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A new CVD Diamond Mosaic-Detector for (n,α) Cross-Section Measurements at the n_TOF Experiment at CERN

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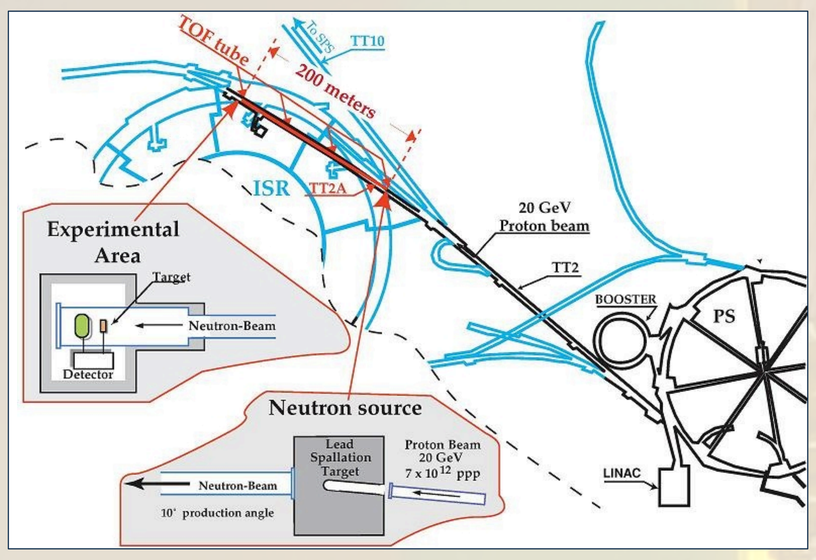
Abstract

At the n_TOF experiment at CERN a dedicated single-crystal chemical vapor deposition (sCVD) diamond mosaic-detector has been developed for (n,α) cross-section measurements. The detector, characterized by an excellent time and energy resolution, consists of an array of 9 sCVD diamond diodes. The detector has been characterized and a cross-section measurement has been performed for the ^{59}Ni(n,α)^{56}Fe reaction in 2012. The characteristics of the detector, its performance and the promising preliminary results of the experiment are presented. CIVIDEC Instrumentation GmbH, Vienna, Austria, sponsored this work.

The n_TOF Facility at CERN



The neutron time-of-flight facility n_TOF at CERN (www.cern.ch/nTOF) is devoted mainly to the measurement of neutron induced cross-sections. Neutrons are produced in a lead spallation target with protons delivered by the CERN Proton Synchrotron (PS).

Proton beam:
- Momentum: 20 GeV / c
- Intensity: $7 \cdot 10^{12}$ protons / pulse

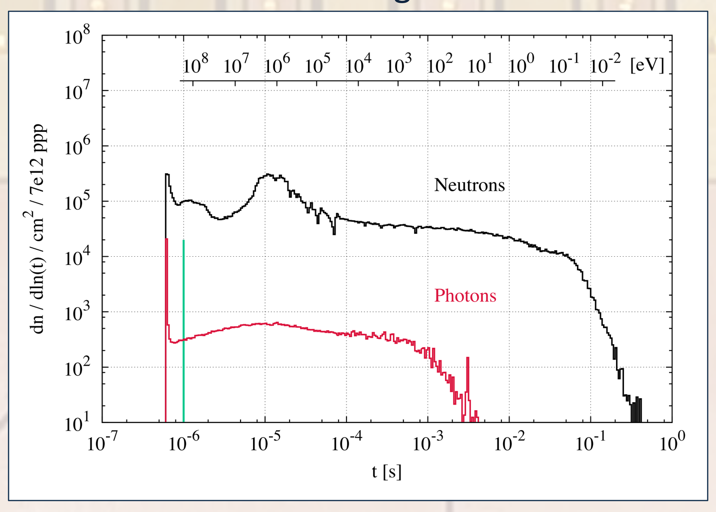
Neutron beam:
- TOF distance: 185 m
- Energy: meV < E_n < GeV
- Intensity: ~10^6 neutrons / pulse (1 - 10^6 eV)
- Shape: Gaussian-like (σ ≈ 7 mm)

The neutrons are moderated in a borated water-layer surrounding the lead spallation target:
⇒ Wide neutron energy spectrum

Charged particles produced during the spallation process are diverted from the beam by a sweeping magnet.

Photons are produced by:
1. The spallation process: prompt photons, arrive first at the measuring station => γ-flash
2. The moderation of the neutrons: delayed photons => in-beam γ-background

Arrival Time of Neutrons and Photons at the Measuring Station



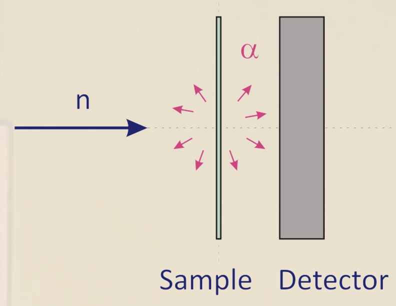
(n,α) Cross-Section Measurements

Experimental challenges:
- Isotropic emission of reaction products
- Small cross-section
- Thin samples for low α-absorption and low α–energy loss

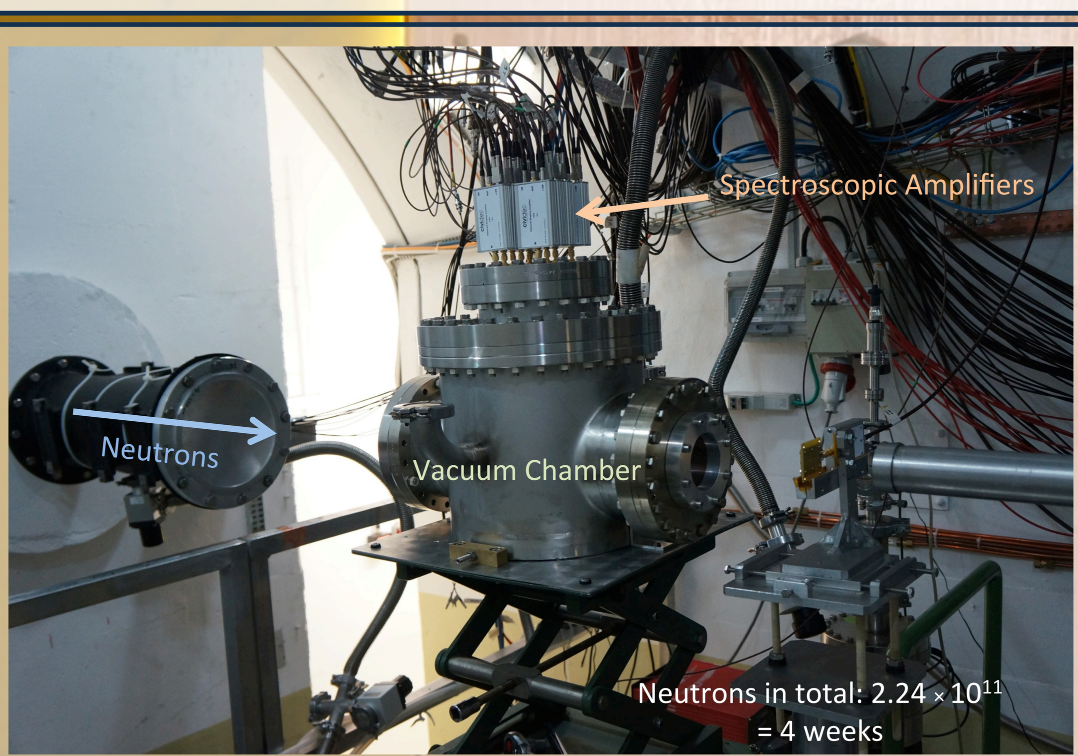
⇒ The detector is placed in the neutron beam in close geometry to the sample, to maximize the angular coverage and maximize the yield

⇒ Background:
- In-beam photons
- Neutron-induced reactions with the detector and structural materials

⇒ For optimal background rejection we require:
- High resolution α-spectroscopy:
  1. Solid-state detector
  2. Low detector-induced noise
  3. Low capacitance
- Low-Z material:
  1. Improved γ-rejection
  2. (n,cp) reactions in the detector material start at higher E_n



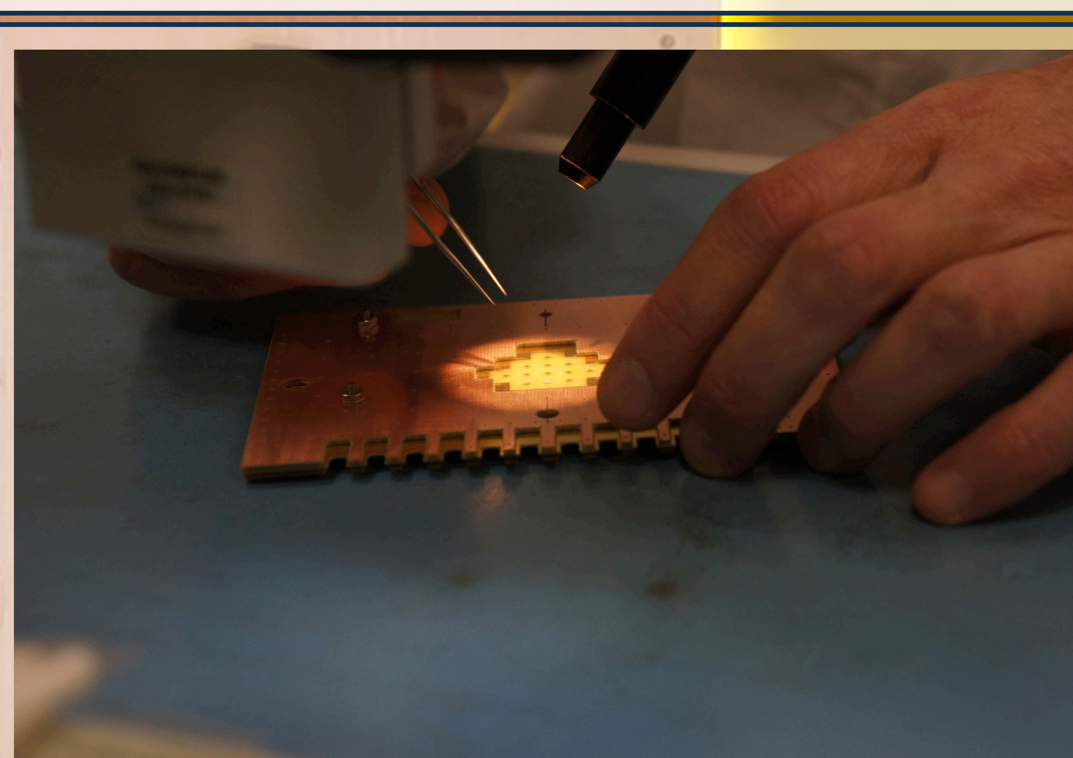
⇒ CVD diamond was chosen as detector material (Z = 6)
⇒ Thin and large area detector
⇒ Compact detector-design
⇒ Little backup materials
⇒ Measurement under vacuum



Experimental Setup at n_TOF:
- Measurement under vacuum: p < 10^{-5} mbar
- Vacuum chamber with 100 μm Kapton windows
- Alignment < 0.5 mm thanks to the mosaic structure

Diamond Mosaic-Detector

9 sCVD diamond diodes, each with:
- Thickness: 150 μm
- Area: 4 mm x 4 mm
- Electrodes: 200 nm Al
- Full metallization on the front side (ground)
- Square electrode 3.8 mm x 3.8 mm on the back side (HV and signal)
- Arranged in a mosaic structure



Glued and bonded on a PCB sandwich structure
- 1 mm PCB material in the beam
- Good shielding – no RF pickup
- High energy resolution (FWHM < 70 keV)

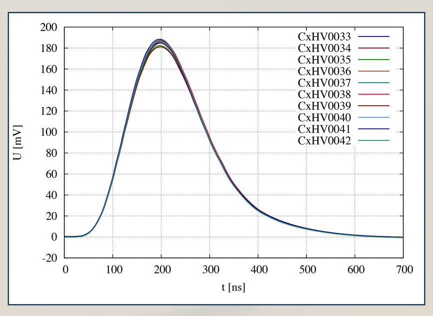
Conclusions

The sCVD diamond material has proven to be suitable for (n,α) cross-section measurements in a heterogeneous beam, where background rejection is indispensable.

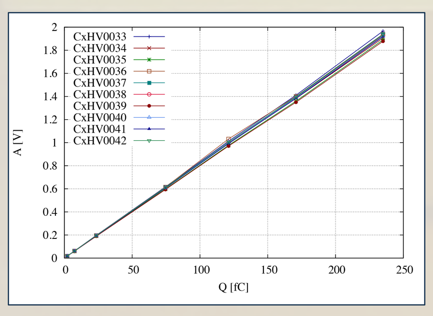
The large-area, RF-tight diamond mosaic-detector allowed a stable, spectroscopic measurement with an energy resolution < 70 keV, in combination with the CIVIDEC Shaping Amplifiers.

Dedicated Electronics

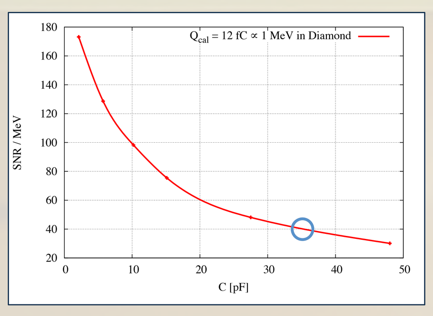
Pulse Shapes



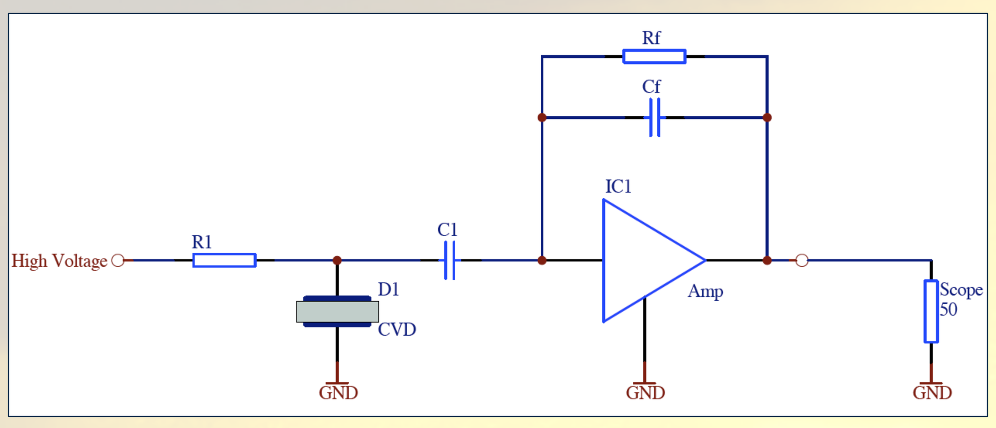
Linearity



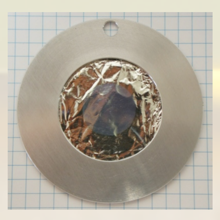
Signal-to-Noise Ratio



Spectroscopic Shaping Amplifier CIVIDEC Cx-Series:
- 180 ns shaping time
- Gain of 8.2 mV/fC – designed for measurements up to 10 MeV neutron energy
- SNR/MeV for the setup = 40
- Energy resolution for the setup = 50 keV



^{59}Ni(n,α)^{56}Fe Cross-Section Measurement 2012 - Results



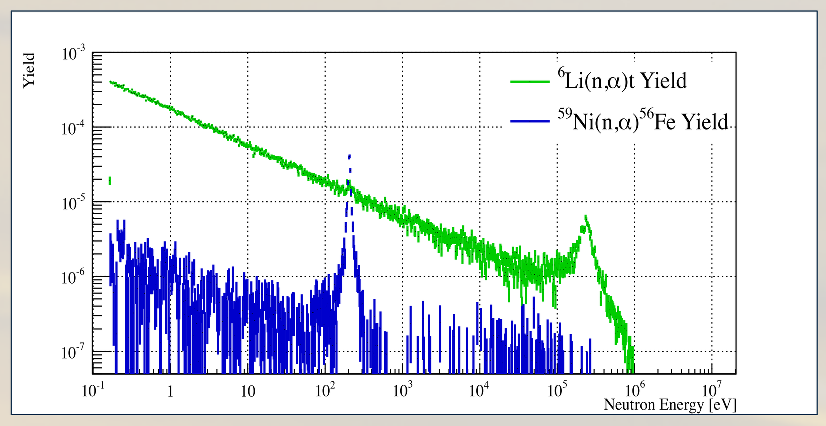
Radioactive isotope ^{59}Ni: Decay via e⁻capture and β^+, with $t_{1/2}$ = 76.000 y
- Decay radiation: X-rays (E_{max} = 7.7 keV), Auger e^- (E_{max} = 6 keV), β^+ (E_{max} = 25 keV)

Sample specifications: Electro-plated on 25 μm Pt foil with 1.5 cm diameter
- (180 ± 5) μg metallic Ni (516 kBq): 95% ^{59}Ni:
  ⇒ Cross-section measurement
- (205 ± 5) μg LiF: 95% ^{6}Li: neutron fluence measurement
  ⇒ Beam Interception Factor (BIF)

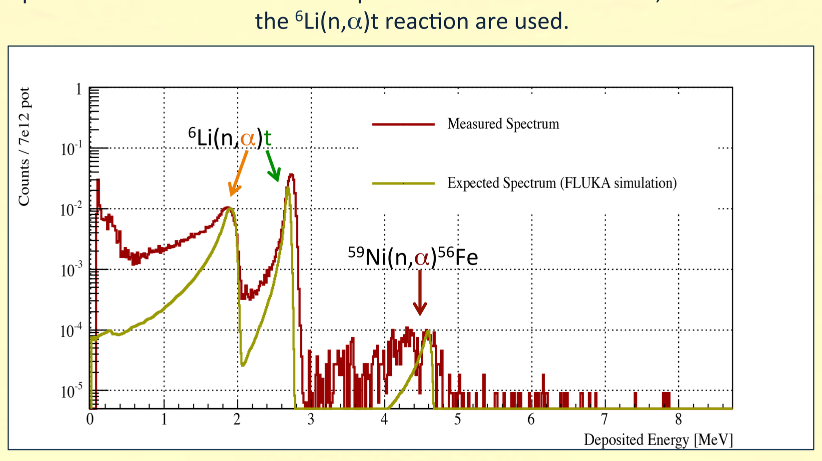
Measurements:
1. Sample
2. In-beam background: Pt foil
3. Detector background: Sample out
4. Background from ^{59}Ni decay: Beam-off
5. Calibration with 4α source

$$Yield(E_n) = \frac{Sample(E_n) - Background(E_n)}{Fluence(E_n) * Efficiency * BIF}$$

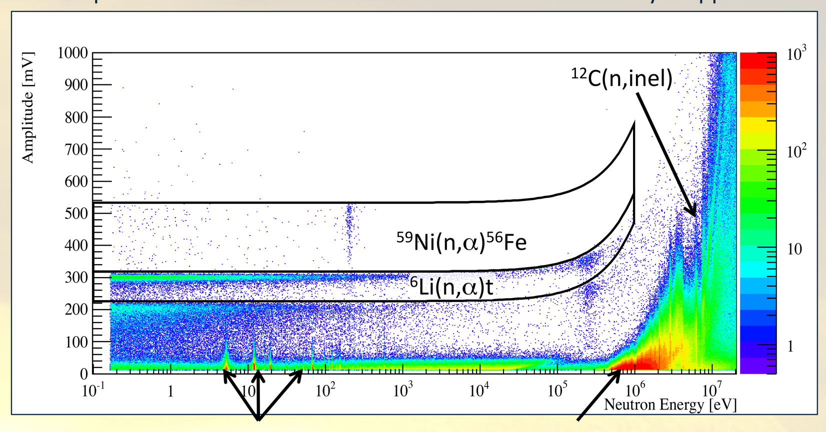
Measured reaction yield for ^{6}Li and ^{59}Ni. For both isotopes the dominant resonance is clearly visible.



Recorded and expected particle spectra for one diode. The expected particles are visible as individual peaks. For the BIF calculation, the tritons of the ^{6}Li(n,α)t reaction are used.



Sample measurement: recorded amplitude spectrum over neutron energy for one diode. For the calculation of the reaction yields, the indicated amplitude cuts are used and a correction for the efficiency is applied.



Resonances from (n,γ) reactions in Au, Pt ^{12}C(n,el)

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