UPGRADE OF GSI HADES BEAM LINE IN PREPARATION FOR HIGH INTENSITY RUNS

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Abstract

HADES is a fixed target experiment using SIS18 heavy-ion beams. It investigates the microscopic properties of matter formed in heavy-ion, proton and pion - induced reactions in the 1-3.5 GeV/u energy regime. In 2014 HADES used a secondary pion beam produced by interaction between high-intensity nitrogen primary beam and a beryllium target. In these conditions beam losses, generated by slow extraction and beam transport to the experimental area, led to activation of the beam line elements and triggered radiation alarms. The primary beam intensity had to be reduced and the beam optics modified in order to keep radiation levels within the allowed limits. Similar beam conditions are requested by HADES experiment for upcoming run in 2018 and in the following years. Therefore, a number of measures have been proposed to improve beam transmission and quality. These measures are: additional shielding, additional beam instrumentation, modification of beam optics and increase of vacuum chambers' apertures in critical locations. The optics study and preliminary results of FLUKA simulations for optimization of location of loss detectors are presented.

INTRODUCTION

HADES beam line connects extraction point of SIS18 synchrotron and HADES experiment. The beam line is about 155 meter long and contains 19 main quadrupoles, 7 dipoles, several orbit correction magnets, beam instrumentation devices and two targets: pion production target and HADES experimental target. The pion production target is located in a heavy concrete shielding about 30 meters upstream of the experiment. This target can be remotely removed from the beam path.

The experiment measures effects of particle collisions with HADES experimental target. Those particles can be heavy ions extracted directly from SIS18 or pions produced in the pion production target. In order to produce enough pions (typical request is 4×10^5 per spill) the primary beam must have the highest possible energy and intensity. Therefore, nitrogen beam with energy of 2 GeV/u and intensity of about 9×10^{10} ions per spill is used.

HADES requested the pion beam in 2011 and 2014. Especially in 2014, due to high beam losses in SIS18 extraction and in the beam line, not only accelerator components were activated, but also radiation alarms triggered several times [1]. Therefore the beam intensity had to be reduced to about 3.4×10^{10} ions per spill. Maximum activation was measured in the extraction area, however hot spots were also measured in switching dipole GTH3MU1 (see Fig. 1, letter **b**) about 20 meters upstream the pion production target.

Requirements of the HADES experiment for 2018 beam time is to maximize the pion flux while keeping stable running conditions which satisfy radiation safety requirements. This is planned to be achieved by changing the beam optics, increasing the vacuum chamber aperture in critical locations and installation of beam loss monitoring system which will measure the loss distribution along the beam line. On the synchrotron side the improvement is adjustment of the position of electrostatic septum. It was done in 2015 and during 2016 beam time a significant increased extraction efficiency was confirmed.

BEAM LOSSES BEFORE UPGRADE

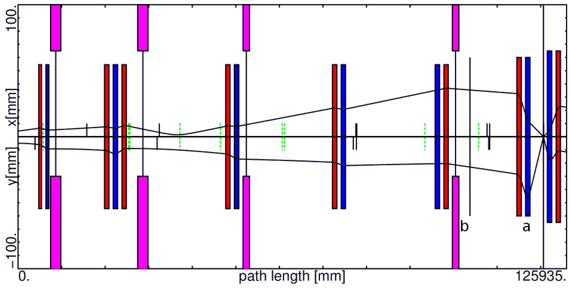

Figure 1: The beam envelope for optics used for the most part of 2014 run. Only part up to the pion target is shown.

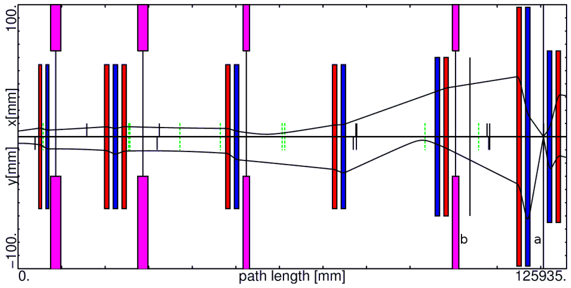

Figure 2: The beam envelope for the new, proposed optics.

The beam envelope for optics used during the 2014 high-current beam time is shown in Fig. 1. The plot, obtained with MIRKO optics program, shows horizontal beam envelope in the upper half and vertical one in the bottom half. The red and blue bars represent the apertures of focusing and defocusing quadrupoles. Magenta bars reach to the apertures limits of dipole chambers. The dipoles themselves are turned off as they are switching dipoles which are used to direct the beam to other beam lines. The beam moves from left to right starting directly behind SIS18. The strong focus on the right hand side of the plot marks the pion target. As

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starting point for the optics calculations the default beam parameters and emittances of 1 $\pi \cdot$ mm $\cdot$ mrad in horizontal and 4 $\pi \cdot$ mm $\cdot$ mrad in vertical planes were used. These emittances were not measured specifically for this beam, what should be remembered when interpreting the results, but are known to be typically close to reality.

The 2014 optics was essentially dictated by focusing strength of the last quadrupole (GHADQD12, letter **a** in Fig. 1) in front of the target. The beam had the highest possible magnetic rigidity of 18.53 T $\cdot$ m and consequently the last quadrupole operated at the upper limit of its specification. From the plot one can conclude that the vertical aperture margin in the last dipole (GTH3MU1, letter **b**) is small, what designates him as a candidate for beam loss location. This observation coincides with the activation measurements.

According to the calculation the beam spot on the target is round with a radius of 0.3 mm. The beam line acceptance is 2.21 $\pi \cdot$ mm $\cdot$ mrad in horizontal and 6.78 $\pi \cdot$ mm $\cdot$ mrad in vertical planes.

NEW OPTICS

The main countermeasure against the beam losses in the HADES transfer line is modification of beam optics. In order to decrease beam losses on GTH3MU1 dipole the beam must be squeezed in vertical direction. This squeeze allows for stronger beam defocusing and larger beam size in the final-focusing quadrupole (GHADQD12). Therefore, this quadrupole should run with higher strength and have a larger aperture. Calculations have shown that the reqired quadrupole field gradient is 10.33 T/m, what is slightly higher than the current limit of 10 T/m. Powering test has been done with the throttles in the cooling circuit removed. Stable operation of the quadrupole was possible even with a current corresponding to the gradient of 10.8 T/m. Therefore, the alternative focusing scheme presented in Fig. 2 is achievable for regular operation.

The vertical beam size in the GHADQD12 quadrupole is about 15% larger in the new optics as in the old one. In order to reduce beam losses in this area it was decided to construct star-shaped chambers which will be installed in both quadrupoles (also in the preceeding GHADQD11 in which the horizontal beam size will increase by 50%). The cross-section of these chambers, shown in Fig. 3, enlarges the geometrical aperture in horizontal and vertical directions from 60 mm to 98 mm.

The changes of optics and vacuum chambers geometry not only reduce the beam losses, but also reduce the beam spot size down to 0.22 mm. In addition the acceptance increases to 2.54 $\pi \cdot$ mm $\cdot$ mrad in horizontal and 9.84 $\pi \cdot$ mm $\cdot$ mrad in vertical planes. Moreover, the margins of the magnet current and of aperture are not exhausted.

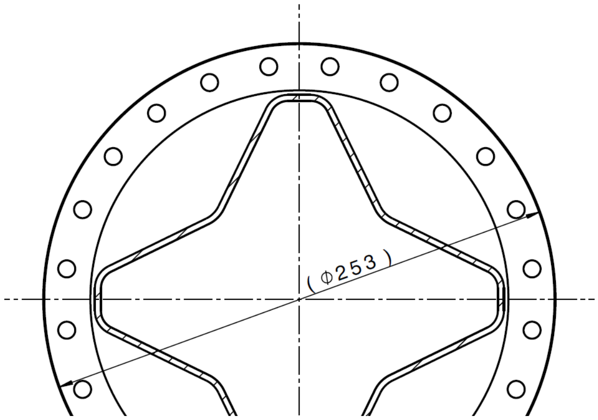

Figure 3: The cross-section of star-shaped vacuum chamber (bottom part removed).

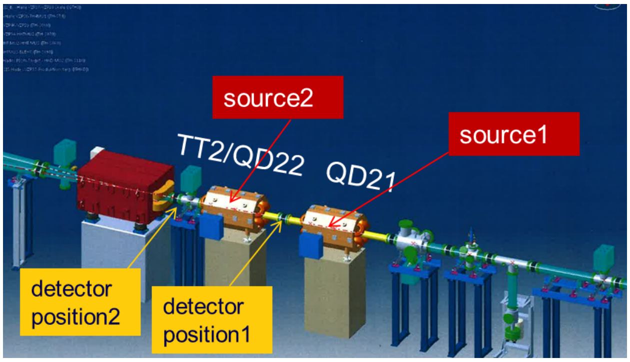

Figure 4: Simulated FLUKA geometry.

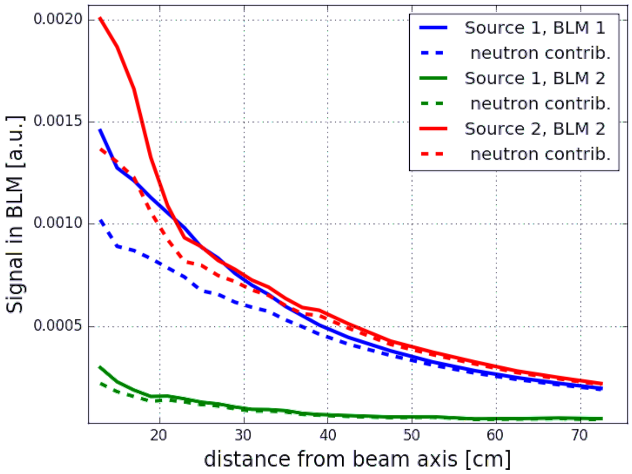

Figure 5: Estimated BLM signal as function of radius for two BLM locations and two loss scenarios.

BEAM LOSS MONITORS

In order to better control and minimize the beam losses it was proposed to install Beam Loss Monitoring system. The system is based on scintillators with 2 × 2 × 7.5 cm^3 size, read out by photomultiplier. The particle signals are counted by LASSIE electronics [2]. Sixteen detectors will be installed along the beam line (see Fig. 6). They are typically located downstream the magnets, because dipoles represent vertical aperture limitation and quadrupoles usually define local maxima of the beam size.

FLUKA [3,4] study has been started in order to optimize the location of the detectors. As a first step a typical setup with two quadrupoles, presented in Fig. 4, is simulated. Two

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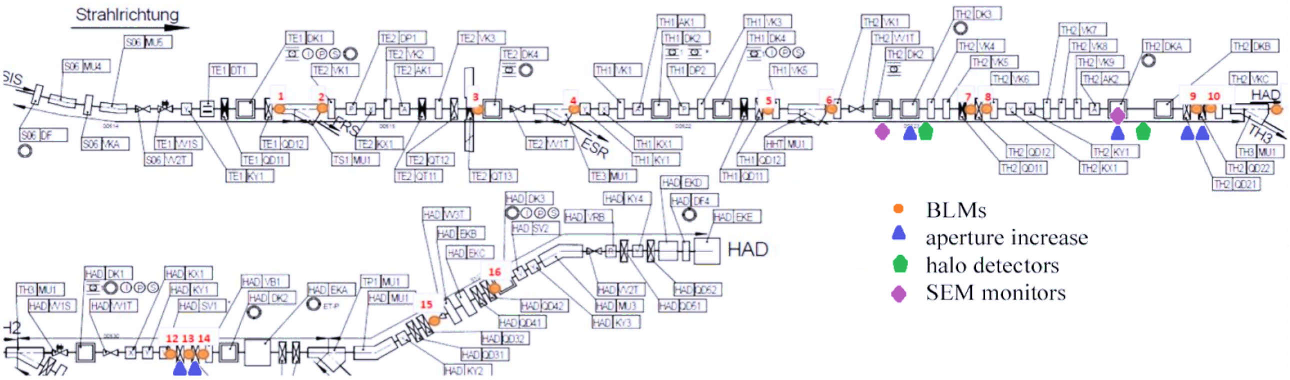

Figure 6: Main changes to HADES beam line.

loss locations are considered: horizontal loss in the first, focusing quadrupole (source 1) and vertical loss in the second, defocusing quadrupole (source 2). Nitrogen-ion beam with energy of 800 MeV/u is impacting in the middle of the magnets with angle of 2.5 mrad, which corresponds to beam missteered in the upstream quadrupole. The losses are point-like.

The particle fluences have been scored between the two quadrupoles (position 1) and after the second quadrupole (position 2). The scoring volume has been divided into 2×2 cm^2 transverse bins with 20 cm length.

Signal in the detectors is mainly generated by fast neutrons through elastic scattering in detector material. Contribution from protons is up to 25% close to vacuum chamber and gradually decreases with distance. Other particle types can be neglected. Figure 5 shows the estimated BLM signal as a function of distance from the beam axis for two BLM positions and two loss scenarios. The signal from loss in the first quadrupole, seen by second detector, is less than 20% of the signal from loss in the second quadrupole. This shows that it will be possible to distinguish local losses from the upstream ones.

OTHER IMPROVEMENTS

Additional improvements are foreseen in both: vacuum system and instrumentation. Two out of ten diagnostic chambers installed along the beam line had apertures significantly smaller than the standard drift chambers. These chambers are being replaced by large aperture ones. Futhermore, some of the chambers inside quadrupole magnets are equipped with heating jackets, however they are not baked-out anymore. Those chambers will be replaced by standard, 60 mm aperture chambers.

Additional instrumentation includes installation of SEM foils [5] to measure transmission or extraction efficiency of the high-intensity beams. Current particle counters accomodate ionization chambers which move into the beam together with SEM. Due to large amount of material, losses generated on such combined devices can trigger radiation alarm. New detectors will have ionization chamber removed.

Other instruments to be installed are vertical and horizontal halo monitors. Each of them is made of 2 scintillators which can be gradually moved into the beam using stepping motors. They allow to scan halo of extracted beam with high spatial and temporal resolutions. In order to asses halo shape on the target the monitors must be installed with phase advance of 180° (or multiple of it) with respect to the target.

The main changes to the HADES beam line are visualized on Fig. 6. In addition to hardware changes facility-wide deployment of a new accelerator control system and data archiving system is planned.

CONCLUSIONS AND PLANS

This paper presents approach which has been applied to a beam line in order to prepare it for the high intensity runs. Main aspects of this approach are change of beam optics, increase of the aperture available to the beam and addition of a possibility to measure local beam losses.

Currently the construction and installation of the new hardware is on the path to be completed for 2018 beam time. Because of lack of completness of measured beam data it is difficult to fully understand beam losses observed in 2014. However, with new measurement devices and a complete FLUKA geometry of the tunnel, it is expected to understand beam loss patterns of the future runs.

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