# RF-BASED BUNCH COMPRESSION IN THE APS-U PARTICLE ACCUMULATOR RING

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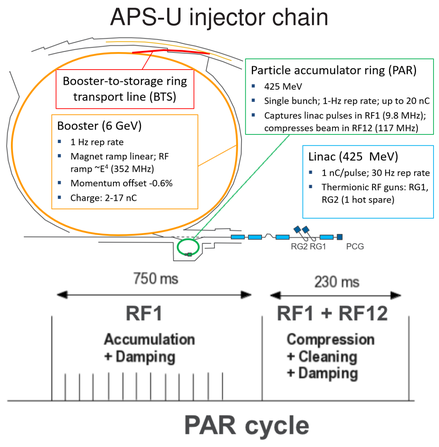
## ABSTRACT

The Advanced Photon Source Upgrade (APS-U) operates using swap-out injection, where depleted bunches in the storage ring are replaced by fresh bunches from the injector [1]. Producing high charge (up to 20 nC) is particularly demanding on the injector chain. To deliver these charge levels to the storage ring, the booster requires bunches with short duration while tolerating relatively large energy spread. Compression using the 12th-harmonic cavity in the PAR alone is insufficient to meet these requirements at high charge. As an alternative, RF gymnastics can be applied near extraction in the PAR to further shorten the bunch [2, 3].

## APS-U Injector

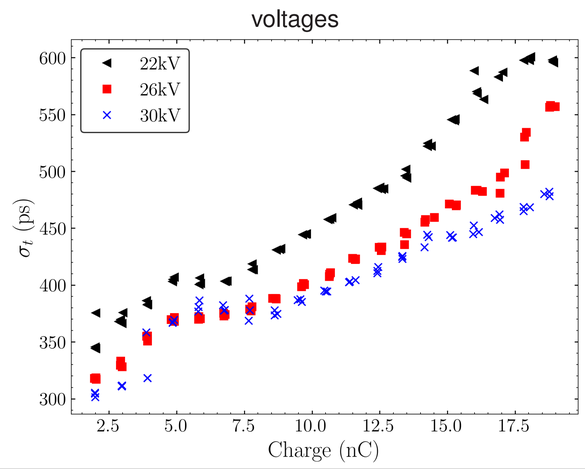
APS-U injector chain




- LINAC bunches (425 MeV) are injected into the PAR.
- PAR RF is used to capture up to 20 nC.
- PAR 12th harmonic is used to reduce the bunch duration.
- Bunch lengthening is observed at higher charge.
- Booster efficiency benefits from a shorter bunch length.

## PAR bunch lengthening

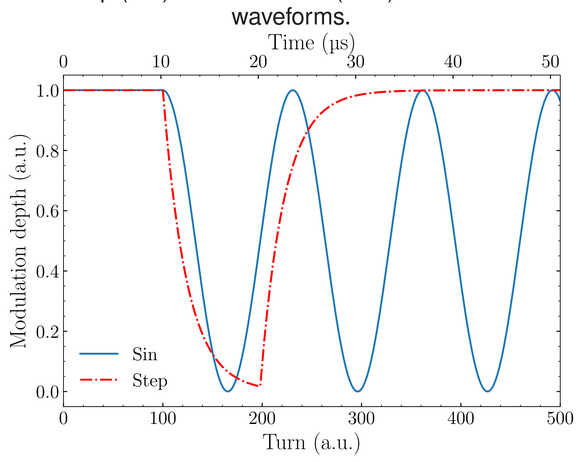
Bunch lengthening at higher charge for different RF12 voltages




- Bunch lengthening is observed in the PAR at different RF12 voltages.
- Booster efficiency increases as the bunch duration decreases.
- At high charges, PAR bunch length remains large. Alternatively, RF gymnastics can be used to compress the bunch further

## SIMULATIONS

Step (red) and sinusoidal (blue) modulation waveforms.




- Two modulation schemes were investigated:
- Sinusoidal modulation:

$$A(t) = A_0 \cos(2\pi f_m t)$$

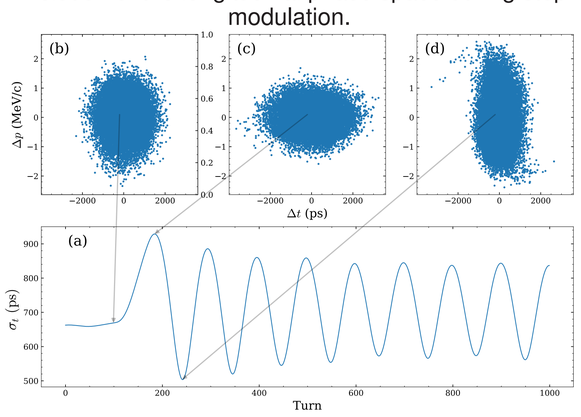
- Step modulation:

$$A(t) = A_0 e^{-t/\tau}$$

- where the cavity decay time is

$$\tau = \frac{Q_L}{\pi f_0}.$$

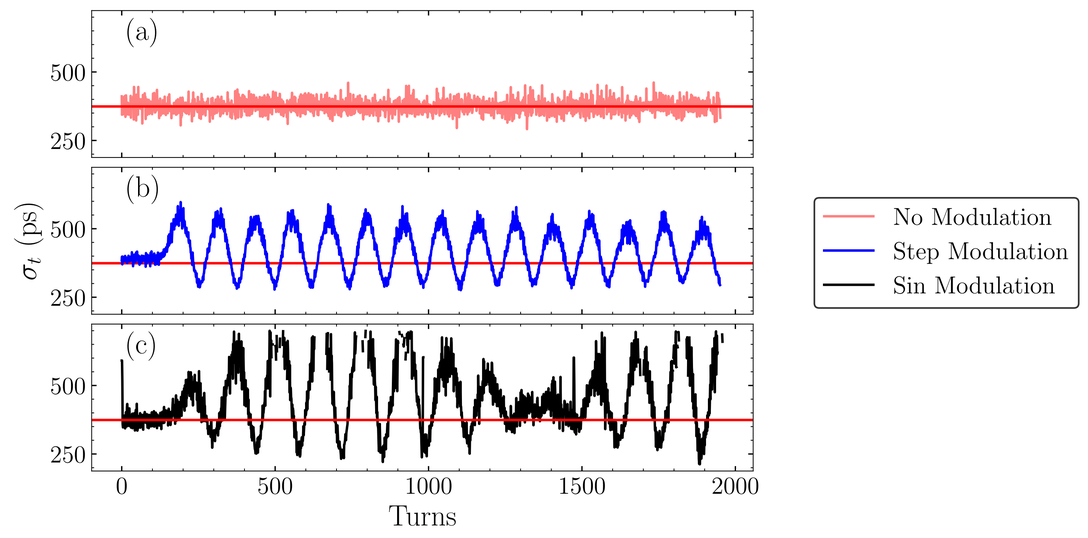
Evolution of the longitudinal phase space during step modulation.



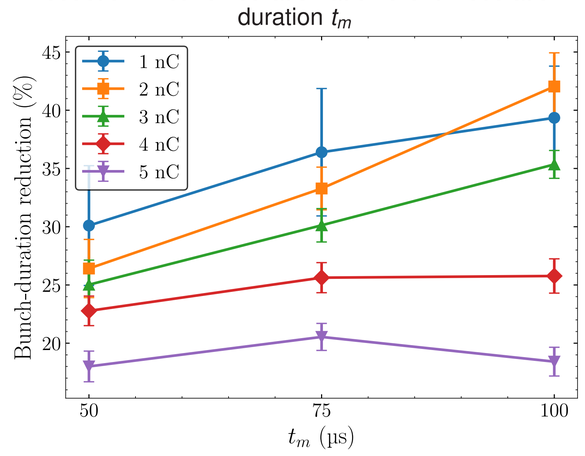

- The modulation initially stretches the bunch, inducing a longitudinal quadrupole oscillation.
- After approximately one-half synchrotron period (half a phase-space rotation), the bunch reaches its minimum bunch duration and maximum energy spread.
- Extracting the beam at this point produces the shortest bunch.
- Simulations indicate that extraction should occur within the first $\sim$ 100 turns ($\sim$ 10 µs in the PAR). The optimum extraction time depends on the modulation parameters.

## EXPERIMENT

1 nC modulation results




Reduction in bunch duration at different modulation duration $t_m$




- We scanned different modulation duration $t_m$ at 100% depth of the modulation.
- As the charge is increased, the bunch shortening effect is reduced.
- More studies will be performed to repeat this at higher charge and higher voltage with better RF control.

## CONCLUSION

- A proof-of-principle experiment for RF modulation in the PAR was demonstrated.
- More work is needed to implement this at higher charge and higher voltage, simulations suggest up to 30% bunch duration reduction at higher charge.
- Extraction into the booster will need to be demonstrated, which is expected to be the most challenging part of this method.

## REFERENCES

[1] M. Borland et al. The Upgrade of the Advanced Photon Source. In *Proc. IPAC'18*, pages 2872–2877. JACoW Publishing, Geneva, Switzerland.

[2] Michiko G Minty, R Akre, FJ Decker, and J Turner. Operation and performance of bunch precompression for increased current transmission at the slc. In *Proceedings of the 1997 Particle Accelerator Conference (Cat. No. 97CH36167)*, volume 2, pages 1569–1571. IEEE, 1997.

[3] Glenn Decker, Michael Borland, Doug Horan, Alex Lumpkin, Nicholas Sereno, Bingxin Yang, and Samuel Krinsky. Transient bunch compression using pulsed phase modulation<? format?> in high-energy electron storage rings. *Physical Review Special Topics—Accelerators and Beams*, 9(12):120702, 2006.

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