## New $\mu$ E4: vertical beam shift at the end of the beamline due to horizontal tilting of WSX

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Considering the beam line vertically as a simple drift the total vertical shift  $\Delta y$  of the beam for an initial vertical deflection  $\phi_{tot}$  due to the two solenoids WSX61 and WSX62 is given by

$$\Delta y = \phi_{tot} \cdot L = (\phi_{WSX61} + \phi_{WSX62}) \cdot L, \tag{1}$$

where L is the total length of the beam line, and  $\phi_{WSX61}$  and  $\phi_{WSX62}$  are the vertical deflection angles of WSX61 and WSX62, respectively.



Figure 1: a) Magnetic field component  $B_{\perp}$  due to horizontal tilting of WSX by an angle  $\alpha$ .  $B_{\perp}$  causes a vertical deflection (out of the plane of view) of the beam. b) Vertical deflection angle  $\phi_{WSX}$  and radius  $r_{WSX}$  of the central trajectory. For small  $\phi_{WSX}$  the arc length s equals to good approximation the effective length  $l_{eff}$  of the WSX solenoid.

The deflection angle  $\phi_{WSX}$  is given by

$$\phi_{WSX} = \frac{s}{r_{WSX}} \simeq \frac{l_{eff}}{r_{WSX}},\tag{2}$$

see Fig. 1. The radius  $r_{WSX}$  of the central trajectory is determined by the particle momentum p and the magnetic field  $B_{\perp}$ :

$$r_{WSX} = \frac{p}{e \cdot B_{\perp}} \simeq \frac{p}{e \cdot \alpha \cdot B}.$$
(3)

Inserting Eq. (3) in (2) and Eq. (2) in (1) yields finally for the vertical deflection of the central trajectory at the end of the beam line

$$\Delta y = (B_{WSX61} + B_{WSX62}) \times \frac{e \cdot \alpha \cdot l_{eff} \cdot L}{p}$$
(4)

$$= 0.03 \times (B_{WSX61} + B_{WSX62}) \times \frac{\alpha \cdot l_{eff} \cdot L}{p}$$
(5)

$$[B] = kG, [\alpha] = mrad, [l] = m, [p] = MeV/c$$

The following table gives an overview on the total bending angle  $\phi_{tot} = (\phi_{WSX61} + \phi_{WSX62})$  of the two WSX and the vertical shift  $\Delta y$  of the beam at the channel end point for different tilt angles  $\alpha$ . The effictive length of each WSX solenoid is 0.666 m,  $B_{WSX61} = 2.6$  kG,  $B_{WSX62} = 1.35$  kG, p = 28 MeV/c and L = 18 m.

α	$\phi_{tot} = (\phi_{WSX61} + \phi_{WSX62})$	$\Delta y$
0.1  mrad (= 0.1  mm / 1 m)	$0.28 \mathrm{\ mrad}$	$0.005~\mathrm{m}$
0.2  mrad (= 0.2  mm / 1 m)	$0.56 \mathrm{\ mrad}$	$0.010~\mathrm{m}$
0.5  mrad (= 0.5  mm / 1 m)	$1.41 \mathrm{mrad}$	$0.025~\mathrm{m}$
1.0  mrad (= 1.0  mm / 1 m)	$2.82 \mathrm{mrad}$	$0.051~\mathrm{m}$

The deviation of the beam center should be less than 5 mm in the area which requires the WSX axis to coincide with the beam axis by better than 0.1 mrad ! The vertical beam steering proposed by D. George (current flowing asymmetrically through the first three QSM's) possibly can help if there are any problems with the adjustment of WSX. The vertical deflection angle is estimated to 6.5 mrad at 10 A additional current in two of the four QSM coils. However, since we do not know how the steering with the QSM's will work it's better to try to adjust horizontally the WSX axis to  $\leq 0.1$  mrad with respect to the beam axis.