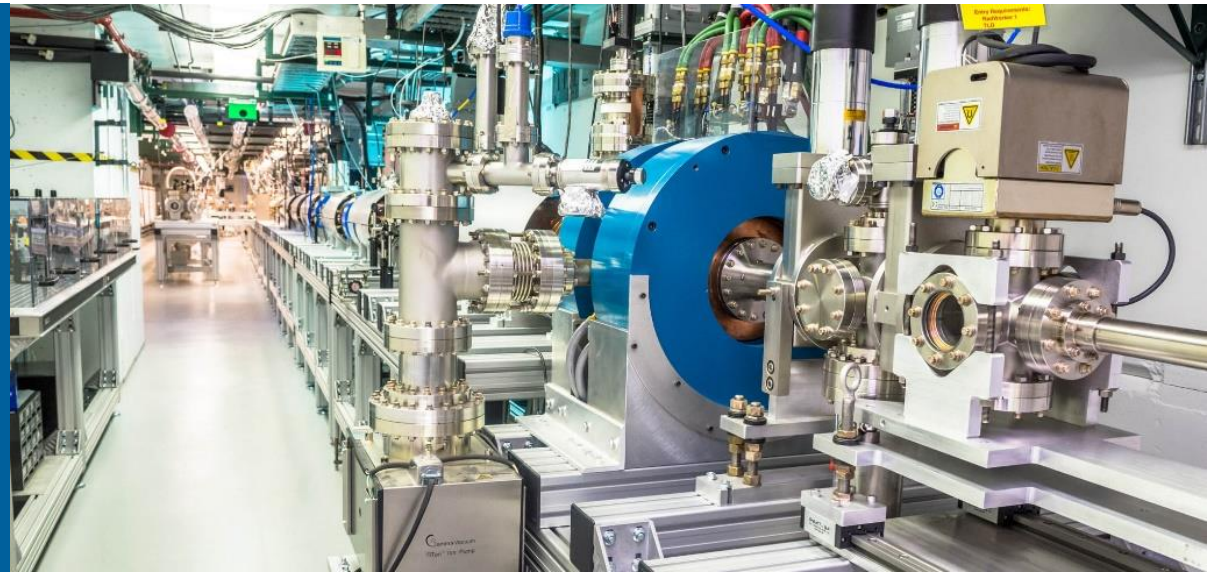
JUNE 22, 2023

Argonne NATIONAL LABORATORY

UPDATE ON ELECTRON BEAM MANIPULATION AT THE ARGONNE WAKEFIELD ACCELERATOR FACILITY



SEONGYEOL KIM
On behalf of Argonne Wakefield Accelerator Group

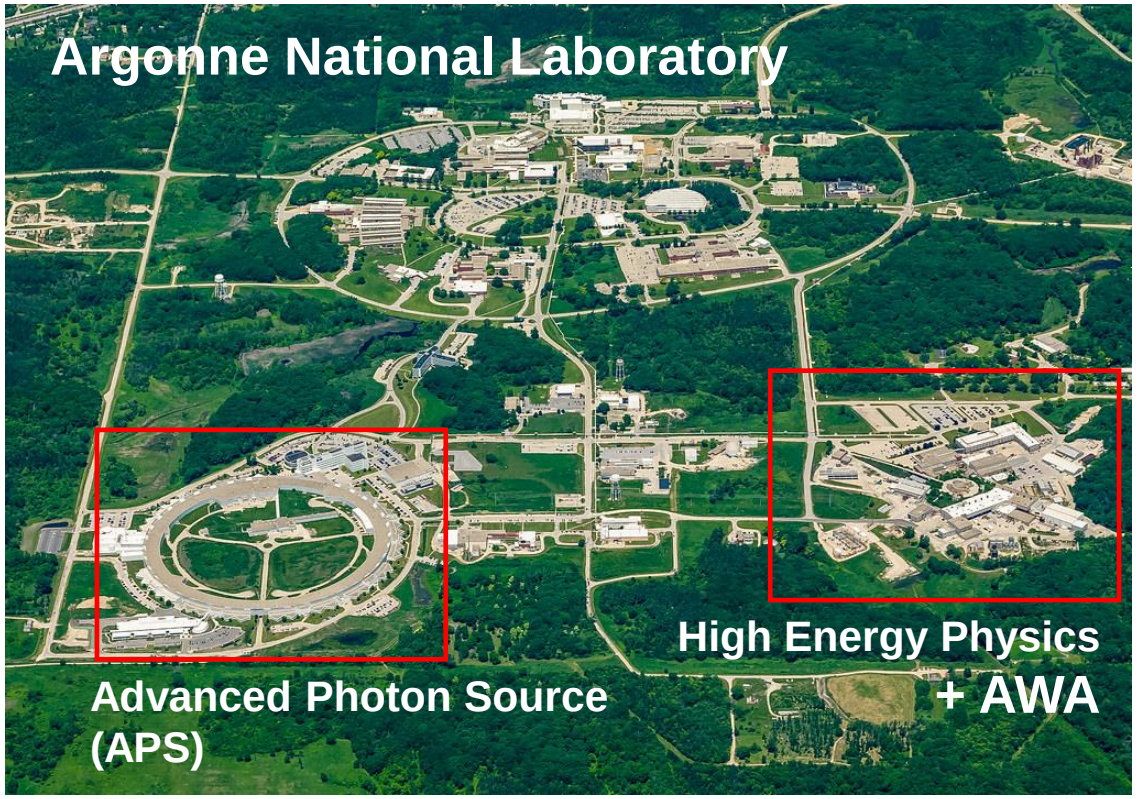
Contents

- **Introduction to AWA facility**
- **Research activities on the beam manipulations**
  - Longitudinal bunch shaping
  - Transverse emittance control and partitioning
  - AI/ML-based phase space reconstruction
- **Future plans and summary**

Introduction to AWA facility in Argonne National Lab

Website: https://www.anl.gov/awa

https://www.flickr.com/photos/argonne/46276624524



Beam test facility

- 100 MeV energy particle beams

Beam test facilities mission

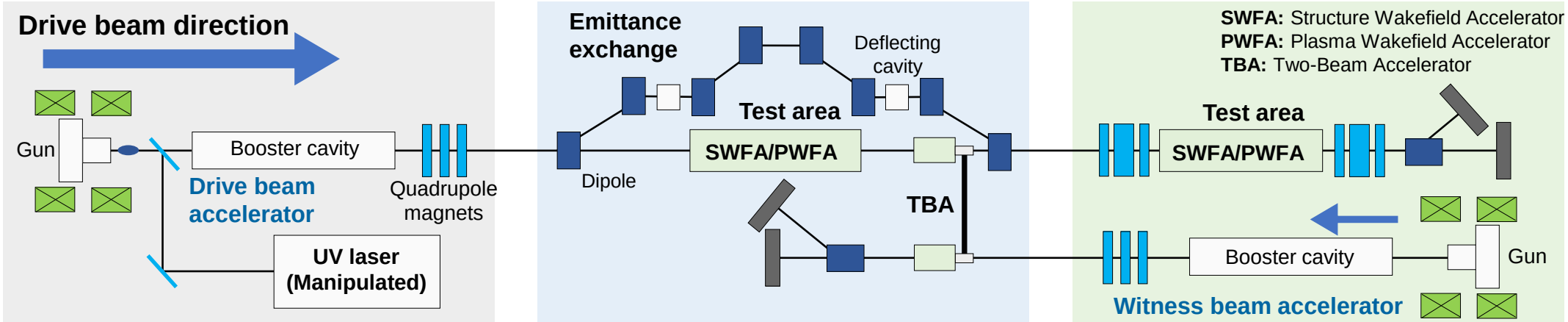
- Providing experimental test beds for the experimental validation emerging accelerator science
- Developing the S&T needed to enable the next generation of science facilities and accelerator applications.
- Educating and training future scientists and engineers.

For more details:
J. Power, The Argonne Wakefield Accelerator Beam Test Facility for Novel Accelerator Research, AAC 2022 workshop

AWA Science: Research Theme

- For more details: John power, invited talk at 09:30 (Tue) @ PAHBB

Simplified schematic view of AWA (Not to scale)



Theme 3: Beam production

- Electron source
  - High-brightness
  - High-intensity

Theme 2: Beam manipulation

- Beam shaping and control
- Beam diagnostics
- AI/ML-based optimization

Theme 1: Advanced Accelerator

- SWFA & PWFA & TBA
  - High-gradient
  - High-efficiency

Novel R&D facility for high-brightness beam and AAC

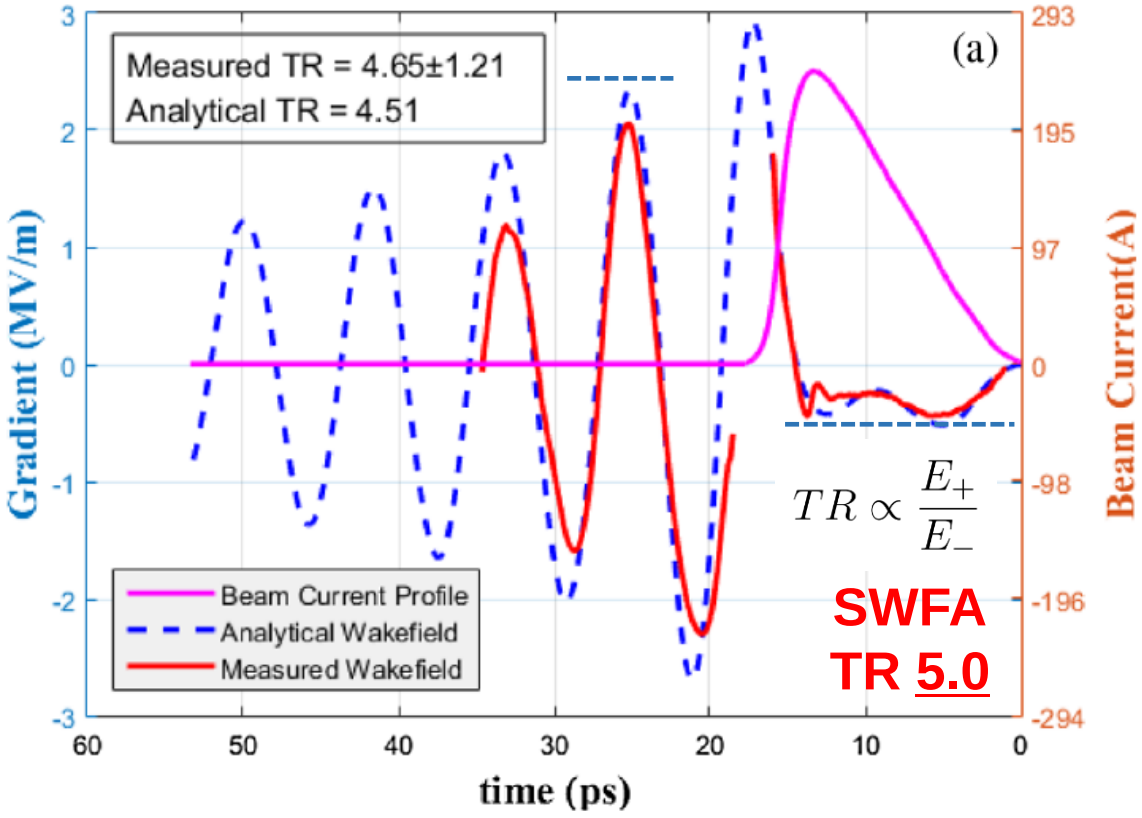
Research programs for beam manipulation

- Longitudinal bunch shaping

Motivation of longitudinal bunch shaping

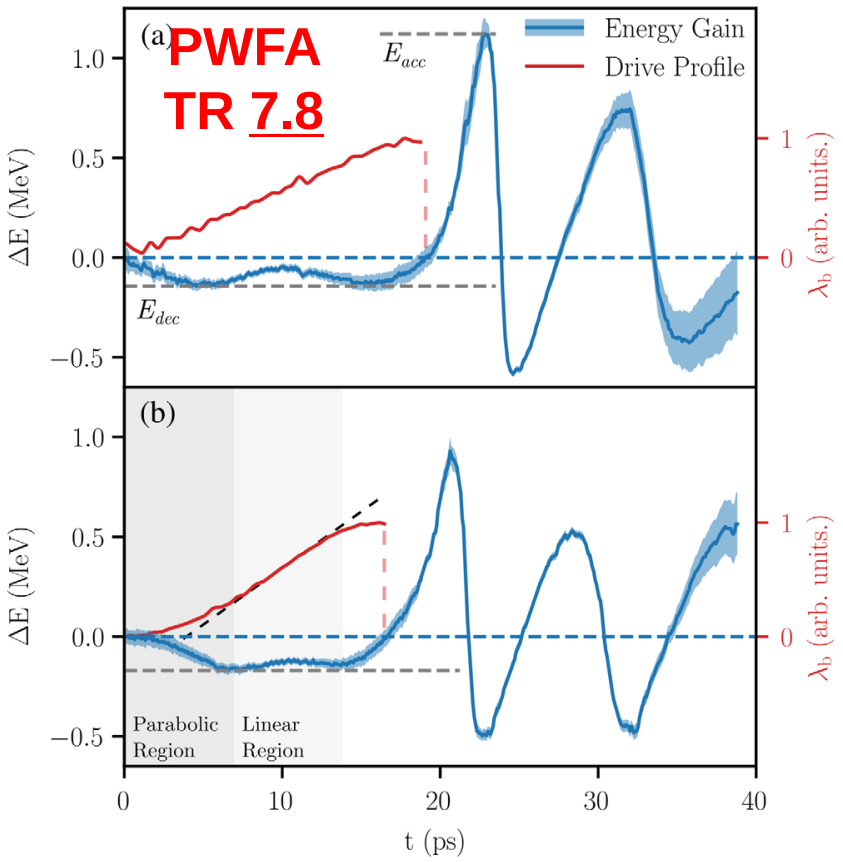
Collaboration study with Tsinghua University

Gao *et al., PRL* **120**, 114801, 2018



UCLA collaboration

Roussel *et al., PRL* **124**, 044802, 2020



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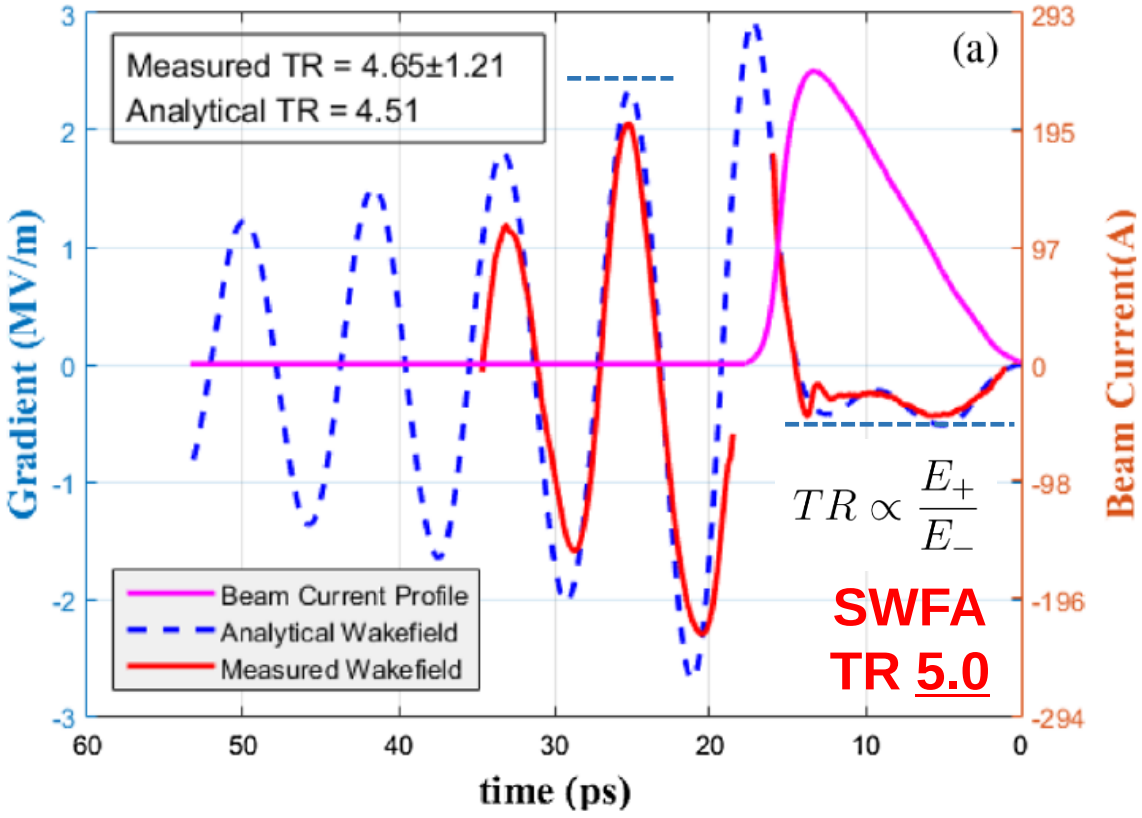

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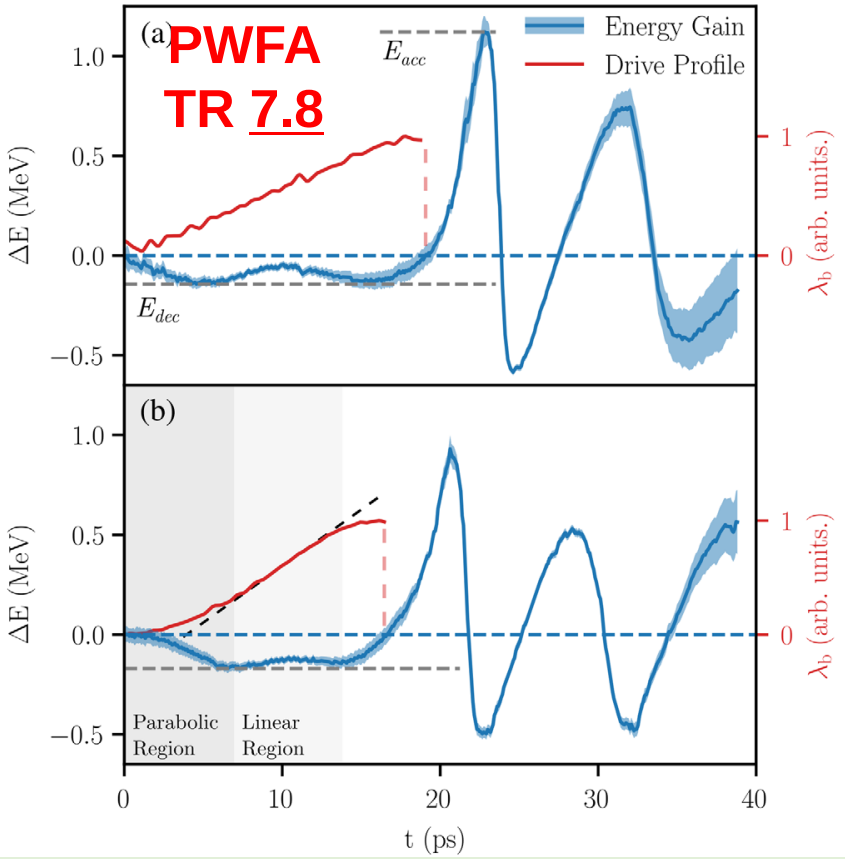
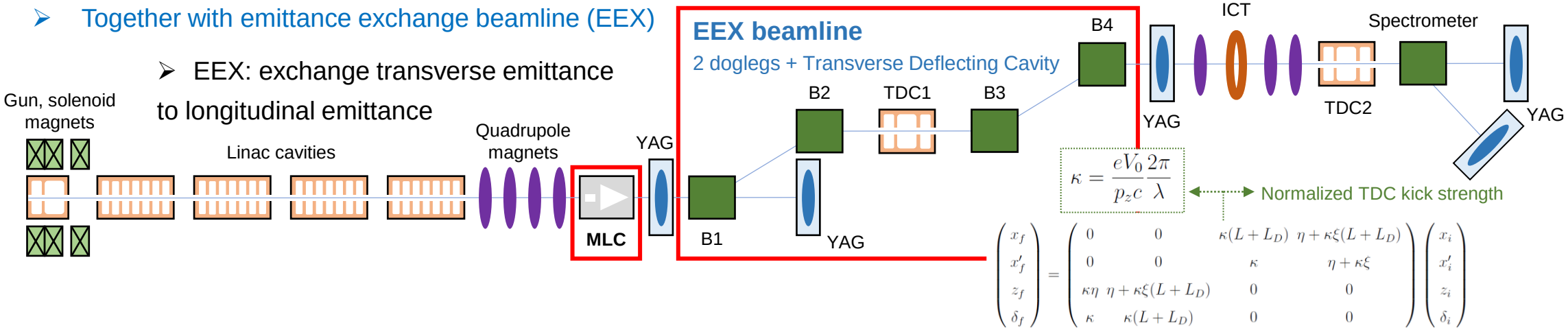


High-gradient, high-transformer ratio wakefield generation:

High-charge bunch shaping (e.g., triangular longitudinal distribution)

UCLA collaboration: Multi-leaf collimator

- Together with emittance exchange beamline (EEX)
  - EEX: exchange transverse emittance to longitudinal emittance



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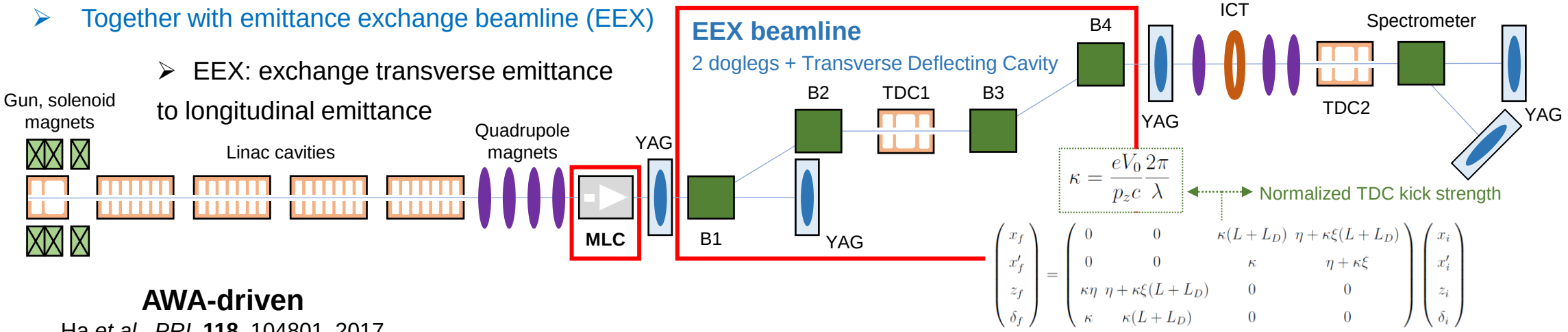
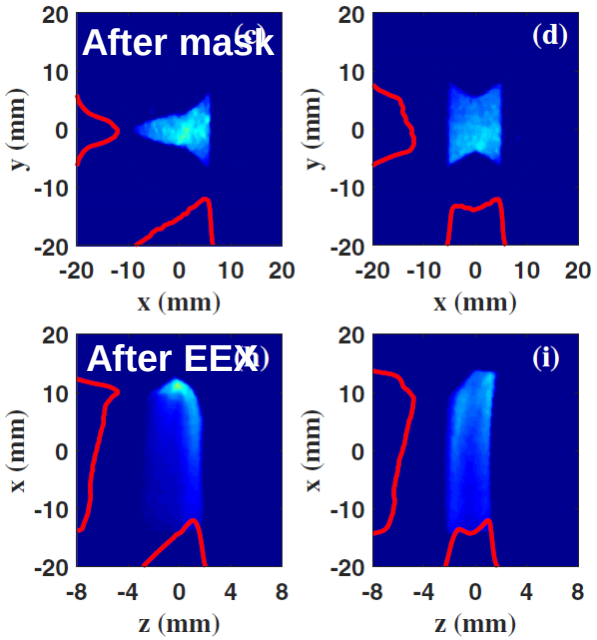
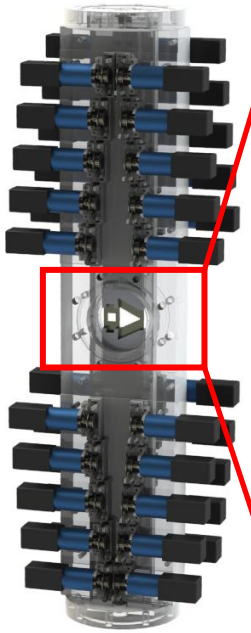


AWA-driven

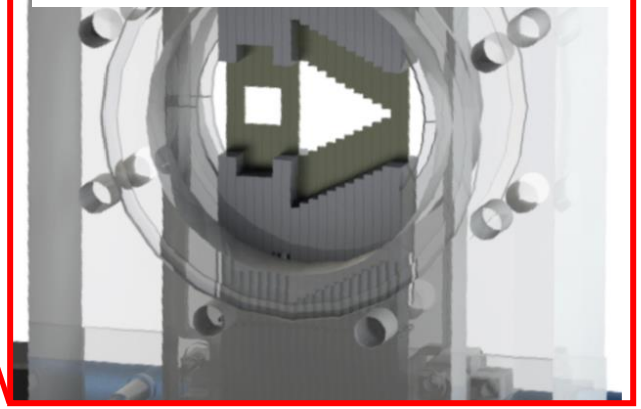
Ha *et al., PRL* **118**, 104801, 2017





Multi-leaf collimator (MLC)

N. Majernik *et al.*,
PRAB **26**, 050701, 2023



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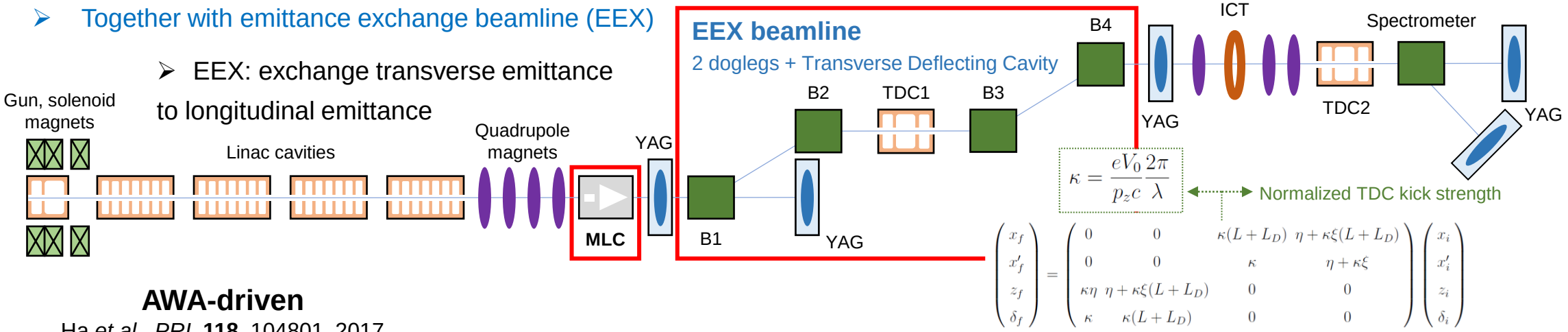

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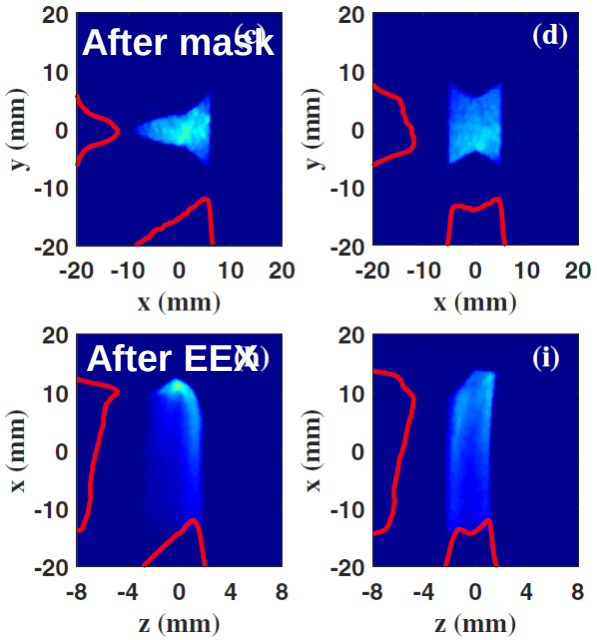

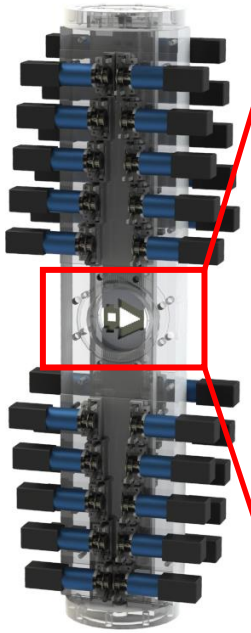

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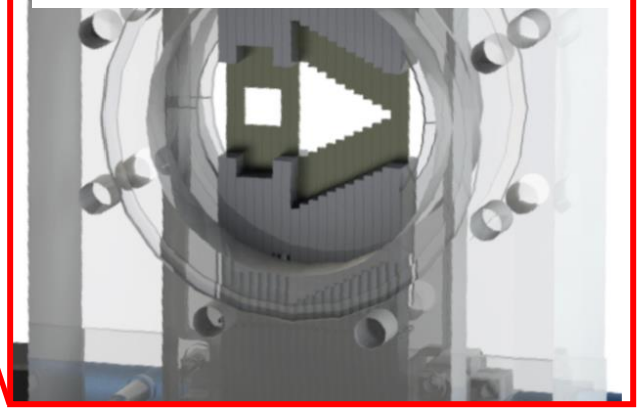
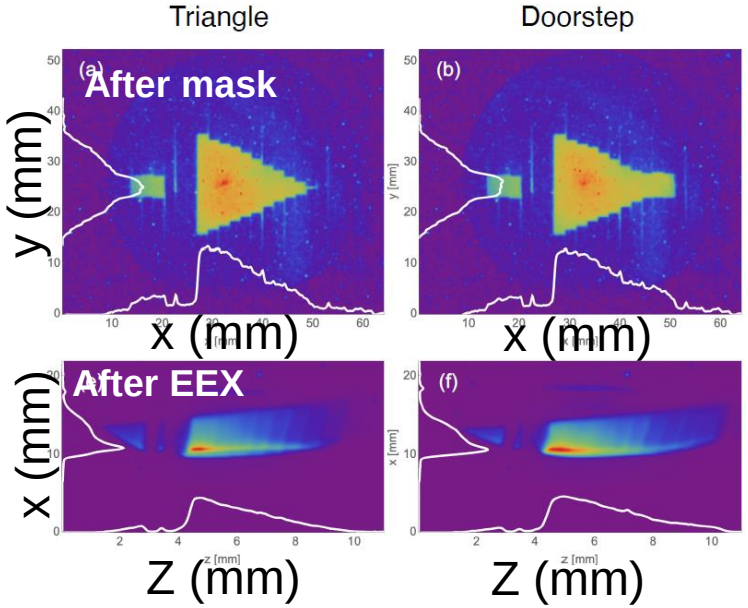


Experimental measurements



* Discussion with the numerical simulations

** TDC: Transverse deflecting cavity

AWA in-house study: TDC-based shaping*

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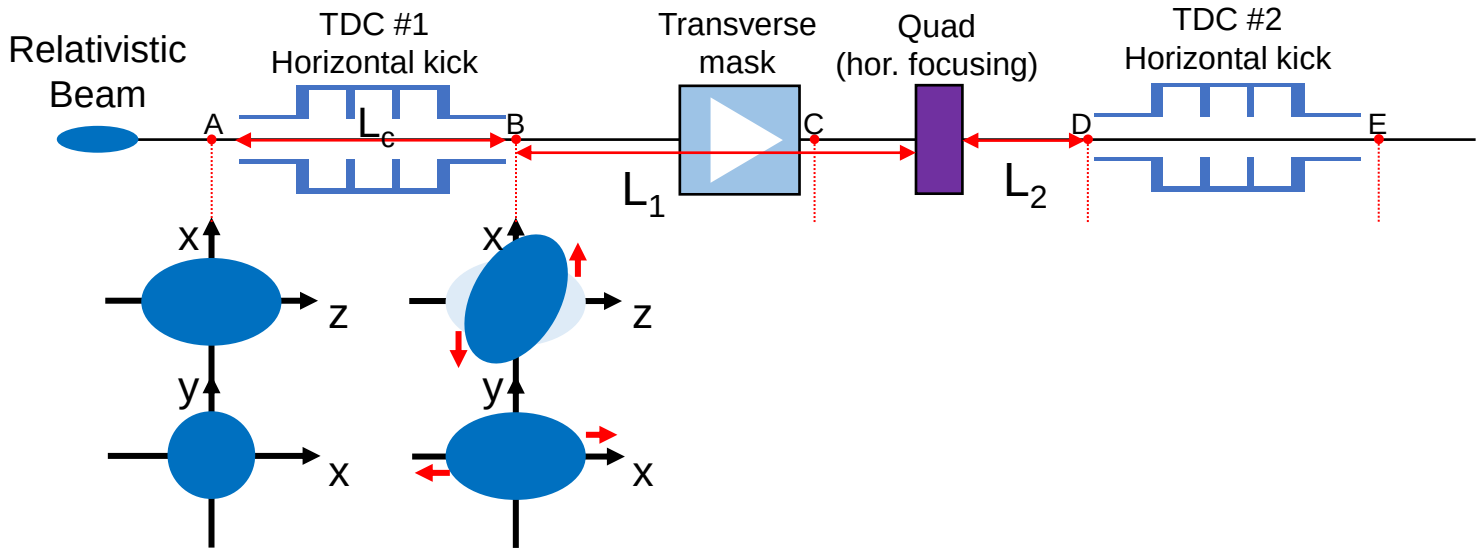

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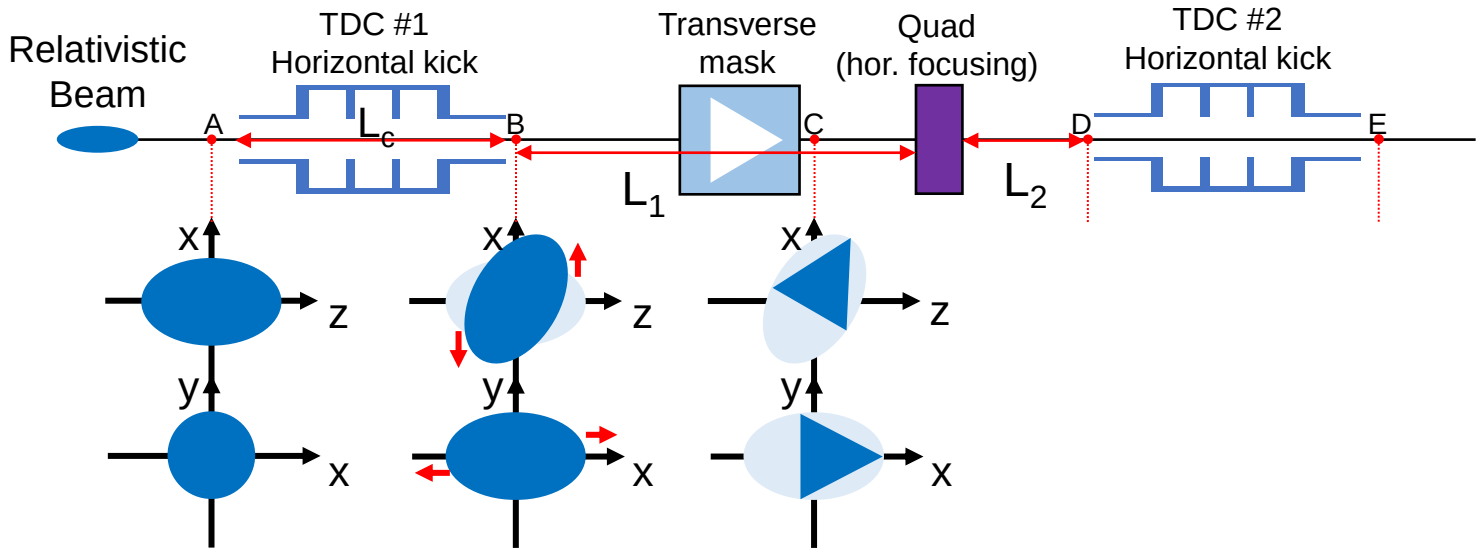

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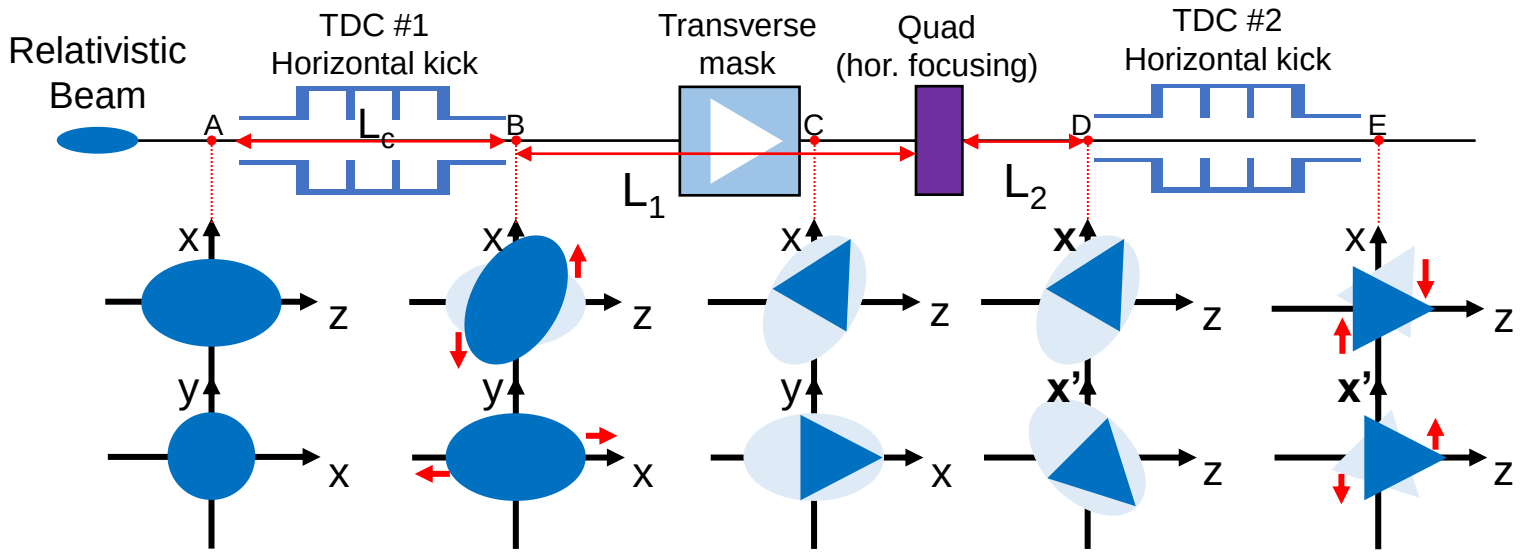

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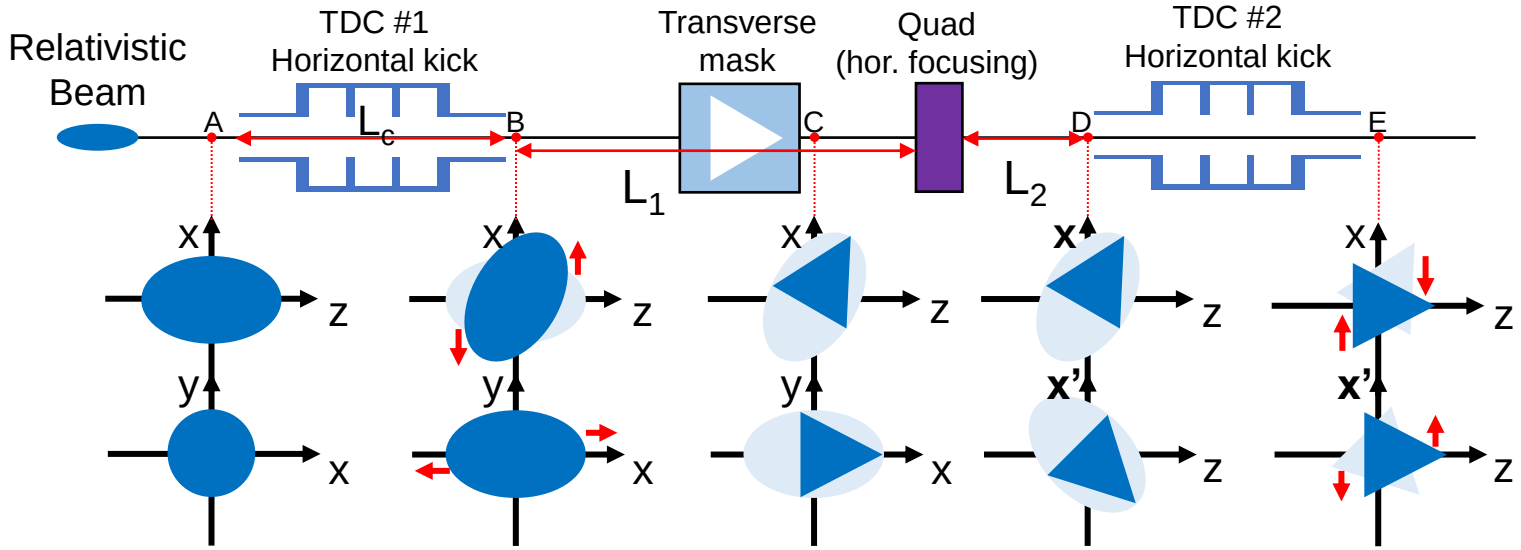
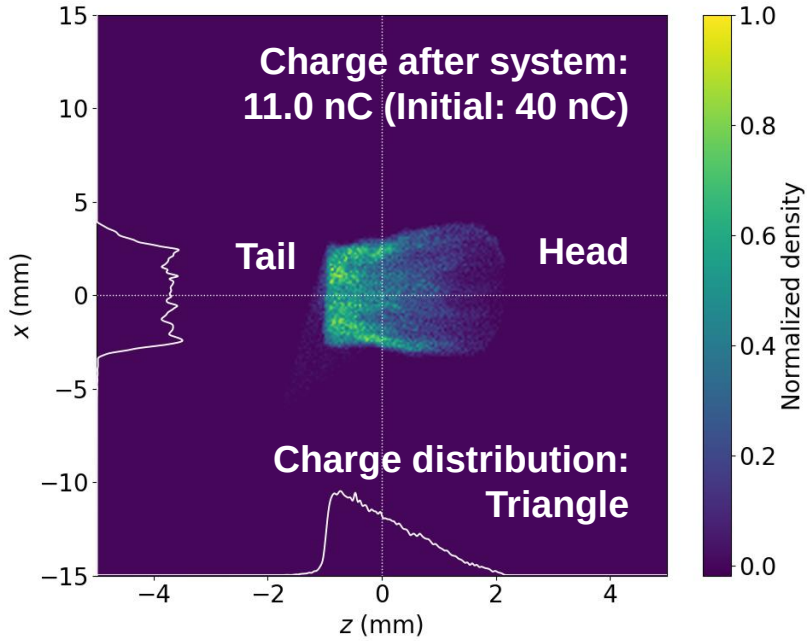
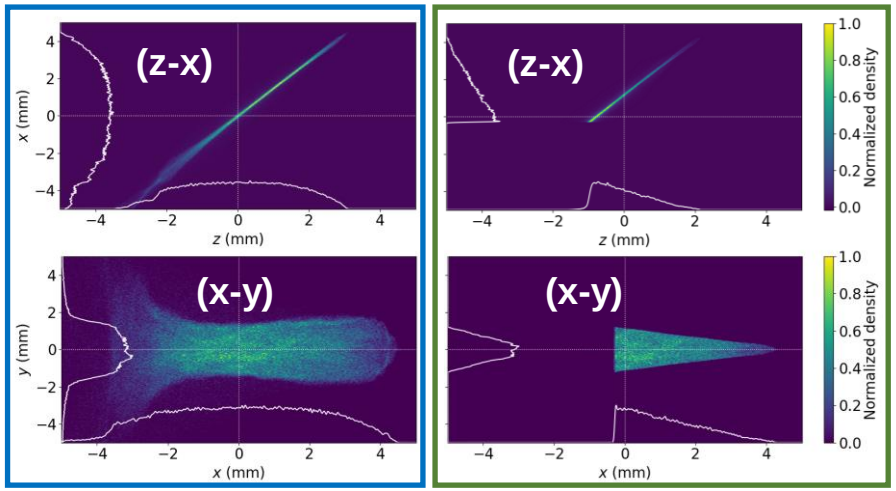


Start-to-end OPAL simulation



Before mask **After mask**



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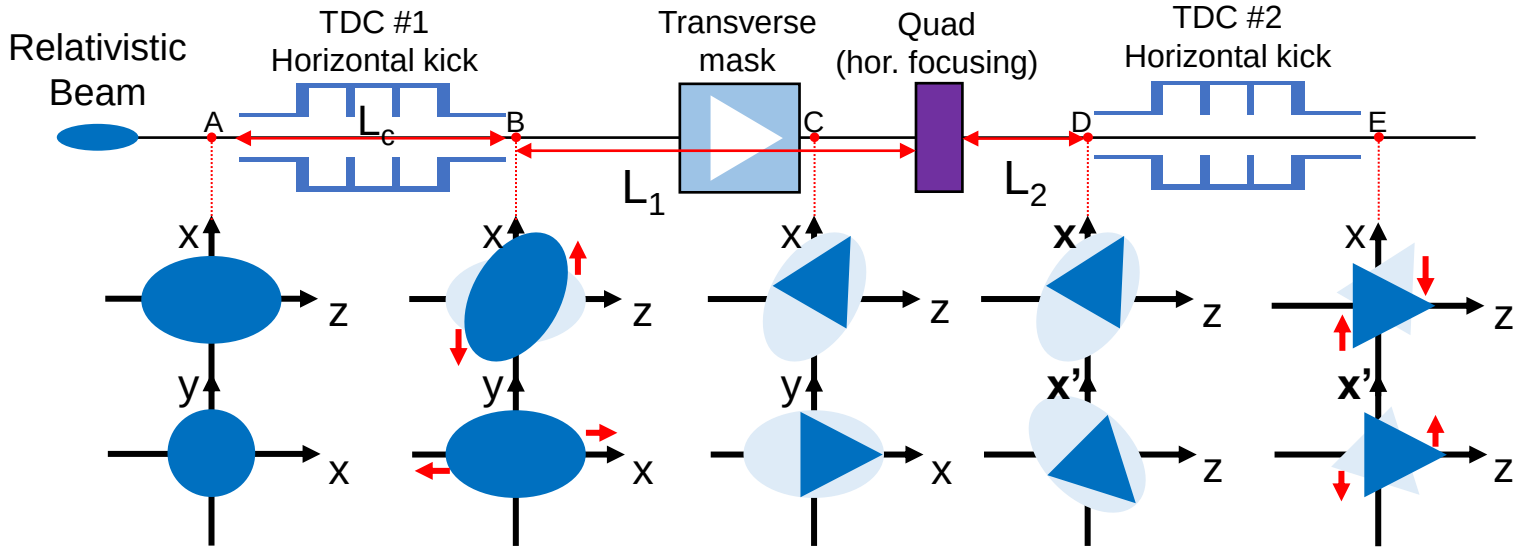

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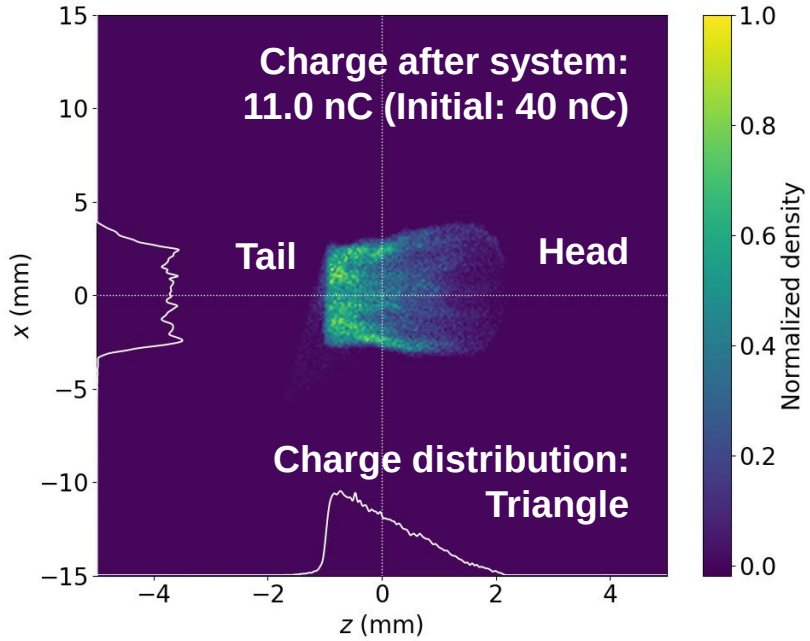

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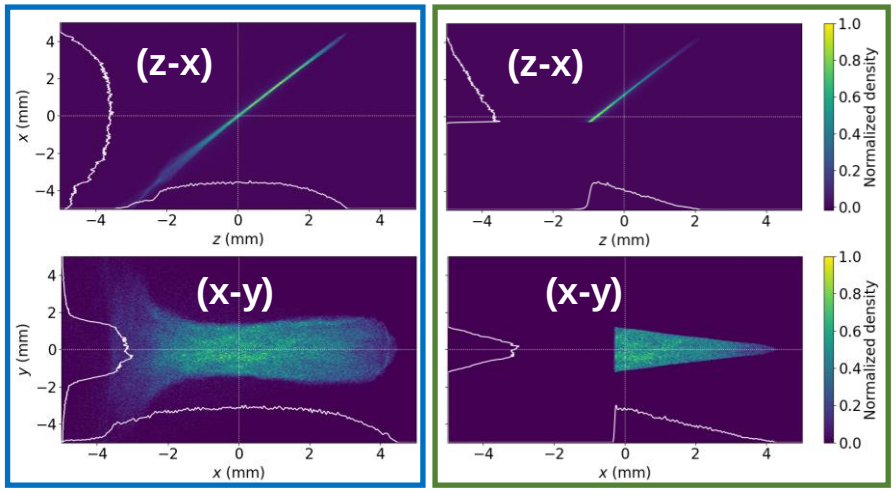


- **Relativistic beam shaping: not sensitive from space charge**
- **No bending magnet is used: synchrotron radiation free**
- **Additional pre-UV shaping helps to increase charge capturing**

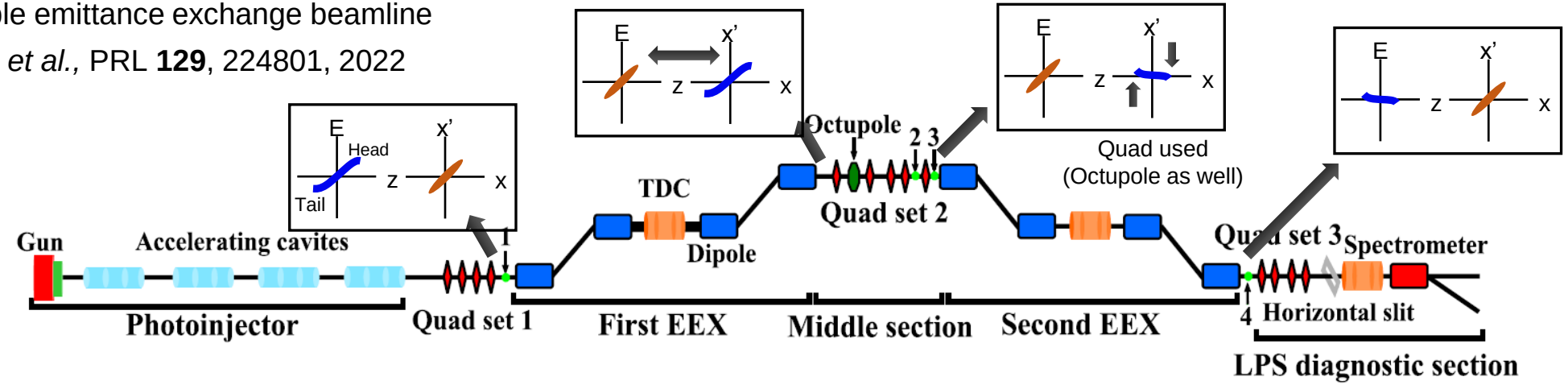
➡ **High-charge (>10 nC) longitudinal bunch shaping is feasible**

UNIST: Ulsan National Institute of Science and Technology (Korea)

LPS = longitudinal phase space

UNIST collaboration: Double EEX beamline

- Double emittance exchange beamline
- Seok *et al.,* PRL **129**, 224801, 2022



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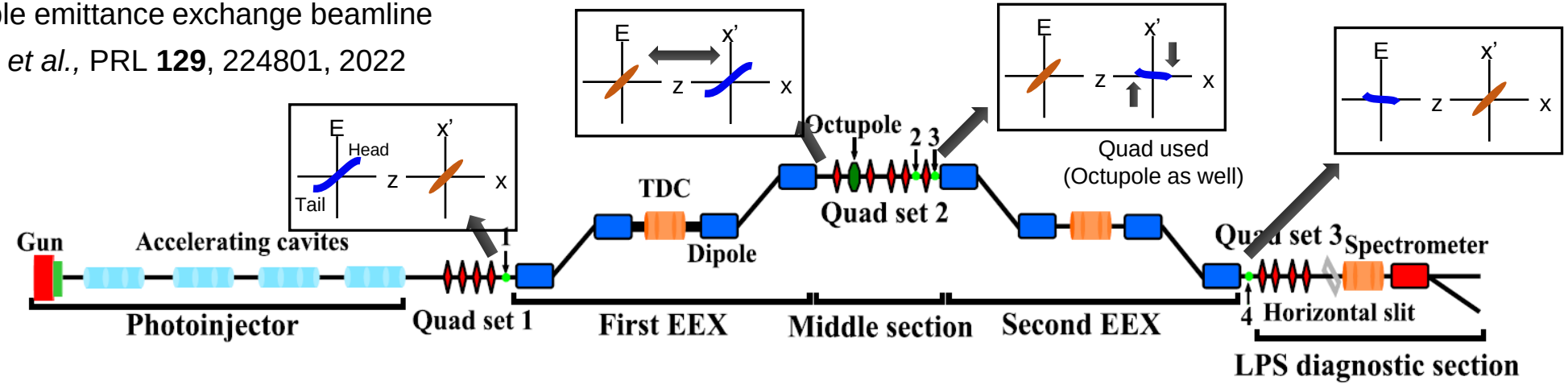

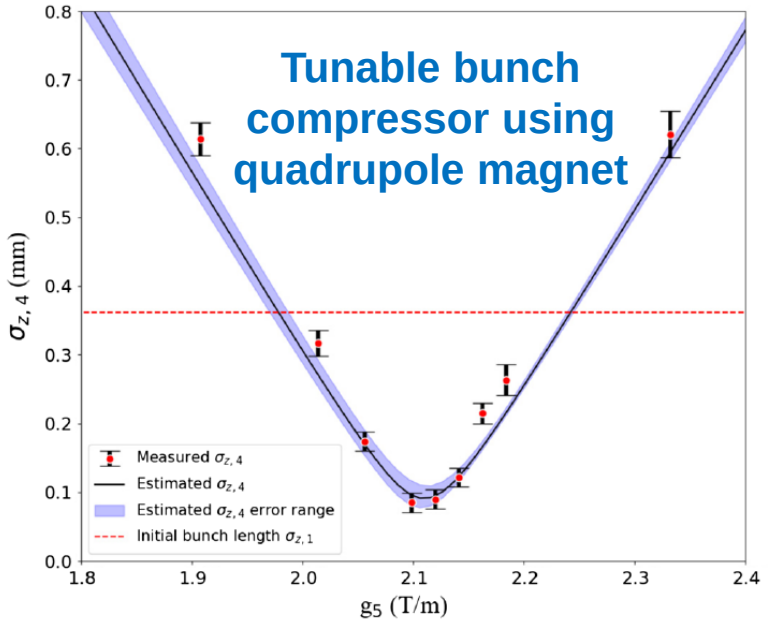

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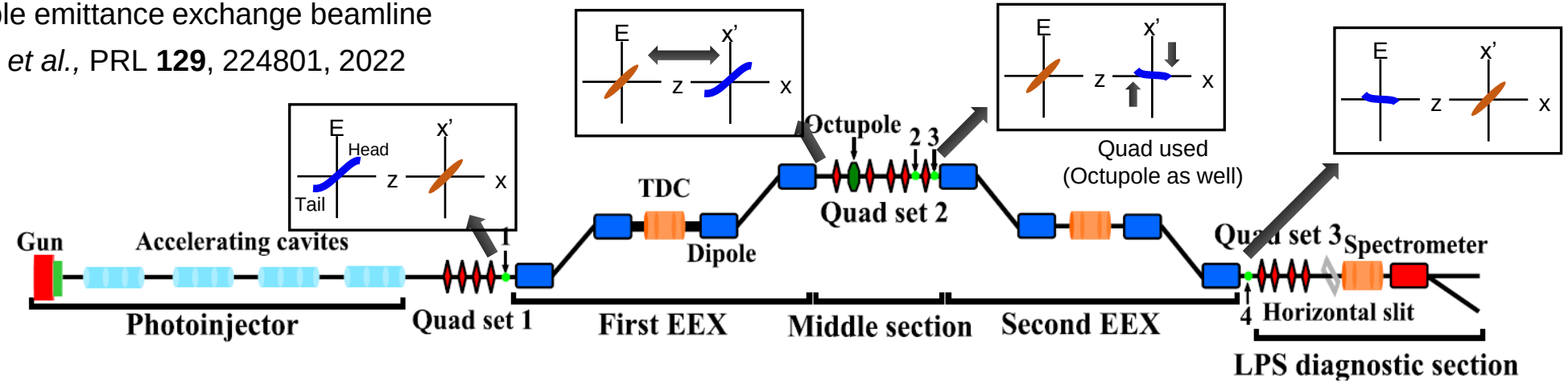
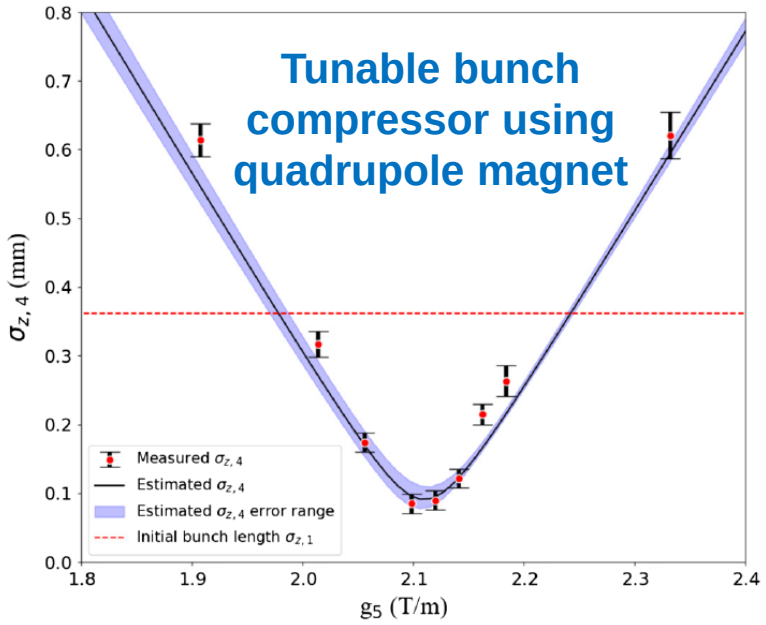
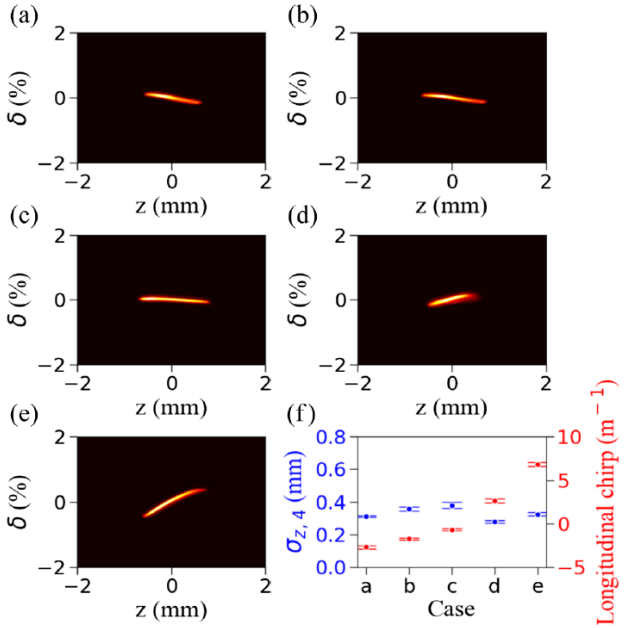
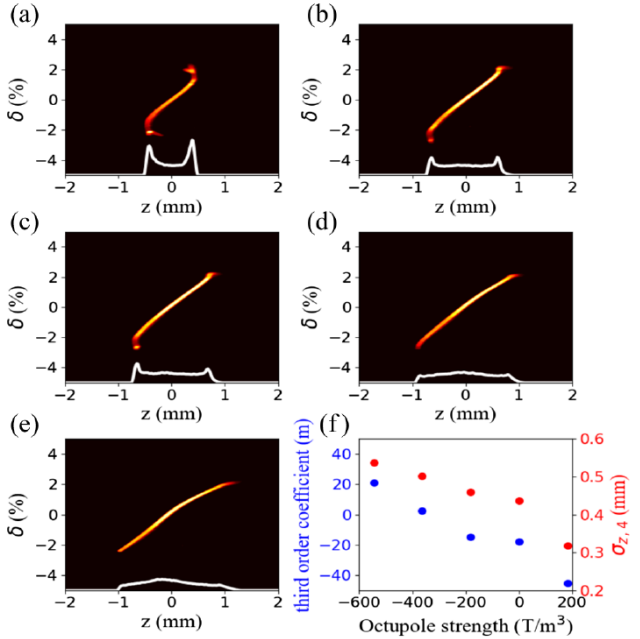






Energy chirp control



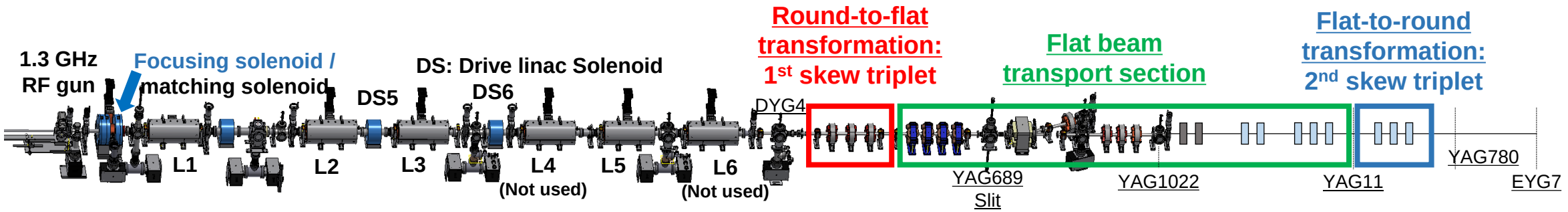
LPS nonlinearity control (octupole)

Research programs for beam manipulation

- Transverse emittance control
- AI/ML-based phase space reconstruction

NIU collaboration: Round-to-flat beam transformation

- Flat beam generation and transform it back to round: S. Kim *et al.,* IPAC'23 presentation
- **Will also be used for asymmetric PWFA: Pratik Manwani, poster presentation @ PAHBB**



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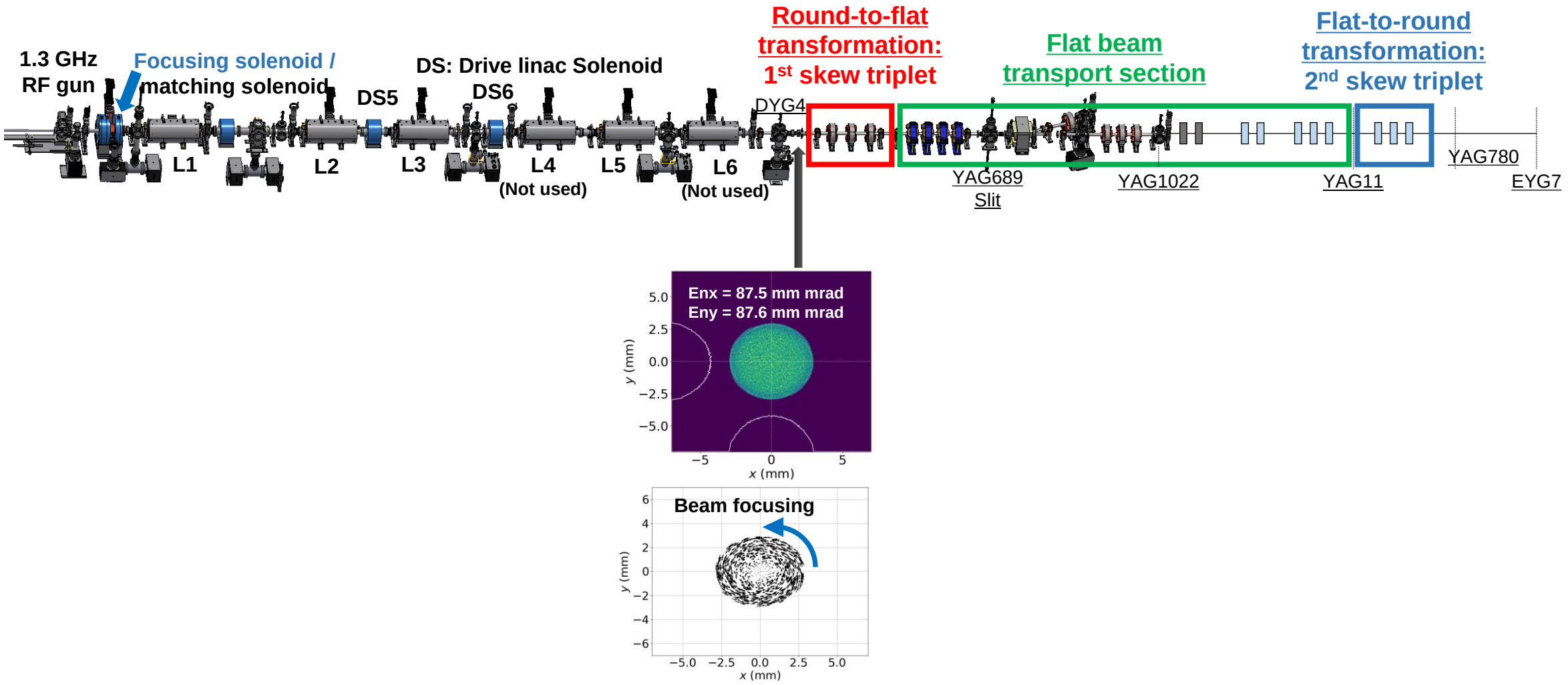

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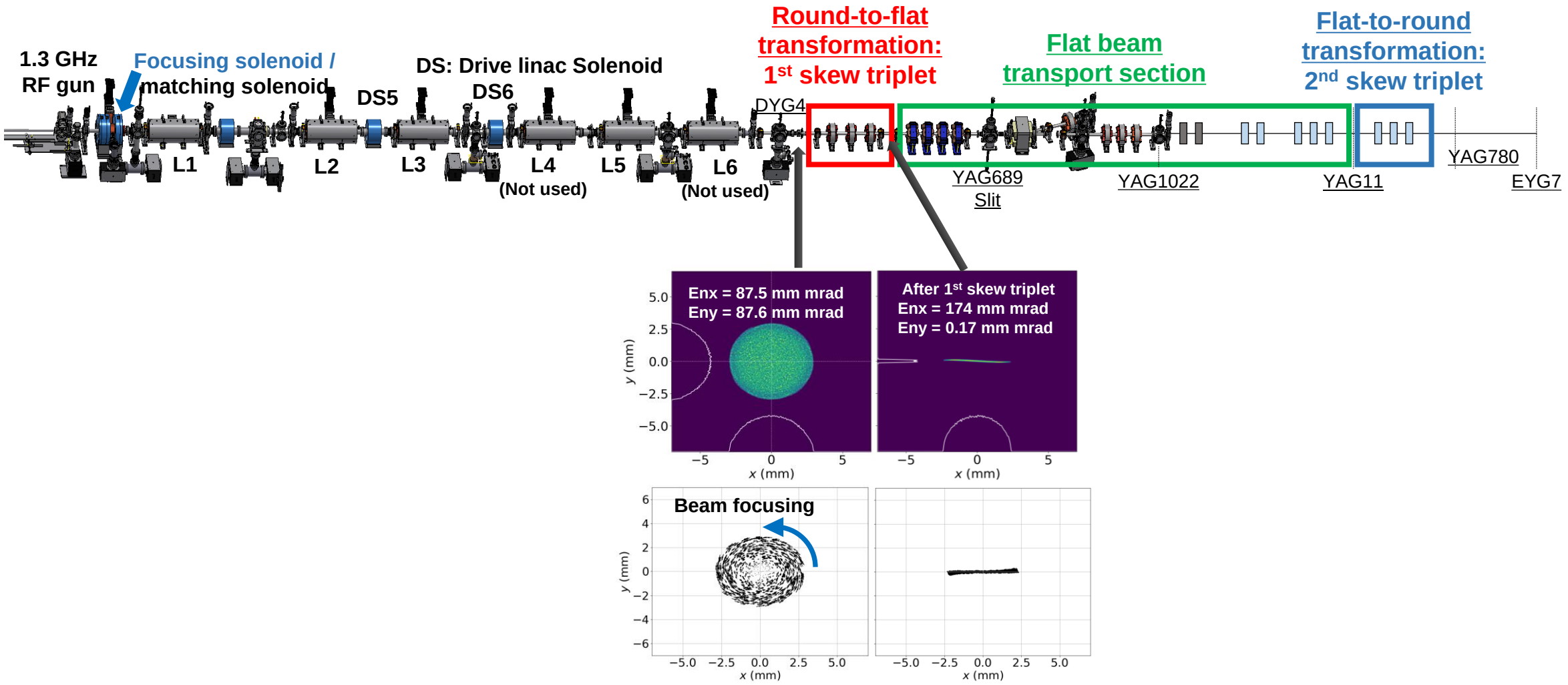

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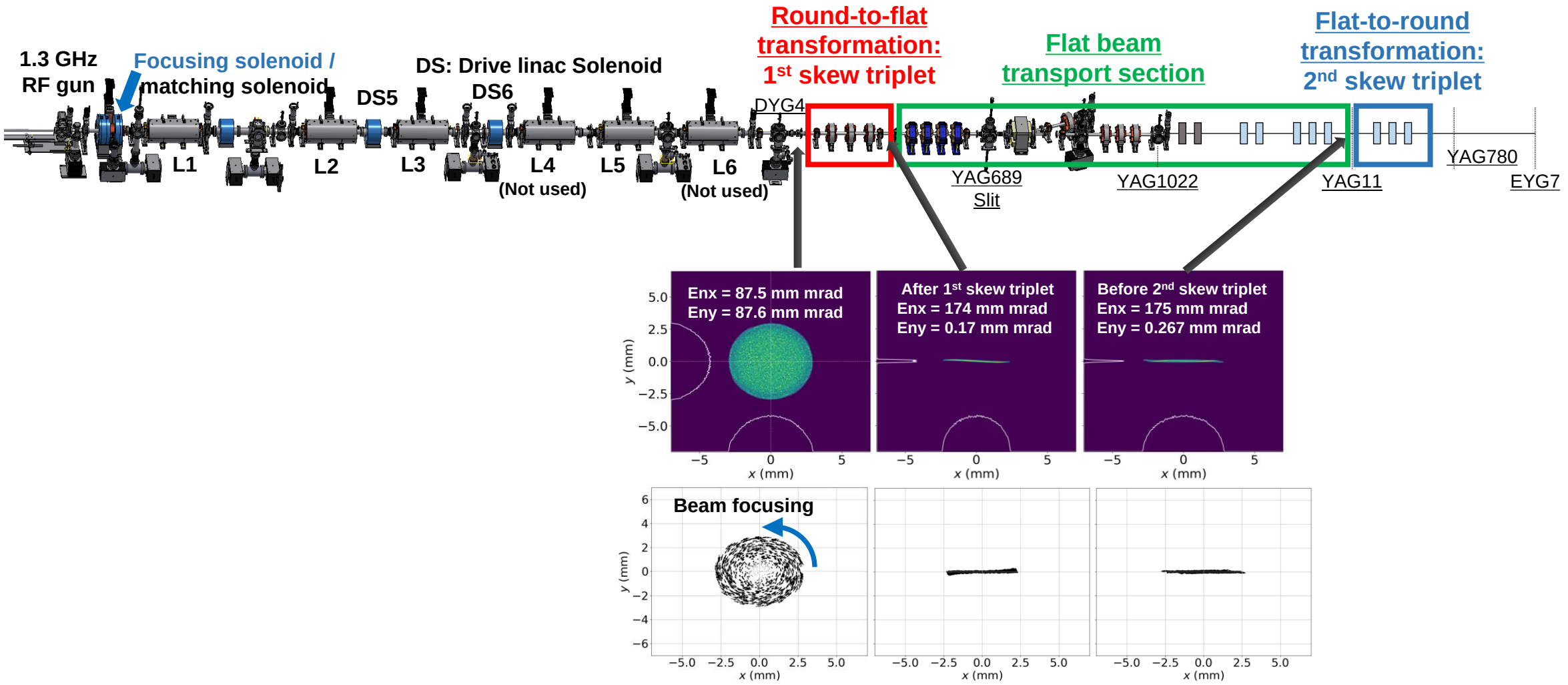

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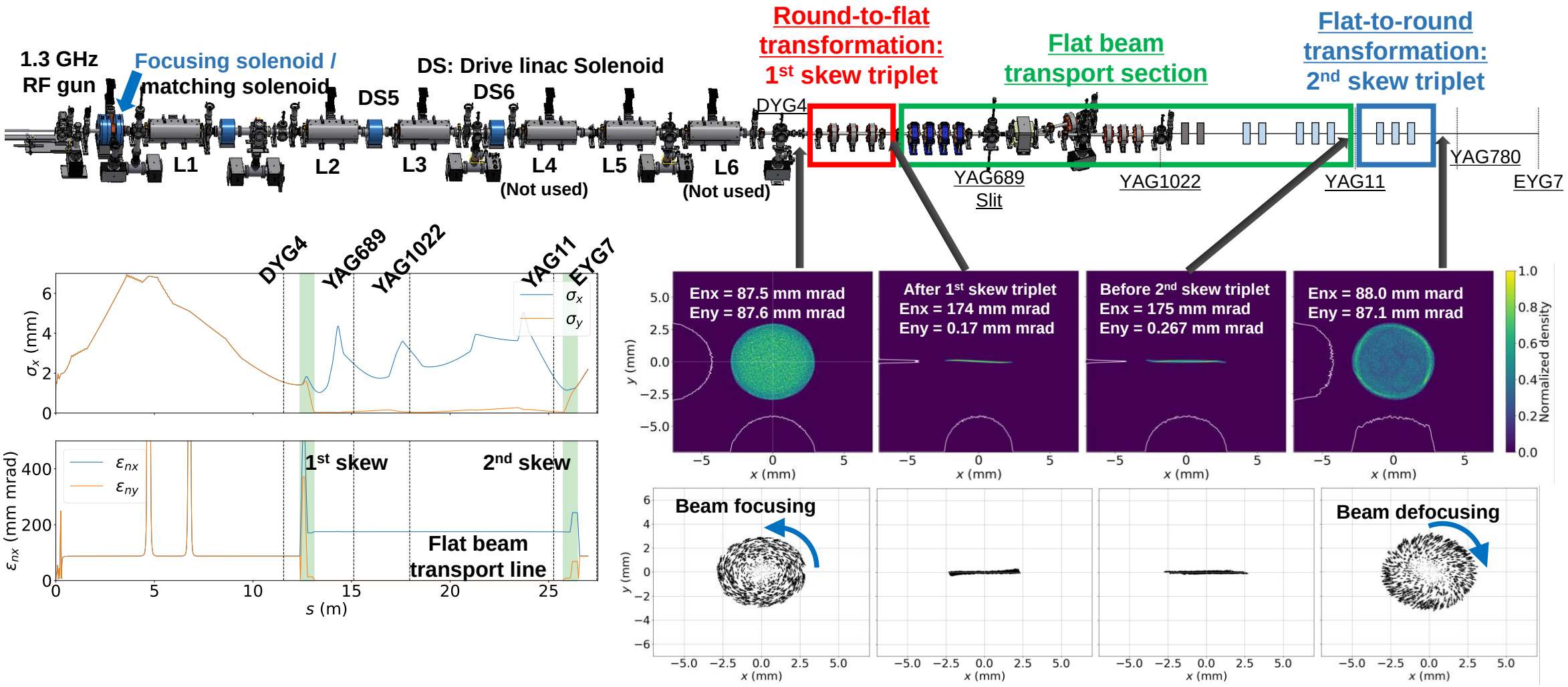
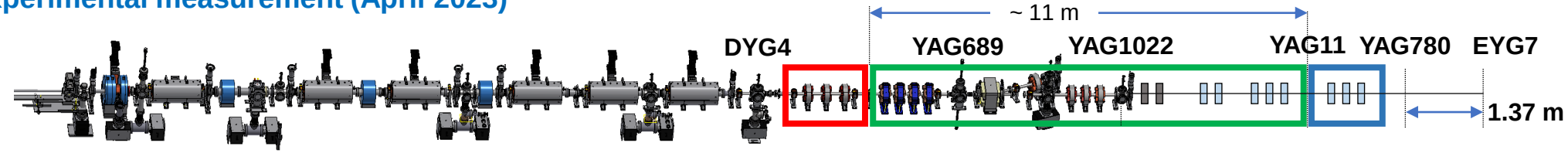
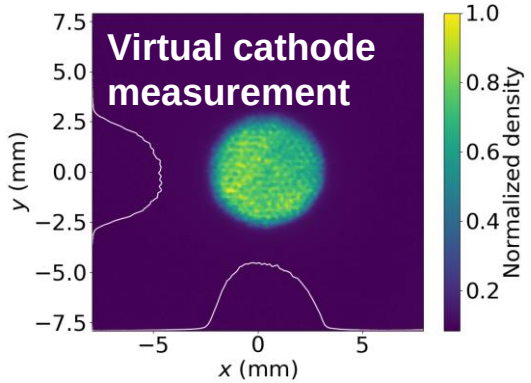


NIU collaboration: Round-to-flat beam transformation

- **Experimental measurement (April 2023)**



Parameter	**Value** (updated)
RMS UV size	1.35 mm
UV FWHM pulse	3.0 ps (flat-top)
Charge	1.0 nC
Focusing solenoid	0.14 T
Magnetization	75 um



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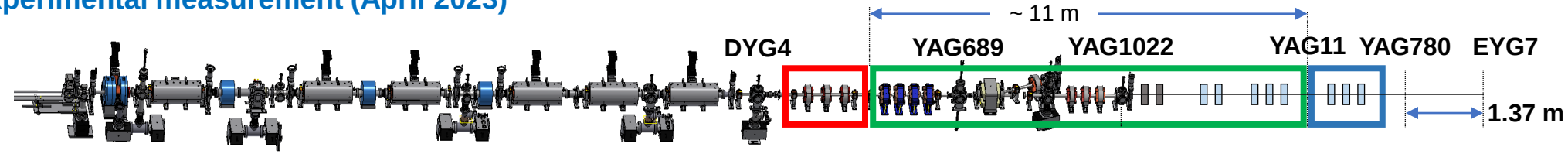

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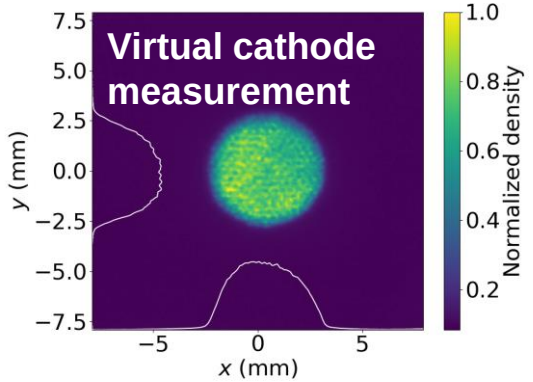

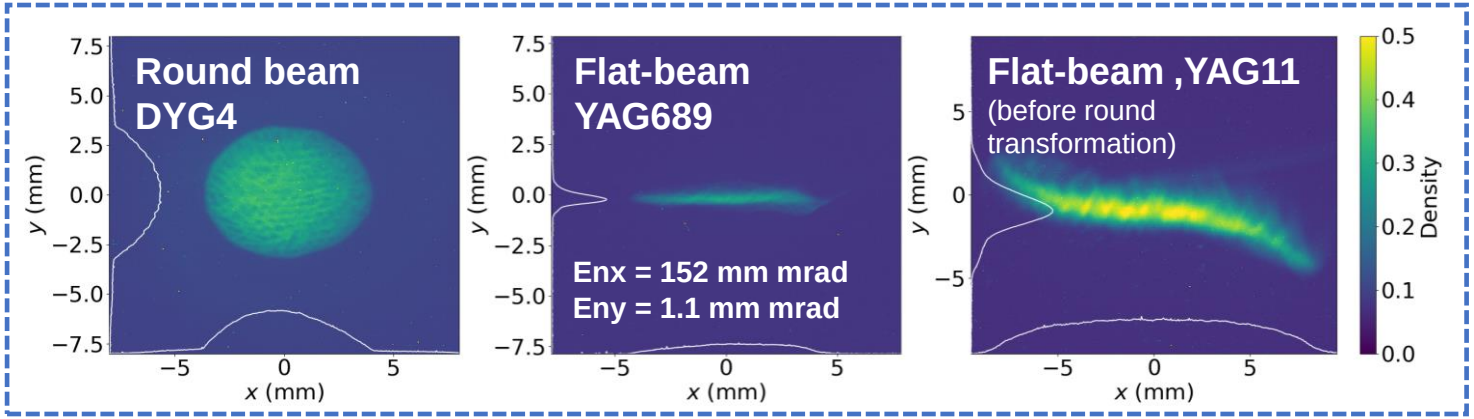

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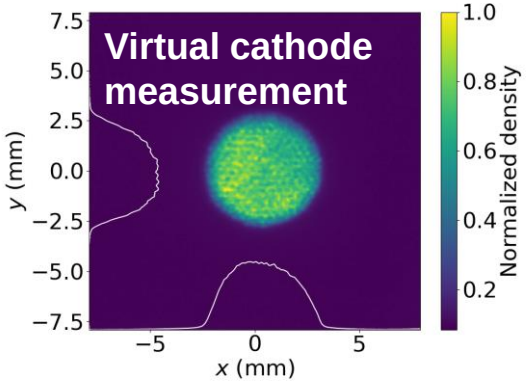
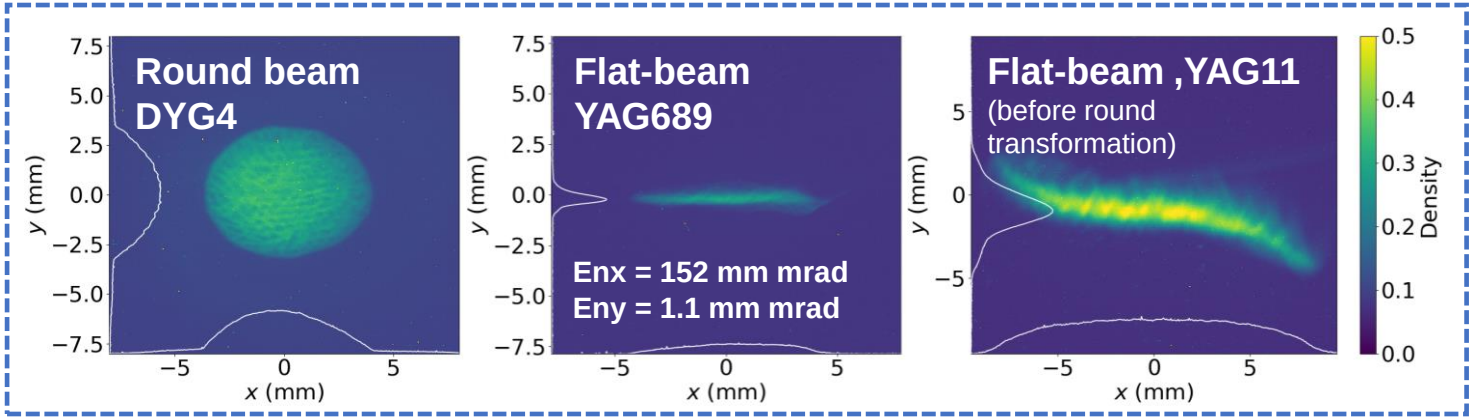
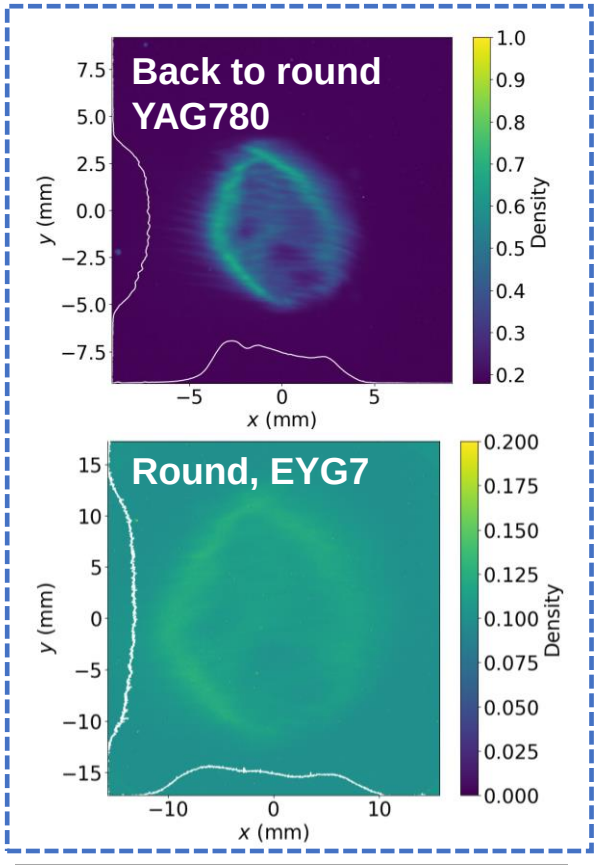




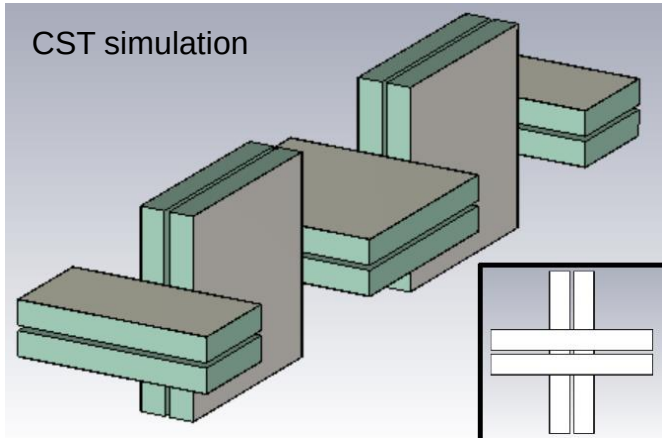


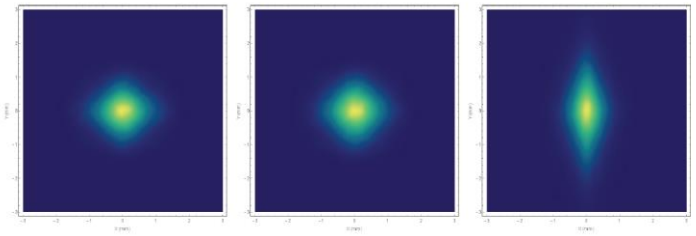
- **S. Kim *et al.*, in preparation**

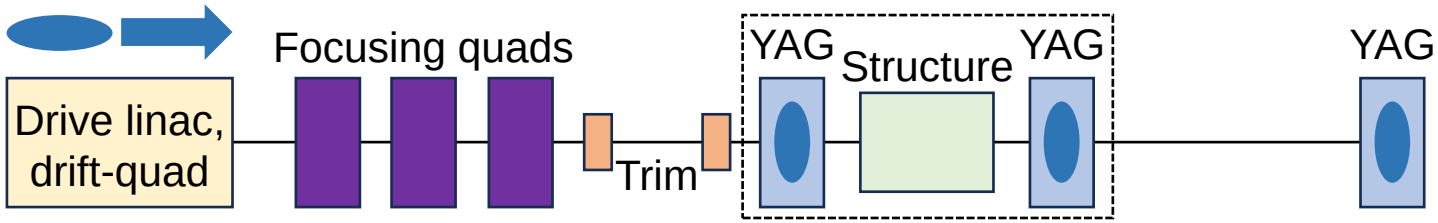
UCLA collaboration: Alternating dielectric structure

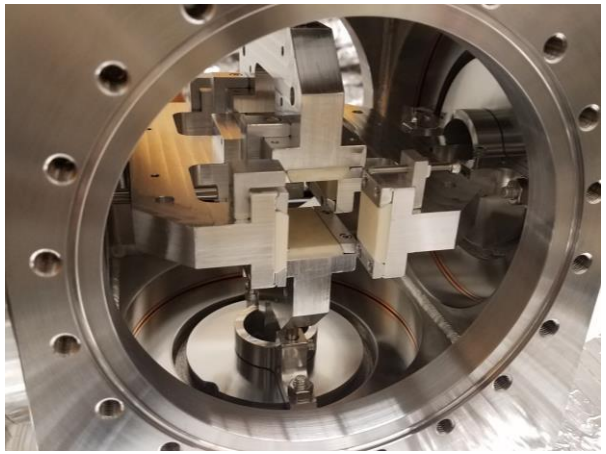
- **For more details: Walter Lynn, contributed talk at 16:00 (Tue)**

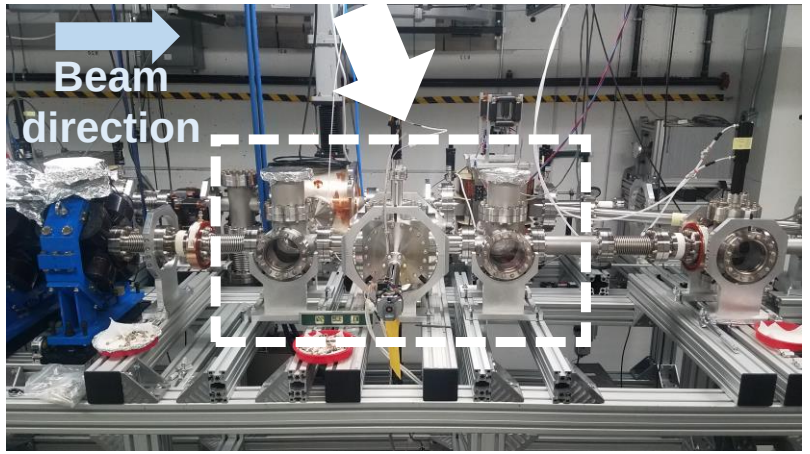
Refs: W. Lynn *et al.*, In. Proc. NAPAC 2022.

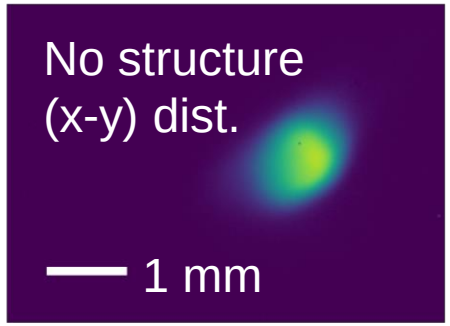


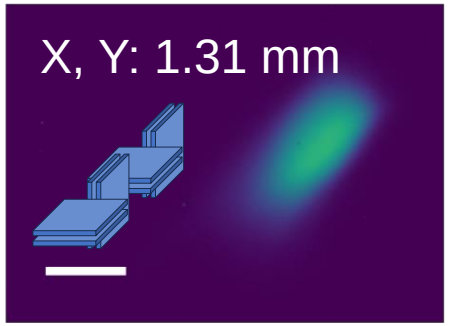


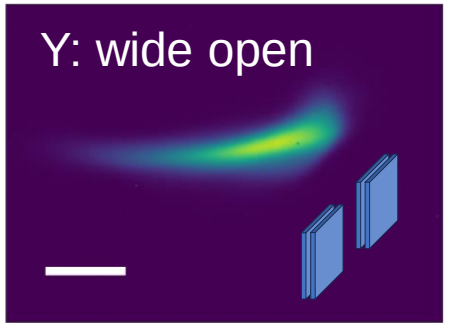










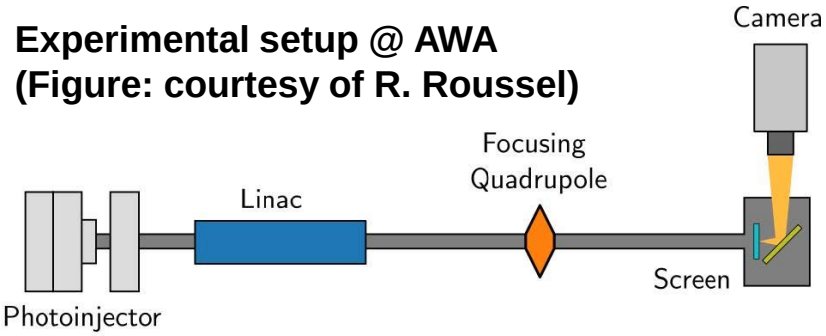


- **W. Lynn *et al.*, in preparation**

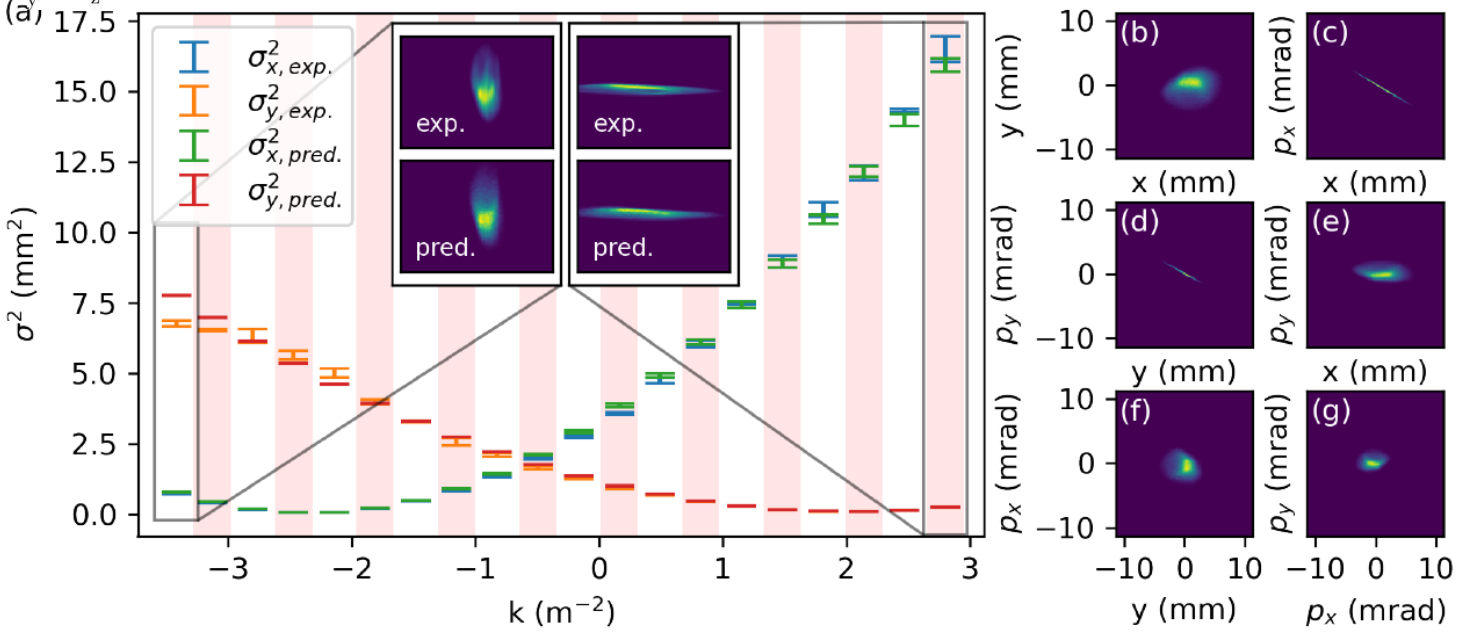
SLAC / Uchicago collaboration: AI/ML-based reconstruction

- For more details: Juan Pablo Gonzalez-Aguilera, contributed talk at 15:20 (Tue)
- For more details on AI/ML: Auralee Edelen, invited talk at 17:25 (Thu)

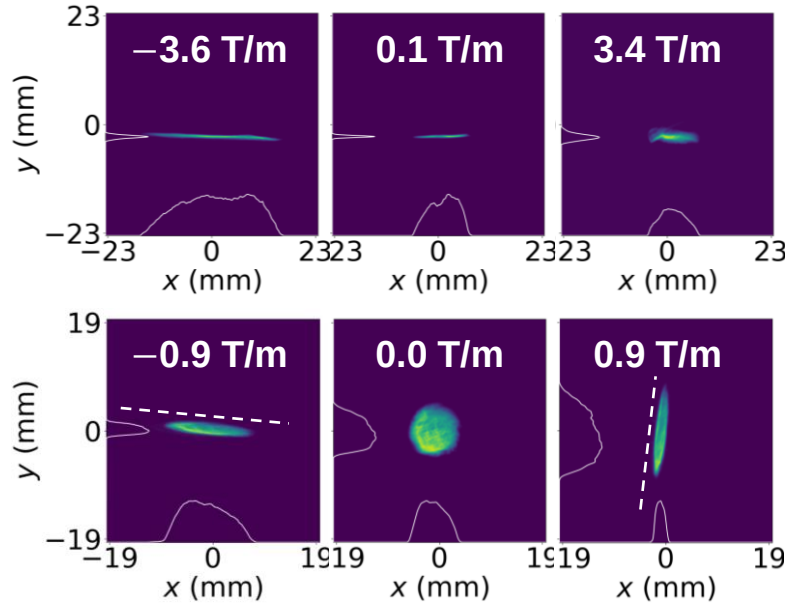
Experimental setup @ AWA
(Figure: courtesy of R. Roussel)



Refs: R. Roussel *et al.*, arXiv2209.04505 (2022), *Phys. Rev. Lett.* **130**, 145001, 2023.



Application to flat-beam and magnetized beam (Below: experimental data)



Characterization of flat-beam emittance, and magnetization (data under analysis)

Future plans on the beam manipulations @ AWA

Future plans on beam manipulations @ AWA

For high-brightness

- AWA drive linac upgrade (RF symmetric gun and linac, solenoid magnet)
- Machine study with tracking simulation (OPAL) to find the optimal beam parameters
- AI/ML-based optimization

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For Beam Control

- Flat-beam generation with low longitudinal emittance
- Emittance partitioning using flat-beam and EEX beamline
- Demonstration of longitudinal bunch shaping using TDC-based system

Future plans on beam manipulations @ AWA

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For Beam Control

- Flat-beam generation with low longitudinal emittance
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- Demonstration of longitudinal bunch shaping using TDC-based system

For AAC

- Asymmetric plasma wakefield acceleration using flat-beam
- High-TR, high-G wakefield generation using shaped bunch from TDC-shaper
- High-efficiency beam acceleration along collinear wakefield accelerator

AWA: facility for beam dynamics and AAC with advanced beam manipulations

Summary

- **Longitudinal bunch shaping studies @ AWA**
  - Real-time bunch shaping has been successfully demonstrated using EEX beamline and multi-leaf collimator: **can be applied for bunch shaping for doorstep/double triangular distributions**
  - High charge beam can be shaped via TDC-based shaping system: **we can achieve high-gradient + high-transformer ratio wakefield**
  - Double EEX beamline: Novel method for **arbitrary longitudinal phase space manipulation**

- **Transverse beam control studies @ AWA**
  - Transverse stability against the wakefield can be controlled by using **alternating dielectric structure accelerator**
  - Flat-to-round and back-to-round **provides the flexibility of emittance partitioning** for various applications such as hadron cooling, damping-ring-free injector, and asymmetric PWFA
  - AI/ML-based phase space reconstruction: novel beam diagnostics for 6D phase space + coupling

- **Future plans for high-brightness beam and novel beam manipulations**
  - AWA drive linac upgrade and machine study → **Actual demonstrations of emittance partitioning, bunch shaping, and CWA acceleration**

Acknowledgements

- **Argonne National Laboratory**

John Power, Gongxiaohui Chen

Scott Doran, Wanming Liu

Charles Whiteford, Eric Wisniewski

- **Northern Illinois University**

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- **UCLA**

James Rosenzweig, Gerard Andonian, Walter Lynn, Nathan Majernik (now at SLAC), Pratik Manawani

- **SLAC**

Auralee Edelen, Ryan Roussel

- **University of Chicago**

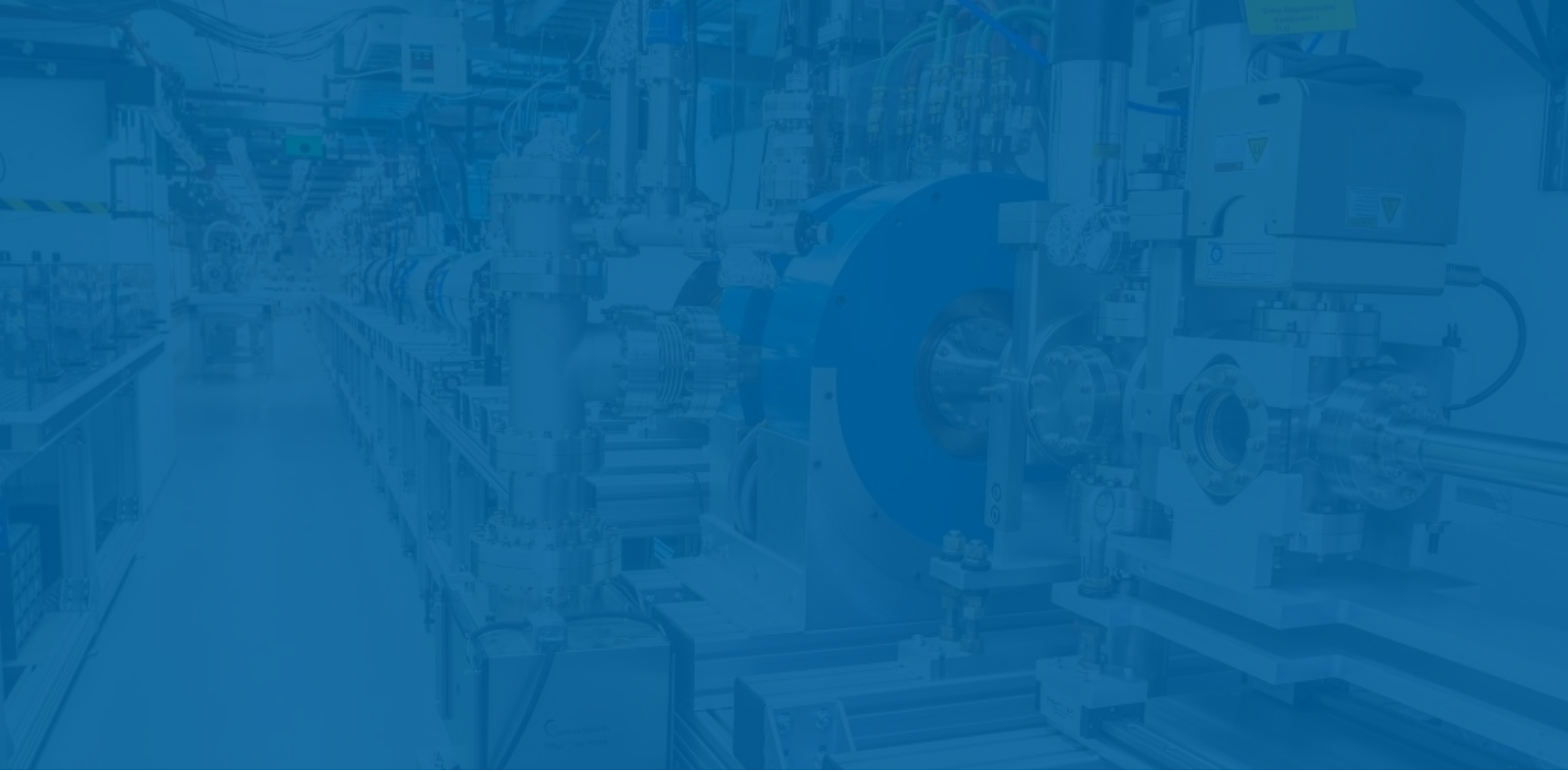
Juan Pablo Gonzalez-Aguilera

- **PSI, Switzerland**

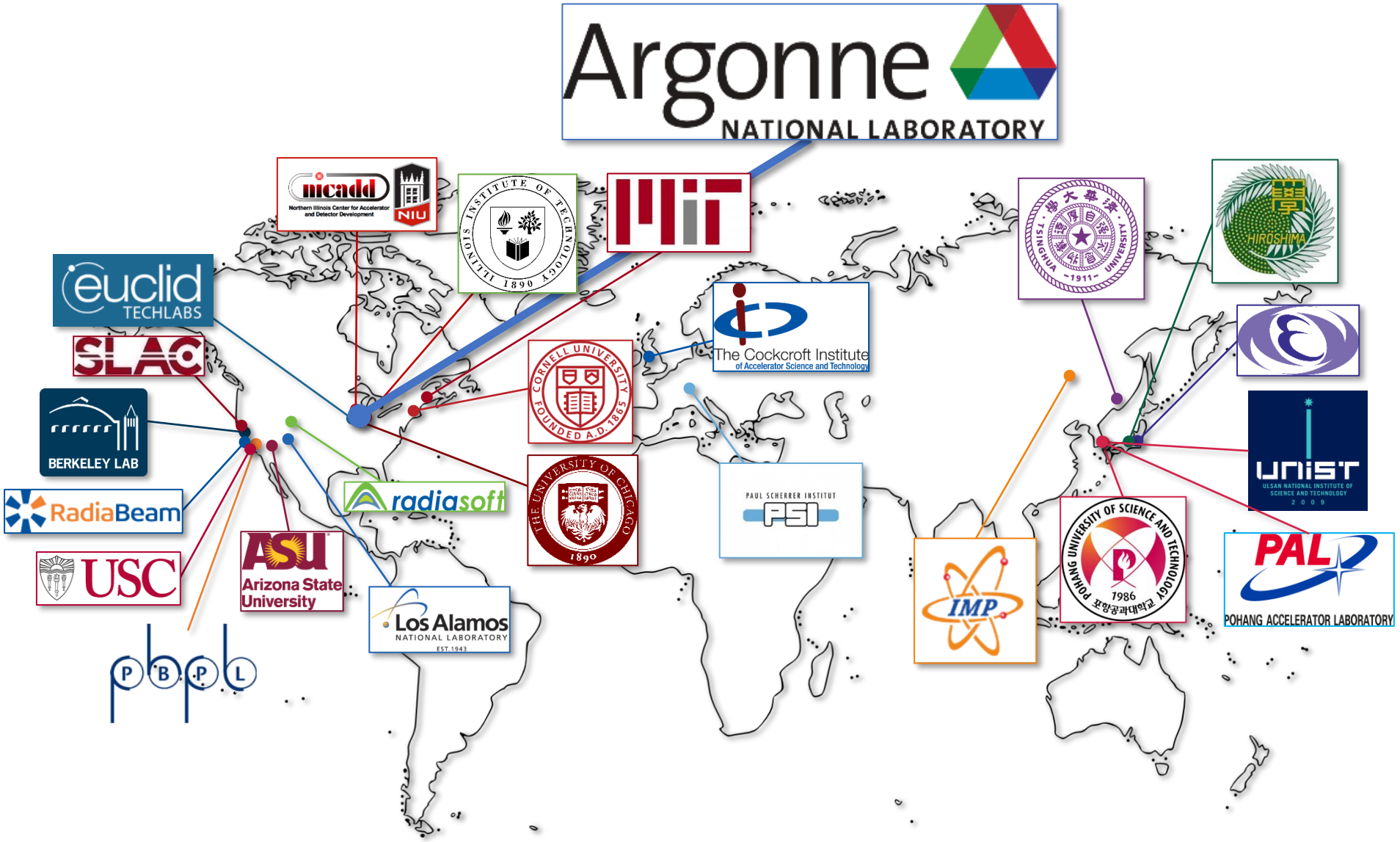
Andreas Adelmann, Sebastian Heinekamp

- **UNIST, Korea**

Moses Chung, Jimin Seok



Appendix: AWA Collaborations



Introduction to AWA facility

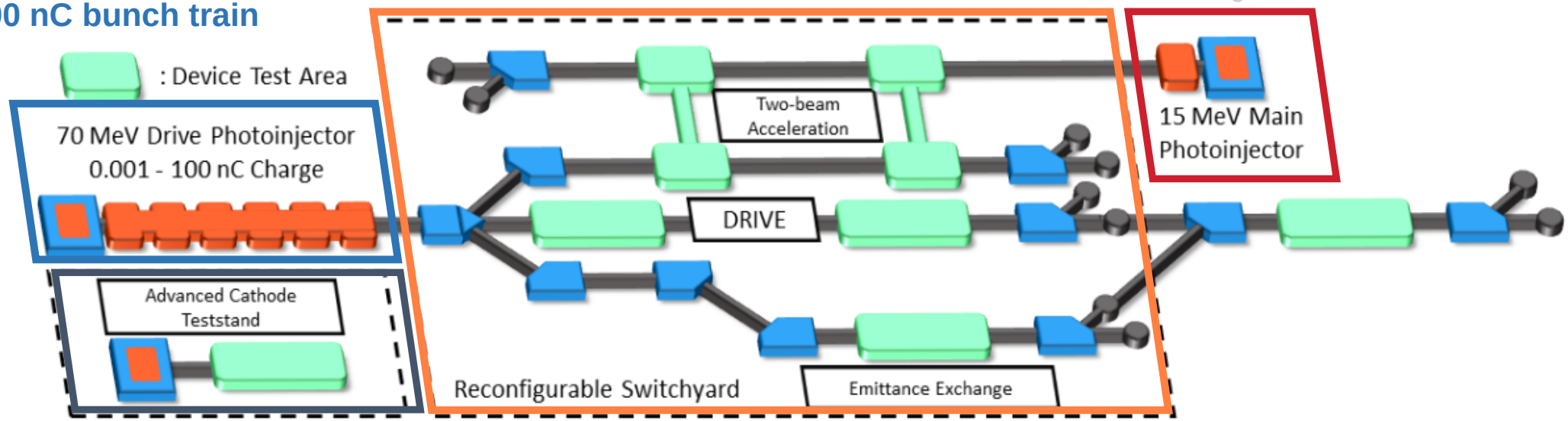
- **Multipurpose R&D test facility for high-gradient, beam-driven wakefield accelerator**

Drive RF photoinjector (6 – 65 MeV)

- **0.1 – 100 nC single bunch**
- **600 nC bunch train**

Witness RF photoinjector (15 MeV)

- Provides two-beam capability
- Bright beams



Argonne Cathode Test Stand – ACT (2 – 4 MeV)

- Cathode research and diagnostics
- Physics of high-gradient breakdown

Experimental Switchyard

- **Highly reconfigurable beamline**
- **6D beam phase space manipulation**
- **Emittance exchange (EEX), Double emittance exchange (DEEX)**