Study of nuclear reactions relevant for the astrophysical s-process with n_TOF at CERN

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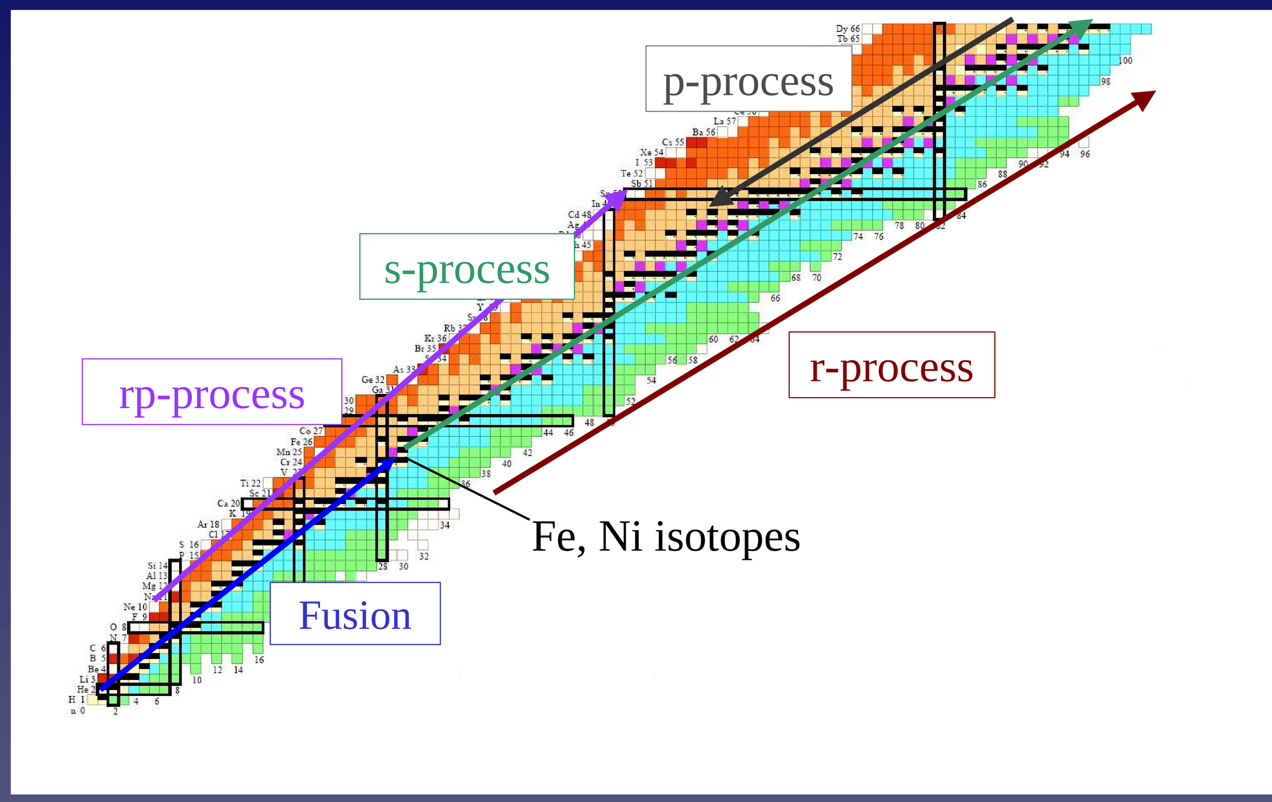
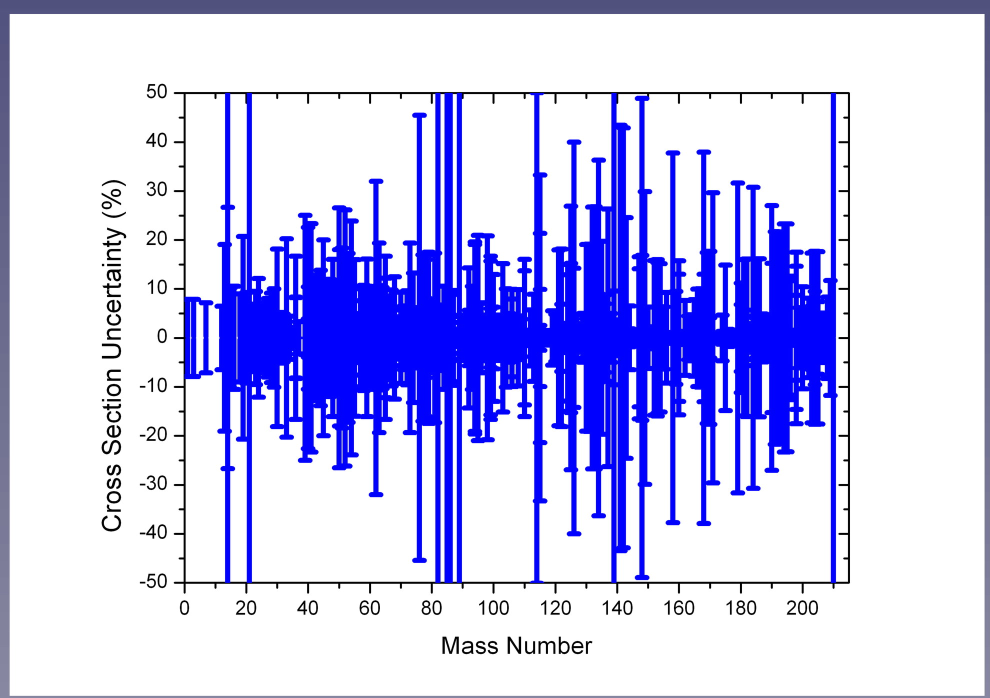
STELLAR NUCLEOSYNTHESIS BEYOND FE

The synthesis of elements heavier than Fe is dominantely caused by neutron capture reactions followed by beta decays.
At low neutron fluxes, the beta unstable nucleus will decay before capturing another neutron. For this process, which is called slow neutron capture (s-process), the generation of elements takes place close to the valley of stability when looking at the nuclear chart. Most stable nuclei between Fe and Bi can be generated by this mechanism. A second process, the rapid neutron capture (r-process), contributing about equally to the overall abundance pattern, takes place at environments with high neutron densities, where subsequently neutrons are captured, before the nucleus can decay. Therefore the r-process path is located close to the neutron drip-line, generating also neutron rich nuclei, which can not be reached by the s-process due to short beta half-lifes of neighbouring isotopes. Some low abundant proton-rich nuclei are produced by photodisintegration or (p,α) reactions (p- and rp-process).





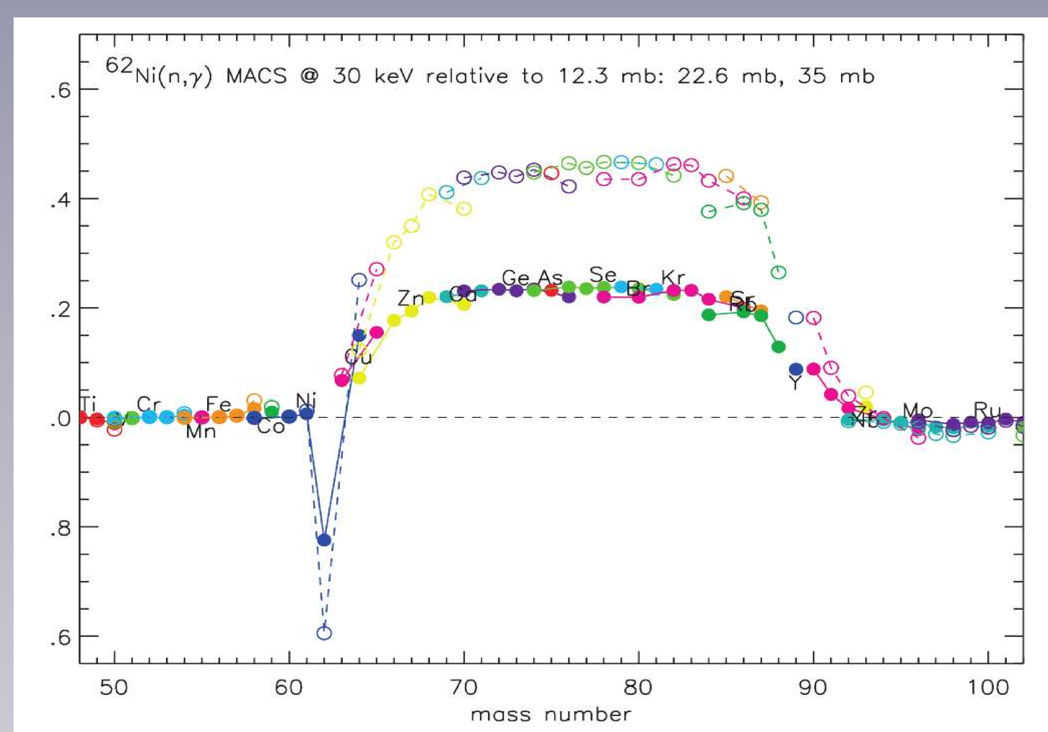
Neutron capture cross-section uncertainties for the Maxwellian-averaged cross-sections at kT=30 keV [2]

UMP OBSERVATIONS RAISE NEW QUESTIONS

The chemical composition of Ultra-Metal-Poor (UMP) stars was found to scale exactly with the r-process abundances of our solar system. The latter is obtained by subtracting the s-process component, which is determined by the respective (n,γ) cross- section, from the total solar composition. However, this agreement is only true for elements heavier than Ba, while for lighter elements a deficiency of about 20% was observed. This fact indicates either the need for a more detailed study of the specific stellar environments (different s- and/or r-process mechanisms), or systematic errors in experimental data, particularly of neutron capture cross-sections. [1]

THE NEED FOR ACCURATE CROSS-SECTION DATA OF $^{54}Fe(n,\gamma)^{55}Fe$ AND $^{62}Ni(n,\gamma)^{63}Ni$

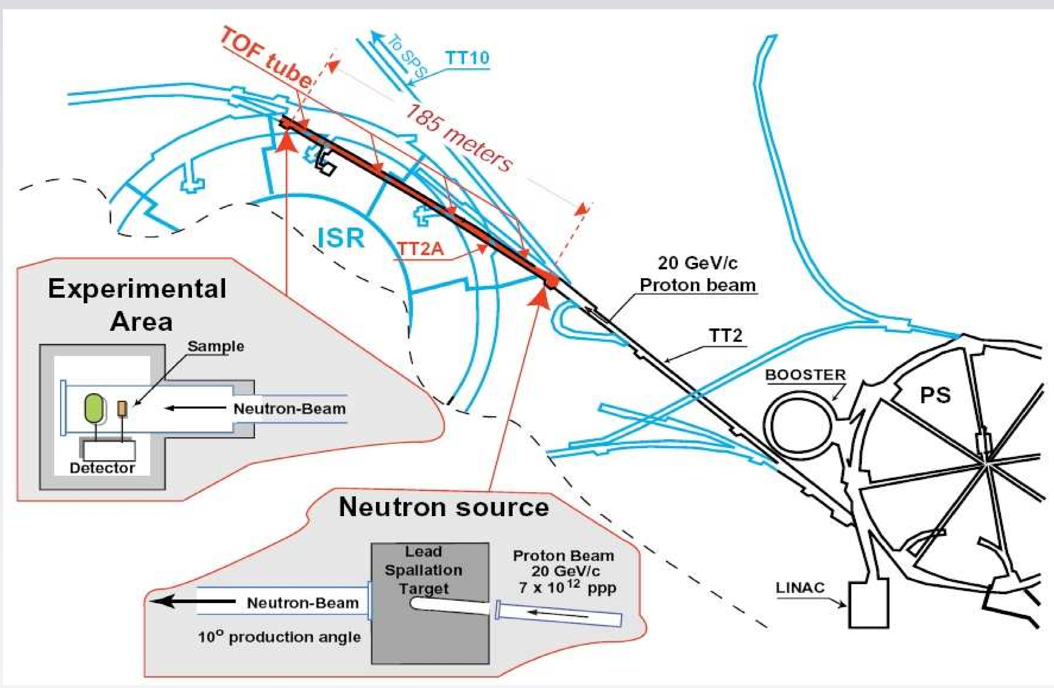
The figure above shows, that neutron capture cross-sections at present suffer from large uncertainties. An accurately known capure cross-section for the Fe and Ni isotopes in the keV neutron energy range is particularly crucial, since the s-process starts in this mass region. As visible in the figure to the right already a small change in the Ni capture cross-section has a significant impact on the abundance pattern of heavier isotopes. Our aim is to measure the cross-sections of the reactions $^{54}Fe(n,\gamma)^{55}Fe$ and $^{62}Ni(n,\gamma)^{63}Ni$ with n_TOF at CERN for a better understanding of the new observations mentioned above [4]. These data will be compared with recent results from independent activation measurements using Accelerator Mass Spectrometry e.g. at VERA (see also talk by K. Buczak).



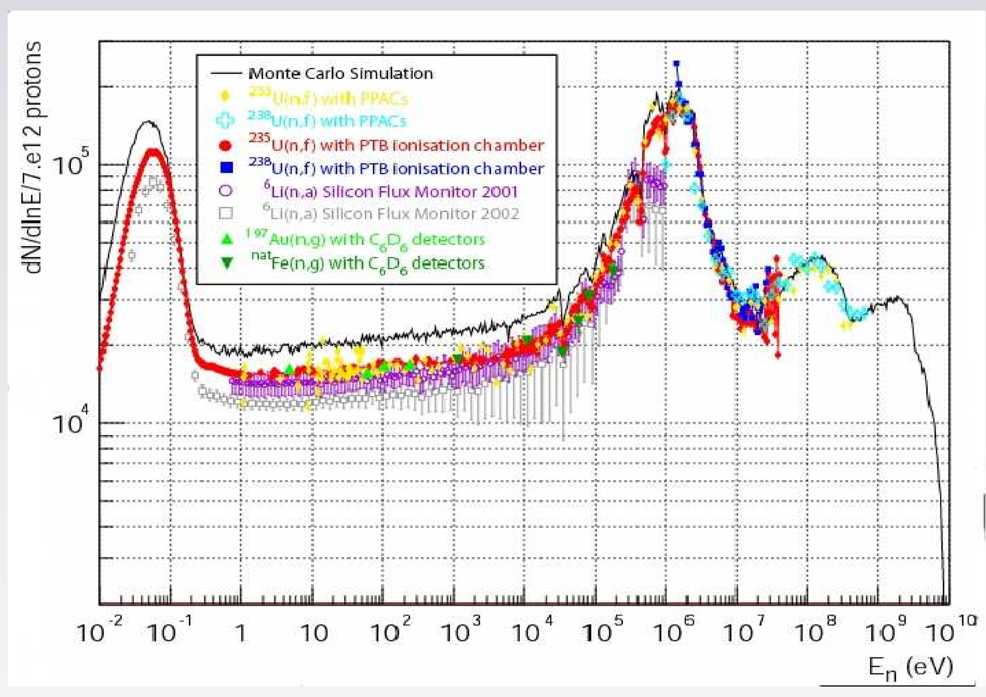
Change of the abundance of elements between Ni and Zr for different $^{62}Ni(n,\gamma)^{63}Ni$ cross sections [3]

THE n_TOF FACILITY

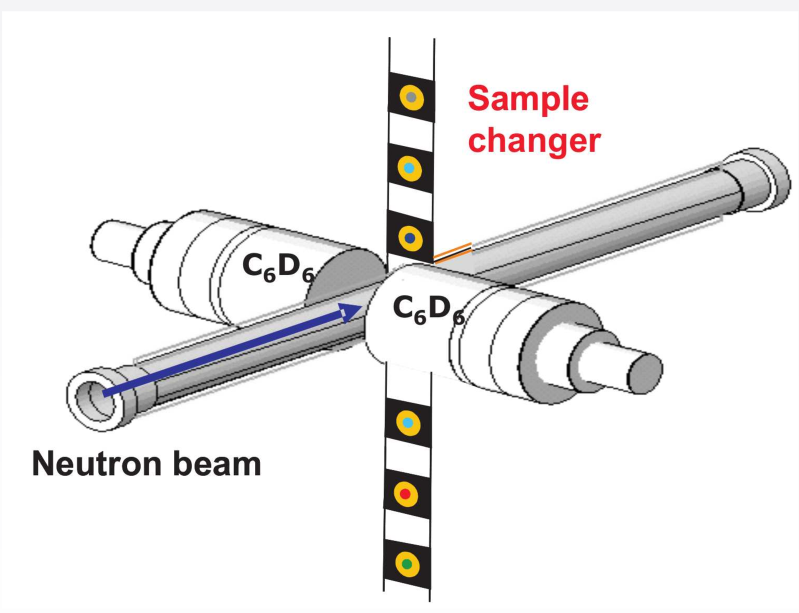
The neutron Time-of-Flight facility n_TOF at CERN provides a flight path of 187.5 m. The neutrons are produced via spallation, obtained by CERN PS protons with an energy of 20 GeV impinging on a Pb-target. The target is surrounded by a water circuit for cooling and moderation.At full intensity one bunch consists of $7 \cdot 10^{12}$ protons with 6 ns width. One proton produces on average 300 neutrons with energies ranging from thermal to some GeV, resulting in a high neutron flux.



Layout of the facility



Neutron flux of the last campaign in 2004 measured with different detectors



C6D6 detector arrangement, samples can be changed remotely

In combination with a set of special designed C6D6 detectors with low neutron sensitivity this setup offers a perfectly suited opportunity to measure neutron capture cross sections of astrophysical interest. [5]

References:
[1] J. L. Tain, C. Domingo, et al. (The n_TOF Collaboration) CERN/INTC/2006-012 INTC/P-208
[2] Z. Y. Bao, H. Beer, F. Käppeler, F. Voss, K. Wisshak and T. Rauscher, “Neutron cross sections for nucleosynthesis studies”, Atomic Data and Nuclear Data Tables 76 (2000) 70;
[3] H. Nassar et al., Phys. Rev. Lett. 94, 092504 (2005)
[4] FWF-standalone project „Nukleosynthese im Labor – Neutroneneinfang an Fe und Ni“ (principal investigator A.Wallner)
[5] U. Abbondanno et al. (The n_TOF Collaboration), CERM n_TOF Facility; Performance Report, CERN/INTC-O-011 INTC-2002-037 CERN-SL-2002-053ECT (2002)

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