Evaluation of In-Vacuum Wiggler Wakefield Impedances for SOLEIL and MAX IV

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Acknowledgements:
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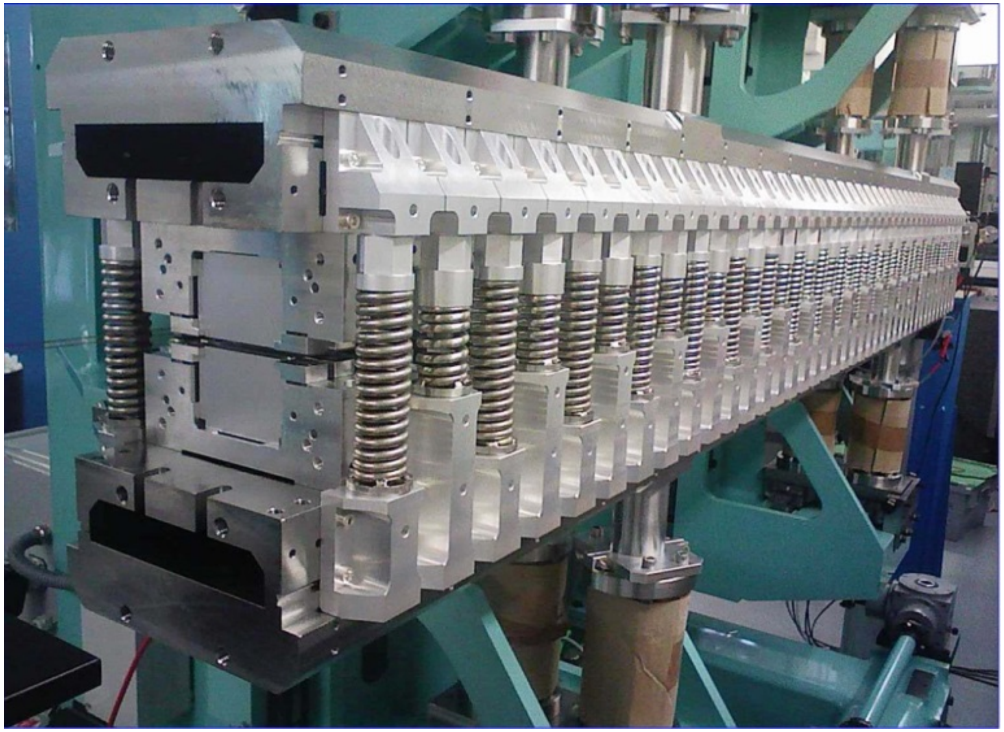
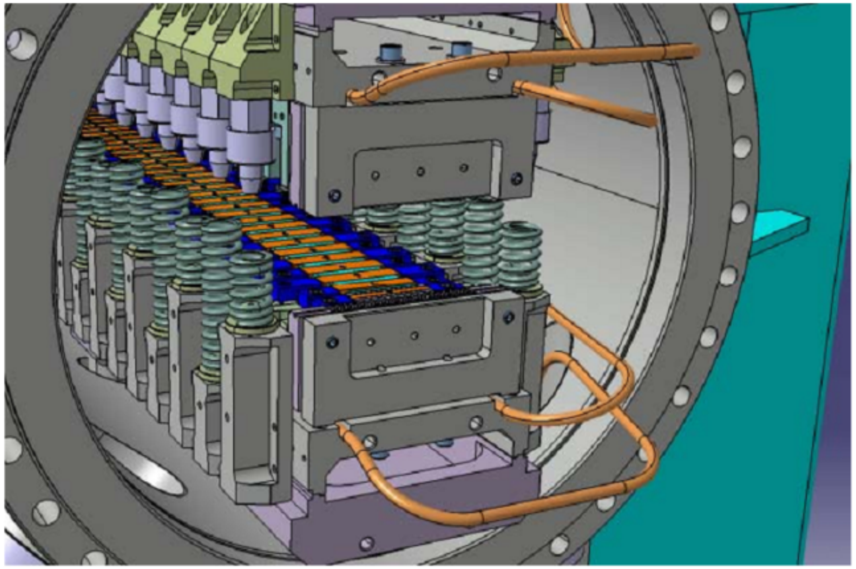
Introduction

- Wakefield impedance of wiggler determined from simulations in GdfidL and ABCI
  - Taper transitions to main vacuum chamber
  - Vacuum tank included in 3D (GdfidL) simulations
- In-vacuum wiggler WSV50
  - Designed and built at SOLEIL
- 1 installed at SOLEIL
  - Preparations to close the minimum gap from 5.5 mm to 4.5 mm
- Similar design for MAX IV 3 GeV ring
  - Must be included in beam stability simulations - so far, threshold currents/growth rates only predicted for bare machine
  - Design includes option for tapered magnetic section

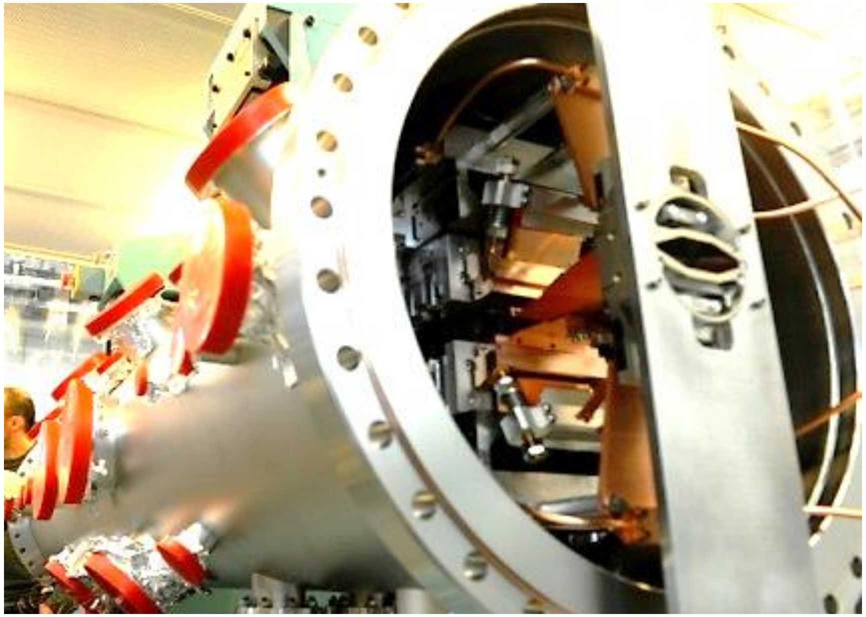
WSV50 (SOLEIL)



Springs along length for magnetic force compensation

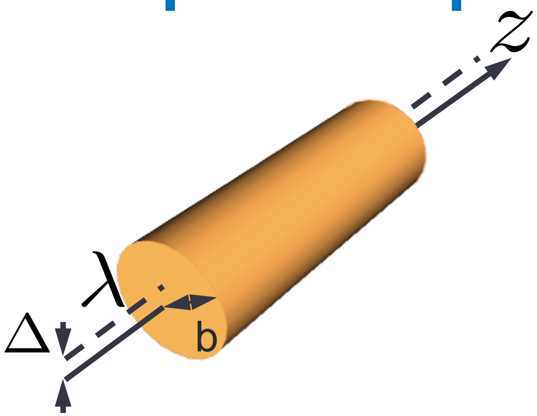


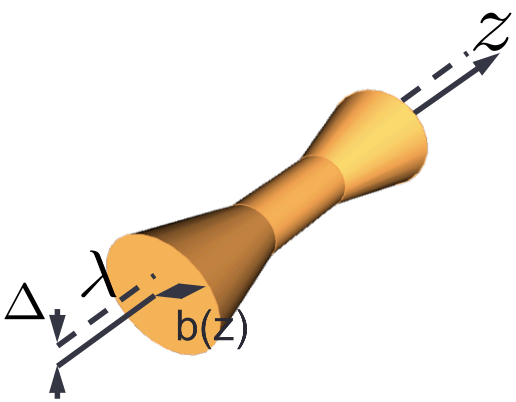
Cylindrical vacuum tank



Taper transition to beam pipe cross section

Taper Impedance Theory

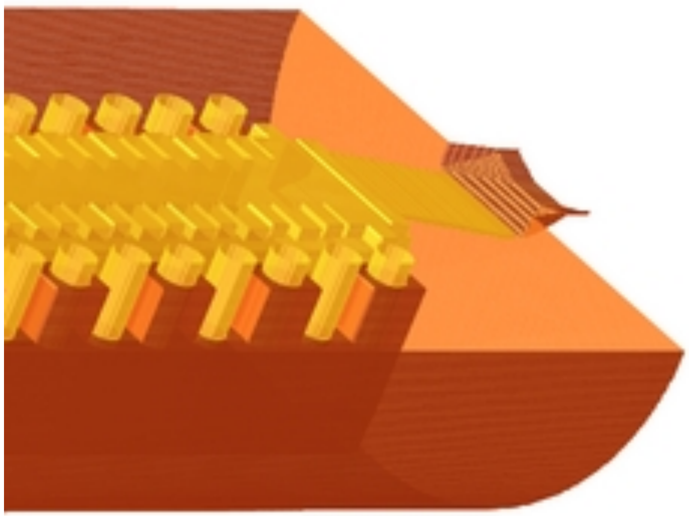




Stupakov G. et al, 2007. *Low Frequency Impedance of Tapered Transitions with Arbitrary Cross Sections,* Phys. Rev. ST. Accel. Beams **10**, 094401 and references

- Perturbation theory applied to field inside tube of constant aperture
  - Perturbative field that allows for small change in beampipe aperture while a still solution of Maxwell's equations
- Properties at low frequency:
  - Purely imaginary
  - Longitudinal impedance inductive
  - Transverse impedance frequency independent
  - Rectangular tapers have larger impedance than circular
  - For small rectangular taper widths, transverse impedance proportional to taper width
- Resonances important at high frequency

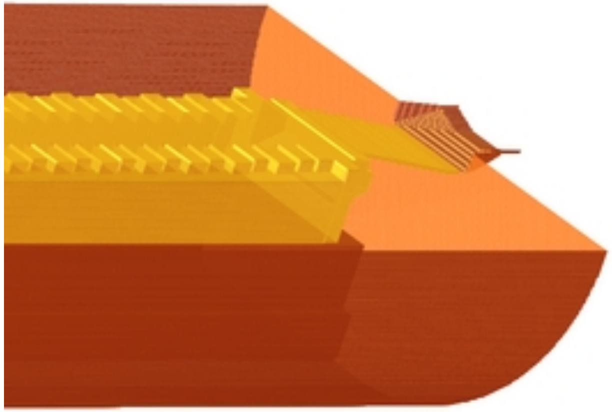
GdfidL Model



- Geometry reconstructed in GdfidL from geometric primitives
- Vacuum tank and springs included
- Springs modelled as cylinders

Other geometries simulated:

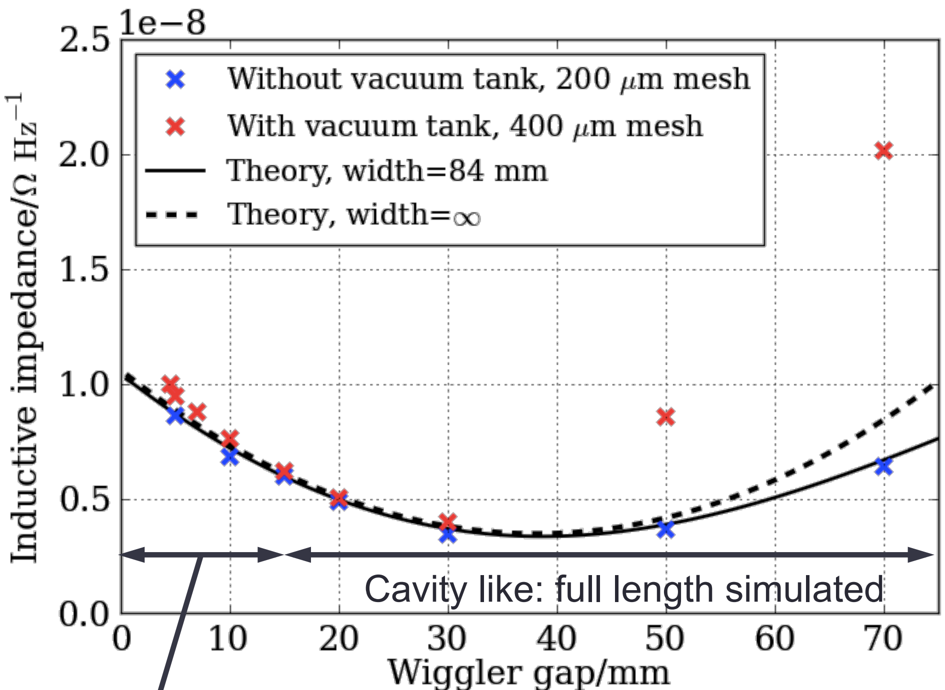
No springs



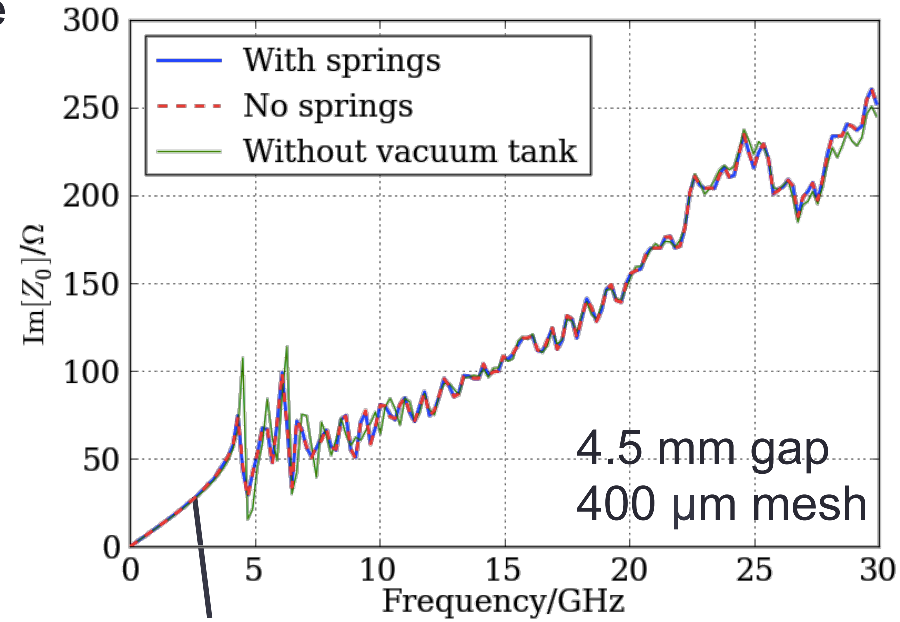
No vacuum tank

Longitudinal Impedance

- Time domain simulation with line charge excitation
- Two symmetry planes (quarter geometry)
- Inductive impedance determined from fits to points below 500 MHz



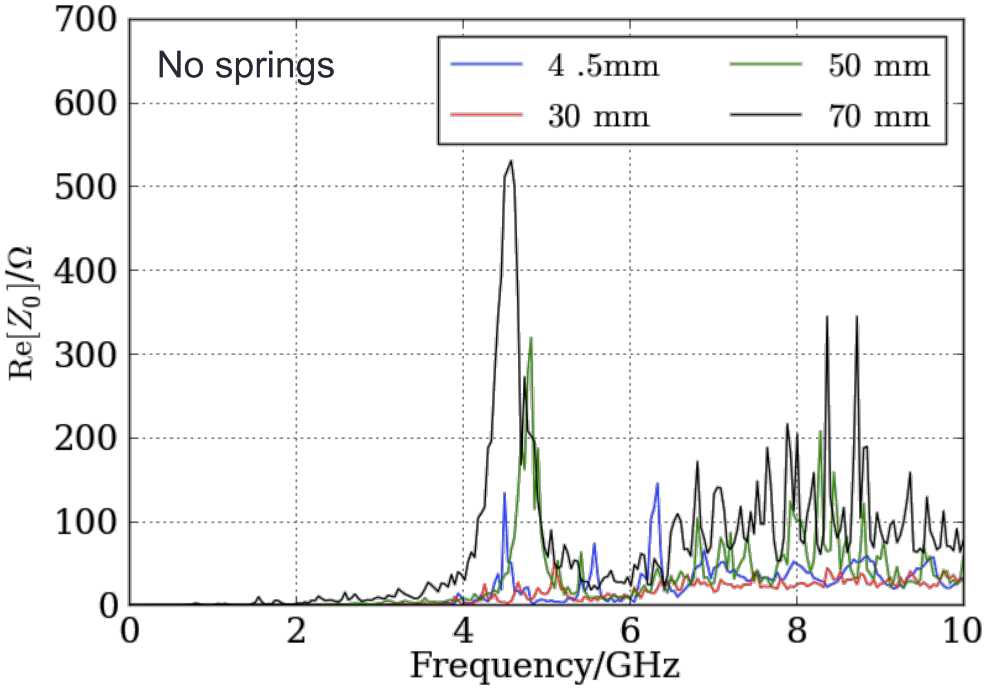
Collimator-like: shortened model



Inductive at low frequencies

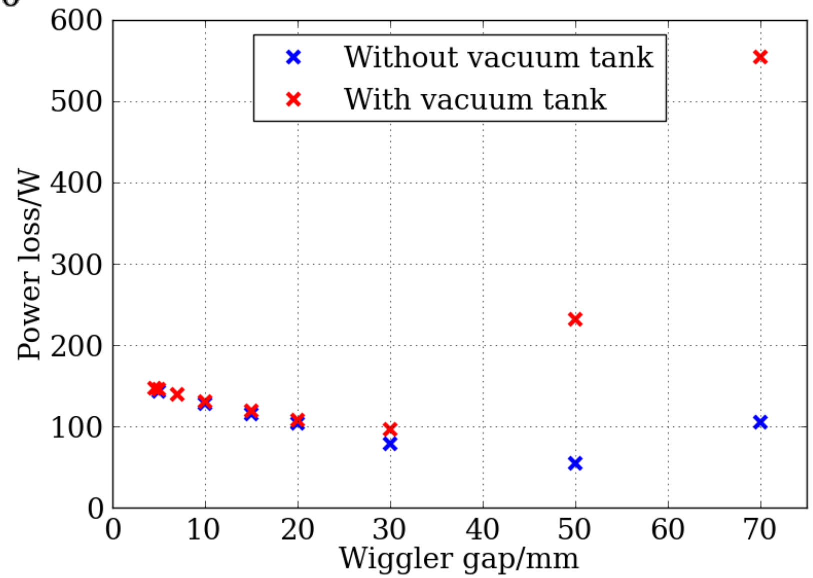
Smaluk et al., 2014. *Coupling Impedance of an In-vacuum Undulator: Measurement, Simulation and Analytical Estimation.* Phys Rev. ST. Accel. Beams **17**, 074402.

Power Loss



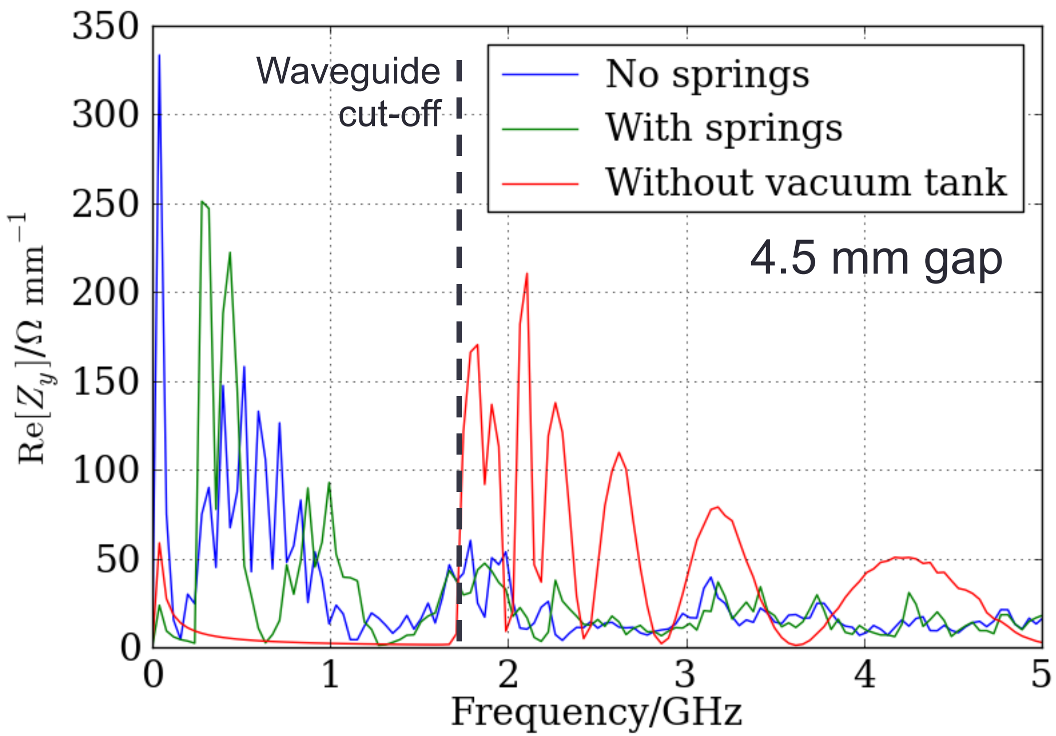
Real part shows resonances that spread into magnetic section as wiggler is opened

- Power loss for SOLEIL, 4.5 mm wiggler gap, 500 mA, uniform fill, 20 ps bunch length: 148 W
- Lower for all other beam configurations

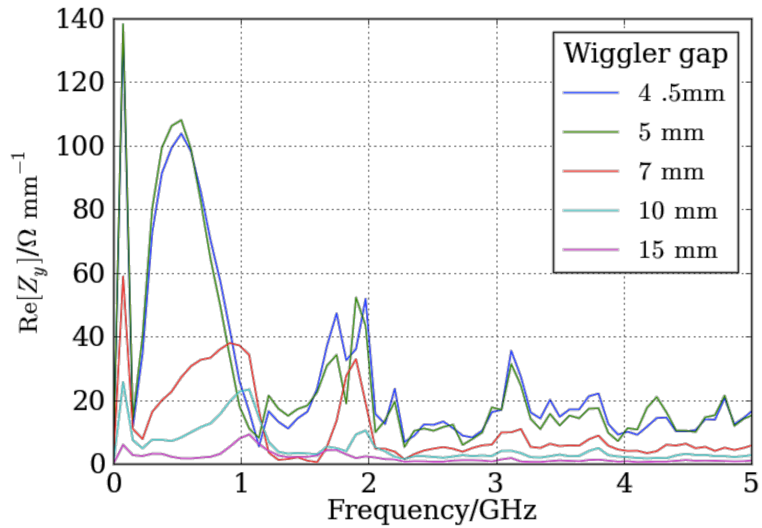


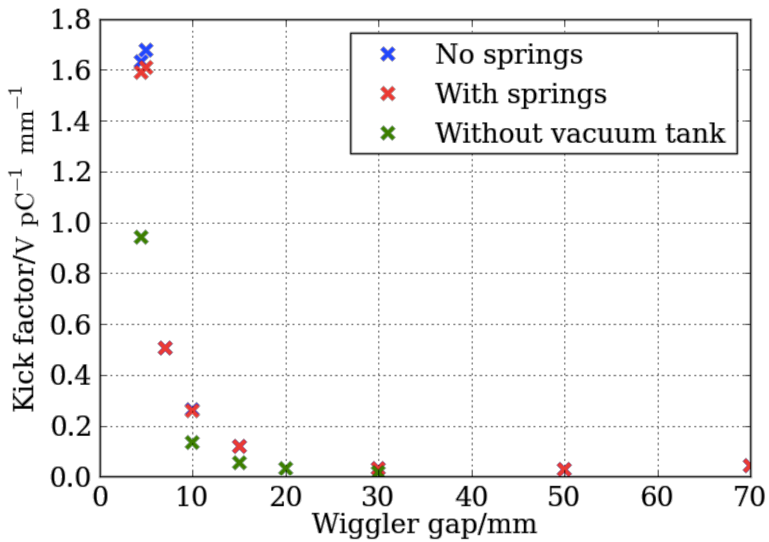
Transverse Impedance

- Half geometry simulated, full length of magnetic section included
- 700 µm mesh



Closely spaced TE-like modes at low frequency





MAX IV

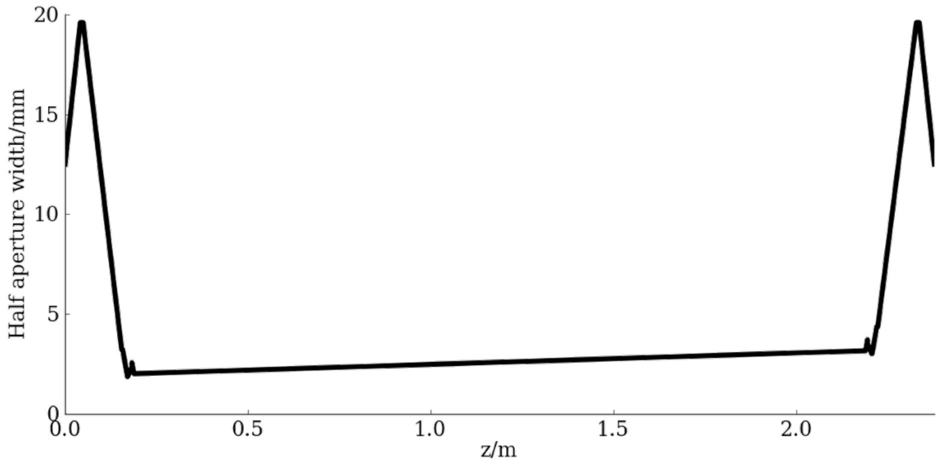
	SOLEIL (uniform fill)	MAX IV
Energy/GeV	2.75	3.0
Design current/mA	500	500
Harmonic number	416	176
RF frequency/MHz	352.2	99.931
e^- per bunch/10^{10}	0.9	3.2
RMS bunch length/ps	20	40
Bunch length with HC/ps	N/A	195

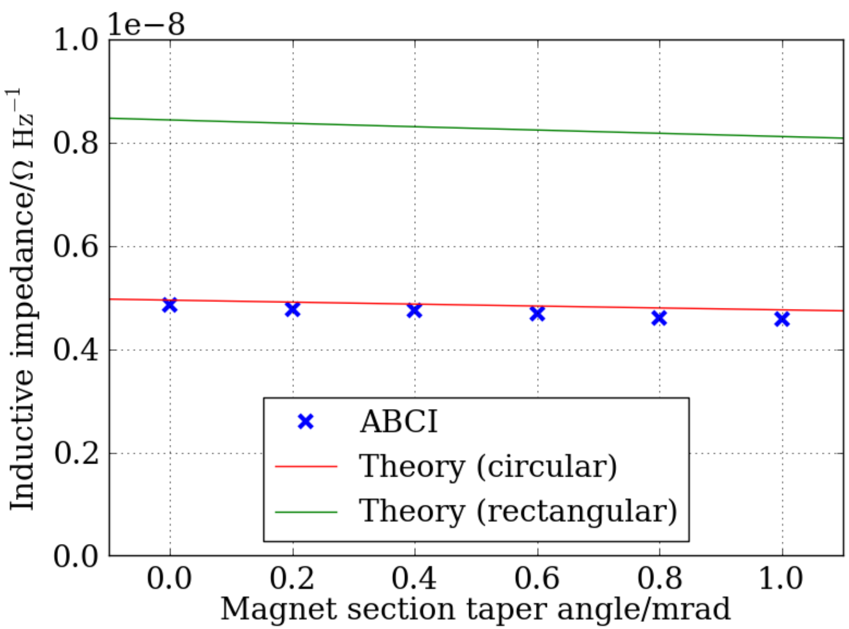
Differences in taper design:

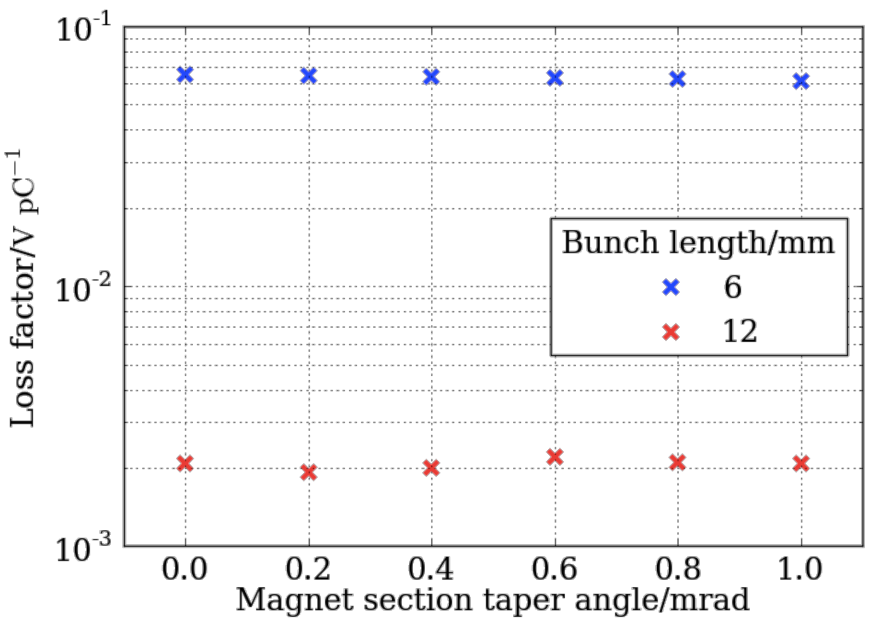
- Dimensions slightly different
- Smaller minimum gap, 4.2 mm
- Longer springs are wider
- Springs do not extend right to end of girder
- Option for wiggler gap to change along magnetic section – additional taper
- Additional transition to MAX IV circular vacuum chamber (not included)

Tapered Magnetic Section

- Simulation performed using ABCI for mesh sizes of 50 µm
- 2D simulation (axial symmetry assumed)
- Maximum 2 mm change in wiggler gap over length of about 2 m
- Direction of the taper makes no difference

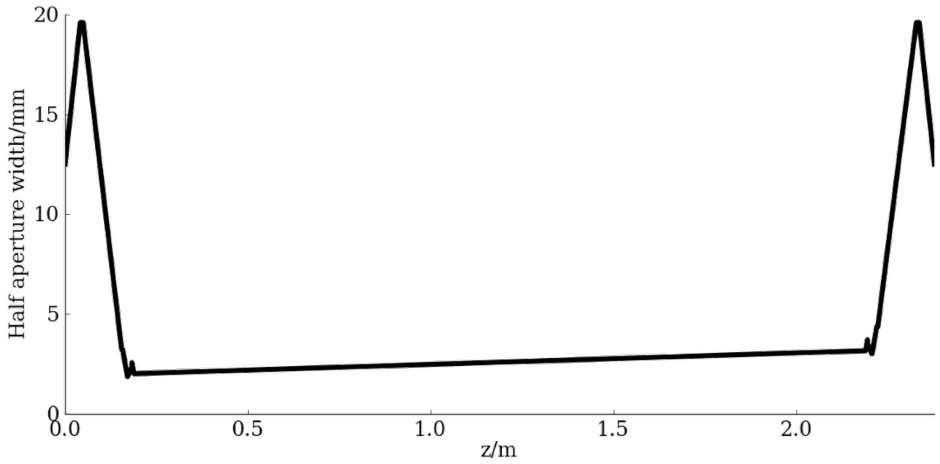


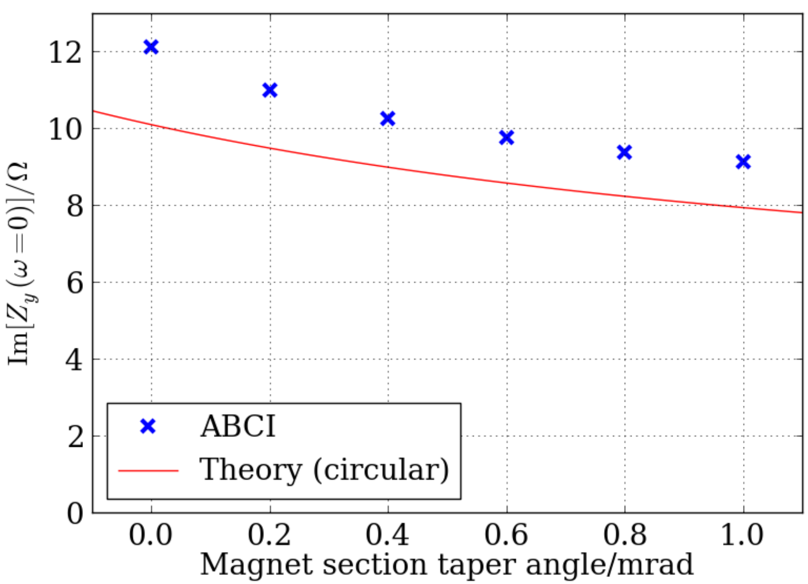


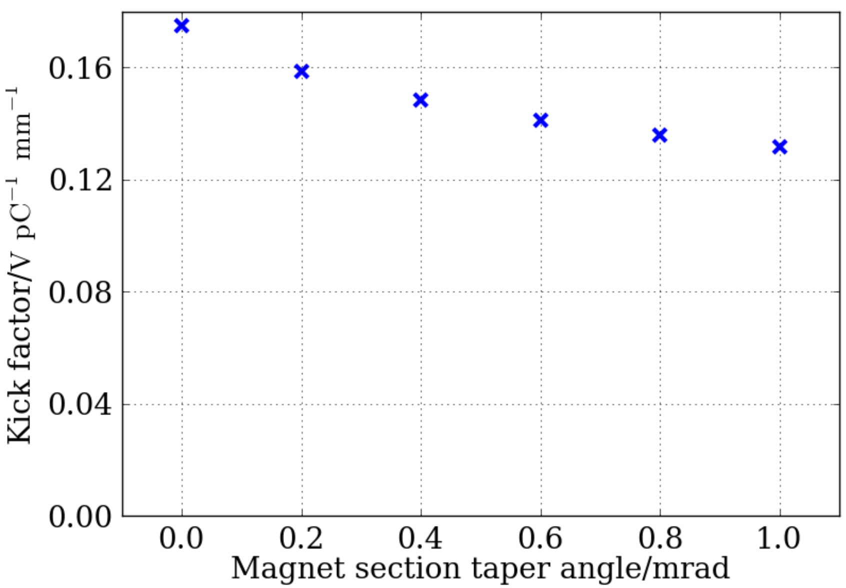


Tapered Magnetic Section

- Imaginary impedance at 0 frequency compared with theory
- Imaginary impedance taken at 60 MHz to avoid transient effects near 0



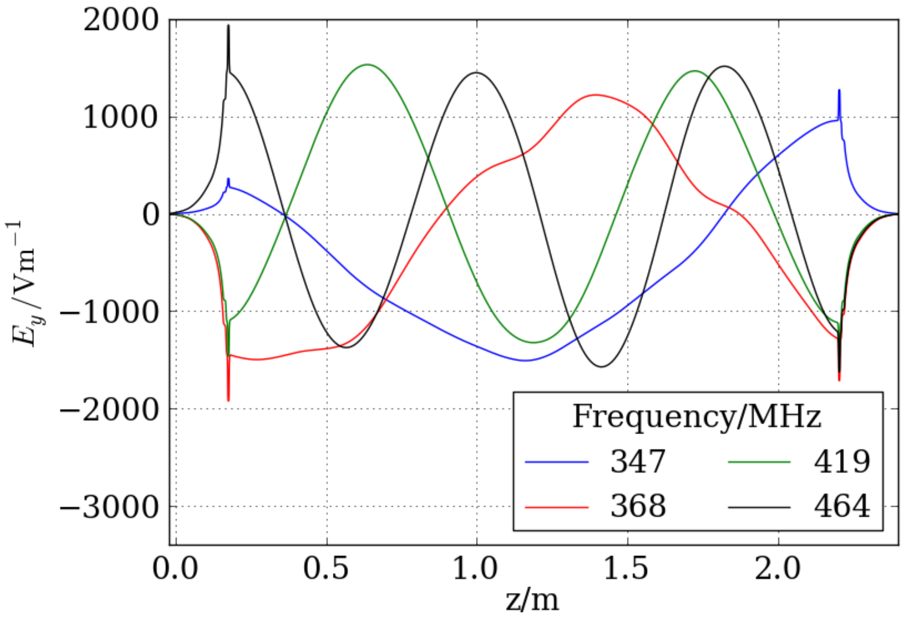




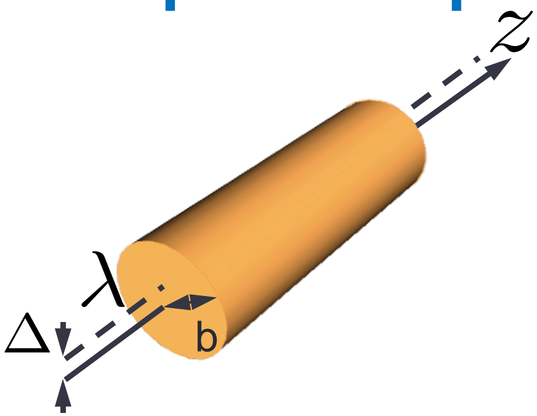
Conclusion and Outlook

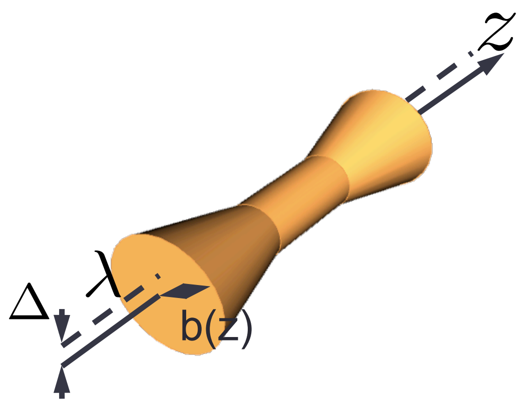
- Longitudinal and transverse impedances of WSV50 have been evaluated for both SOLEIL and MAX IV
- Inductive impedance is in agreement with theory of tapered transition except for at large wiggler gaps with vacuum tank
- Vacuum tank important for transverse impedance
  - Presence of trapped modes
- Similar conclusions can be drawn for MAX IV wiggler
- Tapered magnetic section causes small reduction in impedance
- Results must be added to impedance of MAX IV 3 GeV ring with tracking simulations to estimate the resulting current thresholds

Back up


2000
1000
0
−1000
−2000
−3000
$E_y\,/\mathrm{Vm}^{-1}$
0.0
0.5
1.0
1.5
2.0
z/m
Frequency/MHz
347
419
368
464

Taper Impedance – Perturbation





- Electric field of an offset line charge with charge density λ (electric dipole) inside a perfectly conducting cylinder
- Solve Poissons equation for electric potential φ_0

$$\nabla^2 \phi_0 = -\frac{\rho}{\epsilon_0}$$

$$\phi_0(r, \theta) = 2\lambda\Delta \left(\frac{1}{r} - \frac{r}{b^2} \right) \cos\theta$$

- Add perturbation φ_1 and allow b to vary with z

$$\phi = \phi_0 + \phi_1$$

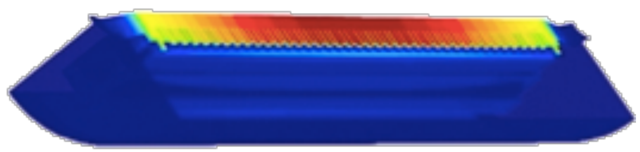
$$\nabla_\perp^2 \phi_1 = -\frac{\partial^2 \phi_0}{\partial z^2}$$

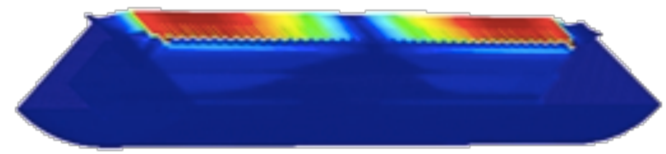
- Similar approach for magnetic field (magnetic dipole) to arrive at transverse impedance

$$Z_T(\omega = 0) = -\frac{i}{\lambda\Delta c} \int_{-\infty}^{\infty} (E_z - H_y) dz$$

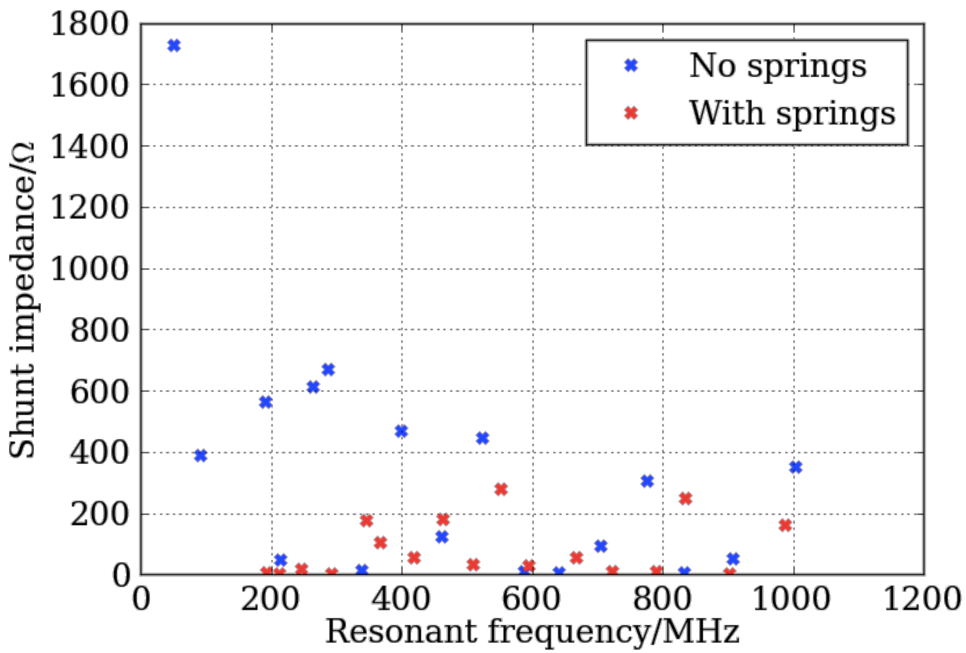
Stupakov G. et al, 2007. *Low Frequency Impedance of Tapered Transitions with Arbitrary Cross Sections,* Phys. Rev. ST. Accel. Beams **10**, 094401 and references

Trapped Modes

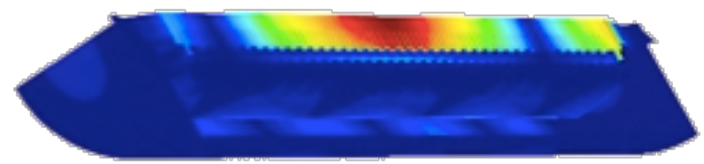


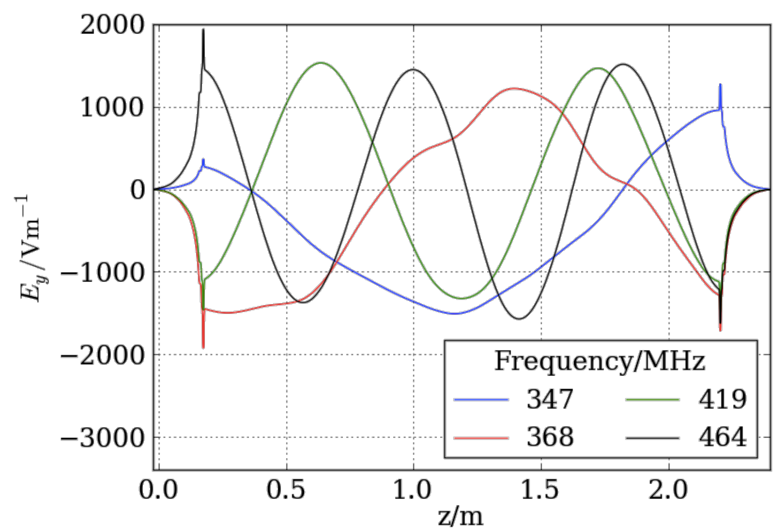


Shunt impedance evaluated at 1 mm offset



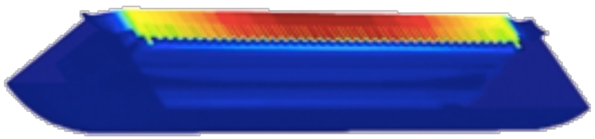
With springs:

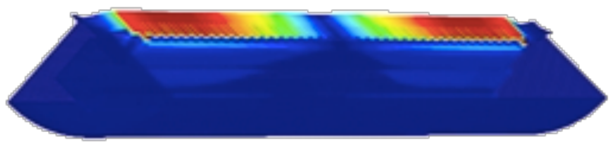




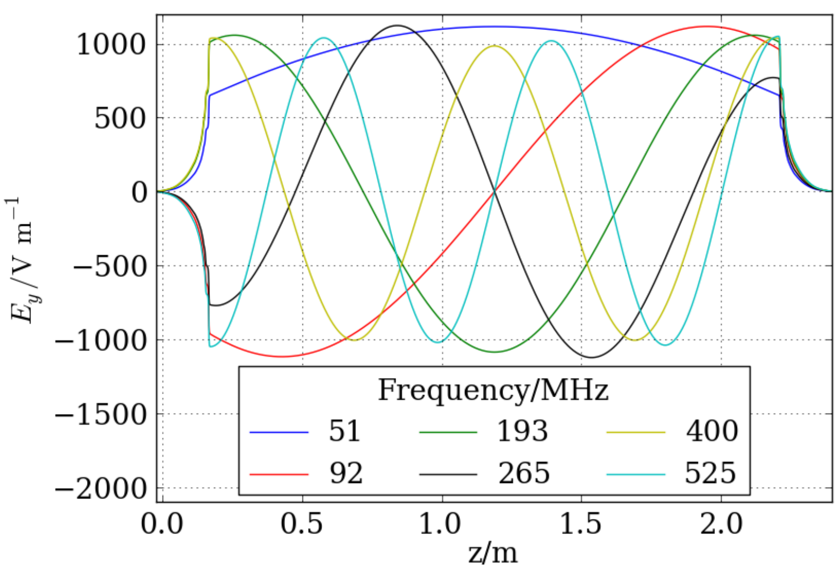
Trapped Modes

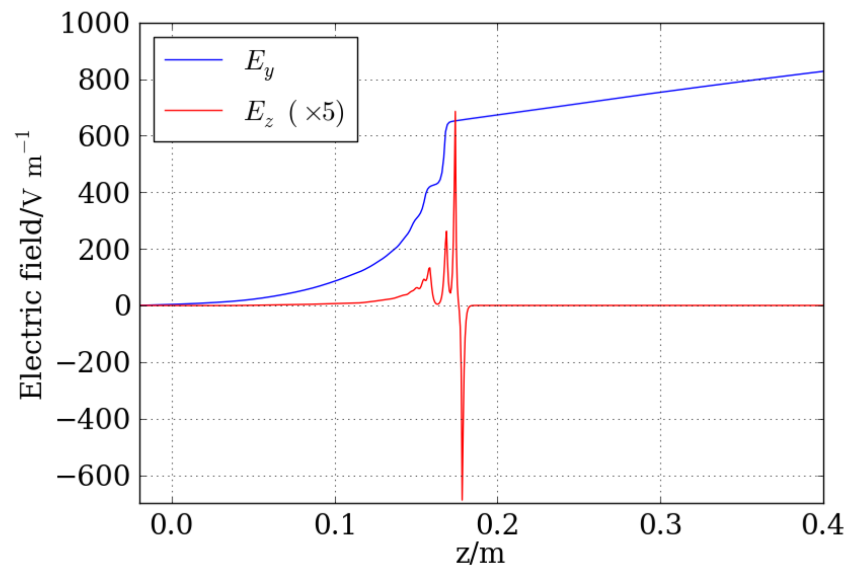
- Low frequency modes found using frequency domain computation
- 600 µm mesh





Resonant frequency/MHz	Shunt impedance/Ω	Internal quality factor
51	431	903
92	97	1053
193	141	3347
265	153	1896
400	117	2438
525	112	2494





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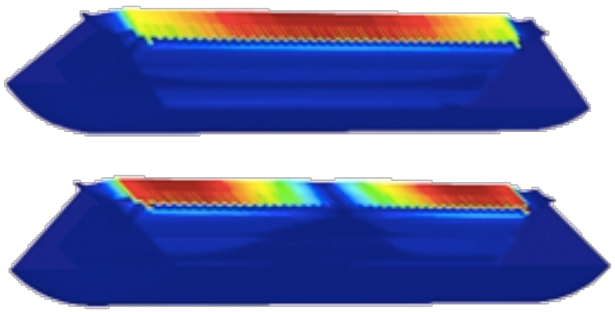
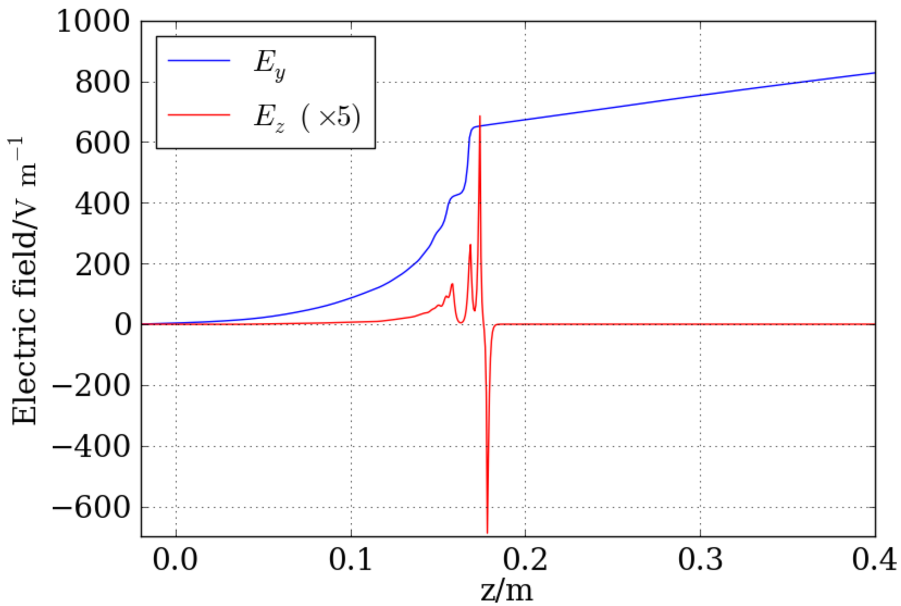
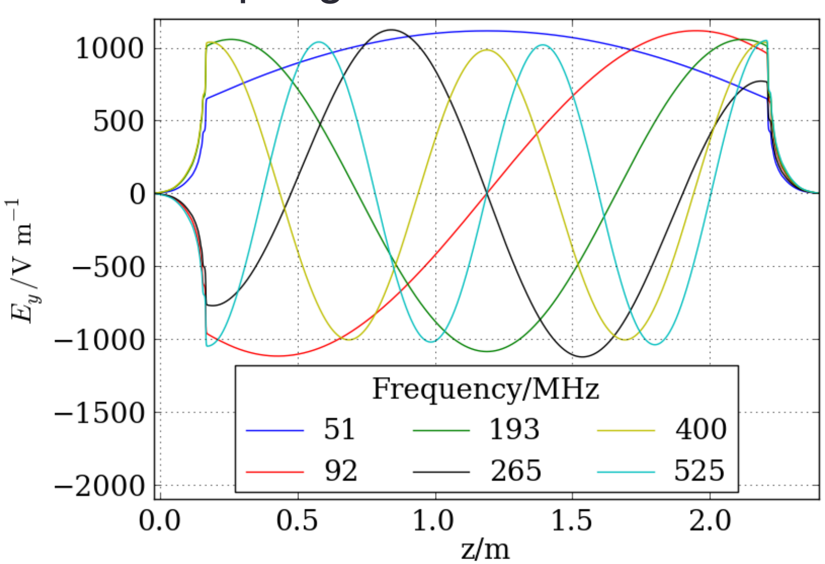




Without springs:



With springs