N.T.U.A.
National Technical University of Athens

Diamond Detector Measurement at the NEAR Station of the n_TOF facility at CERN

Kalliopi Kaperoni, NTUA
Maria Diakaki, NTUA
Michael Bacak, CERN
Cristina Weiss, CIVIDEC Instrumentation
Erich Griesmayer, CIVIDEC Instrumentation

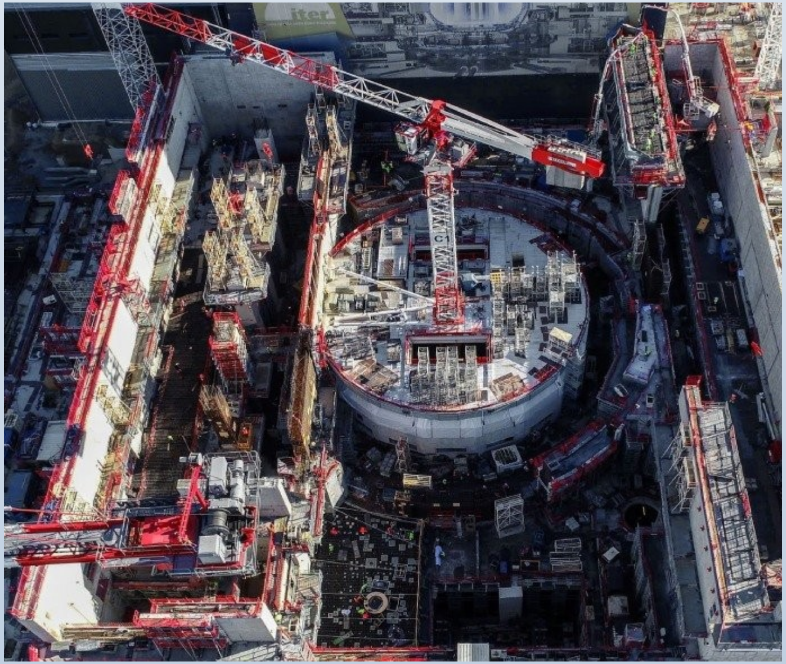
ARIEL Workshop January 2024

Contents of the Presentation

- Motivation
- Diamond Detector Characteristics, Neutron Detection
- Neutron Time of Flight Facility (n_TOF) at CERN
- EAR2 test (November 2022)
- NEAR test (April & October 2023)

Motivation

- Neutron Detection is always a challenge
  - High γ-ray contamination
  - Low efficiency of the detectors
  - Radiation damage
- Diamond detectors are widely used in radiation applications
- Exhibit promising characteristics for neutron detection
- Operational in harsh environmental conditions [1]
  - Space applications [2]
  - Neutron Detection in fusion (ITER) [3]
  - Etc.



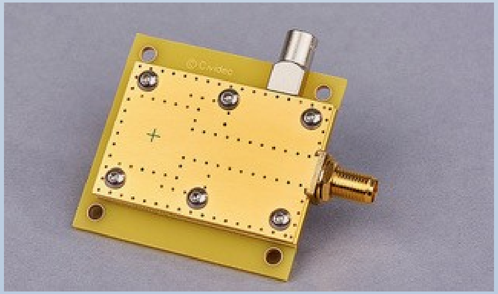
[1] M. Angelone and C. Verona, Review-Properties of Diamond-Based Neutron Detectors Operated in Harsh Environments, J. Nucl. Eng. 2021, 2, 422–470
[2] Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment Volume 514, Issues 1–3, 21 November 2003, Diamond detectors for space applications, E.Pace, A.De Sio
[3] V Krasilnikov, L Bertalot, R Barnsley, and M Walsh. Neutron detector needs for iter. Fusion Science and Technology, 71(2):196–200, 2017.

Goal: Development of a diamond detector system able to measure neutrons in harsh environmental conditions

Diamond Detector Characteristics

Diamond is one of the most popular materials for neutron detection

- High Band-gap Energy → **Low dark current**
- High thermal conductivity → **Easy cool**
- Low dielectric constant → **High energy resolution**
- High displacement energy, yield strength, chemical stability → **High irradiation resistance**
- Low Z → **Reduced γ-ray background**

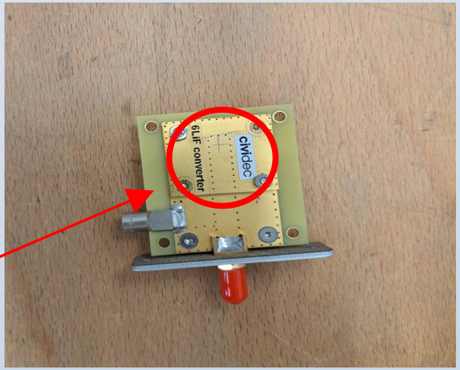


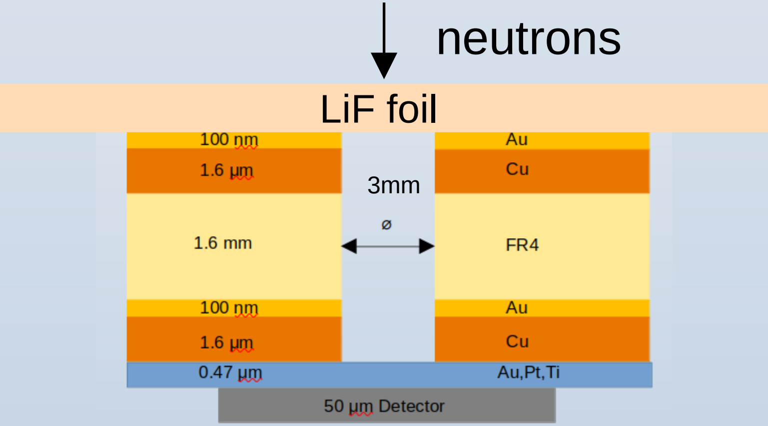
- Diamond sensor was **especially developed by CIVIDEC Instrumentation [1]**
- Single crystalline sensor fabricated via the CVD (Chemical Vapour Deposition) technology

[1] https://cividec.at/

Diamond Detector & Interactions

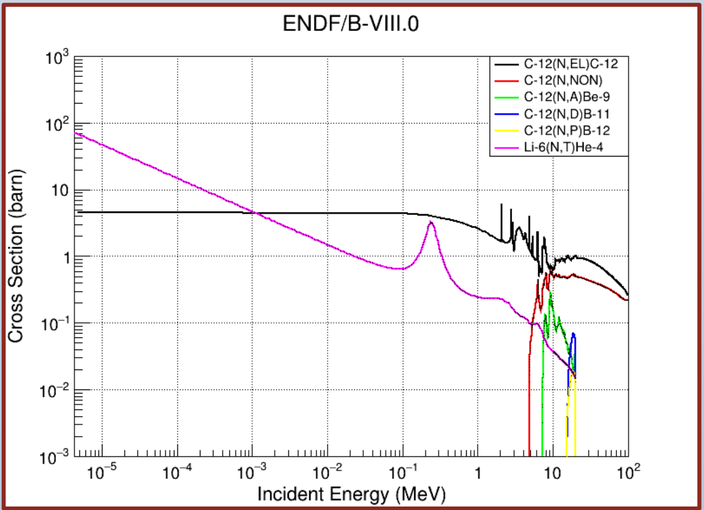
- Diamond Detector (sCVD):
  - Sensor: 4 mm x 4 mm x 50 um
  - Metallization Layers of Au, Cu, FR4 (PCB), Pt,Ti
  - LiF foil (converter)





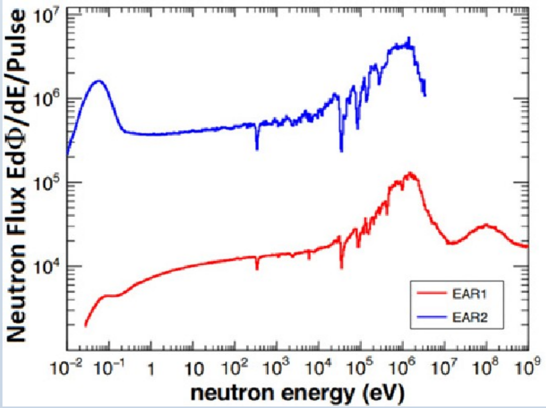
Neutron Detection:

- ^{12}C(n,el/inl) for <u>1 MeV < En < 6 MeV</u>
  → Recoil nucleus → Ionize the material
- $^{12,13}C$(n,x) for <u>En > 6 MeV</u>
  → Secondary charge particles → Ionize the material
- $^{6}Li(n,t)^{4}He$ for <u>En < 1 MeV</u>
  → Secondary charge particles → Ionize the material

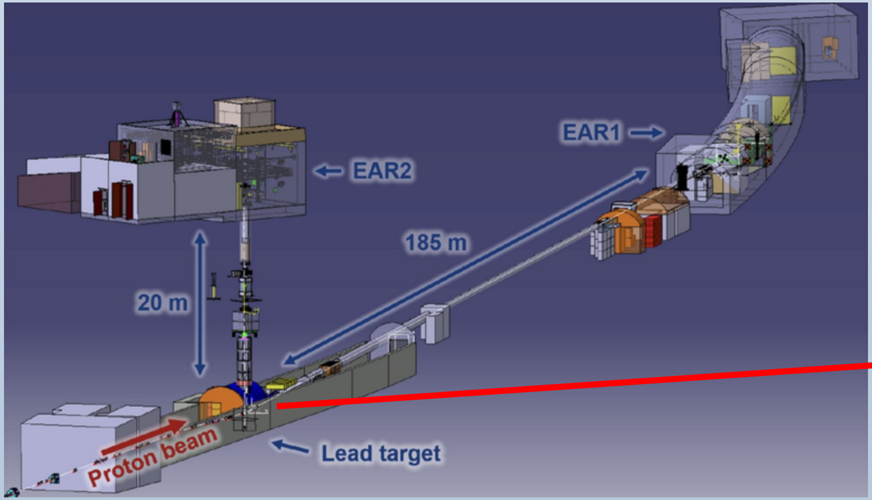


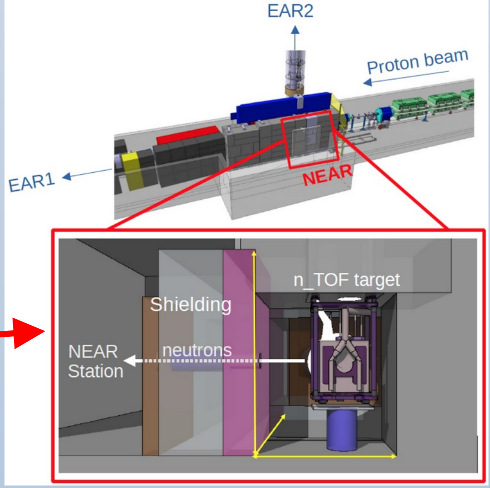
Neutron Time of Flight (n_TOF) Facility

- 20 GeV Proton beam impinges on Lead target
- White neutron beam, 11 orders of magnitude energy [1]
- EAR1 (~185 m), **EAR2 (~20 m)**
- Newly build **NEAR Station (~3 m)**
  - Difficult environment due to high instantaneous neutron flux
  - Measures of neutron flux at NEAR poses a challenge

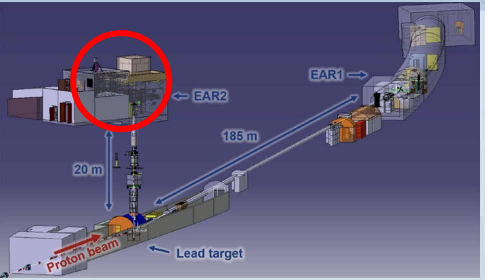


[1] A. Mengoni et al., CERN-INTC-2020-073; INTC-I-222 (2020)

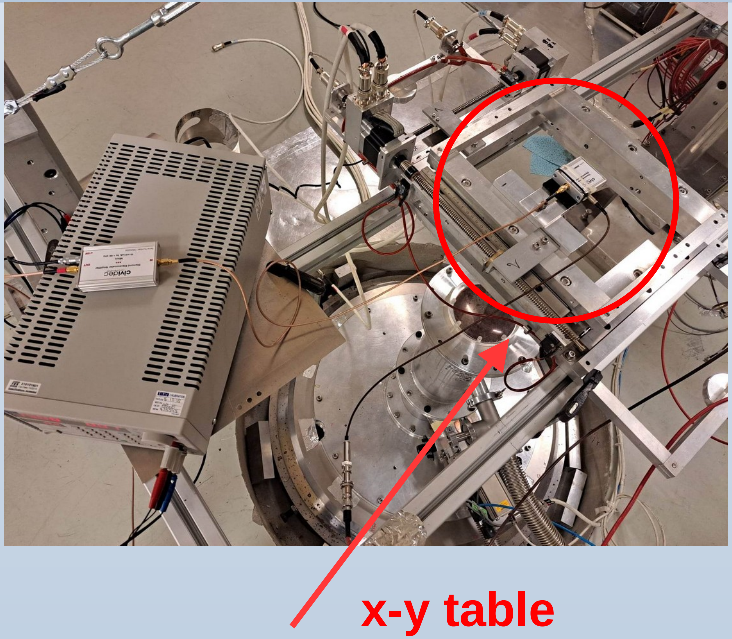


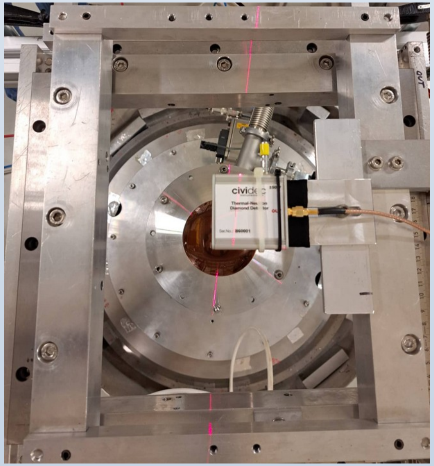


EAR2 Test (November 2022)



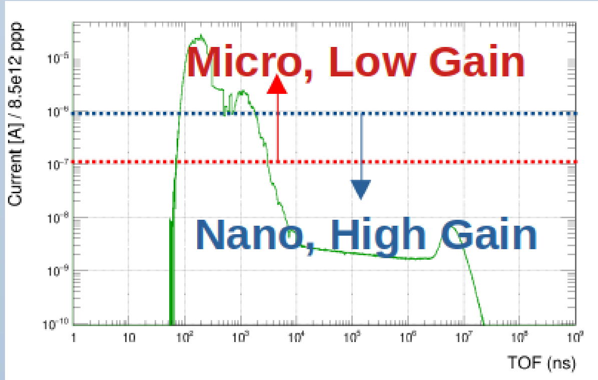
- 20 m distance from the lead target
- First test of the detector and the electronics
- DC Amplifiers **for measuring the current**
  - Micro DC amplifier 66 kHz (Low Gain)
  - Nano DC amplifier 1 kHz (High Gain)
- AC Amplifier **for measuring single events**
  - C2 AC amplifier, 2 GHz





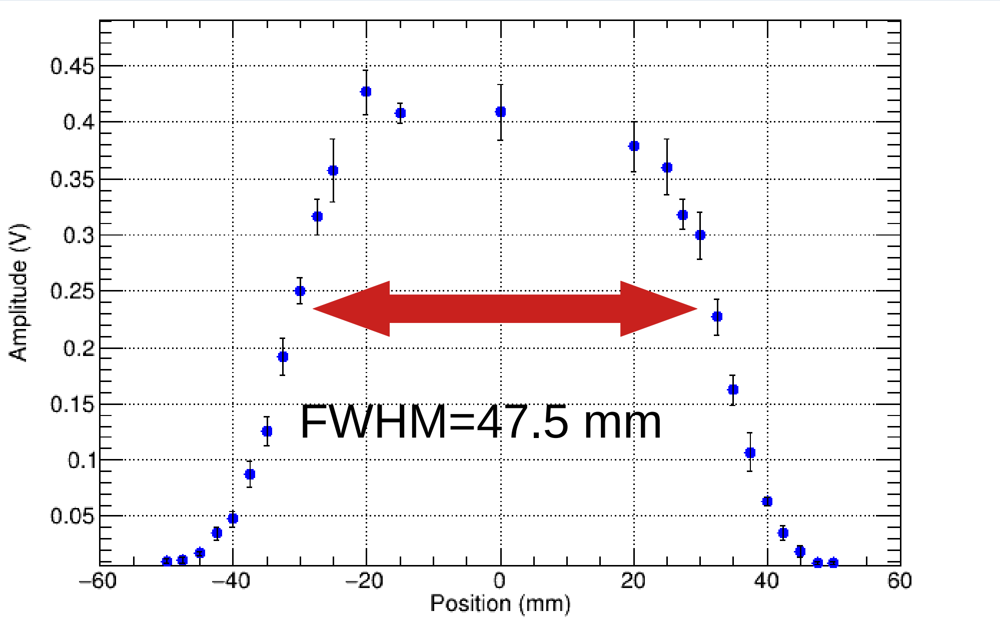
The detector was placed on a table able to move in the x and y axis in order to extract the beam profile

Simulated current in EAR2 for the diamond detector

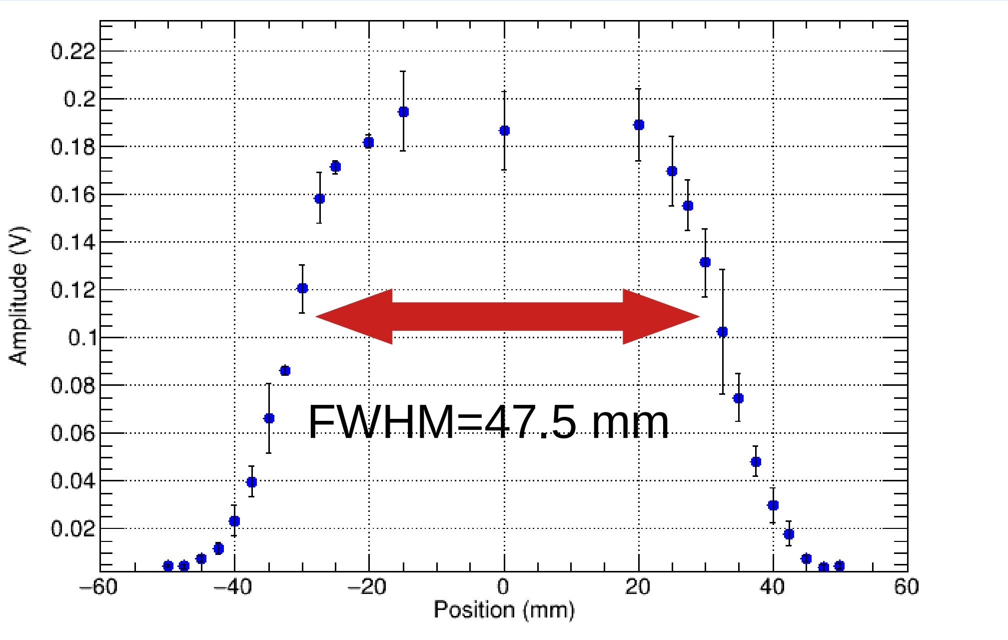


EAR2 Test, Beam Profile

Full beam intensity (Dedicated pulses)



½ beam intensity (Parasitic pulses)

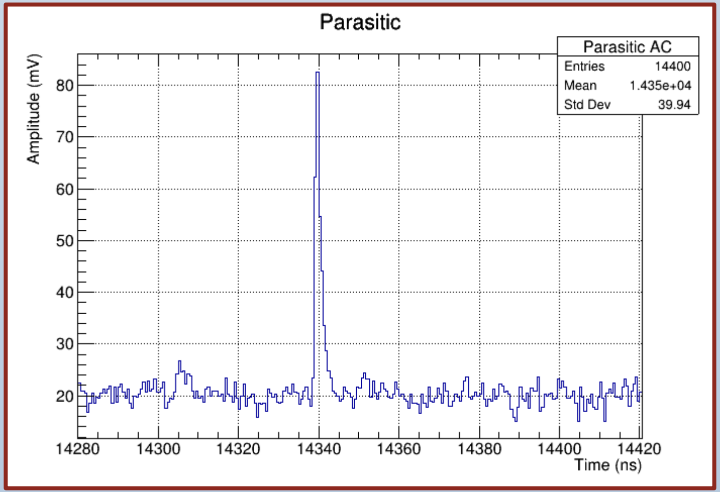


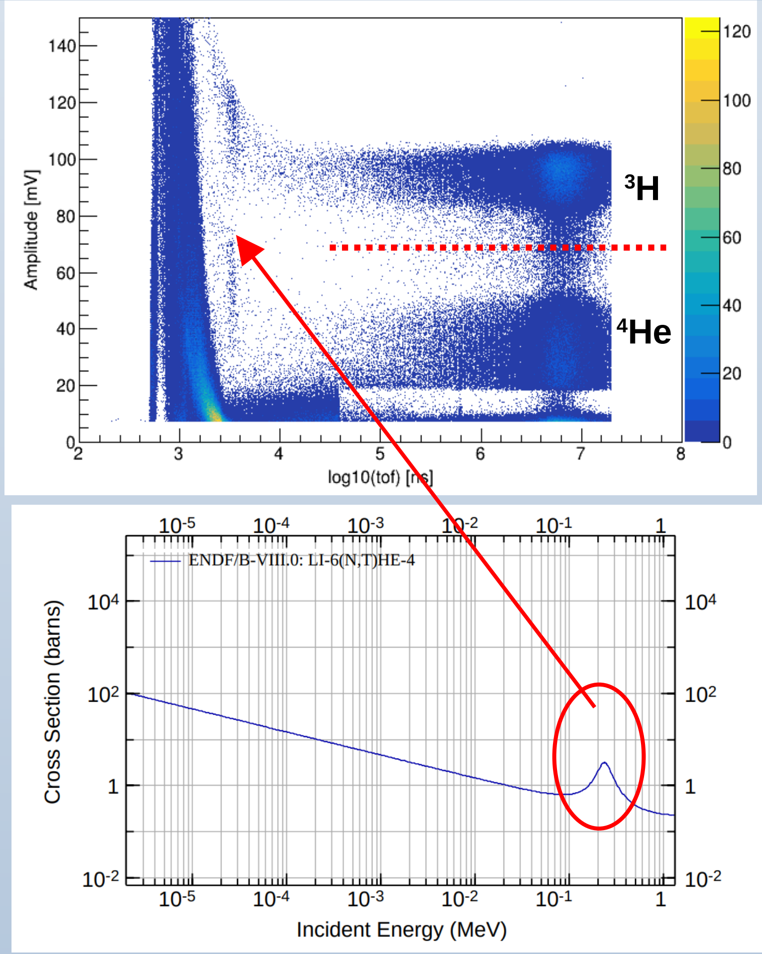
- Plateau area for 40 mm followed by exponential decrease
- In agreement with simulations

EAR2 Results, AC Amplifier

- C2 AC amplifier, 2 GHz Record single events
- Li(n,t)α : Observe the ^{3}H,^{4}He peaks
- Resonance at ~100 keV
- Analysis is ongoing

Typical Signal from the DAQ



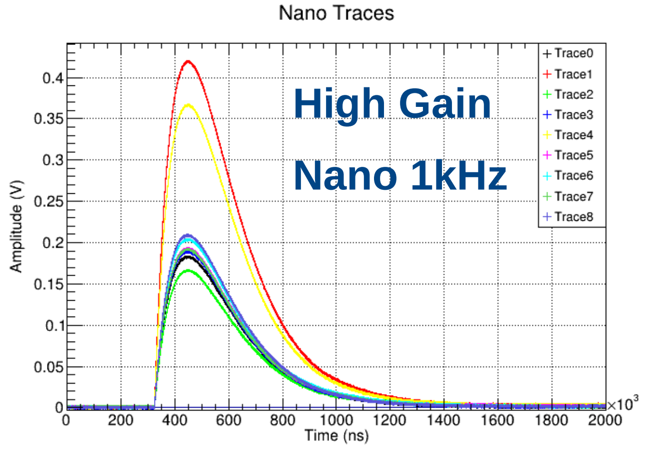


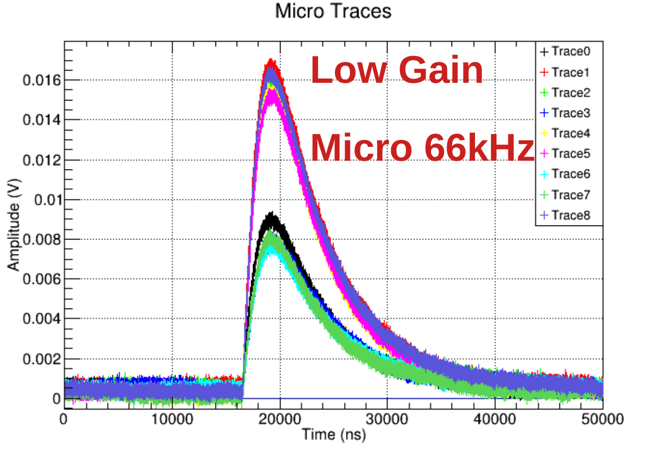
EAR2 Results, DC Amplifiers

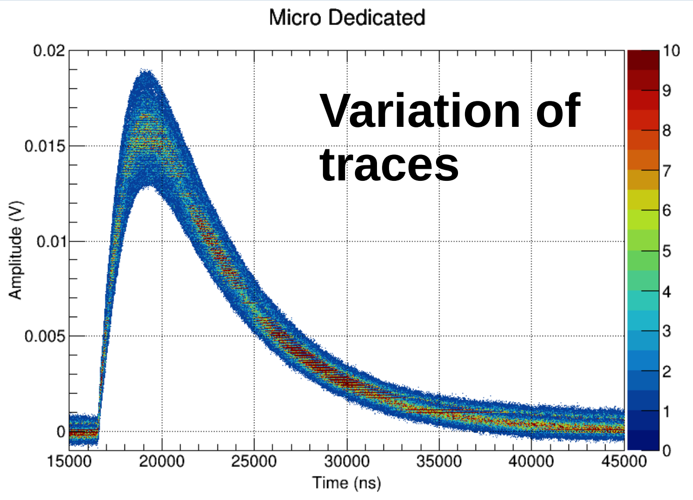
- Data from Oscilloscope
- Dedicated Pulses:

  Full Intensity 8.5e12 ppp
- Parasitic Pulses:

  ½ Intensity 4e12 ppp
- Detector's response as expected
- **New faster electronics developed for NEAR**

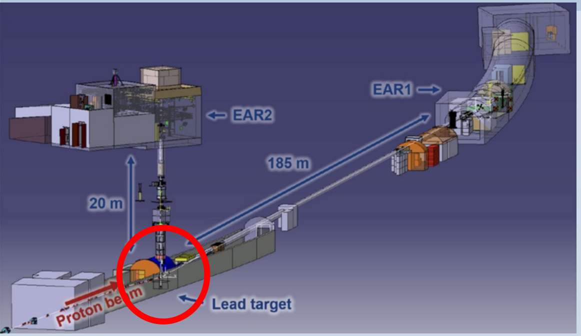






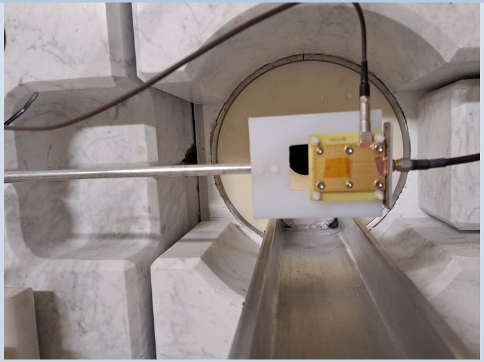
High variation of traces

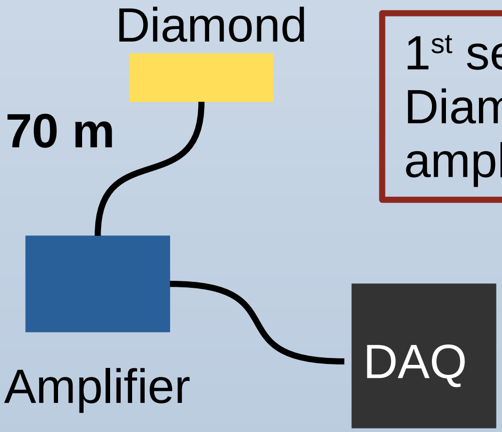
NEAR Test April 2023



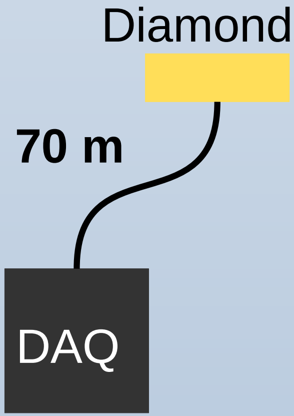
- First test with an active detector
- Amplifiers:

1) DC **C8** amplifier, **24 MHz** → current
2) AC **C2** amplifier, **2 GHz** → single events



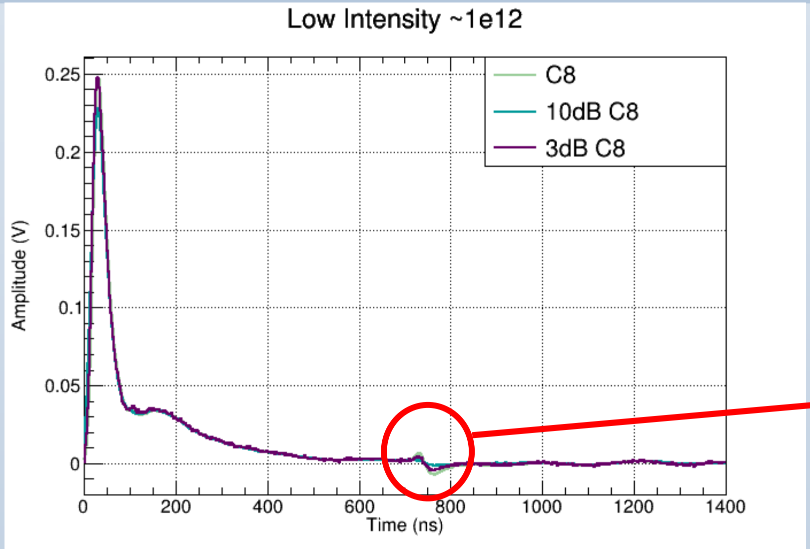


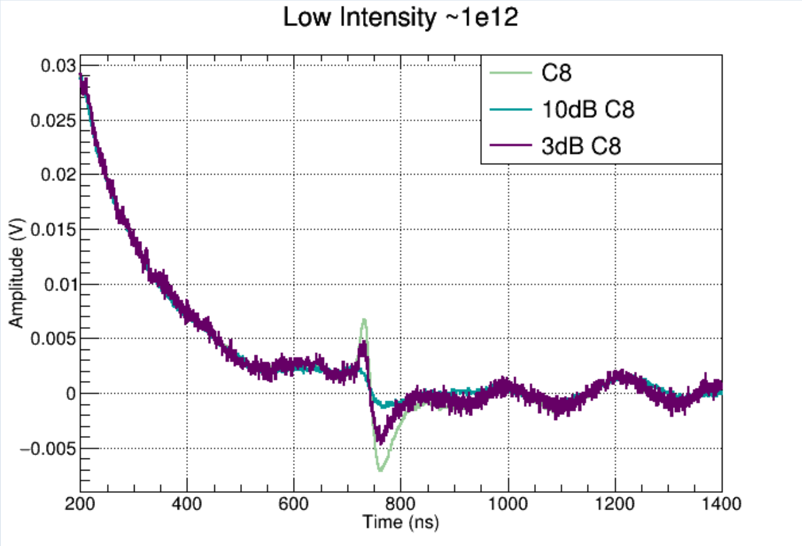
1st set up:
Diamond with amplifier



2nd set up:
Direct from Diamond

NEAR April Test, Reflection



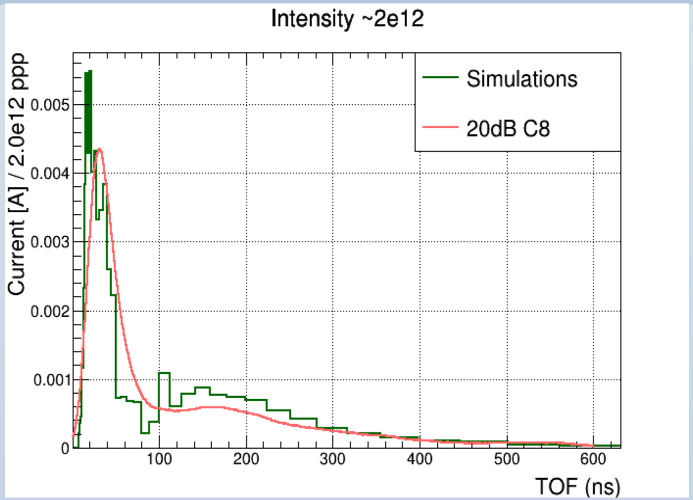


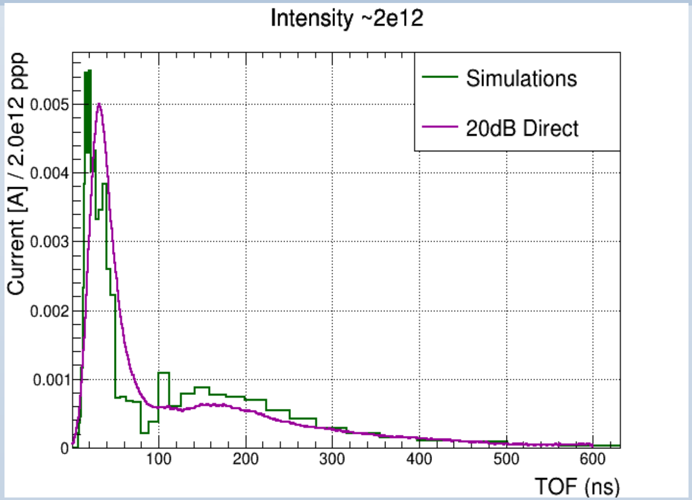
- Three Intensities
  - (1e12 ppp, 2e12 ppp, 8.5e12 ppp)
- Relative impact of reflection is suppressed with attenuators
- Prevent saturation at full intensity

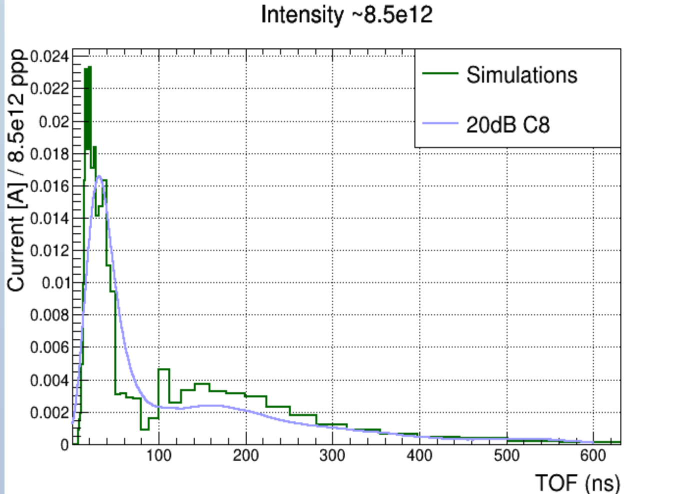
Attenuation	Reflection/maximum
No attenuation	0.026
3dB	0.018
10dB	0.009

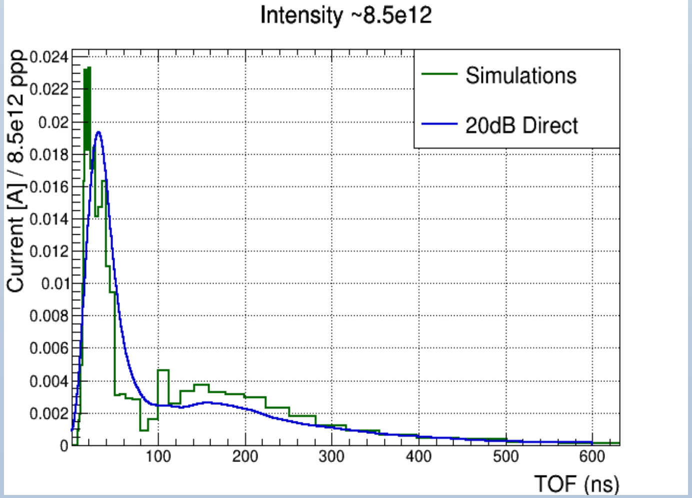
Measurements with 10 dB, 20 dB attenuators

NEAR Test April, Preliminary Results (1)

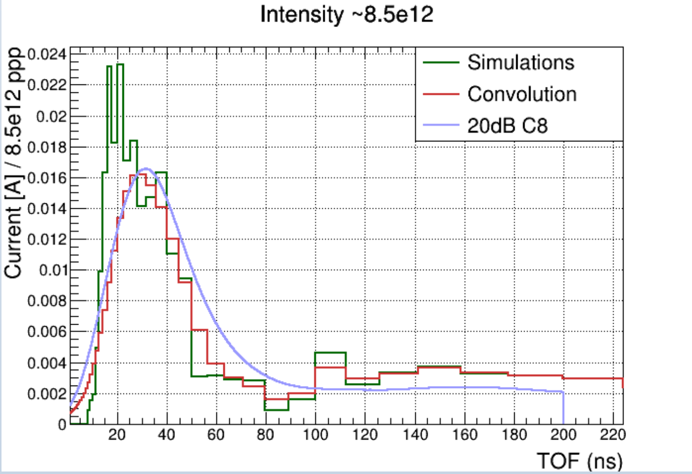




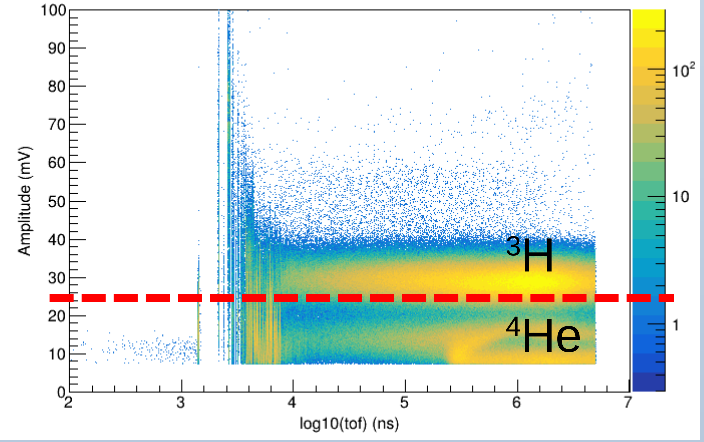




NEAR Test April, Preliminary Results (2)



- Current detection with C8
  - Satisfactory agreement with the simulations
  - Encouraging results



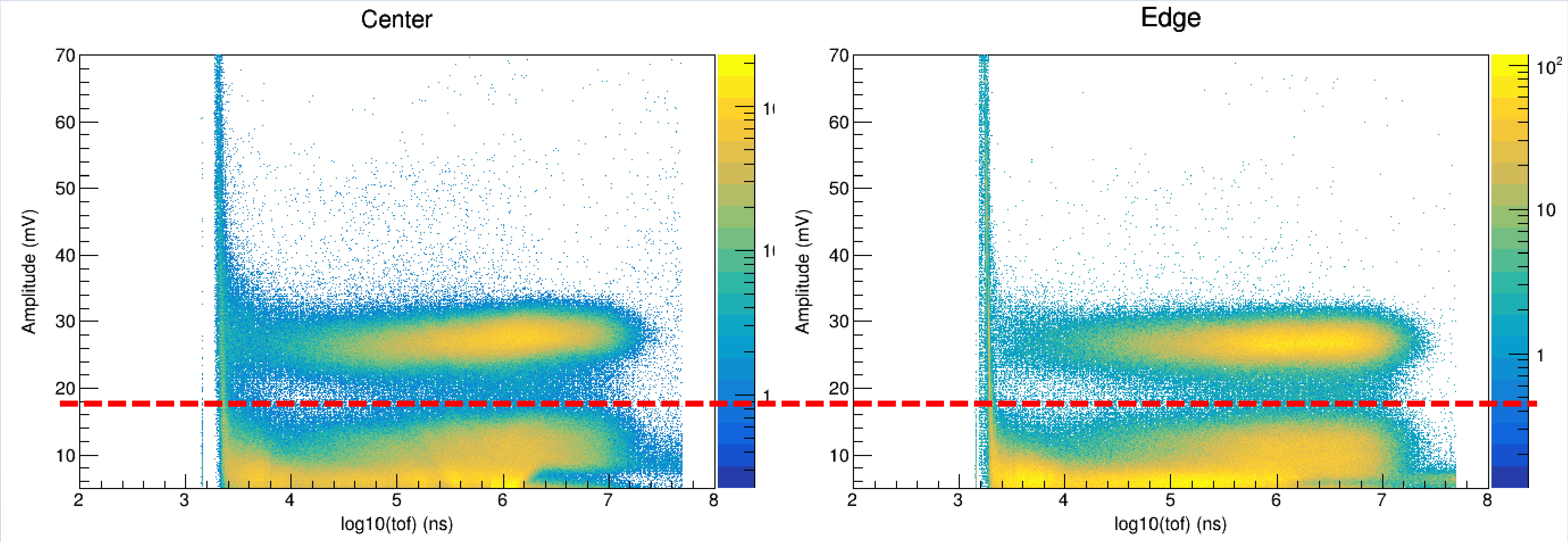
- Single Events detection with C2
  - Ringing at ~30keV
  - Not clear separation of the ^{3}H and ^{4}He peaks
  - Due to the 70 m cable

NEAR Test October 2023

- **Direct connection** between detector and amplifier
- 12 cm distance from the marble wall
- x-y table to scan the beam profile
- Due to the rail: limitations on scanning the y- axis
- C2, 2 GHz amplifier
- Connection problems with the C8 amplifier

xy table

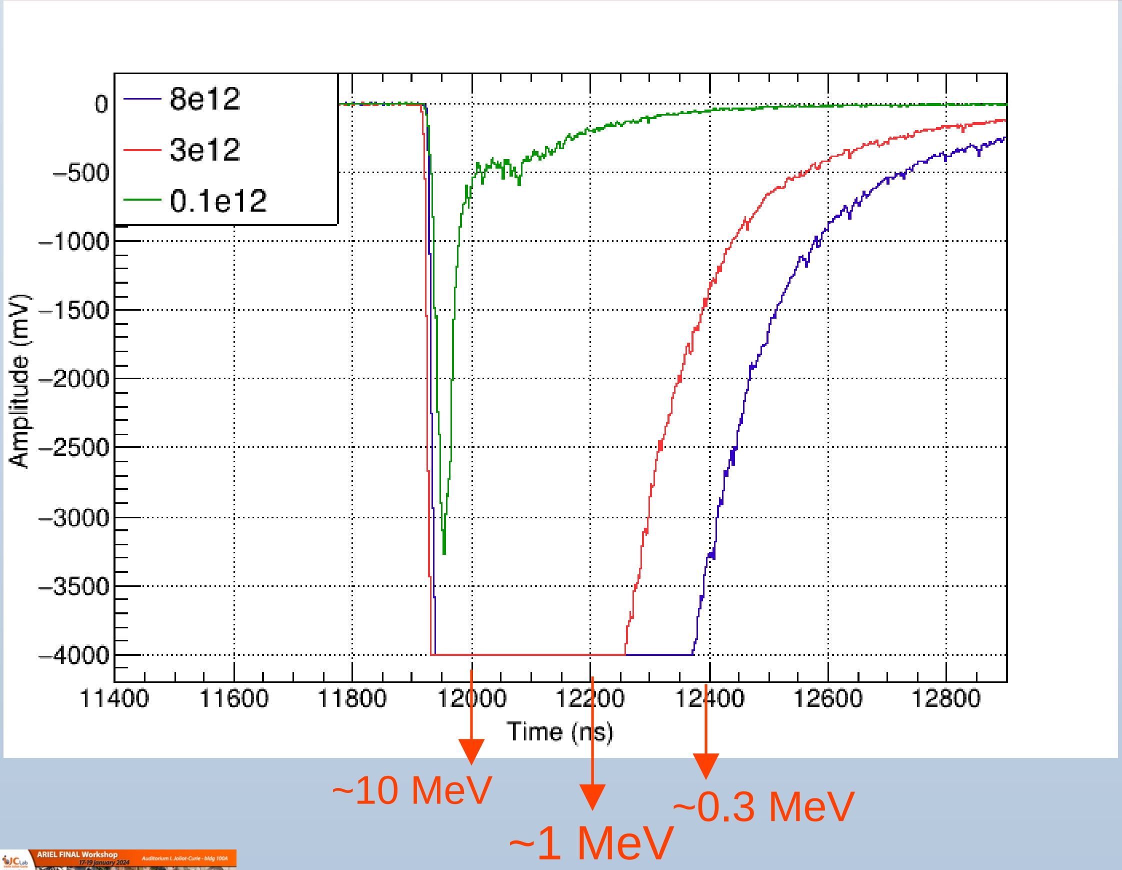
October Test, Preliminary Results

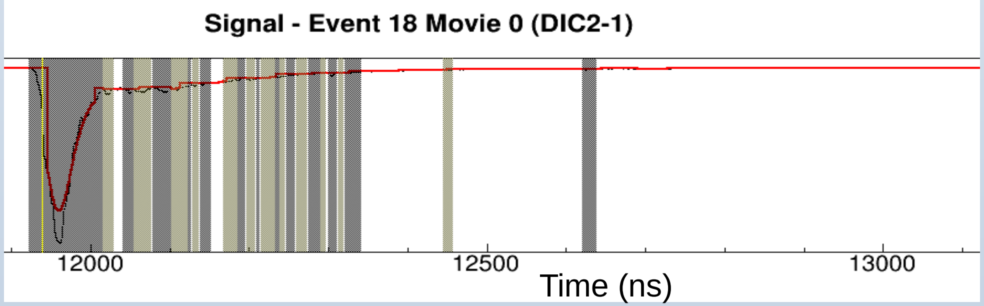


- No ringing due to the direct connection of the detector and amplifier
- Good Separation of the ^3H peak in all positions

Signals for Dedicated, Parasitic and Low Intensity

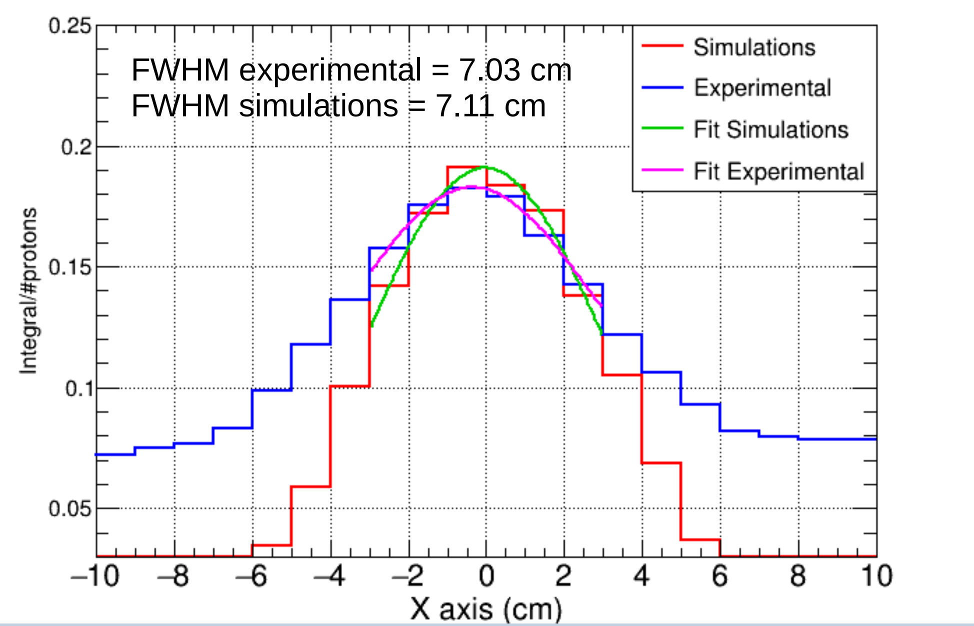
Three intensities measured: 8e12 ppp (Dedicated), 3e12 ppp (Parasitic), 0.1e12 ppp (Low Intensity)

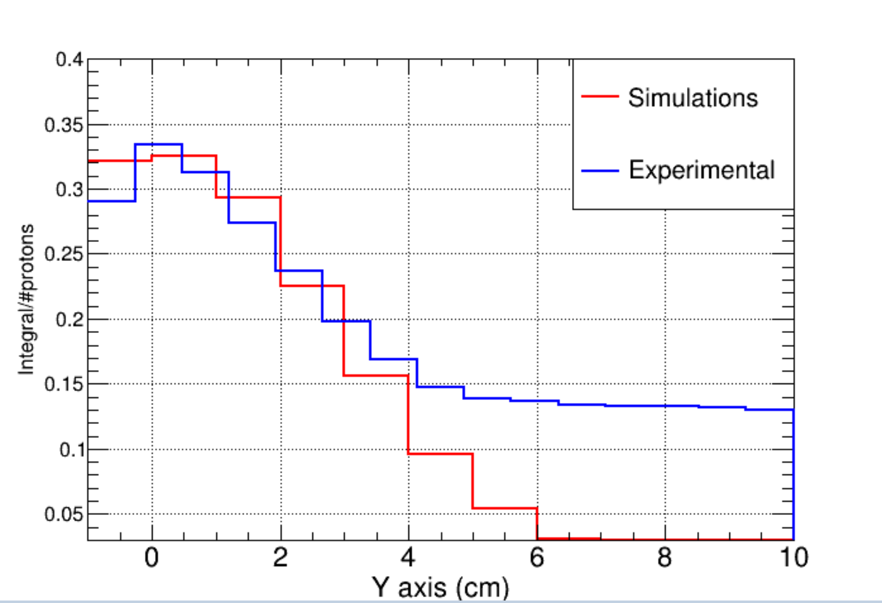




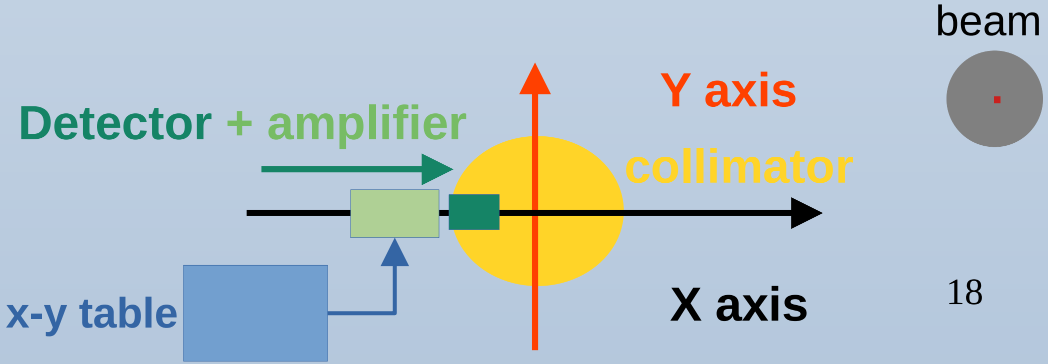
- Resolved energy so far up to ~0.1 MeV
- For low intensity pulses possibility to resolve higher neutron energies

Beam Profile for 0.001 eV < En < 0.01 eV





- Peak Shape Profile
- Agreement with simulations for ~6 cm
- Corrections for simulations (transport code which includes all neutron energies)
- Deviation in left and right edge due to electronics in beam



Discussion and Conclusions

- Three tests with the diamond detector at the n_TOF facility at CERN
- First measurement with an active detector was performed at the NEAR Station
- Implementing a direct connection of the detector and the amplifier provides a good separation of the peaks and reduced noise
- With the x-y table able to extract a beam profile for EAR2, NEAR station
- Analysis is ongoing for all three experiments
  - Refinement of the simulations, better parameters for the processing of the signals
- Part of this work was published at RAP Conference: “NOVEL DIAMOND DETECTOR DEVELOPMENT FOR HARSH NEUTRON FLUX ENVIRONMENTS”, K. Kaperoni, M. Diakaki, C. Weiss, M. Bacak, E. Griesmayer, J. Melbinger, M. Kokkoris, M. Axiotis, S. Chasapoglou, R. Vlastou, and the n_TOF collaboration, DOI: 10.37392/RapProc.2023.16, Pages: 79-83 (www.rap-proceedings.org)
- NEAR measurement with new diamond detector, C8 amplifier and filters (B4C, Au, Fe)

This project has received funding from the Euratom research and training program 2014-2018 under grant agreement No 847594 (ARIEL).

This project was supported by CIVIDEC Instrumentation.

Thank you for your attention!

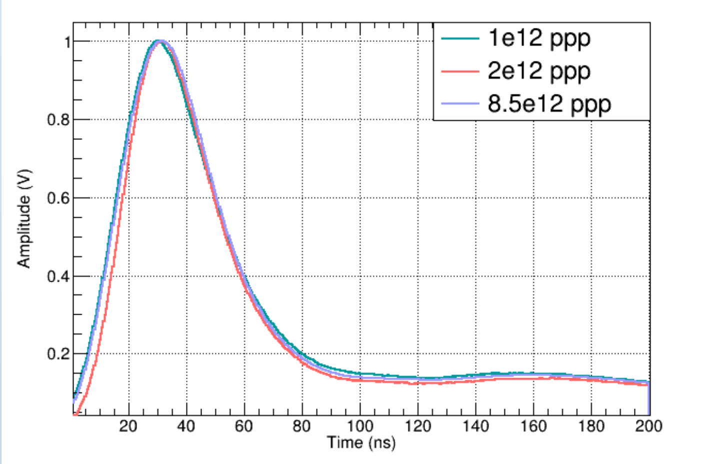
Special thanks to all members of the n_TOF local team!

ARIEL Project Support:

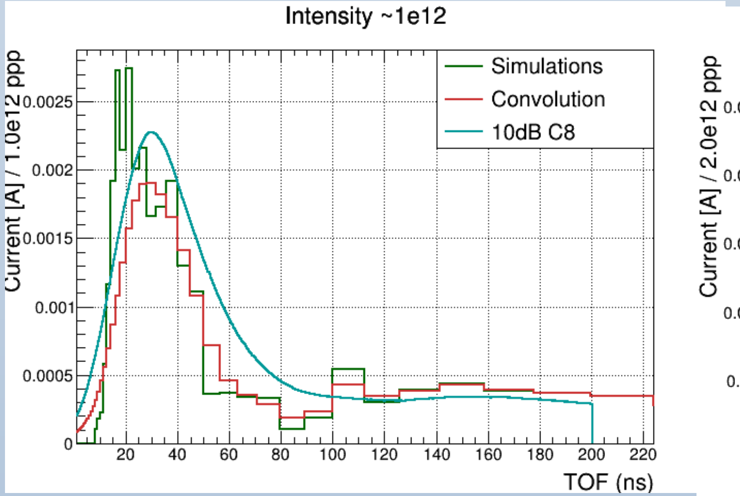
TAA_7_11: Direct measurement of the n_TOF NEAR time of flight neutron fluence with diamond detectors
Spokesperson: Maria Diakaki (NTUA)
Facility: NEAR (n_TOF, CERN)
Access to neutron facilities

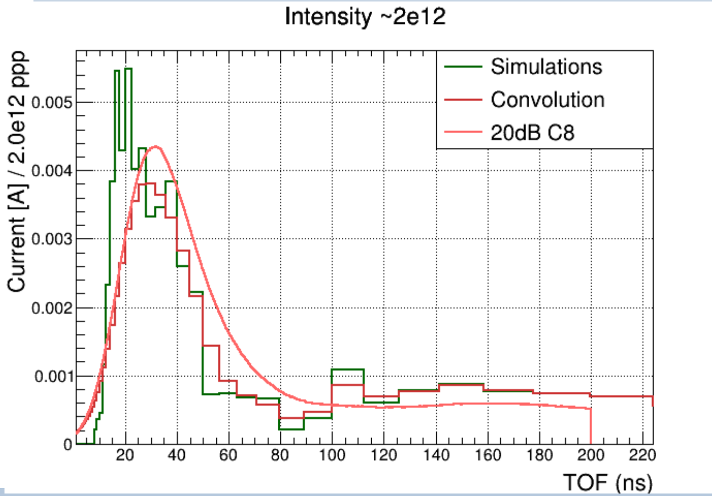
PAC/SV_5_7: Direct measurements of the n_TOF NEAR time of flight neutron fluence with diamond detectors
Facility: n_TOF, CERN
Training of early stage researchers and scientific visits

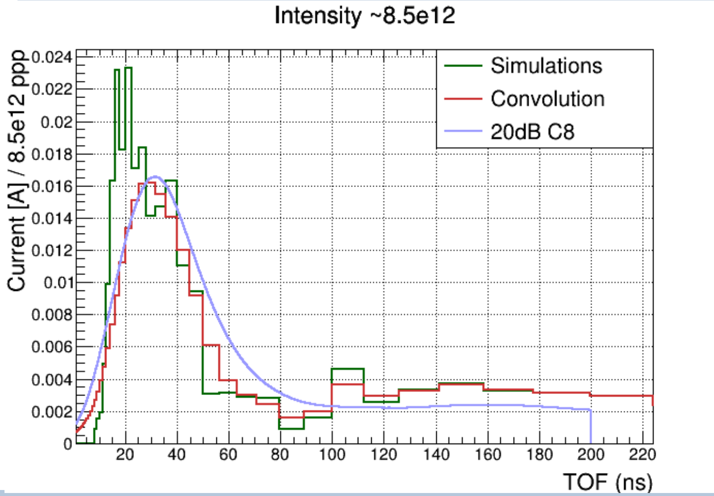
First Step Convolution



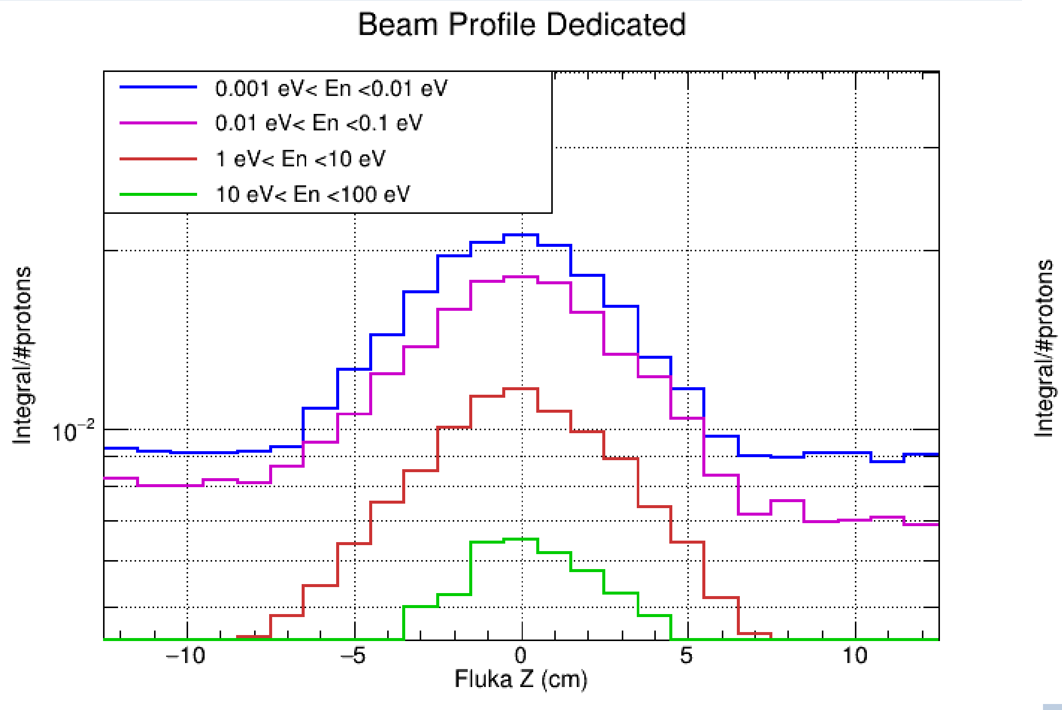
- Width similar to all intensities
- First step convolution
  - Sigma 7.5 ns due to proton beam width
- Extra corrections for electronics resolution function

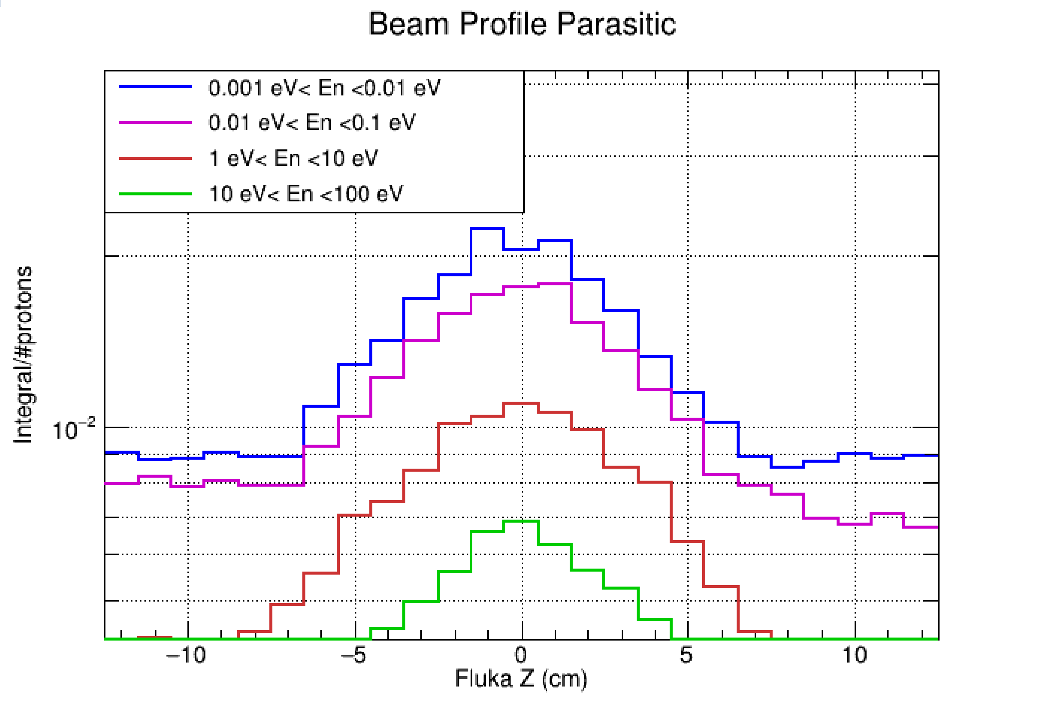






Beam Profile for Different Neutron Energies

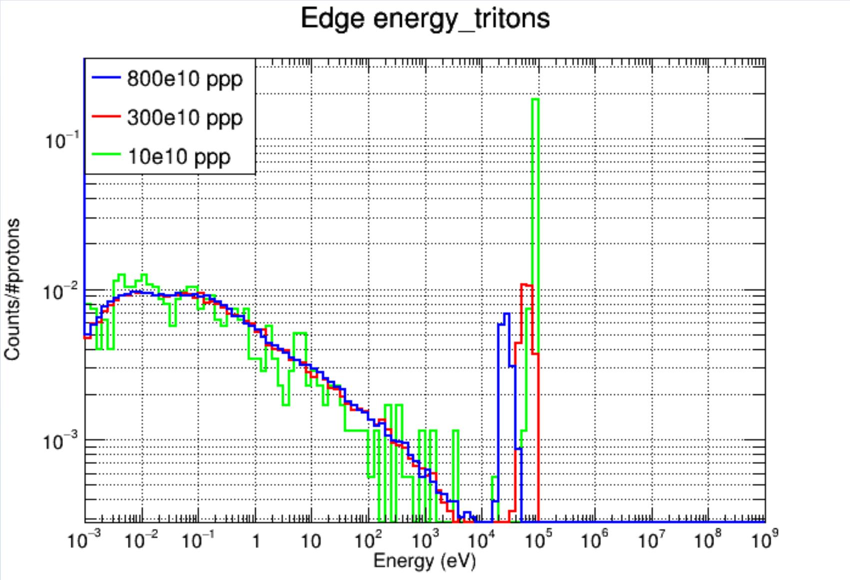


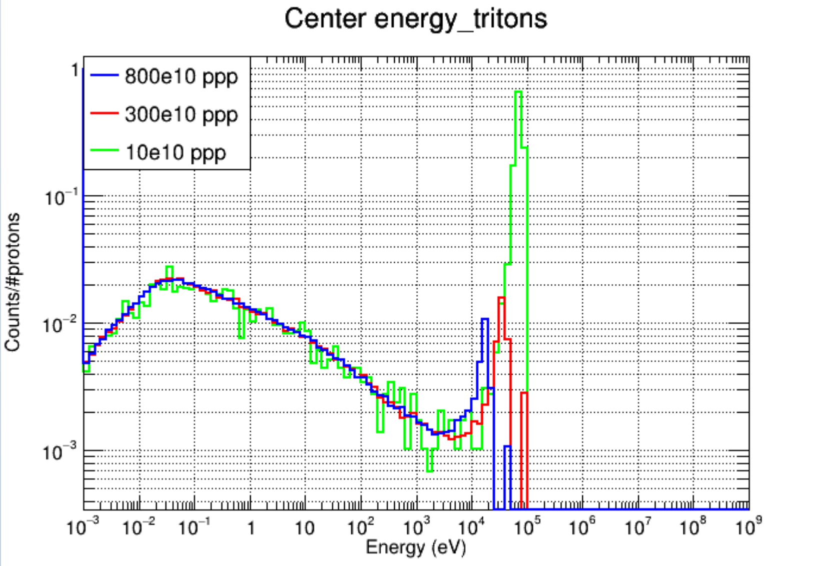


- Similar behavior for the beam profile for Dedicated and Parasitic for different neutron energy intervals
- Higher values for low energy interval due to the shape of the shape of then neutron flux

NEAR Neutron Flux, First Results

Measure in three intensities: 8e12 ppp, 3e12 ppp, 0.1e12 ppp



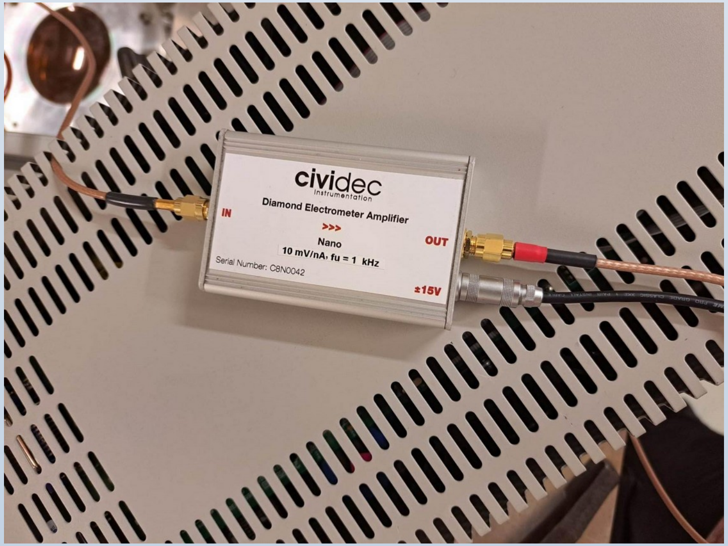


$high_{En}/low_{En}$=19.9

$high_{En}/low_{En}$=306.6

- Low intensity pulses show more counts for high neutron energies in all positions
- On the edge we observe higher contribution of the low energy neutrons

Amplifiers



- C8: R=100 Ω, f=24 MHz, tr=12 ns, stdev=50 uV, Lin+=1.8V
- C2: 2 GHz/40 dB