



Northern Illinois  
University

# Preparation for experimental demonstration of arbitrary correlation generation

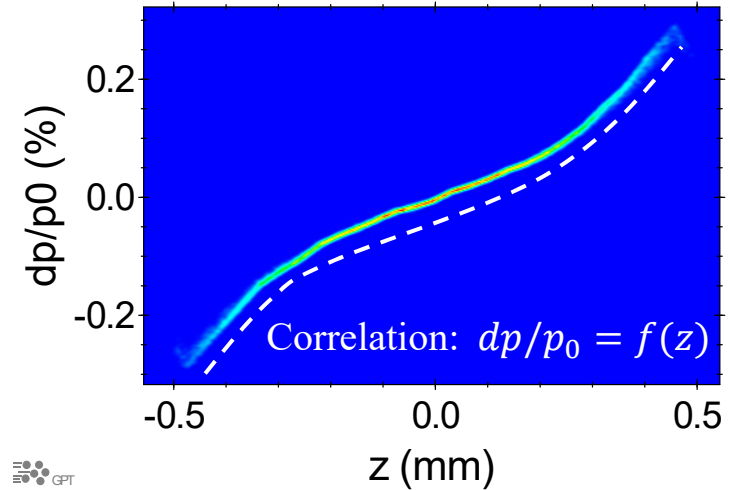
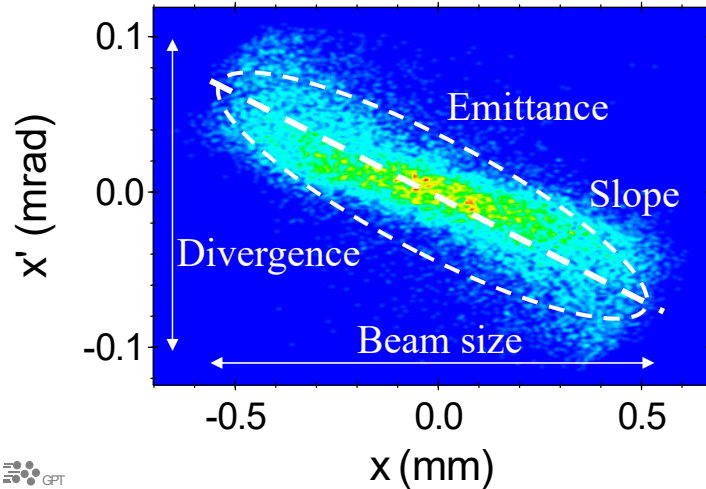
Gwanghui Ha

@ IPAC 2024, May 2024

# What is “correlation”?



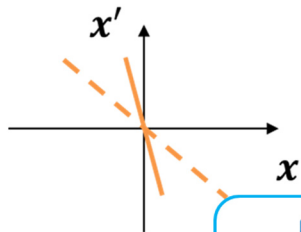
- “Correlation” refers to the relationship between the coordinates of particles.
- By tracking local averages, we can define this relationship in the form of a function.



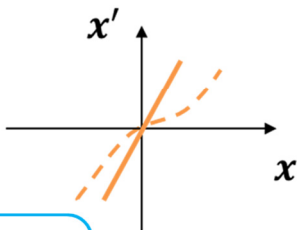
# Correlation control principle



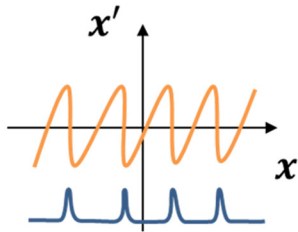
Focusing/compression



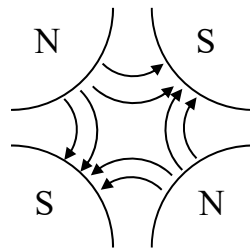
Linearization



Nonlinear pattern



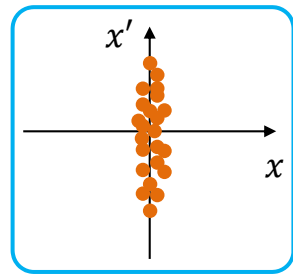
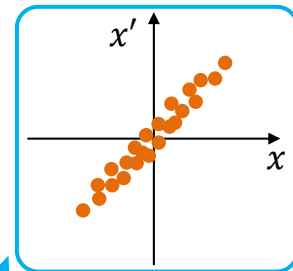
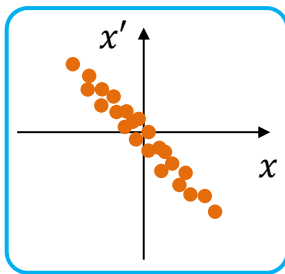
$$\begin{aligned} B_y &= G \times x \\ B_x &= G \times y \end{aligned}$$



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

$$p(x, y, z)$$

$$(x, y, z)$$

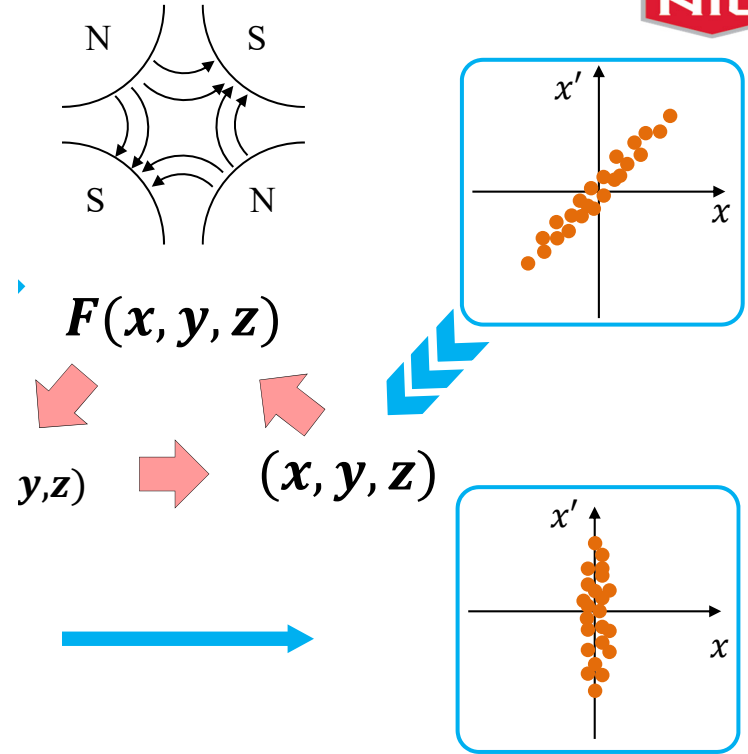


Correlation control is what we do everyday!

# Correlation control principle



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

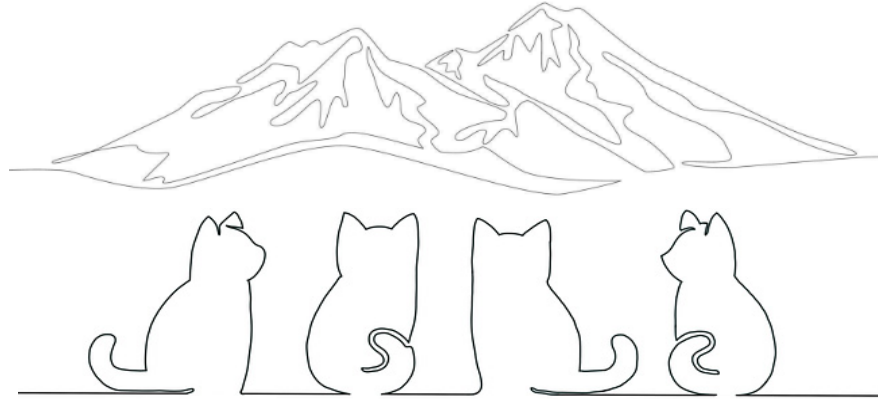


**Correlation control is what we do everyday!**

# Painting on the phase space



Can we draw something like below on the phase space?



# Suggestion for CONCEPT

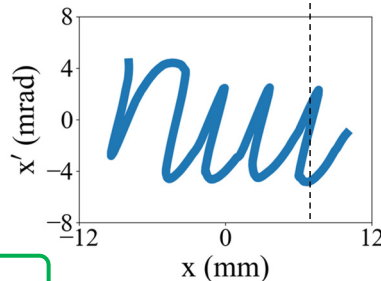


Target arbitrary correlation

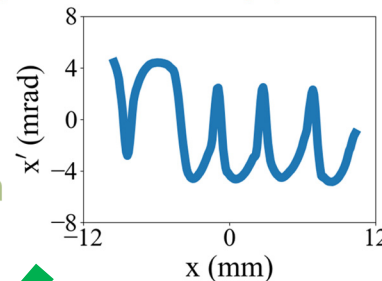
*mill*



Simplified target correlation



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

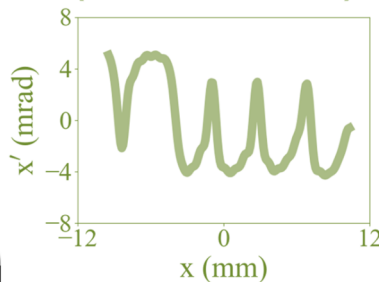


Arbitrary correlation is achievable!

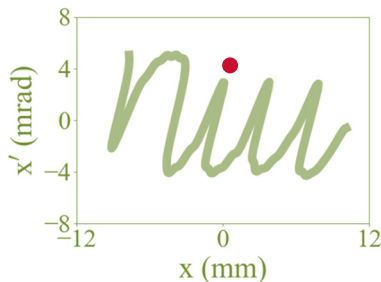
Approximation to cosine sum (e.g., Fourier series)

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

Fourier approximation (70 harmonics)



Final result after drift



# Suggestion for TOOL

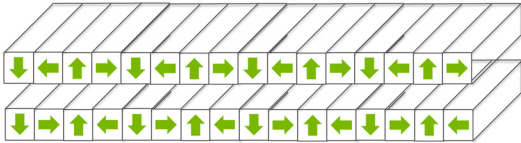


Amplitude control: ?

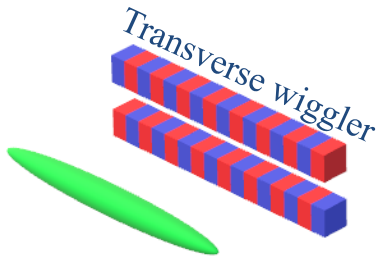
Frequency control: ?

Phase control: ?

## Transverse wiggler



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

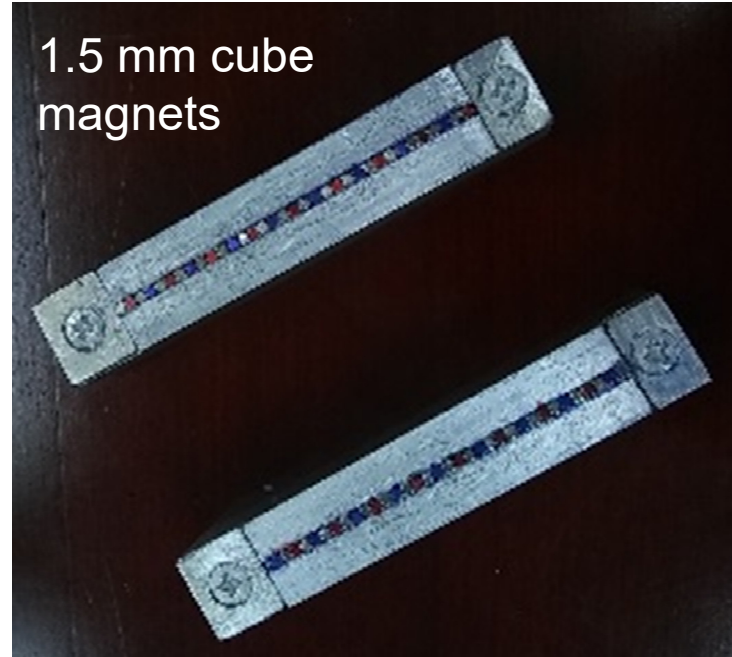


Easy

Not tunable?

Easy

1.5 mm cube magnets

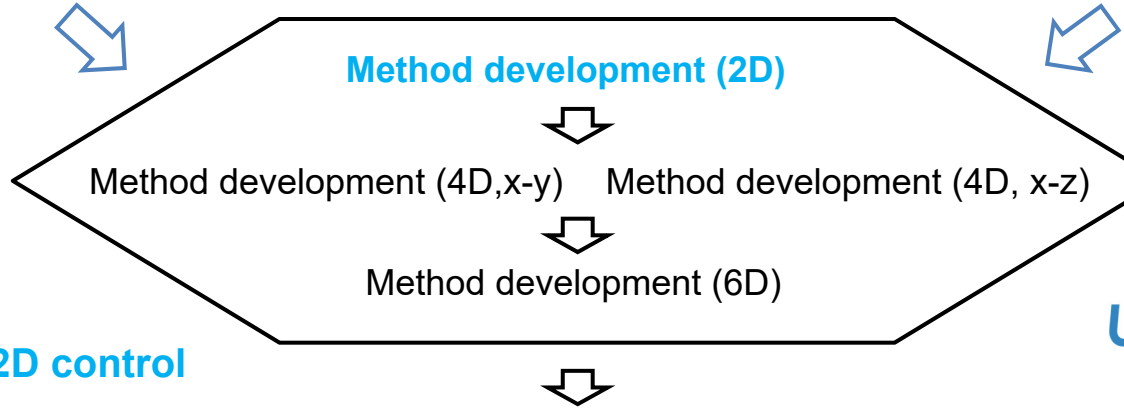


# General plan



Efficient optimization algorithm  
and feedback system

Advanced tool  
development



Tunable-period  
transverse wiggler  
Or Reconfiggler

Argonne   
NATIONAL LABORATORY

UCLA SLAC   
NATIONAL ACCELERATOR  
LABORATORY

Applications of 2D control

Applications

- 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.

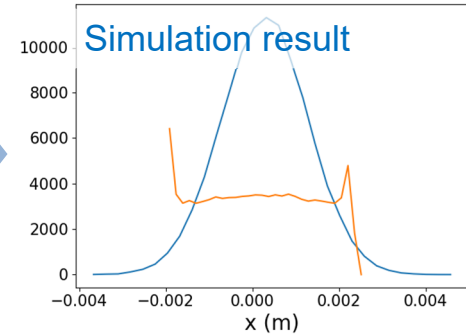
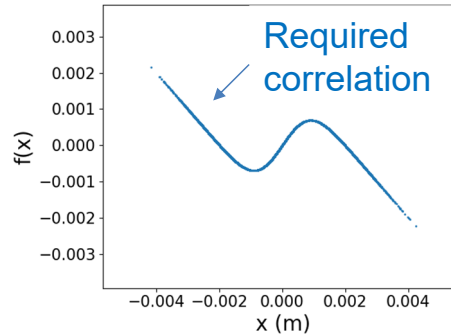
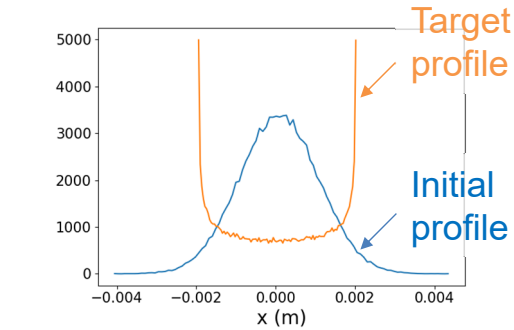
Particle conservation

Map

$$N_f(x_f)dx_f = N_0(x_0)dx_0, \quad M: x_0 \rightarrow x_f$$



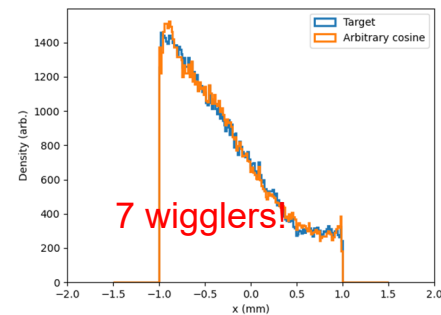
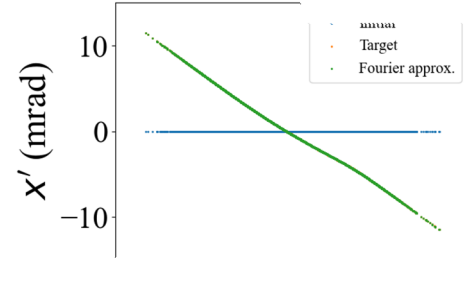
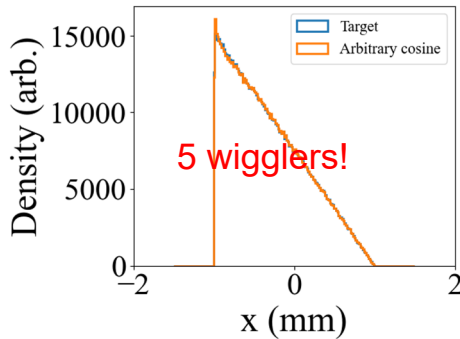
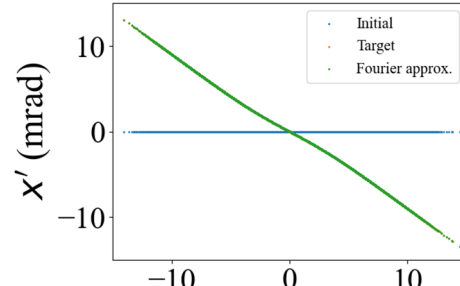
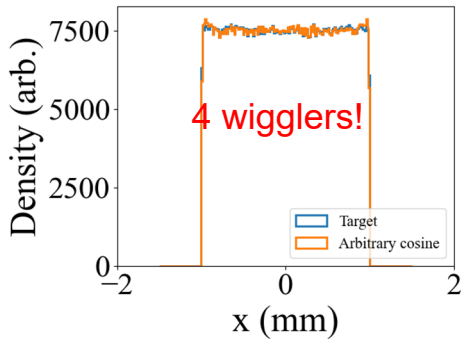
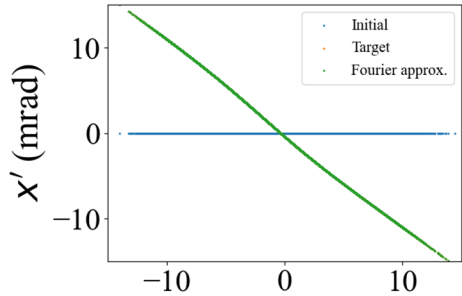
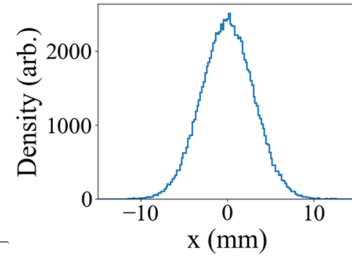
$$N_f(R_{11}x_0 + R_{12}f)\{R_{11} + R_{12}f'\} = N_0(x_0)$$



# Demo I: profile shaping



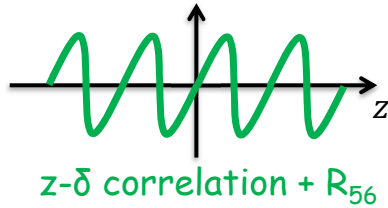
- In principle, we can convert arbitrary input profile to arbitrary longitudinal profile
- Extremely high shaping quality is expected
- Currently, designing transverse wiggler combinations using S2E simulated beam



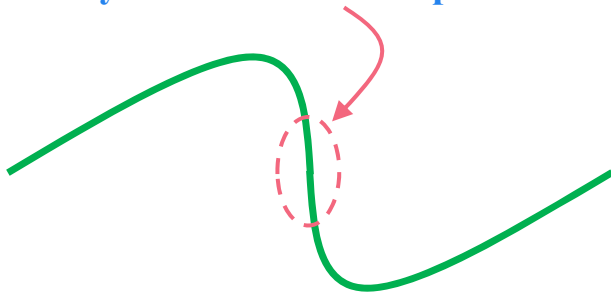
# Demo II: periodic modulation



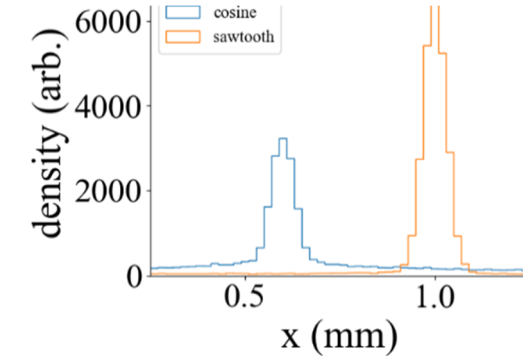
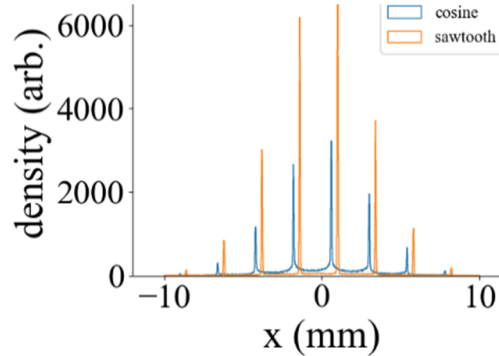
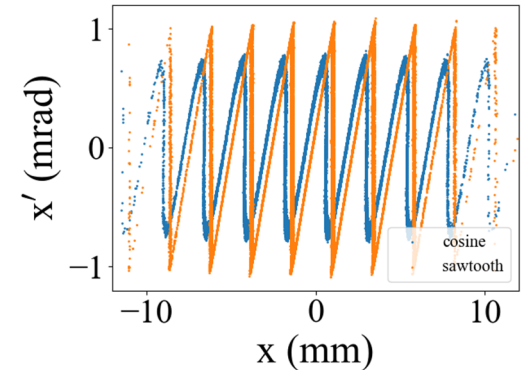
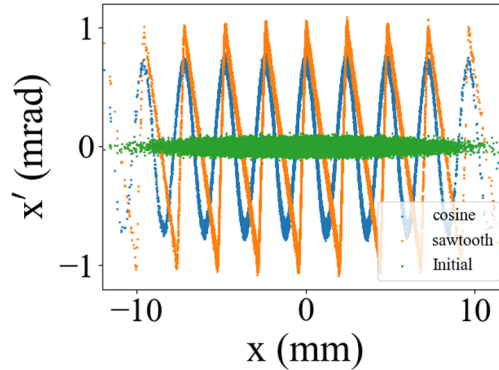
Sine-modulation  
generates density spikes



However, only linear parts  
really contribute on the peak



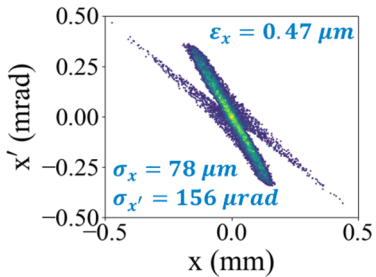
Saw-tooth correlation will significantly enhance the peak



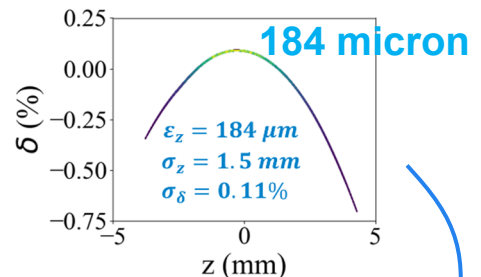
# Demo III: linearization



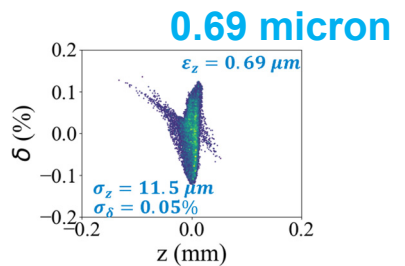
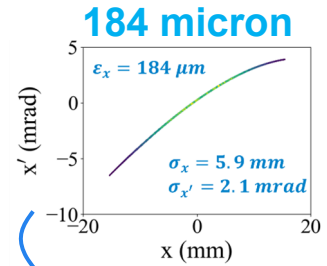
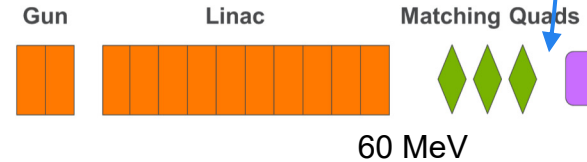
Large longi. emittance is mainly due to nonlinearity → Correction using transverse wigglers



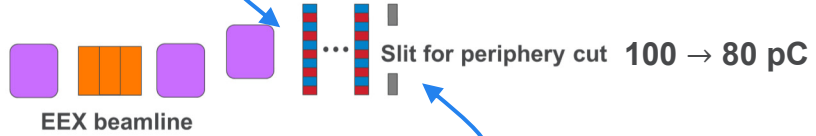
0.47 micron



184 micron



Transverse wiggler linearizer

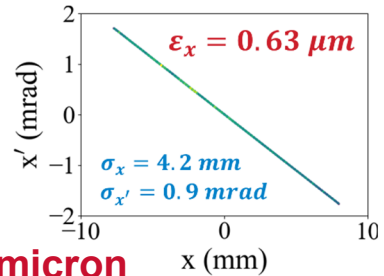


~~Linearizer~~

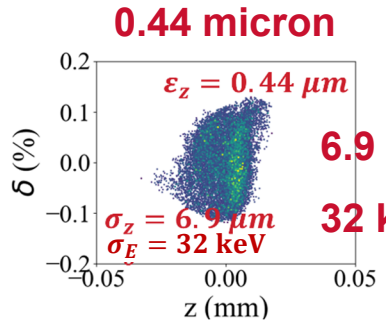
~~Bunch compressors~~

~~Laser heater~~

~~Chirping/dechirping process~~



0.63 micron



0.44 micron

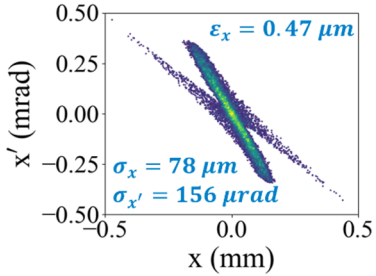
6.9 μm

32 keV

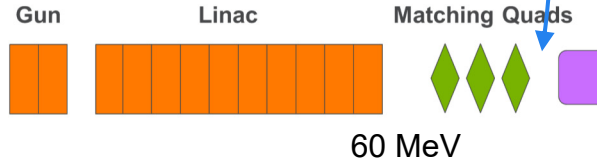
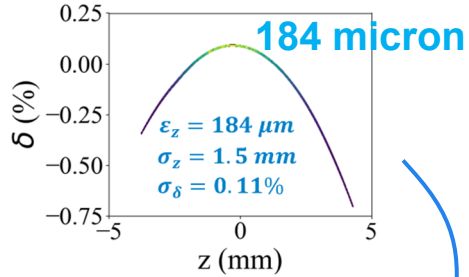
# Demo III: linearization



Large longi. emittance is mainly due to nonlinear



0.47 micron



~~Linearizer~~

~~Bunch compressors~~

~~Laser heater~~

~~Chirping/dechirping process~~

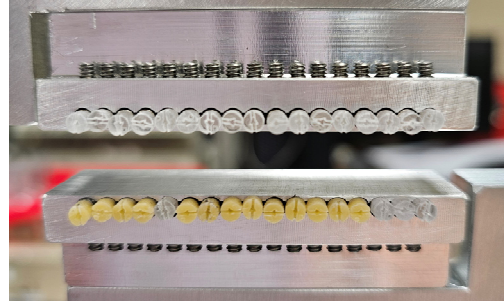
# Recent tool development effort: tunable wiggler



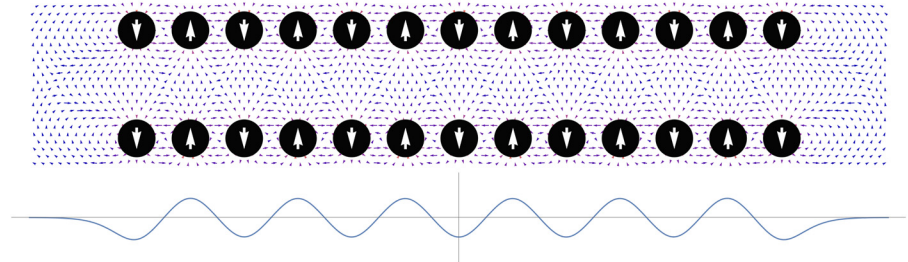
## Rectangular PM-array



## Rotatable cylinder PM-array



## Period and phase tunable

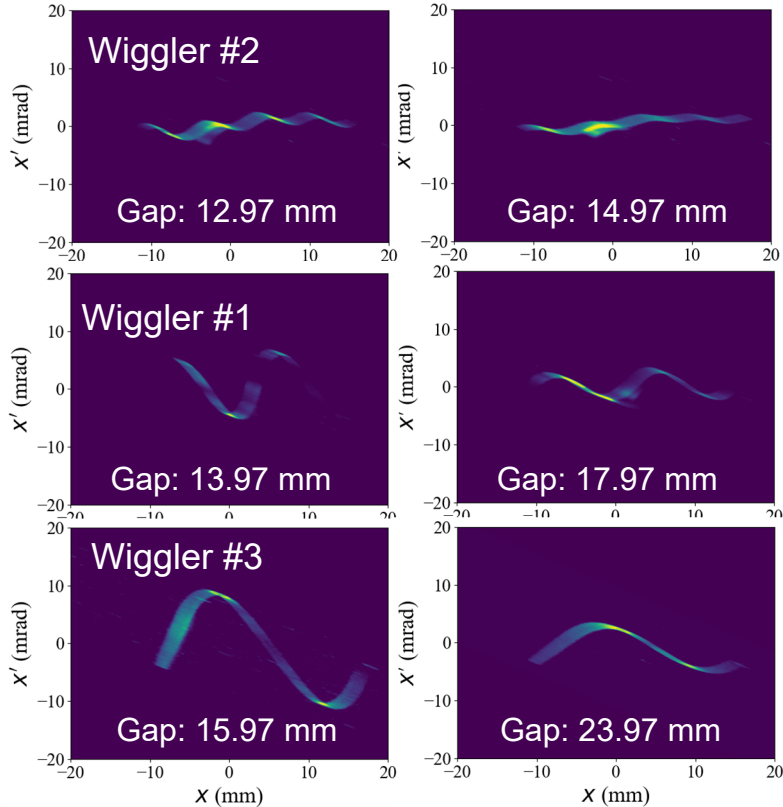


- It is cheap and tiny, so we can prepare many of them having different periods.
- But no period-tunability

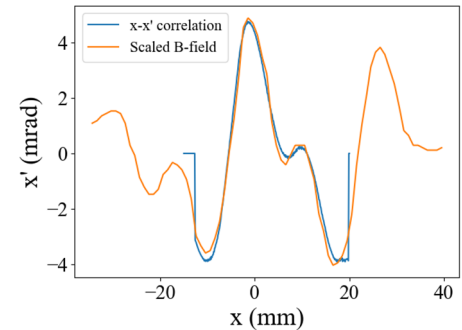
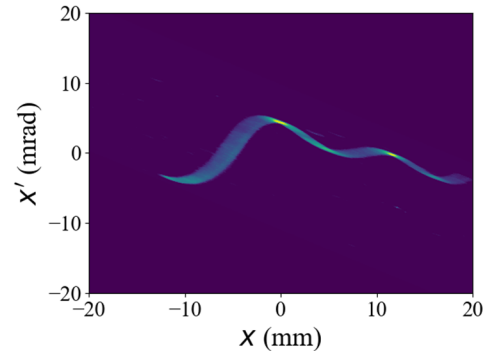
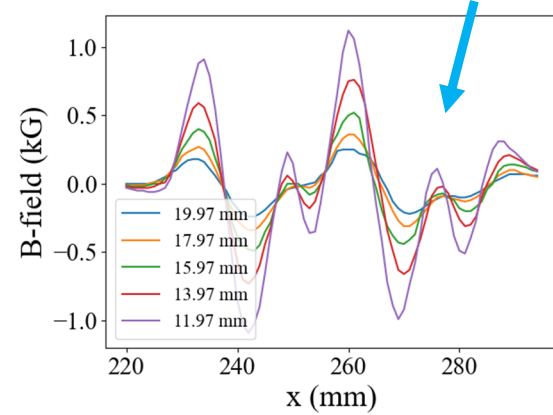
# Experiment results: period tunability



Both amplitude and period tunability were confirmed



Magnet angles were adjusted to generate summation of two sine curves



# Summary

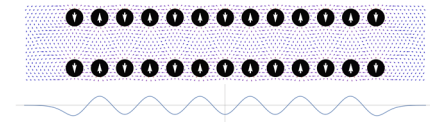
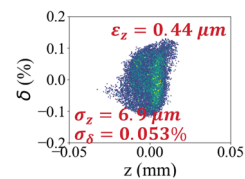
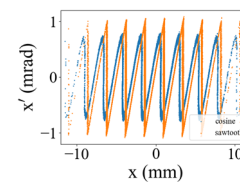
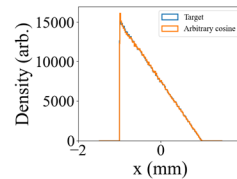
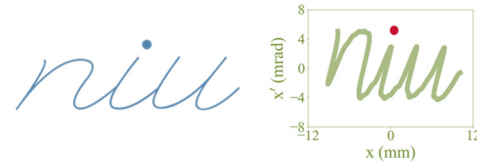
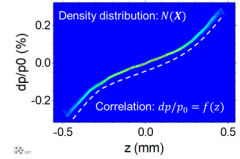
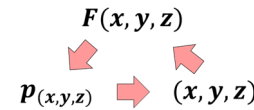


- Many of beam controls belong to the correlation control.
- Proper CONCEPT and TOOLS may provide new opportunities

- 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.





# CAST

DOE funded  
traineeship program  
supporting for  
Master's degree

ILLINOIS INSTITUTE  
OF TECHNOLOGY



Northern Illinois  
University

Join us!

Application deadlines:

**December 1** for Spring 2025

**April 15** for Fall 2025

## Research Areas

- Particle sources
- Novel acceleration methods
- Computational Physics
- Beam control & diagnostics

## Students receive funds to cover

- Stipend and tuition for a Master's degree (2 years)

## Collaboration opportunities

- With National Laboratories (ANL and FNAL)
- With local industrial partners

## Who is eligible?

- U.S. citizen or a legal permanent resident
- At least 18 years of age
- Enrolled full-time graduate program

## CAST

### Chicagoland Accelerator Science Traineeship

Northern Illinois University and Illinois Institute of Technology have teamed up with Argonne National Laboratory and Fermi National Accelerator Laboratory to create the Chicagoland Accelerator Science Traineeship (CAST) program. Funded by the U.S. Department of Energy (DOE), the program provides up to two years of funding for graduate students at NIU and IIT to pursue studies in accelerator science, technology, and particle beam physics with active participation in research at these prominent national laboratories or with local industrial partners.

## CONTACTS

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[torun@iit.edu](mailto:torun@iit.edu)

NIU



IIT



<https://www.niu.edu/clas/nicadd/graduate/CAST.shtml>

<https://www.iit.edu/admissions-aid/apply>