FIRST BEAM TESTS WITH THE NEW SLIT COLLIMATOR IN THE PROTON BEAM LINE TO SINQ

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In order to improve the safety of the planned MEGAPIE target experiment starting in 2006, a new slit collimator, which has been designed and built during the years 2002 and 2003 and installed into the beam line during the shutdown 2004 has been successfully tested over months of HE-production with the full-intensity proton beam. It has been demonstrated, that proton beam fractions of less than 1 % missing the target E already reliably generate an interlock signal via 2 independent devices.

INTRODUCTION

In order to improve the safety of the planned MEGAPIE experiment at SINQ, an additional method has been proposed to avoid proton beam bypassing target E and eventually perforating the MEGAPIE target with too much non-scattered beam (see [1], [2]). The functioning of this method is based on the energy dispersion of the 90° bending system consisting of the magnets AHN and AHO and the field-lens doublet QHI29 / QHJ30 in between (Fig. 1 and 2).

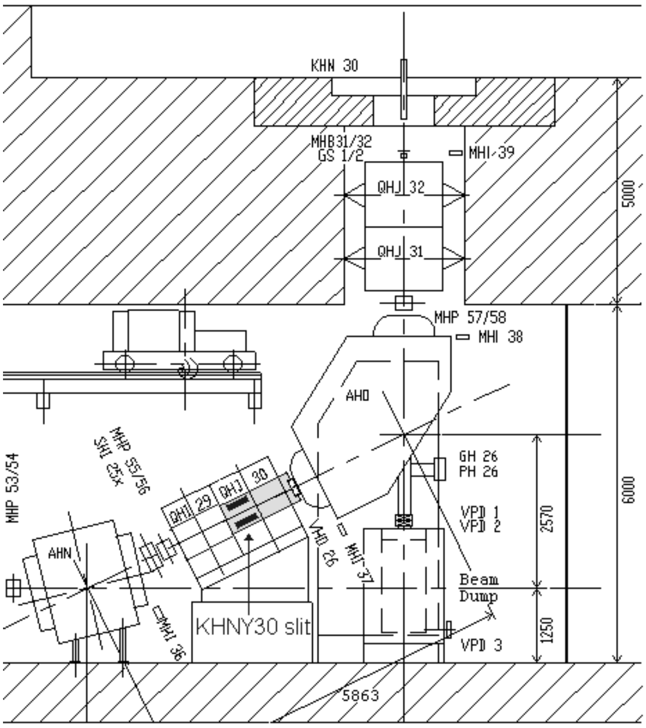


Fig. 1: Side view of the situation of the proton beam line below the SINQ target. The new, vertically acting slit is paced inside the quadrupole lens QHJ30. The nearby ionisation chamber MHI37 detects the spill produced by the beam not traversing target E and therefore hitting the lower jaw of the slit inside QHJ30.

COMPUTER SIMULATION

A model for the Monte-Carlo computer program TURTLE [3] has been developed to simulate the halo at the location of the maximum dispersion (inside QHJ30) as accurately as possible. Some results from these computations are shown in Fig. 3 and 4. The histogram in Fig. 3 shows that for a well centred 1 mA proton beam on target E only a few nA of beam should hit the jaws in the out-position. (This could also be confirmed by the first tests with beam.) If the lower jaw is put into the working position (-25 mm), then according to the model only about 5 nA of the well centred proton beam on target E would hit this jaw and produce some permanent but moderate losses around the slit. The histogram in Fig. 4 shows the profile of the proton distribution inside QHJ30 for a proton beam shifted by 1.5 mm off centre at target E. According to this histogram most of the protons bypassing target E hit the lower slit jaw, if it is put into the working-position around -30 to -40 mm. (Maintenance work in this region is not seriously hampered since it is well shielded by the quadrupole iron yoke surrounding the slits.)

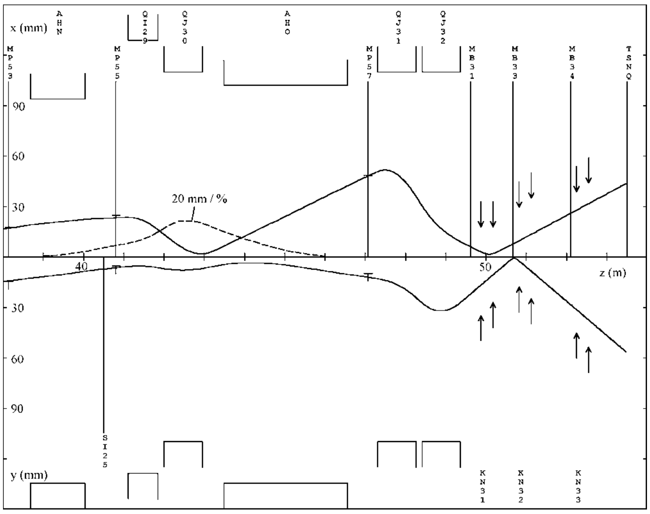


Fig. 2: Portion of the graphic output of the TRANSPORT [4] envelope fit (with target E length = 4 cm) of the proton beam between bending magnet AHN and SINQ-target together with the computed 1 %-dispersion trajectory (dotted line), which reaches a maximum inside the quadrupole lens QHJ30 near the dispersive focus (best separation of the 2 beams).

BEAM SPILL MEASURMENT

The charge of the protons hitting the electrically insulated jaws is collected and measured with MESON units (see control diagram of Fig. 8). But it should be mentioned here, that the measured currents are at least twice the charge of the stopped protons per time unit, because a lot of electrons are knocked out of the copper jaws and flowing to the surrounding vacuum chamber [5]. The produced beam spill is also ionizing the air inside the ionization chamber MHI37 ([6],[7]) placed closely downstream and producing a current signal registered by the LOGCAM2 unit (see control diagram in Fig. 8). Both signals are strong enough to produce an interlock signal already with the small amount of 0.1 % of the beam bypassing target E.

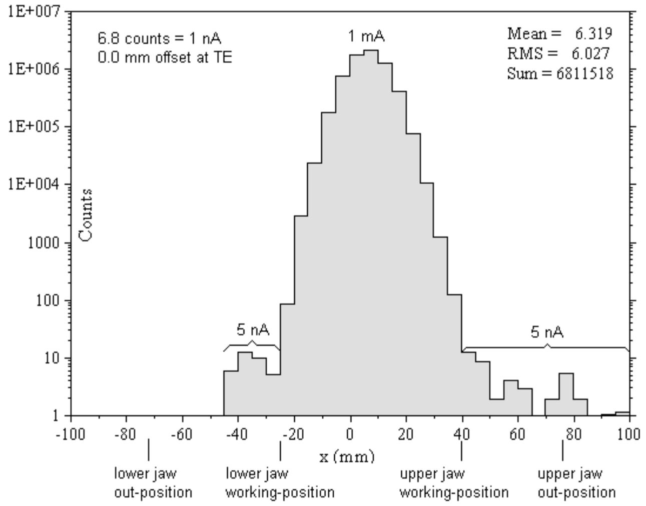


Fig. 3: This histogram represents the computed proton beam distribution in the middle of QHJ30 (the location of the slit) for a well centred beam at target E. The total halo is only of the order of 10 nA for a 1 mA proton beam at the SINQ target. The low-energy halo tail (right side: upper jaw) is longer than the high-energy halo tail (left side: lower jaw).

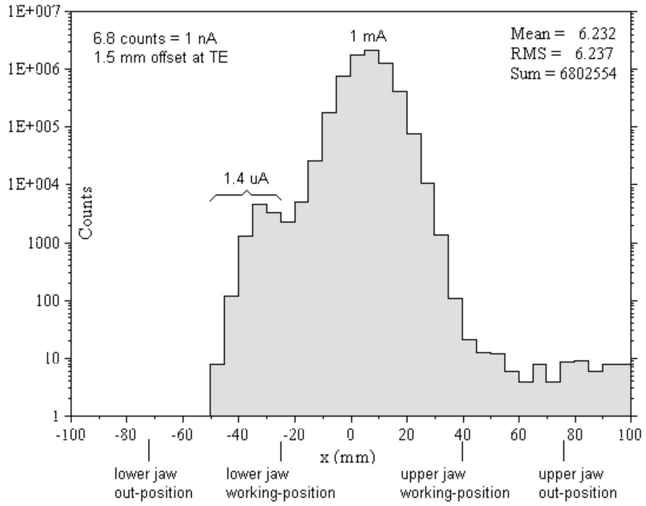


Fig. 4: In this histogram the resulting beam profile at the slit position is shown for the model computation case where the beam on target E is shifted away from the centre by 1.5 mm, so that 0.14 % of the protons are bypassing target E. If the lower jaw is positioned somewhere between -40 and -30 mm, a considerable amount of the protons bypassing target E hit it. Surprisingly also the low-energy tail (right side: upper jaw) is increasing.

MECHANICAL SLIT DESIGN

Fig. 5 shows a simplified drawing of the cross section through the vacuum chamber of the quadrupole lens QHJ30 and the slit plug-in unit. The vacuum chamber of the QHI29/QHJ30 field-lens doublet was build as a so-called 'cross-slit' type chamber like commonly preferred for the high-acceptance pion/muon secondary beam lines at PSI. The initial reason for this was the better transmission of the beam halo because of the presence of relatively large momentum dispersion inside these lenses. In order to avoid a time-consuming reconstruction of the doublet's vacuum chamber, K. Thomsen proposed a design which exploits this special shape of the vacuum chamber with a plug-in unit utilizing this extra outer space for the parking position of the slit jaws in case they are not used. In Fig. 6 a three-dimensional designer's view of this slit plug-in unit with the most important components is shown. A photograph of the interior of the realized and completely assembled slit unit is presented in Fig. 7.

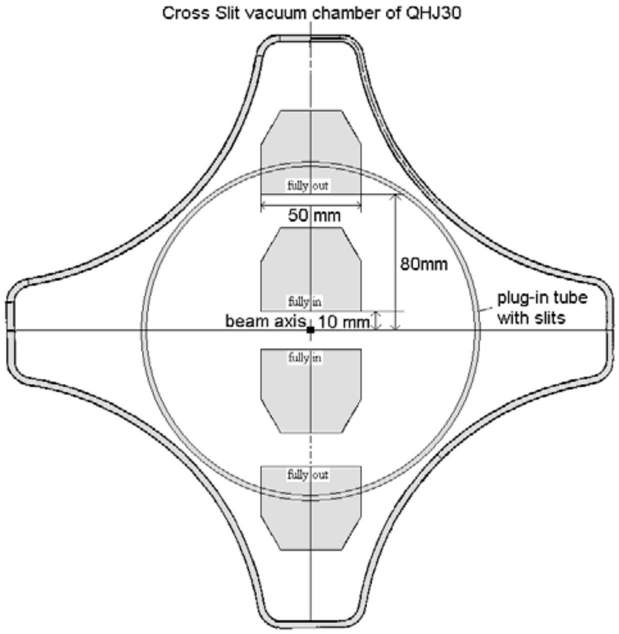


Fig. 5: Simplified cross-section through the quadrupole QHJ30 'cross-slit' vacuum chamber with the KHNY30 slit plug-in unit. The upper and lower slit jaws consisting of solid copper (300 mm long in beam direction) are both shown in their extreme in (10 mm) and out (80 mm) positions.

FIRST TESTS WITH BEAM

The integration of the slit into the control system of the 590 MeV beam line to the SINQ is shown in Fig. 8. One of the fears against the installation of the slit system into the beam line to SINQ was the possible presence of a big enough proton beam halo at large radii inside the QHI30 quadrupole to produce intolerably high losses at the slit jaws even when they are put at their outmost parking positions. But first experiences with the beam after the shutdown 2004 showed that the halo hitting the copper jaws is negligible, namely only a few nA as predicted by the model calculations (Fig. 3). With the lower slit-jaw (KHNY30u) moved from the out position (-72 mm) to-31 mm, the losses at the slit for a well centred beam at target E remain almost identical to those of the jaw in out-position (Fig. 9, left side).

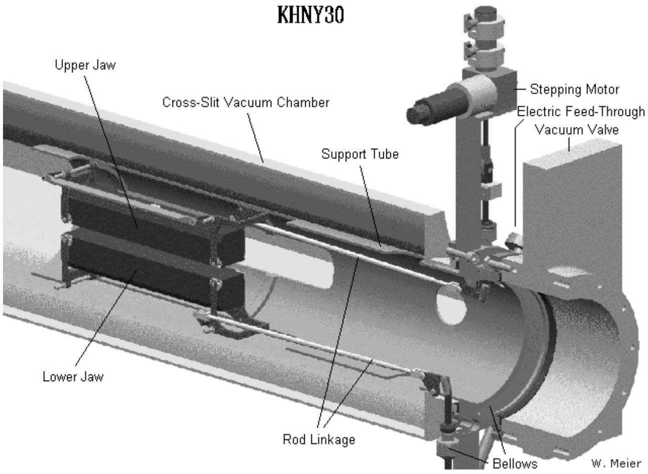


Fig. 6: A 3-dimensional design drawing of the KHNY30 slit collimator unit shows all its important components. The whole unit is plugged into the quadrupole's (QHJ30) 'cross-slit' vacuum chamber (Fig. 1).

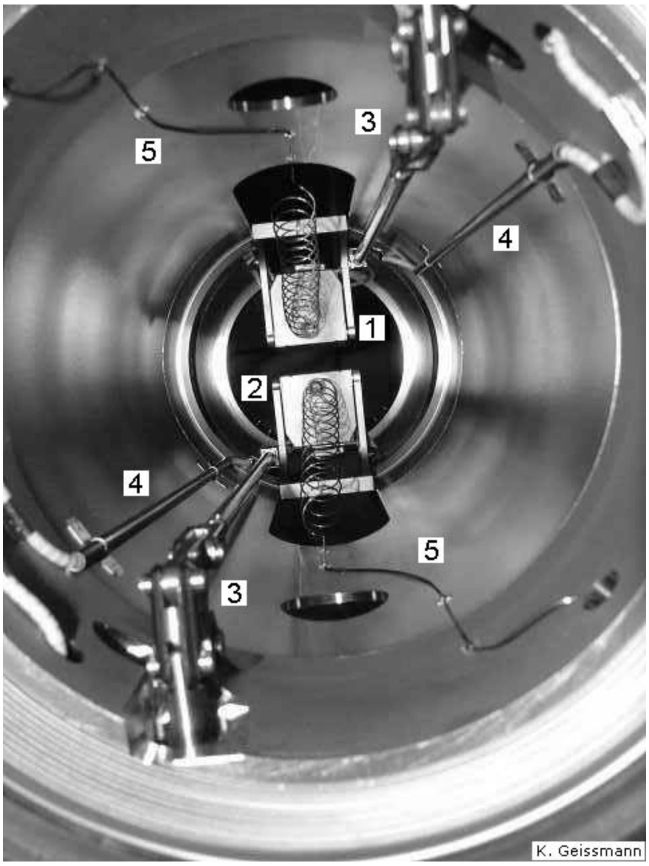


Fig. 7: Photograph of the interior of the KHNY30 slit plug-in unit. The view is in opposite direction of the proton beam. 1: upper copper jaw, 2: lower copper jaw, 3: moving gear, 4: charge collector leads insulated with ceramic pearls, 5: thermo couple leads (partly wound to spring-spirals in order to compensate the longitudinal movement of the jaws). The 2 jaws are shown in closed position.

But a shift of the beam centre at target E by 1 mm towards one side causes about 0.1 % of the protons to bypass the target material and therefore a considerable fraction of them are hitting the lower jaw and produce enough beam spill (mainly detected with the ionisation chamber MHI37) to generate an interlock signal (see Fig. 9, right side and Fig. 10). The shifting of the beam centre at target E was done in a controlled manner with the 'Analog' scanner utility programme by varying the parameter AHPOS of the AHU/AHV/AHSW41 super knob (magnet layout shown in [6], [7] and method described in [8], [9]). At the moment the upper jaw (KHNY30o) of the slit system will not be moved out of its upper parking position, because positioned closer to the main beam, the cut-off halo causes additional losses and therefore activation of the beam line components. Once the MEGAPIE target is inserted, the upper jaw will also be moved closer to the beam in order to avoid, that the beam centre at the position of the slit can be tuned away from the lower jaw without recognition. For security reasons the two slit jaws will then be kept in 'key-locked' positions during the time of the MEGAPIE target tests. As an additional security measure the bending magnet AHN could be kept within narrow limits by applying a current-window (±0.01%) to the hardware controller of its power supply. It is likely that this will restrict the tuning range of the proton beam line during setups.

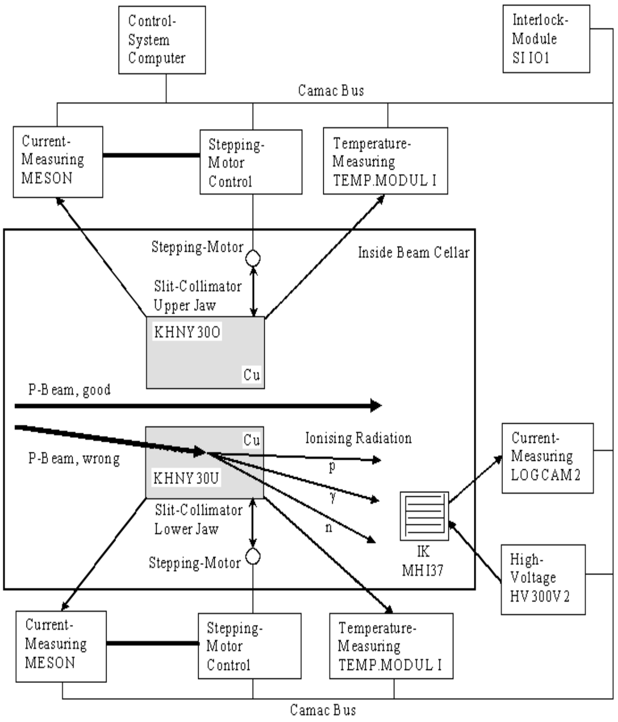


Fig. 8: Diagram of the slit collimator control sub-system. All electronic units are connected with the accelerator control system via the CAMAC bus. Currents, temperatures, voltages, interlock-limits etc. may be read or set via this bus. Not shown in this diagram are the cables needed for transmitting the generated interlock signals to the SII01 CAMAC unit.

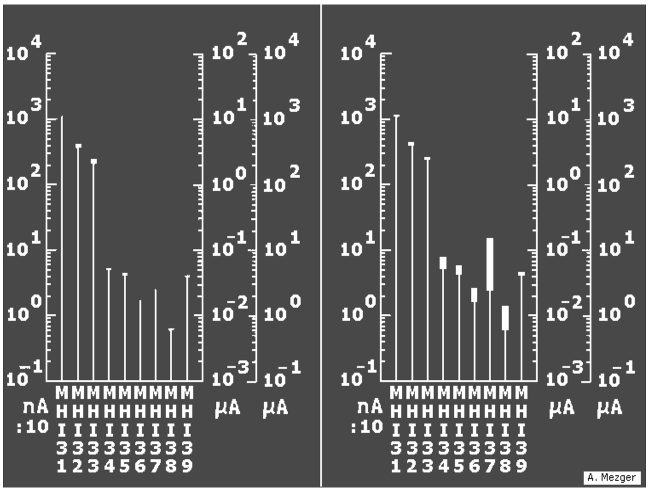
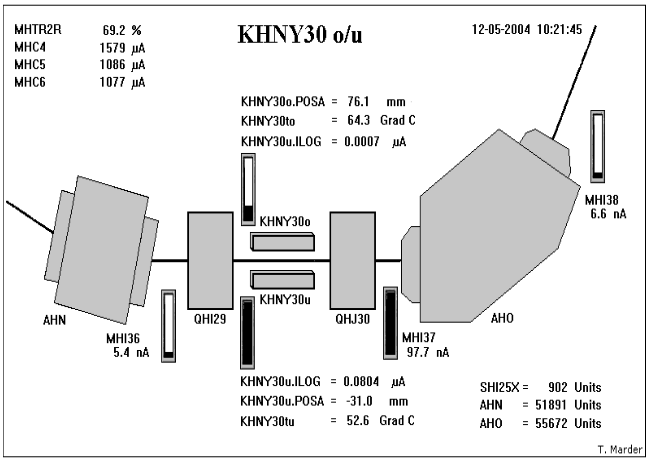


Fig. 9: Synoptic display of the beam losses monitored by the ionisation chambers (MHI31-39) of the proton beam line section between target E and SINQ at 1.25 mA beam current. The left side shows the situation with centred beam on target E. The right side with similar conditions but with the beam shifted by 1 mm towards the edge of target E and KHNY30u at position -30 mm, so that about 0.1 % of the proton beam is missing the target E and a fraction of it is hitting the lower jaw of the slit system. Well visible are the increased losses measured with the ionisation chambers MHI37 and MHI38.


KHNY30 o/u

12-05-2004 10:21:45

MHTR2R 69.2 %
MHC4 1579 µA
MHC5 1086 µA
MHC6 1077 µA

KHNY30o.POSA = 76.1 mm
KHNY30to = 64.3 Grad C
KHNY30u.ILOG = 0.0007 µA

MHI38 6.6 nA
MHI36 5.4 nA
MHI37 97.7 nA

KHNY30u.ILOG = 0.0804 µA
KHNY30u.POSA = -31.0 mm
KHNY30tu = 52.6 Grad C

SHI25X = 902 Units
AHN = 51891 Units
AHO = 55672 Units

Fig. 10: Operator's synoptic screen display of the KHNY30 slit collimator together with all relevant devices in its vicinity. The shown parameter values are for about 0.1 % of the proton beam missing the target E. The MHI37 and KHNY30u.ILOG values are higher than the actual interlock levels (They have been temporarily over-bridged for this screen shot).

CONCLUSIONS

It looks now very likely that in 2006 three well tested and independent systems will be available to reliably protect the MEGAPIE target from destruction by significant percentages of the proton beam missing the target E. Because the 590 MeV proton beam may occasionally be steered enough besides the centre of the target E that the un-scattered portions of the beam produce (through the optical behaviour of the beam line in between) an image on the SINQ/MEGAPIE target with a 10 – 20 times higher proton current density. The two other complementary safety systems are the improved MHC4/MHC5 transmission monitor [10] and the newly developed VIMOS optical monitor [11], [12]. A preliminary comparison of the 3 systems showed already very clearly, that the KHNY30 slit system is about 1 order of magnitude more sensitive than the other 2 systems.

It is also worth to mention that - as for the VIMOS system - a reliability study for the KHNY30 slit system and its monitoring electronics (Fig. 8) has been carried out by the Safety-Analysis Laboratory at the ETH in Zurich [13]. One conclusion of this report is that the KHNY30 slit system is considered as very reliable. Together with the MHC4/MHC5 transmission monitoring and with VIMOS we have 3 independent safety systems, which should deliver enough redundancy to avoid any damage of the MEGAPIE target by overheating caused by the proton beam.

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