Northern Illinois University

Preparation for experimental demonstration of arbitrary correlation generation

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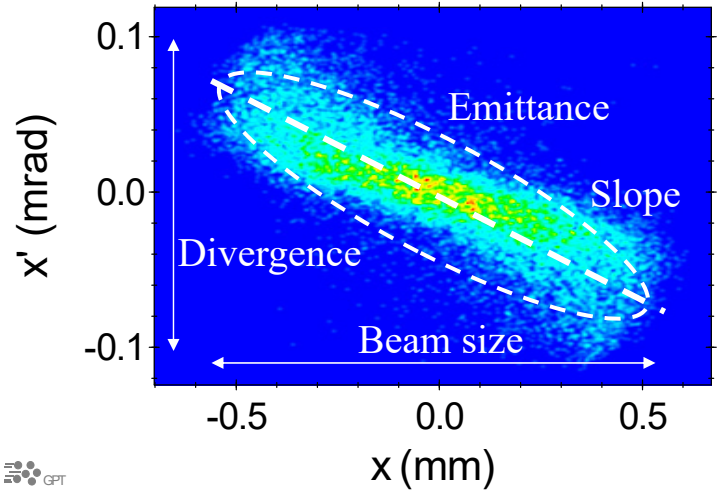
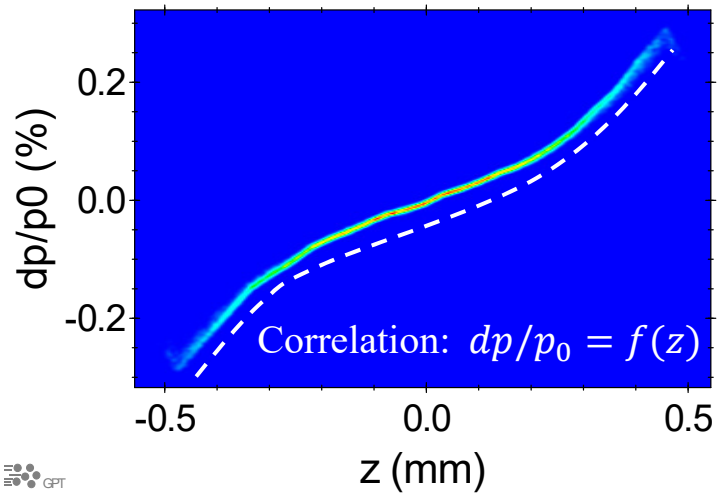
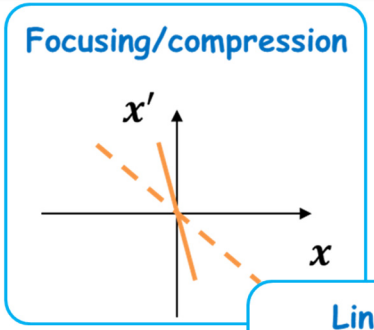
What is “correlation”?

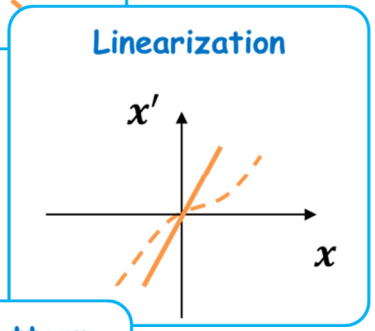
- “Correlation” refers to the relationship between the coordinates of particles.
- By tracking local averages, we can define this relationship in the form of a function.

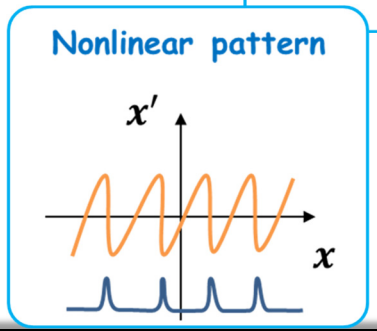


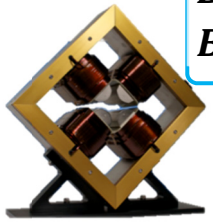


Correlation control principle

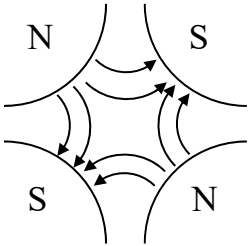


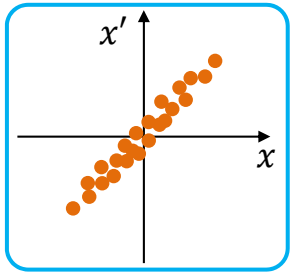






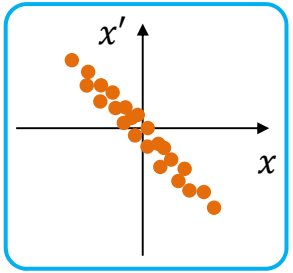
$$B_y = G \times x$$
$$B_x = G \times y$$

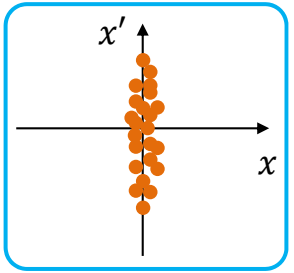




$$F(x, y, z)$$

$$p_{(x,y,z)} \quad (x, y, z)$$

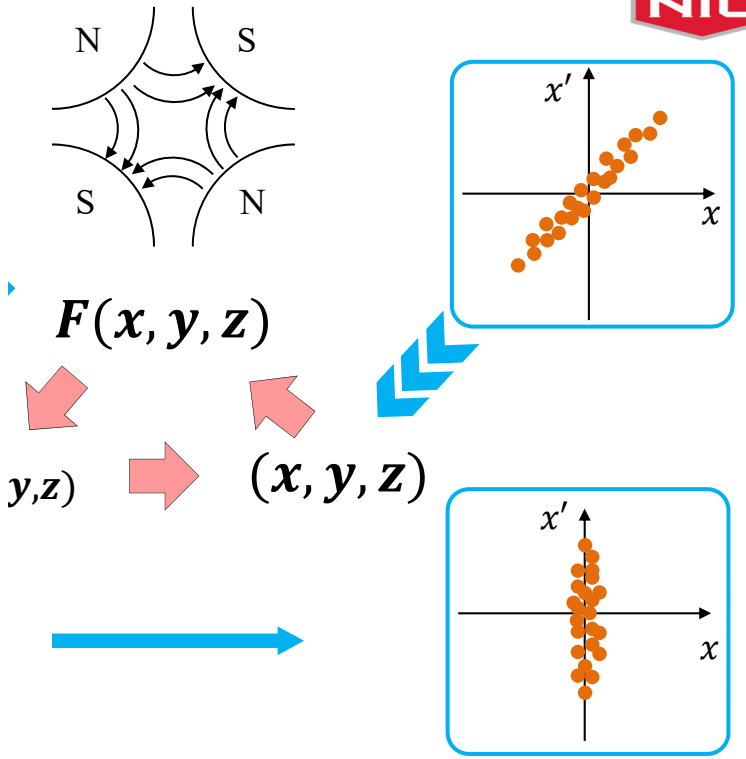




Correlation control is what we do everyday!

Correlation control principle

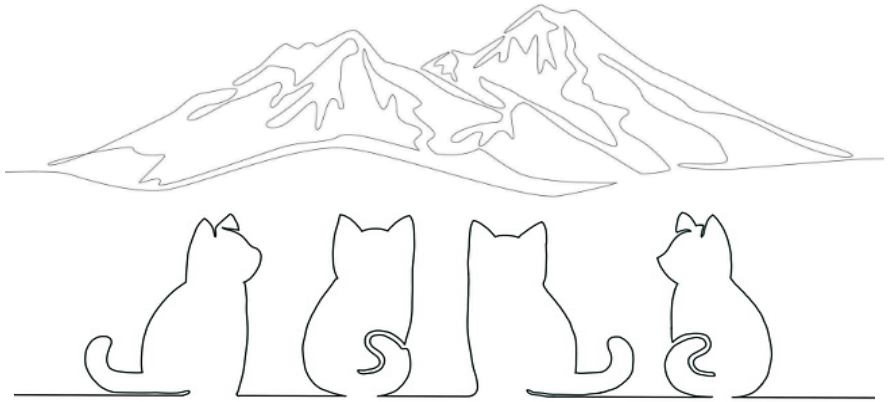
If there are proper **CONCEPT** and **TOOLS**, we can probably do more than this!



Correlation control is what we do everyday!

Painting on the phase space

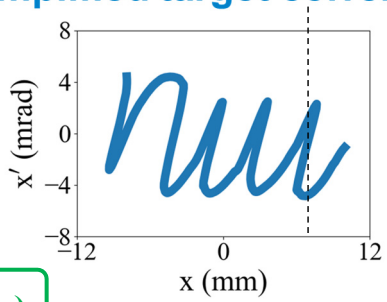
Can we draw something like below on the phase space?



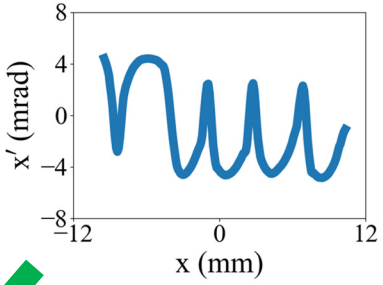
Suggestion for CONCEPT

Target arbitrary correlation

Simplified target correlation



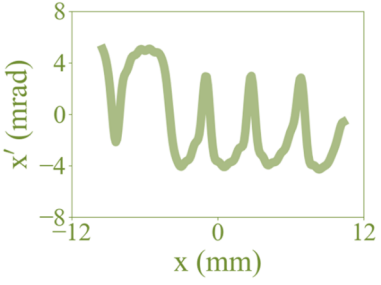
Back-drifting to generate x'=f(x) function



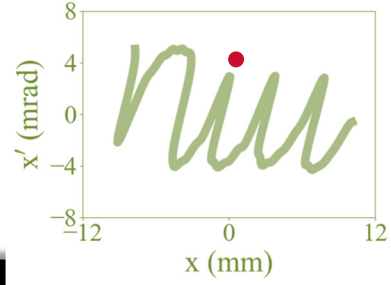
Approximation to cosine sum (e.g., Fourier series)

$$x' = f(x) \approx A_0 + \sum_{n=1}^{N} \left[A_n \cos\left(\frac{2\pi n x}{\lambda}\right) + B_n \sin\left(\frac{2\pi n x}{\lambda}\right) \right]$$

Fourier approximation (70 harmonics)



Final result after drift

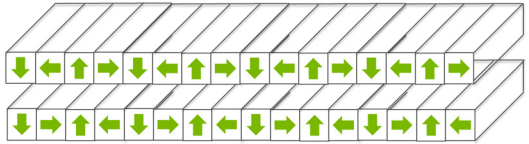


Arbitrary correlation is achievable!

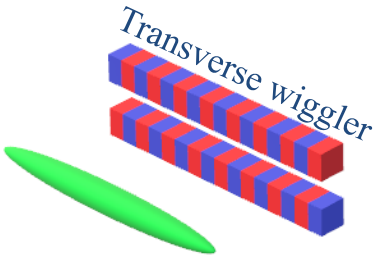
Suggestion for TOOL

Amplitude control: ? **Frequency control: ?** **Phase control: ?**

Transverse wiggler



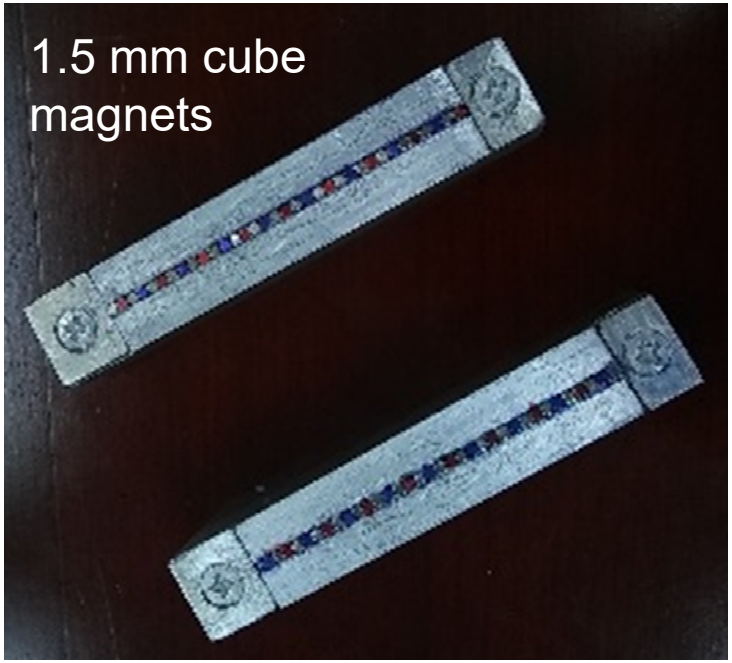
$$B_y \approx -2B_r \cos\left(\frac{2\pi}{\lambda_u}x\right)\exp\left[-\frac{\pi g}{\lambda_u}\right]$$



Easy

Not tunable?

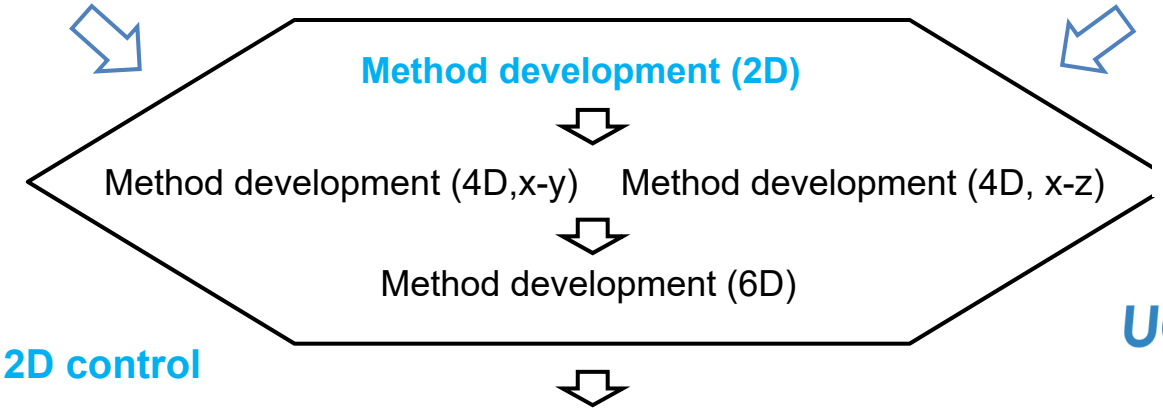
Easy



General plan

Efficient optimization algorithm and feedback system

Advanced tool development



Tunable-period transverse wiggler Or Reconfiggler

Argonne NATIONAL LABORATORY

UCLA SLAC NATIONAL ACCELERATOR LABORATORY

Applications

Applications of 2D control

- **Profile shaping**
- **Bunch train**
- **Linearization**

Demo I: profile shaping

- If we know the initial profile, target profile and downstream optics, we can estimate what correlation is required to generate the target profile.

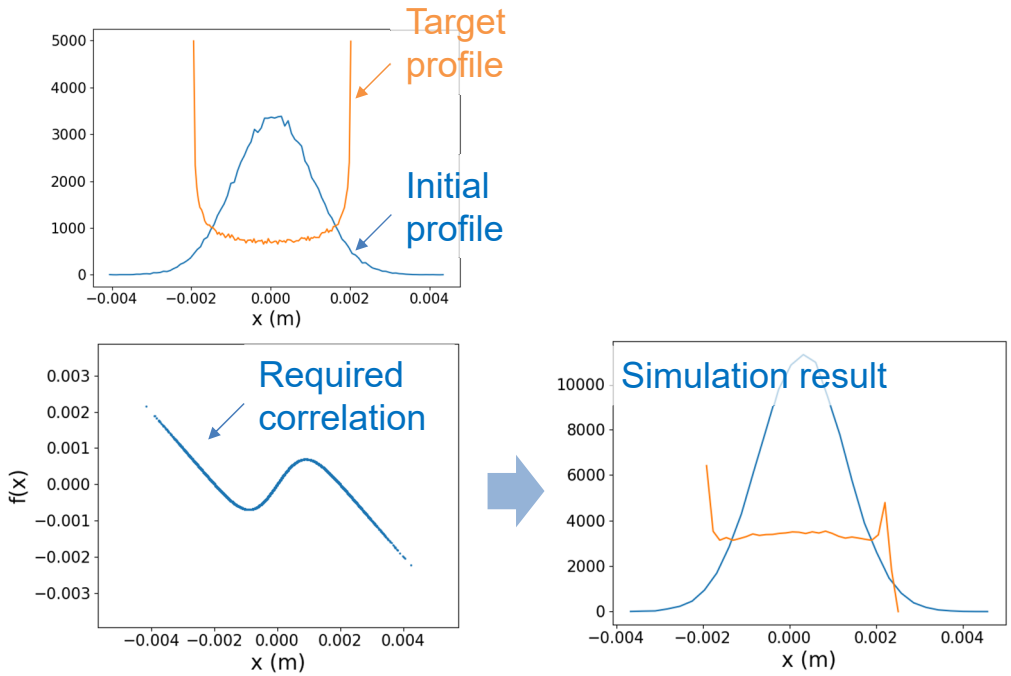
Particle conservation

$$N_f(x_f)\mathrm{d}x_f = N_0(x_0)\mathrm{d}x_0,$$

Map

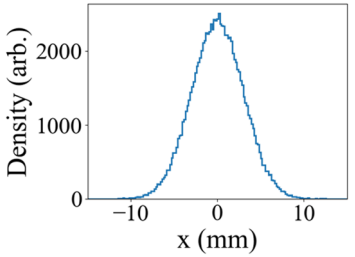
$$M: x_0 \rightarrow x_f$$

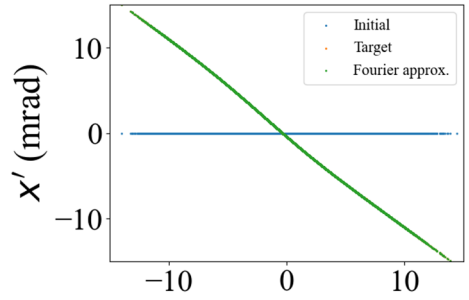
$$N_f(R_{11}x_0 + R_{12}f)\{R_{11} + R_{12}f'\} = N_0(x_0)$$

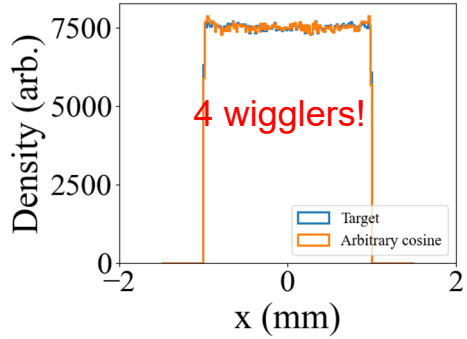


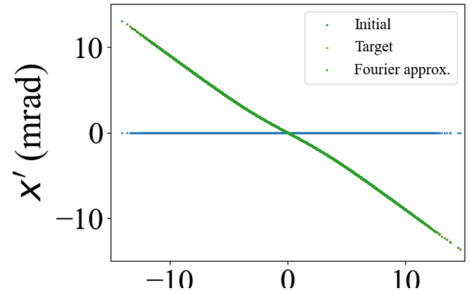
Demo I: profile shaping

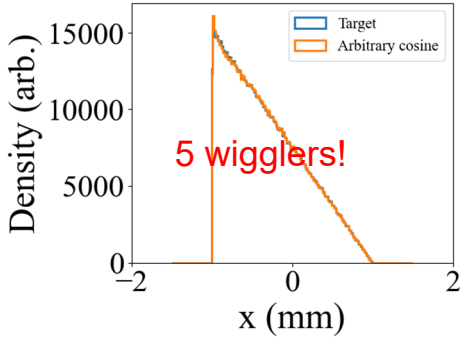
- In principle, we can convert arbitrary input profile to arbitrary longitudinal profile
- Extremely high shaping quality is expected
- Currently, designing transverse wiggler combinations using S2E simulated beam

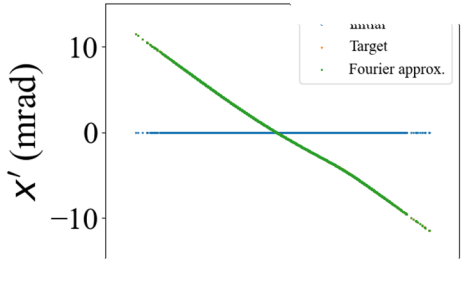


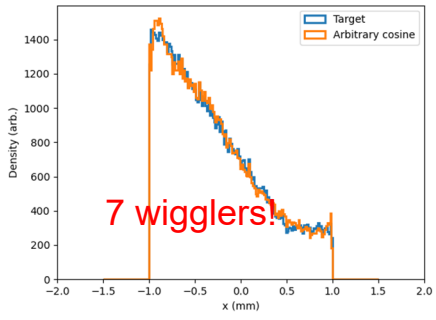






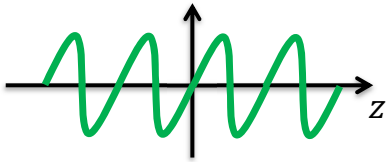






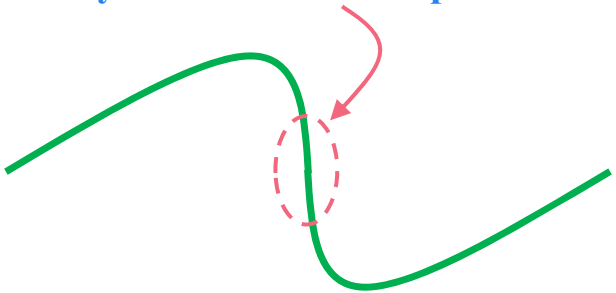
Demo II: periodic modulation

Sine-modulation generates density spikes

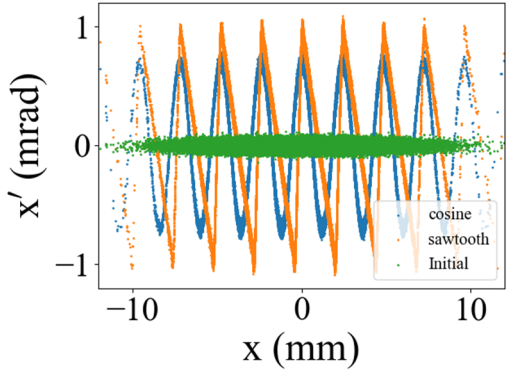


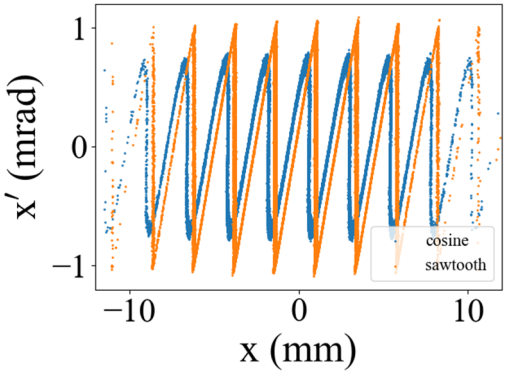
z-δ correlation + R_{56}

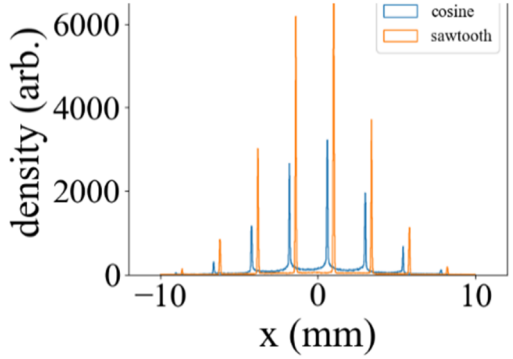
However, only linear parts really contribute on the peak

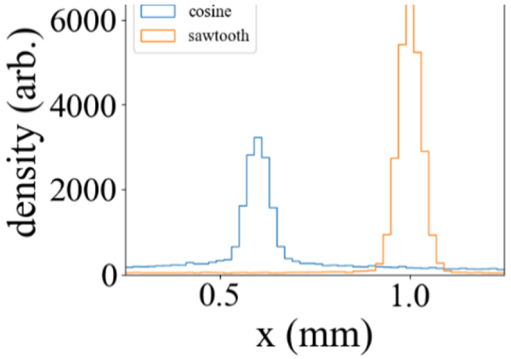


Saw-tooth correlation will significantly enhance the peak



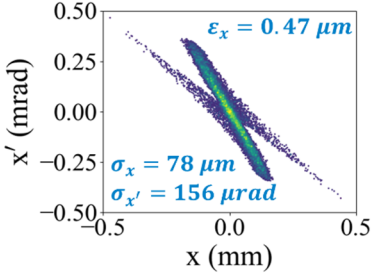




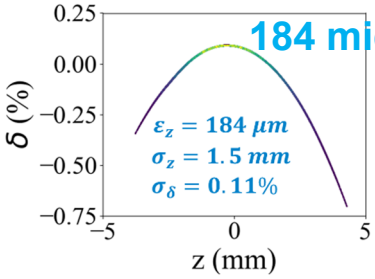


Demo III: linearization

Large longi. emittance is mainly due to nonlinearity ➡ **Correction using transverse wigglers**

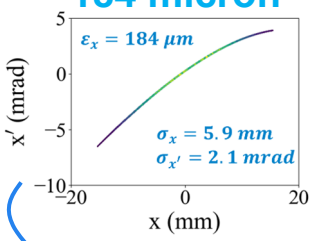


0.47 micron

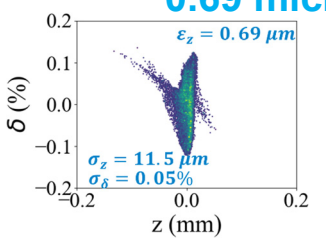


184 micron

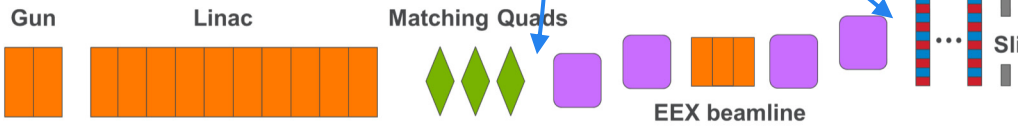
184 micron



0.69 micron

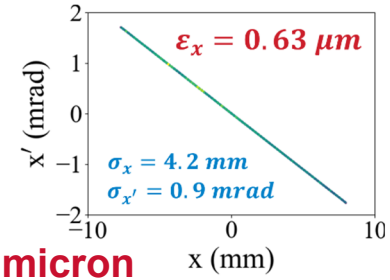


Transverse wiggler linearizer

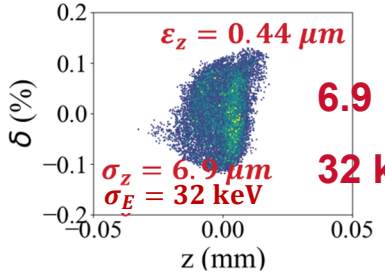


Slit for periphery cut 100 → 80 pC

0.44 micron



0.63 micron



6.9 um

32 keV

~~Linearizer~~

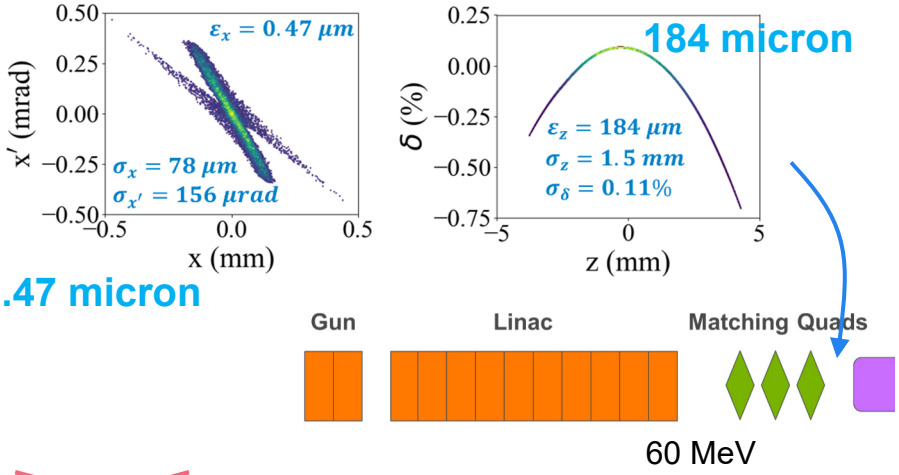
~~Bunch compressors~~

~~Laser heater~~

~~Chirping/dechirping process~~

Demo III: linearization

Large longi. emittance is mainly due to nonline



~~Linearizer~~

~~Bunch compressors~~

~~Laser heater~~

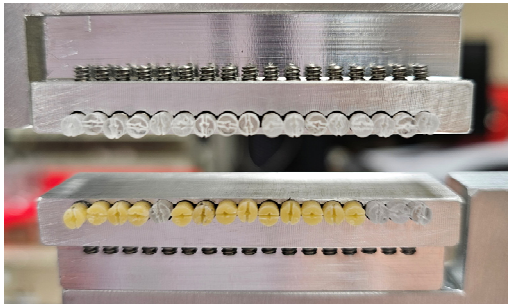
~~Chirping/dechirping process~~

Recent tool development effort: tunable wiggler

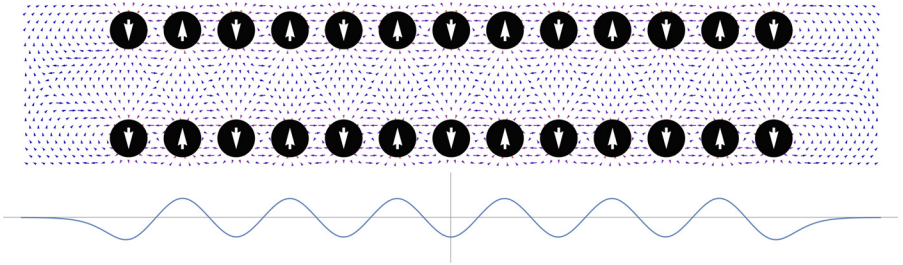
Rectangular PM-array

- It is cheap and tiny, so we can prepare many of them having different periods.
- But no period-tunability

Rotatable cylinder PM-array

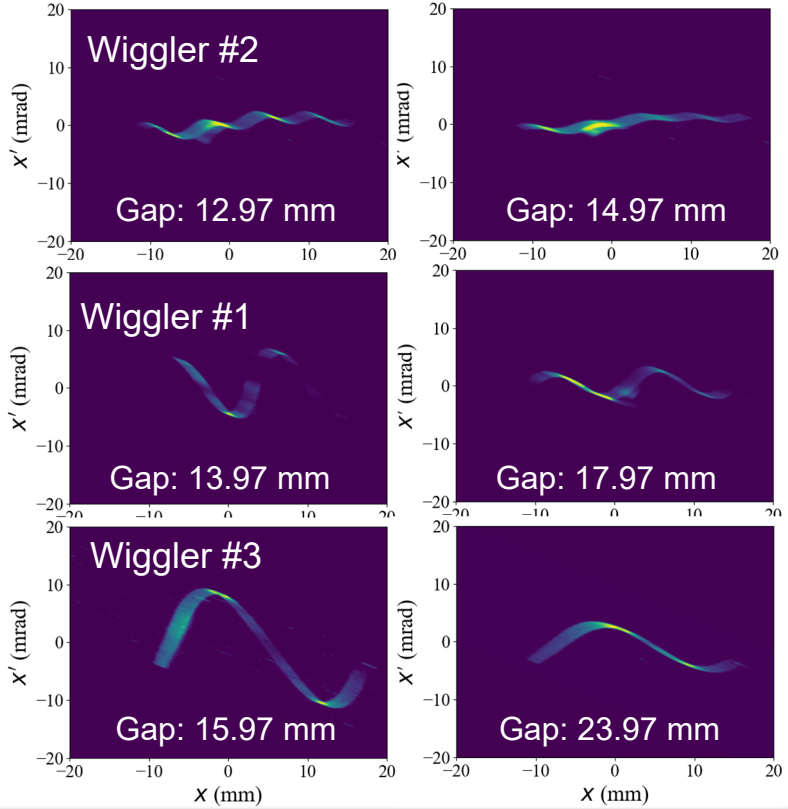


Period and phase tunable

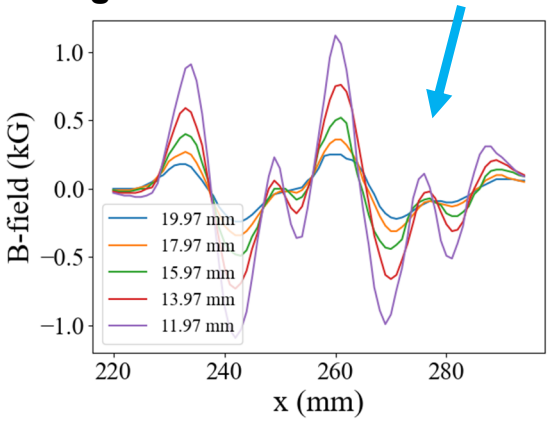


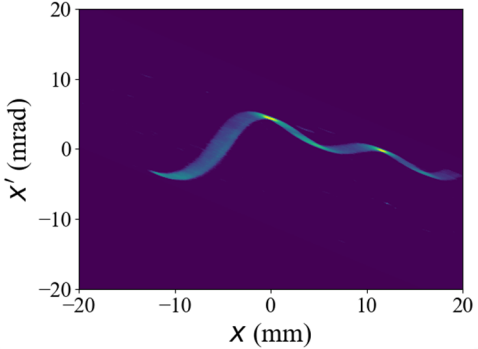
Experiment results: period tunability

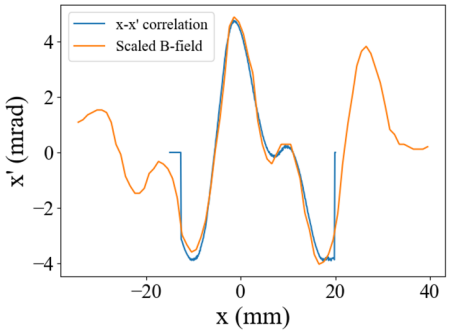
Both amplitude and period tunability were confirmed



Magnet angles were adjusted to generate summation of two sine curves

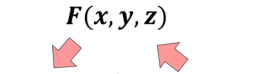


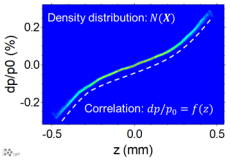




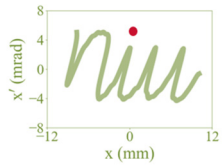
Summary

- Many of beam controls belong to the correlation control.
- Proper CONCEPT and TOOLs may provide new opportunities

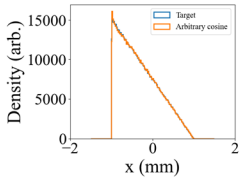


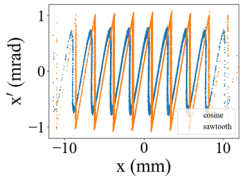


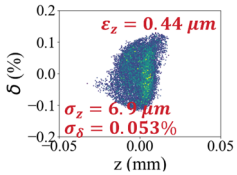
- We plan to demonstrate the generation of designed correlation using Fourier series/cosine sum with transverse wigglers



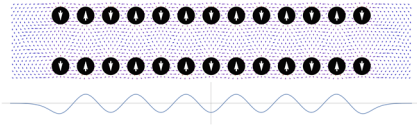
- Three major functions/applications will be demonstrated.







- Prototype tunable transverse wiggler has been demonstrated.



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