OAK RIDGE National Laboratory

The impact of high-dimensional phase space correlations on the beam dynamics in a linear accelerator

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HB Workshop, CERN

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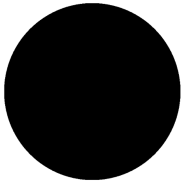
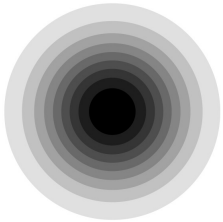
LEDA: halo is sensitive to initial distribution

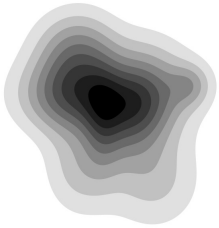
Waterbag

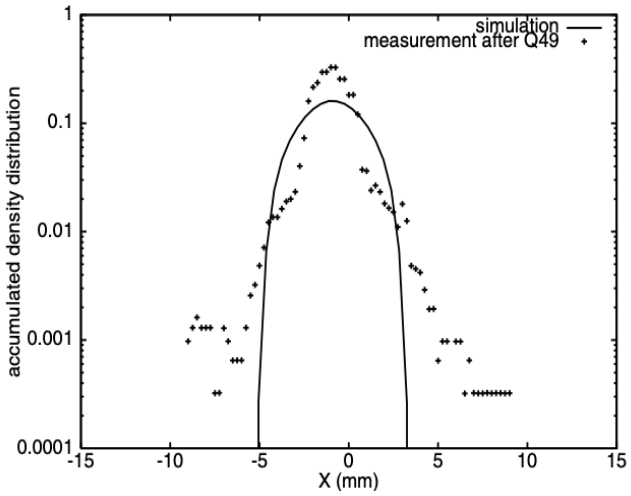


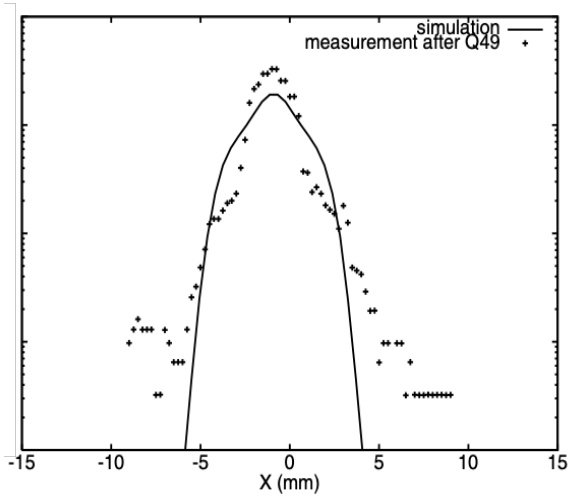
Gaussian

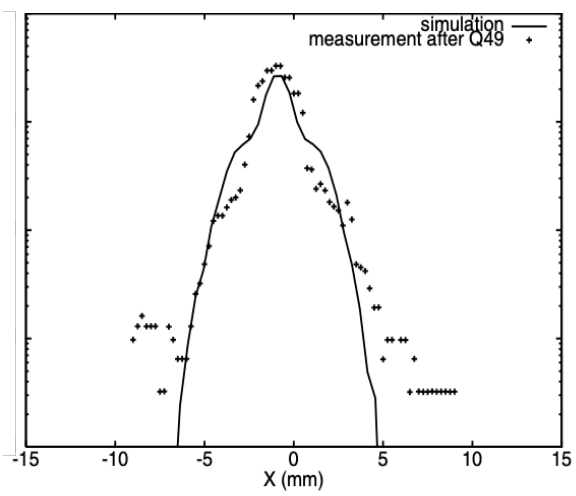


RFQ



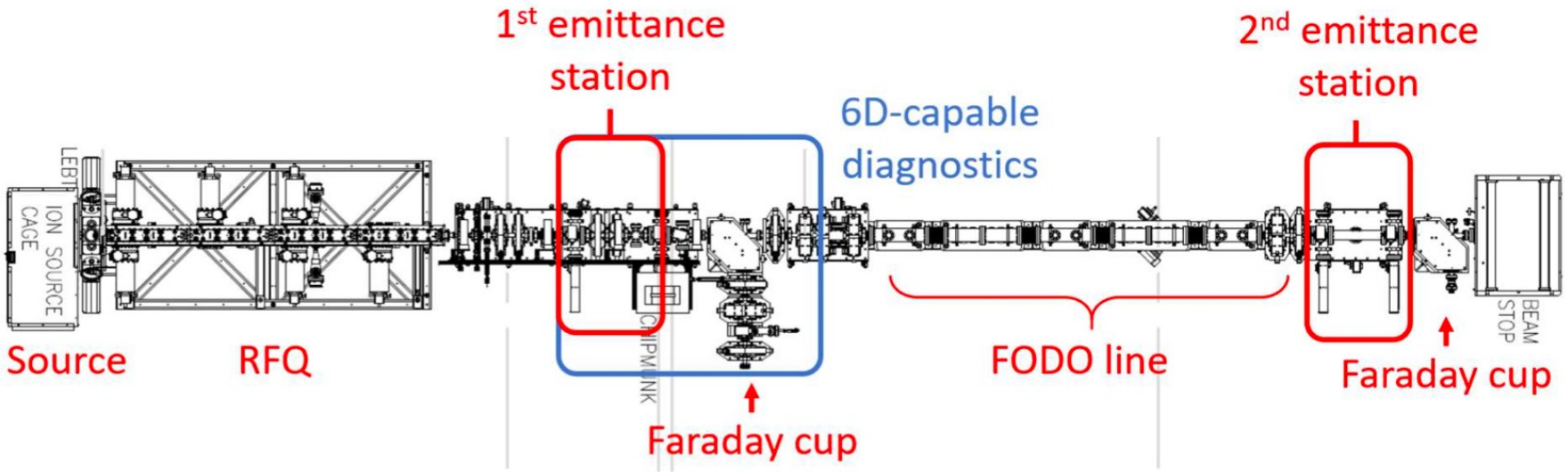






Qiang et al., “Macroparticle simulation studies of a proton beam halo experiment”, PRAB (2002)

The SNS-BTF aims to predict halo formation over a short distance



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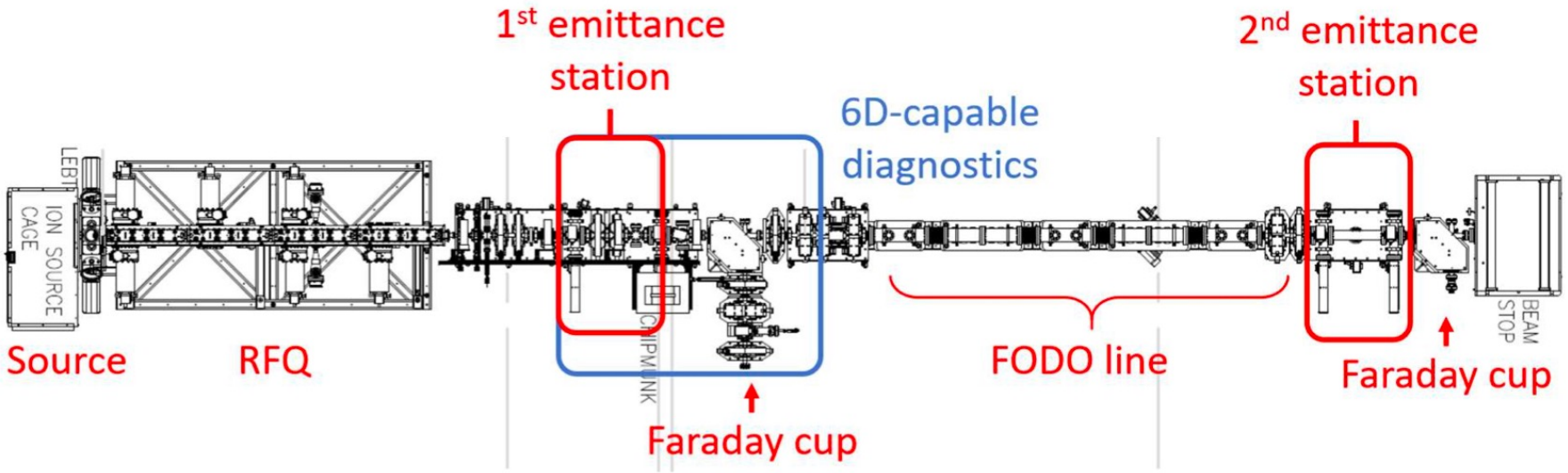
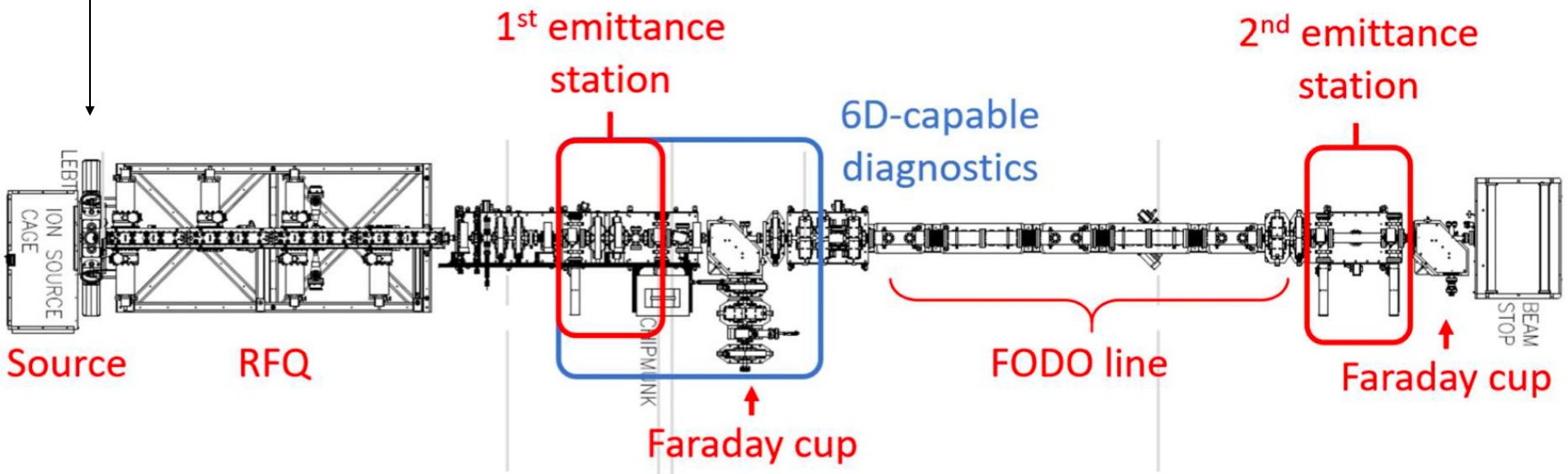


$$f(x, p_x, y, p_y, z, p_z) = f(x, p_x) f(y, p_y) f(z, p_z) \ ?$$

PARMTEQ generates “model” bunch at first measurement station

$\{f(x,p_x), f(y,p_y)\}$ from Ion Source Test Stand



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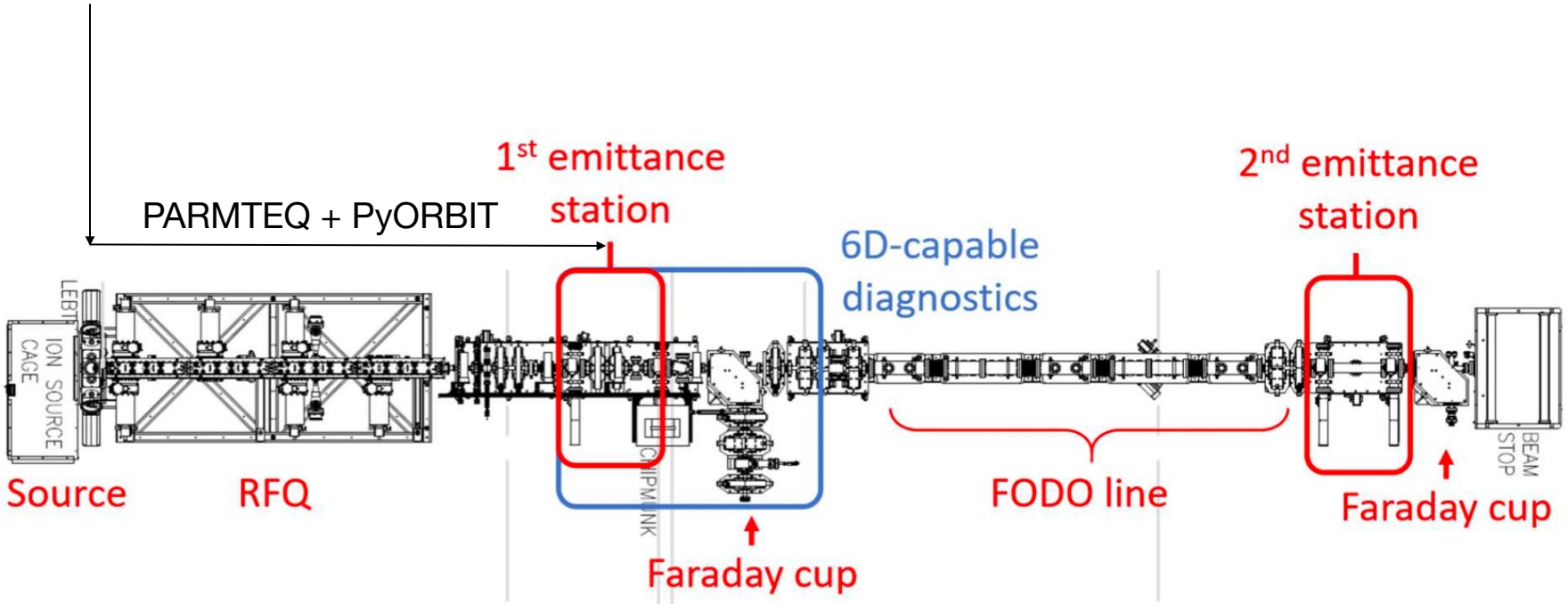

$$f(x,p_x,y,p_y,z,p_z) = f(x,p_x)f(y,p_y)f(z,p_z)\ ?$$

Main points

- RFQ model reproduces measured 6D phase space structure.

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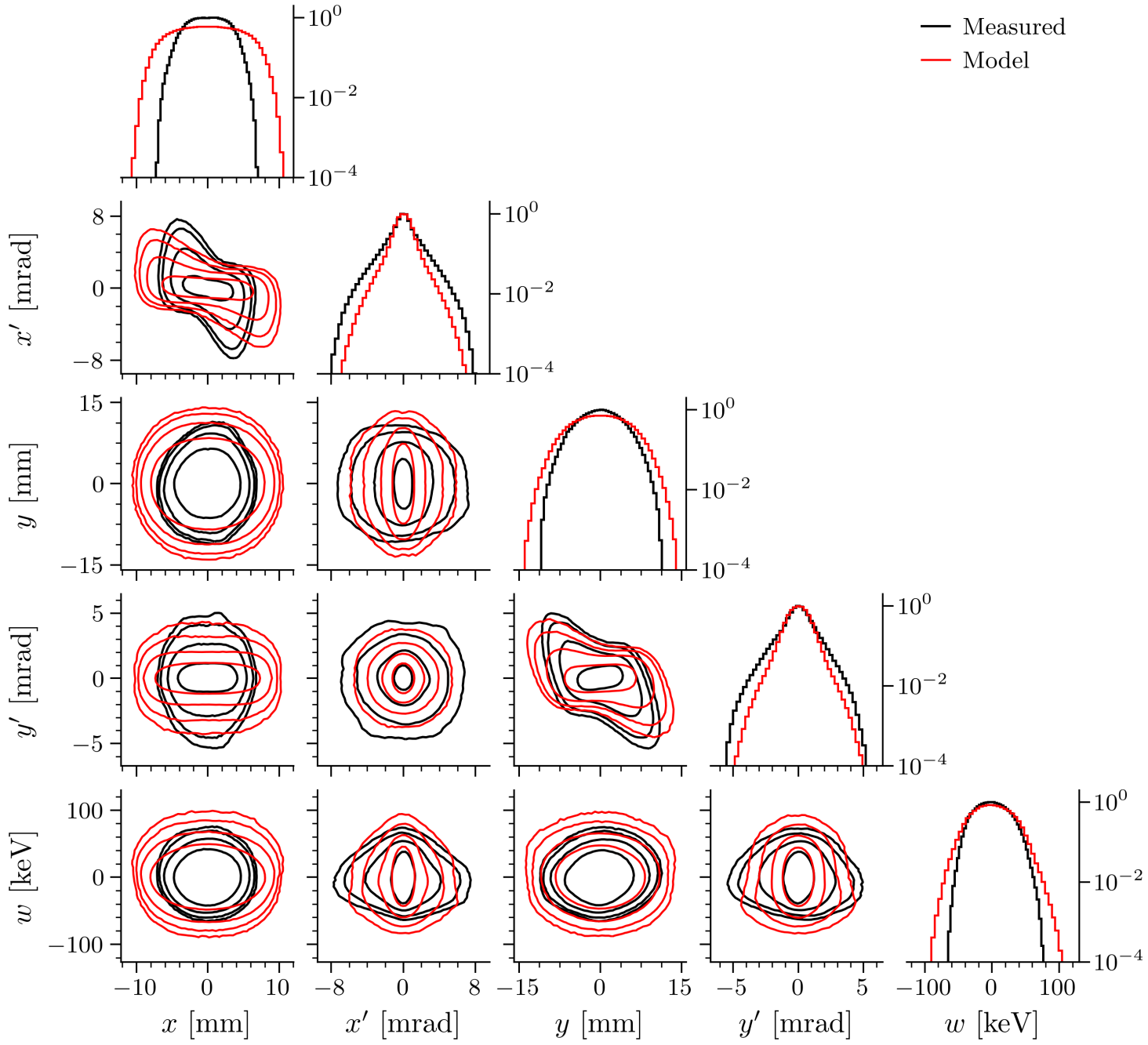
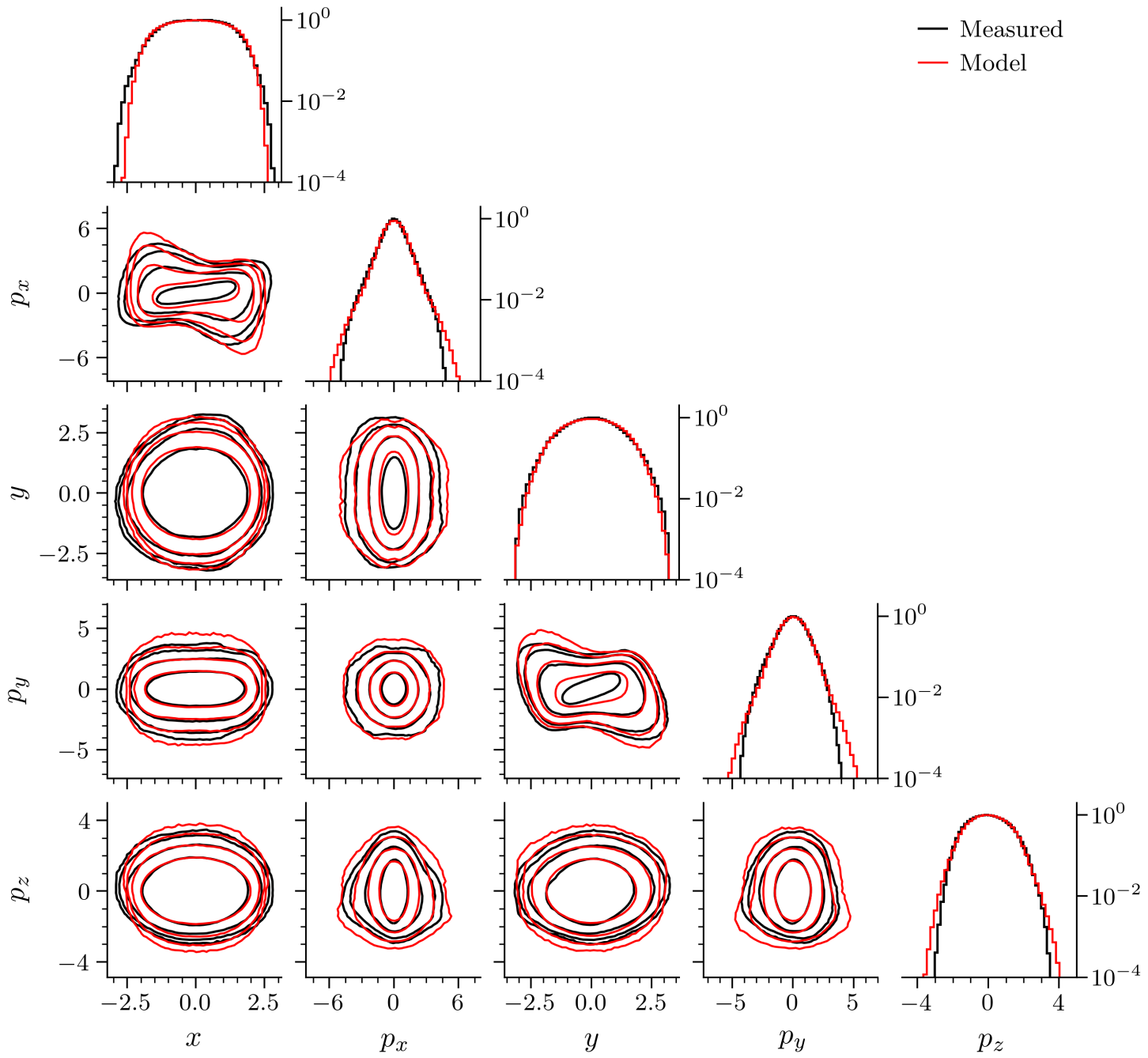
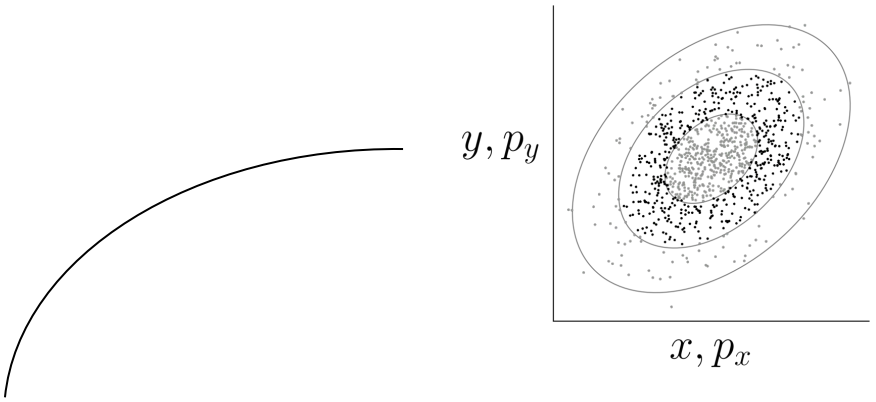
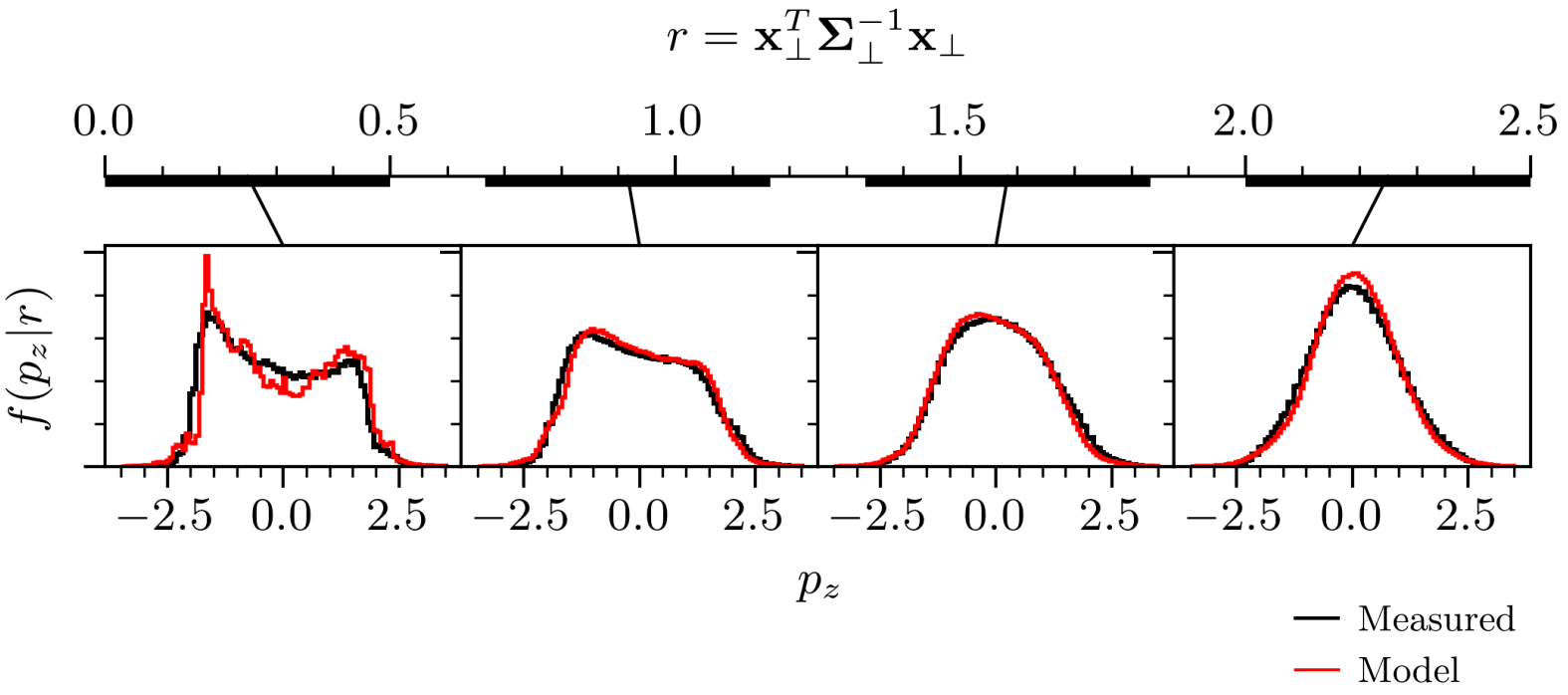

Measured
Model
x [mm]
x' [mrad]
y [mm]
y' [mrad]
w [keV]

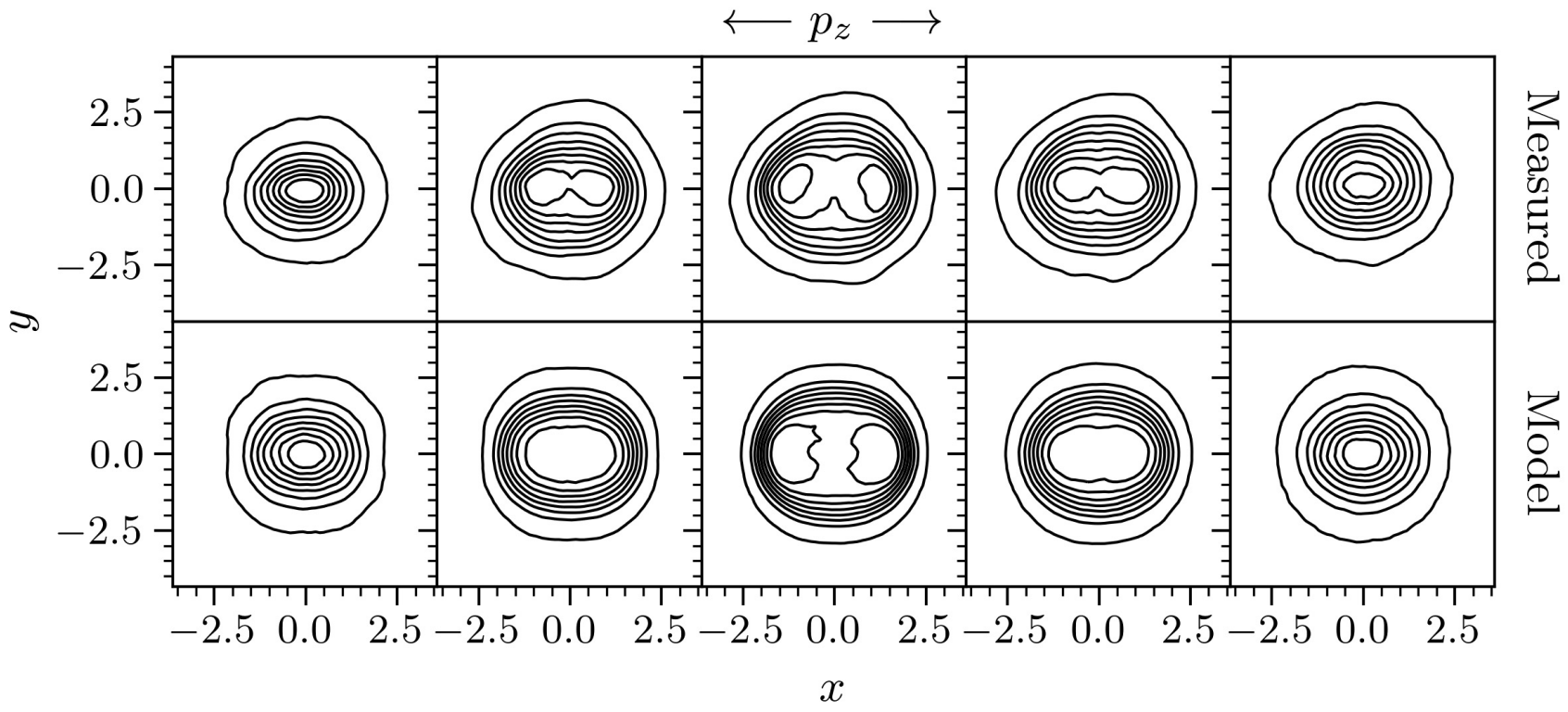

Measured
Model
10^0
10^{-2}
10^{-4}
p_x
y
p_y
p_z
x
6
0
−6
2.5
0.0
−2.5
5
−5
4
−4

Longitudinal hollowing — probably occurs in RFQ





Transverse hollowing — probably occurs in MEBT

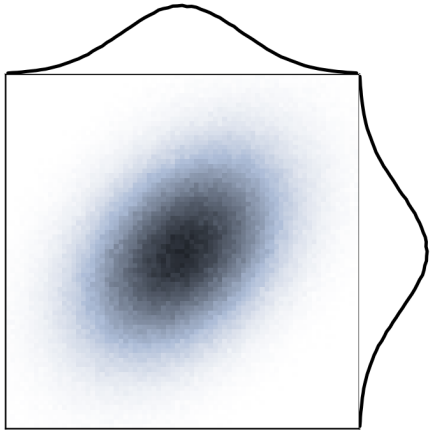


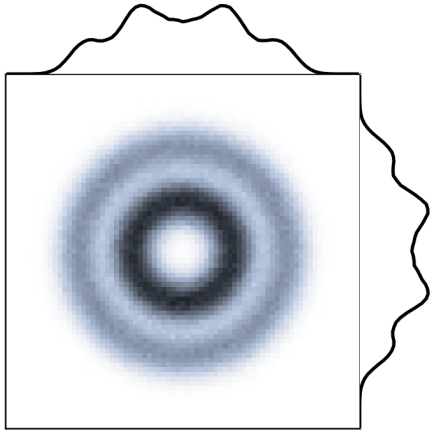
Main points

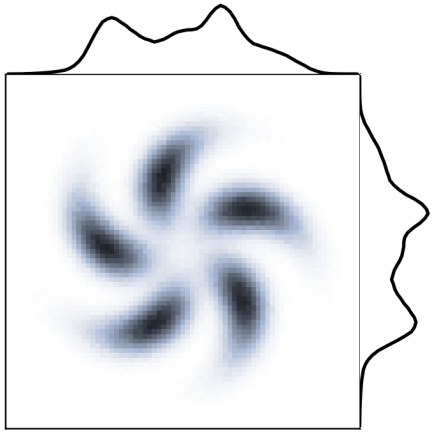
- RFQ model reproduces measured 6D phase space structure.
- **Artificial decorrelation should have a small affect on the beam dynamics.**

Decorrelation removes both linear and nonlinear relationships

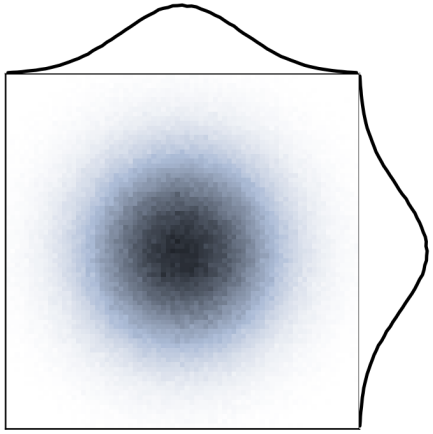
$f(x, y)$

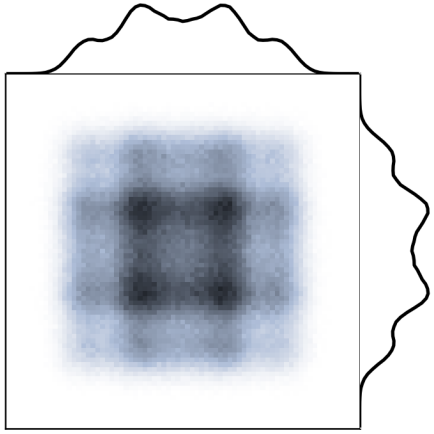


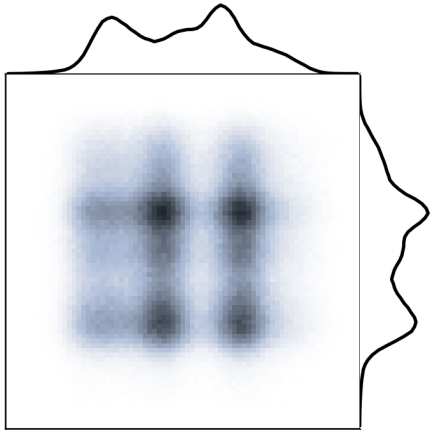


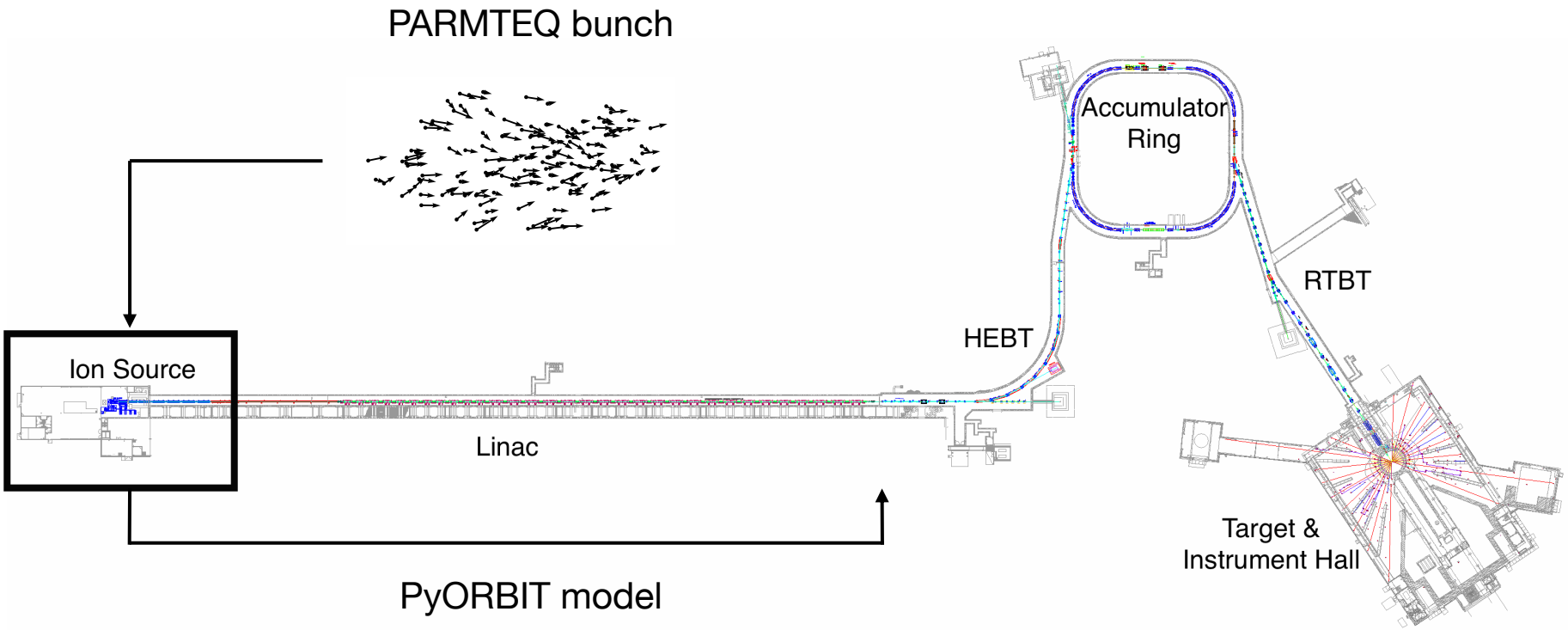


$f(x)f(y)$








PARMTEQ bunch
Accumulator
Ring
RTBT
HEBT
Ion Source
Linac
Target &
Instrument Hall
PyORBIT model

Previous studies found intensity-dependent discrepancy between correlated and decorrelated bunches

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-THXA01

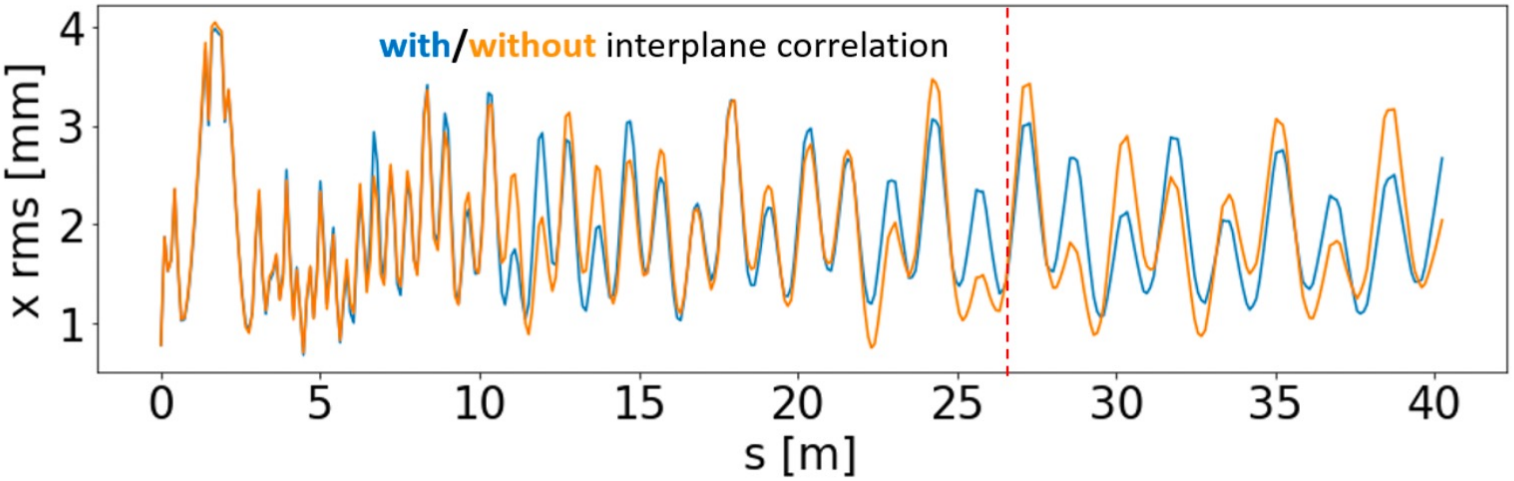


Figure 2: Comparison of horizontal beam size through PyORBIT simulation of SNS MEBT and DTL.

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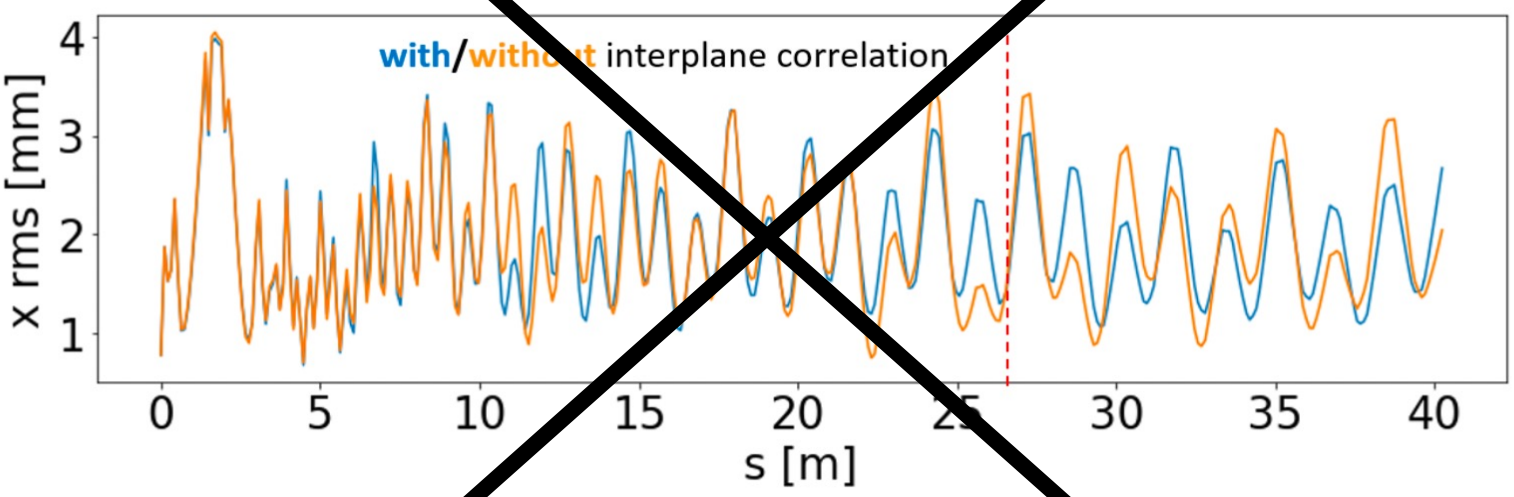

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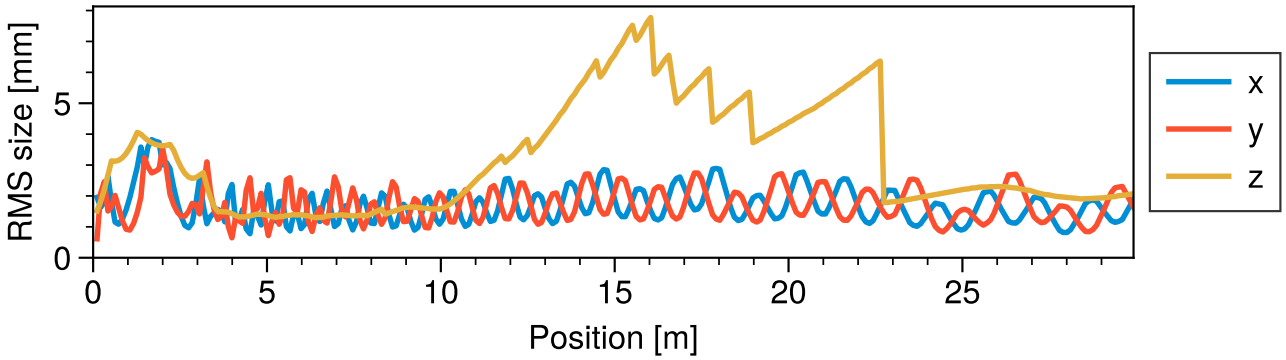
Some particles escape to infinity



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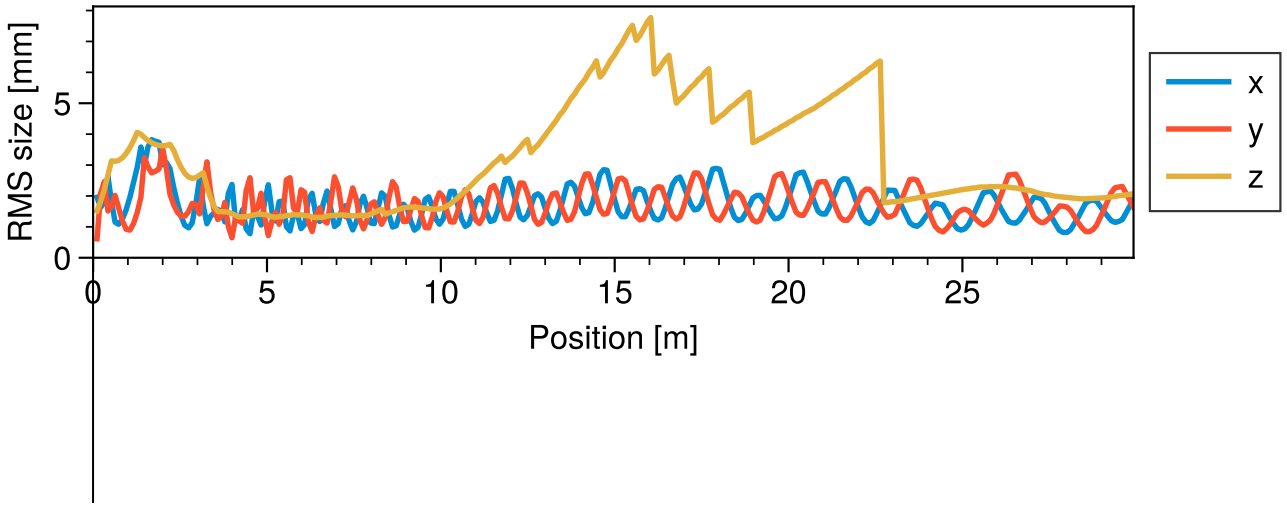

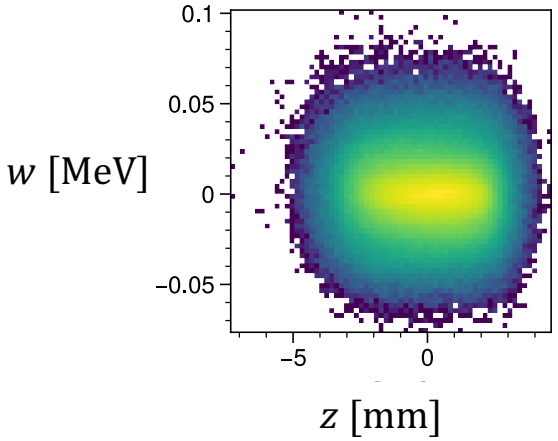

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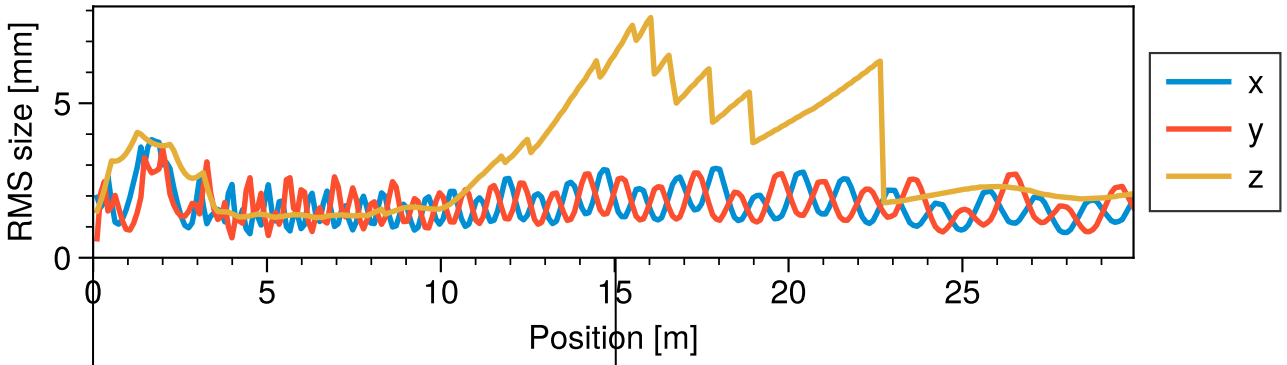

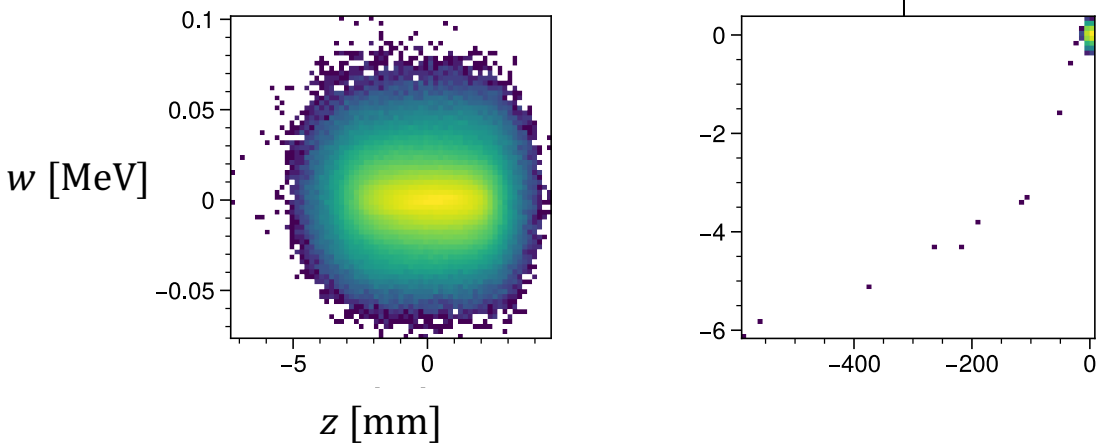

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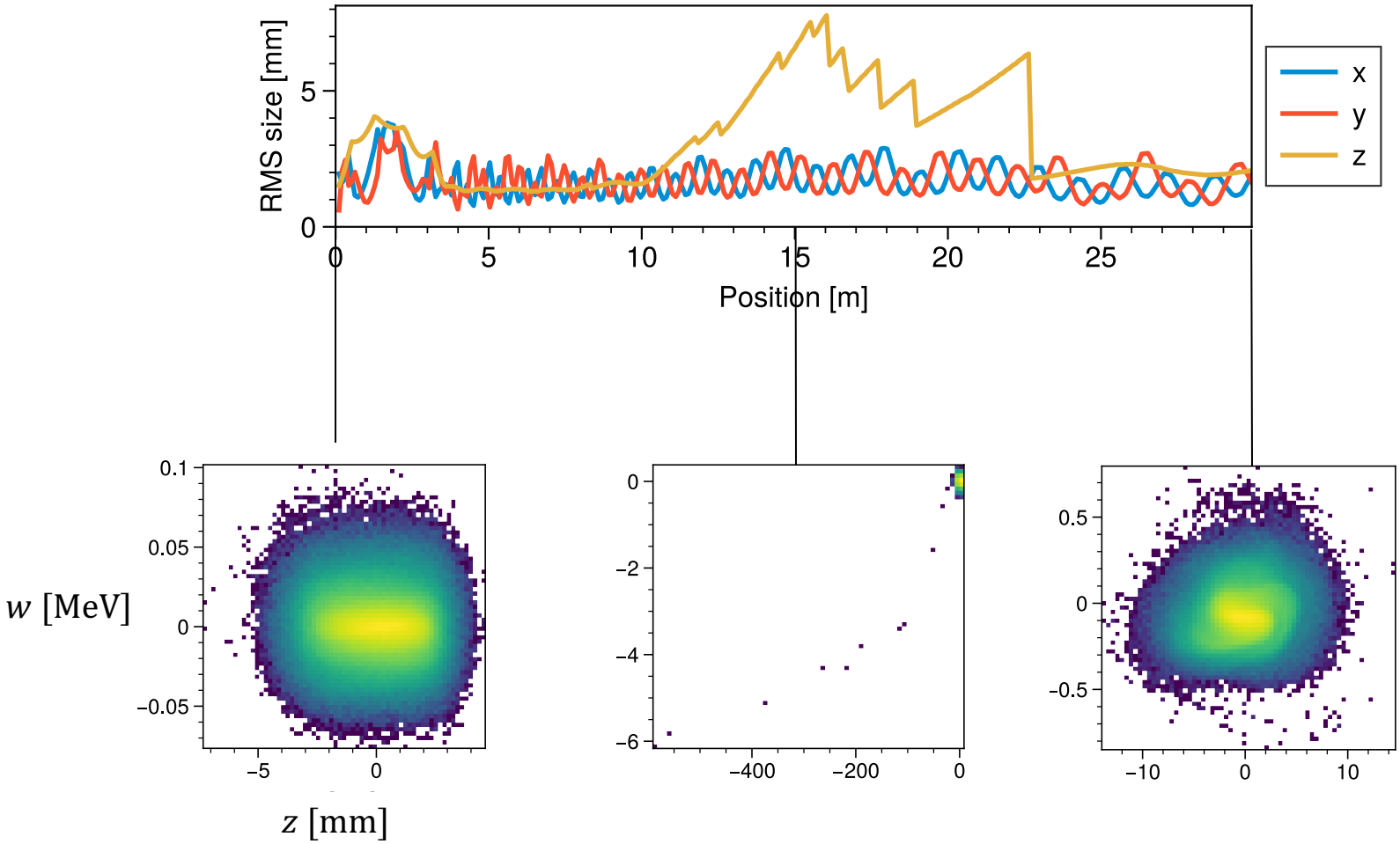
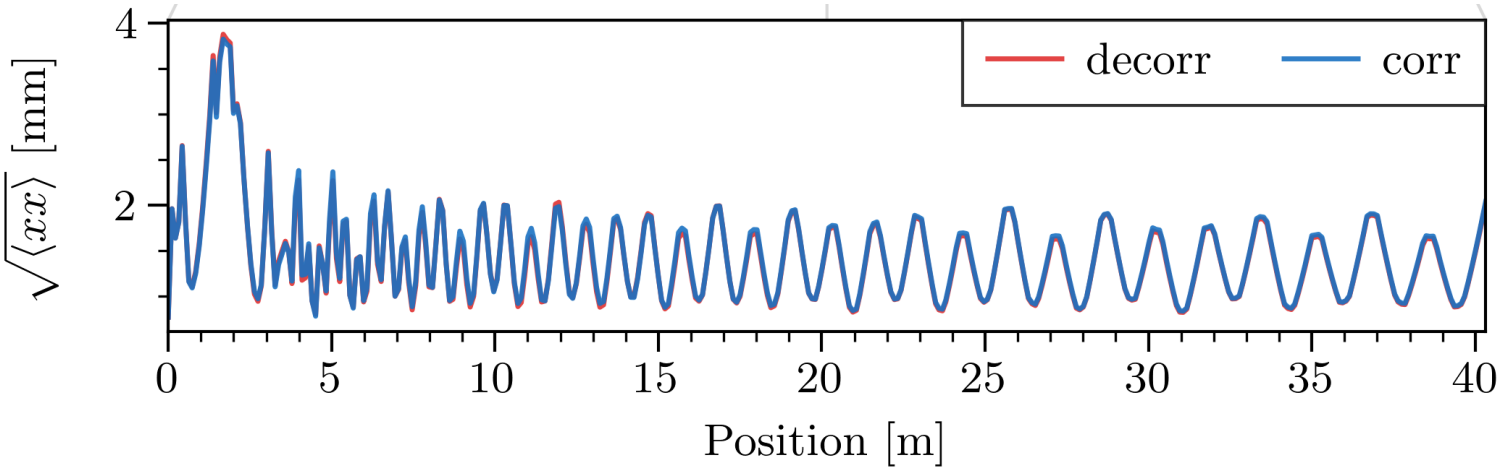


Adding longitudinal apertures resolves discrepancy



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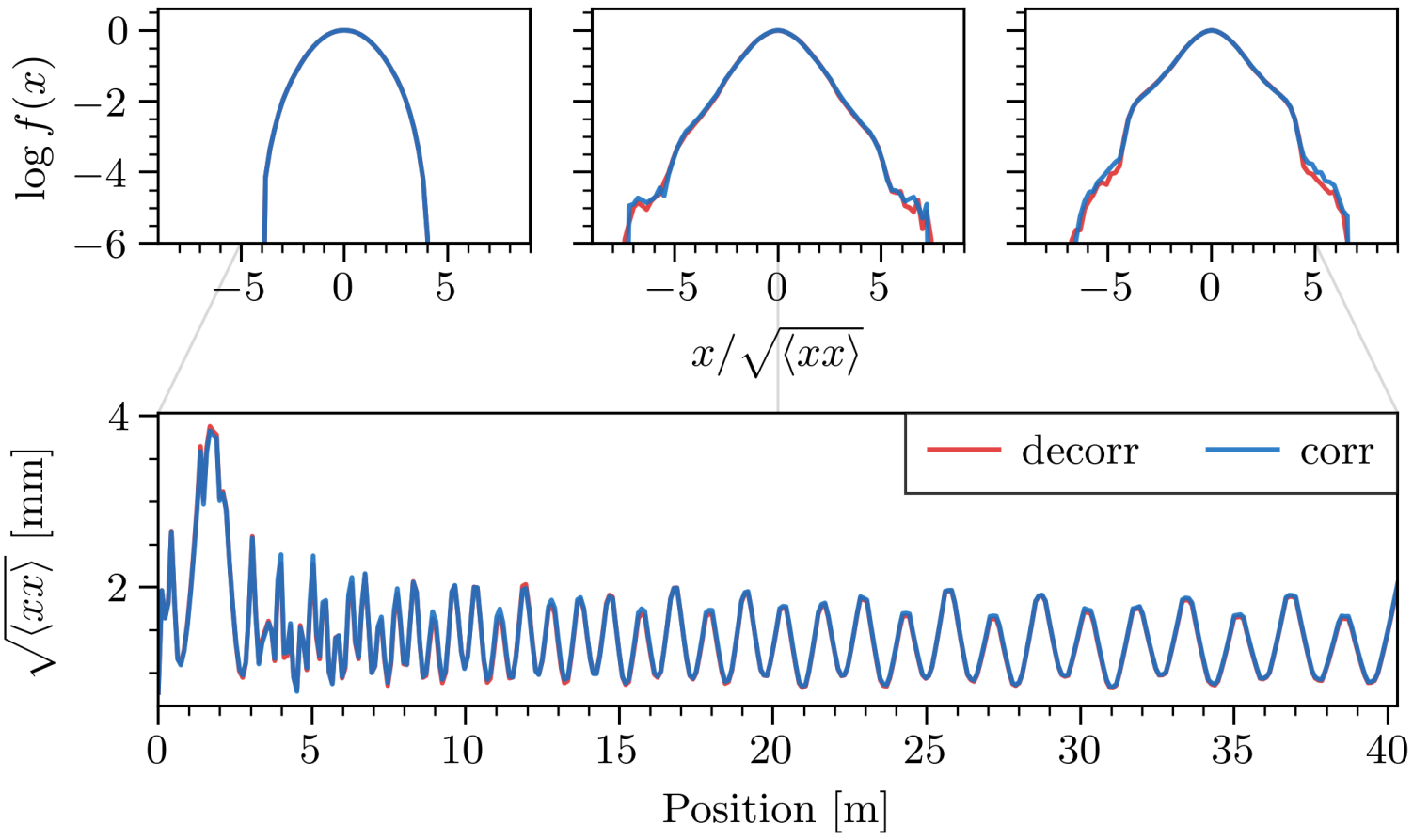
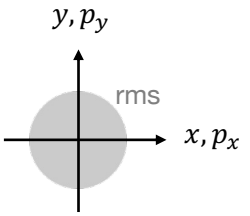


Correlated/decorrelated bunches quickly converge

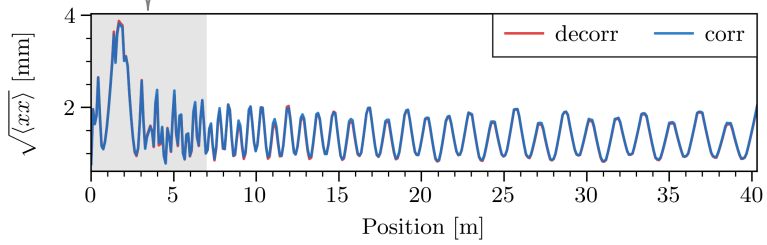


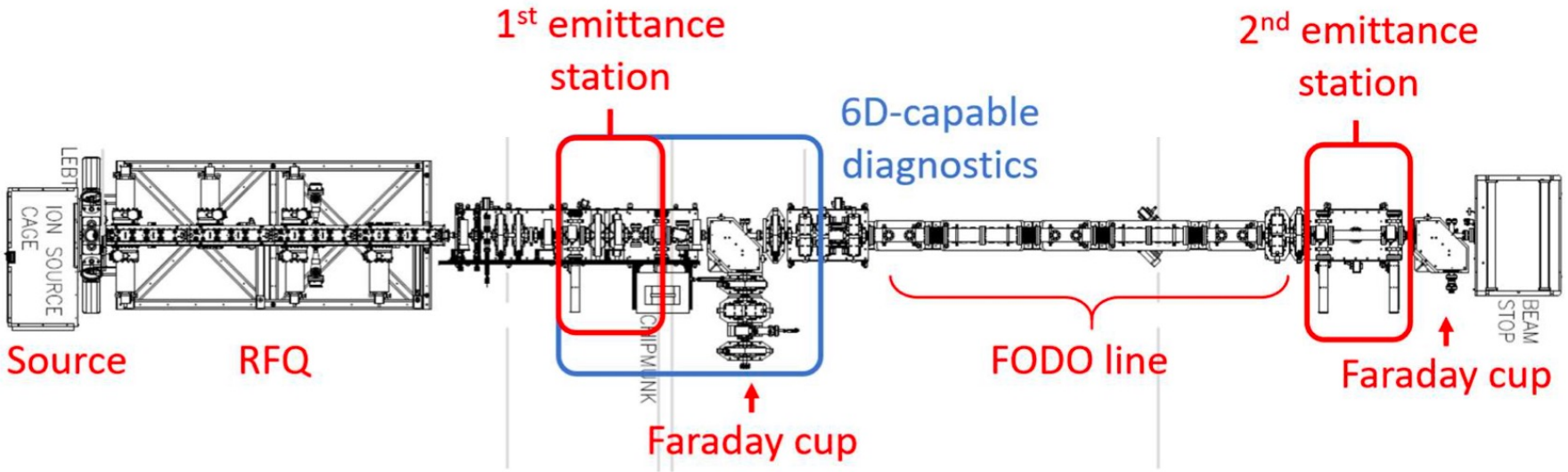
corr

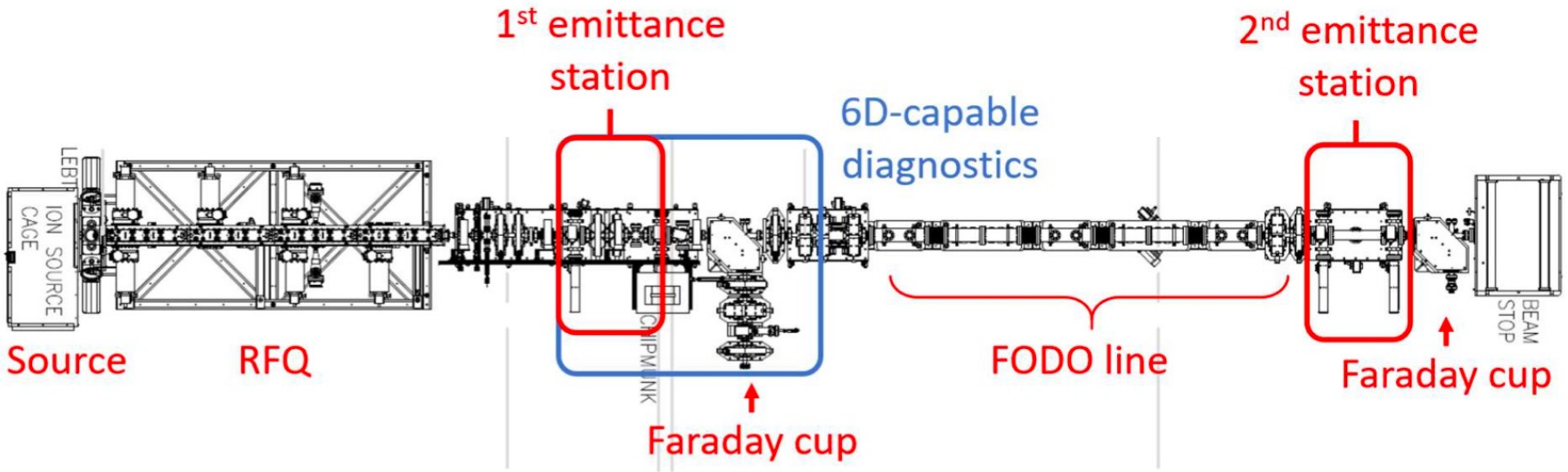
decorr

p_z

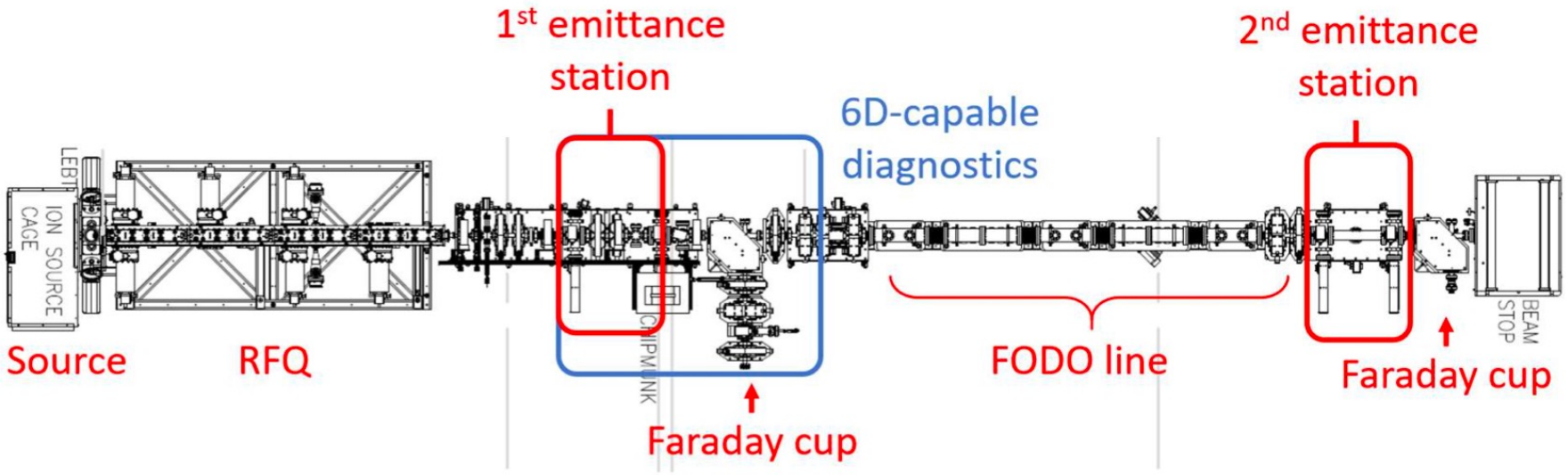
z




1st emittance station
2nd emittance station
6D-capable diagnostics
LEBT
ION SOURCE CAGE
CHIPMUNK
BEAM STOP
Source
RFQ
FODO line
Faraday cup
Faraday cup



Upsample to 5×10^8
Decorrelate



10 hours, np=4

Upsample to 5×10^8
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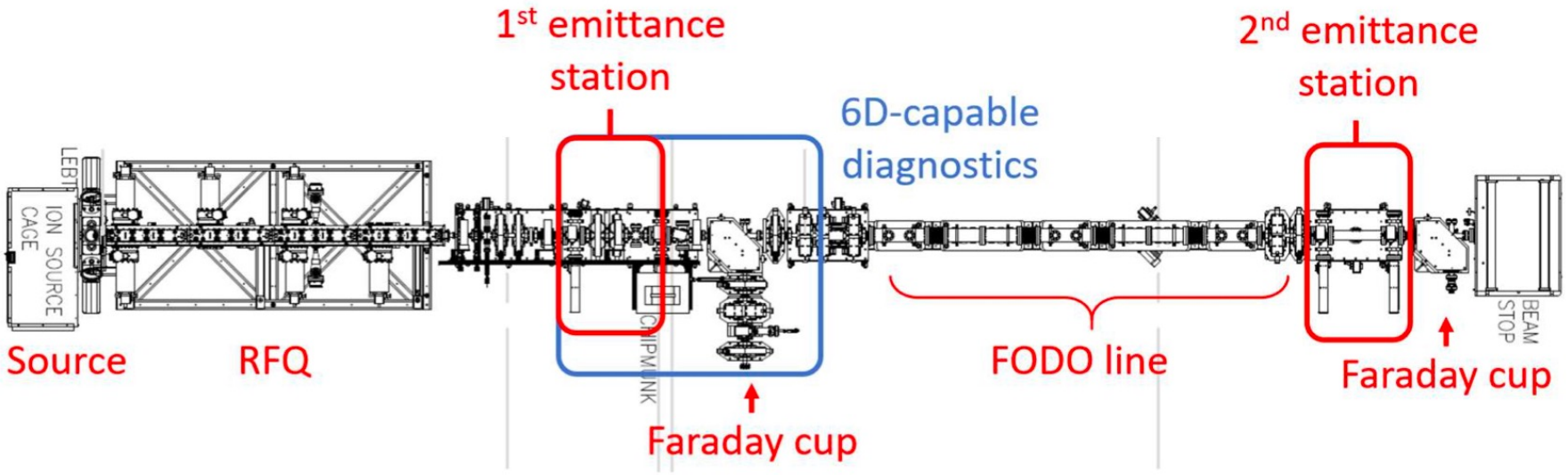
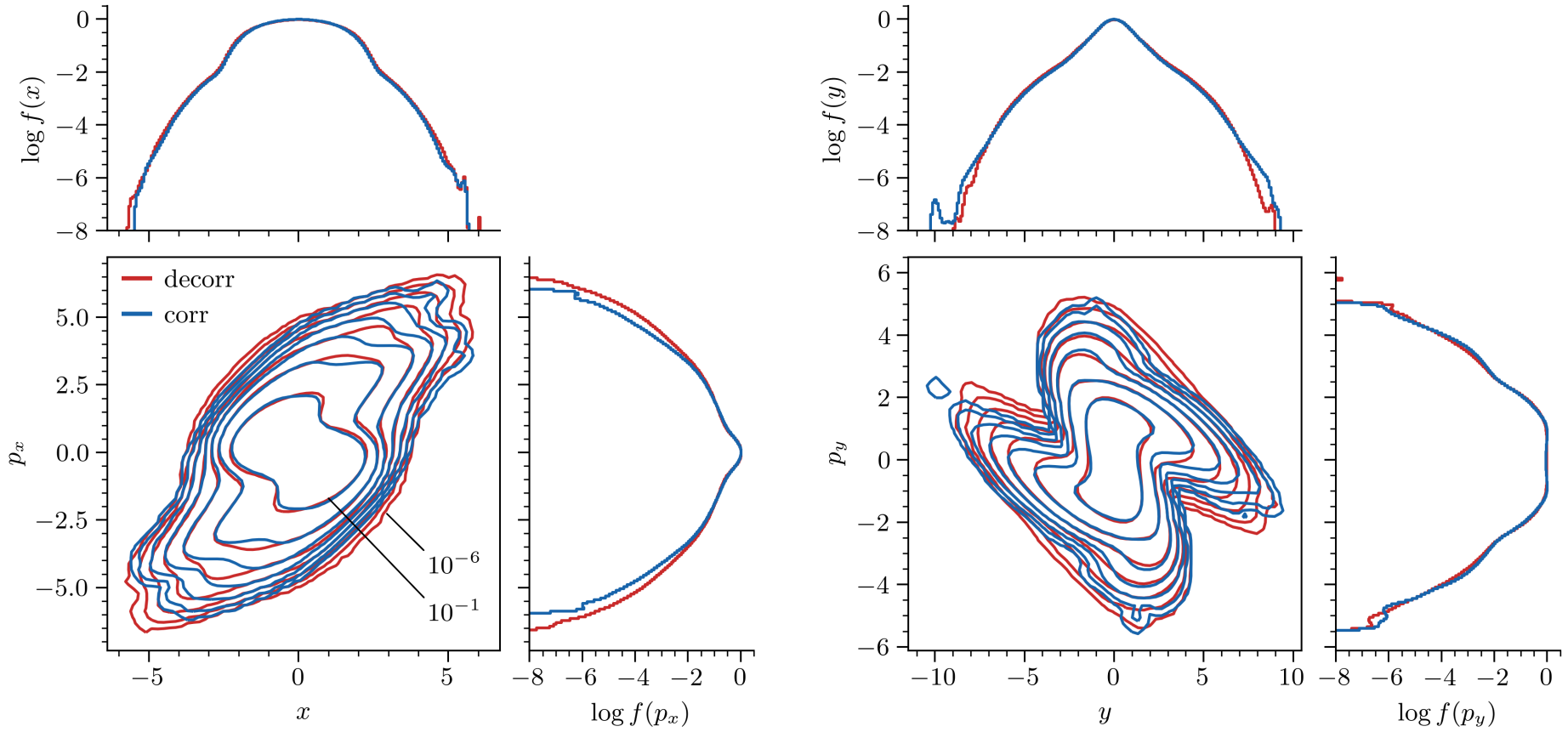


10 hours, np=4

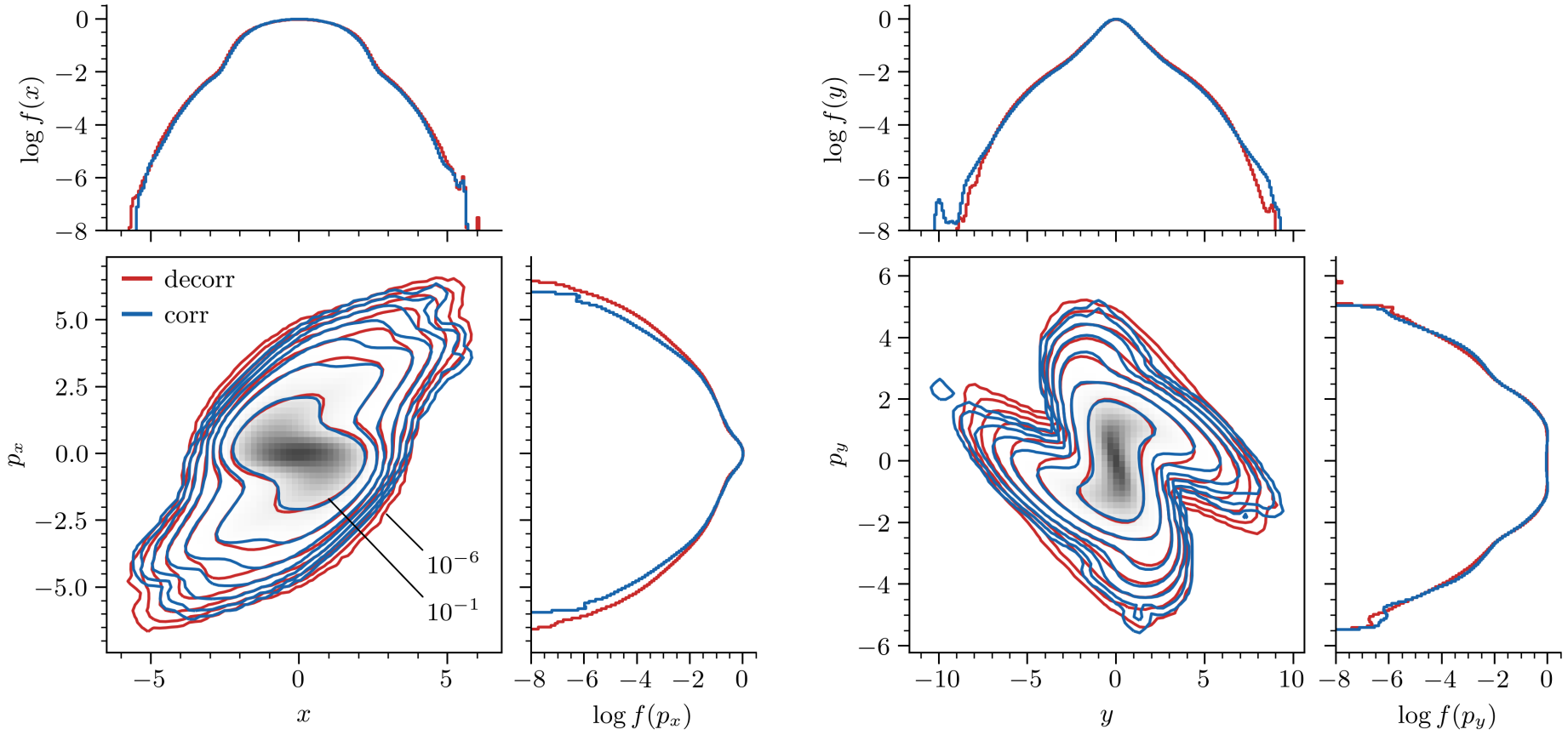
Upsample to 5×10^8
Decorrelate

Compute $f(x, p_x)$

The impact of inter-plane correlations will be small in the BTF



Halo distribution is significantly different than core



$$\langle xp_x \rangle = \langle yp_y \rangle = 0!$$

Conclusions

- RFQ model reproduces measured 6D phase space structure.
- Artificial decorrelation should have a small affect on the beam dynamics.
  - (For RFQ, beam current, and measurement location similar to those used in this study.)
  - Lattice model will be important.
- We expect significant halo in the SNS BTF.

References

- Hoover, A., et al. "Analysis of a hadron beam in five-dimensional phase space." *Physical Review Accelerators and Beams* 26.6 (2023): 064202.
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