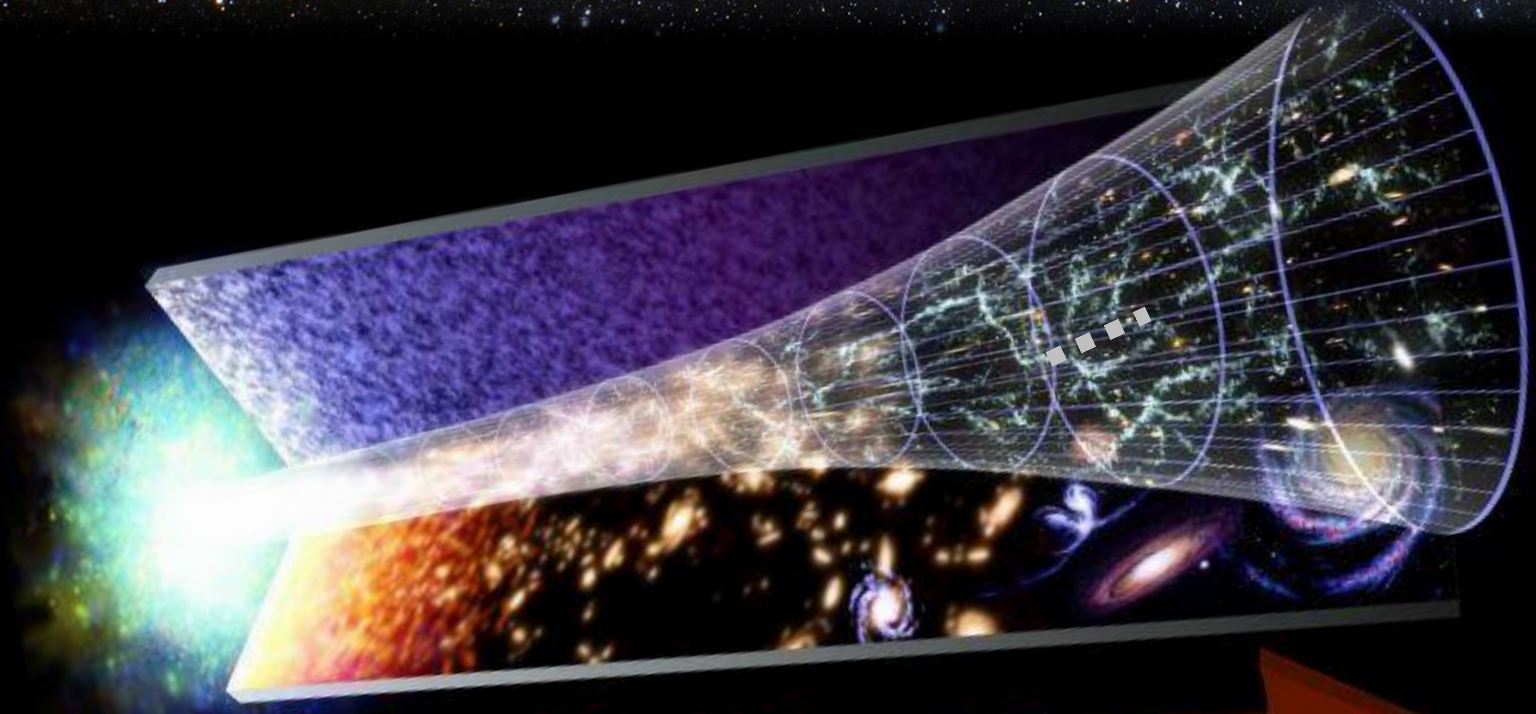
CP-EDM Collaboration Meeting

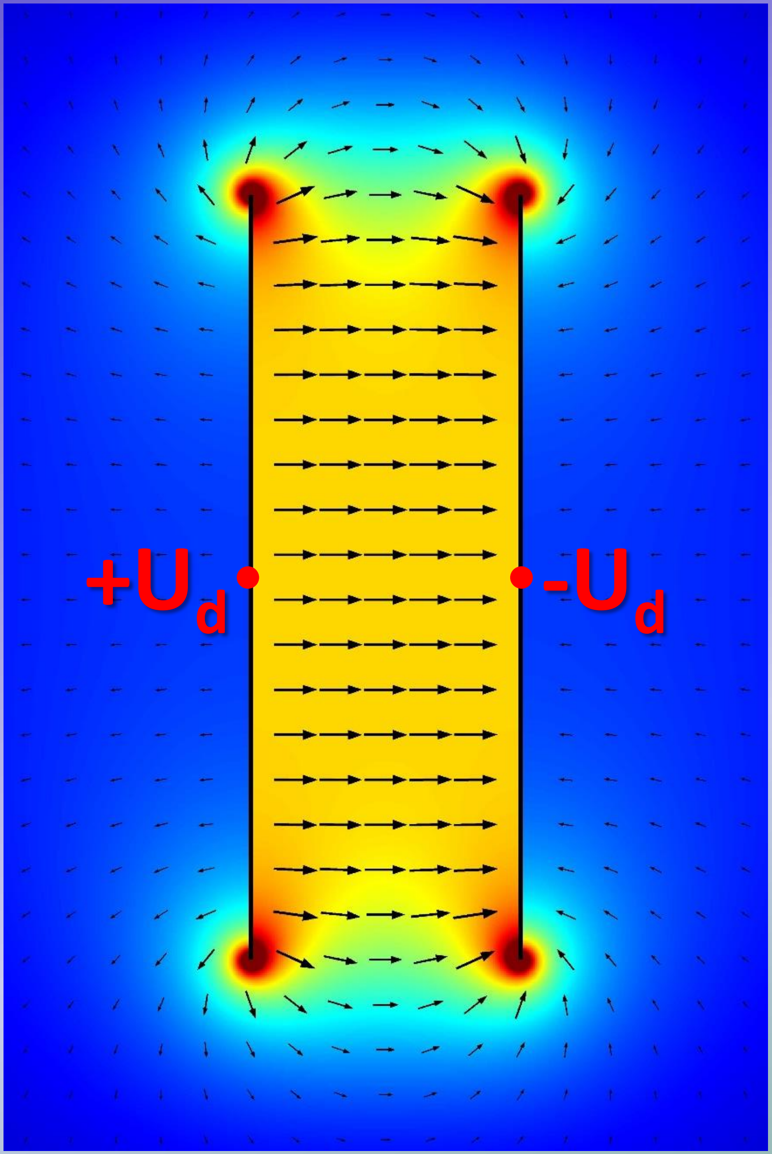
The Fate of Antimatter



Electrostatic Combined Function Elements for the EDM ring

Achim Stahl – RWTH Aachen University – JARA-FAME

THE DIPOLE FIELD

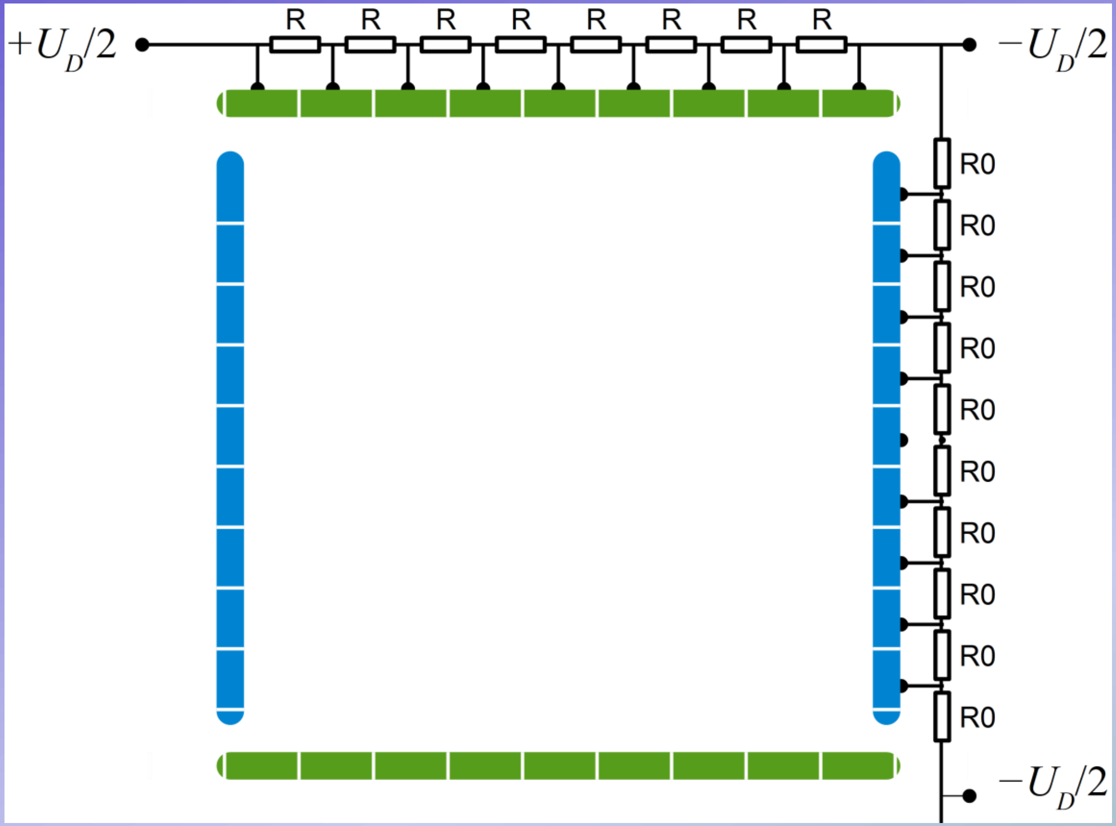


For the small ring:
- $\left|\vec{E}\right| = 10.5\ \mathrm{MV/m}$
- $d = 3\ \mathrm{cm}$
- Voltage: $\mathrm{U_d} = 157.5\ \mathrm{k}V$

Inhomgeneities towards the edges

High capacitance -> risk of destruction

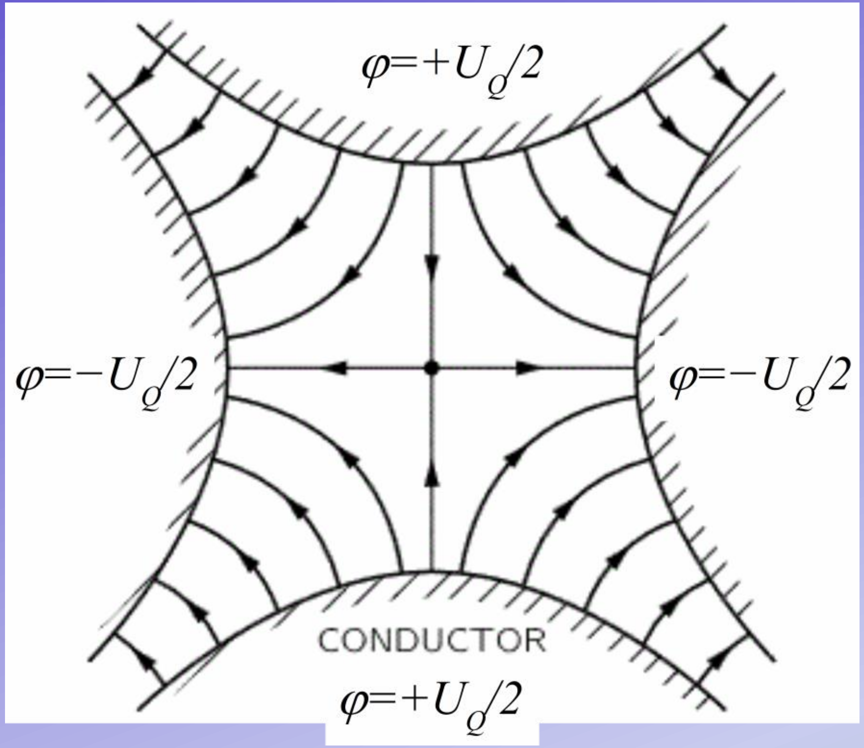
DIPOLE IN A FIELDCAGE

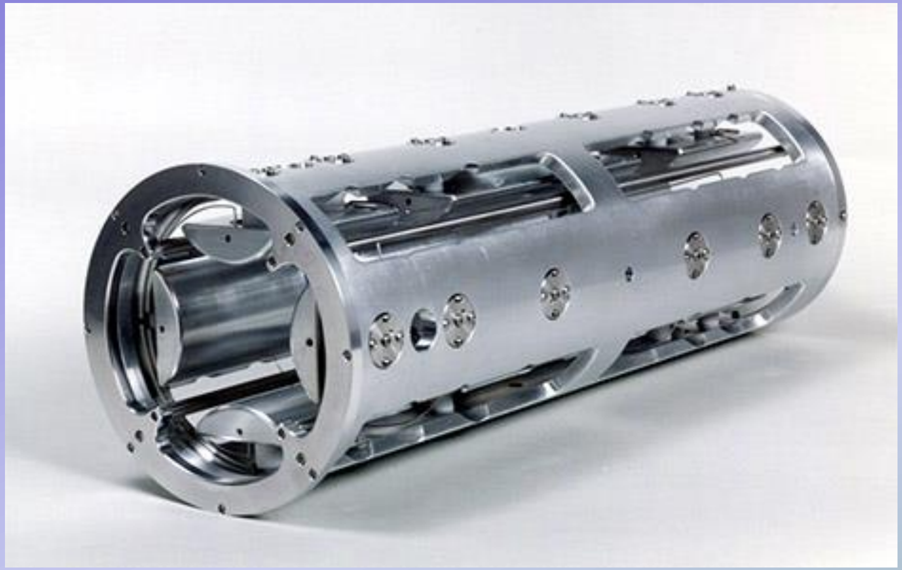


Field shaping electrodes

- more homogenious field
- small capacitance per strip

THE QUADRUPOLE FIELD

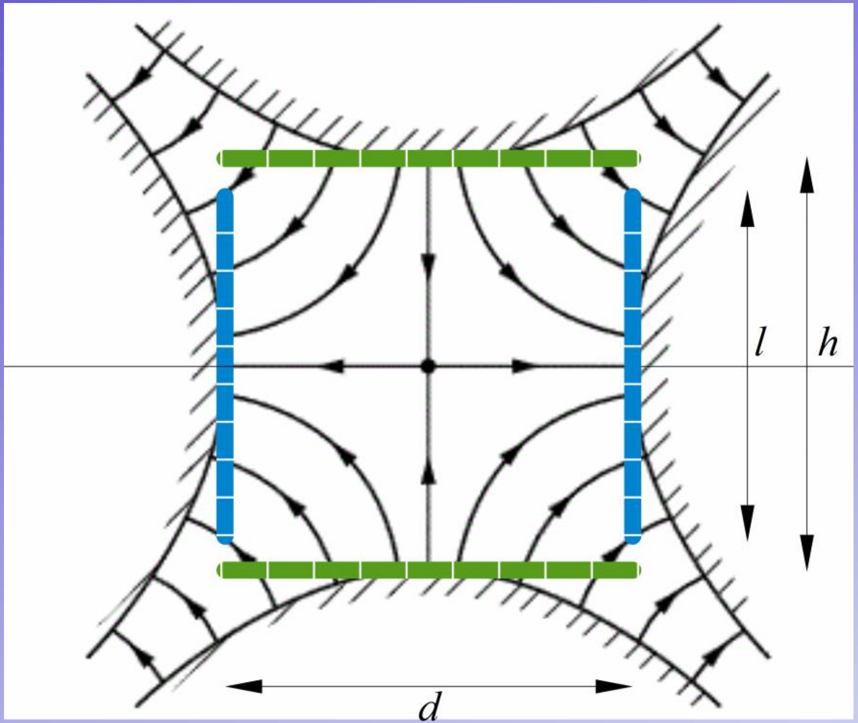




$$\varphi_Q(\vec{r}) = 2U_Q\,\frac{x^2-y^2}{d^2}$$

$$\vec{E}_Q(\vec{r}) = \frac{4U_Q}{d^2}(-x, y, 0)$$

THE QUADRUPOLE FIELD



Electric field fixed by potential:

$$\vec{E} = -\vec{\nabla}\varphi(\vec{r})$$

Potential can be fixed by metal strips

$$U_i = \varphi(\vec{r}_i)$$

Advantage:

- Arbitrary shape of field cage

Disadvantage:

- Need many different voltages
- Finite granularity of field strips

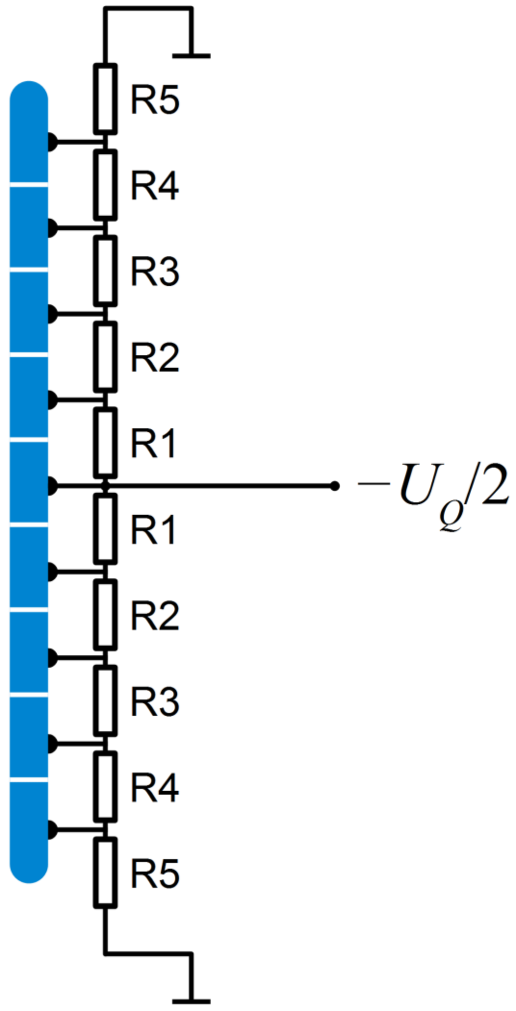
QUADRUPOLE ELECTRODES

Example: 9 strips

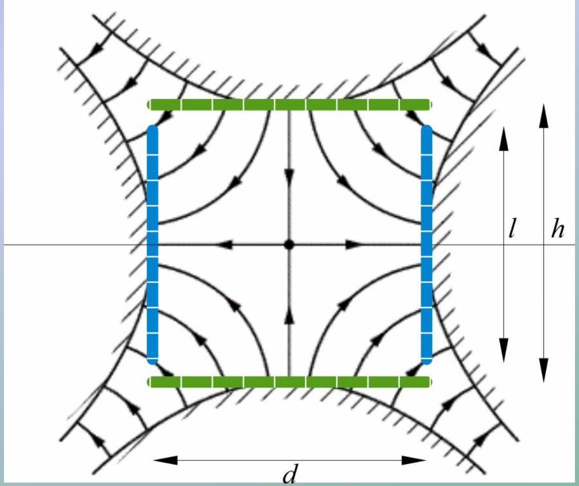
$$\vec{r}_i = \left(\pm\frac{d}{2}, i\frac{l}{9}, 0\right)$$

$$\varphi_{Q,i} = \varphi_Q(\vec{r}_i) = \frac{2U_Q}{d^2}\left(\frac{d^2}{4} - i^2\frac{l^2}{81}\right) = \frac{U_Q}{2}\left(1 - \left(i\frac{2l}{9d}\right)^2\right)$$

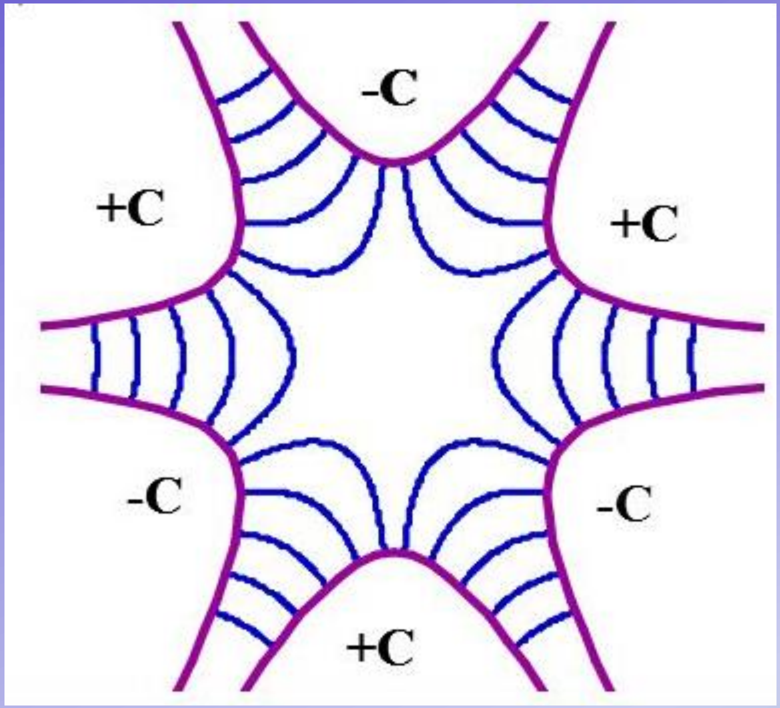
$$\frac{\sum_{k=1}^{i} R_k}{R_g} = \frac{\varphi_{Q,i}}{U_Q/2} \quad \Rightarrow \quad R_i = \left(1 - \left(i\frac{2l}{9d}\right)^2\right) R_g - \sum_{k=1}^{i-1} R_k$$



$$\varphi_Q(\vec{r}) = 2U_Q\frac{x^2 - y^2}{d^2}$$



THE SEXTUPOLE FIELD



Any multipole field can be generated with a field cage!

COMBINED FUNCTION

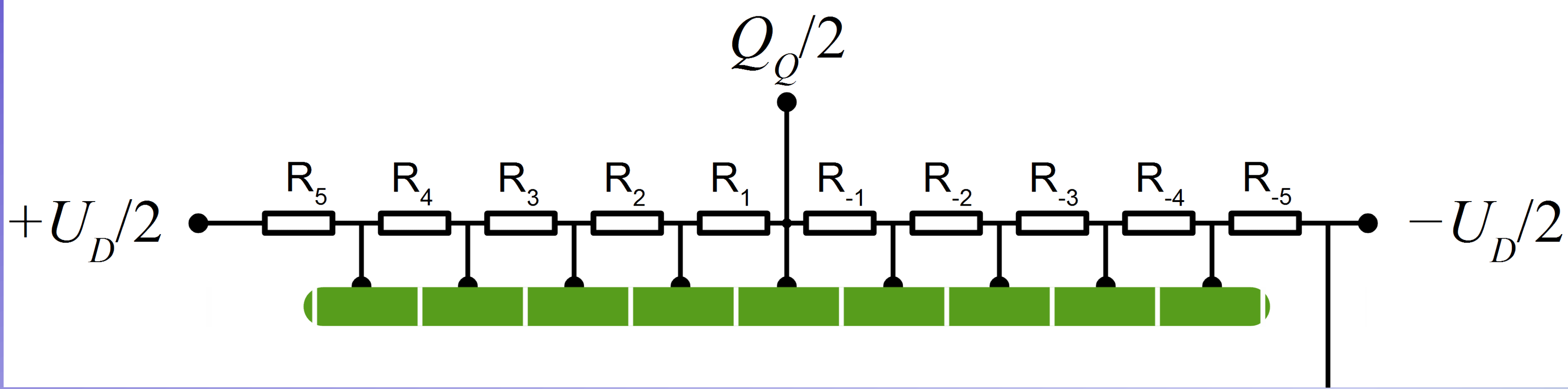
Poisson's equation is linear: $\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0}$

→ potential and electric fields super-impose

Combined Function: $\vec{E}_{c.f.} = \vec{E}_{\mathrm{Dipole}} + \vec{E}_{\mathrm{Quadrupole}} + \cdots$

→ strips: $U_{strip} = U_{Dipole} + U_{Quadrupole}$+...

EXAMPLE: DIPOLE + QUAD



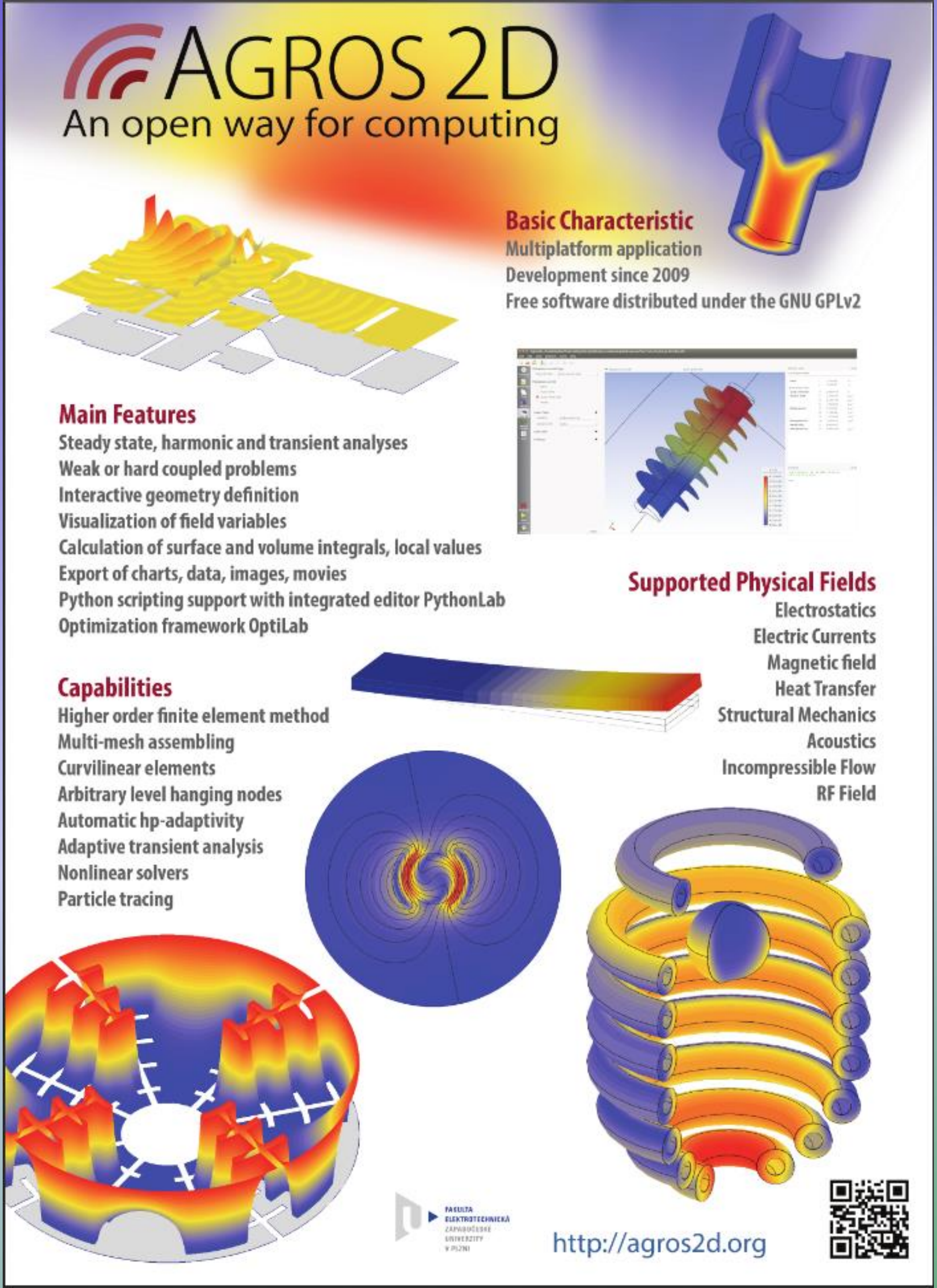
$$R_i = \frac{1}{U_Q/U_D + 1}\left[\left(1 - \frac{4}{81}(i+1)^2\right)\frac{U_Q}{U_D} - \left(\frac{2}{9}(i+1) - \frac{1}{2}\right)\right] R_{g-} - \sum_{k=-5}^{i-1} R_k$$

Problem: Ratio of Dipole/Quad strength fixed by resistors

→ Better to supply each strip with programmable voltage

FEM-CALCULATION

with Agros2d



AGROS 2D

An open way for computing

Basic Characteristic

Multiplatform application
Development since 2009
Free software distributed under the GNU GPLv2

Main Features

Steady state, harmonic and transient analyses
Weak or hard coupled problems
Interactive geometry definition
Visualization of field variables
Calculation of surface and volume integrals, local values
Export of charts, data, images, movies
Python scripting support with integrated editor PythonLab
Optimization framework OptiLab

Supported Physical Fields

Electrostatics
Electric Currents
Magnetic field
Heat Transfer
Structural Mechanics
Acoustics
Incompressible Flow
RF Field

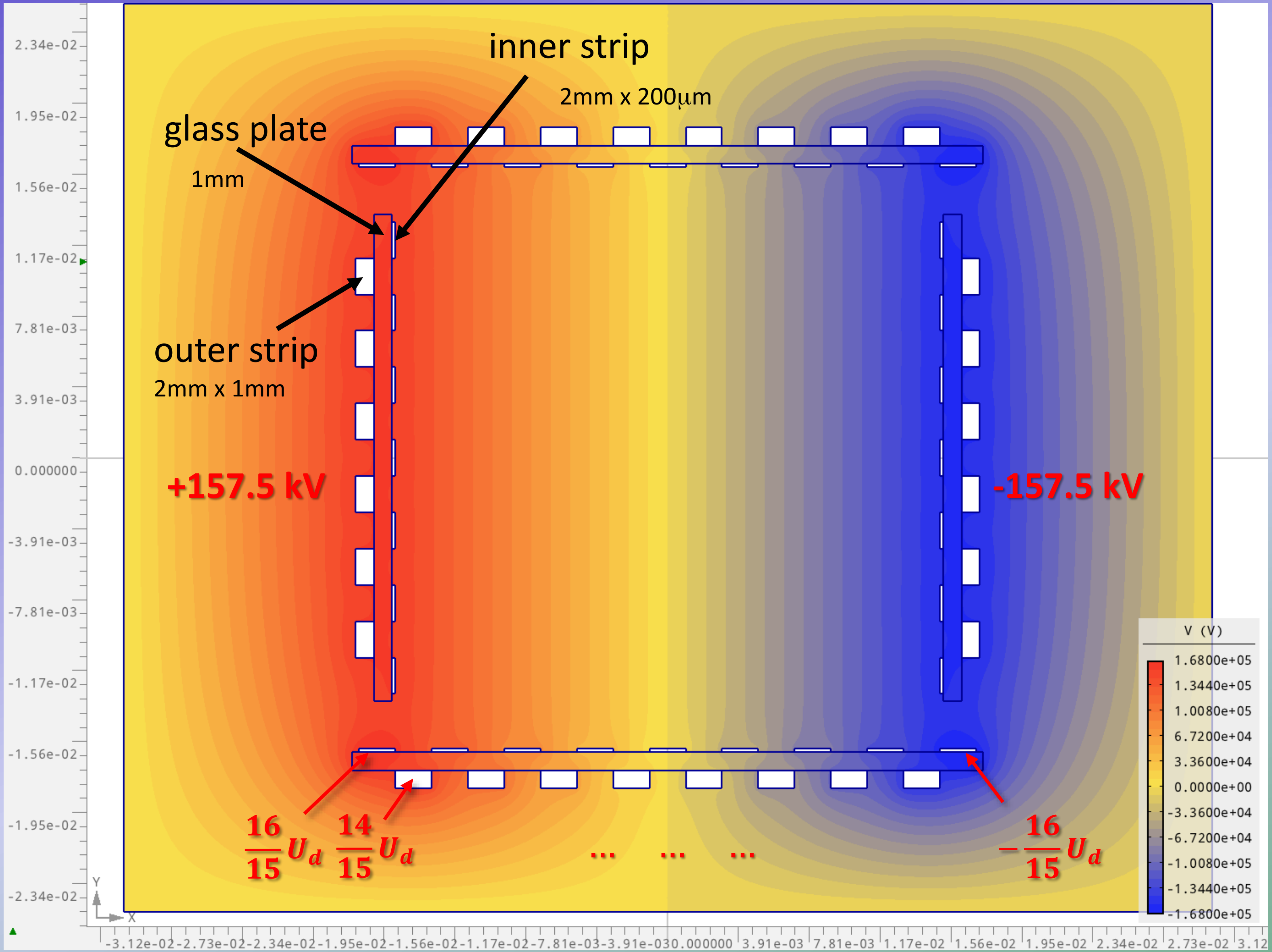
Capabilities

Higher order finite element method
Multi-mesh assembling
Curvilinear elements
Arbitrary level hanging nodes
Automatic hp-adaptivity
Adaptive transient analysis
Nonlinear solvers
Particle tracing

FAKULTA ELEKTROTECHNICKÁ ZÁPADOČESKÉ UNIVERZITY V PLZNI

http://agros2d.org

AGROS: DIPOLE



inner strip

2mm x 200μm

glass plate

1mm

outer strip

2mm x 1mm

+157.5 kV

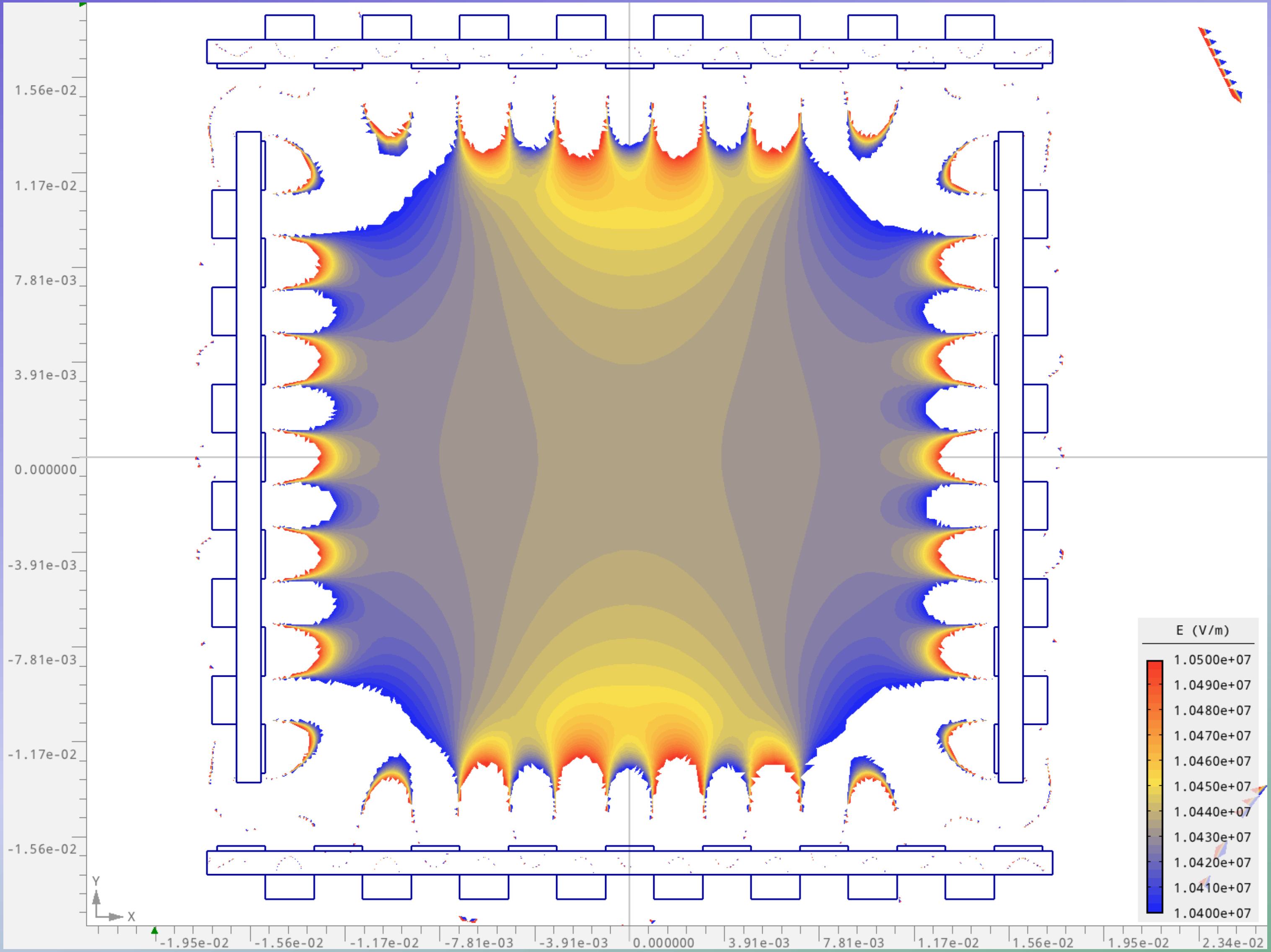
-157.5 kV

$\frac{16}{15}U_d$ $\frac{14}{15}U_d$ … … … $-\frac{16}{15}U_d$

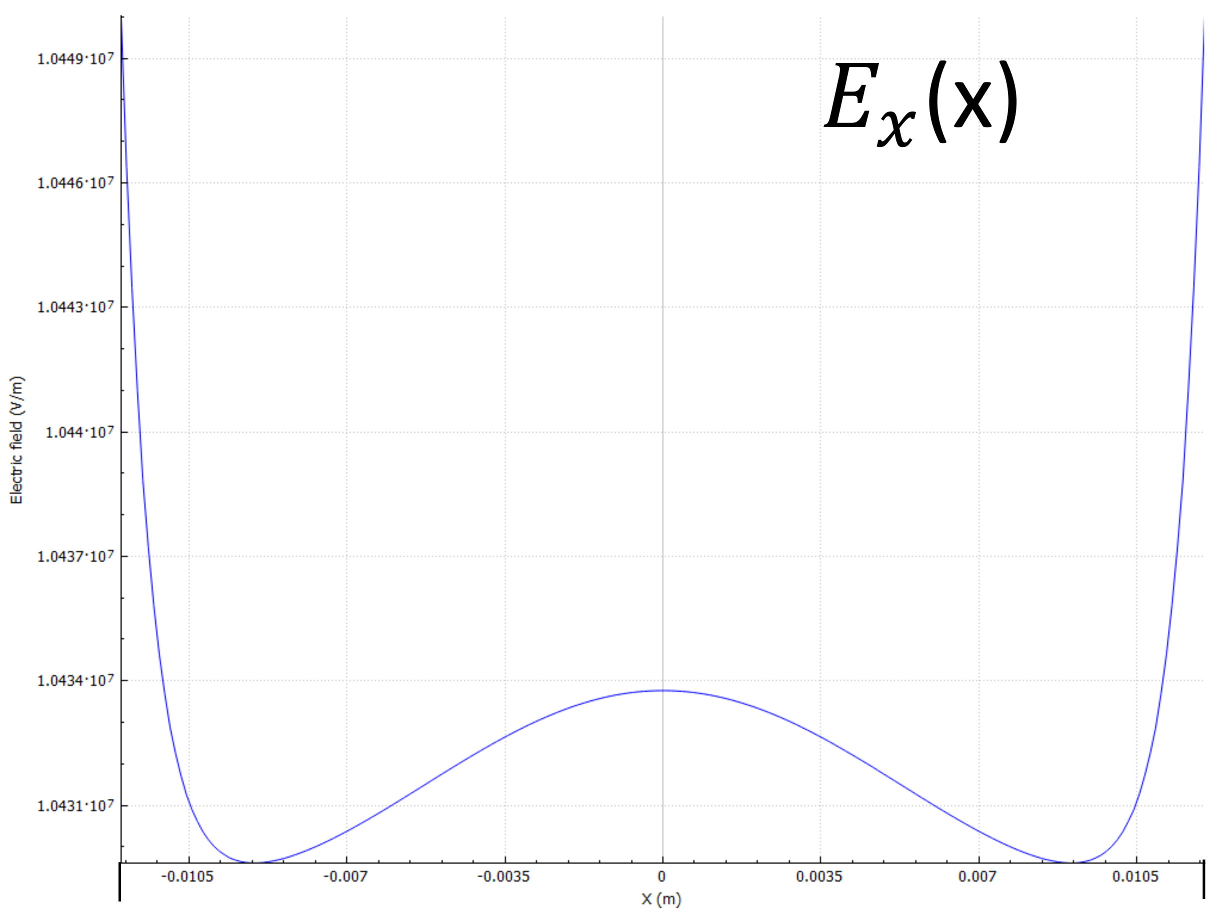
AGROS: DIPOLE

$|\vec{E}|$

scale 1%



AGROS: DIPOLE

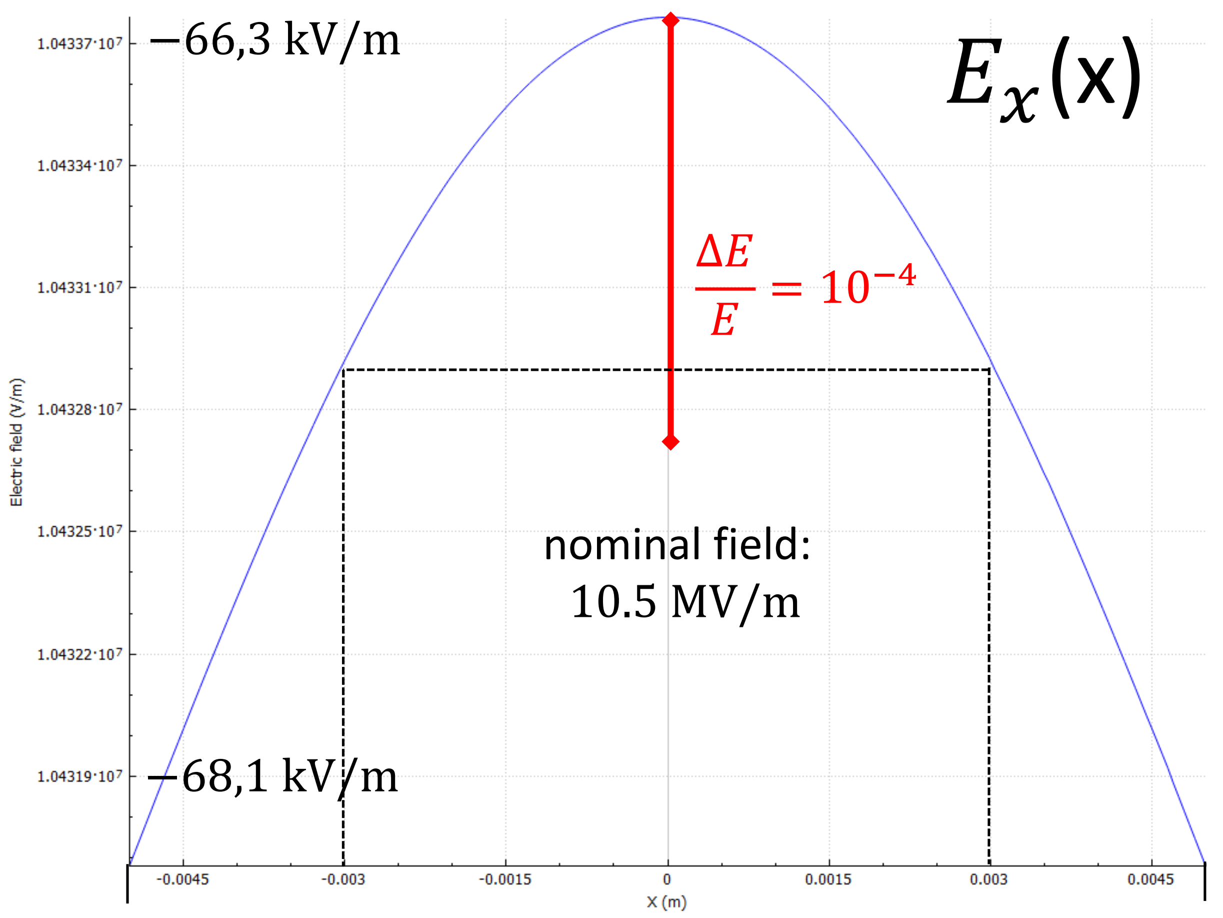


E_x(x)

-12 mm

$+12$ mm

AGROS: DIPOLE



E_x(x)

$-66{,}3\ \mathrm{kV/m}$

$\frac{\Delta E}{E} = 10^{-4}$

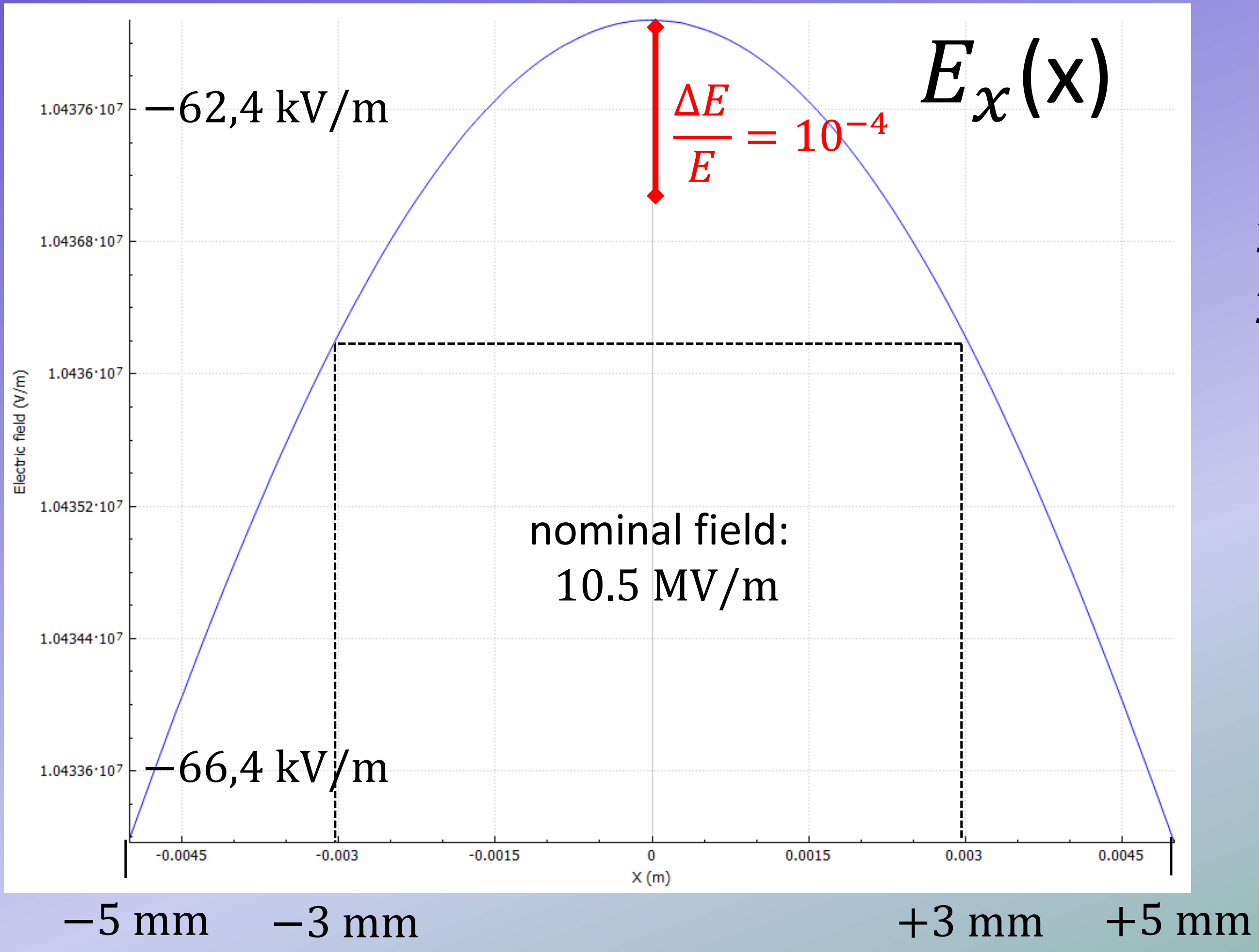
nominal field:
$10.5\ \mathrm{MV/m}$

$-68{,}1\ \mathrm{kV/m}$

$-5\ \mathrm{mm}$ $-3\ \mathrm{mm}$ $+3\ \mathrm{mm}$ $+5\ \mathrm{mm}$

$y = 0\ \mathrm{mm}$

AGROS: DIPOLE



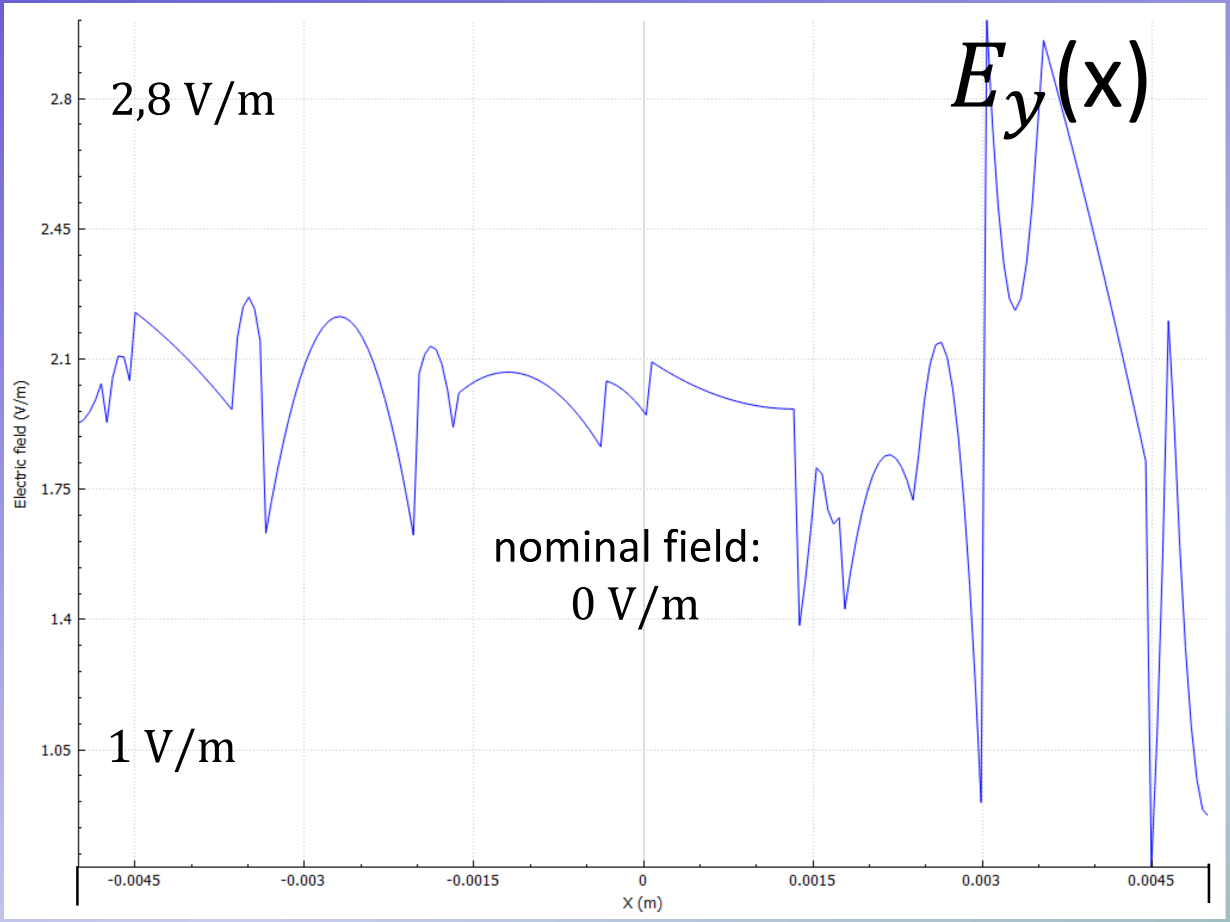
$E_x(x = 0)$

$y = 0\ \mathrm{mm} \quad -66.3\ \mathrm{kV/m}$

$y = 5\ \mathrm{mm} \quad -62.0\ \mathrm{kV/m}$

$y = 5\ \mathrm{mm}$

AGROS: DIPOLE



E_y(x)

2,8 V/m

1 V/m

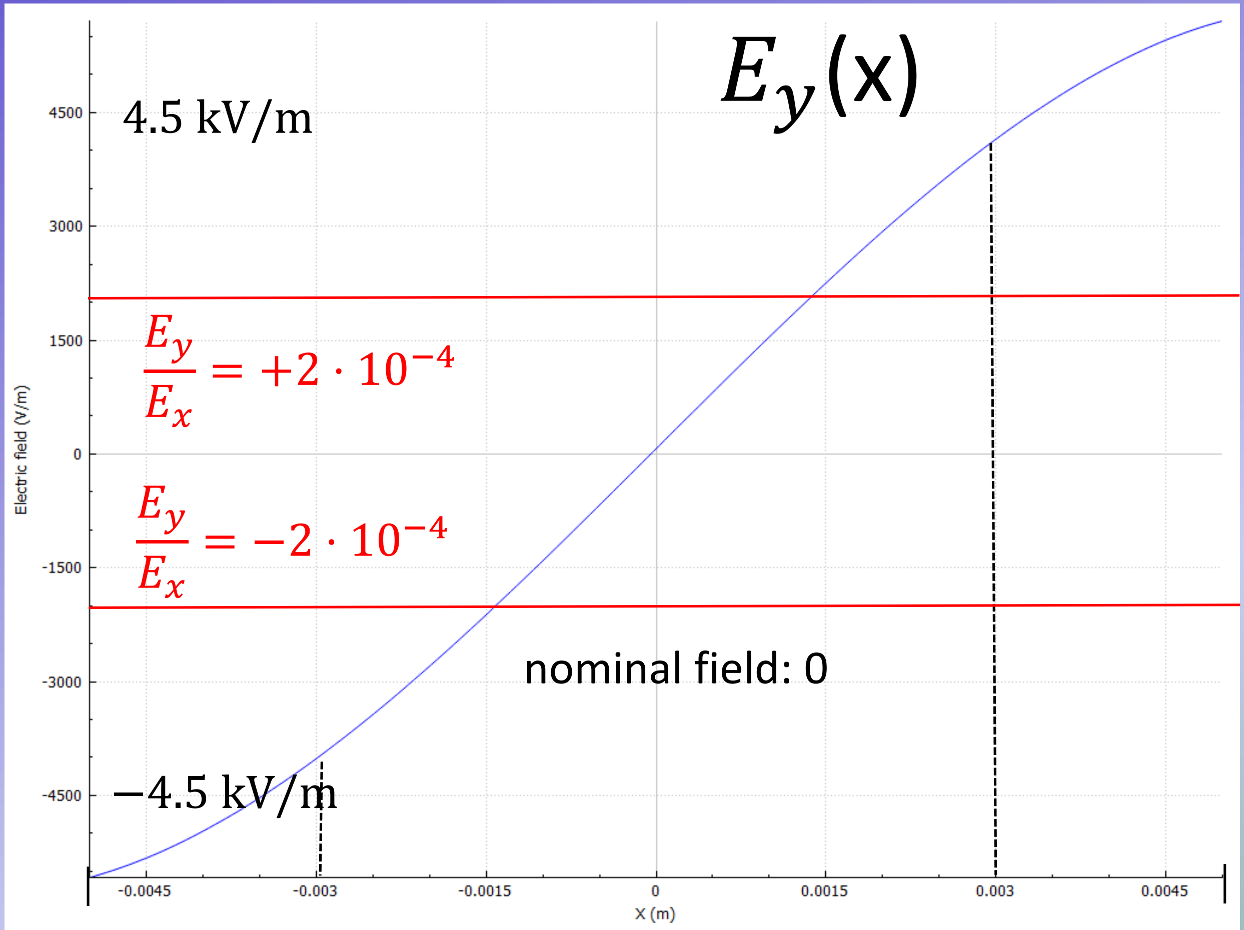
nominal field:
0 V/m

-5 mm

$+5$ mm

$y = 0$ mm

AGROS: DIPOLE



E_y(x)

$4.5\ \mathrm{kV/m}$

$$\frac{E_y}{E_x} = +2 \cdot 10^{-4}$$

$$\frac{E_y}{E_x} = -2 \cdot 10^{-4}$$

nominal field: 0

$-4.5\ \mathrm{kV/m}$

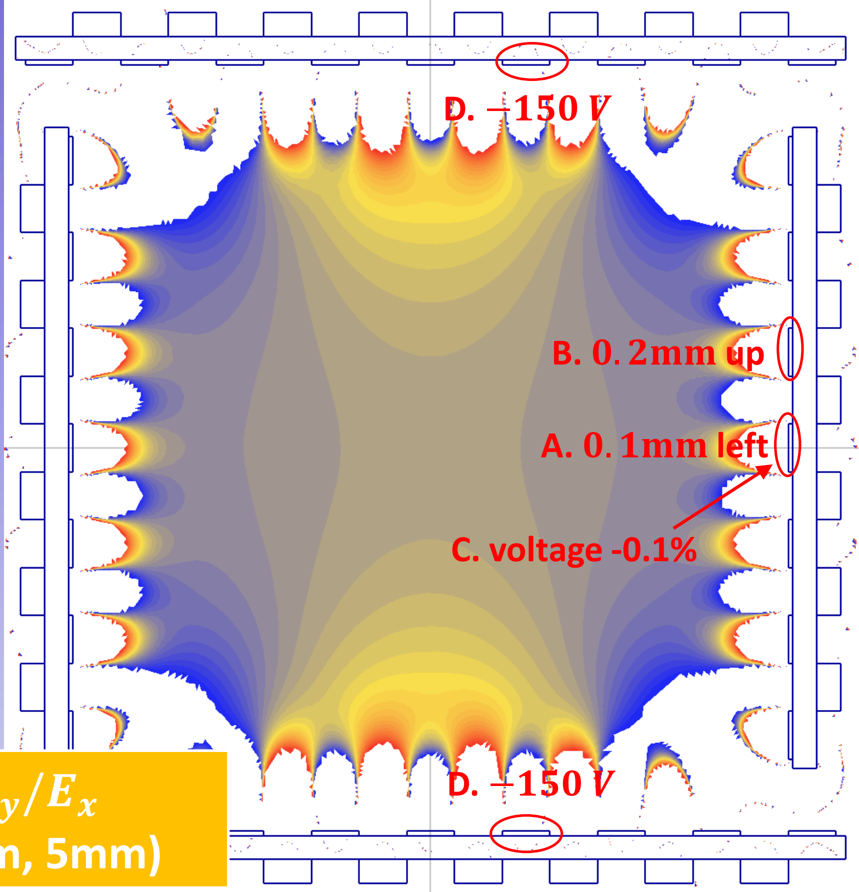
$-5\ \mathrm{mm}$ $-3\ \mathrm{mm}$ $+3\ \mathrm{mm}$ $+5\ \mathrm{mm}$

$y = 5\ \mathrm{mm}$

AGROS: DIPOLE

Impact of imperfections on the field

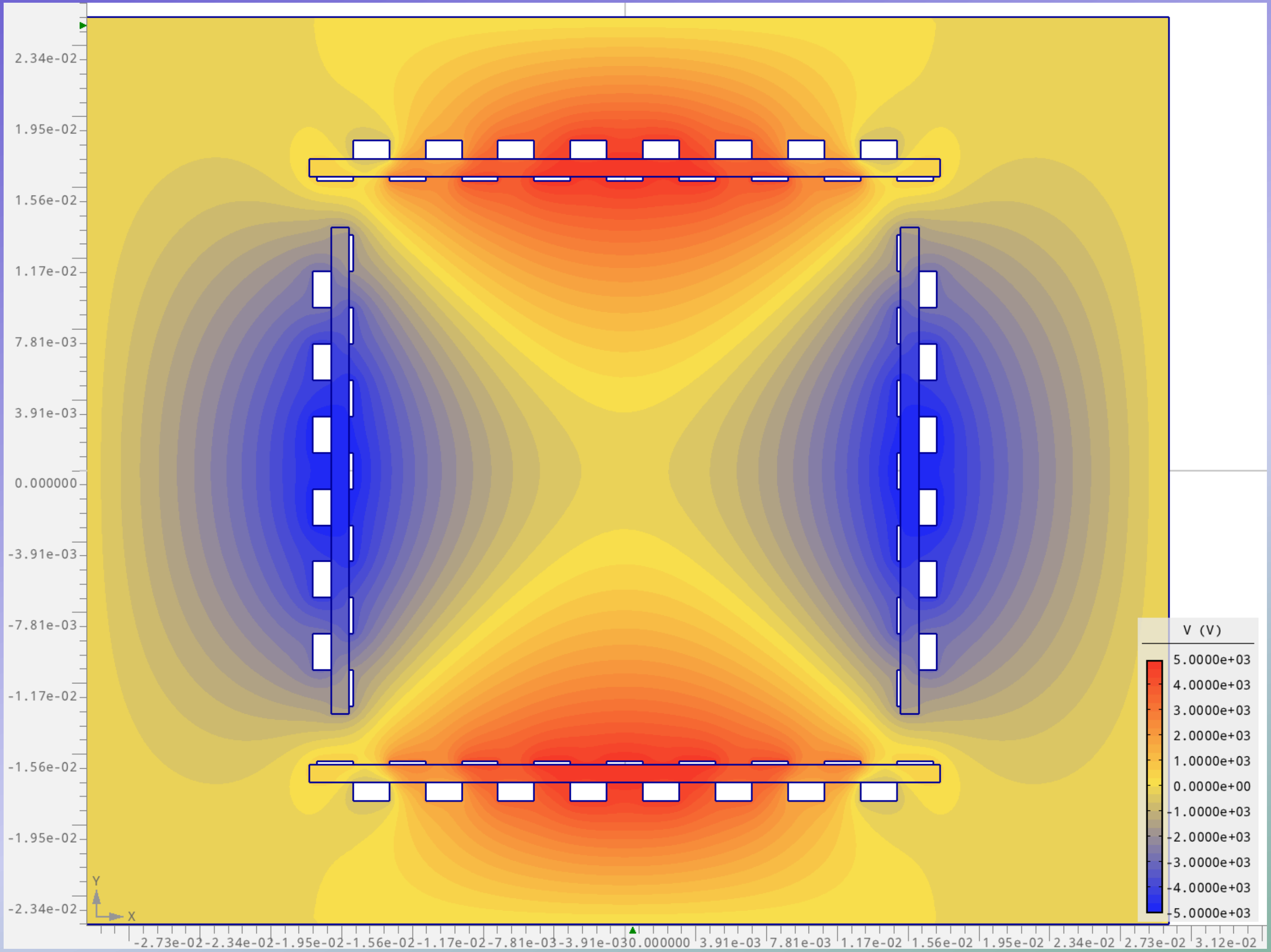
Mechanical percision: better than 0.1 mm
Voltages better than 10^{-3}



	$\Delta E_x / E_x(0,0)$	$\Delta E_x(5mm)/E_x$	E_y/E_x (5mm, 5mm)
nom	0.000 %	-0.024 %	-5500 V/m
A	0.058 %	-0.045 %	-7000 V/m
B	0.001 %	-0.022 %	+ 6500 V/m
C	-0.045%	-0.028 %	-5700 V/m
D	0.003 %	-0.020 %	+6800 V/m

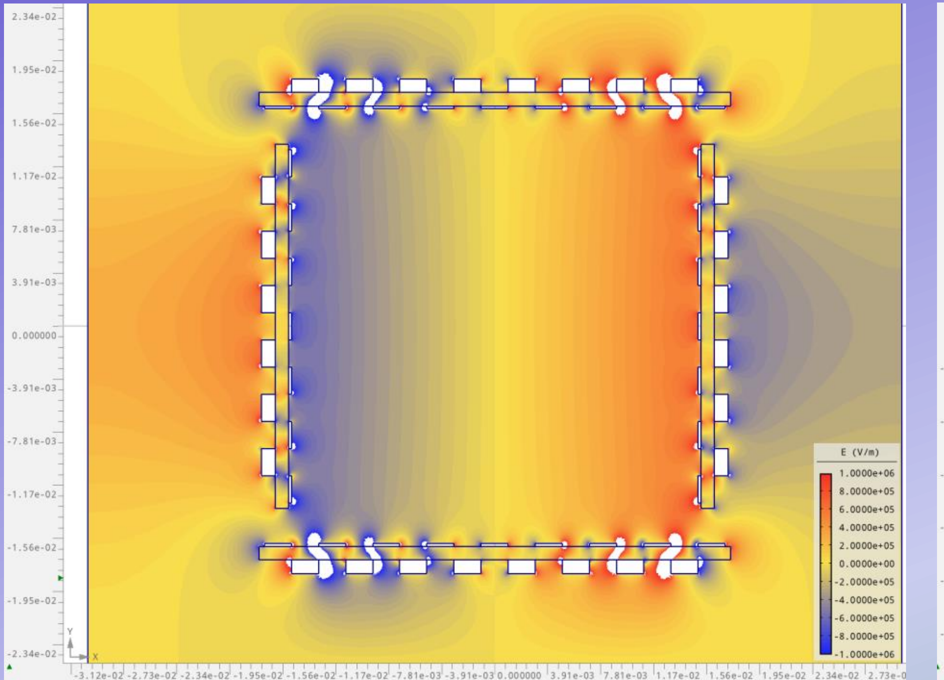
AGROS: QUADRUPOLE

$\varphi(\vec{r})$

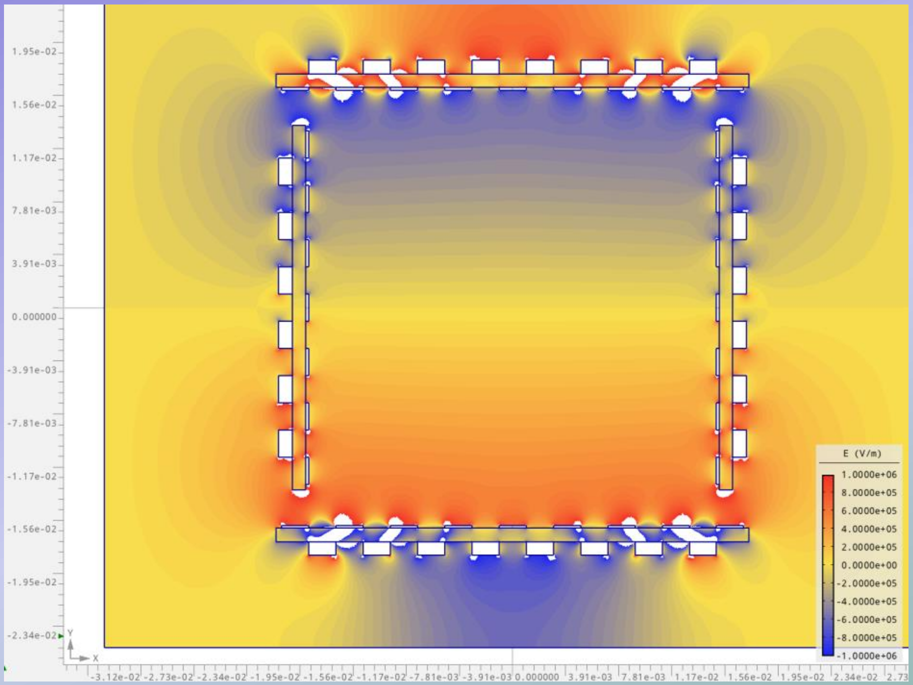


AGROS: QUADRUPOLE

$E_x(\vec{r})$

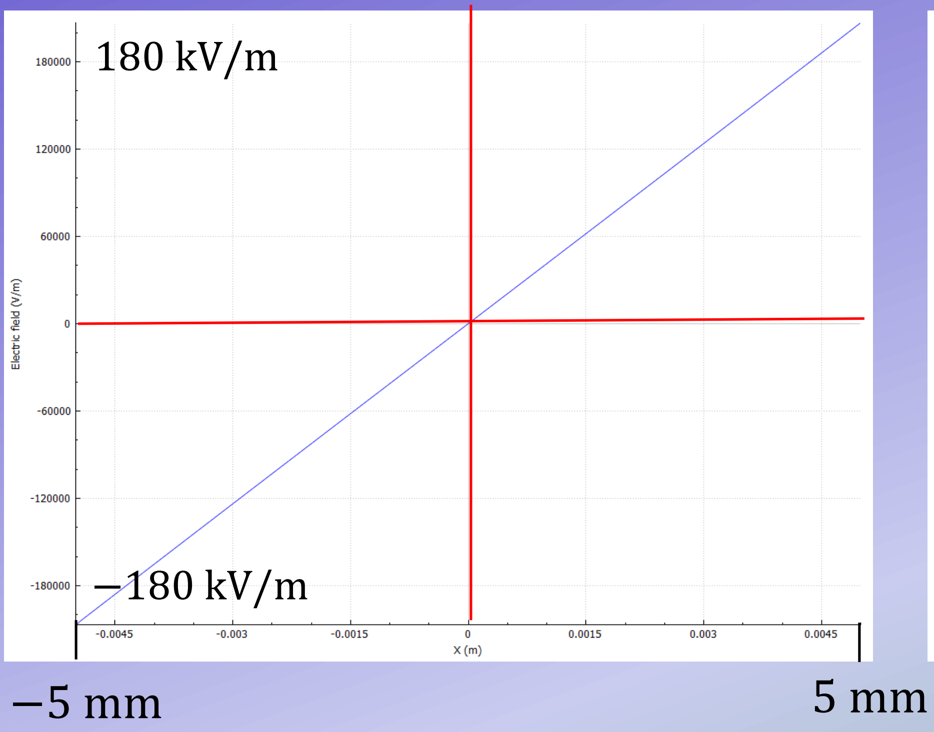


$E_y(\vec{r})$

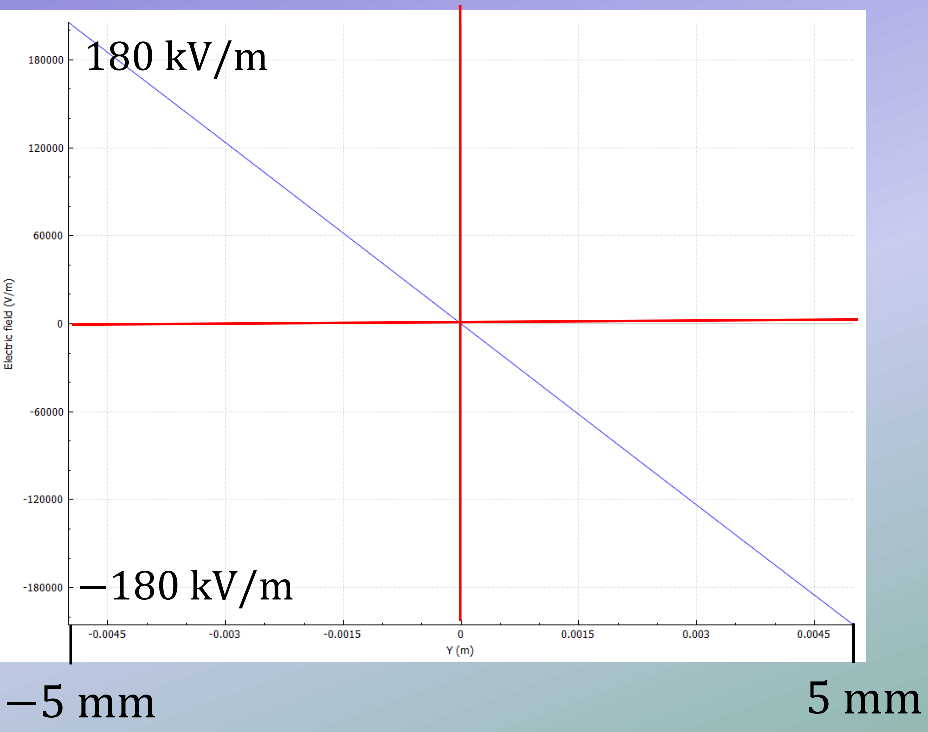


AGROS: QUADRUPOLE

$E_x(x)$

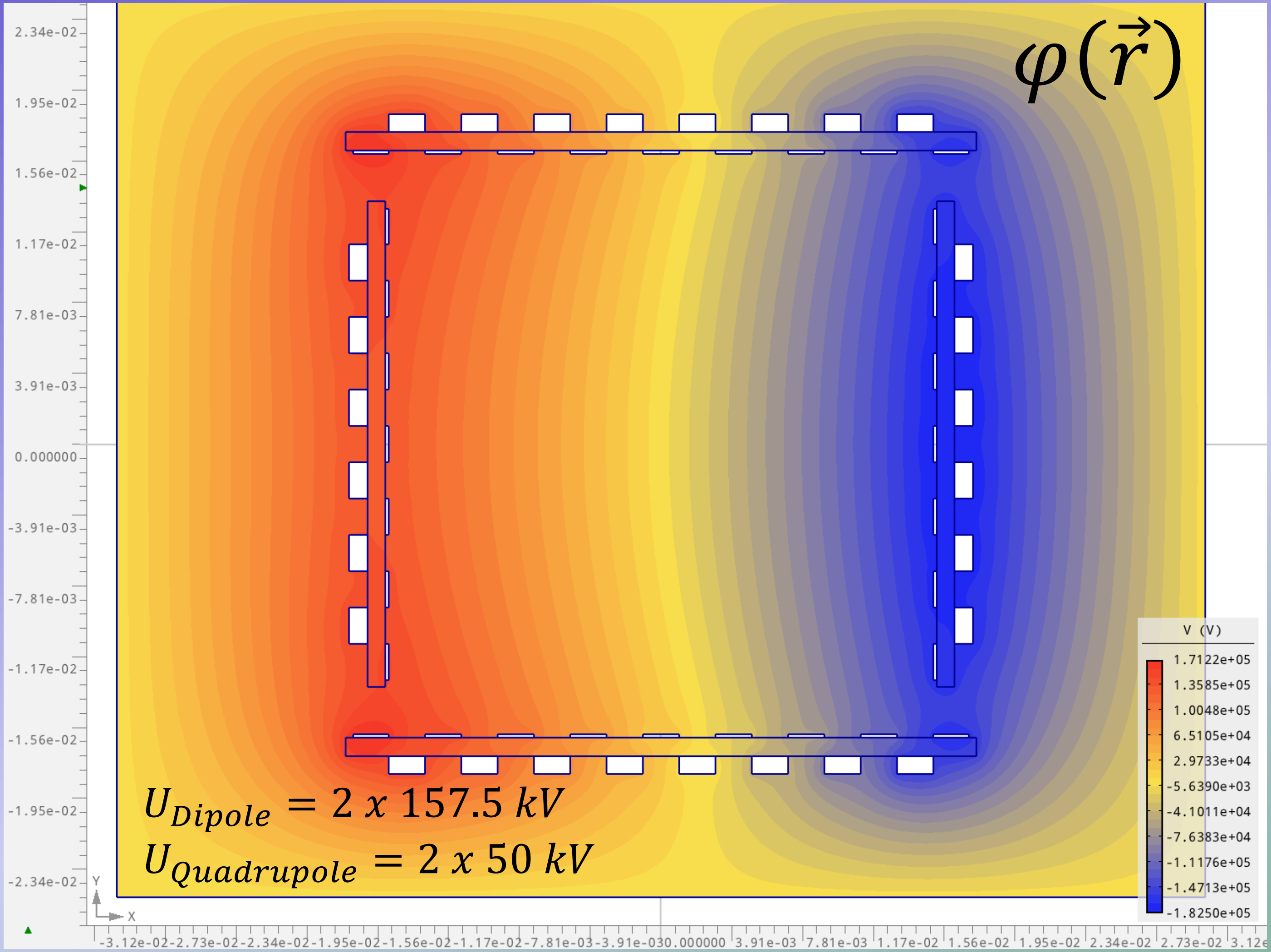


$E_y(y)$



No quality check, yet

AGROS: COMBINED FUNCTION



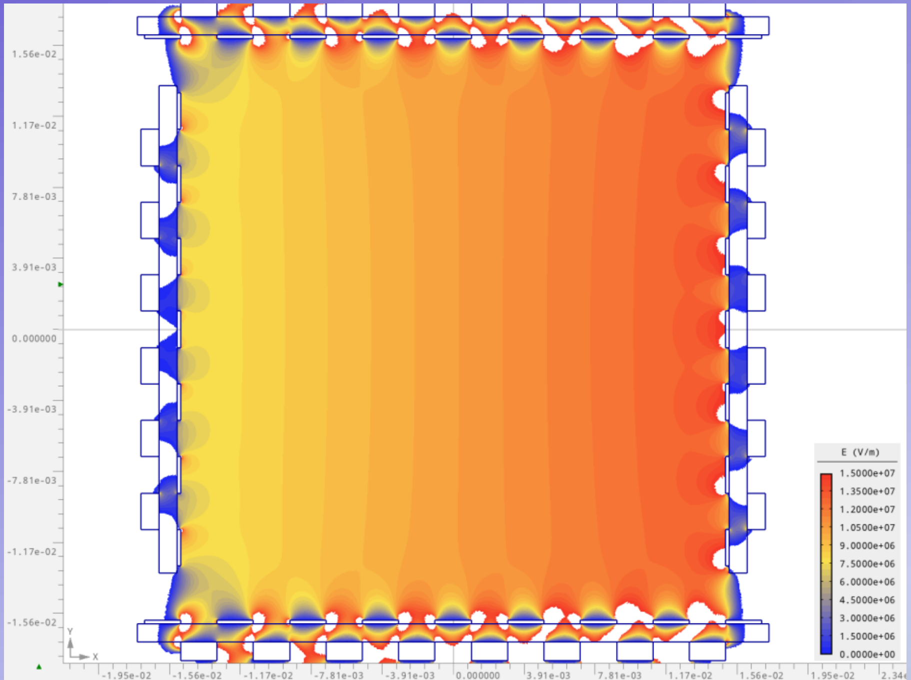
$\varphi(\vec{r})$

$U_{Dipole} = 2\ x\ 157.5\ kV$

$U_{Quadrupole} = 2\ x\ 50\ kV$

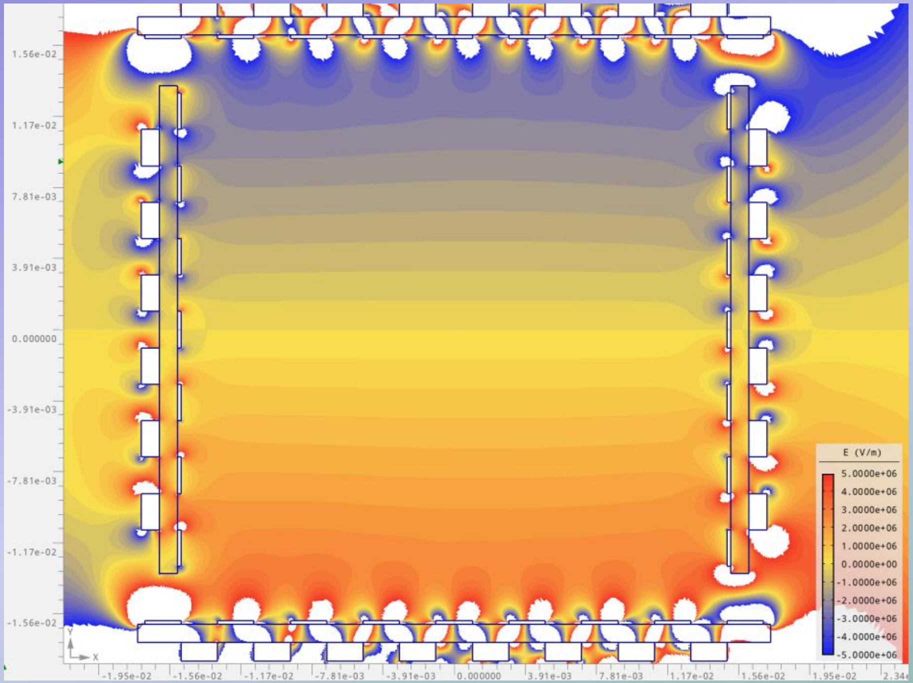
AGROS: COMBINED FUNCTION

$$E_x(\vec{r})$$



scale: $0\,\frac{\mathrm{MV}}{\mathrm{m}}\ \ldots 15\,\frac{\mathrm{MV}}{\mathrm{m}}$

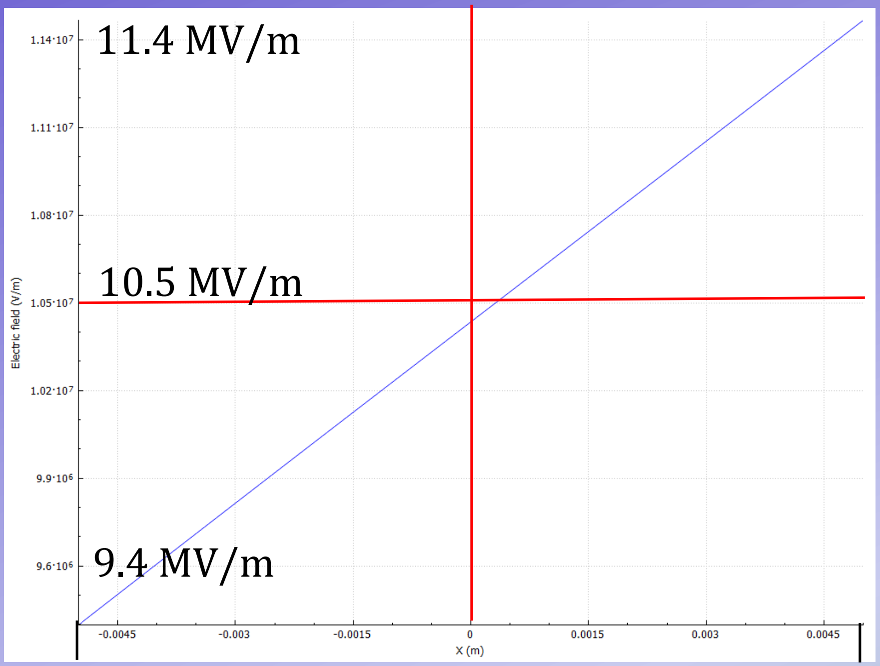
$$E_y(\vec{r})$$



scale: $-5\,\frac{\mathrm{MV}}{\mathrm{m}}\ \ldots +5\,\frac{\mathrm{MV}}{\mathrm{m}}$

AGROS: COMBINED FUNCTION

$E_x(x)$



11.4 MV/m

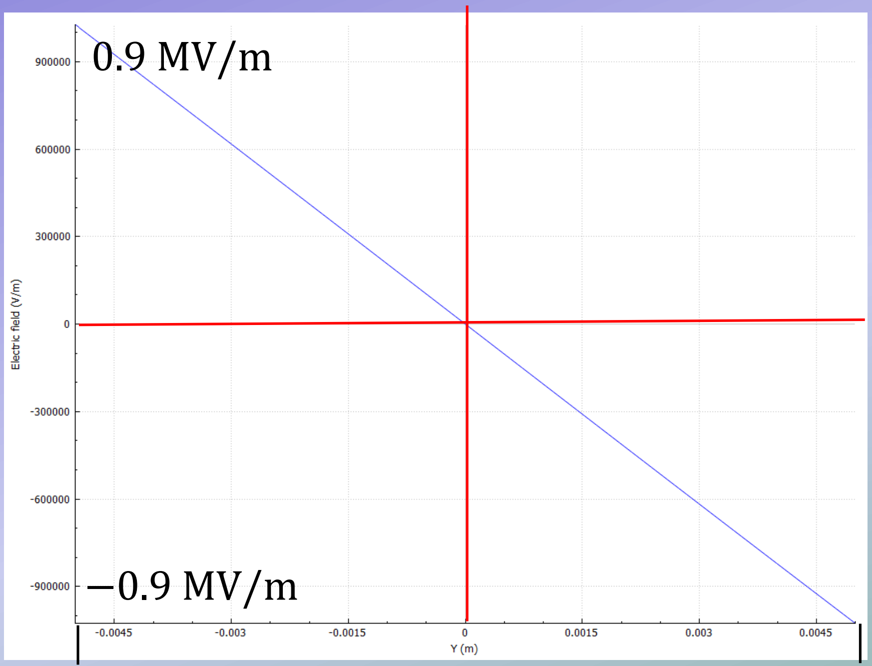
10.5 MV/m

9.4 MV/m

-5 cm

5 cm

$E_y(y)$



0.9 MV/m

-0.9 MV/m

-5 cm

5 cm

No quality check, yet

DEFORMATION OF PLATES

Force on vertical plates

Capacitance: $C = \frac{\epsilon_0 A}{d} = 7.7\,\frac{\mathrm{pF}}{\mathrm{m}}$ (height 2.6 cm, distance 3.0 cm)

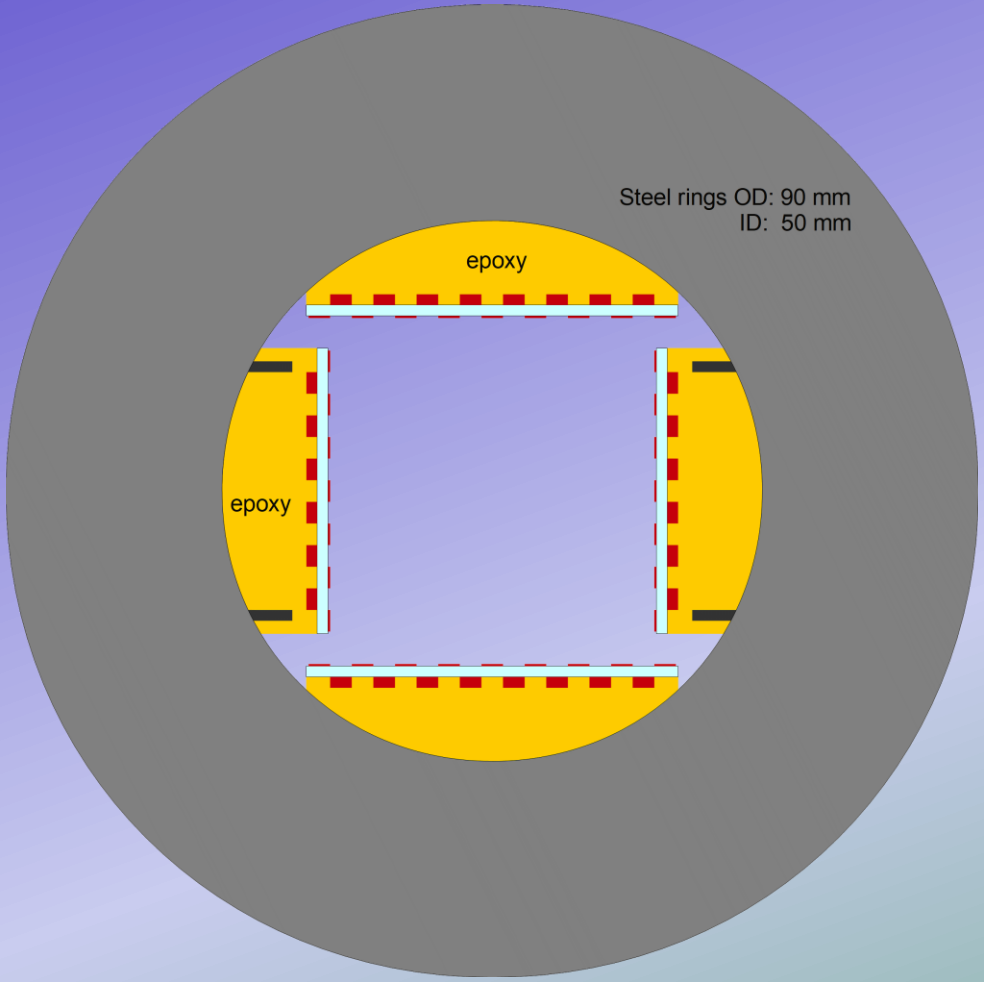
Charge: $Q = C \cdot U = 2.4\ \mathrm{\mu C/m}$ (voltage $2 \cdot 175.5\ \mathrm{kV}$)

Field Strength: $\left|\vec{E}\right| = \frac{U}{d} = 10.5\ \mathrm{MV/m}$

Stored Energy: $E_C = \frac{1}{2} C U^2 = 14\,\frac{\mathrm{mJ}}{\mathrm{strip}}/\mathrm{m}$

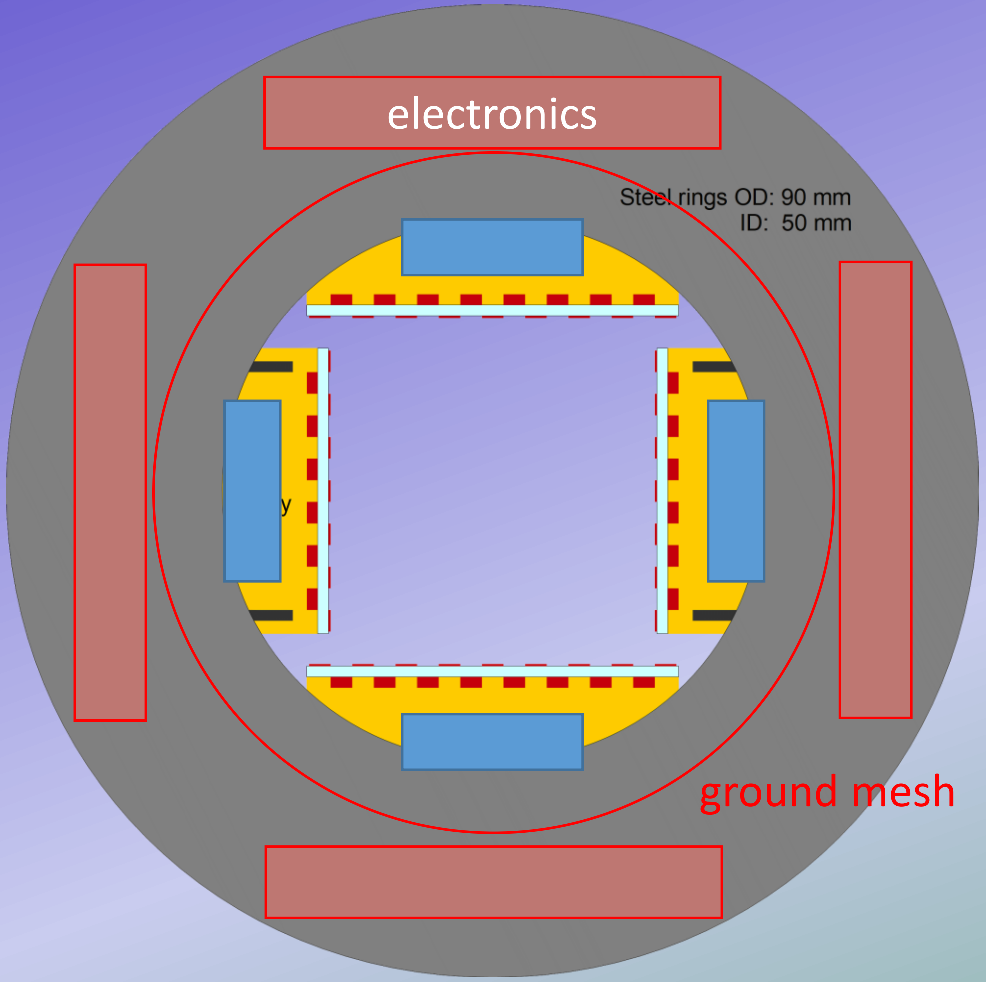
Force on Plate: $F = Q \cdot E = 25\ \mathrm{N/m}$

1ST IDEA ON MECHANICS

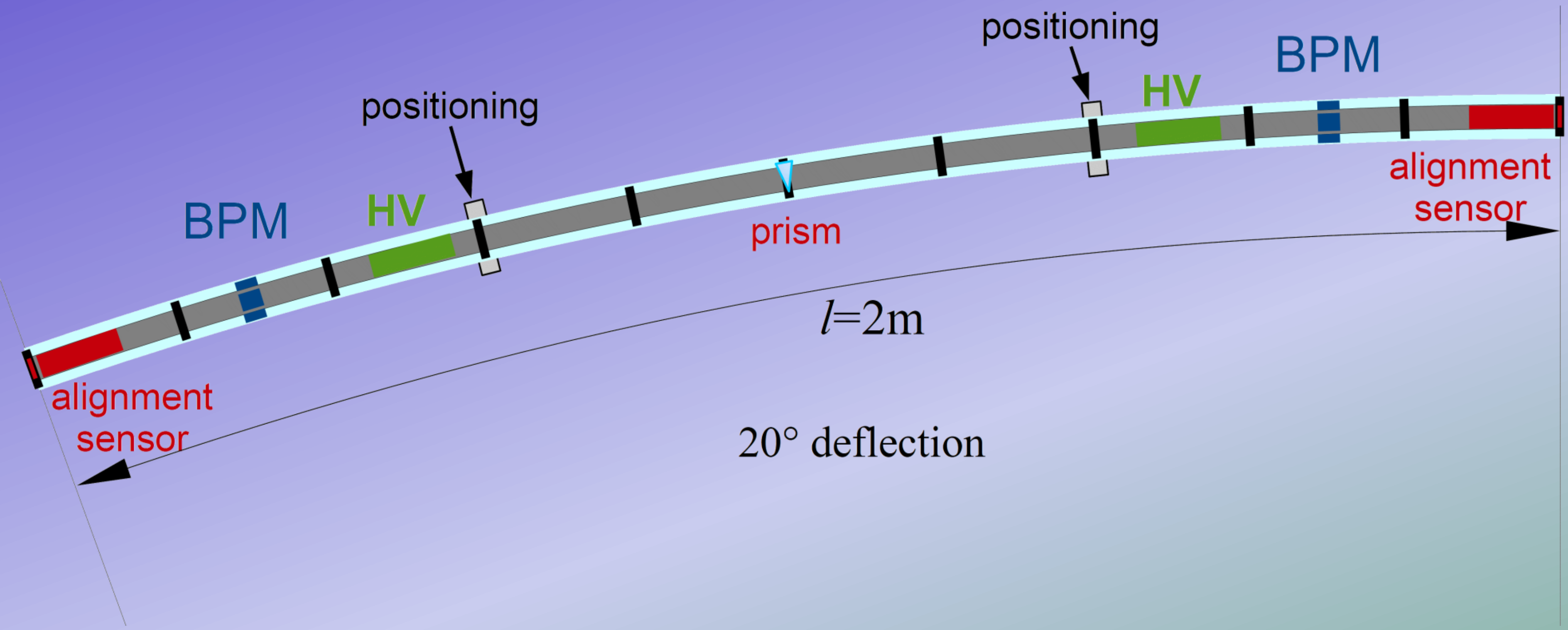


Steel disks every 10 cm (?)
electrodes glued into stiff plates
might need stiffeners inside plates

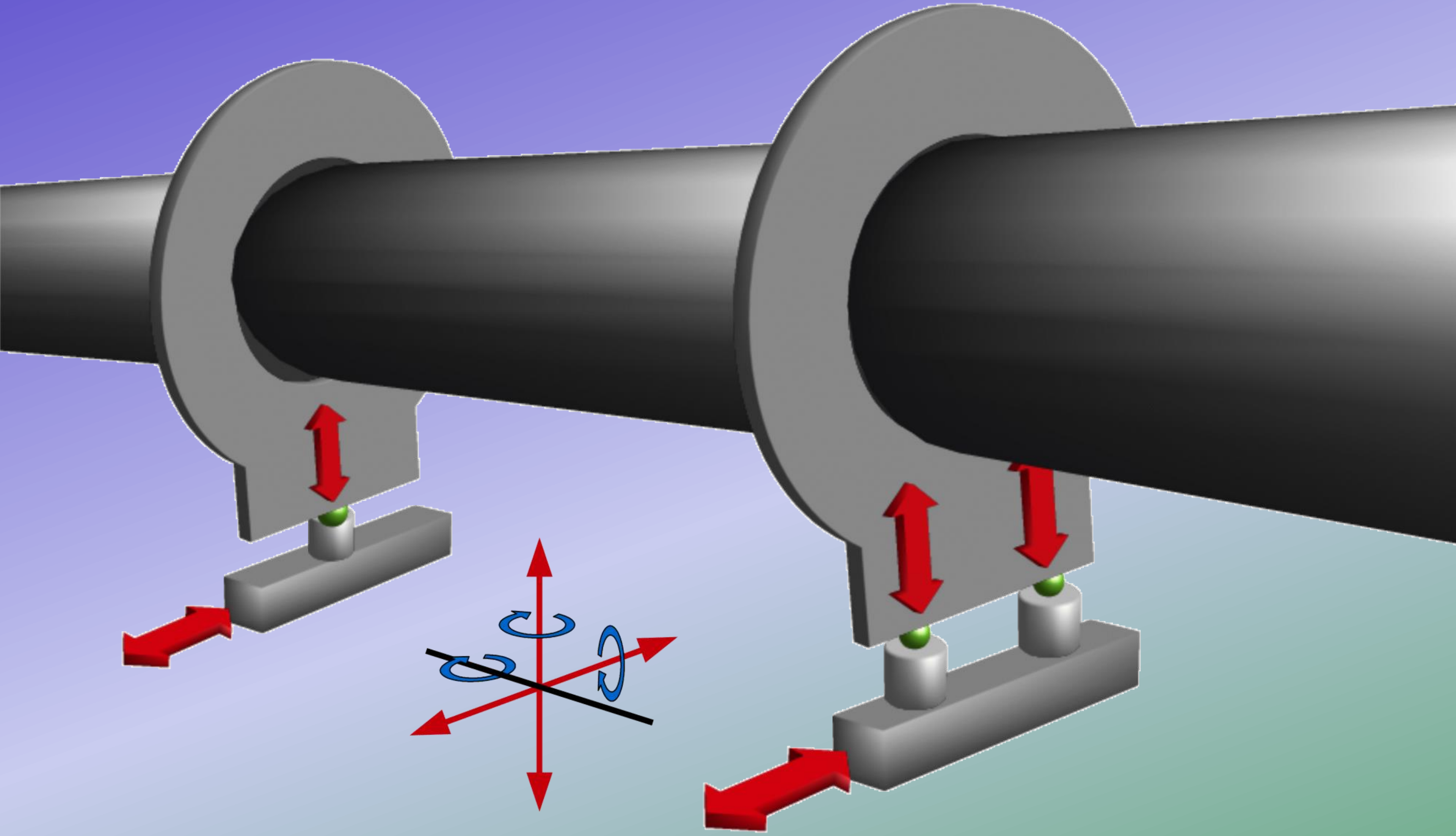
BEAM POSITION MONITORS



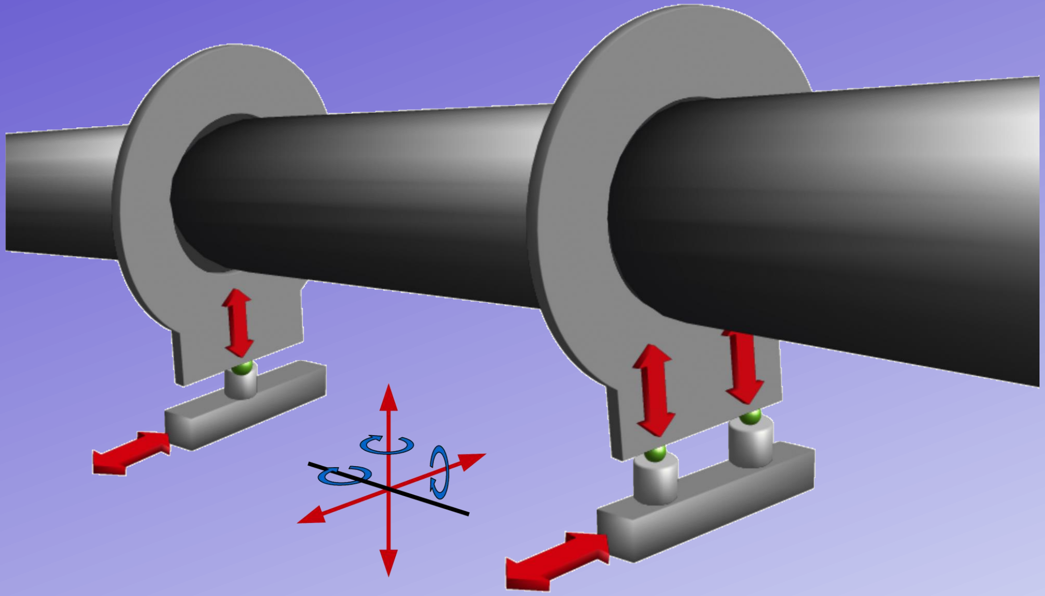
DEFLECTORS


positioning
BPM
HV
positioning
HV
BPM
prism
alignment sensor
alignment sensor
l=2m
20° deflection

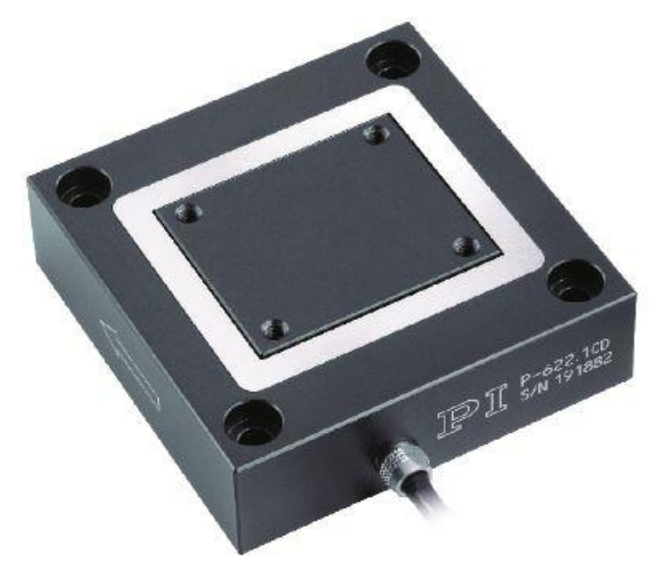
MECHANICAL POSITIONING

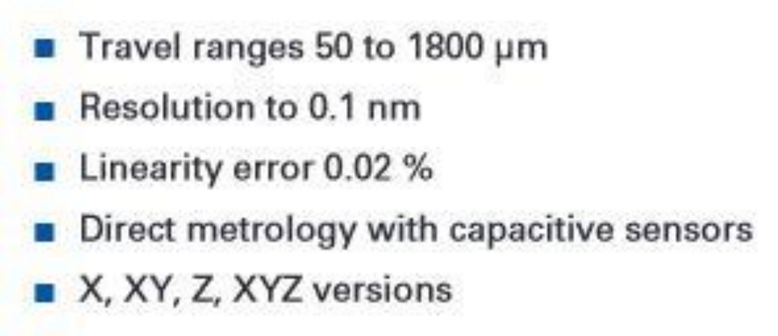


MECHANICAL POSITIONING



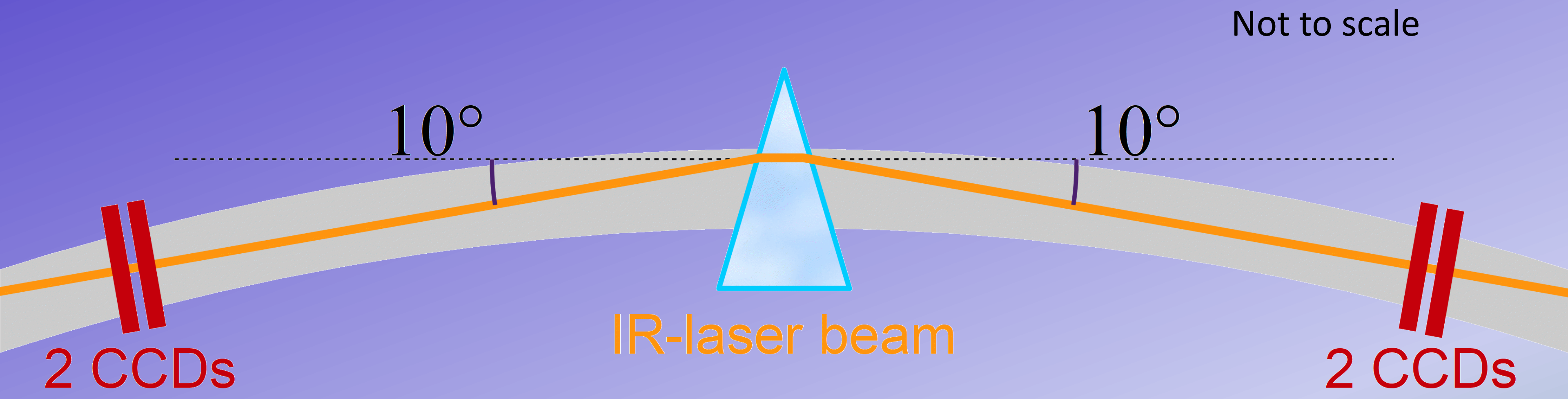
Piezo-Actuators ?





- Travel ranges 50 to 1800 µm
- Resolution to 0.1 nm
- Linearity error 0.02 %
- Direct metrology with capacitive sensors
- X, XY, Z, XYZ versions

LASER ALIGNMENT

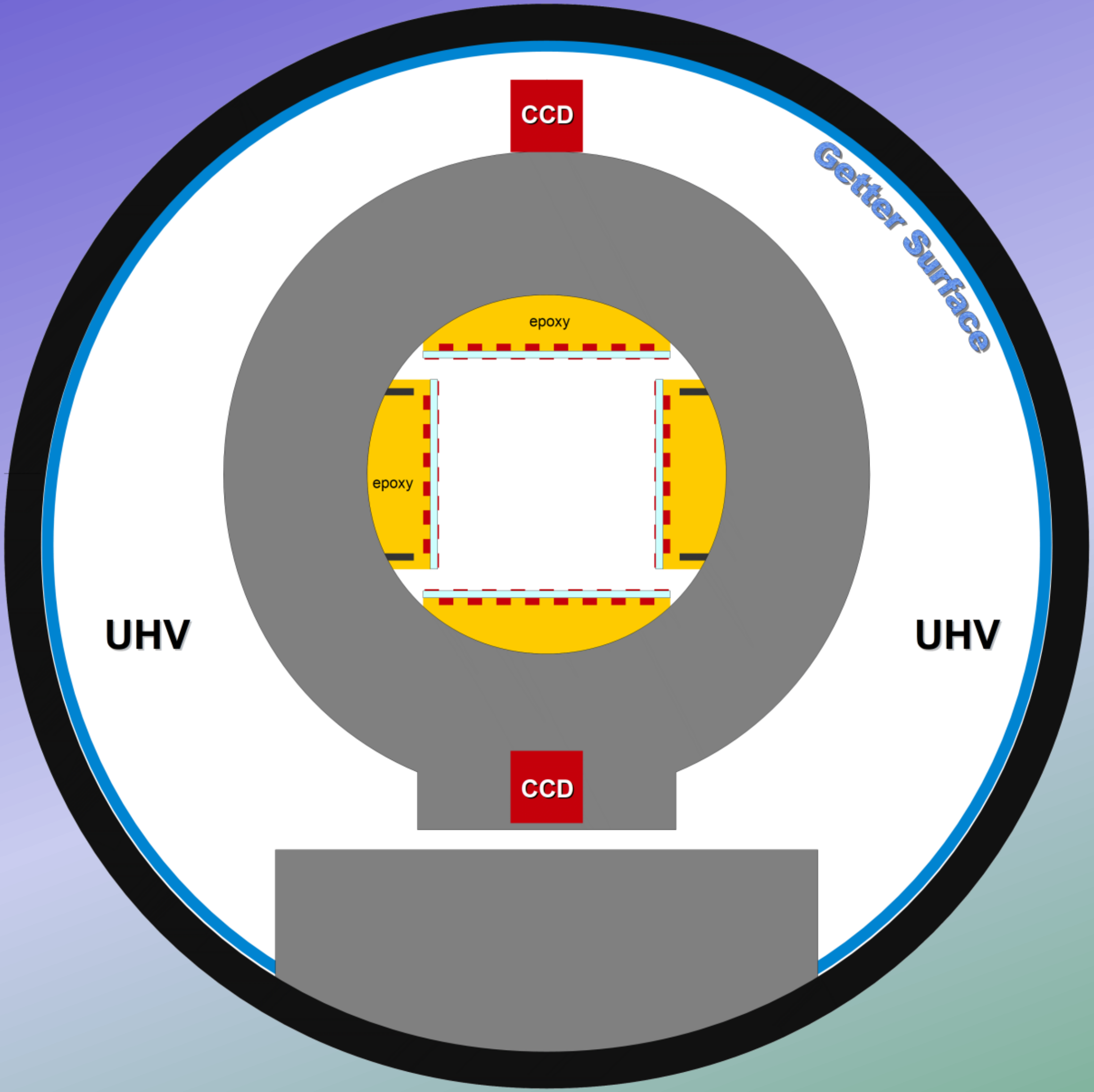


2 systems: above & below deflector

Laser alignment system used for example in CMS (Stefan Schael)

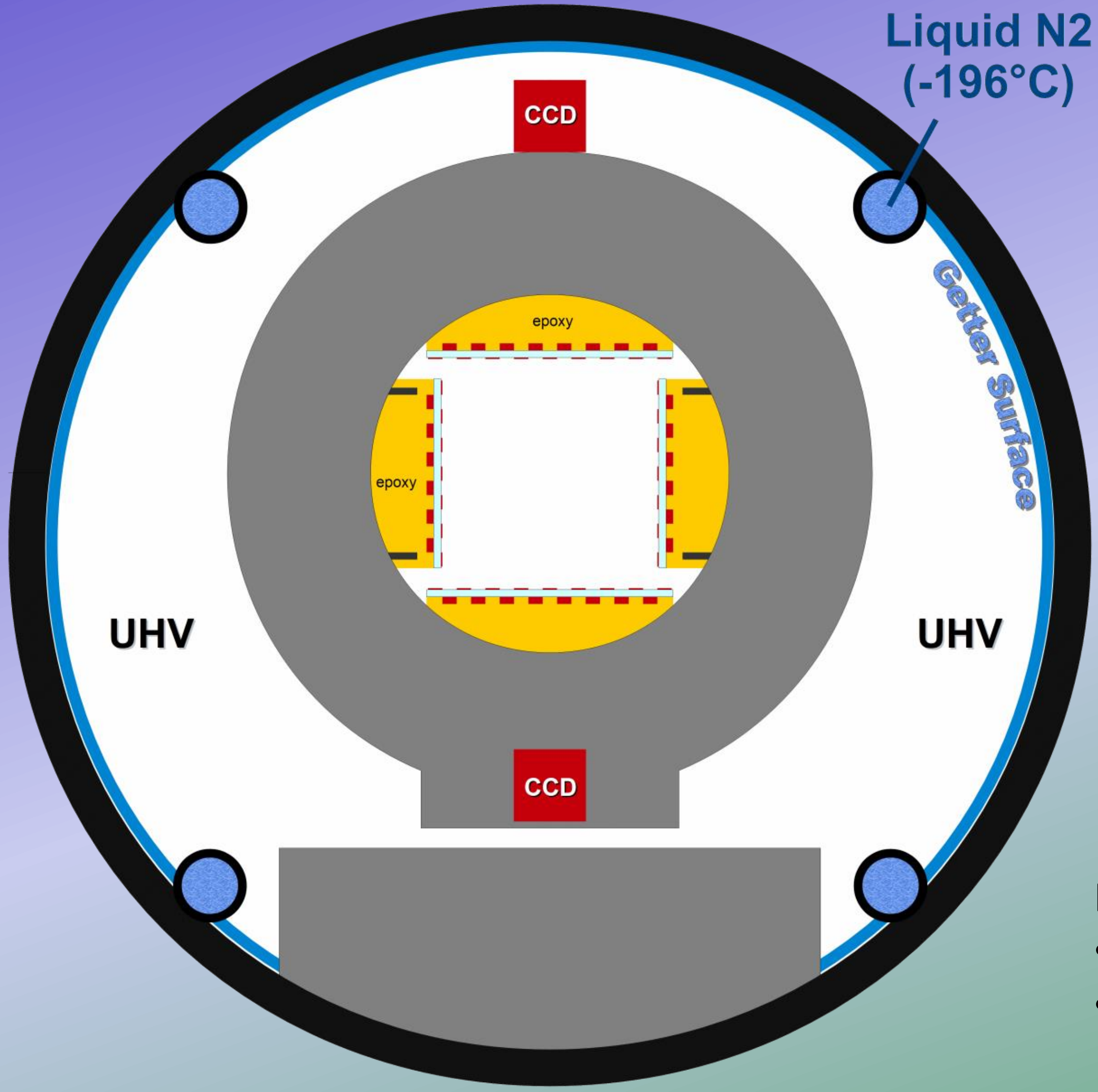
- IR-Laser (amplitude modulated)
- Si-strip detectors detect beam
- Metal layers removed for transmission of IR-beam

VACUUM SYSTEM



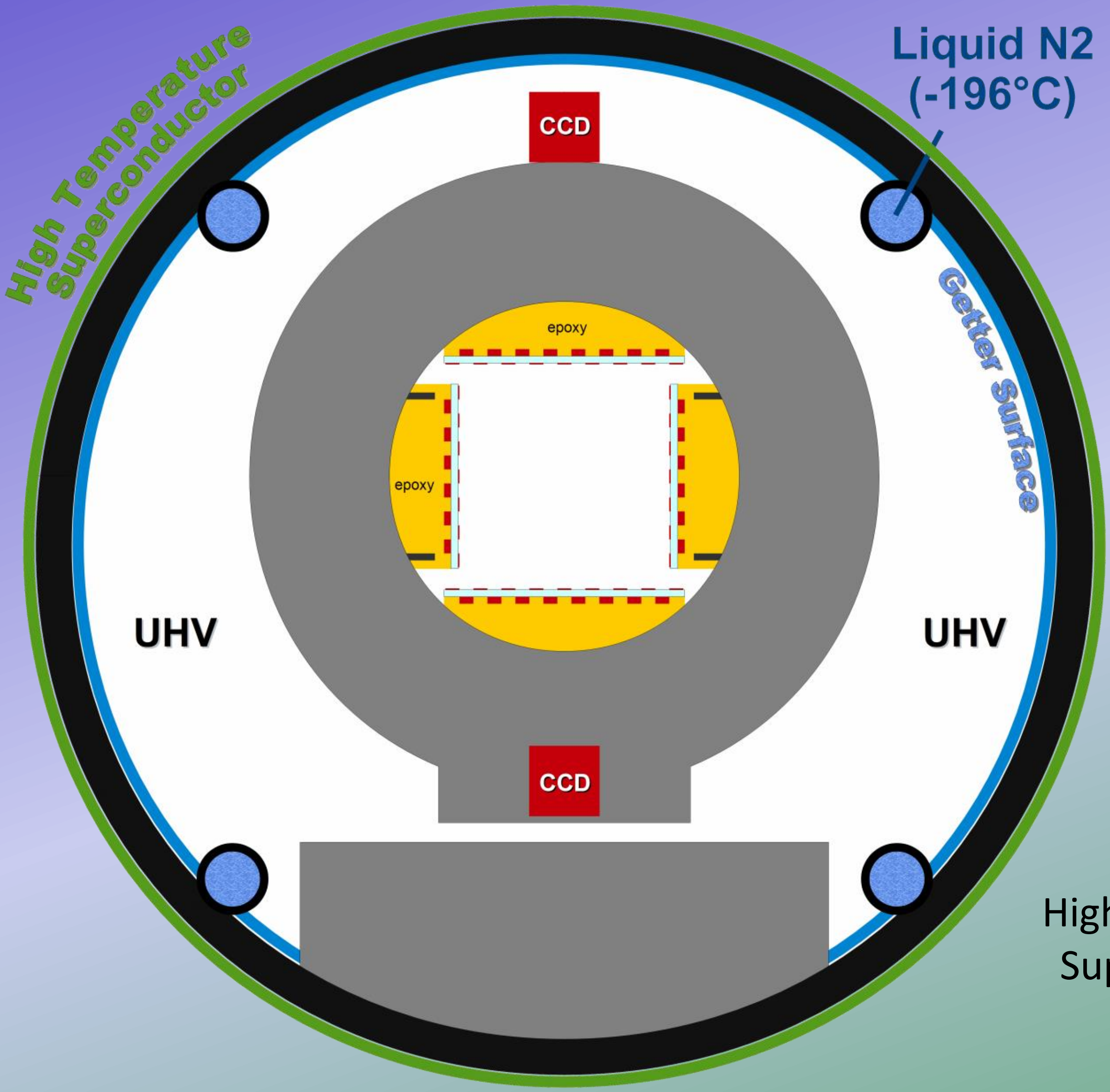
Beam pipe
- Steel pipe
- ID 15 cm

VACUUM SYSTEM



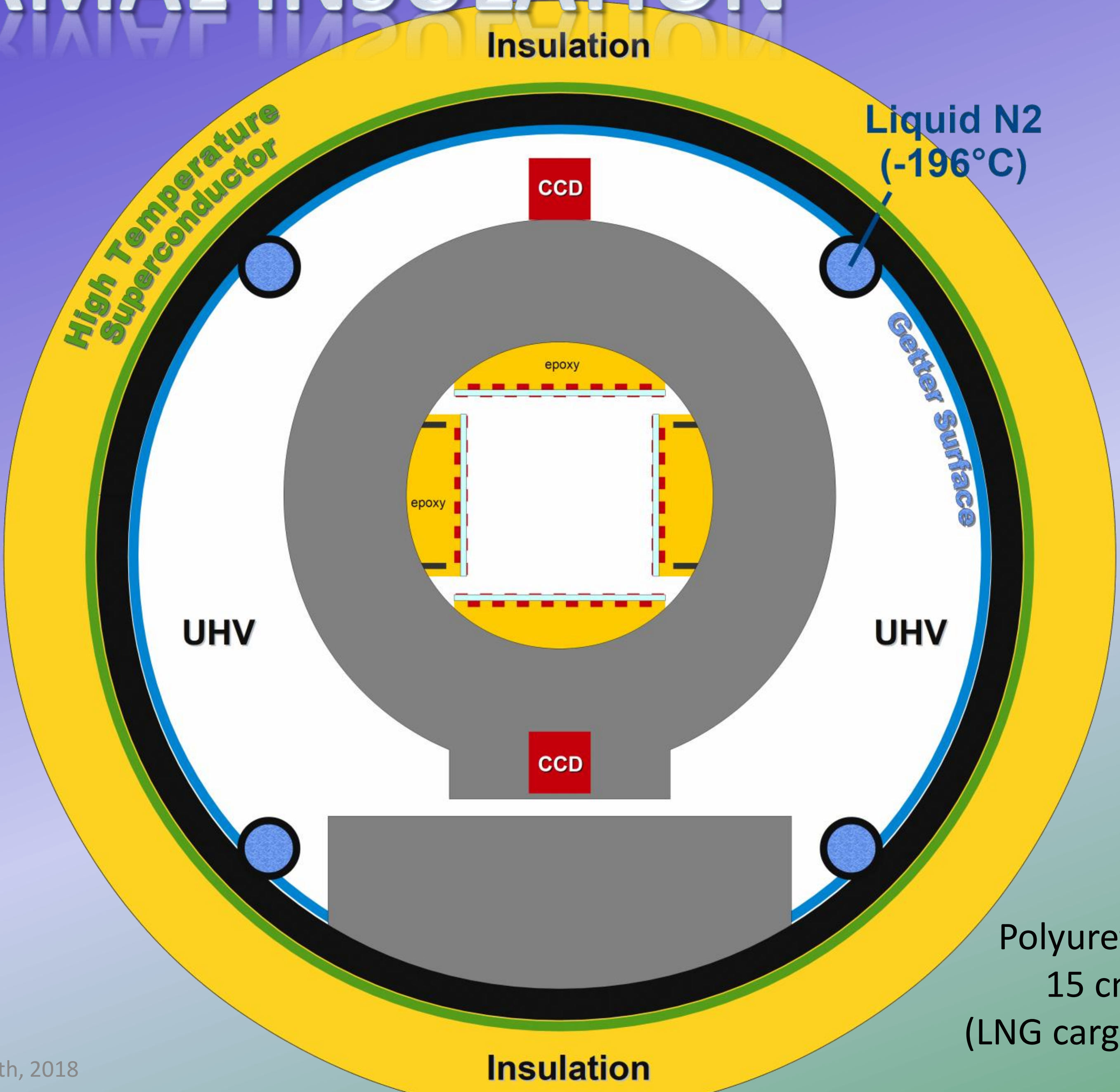
Beam pipe
- Steel pipe
- ID 15 cm

MAGNETIC SHIELDING



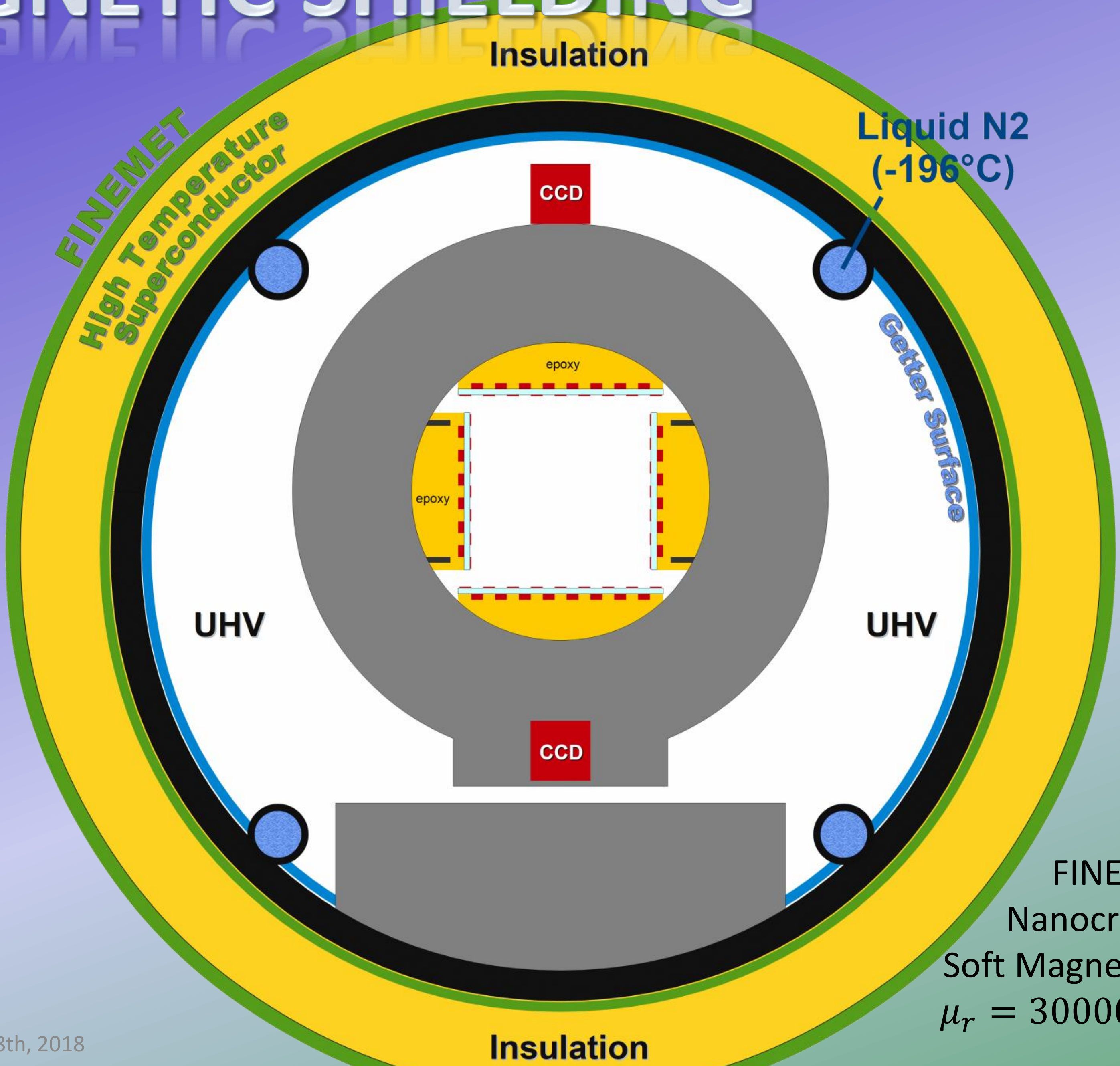
High Temperature Superconductor

THERMAL INSULATION



Polyurethane foam
15 cm shown
(LNG cargo uses 25 cm)

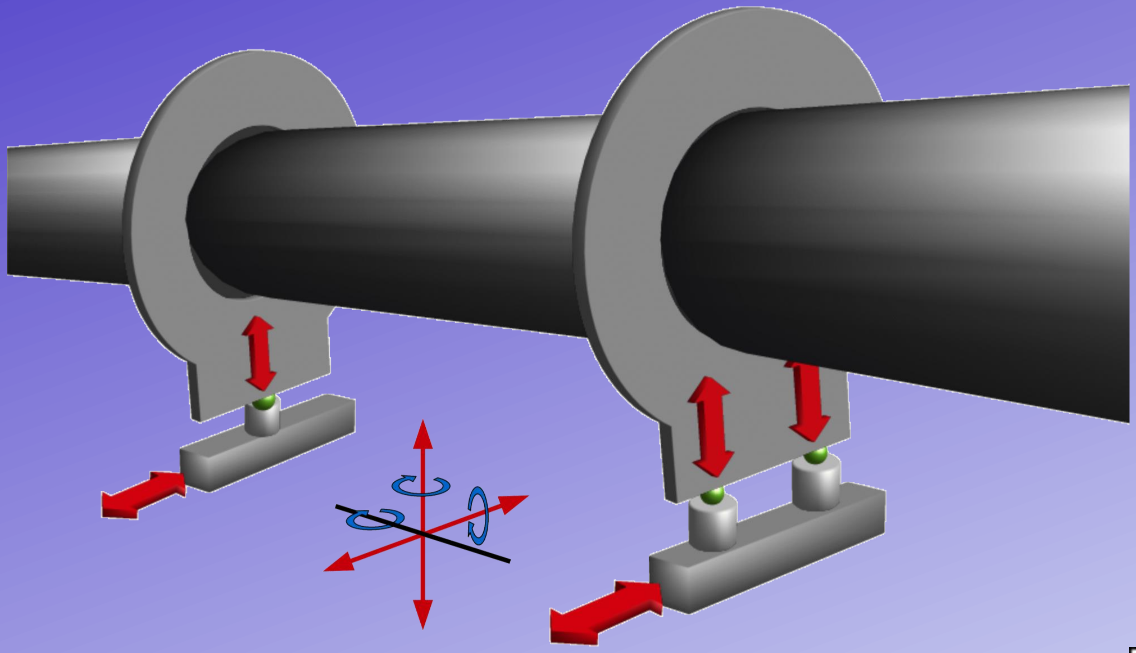
MAGNETIC SHIELDING

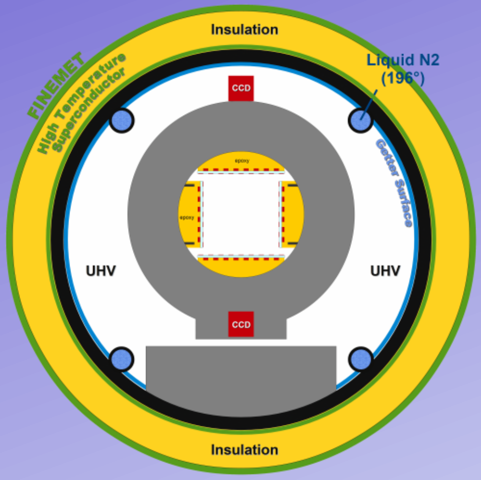


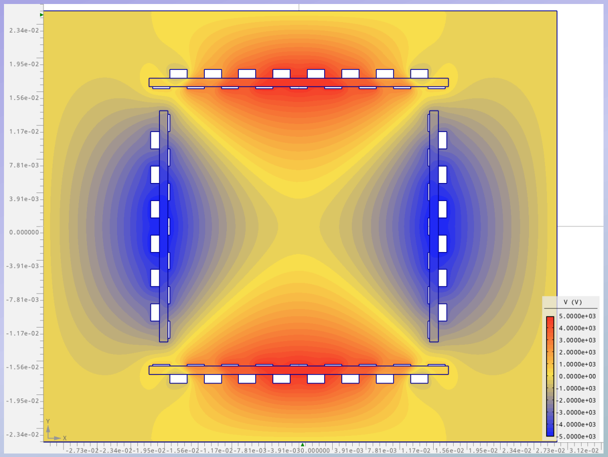
FINEMET
Nanocrystaline
Soft Magnetic Material
$\mu_r = 30000 \ldots 100000$

NEXT STEPS

- Continue Field Calculations (optimize homogenity / study tolerances)
  Understand field of bend deflectors
  (Student starting on April 1st)
- Design HV-network and stabilization
  (Under discussion with Jochen Steinmann)
- Talk to workshops for production methode of plates
- Understand integration of BPMs
- Talk to Stefan on laser alignment system
- Understand effectiveness & cost of HTS shielding




Insulation
Liquid N2
(196°)
FINEMET
High Temperature Superconductor
Getter Surface
CCD
epoxy
epoxy
UHV
UHV
CCD
Insulation


2.34e-02
1.95e-02
1.56e-02
1.17e-02
7.81e-03
3.91e-03
0.000000
-3.91e-03
-7.81e-03
-1.17e-02
-1.56e-02
-1.95e-02
-2.34e-02
-2.73e-02
-2.34e-02
-1.95e-02
-1.56e-02
-1.17e-02
-7.81e-03
-3.91e-03
0.000000
3.91e-03
7.81e-03
1.17e-02
1.56e-02
1.95e-02
2.34e-02
2.73e-02
3.12e-02
Y
X
V (V)
5.0000e+03
4.0000e+03
3.0000e+03
2.0000e+03
1.0000e+03
0.0000e+00
-1.0000e+03
-2.0000e+03
-3.0000e+03
-4.0000e+03
-5.0000e+03

Thanks