Spinning in a Vortex: Getting Wound up over Highly Asymmetric Space-charge-dominated Beams

T11

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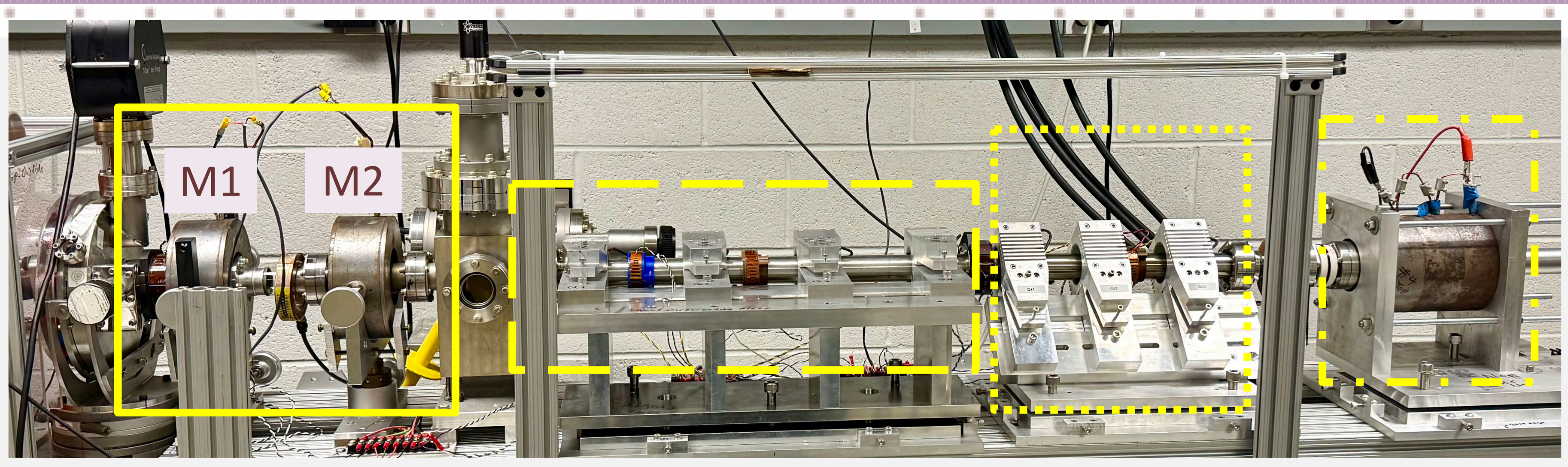
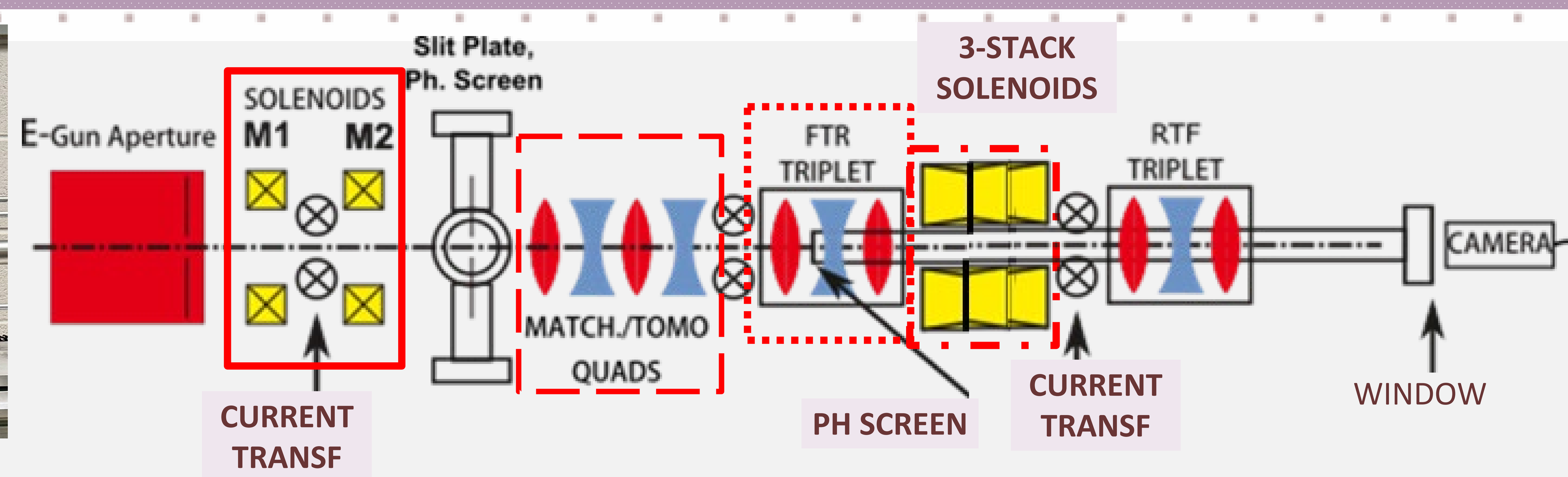
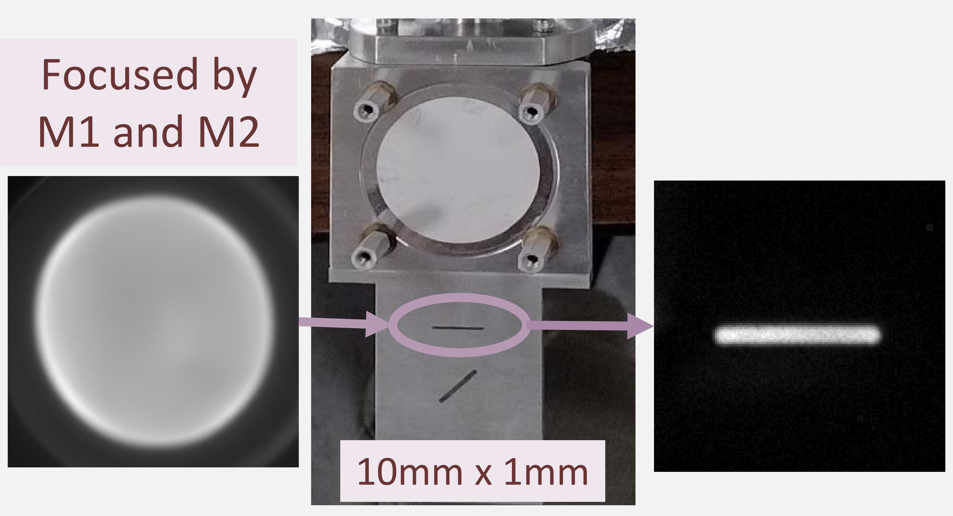
Idealized models of charged-particle beam transport predict beam moments and envelope evolution, but not the detailed beam structure within those envelopes. We combine experiment and simulation to investigate the interplay of space charge and angular momentum in realistic low-energy electron beam distributions. The study is carried out on the Long Solenoid Experiment (LSE), a beam line designed to explore flat-to-round (FTR) and round-to-flat (RTF) beam transformations in a regime where space charge plays a significant role. Particle-in-cell simulations are initialized using phase-space distributions measured directly near the beam source, allowing realistic modeling of the experiment. The simulations reproduce experimental observations with high fidelity and reveal strong sensitivity of the transverse beam dynamics to both the initial beam structure and lattice parameters. In this poster, we highlight three key results:

- flat-to-round ("ish") transformation
- agreement between experiment and simulation in the evolution of the beam envelope and fine phase-space structures
- cancellation of the overall beam rotation corresponding to the vortex beam condition

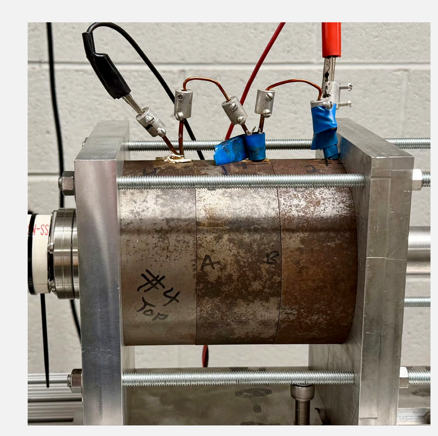
Experimental Setup

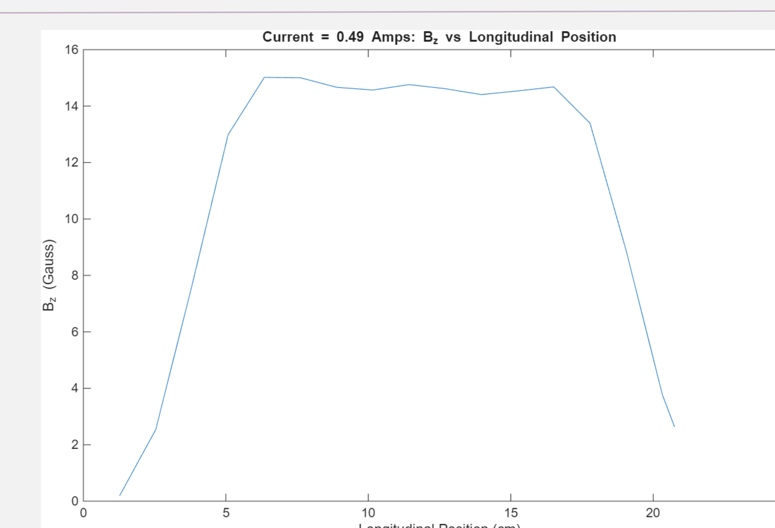




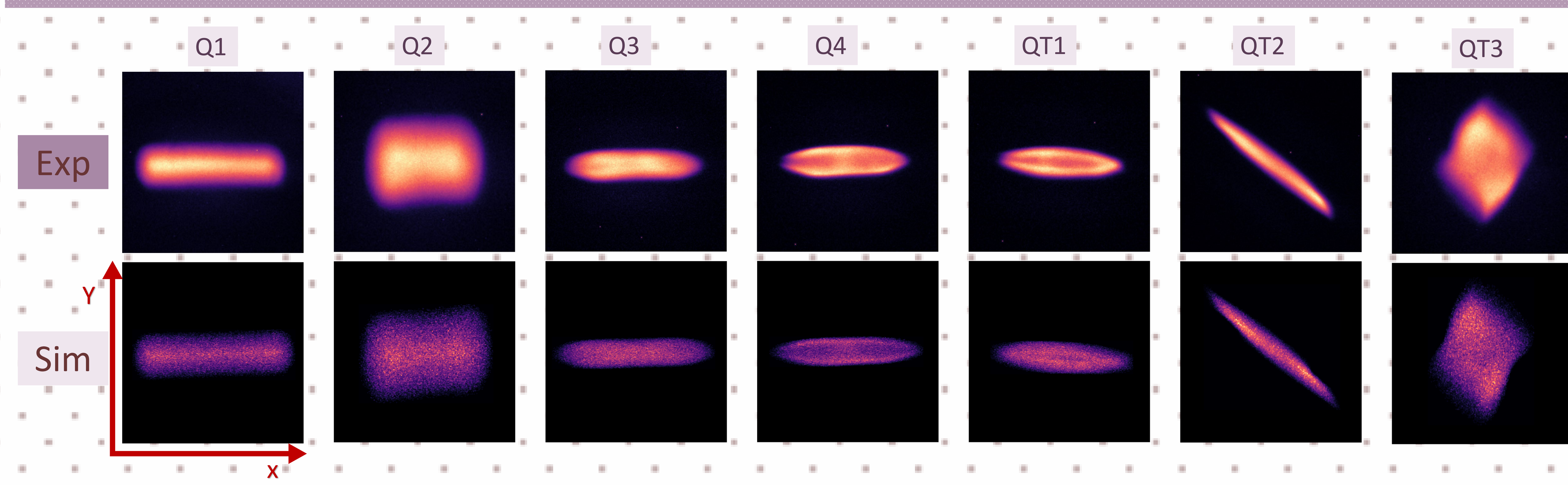


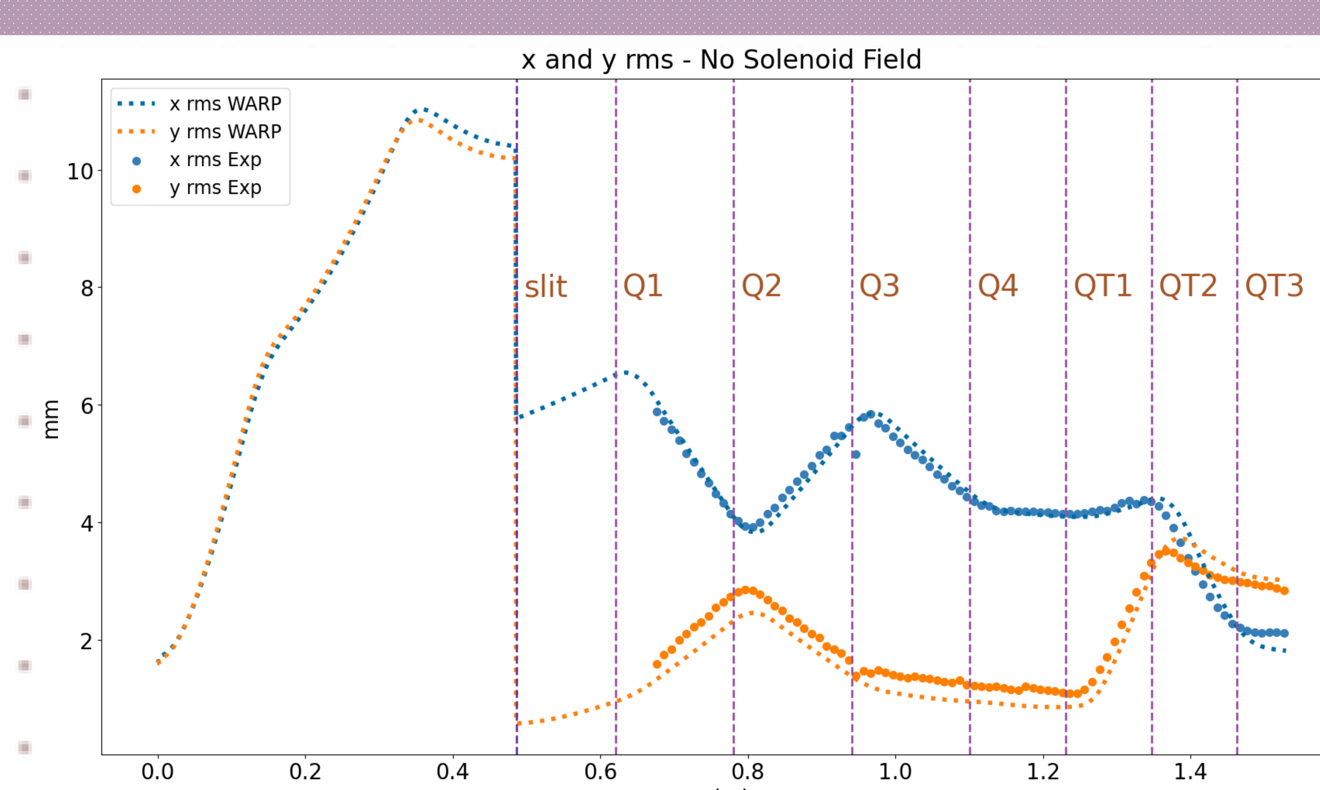
Beam Energy	5keV	
Quad Length	5.16cm	
	Matching Section	FTR Skew Triplet
Distance between Quads	16cm	11.6cm
	Before the Slit	After the Slit
Emittance	$\varepsilon_x = \varepsilon_y$=49.7µm	ε_x=23.2µm ε_y=2.32µm
Current	19mA	0.49mA

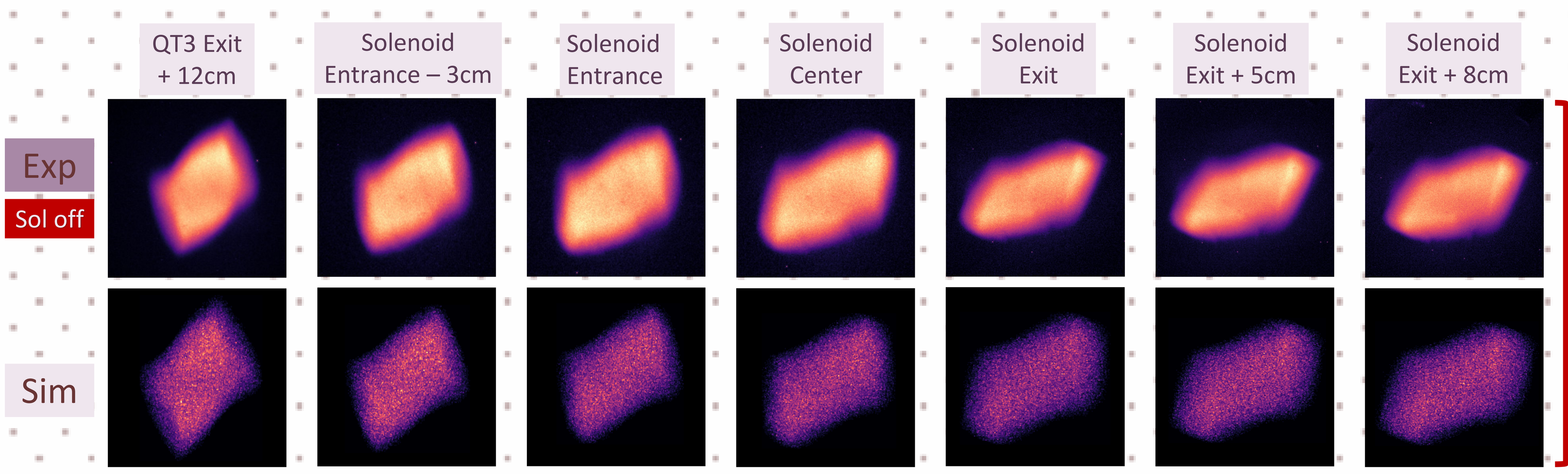


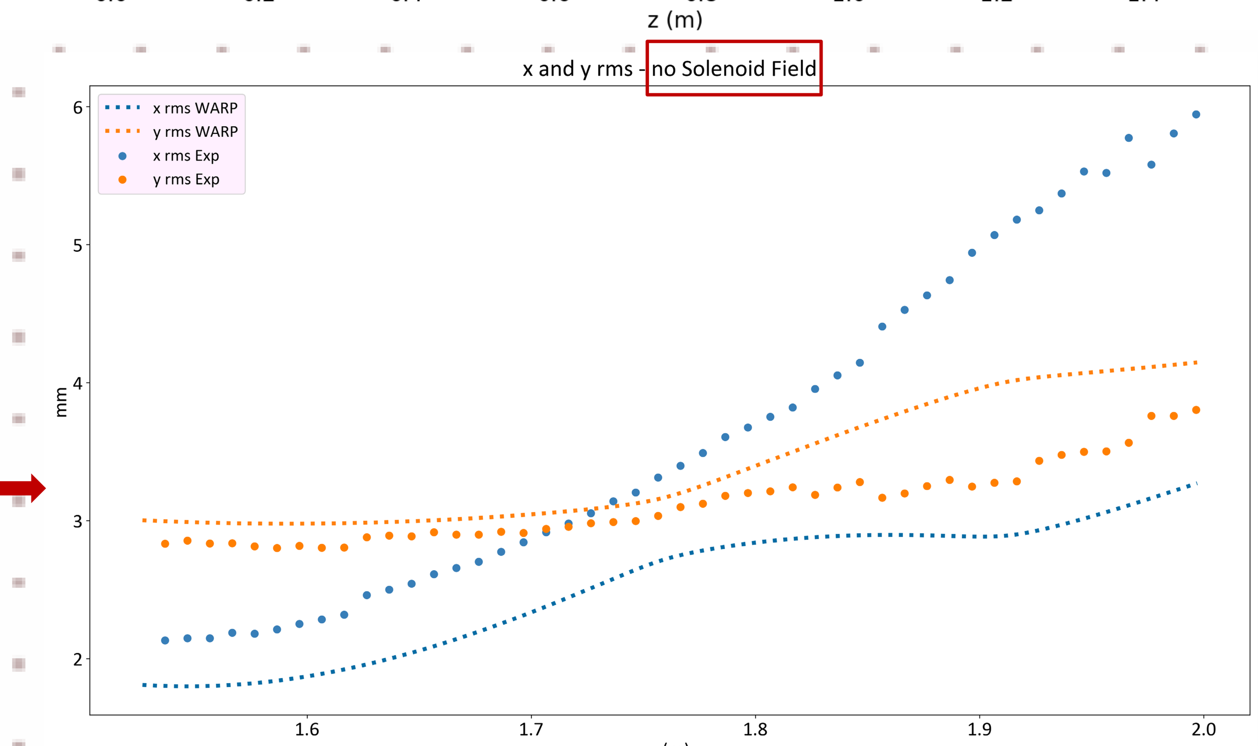


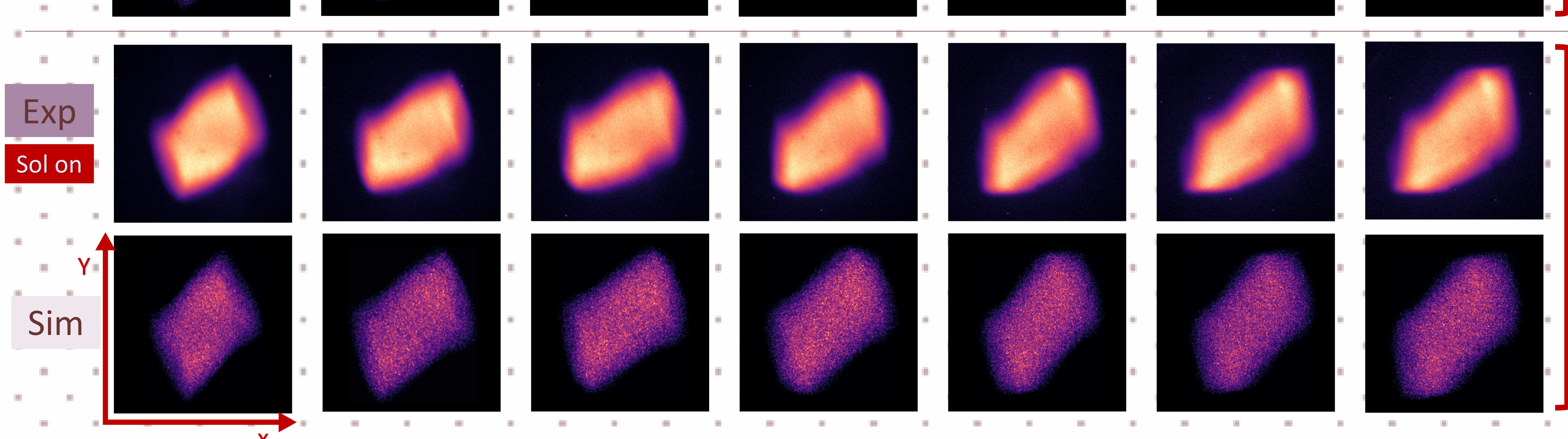
Experiment vs WARP Simulation

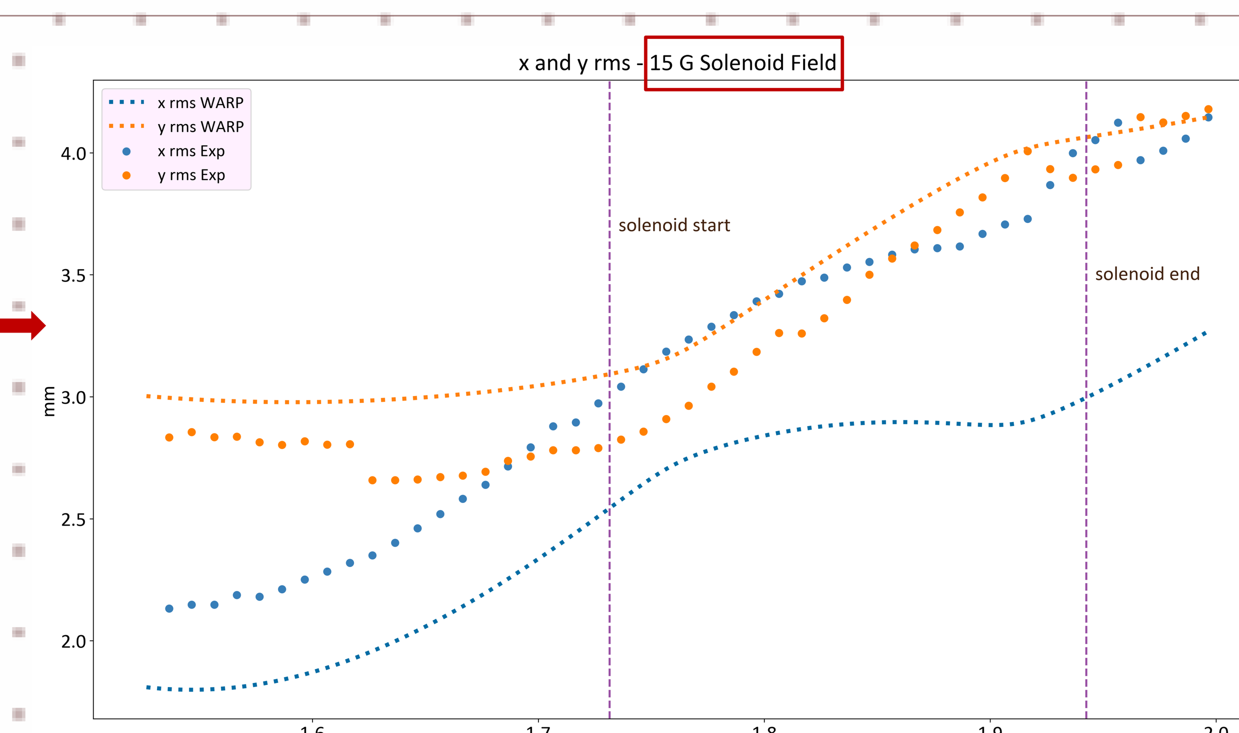












Angular Momentum

- Cancellation of overall beam rotation by the solenoid field
- Canonical Angular Momentum (Theory):

$$\frac{<L>}{p_z} = <xy'> - <yx'>$$

$$\boxed{<L>_{theory} = 21\mu m}$$

- Measurement of Average Beam Angular Momentum:

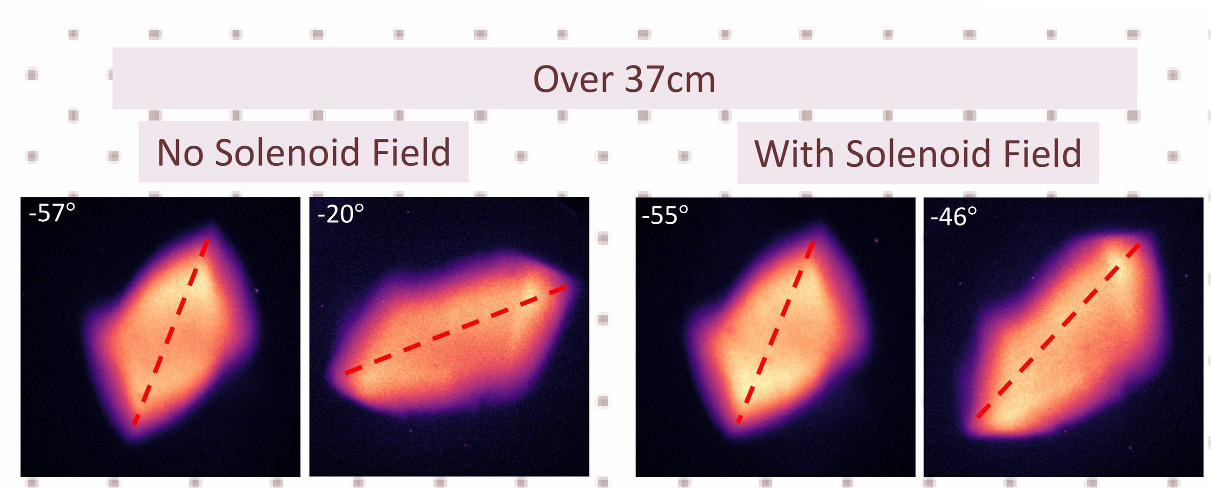
$$<L> = 4p_z \frac{\sigma_1 \sigma_2 \sin\theta}{D}$$

$$\boxed{<L>_{exp} = 23\mu m}$$

where σ_1 and σ_2 are the measured beam's xrms and yrms, and θ is the beam's orientation.

Y.-E Sun et al, *Generation of angular-momentum-dominated electron beams from a photoinjector*, Phys. Rev. ST Accel. Beams, **7**, 123501 (2004)

Over 37cm

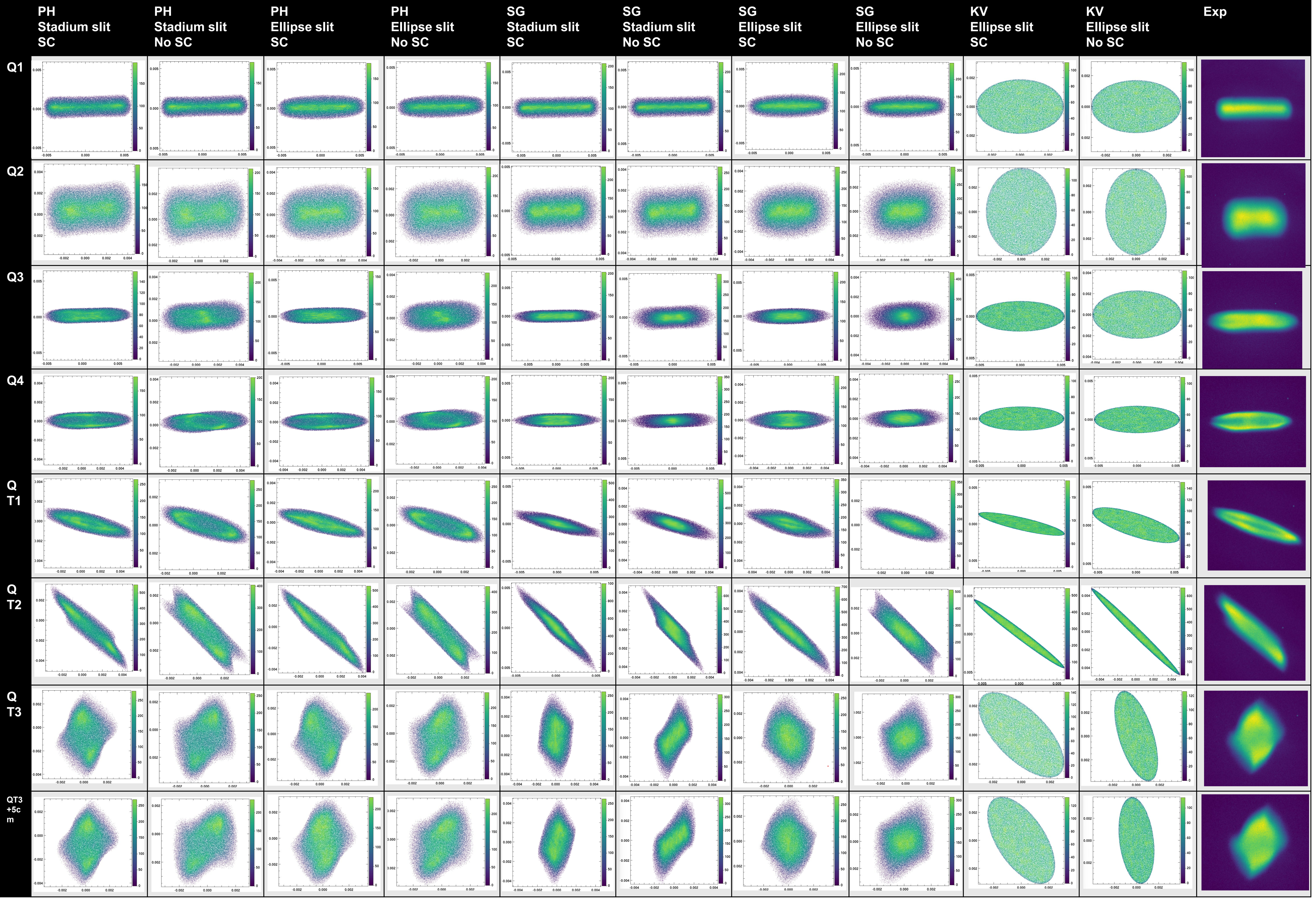


The equation used in ImageJ's Moment Calculator plugin to calculate the orientation is:

$$\theta \text{ (in degrees)} = 0.5 \cdot \arctan\left(\frac{2 \cdot m_{11}}{m_{20} - m_{02}}\right),$$

where m_{20} is the 2nd-order moment along the x-axis, m_{02} is the 2nd-order moment along the y-axis, and m_{11} is the cross-covariance moment.

Work supported by US DOE-HEP grant: DE-SC0022009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PH Stadium slit No SC
PH Ellipse slit SC
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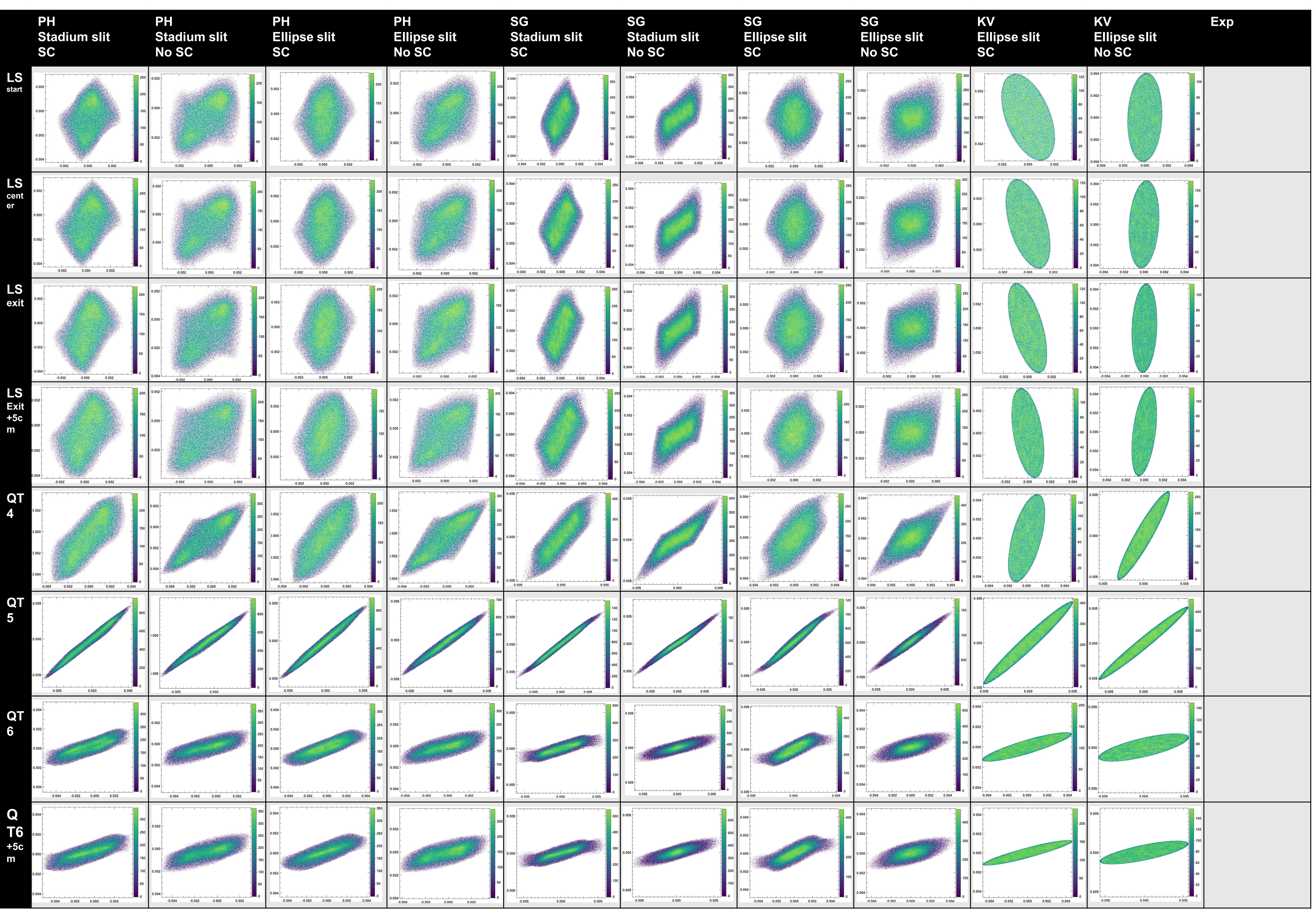
SG Stadium slit No SC
SG Ellipse slit SC
SG Ellipse slit No SC
KV Ellipse slit SC
KV Ellipse slit No SC
Exp
Q1
Q2
Q3
Q4
Q T1
Q T2
Q T3
QT3 +5c m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SG Stadium slit SC
SG Stadium slit No SC
SG Ellipse slit SC
SG Ellipse slit No SC
KV Ellipse slit SC
KV Ellipse slit No SC
Exp
LS start
LS cent er
LS exit
LS Exit +5c m
QT 4
QT 5
QT 6
Q T6 +5c m