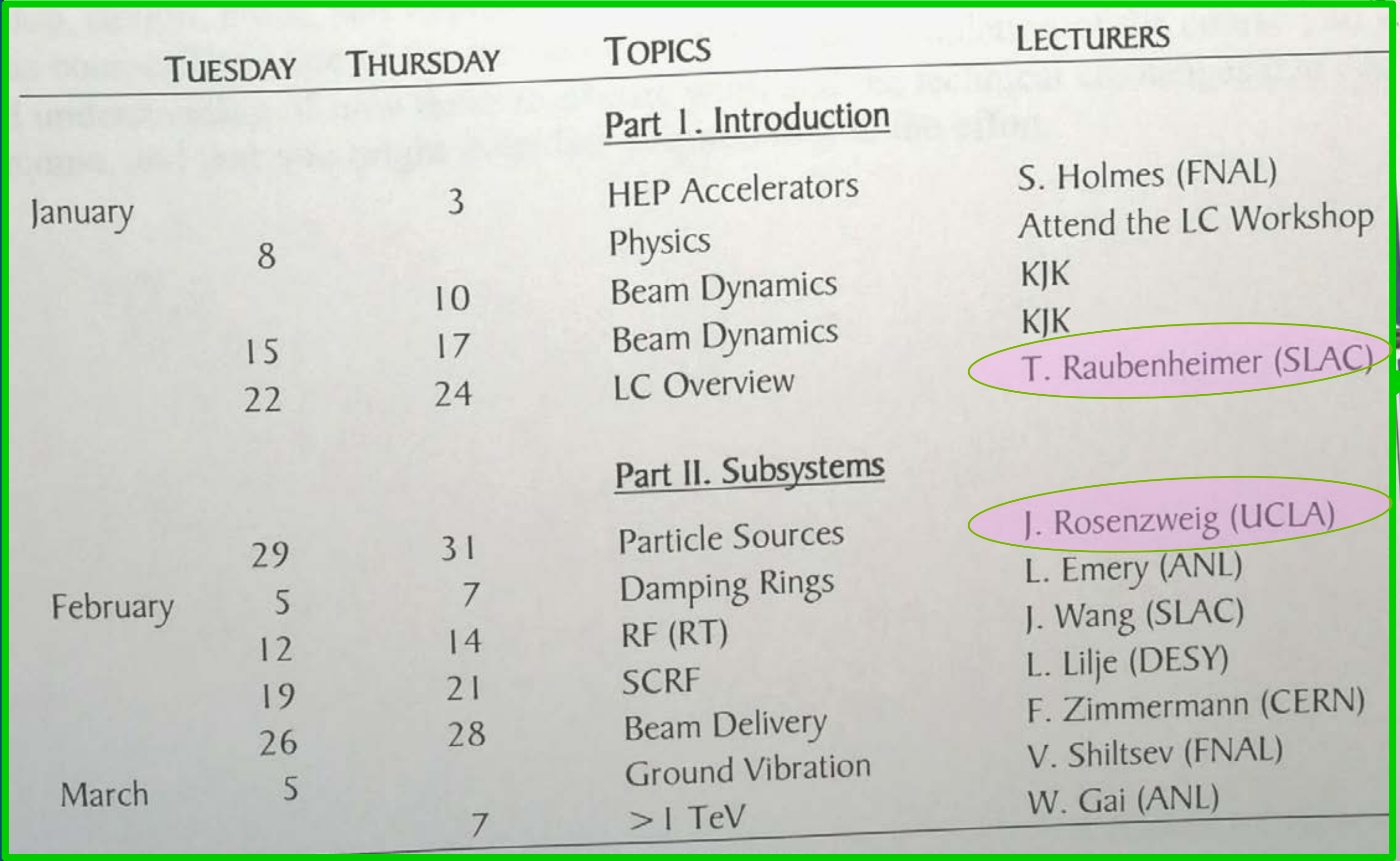
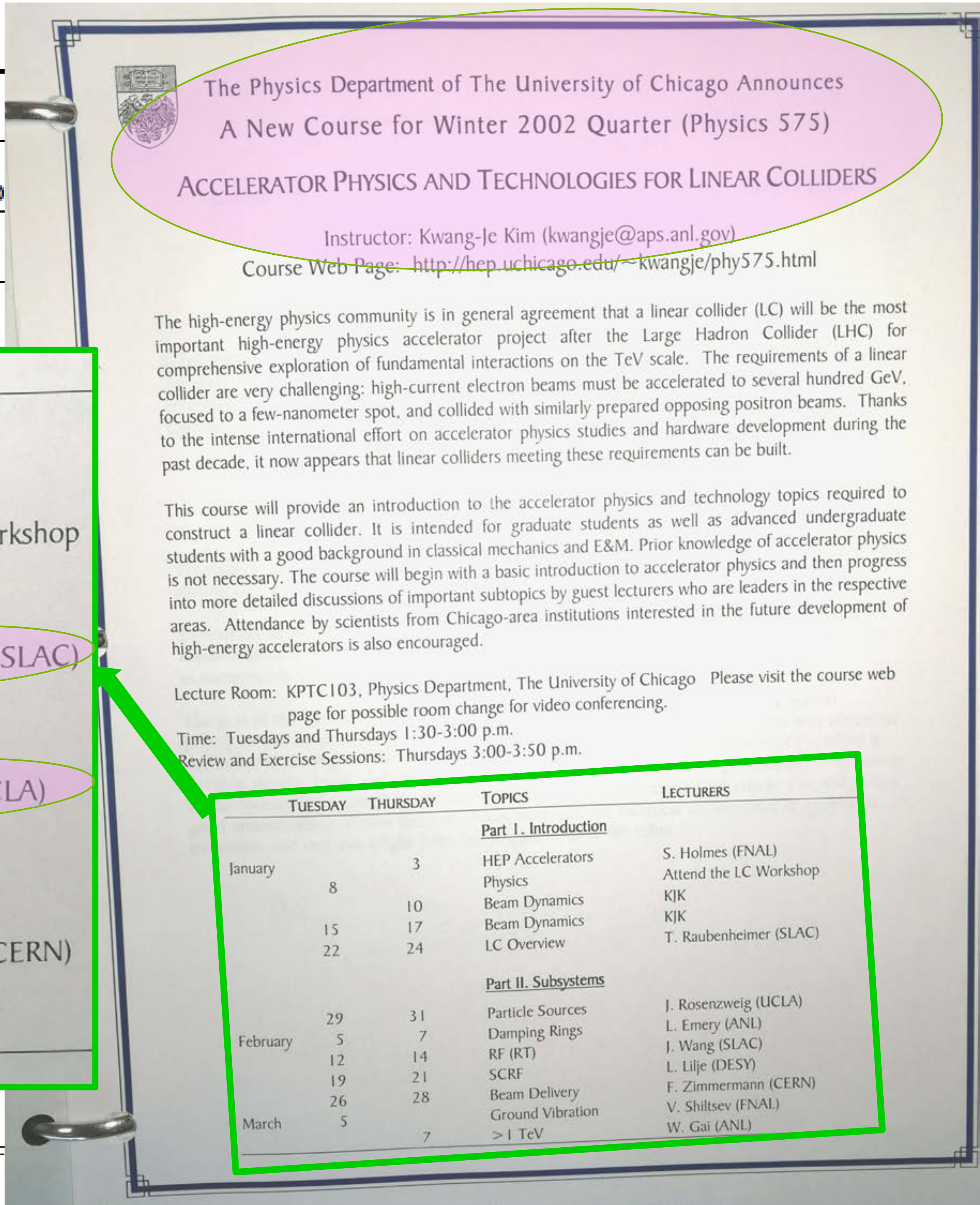
3:25PM	James Rosenzweig	UCLA
3:50PM	Yine Sun	Argonne National Lab
4:15PM	Tor Raubenheimer	Stanford University



Tuesday	Thursday	Topics	Lecturers
		Part I. Introduction	
January	3	HEP Accelerators	S. Holmes (FNAL)
8		Physics	Attend the LC Workshop
	10	Beam Dynamics	KJK
15	17	Beam Dynamics	KJK
22	24	LC Overview	T. Raubenheimer (SLAC)
		Part II. Subsystems	
29	31	Particle Sources	J. Rosenzweig (UCLA)
February 5	7	Damping Rings	L. Emery (ANL)
12	14	RF (RT)	J. Wang (SLAC)
19	21	SCRF	L. Lilje (DESY)
26	28	Beam Delivery	F. Zimmermann (CERN)
March 5		Ground Vibration	V. Shiltsev (FNAL)
	7	>1 TeV	W. Gai (ANL)



The Physics Department of The University of Chicago Announces
A New Course for Winter 2002 Quarter (Physics 575)

ACCELERATOR PHYSICS AND TECHNOLOGIES FOR LINEAR COLLIDERS

Instructor: Kwang-Je Kim (kwangje@aps.anl.gov)
Course Web Page: http://hep.uchicago.edu/~kwangje/phy575.html

The high-energy physics community is in general agreement that a linear collider (LC) will be the most important high-energy physics accelerator project after the Large Hadron Collider (LHC) for comprehensive exploration of fundamental interactions on the TeV scale. The requirements of a linear collider are very challenging: high-current electron beams must be accelerated to several hundred GeV, focused to a few-nanometer spot, and collided with similarly prepared opposing positron beams. Thanks to the intense international effort on accelerator physics studies and hardware development during the past decade, it now appears that linear colliders meeting these requirements can be built.

This course will provide an introduction to the accelerator physics and technology topics required to construct a linear collider. It is intended for graduate students as well as advanced undergraduate students with a good background in classical mechanics and E&M. Prior knowledge of accelerator physics is not necessary. The course will begin with a basic introduction to accelerator physics and then progress into more detailed discussions of important subtopics by guest lecturers who are leaders in the respective areas. Attendance by scientists from Chicago-area institutions interested in the future development of high-energy accelerators is also encouraged.

Lecture Room: KPTC103, Physics Department, The University of Chicago Please visit the course web page for possible room change for video conferencing.
Time: Tuesdays and Thursdays 1:30-3:00 p.m.
Review and Exercise Sessions: Thursdays 3:00-3:50 p.m.

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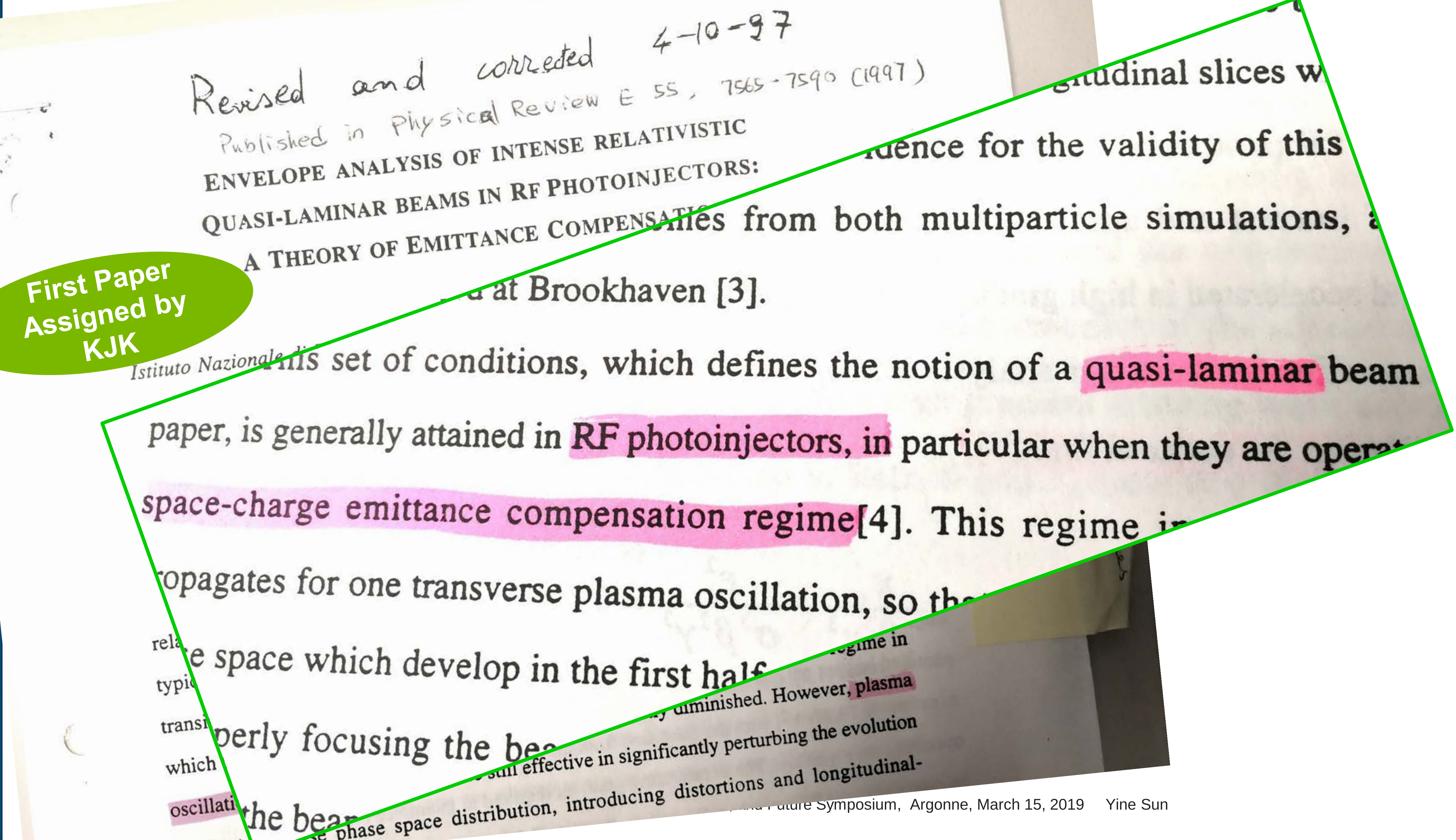

Revised and corrected 4-10-97

Published in Physical Review E 55, 7565-7590 (1997)

ENVELOPE ANALYSIS OF INTENSE RELATIVISTIC QUASI-LAMINAR BEAMS IN RF PHOTOINJECTORS: A THEORY OF EMITTANCE COMPENSATI

Istituto Nazionale

…itudinal slices w…

…idence for the validity of this

…ties from both multiparticle simulations, a…

…at Brookhaven [3].

…his set of conditions, which defines the notion of a quasi-laminar beam

paper, is generally attained in RF photoinjectors, in particular when they are operat…

space-charge emittance compensation regime[4]. This regime i…

…ropagates for one transverse plasma oscillation, so th…

…e space which develop in the first half…

…perly focusing the be…

the bea…

rel… …gime in

typi… …diminished. However, plasma

transi… …still effective in significantly perturbing the evolution

which … phase space distribution, introducing distortions and longitudinal-

oscillati…

First Paper Assigned by KJK

Flat Beam Generation

$$V = \begin{pmatrix} X \\ Y \end{pmatrix}; \qquad X = \begin{pmatrix} x \\ x' \end{pmatrix}; \qquad Y = \begin{pmatrix} y \\ y' \end{pmatrix}; \qquad (') \equiv \frac{d}{dz}$$

and rotation matrix

$$R = \frac{Ic}{-Is}\bigg|\frac{Is}{Ic},$$

where $c \equiv cos\alpha$, $s \equiv \sin\alpha$, and I is the 2×2 unit matrix. Then, the 4×4 matrix of skew block, S, in the transition

$$V_2 = SV_1 \tag{1}$$

can be found as

$$S = R^{-1}\begin{pmatrix} M & O \\ O & N \end{pmatrix} R = \frac{Mc^2 + Ns^2}{(M-N)cs}\bigg|\frac{(M-N)cs}{Ms^2+Nc^2}. \tag{2}$$

Ya. Derbenev, University of Michigan Report No. UM-HE-98-04, 1998.

Flat Beam Generation and Emittance Exchange

Yine Sun
Accelerator System Division
Argonne National Lab.

Coherence in Particle and Photon Beams: Past, Present, and Future Symposium
March 15, 2019

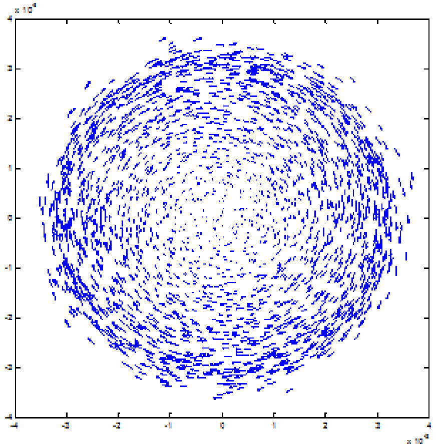
Outline

- Round-to-Flat Beam Transformation
  - Theory;
  - Experimental demonstration.
- Transverse-to-longitudinal Emittance EXchange (EEX)
  - Theory;
  - Experimental demonstration;
  - Longitudinal phase-space shaping via EEX.
- Acknowledgements

Flat Beam Generation: Beam Matrix Formulation

$$\Sigma_{round} = \begin{bmatrix} \varepsilon_{eff}\beta & 0 & 0 & L \\ 0 & \varepsilon_{eff}/\beta & -L & 0 \\ 0 & -L & \varepsilon_{eff}\beta & 0 \\ L & 0 & 0 & \varepsilon_{eff}/\beta \end{bmatrix}$$

General form of the beam matrix of a round beam at waist location.

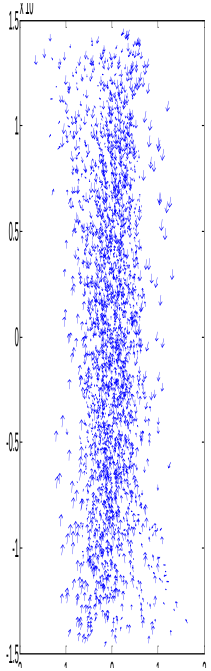


$$\Sigma_{flat} = M\Sigma_{round}\widetilde{M}$$

Going through a round-to-flat beam transformation matrix *M* which is symplectic

$$\Sigma_{flat} = \begin{bmatrix} \varepsilon_{-}\beta & 0 & 0 & 0 \\ 0 & \varepsilon_{-}/\beta & 0 & 0 \\ 0 & 0 & \varepsilon_{+}\beta & 0 \\ 0 & 0 & 0 & \varepsilon_{+}/\beta \end{bmatrix}$$

Beam is decoupled in x and y and a flat beam with emittance ε_{-} and ε_{+} is generated.



Invariants of the Symplectic Transformation→ Flat Beam Emittances

$$I_1 = \varepsilon_{4D} = \sqrt{|\Sigma|} \Rightarrow \varepsilon_+ \varepsilon_- = \varepsilon_{eff}^{\;2} - L^2$$

$$I_2 = -\frac{1}{2}\mathrm{Trace}(J_4 \Sigma J_4 \Sigma) \Rightarrow \varepsilon_+^2 + \varepsilon_-^2 = 2\left(\varepsilon_{eff}^{\;2} + L^2\right)$$

KJK
Phys. Rev. St. Accel Beams **6**, 104002 (2003).

Round beam emittance: $\varepsilon_{eff} = \sqrt{\varepsilon_u^{\;2} + L^2}$

uncorrelated emittance

Const. related to canonical angular momentum $L = \frac{\langle L \rangle}{2Pz}$

Flat beam emittances are given by:

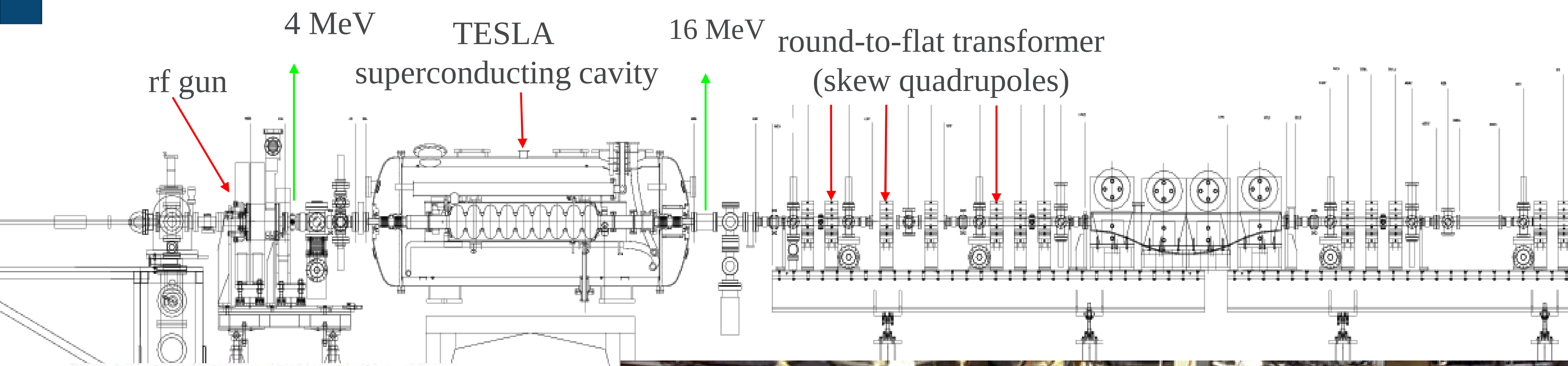
$$\varepsilon_\pm = \sqrt{\varepsilon_u^{\;2} + L^2} \pm L$$

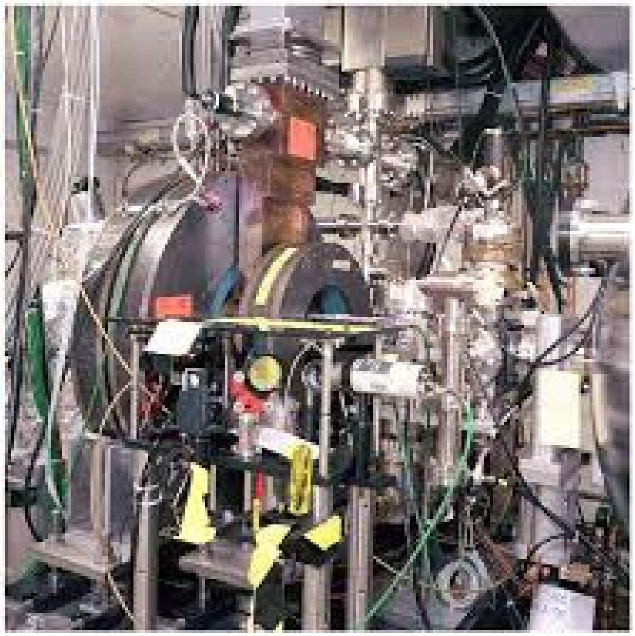
e.g. $L = 20\ \mu m$, $\varepsilon_u = 1\ \mu m$
$\varepsilon_+ = 47\ \mu m$; $\varepsilon_- = 0.02\ \mu m$

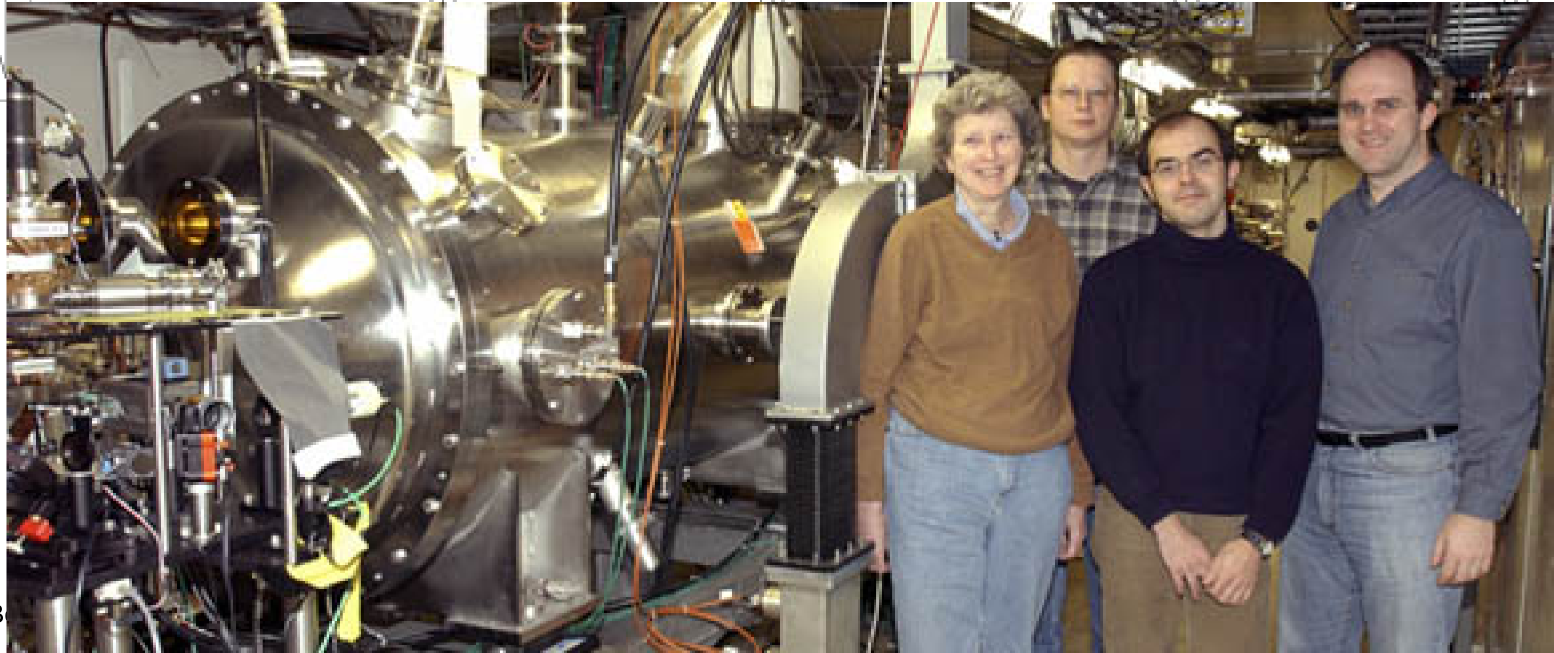
For $L \gg \varepsilon_u$, $\varepsilon_- = \frac{\varepsilon_u^2}{2L} << \varepsilon_u$

Flat beam emittance can be much smaller than the thermal emittance!

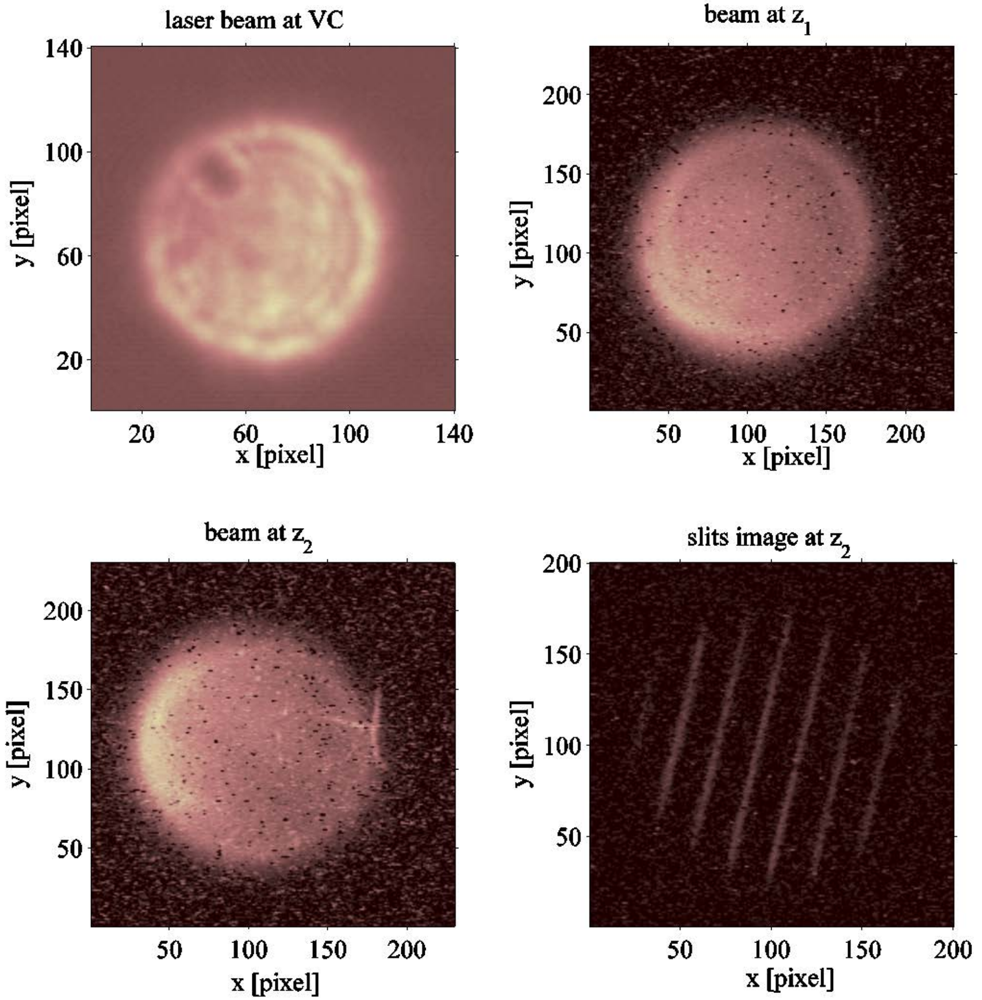
Flat Beam Experiment at Fermilab/NICADD Photoinjector Lab (A0)

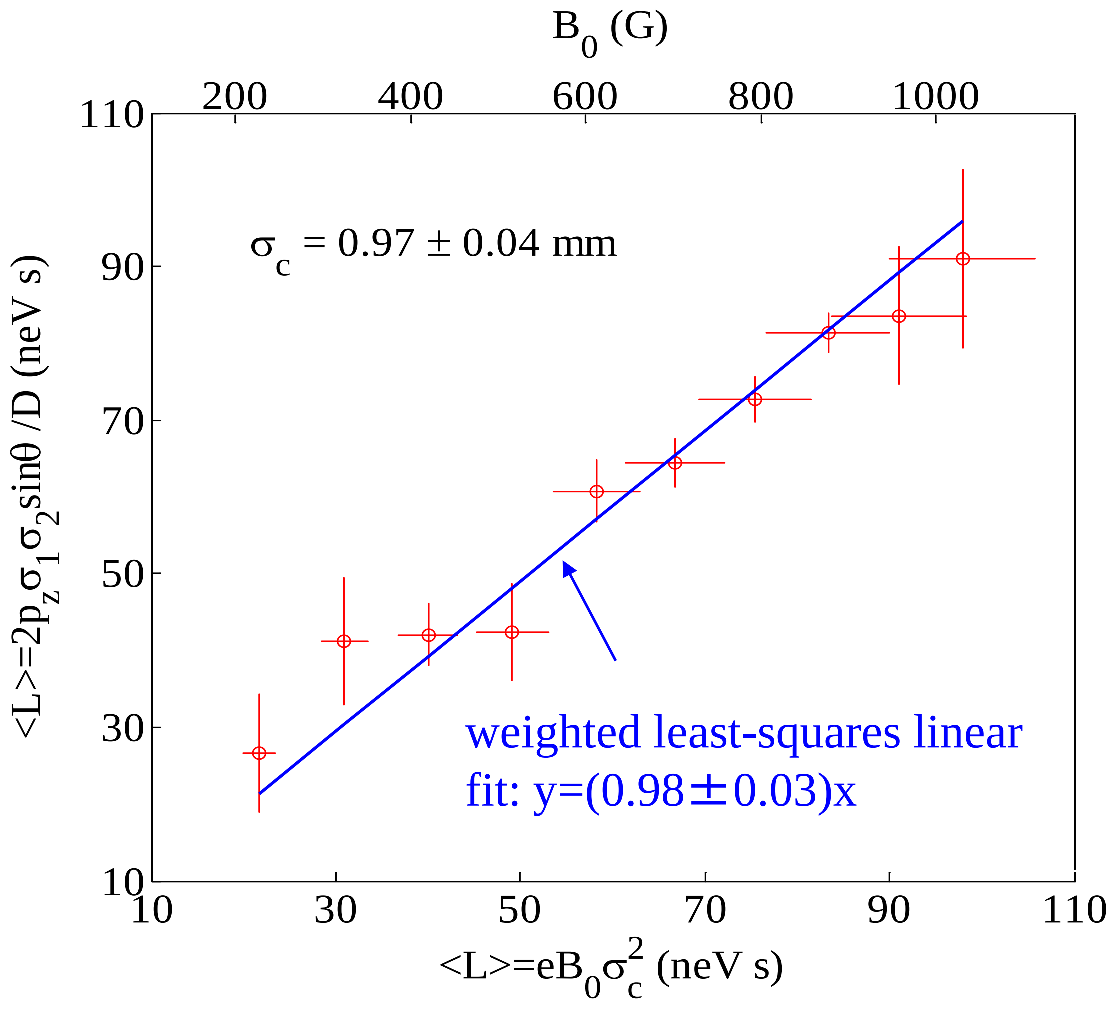




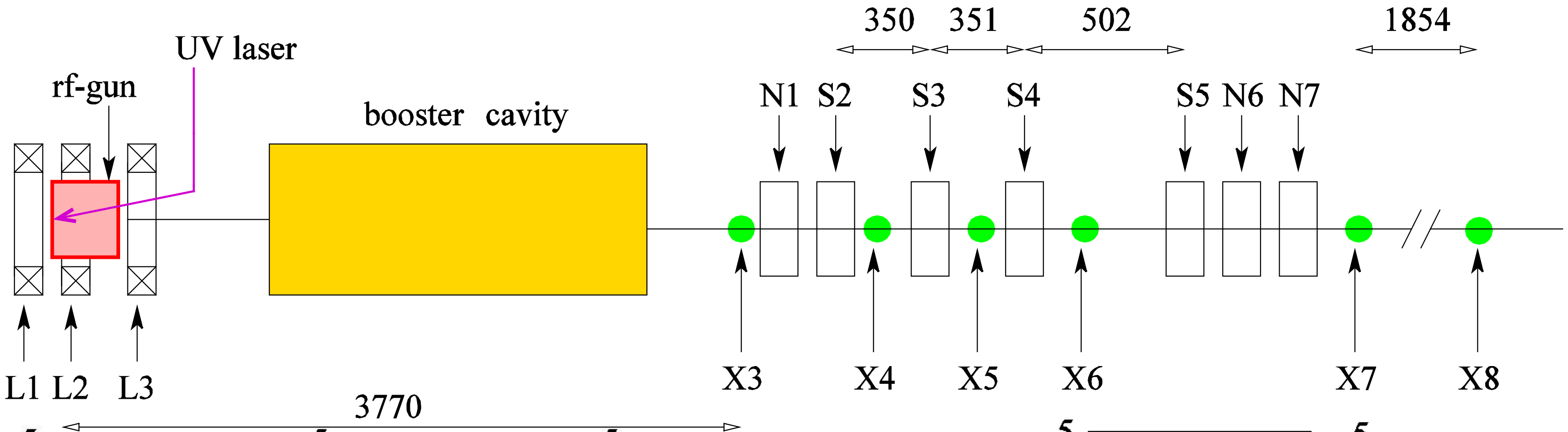


Measurements of the canonical angular momentum
as a function of magnetic field on cathode

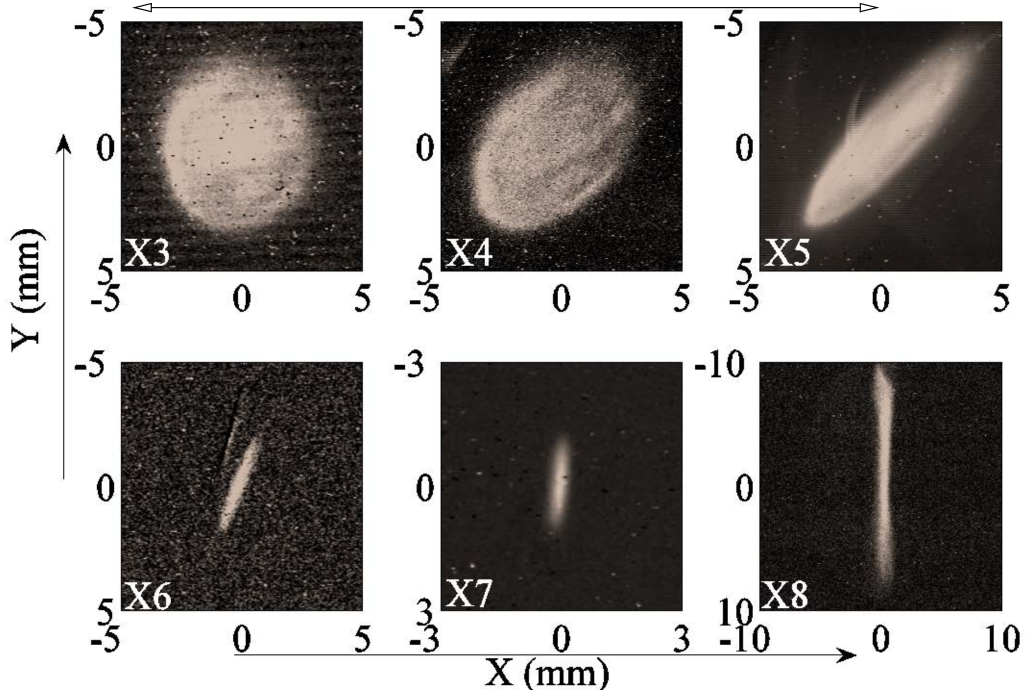




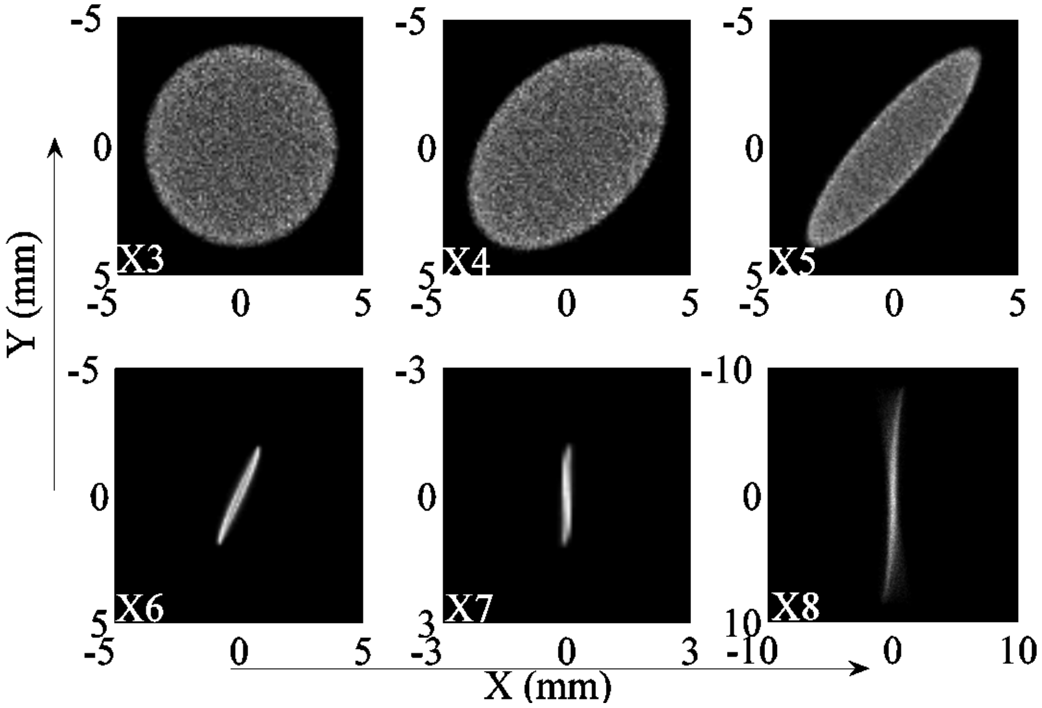
Removal of angular momentum → flat beam generation



εx (μm)	**0.39±0.02**
εy (μm)	**35.2±0.5**
εy/εx	**90±5**



experiment



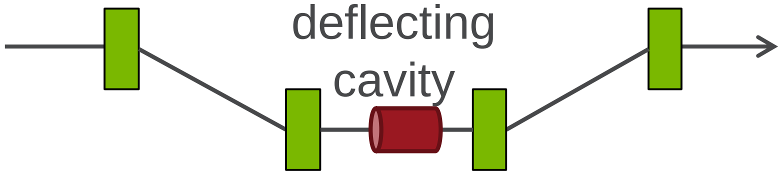
simulation

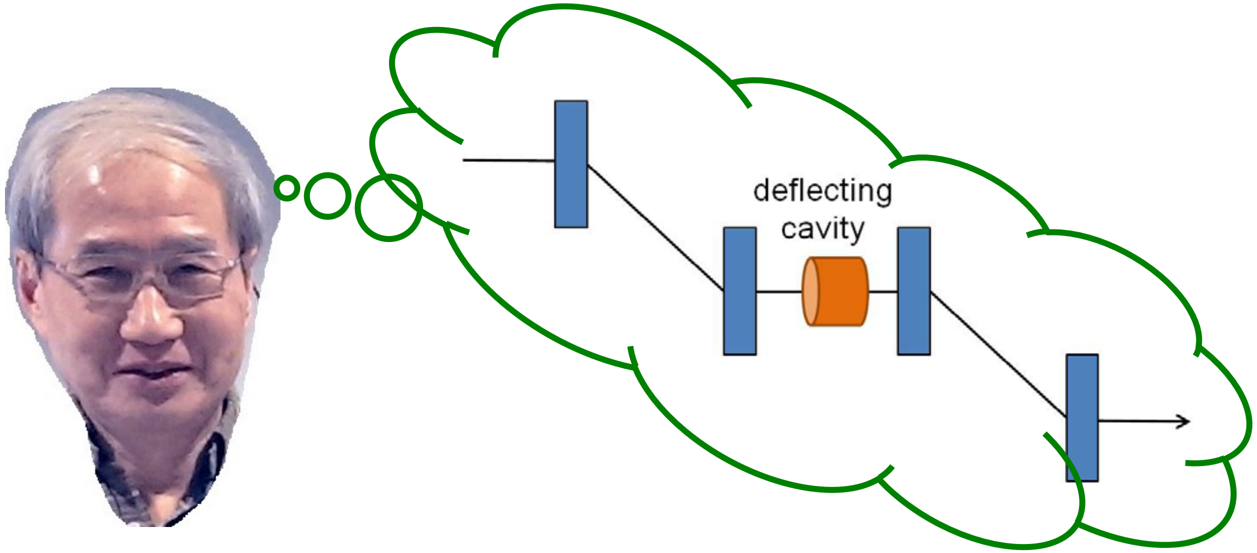
Round-to-Flat
transverse phase-space manipulation

Emittance Exchange
transverse $\leftrightarrow$ longitudinal phase-space manipulation

Transverse-to-Longitudinal Phase-Space Exchange

- EEX therory:
  - 2002: Cornacchia and Emma, PRSTAB 5, 084001.
    - Partial exchange : chicane
  - 2006: Kim, AIP Conf. Proc. No. 821.
    - **Complete Exchange: double-dogleg**
- 2010: Double-dogleg EEX experiment demonstration:
  - J. Ruan et al., PRL 106, 244801 (2011).
- 2010: Applications of EEX in beam current profile modulation:
  - Y. Sun et al., PRL 105, 234801 (2010).
  - G. Ha et al;. PRL 118, 104801 (2017).

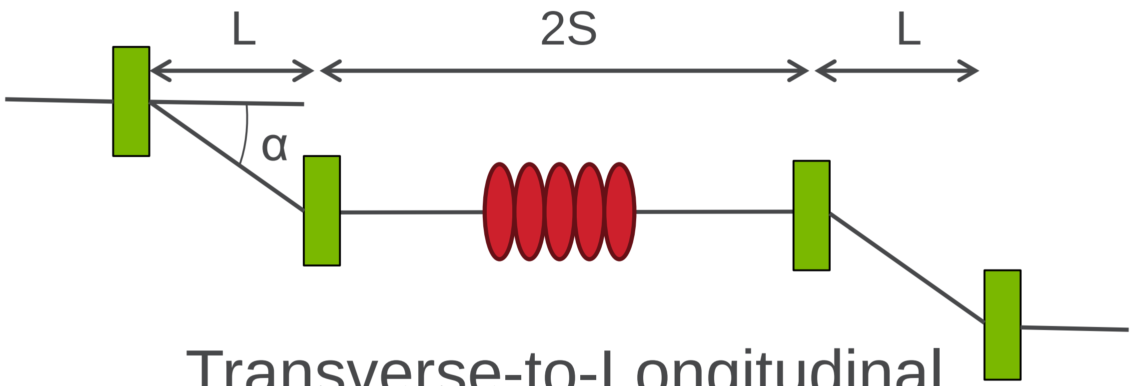




Transverse-to-Longitudinal Emittance EXchange

- Under thin-lens approximation, with proper matching of the deflecting cavity strength (k) and the dogleg dispersion (D), i.e., 1+kD=0, the diagonal sub-block elements of the exchanger's transfer matrix are zero ↔ the initial horizontal phase space is mapped into the longitudinal phase space, vice versa.
- Transfer matrix of a deflecting cavity with strength k under thin lens approximation:

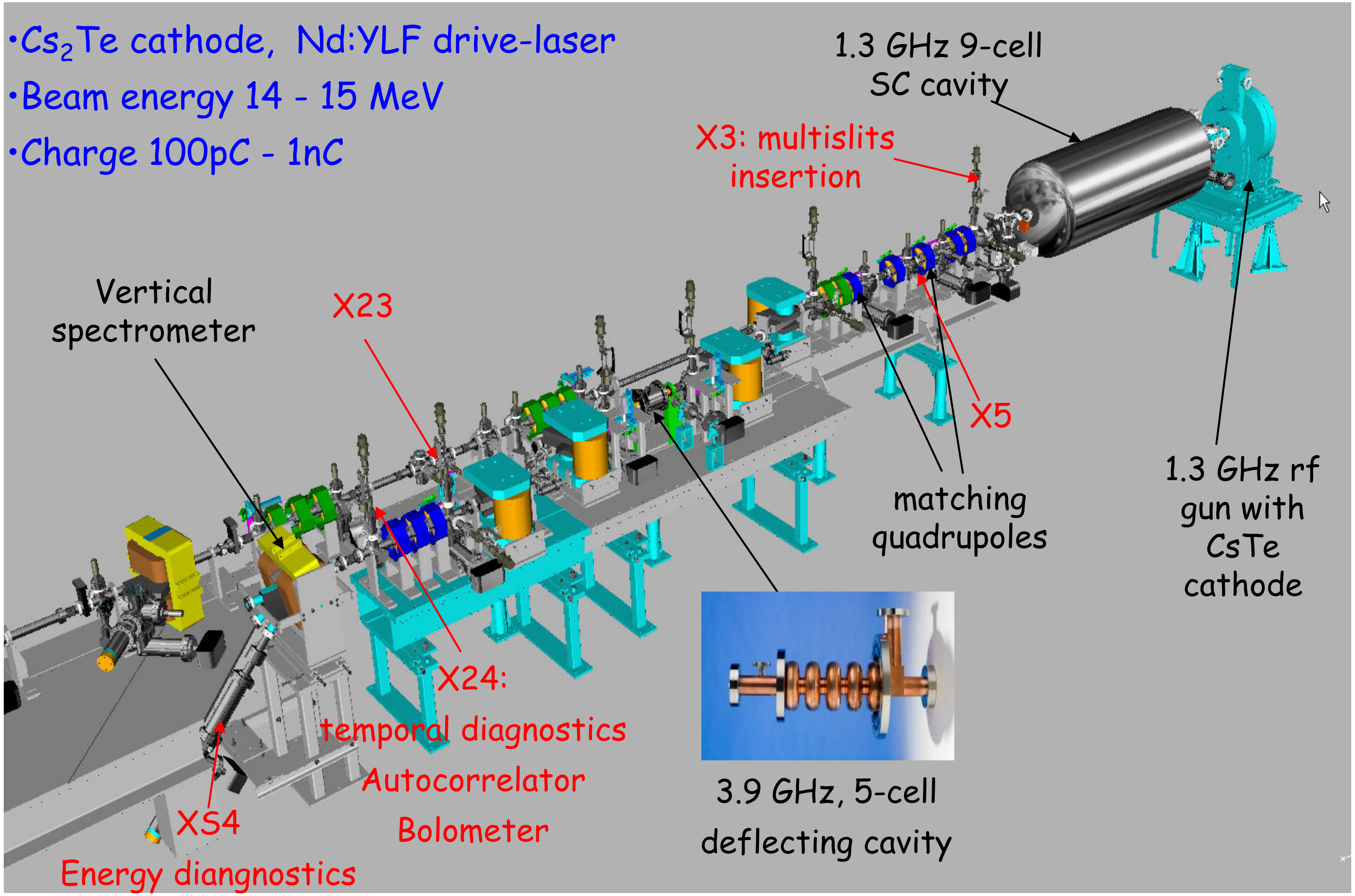
$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & k & 0 \\ 0 & 0 & 1 & 0 \\ k & 0 & 0 & 1 \end{pmatrix}$$



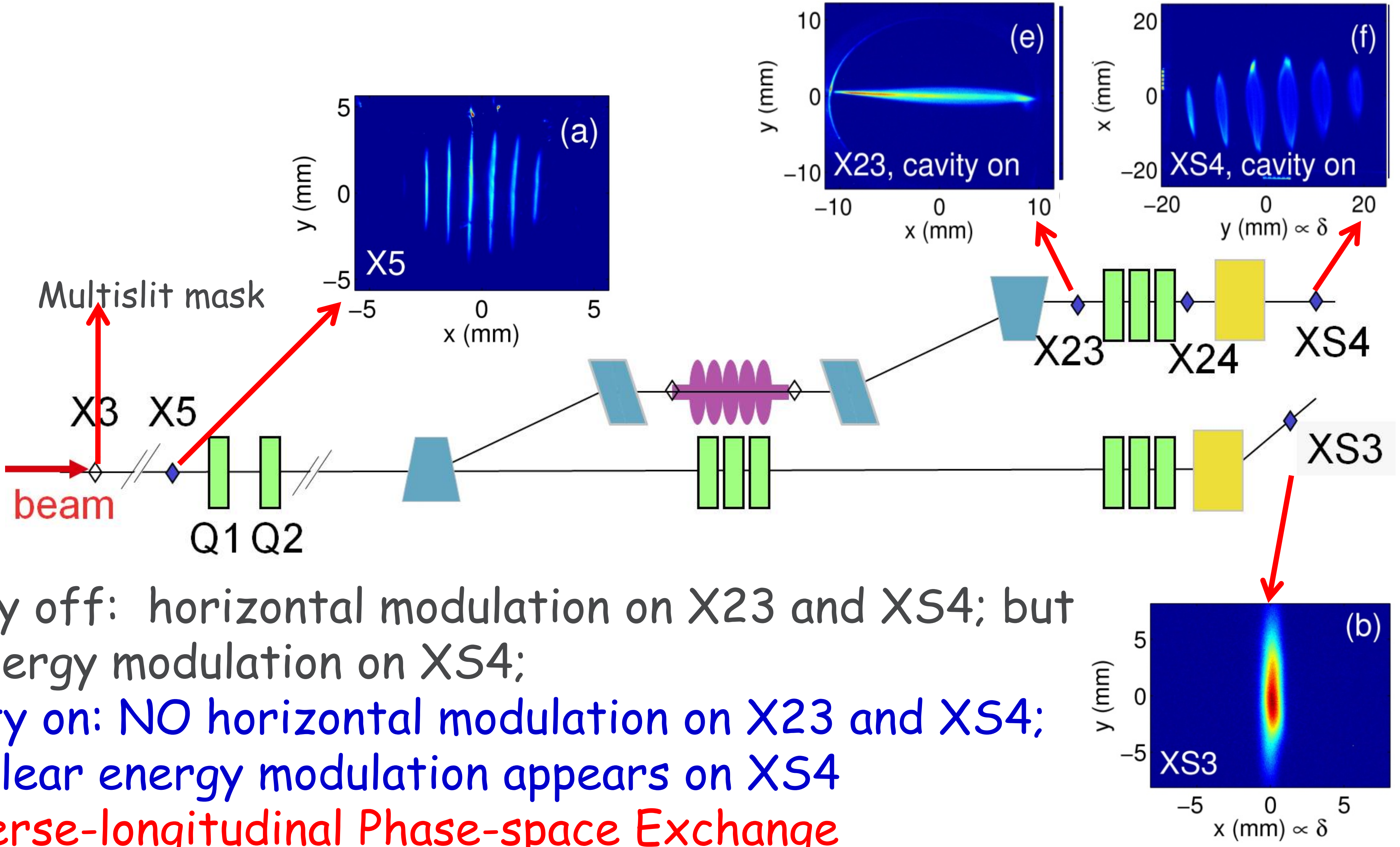
Transverse-to-Longitudinal Emittance EXchange

$$\begin{pmatrix} x \\ x' \\ z \\ \delta \end{pmatrix}_{out} = \begin{pmatrix} 0 & 0 & \frac{L+S}{\alpha L} & \alpha S \\ 0 & 0 & \frac{1}{\alpha L} & \alpha \\ \alpha & \alpha S & 0 & 0 \\ \frac{1}{\alpha L} & \frac{L+S}{\alpha L} & 0 & 0 \end{pmatrix} \begin{pmatrix} x \\ x' \\ z \\ \delta \end{pmatrix}_{in}$$

EEX Beamline at A0 Photo-Injector, Fermilab



Sub-ps Bunch Train Generation using EEX at Fermilab A0

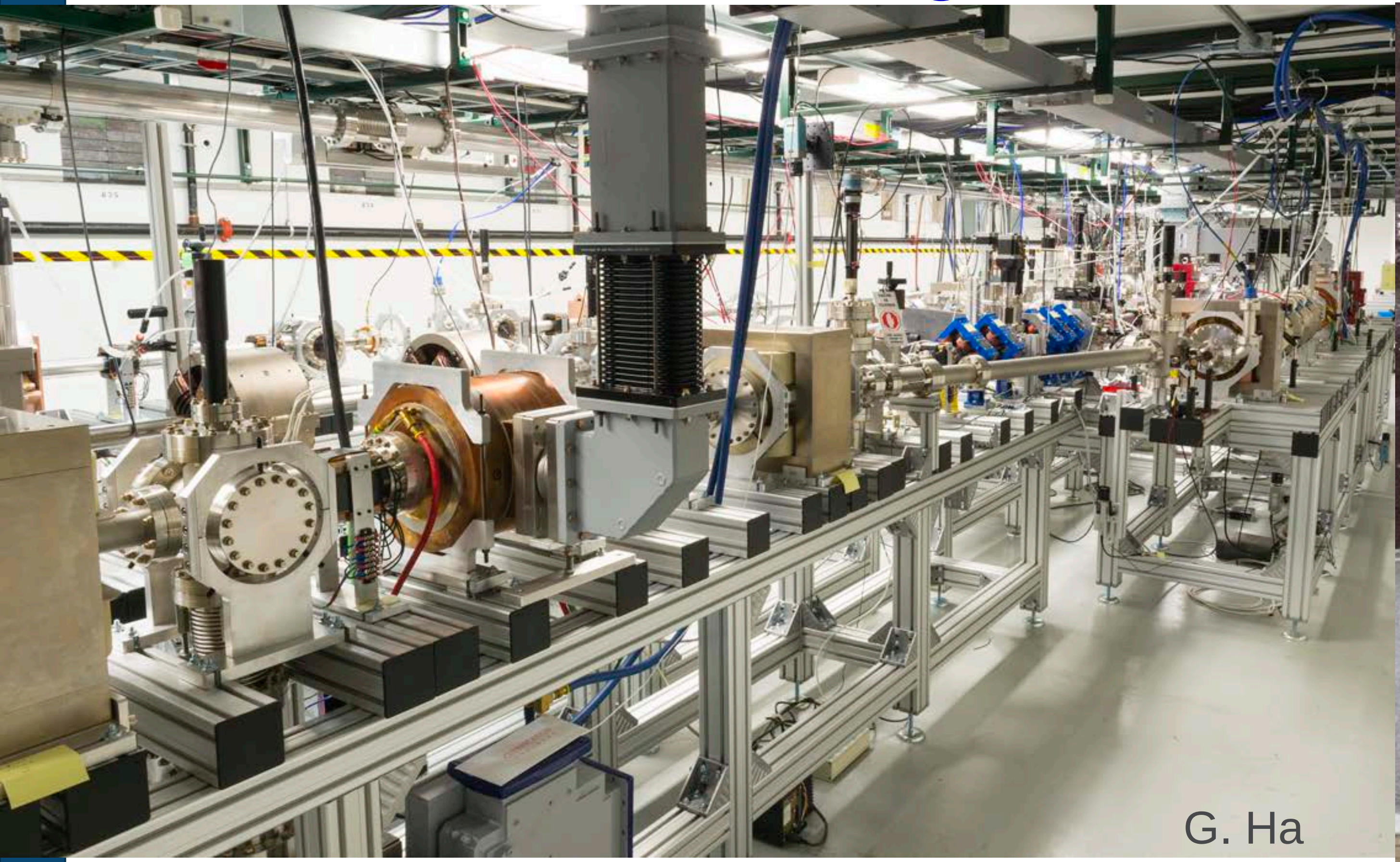


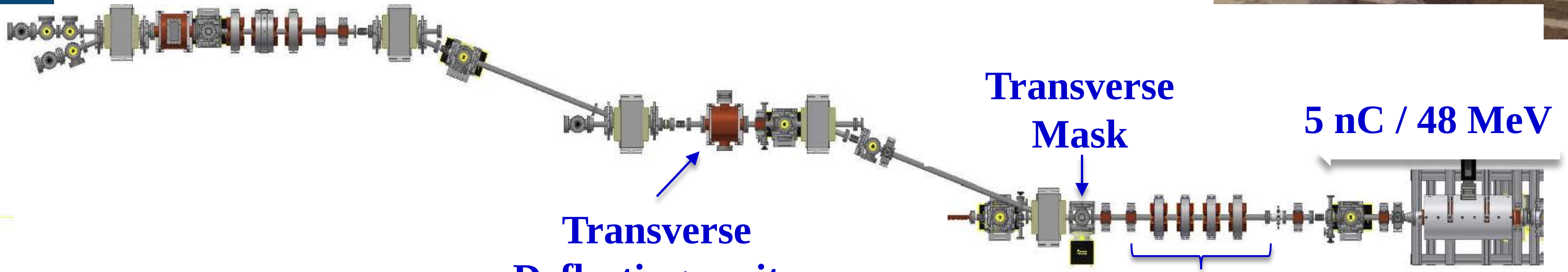
(1)cavity off: horizontal modulation on X23 and XS4; but no energy modulation on XS4;

(2)cavity on: NO horizontal modulation on X23 and XS4; but clear energy modulation appears on XS4

Transverse-longitudinal Phase-space Exchange

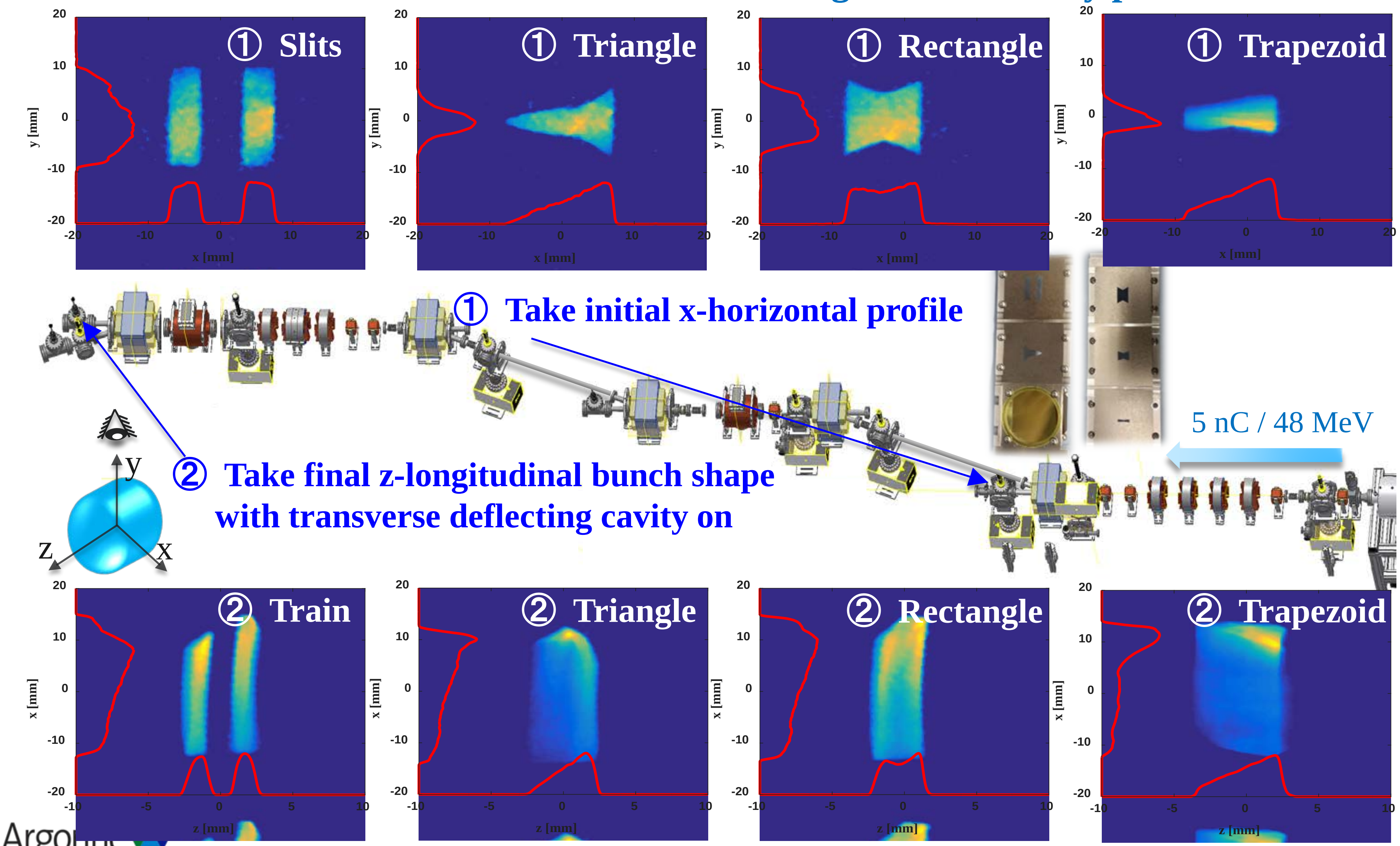
EEX Beamline at Argonne Wakefield Accelerator (AWA)





Precision Control of the Electron Longitudinal Bunch Shape via EEX at AWA/ANL

EXPERIMENT: Transverse mask to tailor longitudinal density profile



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

Acknowledgements

To the brilliant

Kim Kwang-Je

金 光齐

Golden Light-Coherent

Thank you for introducing me to the accelerator field, offering me the first scholarship at UofC, serving as my Ph.D. advisor, and offering your support in every step of my career…

Happy Retirement !