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CONSOLIDATION WORK UNIT DESCRIPTION

LHC wire-scanner electronics consolidation

ABSTRACT:

The LHC wire-scanners are based on a precision linear mechanism that moves a thin carbon wire across the beam at a nominal speed of 1m/s. The shower of secondary particles generated by the beam-wire interaction is monitored by a scintillator-PMT system. The motor controller and photomultiplier acquisition electronics were designed 15 years ago (2005). While it is still possible to operate the scanners, the electronics is suffering from reliability issues and its maintainability is becoming difficult. It is therefore proposed to equip each LHC wire-scanner mechanical unit with the modern electronics recently developed for the LHC injectors within the LIU project. At the same time it is also proposed to consolidate the acquisition system with the same multi-PMT detector readout via fast ADCs being used in the injector system upgrade.

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HISTORY OF CHANGES

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0.1	2019-11-13	-	Creation of the document.

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1. EQUIPMENT/SYSTEM CONCERNED AND MOTIVATION

There are eight Beam Wire Scanners (BWS) installed in the LHC. Four scanners, two in the Horizontal and two in the Vertical plane for Beam 2 in vacuum sector E5L4.R and the same for Beam 1 in vacuum sector E5R4.B. This gives an operational scanner and reserve for each plane and each beam.

These are linear precision scanners which, as sketched in Figure 1, function by passing a carbon filament across the beam, producing a shower of secondary particles which are detected downstream by a scintillator. The resulting beam profile measurement data with these instruments is used primarily as a precision reference (using low intensity beams) for calibrating on-line profile monitors such as the synchrotron light monitor (BSRT). The continuing importance of these BWS instruments for Run 3 and later for HL-LHC has been re-confirmed by the findings of a recent LHC Beam Size Review [1]

The present electronics was designed over 15 years ago and is common for all scanners in the PSB, PS, SPS and LHC, based on rotational or linear actuators operated up to a speed of 20 m/s. All the injector systems will be upgraded as part of the LIU project.

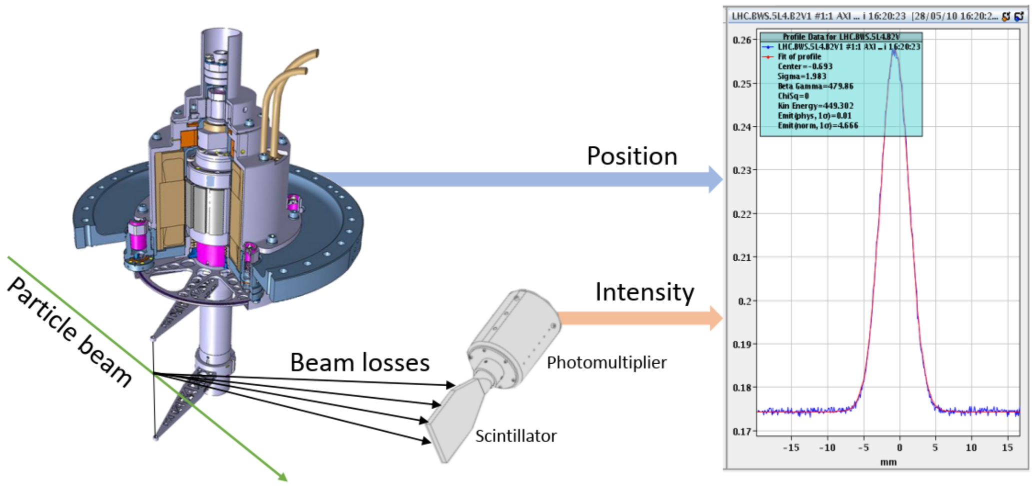

Figure 1: Wire Scanner Principle with the LIU electromechanical part (left), the particles detector (centre) and the resulting signal (right)

LHC scanners consist of linear kinematic units equipped with 30 micron diameter carbon wires moving at a maximum speed of about 1 m/s, driven by DC motors.

Figure 2 shows the LHC linear wire scanner mechanism (left) and the LHC Beam 1 tank with its 4 scanners (right).

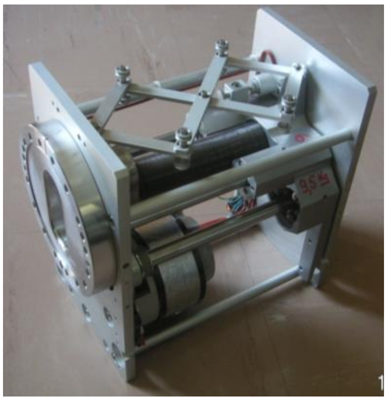

Figure 2: LHC linear wire scanner mechanism (left) and the view of the Beam 1 tank with its 4 scanners (right).

The original LHC electronics consisted of a single VME CPU controlling two control electronics units, one per beam. In 2016-17, a second VME crate was added to decouple Beam1 and Beam 2 systems. The electronics architecture, as installed at the end of 2018, is illustrated in Figure 3. To actuate the four mechanisms for each beam, the output of the control electronics is multiplexed in the LHC tunnel. The control electronics is designed in-house with one VME control board connected to a motor power amplifier located at the back of the VME crate. The digitisation of the PMT signal is performed with analogue integrators (IBMS in the figure).

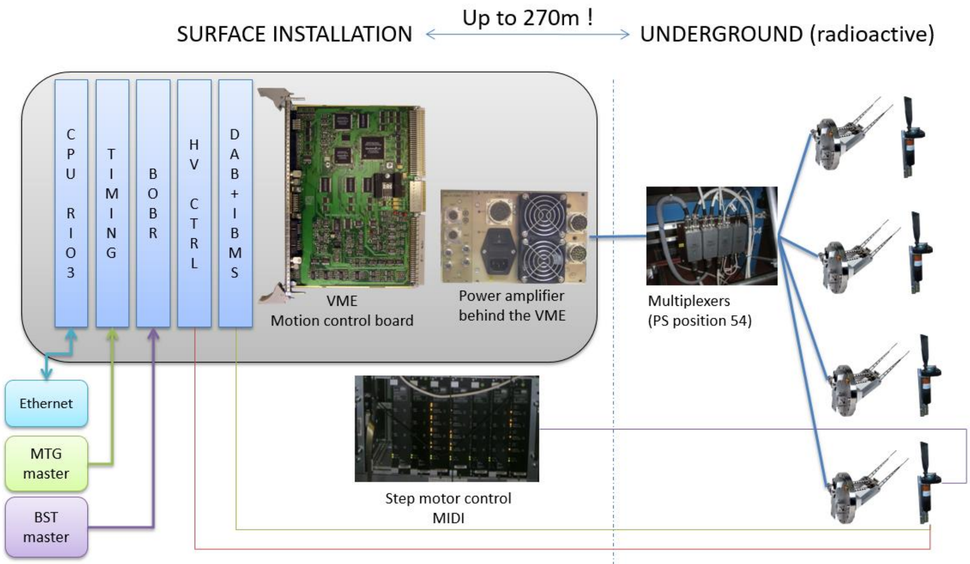

Figure 3: Present LHC wire-scanner electronics architecture for one beam.

The LHC experience has shown that the system reliability is affected by its electronic control architecture and the operating regime of its components. Failures have been observed in both the multiplexers and the motor control power stages, which are operated at the limit of their capability. A comprehensive summary of the electronics limitations and reliability issues encountered during the LHC Run1 can be found in [2].

The present scintillator-PMT detector design includes a set of movable optical density filters between the scintillator and the PMT, to cover the dynamic range of the signal. The user has to adjust 'by-hand' the PMT HV and the optical attenuation depending on the beam conditions. This exposes the setup to human error. The presence of a movable filter wheel is also an additional electro-mechanic component that can fail.

2. POSSIBLE SOLUTION

During LS2, all scanners in the PSB, PS and SPS will be replaced by a new generation (mechanics, detectors and all related electronics) developed over the last few years as part of the LIU project.

For the LHC, the only possible solution that can be implemented in the short term is the adaptation of the new LIU electronics (control and acquisition) to the existing linear scanners, which nevertheless implies some mechanical adaptations.

3. PROPOSED SOLUTION

3.1 DESCRIPTION OF THE SOLUTION

The proposed solution is to adapt the LIU control and acquisition electronics to the LHC system by making minimal changes to its hardware and firmware. The new electronics has the advantage of featuring an intelligent power control unit, which should enhance reliability and easy the diagnostics of software, firmware and hardware issues.

A schematic diagram of the new electronics as foreseen for the LHC is shown in Figure 4.

Each scanner will have its individual control unit with a VME CPU per beam. It is foreseen to move the electronics from the present location (US45 for both beams) to UA47 (Beam1) and UA43 (Beam2). This results in shorter cables, which have already been installed during LS2.

The LHC mechanism is moved by a DC motor while the LIU scanner uses a brushless motor with three phases (PMSM). To minimise modifications to the control electronics, the proposal is to modify the existing wire scanner mechanism to integrate a brushless motor, with a resolver to measure the angular position of the shaft (as is done for the LIU mechanism). The mechanism design before and after consolidation is shown in Figure 5.

The proposed LHC consolidation will also replace the outdated acquisition electronics (scintillator-PMT assemblies with movable filters) with the 4-channel PMT detector acquired with fast VME digital integrators developed for LIU.

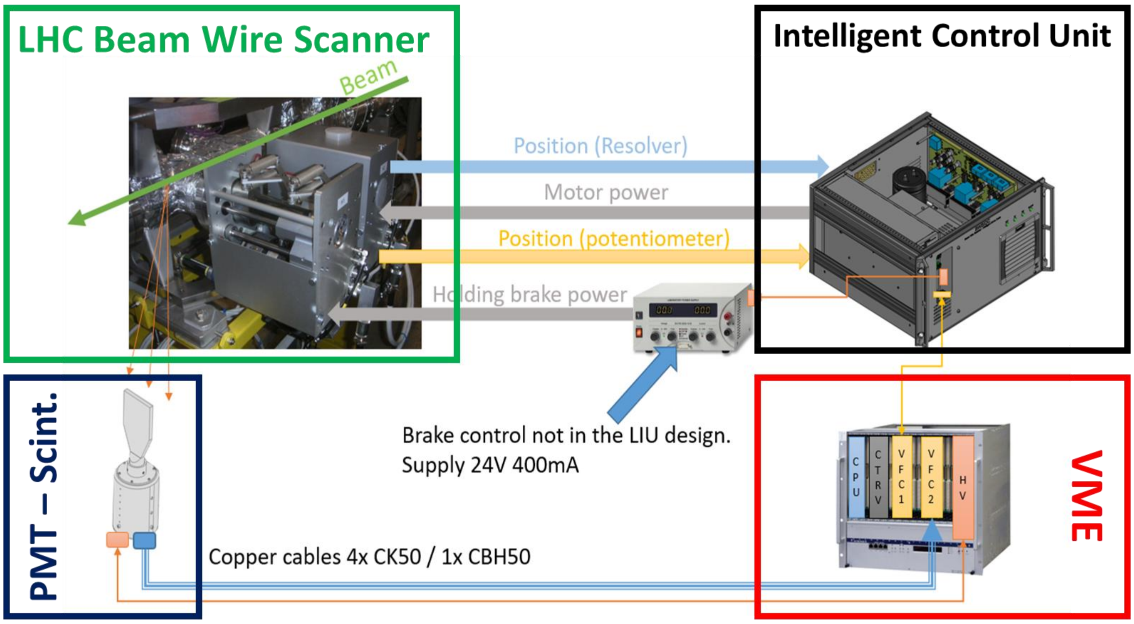

Figure 4: LHC wire-scanner architecture with the LIU electronics

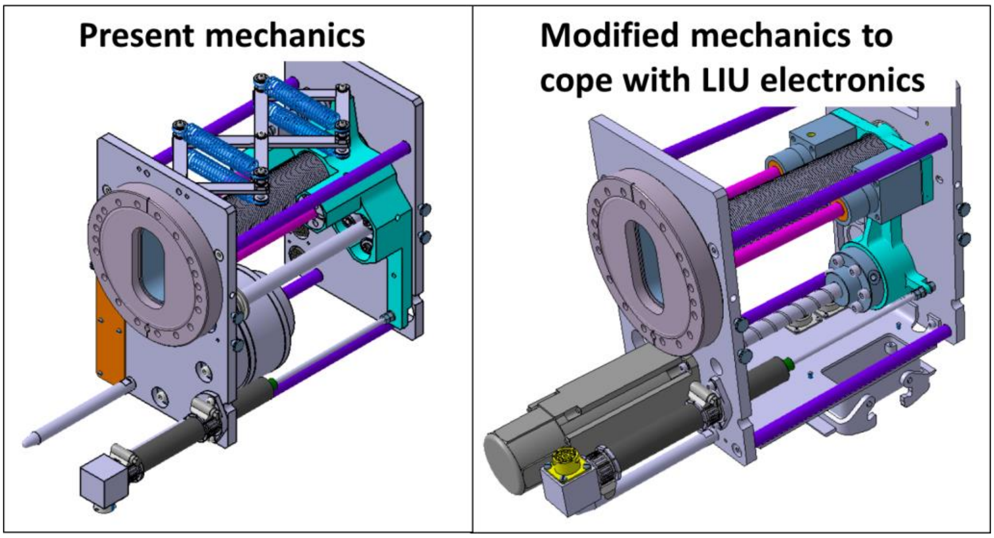

Figure 5: Present mechanics (left) and modified version as foreseen after the consolidation (right)

3.2 OPERATION, RELIABILITY, AVAILABILITY, MAINTAINABILITY, ENVIRONMENTAL ASPECTS

Operation aspects, Impact of delay of consolidation	A consolidation delay would imply a continued degradation in the reliability of the system in Run 3. This has implications for the calibration of the devices on which the LHC relied for accurate emittance measurements.
Reliability Aspects	There have been several examples of reliability issues with the present control and acquisition electronics (scanners not operating, scanners stuck in the beam, …). This can be expected to degrade if the electronics is not consolidated.
Availability Aspects	The multiplexing of the motor control implies that any motor failure leads to the unavailability of all scanners for a given beam, requiring access to fix.
Maintainability and Supportability Aspects	The current electronics is outdated and will be the only such system left after LS2, once all the injector wires canners have moved to the new control architecture. Long term maintainability and supportability for the software and firmware is therefore an issue.
Environmental Aspects	There is no measureable environmental impact that is expected from this project.

3.3 IMPACT ON OTHER ITEMS

3.3.1 IMPACT ON UTILITIES, ON SERVICES, AND ON SAFETY

Requirement	Yes	No	Comments
Cooling, Ventilation and Compressed air		x	
Cryogenics		x	
Electricity, cable pulling DEC/DIC (Demande enlèvement/installation câbles) (power, signal, optical fibres, signal, control…)	x		New cables have to be pulled to be able to control and power the linear scanner having brushless motor operating at around 320V. This has been completed in LS2.
Vacuum (bake outs, sectorisation…)	x		Although no vacuum intervention is required to modify the wire scanner mechanics, it may imply venting the sector to allow the work to proceed in a safe manner.
Special transport/ handling: (Scaffolding…)		x	
Civil engineering works		x	
EIS-Access, EIS-Beam, EIS-Machine		x	
Operational radiation protection (DIMR, ALARA committee…):		x	
Radioactive waste:	x		Parts of the mechanism has been activated and will have to be considered as waste after the consolidation.

3.4 COST, SCHEDULE AND PERFORMANCE

3.4.1 BUDGET PROFILE

The consolidation headings fund materials.

Resources request	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Material [kCHF] (original request)			50	100						
Material [kCHF] (2018 request)			24	80	60					
Material [kCHF] Nov.2019 Update			24	28	90	100	30			
FSU [FTE·Yrs]										
Fellows/students [FTE·Yrs]										

Personnel resources (earmarked and ring-fenced)

Personnel resources	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Needed staff					0.1	0.3	0.2			
Pledged staff					0.1	0.3	0.2			
Missing										

The total cost has increased from the original 150kCHF requested in 2016 to 272kCHF in 2019. This is due to the unforeseen need for mechanical adaptation of the scanner actuators to be compatible with the new motors.

The BE-BI group manpower allocated to maintain and consolidate the LHC in APT would adequately cover the design, test and installation of the concerned devices.

3.4.2 PROPOSED INSTALLATION SCHEDULE

Requirement	2015	YETS 2015 2016	2016	EYETS 2016 2017	2017	YETS 2017 2018	2018	LS2 2018 2019	2020	2021	2022	LS3 2023 2024
Proposed installation schedule and duration									A	B	B	

A: Installation of one prototype of mechanism & LIU electronics.

B: Installation of the systems for the remaining 7 scanners.

3.5 IDENTIFICATION OF STAKEHOLDERS AND PROJECT SPONSORS

- BE/OP and BE/ABP are stakeholders/sponsors. This is a key instrument for operations, machine understanding and optimisation.
- Given the importance of accurate emittance measurements, the LHC experiments can also be considered as sponsors.

4. RISK ASSESSMENT

In order to compare and contrast the consolidation project requests, general information and risk assessment is to be completed. In the following tables, ***system*** refers to the existing solution, ***project*** or ***consolidated system*** refers to the solution being proposed within this consolidation request. Please complete the column(s) on the right hand-side.

Table 1 — Background Information

General Information		
Description:	***Possible Values:***	***Value:***
Number of instances of the system, or proposed composition of the project:	• Chassis • Controllers • Converters • Other (please specify)	8 scanner systems (4 for each beam)
Programs and facilities in which the system/project is or will be installed:	• LHC scientific program (Y/N) • LHC test beams (Y/N) • SPS fixed target scientific program (Y/N) • PS fixed target program (including nTOF) (Y/N) • AD scientific program (Y/N) • ISOLDE scientific program (Y/N)	LHC scientific program
Project development and procurement strategy:	• In-house • Turn-key • Other (please specify)	In-house
When can the project be implemented?	• Any time • Technical Stop (TS) • Year-end technical Stop (YETS) • Long Shutdown (LS)	Year-end technical stop and long shutdown.
If the consolidation project request is not successful, what is the impact on other CERN systems/projects?	• 1 = Insignificant (no impact) • 2 = Moderate (delays to one or more) • 3 = Major (cancellation of one) • 4 = Critical (cancellation of several)	2
If the consolidation project request is successful, what is the impact on other CERN systems/projects?	• 1 = Insignificant (no impact) • 2 = Moderate (one system requires modification for compliance with consolidated system) • 3 = Major (several systems require modification for compliance with consolidated system) • 4 = Critical (complete redesign of one or more systems for compliance with consolidated system)	2

4.1 Failure Modes

For the existing system, it is important to understand the impact of failures, which have been known to occur, or which may occur.

In the table below, identify failure modes **F1** to **F4**, giving the ways in which the system has, or may, fail. Observed, should be completed with a failure mode which has occurred during the operation of the system. Potential implies a failure mode which is possible, but may not necessarily have occurred.

- For potential failures, consider the most credible case.
- Information and thresholds concerning **F4** have been elaborated in collaboration with the HSE department.

Table 2 — Main system failures

Failure modes	
Description:	***Description:***
The most frequently observed, failure mode of the system impacting on *accelerator operation* – **F1**	The scanners not responding to scan requests or acquisition system not in optimal condition. No or poor emittance measurements impacting machine optimisation.
Worst case potential failure mode of the system impacting on *accelerator operation* – **F2**	Electronic failure during operation of the scanner, mechanism stuck in the middle of the vacuum chamber, requiring tunnel access to resume beam operation. The scanners have twice been found stuck in the IN position for a long time, leading to the breakage of the carbon wire, requiring an in vacuum repair.
Worst case potential failure mode of the system impacting on *personnel safety* – **F3**	None
Worst case potential failure mode of the system impacting on *environment* – **F4** (please see appendix)	None

4.2 Failure Mode Occurrence / Likelihood

Historical information about the existing system **reliability** needs to be known, and compared to that which is expected to be achieved by the consolidated system. Using the failure modes which were defined in the previous table, please complete the columns on the right hand side.

System/Project Failure Mode Occurrence / Likelihood			
Description:	***Possible Values:***	***Existing System Value:***	***Consolidated System Value:***
Expected system end-of-life. e.g. the dominant failures of the system are caused by ageing / cumulative effects.	• 1 = 2035 to 2040 • 2 = 2030 to 2035 • 3 = 2025 to 2030 • 4 = ≤ 2025	4	1
Failure frequency per year of **F1**: • For the existing system, average over the last 3 years of operation, sum for all instances. • For the proposed consolidated system, use predictions	• 1 = Low (≤1 failure / year) • 2 = Probable (≈1 failure / year) • 3 = Frequent (≈10 failures / year) • 4 = Very Frequent (> 10 failures / year)	4	2
Estimated frequency per year for **F2**.	• 1 = Low (1 failure / 1000 years) • 2 = Probable (1 failure / 100 years) • 3 = Frequent (1 failure / 10 years) • 4 = Very Frequent (1 failure / year)	4	3
Estimated frequency per year for **F3.**	• 1 = Low (1 failure / 1000 years) • 2 = Probable (1 failure / 100 years) • 3 = Frequent (1 failure / 10 years) • 4 = Very Frequent (1 failure / year)	1	1
Estimated frequency per year for **F4.**	• 1 = Low (once in 10 years) • 2 = Probable (once per year) • 3 = Frequent (once per month) • 4 = Very Frequent (once per week)	1	1

4.3 Failure Mode Impact

The impact of each failure modes is to be defined, please complete the columns on the right-hand side of the table below:

System/Project Failure Mode Impact			
Description:	***Possible Values:***	***Existing System Value:***	***Consolidated System Value:***
When will components / technology of the system become unmaintainable (e.g. due to obsolescence, lack of know-how, exhaustion of spare supply, loss of backup systems)	• 1 = 2035 to 2040 • 2 = 2030 to 2035 • 3 = 2025 to 2030 • 4 = ≤ 2025	4	1
F1 observed downtime: • For existing system, average over the last 3 years of operation, sum for all instances. • For consolidated system, please use predictions	• 1 = < 1 hours • 2 = 1 – 12 hours • 3 = 12 – 24 hours • 4 = > 24 hours	4	2
F2 estimated downtime:	• 1 = < 1 week • 2 = 1 week to 1 month • 3 = 1 month to 1 year • 4 = > 1 year / beyond repair	1	1
F3 estimate consequence:	• 1 = Insignificant (no injury) • 2 = Moderate (injury requiring medical attention, but no loss of working days) • 3 = Major (serious injury requiring medical attention and loss of working days) • 4 = Critical (i.e. loss of life)	1	1
F4 estimated consequence: (please see appendix)	• 1 = minor event • 2 = moderate event • 3 = major event • 4 = critical event	1	1

5. REMARKS AND ADDITIONAL INFORMATION

6. REFERENCES

[1] LHC Beam Size Measurement Review Findings, October 2019. https://indico.cern.ch/event/837340/attachments/1924743/3185135/LHC_Beam_Size_Measurement_Review_-_Findings_Comments_Recommendations.pdf

[2] J.Emery et al., Overview of performance and limitations of current scanners and technical choices for a new wire scanner, May 2013

https://indico.cern.ch/event/229959/contributions/482488/

7. APPENDIX

Considerations for environmental impact:

Air – emissions of greenhouse gasses, noxious substances, radioactivity, etc.

Water – chemical pollution, etc.

Energy – consumption of significant amounts of energy, or significant loss in efficiency.

Other Potential Pollution – soil contamination, noise, visual etc.

Definitions of environmental consequences of failures:

Minor Event: has a low impact and a duration less than 5 years. Such an event is a situation or action having measurable and visible effects on the environment without species mortality or any need to clean-up.

Moderate Event: has a high impact and a duration less than 5 years. Such an event is a situation or action having measurable and visible effects on the environment, without species mortality, requiring <5 years on-site clean-up and/or <1 year off-site clean-up and/or remediation.

Major Event: has a high impact and a duration 5 years or greater. Such an event is a situation or action having measurable and visible effects on the environment, including limited species mortality, requiring >5 years on-site clean-up and/or <5 years off-site clean-up and/or remediation.

Critical Event: has an irreversible and extensive impact: a situation, action or event that has permanent effects on the environment and includes extended species mortality and compulsory active clean-up and remediation.