

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

Advanced Accelerator Concepts

Naperville, IL

July 23rd , 2024

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



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This work was supported by:

- NSF award PHY-1549132, the **Center for Bright Beams**
- DoE contract No. DE-AC02-05CH11231, **NERSC** award BES-ERCAP0023724

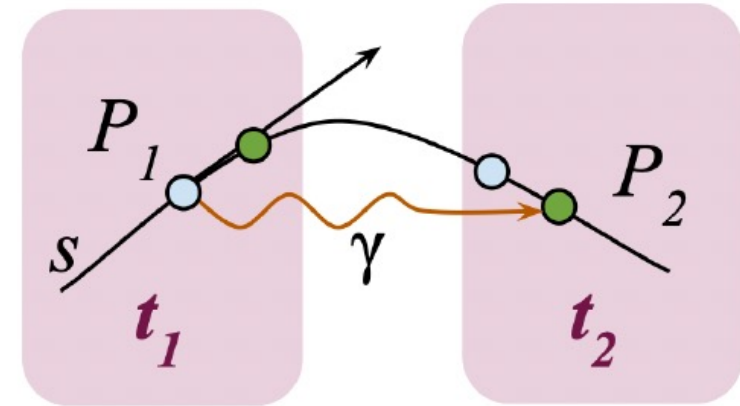
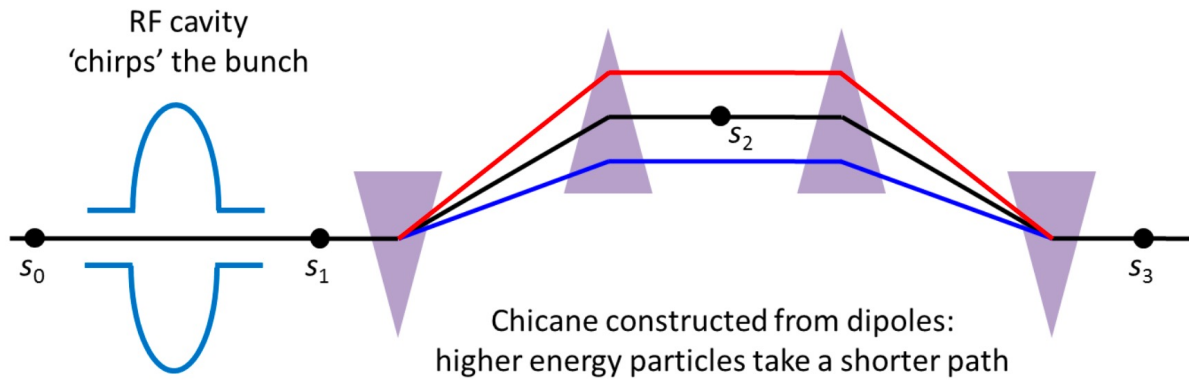


Outline

- Introduction
 - Coherent Synchrotron Radiation (CSR)
 - Importance
 - Measurement
 - 6D generative phase space reconstruction (GPSR – Ryan Roussel's talk)
- Simulation studies of CSR at the Argonne Wakefield Accelerator (AWA)
- Detailed characterization of CSR using GPSR
- Discussion
- Summary and Conclusions

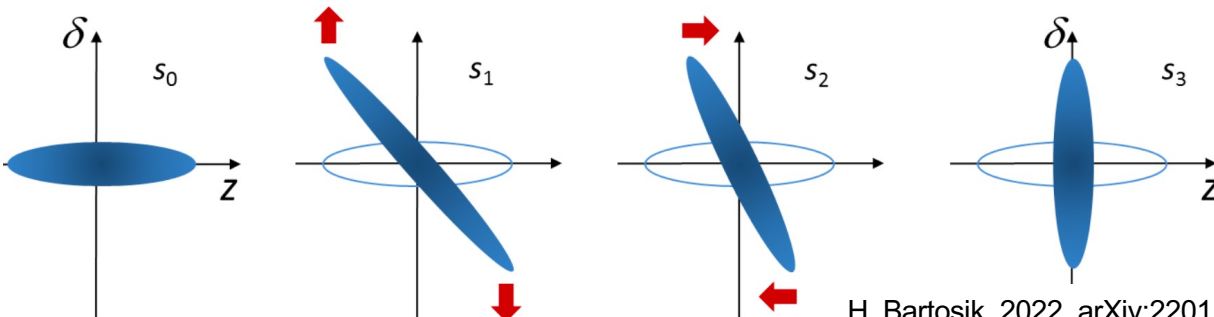
Coherent Synchrotron Radiation (CSR)

- FELs, 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
- CSR degrades beam quality



A. Edelen et al., IPAC 2022

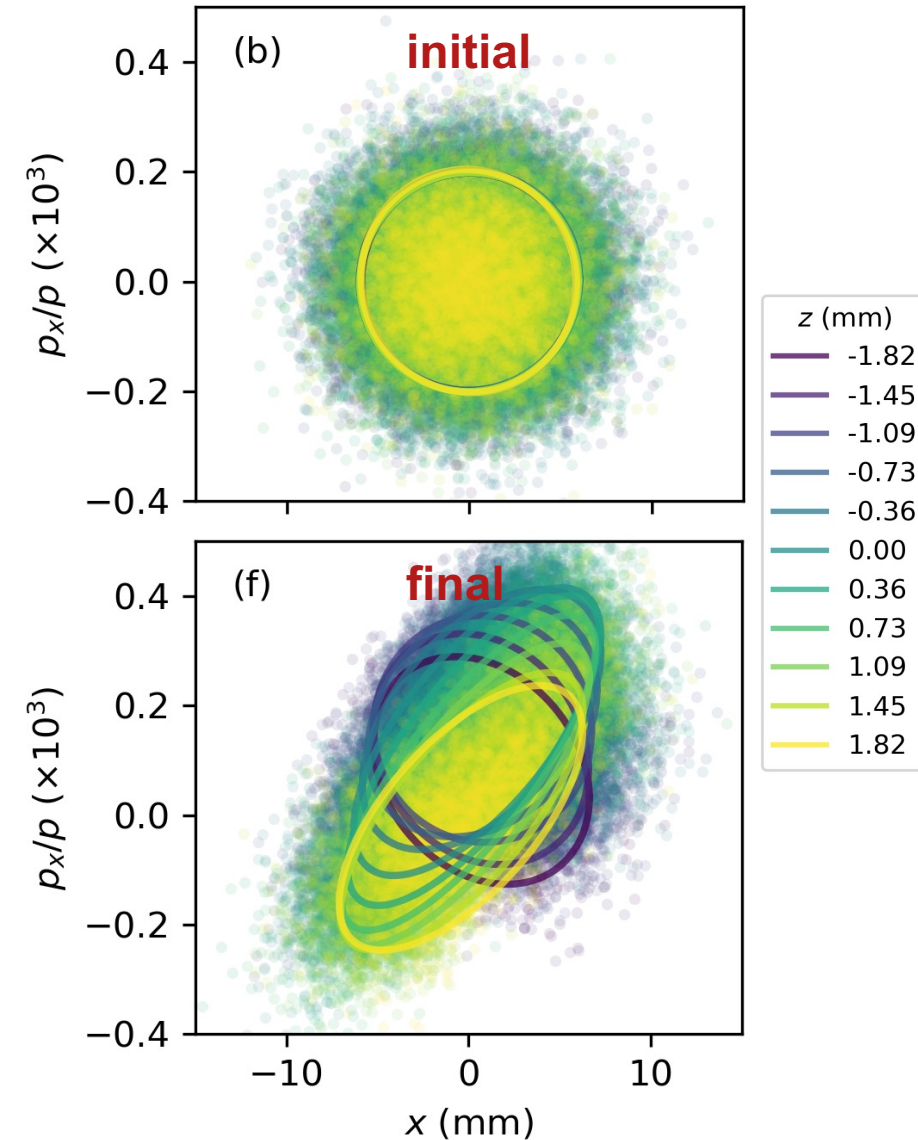
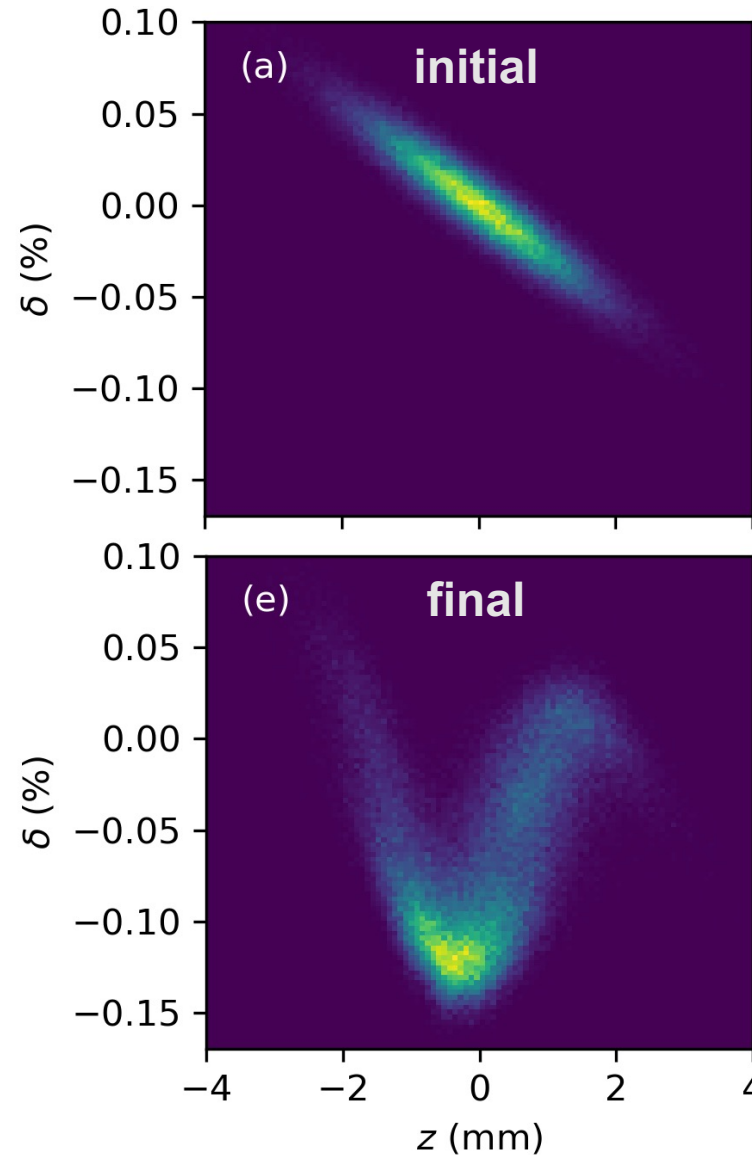
CSR is a complex phenomenon that degrades beam quality



H. Bartosik, 2022. arXiv:2201.01532

CSR Degrades Beam Quality

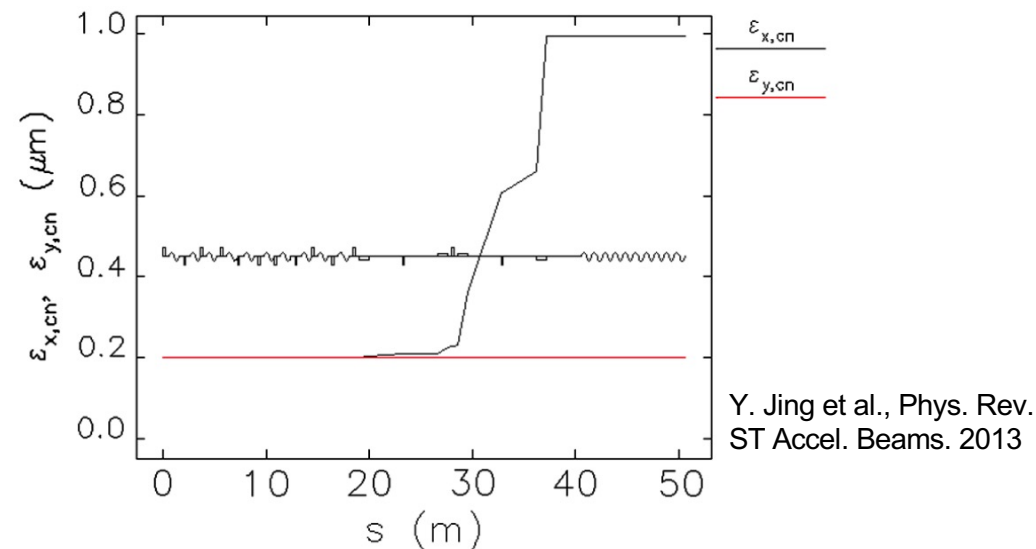
- Short-range CSR wakefield induces nonlinear kick in E vs z
- Dipoles also introduce x, p_x correlations with E
- **Result: rotation and centroid shift of x, p_x longitudinal slices, increasing the projected ε_x**



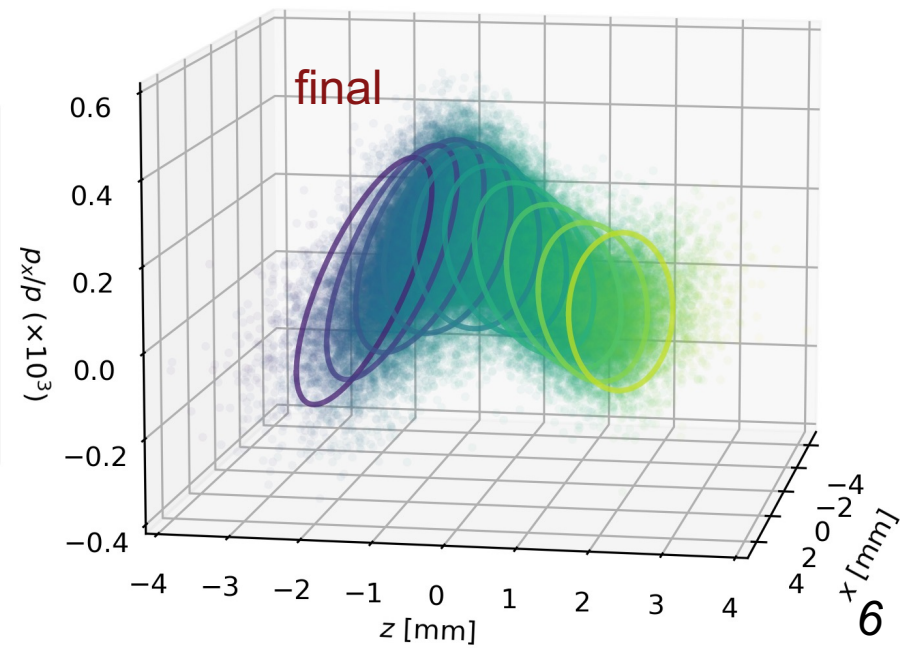
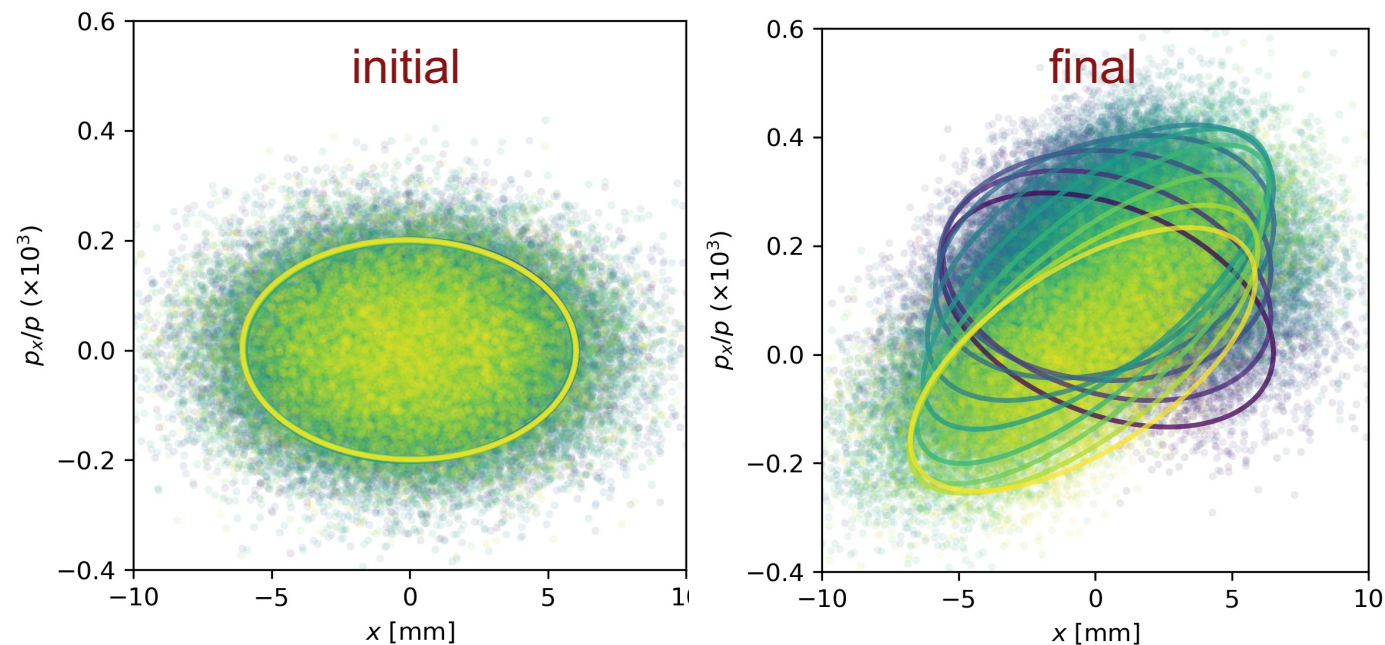
Measurement of CSR Effects

Studies of CSR effects are often limited to **macro-scale** description of beam distribution:

- Projected ε_x growth

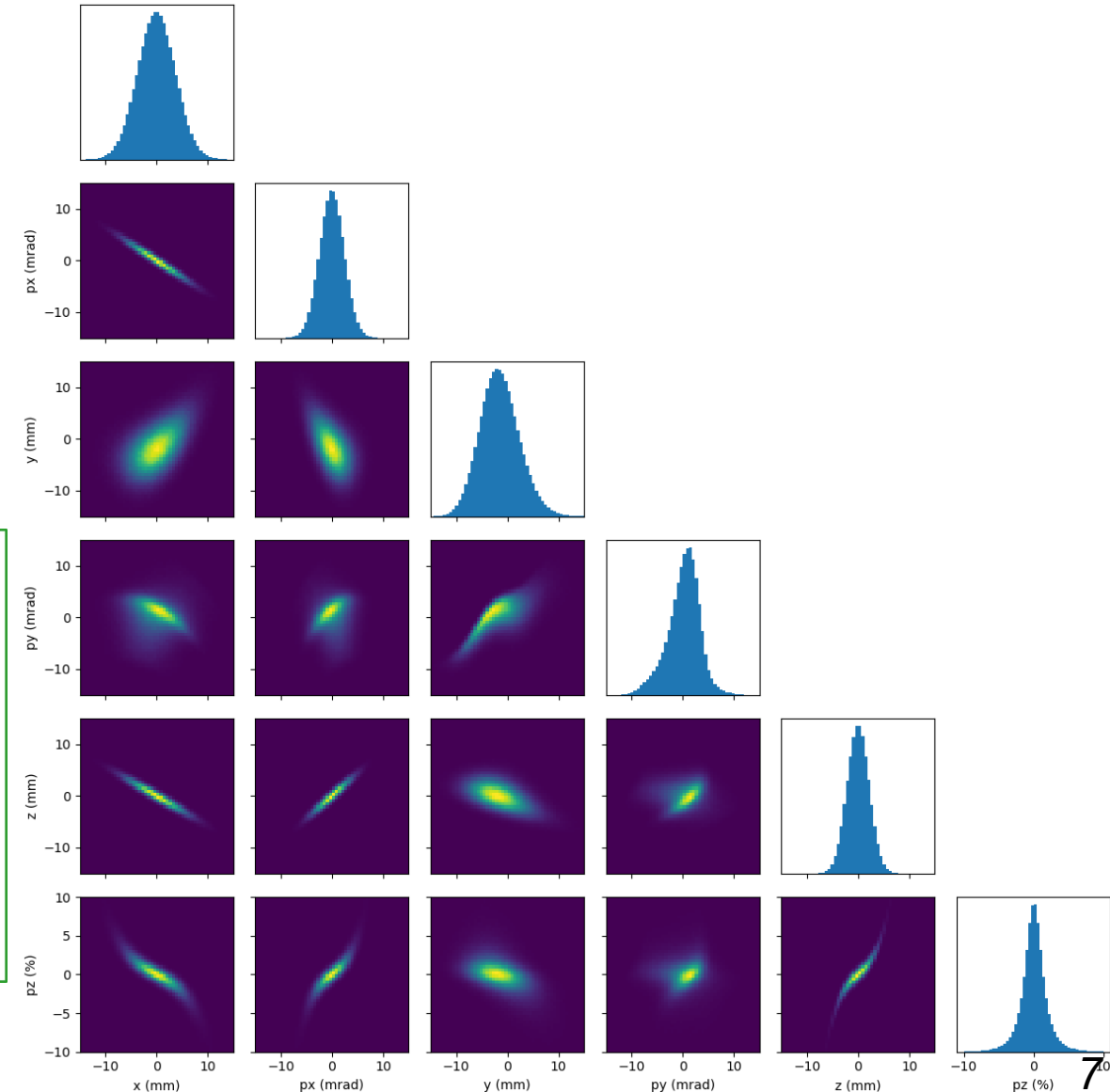
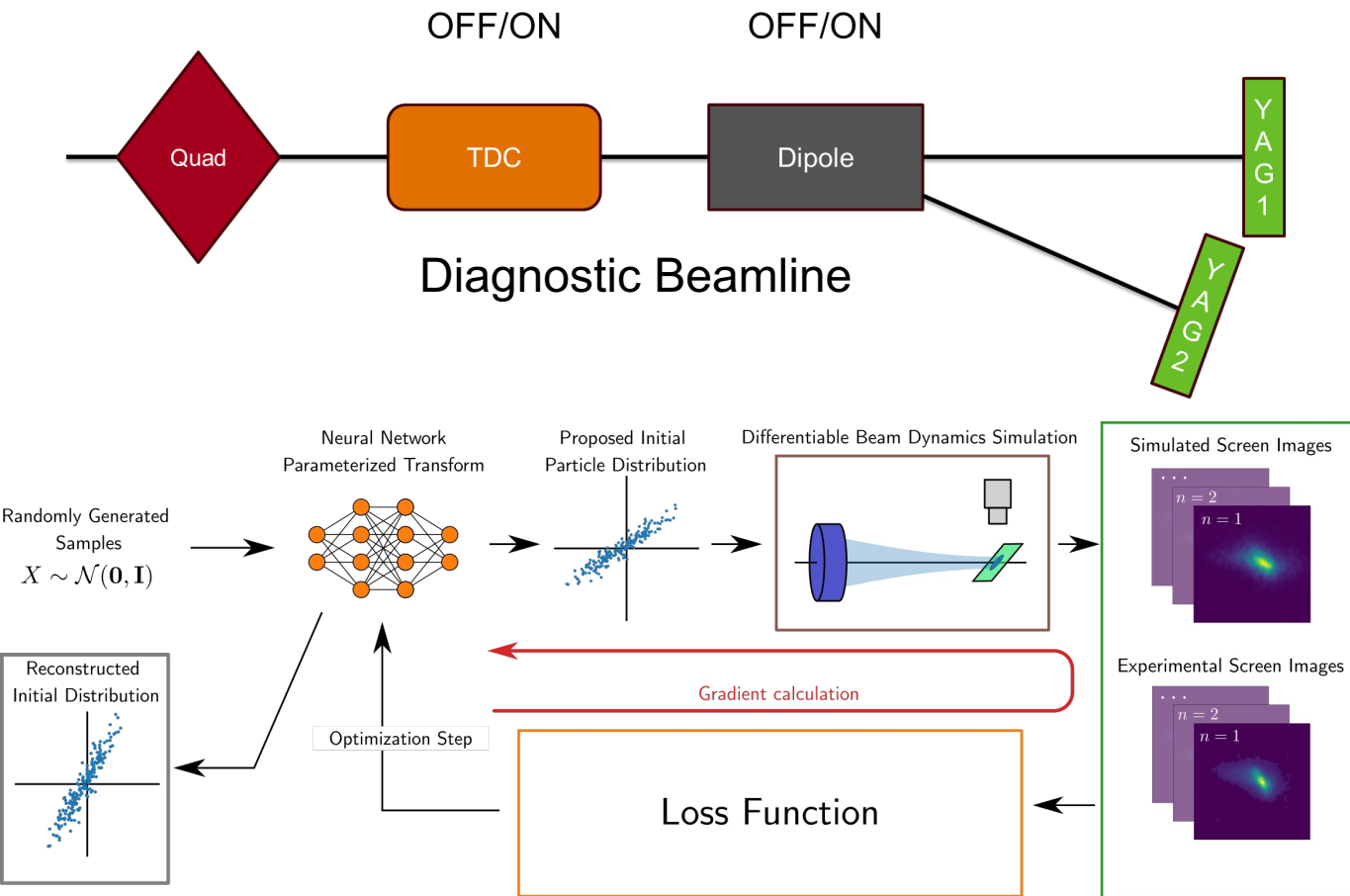


Does not resolve detailed beam structure!



Six-Dimensional Phase Space Reconstruction

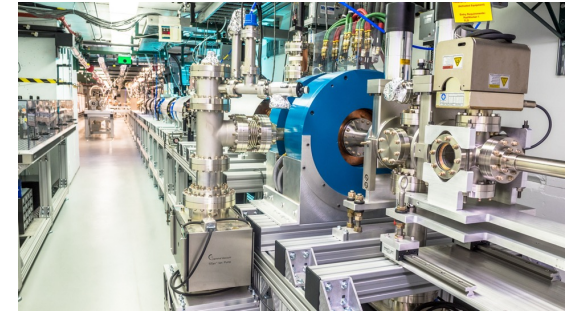
- Generative phase space reconstruction (GPSR) can provide detailed structure of the beam distribution



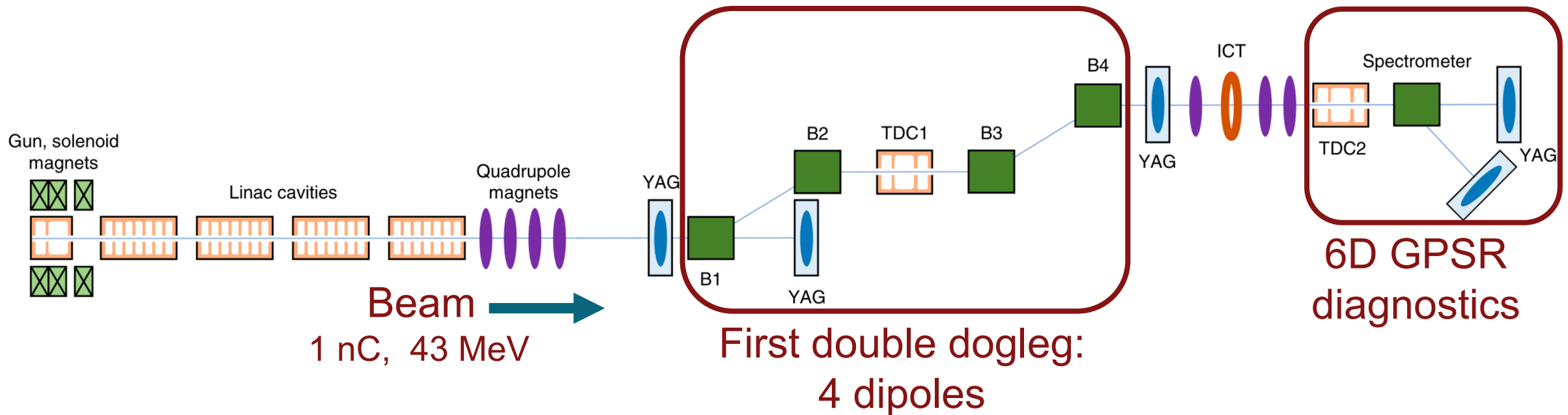
R. Roussel's talk

CSR at AWA

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



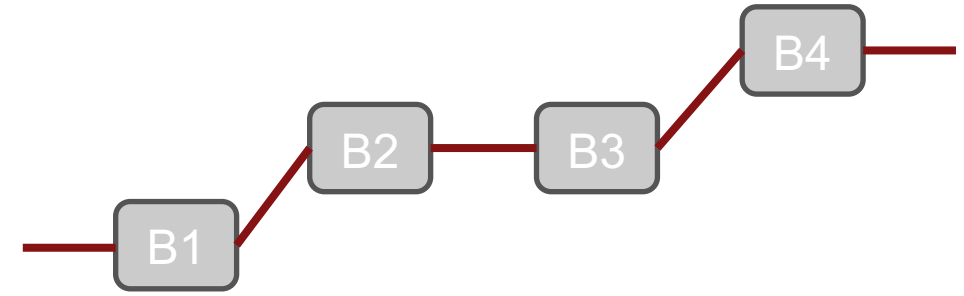
Argonne
NATIONAL LABORATORY



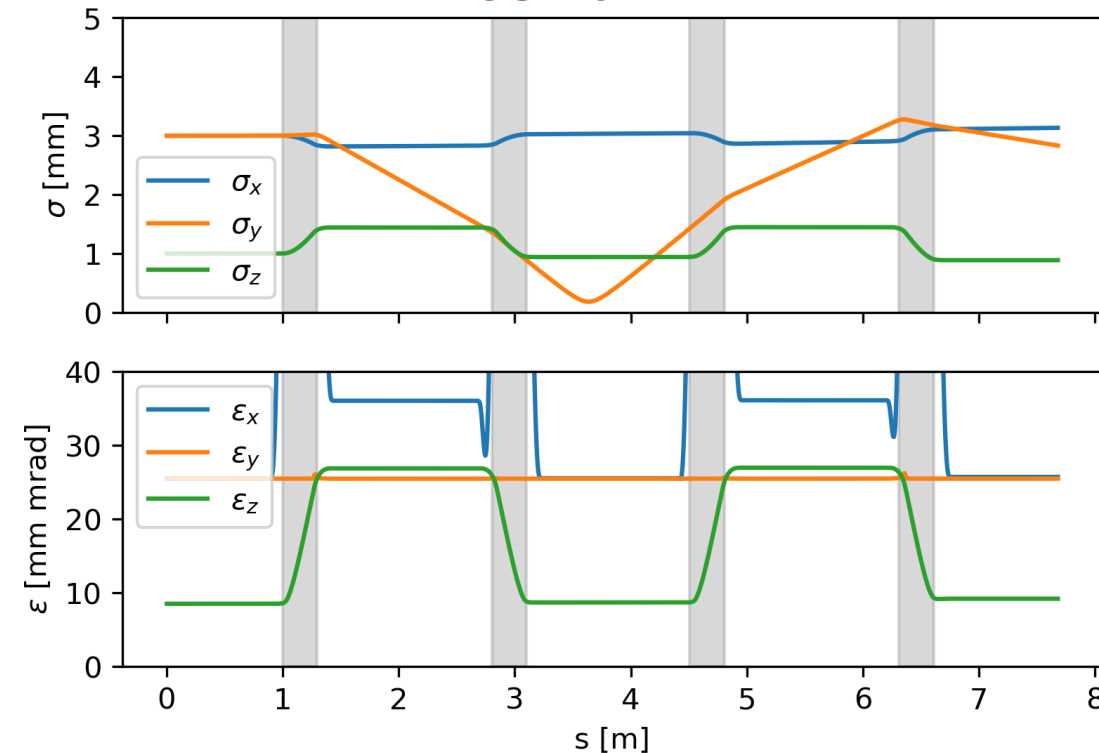
Adapted from *N. Majernik et al., PRAB, 2023.*

Beam Dynamics at AWA Double Dogleg

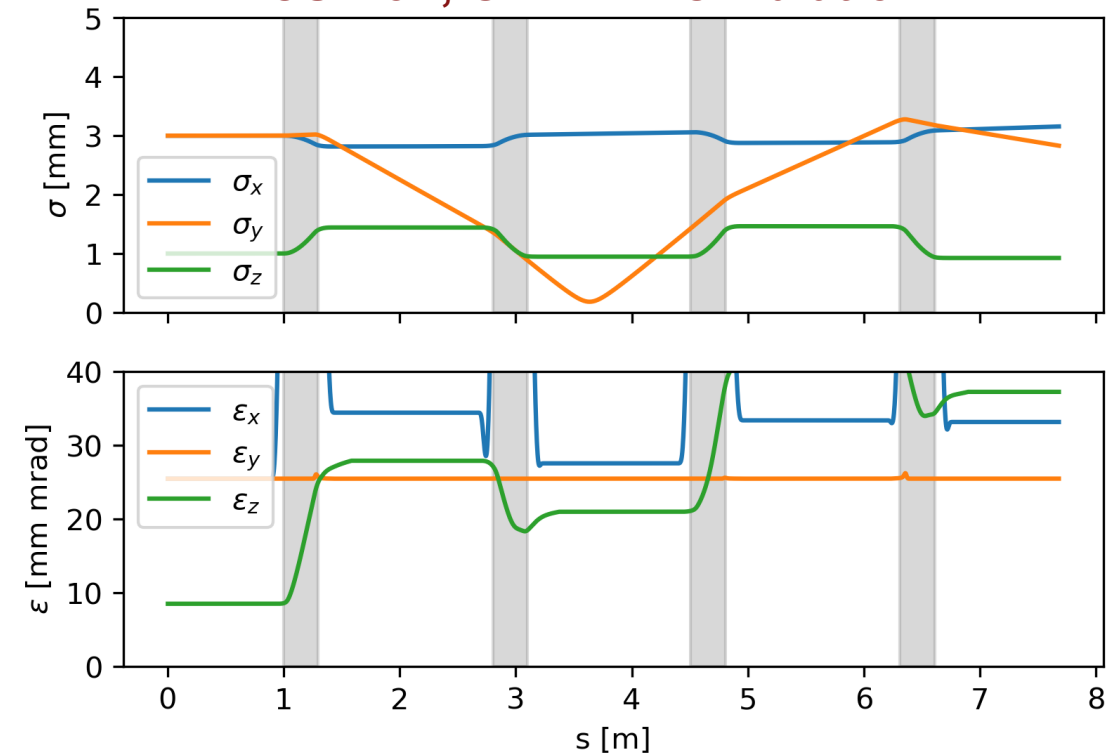
- Can we see CSR effects after double dogleg?
- Initial beam (ideal):
 - 1 nC, 43.4 MeV
 - $\varepsilon_x = 25$ mm mrad
 - 3 mm beam size, 1mm bunch length



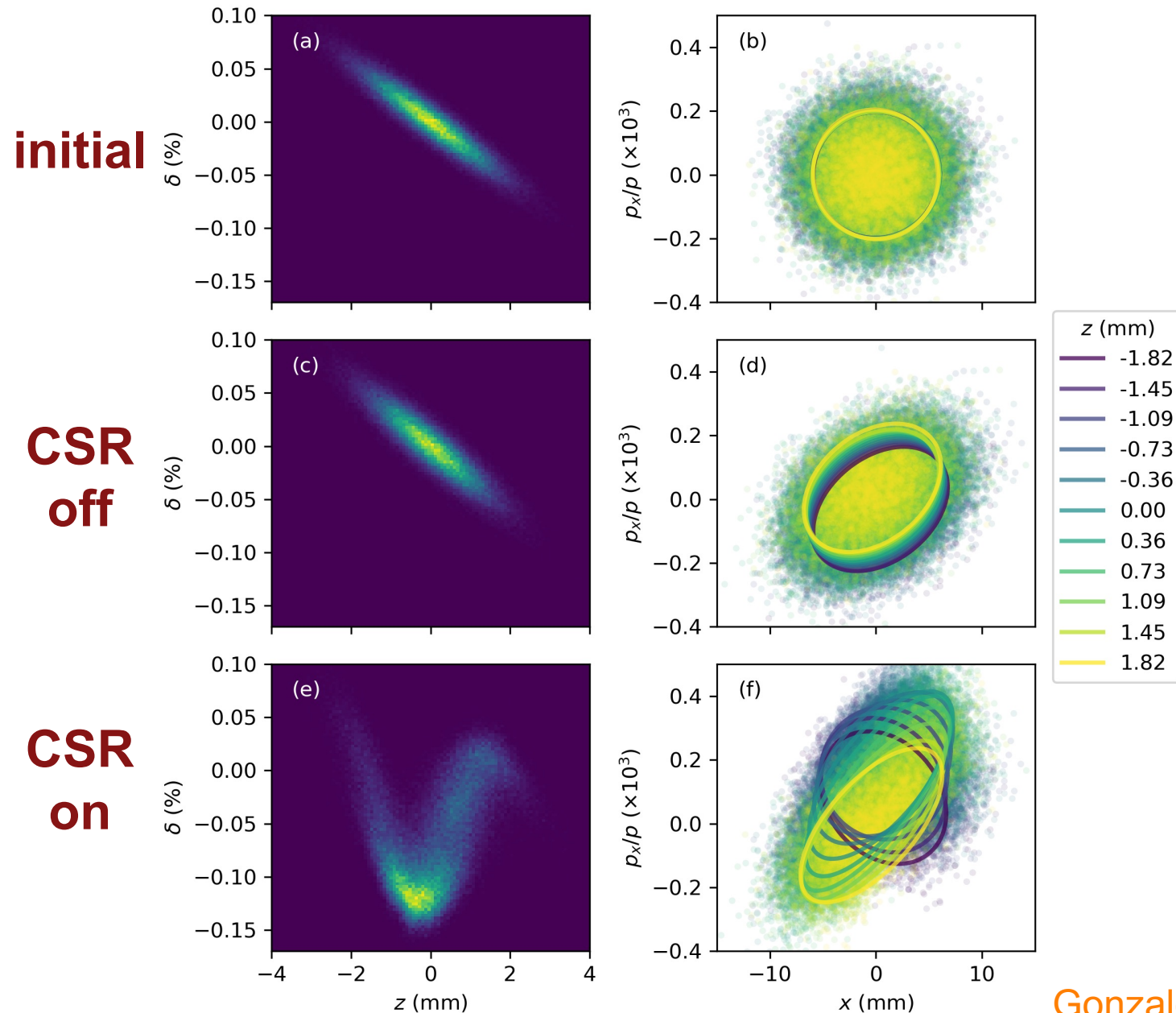
CSR off



CSR on, OPAL 1D simulation



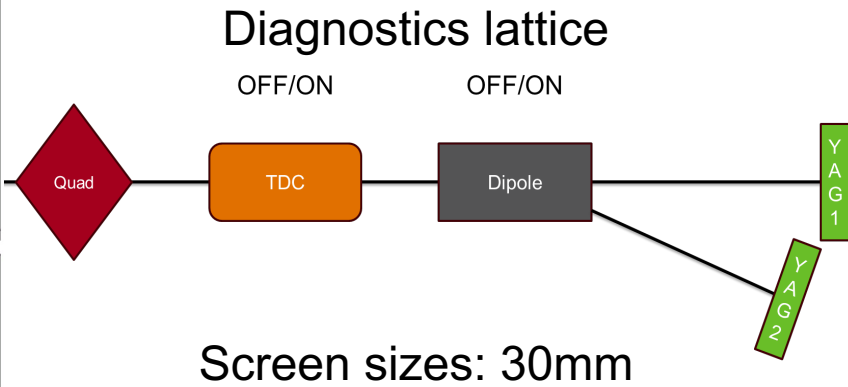
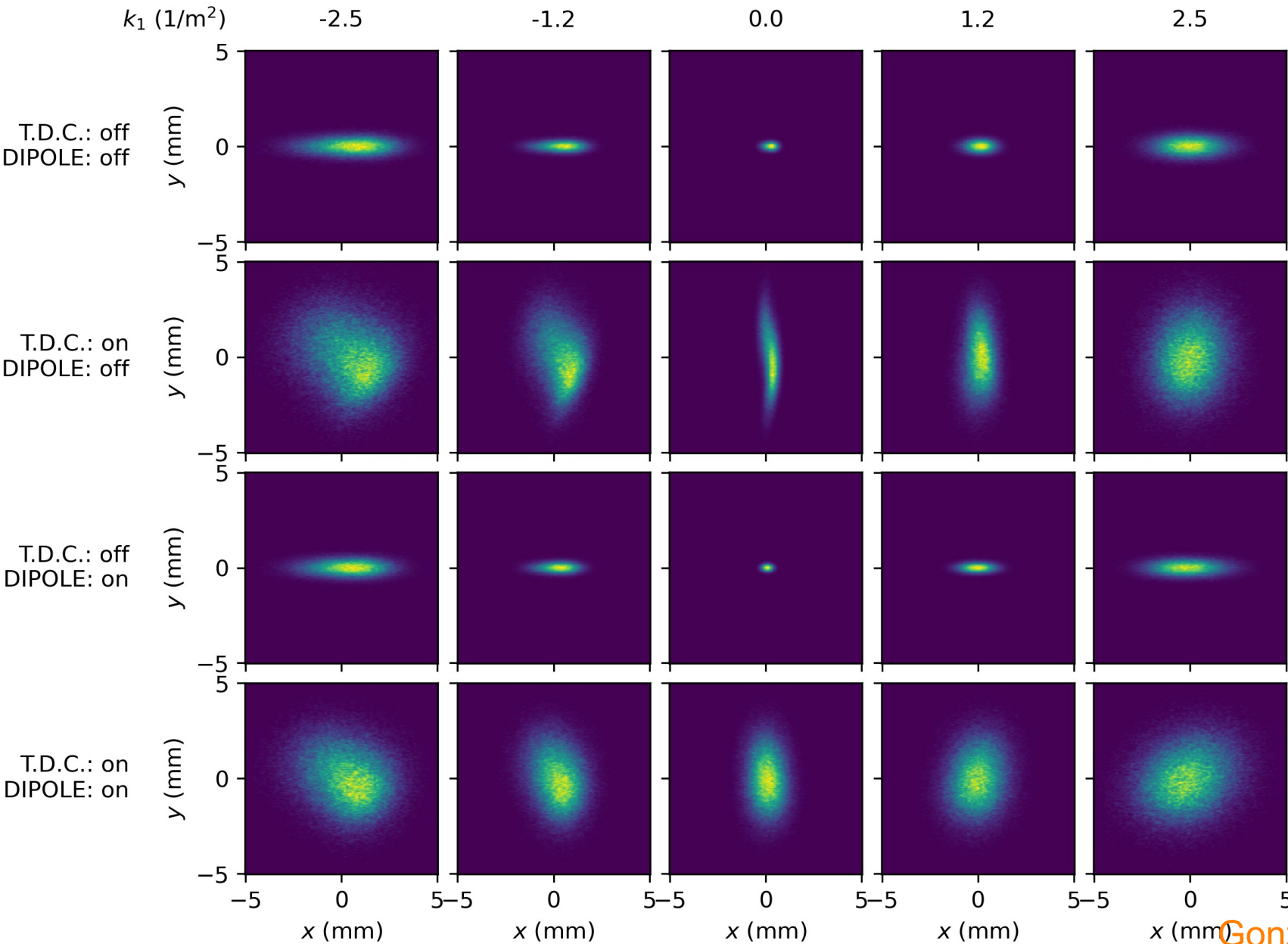
Simulated CSR Effects: $E - z$ and $x - p_x$



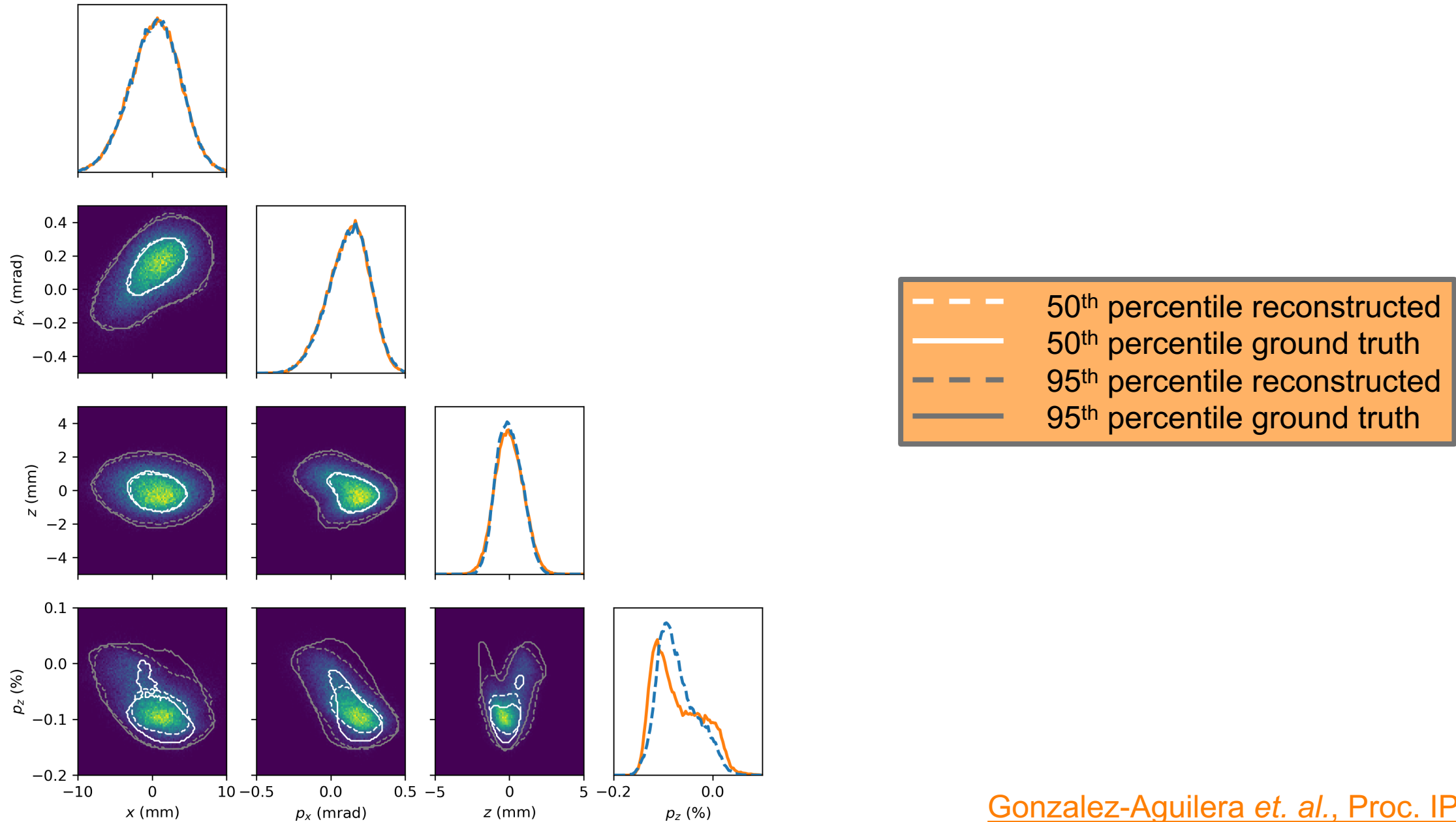
CSR-affected beam

**Can we resolve
using GPSR?**

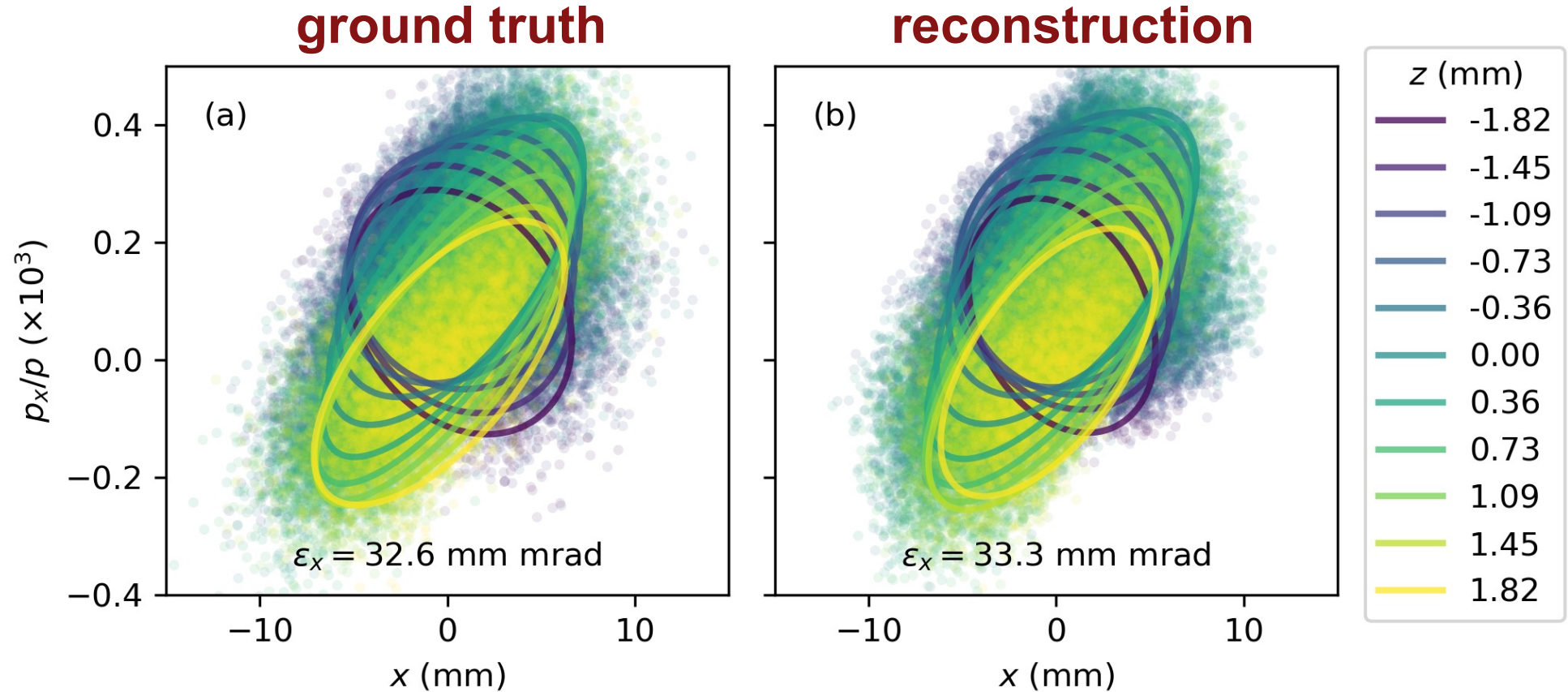
GPSR Training Data



GPSR Results: 2D Projections



Detailed $x - p_x$ Phase Space Slices



Discussion

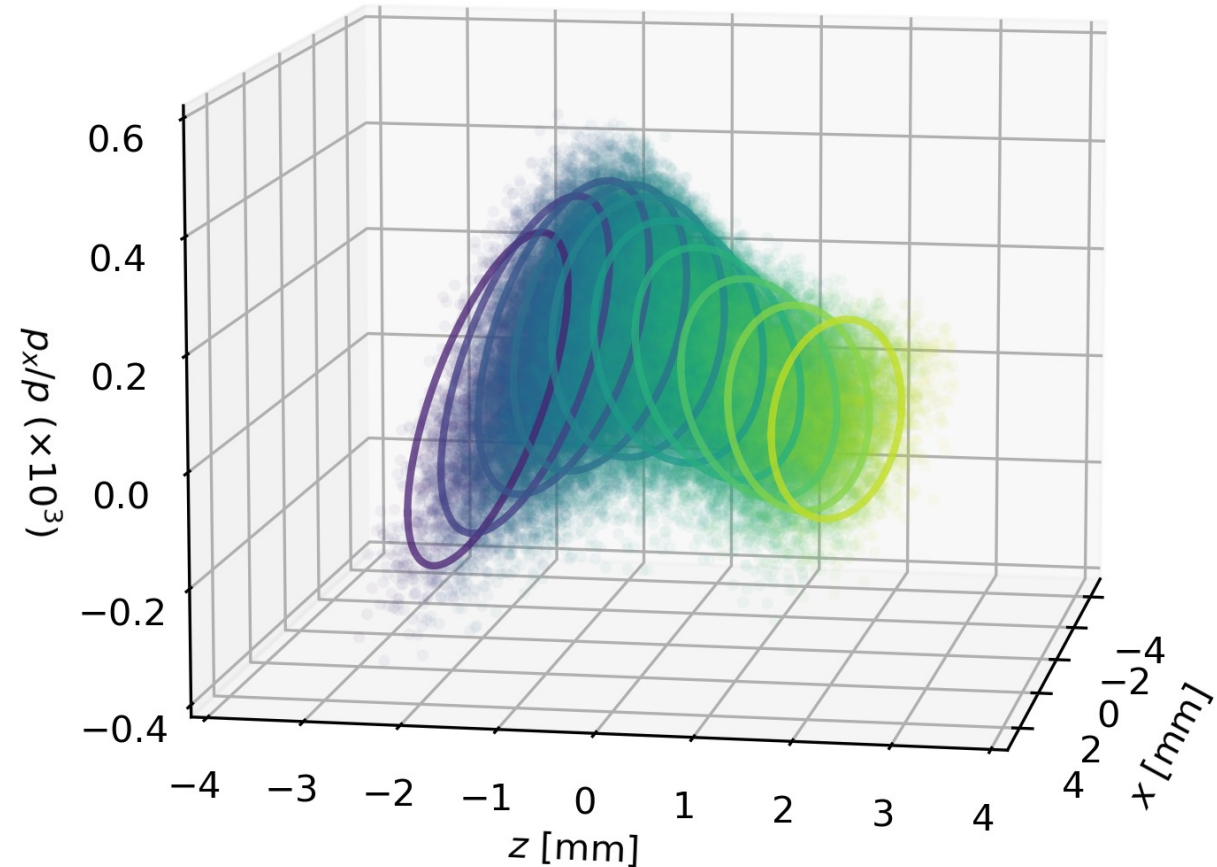
- Need of small emittance and energy spread to resolve CSR
 - GPSR struggles to get correct slice rotations when going beyond $\varepsilon_x = 25$ mm mrad or under $\delta_E = 0.1\%$ at 1nC
 - It seems that these beam parameters are achievable at AWA
- Longitudinal and transverse optics (work in progress):
 - Could compress beam at last dipole to promote CSR wake with larger beams:
 - Hardware: linac RF cavity phase to induce longitudinal chirp
 - Could test transverse optics to change Twiss parameters:
 - Hardware: quadrupoles
- Define metrics to compare >2D beam distributions
 - How can we compare high-dimensional beam distributions quantitatively?

Summary

- AWA double dogleg can produce significant CSR effects
- Simulations show 6D GPSR can resolve CSR effects in the $\varepsilon_x = 25$ mm mrad, $\sigma_x = 3$ mm case
 - Only 20 x-y beam profiles
 - ~10 min, 8 Gb GPU
- Need small ε_x and δ_E to resolve CSR effect
 - Further study of transverse optics is necessary
- Future work:
 - Experimental demonstration coming soon

Thanks! Questions?

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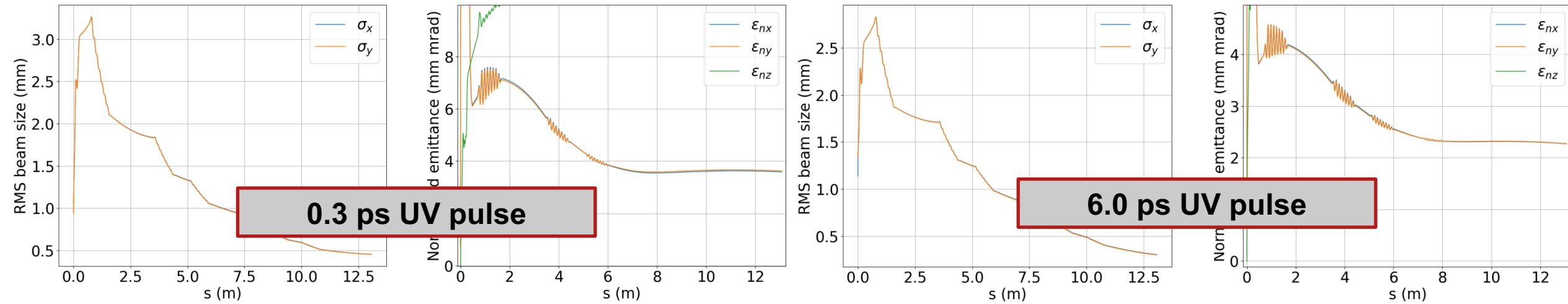


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Backup: AWA realistic parameters



Parameter table

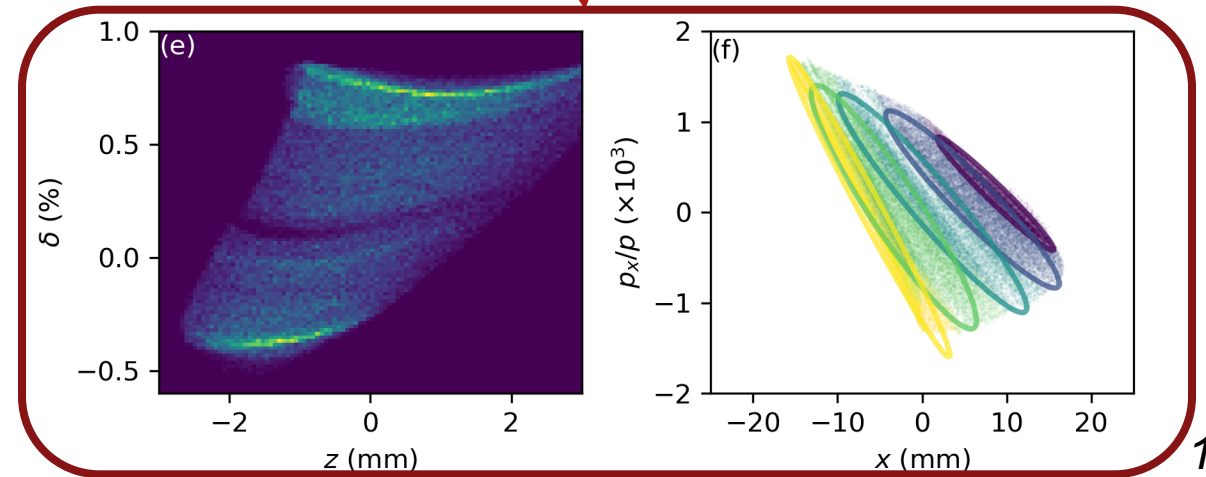
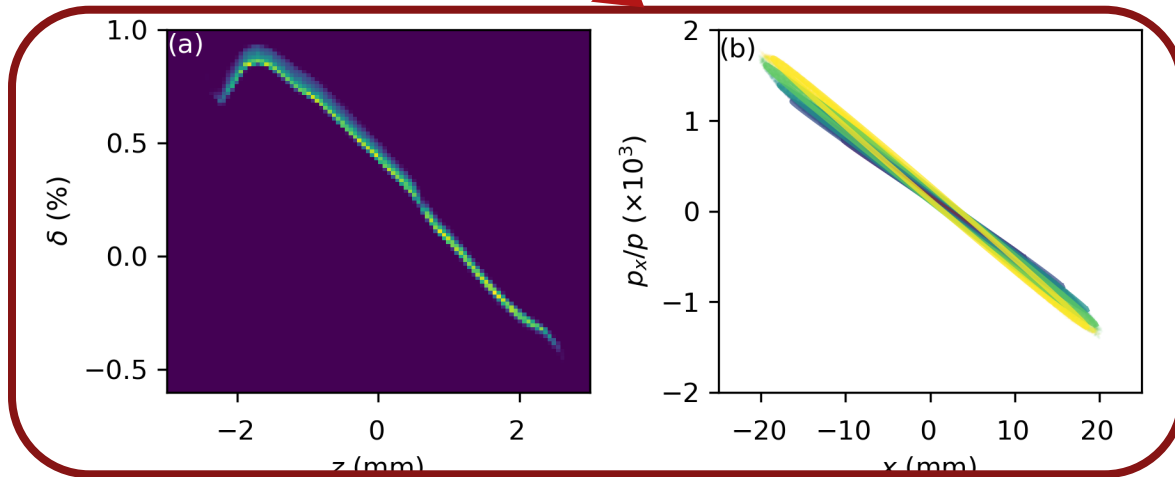
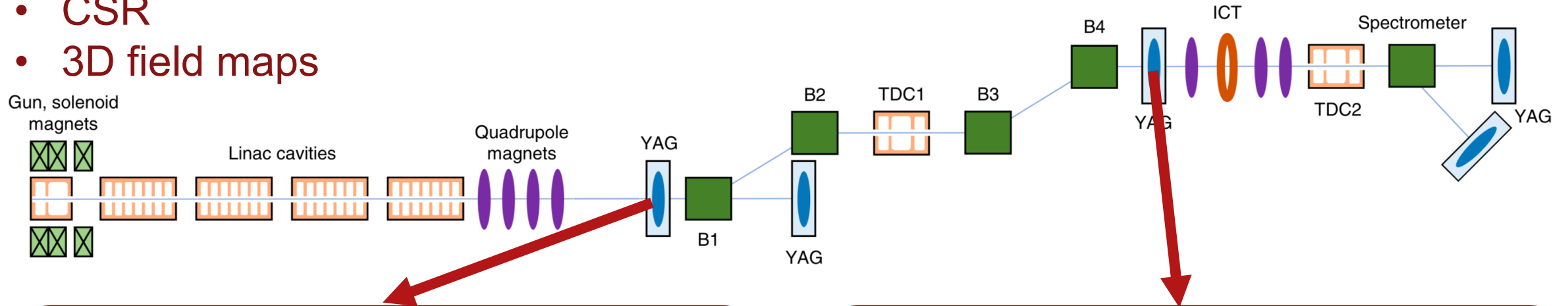
➤ At the end of the drive linac section

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

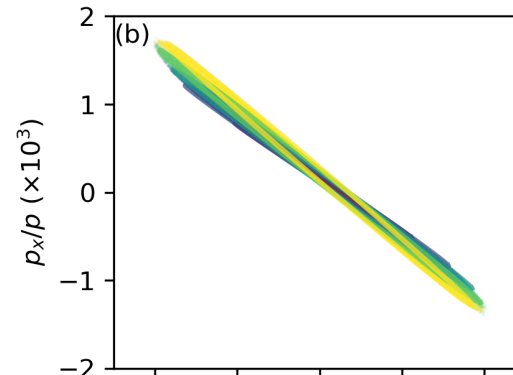
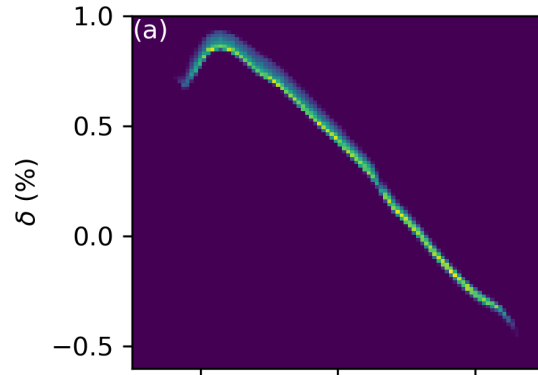
Realistic Beam (preliminary)

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

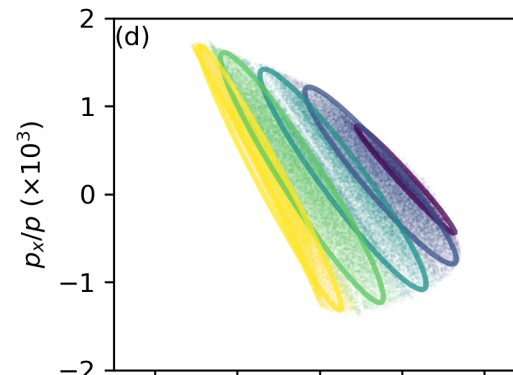
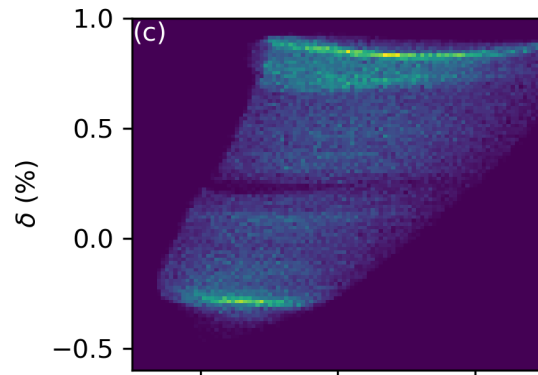


CSR or just dispersion?

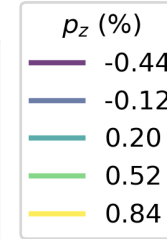
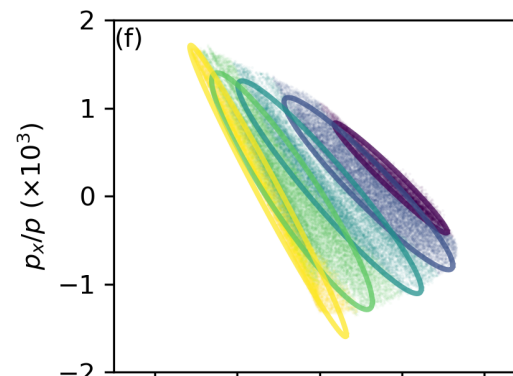
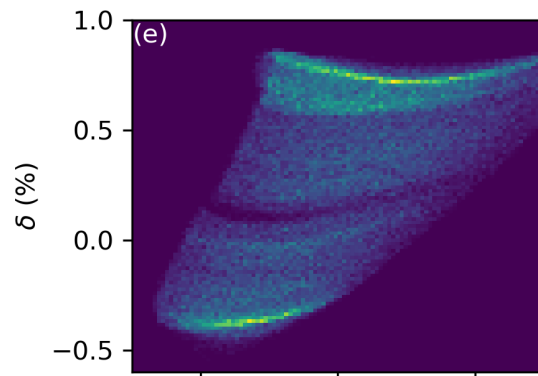
initial



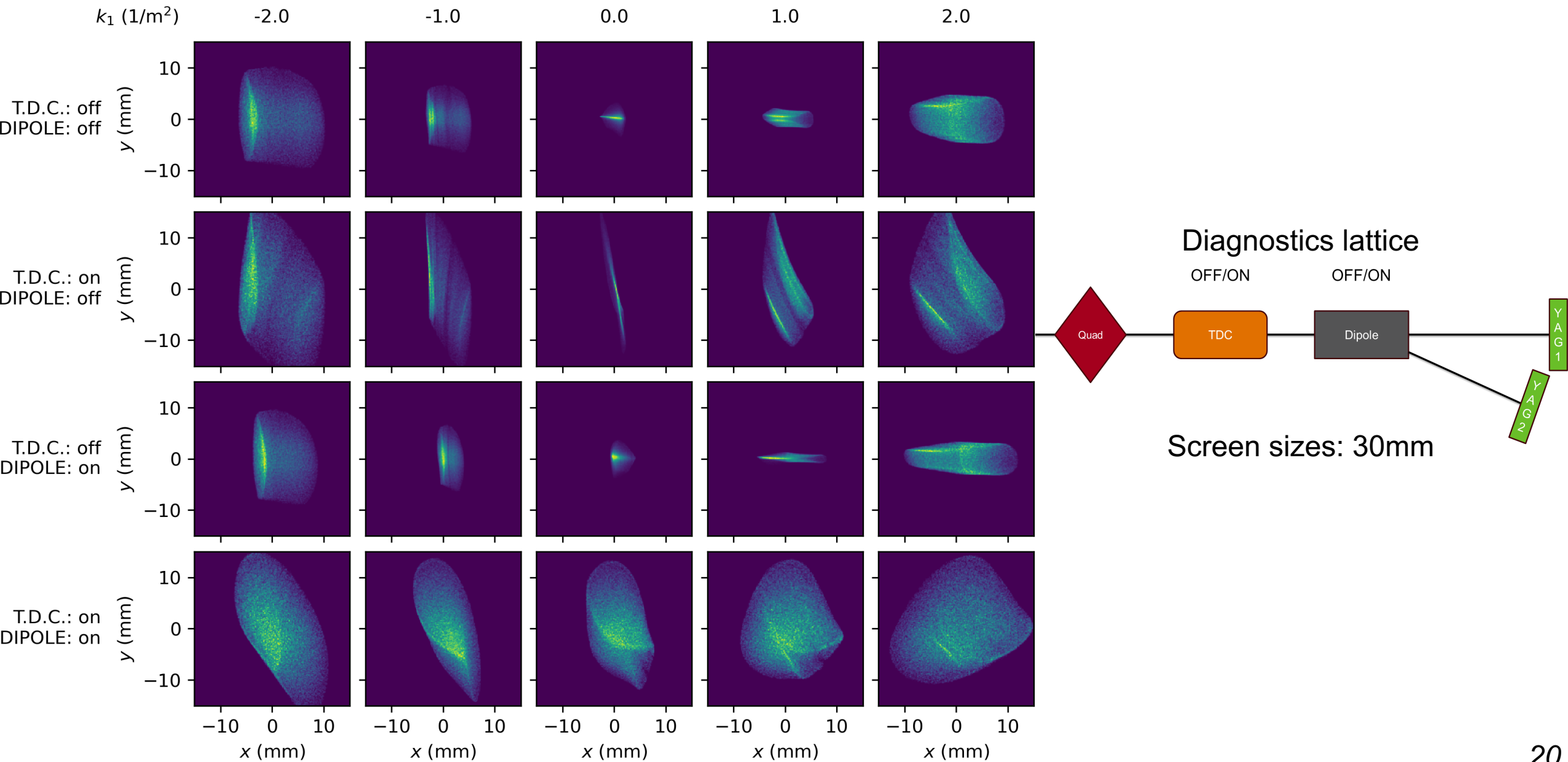
**CSR
off**



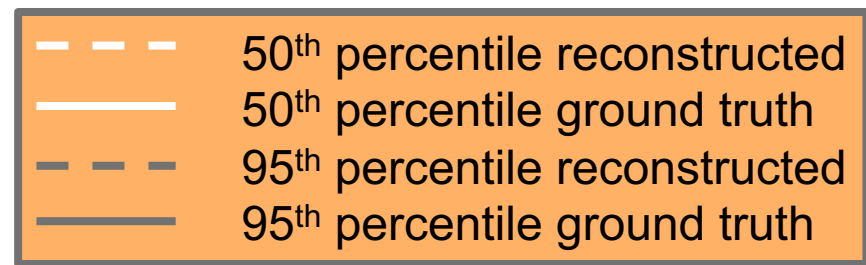
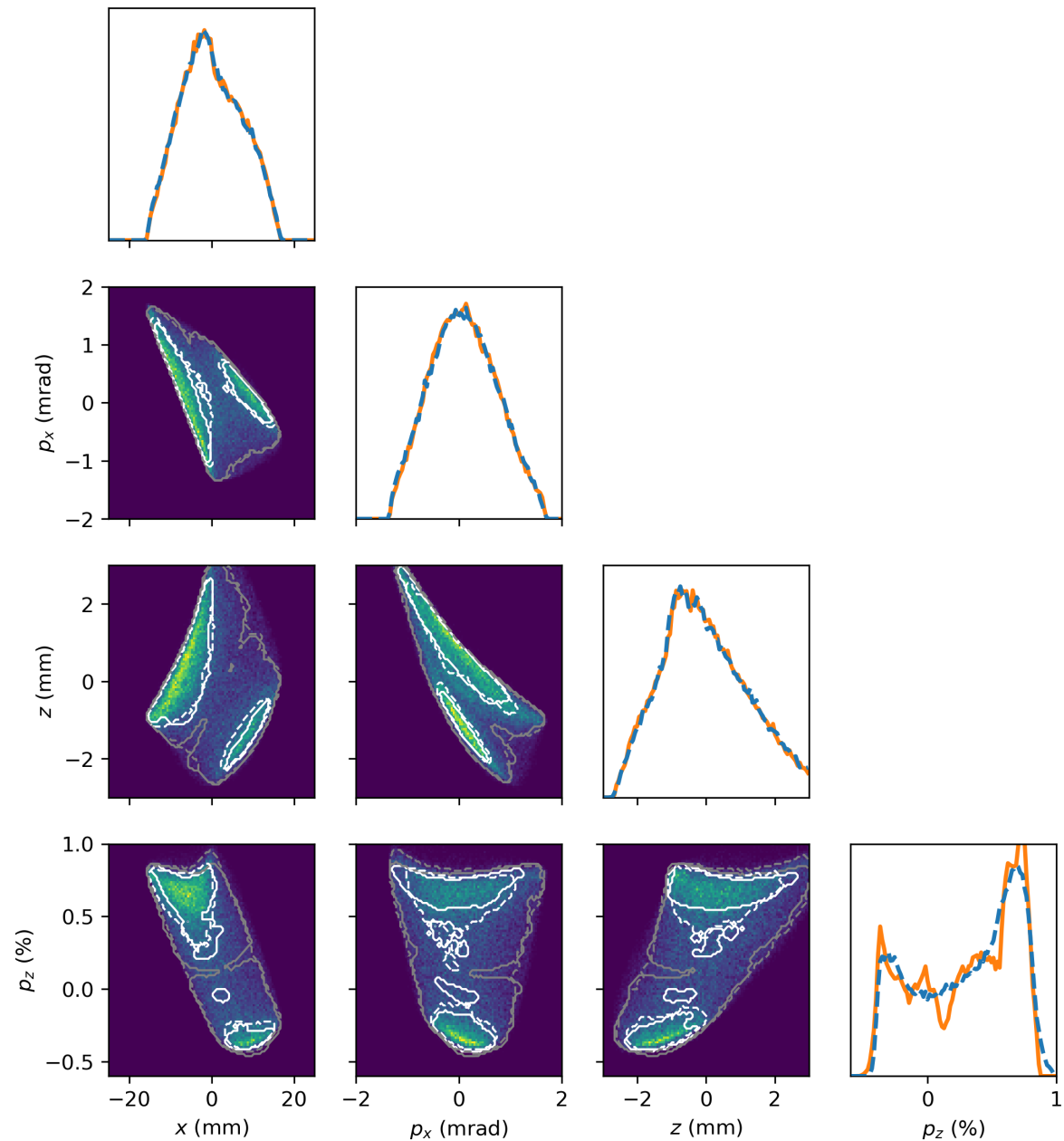
**CSR
on**



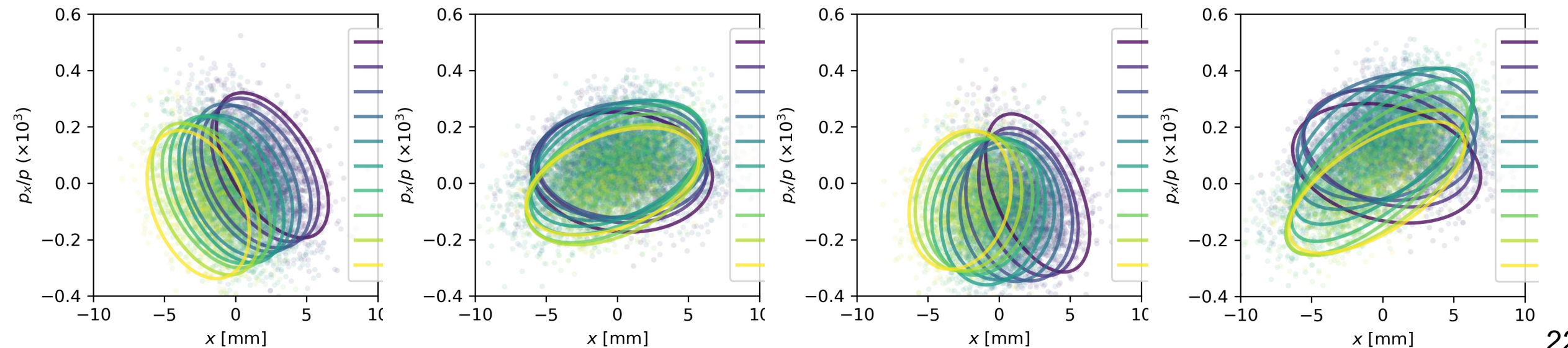
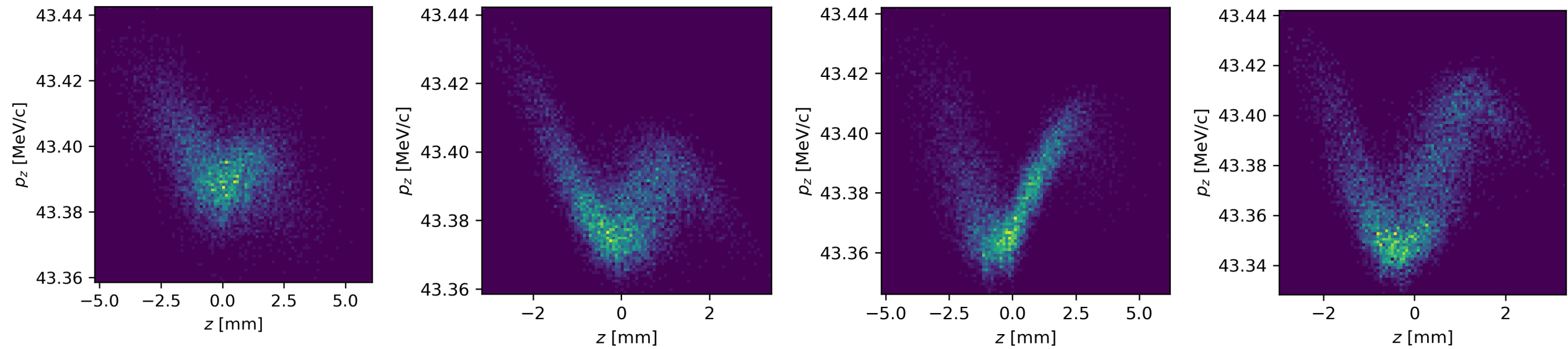
GPSR Training Data



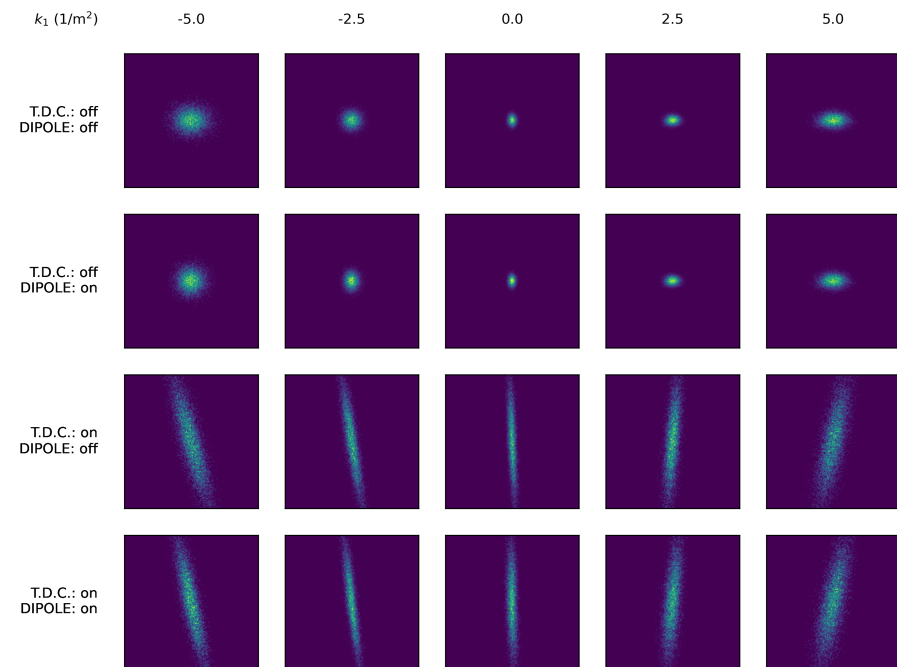
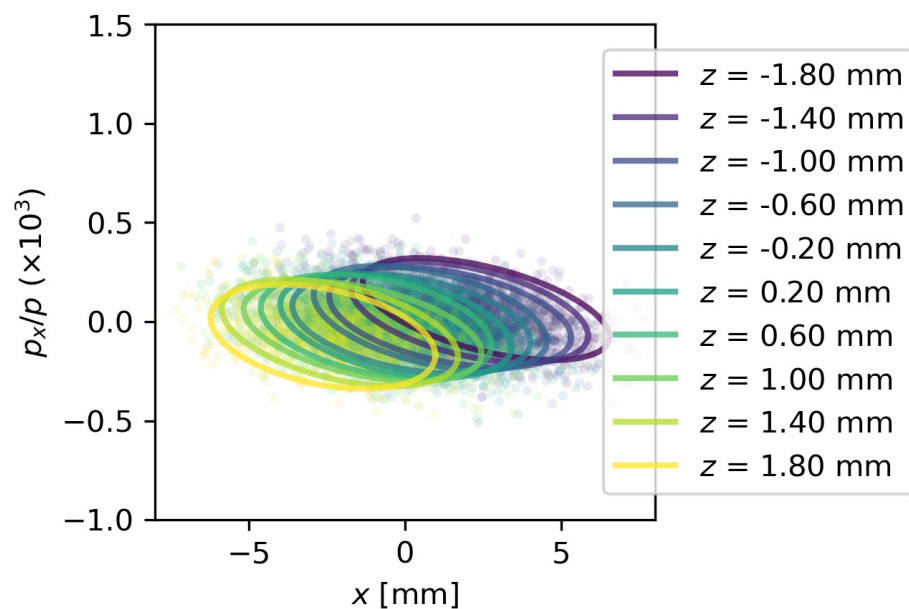
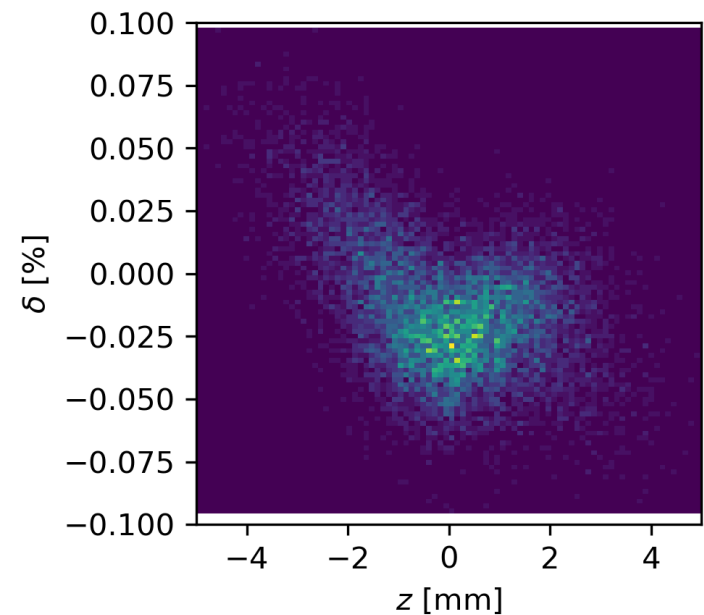
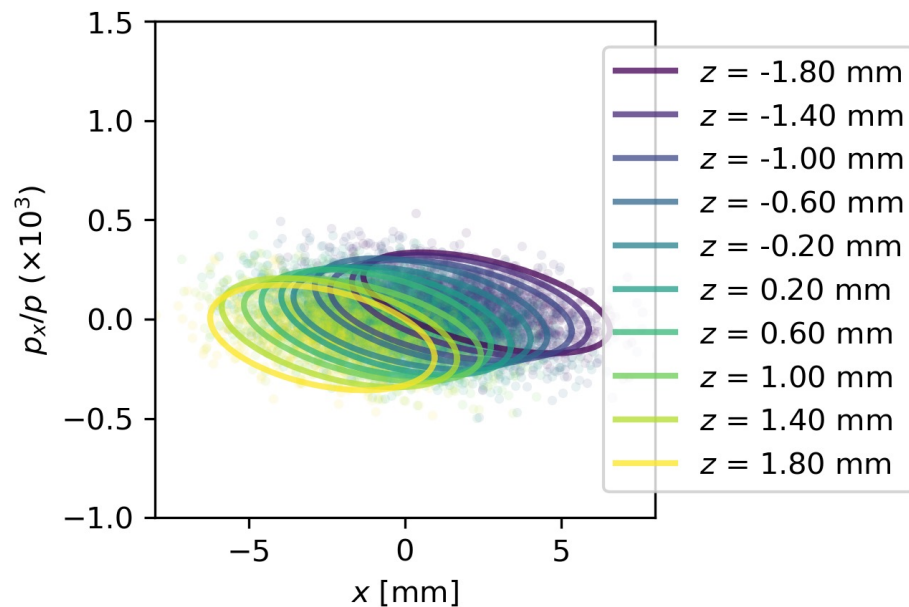
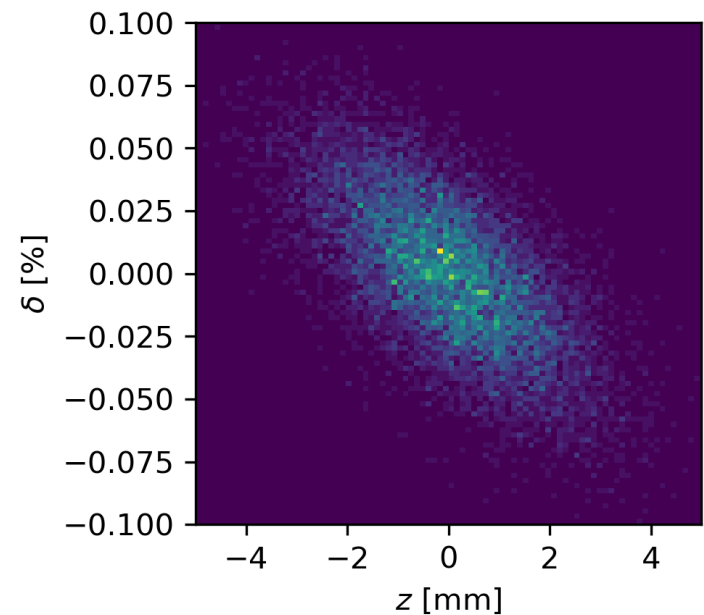
GPSR Results: 2D Projections



Backup: CSR effects after every dipole



Backup: CSR Effects at Diagnostics Spectrometer



Backup: OPAL CSR Settings

- CSR_FILTER:
- FILTER,
- TYPE = "Savitzky-Golay",
- NPOINTS = 20,
- NLEFT = 4,
- NRIGHT = 4,
- POLYORDER = 4;

- CSR_WK:
- WAKE,
- TYPE="1D-CSR",
- NBIN=300,
- FILTERS=CSR_FILTER;