# 3HC parameters and Bunch Lengthening of PLS-II


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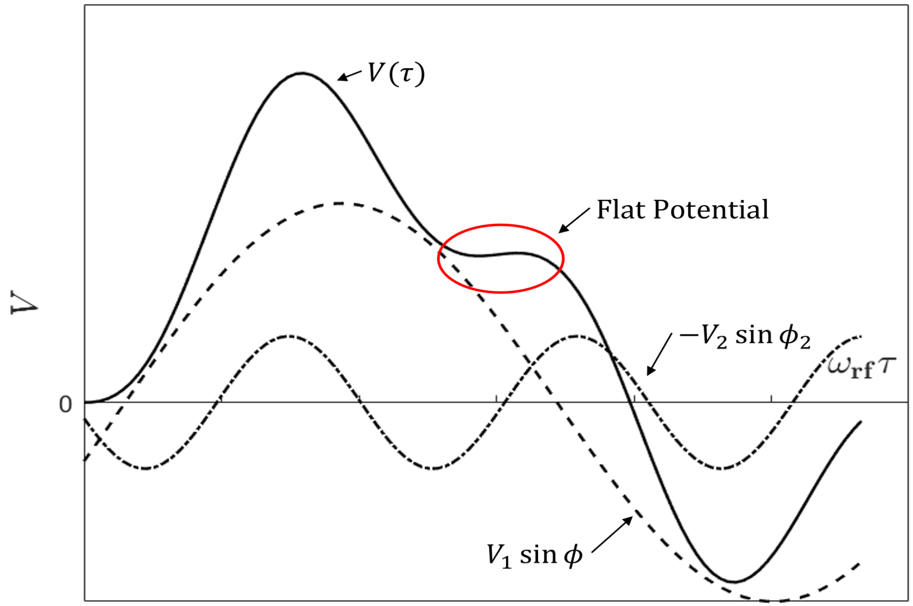
# Outline

# 1. Introduction to 3HC

- Harmonic cavity can *improve the beam quality through bunch size lengthening* which includes providing *Landau damping*, suppressing *coupled bunch instability* and *microwave instability*, enhancing the *beam current per bunch* besides the *lifetime improvement*. [Hou]

$$V(\tau) = V_1[\sin(\omega_{\mathrm{rf}}\tau + \phi_{1s}) - r\sin(m\omega_{\mathrm{rf}}\tau + \phi_{2s})] - \frac{U_0}{e}$$



# 2. RF parameters of PLS-II



Nominal parameters

| | |
|---|---|
| Harmonic number | $h = 470$ |
| RF frequency | $f_{RF} = 499.9742$ MHz |
| Revolution angular frequency | $\omega_0 = 6.6839$ MHz |
| Phase slip factor | $\eta \approx \alpha_c = 0.0013$ |
| Total electron energy loss | $U_0 = 1242.2$ keV |
| Accelerating voltage | $V_1 = 4.50$ MV |
| Synchronous phase | $\phi_{0s} = 155.52°$ |
| RMS bunch length | 6 mm or 20.01 ps |

Optimized 3HC parameters

| | |
|---|---|
| Synchronous phase | $\phi_{1s} = 152.21°$ |
| | $\phi_{2s} = 170.04°$ |
| Voltage ratio | $r = 0.30$ |
| Harmonic Voltage | $V_2 = 1.35$ MV |

# 3. Hamiltonian



- Hamiltonian without 3HC in $(\phi, \delta)$ phase space

$$\mathcal{H}(\phi,\delta) = \frac{1}{2} h\omega_0 \eta \delta^2 + \frac{\omega_0 eV}{2\pi\beta^2 E}[\cos\phi - \cos\phi_s + (\phi - \phi_s)\sin\phi_s]$$

- Hamiltonian without 3HC in $\left(\tau = \frac{\phi - \phi_s}{h\omega_0}, \delta\right)$ phase space

$$\mathcal{H}(\tau,\delta) = \frac{1}{2}\eta\delta^2 + \frac{eV}{2\pi h\beta^2 E}[\cos(\omega_{rf}\tau + \phi_s) - \cos\phi_s - \omega_{rf}\tau\sin\phi_s]$$

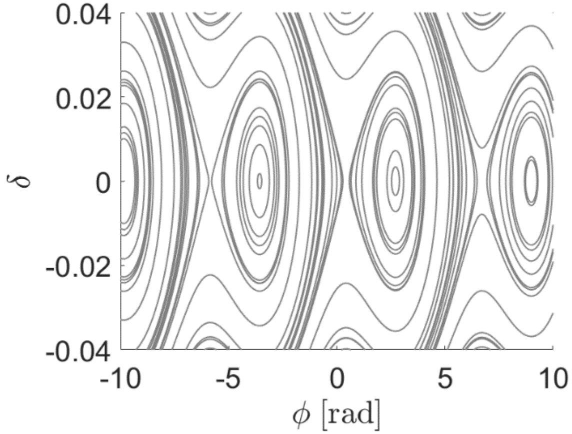
- Hamiltonian with 3HC in $(\tau, \delta)$ phase space

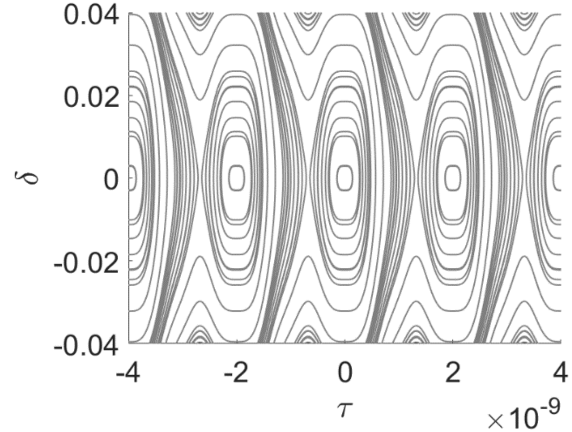
$$\mathcal{H}(\tau,\delta) = \frac{\eta}{2}\delta^2 + \frac{eV}{2\pi h\beta^2 E}\left[\cos(\omega_{rf}\tau + \phi_{1s}) - \cos\phi_{1s} - \frac{r}{m}\cos(m\omega_{rf}\tau + \phi_{2s}) + \frac{r}{m}\cos\phi_{2s} + \omega_{rf}\tau\sin\phi_{0s}\right]$$

# 4. Phase-space diagram

- Hamiltonian

w/o 3HC



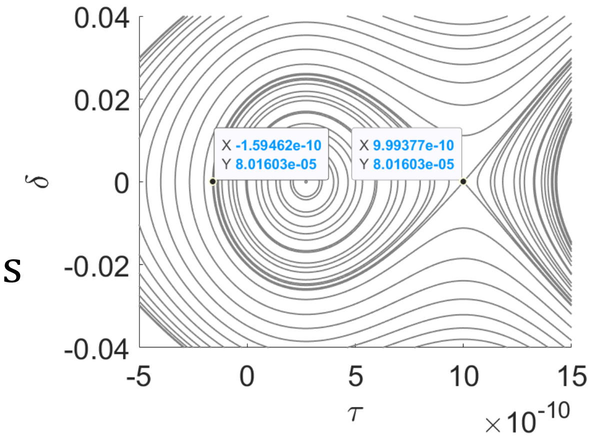



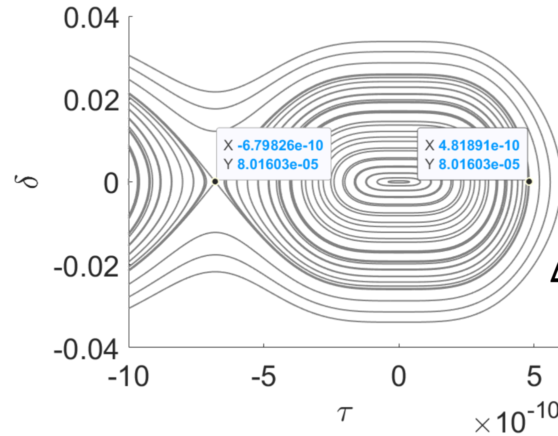

w/ 3HC

- Separatrix

w/o 3HC

$\Delta\tau = 1159$ ps



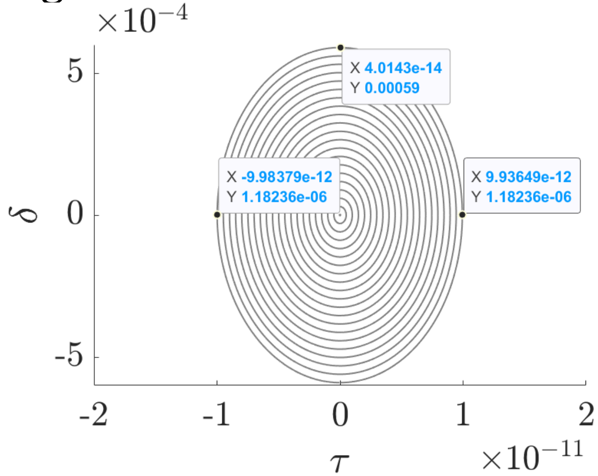




w/ 3HC

$\Delta\tau = 1161.72$ ps

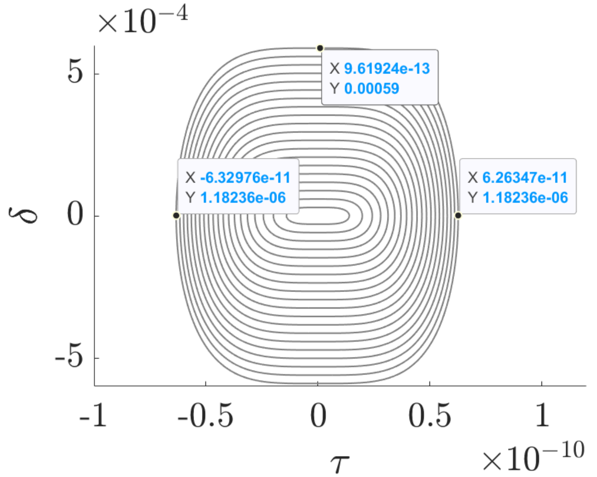
# 5. Bunch lengthening in PLS-II

- Bunch length without 3HC ≈ 6 mm




$\Delta t = 19.92$ ps, $\delta_{\max} = 0.059\%$

- Bunch length with 3HC (maintaining $\delta_{\max} = 0.059\%$)




$\Delta t = 125.96$ ps, $l_b = 37.76$ mm

<u>Bunch lengthening factor = 6.3</u>

# 6. Further Research



- However, 3HC will introduce significant beam loading effects due to operation with a nonuniform filling pattern. This means that the cavity will have a unique influence on each bunch in addition to the same influence on all bunches in a bunch train, which makes the bunches have different motion modes. [Zhou]

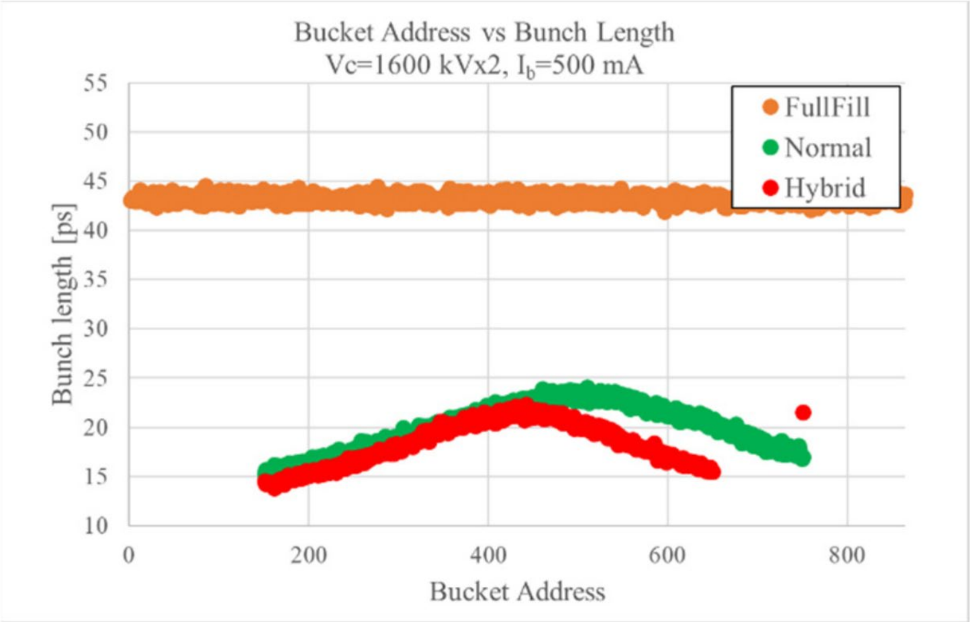



Figure 3: Bunch lengths along the bunch train for different fill patterns.

Image adopted from Ref. [Liu]

# 6. Further Research

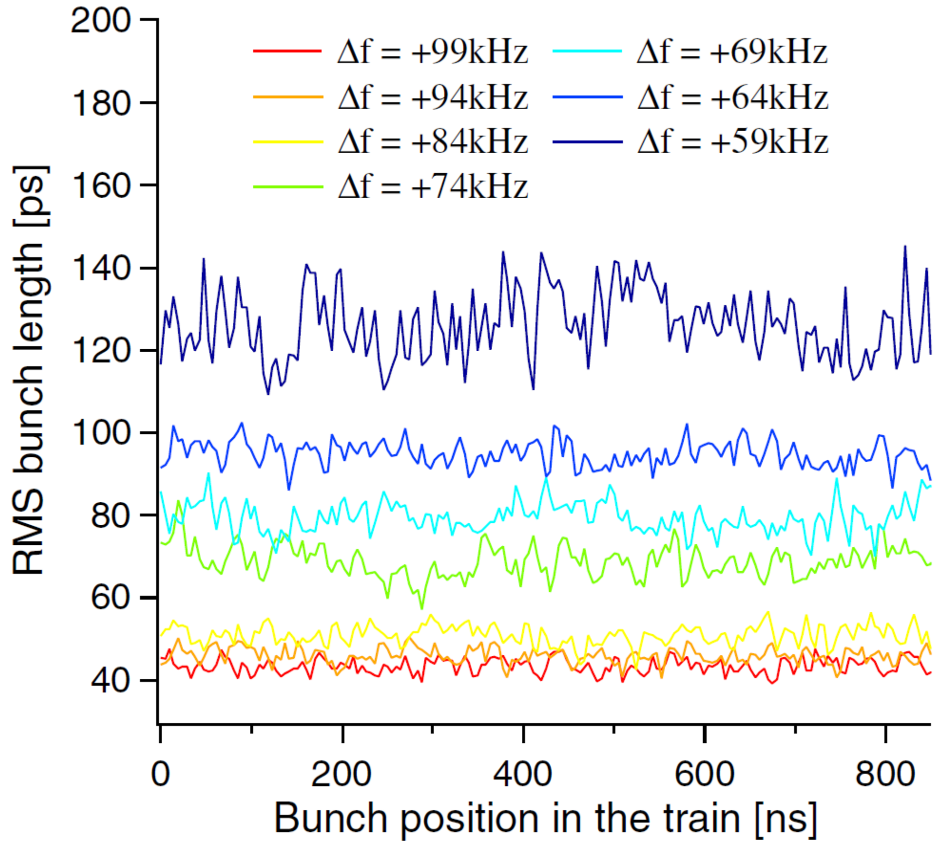



FIG. 11. (Color) rms bunch length along the bunch train for several 3HC tuning for uniform filling; $I_{\text{beam}} = 315$ mA, $E = 2.0$ GeV.

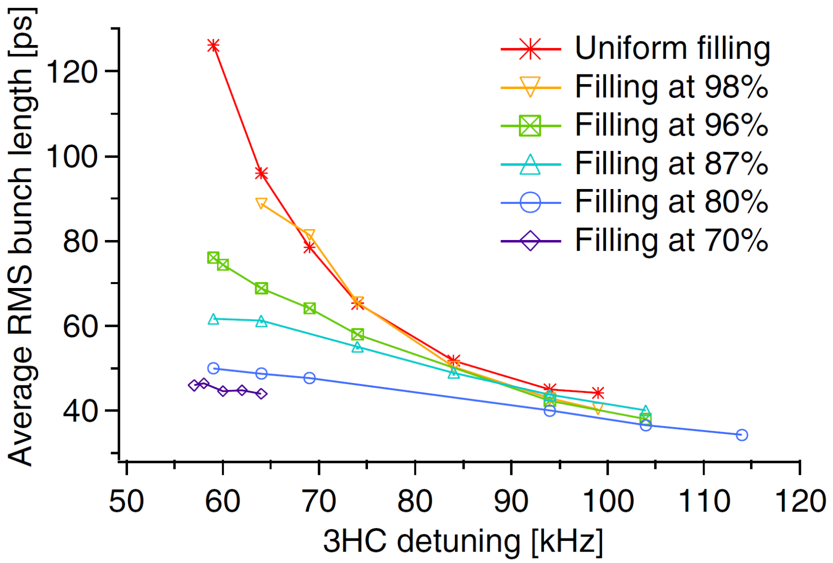



FIG. 13. (Color) Average rms bunch length along the bunch train for several 3HC tuning; $I_{\text{beam}} = 315$ mA, $E = 2.0$ GeV.

Images adopted from Ref. [Penco]

# 6. Further Research

- Bunch overstretching

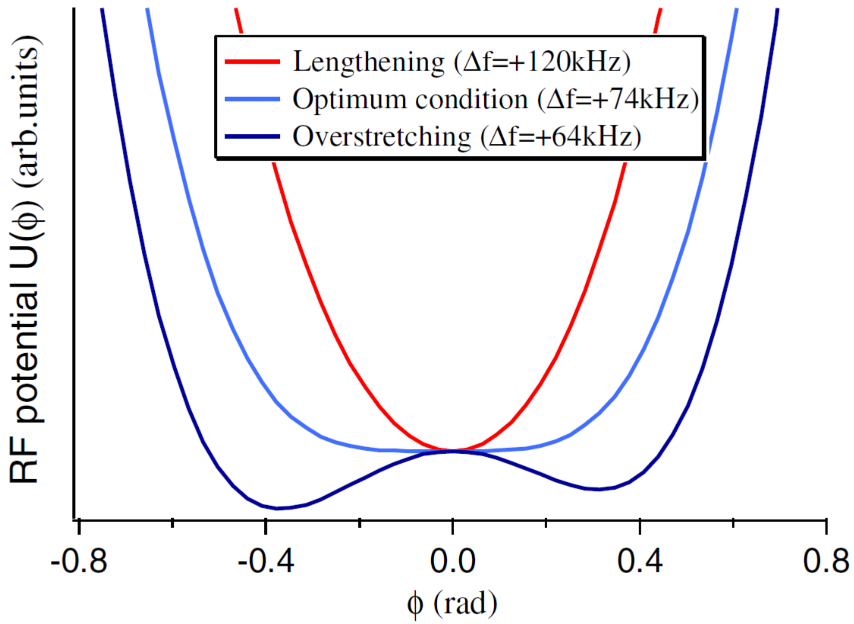



FIG. 14. (Color) Potential well distortion in lengthening mode, at optimum condition (flattened) and in overstretching regime, calculated for $I_{beam}$ = 315 mA by using formula (5).

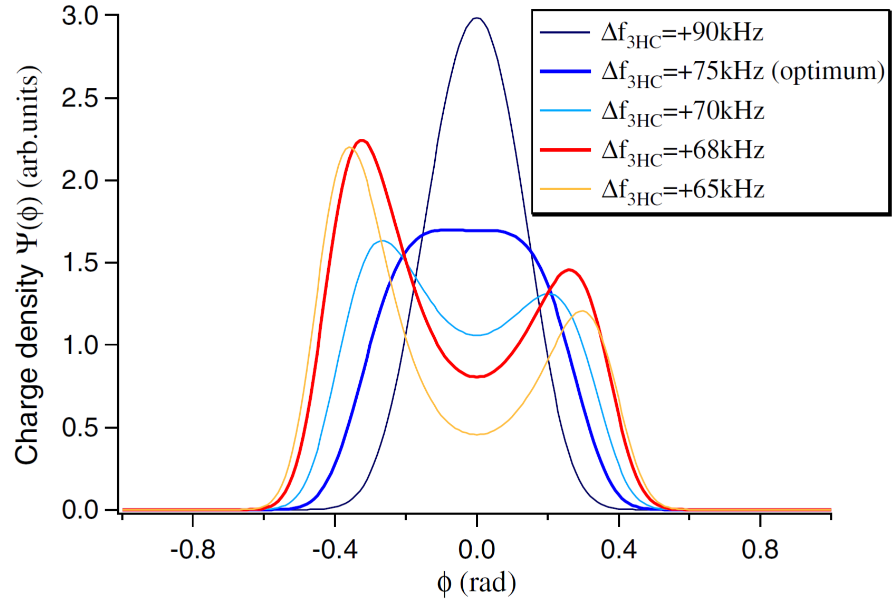



FIG. 15. (Color) Nominal charge density in the bunch in function of the 3HC detuning, calculated in uniform filling and at 315 mA by using formula (9).

$$U(\phi) = \frac{1}{V_2 \cos \phi_{1s}} \int_0^{\phi} [V(\phi) - U_0] d\phi$$

Images adopted from Ref. [Penco]

# References




1. [Zhou] Yimei Zhou, *et al.* Experimant verification and analysis of the beam loading effect based on precise bunch-by-bunch 3D position measurement, *Nucl. Instrum. Methods Phys. Res., Sect. A*, 168201 **1051** (2023)

2. [Liu] Z. –K. Liu, *et al.*, Determination of the Electron Bunch Length with Third Harmonic Cavity for the Taiwan Photon Source, in *Proceedings of the 9th International Particle Accelerator Conference, IPAC2018, Vancouver, BC, Canada, 2018*

3. [Penco] Giuseppe Penco, Michele Svandrlik, Experimental studies on transient beam loading effects in the presence of a superconducting third harmonic cavity, *Phys. Rev. ST Accel. Beams* **9**, 04401 (2006)