I Introduction

At the femtometre length scale, the atomic nucleus can be adequately described as a system of protons and neutrons without having to regard their substructure. The strong interactions which at energy scales above a few GeV have to be described in terms of the nucleonic constituents, *i.e.*, quarks and gluons, can in the case of the present experiment be treated in terms of effective interactions between nucleons, mesons and Δ isobars. The two-body part of the nucleon-nucleon (NN) interaction provides the dominant part of the binding in nuclei. It has a complicated structure, depending, *e.g.*, on the value and relative orientation of spin and isospin of the interacting nucleons, that is attractive at distances above approximately 1 fm, but strongly repulsive at short inter-nucleon distances. The long-range behaviour can be theoretically described by the exchange of a single pion, while the correlated exchange of multiple mesons is used in the description of the intermediate-range part. The short-range part has to be treated in a phenomenological way, either explicitly or described by exchange of heavier mesons like ρ and ω with phenomenological form factors, since at this scale the description of the nucleus in terms of nucleons and mesons is no longer adequate and a theoretical treatment based on quantum chromodynamics is not available. The use of a realistic NN interaction induces correlations among the nucleons in the nuclear wave function.

Several potential models of the NN interaction are available describing the deuteron binding energy and the phase shifts deduced from nucleon-nucleon scattering experiments with a χ^2 per datum of approximately one, *i.e.*, they are phase-shift equivalent. The Bonn potential model [Mac89] is based on the exchange of single and multiple mesons. Since its energy dependence poses difficulties in many-body calculations, derived forms like the Bonn-B interaction are commonly used. The Bonn-B model is constructed in momentum space and is non-local at scales around the nucleons Compton wavelength when expressed in coordinate space (*i.e.*, it contains 'instantaneous' interactions of spatially separated particles). Recently, a new, charge-dependent model CD-Bonn [Mac96] was introduced which provides a better fit to the existing NN scattering data. The Argonne v_{18} potential [Wir95] also uses one-pion exchange for the description of the long-range part, but employs a completely local description. The intermediate- and short-range parts have a more phenomenological nature and the non-local character of the potential is limited. The interactions developed by the Nijmegen group [Sto94] are also local in the description of the one-pion exchange. Of the various models, Nijmegen-II is entirely local and Nijmegen-I and -93 are only mildly non-local in the short- and intermediate-range part. Thus, although close to equivalent in the description of NN scattering data, the models for the two-body interaction describe both long- and especially short-range characteristics in a different way.

Exact calculations of nuclear ground-state properties, based on the aforementioned NN interaction models, are currently possible for $A \leq 7$ [Car98], while in heavier nuclei approximations have to be made. Exact calculations are feasible for breakup reactions in which no more than three nucleons are involved and for energies below approximately 350 MeV [Glö96]. The study of nuclear ground-state properties like, *e.g.*, the binding energy of three-nucleon systems, already provides a means to study the characteristics of the NN interaction; calculations of the triton binding energy reveal differences of up to 375 keV between the various potential models [Nog97] and a discrepancy of 530–900 keV with the experimental value. Additional binding of the triton is provided by the introduction of three-nucleon forces, *e.g.*, based on $\pi - \pi$ exchange, of which the strength is adjusted depending on the NN interaction used.

Exclusive nuclear-breakup processes and the investigation of spin degrees-of-freedom offer more possibilities for the investigation of the structure and dynamics of the few-nucleon systems, as they are sensitive to, *e.g.*, short-range features or small components of the nuclear wave function. They are also sensitive to the off-shell behaviour of the NN interaction, *i.e.*, the total energy of the nucleons involved in the reaction is not the same in the final state and the initial state, something that cannot be probed by elastic nucleon-nucleon scattering experiments. Electron- and photon-induced breakup of the few-nucleon system is suited for such studies, as the electromagnetic part of the interaction is well known. In addition, the use of virtual photons offers the possibility to vary independently the energy and momentum transfer to the system and to use the longitudinal polarization of the virtual photon.

Experimental studies of electromagnetically-induced two-body and three-body breakup of the three-nucleon system have mainly been performed on ^{3}He, because of the experimental difficulties associated with the use of tritium. The experiments include the electron-induced two-body breakup reaction $^3\text{He}(e,e'p)d$ [Jan87, Kei87, Mar88, Duc93, LeG97, Flo99] and the semi-inclusive three-body breakup $^3\text{He}(e,e'p)pn$ [Jan87, Mar88, LeG97, Flo99]. Also two-body breakup experiments of the type $^3\text{He}(e,e'd)p$ have been performed [Kei85, Kei87, Tri96, Spa98]. In these experiments, momentum distributions were obtained up to 500 MeV/c, while at 90 and 260 MeV/c also a longitudinal-transverse separation was performed. Although the cross section is strongly influenced by contributions from meson-exchange currents and final-state rescattering, signatures of NN correlations were observed in these studies for momenta above 300 MeV/c. The proton-proton density distribution was extracted for relative momenta from 200 to 550 MeV/c in a model-dependent analysis of inclusive $^3\text{He}(e,e')$ data by Beck [Bec90].

Exclusive $^3\text{He}(\gamma,p)d$ [Isb94] and semi-inclusive $^3\text{He}(\gamma,p)pn$ [Hos89] reactions were performed using bremsstrahlungs photons. Also photon-induced exclusive three-body breakup, $^3\text{He}(\gamma,pp)n$, was investigated in detail. Measurements by Audit *et al.* [Aud89, Aud91] were performed in a kinematic domain selected to emphasize the production of on-shell pions on the struck nucleon that are subsequently reabsorbed on the nucleon pair. The results were evaluated in a theoretical framework based on a diagrammatic expansion of the reaction amplitude [Lag85]. These measurements indicate an important role for two-step processes in which three nucleons are involved, in particular sequential pion exchange. Such processes were also observed at lower energy transfers, in which the initial pion is assumed to propagate off-shell [Sar93].

The use of tagged photon beams opened the possibility of kinematically complete measurements of the full breakup cross section. Measurements with the large-solid-angle detector DAPHNE [Aud97], again in the Δ resonance region, showed that the cross section for photon-induced breakup at $E_\gamma < 500$ MeV is dominated by two-step three-nucleon processes in those regions of phase space where final-state rescattering effects are minimal. No neutron momentum distribution could be extracted from this dataset. The role of three-nucleon mechanisms was also identified by Kolb *et al.* [Kol96] at lower photon energies. Neutron momentum distributions extracted by Emura *et al.* [Emu94a, Emu94b] in the Δ resonance region (E_γ=200–500 MeV) showed that both two-nucleon and three-nucleon photo-absorption mechanisms are needed to explain the data, but that at low neutron momentum the two-nucleon processes dominate the cross section. Due to the choice of the kinematic domain and the transverse nature of the probe used in these experiments, the absorption of the photon by a two-proton pair observed at low neutron momentum cannot be uniquely attributed to knockout induced by one-body hadronic currents.

The $(e, e'pp)$ reaction provides a tool to investigate the role of NN correlations inside nuclei. At intermediate electron energies, the reaction amplitude is driven by several processes. Firstly, coupling of the virtual photon to one nucleon – described by a one-body hadronic current – can lead to emission of two nucleons due to initial-state correlations. Secondly, two-body hadronic currents, like coupling to mesons (meson-exchange currents or MECs) and excitation of the Δ in an intermediate state, will contribute to the cross section. Also final-state rescattering will give contributions to the cross section. The detection of two protons in the final state has the advantage that it allows measurement of those regions in phase space where the neutron, which remains undetected, has a low momentum and can thus be considered as a spectator particle. In such a 'direct' reaction on a proton-proton pair, the contribution from meson-exchange currents is suppressed since – to first relativistic order – the photon does not couple to the uncharged mesons involved. Also the contribution of Δ excitation is reduced because of angular momentum and parity conservation selection rules.

Study of the momentum transfer dependence of the cross section can be used to investigate the coupling mechanism of the virtual photon to a pair of nucleons. The energy transfer should then be chosen such that the influence of intermediate Δ excitation to the cross section is reduced, *i.e.*, well below the invariant mass of the $N\Delta$ system at 2170 MeV/c^2, but sufficiently high to emit two protons from the nucleus with enough kinetic energy to pass the detector thresholds. On the other hand, variation of the energy transfer allows investigation of meson-exchange and isobar contributions to the cross section.

Preferably, measurements should be performed over a large domain in relative and centre-of-mass momenta of the nucleons involved. Together with knowledge on the reaction mechanism this may provide insight in the bound-state wave function of the ^{3}He nucleus for specific values of relative and centre-of-mass momenta. A detailed comparison with the results of calculations, based on different models of the NN interaction, can subsequently be made.

The recent advance of high duty-cycle electron accelerators has made possible the three-fold coincidence experiments necessary to measure exclusive electron-induced two-nucleon knockout. Experiments aiming at the study of NN correlations by means of the $(e, e'pp)$ reaction were pioneered with the ^{12}C$(e, e'pp)$ experiments by Zondervan *et al.* [Zon95] and Kester *et al.* [Kes95]. Measurements performed by Onderwater *et al.* [Ond98a] at the Amsterdam Pulse Stretcher AmPS facility using large-solid-angle proton detectors revealed signatures of short-range correlations in the ^{16}O$(e, e'pp)^{14}$C reaction. Similar results were obtained with a three-spectrometer setup at the Mainz Microtron MAMI [Ros97]. Experimental evidence for short-range correlations was obtained from the study of the ^{16}O$(e, e'pp)^{14}$C$_{\rm g.s.}$ reaction at various energy transfer values by Starink *et al.* [Sta99a].

In this work measurements of exclusive electron-induced two-proton knockout on ^{3}He are discussed. Chapter 2 is devoted to a description of the kinematics of the ^{3}He$(e, e'pp)$ reaction and discusses calculations of the cross section based on the continuum Faddeev technique employed by Golak *et al.* [Gol95]. Here, also the numerical methods necessary to compare the calculations to data are discussed. The experimental setup is described in chapter 3, where also an overview of the measured kinematic settings is given. The analysis of the data is described in chapter 4. In chapter 5 the extracted cross sections are presented and compared to the results of the continuum Faddeev calculations. The work ends with a summary and an outlook.