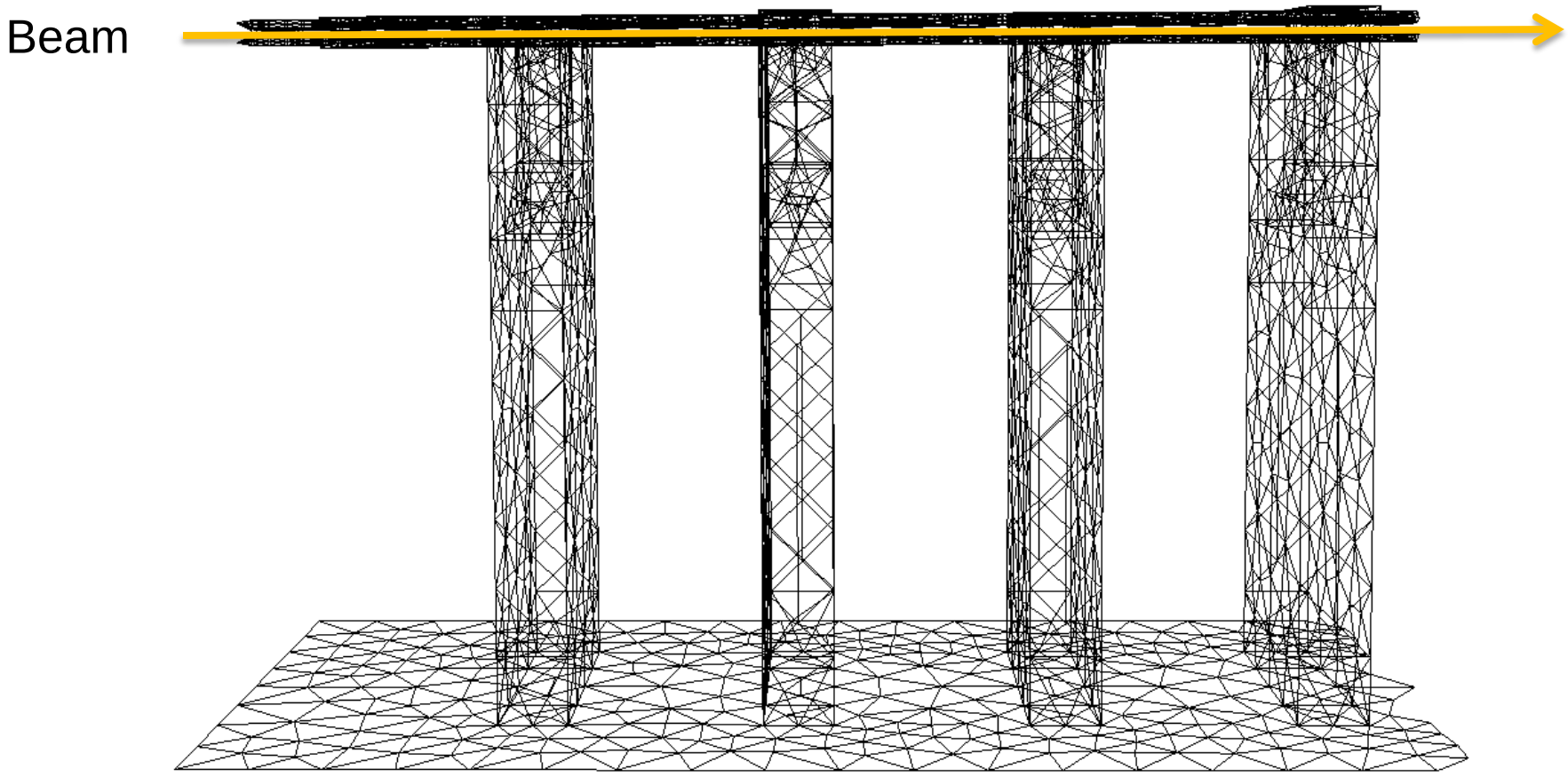
Simulation of a Radio Frequency Quadrupole with the Method of Moments

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Introduction



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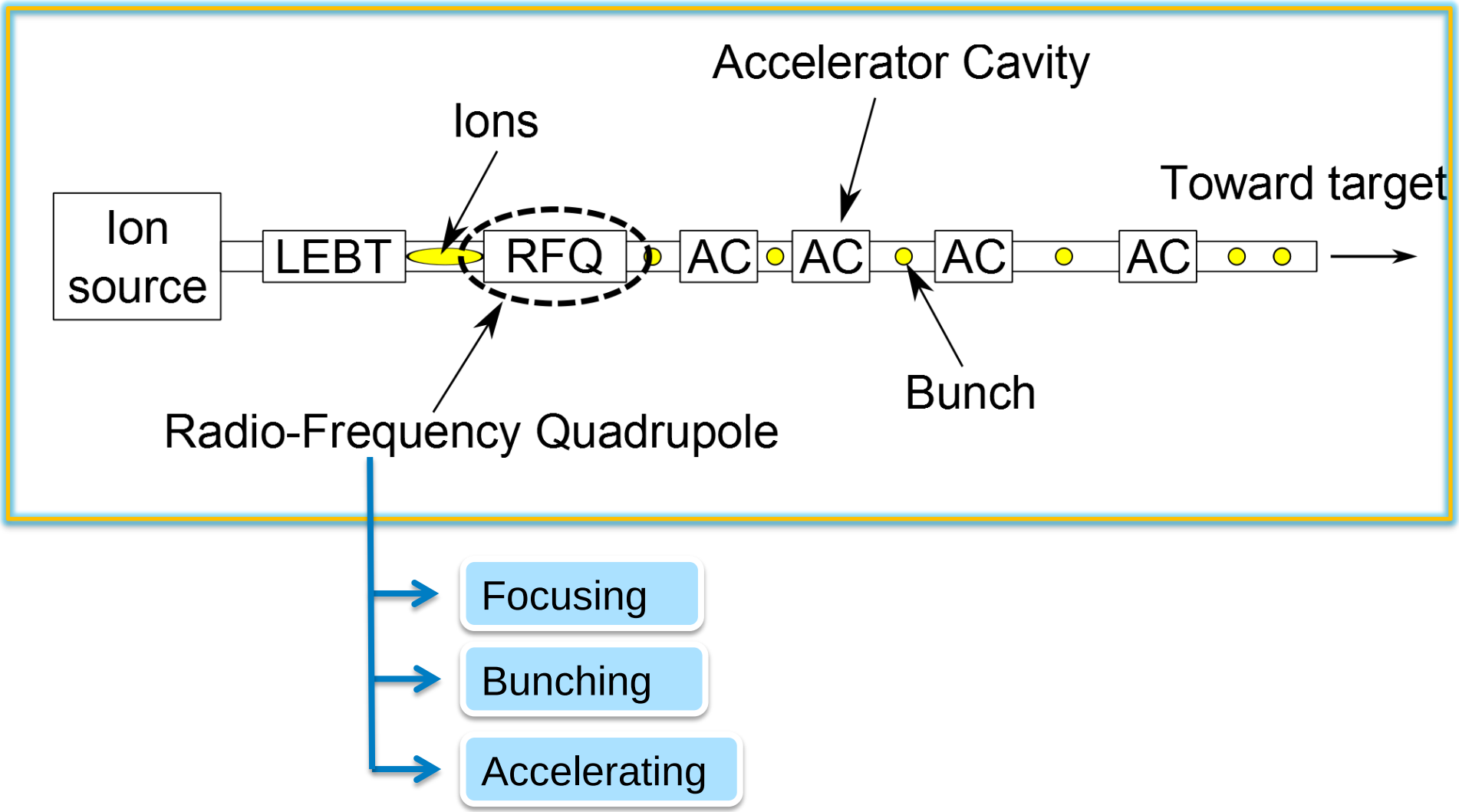
Outline

- LINAC and RFQ
  - What is a RFQ
  - Functionning of a RFQ
- EFIE applied to RFQ
  - Why the EFIE?
  - Low-frequency-breakdown
- Simulations
  - Brute force
  - Loop Tree
- Conclusion

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LINAC and RFQ

LINear ACcelerator



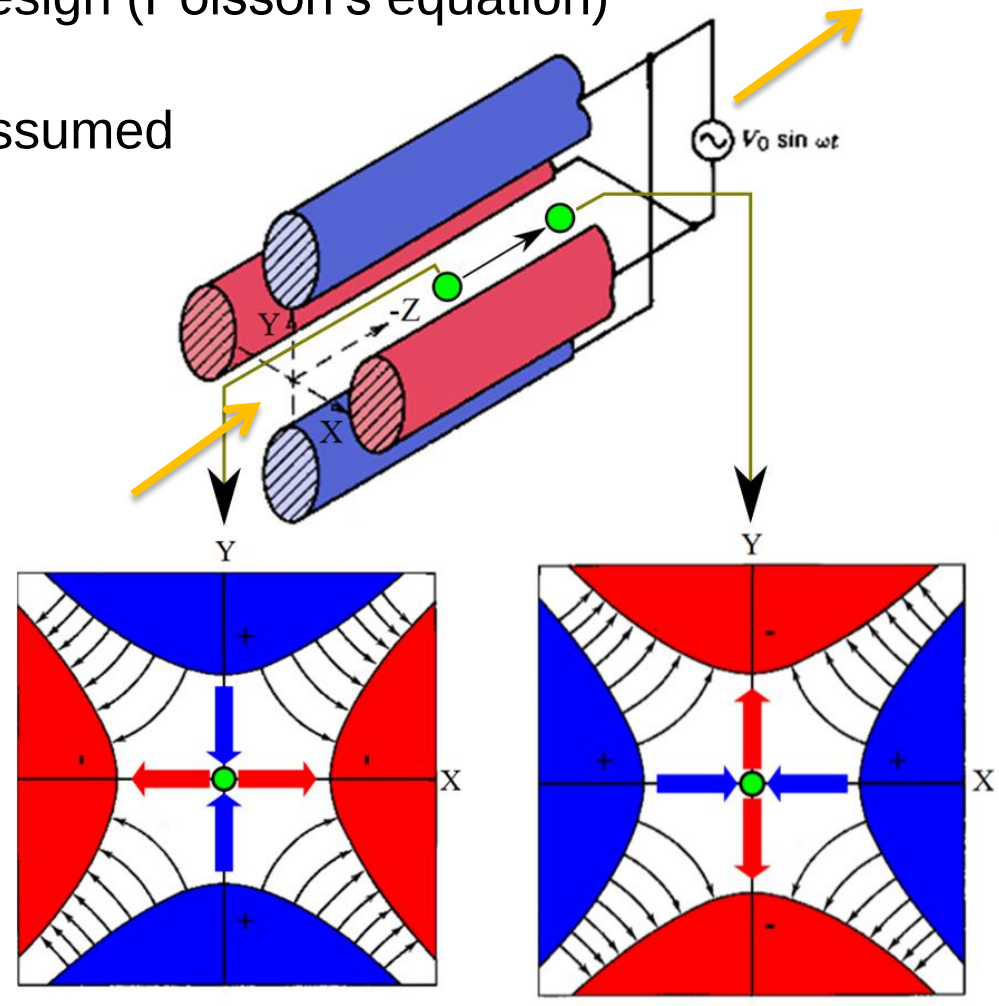
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Functioning of a RFQ - Focusing

→Quasi-static based design (Poisson's equation)

→Perfect conductors assumed

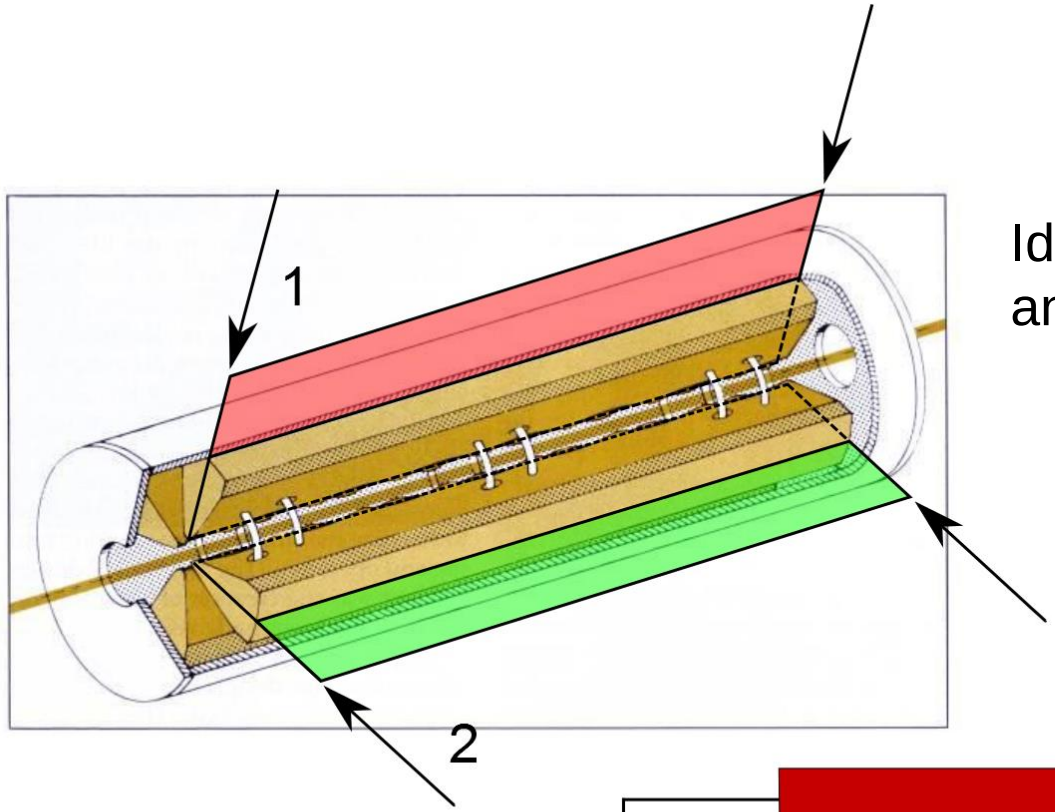
→Hill's equations



Time T_0 Time T_1

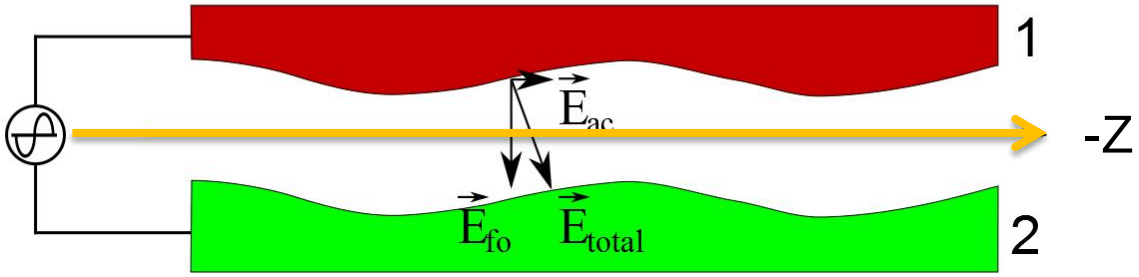
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Functioning of a RFQ – Bunching and Accelerating



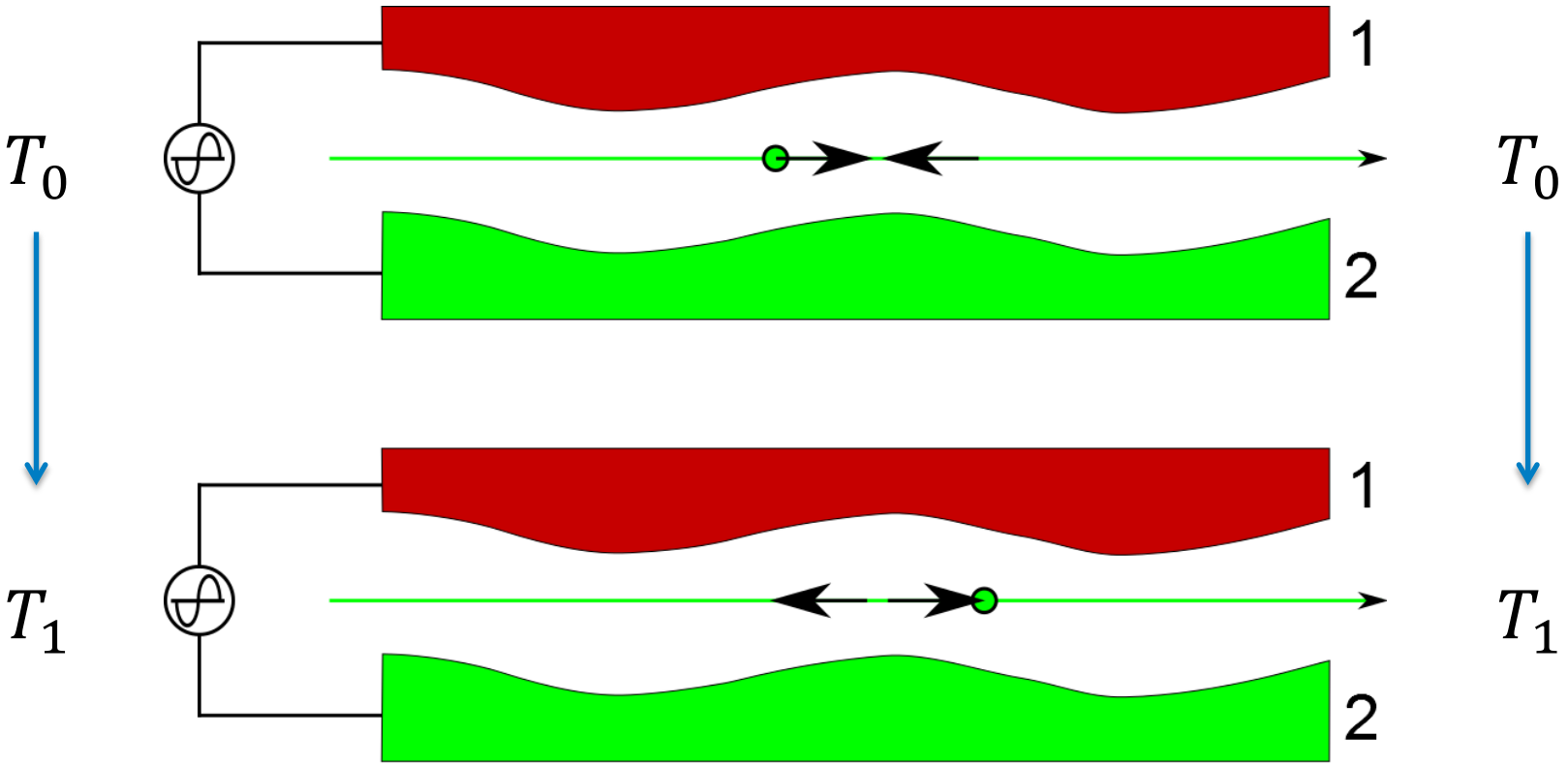
Idea: curving the electrods to create and E-field in the -Z direction

- Bunching
- Accelerating



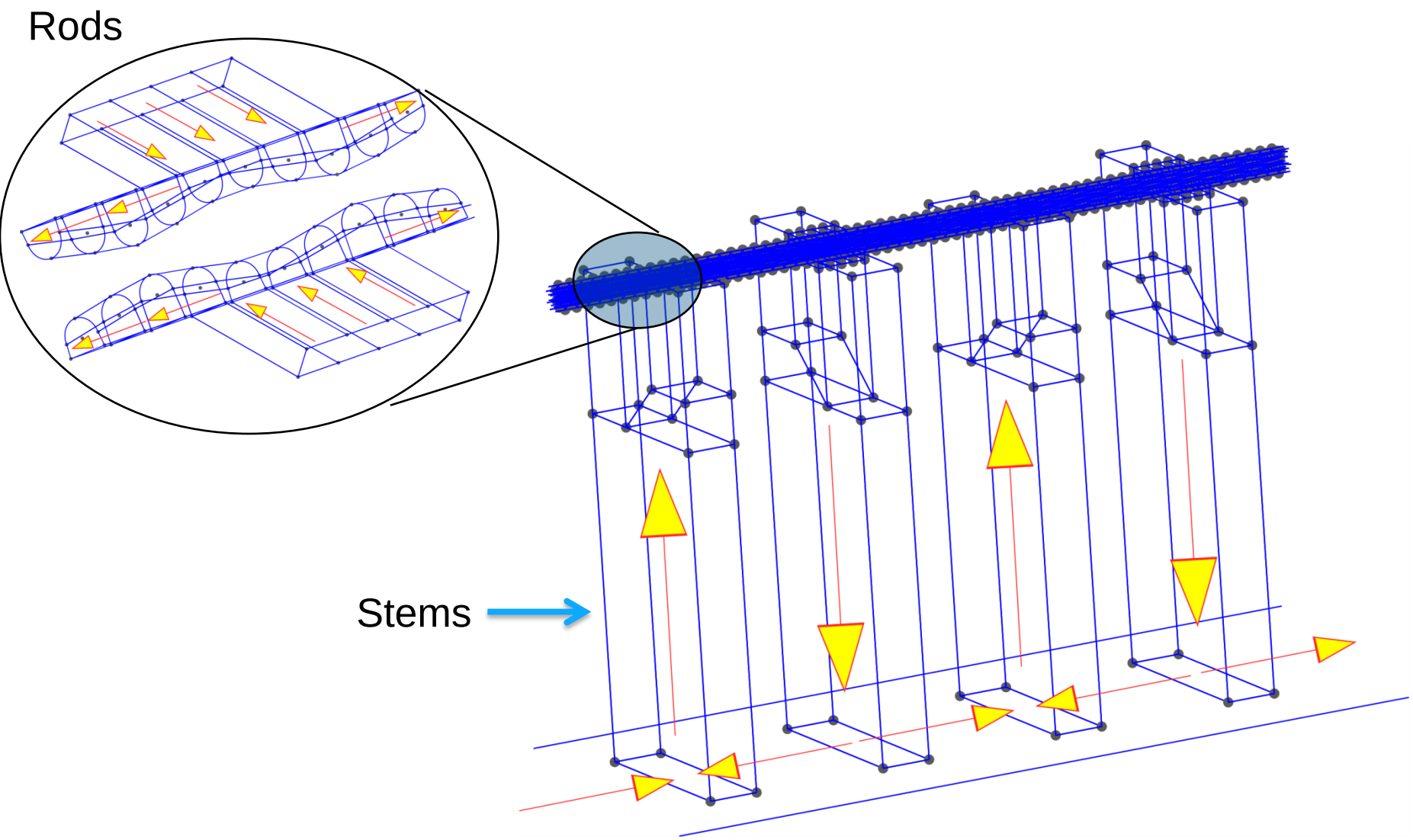
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Functioning and a RFQ - Accelerating



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Functioning of a RFQ – Stems



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Why the EFIE?

1) The E-field of a RFQ can be assumed quasi-static locally …

BUT THE WHOLE RFQ IS OF LENGTH COMPARABLE TO THE WAVELENGTH (~1.5λ)

2) The EFIE involves only unkowns on the surface of the objects

→ Smaller system of equation to solve

In summary: Improve the accuracy of the solution and decrease the computation time

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Low frequency breakdown (1)

Mesh size ~ $\frac{\lambda}{1000}$ to capture the rod's local geometry

→ Low-frequency-breakdown

$$\langle \vec{E}(\vec{f}_{b,n}) | \vec{f}_{t,m} \rangle = Z_{mn} = j\mu c \int_{S_{t,m}} \int_{S_{b,n}} \left(k(\vec{f}_{t,m} | \vec{f}_{b,n}) - \frac{1}{k} [\nabla \cdot \vec{f}_{t,m}][\nabla \cdot \vec{f}_{b,n}] \right) \frac{e^{-jkr}}{4\pi r} dS_t dS_b$$

Proportional to the frequency

Inversly proportional to the frequency

→ The divergence term becomes dominant at low frequency!

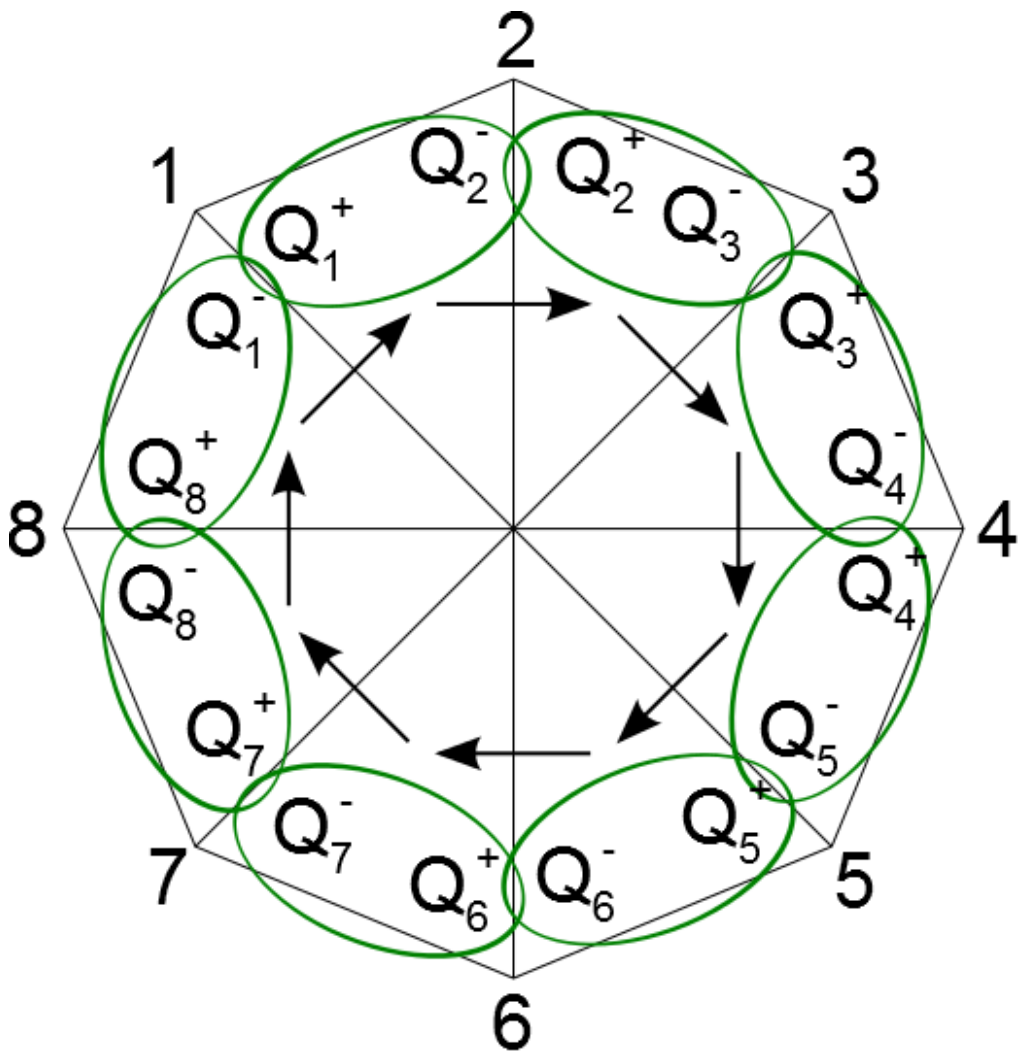
→ MoM system badly conditioned

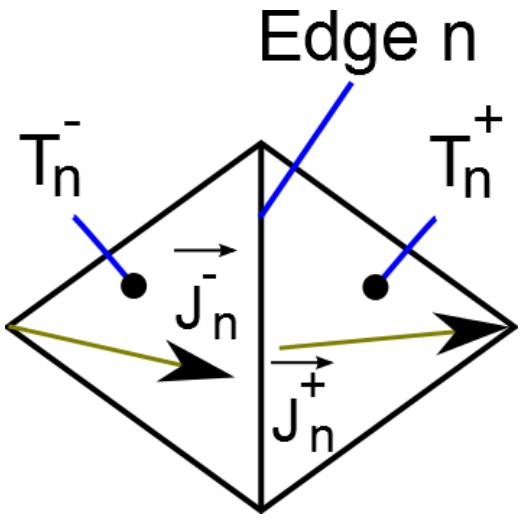
[1] Iterative-solver convergence for loop-star and loop-tree decompositions in method-of-moments solutions of the electric-field integral equation," *Antennas and Propagation, IEEE* , vol.46, no.3, pp.80,85, June 2004

[2] Andriulli, F.P., "Loop-Star and Loop-Tree Decompositions: Analysis and Efficient Algorithms," *Antennas and Propagation, IEEE Transactions on* , vol.60, no.5, pp.2347,2356, May 2012

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Low frequency breakdown (5)





$$Q_n{}^- \equiv \nabla \cdot \vec{J}_n{}^- = \frac{L}{A}$$

$$Q_n{}^+ \equiv \nabla \cdot \vec{J}_n{}^+ = -\frac{L}{A}$$

$$\vec{J} = \sum_{n=1}^{8} \vec{J}_n$$

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Low frequency breakdown (6)

Proportional to k

$$\langle \vec{E}(\vec{J}) | \vec{f}_{t,m} \rangle = j\mu c \int_{S_{t,m}} \int_{S_{b,n}} \left(k(\vec{f}_{t,m} | \vec{J}) - \frac{1}{k} [\nabla \cdot \vec{f}_{t,m}] \underbrace{\sum_{n=1}^{8} \left[\frac{L_n \delta_n^{-}}{A_n^{-}} - \frac{L_n \delta_n^{+}}{A_n^{+}} \right]}_{=0} \right) G \, dS_t dS_b$$

with $\delta_n^{\pm} \equiv \begin{cases} 1 & \vec{r} \in T_n^{\pm} \\ 0 & \vec{r} \notin T_n^{\pm} \end{cases}$ $G \equiv \frac{e^{jkr}}{r}$

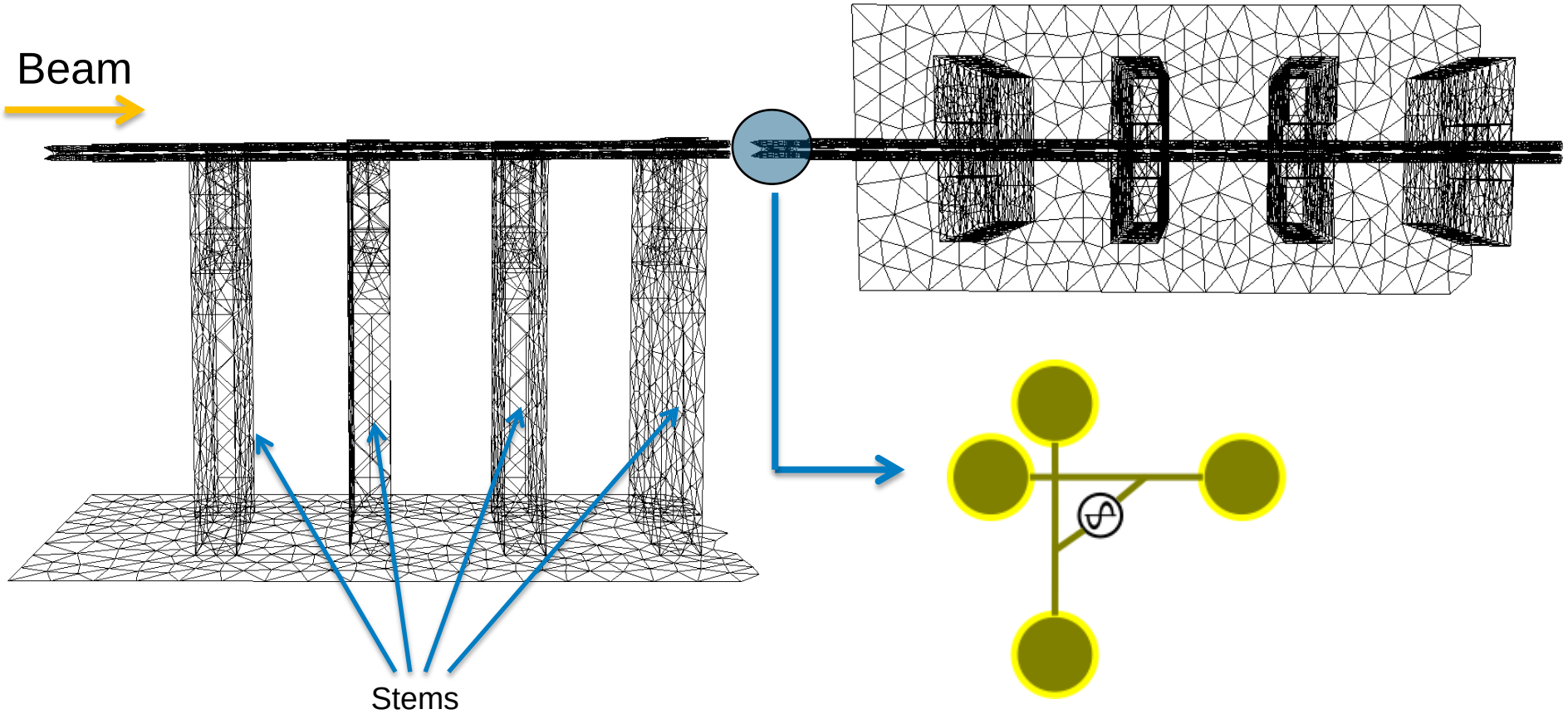
Loop-Tree method

- Generate Loop basis functions
- Remove a RWG per loop
- Rescale the MoM system of equations

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Simulations – Mesh and feeding

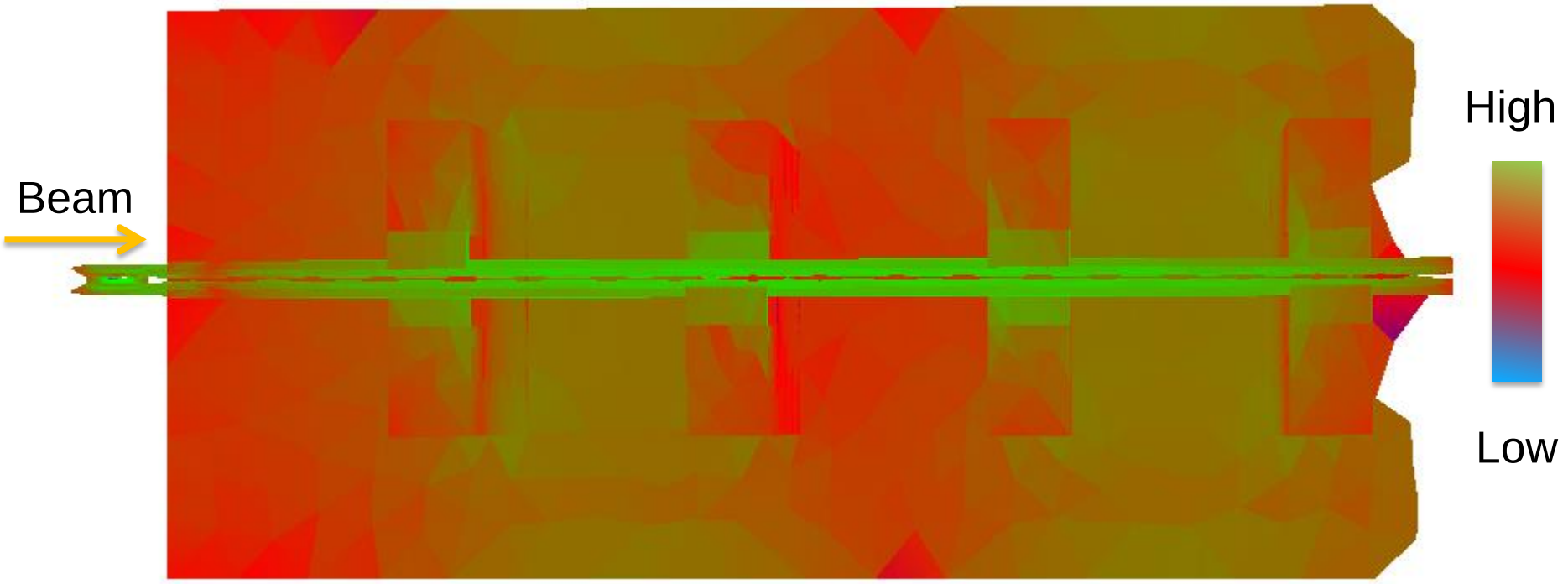
Frequency = 176 MHz



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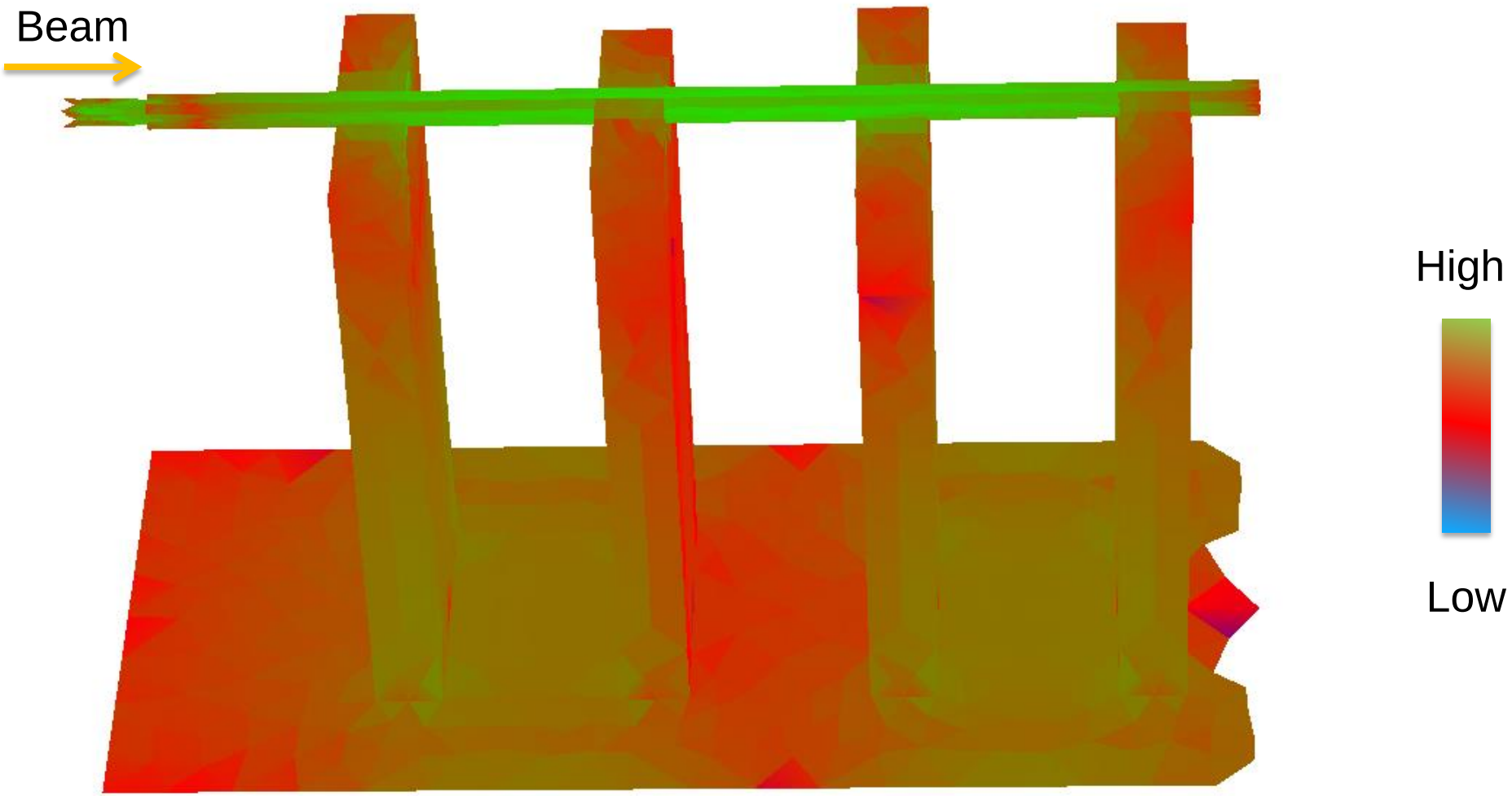
Simulations – Brute force – Currents

Cond = 1.2011e+06



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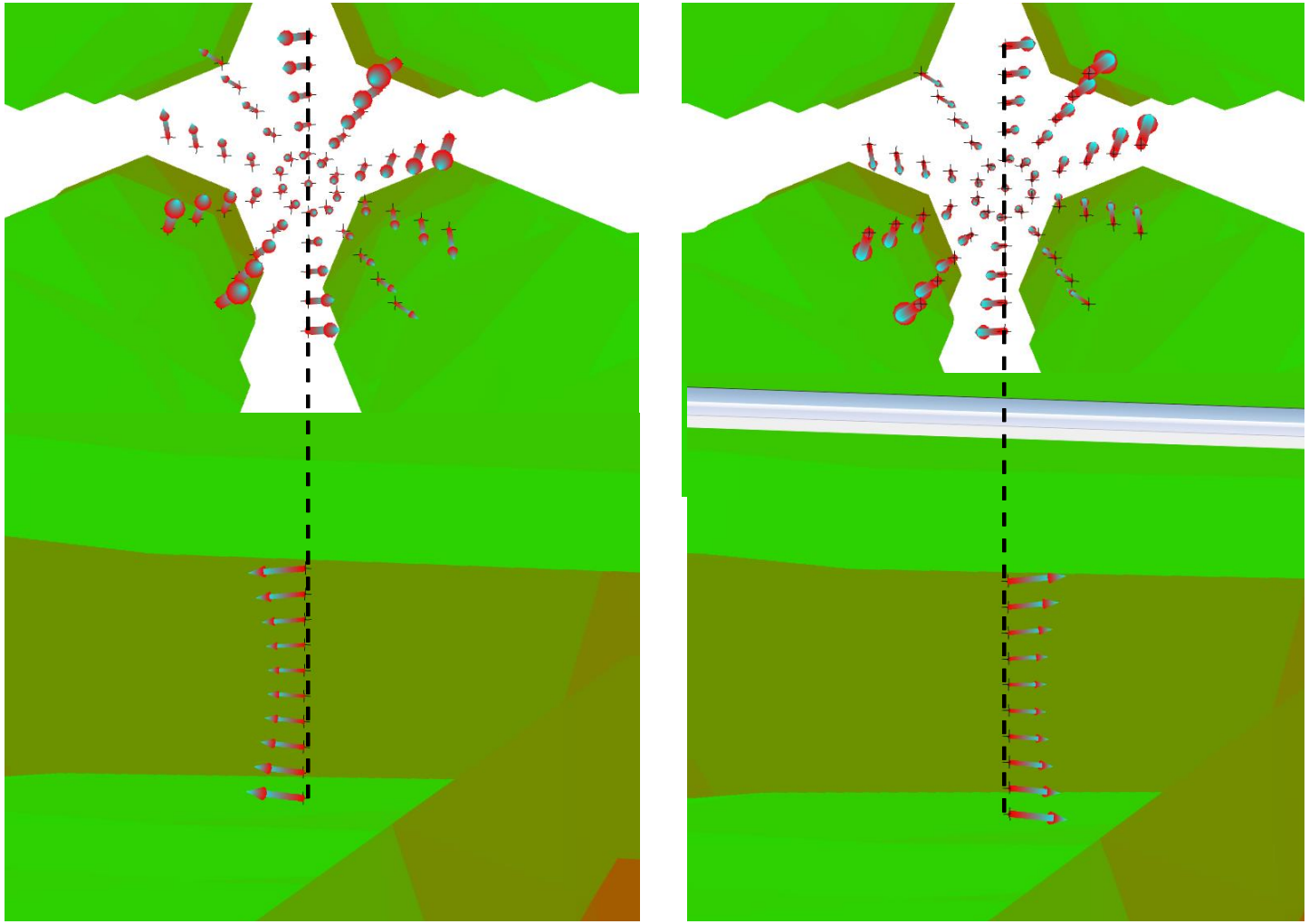
Simulations – Brute force - Currents



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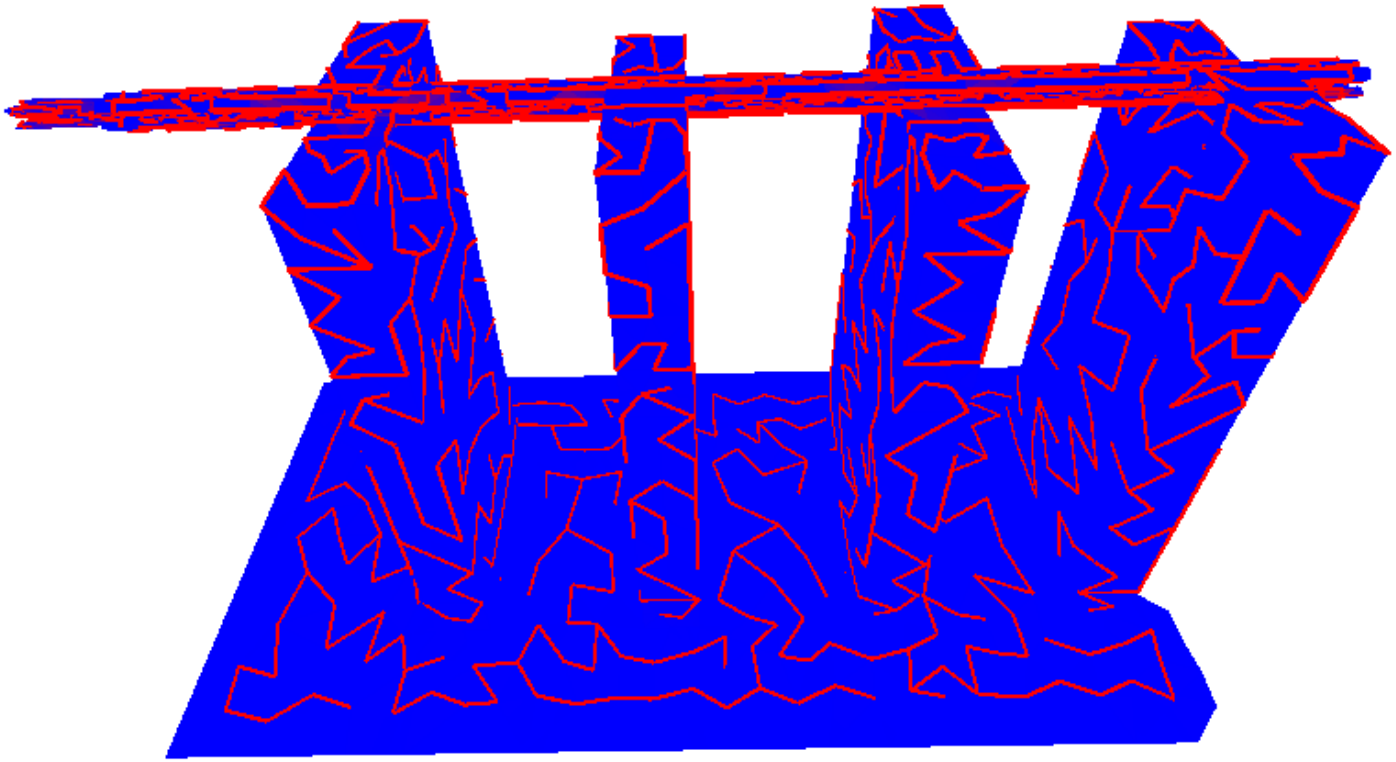
Simulations – Brute force – E-Fields

$\phi = 0$ → $\phi = \pi$



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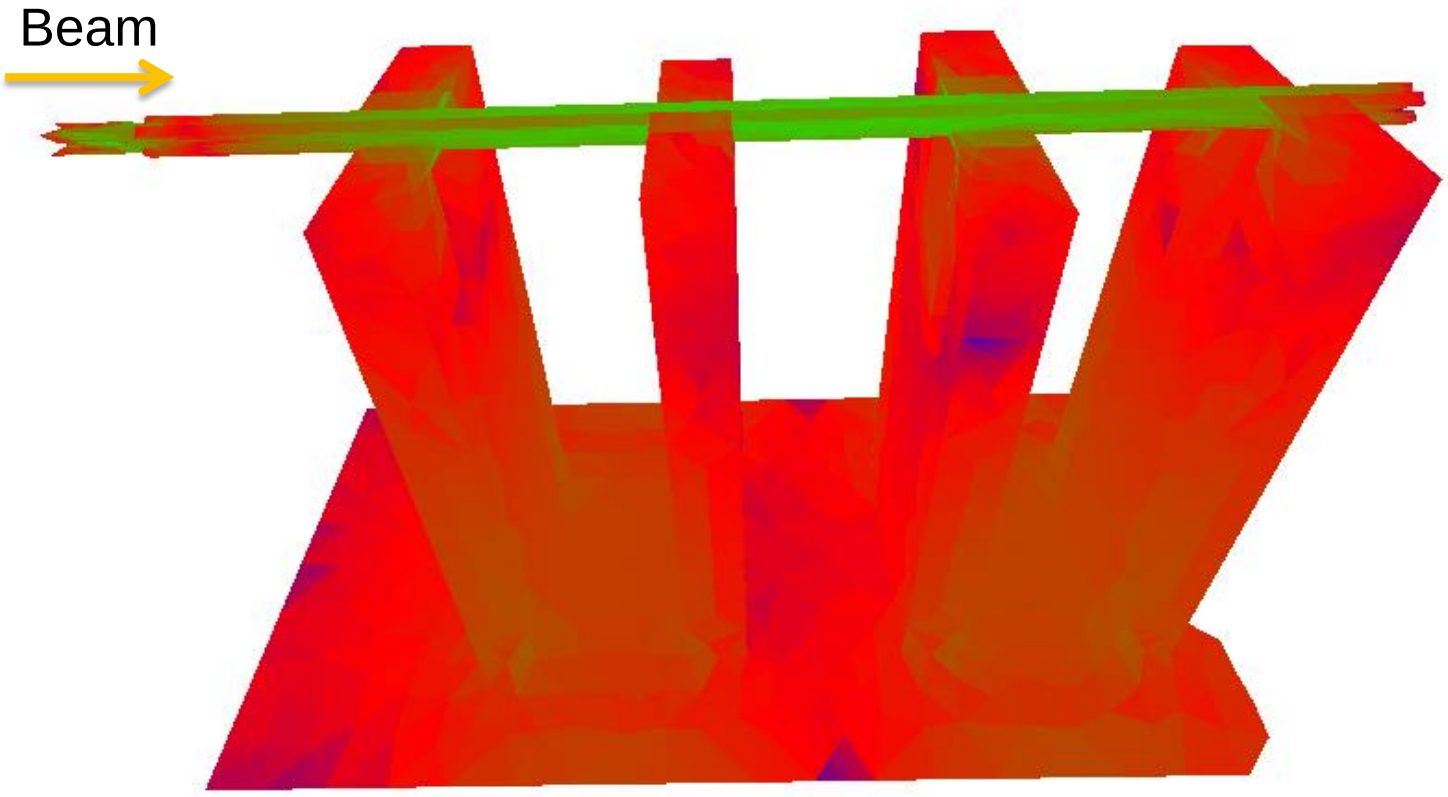
Simulations – Loop-Tree – Tree



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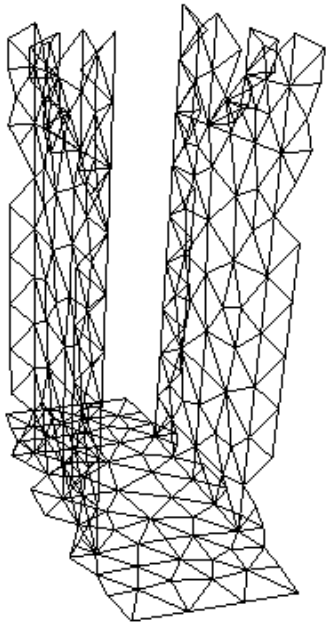
Simulations – Loop-Tree – E-Fields

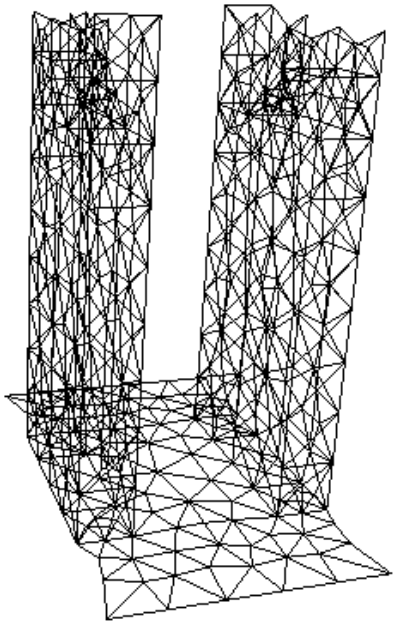
Cond = 1.0114e+10



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Simulations – Loop-Tree – Investigation

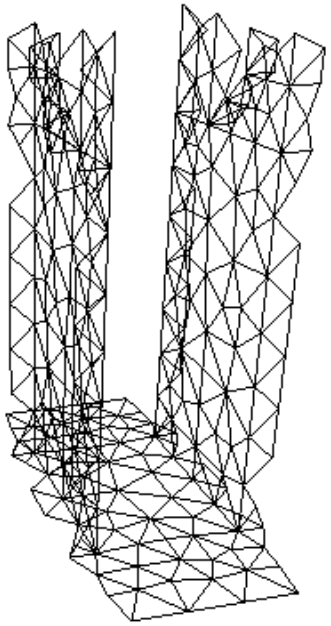


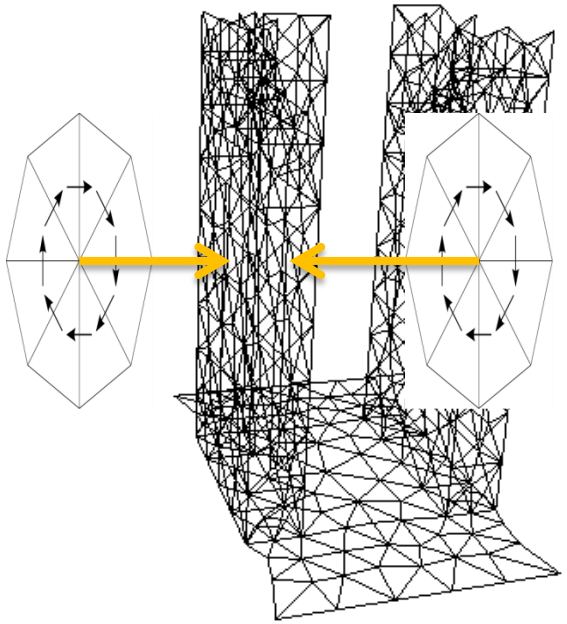


Frequency/method	Brute-force		Loop-Tree	
	open	close	open	close
176 MHz	2.4155e+003	4.0045e+003	4.3074e+004	1.8021e+005
10 MHZ	2.2876e+006	1.2432e+006	7.5002e+005	3.4598e+006

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Simulations – Loop-Tree – Investigation





Frequency/method	Brute-force		Loop-Tree	
	open	close	open	close
176 MHz	2.4155e+003	4.0045e+003	4.3074e+004	1.8021e+005
10 MHZ	2.2876e+006	1.2432e+006	7.5002e+005	3.4598e+006

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Simulations – Loop-Tree – Investigation

- Good results with EFIE
  - The conditioning number acceptable
  - Field shape consistent
  - Slow convergence of GMRES
- The Loop-Tree used method suffer from mesh irregularities, thin rods and thin stems
  - A CFIE is forseen to eliminate the thin element issue
  - A local loop-tree method will be used only for the very fine part of the mesh
- In order to improve the computation time, MBF are currently been implemented.

[3] Xu, Z.; Wang, Z.S.; Chen, X.Z.; Du, J.L.; Tong, M.S., "Efficient Nyström solutions for electromagnetic scattering by thin conducting structures," *Antennas and Propagation, 2013 IEEE* , vol., no., pp.1536,1537, 7-13 July 2013
[4] Gilles, T.E.; Craeye, C.; Piette, M., "E-MFIE Formulation for Arbitrary PEC Sheets," *Antennas and Propagation, IEEE Transactions on* , vol.60, no.8, pp.3744,3753, Aug. 2012

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