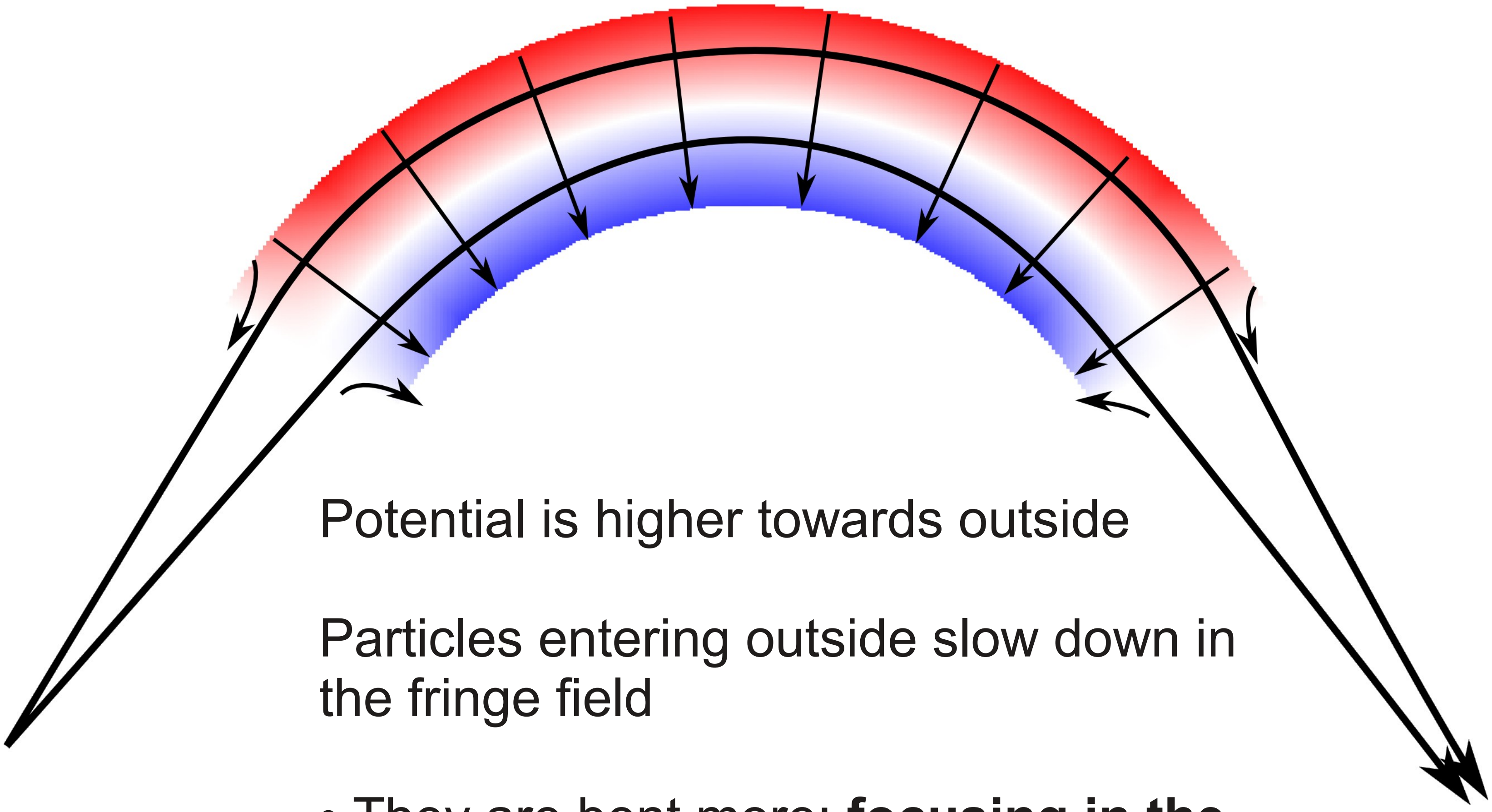
Electrostatic deflector simulation studies

Daniel Barna
Asacusa experiment,
Univ. Tokyo

Electrostatic deflectors: dynamics



Potential is higher towards outside

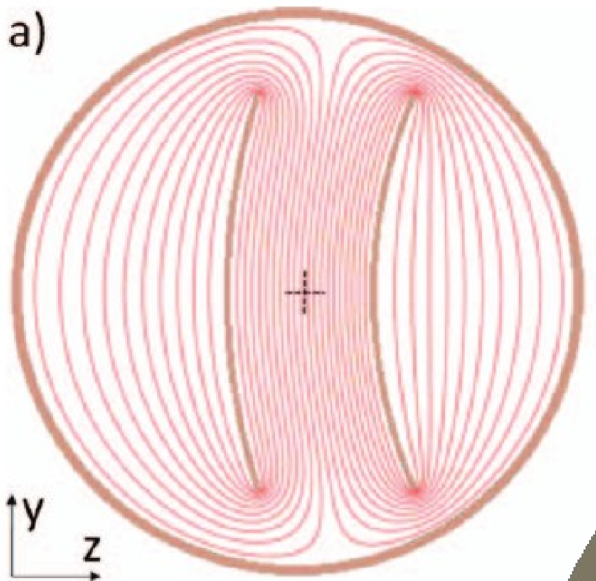
Particles entering outside slow down in the fringe field

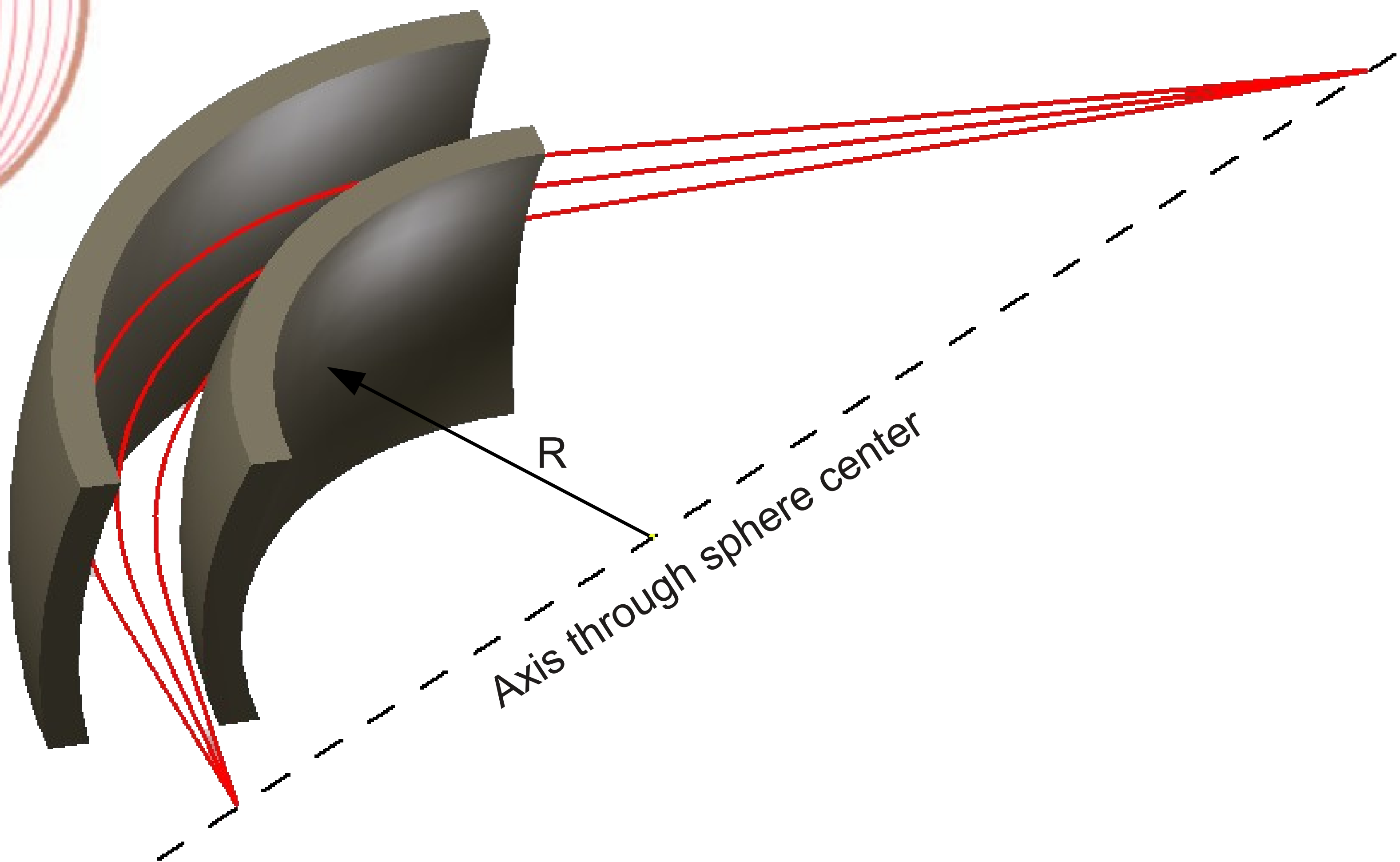
- They are bent more: **focusing in the bending plane**

- Transverse and longitudinal motions are **coupled**

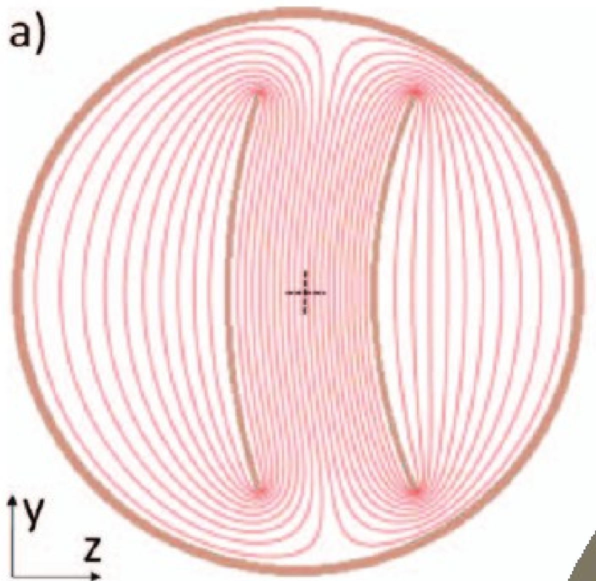
Spherical deflector

$$E_r = E_0 \frac{R_0^2}{r^2}$$

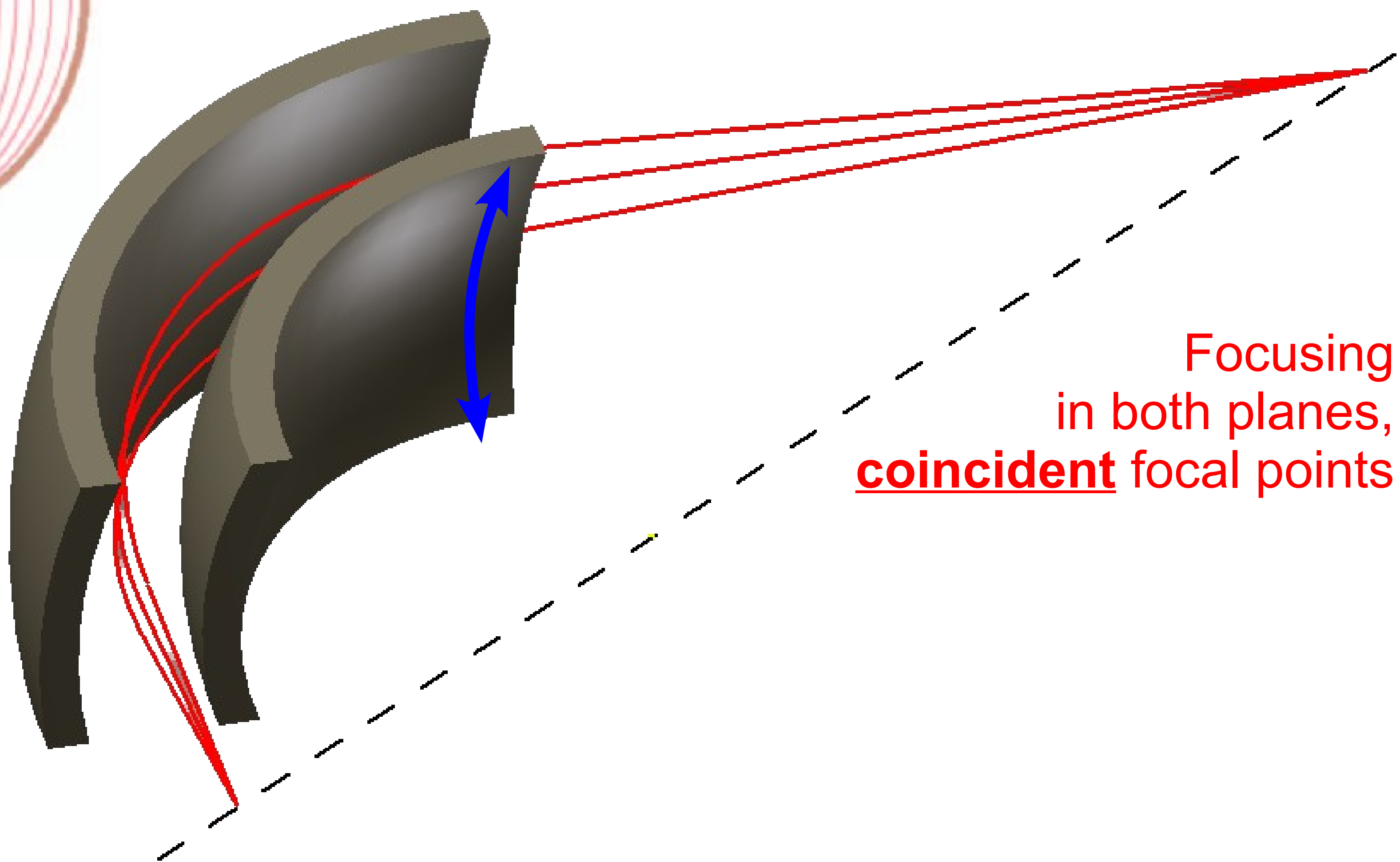




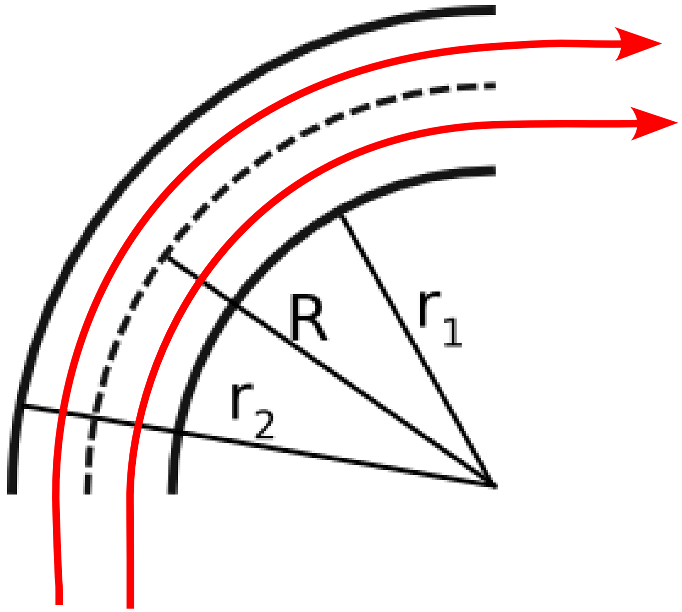
Spherical deflector



$$E_r = E_0 \frac{R_0^2}{r^2}$$



Cylindrical deflector



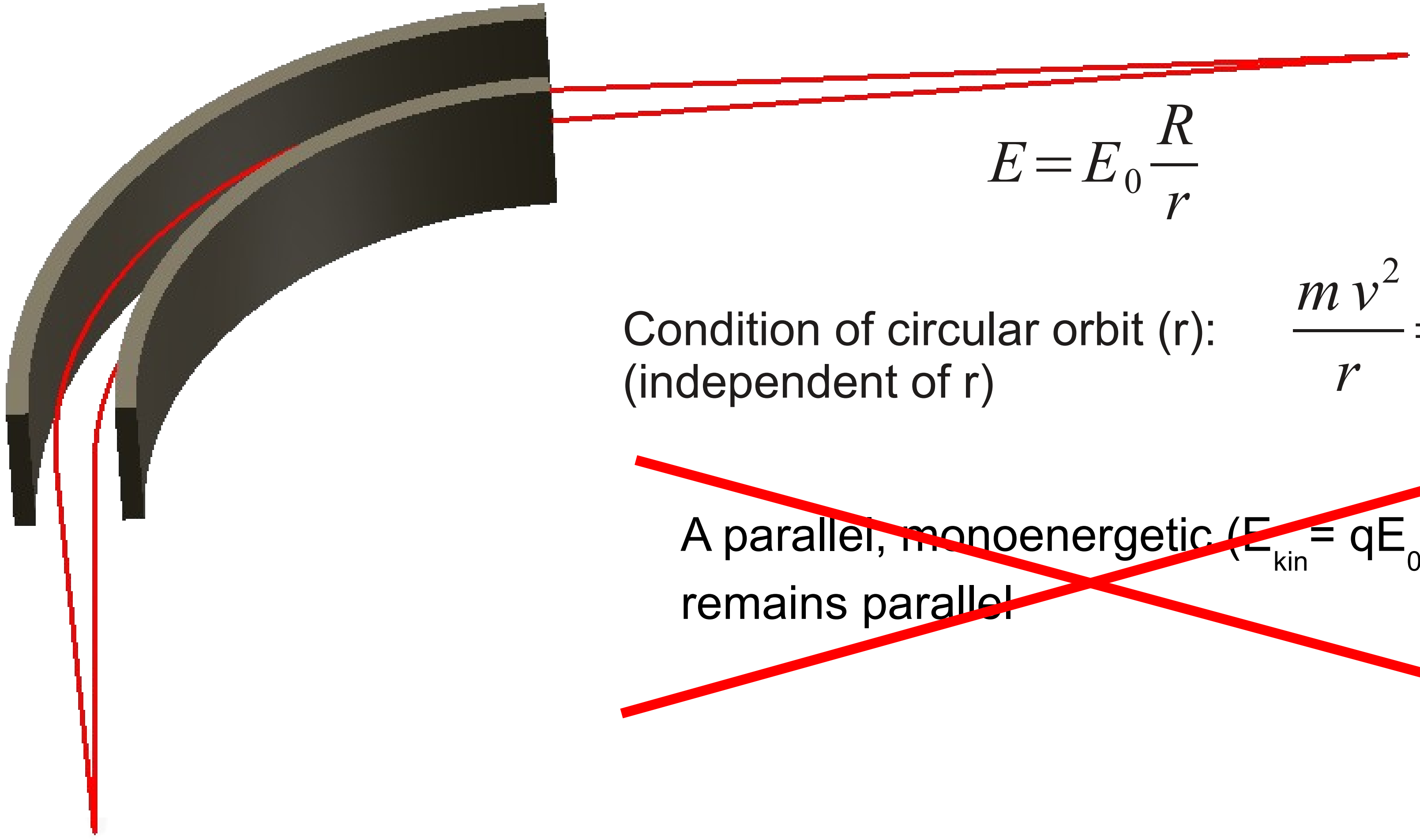
$$E = E_0 \frac{R}{r}$$

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

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

A parallel, monoenergetic (E_{kin}= $qE_0R/2$) beam remains parallel

Cylindrical deflector



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

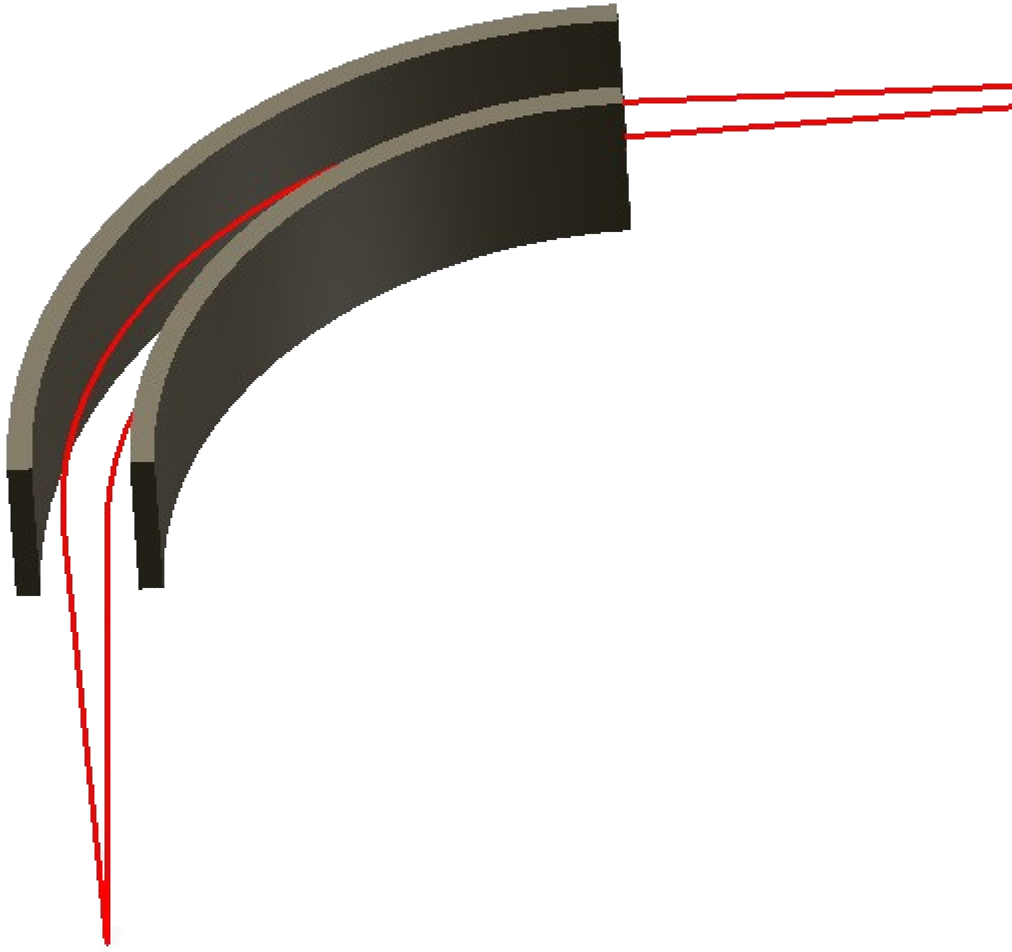
Condition of circular orbit (r):
(independent of r)

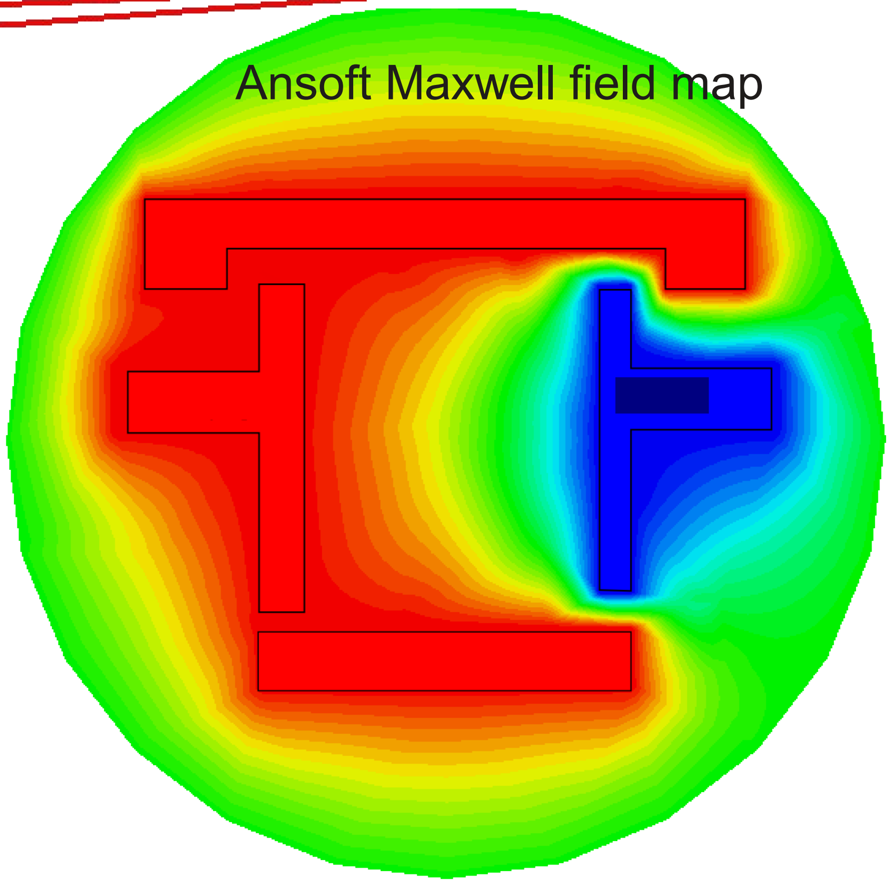
$$\frac{m v^2}{r} = F = q E_0 \frac{R}{r}$$

A parallel, monoenergetic (E_{kin} = $qE_0R/2$) beam remains parallel

Focusing due to fringe fields (only in the bending plane)

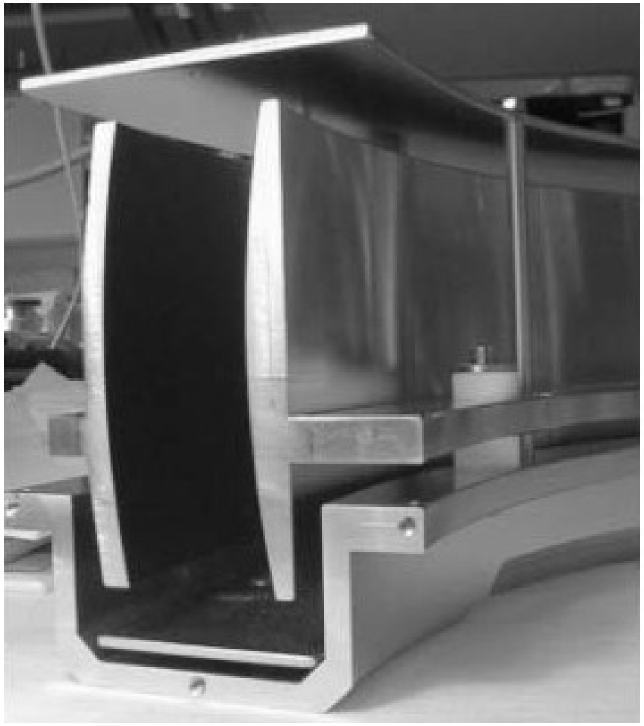
Cylindrical deflector





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

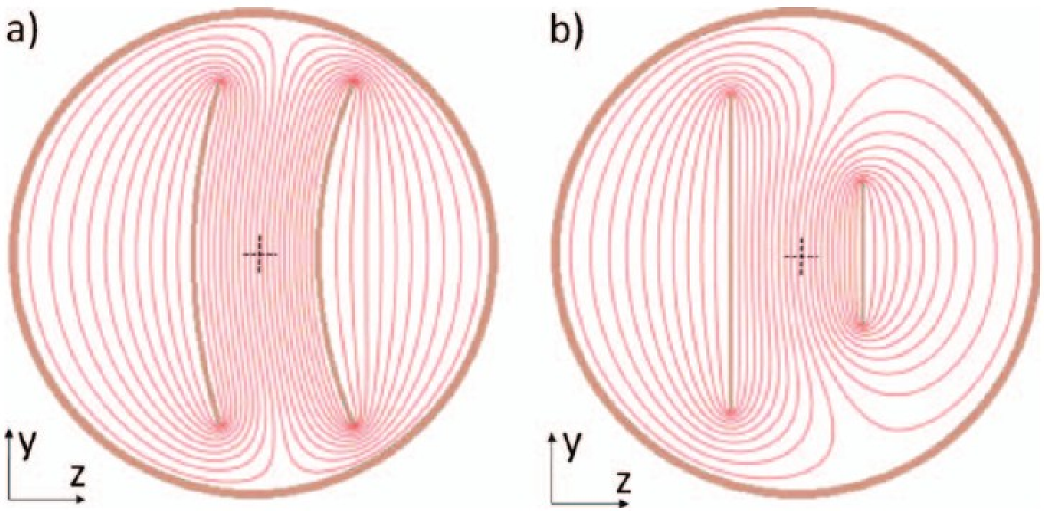


A. Csete: Experimental Investigations of the Energy Loss of Slow Protons and Antiprotons in Matter

(PhD.Thesis, ASACUSA experiment)

Not used anymore.
If there is interest, we can get this device from Aarhus.

Imitating a spherical (doubly-focusing) deflector



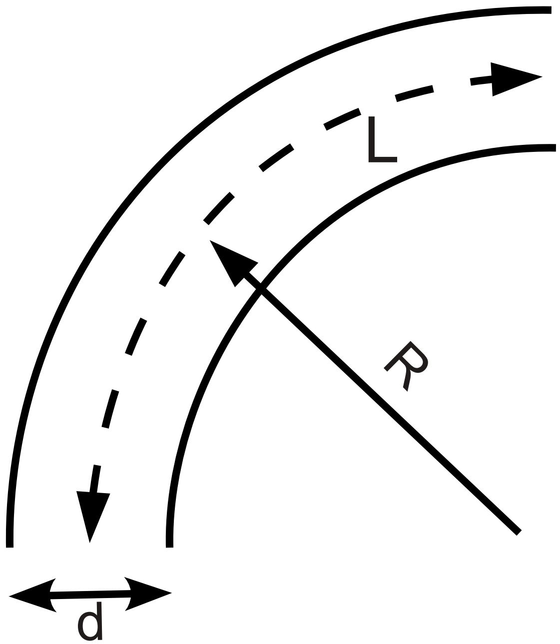
"True" spherical deflector

Cylindrical capacitor with different electrode heights. [*Rev.Sci.Instrum.81(2010)063304*]

Field can be shaped without complicated geometrical structures....

Size, bending radius

Electrode voltages: $\pm \frac{E_{kin} d}{q R}$



@ 100 keV	R = 1.5 m	R = 1 m	R = 0.5 m	R = 0.2 m
d = 8 cm	± 5.3 kV	± 8 kV	± 16 kV	± 40 kV
d = 6 cm	± 4 kV	± 6 kV	± 12 kV	± 30 kV
d = 4 cm	± 2.6 kV	± 4 kV	± 8 kV	± 20 kV

Bending angle: ~180mrad (interspaced with quad FODO cells) [Wolfgang, Glenn]

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

Bending radius:

- L < 30 cm (angle=180 mrad) → R < 1.66 m
- Available on the market (R<=~~1 m~~ for diam=200mm)
- Make it as large as possible (low voltage, less aberrations)

Wrong, largest R is 500mm (kohler.ch)

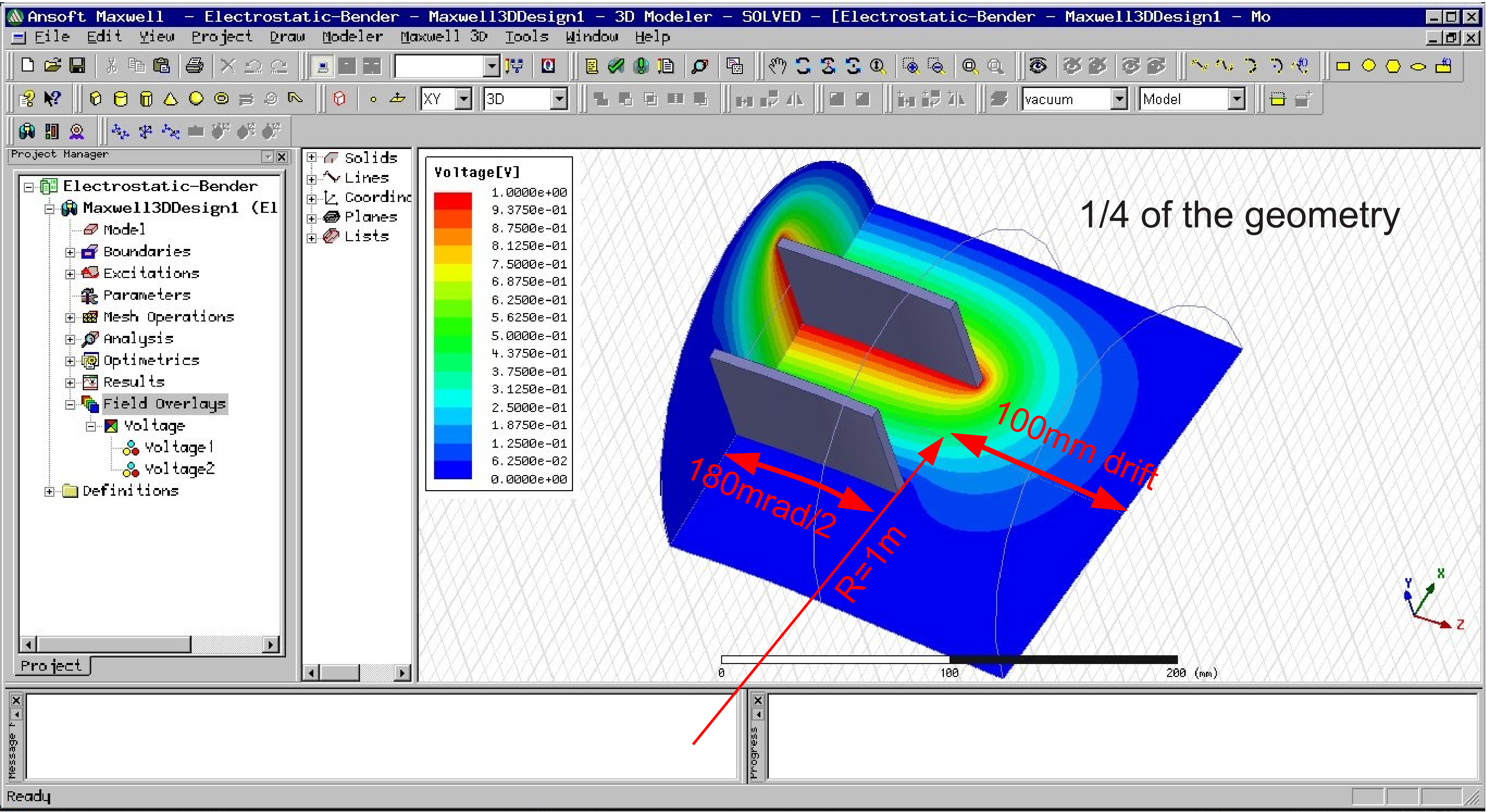
Studied configuration & questions

Do not get lost in studying too many parameters!

- Bending radius: R = 1 m
- Aperture: 6 cm
- Cylindrical electrodes (simplest geometry)
- What should be the height?
  - Fit into the beampipe
  - Have a y-uniform field within -3 cm < y < 3 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

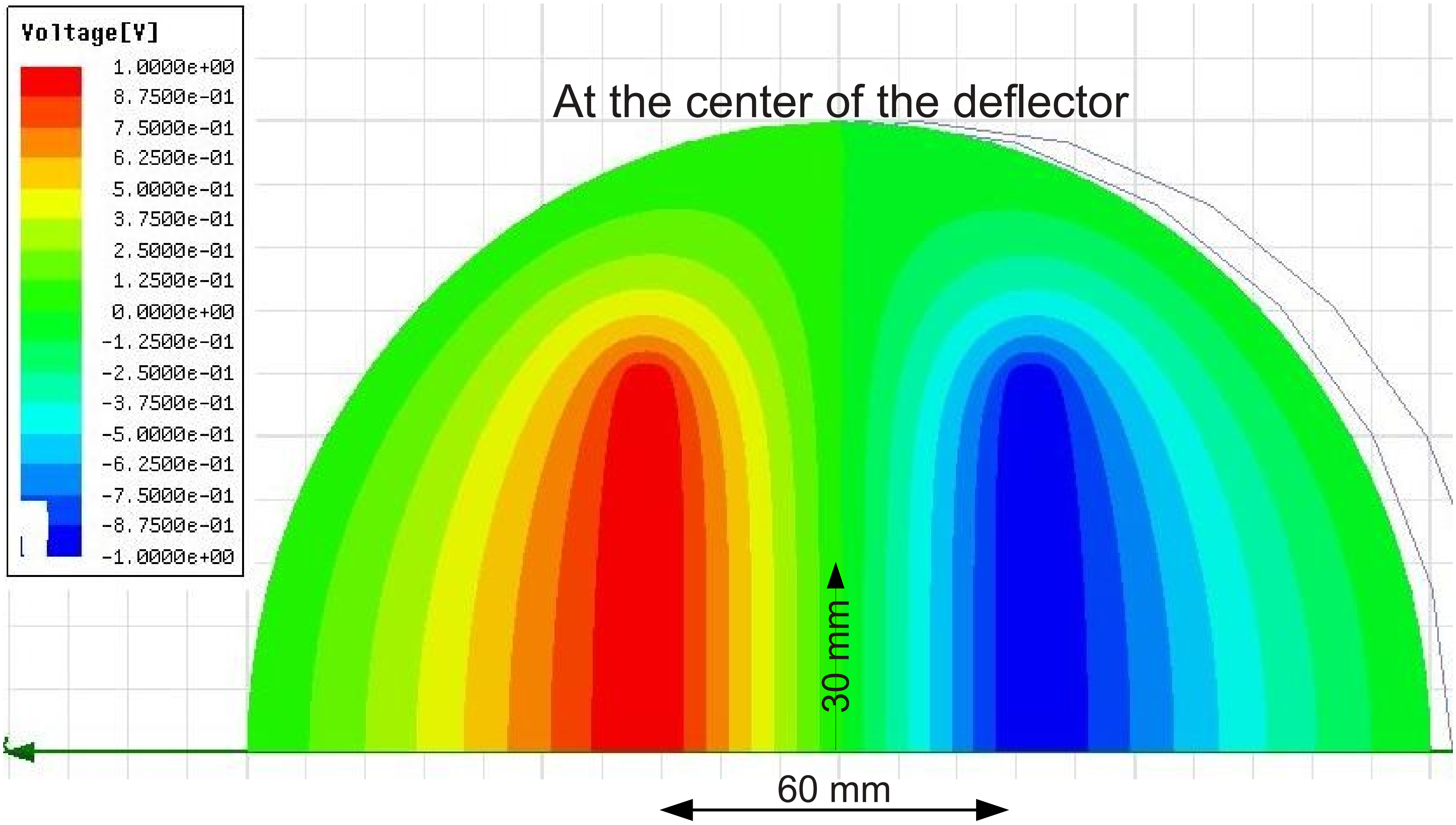


Method (cont'd...)

- 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 $(x_{out}, x'_{out}, \ldots)$ to $(x_{in}, x'_{in}, \ldots)$ etc. (6 χ^2 fits, each with 6 parameters)

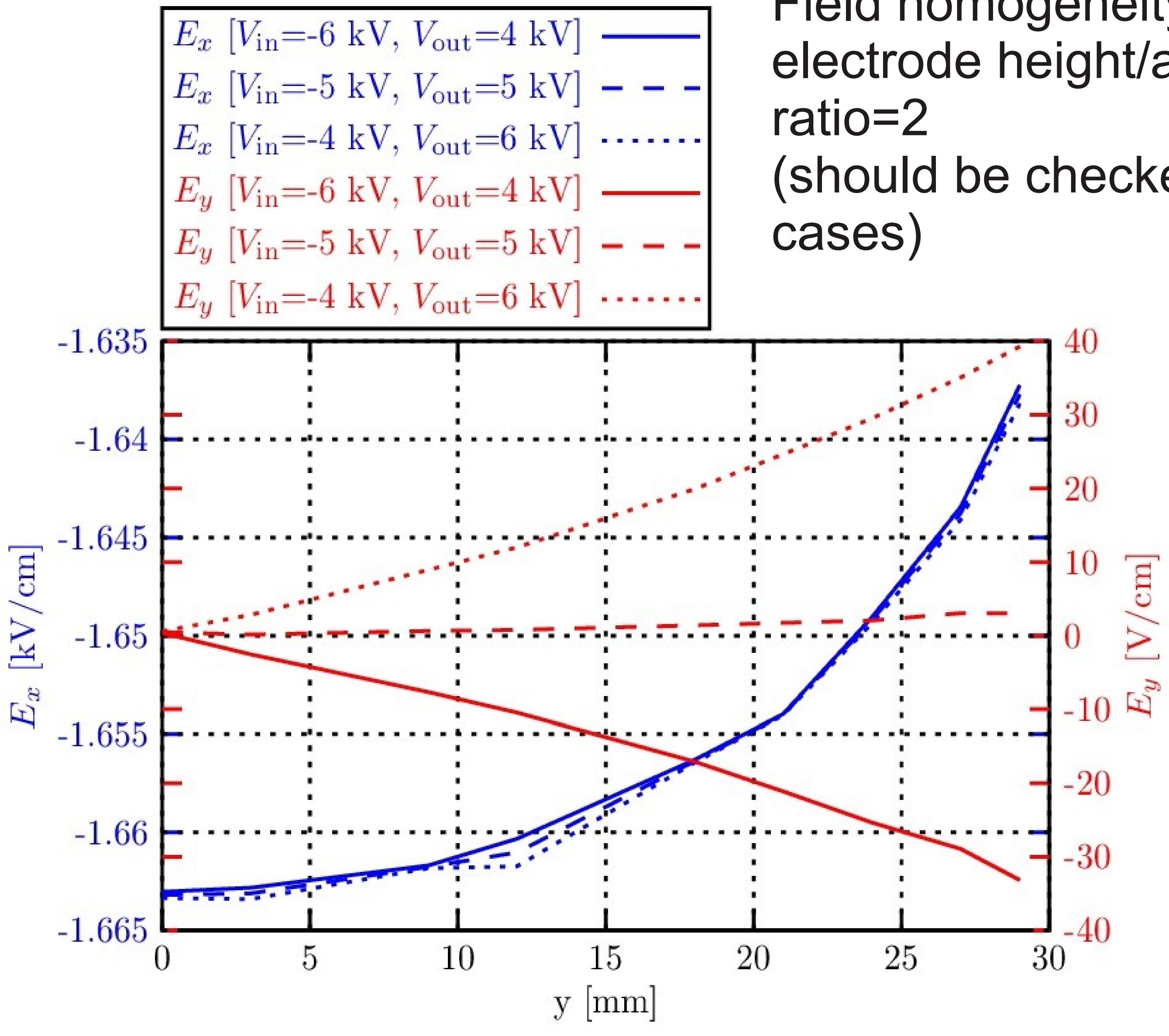
Electrode height?

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



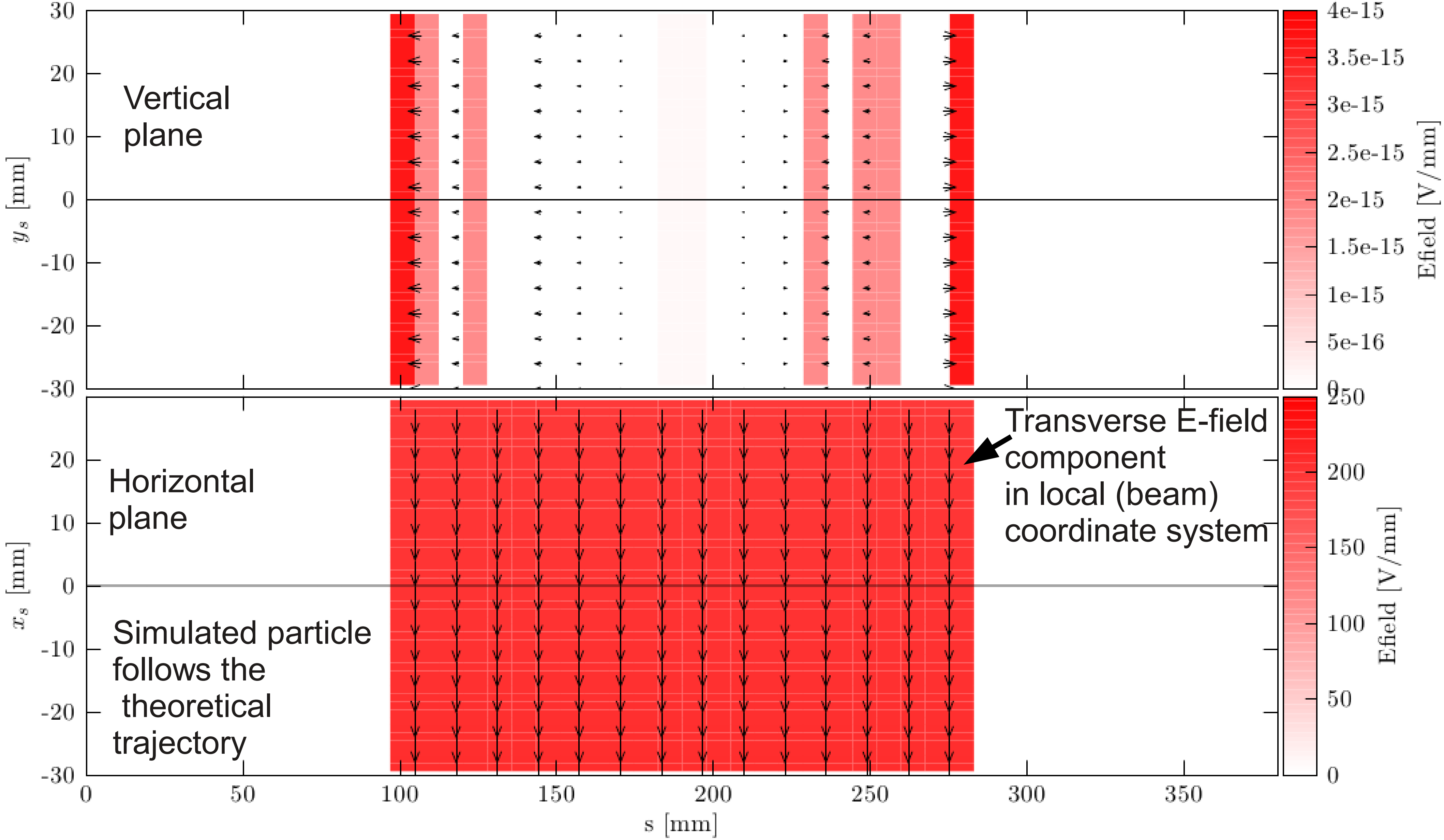
Electrode height?

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

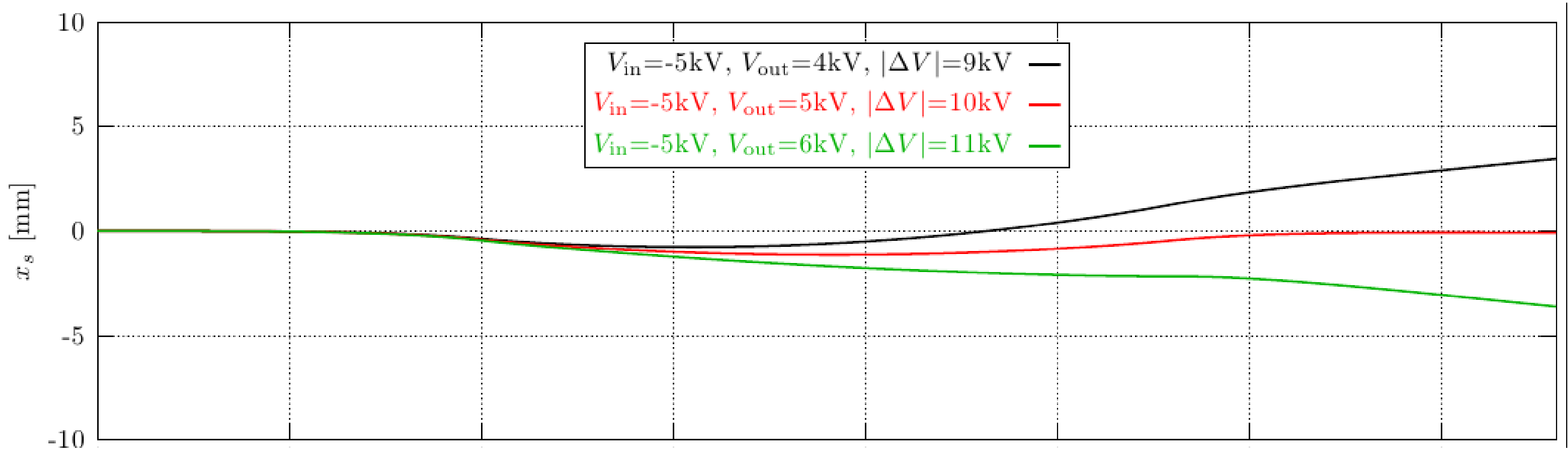


~1.5% change in transverse field between y=0 and y=3cm

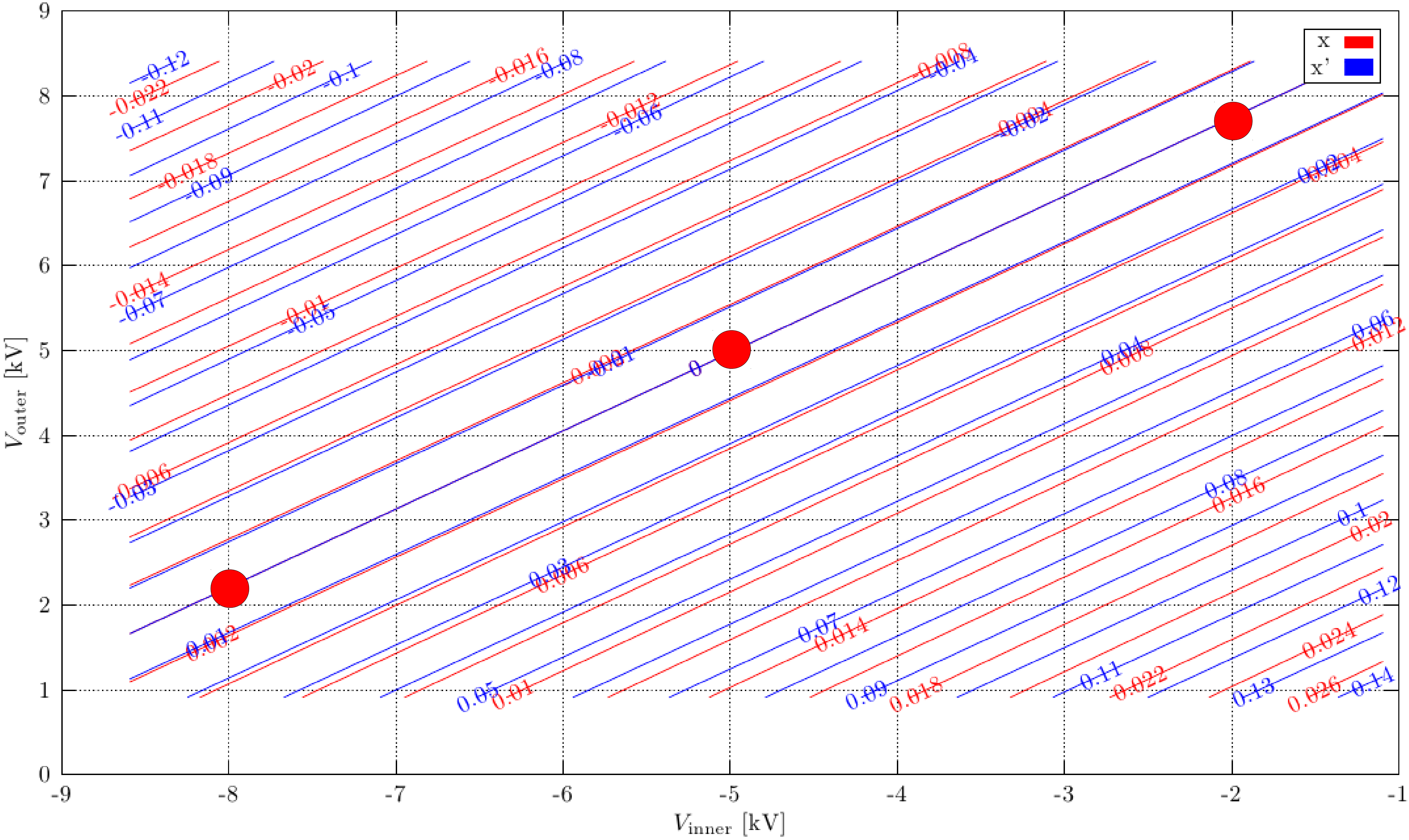
Check: hard-edge ideal field



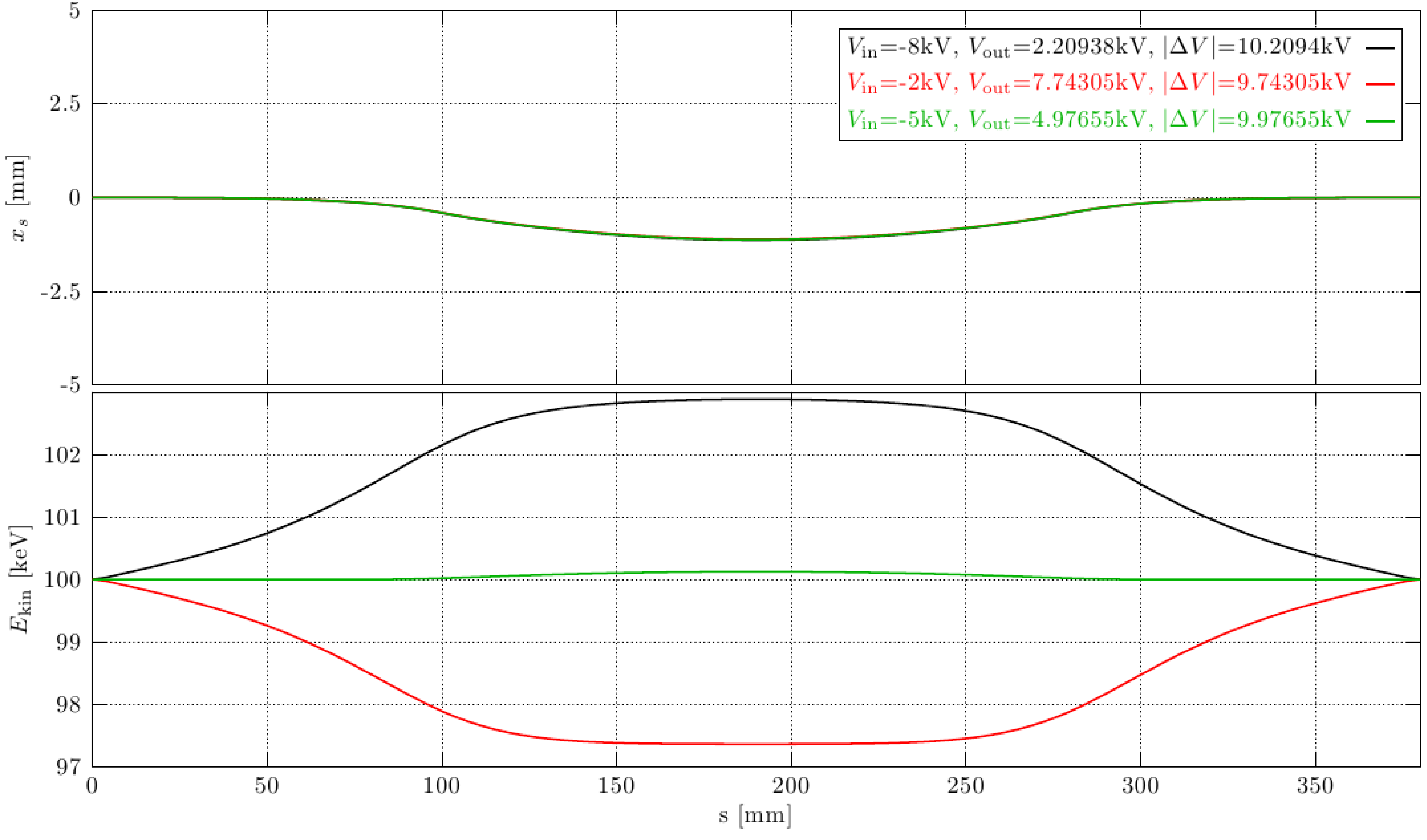
Central input trajectory, varying voltages: output = ?



X & X' isolines for different voltages

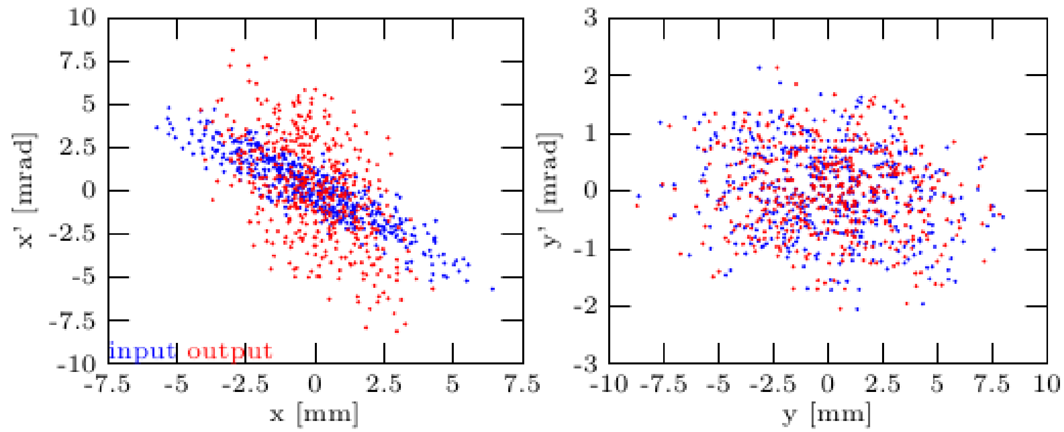


Trajectories for these 3 voltages

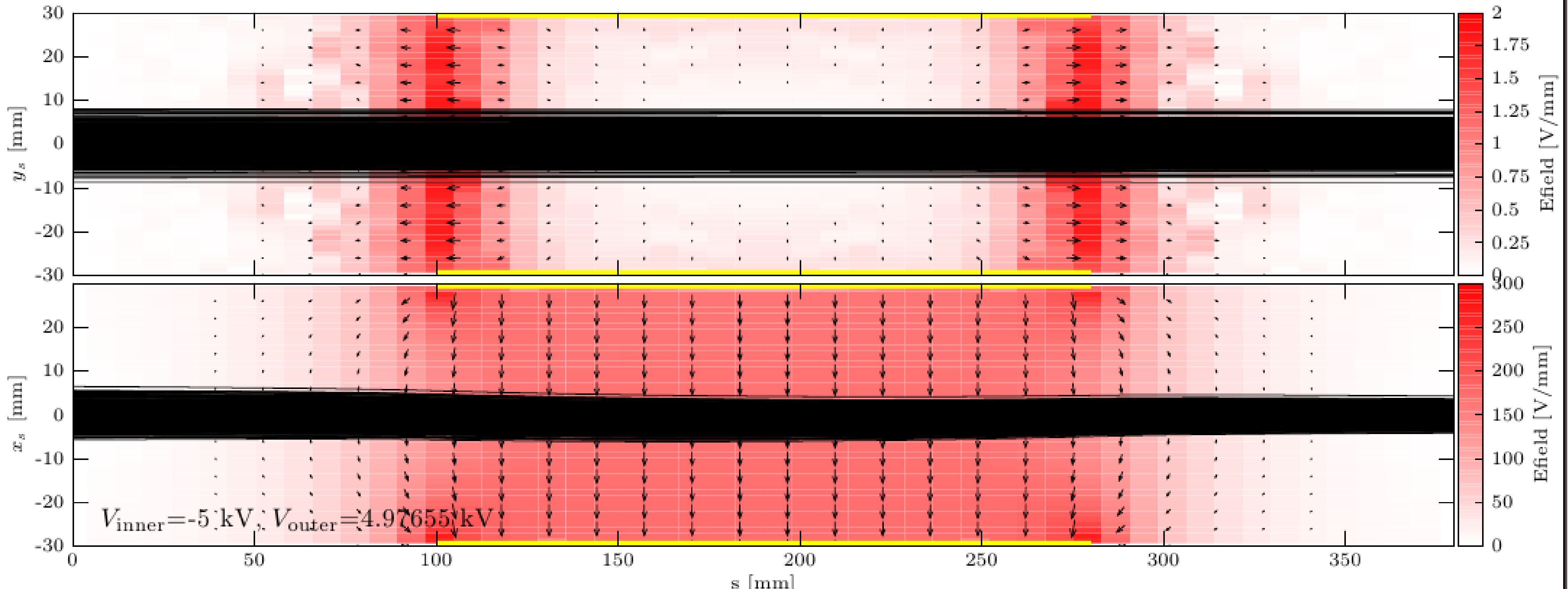


Focal length in bending plane: 4 m

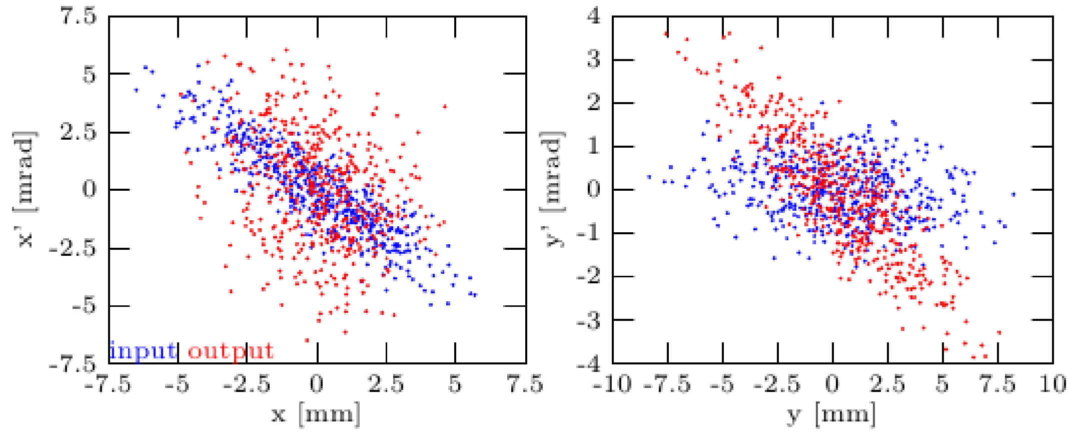
Beam remains parallel in vertical plane



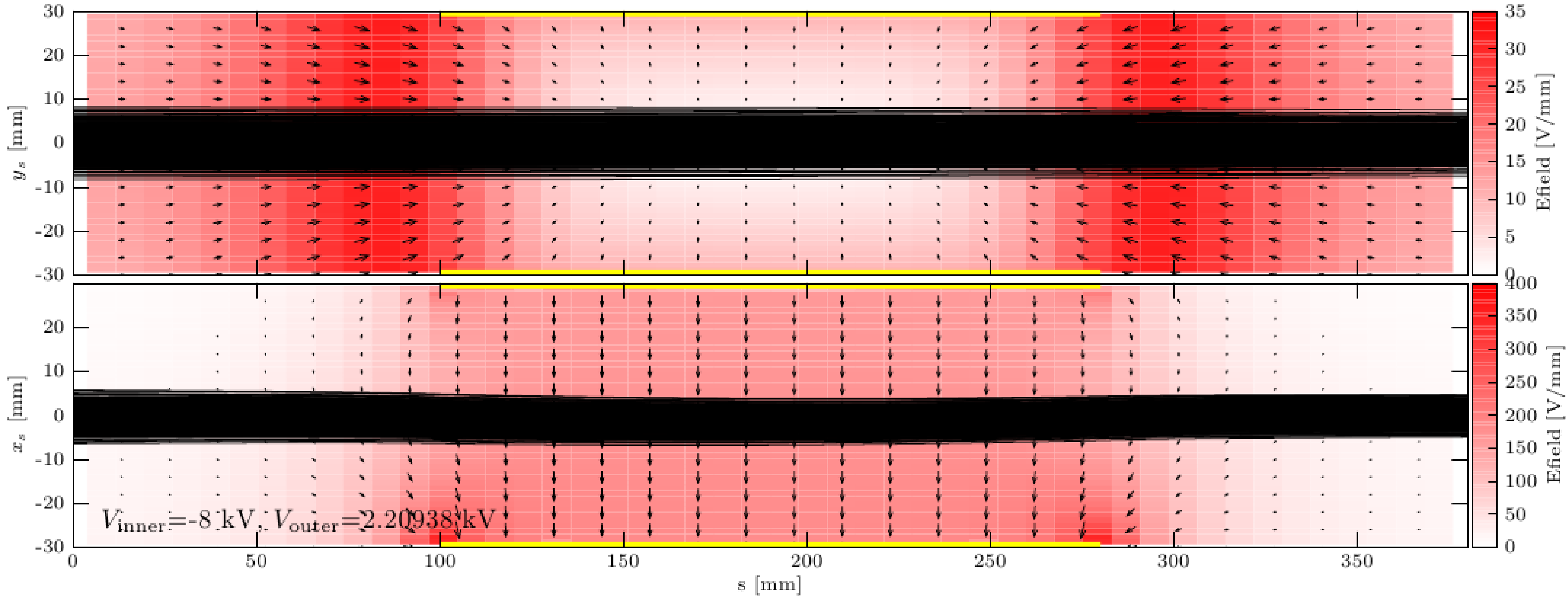
	x_{in} [2.2e-3]	x'_{in} [1.9e-3]	y_{in} [3.0e-3]	y'_{in} [7.2e-4]	$v_0 \delta t_{in}$ [4.1e-1]	$\delta E_{in}/p_0 c$ [7.1e-5]
x_{out} [1.5e-3]	0.952297	0.372175	-0.000169864	0.000743414	9.30234e-07	4.64737
x'_{out} [2.8e-3]	-0.250452	0.955092	-0.000793333	0.00377059	4.92743e-06	24.4165
y_{out} [2.9e-3]	0.000484565	-1.10282e-05	1.00064	0.380189	4.75691e-07	-0.00312333
y'_{out} [7.2e-4]	0.00268336	0.000222125	0.00325001	1.00252	2.54557e-06	-0.0139094
$v_0 \delta t_{out}$ [4.1e-1]	-0.356439	-0.0689779	-0.000403307	-0.00215573	1	25.6576
$\delta E_{out}/p_0 c$ [7.1e-5]	1.13658e-05	-4.47863e-06	2.45183e-07	-3.28455e-06	3.25032e-09	0.999937



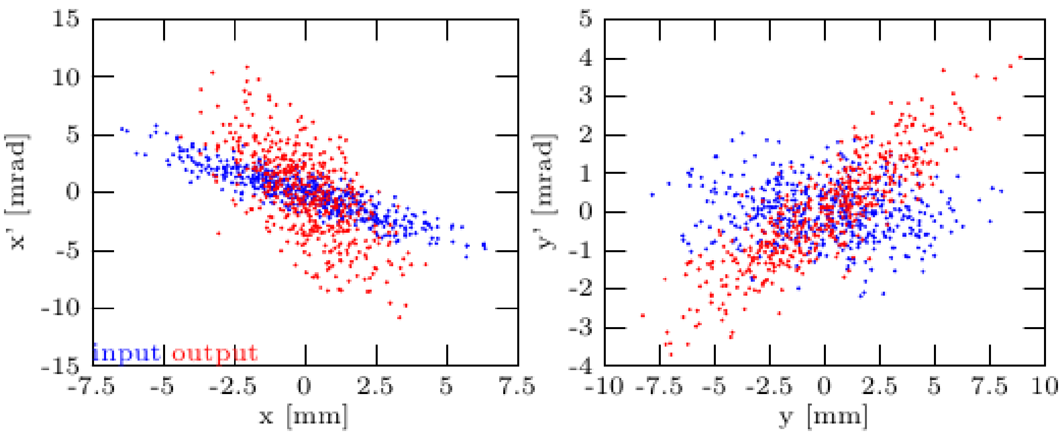
Focal length: 2.5 m



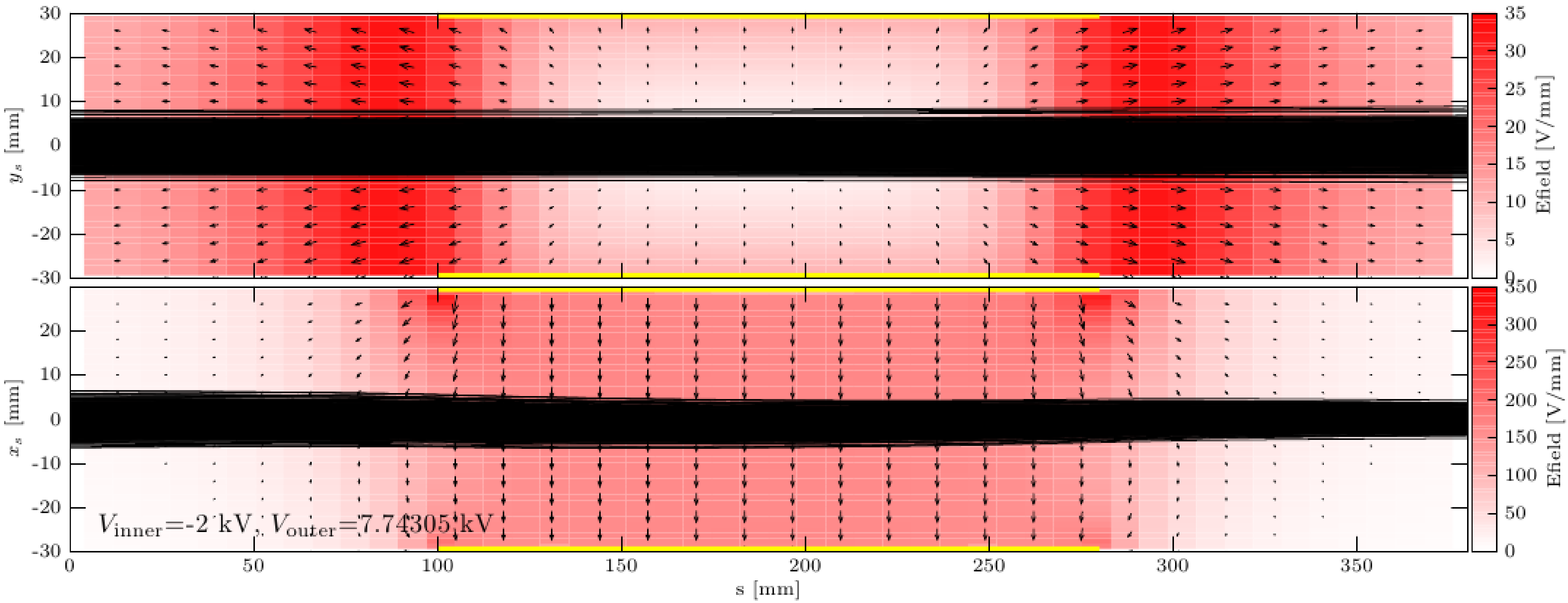
	x_{in} [2.2e-3]	x'_{in} [1.9e-3]	y_{in} [2.9e-3]	y'_{in} [6.8e-4]	$v_0 \delta t_{in}$ [4.1e-1]	$\delta E_{in}/p_0 c$ [7.3e-5]
x_{out} [1.7e-3]	1.04632	0.385049	0.000277703	0.000700923	9.04848e-07	4.60955
x'_{out} [2.3e-3]	0.245992	1.04578	0.00158536	0.00398032	4.34607e-06	24.4964
y_{out} [2.6e-3]	0.000305912	-4.0421e-05	0.928007	0.366112	-7.11273e-08	0.000285316
y'_{out} [1.4e-3]	0.00190364	0.000181256	-0.379366	0.928418	-7.22864e-07	0.000332994
$v_0 \delta t_{out}$ [4.1e-1]	-0.424579	-0.151011	0.126864	0.180403	0.999897	26.562
$\delta E_{out}/p_0 c$ [7.3e-5]	7.12268e-06	1.6783e-05	3.98649e-06	-1.38323e-06	1.50019e-08	1.00022



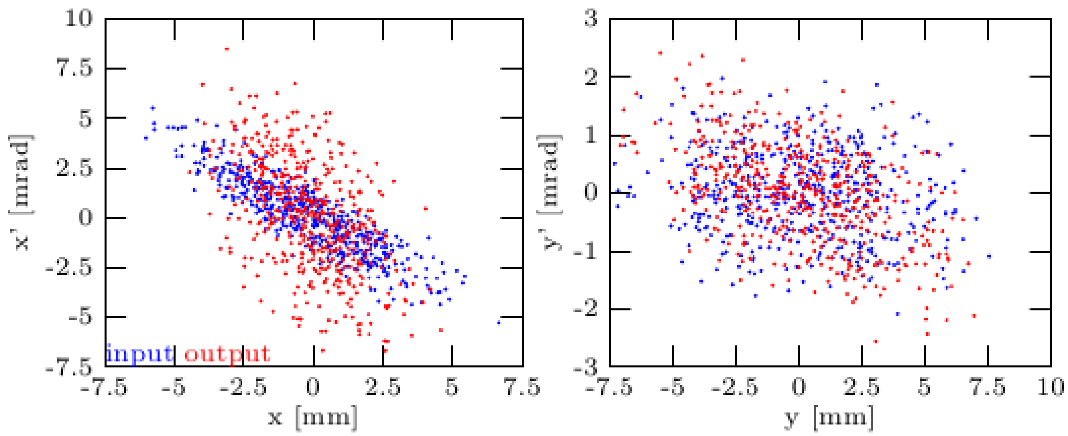
Focal length: 1.3 m



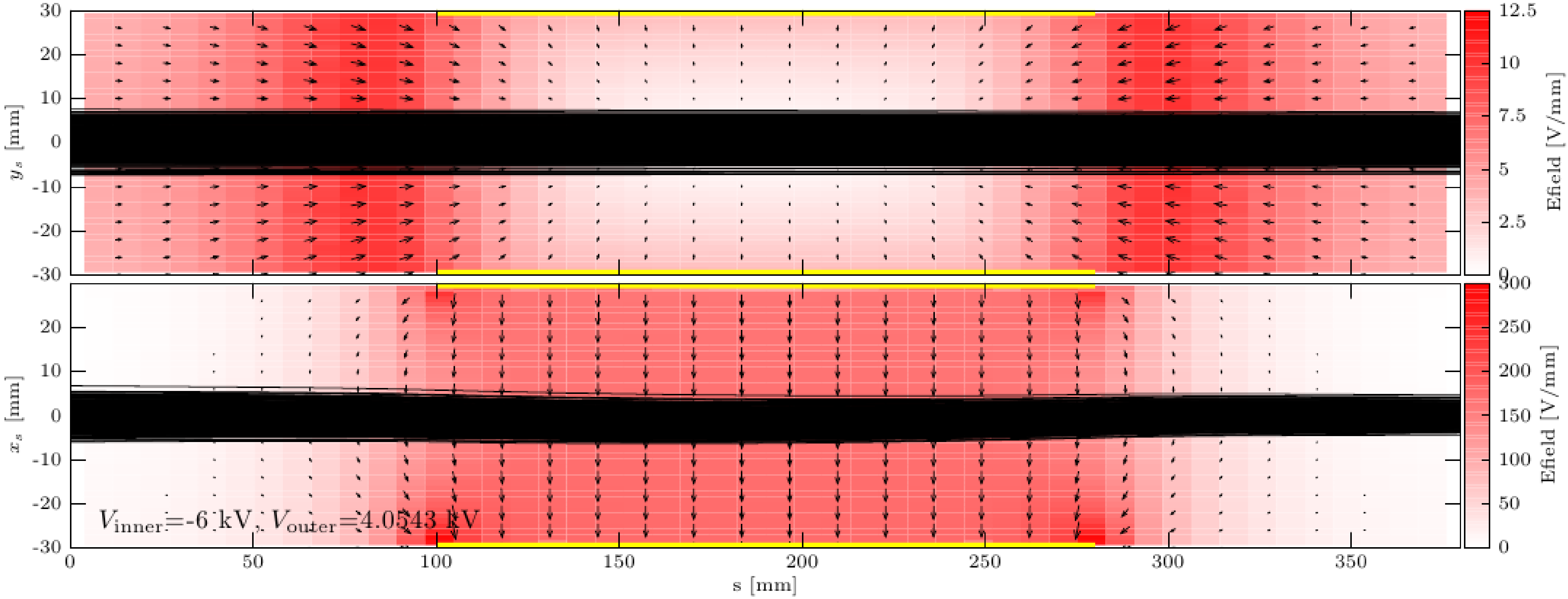
	x_{in} [2.3e-3]	x'_{in} [1.9e-3]	y_{in} [2.8e-3]	y'_{in} [7.2e-4]	$v_0 \delta t_{in}$ [4.2e-1]	$\delta E_{in}/p_0 c$ [6.9e-5]
x_{out} [1.4e-3]	0.854724	0.357268	-8.46512e-05	0.00100226	9.00767e-07	4.68286
x'_{out} [3.7e-3]	-0.75373	0.854881	-0.000402569	0.00509511	4.52721e-06	24.3127
y_{out} [3.0e-3]	0.000644316	0.000705336	1.07748	0.395174	2.86587e-07	0.000539891
y'_{out} [1.3e-3]	0.003278	0.00367896	0.408045	1.0811	1.8035e-06	0.00021198
$v_0 \delta t_{out}$ [4.2e-1]	-0.375901	-0.0574462	-0.0262939	0.0437096	1.00015	26.1681
$\delta E_{out}/p_0 c$ [6.9e-5]	2.17944e-05	-3.33555e-05	1.52418e-06	-8.951e-07	-5.01228e-09	0.999581

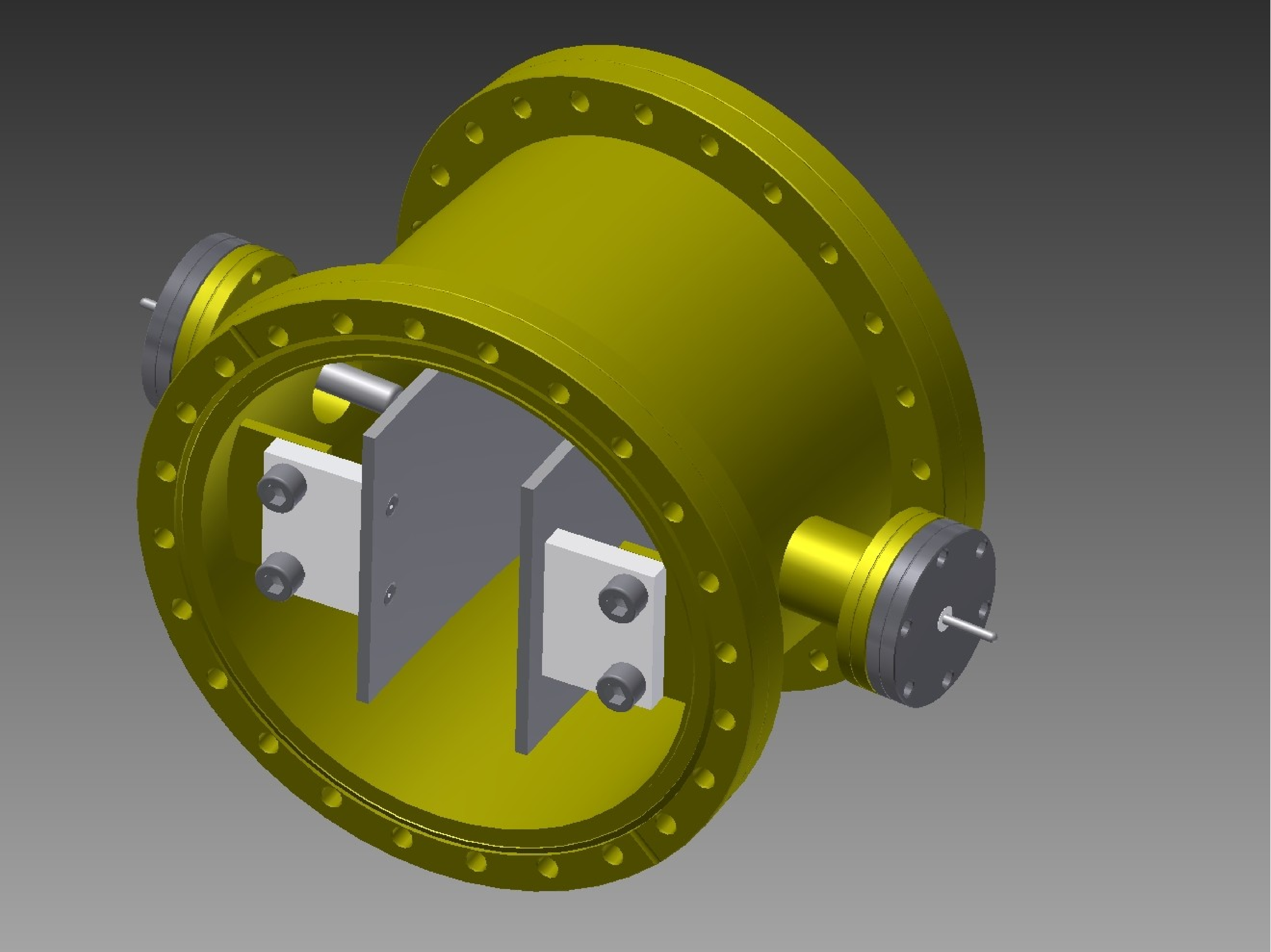


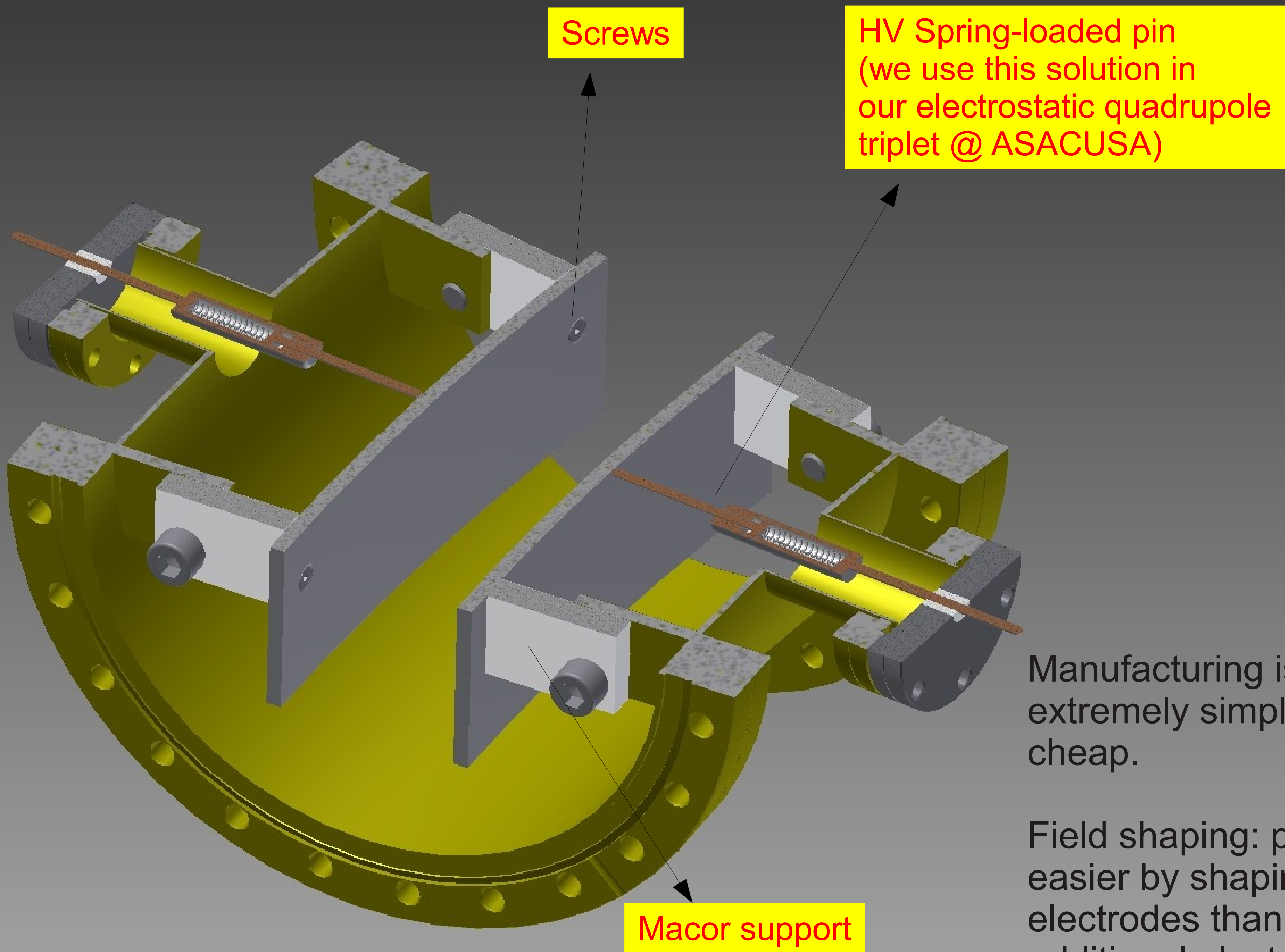
Very little x- and y-focusing (F ~ 10m) @ Vin=-6 kV, Vout=4 kV



	x_{in} [2.2e-3]	x'_{in} [1.9e-3]	y_{in} [2.9e-3]	y'_{in} [7.2e-4]	$v_0 \delta t_{in}$ [4.3e-1]	$\delta E_{in}/p_0 c$ [7.1e-5]
x_{out} [1.6e-3]	0.98308	0.374927	0.000166715	-0.00129246	-4.76053e-07	4.63534
x'_{out} [2.7e-3]	-0.0891274	0.977437	0.000902118	-0.00624836	-2.3185e-06	24.4496
y_{out} [2.8e-3]	-0.000151089	0.000408394	0.975782	0.374917	2.04089e-07	0.00628637
y'_{out} [8.5e-4]	-0.000777002	-0.00196902	-0.12774	0.975089	8.02149e-07	0.0361313
$v_0 \delta t_{out}$ [4.3e-1]	-0.355877	-0.0669165	-0.000426058	-0.00232125	1	25.4274
$\delta E_{out}/p_0 c$ [7.1e-5]	1.01696e-05	2.19053e-06	-2.52263e-06	5.86784e-06	1.75744e-09	1.00005

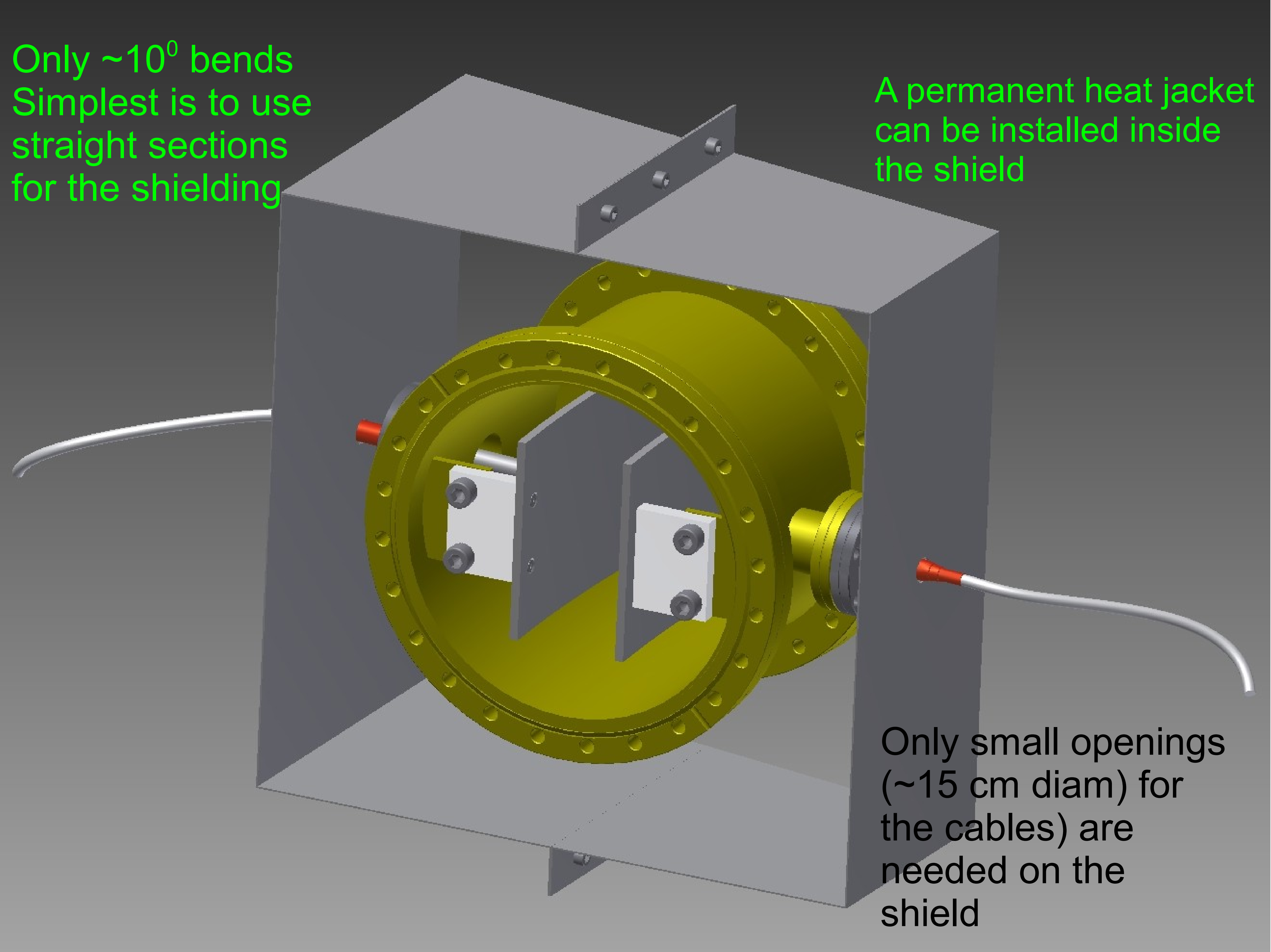






Manufacturing is extremely simple and cheap.

Field shaping: probably easier by shaping the electrodes than by additional electrodes


Only ~10^0 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?