Wakefields, Impedance, and RW Loss Simulations for the HSR Polarimeter

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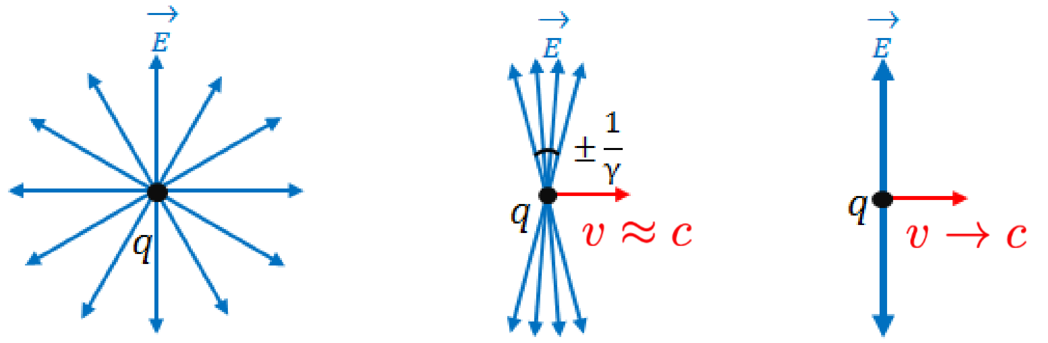
Outline

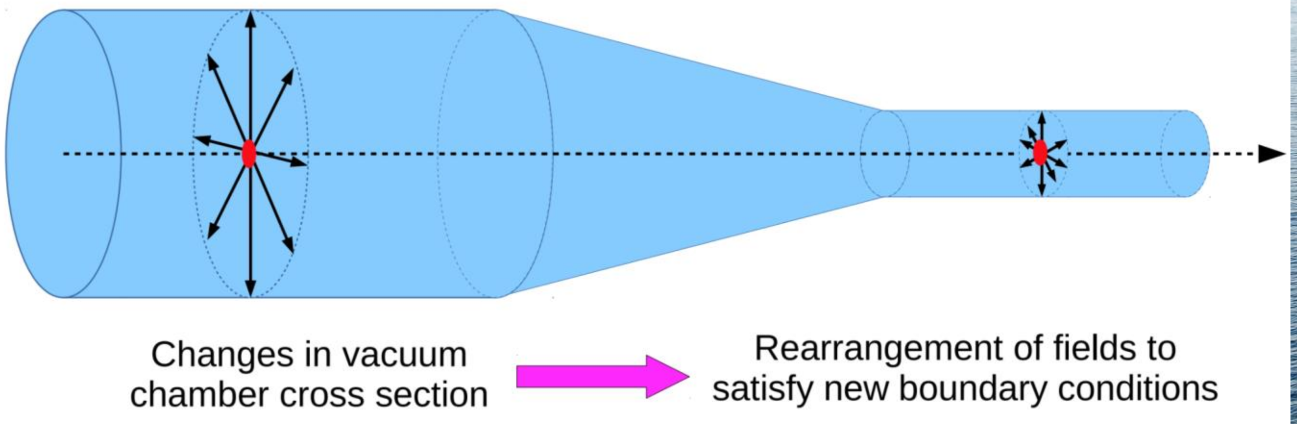
- Introduction to wakefields and impedance
- HSR polarimeter simplified geometry
- Wakefields, impedance and RW comparison between the metallic and dielectric target holders (RHIC and EIC beams)
- Analysis for the shifted target-holder

Wakefields and Impedance

- The Coulomb field of a relativistic electron appears "flattened" into a pancake shape.
- These fields must also satisfy boundary conditions on vacuum chamber walls.
- The new boundary conditions result in EM fields behind the exciting electron (since v ~ c) which are called wakefields.

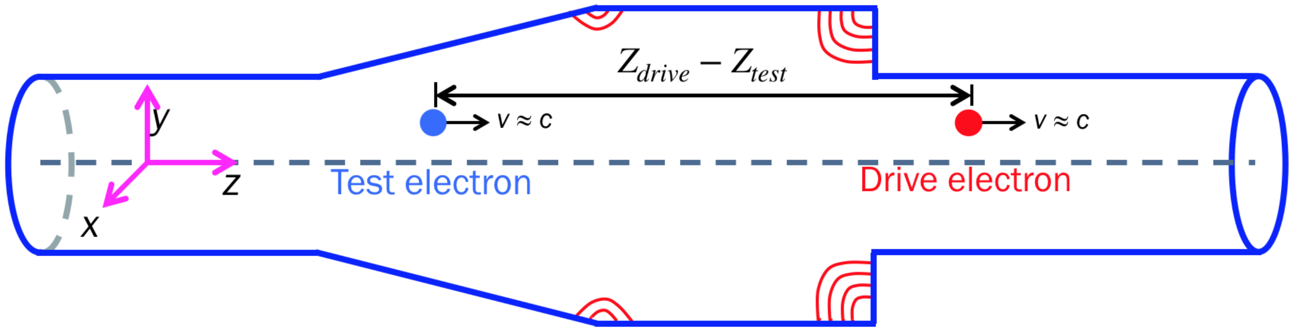


(a) stationary charge (b) relativistic charge (c) ultra-relativistic charge



Water wakes

Wakefields and Impedance



- The FT of the wakefield is called the impedance.

$$Z_{\parallel}(\omega) = \frac{1}{c}\int d\xi e^{i\omega\xi/c} W_{\parallel}(\xi)$$

$$\xi = z_{drive} - z_{test}$$

- The test electron energy changes because of the EM fields of drive electron.
- This energy change can be characterized in terms of wakefields.

$$\Delta\gamma = -\frac{e}{mc^2}\int_{-\infty}^{\infty} ds E_z \equiv -\frac{e^2}{mc^2} W_{\parallel}(x, y, z)$$

energy change — wakefield

- **The strength of wakefields depends upon the conductivity and the cross-section variation of the chamber.**

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Effects of Longitudinal Impedance

Impedance type	Causes	Effects
Broad band impedance (short term wakefield)	• Heating of vacuum chamber components due to energy loss • Buch lengthening • Microwave instability	• Component damage • Increase in energy spread (not a severe effect)
Narrow band impedance (long term wakefield)	• Heating of cavities • Multi-bunch instabilities	• Increase in emittance

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Polarimeter Geometry and Simulations with RHIC Beam

$\boldsymbol{\sigma = 540\, mm}$, $Q_b = 2 \times 10^{11} e = 32.04\, nC$, $M = 120$

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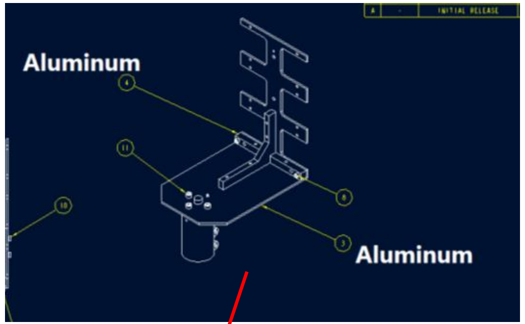
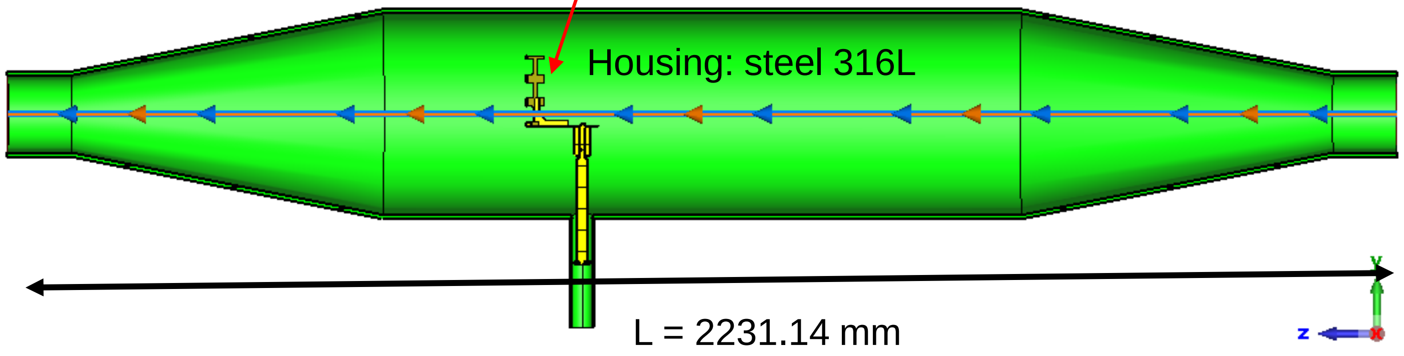
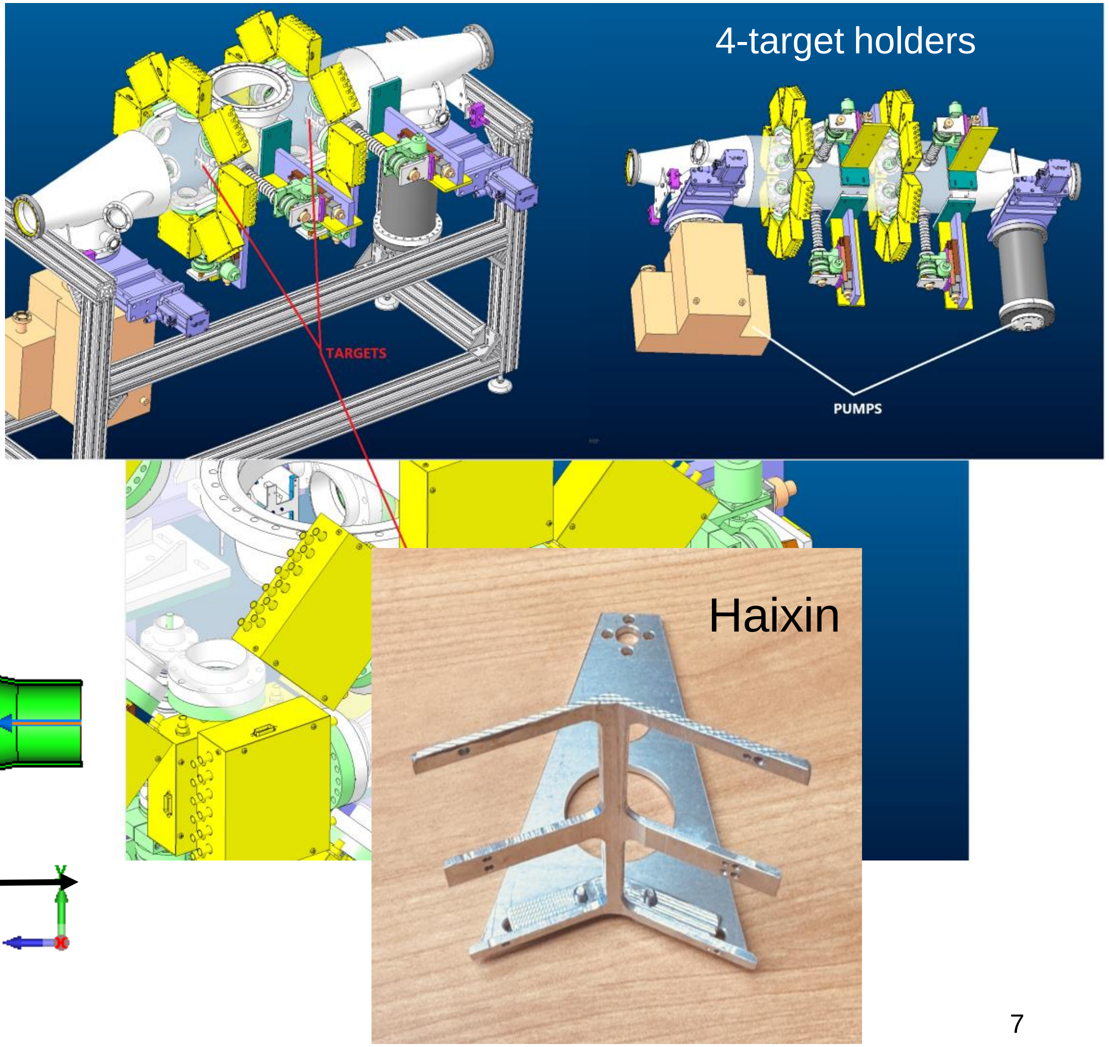
Polarimeter Geometry

- Simplified geometry with a single target for simulation.
- **No carbon fiber**

Picture and geometry: Karim



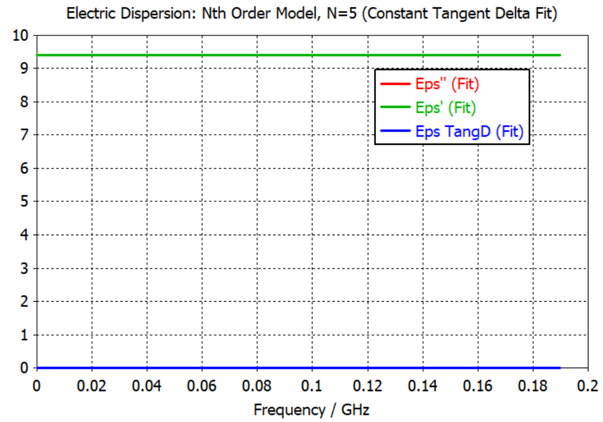


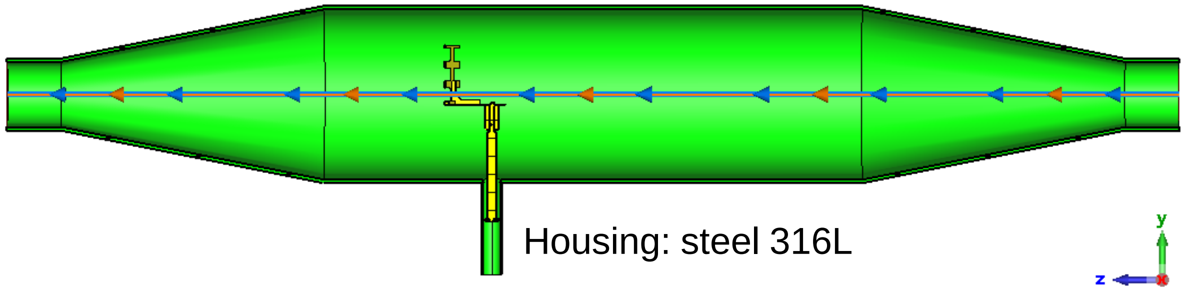


HSR Polarimeter: Material Properties

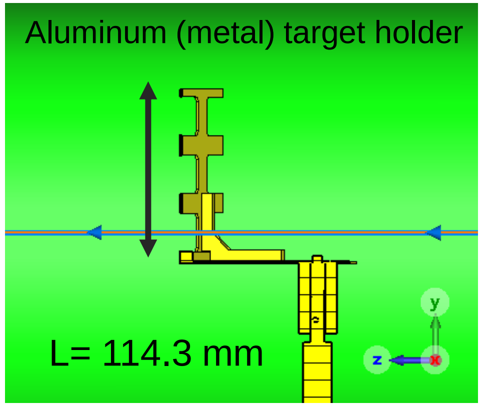
Conductivities

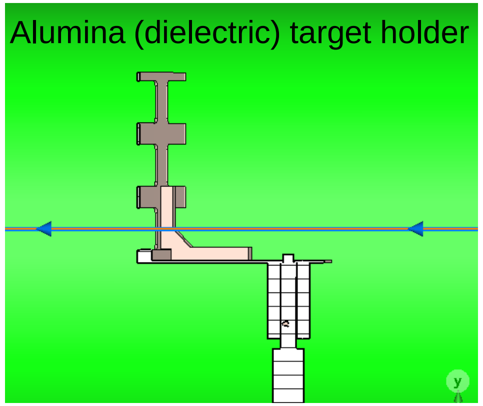
- $\text{Alumium} = 3.56 \times 10^{7}$ S/m
- $\text{Steel 316L} = 1.351 \times 10^{6}$ S/m
- $\text{Alumina (96\% lossy)}, \epsilon_r = 9.4, \quad \tan\delta = 0.004$





Housing: steel 316L





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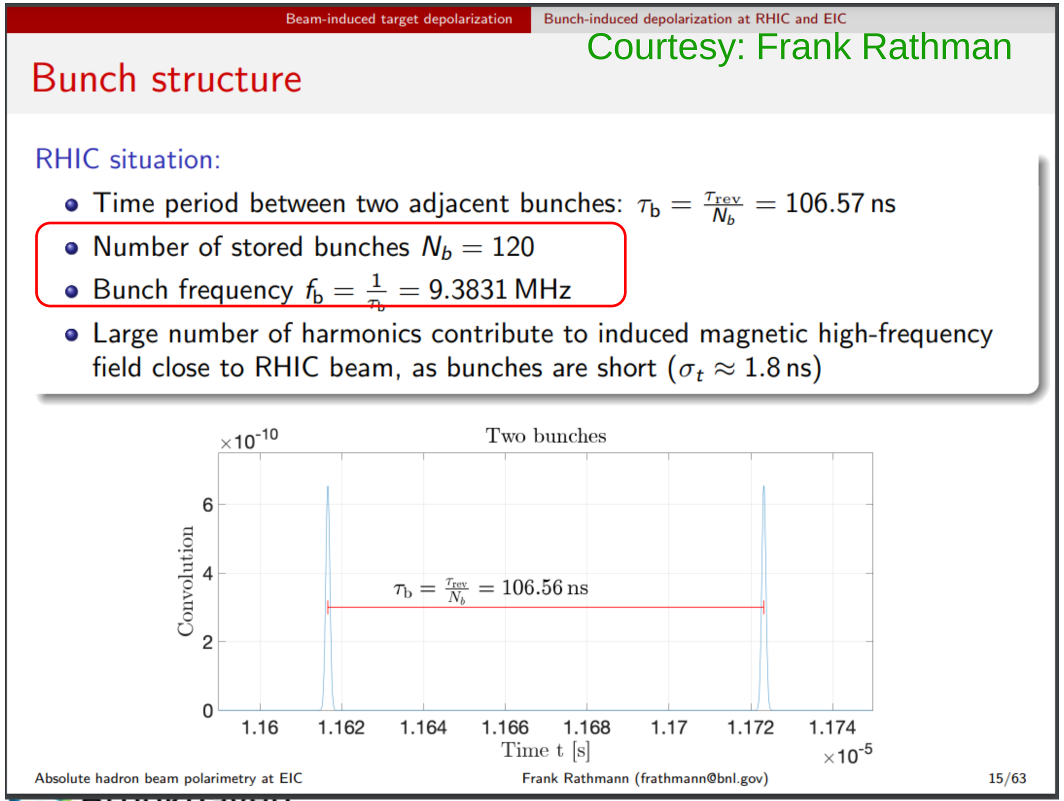
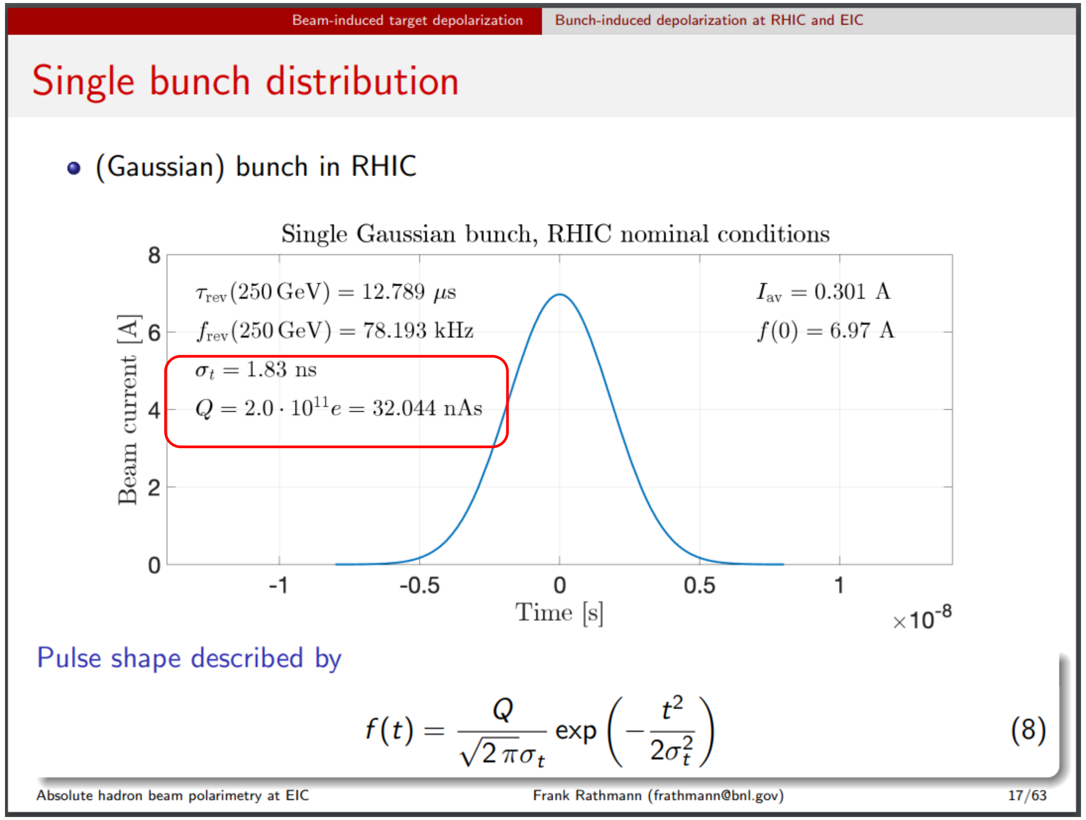
RHIC Beam Parameters for Polarimeter

- Beam Parameters for CST simulations: $\sigma = 1.8\,ns = 539.6\,mm,\ Q_b = 2 \times 10^{11} e = 32.04\,nC,\ M = 120$





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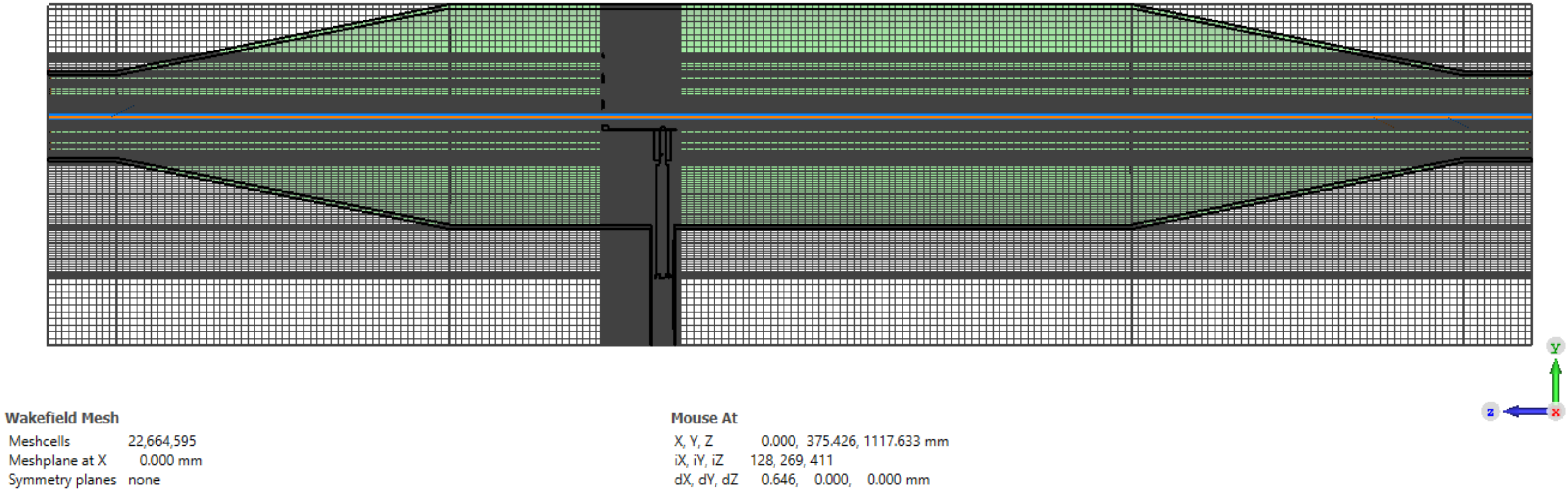
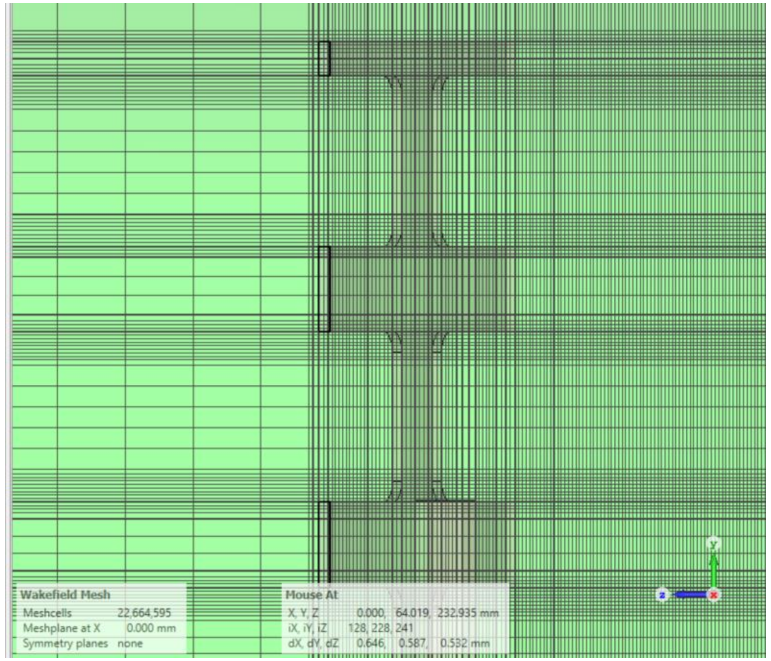
Target with Fine Mesh Resolutions

- Beam Parameters for CST simulations: $\sigma = 1.8\,ns = \ 539.6\,mm,\ Q_b = 2 \times 10^{11} e = 32.04\,nC,\ M = 120$
- The mesh size around the target materials is ~ 0.5 mm.

Total mesh cells 22.66 Millions



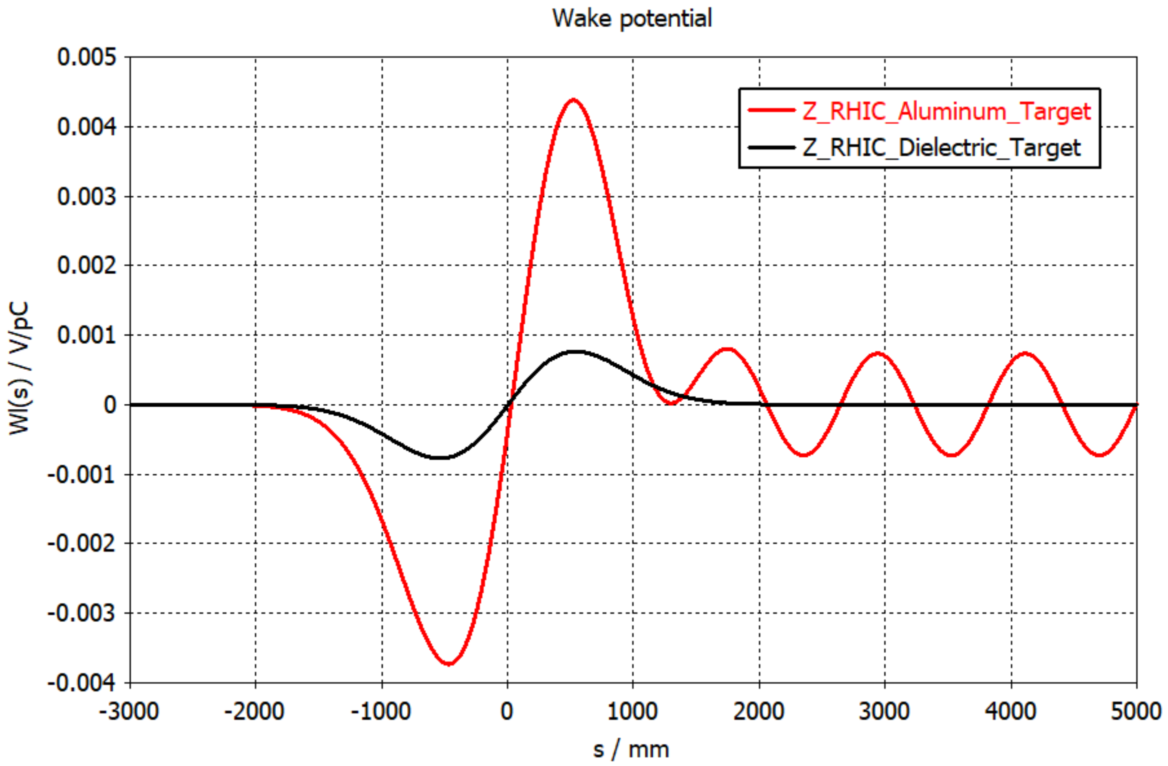
Mesh size ~ 0.5 mm



Wakefields comparison: $\sigma = 539.6\,mm$

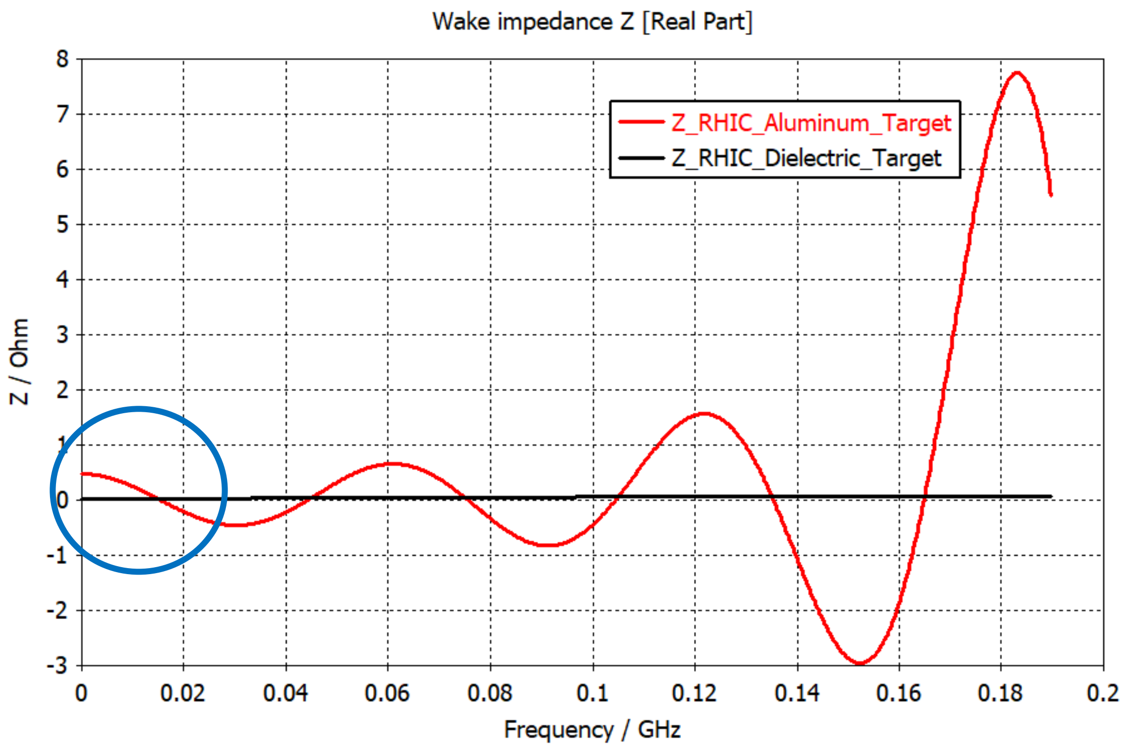
- Compared the longitudinal wakefields for two different target holder materials: aluminum (metal) and alumina (dielectric).
- The dielectric target holder reduced the amplitude of the wakefields significantly (no oscillations).

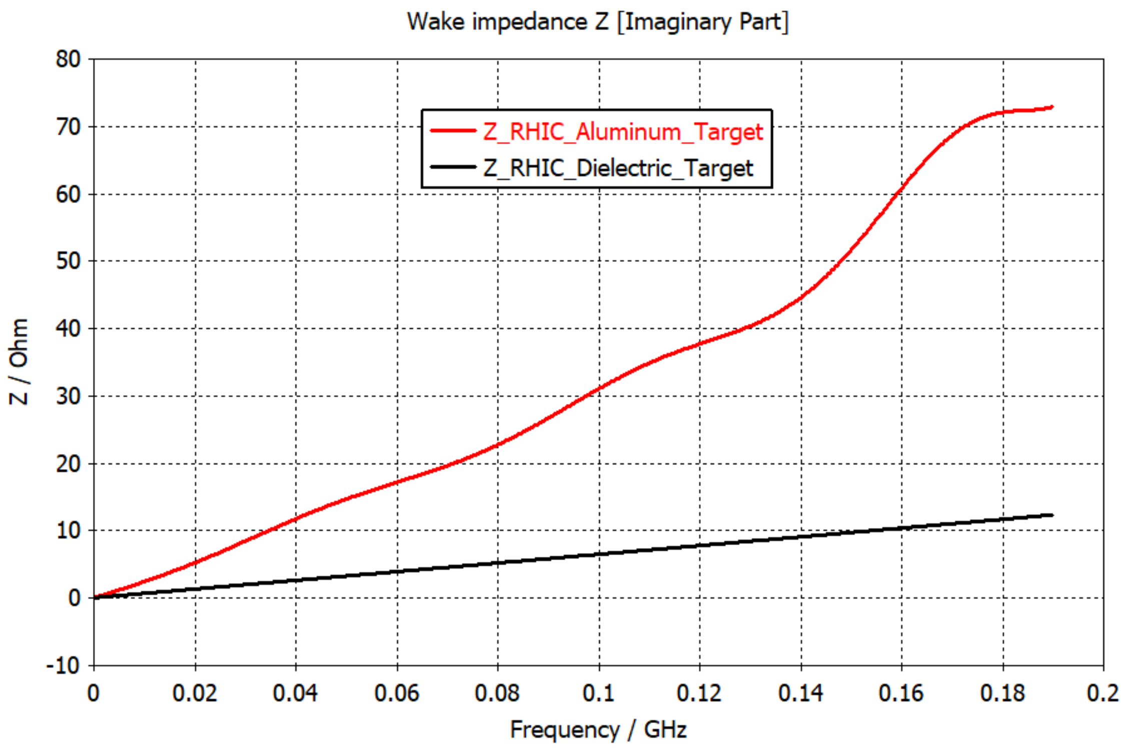
$$\sigma = 539.6\,mm$$
$$Q_b = 32.04\,nC$$
$$M = 120$$



Impedance Comparison: $\sigma = 539.6\,mm$

- Alumina (Al_2O_3) target lowers the both real and imaginary part of the impedances by a factor of ~ 6.





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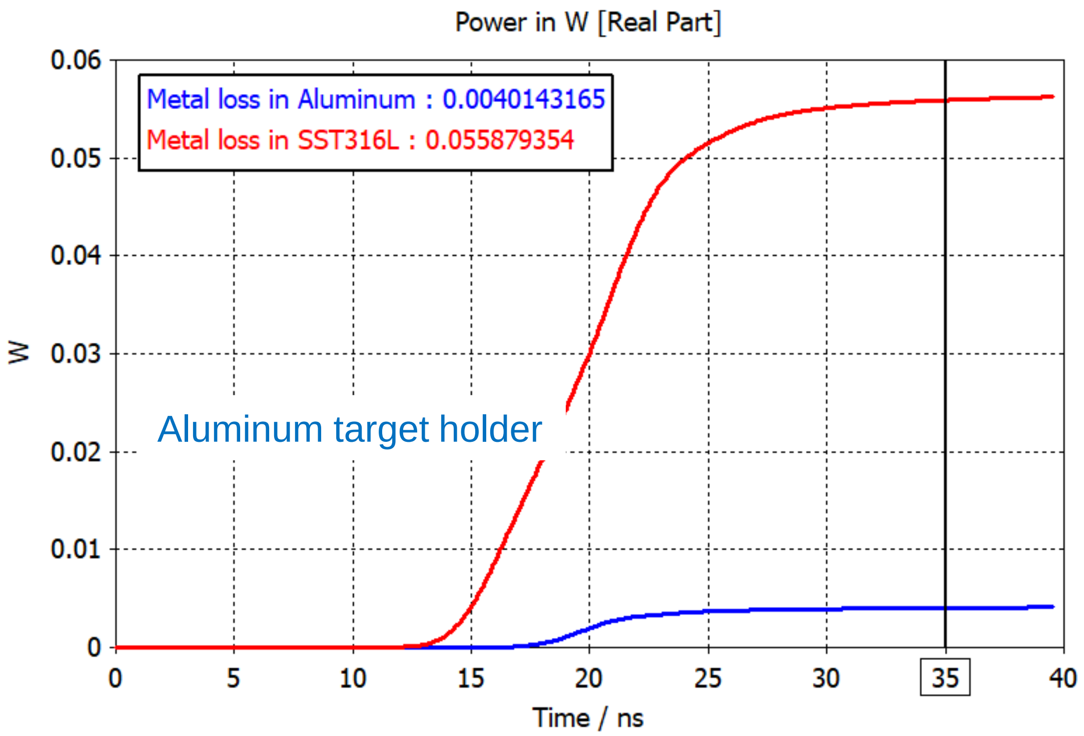
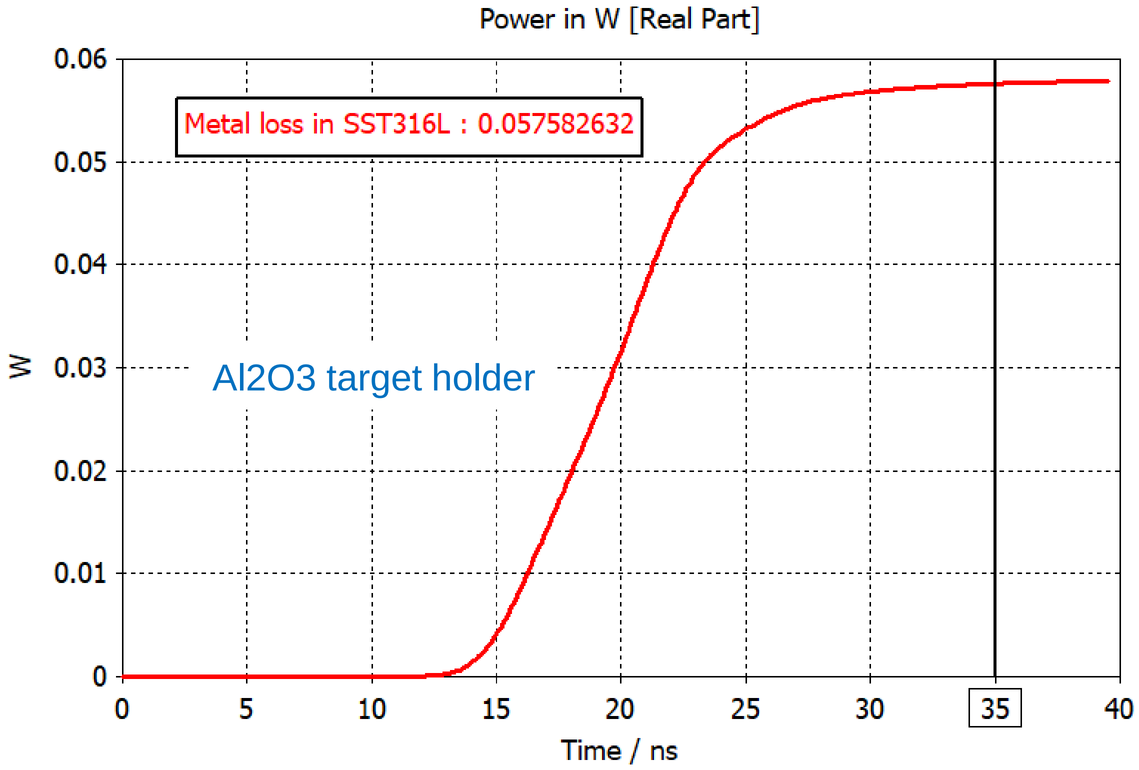
RW Loss Comparison, RHIC beam

- Simulations with RHIC beam: $\sigma = 1.8\,ns = \ 539.6\,mm,\ Q_b = 2 \times 10^{11}e = 32.04\,nC,\ M = 120$
- **Longer RHIC bunch results mostly the same total RW loss.**





Simulation with the EIC Proton Beam Parameters:

$\boldsymbol{\sigma = 60\, mm}$, $Q_b = 2 \times 10^{11} e = 30.5\, nC$, $M = 290$

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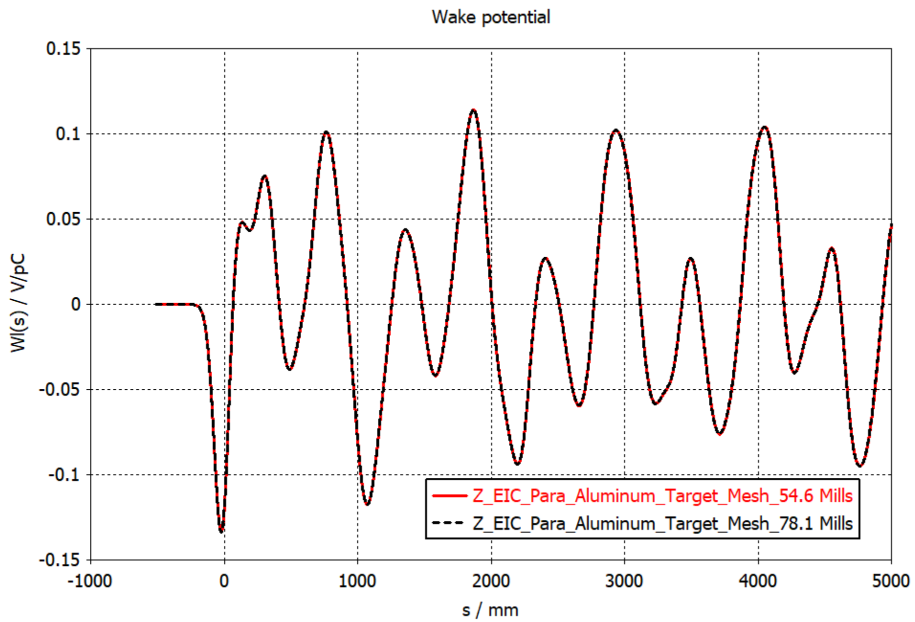
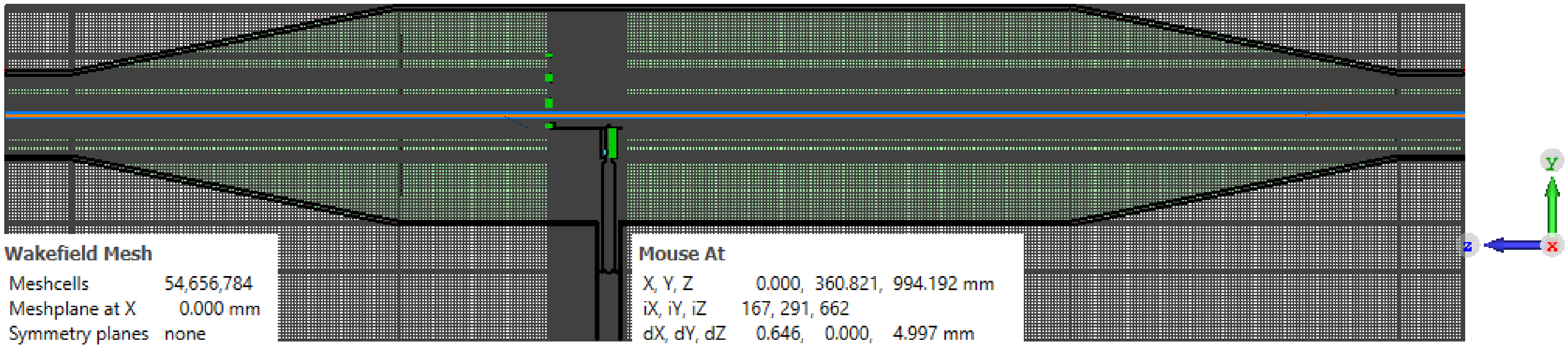
Mesh Convergence

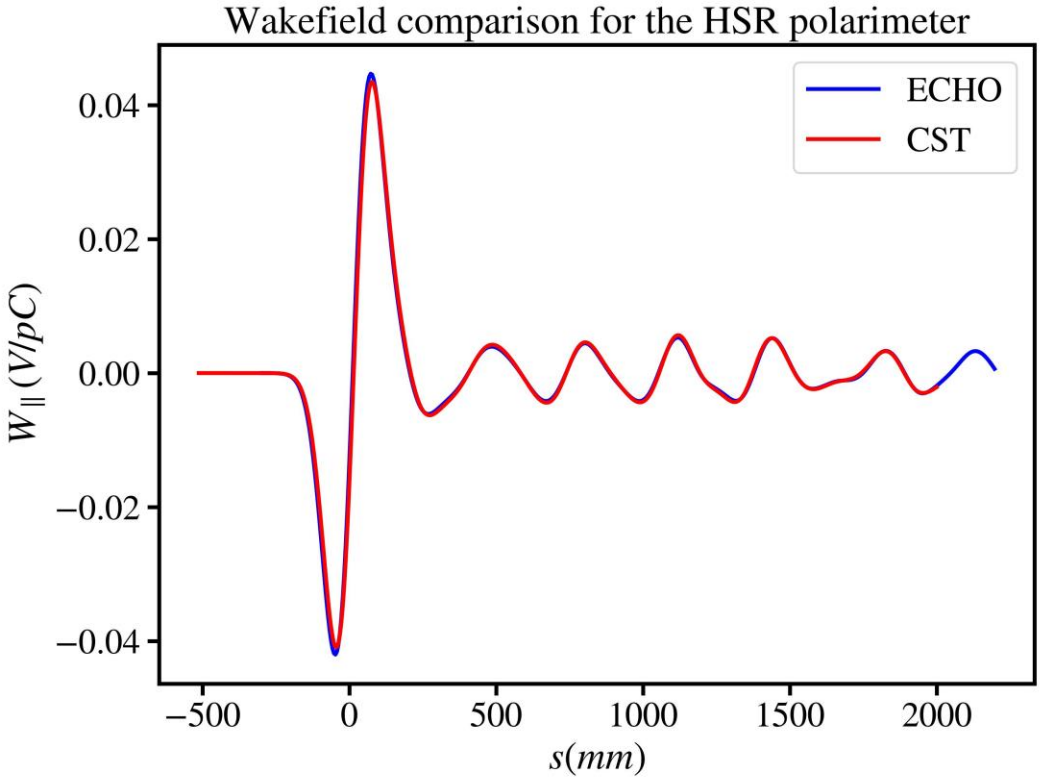
- Wakefields simulation with $\sigma = 60\ mm, Q_b = 30.5\ nC, M = 290$
- Mesh size ranges from 0.5 mm to 5 mm for nominal case (54.6 Mills)
- **Good agreement between two mesh resolutions.**





Good Agreement between Two Codes (w/o target)

- Gang Wang ran the wakefields simulation of the same geometry using another code ECHO 3D.
- Observed a very good agreement between two codes.

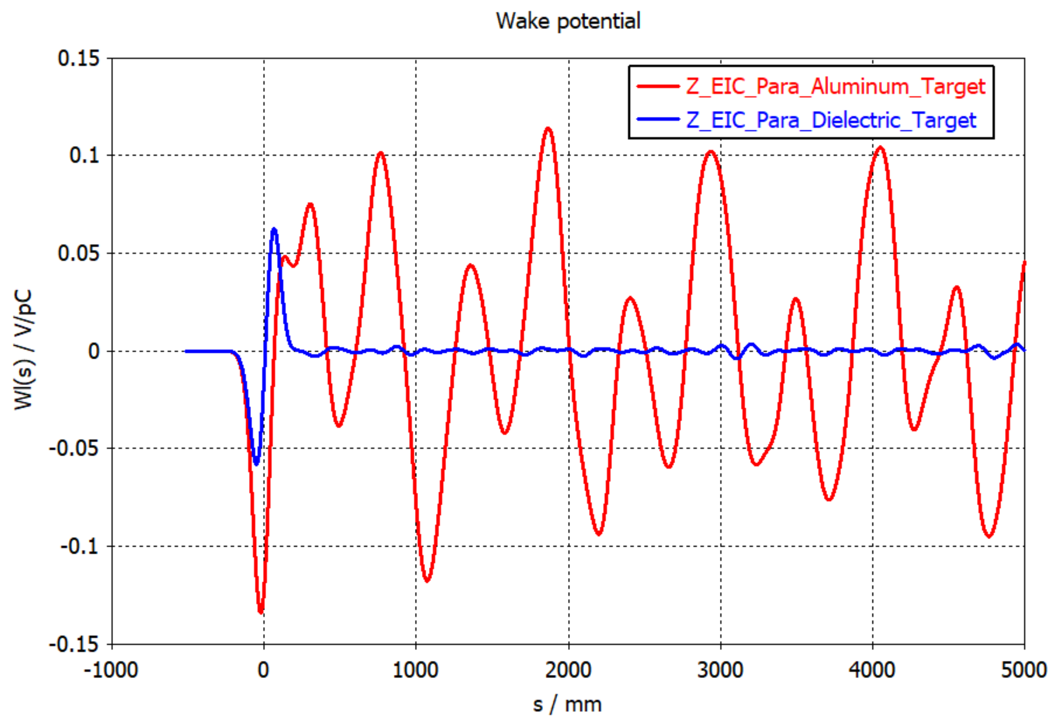


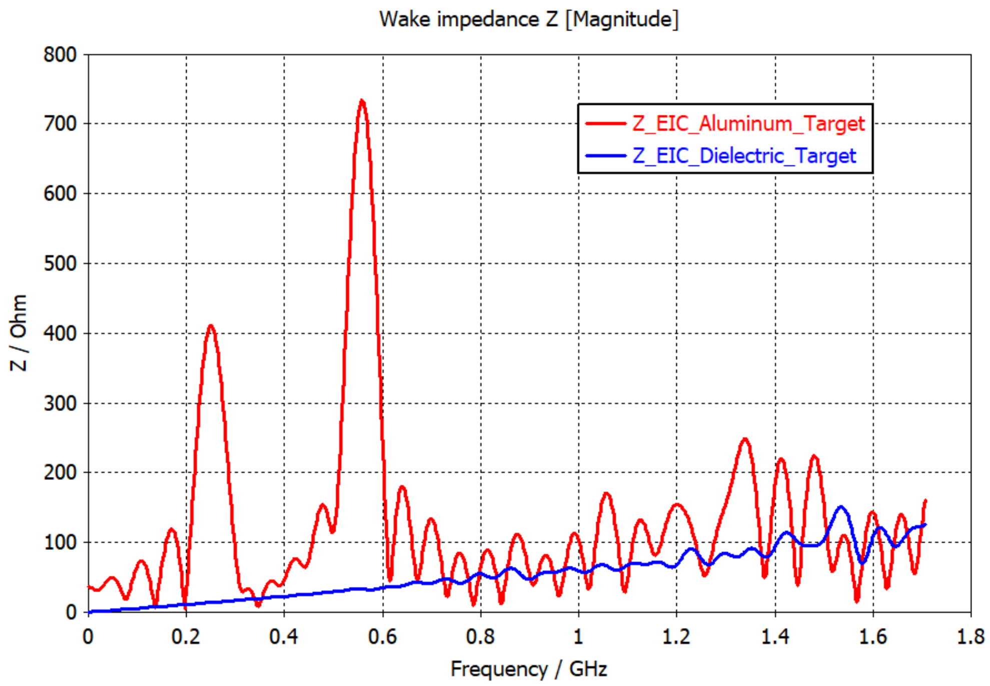
$\sigma = 60\ mm,$

$Q_b = 30.5\ nC$

Wakefields/impedance Comparison: Metal vs Dielectric

- The amplitude of the longitudinal wake is much lower in case of dielectric target.
- In addition, the low frequency resonances observed in the metallic target holder is washed away.





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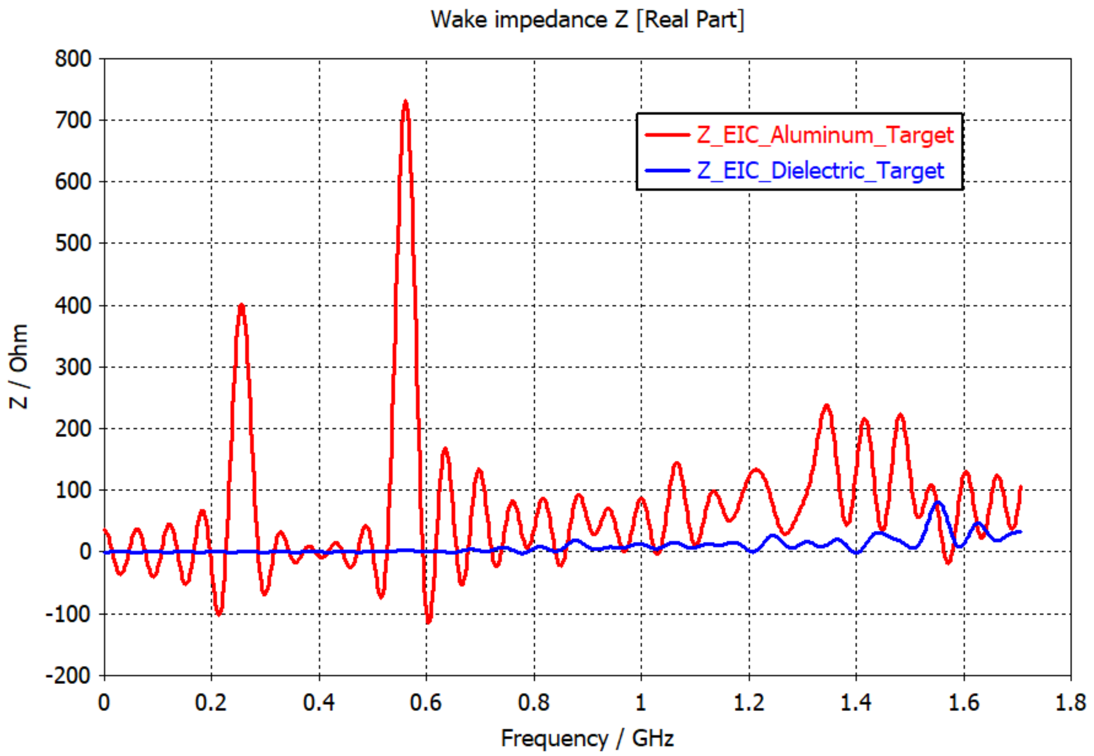
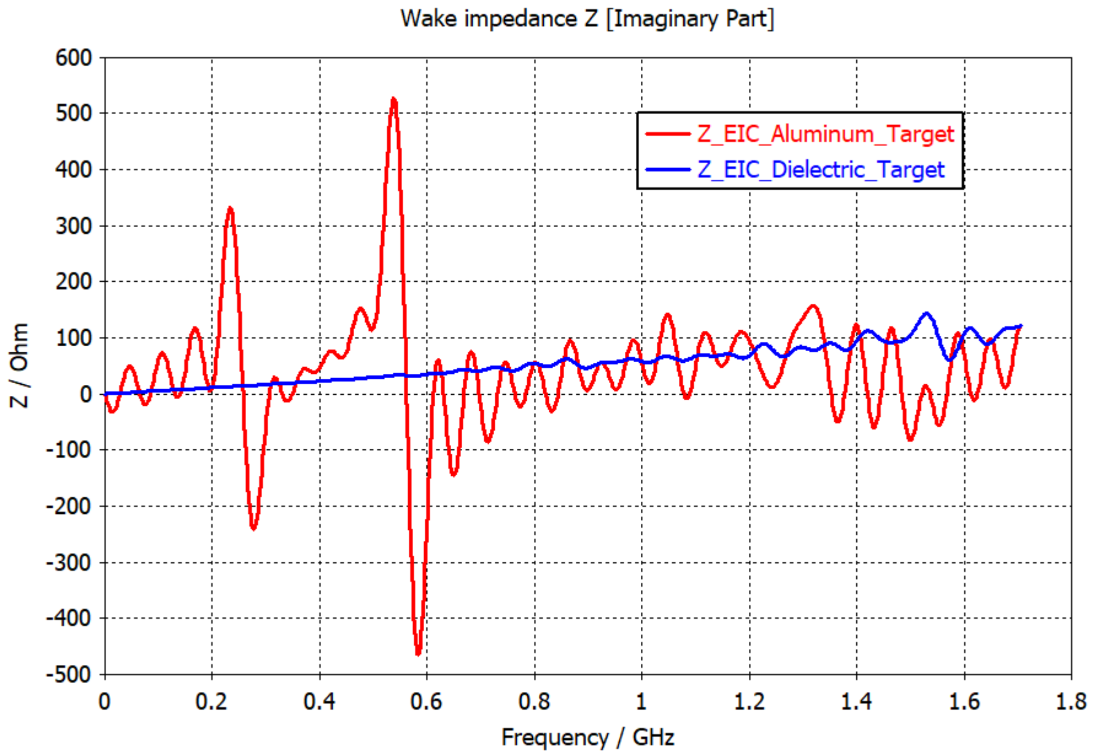
Impedance Comparison: Metal vs Dielectric

- The dielectric target help to wash away the resonances observed at lower frequencies.





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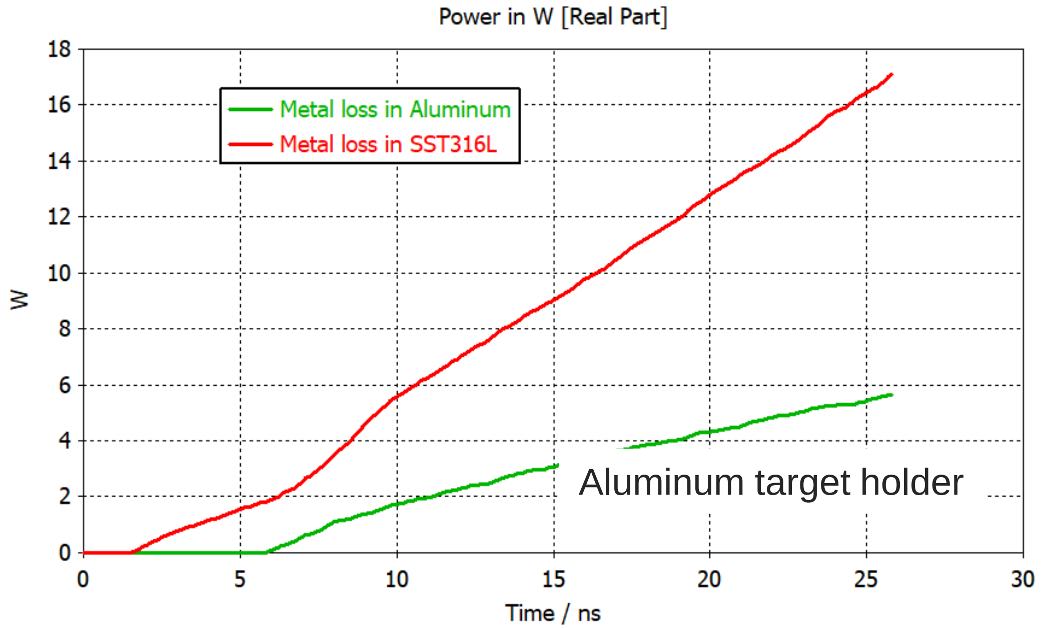
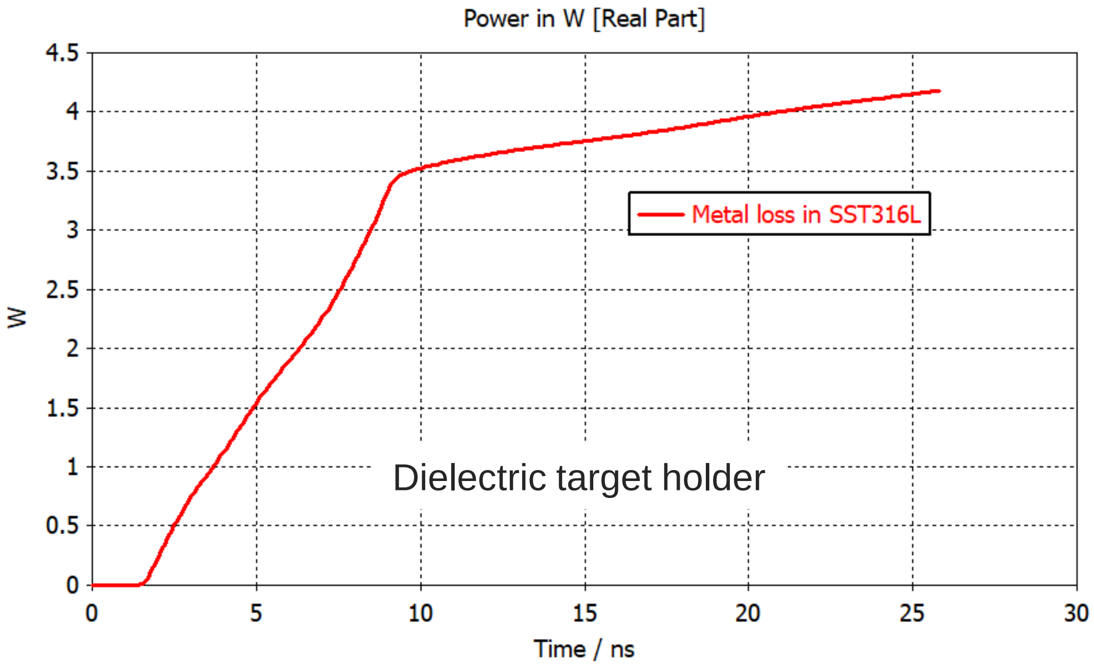
RW Loss Comparison: Metal vs Dielectric

- The dielectric target holder reduces the RW heating significantly. Also, the total RW loss starts to saturate.
- However, in the metallic target, the RW loss is increasing monotonically (potentially due to oscillating wakefields).

EIC proton beam: $\sigma = 60\ mm$

Wake-length: 5 m





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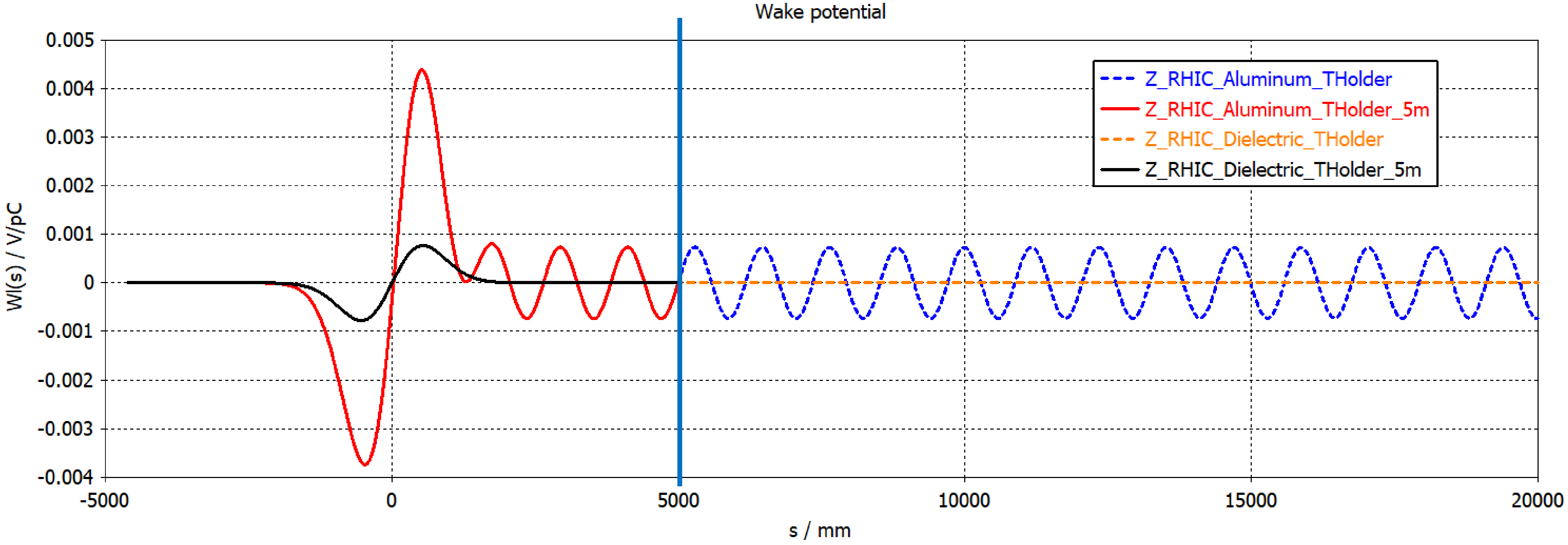
Simulations Comparison with Long-range Wakefields and Impedances

Comparison S/L-range Wakefields: 5m/20m, RHIC Beam

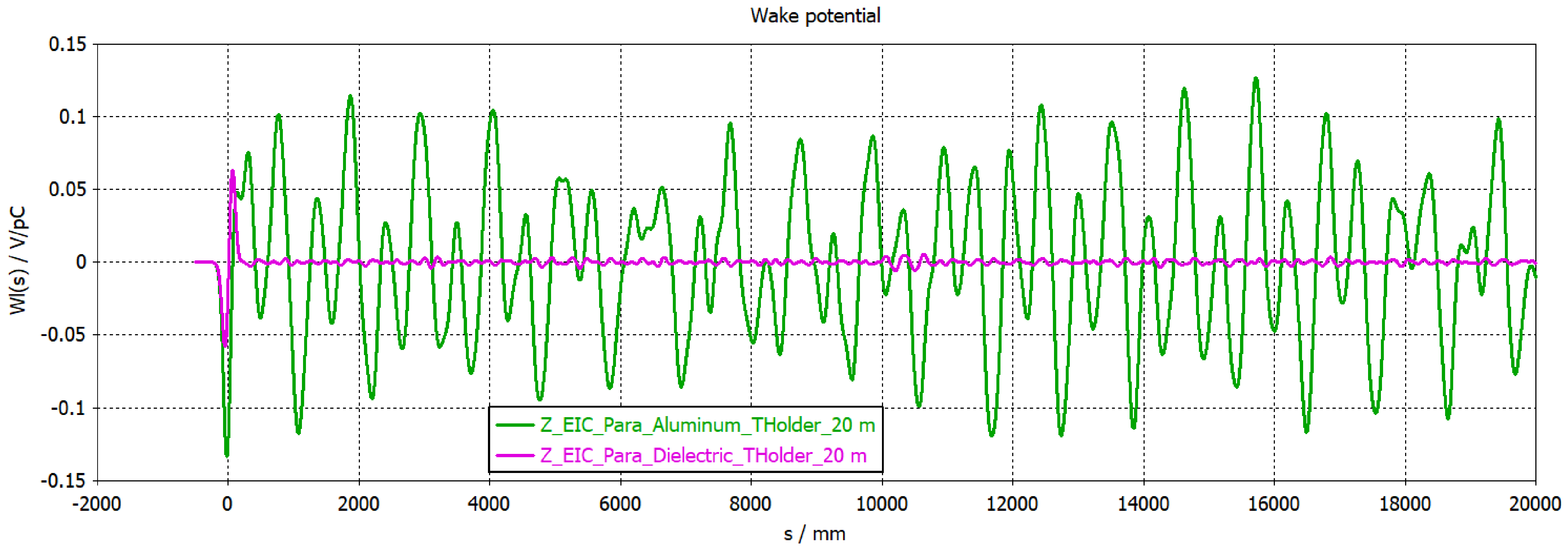
- Observed continuous wakefields oscillation up to 20 m wakelength with the aluminum target holder.
- Amplitude of oscillations remains the same as that of 5 m.

$\sigma = 539.6\ mm$



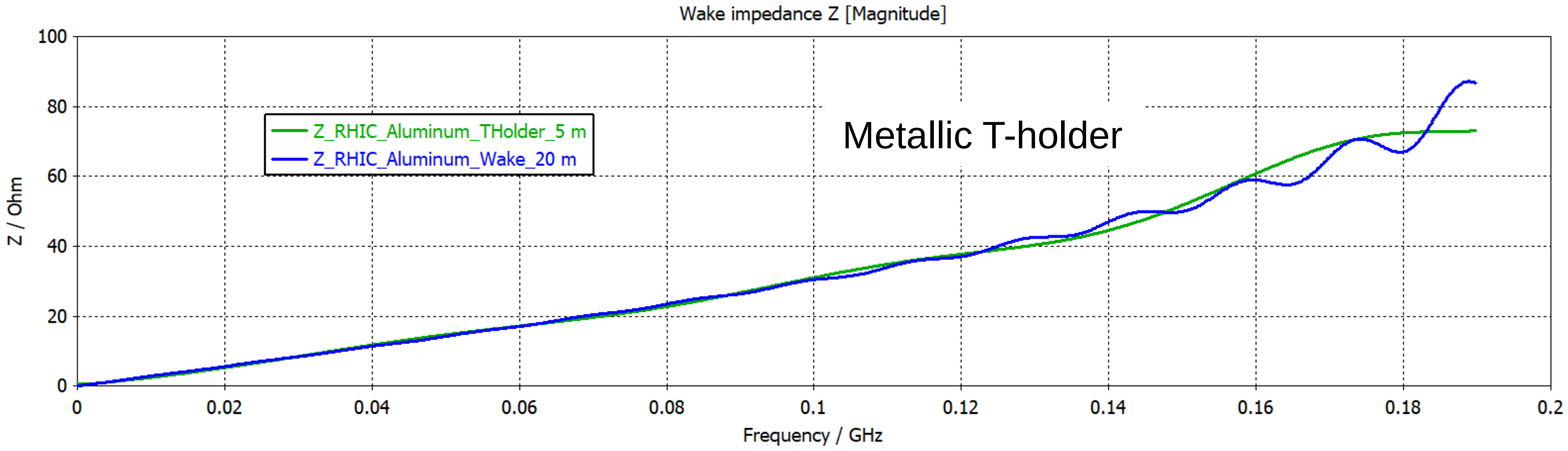
Long Range Wakefield: 20 m, EIC Beam

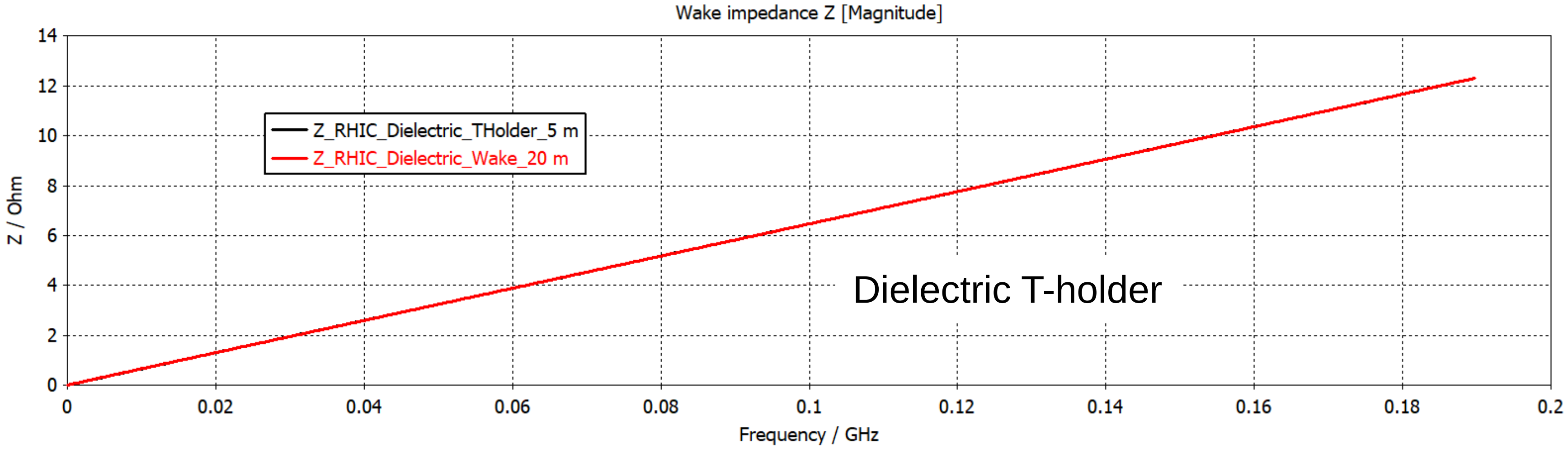
- EIC Beam parameters: $\sigma = 60\ mm, Q_b = 30.5\ nC,\ M = 290$
- Observed continuous wakefield oscillations up to 20 m wakelength with the aluminum target holder.



No Difference in Impedances for RHIC Beam: 5m vs 20m

$\sigma = 539.6\ mm$





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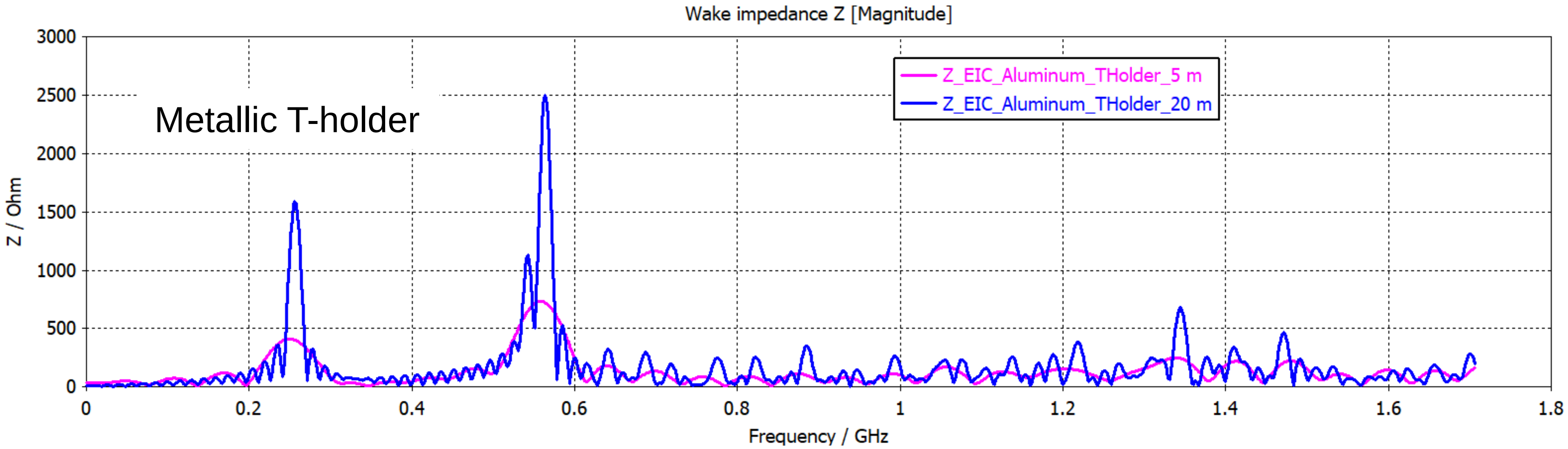
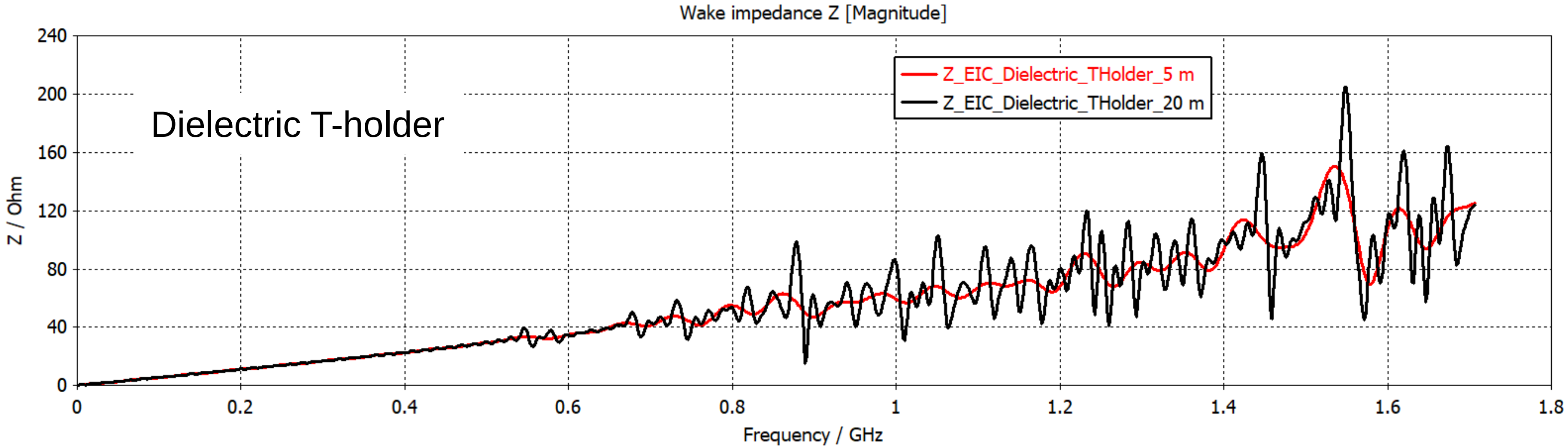
Huge Difference in Impedances for the EIC Beam: 5 m vs 20 m

$\sigma = 60\ mm$





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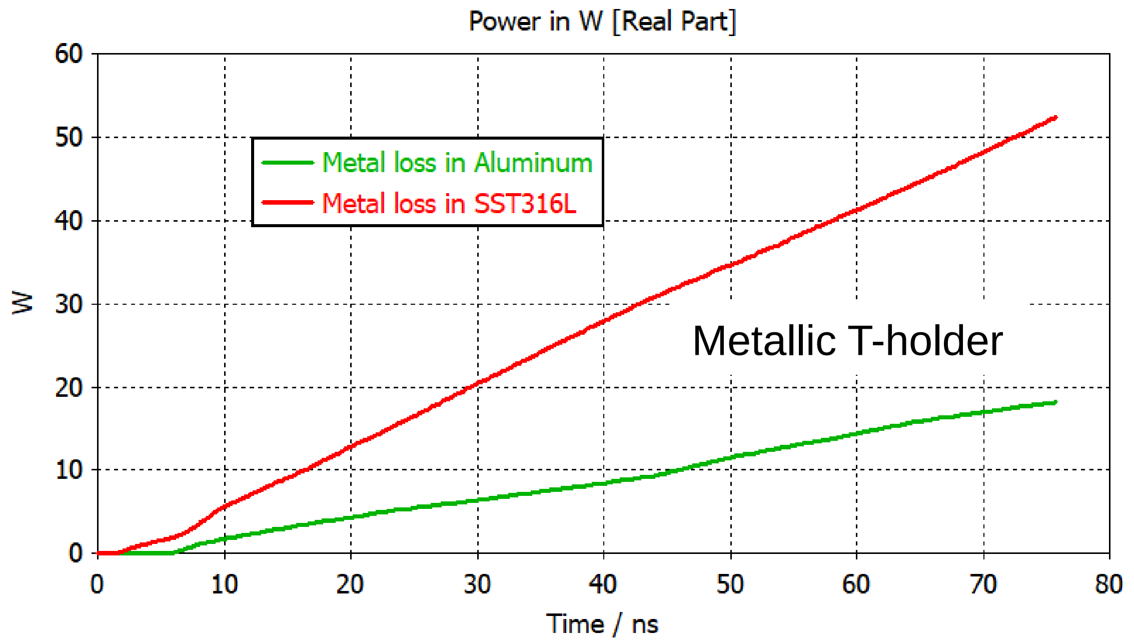
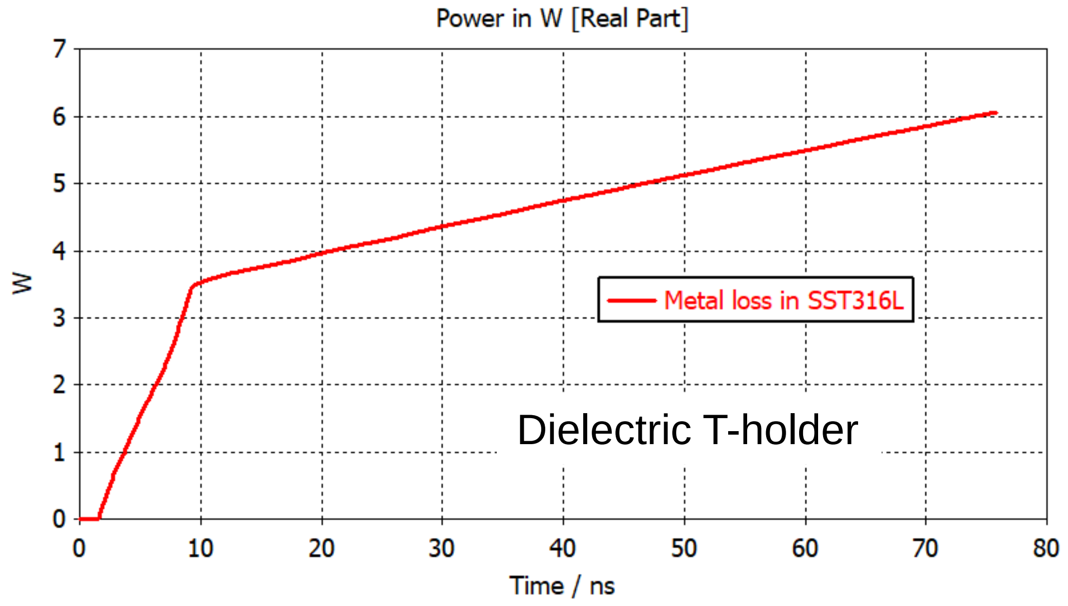
RW Loss Comparison: 20 m, EIC Beam

- The dielectric (alumina) target holder reduces the RW loss significantly and it starts to saturate.
- However, the RW loss is increasing monotonically, which could be due to oscillating wakefields.





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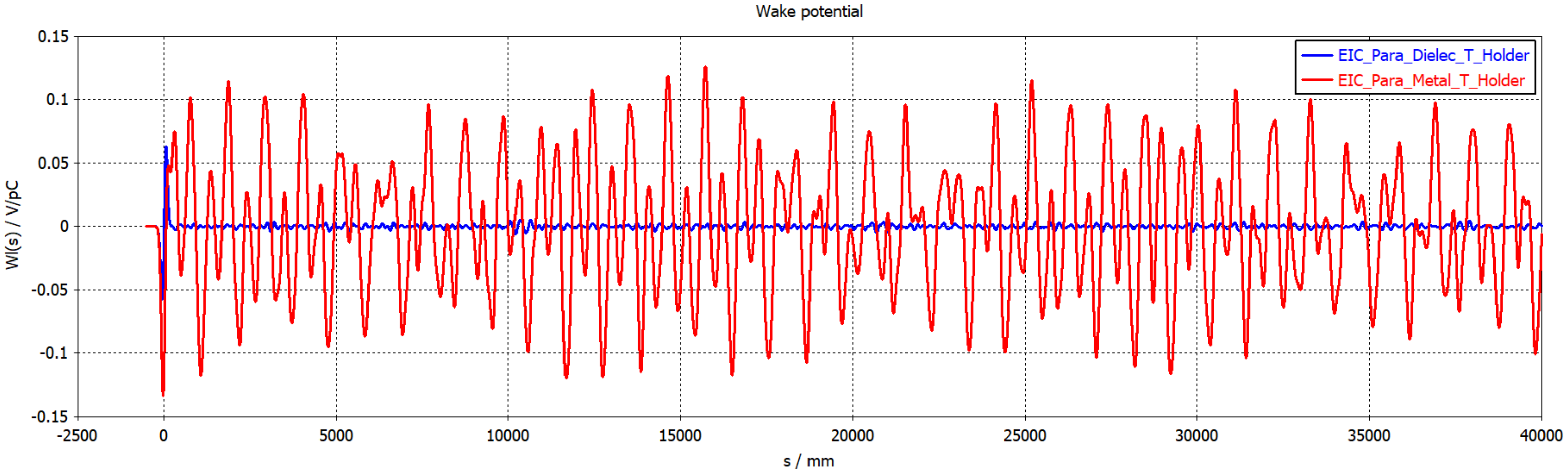
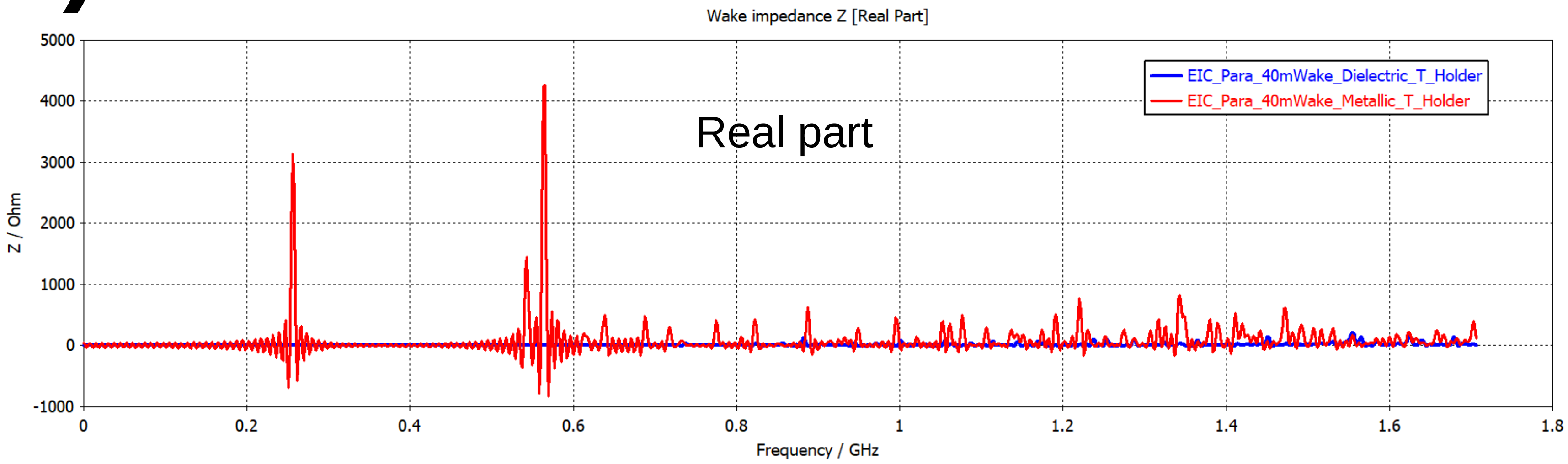
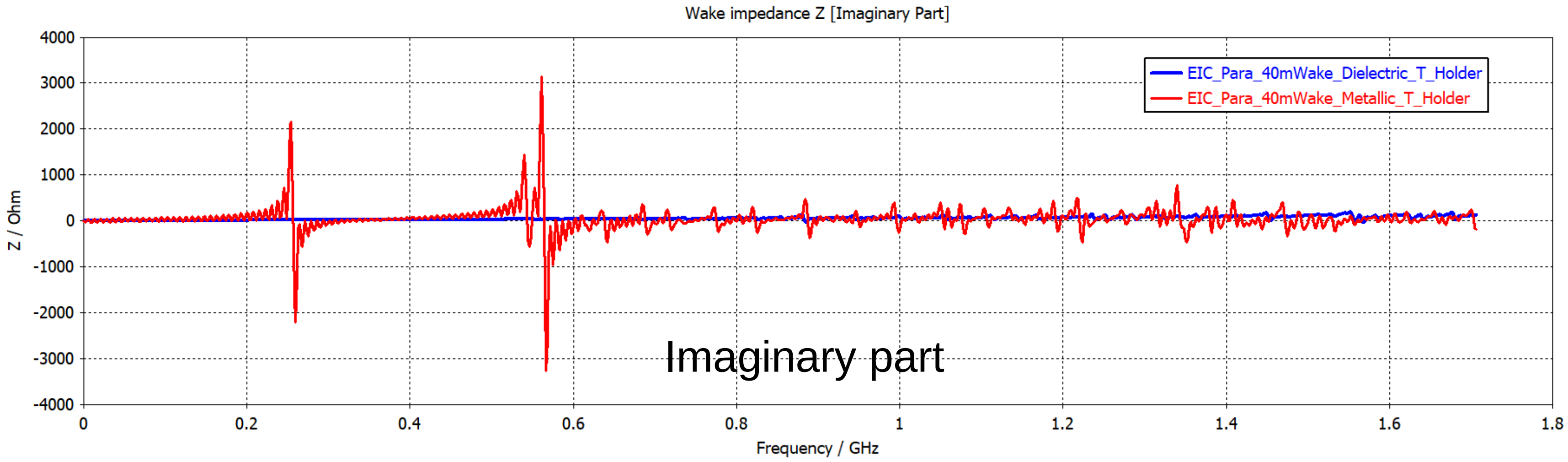
Wakefield Comparison: metal vs dielectric (s = 40 m)

- $\sigma = 60\,mm,\ Q_b = 30.5\,nC,\ M = 290$
- Simulation time: > 35 hours



Impedance Comparison: metal vs dielectric (s = 40 m)





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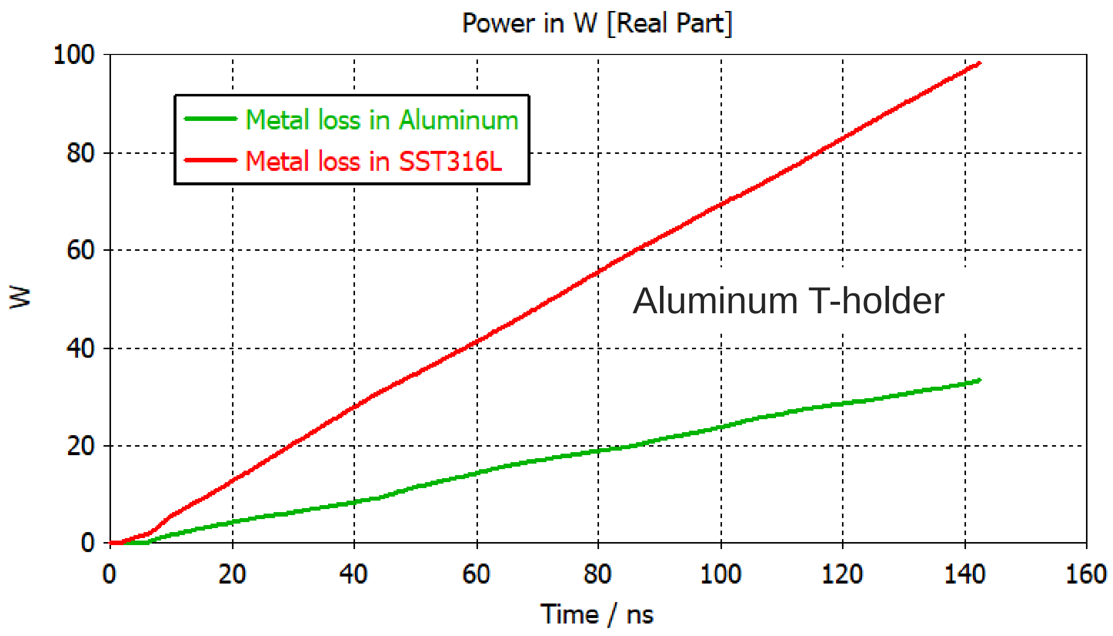
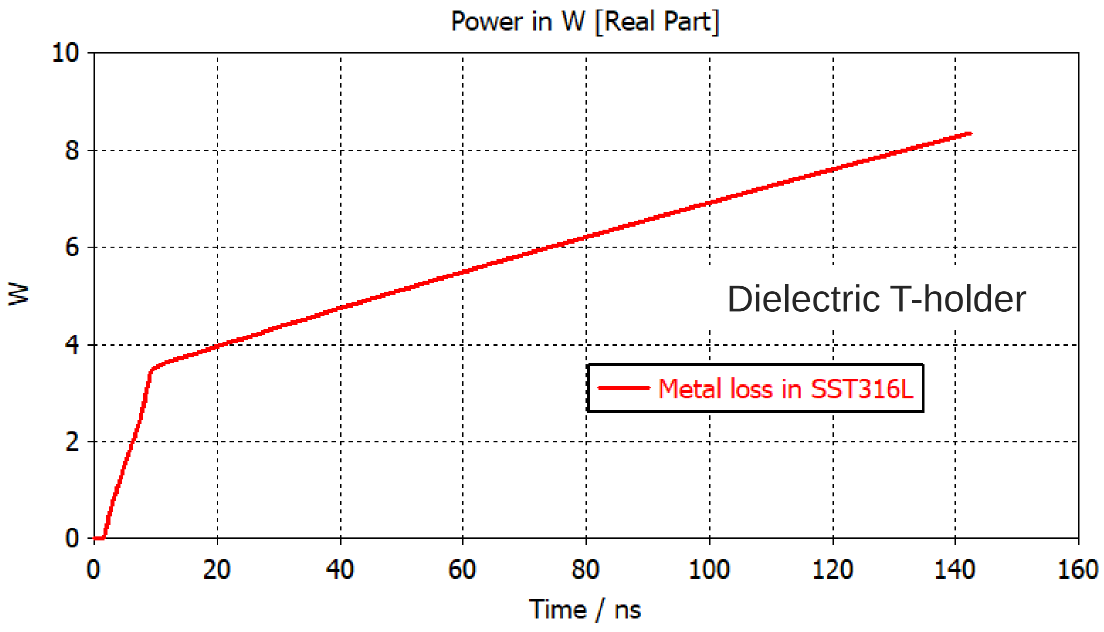
RW Loss Comparison: Metal vs dielectric (s = 40 m)

- The dielectric (alumina) target holder reduces the RW loss significantly and it starts to saturate.
- However, the RW loss for the metallic target holder increases monotonically, which could be due to oscillating wakefields.





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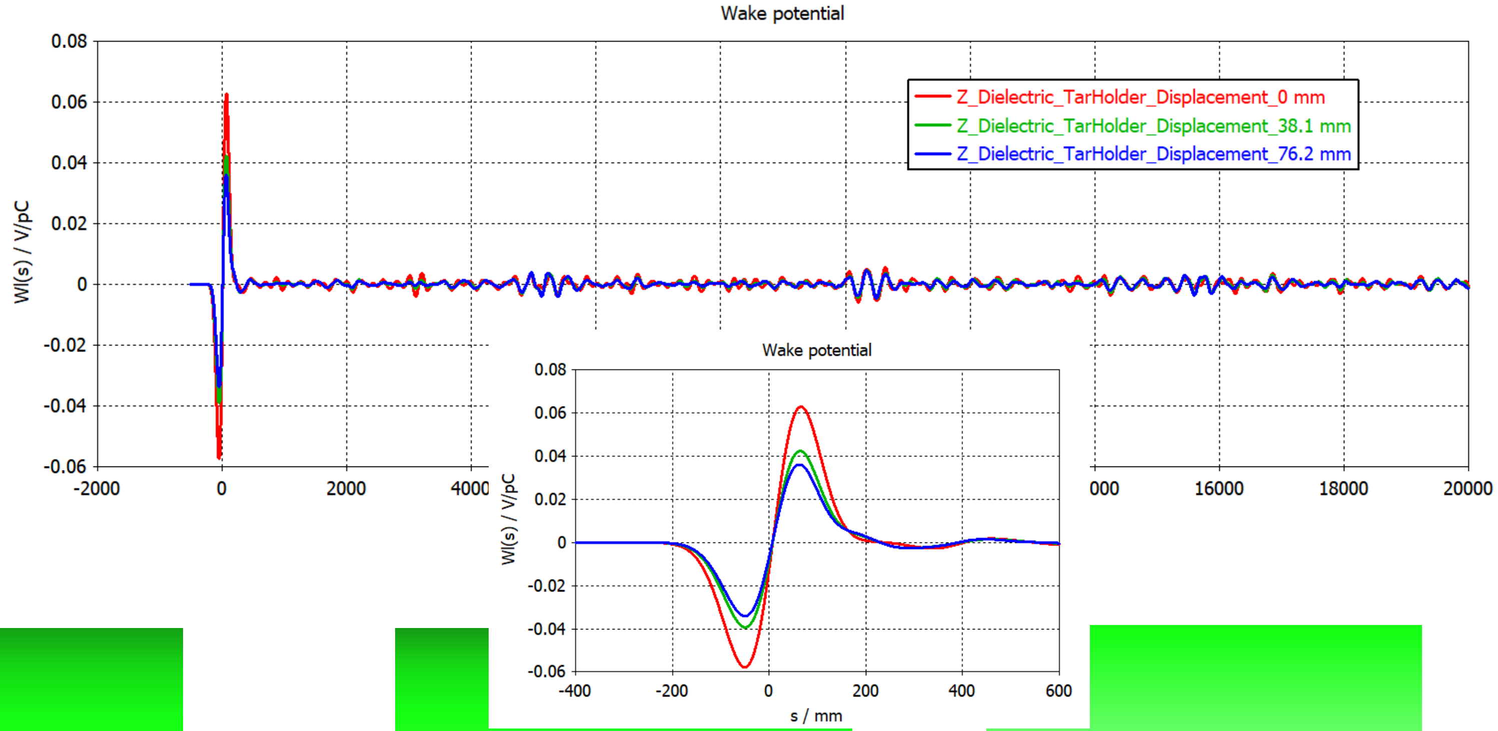
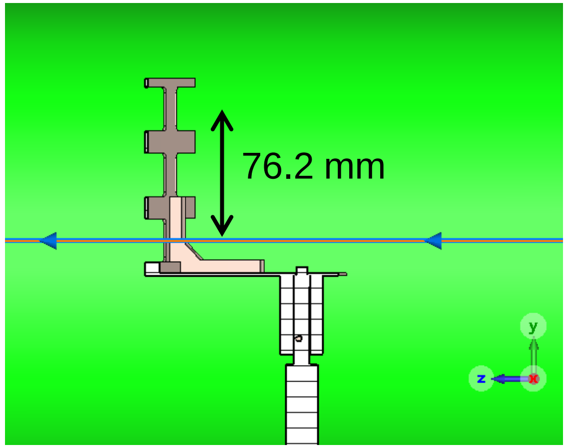
Analysis for the Shifted Target Holder

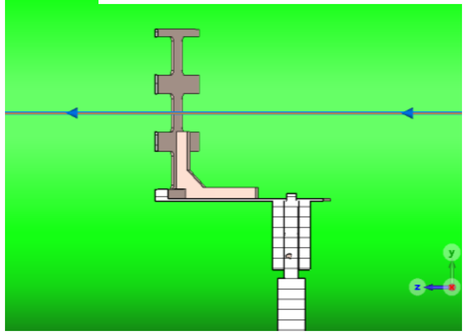
Dielectric Target: Shifted Positions

- Total target holder displacement = 76.2 mm
- Amplitude of the wakefields decreases with the shifted target holder.

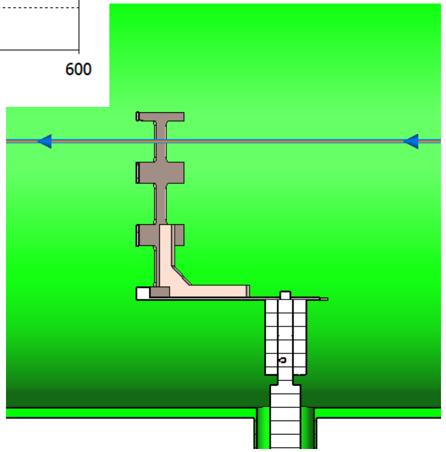




Initial target holder position



Shifted tar holder, 38.1 mm



Shifted tar holder, 76.2 mm

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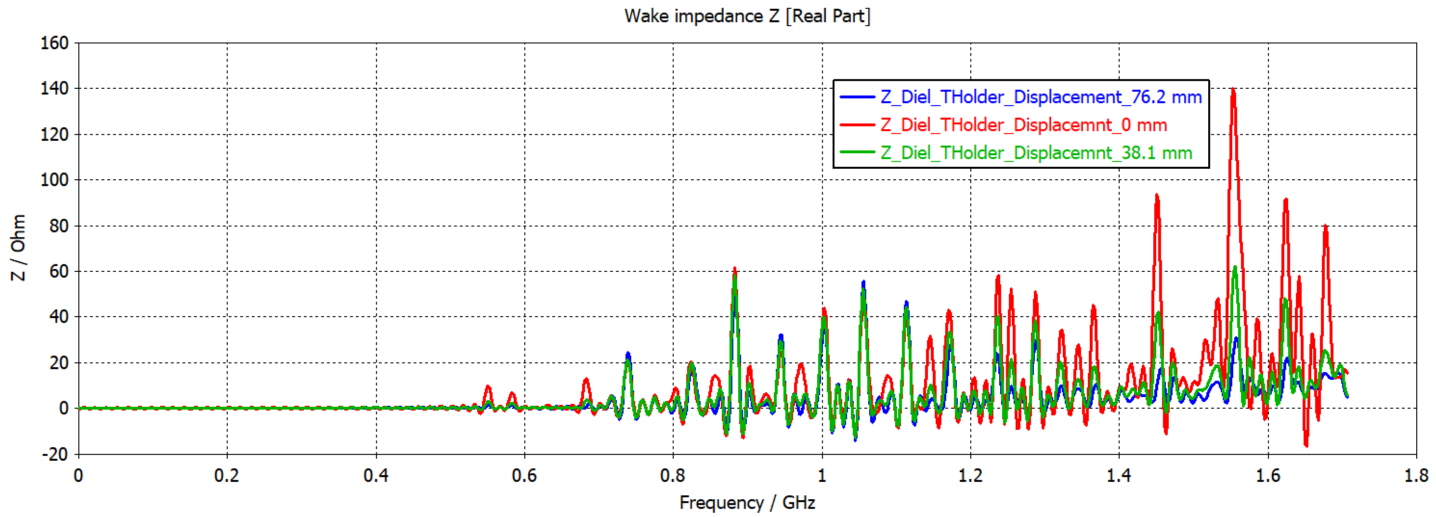
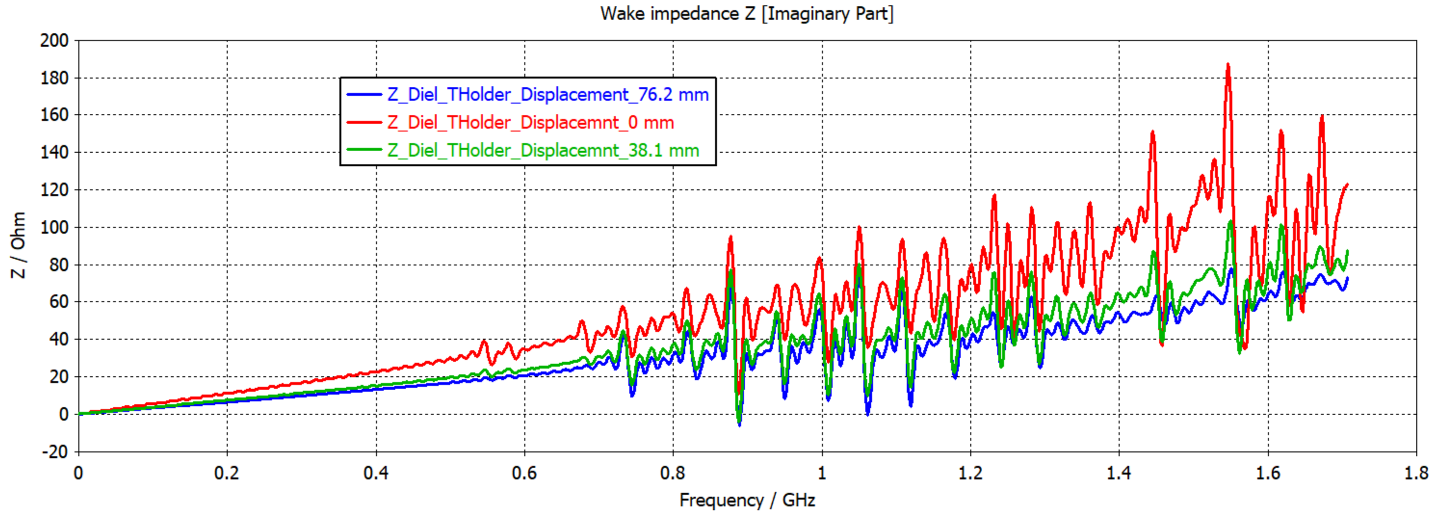
Dielectric Target: Shifted Positions

- The amplitude of the real and imaginary impedance decrease with the shifted target holder.

- The no displacement case (or the initial position) seems more detrimental.





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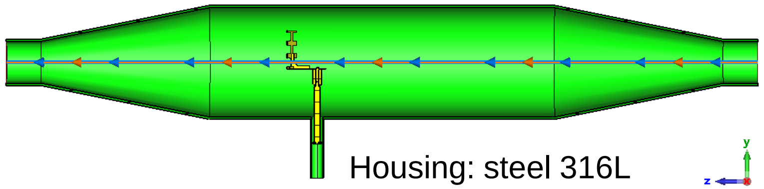
Summary and Future Work

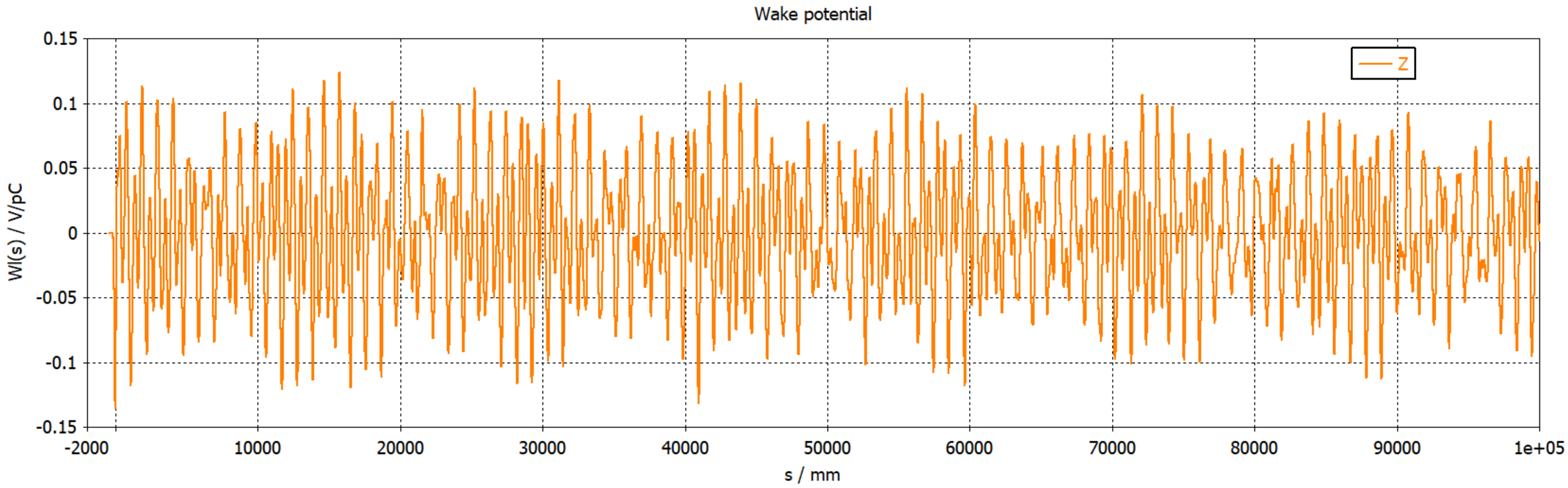
- Performed CST simulations for the HSR polarimeter using both the EIC and RHIC beam parameters.
- Simulated geometry contains only one target holder.
- Compared wakefields and impedance, and the beam induced resistive wall (RW) loss between the metallic and dielectric target holders.
- The amplitude of the wakefield and impedances reduces significantly while using the alumina (dielectric target).
- The beam induced RW loss:
  - RHIC beam: seems comparable for both target holders.
  - EIC proton beam: we observe clear advantages of using the alumina target holder.
- The impedances for the polarimeter can be minimized by optimizing the target holder positions.
- Future work will focus on investigating dielectric target with metallic coatings.

Back Up Slides

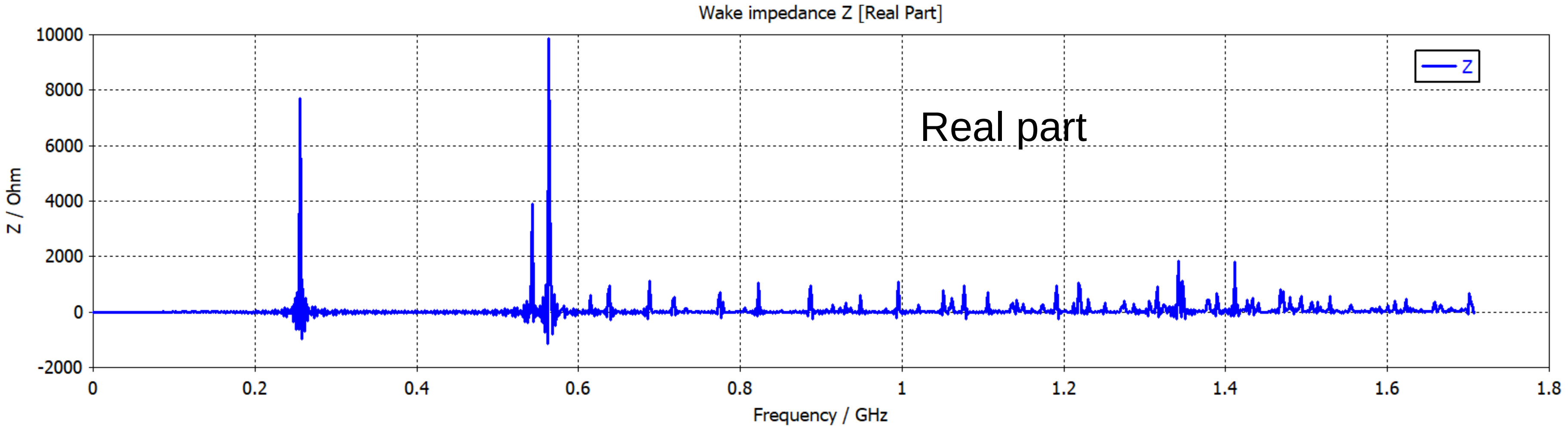
HSR Polarimeter Wakefield up to 100 m

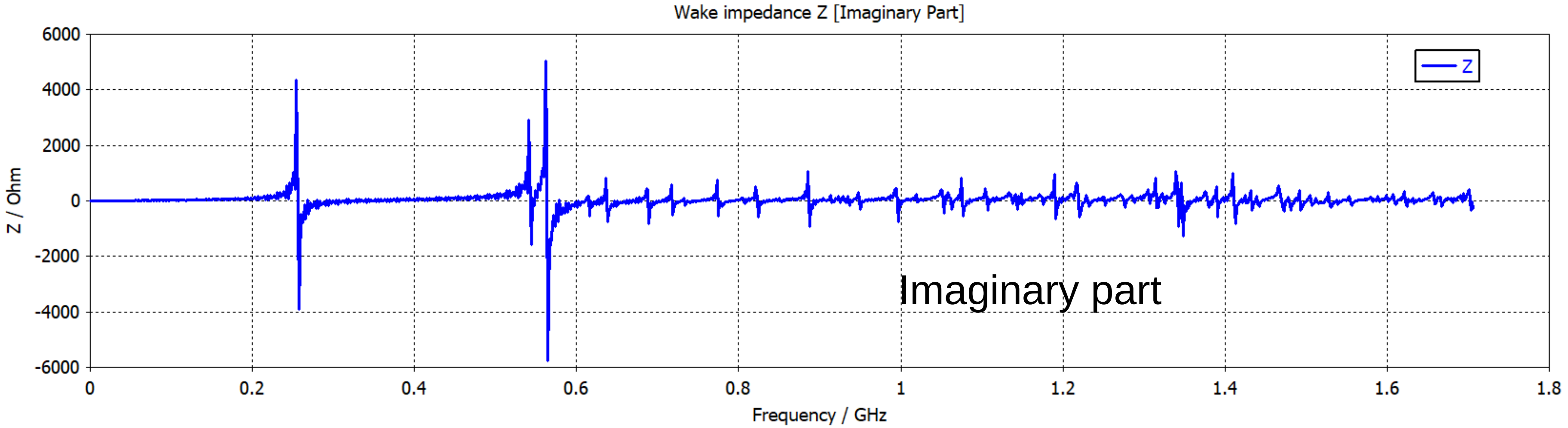
- Wakefields simulation with $\sigma = 60\ mm, \quad Q_b = 30.5\ nC,\ M = 290$
- Mesh size slightly reduced: ranges from 0.6 mm to 7 mm (22.2 Mills)
- Simulation time: about 25 hours


Housing: steel 316L



HSR Polarimeter: Impedances (s = 100 m)





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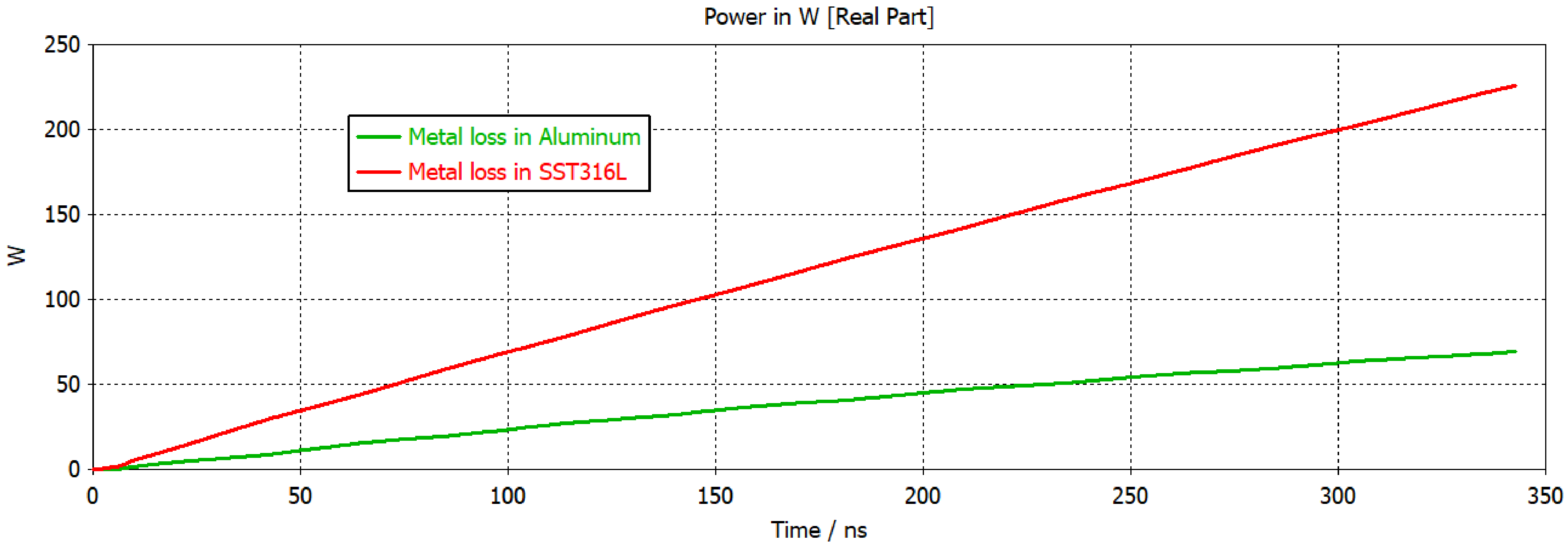
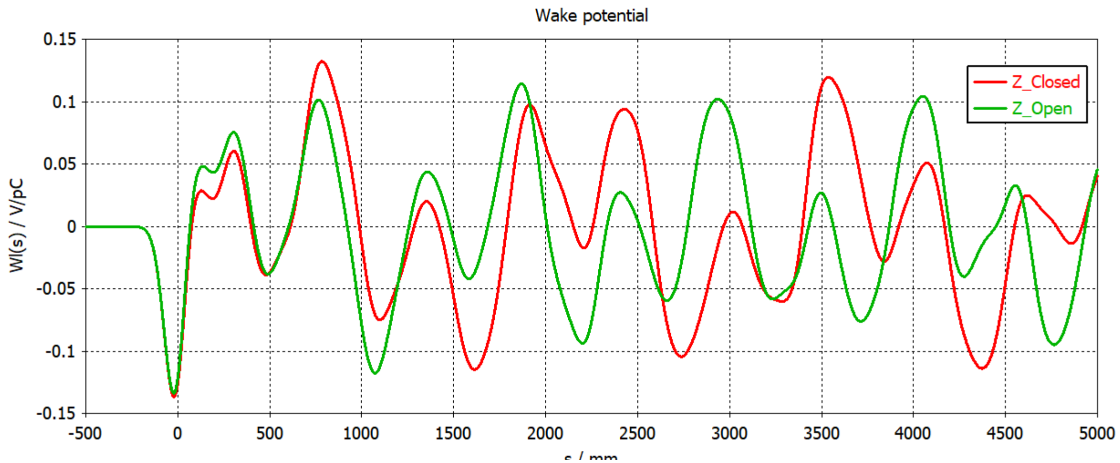
HSR Polarimeter: RW Losses (s = 100 m)

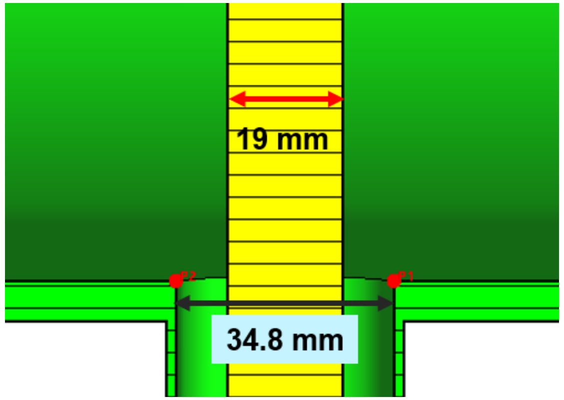
- Wakefields simulation with $\sigma = 60\,mm, \quad Q_b = 30.5\,nC,\ M = 290$
- The beam induced resistive wall losses still didn't observe saturation (unfortunately).



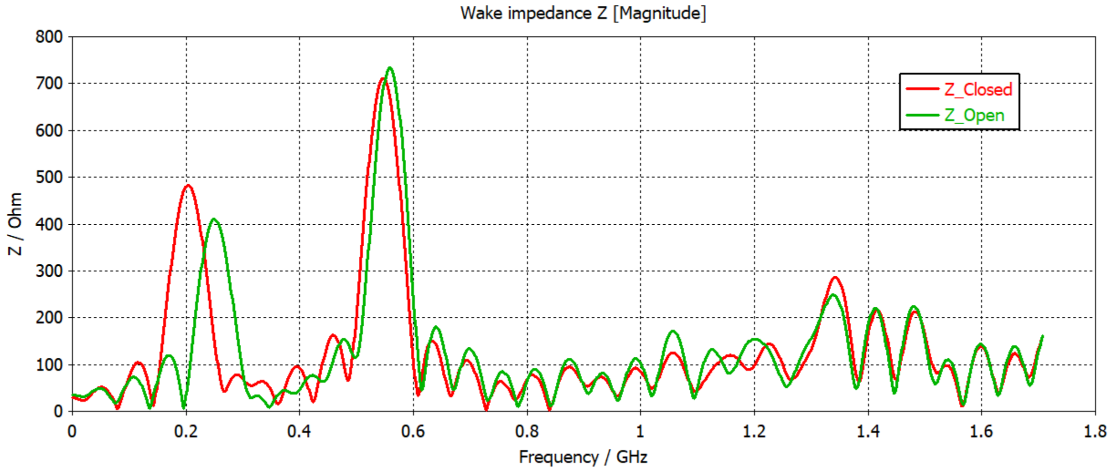
Closed Opening: No Crucial Difference

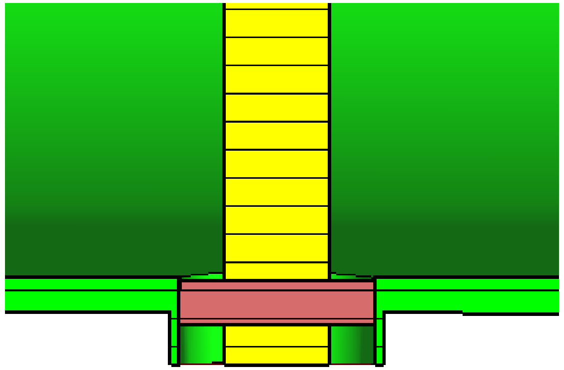
- $\sigma = 60\ mm,\ Q_b = 30.5\ nC,\ M = 290$
- No significant difference between wakefields and impedance between open and closed position with metallic target holder.





Round clearance at target holder





No round clearance, closed position

Material Properties

- $Copper = 5.8 \times 10^{7}$ S/m
- $Alumium = 3.56 \times 10^{7}$ S/m
- $Steel\ 316L = 1.351 \times 10^{6}$ S/m

Alumina (96%) (lossy)

Type	Normal
Epsilon	9.4
Electric tand	0.0004 (Const. fit)
Mu	1
Rho	3800 [kg/m^3]
Transparent for particles	no (auto)
Thermal cond.	25 [W/K/m]
Specifc heat	880 [J/K/kg]
Diffusivity	7.47608e-06 [m^2/s]
Young's modulus	300 [kN/mm^2]
Thermal expan.	7 [1e-6/K]

- Aluminum and Steel (conductivity)
- Alumina: epsilon, epsilon prime
- CST Library (conductivity at 1 GHz), omega * epsilon’’*epsilon_0 = 2pi*f, (f = 1 GHz) * epsilon’’*epsilon_0
- Epsilon_0 = 8.856*10^-12
- Investigate the size of the target holder