OAK RIDGE National Laboratory

Measurements of the five-dimensional phase space distribution of an intense ion beam

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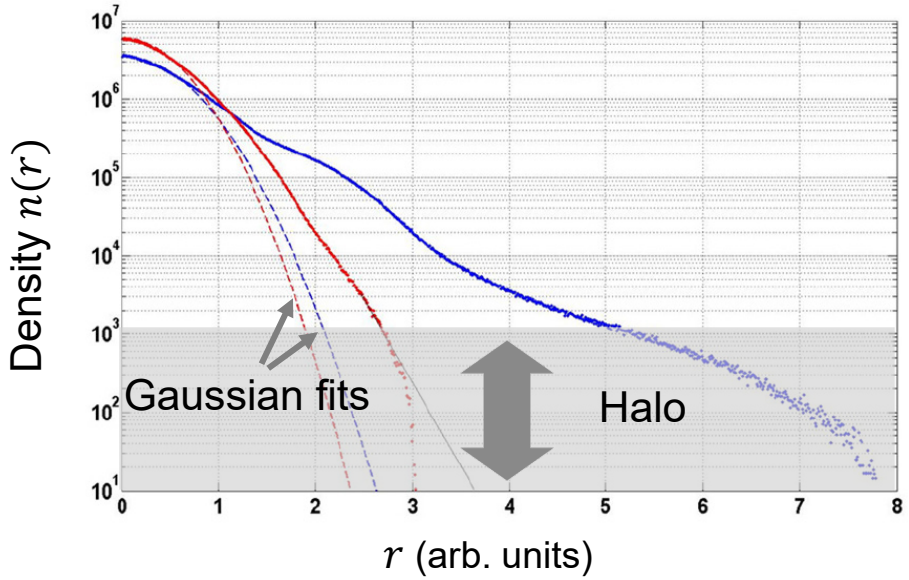
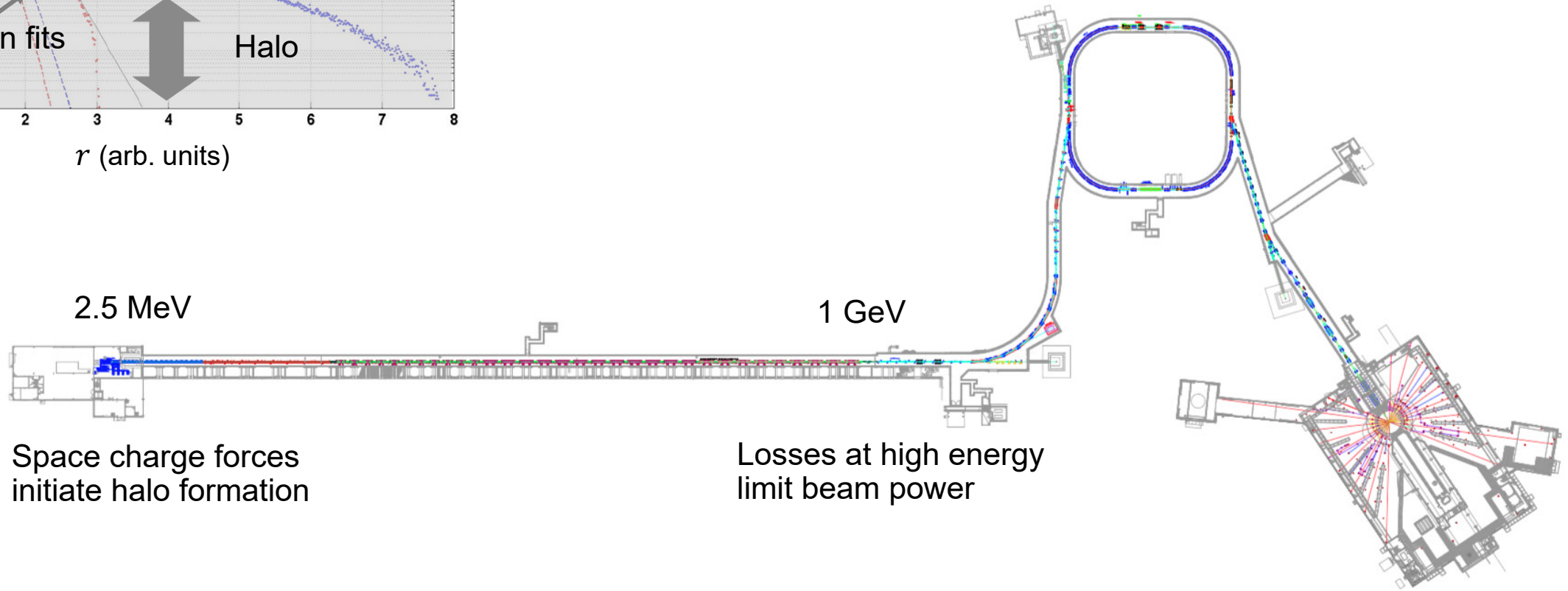
Higher beam intensities will require halo-level prediction



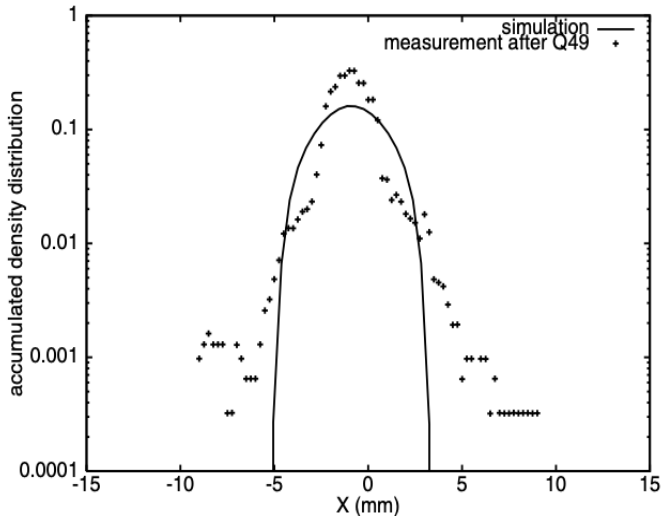


Space charge forces initiate halo formation

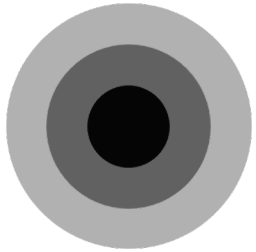
Losses at high energy limit beam power

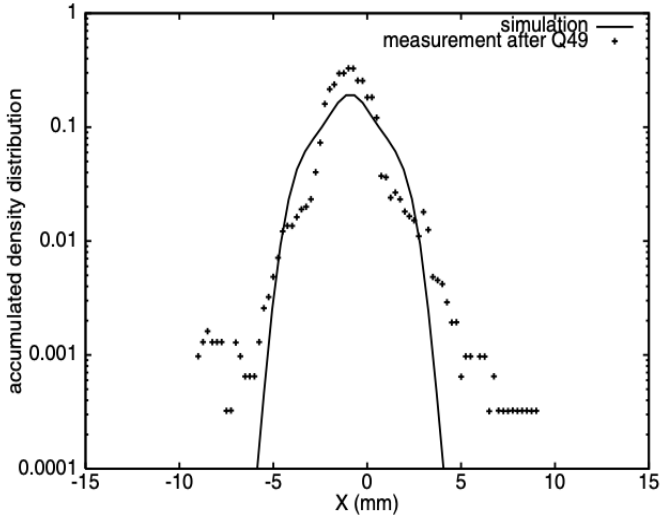
Details of beam halo depend on initial 6D phase space distribution

Waterbag

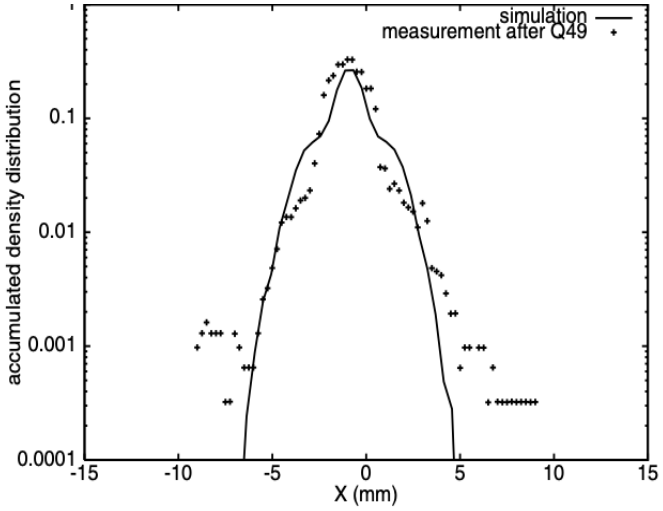


Gaussian



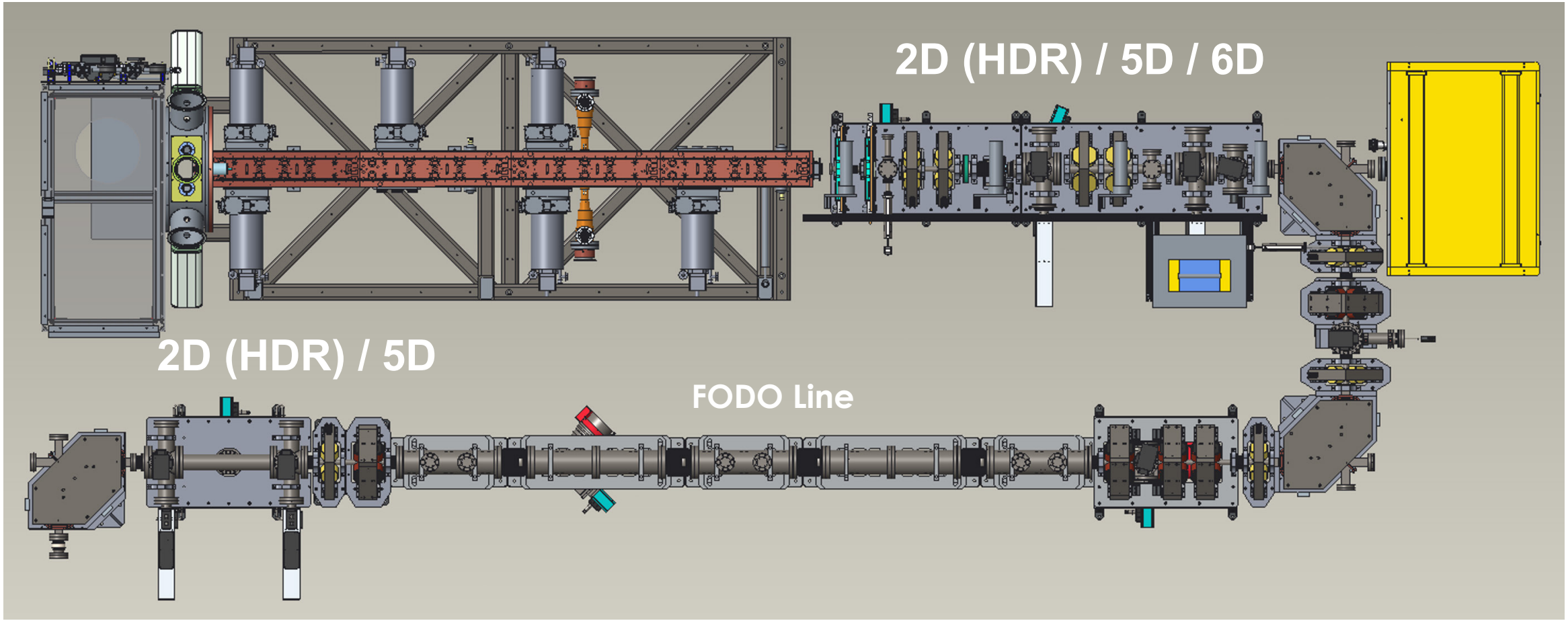


LEBT/RFQ

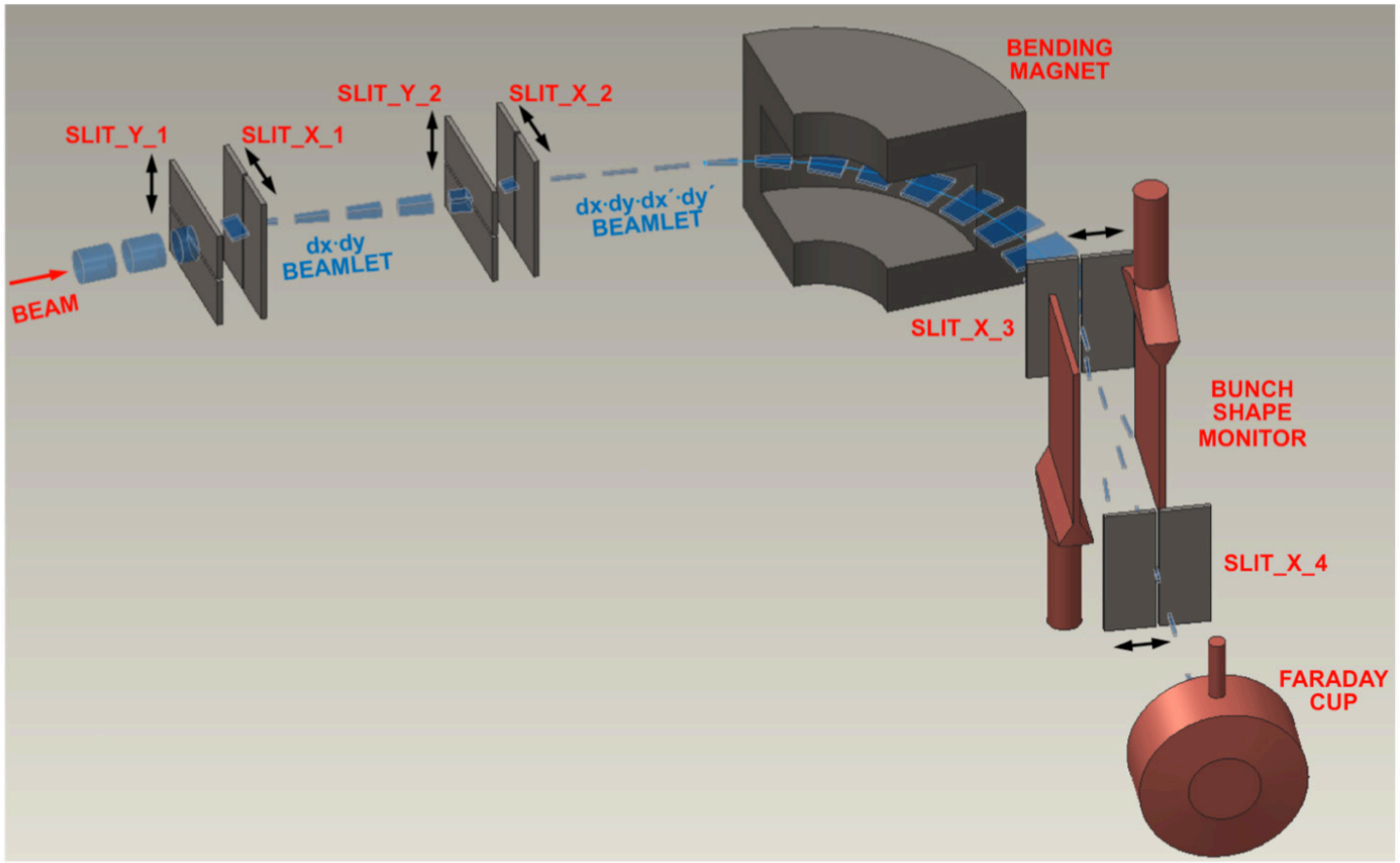


Qiang et al., *Macroparticle simulation studies of a proton beam halo experiment,* PRAB (2002)

SNS Beam Test Facility (BTF): high-dynamic-range and high-dimensional phase space measurements

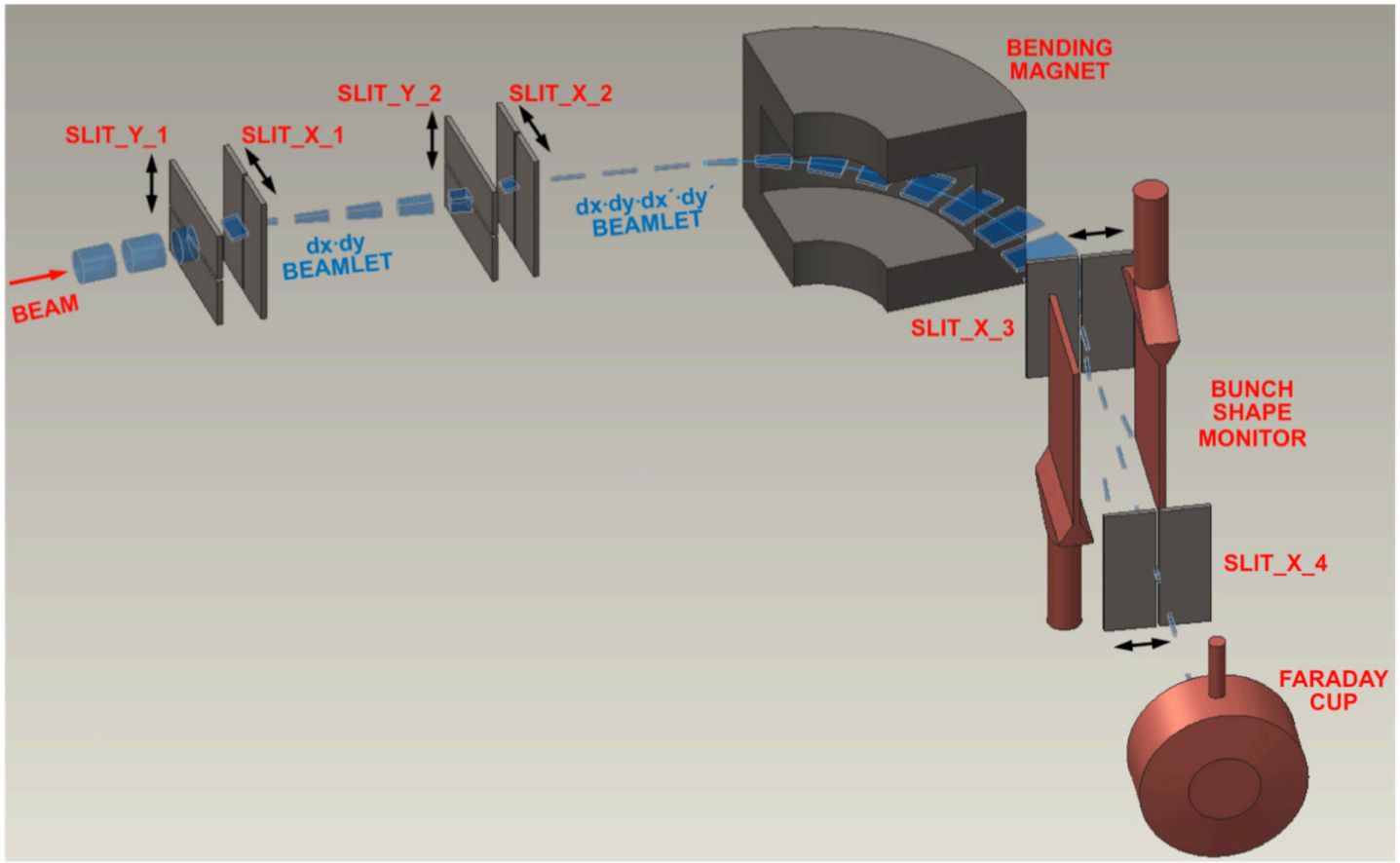


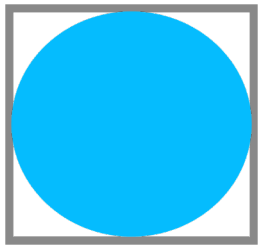
6D measurement has limited resolution and dynamic range



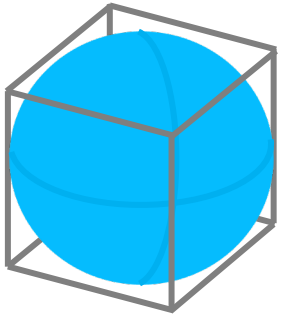
10 points per dimension, 10^1 dynamic range, **24 hours**

6D measurement has limited resolution and dynamic range





78% in 2D



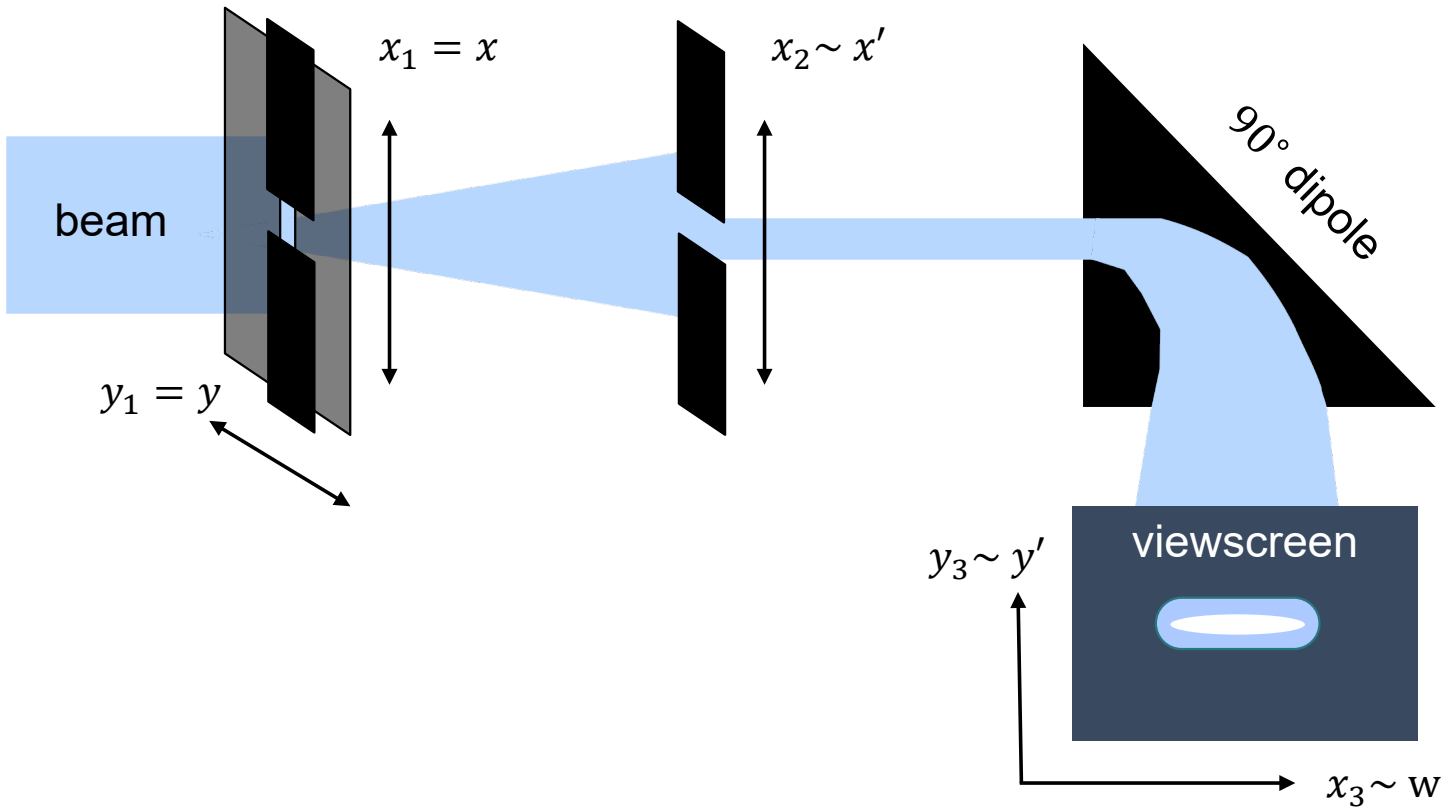
52% in 3D

⋮

8% in 6D

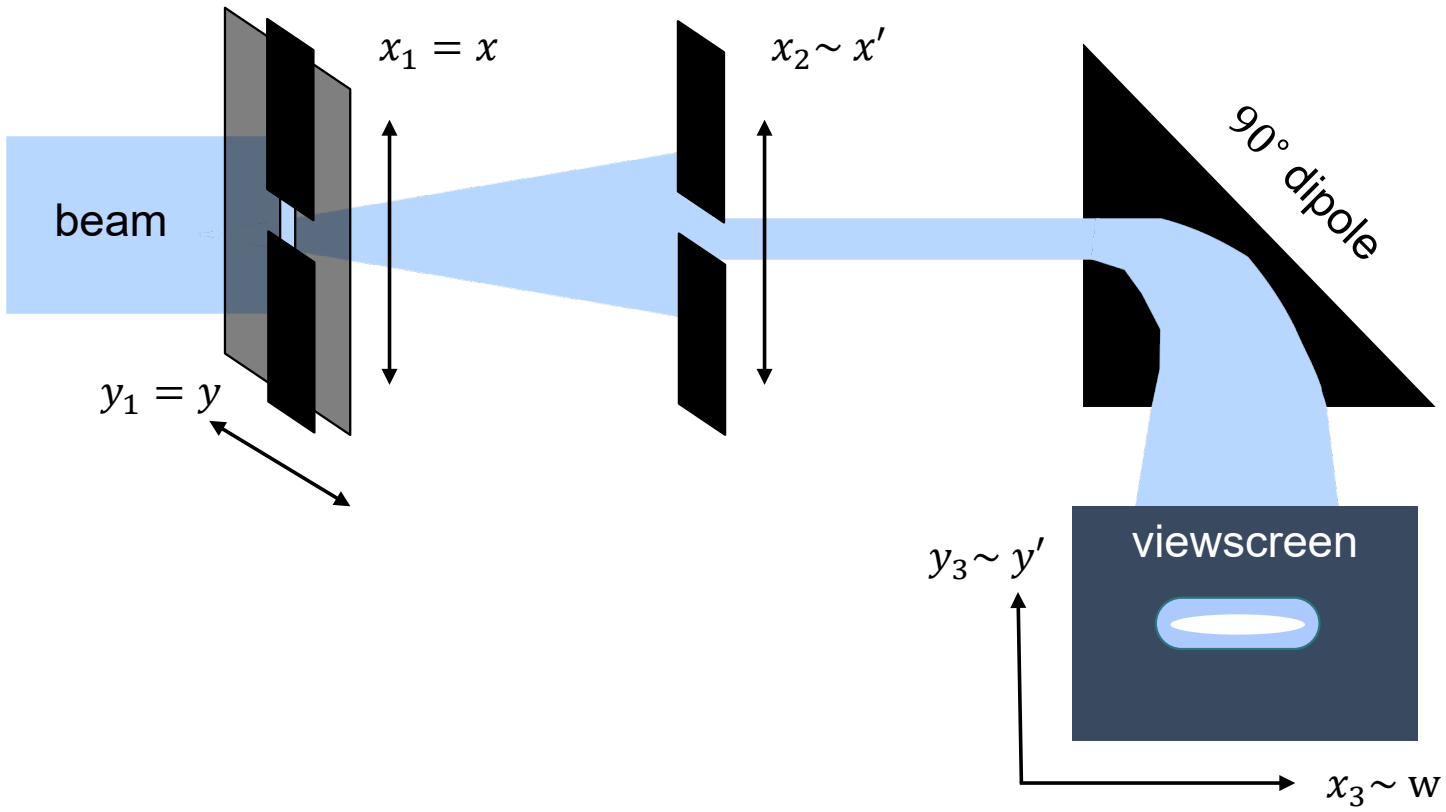
10 points per dimension, 10^1 dynamic range, **24 hours**

5D phase space distribution can be measured with three slits and one screen



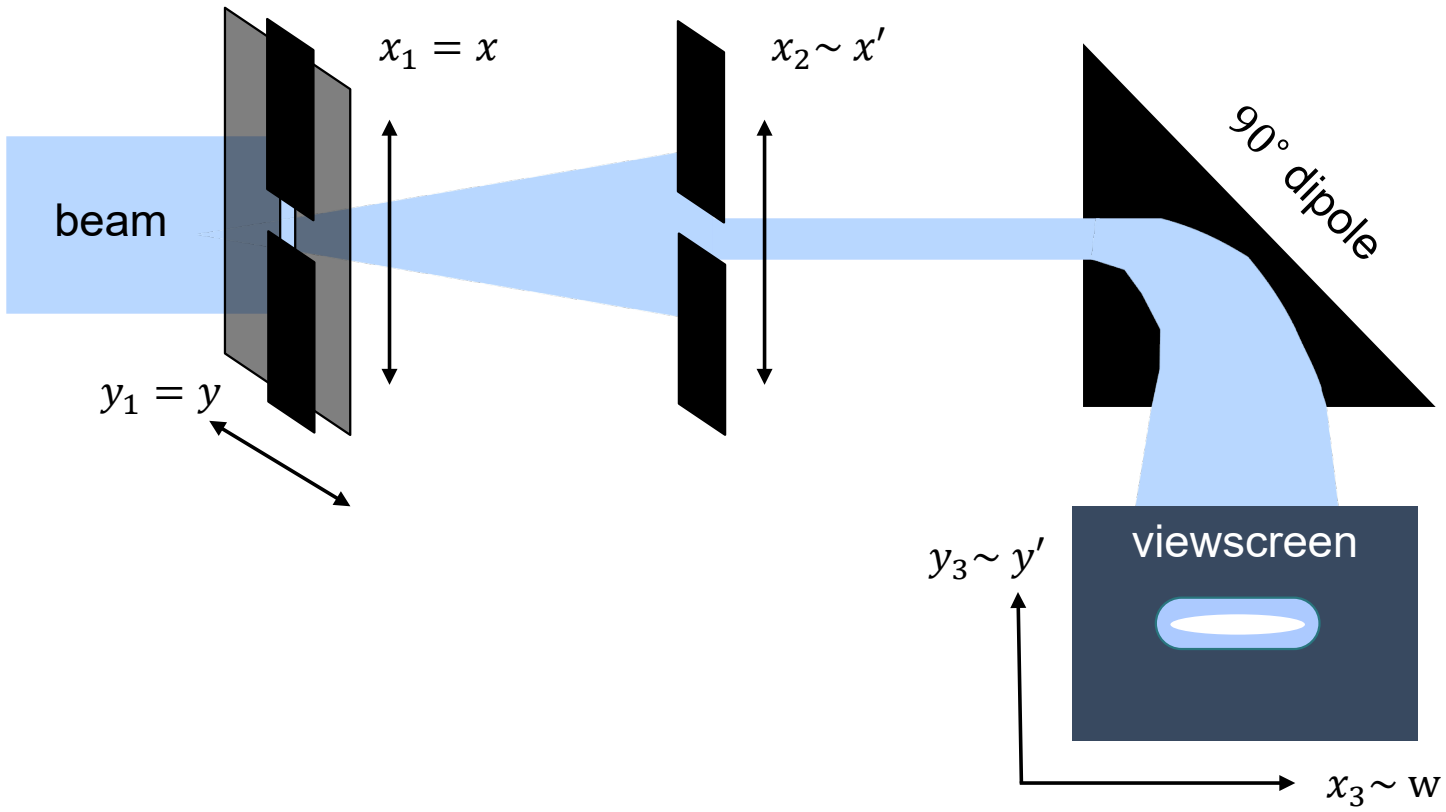
- dynamic range

5D phase space distribution can be measured with three slits and one screen



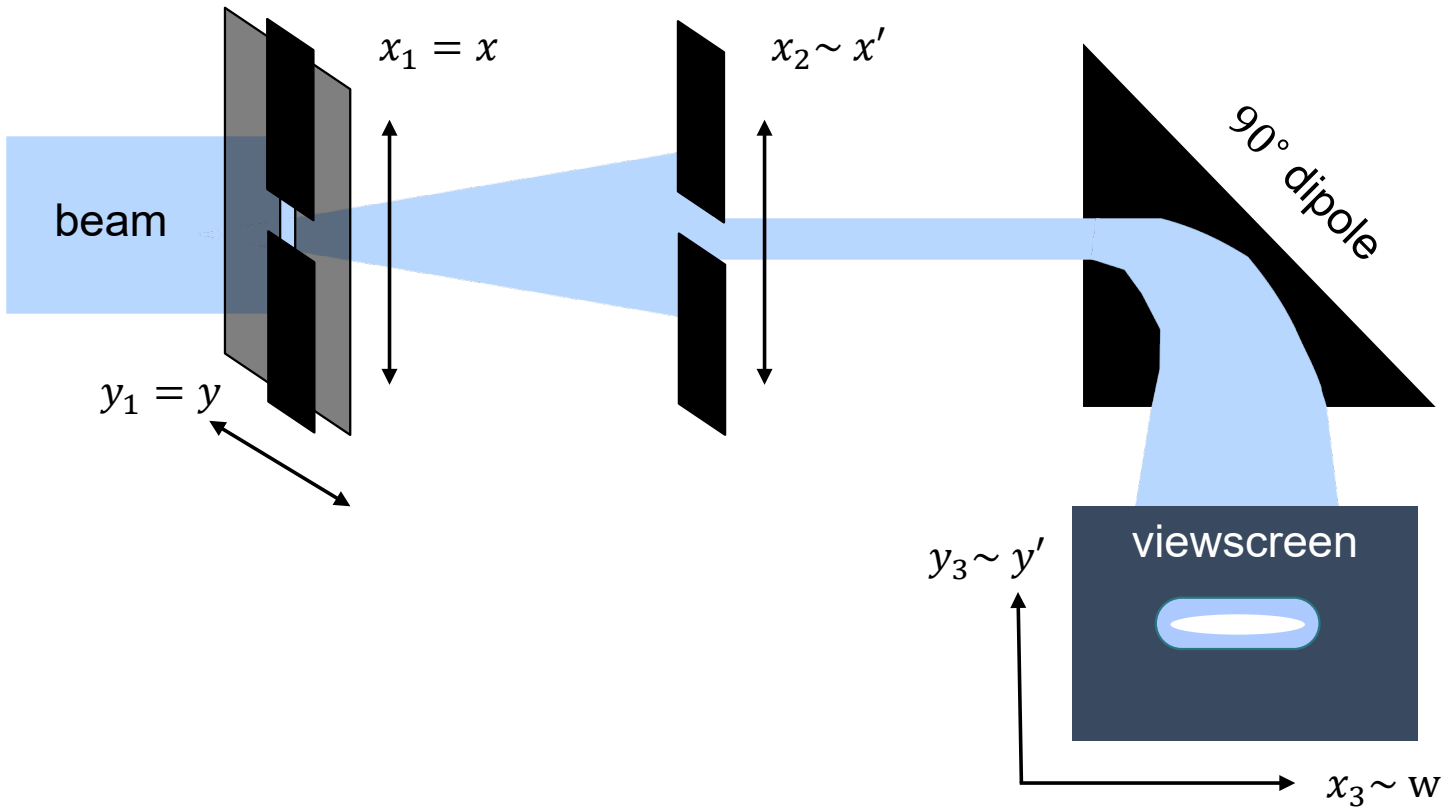
- 64 points per dimension **(16 hours)**
- dynamic range

5D phase space distribution can be measured with three slits and one screen

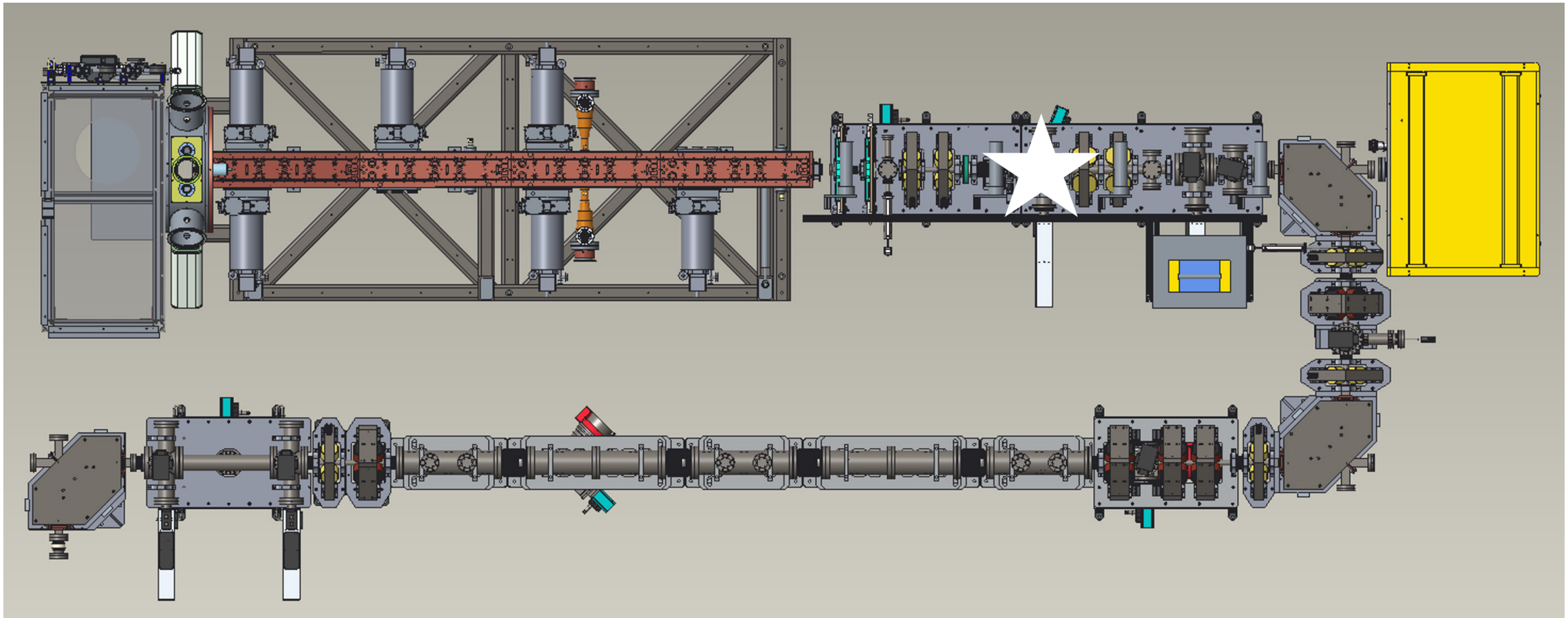


- *0 10 3 3 10 3* dynamic range
- 64 points per dimension **(16 hours)**
- 10 3 dynamic range

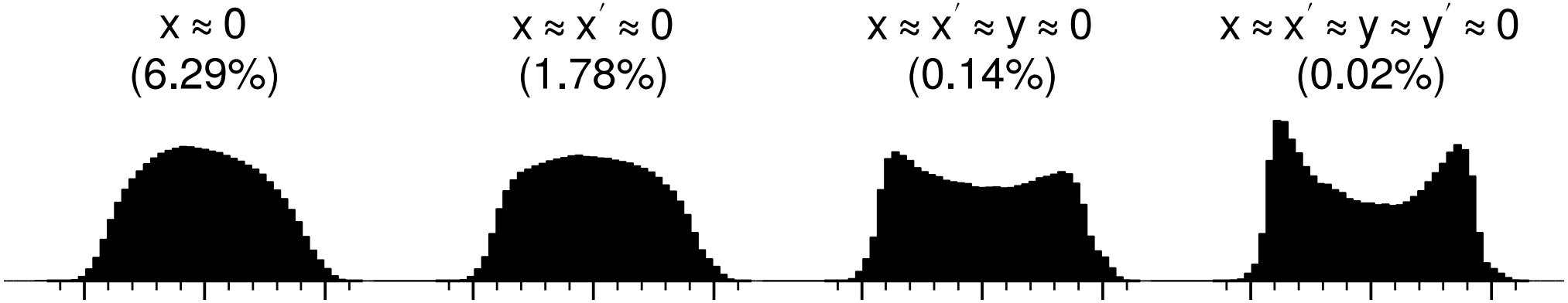
5D phase space distribution can be measured with three slits and one screen

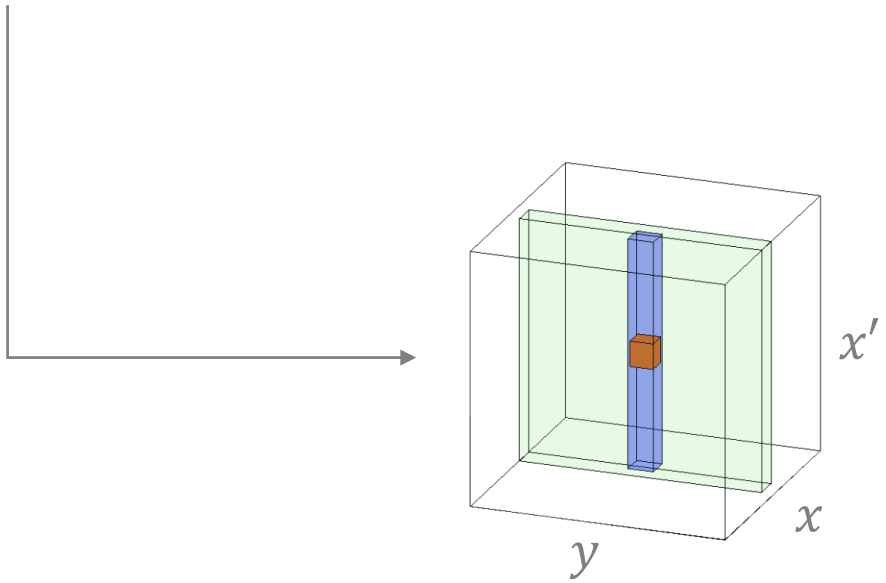


- *0 10 3 3 10 3* dynamic range
- 64 points per dimension **(16 hours)**
- Both emittance stations

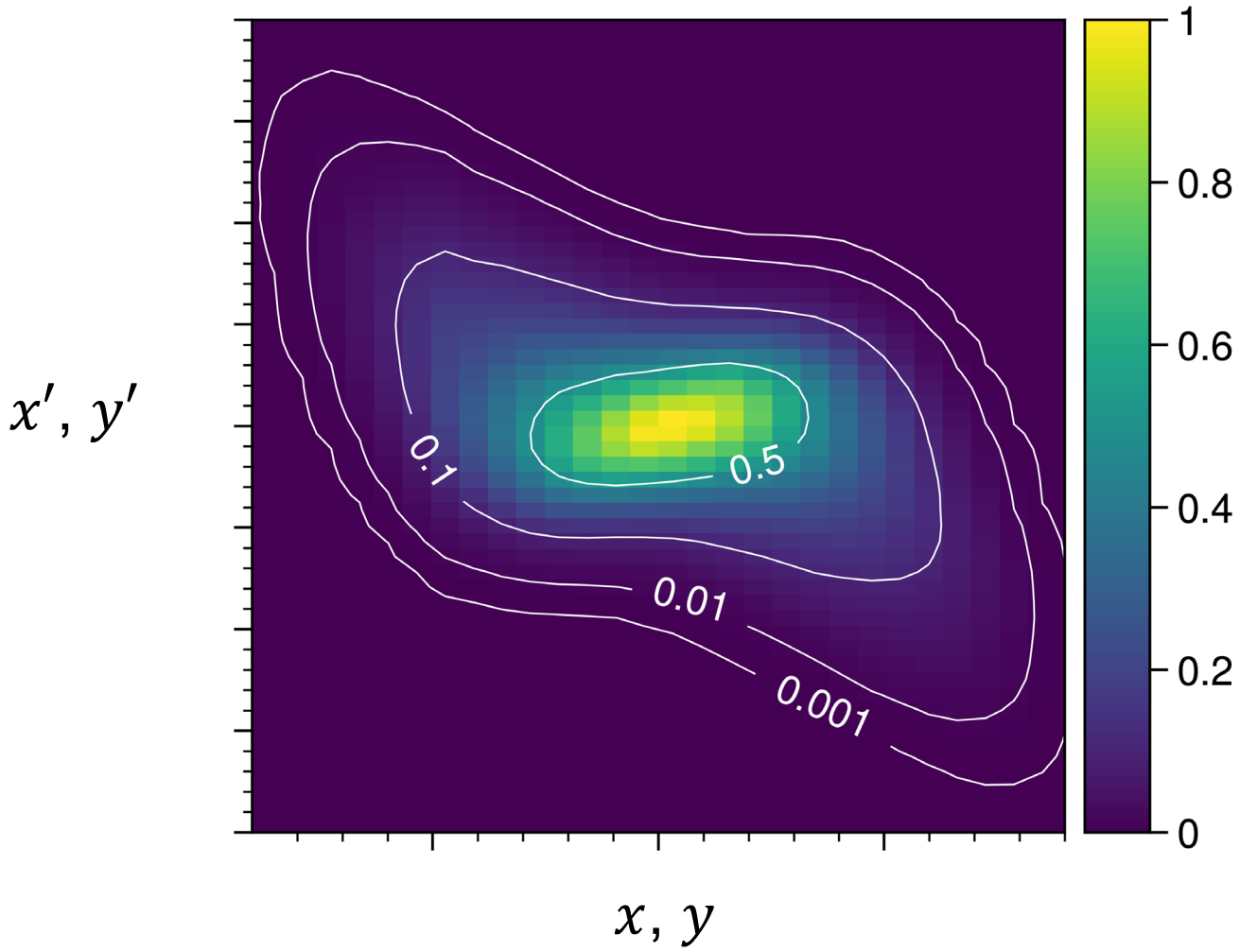


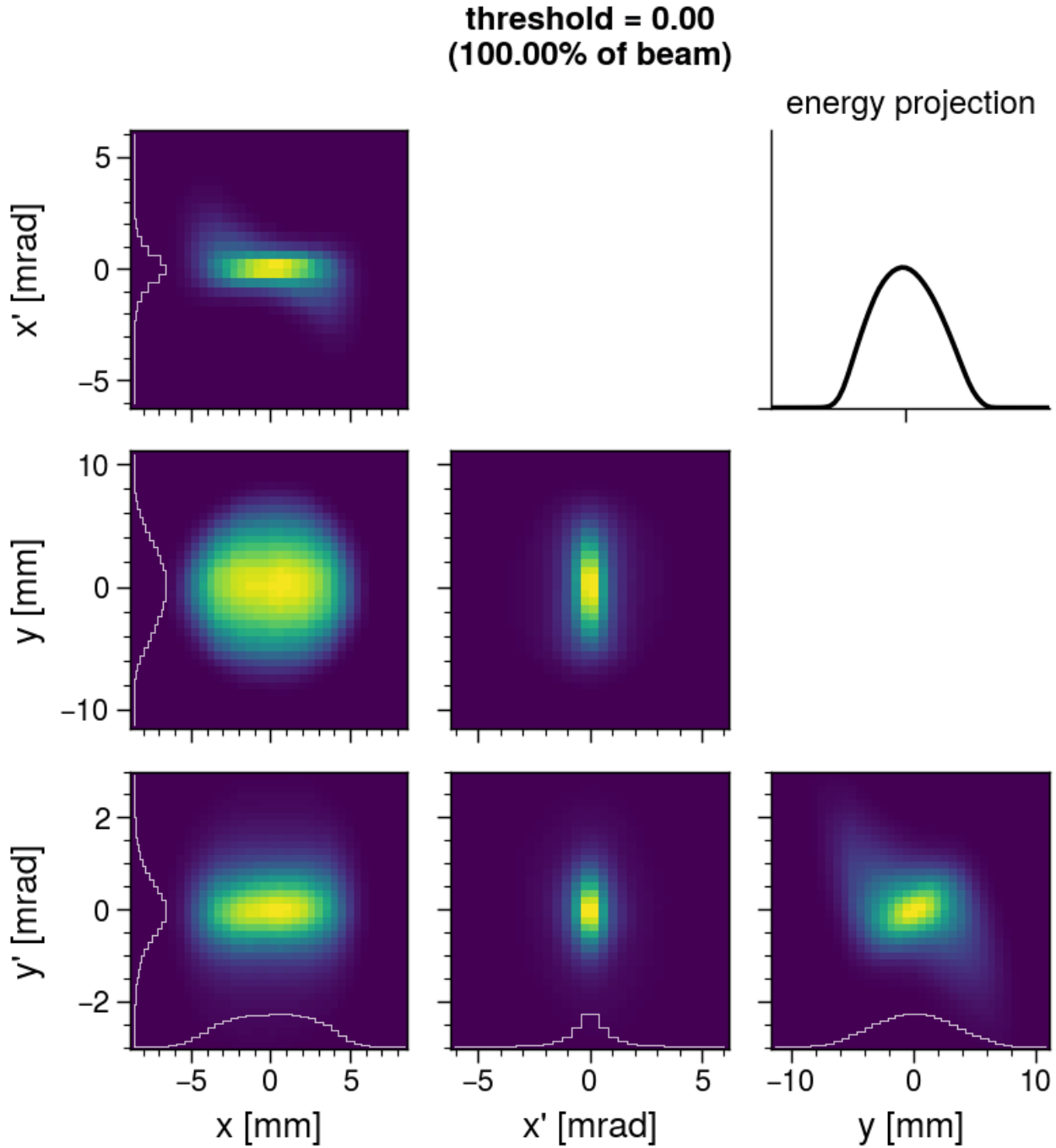
Energy distribution is hollow in beam core



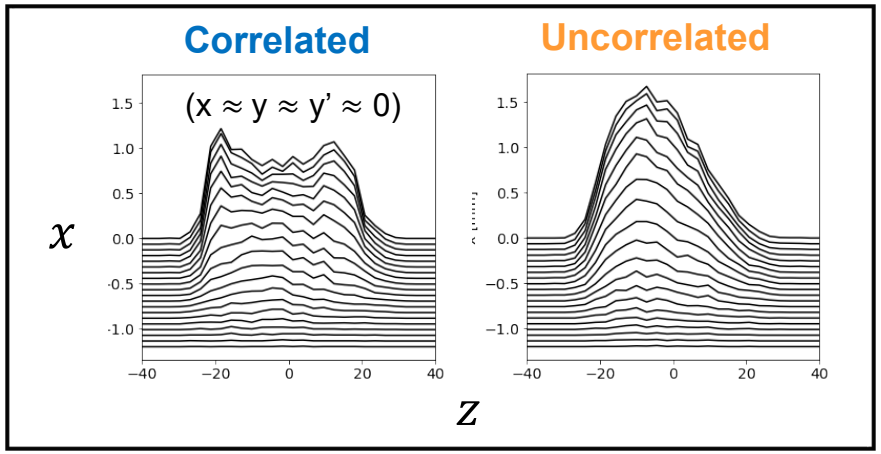


How far does hollow-energy core extend in 4D transverse phase space?

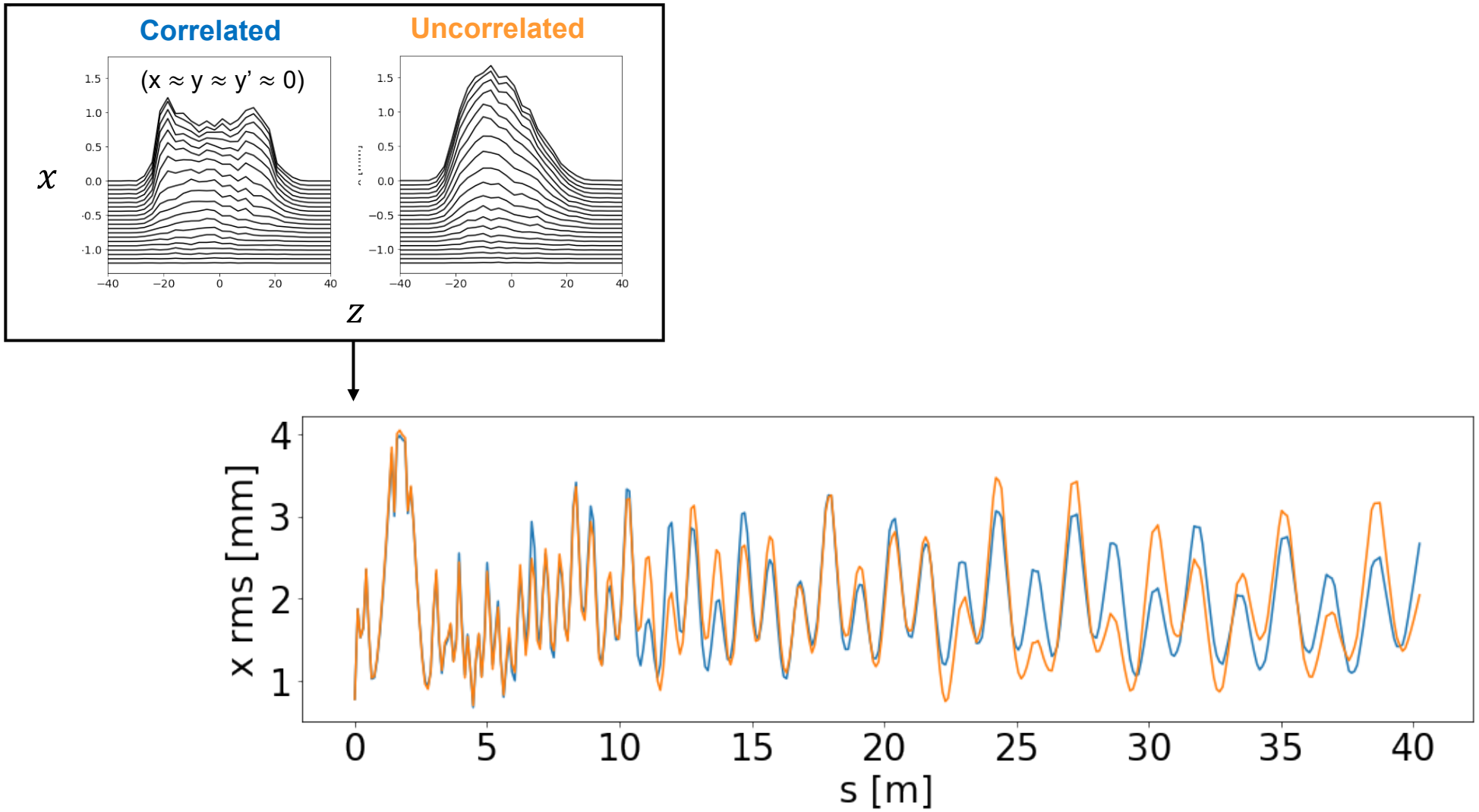



threshold = 0.00
(100.00% of beam)
energy projection
x' [mrad]
y [mm]
y' [mrad]
x [mm]
x' [mrad]
y [mm]
5
0
−5
10
0
−10
2
0
−2
−5
0
5
−10
0
10

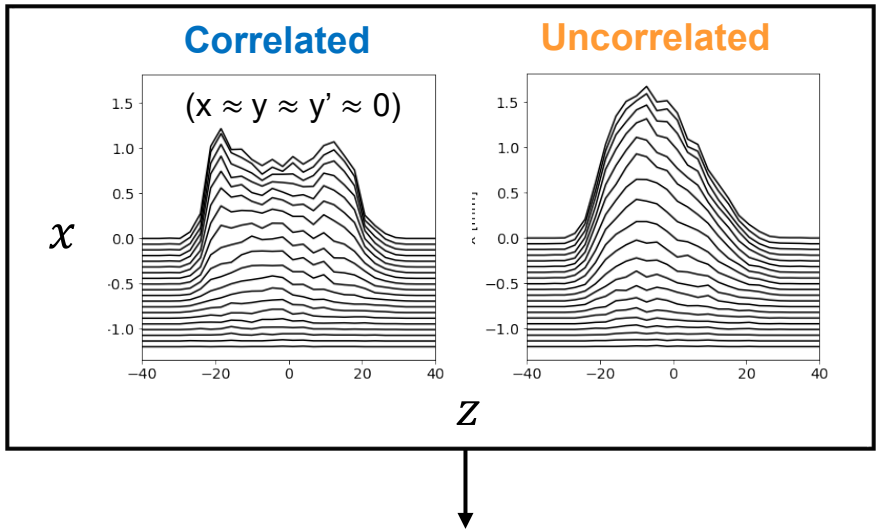
RFQ simulations produce beams with similar “hidden” correlations

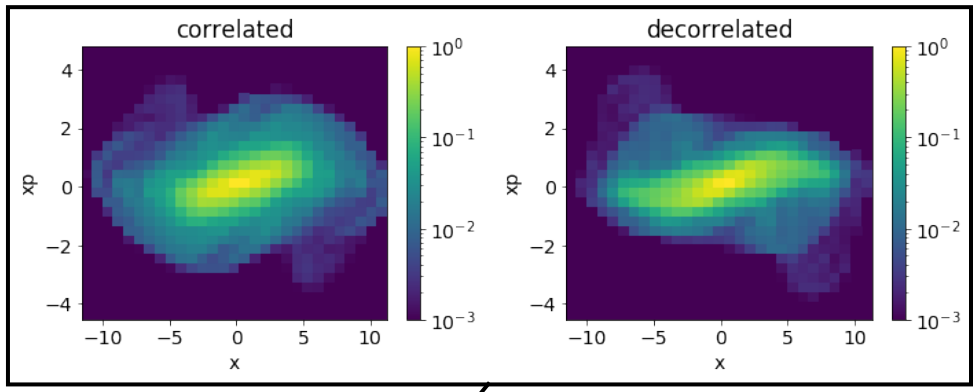


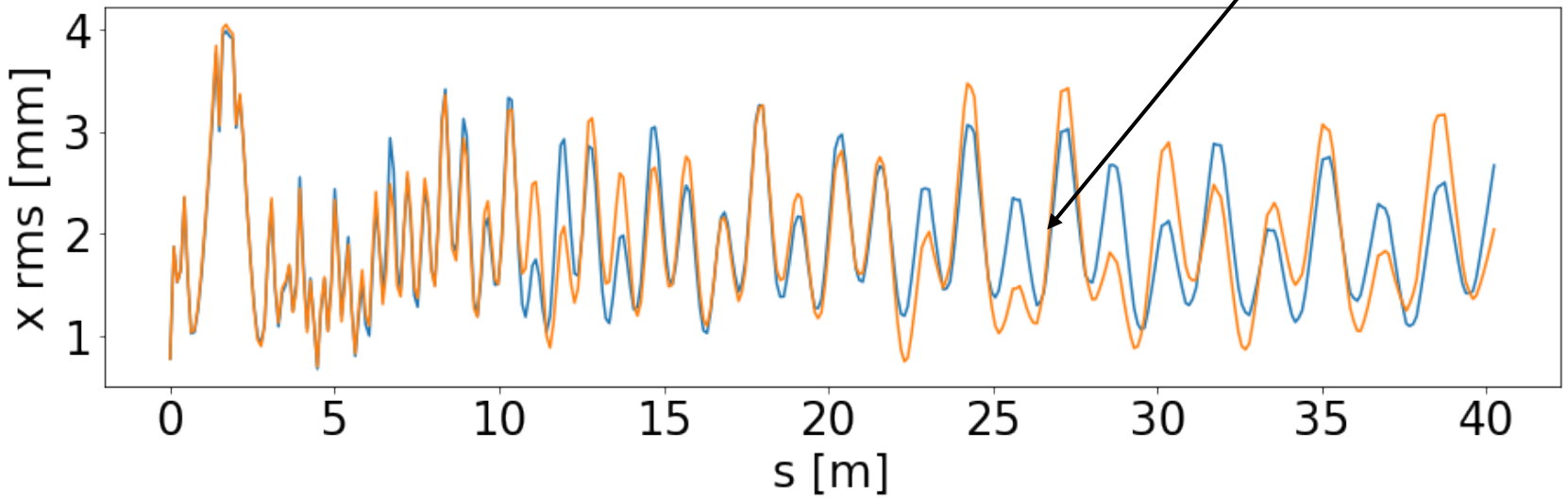
Correlations expected to affect RMS beam sizes in SNS linac (IPAC-2021)



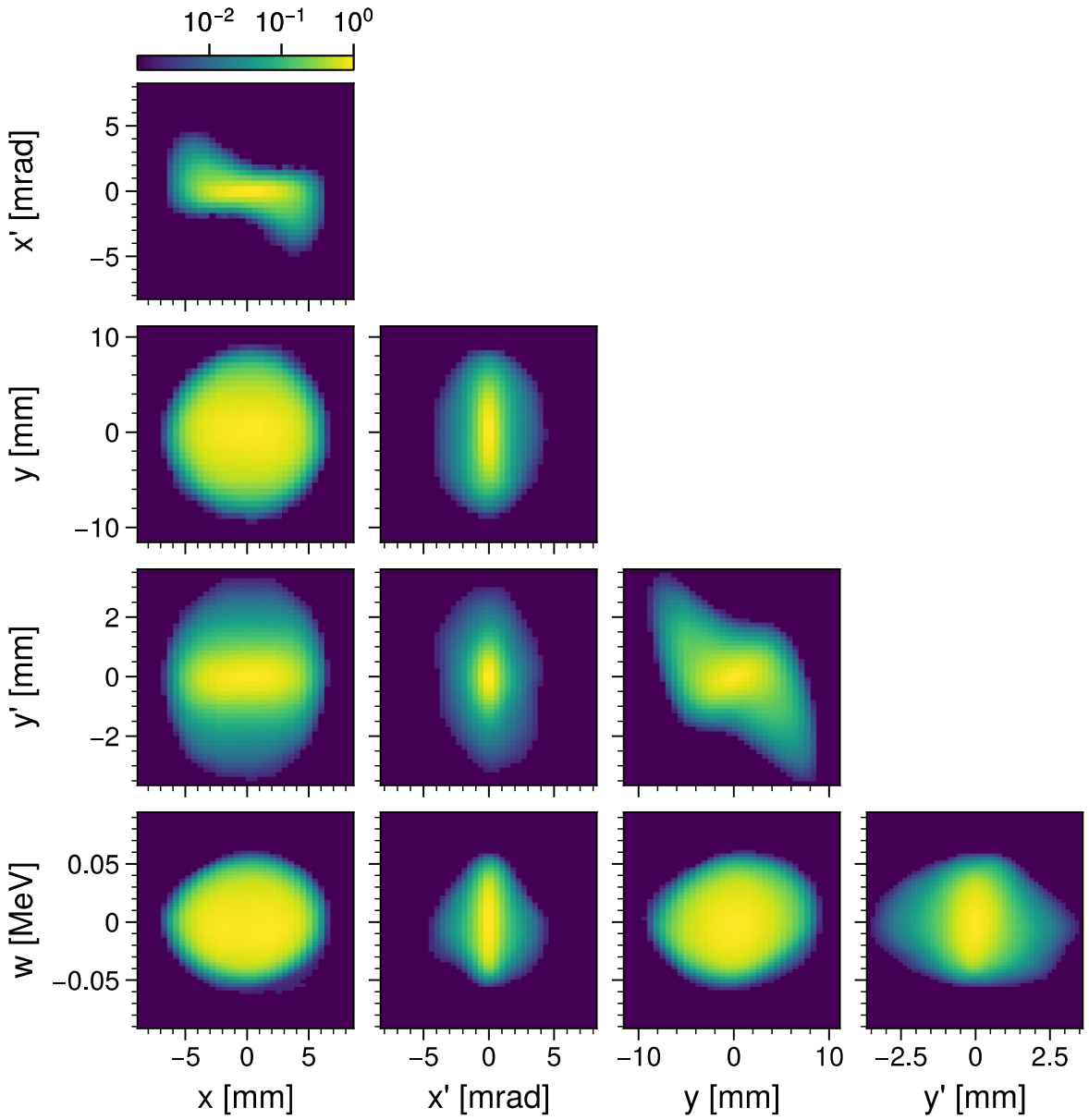
Correlations expected to affect RMS beam sizes in SNS linac (IPAC-2021)







Can the 6D distribution be reconstructed from its projections?



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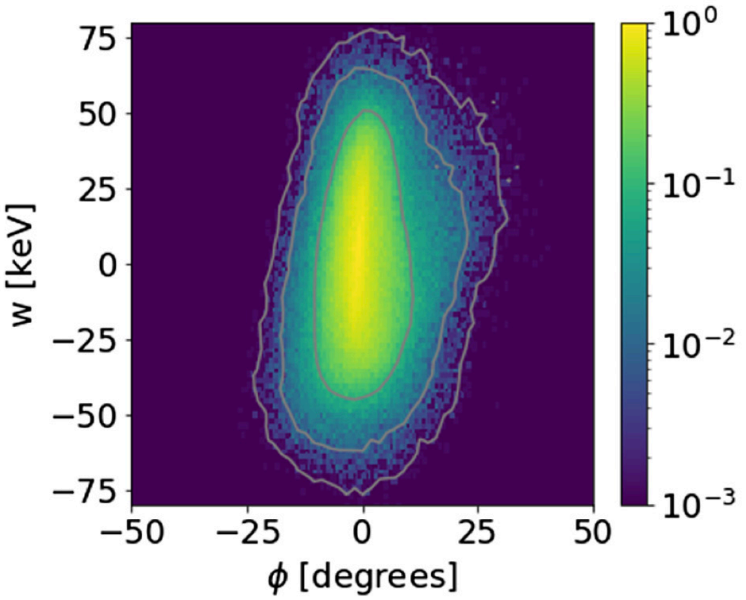

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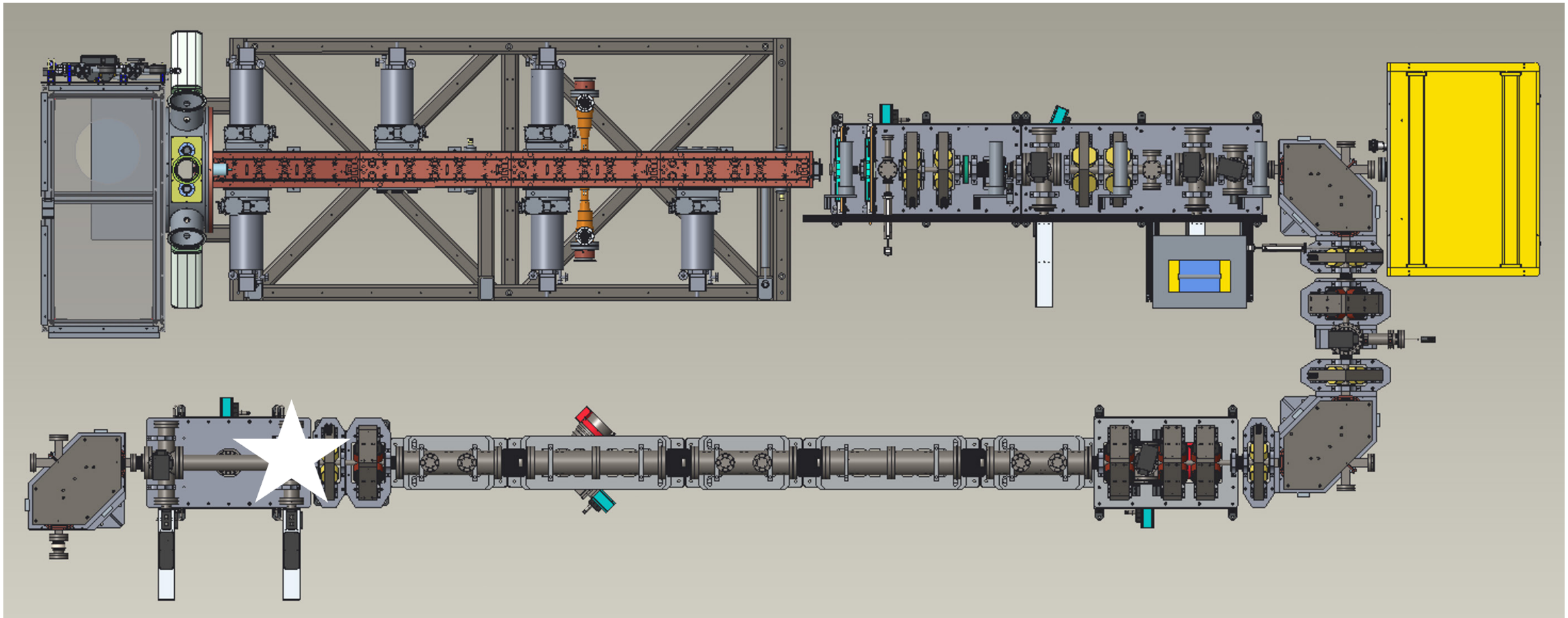
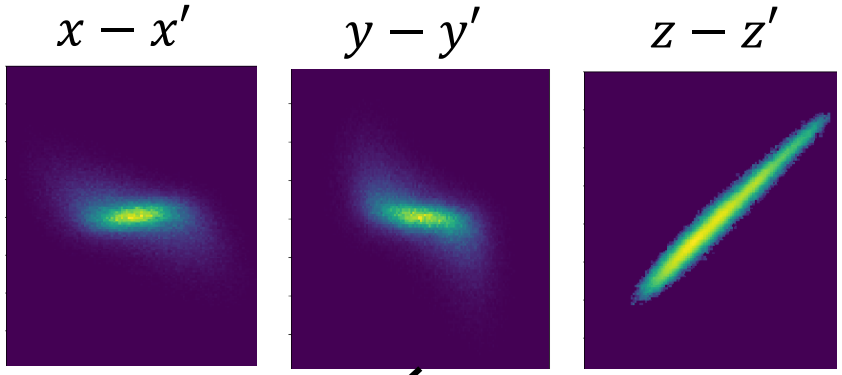
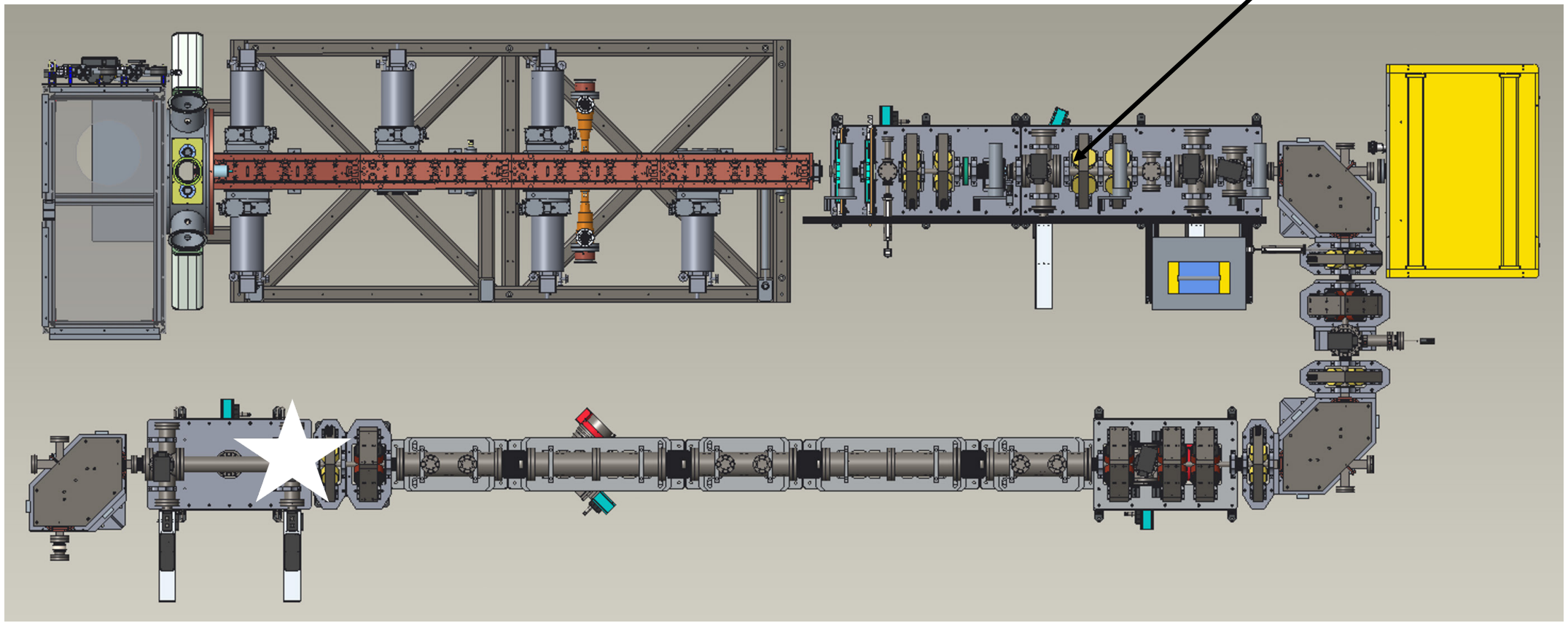
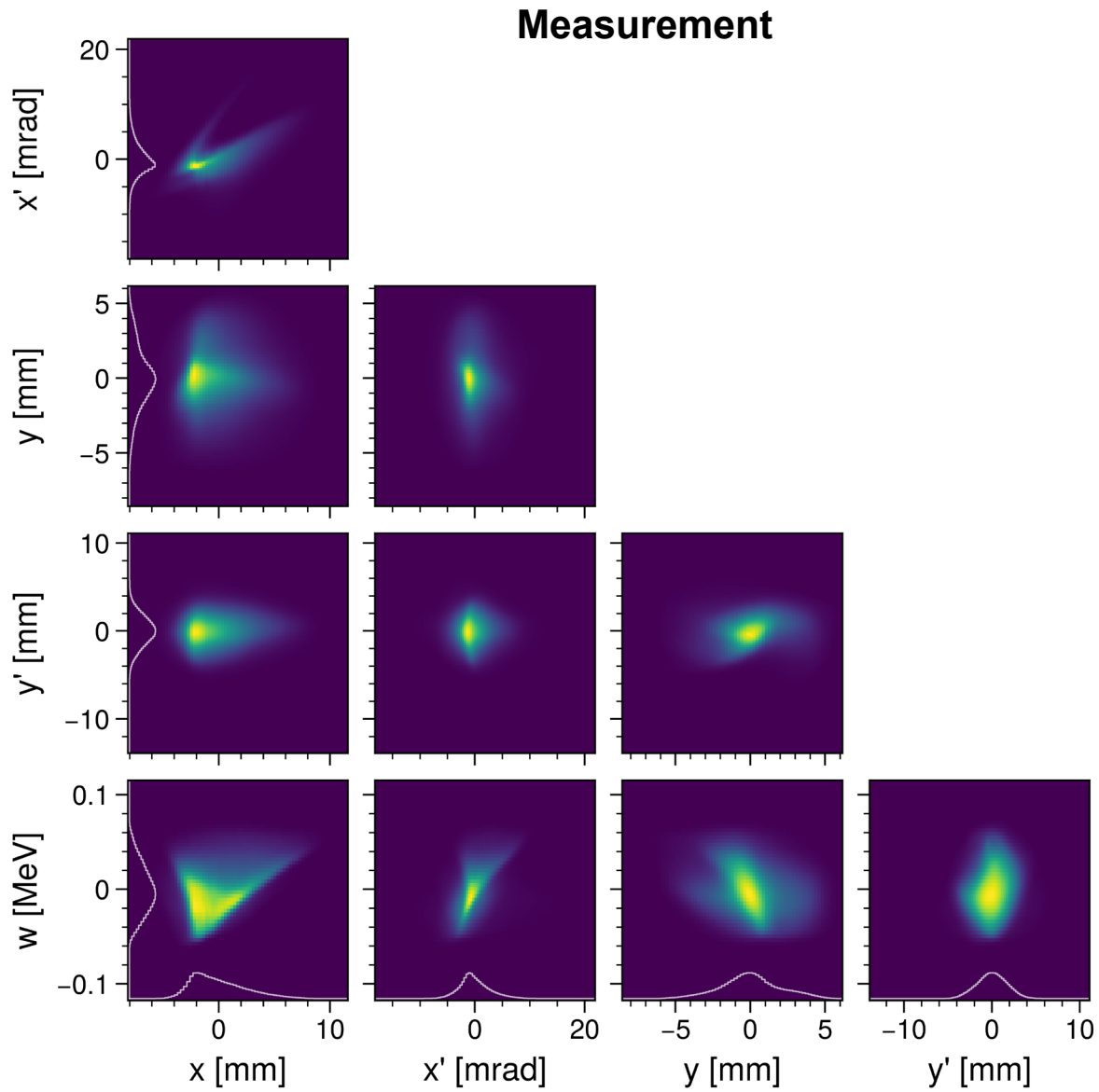


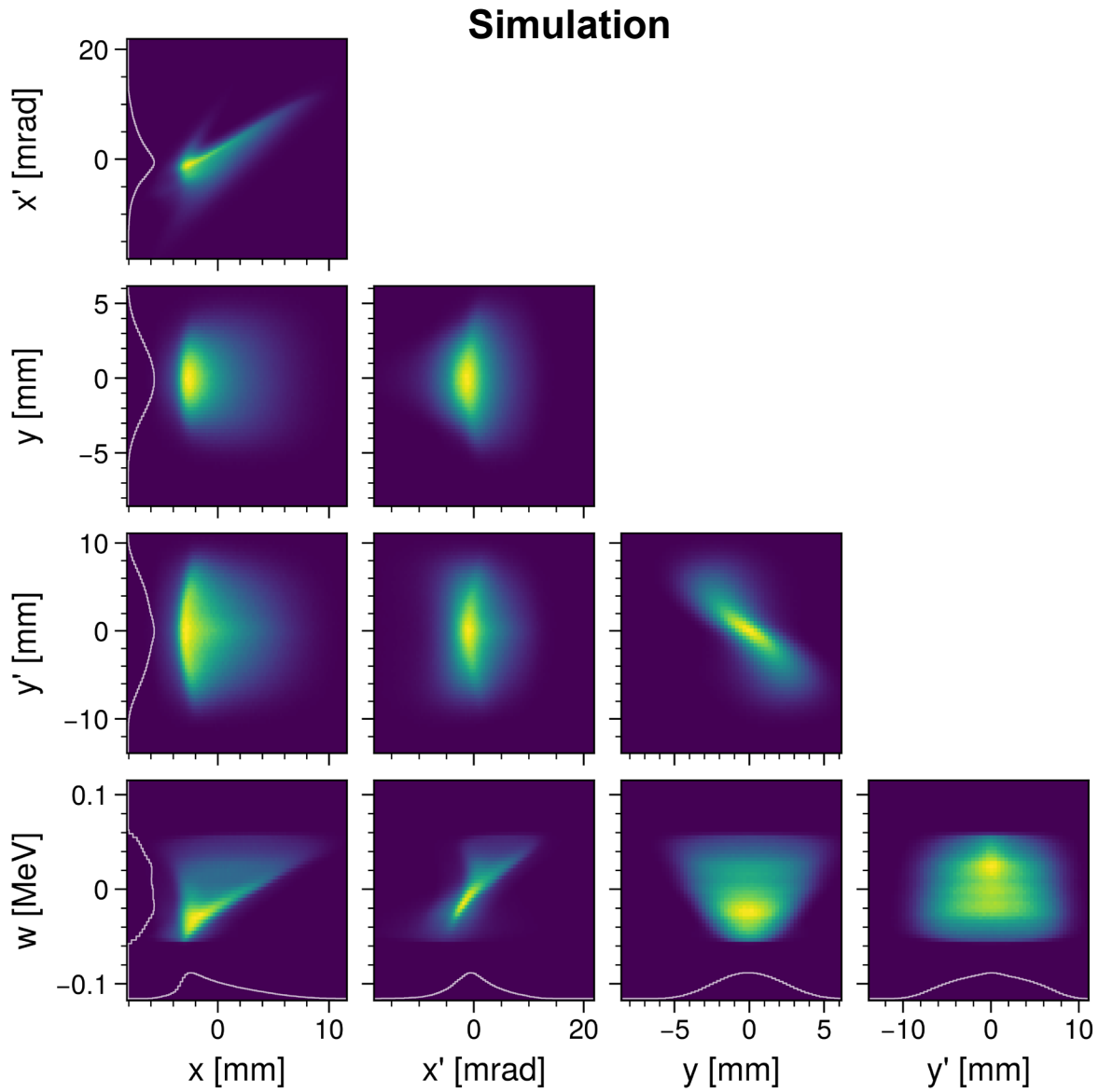
Follow previous work for now, assuming
$f(x, x', y, y', z, z') \approx f(x, x') f(y, y') f(z, z')$



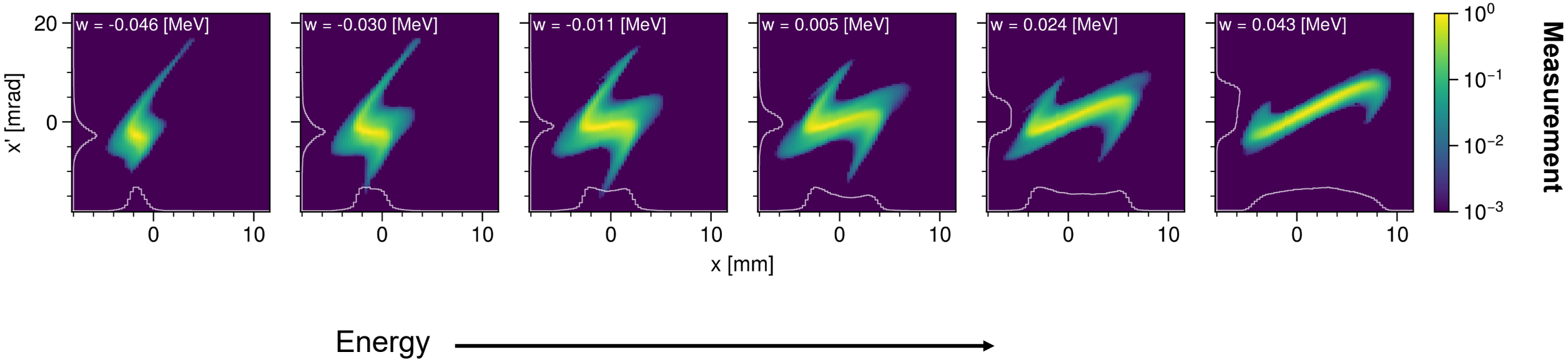


Reasonable x-x'-w agreement; y-y' discrepancies unresolved



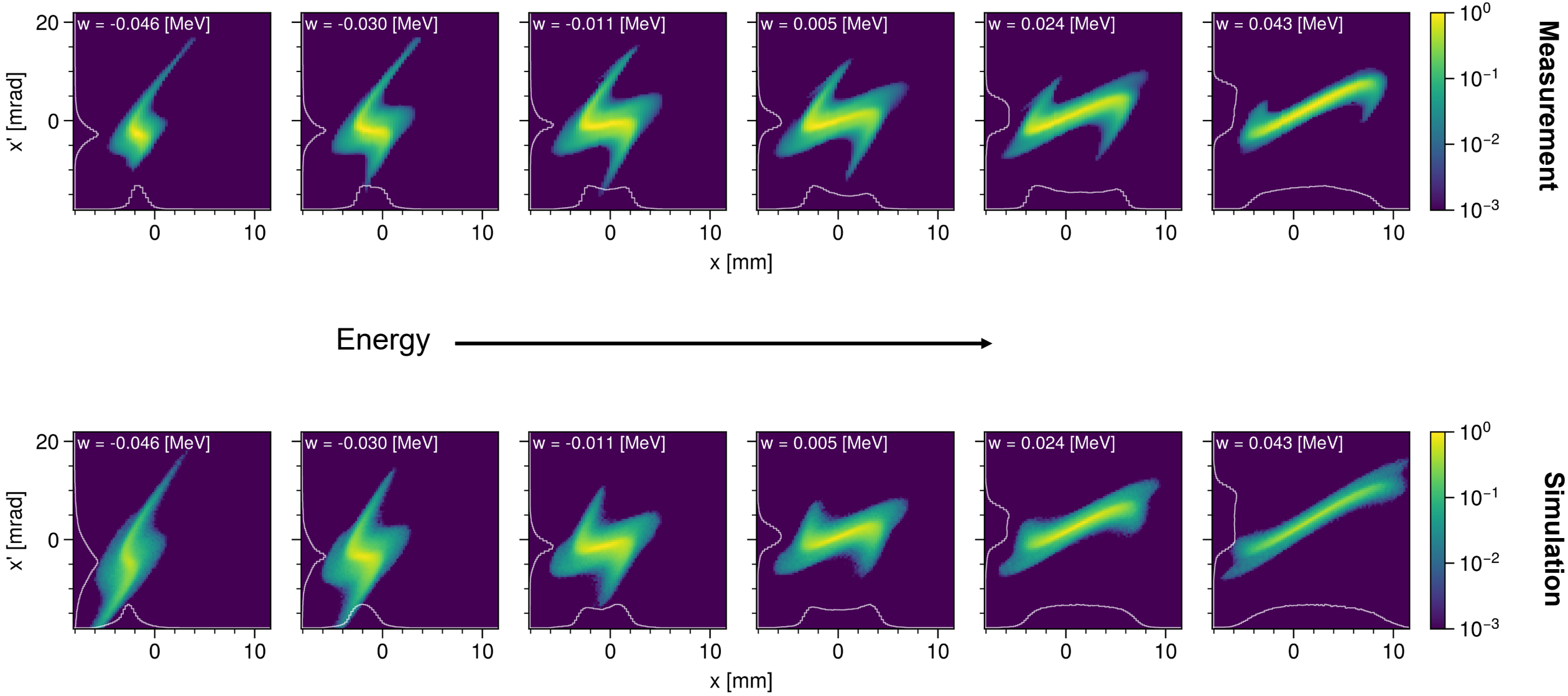


Energy slices give insight into x-x’ distribution



Energy →

Energy slices give insight into x-x’ distribution



Summary

- 5D measurements trade z dimension for resolution and dynamic range
- Examined transverse-longitudinal correlation in beam core
- Several ideas to reconstruct 6D distribution from 5D measurements
- Initial 5D benchmark of simulation (okay in x-x'-w; discrepancies in y-y')