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MDT commissioning procedures

Guidelines for certifying RFI chambers

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Contents

1. Introduction

Aim of the document is the definition of a common set of guidelines and test procedures for commissioning the MDT chambers. Almost all of them are produced, and most are already equipped with gas and electrical services. Some are being tested under cosmic rays in the production sites, while others are being equipped and integrated now at CERN, and must be completely tested. All chambers, sooner or later, must be transported to CERN, where they have to be commissioned. Commissioning is the series of tests required in order to certify single chambers ready for installation (RFI).

Commissioning is different for Barrel and Endcap chambers. The former will be tested at a single chamber level before going to the ATLAS pit, ready for the last quick test before final installation, while the latter will be first tested at a single chamber level (phase one), then installed into the Small and Big Wheel sectors (SW and BW), tested after the integration (phase two) and transported to the ATLAS pit for final wheel installation.

The present document concerns all tests, including those of phase two for Endcap chambers, but it is possible that some specific tests, at the moment not planned, will be implemented during the Endcap phase two commissioning. It is composed of three sections:

1 – Guidelines for checking chamber conformity, where the main rules for declaring that chambers conform to the reference drawings and requirements are described;

2 – Commissioning tests, where the minimal required tests, and their procedures, are detailed;

3 – Database information, where the database structure and the minimal required information to be stored into it are illustrated and listed.

2. Guidelines for checking chamber conformity

Before commissioning, chambers must be checked for their conformity to all requirements and reference drawings. Here, the major checks that every construction group has to perform in order to proceed to commission chambers are listed.

2.1 Layout

1 – Chamber must comply with the envelope defined by ATLAS Technical Coordination (TC). Every part of it must not exceed envelope, unless a specific request of modification was sent to Olga Beltramello and accepted by her. The final envelope of each chamber type should be made available on drawing to the TC and to the MDT collaboration, so to make possible to them further checks;

2 – All official barcode labels must be attached to chambers, in accessible and visible places, not covered by cables, gas pipes, electronics services or any other thing that can make difficult scanning them. Old official barcodes, not always readable, must be replaced with the new ones;

3 – All chamber and services parts must be diamagnetic. They must be checked before starting commissioning, and magnetic parts must be replaced before installation. Magnetic parts can only be accepted if there is no technical possibility of replacing them. Examples of magnetic parts not replaceable are I/O connectors of RasMuxes and ELMBs and precision positioning pins of the axial/praxial platforms. Each group must inform TC about any magnetic piece not replaceable.

2.2 Alignment

1 – All alignment platforms must be glued in proper position. For Barrel chambers, reference drawings can be found at

https://edms.cern.ch/cdd/plsql/c4w_atlas_guided.search?cookie=718238&p_c_id=1048829168&p_project_code=ATL

under ATLMAM: MDT Alignment Systems. Tooling for gluing platforms can be found at the same web address, under ATLMAG: Positioning Tools (Platform gluing).

For Endcap chambers, reference drawings of alignment system, B sensors and survey targets are at http://www.hep.brandeis.edu/ddb/

General descriptions of the layouts of Barrel and Endcap alignment systems can be found at

http://atlas.web.cern.ch/Atlas/GROUPS/MUON/alignment/muon_align.html.

2 – Platforms must be properly glued, in order to avoid possible falls when chambers are installed. Gluing procedures for Barrel Projective and Reference platforms can be found at

http://www.pv.infn.it/~servel/atlas/commissioning/index.html;

For Endcap chambers, some documentation can be found at

http://ganesh.physics.lsa.umich.edu/~atlas/integration/drawings/drawings.html;

3 – RasCams of the in-plane system must be electrically insulated from the crossplate to which they are mounted. Each chamber must be checked for this. Short-circuits, if not recoverable, must be marked and reported to the TC;

4 – RasCams, lenses and masks must be rigidly connected to the crossplates. In order to improve their stability, it is recommended to glued them on the crossplates;

5 – Endcap, BOS and BOG chambers have survey targets. These are installed at the positions specified in the Brandeis drawings, for Endcap, and in the Saclay drawings, for Barrel. Positions after gluing are checked, and any deviation outside allowed tolerances is recorded in the database.

2.3 Services

1 – On-chamber gas pipes must be referred to chamber ground, so to avoid EMI pick-up due to antenna affect. Connections to the gas main system must be insulated from chamber ground, in order to avoid ground loops out of control. Every chamber must be checked for this, and bad connections must be fixed before commissioning;

2 – Valves connected to the on-chamber gas pipes should be certified (by CERN, ask F. Hahn or S. Palestini) to be silicon and lubricant free. Grease inside valves is allowed, if certified by CMS or ATLAS (Pedro Canada or Apiezon). Not certified valves can still be used, but only at the chamber outlets, and no gas should flow through them to the chamber, in order to avoid contaminants transported by gas to the chamber internal. In any case, not certified valves must be dismounted before installation.

It is recommended that all chambers are equipped with valves, in order to keep them under pressure before and after commissioning. For chambers not yet equipped with safe valves, a proposal concerning the use of commercial valves available at the CERN Store was circulated by S. Palestini and L. Pontecorvo, and is reported in Appendix 2.

3 – On Barrel, HV splitter enclosure must be connected to chamber ground, while on Endcap, it must be connected to the wheel structure. ELMB and RasMux (AMB for Endcap) enclosures must be insulated from chamber ground. CSM motherboard must be supported with metallic standoffs, so its ground is connected to the chamber ground.

2.4 Cabling

1 – All alignment, temperature and B sensor cables must be placed in the proper positions, and connected to RasMux (AMB for Endcap) and ELMB. RasMux connection positions for Barrel chambers are defined in the document RasMux cabling tables for all chambers , available at http://atlas.web.cern.ch/Atlas/GROUPS/MUON/alignment/muon_align.html.

ELMB connection positions are not defined, and must be established by each group, which has to record them.

AMB (Alignment Multiplexer from Brandeis) and temperature cabling for Endcap chambers are described at

http://ganesh.physics.lsa.umich.edu/~atlas/integration/drawings/drawings.html.

2 – All cables must be properly labeled on both sides. In particular, Barrel alignment labels must follow the defined rules, available at

http://atlas.web.cern.ch/Atlas/GROUPS/MUON/alignment/muon_align.html

under Labeling scheme for alignment sensor cables;

3 – All sensor cables must be tested for continuity and shorts before sensor installation;

4 – Cable supports, trays, adhesives or any other plastic piece used for supporting cables must be halogen-free and radiation resistant. Cable supports must be fixed to chambers in a safe way, by means of screws or directly glued.

3. Commissioning tests

All MDTs under commissioning at CERN are supposed to have passed all tests done locally at the test sites. Generally, alignment, DCS and HV cabling should be performed locally, while RO cables could be connected after the integration with RPCs.

Chambers can be fully commissioned only if for each of them all electronics components are available and functional, and the related cables are properly connected. The following electronics components are needed:

- HV splitter
- ELMB
- CSM motherboard
- Rasmux (AMB for Endcap)

If one or more of the above mentioned components are not available, chambers can be commissioned, but specific tests must be foreseen after the procurement of the missing pieces, in order to verify the correctness and functionality of the cable connections.

The necessary tests and compensations to be performed for certifying a chamber RFI (Ready For Installation) are listed in the following. For Barrel chambers, they should be done sequentially all together, while for Endcap chambers some of them are done in the first phase of commissioning, and others in the second phase, after having installed chambers in the BW and SW sectors. The chronological sequence depends on the setups and available hardware, so it can be different from site to site.

Barrel:

1 – alignment

2 – sag compensation

3 – T, B and alignment sensors

4 – gas leak, short and long term

5 – hedgehog card and wire continuity check

5 – current leak

6 – noise

7 – cosmic rays

Endcap, phase one:

1 – gas leak, short and long term

2 – in-plane alignment

3 – T sensors

4 – current leak

5 – hedgehog card and wire continuity check

6 – noise

7 – cosmic ray

Phase two :

1 – sag compensation

2 – alignment

3 – current leak

4 – B sensors

The here described Endcap commissioning refers to the tests performed on chambers at CERN. The Boston groups are doing a first phase commissioning in Boston, following a simplified procedure. A document describing Boston commissioning is available at:

http://huhepl.harvard.edu/~marin/integration/integrated chambers/BMC_Integration2.ppt

The document describing all tests performed by the US groups for Endcap phase one commissioning at CERN is reported in Appendix 3.

3.1 Alignment

Axial/praxial and projective platform positions should be measured before sensor installation. In-plane system must be tested, and new zero-readings should be measured, in order to adjust the sag.

Method of tests – Positions of axial/praxial and projective platforms for Barrel chambers are measured by means of special tools built and maintained by Saclay. They are read-out by means of a standard RasMux unit, not belonging to the chamber under test. Hardware and software are provided by Saclay and Nikhef.

No platform position measurement is foreseen for Endcap chambers.

In-plane measurements for Barrel are done using the on-chamber RasMux unit. Software is provided by Saclay, and it should be tested once in order to be sure to get the same results as the RasNik software used to measure the zero-readings at the sites (IcaRas program gives different results depending on the program or library version).

The sag compensation needs the knowledge of the zero-readings. They are taken for all chambers during assembly on the marble table, but unpredictable movements of some elements of the in-plane system can change significantly the values. For this reason, new zero-readings should be taken during the in-plane test, in order to check the old values, but for chambers carrying RPCs this is very difficult or not possible, so for them (BM and BO) zero-readings should be taken before integration with RPCs. Particular care has to be taken when measuring zero-readings, in order to avoid biases due to gravitational chamber distortions.

Time necessary for all alignment measurements should be of the order of half a day.

For Endcap chambers, it is only necessary to obtain a valid RasNik image. Brandeis is developing tools for calibrating the PMO (Proximity) system.

Action on failure – In order to measure the platform positions, a free space of 15 cm (along Z) times 20 cm (along X) behind the platforms (on the X direction) is necessary. Axial/praxial measurement is mandatory for all Barrel chambers, while projective platforms were already measured after gluing, so they can be skipped if the needed space is not available.

There is no possible adjustment for platforms found out of position. The only requirement is to record the measured positions in the database.

If measurement fails, for both Barrel and Endcap chambers, the in-plane cabling and the related RasMux (AMB) channels must be checked, together with possible obstructions along the optical paths. If a RasCam (CCD) or a RasLed doesn’t work anymore, it must be replaced, even if this invalidates the zero-readings.

3.2 Sag compensation

Barrel chambers belonging to all sectors, apart 1 and 9, need to compensate the different gravitational sag between wires and tubes. In order to be performed, compensation requires readings of the in-plane system. Sag is compensated by means of four tension rods put close to the longbeams.

Chamber under compensation must be supported on its final supports, and not on a table, with multilayer 1 on bottom (for chambers of sectors 2, 3, 4, 6, 7 and 8), or on top (for chambers of sectors 10, 11, 12, 14, 15 and 16). The length of tension rods must be adjusted until the read-out values show that the chamber sag is equal to the calculated value for the wire sag. For all chambers other than the ones of sectors 5 and 13, the compensation must be corrected by the angle on the XY plane , 22.5º or 45º.

Reference values for wire sag at different angles must be calculated and available before starting compensation. Compensation can be considered terminated when in-plane values are within 10 microns or better from reference values.

For Endcap chambers there is no sag compensation, due to their vertical position. However, there is an equivalent tension rod adjustment to straighten chambers when mounted on sectors. Adjustment is done to best reproduce the zero-readings. Details on how to do this adjustment have to be still agreed upon by the Endcap groups.

Action on failure – Compensation is an iterative process, and can be very time consuming. If read-out values are unable to go closer than 10 microns from reference values, compensation should be terminated in any case after a reasonable number of attempts.

3.3 T, B and alignment sensors

All on-chamber sensors must be tested. T and B sensors are connected to the ELMB, while all alignment sensors are connected to the RasMux (AMB for Endcap).

Method of tests – ELMB is acquired by means of a PC CANBus interface board, already available to all commissioning sites. B sensors are already tested and calibrated at CERN. In order to check their functionality, measurement should be done putting a small magnet in front of them, so that to avoid zero readings ambiguity. When B sensors are tested, their ID number and locations must be recorded.

Alignment sensors for Barrel are individually tested and calibrated by Saclay, but on-chamber test requires special tools. For some sensors, for example BIM-BIR connection, testing before installation is very complicated. It has to be understood whether the test is feasible during the commissioning phase, or if it could be simpler during the installation phase.

For Endcap chambers, deviations of B sensor platforms from specifications are measured and stored in the database. B sensor ID numbers must be read-out electronically, because they are not written on the sensor card. T sensors readout values are checked against the crossbeam temperature gradient, so to be able to detect inconsistencies and wrong installation order.

Action on failure – T sensor readings must be compared with the effective temperature in the hall, and there should be a reasonable agreement between the two. Temperature differences between sensors of the order of 1

ºC are acceptable. If a sensor is not responding, first the connection cable must be checked, and then the ELMB or RasMux (AMB) channel. If no failure is found, the sensor can be malfunctioning, and must be fixed or replaced. Alignment sensors, which are calibrated as a function of their chamber position, cannot be swapped, and must be replaced by Saclay (Brandeis for Endcap).

3.4 Gas leak

Due to the fact that not all the chambers are certified at the production sites, two types of tests are foreseen: a short term test, needed for chamber certification, and a long term test, necessary to follow along time possible leak increases. Short term test is more precise, but is also more time consuming, so for already certified chambers it should be not mandatory. Nevertheless, all chambers ready for commissioning were transported to CERN under uncontrolled conditions, and can have been damaged by very high or very low temperatures, or by strong vibrations. Therefore, it is required to know the leak condition of each chamber before starting its commissioning. If leak cannot be measured by a long term test, i.e. if chamber was not taken under pressure for at least some weeks before starting its commissioning, a short term test, even for a reduced time, must be performed.

Type of test – Gas leak is measured in two ways: a short term test, which duration should last until the measurement error is smaller than the measured value, and a long term test, which will last up to the installation. On Endcap chambers, it can only be performed up to the sector installation, then a new certification must be done for the complete sector. When pieces are added to the chamber gas system without dismantling anything, for example when on-chamber gas pipes are connected to the gasbars, it is only required to check the new connections by means of a leak detector.

Method of test, short term - Two different techniques are used in the test sites, one based on differential manometers and the other based on precision absolute pressure gauges. Both require a quite accurate (less than 0.1 ºC) gas temperature measurement. Chambers are filled in with gas (Ar only, or the baseline mixture Ar/CO_2 93/7, or with addition of 200 – 300 mbar He, if the use of a leak detector is planned) between 3.0 and 3.5 bara, and pressure drop is measured with one of the two techniques. Also temperature must be recorded, and pressure must be temperature compensated.

Time necessary for concluding this test can range from some hours to five days for both techniques, depending on the precision required and on the chamber volume.

Method of test, long term – Chambers must be filled in with Ar/CO_2 93/7 between 3.0 and 3.5 bara and disconnected from the gas line. Pressure drop is measured by means of a low precision pressure gauge (1 to 10 mbar resolution). This method requires chambers equipped with valves. There are two constraints for these valves: they have to be tight, at the level of 10^{-8} bar*l/s or better, and they must have been certified silicon and lubricant free by CERN. See point 2 of paragraph 2.3 for details on their use. Not certified, or not conforming valves can still be used for the long term test, but they have to be installed on the two outlets, so no gas directed inside the chamber can flow through them, and chambers must be filled in following the procedure #1 described in Appendix 1. Not certified valves must be removed from chambers before installation. This requirement is mandatory.

Chambers already flown through not certified valves can be recovered using the procedure #2 in Appendix 1, after removal of valves.

Measurements must be done periodically, taking care that leak caused by inserting the gauge must be negligible with respect to the expected pressure drop. Depending on chamber volume, temperature and gauge precision, two-three weeks is considered the minimal required time for this test.

Acceptance criteria – Gas leak threshold, since 1999, was established to be for one multilayer:

$$2 * \text{number-of-tubes} * 10^{-8} \qquad \text{(bar*l/s)}$$

or

$$(2 * \text{volume-of-single-tube-in-liters}) * 10^{-5} * 3600 * 24 \qquad (\text{mbar/day})$$

Multilayers leaking few threshold units (< 10) are still acceptable, if it is proven that leak is distributed and not coming from very few tubes, but for them the long term test is mandatory, in order to understand whether the leak is stable or increases in time. It is known that chambers leaking up to 100 threshold units can still work fine, but in order to maintain at least one order of magnitude as a safety factor over 10 years of ATLAS operation, 10 threshold units are the maximum leak allowed.

Action on failure – Short term check should be performed before noise and cosmic ray tests, because leaks that lead to failure must be fixed. If leak of one multilayer is greater than 10 threshold units, it must be detected and fixed, if technically possible. When not possible, the leaking tube must be insulated from chamber gas system and disconnected from HV, as reported in Appendix 1.

Summary of requirements – All chambers must be certified at least once, at production sites or at commissioning sites.

Barrel chambers carrying RPCs must be certified at CERN by means of a short term test. Other chambers, already certified locally, can be commissioned if they were monitored for long enough to get a measurement error of the order of 1 mbar/day, otherwise they must pass a short term test.

All chambers should be equipped with valves, in order to perform the long term test. For chambers not equipped with valves, some short checks must be foreseen periodically.

3.5 Hedgehog card and wire continuity check

If not yet done at the production sites, the chain HV hedgehog-wire-RO hedgehog must be checked for circuit continuity. Recommended hardware is the Mecca card, designed by Michigan University. Instructions on how to perform the test can be found at

http://atlas.physics.lsa.umich.edu/docushare/dsweb/View/Collection-395

Some RO hedgehogs have coated foams on their socket pins, which lead to poor or flicky contacts between corresponding mezzanine card sockets. They have to be cleaned, using the following method:

- immerse the 2/3 in depth of the RO hedgehog sockets in acetone for 10 minutes, taking care of avoiding any contact between acetone and the conformed card surface;
- carefully brush the pins with an electric tooth brush.

3.6 Current leak

This test is performed at two different voltages, after having flushed the chamber for at least 4 volume exchanges: at the nominal working voltage, 3.08 kV, with data acquired possibly all the time the chamber is supplied at that voltage (during noise and cosmic ray tests), and at 3.4 kV, the voltage at which all tubes were tested, with data acquired for short time, of the order of 10 minutes. Chamber can be longer tested at 3.4 kV, but it has to be taken in account that ageing can increase for long times, especially if chambers are equipped with not certified valves. However, the duration of the test at 3.4 kV also depends on how long current takes to be stable. Normally, this time is very short, of the order of tens of seconds if chamber stands at 3.08 kV for some hours before raising voltage to 3.4 kV.

Acceptance criterion is only applied to the 3.4 kV test, voltage at which weak or bad tubes show up.

Method of test – Chambers must be filled in with the correct mixture Ar/CO_2 93/7 at the correct pressure, 3.0 bara, and moisture should not exceed 55- 60%. Currents must be measured and recorded independently for both multilayers, with a resolution of at least 10 nA, using standard commercial HV modules or custom equipments. The ramp-up and ramp-down parameters of the HV power supply must be set to 100 V/s or less. Chambers under commissioning should have installed and connected to the Faraday cages the HV splitter, and this prevents any measurement at layer level. However, if the HV splitter is not present, as it is the case for Endcap chambers during commissioning phase one, measurements can be done separately for each layer, and compared one to each other in order to catch for possible leaking tubes layer by layer.

Acceptance criteria – For one multilayer, current threshold at 3.4 kV is:

2 * length-of-single-tube-in-meters * number-of-tubes + 5 * number-of-hedgehogs (nA)

where number of hedgehogs is computed summing both RO and HV.
For single tube, threshold is:

2 * length-of-tube-in-meters (nA)

Action on failure – The cause of current leak must be identified (if tube, HV or RO hedgehog) and replaced. Generally, multilayer current should be compared to reference currents, taken from good multilayers. If it is significantly higher, in order to identify the leaking tube (or tubes) it is necessary to open the HV Faraday cage and disconnect layers and HV hedgehogs, removing jumpers, until the leaking zone, 6 or 8 tubes, is identified. Then, the corresponding HV and/or RO hedgehog must be removed, and leaking tube can be identified supplying HV to single tubes by means of a proper HV cable.

Generally, high current tubes are also noisy, and they can be much more easily detected with the noise test. If high current is due to something else than discharges, like dirty paths between HV and ground on endplugs, the only worry is related to possible leak increase in time that can lead the HV power supply to a trip. As a rule of thumb, tubes with leaks exceeding the whole multilayer limit and not noisy should be disconnected from HV.

Tubes with large leaks must be cured with reverse voltage, as explained in Appendix 1. The greatest part of leaking tubes are recovered after curing. Tubes still showing large leaks should be checked against noise in order to decide whether disconnecting them from HV or rewiring them, if this technique is available to the group. Tubes with leaks exceeding the whole multilayer limit after curing should be disconnected or rewired.

All cured and disconnected/rewired tubes must be flagged with a fail code in the database.

3.7 Noise

Noise is related to many parameters, some of them under control, like ASD threshold and hysteresis, and others dependent on the setup, on the environment or on some tube defects, like ground loops, EMI pick-up or HV discharges in tubes. Aim of the test is to measure the chamber noise distribution as a function of the controlled parameters, minimizing the external interferences, so to be able to catch at the discharging tubes, and in most cases to cure them. Since the noise distribution of all mezzanine cards as a function of threshold was already measured in Boston, it is necessary taking data at only one threshold value.

Method of test – Chambers must be filled in with Ar/CO_2 93/7 at 3.0 bara, and flushed for at least 4 volume exchanges before starting test. Test must be performed at HV off and on, at nominal voltage of 3.08 kV. Minimum number of collected events for each of the two different conditions depends on available time and on required precision. It could be as small as few thousand events (for 50k events the error for 100 Hz noise rate is 20%) up to some million events, if one wants to also check noise stability in time.

The simplest way of taking noise data is using a random trigger at a rate close to the maximum allowed by the acquisition setup. Test time should not be longer than one – two hours.

The way of programming threshold, hysteresis and all other read-out parameters is reported in [2]. Setting threshold for the noise test depends on hysteresis and offset voltage of mezzanines channels. An "effective threshold" is defined by the formula:

$$V_{eff} = V_{th} - V_{hys} + V_{ofs}$$

where V_{ofs} is the signed offset voltage of the channel. Offsets were measured for all mezzanine channels, and are available in the mezzanine production database at
http://hepldb.harvard.edu/mezz1/ASDmain.asp
Because of the fact that thresholds are programmable for single ASD, i.e. they are equal for groups of 8 channels, effective threshold is not the same for all channels within an ASD. Suggested effective threshold, used by US groups, is the following:

$$V_{eff} = V_{th} - V_{hys} + 0.5*(V_{omin} + V_{omax}) \qquad \text{when } V_{ofs} \leq 12 \text{ mV}$$
$$V_{eff} = V_{th} - V_{hys} + 0.5*(V_{omin} + V_{omax}) - 2 \text{ mV} \qquad \text{when } 12 \text{ mV} < V_{ofs} \leq 14 \text{ mV}$$
$$V_{eff} = V_{th} - V_{hys} + 0.5*(V_{omin} + V_{omax}) - 4 \text{ mV} \qquad \text{when } 14 \text{ mV} < V_{ofs} \leq 16 \text{ mV}$$

where V_{omin} and V_{omax} are respectively the minimum and maximum V_{ofs} among the 8 channels belonging to one ASD.

For this test, hysteresis should be V_{hys} = 8.75 mV, and effective threshold should be V_{eff} = -50 mV. V_{th} varies as a function of V_{ofs}.

Acceptance criteria – They depend on the adopted ASD parameters. With an effective threshold V_{eff} = -50 mV , the acceptance threshold referred to a complete chamber is:

Average noise rate per tube = 5 kHz

including all chamber tubes. In case of presence of very high noisy tubes, they must be cured and noise test must be repeated. A careful check of histograms of all tubes is recommended, in order to evaluate the single tube noise.

Average noise rate is not the only needed criterion. Few tubes can have a very high rate, while the average noise is not over threshold. Single tube rate can downgrade track reconstruction, so it should be limited to a value much lower than the expected physical background in ATLAS. The worst case background rate is estimated 100 Hz/cm^2, so for the longest tubes in the hottest region

(EIL) a rate of about 90 kHz/tube is expected. Taking an increase of rate, due to the noise, of less than 10%, the maximum allowed rate for the single tube is around 40 kHz. Rescaling this value for the suggested noise test threshold of –50 mV, the maximum allowed rate for any single tube is:

Maximum rate per tube = 5 kHz

If a tube is over this rate, it must be cured with reverse HV, assuming the noise is only due to internal discharges. In order to be sure of this, HV and RO hedgehogs and mezzanine should be replaced before curing the tube, and its ground contacts should be carefully inspected.

If a tube still shows a very high rate after curing, first it must be software disabled. After this, if crosstalk to adjacent channels is too high, compromising their performance, tube must be hardware disconnected from HV.

How to disconnect a tube from HV is explained in Appendix 1.

Action on failure – If a chamber is over the limit, and many tubes are noisy, all attempts must be made in order to check the ground and HV connections. Major checks are summarized here:

- HV must be supplied by means of the HV splitter. Check integrity of splitter;
- Check cable connections on the HV hedgehog;
- Check for good ground connection (less than 0.5 Ω) of Faraday cages and of crossplates and longbeams;
- Check earth connection of the chamber support frame;
- Bottom plates must be screwed to all endplugs. Check that all screws are present and tight, and the same for all ground pins.

If a tube is over the limit, its HV and RO hedgehogs, and mezzanine, must be replaced, in order to be sure that they are not the source of noise. If the noise doesn't change, tube must be cured reversing HV. Technical details on curing a tube and disconnecting it from HV are described in Appendix 1.

3.8 Cosmic rays

Overall chamber performance can be tested using cosmic rays. In particular, cable mismatches can only be detected with this test.

Method of test – Cosmic test stands are already functional in all the three commissioning sites. Each stand can host more than one chamber at a time, up to three. Test can therefore be performed in parallel. Chambers to be tested must be equipped at least with the CSM motherboard and the HV splitter, and must be connected in a proper way to earth, avoiding loops. They must be filled in with standard gas at standard pressure, and flushed at about 10 volumes/day for the first 12 hours. After this time, flow must be decreased up to 1 volume/day or less, and standard HV can be applied.

RO parameters should be close to the nominal, so effective threshold should be V_{eff} = -40 mV, with V_{hys} = 8.75 mV. V_{eff} = -40 mV corresponds to discriminating around the 23^{rd} primary electron.

Following [4], collected hits per tube should be at least 30k, corresponding to about 2M events per chamber. With a trigger rate of 100 Hz, the time needed to take 2M events is of the order of 6 hours, but some more time is needed in order to analyze data and, if necessary, to fix possible problems. If no problems are detected, two days can be considered sufficient for testing up to three chambers.

Analysis – It should be performed on-line, or at least immediately after the availability of data, but only for the minimal set of parameters needed to characterize the chamber. They are:

- Hit maps for each layer;
- Average drift time for all tubes (average T_{max} – average T_0);
- TDC spectra for all tubes
- Charge distribution

Read-out electronics performance can be analyzed taking threshold scans. This test can detect deviations of parameters, like offset voltages, with respect to the accepted range. Anyway, all mezzanines were already tested on a bench test, so threshold scans are optional.

Acceptance criteria – Chamber passes the test if:

- tube occupancies show no major inefficiencies;
- all tube have drift times within 20 ns from the average drift time of the chamber. Generally, drift time differences within a chamber are of the order of 2 – 3 ns, but wrong gas flow on single tubes, typically due to obstructed or partially obstructed tubeles, gives drift time differences of more than 50 ns. The limit of 20 ns fits well with data accumulated in all three commissioning sites.

Charge distribution analysis is mandatory when no threshold scan is made, so to be able to identify possible read-out malfunctioning. Charge distribution histograms must be checked for all single tubes.

Action on failure – Broken wires should have been detected during the wire continuity test, anyway the cosmic ray test is normally the last done, so any broken wire must be detected with this test and flagged. When possible, broken wires should be replaced using one of the three available techniques.

In case of low occupancy of some tubes, gas system, hedgehogs and mezzanines must be checked, and possibly replaced. Low occupancy can be caused by big gas leak, or by high effective threshold. In the first case, low occupancy should affect one or few tubes only, while in the second case clusters of 8 tubes or multiples of 8 can be affected.

Test	Chamber parameters	RO parameters	Acceptance criteria	Action on failure	Estimated working time
Alignment	Chamber positioned horizontally on a rigid table first with LM1 on top, and then with ML1 on bottom	None	Readings are coherent in both positions	Check in-plane cabling and RasMux (AMB) channels	½ day
Sag compensation	Chamber positioned on its supports and with ML1 on bottom (sect. 2, 3, 4, 6, 7 and 8) or on top (sect. 10, 11, 12, 14, 15 and 16)	None	Sag adjusted	Check in-plane cabling and RasMux (AMB) channels	2 hours
T, B and alignment sensors	Final sensors connected to RasMux and ELMB	None	All sensors OK	Check alignment/B cabling and RasMux (AMB)/ELMB channels	½ day
Hedgehogs and wire continuity	All hedgehogs mounted on chamber. Test performed with the MECCA card.	None	No bugs	Fix all bugs replacing hedgehogs	½ hour
Gas leak	Gas = Ar or Ar/CO_2 93/7 P = 3 – 3.5 bar	None	$\Delta P < 10$ units	Find the leak source and fix it	From ½ to 3 days
Noise	Gas = Ar/CO_2 93/7 P = 3.0 bar HV = 3.08 kV	Effective threshold = -50 mV	Av. Rate/tube = 5 kHz Max rate/tube = 5 kHz	See § 3.7	few hours + time for filling in and flushing chamber (common with cosmics)
Current leak	Gas = Ar/CO_2 93/7 P = 3.0 bar HV = 3.4 kV	None	2 * length-of-tube-in-meters * number-of-tubes + 5 * hedgehog-number	See § 3.6	½ hour
Cosmic rays	Gas = Ar/CO_2 93/7 P = 3.0 bar HV = 3.08 kV	Effective threshold = -40 mV	All drift times within 20 ns. No low occupancy channels	See § 3.8	2 days for three chambers, including cleaning

Test summary table

4. Database information

The global database is based on Oracle, already used by TGC. It will be modified and adapted to the MDT requirements. All relevant information collected during commissioning must be saved into the global database, but groups can adopt as local database a different approach, like Access or text files. Local databases has to be maintained directly by each group that use them.

If a local database is used, information can be stored either simultaneously on local and global databases, or on local database first and after, periodically, on global database. The first approach is recommended. If global database is updated periodically, the period should be less than one week.

Summary reports should also be saved into Oracle database, while raw data files must be in a file structure pointed to from Oracle database.

In the following, it is assumed that all general information (chamber ID, operator name, date, etc.) is already loaded in the database, so only information related to chamber status and to the specific tests is discussed.

4.1 Chamber specific information

All known information concerning chamber status before starting commissioning should be recorded:

- Broken wires, or disconnected tubes, if any (tube ID);
- leaking tubes, if any (tube ID);
- leaking tubes or endplugs fixed with glue, if any (tube ID)
- high current tubes, if any (tube ID);
- noisy tubes, if any (tube ID) ;
- low efficiency tubes, if any (tube ID).
- HV splitter barcode (4 digits)
- CSM motherboard barcode (16 digits);
- ELMB barcode (14 digits) and ELMB serial number (written on the cover);
- Rasmux barcode (14 digits);
- B sensor ID and location. For Endcap chambers location is implicit in cabling. There is no barcode on sensors, ID is read-out electronically;
- T sensor ID numbers (for Endcap only)
- Mezzanine card ID barcode, if not already done in the production database;

- RO and HV hedgehog serial numbers, is not already done in the production database.

4.2 Alignment

- All data recorded by test programs provided by Saclay and Brandeis;
- One in-plane measurement.

4.3 Sag compensation

- readings of the in-plane system before compensation;
- readings of the in-plane system after compensation.

4.4 T, B and alignment sensors

- One measurement of T, B and alignment sensors. For Barrel chambers, alignment sensors should be subdivided in axial/praxial, projectives, Reference, CCC (Chamber to Chamber Connection) and BBC (BIM-BIR Connection).

4.5 Gas leak

For short term test:

- Gas type and pressure in bar;
- Chamber or gas temperature;
- Leak rate of the two multilayers separately, in mbar/day;

For long term test:

- Chamber temperature;
- Date of first measurement;
- First measured pressure, in mbar;
- Dates of successive measurements;
- Measured pressures, in mbar;
- Estimated leak rate of the two multilayers separately, in mbar/day.

Long term test needs many measurements. If saving many unknown measurements is not possible, the estimated leak is overwritten at every new measurement.

4.6 Current leak

- Voltage used in the test, in Volt;

- Measured current, for each multilayer (or for each layer), in nA;
- Fail code for high current tubes;
- Fail code for cured tubes;
- Fail code for rewired tubes.

4.7 Noise

- Rate for every tube, in Hz;
- Fail code for tubes over 5 kHz limit;
- Fail code for disconnected tubes;
- Fail code for rewired tubes.

4.8 Cosmic rays

- Chamber working conditions (gas pressure (in bar), mixing percentage, gas flow rate (in nl/hour));
- Environmental conditions (temperature and RH);
- Pointer to the function and fit range definitions for determining T_0 and drift times, in order to get the same parameters for all groups;
- T_0 for every tube, in ns;
- Drift time for every tube, in ns;
- Fail code for tubes with drift time out of requirement;
- Fail code for tubes with low occupancy.

5. Summary report

Use of summary reports for each chamber under commissioning is strongly recommended. They have to be both recorded as files and printed out as paper attached to chambers.

Two summary reports, the first used by US groups and the second by the BIL groups, can be found in Appendix 4, as examples of very complete (the first) and very compact (the second) reports.

References

[1] H. Kroha: Quality Assurance and Control Reference Document for ATLAS MDT Construction, version 1.1.3. 28-05-1999 (http://www.pv.infn.it/~servel/atlas/commissioning/qaqc_ref-doc.zip).

[2] J. Oliver, C. Posh: MDT-ASD Parameter Setup Manual, version 1.04. 11-08-2003 (http://huhepl.harvard.edu/~mdt_elx/octal_mezz_info/MDTparams_Ver1_04.pdf).

[3] J. Dubbert: Commissioning and Calibration of BOS/F MDT Chambers at the LMU Cosmic Ray Facility. 01-07-2004 (http://agenda.cern.ch/askArchive.php?base=agenda&categ=a042763&id=a042763s1t9/transparencies)

[4] P. Bagnaia at al: Performance of an MDT cosmic test stand: a Montecarlo evaluation. ATL-MUON-2004-014, May 2004 (http://doc.cern.ch//archive/electronic/cern/others/atlnot/Note/muon/muon-2004-014.pdf).

Appendix 1

Suggested methods for recovering from failures

#1 - *How to fill in chambers equipped with non-certified valves.* *A simple method, already described in the document reported in Appendix 2, is illustrated here with some variants. It is very practical and cheap, and works well with chambers already equipped with the "Freiburg connectors" type 1A and 2 at the inlets:*

- *cut two short 6 mm diameter Rilsan pipes [SCEM 38.40.30.606.2], each 10 cm long, and equip them at the two extremes with nuts, olives and ferrules;*
- *build two adapters, each one composed of one connector type 2 screwed to one connector type 1A, after having cleaned them in Ethyl alcohol for at least 24 hours;*
- *install the adapters at one extreme of the two Rilsan pipes;*
- *connect the other extreme of the two Rilsan pipes to the two chamber inlets;*
- *connect the main gas line to the two adapters, and fill in the chamber up to the wished pressure;*
- *squeeze the center of one Rilsan pipe by means of a clamp tool, like the parallel jaw clamps [SCEM 34.64.80.203.6] until the pipe is completely squeezed;*
- *disconnect the main gas line;*
- *close the free extreme of the adapter with a brass nut and plug;*
- *repeat the last three operations on the other Rilsan pipe;*
- *chamber is pressurized and pressure measurement can be done on the valve sides.*

#2 - *How to clean chambers flown through not certified valves.* *They must be flushed for some days, after having removed valves, at a quite high rate, around 10 volumes/day, and possibly at a relatively high temperature, around 30 ºC.*

#3 - *How to insulate a tube from gas system* – *A simple way to do this is cutting the tubelets that supply the tube on both sides on the straight part, and glue them on the cut with a proper pasty and allowed epoxy glue, like Torr Seal (by Varian).*

A possible alternative for Barrel chambers is replacing the black plate on gasbar with another one, on which the tubelet supplying the leaking tube is replaced by a closing pin of the same diameter. For Endcap chambers, the tubelet must be replaced with a closing pin of the same diameter.

#4 - *How to cure a current leaking tube* – *A negative 4 kV, 1 mA HV module, and a special HV cable, terminated with two receptacles, so they can be inserted on the ground pin and closing cap, must be available. HV hedgehog must be removed, in order to access to the tube, and also mezzanine card from the RO hedgehog, in order to be safe and avoid ASD damaging. After having done this, current limit of the HV power supply must be set to 200 – 500 μA, voltage limit to 3.5 kV and trip feature must be disabled, so the power supply can work in current limiting mode. Then, negative HV has to be supplied to the tube, by means of the special HV cable, for 5 – 10 minutes. At the beginning, current goes up to the limit, but after few minutes it should decrease, and corresponding HV starts increasing. Tube should be cured when current is again stable after the decrease.*

#5 - *How to insulate a tube from HV* – *One proper solution is replacing the brass signal cap on the HV side with a Noryl or Pocan or Polycarbonate equivalent, but with no pin. This plastic signal cap can be easily machined in every workshop, using the drawing available at:*
https://edms.cern.ch/cdd/bin/get-dessin-drawing.pl?server=nicewww.cern.ch&port=80&path=/optique/0816/17/0003&mime=image/hpgl

Another good solution, similar to the above described, is covering the signal cap, after having cut its pin, with a thin-shaped cap, made of plastics allowed in underground operation. A drawing of such cap, shown in [3], is available at:
http://www.etp.physik.uni-muenchen.de/atlas/drawings/insulating_cap.eps

This solution has the advantage of avoiding any signal cap removal, so chamber gas leak doesn't need to be rechecked. This is extremely useful if removal must take place just before chamber installation.

For a complete list of allowed plastics, see CERN rules IS41, available at:
http://edms.cern.ch/file/335806/LAST_RELEASED/IS41_E.pdf

Other solutions, like cutting the 1MΩ resistor on the HV hedgehog, should be avoided, due to the possibility of creating discharge paths on the HV hedgehog itself.

Appendix 2

Proposal for equipping MDT chambers with gas valves

Gas equipment and operations for MDT storage and test
(LP and SP, 27 Aug 2004)

General approach.
The chambers should be stored before the installation with pressure close to nominal value, in such a way to control during long periods the leak tightness.
Furthermore, the final test just before the installation (to be performed in the surface building as part of the commissioning operation) will be much easier and fast if the chambers will arrive at the pit with the 93% 7 % Ar-Co2 mixture.

On the other hand, the chambers will not need to be under pressure while being installed. If we had to do that, we would have either:
(a) to unplug the chambers when connecting to the fixed pipes, causing a sudden pressure variation that some consider dangerous for the detector, or
(b) use a quick connector or a valve on each connection (4 per chamber) to allow connection to the gas system at (nearly) constant pressure.

We rather prefer the approach of discharging the gas pressure (in a controlled way) to a nearly atmospheric pressure (i.e.: about 1.2 bars) and then proceeding with installation and connection to the detector pipes. This approach is more convenient in term of cost, and simpler that alternative schemes.
(It is not clear whether this option would significantly increase the gas consumption; in any case, the cost of premixed gas, which is likely to be used during installation, is in the range of ~10 to 25 CHF/m3.)

Check valves
Using check-valves (bicycle valves), in order to perform repeated pressure measurements has been investigated/tested by some production sites. However, it has proven to be difficult to obtain a check-valve which is both inexpensive and clean.
Valves used by the Michigan group and developed by the Pavia group have been analyzed chemically at CERN. The US valve showed an absorption spectrum not similar to Silicone lubricant, but also not compatible with C-H compounds. The Italian valve was measured in several occasions, and it reached in some conditions a very low level of contaminants, which however are suggestive of Silicone lubricant.
We therefore suggest limiting the use of these and similar valves. In any case, they should not be used to flow gas into the chamber (purging or filling), but only for pressure check (as they are currently used by the US groups).
A development of a new check-valve is currently under way in Pavia.

Components on chamber during storage & test.
We propose to equip the MDTs in the following way:
- The two multi-layers are connected together, via T-junctions, on both input and output sides.
- The input side is equipped with a single valve, or a quick-connector. These components must be of approved standard of cleanliness, and they will be used for filling the chamber.
- On the other side, the gas connection will be closed, or possibly connected to a check-valve of the kind discussed above.

In this scheme, the pressure check is done either via the valve/quick connector, or maybe via the check-valve on the other side.

List of components.
<u>With manual valves:</u>

- Valve. The recommended valve is the Tri-Matic ¼ turn valve with SCEM number 40.40.75.604.9, which has ¼" gas (cylindrical) female connections. It is delivered clean, and for use described above, it does not need dismounting, additional cleaning and remounting of components, as done for the valves used on the ATLAS racks. Cost: 37.50 CHF/piece.
- Adaptor. The adaptors FBO (Vebeo) SCEM 41.33.10.186.7 allow the connection of a 6 mm (OD) tube. Tightness is provided by O-rings on both sides (valve and tube). Cost: 13.00 CHF + 2.5 CHF (approx.) for the O-rings (VITON or EPDM).
- T-junction. Could be the Legris, SCEM 41.34.10.210.5. They would need to be cleaned before assembly. Cost: 6.10 FS, plus ~1 CHF for cleaning, and to be mounted on both sides.
- Pipes. Copper pipes could be used (diam 4/6 mm). Plastic pipes could also be used.

The total cost per chamber amounts to about 65 FS. An alternative scheme would have the T connection directly mounted on the valve, avoiding the adaptor. This is not on the CERN catalogue and an enquiry with FBO is underway. This option would be more practical and presumably not more expensive. For a significant order (~500 pieces or more, the costs may result lower. (A ~10 CHF cheaper valve, the SCEM 40.40.64.504.1 could be considered: it passed chemical tests, but it not as clean as the one listed above.)

<u>With quick connectors:</u>
- The quick connector made by SERTO, SCEM 41.61.25.120.1; "nipple" quick connector, and ¼" female (cyl.) thread connection would be used. Notice that this is the series used in the racks, which holds an O-ring for tightness on the thread connection. (It is assembled at the firm with cleaned parts, and lubricated with carbon-hydrogen lubricant. It passed chemical and ageing tests). Cost: 23.50 CHF. The corresponding "coupler" quick connector costs 37.00 CHF.
- T-junction. An enquiry on the SAGANA TM-6-1/4T-L (which is not on the CERN catalogue) is underway. The cost should be of the about 10 FS. On the other side of the chamber, a Legris T-junction could be used.

(Alternative: use the cheaper SERTO connector, without O-ring on the ¼" connection, together with a Vebeo adaptor: the total cost is similar to the above, but the compatibility must be tested. Without the adaptor, the gas tightness in the connection with the T, or any other connection together with an O-ring, is uncertain.)
The cost of this option is approximately 40-45 CHF per chamber. It requires a small number of complementary quick connectors to be used for tests.

Filling/testing operations.
The following procedure could be used:
1. flow gas at 1.2 Bar for 2 gas changes;
2. put on the output one closing cap (this implies exposing the chamber to air to some extent);
3. rise the pressure by flowing gas through the input valve/quick connector; the pressure is monitored via a T upstream of the chamber;
4. at 3 bar-a, the valve is closed (or quick connector detached), and the chamber is stored;
5. leak rate is measured through the valve every months or so;
6. the pressure is measured just before the transport to point 1, and checked again after arrival in the surface building;
7. All the final test (pre-commissioning) are performed with the chamber at 3 bar-a, then slowly the pressure is brought near 1 bar-a, flowing the gas through a flow meter or a flow restrictor;
8. the T's, with associated gas pipes are dismounted, the chamber are closed and sent down to the pit for installation; *(so, tightness, leak currents etc. are not tested after transport down to the pit and before installation)*

Alternative solution for gas equipment
An inexpensive, but less flexible alternative is to equip. the chambers with plastic pipes, with, for example, Legris junction. The other side is equipped with check (bicycle valve). Gas filling is done on the former side, and the line are closed after folding the plastic pipe in order to temporarily close the pipe, and mount a Legris plug. Subsequently, gas will never be added, and the pressure tested via the check-valves. This option might cost 10-15 CHF per chamber (depending also on whether the multilayer are connected or left independent.

Appendix 3

Endcap test document for phase one commissioning

Chamber Testing & Certification

Introduction

For Phase I testing we wish to do the most thorough testing of completed chambers. These single chamber tests are intended to be the primary chamber operational QA/QC and therefore require uniform procedures. When chambers are mounted on structures less elaborate testing will be done to confirm that nothing has been disturbed in handling. Implementation of these procedures via the MiniDaq software are described at:
`http://cdfrh0.grid.umich.edu/~claudiof/Atlas/b184/cerntest.html`

The sections below specify the data collected and the acceptance criteria applied. A separate section elaborates on the analysis done on the collected data. The goal is to determine the noise present on each channel, the efficiency of the channel, the linearity of the time measurement, the pulse amplitude to pulse width function, and the drift time spectra from each channel. The noise is related to the ASD threshold channel by channel and to the characteristics of the wire of the channel. When a channel is seen to have a high rate of hits with the HV off, the ASD is suspect. A high hit rate at nominal threshold can be due to a large ASD threshold offset when the offset direction reduces the effective threshold. High noise rates can also result from wire properties.

For all tests

- Effective threshold = ASD threshold - hysterisis + (compensation from ASD V_{offset}), where compensation from ASD is done as:
  ½ (min V_{offset} + max V_{offset}) for (V_{offset} span < 12mV)
  ½ (min V_{offset} + max V_{offset}) - 2mV for (V_{offset} span 12mV to 14mV)
  ½ (min V_{offset} + max V_{offset}) - 4mV for (V_{offset} span 14mV to 16mV)

High voltage off tests to be performed in order (checks performed)

- Daq hardware testing to insure that test operation can be performed. *(observe any errors reported during operations)*
- Noise measurements with no HV with threshold settings of -50 mV, 8.75mV hysteresis, and TTCvi random trigger rate setting of 5KHz (effectively 9.2KHz). Twenty minutes of data collection is suggested. *(ASD noise rate < 5KHz for any channel/tube).*
- Threshold sweeps from -84mV to -10mV and 10mV to 84mV in steps of 2mV. These tests require care to insure that high data rates from hot channels do not suppress data from other channels distorting the rates of the other channels. A total of 76 runs, each with 10K events is required. Hysteresis is set at zero, ASD calibration capacitor is set to 50fC, TTCvi trigger is set to one-shot random, and the typical Daq rate is 2.5KHz. (*All correlation efficiencies should be larger than 70%. See analysis details below. Attention should be paid to success of these test since extreme noise can make V_{offset} measurement impossible. Large offsets greater than 15mV suggests a bad Mezzanine card.)*

- Twenty four Injection scans, each with 10K events, ASD threshold of -50mV, ASD Hysteresis of 2.5mV, ASD calibration capacitor of 250fF, and TTC random trigger. Daq rate is typically 2.5KHz. *(Efficiency must be > 95%, Crosstalk < 20% for channel 0, 8 and 16, and < 5% for other channels.)*
- Nineteen Timing calibration tests of the AMT linearity using 250fC injection capacitors, -50mV threshold, ASD Hysteresis of 2.5m, and a TTCvi random trigger. Points are taken in 50ns steps of the calibration signal at a typical Daq rate of 2.5KHz. *(Time Resolution must be < 3 units (0.78ns/unit), ABS(1 - linearity) < 0.01 where: time resolution is calculated by using only hits near the time peak. The linearity is defined as the slope of expected TDC time vs measured TDC time, a fit is performed to determined the slope.)*
- Seven runs of ASD gain tests of 10K events each with injection capacitors from 100fC to 400fC, a threshold of -50mV, ASD hysteresis of 2.5mV, and a TTCvi random trigger, and typical Daq rate of 2.5KHz. *(*linear fit χ^2/DOF < 1.0).

High voltage on tests to be performed in order *(checks performed)*

- Daq hardware testing to insure that test operation can be performed. *(observe any errors reported during operations)*
- Noise measurements with no HV with threshold settings of -50 mV, 8.75mV hysteresis, and TTCvi random trigger rate setting of 5KHz (effectively 9.2KHz). Twenty minutes of data collection is suggested. *(ASD noise rate < 5KHz for any channel/tube and no dead tubes are observed).*
- An optional test with a threshold is -50mV, ASD Hysteresis is 8.75mV, and Cosmic-ray Trigger *(Expected hit distributions in each chamber, good tube relative efficiency, between 0.9 to 1.1, normal ADC (width) distribution for all tubes, and fraction of unpaired leading edge is < 5%.)*
- Seventy six threshold scan tests each with 10K events and HV on, ASD Hystersis is zero, ASD calibration capacitor at 50fF, random TTCvi trigger, and typical DAQ rate of 2.5KHz. *(Correlation efficiencies should be > 70%, ASD noise rate of any individual channel < 20KHz, no more than 3 channels with ASD noise rates > 5KHz.)*
- Repeat Injection scan tests with HV on.
- Repeat Linearity scan tests with HV on.
- Repeat Gain scan tests with HV on.
- Long Cosmic-ray test > 15 hours with threshold of -40mV, ASD Hysteresis at 8.75mV, Cosmic Ray Trigger, yielding 40K hits/tube. *(Tube efficiency (between 0.9 to 1.1), normal TDC time spectrum for all tubes, fast time rising near T0, normal ADC (width) distribution for all tubes [i.e. a minimum ASD noise rate seen as narrow width pulses], no channel with ASD noise rate > 50KHz, fraction unpaired leading edge is around 10% level, normal background before T0 and after TMAX [~700ns], normal T0 (i.e., all tubes have similar T0, and normal TMAX).*

The analysis done on the test results

- The noise rate for each channel is to be calculated from the total number of hits and triggers in the known search window setting. Search window = 1.25μs.
- The rate of hits for each threshold setting is to be calculated and fitted to the Gaussian formula $R(x) = N_0 \cdot e^{-\frac{(x-Voffset)^2}{2\cdot\sigma^2}}$. Due to Daq rate limitations only the wings of the distribution

are fitted for V_{offset}, σ, and N_0. In threshold scan tests, the ASD noise rate could be up to 20MHz which is far beyond the AMT ability, 300KHz per channel, to transfer data. In order to minimize interference between 3 ASDs in threshold scan test, the ASD's thresholds are arrange if one ASD with low threshold, other two ASDs have high threshold. Correlation is calculated as: $$coef = \frac{|(x_i - x_{ave}) \times (y_i - y_{ave})|}{\sqrt{|(x_i - x_{ave})^2|} \times \sqrt{|(y_i - y_{ave})^2|}}$$ where x_i is the measured threshold on the chamber, y_i is the measured threshold from the ASD database and the index i is summed. x_{ave} and y_{ave} are the average values for the sum.

- The efficiency and crosstalk determined according to the rules: Efficiency = #hits /number injections, Cross-talk = #hits from all other 23 channels/number injections. Note: calibration signal is injected to one channel at a time.
- The average digitized time is to be determined for a single calibration input and the σ of the spread of times is determined.
- The average digitized time is to be determined for each calibration pulse input times and fitted to a straight line, the slope of the line extracted, and the quality of fit χ^2 determined.
- The pulse width of the time digitizations, leading edge to trailing edge, is to be determined as a function of the injection capacitor. The measured ADC (width) with 7 calibration capacitor settings (100, 150, 200, 250, 300, 350 and 400 fF) are fitted with a width function (note: calibration signal are delta charge). $Width = Width_0 + C_1 C_{cal}(1 - e^{-C_2/C_{cal}})$ where C_{cal} is the calibration capacitior capacitor width$_0$ is the ASD charge time, C_1 and C_2 are constants. C_1 is related with ASD rundown current C_2 is related with ASD charge integration time and its resistor, R, value.
- Analysis of cosmic-ray data includes the identification of:
  - A tube efficiency < 0.1 is a dead tube/channel. *(should be resolved)*
  - A tube efficiency > 2 is a very hot tube). *(check against 5KHz noise rate)*
  - A tube efficiency between 0.2 to 0.9 is a low efficiency. *(further understanding/study is necessary)*
  - A tube efficiency between 1.1 to 2 is a hot channel. *(check whether the corresponding tube ADC width distribution spectrum is normal*)
  - A tube with > 5% unpaired leading edge implies a Mezzanine card problem or tube has very long maximum drift time. *(examine spectrum)*
  - A very large V_{offset} > 15mV suggests mezzanine card trouble.

Mezzanine Card Pre-selection Criteria

Locate the mezzanine card ID and the ASD chip IDs in the mezzanine and ASD databases. Examine the data and reject the card if:

- It cannot be found in Mezzanine Card database or the ASDs on the card cannot be found in the ASD database.
- If mezzanine card or ASD information is not correct as recorded in databases.
- If any of its ASD chips have offset span, (maxVoff - minVoff), > 16 mV.

For mezzanine cards failing the three requirements above, return them to Harvard. A program exists to perform the above tests, for more information, contact: Claudio Ferretti <claudiof@umich.edu>.
If any of the card's ASD chips have V offset span between 12mV to 16mV, keep the cards as spare, *i.e.,* do not use them on chamber.

Appendix 4

1 - US summary report

Instructions and Checklist for Operators
(This check list should travel with the chamber)

Crate opened on (m/d/y): 08/25/ 2004
Crate closed on (m/d/y): / / 2004
Operator's name: Alan, Reza, Joe Supervisor's name: Z. Zhao

Useful chamber data
Chamber ID: EMS5C02 MIC: C000010 Tubelet type: US Brass
Barcode ID on chamber:
Barcode ID on box:
Layer definition for operators: ML1 is top for EML and bottom for EMS
Chamber tube displacement during the gluing:

Tube number (MLx-y-z)	Direction (HV/RO end)	Displacement (mm)

Disconnected tube:

Comments:

Uncrating

- ☐ Schedule removal of crate top.
- ☐ Open ends of crate.
- ☐ Stick chamber barcode to the chamber, two on HV end and two on RO end.
- ☐ Check the consistency of all chamber bar code put on chamber and chamber crate.
- ☐ Check whether "HV" and "RO" ends were correctly marked on the space frame.
- ☐ Mark all parts (top, sides, foam, and plastic) with chamber number and position before removing.

Chamber inspection

- ☐ Inspect the chamber and record any abnormalities.
- ☐ Tension bars should not be tightened.
- ☐ Check spacing between tubelets and signal caps, correct those with less than 3 mm.
- ☐ Check whether there are loose clips on the gasbar. Gently tighten the loose clips.
- ☐ Check whether the corner tubelets are out of dimension
- ☐ Check ground pins on both HV and RO ends (all in, straight and in the same plane)

Chamber gas long term tightness

- ☐ Measure chamber pressure with digital pressure gauge and record the values

Date (m/d/y)	Top ML (bar)	Bottom ML (bar)	Duration(day)	Comments

Leak rate(mbar/day)				

Epoxy tubelets

- ☐ Depressurize the chamber slowly (>1 hour)
- ☐ For the top multiplayer, epoxy all half jumper locations and bends of brass tubelets. Let them cure for 24 hours. For stainless steel (SS) tubelets, only apply epoxy to the half jumper location.
- ☐ Glue survey target/B platform.
- ☐ Go to "Spacer frame, alignment and T sensor cabling."

- ☐ Measure the chamber height at the four corners

Date(m/d/y): / /2004

Unite: mm	RO end	HV end
Long tube side		
Short tube side		

- ☐ Mount the chamber to the transportation cart and flip the chamber.
  This operation should be done by officially certified persons.
  Remember to check the kinematic mount bearings. Gently tighten set screws.
- ☐ Apply epoxy to the top multilayer (the bottom multilayer before flipping).
- ☐ Replace all 4 ETs with Final ETs (RO and HV ends take different ETs). Be careful not to damage the threads on the gasbar.

All final ET's have one end (away from chamber) that needs a brass ring and then a #010 O-ring. The other end needs either a #009 o-ring (for EMS4,5) or #010 o-ring for EML3,4,5.

Chamber flushing and pressurization

- ☐ Connect both multilayers for gas flushing
- ☐ Flush the tubing with Ar(93%)+CO_2(7%) before attaching to ETs. Pressurize the chamber to 3 bars.
- ☐ Use Q196 to detect leaks around ALL ETs (Q196 set to group 4 for Ar)

When necessary, re-certify chamber gas leak rate. This includes the following chambers, as well as those with a long term leak rate greater than 1 mbar/day for Ar+CO_2

EMS4C04, EMS4C08 need special caution. These have endplugs known to have cracks.
EMS4C16(5.4, 1.1) <---- (bottom and top leak rate mbar/day)
EMS5A02(1.2, 2.2), EMS5A04(2.0, 2.6), EMS5A08(5.4, 8.4)
EMS5C10(5.0, 4.8), EMS5C16(1.1, 8.4)
EML4C03(1.7, 2.2), EML4C05(1.5, 2.5), EML4C07(4.0, 5.8), EML4C09(2.1, 2.0)
EML4C11(3.8, 2.4)

Certified leak rate (Initial: when chamber was built. Rough: during integration and test)

	Date (m/d/y)	Top ML (mbar/day)	Bottom ML (mbar/day)	Duration(hrs)	Gas
Initial					

Rough					

☐ Flush the chamber for at least 4 chamber volumes.

	EMS4	EMS5	EML3	EML4	ELM5
$V_{chamber}$(L)	760	900	926	1200	1412

☐ Close output valves

Install High Voltage (HV) and signal HH cards

☐ Clean pins on ALL SHH cards to be installed
- immerse SHH pins in wash basin with acetone for 5 minutes
- clean pins with electronic tooth brush

☐ Check ground pins on both HV and RO ends (all in, straight and in the same plane)

☐ Mount HV cards (8 for each multiplayer)

☐ Connect HV jumpers (don't mix up the sub-layers!)

☐ Mount signal HH cards (check the three sockets on the card, some of them were bent. Don't mount such a kind of card on to the chamber)

☐ Install SHV box and connect asymmetric HV jumpers from SHV box to HV cards according to tagged colors.

☐ Record HV card ID numbers.

Long [Short] tube side **Type A [C]** **Short [Long] tube side**

TOP								
BOTTOM								

☐ Record SHH card ID numbers.

Short [Long] tube side **Type A [C]** **Long [Short] tube side**

TOP								
BOTTOM								

☐ Check whether the capacitors and resistors are too close to the tubes.

Continuity test, install HV/HH covers

☐ Continuity test HV cards for each layer

☐ MECCA Test:
- Connect pulser to SHV box via a splitter and do MECCA test on SHH cards. The test should repeat three times by changing pulse amplitude from zero to maximum, maximum to zero
- Try to fix malfunctioning tubes by replacing HV and/or signal HH cards.
- If tube still fails to work, remove both SHH cards and test tube for continuity.

☐ List tube or HV/SHH cards having problem with continuity after MECCA test

☐ Put the bad HV/SHH cards into their bags and write down the reason of rejecting using the cards.

☐ Report to supervisor if any tube has problem with continuity

Comment to continuity test:

Dark Current Test

- ☐ Put the sign "HV ON" around the chamber
- ☐ Connect HV cables to SHV box
- ☐ Make sure HV power supply is set to HV=0 and current to mA
- ☐ Slowly increase HV to 3.4 kV (>2 minutes)
  Stop increasing HV if the current is high and the current indicator needle bounces forward and backward rapidly.

  If dark current remains high, apply negative high voltage (HV=-3000 -3400V)
  There should be about 15 minutes lapse time between positive and negative HV.

- ☐ Set "current" to "10" µA, fill the dark current value (unit in nA) to the table below

Date(M/D/Y): / /2004 Current unit in nA

HV(kV)	RH(%)	ML1-1	ML1-2	ML1-3	ML2-1	ML2-2	ML2-3
3.4							
3.4							
3.4							
Comments:							

The ATLAS specification is: 2nA/m at 3.4kV and RH=45%±10%
Maximum dark current for one sub-layer of UM chambers are

Chamber Type	EMS4	EMS5	EML3	EML4	EML5
I_{dark}(nA)	365	431	433	556	679

Report to supervisors if

(1) the measured dark current is very close to the maximum values listed;
(2) even if the dark current is not greater than the specification, but the current is unstable when it is set to 1 µA

- ☐ Set HV to zero when done
- ☐ How to deal with high dark current
  - find the source of high dark current
  - if the source is from tube, apply –HV=3.0—3.4 kV to the tube for about 10 minutes

  Note: switch from +HV to –HV, or –HV to +HV, one needs to wait for about half an hour so as to not damage electronics.
- ☐ Apply HV=3.1 kV to the chamber as long as you can. Don't forget to put clear signs indicating "HV ON" around the chamber.

Install Faraday Cage Pieces

- ☐ Install gas panels
- ☐ Install HV covers

- ☐ Install signal HH covers
- ☐ Install alignment cable hold-downs on top of HV covers
- ☐ Install ET holder brackets.
  Holes on the brackets and FC must be well aligned. No force should be applied to the ETs due to installed brackets

Motherboard and mezz cable pre-assembly and tagging

- ☐ Use paint pen to mark "A, B, C, D" on Mezz cables according to the cable polarity.
- ☐ Number the Mezz cable with paint pen (1, 3, 5, 7, 9, 11, 13, 15; 0, 2, 4, 6, 8, 10, 12, 14) according to the Mezz cable polarity and channel numbers on motherboard.
- ☐ Connect Mezz cables to motherboard
- ☐ Check whether all cables are firmly inserted into motherboard
- ☐ Check whether cable numbers and polarity match the motherboard

Install motherboard and mezz cards on to the chamber

- ☐ Number mezz channels on to FC according to the two tables below.
- ☐ Assemble 6 standoffs on baseplate.
- ☐ Install baseplate on RO cross plate with "LVP" towards short side.
- ☐ Install motherboard onto baseplate with LV connector towards short side of chamber and install cable clamps to hold the mezz cables flat to baseplate.
- ☐ Install mezz card standoff on to mezz card.
  Always wear grounding strap when handling the mezz cards!
- ☐ Install mezz cards gently. If you feel abnormal resistance, check the pins on SHH.
- ☐ Record Mezz card ID in following tables *and* on the SHH FC.

Short [Long] tube side **Type A [C]** **Long [Short] tube side**

TOP	1 [14]	3 [12]	5 [10]	7 [8]	9 [6]	11 [4]	13 [2]	15 [0]
BOTTOM	0 [15]	2 [13]	4 [11]	6 [9]	8 [7]	10 [5]	12 [3]	14 [1]

- ☐ Mother board serial number:
- ☐ Chamber serial number:
- ☐ Check mezz card position
- ☐ Scan mezz ID and MB ID into data base with bar code reader and save the data
- ☐ Install mezz FC covers with 3 bolts.
- ☐ Connect mezz cables onto corresponding mezz cards according to tagged numbers
- ☐ Check whether the connectors are fully locked
- ☐ Attach mezz cable ground wire and cable clip to mezz FC cover.
- ☐ Check whether Mezz card ID on chamber and PC after scanning with bar code reader
- ☐ Install DCS box and record its ID (?)
- ☐ Install Seattle T sensor board into DCS
- ☐ Install JTAG cable from DCS to CSM MB

DCS mode: DCS NIKHEF ID: DCS barcode
Orientation(?):

☐ Check whether the T sensor cables are correctly plugged in

Spacer Frame

☐ Check for 4 ground straps: Short side RO end; Short side HV end; Short side center crossbeam; Long side center crossbeam

☐ Check tension rods (4): installed and with all nuts.

Alignment & T sensor cabling

☐ EMS5, EMS4: Glue on T sensors using set labeled for given chamber.

☐ EML3, EML4, and EML5A01, EML5A03, EML5A05:
Pry off and re-glue center crossbeam T sensors in proper position.

☐ Attach shrink wrap on T sensor PC boards if there is none.

☐ Install alignment mux (AMB). "Root" socket goes towards short side.

☐ Install RASNIK LED boards on RO end, and apply epoxy on the three legs

☐ Install alignment and T sensor cables + various hold-downs. Use cable sets labeled by chamber. Glue aluminum strips to chamber top for PMO cables;
6 curls per long beam; 8 safety straps on end crossbeams; Angled cable hold-downs on crossbeams as needed. Make sure cables are well secured and within chamber envelope.

Inplane

☐ Plug in cables

☐ Test read-out of alignment mux using Brandeis LWDAQ test fixture and LWDAQ program. Be sure that all inplane RASNIK images are fully visible and analysable. For PMO cables plug in spare CCD cameras to obtain unfocused "white" images to verify cable operation

☐ For EMS5A02 – EMS5C06 we need to measure the orientations of the inplane system. Do this by taking inplane measurements with the chamber on the rolling cart. Take one set of measurements with the chamber horizontal and one with the chamber vertical

☐ Save the measured files

T sensors

☐ Double check string numbering of sensors.

☐ Plug cables into sensors and Seattle test fixture and read out with TSENS program.

☐ Plug cables into Seattle DCS input board and read out T sensors via DCS (TBD)

B sensors/Survey mounts (must be double checked before gluing)

☐ Glue B sensors platforms on EMS4, EMS5 and EML3 chambers
EMS chambers: B sensor platforms on chamber bottom
EML chambers: B sensor platforms on chamber top
Use positioning rods labeled by chamber on platform location.

☐ EMS5, EMS4A: Glue 8 survey platforms, 4 per chamber side.
Use positioning rods labeled by chamber on platform location
All chamber types: Record ID numbers in table below.

Location #: ID	5:	6:	7:	8:
Distance to rod (mm)				
Location #: ID	9:	10:	11:	12:
Distance to rod (mm)				

Note: distance measure with feeler gauge.
For + sign: real distance = length of checking rod + measured distance
For – sign: real distance = length of checking rod + measured distance
Checking rod is 100 µm shorter than the nominal value

- ☐ Cable B sensor (TBD)
- ☐ Record B sensor ID and mount location

	EML3,EMS4,EMS5		EMS4 Only	
Location	13	14	15	16
Sensor ID				

- ☐ PMO target information

	EMS4, EMS5	All
Location	2(A) or 1(C)	3(A) or 4(C)
Mask ID		

Chamber electronics readout and cosmic ray test

- ☐ Set up DAQ test system with scintillator trigger paddle.
- ☐ Perform mezz card test with DAQ system. First HV off, then HV on
- ☐ Check threshold, resolution, off set and efficiency
- ☐ Apply HV=1960 V to trigger PMT, and HV=3080 V to chamber
- ☐ Take cosmic ray data and record:

Run # Date:

HV (V) For trigger	HV (V) for chamber	Dark ML1(nA)	Current ML2(nA)	T (C^0)	RH (%)	Chamber Pressure (bar)

- ☐ Check whether the data files are stored
- ☐ CR data analysis
- ☐ Total number of hot channels:
  List of hot channels (mezz ID, electronic channel, off set)

- ☐ Total number of low efficiency channels:
  List of low efficiency channels:

- ☐ Attach following plots to the travler:
  - hit map of the sublayers
  - TDC spectrum and width distribution of each Mezz card
  - Tracks of both multilayer for each sector (8)

How to deal with dead channels?

1) Replace mezz card, HV card, SHH card step by step and see whether the dead channel disappears. Using MECC card to test continuity after replacing any one of these cards.
2) If dead channel stays, measure continuity of the corresponding tube.

How to deal with hot channels?

1) Cooking chamber with HV long enough. If hot channel stays, apply negative HV=3000V for about 10 minutes.
2) If hot channel still stay, replacing mezz/SHH/HV card step by step.
3) Measure continuity and dark current of the corresponding tube, compare with the other tubes.

Comments:

Final work before crating the chamber

- ☐ Install set screw on ET holder bracket
- ☐ Use a Q196 to detector leaks from ETs.
- ☐ Remove the four kinematic mount bearings and set screws. Put them in cabinet 1.
- ☐ Remove CSM gently and cover the mother board with plastic foil
- ☐ Make a hard copy of the traveler
- ☐ Call your supervisor for approval
- ☐ Re-crate the chamber. Foams should be carefully replaced to protect the chamber.
- ☐ Print "CR Tested Chamber ID m/d/y" page and stick on both ends of the crate
- ☐ Bring your traveler with you to the PC and fill the data base

2 - BIL summary report

I. Travel Document

Barcode (ID CERN): [ ]

Chamber number (ex: Rm1-0123): [ ]

Shifters name: ____________________ Date: ____________

Chamber type: 24 ☐ 30 ☐ 36☐

Disconnected tube	Reason of disconnection

Measure chamber pressure with digital pressure gauge and record the values:

Data	P ML1 (BarR)	P ML2 (BarR)	T (°C)	P ML1 (BarR) @ 20°C	P ML2 (BarR) @ 20°C	Operator

What to do	**“ X” when done**
HV HedgeHogs mounted	
Jumpers on HV HH mounted	
Mecca Test done	
Faraday Cage (FC) mounted	
Blocking Nuts for FC mounted	
HH serial numbers written on FC (external side of the chamber)	
FC Covers mounted	
Closing Plate for FC mounted	
Mezzanine mounted	
Check Mezzanine Numbers (with respect to the “bad list”)	
Mezzanine Cables mounted	
Covers for Mezzanines mounted (with the serial numbers of the mezzanines written on it)	
Platform for magnetic field glued.	
Reference Platforms (if needed)	
Projective Platforms (if needed)	
CCC Platforms (if needed)	
BIM-BIR Connection Platforms (if needed)	
Service Platform	
Platform for gas pipe support	
Platforms for adhesive supports (for panduit)	
Panduits for tie-rod	
Cabling	
Temperature Sensors mounted	
Splitter (write serial number)	
ELMB (write serial number)	
MotherBoard (write serial number)	
Rasmux (write serial number)	
Gas Pipes and Connectors	
Sniffing of Gas Pipe Connections	
Gas Test (short term)	

Noise Test	
Cosmics Test	
Leakage Current Test	
Temperature Sensors Reading	
Sag Compensation	
Alignment Test	
RFI	

Complete the steering program with all the information you have at the moment.

File names of Alignment results:
Inplane:____
Praxial:____
Projective:____
Comments:____
____
____

Leakage Current Test:
ML1: I(3400V) = _____________ μA
ML2: I(3400V) = _____________ μA

File name of Noise Test results:
H.V.off:____
H.V.on:____
Comments:____
____
____

File name of Cosmics acquisition results:
____
Comments:____
____
____

Insert serial numbers of RO Hedgehogs as seen from RO side (when ML2 is on the top)

ML 2						
ML 1						

Insert serial numbers of mezzanines as seen from RO side (when ML2 is on the top)

ML 2						
ML 1						

Insert serial numbers of HV Hedgehogs as seen from HV side (when ML2 is on the top)

ML 2						
ML 1						