Characterization of Detector Systems for Photofission Studies ◇

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One of the central goals of the DFG Cluster of Excellence MAP (Munich-Centre for Advanced Photonics) is the development of a brilliant source of ultra-short X-ray photon beams. Therefore strong efforts are presently conducted to develop a laser-driven table-top free-electron laser (TT-XFEL) [1] with the longterm perspective to rival and even surpass the performance of its large-scale, accelerator-based counterparts.

Amongst the wide range of applications from medical phase-contrast imaging (applicable e.g. to tumour or cartilage diagnostics) to 4D imaging in molecular chemistry and biology, such brilliant photon beams will offer also new perspectives for photon-induced nuclear structure studies. Especially structure studies in the second and third minimum of actinide nuclei could largely benefit from the availability of such photon beams.

Highly monochromatic photon beams ($\Delta E/E \sim 10^{-3}$) can be expected with unprecedented photon flux intensities of up to 10^{12} photons/pulse at 8 MeV photon energy, operated at a (laser) repetition rate of 10 Hz. In view of the exceptionally high photon flux one may even consider to add a monochromator to realize an energy resolution around 100 eV at the expense of about 4 orders of magnitude reduction of the photon flux, still ending up with an intensity similar to world-leading γ-ray sources like the HIγS facility at Duke University (USA) with 10^8 photons/sec at 5 MeV [4].

Photofission had extensively been studied in the past by the Stuttgart group (U. Kneissl et al.), however, these activities have ceased due to retirements and topical reorientations. Fortunately the photofission detector equipment could be transferred to Munich, forming the basis of external preparatory experiments on the way to future photofission experiments at the TT-XFEL. Presently four Parallel Plate Avalanche gas detector (PPAC) arrays are available for photofission studies, each equipped with a stack of 15-25 large area fissile actinide targets (target diameter 6.5 cm, thickness: 2.3 mg/cm^2) on 50 μm aluminum foils [2]: (a) ^{232}Th: 25 targets, (b) ^{235}U: 16 targets, (c): ^{238}U: 15 targets. In these detector stacks the actinide targets simultaneously act as detector electrodes, operated alternatively at about U= +450 V or ground potential. In addition a fourth array with 23 ^{238}U targets allows for coincidence measurements of both fission fragments.

The multidetector array designed for coincident detection of both fission fragments (shown in Fig. 2) consists of 23 ^{238}U targets (2 mg/cm^2) on 5μm Al foils. The cathodes are made of thin (2 μm) hostaphan foils, while the anodes consist of thick (50 μm) aluminum, thus preventing double counting of fragments in adjacent detector array sections.

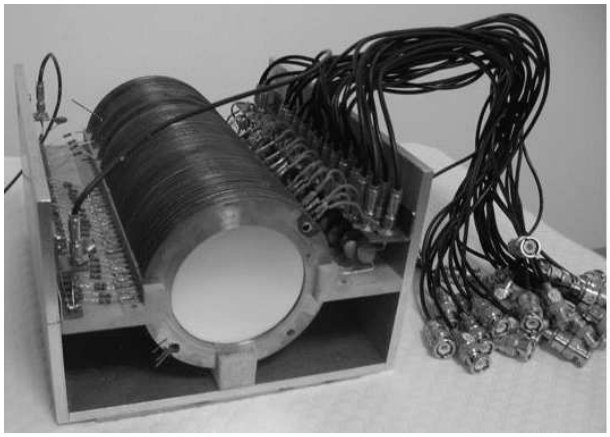

Fig. 1: PPAC array (25 targets) for the detection of fission fragments from ^{232}Th photofission.

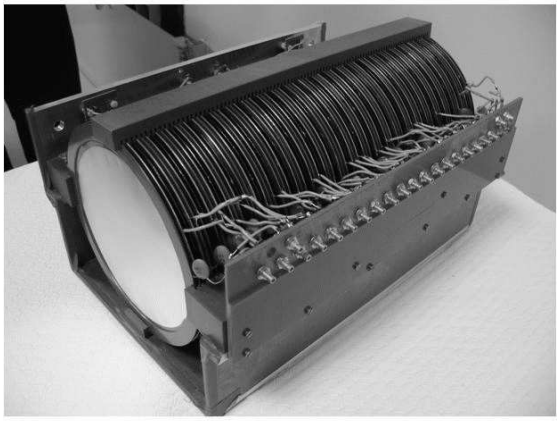

Fig. 2: PPAC detector array (23 targets) for the coincident detection of fission fragments from photofission of ^{238}U.

The setup schematics for the PPAC detector stacks using ^{235,238}U and ^{232}Th targets is shown in Fig. 3.

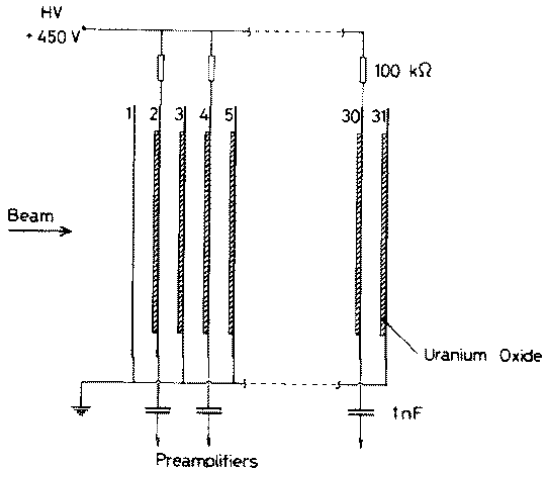

Fig. 3: Schematics of the setup of the PPAC stack arrays for photofission studies of ^{235,238}U and ^{232}Th [2].

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A schematical view of the coincidence detector setup and its signal processing electronics is shown in Fig. 4.

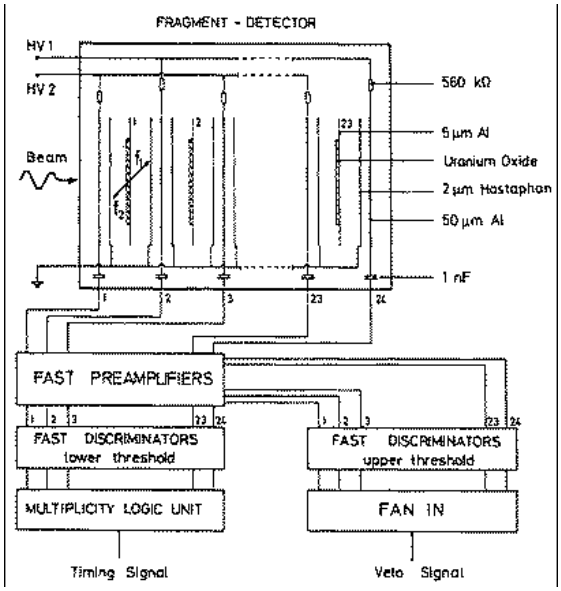

Fig. 4: Schematics of the PPAC array for coincident detection of fission products from ^{238}U photofission with its signal processing electronics [2].

The detector arrays were tested and characterized at the ATOMKI institute in Debrecen, using the ^{27}Al(p,n) reaction with proton beams from the Debrecen cyclotron (E_p = 14 MeV). In parallel the signal processing electronics was upgraded by an improved fast, low-noise preamplifier design. The detectors were operated with 5 mbar isobutane at an electric field of about 1.5 kV/cm (U≈450 V at 3 mm gap distance). Fig. 5 displays results from studies of the gas amplification as a function of the operational high voltage, while Fig. 6 shows the time difference of fission fragments detected in neighbouring PPAC detectors ranging from 1.4 ns to 1.7 ns.

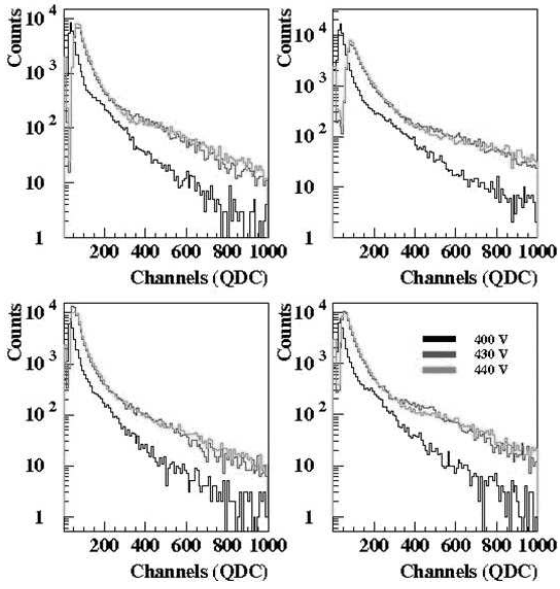

Fig. 5: Signal amplitudes from the ^{238}U coincidence PPAC array studied as a function of the operational high voltage, obtained by neutron-induced fission following the ^{27}Al(p,n) reaction.

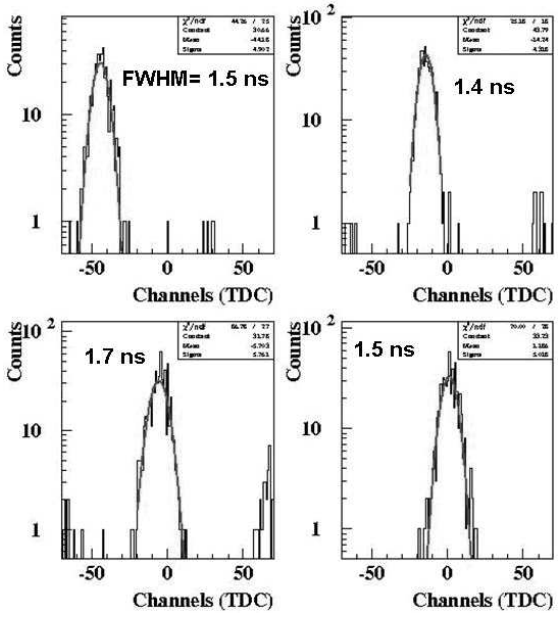

Fig. 6: Time difference of fission fragments detected in neighbouring elements of the ^{235}U multi-detector PPAC array by neutron-induced fission following the ^{27}Al(p,n) reaction.

It is planned to perform first photofission experiments with the PPAC detector arrays in summer 2008 at the new photon tagger NEPTUN operated at the S-DALINAC in Darmstadt [3]. There the energy loss of electrons during the generation of Bremsstrahlung can be determined with a magnetic spectrometer, thus allowing to tag the energy of individual photons from bremsstrahlung with excellent accuracy (about 25 keV at 10 MeV). At NEPTUN a tagged photon flux of about 10^4 photons/(keV·s) can be expected.

First experiments will focus on photofission of ^{238}U, because here the largest values of the fission probability in the low-energy region above 3 MeV in the region of the 'isomeric shelf' have been reported [5,6]. The isomeric shelf denotes a sudden change of the slope of the prompt photo-fission probability, explained by Bowman [7,8] by an increased fission yield passing through the fission isomer for excitation energies below the kink compared to the prompt fission probability for higher values of the excitation energy. Whereas the older measurements were performed with (untagged) Bremsstrahlung, resulting in a broad energy resolution averaging out all resonant structures, with the improved quality of tagged photon beams we are confident to be able for the first time to resolve possible resonance structures in the energy region of the isomeric shelf down to about 3 MeV excitation energy. These measurements will prepare for future studies with photon intensities increased by orders of magnitude at an energy resolution that will allow to resolve individual states in the super- and hyperdeformed second and third potential minima of actinide isotopes.

References

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