Détecteurs de perte de faisceaux nBLM pour l'ESS

Laura Segui

Présentation au Réseau Instrumentation Faisceau IN2P3 du 21/03/2024

nBLM Team at CEA

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OUTLINE

- Context & Motivation
  - ESS nBLM Project
- nBLM detectors
  - Micromegas
- Results R&D Phase
- Production
- ESS results

1. Context and Motivation

Context and Motivation

- 2015 Jacques Marroncle (CEA) contacted by Tom Shea (ESS)
- Thomas Papaevangelou (CEA) expert in the use of Micromegas
- I joined the group in 2016 at the kick-off

Le problème :

- Perte accidentelle de faisceau dans les accélérateurs linéaires de haute puissance:
  - activation des matériaux ➔ **surveiller les faibles pertes de faisceau / tunning of machine**
  - endommager l'accélérateur ➔ **alarme rapide**
- Maintenir les pertes <~ 1 W/m pour permettre une maintenance pratique
  - ESS 5MW → $2x10^{-5}$ /m de la puissance totale (0.02 ‰)
- **Solutions pas adaptées pour la partie basse énergie d'un accélérateur de hadrons**

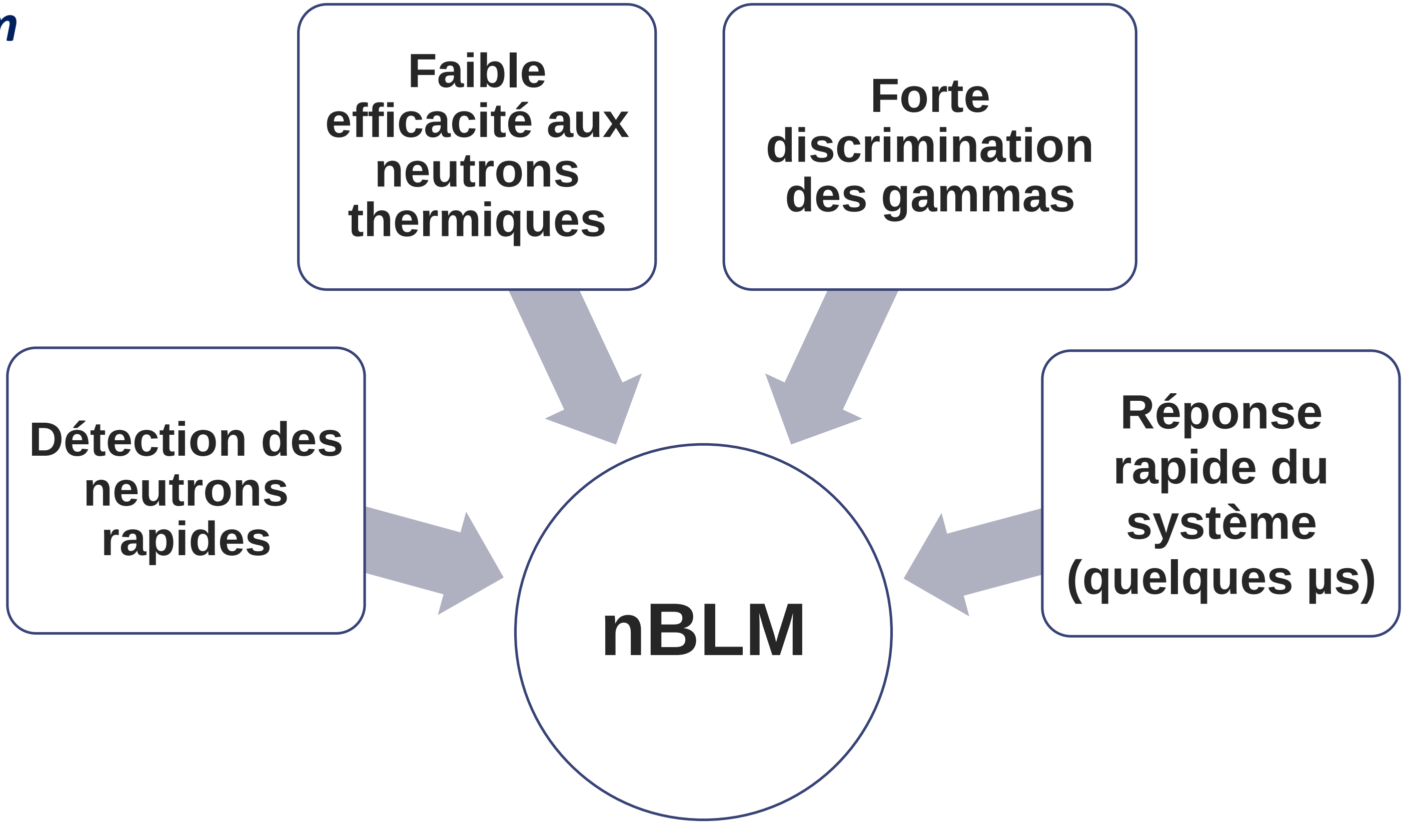
Le positionnement du BLM est important

- À faible énergie de faisceau, seuls les neutrons et les photons peuvent s'échapper du tube de faisceau.
- Faibles taux de comptage car proches des seuils de réaction
- RF x-rays posent un problème pour la mesure des pertes dans les linacs.
- Efforts initialisés à SNS pour développer un détecteur sensible aux neutrons uniquement

☞ Nécessité de détecter les **neutrons rapides** avec une **très grande plage dynamique** dans un **environnement gamma intense**!

Context and Motivation

nBLM = *neutron Beam Loss Monitor*

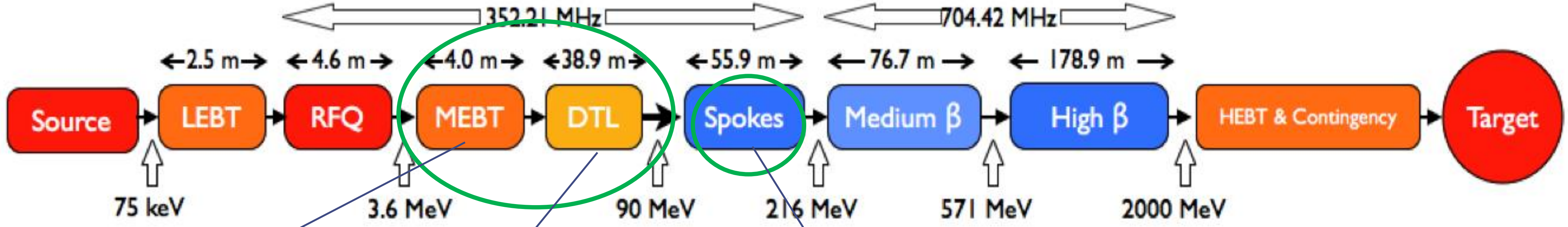


Adapter un **détecteur de particules** (**Micromegas**) pour le diagnostic des faisceaux en utilisant une combinaison de convertisseurs et de modérateurs de neutrons.

➔ **Détecter les neutrons individuels (compteur)**

Context: ESS-nBLM Project

Le projet ESS-nBLM : in-kind Contrat entre la source de spallation européen (ESS) et l'IRFU
Conception, construction, essais et mise en service de **84 détecteurs** (42 rapides + 42 lents) et de **sous-systèmes auxiliaires**.



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

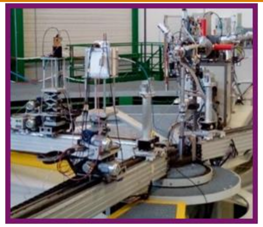
ESS BLM system lead: *I. Dolenc Kittelmann*
CEA coordinator: *T. Papaevangelou / L. Segui*

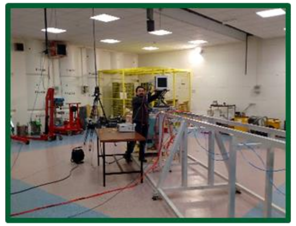
Context: ESS-nBLM Project

2015 | 2016 | PDR 1 12/2016 | 2017 | PDR 07/2017 | 2018 | 2019 | CDR 02/2019 | 2020 | 2021 | 2022 | SAR 11/2022 | 2023

Commissioning start @ ESS: April 2022

idea → conception & design → prototyping & testing → production & validation → installation & commissioning





- July 2016 — Kick-off
- MC40- Cyclotron Birmingham, UK — Dec 2017 — Correlation rate and intensity of the beam
- IPHI, CEA, France — Jan. 2018 — Time Response
- AMANDE, IRSN France — Mar. 2018 — Calibration; n/γ discr.
- ORPHEE, CEA France — Apr. 2018 — Thermal neutrons
- LINAC4 (CERN) — Nov-Dec. 2018 — Real accelerator conditions
- High intense n/γ sources, CEA France — Feb. 2019 — n/γ discrimination

2. nBLM Detectors

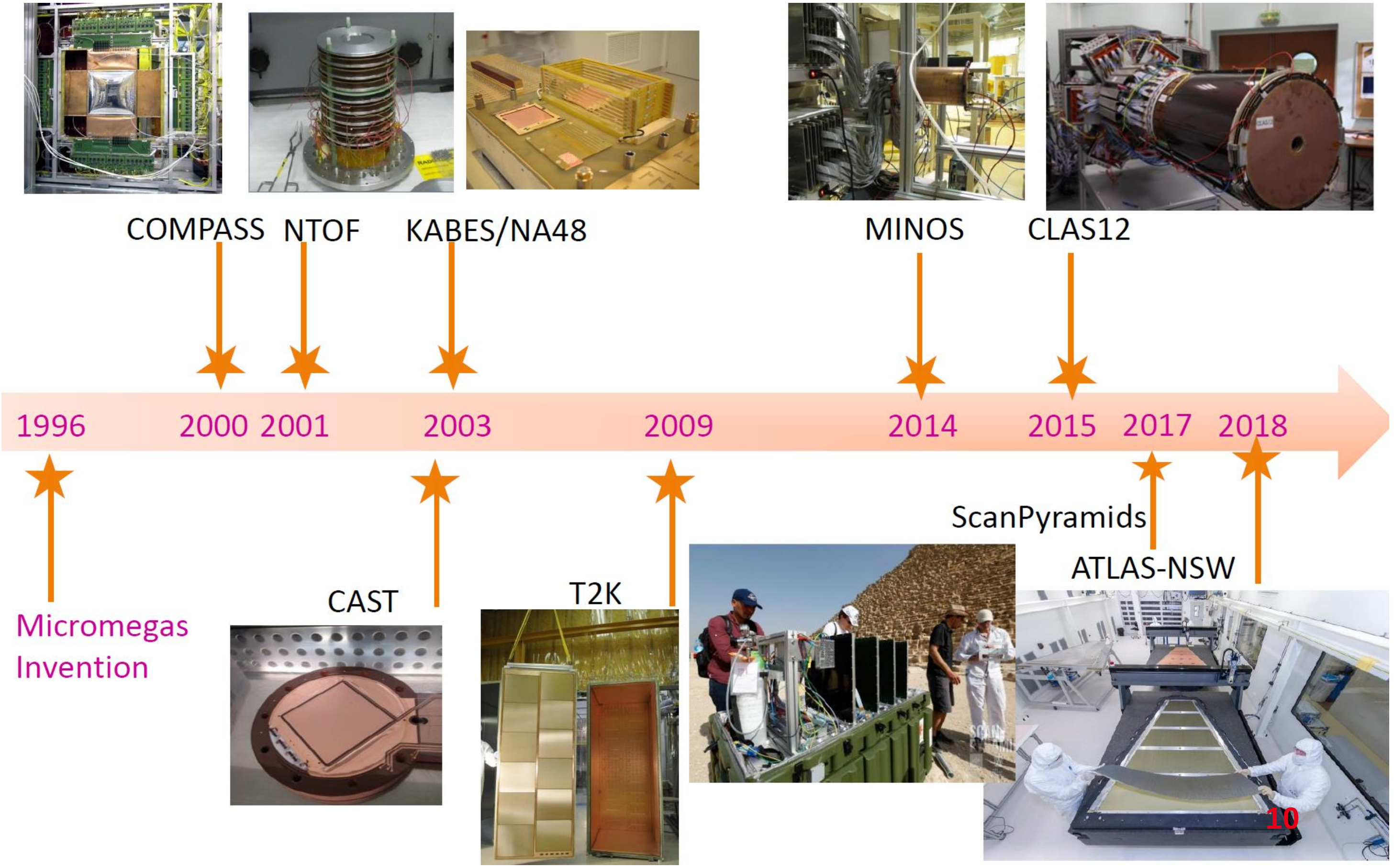
MICROMEGAS

Micromegas

Y. Giomataris, P. Rebourgeard, J.P. Robert and G. Charpak, Nuc. Instrum. Meth. A 376 (1996) 29.

Micromegas:

- Invented in 1996 at **CEA** Saclay by I. Giomataris
- Micro-Pattern Gaseous Detector for **charged particles**, designed for **physics experiments**
- improved amplification structure to measure the ionization signal in a gaseous detector.
- Advanced characteristics: **large-area** scalability, **high rate** capabilities, **low cost**, large **dynamic range**, high **gain**, fast signals, are rad. hard, robust and stable
- Versatility: particle tracking, TPC, imaging



Micromegas Detectors

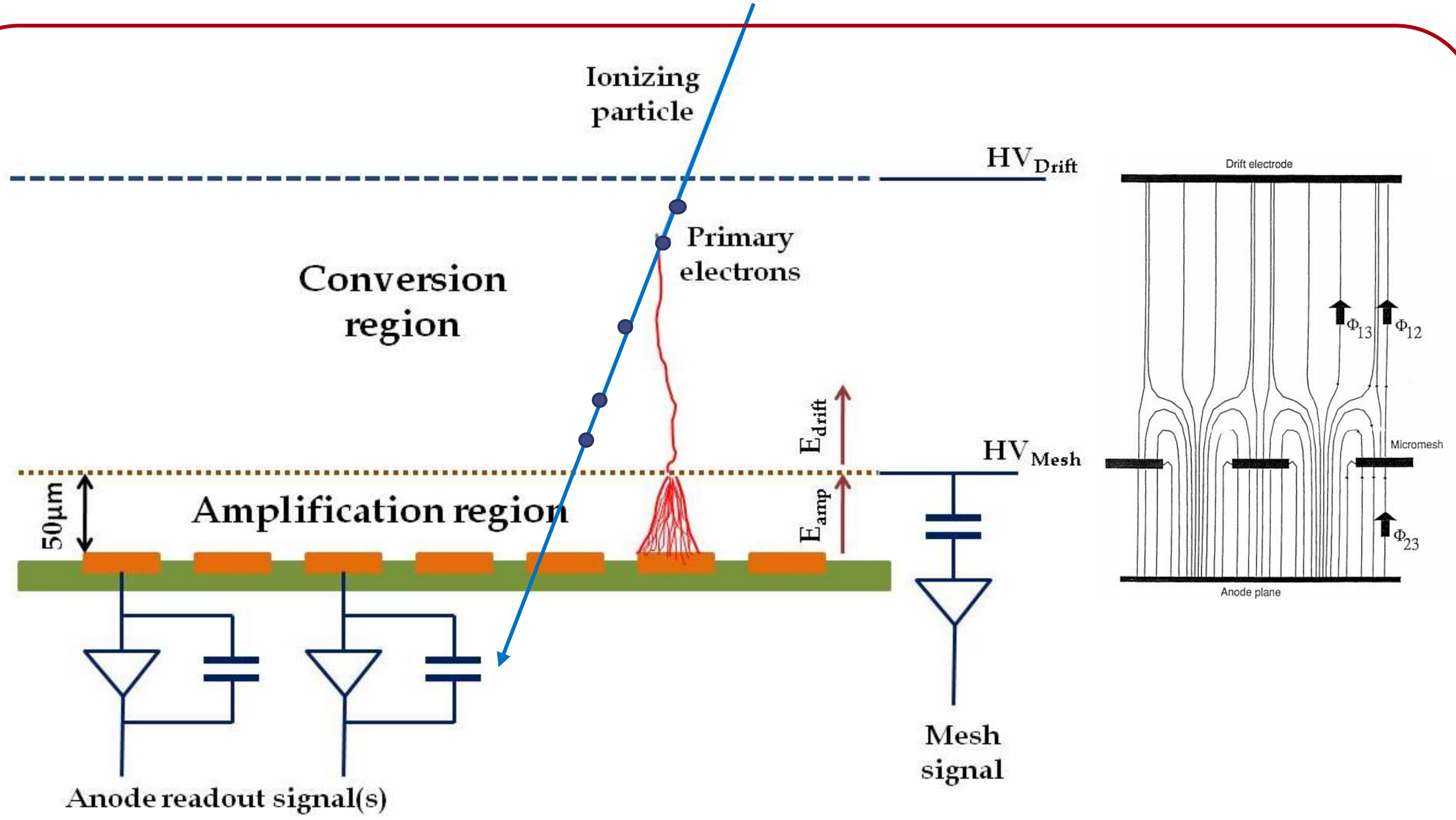
Y. Giomataris, P. Rebourgeard, J.P. Robert and G. Charpak, Nuc. Instrum. Meth. A 376 (1996) 29.

***Two-region gaseous detector* separated by a *Micromesh* :**

To detect neutrons we need a neutron-to-charge particle convertor: it can be placed at the entrance of the conversion zone

$\vec{E}$ =10^2-10^3 V/cm

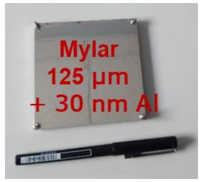
$\vec{E}$ =10^4-10^5 V/cm

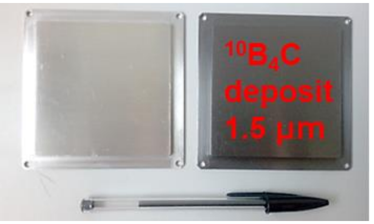


nBLM Detectors Geometry

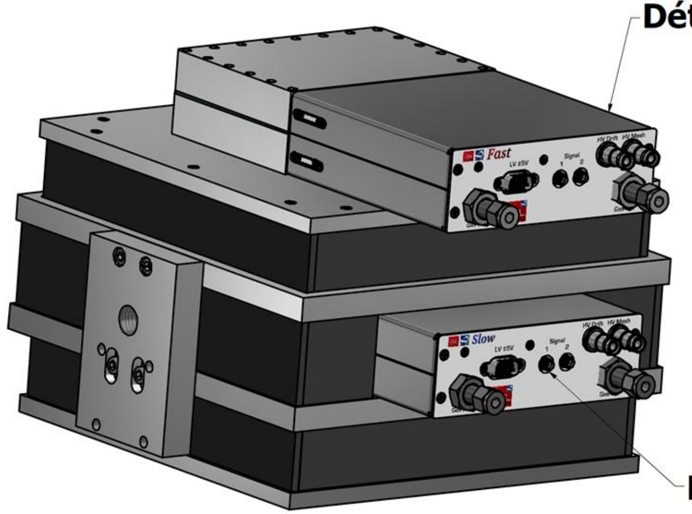
Two detector types: « fast » & « Slow »

- ✓ 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





Done at ESS Detector Coatings Workshop in Linköping



Détecteur rapide

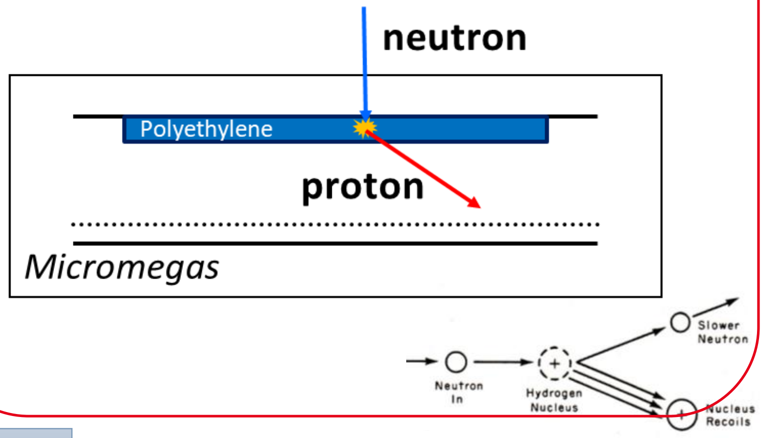
~ 25 ×15 × 5 cm³
~ 1 kg

Détecteur lent

~ 30 × 30 × 20 cm³
~ 10 kg

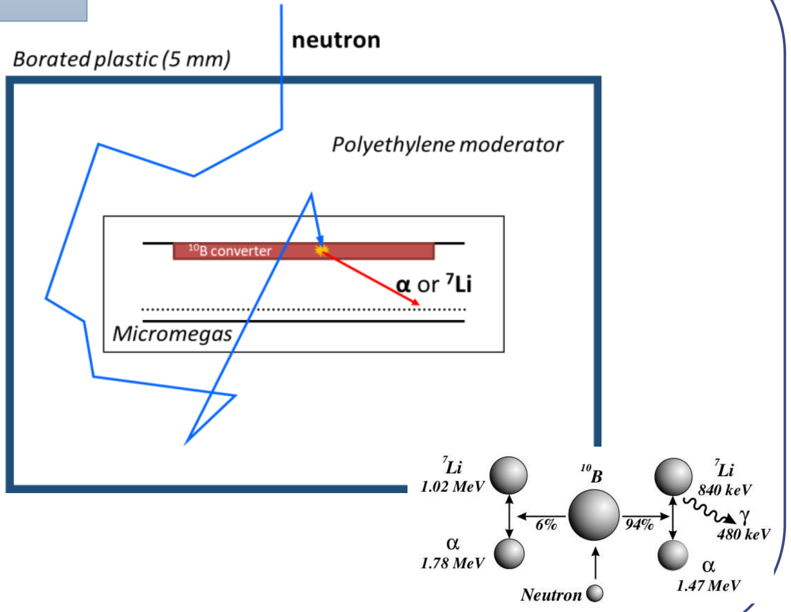
FAST

Fast response

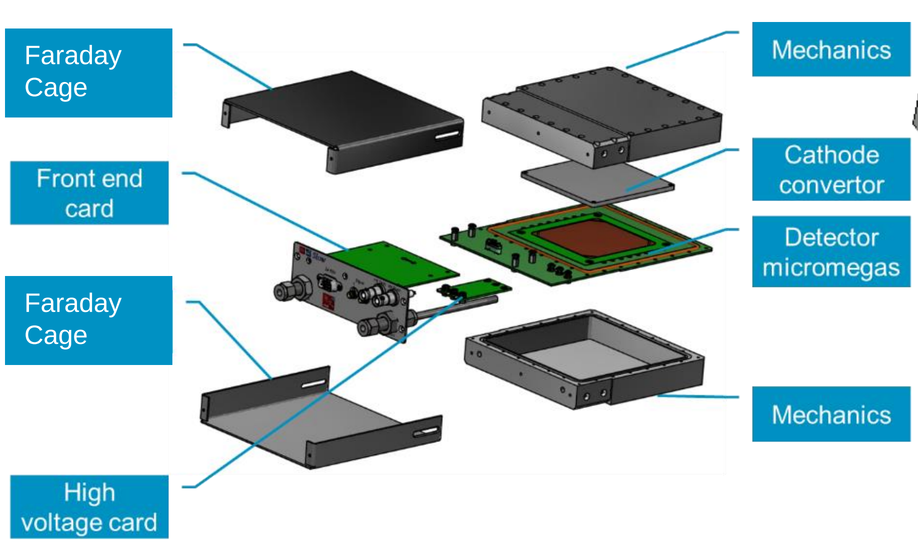


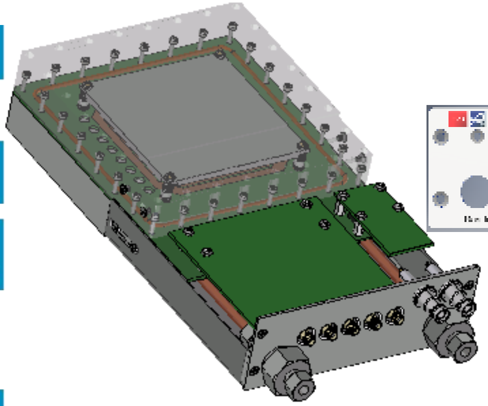
SLOW

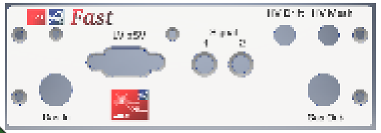
High sensitivity



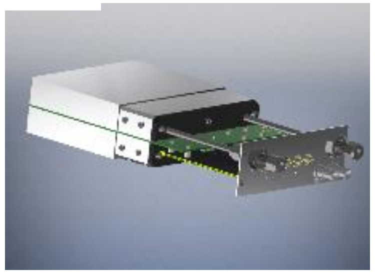
nBLM Detectors Geometry







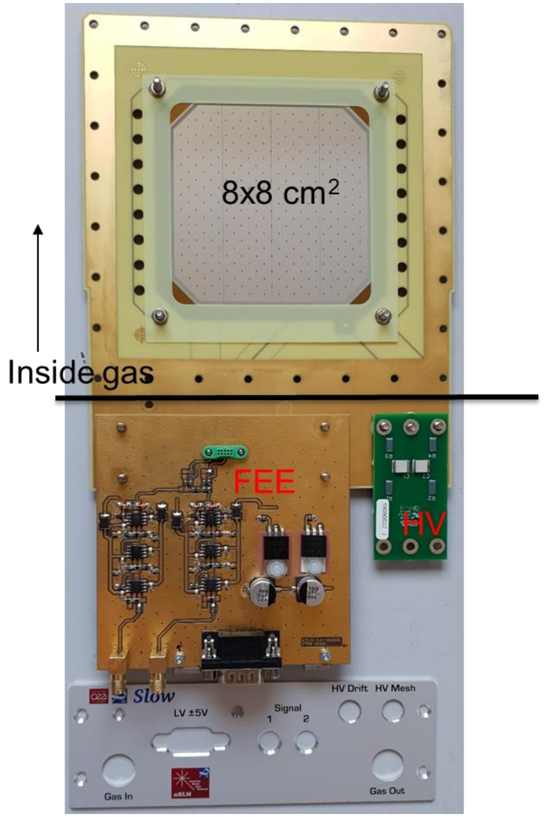
Chamber + Faraday Cage ~ 20 x 15 x 2 cm^3



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

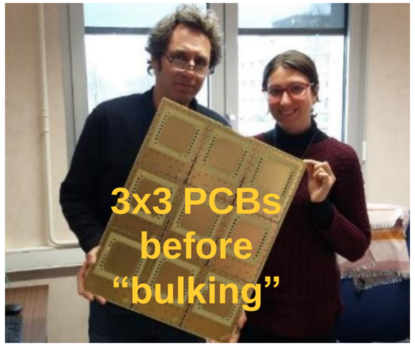
Moderator + absorber

nBLM Micromegas and FEE



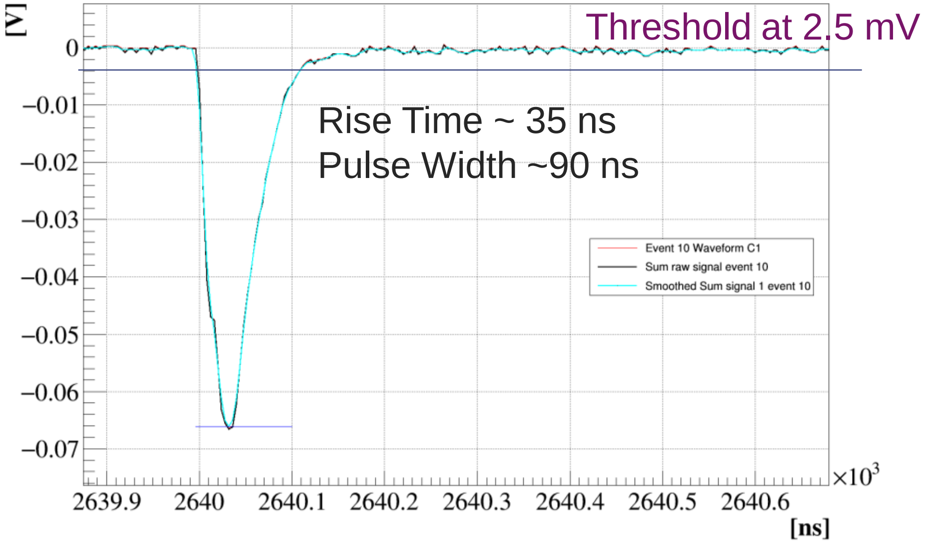
Bulk Micromegas (MPGD workshop at CEA/Saclay)

- Segmented in 4 sectors to accommodate for final rates
- Small drift gap: ~2 mm. Operating in He+10% CO_2 or He + ethane, 1 atm, circulation mode (1l/h/detector)

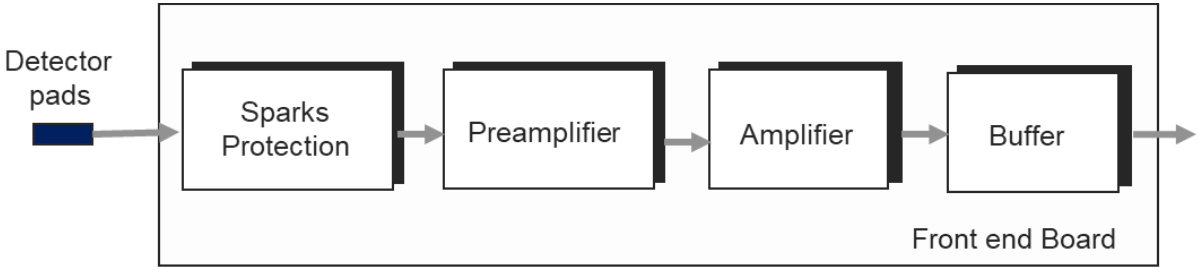


FEE card and amplifiers designed at CEA

- On board FEE → detection of small signals!
- Fast signals capability:
- Irradiation up to 200 kGy ➔ OK!
- Adaptable card to read from 1 to 4 sectors
- Radiation hardness connectors
- **Can operate in counting and charge mode**



Single neutron acquired with the FEE final nBLM electronics at LINAC4

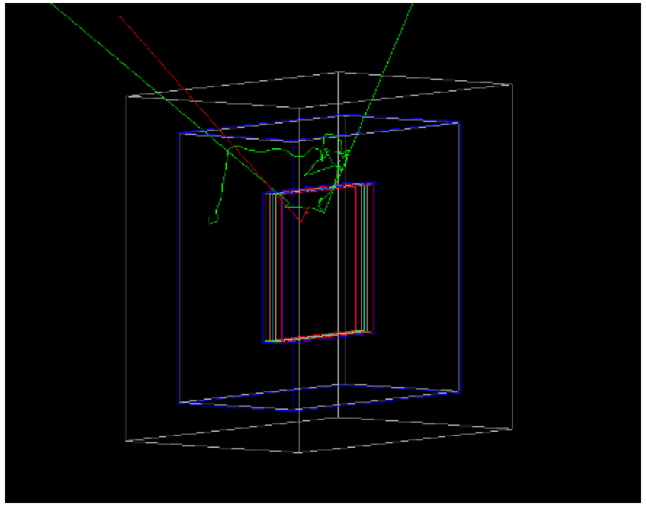


3. Results R&D Phase

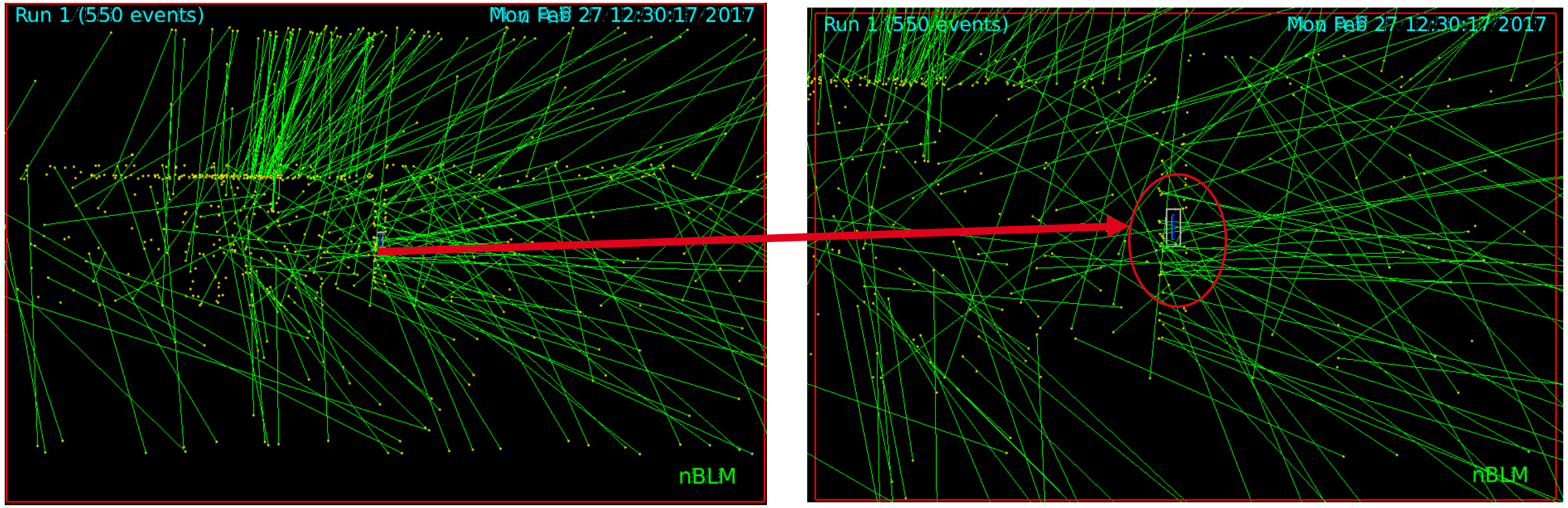
MonteCarlo Studies

Monte Carlo simulations have been carried out in order to:

- Optimize the detectors features
- Estimate the expected response using as input data simulated by ESS-BI (I. Dolenc-Kittlemann) of normal, uniform and dramatic loss conditions



Simulations to study the geometry



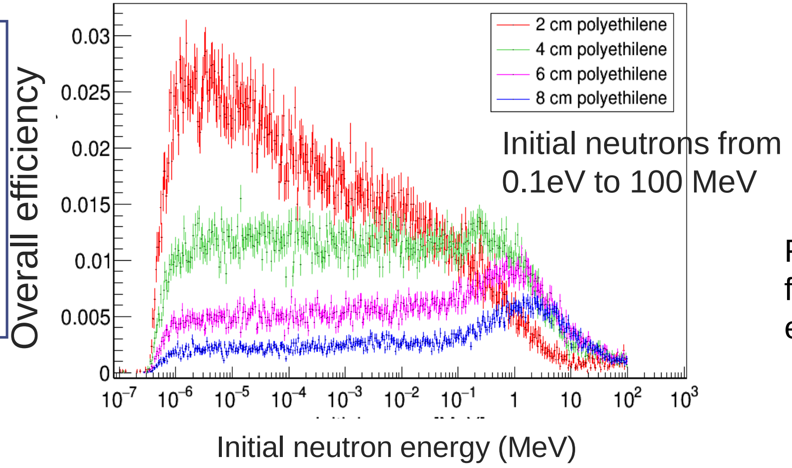
Simulated dramatic loss at ¾ DTL1
Fast nBLM placed between DTL1 and DTL2

Simulations done in GEANT4

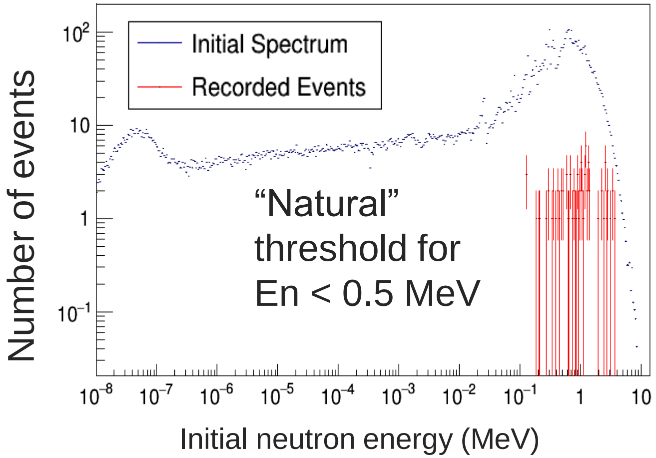
MonteCarlo Studies : Optimize detector features

Efficiency

SLOW



FAST



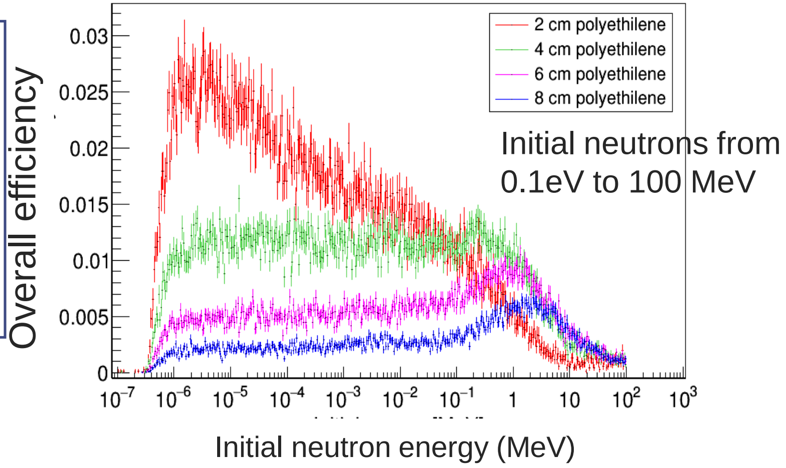
For the slow,neutrons between 0.1 eV and 100 MeV have been simulated following a double exponential decay and isotropically distributed from the external surface with an incident angle ranging from 0 to 2π

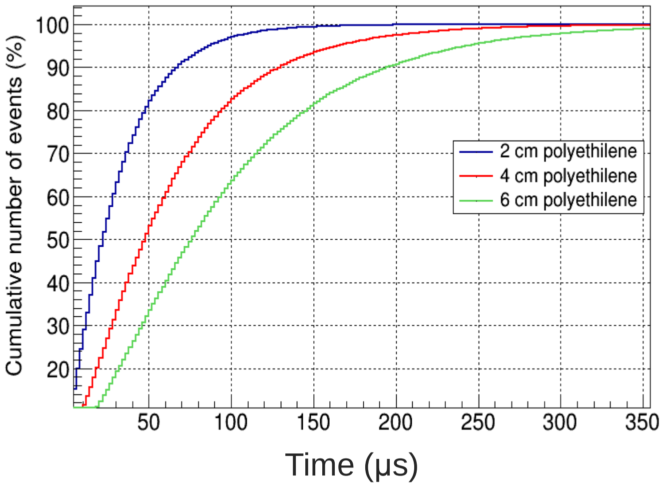
MonteCarlo Studies : Optimize detector features

Efficiency

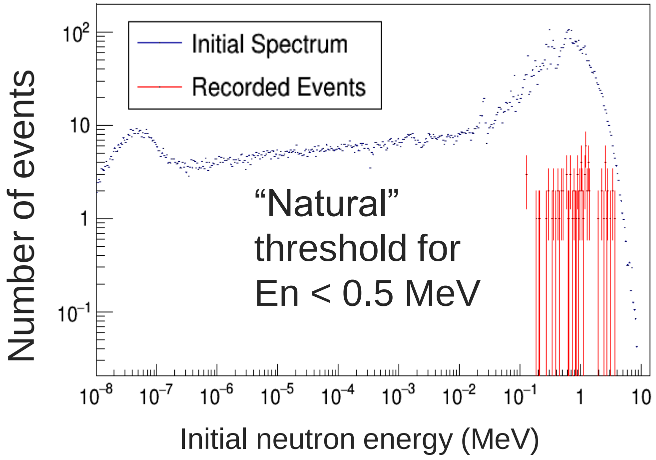
Time response

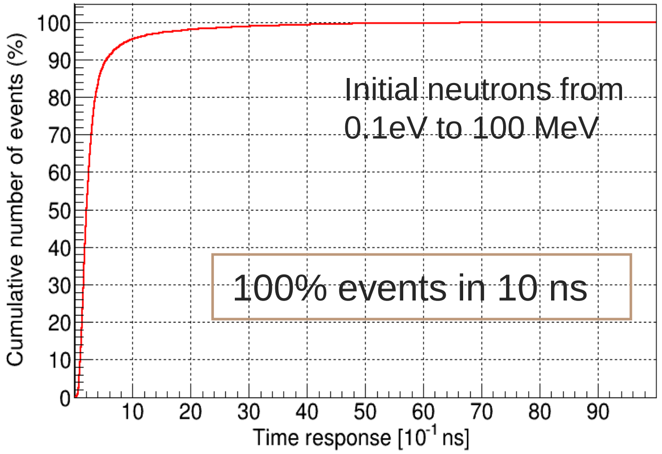
SLOW





FAST





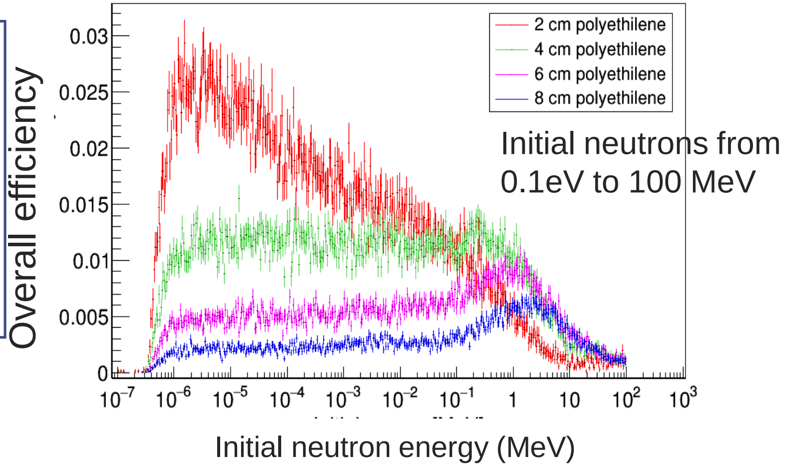
MonteCarlo Studies : Optimize detector features

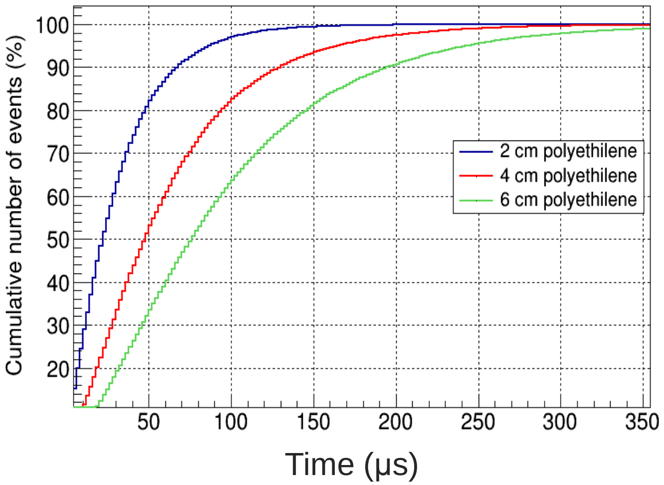
Efficiency

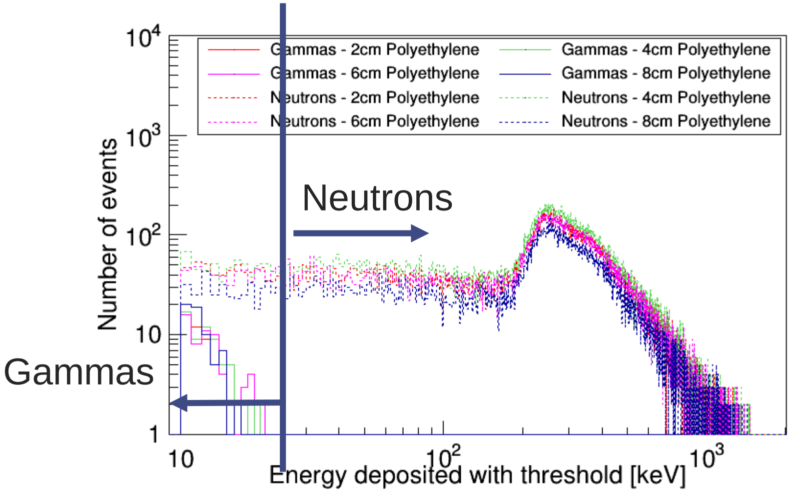
Time response

Gammas and neutrons response

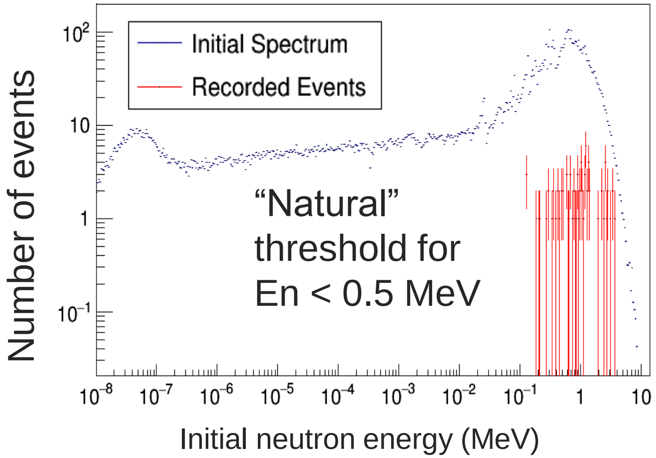
SLOW

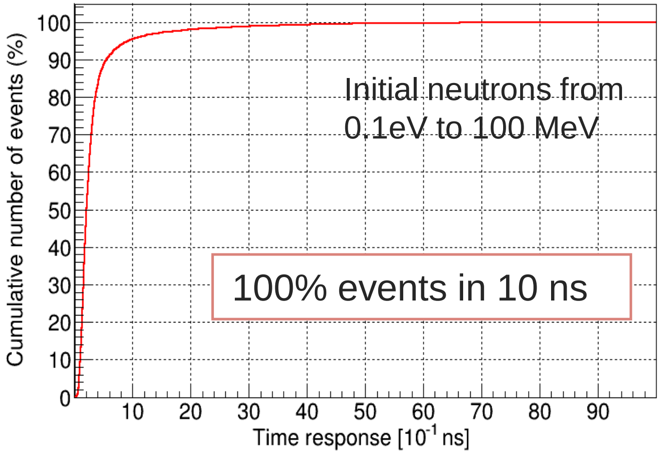


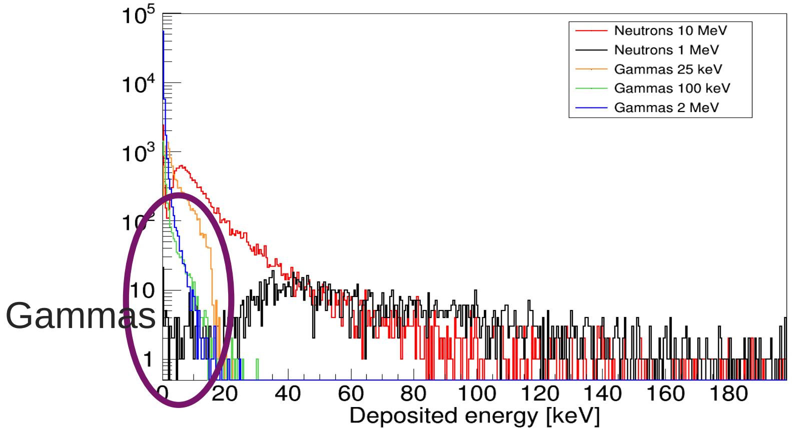




FAST





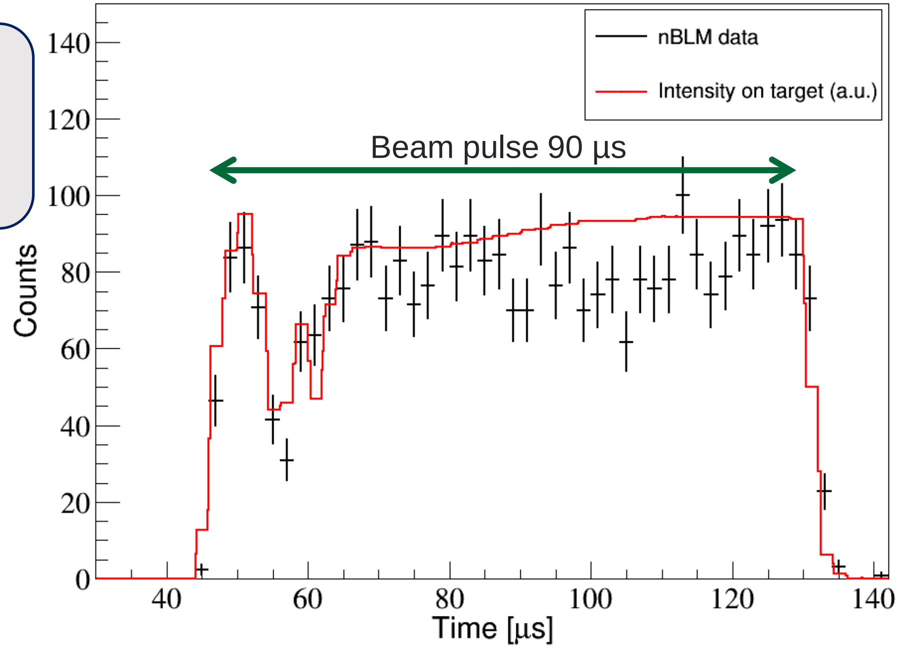


Experimental Results : Time Response

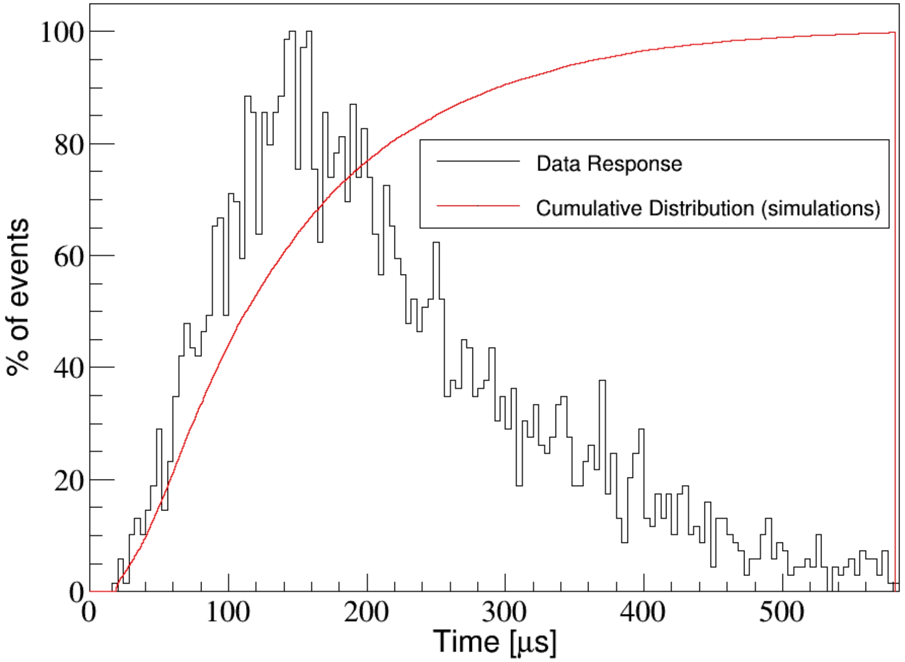
IPHI@CEA 3MeV p beam n produced with Be target

Data acq with a fast oscilloscope at 250 MS/s

FAST



SLOW



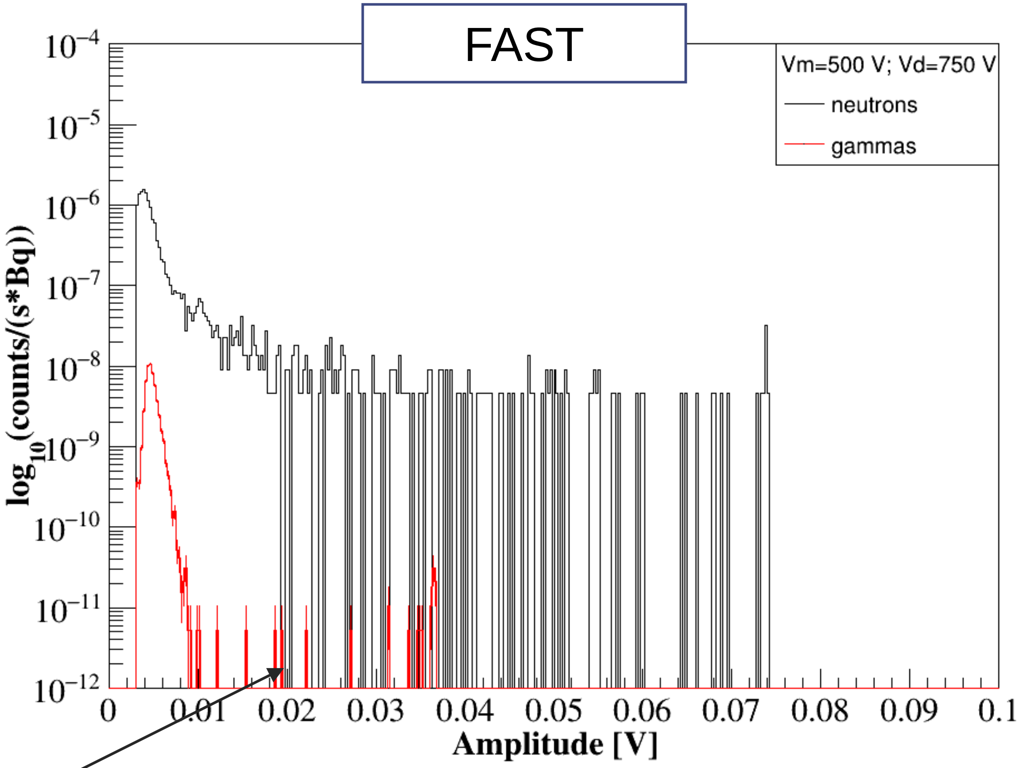
- Immediate response
- Count rate in direct correlation with beam current intensity

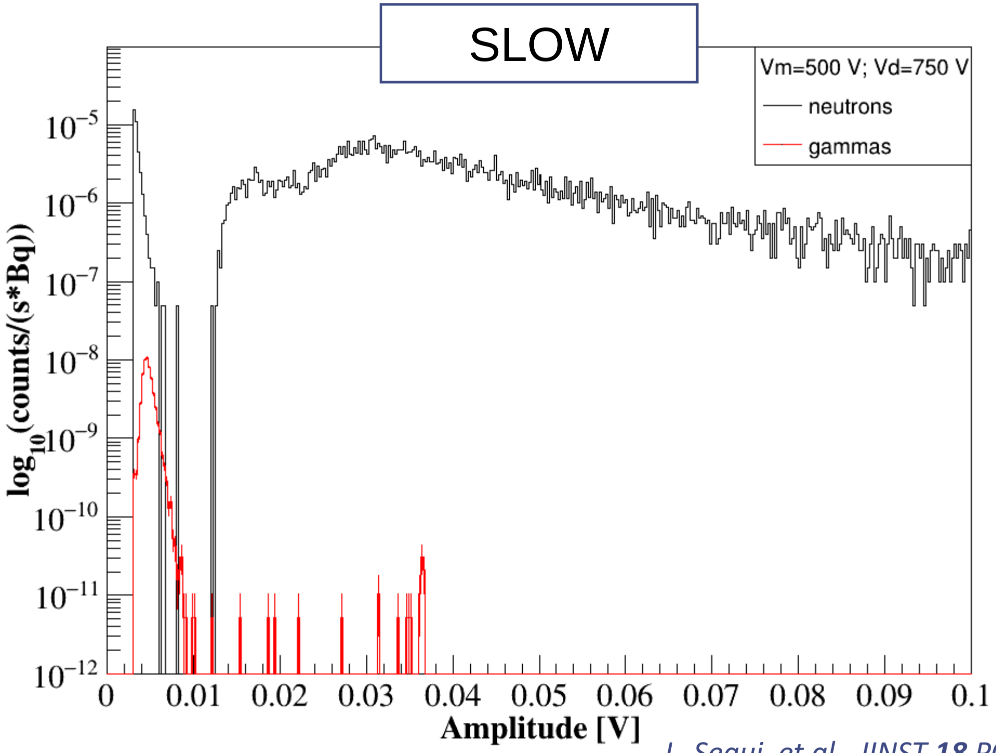
- Delay in signal: Convolution of moderation in polyethyelene + proton beam pulse duration (90 µs)
- ~ 200 µs from simulations for a instantaneous pulse

L. Segui et al., in Proceedings IBIC 2018, 9–13, TUPA02, pp. 211-214.

Experimental Results : n/g discrimination

Collaboration with CEA-Saclay Radioprotection Service (SPR):
AmBe 10^{11} Bq (n up to 11 MeV)
^{60}Co ~ 8 × 10^{10} Bq (1.17, 1.33 MeV gammas)





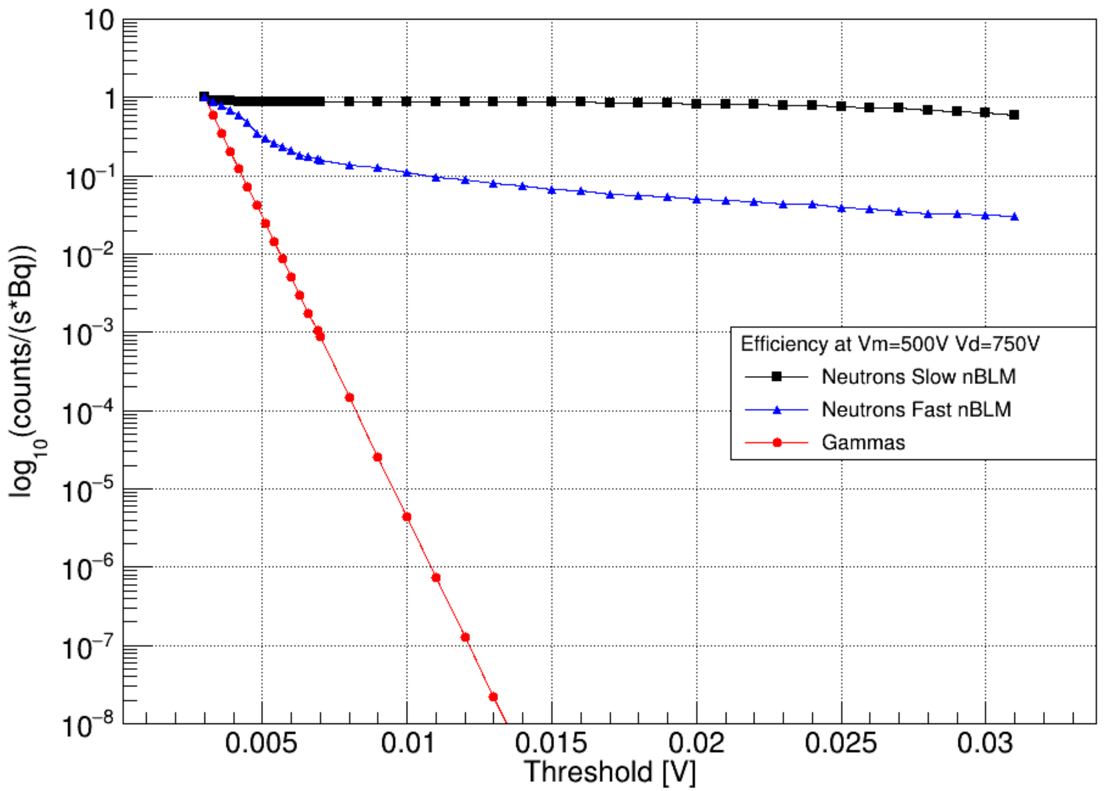
*L. Segui. et al., JINST **18** P01013 (2023).*

Background from neutron source stored close by

- The gammas follow an exponential decay as was also observed in the simulations
- For an initial neutron spectrum with several energies the separation for the fast worsen

Experimental Results : n/g discrimination

Collaboration with CEA-Saclay Radioprotection Service (SPR):
AmBe 10^{11} Bq (n up to 11 MeV)
^{60}Co ~ 8 × 10^{10} Bq (1.17, 1.33 MeV gammas)



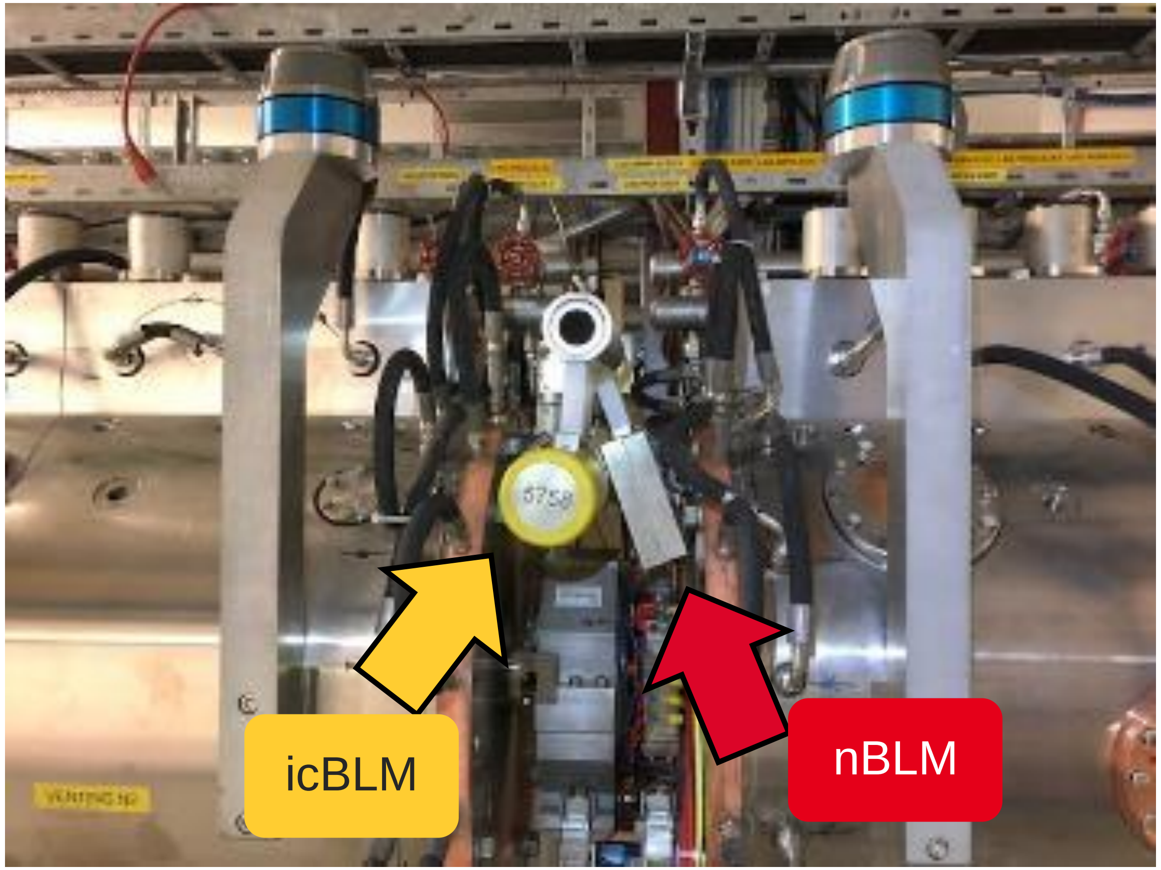
Relative efficiency loss with respect to different amplitude thresholds for neutrons in the **slow** module, neutrons in the **fast** module and gammas in slow module

*L. Segui. et al., JINST **18** P01013 (2023).*

- In the case of the fast the discrimination is strongly dependent on the energy threshold and varies with the neutron energy

LINAC 4 Results

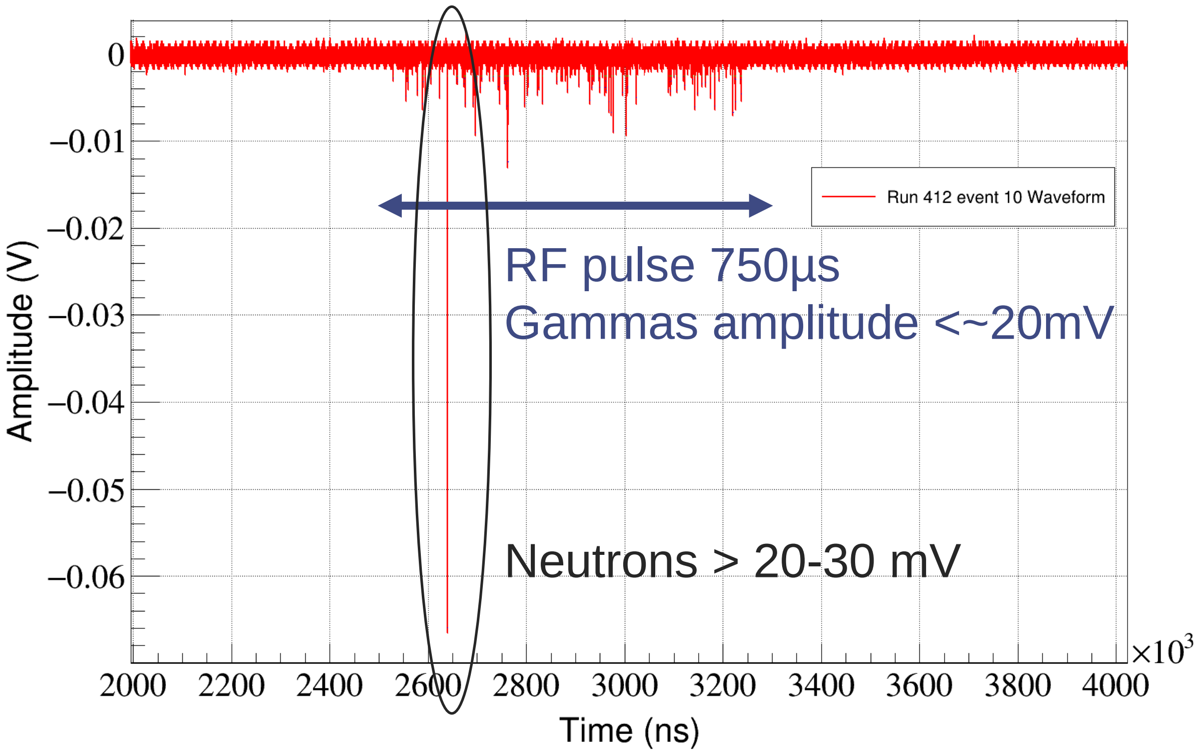
- **Fast nBLM module** installed between two DTLs at ~**13 MeV proton region**
- Final mechanics and electronics (*pre-series*)
- Gas: He + 10% CO_2
- Two data campaigns
  - November 2018
    - Understanding the detector
  - December 2018
    - Losses were produced



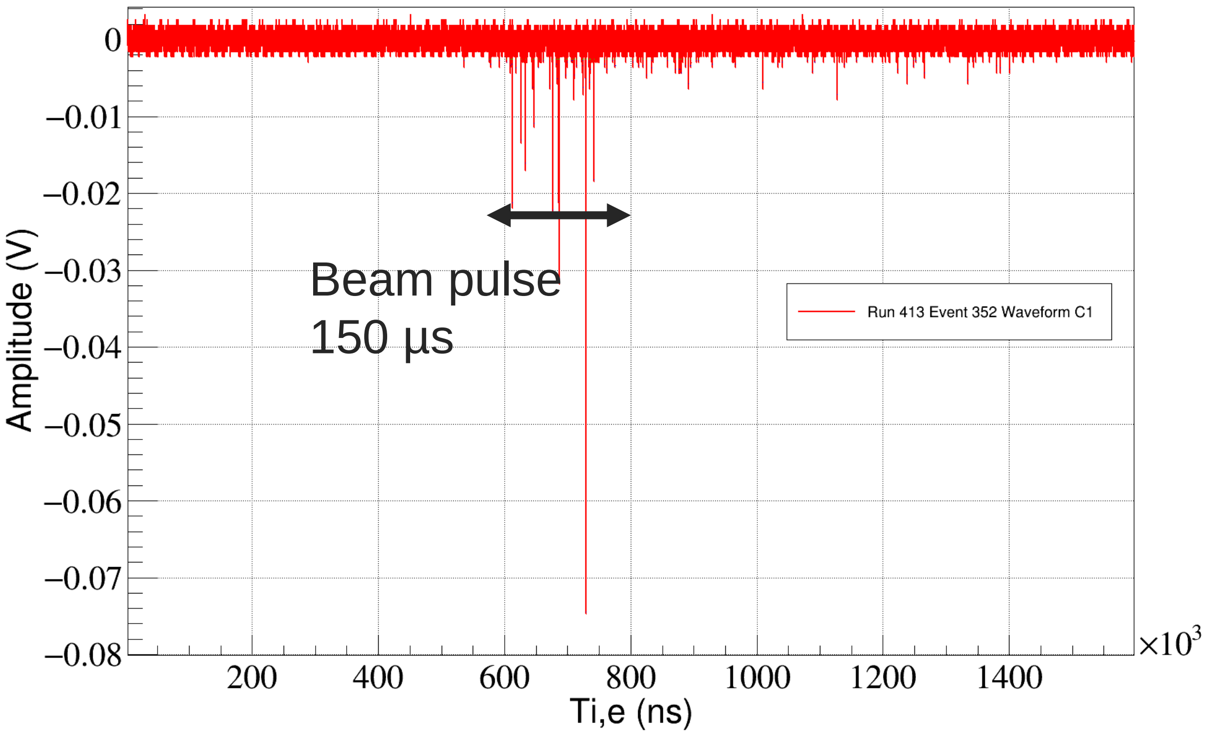
- Data taking with a fast oscilloscope
  - 250 Ms/s, Full bandwidth
  - With trigger of Linac4 also recorded
- Data were acquired in parallel with the final ESS nBLM system acquisition

LINAC 4 Results

Waveforms from oscilloscope



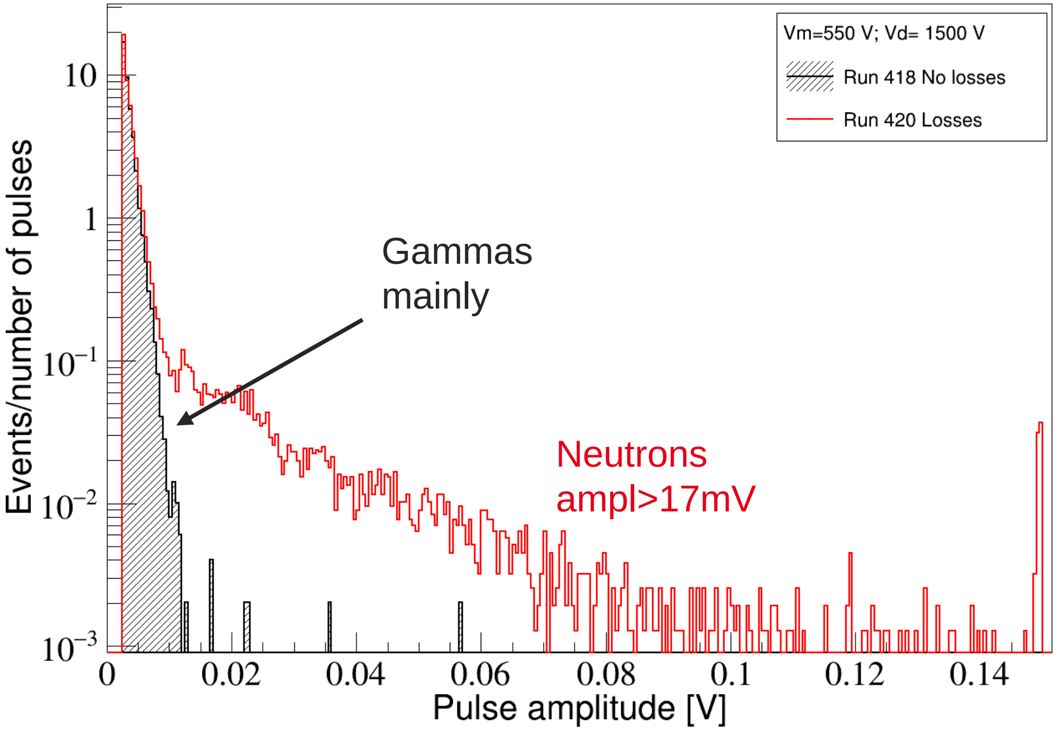
Normal operation



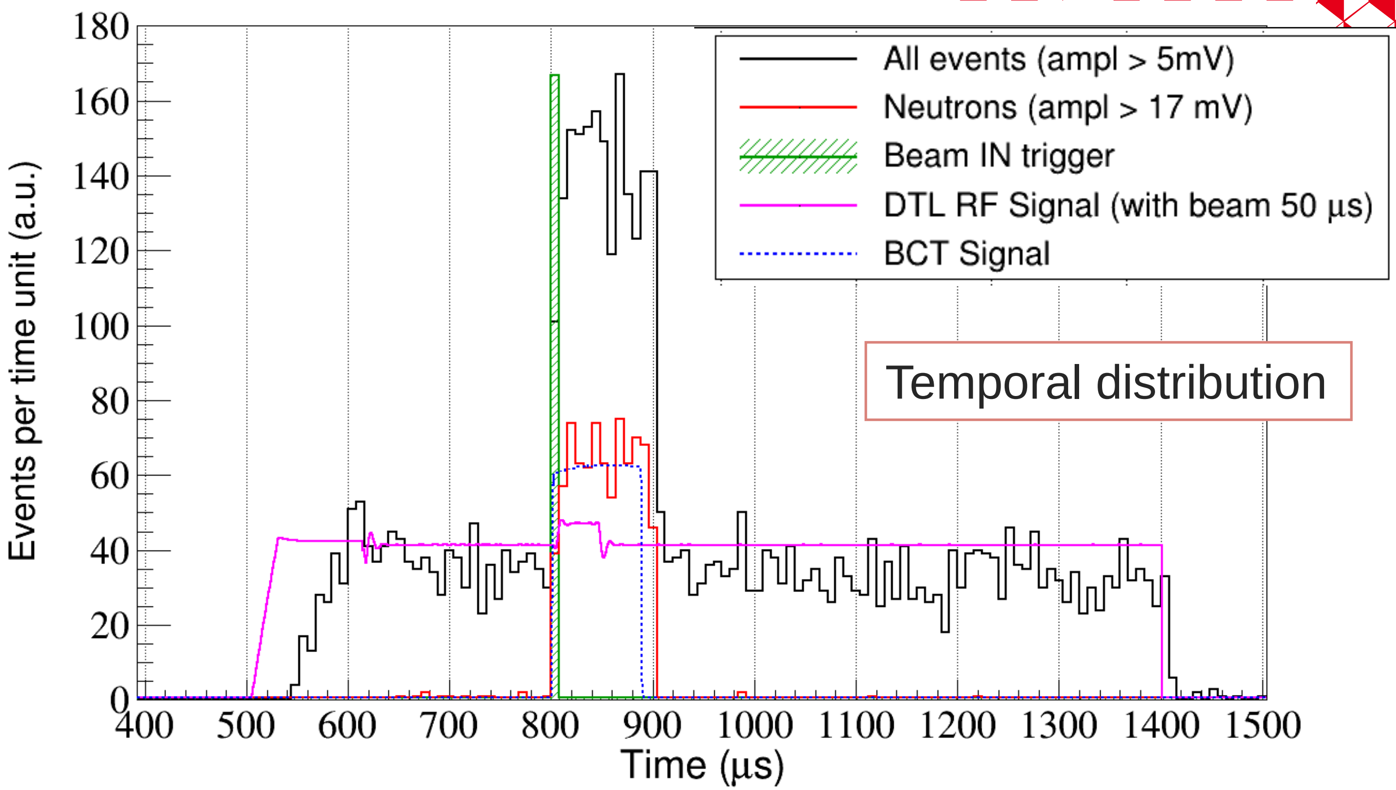
Provoked losses

*L. Segui. et al., JINST **18** P01013 (2023).*
*ESS DAQ results I. Dolenc-Kittelmann et al. Phys. Rev. Accel. Beams **25**, 022802 (2022)*

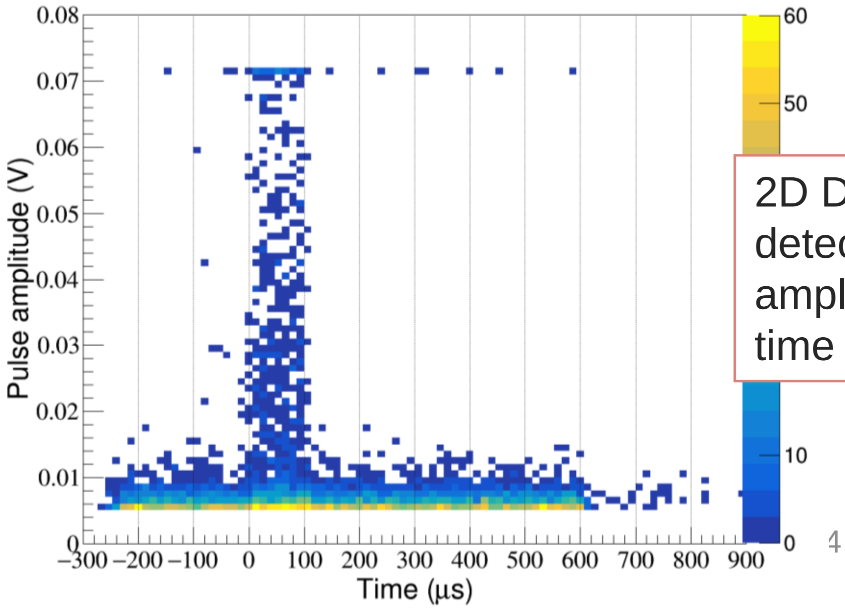
LINAC 4 Results



Amplitude distribution run with/without losses



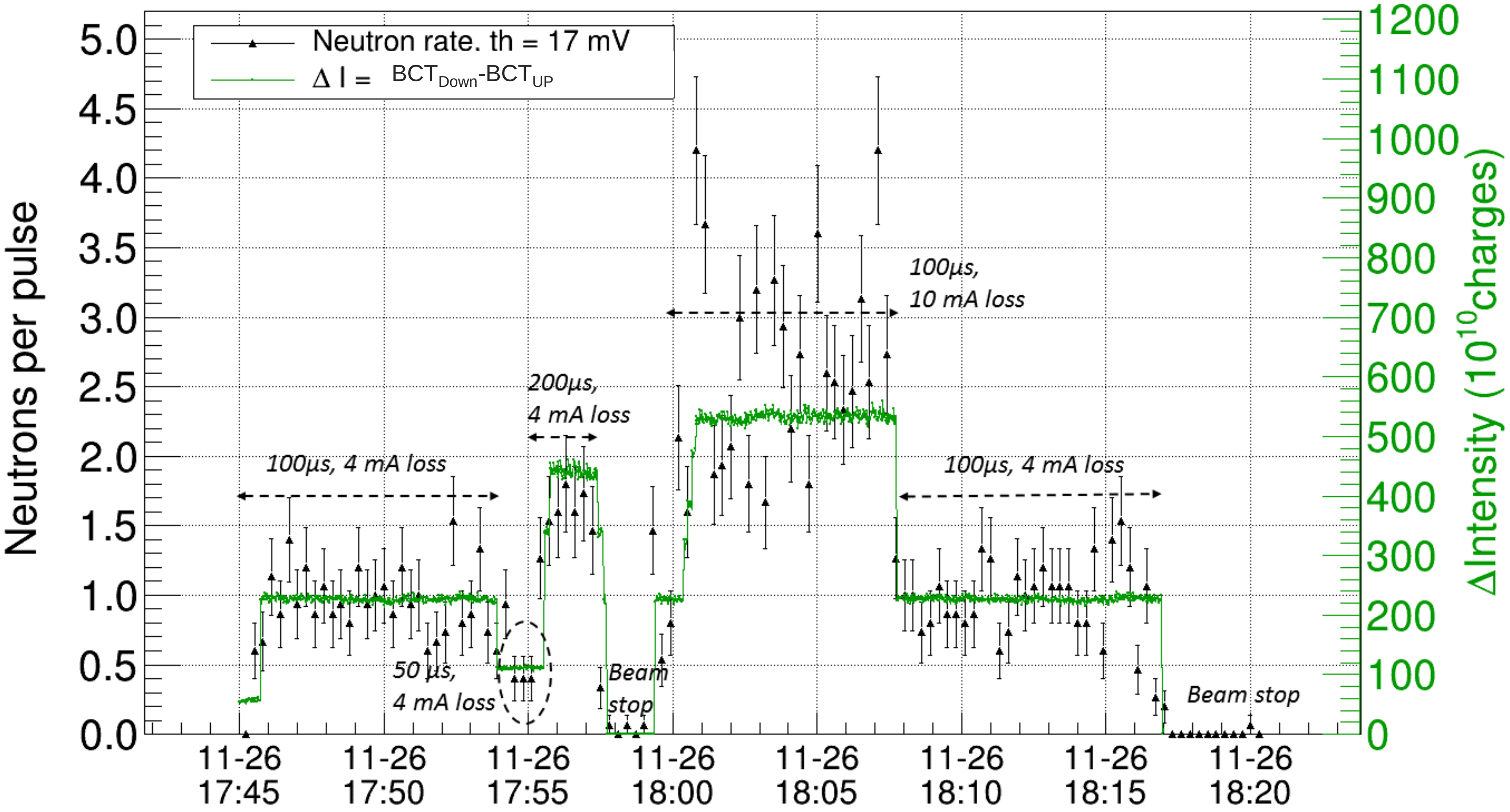
Temporal distribution



2D Distribution of detected events amplitude and time

LINAC 4 Results

Correlation between BCT current and nBLM count rate in different beam loss scenarios



*L. Segui. et al., JINST **18** P01013 (2023).*
*ESS DAQ results I. Dolenc-Kittelmann et al. Phys. Rev. Accel. Beams **25**, 022802 (2022)*

4. nBLM Production

nBLM Production

84 modules integrated and validated at IRFU 06/2019-02/2022

Polyethylene

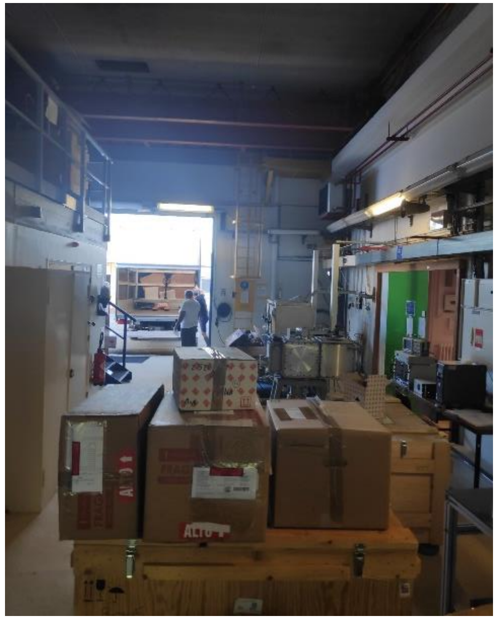
Mirrobor

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

Detector integration lab

nBLM Delivery

- 4 deliveries between 2019 and 2022
  - 2 August 2022 : Final delivery of all detectors & sub-systems



ESS lab setup in 2020

nBLM Detectors @ ESS lab

nBLM Detectors Verification

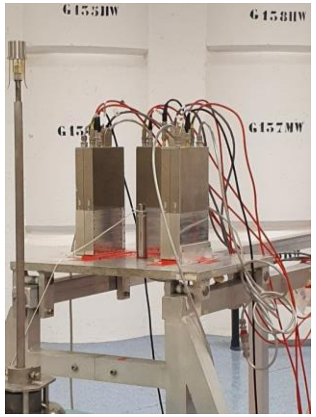
- **Gas leak test**
- **High voltage test**
- **Neutron irradiation**
  - Detector validation lab (^{252}Cf source - weak)
  - SPR intense AmBe source (50 GBq)
  - Each detector monitored for a minimum amount of time & number of neutrons.
- Detectors not meeting required performance are **repaired or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

  - **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

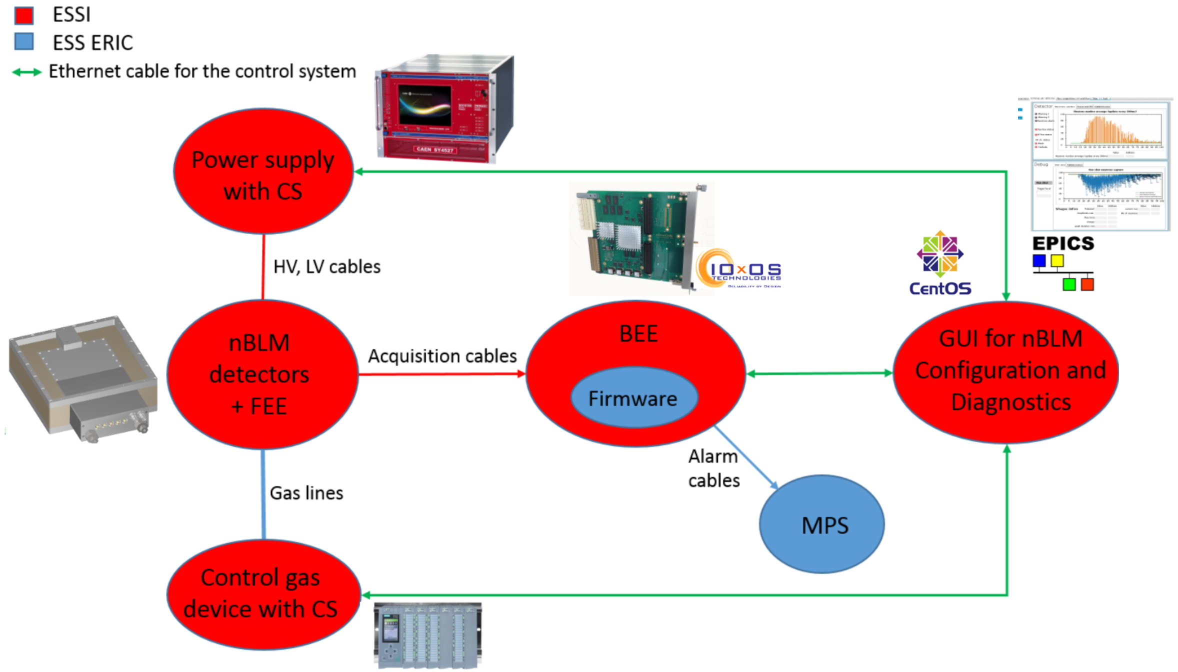
Detector leak test lab b.534



Detector testing @ SPR

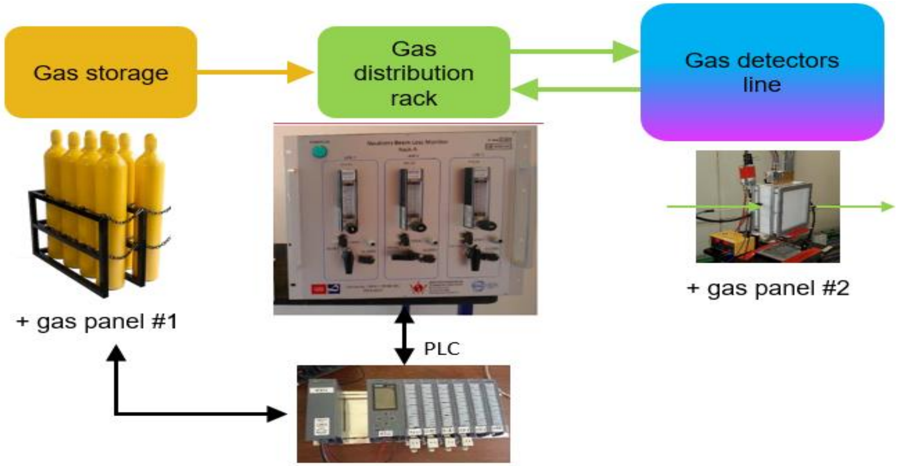
nBLM System

…not only detectors



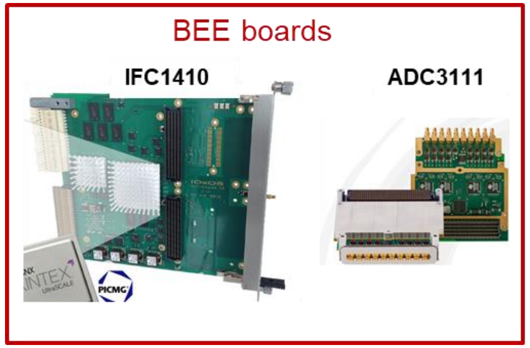
Control System architecture at IRFU(DIS)

Gas system at IRFU



ESS ICS standardisation

- µTCA.4 + IOxOS CPU IFC_1410
- IOxOS ADC_3111 FMC boards



nBLM System

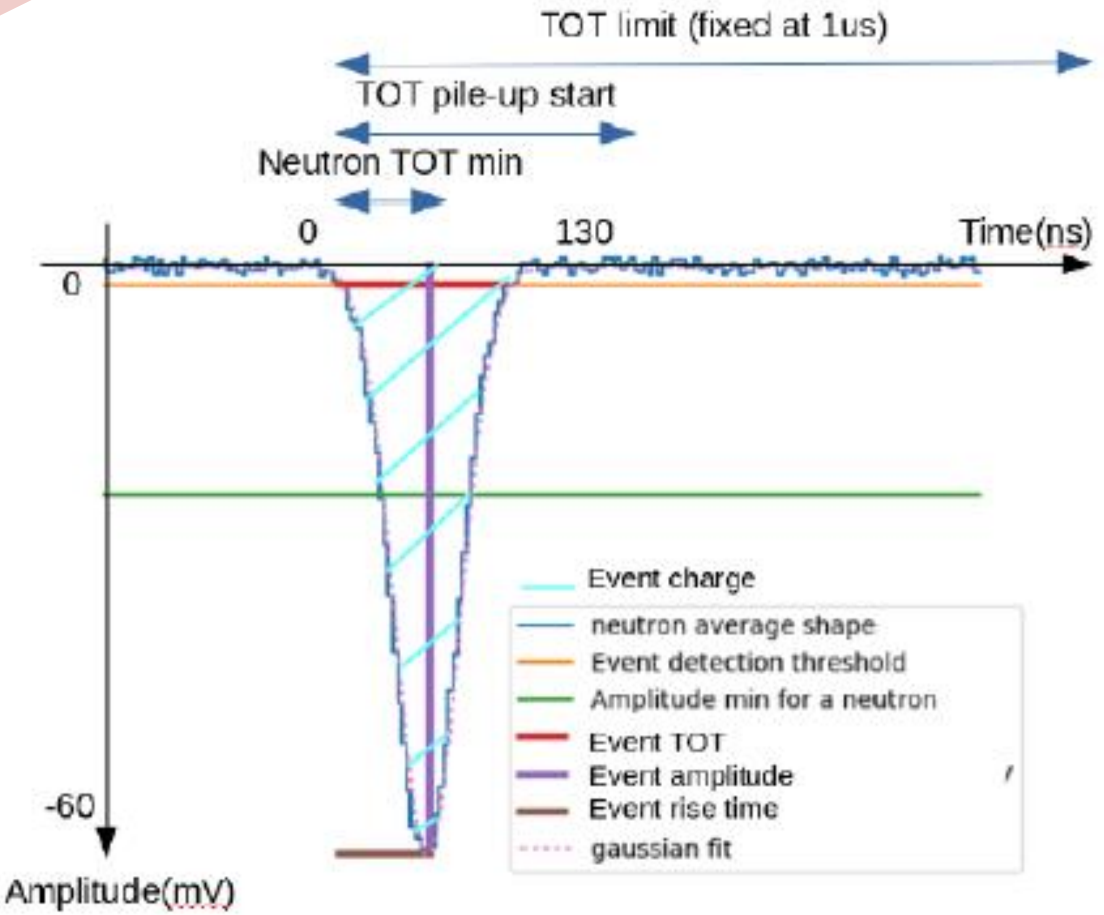
…not only detectors

Developed between IRFU, ESS and Lodz Uni.

. Jabłoński *et al*., *2019 MIXDES* -, pp. 101-105,.

Acquisition logic

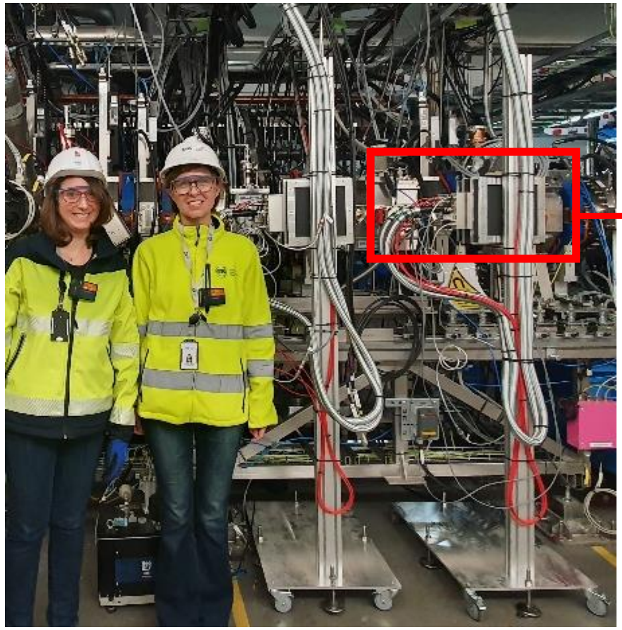
- FMCs provide data continuously, every **4 ns**
- The algorithm compares the values to a threshold
  - When trigger, pulse parameters are provided (TOT, amplitude, …)
- Neutron to gamma discrimination is based on **amplitude threshold**
- The number of neutrons per µs and the total charge (integral) is provided
  - When pileup observed counting is based on charge
- Continuous integration is equivalent to current mode (1 reading per µs)
- Self -calibration of pulse amplitude and pedestal runs to check stability



5. ESS Installation and first Results

nBLM at ESS

- **36 detectors** already installed
  - 4 around MEBT (10/2021) and 8/DTL1-4 (05/2022)
- Data taking with source in tunnel to check all the line



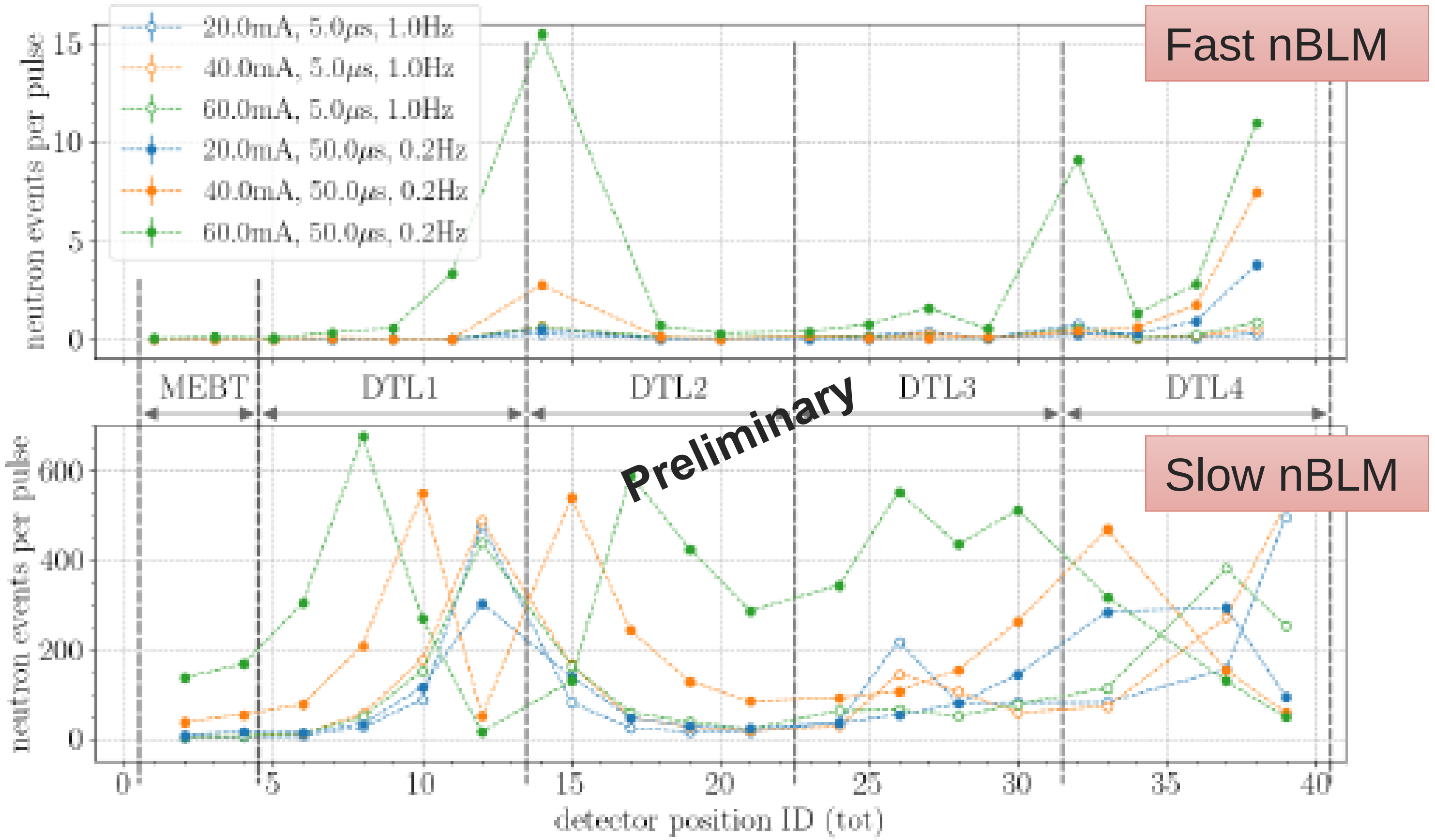
2 pair fast+slow in MEBT

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

nBLM at ESS

- **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.



- Data taking with 38 detectors at same time
- Fast detectors : peaks consistent with activation surveys and/or simulations
- **Slow detectors: pile-up**! Corrections on-going

I. Dolenc-Kittlemann, IBIC 2023, paper TU1I02

CONCLUSIONS

- Conception d'un **nouveau type de moniteur de perte de faisceau**, nBLM, basé sur des détecteurs **Micromegas**
- Augmenter la sensibilité dans les régions basse énergie des accélérateurs de hadrons
- Conception, production et validation de **84 nBLM** à l'IRFU et de ses systèmes auxiliaires de 2019 à 2022
- Installation et commissioning en cours à l'ESS.
- Commissioning est essentielle : Validation des performances et établissement en tant que système critique pour les linacs.

MERCI!

nBLM ESS Team

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