Dispersion Matching between WS Beam Line and Grand Raiden Spectrometer for Light Nuclei

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We have designed and constructed a new beam line (WS beam line) [1] which can accomplish both lateral and angular dispersion matching with the Grand Raiden spectrometer. In dispersive mode, nominal lateral and angular dispersions of the beam line are b_{16}=37.1 m and b_{26}=−20.0 rad, respectively. These dispersions satisfy matching conditions for reactions with a kineamtic factor of $K = 0$. The kinematic factor K is defined as

$$K = \frac{1}{p_{\rm out}} \frac{\partial p_{\rm out}}{\partial \alpha} \ , \tag{1}$$

where $p_{\rm in}$ and $p_{\rm out}$ are the momenta of incident and scattered particles, respectively, and α is the reaction angle. The K values for reactions with light targets are significantly different from zero, which significantly changes the dispersion matching conditions as described below.

The coordinates (x, θ) in the medium plane at the focal plane location of Grand Raiden are related to the coordinates $X_0 = (x_0, \theta_0, \delta_0)$ at the exit of the Ring Cyclotron (at the beginning of the WS beam line) as

$$\begin{aligned} x &= (s_{11}b_{11}T + s_{12}b_{21})x_0 + (s_{11}b_{12}T + s_{12}b_{22})\theta_0 \\ &\quad +(s_{11}b_{16}T + s_{12}b_{26} + s_{16}C)\delta_0 + (s_{12} + s_{16}K)\Theta \ , \qquad (2) \\ \theta &= (s_{21}b_{11}T + s_{22}b_{21})x_0 + (s_{21}b_{12}T + s_{22}b_{22})\theta_0 \\ &\quad +(s_{21}b_{16}T + s_{22}b_{26} + s_{26}C)\delta_0 + (s_{22} + s_{26}K)\Theta \ . \qquad (3) \end{aligned}$$

where b_{ij} and s_{ij} are the matrix elements of the beam line and spectrometer, respectively, T the target function, C the kinematic factor, and Θ the relative reaction angle.

For K=C=0 reactions, the WS beam line with nominal lateral and angular dispersions can satisfy the dispersion matching conditions for Grand Raiden by setting the beam line and spectrometer to b_{12}=s_{12}=0. For $K \neq 0$, the focus of the spectrometer is changed to meet the kinematical correction of $(s_{12} + s_{16}K) = 0$. This correction can be accomplished by the displacement $L = -s_{16}K/(s_{22} + s_{26}K)$ of the focal plane of the spectrometer. The matrix elements s'_{ij} of the spectrometer at the displaced focal plane location become

$$S' = \begin{pmatrix} 1 & L & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} S = \begin{pmatrix} s_{11} + Ls_{21} & Ls_{22} & s_{16} + Ls_{26} \\ s_{21} & s_{22} & s_{26} \\ 0 & 0 & 1 \end{pmatrix} \ . \tag{4}$$

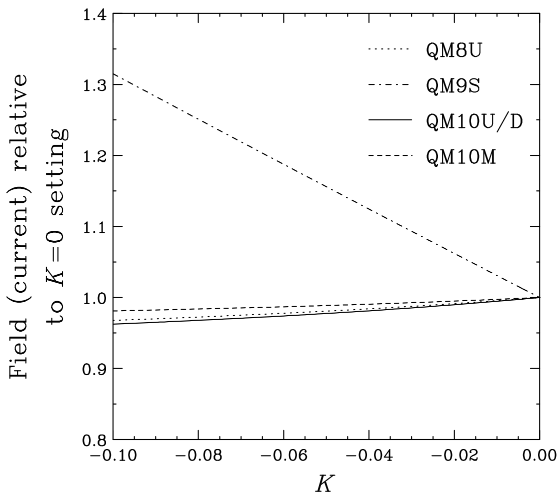

Figure 1: Current settings of quadrupole magnets in the WS beam line relative to the settings for $K = 0$ as a function of K.

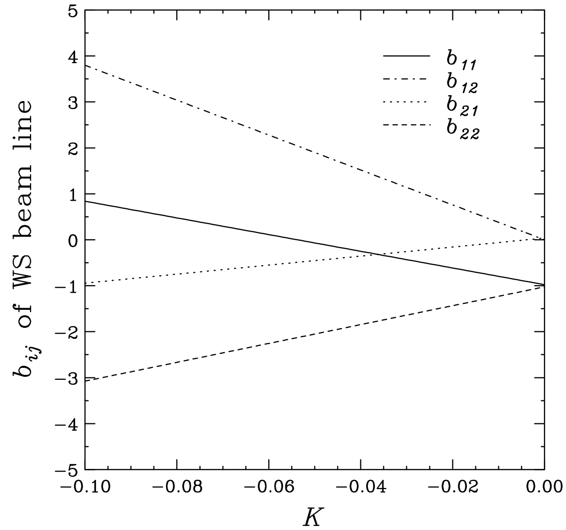

Figure 2: Matrix elements b_{ij} of the WS beam line in dispersive mode as a function of K.

Now lateral and angular dispersion matching conditions at the displaced focal plane location are expressed as

$$s'_{11}b_{16}T + s'_{12}b_{26} + s'_{16}C = 0 \,, \quad (5)$$

$$s'_{21}b_{16}T + s'_{22}b_{26} + s'_{26}C = 0 \,, \quad (6)$$

$$s'_{11}b_{12}T + s'_{12}b_{22} = 0 \,. \quad (7)$$

These conditions are satisfied by displacing the focus point of the beam line from the target location to a downstream location ($b_{12} > 0$), while keeping lateral (b_{16}) and angular (b_{26}) dispersions to nominal values.

The dispersion matching for $K \neq 0$ can be accomplished by altering the current settings of quadrupole magnets. The matching conditions in Eqs. (5)–(7) for C=0 reactions can be summarized as

$$b_{16} = 37.1 \text{ m}, \; b_{26} = 20.0 \text{ rad}, \; b_{12} = -\frac{s'_{12}}{s'_{11}}b_{22}, \; b_{34} = 0 \,, \quad (8)$$

where we have added another condition of the vertical focus at the target location (b_{34}=0). These four conditions can be satisfied by using four quadrupole magnets of QM8U, QM9S, QM10U(=QM10D), and QM10M in the WS beam line. Figure 1 shows the current settings of these magnets relative to the settings for K=0 as a function of K. It is found that we should change the current setting of QM9S significantly for $K < 0$. Figure 2 shows the matrix elements of the WS beam line as a function of K. The beam is focused (b_{12}=0) at the target location for K=0, while the beam should be defocused ($b_{12} > 0$) for $K < 0$.

References

[1] T. Wakasa *et al.* Nucl. Instrum. Methods Phys. Res. A, submitted.