# FIRST BEAM TESTS WITH THE FAST KICKER MAGNET FOR THE ULTRA COLD NEUTRON FACILITY

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*The proposed new type of ultra cold neutron source to be built and installed at PSI requires the full intensity 590 MeV proton beam (currently 1.85 mA) to be switched onto the spallation target, located at the center of the UCN facility, for about 8 seconds every 15 minutes. For this purpose, a fast kicker magnet (rise-time $\leq$ 1 ms) located just in front of the existing DC-splitter device (EHT) has been proposed. One conclusion of the "Technical Review of the UCN Source Project Proposal at PSI", which took place on Nov.14 and 15, 2000, was that an early demonstration of the functioning of the fast kicking process was desirable before embarking on the overall construction effort for the whole facility. In the meantime, the required magnet, power-supply and control system have been manufactured by PSI. During the shutdown at the beginning of 2002, the required space for installing the kicker magnet had already been accomplished by modifying the proton beam line in front of the DC-splitter. The ceramic vacuum chamber for the magnet was also installed at this time. On December 4, 2002 a successful test of the fast switching process with 20 $\mu$A of proton beam intensity could be performed for the first time.*

## INTRODUCTION

Fig. 1 shows the region where the kicker magnet (AHKI) is placed. This device is mounted just in front of the DC-splitter (EHT4) because it is necessary to have it as close to the EHT4 as possible in order to keep the displacement of the beam - and therefore the losses produced by it at the EHT4 foil - as low as possible (see Fig. 2). The space requirements for the kicker are about 40 cm in the beam direction. During the last shutdown, the profile monitor-box MHP5/6 and the quadrupole QHA4 were moved towards the cyclotron by this amount. In order to gain this space, the vacuum pump PH11 and the valve VHD1 were replaced by less space-consuming modern devices (see Fig. 1). The optical influence of this modification is minimal and therefore does not affect the quality of the proton beam.

Because of the low duty-cycle (1%) and the fast switching time of about 0.5 ms [1], accumulation of excessive beam losses at the collimator in front of the septum magnet ABS is not possible. The sum of the beam losses with 3 kicks (2 for diagnostic purposes) per 15 minutes and a transition time of 0.5 ms would sum up only to 3 ppm. About half (2 W average thermal power with 2 mA beam intensity) is concentrated on the radiation-cooled ABS collimator, which will be hit head-on with a relatively small beam spot ($\sigma_x$ = 2 mm, $\sigma_y$ = 3 mm, see Fig. 3). Installation of a new water-cooled collimator is not necessary; because the surface of the plate-shaped collimator (750 cm²) is sufficiently large to keep it cool ($\Delta$T< 10°C for 3 kicks within 15 min). The activation of the collimator will remain relatively low. Long living

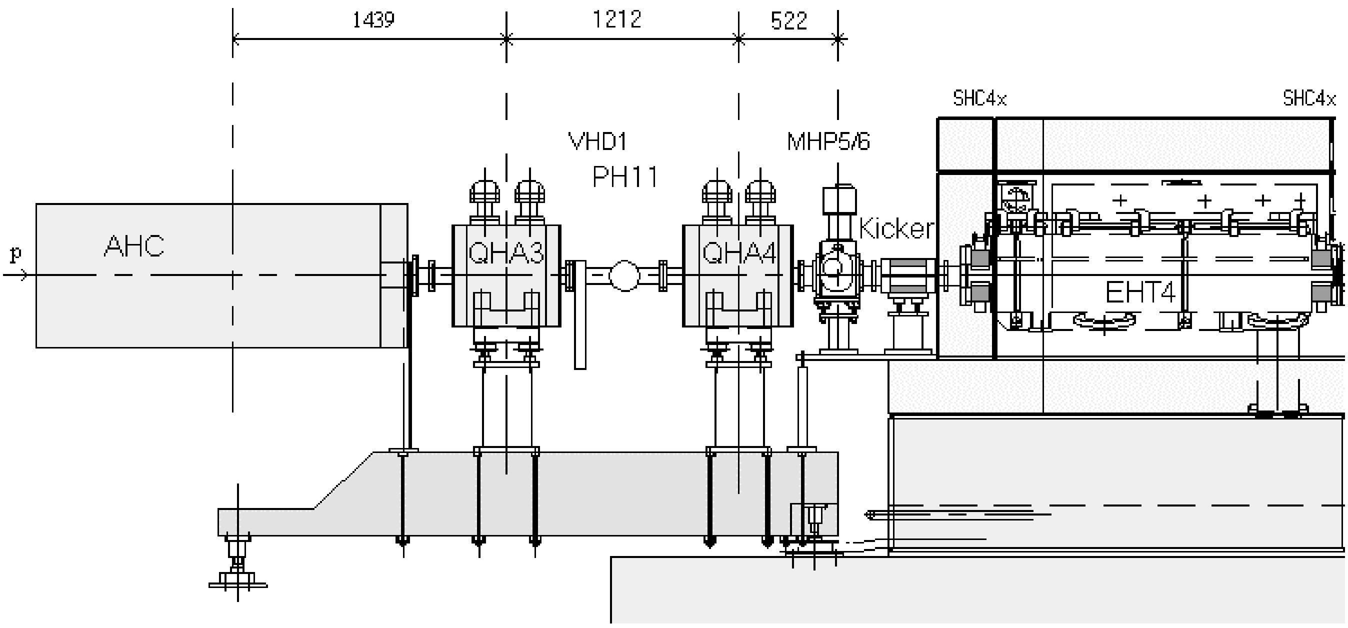


**Fig. 1:** New layout of the section of the proton beam line for switching with the fast kicker magnet. AHC: bending magnet; QHA3/4: quadrupole lenses, PH11: vacuum pump; VHD1: vacuum valve; MHP5/6: beam monitors; EHT4: electrostatic beam splitter; SHC4x: steering magnets; Kicker: newly installed fast deflecting magnet [2].

isotopes do not have a chance to build up significantly, because the integrated time for beam hitting the collimator is only about 50 seconds per year (with 0.5 ms switching time). The insulation of the coils of the septum magnet is non-organic (radiation hard) and will not be damaged by the radiation produced. A photograph of the kicker-magnet [2] mounted in front of the EHT inside its shielding cage is shown in Fig 4. After a thorough test in the laboratory together with the power-supply [1] and the control system [3], the magnet was successfully installed in a two-day service period in early December 2002.

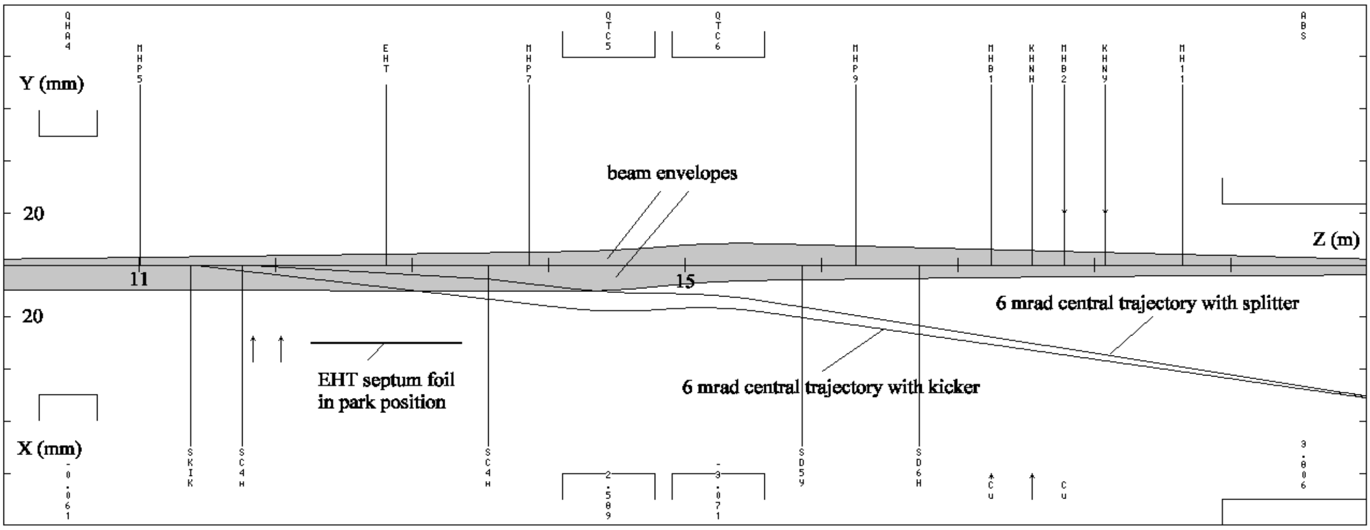


**Fig 2:** The kicked and the statically deflected proton beam central trajectories (6 mrad deflection angle) together with the x- and y-beam envelopes (2σ). The kicked beam will produce larger losses at the parked septum foil than the statically deflected beam.

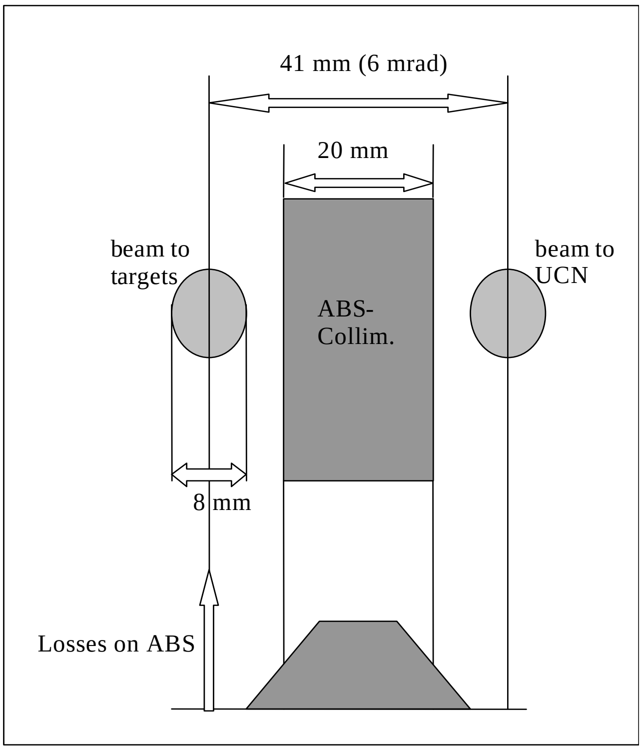


**Fig 3:** The beam situation in front of the magnetic septum magnet (ABS). If the transition with time were linear, then about 50% of the beam spill produced by the 6-mrad-kick would be deposited on the purely radiation-cooled ABS tungsten collimator. The width of the collimator is 20 mm and the beam separation ca. 41 mm. The 4σ width of the 2 mA proton beam is expected to be about 8 mm. The 20 mm sweep over the collimator is done within 200 μs [1].

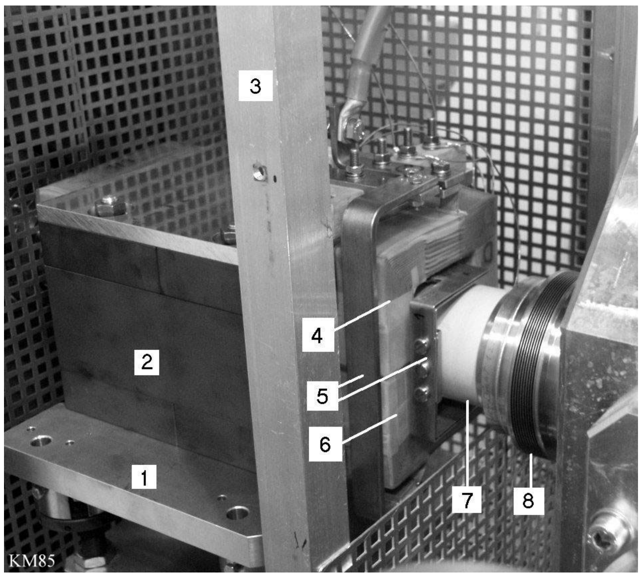


**Fig 4:** Photograph of the kicker magnet. 1: adjustable base plate, 2: ferrite yoke, 3: partially opened shielding cage, 4: upper coil, 5: current leads, 6: lower coil, 7: ceramic vacuum tube, 8: bellows. See also reference [2].

**FIRST TESTS WITH BEAM**

At the moment there is no high power beam dump for 2 mA available in the NA-beam line branch, which leads to the future UCN-source. Therefore, the first kicker tests with beam could only be performed with

| Beam currents in Micro-Amps | | | | |
|---|---|---|---|---|
| MHC1 | 23.3 | | MBC1 | 18.1 |
| Beam position monitors in mm | | | | |
| MBS1 | -15 | | MCS1 | 0.3 |
| MBS2 | | | MCS2 | -0.9 |
| MBS3 | -7.4 | | MCS3 | 4 |
| MBS4 | 0.8 | | MCS4 | 0.6 |
| MBS5 | -6.8 | | MCS5 | -5.5 |
| MBS6 | -0.3 | | MCS6 | 1.5 |
| MBS7 | -6.1 | | MCS7 | 5.2 |
| MBS8 | -0.4 | | MCS8 | -1.7 |
| MBS9 | -2.1 | | MCS9 | 7.2 |
| MBS10 | -1 | | MCS10 | -0.8 |
| MBS11 | -18.7 | | MCS11 | 0.9 |
| MBS12 | -0.2 | | MCS12 | -0.4 |
| MBS13 | -10.4 | | | |
| MBS14 | 0.8 | | | |
| Beam loss monitors in nA | | | | |
| MBI1 | 2.3 | | MCI1 | 0.4 |
| MBI2 | 9 | | MCI2 | 4 |
| MBI3 | 5.7 | | MCI3 | 20.3 |
| MBI4 | 0.1 | | MCI4 | 0.1 |
| MBI10 | 0.1 | | | |

**Table 1:** A Live-Display of the first beam-kick with 20 µA of beam current. Displayed are the relevant beam current monitors, the BPMs and the loss monitors. (MHC1 is optimized for 2 mA and has not been recalibrated for low currents.)

up to 20 µA onto the PIREX target station. Because of safety requirements, the interlock levels for the MHC1 and MHC2 current monitors in the main beam line branch leading to the targets M and E had to be set temporarily to 25 µA as is the case for the MBC1 current monitor in the NA-beam line leading to PIREX. We performed the first kick with 2 µA for 2 seconds in order to avoid any vacuum leak. A running live-display program with a repetition rate of 2 Hz displaying the measured beam currents, the beam position monitor (BPM) readings and the losses along the beam line leading to the PIREX target showed immediately that the beam reached the PIREX target without any corrections to the magnet settings, which were established with the statically deflected beam by using the SHC4x magnets of the DC-splitter for steering the beam to the PIREX target. The central trajectories of the 2 modes are shown in Fig 2. They are very close. Afterwards, the beam intensity was increased to 10 and then to 20 µA. Table 1 shows a hardcopy of the first beam kick with 20 µA. The values shown look almost the same as for the statically deflected beam with the exception that the losses along the beam line were about a factor of 2 higher. This is probably due to the fact that we could not carefully center the beam and that there are larger losses at the DC-splitter's septum-foil in the park position.

Fig. 5 shows an envelope fit using the profile data gained from different consecutive beam kicks of 8 seconds duration. During each of these beam-on periods, 3 to 4 different pre-selected profiles could be run and the graphic output stored on a computer screen. Because of the 1%-duty-cycle of the kicker power-supply, we had to wait 15 minutes for the next beam kick. It took us about 2 hours to get the required profile data to complete a 2σ-width data set for performing the desired envelope fit. A comparison of the resulting fit with the one gained from profile data taken with the direct, statically deflected beam (not shown in this article), showed no significant differences within the statistical fluctuation. It should be mentioned here that the quality of the 20 µA-beam was not very good. Prior to our beam shift, the cyclotron had been optimized to produce 1.85 mA and there was no time available to retune and improve the quality of the required low intensity proton beam.

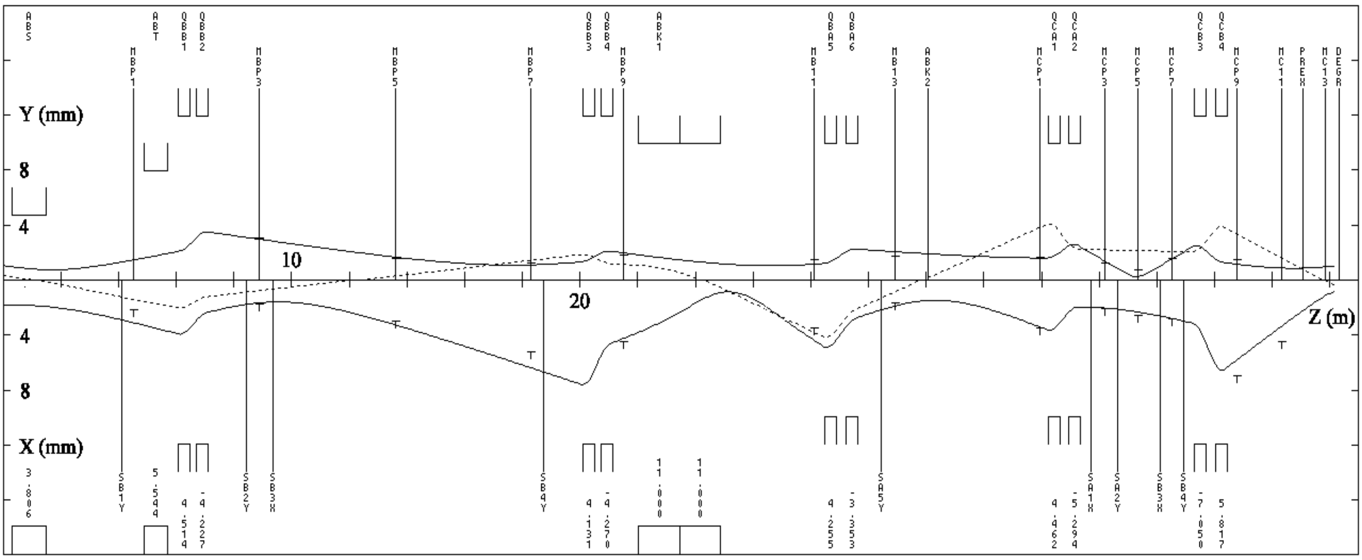


**Fig 5:** Envelope fit with the measured beam profile widths of the kicked proton beam at 20µA intensity. The measured 2σ-widths are marked with ⊥ and T, whereas the solid curves represent the fitted x- and y-envelopes. The dotted line is an assumed 1-permille-dispersion trajectory. Per kick only 3 to 4 profiles could be recorded. Therefore 7 runs with a waiting time of about 15 minutes in between were needed to gather the required data.

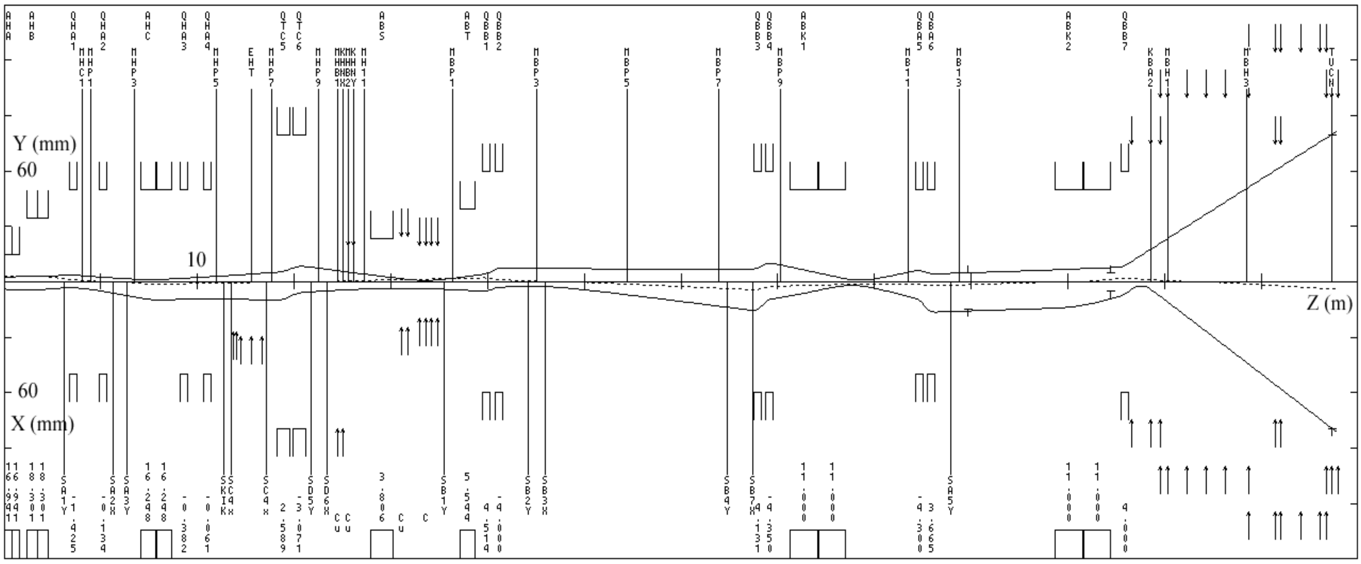


**Fig. 6:** Beam envelopes of the proton beam transport to the planned UCN facility. The emittance used is that of the 1.85 mA beam in December 2002. In order to keep the beam losses low, the beam size is kept as small as possible along the first 58 m from the cyclotron extraction to the last quadrupole lens. The latter acts as a beam-widener on the last 12 m so that, at the UCN spallation target, the beam size reaches the required 1σ-width of 40 mm in both transverse directions. On the last 12 m, several pairs of ↑↓ indicate the relatively large aperture size (vacuum tube, collimator and target) of the new section of beam line for the UCN facility. About half of this last 12 m section is already installed but not yet equipped with the planned diagnostic elements and not yet tested with beam.

## FUTURE DEVELOPMENTS

Fig. 6 shows the expected beam envelopes of the 2 mA beam between the 590-MeV cyclotron-extraction and the planned UCN spallation target. The emittance used is the one measured today with the 1.85 mA beam to the targets M and E. We do not expect that it will be significantly different when the UCN facility is ready. In order to save time and costs, several items necessary for UCN-production were not available for the first beam tests, but are required to be operational by 2006:

(1) During the beam pulse of 8 seconds, the efficiency of collecting beam profiles at 2 mA of beam intensity should be improved by synchronization of the profile monitors with the beam kicker.

(2) 2 pairs of harp monitors for the new section of beam line between QBB7 and the UCN target. They have the advantage of being profile monitor and BPM in one device and being able to stay in the beam continuously.

(3) In order to detect the beam position along the beam line during short beam pulses of 5 ms duration, new fast BPMs with a sampling rate of 1 kHz are required. During this short time interval of beam, no interlock will turn off the beam and no damage to any component will occur.

(4) At the collimator located in front of the UCN-target, a halo monitor consisting of 4 segments will be mounted. This fast device is capable of detecting small beam sizes, which could destroy the target.

(5) Because of the relatively weak radiation shielding, the intensity of the beam line leading to the UCN target cannot be tuned up slowly to 2 mA. A ‘Virtual beam centering program’ is required. This program has to process the beam centers recorded by the fast detecting BPMs during a short beam pulse of 5 ms duration. During the recovery time of the kicker power supply, the program computes and sets the required corrections of the currents of the beam line bending and steering magnets. A second short pulse is used to confirm that the beam is well centered and that the main pulse of 8 seconds duration will cause no interlock due to excessive losses.

## REFERENCES


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[3] T. Korhonen, *First operation of a VME DSP-based controller board*, Scientific and Technical Report 2002, VI.