CONCEPTS OF OPERATION FOR THE MAGNET SPECTROMETER "BIG KARL"

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Abstract

The variable dispersion QQDDQ magnet spectrometer "Big Karl" has been designed to cover a wide range of applications in high acceptance, high resolution experiments. In order to meet these requirements, direct field control in the quadrupoles and multipole tuning by so-called Ht-windings in the dipole magnets are used to correct for ion-optical aberrations. The latter are determined by an experimental raytracing method during the set-up phase of the spectrometer. On-line reconstruction of events with free parameter definition helps to suppress background and to further improve the resolution by focal plane reconstruction in software.

Introduction

Setting up and performing a magnet spectrometer experiment with "Big Karl"[1] requires some rather complex tasks to be mastered by the experimentalist. A set of DCL-procedures[2] and utility programs provide him with the necessary support on Big Karl's data acquisition VAX-11/780 and PDP-11 control computers. Control is handled by a more or less conventional CAMAC system on the PDP whereas a special data acquisition hardware "MEMPHIS"[3] had been developed to allow fast hardware event preprocessing and buffered DMA data transfer to the VAX.

Getting started

Defining the goal of an experiment consists in choosing the appropriate beam particle and energy, the reaction targets and outgoing particles to identify, and the appropriate energy resolution or excitation energy range to be observed at once. The two utilities BRHO and BKARLO generate graphic or numerical representations of reaction kinematics including composite target and multilayer detector energy losses. These are used to search for possible calibration reactions in both absolute reaction angle and energy, and for a proper setup of detectors and particle identification.

Setting the magnets

The magnets involved in tuning the spectrometer are the last four beam line quadrupoles QB, the two focussing quadrupoles Q1 and Q2, the main dipole magnets D1 and D2 with their 22 so-called H_t-correction windings[4], and the "variable dispersion"-quadrupole Q3 (Fig. 1).

Special care has to be taken in order to achieve the required field shape reproducibility in the dipole magnets. The H_t-correction windings embedded in the iron of the magnet pole faces exhibit a strong and nonlinear dependence on each other and on the main dipole field. A significant change in H_t-current always requires a "CYCLING"-loop through saturation of the main current (Fig. 2). The same procedure is used for initial setup. Small field variations of a few percent are usually done by just "MOVING" the current with direction-dependent undershoot. This, however, if repeated frequently tends to destroy the original field shape which then has to be restored by "CYCLING".

In good approximation for small H_t-currents at medium field levels a n'th order multipole field correction is generated by a (n-1) th order gradient in the H_t-current distribution perpendicular to the central trajectory. H_t-control therefore directly takes the multipole expansion coefficients as input parameters and generates the corresponding single-H_t currents (Fig. 3)

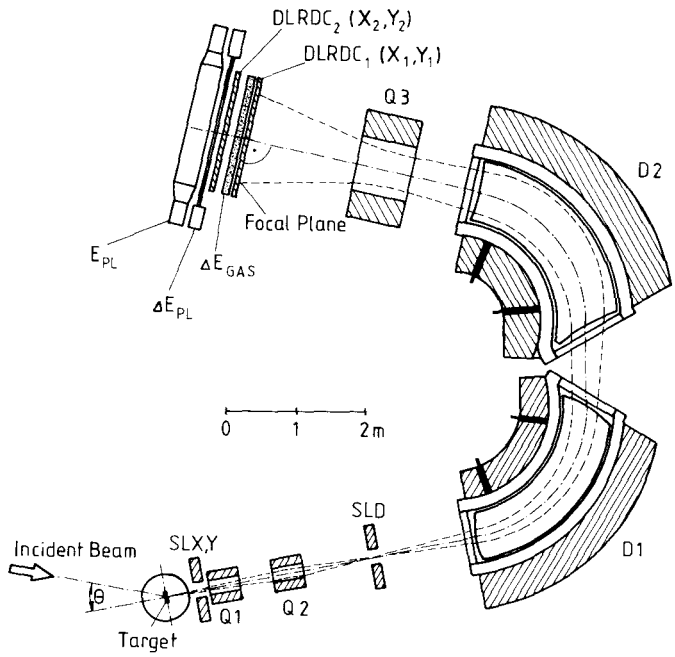


Figure 1: Big Karl layout.

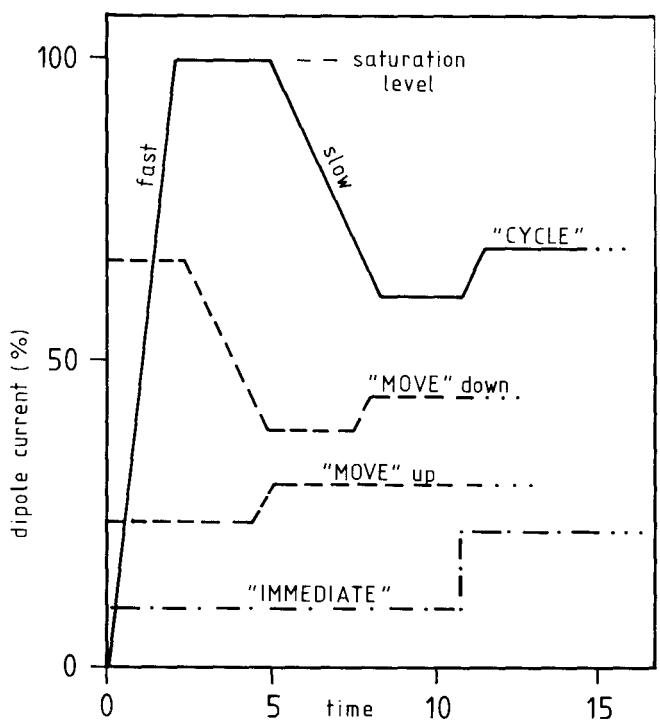
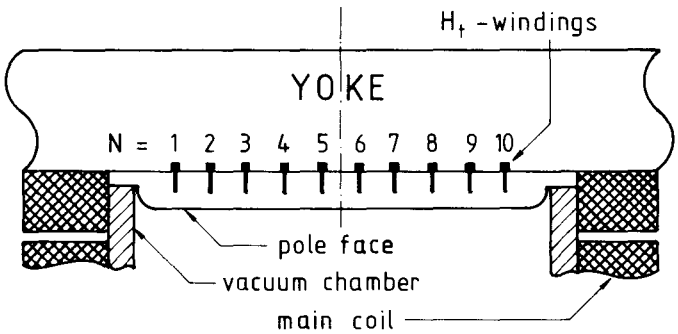


Figure 2: Dipole control.



H_t -multipole setting:

$K_N = \sum_{i=0}^{4} I_i * (5.5 - N)^i$ %

K_N = current of N'th H_t-winding

I_i = multipole coefficient

i = 0 quadrupole correction

= 1 sextupole correction

etc...

Figure 3: H_t-correction windings.

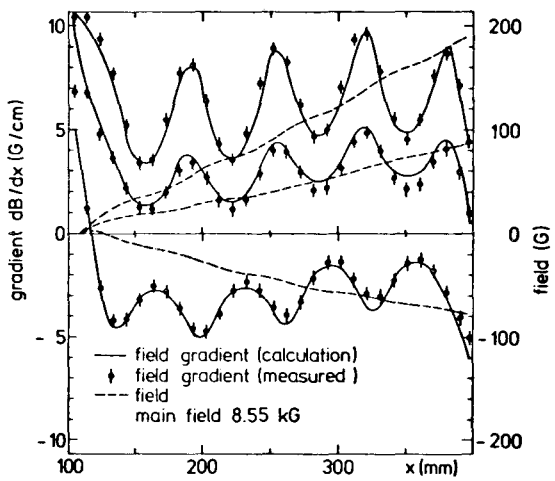
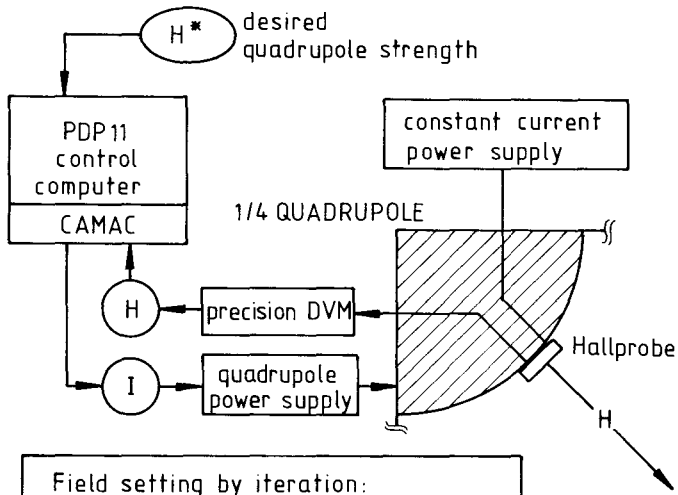


Figure 4: Field gradients and field shapes produced by six equal Ht currents (IØ = const.).

The differential field variations and corresponding field shapes are shown in Fig. 4 for three different settings of Iθ (= quadrupole component).

The resulting field shapes and absolute values in the dipoles are measured regularely during an experiment by means of four so-called "fumble"-probes moving into the magnets in radial direction. The fields measured by NMR or Hall probes are displayed on-line and analyzed in terms of multipole coefficients.

Control for the three main quadrupoles Q1 to Q3 is realized in a somewhat unusual way: In order to gain independency of the current-to-field calibrations which were found to slowly change in time the pole-tip field strength is adjusted directly by the computer in an iterative way (Fig. 5). This takes in the order of half a minute to settle the fields with a precision determined by the Hall probe readout.



Field setting by iteration:

$I_{N+1} = I_{N-1} + (H^* - H_{N-1}) * \frac{(I_N - I_{N-1})}{(H_N - H_{N-1})}$

H = pole tip field strength

I = quadrupole current

Figure 5: Quadrupole control.

Spectrometer optimization through experimental ray tracing

a) Method

Start values for the quadrupole, dipole, and the H_t-correction currents for a desired energy and dispersion are calculated by a utility program "MAGSET" which combines TRANSPORT-calculations with empirical data obtained in earlier optimization runs. Several steps are then taken to improve the energy resolution along the focal plane by an experimental ray tracing technique: The entrance slits SLY or SLX are closed to a few mrad and moved in vertical or horizontal direction such as to define different entrance angles θ_0 and ρ_0 of a pencil beam into the spectrometer. The displacement of several spectrum lines in the focal plane x- and y-directions are then fitted as polynomial functions of these angles. The analysis in terms of ionoptical first and higher order aberrations is performed using the interactive "MATRIX"[5] utility. Heavy target nuclei are used for optimization in order to exclude kinematical side-effects.

b) Ionoptical aberrations

Proper focussing at the position of the detector is established by zeroing the opening angle aberrations

$R_{12} = (x/\theta_0)$ using the quadrupole Q2
and $R_{34} = (y/\rho_0)$ using the quadrupole Q1

Fig. 6 shows a typical x of θ_0 dependence for a non-optimized and optimized Q2. The curvature and the polynomial fit performed by MATRIX reveal second and higher order terms which can be corrected by appropriate multipoles of same order. The main contribution usually arises from a $T_{122} = (x/\theta_0^2)$ term which is corrected by changing the I1-component of the H_t-currents in D1.

This is done after correcting the dispersive $T_{126} = (x/\theta_0\delta_0)$ aberration first by an I1-term in D2 since the latter is not sensitive to a change of I1 in D1. Fig. 7 shows two such terms R_{12} and T_{122} before and after correction as functions of δ, the central momentum deviation at different focal plane positions. The dispersive terms describe the remaining tilt and curvature of the effective focal plane which have to be small in order to take full advantage of the 1 m detector length.

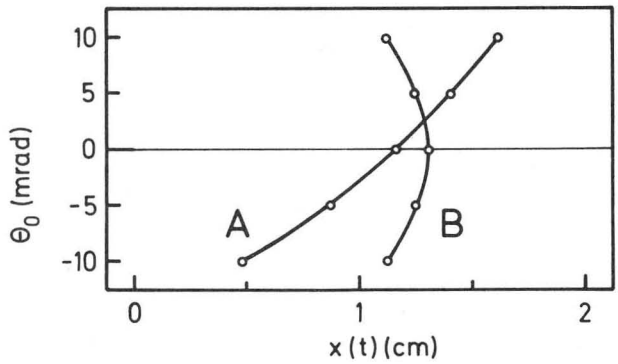


Figure 6: Change of $x(\theta_0)$ with Q2 setting.

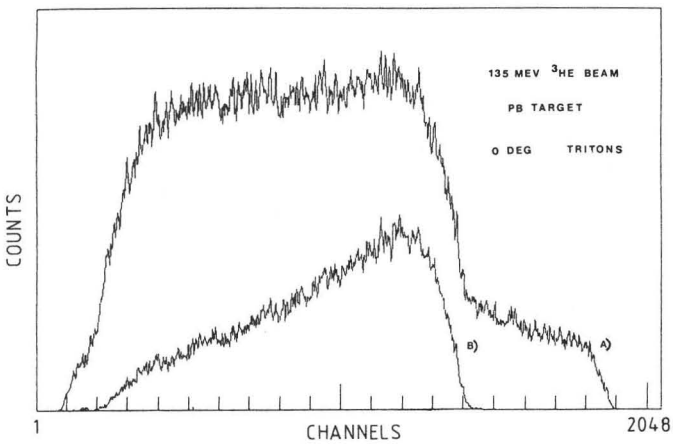


Figure 8a: Resulting background suppression.

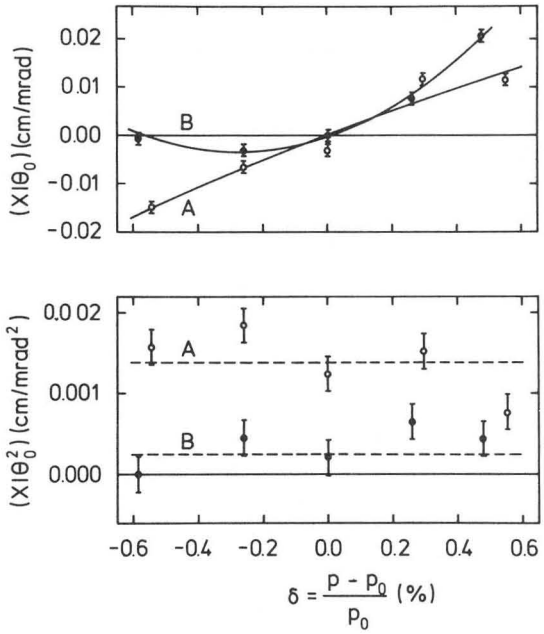


Figure 7: R_{12} and T_{122} aberrations before (A) and after (B) correction.

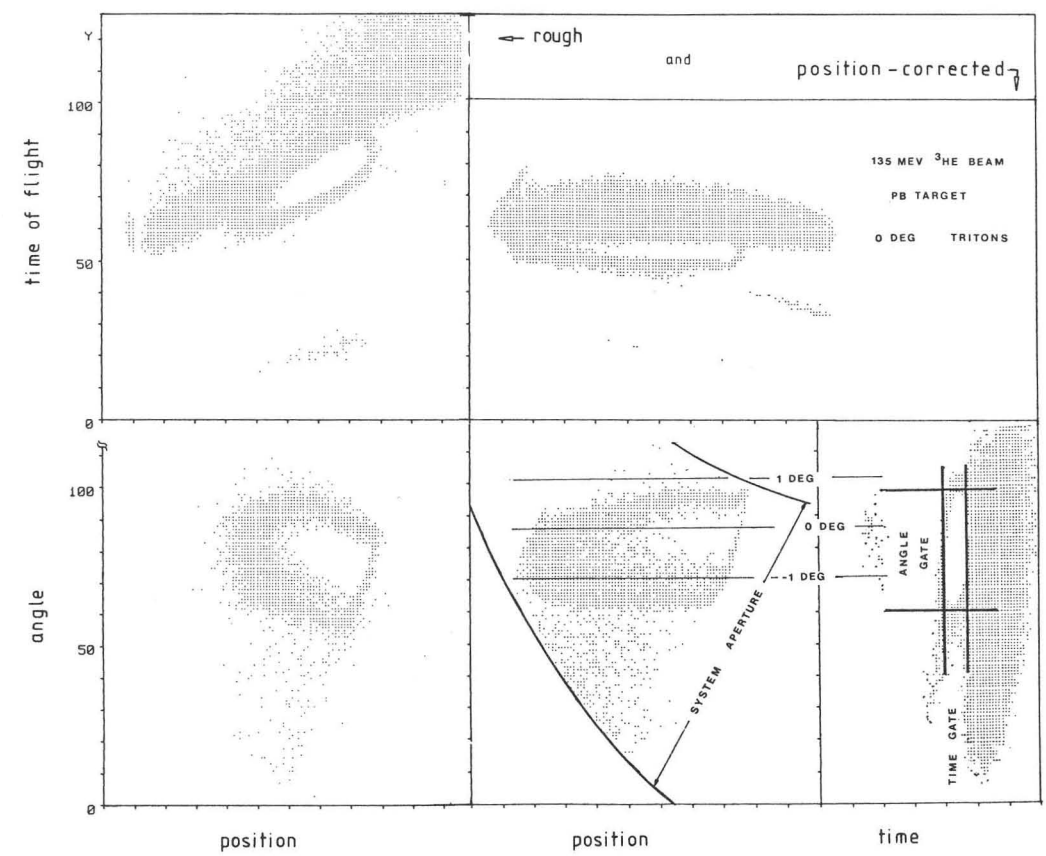


Figure 8b:
Off-line event reconstruction with position-corrected angle and time of flight.

c) Matching beam and spectrometer

Matching consists of compensating the line broadening introduced by the kinematics at larger opening angles, and in correcting for the momentum spread and angular divergence of the incoming beam.

"Kinematic displacement" corrects the line broadening otherwise introduced by a kinematical shift of the focal plane at higher K-values. This is realized by readjusting Q2 in order to keep the focus at the detector position according to values given by the utility KIN1.

"Kinematic defocussing" shifts the target focus downstream the spectrometer by readjusting the last two beamline quadrupole doublets. The actual focus position is measured by varying the entrance angle of a pencil beam into the beam line and observing the displacement at the target position. This compensates the momentum deviation due to different effective reaction angles for particles hitting the target at different incident angles.

"Dispersion matching" finally adjusts the beam line dispersion to the dispersion/magnification ratio of the spectrometer in order to become independent of the momentum spread of the cyclotron beam. This is accomplished by a "plunger"-method comparing the beam line properties to TRANSPORT calculations.

Data acquisition and event reconstruction

The standard detector system consists of the two 1 m by 90 mm x/y multiwire drift chambers (Morris-type[6]), a gas energy loss detector, two plastic scintillators, and an optional time of flight detector. The very flexible data acquisition utility ACON allows on-line hard- and software definition of pseudo-parameters to directly generate the desired monitor spectra. Production data are in addition recorded on magnetic tape for later reanalysis through the off-line sorting utility PLSORT with improved detector calibration (MOCAL) and particle identification.

The detector providing position and angle information at once allows to correct for the position dependence of incident angle and time of flight in the focal plane as caused by the variations of particle path through the spectrometer. This yields a drastic background suppression as illustrated by Figs. 8a and 8b for a forward angle experiment.

References

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2) Digital Equipment, VAX/VMS operating system V3.2

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