AN ELECTROSTATIC BEAM SPLITTER FOR THE PSI 590 MEV-1 MW PROTON BEAM LINE

E. Mariani, M. Olivo*, D. Rossetti
Paul Scherrer Institute (PSI), CH-5232 Villigen-PSI, Switzerland

Abstract

The 590 MeV proton ring cyclotron was upgraded in several steps from 200 μA in the late eighties to the present 1.5 mA in order to deliver a high intensity beam for new experiments in particle physics and for the spallation neutron source. The beam splitter originally designed to provide simultaneously a 200 μA proton beam to the meson production targets and up to 20 μA to the experimental and medical proton irradiation facilities had to be substantially upgraded as well, in order to still peel-off 20 μA from the now 1.5 mA main proton beam. Constructional details of the new beam splitter and operational experience are presented.

1 INTRODUCTION

The Paul Scherrer Institute (PSI) operates a 590 MeV, 1.5 mA high intensity proton isochronous ring cyclotron for the production of intense beams of pions and muons[1]. A spallation neutron source (SINQ) was added to the PSI facility and became fully operational towards the end of 1997. An electrostatic beam splitter (EHT), located in the 590 MeV beam line, peels off a small fraction from the main beam to serve the proton therapy, nuclear structure, and material irradiation facilities.

During the 1995/96 accelerator shutdown the existing beam splitter[2] and its protection collimators were replaced by new versions. Two major improvements were introduced:

- Because of the new cathode/anode arrangement the new splitter can peel-off, at comparatively lower beam losses, up to 20 μA from the 1.5 mA main proton beam without undergoing physical damage.
- The handling of the splitter and protection collimators is done remotely, thus ensuring low exposure to the service personnel.

2 DESIGN DESCRIPTION

A schematic drawing of the new splitter channel is shown in Fig. 1. In the old design, only the septum was moved into the beam. As a consequence of this, the voltage applied to the cathodes (i.e., the magnitude of the electric field left and right of the septum) depended on the septumposition. Furthermore, the mechanical tension applied to the strips was a compromise between beam losses (the non-uniformity in the electric forces acting on the strips led to an increase in the effective thickness of the septum) and lifetime of the strips.

The advantages of the new configuration are twofold:

- The net electric force acting on the wires/strips is always zero. The mechanical tension applied to the wires can be lowered, thus a higher working temperature can be tolerated before reaching creep limitations[3].
- The H.V. applied to the cathodes is not varied during operation. This is an important feature because there is no H.V. deconditioning.

Two EHT splitters were built. Both are identical except for the septum. In the version (labelled ”wire” splitter) the upstream portion of the septum (1/3 of a total length of 1100 mm) is made up of 55 (W+3%Re)-wires, 50 μm dia., the remaining 2/3, of 118 Mo-strips, 50 μm thick x 3 mm wide. In the other version (labelled ”strip” splitter) only

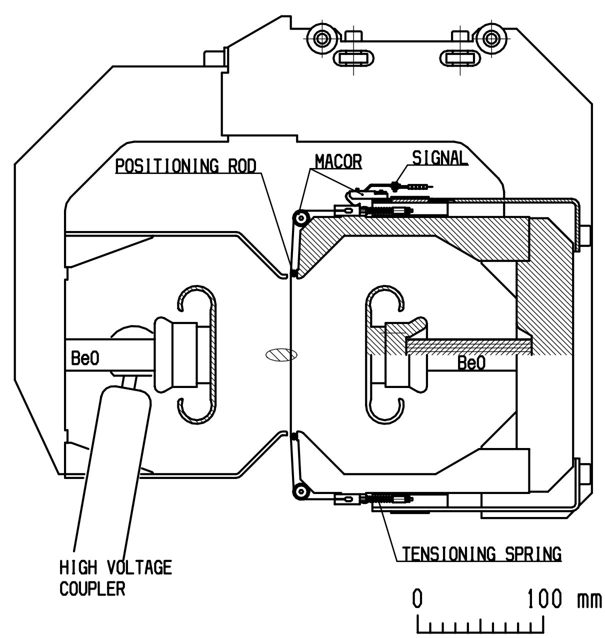

Figure 1: *The septum is located equidistant from the cathodes, at 60 mm. The septum/cathode assembly is moved as a whole into the beam. The aluminium cathodes (AlMgSi1) are supported by BeO insulators. Each wire/strip is separately tensioned at 10 kg/mm^2. If a wire/strip breaks the tensioning springs pull the fragments into the upper and lower storage containers. The first 3 wires/strips are electrically insulated. A current signal, arising from the emission of secondary electrons, gives an indication on the status of the wire/strip. The operating voltage is -172 kV.*

*present address:
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3, Canada

the first 1/3 is different, consisting of 55 (W+1.5%ThO$_2$)-strips, 50 μm x 2 mm.

The number and average energy loss of the protons that collide with the septum and their average multiple scattering angle after they leave the septum was calculated for a splitting case in which 21 μA are "peeled-off" from a 1.5 mA-590 MeV incoming beam, using a Monte-Carlo based code[4]. The particles are assumed to follow a binomial distribution parametrized by m=3.0[5]. From the power loss the temperature of the first wire/strip was estimated for a Molybdenum and Tungsten septum[6]. The results are summarized in Table 1. Based on the temperature results, Tungsten was chosen as a material for the first 1/3 portion of the septum.

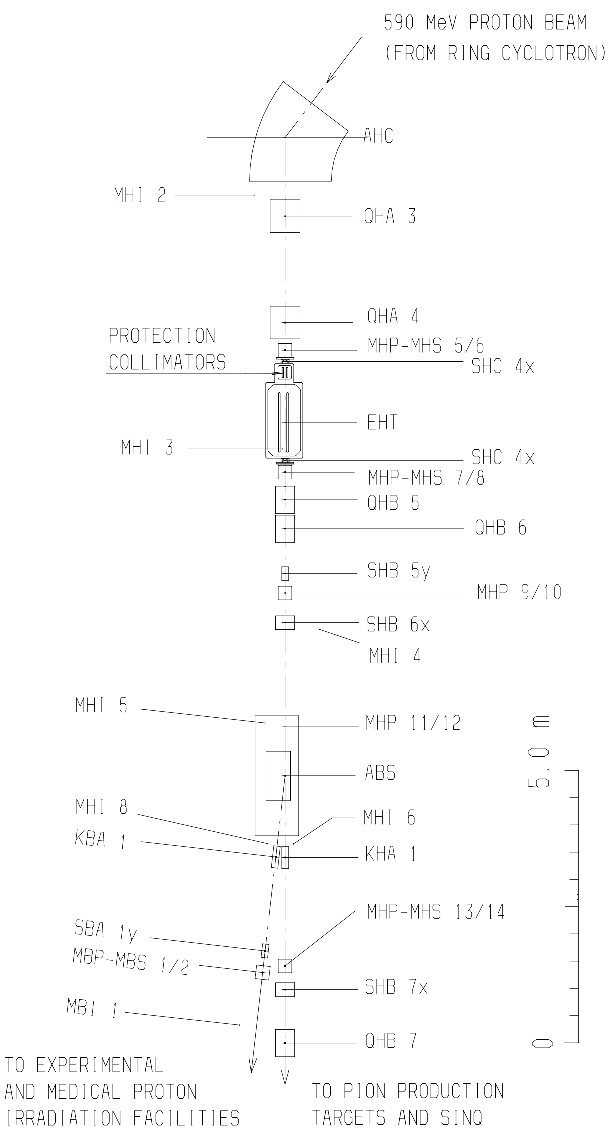

Figure 2: *Location of the splitter (EHT) in the 590 MeV B.T.L. The EHT causes the main and peeled-off beams to clear the 20 mm thick septum coil of the C-shaped ABS bending magnet. The M(H,B)(P,S)'s are profile and centre-of-charge monitors. The M(H,B)I's are ionization chambers to monitor beam losses.*

Table 1: *The values shown in this table were calculated from measured beam profiles with 4-σ_x=18 mm and 4-σ_y=9 mm at the entrance of the splitter.*

SEPTUM	MATE-RIAL	ΔE (MeV)	$<\theta>$ (mrad)	T (°C)
WIRE 50μ dia.	Mo	0.33	2.0	1188
	W	0.41	2.8	1337
STRIP 50μm $\times$ 2mm	Mo	5.42	8.5	1349
	W	7.12	12.3	1552

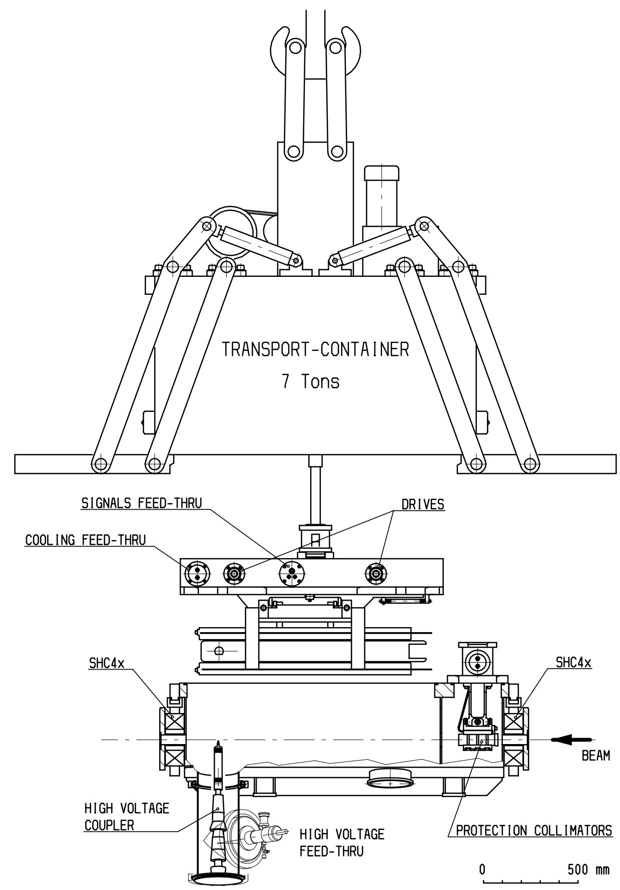

Figure 3: *Splitter vacuum chamber. To reduce the exposure to the service personnel the handling of the splitter is done remotely. There is a smaller transport container for the removal of the protection collimators. Both devices can be repaired/disposed using tools driven by manipulators. When the splitter is lowered the cathode self-connects to the flexible high voltage coupler. The cathodes are joined at the entrance of the splitter by two half-ring conductors, located above and below the beam plane. A high precision gear system coupled to a fast d.c. motor positions the splitter channel to better than 0.1 mm. A second motor, moving along with the d.c motor, allows the alignment of the splitter channel to the incoming beam in order to minimize beam losses due to septum shadow effects. Ionization chambers provide this information.*

3 LAYOUT AND OPERATION

The location of the splitter (EHT) in the 590 MeV beam transport line (B.T.L.) is shown in Fig. 2. Special equipment has been built to service the splitter and collimators. This is shown schematically in Fig. 3.

The combined action of the splitter channel and the two SHC4x magnets on the main and splitted beams is outlined in Fig. 4.

First the "wire" and later the "strip" splitters were in operation from May 1996 until the end of 1997 (each for a period of about 7 months) peeling-off up to 20 μA from the 1.5 mA incoming beam. Up to 2 μA of beam collide with the septum and lost along the BTL. This value depends strongly on the width and shape of the main beam at the entrance of the splitter channel. Because of the low average angle of the protons scattered at the wire septum (see Table 1), most of the spill was taking place in regions far away from the splitter. Owing to the difficulty in dealing with the activation in these regions, operation was continued using the "strip" version to the end that the losses were now confined mainly in the neighbourhood of the splitter[7]. In the 1997/98 shutdown a short portion of the BTL, following the splitter, was modified to cope with the high radiation levels present[8]. Operation of the splitter will be restricted to the strip version.

For a still not clear reason voltage breakdown occurs when the septum is in the beam. Furthermore, the sparking rate increases with the amount of beam being peeled-off and is higher with the "strip" septum (0.2 sparks/min) than with the "wire" septum (a factor of three less). The cause could be due to positively charged aggregates (clumps) released by the hot strips/wires which, after they reach the cathode, generate an avalanche of electrons[9]. To test this hypothesis both cathodes (the upstream 1/3 portion) have been fitted with two rows of 3x3 mm^2 permanent magnets with a 3 kGauss surface field. The permanent magnets are located within and along the cathodes, 15 mm above and below the beam plane with the aim of trapping the electrons as they leave the cathode.

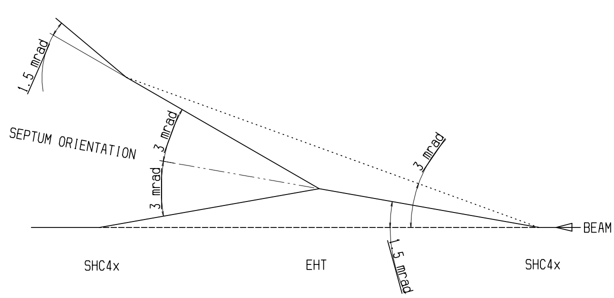

Figure 4: *The splitter deflects the main and peeled-off beams by 3 mrad to the left and to the right of the septum respectively. Two identical steering magnets (connected in series and located upstream and downstream of the splitter channel) compensate for the effect of the electric field on the main beam (i.e., each imparts a 1.5 mrad bend). Because the SHC4x magnets are not placed equidistant to the EHT channel there is a small parallel shift (less than 1 mm) in the beams exiting the downstream SHC4x steering magnet. If the splitter is defect the beam can either be directed to the SINQ target (SHC4x magnets off) or to the irradiation facilities (SHC4x magnets at twice their normal excitation).*

4 CONCLUSION

In the 1998 beam period the splitter with the permanent magnets will be tested. If voltage breakdown still persists the present splitter can be modified to a single-cathode version[10]. In this case the main beam will not be affected when a voltage breakdown occurs (in the present design it is the instability in the high intensity portion of the beam exiting the splitter channel that causes a machine interlock further down the beam line). The trade-off will be higher beam losses due to the uneven deformation of the strips by the electric field. Further, the electric field in the channel will have to be a factor of two higher.

5 ACKNOWLEDGEMENT

It is a pleasure to acknowledge the excellent support of the PSI staff, in particular the technical assistance of D. Goetz, and of H. Blumer and his team from the PSI workshop.

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