REPORT

NBLM PROJECT

CDR1.2 - FINAL

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CONTENTS

1. Introduction

1.1. Purpose

This is the final CDR1.2 for the nBLM Project. It was split in two to avoid delays in the procurement of material. In July 2018 a CDR1.2.1 was presented with the focus on the mechanical design of the detectors and gas system (https://indico.esss.lu.se/event/1083/).

The document is complemented with further documentation listed in section 1.3. The general requirements and specifications of the system can be found in [1].

1.2. Documents sent in nBLM CDR1.2 package

Document	Description
nBLM_CDRfinal.pdf	This document
Capteur lent V5-1 F - Dossier de plans complet pour Fab.pdf	Detector drawings
Rails et supports – plans.pdf	Detector support drawings
nBLM_GasPipes_v2_withPIDs.pdf	Gas system specifications and P&IDs
nBLM_verification_plan.pdf	nBLM verification plan
nblm_control_system_design_2019_02_01.pdf	nBLM control system design
nBLM_CDRfinal_ReportTests.pdf	Report with the results of the tests done at different irradiation facilities with the prototypes including real loss detection at LINAC4
Requirements and technical specifications - ess nblm system.pdf	Requirements and technical specifications - ess nblm system.pdf
Preliminary results of the ESS nBLM DAQ test at Linac4.pdf	Preliminary results of the ESS nBLM DAQ test at Linac4
nBLM FW implementation.pdf	FPGA implementation

1.3. List of acronyms and abbreviations

Name or acronym	Definition
BEE	Back-End Electronics
BIS	Beam Interlock System
BNC	Bayonet Neill–Concelman (Connector)
CA	Channel Access
CEA	Commissariat à l'Energie Atomique
CPU	Central Processor Unit
CS	Control System
DTL	Drift Tube Linac
EEE	ESS EPICS Environment
ESS	European Spallation Source ERIC
EPICS	Experimental Physics and Industrial Control System
ESSI	ESS Irfu project
FEE	Front-End Electronics
FPGA	Field Programmable Gate Array
GND	Ground
GUI	Graphical User Interface
HEBT	High Energy Beam Transport
HWR	Half Wave Resonator
IKA	In-kind agreement
I/O	Input / Output
ICS	Integrated Control System
LCS	Local Control System
LINAC	Linear Accelerator
MCA	Multi-channel Analyzer
MEBT	Medium Energy Beam Transport
MMs	Micromegas detector
MPGD	Multi Pattern Gaseous Detectors
MPS	Machine Protection System
MTCA	Micro Telecommunications Computing Architecture
nBLM	Neutron sensitive Beam Lost Monitor
PA	Preamplifier
PCB	Printed Circuit Board
PDR	Preliminary Design Review
PLC	Programmable Logic Controller
PV	Process Variable
P&ID	Piping and Instrumentation Diagram
SAR	System Acceptance Review
SMA	SubMiniature version A (Connector)
SoW	Scope of Work
SHV	Safe High Voltage (Connector)
TBC	To Be Confirmed
ToT	Time Over Threshold

2. Description of detectors objectives

In the document [2] attached to the CDR1.1 package we clarify the differences between what we called slow and fast detector in the nBLM system. In this section we give a brief overview.

The nBLM system is a new Beam Loss Monitor based on the detection of neutrons using a Micromegas detector. It is complementary to other BLM systems in ESS. It was originally conceived to operate in counting mode, in the region where others BLMs have a small sensitivity, i.e. in the low energy region of the accelerator. The expected rate during normal operation discussed during the conceptual design of the system was of few n/s. In addition, in the low energy region, only neutral particles (neutrons and photons) are able to escape from the accelerator. The detector we propose is only sensitive to neutrons and insensitive to gammas, presenting a big advantage compared with icBLM where an x-ray background from the RF could hide or mimic a lost from the accelerator.

Micromegas [3] detectors are a type of MPGD (MicroPattern Gaseous Detectors) used very extensively in a wide range of particle and nuclear physics experiments, including neutron detection, for example in the nTOF experiment. As indicated by its name it is a gaseous detector where the charged particles arriving to the chamber will ionize the gas and this ionization is amplified and detected in the Micromegas detector.

The expected signal in a Micromegas detector are from few tens to few hundreds of mV. The requirements from ESS for such a system is to be able to give a response in 5 μs and to be able to monitor losses of 100 mW/m.

The detectors we propose are in fact the combination of two detectors, that we call “Slow” and “Fast”, based on their time response. However, they have also another differences between them, mainly determined by the way the neutrons are converted into charged particles that produce a signal in the chamber. A Micromegas detector, as any ionization detector, detects charged particles, therefore, we need to use a convertor in order to detect the neutrons. In the aforementioned document a comparison between the signal formation, the expected sensitivity and the expected function of each one is discussed. They were conceived to have a complementary functionality. In Table 1 the characteristics of each detector are summarized.

	SLOW	FAST
Convertor	B_4C	Mylar or Polypropylene
Reaction	$^{10}B(n,\alpha)$	(n,p)
Signal	Fast neutrons after moderation	Fast neutrons
Detected energy	~constant for all neutron energies	Depends on initial neutron energy
Sensitivity	10^{-6} < En < 100 MeV	En > 0.5 MeV
Solid angle	4π	2π, n coming from the front only
Sensitivity	~few $n \cdot cm^{-2} s^{-1}$	~10-100 times smaller
Response time	~200µs	~0.01µs
Objective	Monitoring of small losses	Alarm (in 5 µs) Fine structure of the lost
Shielding	Yes, for thermal neutrons	Not needed

Table 1: *Summary of the characteristics of each detector. Note that "En" is the energy of the neutron detected.*

3. Mechanics Design

3.1. Detector designs

The design of the detectors was presented and approved in in the nBLM CDR1.2.1 detector review [4] in July 2018. Since then, very little modifications have been made. The main ones are the front face of the detectors with space for the tracking label and a change in the screen-printed characters, and the piece to attach to the mechanical support to be made in PEEK and not in stainless steel to decouple from the ground. The final version of the design, used for the procurement of the material is attached as external document called *Capteur lent V5-1 F - Dossier de plans complet pour Fab.pdf*.

3.2. Detectors Support design

The location of the 84 detectors (42 nBLM slow modules and 42 nBLM fast modules) was presented and approved during the CDR1.1 [5]. Based on this distribution, three different kind of supports are foreseen and have been designed. The full design is attach in the documentation package, document name *Rails et supports – plans.pdf*.

The designs were discussed with ESS-BI and crosschecked with the ESS 3D model to identify possible issues in terms of space. The actual status is that the one corresponding for the DTL is approved and included at the ESS 3D Model, while for the other two, their validation is on-going.

The designs consist on:

- For the DTL Section

  There are 8 detectors per DTL (4 slow and 4 fast) placed interleaved every meter approximately. A rail has been conceived to place all of them along the DTL. An image can be seen in Figure 1 and in Figure 2.

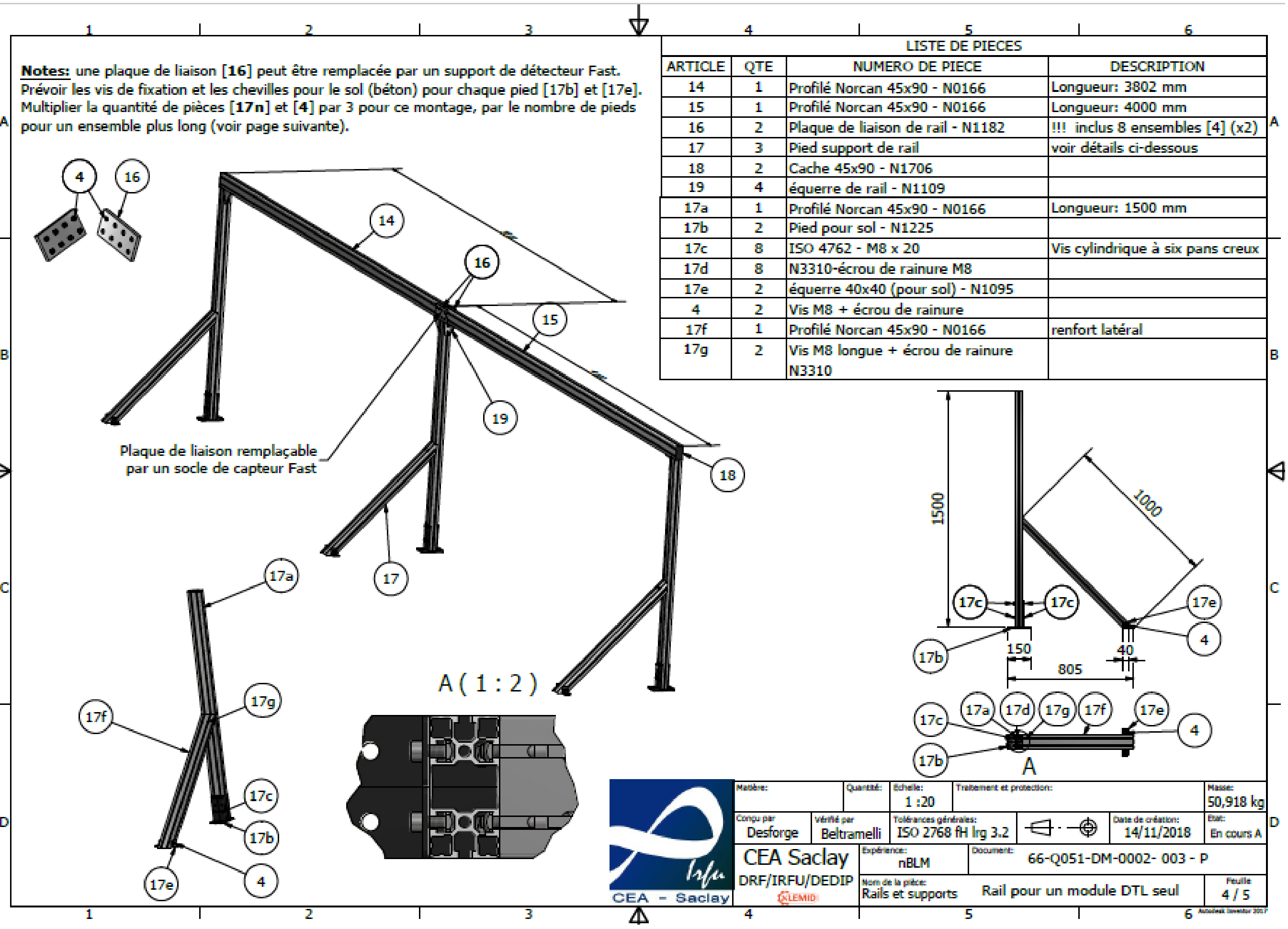


***Figure 1:** Mechanical support for the nBLMs proposed by CEA for the DTL region*

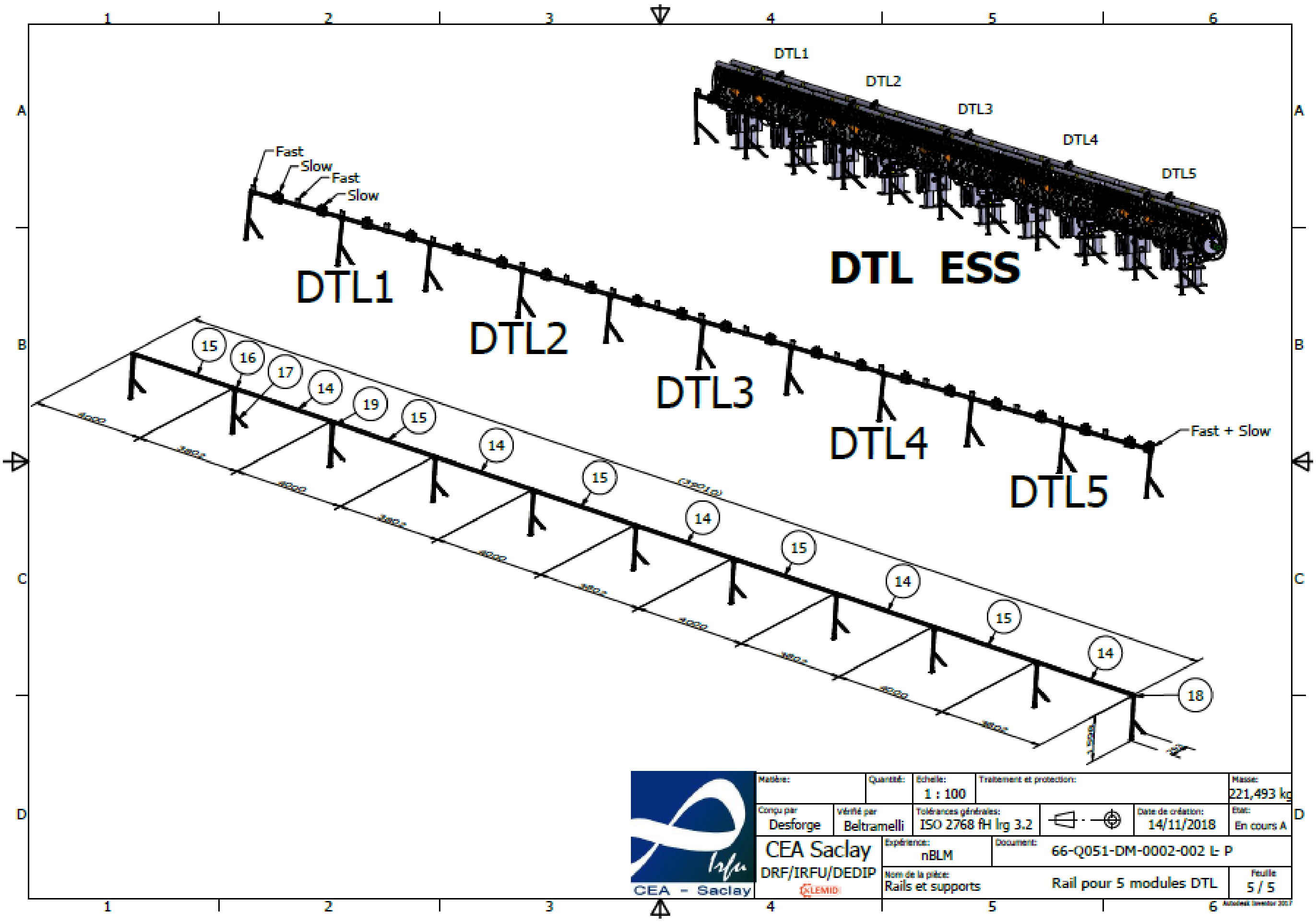


Figure 2: *Mechanical support for the nBLMs proposed by CEA for the DTL region*

- For the Spokes, MB, HB, HEBT and A2T.

  In the spoke region a nBLM fast module will be placed per quad pair and a slow one per cryomodule. In the other regions a pair of a slow and fast will be placed together. The exact places are in the MB LWU5, in the HB LWU11, one around the first bending magnet and two more in the 2 last quad pairs.

  In all cases they are separated a long distance. Therefore, an individual support has been designed. ESS-BI has identified positions were this can be attached to some places in the tunnel. See figure Figure 3. And based on that our proposition is shown in Figure 4 and in *Figure 5* for an inclination of 45°.

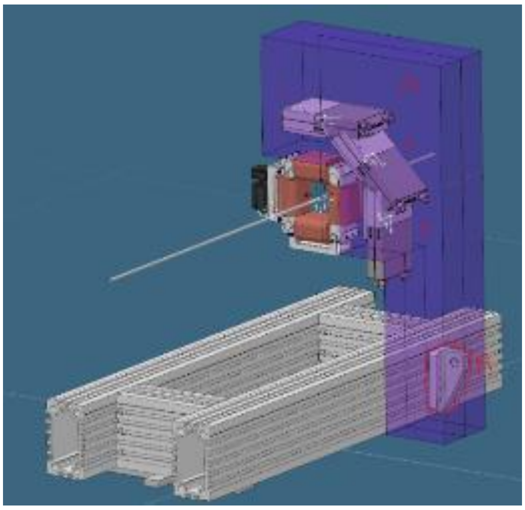


Figure 3: *ESS proposition for the installation of the nBLM modules in the Spokes region and at higher energies.*

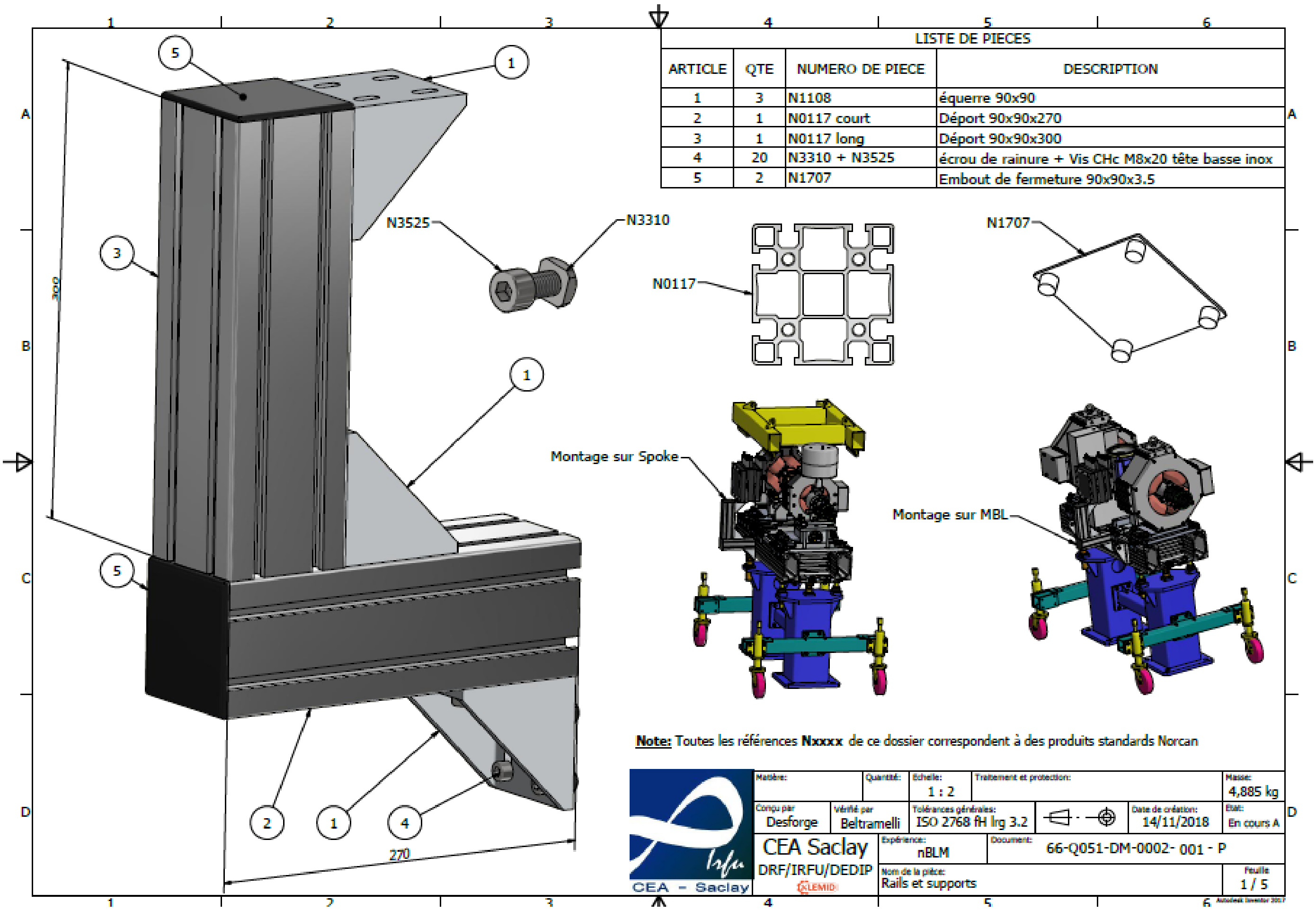


Figure 4 : *Mechanical support for the nBLMs proposed by CEA for the Spokes and higher energies region.*

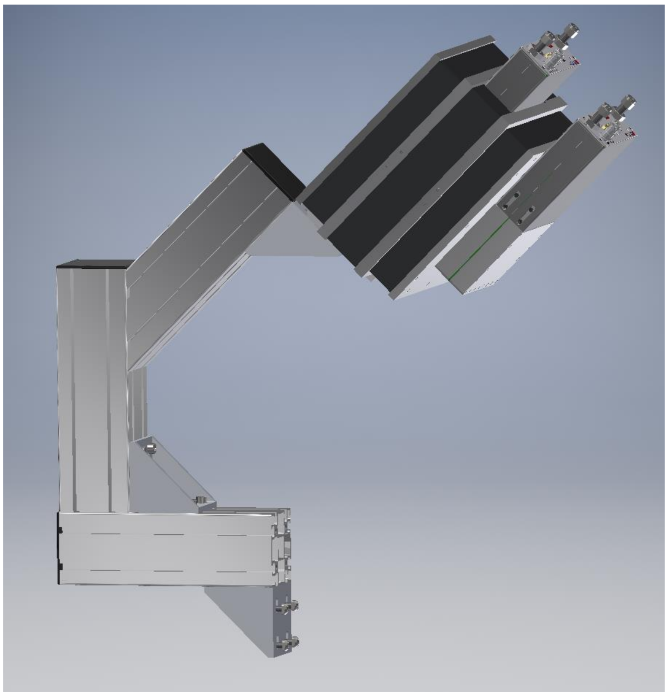


Figure 5: *Possible design to place the detector with an orientation of 45° with respect to the beam.*

- For the MEBT Section.

  A pair of a slow and fast will be placed together in two positions: before the chopper and after the dump. In this case we can't attach them to the MEBT so an individual support is foreseen to be placed or screwed to the floor of the tunnel ().

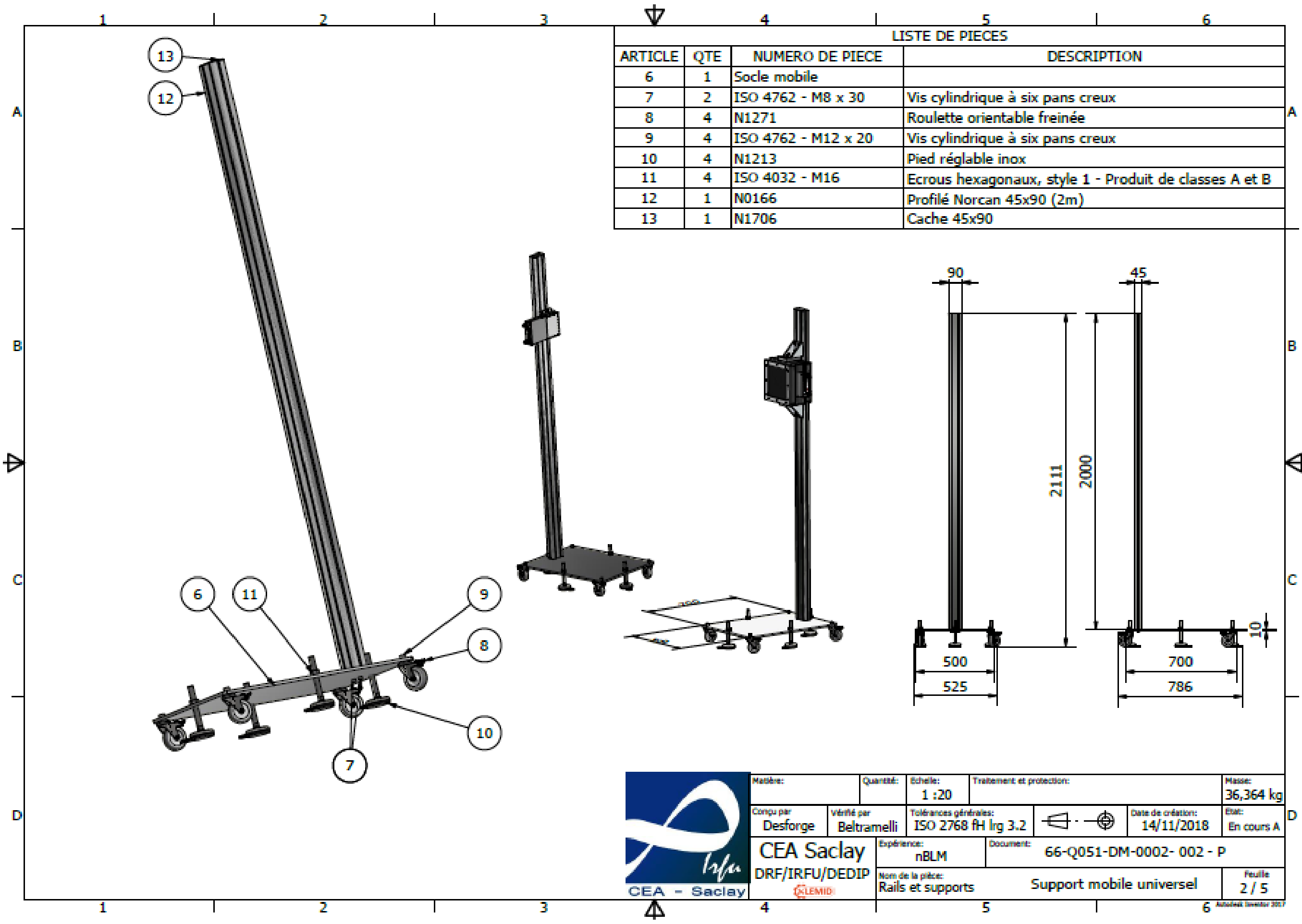


Figure 6: *Mechanical support for the nBLMs proposed by CEA for the MEBT.*

In all cases the detector can be placed with three different orientations that will be fixed during the commissioning. If a more flexible design for the angle is required, it should be specified during this CDR.

4. Gas system design

The gas system design was also presented and approved in July 2018. Special attention was placed in the design of the gas rack whose procurement had to start soon. The documentation can be found in [6] and in [7]. The specifications of the system are in [8] where also the final P&IDs can be found. This document accompanies the CDR for completeness.

For the long pipes that will bring the gas from the main gas rack (where the controls are) to the detectors, the status is that their integration in the ESS 3D model is almost finished and there are ready to ask for procurement after the CDR.

Six long IN distribution lines and 6 long OUT distribution lines will bring the gas to a group of detectors. They are grouped as shown in Table 2. A rough calculation of the time needed to put the system in operation was made. Several assumptions were done: assume a distance from the bottles to gas rack of 10 m, assume a distance from the gas rack to the ion source of 50 m, and use always a diameter for the tubes of 6 mm in although the ones to the detectors will be reduced to 4 mm. As a general rule of thumb, the volume of gas needs to be renewed 20 times to assure homogeneity. However, this is reduced to 4 times in case of detector replacement or intervention as the rest of the system will be kept sealed. Assuming a flow of 8 l/h the times are shown in Table 3. For all the regions except at very high energy this time is of 5-6 hours.

In LINES

Gas line	Detectors in	Number of detectors	Pipe end-point
Line 1	MEBT-DTL1	12	Beginning of MEBT
Line2	DTL2+ DTL3	8 + 4 = **12**	Beginning of DTL2
Line 3	DTL3 + DTL4	4 + 8 =**12**	Middle of DTL3
Line4	DTL5 + SPK1-4	10 + 8 =**18**	Beginning of DTL5
Line 5	SPK5-13	18	Beginning of SPK5
Line6	MB-HB + Bend Magnet	2 + 2 + 6 = **10**	All along accelerator

OUT LINES

Gas line	Detectors in	Pipe end-point
Line 1	MEBT-DTL1	End DTL1
Line2	DTL2+ DTL3	Middle of DTL3
Line 3	DTL3 + DTL4	End DTL4
Line4	DTL5 + SPK1-4	End SPK4
Line 5	SPK5-13	End SPK13
Line6	MB-HB + Bend Magnet	All along accelerator

Table 2 : *Number of gas lines arriving to the tunnel from the gas rack and approximate position in the tunnel. The number of detectors per line is also shown.*

Detectors in	Detectors IN	Total Length in tunnel [m]	Number detectors	Time to change gas 1 time [h]	**Time to change gas 4 times [h]**
MEBT-DTL1	MEBT-DTL1	36.7	12	1.01	**4.03**
DTL2+ DTL3	DTL2+ DTL3	70	12	1.13	**4.51**
DTL3 + DTL4	DTL3 + DTL4	81	12	1.17	**4.66**
DTL5 + SPK1-4	DTL5 + SPK1-4	136	18	1.59	**6.35**
SPK5-13	SPK5-13	208	18	1.84	**7.37**
MB-HB + Bend Magnet	MB-HB + Bend Magnet	1210	10	5.08	**20.32**

Table 3: *Estimated times needed to flush the detectors after an intervention (change volume 4 times).*

After the approval in July 2018 of the gas rack, the first two chassis were made by Serv'Instrumentation Company and are at CEA (Figure 7 and Figure 8). They consist on the main chassis that controls the main input from the bottle and the exhaust line and distribute the gas to the distribution chassis, and one of the distribution chassis that will controlling 3 IN and 3 OUT of the distribution lines. There will be three distribution chassis: two in use for the 12 distribution lines and one ghost to connect either in the future with more detectors or in case of failures in the other two. For both chassis we are currently completing their instrumentation (cabling, etc) and will be tested with a long gas tube and 2 nBLM modules connected in the following months.

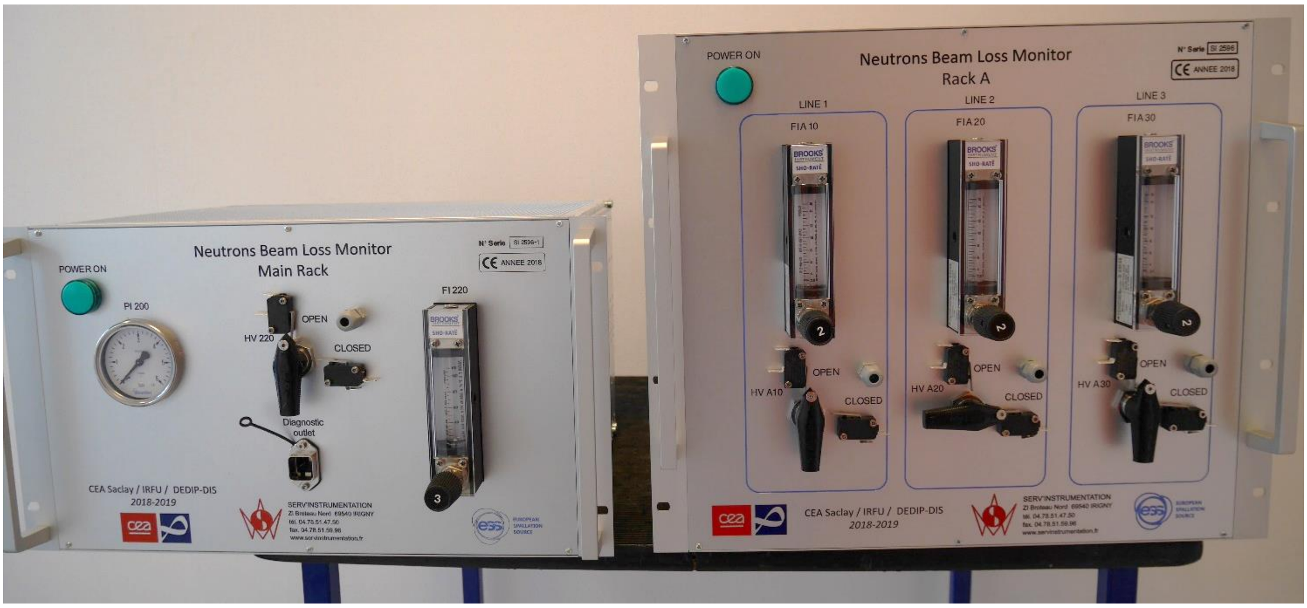


Figure 7: *Gas rack first two chassis received in Saclay. On the left the main one, managing the general input and output line and on the right one of the three distribution chassis that will control 3 IN and 3 OUT distribution lines. In this front view we can see the manual controllers that in case of a failure of the electrovalve will allow to continuous the operation and the POWER ON indicator of the racks. In Figure 8 the inner part of the main rack and the back panel can be seen.*

Figure 8: *Inner view (left) of the main gas rack chassis. (Right) View of the back panel with the electrical connections and output of the distribution gas lines.*

For the actual status of the PLC and controls design we refer the reader to the attached document *nblm_control_system_design_2019_02_01.pdf.*

5. FEE and HV cards design;

All the electronics components and elements can be found in [9]. The FEE card design was presented and approved during CDR1.1 [9]. A first batch of 2 cards was received in July 2018 Figure 9 left. One of them was integrated in the detector tested at LINAC4 . The obtained performance is very satisfactory as can be seen in the tests report accompanying this document. As each card follows a test procedure when arriving to CEA, more details will be given during the presentation about their performance.

After the test at LINAC4, 5 first cards with the final design have been ordered. The only difference with the one tested at linac4 are the emplacement of the connectors to match the final design of the mechanics, but not modification of the electronic components was done. We have received 2 of them (Figure 9 left) and they are being tested along this week and next week (weeks 5 and 6). However, the company is ready to produce and send the rest 150 cards once we finish with these verification tests.

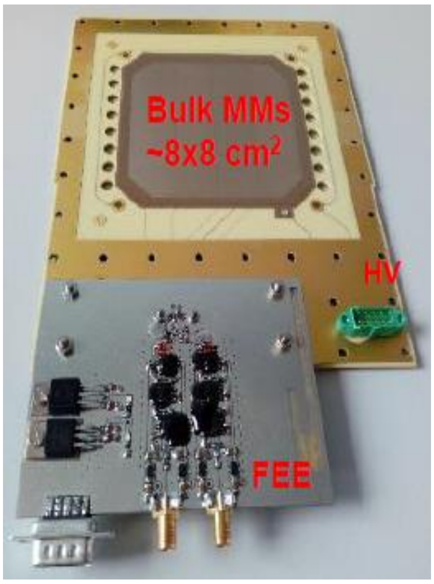


Figure 9: *(left) FEE pre-series card integrated in one Micromegas detector used at Linac4. (Right) Final FEE card.*

The HV card was also presented during CDR1.1 and tested along the summer. It has been slightly modified and this modification was presented and approved in the nBLM CDR1.2.1 detector review [4]. The final HV design is shown in **Error! Reference source not found.**. The total of 150 cards were ordered in December 2018. However, the company claims they did not receive the order until January 2019 and for the moment we do not have an answer for when we will receive them.

LV distribution box

As indicated in [1] each LV cable from the rack will feed a group of up to 6 detectors. The schema of the LV layout is shown in Figure 10. At the rack level and installed in the rack will be a first distribution box that will gather the output of the LV card and distributed into 4 LV cables per card that will go into the tunnel. Once in the tunnel, each cable will go to a distribution box that will distribute the voltages to up to 6 detectors. The exact design and location of such distribution box is being finalized.

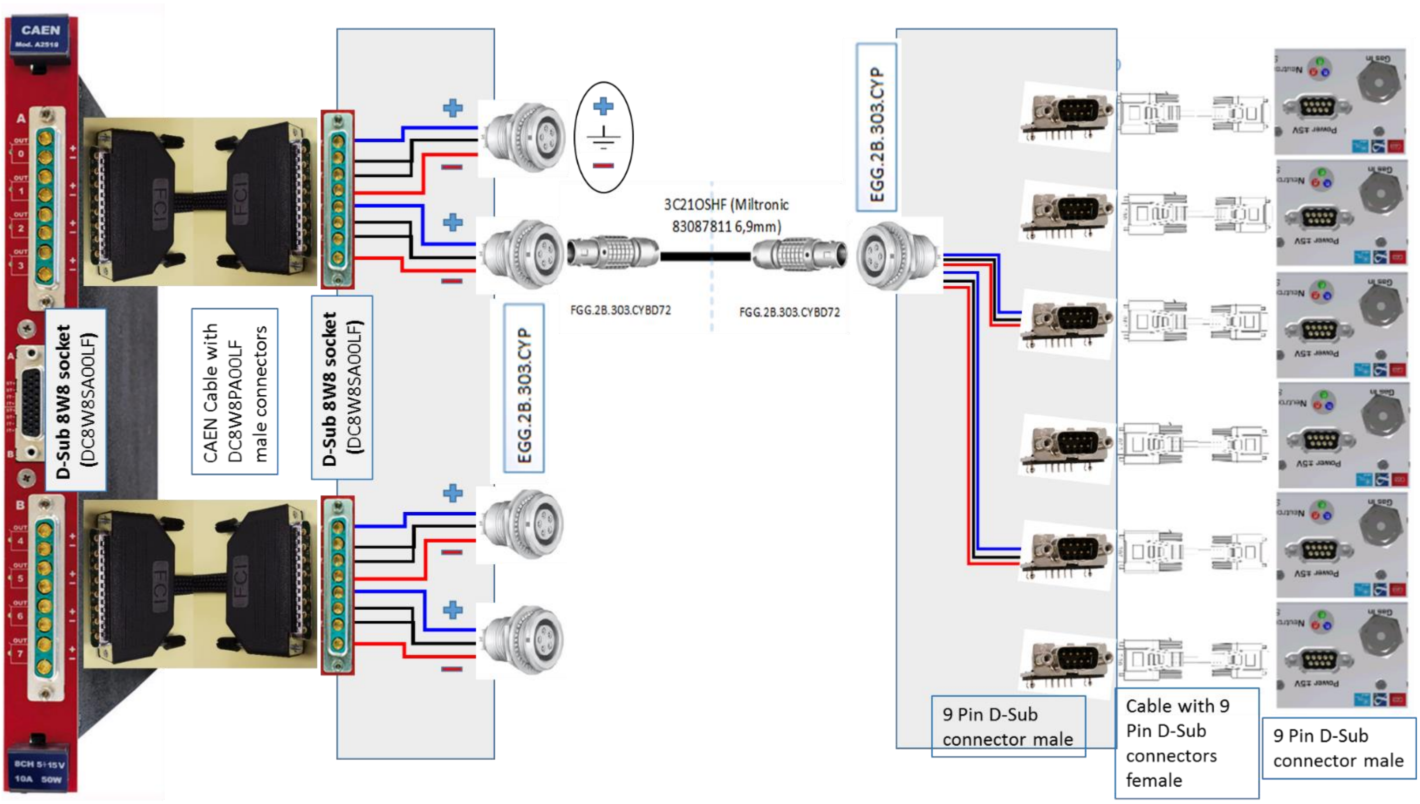


***Figure 10:** schematic of the nBLM detectors LV layout.*

For the signal cable, in the tunnel, a cable support (Figure 11) have been designed to hold the cable weight and protect the PCB of the detector.

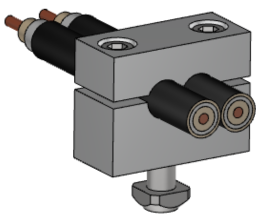


Figure 11: Cable support for signal cables arriving to the detector in the tunnel. It will be screwed into the support shown in *Figure 1* and *Figure 4*.

6. DAQ and control system design

The control system design and architecture is discussed in detail in the document *nblm_control_system_design_2019_02_01.pdf* [10] accompanying this document.

For the FPGA and DAQ tests the reader is referred to documents included in the package *nBLM FW implementation.pdf* [11] and *Preliminary results of the ESS nBLM DAQ test at Linac4.pdf* [12].

7. Procurement and verification tests

In July 2018 the design of the detector chambers, including the Faraday Cage and gas tube connections [4] was approved to be able to start the procurement of the material. In addition, also the design of the gas rack and the distribution of the lines were also reviewed and approved, as discussed in previous points.

From then until now, we have order most of the mechanics, and big part is delivered. The list of orders, indicating the status of each one, are listed in Table 4. For the ones not yet passed the company has been identified and the expected delivery date is known in most cases.

The production plan of the detectors, explained in next sections, will allow to send the first 12 detectors to ESS by April 2019 as requested. The ancillary systems, as control system and DAQ, will not be in their final version by then, as the approval is happening during this CDR.

Material	Company	Status
Polyethylene (moderator)	Numeca	Delivered
Neutron absorber	Mirrotron	Delivered
Detector chamber	Numeca	Delivered
Detector front face		Mars 2019
Detector chamber components	Swagelok, numeca, …	Delivered
PCB boards	Elvia	2 boards delivered Rest in 4-6 weeks after passing the order
PCB Bulk	MPGD Lab CEA	Along reception of the PCB boards First one done and under tests
Shielding + Moderator support	CEA Workshop	February-March 2019 for first 12 Rest to be decided
Supports for ground decoupling	CEA Workshop	March 2019 for first 12 detectors Rest to be decided
Detectors support	TBD	2-3 months for MEBT and DTL Waiting final approval from ESS for the rest
Cathodes	Sermo	Delivered
Boron convertors	ESS Detector Coatings Workshop (Linkoping)	Delivered
Mylar (fast convertor)	Good Fellows	Ordered (expected in February 2019)
Gas rack	Serv'Instrumentation	Delivered main chassis and one of the distribution one (3 lines) Rest 10-12 weeks after passing the order
Gas valves, pressuremeter, etc	Serv'Instrumentation	10-12 weeks after passing the order
Gas short tubes	RS	1 week days after passing order
Gas fast connectors	Swagelok	4 weeks after passing order
PLC, I/O, (gas system)		Delivered
HV A-7030 cards (3+1)	CAEN	One under tests at CEA Rest 3 months after passing the order
LV A2519 cards (3)	CAEN	One under tests at CEA Rest 3 months after passing the order
SY- 4527B (2)	CAEN	One under tests at CEA Rest 3 months after passing the order

R-648 (Cable from pin to SHV HV)(aka HV patch panel)	CAEN	One at CEA Rest 3 months after passing the order
LV cable	CAEN	One at CEA Rest 1 months after passing the order
ADC3111	IOxOS	1 under tests at CEA Rest to be ordered after CDR approval 10 weeks after receive the order
Short-cables (stubs/patch panels to detectors)	TBD	2-3 months after receive the order Need to fix required length with ESS-BI
LV distribution box	TBD	

Table 4: *List of all the elements (ordered or to be delivered).*

For the cathodes, we should also specify that the $^{10}B_4C$ deposit has been already done by the ESS Detector Coatings Workshop in Linkoping. For the cathodes of the fast module, the Mylar layer will be prepared and glued in our laboratory, process that will take few weeks and will start in February 2019.

7.1. Production flow and planning

The production chain will start with the bulk[1] of the PCB boards. Each PCB board includes 3x3 detectors. Each board is bulk in a single process producing 9 Micromegas. The flow process is as shown in Table 5.

	Process	Time	Where
1	Bulk of 9 detectors	1 week	MPGD Lab
2	Partial Integration of the 9 detectors	½ week	Clean room
3	Soldering of the connectors	½ week	Integration lab
4	Finalize Integration of the 9 detectors	1 week	Integration lab
5	Verification tests of the 9 detectors	1 week	Verification lab
	TOTAL for 9 detectors	**4 weeks**	

Table 5: *List of process to make 9 nBLM modules*

For the first two 3x3 PCB boards we will not overlap the process every week, but leave a margin of one extra week as we expect some learning process and adjustments to the procedures. In any case we have also previewed training weeks that overlap with the CDR preparation and presentation, weeks we expected not to have the time to start with the real production.

[1] Process to make the bulk Micromegas detector once we have received the PCB board

Once the two first PCB boards have been integrated in the mechanics, and they have been tested, we will continue with the rest. In this case, we expect that while one process is being doing, the rest can also continue for the previous set of detectors. Therefore for the 84 detectors we expect in total 16 weeks of work, which will bring us to end of Mai 2019, as can be seen in Figure 12.

		2019																		
		February				**March**				**April**					**Mai**				**June**	
		week 6	week 7	week 8	week 9	week 10	week 11	week 12	week 13	week 14	week 15	week 16	week 17	week 18	week 19	week 20	week 21	week 22	week 23	week 24
		4 to 8	*11to15*	*18to22*	*25to1*	*4to8*	*11 to5*	*18 to22*	*25to29*	*1to5*	*8to12*	*15to19*	*22to26*	*29to3*	*6to10*	*13to17*	*20to24*	*27to31*	*3to7*	*10to14*
Saclay nBLM AIT Operations	*Bulk*	CDR & TRAINNING			Det 1-9		Det 10-18		Det 19-27	Det 28-36	Det 37-45	Det 46-54	Det 55-63	Det 64-72	Det 73-81	Det 82-90	Contingency detectors			
	Soldering					Det 1-9		Det 10-18		Det 19-27	Det 28-36	Det 37-45	Det 46-54	Det 55-63	Det 64-72	Det 73-81	Det 82-90	Contingency detectors		
	Integration						Det 1-9		Det 10-18		Det 19-27	Det 28-36	Det 37-45	Det 46-54	Det 55-63	Det 64-72	Det 73-81	Det 82-90	Contingency detectors	
	Gas leak							Det 1-9		Det 10-18		Det 19-27	Det 28-36	Det 37-45	Det 46-54	Det 55-63	Det 64-72	Det 73-81	Det 82-90	Contingency detectors
	252Cf							Det 1-9		Det 10-18		Det 19-27	Det 28-36	Det 37-45	Det 46-54	Det 55-63	Det 64-72	Det 73-81	Det 82-90	Contingency detectors

Figure 12: *Planning for the production of the 84 nBLM detectors.*

The flow of work is shown in the diagram in Figure 13. For each procedure an official document will be included in the delivery as explained in more detail in Section 8.3 including the QA/QC tests and the characteristics of the process.

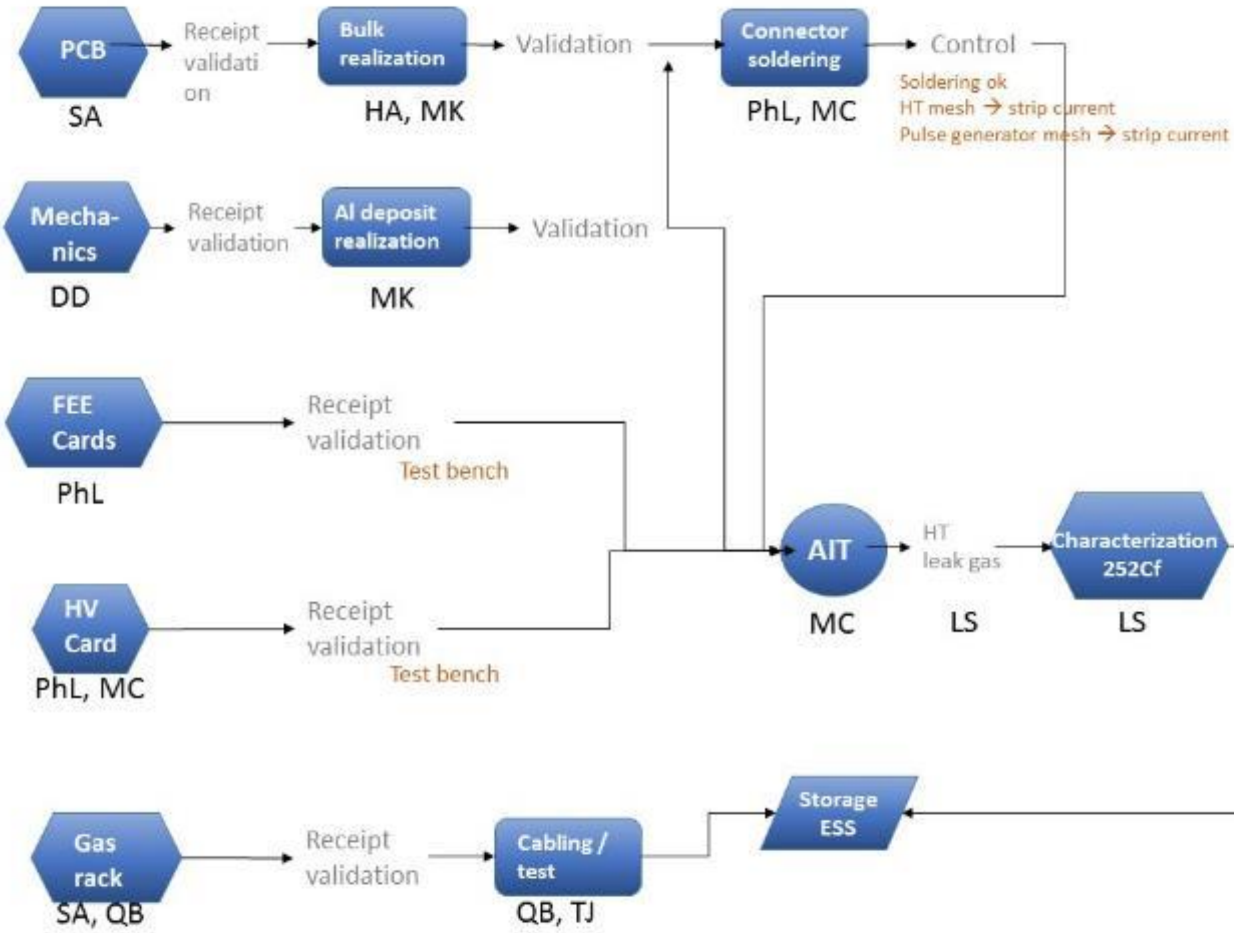


***Figure 13:** Process flow for the nBLM modules production. The initials indicate the person of the team in charge[2]. For each process, different validation tests are planned and a QA/QC foil will be filled.*

7.2. Production laboratories

For the production of the 84 detectors, three laboratories have been prepared at CEA/Saclay. In one the integration of the mechanics will be done. Part of it will be done in a clean room ISO7 for the installation of the drift and the Micromegas in the chamber to minimize any dust contamination entering in the Micromegas. The soldering of the connectors will be done once the Micromegas is installed in the chamber has been closed. After the soldering, the FEE and Faraday Cage is placed and the 9 modules are moved to the verification laboratory.

In the verification laboratory (Figure 17) several modules (5-6) will be place in gas at same time. In the Verification document there are more details about the tests of the modules. Essentially, we will test the gas tightness and the gain of the detector with a neutron source.

[2] SA (Stephan Aune), MK (Mariam Kebiri), HA (Helder Alves), PhL (Philippe Legou), MC (Michel Combet), DD (Daniel Desforge), LS (Laura Segui), QB (Quentin Bertrand), TJ (Tom Joannem)

The storageof the material before mounting is done in a mezzanine space with different cupboards, as shown in Figure 14. Once the detectors have passed all QA/QC tests they will be stored in the delivery boxes.

Figure 14: *Storage of the mechanics for production of the 84 detectors (from left to right: polyethylene, mirrobor)*

Figure 15 : *Mechanics of nBLM detector chambers (for 84 modules) at CEA*

Figure 16 : *Integration laboratory*

Figure 17: *Detectors Verification laboratory*

7.3. Detector identification and tracking

Each detector will be identified with a single number. This number will be registered in a database with access to the rest of the information as ID of the FEE card, results of tests and links to each of the QA/QC document. In detail, we will have the following documentation:

- Each Micromegas detector: ID number + QA/QC sheet (example in Appendix A).
- Each FEE: ID number + QA/QC sheet
- Each detector: General ID number + Properties sheet from the integration (convertor thickness, drift gap, etc)
- Each detector: Verification and test results data sheet
- General database with all the previous information (probably in links)

These documentation is being finalized and will be adjusted if needed during the training session will be held before the first detector production started. An example is shown in the appendix A for the bulk process.

8. Report on beam test measurements

Different tests have been performed at different irradiation facilities as listed in Table 6. All the results are shown in detail in the accompanying document *nBLM_CDRfinal_ReportTests.pdf* [13].

Installation	Date	Goal of test	Results
MC40 (Birmingham)	Nov-17	First test in an accelerator	Linear response with beam current
IPHI (Saclay)	Jan-18	First test in a beam pulsed accelerator First test of FEE in accelerator First test of fast module with big neutron flux	Time Response Neutron identification (FEE test) Algorithm development
AMANDE (Cadarache)	March-18	Calibration of detectors Moderator optimization Fast module tested at high energies First gamma/neutron discrimination	Response curves as a function of moderator thickness and neutron energy
ORPHEE (Saclay)	March-18	Response to thermal neutron B4C thickness studies	Response to thermal neutrons Signal characteristics B4C thickness studies
LINAC4 (CERN)	Oct/ Dec-18	Test in real accelerator conditions Test the FEE, the DAQ and the detectors	Response to beam losses Response to gammas from RF
Saclay	Jan-19	Detailed study neutrons vs gamma Test of one final nBLM module	Gain curves for neutrons and gammas

Table 6: *List of irradiation facilities and tests performed in each one with the nBLM prototypes and the nBLM pre-series to study their responses.*

9. Risk and hazard analysis

Each component of the nBLM system have been chosen following ESS safety regulations and in discussions with the safety team and the radiation hardness team. In any case, a possible list of risks and hazards regarding safety are listed in the following. A risk analysis of the failure in the system itself was presented in CDR11 [14].

The types of hazards and their risks are listed in the following:

Hazard	Risk	Likelihood	Control measures
Electrical	Electrical shock from HV	Very unlikely	▪ **Current limited to 500 – 1000 µs** ▪ SHV cables ▪ No floating grounds ▪ Cable length no problem for loss capacitance ▪ Use supply suitably and check for damage before use.
Gas	Anoxia	Very unlikely	▪ **Max. possible flow 50 l/h.** ▪ Use of appropriate gas tubes and connectors with a leak rate of 10^{-5}-10^{-6} mbar l/s ▪ Gas bottles outside buildings ▪ Monitor ratio between flow in and out of system continuously to identify leaks
Radiological	Possible dose received by user when calibrating the detectors in the tunnel	Very unlikely	▪ Tests to be done with guidance from the ESS Radioprotection department
Injury	Heavy pieces during installation / manipulation	Unlikely	▪ Handle equipment with appropriate care ▪ Wear safety equipment according to ESS regulations

Table 7: *Hazard and risk analysis of the nBLM system.*

10. References

[1] I. D. Kittelmann, “Requirements and Technical Specifications - ESS nBLM System,” https://jira.esss.lu.se/browse/BIG-1245, October 2018.

[2] L. Segui, “Modes Covered by nBLM System,” https://indico.esss.lu.se/event/948/, 2017.

[3] Y. Giomataris Ph. Rebourgeard J.P. Robert G. Charpak, “MICROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-flux environments,” *NIM A,* vol. 376, no. 1, pp. 29-35, 1996.

[4] L. Segui, and and T. Papaevangelou, “ESS NBLM SYSTEM: Detector design and material selection,” https://indico.esss.lu.se/event/1083/attachments/466/674/nBLM_materialsMechanicalDesignReview.pdf, https://indico.esss.lu.se/event/1083/, July 2018.

[5] I. D. Kittelmann, “nBLM General overview and ESS-0191514,” https://indico.esss.lu.se/event/948/, CDR11, December 2017.

[6] Q. Bertrand, “Gas Rack Design and Gas Components,” July 2018.

[7] Q. Bertrand, “Gas Box Design ESS Neutrons Beam Loss Monitor (v1.0),” https://indico.esss.lu.se/event/1083/attachments/465/673/nBLMGasBoxDesign.pdf, July 2018.

[8] T. P. L. S. S. Aune, “Gas Pipes Specifications for nBLM system,” https://confluence.esss.lu.se/display/BIG/BLM+documents, Updated July 2018.

[9] L. S. e. al, “nBLM CDR 1.1,” https://indico.esss.lu.se/event/948/, Dec 2017.

[10] Y. Mariette, “nBLM Control System Design,” https://indico.esss.lu.se/event/1173/, February 2019.

[11] G. Jablonski, “nBLM FW implementation,” https://indico.esss.lu.se/event/1173/, February 2019.

[12] I. D. Kittlemann, “Preliminary results of the ESS nBLN DAQ tests at Linac4,” https://indico.esss.lu.se/event/1173/, February 2019.

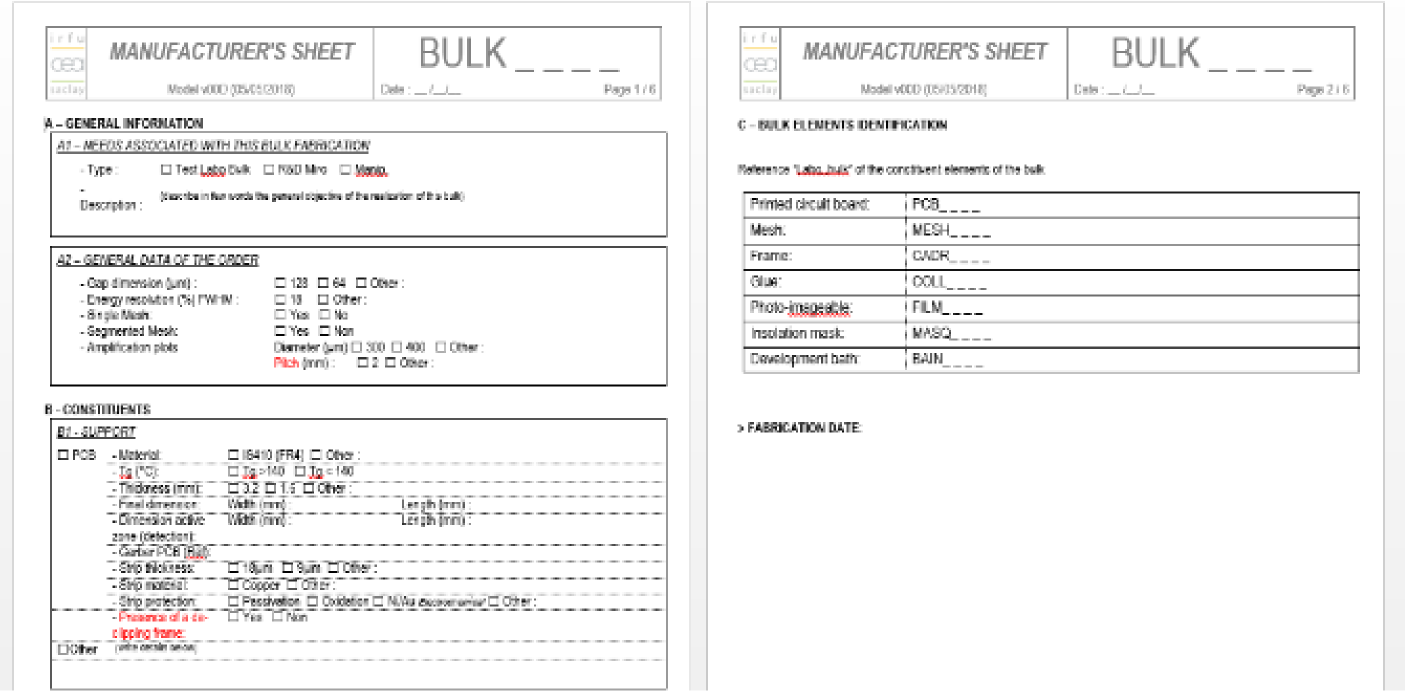
[13] L. Segui, “nBLM Final Report Tests for CDR1.2,” https://indico.esss.lu.se/event/1173/, February 2019.

[14] L. Segui, “nBLM System Risk Analysis,” https://indico.esss.lu.se/event/948/attachments/7389/10537/nBLM_subsystemsRiskFailuresAnalysis.pdf, Dec. 2017.

[15] L. S. T. Papaevangelou, “ESS nBLM Sysytem: Detetcor Design and Material Selection for 84 deliverable detectors production,” July 2018.

APENDIX A

Include examples of the documentation


MANUFACTURER'S SHEET

BULK _ _ _ _

Model v00D (05/03/2018)

Date : __/__/__

Page 1 / 6

A – GENERAL INFORMATION

A1 – NEEDS ASSOCIATED WITH THIS BULK FABRICATION

- Type : ☐ Test Labo Bulk ☐ R&D Micro ☐ Manip.
- Description : (describe in few words the general objective of the realization of this bulk)

A2 – GENERAL DATA OF THE ORDER

- Gap dimension (µm) : ☐ 128 ☐ 64 ☐ Other :
- Energy resolution (%) FWHM : ☐ 18 ☐ Other :
- Single Mesh: ☐ Yes ☐ No
- Segmented Mesh: ☐ Yes ☐ Non
- Amplification plots Diameter (µm) ☐ 300 ☐ 400 ☐ Other :
  Pitch (mm) : ☐ 2 ☐ Other :

B - CONSTITUENTS

B1 - SUPPORT

☐ PCB
- Material: ☐ IS410 (FR4) ☐ Other :
- Tg (°C): ☐ Tg >140 ☐ Tg <140
- Thickness (mm): ☐ 3.2 ☐ 1.6 ☐ Other :
- Final dimension: Width (mm) : Length (mm) :
- Dimension active zone (detection): Width (mm) : Length (mm) :
- Gerber PCB (Ref):
- Strip thickness: ☐ 18µm ☐ 9µm ☐ Other :
- Strip material: ☐ Copper ☐ Other :
- Strip protection: ☐ Passivation ☐ Oxidation ☐ Ni/Au ☐ Other :
- Presence of a de-clipping frame: ☐ Yes ☐ Non

☐Other

MANUFACTURER'S SHEET

BULK _ _ _ _

Model v00D (05/03/2018)

Date : __/__/__

Page 2 / 6

C – BULK ELEMENTS IDENTIFICATION

Reference "Labo_bulk" of the constituent elements of the bulk

Printed circuit board:	PCB_ _ _ _
Mesh:	MESH_ _ _ _
Frame:	CADR_ _ _ _
Glue:	COLL_ _ _ _
Photo-imageable:	FILM_ _ _ _
Insolation mask:	MASQ_ _ _ _
Development bath:	BAIN_ _ _ _

> FABRICATION DATE:

Example of the Bulk manufacturer sheet