

DETECTOR DEVELOPMENT AND CALIBRATION

K600 TRANSMISSION MODE FOR 0° INELASTIC SCATTERING

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The K600 Transmission Mode was originally used to understand and eliminate the beam halo at the target location of the K600 High Resolution Spectrometer.¹ This mode was developed into a fully operational experimental mode of the K600 and was used successfully in two experiments involving inelastic scattering^{2,3} where the particle momentum is very close to the incident beam momentum. This report summarizes the technical features of this mode. The following list highlights the main characteristics:

- 1) The resolution is typically 25–30 keV using standard dispersion matching procedures.
- 2) The full acceptance in scattering angle is $0^\circ \pm 2^\circ$.
- 3) Scattering angles can be calibrated to a precision of $\pm 0.1^\circ$ over the full acceptance.
- 4) The beam direction (0°) may be established with $\pm 0.1^\circ$ precision.
- 5) The total momentum range is $\approx 4.2\%$.
- 6) The highest momentum in the focal plane spectrum is 2.4% below the beam momentum (e.g., $E_{x,min} \approx 8.3$ MeV (6.7 MeV) for 200 MeV (160 MeV) incident protons).
- 7) Setup procedures exist for halo-free beam.
- 8) Background can be reduced with an active collimator at the K600 entrance.
- 9) Redundant particle detection in the focal plane reduces background to produce clean spectra.

The K600 configuration is shown in Fig. 1. The beam is stopped in the transmission cup mounted on the high momentum side of the focal plane detector when it is placed on the high dispersion port. The dipole ratio, $R = B(D1)/B(D2) = 1.49$, is actually set higher than the designed high dispersion mode ($R = 1.33$) of the spectrometer. This improves clean transmission of the beam through the dipole gaps and increases the dispersion from $D = 9.8$ to 10.9 cm/% for better separation of the beam and access to low excitation energies.

Since a narrow slit at the K600 entrance for dispersion matching is not possible in transmission mode, matching the beam line dispersion to the K600 needs to be performed at a finite scattering angle, typically 20° . Using a high Z target like gold ensures that the kinematic factor $k = (1/p')(dp'/d\Theta) \approx 0$, as is needed for 0° measurements. Resolutions of 25 to 30 keV are typical.

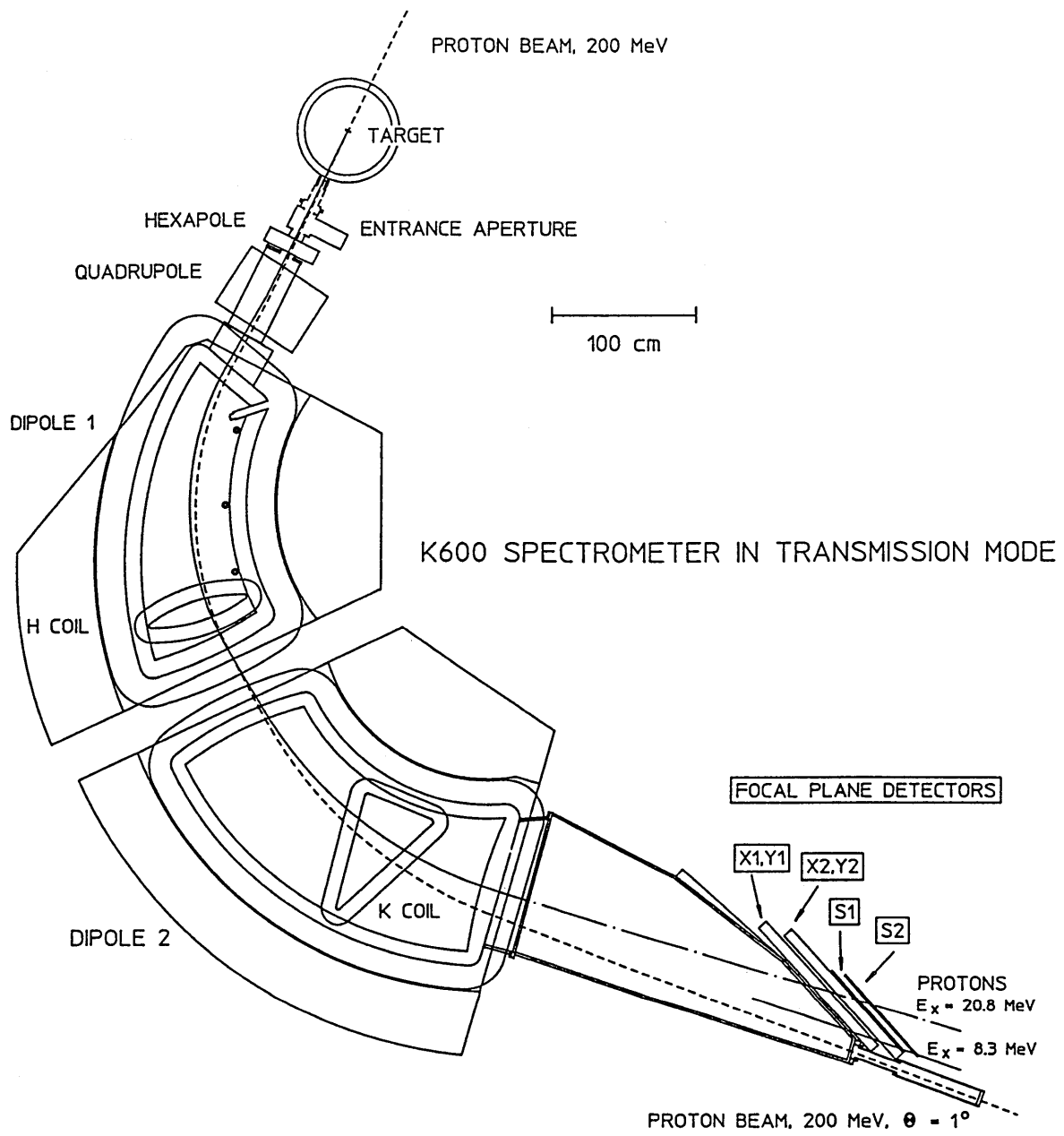


Figure 1. Schematic layout of the K600 spectrometer, detector system and Faraday cup in Transmission Mode. As an example, a 200 MeV proton beam and two rays of inelastically scattered protons corresponding to an 8.3 and 20.8-MeV excitation energy are shown.

In principle the beam can be aligned to enter the spectrometer anywhere within its circular acceptance of $\pm 2^\circ$. It is preferred, however, to send the beam through the center of the acceptance in order to minimize background from the remaining beam halo and the slit edge scattering of particles from the target.

The scattering angle Θ_{scat} can be determined by reconstructing the horizontal angle Θ_{tgt} and vertical angle Φ_{tgt} components from measured focal plane parameters. The horizontal angle Θ_{tgt} can be obtained from the horizontal focal plane angle. The horizontal angle magnification of the spectrometer (-2) makes this relatively easy. With a vertical angle magnification of about 0.08, the same procedure is not possible for Φ_{tgt} . Therefore, we modified the spectrometer settings by reducing the K600 quadrupole strength to obtain vertical point-to-parallel ion optics across the full momentum range. More than adequate vertical angle information was available from the drift chamber position in the spectrometer focal plane.

Also, with a large vertical magnification of about 12, the vertical beam size on target has to be reduced to about 0.2 mm. This is necessary to keep the vertical image below about 2.4 mm and maintain good resolution for the target angle reconstruction. To achieve a small enough vertical beam spot, we adjusted quadrupole 9 in beam line 8 for the minimum line width of the slit images shown in Fig. 2. Figure 2 also illustrates the spread of vertical images as a function of horizontal (bend plane) position across the focal plane. This pattern was made with an entrance aperture containing 5 slits arranged in a vertical pattern, and a

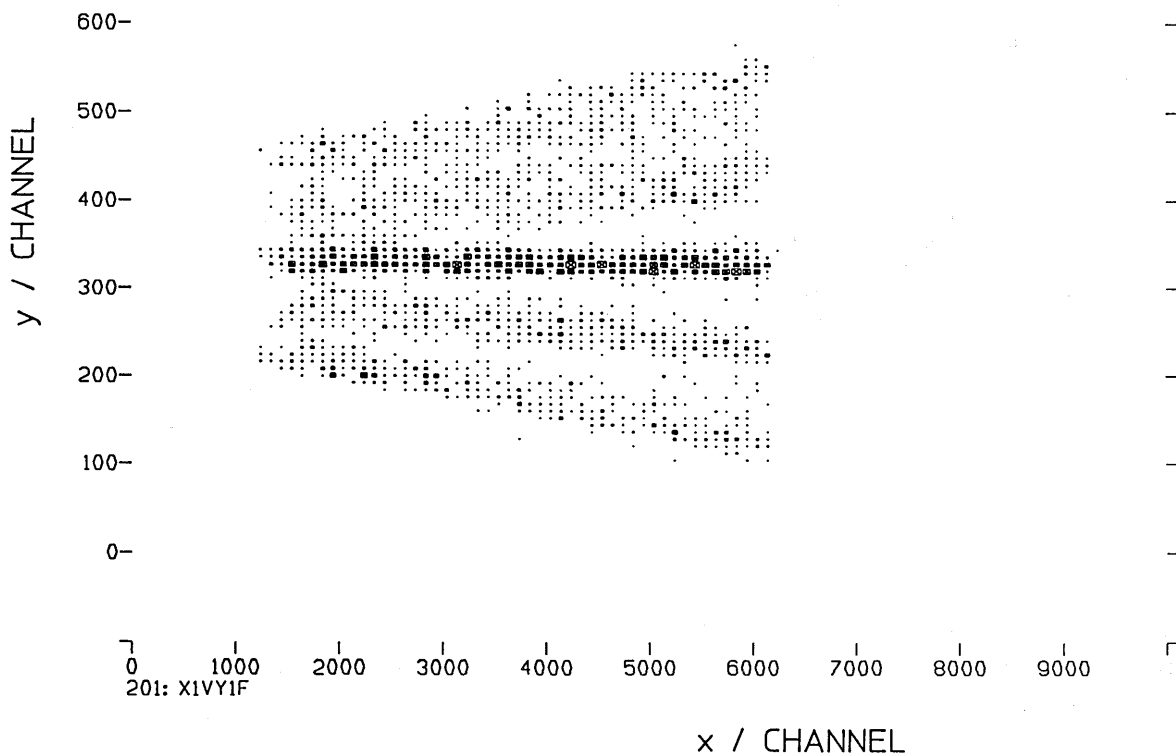


Figure 2. This x - y scatter plot in the focal plane shows the images of five entrance slits in the vertical direction separated by 14.5 mrad. This information is used to calibrate the vertical component of the scattering angle.

portion of a continuum spectrum projected onto the focal plane. The slits were separated by 14.5 mrad and the images are well resolved. The smallest apparent beam sizes of 2 mm on a scintillator as viewed by TV cameras are obviously limited by glare in the scintillator material. Tests with 0.2 mm wide strip targets showed that vertical target spot sizes of about 0.2 mm can be routinely achieved.

Figure 3 shows the Θ_{tgt} and Φ_{tgt} images and their projections as produced by a square grid multi-hole entrance aperture. The horizontal and vertical angle separations between aperture holes are 14.5 mrad and the hole diameters are 4.5 mrad, except for the center hole which is 6.8 mrad for identification purposes. While the horizontal calibration parameters used in this online fit were quite good, the vertical calibration is smeared by correlations between Φ_{tgt} and Θ_{tgt} . This correlation may be removed by a suitable variable transformation in the data acquisition software. The angular resolutions was measured using a 2.1 mrad wide slit. A resolution of better than 2.1 mrad FWHM vertically and 3.0 mrad FWHM horizontally was achieved.

The beam direction, which defines the scattering angle, needs to be established after every change in beam-line tune. This was done by comparing the beam position on a scintillator at the target location with the readout from a beam stop located in the aperture cassette. A special beam stop with a center hole of 6.4 mm and a second, electrically-isolated stop behind the hole was used to locate the horizontal and vertical beam direction at the aperture cassette. For this purpose the beam current ratio of the center and ring stop was measured as a function of the upstream horizontal and vertical steerers until the point of maximum transmission to the second stop was found. Various steerer combinations could be checked to determine a set that would center the beam in both locations. The beam could also be centered into the acceptance of the spectrometer at the entrance slit by adjusting the spectrometer angle.

The most critical setup procedure for the Transmission Mode is the beam tune for an extremely clean beam. If only a very small fraction of the typical beam current of 2 nA touches any element in beam line 8 or any spectrometer element, the background count rate becomes prohibitively large. The goal is to reduce the wire chamber coincidence rate to less than 100-200 Hz without any target. The ideal beam line design goal of large beam pipes and no slits is not possible in our case for several reasons. First, the beam line and magnetic elements already exist and cannot be modified without major reconstruction. Second, a horizontal beam size of 0.5 mm at the object location ahead of the QDDM analyzing system is a necessary condition for high resolution in the focal plane. Normally this is ensured by an "object slit" of 0.5 mm width with a transmission of 50-80%. Since this slit produces a prohibitive background, we created the object point beam size of 0.5 mm by using the horizontal slit in front of the upstream bending magnet B2 in beam line 8. It was found that the background was significantly reduced while a resolution of 30 keV or better was still possible.

A strict beam line procedure to center the beam in the complete beam line has to be followed. Above all a "stable beam" is needed which depends in part on how long the cyclotron has been operating at the same energy. This stability is particular important for the transmission mode because of the long setup procedure which has to be repeated if important beam line parameters are ever lost. Even when the beam line is set up in this

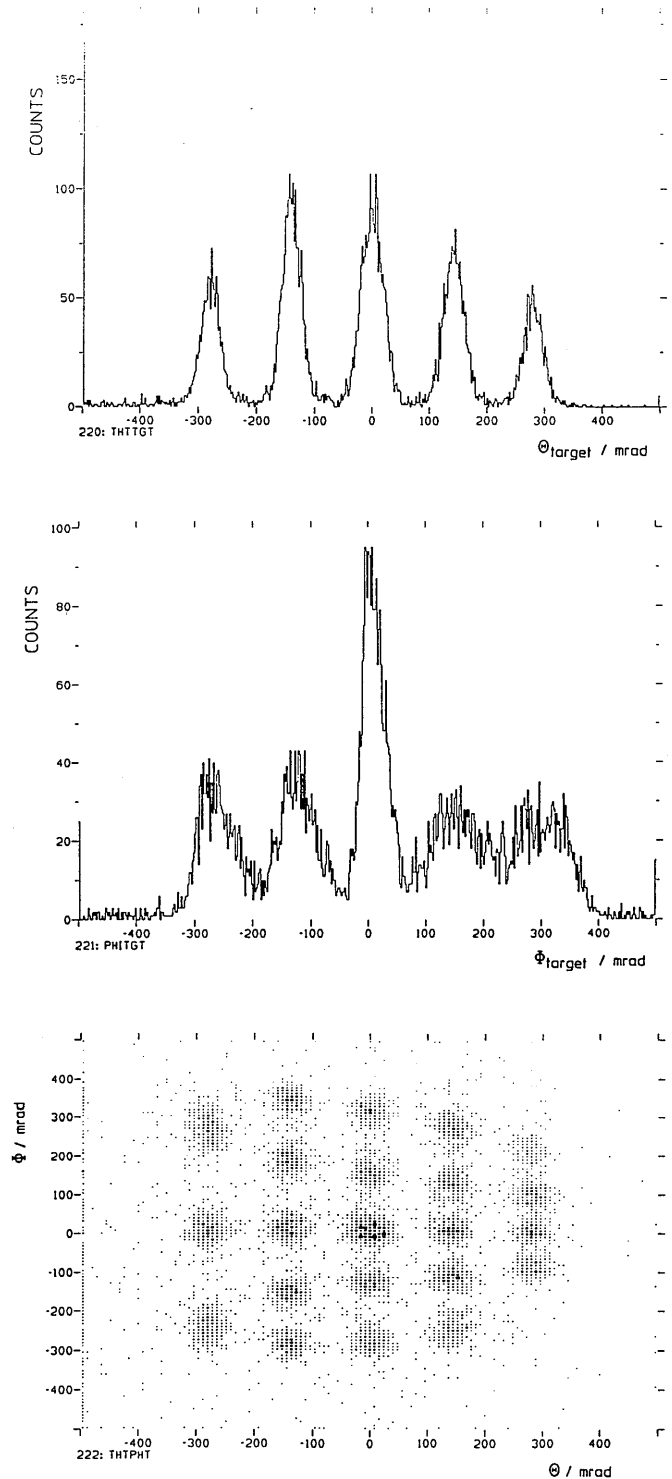


Figure 3. The lower part of the figure shows an online plot of the calculated scattering angle components horizontally and vertically, as explained in the text. Also shown are both projections onto the axis. The vertical calibration still contains correlations between Φ_{tgt} and Θ_{tgt} .

way, the typical focal plane count rate is still a few kHz without the target as measured with the two focal plane scintillators in coincidence. Further beam tuning using this count rate as the diagnostic tool continues until the beam background is reduced to less than 100-200 Hz. While the ratemeter is convenient and fast it may require a measurement with the full focal plane detector system to identify and eliminate background sources. On occasion, closing beam line slits in front of beam line 8 to limit beam emittance may be necessary to reduce the beam components which produce background. Once this goal is achieved, the target can be inserted. Typical count rates during data taking are 600 Hz with a live time of about 85% (e.g., for a ^{48}Ca target of 4 mg/cm² thickness and a 2-nA beam).

The complete standard K600 detector system consists of two sets of x and y position-sensitive wire chambers separated by 10.5 cm in order to allow angle measurements. The two scintillation detectors mentioned above are mounted behind these wire chambers. They provide particle identification and give fast timing signals for the time-of-flight spectra relative to the phase-compensated cyclotron RF. All data from these detectors are needed to reduce background in replay as much as possible.

We also included an active collimator in our data stream. This detector is mounted at the location of the entrance aperture. It consists of a circular scintillator ring behind the aperture with a light guide connected to a photomultiplier tube outside the vacuum box. The active collimator is used to detect scattered particles from the target that come outside the collimator limit and to veto these events from the data stream. In the $^{48}\text{Ca}(p,p')$ experiment at 200 MeV, the background rate relative to the measured rate in the peaks was improved up to a factor of five in some parts of the spectrum.

1. G.P.A. Berg, *et al.*, IUCF Sci. and Tech. Rep., May 1990 – April 1991, p. 221.
2. B.F. Davis, *et al.*, IUCF Sci. and Tech. Rep., May 1992 – April 1993, p. 34; and B.F. Davis, *et al.*, this report.
3. D. Mercer, *et al.*, IUCF Sci. and Tech. Rep., May 1992 – April 1993, p. 31.