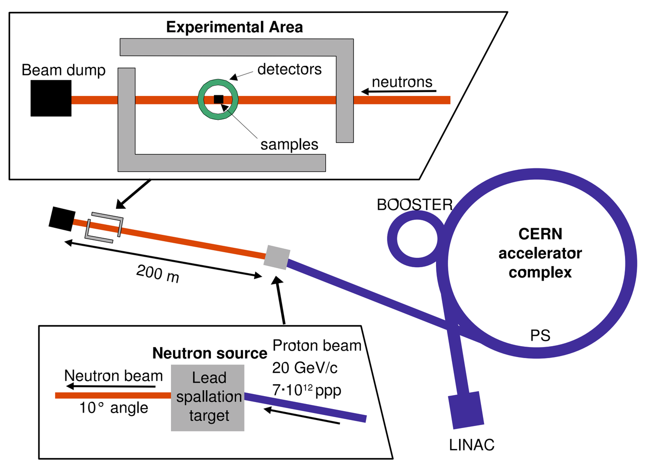
n_TOF collaboration from CERN

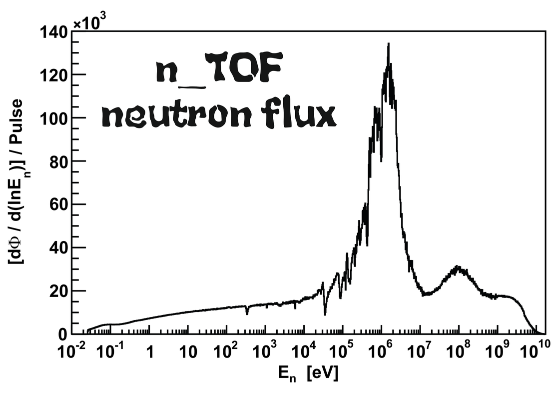
P. Žugec, D. Bosnar, N. Colonna

Neutron time of flight facility n_TOF at CERN

Neutron production



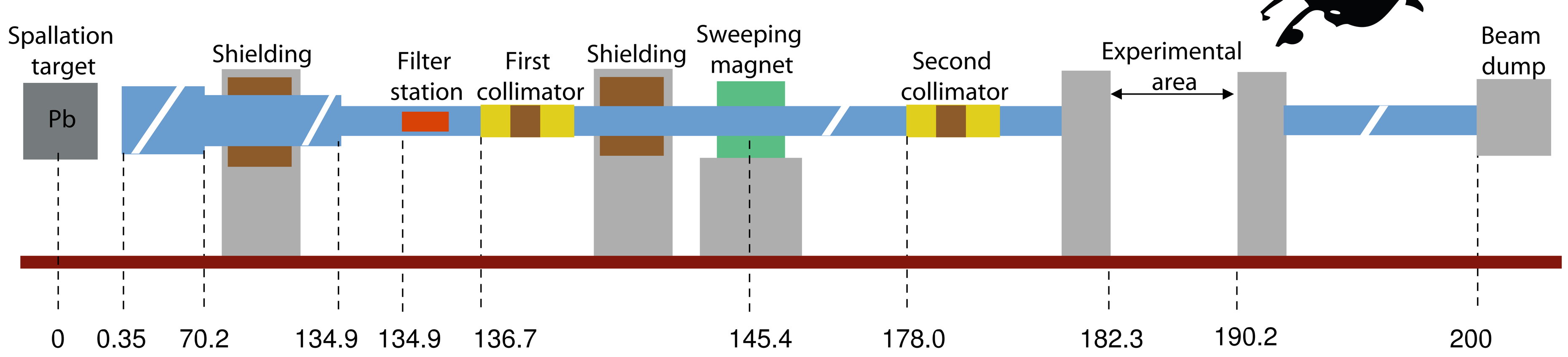
- CERN Proton Synchrotron provides a pulsed beam of 20 GeV protons, which irradiate the massive lead (Pb) spallation target
- during spallation, 300 neutrons are released per incident proton, up to 2×10^{15} neutrons per pulse
- initially fast neutrons are moderated by the Pb block, 1 cm layer of water from the target cooling system, together with the additional 4 cm layer of borated water
- final outgoing neutron flux spans 12 orders of magnitude in energy: from 10 meV up to 10 GeV [1]



Time of flight technique

- as soon as the proton beam hits the spallation target, an intense γ-flash is produced, which arrives at the experimental hall and marks the start-signal for neutron timing
- after being released into evacuated beamline, neutron traverse the path length of approximately 185 m to the experimental area
- detection of the prompt decay products (γ-rays, charged particles) from neutron-induced reactions marks the stop-signal for neutron timing
- from a time of flight T, inferred from a time difference between the stop- and start-signal, and known path length L, a kinetic energy of the neutron is reconstructed according to:

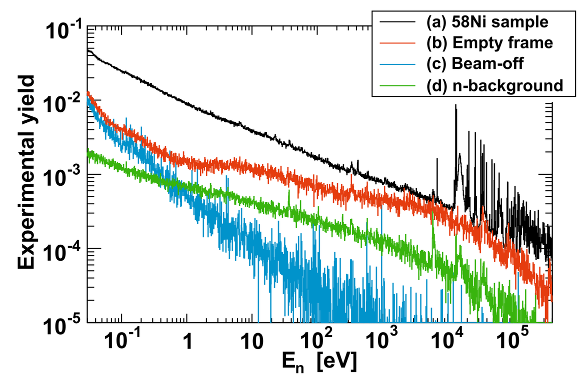
$$E_n = m_n c^2 \left(\frac{1}{\sqrt{1-\left(\frac{L}{cT}\right)^2}} - 1 \right)$$



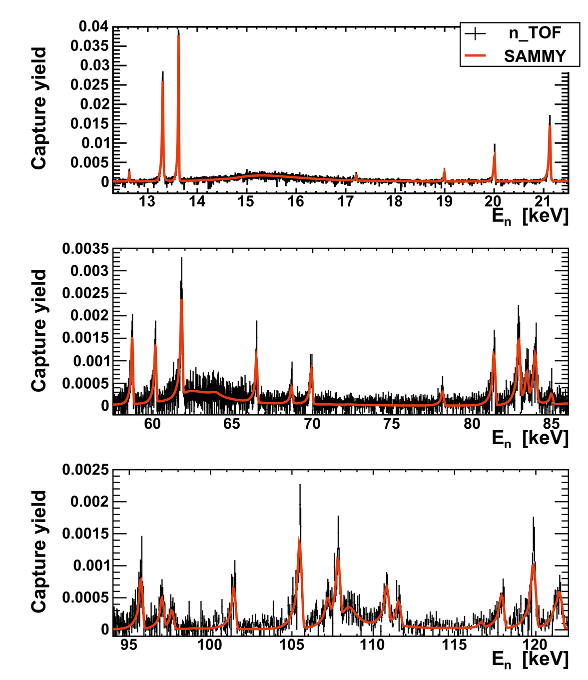
Neutron resonance spectroscopy

- measurements of the nuclear level densities near the neutron separation energy (several MeV above the ground state)
- applications: calculation of the nuclear reaction rates for the astrophysical processes and nuclear reactor devices

^{58}Ni neutron capture cross section measurements

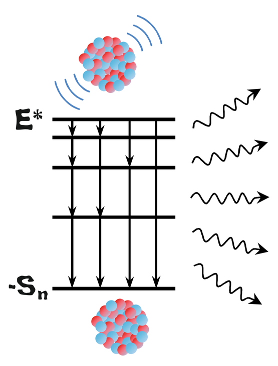


- ^{58}Ni experimental campaign is a representative example of the neutron capture cross section measurements at n_TOF [5]
- aim of the data analysis is to calculate the capture yield, which is a neutron-energy-dependent probability for a capture reaction
- in order to extract the true capture yield from the totality of measured data, several sources of background must be identified and accounted for: the environmental background (due to the natural and induced radioactivity), the empty-frame background (due to the neutron beam irradiating the surrounding experimental apparatus) and the so-called neutron background (due to the neutrons scattered by the sample itself)

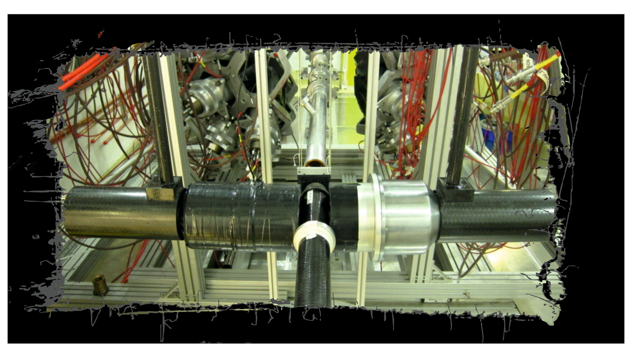


- alongside the capture cross section, the capture yield is heavily affected by the resolution function of the neutron beam, Doppler broadening of the capture resonances, multiple scattering and self-shielding effects
- in order to properly account for these effects and reconstruct the true capture cross section and resonance parameters, the measured yield is analyzed by means of a dedicated multilevel R-matrix code, such as SAMMY
- from a set of capture cross section parameters, quantities of central importance for the nuclear astrophysics, such as Maxwellian averaged cross sections (MACS), may then be calculated

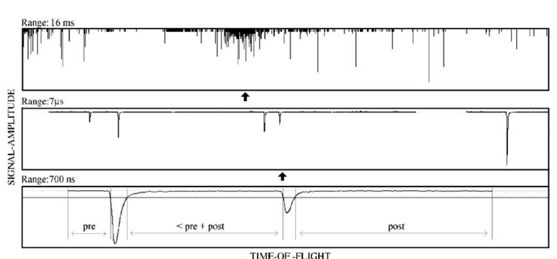
Experimental techniques for capture measurements



- following the neutron capture, a compound nucleus is left in a highly excited state, above the neutron separation energy, so it deexcites "stumbling" through the intermediate nuclear states, emitting a cascade of prompt γ-rays in the process
- out of many γ-rays emitted per single capture event, only one is to be detected by one of the two C_6D_6 (deuterated benzene) liquid scintillation detectors, marking the arrival of the captured neutron, i.e. its time of flight

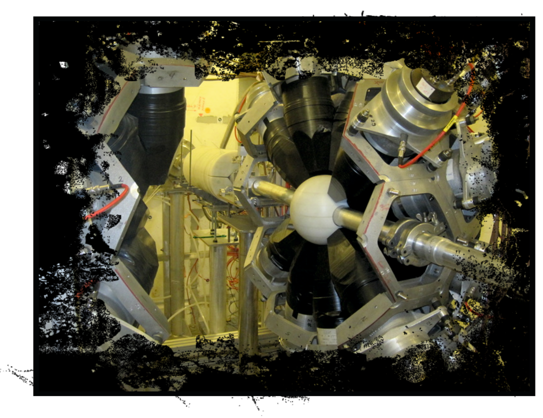


- C_6D_6 detectors [2] are used due to the very low intrinsic neutron sensitivity (realized through the extremely low neutron capture of both carbon and deuterium), thus reducing the background of capture reactions by the experimental apparatus itself



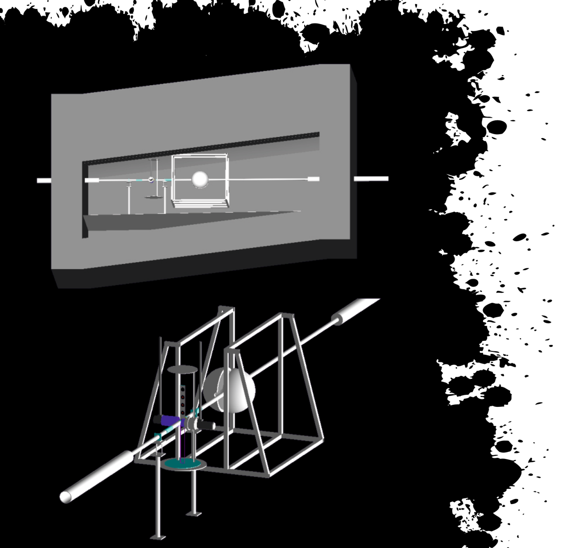
- the electronic signals are recorded by a high-performance digital data acquisition system [3], based on 8-bit flash analog-to-digital units operating at the sampling rate of 500 Mhz
- the data acquisition window of 96 ms allows to reach from MeV-region all the way down to the thermal neutron energies (~20 meV), in a single measurement sweep

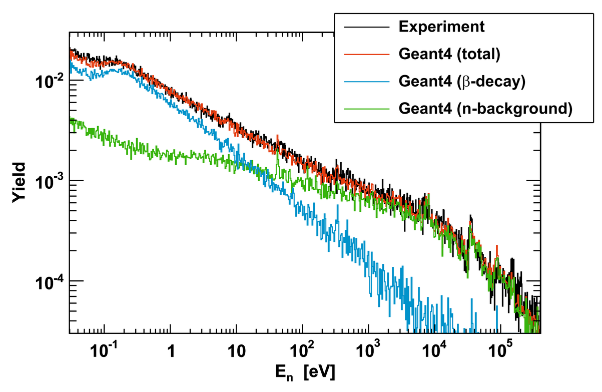
- fission measurements can also be performed at n_TOF, for which a different detector system is used, based on the 4π total absorption calorimeter (TAC) made of 40 BaF_2 scintillation crystals [4]



Neutron background simulations

- while the environmental and empty-frame background are easily measured by removing the sample, the neutron background, caused by the neutrons scattered off the sample itself, may not be as easily determined
- for this purpose GEANT4 was employed - the most contemporary toolkit for the simulation of the passage of particles through matter
- in the simulations a detailed software replica of the experimental hall and the materials inside it was implemented, with all the relevant physical processes taken into account [6]





- reliability of the simulated results was confirmed by comparing them against the experimental data, in particular for the sample of natural carbon, a material specially suited for the neutron background calibration

- thus, for the first time at n_TOF, the neutron background was clearly identified and used for reaching the new precision standards in the analyses of the experimental capture data

[1] C. Guerrero et al., Eur. Phys. J. A 49, 27 (2013)
[2] R. Plag et al., Nucl. Instr. and Meth. A 496, 425 (2003)
[3] U. Abbondanno et al., Nucl. Instrum. Meth. A 538, 692 (2005)
[4] C. Guerrero et al., Nucl. Instr. and Meth. A 608, 424 (2009)
[5] P. Žugec et al., Phys. Rev. C 89, 014605 (2014)
[6] P. Žugec et al., Nucl. Instrum. Meth. A 760, 57 (2014)