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ATLAS NOTE

April 5, 2016

Support document for the Muon Phase-2 upgrade Intial Design Review

ATLAS Muon Collaboration

Abstract

The abstract

Contents

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Part I

Chamber technology, layout and construction

Chapter 1

TGC chambers

1.1 Replacement in the EM forward chambers : (Shikma, Masaya)

1.1.1 introduction

In view of phase-2 Muon trigger upgrade, it has been studied to use the MDT drift-time information for the Level-0 muon trigger to improve the momentum resolution and for getting a shaper turn-on curve in terms of muon p_T. The ATLAS muon spectrometer consists of three stations, inner, middle and outer station, in the both barrel and endcap regions. The highest hit occupancy of xxx Hz/cm^2 at the luminosity of $5 \times 10^{34} cm^{-2} s^{-1}$ is estimated in the region of endcap-inner (EI) station, where new chambers, Micro-Megas and sTGC, will be installed as a part of the ATLAS phase-1 upgrade project. The characteristic of high-rate tolerance was one of the important point for the technology choice, and both technologies satisfies the requirement to work as precision trackers and trigger chambers.

The second highest occupancy is observed in the endcap-middle (EM) station especially in the nearest chambers to the beam-line. The hit rate of xxx Hz at the luminosity of $5 \times 10^{34} cm^{-2} s^{-1}$ is estimated. The chamber technologies used in the EM station are MDT for precision tracking and triplet-TGC for trigger. Both of them still survive under the hit rate of yyy Hz/cm^2 and no concerns about aging for the entire life of HL-LHC, a worry was expressed that the efficiency for finding track-segments in the EM station of the MDT trigger may be deteriorated due to this higher hit occupancy. With this background, a possibility to replace EM forward chamber has been discussed.

1.1.2 Expected hit rate

- Require some studies (Ilia? or studies may be available)

1.1.3 segment finding efficiency as a function of MDT hit occupancy

- to ask inputs from Oliver

1.1.4 discussion and conclusion

- The current EM1 MDT chambers still work for the MDT trigger.
- The current TGC forward chambers survive under the hit occupancy of ...

1.2 A proposal to replace EIL4 chambers : (Shikma, Masaya)

In the transition region of the ATLAS muon spectrometer between barrel and endcap, 1.0 ¡ η ¡ 1.3, has a complexed structure due to interference between detectors and the structure of the toroid magnets. The endcap region is covered by the EIL4 TGC doublets for trigger and MDT chambers for precision tracking for 70% (?) in the azimuthal angle. The rest will be covered by the BIS-7/8 RPC triplets for trigger and sMDT chambers and this is a part of the ATLAS phase-1 upgrade project.

*** better to have a reference figure to guide***

A majority logic of 2 out of 3 coincidence will be applied to the BIS-7/8 RPC and provided for taking further coincidence between the Big-Wheel TGC, while 70% of the transition region is covered by EIL4-TGC and taking ”OR” of two layers. Due to high occupancy in the endcap inner-station and the poor algorithm due to limited number of layers, the probability for taking chance coincidence will be increased significantly. (quantatively ?)

1.2.1 Expected hit rate

- Require some studies (Ilia? or studies have been available ?)

1.2.2 Current configuration - low granularity doubles

Require some studies (Daniel?)

The readout electronics of the TGC EIL4 chambers are shared by the current TGC Small-Wheel chambers. The TGC FI chambers will be removed when the New Small-Wheel is installed. The legacy electronics boards stay in the pit as long as the EIL4 TGC stay in the pit which may cause different type of difficulties in terms of maintenance.

1.2.3 High granularity triplets / quadruplets ?

Require some studies (Daniel?)

It might be good to consider EIL4 TGC to the new technology having at least 3-layers to apply a coincidence logic.

Masaya, Shikma

Chapter 2

RPC chambers and front-end electronics

Giulio, Roberto, waiting recommendations on BI upgrade

Chapter 3

sMDT chambers

Hubert, waiting recommendations on BI upgrade

Chapter 4

MicroMegas chambers

Otmar, waiting recommendations on BI upgrade

Chapter 5

High-η tagger

Tatsuo

Part II

Read-out and trigger

Chapter 6

General Scheme for trigger and readout

Masaya

Chapter 7

MDT readout electronics

Thomas, Robert

Chapter 8

Endcap trigger with trigger chambers

Osamu, Makoto

Chapter 9

Barrel trigger with trigger chambers

Riccardo, Massimo

Chapter 10

MDT trigger

Oliver, Yasuyuki, Hubert

Part III

Services, controls and installation

Chapter 11

Alignment

Florian

11.1 Actual Barrel alignment implementation

The existing alignment scheme has been discussed in different publications (see [**?**]). Views of the optical lines in the BI layer, can be seen in figure 11.1, 11.2 and 11.3.

The backbone of the Barrel alignment system are the projective lines which connect optically 3 chambers of one tower and which are pointing toward the interaction point. The projective system works with Rasniks, where BI holds the mask, BM the lens and BO the CMOS.

In the current final layout, 117 projective lines are in use. In order to maintain a high detector hermeticity, the number of projective lines has been limited to few corridors, which were the object of intense design efforts. Actually, 2 out of 3 MDTs in the large towers are equipped with projective lines, while small chambers could not be equipped at all.

This means that MDT towers, lacking projective lines, have to be optically linked to the MDT towers equipped with projectives. Within small and large MDT planes, neighboring chambers have 2 kinds of optical links: Small lever arm connections called Praxial (PRoximity Axial), and long-lever arms, called Axial. Both systems work with Rasniks: at each corner a given MDT is equipped with a CMOS, while the neighbouring MDT is equipped with a mask (the lens is either on one or the other MDT).

Small MDT towers are connected via SaCams to the large MDT towers (this type of line is called CCC).

Another optical link connects the barrel MDTs to external points mounted on the toroid warm structure. This system is called reference system and resolves weak modes affecting the sagitta resolution. Furthermore, the reference system optically connects the 8 toroid coils, forming 4 optical rings (two rings at $z < 0$ and two at $z > 0$).

A special type of optical line are the so-called BIR-BIM connection, which connect the BIR and BIM type chambers together.

Another special setup is the Inplane system: one or more Rasniks mounted inside the MDT monitor deformations such as sagitta, torsion or width differences between opposite chamber sides. The Inplane system is the reason for the word "monitored" in *Monitored Drift Tube* chamber.

Most optical elements are not positioned directly on the MDT chambers and a 2 or 3 stage mechanical setup has been used:

- a plateform is glued onto the chamber with repect to the wire positions.

- a mecanical extension is fixed to the plateform, in the case of projective, CCC and reference lines. These extensions consists of a three ball positioning system at each end. All extensions were properly calibrated under XMM machines.

- a optical element mounts, containing a CCD, lens, mask or camera (CCD+lens). These mounts are calibrated in the laboratory.

Over thousands extension plates have been built and have been calibrated on a CMM with a precision better than 30 microns. The weight of a single 2 or 3 stage mechanical setup is around several kilos. It should be noted that the Axial and Praxial plateforms are the only plateforms, which were glued with respect to the MDT wires. All other plateforms were glued with respect to the Axial and Praxial plateforms.

The amount of work done in the past for the actual barrel alignment setup is estimated to 150 FTE. This estimate contains test, layout, design, production, calibration, installation, description and software. All the 1500 alignment drawings as well as the calibration constants, have been implemented in the software. The outcome of this work in terms of performance is a barrel alignment contribution for the reconstruction of a p_{T} = 1 TeV muon of 38μm in the large sectors and 68μm in the small sectors.

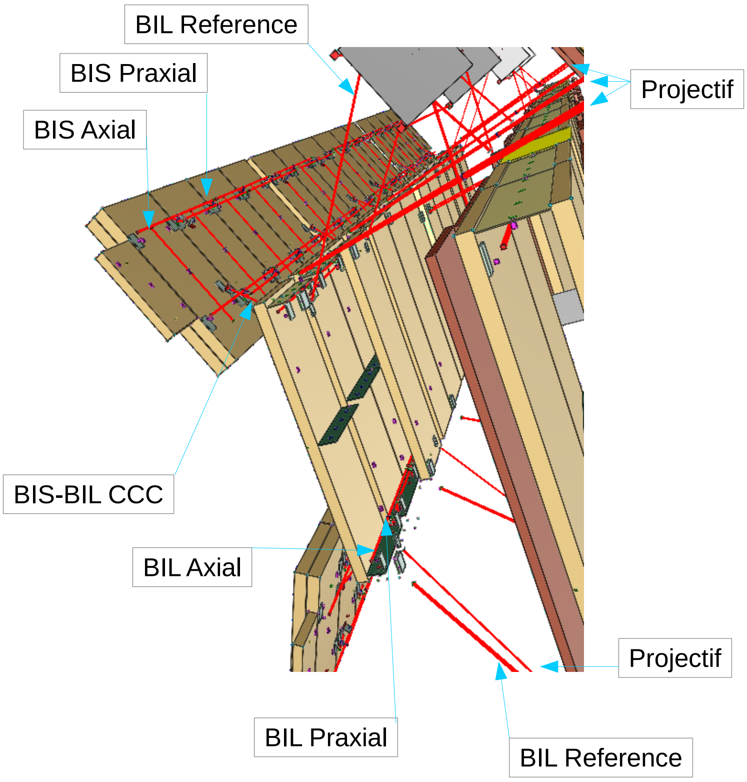

Figure 11.1: A actual view of the various optical lines in the BI sector 12, 13 and 14. The outer multilayer of 2 BIL was ommited to show the axial and praxial lines. The inplane lines were omited in order to simplify the view. This view was generated by the actual barrel alignment program ASAP.

11.2 Replacement of the BI chambers

Different replacements of the BI layer discussed, which are:

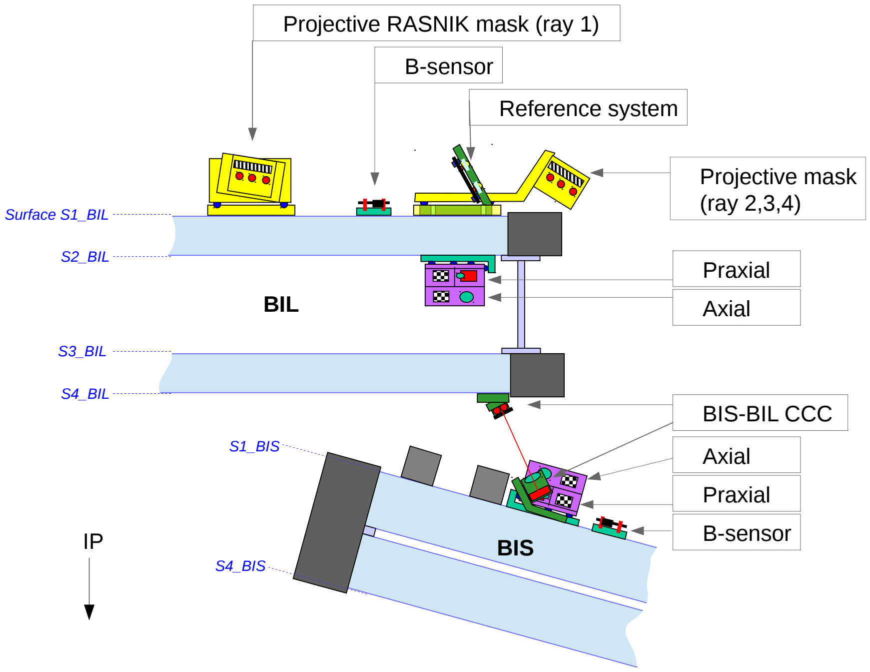

Figure 11.2: A view of the optical elements, which are mounted on BIL and BIS chamber for a so-called standard sector.

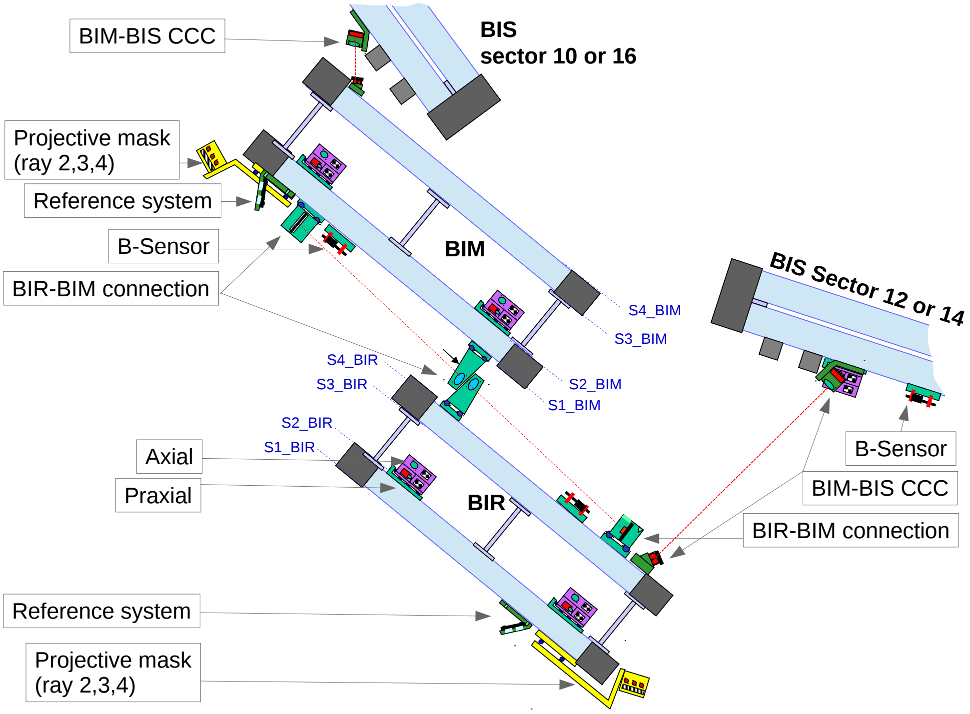

Figure 11.3: A view of the optical elements, which are mounted on BIR and BIM chamber in the sector 11 and 15.

- R1: replacement of 96 BIS chambers out of actually 128 BIS chambers. In 2018, the actual 32 BIS7 and 32 BIS8 chambers will be merged into 32 so-called BIS78 chambers. These 32 chambers would be left unchanged.
- R2: replacement of 72 BIL chambers (sector 01, 03, 05, 07, 09, 13).
- R3: replacement of 24 BIR and 20 BIM chambers (sector 11, 15).

Thus in the maximal scenario ($R1 + R2 + R3$), 212 BI chambers would be reimplaced. With a total of 628 MDT chambers in the Barrel, this corresponds to 34%.

11.3 Alignment in the BI layer

A partial or total replacement of the BI layer impact the existing alignment in a significant manner (39% of the non inplane lines would be affected). In table 11.1 the numbers of lines affected in the three different BI replacement scenarii are shown.

Name	Total	all BI R1+R2+R3	BIS R1	BIL R2	BIR/M R3
Inplane	2110	532	96	284	152
Praxial	2006	760	416	232	112
Axial	1036	380	192	116	72
Projective	117	117	0	89	28
Reference	256	64	0	48	16
CCC	260	100	72	76	24
Bir-Bim	32	32	0	0	32
Total	5817	1985	776	845	436
Non inplane total	3707	1453	680	561	284

Table 11.1: The number of optical lines which would be affected in the various BI replacement scenarii. Optical lines related to BIS78 were left out in the various replacement scenarii.

The possible strategy consists in reusing the existing alignment mechanics, in order to save a tedious redesign, remanufacturing and calibration of the various plateforms, extensions and optical elements. Furthermore many of the optical lines use alignment corridors which can not be changed, without disturbing the present layout.

This strategy has different drawbacks, which are:

- the positions of some of the surfaces of new BI chambers are frozen to the present MDT surfaces.
- the sizes of the new BI chambers, along z, are frozen.
- in many cases cutouts in the RPC layer are unavoidable.

11.3.1 BI chamber surfaces

Whatever detection technology is choosen (small tube chambers or Micromegas), some of the surfaces on which the plateforms are glued, should be at the same location in R as the present MDT chambers (see figure 11.2 and 11.3).

Here we go through the different cases:

BIS chambers:

For BIS chambers only the outward multilayer surface (called $S1\_BIS$ in figure 11.2) is equipped with optical sensors. The new muon chamber should be constructed and placed in such a way, that the surface $S1\_BIS$ of the present and new muon chambers match in R. Therefore the natural place to put a BIS RPC layer, would be on the $S4\_BIS$ surface (which is the surface closest to the HCAL).

BIL chambers:

On BIL chambers, three surfaces are used ($S1\_BIL$, $S2\_BIL$ and $S4\_BIL$) by the alignment devices. Therefore the new muon chamber should at least be constructed and placed in such a way, that the $S1\_BIL$ and $S4\_BIL$ surface of the present and new muon chambers match in R. If this is not possible, preference should be given to a match of $S1\_BIL$ and a new design, manufacturing and calibration of the CCC connection, which lays on $S4\_BIL$ would become neccessary. On BIL chambers, the only surface free of alignment sensors is $S3\_BIL$, which is not very appropriate to place a RPC. and the surface $S4\_BIL$, would be the natural place to put a RPC layer, but cutouts for the CCC connection should be foreseen.

Axial and Praxial lines were positioned in between the multilayers of the actual MDT, in order to avoid clashes with the outside environment (calorimeter gas pipes, cables, already existing alignment sensors etc.) of the chambers. This design has to be maintained, which implies that whatever new detector wil be built, BIL chambers should consist of 2 multilayers. So-called compact chamber layout should be avoided for BIL chambers.

BIR and BIM chambers:

On BIR and BIM chambers, three surfaces are used ($S1$, $S2$ and $S4$). The new muon chamber should at least be constructed and placed in such a way, that the $S1\_BIR$ and $S4\_BIR$ (or $S1\_BIM$ and $S4\_BIM$) surface of the present and new muon chambers match in R. The situation is comparable to the BIL chambers: $S3$ is alignment sensor free, but not very appropriate to place a RPC. $S4\_BIM$ could be used to place a RPC, if cutouts are provided for the CCC connection. For the BIR chambers, $S4\_BIR$ needs additional large cutouts for the BIR-BIM connections. It should be noted that the replacement of BIR and BIM chambers is a very challenging operation and probably unreasonable.

11.3.2 BI chamber dimensions

If one wants to avoid a redesign of the present Axial system, the size along z of the BI chambers should be maintained to the present one. Furthermore in order to keep the Praxial system working the distances between chambers should be maintained as well.

11.3.3 Positioning tolerances for the various optical lines.

We will briefly discuss the position tolerances, which are left for the various alignment types.

Projectif

The position of the 117 projectif BI masks are frozen to the mm level, because their counterpart on BM and BO can not be moved anymore. The only degrees of freedom left is along the optical axes, when playing with the focal depth, which is of the order of several millimeters.

Axial and Praxial

Theoretically Axial and Praxial sensors could be moved along the tubes (provided all other Axial and Praxial in the same plane are moved by the same amount). Along their line of sight the degree of freedom of the Axial and Praxial are few millimeters (which imposes that the distances between chamber and the chamber size at the millimeter level). Furthermore if on does not want to change the Axial layout, the size of the chamber should be maintained as they are in the actual layout.

Reference

The position of the reference sensors is given by the position of the reference plates glued on the ribs of the toroid. The viewing range is at the millimeter level. The focal depth of the system is at teh decimeter level.

CCC

If ones replace both BIL and BIS, theoretically the position of the CCC along z could be changed, provided new alignment corridors are available. The focal depth of the system is at the decimeter level.

BIR-BIM connection

Theoretically the position of the BIR-BIM connection can be displaced along z, provided new alignment corridors are available. Moving the BIR-BIM connection along the tube direction might be more complicated, as this connection already spans over the total length of BIR and BIM. The interdistance along R of the BIR and BIM should remain untouched at the millimeter level.

11.4 Radiation hardness of the Barrel alignement electronics during HL-LHC

A study about the radiation hardness of the various Barrel alignement components have been done in 2002. The reference can be found here [**?**]. The various RASNIK components have been tested for:

- TID: Total Ionisation Dose ($Gy(10y)^{-1}$).
- NIEL: Non-Ionising Energy Loss ($10^{11} neutron \quad cm^{-2}(10y)^{-1}(1MeVeq.)$).
- SEE: Single Event Effects ($10^{11} hadron \quad cm^{-2}(10y)^{-1}(40MeVeq.)$)

11.4.1 LHC requirements

The radiation requirements emited in 2003 are given in table 11.2, and were calculated the following manner:

$$AMBDR(LHC) = SRL \times SF_{sim} \times SF_{ldr} \times SF_{lot} \tag{11.1}$$

where AMBRD(LHC) is the Atlas Muon Barrel Required Dose over 10 LHC years (estimated to correspond to $1000 fb^{-1}$), SRL is the Simulated Radiation Level over 10 years and SF are the various safety factors (respectively due to simulation, to low dose rate effects and to the uncertainty due to testing different production batches).

	AMBRD (LHC)	SRL	SF_{total}	SF_{sim}	SF_{ldr}	SF_{lot}
TID	328	4.69	70	3.5	5	4
NIEL	6.1	0.301	20	5	1	4
SEE	0.47	0.095	20	5	-	4

Table 11.2: The Atlas Muon Barrel Required Dose (AMBRD) as calculated for the LHC in 2003

	AMBRD (HL-LHC)	SRL	SF_{total}	SF_{sim}	SF_{ldr}	SF_{lot}	F_{HL-LHC}
TID	85	4.69	18	1.5	1	4	3
NIEL	7.2	0.301	24	2	1	4	3
SEE	2.3	0.095	24	2	-	4	3

Table 11.3: The Atlas Muon Barrel Required Dose (AMBRD) as calculated for the HL-LHC, taking into account the increase in luminosity and the actual (2016) knowledge on the safety factors

	Test Dose	Number of AMBRD(LHC)	Number of AMBRD(HL-LHC)
TID	377	1.15	4.00
NIEL	6.1	1.00	0.84
SEE	2.7	5.70	1.17

Table 11.4: The doses used in the various irradiation tests

11.4.2 HL-LHC requirements

With the LHC run 1, comparison between data and simulation became avalaible, which lead to a decrease of some of the safety factors. On the other hand, the expected luminosity of the HL-LHC is foreseen to be $3000 fb^{-1}$, thus 3 times more than what was expected for the LHC estimates in 2003.

The current radiation requirements for the muon Barrel are given in table 11.2, and were calculated the following manner:

$$AMBDR(HL-LHC) = SRL \times SF_{sim} \times SF_{ldr} \times SF_{lot} \times F_{HL-LHC} \tag{11.2}$$

11.4.3 Radiation hardness of the alignment electronics

As reported in [?], various test were excuted to qualify the alignment electronics. The tested devices were RasLeds, RasCam and the multiplexing device RasMux. One electronical component of the Barrel alignment system has not been tested, which is the SacLed. The results for the Sacled should be comparable to the RasLed, because the same components were used in both electronical boards.

The TID was tested up to 377 Gy corresponding to 1.15 AMBDR(LHC) and well above the 85 Gy expected at the HL-LHC. The authors conclude that all tested RASNIK components survived the dose.

The Niel test, was undertaken at respectively 1.0, 6.7, 8.4, 16.4 AMBRD(LHC) and a decrease of the performance of the 10, 22, 30 and 80% has been observed for the Rasled and 5, 25, 36, 80 % for the RasCam. The Rasmux was still working after a dose correspondig to 8.4 AMBRD(LHC).

The SEE test did not show any effect on the RasLed and RasCam, after an irradiation corresponding to 5.7 AMBRD(LHC).

The conclusion is that the alignment electronics should be able to cope the expected radiation of the HL-LHC.

11.5 Other sensors

Other sensors have been mounted on the existing MDT chambers, which should be used on the new chamber type. These are the T-sensors (10 per BIS, 5 per BIL/R/M) and the B-field sensors (2 per BIS chamber).

Chapter 12

Installation

Christoph

Bibliography

[1] ATLAS Collaboration,, Journal of Instrumentation **3** (2008) S08003, `http://stacks.iop.org/1748-0221/3/i=08/a=S08003`.

[2] H. van der Graaf and H. Groenstege, *The Radiation Hardness of RASNIK Components for the ATLAS Muon Barrel Spectrometer*, tech. rep., 2002. `http://doc.cern.ch//archive/electronic/cern/others/atlnot/Note/elec/elec-2002-002.pdf`.