1 The Muon System, version 1, 10p

1.1 Introduction, 0.5p

The muon system [1, 2, 3] is the more shielded sub-detector and the primary component of particle flux is less dominant than in other subsystems. Nevertheless, aging of detectors, their rate capabilities, the long term survival of present electronics and the performances in the identification of muons in a high radiation environment, are the main concerns for the system in a high luminosity run. The station M1 will be no longer needed in the upgrade, as the improvement in the L0 muon momentum resolution will be performed by the tracking stations and the very high rate expected will make it useless.

Most of the hits recorded by the muon chambers in the stations M2-M5 are produced by secondary particles coming from electromagnetic and hadronic showers and by the low energy uncorrelated background. The actual value of this component, simulated in the LHCb MC with a safety factor, could be determined from the first year operation of the detector. Anyhow the extrapolation of these values to a luminosity up to ten times higher has to be taken with caution, as eg. the neutron background induced in the cavern could be very different at different luminosities.

Several informations will be also gained after the current year of run about MWPC and GEM stability during beam operation, about reliability of electronic components and of service systems (HV, LV and gas). The muon system FEE is already readout at 40 MHz, as it is currently sending data at this rate to the L0 trigger, while the full TDC information is currently sent at 1 MHz to DAQ system. This scheme has to be modified, so to have a system fully integrated with the interaction trigger and with the rest of the upgraded DAQ. As a global strategy, it is planned to have a set of minimal changes for the muon system, so to operate the detector with the rest of LHCb since the startup of the high luminosity run.

1.2 Aging of MWPC detectors, 2p

(Alessia, Burkhard, Giacomo, Giulio) Evaluation of rates from past MC simulations [4] and from hit densities. See tab. 1.

	R1	R2	R3	R4
M2	0.67	0.42	0.10	0.02
M3	0.17	0.08	0.02	0.01
M4	0.22	0.06	0.01	0.004
M5	0.15	0.03	0.01	0.003

	R1	R2	R3	R4
M2	0.81	0.55	0.12	0.10
M3	0.24	0.11	0.03	0.04
M4	0.09	0.07	0.04	0.03
M5	0.07	0.07	0.04	0.02

Table 1: radiation dose (C/cm of wire) in the most irradiated chamber after 50 fb^{-1} (left); rates on a single FEE channel (MHz) in the most irradiated chamber at 10^{33} $cm^{-2}s^{-1}$ (right).

Extensive aging tests were performed on MWPC prototypes at the CERN-GIF and at the ENEA-Calliope gamma irradiation facilities [5, 6]. The goal of the tests was to prove that the performance of the chambers is not deteriorated by the large radiation dose expected in the experiment in ten years of operation at the nominal luminosity $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$. In the two tests, charges up to respectively, 0.25 C/cm and 0.44 C/cm were accumulated without any apparent loss of performance over a period of six and one months. These values, when compared with the doses expected at 10^{33} $cm^{-2}s^{-1}$, suggest that, most of the chambers of the muon stations M2-M5 should sustain the dose at high luminosity. However, the experience of MWPC operation during the first year, shows that few gaps in the chambers have suffered from trips already at luminosities which are ten times smaller than the nominal one. This problem has been cured with a new training of these chambers and the problem is currently ascribed to insufficient cathode cleaning during the production.

A method to infer the actual radiation rate on the chambers from real data using hit densities has been developed (see fig. 1 - temporary figure).

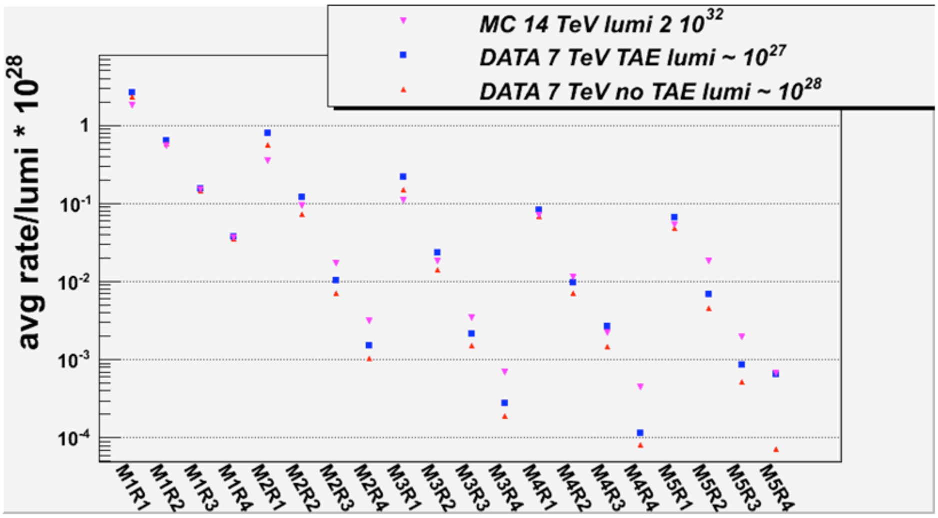

Figure 1: Rate evaluation from hit densities in the muon system at different LHC luminosities.

1.3 High rate limitation of the FEE, 1.5p

The high-rate performance of a MWPC was tested [7] using a 100 GeV muon beam superimposed on a 662 keV γ flux of variable intensity produced by the ^{137}Cs radioactive source of the CERN-GIF. The current drawn by each gap of the chamber was measured as a function of the chamber HV also with a lower intensity source [8] . The results of these measurements are reported in fig. 2 (left). One of the main result of the test is that the similar behavior of the two curves ensures that no evident saturation effect is present up to a the maximum tested current density of approximately 30 nA/cm^2. To evaluate the significance of this result, this value must be compared with the one expected on the apparatus at $10^{33}\ cm^{-2}s^{-1}$. In this condition, we expect in the M2-M5 stations, currents below 15 nA/cm^2. Therefore we expect that no significant space charge effect will spoil the chamber performances.

By means of the muon beam it was also possible to study the behavior of the front-end electronics in high rate environment. The muon detection efficiency and the response time resolution were studied as a function of the hit rate up to 1 MHz per front-end electronics channel. Results are shown in fig. 2 (right). For each configuration the chamber performance was measured with the source ON and OFF. Once the detection efficiencies have been corrected for the effects of the dead time ($2.0\% \div 2.5\%$), both parameters show a behavior, in presence of high rate, very similar to the one measured without photon background. Therefore, except for dead time effects, no deterioration is expected in the front-end electronics behaviour. The rate of 1 MHz per channel is considered also the limit of operation without sensible degradation of chamber performances.

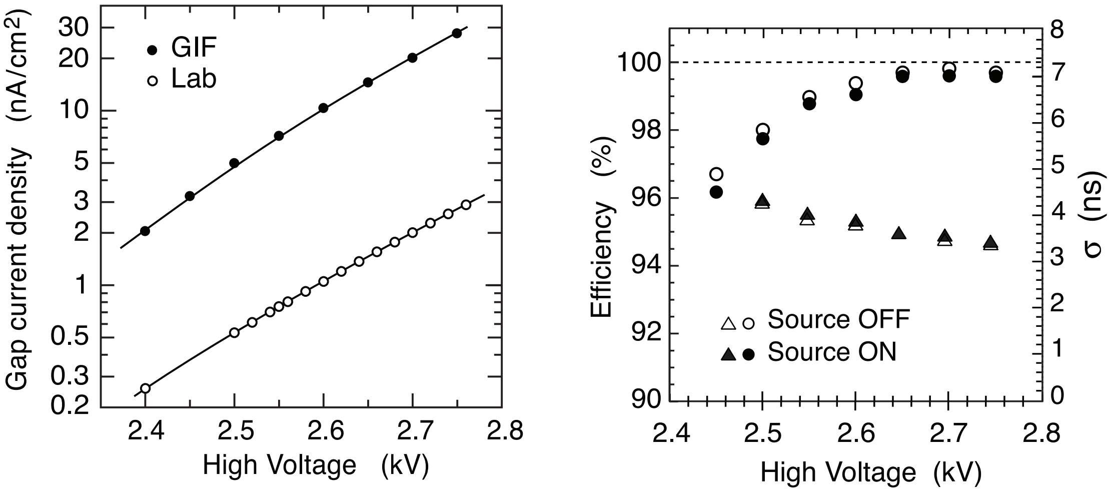

Figure 2: average current densities of a MWPC gap vs. HV in measurements at the CERN-GIF and at a lower intensity ^{137}Cs source (left); MWPC detection efficiency (circles) and time resolution (triangles) vs. HV in a 20 ns time window with GIF source ON and OFF (right).

1.4 Electronics and services, 3.5p

The block scheme of the muon electronics architecture in the upgrade layout is shown in fig. 3. The muon electronics architecture going from the front-end CARDIAC board [9] to the Off Detector Electronics (ODE) board [10] is the same used in the current layout [2] and will be maintained with the exception of the first muon station M1 that will be removed. In the current readout at 1 MHz, the signals from the ODE boards are received by the TELL1 boards [2], which will be upgraded to the TELL40 boards [11] to cope with a 40 MHz data rate. As described in the following all the modifications of the muon electronics architecture foreseen for the upgrade will be done at the entrance of the TELL40 board.

1.4.1 The Front End Electronics

In the current layout the signals generated on the muon chambers are digitized at the electronic Front-End level by the CARDIAC board [9]. This board hosts two ASIC: the CARIOCA [12], which is an amplifier, shaper and discriminator, and the DIALOG [13], with configurable settings, which apply a logical combination to the input channels, region by region, according with the required L0 muon trigger granularity. The LVDS outputs of these boards are sent, through two stages of logic combination to ODE boards which collect the chamber hits at a rate of 40 MHz.

(Here we should say FEE are rad hard (up to?rad?) and we should not change them)

The two ASICs CARIOCA and DIALOG are both realized in IBM 0.25 μm technology, using specific layout techniques (enclosed gate structures) suitable to increase the radiation resistance up to tens of Mrads without significant performance loss. Therefore under the conditions presently foreseen for the upgrade, the current FEE layout will be maintained.

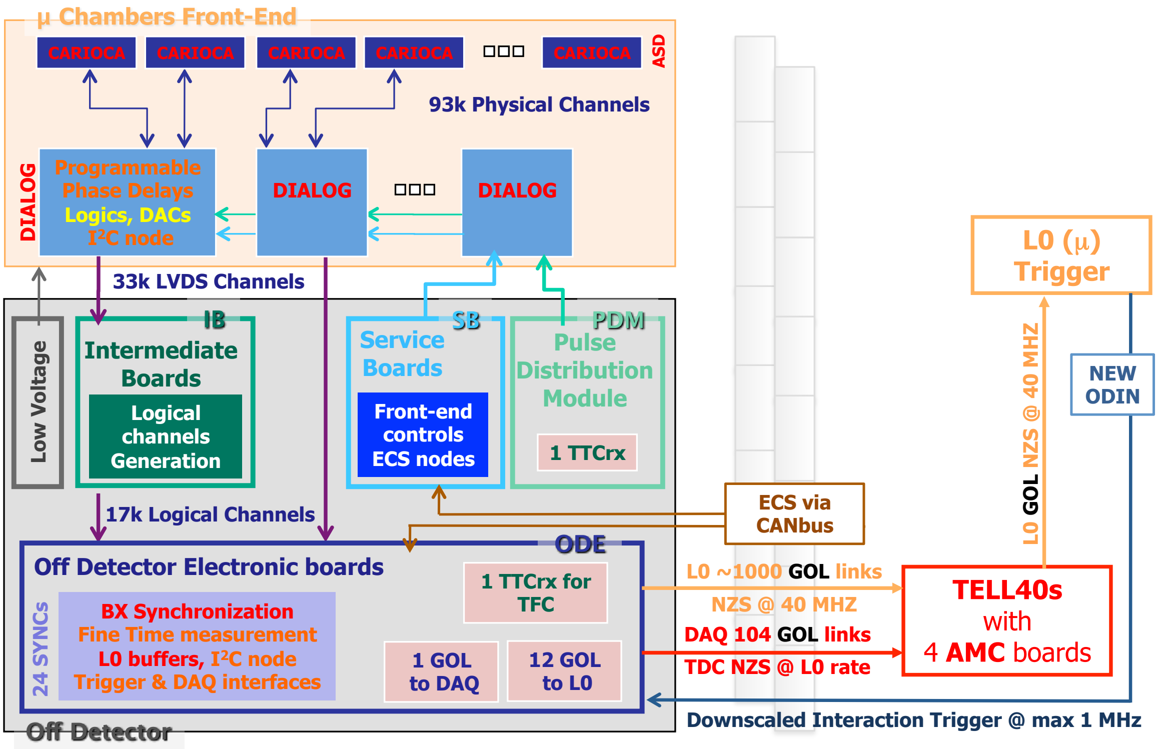

Figure 3: Block scheme of the muon electronics architecture in the upgrade layout.

1.4.2 The Off Detector Electronics

The ODE board is synchronous with the LHC clock. In the current layout all the synchronous signals are distributed by the ODIN board and received on the ODE by the TTCrx [14] protocol and the 192 ODE input channels are processed every 25 ns by the SYNC ASIC [15]. The Non Zero Suppressed (NZS) 1 bit information of fired input channel is extracted and is sent to the L0 trigger processor at 40 MHz using 12 GOL [16] chips as data serializers. This information is used by the L0 trigger algorithms to generate the trigger decision (L0yes signal). Beside, for each input channel, a time measurement is done by the SYNC ASIC using a custom 4 bits TDC; a Bunch Crossing Identifier (BXid) is associated to each event and data are stored in a pipeline. After the fixed L0 latency of 4 μs, the SYNC chip receives back from the ODIN board the L0yes signal to acquire the correspondent pipeline data. The triggered events are sent to the TELL1 boards at the maximum rate of 1 MHz from the 24 SYNC chips through one GOL chip. This timing information is very useful to monitor and to fine tune the timing alignment of the muon detector. From the 4 bits TDC information a single bit/channel information is extracted and used by the reconstruction to select the muon tracks. All the data exiting the ODE are Non Zero Suppressed (NZS).

The requirement for the electronics upgrade is to process and save the data coming from the detector at 40 MHz, instead of the nominal 1 MHz of the current layout. As described, the ODE boards process the muon detector signals at 40 MHz already in the current layout; for this reasons no changes at the level of the ODE boards are foreseen for the upgrade. Moreover the L0 muon trigger will maintain the present configuration, to which the muon system must continue to comply. All the synchronous signals are currently distributed by the ODIN board [2] which will be upgraded with the new ODIN board [17]. In both cases those signals are transmitted to the ODE board with the TTCrx protocol. The L0yes signal currently received by the ODE boards is upgraded to the logical AND of the Interaction Trigger and the L0 muon Trigger.

1.4.3 TELL40 implementation

As presented in the previous section, two kinds of optical links are output from the ODE boards, named in the following the **L0-link** and the **DAQlink**. On these links NZS data are transmitted from the ODE boards with the 40 bits GOL data format.

In the upgrade layout both links will be connected to the TELL40 boards. In the L0-link the information of fired/not-fired channel with 1 bit/channel at 40 MHz. A maximum of 28 ODE channels are transmitted for each link together with the two less significant bits of the corresponding BXid. In the DAQlink the time measurement of 4 bits/channel is coded. For each trigger signal the timing information of all the 192 ODE channels are transmitted together with the complete BXid and some ODE board check bits. The impklementation of the muon Electronics Upgrade will be performed with an AMC mezzanine board [18] to be installed on TELL40 [11] boards

The L0-link and the DAQlink are transmitted at different rates to the TELL40 board input stage which is constituted by the AMC mezzanine board [18]. One TELL40 board embeds 4 AMC boards, while each AMC board will be connected to only one ODE. A block scheme of the AMC mezzanine board is shown in fig. 4. Since the L0 muon trigger processor will not change with respect to the current implementation, it must receive the L0-link as it exits from the ODE with the GOL data format. On the contrary the TELL40 board is designed to receive data with the 120 bits GBTX [19] data format. Therefore, the L0-link information, once has arrived on the AMC board, must be duplicated. The first copy is forwarded from the AMC board to the L0 muon trigger processor, maintaining the GOL data format as required. The implementation of the L0 muon trigger algorithm does not consume all the 4 μs of latency and few clock cycles can be used to duplicate and format the L0-link. The second copy is processed by the AMC board programmable logic in order to zero suppress data, if necessary. The DAQlink data is processed as well by the AMC board programmable logic and undergoes zero suppression.

For each event the muon Bank is created using the data coming from both the L0-link and the DAQlink. The events sent trough the DAQlink are a subset of the total events triggered by the Interaction Trigger. Since the two links are sent with different rates and the DAQlink has a latency (at least: 4 μs related to the L0 latency, plus the time needed to read back the TDC information from the ODE board: around 900 ns), a L0pipeline for the L0-link data is foreseen inside the AMC board programmable logic. Finally the information related to the muon bank is converted to the GBT data format. For each Interaction Trigger this information is sent to the farm.

1.4.4 Service Systems: HV, LV and gas

(Nikolay - Oleg - Paolo - Burkhard)

The **HV system** will undergo an upgrade so to connect each gap of the MWPC system to an independent HV channel. In the present layout, four gaps of R4 chambers are connected to a single HV channel. If a gap trips, a total of four has to be disconnected. To increase the operation efficiency of the system and to reduce at a minimum the disconnected gaps during data taking, the UF-PNPI HV system will double the number of available channels,

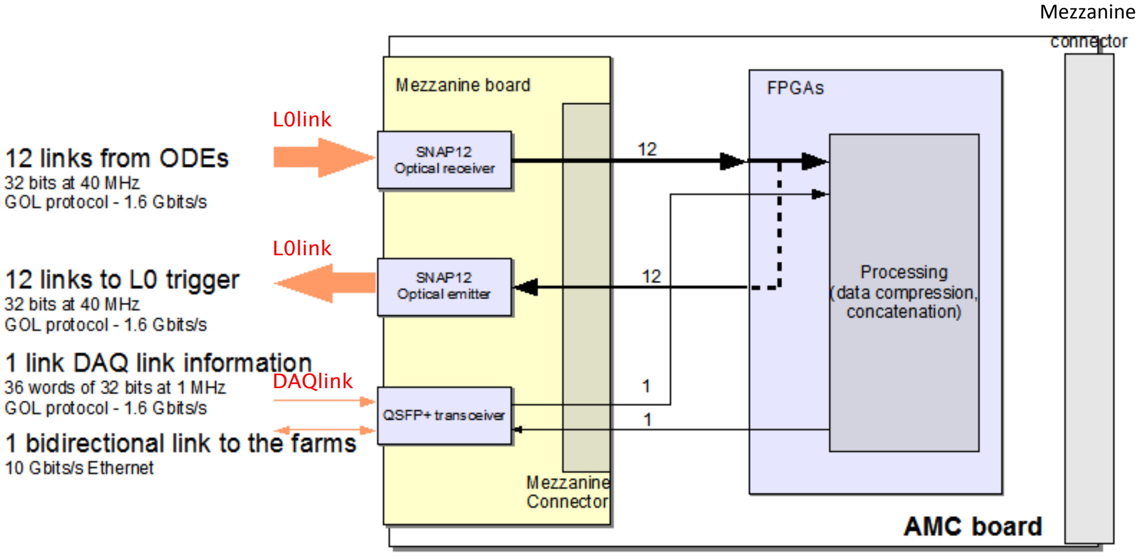

Figure 4: Block scheme of the AMC mezzanine board.

from the current 1920 to 3840. The construction of the modules will start in 2011, so to have the upgraded system installed by the restart of data taking in 2013. (? radiation hardness of modules ?)

The **LV system** supplies electrical power to the FEE (CARDIAC boards) and to the off detector electronics (ODE system). The present LV scheme is based on the Wiener Maraton power supply which foreseen to be used also in the upgrade. The higher rate on the FEE electronics will cause a minimal increase in power consumption: less than 10% is expected. In the present configuration, the hottest channels of power supplies are used at 80% of full load, and therefore the power increase is not a main concern.

About the radiation hardness, the present estimated worst area for the electronics is in M2 racks, where, for 10 years with a luminosity of $2 \cdot 10^{32}\ cm^{-2}s^{-1}$, a total dose of 2.2 krad and a 1Mev neutron equivalent flux of 3.4x$10^{11} n/cm^2$ are foreseen (with a safety factor 2 included). Even an increase in the total dose of a factor 5 with respect to the present one, the qualification of the power supply up to to 14 krad and 5.6x$10^{12} n/cm^2$, should guarantee a safe operation. Also the MTBF of each Maraton component (higher than 100.000 hours) should guarantee the reliability of the system.

1.4.5 Detector Control System

(Davide, Maurizio, Valerio) The muon detector electronics and services are remotely controlled with a dedicated PVSS-SCADA software. No changes with respect to the software used in the LHCb experiment are foreseen except to the part related to the control of the TELL40 board. (? ELMB rad hard ?)

1.5 GEM detectors, 1p

Plans for GEM detectors: R&D on large area GEM detectors (Gianni, Alessandro)

1.6 System Maintenance

1.7 Muon Identification, 1p

(Pierluigi, Gaia, Sara, Alessia) Muon identification and effects on physics channels by a high luminosity environment.

1.8 Plans, 0.5p

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