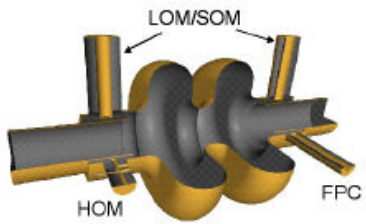
Update on n-Pole Error in Actual Compact Crab-Cavities Designs

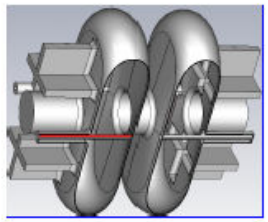
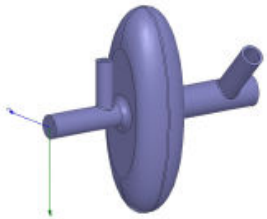
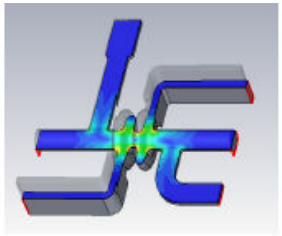
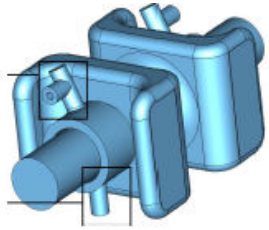
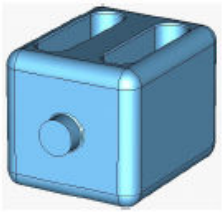
María Navarro-Tapia Alexej Grudiev Rama Calaga

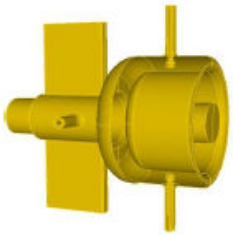
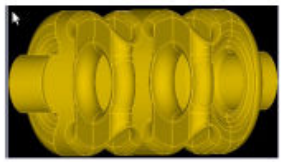
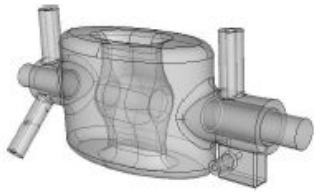
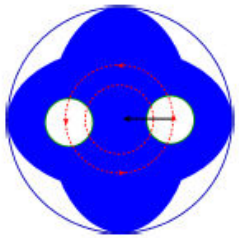
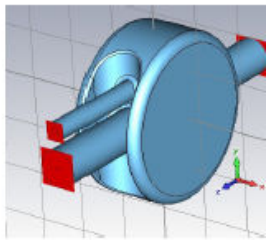
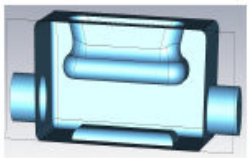
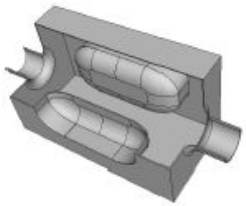
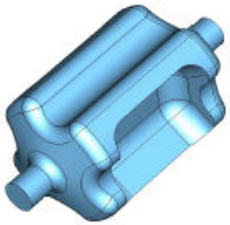
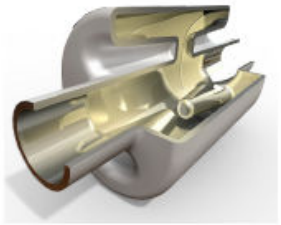
Radiofrequency Group, Beams Department
CERN, Geneva (Switzerland)

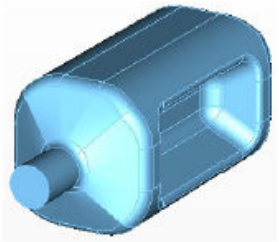
2nd Joint HiLumi-LARP Annual Meeting 2012

Cavity Designs Proposed for LHC



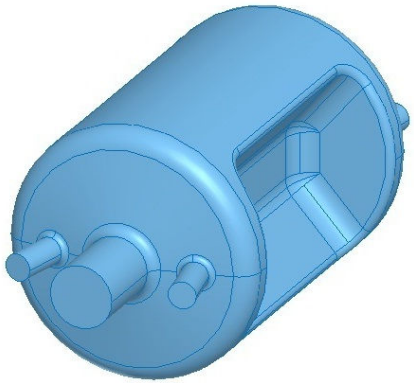












R. Calaga

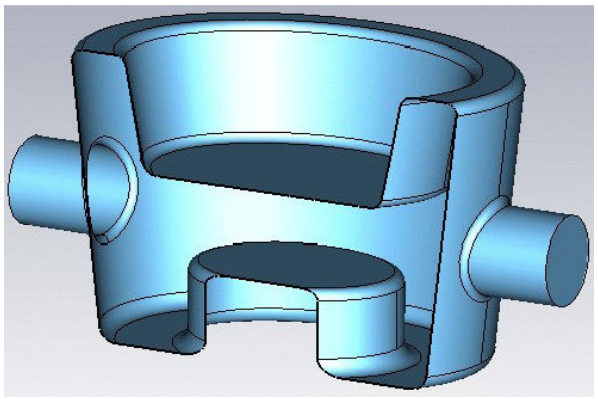
LHC CC Prototypes Already Studied

RF dipole



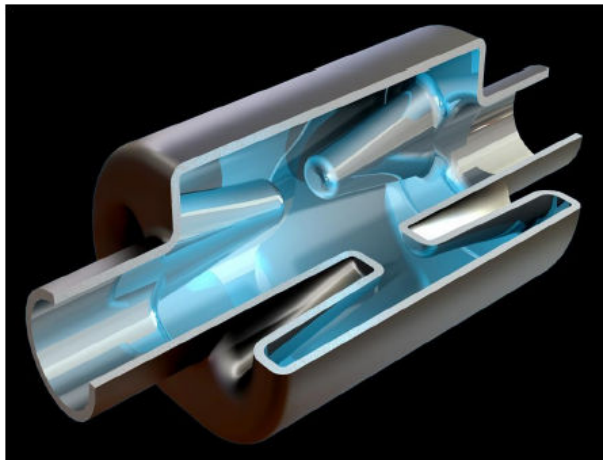
Courtesy of
Z. Li, J. Delayen *et al.*
ODU/SLAC

$\frac{1}{4}$-wave



I. Ben-Zvi *et al.*
BNL

4-rod



G. Bull, B. Hall
UK

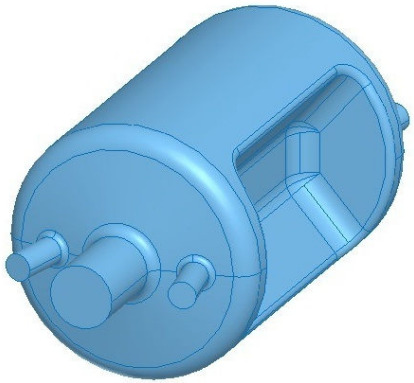
Non-axial symmetry

Higher order multipolar components of the main deflecting mode

RF-kicks influencing the beam dynamics

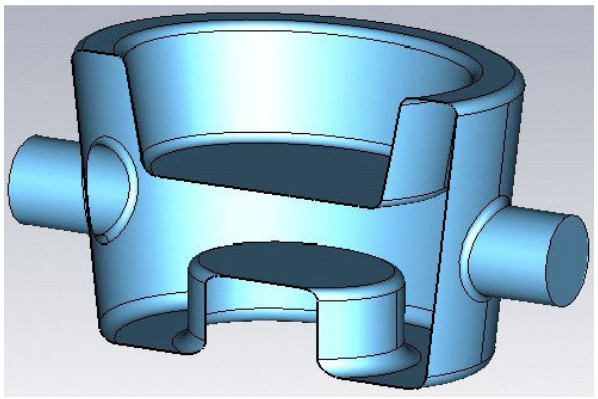
LHC CC Prototypes Already Studied

RF dipole



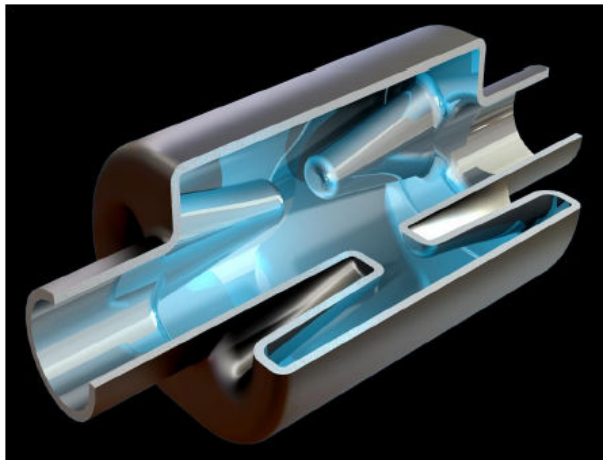
Courtesy of
Z. Li, J. Delayen *et al.*
ODU/SLAC

$\frac{1}{4}$-wave



I. Ben-Zvi *et al.*
BNL

4-rod



G. Bull, B. Hall
UK

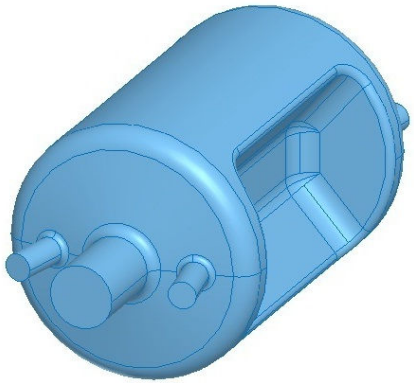
Non-axial symmetry

Higher order multipolar components of the main deflecting mode

RF-kicks influencing the beam dynamics

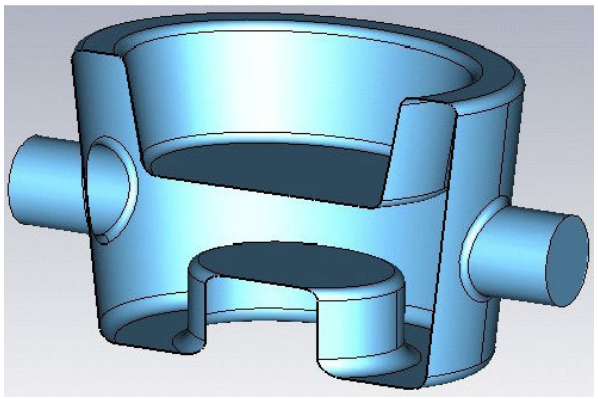
LHC CC Prototypes Already Studied

RF dipole



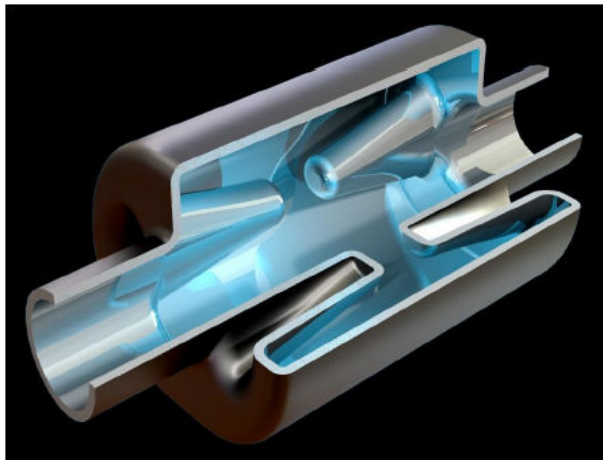
Courtesy of
Z. Li, J. Delayen *et al.*
ODU/SLAC

$\frac{1}{4}$-wave



I. Ben-Zvi *et al.*
BNL

4-rod



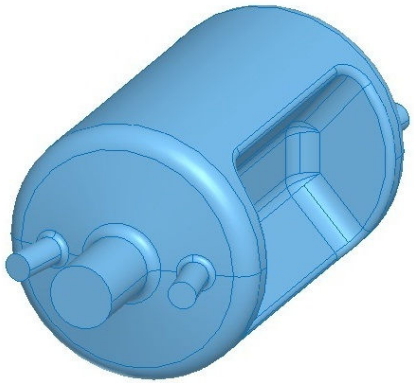
G. Bull, B. Hall
UK

Non-axial symmetry → Higher order multipolar components of the main deflecting mode

RF-kicks influencing the beam dynamics

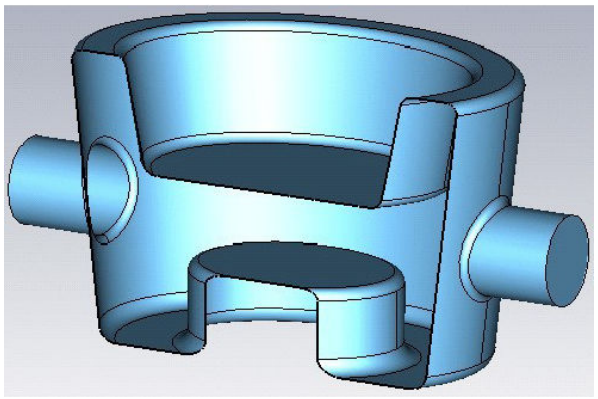
LHC CC Prototypes Already Studied

RF dipole



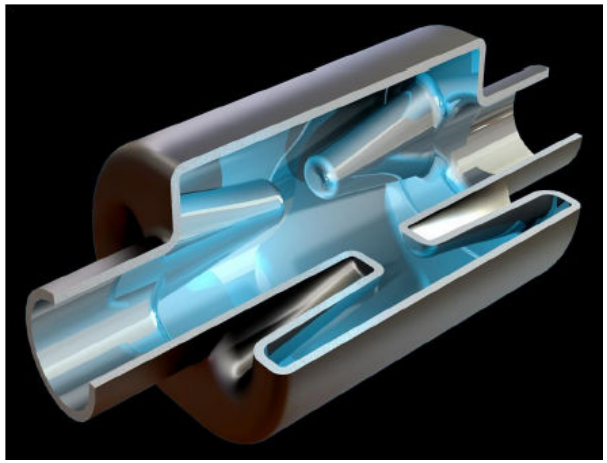
Courtesy of
Z. Li, J. Delayen *et al.*
ODU/SLAC

$\frac{1}{4}$-wave



I. Ben-Zvi *et al.*
BNL

4-rod

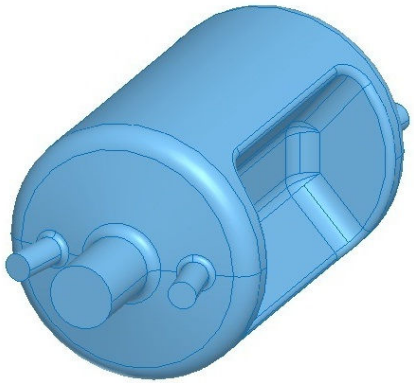


G. Bull, B. Hall
UK

Non-axial symmetry → Higher order multipolar components of the main deflecting mode → RF-kicks influencing the beam dynamics

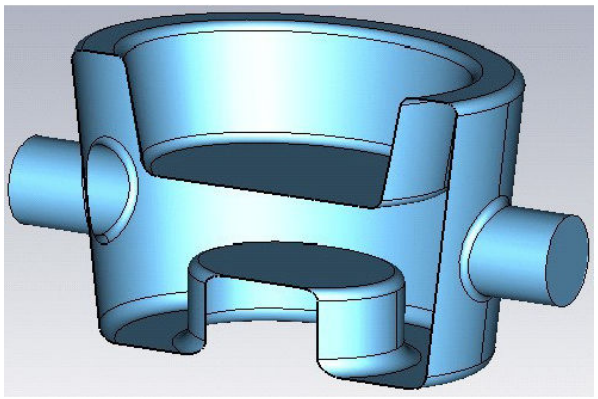
LHC CC Prototypes Already Studied

RF dipole



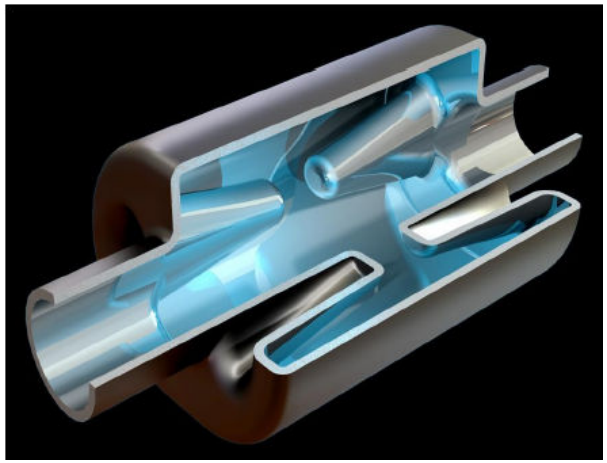
Courtesy of
Z. Li, J. Delayen *et al.*
ODU/SLAC

$\frac{1}{4}$-wave



I. Ben-Zvi *et al.*
BNL

4-rod



G. Bull, B. Hall
UK

Non-axial symmetry

Higher order multipolar components of the main deflecting mode

RF-kicks influencing the beam dynamics

Studies on Multipolar RF Quicks

Non-Linearity of Deflecting Field in LHC crab-cavities

A.Grudiev, CERN, BE-RF

15.11.2011

LHC-CC11, 14-15.11.2011, CERN

Studies on Multipolar RF Quicks

Non-Linearity of Deflecting Field in LHC crab-cavities

A.Grudiev, CERN, BE-RF

15.11.2011

LHC-CC11, 14-15.11.2011, CERN

Proceedings of IPAC2012, New Orleans, Louisiana, USA TUPPR027

STUDY OF MULTIPOLAR RF KICKS FROM THE MAIN DEFLECTING MODE IN COMPACT CRAB CAVITIES FOR LHC*

J. Barranco García, R. Calaga, R. De Maria, M. Giovannozzi, A. Grudiev, R. Tomás
CERN, Geneva, Switzerland

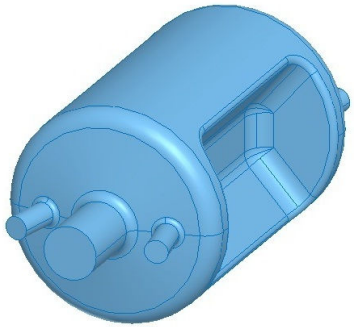
Abstract

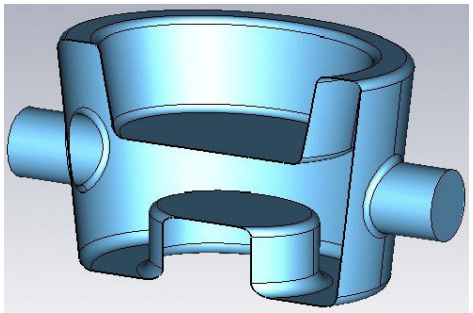
A crab cavity (CC) system is under design in the framework of the High Luminosity LHC project. Due to

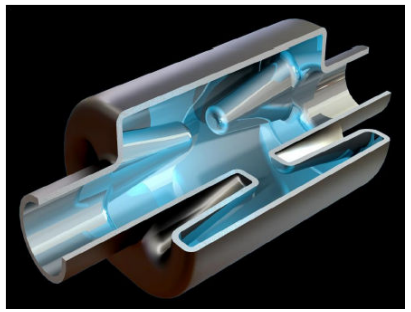
where Z_0 is vacuum impedance, u_z the unit vector in Z direction, $E_{kick} = E_{\perp} \cdot e^{j\omega z/c}$; $H_{kick} = H_{\perp} \cdot e^{j\omega z/c}$ are the electric and magnetic fields in the particle frame,

Updated Geometries

Prototypes dated on 2011



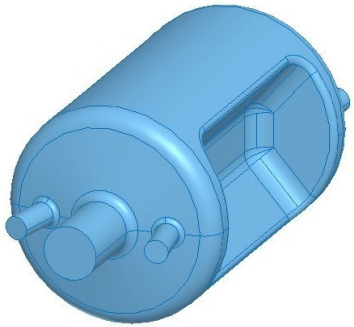


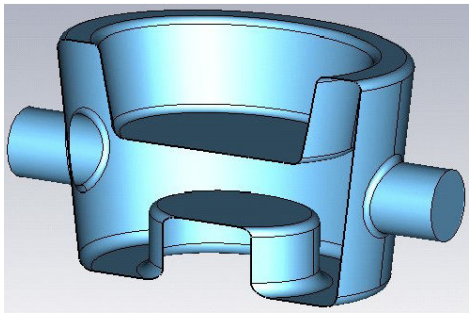


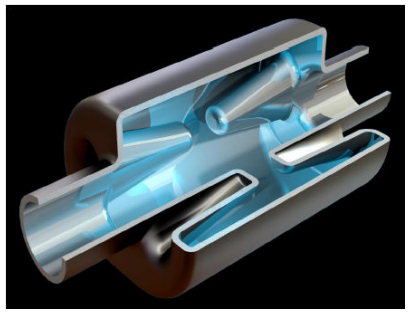
Latest prototypes as of 2012

Updated Geometries

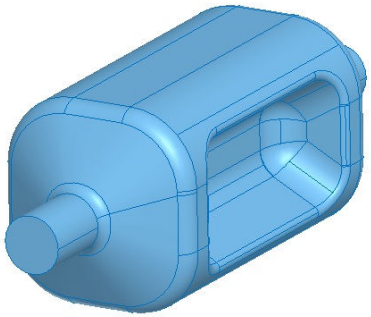
Prototypes dated on 2011

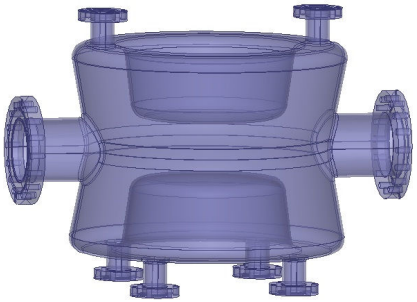


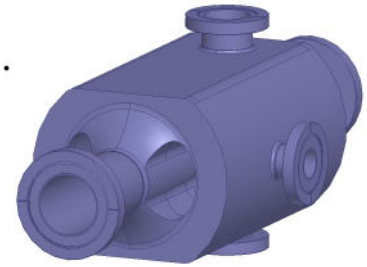




Latest prototypes as of 2012



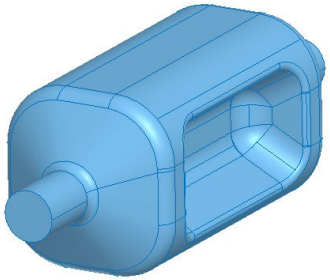
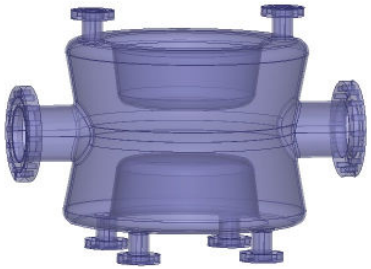
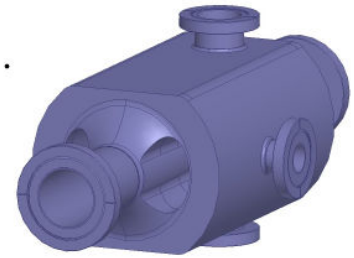




* No couplers yet

Motivation and Objectives

Updated geometries

Aim of this work

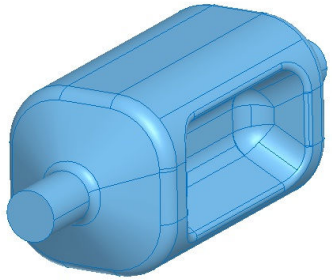
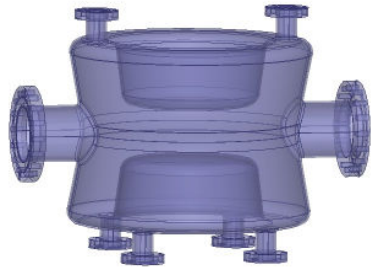
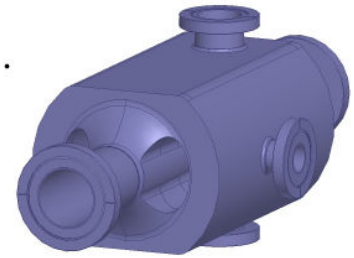
Study of the **multipolar error** on the **updated cavities**.

Tolerances from the beam-dynamic study

- Assess the strengths of the higher-order terms.
- Propose some mitigation techniques.

Motivation and Objectives

Updated geometries

Aim of this work

Study of the **multipolar error** on the **updated cavities**.

Tolerances from the beam-dynamic study

- Assess the strengths of the higher-order terms.
- Propose some mitigation techniques.

Outline

Outline

Fields Harmonics or Multipole Coefficients

Fields in the aperture of accelerator magnets

described by

Fourier coefficients (*field harmonics* or *multipole coefficients*)

Fourier expansion of the radial field components

$$B_r(r_0, \phi) = \sum_{n=1}^{\infty} [B_n(r_0) \sin n\phi + A_n(r_0) \cos n\phi]$$
$$B_\phi(r_0, \phi) = \sum_{n=1}^{\infty} [B_n(r_0) \sin n\phi - A_n(r_0) \cos n\phi]$$

Applying the field expansion to the RF fields inside a cavity

Fields Harmonics or Multipole Coefficients

Fields in the aperture of accelerator magnets

described by

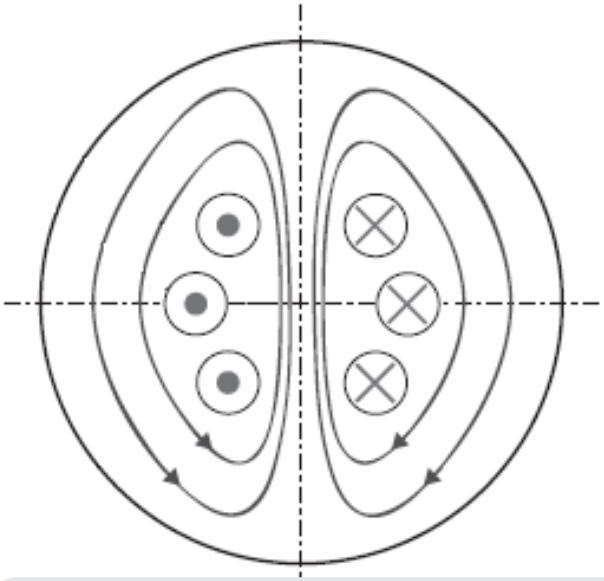
Fourier coefficients (*field harmonics* or *multipole coefficients*)

Fourier expansion of the radial field components

$$B_r(r_0, \phi) = \sum_{n=1}^{\infty} [B_n(r_0) \sin n\phi + A_n(r_0) \cos n\phi]$$
$$B_\phi(r_0, \phi) = \sum_{n=1}^{\infty} [B_n(r_0) \sin n\phi - A_n(r_0) \cos n\phi]$$

Applying the **field expansion** to the **RF fields inside a cavity**

Effects of the cavity symmetry



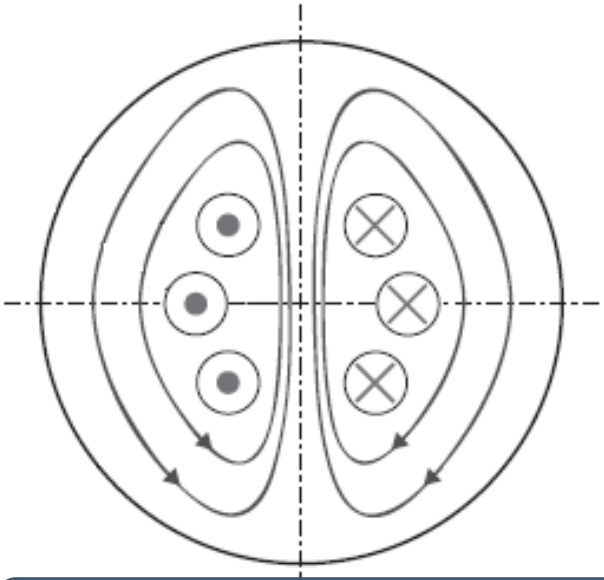
Main deflecting mode (TM_{110} mode) of an axially symmetric cavity:

- Only dipolar variation ($n = 1$)

As long as the cavity is far from axial symmetry...

All the remaining multipolar components ($n > 1$) might be present!

Effects of the cavity symmetry



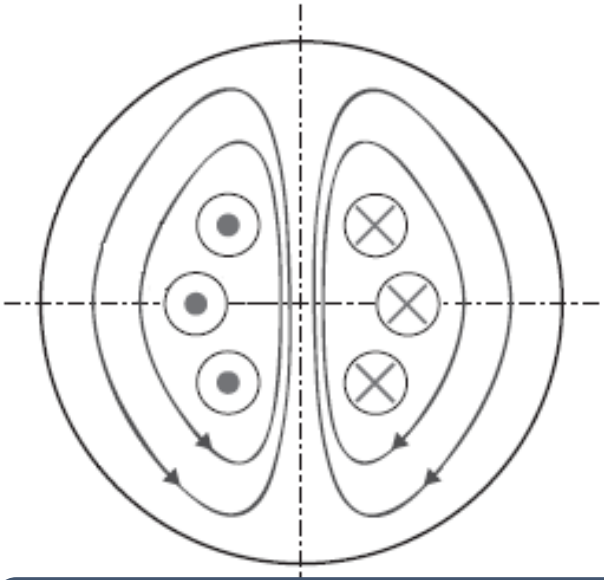
Main deflecting mode (TM_{110} mode) of an axially symmetric cavity:

- Only dipolar variation ($n = 1$)

As long as the cavity is far from axial symmetry...

All the remaining multipolar components ($n > 1$) might be present!

Effects of the cavity symmetry

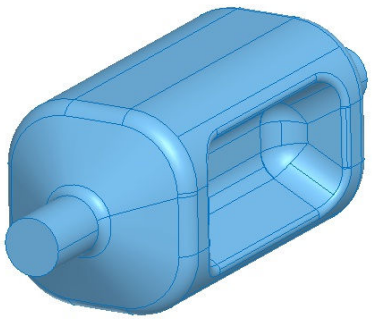


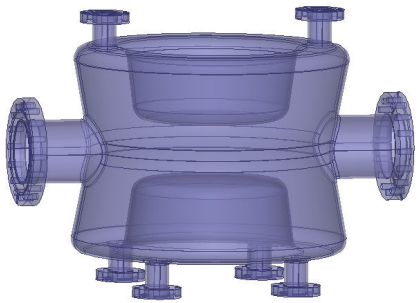
Main deflecting mode (TM_{110} mode) of an axially symmetric cavity:

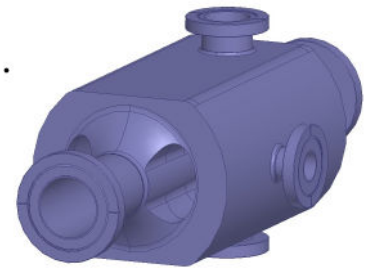
- Only dipolar variation ($n = 1$)

As long as the cavity is far from axial symmetry...

All the remaining multipolar components ($n > 1$) might be present!







Some comments on the analysis

Calculation of the multipolar components of the transverse kicks:

1. Lorentz force.
   $F_\perp = q\left[E_\perp + v_z \times B_\perp\right]$
2. Panofsky-Wenzel theorem
   $$\Delta p_\perp(r,\phi) = \frac{jq}{\omega}\int_0^L \nabla_\perp E_{acc}(r,\phi,z)\,\mathrm{d}z,$$
   where $E_{acc} = E_z e^{jkz}$ is the accelerating field.

Assumptions made valid for the LHC:

- The particle is moving parallel to the z axis,
- at the speed of light.

Some comments on the analysis

Calculation of the multipolar components of the transverse kicks:

1. Lorentz force.
   $F_\perp = q\,[E_\perp + v_z \times B_\perp]$
2. Panofsky-Wenzel theorem
   $$\Delta p_\perp(r,\phi) = \frac{jq}{\omega}\int_0^L \nabla_\perp E_{acc}(r,\phi,z)\,\mathrm{d}z,$$
   where $E_{acc} = E_z e^{jkz}$ is the accelerating field.

Assumptions made valid for the LHC:

- The particle is moving parallel to the z axis,
- at the speed of light.

Some comments on the analysis

Calculation of the multipolar components of the transverse kicks:

1. Lorentz force.
   $F_\perp = q\,[E_\perp + v_z \times B_\perp]$
2. Panofsky-Wenzel theorem
   $$\Delta p_\perp(r,\phi) = \frac{jq}{\omega}\int_0^L \nabla_\perp E_{acc}(r,\phi,z)\,\mathrm{d}z,$$
   where $E_{acc} = E_z e^{jkz}$ is the accelerating field.

Assumptions made valid for the LHC:

- The particle is moving parallel to the z axis,
- at the speed of light.

Some comments on the analysis

Calculation of the multipolar components of the transverse kicks:

1. Lorentz force.
   $F_\perp = q\,[E_\perp + v_z \times B_\perp]$
2. Panofsky-Wenzel theorem
   $$\Delta p_\perp(r,\phi) = \frac{jq}{\omega}\int_0^L \nabla_\perp E_{acc}(r,\phi,z)\,\mathrm{d}z,$$
   where $E_{acc} = E_z e^{jkz}$ is the accelerating field.

Assumptions made valid for the LHC:

- The particle is moving parallel to the z axis,
- at the speed of light.

Transverse RF Kick

Summary

Lorentz Force

$$\Delta p_{\perp}^{(n)} = \frac{1}{v_z} r^{n-1} \left[\vec{u}_r \cos(n\phi) + \vec{u}_\phi \sin(n\phi)\right] \int_0^L F_{\perp}^{(n)} \, \mathrm{d}z$$

Panofsky-Wenzel

$$\Delta p_{\perp}^{(n)} = \frac{jq}{\omega} n r^{n-1} \left[\vec{u}_r \cos(n\phi) + \vec{u}_\phi \sin(n\phi)\right] \int_0^L E_{acc}^{(n)}(z) \, \mathrm{d}z$$

RF Multipoles versus Magnetic Multipoles

Magnetic multipoles

- Static.
- Kick non-dependent on the longitudinal position of particles.

RF multipoles

- Harmonically oscillating (ω_{RF}).
- Kick does depend on the RF phase of the particle.

Equating the RF and magnetic multipoles...

$$B_{\perp}^{(n)} = \frac{1}{qc} F_{\perp}^{(n)} = \frac{nj}{\omega} E_{acc}^{(n)} \qquad [Tm/m^n]$$

The RF kick coefficients...

$$b_n = \int_0^L B_{\perp}^{(n)} \, \mathrm{d}z \in \mathbb{C} \qquad [Tm/m^{n-1}]$$

RF Multipoles versus Magnetic Multipoles

Magnetic multipoles

- Static.
- Kick non-dependent on the longitudinal position of particles.

RF multipoles

- Harmonically oscillating (ω_{RF}).
- Kick does depend on the RF phase of the particle.

Equating the RF and magnetic multipoles...

$$B_{\perp}^{(n)} = \frac{1}{qc} F_{\perp}^{(n)} = \frac{nj}{\omega} E_{acc}^{(n)} \qquad [Tm/m^n]$$

The RF kick coefficients...

$$b_n = \int_0^L B_{\perp}^{(n)} \, \mathrm{d}z \in \mathbb{C} \qquad [Tm/m^{n-1}]$$

RF Multipoles versus Magnetic Multipoles

Magnetic multipoles

- Static.
- Kick non-dependent on the longitudinal position of particles.

RF multipoles

- Harmonically oscillating (ω_{RF}).
- Kick does depend on the RF phase of the particle.

Equating the RF and magnetic multipoles...

$$B_{\perp}^{(n)} = \frac{1}{qc} F_{\perp}^{(n)} = \frac{nj}{\omega} E_{acc}^{(n)} \qquad [Tm/m^n]$$

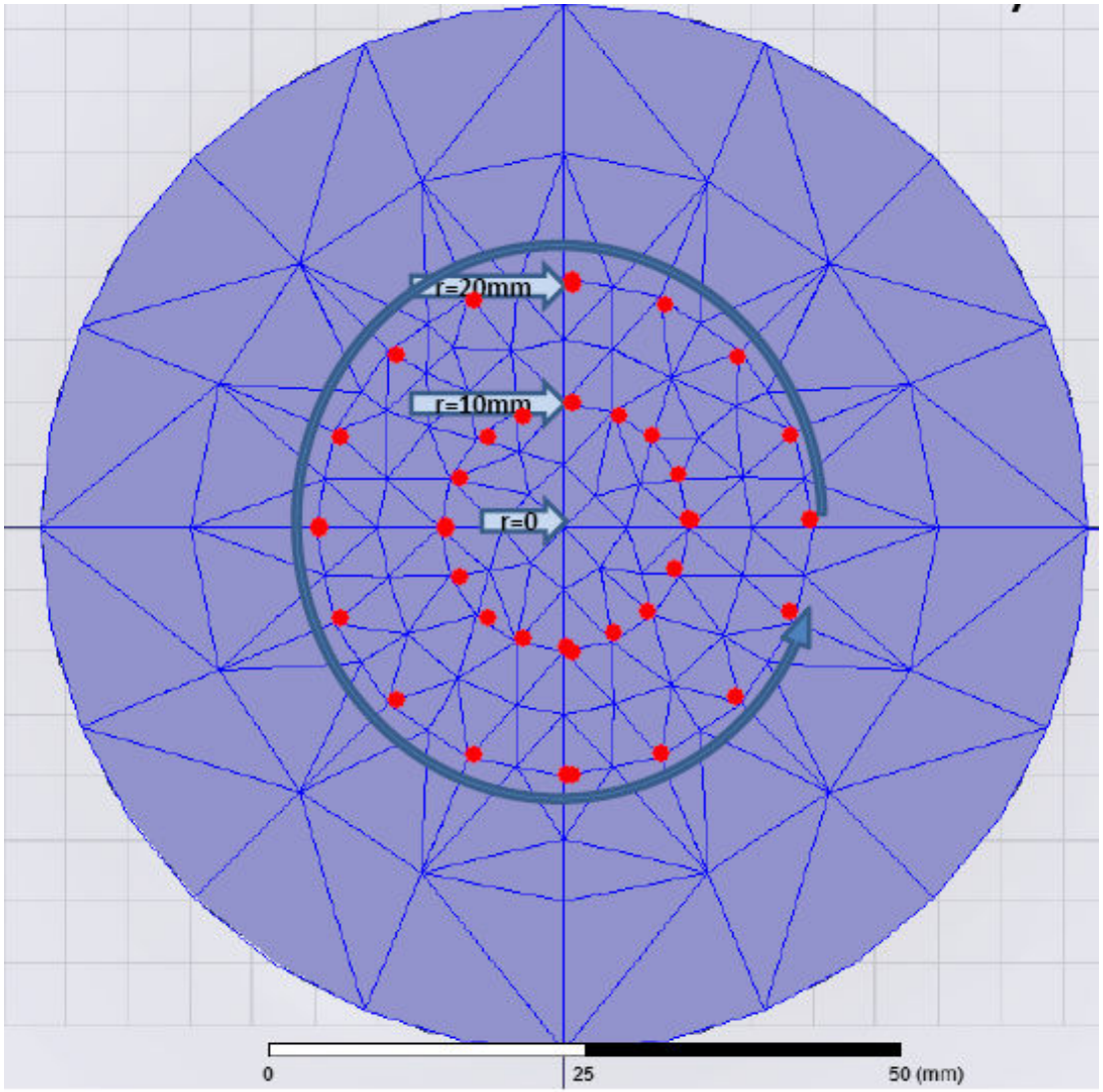
The RF kick coefficients...

$$b_n = \int_0^L B_{\perp}^{(n)} \, \mathrm{d}z \in \mathbb{C} \qquad [Tm/m^{n-1}]$$

Outline

Mesh definition

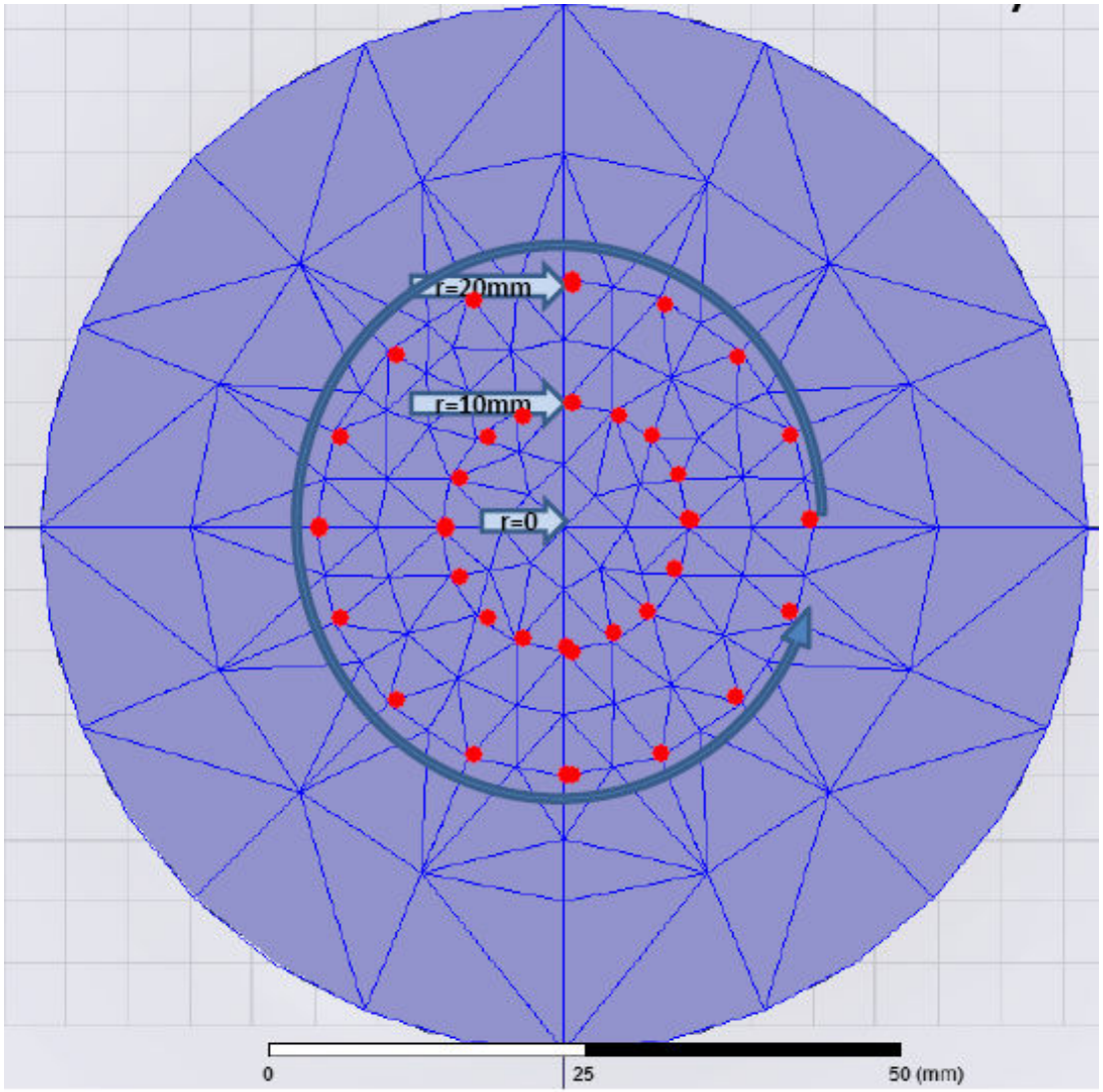
- Mesh in the vicinity of the beam axis:
  - 7 mm for $r < 20$ mm
  - 15 mm for $r < 30$ mm
- Surface approx. of 1mm.
- # tetrahedra $\backsim 3.8\,10^5$
- Server: 1.00 TB of RAM, 4 processors @ 2.67 GHz
- Simulation time $\backsim 6 - 12$ hours



A. Grudiev

Mesh definition

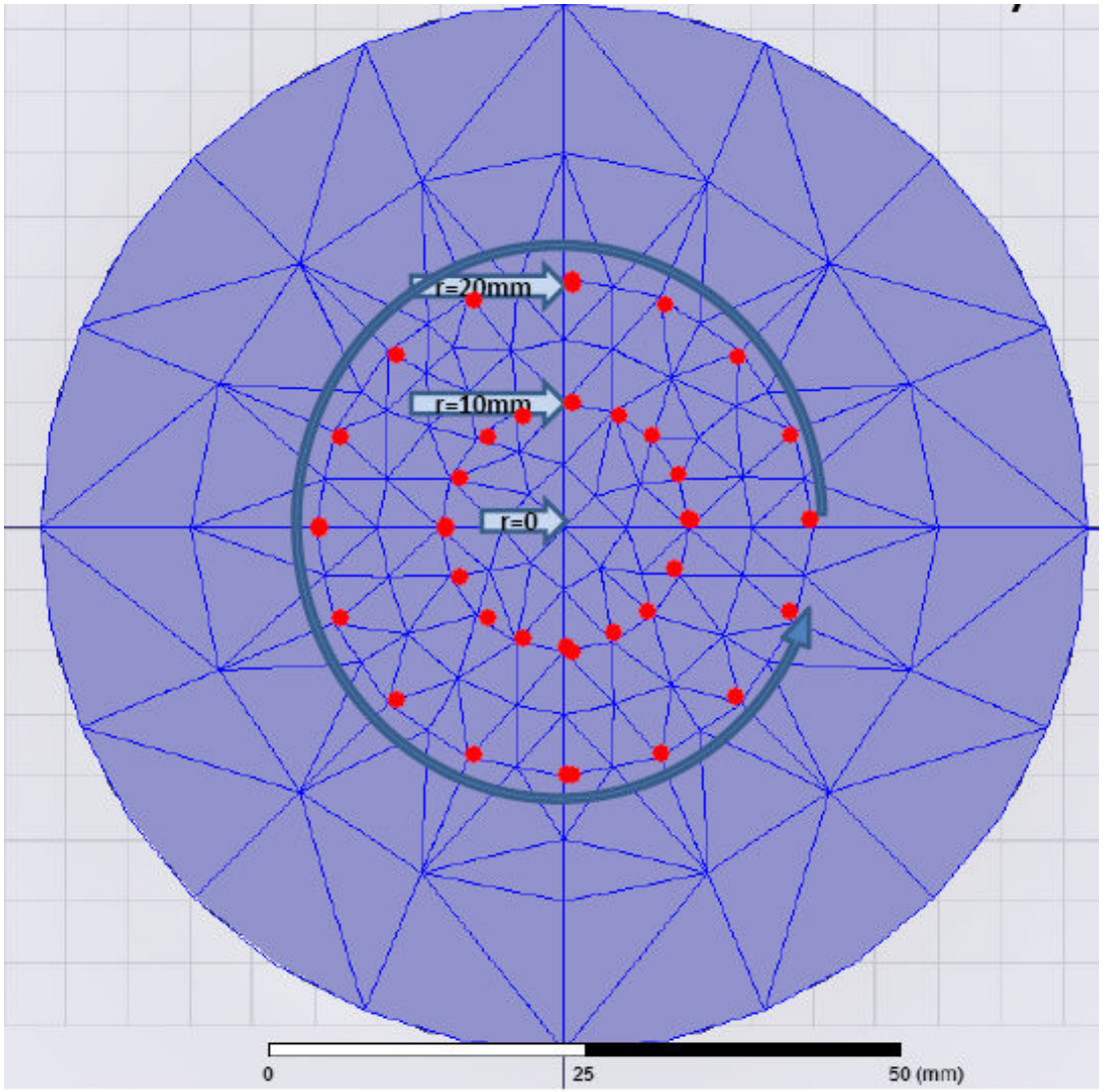
- Mesh in the vicinity of the beam axis:
  - 7 mm for $r < 20$ mm
  - 15 mm for $r < 30$ mm
- Surface approx. of 1mm.
- # tetrahedra $\backsim 3.8\,10^5$
- Server: 1.00 TB of RAM, 4 processors @ 2.67 GHz
- Simulation time $\backsim 6 - 12$ hours



A. Grudiev

Mesh definition

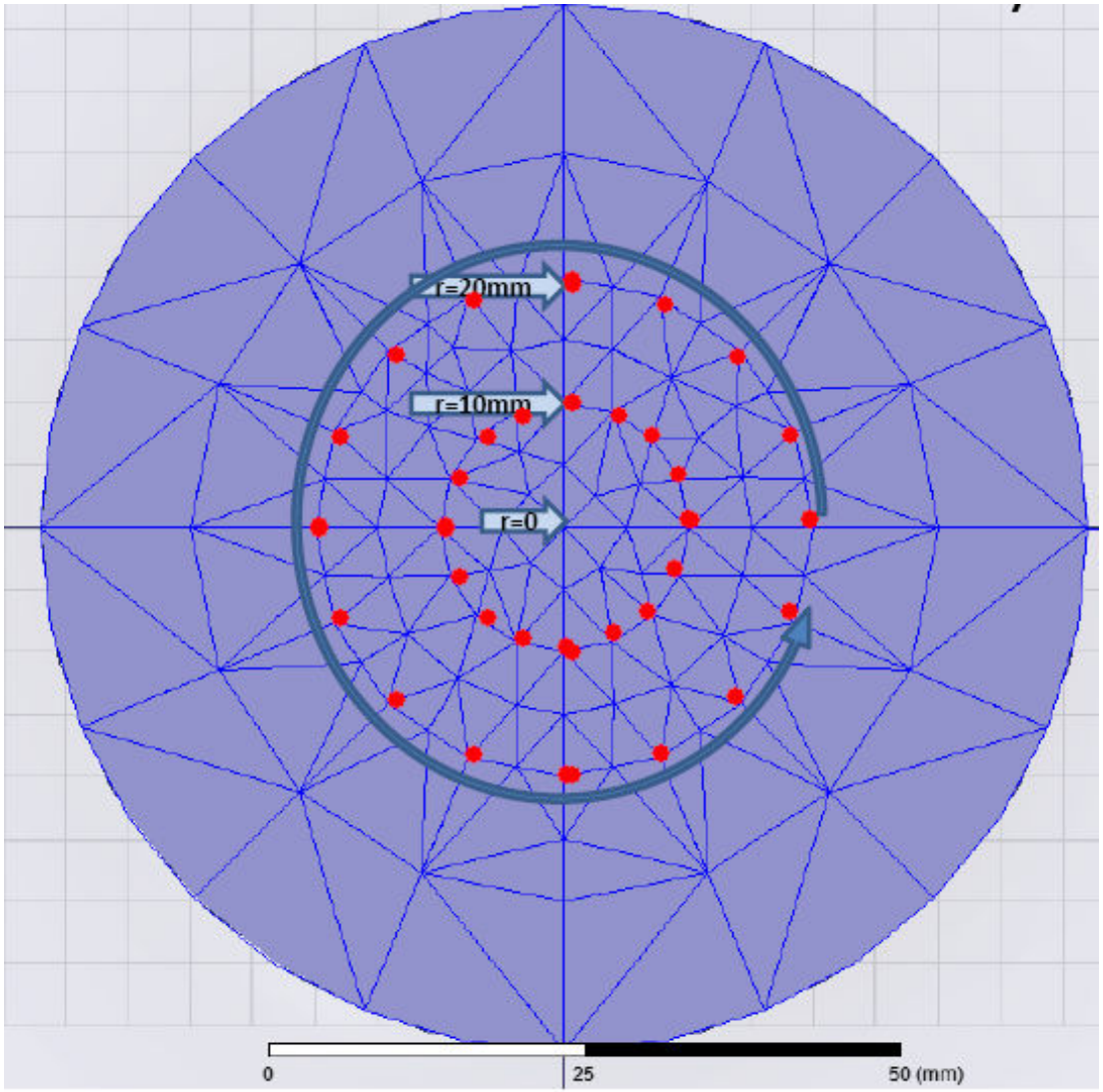
- Mesh in the vicinity of the beam axis:
  - 7 mm for $r < 20$ mm
  - 15 mm for $r < 30$ mm
- Surface approx. of 1mm.
- # tetrahedra $\backsim 3.8\,10^5$
- Server: 1.00 TB of RAM, 4 processors @ 2.67 GHz
- Simulation time $\backsim 6 - 12$ hours



A. Grudiev

Mesh definition

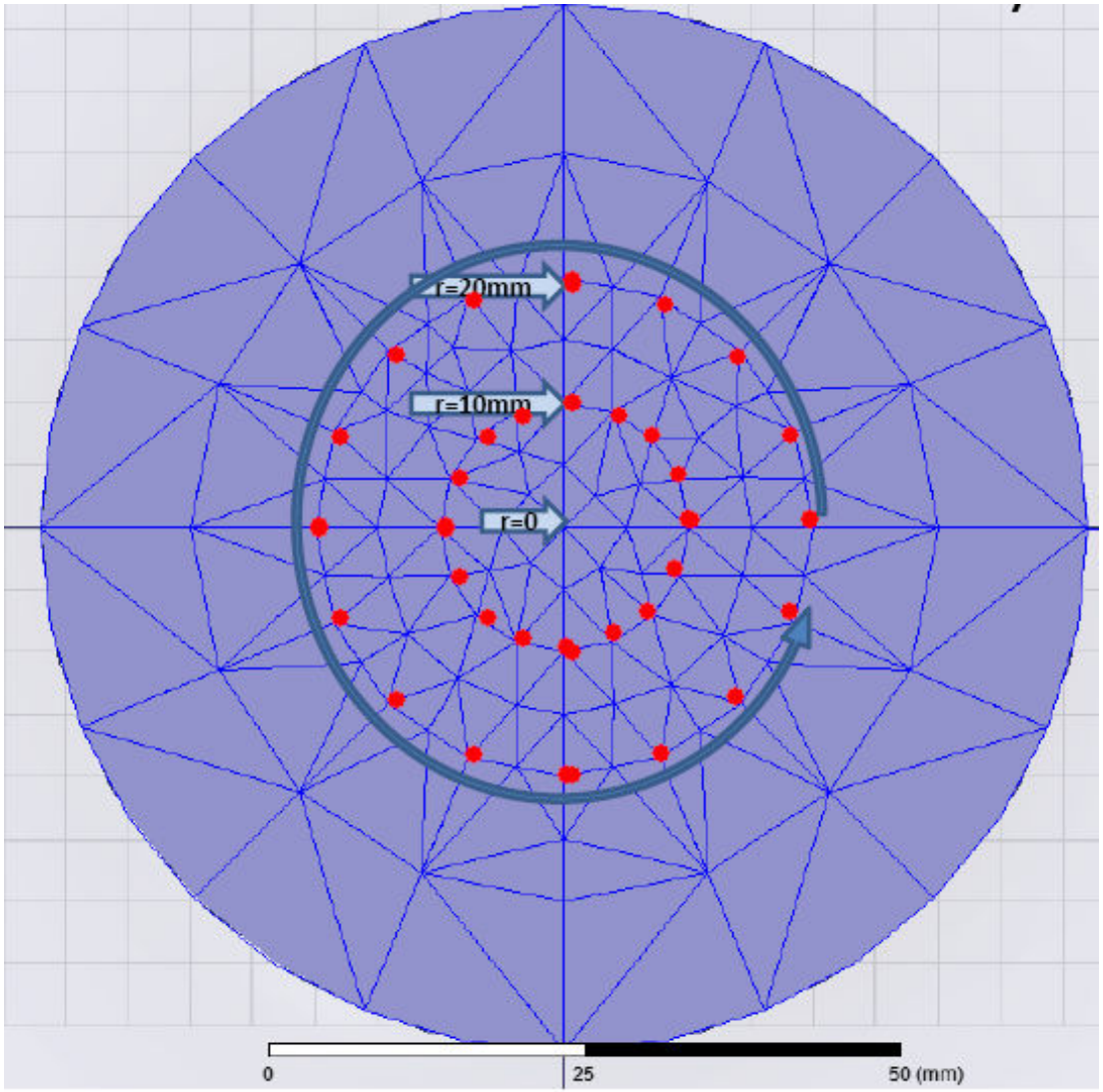
- Mesh in the vicinity of the beam axis:
  - 7 mm for $r < 20$ mm
  - 15 mm for $r < 30$ mm
- Surface approx. of 1mm.
- # tetrahedra $\backsim 3.8\,10^5$
- Server: 1.00 TB of RAM, 4 processors @ 2.67 GHz
- Simulation time $\backsim 6 - 12$ hours



A. Grudiev

Mesh definition

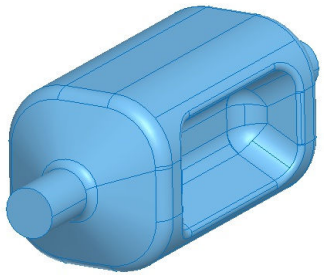
- Mesh in the vicinity of the beam axis:
  - 7 mm for $r < 20$ mm
  - 15 mm for $r < 30$ mm
- Surface approx. of 1mm.
- # tetrahedra $\backsim 3.8\,10^5$
- Server: 1.00 TB of RAM, 4 processors @ 2.67 GHz
- Simulation time $\backsim 6 - 12$ hours

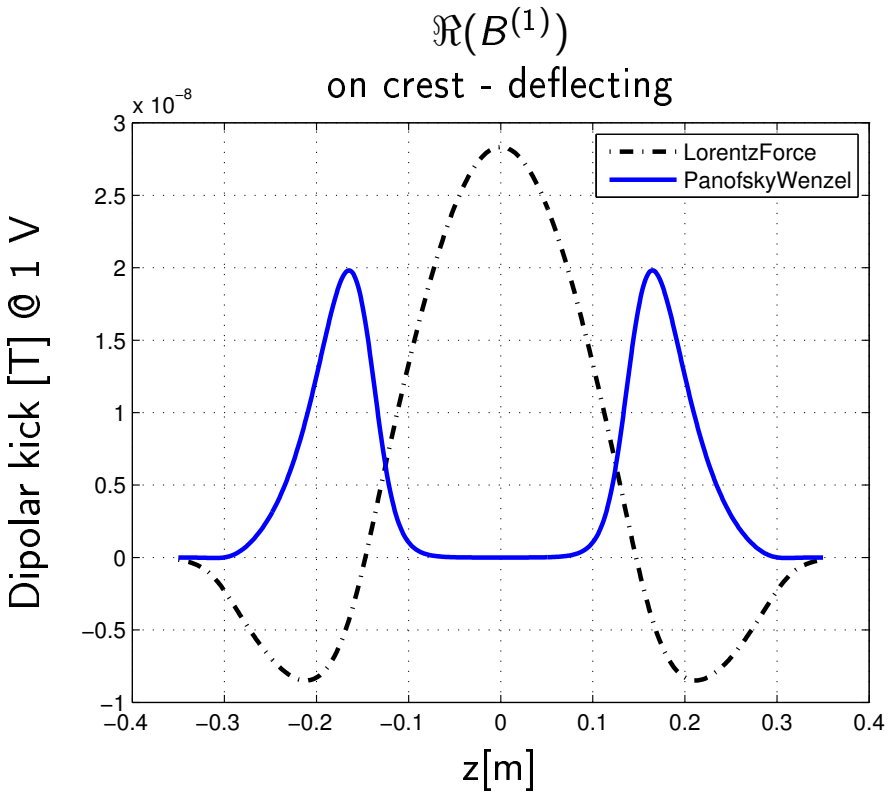


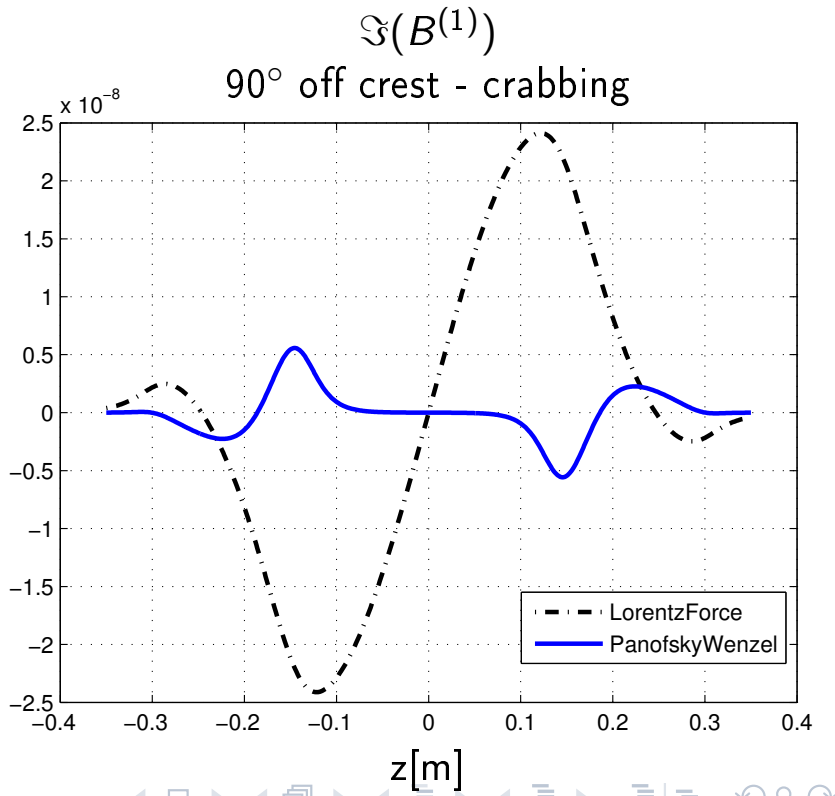
A. Grudiev

Dipolar Kick at $V_x = 1$ V

Example: RF dipole (ridge) cavity

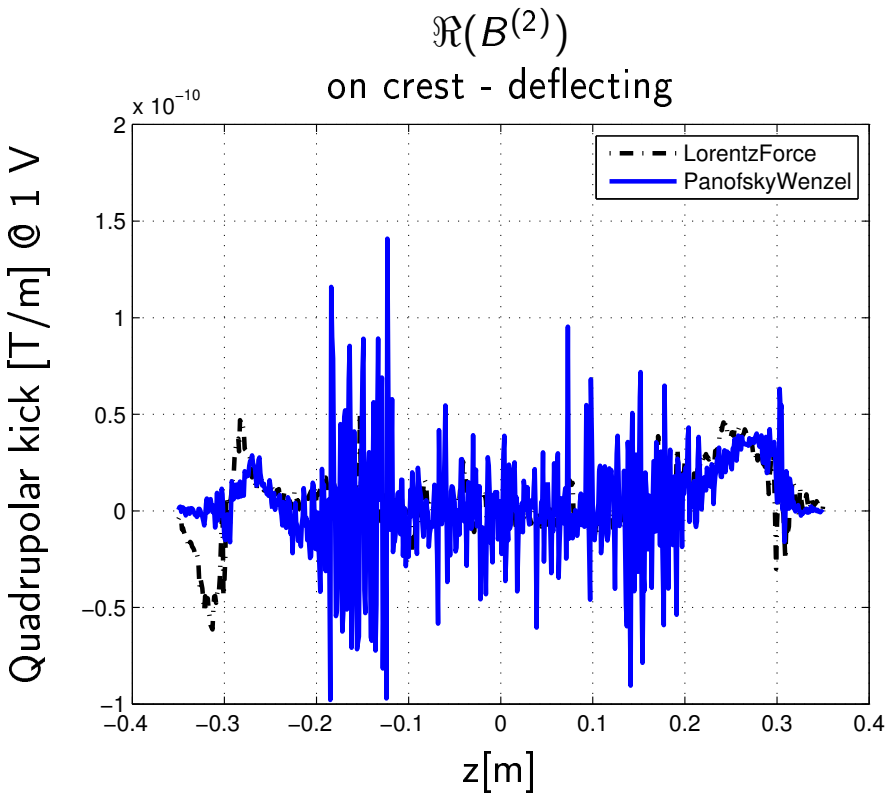


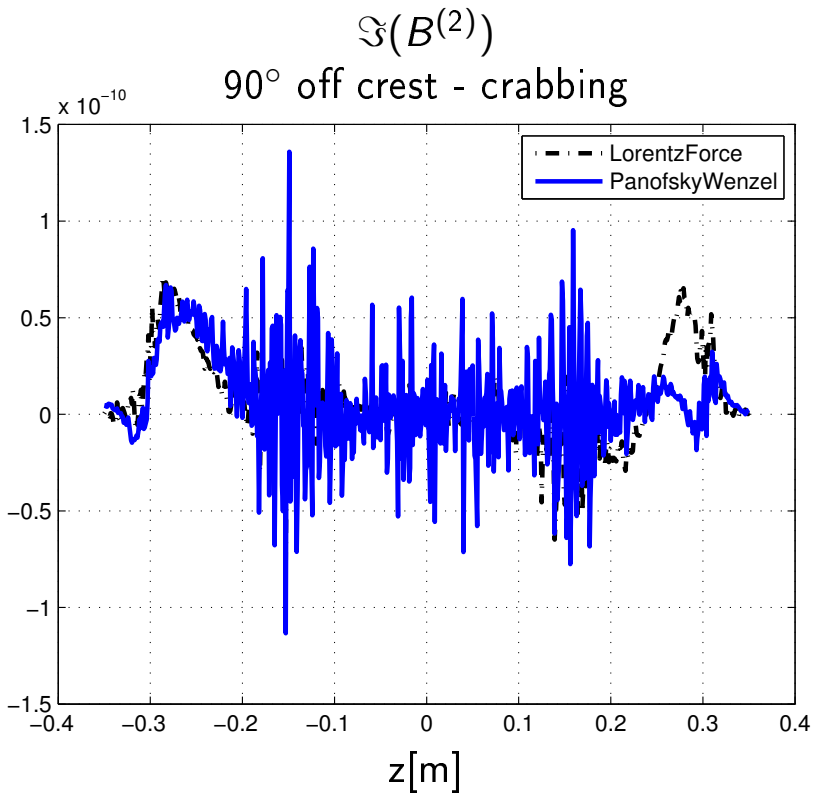




Quadrupolar Kick at $V_x = 1$ V

Example: RF dipole (ridge) cavity



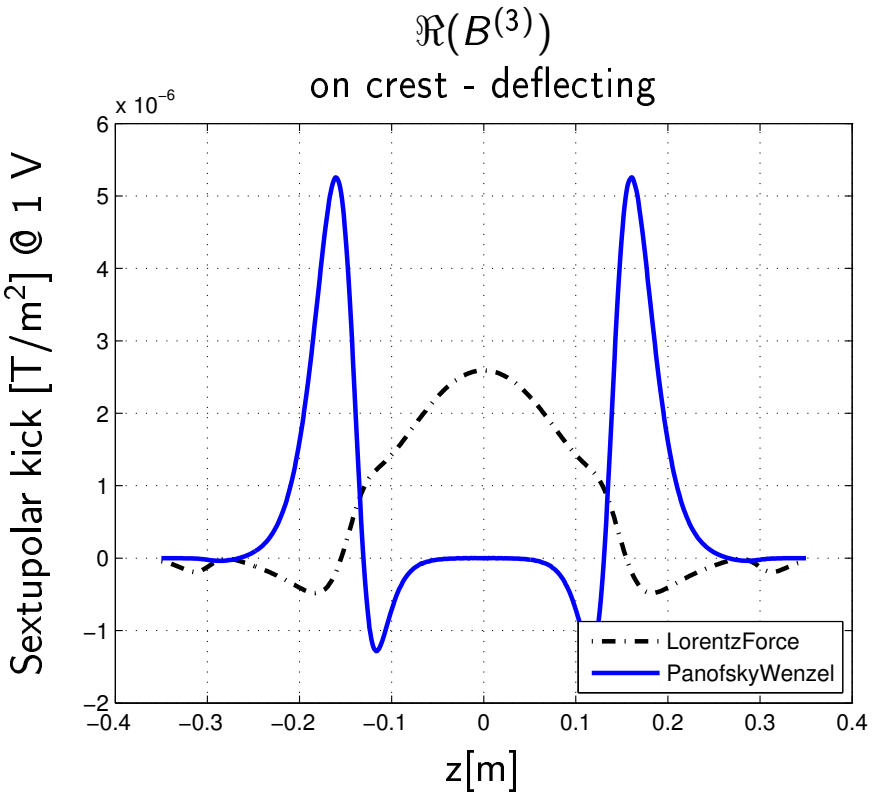


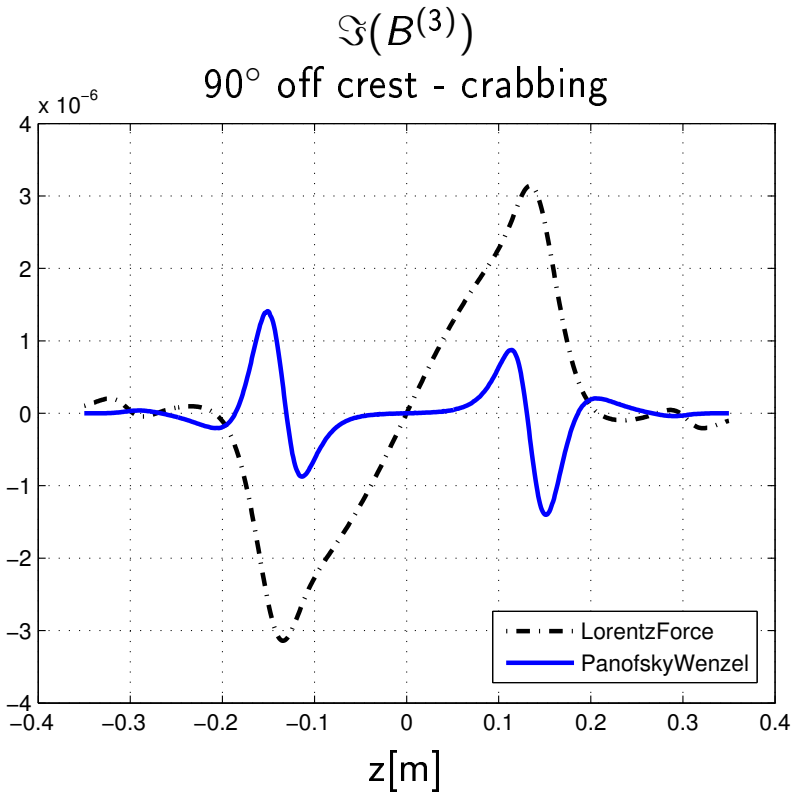
$$b_2(LF) = \int_0^L \frac{1}{qc} F_\perp^{(2)} \, \mathrm{d}z = 0.00 + j0.01 \quad [nTm/m]$$

$$b_2(PW) = \int_0^L \frac{j2}{\omega} E_{acc}^{(2)} \, \mathrm{d}z = 0.00 + j0.01 \quad [nTm/m]$$

Sextupolar Kick at $V_x = 1$ V

Example: RF dipole (ridge) cavity



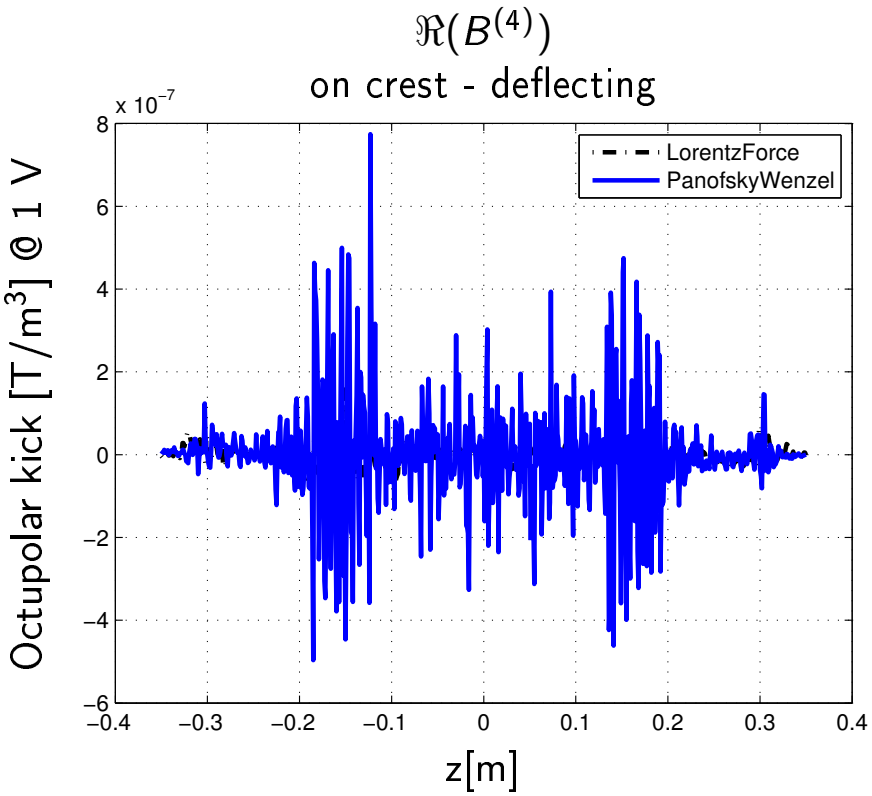


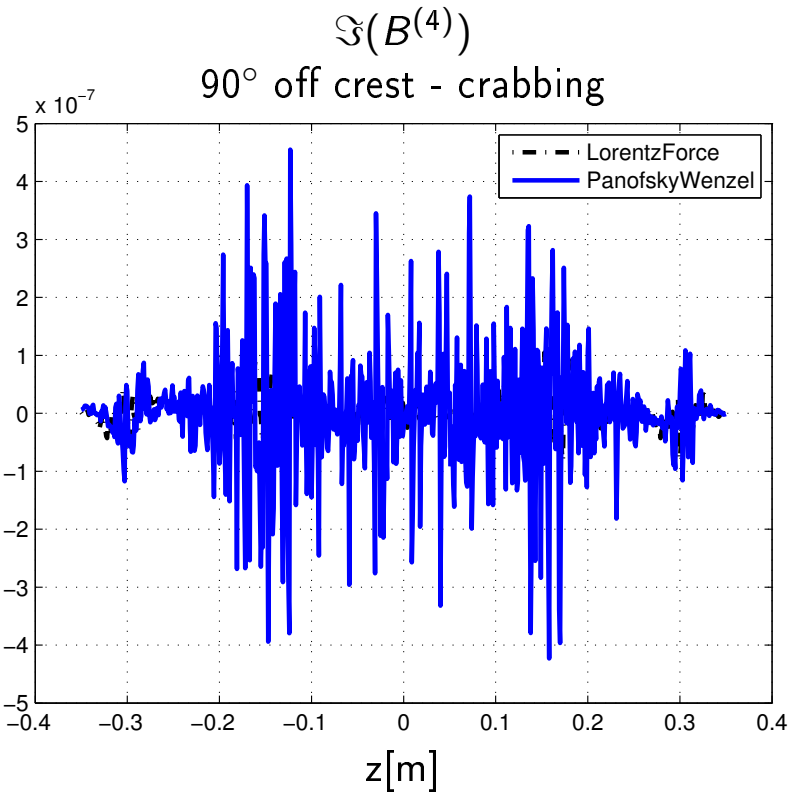
$$b_3(LF) = \int_0^L \frac{1}{qc} F_\perp^{(3)} \, \mathrm{d}z = 452.67 - j0.04 \quad [nTm/m^2]$$

$$b_3(PW) = \int_0^L \frac{j3}{\omega} E_{acc}^{(3)} \, \mathrm{d}z = 451.73 - j0.04 \quad [nTm/m^2]$$

Octupolar Kick at $V_x = 1$ V

Example: RF dipole (ridge) cavity

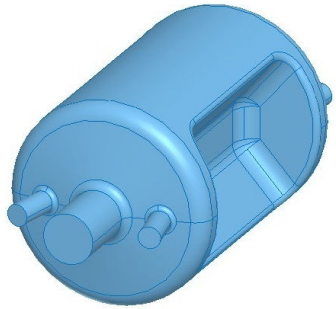


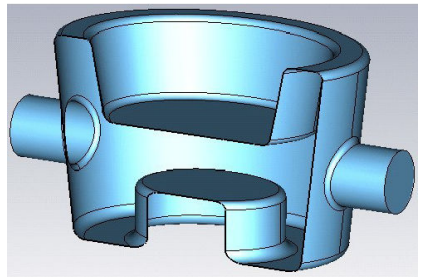


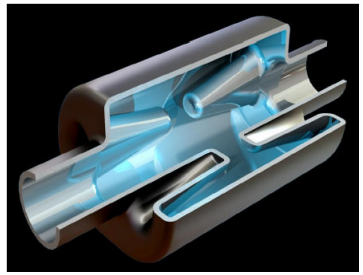
$$b_4(LF) = \int_0^L \frac{1}{qc} F_\perp^{(4)} \, \mathrm{d}z = -0.24 + j1.11 \quad [nTm/m^3]$$

$$b_4(PW) = \int_0^L \frac{j4}{\omega} E_{acc}^{(4)} \, \mathrm{d}z = 1.26 + j0.52 \quad [nTm/m^3]$$

2011 prototypes



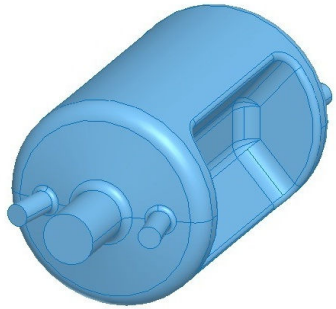


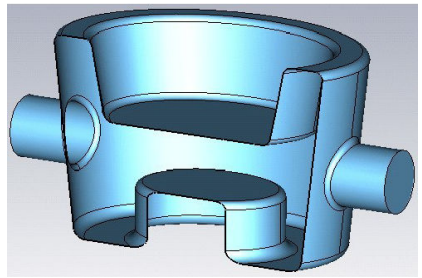


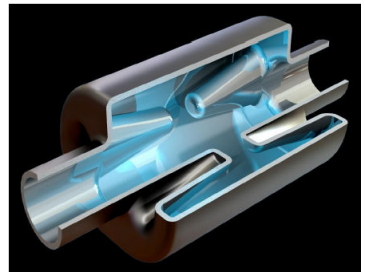
$V_x = 10$ MV	$b_2[mTm/m]$		$b_3[mTm/m^2]$		$b_4[mTm/m^3]$	
	$\Re(b_2)$	$\Im(b_2)$	$\Re(b_3)$	$\Im(b_3)$	$\Re(b_4)$	$\Im(b_4)$
RF dipole	−0.01	0.22	3203.29	−0.17	50.03	59.66
$\frac{1}{4}$**-wave**	111.34	0.00	1266.72	−0.15	1821.02	11.48
4-rod	0.02	0.02	900.90	−0.33	74.31	40.57
RF dipole	0.03	0.05	4526.66	−0.41	−2.39	11.12
$\frac{1}{4}$**-wave**	0.36	0.06	1076.75	0.01	90.86	−17.94
4-rod*	−3.66	−1.91	−21561.95	692.32	−2100.47	699.00

* Geometry for this cavity should be revised.

2011 prototypes







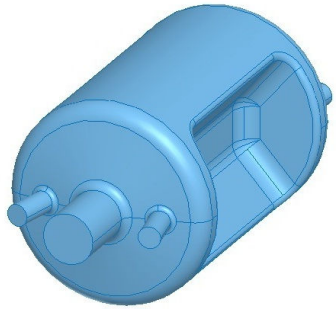
$V_x = 10$ MV	$b_2[mTm/m]$		$b_3[mTm/m^2]$		$b_4[mTm/m^3]$	
	$\Re(b_2)$	$\Im(b_2)$	$\Re(b_3)$	$\Im(b_3)$	$\Re(b_4)$	$\Im(b_4)$
RF dipole	−0.01	0.22	3203.29	−0.17	50.03	59.66
$\frac{1}{4}$**-wave**	111.34	0.00	1266.72	−0.15	1821.02	11.48
4-rod	0.02	0.02	900.90	−0.33	74.31	40.57

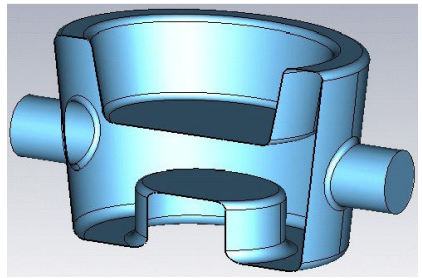
RF dipole	0.03	0.05	4526.66	−0.41	−2.39	11.12
$\frac{1}{4}$**-wave**	0.36	0.06	1076.75	0.01	90.86	−17.94
4-rod*	−3.66	−1.91	−21561.95	692.32	−2100.47	699.00

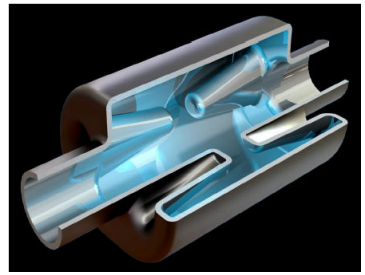
2012 Updated geometries

* Geometry for this cavity should be revised.

2011 prototypes



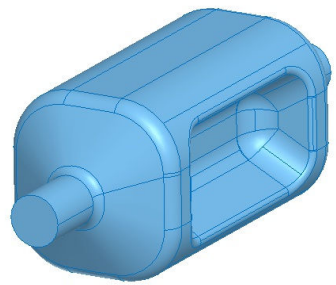




$V_x = 10$ MV	$b_2[mTm/m]$		$b_3[mTm/m^2]$		$b_4[mTm/m^3]$	
	$\Re(b_2)$	$\Im(b_2)$	$\Re(b_3)$	$\Im(b_3)$	$\Re(b_4)$	$\Im(b_4)$
RF dipole	−0.01	0.22	3203.29	−0.17	50.03	59.66
$\frac{1}{4}$**-wave**	111.34	0.00	1266.72	−0.15	1821.02	11.48
4-rod	0.02	0.02	900.90	−0.33	74.31	40.57

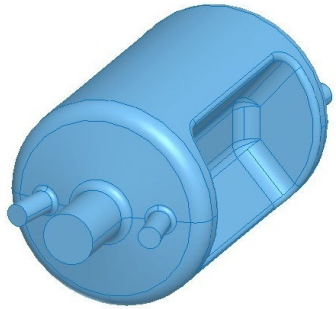
RF dipole	0.03	0.05	4526.66	−0.41	−2.39	11.12
$\frac{1}{4}$**-wave**	0.36	0.06	1076.75	0.01	90.86	−17.94
4-rod*	−3.66	−1.91	−21561.95	692.32	−2100.47	699.00

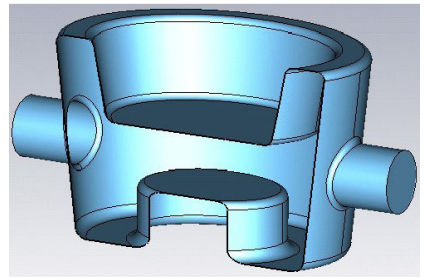
2012 Updated geometries

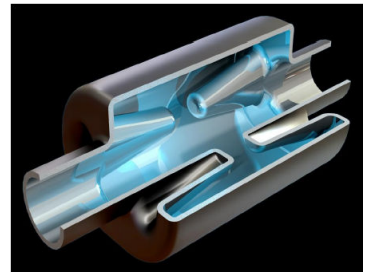


* Geometry for this cavity should be revised.

2011 prototypes



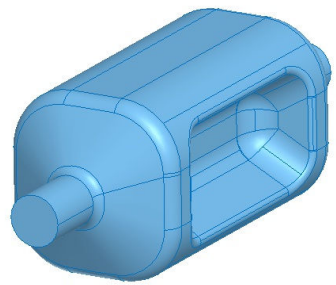


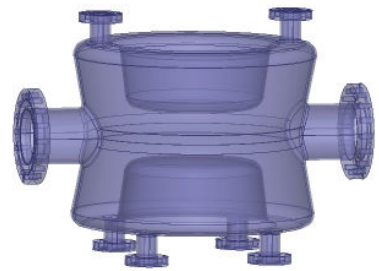


$V_x = 10$ MV	$b_2[mTm/m]$		$b_3[mTm/m^2]$		$b_4[mTm/m^3]$	
	$\Re(b_2)$	$\Im(b_2)$	$\Re(b_3)$	$\Im(b_3)$	$\Re(b_4)$	$\Im(b_4)$
RF dipole	−0.01	0.22	3203.29	−0.17	50.03	59.66
$\frac{1}{4}$**-wave**	111.34	0.00	1266.72	−0.15	1821.02	11.48
4-rod	0.02	0.02	900.90	−0.33	74.31	40.57

RF dipole	0.03	0.05	4526.66	−0.41	−2.39	11.12
$\frac{1}{4}$**-wave**	0.36	0.06	1076.75	0.01	90.86	−17.94
4-rod*	−3.66	−1.91	−21561.95	692.32	−2100.47	699.00

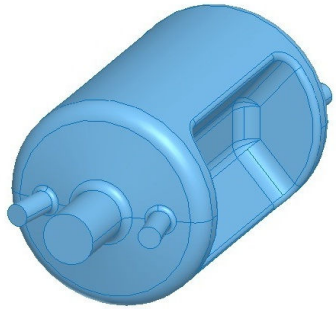
2012 Updated geometries

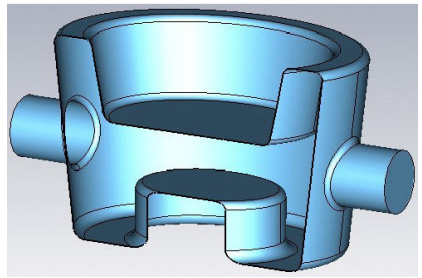


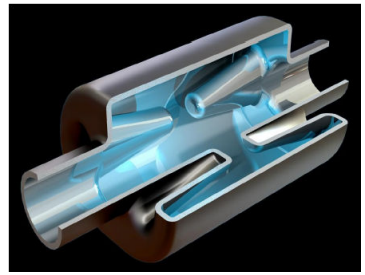


* Geometry for this cavity should be revised.

2011 prototypes

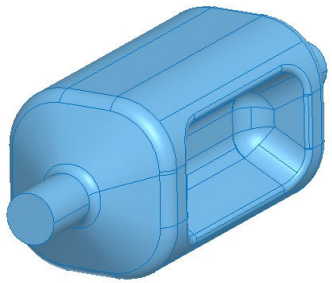


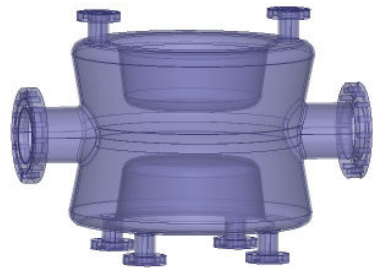


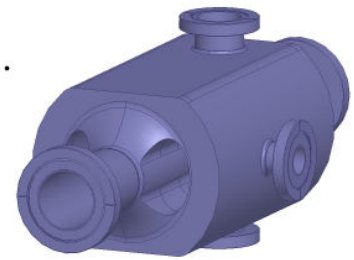


$V_x = 10$ MV	$b_2[mTm/m]$		$b_3[mTm/m^2]$		$b_4[mTm/m^3]$	
	$\Re(b_2)$	$\Im(b_2)$	$\Re(b_3)$	$\Im(b_3)$	$\Re(b_4)$	$\Im(b_4)$
RF dipole	−0.01	0.22	3203.29	−0.17	50.03	59.66
$\frac{1}{4}$**-wave**	111.34	0.00	1266.72	−0.15	1821.02	11.48
4-rod	0.02	0.02	900.90	−0.33	74.31	40.57
RF dipole	0.03	0.05	4526.66	−0.41	−2.39	11.12
$\frac{1}{4}$**-wave**	0.36	0.06	1076.75	0.01	90.86	−17.94
4-rod*	−3.66	−1.91	−21561.95	692.32	−2100.47	699.00

2012 Updated geometries







* Geometry for this cavity should be revised.

Outline

Future Work (i)

Accuracy

- Obtain an **estimation** of the **numerical accuracy** achieved.
- Error analysis.

Measurements. Feasibility Study

- Aluminium prototype of the 1/4-wave cavity.
- A bead-pull set up is being under consideration (3D).

Future Work (i)

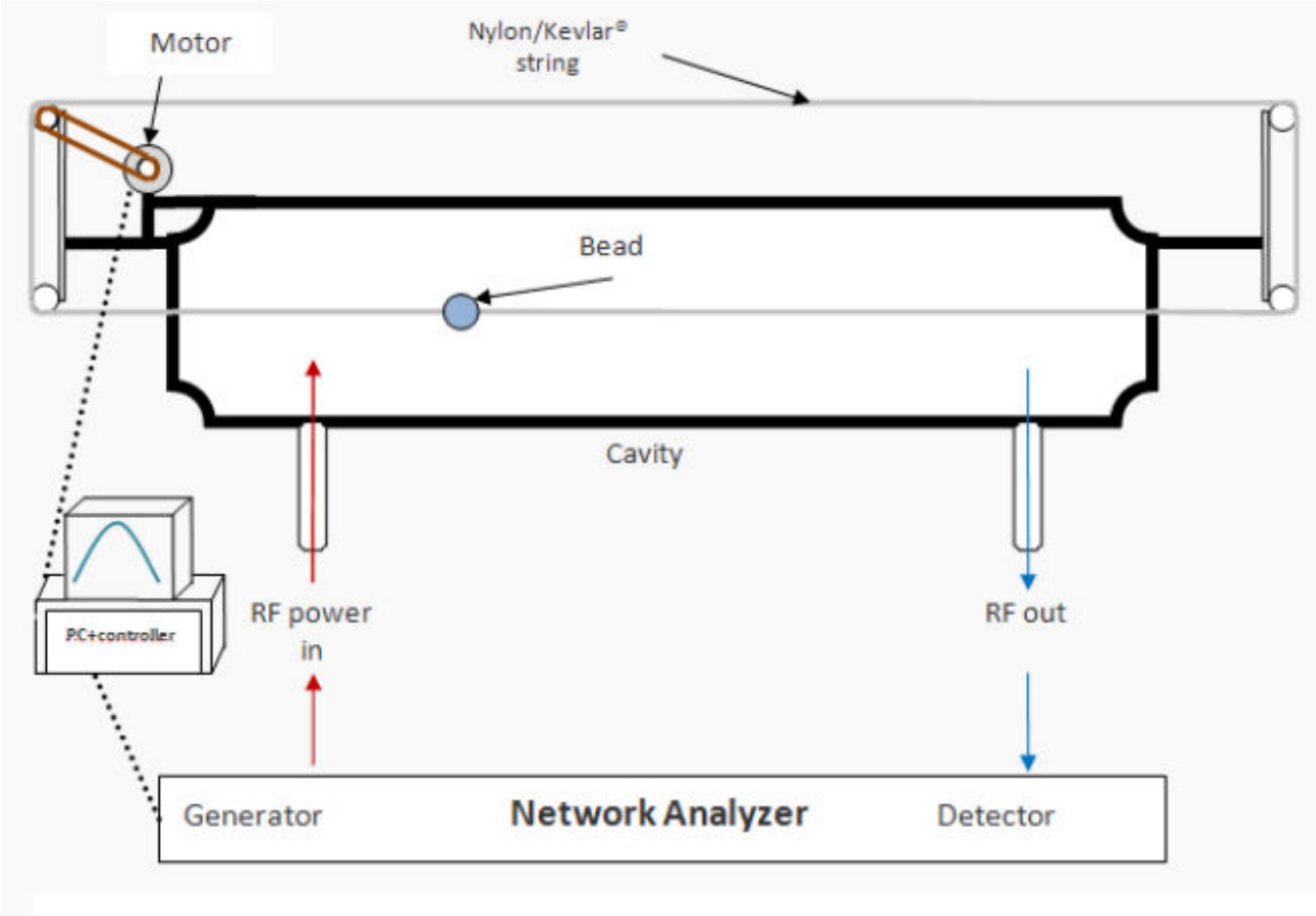
Accuracy

- Obtain an **estimation** of the **numerical accuracy** achieved.
- Error analysis.

Measurements. Feasibility Study

- Aluminium prototype of the 1/4-wave cavity.
- A bead-pull set up is being under consideration (3D).

Future Work (ii)



Source: Michal Jarosz, "Bead-Pull Measurments", CERN project report.

Outline

Summary and conclusions

- Three different cavities (**RF dipole, 1/4-wave and 4-rod**) have been studied for the **higher-order multipole** viewpoint.
- The **old prototypes** previously analyzed by Alexej have been considered as a **benchmark** to validate the actual multipole analysis employed.
- The **multipole coefficients** for the 3 updated cavities have been computed.
- Waiting for tolerances from the beam-dynamic study to apply mitigation techniques.

Summary and conclusions

- Three different cavities (**RF dipole, 1/4-wave and 4-rod**) have been studied for the **higher-order multipole** viewpoint.
- The **old prototypes** previously analyzed by Alexej have been considered as a **benchmark** to validate the actual multipole analysis employed.
- The **multipole coefficients** for the 3 updated cavities have been computed.
- Waiting for tolerances from the beam-dynamic study to apply mitigation techniques.

Summary and conclusions

- Three different cavities (**RF dipole, 1/4-wave and 4-rod**) have been studied for the **higher-order multipole** viewpoint.
- The **old prototypes** previously analyzed by Alexej have been considered as a **benchmark** to validate the actual multipole analysis employed.
- The **multipole coefficients** for the 3 updated cavities have been computed.
- Waiting for tolerances from the beam-dynamic study to apply mitigation techniques.

Summary and conclusions

- Three different cavities (**RF dipole, 1/4-wave and 4-rod**) have been studied for the **higher-order multipole** viewpoint.
- The **old prototypes** previously analyzed by Alexej have been considered as a **benchmark** to validate the actual multipole analysis employed.
- The **multipole coefficients** for the 3 updated cavities have been computed.
- Waiting for tolerances from the beam-dynamic study to apply mitigation techniques.

Acknowledgements

The HiLumi LHC Design Study (a sub-system of HL-LHC) is cofunded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404

Update on n-Pole Error in Actual Compact Crab-Cavities Designs

María Navarro-Tapia Alexej Grudiev Rama Calaga

Radiofrequency Group, Beams Department
CERN, Geneva (Switzerland)

2nd Joint HiLumi-LARP Annual Meeting 2012