Beam loss (micromegas) instrumentation for LINAC commissioning

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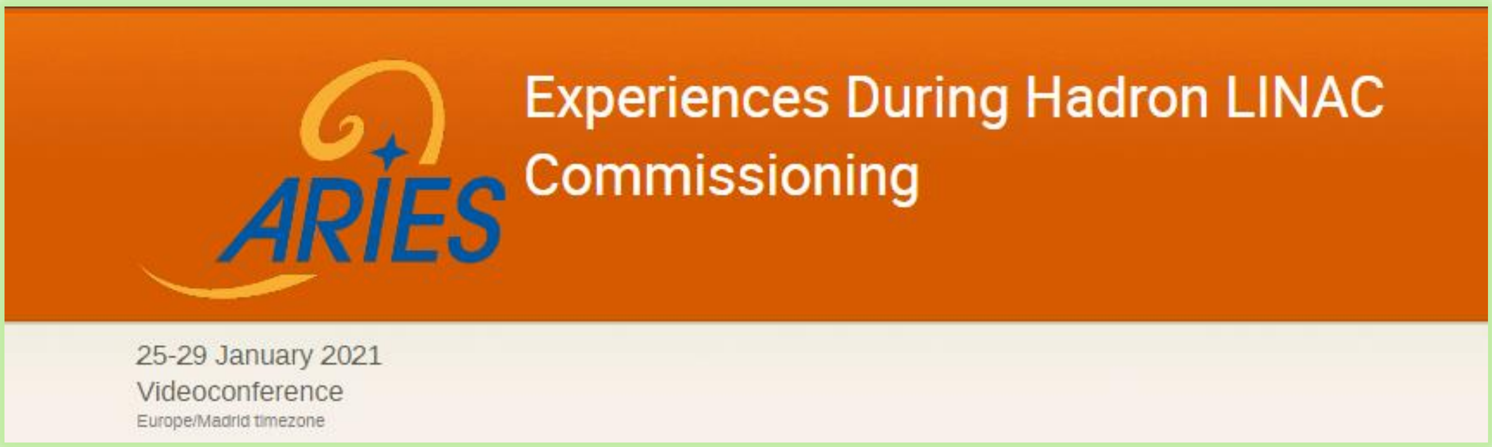
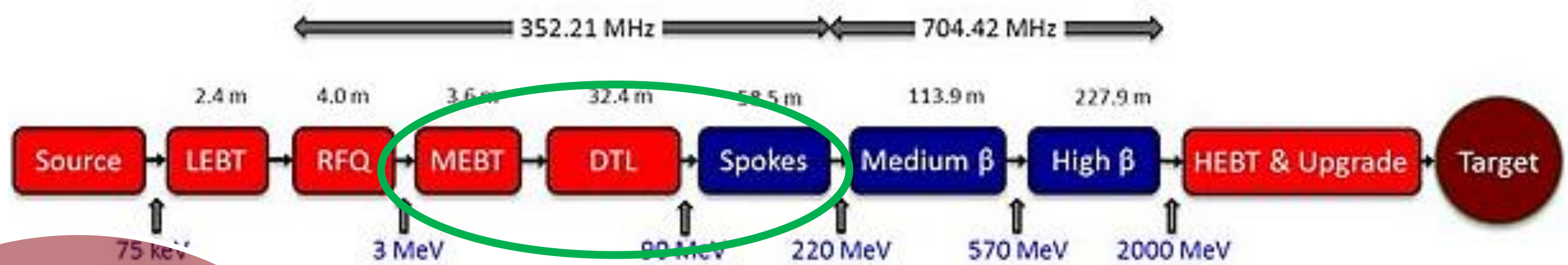


OUTLOOK

1. Motivation & Context
2. neutron Beam Loss Monitors
3. Proof of concept in LINAC operation
4. Conclusions

Context: ESS-nBLM System

- **Motivation:** Develop a detector to enlarge losses sensitivity at low energy regions of a LINAC
  - At **low beam energy** only neutrons and photons can escape the beam pipe
- **Project: In-kind** contract between the **European Spallation Source (ESS)** and **IRFU**
  - Design, construction, test and delivery of 84 detectors + subsystems (gas, HV, LV, …)
  - Part of the Beam Instrumentation systems



ESS-nBLM System

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

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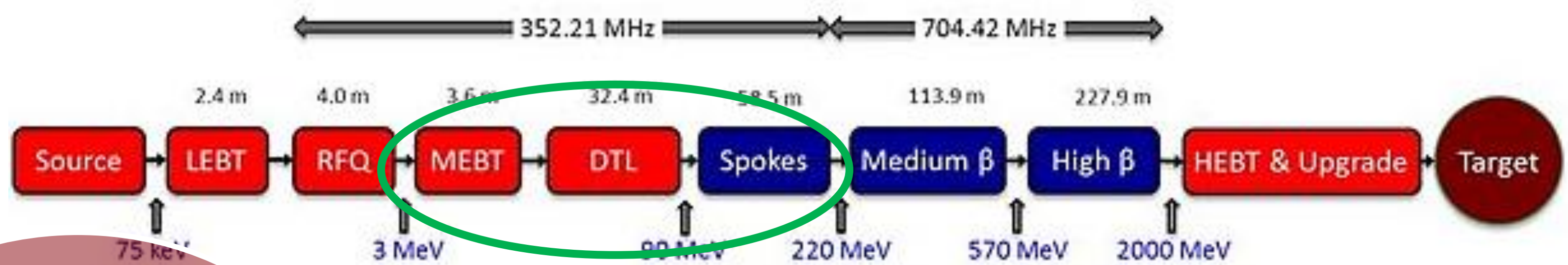

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More projects on-going
Saraf → 17 modules
DONES

nBLM Detector Definition

- **Detection of fast neutrons**
  - Neutrons produced by fission reactions
  - Energies 0.5 MeV - 20 MeV
  - “Directional”
- **Low efficiency to slow neutrons**
  - Fast neutrons slowed down after a set of collisions on atomic nuclei
  - Slow neutrons for us anything below 0.1 MeV
  - Loss information of directionality
- **Strong suppression of gammas**
  - Natural background coming from the RF cavities
  - Can hide a real loss signal
- **Fast system response (few µs)**
  - If connected to MPS

nBLM (*neutron Beam Loss Monitor)* →
Fast neutron detector **based on Micromegas** (MMs) equipped with a combination of neutron convertors and moderators

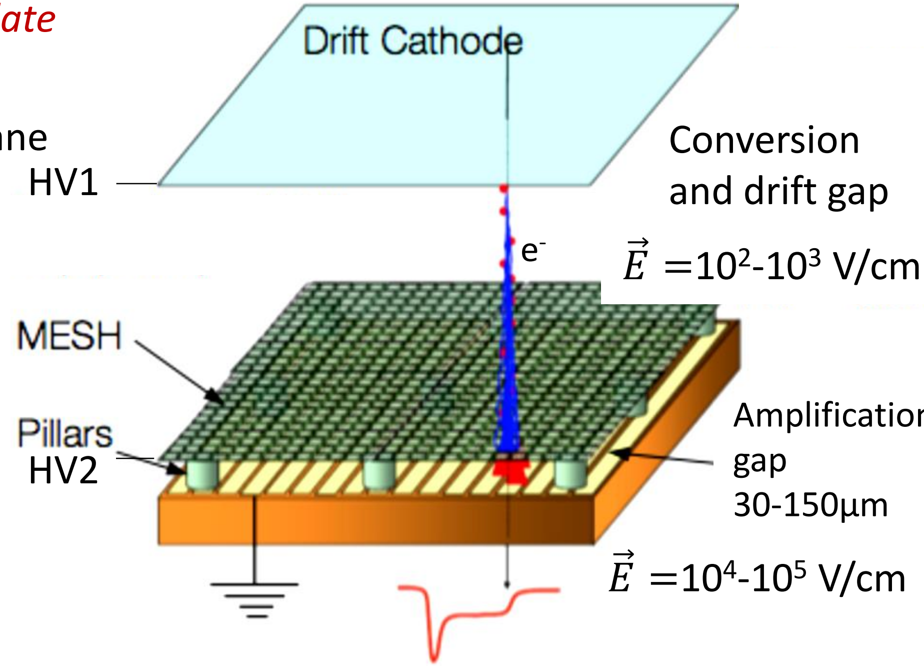
Micromegas Detectors

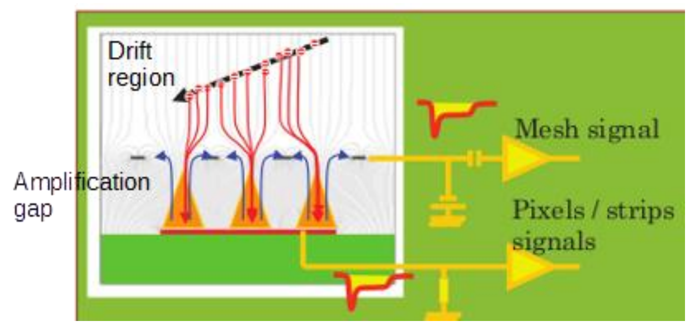
MicroMesh Gaseous Structures (**Micromegas**[1])

[1]*Giomataris, Charpak NIM A 376 (1996) 29*

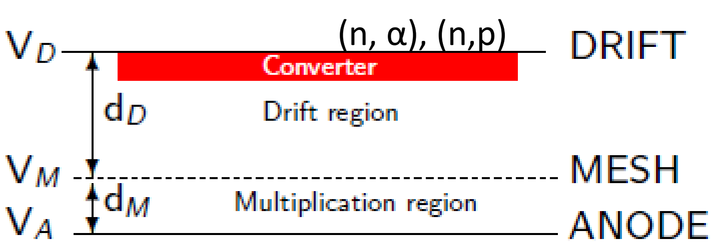
The device functions as a two-stage parallel plate avalanche chamber separated by a mesh

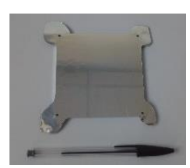
- a metallic micromesh suspended over an anode plane by insulator pillars
- Two separate zones
  1. Conversion region
     - Primary ionization
     - Charge drift towards amplification gap
  2. Amplification region
     - Avalanche production
     - Readout layout
       - Strips (single/multi) / Pixels





Neutron Detection





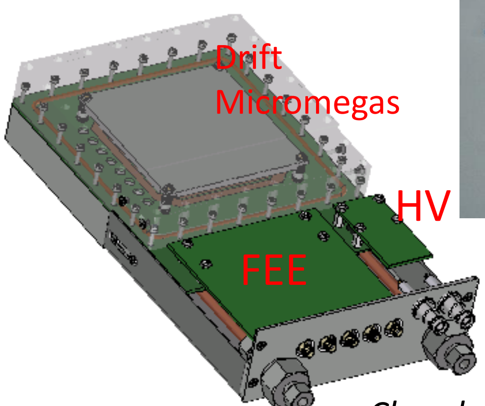
nBLM Detector Definition

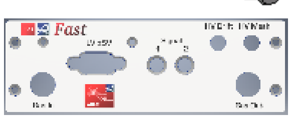
Two complementary modules, only differences:

- **neutron-to-charged particle convertor (the cathode)**
- **and the surrounding of the slow with absorber + moderator to increase efficiency**

Fast detector

- To detect "fast losses", i.e. losses in case of problems, be able to give an alarm
- Detect **fast neutrons**





Chamber + Faraday Cage ~ 20 x 15 x 2 cm^3, 1kg

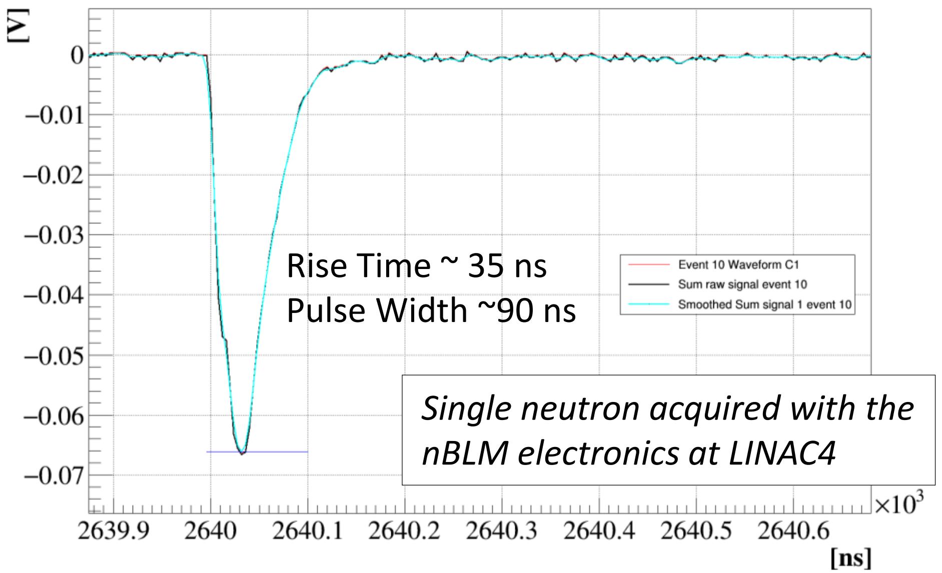
Slow detector

- To detect "slow losses", i.e. losses in normal operation, determine activation of materials, monitoring of losses
- Detect **fast neutrons**
- Slower time response

+moderator polyethylene 5 cm thick
+ borated rubber to absorb thermal neutrons

Operation

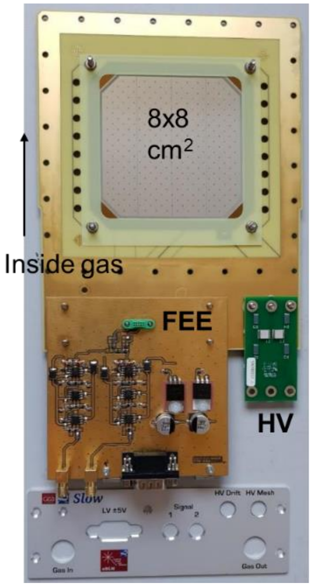
- **Single event detection**
  - → Operate in counting mode
  - → Larger sensitivity to small losses
  - → n/gamma discrimination
- Pulse analysis to identify different parameters that will identify the event as a neutron
  - Max amplitude, charge, ToT, …
- Transition to "current mode" (i.e. charge integration) in case of high flux (pile-up)



Single neutron acquired with the nBLM electronics at LINAC4

Operation

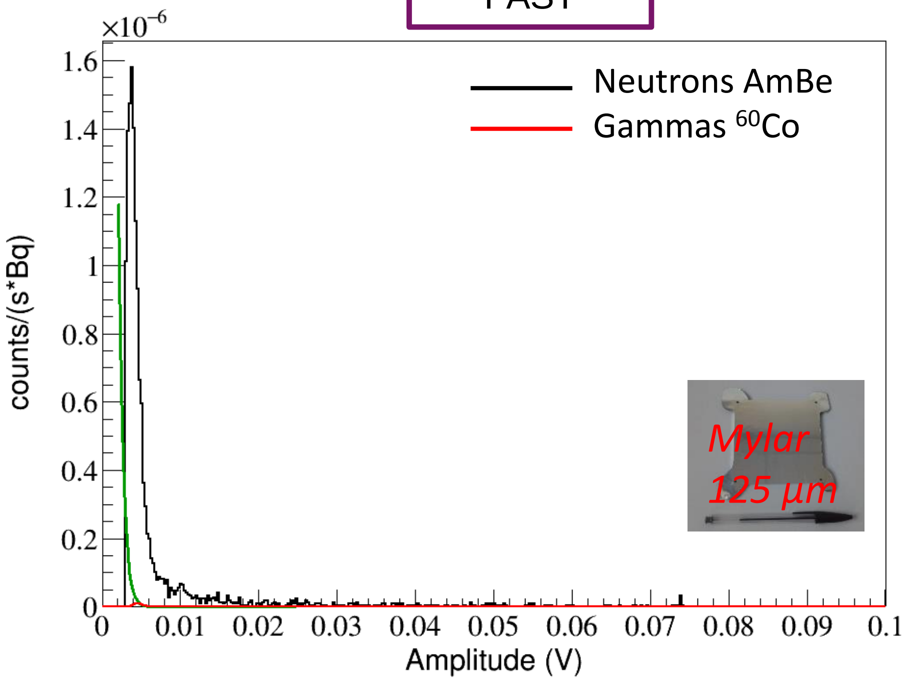
- Signal from detector is amplified in a **current amplifier** on board of detector
- Then the signal is digitized and analyzed in a FPGA
- Compare the neutron rate with the neutron rate in normal conditions
  - Limits will be defined during commissioning of the accelerator



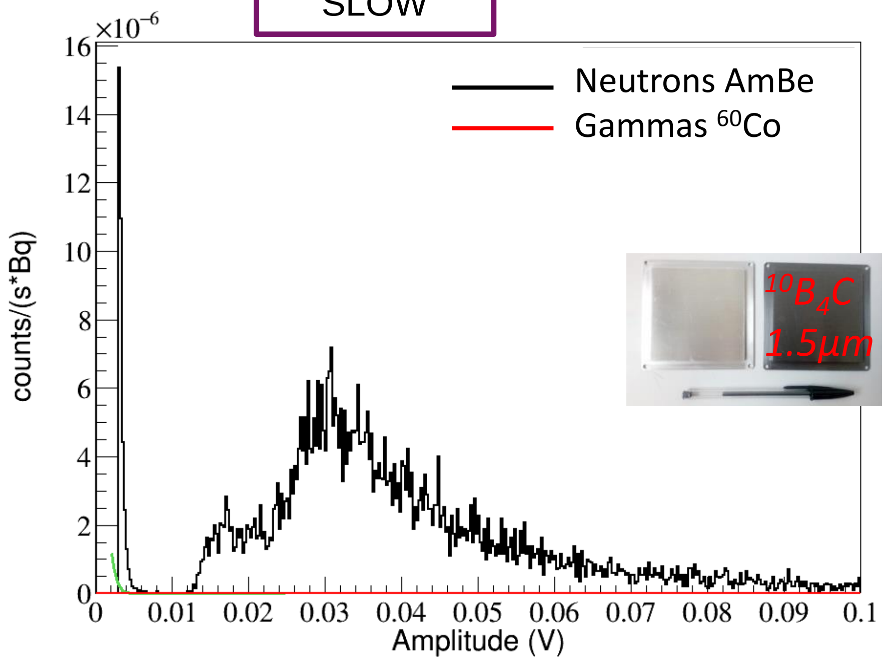
Neutron/gamma suppression

- Different ionization in gas for different type of particles → different charge and amplitude deposition
  - Suppresion based on an amplitude cut
  - At low gain, detector completely gamma free as the gamma signal will be comparable to the noise level

FAST



SLOW



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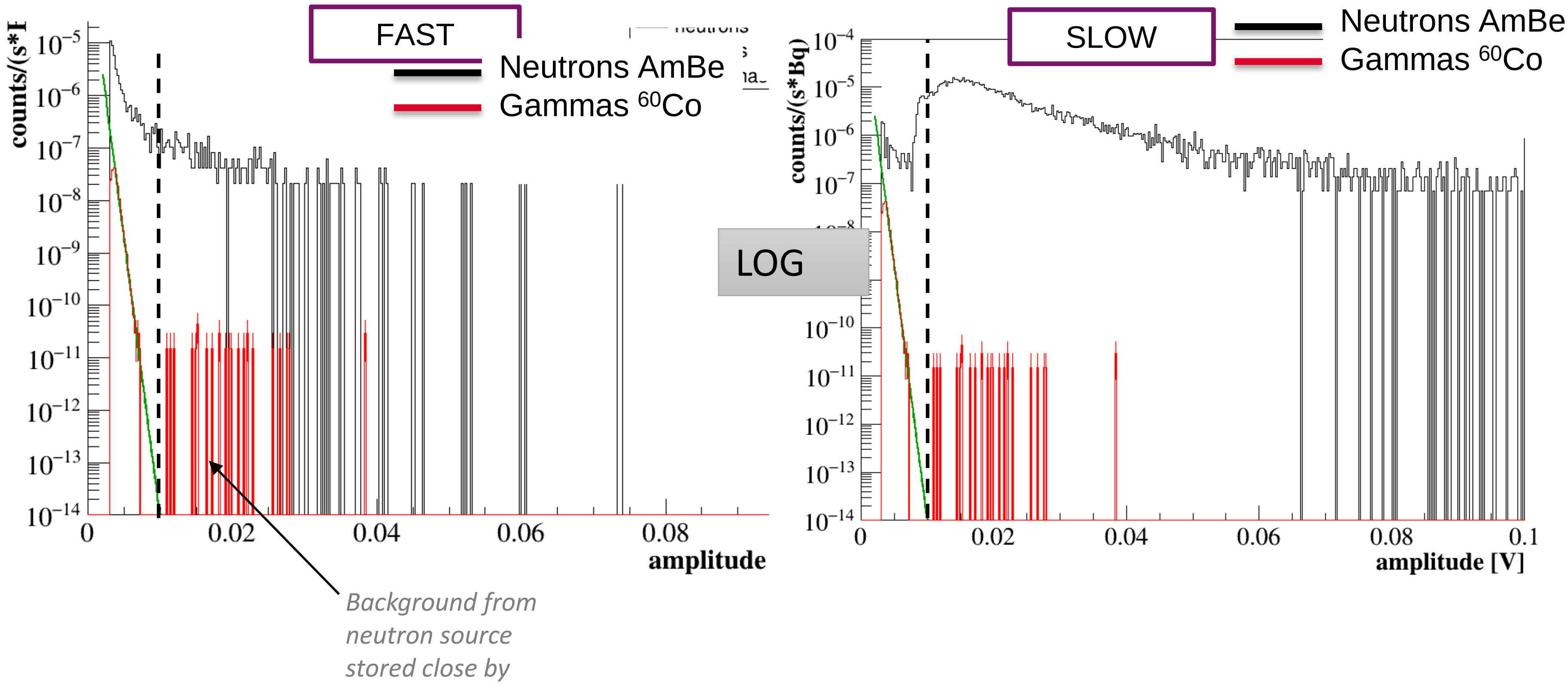
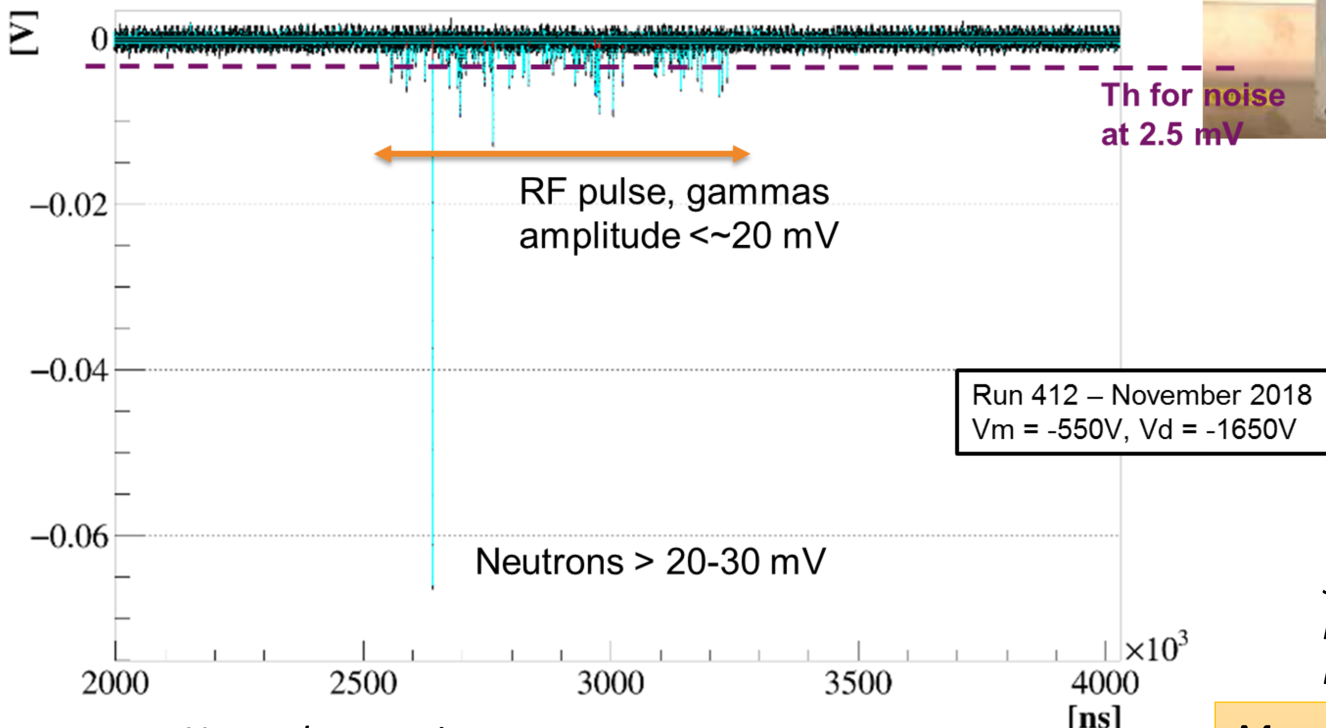
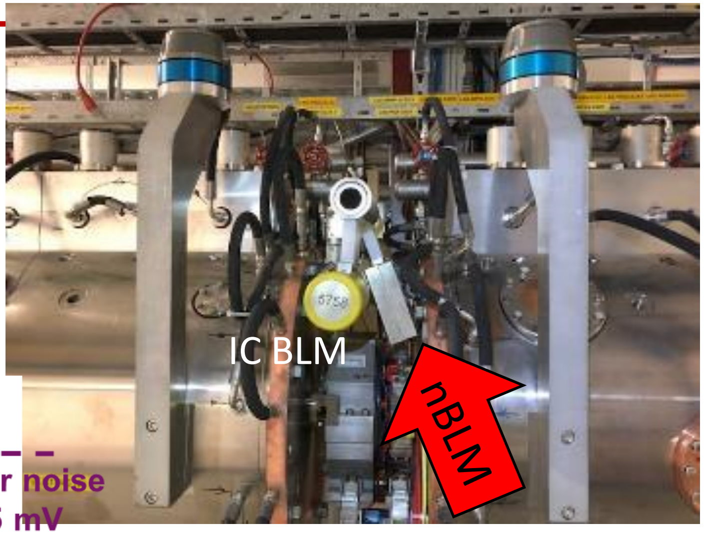


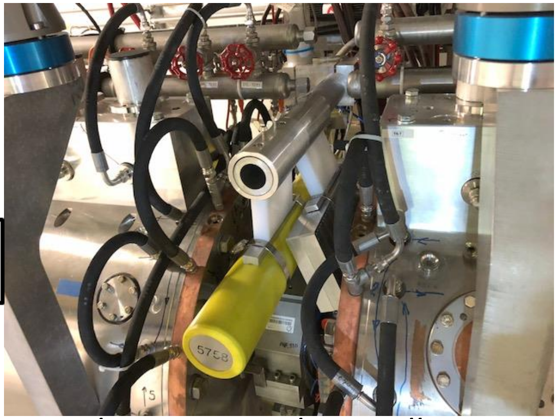
Proof of concept in LINAC operation: LINAC4

- Test one fast module at **LINAC4, CERN**
- Placed between two DTLs at ~13 MeV
- Controlled beam losses produced by the LINAC4 operation and commissioning team
- Data acquired with a fast oscilloscope, analysis offline



Normal operation



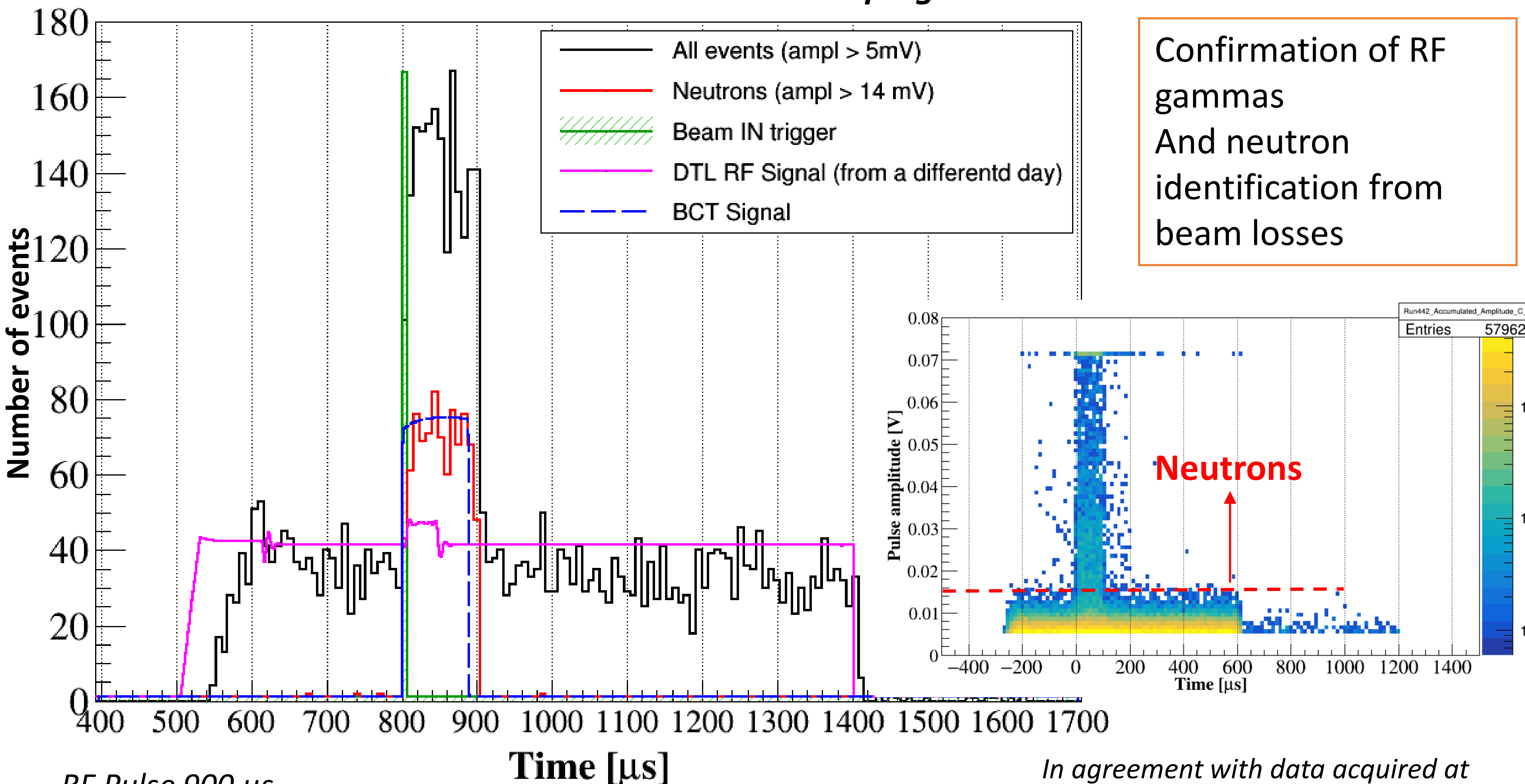


Special support to electrically isolate the module and to place it together a ICBLM

Many thanks to Jiri Krai, Joshua D. Shackleton, Bettina Mikulec, William Vigano and Christos Zamantzas

Proof of concept in LINAC operation: LINAC4

November 2019 Campaign



Confirmation of RF gammas
And neutron identification from beam losses

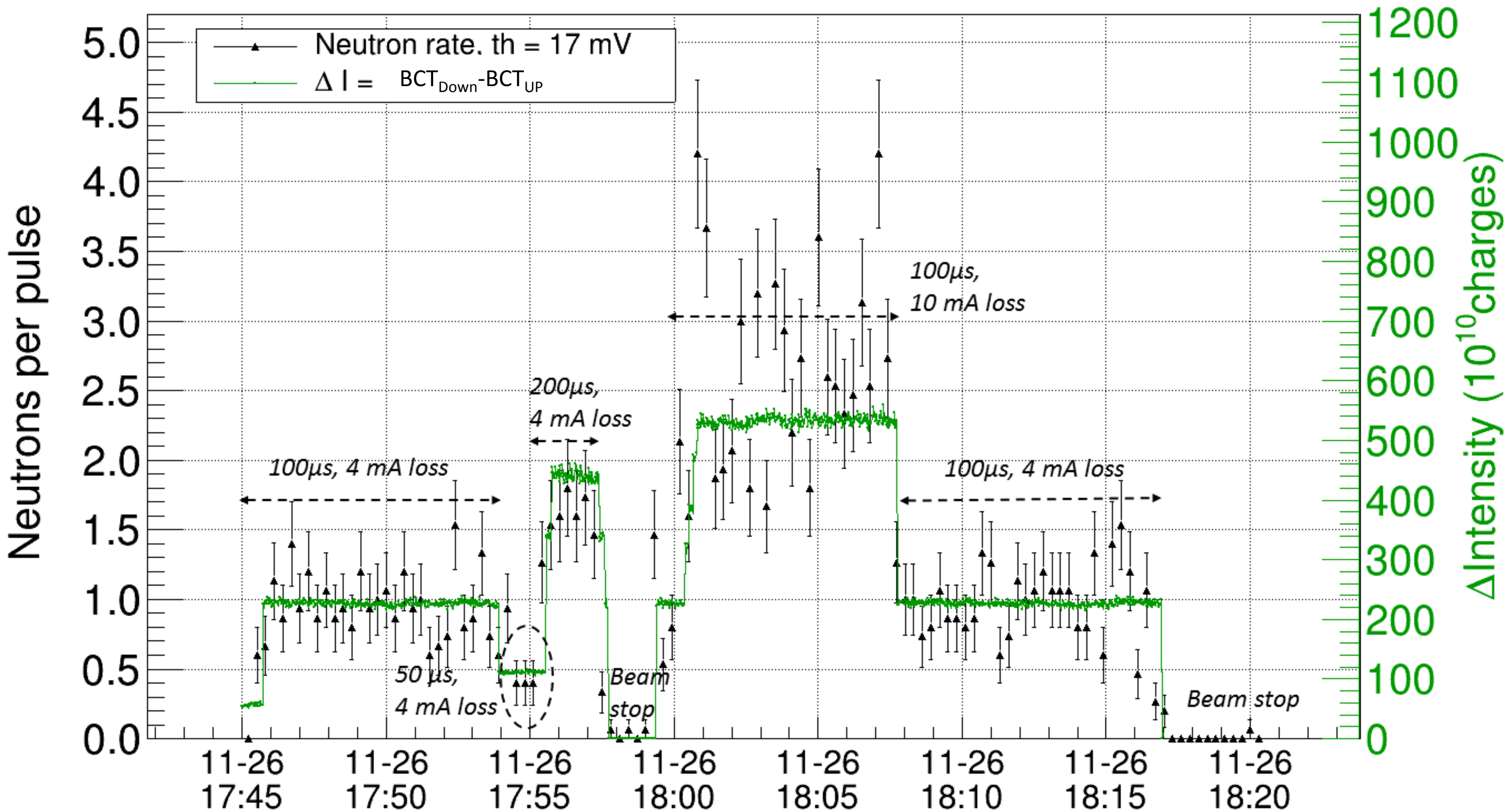
RF Pulse 900 µs
Beam Pulse 100 µs

In agreement with data acquired at same time with final daq
I. Dolenc-Kittelmann, MOPP022, IBIC'19
L. Segui, MOBO04, IBIC'19
Papers under submission

Proof of concept in LINAC operation: LINAC4

November 2019 Campaign

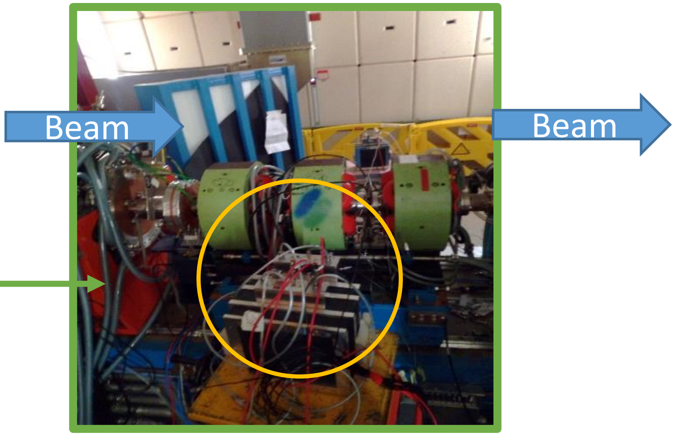
- Different **beam loss scenarios** produced→ different neutron rates
- The losses were generated by horizontal defocusing of the last quadrupole magnet in the MEBT
- Nothing detected in the ICBLM

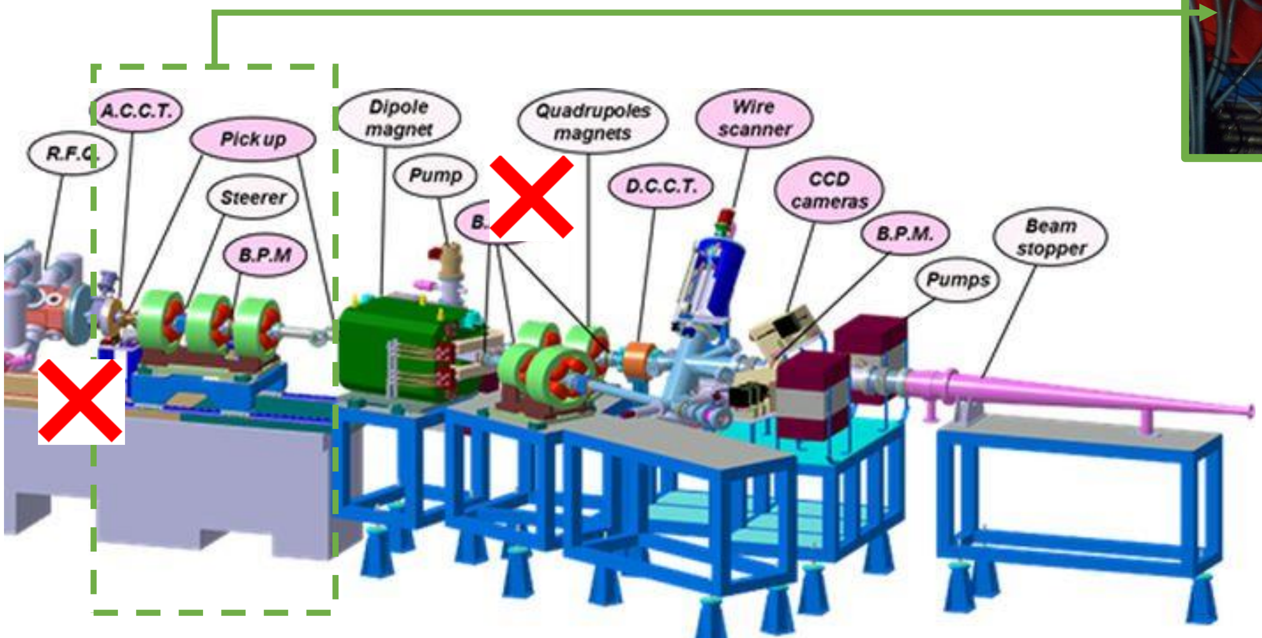


Proof of concept in LINAC operation: IPHI

IPHI (High-intensity proton injector):

- 3 MeV proton, 100 mA (nominal)
- Two slow detectors installed in different positions : after RFQ and another after dipole
- Gas He +3.5 % ethane at << 1l/h
- Helped to tune the accelerator to minimize the losses





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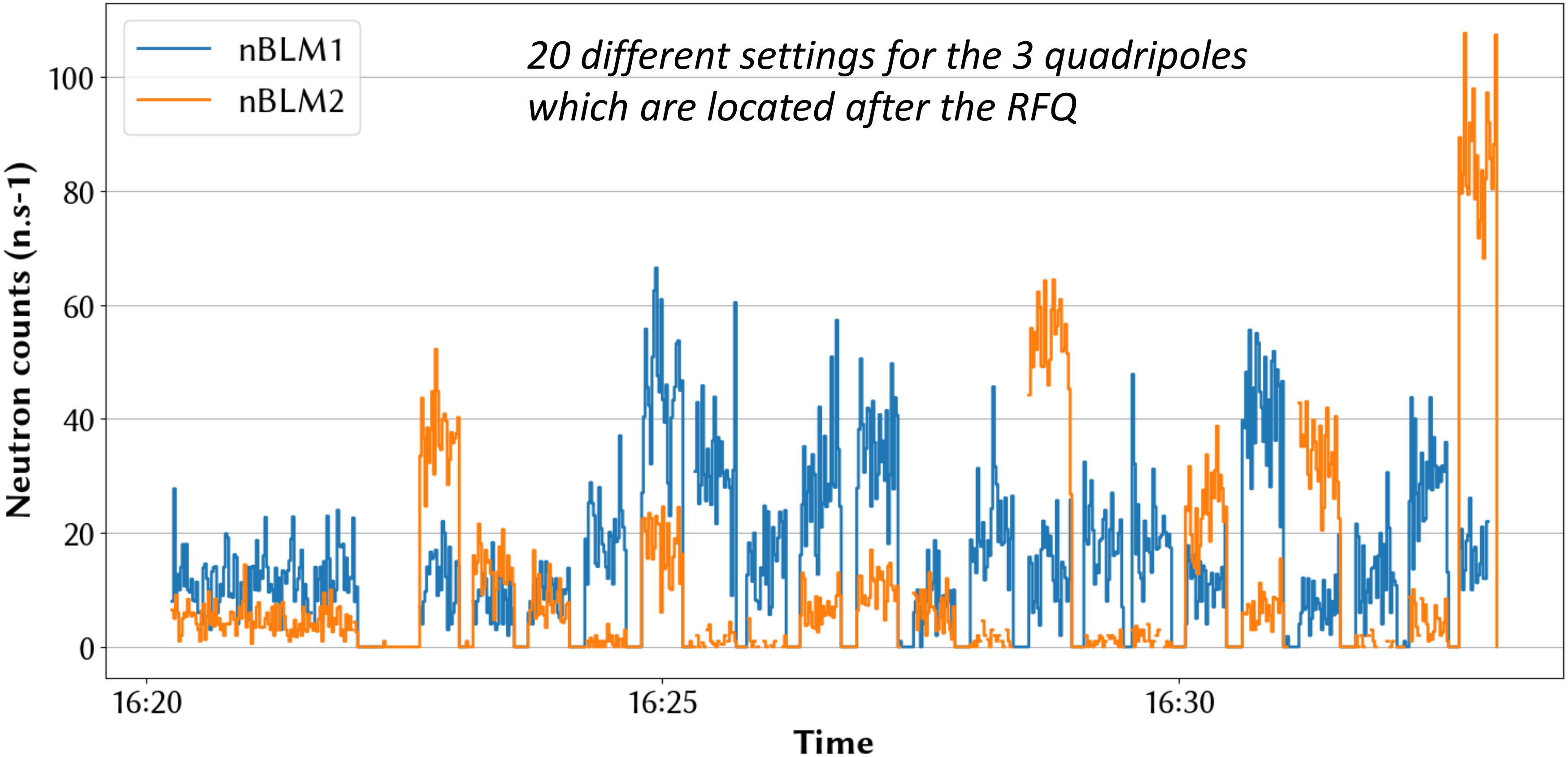
- 3 MeV proton, 100 mA (nominal)
- Two slow detectors installed in different positions : after RFQ and another after dipole
- Gas He +3.5 % ethane at << 1l/h
- Helped to tune the accelerator to minimize the losses. Operating at 35 mA and low duty cycle (~1%



Conclusions

- New beam loss monitor based on **Micromegas** detectors
- For low energy region of **hadron accelerators**
- Signal produced by **fast neutrons**, single events detected, operates in counting and charge mode
- Capable to **discriminate neutrons from x-rays event by event**
- Sensitivity to monitor small losses and to react in case of Fast losses
- Clearly **detect beam losses at LINAC 4**

THANK YOU!!

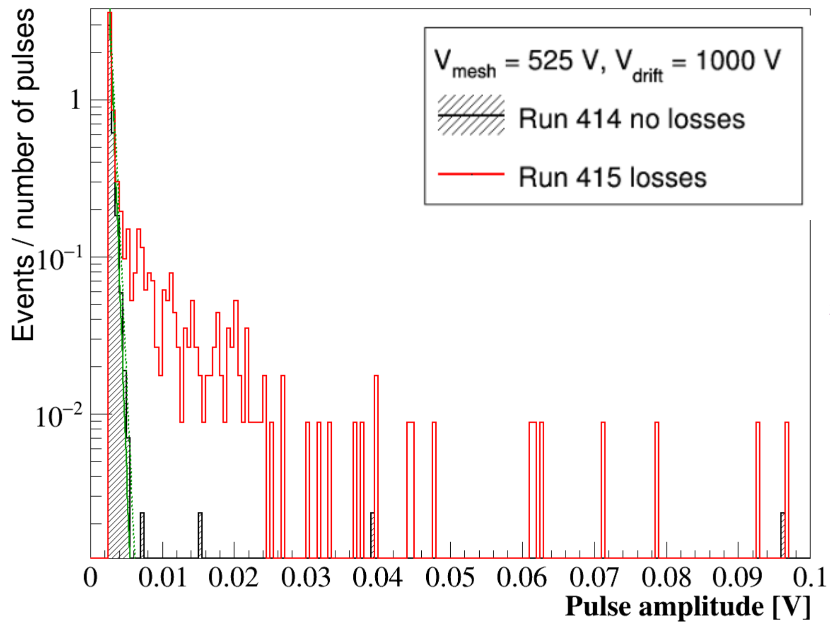
BACK-UP

LINAC4 data – Provoked losses

December 2018 Campaign

Vmesh = - 525 V
Vdrift = - 1000 V

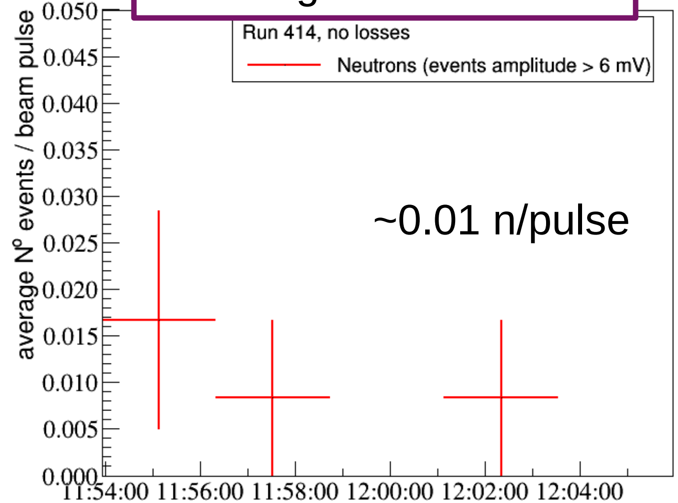
Amplitude



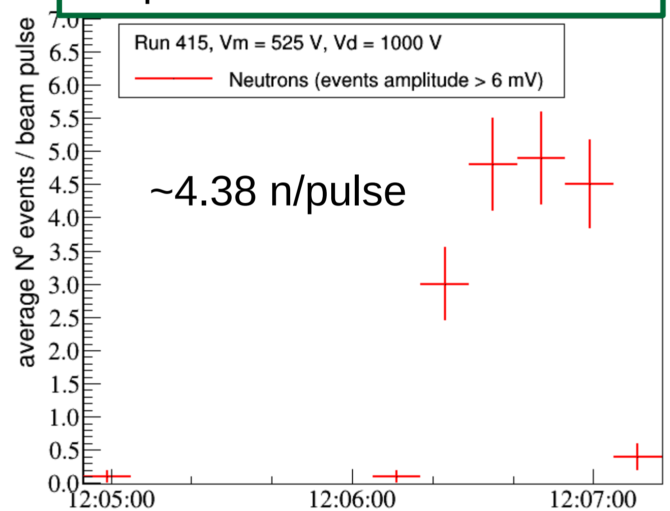
Run 414, No losses

Run 415 Losses

Average neutron rate



Applying Neutron selection:
Ampl Th = 6 mV



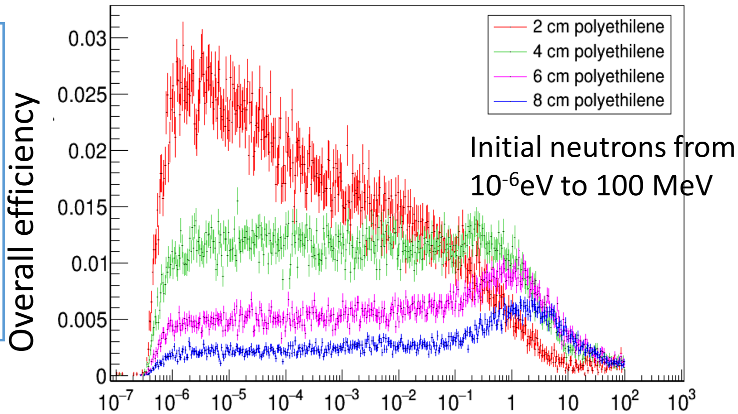
nBLM MONTECARLO STUDIES

Monte Carlo simulations to:

- **Optimize the detectors geometry**
- **Study the expected Response**

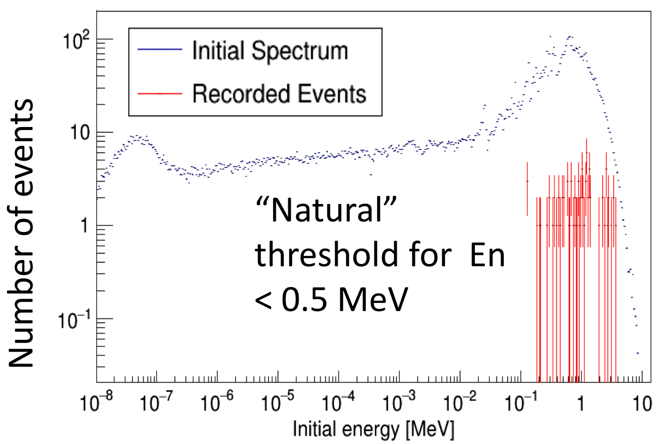
Efficiency

SLOW

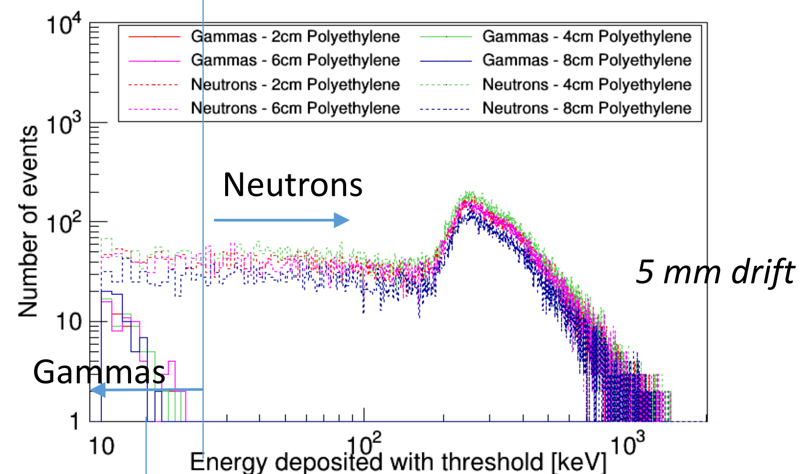


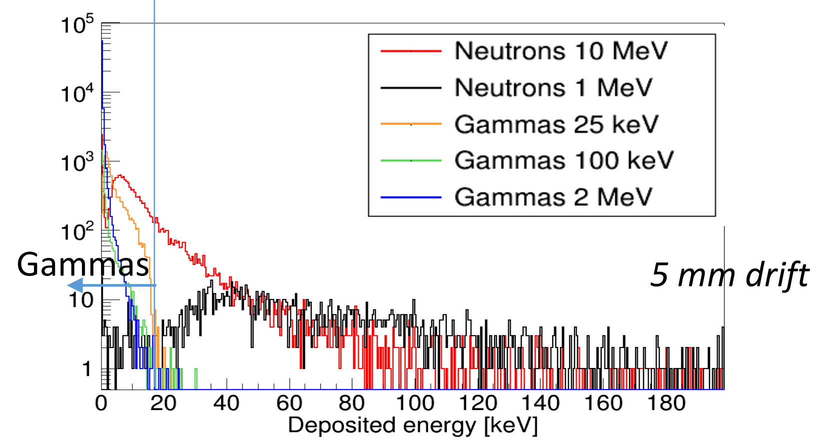
Initial neutron energy (MeV)

FAST



Gammas and neutrons response



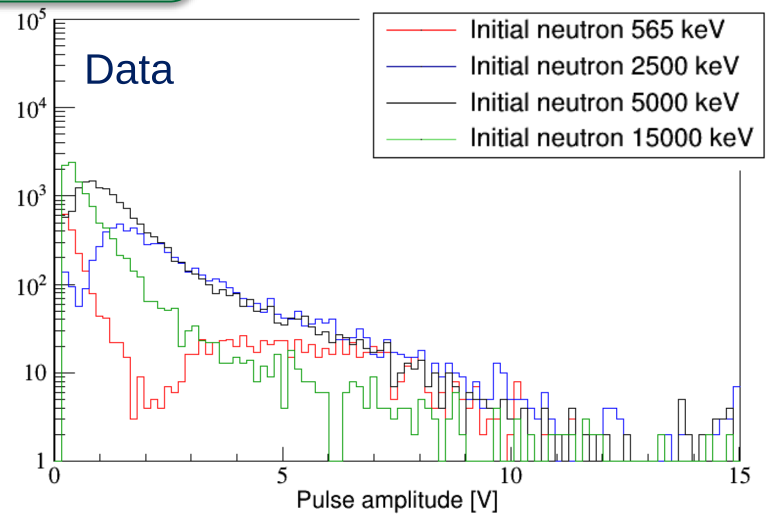


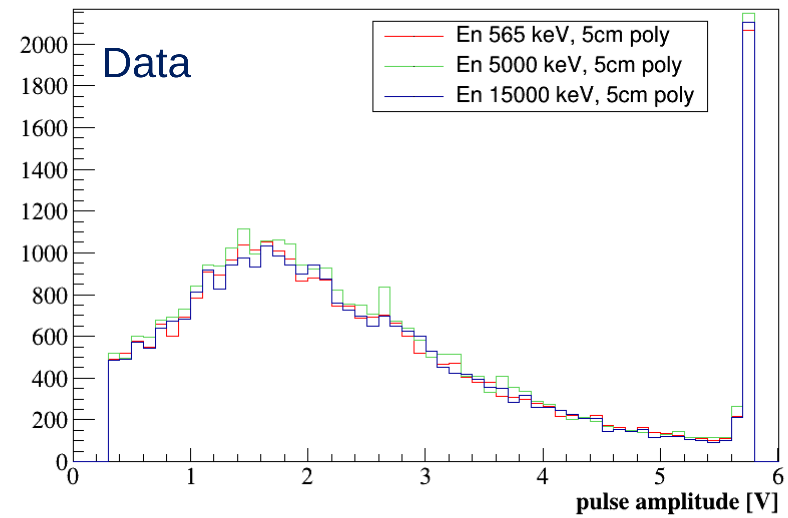
nBLM – Energy Response – Monoenergetic Neutrons

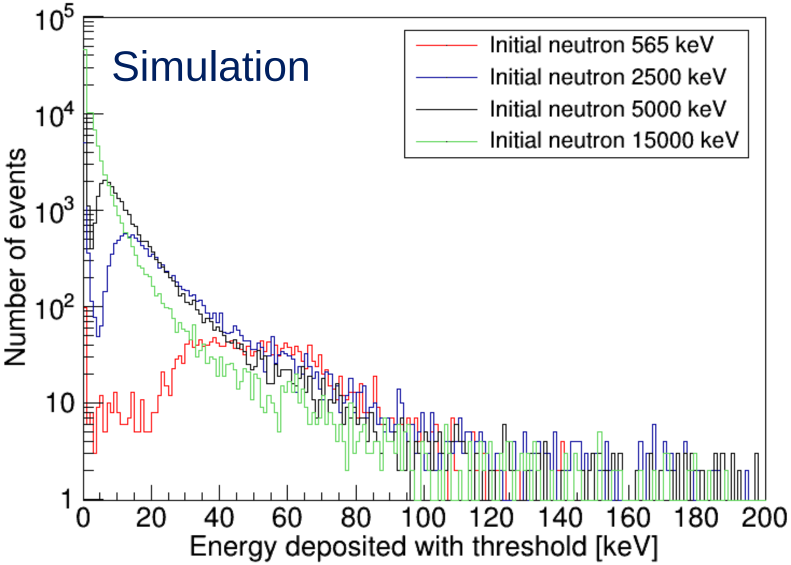
AMANDE (IRSN) monoenergetic neutron facility

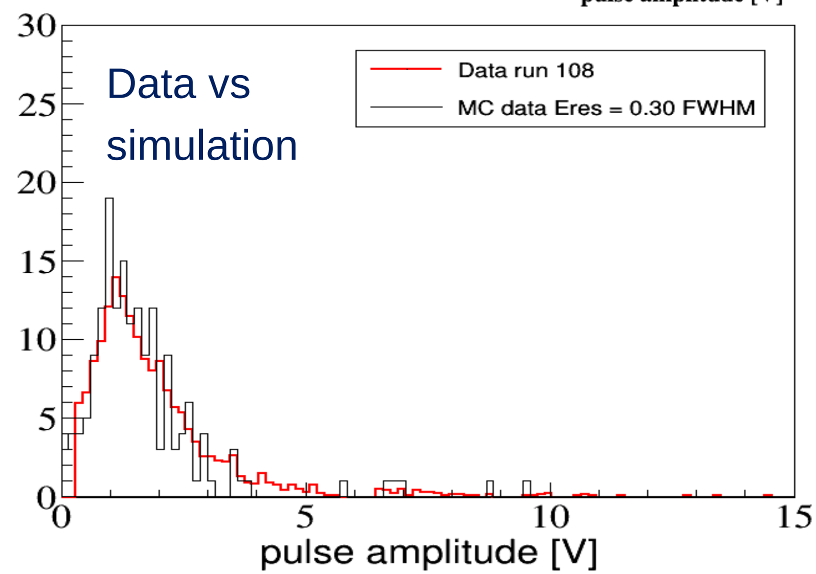
FAST

SLOW





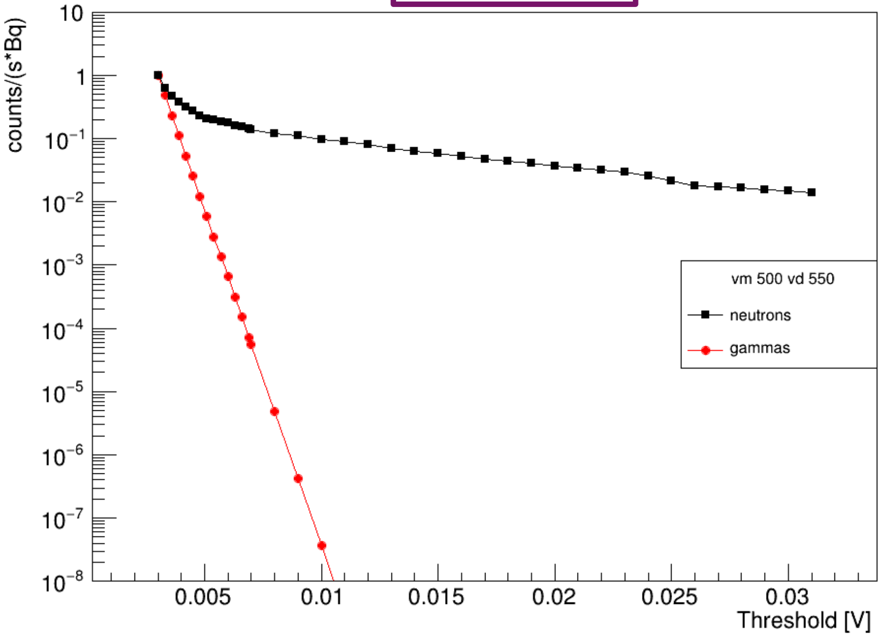




Neutron/Gamma Discrimination

- In the case of the fast the discrimination is strongly dependent on the energy threshold
- A relative efficiency is computed for a range of energy thresholds

FAST



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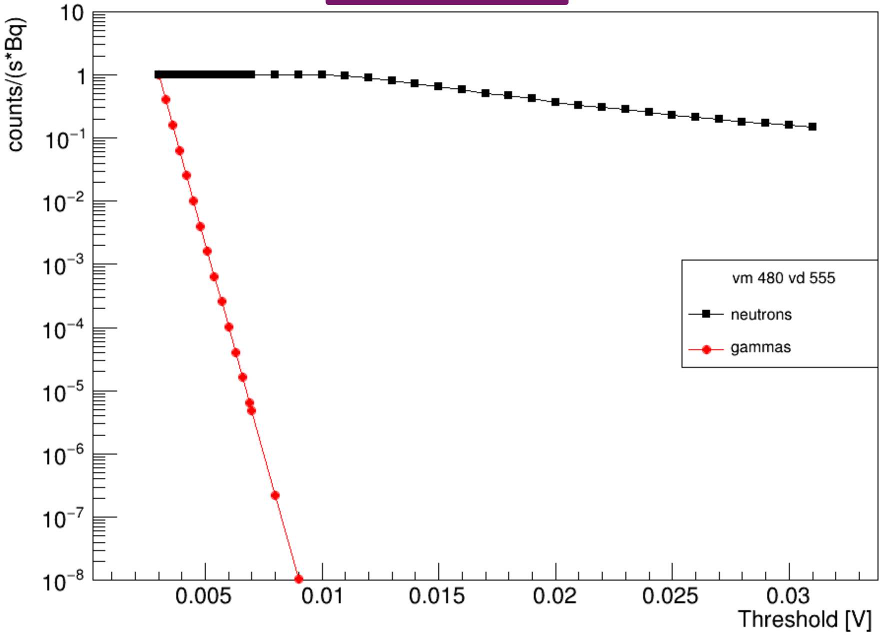
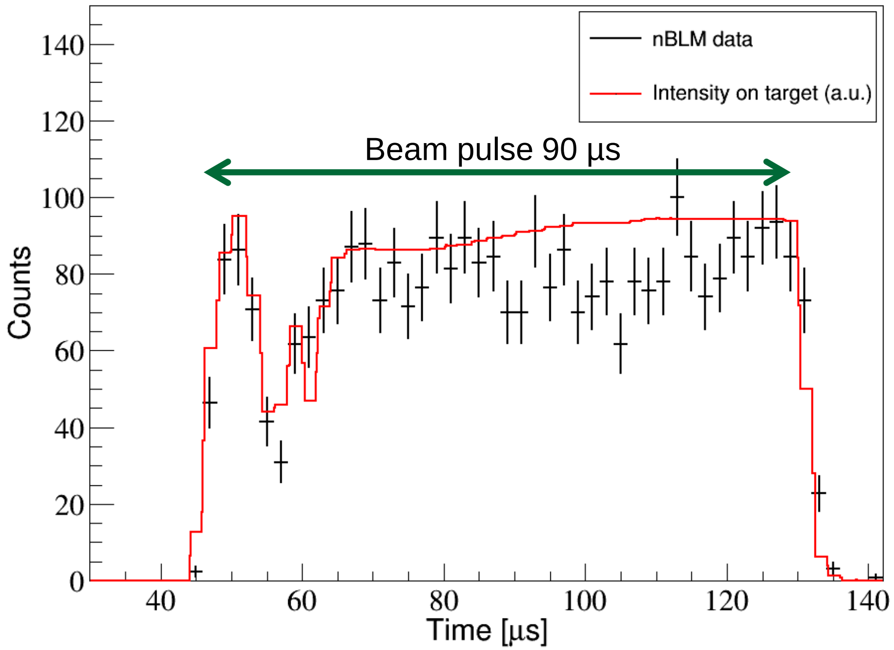


nBLM Time Response

IPHI 3MeV p beam
n produced with
Be target

FAST



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

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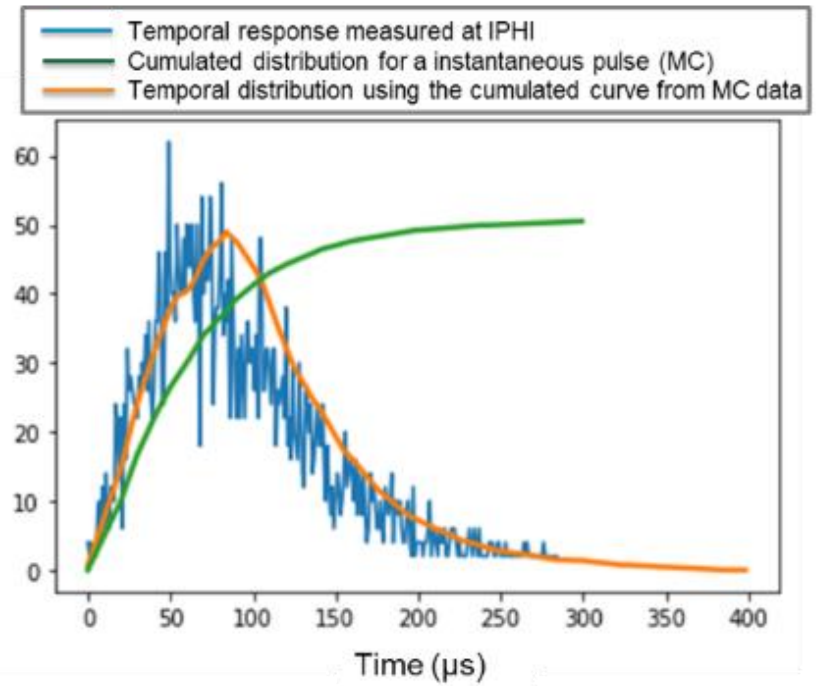
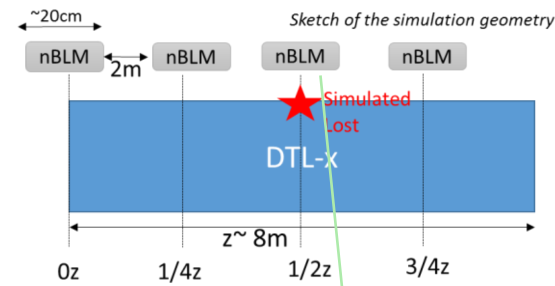


- Delay in signal: Convolution of moderation in polyethylene + proton beam pulse duration (90 µs)
- ~ 100 µs from simulations for a instantaneous pulse

MONTECARLO SIMULATIONS

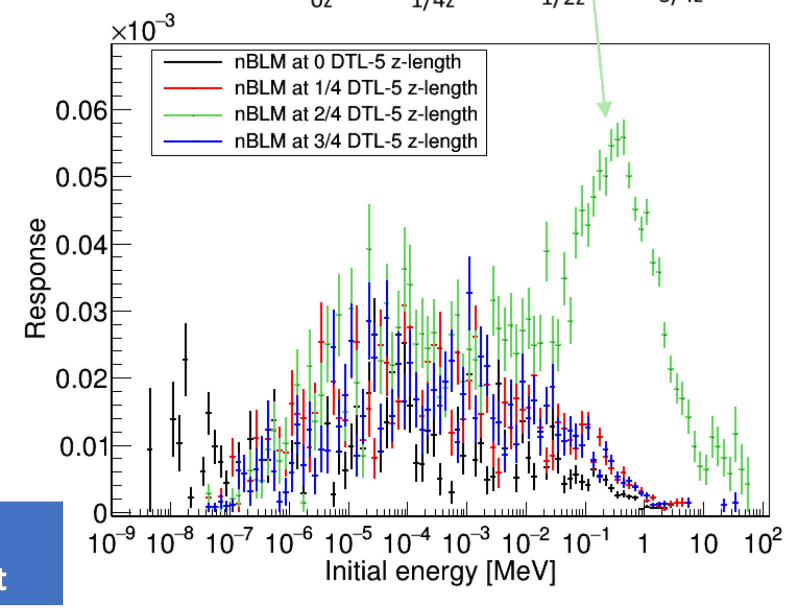
Monte Carlo simulations have been carried out in order to:

- **Estimate the expected response in normal conditions and in the case of beam losses simulated both by ESS-BI (I. Dolenc-Kittlemann)**

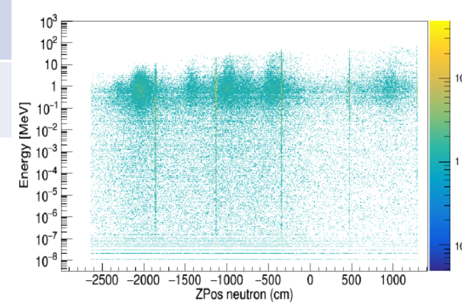


➢ Determine the distribution of detectors
  - Capability of the system to determine the position of the loss

➢ Preliminary estimation of the expected rates under different conditions.
  - Pile-up may be expected in case of fast big losses → system designed to transit from counting mode to current mode



Proton energy	Response for the required sensitivity to 0.01 W/m loss	Expected response "dramatic" accident
5 MeV	1.02 ± 0.03 kHz	54 counts in 1 µs
90 MeV	0.22 ± 0.01 kHz	7500 counts in 1 µs



Expected response obtained by MC simulations with Geant4 in the slow module

Gammas and neutrons with fast module
He+~5% Ethane