The recent closure of the Amsterdam Pulse Stretcher marks the end of 30 years of electron accelerators in the Netherlands.

The turn of the year was significant for the Dutch NIKHEF laboratory: 1998 was the last year in which data were taken at the institute’s Amsterdam Pulse Stretcher (AmPS). Even before the AmPS was built, funding organizations had decided that it would only be exploited from 1992 to 1998 because it was a heavy load on the Dutch science budget.

The first steps towards electron scattering experiments in Amsterdam were taken at the beginning of the 60s when institute director Prof. Gugelot sent his former PhD student Conrad de Vries to Stanford. There, at the cradle of electron scattering, de Vries worked in Robert Hofstadter’s group. The 3 km linear electron accelerator was being designed next door at SLAC. On his return to Amsterdam, de Vries convinced the institute (then called IKO, the Instituut voor Kernfysisch Onderzoek) that electron scattering provided the best possibilities for future nuclear physics experiments.

While de Vries formed a research group and designed experiments, a linear accelerator was constructed in a joint effort by IKO and the Philips company. In 1946 Philips had built the synchrocyclotron at IKO – the first in Europe. Now it wanted to gain experience in constructing linear accelerators, thereby using superconductivity. It was an ambitious goal, and when the detectors were ready there were still problems with the accelerator. Long delays were foreseen and de Vries turned to his former colleagues in Stanford. In 1966 the US Atomic Energy Commission approved a plan to send two spare SLAC sections to Amsterdam – officially “on permanent loan”. The two 3 metre sections formed a 90 MeV linear accelerator (with the Dutch acronym EVA), which became operational in 1968.

Since the Netherlands could not go for large accelerators or huge projects, de Vries decided to aim for precision measurements. Very precise data on the charge radius of carbon-12 are still standard today. The spatial magnetic distribution was measured for a variety of nuclei, ranging from lithium-6 to indium-115. At these low energies it is difficult to separate the small magnetic contribution from the much larger charge contribution, with one exception: at a scattering angle of 180° only the magnetic component contributes. In a specially built 180° arrangement – comparable to the one built by Barber and Peterson at SLAC – magnets were used to separate back-scattered electrons from the incoming electron beam. The resulting data were complementary to higher energy results at the 600 MeV electron accelerator (ALS) at Saclay.

From the start it was clear that a larger accelerator than EVA was needed, and the first plans for a medium-energy accelerator (MEA) were submitted at the end of the 60s. The cost of this 500 MeV machine – about 40 million guilders for construction – was very high by Dutch standards, and the project required much prior organization. Construction started only in 1975 and the first measurements with MEA electrons were made in 1981. In 1983 MEA could deliver up to 40 microamps at a duty factor of 1%. This was lower than the 10% originally aimed for, but much higher than the 0.02% of EVA.

Precision measurements

Again the emphasis was on precision measurements, including experiments in which a proton was knocked out of the nucleus by the electron. By carefully measuring the momenta of the emerging proton and of the incoming and scattered electron, the initial momentum of the proton in the nucleus can be reconstructed. For this, two spectrometers were built with precisely known magnetic fields and a momentum resolution of 10^{-4}. Each covered a limited angular range but they could be moved with respect to the target and precisely positioned over a wide range of angles. The obtained resolution on the missing mass – the energy of the proton in the nucleus – was 100 keV. An intriguing result of measurements on a variety of nuclei was that about 35% of the protons in the nuclei were missing! An explanation was that the "missing protons" were moving much faster in the nucleus than expected, and faster than could be detected in the MEA measurements. Such high proton momenta could be due to strong repulsive forces between nucleons.
scattering in Amsterdam

The QDD- (left) and QDQ-spectrometers, with their precisely known magnetic fields and high momentum resolution, carried out precision studies of nuclear proton knockout by electrons.

that were close together.

To solve the puzzle of the high-momenta protons, a new generation of more precise experiments was needed. This was one reason to extend the accelerator with a pulse stretcher and storage ring (AmPS), which was duly completed in 1992. Electrons revolve around this 212-metre-circumference ring in 0.7 microseconds. MEA pulses of between 0.7 and 2.1 microseconds are therefore stretched to a continuous electron stream which, in stretcher mode, is then slowly extracted. The continuous low-intensity electron beam allows detectors to work more efficiently than when intense pulses lead to saturation. It also allows for a much better background suppression.

In 1997 first results were obtained on measurements of simultaneous two-proton knockout in helium-3 and oxygen-16 (December 1997 p16). The protons were detected in two “HADRON” detectors, built by NIKHEF and the Free University in Amsterdam. The scattered electron was detected, as before, in one of the spectrometers. The measured proton and electron momenta allowed reconstruction of the momentum of the proton pair and of the excitation energy of the resulting nucleus. This led to a better insight into nucleon correlations, especially at short distances, and an improved description of the dynamics of nucleons inside the nucleus. With the NIKHEF experimental programme terminated, further measurements on helium-3 and oxygen-16 will be performed at the MAMI electron accelerator in Mainz.

With AmPS used in storage mode, polarized electron bunches from MEA – a current of 4 milliamps and a length of 0.7 microseconds – are injected and stacked in the ring (January 1997 p5). Stable operation with 150 milliamps of circulating current and a lifetime up to 45 minutes is possible while the energy can be ramped up to 900 MeV. The spin-polarized electrons are produced via photoemission from a gallium arsenide source built at the Budker Institute in Novosibirsk, which has been closely co-operating with NIKHEF since 1986. When injected into AmPS, the electron spins – which are longitudinally polarized – precess around the vertical fields of the ring’s dipole magnets. To achieve the strictly longitudinal polarization at the target, as required by the experiments, a so-called “Siberian Snake” was used.

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Variation in longitudinal polarization for 442 MeV electrons with spin angle. The data were obtained from Compton back-scattering with a laser and reveal a maximum longitudinal polarization at the target of 61 ± 3%, only slightly less than the longitudinal polarization at the electron source (69.8 ± 1.3%) measured with Mott scattering. This was the first time (1996) that polarized electrons were injected and their longitudinal polarization was preserved in a storage ring for substantial periods of time.

The neutron charge-form factor measured at AmPS compared with other measurements.

resulted in data with systematic uncertainties of about 5%.

A new series of measurements of the charge-form factor of the neutron scatter polarized electrons from neutrons in polarized deuterium or helium-3 nuclei. Due to interference effects the small charge-form factor is amplified by the dominant magnetic-form factor. When measuring the effect for opposite spin directions, an asymmetry is found from which the form factor can be deduced. There is a worldwide effort to measure the charge-form factor from this asymmetry, with experiments using external beams being carried out at MAMI in Mainz, at the Jefferson Laboratory (previously CEBAF) in Newport News, and at MIT-Bates. At NIKHEF, measurements on helium-3 and deuterium have been completed, and preliminary data for deuterium reveal the precision that can be achieved using internal targets.

Other scattering experiments use polarized hydrogen and deuterium. In the latter the electric monopole- and quadrupole-form factors of the deuteron were separated. The spin structure of the deuteron was studied via polarized electron-induced proton knock-out from polarized deuterium. These and other data together form a rich harvest of electromagnetic spin observables for the nucleon and few-body systems. Spin-dependent electronuclear internal target physics will now continue in the US with the recently approved BLAST-programme at MIT-Bates.

The curtain has now fallen for AmPS, on which 40 Dutch physicists and 60 physicists from 25 foreign institutes collaborated. It is not all over, however, because the MEA-AmPS installation will be shipped to the Joint Institute for Nuclear Research in Dubna for a new life as a synchrotron.

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