Measurement of CSR-Affected Beams using Generative Phase Space Reconstruction*

Advanced Accelerator Concepts

Naperville, IL

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J.P. Gonzalez-Aguilera

University of Chicago

jpga@uchicago.edu

*Gonzalez-Aguilera *et. al.*, Proc. IPAC'24

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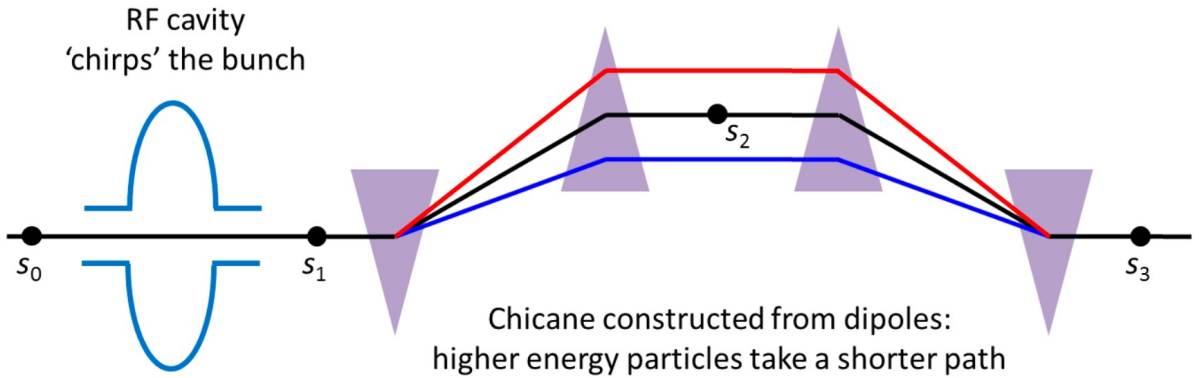
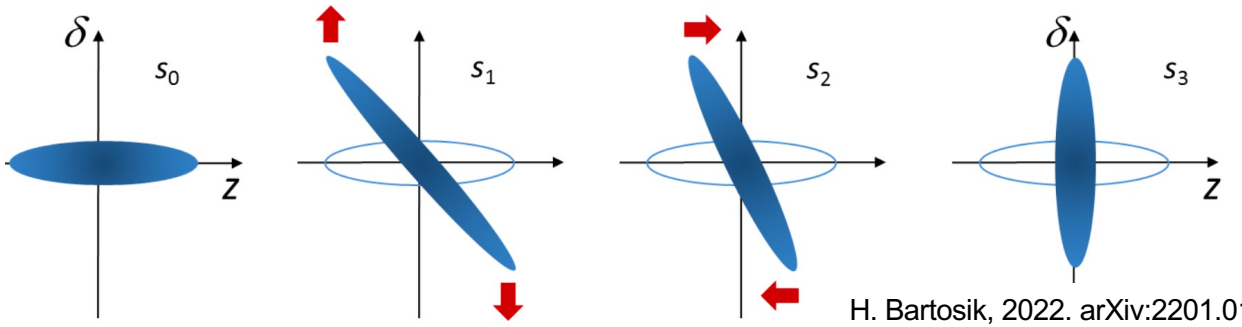
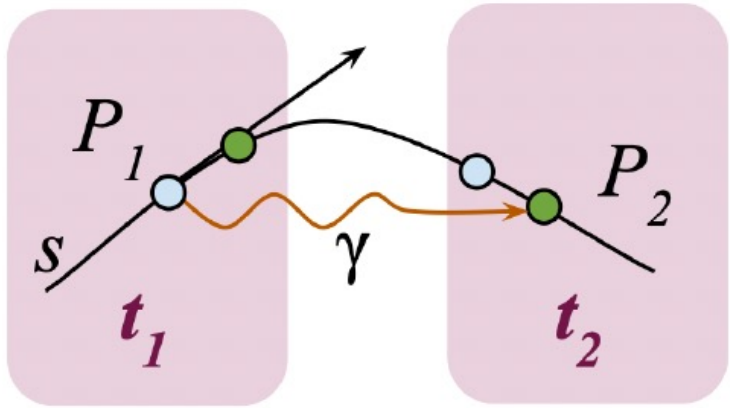
Coherent Synchrotron Radiation (CSR)

- AAC, FEL applications need highly compressed beams longitudinally
- Dispersive lattices are used to compress the beams (e.g., chicanes)
- Coherent synchrotron radiation (CSR) is produced when bending beam trajectory





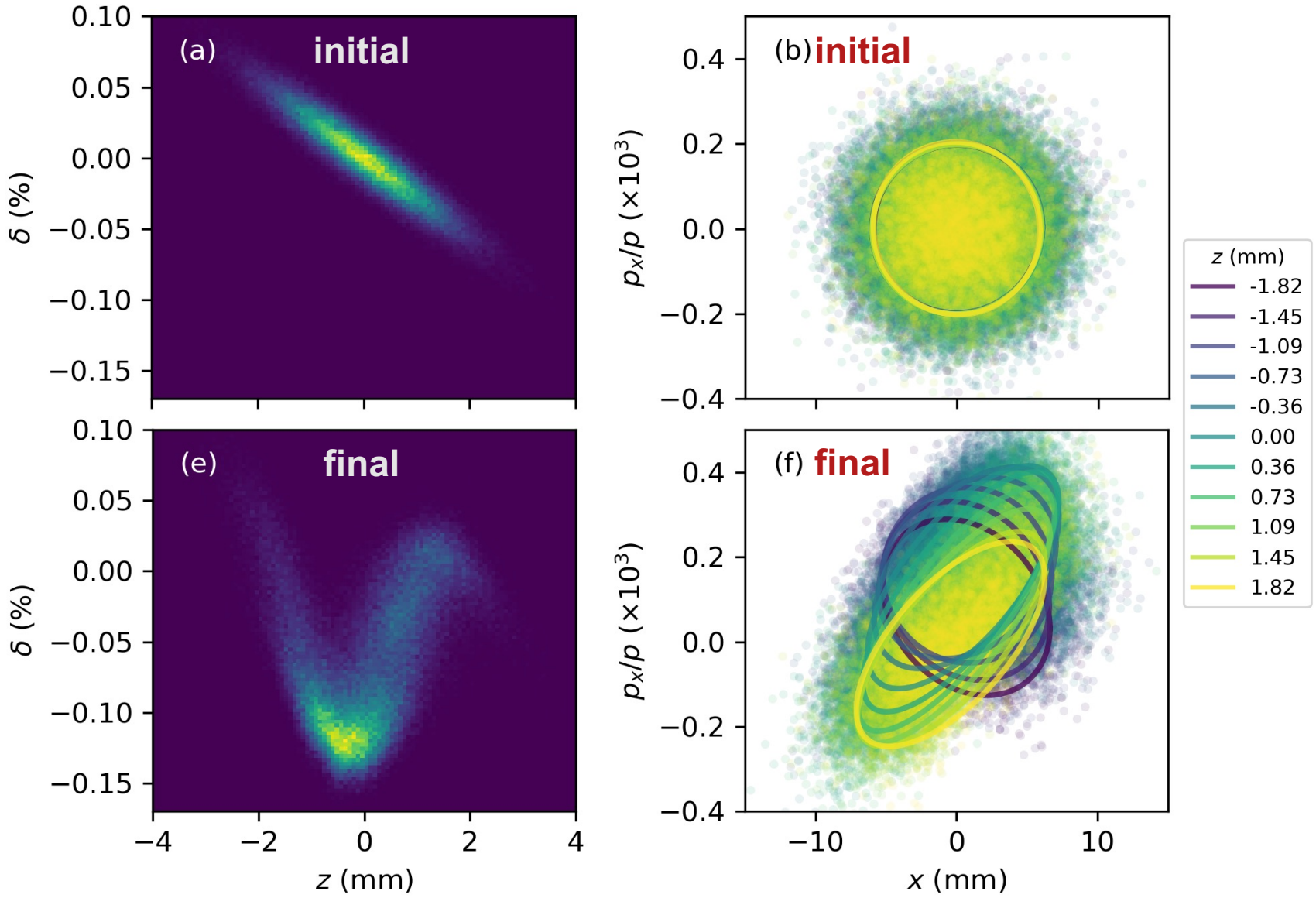
H. Bartosik, 2022. arXiv:2201.01532



A. Edelen et al., IPAC 2022

CSR Degrades Beam Quality

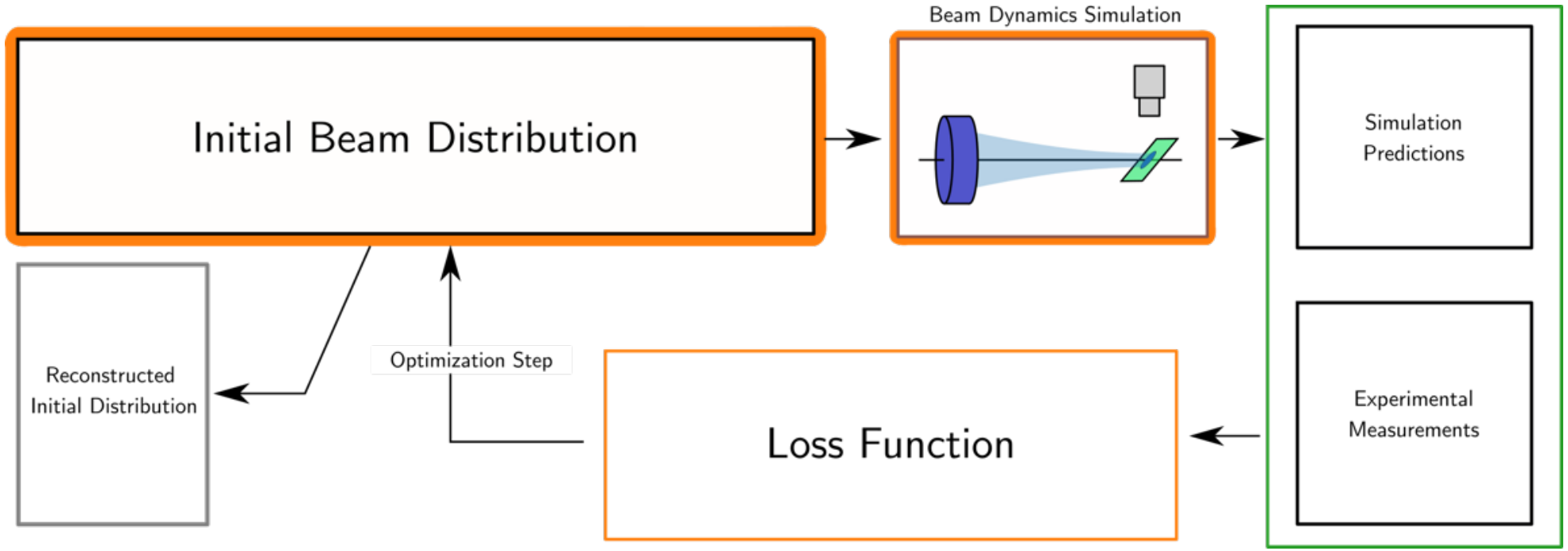
- Short-range CSR wakefield induces nonlinear kick in E vs z
- Dipoles also introduce x, p_x correlations with E
- **Result: rotation and centroid shift of x, p_x longitudinal slices, increasing the projected ε_x**



6D Generative Phase Space Reconstruction

(1) Use **generative machine learning** to represent complex 6D beam distributions.

(2) Implement **differentiable** beam dynamics simulations to enable learning

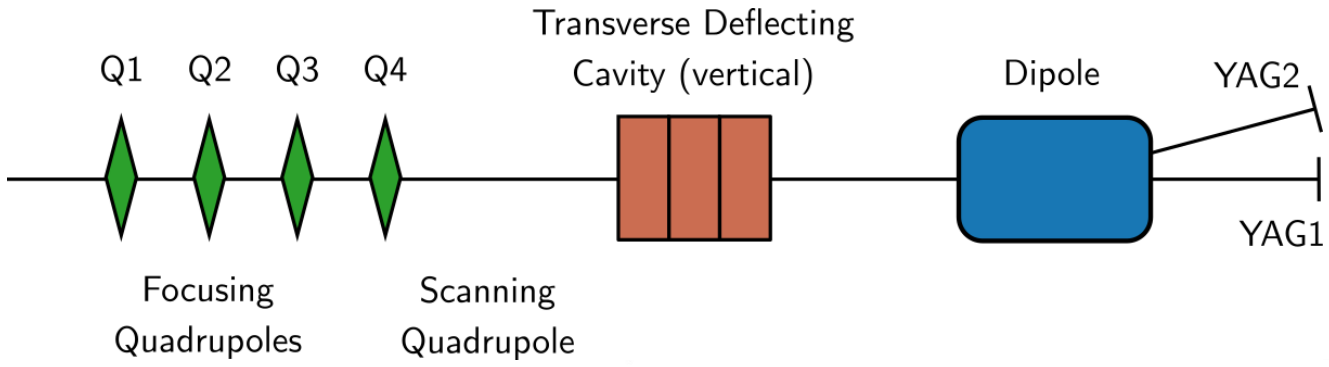


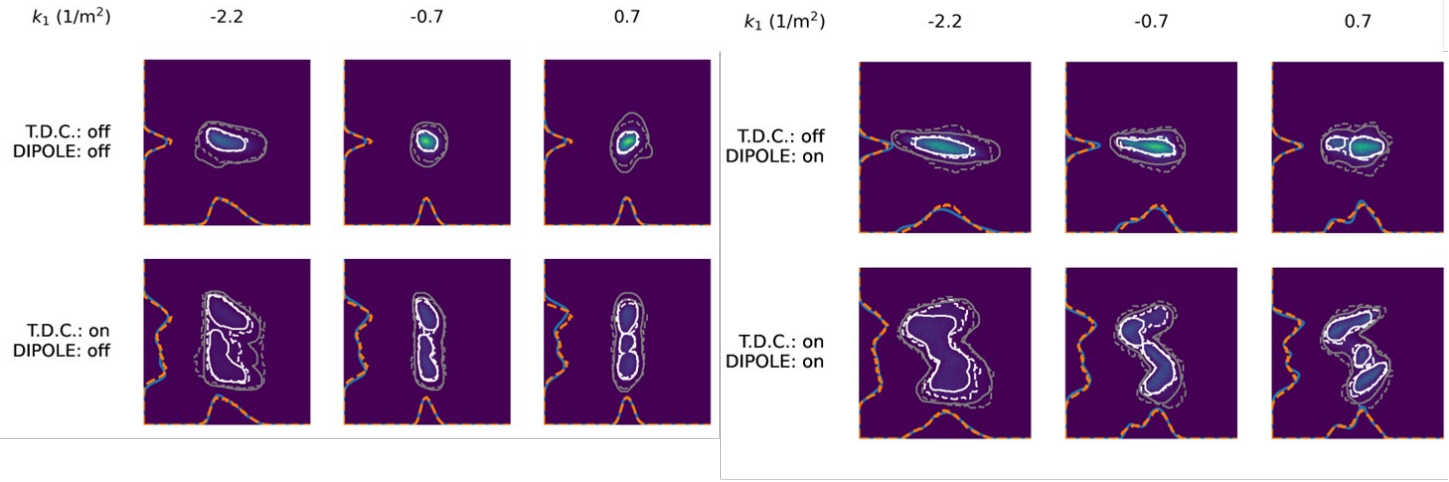
Analogous to quadrupole scan analysis

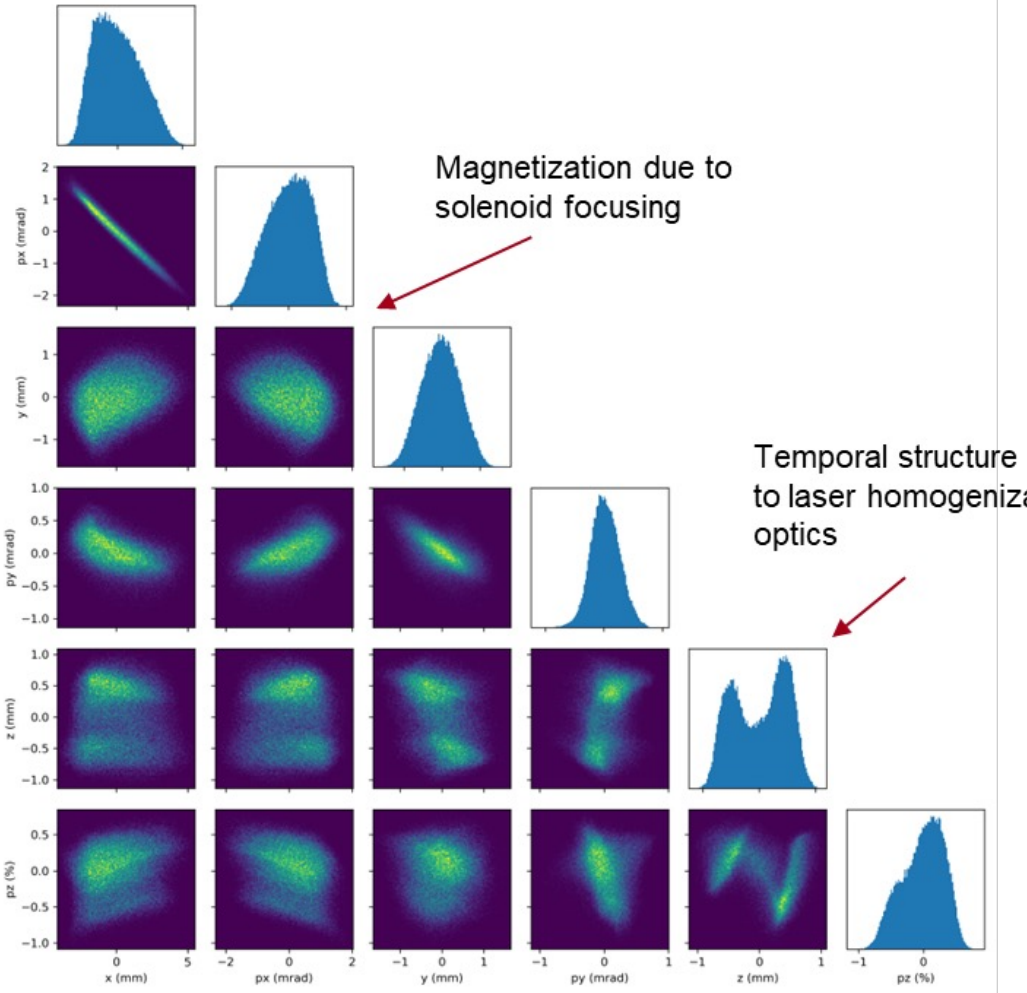
Roussel *et al.*, arXiv:2404.10853 (Submitted to PRAB)

6D Generative Phase Space Reconstruction

- Perform 6-dimensional phase space reconstruction of a beam distribution from 20 experimental measurements (no pre-training)

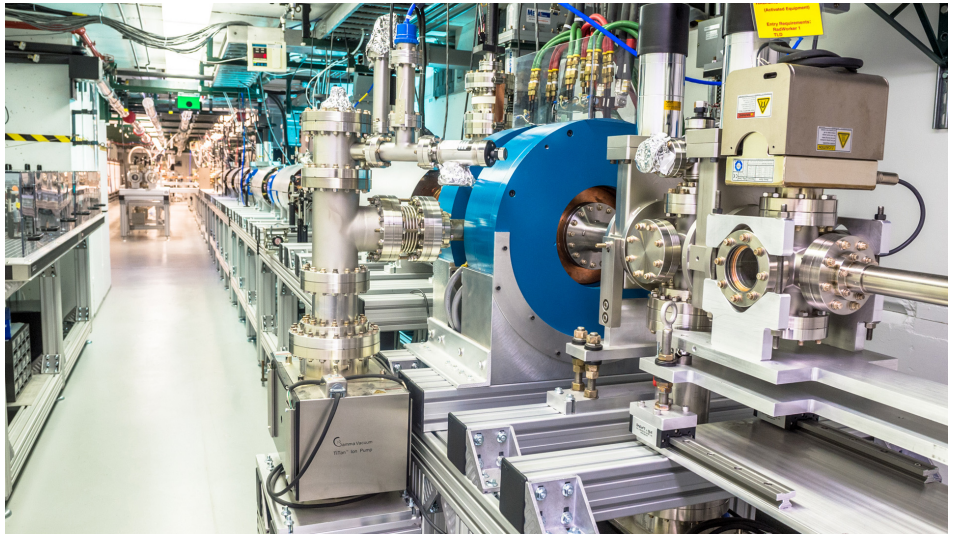




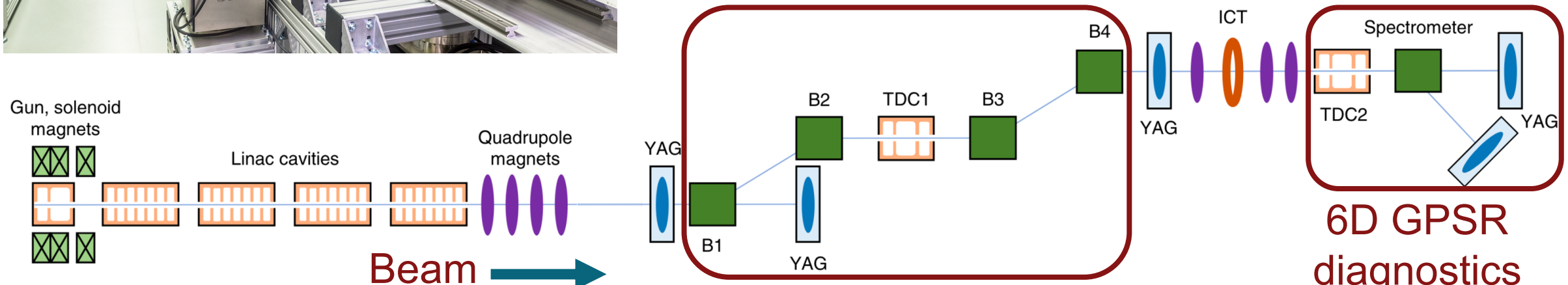


CSR at the Argonne Wakefield Accelerator

Argonne NATIONAL LABORATORY



- Generate a beam influenced by CSR in double dogleg
- Measure phase space after 4th dipole with beam diagnostics



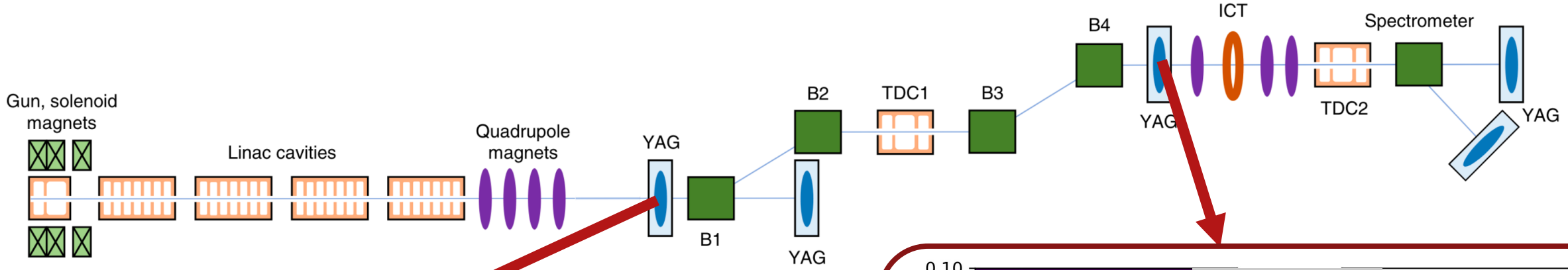
Beam
1 nC, 43 MeV

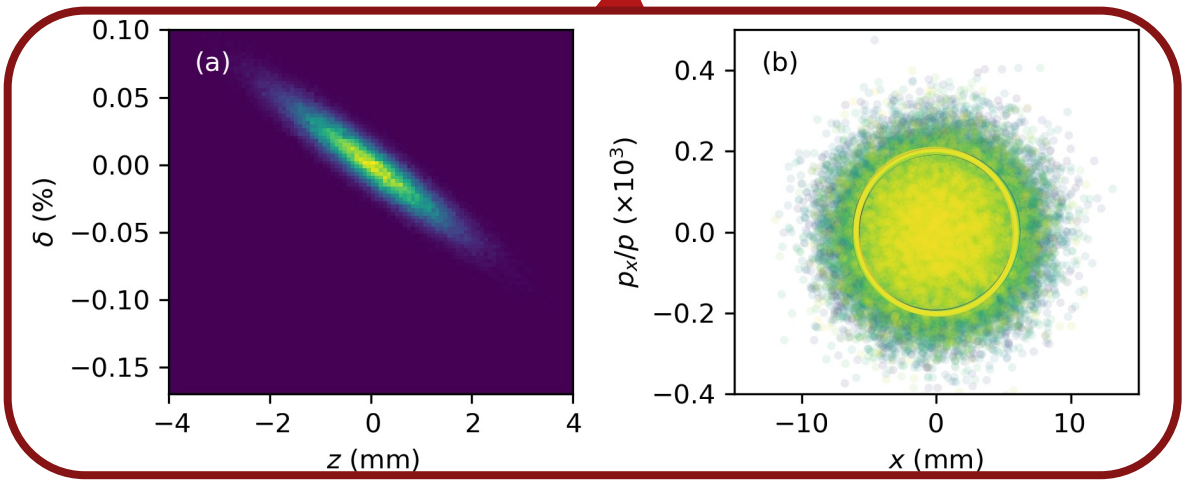
First double dogleg:
4 dipoles

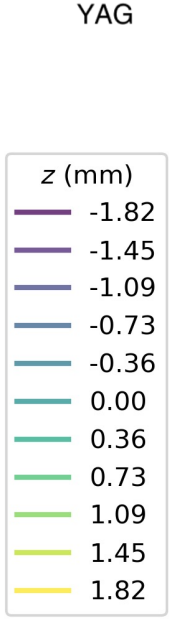
6D GPSR diagnostics

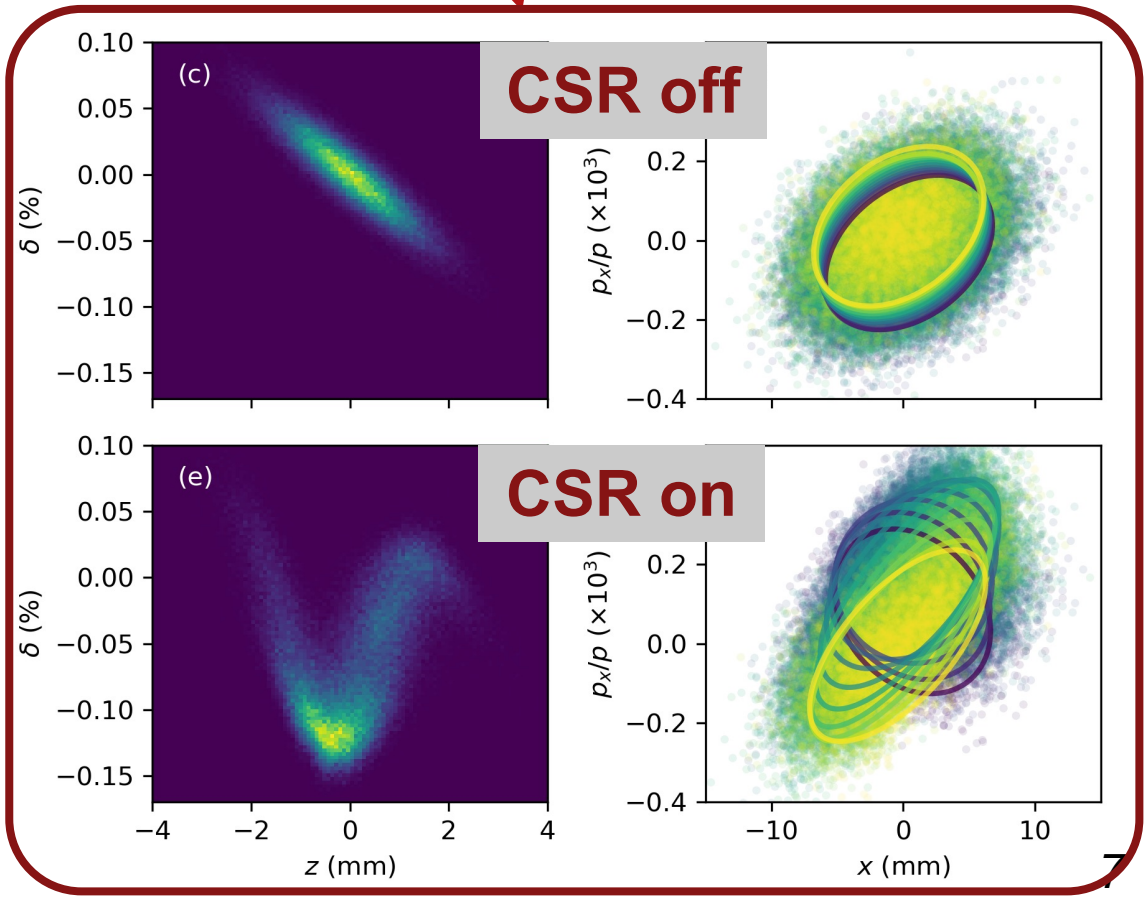
Adapted from *N. Majernik et al., PRAB, 2023.*

Simulated CSR Effects: $E - z$ and $x - p_x$

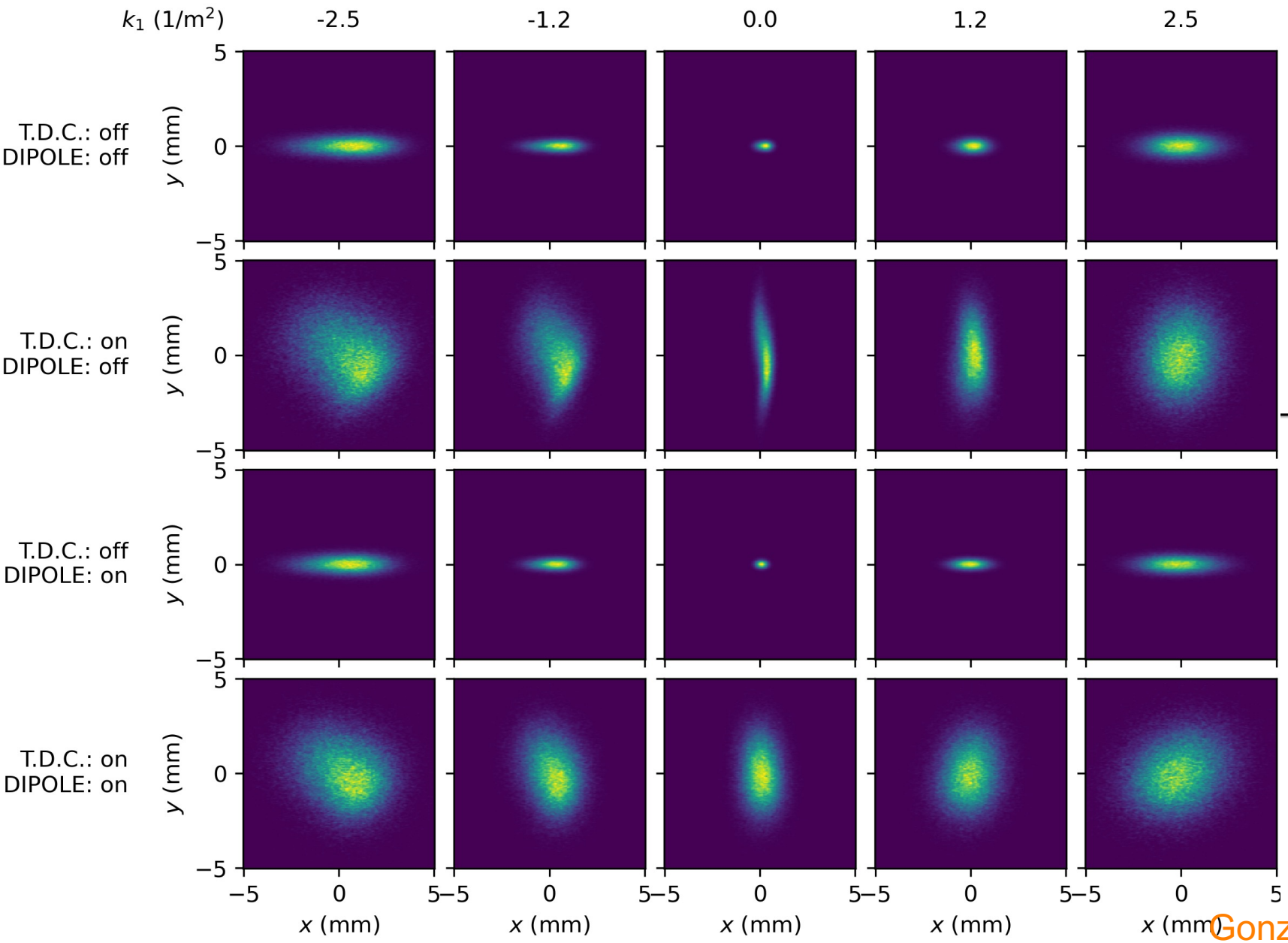


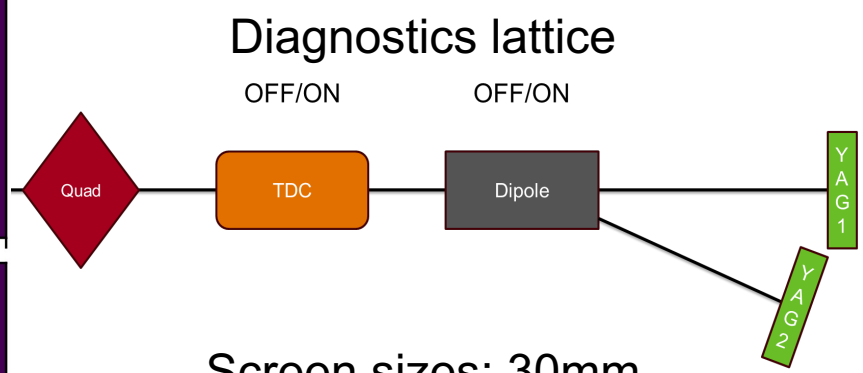






GPSR Training Data





Screen sizes: 30mm

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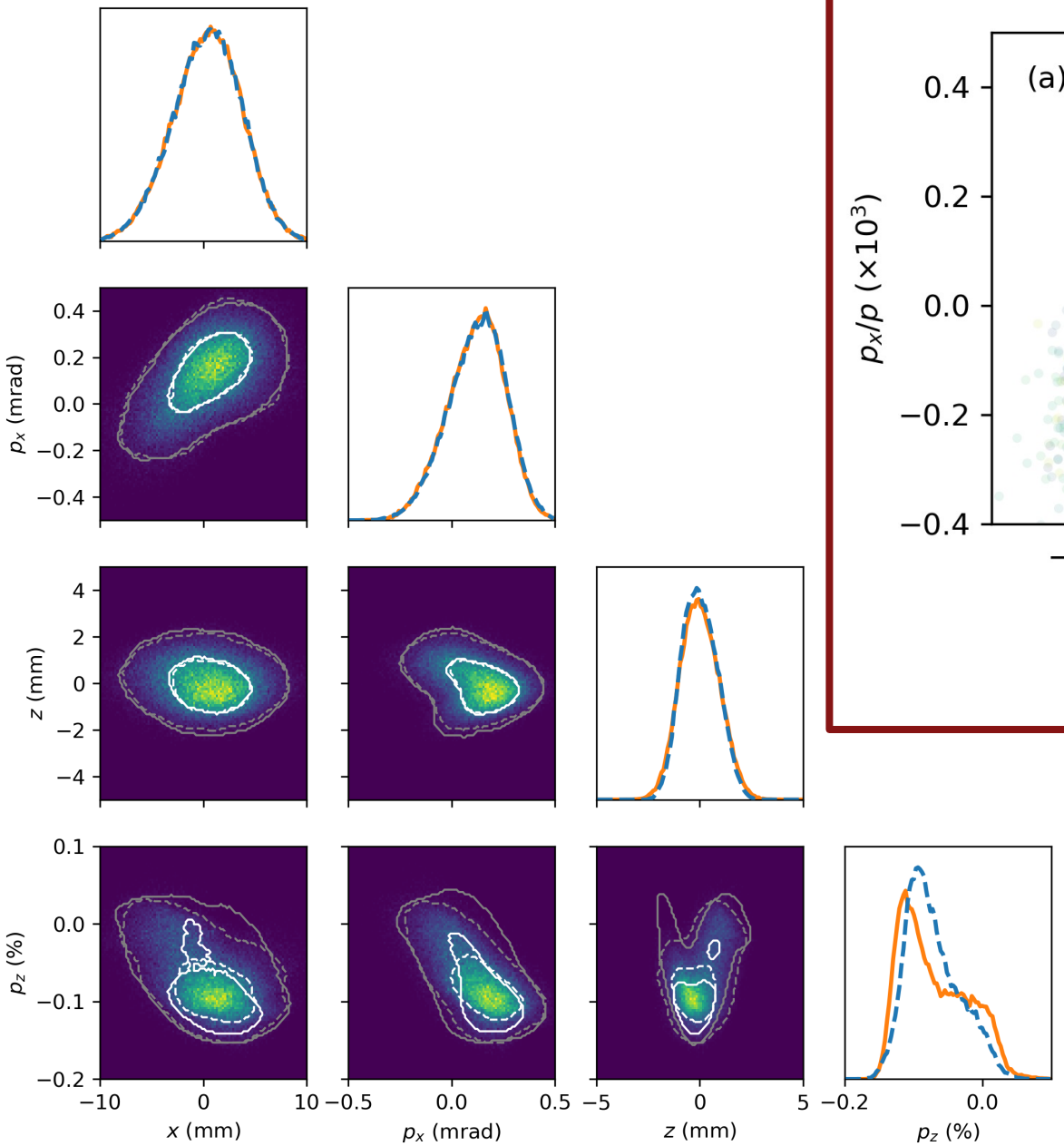
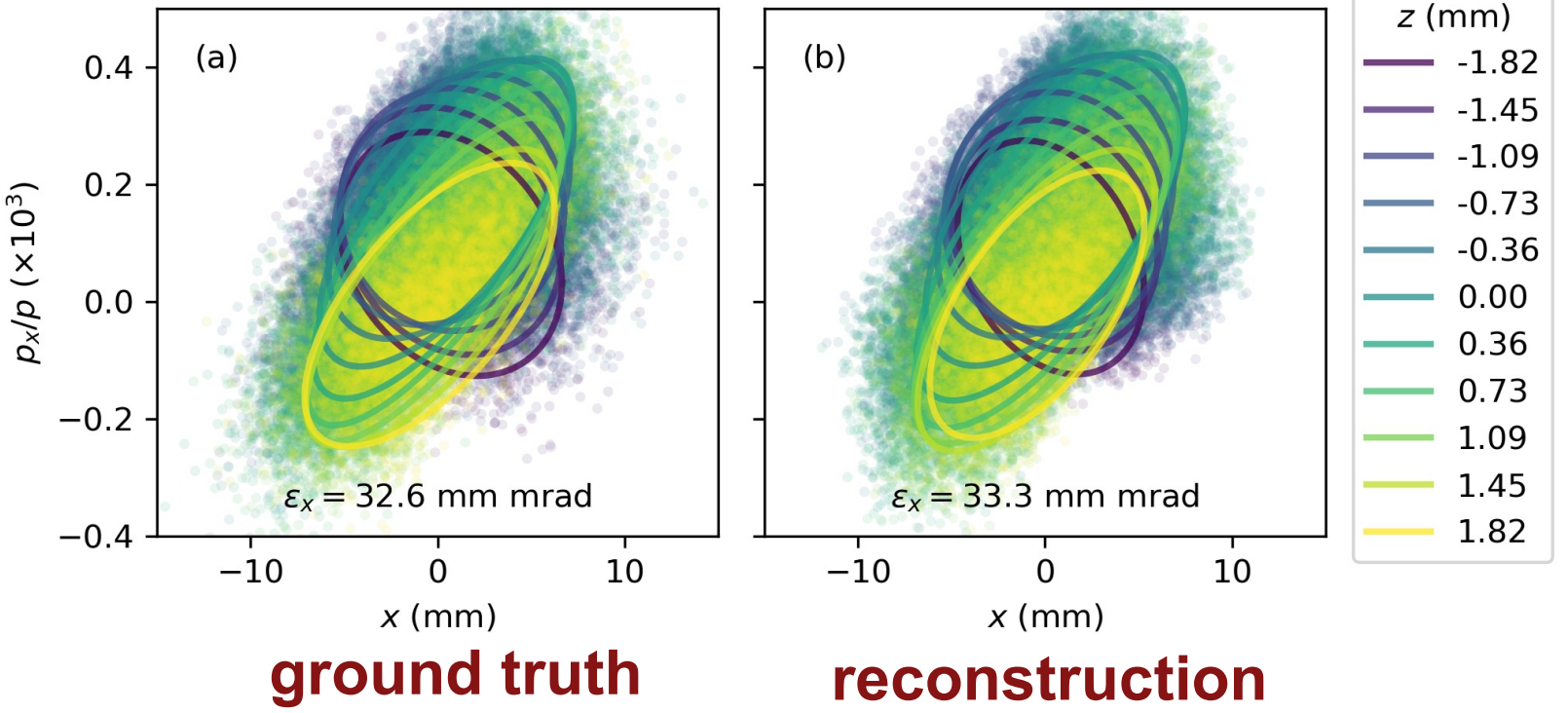
GPSR Results





ground truth **reconstruction**

- 50th percentile reconstructed
- 50th percentile ground truth
- 95th percentile reconstructed
- 95th percentile ground truth

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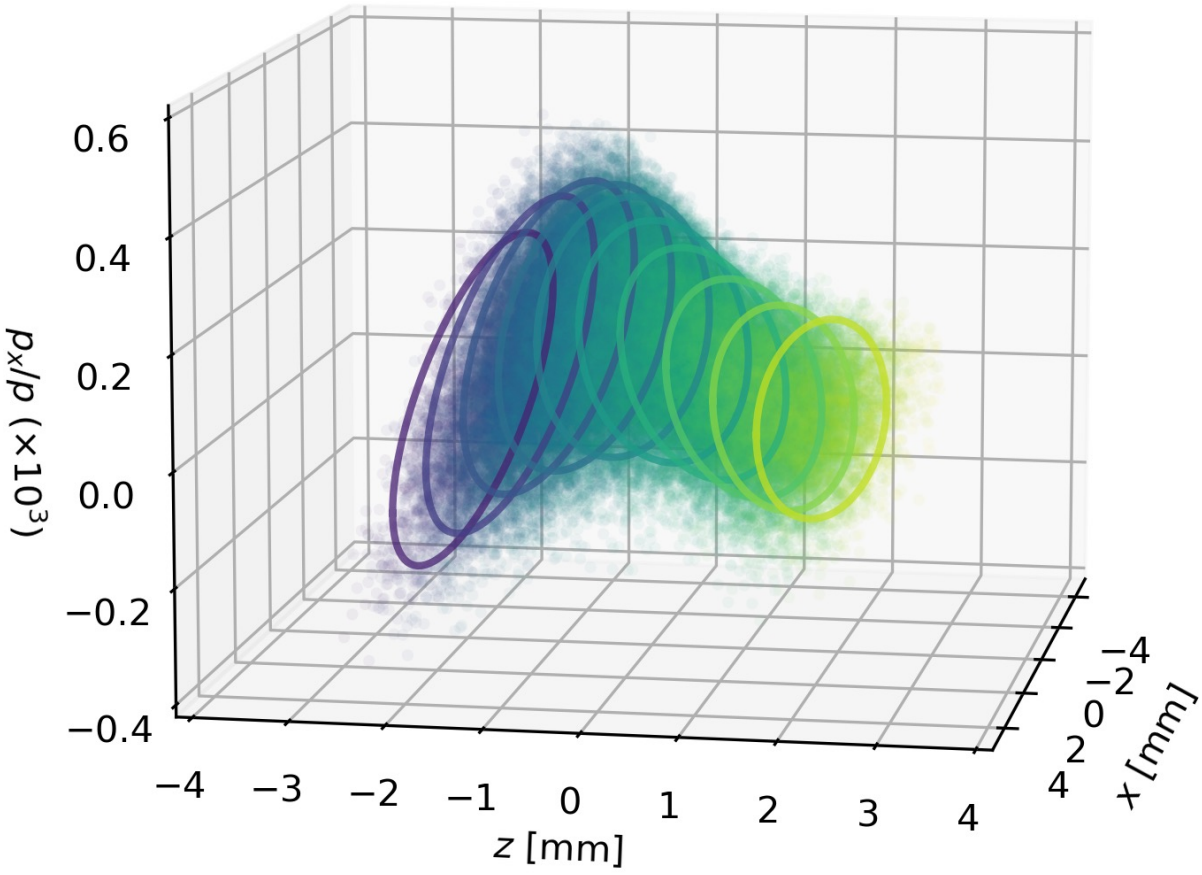
Summary

- AWA double dogleg can produce significant CSR effects
- Simulations show 6D GPSR can resolve CSR effects in the
  $\varepsilon_x = 25\ \mathrm{mm\ mrad}, \sigma_\delta = 0.2\%$ case
  - Only 20 x-y beam profiles
  - ~10 min, 8 Gb GPU
- Experimental demonstration coming soon!



Our Team

THE UNIVERSITY OF CHICAGO

Young-Kee Kim

J.P. Gonzalez-Aguilera

SLAC NATIONAL ACCELERATOR LABORATORY

Ryan Roussel

Auralee Edelen

Argonne NATIONAL LABORATORY

Eric Wisniewski

Wanming Liu

Alexander Ody

John Power

Philippe Piot

The Center for BRIGHT BEAMS
A National Science Foundation Science & Technology Center

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Thanks!
Questions?

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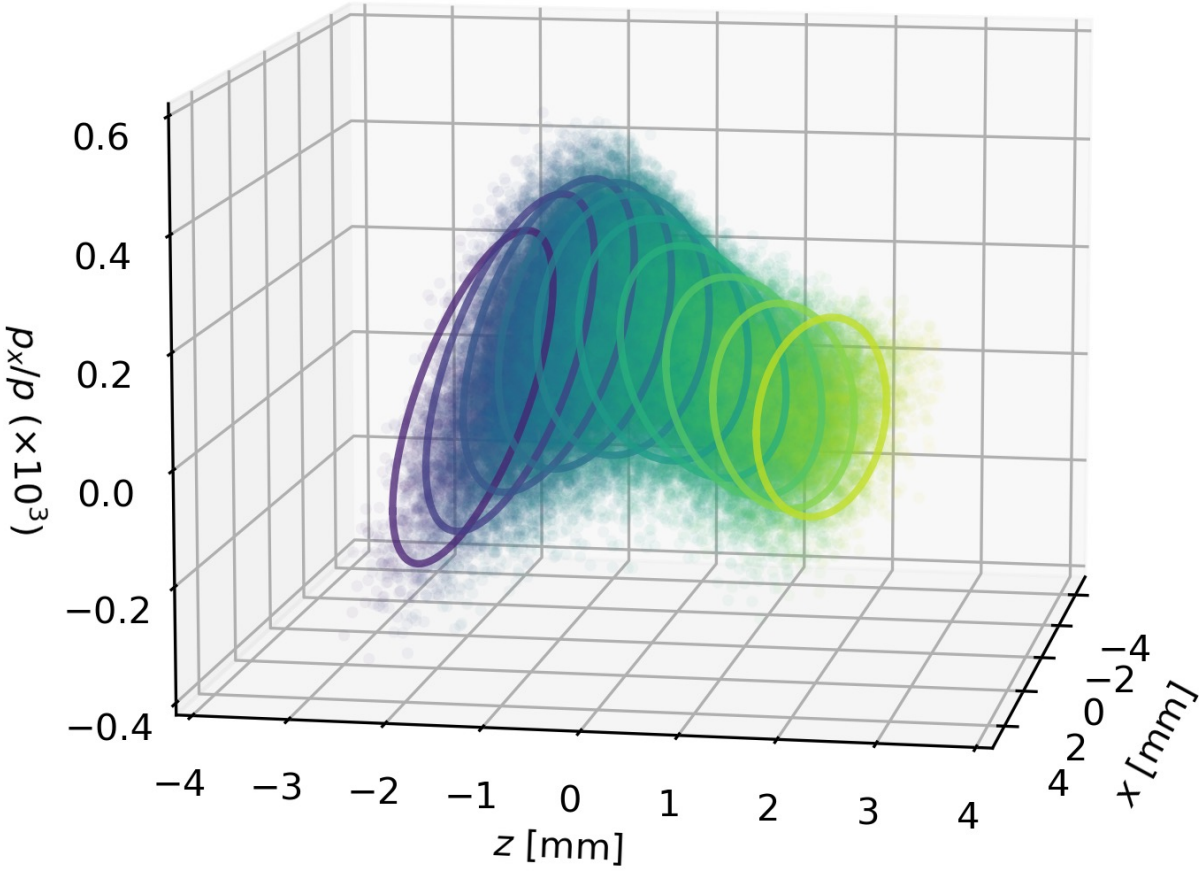

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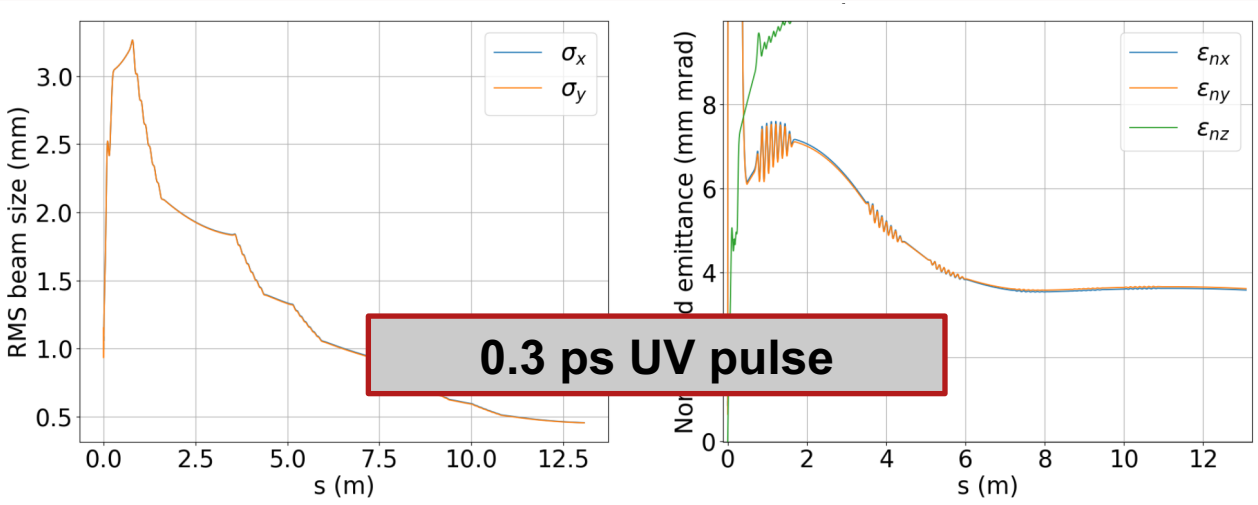
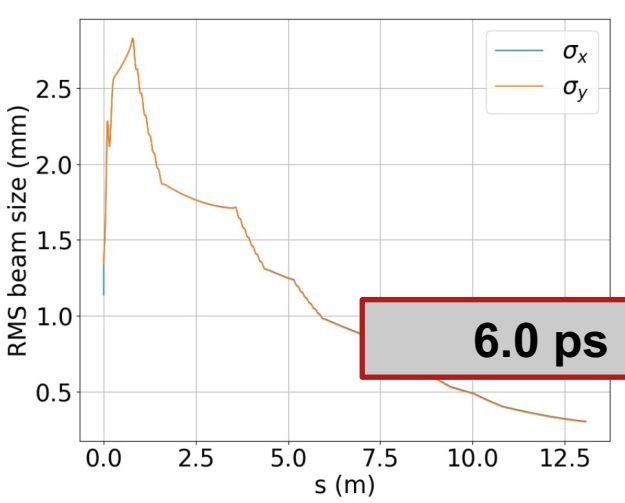
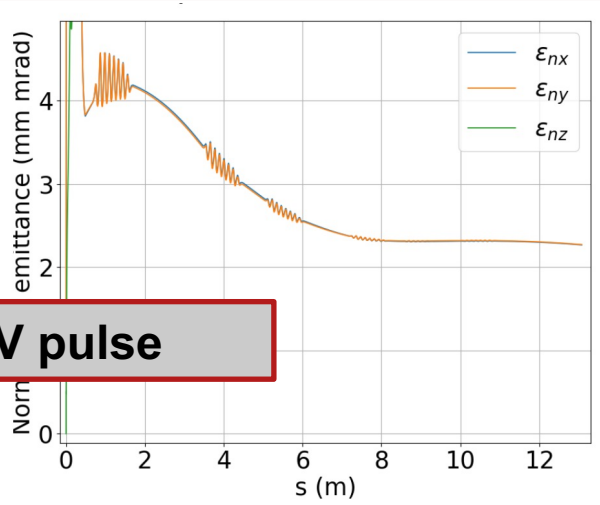
Backup: AWA realistic parameters



0.3 ps UV pulse





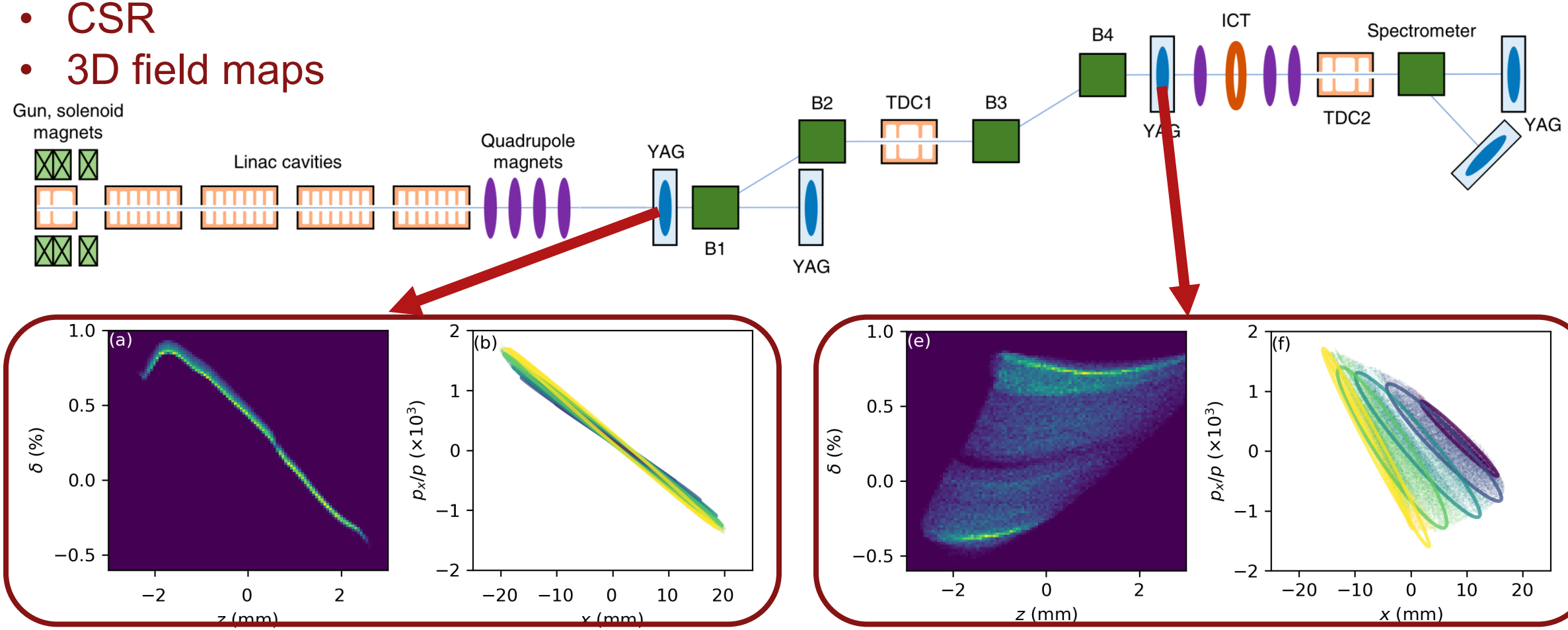
6.0 ps UV pulse

Parameter table

- **At the end of the drive linac section**

Parameters	Short pulse case (0.3 ps)	Long pulse case (6.0 ps)
RMS beam size	0.45 mm (without quads)	0.3 mm (without quads)
RMS bunch length	0.4 mm	0.64 mm
RMS energy spread	0.43%	0.25%
Normalized emittance	3.6 mm mrad	2.3 mm mrad

Courtesy of Seongyeol Kim, 2022

Backup: Chirped Beam

- 1 nC
- Simulations from photocathode
- Space charge
- CSR
- 3D field maps