# Micromegas for beam loss monitoring

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Motivation

- nBLM-ESS Project

nBLM Detectors

- Fast and Slow

Detector characte-rization

- 1st beam loss detection

Conclusions

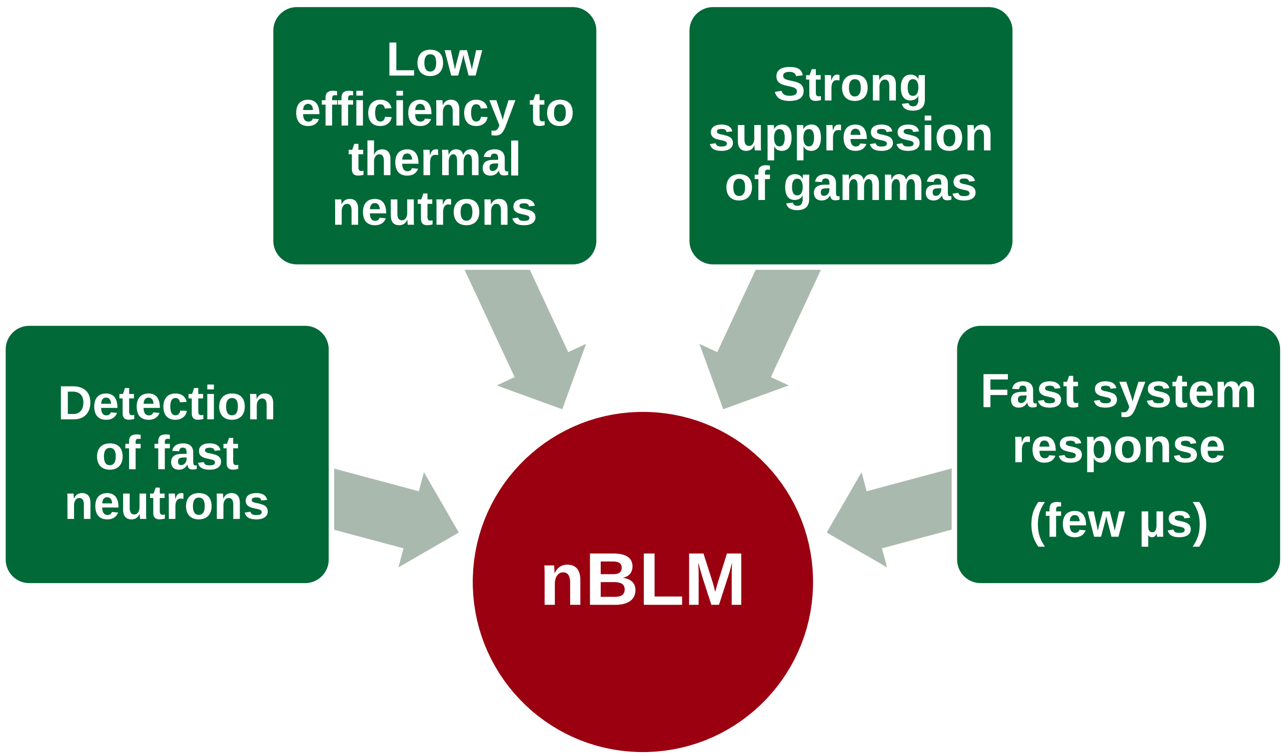
# MOTIVATION

## Why new Beam Loss Monitors (BLM)?

- A need in the accelerator community:
- In new high intensity hadron linear accelerators even low energy beam could damage the accelerator or activate materials
  - Crucial to monitor **any small loss**
  - Keep the loss <~ 1 W/m to allow hands-on maintenance
    - ESS 5MW → $2\times10^{-5}$ /m of the total power (0.02 ‰)
- Positioning of the BLM is important
  - Different beam lost signature in different areas of accelerator
  - At **low beam energy** only neutrons and photons can escape the beam pipe
  - Standard used ionization chambers have little sensitivity in this area and are affected by RF emission.

*"…the x-ray component is quite significant and can be even greater than the loss itself. A detector that is sensitive to neutrons and not sensitive to x-rays could be a possible solution. Unfortunately it is hard to create such a detector that would work in analog mode."*

**A. Zhukov, WEYA2, PAC2013**

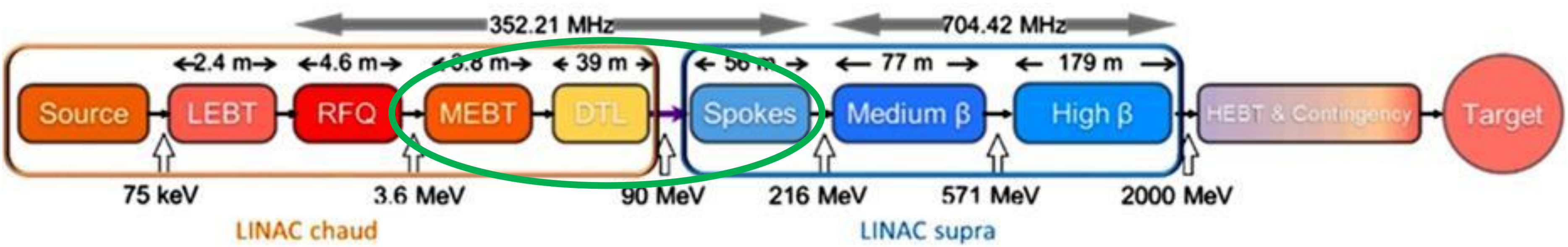



**nBLM (*neutron Beam Loss Monitor)* →**

- Fast neutron detector **based on Micromegas** (MMs) equipped with a combination of neutron convertors and moderators

# CONTEXT: ESS NBLM SYSTEM

- **Project: In-kind** contract between the European Spallation Source (ESS) and IRFU
  - Design, construction, test and commissioning of 84 detectors by Nov 2019
  - Part of the Beam Instrumentation systems of the ESS Accelerator (Lund, Sweden)
  - Dedicated mainly to the low energy region of the accelerator.




| | |
|---|---|
| Pulse length (ms) | 2.86 |
| Energy (GeV) | 2 |
| Peak current (mA) | 62.5 |
| Pulse repletion freq. (Hz) | 14 |
| Average power (MW) | 5 |

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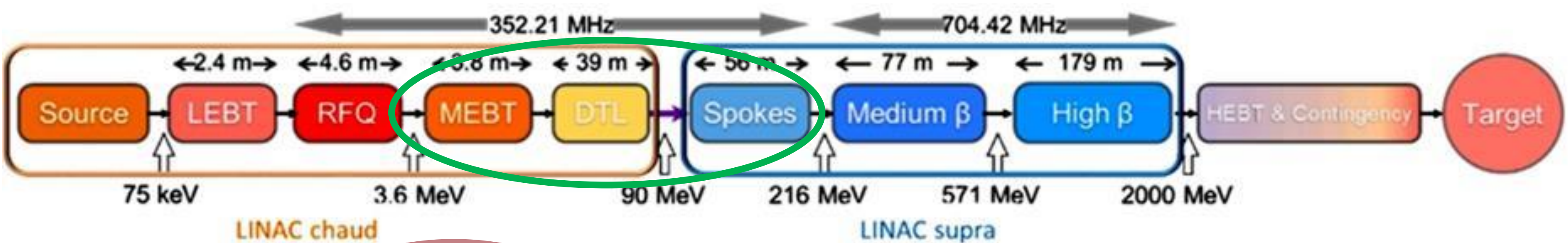


## nBLM-ESS System

- Req. & spec. develop. : ESS
- Concept: CEA + ESS
- Detectors: CEA
- Gas System: CEA
- DAQ firmware: LUT
- Control System: CEA
- Integration: ESS

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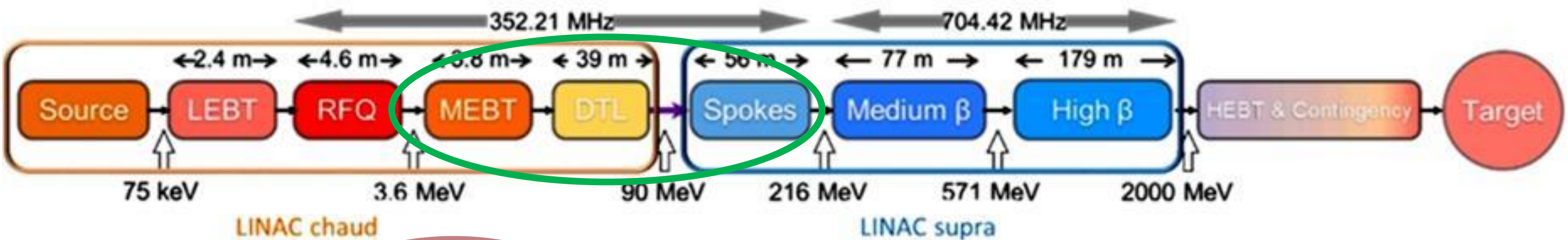


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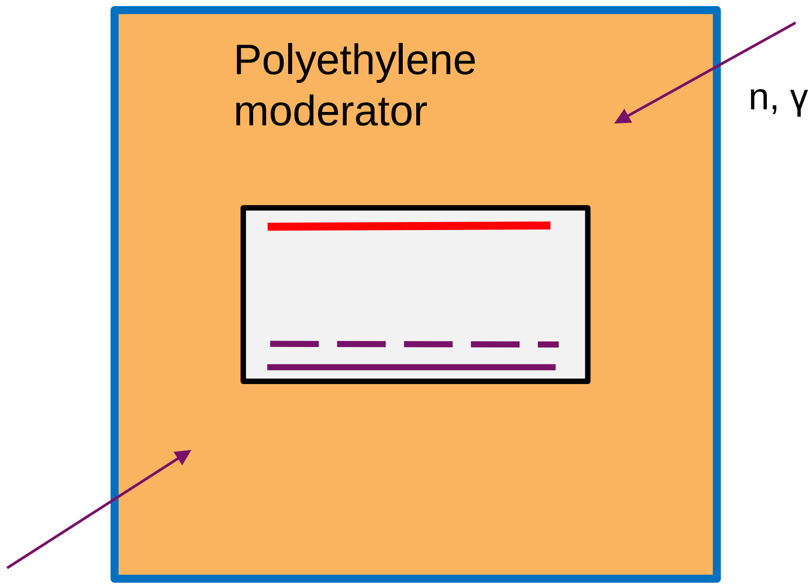
# NBLM DETECTORS GEOMETRY

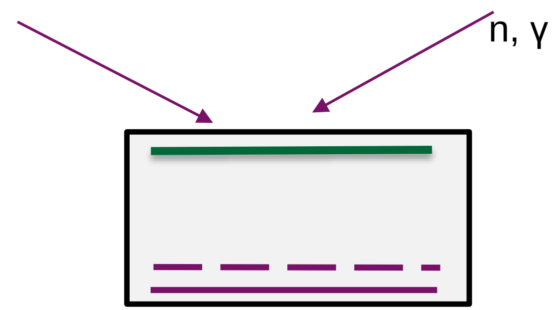
**Two complementary modules**
**Detector chamber identical**
**differences: neutron-to-charge particle convertor**
**and the surrounding of the slow with absorber + moderator**

SLOW




- Borated rubber (5 mm)
- Polyethylene (5 cm)
- Aluminium chamber
- **B4C deposited on Al**
- $He+CO_2$ gas
- MMs detector

FAST

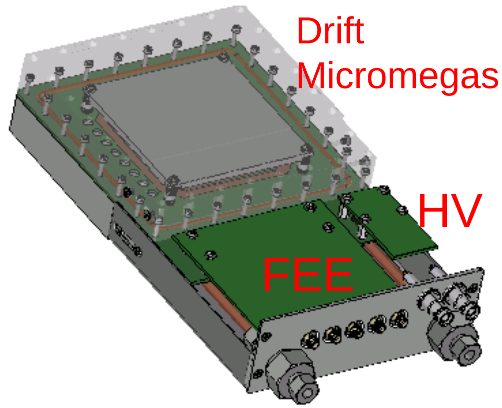


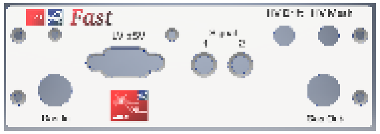

- Aluminium chamber
- **Plastic convertor on Al**
- $He+CO_2$ gas
- MMs detector

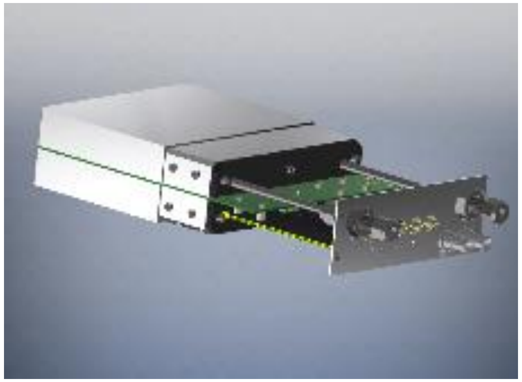
# NBLM DETECTORS CHARACTERISTICS

| | SLOW | FAST |
|---|---|---|
| **neutron-to-charged particle convertor** | $B_4C$ | Mylar or Polypropylene |
| **Reaction** | $^{10}B(n,\alpha)^{7}Li$ | (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 | Alarm (in 5 µs)<br>Fine structure of the lost |
| **Shielding** | Yes, for thermal neutrons | Not needed |

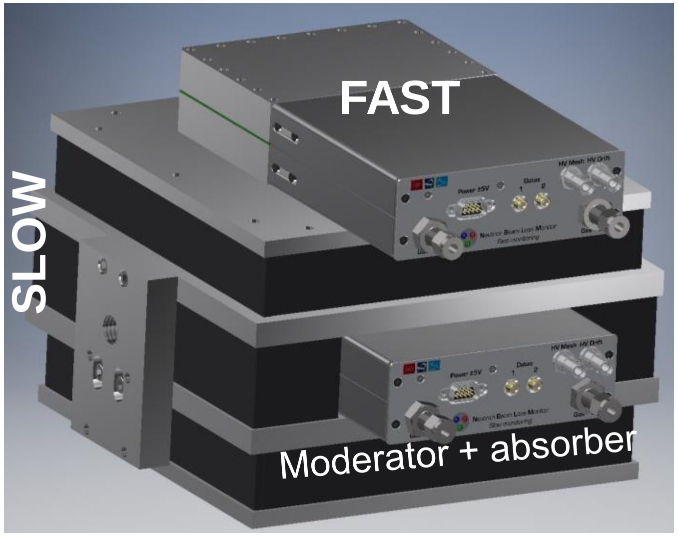
# THE NBLM FINAL CHAMBERS



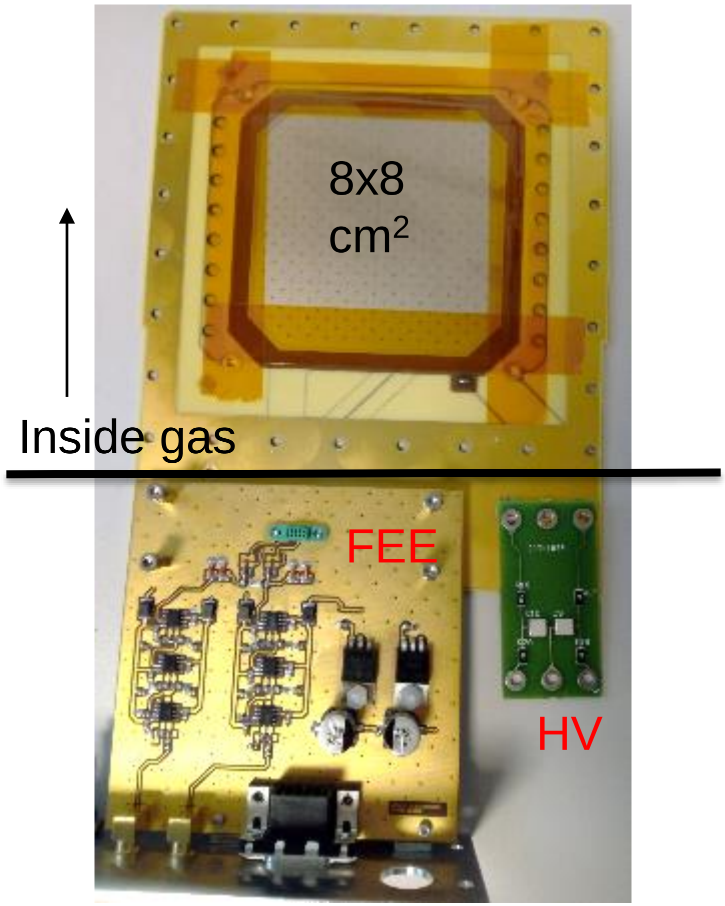



*Chamber +*
*Faraday Cage ~ 20 x 15 x 2 cm$^3$*



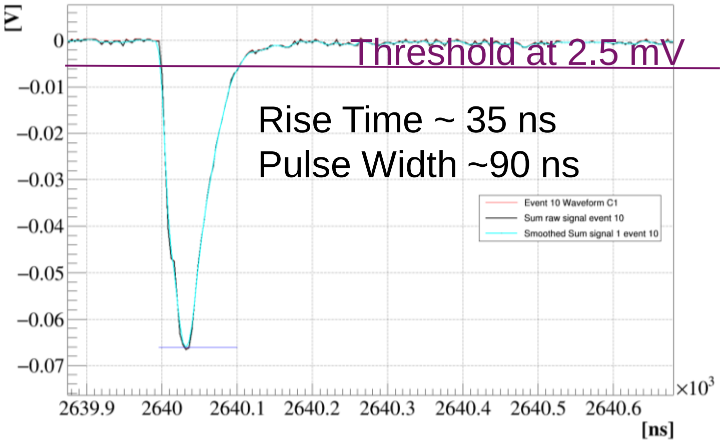

*Assembly of a fast and a slow detector size ≈ 20 × 25 × 25 cm$^3$ (~14 kg)*

*Moderator + absorber*

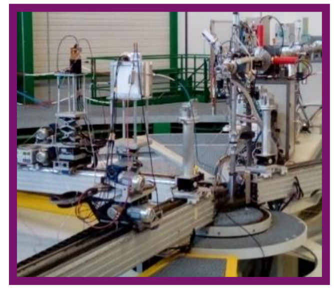
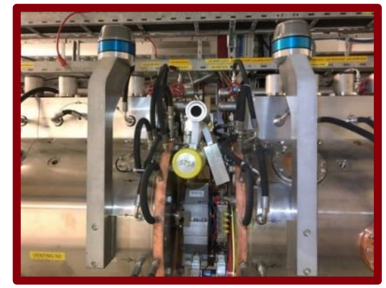
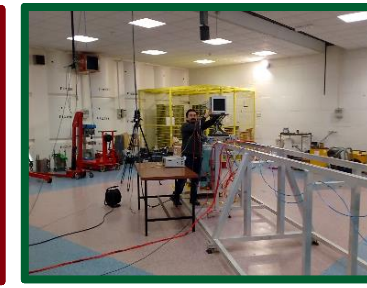

- Bulk Micromegas (MPGD workshop at CEA/Saclay)
- Segmented in 4 sectors to accommodate for final rates
- Only one signal output (adding 1 to 4 segments together)
- Small drift gap: ~2 mm
- Operating in He+10% $CO_2$, 1 atm
- FEE card and amplifiers designed at CEA
- Can operate in counting and charge mode

*Single neutron acquired with the nBLM electronics*



# NBLM EXPERIMENTAL TESTS



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

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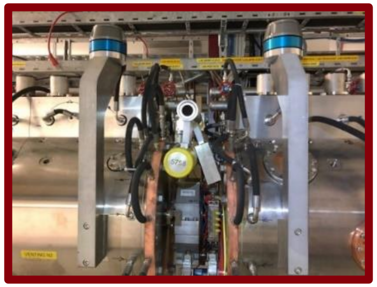

July 2016 — Kick-off

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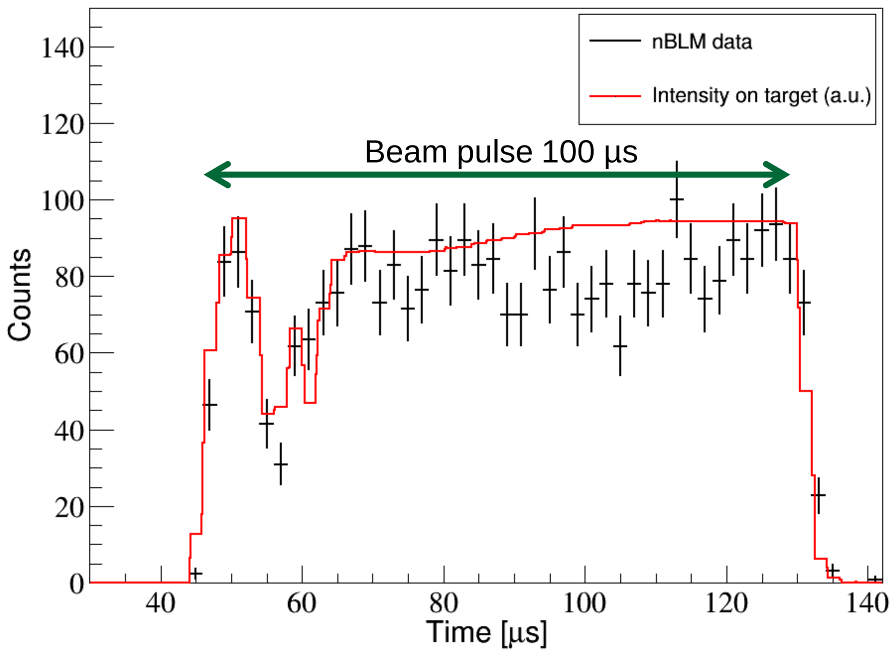
*Paper under preparation*

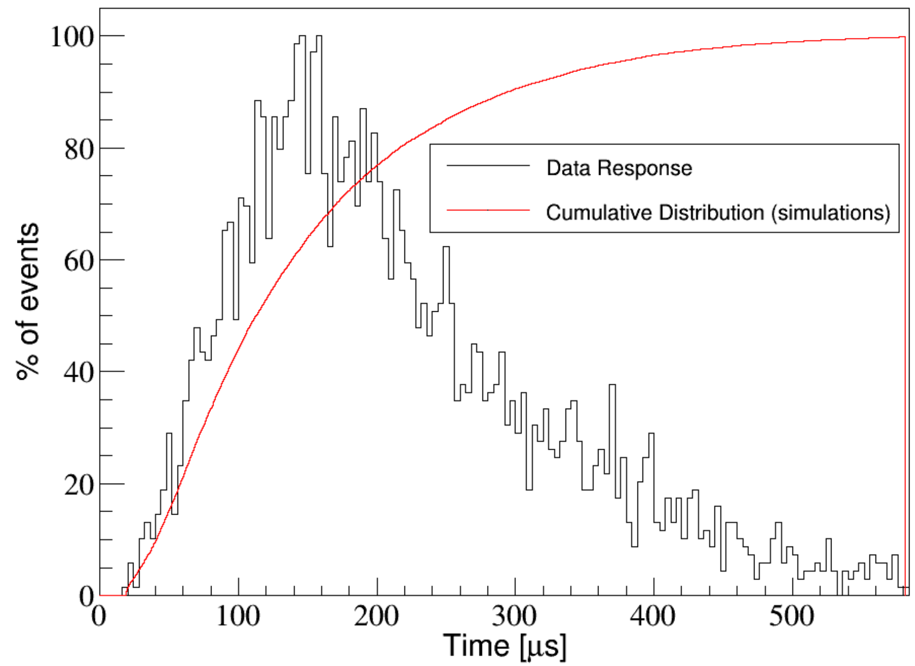
# NBLM TIME RESPONSE

FAST




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

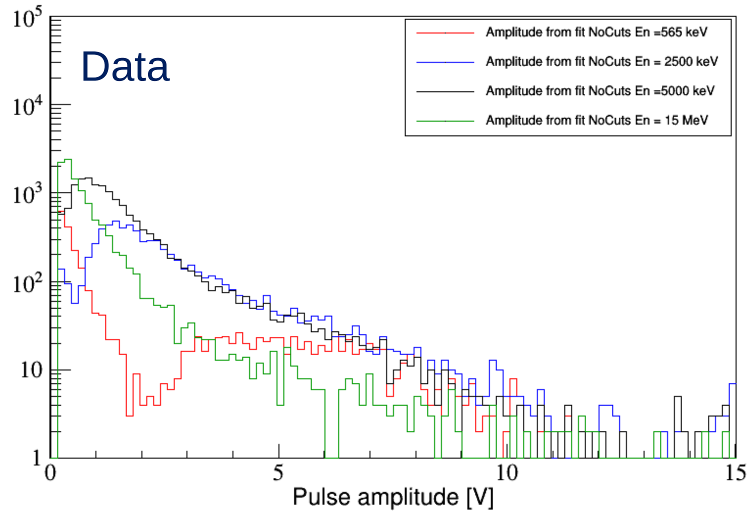
SLOW

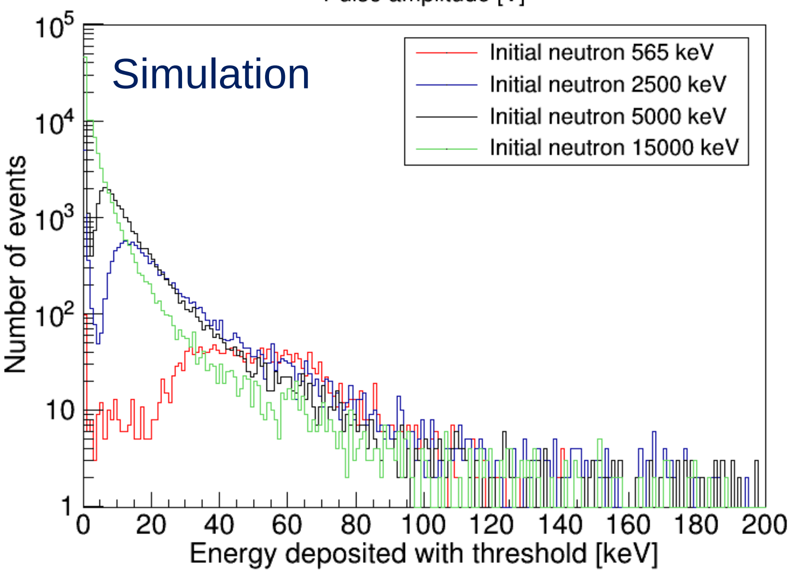



- Delay in signal: Convolution of moderation in polyethyelene + proton beam pulse duration (100 µs)
- ~ 200 µs from simulations for a instantaneous pulse

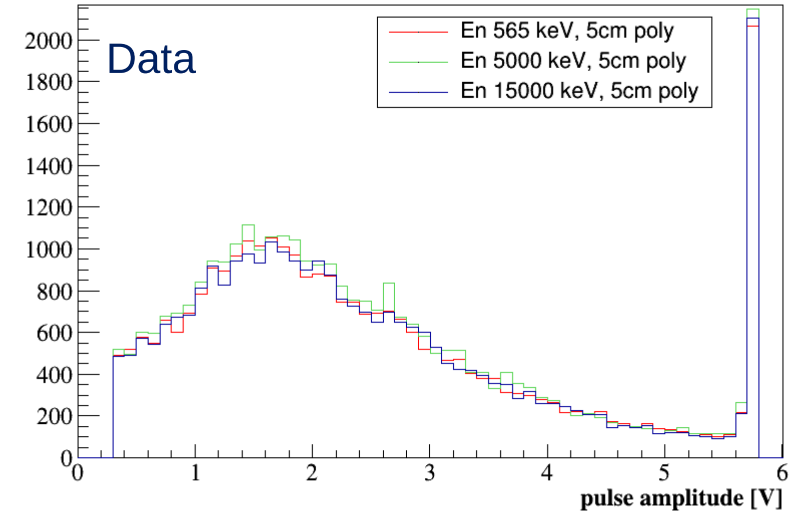
# EFFICIENCY MEASUREMENTS

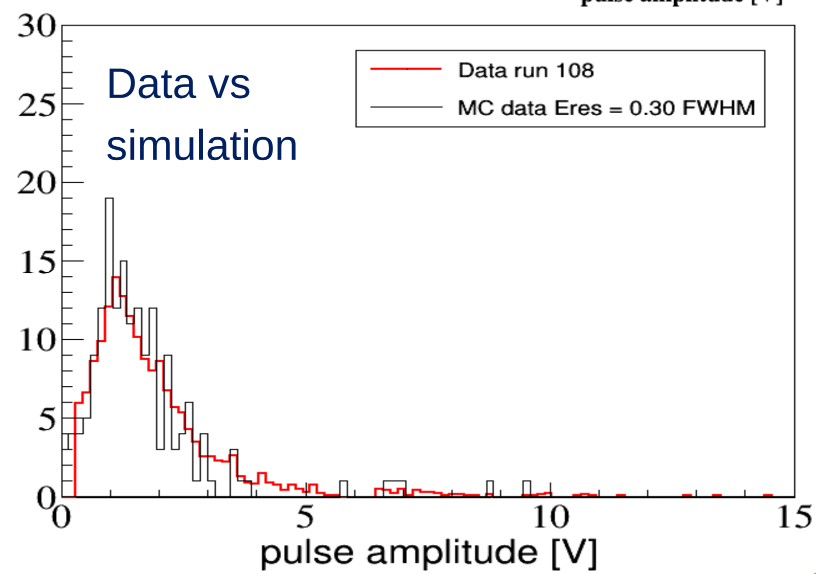
FAST




SLOW



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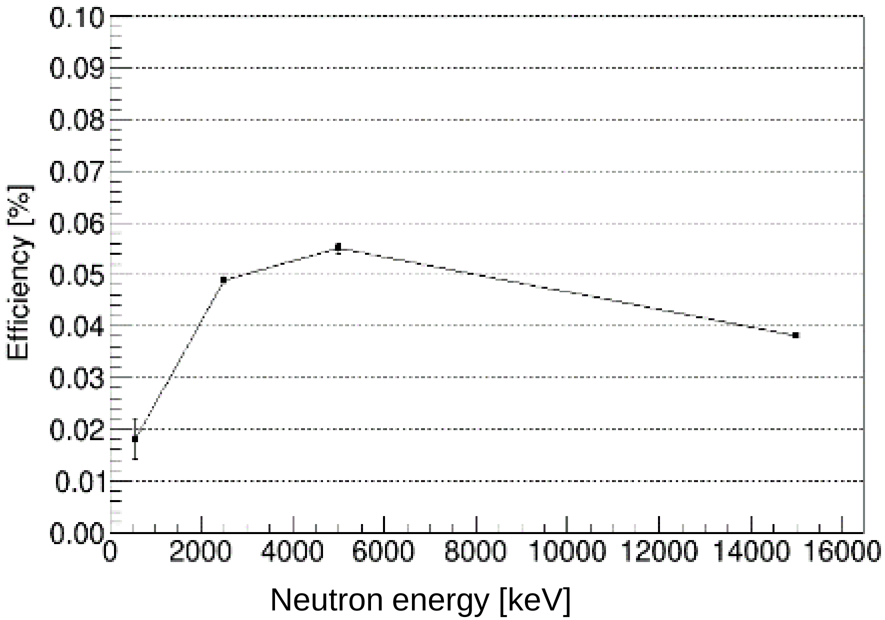
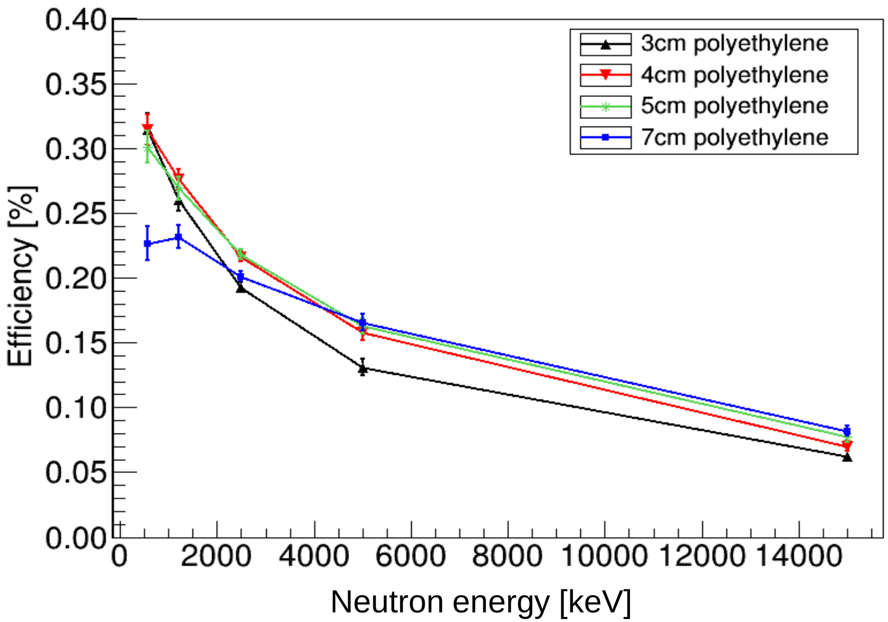



SLOW



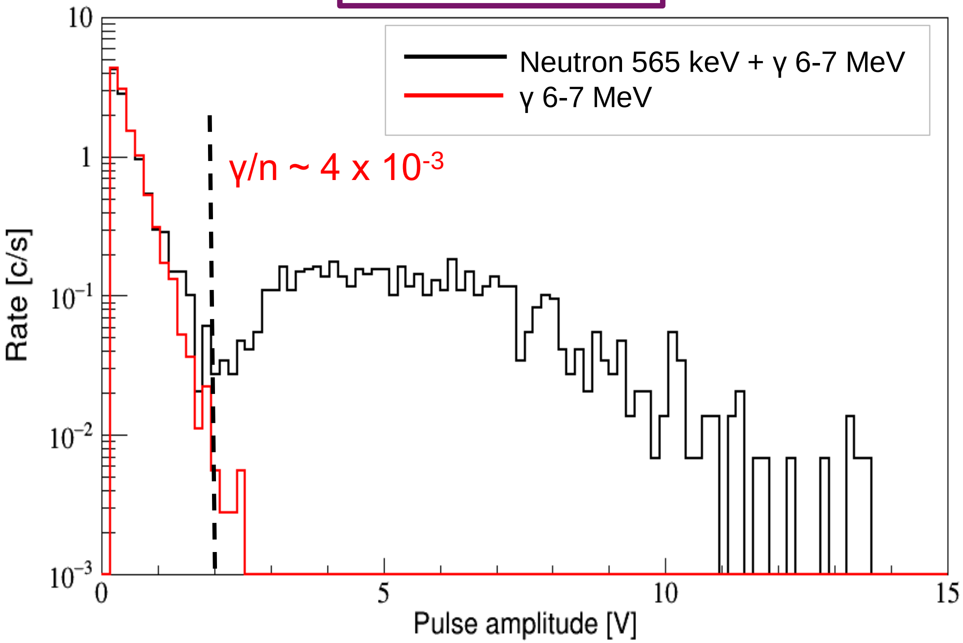

- Efficiency strongly dependent
  - on threshold
  - on initial neutron energy
- Efficiency 5-20 smaller than slow module

- Count rate of few /s for a neutron fluence rate of 1/s/cm$^2$

# GAMMA/NEUTRON SUPPRESSION

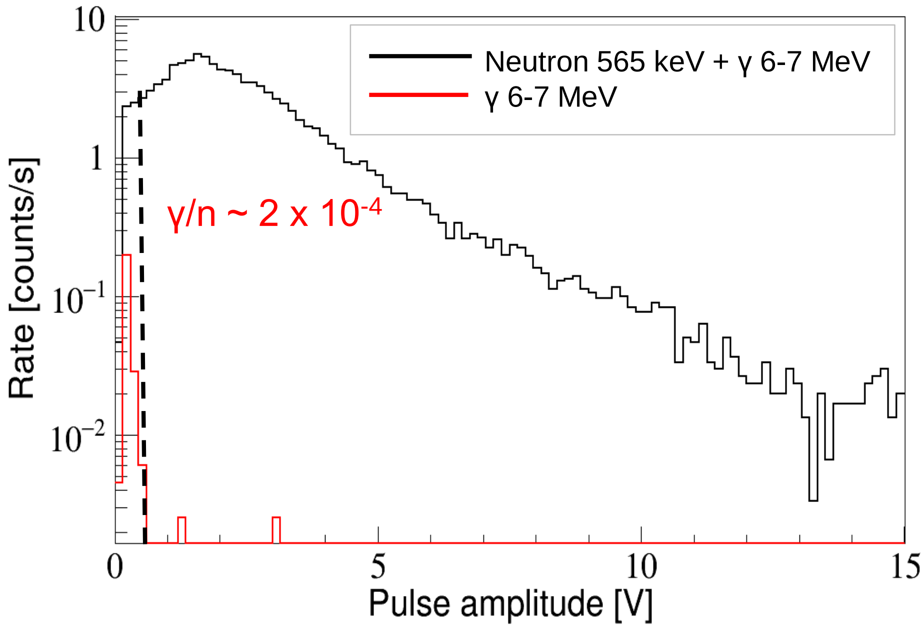
*Vm = - 500 V*
*Vd = - 700V*

FAST




*Vm = - 500 V*
*Vd = - 540V*

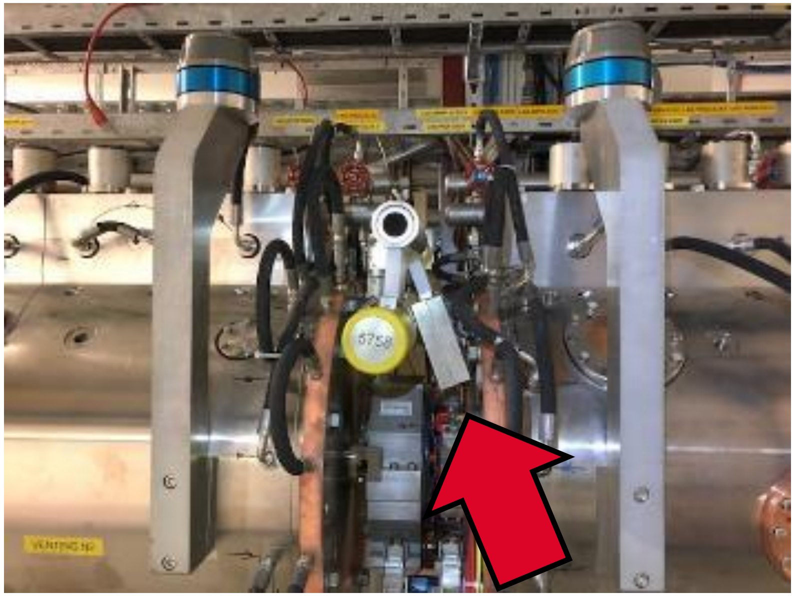
SLOW




- The choice of He gas enhances the suppression
- Values are threshold and gain dependent
- The difference in rate observed between fast and slow is due to different drift distance (1.9 mm in fast / 0.4 in slow)

# LINAC4 DATA

- **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, test FEE in accelerator conditions…
  - December 2018
    - Losses were produced



- Data taking with a fast oscilloscope
  - 250 Ms/s
  - Full bandwidth
  - With trigger of Linac4 also recorded

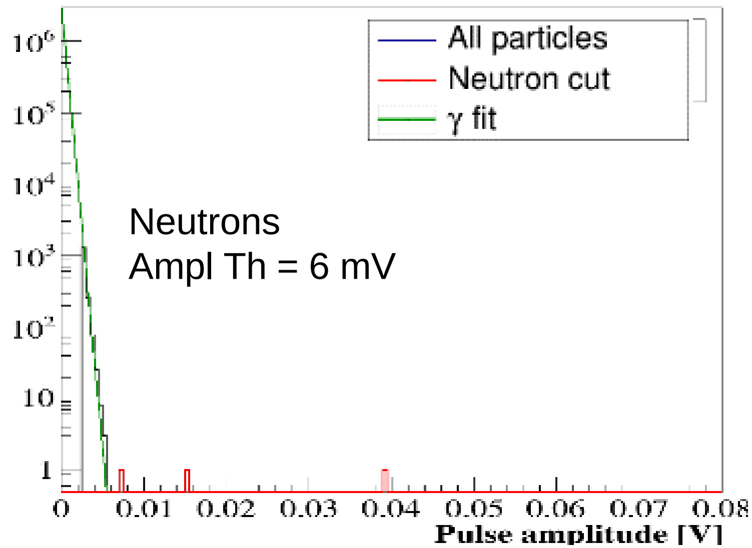
# LINAC4 DATA – PROVOQUED LOSSES

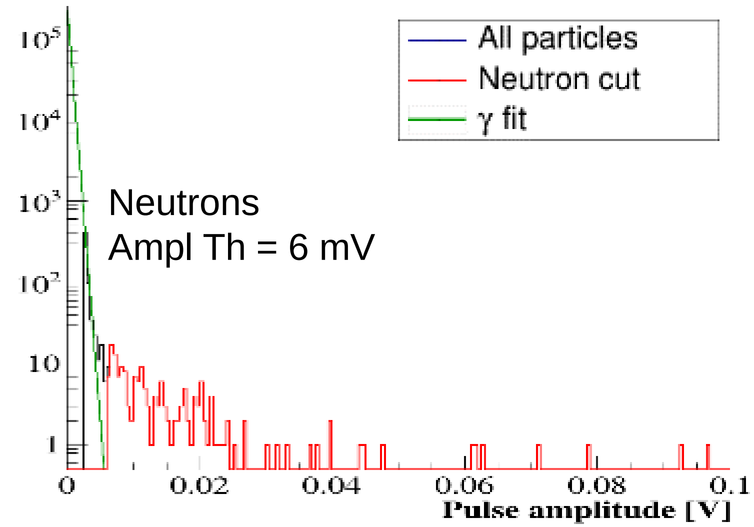
Vmesh = - 525 V
Vdrift = - 1000 V

Run 414
No losses

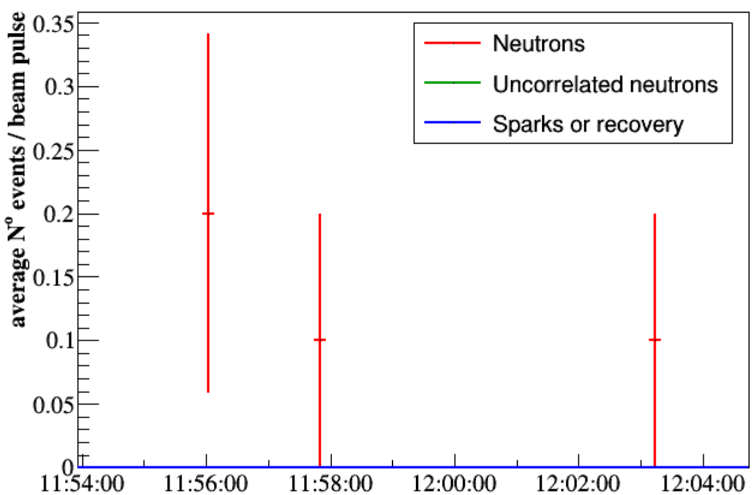
Run 415
Losses

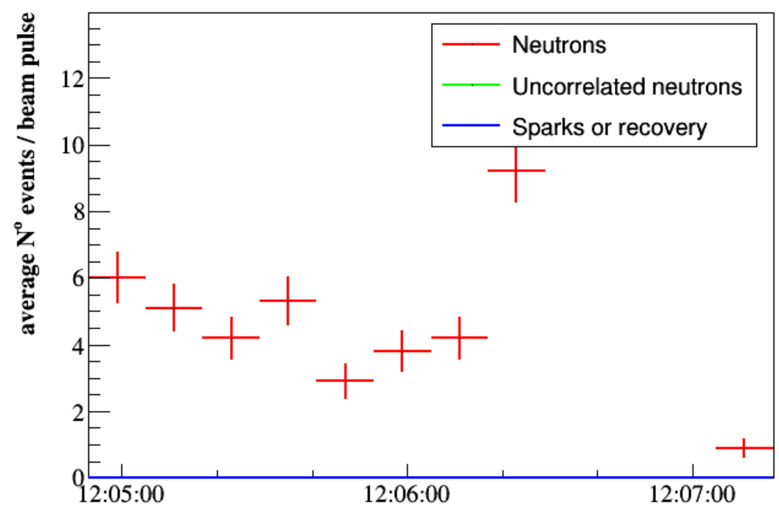
Amplitude



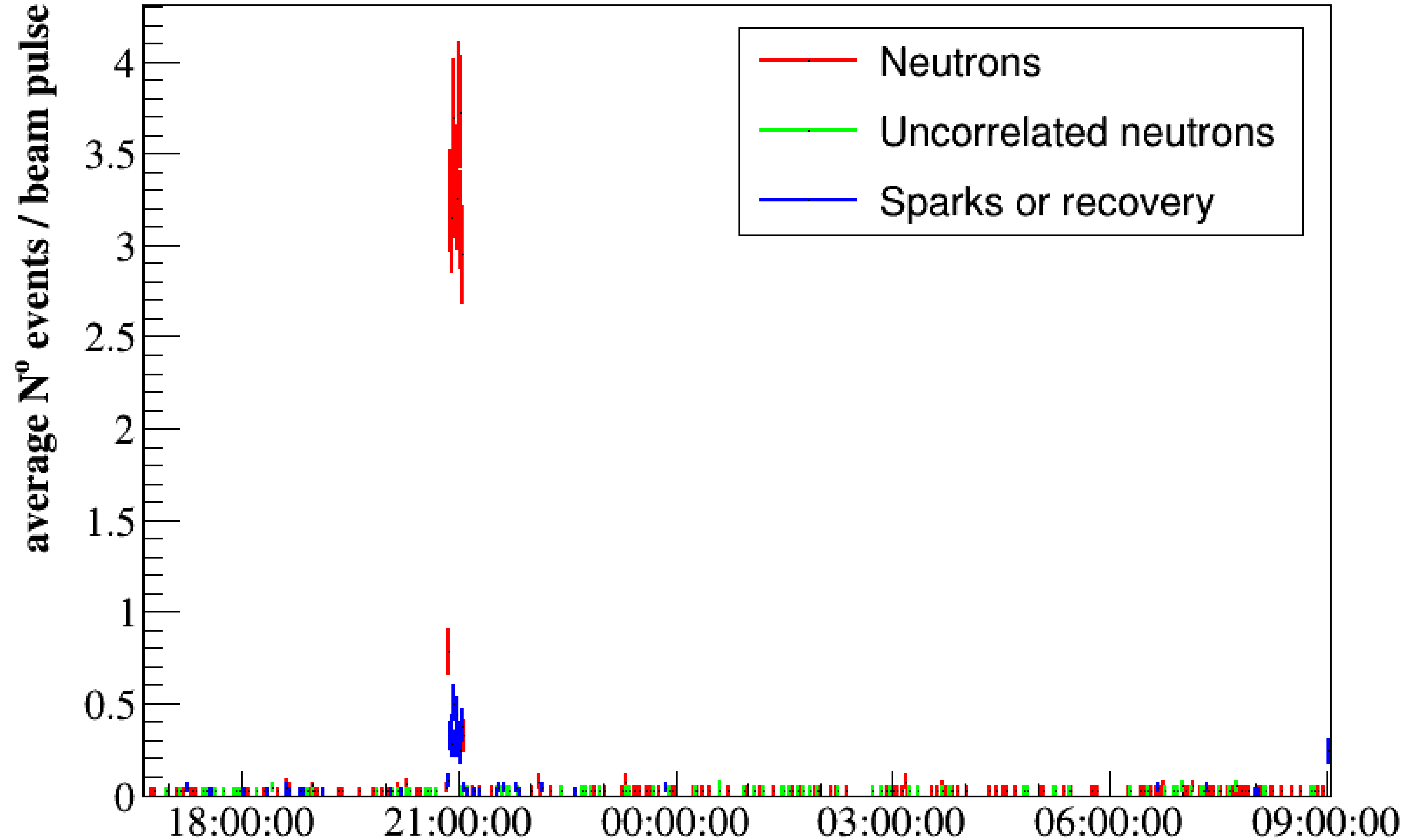




Average rate



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



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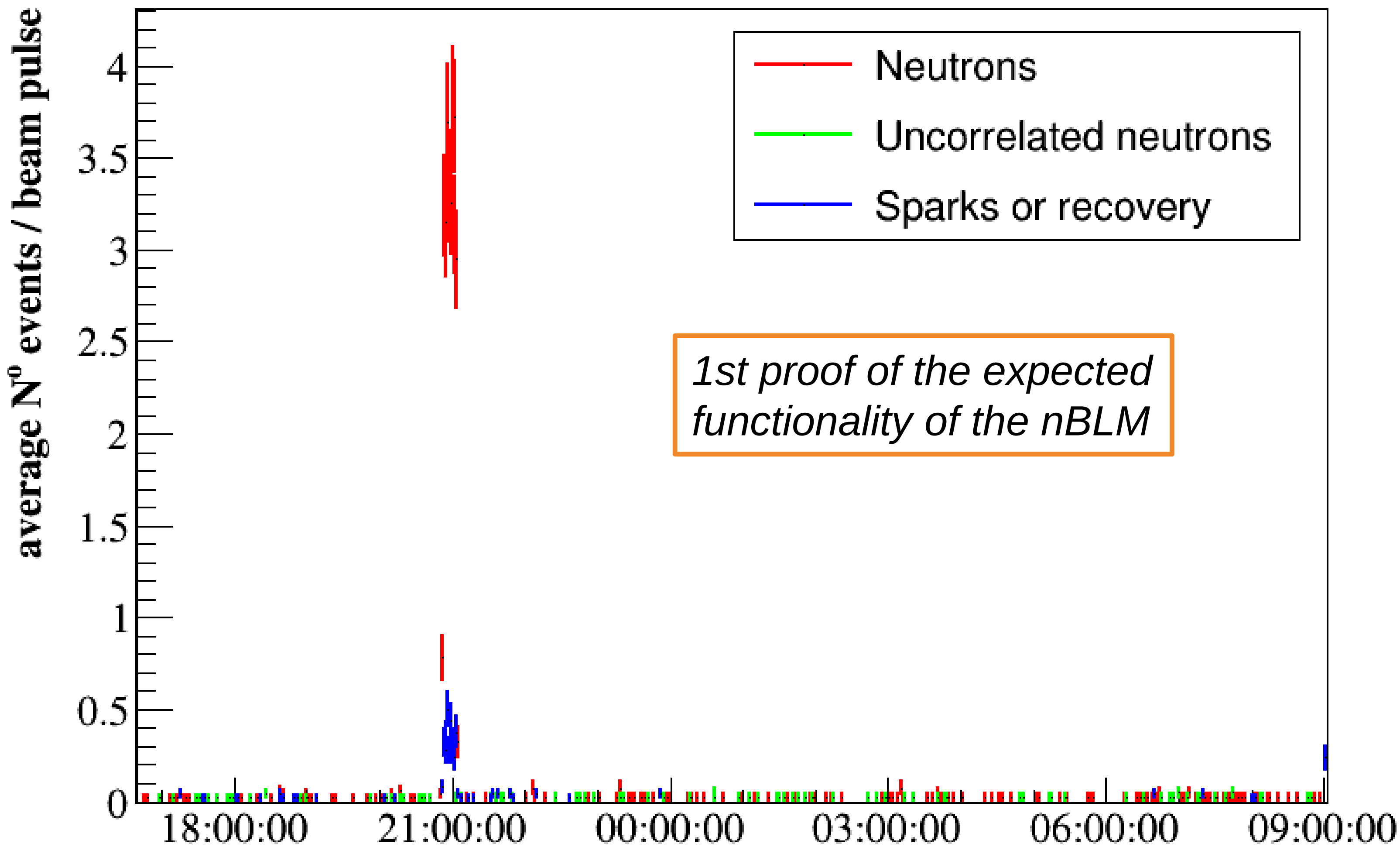



*1st proof of the expected functionality of the nBLM*

# CONCLUSIONS

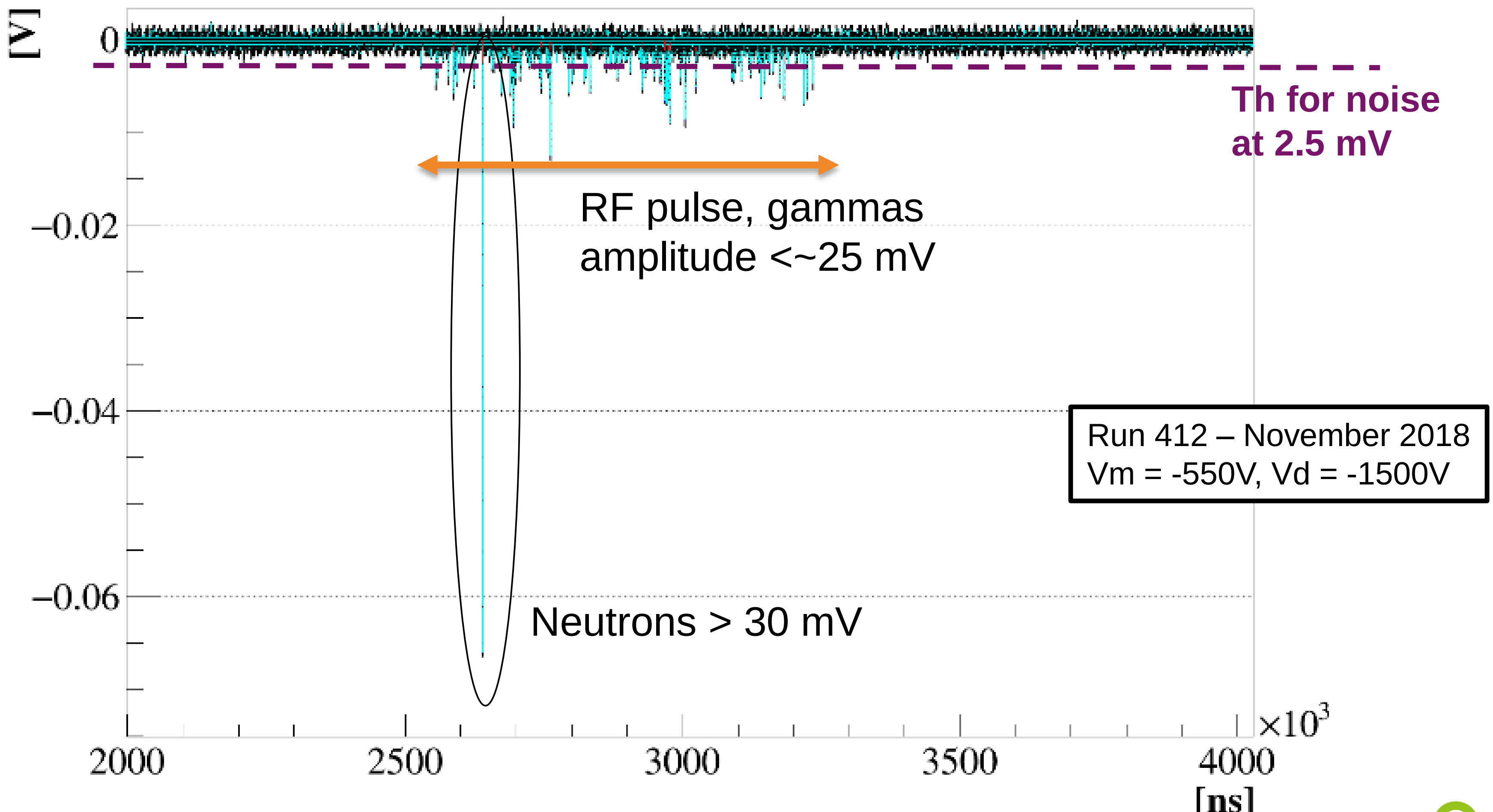
- New application of Micromegas detectors
- A lot of interest from the accelerator community
- Detector concept, design, first prototypes and proof of concept in irradiation facilities in ~2 years
- Proof fast response, n/g rejection and efficiency and FEE
- Clearly detect beam losses at LINAC 4
- Production project of 84 detectors system with ESS

# Thank you for your attention!

# Back-up

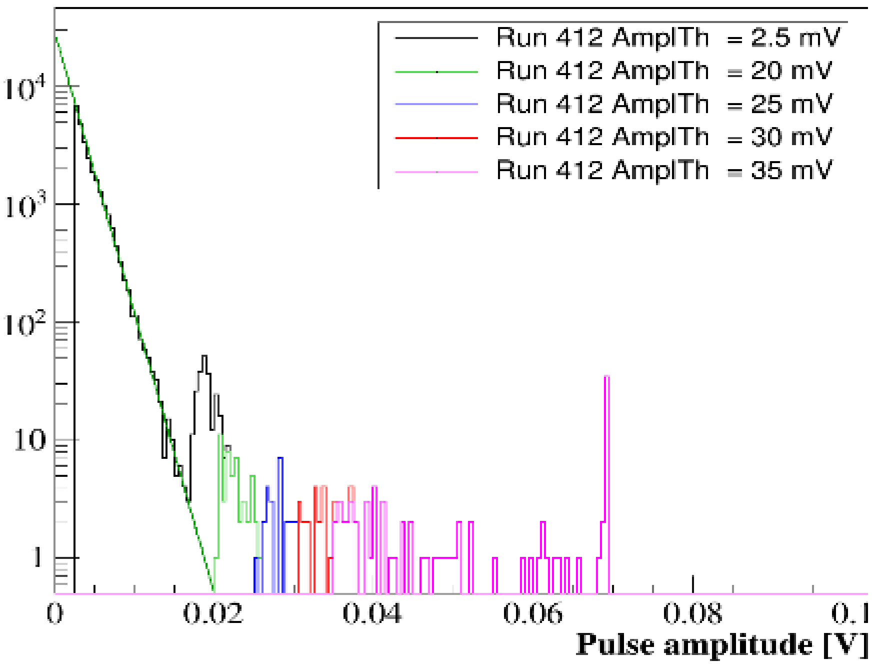
# LINAC4 DATA

- Some history… Initially at Linac 4 we were detecting nothing so we increase the gain of the detector to force sparks to check detector was alive
- We start having events at 550V… ~50 -75 V higher gain than nominal

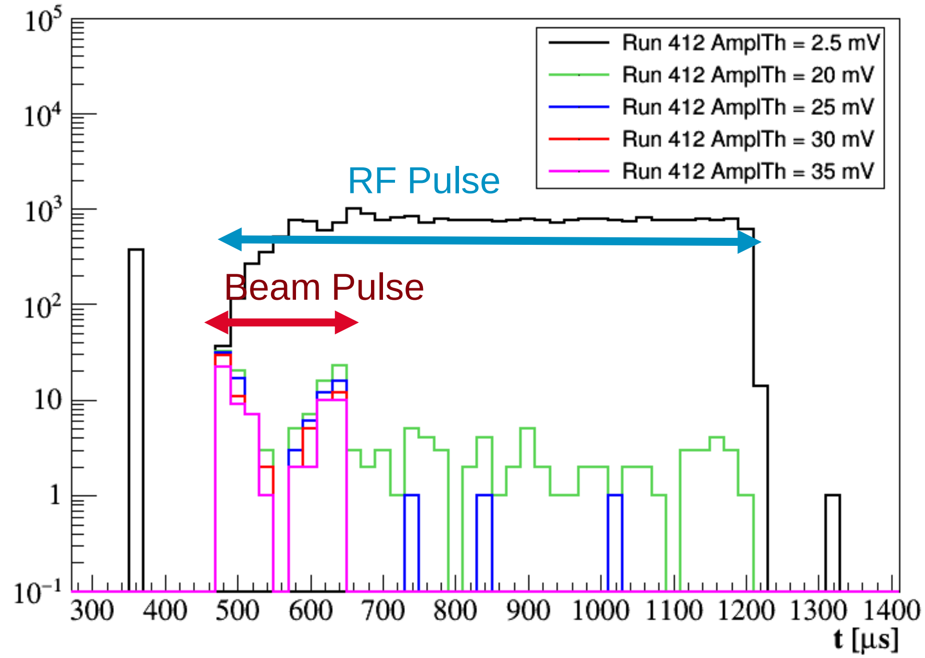


Run 412 – November 2018
Vm = -550V, Vd = -1500V

## Amplitude



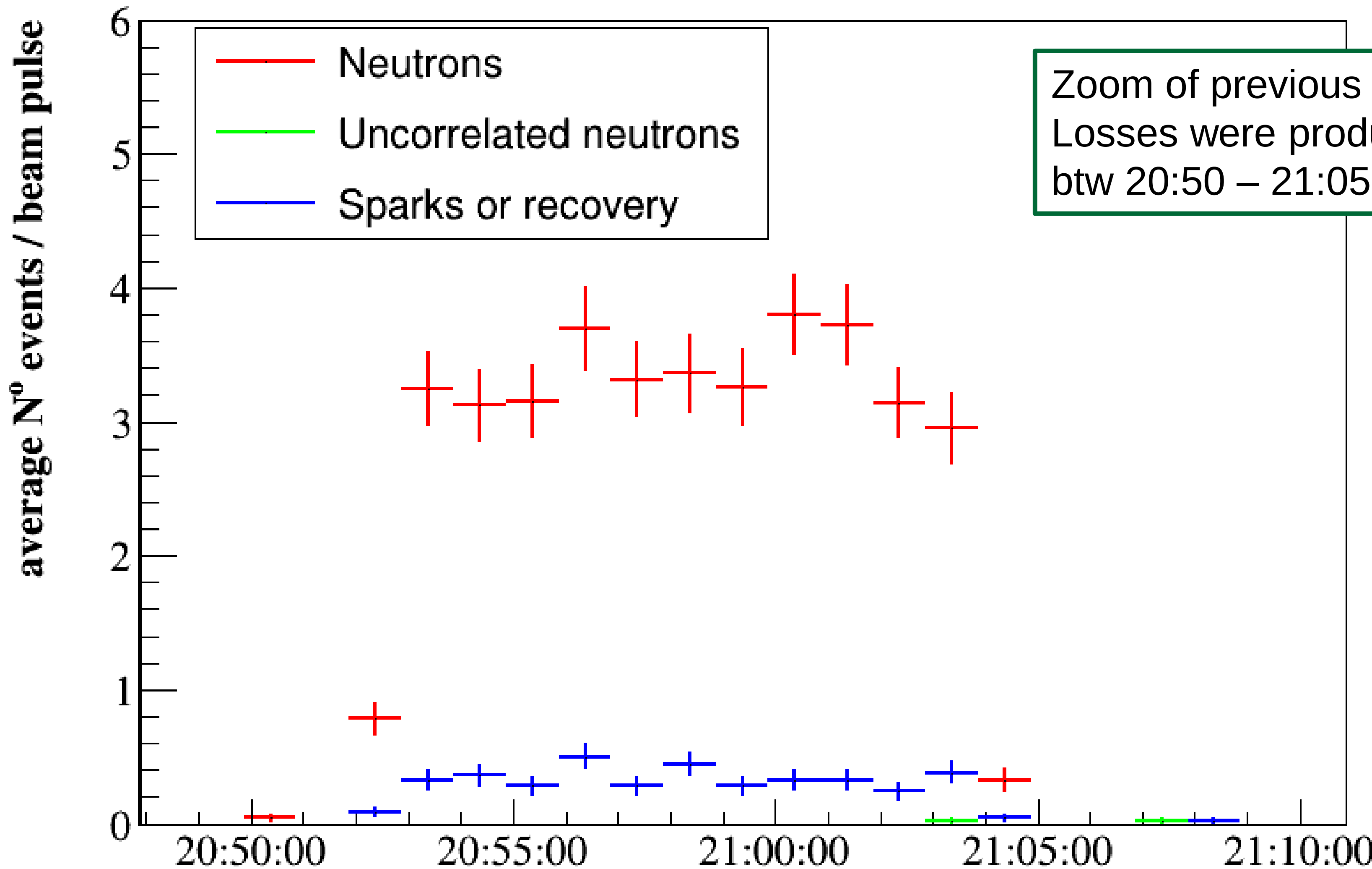

## Beam Structure




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

# LINAC4 DATA – DEC. 2018 – PROVOQUED LOSSES

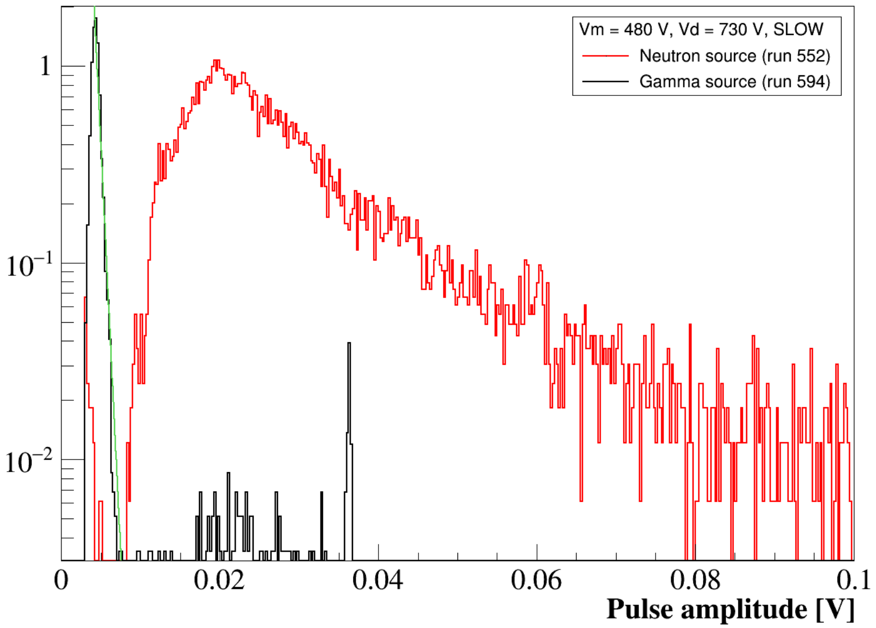
Run 420 – December 2018
Vm = -550V, Vd = -1500V

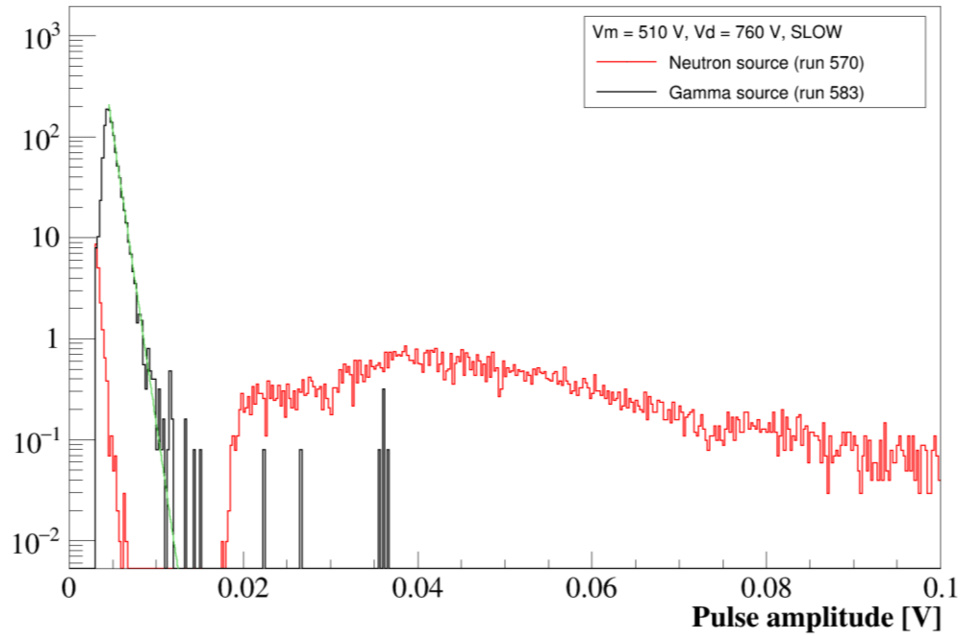



Zoom of previous slide
Losses were produced
btw 20:50 – 21:05

# NBLM DATA – NEUTRON AND GAMMA SOURCES

SLOW



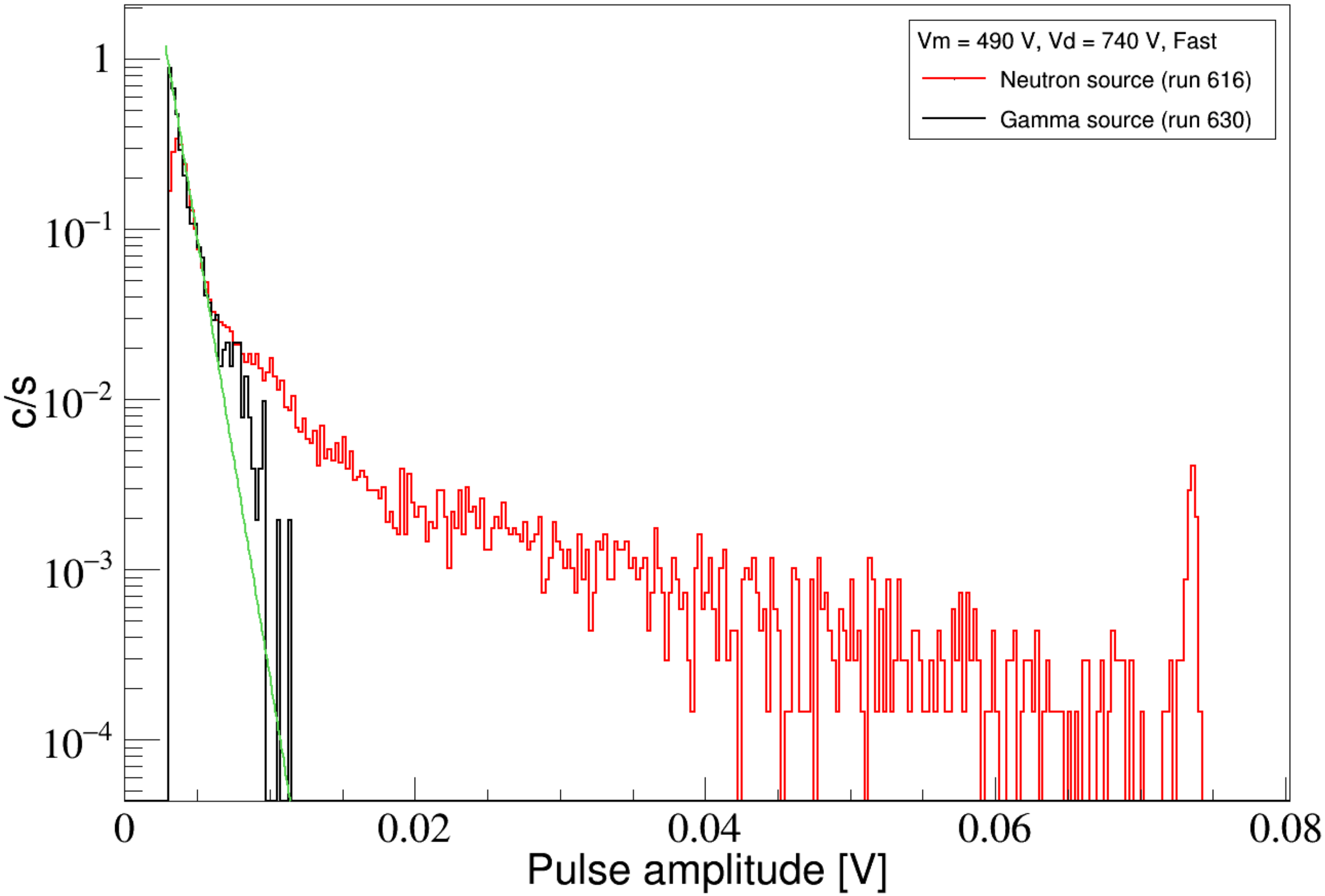




Lower gain (480 V)

Higher gain (510 V)

# NBLM DATA – NEUTRON AND GAMMA SOURCES

FAST



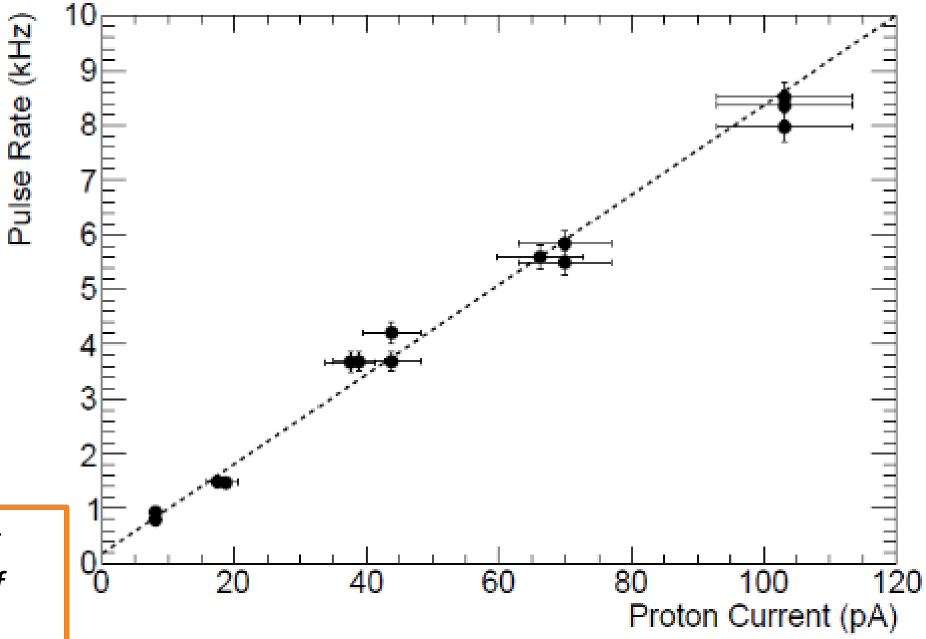
## MC40 Cyclotron (Birmingham University, UK):

Slow nBLM module

Aluminium plate

Proton beam

- Medical synchrotron
- Protons up to 30 MeV
- Beam diameter ~1cm
- Continuum pulse
- Data taken at 28 MeV and different intensities
- Proton beam into Al plate $\phi$=1cm

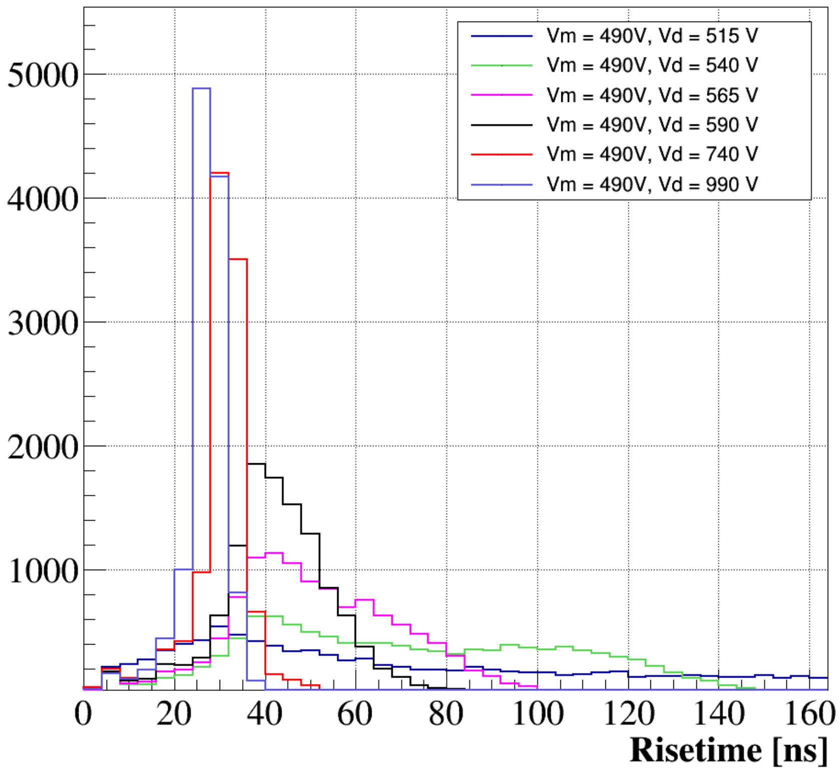



*Correlation of the count rate with the intensity of the proton beam*

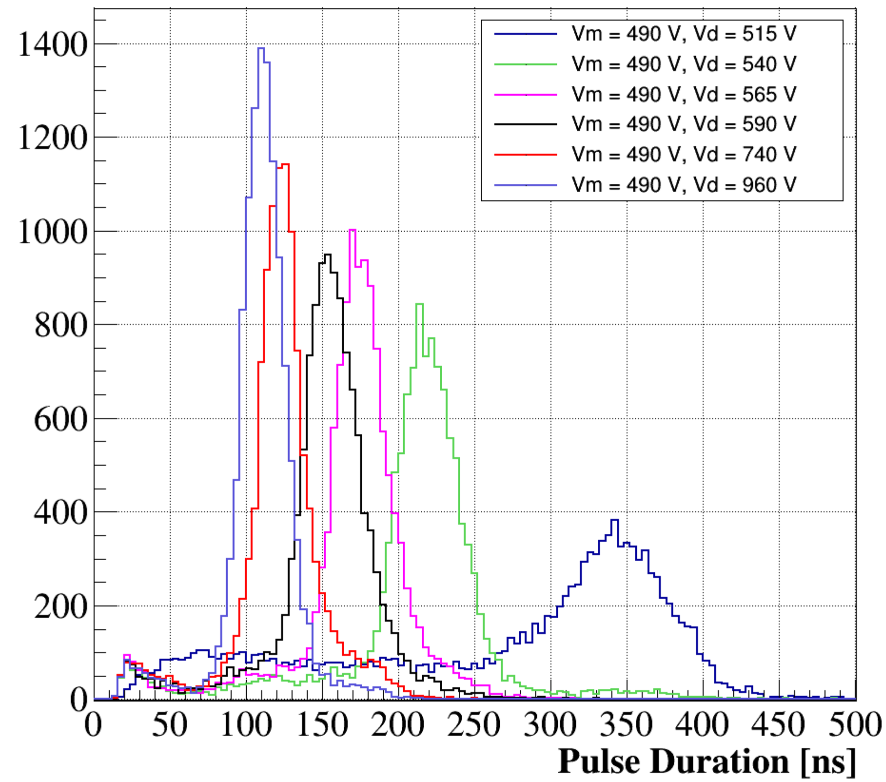
# NBLM DATA – SIGNAL CARACTERISTICS

Dependency with drift voltage

Rise Time




Pulse width

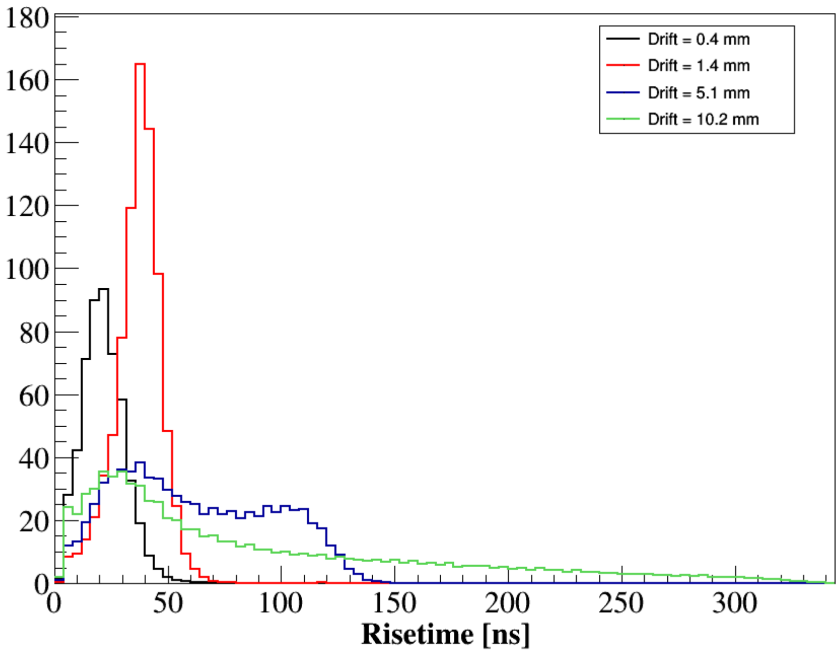


# NBLM DATA – SIGNAL CARACTERISTICS

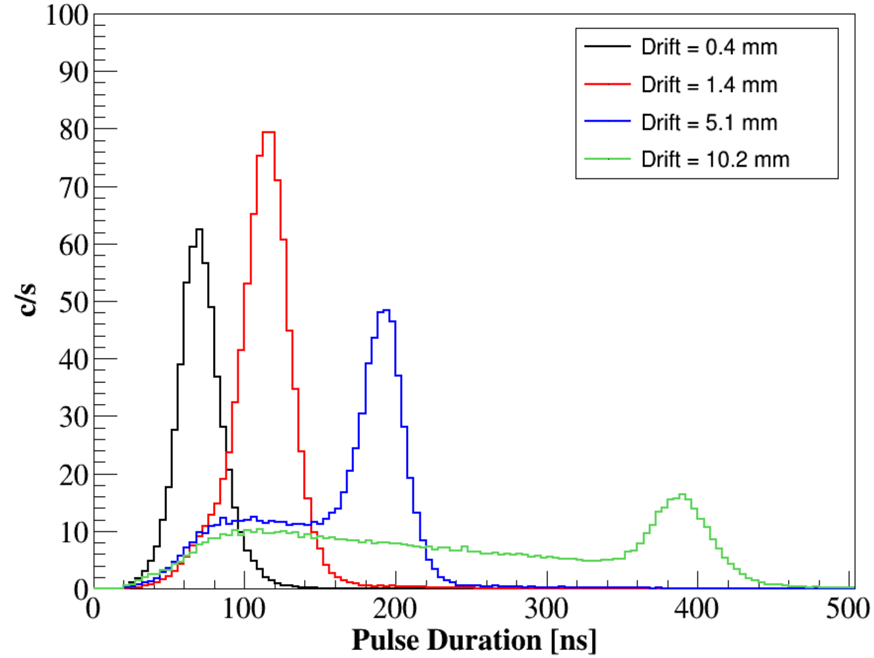
*ORPHEE nuclear reactor LLB, CEA Saclay: 0.01 eV neutrons, flux 2×10$^{6}$ s$^{-1}$ cm$^{-2}$*

Dependency with drift distance

Rise Time

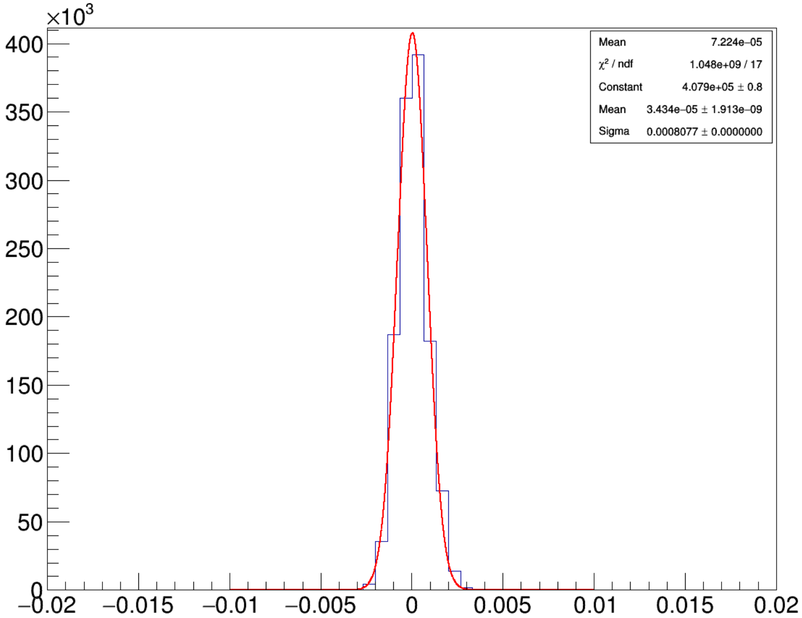


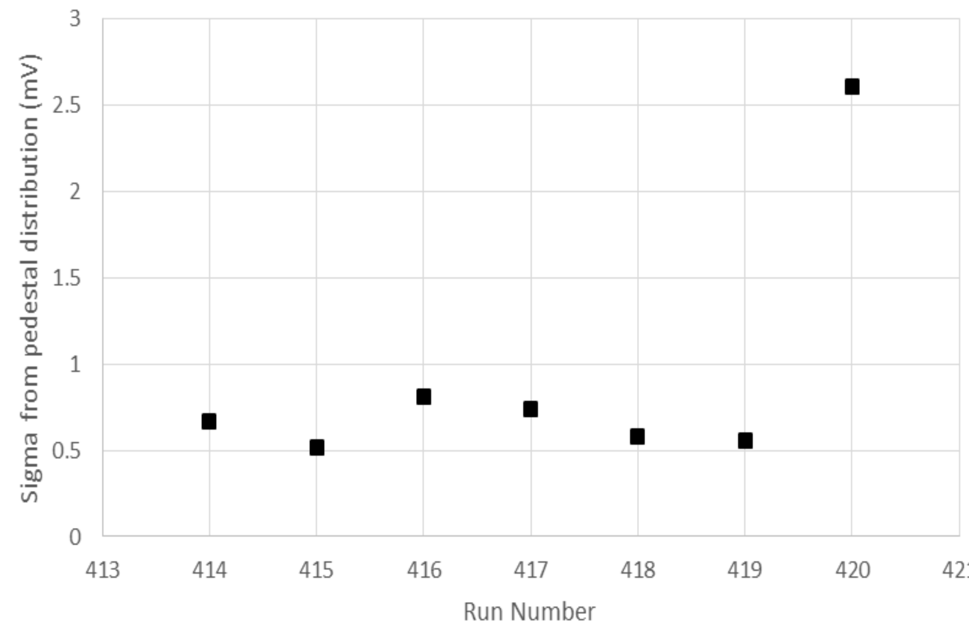

Pulse width




- Optimum **value ~2 mm**
  - Rise Time ~ 45 ns and very stable
  - Pulse duration ~ 60 ns → in 1µs ~ >10 pulses/window before pile-up (~10 MHz)
- Optimized to avoid also to be very close to sparking point

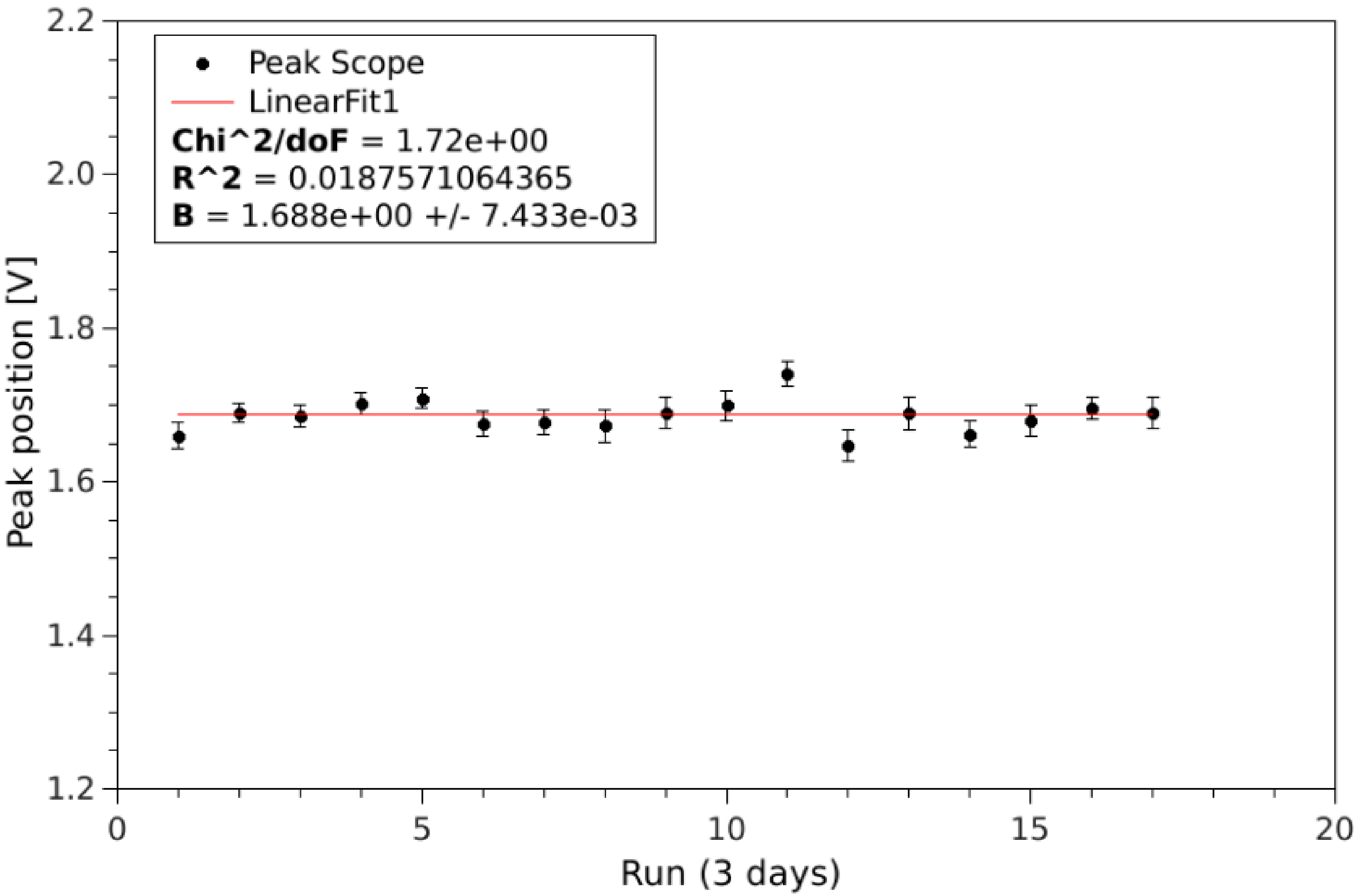
# BASELINE STABILITY



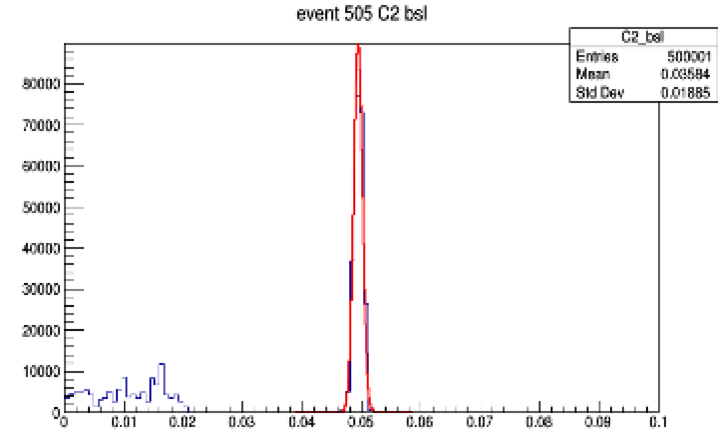



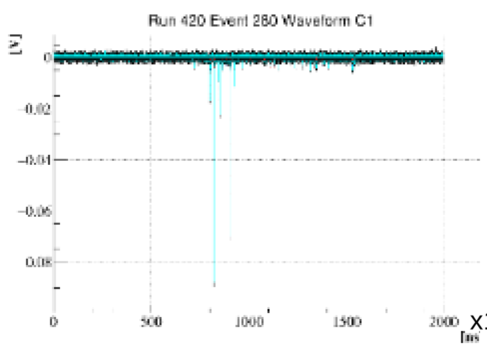

*Example of a pedestal distribution for one of the runs taken during the December 2018 campaign (left). (Right) The sigma of the pedestal distributions for different runs. Run 420 was when quite important beam losses were produced and this produced some sparks as explained in the text that broad the pedestal distribution.*

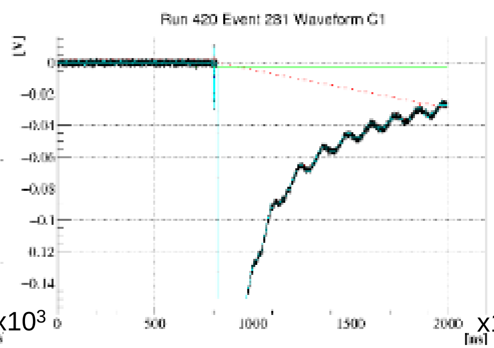
# GAIN STABILITY

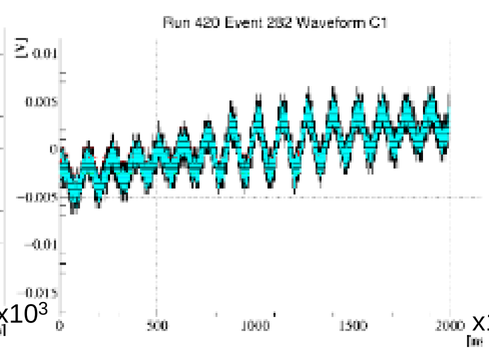


- Identified pulse by pulse if
  - Sigma of baseline too large
  - Charge of pulse too large



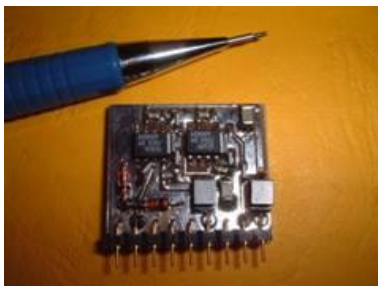



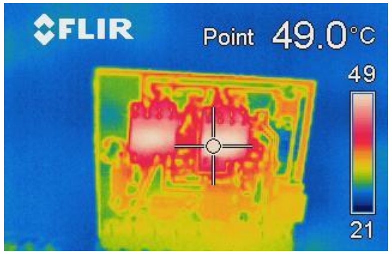

Designed by Philippe Legou

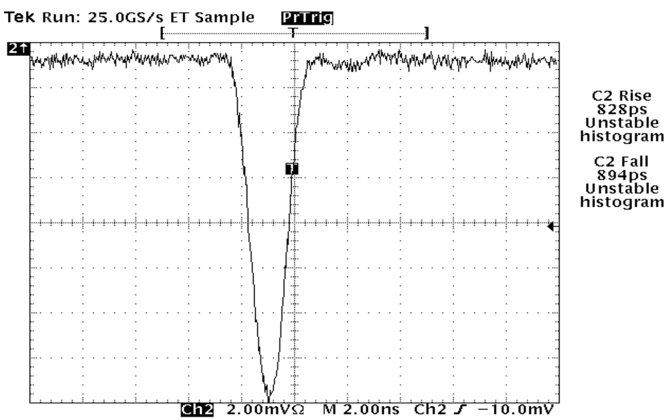
# Front end electronics for nBLM prototype

FAMMAS front-end module

( Fast Amplifier Module for Micromegas ApplicationS)






*In few figures …*

- *Power supply : + 5V -5V*
- *Consumption ≃50 mW*
- *Input: positive or negative*
- *Noise: **600 µV rms***
- *Rise time : **< 1ns***
- *Bandwidth adjustable up to few GHz*
- *Configurable gain, in these results 40dB (equals x 100)*
- *Very robust to sparks*

# THE ACQUISITION SYSTEM

➢ **Fast acquisition**

ICS standardisation for fast acquisition is based on:

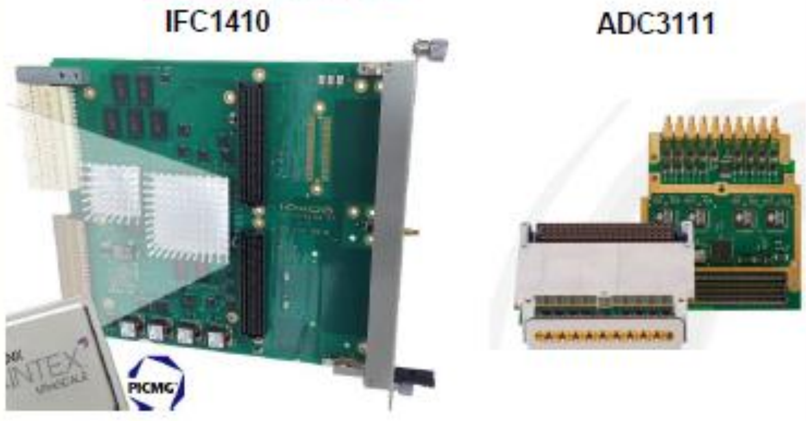
- µTCA.4
- IOxOS CPU IFC_1410
- IOxOS ADC_3111 FMC boards
  - Total 16 cards (128 channels)
  - Input voltage range is -0.5V to 0.5V
  - Sampling frequency of 250 MSamples/s

➢ **FPGA firmware**

The FPGA will have the following tasks:

- Detection of neutrons and counting. Automatic switch to current mode.
- Beam Permit signal to the Beam Interlock System
- Acquire post-mortem data
- Provide debug and diagnostic data
- Provide oscilloscope functionality
- Generate warnings/health status of subsystems

BEE boards




- Only one ADC3111 FMC per IFC1410 board
- Pairs of fast and slow acquisition for software architecture convenience.
- Cross detector pairs on different ADC3111 modules to avoid blind regions in case of card failure