Report on the corrosion of the low voltage warm cables and feedthrough pins during the summer 2005 cold test of endcap A

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1 Synopsis

Some of the channels of the endcap signal feedthroughs carry low voltage for the HEC preamplifiers [1, 2, 3]. The cross section of the copper conductor in these channels is larger than that of the signal channels, resulting in greater heat conduction between the cryogenic bottom of the feedthrough and the ambient top. The feedthrough pins of the low voltage channels are therefore particularly susceptible to condensation should the temperature of the feedthroughs be allowed to fall below the dew point. The risk of damage to the low voltage feedthrough pins is exacerbated by the voltage on the pins, which in combination with moisture will lead to corrosion through a process which is essentially electrolysis.

The cold test of endcap A performed in Bat 180 during the summer of 2005 was done during a period when the weather conditions were particularly hot and humid. Although the feedthroughs are equipped with heaters to prevent condensation, the heaters were held at a temperature of 20 °C during the cold test. This temperature was below the dew point and consequently resulted in corrosion on some of the feedthrough pins of the low voltage channels as well as on the corresponding sockets of the low voltage warm cables. The corrosion was discovered when uninstalling the pedestals of the lower quadrants of endcap A in preparation for lowering into the ATLAS pit. Pictures of one corroded pin carrier and low voltage warm cable of endcap A are shown in Figure 1. The low voltage feedthrough pins and warm cables of the lower quadrants of endcap C were subsequently inspected but showed no sign of corrosion; the cold test of that endcap was done during winter months early in 2005 when the dew point was well below the feedthrough heater temperature of 20 °C.

2 Testing and Repair

2.1 Warm Cables

A small sample of the corrosion on a warm cable was removed and analyzed at CERN using an electron microscope technique. The elements found in the sample were primarily copper and oxygen, along with a trace amount of carbon which could have come from some contamination of the sample. The presence of copper and oxygen suggest that the corrosion was simply copper oxide, as would be expected. The relative amounts found for those two elements were not consistent with the copper oxide hypothesis, so the exact nature of the corrosion remains uncertain. The important thing to note, however, is the absence of any elements which might have come from solder flux or any other undesirable exotic chemical residue in the warm cables.

The corrosion was easily reproduced on a test bench in Victoria using parts left over from the construction of the feedthroughs. A cable was attached to a pincarrier wetted with distilled water. A power supply was then used to apply 24 V to some of the lines of the cable, with the pincarrier body attached to ground. The apparatus was typically left in this state for twelve hours, after which the cable was removed and the pincarrier and cable connector inspected. As can be seen in Figures 6 and 7, there is significant corrosion on those channels which were held at 24 V. The pincarriers thus corroded provided test samples for gauging the effectiveness of various cleaning methods, discussed below in Section 2.2.

All low voltage warm cables on endcap A were uninstalled and returned to the University of Victoria in February 2006 for testing and repair. The testing consisted of plugging both ends of a cable into a test apparatus which performed a precise resistance measurement between the two ends of each channel. The precision is high enough to provide a good measure of the contact resistance between the pins of the test apparatus and the corroded sockets of the cable. This test was done before any repair of the cable, and the results are summarized in Figures 2 and 3. As is evident in the resistance plots, there are many channels whose resistance lies significantly above the ~ 40 mΩ average.

Repair of the low voltage warm cables consisted of placing them in an ultrasonic bath of methyl alcohol for about 30 minutes each. The resistance tests were then repeated after the ultrasonic bath, and the results of those tests are summarized in Figures 4 and 5. After cleaning, the resistance of all channels are very uniform and close to 40 mΩ, indicating consistent good electrical contact between the pins and sockets after the ultrasonic bath.

2.2 Pincarriers

The pincarriers deliberately corroded in the Victoria lab provided good samples for testing the effectiveness of various cleaning techniques. The insulator between the pins and the pincarrier body is glass, so the corroded pincarriers could be placed on a light table and the back-lit glass beads viewed with a microscope. Any corrosion residue which ends up on the glass bead could potentially lead to a conduction path between the pin and the pincarrier body. A picture of one such corroded pincarrier with corrosion residue on the insulating glass beads is shown in Figure 6. Resistance between a pin and the pincarrier body was also measured using an ohmmeter cable of measuring in the TΩ range. Some resistances before cleaning were measured as low as 25 MΩ.

A number of cleaning methods were tried, using both visual inspection and measured resistance to check their effectiveness. The most effective cleaning method found was to dip a thin Teflon capillary tube into alcohol, then place the tube over a pincarrier pin and onto the contaminated glass bead. The dimensions of the Teflon tube were carefully chosen so that the ID of the tube fit easily over the pin, and the wall thickness of the tube covered most of the glass bead. With the glass bead wetted by the alcohol in the tube, the tube was gently twirled in order to *scrub* the glass bead. The loosened residue was finally blown away using canned air. After cleaning, resistance between pin and pincarrier body was typically on the order of 1 TΩ and the glass beads visually much cleaner.

During June 2006, this cleaning prescription was applied to all corroded pincarriers on the HEC feedthroughs of Endcap A.

3 Feedthrough Cold Tests

As mentioned above, all signal feedthroughs are equipped with flange heaters to prevent condensation on the warm flange. The heaters are instrumented with temperature monitors so that the heater plates can be held at a set temperature. There is, however, a temperature gradient between the flange heater and the pincarrier pins. This is particularly true with the pins connected to the low voltage cables in the HEC feedthroughs. Tests were conducted in Victoria in June 2002 during the construction of the feedthroughs to measure that temperature difference. The coldbox of HEC ft48 (the part of the feedthrough wetted with liquid argon under normal ATLAS operating conditions) was filled with liquid nitrogen and the flange heater set to 25.4 °C, 3.4 °C above the ambient room temperature of 22 °C. After allowing the temperature to stabilize for several hours, a thermocouple probe was used to measure the temperature at the base of several pins. The coldest pin found was 15 °C, 10.4 °C lower than the flange heater set point. The temperature of the flange heater was then boosted to 28.3 °C and the pin temperatures remeasured. The coldest pin found this time was 17 °C, 11.3 °C lower than the flange heater set point.

It should be noted that this these tests were conducted with no warm cables attached to the pincarriers and no pedestal enclosure. Although there is no data to corroborate, it is felt that effects of the warm cables and pedestal will be to make the temperature within the pedestal enclosure more uniform and so the measured temperature gradients might indeed be overestimates of those to be encountered under normal ATLAS operating conditions.

4 Recommendations

While the extreme temperature and humidity conditions which led to the corrosion of the HEC feedthrough pins on endcap A are unlikely to be encountered during normal ATLAS operation in the pit, it is important to ensure that the feedthrough flange heaters are operated in such a way that condensation on the pins will not occur. The key to this is never to allow the temperature of the pins fall below the dew point.

It is my understanding that the ATLAS pit environment will be controlled with the relative humidity held at 50%. At that relative humidity and an ambient temperature of 20 °C the dew point would be about 9 °C, or about

11 °C below ambient. At a more extreme ambient temperature of 30 °C the dew point would be about 18 °C, or about 12 °C below ambient. Similarly, at an ambient temperature of 15 °C the dew point would be about 5 °C, or about 10 °C below ambient. From these numbers, it can be seen that the dew point in the ATLAS pit will remain about 10 - 12 °C below the ambient temperature.

From the tests discussed above in Section 3, we found that the temperature of the low voltage pins is about 10 - 11 °C lower than the temperature of the flange heater. In principle then, the temperature of the feedthrough pins should remain above the dew point even with the flange heaters operated at just 1 - 2 °C above the ambient temperature in the ATLAS pit. A larger safety margin, however, would be more prudent. It would therefore be recommended to maintain the HEC feedthrough flange heaters at a temperature *at least* 15 °C above the dew point in the ATLAS pit.

References

[1] C.Cerna, et al., *Cabling of the liquid argon calorimeters*, ATLAS internal note ATL-A-EN-0001, 7 December 2004.

[2] D.Axen, et al., *Signal feedthroughs for the ATLAS barrel and endcap calorimeters*, Review of Scientific Instruments **76**, 063306 (2005).

[3] M.Fincke-Keeler, M.Lefebvre, *A Proposal for a Low Voltage Vacuum Cable Design for the HEC Feedthroughs in the ATLAS Endcap Cryostat*, ATLAS internal note **HEC 068**, (December 1998).

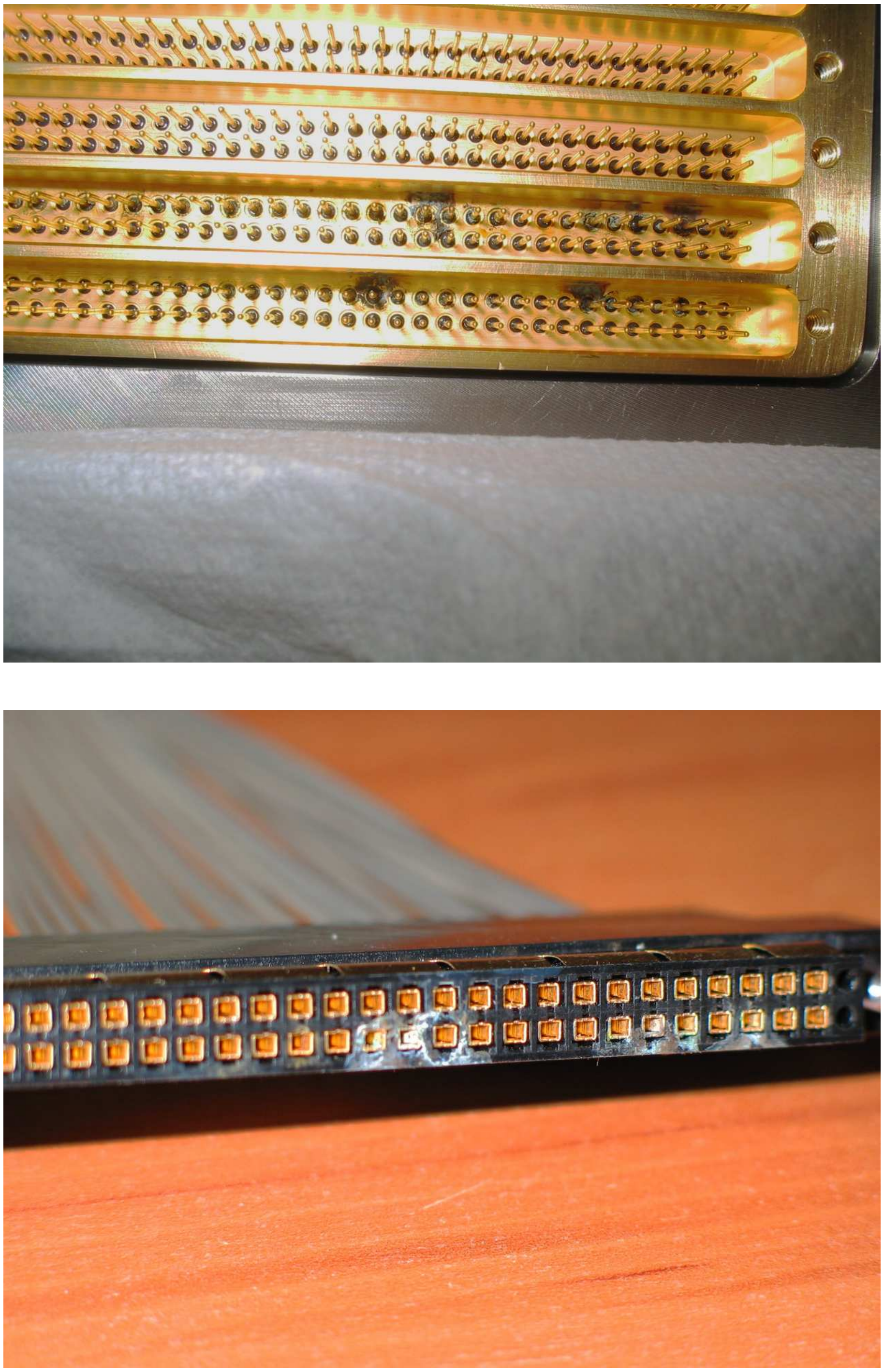

Figure 1: Corroded pin carrier (top) and low voltage warm cable (bottom) from endcap A.

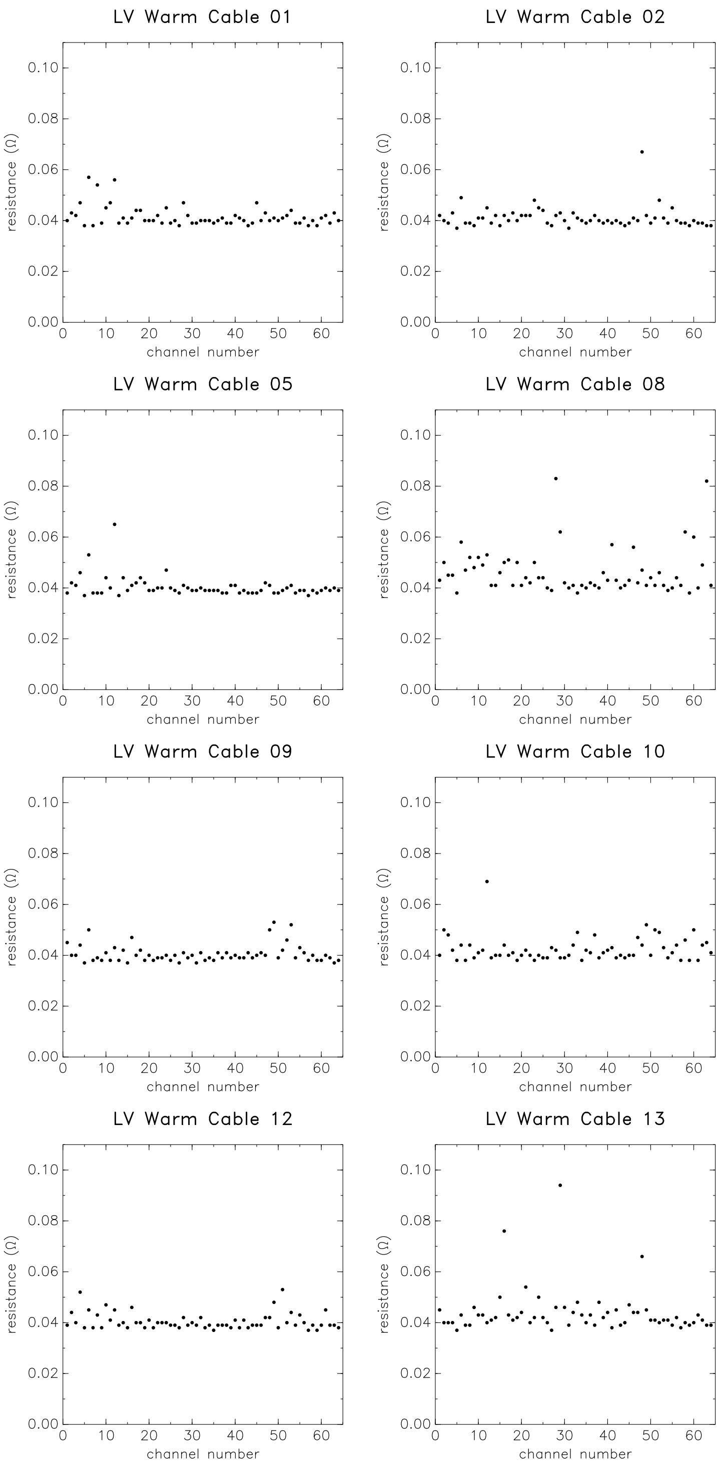

Figure 2: Resistances measured before ultrasonic bath (a)

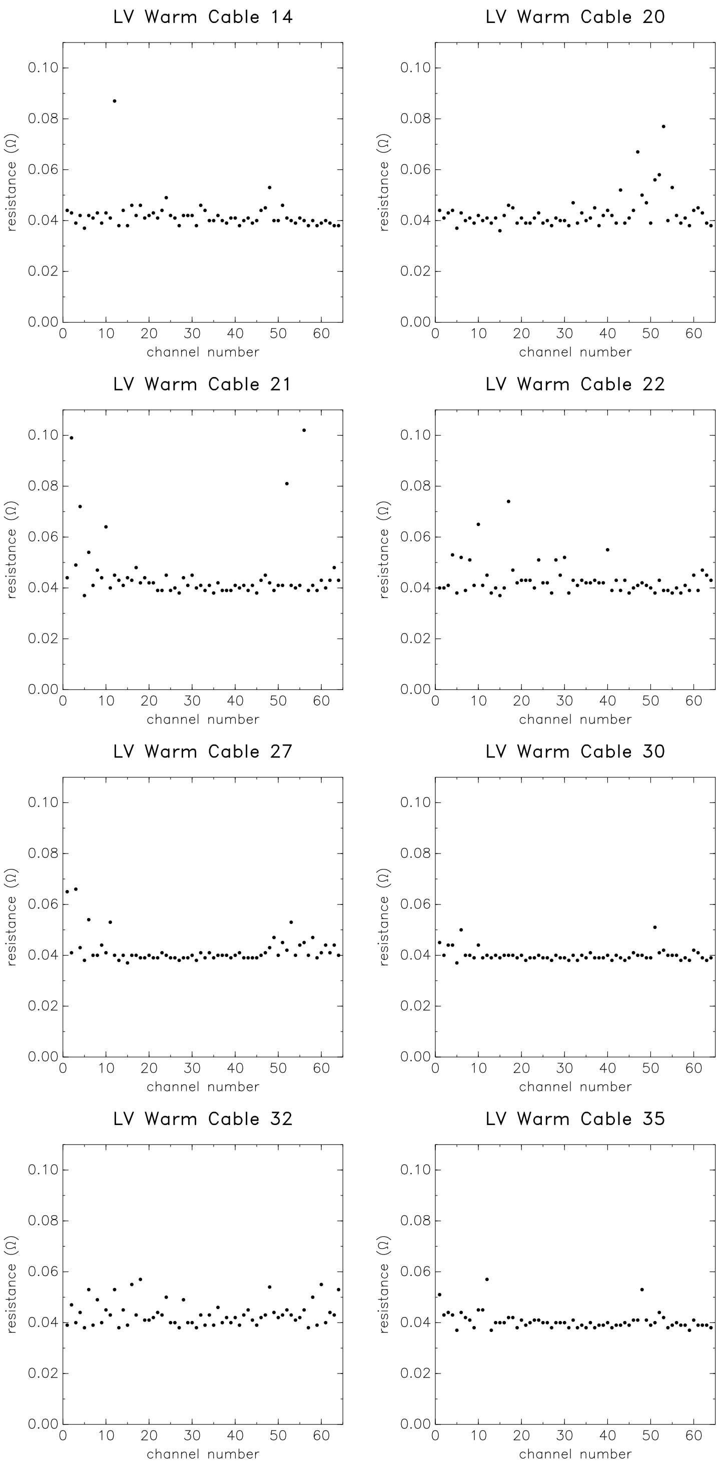

Figure 3: Resistances measured before ultrasonic bath (b)

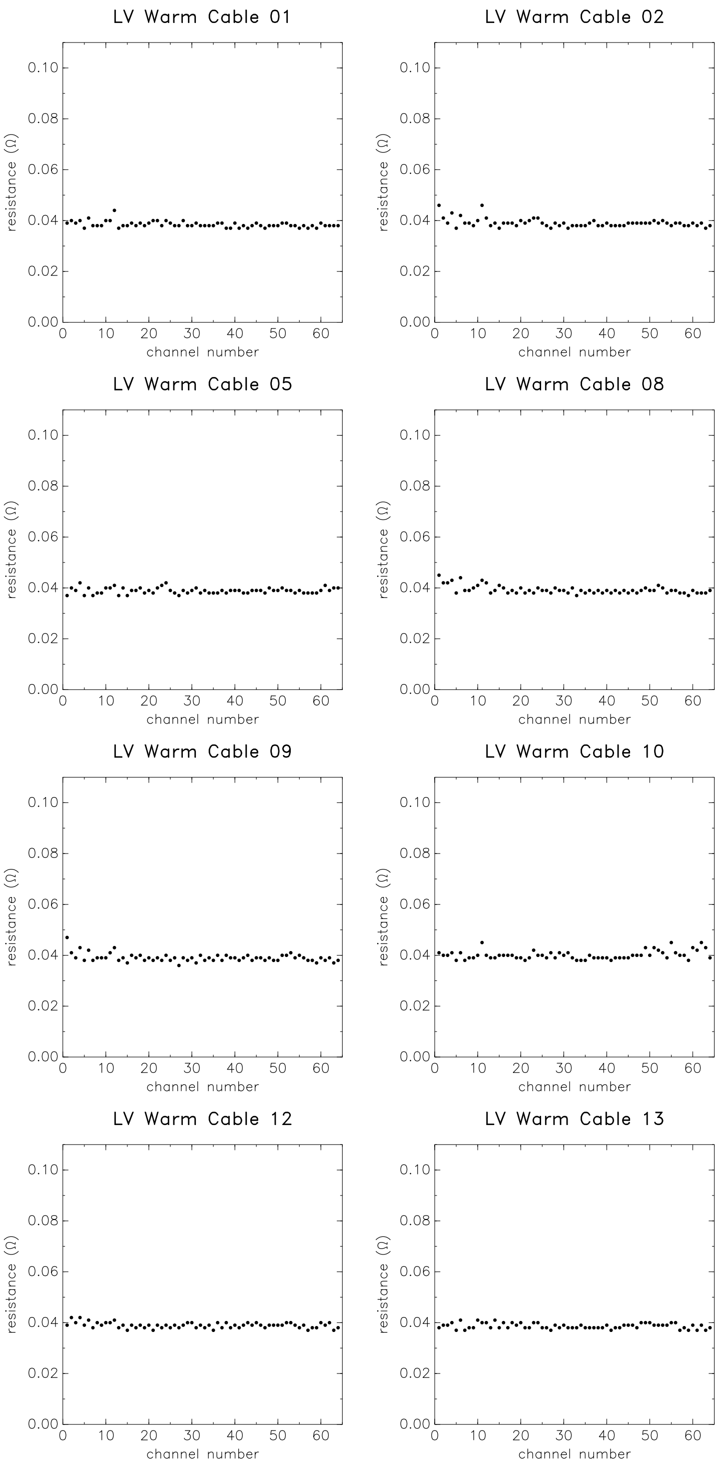

Figure 4: Resistances measured after ultrasonic bath (a)

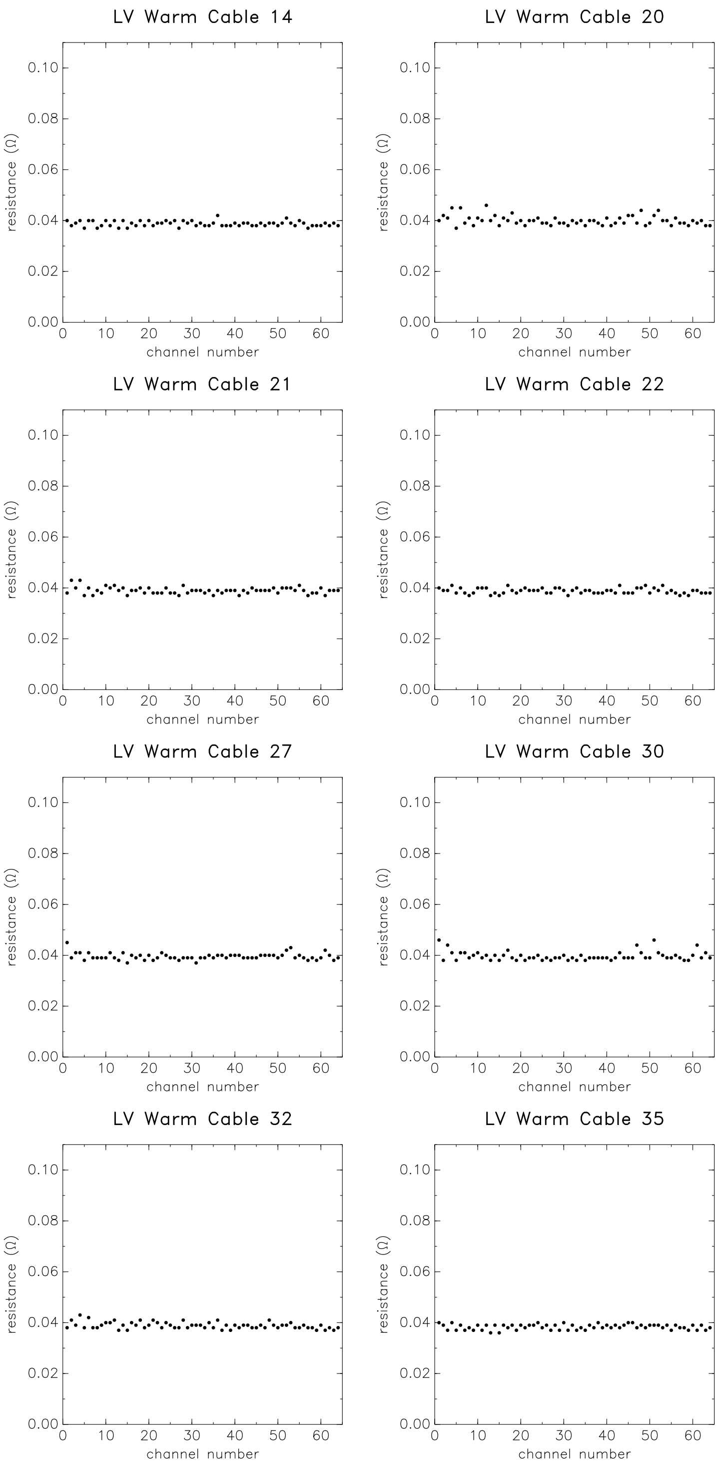

Figure 5: Resistances measured after ultrasonic bath (b)

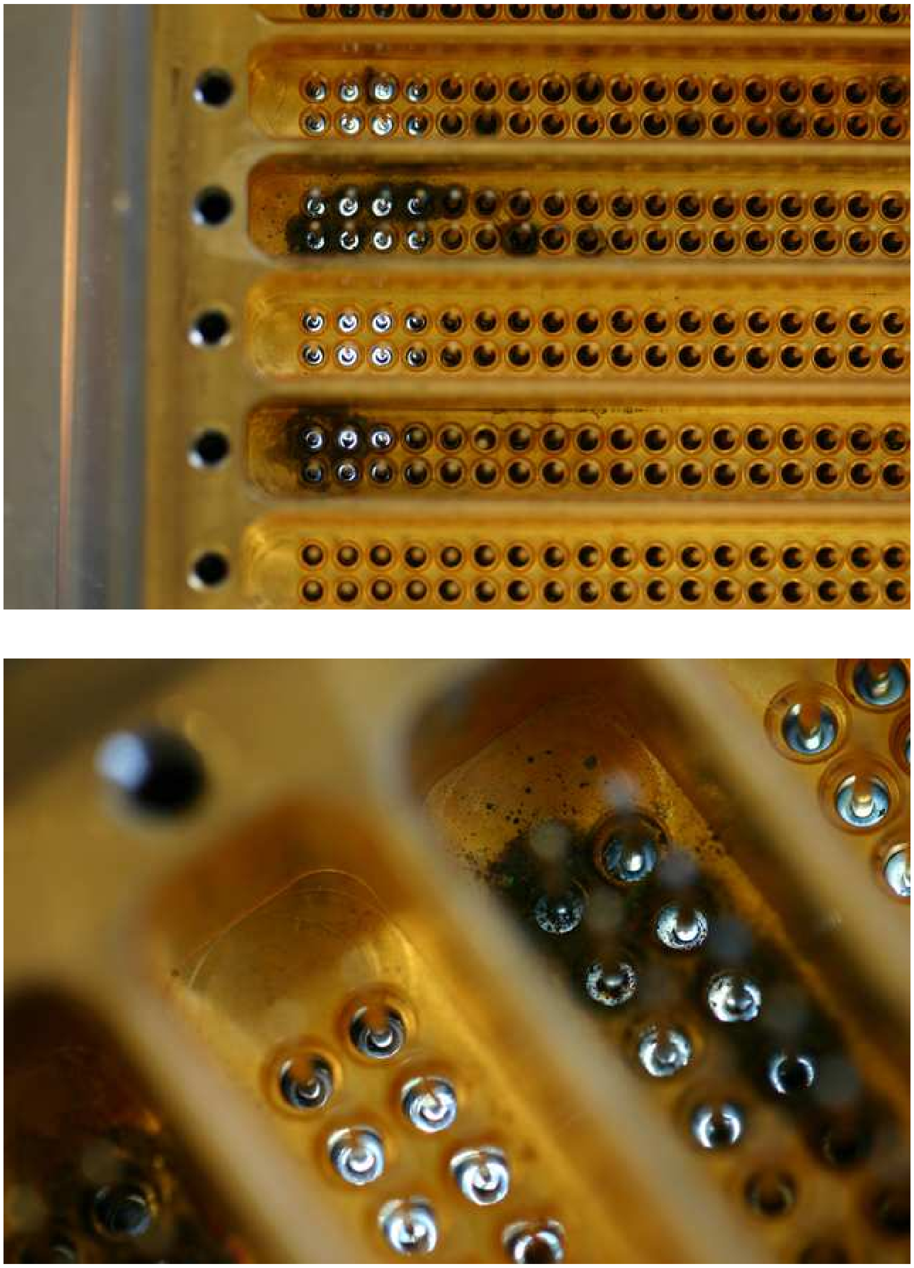

Figure 6: Corroded pin carrier from Victoria bench tests. The pincarrier is on a light table to illuminate the glass bead insulating the pin from the pincarrier body. Note the corrosion debris on some of the glass beads in the bottom picture.

Figure 7: Corroded cable from Victoria bench tests.