Production of the nBLM detectors for ESS

Laura Segui

RD51 Collaboration Meeting 4-8/12/2023

Talk

nBLM ESS Projet

nBLM Detectors & Integration

nBLM System

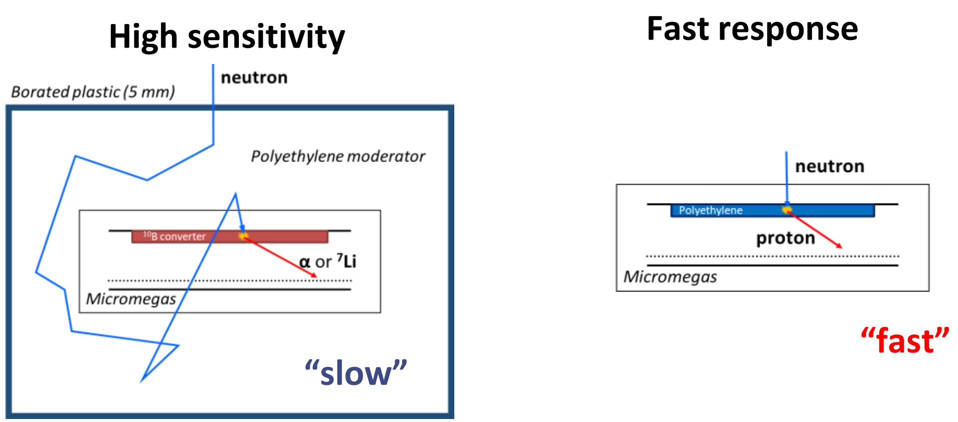
nBLM at ESS

ESS nBLM Project - Context

The problem:

- Accidental **beam loss** in high power linear accelerators:
  - activate materials ➔ *monitor small beam loss*
  - damage the accelerator ➔ *need for fast alarm*
- **No solution** at the **low energy** part of the accelerator:
- **Need to detect fast neutrons** with **very large dynamic range** under a ***strong gamma background*** *!*

Two complementary modules



Our proposal: **nBLM (*neutron Beam Loss Monitor*)**

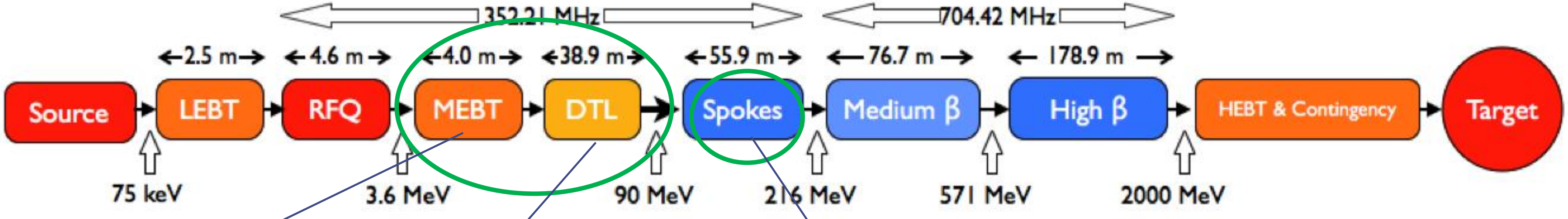
Adapt a particle detector (Micromegas) for beam diagnostics using a combination of neutron convertors and moderators.

➔ ***Detect individual neutrons** (**counter**)*

Fast *: React to big losses. Alarm. Connected to MPS*
Slow *: monitoring small losses, activation*

ESS nBLM Project

The nBLM-ESS project: Design, construction, testing and commissioning of **84 detectors** (42 fast + 42 slow) & **auxiliary subsystems**



4 Detectors:
2 fast + 2 slow

8 Detectors / DTL:
4 fast + 4 slow
+ (1 fast + 1 slow) i/b

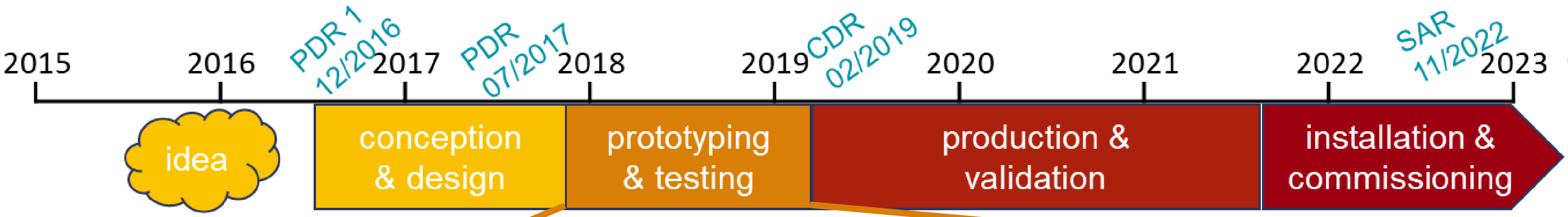
2 Detectors / Spoke:
1 fast + 1 slow

10 detectors @ high energy part for R&D
5 fast + 5 slow

55% of the total

30% of the total

ESS nBLM Project



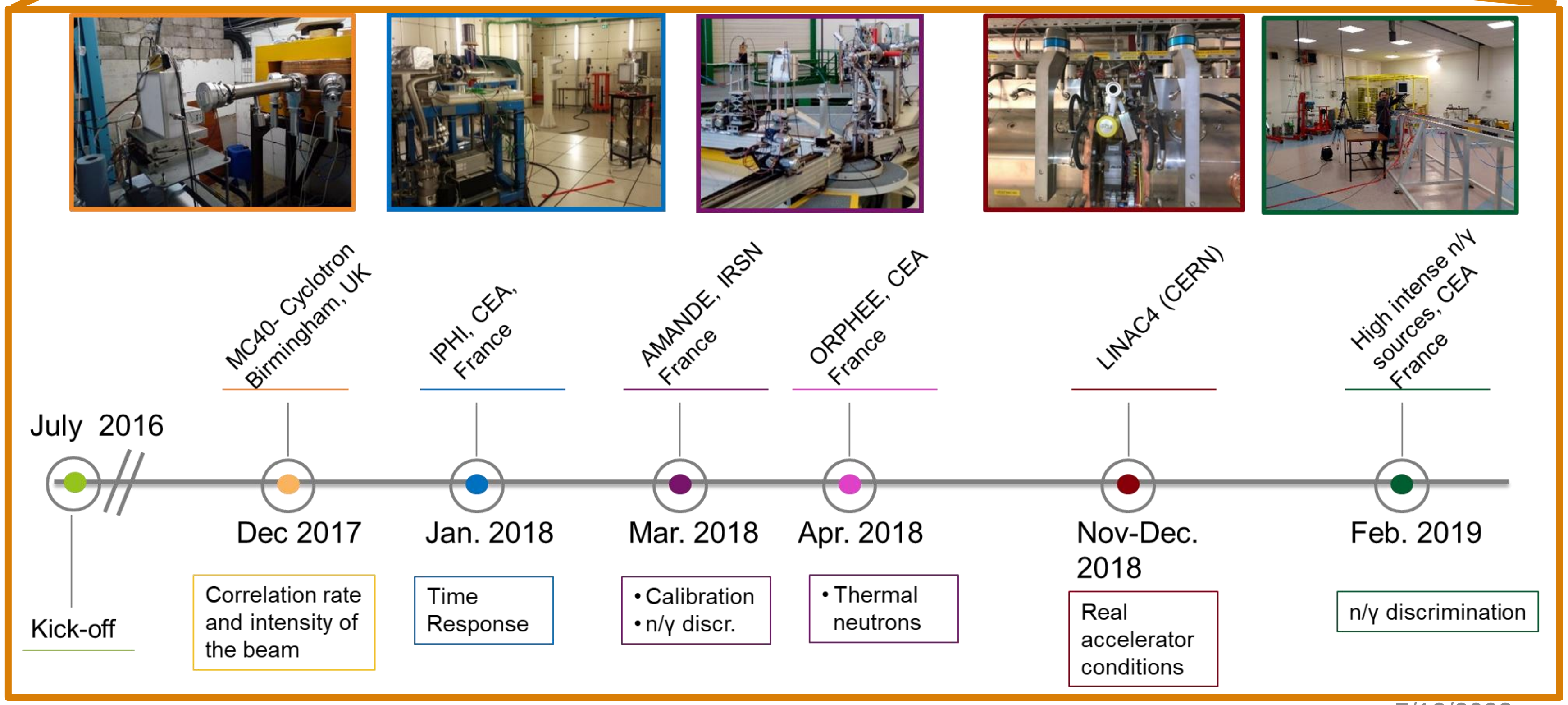
Commissioning start @ ESS: April 2022

All materials need to be approved by ESS

+ monthly reports

Weekly meetings

Real collaboration with ESS (I. Dolenc Kittlemann)

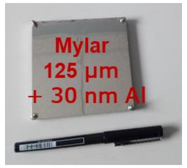


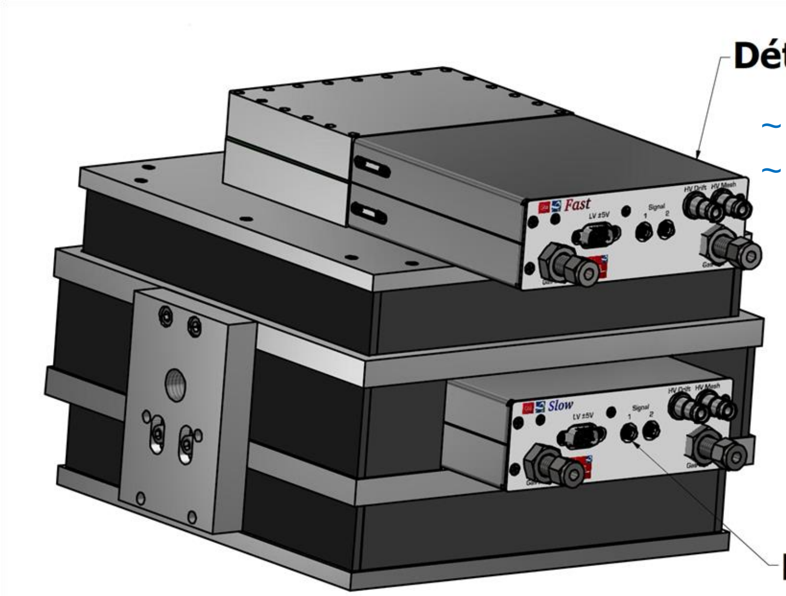
The nBLM Detectors

Two detector types: « fast » & « & Slow »

- ✓ The same detector and gas chamber and Electronics

- ✓ Different ***neutron-to-charge*** convertors
  - ➢ *Fast :* mylar → (n,p) recoils from neutron scattering
  - ➢ *Slow :* $^{10}B_4C$ → réaction (n, α) + Polyethylene moderator to increase the efficiency



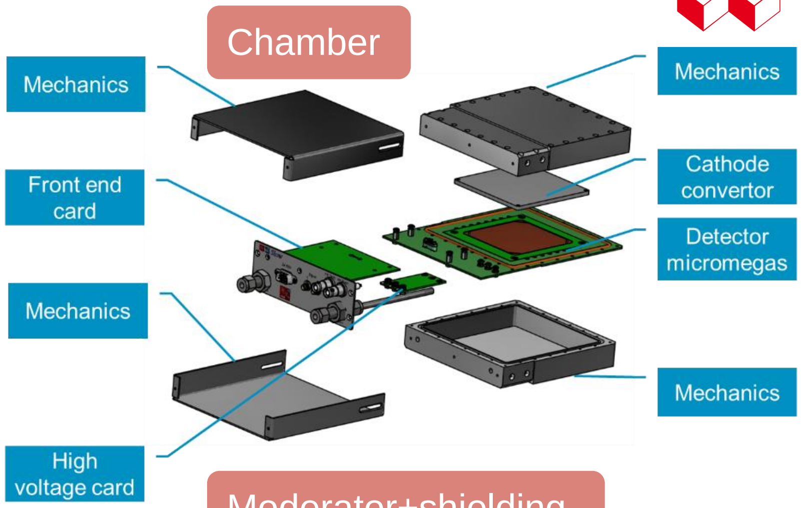


Détecteur rapide

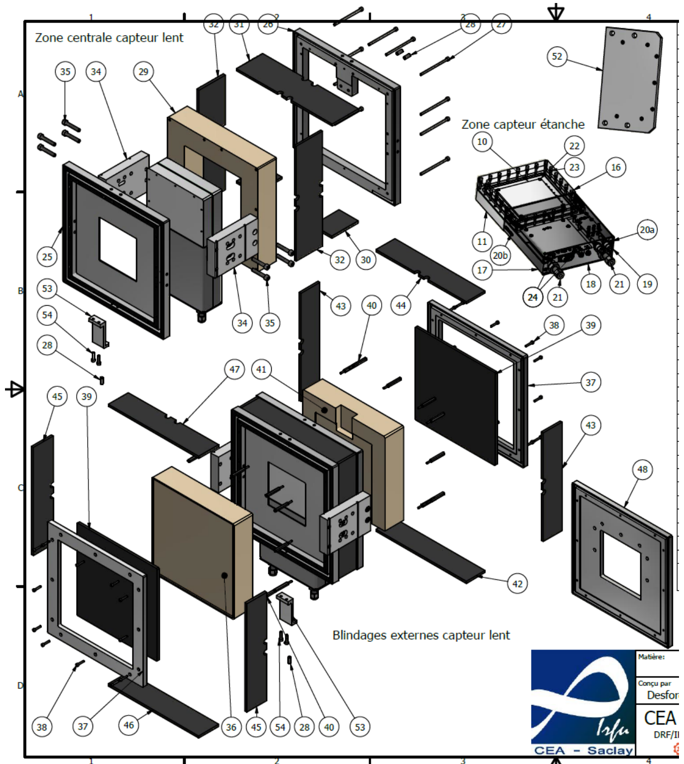
~ 25 ×15 × 5 cm^3
~ 1 kg

Détecteur lent

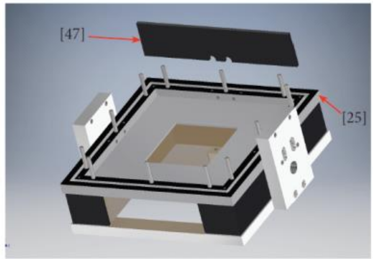
~ 30 × 30 × 20 cm^3
~ 10 kg

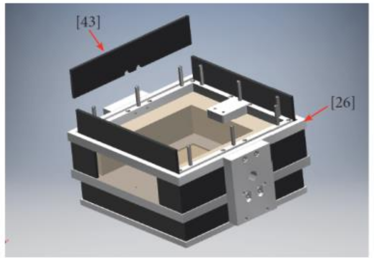


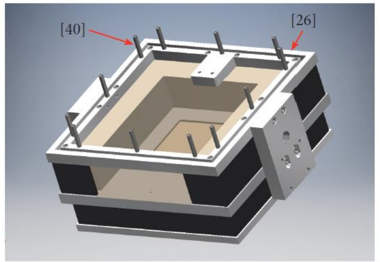
Moderator+shielding

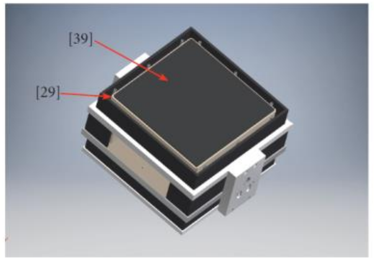


nBLM Detector Fabrication Procedure

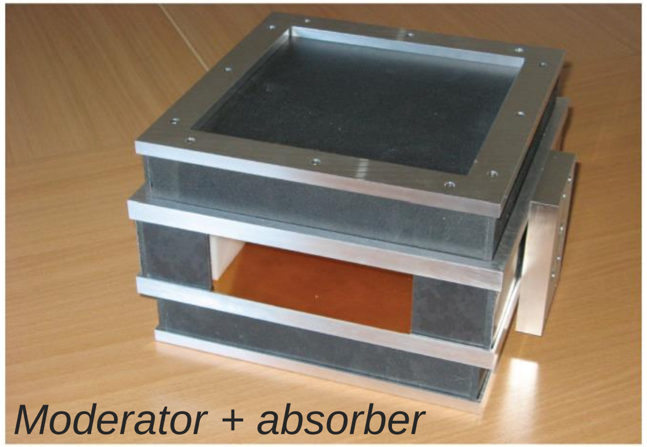






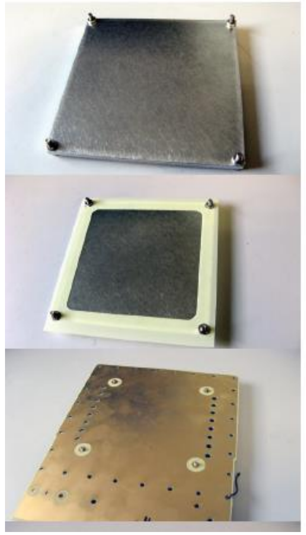


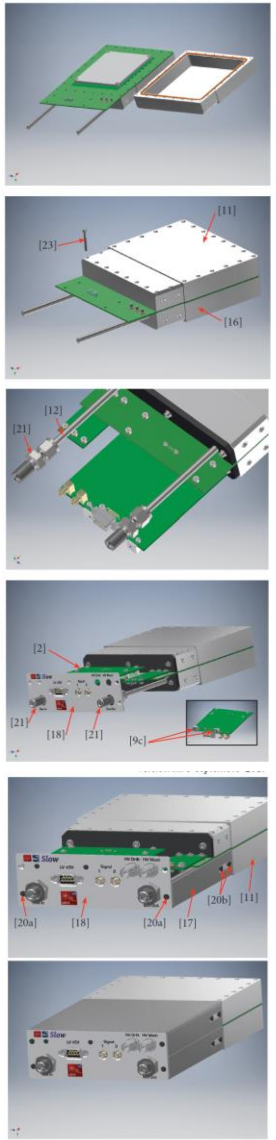
Montage du blindage nBLM - 10

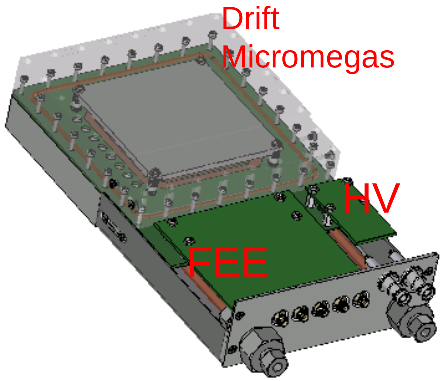


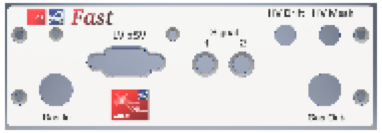
Moderator + absorber

Assembly of a fast and a slow detector size ≈ 20 × 25 × 25 cm^3 (~14 kg)



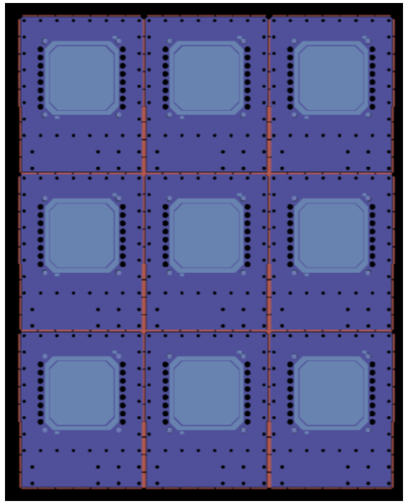






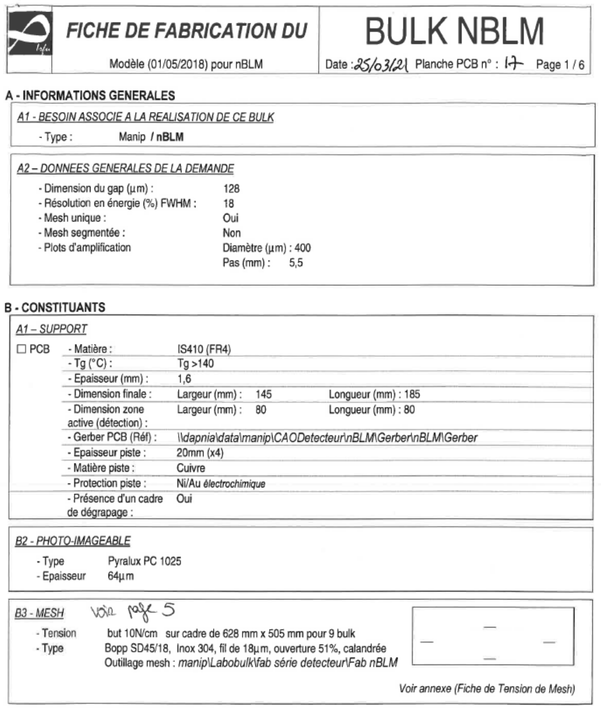
Chamber + Faraday Cage ~ 20 x 15 x 2 cm^3

nBLM Micromegas



Gerber for 3x3 MMs board

- Bulk Micromegas
  - 128 microns gap, 45/18 mesh, pyralux
- Produced at MPGD workshop at CEA (2 also at ELVIA for industrialization)
- Establishment of **detector production line & validation procedure**
- Pace of production according to project needs
  - MPGD workshop moved to a different lab at the end of 2019
  - 6 boards done in 2019, 1 in 2020 and 7 in 2021 → 126 nBLM



FICHE DE FABRICATION DU BULK NBLM
Modèle (01/05/2018) pour nBLM
Date : 25/03/21 Planche PCB n° : 17 Page 1 / 6

A - INFORMATIONS GENERALES

A1 - BESOIN ASSOCIE A LA REALISATION DE CE BULK
- Type : Manip / nBLM

A2 – DONNEES GENERALES DE LA DEMANDE
- Dimension du gap (µm) : 128
- Résolution en énergie (%) FWHM : 18
- Mesh unique : Oui
- Mesh segmentée : Non
- Plots d'amplification : Diamètre (µm) : 400, Pas (mm) : 5,5

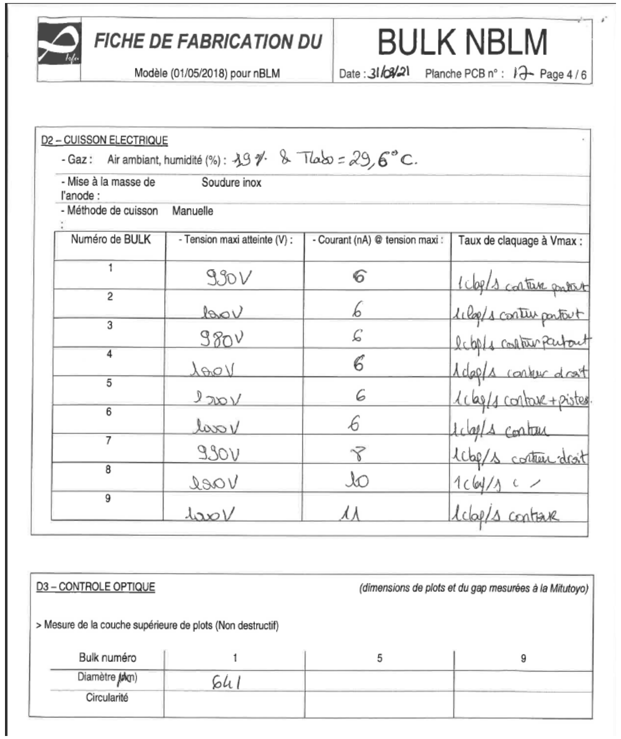
B - CONSTITUANTS

A1 – SUPPORT
☐ PCB
- Matière : IS410 (FR4)
- Tg (°C) : Tg >140
- Epaisseur (mm) : 1,6
- Dimension finale : Largeur (mm) : 145 Longueur (mm) : 185
- Dimension zone active (détection) : Largeur (mm) : 80 Longueur (mm) : 80
- Gerber PCB (Réf) : \\dapnia\data\manip\CAODetecteur\nBLM\Gerber\nBLM\Gerber
- Epaisseur piste : 20mm (x4)
- Matière piste : Cuivre
- Protection piste : Ni/Au électrochimique
- Présence d'un cadre de dégrapage : Oui

B2 - PHOTO-IMAGEABLE
- Type : Pyralux PC 1025
- Epaisseur : 64µm

B3 - MESH voir page 5
- Tension : but 10N/cm sur cadre de 628 mm x 505 mm pour 9 bulk
- Type : Bopp SD45/18, Inox 304, fil de 18µm, ouverture 51%, calandrée
Outillage mesh : manip\Labobulk\fab série detecteur\Fab nBLM

Voir annexe (Fiche de Tension de Mesh)



FICHE DE FABRICATION DU BULK NBLM
Modèle (01/05/2018) pour nBLM
Date : 31/03/21 Planche PCB n° : 17 Page 4 / 6

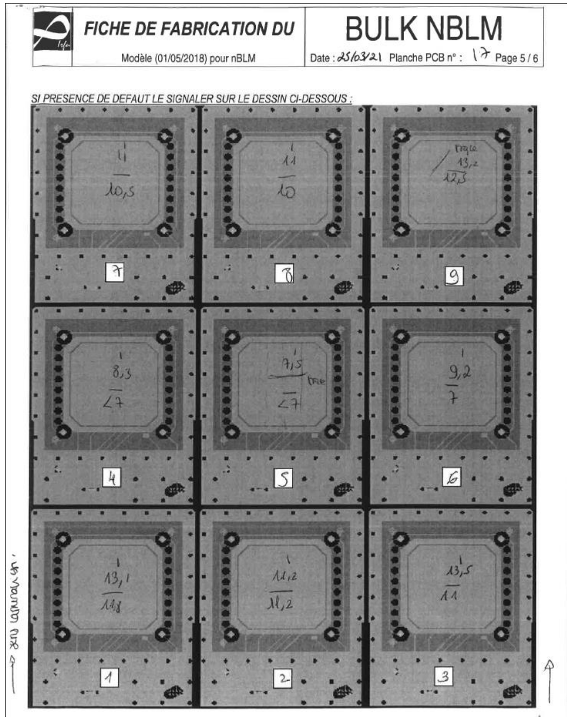
D2 – CUISSON ELECTRIQUE
- Gaz : Air ambiant, humidité (%) : 19 % & Tlabo = 29,6 °C
- Mise à la masse de l'anode : Soudure inox
- Méthode de cuisson : Manuelle

Numéro de BULK	- Tension maxi atteinte (V) :	- Courant (nA) @ tension maxi :	Taux de claquage à Vmax :
1	990V	6	1clq/s contour partout
2	1000V	6	1clq/s contour partout
3	980V	6	1clq/s contour partout
4	1000V	6	1clq/s contour droit
5	1000V	6	1clq/s contour + pistes
6	1000V	6	1clq/s contour
7	990V	8	1clq/s contour droit
8	1000V	10	1clq/s " "
9	1000V	11	1clq/s contour

D3 – CONTROLE OPTIQUE (dimensions de plots et du gap mesurées à la Mitutoyo)

> Mesure de la couche supérieure de plots (Non destructif)

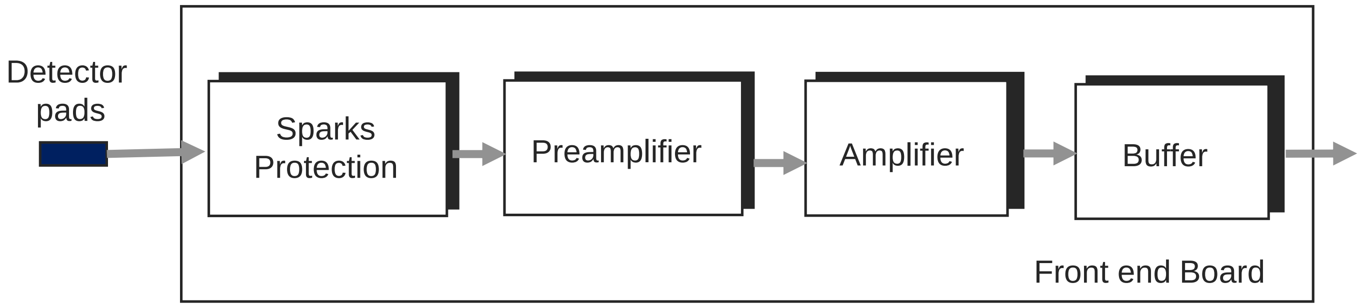
Bulk numéro	1	5	9
Diamètre (µm)	641		
Circularité			

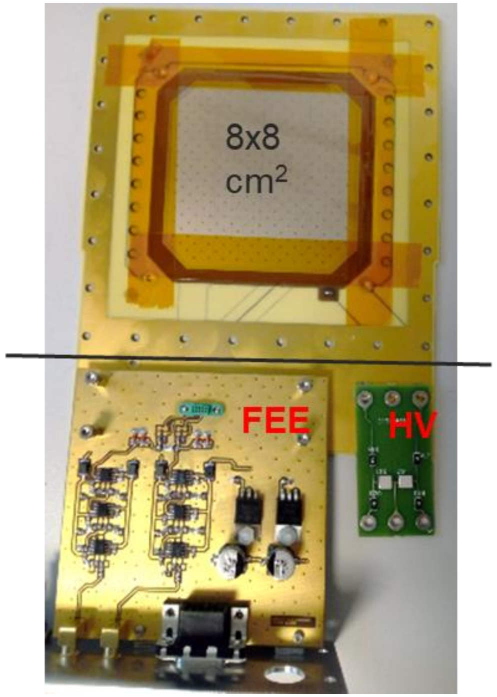


FICHE DE FABRICATION DU BULK NBLM
Modèle (01/05/2018) pour nBLM
Date : 25/03/21 Planche PCB n° : 17 Page 5 / 6

SI PRESENCE DE DEFAUT LE SIGNALER SUR LE DESSIN CI-DESSOUS :

nBLM Front End Electronics (FEE)

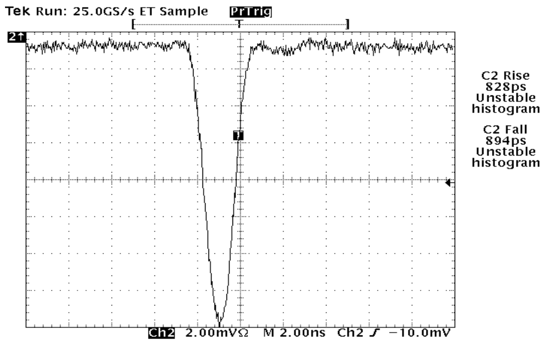


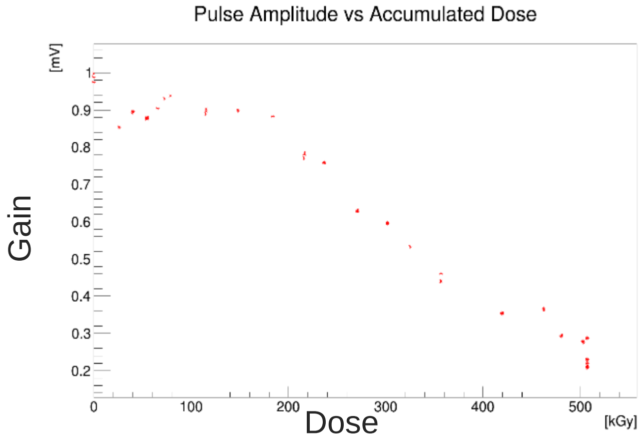


FEE board mounted on the detector

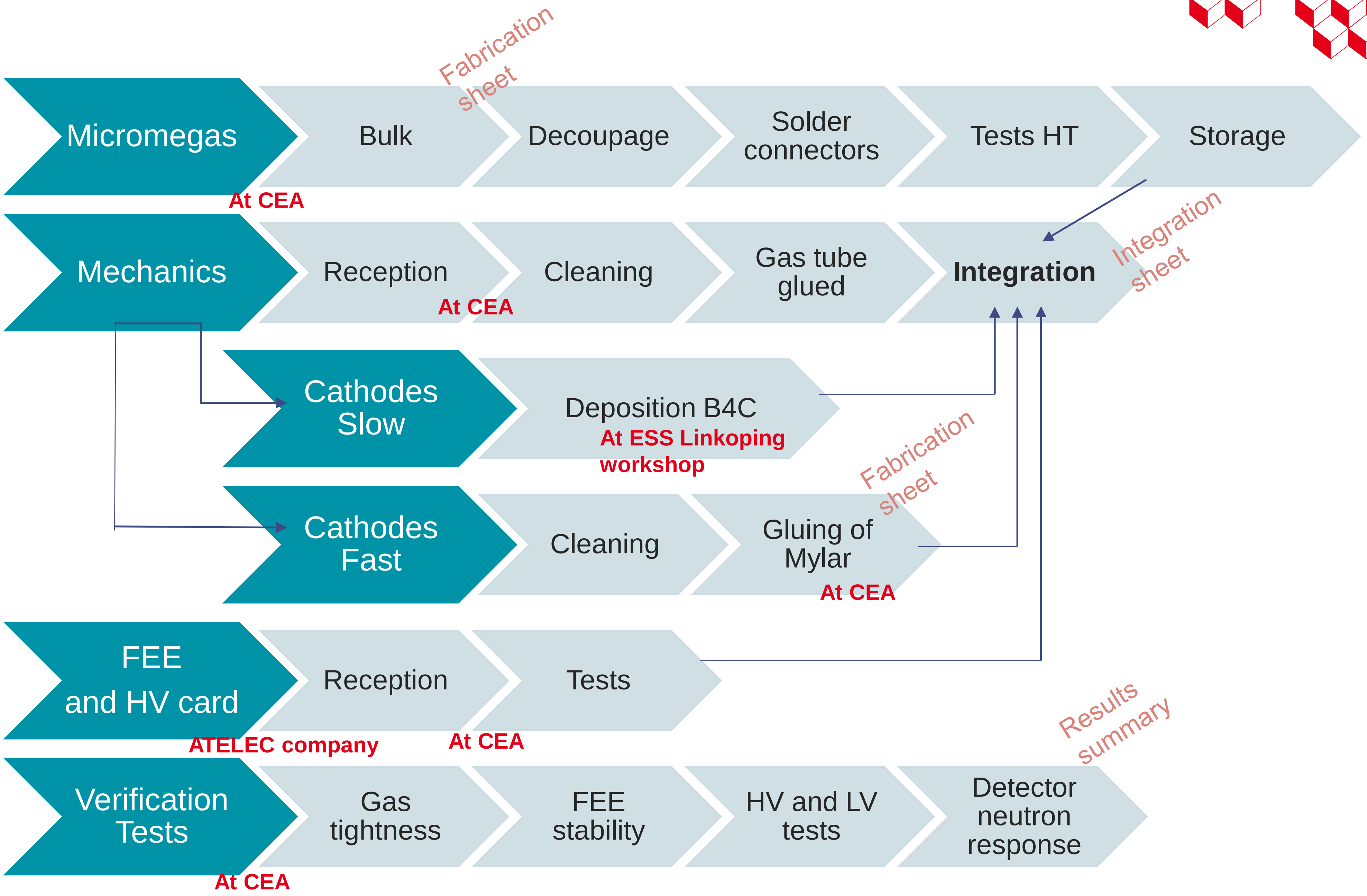
Fast Voltage Amplifier by Ph. Legou at IRFU

- On board FEE → detection of small signals!
- Fast signals capability: rise time < 1ns
- Low noise < 1mV
- Gain ≈ 34
- Irradiation up to 200 kGy ➔ OK!
- Adaptable card to read from 1 to 4 sectors
- Radiation hardness connectors





nBLM Detectors integration flow



nBLM ESS detectors Production at IRFU: plan

START

02/2019

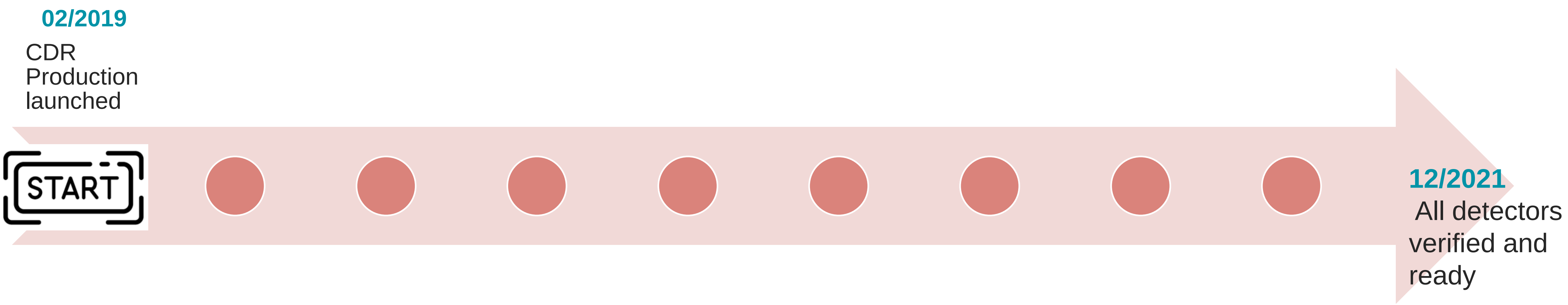
CDR

Production launched

12/2019

all detectors verified and ready

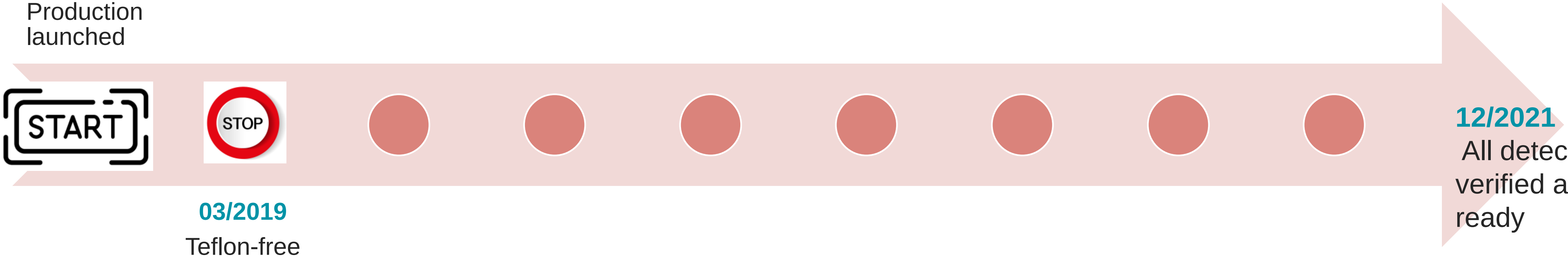
nBLM ESS detectors Production at IRFU: reality



nBLM ESS detectors Production at IRFU: reality

02/2019

CDR
Production
launched



03/2019

Teflon-free
connectors
asked by
ESS

12/2021

All detectors
verified and
ready

Production & validation of 150 FEE cards with Teflon-free connectors in Jan. 2021

Received batches at different periods. Last batch had stabilities problems → sent back for reparation

nBLM ESS detectors Production at IRFU: reality

02/2019
CDR
Production
launched

START

STOP

03/2019
Teflon-free
connectors
asked by
ESS

09/2019

Delivery of 4 first
detectors + auxiliar
systems to cover
up to 12

12/2021
All detectors
verified and
ready

Integration of first 12 with Teflon connectors for low energy part

nBLM ESS detectors Production at IRFU: reality

02/2019
CDR Production launched

START

03/2019
Teflon-free connectors asked by ESS

STOP

09/2019
Delivery of 4 first detectors + auxiliar systems to cover up to 12

02/2020
During validation of first 12 detectors some sparks
Proposition to change quenche
New studies → Delay in prod

03/2020
Sent of 8 detectors + gas crates

12/2021
All detectors verified and ready

Integration of first 12 with Teflon connectors for low energy part

nBLM ESS detectors Production at IRFU: reality

START

02/2019
CDR
Production
launched

STOP

03/2019
Teflon-free
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03/2020
Sent of 8
detectors +
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STOP

COVID

12/2021
All detectors
verified and
ready

Integration of first 12 with Teflon
connectors for low energy part

nBLM ESS detectors Production at IRFU: reality

02/2019
CDR Production launched

03/2019
Teflon-free connectors asked by ESS

09/2019
Delivery of 4 first detectors + auxiliar systems to cover up to 12

02/2020
During validation of first 12 detectors some sparks
Proposition to change quencher
New studies → Delay in prod

03/2020
Sent of 8 detectors + gas crates

COVID

09/2020-11/2020
Task Force
All detectors integrated

12/2021
All detectors verified and ready

Integration of first 12 with Teflon connectors for low energy part

nBLM ESS detectors Production at IRFU: reality

02/2019
CDR Production launched

START

03/2019
Teflon-free connectors asked by ESS

STOP

09/2019
Delivery of 4 first detectors + auxiliar systems to cover up to 12

02/2020
During validation of first 12 detectors some sparks
Proposition to change quencher
New studies → Delay in prod

03/2020
Sent of 8 detectors + gas crates

STOP

COVID

09/2020-11/2020
Task Force
All detectors integrated

02/2021
Problem with drift gap spacers**, identified during analysis** of data
➔ re-validation of all detectors

12/2021
All detectors verified and ready

Integration of first 12 with Teflon connectors for low energy part

R&D on glue for gas tubes
Different method to glued also the mylar in cathode fast

nBLM Integration Laboratories

Polyethylene

Mirrobor

Mechanics of the nBLM detector chambers (for 84 modules) at CEA

Detector integration lab

nBLM Detector Verification

- **Gas leak test**
- **High voltage test**
- **Neutron irradiation**
  - Detector validation lab (^{252}Cf source - weak)
  - SPR intense AmBe source (50 GBq)
  - Each detector monitored for a minimum amount of time & number of neutrons.
- Detectors not meeting required performance are **repaired or replaced**

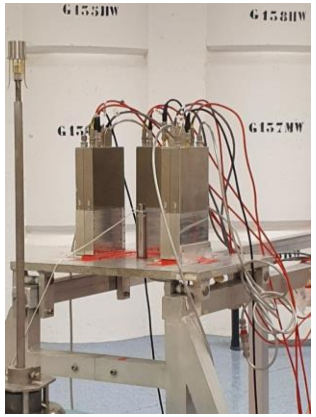
- **All detectors validated by Feb 2022**

Detector validation lab b.534

Rack with (from top to bottom)

1. MTCA+FMC card
2. SY4527 CAEN Crate with the HV A7030 and LV A2519
3. Gas distribution chassis
4. Gas main control chassis

Detector leak test lab b.534



Detector testing @ SPR

nBLM Detector Validation Report

Several files provided for each detector:

- **Fabrication and integration sheet.**
- **Leak test summary.**
- **Performance Summary sheet:**

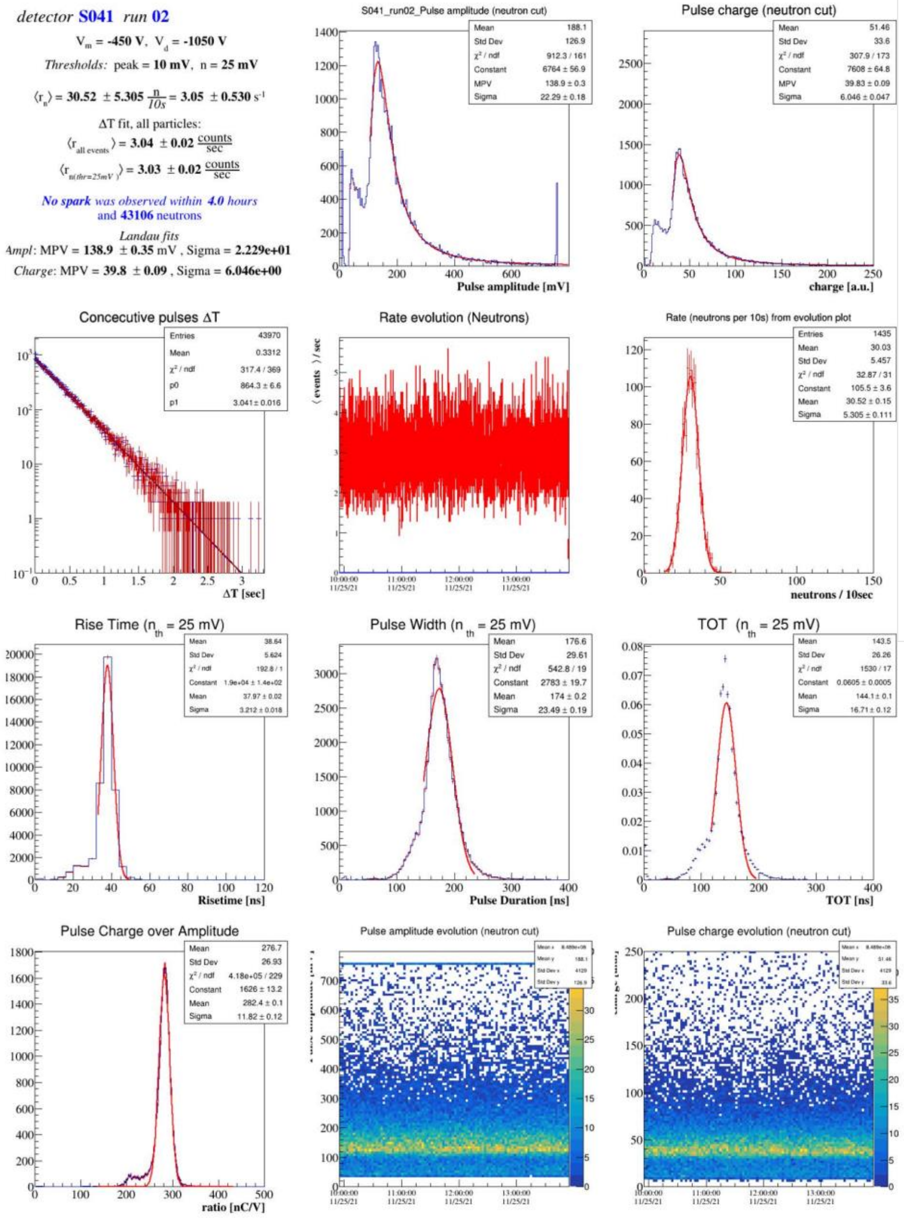
  A PDF file with all the relevant parameters and graphs is created by the analysis routine. This file is provided as characteristic sheet for the detector.

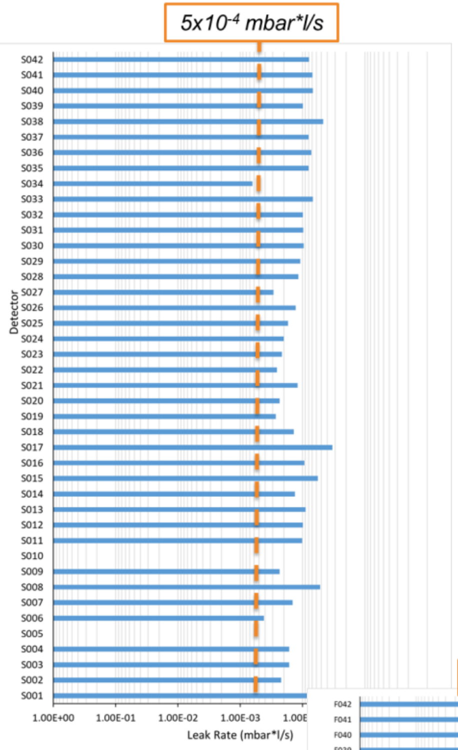
- **ROOT data file:**

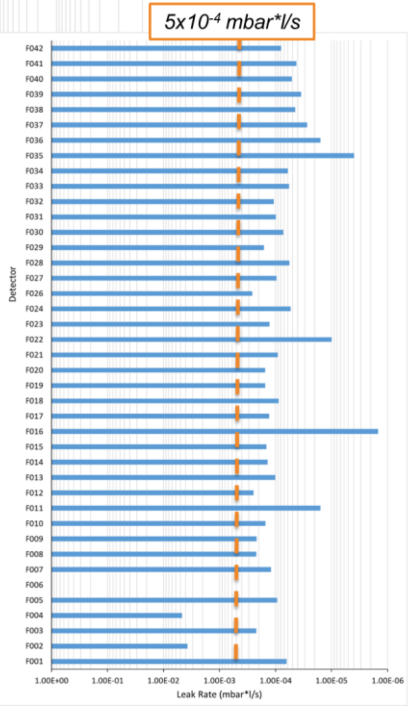
  A ROOT file for each detector is also provided. The file contains the different histograms and data created during the analysis. The file does not have the raw signal data, but they can be provided on demand.

Important: NO sparks during neutron irradiation!

Analysis summary report by Florian Benedetti

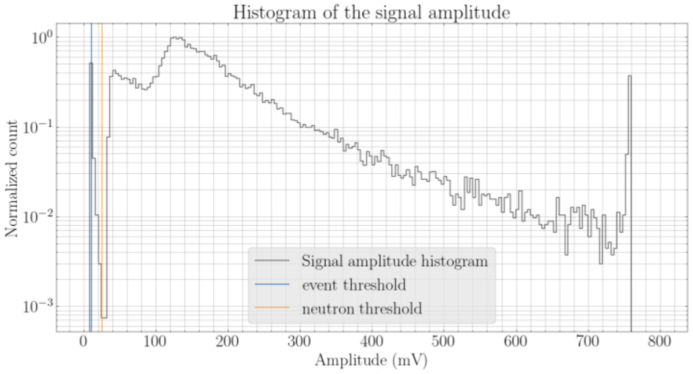




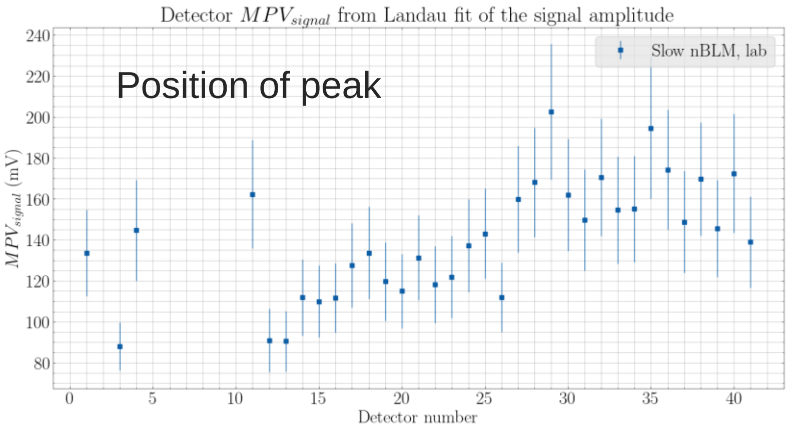


nBLM Detector Summary plots: examples

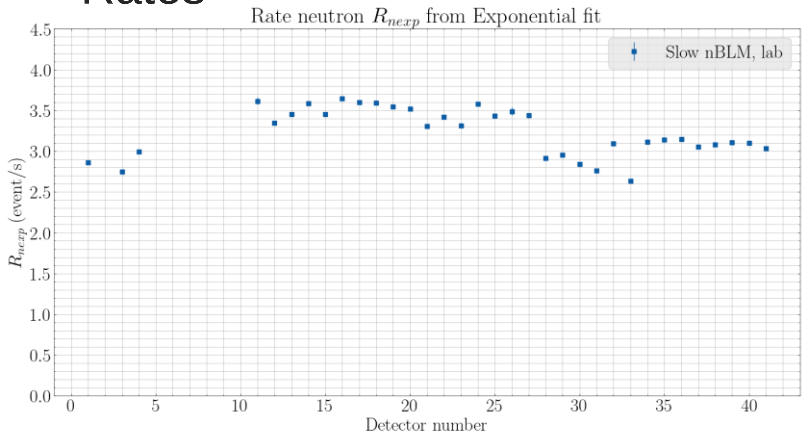
Slow Amplitude typical spectrum



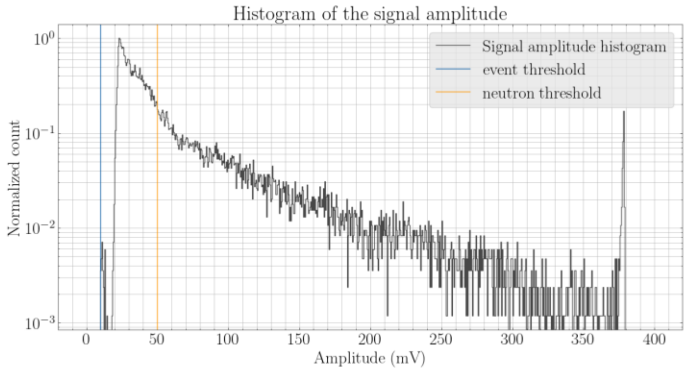
Position of peak



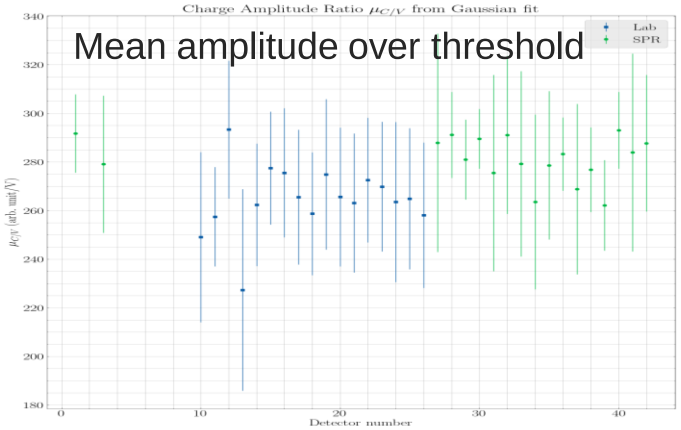
Rates



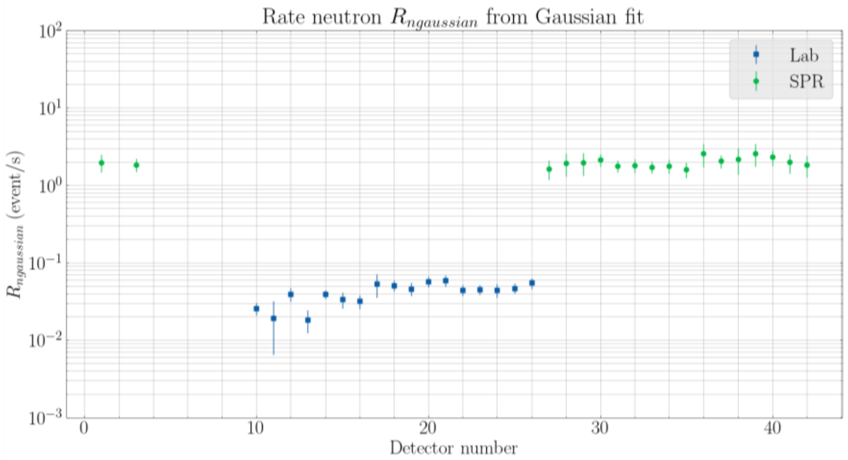
Fast Amplitude typical spectrum



Mean amplitude over threshold



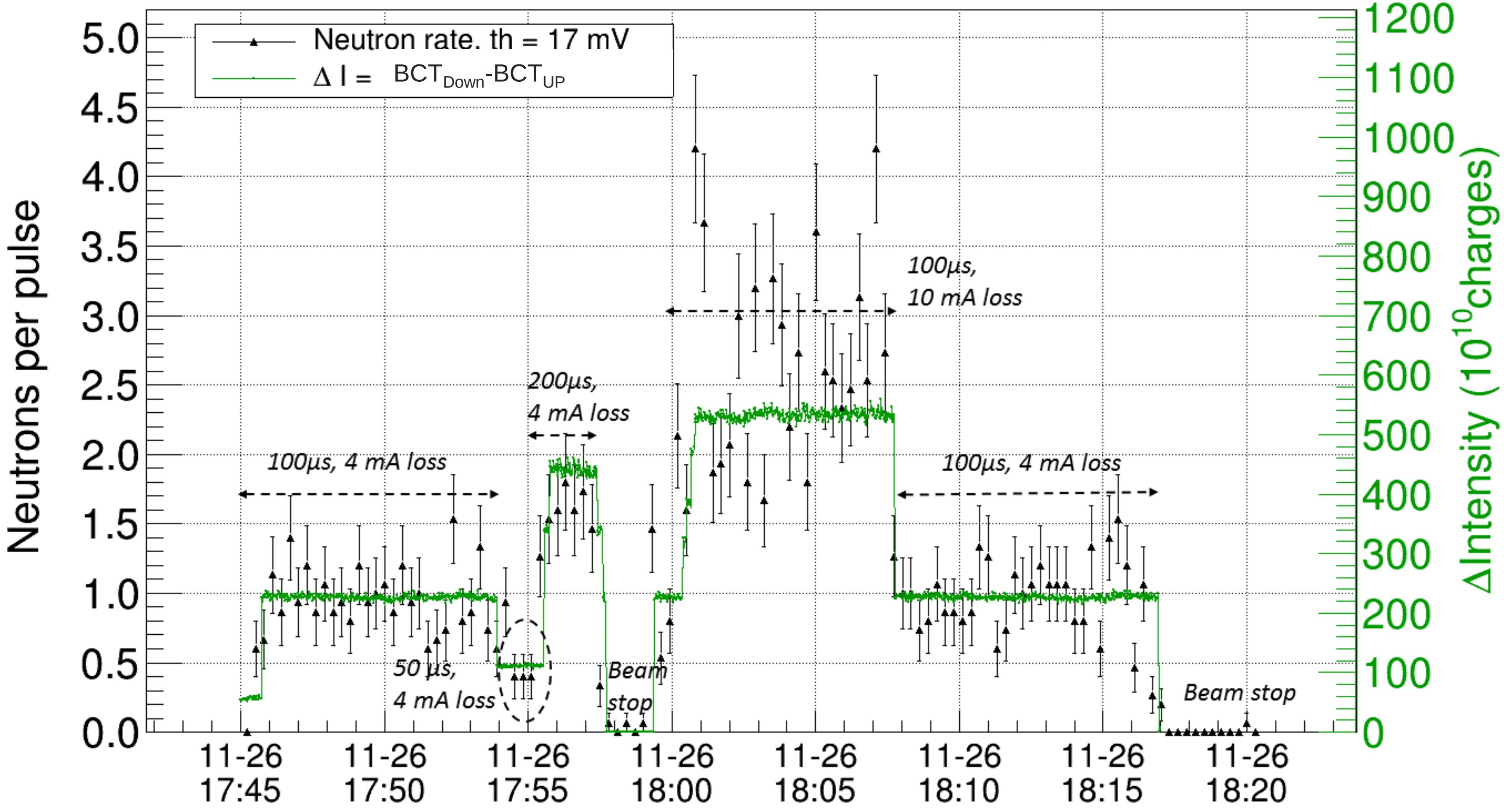
Rates



Analysis done by Florian Benedetti

nBLM System validation: Linac 4 test

Correlation between BCT current and nBLM count rate



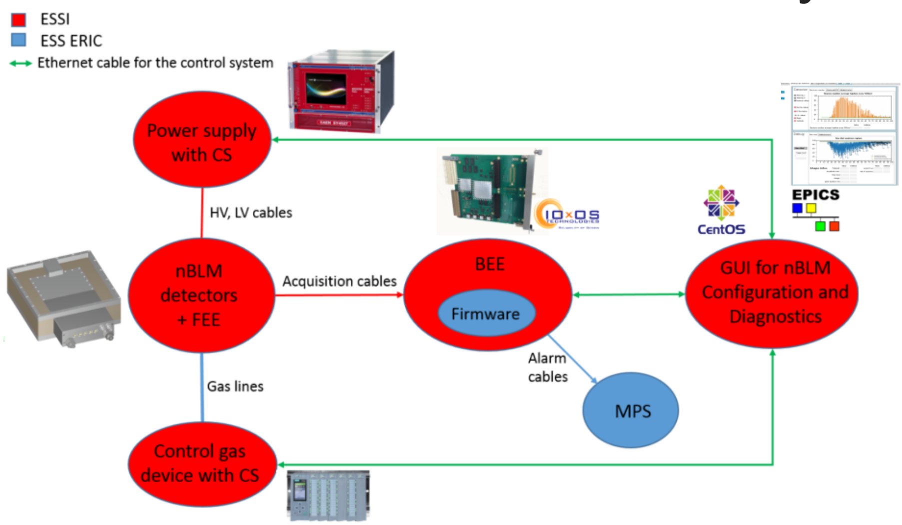
L. Segui. et al. Detector design and performance tests of the ESS-neutron Beam Loss Monitor detectors, JINST **18** P01013 (2023).

*ESS DAQ same results Phys. Rev. Accel. Beams **25**, 022802*

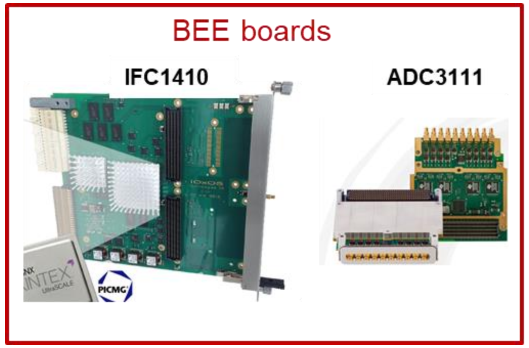
nBLM System

…not only detectors

Developed between IRFU, ESS and Lodz Uni.



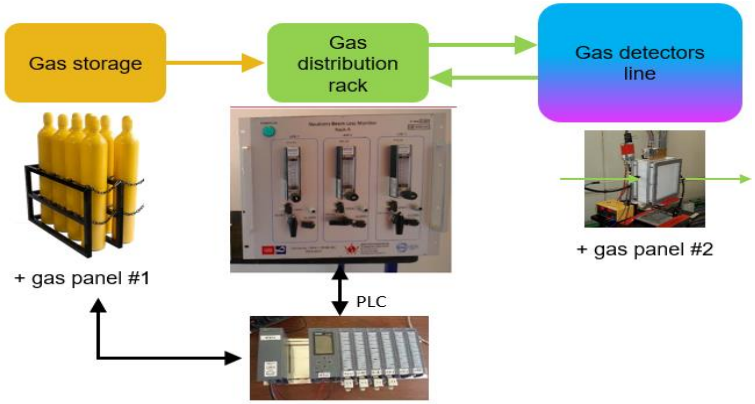
Control System architecture at IRFU(DIS)

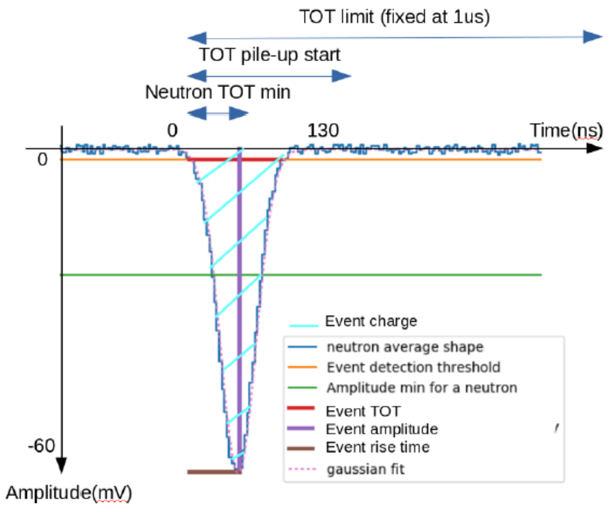


Acquisition logic

- FMCs provide data continuously, every **4 ns**
- The algorithm compares the values to a threshold
- When trigger, pulse parameters are provided (TOT, amplitude, charge)
- Neutron to gamma discrimination is based on **amplitude threshold**
- The number of neutrons per µs and the total charge (integral) is provided
- When pileup observed counting is based on charge
  ➔ The pulse charge distribution from neutron events has a constant shape. The mean value can be used to calculate the average number of neutrons
- Continuous integration is equivalent to **current mode** (1 reading per µs)
- Self - calibration of pulse amplitude and pedestal runs to check stability

Gas system at IRFU

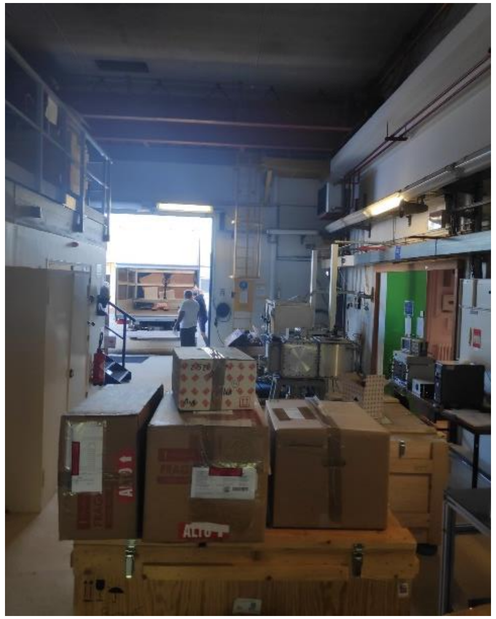




nBLM Delivery

- 4 deliveries between 2019 and 2022
  - September 2019 : first 4 detectors + auxiliaries for at least 12
  - Mars 2020 : 8 detectors + gas crates
  - January 2021 : 30 detectors + auxiliary LV boxes
  - 2 August 2022 : Final delivery of all detectors & sub-systems

nBLM Detectors @ ESS lab (2021)



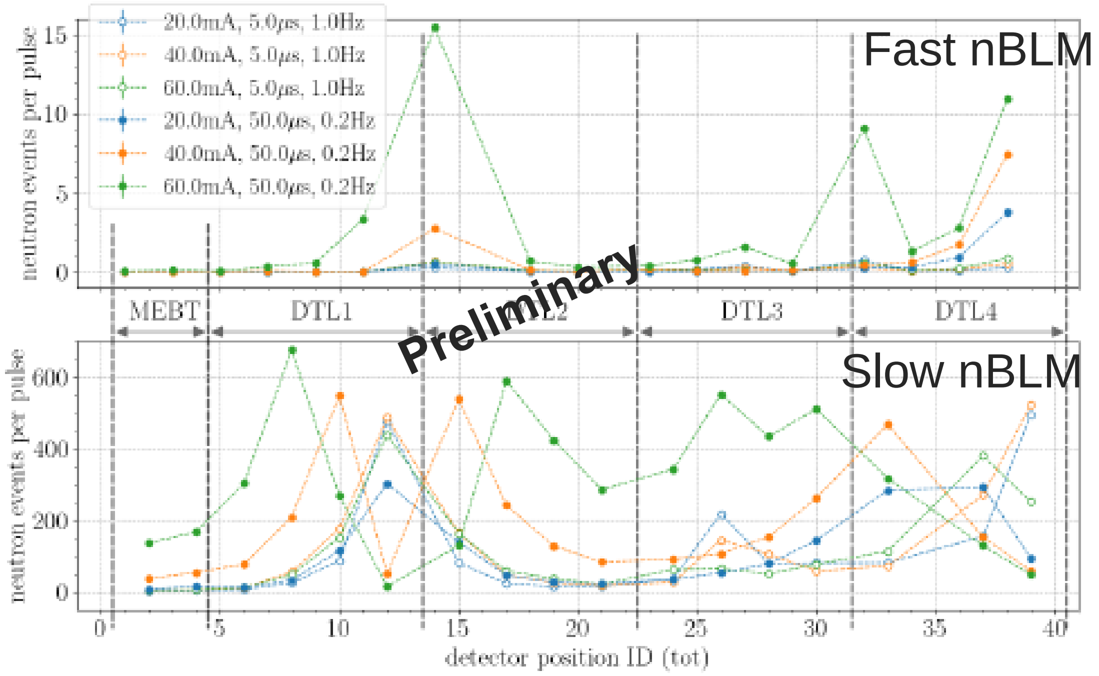
ESS lab setup in 2020

nBLM at ESS

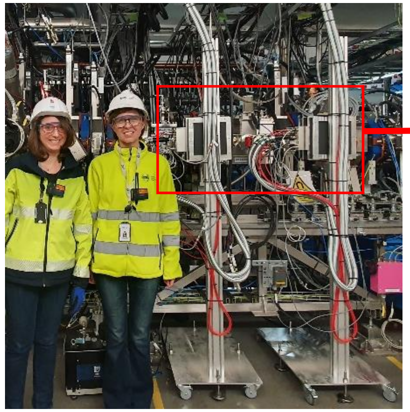
- **36 detectors** already around MEBT (10/2021) and DTL1-4 (05/2022)
  - Find out that the signal cable has been changed!! extra shielding, not adapted for the mechanical pieces designed to hold it in place.
  - In February 2022 it was discovered that almost all HV cables have been damaged, connector is loose…it was not like this during the installation
- ➢ Data taking with source in tunnel to check all the line
- ➢ **1st commissioning** test @ **ESS**: 9th March 2022

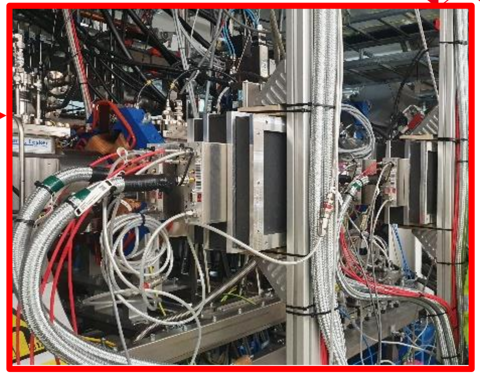
  ➔ May 2022: ***front page in ESS Confluence***: ***First neutrons seen at ESS!***

In 2023 data taking during DTL4 commissioning run.



I. Dolenc-Kittlemann, IBIC 2023, paper TU1I02





2 pair fast+slow in MEBT

- ➢ Set-up **gas system** (**October 2021**)
  - Errors found in the labelling of the gas pipes
  - Set-up the line for MEBT-DTL1 + gas crates
  - Operation in **manual mode** for the moment

Outlook

- **Conception of a new type of beam loss monitor : nBLM (neutron Beam Loss Monitor)**
  - Based on Micromegas detectos
  - To enlarge sensitivity in the low energy parts of hadron accelerators
- Design, production and validation of **84 nBLM** at IRFU and **its auxiliary systems** from 2019 to 2022
- Installation and commissioning on-going at ESS.
  - ➢ Commissioning is critical:
    - ☞ Performance validation
    - ☞ Establishment as a critical system for linacs

Prospects

- ➢ nBLM System for **SARAF**, Israel (CEA project)
  - Smaller scale (17 detectors)
  - Production of detectors & subsystems is completed
  - Installation on-going
- ➢ nBLM System for CEA Saclay for IPHI rejuvenation
  - Similar scale to SARAF
  - Production on-going
  - Part of the system **already in use at IPHI**
- ➢ nBLM as **neutron beam monitors** for **ESS instruments ??**
  - On-going studies
  - 2 prototypes for 2024?

Thank you!

nBLM Team at CEA

K. Aivazelis, S. Aune, M. Combet, D. Darde, D. Desforge, F. Gougnaud, T. Joannem, M. Kebbiri, C. Lahonde-Hamdoun, P. Legou, Y. Mariette, A. Marcel, J. Marroncle, V. Nadot, **T. Papaevangelou, L.Segui**, G. Tsiledakis,

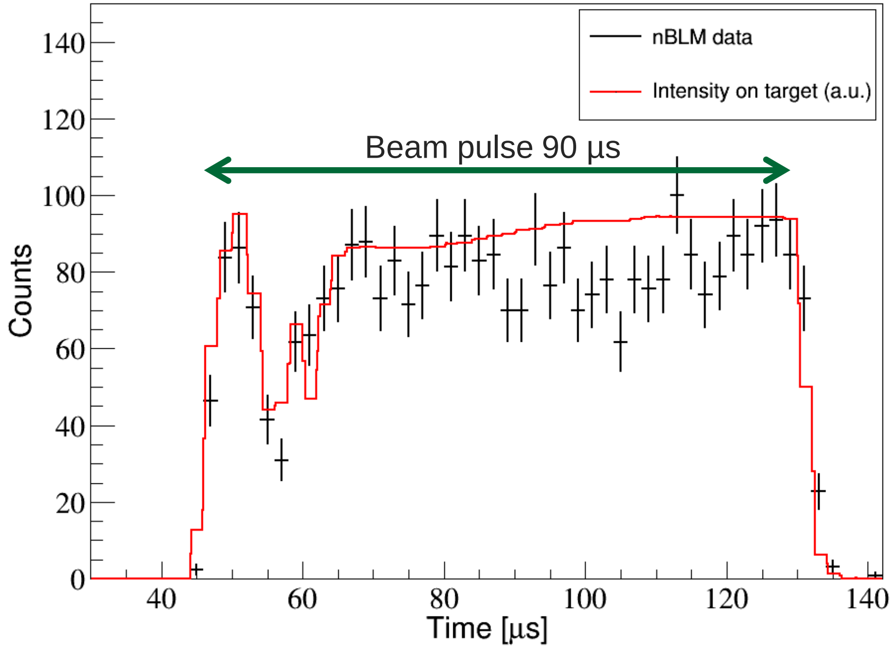
nBLM Detector Characteristics

	SLOW	FAST
neutron-to-charged particle convertor	B_4C	Mylar or Polypropylene
Reaction	$^{10}B(n,\alpha)^7Li$	(n,p)
Signal produced by	Fast neutrons after moderation	Fast neutrons
Detected energy	~constant for all initial neutron energy	Depends on initial neutron energy
Sensitivity	10^{-4} < En < 100 MeV	En > 0.5 MeV
Solid angle	4π	2π, n coming from the front only
Efficiency	~few $n \cdot cm^{-2} \cdot s^{-1}$	~10-100 times smaller
Response time	~200 µs	~0.01 µs
Objective	Monitoring of small losses	Fast detection (response in 5 µs) Fine structure of the lost
Shielding	Yes, for thermal neutrons	Not needed

EXPERIMENTAL RESULTS
NBLM TIME RESPONSE

IPHI 3MeV p beam
n produced with
Be target

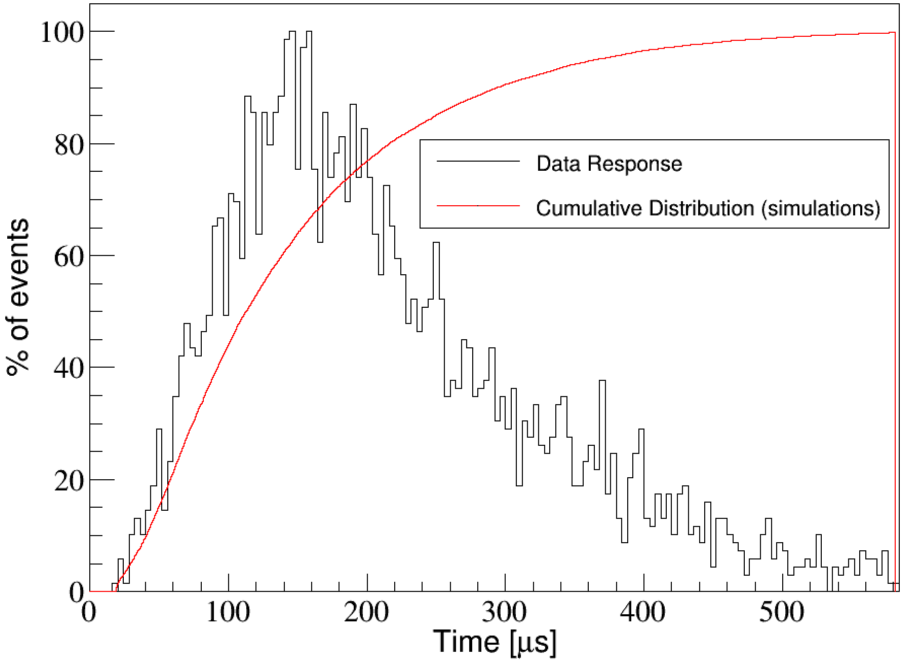
FAST



- Immediate response
- Count rate in direct correlation with beam current intensity

SLOW

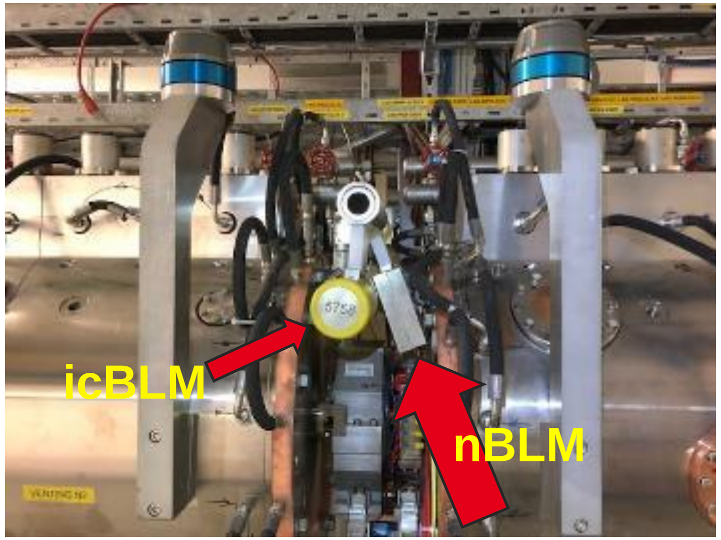
Data acq with a fast oscilloscope at 250 MS/s

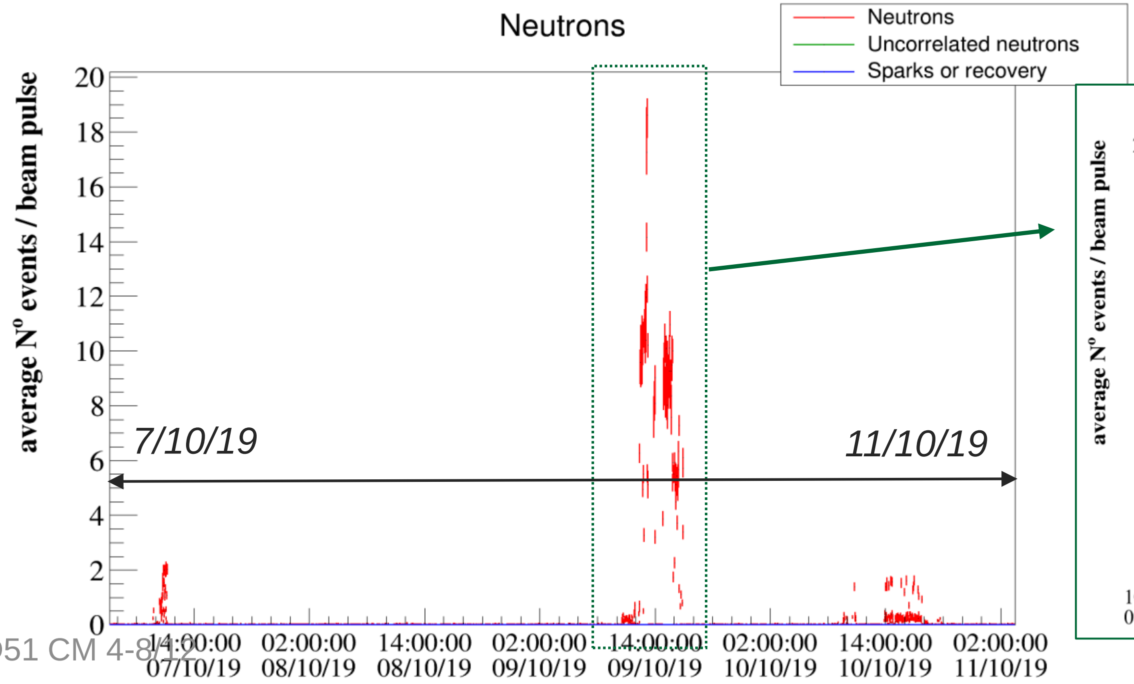


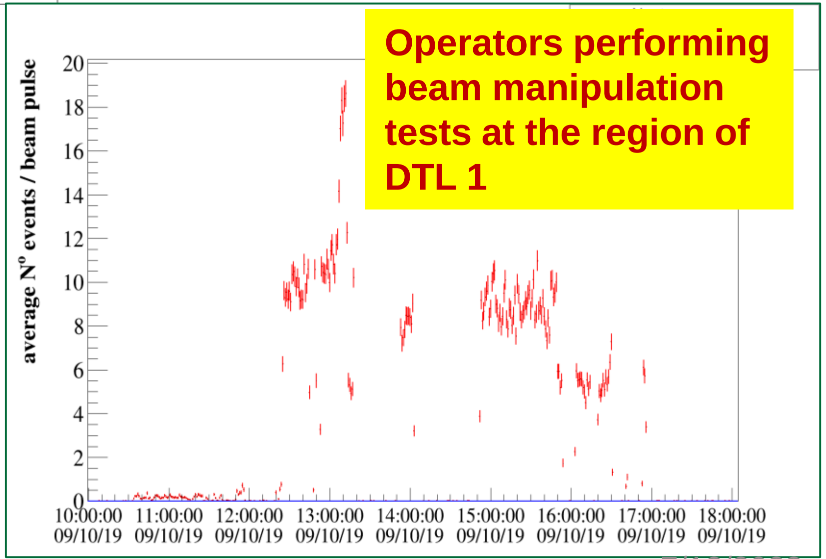
- Delay in signal: Convolution of moderation in polyethyelene + proton beam pulse duration (90 µs)
- ~ 200 µs from simulations for a instantaneous pulse

nBLM SYSTEM VALIDATION: LINAC 4 TEST

- More data acquired with fast nBLM module installed at Linac4, during machine commissioning.
- Detector **stable after one year** in place
- Data taking continuously with oscilloscope for 10 days, recording also trigger from Linac4
- Data taking with the **a version of the ESS-nBLM DAQ** in November 2019 ➔ successful!
- neutrons rates from 0.01 c/s to 20c/s
- ***The icBLM placed just together didn't see anything.***





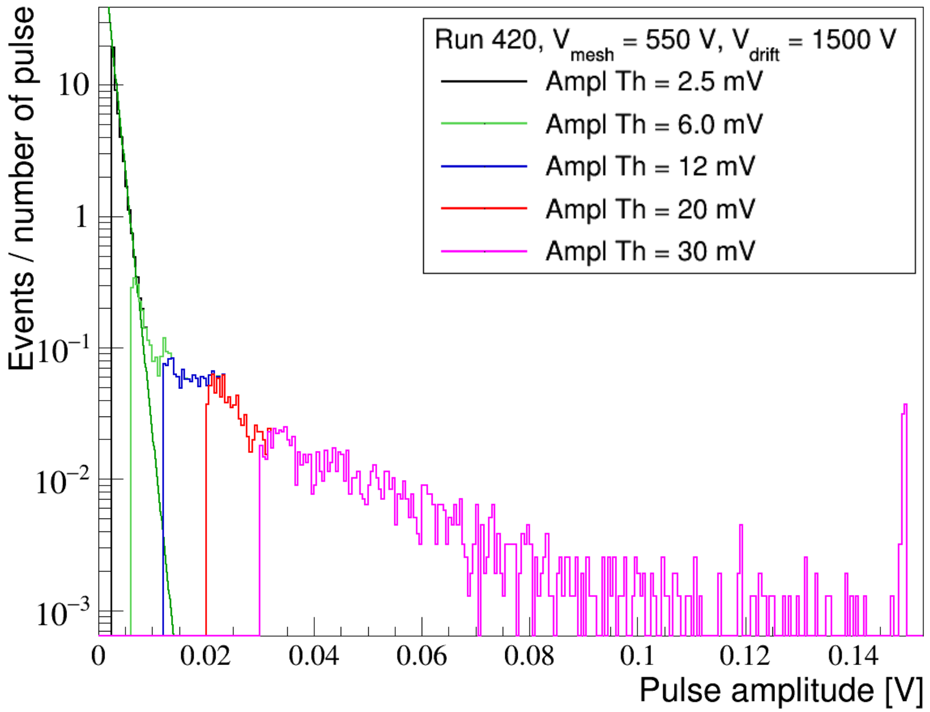


LINAC4 data

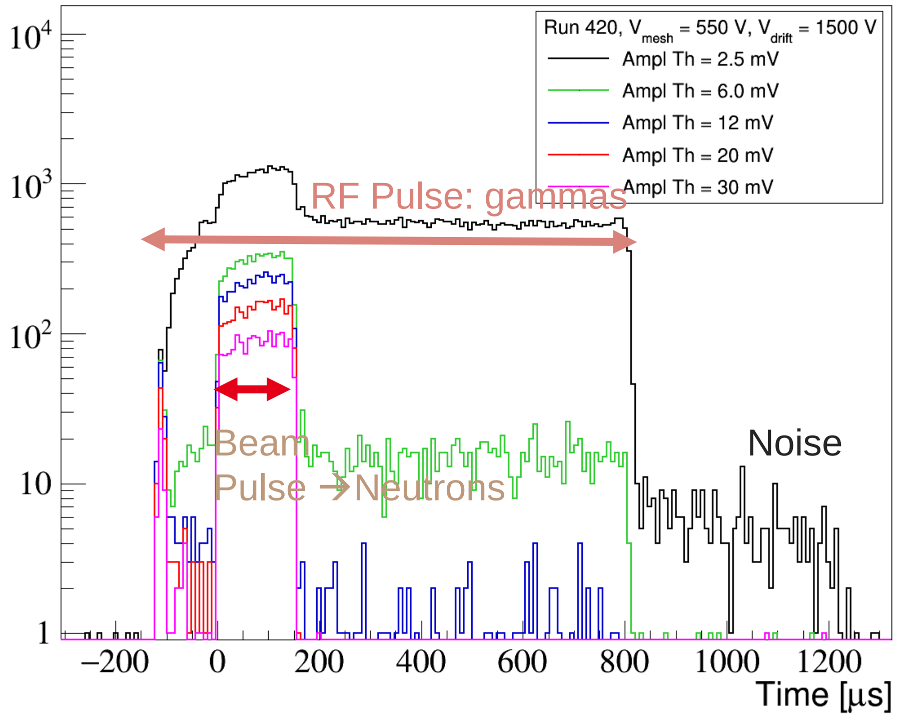
Run 420 – December 2018
Vm = -550V, Vd = -1500V

Observations in agreement with data acq. using the FMC
See poster MOPP022

Amplitude



Time distribution



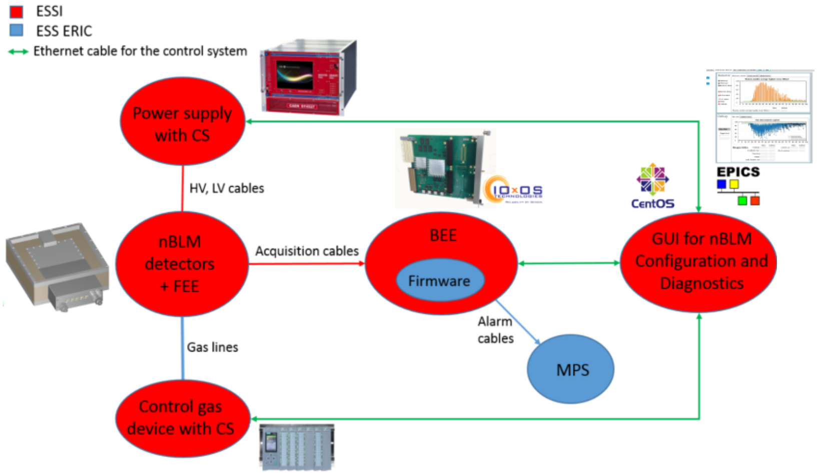
Applying amplitude cut, we recover the beam duration
→ Neutrons produced by beam
→ Gammas distributed all along RF pulse

nBLM SYSTEM

An nBLM "NEEDS":

- Two high voltages (500-1200 V)
- 1 LV cable with two voltages (+8V and -8V) to power the preamplifiers on board
- One coaxial signal cable
- Gas (He based mixture, quencher: ethane at 3.5%)

➔ Acquisition system
➔ HV & LV power supplies
➔ Gas System



Control System architecture (DIS)

GAS SYSTEM

nBLM gas system:

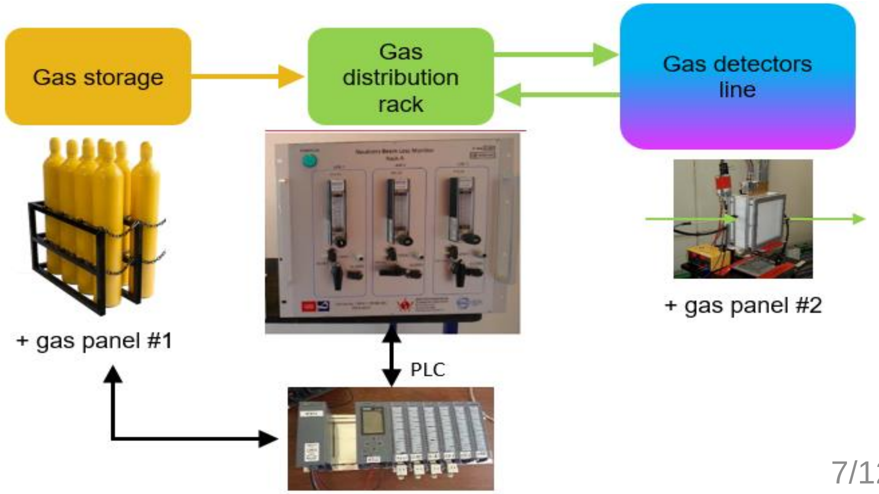
- 5+1 gas lines for 84 detectors (groups of 10-20 in series)
- 1 main rack
- 2+1 distribution racks (3 lines each)
- Gas storage 6+6 premised bottles (50 lt/180bar)
- PLC control
- Possibility for **manual bypass**3.5%)

Gas Type	He + 3.5% ethane	Used of premixed bottles
Total Flow	5 – 10 l/h (feeding/exhaust line)	Limitation of maximum flow immediately after gas bottle at ~20-30 l/h with a rotameter (0-60 l/h)
Flow per Line	During operation 1-2 l/h[1] (distribution/return lines)	Detectors in series
Pressure after bottle	5 bar total	
Pressure at gas lines	1-2 bar	Depends on final pipe length
Pressure at exhaust	1atm + 50 mbar	P and flow will be controlled by PLC

Validation:

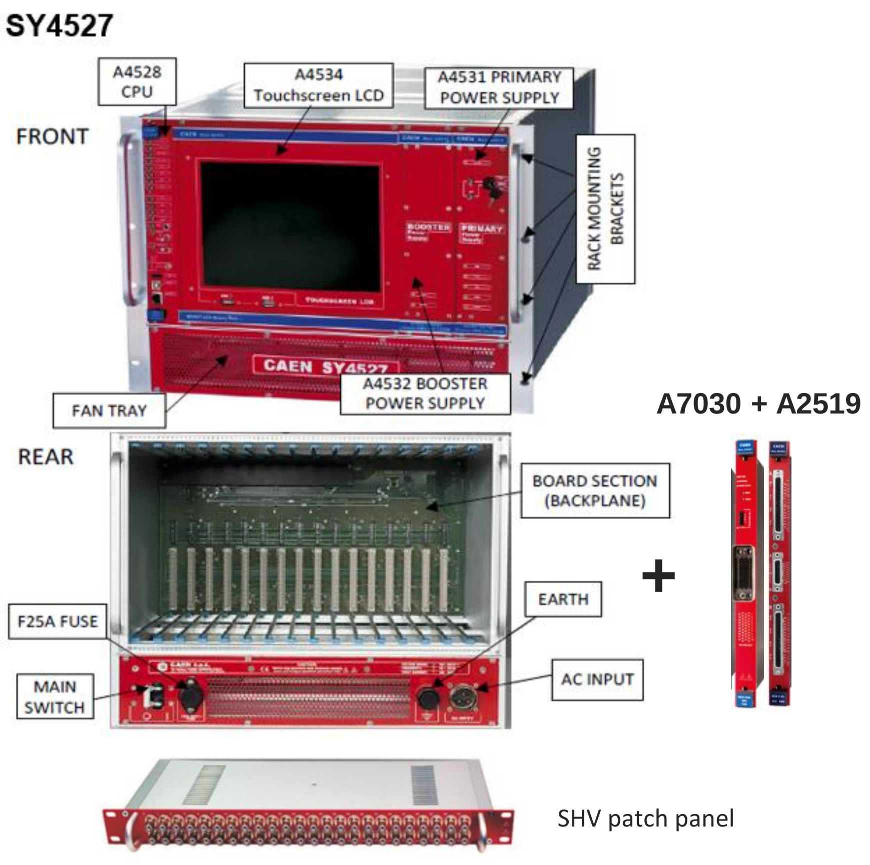
- ✓ Racks leak-tested before sending to ESS
- ✓ Basic operation checked

➔ *Need to replace gas exit connectors & small tubes.*
Part of the intervention @ ESS



VOLTAGE SUPPLIES

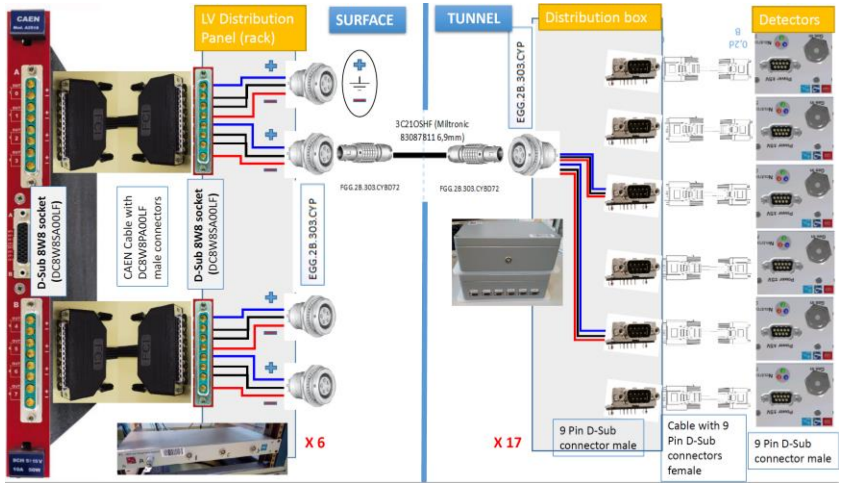
HV and LV crate



nBLM Voltage supplies:

- 2+1 CAEN SY4725 crates
- 5 A2519 HV cards (48 channels each)
- 8 A7030 LV cards
- 17 LV distribution boxes
- EPICS Control System

LV connectivity scheme

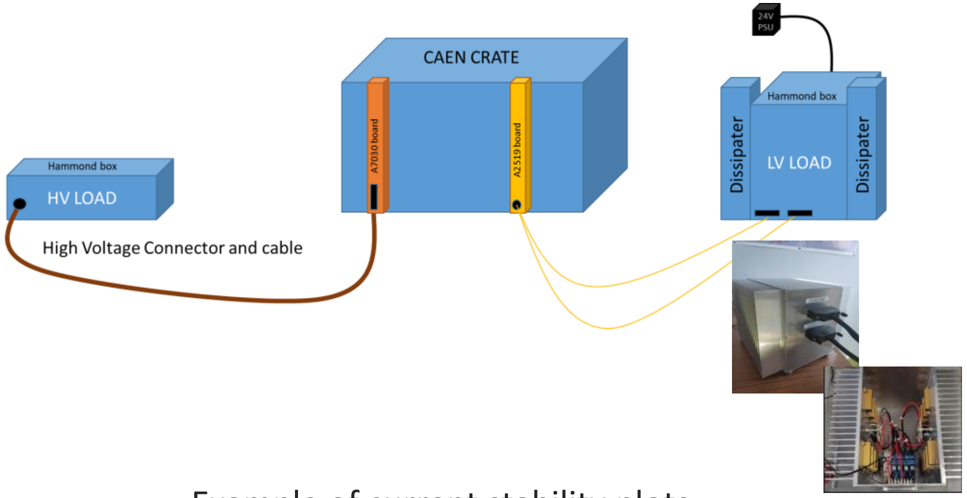


HV & LV MODULE VALIDATION

Validation procedure

- EPICS functionality of each card / crate is checked with automated code (DIS)
- Each card is connected to “**load boxes**” that emulate the **total load of the maximum number** of nBLM detectors that can be fed by the card
- Extensive run for minimum 1 week @ full load
- Monitoring of critical parameters:
  - V stability
  - I stability
  - Consumption
  - Temterature
- Modules with **even one** problematic channel were sent to CAEN for **reparation / replacement**

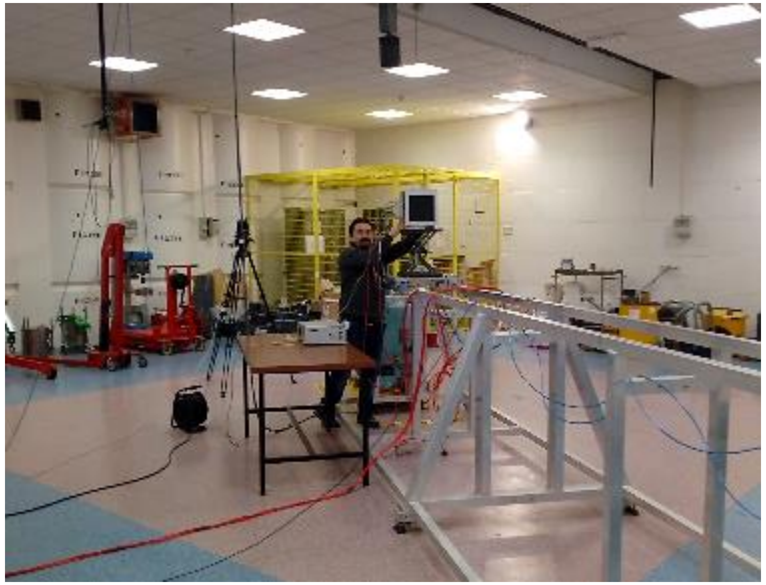
“Full load” validation setup



Example of current stability plots

nBlm data – neutron and gamma sources

- High intensity neutron and gamma sources available from the CEA radioprotection department
- Data taken with slow module on the 6/02 – 08/02
- Gain curves for gammas and neutrons to determine operational point



Source	Activity (Bq)	H^*_{10} at 0.5 m
AmBe (Neutrons)	10^{11}	275 µSv/h
Co-60	10^{8}	1 mSv/h
Co-60	10^{8}	100 mSV/h

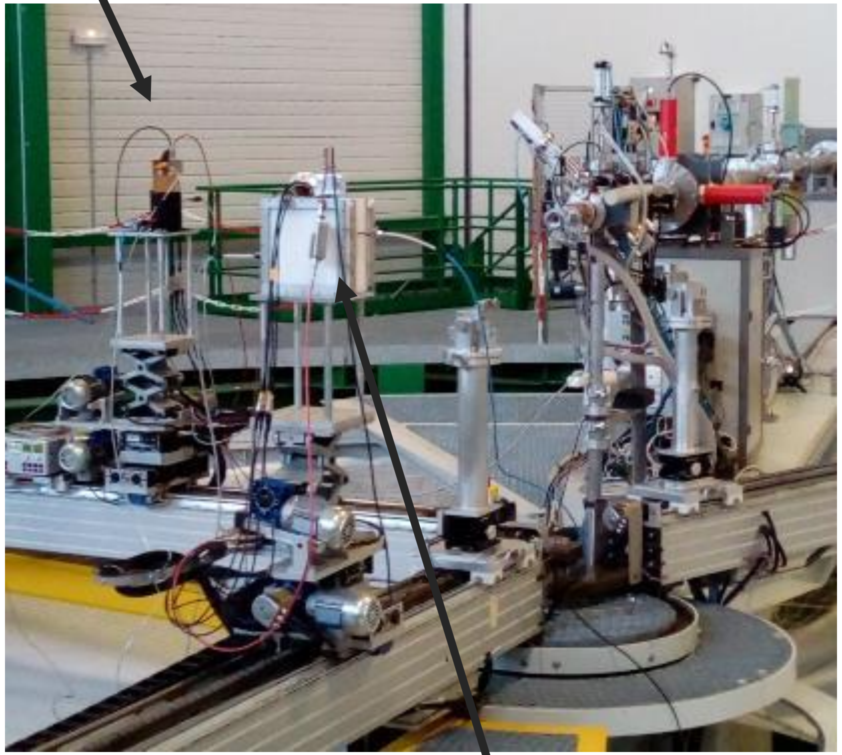
Neutron BLM: CHARACTERISATION AT DIFFERENET IRRADIATION FACILITIES

nBLM

AMANDE FACILITY (IRSN-Cadarache): monoenergetic neutron reference fields

- Metrology
- Testing and calibrating neutron sensitive devices (between 2 keV -20 MeV).

Fast module
2mm drift



Slow module
0.4 mm drift,
1.5µm B_4C

- Data campaign in March 2018
- Slow and fast module tested, He+10%CO_2
- At diff neutron energies:
  - 565, 1200, 2500, 5000 and 15000 keV