THE BEAM-GUIDING SYSTEM OF AGOR

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ABSTRACT

The design and status of the beam guiding system between the AGOR cyclotron and two target stations (among which a magnetic spectrometer) is discussed. An overview of the optics and the matching of the extracted beams is given. Examples of beam-transport calcualtions are shown and some devices for beam diagnostics are discussed.

1. INTRODUCTION

In 1994 the super-conducting cyclotron AGOR will be installed at the KVI in Groningen. It will replace the existing Philips cyclotron. Within the existing building, a new layout of the experimental area is made and new experimental setups will be installed at new target stations: a large scattering chamber "Huygens Vat" and a new QQD-type magnetic spectrometer (resolution $\Delta p/p = 2 \times 10^{-4}$). For the moment only the new beam lines to the QQD spectrometer and to the Huygens Vat have been designed in detail. In a later stage also beam lines to other target stations (for polarization experiments, gamma-ray spectroscopy, applied research and a facility for radio-therapy with protons) are foreseen.

2. THE DESIGN OF THE BEAM-LINE OPTICS

2.1. Global Description

The beam lines are designed for particles with momentum rigidities up to 3.7 Tm. For the two target stations different types of beam-transport are possible:
QQD spectrometer:
-High resolution transport, dispersion matched beam.
-Achromatic transport, mainly intended for heavy ions.
Huygens Vat:
-Achromatic transport, mainly intended for heavy ions.

The beam lines are separated into several optical sections. In Fig. 1 the layout of the beam lines is shown. Globally the following functions are assigned to different sections:

1) From extraction until Slit-1 the phase-space of the beam is matched using five quadrupoles. The extracted beams may be regarded as originating at a virtual waist in the extraction channel. The horizontal and vertical waists have been chosen as object points for the transport calculations. These object points are imaged to the center of a small bending magnet, located at the position where all extracted beams will meet, each at a slightly different angle. Using the small bending magnet at the meeting point and the steering properties of the first two Q-poles in the extraction channel, the extracted beams can be aligned onto the optical axis of the beam guiding system. A triplet following the bending magnet makes an image at slit-system Slit-1.

2) In addition to the betatron motions of the extracted particles, there exist large correlations between the momenta and horizontal positions of the particles. The correlations correspond to dispersions between 1.6 and 5.0 cm/(%$\Delta p/p$) and may have a large uncertainty.

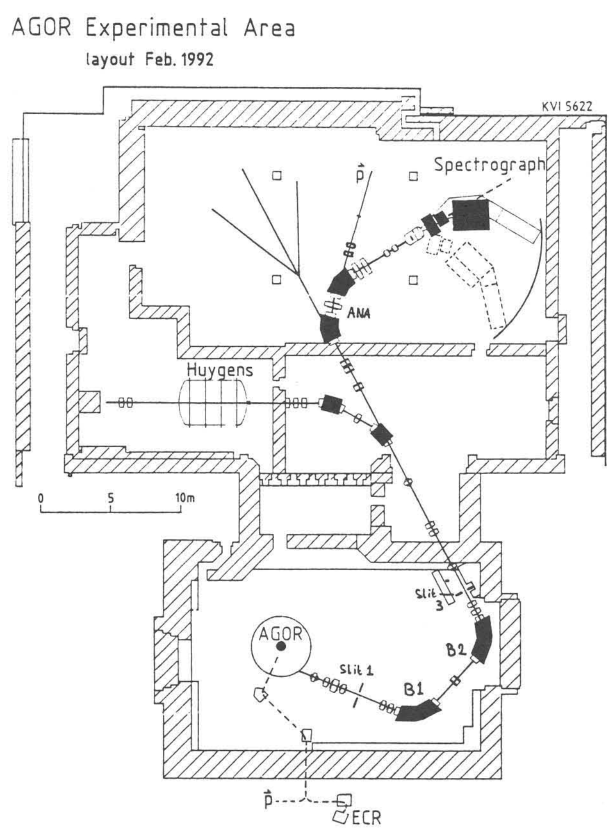

Fig.1. AGOR experimental area and beam-line layout at the KVI.

*This work was performed as part of the research program of the "Stichting voor Fundamenteel Onderzoek der Materie" (FOM) with financial support from the "Nederlandse Organisatie voor Wetenschappelijk Onderzoek" (NWO).

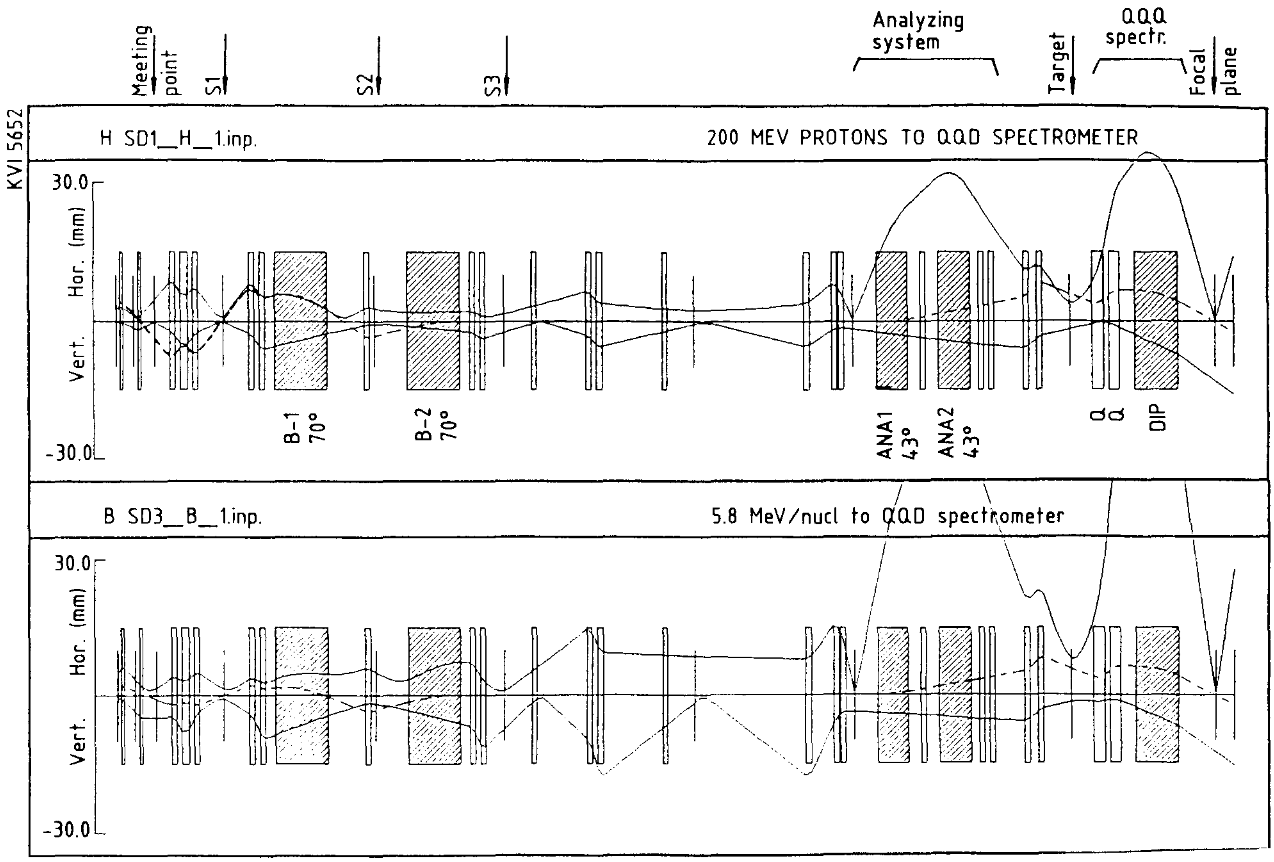

Fig. 2. Envelopes and dispersion lines (dashed) for two AGOR beams in high-resolution mode to the QQD magnetic spectrometer.

These correlations could easily cancel the dispersion of the analyzing system necessary for high resolution experiments. Therefore, after Slit-1 the momentum correlations in the extracted beam are compensated using the system with the two bending magnets B1 and B2. Then at Slit-3 (located just before the exit of the cyclotron vault) there are no correlations between particle momenta and horizontal positions anymore.

3) Slit-3 serves as a new object point for the transport to the targets. Starting at this point the beam transport is the same for all AGOR beams so that, for the optical mode selected, the magnet settings just scale with beam momentum.

4) Matching to the target conditions is performed in the last sections.[1)]

-The beam is transported to the Huygens Vat in an achromatic mode. For heavy ion beams the target-spot size depends strongly on the dispersion at the target, which should therefore be minimized.

-At the QQD target the momentum dispersion $D_a \approx$ 5.6 cm/(%$\Delta p/p$) due to the analyzing magnets ANA1+2 can be matched to the QQD dispersion and the reaction kinematics, so that the spread in beam momentum does not contribute to the spot size in the focal plane. Slit-3 is imaged with a magnification factor $M = 1/5$ to the target. Then at the target the dispersion R_{16} is:

$$R_{16} = M \cdot D_{slit3} + D_a$$

In this way the effect of a possible error D_{slit3} in the compensation of the momentum correlations, is decreased with a factor 5. Further more, a large slit opening decreases the contribution of slit scattering, which is very important for experiments at zero-degree. It is also possible to tune the analyzing system as an achromat, allowing a larger acceptance and a smaller target-spot size, which may be important for heavy ion beams.

2.2. Transport Calculations

Beam-transport calculations have been performed using the characteristics of 11 different beams at extraction, as calculated by the AGOR theory group. For these beams, scattered over the whole operating diagram of AGOR, the phase space properties have been calculated and the positions of the virtual waists have been derived.

In Fig. 2. TRANSPORT calculations of the envelopes of 200 MeV proton- and 5.6 MeV/nucl. heavy ion beams to the QQD spectrometer are shown (point H and B in the AGOR operating diagram). In the figure the dashed line represents the dispersion. The compensation of the dispersion present in the extracted beam is performed with B1 and B2. As can be seen, at the focal plane of the spectrometer the dispersion equals 0.0, reflecting the effect of dispersion matching at the target. It is possible to change the lateral and angular dispersion, the horizontal and the vertical spot size at the target within certain ranges, which may be necessary to compensate for reaction kinematics.[2]

In general, only in the first part of the beam line the magnet setting depends on the beam properties. It has been found that only 4 different "basic settings" are needed for the beam transport to Slit-1, while the setting of the lenses between Slit-1 and Slit-3 is directly related to the type of basic setting used before. After Slit-3 in principle only a choice has to be made between an achromatic- or a dispersion-matched setting.

Second order transport calculations have shown that aberrations induced by the analyzing magnets and two 3°-bending magnets, used for shifting the beam axis 35 cm in the vertical direction, increase the incoherent spot-size at the QQD-target more than a factor 3. However, by adding two small sextupoles to the analyzing system these second order aberrations can be compensated sufficiently.

3. BEAM DIAGNOSTICS AND CONTROL

Beam diagnostics will be performed with beam-profile monitors, non-intercepting beam-current monitors, electrostatic pick-up electrodes and direct beam current measurements with Faraday cups and slit systems. The beam profile monitors are mostly "harps": grids of 48 wires of 20μm mounted on an actuator. Measurement of the secondary-emission current on the wires gives a spatial beam-intensity distribution. Also several non intercepting beam-profile monitors using the residual gas in the beam pipe[3] will be used.

The read-out electronics for the profile monitors has been bought at the IPN at Orsay and it has arrived this year. The electronics for the pick-up electrodes is designed and prototypes have been tested succesfully.

A non-intercepting beam current measurement device has been tested successfully. Basically it is a toroid with a high-μ_r core, surrounding the beam pipe. It serves as a current transformer, with the (chopped) beam current as the primary current. With electronics developed at the KVI, beam currents from 1eμA down to one enA. can be measured by integrating the secondary current in the toroid, see Fig. 3. Several pieces of this device have been built at the KVI.

Signals from the instruments for beam diagnostics will be sent to a Micro-Vax of the central control system,[4] via a BitBus line. Also the power supplies of the magnets will be controlled with BitBus. The control system is based on a local micro-controller, serving as a BitBus node. Every instrument (e.g. power supply or harp) is, in principle, interfaced to one node. In this way the central control system is relieved from details (of the instruments at the nodes; only the principal messages (e.g. "set current" or "give profile") are sent and received via BitBus.

The beam line has been divided into several vacuum sections and the PLC of the vacuum control system can also be connected via BitBus to a Micro Vax of the central control system. Then the PLC is also regarded as one BitBus node.

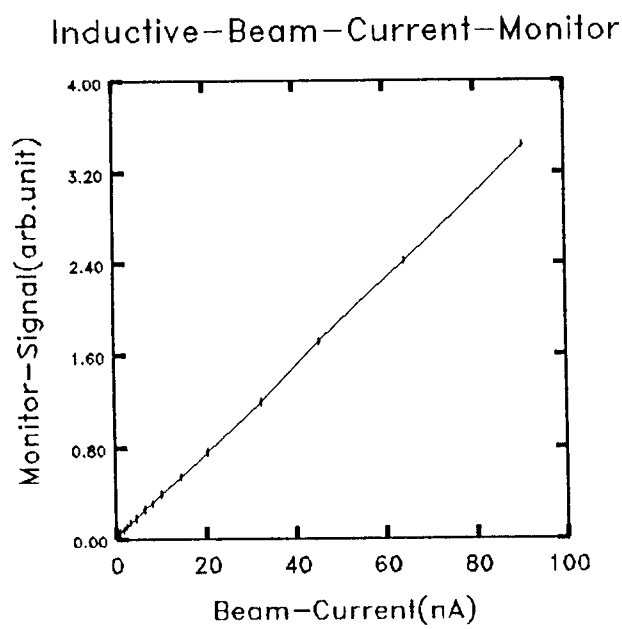

Fig.3. Signal from the inductive beam-current monitor, measured as function of beam intensity, simulated by a chopped current.

4. PRESENT STATUS OF THE BEAM LINES

In march 1992 the manufacuring of the magnets has started at Danfysik. The first batch of magnets is expected to be delivered in the autumn of 1992, at which date the building phase of the beam lines will start.

The manufacturing of almost all necessary components for diagnostics and the vacuum system has been completed now.

The design and first tests of the control of the vacuum system has started. Local pump control-stations have been built and are ready for installation now.

5. REFERENCES

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