

NAPAC2019

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APPLICATIONS AND OPPORTUNITIES OF THE EMITTANCE EXCHANGE BEAMLINE

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September 06, 2019
Lansing, Michigan

WHAT IS EEX?

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS, VOLUME 5, 084001 (2002)

Transverse to longitudinal emittance exchange

M. Cornacchia* and P. Emma†

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309

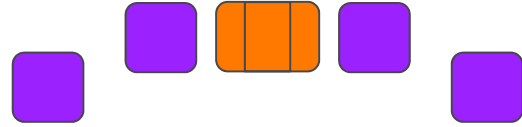
(Received 13 June 2002; published 29 August 2002)

A scheme is proposed to exchange the transverse and longitudinal emittances of an electron bunch. A general analysis is presented and a specific beam line is used as an example where the emittance exchange is achieved by placing a transverse deflecting mode radio-frequency cavity in a magnetic chicane. In addition to reducing the transverse emittance, the bunch length is also simultaneously compressed. The scheme has the potential to introduce an added flexibility to the control of electron beams and to provide some contingency for the achievement of emittance and peak-current goals in free-electron lasers.

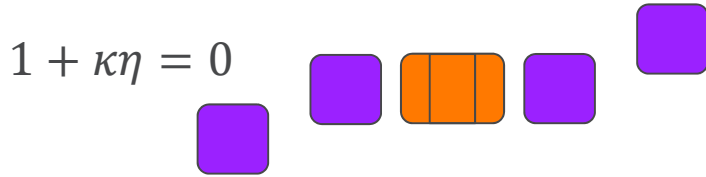
DOI: 10.1103/PhysRevSTAB.5.084001

PACS numbers: 29.27.-a

$$1 - \kappa\eta = 0$$



$$\begin{bmatrix} x_f \\ x'_f \\ z_f \\ \delta_f \end{bmatrix} = \begin{bmatrix} 0 & 2L & \kappa L & -\eta + \kappa\xi L \\ 0 & 2 & \kappa & \kappa\xi \\ \kappa\xi & -\eta + \kappa\xi L & 0 & 2\xi \\ \kappa & \kappa L & 0 & 2 \end{bmatrix} \begin{bmatrix} x_i \\ x'_i \\ z_i \\ \delta_i \end{bmatrix}$$



$$1 + \kappa\eta = 0$$

$$\begin{bmatrix} x_f \\ x'_f \\ z_f \\ \delta_f \end{bmatrix} = \begin{bmatrix} 0 & 0 & \kappa L & \eta + \kappa\xi L \\ 0 & 0 & \kappa & \kappa\xi \\ \kappa\xi & \eta + \kappa\xi L & 0 & 0 \\ \kappa & \kappa L & 0 & 0 \end{bmatrix} \begin{bmatrix} x_i \\ x'_i \\ z_i \\ \delta_i \end{bmatrix}$$

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 9, 100702 (2006)

Transverse-to-longitudinal emittance exchange to improve performance of high-gain free-electron lasers

P. Emma and Z. Huang

Stanford Linear Accelerator Center, Stanford, California 94309, USA

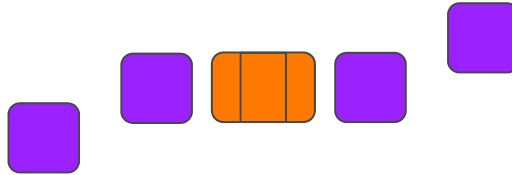
K.-J. Kim

Argonne National Laboratory, Argonne, Illinois 60439, USA

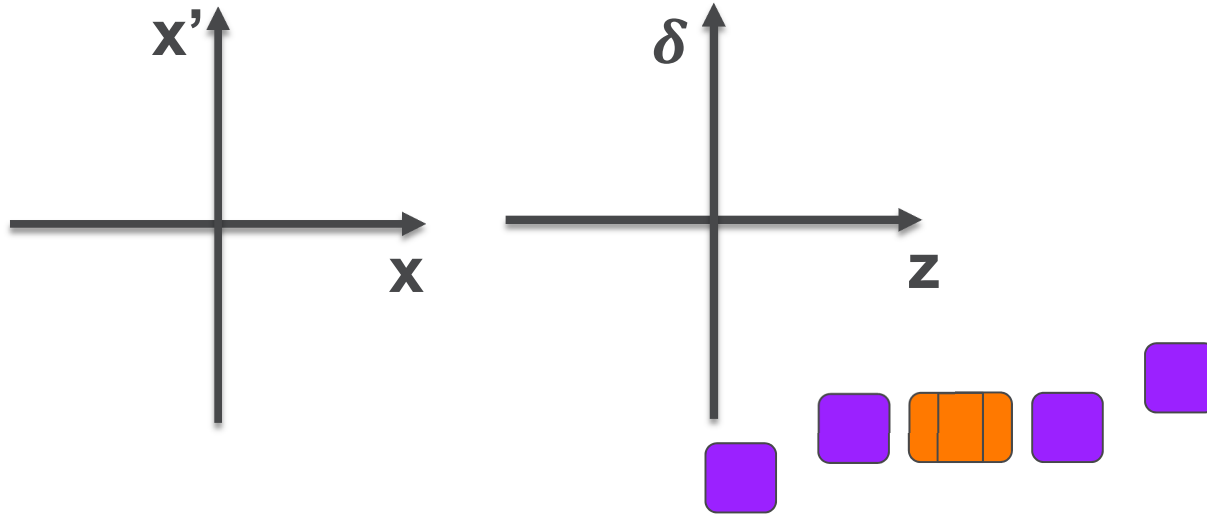
P. Piot

Northern Illinois University, DeKalb, Illinois 60115, USA
and Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
(Received 1 August 2006; published 25 October 2006)

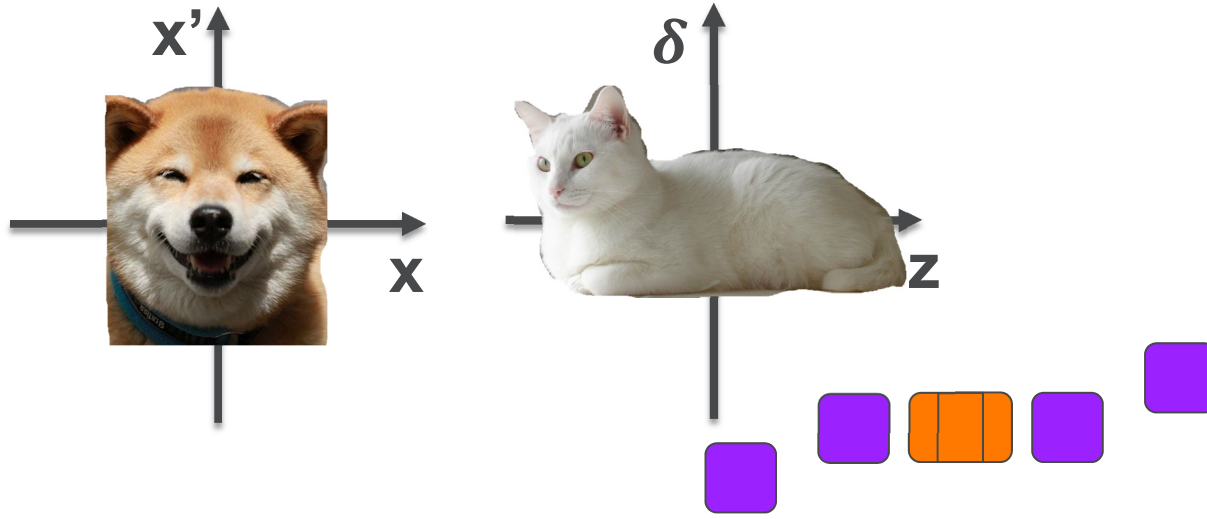
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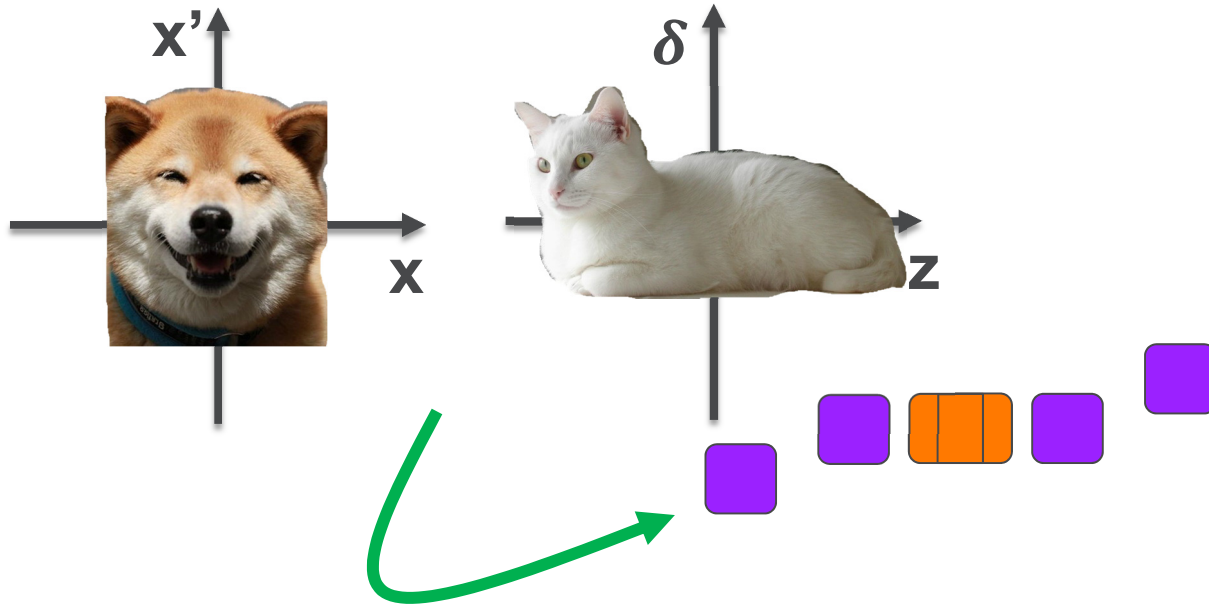
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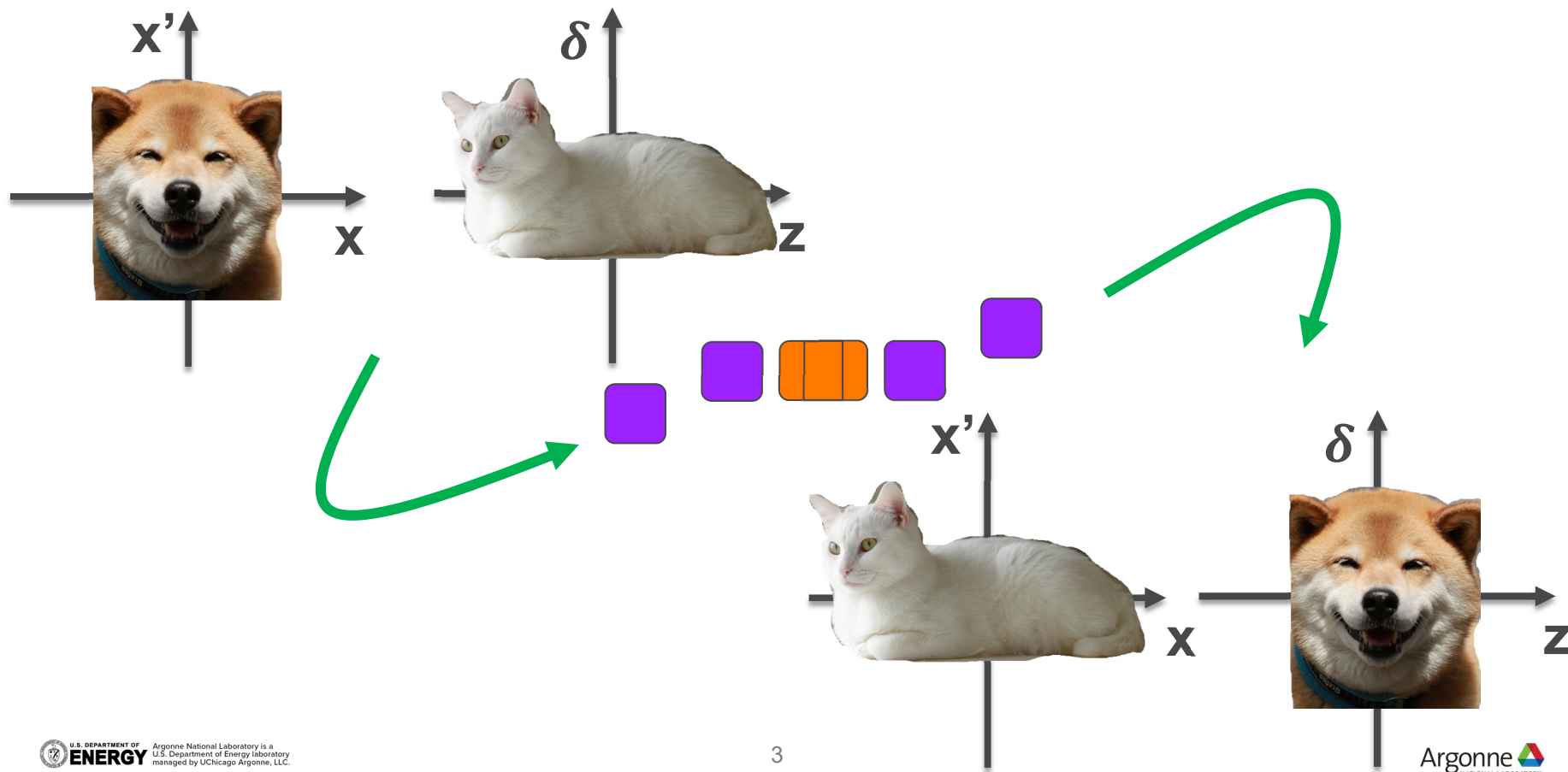
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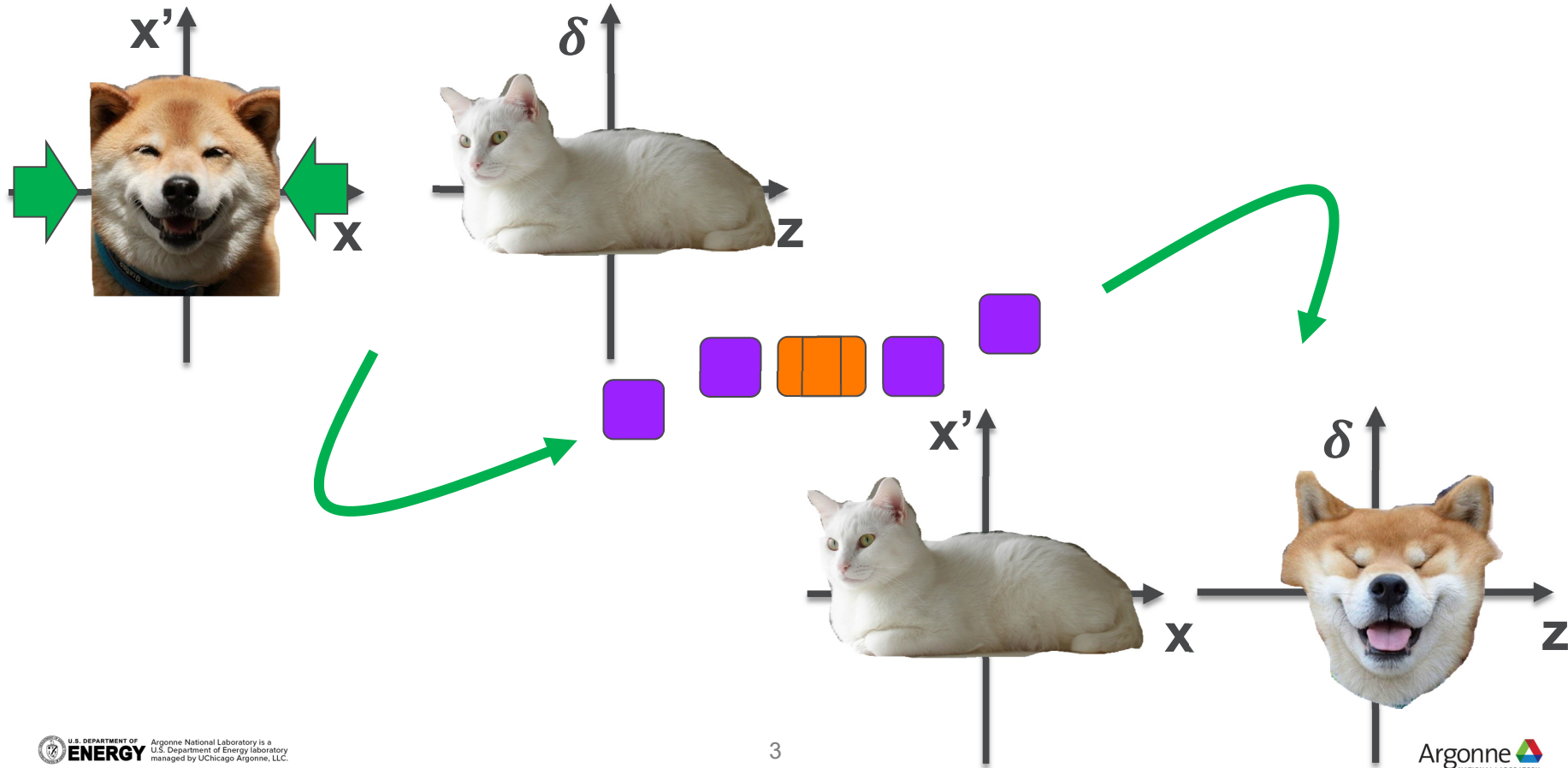
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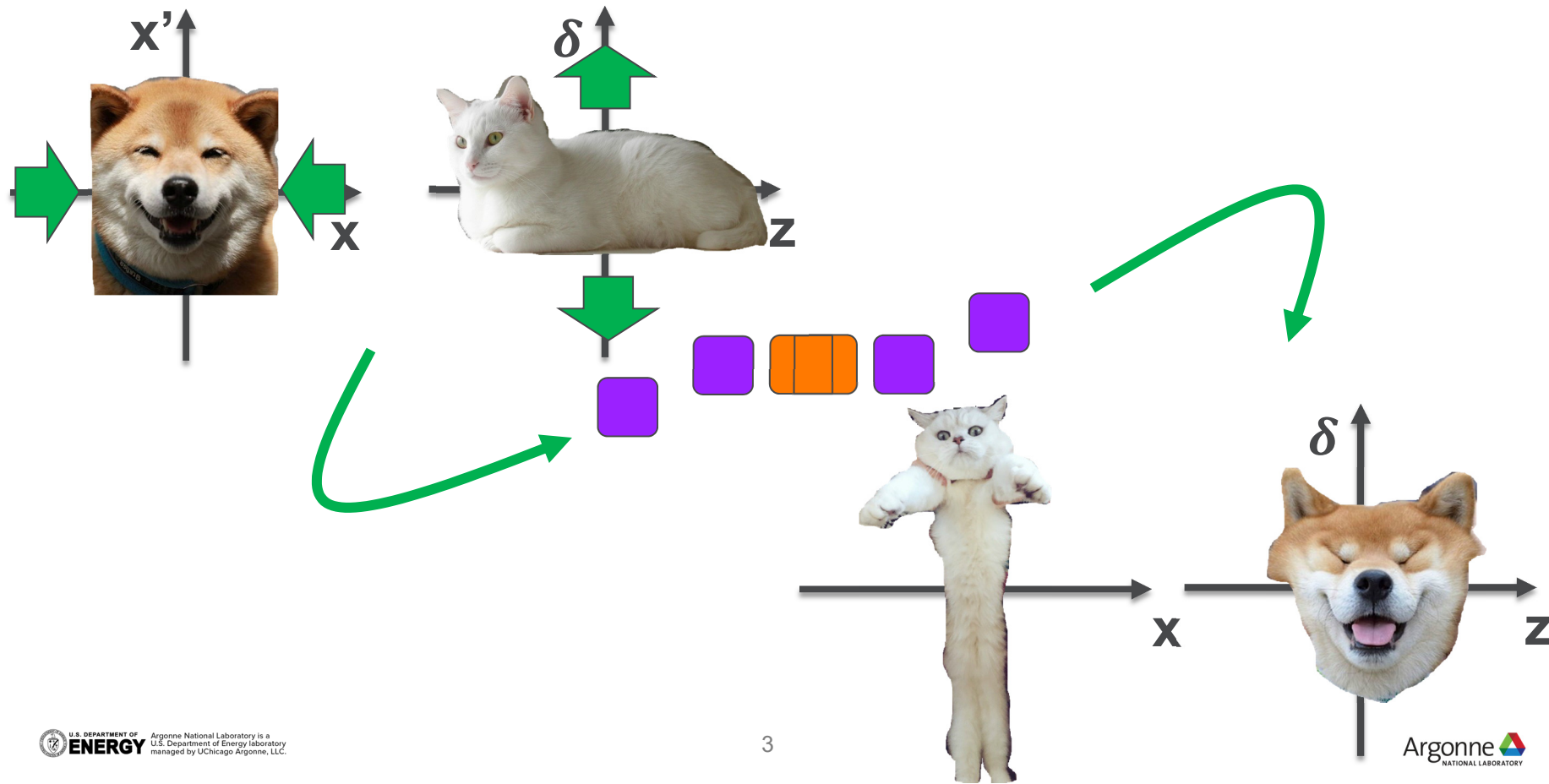
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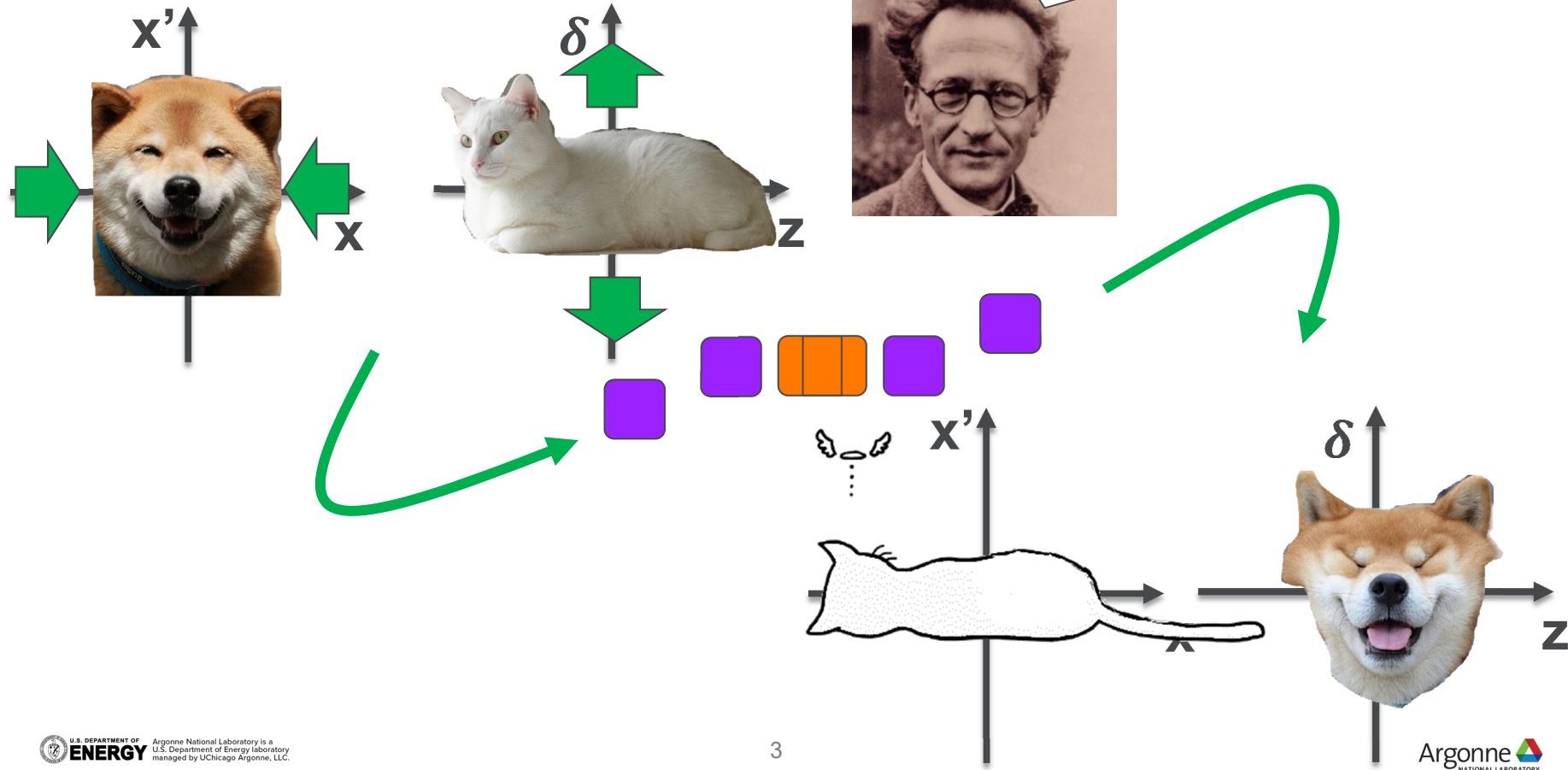
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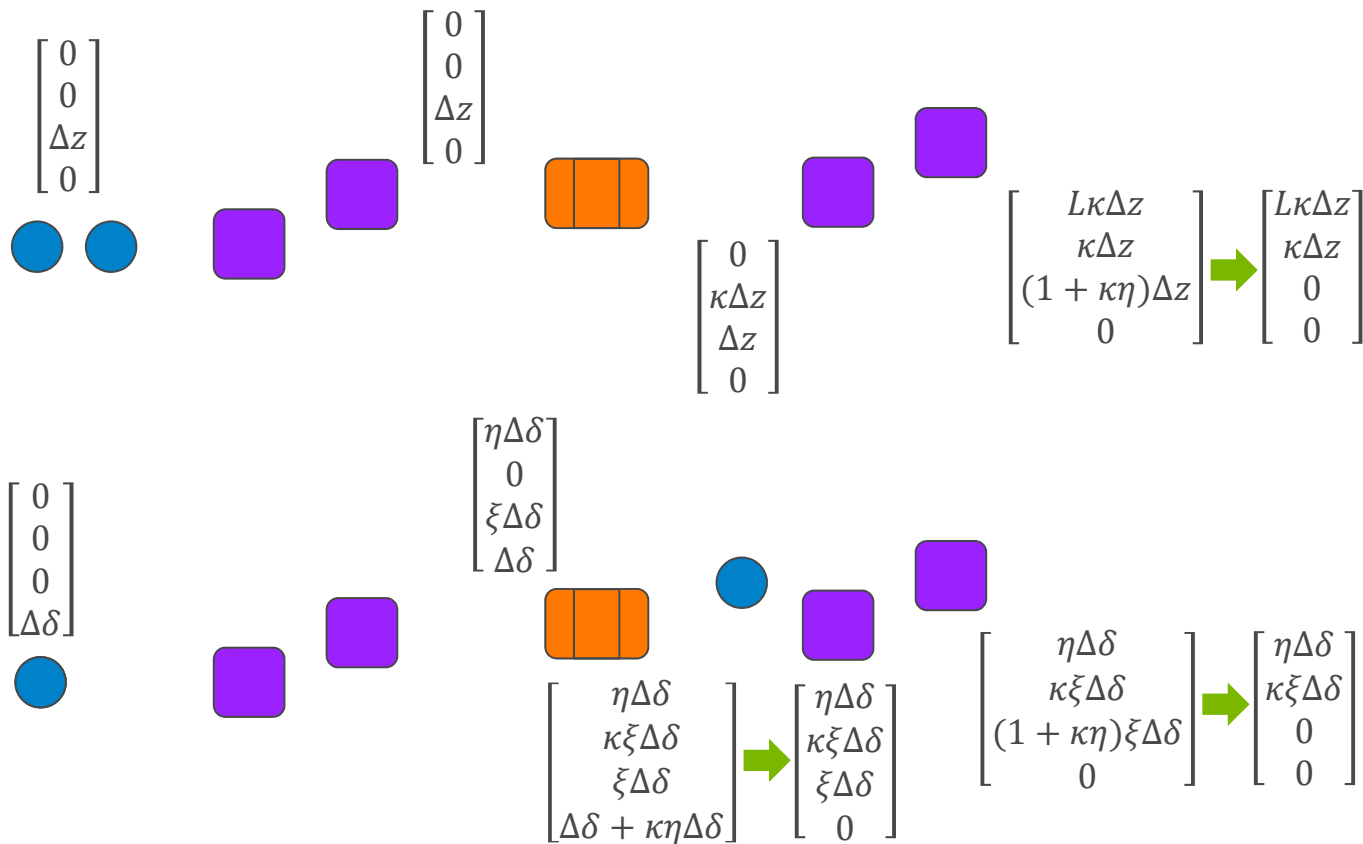
WHAT IS EEX?



WHAT IS EEX?



LONGITUDINAL EXCHANGE EXAMPLE

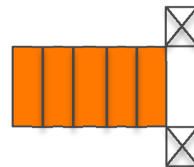
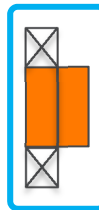


AWA RESEARCHES ON EEX APPLICATIONS

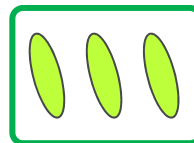
AWA RESEARCH 1: REPARTITIONING

Parameters	ILC	CLIC	P/DWFA	LPA
Energy (TeV)	0.5	3	3	3
$\epsilon_x (\mu\text{m})$	10	0.66	10	$50 \cdot 10^{-3}$
$\epsilon_y (\mu\text{m})$	$35 \cdot 10^{-3}$	$20 \cdot 10^{-3}$	$35 \cdot 10^{-3}$	$8 \cdot 10^{-3}$
bunch length(μm)	300	44	20	8
energy spread (%)	~ 0.1	0.35	~ 0.1	—
$\epsilon_z (\mu\text{m})$	$3 \cdot 10^6$	$92 \cdot 10^4$	$12 \cdot 10^4$	—
$\epsilon_{6d} (\mu\text{m})$	101	23	35	—

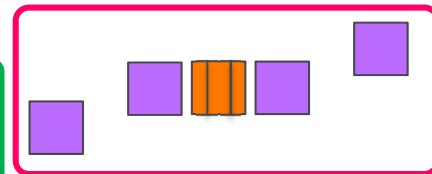
Magnetized
beam



FBT



EEX



$$\epsilon_x = 45 \mu\text{m}$$

$$\epsilon_y = 45 \mu\text{m}$$

$$\epsilon_z = 10 \mu\text{m}$$

$$\epsilon_x = 67500 \mu\text{m}$$

$$\epsilon_y = 0.03 \mu\text{m}$$

$$\epsilon_z = 10 \mu\text{m}$$

$$\epsilon_x = 10 \mu\text{m}$$

$$\epsilon_y = 0.03 \mu\text{m}$$

$$\epsilon_z = 67500 \mu\text{m}$$



Flat beam

1 nC

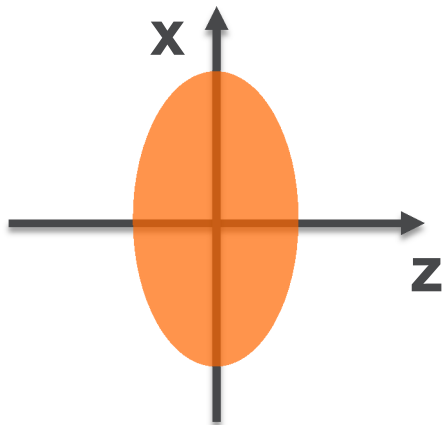
$$\epsilon_x / \epsilon_y = 100$$

*T. Xu et al., IPAC19, WEPTS094 (2019)

**M. Kuriki et al., IPAC19, MOPMP009 (2019)

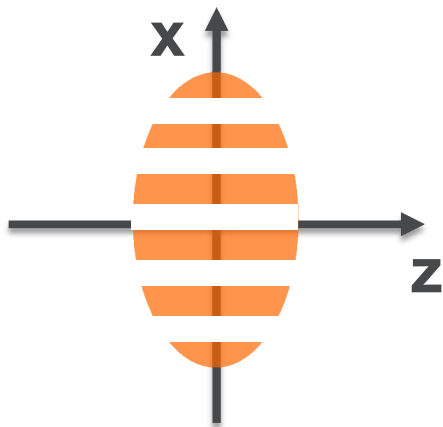
AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

Discrete modulation



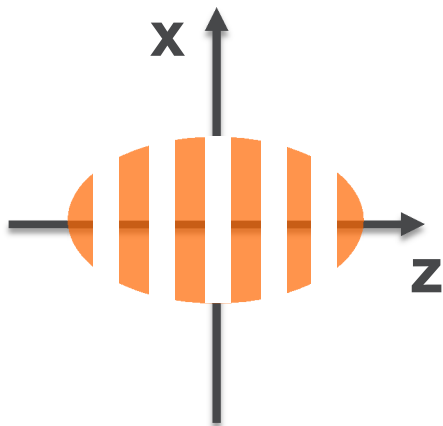
AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

Discrete modulation



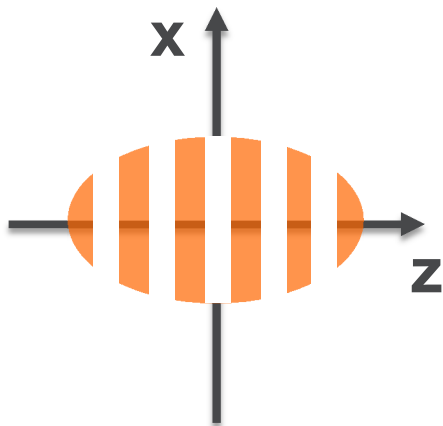
AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

Discrete modulation

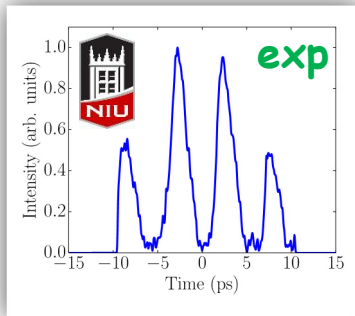
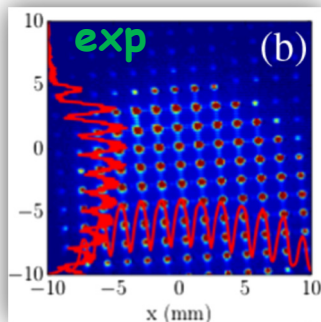


AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

Discrete modulation

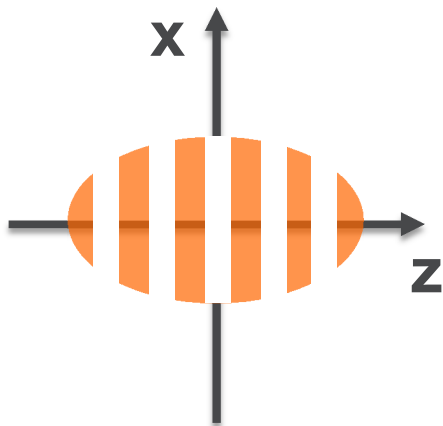


MLA

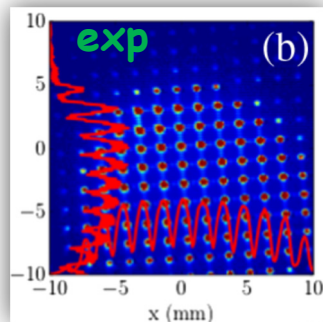


AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

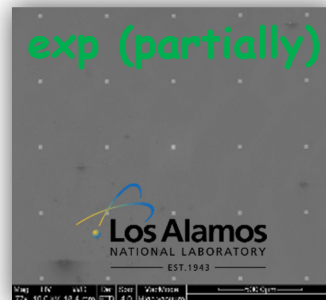
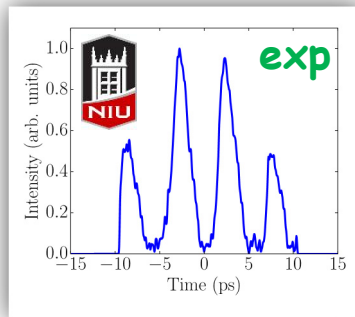
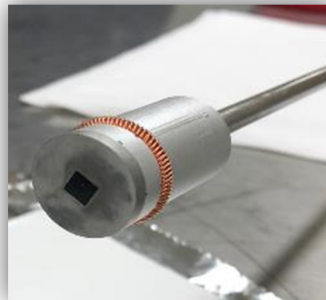
Discrete modulation



MLA

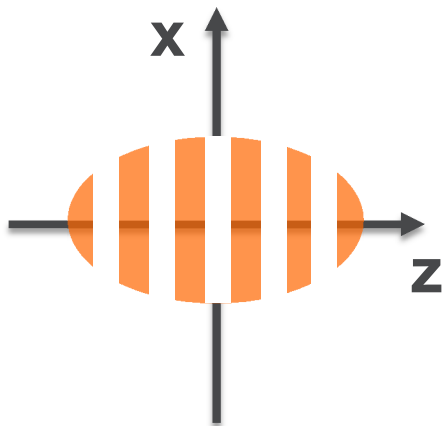


Cathode array

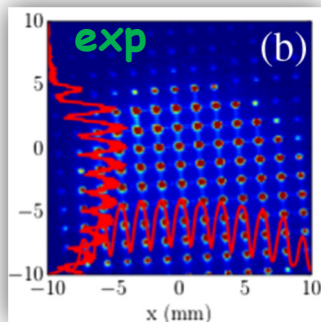


AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

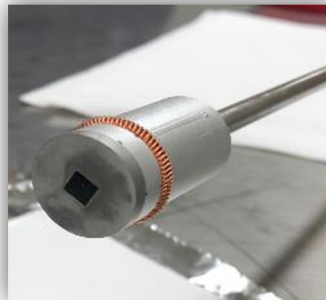
Discrete modulation



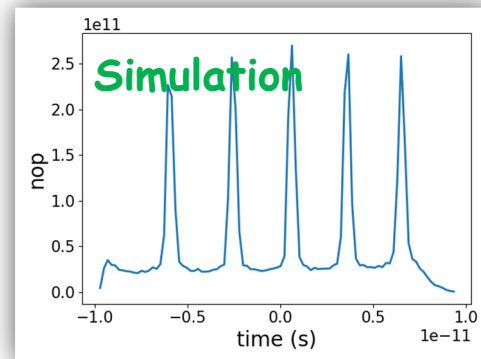
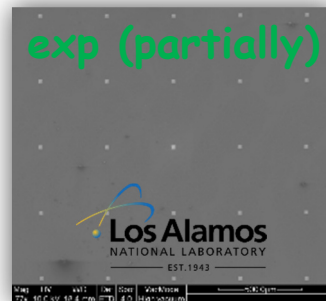
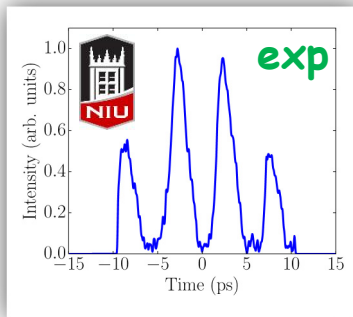
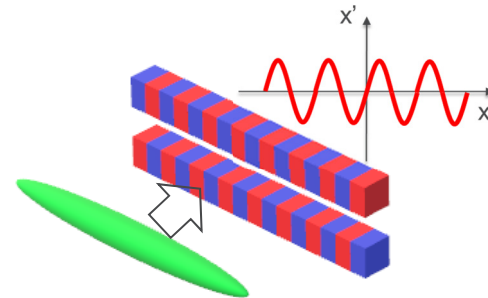
MLA



Cathode array



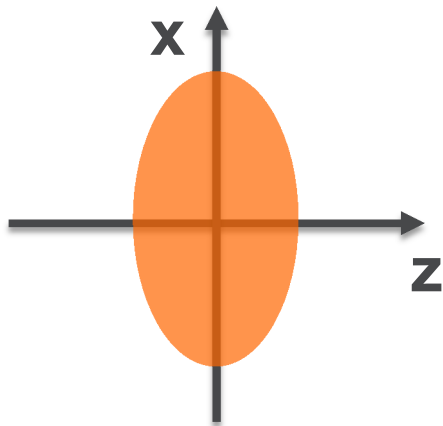
Transverse wiggler



Y.-E Sun et al., PRL 105, 234801 (2011)
A. Halavanau et al., arXiv 1907.02089 (2019)
K. E. Nichols et al., IPAC19, TUPTS090 (2019)
G. Ha et al., IPAC19, TUPGW089 (2019)

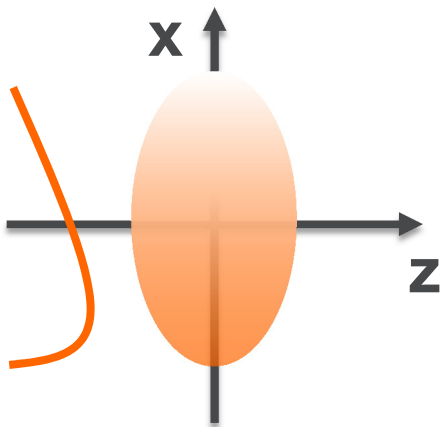
AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

Continuous profile shaping



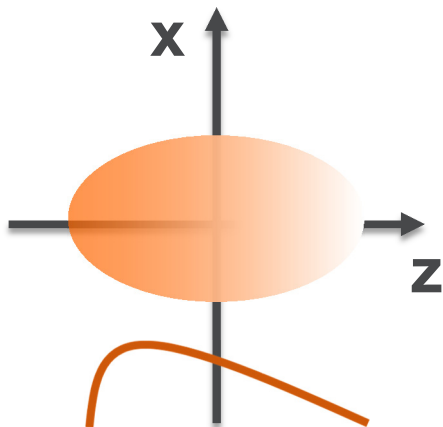
AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

Continuous profile shaping



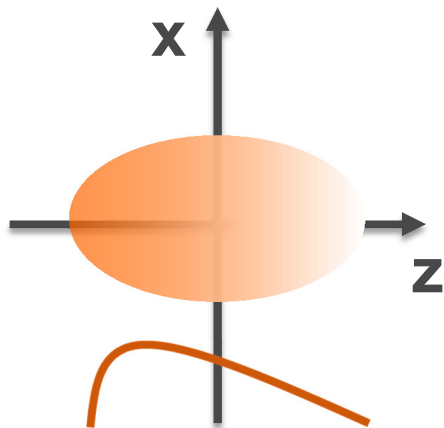
AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

Continuous profile shaping



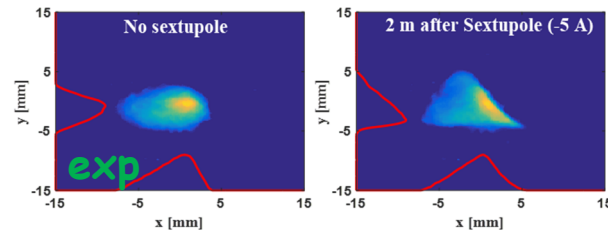
AWA RESEARCH 2: LONGITUDINAL PROFILE SHAPING

Continuous profile shaping

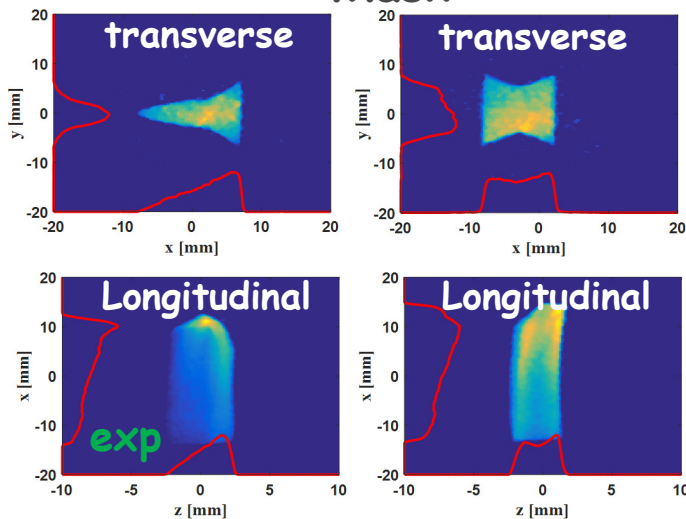


Shaped laser
Cathode array

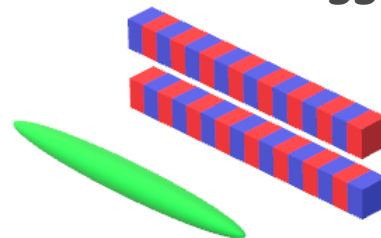
Nonlinear magnet



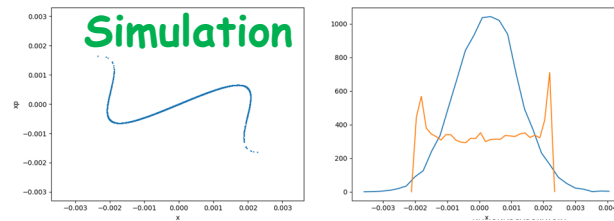
Mask



Transverse wiggler

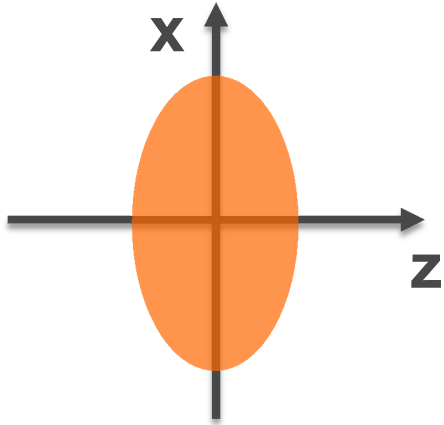


Simulation



G. Ha et al., PRL 118, 104801 (2017)
G. Ha et al, this proceeding, TUPLM15

AWA RESEARCH 3: COMPRESSION

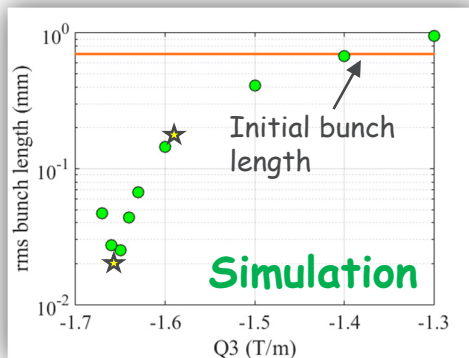


U.S. DEPARTMENT OF
ENERGY

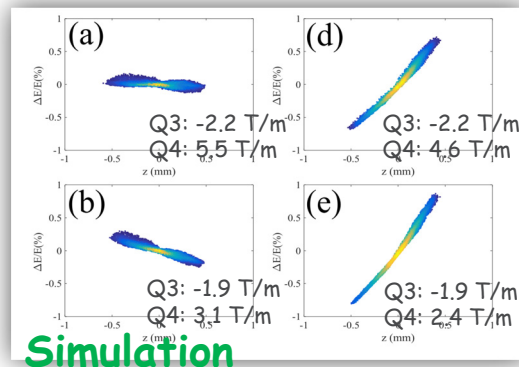
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AWA RESEARCH 3: COMPRESSION

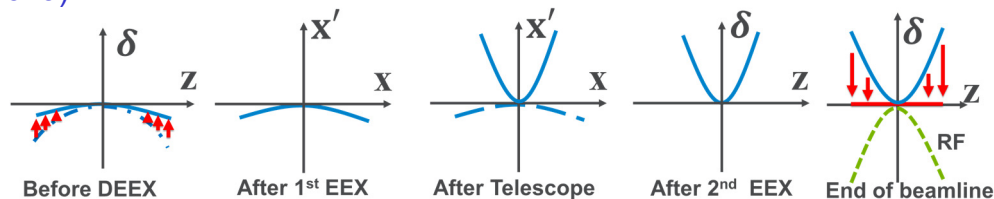
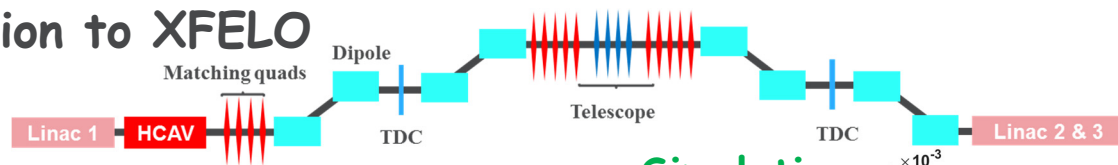
Tunable compression



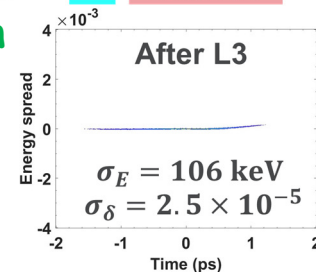
Tunable chirp



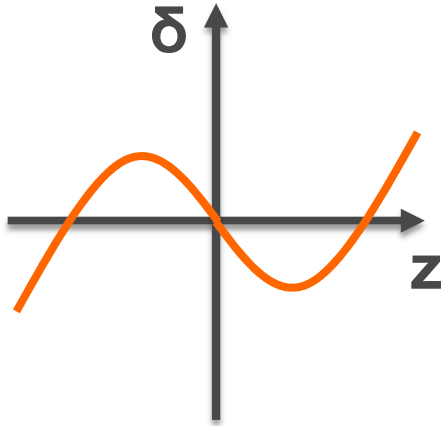
Application to XFEL



Simulation

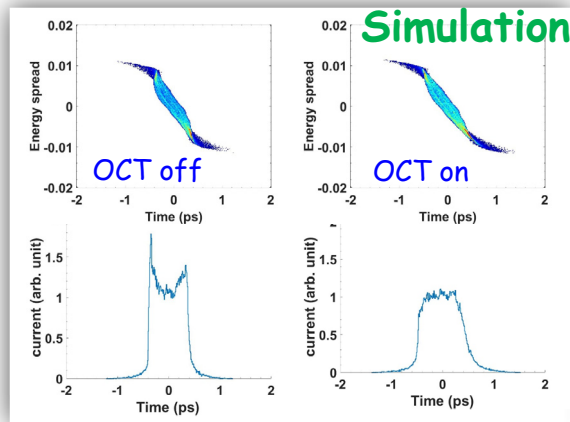


AWA RESEARCH 4: LINEARITY

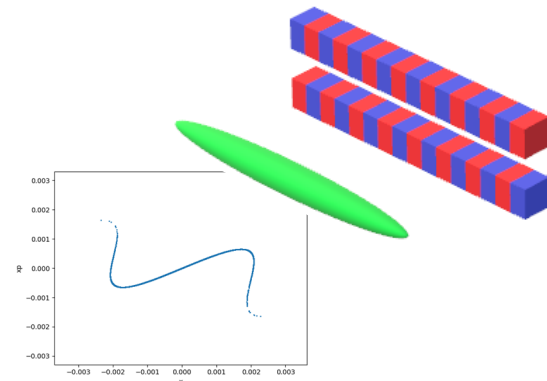


AWA RESEARCH 4: LINEARITY

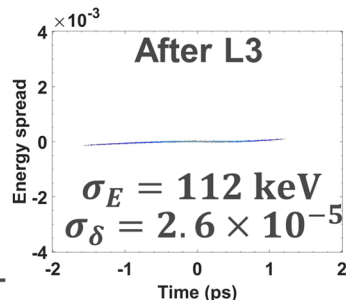
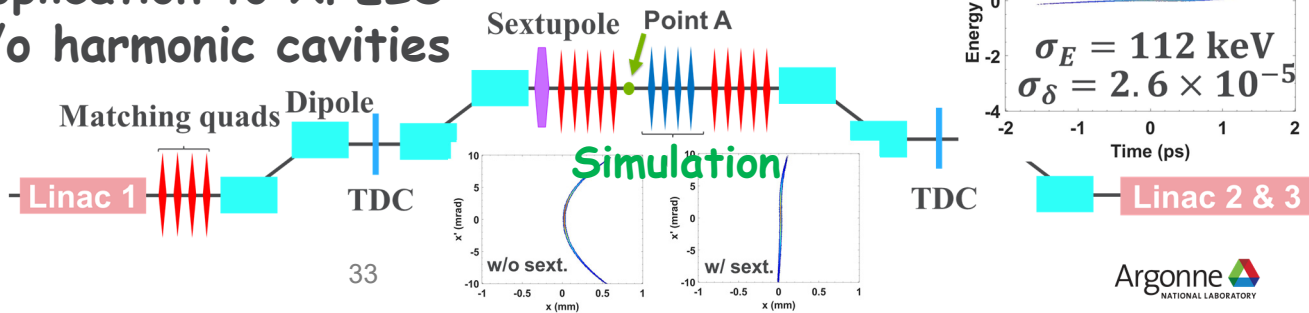
Double-horn suppression



Transverse wiggler

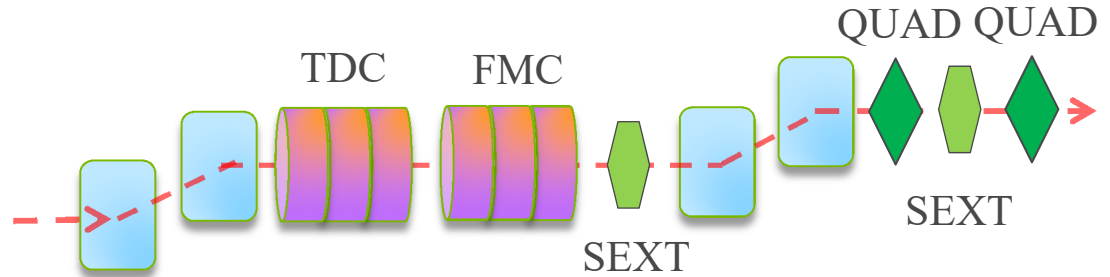
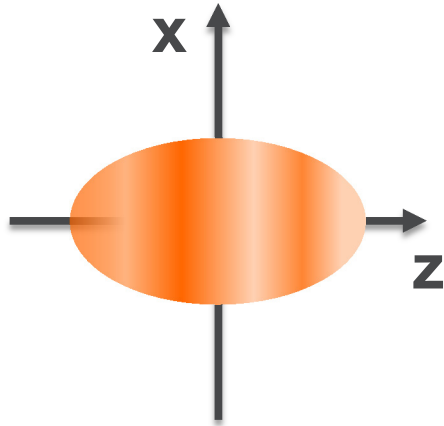


Application to XFEL w/o harmonic cavities

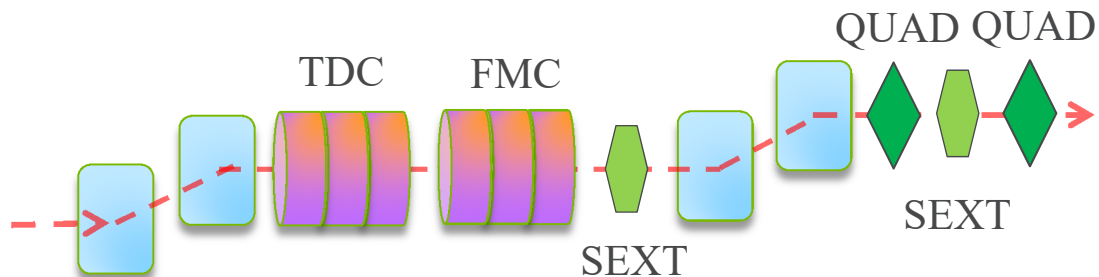
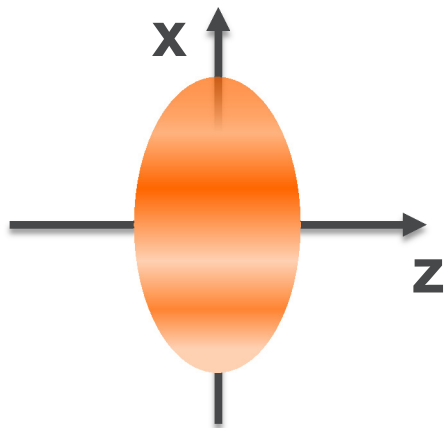


J. Seok et al, this proceeding, TUPLH05

AWA RESEARCH 5: DIAGNOSTICS



AWA RESEARCH 5: DIAGNOSTICS



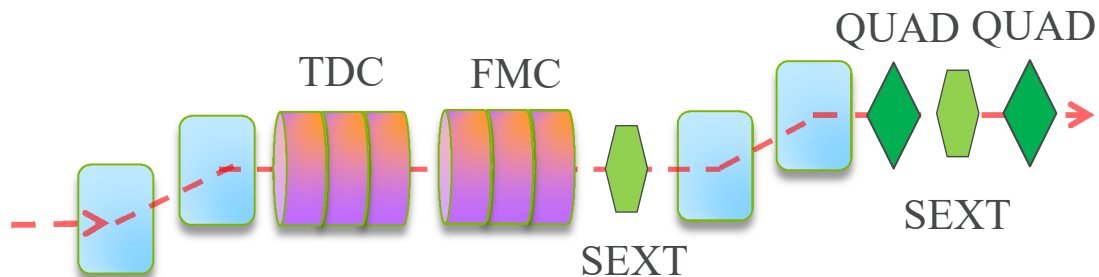
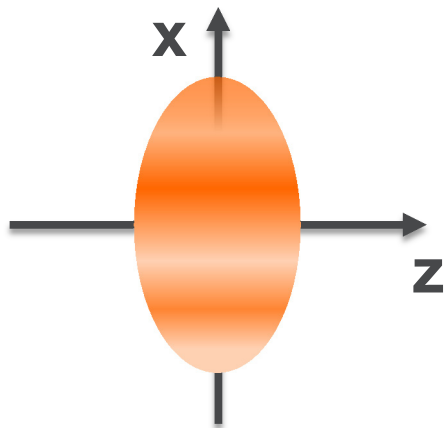
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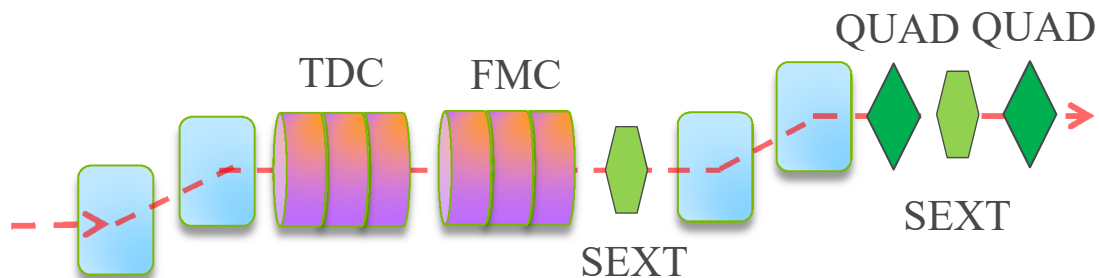
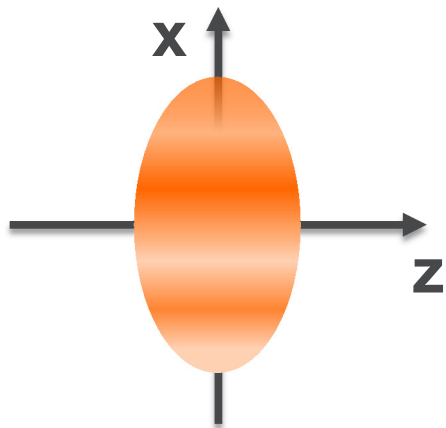
AWA RESEARCH 5: DIAGNOSTICS

$$x_f = Cz_i + Ax_i + Bx'_i + H.O.$$



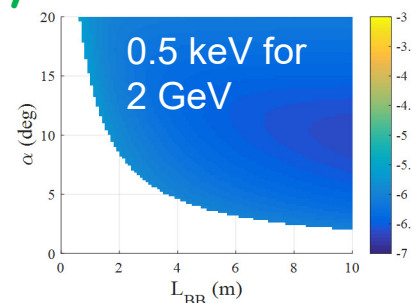
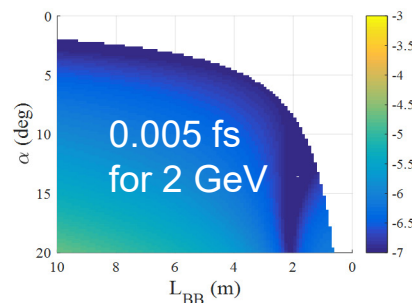
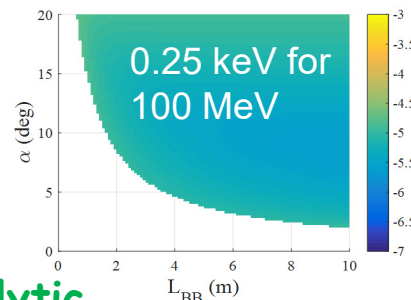
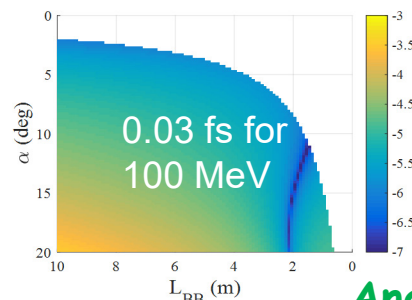
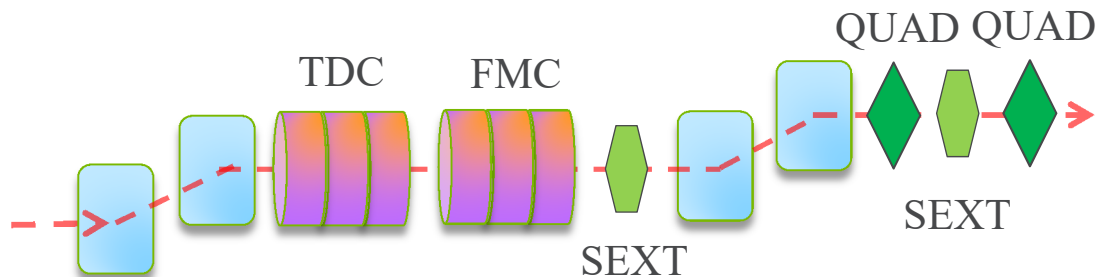
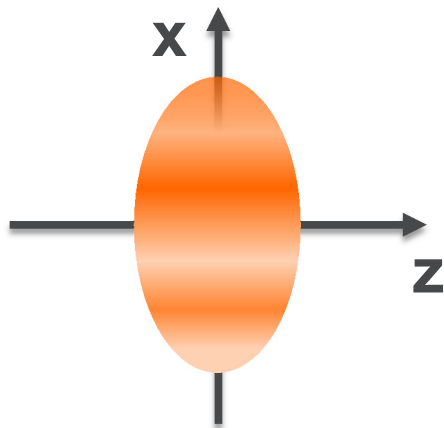
AWA RESEARCH 5: DIAGNOSTICS

$$x_f = Cz_i + \cancel{Ax_i} + \cancel{Bx'_i} + H.O.$$

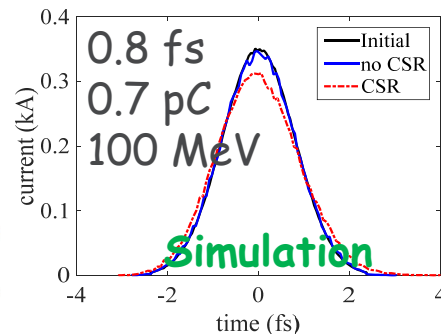


AWA RESEARCH 5: DIAGNOSTICS

$$x_f = Cz_i + \cancel{Ax_i} + \cancel{Bx_i'} + H.O.$$



Analytic

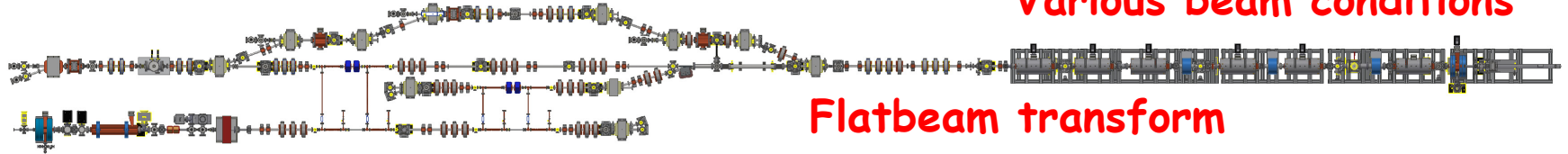


G. Ha et al, IPAC15, MOPJE020

ARGONNE WAKEFIELD ACCELERATOR FACILITY

World only operating EEX beamline

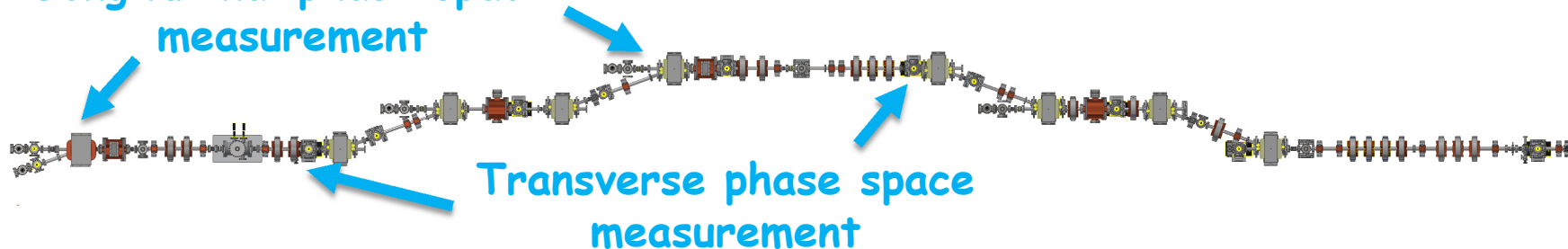
Various beam conditions



Flexible experiment area

Charge	0.01 – 100 / 60 nC	Single / 8 bunch
Energy	6 / 24 / 42 / 60 MeV	Each KLY: 18 MeV
Laser radius	0.1 – 12 mm	
Laser pulse	0.3 – 10 ps FWHM	

Longitudinal phase space measurement



SUMMARY

- EEX provides an exchange of phase spaces
- AWA group is exploring various applications of EEX
 - Repartitioning of emittance
 - Profile control
 - Compression
 - Linearity control
 - Longitudinal diagnostics



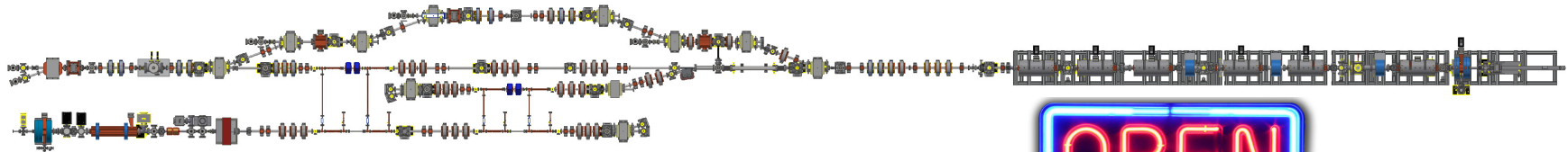
SUMMARY

- EEX provides an exchange of phase spaces
- AWA group is exploring various applications of EEX
 - Repartitioning of emittance
 - Profile control
 - Compression
 - Linearity control
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Thank you