Preliminary modeling of the Gun5.1 field profile

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PPS, 26.08.2021

Modeling Gun5.1 field profile

Motivation

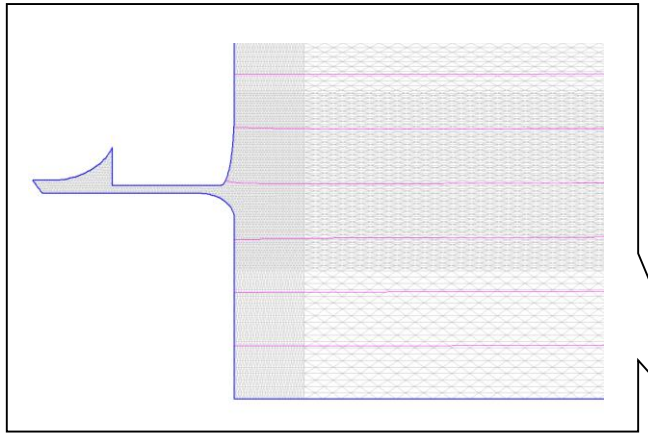
- Goal: generate Ez(z) field distribution:
  - Electromagnetically consistent (Superfish SF model H. Qian)
  - Fits the bead-pull measurements (31.03.2021, A. Oppelt)

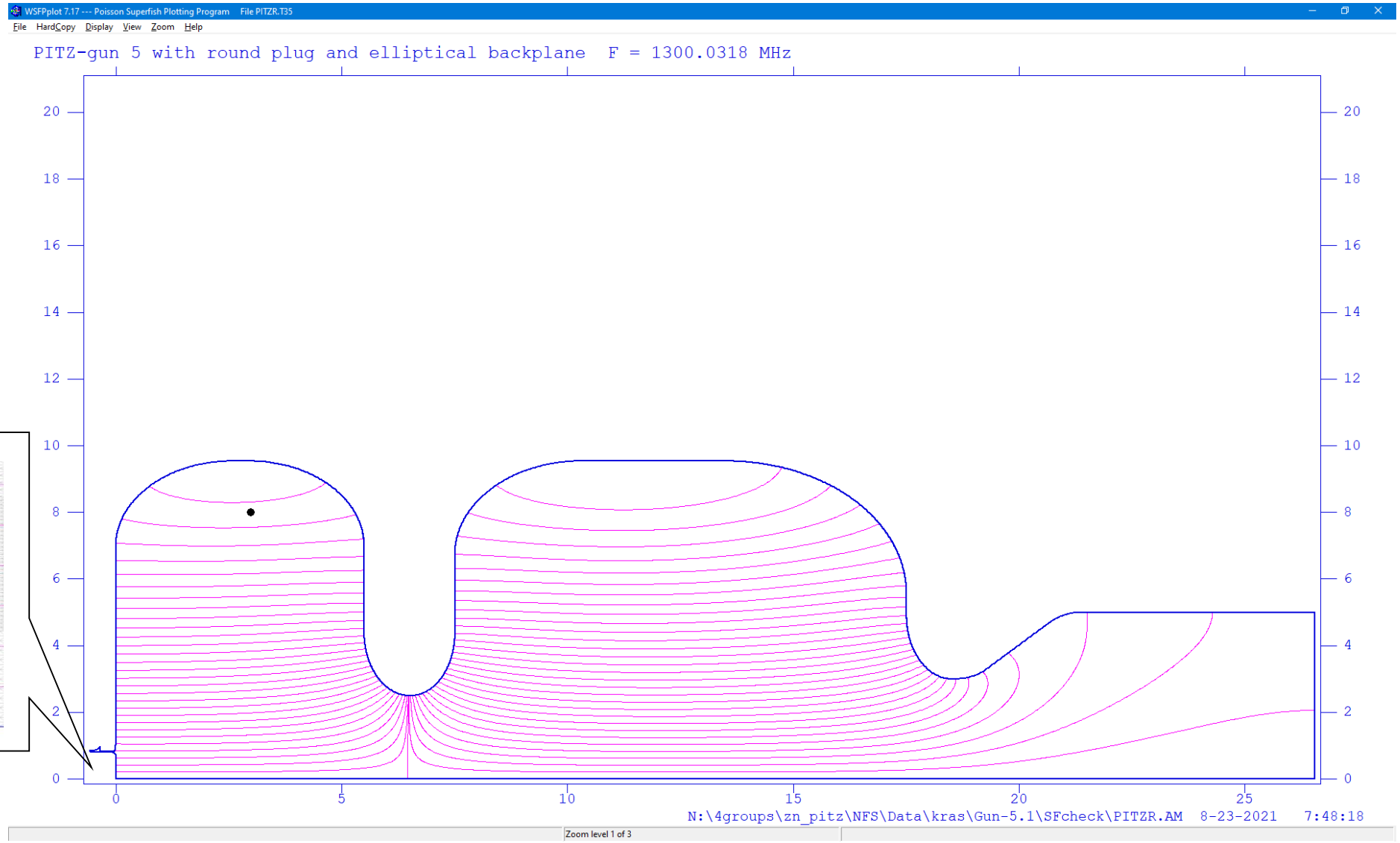
- Application:
  - Simulate curve max <Pz> vs. Ecath → Ecath, MMMG phase vs. max <Pz>
  - The profile Ez(z) to be used for beam dynamics simulations of experiments with Gun5.1

Gun5 nominal geometry

Superfish (SF) model (H. Qian)

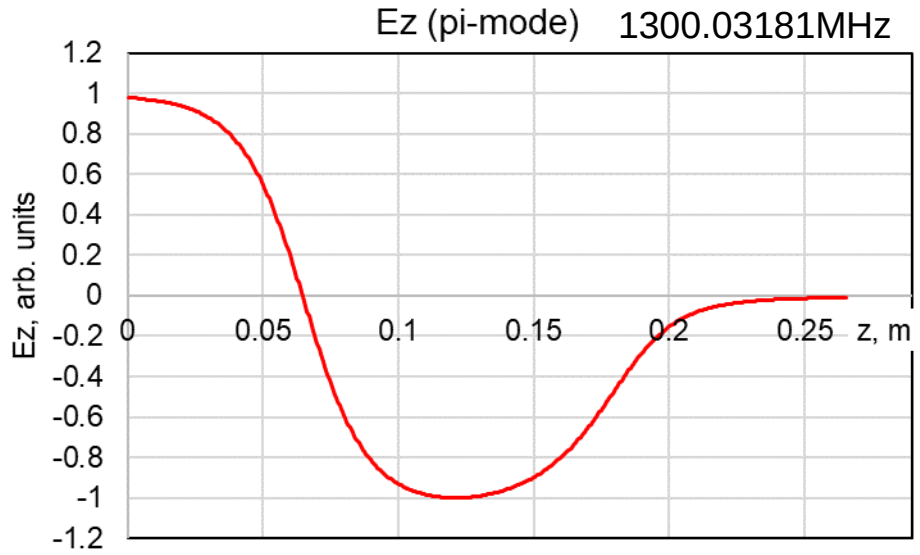
- Included:
  - Cathode hole / plug
  - Mesh refinement
- Not included:
  - Coaxial coupler antenna

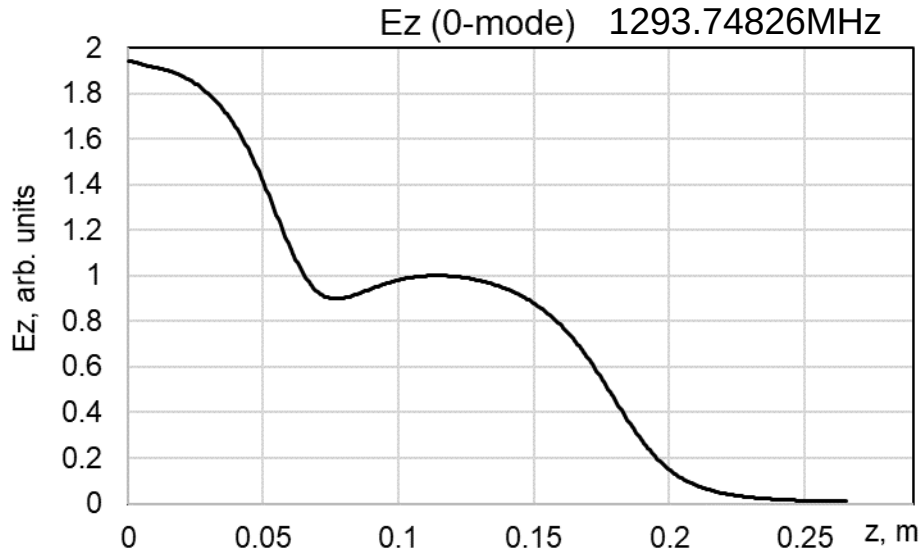


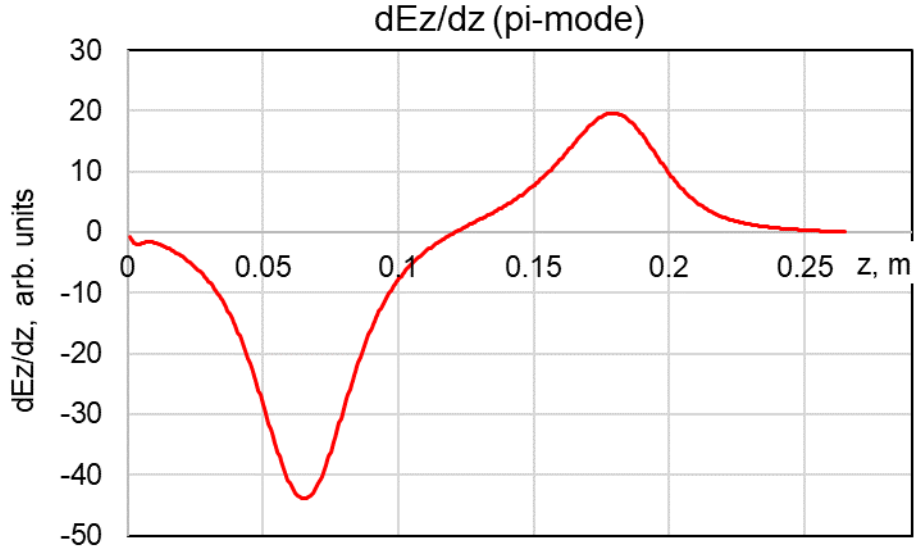


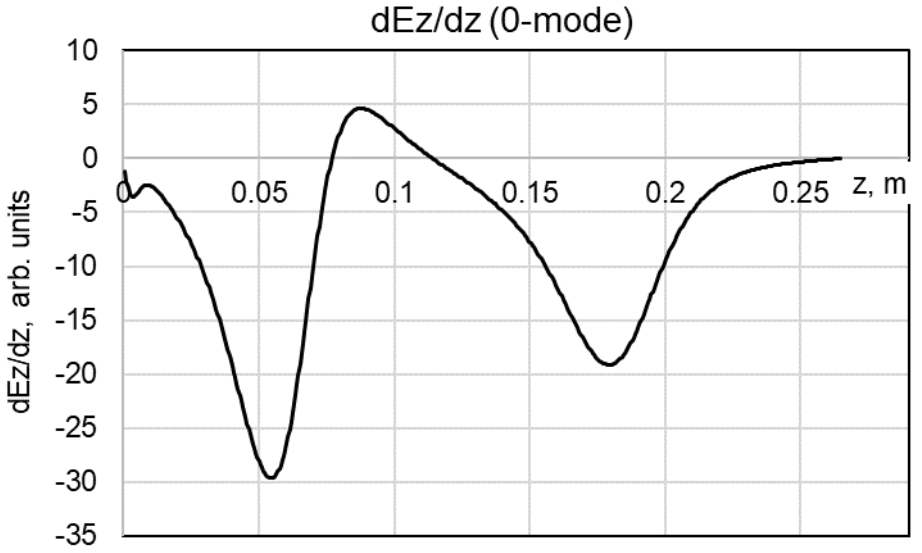
Superfish simulations with nominal geometry

Field balance for the pi-mode → 0.980





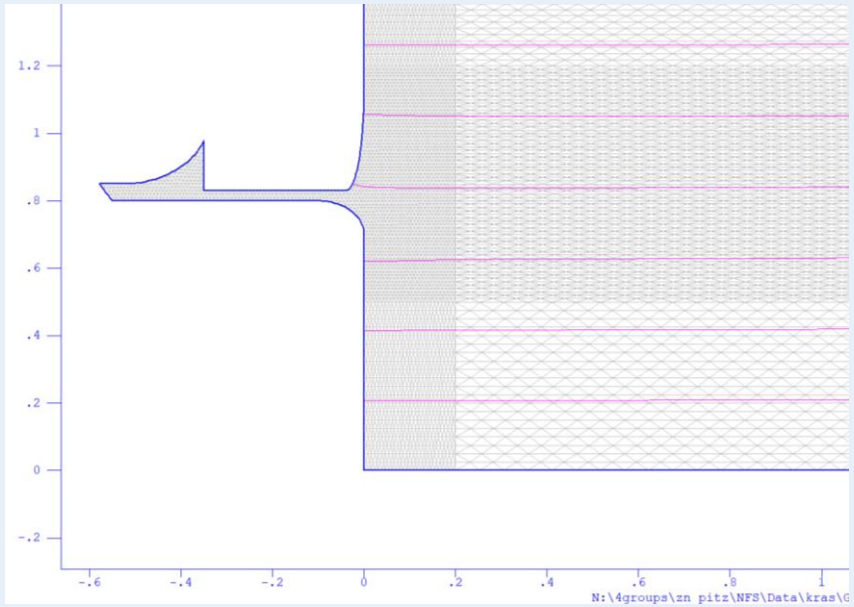


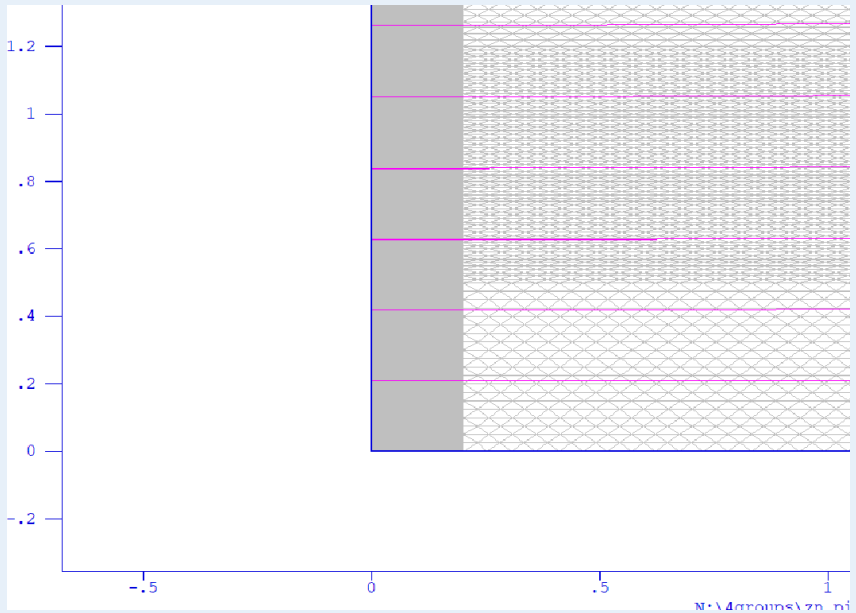


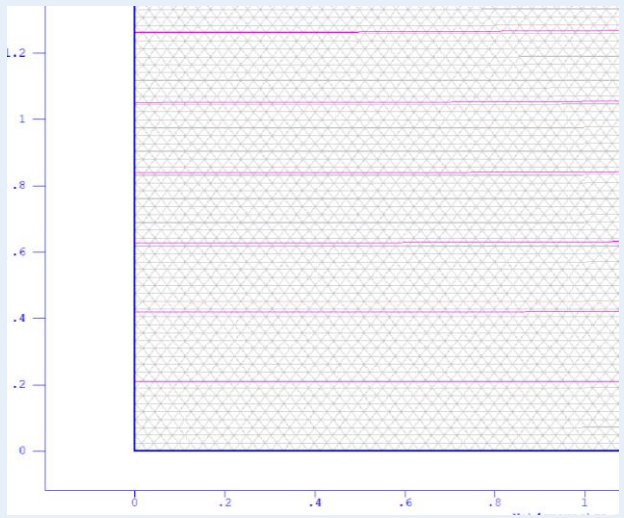
Superfish simulations with nominal geometry

Various options w/o antenna

Case 1 (+cath+MR-CA)	Case 2 (-cath+MR-CA)	Case 3 (-cath-MR-CA)
Cathode Mesh refinement (MR) No coaxial antenna (CA)	No cathode Mesh refinement (MR) No coaxial antenna (CA)	No cathode No mesh refinement No coaxial antenna (CA)





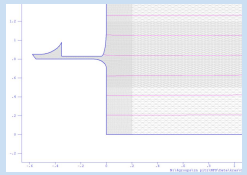


Superfish simulations with nominal geometry

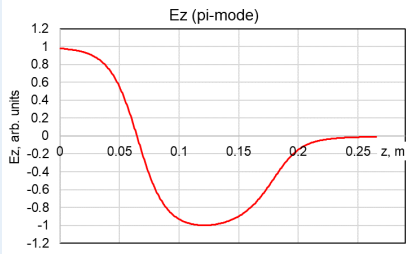
Various options w/o antenna

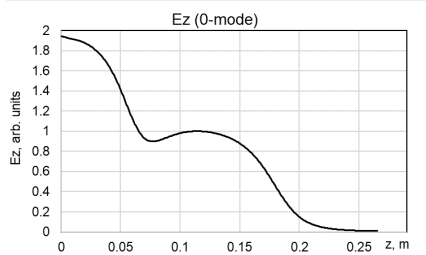
Case 1 (+cath+MR-CA)

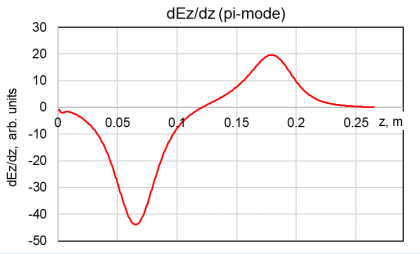
Cathode
Mesh refinement (MR)
No coaxial antenna (CA)

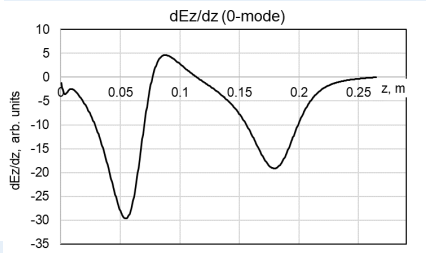


f(pi)=1300.03181MHz
FB(pi)=0.980



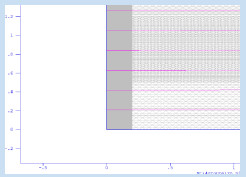




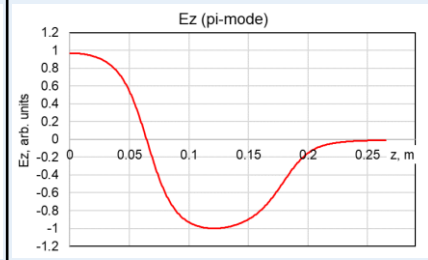


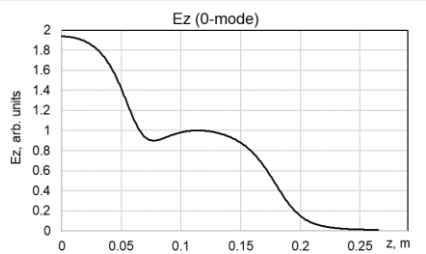
Case 2 (-cath+MR-CA)

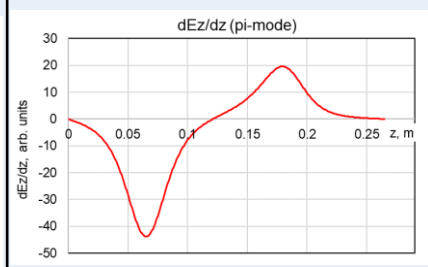
No cathode
Mesh refinement (MR)
No coaxial antenna (CA)

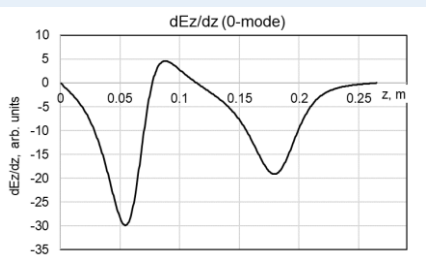


f(pi)=1300.02116MHz
FB(pi)=0.969



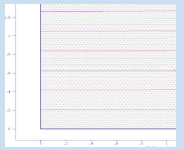




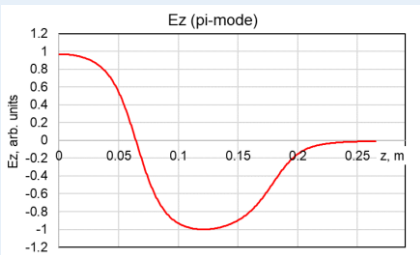


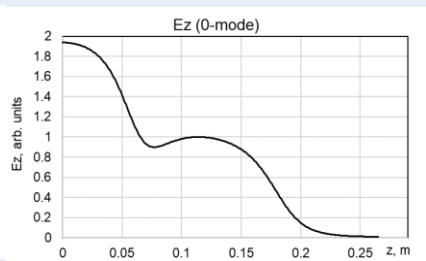
Case 3 (-cath-MR-CA)

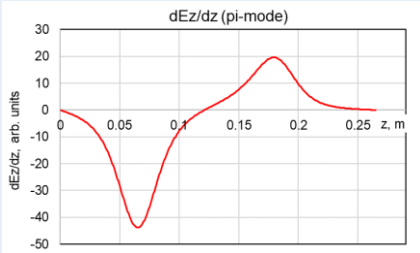
No cathode
No mesh refinement
No coaxial antenna (CA)

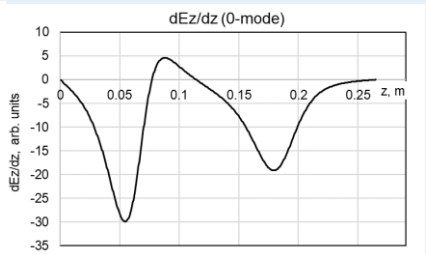


f(pi)=1300.01399MHz
FB(pi)=0.969



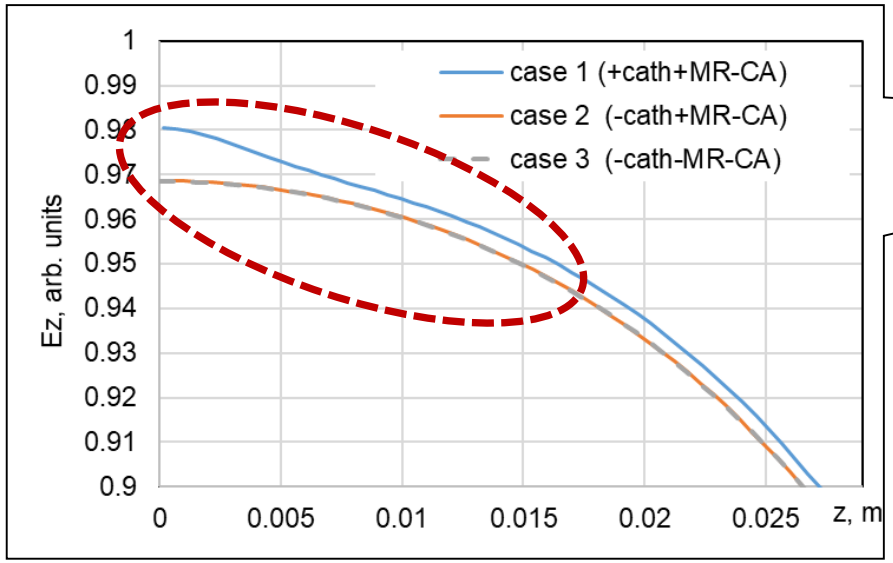


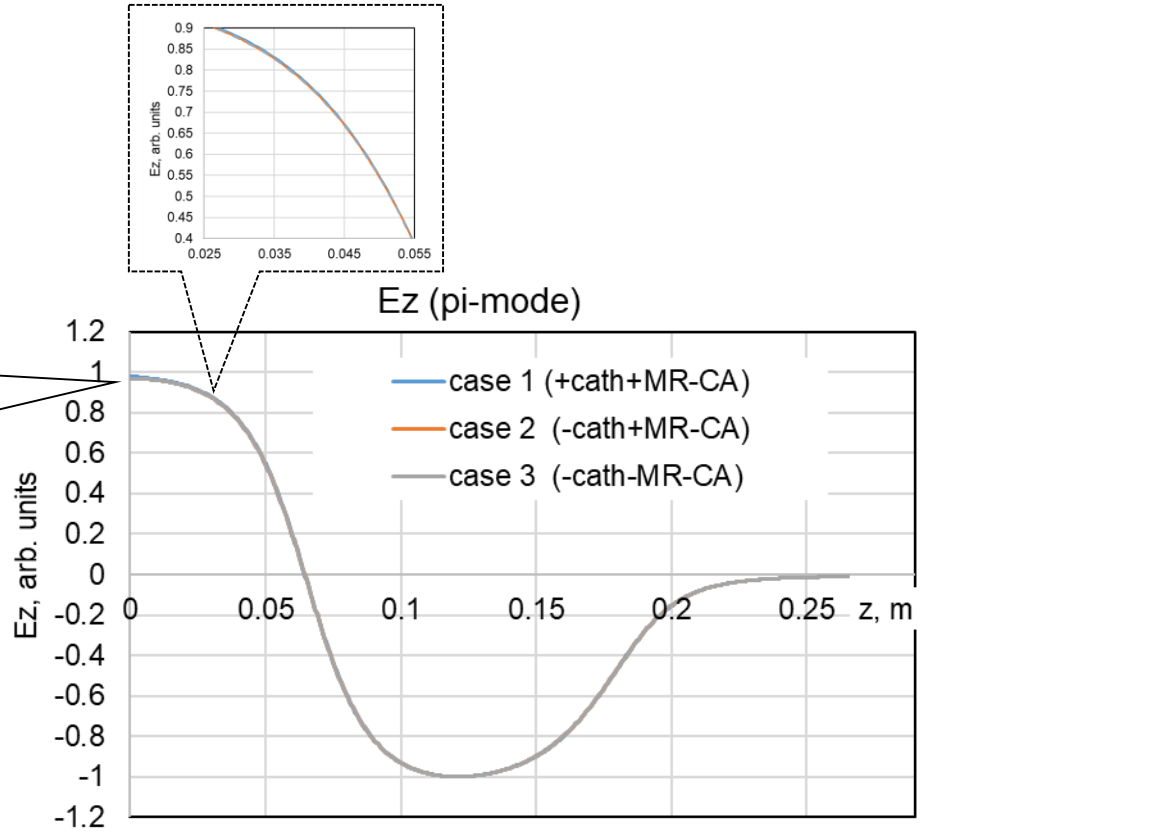


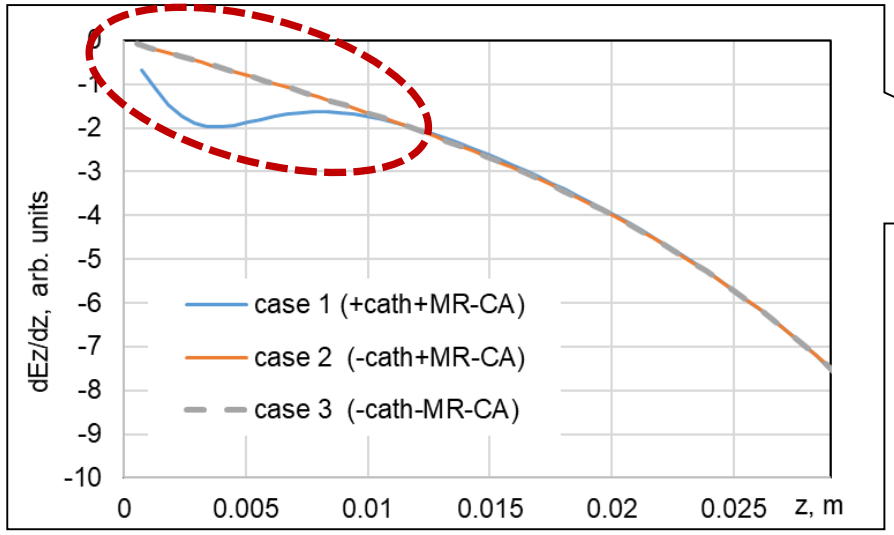


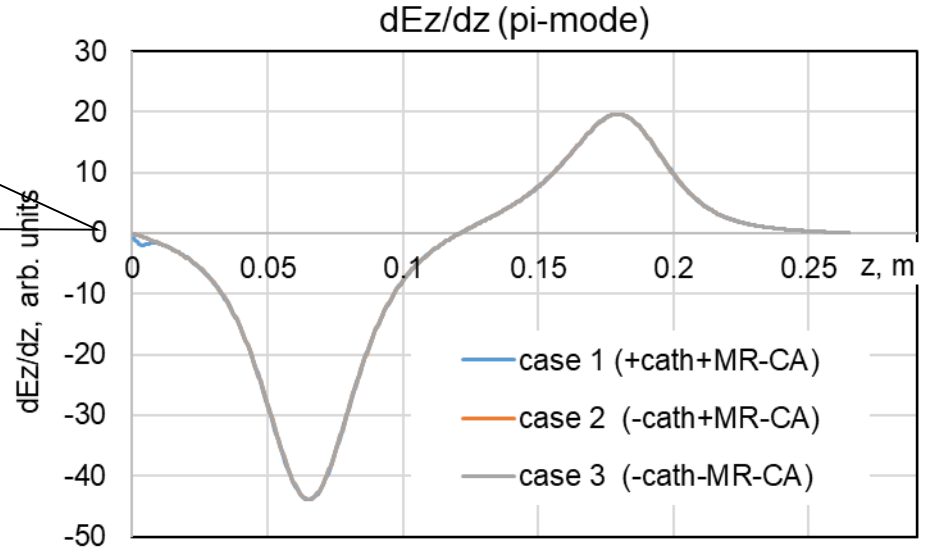
Simulated field profiles

Cases 1-3





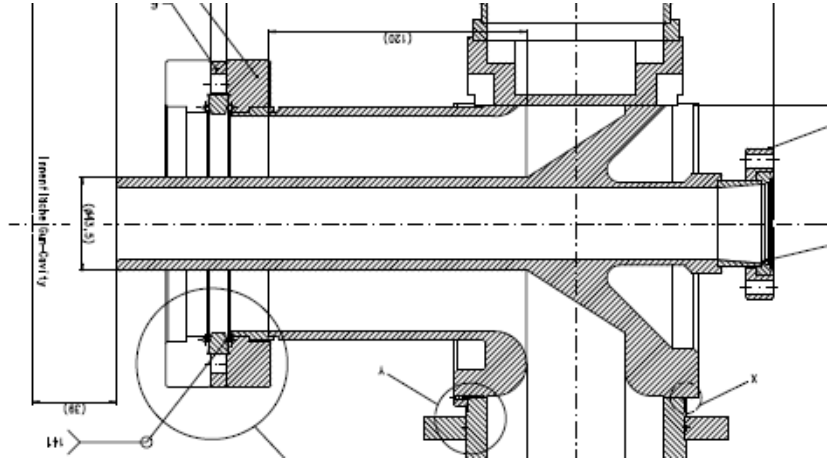


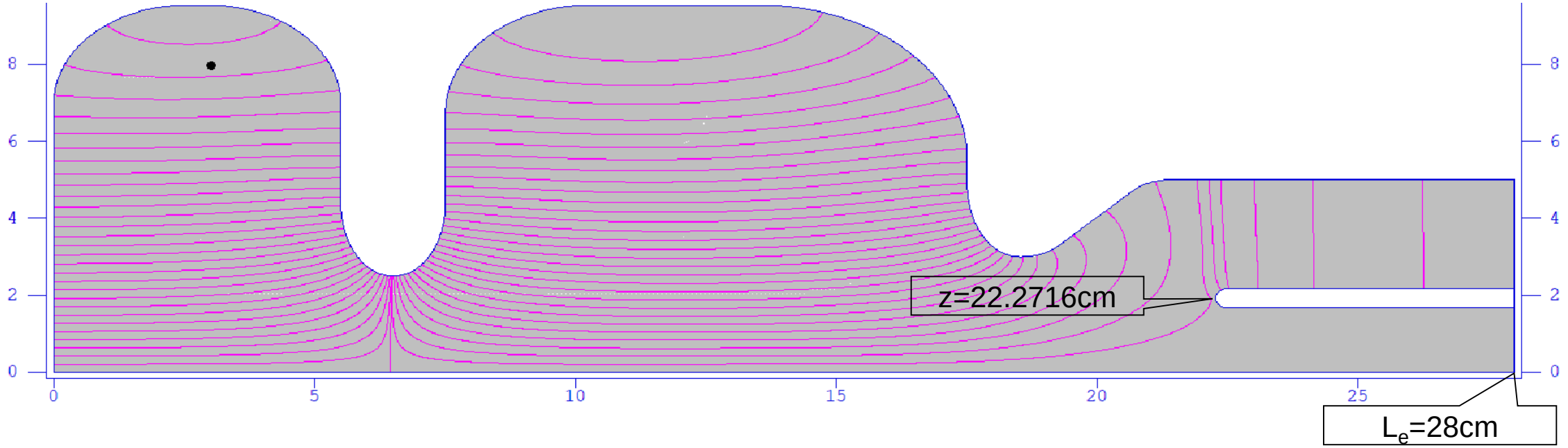


Superfish model with coaxial antenna

Case 4 = (-cath-MR+CA)

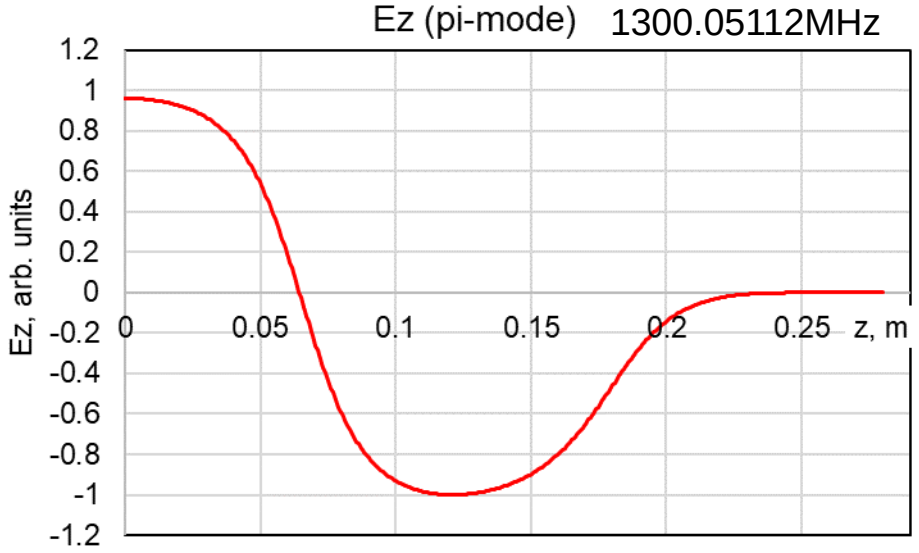
- Adding coaxial power coupler antenna:
  - Adjusting the nose position (S. Philipp → 222.716mm)
  - Longer right boundary (z=28cm – not yet fine tuned*)

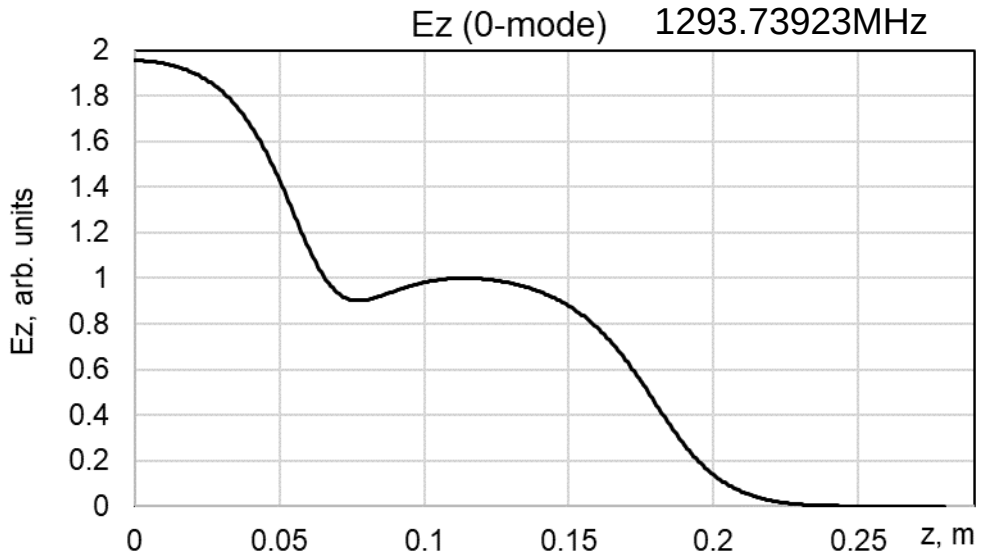


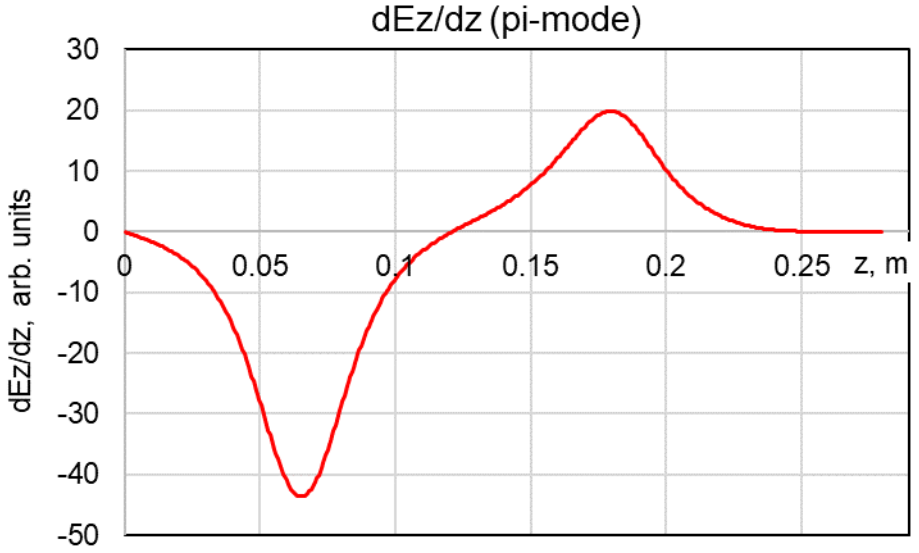


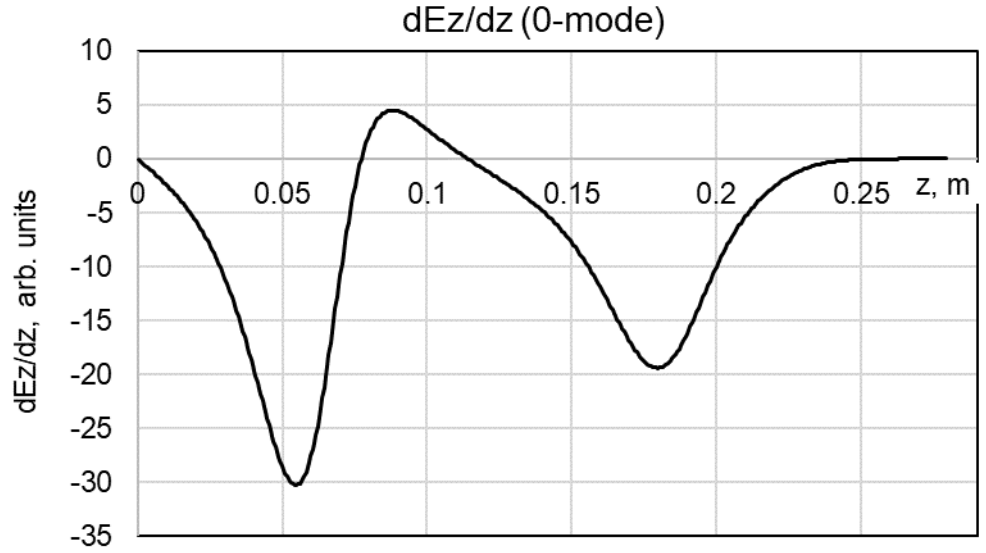
Superfish simulations with Case 4 geometry

Case 4 = (-cath-MR+CA) → Field balance for the pi-mode → 0.960



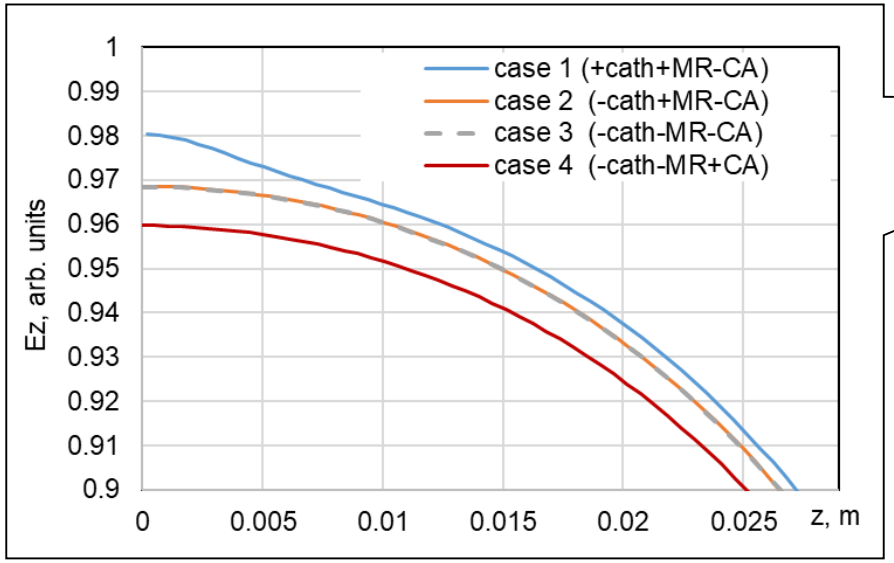


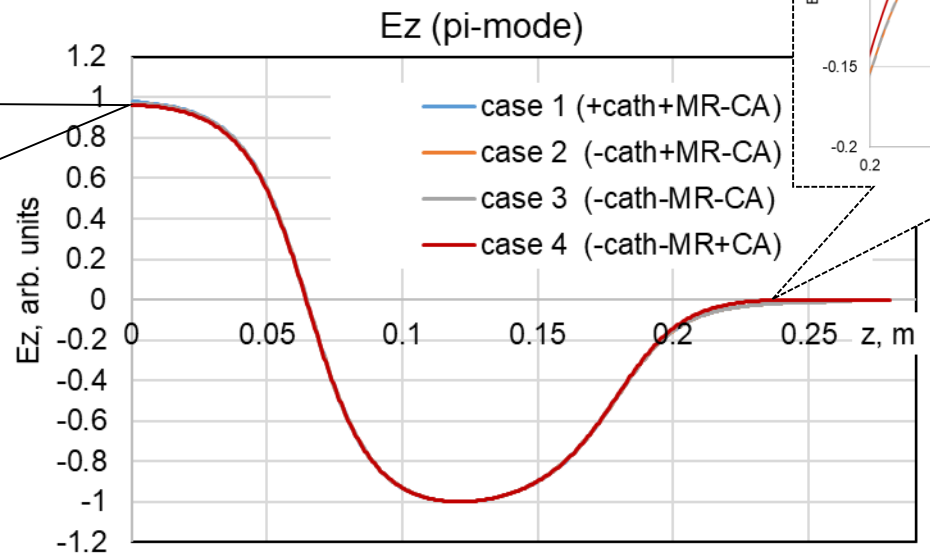


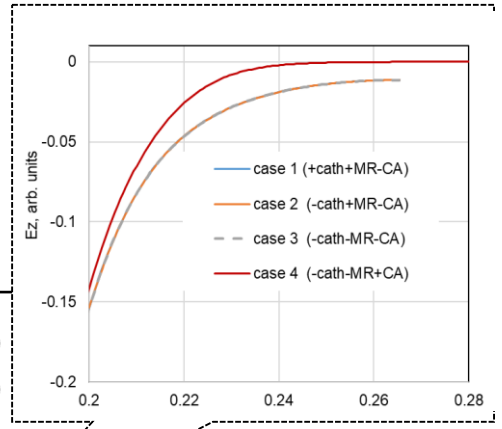


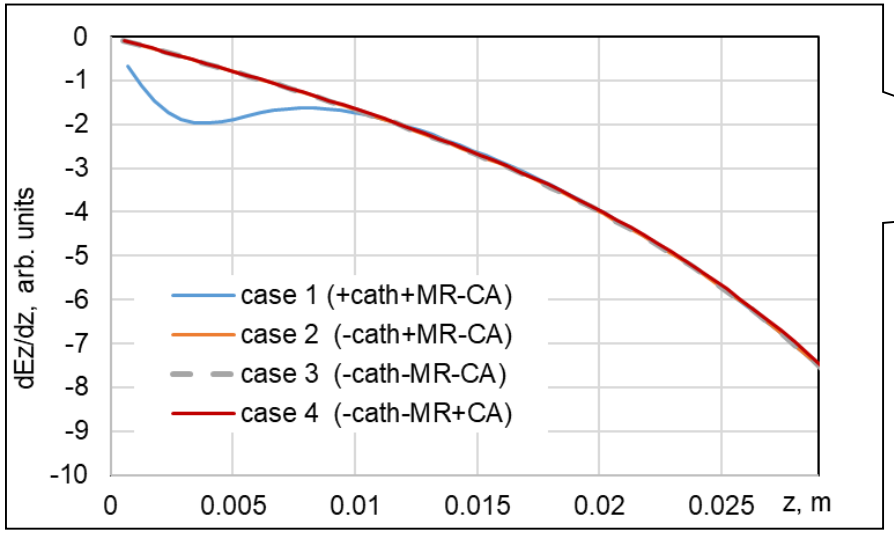
Simulated field profiles

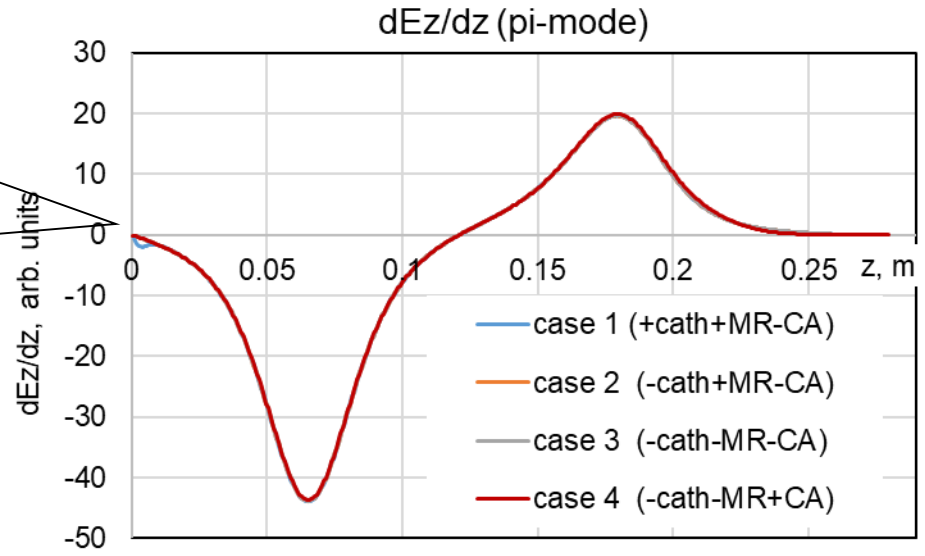
Cases 1-4





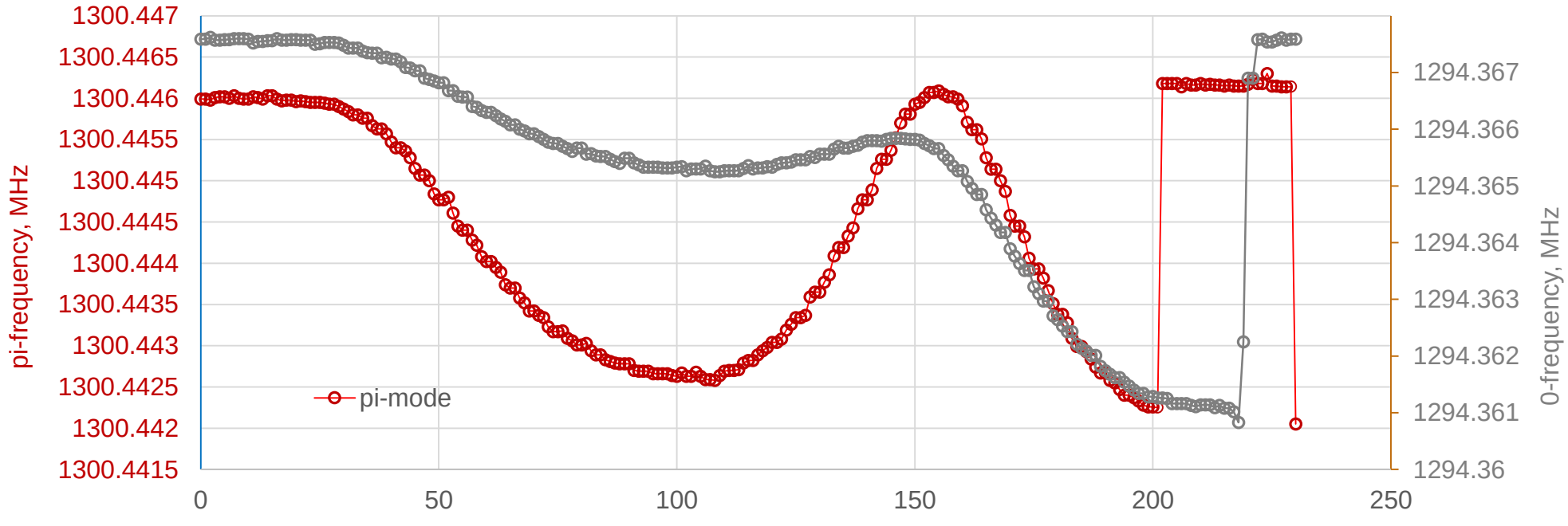


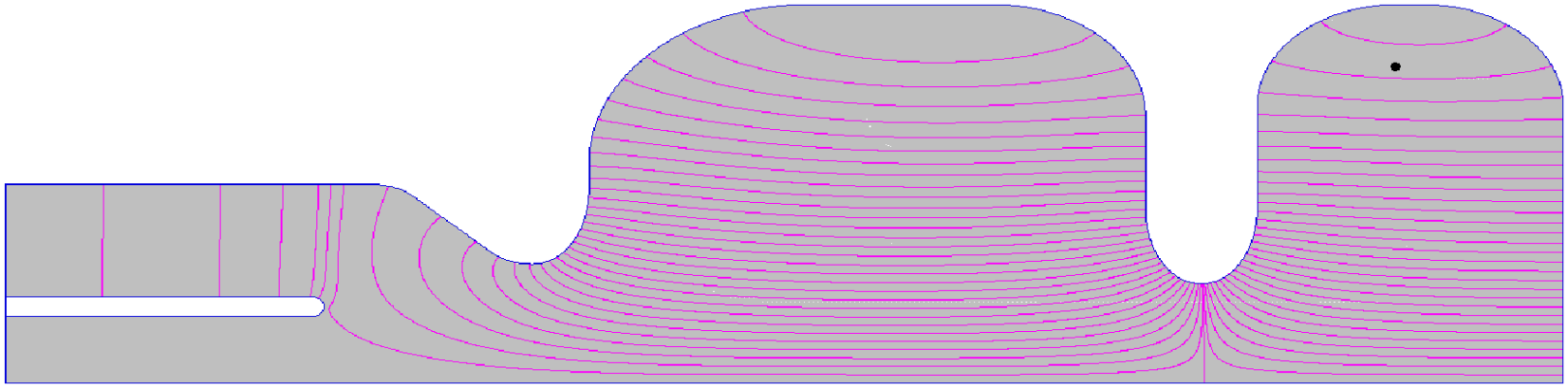




Bead pull measurements

A. Oppelt, 31.03.2021





Bead pull measurements

Preliminary considerations

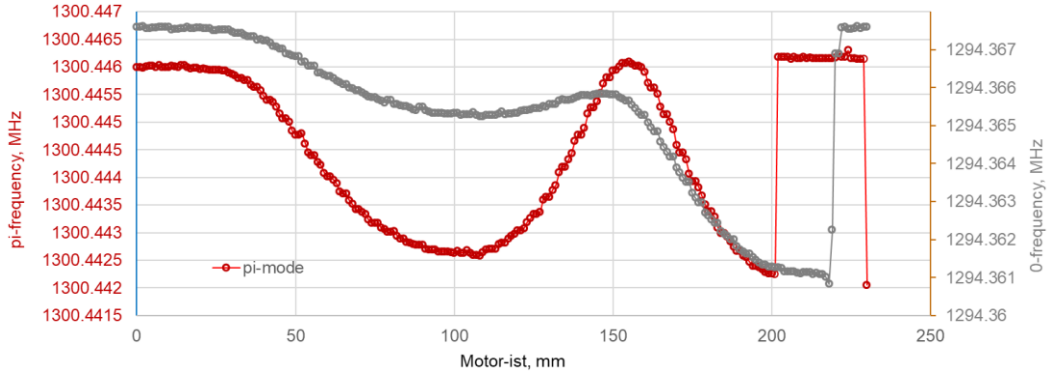
- PI-mode measurements : shorter z-range at the cathode hole:
  - → Uncertainty in the field balance evaluation
  - Z scales for 0 and pi are ≠
  - ? Inhomogeneous z-axis
- Overall shorter z-range:
  - E.g. for pi-mode “iris” frequency is regularly higher than the “0-base line” → uncertainty in the background subtraction
- General formula for the bead pull measurements:

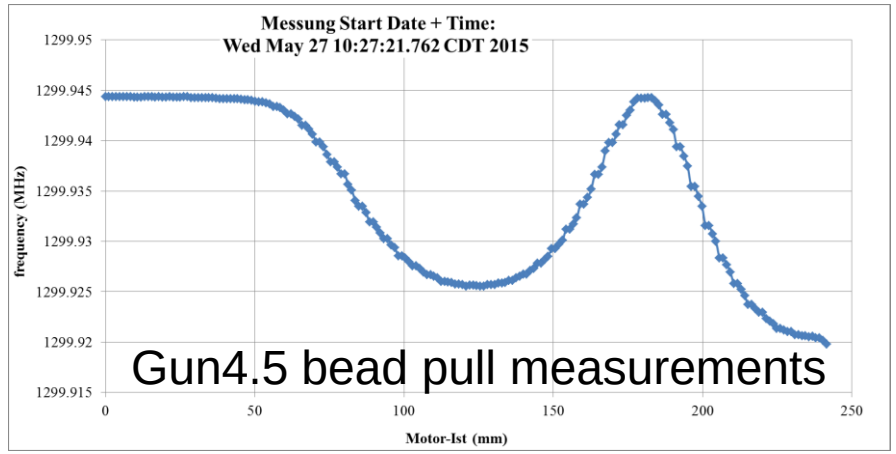
$$\frac{\Delta f(z)}{f}\frac{F_{bead}}{\omega} = \frac{|Ez(z)|^2}{\omega U}$$

- How to proceed:
  - Fit the bead pull measurements (SF → Ez^2)
  - Simultaneous fit of 0- and pi-modes
  - Tuning parameters: z_0; f_0, z_{scale}, f_{scale}
  - …

$$z = z_{scale} \cdot (z_0 - z_{motorRDBK})$$
$$|E(z)|^2_{meas} = f_{scale} \cdot (f(z) - f_0)$$

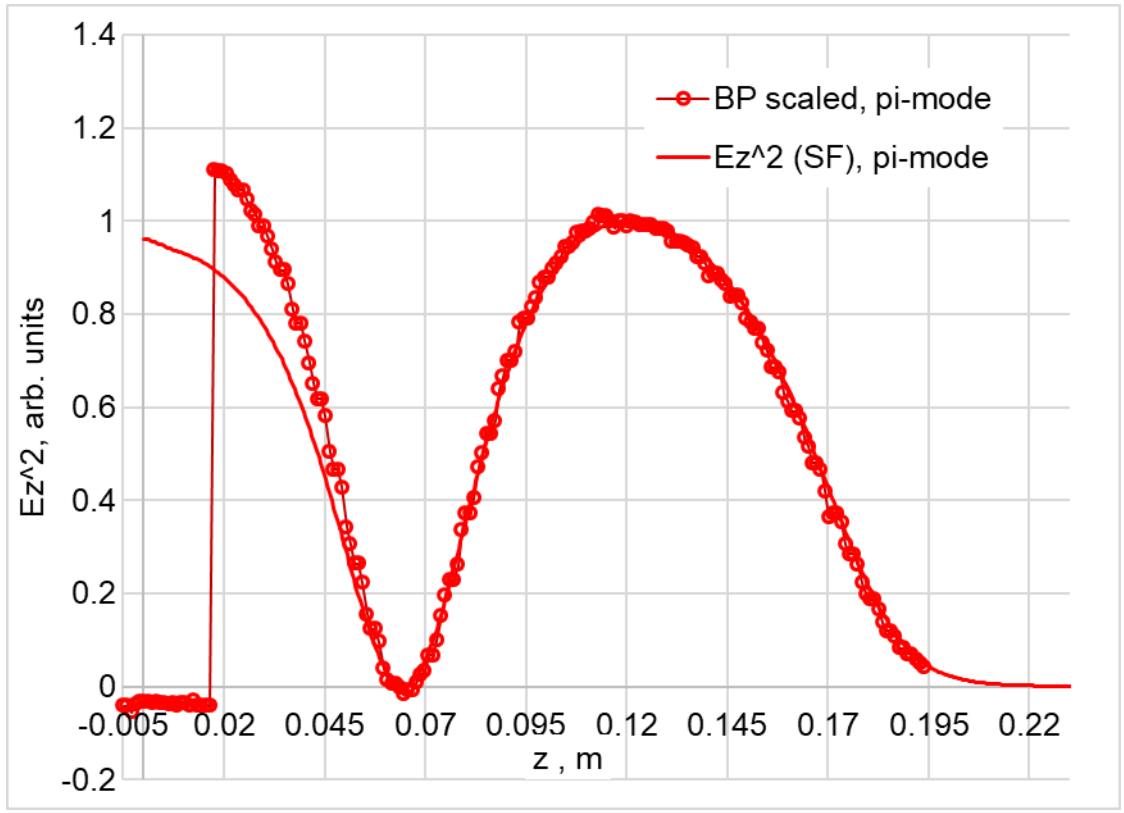
f(pi-mode)=1300.464MHz
f(0-mode)=1294.387MHz

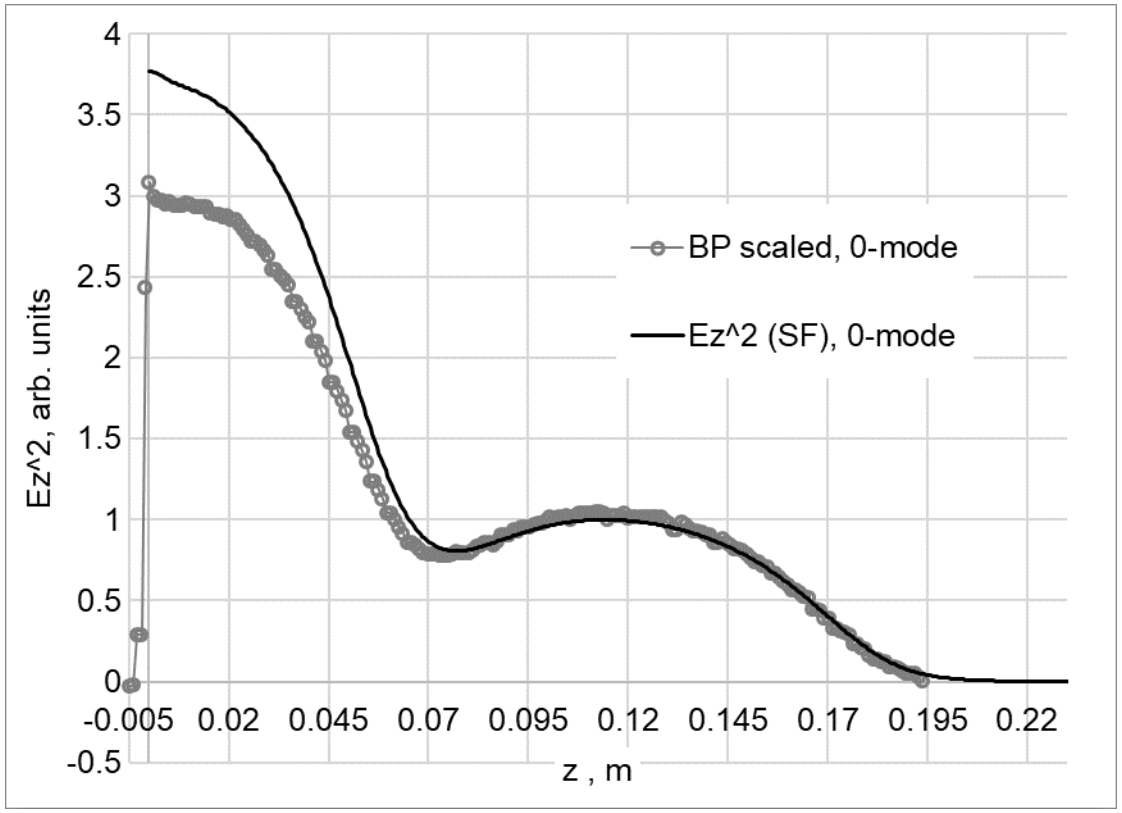


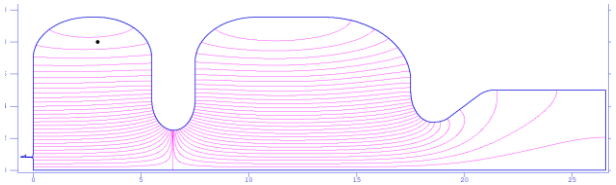


Simulated field profile vs. bead-pull measurements

Case 1 vs bead-pull







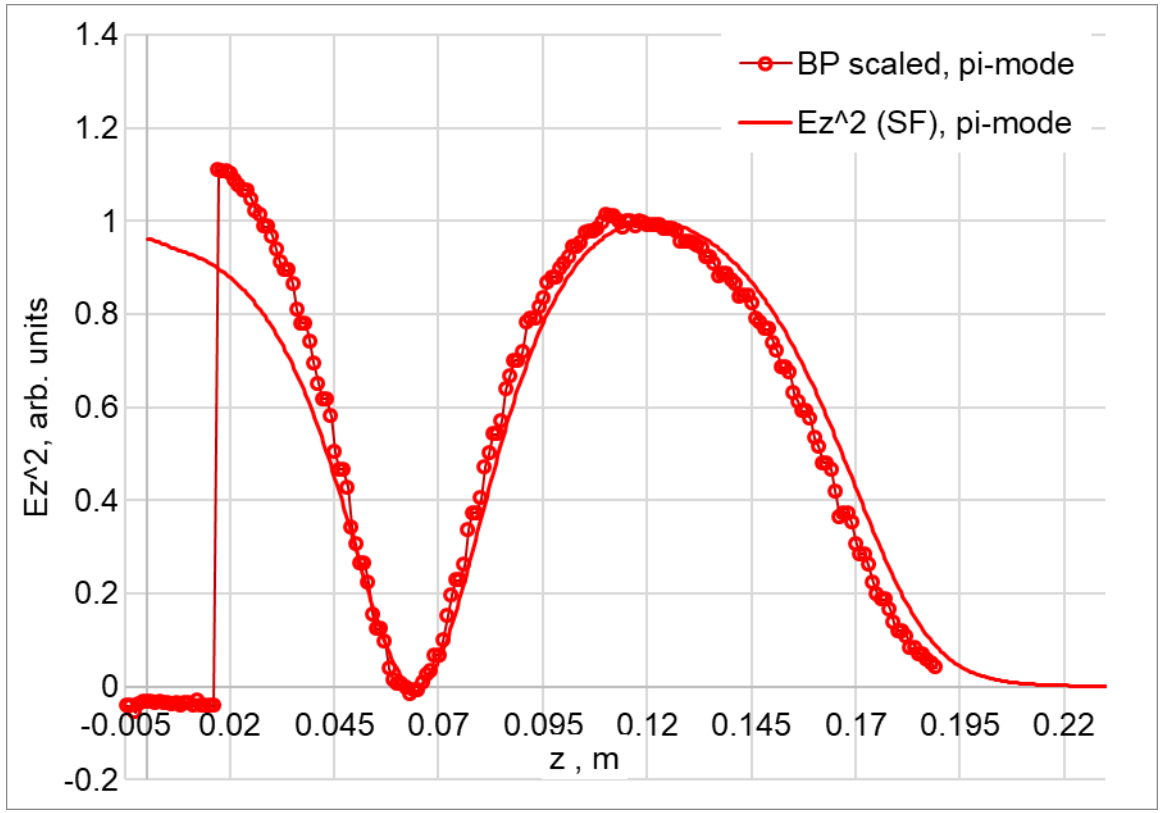
$$z = z_{scale} \cdot (z_0 - z_{motorRDBK})$$

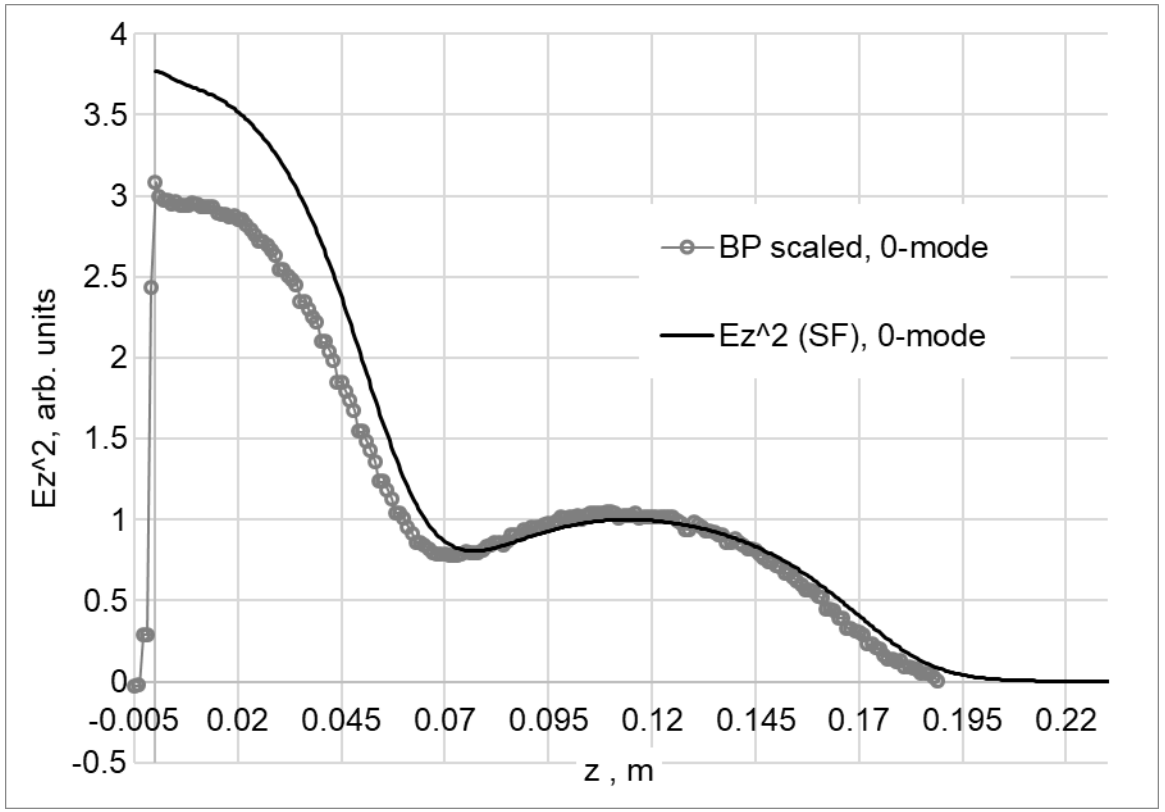
$$|E(z)|^2_{meas} = f_{scale} \cdot (f(z) - f_0)$$

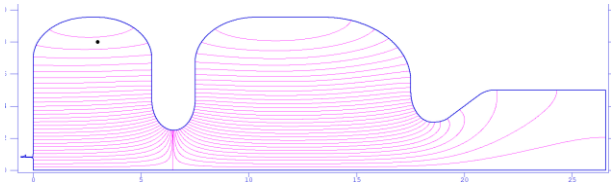
	pi-mode	0-mode
z_0, m	0.2182	0.2182
f_0, MHz	1300.44604	1294.367528
z_{scale}	1.025	1.025
f_{scale}	293	460

Simulated field profile vs. bead-pull measurements

Case 1 vs bead-pull, BUT no z-scaling







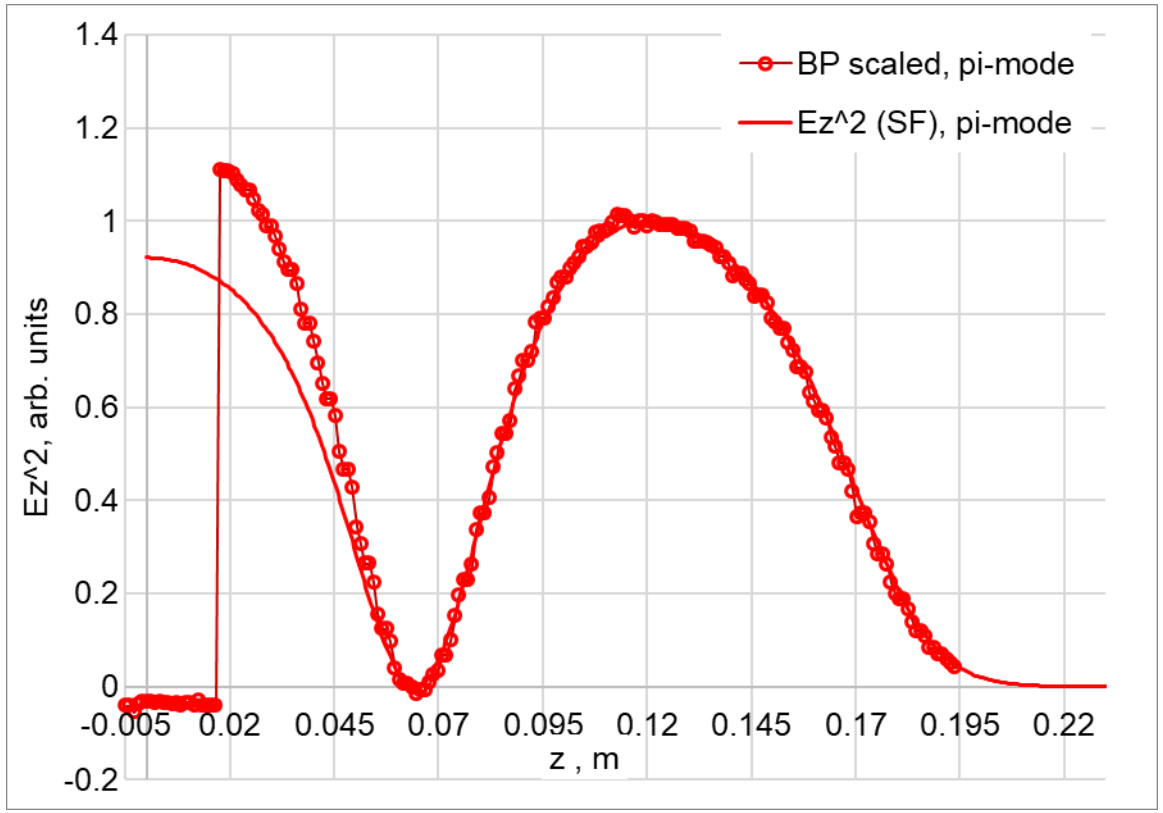
$$z = z_{scale} \cdot (z_0 - z_{motorRDBK})$$

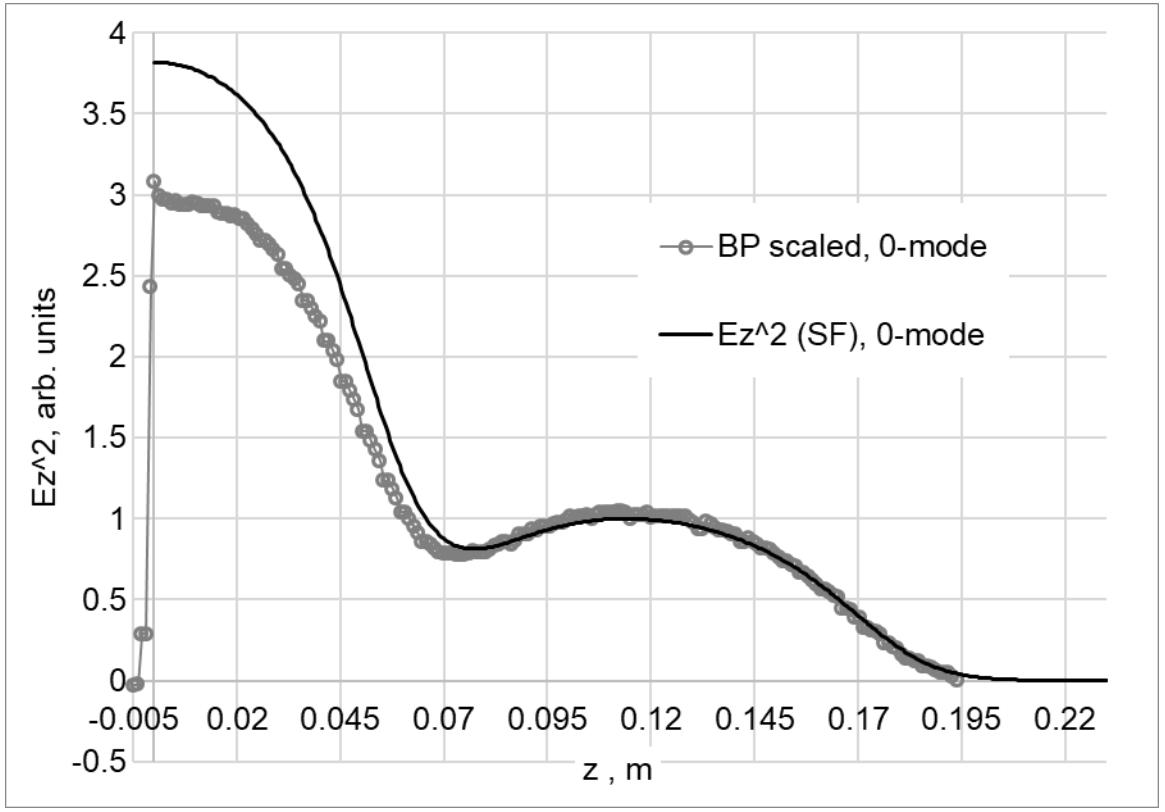
$$|E(z)|^2_{meas} = f_{scale} \cdot (f(z) - f_0)$$

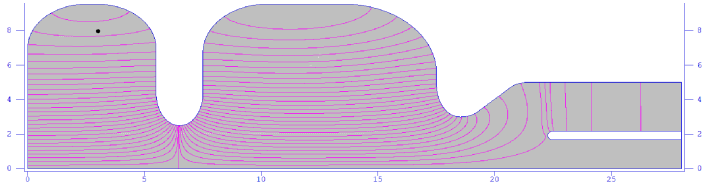
	pi-mode	0-mode
z_0, m	0.2182	0.2182
f_0, MHz	1300.44604	1294.367528
z_{scale}	1	1
f_{scale}	293	460

Simulated field profile vs. bead-pull measurements

Case 4 vs bead-pull







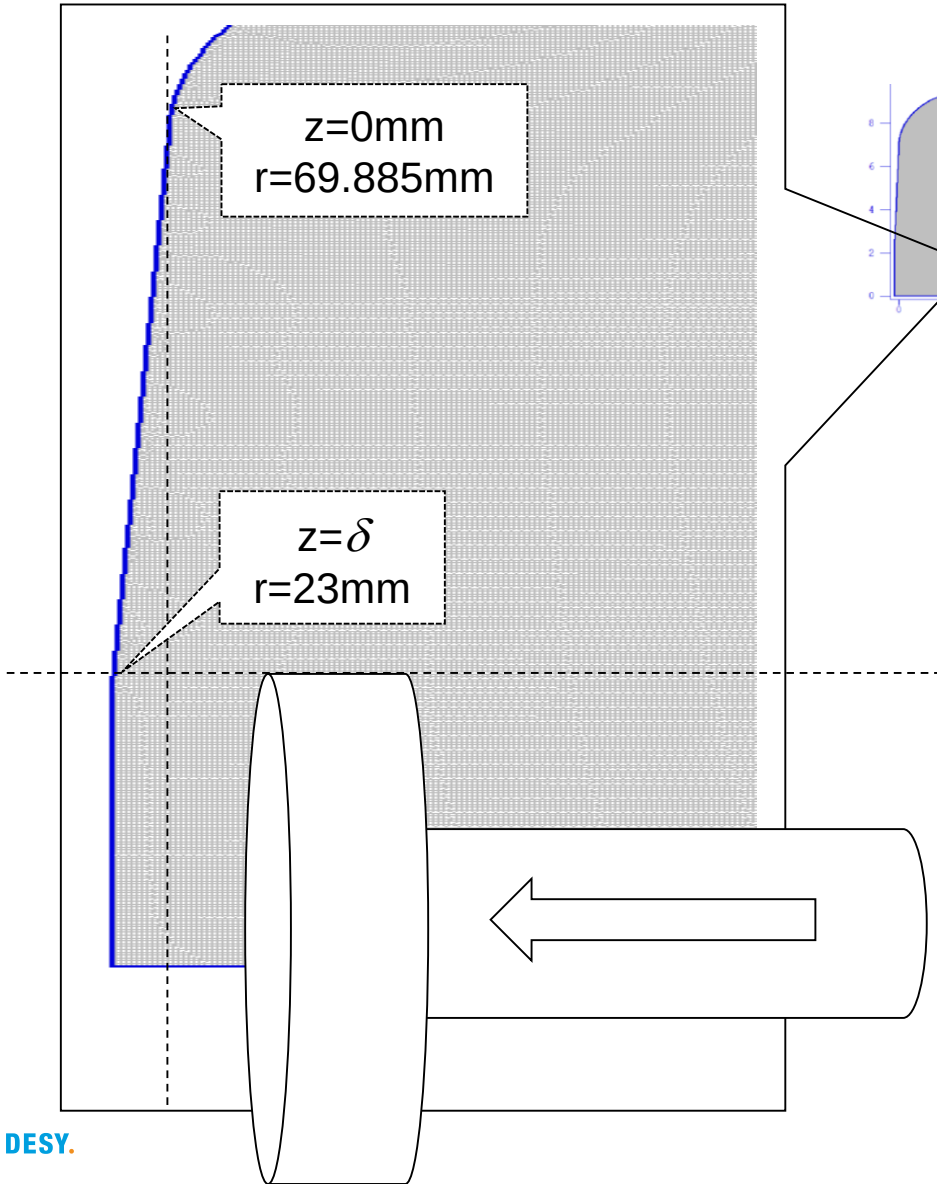
$$z = z_{scale} \cdot (z_0 - z_{motorRDBK})$$

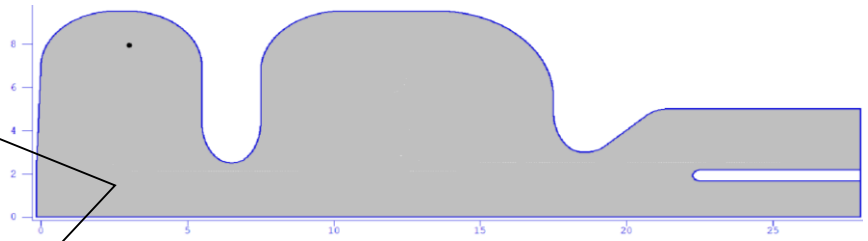
$$|E(z)|^2_{meas} = f_{scale} \cdot (f(z) - f_0)$$

	pi-mode	0-mode
z_0, m	0.2182	0.2182
f_0, MHz	1300.44604	1294.367528
z_{scale}	1.025	1.025
f_{scale}	293	460

Try to simulate the tuning procedure

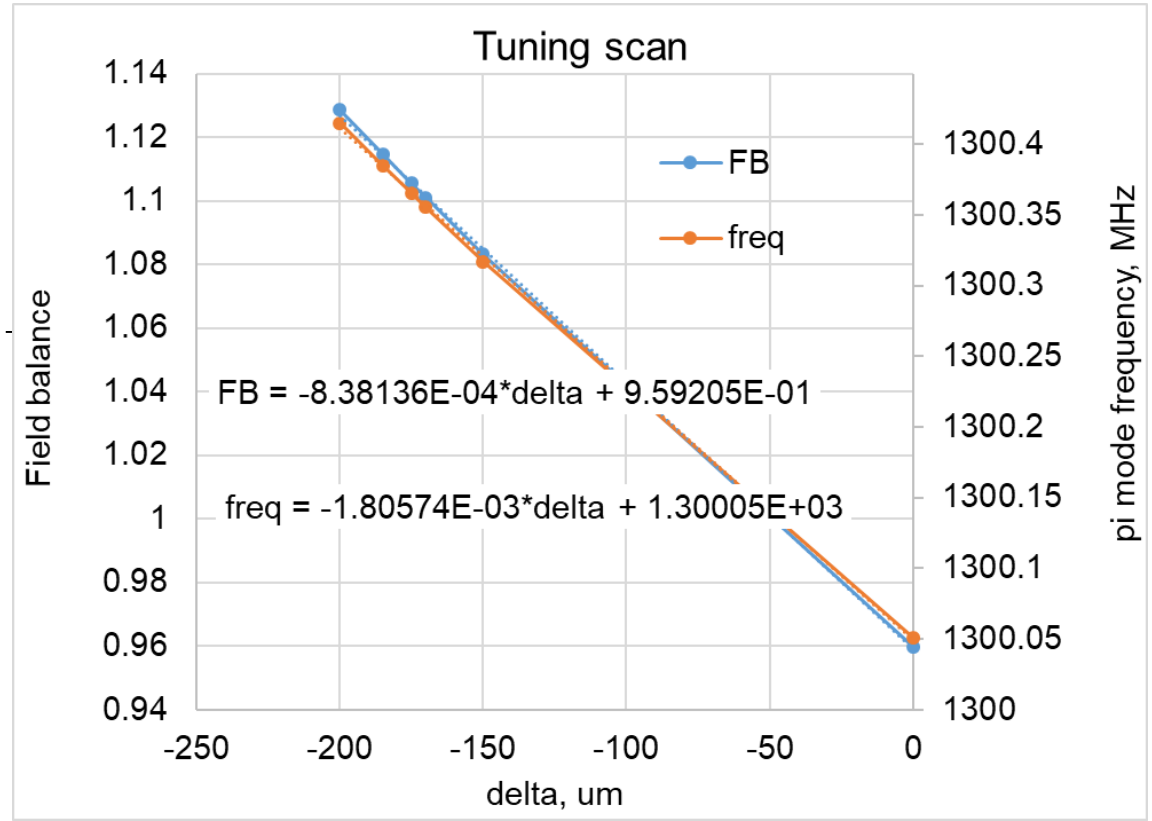
Case 5 = Case 4 + deformation of the back (cathode) wall ➔ rough scan*





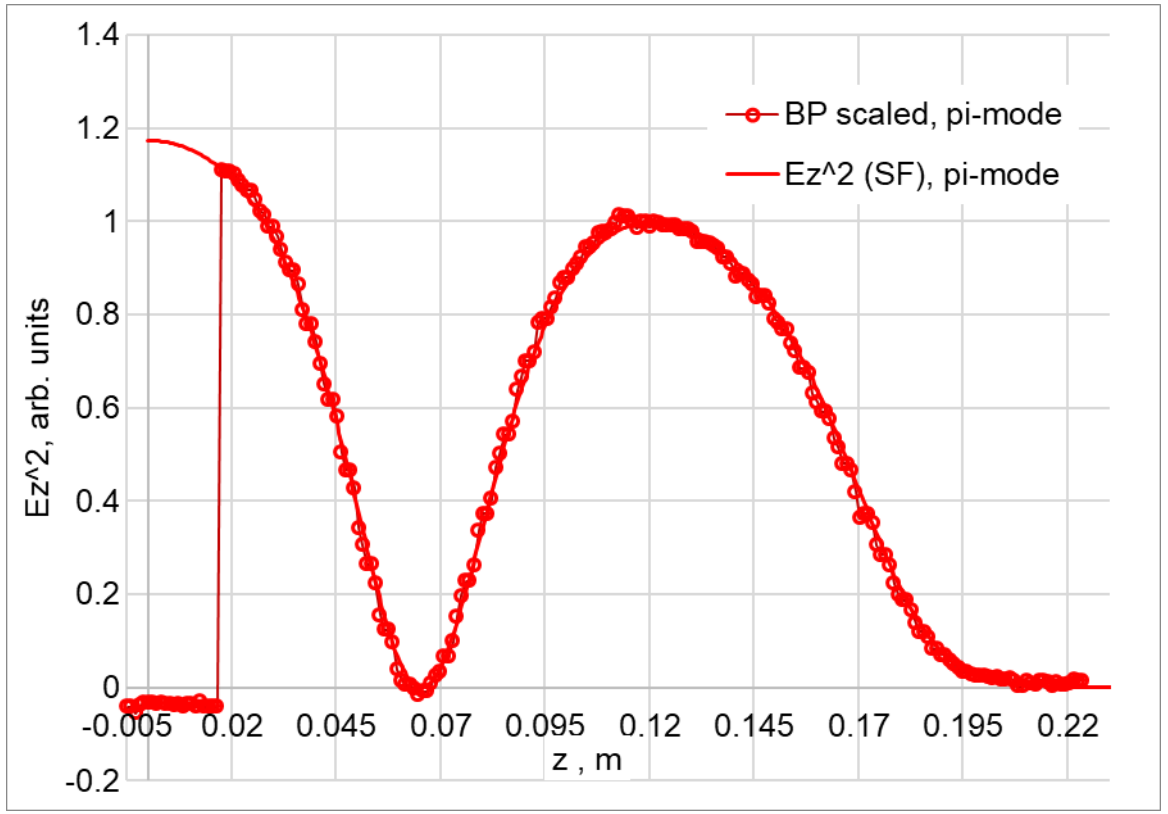
$$\frac{df_\pi}{d\delta} \sim -1.8\ kHz/\mu m$$

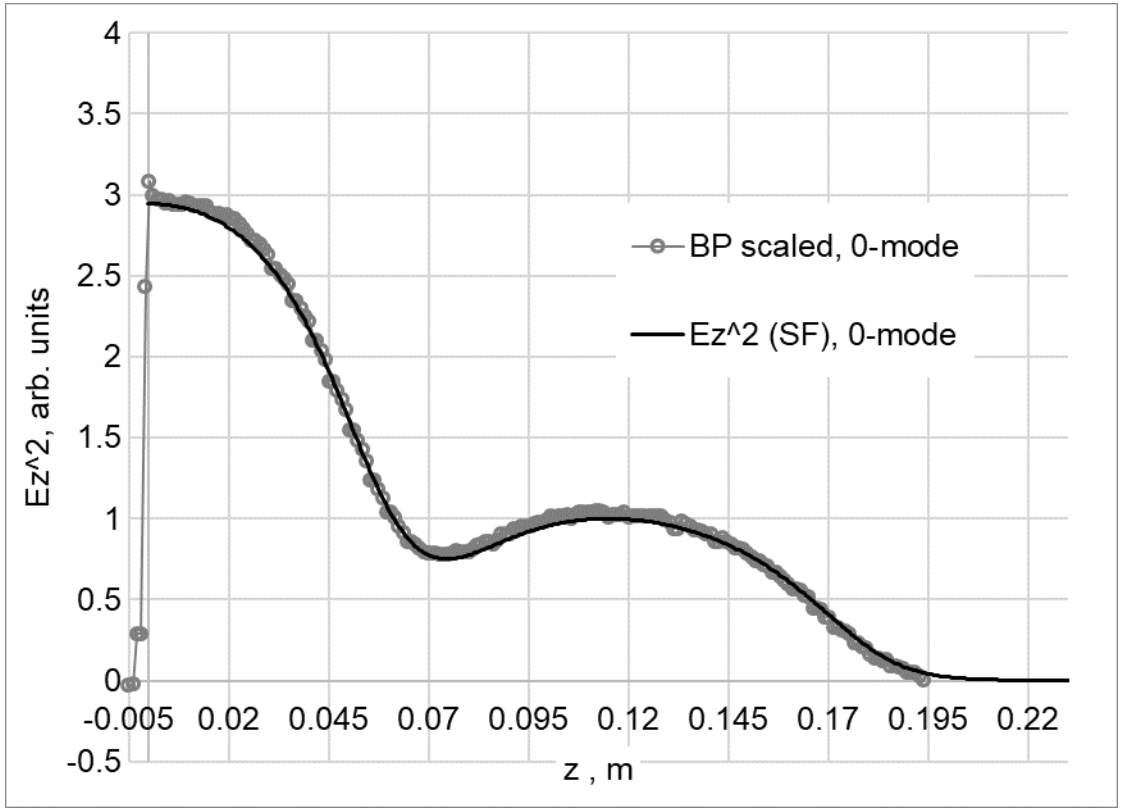
$$\frac{dFB}{d\delta} \sim -0.0008/\mu m$$



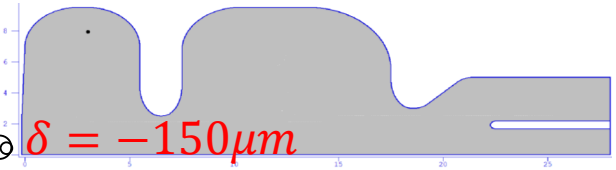
Simulated field profile vs. bead-pull measurements

Case 5 + deformation vs bead-pull





How good is it reproduced with mesh? (Δz~80um)



$$z = z_{scale} \cdot (z_0 - z_{motorRDBK})$$

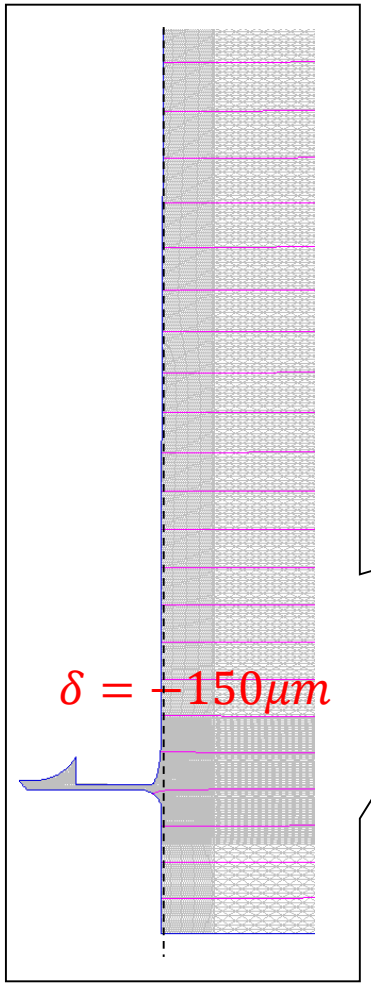
$$|E(z)|^2_{meas} = f_{scale} \cdot (f(z) - f_0)$$

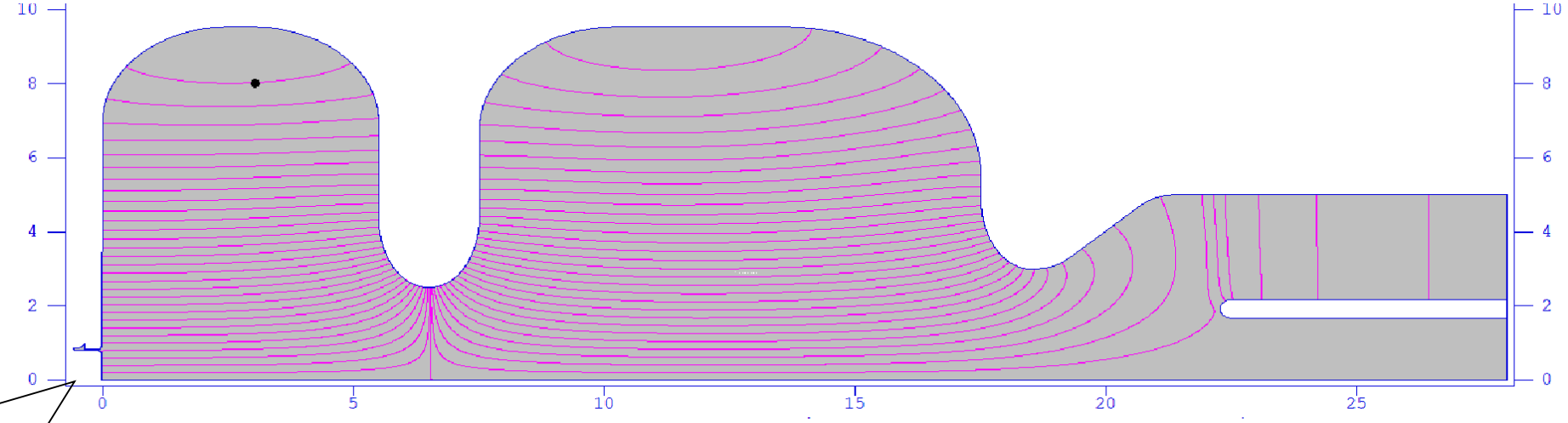
	pi-mode	0-mode
z_0, m	0.2182	0.2182
f_0, MHz	1300.44604	1294.367528
z_{scale}	1.025	1.025
f_{scale}	293	460

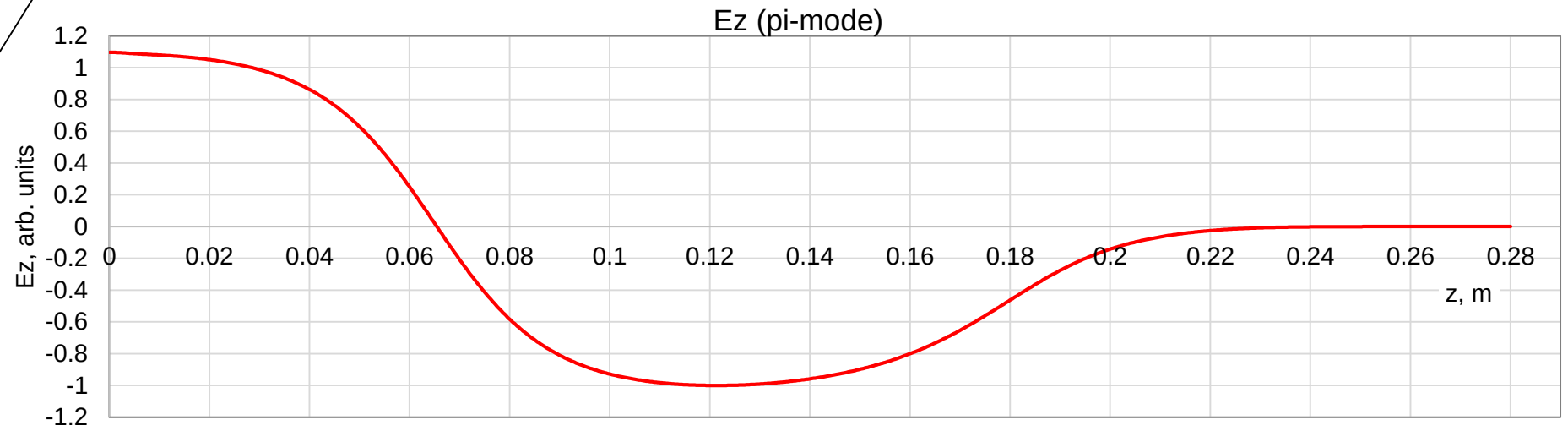
NB: only field profile fitted, not exact resonance frequency!

Superfish simulations for deformed full model

Case 6 (+cath+MR+CA+fixed_deformation)





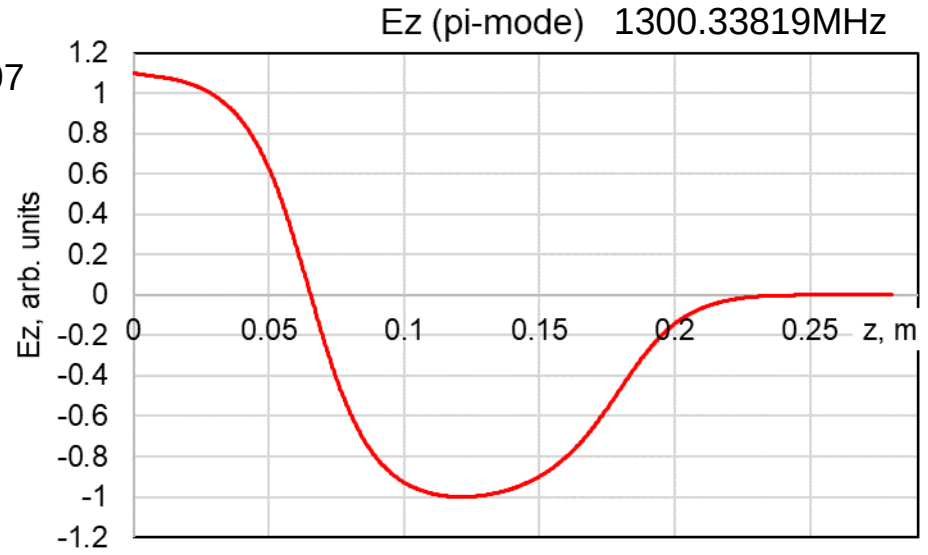


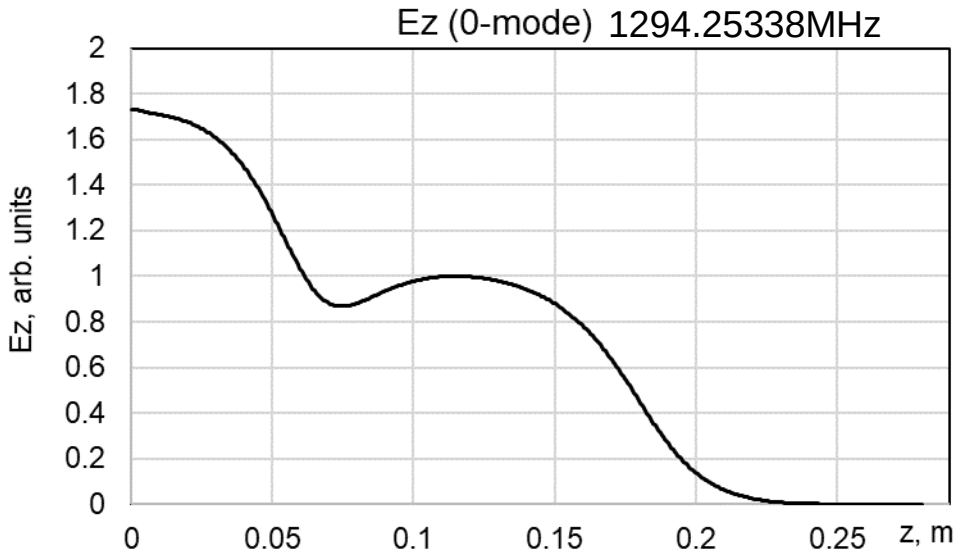
Superfish simulations for deformed full model

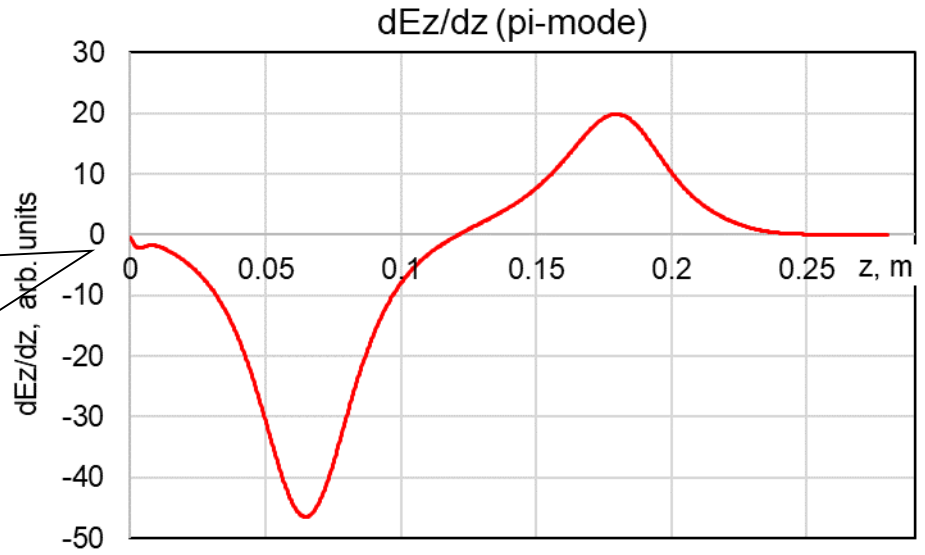
Case 6 (+cath+MR+CA+fixed_deformation)

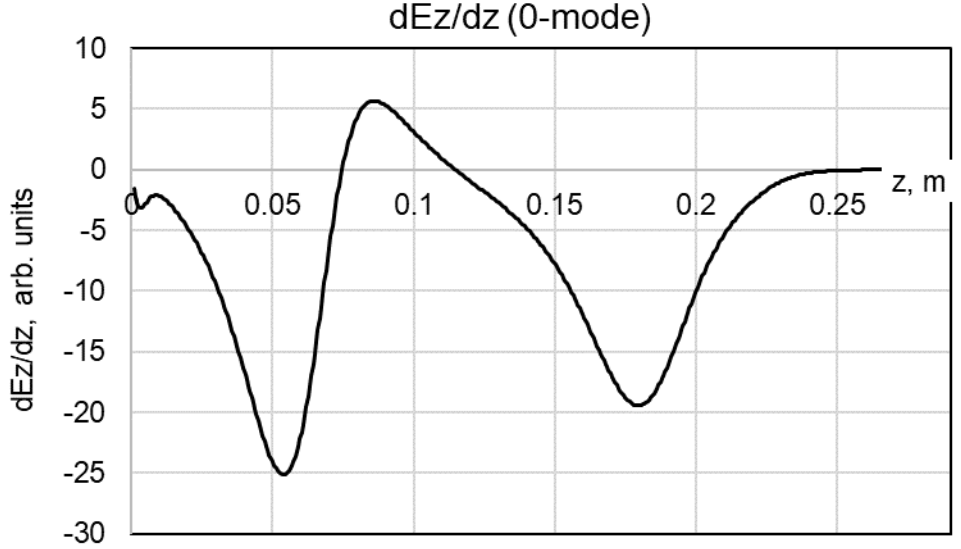
NWA measurements:
f(pi-mode)=1300.464MHz
f(0-mode)=1294.387MHz

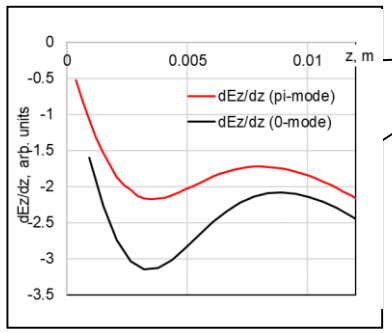
FB=1.097







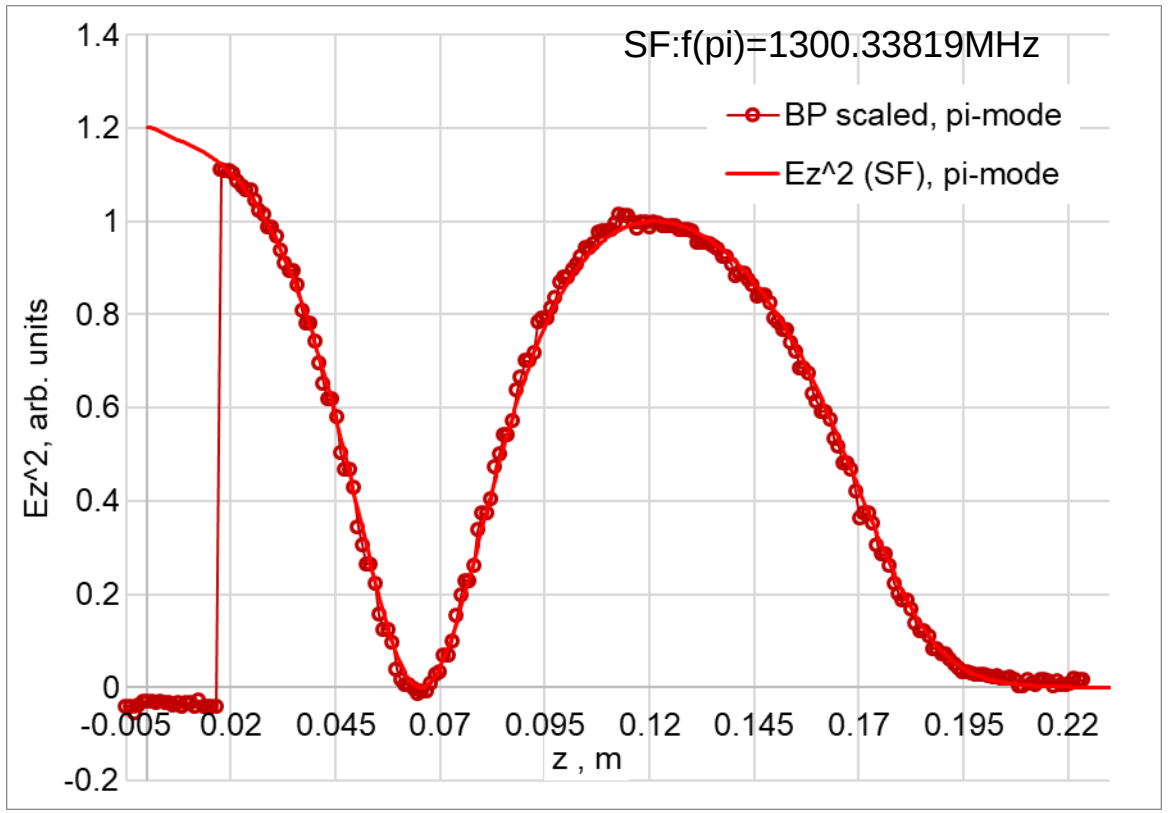


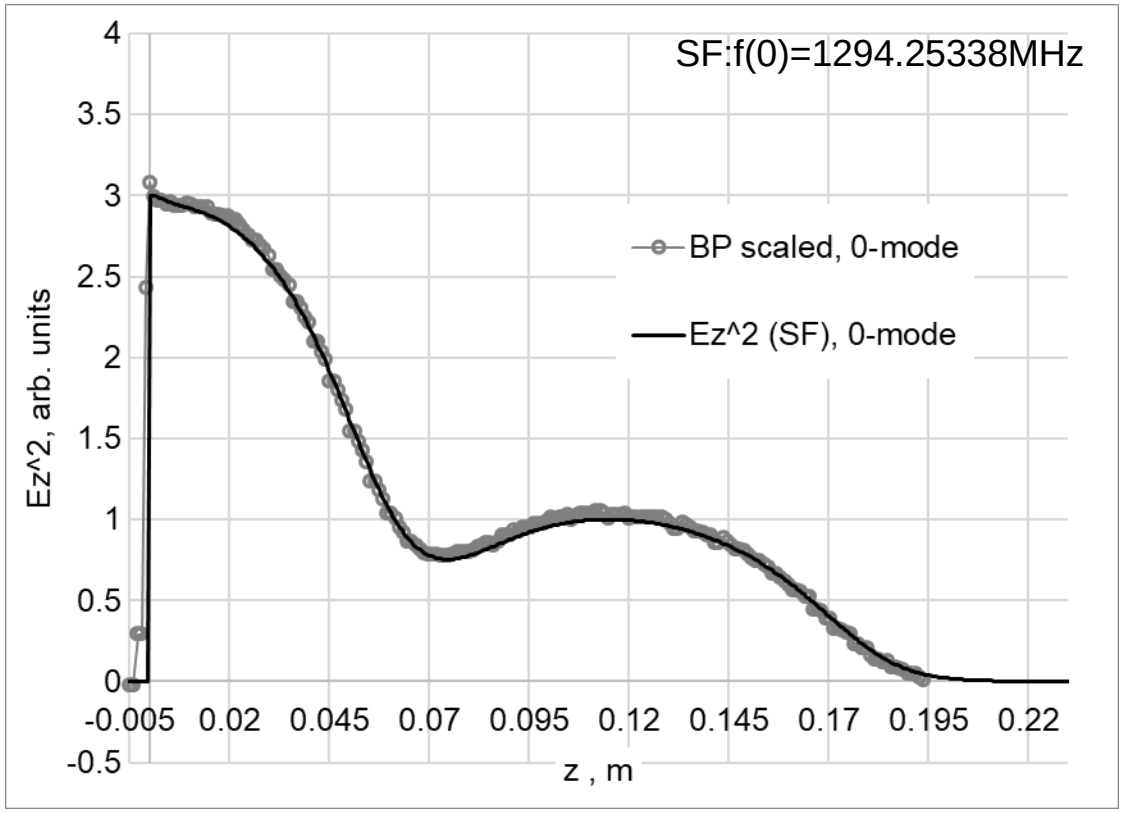


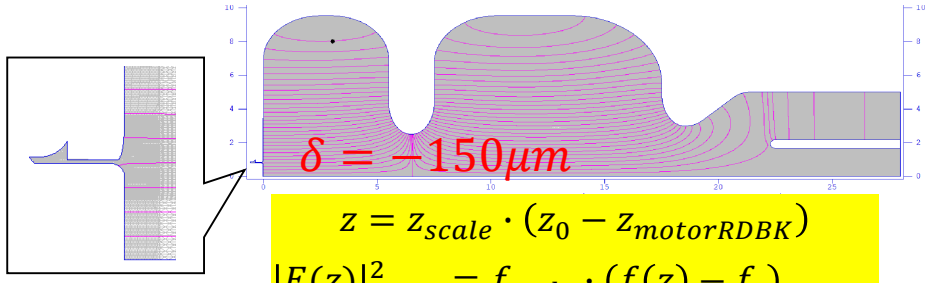
BP: f(pi-mode)=1300.464MHz?

Simulated field profile vs. bead-pull measurements

Case 6 (+cath+MR+CA+fixed_deformation) vs bead-pull







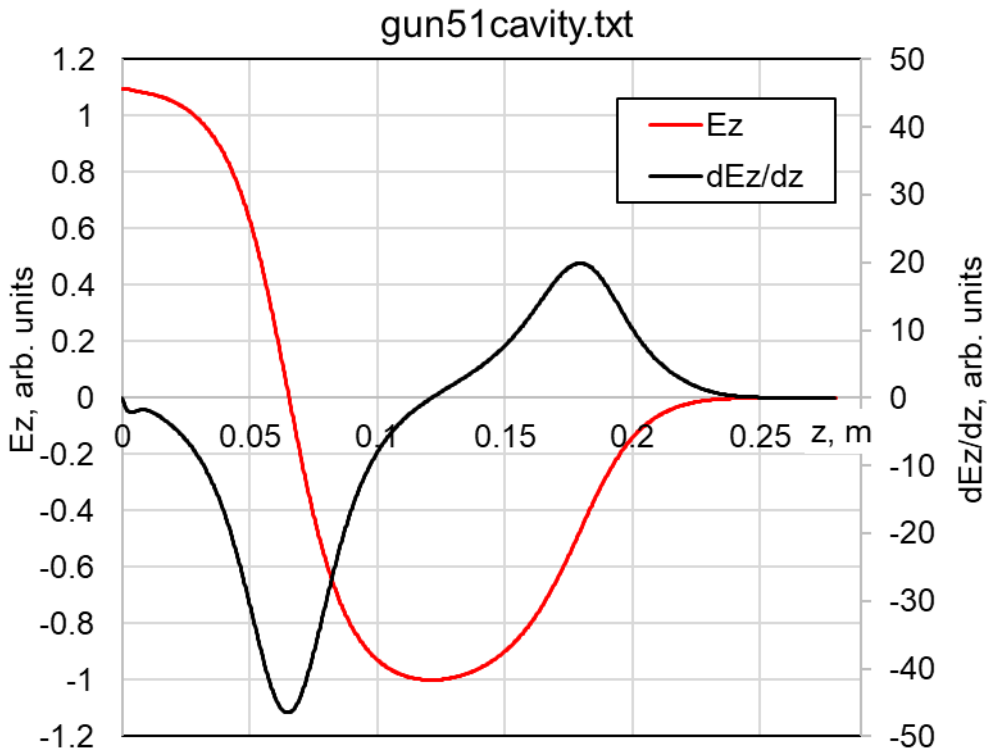
$$z = z_{scale} \cdot (z_0 - z_{motorRDBK})$$

$$|E(z)|^2_{meas} = f_{scale} \cdot (f(z) - f_0)$$

	pi-mode	0-mode
z_0, m	0.2182	0.2182
f_0, MHz	1300.44604	1294.367528
z_{scale}	1.025	1.025
f_{scale}	293	460

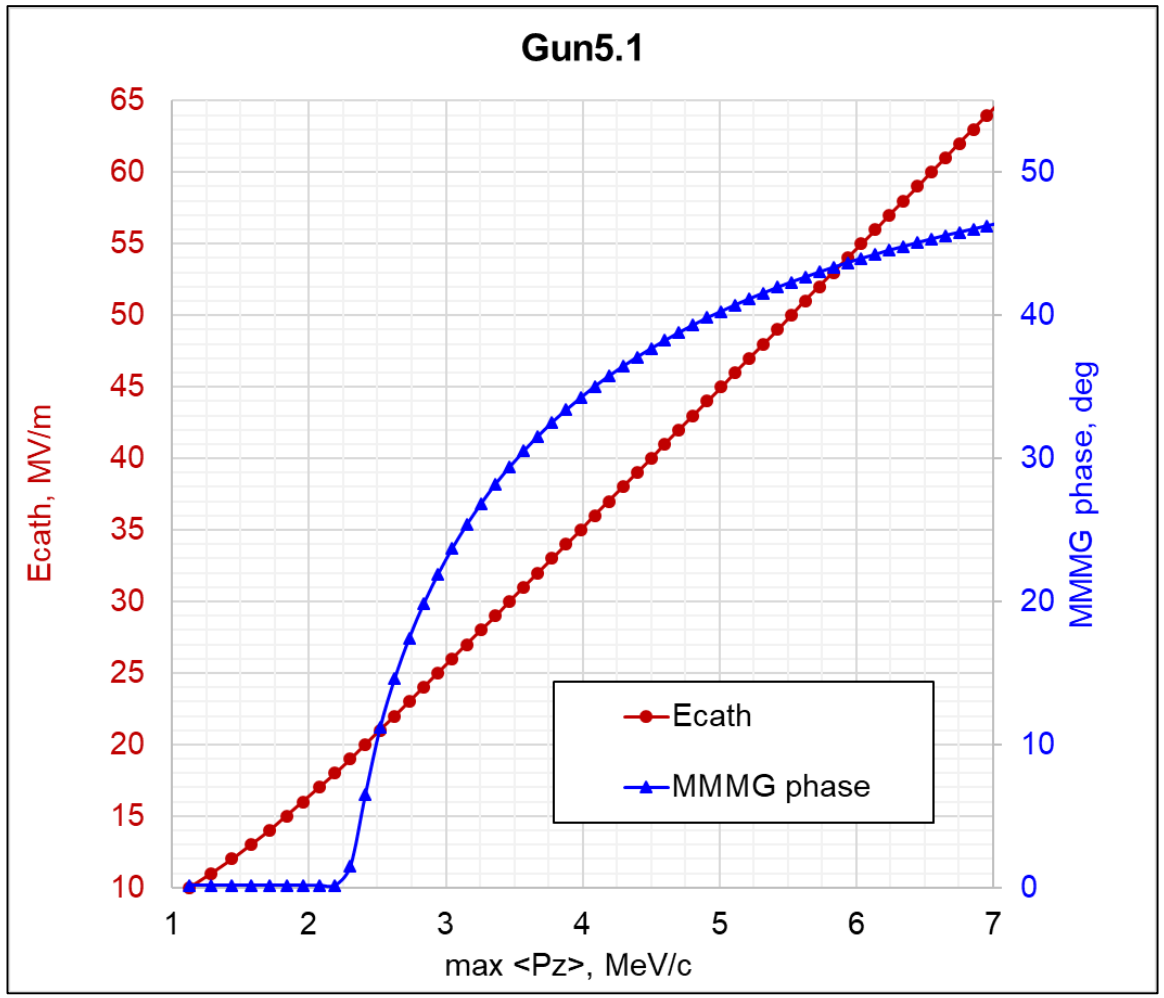
Beam momentum with Gun5.1

Single particle tracking using obtained field profile – gun51cavity.txt



File gun51cavity.txt:

- FB=1.097
- ~1000 points
- <dz>=286um
- Z=0:
  - dz=-66um
  - Ez=1.0968 (parabolic approx., forcing dEz/dz→0)
- …



E.g., Ecath=60MV/m:

- Max <Pz>=6.55MeV/c
- MMMG phase = 45.3deg

Summary

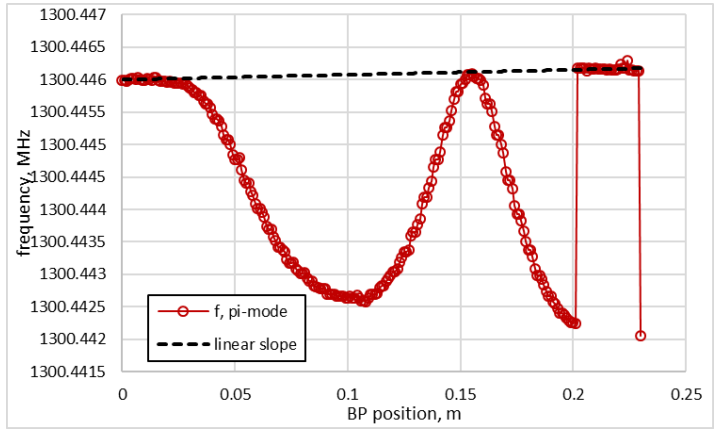
Modeling Gun5.1 field profile

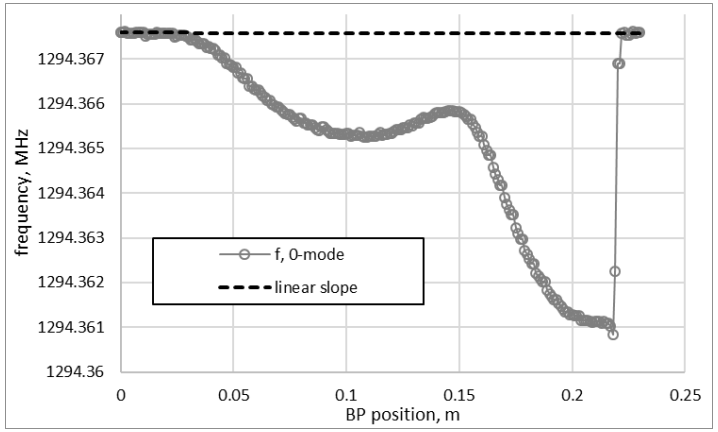
- Gun 5 → new geometry is implemented in Superfish (H. Qian), including cathode model, but no coaxial coupler antenna
- Nominal geometry yields:
  - Field balance FB=|Ecath/Efullcell|=0.98 for the pi-mode
  - Some feature (dEz/dz) close to z=0 → might be simulation challenge
- Several methodic studies:
  - Simplified cathode model (plane wall)
  - Mesh refinement +/-
  - FB=0.97
- The model w/o cathode details is completed with a coaxial coupler antenna with actual nose position (z=222.716mm, Le=28cm) yields FB=0.96
- Beam-pull measurements (A. Oppelt, 31.03.2021)
  - Pi- and 0-modes measured after tuning (cathode wall pressed)
  - Uncertainty in z-scale of bead positions and background frequency determination
- Fit of the simulated field profiles w/o geometry changes → huge discrepancy with bead-pull measurements:
  - Needs separate z-shift for pi- and 0-modes, and z-scaling (assuming homogeneous z-mesh) z_{scale}=1.025
- Back (cathode) wall deformation (r=23mm) of the model w/o cathode with antenna → -150um better agreement, but no frequency fitted!
- This deformation applied to the full model (cathode and antenna) → acceptable agreement with bead-pull measurements for both modes
- The field profile gun51cavity.txt is generated, first beam momentum simulations (single particle tracking) done
- Possible next steps (?):
  - Simultaneous (auto) fit bead-pull + frequencies of both modes, including Le and other (more realistic?)deformations
  - More detailed tolerance studies
  - More accurate bead-pull treatment (linearly sloped bkg – see backup slide)

Backup

Simulated field profile vs. bead-pull measurements*

Case 6 (+cath+MR+CA+fixed_deformation) vs bead-pull **(linear slope subtracted)**

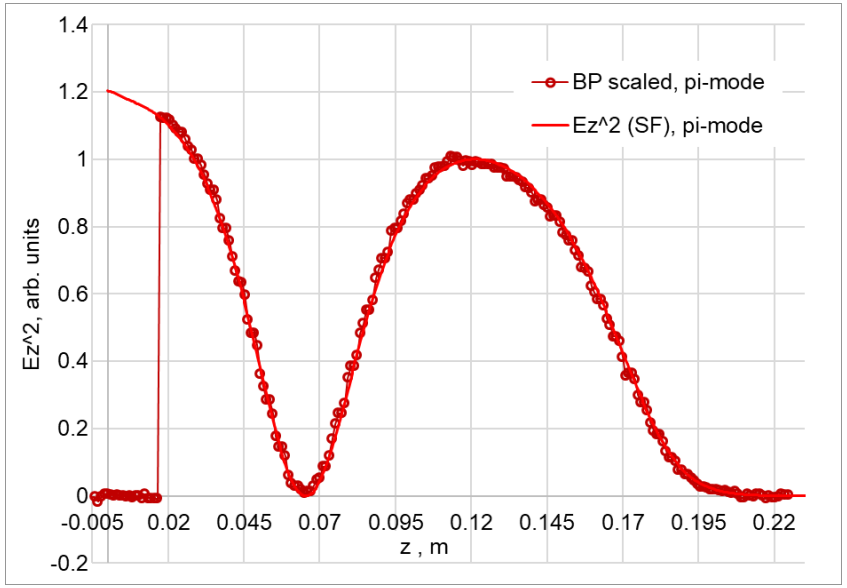


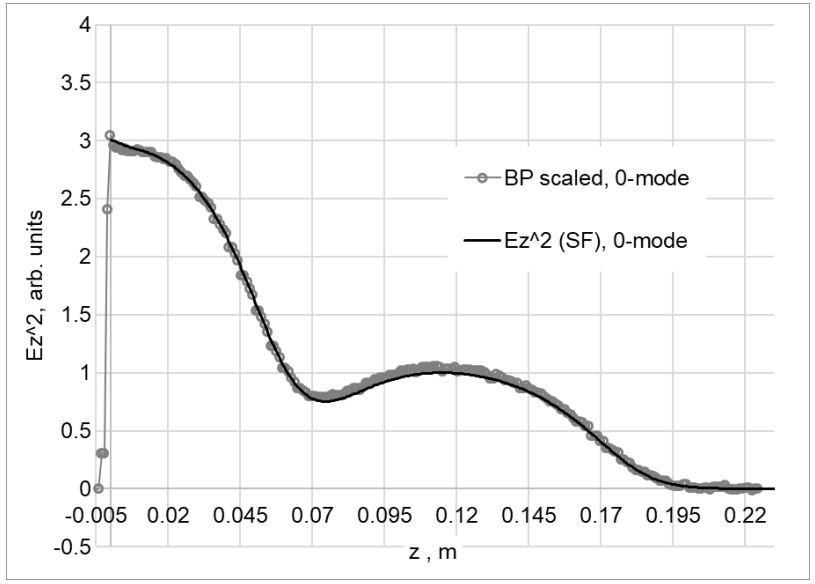


$$z = z_{scale} \cdot (z_0 - z_{motorRDBK})$$

$$|E(z)|^2_{meas} = df_{scale} \cdot \left(\frac{f(z)}{f_{BkgLinear}(z)} - 1\right)$$

Uncertainty in slope determination?





	pi-mode	0-mode
z_0, m	0.218	0.218
$f_{BkgSlope}$, MHz/m*	**7.6E-04**	**-6.2E-05**
z_{scale}	1.03	1.03
df_{scale}	293	460

Bead pull measurements during cavity tuning

Last two measurements of the pi-mode