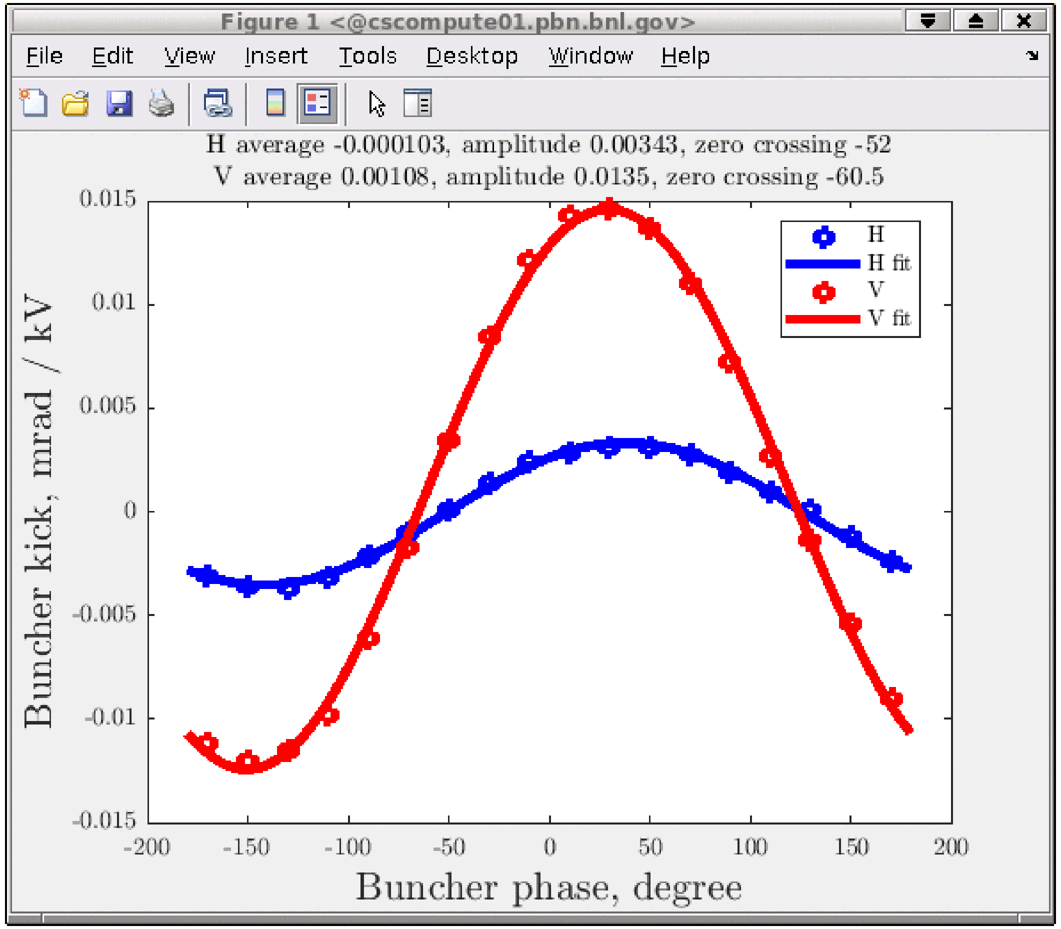
Kicker for
Buncher transverse Kick Compensation

VL, June 11, 2022

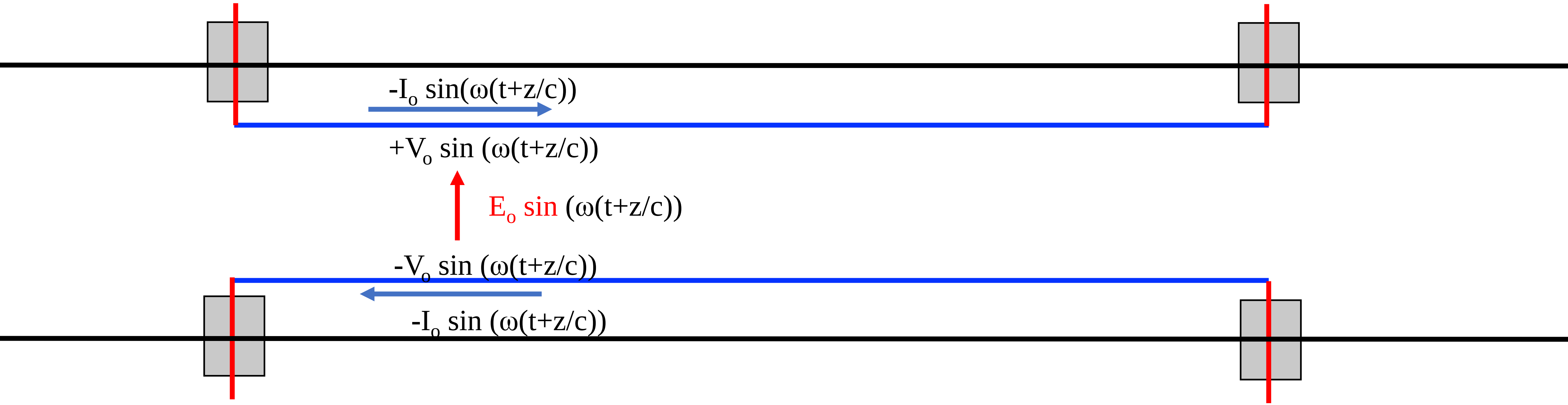
Measurements

- Measurements show 13.5 µrad/kV vertical and 3.43 µrad/kV horizontal kicks for 350 psec bunch
- For 350 nsec and 500 MHz we have Φ=0.95 and 14.2 µrad/kV vertically and 3.5 µrad/kV horizontally
- Requirements: We need to compensate the kick for nominal 180 kV, but it is good to have margin to about 200 KV. It means that we need to 2.85 mrad vertically and 0.72 mrad horizontally
- In our case for 1.25 kinetic energy, pc=1.685 MeV and vertical kicker requires transverse kick of 4.8 keV/c.

$$q(j) = q_o \cdot \sin j \cdot F(WT); F(WT) = \frac{\sin\left(\frac{WT}{2}\right)}{\left(\frac{WT}{2}\right)}$$



λ/4 strip-line



Kick from a quarter-wavelength strip-line kicker

E-M wave has to propagate towards electron beam:

$$E = E_o \cos \omega\left(t + \frac{z}{c}\right); \ \omega = 2\pi \frac{c}{\lambda}, \qquad (2)$$

and with electron position advancing as

$$z = \mathrm{v}t \equiv \beta c t \qquad (3)$$

the EM field kicks the electron with the force of

$$\frac{dp_\perp}{dt} = -e\left(E + \beta H\right) = -eE_o\left(1+\beta\right)\cos\left(\omega t\left(1+\beta\right)\right)$$

$$\Delta p_\perp = -eE_o \int_{-\frac{\pi}{2\omega(1+\beta)}}^{\frac{\pi}{2\omega(1+\beta)}} \cos\left(\omega t\left(1+\beta\right)\right)\left(1+\beta\right)dt = -\frac{eE_o}{\omega}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} d\varphi \ \cos\varphi = -\frac{2eE_o}{\omega}; \qquad (4)$$

$$\theta = \frac{\Delta p_\perp}{p} = \frac{2eE_o}{pc} = \frac{eE_o}{pc}\cdot\frac{\lambda}{\pi} \Rightarrow E_o = \frac{\pi\theta}{\lambda}\cdot\frac{pc}{e} \qquad (5)$$

To get to 2.85 mrad kick with λ=0.6 m for 500 MHz, we will need amplitude of electric field to be 25 kV/m. To estimate power requirements for the kicker, we need ratio between voltages applied to opposite plates and electric filed on the axis:

$$a = \frac{V_o}{E_o}; \ V_o = \theta \cdot \frac{\pi a}{\lambda} \cdot \frac{pc}{e}$$

$$V_o[kV] = 5.3 \cdot \frac{a}{\lambda} \cdot \theta[mrad] \qquad (6)$$

and for vertical kicker with 2.85 mrad we have requirement of

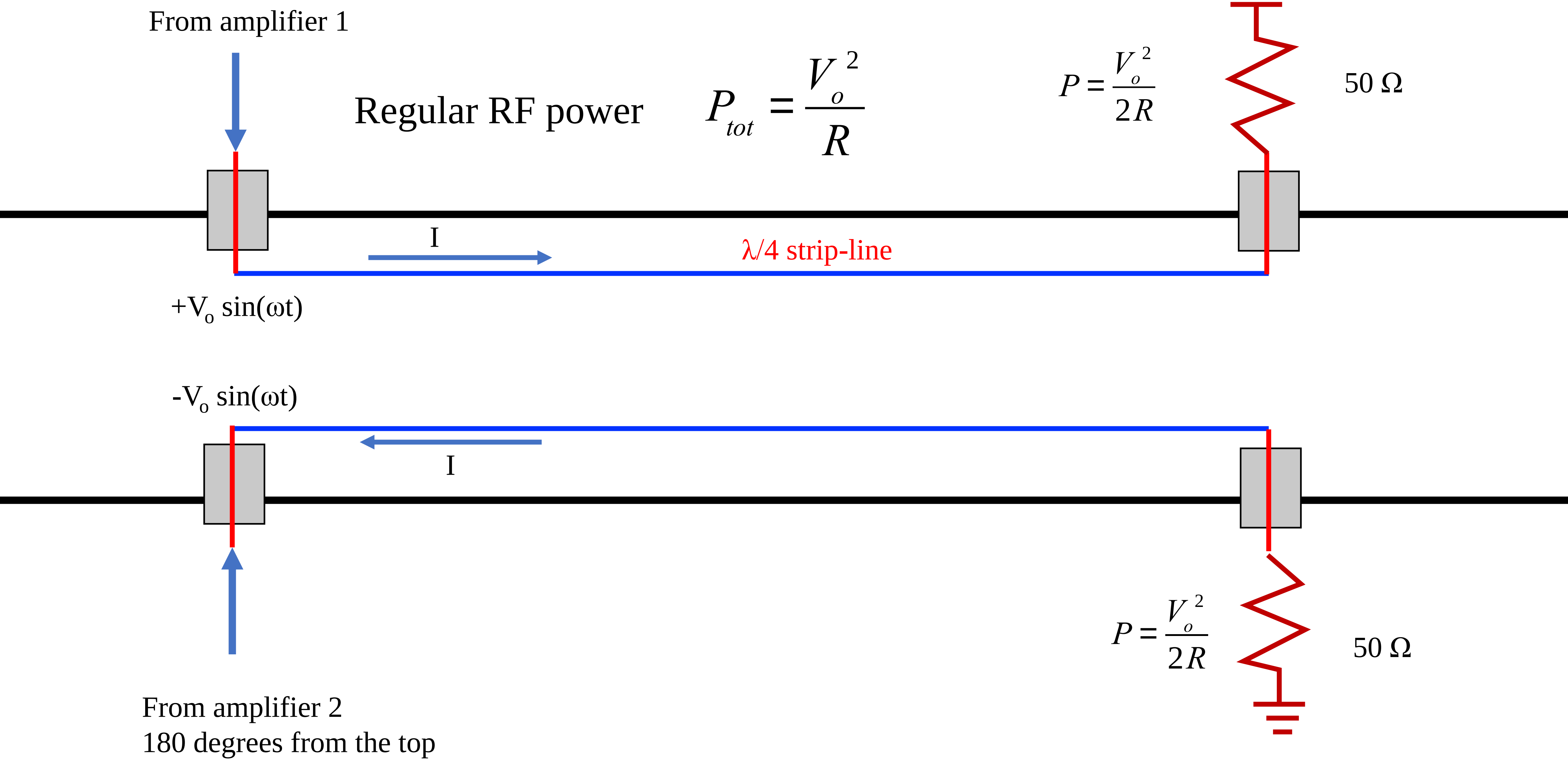
$$V_o = 15.1[kV] \cdot \frac{a}{\lambda} = 25.2[kV] \cdot a[m] \qquad (7)$$

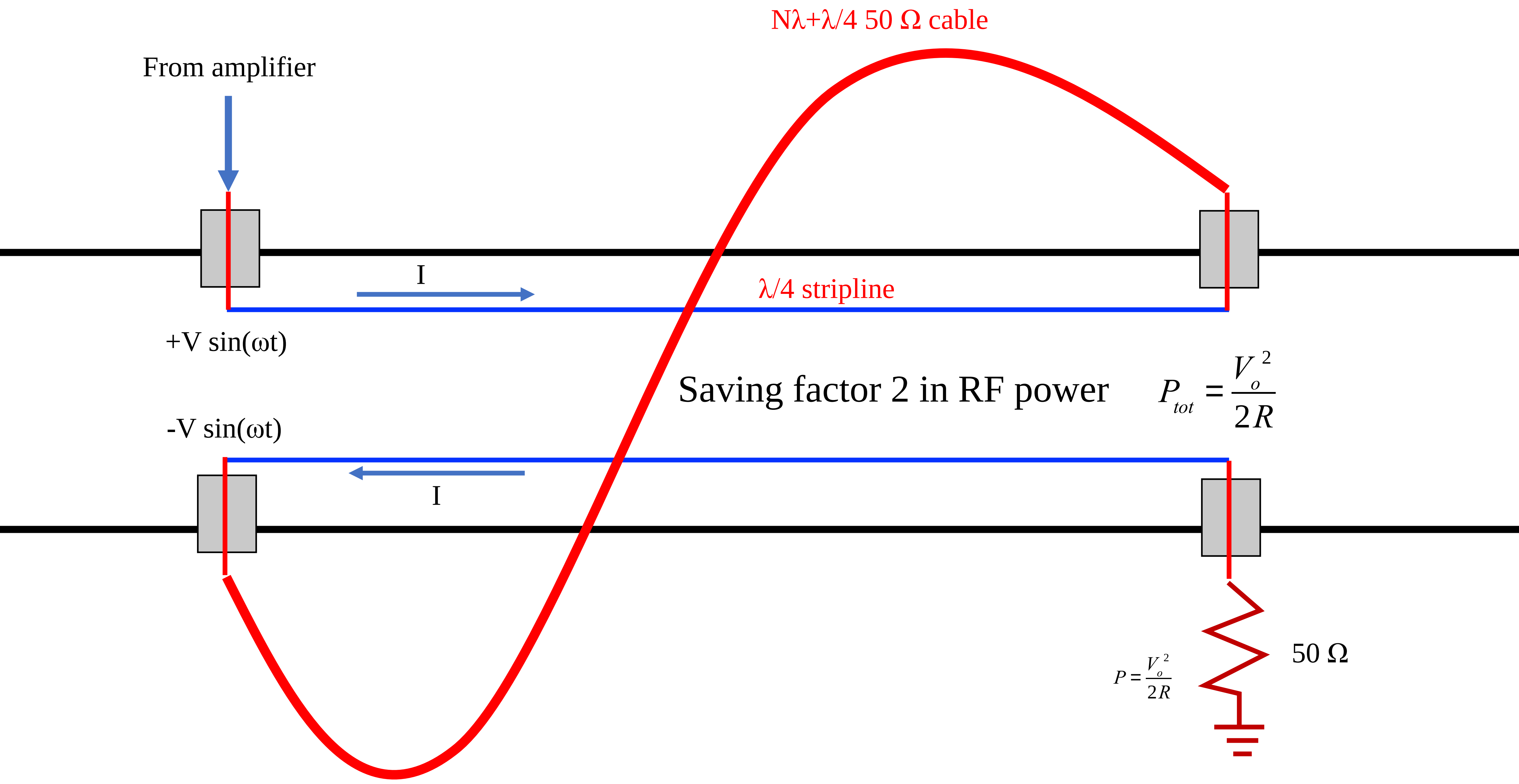
Hence, we just need to get value for effective half gap *a*.

[1] In vacuum strip-line electric and magnetic field are perpendicular to each other and equal in amplitudes, $E_o = H_o$. I am using Gaussian units.

Regular configuration: individual feed

Regular RF power $P_{tot} = \frac{V_o^2}{R}$



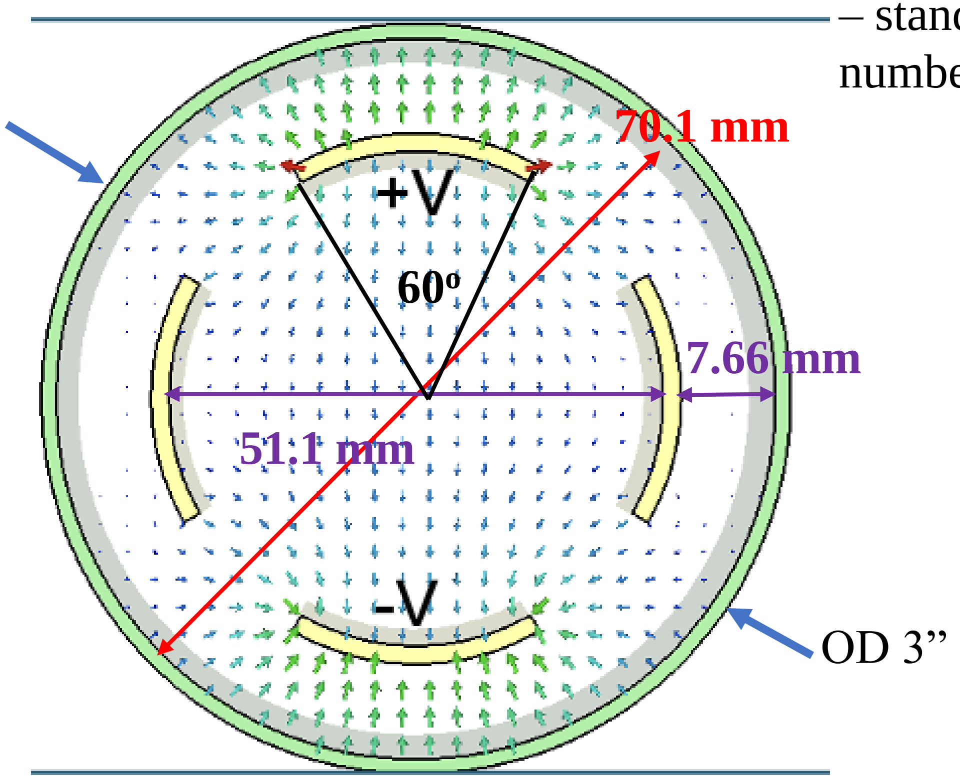

Nλ+λ/4 50 Ω cable
From amplifier
I
λ/4 stripline
+V sin(ωt)
Saving factor 2 in RF power
$P_{tot} = \frac{V_o^2}{2R}$
-V sin(ωt)
I
50 Ω
$P = \frac{V_o^2}{2R}$

Scaling from NSLS II 4-stipline design:

STRIPLINE KICKER DESIGN FOR NSLS2 STORAGE RING, W. Cheng, A. Blednykh, S. Krinsky, O. Singh, Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA, p. 603

	NSLS II	CeC	
Length	15	15	cm
R (inner chamber radius)	38	35.05	mm
d (plate to chamber)	8.3	7.66	mm
t (plate thiknes)	2	1.84	mm
b	27.7	25.55	mm
Stipline size	29.0	26.8	mm
θ, degrees (plate)	60	60	degrees
Number of electrodes	4	4	
Z, dipole mode	50.2	50.2	Ohm

Vacuum pipe OD 3", ID 2.76" – standard size number from Cliff



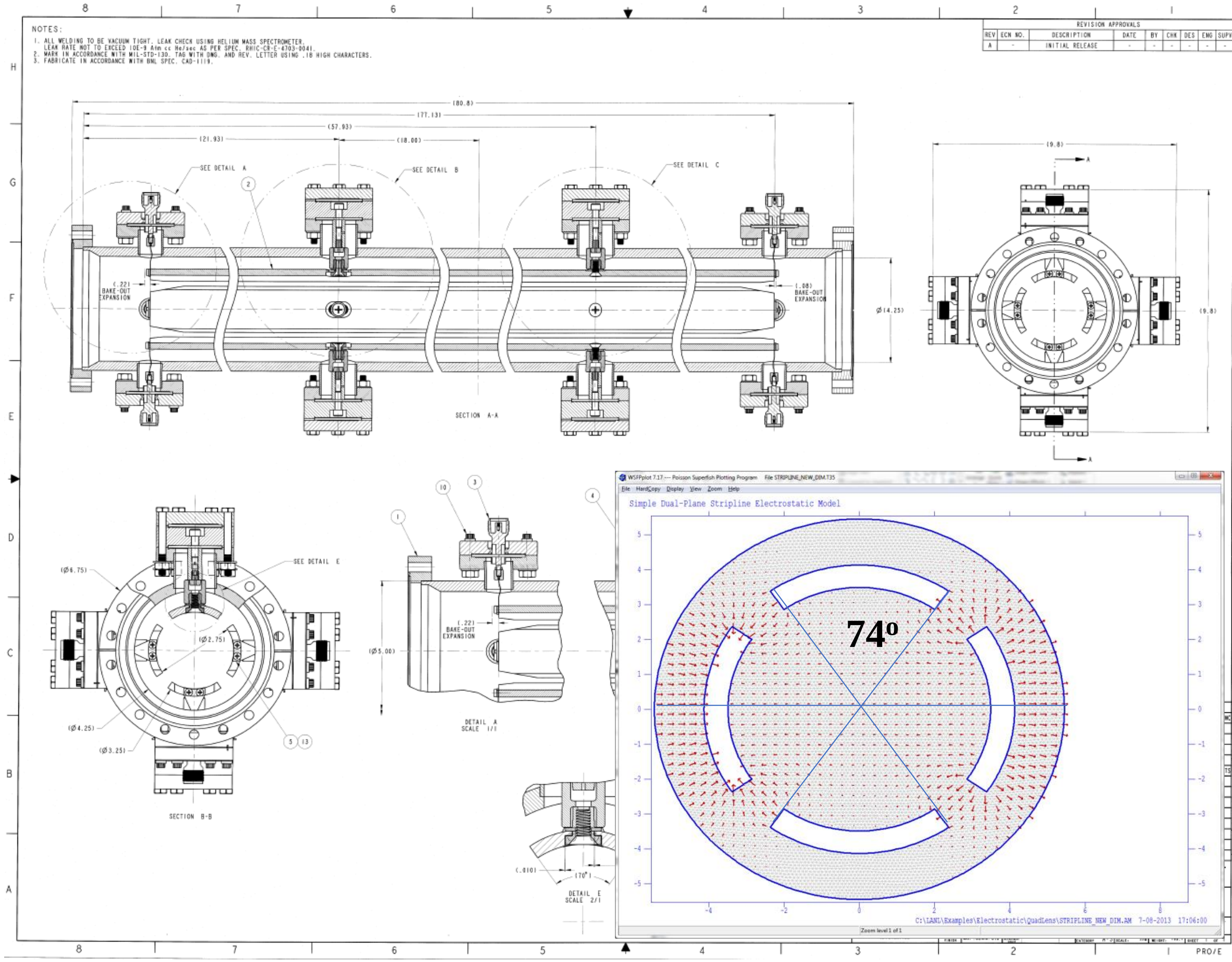
By today, the only calculations were done using Igor Pinayev using "MATLAB script for solving 2D electrostatic problem with Green function" : ±1V applied to strip-lines will create 31.8 V/m electric field on axis: a=0.032 m
Required voltage is 0.8 kV, required power for vertical kicker is 8.3 kW in optimum configuration

RHIC Kicker strip-lines

- Provided by Kevin Mernick
- Dual-plane 2 meter striplines
- Use 2 back-to-back to get more kick
- 2.75” clear aperture
- ~25 V/m electric field at center for +/- 1 V drive

- Scaling to 2” for CeC with length of 15 cm
- ~27.5 V/m electric field at center for +/- 1 V drive
- Effective aperture a~0.036 m
- Voltage required for vertical kicker is ~0.92 kV
- Required power is ~8.4 kW

- **Need to confirm estimate of ~25 V/m**



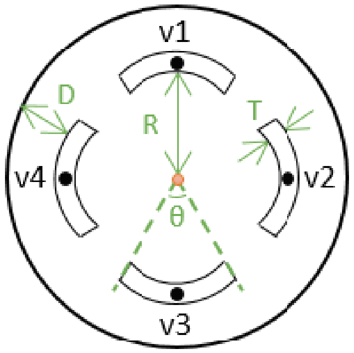
What is needed

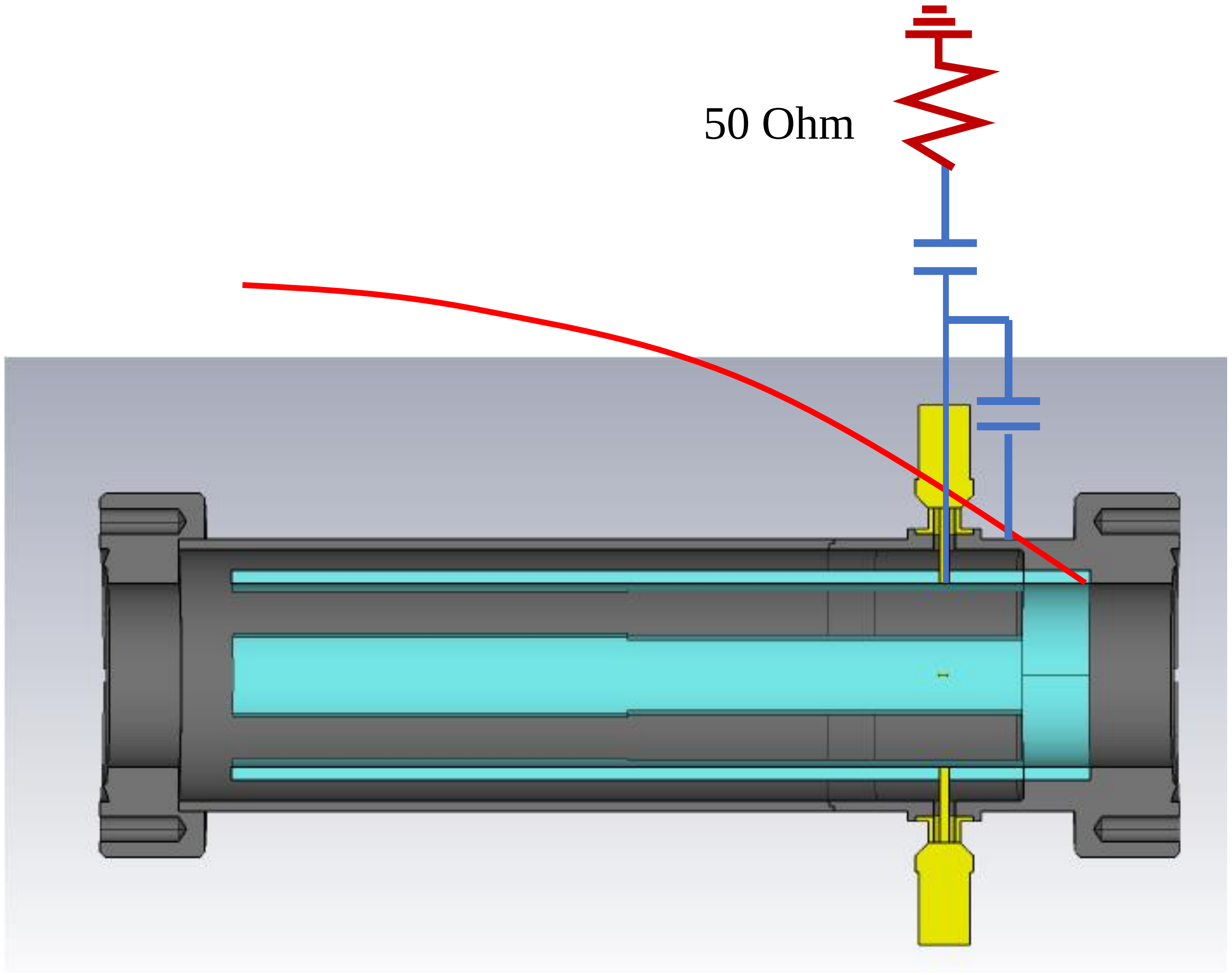
- In 2D geometry calculate vertical electric field on the axis with voltage ±V on vertical plates and grounded horizontal plates
- My guess, Super fish can do it…
- By today, the only calculations were done using Igor Pinayev using "MATLAB script for solving 2D electrostatic problem with Green function" – for NSLS II type design, ±1V applied to strip-lines will create 15.9 V/m electric field on axis
- For required 25 kV/m, we will need ±0. 8 kV, which would require 8.3 kW of the RF propagating along each of 50 Ohm strip-lines. It is clearly a problem, even with feeding strip-lines in series. With cable losses, it is probably will result ~ 10 kW transmitter.
- Even with RHIC-type kicker, power requires is ~ 10 kW
- **Bottom line: we need another solution**

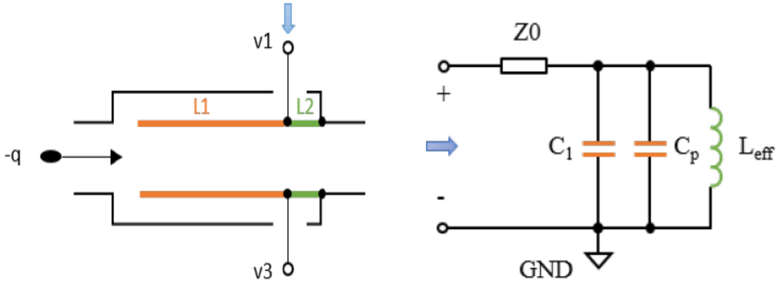
Resonant kicker: standing wave

$$Z_{in}1 = -jZ\cot(\beta \cdot L1) = -j\frac{1}{\omega \cdot C_1}$$

$$Z_{in}2 = jZ\tan(\beta \cdot L2) = j\omega \cdot L_{eff}$$







(a) Basic model. (b) Equivalent circuit.

Considering the parasitic capacitor C_p at the longitudinal gap (denoted as gap_z below) between the stripline and the vacuum pipe, the equivalent circuit can be simplified as the parallel LC circuit of Fig. 2b, where the total equivalent capacitance is $C_{eff} = C_1 + C_p$. In this circuit, Z0 is the characteristic impedance of feedthrough (50 Ω) and the inner losses along the transmission line are ignored. Accordingly, the resonant frequency f_0 and the external quality factor Q_e follows Eq. (2):

$$f_0 = \frac{1}{2\pi\sqrt{L_{eff} \cdot (C_1 + C_p)}} \qquad Q_e = Z0\sqrt{\frac{(C_1 + C_p)}{L_{eff}}} \tag{2}$$

$$C_p \propto \frac{\theta \cdot T}{gap_z}$$

$$C_1 \propto \frac{L1}{Z}$$

$$L_{eff} \propto Z \cdot L2$$

While there is equivalent circuit and approximate methods of calculating resonant frequency and load/feed 50 Ohm cable connection, proper simulation using CST are needed to optimize the performance.