Beam loading compensation on capture linac of e-driven positron source

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# International Linear Collider(ILC)

- Center of mass energy is 250GeV~1TeV.

- Electron-positron linear collider.

- Detailed research on the Higgs boson and discovery of new particles are expected.

- Kitakami mountain (Iwate, Japan) is one candidate for ILC.

- By incident an electron beam on a metal target, positrons are generated by bremsstrahlung and pair creation. (e-driven method)

- Not only positron but also electron are produced.

Schematic view of ILC

Kitakami mountain

1000km
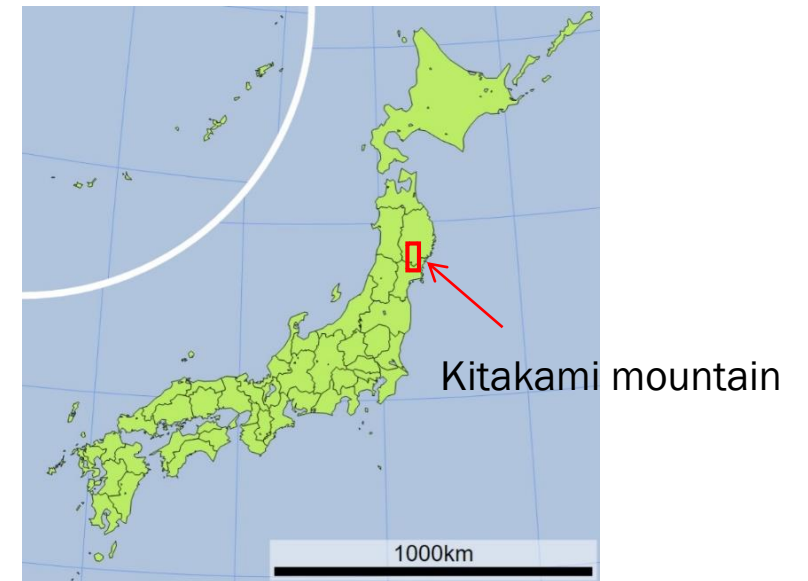
Constitution of e-driven positron source
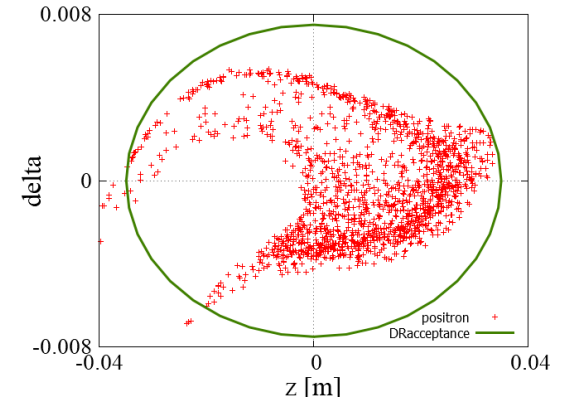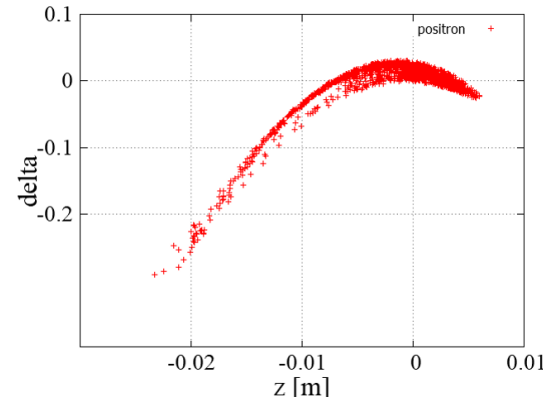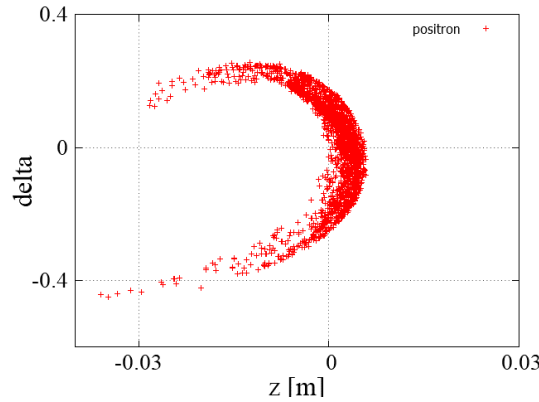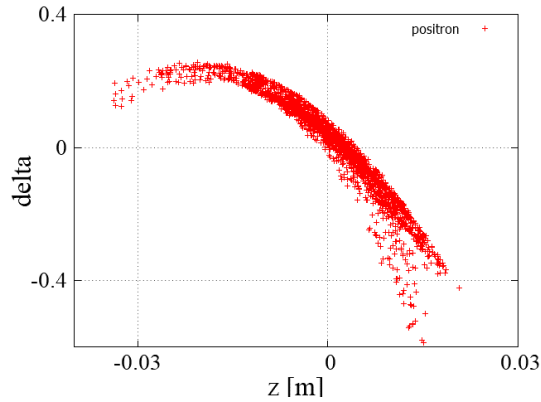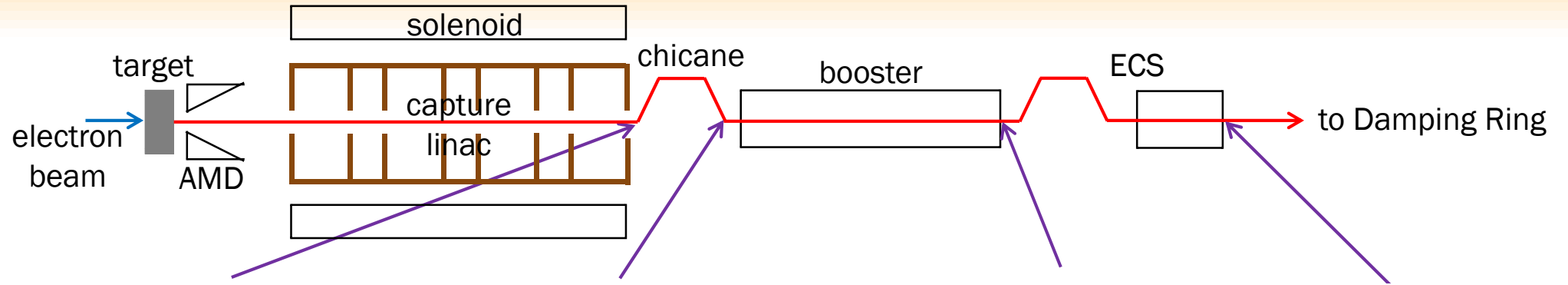
$$z = s - s_{ave}$$

$$\delta = \frac{\gamma - \gamma_{ave}}{\gamma_{ave}}$$

Positron capture late η

$$\eta = \frac{The\ number\ of\ captured\ positron}{The\ number\ of\ incident\ electron} = 1.17$$

Below the target destruction limit

Conditions for captured positrons

$$\left(\frac{z}{0.035}\right)^2 + \left(\frac{\delta}{0.0075}\right)^2 < 1$$

$$\gamma A_x + \gamma A_y < 0.07$$

Positron beam

- The ILC's positron beam has a multi-bunch structure with 33 bunches for 1 train and 2 trains for 1 pulse.

- Bunch interval is 6.15nsec, train interval is 80nsec.

- Since electrons are generated in addition to positrons, the beam loading current cannot be ignored.
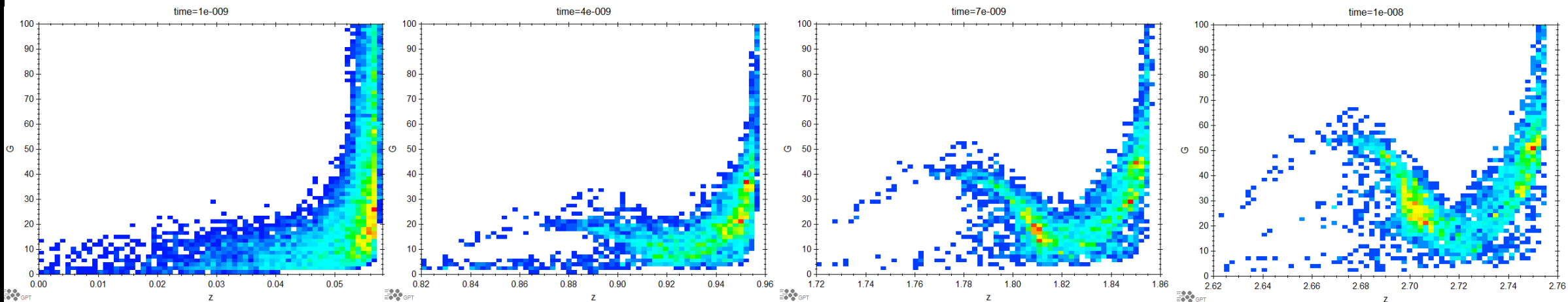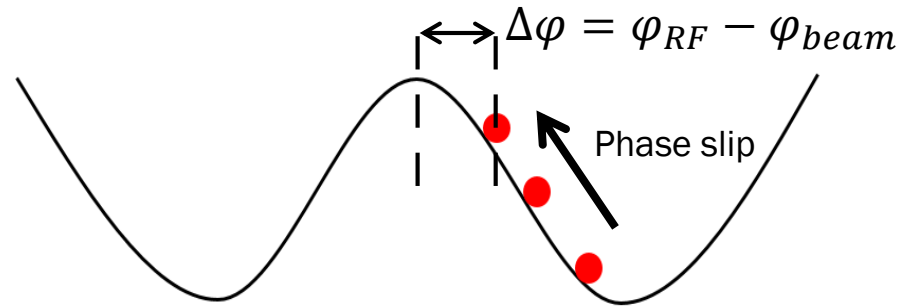
Beam loading

- When the beam passes through the cavity, a field due to the beam is excited. (beam loading)

- Due to beam loading, the cavity voltage is not constant, which affects η for each bunch.

The structure of positron beam
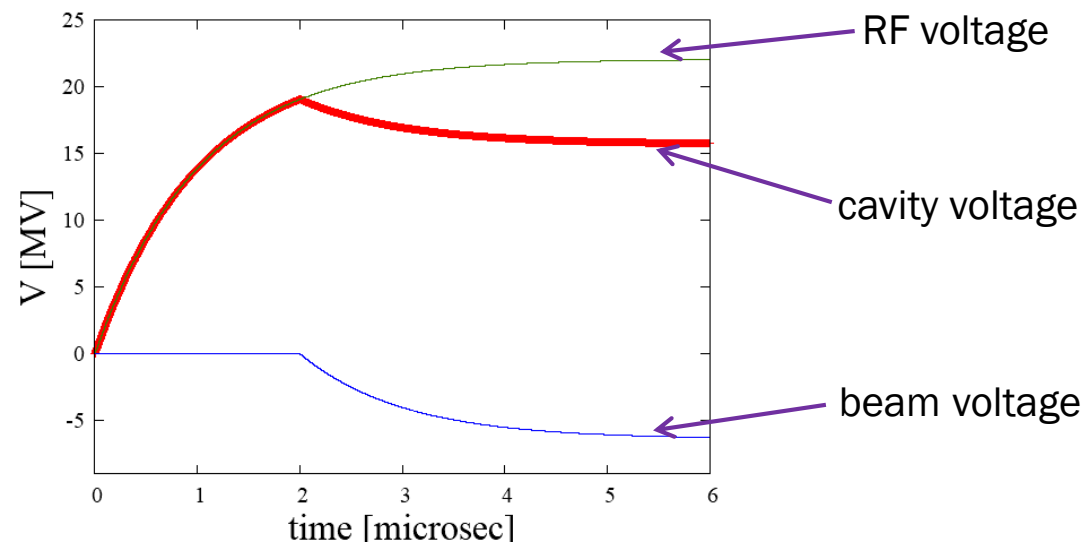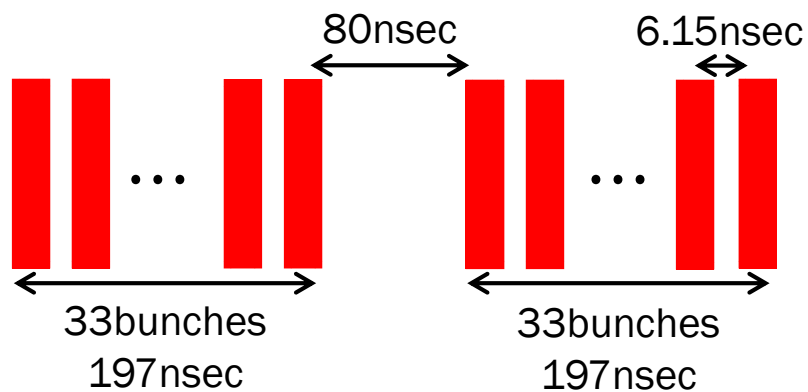
Deceleration capture method

- The electrons and positrons generated by the target have a large transverse energy spread.

- If accelerated in this situation, the phase on which the particles ride will be delayed due to phase slip.

- Efficient acceleration is possible by using the deceleration capture method.

- There is a difference between the particle phase and the maximum acceleration phase of RF. (off-crest)

$$\Delta\varphi = \varphi_{RF} - \varphi_{beam}$$

Phase slip

Particle distribution at capture linac

Beam loading compensation (On-crest)

- First, consider beam loading compensation when $\Delta\varphi = 0$ (on-crest) for simply.

- The transient state of the cavity voltage is expresses as follows.
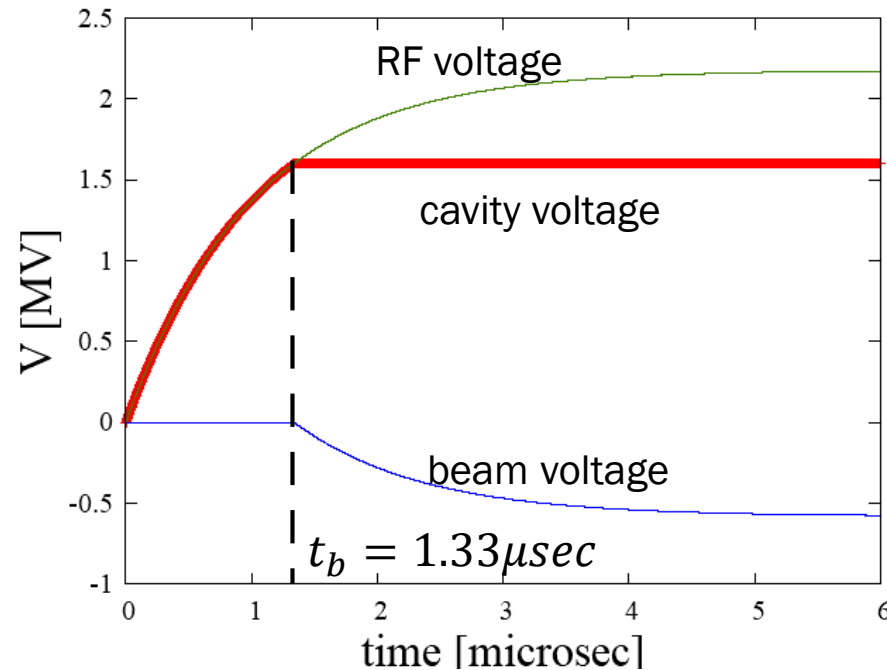
$$V(t) = V_{RF}\left(1 - e^{-\frac{t}{\tau}}\right) - V_{beam}\left(1 - e^{-\frac{t-t_b}{\tau}}\right)$$

V_{RF} : steady stare RF voltage
V_{beam} : steady state beam voltage
τ : time constant
t_b : time to start beam input

- Since the time constant of RF and beam are equal, the cavity voltage becomes constant if the amount of change is equal.
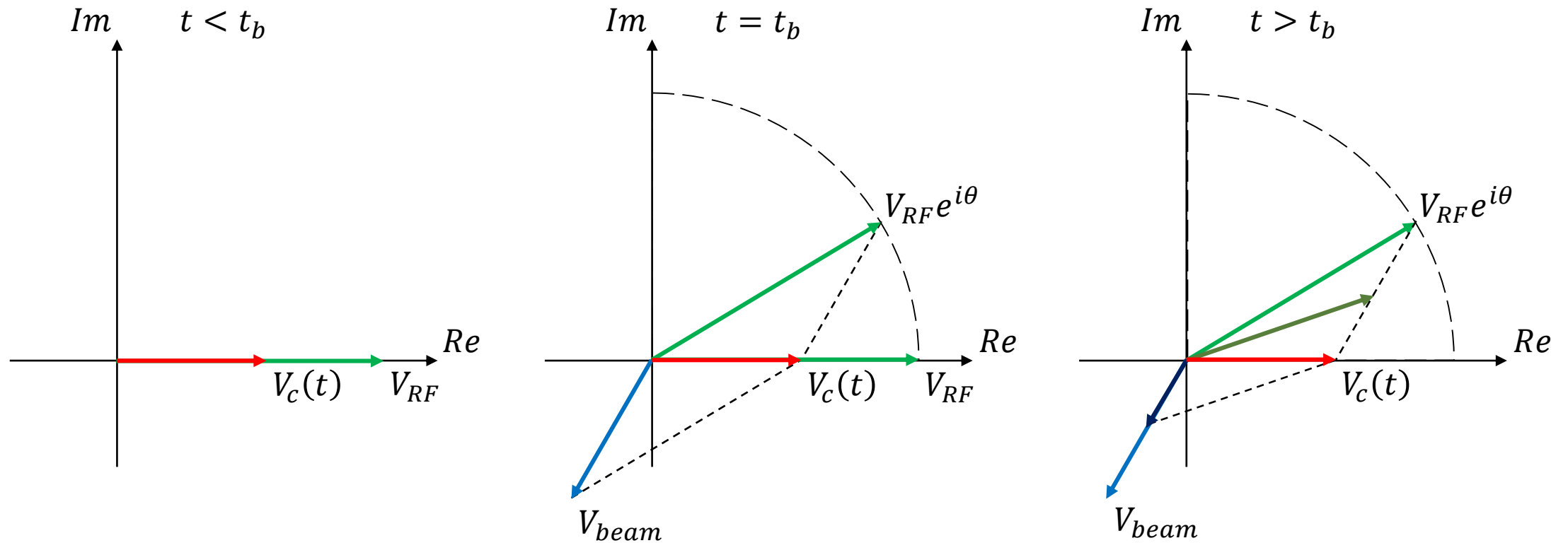
$$\frac{dV(t)}{dt} = 0$$

$$t_b = \tau\ln\frac{V_{RF}}{V_{beam}}$$

Time evolution of voltage
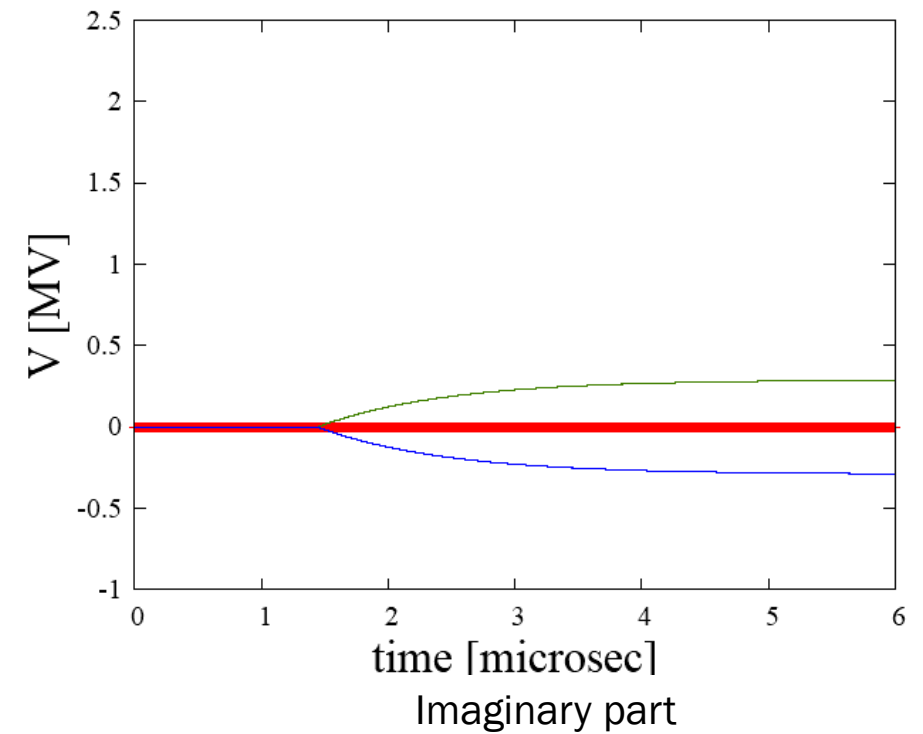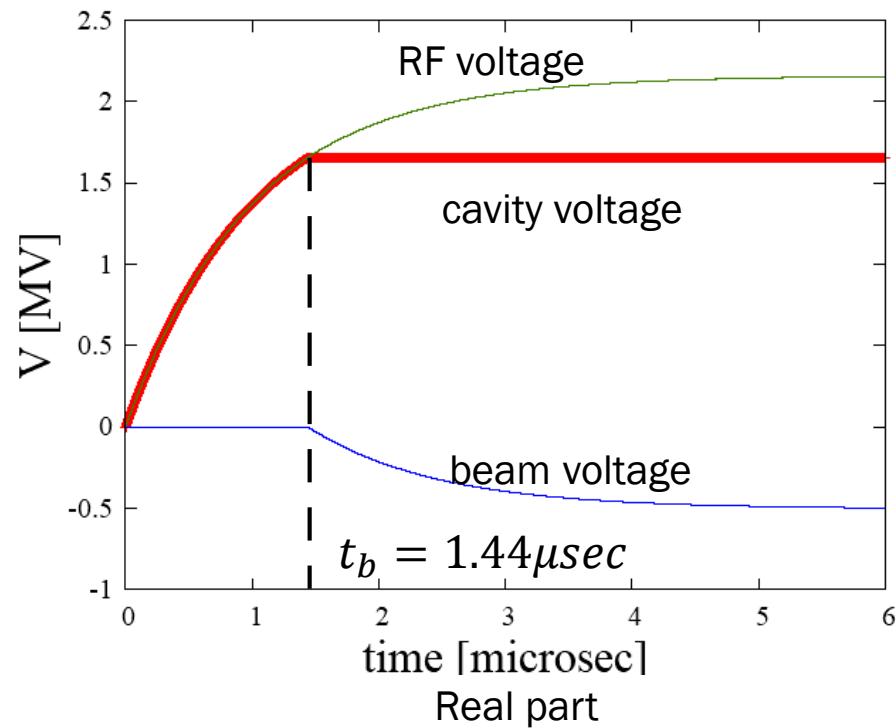
Beam loading compensation (Off-crest)

- In off-crest, the beam voltage has an imaginary component.

- By applying phase modulation, compensation is possible.

Time variation of voltage in the complex plane

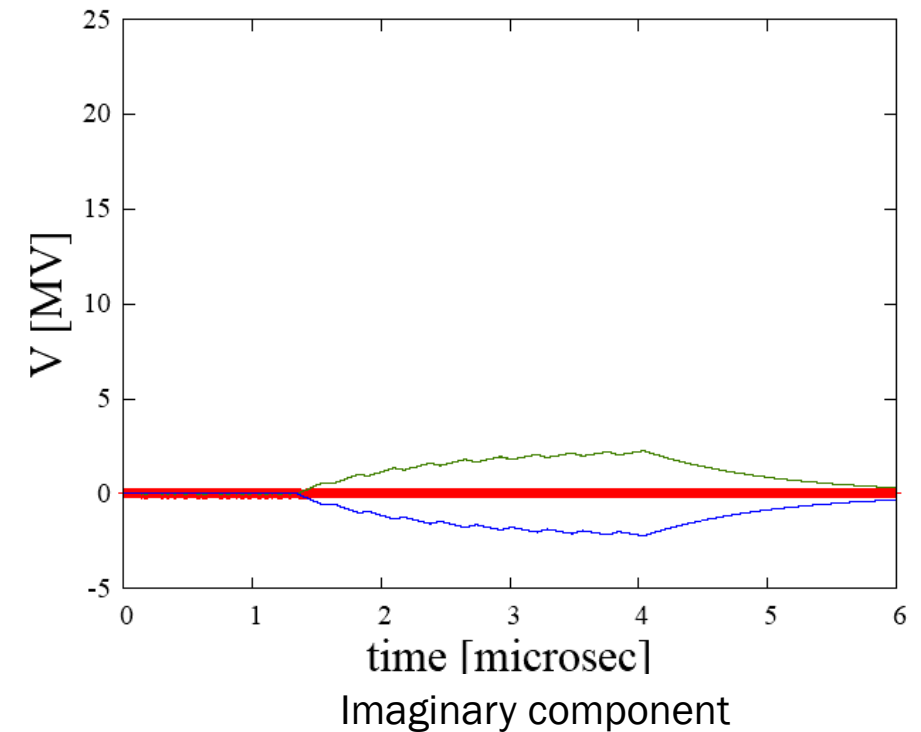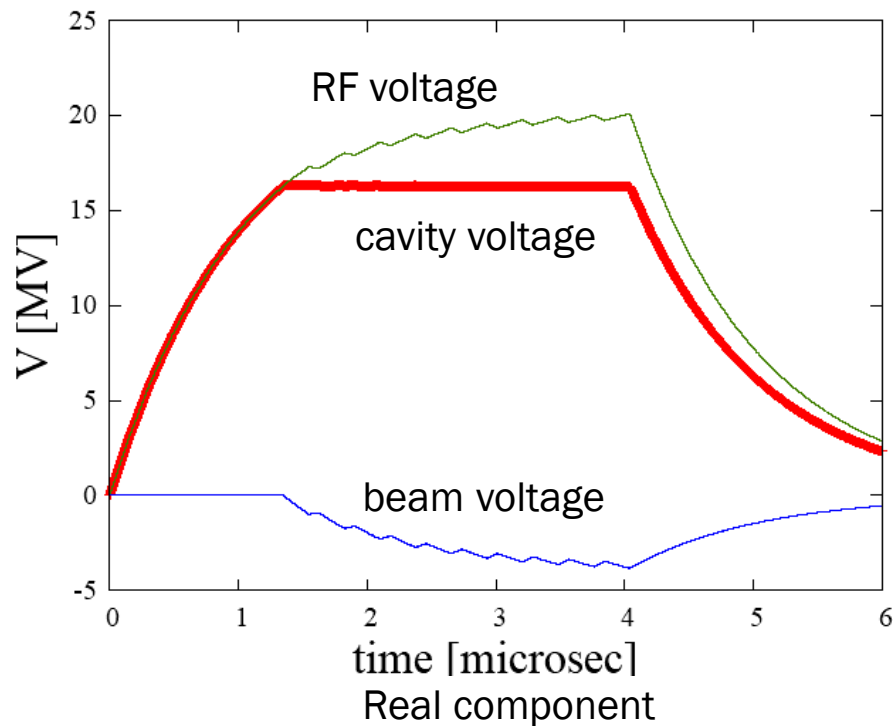# Beam loading compensation (Off-crest)

$\Delta\varphi$[rad]	Input power [MW]	Beam loading current[A]
$\dfrac{\pi}{6}$	22.5	1.0

Real part

Imaginary part

Beam loading compensation in multi-bunch

- The ILC's positron beam has a bunch gap.

- To keep the cavity voltage, RF voltage should be controlled.

$$V_{RF} = \begin{cases} V_{RF} & (0 < t < t_b) \\ V_{RF}e^{i\theta} & for\ beam \\ V_c & for\ gap \end{cases}$$

Real component

Imaginary component

Summary

- We designed e-driven positron source.

- Since electrons are also generated by this method, the influence of beam loading current cannot be ignored.

- In addition, because we use deceleration capture method, beam loading compensation at off-crest is required.

- At on-crest, beam loading compensation is possible by adjusting t_b.

- At off-crest, by applying phase modulation to RF, beam loading compensation is possible both the real part and the imaginary part.

- In the case of multi-bunch, beam loading compensation is possible by applying phase modulation when beam passes.

- From this result, it was expected that η would be kept constant in each bunch.