

Reactions with polarized electrons and photons at low momentum transfers at the superconducting Darmstadt electron linear accelerator S-DALINAC

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Abstract. A source of polarized electrons has been installed at the superconducting Darmstadt electron linear accelerator S-DALINAC. Experiments with polarized electrons from 100 keV to about 80 MeV are expected to commence in early 2011. This contribution summarizes the status of the polarized source as well as ongoing preparations for the experimental program with polarized beams. In particular, we present results on unpolarized test experiments of the $^{234,238}\text{U}(\gamma, f)$ reactions and considerations for the $^2\text{D}(\vec{e}, e'p)$ and $^3\text{He}(\vec{e}, e'p)$ reactions.

1. Polarized electron beams at the S-DALINAC

The superconducting Darmstadt electron linac S-DALINAC [1] provides electron beams with currents up to 60 μA for nuclear structure physics experiments. At the superconducting injector linac, energies up to 10 MeV are achieved for photon scattering and photo-activation experiments [2]. The main linac is designed for energy gains of up to 40 MeV, yielding a total maximum energy of the S-DALINAC of 130 MeV after two recirculations. The beam is then transferred to either the low-energy photon tagger system NEPTUN [3], to a setup for un-marked bremsstrahlung [4] or to a QClam-type large-acceptance magnetic spectrometer for $(e, e'x)$ coincidence [5] and single-arm (e, e') experiments at 180° [6]. A high-resolution magnetic spectrometer [7] that can be operated in dispersion-matched mode completes the facility.

To enhance experimental capabilities, a source of polarized electrons has been installed. The source has undergone successful bake-out at 250°C . In parallel, the beam line to the superconducting injector was optimized and upgraded, including a new chopper-buncher system.

Prior to its installation the source of polarized electrons was tested at a stand separate from the S-DALINAC. An overview of the source teststand performance and the implementation process at the S-DALINAC is summarized in recent conference reports, *e.g.* reference [8]. Typical

normalized emittances of < 0.2 mm mrad were achieved at 100 keV with a maximum degree of polarization of 86(3)%. Beam currents of above $50 \mu\text{A}$ were realized. The cathode lifetime amounted to about 100 hours at a pressure below $1.6 \cdot 10^{-11}$ mbar in the cathode chamber.

We foresee to operate the source with two different laser systems: A diode-laser system will provide the robust operation of the source with a repetition frequency of 3 GHz, the fundamental frequency of the S-DALINAC. In addition, a Ti:Sapphire laser system has been prepared providing short (> 200 fs) pulses at a repetition frequency of 75 MHz or fractions thereof, *e.g.* for time-of-flight measurements. Various laser diagnostic elements have already been established or are to be completed in the near future.

The laser systems are located in a dedicated laboratory 40 m from the source. While the light of the diode laser system – in the future maybe also a mode-locked vertical-external-cavity surface-emitting laser – is transported via an optical polarization-conserving mono-mode fibre, the high-power Ti:Sapphire pulses are guided using an evacuated beam line with an active pointing and centering system that is being set up at the moment. First tests indicate that vibrations up to about 500 Hz may be corrected with this system to sufficient accuracy.

The commissioning of the polarized source is scheduled for early 2011. Mott polarimeters for 100 keV and 5-10 MeV electrons have already been installed. A Compton transmission polarimeter has been constructed and successfully tested [9] at the injector of the Mainz Microtrons (MAMI). A Møller polarimeter for beam energies above 50 MeV is being developed.

In the following, selected examples for proposed experiments with polarized electron and photon beams at the S-DALINAC will be presented. For another important example, the measurement of the correlations between bremsstrahlung polarization and electron polarization, we refer to results from our teststand (cf. these proceedings and a forthcoming article [10]).

2. Search for parity non-conservation (PNC) in photo-induced fission

Nuclear fission induced by polarized neutron beams exhibits a forward-backward asymmetry in the angular distribution of the light and heavy fragments [11]. This parity non-conserving effect is attributed to the influence of the weak interaction on the nuclear system. The effect's magnitude of $\sim 10^{-4}$ is larger than expected from the ratio of the coupling constants of the weak and strong interactions. Enhancement may arise, *e.g.*, due to the high level density [12, 13], but an unambiguous quantitative interpretation is still missing. Hence, further studies using a different probe are in order. Intense polarized γ -ray beams will be available at the S-DALINAC from the bremsstrahlung of polarized electrons. In photofission, the excitation energy range through bremsstrahlung is rather broad, but additional enhancement effects may arise, such as the statistical enhancement discussed by Flambaum and Gribakin [12].

First experiments with unpolarized beams from the thermionic electron source of the S-DALINAC have been carried out at the injector experimental site. Goals of the experiment were (i) to determine the fragment yield for a possible PNC experiment and (ii) to test a double ionization chamber as a possible device for that purpose. A twin-ionization chamber detects both fragments in coincidence and makes use of the double-kinetic-energy technique. (iii) The angles of the emitted fragments needed to be determined with respect to the target orientation, and (iv) the fission characteristics of $^{234,238}\text{U}$ when excited by photons were studied.

The functionality of the twin Frisch-grid ionization chamber [14] turned out to be excellent in the bremsstrahlung environment. The entire chamber including the target was oriented at 45° with respect to the beam in order to maximize the yield as the fission fragments are mainly emitted perpendicular to the beam direction [15]. Hence during the tests, no angular distribution of the fragments with respect to the beam direction could be determined as no segmentation was used with the anodes. Knowledge of the fragment emission angle, however, with respect to the uranium target is necessary to correct for the slowing down of the fragments in the target material. The experiments showed [16] that this angle can be determined from the measurement

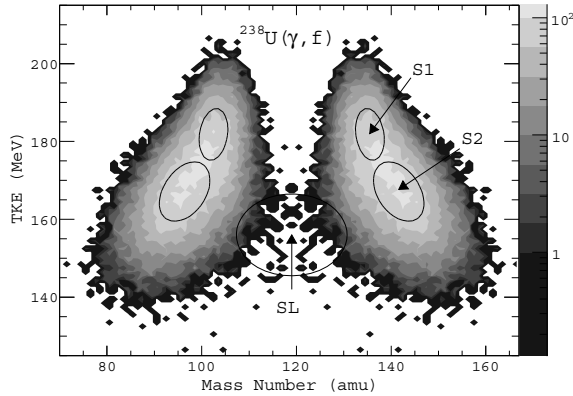


Figure 1. Fission-fragment yield as function of the mass number and $\langle \text{TKE} \rangle$ from $^{238}\text{U}(\gamma, f)$ at $\langle E_x \rangle = 7.06$ MeV. The ellipses labeled S1 and S2 are contours of the standard fission modes from a fit to the data. The region of the unobserved super-long mode is labeled SL.

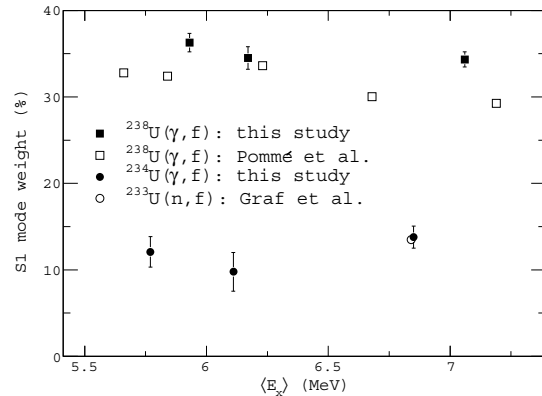


Figure 2. S1 mode weights as function of the average excitation energy for $^{238}\text{U}(\gamma, f)$ from this study (full squares) and from Pommé *et al.* ([17], open squares), for $^{234}\text{U}(\gamma, f)$ from this study (full circles) and from $^{233}\text{U}(n, f)$ by Graf *et al.* ([20], open circle).

of the drift times to the anode with an accuracy comparable to other experimental techniques.

The characteristics of photo-induced fission of $^{234,238}\text{U}$ were determined at three endpoint energies of the bremsstrahlung for each target. Endpoint energies between 6 and 9 MeV correspond to average excitation energies in the barrier region. From the anode pulse heights of both sides of the twin ion chamber and the drift times of the electrons to the anode, energies and masses of the fragments have been reconstructed. For $^{238}\text{U}(\gamma, f)$, good agreement with existing data by Pommé *et al.* [17] is found, corroborating the validity of our analysis [18]. From the average total kinetic energy $\langle \text{TKE} \rangle$ and the masses, a two-dimensional distribution is extracted (figure 1) that is analyzed within the fission-mode concept of Brosa and co-workers [19]. We do not find a symmetric mass split in $^{234,238}\text{U}(\gamma, f)$ close to the barrier region, and the two-dimensional distribution can be well described using the “standard” modes of fission, S1 and S2, indicated by ellipses in figure 1. Figure 2 displays the extracted weight of the S1 mode in the two investigated nuclei as a function of the average excitation energy. While the mode weights do not vary strongly with excitation energy, we find that the S1 mode weights change quite substantially between ^{234}U and ^{238}U . This is comparable to the findings in Pu isotopes [21].

With respect to a PNC experiment, the tests demonstrate insufficient sensitivity for a 10^{-4} effect, even at endpoint energies above the fission barrier. However, neither the electron beam current nor the thickness of a solid target can be increased sufficiently. This is shown in figure 3 for the measured angle resolutions [16] for $^{234,238}\text{U}$ from our test experiment. Figure 4 displays Monte-Carlo simulations on the influence of the target thickness on mass resolution (see [18] for details).

A possible solution to the luminosity limitation is an active gas target. Uranium hexafluoride (UF_6) is gaseous at temperatures above 57°C . However, several challenges arise considering such a target: (i) The handling of UF_6 is demanding: Heating, gas-flow control, exchange of the counting gas, filling, and evacuating the system need special care. (ii) Chamber materials need to be resistant with respect to possible chemical products (esp. hydrofluoric acid). (iii) The fragment ranges decrease due to the high stopping power of UF_6 if operated close to atmospheric pressure. Hence, a fine segmentation may be required. (iv) The performance of UF_6 as a counting gas, typical electron drift times, and the role of quenching must be studied. In order to

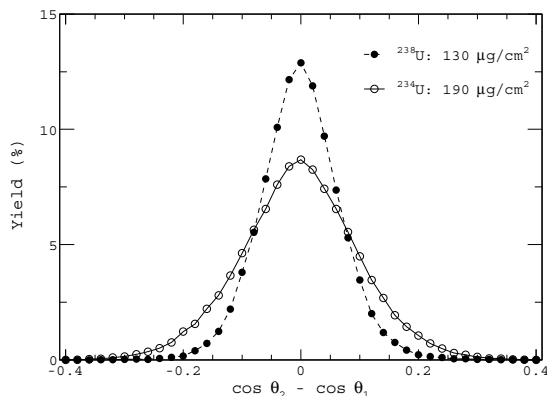


Figure 3. Target thickness effect on the angle resolution from the difference of the cosine of the fragment emission angles as obtained experimentally.

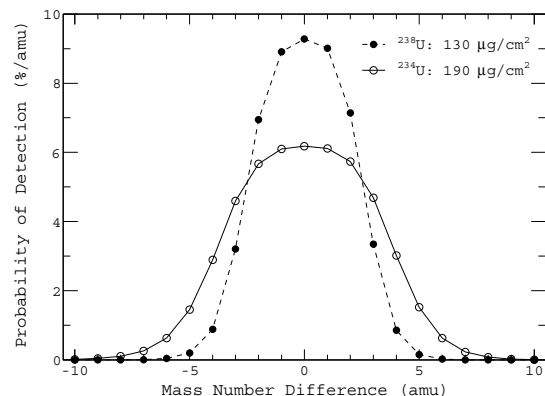


Figure 4. Target thickness effect on the mass resolution as obtained from a Monte-Carlo simulation. The probability of detection is shown as a function of the difference between the true and the detected mass.

address these issues, we have constructed a single Frisch-grid test ion chamber. Nearly all metal components have been made from stainless steel, and as insulation material teflon was chosen. First successful tests have been carried out with argon as counting gas and using an α -source at the cathode. Loading the system with UF_6 is foreseen for the immediate future.

3. Polarized break-up of light nuclei

In addition to the research program with polarized photons, we foresee studies on electron-induced reactions with light nuclei. With a polarized incident electron beam, five terms contribute to the electron scattering cross section [22]. One of these – the so-called fifth structure function – depends on the electron's helicity and is sensitive, among others, to the final-state interaction of the break-up product and the reaction residue.

The fifth structure function had first been measured at the Bates linear accelerator for quasi-elastic kinematics on $^2\text{D}(\vec{e}, e'p)$ and $^{12}\text{C}(\vec{e}, e'p)$, see references [23, 24]. Our experiment is aimed at much lower momentum transfers. It complements experiments on one of the unpolarized exclusive structure functions [5]. Here, deviations from the predictions of potential models [5] as well as pion-less chiral effective field theory [25] occurred, while these calculations otherwise describe experimental data extremely well. Predictions on the fifth structure function in the deuteron break-up are available [26] that suggest that an experiment using the same experimental parameters as reference [5] can be performed within a few weeks of beam time. We note that in addition to the exclusive data, a recent 180° electron scattering experiment at the S-DALINAC [6] was capable of extracting the transverse structure function at low momentum transfer, in good agreement with theoretical predictions.

In addition, a high-luminosity helium gas target is presently being set up for electron scattering at the S-DALINAC. Quantitative predictions for typical experimental conditions of a $^3\text{He}(\vec{e}, e'p)$ experiment at the S-DALINAC have already been worked out by Golak using nonrelativistic Fadeev calculations and the AV18 potential along the lines of reference [27]. These calculations indicate a subtle interplay of final-state interaction, contributions from mesonic exchange currents, and three-body effects.

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