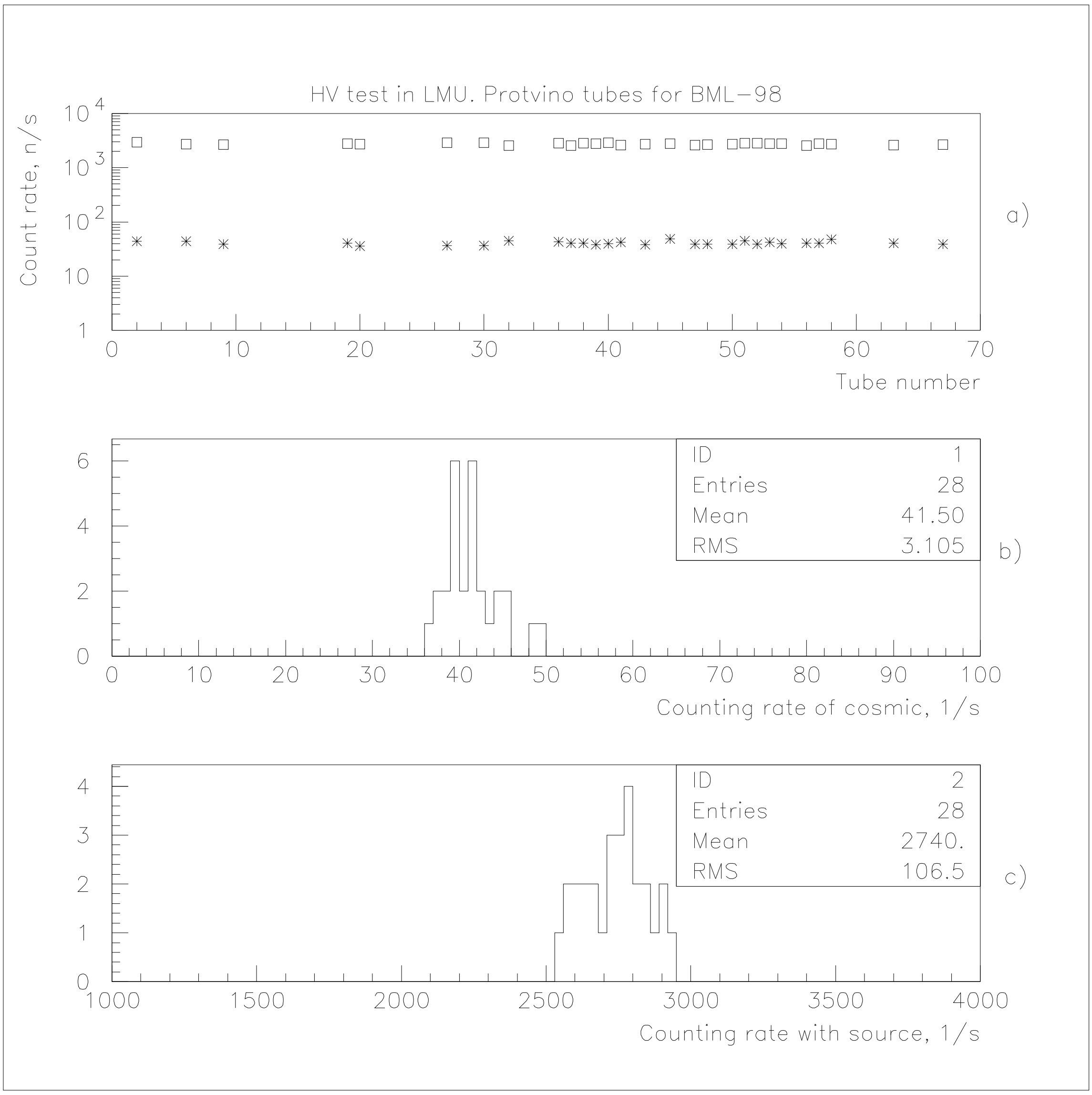

Figure 22: HV test results from LMU.

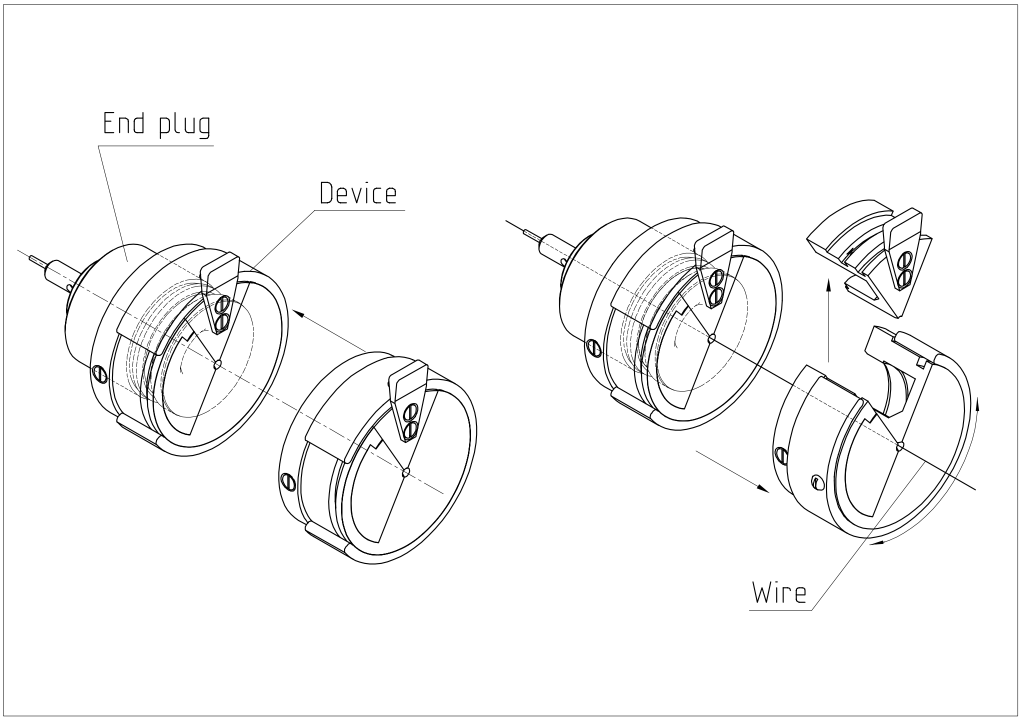

Figure 23: Tools for wire inserting.

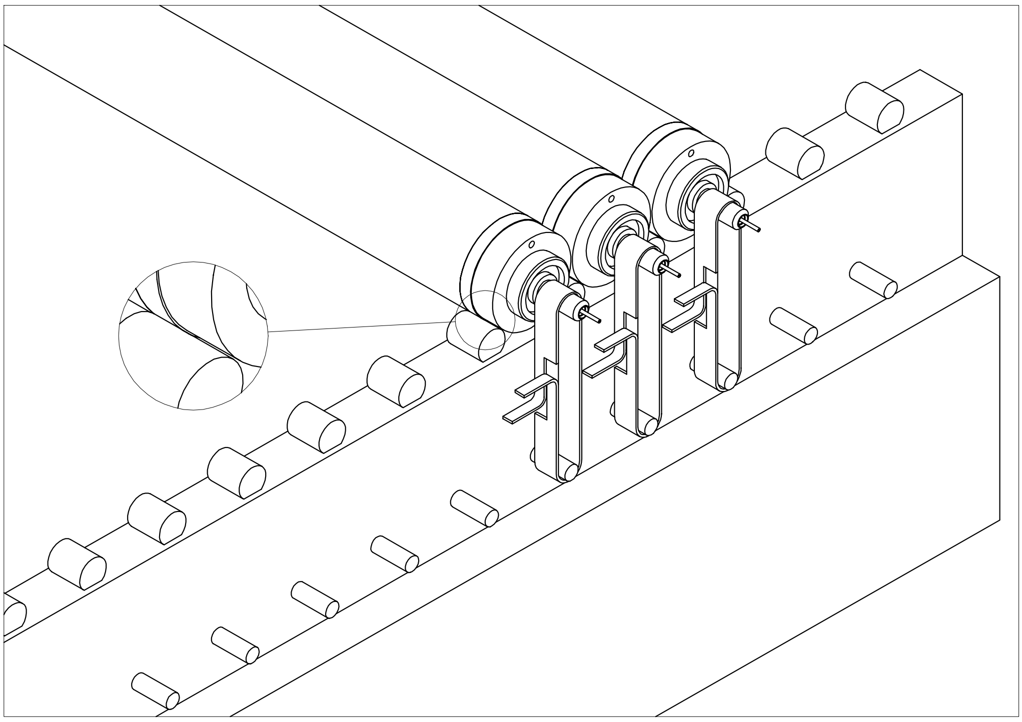

Figure 24: An example of using a spring instead of vacuum suckers.

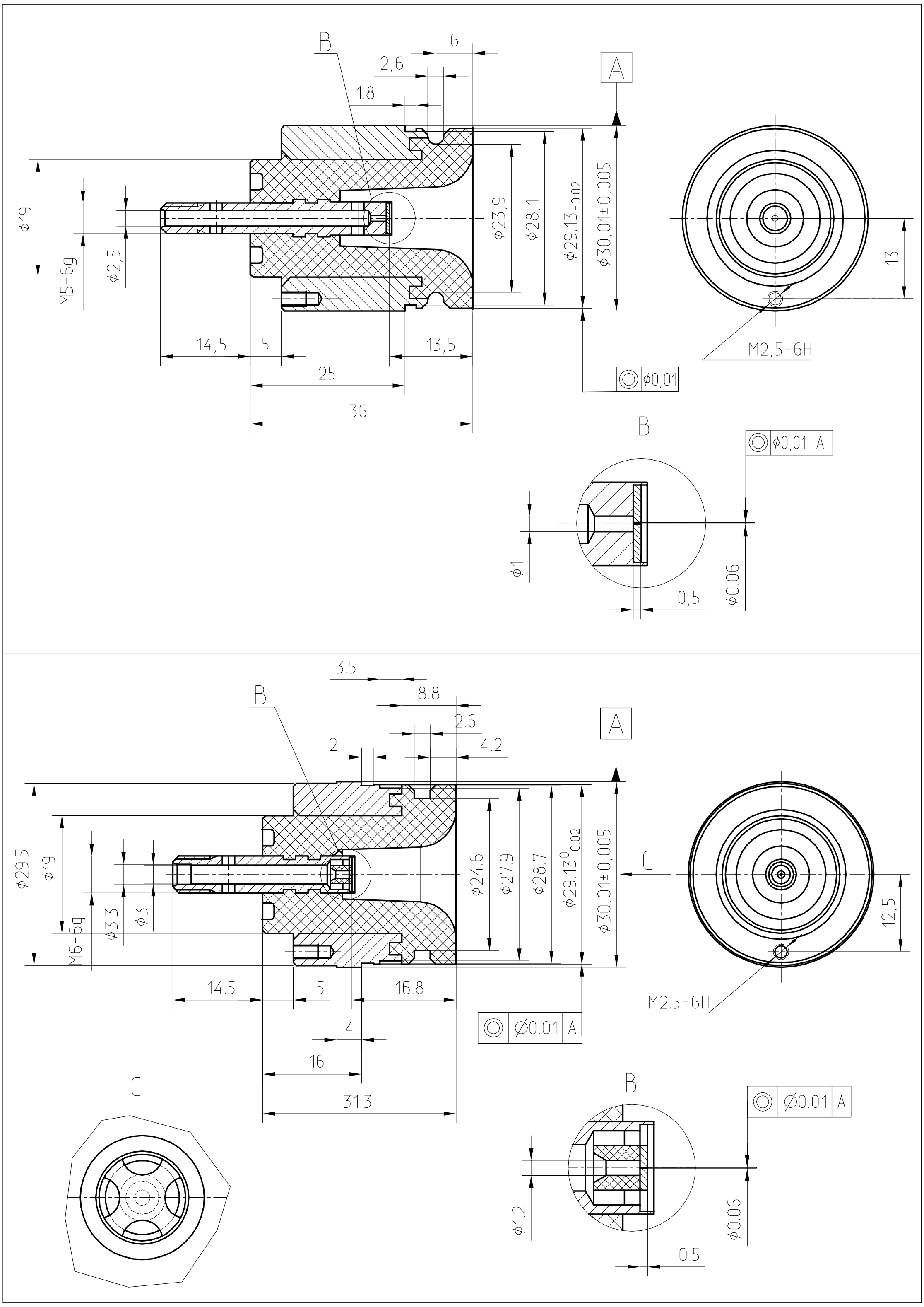

Figure 25: End plug already done (up) and proposed (down)

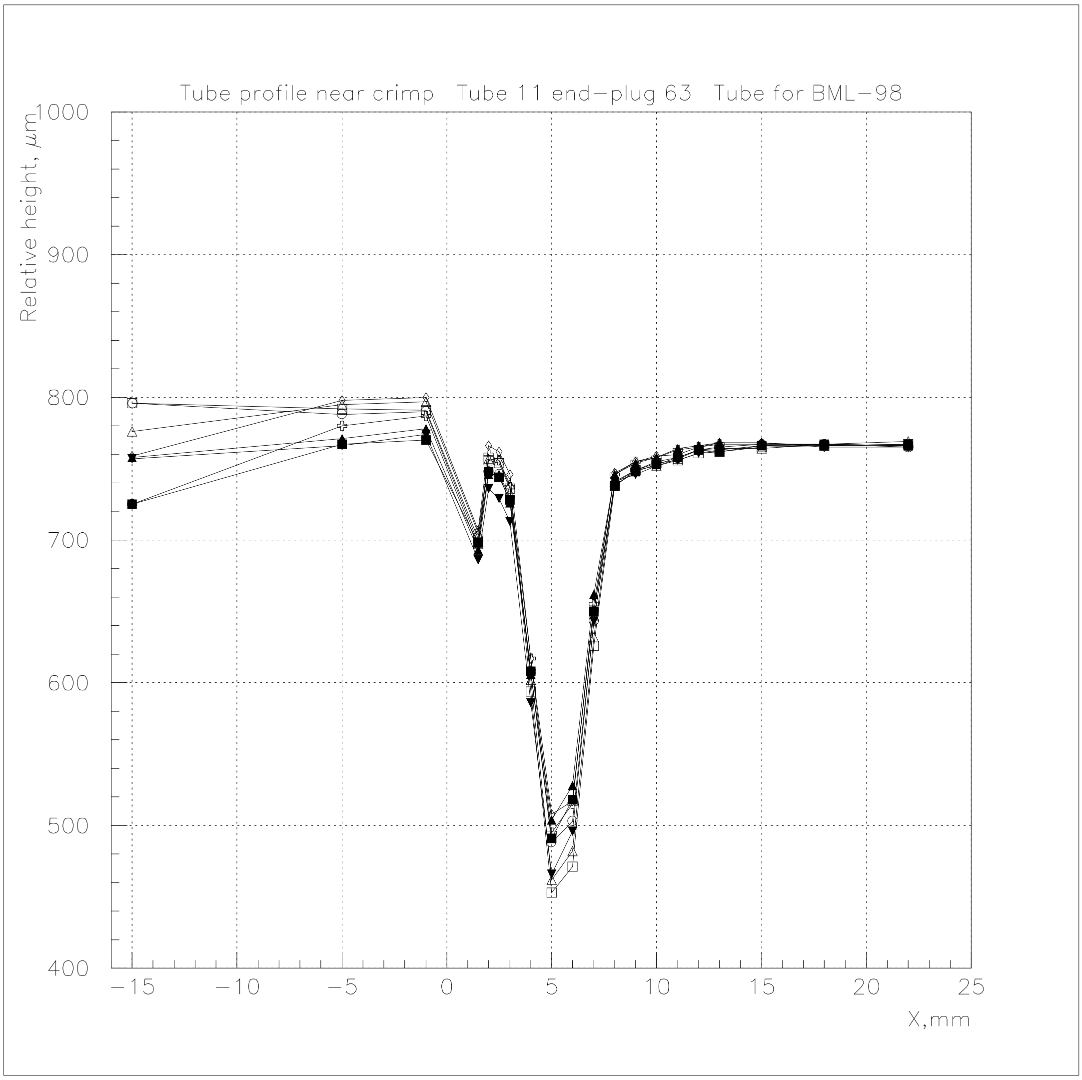

Figure A1: Relative gauge position at top of tube vs. X.

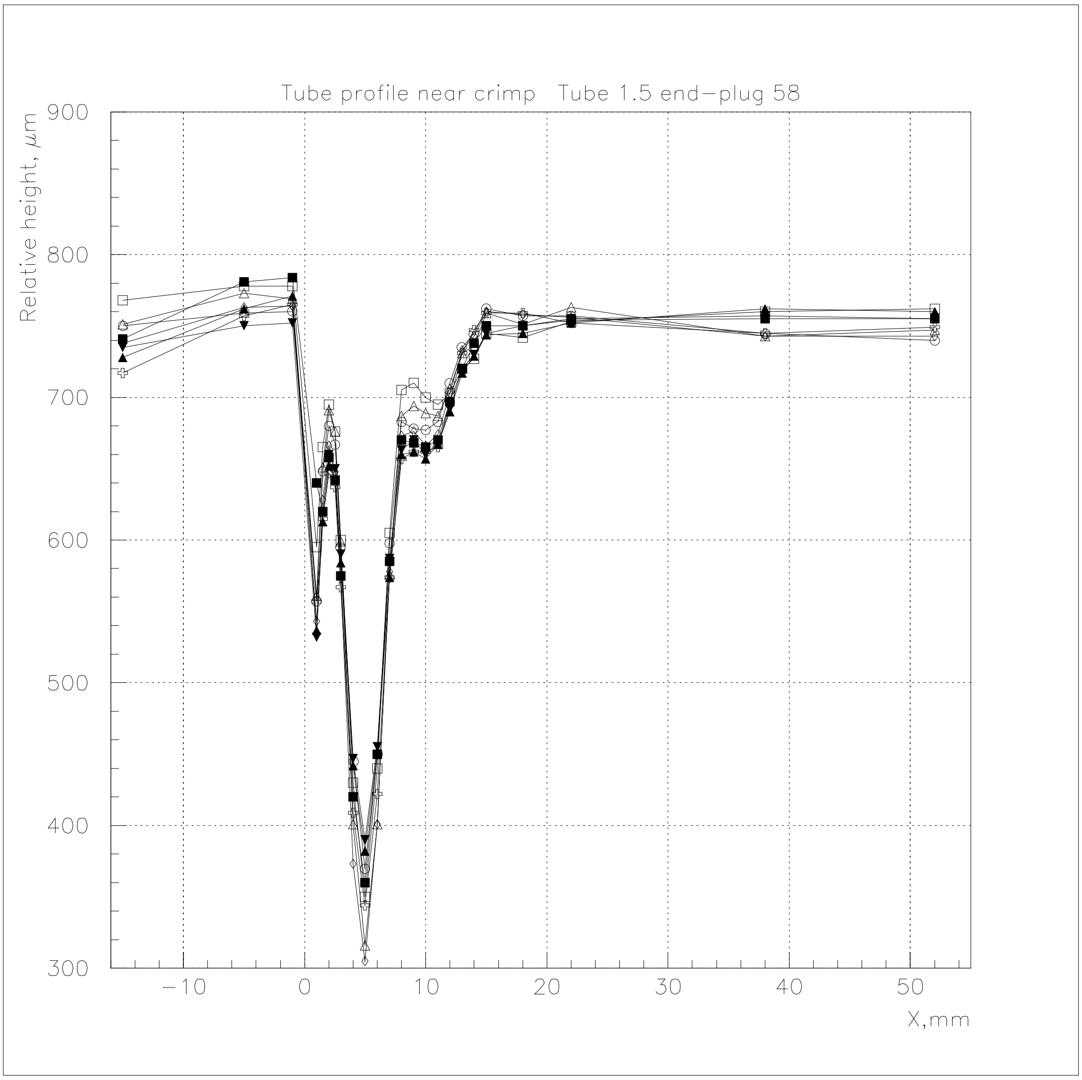

Figure A2: Relative gauge position at top of tube vs. X

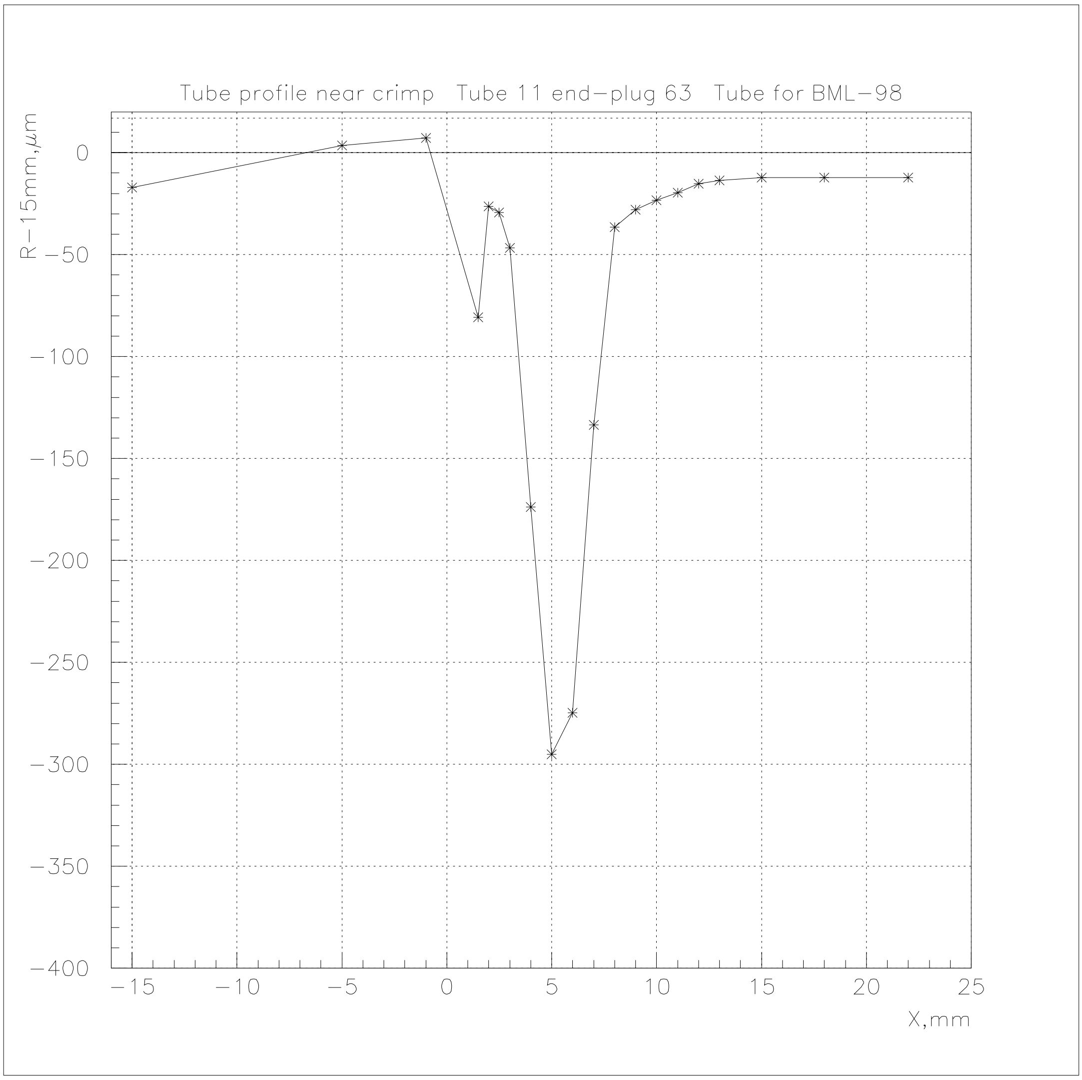

Figure A3. Radius of tube vs. X.

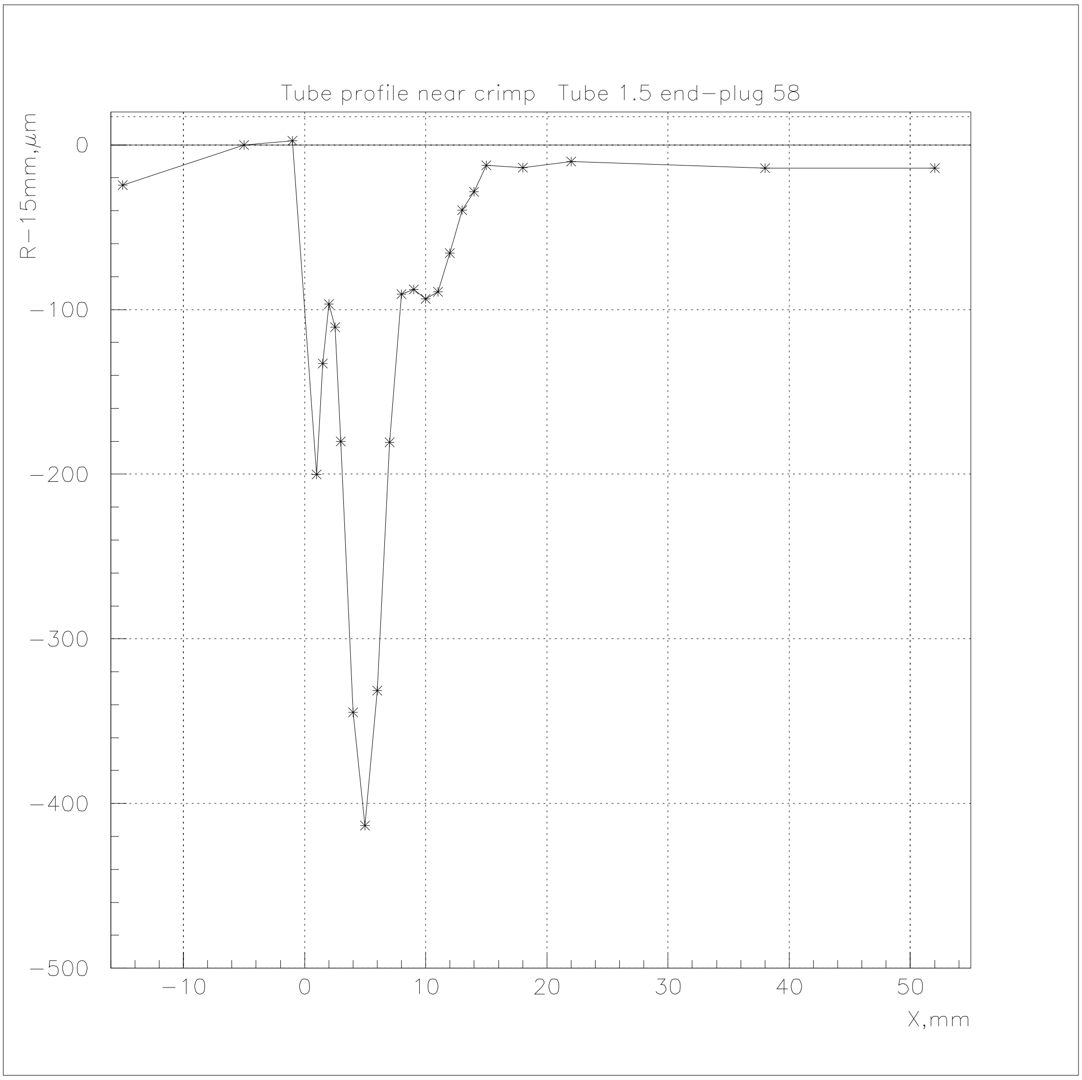

Figure A4: Radius of tube vs. X.