Simulation of beam loading for CLIC accelerating structures

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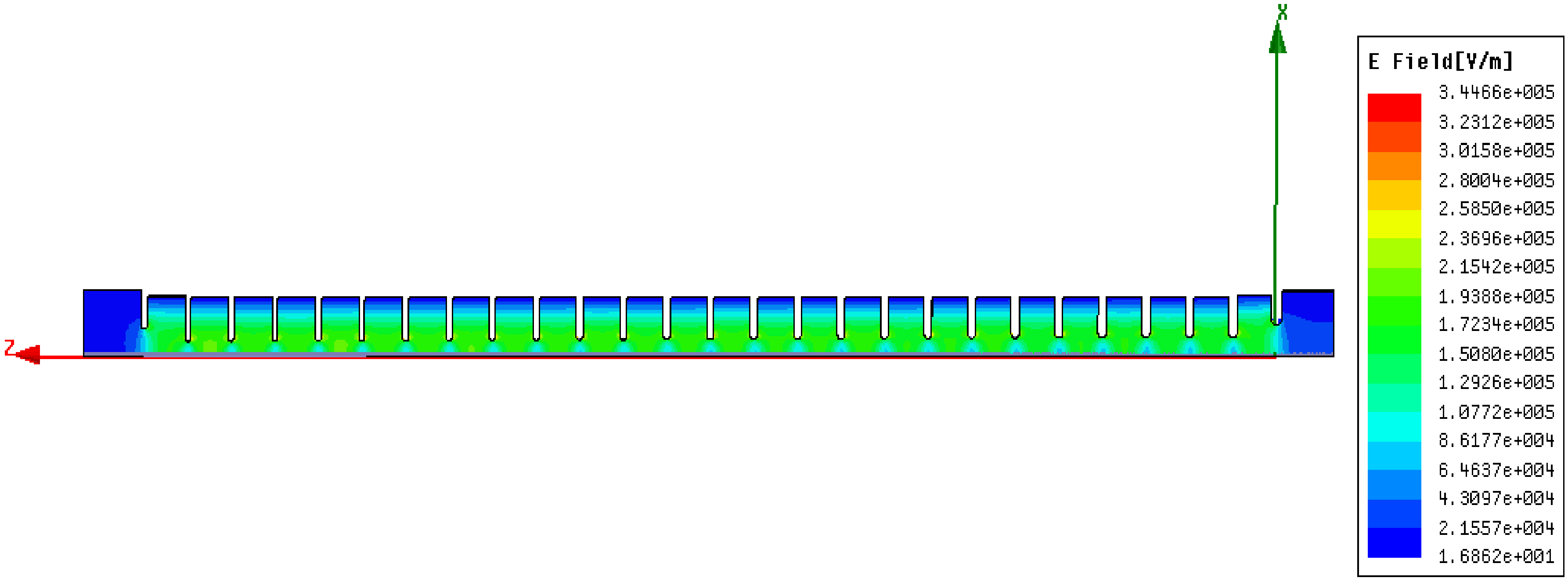
Introduction: E-field in T24 structure



Considering T18, T24 CLIC structures

Unloaded gradient calculation scheme

$E_z(z,f) \longrightarrow [\ \exp\ (\ \pm\ i\ {*}z\ {*}\omega/c\ )\ ] \longrightarrow \boldsymbol{G_0\,(z,f)}$

$[\ \mathrm{ift}\ ] \longrightarrow G_0(z,\ t) \longrightarrow [\mathrm{conv}\ p(t)] \longrightarrow \boldsymbol{G(z,t)} \longrightarrow [\int dz]$

$\uparrow$ $\boldsymbol{G_0\,(z,f)}$ $\downarrow$

$\downarrow$ $\boldsymbol{V_{acc}\,(t)}$ $\uparrow$

$[\ \int dz\ ] \longrightarrow V_0\,(f) \longrightarrow [\ \mathrm{ift}\ ] \longrightarrow \boldsymbol{V_0\,(t)} \longrightarrow [\ \mathrm{conv}\ p(t)\ ]$

Beam loading: steady-state

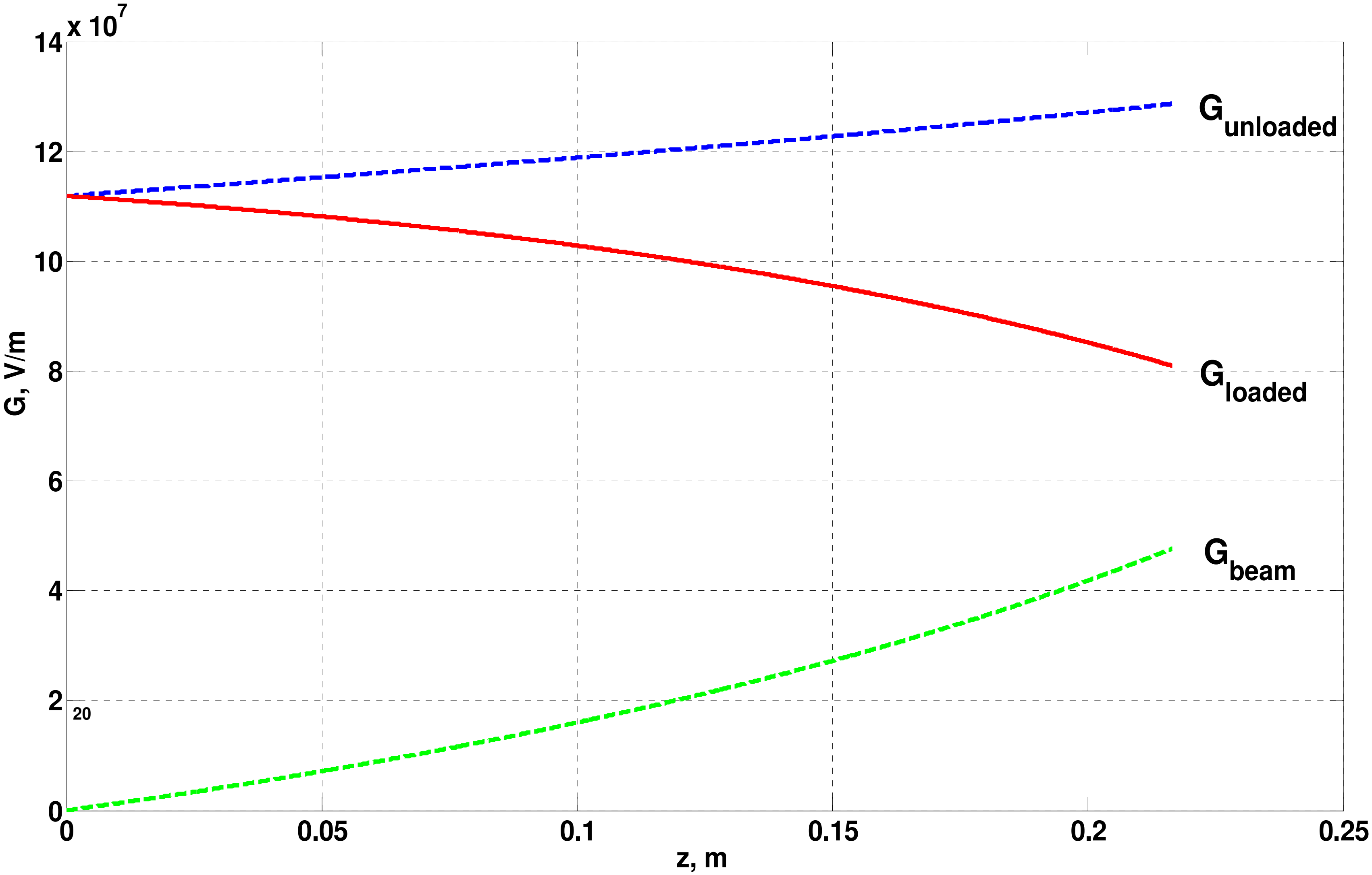
$$\mathbf{d}P \,/\, \mathbf{d}z = -\omega \,* W(z) \,/\, Q(z) - G(z) * I$$

$$G(z) = G_0(z)\left[1 - \int_0^z I\,\omega\,\rho(z) \,/\, \left(G_0(z)\, v_g(z)\right) dz\right]$$

$$G_0(z) = g_0 * F\left(v_g(z), Q(z), \rho(z)\right)$$

*Beam loading for arbitrary traveling wave accelerating structure. A. Lunin, V. Yakovlev

Beam loading: steady-state



Beam loading model

Time discretization:

- $\mathbf{T_{bunch\ per\ cell}} = C_{length} / c \approx 0.0278$ ns
- $T_{RF\ cycle} = 1 / f_0 = \mathbf{3 * T_{bunch\ per\ cell}} \approx 0.0834$ ns
- $T_{bunch\ separation} = 6 * T_{RF\ cycle} = \mathbf{18 * T_{bunch\ per\ cell}}$
- $T_{energy\ per\ cell} = C_{length} / v_g\,(C) = w_{pec}\,(C) / P_{in} \approx 1.5\text{-}3$ns

⇩

$$f_{max} = 1 / \mathbf{T_{bunch\ per\ cell}}$$

Beam loading model

Longitudinal discretization by cells:

- Energy density: $w(C) = \varepsilon_0 /2 \int |E(x,y,z,f_0)|^2 \, dV_C / C_{length}$
- Loss factor: $k'(C)=G(C,f_0)^2/(4*w(C))$
- Averaged gradient: $G(C,f_0)= \int G(z,f_0) \, dL_c / C_{length}$
- Group velocity: $v_g(C)=P_{in}*C_{length} / w_{pec}(C) \approx 0.8\text{-}1.6\ \%\ c$

Beam loading model

- Energy lost per bunch per cell:

  $$\Delta W_{\text{bunch}}(t,C) = k'(C) * q^2(t,C) * C_{\text{length}}$$

  $$\Delta W_{\text{field}}(t,C) = G(t,C) * q(t,C) * C_{\text{length}}$$

- Energy moves with $v_{\text{g}}(C)$

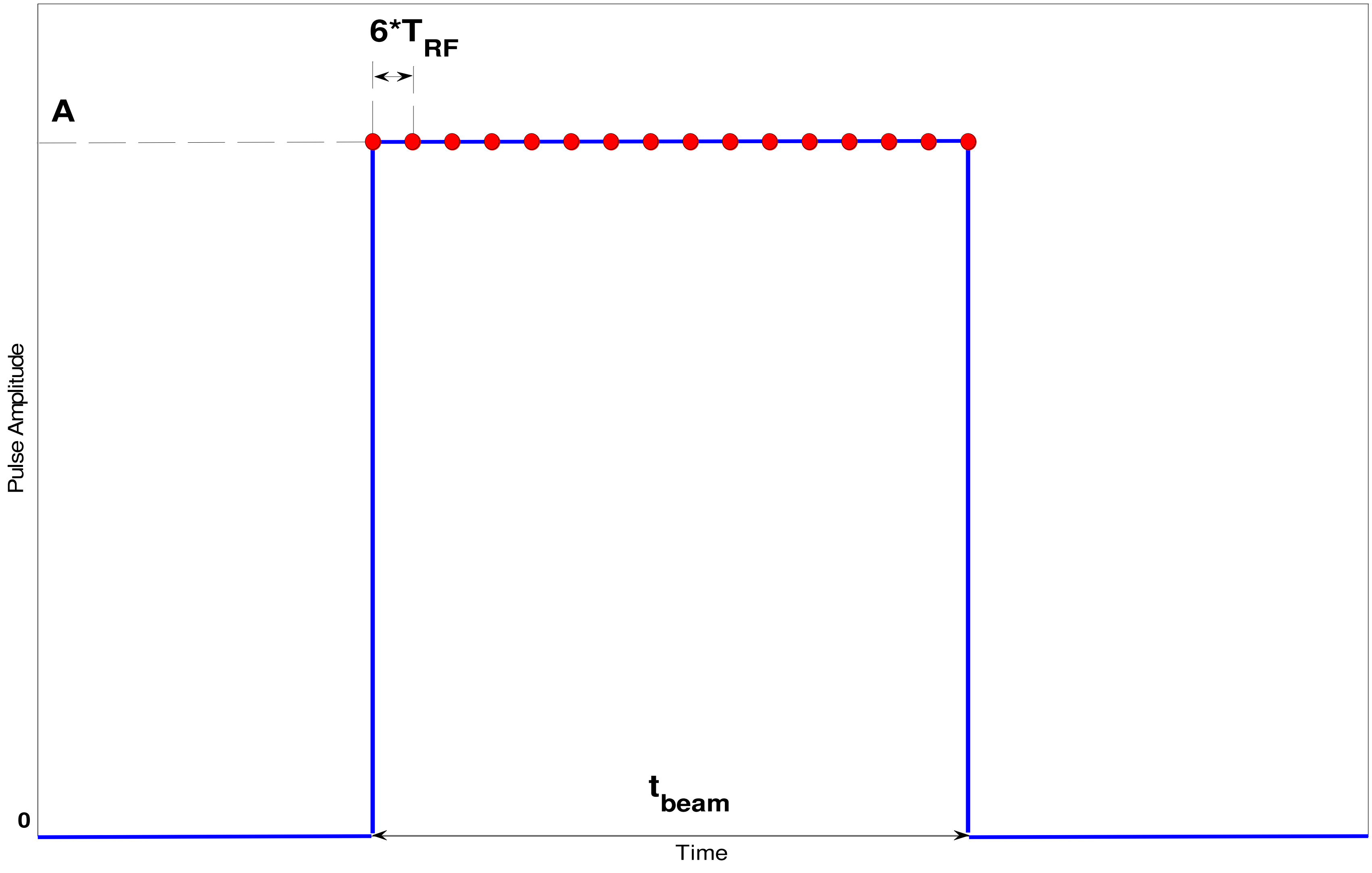
- Wall losses $P_{\text{walls}}(C) = \omega * W(C) / Q(C)$

Beam loading model

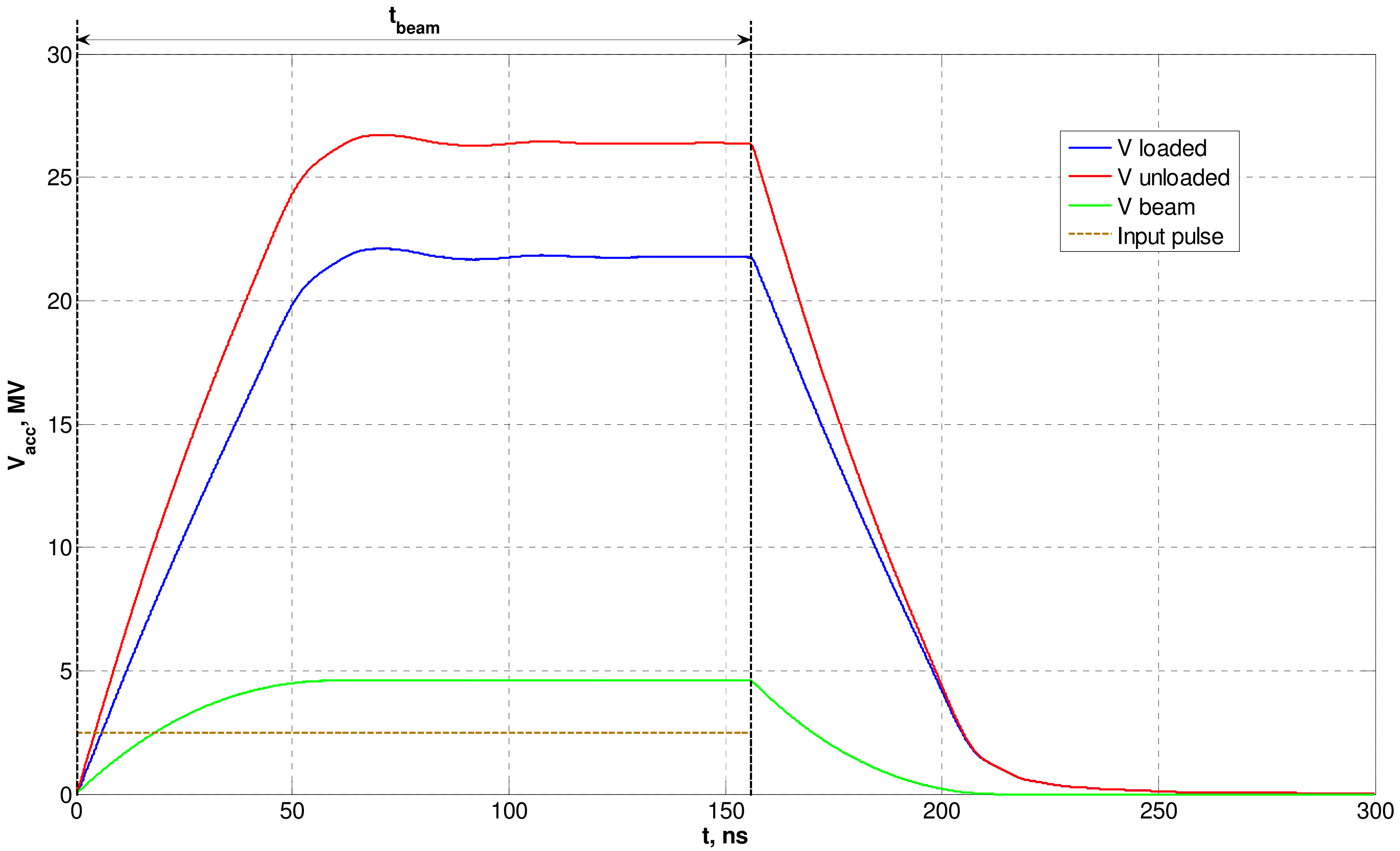
- Total energy: $W(t,C) = \sum \Delta W$
- Gradient: $G(t,C)=2*\mathrm{sqrt}(k'(C) * W(t,C) / C_{length})$
- Comparison could be performed for the steady-state phase

Beam loading simulation

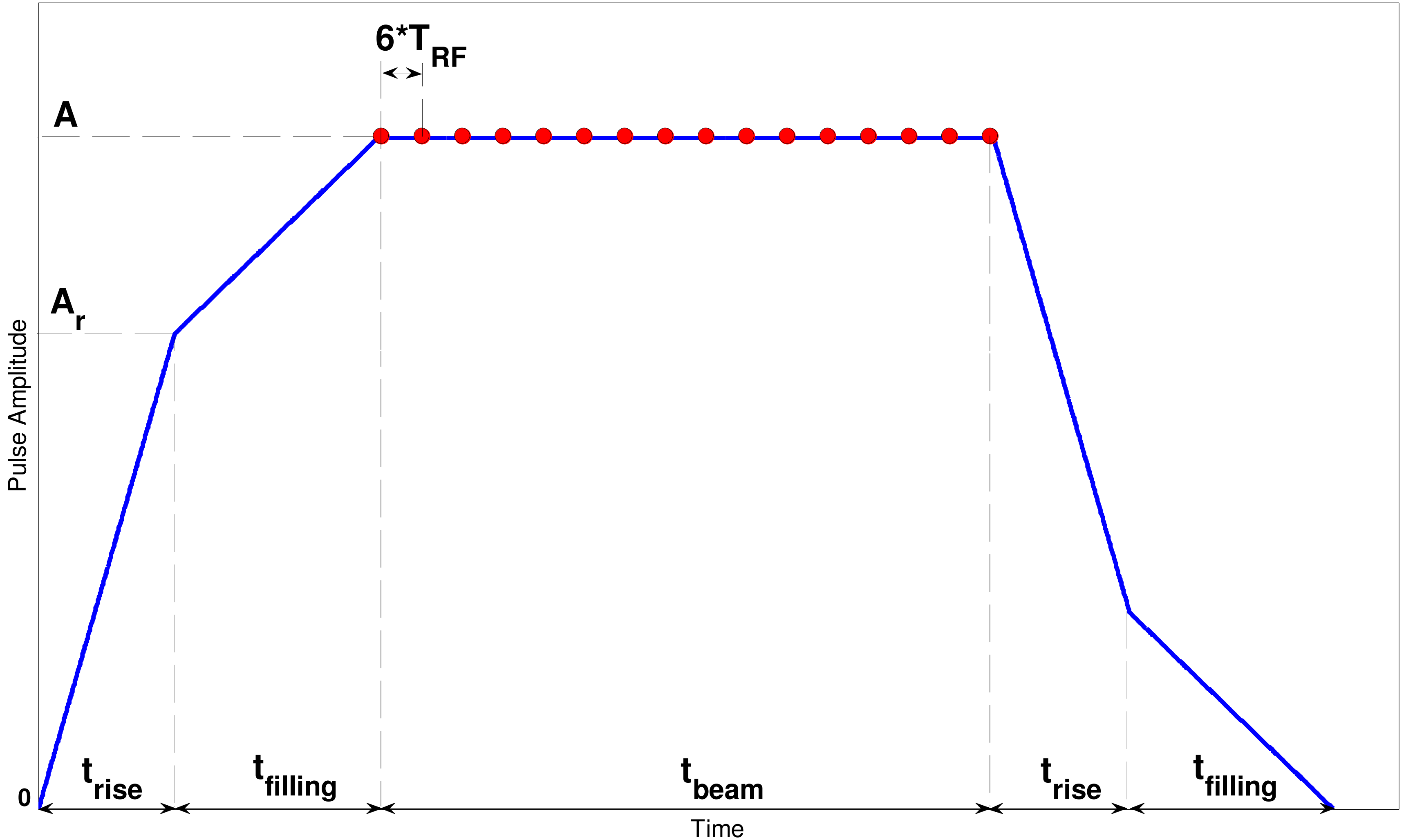
Rectangular pulse



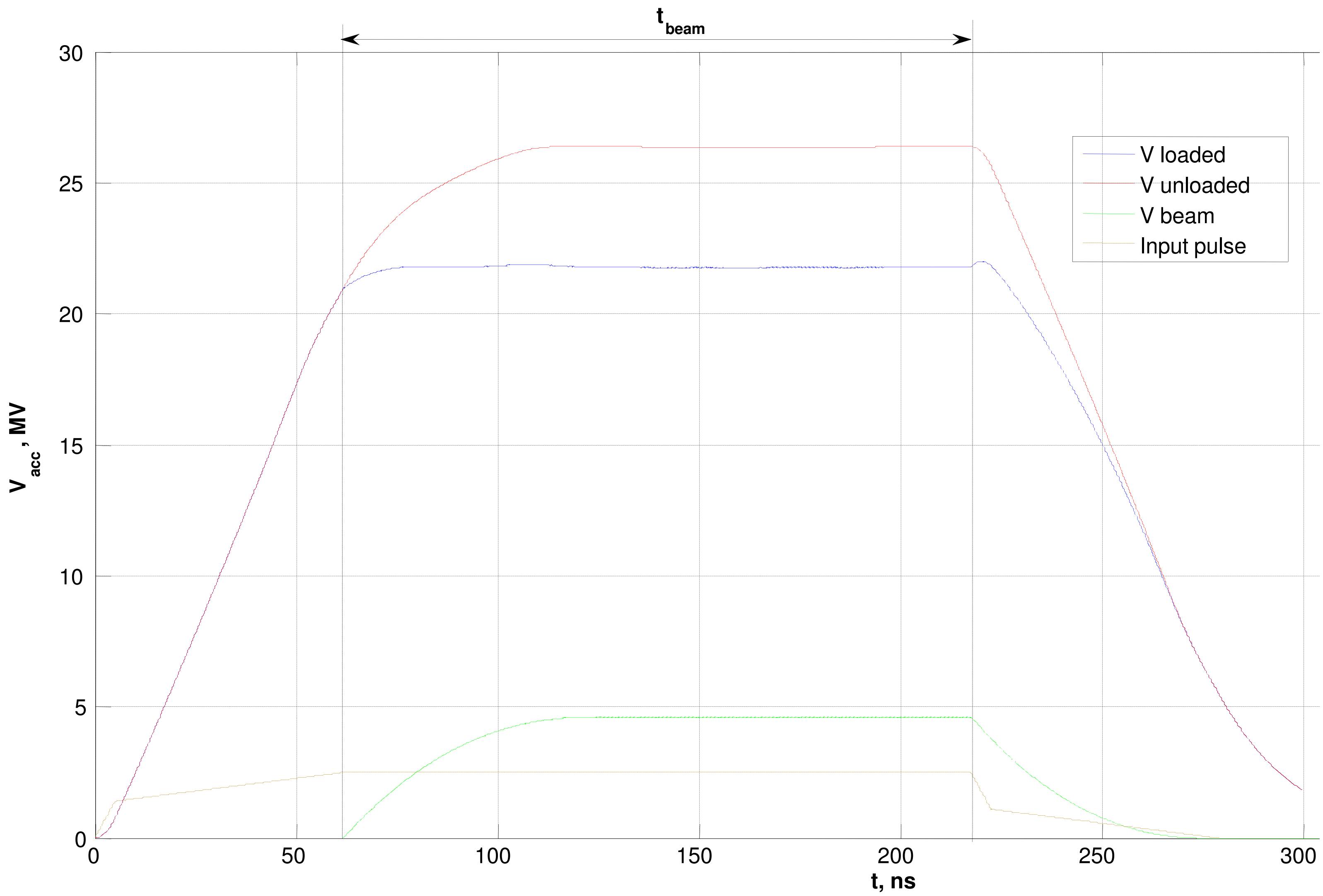
Accelerating voltage in T24



Ramped pulse



Accelerating voltage in T24



Conclusions

1. Beam loading model is developed and simulations are carried out.

2. Comparison with the steady state case is performed.

3. Optimization of the pulse shape is necessary

4. More detailed beam loading calculations are needed

Thank you for the attention!