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Transient Electromagnetic Analysis of MEBT Kickers for PXIE

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PIP-II

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Outline

- Introduction: MEBT Chopper
- Proposed Kicker Structures
- Electromagnetic Tool
- Dispersion Wide Pulse
- Field on Axis Wide Pulse
- Dispersion of Actual Pulse
- Kick Efficiency
- Paraxial PIC Simulation

MEBT Chopper Requirments

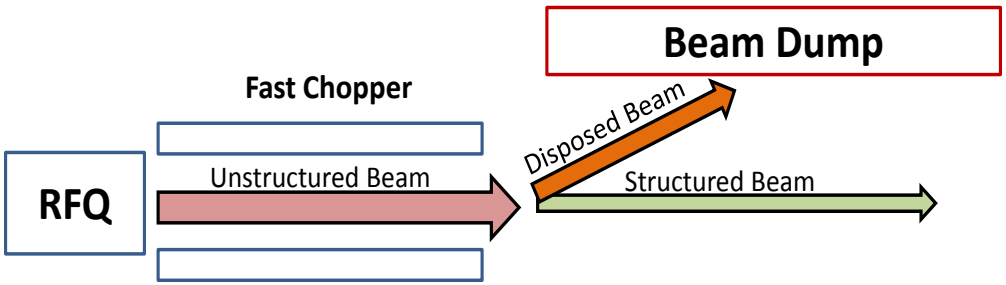
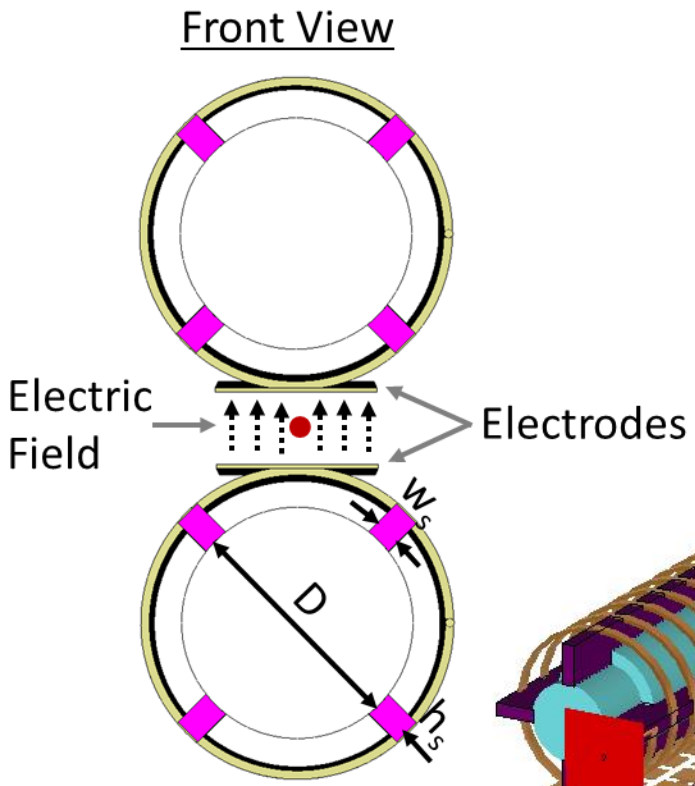


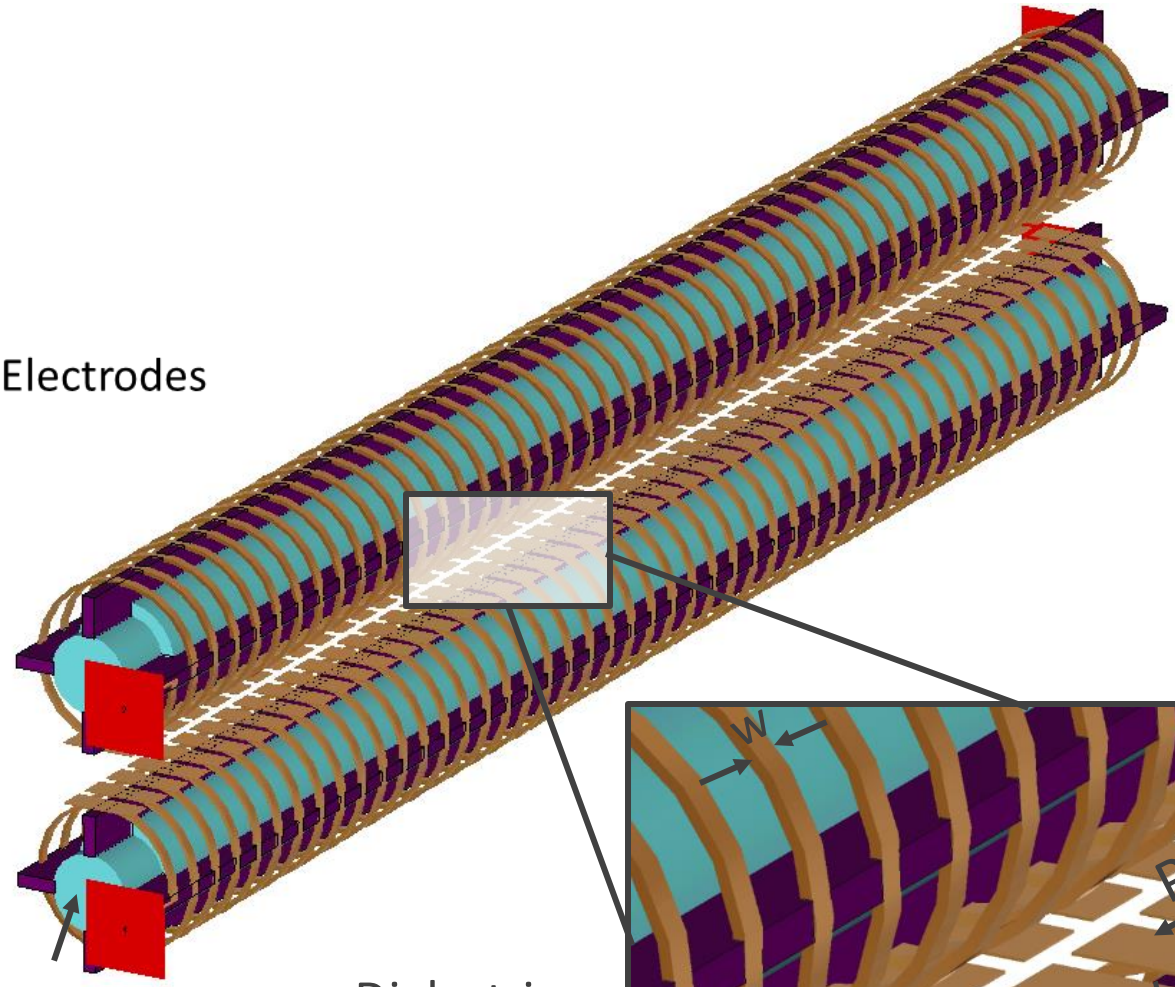
Table 1. Typical beam parameters

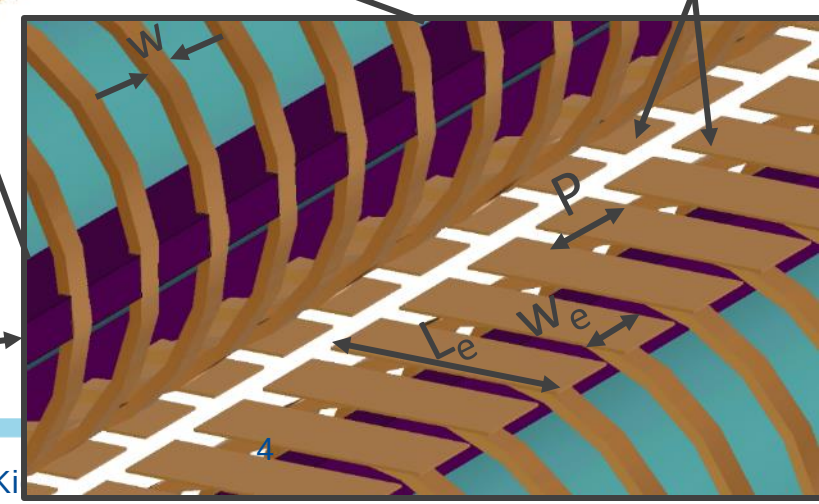
Ion type	H-
Beam energy	2.1 (+/-1%) MeV
Velocity (beta)	0.0668
Frequency of bunches (CW)	162.5 MHz
Beam current , nominal/range	5/(1 – 10) mA
Nominal charge per bunch	30 pC
Relative residual charge of removed bunches	$< 10^{-4}$
Beam loss of pass through bunches	< 5%
Bunch size, 6-sigma X/Y (horizontal/vertical)	16/12 mm
Bunch length, , 6-sigma	1.3 ns

- Chopper consists of sections of 2 travelling-wave kicker assemblies working in sync (each is 500 mm in length, electrode to electrode distance ≥16 mm)
- Any bunch of the 162.5 MHz (β=0.0668) CW train can either pass or be removed
- Kick is in the vertical direction
- A 3.7 mrad deflection angle is required per each kicker assembly (bipolar scheme)
- Voltage on plate with respect to ground (bipolar drive scheme) 250 ±25 V, -250 ±25 V
- A minimum length of time of ±0.65 ns with respect to the bunch center
- 5% uniformity of the kicker electric field within 6σ=±8 mm
- Any reduction in integral kick is compensated by increasing the applied voltage
- Any difference between kicker and beam velocities is corrected by widening the flattop
- $2 \cdot 10^{-7}$ Torr vacuum level

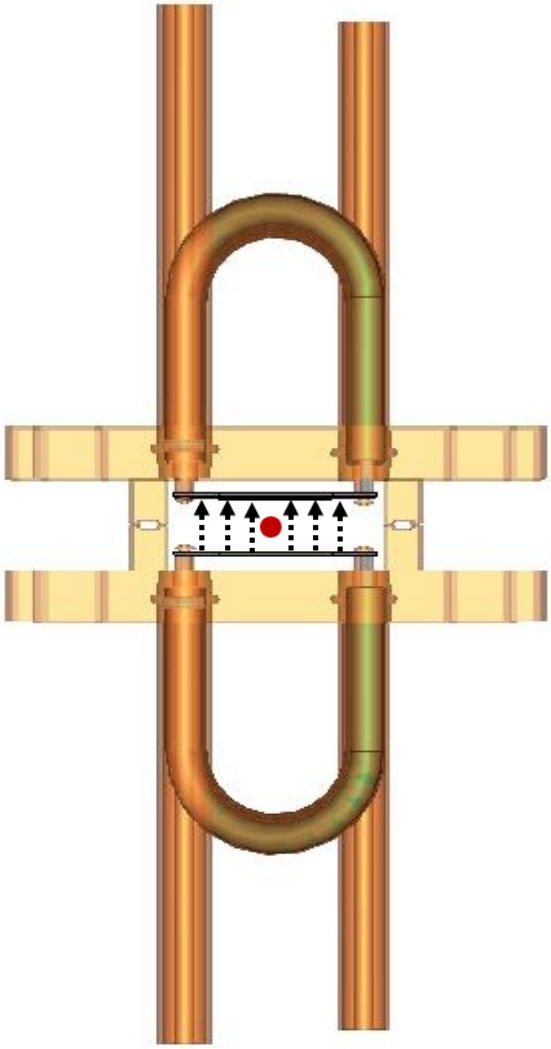
Proposed Kicker Structures: 200Ω Kicker

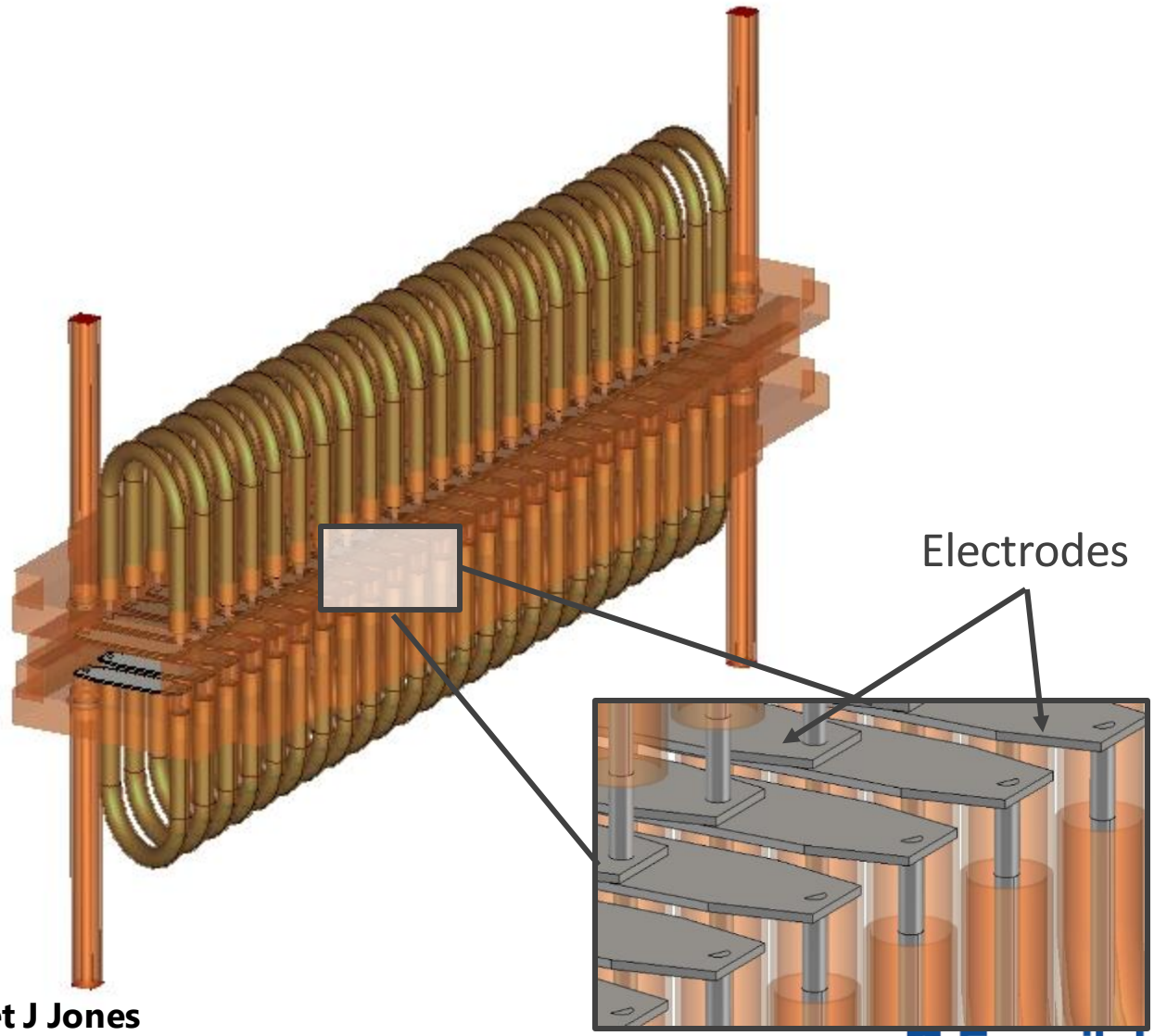






Proposed Kicker Structures: 50Ω Kicker



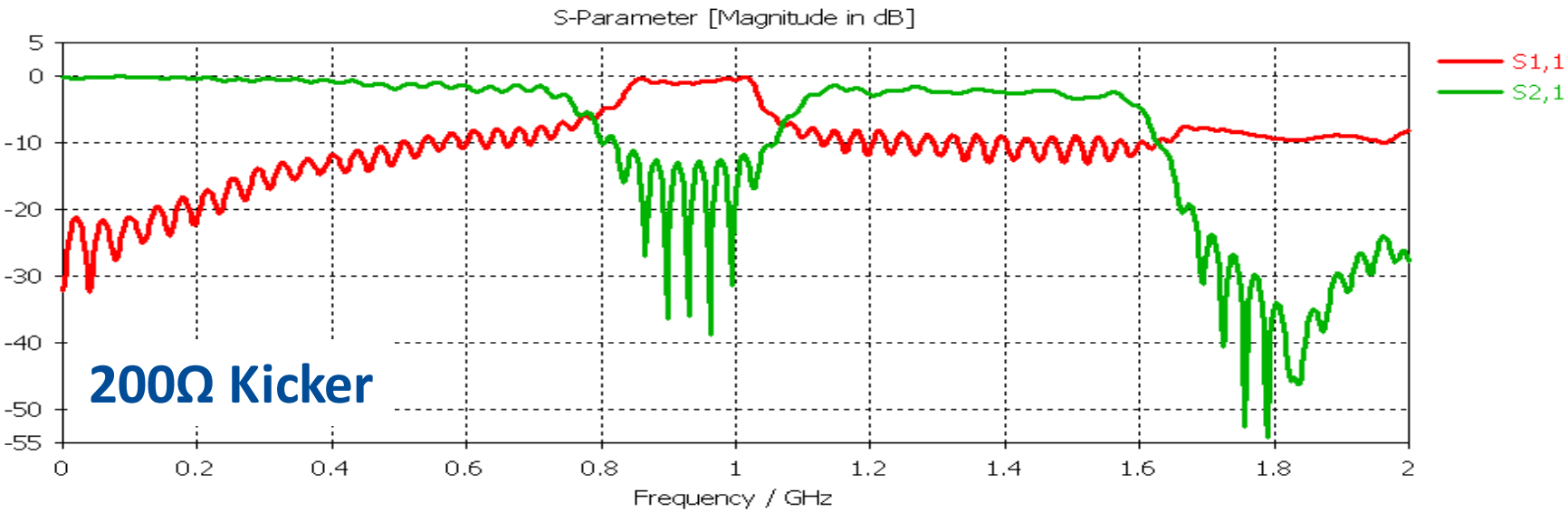


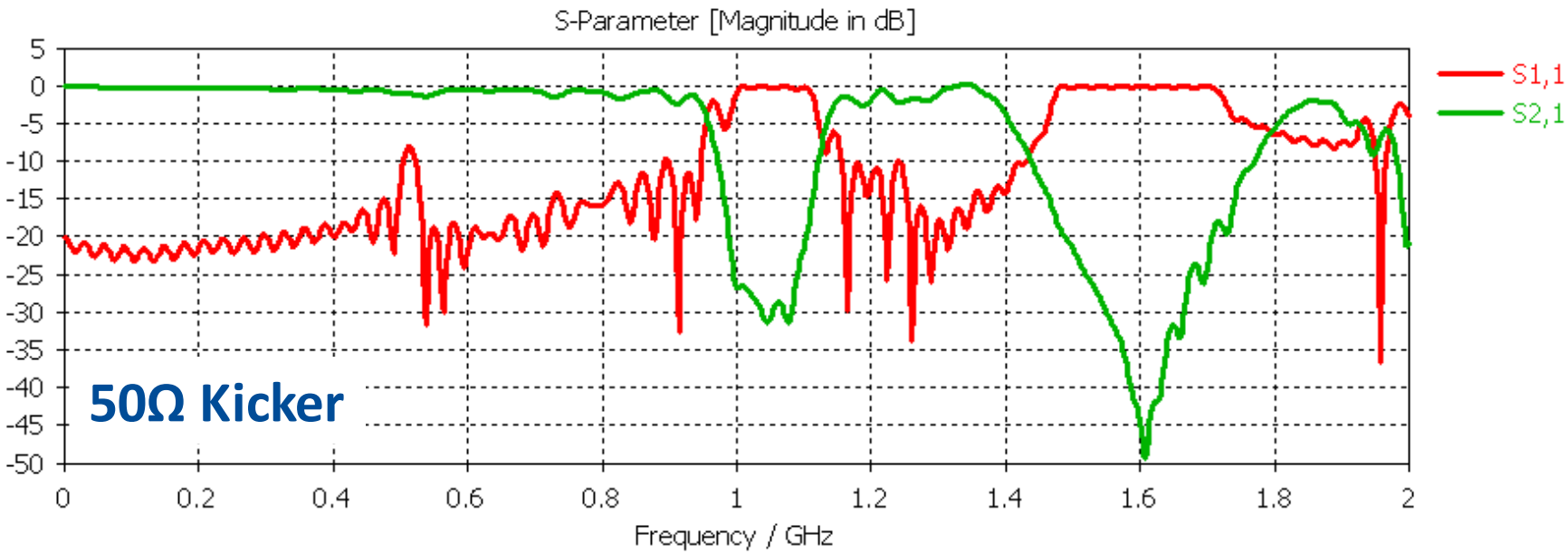
Geometry provided by Margaret J Jones

Tools

- Time domain solver of CST is used
- Excite the geometry with a pulse and examine the transient time response
- Investigate the following
  - Transmitted signal to the output port
  - Delay and the group velocity
  - Transverse electric field on beam axis
  - Characteristic impedance
  - Dispersion
- Three kind of pulse excitations are used
  - Gaussian pulse: useful to find the frequency response
  - Wide rectangular pulse: useful to see the pulse dispersion on flattop
  - Actual pulse to be used in kicker

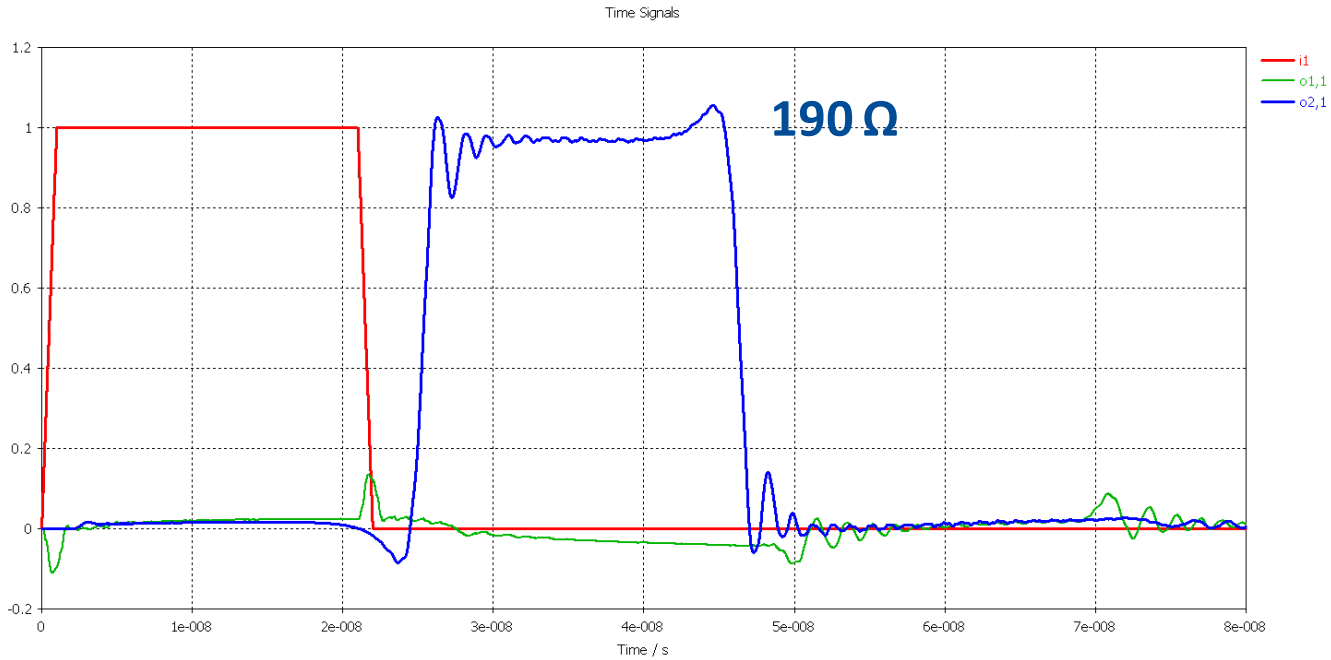
Kicker Frequency Response (using Gaussian Pulse)

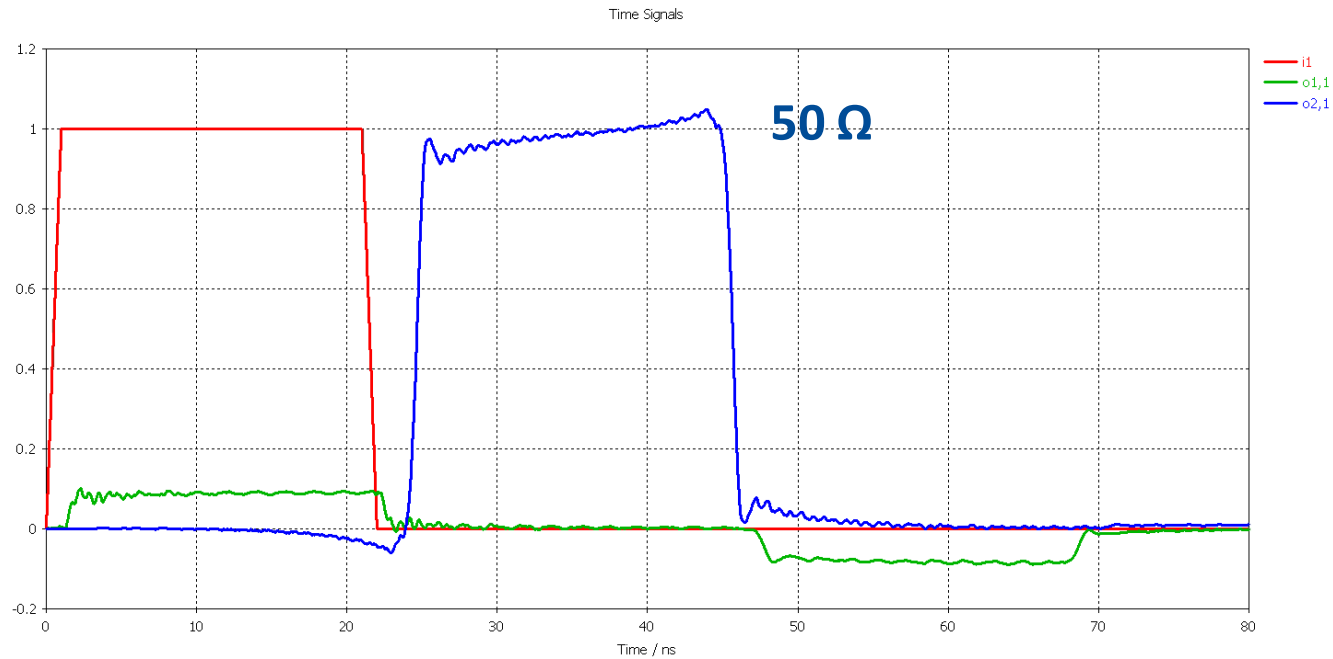




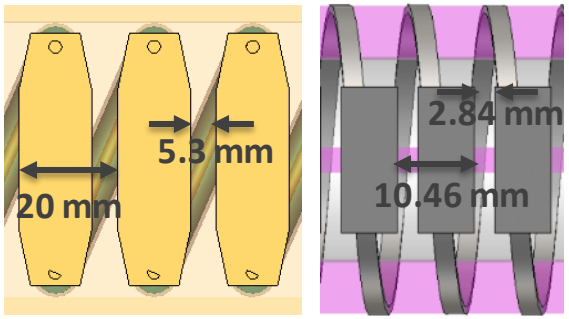
Kicker: Dispersion (Wide Pulse)

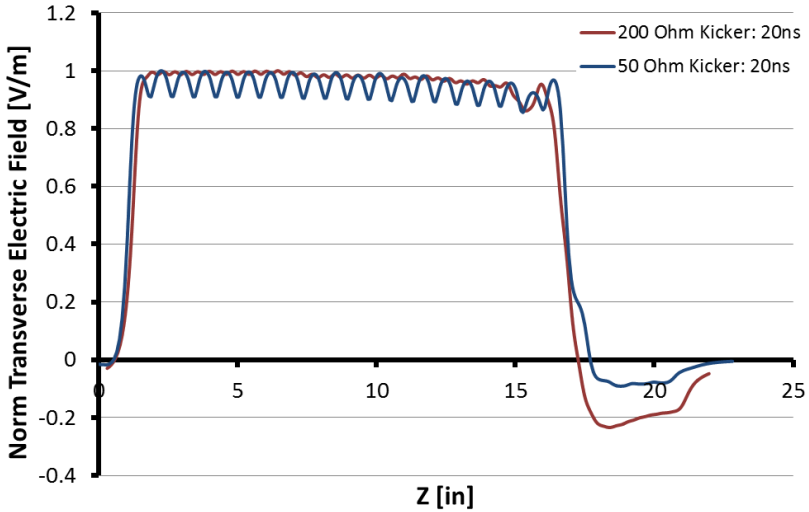
Characteristic impedance was calculated by changing the port impedance to minimize reflections

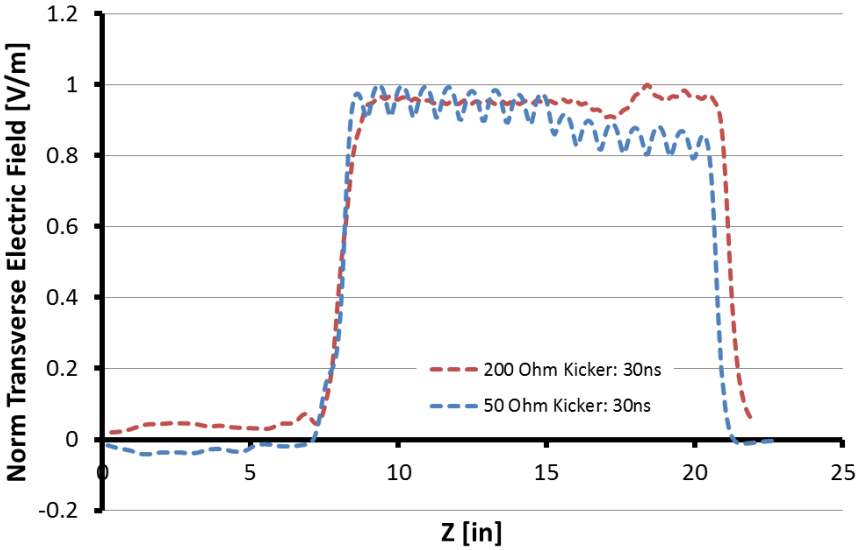




Field on Axis (Wide Pulse)

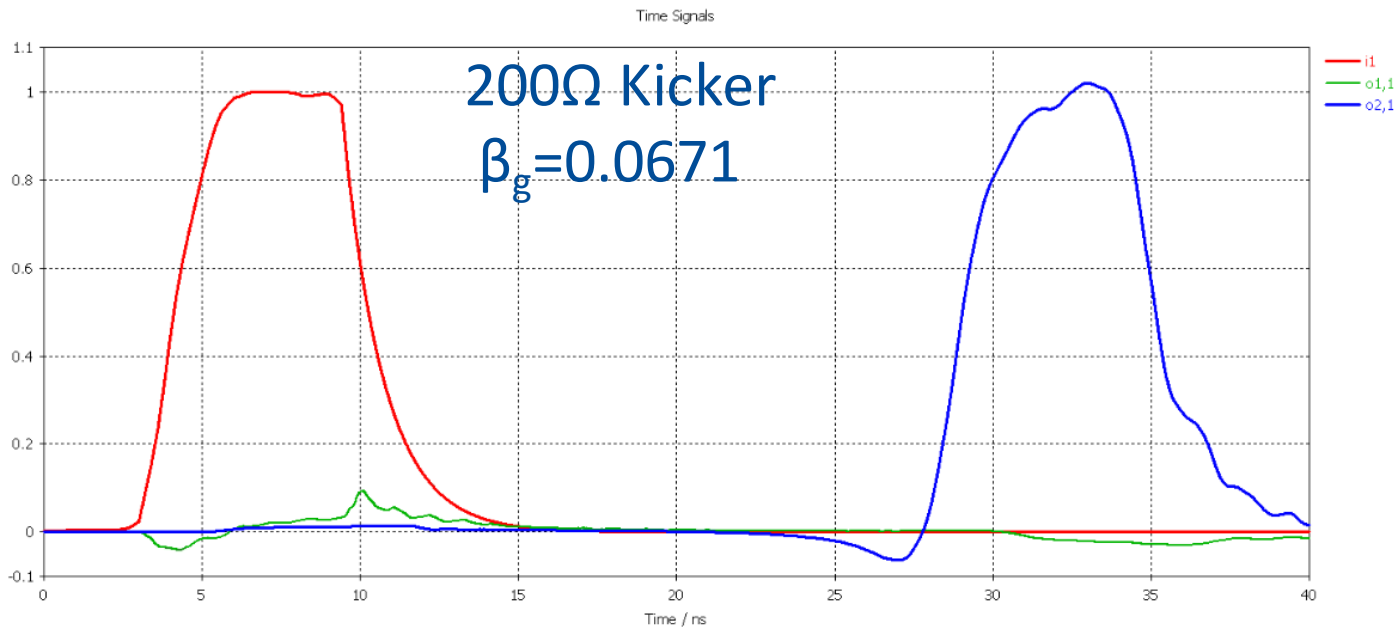






200Ω Kicker: Actual Pulse

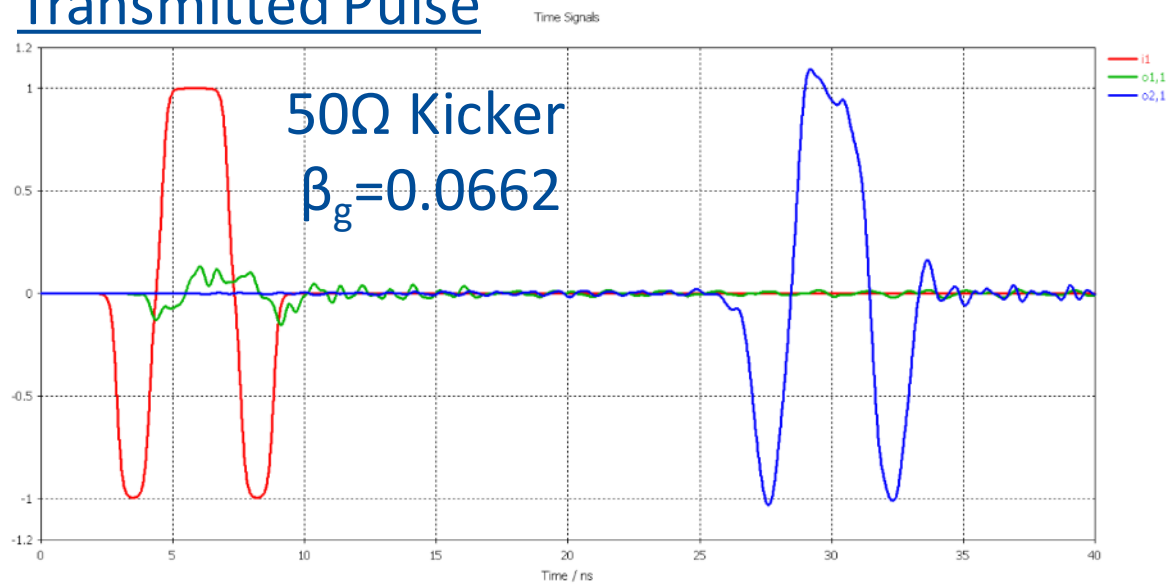
Transmitted Pulse



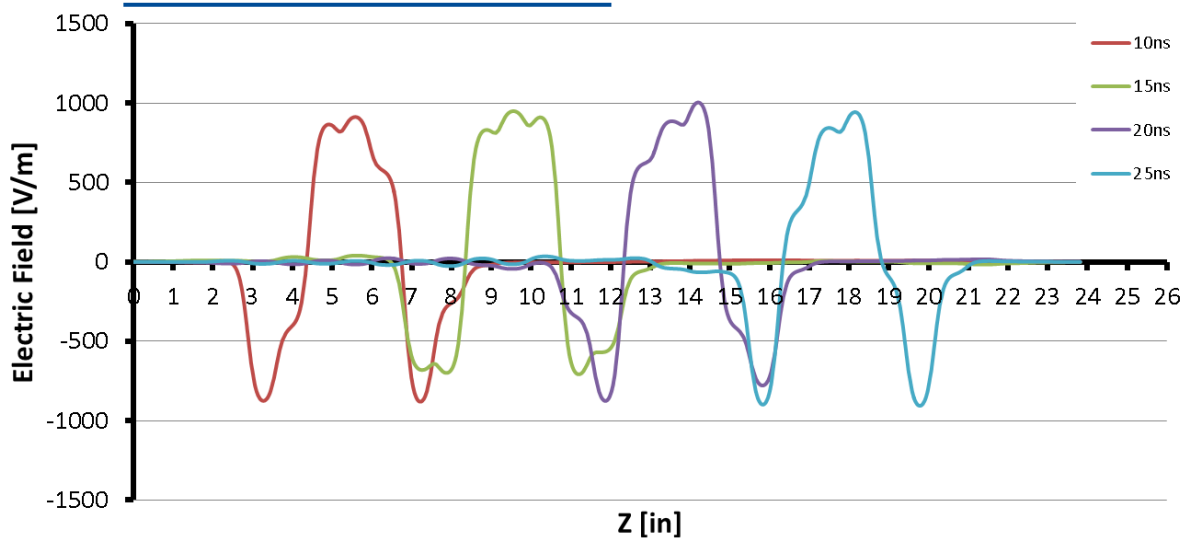
50Ω Kicker: Actual Pulse

- Dispersion is noticeable on the transmitted pulse
- Shape of electric field is different than shape of transmitted pulse

Transmitted Pulse



Field on Beam Axis



Kick Efficiency: Definition

- In order to estimate the kick efficiency, it was necessary to have a reference case of parallel plate structure simulated under the same conditions and excitation
- By comparing the transverse field perpendicular to the electrodes we can estimate the kick efficiency defined as

$$Eff_{Kick} = \frac{V_{Kick}^{K}}{V_{Kick}^{P}} \frac{V_{E}^{P}}{V_{E}^{K}}$$

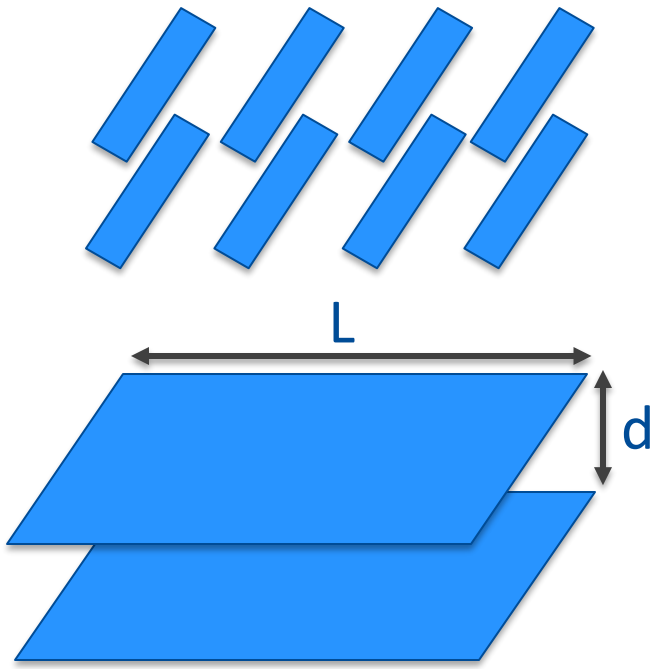
Where

Kick Voltage

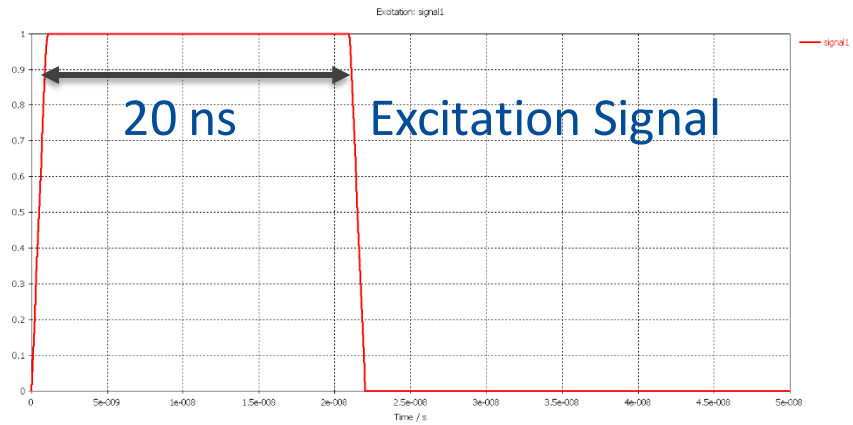
$$V_{kick} = \int_{0}^{L} E_y \Big|_{beam} dz$$

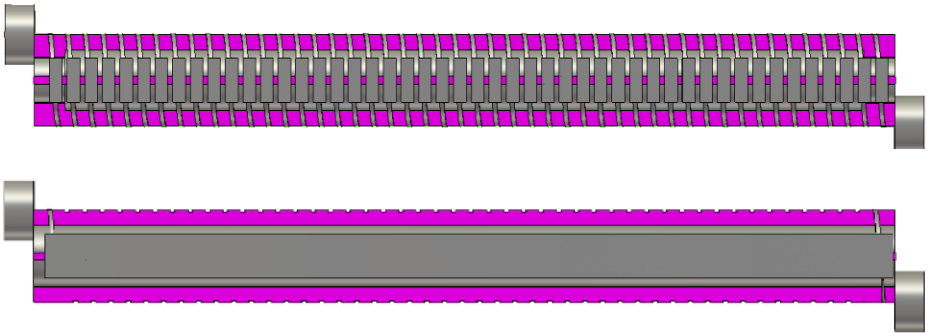
Voltage difference between electrodes

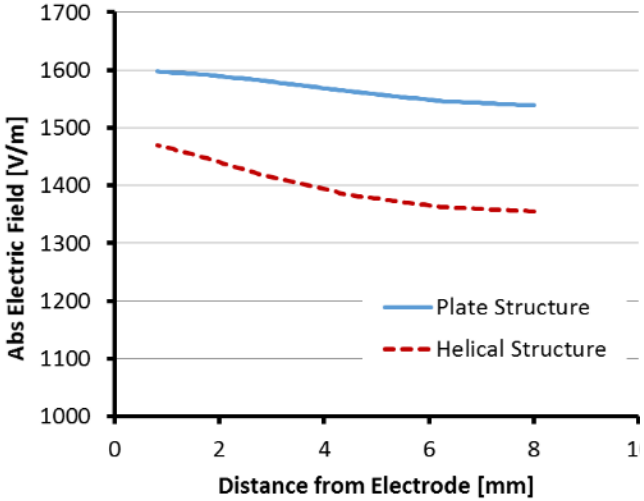
$$V_E = \int_{0}^{d} E_y \Big|_{Z=Zm} dy$$

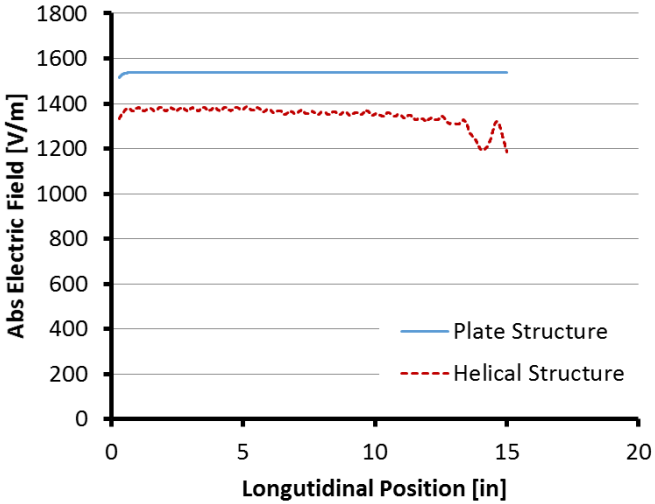


200Ω Kicker: Efficiency





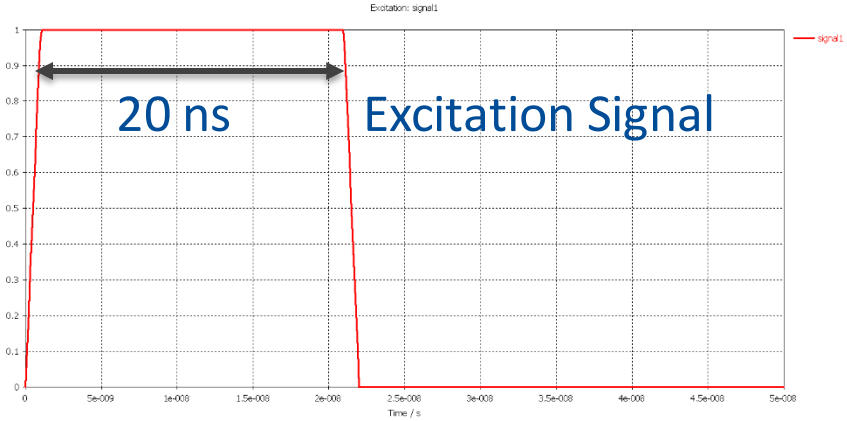


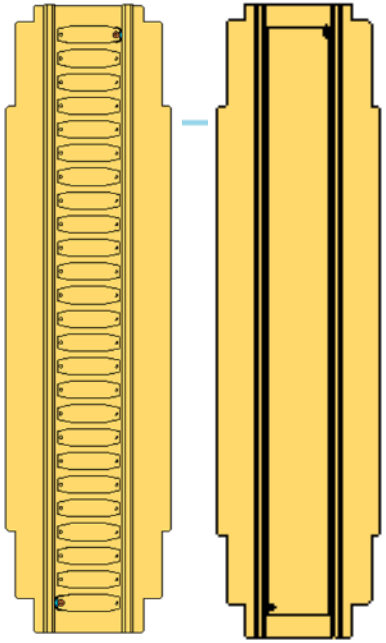


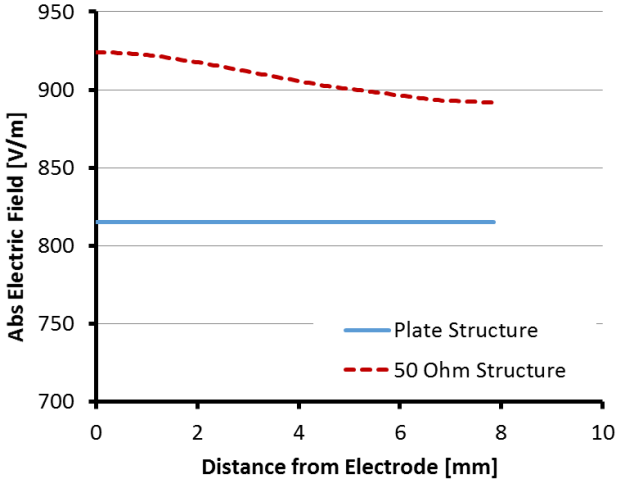
	Electrode Voltage [V]	Kick Voltage [V]
Parallel Plate Structure	11.1	567.2
Helical Structure	9.9	497.1

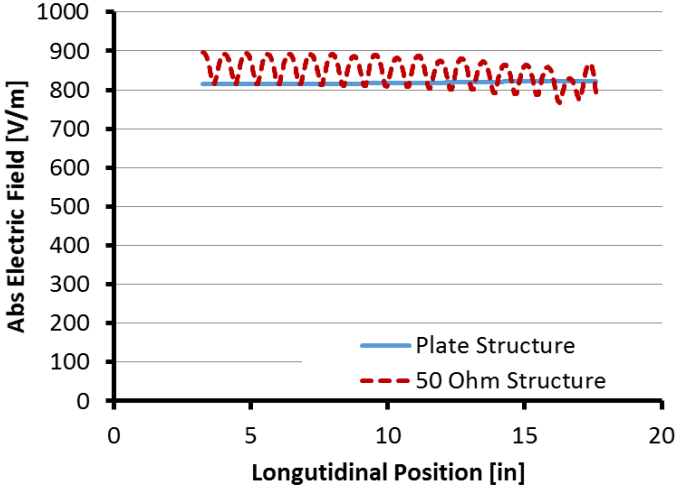
Efficiency is 98%

50Ω Kicker: Efficiency









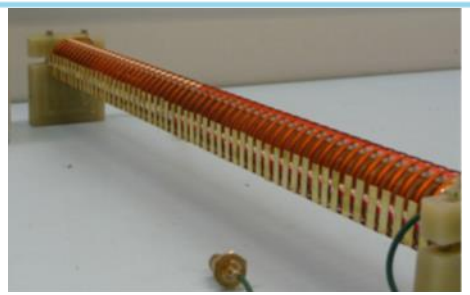
	Electrode Voltage [V]	Kick Voltage [V]
Parallel Plate Structure	6.52	298.1
Meanderline	7.25	308.7

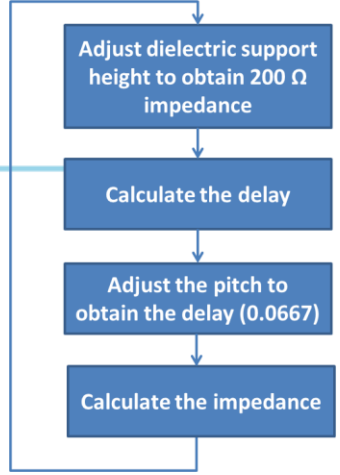
Efficiency is 93%

Plate structure has lower characteristic impedance compared to the meanderline. That is why its field is lower

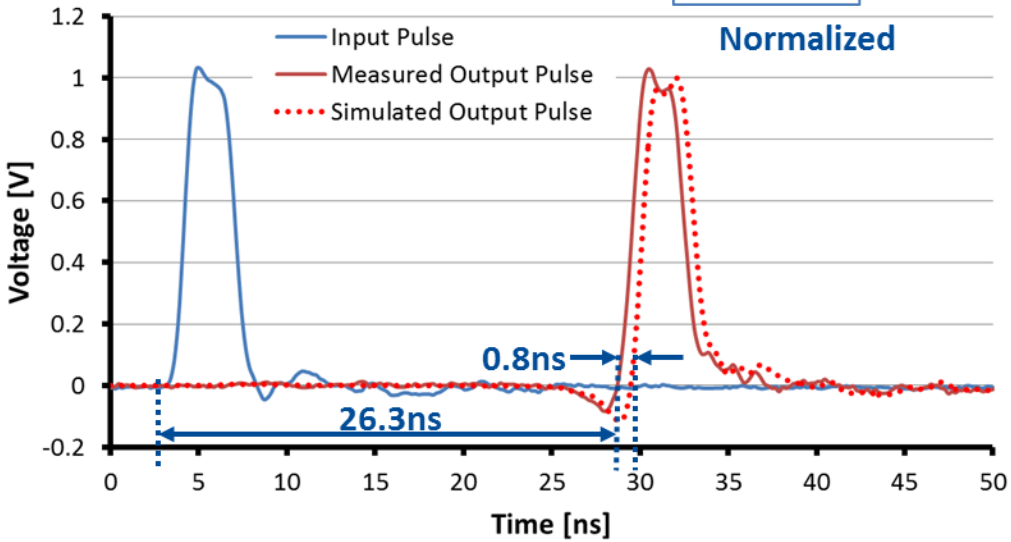
200Ω Kicker: Simulation vs Measurements

- Earlier prototype
- Structure simulated open to air
- Actual pulse with 1ns rise\fall time was used as excitation





- Simulated pulse delay for **0.333"** pitch is 26.3 ns
- Need to account for 1" input/output coaxial ports 2"/3e8=0.17 ns
- Delay in the helical structure is 26.1 ns (β=0.06)

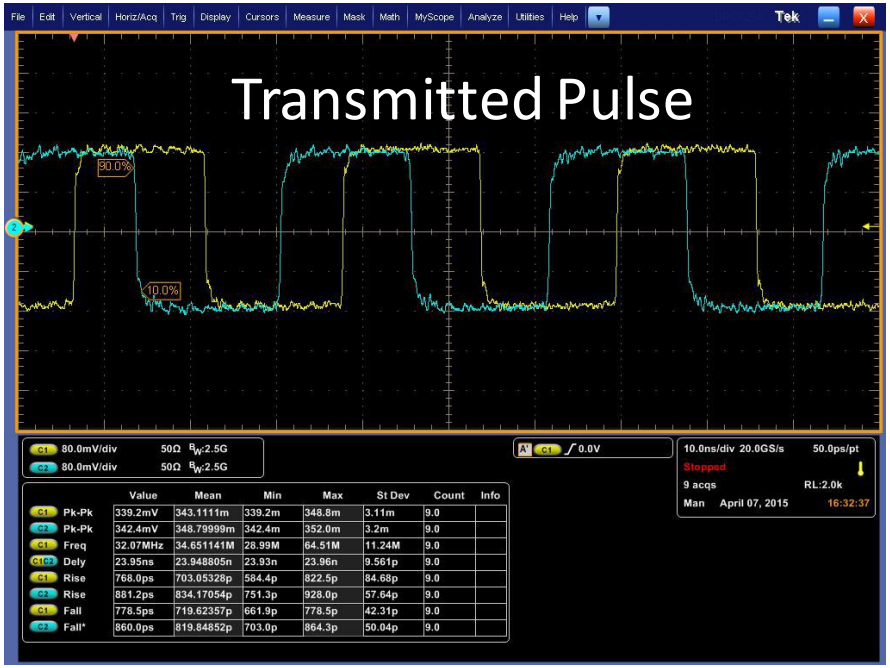


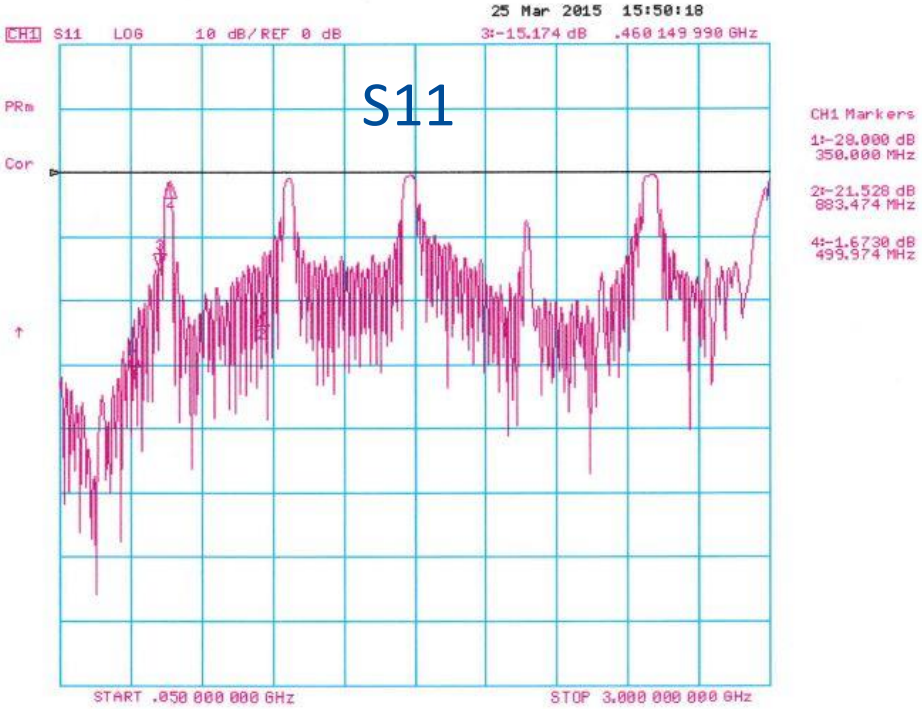
- About 0.8 ns difference between the simulated and measured transmission pulses (tolerances and dielectric constant variations)
- The structure was optimized to adjust both delay, and impedance. A new prototype is under development

Measurement data provided by Greg Saewert

50Ω Kicker: Measurements

For comparison it will be great to have the measurements in data format





Measurement data provided by Ding Sun

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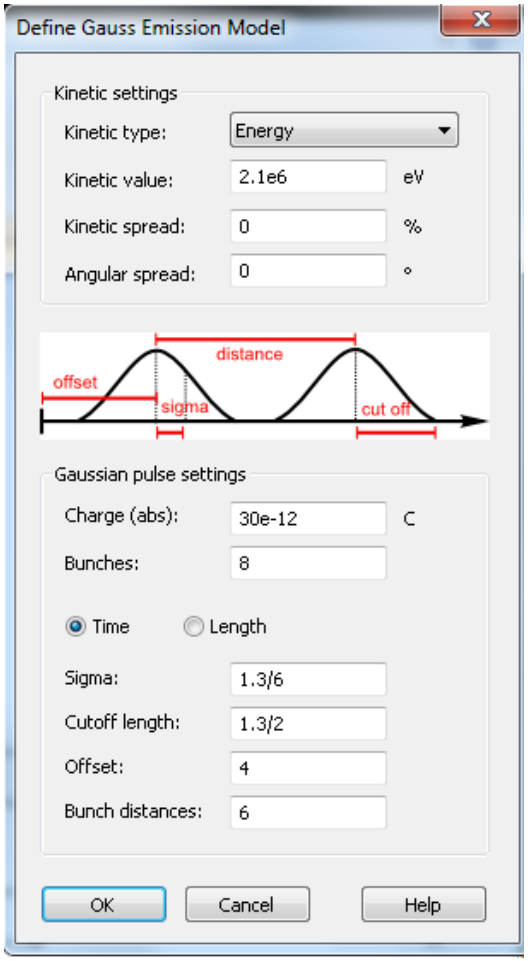
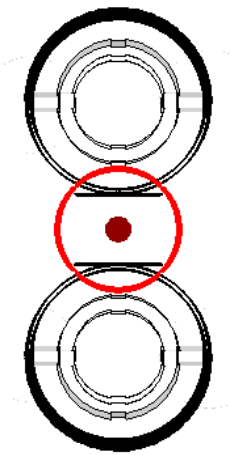
Particle in Cell Simulation

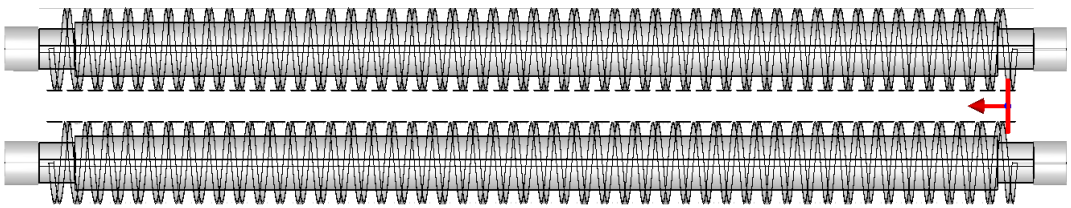
Tools

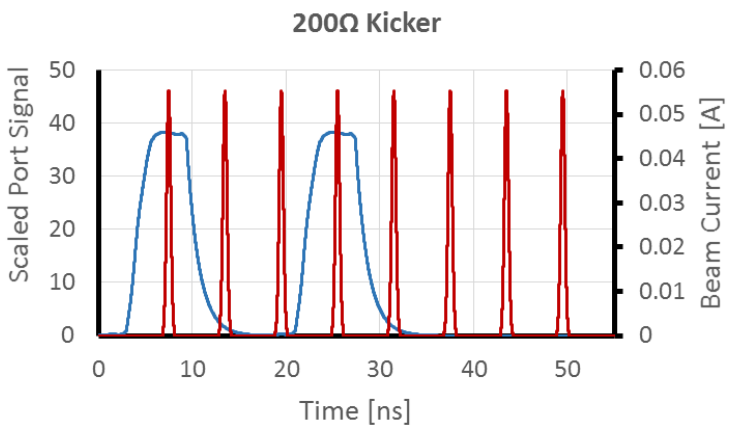
- PIC simulation to find the kick angle
  - Actual pulse excitation
  - Paraxial Particle of 2.1MeV
  - No kinetic nor angular spreads
  - Eight bunches
  - 6σ=1.3ns
  - 6ns bunch distance
  - Offset bunch to synch with RF



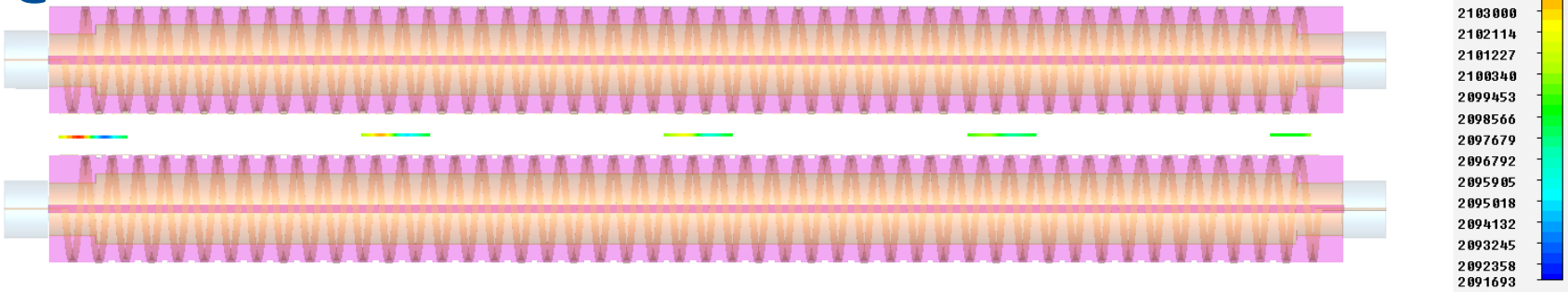
200Ω Kicker: Paraxial PIC Simulation



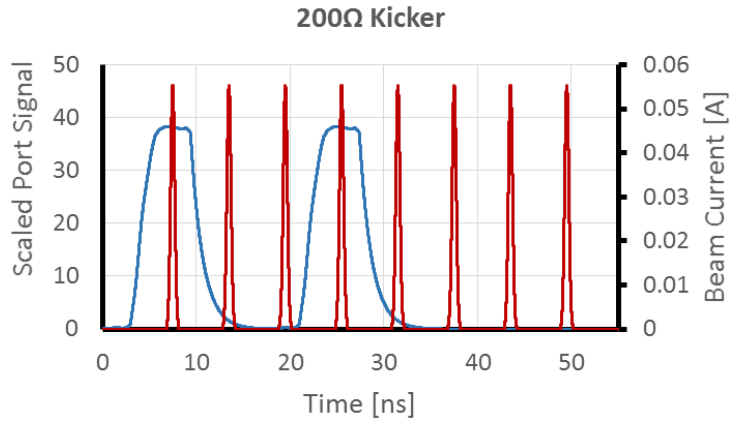


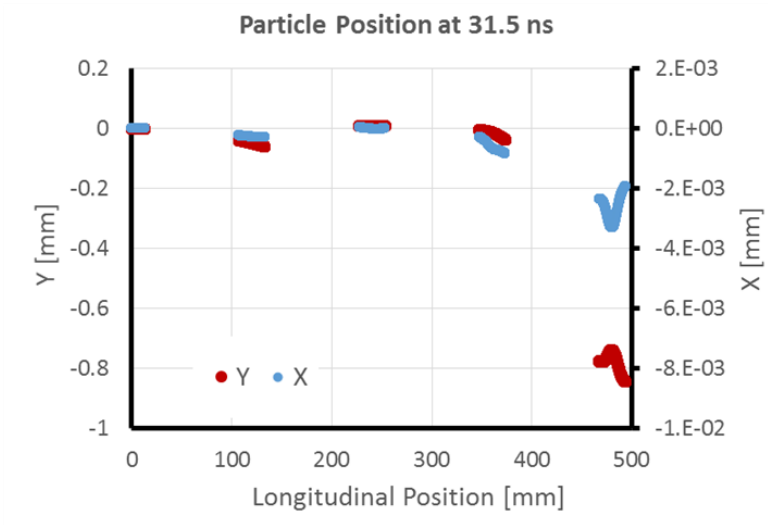


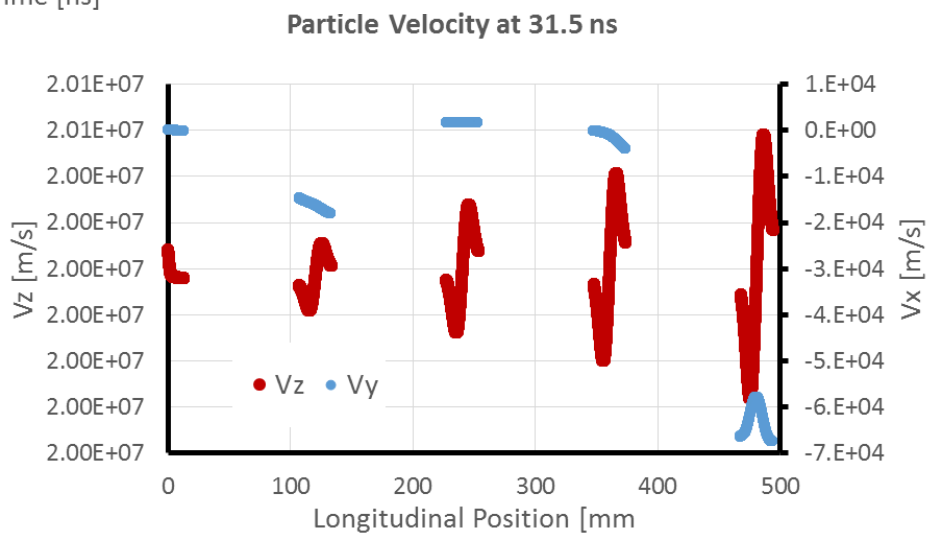
@31.6 ns



200Ω Kicker: Paraxial PIC Simulation

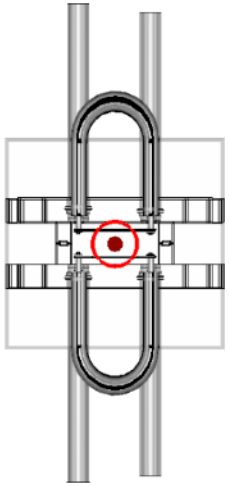


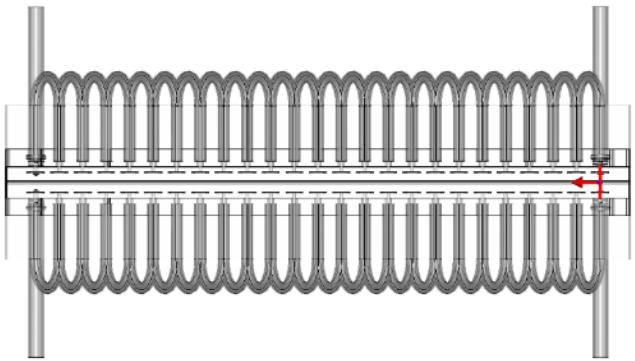


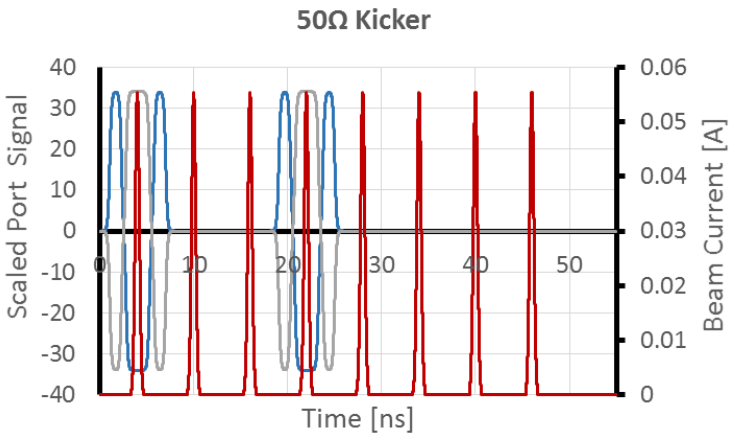


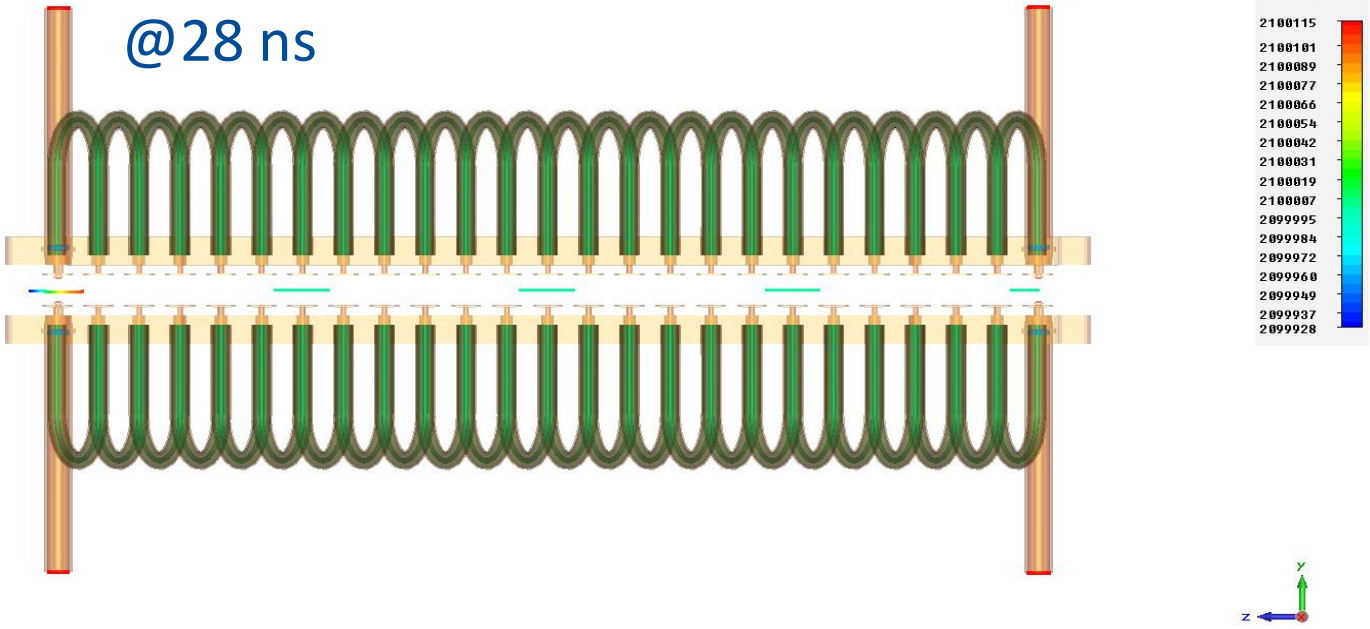
θy=3.37 mrad θx=15.8 μrad
Per 497.4V plate voltage

50Ω Kicker: Paraxial PIC Simulation

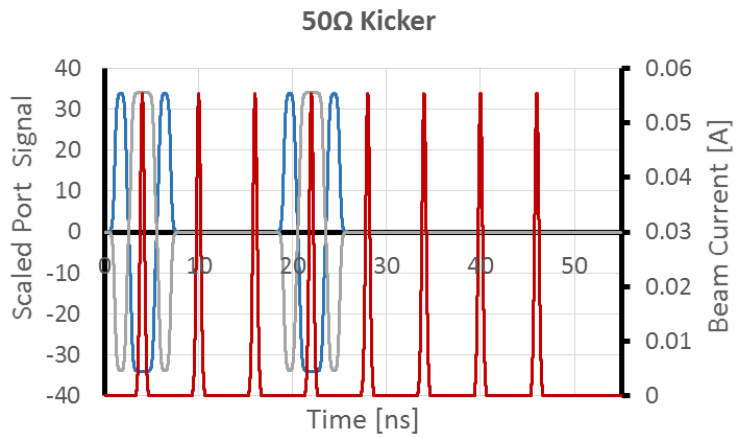


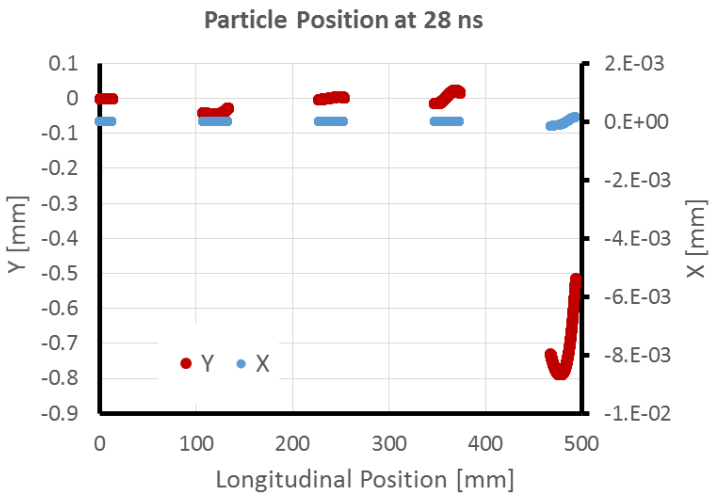


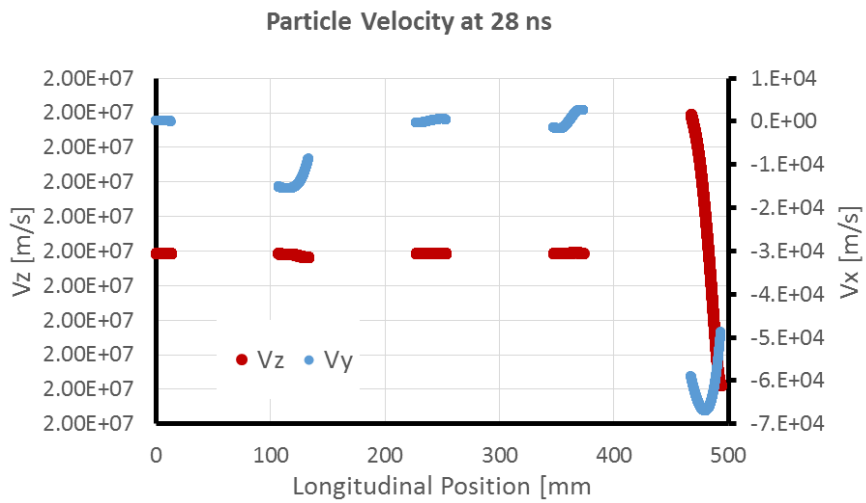




50Ω Kicker: Paraxial PIC Simulation







θy=3.34 mrad θx=1.4 μrad
Per 500.1 V plate voltage

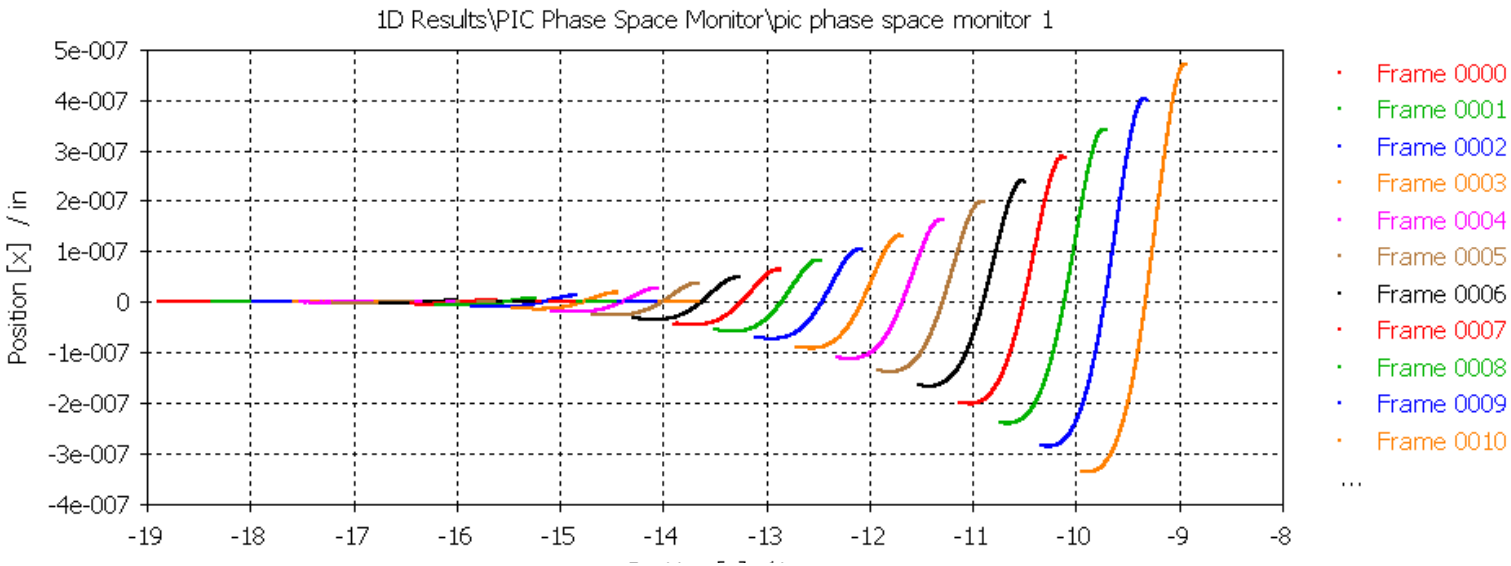
Future Plans

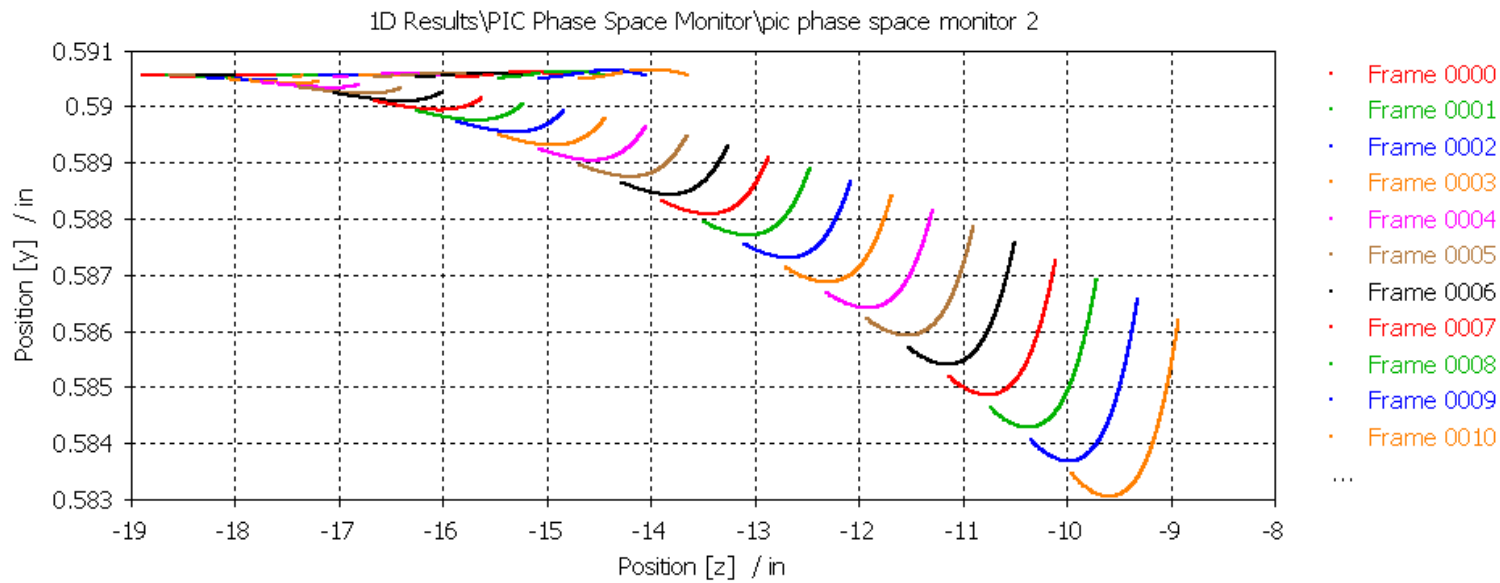
- Need to compare the simulations and measurements of the 50Ω kicker
- Need to compare the simulations and measurements of the final 200Ω kicker prototype
- Further PIC simulations with paraxial beam
- Find precisely the kick angle for both kickers
- More realistic PIC simulations?

Conclusion

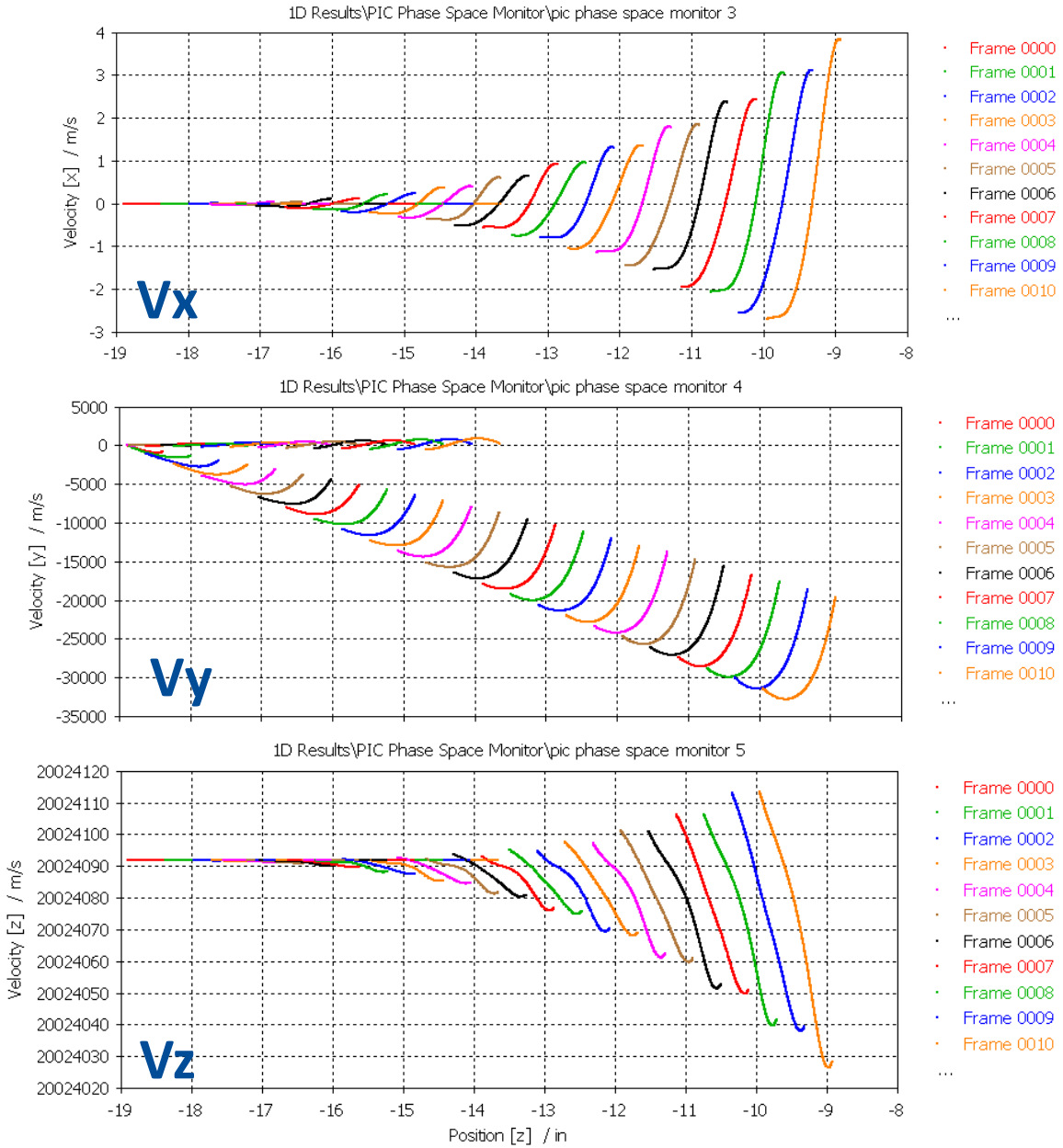
- 200Ω kicker has less ripples for the field on axis (smaller distance between electrodes)
- 200Ω kicker has a 98% efficiency vs 93% for the 50Ω one
- Kick angle is 3.37 mrad (plate voltage 497.4V) for the 200Ω kicker while it is 3.34 mrad (plate voltage 500.1V) for the 50Ω kicker

50Ω Kicker Phase Space Monitors (Position)

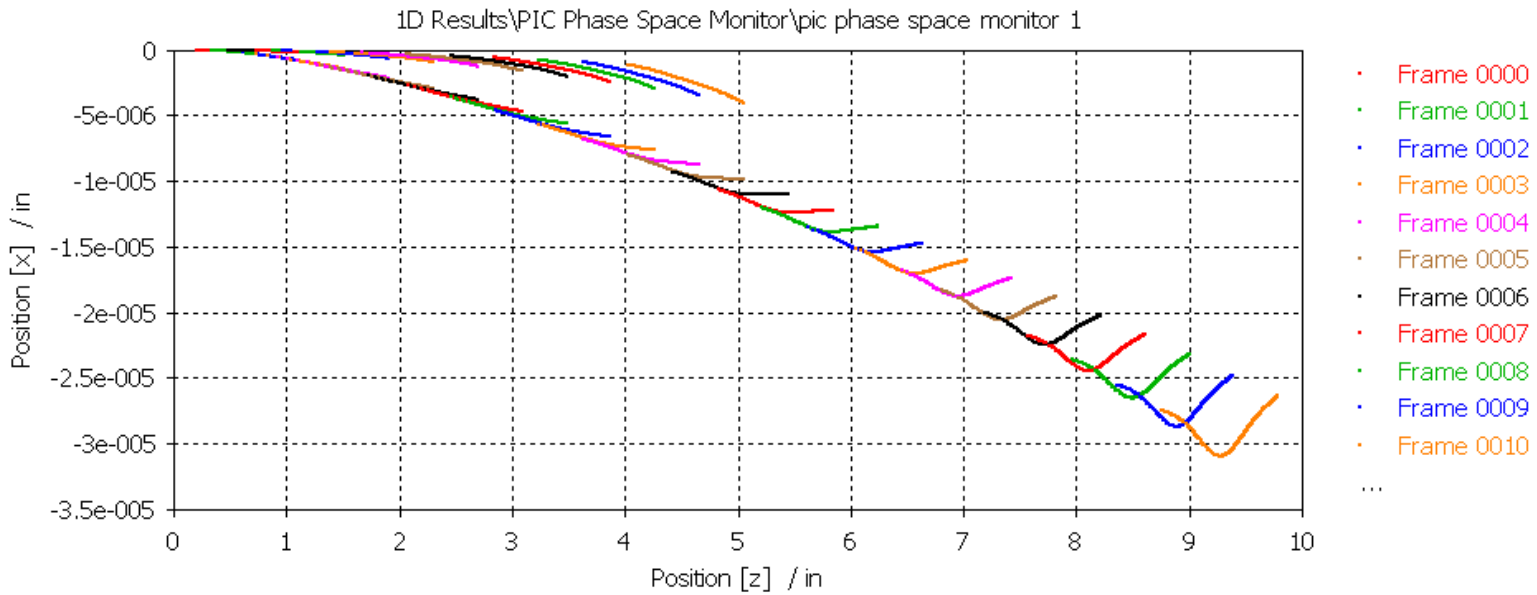


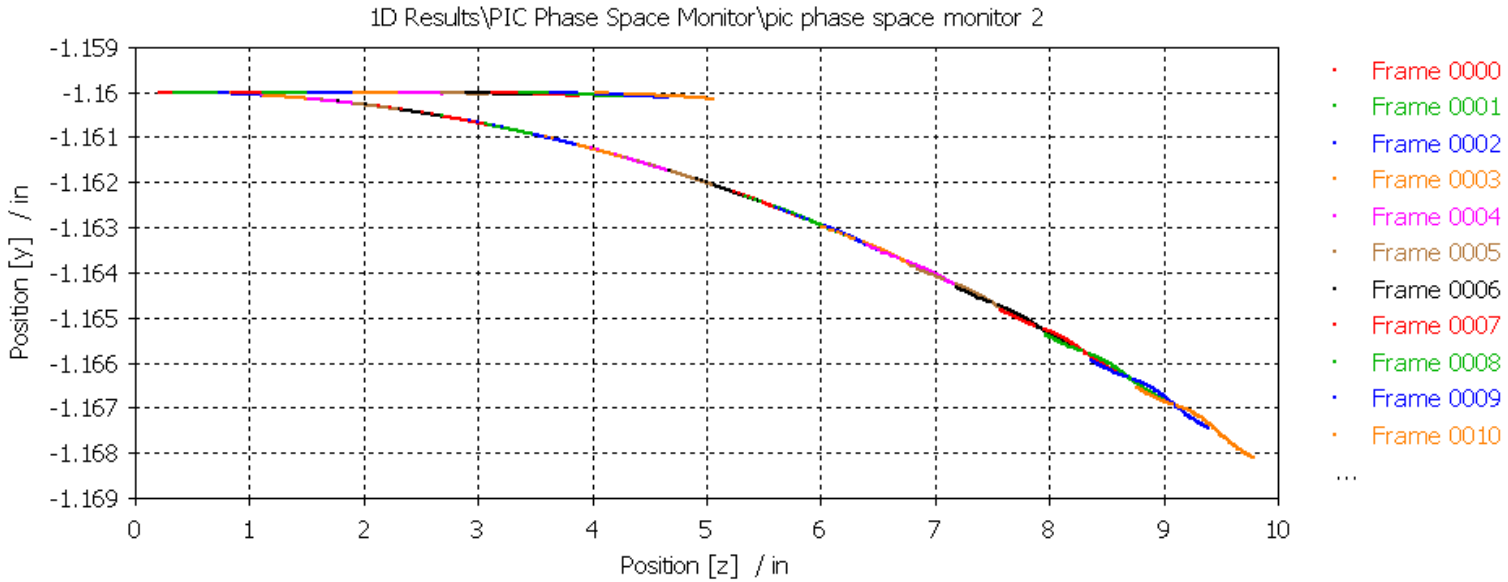


50Ω Kicker Phase Space Monitors (Velocities)

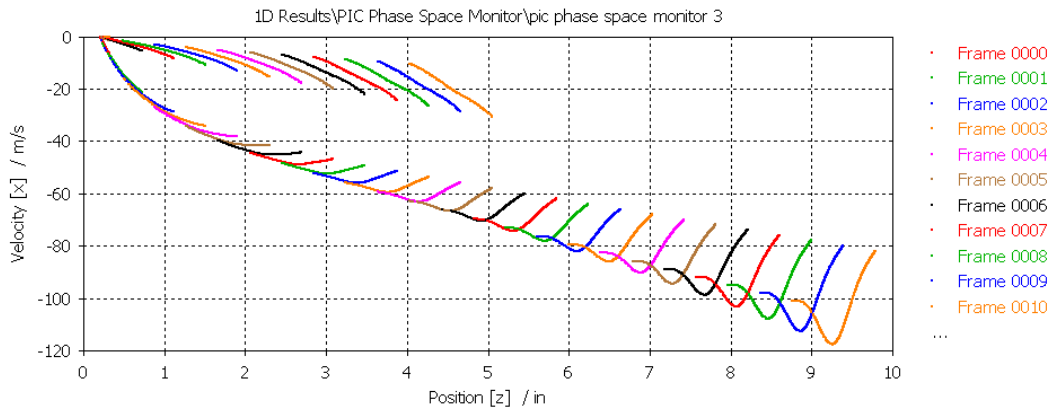


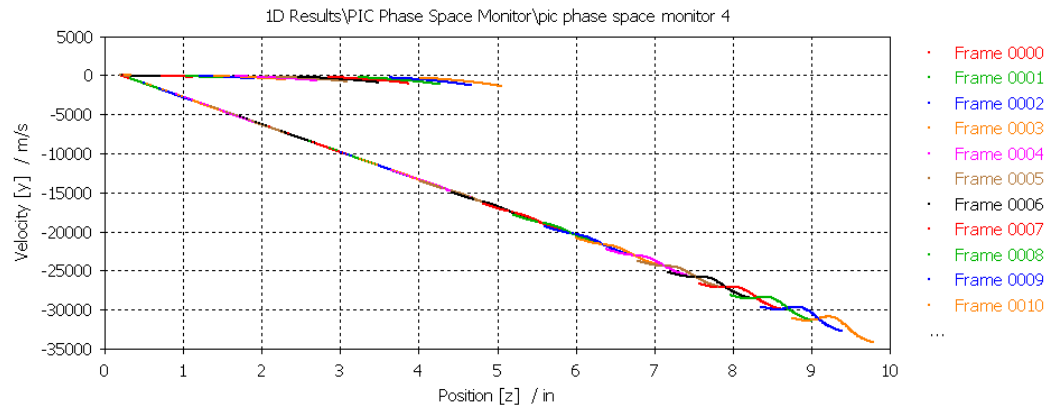
200Ω Kicker Phase Space Monitors (Position)

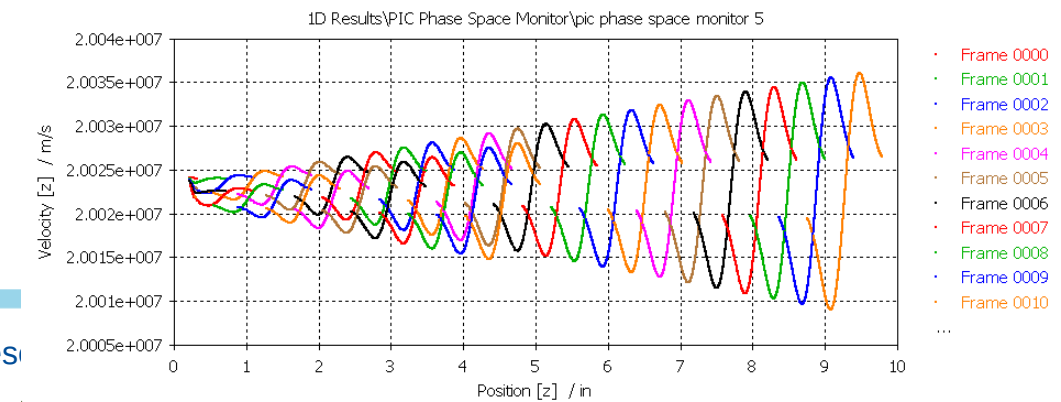




200Ω Kicker Phase Space Monitors (Velocities)

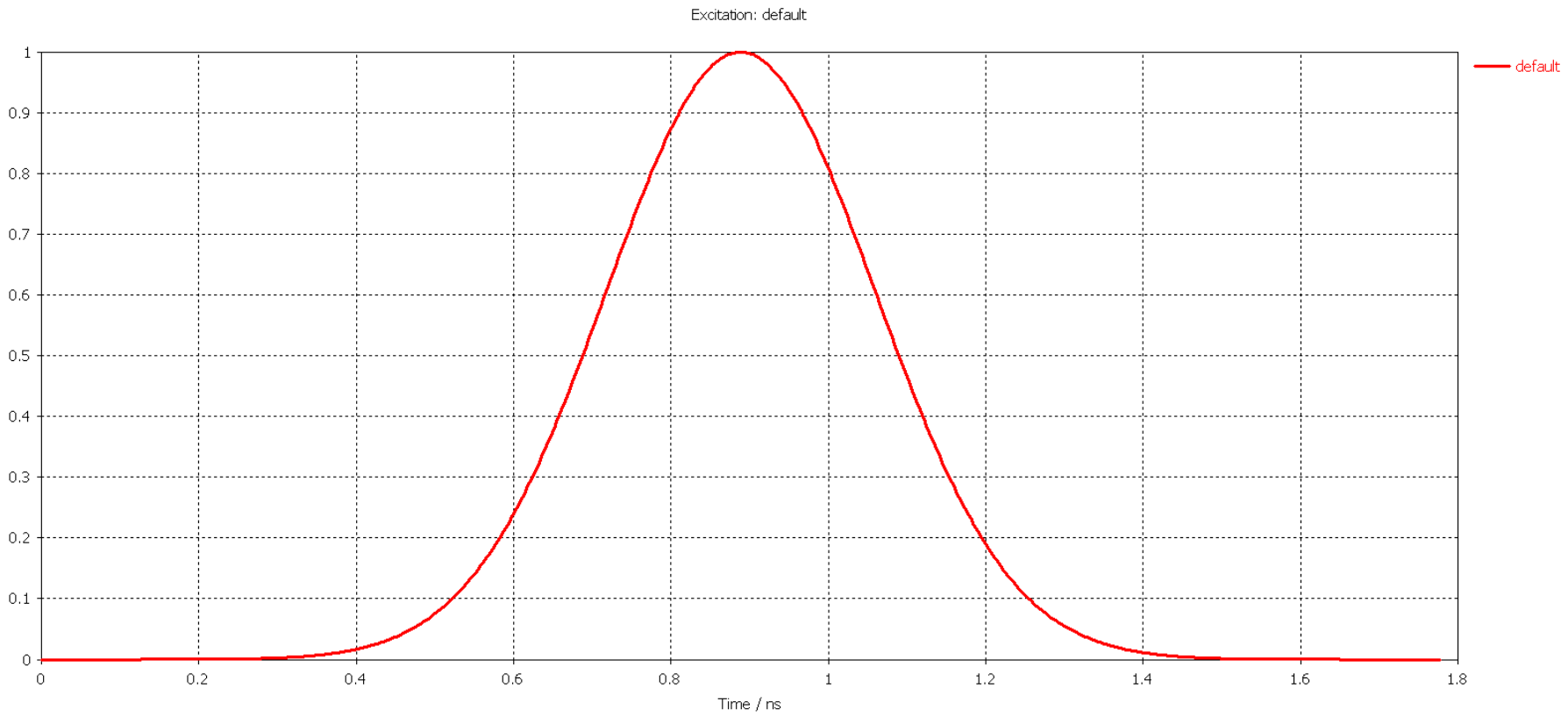






CST Transient Signal Excitation

- CST used by default signals normalized for 1W power

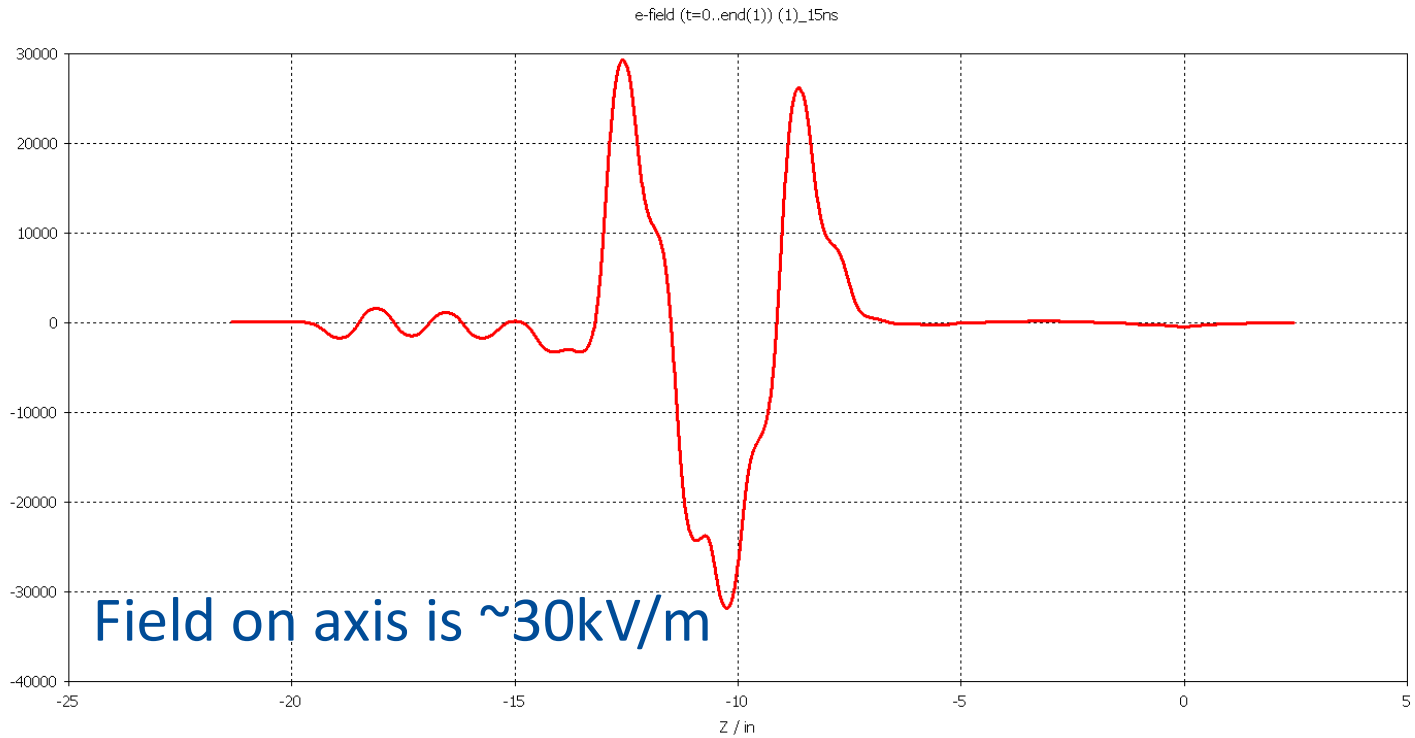


Parallel Plate Kick

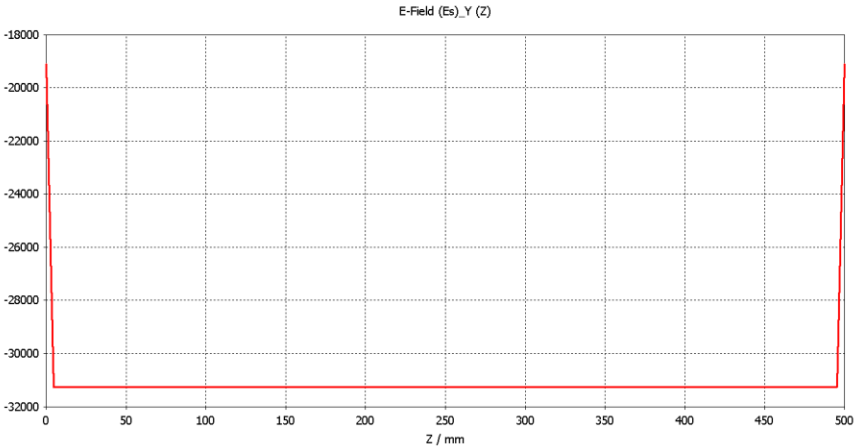
E=500/16e-3=31.25kV/m

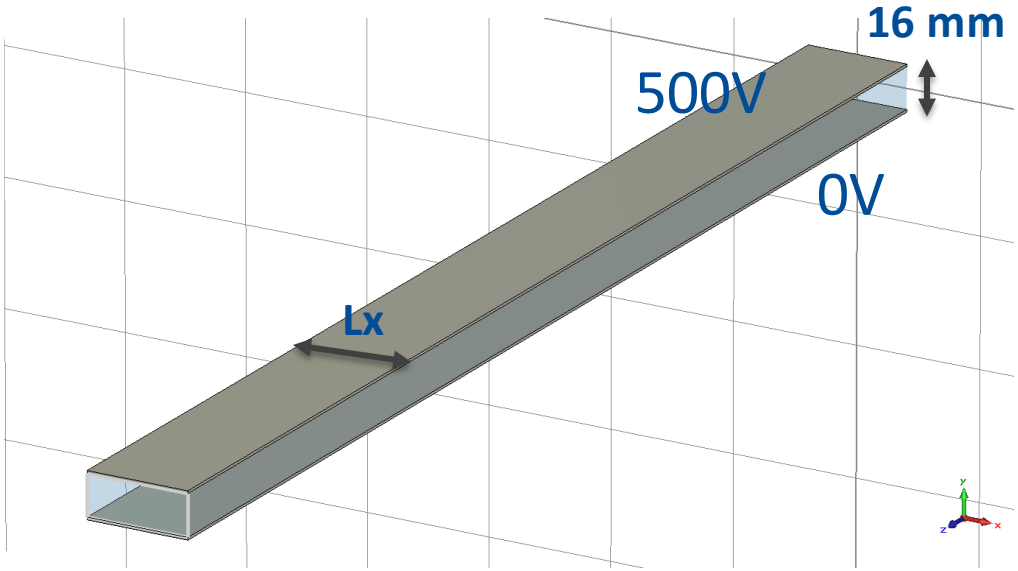
For 0.5 mm Kick is 15.625kV

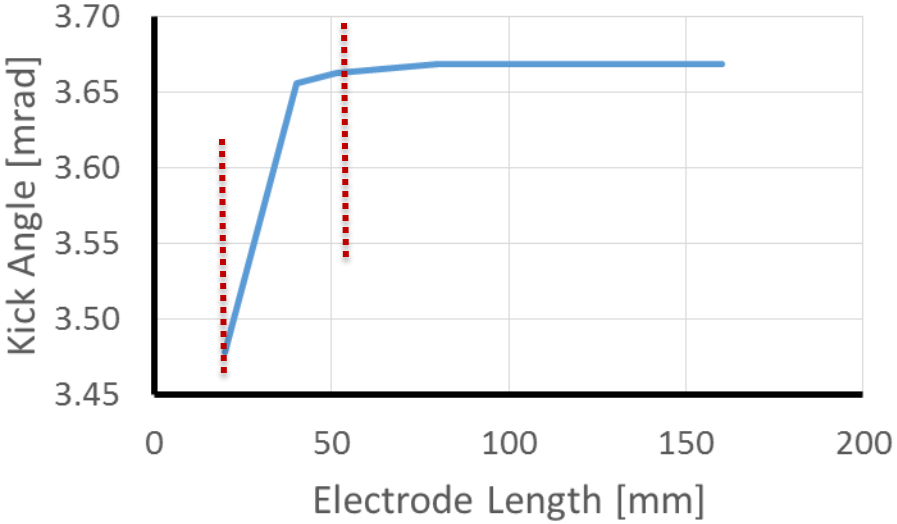
15.625e3/2*2.1e6=3.7e-3



Ideal Electrostatic Case of Parallel Plate

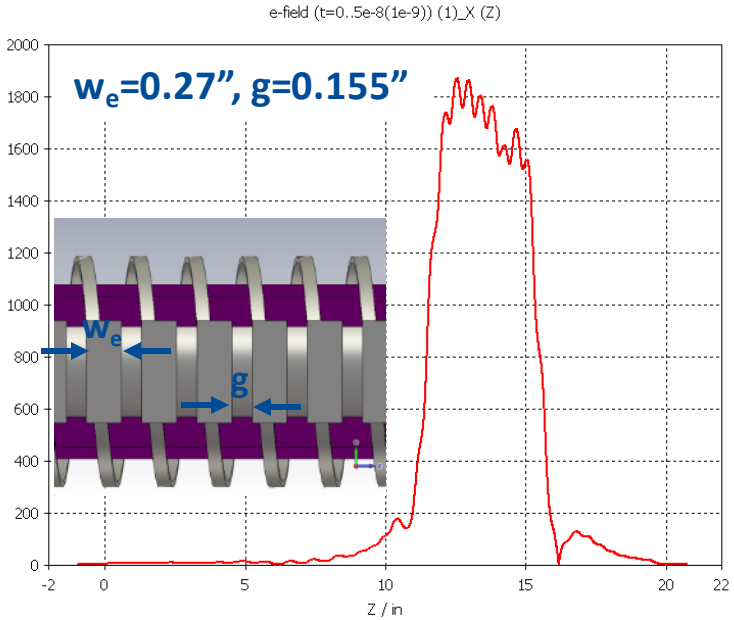


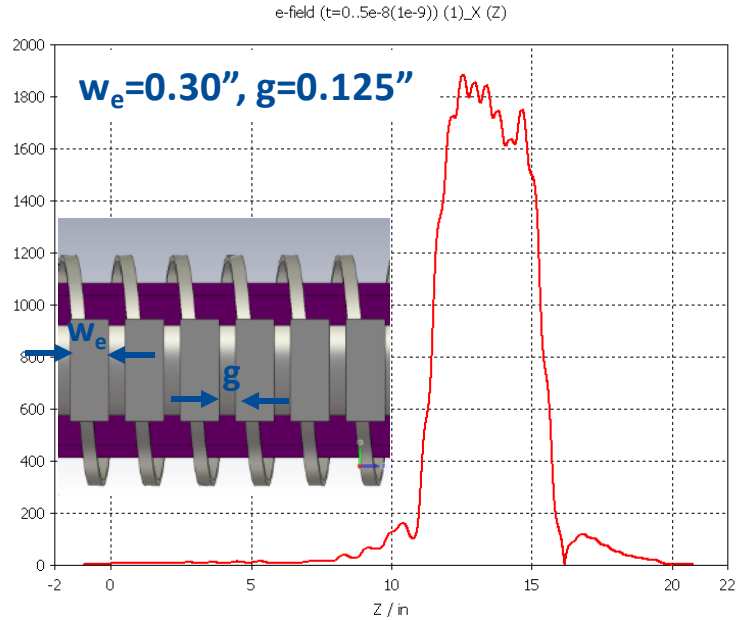


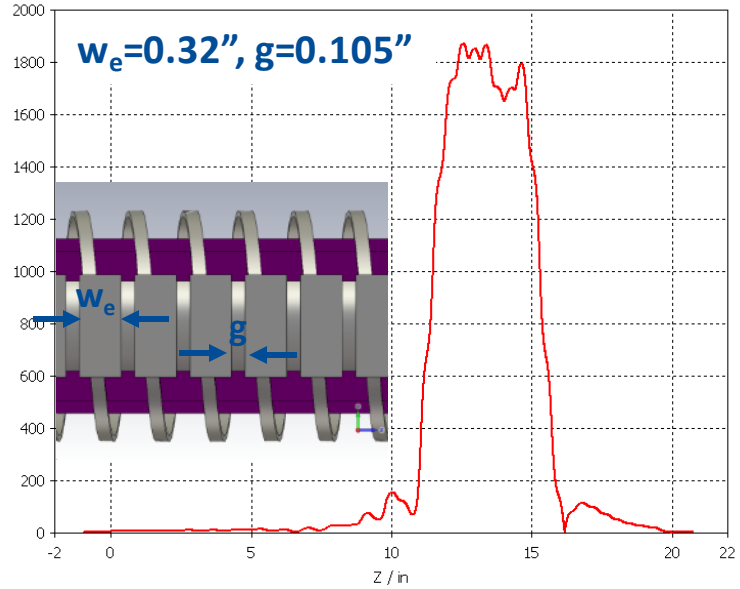


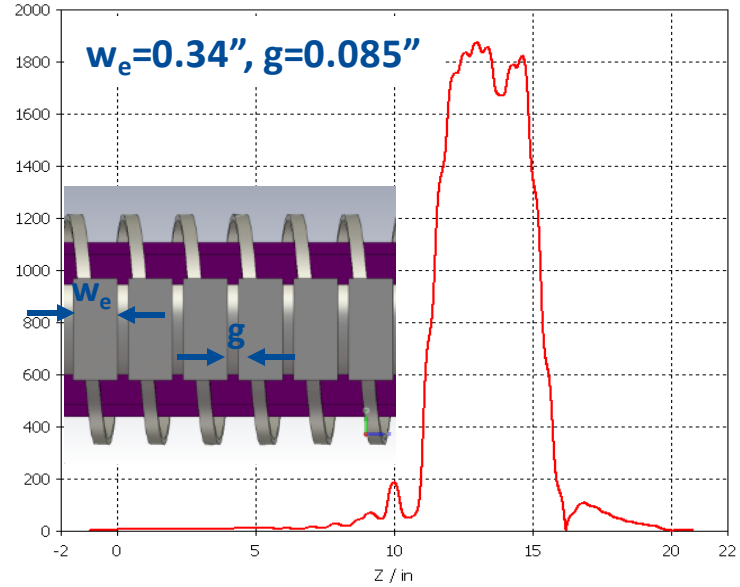
Lx=40 mm
Vy=73.208e3
Vz=2.00242e7
θy=3.656 mrad

Effect of Changing Electrode Size









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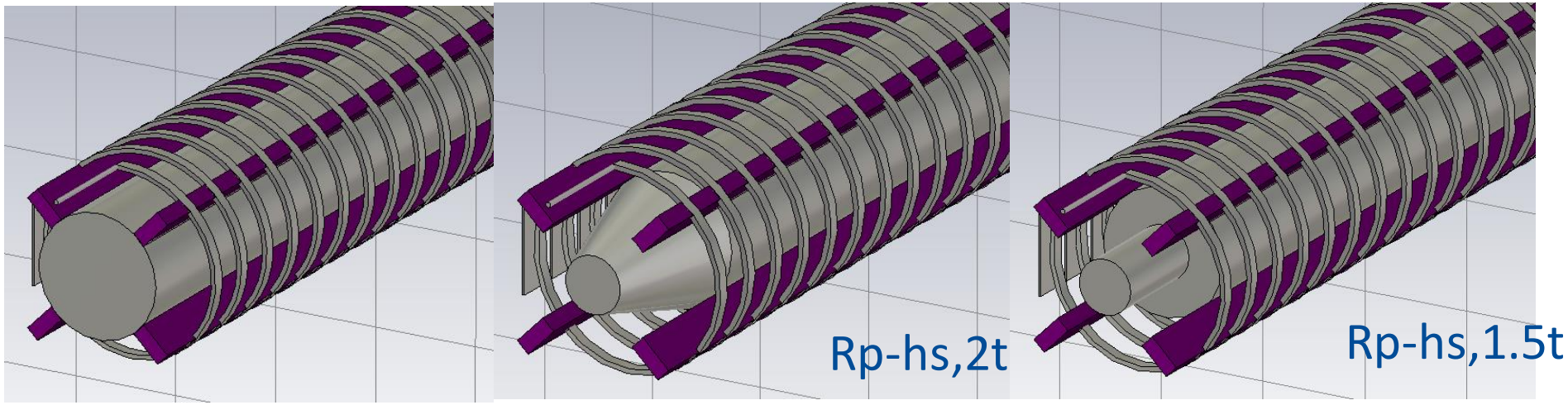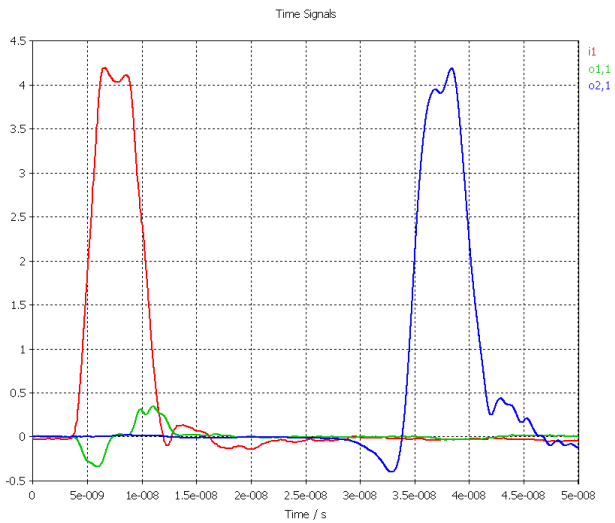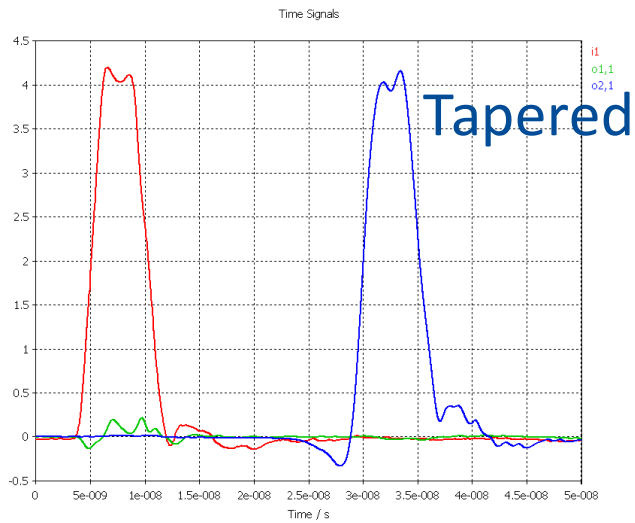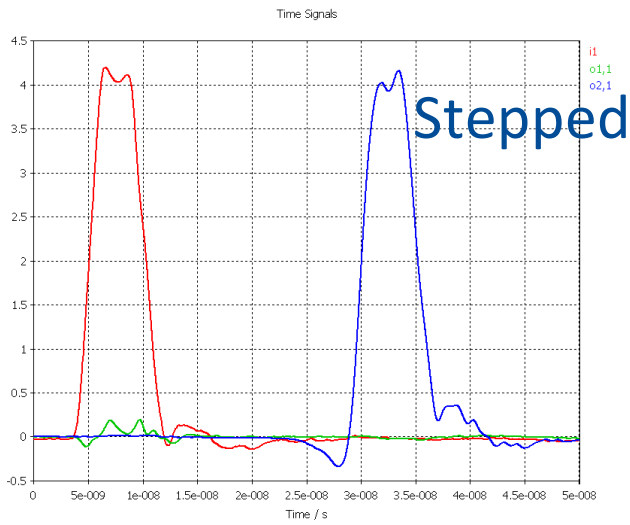
Helical Kicker: End Effect Compensation