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HORIZON EUROPE PROGRAMME – TOPIC HORIZON-CL5-2022-D2-01-06
Embedding smart functionalities into battery cells (embedding sensing and self-healing functionalities to monitor and self-repair battery cells)
(Batteries Partnership)

PHOENIX

Building more reliable and performant batteries by embedding sensors and self-healing functionalities to detect degradation and repair damage via advanced Battery Management System

Grant Agreement No. 101103702
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Deliverable D6.1
BMS requirements

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SHORT ABSTRACT FOR DISSEMINATION PURPOSES

Abstract

This deliverable concludes the work carried out in task 6.1; it contains the requirements of the PHOENIX Battery Management System. This document ensures that: a) the sensor values can be accessed and that the self-healing set-points can be sent, b) BMS users can have access to the needed cell sensor data and develop the algorithms as required, c) the developed cells can easily be connected to the BMS

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ABBREVIATIONS

ACRONYM	DESCRIPTION
BMS	Battery Management System
CMS	Cell Management System
DES	Dielectric Elastomer Sensor
GA	Grant Agreement
NTC	Negative Temperature Coefficient
PP-board	Pre-processing board
RE	Reference electrode
SH	Self-Healing
TBC	To be confirmed
WP	Work package

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EXECUTIVE SUMMARY

The objective of this deliverable is to provide the Battery Management System (BMS) requirements. These requirements were collected from all relevant parties (WP3: self-healing (SH) developers and sensor developers, WP4/WP5: BMS users). This work will directly guide the BMS development that will be carried out in T6.2 First BMS manufacturing and testing.
This deliverable is aligned with the expectations of the Grant Agreement (GA).

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1. INTRODUCTION: BMS HIGH LEVEL REQUIREMENTS

The objective of this document is to provide the Battery Management System (BMS) requirements. Figure 1 provides an overview of the BMS integration within the project. In order to facilitate the reading of the requirement and to ensure that relevant partners find the needed information, the requirement document is broken down into:

- **Chapter 2** (SENSOR AND SH INTERFACE REQUIREMENTS), to clarify how to:
  - Receive the sensor data of WP3,
  - Send SH activation commands to the developments of WP2 via the activation mechanisms of WP3.
- **Chapter 3** (BMS TO USER INTERFACE), provides details about:
  - How WP4 and WP5 users can gather information from multiple cells,
  - How WP4 and WP5 users can send SH activation signals.
- **Chapter 4** (ALGORITHM HOSTING), explains:
  - How algorithms aiming to detect degradation and trigger SH (developed by partners in WP4 and WP5) can be included in the BMS.
- **Chapter 5** (BATTERY MANAGEMENT), provides:
  - Requirements in terms of battery management features.
- **Chapter 6** (MECHANICAL AND OTHER REQUIREMENTS), gives:
  - Requirements that do not belong to the previous chapters (in particular mechanical, financial).

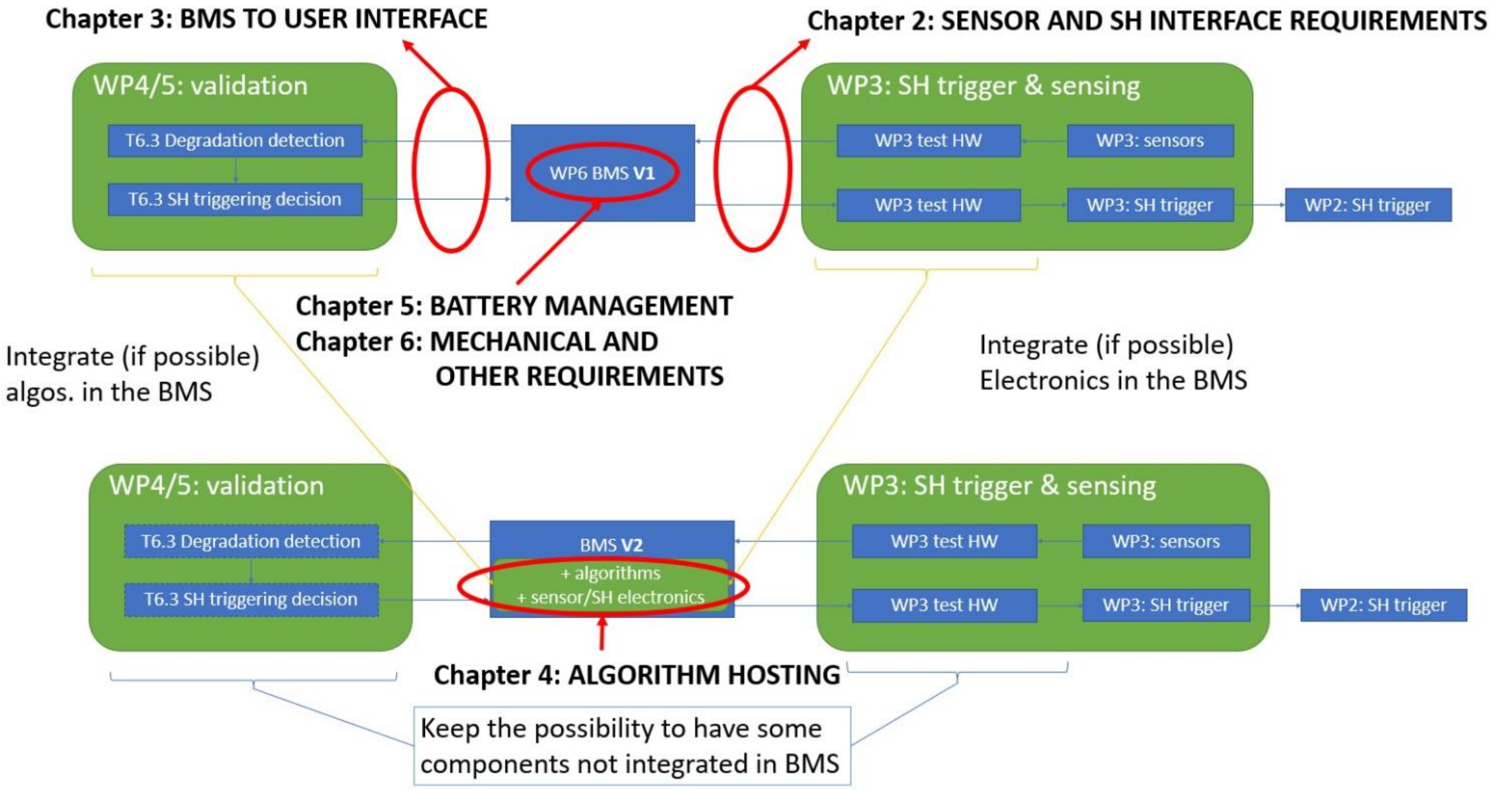

Figure 1. Interaction of BMS V1 (top part) and V2 (bottom part) with WP 2, 3, 4, and 5

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2. SENSOR AND SH INTERFACE REQUIREMENTS

One of the goals of the BMS is to allow the cell users (of WP4 and WP5) to conveniently interact with the cells, by having a single point of contact. As a reminder, the PHOENIX cells will be equipped with:

a) **Triggering mechanisms** (all from T3.1), as summarized in **Table 1**:
   1. Thermal triggering
   2. Magnetic triggering
   3. Pressure triggering (Hazel actuator)

b) **Sensing**, as summarized in Table 2 :
   1. Ultrasonic sensors (T3.2)
   2. Dielectric elastomers sensors (DES) (T3.3)
   3. Negative temperature coefficient (NTC) based sensor and optical fibre-based temperature sensors (T3.4)
   4. Gas sensors (T3.5)
   5. Reference electrodes (RE) (T3.6)

Figure 2 provides a high-level view of the interactions of these different elements, note that one of the strength of the proposed solution is the usage of the PP-board from FHG that connects to all FHG sensors/actuators:

- For the gas sensors, two options are foreseen:
  - **option a**: keep using the existing off the shelf electronics. These are already equipped with interface to standard PCs. **It is not yet clear if interfacing such electronics with the BMS is feasible or even desired (as these electronics are already equipped to communicate with standard PCs passing though the BMS might induce unnecessary complexity and development costs).**
  - **option b**: use the same PP-board to interface with the gas sensors. DLR are to conduct additional tests to clarify this possibility.
- For the optical fibre temperature sensing, **computationally intensive analysis scripts are required, based on the current tests it is very likely that these will remain on a PC-based solution. If so, having them run directly on the test PC of WP4 and WP5 could be a reasonable option.**

Figure 3, provides an illustration of a potential fallback solution.

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Table 1. Triggering mechanisms high level requirements

Triggering mechanism	Interfaced to	Number of triggering devices	Amplitude signal	Duration signal	Data format
a.1: Thermal triggering	PP-board	1	ON/OFF (maybe, temperature in spare)	No explicit duration, keep sending "ON". Send around 1x/minute.	Bool & unsigned int
a.2: Magnetic triggering	PP-board	1	ON/OFF (maybe, temperature in spare)	No explicit duration, keep sending "ON". Send around 1x/minute.	Bool & unsigned int
a.3: Pressure triggering	PP-board	1	ON/OFF	No explicit duration, keep sending "ON". Send around 1x/minute	Bool

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Table 2. Sensing mechanisms high level requirements

Sensing mechanism	Interfaced to	Number of sensors	Measured value	Measurement frequency	Data format
b.1: Ultrasonic sensors	PP-board	1	Time of flight [uS] with a resolution of 0.01 [uS]	~1 sample per minute	Unsigned int (divider on target system: 1000)
b.2: Dielectric elastomer sensors	PP-board	1	Deformation [um] with a resolution of 0.1 [um] (absolute value 50um)	~1 sample per minute	Unsigned int
b.3 NTC: Negative temperature coefficient	PP-board	1 (might be increased to 9)	Temperature [°C] from -10 to 80°C	~1 sample per minute	Table of signed int
b.3 Fibre: Optical fibre-based temperature	BMS, via serial communication (the optical fibre algo. runs on a PC).	1 (**~10 measurement points**)	Several (around 10), temperature readings [°C] from -10 to 80°C, evenly spaced around the fibre	Not faster than 1 sample per second	Table of signed int
b.4: Gas sensors (**OPTION A**)	PP-board (TBC by tests of DLR)	1	Resistance [ohm], that translates into gas concentration. Range and resolution TBC by further experiments. DLR is currently performing experiments to define these values. For the 1st tests it is proposed to use option B (i.e. Keithley electronics)	Around 1 sample per minute	TBC by further experiments.
b.4: Gas sensors (**OPTION B**)🡪 not through BMS ideally	BMS to Keithley 2635A (RS-232, ethernet, USB)	1	Resistance [ohm], that translates into gas concentration. Range and resolution TBC by further experiments.	Around 1 sample per minute	TBC by further experiments.
b.5: Reference electrodes	BMS	2	i) Half cell voltage [V] between reference electrode and anode/cathode. Range 0-5V with a resolution of 0.01V (**in practice it will be measured at: a) bat. + and gnd, and RE and gnd**).	i) 1 sample per minute or less	i) Float 32 ii) Table of uint16

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			ii) EIS between the reference electrode and the cathode/anode (**in practice it will be measured at: a) bat. + and gnd, and RE and gnd**).	ii) EIS performed "once per cycle at most"	

Table 3. BMS to PP-board requirements

Protocol: serial
Implementation: it is proposed to use an implementation similar as the one carried out in the EU project SPARTACUS (https://www.spartacus-battery.eu/), **but bi-directional.** Doing so would allow CSEM and FHG to start working on known ground and thus reduce development time and risks.
Important: same naming convention between PP-board / BMS and BMS WP4/WP5 users
A timing diagram proposal is shared in Figure 4. The objective is to avoid continuous messaging from the PP-board to the BMS (as: a) there will be commands coming from the lab PC ➔ to the BMS ➔ to the PP-board b) the BMS is "not a PC" and has limited capacity
Mechanical: foresee 4 mounting holes on the PP-board (host)
Electrical: host as close as possible to BMS

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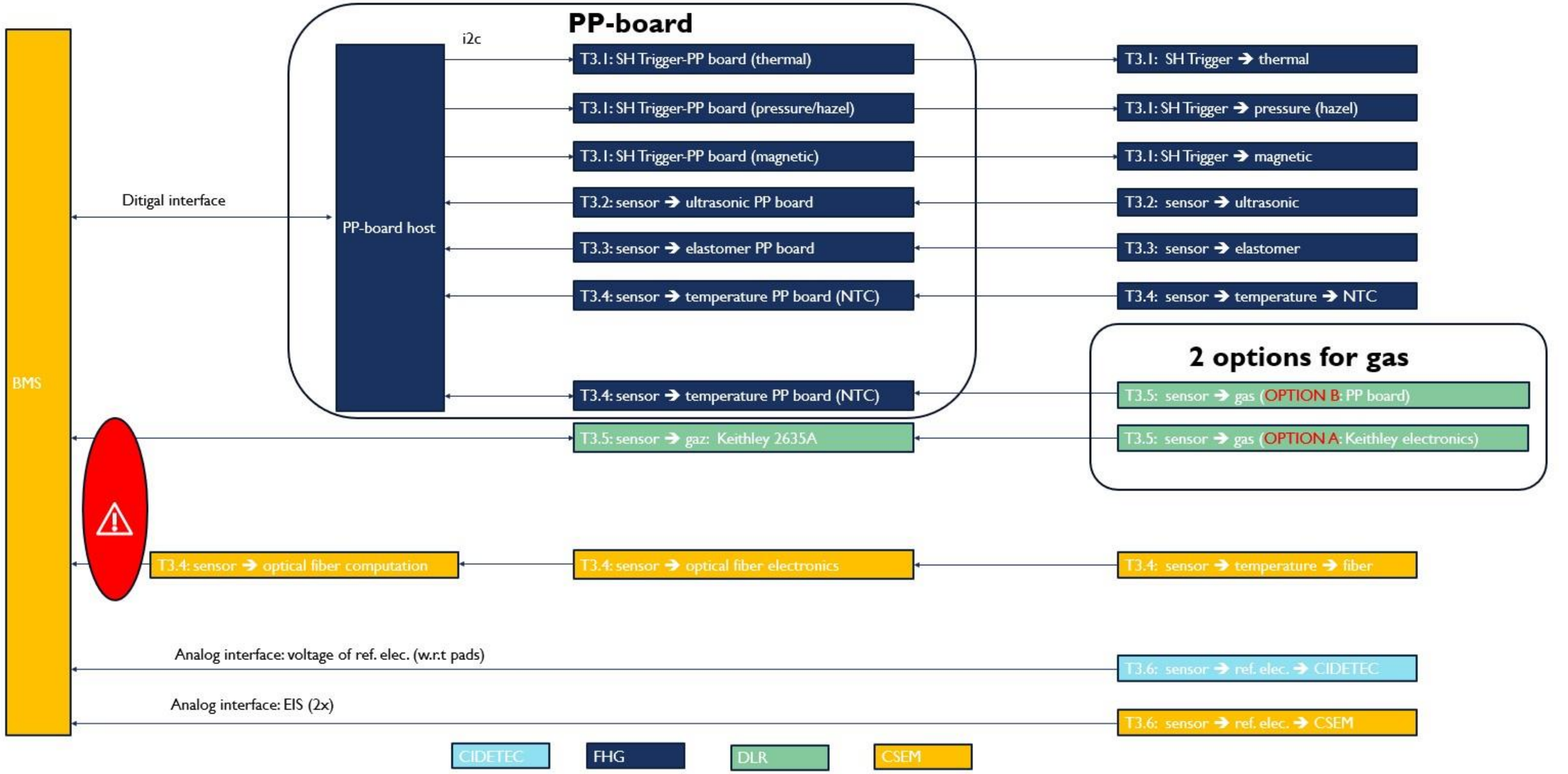

Figure 2. Possible BMS-PP-BOARD-SENSOR proposal (ideal case)

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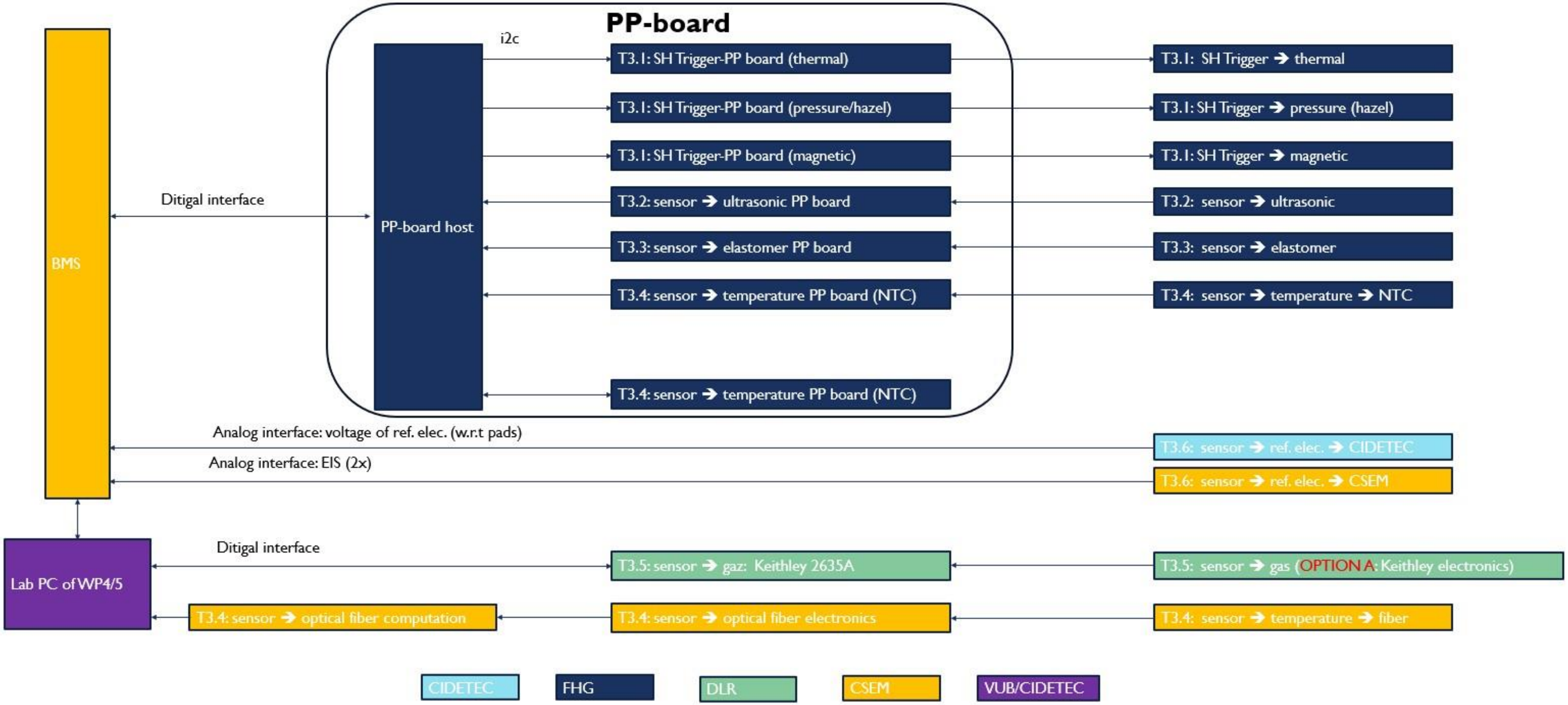

Figure 3. Possible BMS-PP-BOARD-SENSOR proposal (possible fallback solution)

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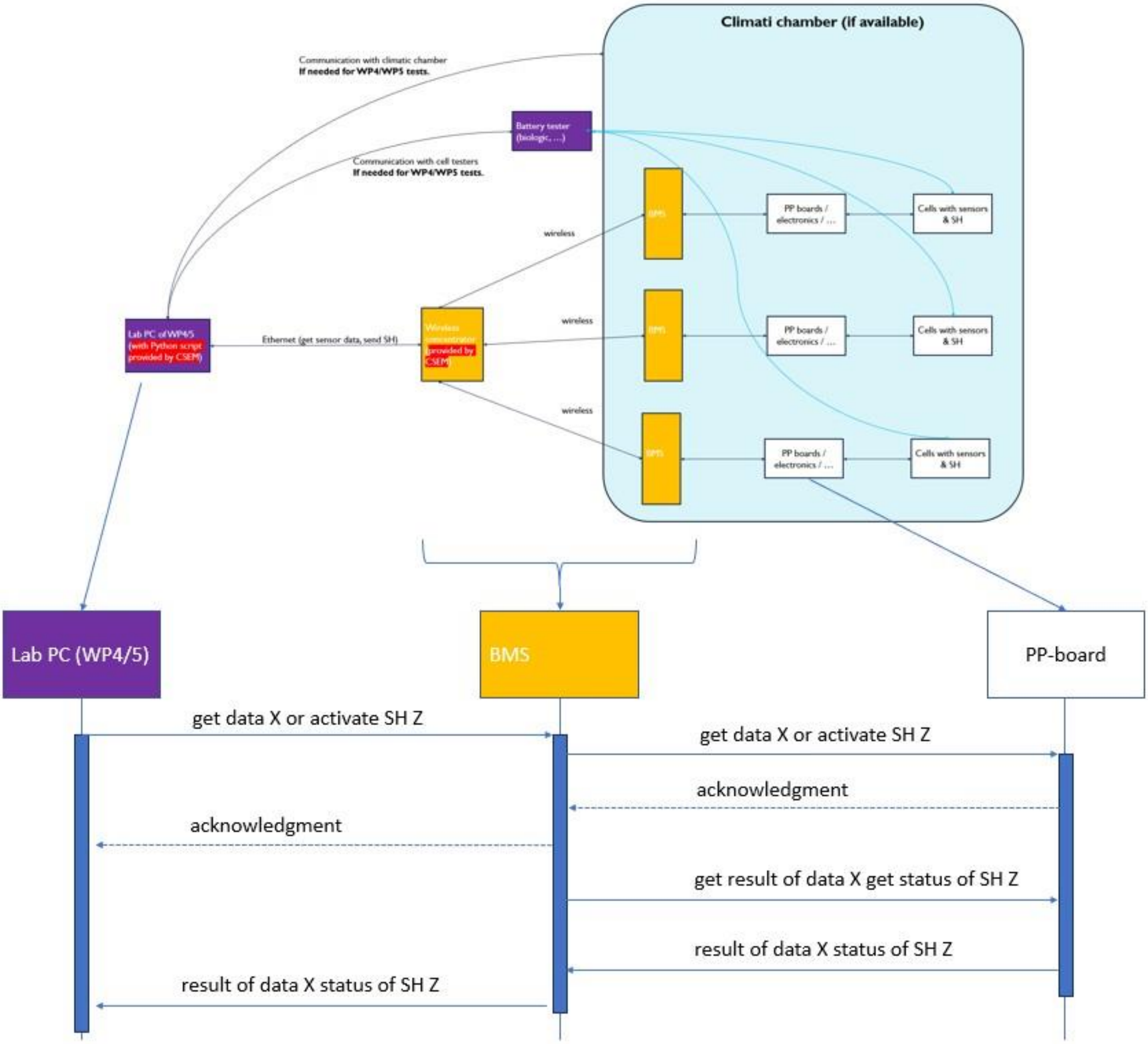

Figure 4. Bottom: timing diagram proposal between Lab PC, BMS and PP-board, top: see **Figure 5**

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3. BMS TO USER INTERFACE

The BMS will be used in WP4 (single layer cells) and in WP5 (multi-layer cells).
From a user point of view, the main requirements are summarized in **Table 4**.

Table 4. BMS user high level requirements

Item	**Requirement**
Number of cells cycled at a same time	Between 10 and 20, **insulated from each other (i.e. the cells are not put electrically in series to make a battery pack/module)**.
Data access (bi-directional)	Requires "little-to-no" development time for the BMS user to get data and send commands.
Testing strategy	**Not all cells will be equipped with all sensors and SH triggering (i.e. the BMS must be able to work also if not all sensors / SH are connected).**
Commissioning	The commissioning linked to the BMS (in particular cabling) shall be minimal. Wireless communication is foreseen, a wired fall back solution (for instance RS485) will be put in place if needed.
Powering	The BMS is powered by the battery cell

The proposed BMS layout is illustrated in **Figure 5**. To minimize the cabling issues, but also to be closer to the final reality (where cells will be manufactured with the BMS fully integrated), wireless communication will be put in place.

To ease the work on the BMS users, a **wireless dongle (also called wireless concentrator) will be provided by CSEM.** The latter is used for the bi-lateral exchange between the BMSs and the PC. **This dongle is connected to the PC via ethernet (this is required as the control PC might be in a different room than the BMS)** used to bi-directionally exchange data between the PC and the BMSs.

To communicate with the BMS, an application will be provided. The latter allows to: a) initialize the wireless network, initiate the data saving, send SH activations. This application can be launched via Python for instance. A high level timing diagram is provided in Figure 6.

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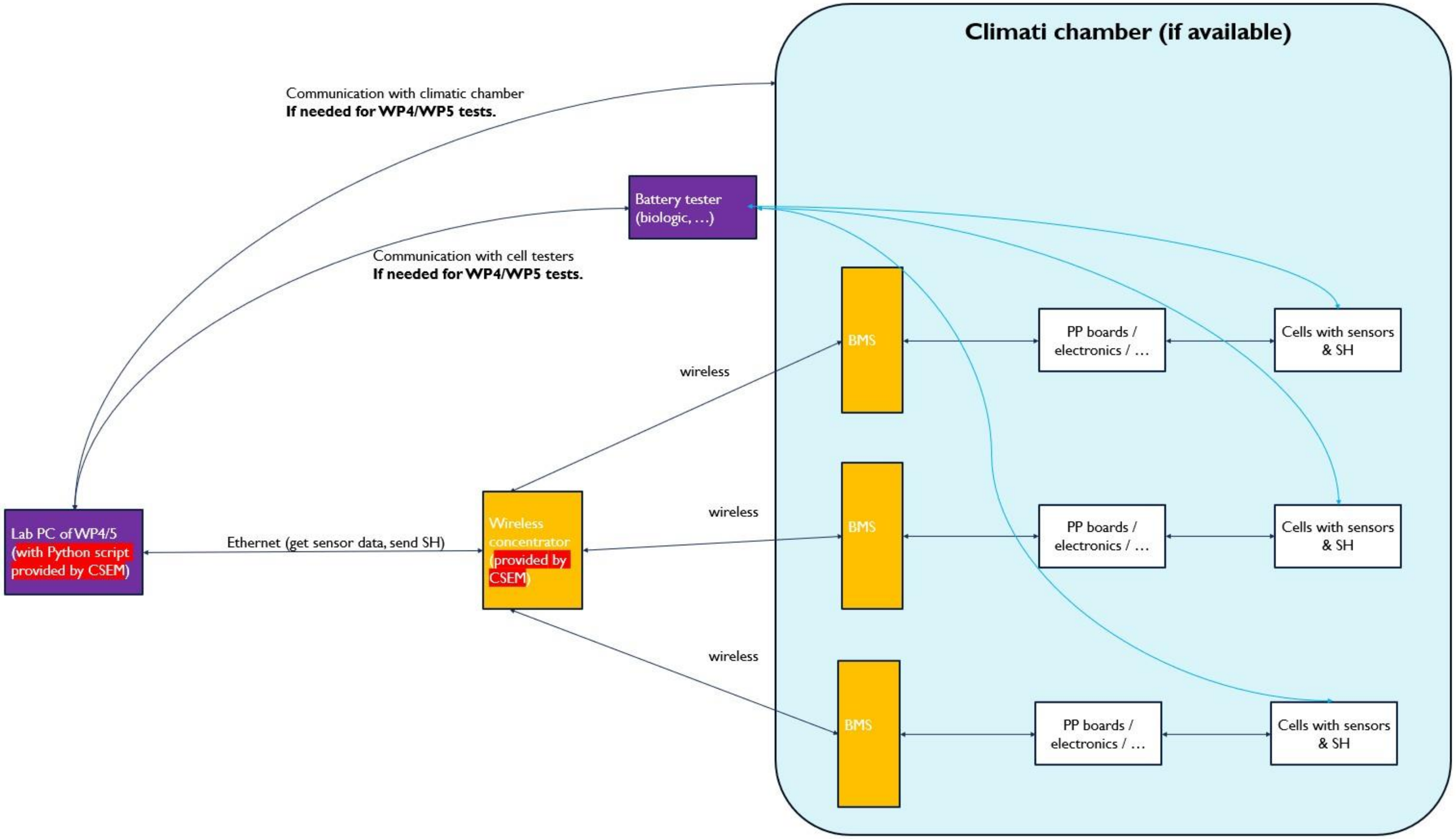

Figure 5. BMS and user interface proposal

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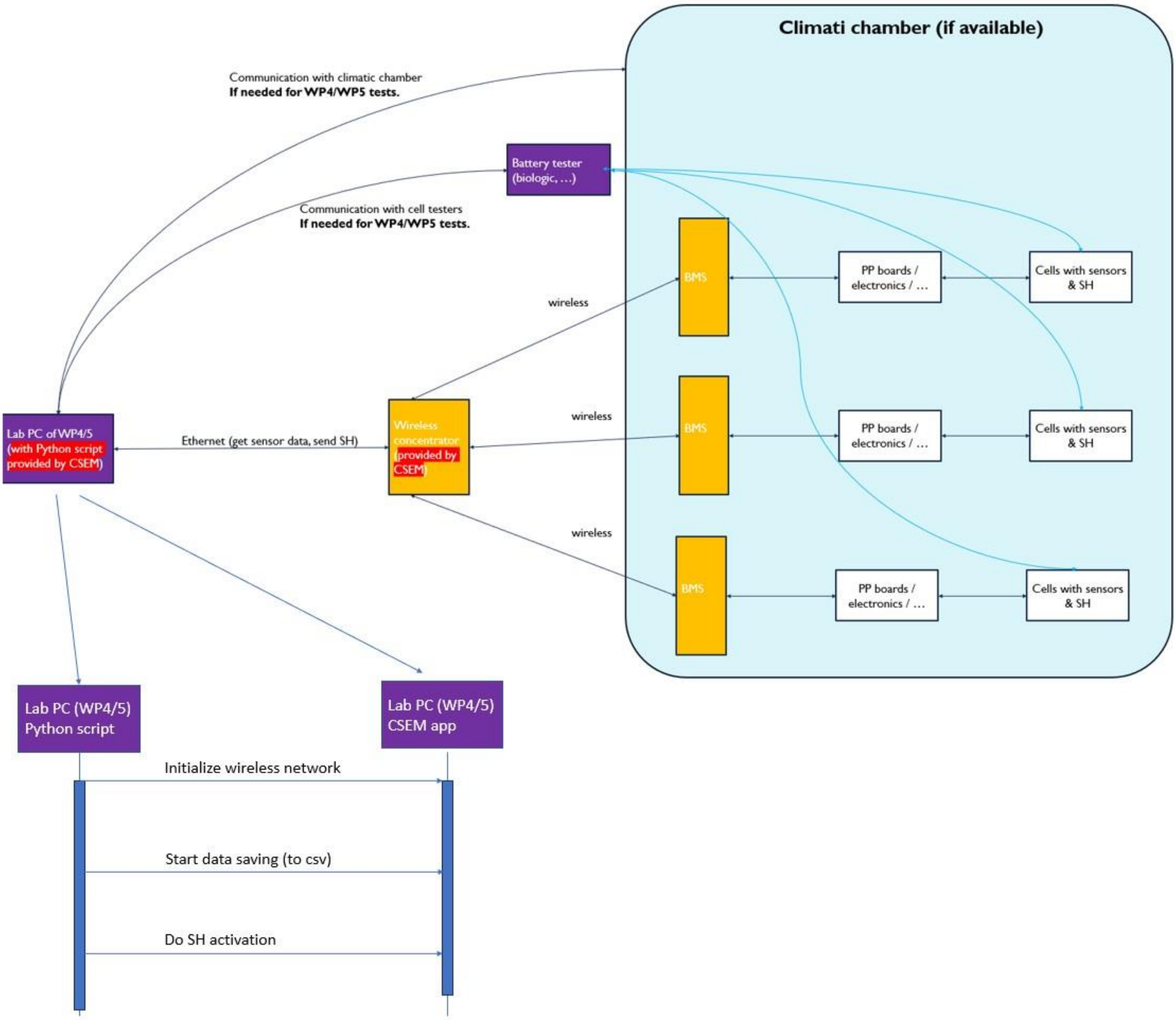

Figure 6. High level timing diagram (setup the wireless network, save data, send SH activation)

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4. ALGORITHM HOSTING

The algorithms developed in WP4/5 (to detect degradation and decide when to activate SH), should ideally be hosted in the BMS, as proposed in the GA (**Figure 1**):

- For the BMS V1 (MS10), the algorithms will on a dedicated PC. To allow partners to freely develop the code.
- For the BMS V2 (MS11), the objective is to include algorithms into the BMS, while keeping the possibility to have some running on a similar PC as in WP4.

The ability to put code in the BMS is given by practical limits, in particular due to the used microcontrollers that need to meet financial requirements. The main limitations are summarized in **Table 5**. **In consequence, the algorithms are to be small in size and require a reasonably small computing capability.**

Table 5. BMS algorithmic main limitations

Item	Requirement
Supported code	C for ARM M4f @80MHz
Maximal size	Total 1M flash 128kB of RAM (some of it used by BMS functions).
Maximal computing capacity	ARM M4f @80MHz → 100 millions instructions per second (MIPS)

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5. BATTERY MANAGEMENT

As a BMS, the proposed solution is to carry out all the key features that are summarized in Table 6.

Table 6. Battery management features

Feature	Requirement
Cell voltage	0-5V, 0.01V resolution
Over/under-voltage detection	Continuous monitoring.
Temperature monitoring	-30 to 80°C, 0.1°C resolution, precision 1°C (**1 NTC placed close to the anode**).
Sensor management	The BMS shall manage the sensors as described in Chapter 2 (in particular, **Table 2**)
SH management	The BMS shall manage the SH as described in Chapter 2 (in particular, **Table 1**)
Communication management	The BMS shall manage the sensors as described in Chapter 2 (in particular **Table 3**) and in Chapter 3 (in particular, **Table 4**).
BMS self power management	The CMS is self powered by the cell ➔ the HW and FW will be optimized accordingly (i.e., it will be low power).

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6. MECHANICAL AND OTHER REQUIREMENTS

From a mechanical point of view, the main constraints are imposed by the cell dimensions (in particular the tabs, see Figure 7). From a financial standpoint, real life applications are the main driver, this mainly impacts the processing capabilities of the BMS. These considerations are summarized in **Table 7**.

Table 7. BMS algorithmic main limitations

Item	Requirement
Cell connection	The BMS must be compatible with the cell, in particular the BMS must be designed to allow the tabs to be fixed correctly.
Reference electrode connection to BMS	The reference electrode will be fixed using the same method as for the cell tabs (see above). The **preferred** location for the reference electrode location on the BMS is between the cell tabs.
BMS dimension	The BMS must be reasonably small, compared to the cell.
BMS-PP-board assembly	The BMS and PP-board will be fixed on a mechanical plate **(the BMS and PP-boards must have holes foreseen for this).**
Reference electrode connection to BMS	The reference electrode will be fixed using the same method as for the cell tabs (see above)

For the cell fixation, several options are possible. It is expected that several cells will be tested using the same BMS, in particular for the tests in WP4. In consequence we propose to either:

a) Fix the cell by making holes in the tabs (by the means of a hole puncher) and using a screw with washers for the mechanical & electrical fixation, see Figure 8 (this is the **preferred option**)

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b) Using alligator clips, this solution can be acceptable for lower currents (WP4), but is not the preferred option.

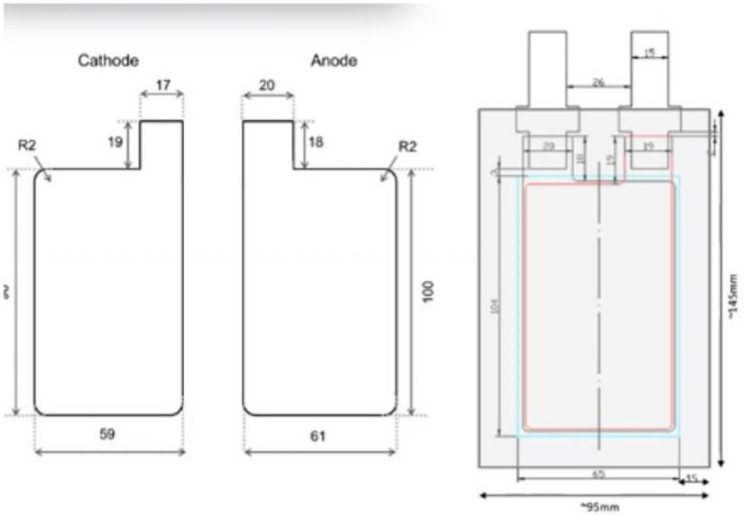

Figure 7. Single layer cell estimated dimensions (WP4)

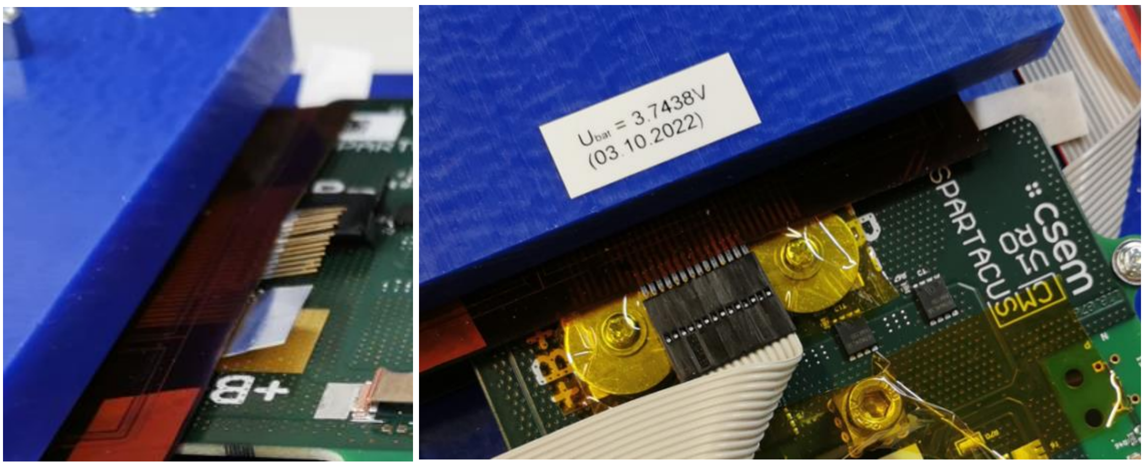

Figure 8. Left: before fixation, right: cell fixed usin screws and washers (with insulation material on top)

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7. CONCLUSIONS

This document contains the BMS requirements. It will be used to manufacture the BMS V1 in T6.2.

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