IRRAD diode measurements with protons and heavy ions

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Special thanks to Federico, Giuseppe and Matthew.

SY-STI-BMI - R2E Project

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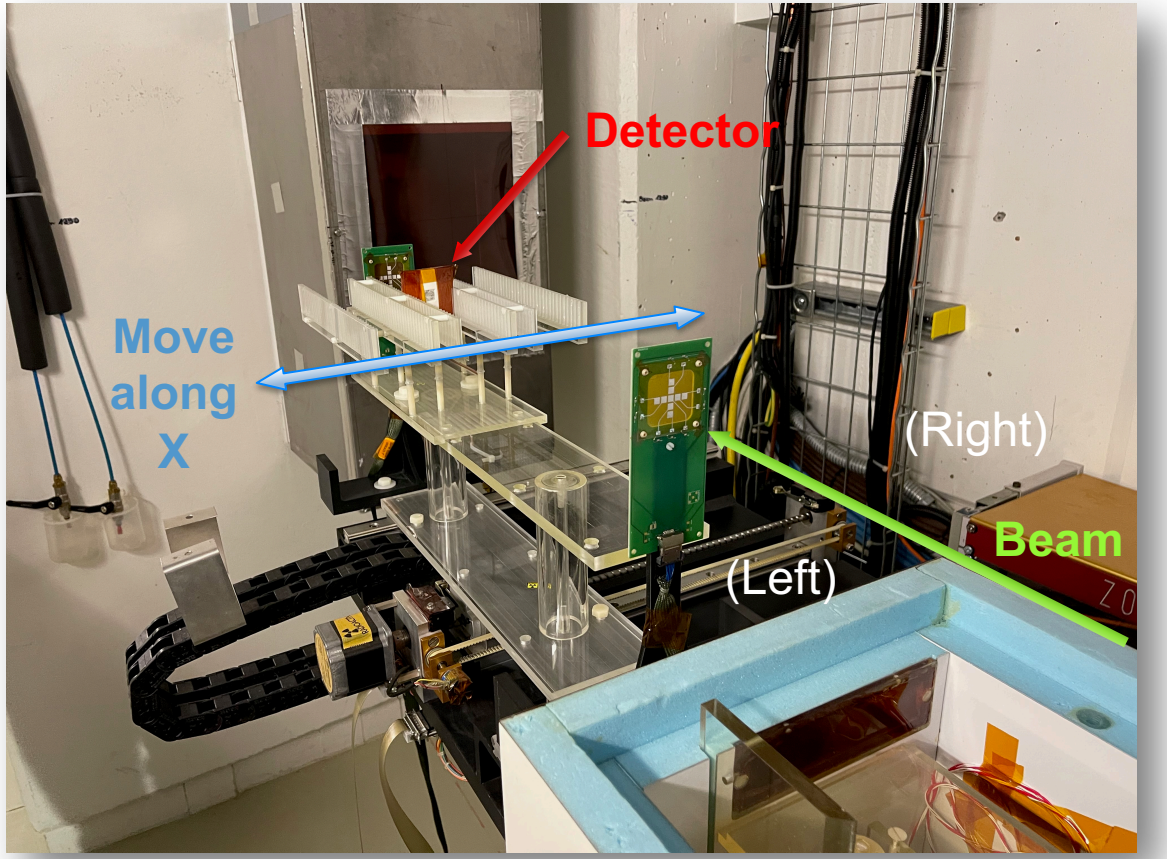
TEST CAMPAIGN OVERVIEW

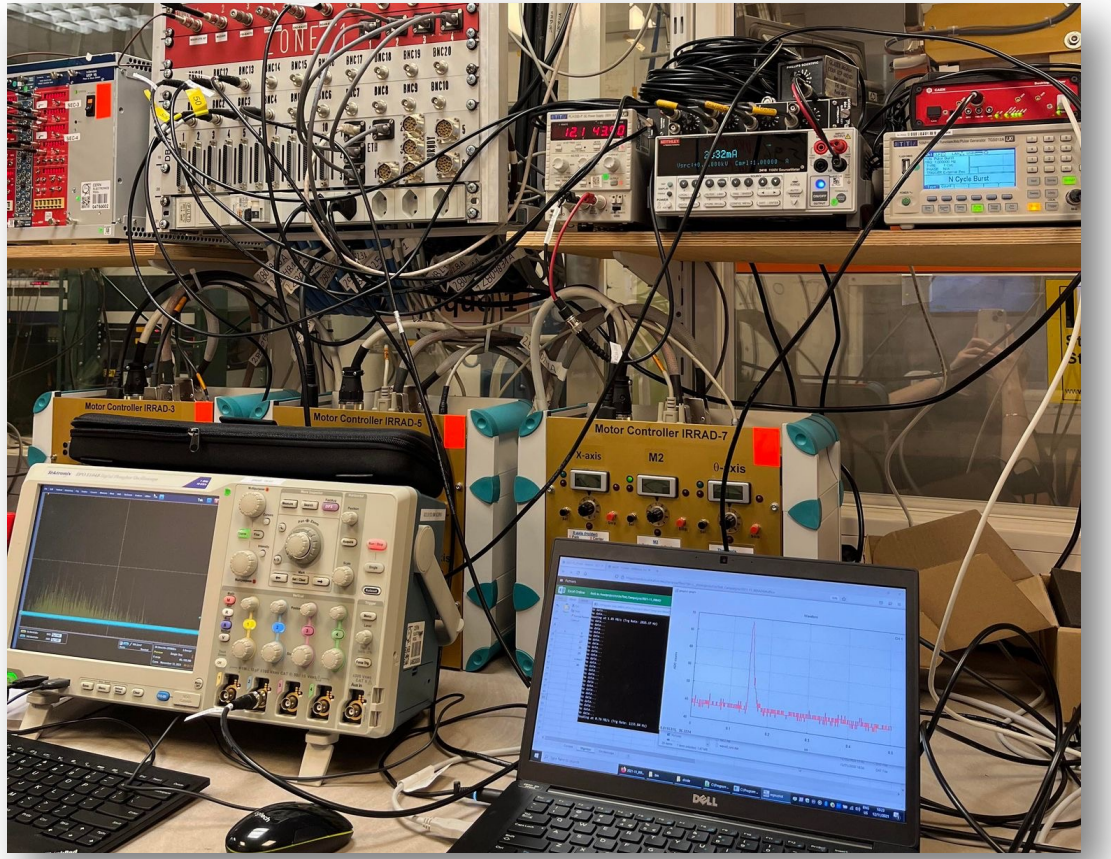
- Where: IRRAD @ CERN
- When: November 3rd – 14th, 2021
- Detector: Silicon diode
- Particles:
  - 24 GeV protons
  - 5 GeV/n Pb^{82+} ions
- Objectives:
  - Time structure of the proton beam
  - Heavy ions on T8 for CHIMERA

TEST SETUP

Experimental area (zone1)



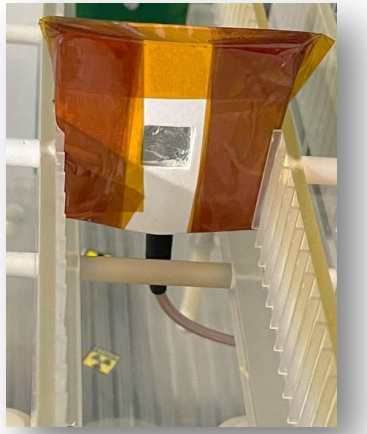
IRRAD Control room



TEST SETUP: FRONT-END

DETECTOR

- Model: Canberra FD 50-14-300 RM
- Active area: 50 mm^2
- Thickness: 300 µm
- Bias voltage: + 110 V
- Leakage current: 14 – 28 µA
- **P-in-N diode, shielded with 30 µm of Aluminium.**

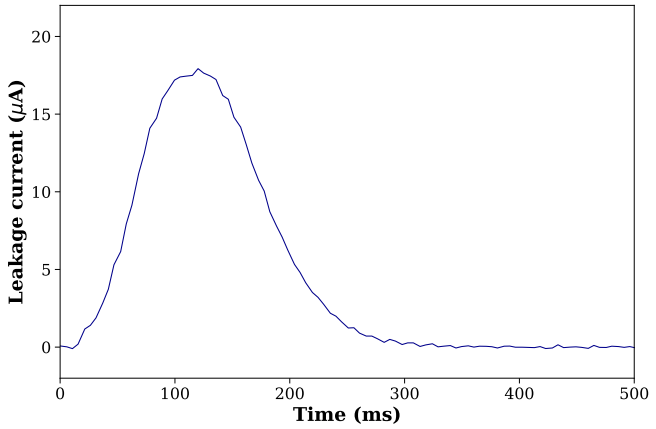


PREAMPLIFIER

- Model: Cividec C1HV0089
- Certified gain: 21.9 dB
- Bandwidth: 1 MHz – 2 GHz
- Output saturation: > 1 V
- Output impedance: 50 Ω
- AC coupled, bipolar, non-inverting.
- **Needed to bias & readout the diode.**

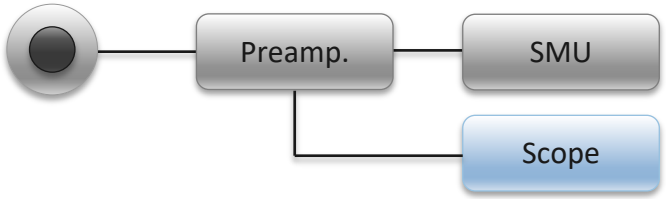
TEST SETUP: ACQUISITION MODES

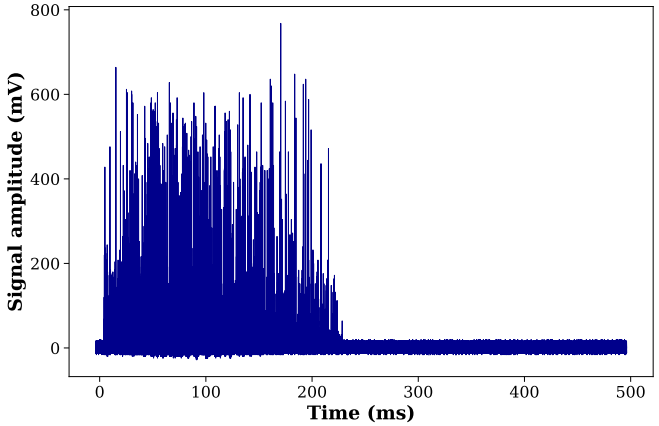
1. SMU CURRENT



- Continuous acquisition
- One or several consecutive spills
- Sampling frequency: **200 Hz**

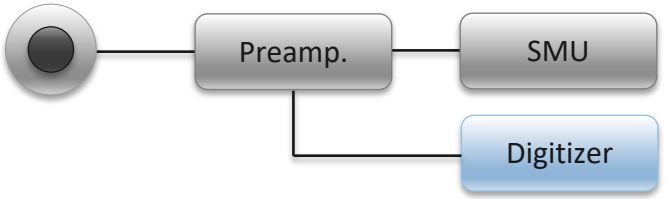
2. OSCILLOSCOPE

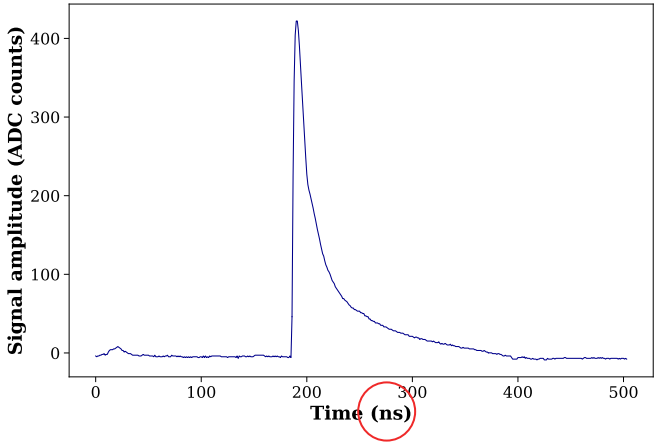




- IRRAD trigger on spill start
- One full spill per run
- Sampling frequency: **500 MHz**

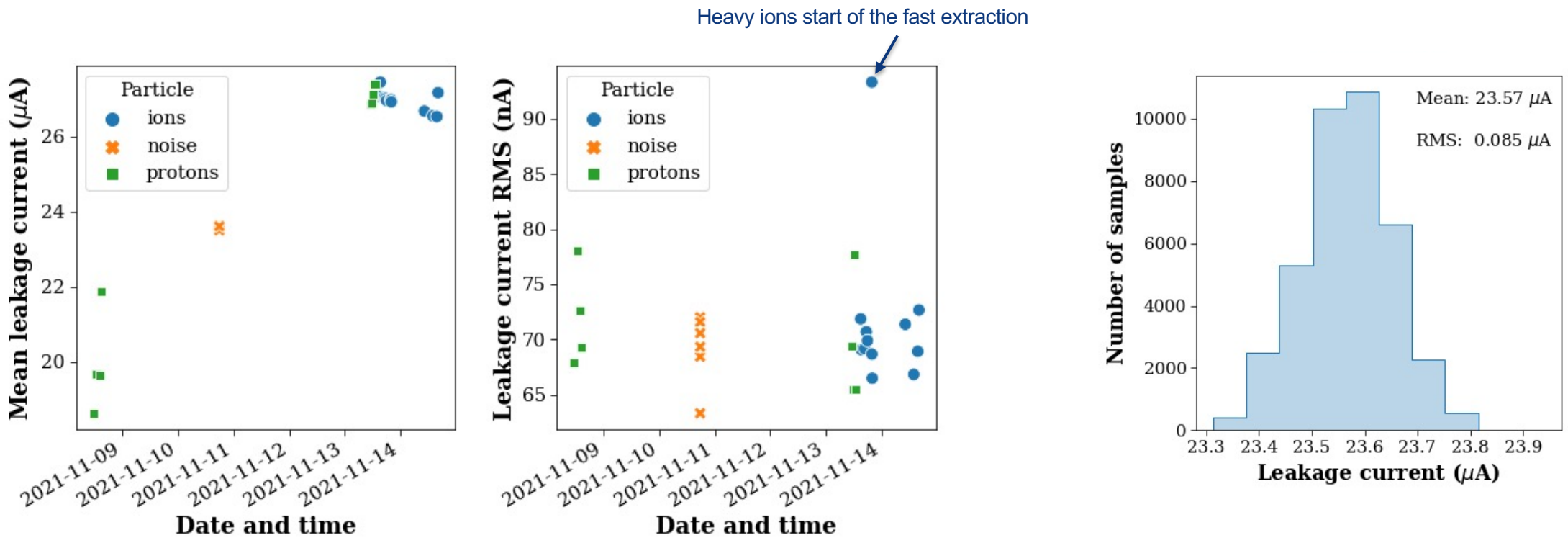
3. DIGITIZER (ADC)





- Self trigger
- Single events (500 ns frames)
- Sampling frequency: **1 GHz**

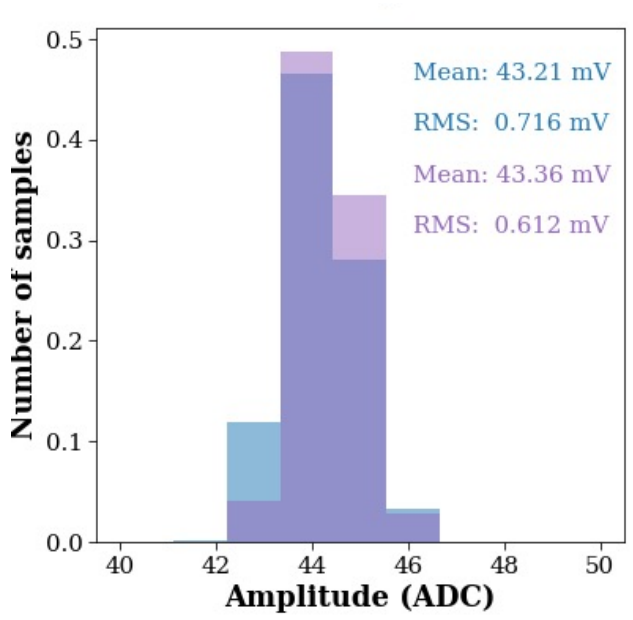
NOISE: DIODE



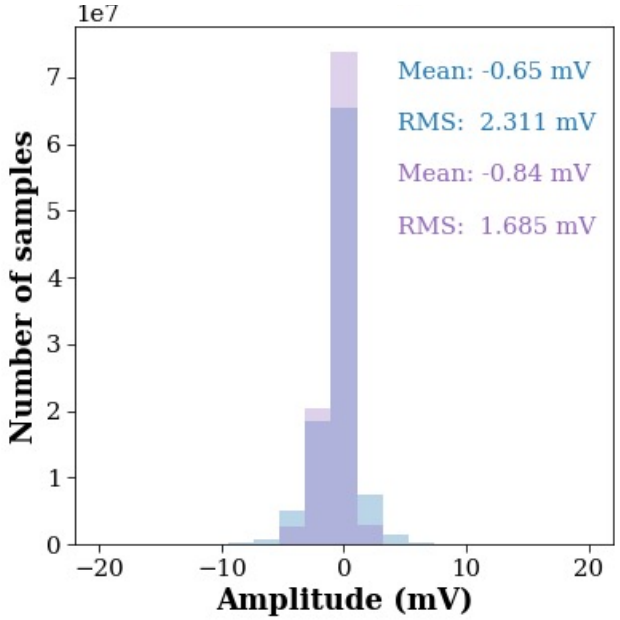
- Leakage current increases over time due to radiation damage (14 µA before the test - 28 µA after).
- Leakage current dispersion remains constant ⟶ RMS noise independent of the incoming radiation
- Noise of the diode measured over ~ 4 min without beam: **0.085 µA**

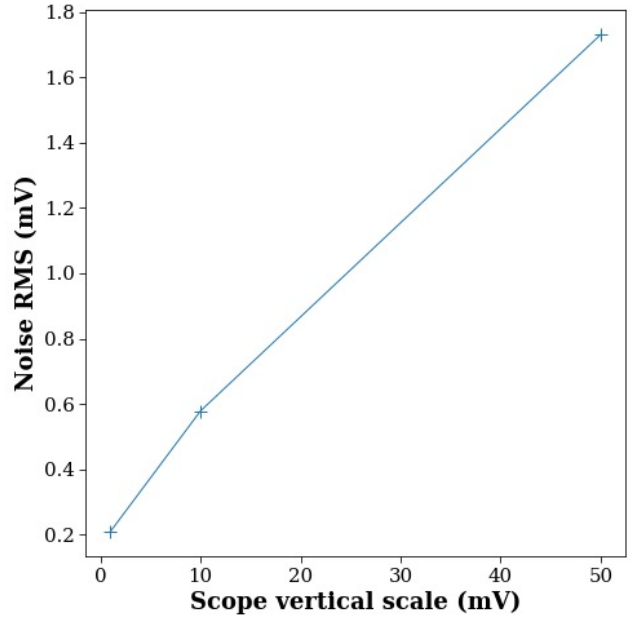
NOISE: REST OF THE SETUP

DIGITIZER NOISE



SCOPE NOISE

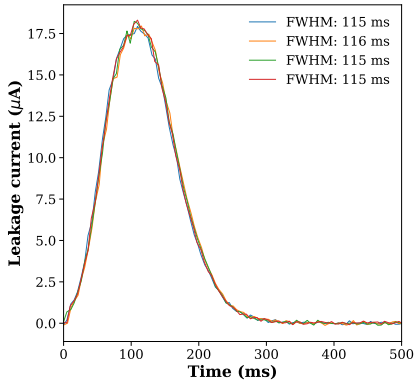




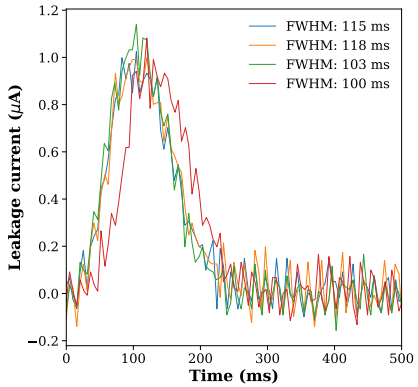
- Noise of the preamplifier (from data sheet): 0.46 µA ⟶ order of magnitude higher than the diode
- Noise of the overall setup is very low (± 2 ADC counts)
- Determined by the vertical ADC resolution (fixed for the digitizer and selectable for the scope)

SMU: DIODE AS SPILL MONITOR

4 cm

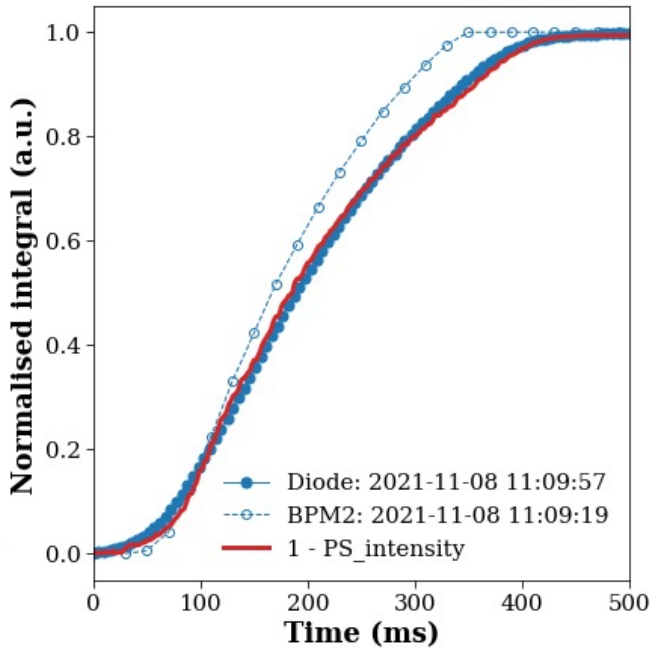


10.5 cm

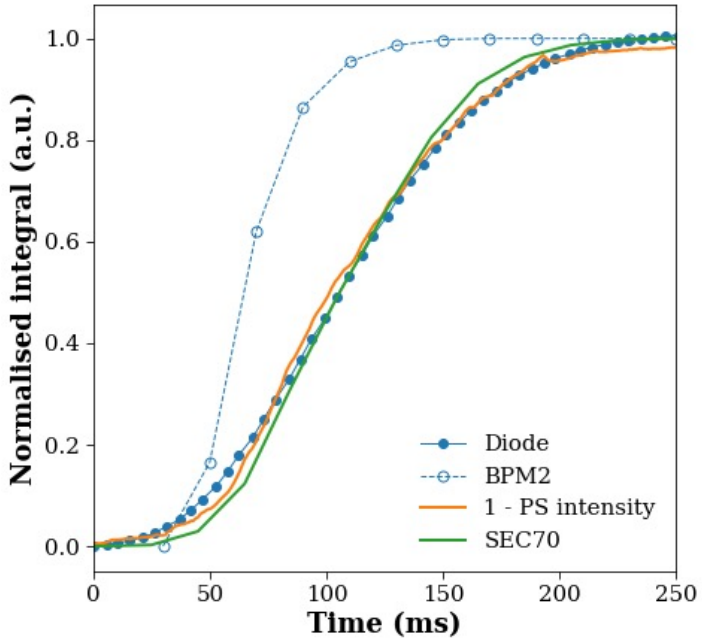


Integral

Protons



Heavy ions

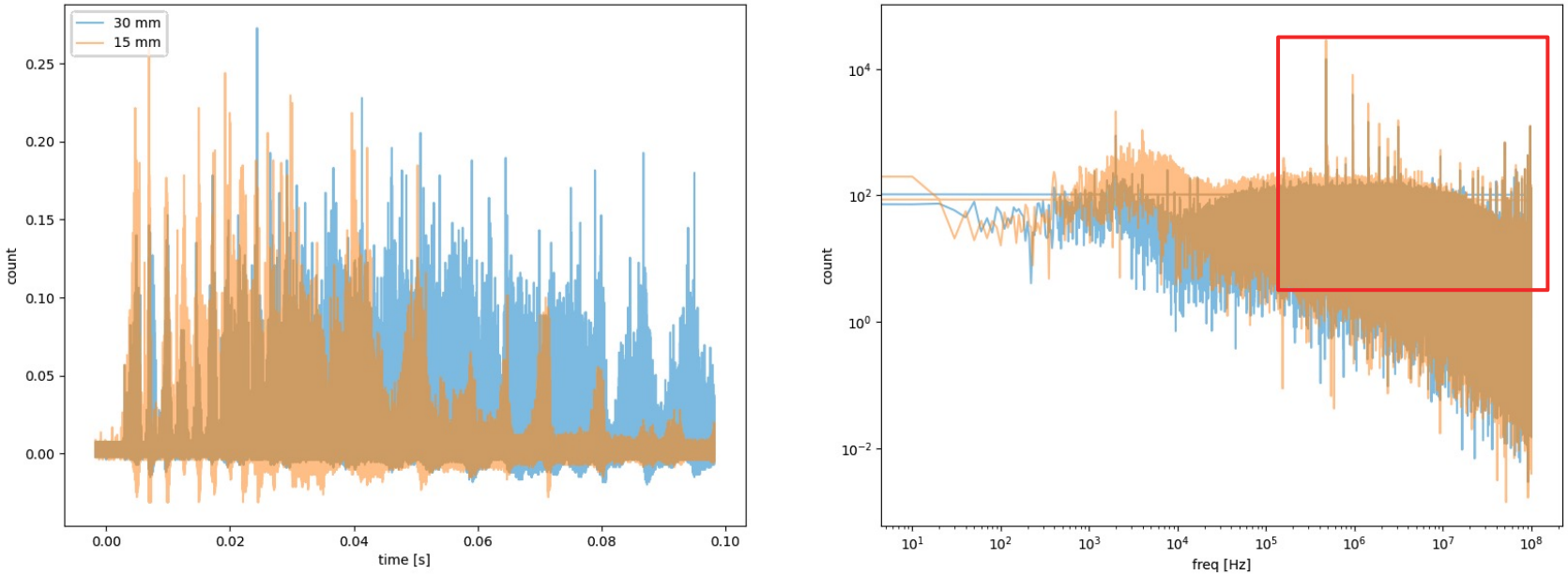


- SMU current ⟶ time profile of the spill sampled at 200 Hz.
- Distance of the diode from the beam center has no influence of the spill shape, only on signal amplitude.
- **Integrated diode signal shows a good agreement with other instruments for protons and heavy ions.**

SCOPE: TIME STRUCTURE OF THE BEAM

TIME DOMAINE

FREQUENCY DOMAINE

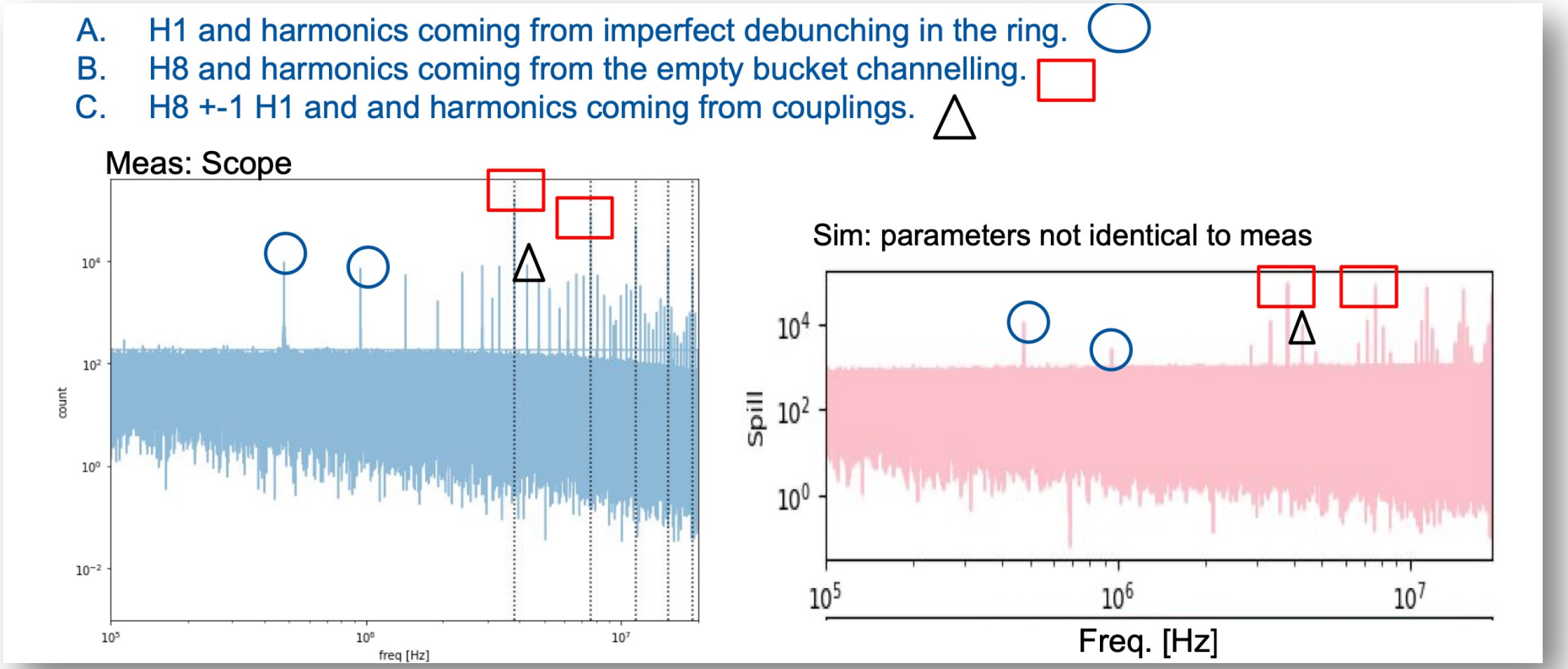


Courtesy: Pablo Andreas Arrutia Sota (https://indico.cern.ch/event/1099820/)

- Spills measured at different distances from the beam center look different in time domain.
- Slight differences observed in frequency domain, but the revolution harmonics are present in both.

⟶ **Distance of the diode from the beam has only a small impact on the frequency spectrum in the MHz range.**

SCOPE: EMPTY BUCKET CHANNELING

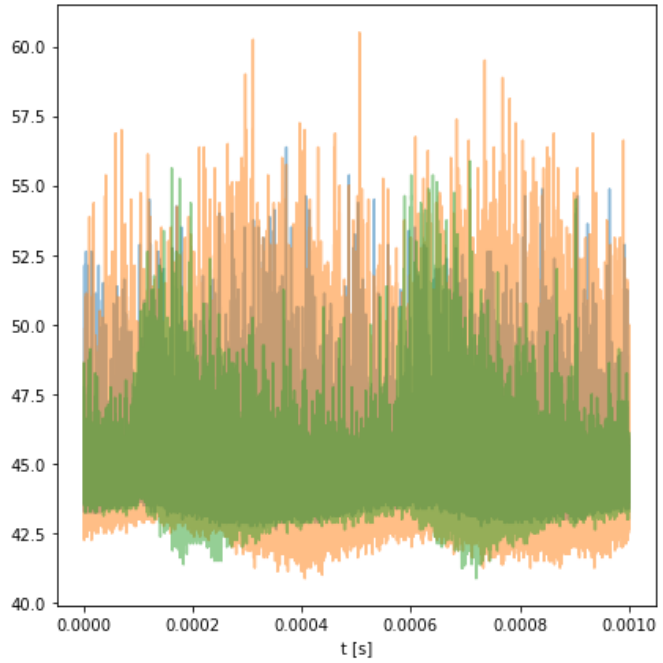


Courtesy: Pablo Andreas Arrutia Sota (https://indico.cern.ch/event/1099820/ & https://indico.cern.ch/event/1089918/)

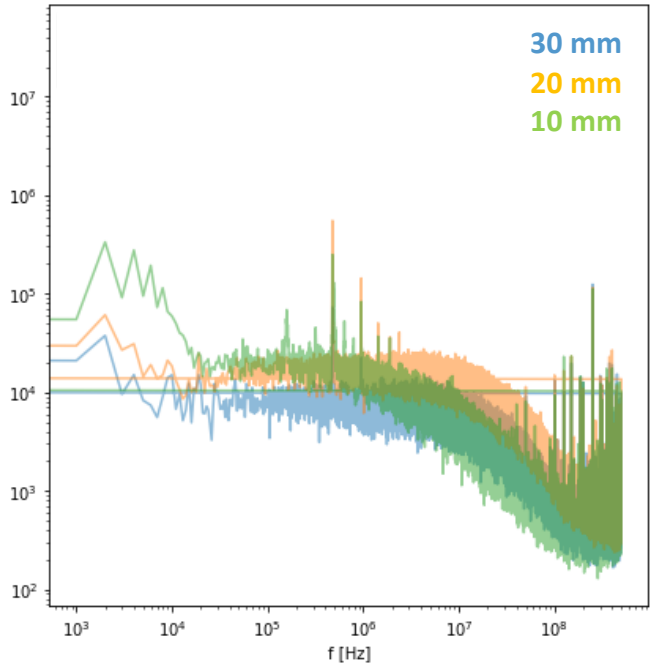
- Diode measurement of protons spills sampled at high frequency with the scope could be used as a **proof of concept for the empty bucket channeling with protons.**

DIGITIZER: TIME STRUCTURE OF THE BEAM

TIME DOMAINE



FREQUENCY DOMAINE

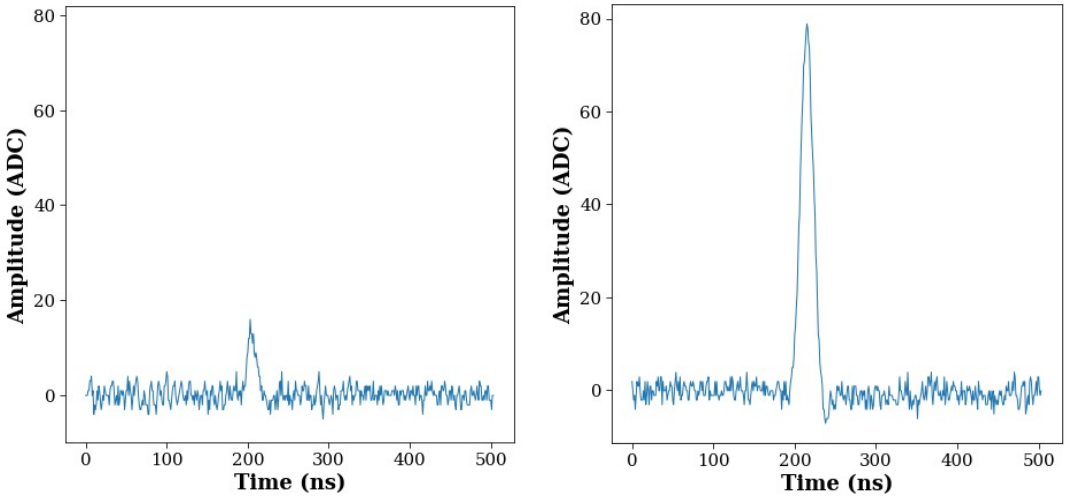


Courtesy: Pablo Andreas Arrutia Sota (https://indico.cern.ch/event/1099820/)

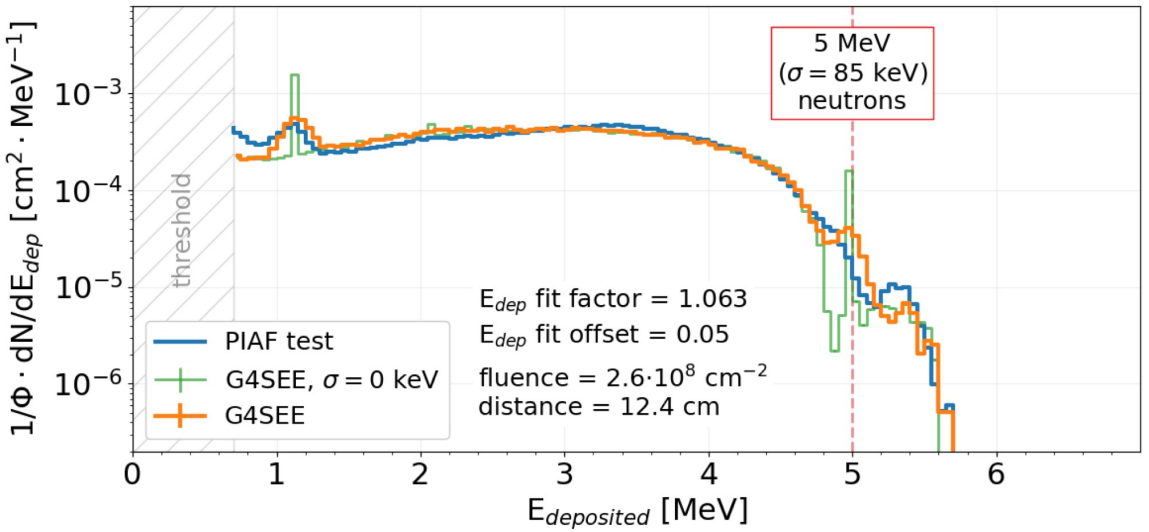
- Diode measurement of protons spills sampled at very high frequency with the digitizer confirms that the diode distance from the beam center has small impact on the high frequency component

DIGITIZER: A TYPICAL MEASUREMENT

EXAMPLE: SINGLE EVENT PULSES (NEUTRONS)



EXAMPLE: ENERGY SPECTRUM



- Diode read out at high frequency by the digitizer: typically used in spectroscopic applications
- One frame = one single event pulse
- Integral of the pulse ∝ deposited charge ∝ energy

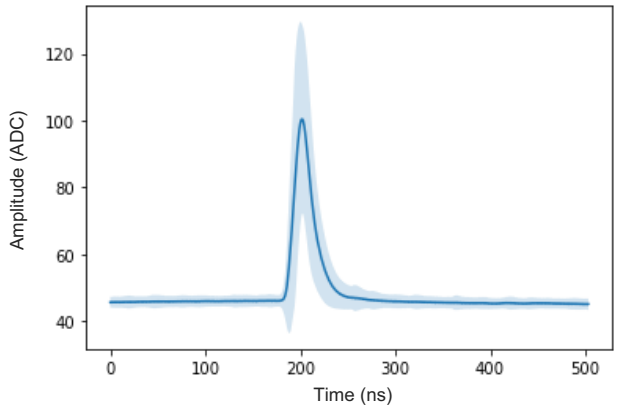
D. Lucsányi, R. G. Alía, K. Biłko, M. Cecchetto, S. Fiore and E. Pirovano, "G4SEE: a Geant4-based Single Event Effect simulation toolkit and its validation through monoenergetic neutron measurements," in *IEEE Transactions on Nuclear Science*, doi: 10.1109/TNS.2022.3149989, https://ieeexplore.ieee.org/document/9707797

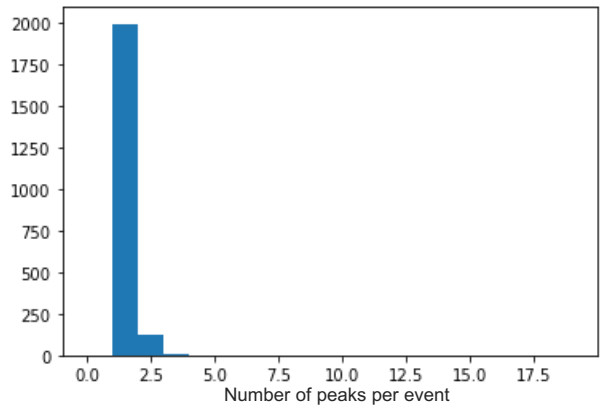
DIGITIZER: IRRAD HEAVY ION MEASUREMENT

High intensity - far from the beam

- Beam intensity: 5e10
- Position: 10.5 cm

98% of frames are single pulses

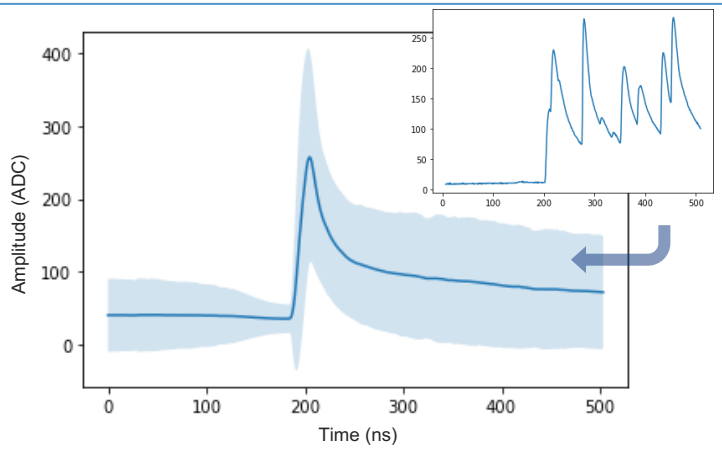


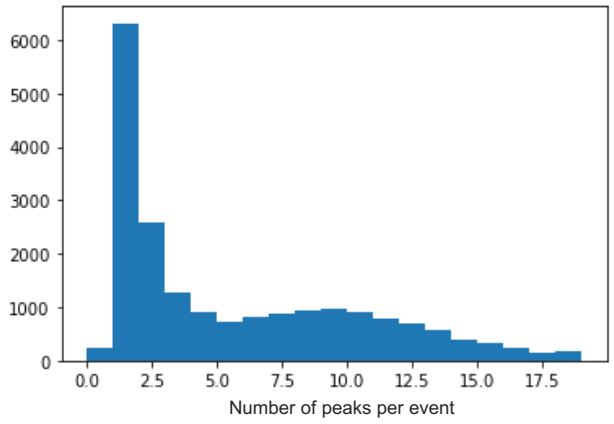


Low intensity - in the beam

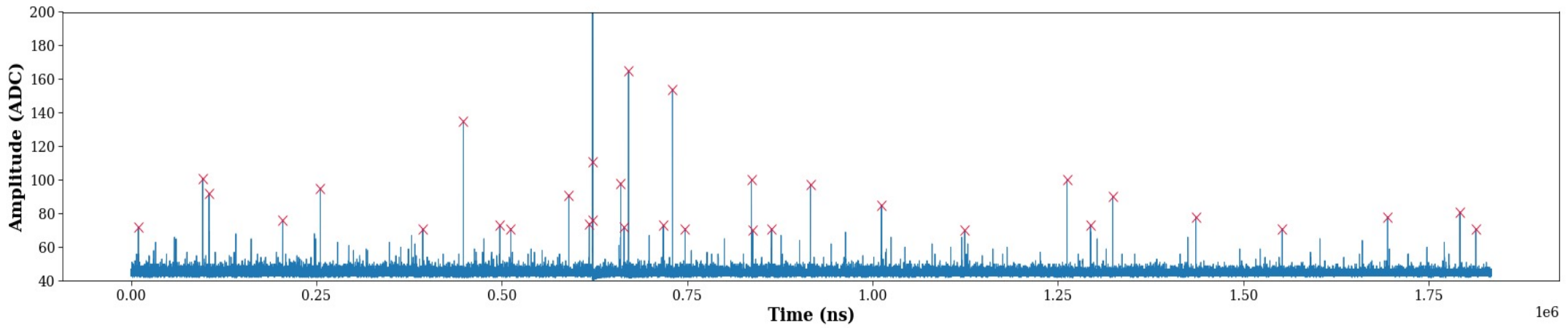
- Beam intensity: 1.6e10
- Position: 2.5 cm (actual center)

Only 33% of frames are single pulses
→ pileup

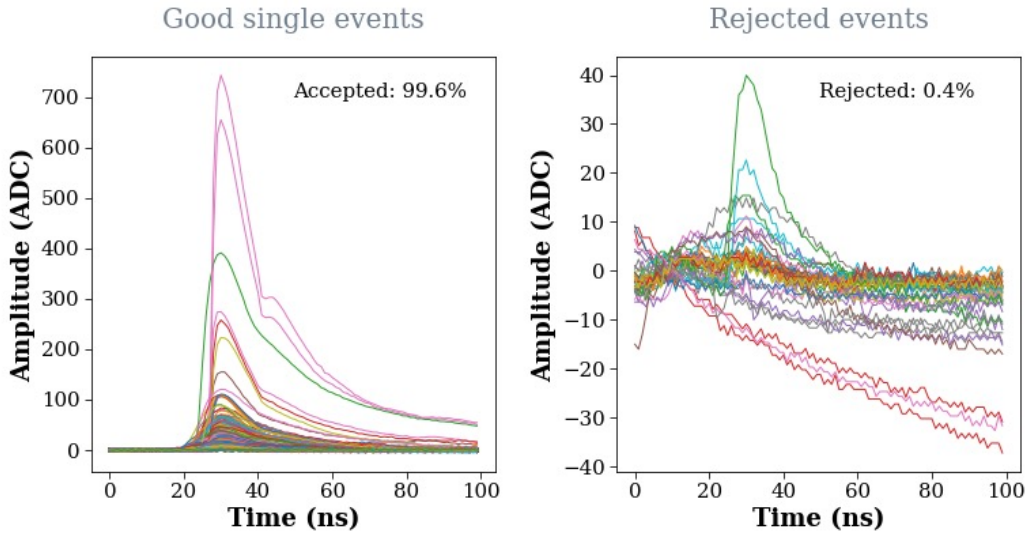




DIGITIZER: FROM LONG FRAMES TO ENERGY



- Heavy ions measurement with digitizer
- Finding peaks above a given threshold
- Cutting the long frame into short frames around the peak
- Select single peaks with a flat baseline
- Tricky and very threshold dependent analysis



SUMMARY & TAKE-HOME MESSAGES

- A simple diode setup was demonstrated to be a powerful tool allowing various types of measurements:
  - SMU current measurement:
    - Low frequency time profile of the spill
    - Showed a good agreement with existing instruments for both protons and heavy ions
    - Could be used for the CHIMERA project
  - Scope and digitizer measurements:
    - High frequancy time structure of the spill and the frequency spectrum
    - Proof of concept for the empty bucket channeling technique with protons
    - Single event measurement of the energy spectrum: complicated due to high intensity and pileup
- The distance of the diode from the beam centre has no big impact on the measurements.

Thank you for your attention!

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