KfK 2972
Dezember 1980

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ISSN 0303-4003

Abstract

The ion optical design of a simple magnetic spectrograph for nuclear reaction studies at the Karlsruhe Isochronous Cyclotron is described. The spectrograph enables to detect charge, mass number, reaction angle and momentum (energy) of charged reaction products emitted from the target. The performance of the spectrograph covers a reasonable range of nuclear reactions induced by light and heavier projectiles up to mass number A = 20 at an energy of E_{Lab} = 26 MeV per nucleon.

The design is based on beam transport calculations using first and second order matrix formalism and ray tracing. Dispersion, focussing, and second order corrections are independently provided by separate magnetic units. The spectrograph consists of two quadrupoles, one 60^{o}-deflecting dipole, and one sextupole magnet combined to a QQDS configuration.

Entwurf eines einfachen Magnetspektrographen für das Isochron-Zyklotron Karlsruhe

Zusammenfassung

Der ionenoptische Entwurf eines einfachen Magnetspektrographen zum Studium von Kernreaktionen am Karlsruher Zyklotron wird beschrieben. Der Spektrograph ermöglicht die Bestimmung von Kernladung, Massenzahl, Reaktionswinkel und Impuls (Energie) von geladenen Teilchen, die nach Kernreaktionen aus dem Target emittiert werden. Die Eigenschaften des Spektrographen überdecken einen geeigneten Bereich möglicher Kernreaktionen, die von leichten und schweren Projektilen bis zur Massenzahl A = 20 bei einer Energie von 26 MeV pro Nukleon induziert werden.

Der Entwurf basiert auf Strahltransport-Rechnungen im Matrixformalismus erster und zweiter Ordnung. Dispersion, Fokussierung und Korrekturen zweiter Ordnung werden durch unabhängige Magneteinheiten erzielt.
Der Spektrograph besteht aus zwei Quadrupol-, einem 60^{o}-ablenkenden Dipol- und einem Sextupolmagneten, die in einer QQDS Konfiguration angeordnet sind.

1. INTRODUCTION

A considerable part of fundamental nuclear physics research performed at the Karlsruhe Isochronous Cyclotron is covered by studies of nuclear reactions induced by charged particles in the entrance channel and detection of charged reaction products in the exit channel [1]. For an unambiguous identification and description of a nuclear reaction the characteristic quantities of the reaction products ejected from the target which are mass and charge numbers (A), (Z), and kinetic energy (E_f) as well as the reaction angle ψ with respect to the incoming projectile have to be measured by suitable detection systems. The kind of these detection systems depends on the properties of the projectiles and ejectiles and on the particular nuclear reaction to be studied.

Table 1: Properties of the beams extracted from the Karlsruhe Isochronous Cyclotron

Particle	Mass number A	Charge state ζ	E (MeV)	I_{max} (μA)
a) Internal ion sources				
p (H_2^+)	1	1^+	26	5
d	2	1^+	52	10
α	4	2^+	104	5
b) External ion sources				
d↑	2	1^+	52	0.05
^6Li	6	3^+	156	0.1
c) Particles from external ECR-source HISKA (not yet available)				
^{12}C	12	6^+	312	
^{14}N	14	7^+	364	
^{16}O	16	8^+	416	
^{20}Ne	20	10^+	520	

At present the different particle beams quoted in table 1a and b are available at the Karlsruhe Isochronous Cyclotron. In near future an Electron-Cyclotron-Resonance ion source will be brought into operation[2] which will provide the additional beams of light heavy ions compiled in table 1 c. Since the cyclotron is a fixed frequency machine all particles extracted must be fully stripped ; they have a given ratio $Z/A = 1/2$ and a fixed energy per nucleon $E/N = 26$ MeV. (The beam energy, however, can be reduced by a beam degrader installed in the external beam handling system). The energy spread of the beam usually amounts to $\Delta E/E = 4 \cdot 10^{-3}$. It can be improved to a value of about $4 \cdot 10^{-4}$ (FWHM) when using the monochromator magnet. Thereby, the beam current is reduced by a factor of 10.

The charged reaction products emitted from the target after a nuclear collision are at present most frequently detected by semiconductor detector telescopes (Si-surface barrier, intrinsic Ge-detectors). These detector systems are easily to handle, have reasonable energy, charge and mass number resolution and, therefore, are applicable for a wide range of nuclear reaction experiments. However, there are several limitations of solid state detectors, in particular for higher energies and heavier ions ($A > 4$) disabling to perform a varity of interesting experiments. The most important disadvantages are the limited energy resolution for heavier particles [3], the small stopping power for light particles ($Z = 1$) of higher energy (> 50 MeV), and the limited peak to background ratio in particular at very small reaction angles ψ. In addition, the semiconductor detectors are damaged by radiation limiting their life-time in general, in some cases even to a few days of operation (Ge(Li)).

A magnetic spectrograph is the only favourable instrument to overcome all these experimental limitations. Different types of spectrographs have been built up in several accelerator laboratories [4]. These big spectrographs cover nearly all charged particle nuclear reactions which can be induced by the corresponding accelerator beams. In addition, they were designed for optimal efficiency (solid angle). Hence, they were rather expensive, need a large experimental area to be placed at and considerable man-power to develop and operate it. These reasons exclude to build up a similar spectrograph at the Karlsruhe Cyclotron Laboratory.

However, it seems to be worthwhile to think about a small spectrograph covering a limited class of nuclear reaction experiments for which the Karlsruhe fixed energy cyclotron is especially suited, in particular with the future heavy ion beams. In this report, the experimental requirements and the design philosophy for such a simple magnetic spectrograph are discussed. An ion optical design basing on beam transport calculations is presented. The resulting spectrograph named "Little John" has been decided to be built up and installed in the experimental hall of the Karlsruhe Isochronous Cyclotron.

2. EXPERIMENTAL REQUIREMENTS

The dominant factors contributing to the costs of a magnetic spectrograph are the accepted solid angle Ω, the energy resolution $\Delta E/E$ and the mass-energy-product AE/Z^2 characterizing the maximum magnetic rigidity of the particles which can be deflected by the magnets. For a low-cost spectrograph the limits of these important features have to be restricted in general. The suitable choice of the restricted values must be optimized comparing the experimental aims on the one hand and the possibilities to realize it by a limited budget on the other hand. The experimental requirements for the spectrograph under discussion can be divided into two classes:

(i) For the light particles ($A \leqq 4$) precision measurements (in particular at very forward angles) of elastic and inelastic scattering exciting low energy states are of dominant interest. This requires a rather small energy range ($\sim$ 10 MeV) and a maximum mass-energy-product of about 100 MeV amu/e^2 given by the beam particles. In addition the observation of transfer reactions induced by the light particles should also be possible. For that purpose, however, a considerable increase of the mass-energy-product up to about 300 MeV amu/e^2 is necessary in order to detect e.g. tritons from the reaction (α, t).

(ii) For the heavier particles ($A \geq 6$) besides the elastic scattering the exitation of broad structures like giant resonances and deeply inelastic reactions, and the break-up and fragmentation of the projectiles is mostly interesting. The latter reactions also require the detection of broad energy distributions of fragments having beam velocity. Hence, a large energy acceptance (> 50 MeV) is important. For most of the reaction products a mass-energy-product of about 200 MeV amu/e^2 is sufficient. Only deuterons and tritions being important in particular in ^{6}Li-induced reactions require a considerably higher value.

Both groups of experiments quoted above are expected to show the most interesting features mainly at very forward reaction angles. At these angles the cross sections are in the range of mb to b. Therefore, a limited solid angle of about 1 msr is not a too strong restriction of the applicability of the spectrograph. This value is still ten to fifty times larger than that of semiconductor telescopes presently used for the experiments [5]. With the given limited solid angle, on the other hand, a large mass-energy-product does not increase the costs of the magnets so dramatically. A value close to 300 MeV amu/e^2 should be aimed at to cover also the remarkable ^{6}Li-induced reactions.

In contrast to the required solid angle and mass-energy-product which are rather similar for both classes of experiments, the requirements are opposite concerning the accepted energy range and energy resolution. For the energy resolution the optimal possible value is already determined by the existing beam monochromator system ($\Delta E/E = 4 \cdot 10^{-4}$). Reaching this limit closely by the spectrograph is sufficient for the experiments of both classes (i) and (ii). It would be a clear improvement of the resolution for light ions ($A \leq 4$) compared with semiconductor detectors. For heavier ions ($A \geq 6$) at E_{Lab} = 26 MeV/N the quoted energy resolution of a spectrograph is not by far provided by solid state detectors.

For most of the experiments of the second group, however, the energy resolution is less important than a large energy range. Since the energy resolution and range both are determined by the dispersion of the spectrograph (see Appendix A) the different experimental requirements suggest a variable dispersion or at least the possibility to operate the spectrograph at two different dispersion values.

In addition, for the heavy ion experiments another feature becomes relevant namely the kinematical broadening due to a strong dependence of the momentum of the reaction products on the reaction angle ψ_o. This dependence usually is characterized by the kinematical parameter k defined as

(1) $$k\ (\psi_o) = \frac{1}{p_f} \left. \frac{dp_f}{d\psi} \right|_{\psi_o}$$

Here p_f is the momentum of the reaction product and ψ_o is the mean reaction angle. Due to the finite aperture angle $\pm\ \Delta\Theta$ of the spectrograph the momenta of ejectiles from a specific reaction (i. e.: with well-defined energy loss) entering the spectrograph are smeared out according to the first order relation

(2) $$p_f(\psi_o \pm \Delta\Theta) = p_f(\psi_o) \pm k\ p(\psi_o)\ \ \Delta\Theta$$

This kinematical broadening can be ion optically compensated by the spectrograph for a certain range of k as shown in sect. 4.3. The range of the kinematical parameter k for some characteristic light and heavy ion elastic scattering is displayed in fig. 1. For reactions with large Q-values the k-values are even larger.

For the interesting symmetrical systems like $^{12}C + {}^{12}C$ for example the compensation of large k-values ($|k| > 5 \cdot 10^{-4}$ mrad^{-1}) is required even at forward angles. The compensation should easily be performed by the spectrograph.

Summarizing the above considerations the design goals of the spectrograph are compiled in table 2.

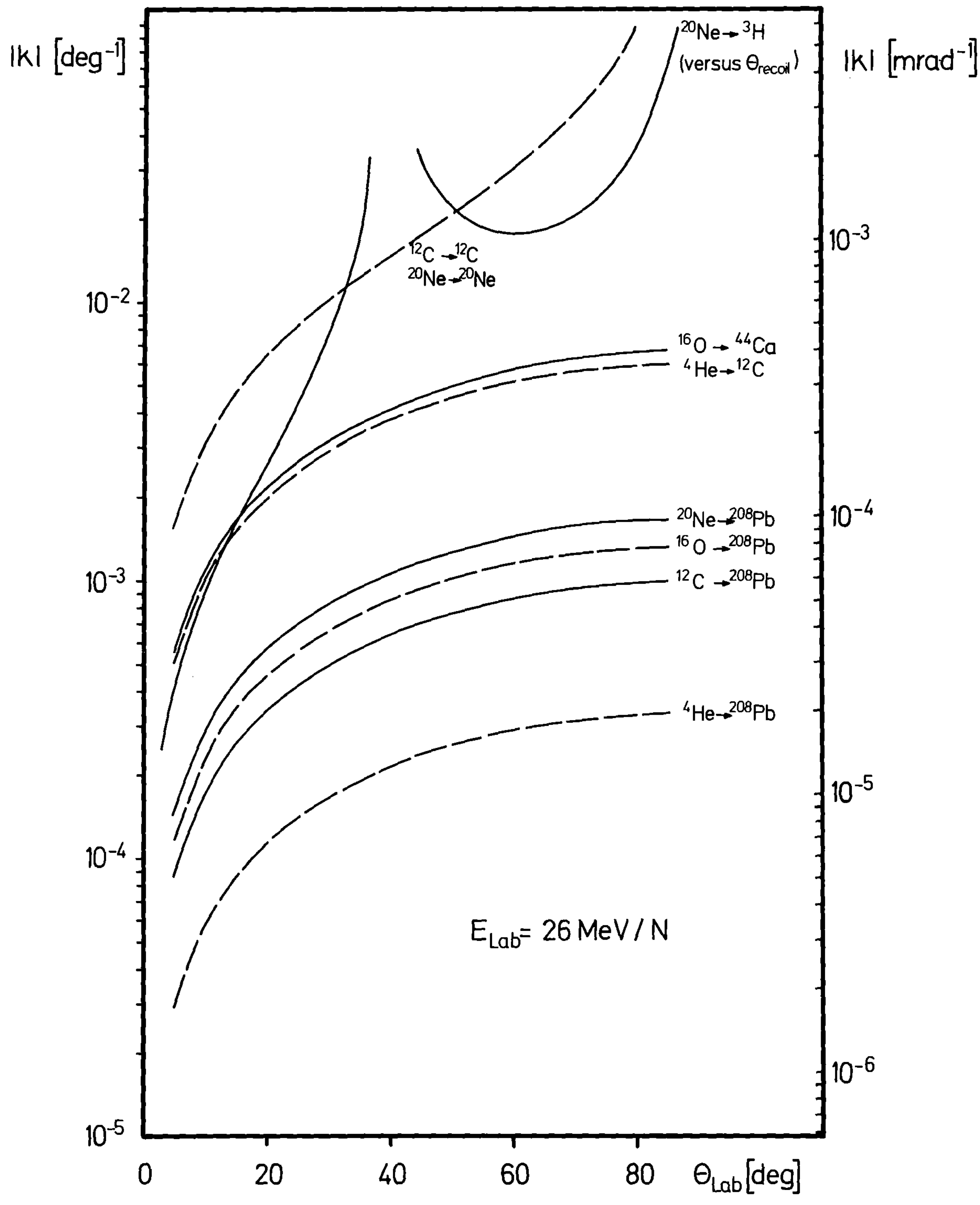

Fig. 1 Kinematical parameter $|k|$ (see eq. 1) for elastic scattering of different projectile-target combinations.

Table 2: Design goals of the magnetic spectrograph

a) General

Solid angle Ω (msr)	> 1
Mass-energy-product AE/Z^2 (MeV amu/e^2)	∿300

b) High resolution mode

First order energy resolution ΔE/E	$5 \cdot 10^{-4}$
Energy range (%)	10
Kinematical parameter $\|k\|$ (rad^{-1})	>0.2

c) Large energy range mode

First order energy resolution ΔE/E	10^{-3}
Energy range (%)	> 25
Kinematical parameter $\|k\|$ (rad^{-1})	> 1

3. DESIGN PHILOSOPHY

In order to have the spectrograph in operation as early as possible (and also to save money) it should be installed in the existing experimental hall of the cyclotron laboratory. Since some beam lines are traversing the hall to feed other experimental areas and since the monochromator magnet (150^o deflection angle, 130 cm mean orbit radius) and the big scattering chamber (130 cm diameter) have also to be placed there only a small area of about 8 m times 8 m is available for the spectrograph. In addition the load on the floor is limited to a rather small value so that the spectrograph should be as light as possible.

An important question influencing further decisions like detector performance and ion optical imaging is whether to use horizontally bending magnets (in the reaction plane) or to put the spectrograph upright bending vertically out of the reaction plane. The latter alternative has advantages concerning background reduction and correction of kinematical effects in particular at larger reaction angles. At very forward angles, however, these arguments are less important. In addition practical aspects like the easy access of the detector system by the experimentator favour the conventional horizontal installation of the bending magnet(s).

The focal plane length determining the size of the detector should be reasonably small since the time and man-power necessary for the development and test of a suitable focal plane detection system increases remarkably for large detectors. A short focal plane of about 0.5 m implies a rather small dispersion in order to fulfill the requirement of a large energy range. This has consequences on the optical imaging which is point-to-point in the horizontal plane. Assuming a target spot size of 1 mm diameter and a position resolution of the detector of less than 0.5 mm the horizontal magnification should be smaller than 1 in order to obtain a good energy resolution in spite of the low dispersion (see Appendix A). The vertical imaging is of less importance and can be either point-to-point or point-to-parallel. However, the image size in the detection plane should be in the order of a few cm. Thereby the density of particle rays impinging on the detector per unit area is reduced.

To realize all the quoted requirements for the magnetic spectrograph in spite of a limited fund it seems most reasonable to use simple magnets without focussing edges, curved edges or correction coils. Because of the rather wide mode of application the dispersion, focussing, and higher order corrections (at least tilt of the focal plane; see Appendix A) should be provides by separate magnets. A further correction of ion optical aberrations of higher order is assumed to be performed by reconstruction of the particle trajectories off-line on a computer. For that purpose the space and angular coordinates of the particle have to be determined by the focal plane detector [6), 7)].

4. ION OPTICAL LAYOUT

4.1 Magnetic configuration

As pointed out above a spectrograph with variable dispersion would at best fulfill the experimental requirements. Variable dispersion, however, is usually provided only by highly sophisticated spectrographs [4,8)]. For

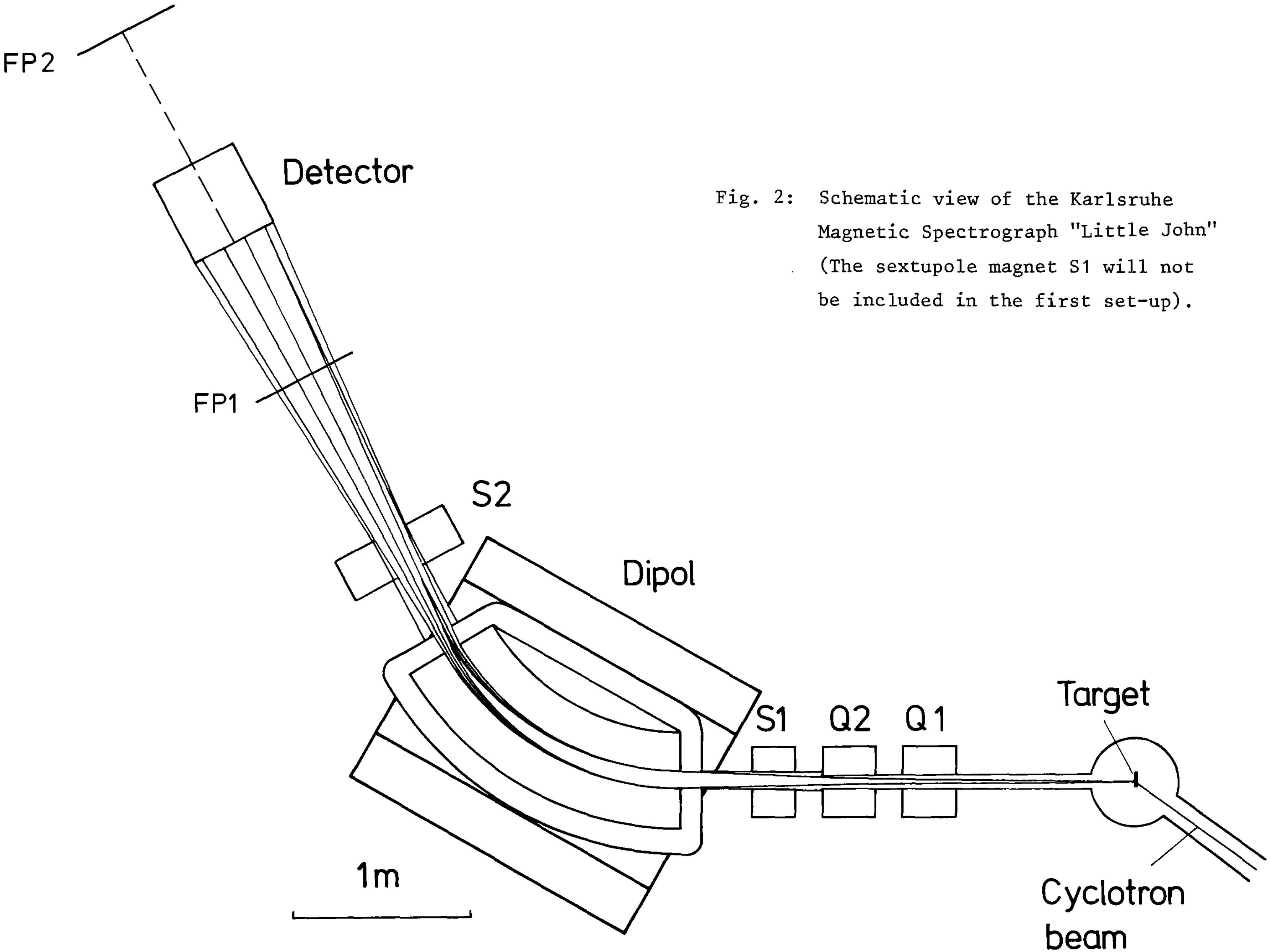

Fig. 2: Schematic view of the Karlsruhe Magnetic Spectrograph "Little John" (The sextupole magnet S1 will not be included in the first set-up).

any magnetic configuration of a spectrograph the dispersion is (in first order) a linear function of the distance of the focal plane from the last magnet of the spectrograph. Therefore, the simplest method yielding different dispersions is just to place the focal plane at different distances behind the magnets. Doing so, however, requires a very flexible focussing system for both the horizontal and vertical plane. For that purpose, at least two quadrupole magnets are necessary. Consequently, as one of the simplest magnetic configuration fulfilling the stated features a QQDS system was selected with two quadrupoles (Q) for horizontal and vertical focussing, a homogeneous field 60^{o} deflecting dipole magnet (D) providing dispersion and a sextupole magnet (S) enabling to adjust the focal plane tilt according to the requirements of the experiment and the detector.

To reach the required mass-energy-product of 300 MeV amu/e^2 at a reasonable dipole field strength, the main orbit radius was chosen to be 1.50 m. The deflection angle of 60^{o} of the dipole yields sufficient dispersion on the one hand and provides a good time resolution (due to small path length differences of the extreme trajectories) on the other hand. The latter is usefull for obtaining a good mass

Table 3: Some technical features of the spectrograph

Magnetic configuration	QQDS
Main orbit radius (m)	1.5
Deflection angle	60°
Max. magnetic dipole field (kG)	16.8
Max. mass-energy product (MeV amu/e^2)	300
Max. power (kW)	70
Total weight (t)	25
Total system length (m)	8

number resolution. The further detailed layout of the spectrograph was worked out by beam transport calculations in first and second order using the program TRANSPORT [9]. In particular the possibilities of varying the dispersion and the kinematical corrections as discussed in sects. 4.2 and 4.3 were studied by these calculations. A schematic view of the final configuration including an additional sextupole magnet for correction of spherical aberrations is shown in fig. 2. Table 3 compiles some technical features of the spectrograph.

4.2 Variable Dispersion

The quadrupole duplet provides a flexible focussing which allows to place the focal plane at any position inside a range of 2.3 m between the extreme positions indicated in fig. 2. Thereby, the momentum dispersion is varied between 2 cm/% and 4 cm/%. This enables low resolution experiments with large momentum (energy) acceptance of ± 10 % (± 20 %) and high resolution experiments with a reduced momentum acceptance of ± 5 %.

Since one experiment is performed with a fixed prechosen dispersion the variation of the dispersion by dismounting the detector and mounting it at another position cannot be regarded as a too serious disadvantage compared to the variation of the dispersion by a quadrupole magnet as performed elsewhere[4,8]. On the other hand, in the present case the horizontal and vertical magnifications are nearly the same for any focal plane position as shown by the characteristic trajectories in fig. 3. This is in contrast to other solutions where the variation of the dispersion is accompanied by a rather strong change of other optical parameters [4,8].

Some characteristic first order ion optical features for the two extreme focal plane positions are compiled in table 4.

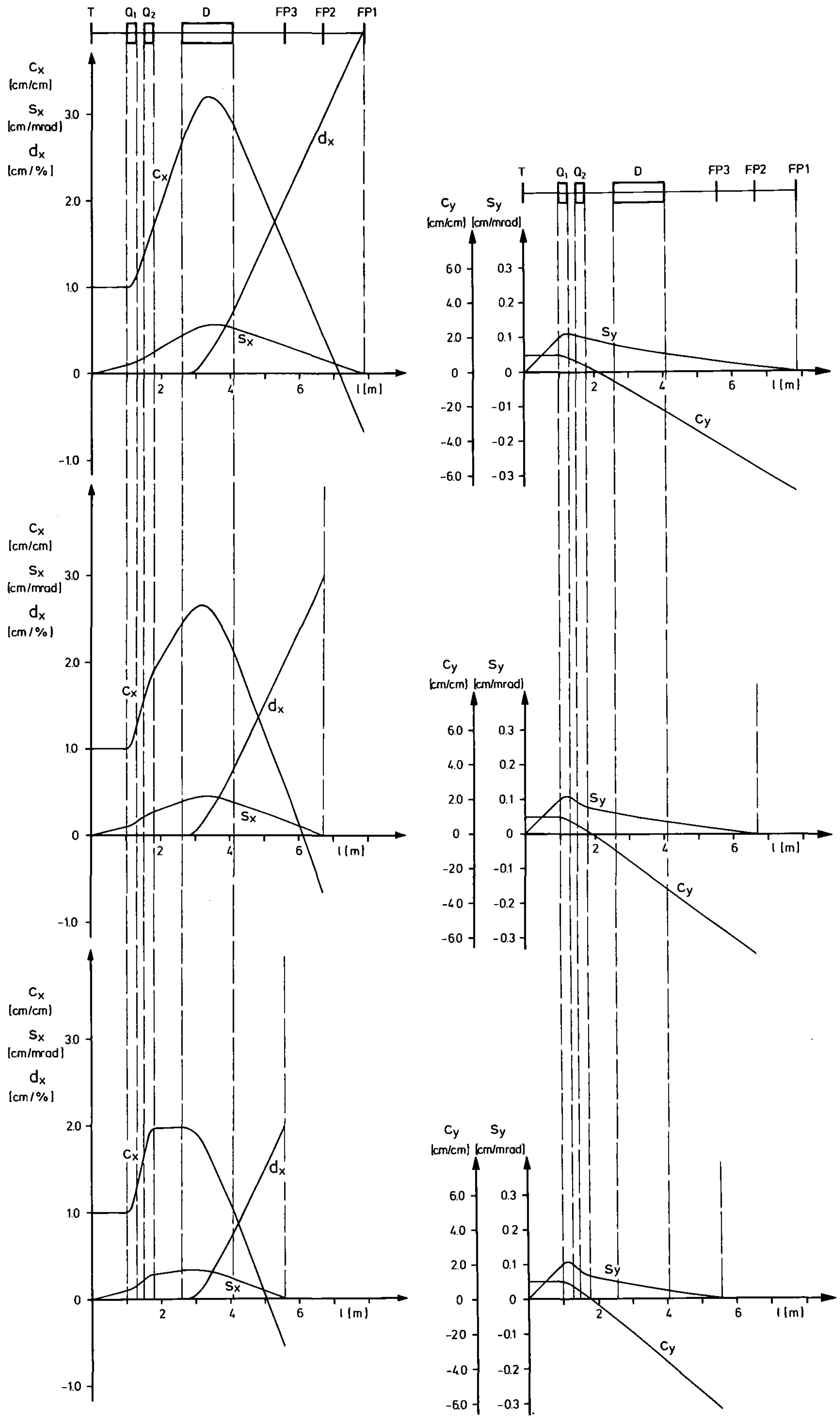

Fig. 3: Characteristic trajectories of the magnetic spectrograph for three different focal plane positions (Notation from Ref. 9).

Table 4: First order characteristics of the magnetic spectrograph at two different focal plane positions for $k = 0$, $2\,x_o = 0.1$ cm and $2\,\Theta_o = 25$ mrad

	FP1	FP2
Dispersion R_{16} (cm/%)	2	4
Horizontal magnification	-0.64	-0.73
Vertical magnification	-5.9	-6.1
Momentum resolution R_p	3100	5500
Time-of-flight resolution R_t	58	56
Combined resolution $R_p.R_t$	$1.8\cdot10^6$	$3\cdot10^6$
Momentum acceptance (%)	$\pm$ 10	$\pm$ 5

4.3 Kinematical Corrections

In the notation of Brown [10] (see Appendix A) the focal plane position x of particle starting from the target with the coordinates x_o, Θ_o, δ in first order transport formalism is given by

(3) $$x_f = R_{11}\,x_o + R_{12}\,\Theta_o + R_{16}\,\delta$$

If the kinematical parameter $k \neq 0$ the relative momentum deviation δ can be written according to eq. 2.

(4) $$\delta = (p_f(\psi_o + \theta_o) - p_f(\psi_o))\;/\;p_f(\psi_o) = \delta_o + k\,\theta_o$$

where $\Theta_o = \Delta\psi$ Inserting eq. 4 into eq. 3 one gets

(5) $$x_f = R_{11}\,x_o + (R_{12} + k\,R_{16})\,\Theta_o + R_{16}\,\delta_o$$

Point-to-point focussing requires the transfer coefficient of Θ_o (which is now $R_{12} + k\,R_{16}$) to be zero (see Appendix A).

(6) $$R_{12} = -k\,R_{16}$$

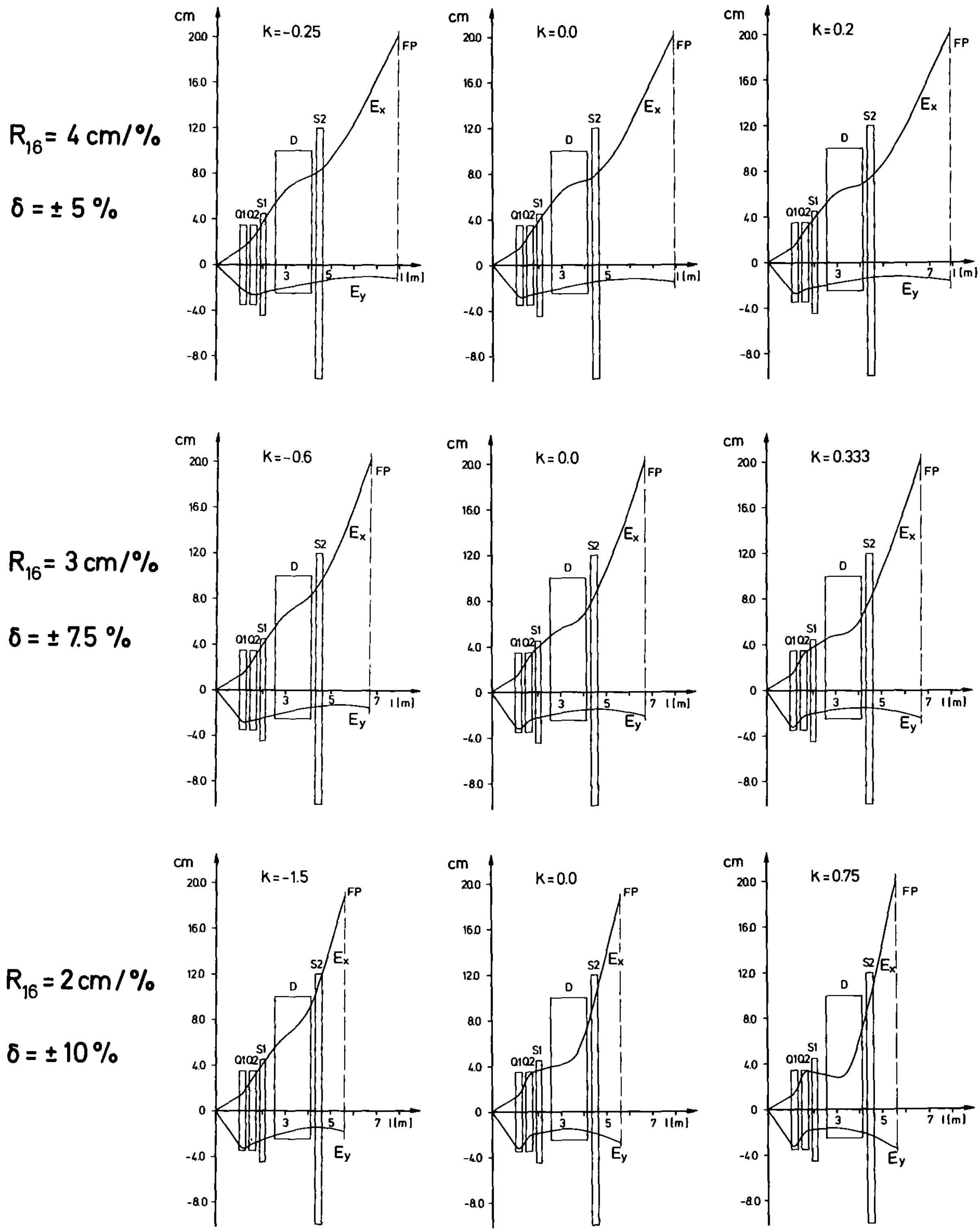

Fig. 4: Horizontal (E_x) and vertical (E_y) beam envelopes of the spectrograph calculated for an angular acceptance of $\Theta_o = \pm$ 12.5 mrad and $\phi_o = \pm$ 30 mrad and different kinematical parameters and momentum acceptances.

This condition for the kinematical corrections has to be fulfilled by a suitable setting of the quadrupole magnets. The possible range of k for doing so is different for different dispersions. The possible extreme solutions and the corresponding beam envelopes in the horizontal as well as in the vertical plane are displayed in fig. 4. The corresponding first and second order transport matrices and phase space ellipsoids are given in Appendix B.

4.4 Second Order Effects

The second order aberrations of the spectrograph have been determined by use of the beam transport program[9]. The effect of the aberrations on the width and shape of a reaction peak observed by the focal plane detector can be simulated by ray-tracing calculations [11]. For that purpose many ($\sim 10^6$) randomly chosen particle rays emerging from the target beam spot with the phase space ellipsoid given in table 5 have been transformed to the focal plane according to the first and second order transform matrices (see Appendix A).

Table 5: Assumed intensity distribution of particle rays inside the accepted entrance phase space of the spectrograph

Coordinate	Shape	Width (FWHM)
x_o	Gaussian	1 mm
Θ_o	Uniform	25 mrad
y_o	Gaussian	2 mm
ϕ_o	Uniform	60 mrad
$t_o(l_o)$	Gaussian	1.5 nsec
δ_o	Gaussian	$2\cdot 10^{-4}$

The resulting intensity distribution in the focal plane is schematically displayed over the x-y and x-Θ plane, respectively, in fig. 5 a and b.

The half-moon shaped distributions observed in the x-Θ plane are mainly due to the spherical aberration in the horizontal plane (matrix element T_{122}). A similar (less pronounced) shape can be observed in the x-ϕ plane (T_{144}). These dominant aberration terms cause a broadening of

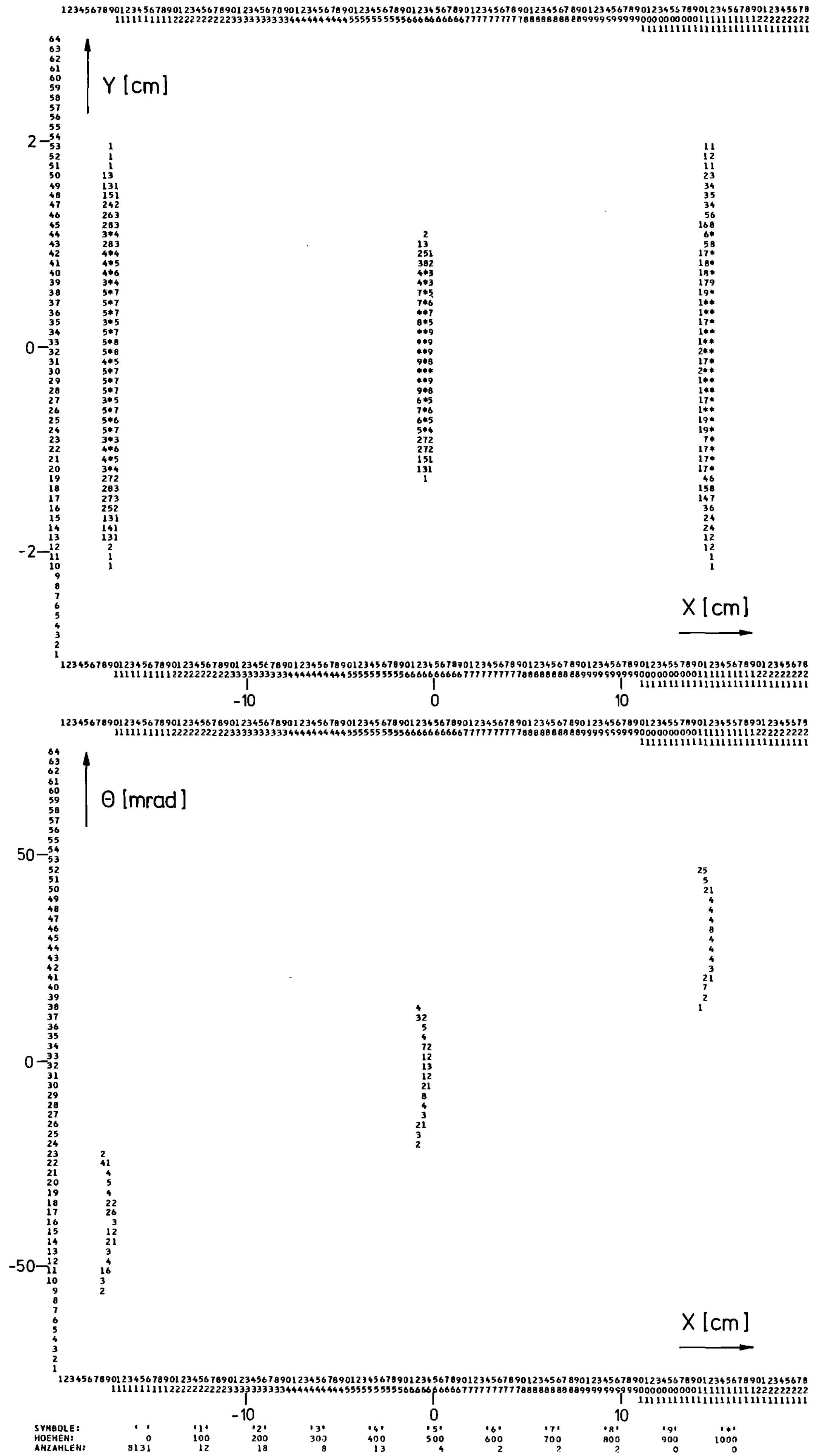

Fig. 5: Intensity distribution of three particle "peaks" at p_o - 4 %, p_o, p_o + 4 % in the detection plane calculated from the entrance phase space distribution given in table 5.

the line width and distortion of the shape the absolute amount of which is determined by the horizontal (Θ_o)and vertical ($\emptyset_o$) acceptance, respectively. Calculating the projection of the intensity distribution on the x-axis (which is in first order proportional to the momentum of the particle) the broadening is clearly indicated when performing the beam transformation calculation only in first or in first and second order, respectively, as shown in fig. 6.

It is clearly indicated that the aberrations are too large to obtain the required energy resolution since no higher order corrections are performed by suitable correction coils, curved dipole edges or sextupole magnets (except of the focal plane tilt angle adjusted by the sextupole). As pointed out in the design philosophy it is planned to reconstruct the particle trajectories from the measured space and angular coordinates and to compute the corrected x-position off-line after the experiment. For that purpose, the higher order aberrations which should be respected in the correction have to be known.

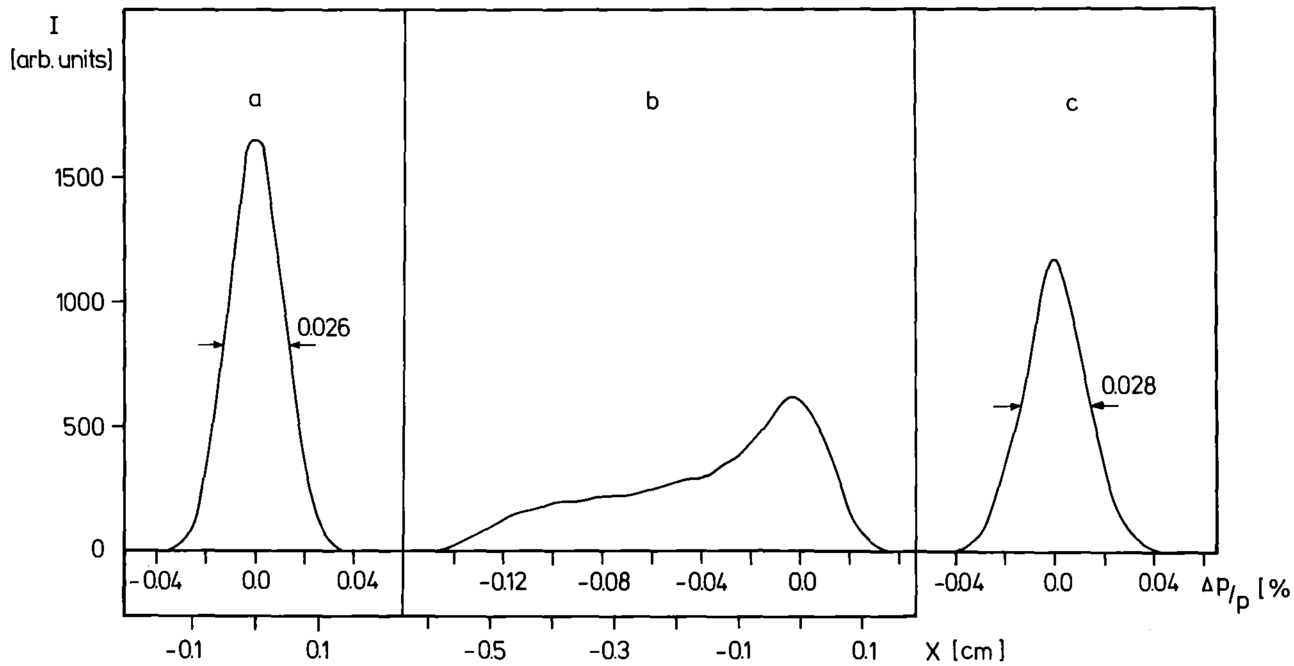

Fig. 6: Projected intensity distributions in the x-plane of the focal plane detector. a) Without second order aberrations, b) with second order aberrations, c) with second order aberrations and subsequent off-line correction. The momentum scale corresponds to the first order proportionality of x and p.

The dominant second order terms T_{122} and T_{144} can quite easily be measured by closing the acceptance slits to a very small width and shifting it over the full acceptance range either in horizontal $\Delta\Theta$ or vertical $\Delta\emptyset$ direction. The corresponding shift Δx of a narrow reaction peak (e.g. elastic scattering) in the x-direction of the focal plane directly determines the aberrations according to eq. A-1 (for k=0).

$$(7) \qquad \begin{aligned} &\text{horizontally}: && \Delta x = T_{122} \cdot (\Delta\,\Theta)^2 \\ &\text{vertically}: && \Delta x = T_{144} \cdot (\Delta\,\emptyset)^2 \end{aligned}$$

In addition to the aberrations itself which once have to be determined after setting the magnetic fields of the spectrograph the emission angles Θ_o and $\emptyset_o$ (with respect to the central ray) of each individual particle detected in the focal plane have to be determined. This can either be performed directly by a position sensitive start detector placed just after the acceptance slits. The second, more complicated method is to determine the emission angles $\Theta_o,\emptyset_o$ from the angles Θ_f, $\emptyset_f$ with which the particles impinge on the focal plane detector. For that purpose the first and part of the second order angular transformation coefficients have experimentally to be determined for each magnetic setting similar to the procedure described above (for the spherical aberrations). After determining Θ_o and $\emptyset_o$ in an iterative procedure[11], the corrected x-position of a detected particle is finally given by

$$x_{corr} = -0.5\, R_{16}/T_{166} \pm \sqrt{(x_f - T_{122}\,\Theta_o^2 - T_{144}\emptyset_o^2)/T_{166} + 0.25\,(R_{16}/T_{166})^2}$$

where the sign in front of the square-root is equal to the sign of $R_{16} \cdot T_{166}$. (The quadratic term T_{166} of the dependence of x on δ_o is already considered in this formula so that x_{corr} is proportional to δ_o). The corrected intensity distribution is displayed in fig. 6c yielding a second order momentum resolution of $\Delta p/p = 2.8 \cdot 10^{-4}$ (FWHM). This value fulfilling nearly the first order design value can be improved by including also the vertical spherical aberrations in the iteration procedure on the computer[11].

5. BEAM LINE SYSTEM AND INSTALLATION

The beam line system for the magnetic spectrograph as well as for the big scattering chamber and for other experimental facilities for nuclear reactions is shown in fig. 7. It mainly consists of the monochromator part followed

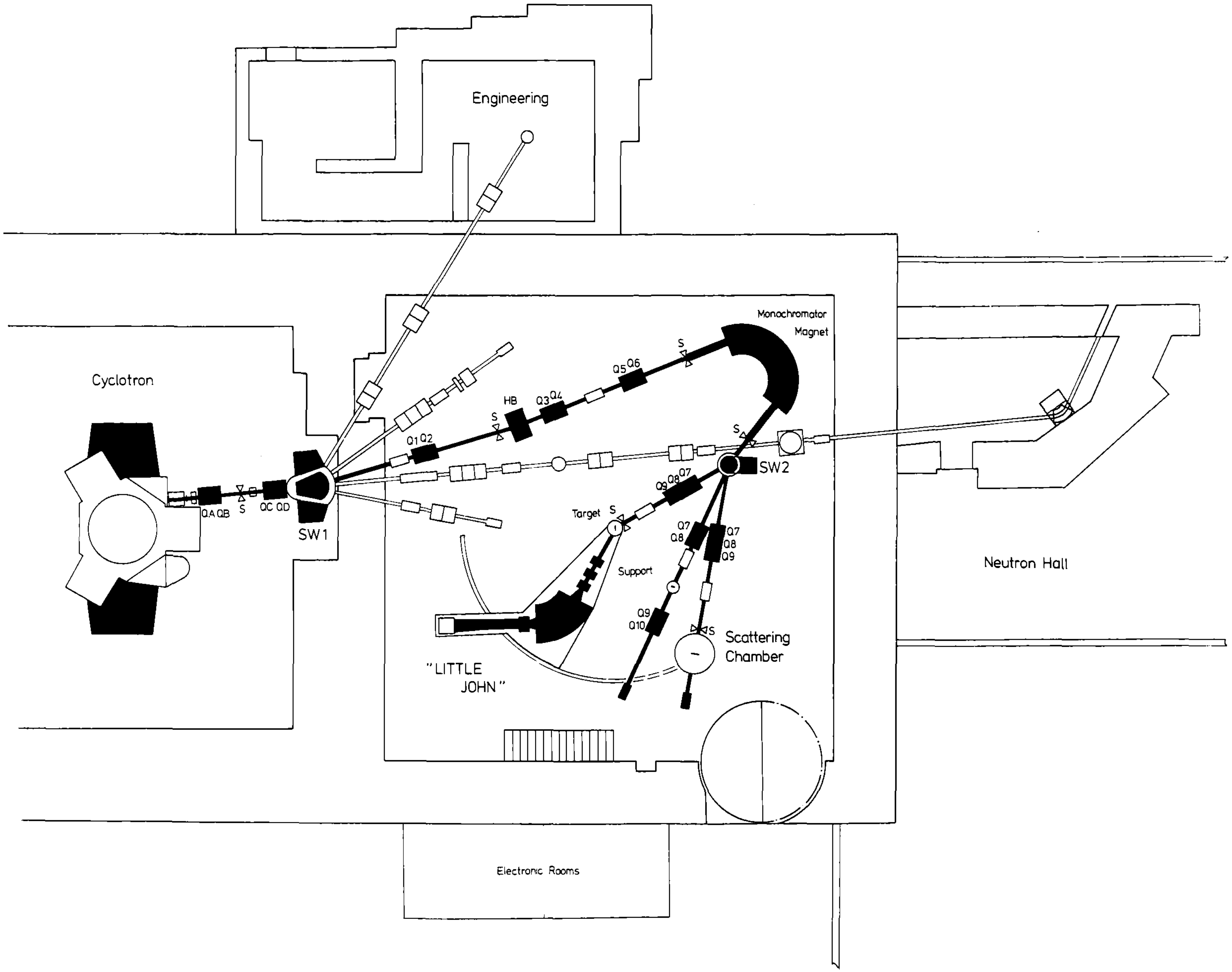

Fig. 7: Experimental area for nuclear reaction experiments at the Karlsruhe Isochronous Cyclotron.

by a switching magnet which feeds three target positions

I The magnetic spectrograph

II The particle-gamma-coincidence measurements position

III The 130 cm Ø scattering chamber

In contrast to the former high-resolution beam line all these target positions are assumed to be rather free of slit scattering background produced at the analyzing slits of the monochromator magnet, because after these slits the beam is deflected by at least 14° by the switching magnet.

Due to the limited space in the experimental hall the full angular range of the spectrograph (88°) can only be reached when removing beam lines 3, II and 3,III.

The ion optical features of the new beam line system up to now where only calculated for the important parts between the entrance slit of the monochromator magnet and the three target positions. Satisfying focussing can be obtained at each of these positions. The matching of the beam to the entrance slit of the monochromator should be easier than for the former arrangement since the positioning of the quadrupole duplets allows rather flexible variations.

Acknowledgements

I wish to thank Prof. Dr. G. Schatz and Prof. Dr. H. Rebel for their encouraging interest in the project, Mrs. K. Feißt for help in the calculations and preparing the drawings and Dr. D. Heck for clarifying discussions.

APPENDIX A

First and Second Order Matrix Formalism

The first and second order matrix formalism[10)] for charged particle optics is shortly described in this section in order to provide an unambiguous definition for all expressions used in the main part of the report.

In this matrix formalism the magnetic fields (dipole, quadrupole, or higher order multipoles) are assumed to be symmetrical with respect to a given plane. The position along the beam axis is defined by the path length z of the central trajectory (lying in the symmetry plane) starting from a given point z=0 of the system. The coordinates of a particle on an arbitrary trajectory are given by the z-position and the deviations from the central trajectory at this position. In the notation of Brown[10)] these coordinates are

$x_1 = x$	space deviation in the horizontal plane
$x_2 = \Theta = \frac{dx}{dz}$	angular deviation in the horizontal plane
$x_3 = y$	space deviation in the vertical plane
$x_4 = \emptyset = \frac{dy}{dz}$	angular deviation in the vertical plane
$x_5 = 1$	path length difference with respect to the central trajectory
$x_6 = \delta = \frac{\Delta p}{p_o}$	momentum deviation with respect to the momentum of the central ray p_o

The coodinates $x_1, \ldots x_6$ at the starting point of the system (z=0) are usually characterized by the index 0: $(x_o, \Theta_o, y_o, \emptyset_o, 1_o, \delta_o)$. In second order Taylor expansion of the differential equations of motion the coordinates x_i of a particle at any point z of the system can be expressed in terms of the starting coordinates $x_i(0)=(x_o, \Theta_o, y_o, \emptyset_o, 1_o, \delta_o)$ by the transformation

$$\text{(A-1)} \quad x_i(z) = \sum_{j=1}^{6} R_{ij}(z) \cdot x_j(0) + \sum_{j=1}^{6} \sum_{k=j}^{6} T_{ijk}(z)\, x_j(0)\, x_k(0)$$

If only bending magnets in the horizontal plane are assumed the first order matrix R has the general form

$$\begin{bmatrix} R_{11} & R_{12} & 0 & 0 & 0 & R_{16} \\ R_{21} & R_{22} & 0 & 0 & 0 & R_{26} \\ 0 & 0 & R_{33} & R_{34} & 0 & 0 \\ 0 & 0 & R_{43} & R_{44} & 0 & 0 \\ R_{51} & R_{52} & 0 & 0 & 1 & R_{56} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

This means that the horizontal and vertical space and angular coordinates are uncoupled and space (R_{16}) and angular dispersion (R_{26}) occur only in the horizontal plane. The matrix R is the product of the characteristic matrices R_i of each individual part of the system like drift ways, quadrupole magnets, dipole magnets etc. The values of the matrix elements of the characteristic constituents of the system are compiled in Ref. [10].

Imaging features of a whole system are characterized by particular values of matrix elements.

The most important imaging features are:

Point-to-point horizontal		$R_{12} = 0$
	with	R_{11} = magnification
Point-to-point vertical		$R_{34} = 0$
	with	R_{33} = magnification

For point-to-point imaging the momentum resolution $R_p = p/\Delta p$ is given by

(A-2) $$R_p = \frac{R_{16}}{R_{11} \cdot 2 \cdot x_o}$$

The time resolution $R_t = t/\Delta t$ due to different path length in the ion optical system is

(A-3) $$R_t = \frac{l_o}{R_{52} \cdot 2 \cdot \Theta_o}$$

where l_o is the total length of the system.
The tilt χ of the focal plane with respect to the normal on the central ray is determined by (for k = 0)

(A-4) $$\tan \chi = - \frac{T_{126}}{R_{16} \cdot R_{22}}$$

APPENDIX B

Transport Matrices for Different Modes of Operation of the Spectrograph "Little John"

R_{16} = 4 cm / %

K = 0.0

```
 SPECTROGRAPH QQD R = 1.5 M  60 DEGREES


*2ND ORDER 17.0     MOM   1.0 0.0 3.0
         LABEL = SEC


*BEAM*      1.000000     0.44 GEV
         LABEL = BEAM
                                                                            0.0 M           0.0      0.050 CM
                                                                                            0.0     12.500 MR    0.0
                                                                                            0.0      0.100 CM    0.0     0.0
                                                                                            0.0     20.000 MR    0.0     0.0     0.0
                                                                                            0.0     10.000 CM    0.0     0.0     0.0     0.0
                                                                                            0.0      5.000 PC    0.0     0.0     0.0     0.0     0.0

*DRIFT*     3.0      1.0000 M
         LABEL = DR1
                                                                            1.0 M           0.0      1.251 CM
                                                                                            0.0     12.500 MR    0.999
                                                                                            0.0      2.002 CM    0.0     0.0
                                                                                            0.0     20.000 MR    0.0     0.0     0.999
                                                                                           -0.028   10.000 CM    0.0     0.0     0.0     0.0
                                                                                            0.0      5.000 PC    0.0     0.0     0.0     0.0     0.0

*QUAD*      5.00    0.30000 M    -1.8984 KG    3.500 CM  (  -0.854 M  )
         LABEL = Q1
                                                                            1.3 M           0.0      1.861 CM
                                                                                            0.0     29.284 MR    1.000
                                                                                            0.0      2.246 CM    0.0     0.0
                                                                                            0.0      4.463 MR    0.0     0.0    -0.944
                                                                                           -0.036   10.000 CM    0.0     0.0     0.0     0.0
                                                                                            0.0      5.000 PC    0.0     0.0     0.0     0.0     0.0

*DRIFT*     3.0      0.1500 M
                                                                            1.4 M           0.0      2.300 CM
                                                                                            0.0     29.284 MR    1.000
                                                                                            0.0      2.183 CM    0.0     0.0
                                                                                            0.0      4.463 MR    0.0     0.0    -0.940
                                                                                           -0.043   10.000 CM    0.0     0.0     0.0     0.0
                                                                                            0.0      5.000 PC    0.0     0.0     0.0     0.0     0.0
```

```
*QUAD*     5.00   0.30000 M     0.0372 KG    3.500 CM  (  46.094 M  )
       LABEL = Q2
                                                       1.7 M        0.0       3.170 CM
                                                                    0.0      28.689 MR     1.000
                                                                    0.0       2.064 CM     0.0     0.0
                                                                    0.0       4.028 MR     0.0     0.0    -0.919
                                                                   -0.056    10.000 CM     0.0     0.0     0.0     0.0
                                                                    0.0       5.000 PC     0.0     0.0     0.0     0.0     0.0

*DRIFT*    3.0     0.8000 M
       LABEL = DR2
                                                       2.5 M        0.0       5.465 CM
                                                                    0.0      28.689 MR     1.000
                                                                    0.0       1.773 CM     0.0     0.0
                                                                    0.0       4.028 MR     0.0     0.0    -0.888
                                                                   -0.089    10.000 CM     0.0     0.0     0.0     0.0
                                                                    0.0       5.000 PC     0.0     0.0     0.0     0.0     0.0

*PARAM*    16.0     4.0 1.200E+01

* G/2 *    16.0     5.0 2.500E+00

* K1 *     16.0     7.0 7.000E-01

* K2 *     16.0     8.0 4.400E+00

*ROTAT*    2.0      0.0  D
                                                       2.5 M        0.010     5.465 CM
                                                                    0.0      28.689 MR     1.000
                                                                    0.0       1.773 CM     0.0     0.0
                                                                    0.0       3.800 MR     0.0     0.0    -0.869
                                                                   -0.089    10.000 CM    -0.000   0.0     0.0     0.0
                                                                    0.0       5.000 PC     0.0     0.0     0.0     0.0     0.0

*BEND*     4.000   1.57079 M     9.791 KG    0.0000 (  59.999 D )
       LABEL = D
                                                       4.1 M       -0.127     7.471 CM
                                                                   -2.587    46.733 MR     0.149
                                                                    0.0       1.288 CM     0.0     0.0
                                                                    0.0       3.800 MR     0.0     0.0    -0.732
                                                                   -0.164    12.218 CM    -0.542   0.105   0.0     0.0
                                                                    0.0       5.000 PC     0.502   0.927   0.0     0.0    -0.111
```

```
*ROTAT*    2.0      0.0  D
                                                            4.1 M          -0.132   7.471 CM
                                                                           -2.587  46.733 MR    0.149
                                                                            0.0     1.288 CM    0.0    0.0
                                                                            0.0     3.803 MR    0.0    0.0   -0.652
                                                                           -0.164  12.218 CM   -0.542  0.105  0.0    0.0
                                                                            0.0     5.000 PC    0.502  0.927  0.0    0.0   -0.111

*DRIFT*    3.0      0.2000 M
        LABEL = DR3
                                                            4.3 M          -0.184   7.666 CM
                                                                           -2.587  46.733 MR    0.267
                                                                            0.0     1.240 CM    0.0    0.0
                                                                            0.0     3.803 MR    0.0    0.0   -0.616
                                                                           -0.186  12.218 CM   -0.516  0.105  0.0    0.0
                                                                            0.0     5.000 PC    0.602  0.927  0.0    0.0   -0.111

*SEXT*    18.00   0.3000 M    0.192 KG 10.0
        LABEL = S2
                                                            4.6 M          -0.297   8.154 CM
                                                                           -4.972  46.886 MR    0.423
                                                                            0.0     1.175 CM    0.0    0.0
                                                                            0.0     3.985 MR    0.0    0.0   -0.496
                                                                           -0.219  12.219 CM   -0.467  0.105  0.0    0.0
                                                                            0.0     5.000 PC    0.725  0.924  0.0    0.0   -0.111

*DRIFT*    3.0      0.5000 M
        LABEL = DR41
                                                            5.1 M          -0.545   9.388 CM
                                                                           -4.972  46.886 MR    0.617
                                                                            0.0     1.090 CM    0.0    0.0
                                                                            0.0     3.985 MR    0.0    0.0   -0.352
                                                                           -0.273  12.220 CM   -0.379  0.106  0.0    0.0
                                                                            0.0     5.000 PC    0.861  0.924  0.0    0.0   -0.111

*DRIFT*    3.0      0.4443 M
        LABEL = DR41
                                                            5.6 M          -0.766  10.798 CM
                                                                           -4.972  46.886 MR    0.729
                                                                            0.0     1.041 CM    0.0    0.0
                                                                            0.0     3.985 MR    0.0    0.0   -0.198
                                                                           -0.322  12.222 CM   -0.308  0.106  0.0    0.0
                                                                            0.0     5.000 PC    0.926  0.924  0.0    0.0   -0.111
```

```
*DRIFT*     3.0      1.1547 M
        LABEL = DR42
                                                                6.7 M         -1.340  15.204 CM
                                                                              -4.972  46.886 MR    0.874
                                                                               0.0     1.051 CM    0.0    0.0
                                                                               0.0     3.985 MR    0.0    0.0    0.241
                                                                              -0.448  12.228 CM   -0.180  0.107  0.0    0.0
                                                                               0.0     5.000 PC    0.987  0.924  0.0    0.0    -0.111

*DRIFT*     3.0      1.1547 M
        LABEL = DR43
                                                                7.9 M         -1.915  20.108 CM
                                                                              -4.972  46.886 MR    0.930
                                                                               0.0     1.245 CM    0.0    0.0
                                                                               0.0     3.985 MR    0.0    0.0    0.573
                                                                              -0.574  12.236 CM   -0.106  0.108  0.0    0.0
                                                                               0.0     5.000 PC    0.995  0.924  0.0    0.0    -0.111

 *TRANSFORM* 1
          -0.72686  -0.00000   0.0        0.0        0.0        4.00081
          -9.33888  -1.37577   0.0        0.0        0.0        8.66018
           0.0       0.0      -6.13787  -0.00000    0.0        0.0
           0.0       0.0     -10.75974  -0.16292    0.0        0.0
          -3.10684  -0.55042   0.0        0.0        1.00000   -0.27175
           0.0       0.0       0.0        0.0        0.0        1.00000

  *2ND ORDER TRANSFORM *
  1 11 -1.031E-01
  1 12 -3.915E-02   1 22 -3.730E-03
  1 13  0.0         1 23  0.0         1 33  4.406E-02
  1 14  0.0         1 24  0.0         1 34 -3.070E-03   1 44 -2.059E-05
  1 15  0.0         1 25  0.0         1 35  0.0         1 45  0.0         1 55  0.0
  1 16  4.831E-03   1 26  2.220E-08   1 36  0.0         1 46  0.0         1 56  0.0         1 66 -5.295E-02

  2 11 -2.918E-01
  2 12 -1.127E-01   2 22 -1.088E-02
  2 13  0.0         2 23  0.0         2 33  1.893E-01
  2 14  0.0         2 24  0.0         2 34 -1.074E-02   2 44 -4.214E-05
  2 15  0.0         2 25  0.0         2 35  0.0         2 45  0.0         2 55  0.0
  2 16 -1.435E-02   2 26 -9.143E-03   2 36  0.0         2 46  0.0         2 56  0.0         2 66 -1.303E-01
```

3 11 0.0					
3 12 0.0	3 22 0.0				
3 13 -1.281E-01	3 23 -2.593E-02	3 33 0.0			
3 14 -1.984E-03	3 24 -3.477E-04	3 34 0.0	3 44 0.0		
3 15 0.0	3 25 0.0	3 35 0.0	3 45 0.0	3 55 0.0	
3 16 0.0	3 26 0.0	3 36 -4.870E-02	3 46 1.079E-02	3 56 0.0	3 66 0.0

4 11 0.0					
4 12 0.0	4 22 0.0				
4 13 -3.137E-01	4 23 -6.520E-02	4 33 0.0			
4 14 -7.972E-05	4 24 7.859E-05	4 34 0.0	4 44 0.0		
4 15 0.0	4 25 0.0	4 35 0.0	4 45 0.0	4 55 0.0	
4 16 0.0	4 26 0.0	4 36 -2.210E-01	4 46 2.021E-02	4 56 0.0	4 66 0.0

5 11 -3.478E-02					
5 12 -1.224E-02	5 22 -1.167E-03				
5 13 0.0	5 23 0.0	5 33 -3.765E-02			
5 14 0.0	5 24 0.0	5 34 -9.592E-04	5 44 -9.717E-05		
5 15 0.0	5 25 0.0	5 35 0.0	5 45 0.0	5 55 0.0	
5 16 5.379E-02	5 26 7.127E-03	5 36 0.0	5 46 0.0	5 56 0.0	5 66 -1.408E-02

6 11 0.0					
6 12 0.0	6 22 0.0				
6 13 0.0	6 23 0.0	6 33 0.0			
6 14 0.0	6 24 0.0	6 34 0.0	6 44 0.0		
6 15 0.0	6 25 0.0	6 35 0.0	6 45 0.0	6 55 0.0	
6 16 0.0	6 26 0.0	6 36 0.0	6 46 0.0	6 56 0.0	6 66 0.0

LABEL = PR1

LENGTH   7.8745 M

```
*TRANSFORM* 1
          -0.19814   0.10000   0.0        0.0        0.0        4.00081
          -7.63632  -1.19294   0.0        0.0        0.0        8.66018
           0.0       0.0      -4.81061   -0.00000    0.0        0.0
           0.0       0.0      -8.99767   -0.20787    0.0        0.0
          -2.88356  -0.56387   0.0        0.0        1.00000   -0.27175
           0.0       0.0       0.0        0.0        0.0        1.00000
```

```
*2ND ORDER TRANSFORM *
1 11 -9.991E-02
1 12 -4.198E-02   1 22 -4.425E-03
1 13  0.0         1 23  0.0         1 33  1.937E-02
1 14  0.0         1 24  0.0         1 34 -3.324E-03   1 44 -3.206E-05
1 15  0.0         1 25  0.0         1 35  0.0         1 45  0.0         1 55  0.0
1 16 -1.041E-02   1 26 -2.663E-03   1 36  0.0         1 46  0.0         1 56  0.0         1 66 -5.327E-02

2 11 -2.892E-01
2 12 -1.231E-01   2 22 -1.311E-02
2 13  0.0         2 23  0.0         2 33  8.920E-02
2 14  0.0         2 24  0.0         2 34 -1.133E-02   2 44 -6.432E-05
2 15  0.0         2 25  0.0         2 35  0.0         2 45  0.0         2 55  0.0
2 16 -4.836E-02   2 26 -1.556E-02   2 36  0.0         2 46  0.0         2 56  0.0         2 66 -1.312E-01

3 11  0.0
3 12  0.0         3 22  0.0
3 13 -1.113E-01   3 23 -2.453E-02   3 33  0.0
3 14 -2.233E-03   3 24 -4.299E-04   3 34  0.0         3 44  0.0
3 15  0.0         3 25  0.0         3 35  0.0         3 45  0.0         3 55  0.0
3 16  0.0         3 26  0.0         3 36 -3.279E-02   3 46  1.098E-02   3 56  0.0         3 66  0.0

4 11  0.0
4 12  0.0         4 22  0.0
4 13 -2.624E-01   4 23 -5.919E-02   4 33  0.0
4 14  6.339E-04   4 24  2.558E-04   4 34  0.0         4 44  0.0
4 15  0.0         4 25  0.0         4 35  0.0         4 45  0.0         4 55  0.0
4 16  0.0         4 26  0.0         4 36 -1.517E-01   4 46  2.196E-02   4 56  0.0         4 66  0.0

5 11 -2.745E-02
5 12 -1.083E-02   5 22 -1.169E-03
5 13  0.0         5 23  0.0         5 33 -2.485E-02
5 14  0.0         5 24  0.0         5 34 -1.040E-03   5 44 -1.201E-04
5 15  0.0         5 25  0.0         5 35  0.0         5 45  0.0         5 55  0.0
5 16  4.739E-02   5 26  6.835E-03   5 36  0.0         5 46  0.0         5 56  0.0         5 66 -1.408E-02
```

R_{16} = 4 cm / %

K = -0.25

```
6 11  0.0
6 12  0.0           6 22  0.0
6 13  0.0           6 23  0.0           6 33  0.0
6 14  0.0           6 24  0.0           6 34  0.0           6 44  0.0
6 15  0.0           6 25  0.0           6 35  0.0           6 45  0.0           6 55  0.0
6 16  0.0           6 26  0.0           6 36  0.0           6 46  0.0           6 56  0.0           6 66  0.0
```

```
       LABEL = PR1


*LENGTH*     7.8745 M


*TRANSFORM* 1
          -1.24622  -0.08000   0.0         0.0        0.0        4.00081
          -9.98477  -1.44338   0.0         0.0        0.0        8.66018
           0.0       0.0      -6.88978     0.00000    0.0        0.0
           0.0       0.0     -11.82622    -0.14514    0.0        0.0
          -2.91546  -0.50819   0.0         0.0        1.00000   -0.27175
           0.0       0.0       0.0         0.0        0.0        1.00000

 *2ND ORDER TRANSFORM *
1 11 -7.977E-02
1 12 -3.010E-02     1 22 -2.858E-03
1 13  0.0           1 23  0.0           1 33  5.922E-02
1 14  0.0           1 24  0.0           1 34 -2.959E-03     1 44 -1.681E-05
1 15  0.0           1 25  0.0           1 35  0.0           1 45  0.0           1 55  0.0
1 16  1.924E-02     1 26  2.109E-03     1 36  0.0           1 46  0.0           1 56  0.0           1 66 -5.273E-02

2 11 -2.179E-01
2 12 -8.438E-02     2 22 -8.177E-03
2 13  0.0           2 23  0.0           2 33  2.524E-01
2 14  0.0           2 24  0.0           2 34 -1.047E-02     2 44 -3.482E-05
2 15  0.0           2 25  0.0           2 35  0.0           2 45  0.0           2 55  0.0
2 16  1.635E-02     2 26 -4.337E-03     2 36  0.0           2 46  0.0           2 56  0.0           2 66 -1.297E-01

3 11  0.0
3 12  0.0           3 22  0.0
3 13 -1.137E-01     3 23 -2.366E-02     3 33  0.0
3 14 -1.715E-03     3 24 -2.959E-04     3 34  0.0           3 44  0.0
3 15  0.0           3 25  0.0           3 35  0.0           3 45  0.0           3 55  0.0
3 16  0.0           3 26  0.0           3 36 -5.047E-02     3 46  1.142E-02     3 56  0.0           3 66  0.0
```

R_{16} = 4 cm / %

K = 0.2

4 11 0.0					
4 12 0.0	4 22 0.0				
4 13 -2.755E-01	4 23 -5.957E-02	4 33 0.0			
4 14 -5.482E-04	4 24 -9.550E-06	4 34 0.0	4 44 0.0		
4 15 0.0	4 25 0.0	4 35 0.0	4 45 0.0	4 55 0.0	
4 16 0.0	4 26 0.0	4 36 -2.457E-01	4 46 2.066E-02	4 56 0.0	4 66 0.0
5 11 -3.406E-02					
5 12 -1.151E-02	5 22 -1.064E-03				
5 13 0.0	5 23 0.0	5 33 -4.654E-02			
5 14 0.0	5 24 0.0	5 34 -1.041E-03	5 44 -9.464E-05		
5 15 0.0	5 25 0.0	5 35 0.0	5 45 0.0	5 55 0.0	
5 16 5.160E-02	5 26 6.656E-03	5 36 0.0	5 46 0.0	5 56 0.0	5 66 -1.408E-02
6 11 0.0					
6 12 0.0	6 22 0.0				
6 13 0.0	6 23 0.0	6 33 0.0			
6 14 0.0	6 24 0.0	6 34 0.0	6 44 0.0		
6 15 0.0	6 25 0.0	6 35 0.0	6 45 0.0	6 55 0.0	
6 16 0.0	6 26 0.0	6 36 0.0	6 46 0.0	6 56 0.0	6 66 0.0

LABEL = PR1

LENGTH 7.8745 M

```
 SPECTROGRAPH QQD R = 1.5 M  60 DEGREES


*2ND ORDER 17.0     MCM   1.0 0.0 3.0
        LABEL = SEC


*BEAM*     1.000000    0.44 GEV
        LABEL = BEAM
                                                                 0.0 M        0.0     0.050 CM
                                                                              0.0    12.500 MR    0.0
                                                                              0.0     0.100 CM    0.0     0.0
                                                                              0.0    25.000 MR    0.0     0.0     0.0
                                                                              0.0    10.000 CM    0.0     0.0     0.0     0.0
                                                                              0.0     6.670 PC    0.0     0.0     0.0     0.0     0.0


*DRIFT*    3.0      1.0000 M
        LABEL = DR1
                                                                 1.0 M        0.0     1.251 CM
                                                                              0.0    12.500 MR    0.999
                                                                              0.0     2.502 CM    0.0     0.0
                                                                              0.0    25.000 MR    0.0     0.0     0.999
                                                                             -0.039  10.000 CM    0.0     0.0     0.0     0.0
                                                                              0.0     6.670 PC    0.0     0.0     0.0     0.0     0.0


*QUAD*     5.00    0.30000 M   -2.7407 KG   3.500 CM  (  -0.578 M  )
        LABEL = Q1
                                                                 1.3 M        0.0     1.969 CM
                                                                              0.0    37.305 MR    0.999
                                                                              0.0     2.617 CM    0.0     0.0
                                                                              0.0    17.883 MR    0.0     0.0    -0.985
                                                                             -0.051  10.000 CM    0.0     0.0     0.0     0.0
                                                                              0.0     6.670 PC    0.0     0.0     0.0     0.0     0.0


*DRIFT*    3.0      0.1500 M
                                                                 1.4 M        0.0     2.528 CM
                                                                              0.0    37.305 MR    1.000
                                                                              0.0     2.353 CM    0.0     0.0
                                                                              0.0    17.883 MR    0.0     0.0    -0.982
                                                                             -0.064  10.000 CM    0.0     0.0     0.0     0.0
                                                                              0.0     6.670 PC    0.0     0.0     0.0     0.0     0.0
```

R_{16} = 3 cm / %

K = 0.0

```
*QUAD*     5.00    0.30000 M     1.0534 KG    3.500 CM  (    1.678 M  )
          LABEL = Q2
                                                 1.7 M          0.0      3.383 CM
                                                                0.0     18.814 MR    1.000
                                                                0.0      2.032 CM    0.0       0.0
                                                                0.0      5.183 MR    0.0       0.0     -0.808
                                                               -0.089   10.000 CM    0.0       0.0      0.0      0.0
                                                                0.0      6.670 PC    0.0       0.0      0.0      0.0      0.0

*DRIFT*    3.0     0.8000 M
          LABEL = DR2
                                                 2.5 M          0.0      4.888 CM
                                                                0.0     18.814 MR    1.000
                                                                0.0      1.714 CM    0.0       0.0
                                                                0.0      5.183 MR    0.0       0.0     -0.715
                                                               -0.104   10.001 CM    0.0       0.0      0.0      0.0
                                                                0.0      6.670 PC    0.0       0.0      0.0      0.0      0.0

*PARAM*    16.0     4.0 1.200E+01

* G/2 *    16.0     5.0 2.500E+00

* K1 *     16.0     7.0 7.000E-01

* K2 *     16.0     8.0 4.400E+00

*ROTAT*    2.0      0.0  D
                                                 2.5 M          0.009    4.888 CM
                                                                0.0     18.814 MR    1.000
                                                                0.0      1.714 CM    0.0       0.0
                                                                0.0      5.000 MR    0.0       0.0     -0.688
                                                               -0.104   10.001 CM   -0.000     0.0      0.0      0.0
                                                                0.0      6.670 PC    0.0       0.0      0.0      0.0      0.0

*BEND*     4.000   1.57079 M     9.791 KG    0.0000 (  59.999 D )
          LABEL = D
                                                 4.1 M         -0.260    7.008 CM
                                                               -4.068   61.037 MR    0.467
                                                                0.0      1.301 CM    0.0       0.0
                                                                0.0      5.000 MR    0.0       0.0     -0.305
                                                               -0.141   11.626 CM   -0.450     0.002    0.0      0.0
                                                                0.0      6.670 PC    0.714     0.946    0.0      0.0     -0.156
```

```
*ROTAT*    2.0     0.0  D
                                                             4.1 M          -0.263   7.008 CM
                                                                            -4.068  61.037 MR     0.467
                                                                             0.0     1.301 CM     0.0     0.0
                                                                             0.0     5.170 MR     0.0     0.0    -0.212
                                                                            -0.141  11.626 CM    -0.450   0.002   0.0     0.0
                                                                             0.0     6.670 PC     0.714   0.946   0.0     0.0    -0.156

*DRIFT*    3.0     0.2000 M
        LABEL = DR3
                                                             4.3 M          -0.345   7.654 CM
                                                                            -4.068  61.037 MR     0.587
                                                                             0.0     1.283 CM     0.0     0.0
                                                                             0.0     5.170 MR     0.0     0.0    -0.134
                                                                            -0.179  11.626 CM    -0.411   0.003   0.0     0.0
                                                                             0.0     6.670 PC     0.805   0.946   0.0     0.0    -0.156

*SEXT*    18.00   0.3000 M    0.322 KG 10.0
        LABEL = S2
                                                             4.6 M          -0.529   8.856 CM
                                                                            -8.443  61.623 MR     0.711
                                                                             0.0     1.280 CM     0.0     0.0
                                                                             0.0     5.690 MR     0.0     0.0     0.089
                                                                            -0.234  11.627 CM    -0.354   0.004   0.0     0.0
                                                                             0.0     6.670 PC     0.891   0.937   0.0     0.0    -0.156

*DRIFT*    3.0     0.5000 M
        LABEL = DR41
                                                             5.1 M          -0.951  11.257 CM
                                                                            -8.443  61.623 MR     0.833
                                                                             0.0     1.335 CM     0.0     0.0
                                                                             0.0     5.690 MR     0.0     0.0     0.298
                                                                            -0.327  11.630 CM    -0.276   0.005   0.0     0.0
                                                                             0.0     6.670 PC     0.957   0.937   0.0     0.0    -0.156

*DRIFT*    3.0     0.4443 M
        LABEL = DR41
                                                             5.6 M          -1.326  13.623 CM
                                                                            -8.443  61.623 MR     0.889
                                                                             0.0     1.431 CM     0.0     0.0
                                                                             0.0     5.690 MR     0.0     0.0     0.455
                                                                            -0.409  11.633 CM    -0.226   0.007   0.0     0.0
                                                                             0.0     6.670 PC     0.980   0.937   0.0     0.0    -0.156
```

```
*DRIFT*    3.0     1.1547 M
        LABEL = DR42
                                                              6.7 M         -2.301   20.215 CM
                                                                            -8.443   61.623 MR    0.951
                                                                             0.0      1.826 CM    0.0     0.0
                                                                             0.0      5.690 MR    0.0     0.0     0.716
                                                                            -0.623   11.648 CM   -0.146   0.010   0.0     0.0
                                                                             0.0      6.670 PC    0.990   0.937   0.0     0.0    -0.156


 *TRANSFORM* 1
          -0.66487   -0.00000    0.0        0.0        0.0        3.00081
         -10.57128   -1.50405    0.0        0.0        0.0        8.66018
           0.0        0.0       -6.31684   -0.00000    0.0        0.0
           0.0        0.0      -13.23448   -0.15831    0.0        0.0
          -2.59645   -0.45134    0.0        0.0        1.00000   -0.27175
           0.0        0.0        0.0        0.0        0.0        1.00000

 *2ND ORDER TRANSFORM *
 1 11 -5.543E-02
 1 12 -2.112E-02   1 22 -2.038E-03
 1 13  0.0         1 23  0.0         1 33  1.100E-01
 1 14  0.0         1 24  0.0         1 34 -2.965E-03   1 44 -5.878E-06
 1 15  0.0         1 25  0.0         1 35  0.0         1 45  0.0         1 55  0.0
 1 16  8.236E-03   1 26  2.201E-07   1 36  0.0         1 46  0.0         1 56  0.0         1 66 -4.451E-02


 2 11 -2.129E-01
 2 12 -8.506E-02   2 22 -8.509E-03
 2 13  0.0         2 23  0.0         2 33  6.485E-01
 2 14  0.0         2 24  0.0         2 34 -1.519E-02   2 44 -1.477E-05
 2 15  0.0         2 25  0.0         2 35  0.0         2 45  0.0         2 55  0.0
 2 16 -4.706E-02   2 26 -1.863E-02   2 36  0.0         2 46  0.0         2 56  0.0         2 66 -1.598E-01


 3 11  0.0
 3 12  0.0         3 22  0.0
 3 13 -1.342E-01   3 23 -2.817E-02   3 33  0.0
 3 14 -6.611E-04   3 24 -1.117E-04   3 34  0.0         3 44  0.0
 3 15  0.0         3 25  0.0         3 35  0.0         3 45  0.0         3 55  0.0
 3 16  0.0         3 26  0.0         3 36 -6.290E-02   3 46  1.027E-02   3 56  0.0         3 66  0.0


 4 11  0.0
 4 12  0.0         4 22  0.0
 4 13 -5.127E-01   4 23 -1.114E-01   4 33  0.0
 4 14  1.978E-03   4 24  4.718E-04   4 34  0.0         4 44  0.0
 4 15  0.0         4 25  0.0         4 35  0.0         4 45  0.0         4 55  0.0
 4 16  0.0         4 26  0.0         4 36 -4.667E-01   4 46  2.309E-02   4 56  0.0         4 66  0.0
```

```
5 11 -2.664E-02
5 12 -8.857E-03   5 22 -8.272E-04
5 13  0.0         5 23  0.0         5 33 -4.908E-02
5 14  0.0         5 24  0.0         5 34 -1.184E-03   5 44 -9.577E-05
5 15  0.0         5 25  0.0         5 35  0.0         5 45  0.0         5 55  0.0
5 16  3.645E-02   5 26  4.415E-03   5 36  0.0         5 46  0.0         5 56  0.0         5 66 -9.746E-03


6 11  0.0
6 12  0.0         6 22  0.0
6 13  0.0         6 23  0.0         6 33  0.0
6 14  0.0         6 24  0.0         6 34  0.0         6 44  0.0
6 15  0.0         6 25  0.0         6 35  0.0         6 45  0.0         6 55  0.0
6 16  0.0         6 26  0.0         6 36  0.0         6 46  0.0         6 56  0.0         6 66  0.0

       LABEL = PR2


*LENGTH*     6.7198 M



*TRANSFORM* 1
           0.48687   0.18000   0.0        0.0        0.0        3.00081
          -9.25483  -1.36766   0.0        0.0        0.0        8.66018
           0.0       0.0      -4.90221   -0.00000    0.0        0.0
           0.0       0.0     -10.80333   -0.20399    0.0        0.0
          -3.19884  -0.56629   0.0        0.0        1.00000   -0.27175
           0.0       0.0       0.0        0.0        0.0        1.00000

 *2ND ORDER TRANSFORM *
 1 11 -1.146E-01
 1 12 -4.315E-02   1 22 -4.075E-03
 1 13  0.0         1 23  0.0         1 33  5.788E-02
 1 14  0.0         1 24  0.0         1 34 -2.996E-03   1 44 -9.949E-06
 1 15  0.0         1 25  0.0         1 35  0.0         1 45  0.0         1 55  0.0
 1 16 -2.780E-02   1 26 -5.329E-03   1 36  0.0         1 46  0.0         1 56  0.0         1 66 -4.441E-02


 2 11 -4.942E-01
 2 12 -1.888E-01   2 22 -1.804E-02
 2 13  0.0         2 23  0.0         2 33  3.484E-01
 2 14  0.0         2 24  0.0         2 34 -1.523E-02   2 44 -2.537E-05
 2 15  0.0         2 25  0.0         2 35  0.0         2 45  0.0         2 55  0.0
 2 16 -1.631E-01   2 26 -3.710E-02   2 36  0.0         2 46  0.0         2 56  0.0         2 66 -1.594E-01
```

R_{16} = 3 cm / %

K = -0.6

3 11 0.0					
3 12 0.0	3 22 0.0				
3 13 -1.723E-01	3 23 -3.352E-02	3 33 0.0			
3 14 -1.024E-03	3 24 -1.782E-04	3 34 0.0	3 44 0.0		
3 15 0.0	3 25 0.0	3 35 0.0	3 45 0.0	3 55 0.0	
3 16 0.0	3 26 0.0	3 36 -5.507E-02	3 46 8.722E-03	3 56 0.0	3 66 0.0

4 11 0.0					
4 12 0.0	4 22 0.0				
4 13 -6.674E-01	4 23 -1.318E-01	4 33 0.0			
4 14 4.912E-03	4 24 1.002E-03	4 34 0.0	4 44 0.0		
4 15 0.0	4 25 0.0	4 35 0.0	4 45 0.0	4 55 0.0	
4 16 0.0	4 26 0.0	4 36 -3.595E-01	4 46 2.151E-02	4 56 0.0	4 66 0.0

5 11 -3.125E-02					
5 12 -1.134E-02	5 22 -1.113E-03				
5 13 0.0	5 23 0.0	5 33 -3.101E-02			
5 14 0.0	5 24 0.0	5 34 -9.626E-04	5 44 -9.814E-05		
5 15 0.0	5 25 0.0	5 35 0.0	5 45 0.0	5 55 0.0	
5 16 4.572E-02	5 26 5.953E-03	5 36 0.0	5 46 0.0	5 56 0.0	5 66 -9.746E-03

6 11 0.0					
6 12 0.0	6 22 0.0				
6 13 0.0	6 23 0.0	6 33 0.0			
6 14 0.0	6 24 0.0	6 34 0.0	6 44 0.0		
6 15 0.0	6 25 0.0	6 35 0.0	6 45 0.0	6 55 0.0	
6 16 0.0	6 26 0.0	6 36 0.0	6 46 0.0	6 56 0.0	6 66 0.0

LABEL = PR2

LENGTH   6.7198 M

TRANSFORM 1

-1.35923	-0.10000	0.0	0.0	0.0	3.00081
-10.95177	-1.54144	0.0	0.0	0.0	8.66018
0.0	0.0	-6.98064	0.00000	0.0	0.0
0.0	0.0	-14.43201	-0.14325	0.0	0.0
-2.10930	-0.37596	0.0	0.0	1.00000	-0.27175
0.0	0.0	0.0	0.0	0.0	1.00000

*2ND ORDER TRANSFORM *

1 11 -2.816E-02					
1 12 -1.119E-02	1 22 -1.163E-03				
1 13 0.0	1 23 0.0	1 33 1.403E-01			
1 14 0.0	1 24 0.0	1 34 -2.987E-03	1 44 -4.659E-06		
1 15 0.0	1 25 0.0	1 35 0.0	1 45 0.0	1 55 0.0	
1 16 3.007E-02	1 26 2.978E-03	1 36 0.0	1 46 0.0	1 56 0.0	1 66 -4.468E-02
2 11 -8.564E-02					
2 12 -3.890E-02	2 22 -4.452E-03				
2 13 0.0	2 23 0.0	2 33 8.216E-01			
2 14 0.0	2 24 0.0	2 34 -1.531E-02	2 44 -1.141E-05		
2 15 0.0	2 25 0.0	2 35 0.0	2 45 0.0	2 55 0.0	
2 16 2.474E-02	2 26 -8.295E-03	2 36 0.0	2 46 0.0	2 56 0.0	2 66 -1.606E-01
3 11 0.0					
3 12 0.0	3 22 0.0				
3 13 -8.308E-02	3 23 -2.145E-02	3 33 0.0			
3 14 -4.959E-04	3 24 -8.435E-05	3 34 0.0	3 44 0.0		
3 15 0.0	3 25 0.0	3 35 0.0	3 45 0.0	3 55 0.0	
3 16 0.0	3 26 0.0	3 36 -6.376E-02	3 46 1.140E-02	3 56 0.0	3 66 0.0

R_{16} = 3 cm / %

K = .3333

4 11 0.0					
4 12 0.0	4 22 0.0				
4 13 -2.922E-01	4 23 -8.280E-02	4 33 0.0			
4 14 6.796E-04	4 24 2.659E-04	4 34 0.0	4 44 0.0		
4 15 0.0	4 25 0.0	4 35 0.0	4 45 0.0	4 55 0.0	
4 16 0.0	4 26 0.0	4 36 -5.117E-01	4 46 2.489E-02	4 56 0.0	4 66 0.0

5 11 -2.524E-02					
5 12 -7.921E-03	5 22 -7.181E-04				
5 13 0.0	5 23 0.0	5 33 -5.898E-02			
5 14 0.0	5 24 0.0	5 34 -1.320E-03	5 44 -9.857E-05		
5 15 0.0	5 25 0.0	5 35 0.0	5 45 0.0	5 55 0.0	
5 16 2.860E-02	5 26 3.324E-03	5 36 0.0	5 46 0.0	5 56 0.0	5 66 -9.746E-03

6 11 0.0					
6 12 0.0	6 22 0.0				
6 13 0.0	6 23 0.0	6 33 0.0			
6 14 0.0	6 24 0.0	6 34 0.0	6 44 0.0		
6 15 0.0	6 25 0.0	6 35 0.0	6 45 0.0	6 55 0.0	
6 16 0.0	6 26 0.0	6 36 0.0	6 46 0.0	6 56 0.0	6 66 0.0

LABEL = PR2

LENGTH 6.7198 M

SPECTROGRAPH QQD R = 1.5 M 60 DEGREES

R_{16} = 2 cm / %

K = 0.0

```
*2ND ORDER 17.0    MOM   1.0 0.0 3.0
        LABEL = SEC

*BEAM*      1.000000    0.44 GEV
        LABEL = BEAM
                                                             0.0 M        0.0      0.050 CM
                                                                          0.0     12.500 MR    0.0
                                                                          0.0      0.100 CM    0.0     0.0
                                                                          0.0     30.000 MR    0.0     0.0     0.0
                                                                          0.0     10.000 CM    0.0     0.0     0.0     0.0
                                                                          0.0      9.000 PC    0.0     0.0     0.0     0.0     0.0

*DRIFT*     3.0      1.0000 M
        LABEL = DR1
                                                             1.0 M        0.0      1.251 CM
                                                                          0.0     12.500 MR    0.999
                                                                          0.0      3.002 CM    0.0     0.0
                                                                          0.0     30.000 MR    0.0     0.0     0.999
                                                                         -0.053   10.000 CM    0.0     0.0     0.0     0.0
                                                                          0.0      9.000 PC    0.0     0.0     0.0     0.0     0.0

*QUAD*      5.00    0.30000 M   -3.3069 KG   3.500 CM  (  -0.471 M  )
        LABEL = Q1
                                                             1.3 M        0.0      2.043 CM
                                                                          0.0     42.934 MR    0.999
                                                                          0.0      2.990 CM    0.0     0.0
                                                                          0.0     31.192 MR    0.0     0.0    -0.982
                                                                         -0.069   10.000 CM    0.0     0.0     0.0     0.0
                                                                          0.0      9.000 PC    0.0     0.0     0.0     0.0     0.0

*DRIFT*     3.0      0.1500 M
                                                             1.4 M        0.0      2.687 CM
                                                                          0.0     42.934 MR    0.999
                                                                          0.0      2.532 CM    0.0     0.0
                                                                          0.0     31.192 MR    0.0     0.0    -0.975
                                                                         -0.090   10.000 CM    0.0     0.0     0.0     0.0
                                                                          0.0      9.000 PC    0.0     0.0     0.0     0.0     0.0
```

```
*QUAD*     5.00   0.30000 M    1.9681 KG   3.500 CM  (    0.923 M  )
         LABEL = Q2
                                                   1.7 M        0.0      3.450 CM
                                                                0.0      6.736 MR   0.966
                                                                0.0      2.021 CM   0.0     0.0
                                                                0.0      7.751 MR   0.0     0.0    -0.597
                                                               -0.131   10.001 CM   0.0     0.0     0.0     0.0
                                                                0.0      9.000 PC   0.0     0.0     0.0     0.0     0.0

*DRIFT*    3.0     0.8000 M
         LABEL = DR2
                                                   2.5 M        0.0      3.973 CM
                                                                0.0      6.736 MR   0.974
                                                                0.0      1.724 CM   0.0     0.0
                                                                0.0      7.751 MR   0.0     0.0    -0.340
                                                               -0.134   10.001 CM   0.0     0.0     0.0     0.0
                                                                0.0      9.000 PC   0.0     0.0     0.0     0.0     0.0

*PARAM*    16.0    4.0 1.200E+01

* G/2 *    16.0    5.0 2.500E+00

* K1 *     16.0    7.0 7.000E-01

* K2 *     16.0    8.0 4.400E+00

*ROTAT*    2.0     0.0  D
                                                   2.5 M        0.008    3.973 CM
                                                                0.0      6.736 MR   0.974
                                                                0.0      1.724 CM   0.0     0.0
                                                                0.0      7.664 MR   0.0     0.0    -0.309
                                                               -0.134   10.001 CM  -0.000   0.0     0.0     0.0
                                                                0.0      9.000 PC   0.0     0.0     0.0     0.0     0.0

*BEND*     4.000   1.57079 M    9.791 KG   0.0000 (  59.999 D )
         LABEL = D
                                                   4.1 M       -0.480    7.369 CM
                                                               -7.093   81.039 MR   0.801
                                                                0.0      1.760 CM   0.0     0.0
                                                                0.0      7.664 MR   0.0     0.0     0.376
                                                               -0.147   11.022 CM  -0.341  -0.127   0.0     0.0
                                                                0.0      9.000 PC   0.916   0.962   0.0     0.0    -0.222
```

```
*ROTAT*     2.0       0.0  D
                                                        4.1 M          -0.482   7.369 CM
                                                                       -7.093  81.039 MR     0.801
                                                                        0.0     1.760 CM     0.0     0.0
                                                                        0.0     8.052 MR     0.0     0.0     0.433
                                                                       -0.147  11.022 CM    -0.341  -0.127   0.0     0.0
                                                                        0.0     9.000 PC     0.916   0.962   0.0     0.0    -0.222

*DRIFT*     3.0       0.2000 M
        LABEL = DR3
                                                        4.3 M          -0.624   8.721 CM
                                                                       -7.093  81.039 MR     0.862
                                                                        0.0     1.836 CM     0.0     0.0
                                                                        0.0     8.052 MR     0.0     0.0     0.503
                                                                       -0.212  11.022 CM    -0.311  -0.126   0.0     0.0
                                                                        0.0     9.000 PC     0.953   0.962   0.0     0.0    -0.222

*SEXT*     18.00     0.3000 M     1.002 KG 10.0
        LABEL = S2
                                                        4.6 M          -1.106  10.924 CM
                                                                      -26.430  88.285 MR     0.876
                                                                        0.0     1.999 CM     0.0     0.0
                                                                        0.0     9.909 MR     0.0     0.0     0.687
                                                                       -0.309  11.024 CM    -0.274  -0.108   0.0     0.0
                                                                        0.0     9.000 PC     0.975   0.883   0.0     0.0    -0.222

*DRIFT*     3.0       0.5000 M
        LABEL = DR41
                                                        5.1 M          -2.427  14.943 CM
                                                                      -26.430  88.285 MR     0.936
                                                                        0.0     2.367 CM     0.0     0.0
                                                                        0.0     9.909 MR     0.0     0.0     0.789
                                                                       -0.472  11.030 CM    -0.228  -0.100   0.0     0.0
                                                                        0.0     9.000 PC     0.973   0.883   0.0     0.0    -0.222

*DRIFT*     3.0       0.4443 M
        LABEL = DR41
                                                        5.6 M          -3.601  18.665 CM
                                                                      -26.430  88.285 MR     0.959
                                                                        0.0     2.727 CM     0.0     0.0
                                                                        0.0     9.909 MR     0.0     0.0     0.846
                                                                       -0.616  11.040 CM    -0.199  -0.094   0.0     0.0
                                                                        0.0     9.000 PC     0.965   0.883   0.0     0.0    -0.222
```

TRANSFORM 1

-0.63614	-0.00000	0.0	0.0	0.0	2.00081
-11.26077	-1.57199	0.0	0.0	0.0	8.66018
0.0	0.0	-5.86292	-0.00000	0.0	0.0
0.0	0.0	-15.72377	-0.17056	0.0	0.0
-1.70216	-0.31453	0.0	0.0	1.00000	-0.27175
0.0	0.0	0.0	0.0	0.0	1.00000

*2ND ORDER TRANSFORM *

1 11 -1.789E-02					
1 12 -7.401E-03	1 22 -8.677E-04				
1 13 0.0	1 23 0.0	1 33 3.152E-01			
1 14 0.0	1 24 0.0	1 34 -3.267E-03	1 44 -1.258E-07		
1 15 0.0	1 25 0.0	1 35 0.0	1 45 0.0	1 55 0.0	
1 16 1.997E-02	1 26 1.929E-09	1 36 0.0	1 46 0.0	1 56 0.0	1 66 -4.282E-02

2 11 -7.471E-02					
2 12 -4.257E-02	2 22 -6.216E-03				
2 13 0.0	2 23 0.0	2 33 3.389E+00			
2 14 0.0	2 24 0.0	2 34 -3.144E-02	2 44 6.511E-06		
2 15 0.0	2 25 0.0	2 35 0.0	2 45 0.0	2 55 0.0	
2 16 -8.535E-02	2 26 -4.935E-02	2 36 0.0	2 46 0.0	2 56 0.0	2 66 -3.148E-01

3 11 0.0					
3 12 0.0	3 22 0.0				
3 13 -9.843E-02	3 23 -3.011E-02	3 33 0.0			
3 14 -6.528E-05	3 24 -2.337E-06	3 34 0.0	3 44 0.0		
3 15 0.0	3 25 0.0	3 35 0.0	3 45 0.0	3 55 0.0	
3 16 0.0	3 26 0.0	3 36 -1.321E-01	3 46 9.855E-03	3 56 0.0	3 66 0.0

4 11 0.0					
4 12 0.0	4 22 0.0				
4 13 -7.393E-01	4 23 -2.498E-01	4 33 0.0			
4 14 2.688E-03	4 24 8.697E-04	4 34 0.0	4 44 0.0		
4 15 0.0	4 25 0.0	4 35 0.0	4 45 0.0	4 55 0.0	
4 16 0.0	4 26 0.0	4 36 -1.766E+00	4 46 3.027E-02	4 56 0.0	4 66 0.0

5 11 -1.929E-02					
5 12 -5.838E-03	5 22 -5.401E-04				
5 13 0.0	5 23 0.0	5 33 -5.600E-02			
5 14 0.0	5 24 0.0	5 34 -1.465E-03	5 44 -1.023E-04		
5 15 0.0	5 25 0.0	5 35 0.0	5 45 0.0	5 55 0.0	
5 16 1.058E-02	5 26 8.381E-04	5 36 0.0	5 46 0.0	5 56 0.0	5 66 -5.416E-03

```
6 11  0.0
6 12  0.0           6 22  0.0
6 13  0.0           6 23  0.0           6 33  0.0
6 14  0.0           6 24  0.0           6 34  0.0           6 44  0.0
6 15  0.0           6 25  0.0           6 35  0.0           6 45  0.0           6 55  0.0
6 16  0.0           6 26  0.0           6 36  0.0           6 46  0.0           6 56  0.0           6 66  0.0


      LABEL = PR3


*LENGTH*     5.5651 M




*TRANSFORM* 1
          1.37501    0.30000    0.0        0.0        0.0        2.00381
         -9.93513   -1.44037    0.0        0.0        0.0        8.66018
          0.0        0.0       -4.21898   -0.00000    0.0        0.0
          0.0        0.0      -12.02389   -0.23703    0.0        0.0
         -3.17862   -0.54800    0.0        0.0        1.00000   -0.27175
          0.0        0.0        0.0        0.0        0.0        1.00000

 *2ND ORDER TRANSFORM *
1 11 -1.280E-01
1 12 -4.701E-02     1 22 -4.328E-03
1 13  0.0           1 23  0.0           1 33  1.269E-01
1 14  0.0           1 24  0.0           1 34 -2.792E-03     1 44 -2.408E-06
1 15  0.0           1 25  0.0           1 35  0.0           1 45  0.0           1 55  0.0
1 16 -6.588E-02     1 26 -1.179E-02     1 36  0.0           1 46  0.0           1 56  0.0           1 66 -3.934E-02


2 11 -1.122E+00
2 12 -4.182E-01     2 22 -3.897E-02
2 13  0.0           2 23  0.0           2 33  1.417E+00
2 14  0.0           2 24  0.0           2 34 -2.703E-02     2 44 -6.971E-06
2 15  0.0           2 25  0.0           2 35  0.0           2 45  0.0           2 55  0.0
2 16 -7.105E-01     2 26 -1.388E-01     2 36  0.0           2 46  0.0           2 56  0.0           2 66 -2.826E-01


3 11  0.0
3 12  0.0           3 22  0.0
3 13 -2.738E-01     3 23 -5.118E-02     3 33  0.0
3 14 -2.831E-04     3 24 -4.698E-05     3 34  0.0           3 44  0.0
3 15  0.0           3 25  0.0           3 35  0.0           3 45  0.0           3 55  0.0
3 16  0.0           3 26  0.0           3 36 -8.804E-02     3 46  7.061E-03     3 56  0.0           3 66  0.0
```

$R_{16} = 2$ cm %

$K = -1.5$

4 11 0.0					
4 12 0.0	4 22 0.0				
4 13 -2.302E+00	4 23 -4.340E-01	4 33 0.0			
4 14 1.458E-02	4 24 2.741E-03	4 34 0.0	4 44 0.0		
4 15 0.0	4 25 0.0	4 35 0.0	4 45 0.0	4 55 0.0	
4 16 0.0	4 26 0.0	4 36 -1.098E+00	4 46 2.507E-02	4 56 0.0	4 66 0.0

5 11 -2.658E-02					
5 12 -9.618E-03	5 22 -9.482E-04				
5 13 0.0	5 23 0.0	5 33 -3.104E-02			
5 14 0.0	5 24 0.0	5 34 -1.049E-03	5 44 -9.532E-05		
5 15 0.0	5 25 0.0	5 35 0.0	5 45 0.0	5 55 0.0	
5 16 3.554E-02	5 26 4.313E-03	5 36 0.0	5 46 0.0	5 56 0.0	5 66 -5.416E-03

6 11 0.0					
6 12 0.0	6 22 0.0				
6 13 0.0	6 23 0.0	6 33 0.0			
6 14 0.0	6 24 0.0	6 34 0.0	6 44 0.0		
6 15 0.0	6 25 0.0	6 35 0.0	6 45 0.0	6 55 0.0	
6 16 0.0	6 26 0.0	6 36 0.0	6 46 0.0	6 56 0.0	6 66 0.0

LABEL = PR3

LENGTH 5.5651 M

TRANSFORM 1

-1.71147	-0.15000	0.C	0.0	0.0	2.00081
-11.52820	-1.59467	0.C	0.0	0.0	8.66018
0.0	C.0	-6.58755	-0.00000	0.0	0.0
0.0	C.0	-17.44852	-0.15180	0.0	0.0
-0.82441	-0.18916	0.C	0.0	1.00000	-0.27175
0.0	0.C	0.C	0.0	0.0	1.00000

*2ND ORDER TRANSFORM *

1 11 -1.647E-02					
1 12 -2.317E-03	1 22 -2.165E-04				
1 13 0.0	1 23 0.0	1 33 5.077E-01			
1 14 0.0	1 24 0.0	1 34 -4.017E-03	1 44 1.252E-06		
1 15 0.0	1 25 0.0	1 35 0.0	1 45 0.0	1 55 0.0	
1 16 7.935E-02	1 26 7.213E-03	1 36 0.0	1 46 0.0	1 56 0.0	1 66 -4.814E-02

R_{16} = 2 cm / %

K = 0.75

2 11 -6.859E-02					
2 12 3.058E-03	2 22 -2.451E-04				
2 13 0.0	2 23 0.0	2 33 5.288E+00			
2 14 0.0	2 24 0.0	2 34 -3.828E-02	2 44 1.735E-05		
2 15 0.0	2 25 0.0	2 35 0.0	2 45 0.0	2 55 0.0	
2 16 3.818E-01	2 26 8.112E-03	2 36 0.0	2 46 0.0	2 56 0.0	2 66 -3.639E-01

3 11 0.0					
3 12 0.0	3 22 0.0				
3 13 1.266E-01	3 23 -4.366E-03	3 33 0.0			
3 14 -2.014E-04	3 24 -7.956E-06	3 34 0.0	3 44 0.0		
3 15 0.0	3 25 0.0	3 35 0.0	3 45 0.0	3 55 0.0	
3 16 0.0	3 26 0.0	3 36 -1.864E-01	3 46 1.158E-02	3 56 0.0	3 66 0.0

4 11 0.0					
4 12 0.0	4 22 0.0				
4 13 1.306E+00	4 23 -1.651E-02	4 33 0.0			
4 14 -3.451E-03	4 24 7.936E-05	4 34 0.0	4 44 0.0		
4 15 0.0	4 25 0.0	4 35 0.0	4 45 0.0	4 55 0.0	
4 16 0.0	4 26 0.0	4 36 -2.402E+00	4 46 3.496E-02	4 56 0.0	4 66 0.0

5 11 -2.626E-02					
5 12 -7.008E-03	5 22 -5.660E-04				
5 13 0.0	5 23 0.0	5 33 -6.917E-02			
5 14 0.0	5 24 0.0	5 34 -1.648E-03	5 44 -1.080E-04		
5 15 0.0	5 25 0.0	5 35 0.0	5 45 0.0	5 55 0.0	
5 16 -3.847E-03	5 26 -1.031E-03	5 36 0.0	5 46 0.0	5 56 0.0	5 66 -5.416E-03

6 11 0.0					
6 12 0.0	6 22 0.0				
6 13 0.0	6 23 0.0	6 33 0.0			
6 14 0.0	6 24 0.0	6 34 0.0	6 44 0.0		
6 15 0.0	6 25 0.0	6 35 0.0	6 45 0.0	6 55 0.0	
6 16 0.0	6 26 0.0	6 36 0.0	6 46 0.0	6 56 0.0	6 66 0.0

LABEL = PR3

LENGTH 5.5651 M

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