UPPSALA UNIVERSITET

# Filling time estimation of ESS double spoke cavity

Han Li

On behalf of FREIA team

FREIA Laboratory, Uppsala University

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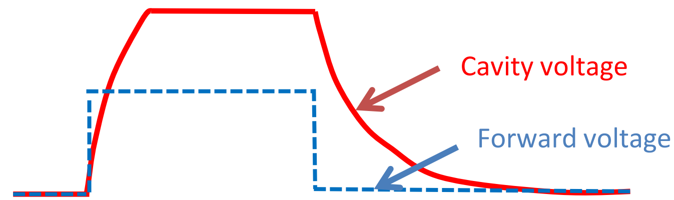
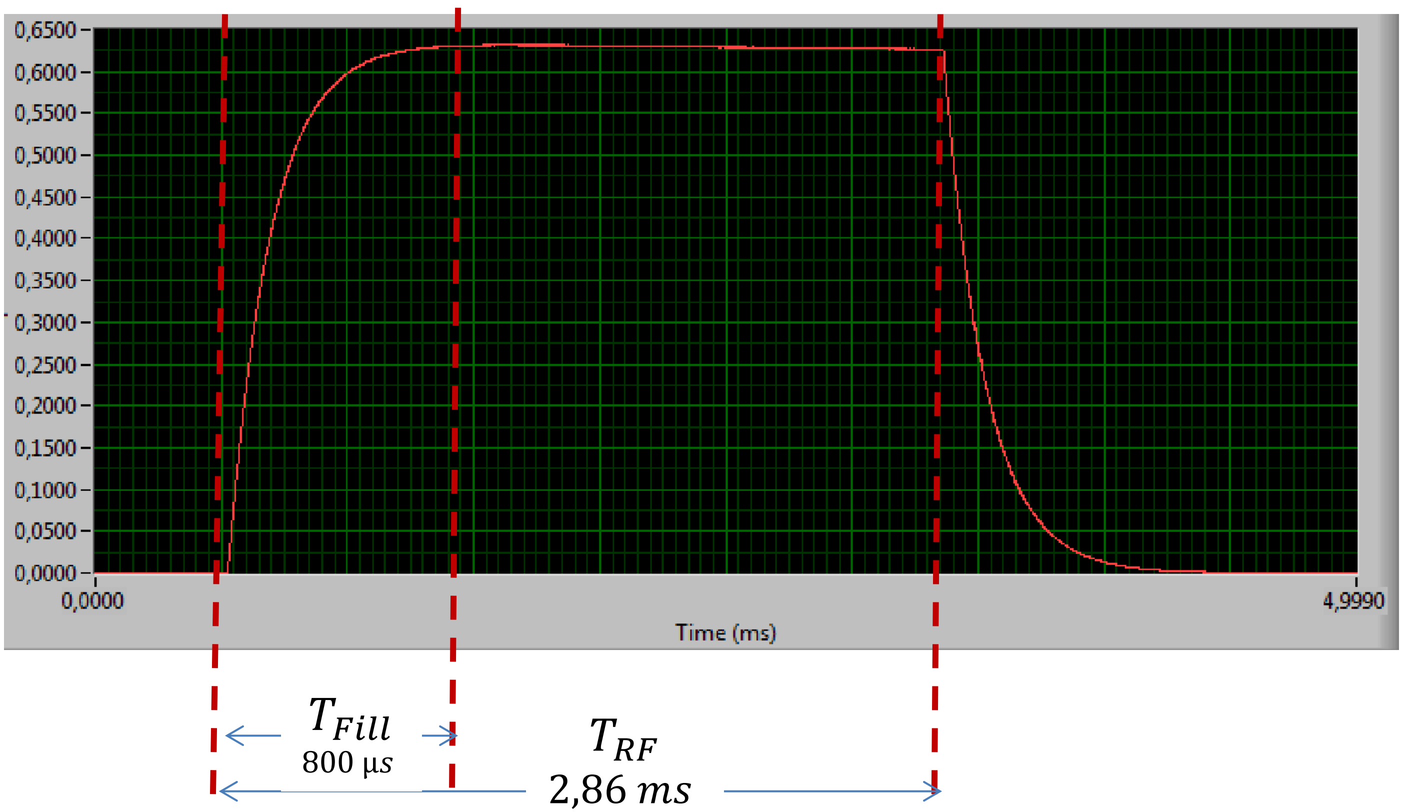
# Cavity profile of Romea

- Cavity profile of Romea during pulse

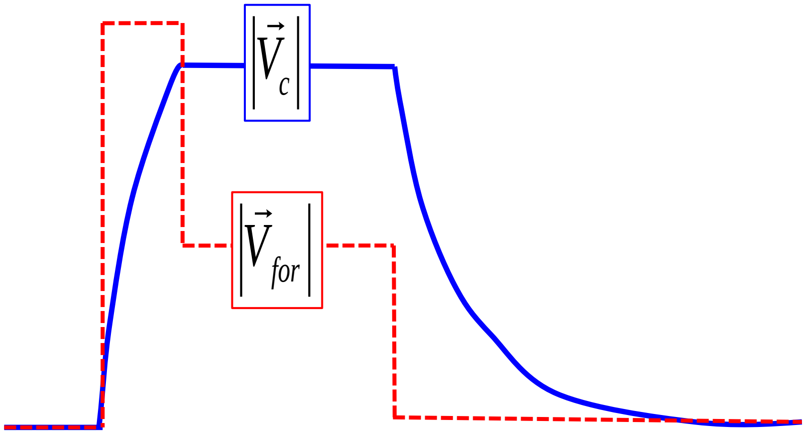
Cavity package was driving by a pulse SEL
With an input power of 110 kW



# Cavity profile of Romea (cnt.)

- From the requirment of LLRF, ESS double spoke cavity should have a filling time within 300 μs
- Cavity filling time with 110 kW pure rectangle pulse is 800 μs > 300 μs
- In order to charge cavity as soon as possible, a tradition way is using higher forward power during filling time.



# RF Power Dissipation at Filling Stage

- Filling of cavity: fill the cavity to a desired voltage V0 from 0 within a period of Tfill
- Factors influence the required filling power
  - Desired cavity flattop voltage (V0)
  - Filling time (Tfill)
  - Loaded Q of cavity (QL)
  - Detuning of cavity (Δω)
- From the cavity transient behavior, the RF power required for filling stage is

$$P_{fill} = \frac{V_0^2\left(\omega_0^2 + 4Q_L^2\Delta\omega^2\right)}{4\left(\frac{r}{Q}\right)Q_L\omega_0^2 \cdot \left[1 + e^{-\frac{\omega_0 T_{fill}}{Q_L}} - 2e^{-\frac{\omega_0 T_{fill}}{2Q_L}}\cos\left(\Delta\omega T_{fill}\right)\right]}$$

# RF power Distribution at Filling Stage (cnt.)

$$\frac{d\vec{V}_c}{dt} + \left(\omega_{1/2} - j\Delta\omega\right)\vec{V}_c = 2\omega_{1/2}\vec{V}_{for}$$

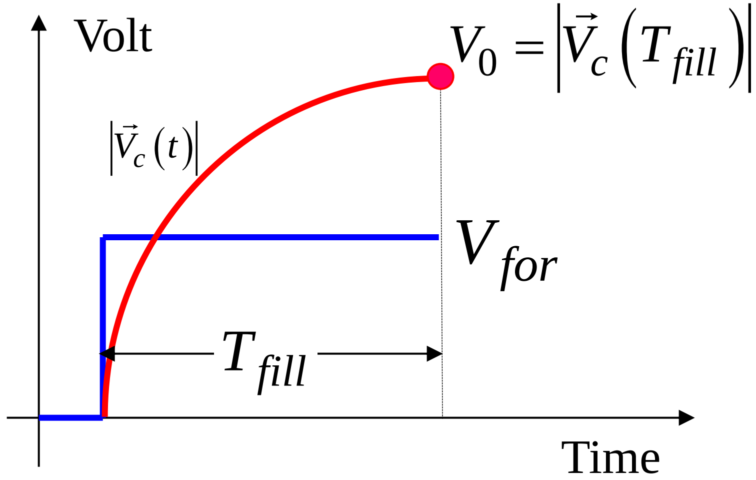
$$P_{fill} = \frac{V_{for}^2}{2R_L}$$

⇓ *Transient behaviour*

$$\vec{V}_c(t) = \frac{2\omega_{1/2}\vec{V}_{for}}{\omega_{1/2} - j\Delta\omega}\left(1 - e^{-\left(\omega_{1/2} - j\Delta\omega\right)t}\right)$$

⇓ *Assume* $\vec{V}_{for} = V_{for}e^{j\cdot 0}$

$$\vec{V}_c(t) = \frac{2\omega_{1/2}V_{for}}{\omega_{1/2} - j\Delta\omega}\left(1 - e^{-\left(\omega_{1/2} - j\Delta\omega\right)T_{fill}}\right)$$




⇓

$$V_0 = \left|\vec{V}_c\left(T_{fill}\right)\right| = \frac{2\omega_{1/2}V_{for}}{\sqrt{\omega_{1/2}^2 + \Delta\omega^2}}\left|1 - e^{-\omega_{1/2}T_{fill}}\cos\left(\Delta\omega T_{fill}\right) - je^{-\omega_{1/2}T_{fill}}\sin\left(\Delta\omega T_{fill}\right)\right|$$

# RF power Distribution at Filling Stage (cnt.)

$$V_0 = \left|\vec{V}_c\left(T_{fill}\right)\right| = \frac{2\omega_{1/2}V_{for}}{\sqrt{\omega_{1/2}^2+\Delta\omega^2}}\left|1-e^{-\omega_{1/2}T_{fill}}\cos\left(\Delta\omega T_{fill}\right)-je^{-\omega_{1/2}T_{fill}}\sin\left(\Delta\omega T_{fill}\right)\right|$$

$$V_0 = \frac{2\omega_{1/2}V_{for}}{\sqrt{\omega_{1/2}^2+\Delta\omega^2}}\sqrt{1-2e^{-\omega_{1/2}T_{fill}}\cos\left(\Delta\omega T_{fill}\right)+e^{-2\omega_{1/2}T_{fill}}}$$

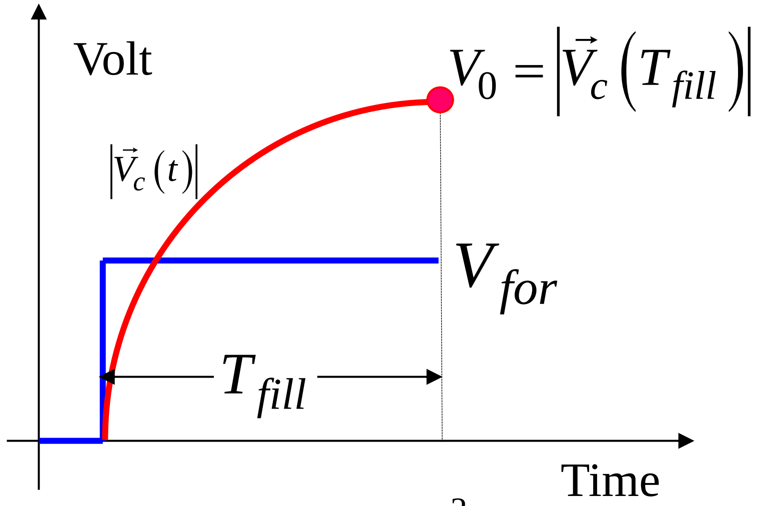
$$V_{for} = \frac{V_0\sqrt{\omega_{1/2}^2+\Delta\omega^2}}{2\omega_{1/2}\sqrt{1-2e^{-\omega_{1/2}T_{fill}}\cos\left(\Delta\omega T_{fill}\right)+e^{-2\omega_{1/2}T_{fill}}}}$$

$$P_{for} = \frac{V_{for}^2}{2R_L}$$

$$P_{for} = \frac{V_0^2\left(\omega_{1/2}^2+\Delta\omega^2\right)}{4\omega_{1/2}^2\left(1-2e^{-\omega_{1/2}T_{fill}}\cos\left(\Delta\omega T_{fill}\right)+e^{-2\omega_{1/2}T_{fill}}\right)\cdot 2R_L}$$

$$R_L = \frac{1}{2}\left(r/Q\right)Q_L \qquad \omega_{1/2} = \frac{\omega_0}{2Q_L}$$

$$P_{fill} = \frac{V_0^2\left(\omega_0^2+4Q_L^2\Delta\omega^2\right)}{4\left(\frac{r}{Q}\right)Q_L\omega_0^2\cdot\left[1+e^{-\frac{\omega_0 T_{fill}}{Q_L}}-2e^{-\frac{\omega_0 T_{fill}}{2Q_L}}\cos\left(\Delta\omega T_{fill}\right)\right]}$$




$$P_{fill} = P_{for} = \frac{V_{for}^2}{2R_L}$$

# Parameter for spoke cavity

- main parameter of ESS double spoke cavity

$V_0 = E_{acc} \times L_{eff} = 5{,}751$ MV $\qquad L_{eff}$ =0,639 m

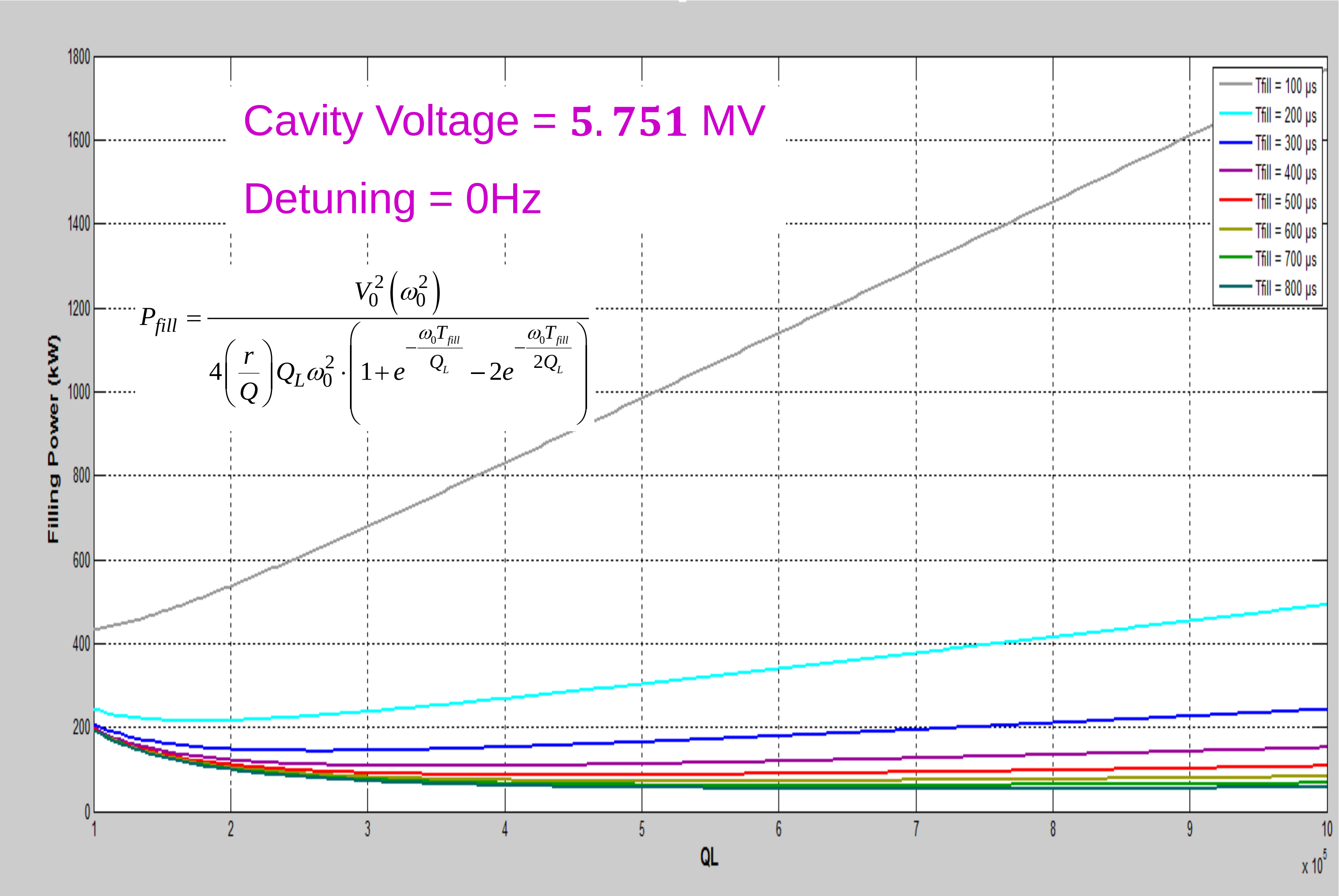
$\frac{R}{Q}$ = 426 Ω $\qquad Q_L$ =1,8e5

$f_0 = 352{,}3725\ MHz\ at\ 2\ K$

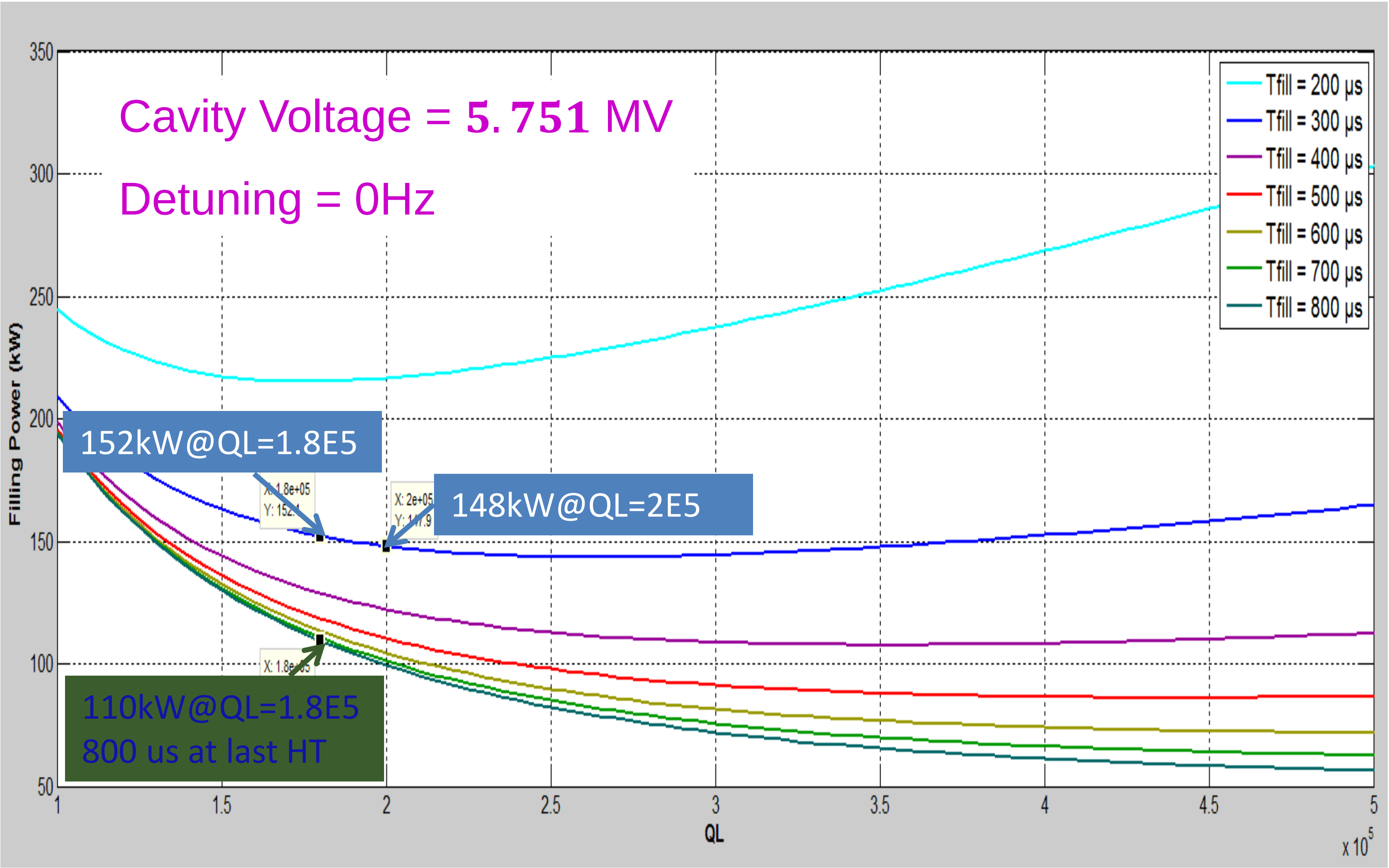
$\Delta\omega$ consists of pretuning, LFD and microphonics

$$P_{fill} = \frac{V_0^2\left(\omega_0^2 + 4Q_L^2\Delta\omega^2\right)}{4\left(\frac{r}{Q}\right)Q_L\omega_0^2 \cdot \left[1 + e^{-\frac{\omega_0 T_{fill}}{Q_L}} - 2e^{-\frac{\omega_0 T_{fill}}{2Q_L}}\cos\left(\Delta\omega T_{fill}\right)\right]}$$

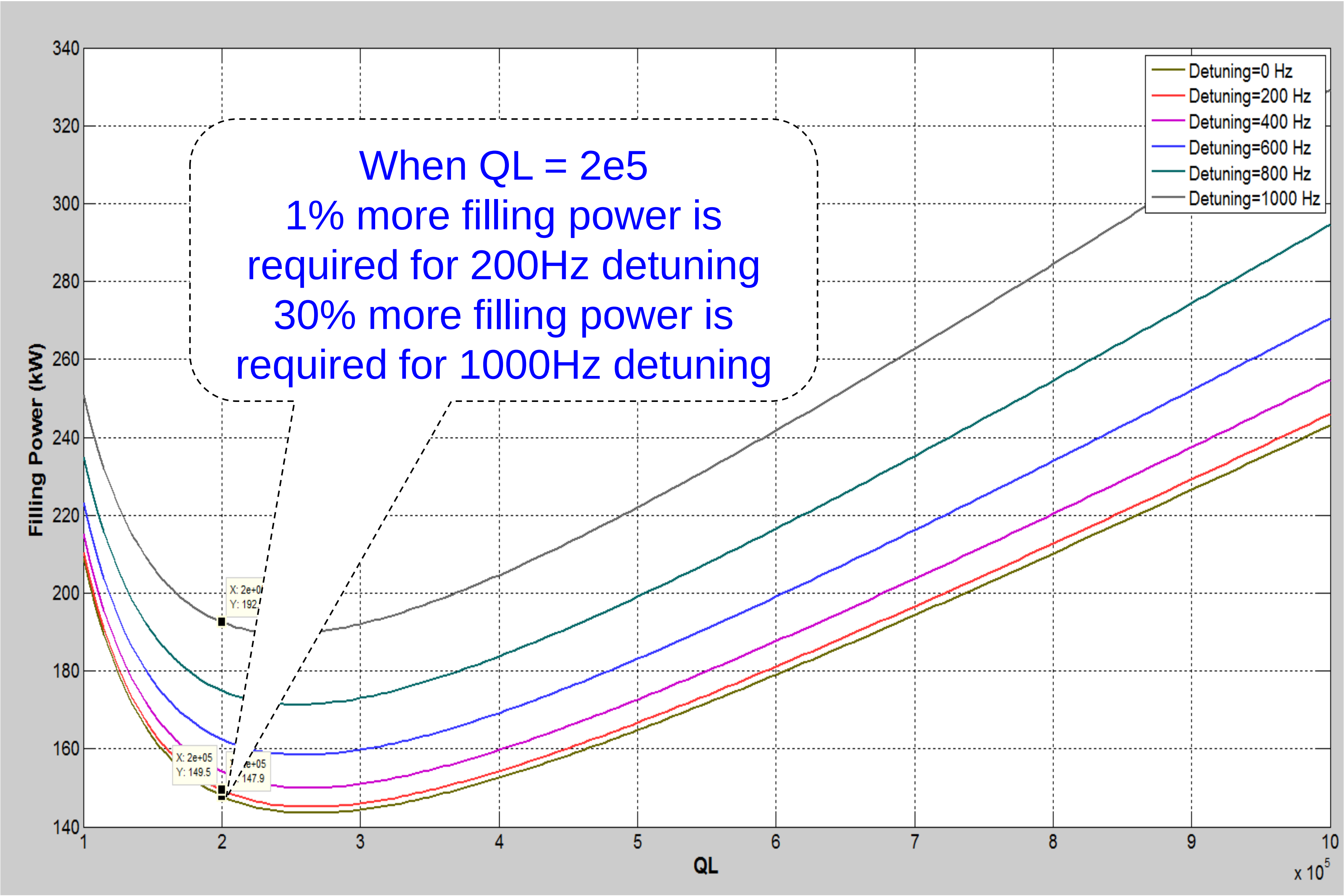
# Filling Power for Different Loaded Q and Filling Time



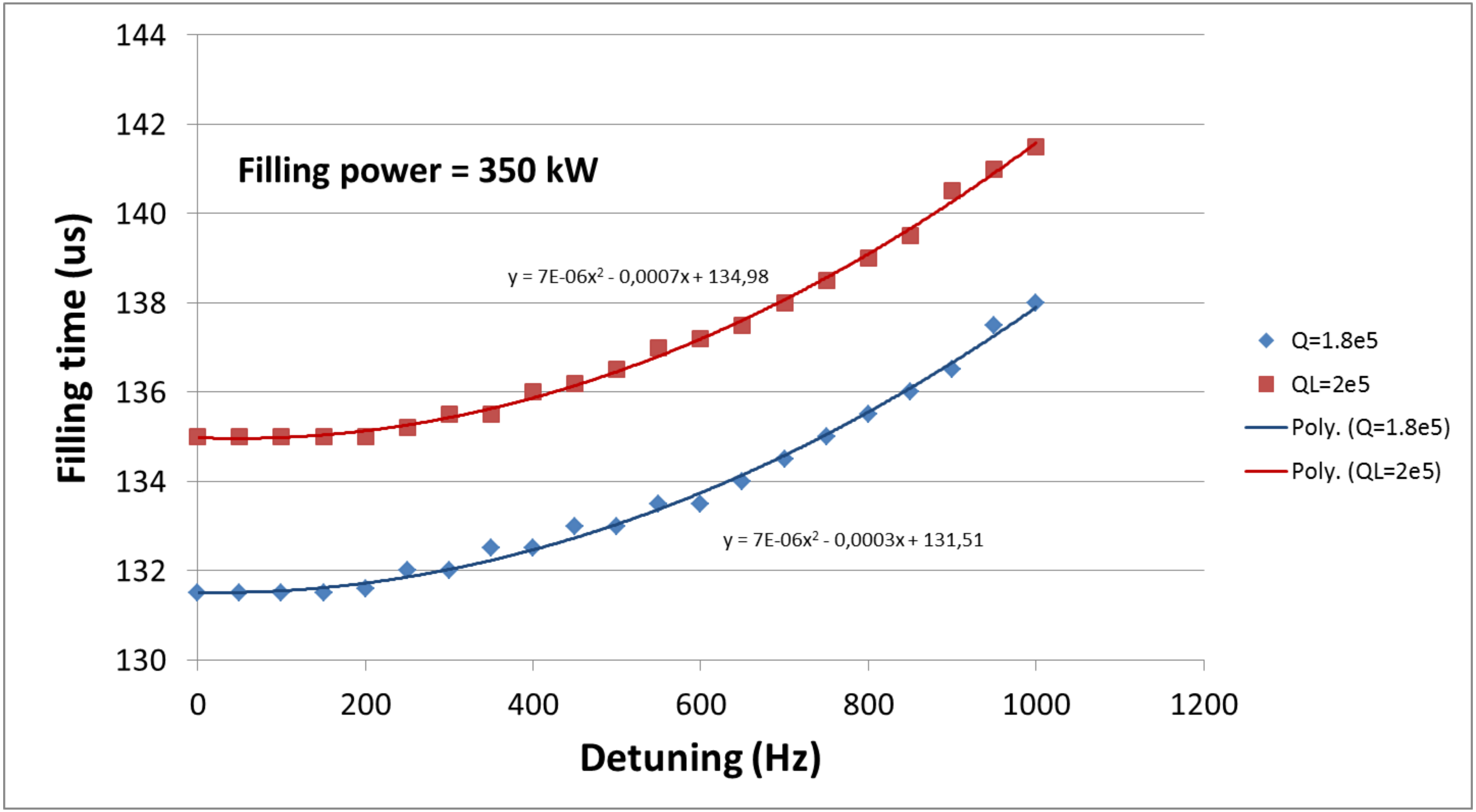
# Filling Power for Different Loaded Q and Filling Time



# Filling Power for Different Loaded Q and Detuning

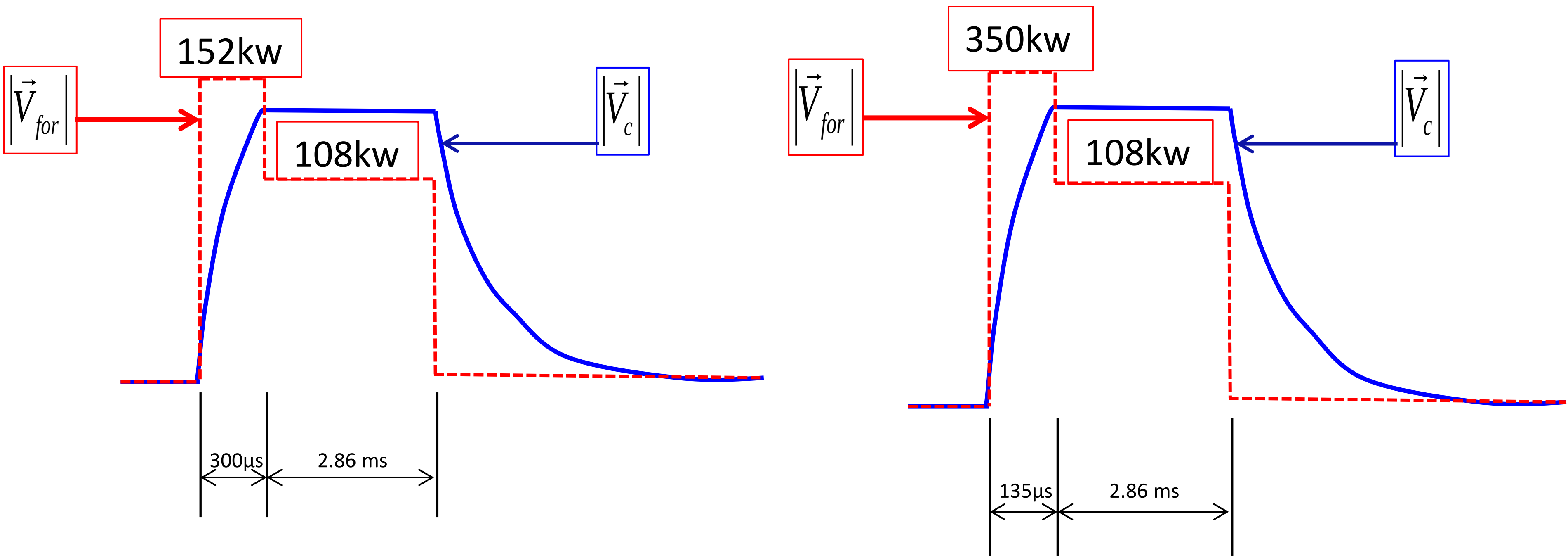


# Filling time for different detuning



# Summary for Spoke cavity

For steps filling:




(a) (b)

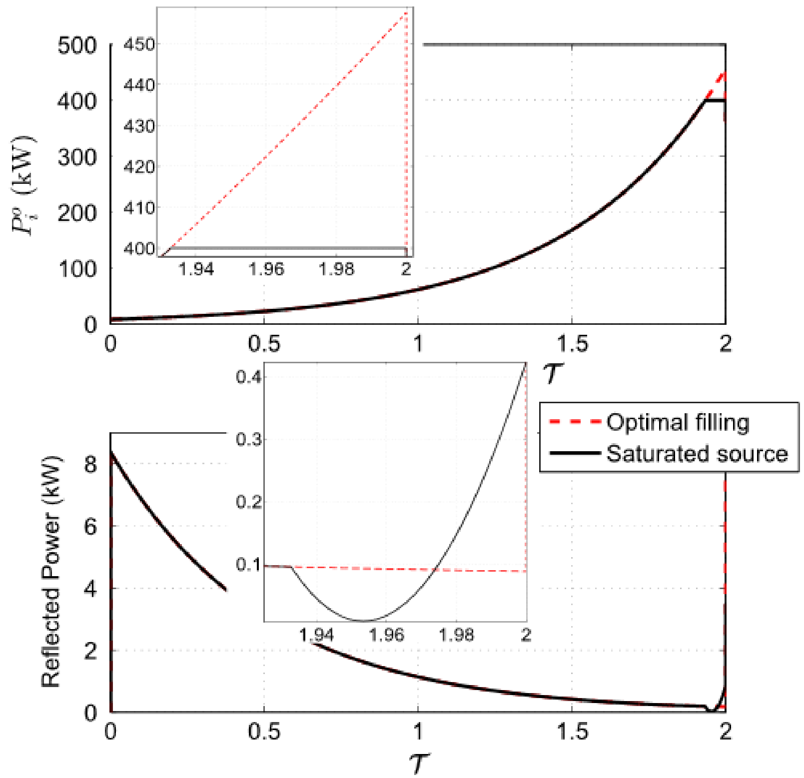
From A.K.Bhattacharyya’s paper

$$V^o(\tau) = V_c \frac{\sinh(\tau)}{\sinh(\hat{\tau}_i)}$$

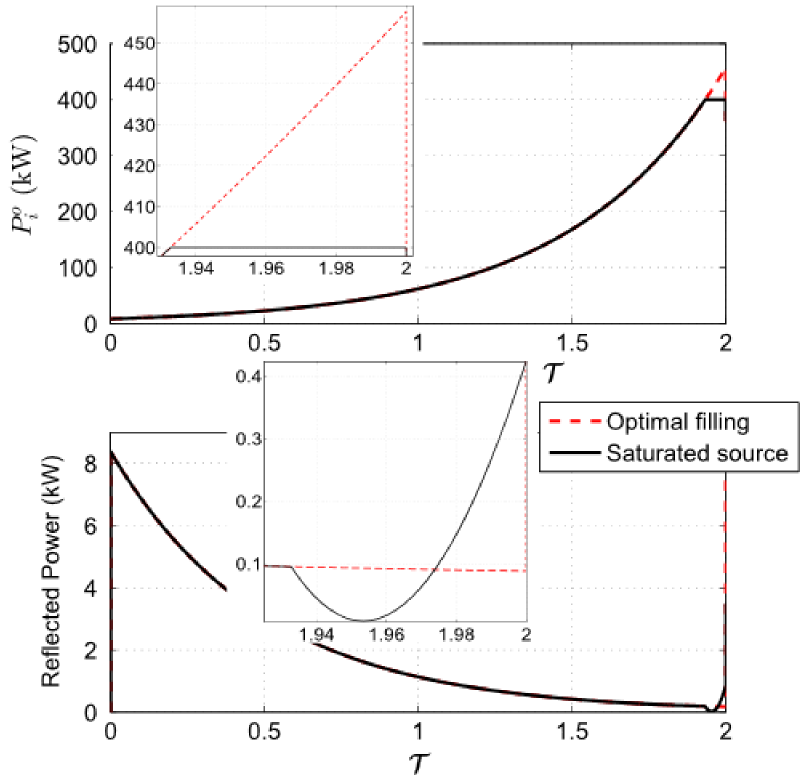
$$P_i^o(\tau) = \frac{V_c^2}{2Z_L} \frac{\exp(2\tau)}{4\sinh^2(\hat{\tau}_i)}$$

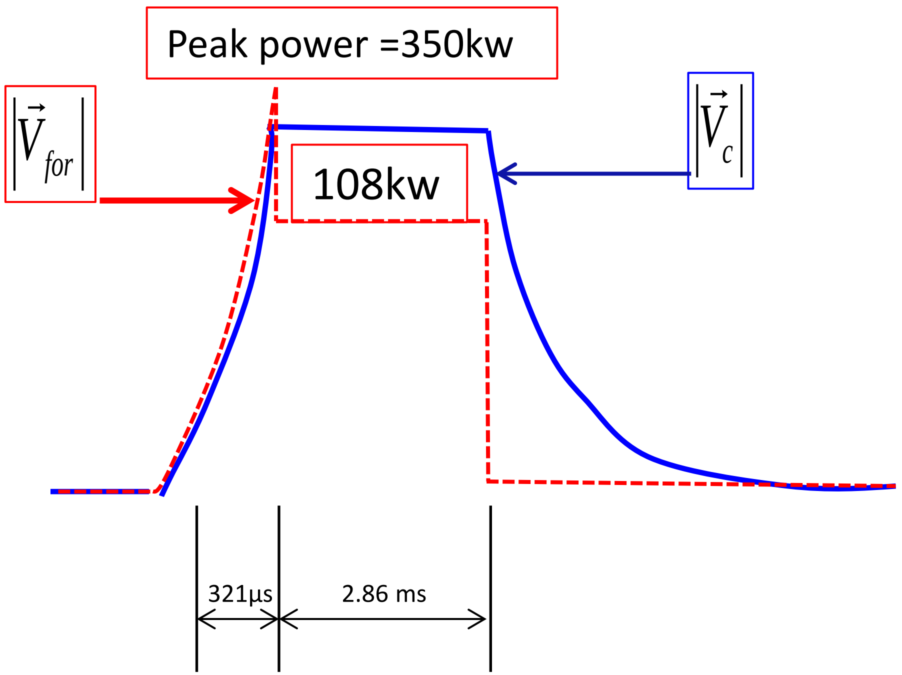
$$E_r^o(\hat{\tau}_i) = t_F \frac{V_c^2}{4Z_L} \frac{\exp(-2\hat{\tau}_i)}{1-\exp(-2\hat{\tau}_i)}$$

$$E_g^o(\hat{\tau}_i) = \frac{t_F}{4Z_L} \frac{V_c^2}{1-\exp(-2\hat{\tau}_i)}.$$

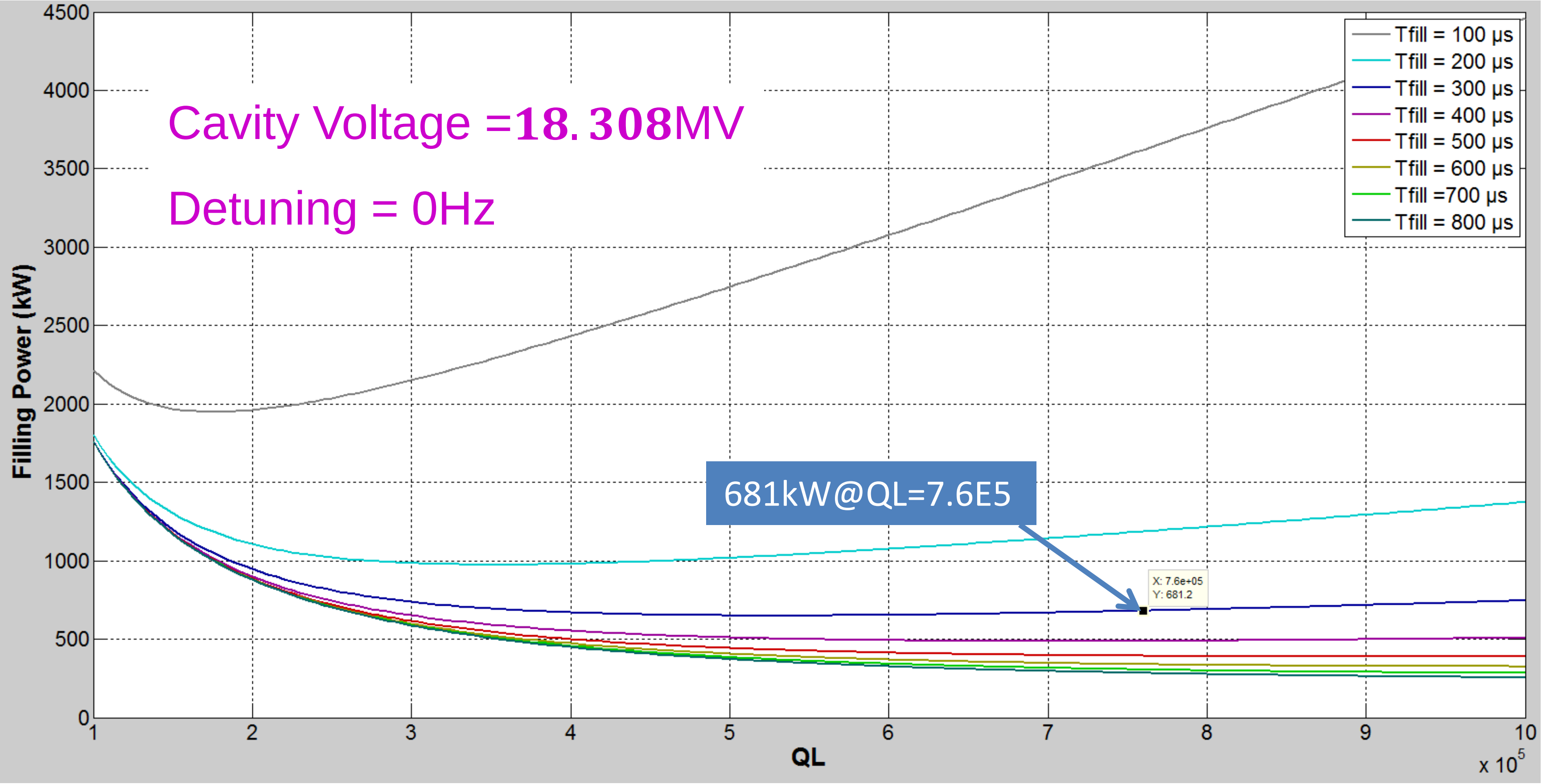


For optimal filling:

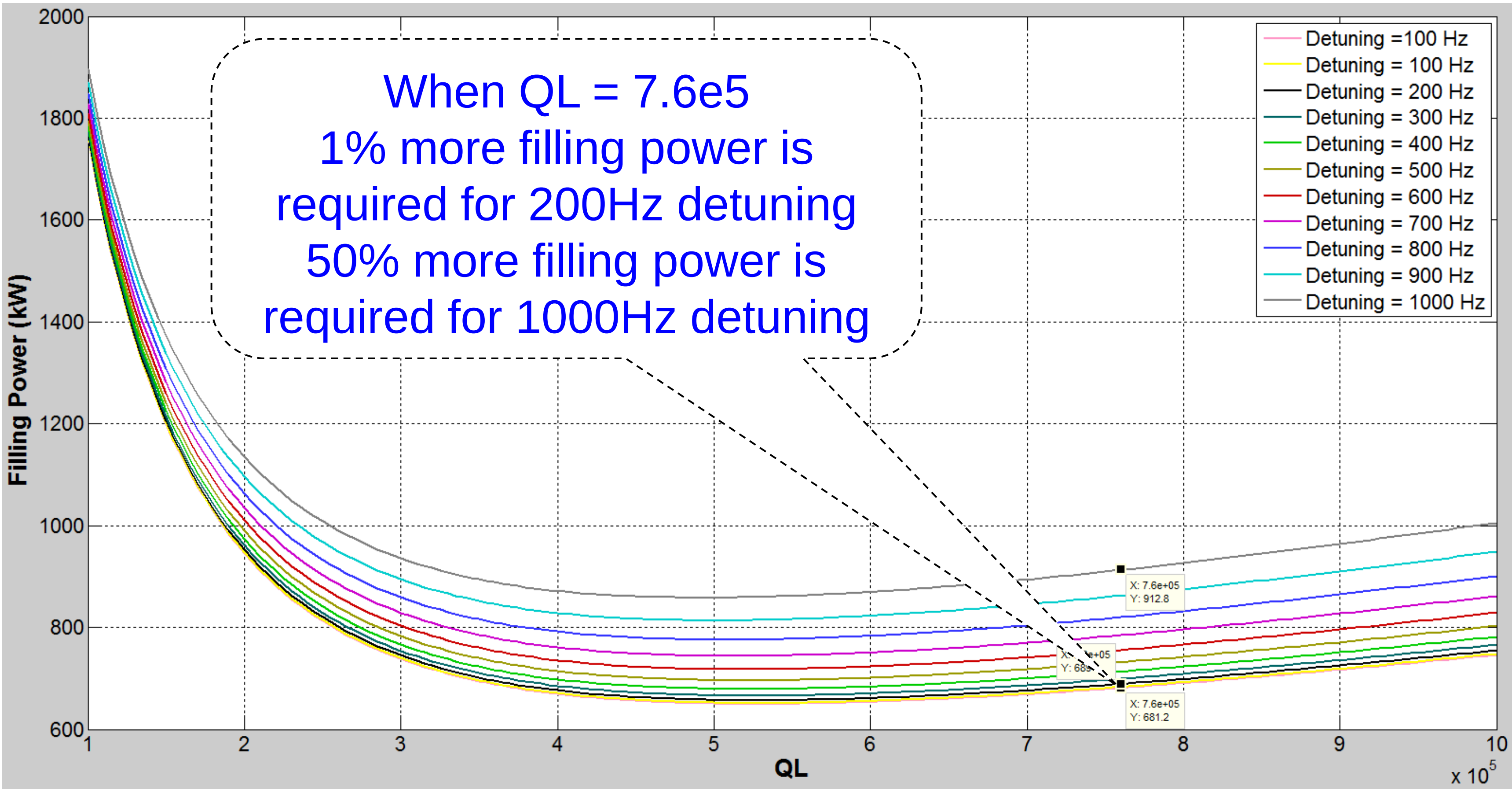


# High Beta elliptical cavity

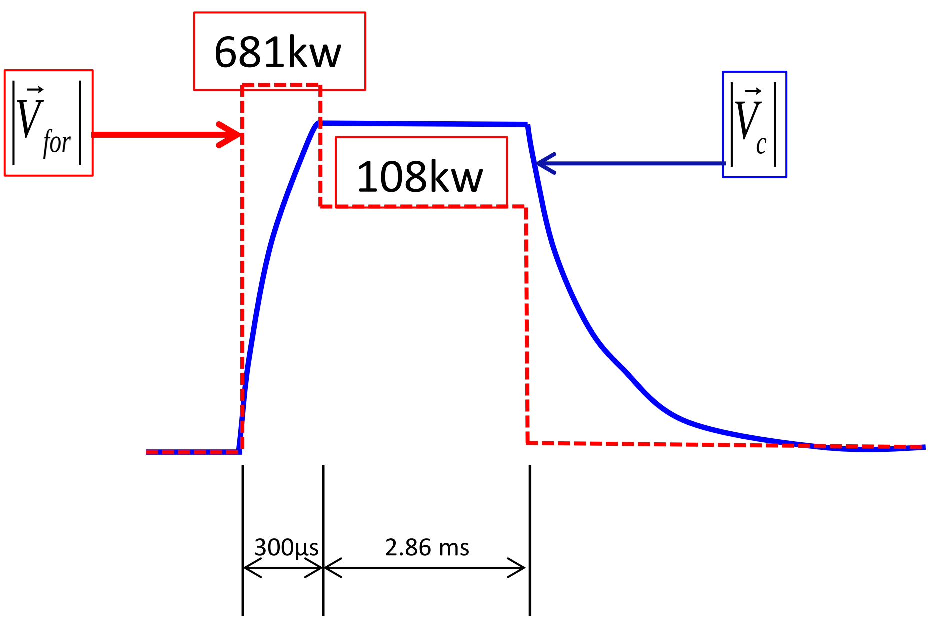



Enough RF power for us to try the charging time experiment !

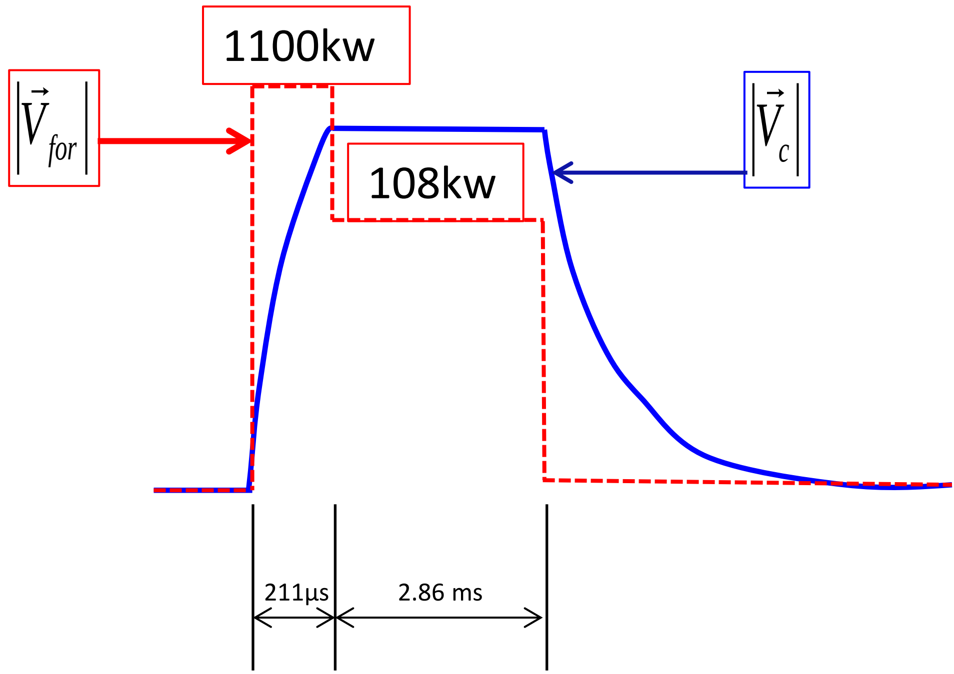

When QL = 7.6e5
1% more filling power is
required for 200Hz detuning
50% more filling power is
required for 1000Hz detuning
Filling Power (kW)
2000
1800
1600
1400
1200
1000
800
600
1
2
3
4
5
6
7
8
9
10
QL
x 10^5
Detuning =100 Hz
Detuning = 100 Hz
Detuning = 200 Hz
Detuning = 300 Hz
Detuning = 400 Hz
Detuning = 500 Hz
Detuning = 600 Hz
Detuning = 700 Hz
Detuning = 800 Hz
Detuning = 900 Hz
Detuning = 1000 Hz
X: 7.6e+05
Y: 912.8
X: 7.6e+05
Y: 681.2

# Summary for elliptical cavity

For steps filling:




(a)




(b)

For optimal filling: