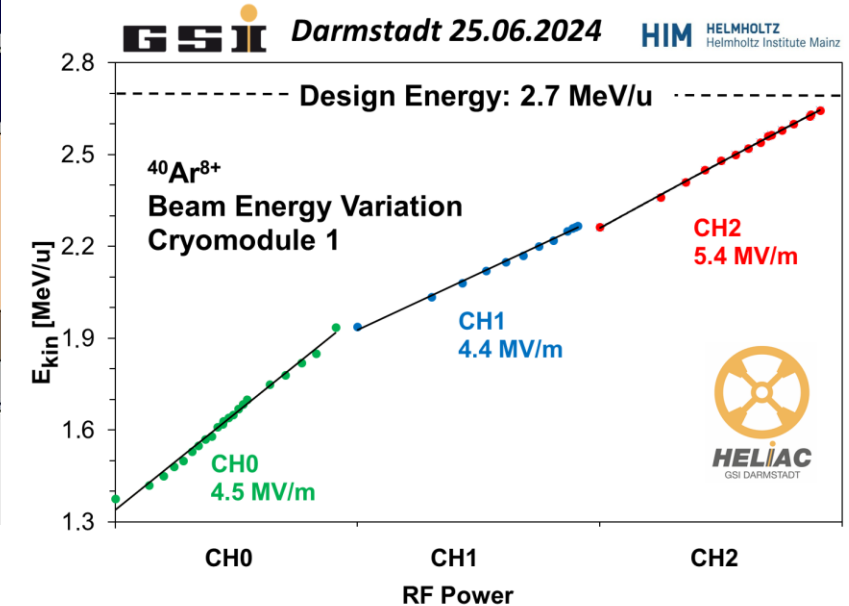
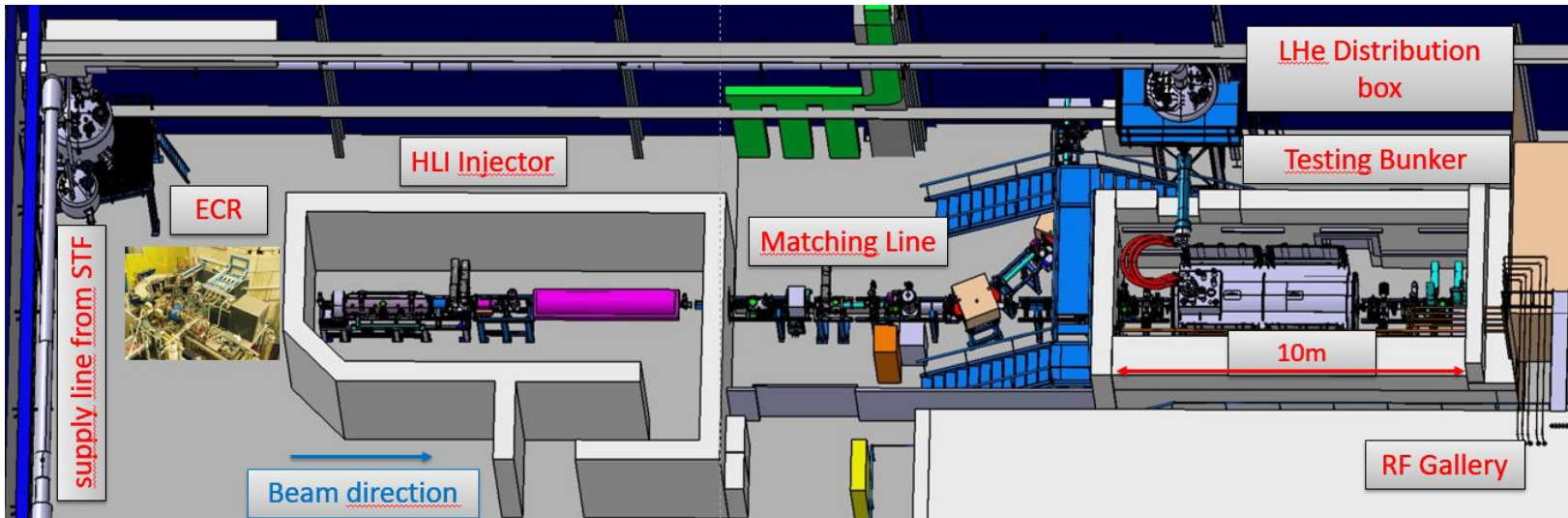




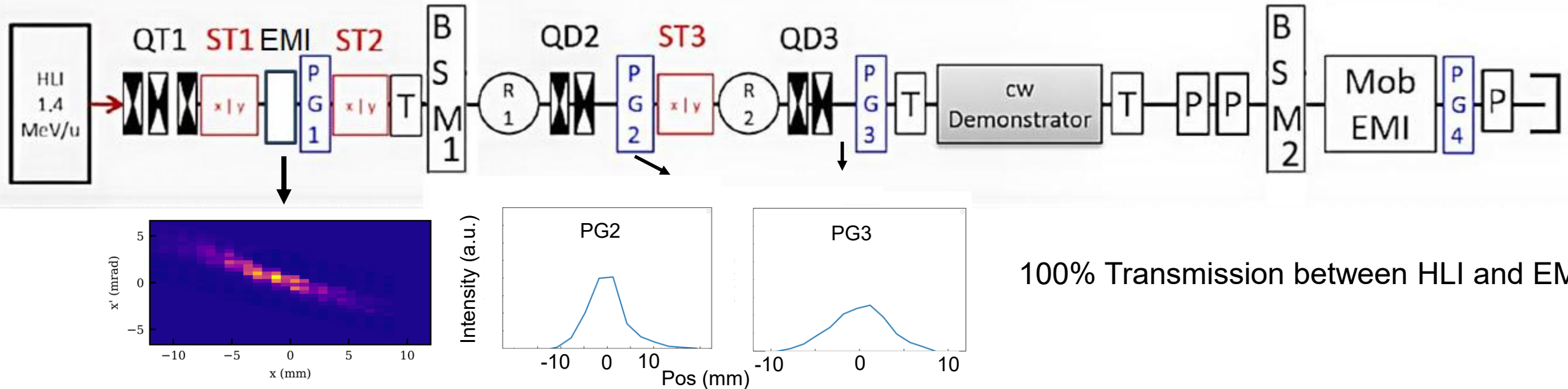
Beam tests on the Advanced Demonstrator

Test area @GSI for cryogenic accelerator modules



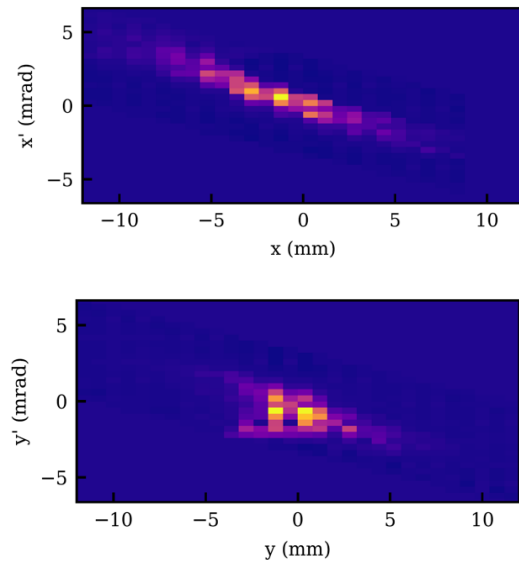
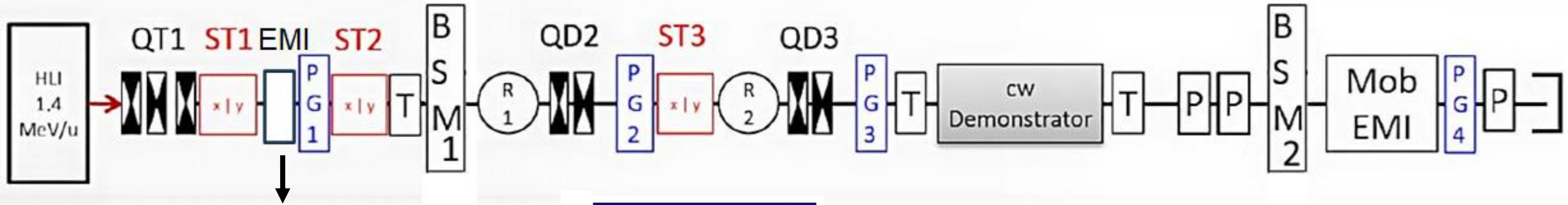
- The first cryomodule from HELIAC has been in experimental operation since December 2023
- Design energy has been achieved and transmission is at approximately 90%
- Detailed knowledge of the longitudinal and transverse phase space is required to better adapt the HLI beam to the cryomodule

Beam guidance: Transverse measurement setup

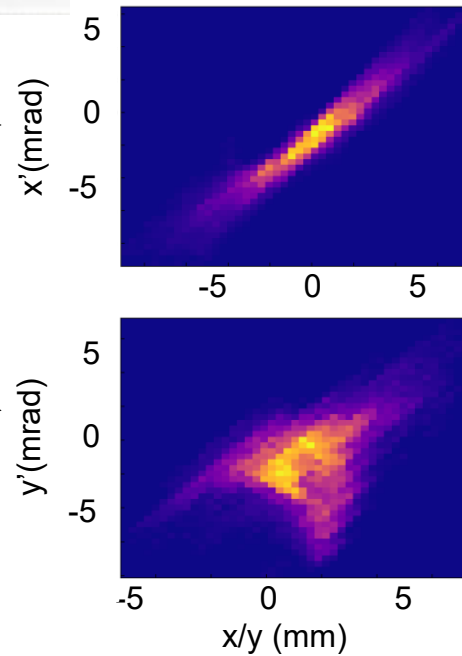


- Goal: reconstruction of the 4D particle distribution at the HLI exit
- The slit grid measurement system provides only projections of $x-x'$ and $y-y'$. The assignment of particles $x-x'$ to measurements $y-y'$ is missing (i.e. the correlation is missing)
- The $x-y$ and $x'-y'$ data is missing. Profile grids $I(x)$ and $I(y)$ are required to check the constructed particle distribution

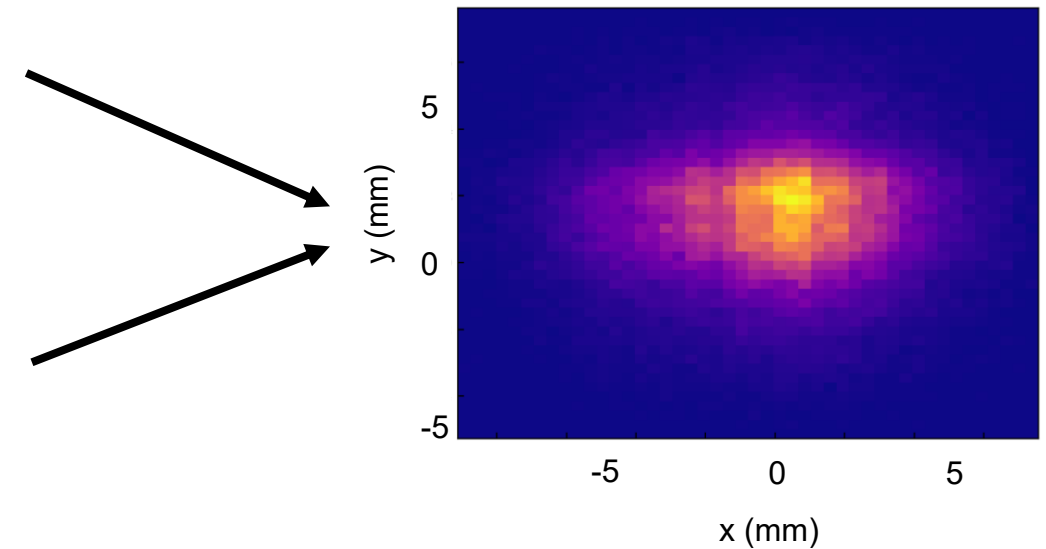
Reconstruction: Transversal



Measured at EMI

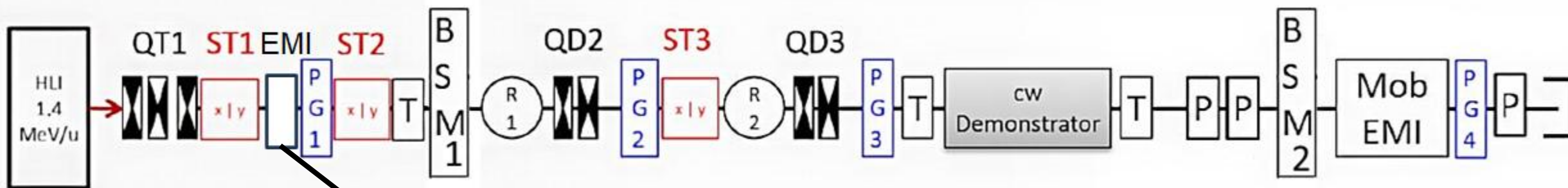


Backtracked to HLI



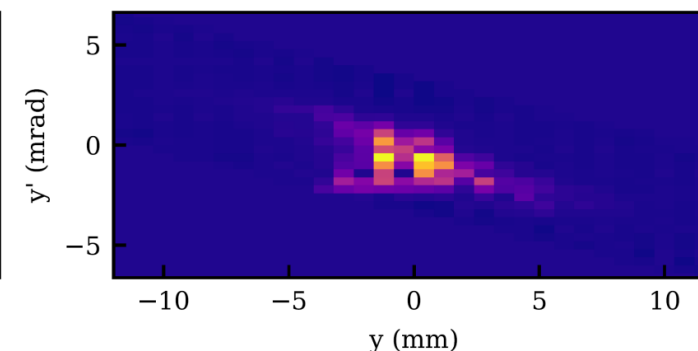
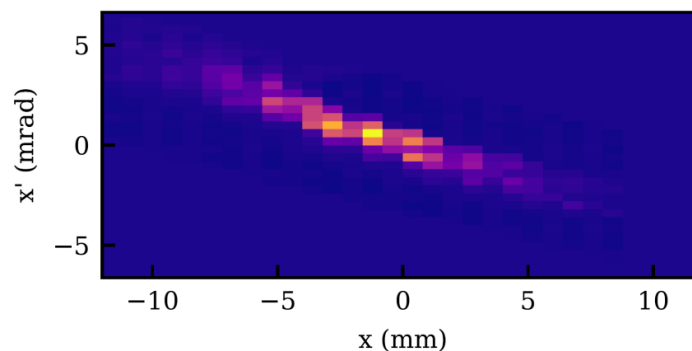
Combined 4D distribution

Reconstruction: Transversal

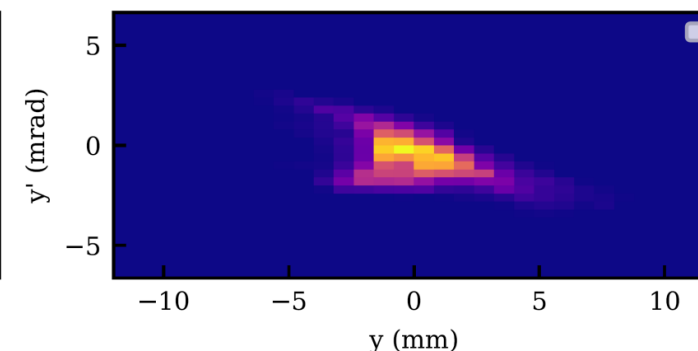
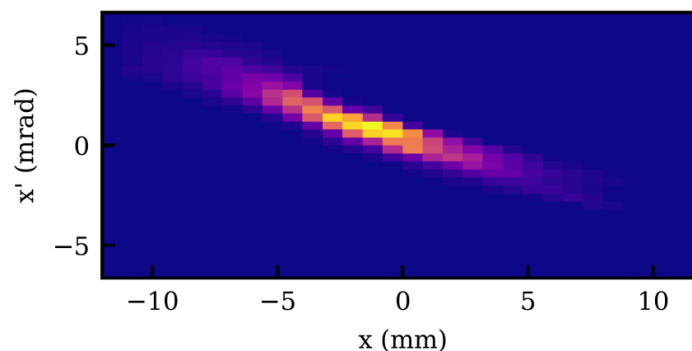


Comparison of Measurements and Simulation as Density-Plot

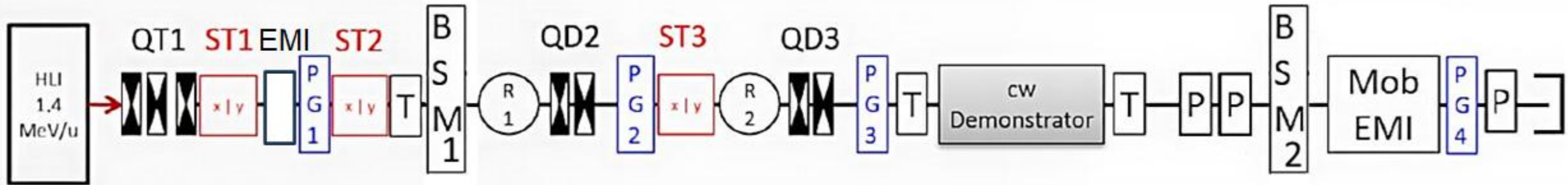
Measurement



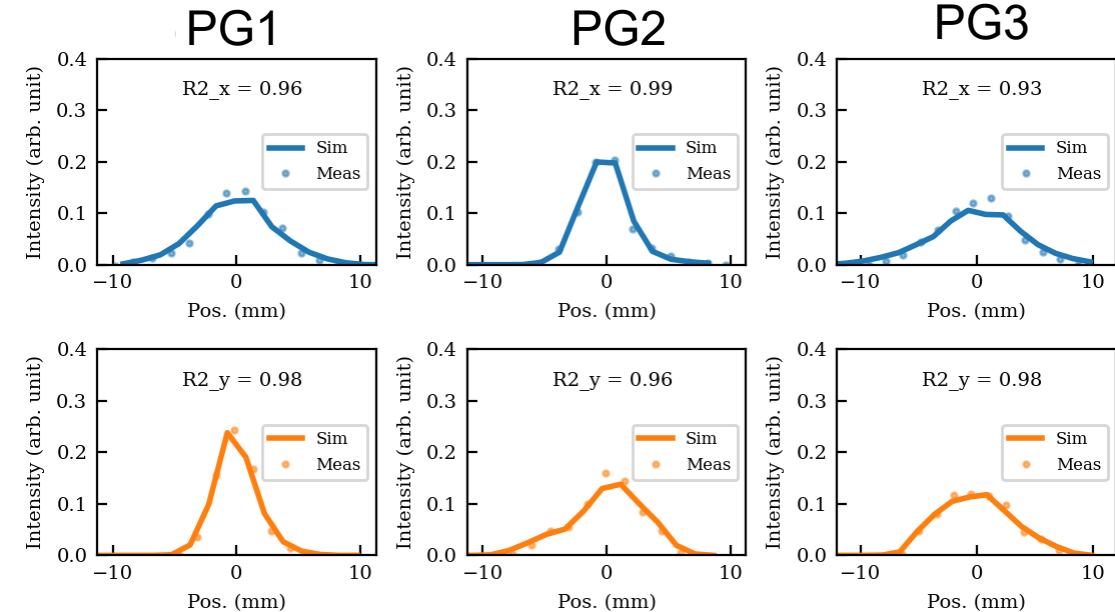
Simulation



Reconstruction: Transversal

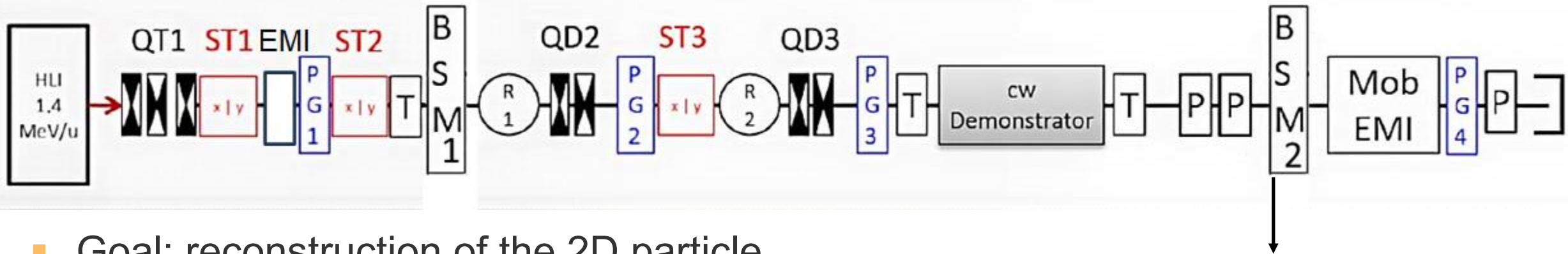


- Beamline quadrupoles settings were changed to observe agreement between simulation and measurement

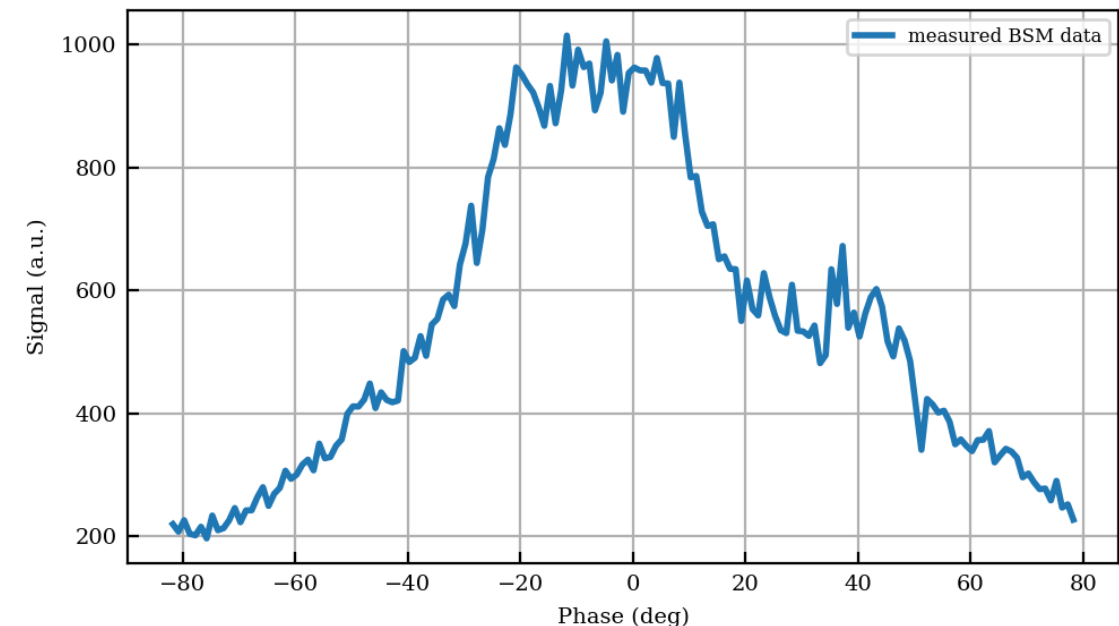


High agreement in transversal plane

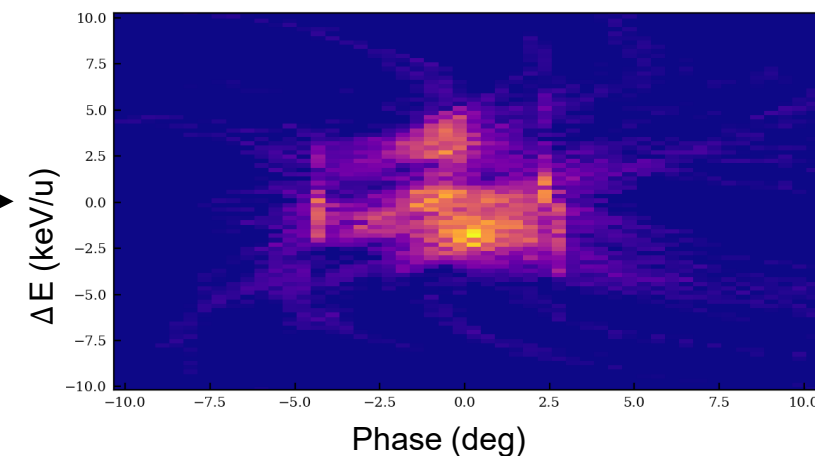
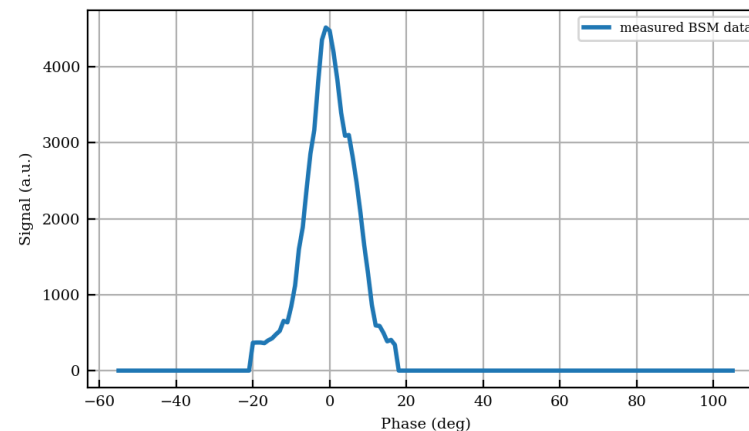
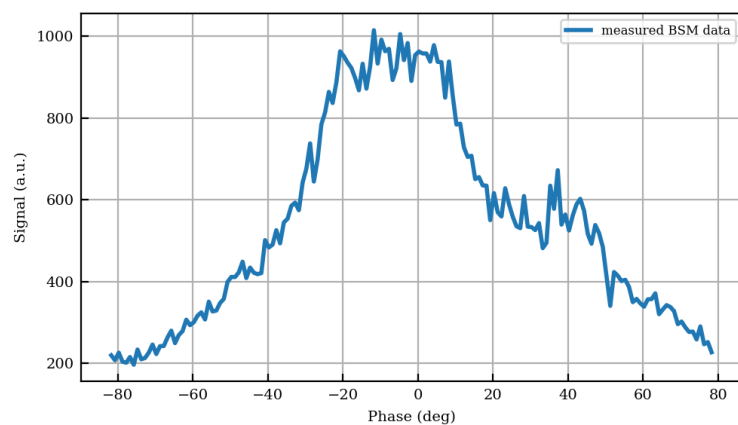
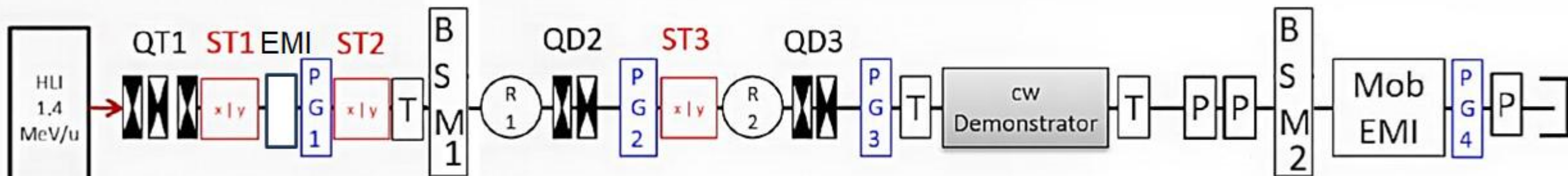
Beam guidance: Longitudinal measurement setup



- Goal: reconstruction of the 2D particle distribution at the HLI output
- The BSM provides only projections of the bunch onto the time axis. Intensity: $I(t)$
- Rebunchers R1 & R2 allow transformation of the bunch
- Measurement at the location of BSM2 for different buncher (R1 & R2)
- BSM1 controls the measurement

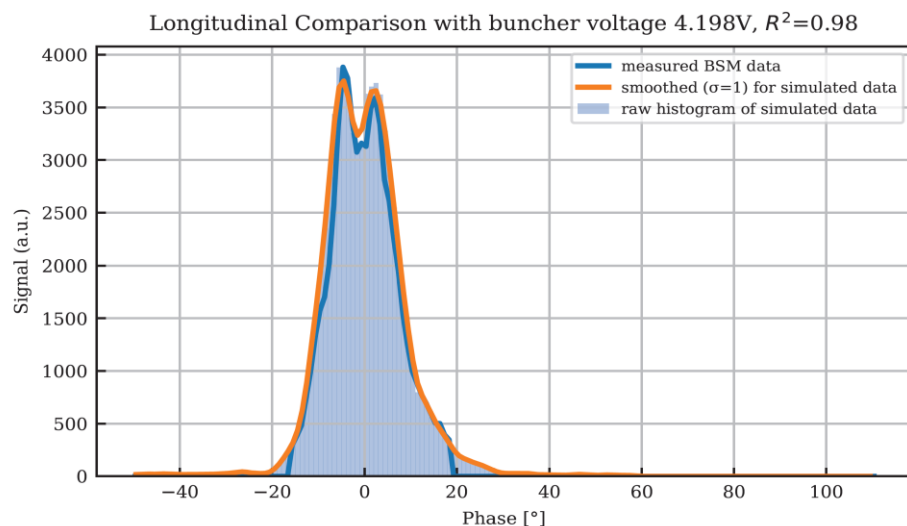
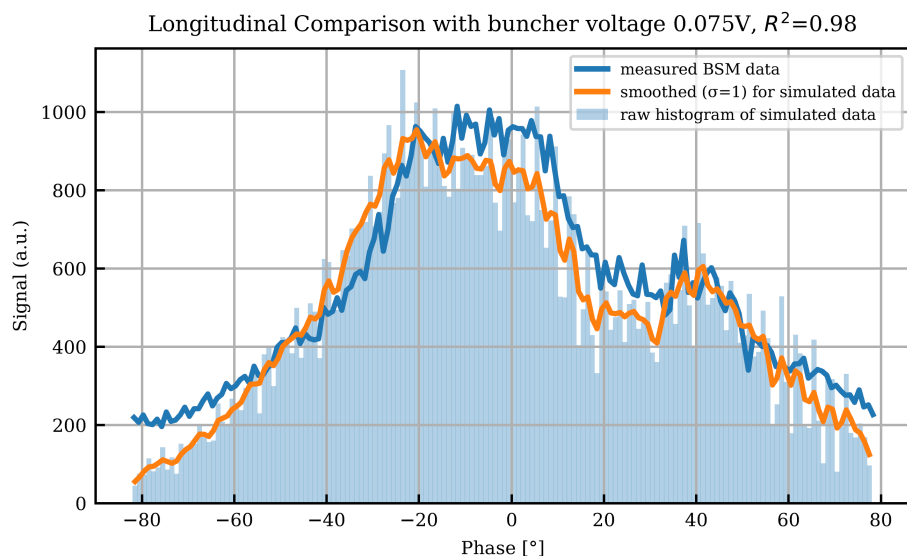


Reconstruction: Longitudinal

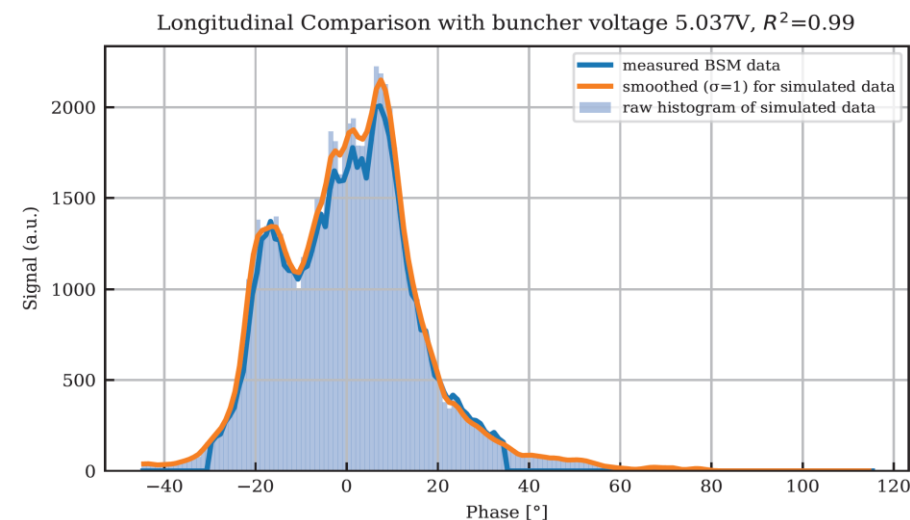
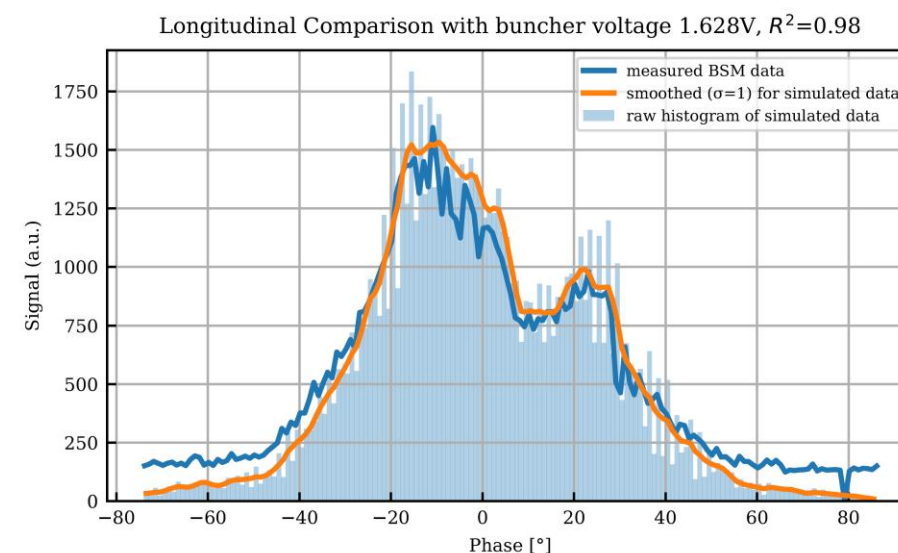


Tomographic reconstruction, Around 40 measurements

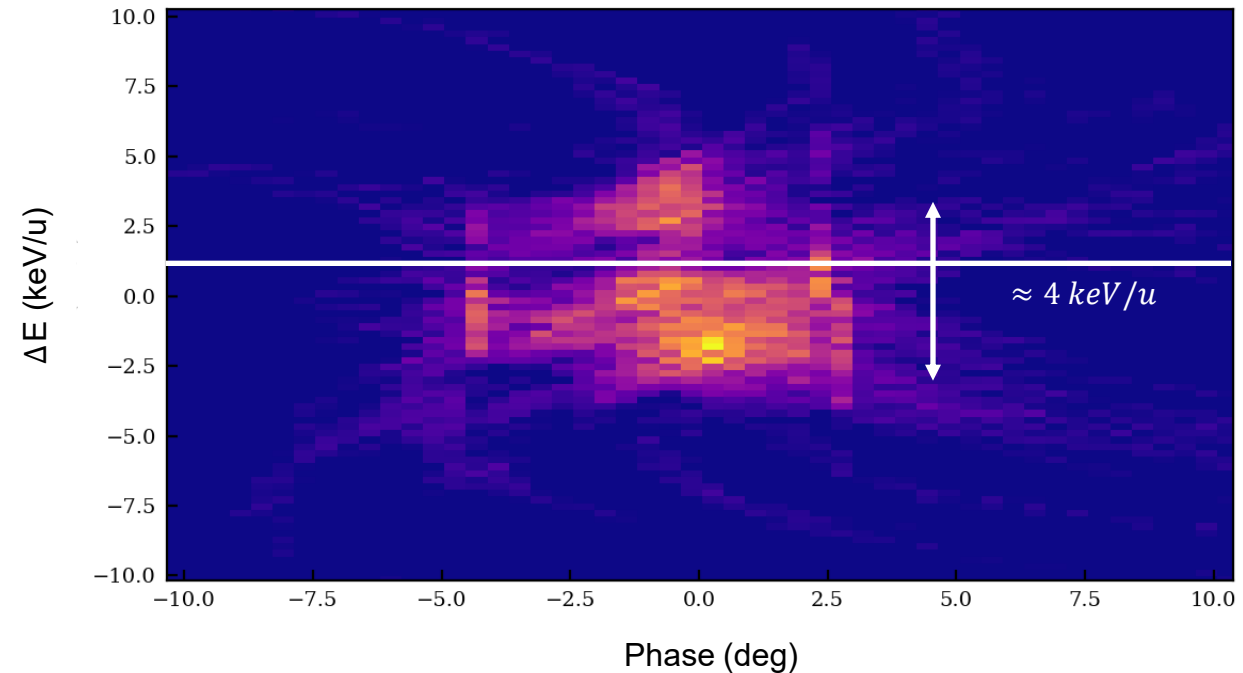
Reconstruction: Longitudinal

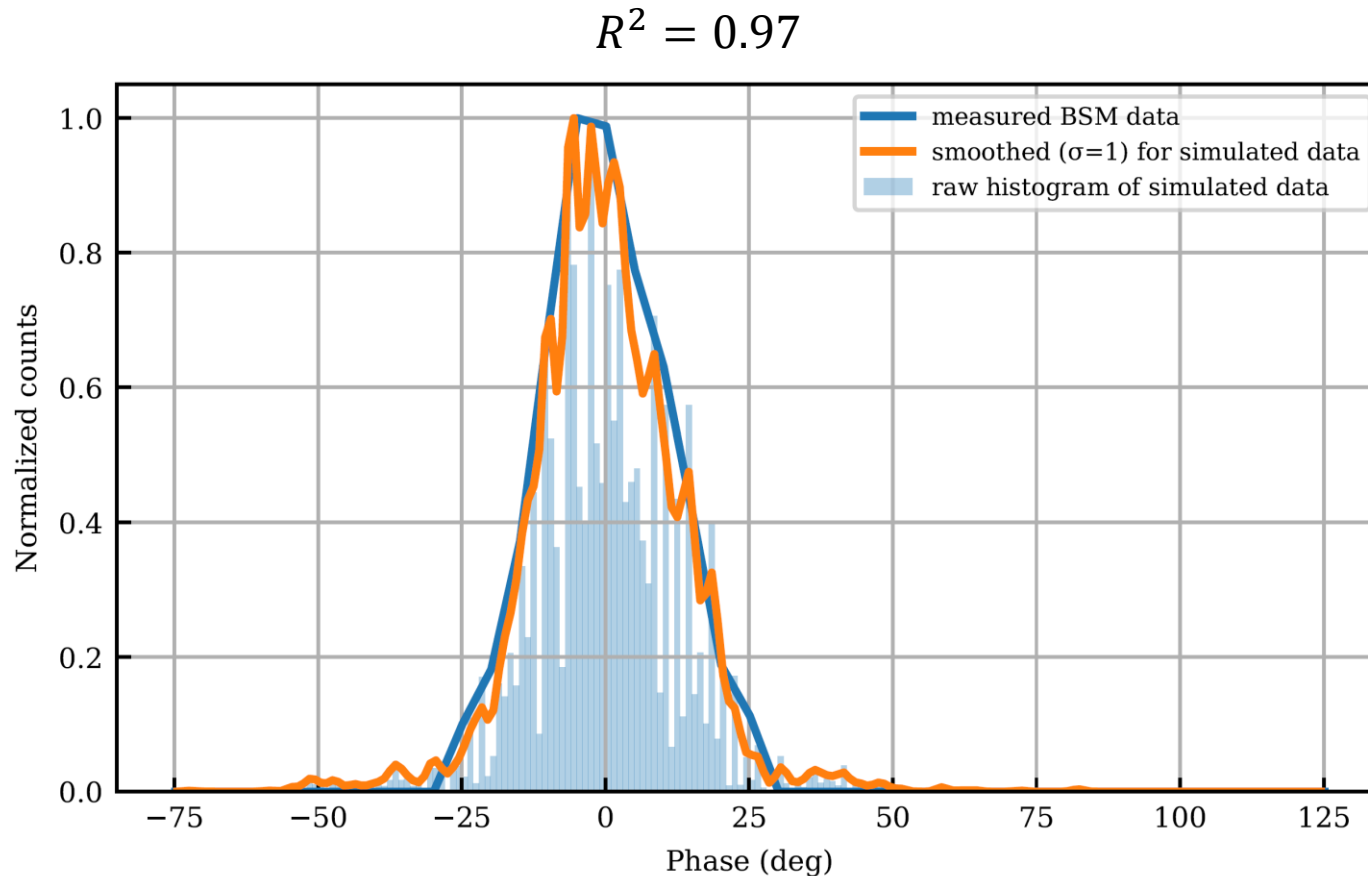


$$\overline{R^2} = 0.98$$



- It is evident that two beams exhibit disparate energy levels
- Approximately 30% of the beams demonstrate an energy deviation that exceeds 1.6 keV/u
- The discrepancy in the beam cores is approximately 4 keV/u
- This corresponds to a phase difference of 16 degrees at BSM1

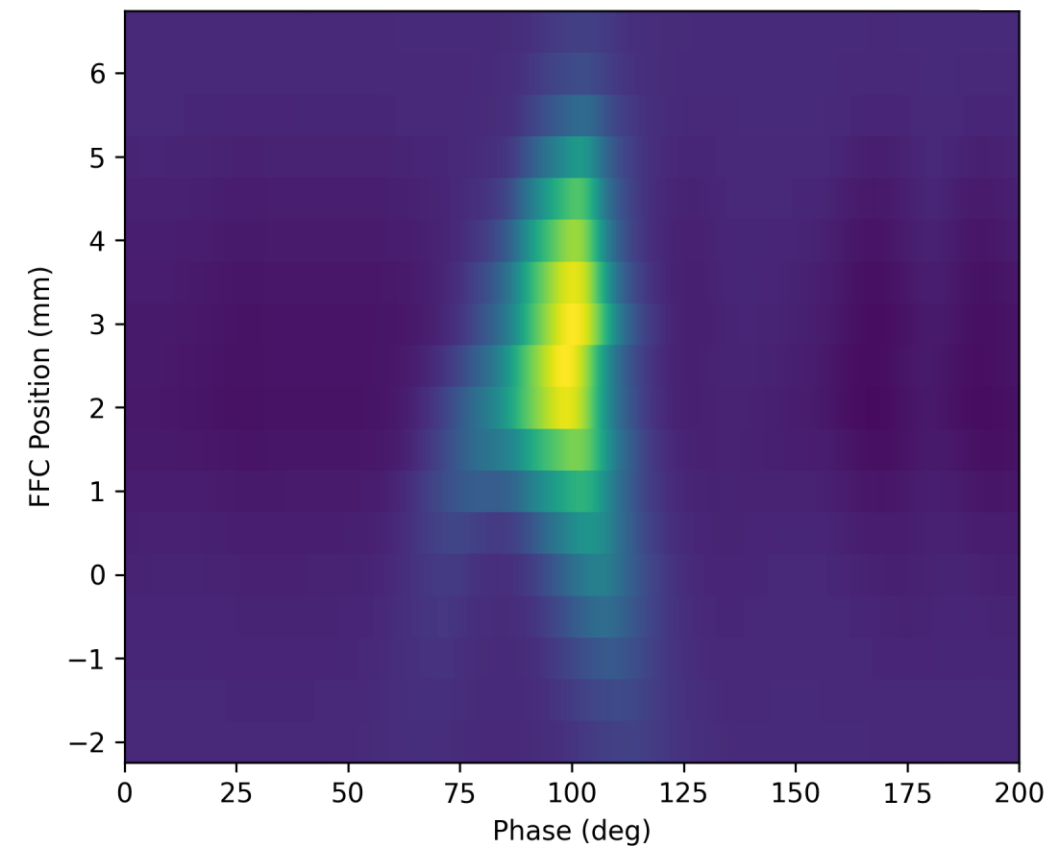




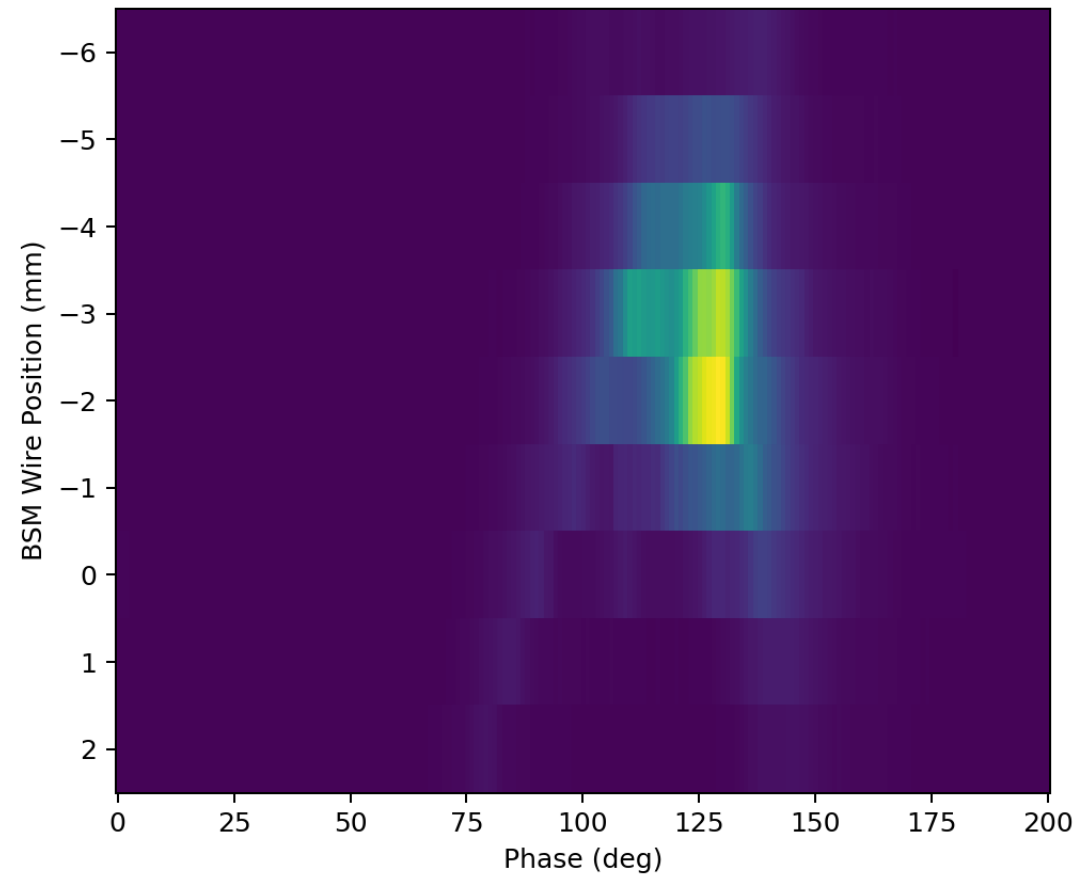
Comparison between simulation and BSM1 measurement

High agreement in longitudinal plane

Transverse-Longitudinal Correlation



FFC measurement for different wire positions



BSM 1 measurement for different wire positions

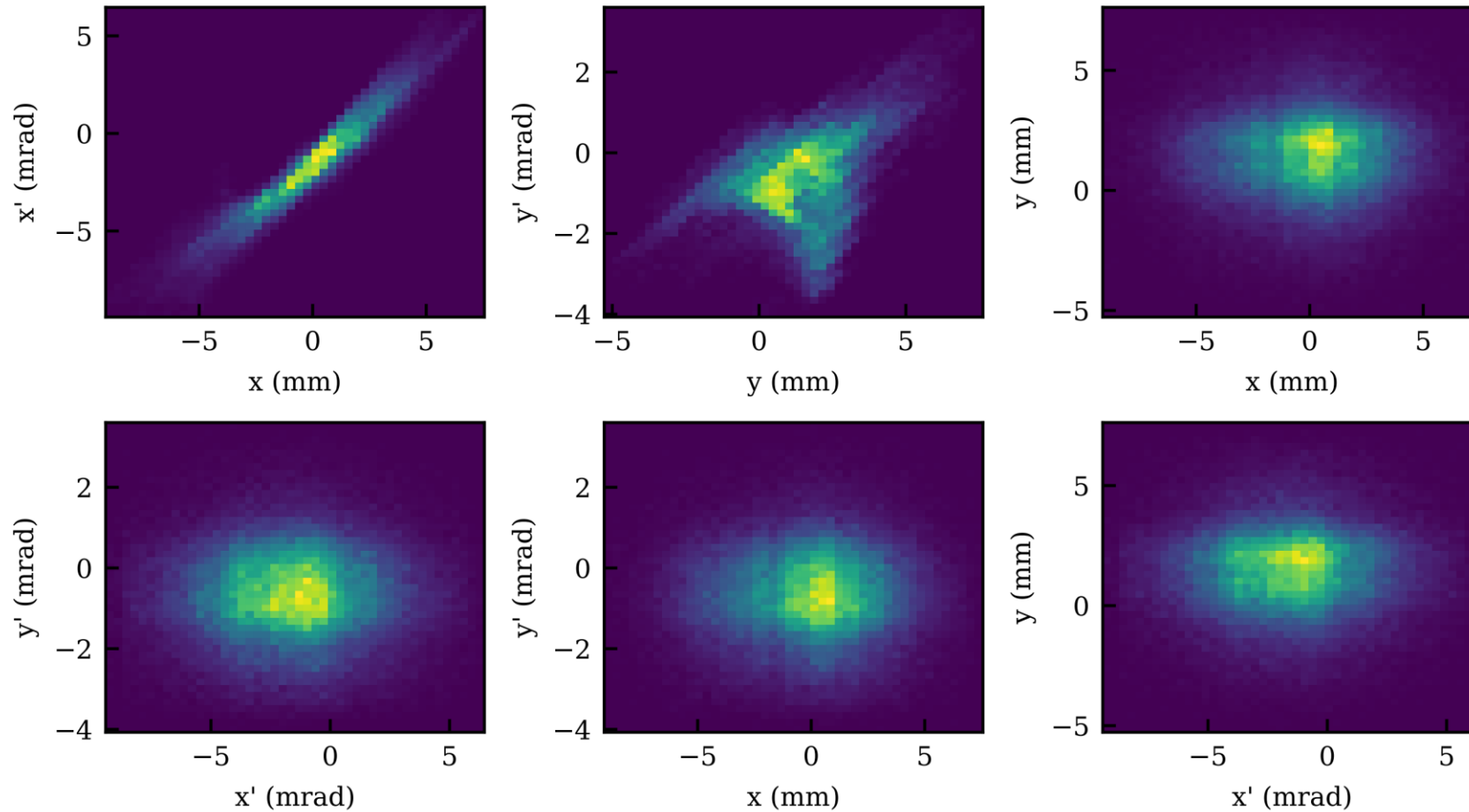
Summary:

- Measured transverse and longitudinal particle distribution
- Reconstructed 6D particle distribution
- Reconstructed distribution is experimentally validated
- Numerical model of beamline is validated

Outlook:

- The search for settings for "UN6/GUCW" beamline which provides 100% transmission through CM1

Transverse Particle Distribution

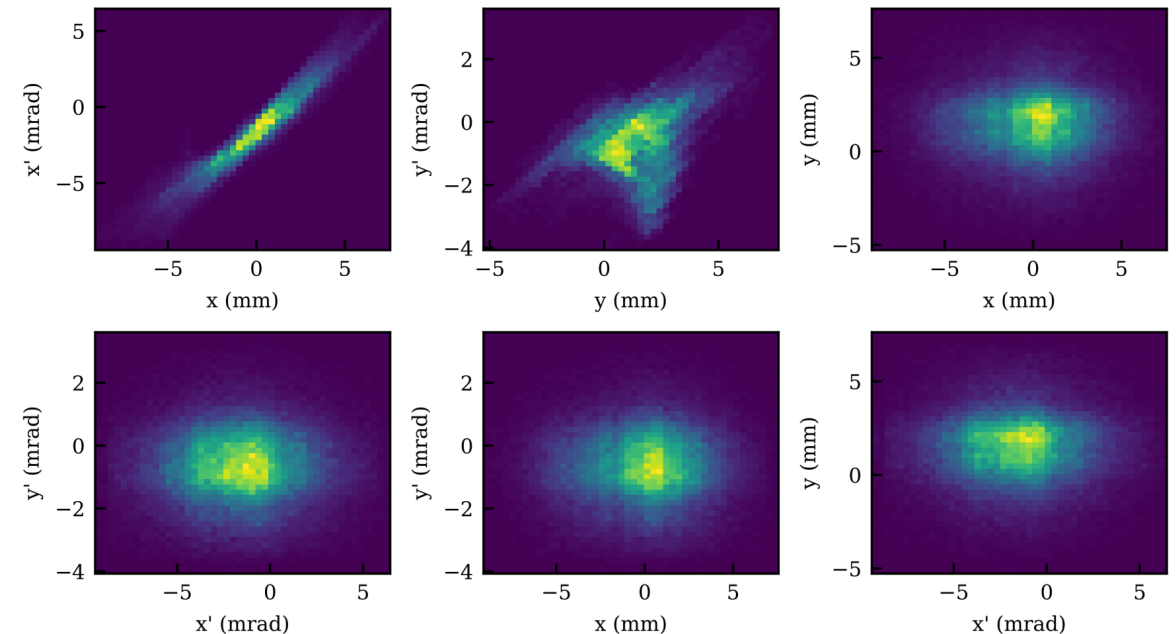


Reconstructed transverse 2D particle projections

Transverse Particle Distribution

Reconstructed distribution shows:

- Beam is not centered
- Beam is inserted oblique
- Beam is divergent and elliptic in horizontal plane
- Unexpected, non elliptic shape in vertical plane
- Unmeasured projections show symmetric and circular shape as expected

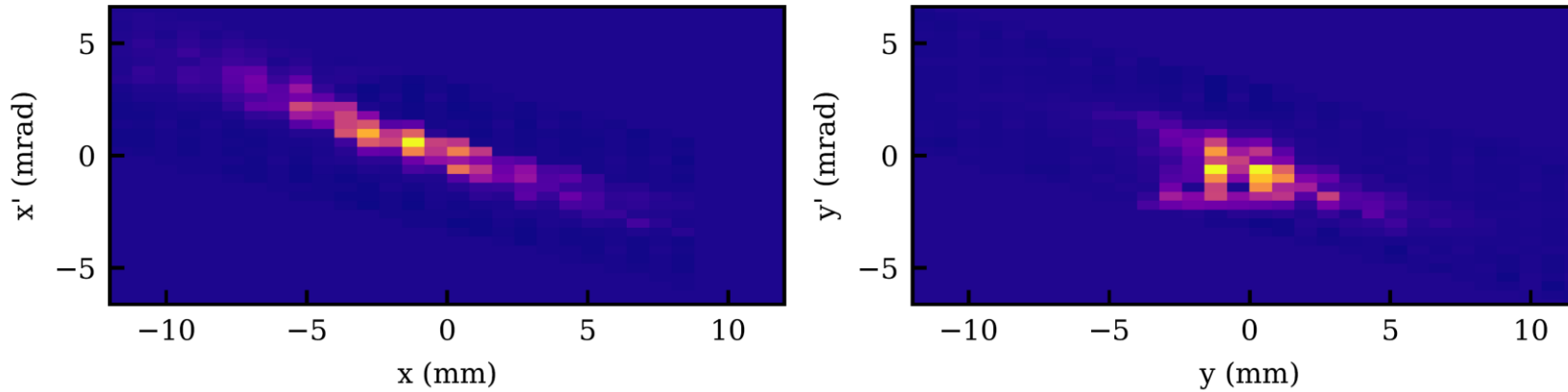


Reconstructed transverse 2D particle projections

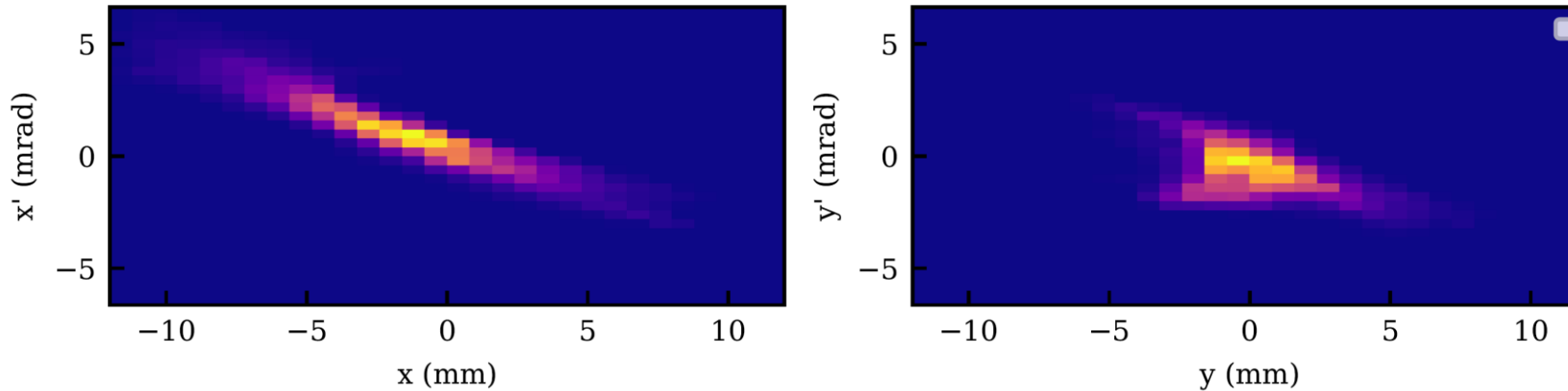
Transverse Validation

Comparison of Measurements and Simulation as Density-Plot

Measurement



Simulation



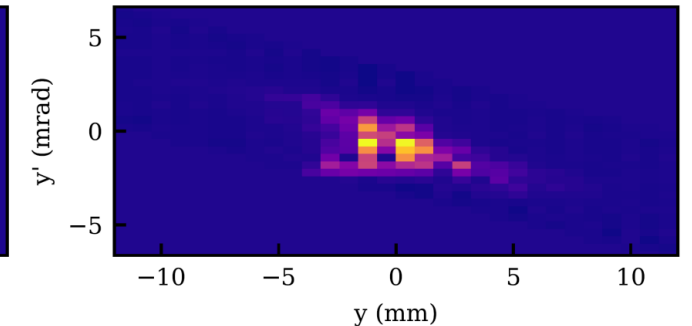
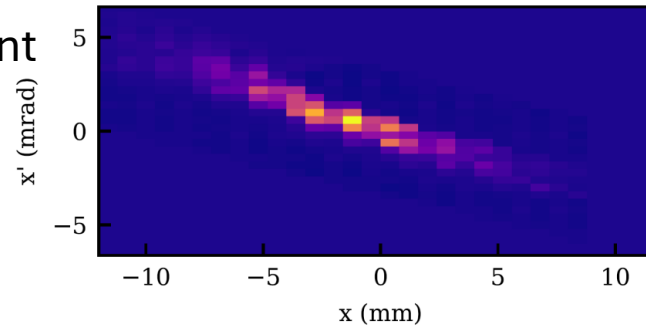
Comparison of phase-space measurement and simulation

Transverse Validation

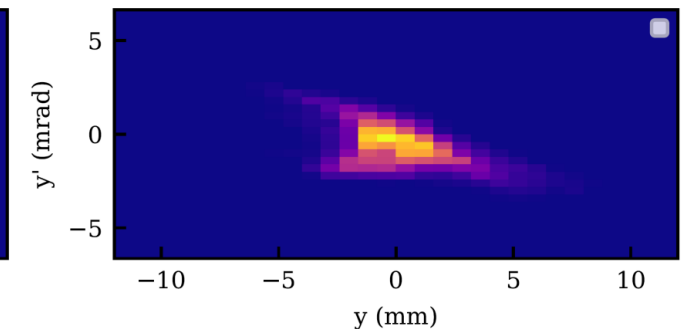
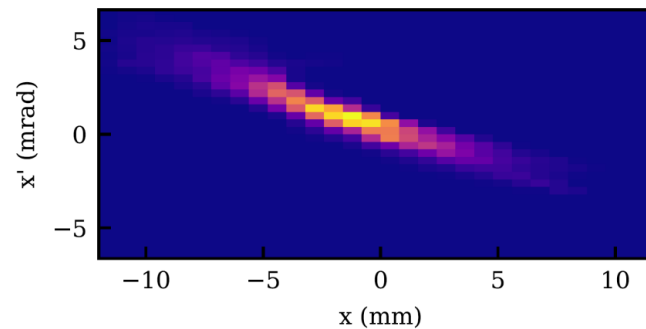
Comparison shows:

- Similar shape in both planes
- Similar intensity at center
- Same offset of center
- Distribution is filled and without holes

Measurement



Simulation

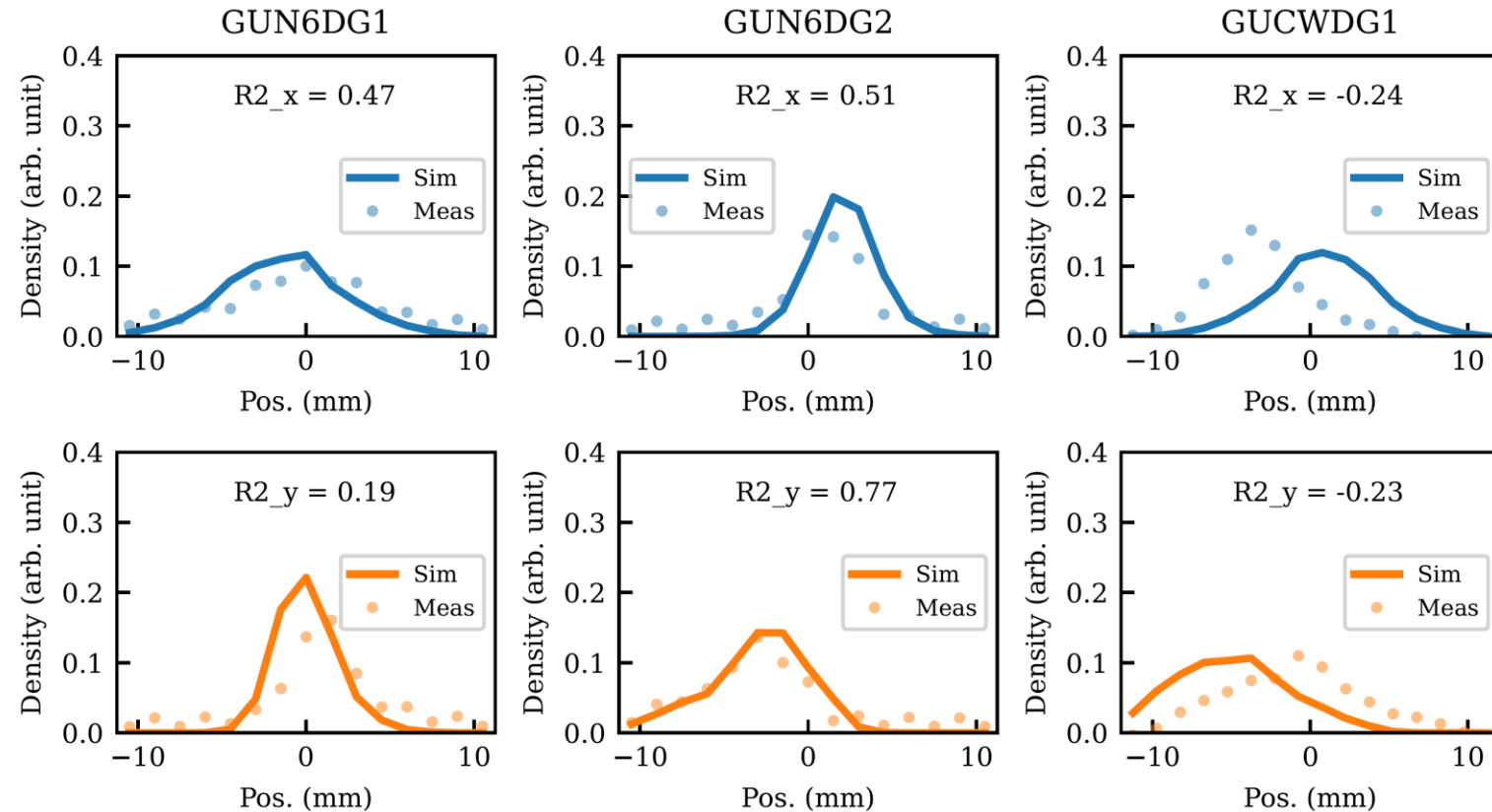


Comparison of phase-space measurement and simulation

Transverse Simulation

$$R^2 = 1 - \sum \frac{(y_{sim} - y_{meas})^2}{(y_{meas} - \bar{y}_{meas})^2}$$

Coefficient of determination

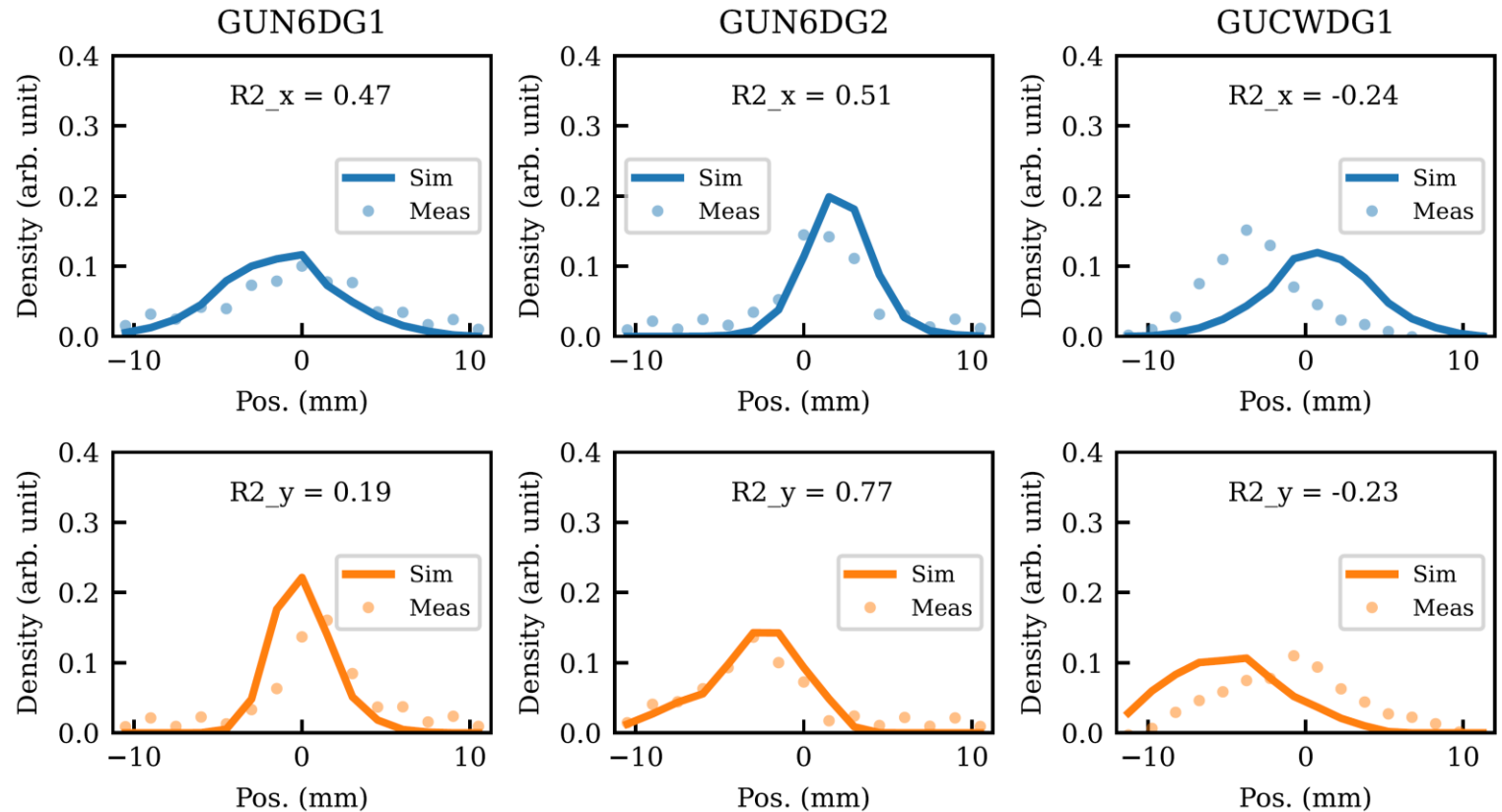


Comparison of simulated and measured profile grids (blue: hor, orange: ver).

Transverse Simulation

Beam Alignment Problems:

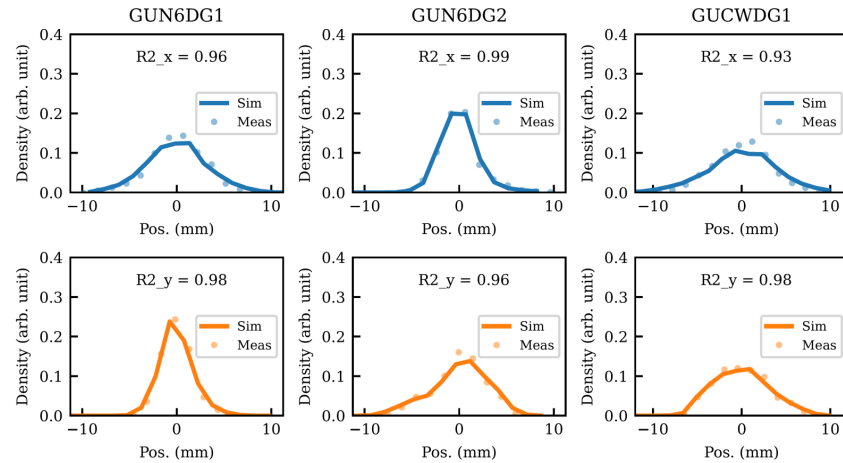
- Wrong steering in simulation
- Expected reason is hysteresis of steering magnets.
- Data needs to be centered for comparison



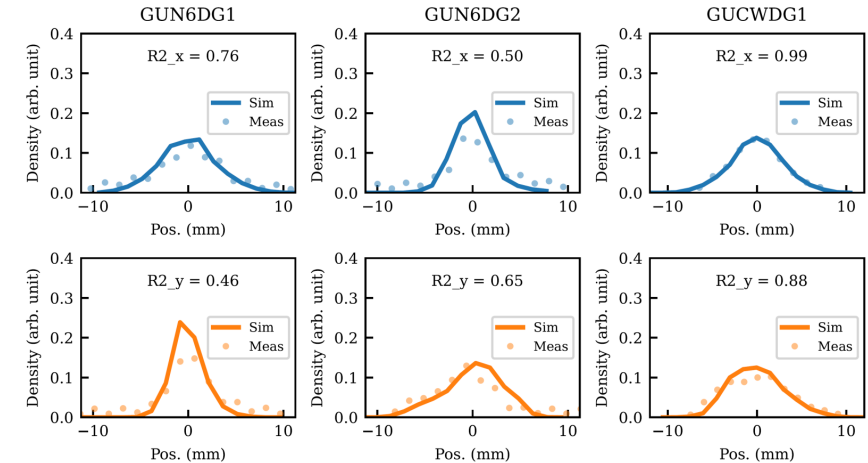
Comparison of simulated and measured profile grids (blue: hor, orange: ver).

Transverse Simulation

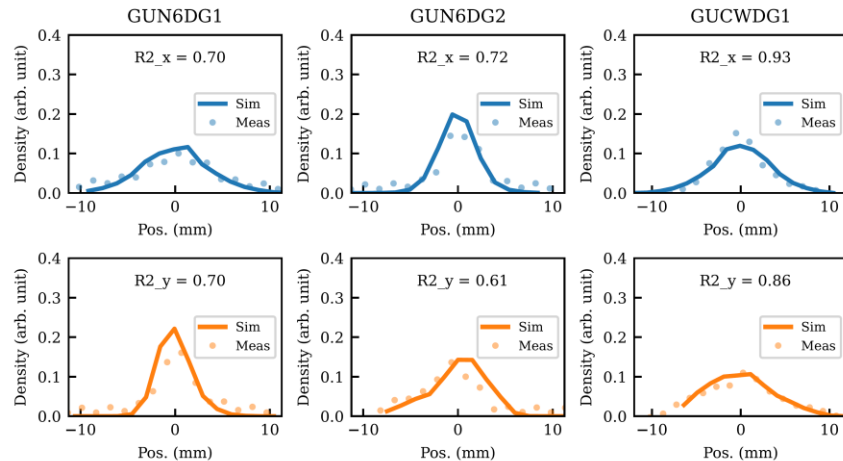
1



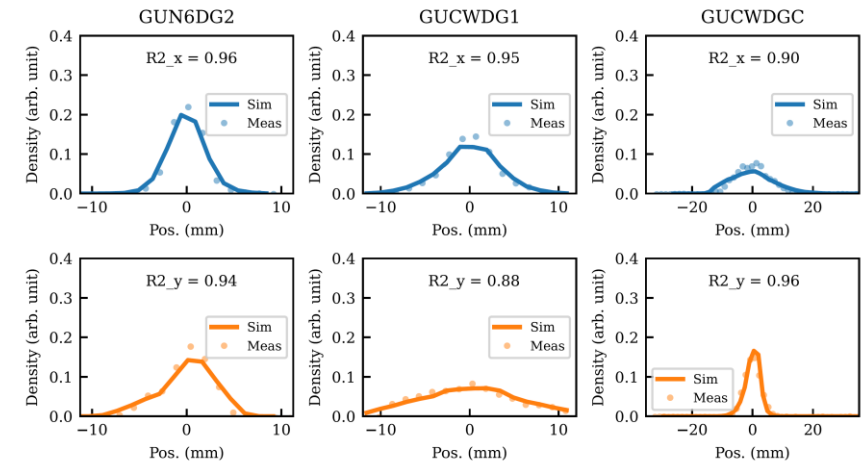
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3

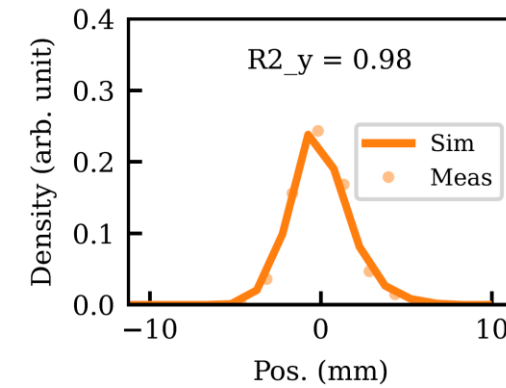
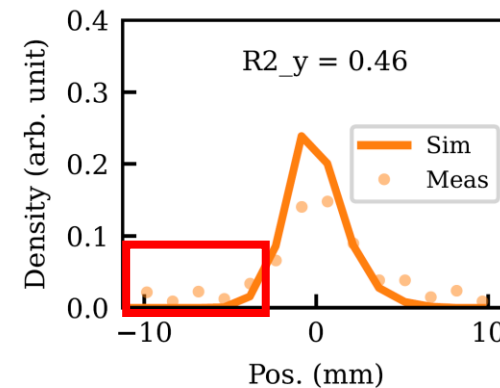
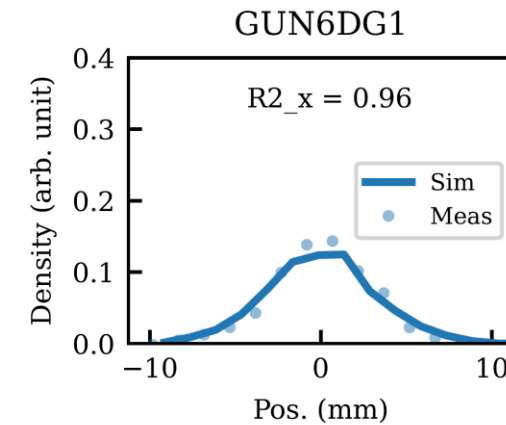
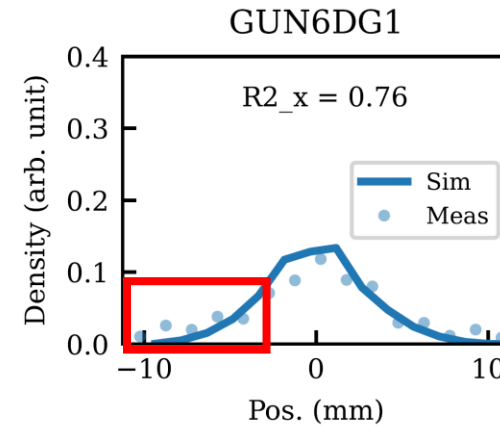


4

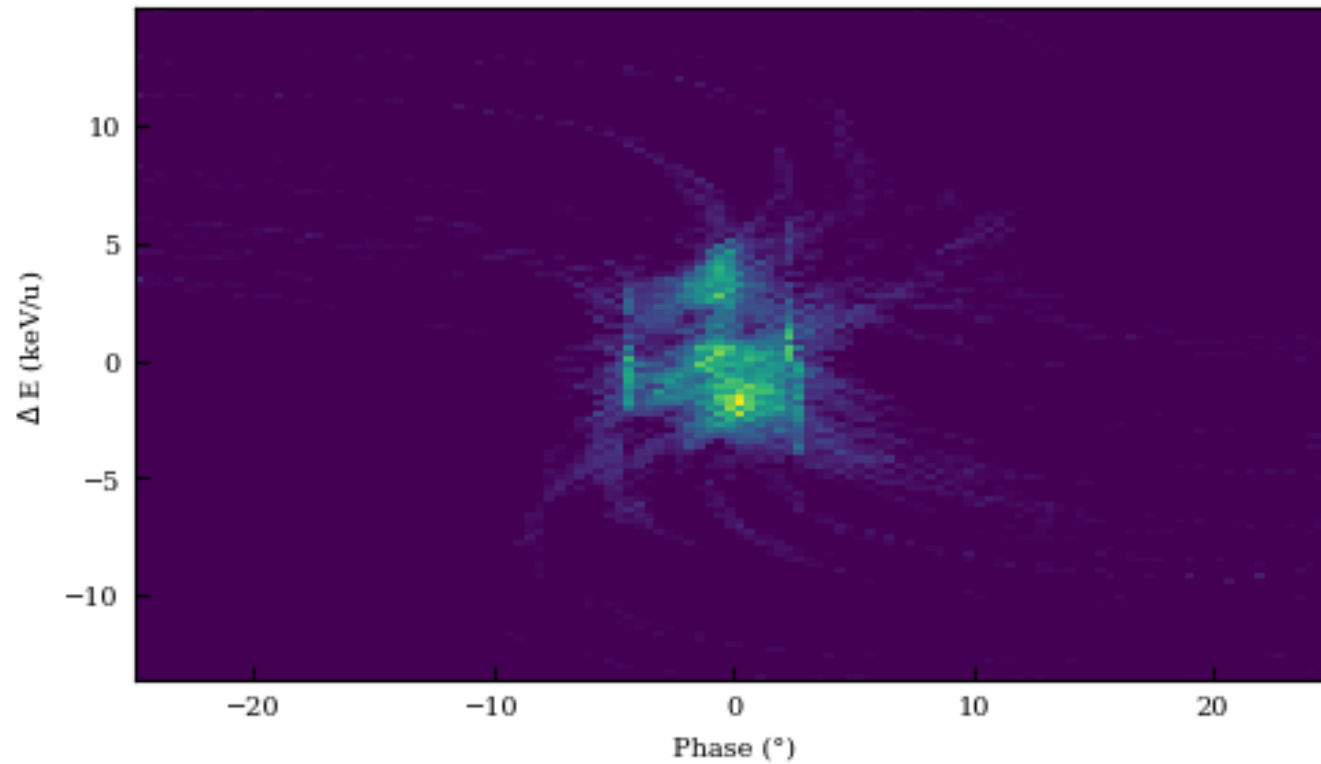


Transverse Simulation

- Profile grid comparison shows:
- Good agreement in total
- Deviation at GUN6DG1/2 for some measurements
- Communication problems with control system
- Influences normalization, resulting in higher deviation and smaller R^2 value
- Measurements without these anomalies have high agreement
- New measurements need to be done without inaccuracies



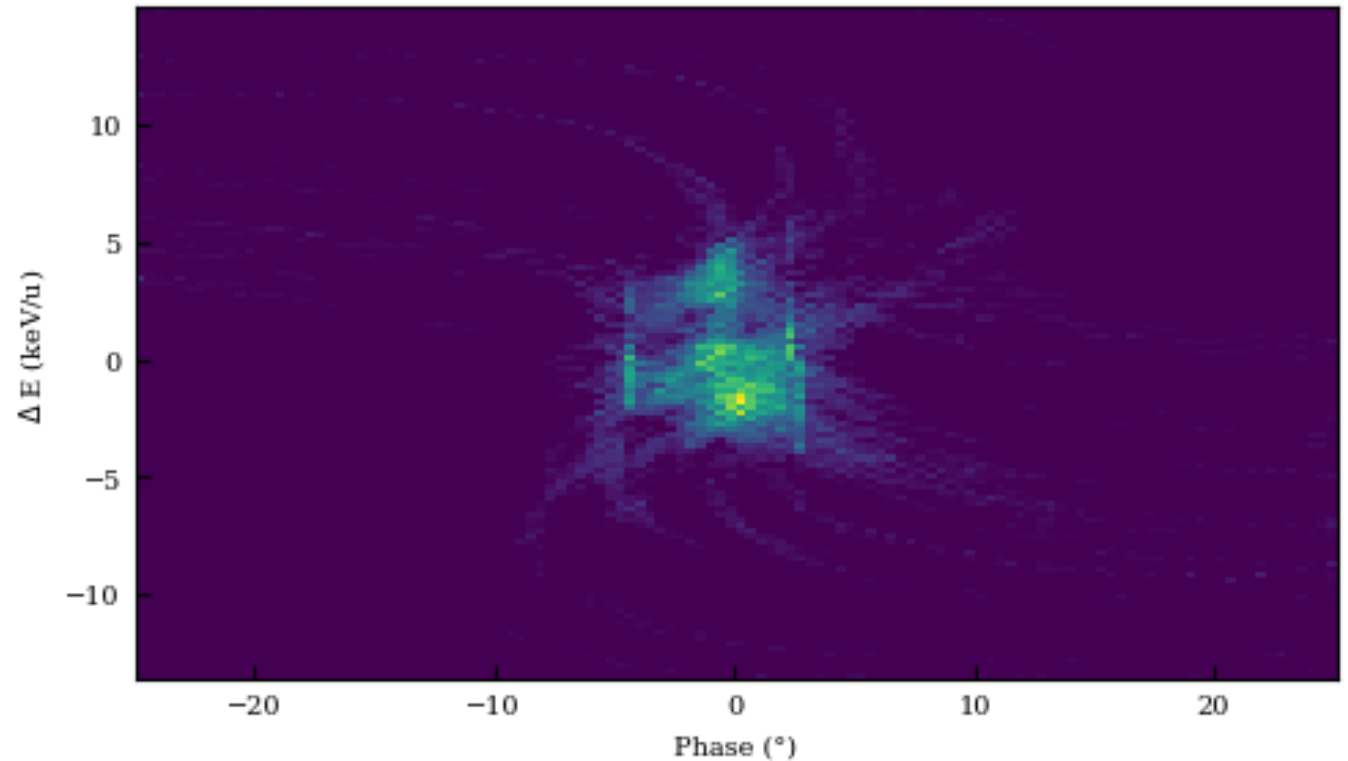
Longitudinal Validation



Reconstructed longitudinal phase-space

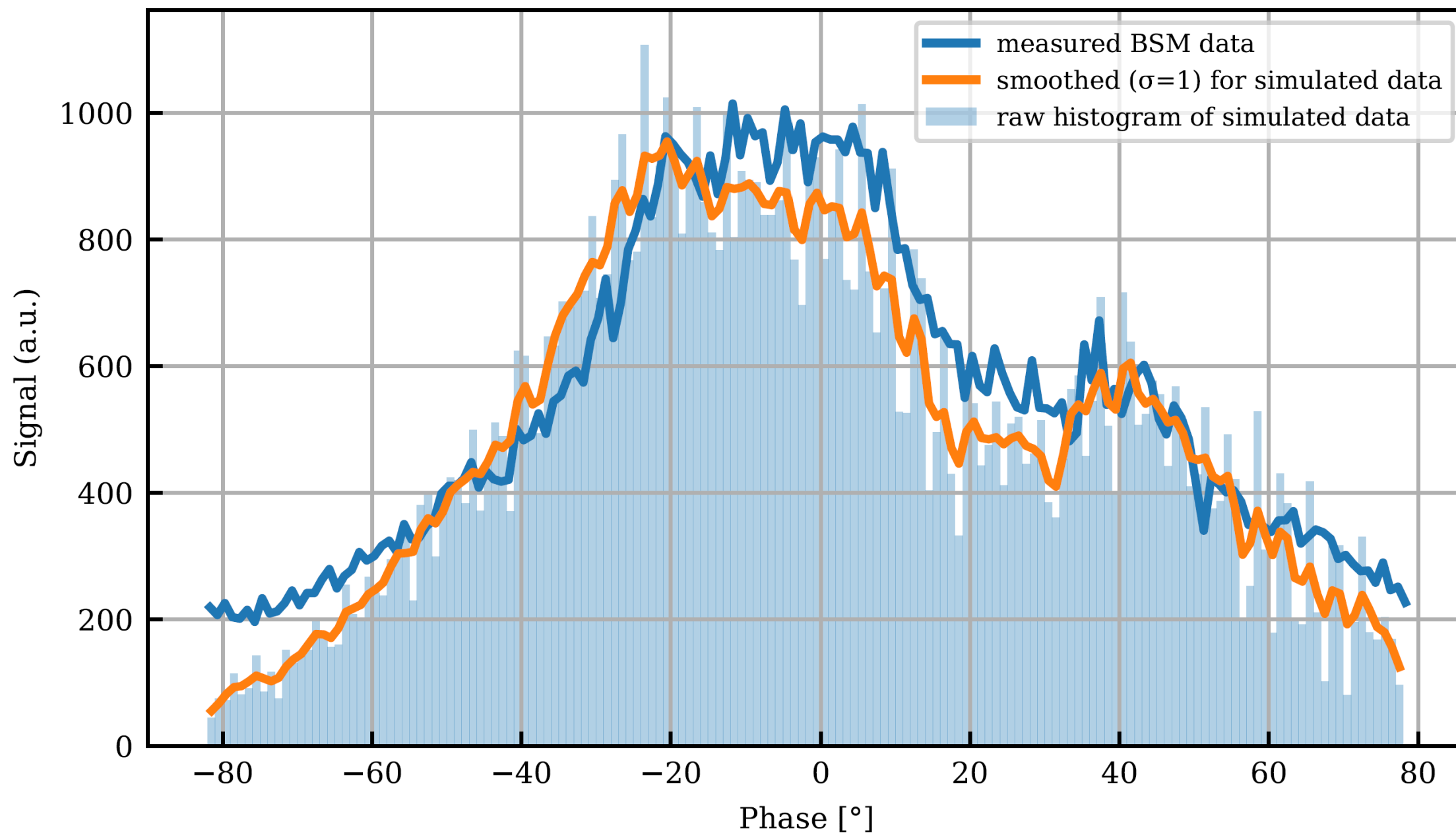
Longitudinal Distribution

- Grid shape visible
- Asymmetric shape
- Multiple tails
- Center around $\Delta E = 0$
- Small part deviates for $\Delta E = 0$, seems like a second beam with higher energy

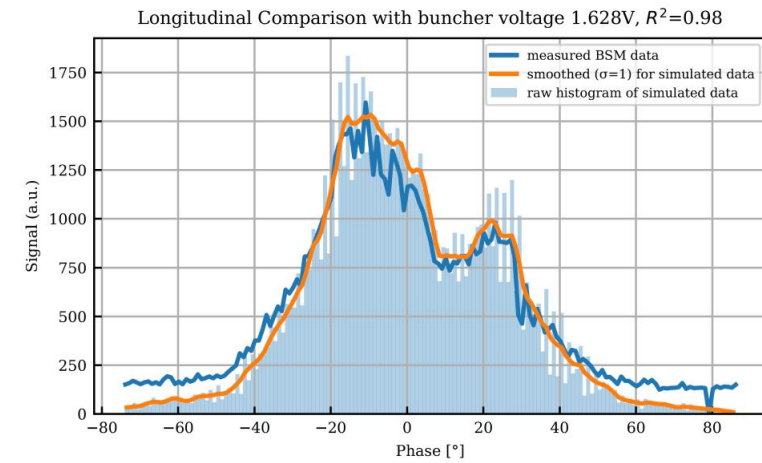
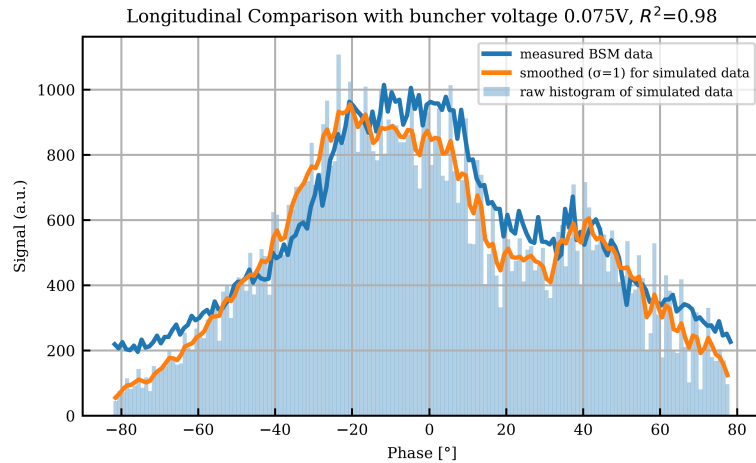


Reconstructed longitudinal phase-space

Longitudinal Comparison with buncher voltage 0.075V, $R^2=0.98$



Longitudinal Validation



$$\overline{R^2} = 0.98$$

