Electrostatic deflector simulation studies

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Electrostatic deflectors: dynamics

Potential is higher towards outside

Particles entering outside slow down in the fringe field

- They are bent more: **focusing in the bending plane**

- Transverse and longitudinal motions are **coupled**
Spherical deflector

\[ E_r = E_0 \frac{R_0^2}{r^2} \]
Spherical deflector

\[ E_r = E_0 \frac{R_0^2}{r^2} \]

Focusing in both planes, **coincident** focal points
A parallel, monoenergetic ($E_{\text{kin}} = qE_0R/2$) beam remains parallel.

**Condition of circular orbit ($r$):** (independent of $r$)

$$E = E_0 \frac{R}{r}$$

$$\frac{m v^2}{r} = F = q E_0 \frac{R}{r}$$
Cylindrical deflector

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Condition of circular orbit (r):
(independent of r)

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Focusing due to fringe fields (only in the bending plane)
2 more electrodes with proper dimensions & voltages: focusing in both planes can be restored, with coincident focal points

[Fishkova, Ovsyannikova, NIM A363 (1995) 494]
Electrostatic spectrometer
Aarhus group @ ASACUSA

A. Csete: Experimental Investigations of the Energy Loss of Slow Protons and Antiprotons in Matter

(PhD. Thesis, ASACUSA experiment)

Not used anymore.
If there is interest, we can get this device from Aarhus.
Imitating a spherical (doubly-focusing) deflector

“True” spherical deflector

Cylindrical capacitor with different electrode heights.


Field can be shaped without complicated geometrical structures....
Size, bending radius

Electrode voltages: \( \pm \frac{E_{\text{kin}} d}{q R} \)

<table>
<thead>
<tr>
<th>@ 100 keV</th>
<th>R = 1.5 m</th>
<th>R = 1 m</th>
<th>R = 0.5 m</th>
<th>R = 0.2 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>d = 8 cm</td>
<td>± 5.3 kV</td>
<td>± 8 kV</td>
<td>± 16 kV</td>
<td>± 40 kV</td>
</tr>
<tr>
<td>d = 6 cm</td>
<td>± 4 kV</td>
<td>± 6 kV</td>
<td>± 12 kV</td>
<td>± 30 kV</td>
</tr>
<tr>
<td>d = 4 cm</td>
<td>± 2.6 kV</td>
<td>± 4 kV</td>
<td>± 8 kV</td>
<td>± 20 kV</td>
</tr>
</tbody>
</table>

Bending angle: \( \sim 180 \text{ mrad} \) (interspaced with quad FODO cells) [Wolfgang, Glenn]

Aperture (d): same as the quadrupoles = 6 cm

Bending radius:
- \( L < 30 \text{ cm} \) (angle=180 mrad) \( \rightarrow R < 1.66 \text{ m} \)
- Available on the market (\( R \leq 1 \text{ m} \) for diam=200mm)
- Make it as large as possible (low voltage, less aberrations)

Wrong, largest \( R \) is 500mm (kohler.ch)
Studied configuration & questions

Do not get lost in studying too many parameters!

- Bending radius: \( R = 1 \text{ m} \)
- Aperture: 6 cm
- Cylindrical electrodes (simplest geometry)
- What should be the height?
  - Fit into the beampipe
  - Have a y-uniform field within \(-3 \text{ cm} < y < 3 \text{ cm}\)
- Voltages to be used?
- Fringe fields? Transfer matrix?
- What should we optimize on? (everything should be simulated and studied in the context of the whole beamline optics/dynamics)
**Method**

- Simulate the field by Ansoft MAXWELL (one electrode @ 1V, other at ground - and vice versa)
- Write the full 3D fieldmap to a file on a rectangular grid
Method (cont'd...)

- Read the two fieldmaps in a C++ code, (quasi)linear interpolation between grid points.
- Scale them by the desired voltages on the two electrodes, take their superposition.
- Follow particles: 4-th order Runge-Kutta.
- Transfer matrix obtained by simulating a bunch of particles with realistic Twiss-parameters, and relating $(x_{\text{out}}, x'_{\text{out}}, \ldots)$ to $(x_{\text{in}}, x'_{\text{in}}, \ldots)$ etc. ($6 \chi^2$ fits, each with 6 parameters)
Electrode height?

Electrode height = 2*aperture = 120 mm seems to be OK.

At the center of the deflector
Electrode height?

Field homogeneity check for electrode height/aperture ratio=2 (should be checked for more cases)

$E_x [V_{in}=-6 \text{ kV}, V_{out}=4 \text{ kV}]$
$E_x [V_{in}=-5 \text{ kV}, V_{out}=5 \text{ kV}]$
$E_x [V_{in}=-4 \text{ kV}, V_{out}=6 \text{ kV}]$
$E_y [V_{in}=-6 \text{ kV}, V_{out}=4 \text{ kV}]$
$E_y [V_{in}=-5 \text{ kV}, V_{out}=5 \text{ kV}]$
$E_y [V_{in}=-4 \text{ kV}, V_{out}=6 \text{ kV}]$

~1.5% change in transverse field between $y=0$ and $y=3\text{cm}$
Check: hard-edge ideal field

Transverse $E$-field component in local (beam) coordinate system

Simulated particle follows the theoretical trajectory
Central input trajectory, varying voltages: output = ?

\[ V_{\text{in}} = -5\text{kV}, \ V_{\text{out}} = 4\text{kV}, \ |\Delta V| = 9\text{kV} \]
\[ V_{\text{in}} = -5\text{kV}, \ V_{\text{out}} = 5\text{kV}, \ |\Delta V| = 10\text{kV} \]
\[ V_{\text{in}} = -5\text{kV}, \ V_{\text{out}} = 6\text{kV}, \ |\Delta V| = 11\text{kV} \]
X & X' isolines for different voltages
Trajectories for these 3 voltages

$V_{in} = -8\text{kV}$, $V_{out} = 2.20938\text{kV}$, $|\Delta V| = 10.2094\text{kV}$

$V_{in} = -2\text{kV}$, $V_{out} = 7.74305\text{kV}$, $|\Delta V| = 9.74305\text{kV}$

$V_{in} = -5\text{kV}$, $V_{out} = 4.97655\text{kV}$, $|\Delta V| = 9.97655\text{kV}$
Focal length in bending plane: 4 m

Beam remains parallel in vertical plane

V_{inner} = -5\, kV; V_{outer} = 4.97655\, kV
Focal length: 2.5 m

\[ V_{\text{inner}} = -8 \text{kV}; \quad V_{\text{outer}} = 2.20938 \text{kV} \]
Focal length: 1.3 m

$V_{\text{inner}} = -2\, \text{kV}$, $V_{\text{outer}} = 7.74\, \text{305 kV}$
Very little x- and y-focusing (F ~ 10m)
@ Vin=-6 kV, Vout=4 kV
HV Spring-loaded pin (we use this solution in our electrostatic quadrupole triplet @ ASACUSA)

Macor support

Screws

Manufacturing is extremely simple and cheap.

Field shaping: probably easier by shaping the electrodes than by additional electrodes
Only ~10° bends
Simplest is to use straight sections for the shielding.

A permanent heat jacket can be installed inside the shield.

Only small openings (~15 cm diam) for the cables) are needed on the shield.
Conclusions

- Studied (and suggested?) geometry: R=1m, aperture=6cm
- Voltages: <=6 kV
- Inner- and outer-electrodes need separately adjustable voltages
- Different transfer properties can be realized by tuning the voltages
- Focal lengths of 1.3 m(x) and 2.5 m(y) can be realized with V <= 8 kV
- Due to the small bending angle (~10 deg), very simple/cheap electrode and shielding geometry is possible. Field shaping by adjusting the electrode heights?