(ON GOING)

4D COUPLED TRANSVERSE PHASE SPACE INVESTIGATIONS AT PITZ.

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DESY PITZ

24.06.25

HELMHOLTZ

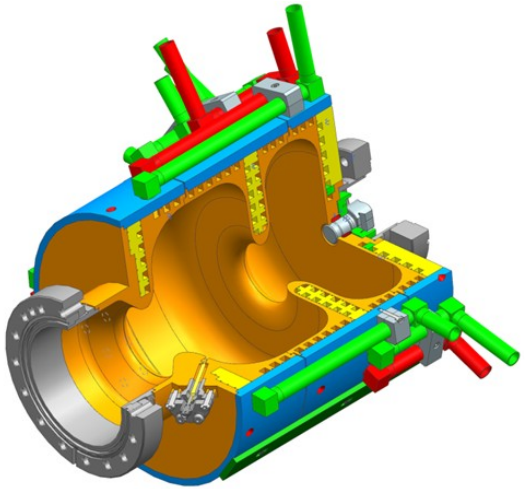
DESY.

Photo Injector Test facility at DESY in Zeuthen (PITZ)

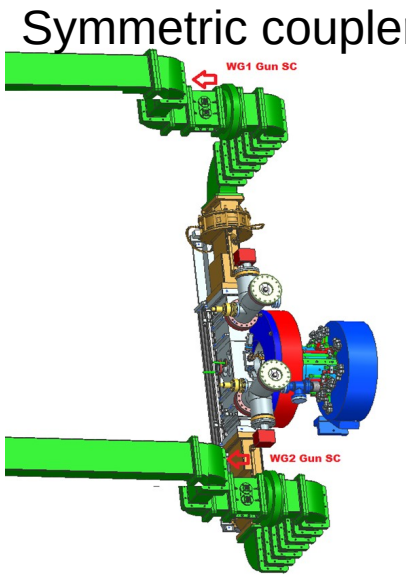
Main goal: Provide optimized electron sources for FLASH and European XFEL

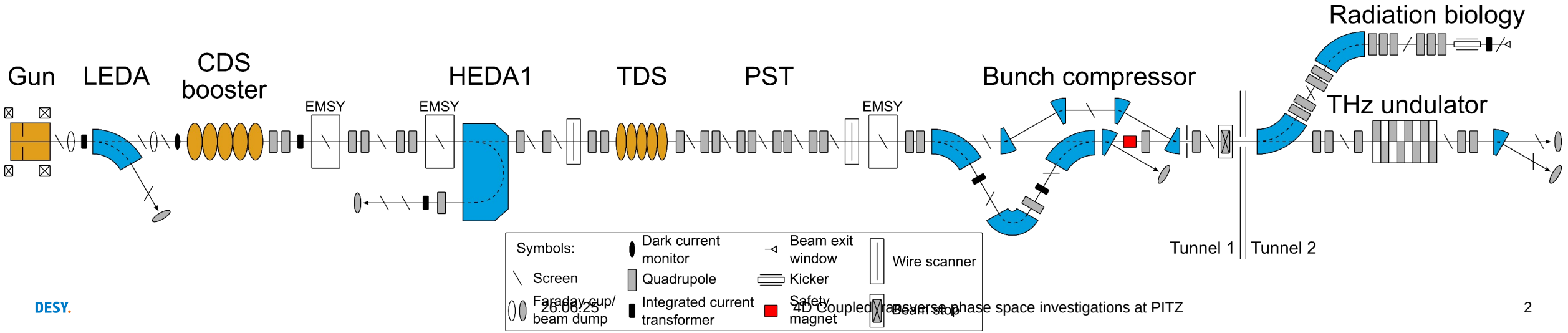
Beam characterization

- Momentum – low and high energy disperive arms
- Bunch size – scintillating screens
- Bunch length – TDS
- Longitudianl phase space – TDS, tomography
- Transverse phase space – Slit-screen scans



Gun 5.2



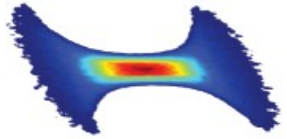


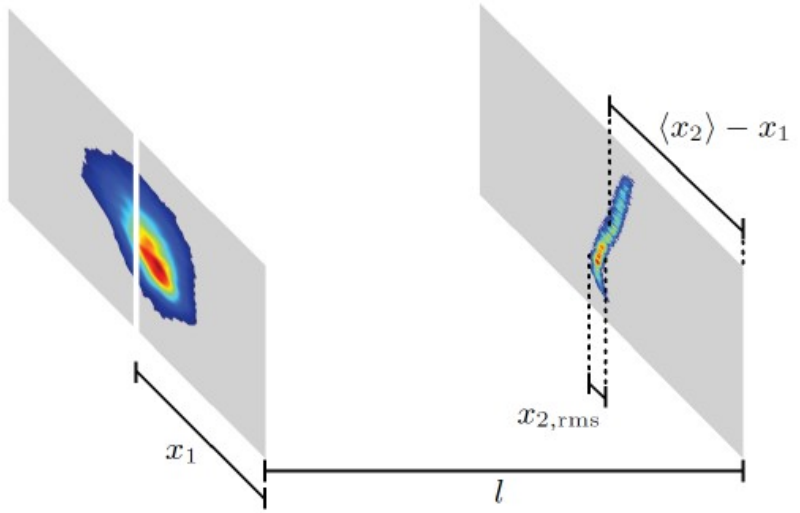
2D phase space measurements

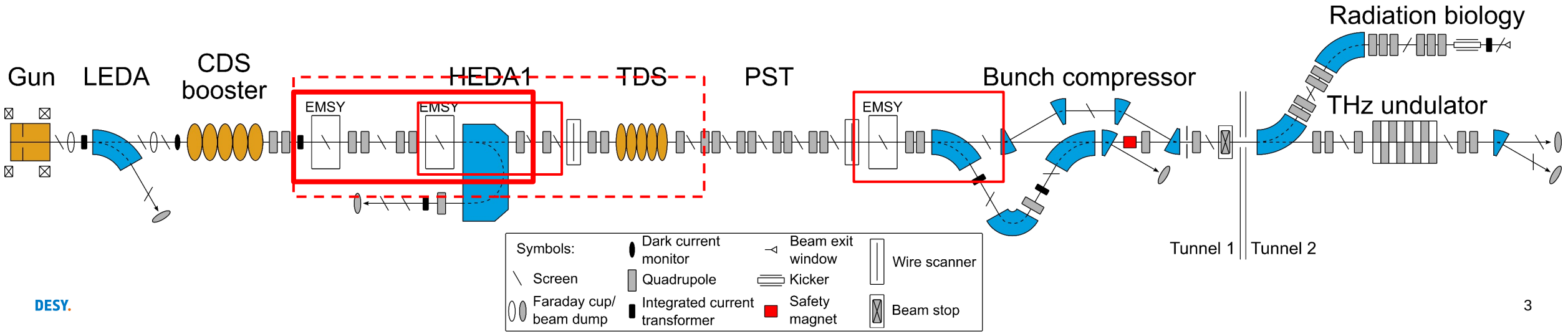
Use slit-screen method to measure the X and Y phase spaces

Beam characterization

- Insert slit into beam. Measure beamlet profile downstream with screen.
- Beamlet profile is dominated by divergence at the slit → use to reconstruct the angle profile
- Step slit through the beam to measure local angle profiles across the whole beam
- Combine profiles to reconstruct the phase space







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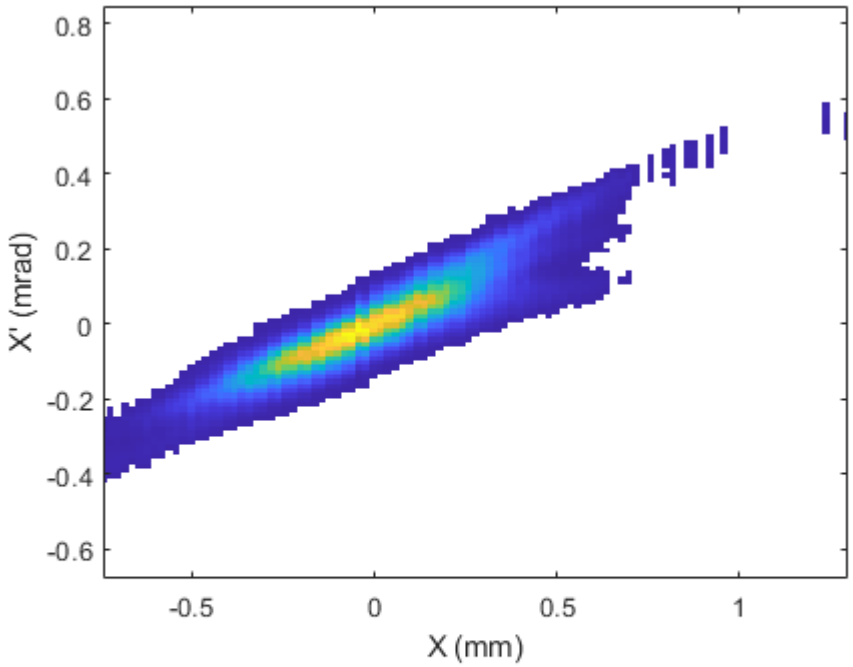
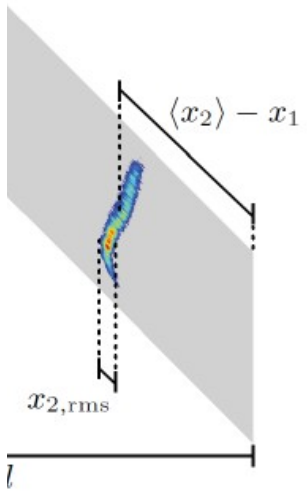
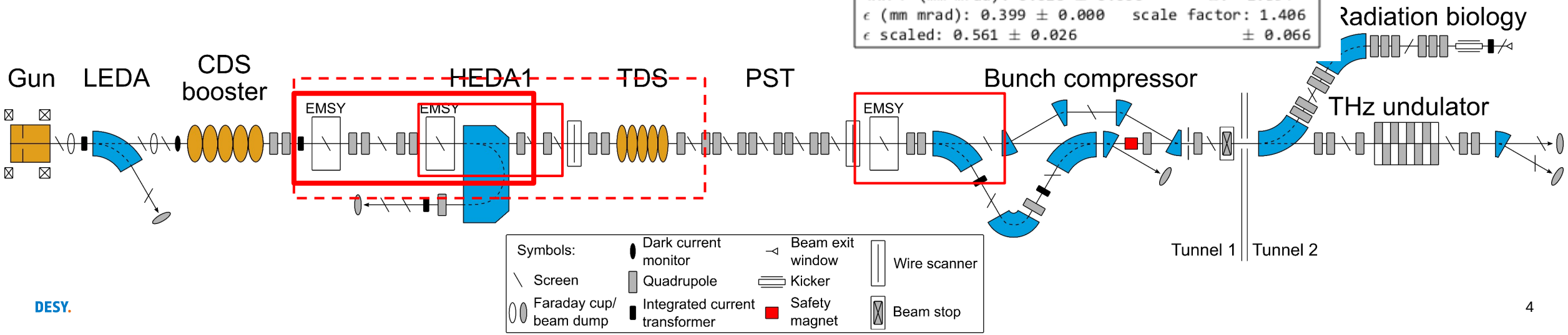





```
X rms (mm): 0.245 ± 0.000          β: 5.446
X' rms (mrad): 0.117 ± 0.000       γ: 1.236
<XX'> (mm mrad): 0.026 ± 0.000     α: -2.394
ϵ (mm mrad): 0.399 ± 0.000   scale factor: 1.406
ϵ scaled: 0.561 ± 0.026                ± 0.066
```



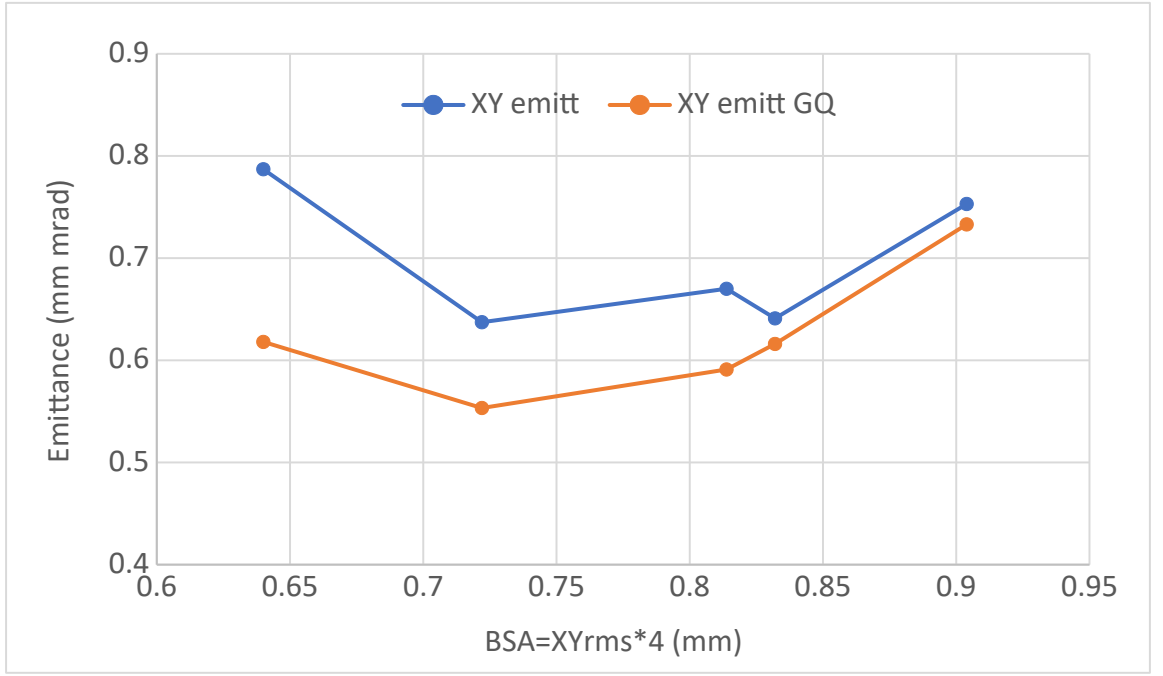
Optimizing 2D emittance [1]

Gun quads reduce emittance but keep x-y disparity

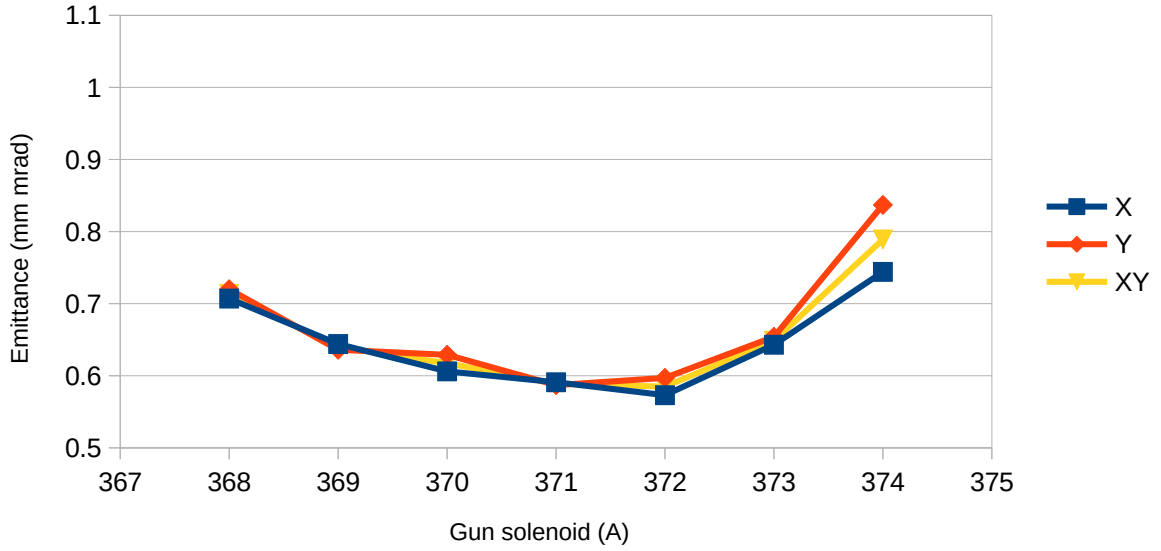
Optimization procedure: Scan gun solenoid and laser spot size to find lowest emittance

Standard practice: symmetrize beam size with normal and skew quad near exit of the gun

- Typically see some difference between X and Y emittances, but it is removed when the X and Y beam sizes is symmetrized
  - This was the case for gun 5.1 and previous generations
- For gun 5.2, this procedure significantly reduced the emittance
  - But X-Y disparity remains → Problem was caused by a change in the beamline from gun 5.1 to 5.2



Gun 5.1 with gun quads - 01.2023



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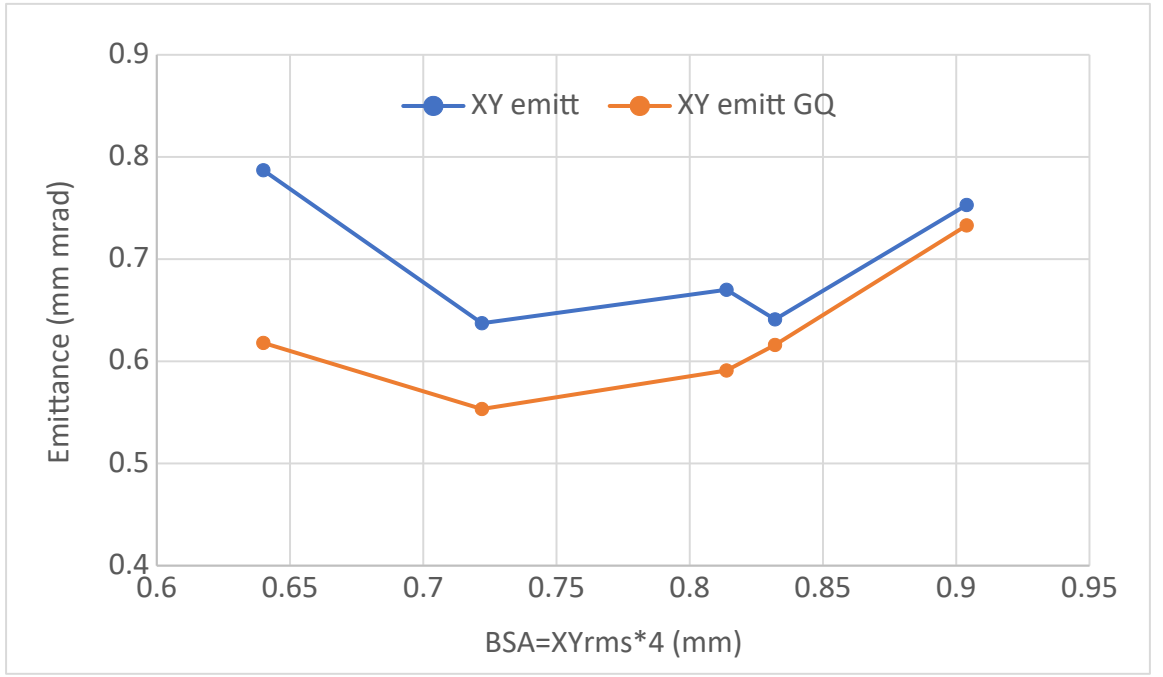
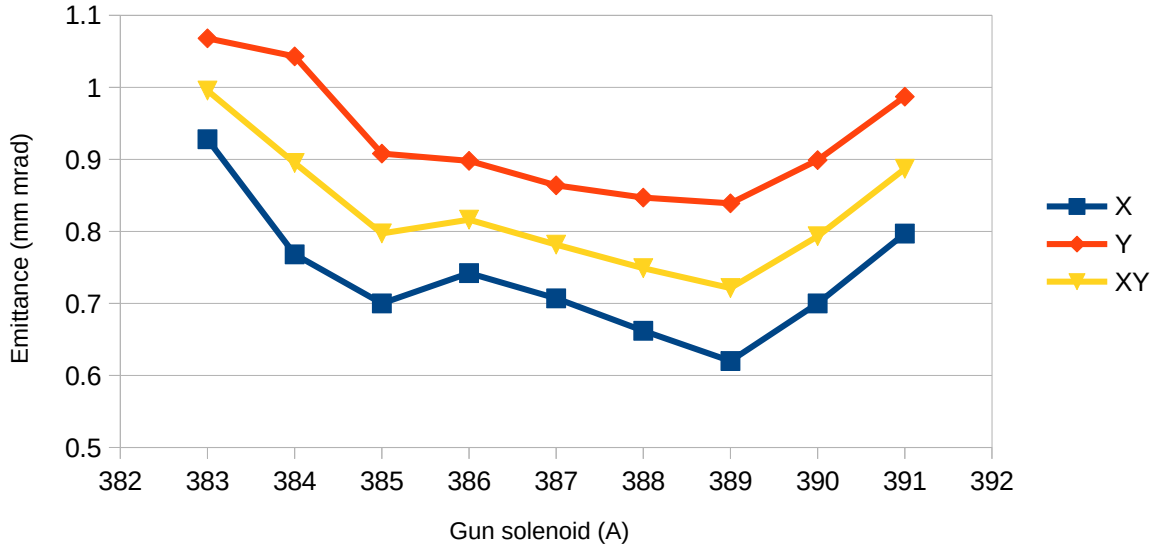


Gun 5.2 with gun quads - 06.2025



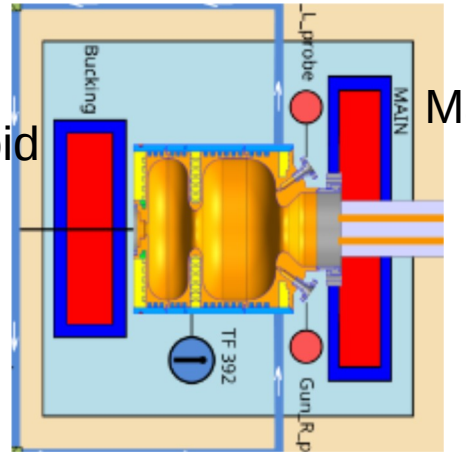
Attempts to optimize 2D emittance [2]

Bucking coil on gun 5.2 was was exchanged due to vacuum leak

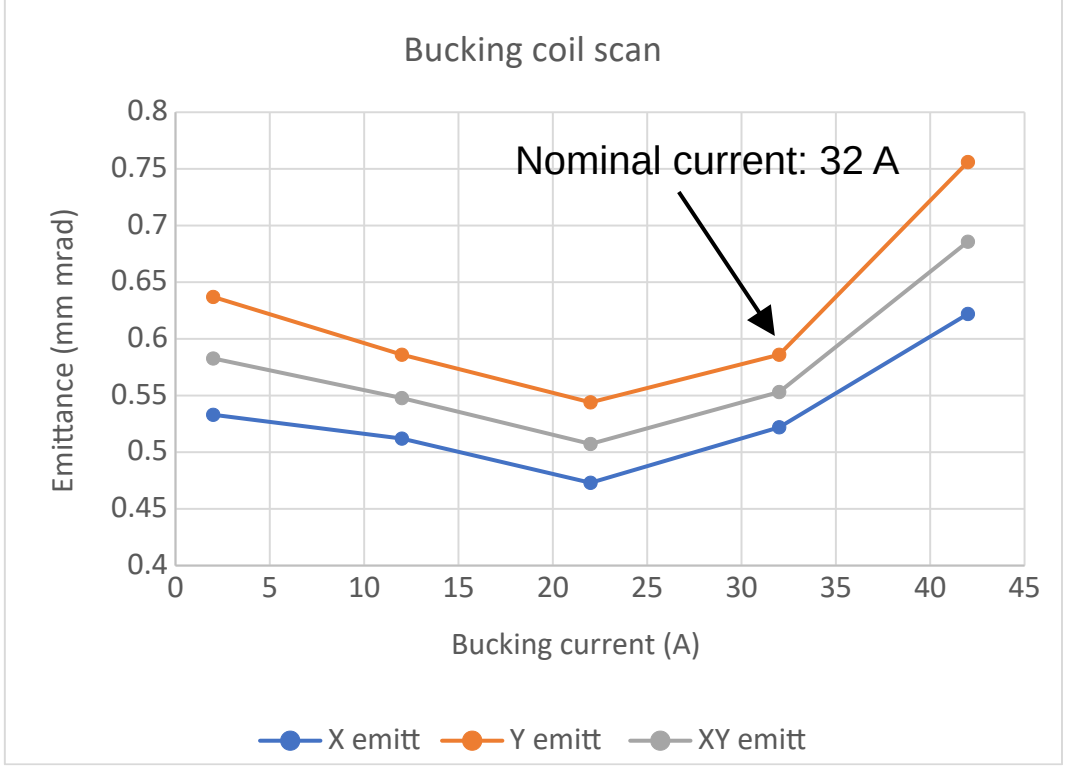
There is a bucking solenoid behind the gun to ensure zero magnetic field on the cathode

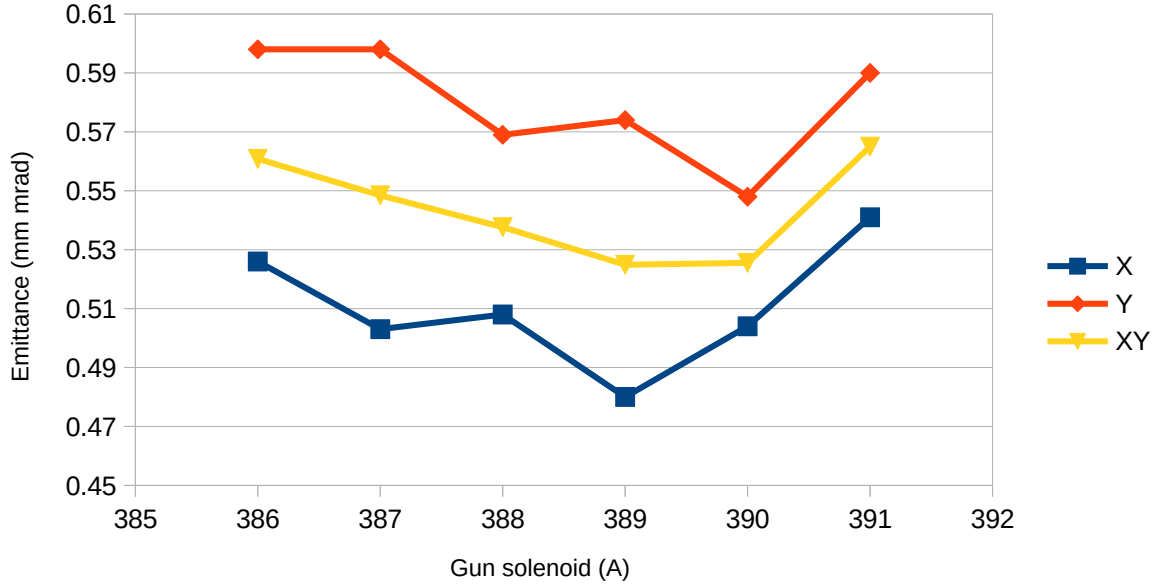
- This magnetic was recently exchanged.
  - Field from the new magnet may be different → Need new working set point
- Scanning the bucking coil current shows some improvement to the emittance
  - But still doesn't remove the X-Y disparity

Bucking solenoid



Main solenoid



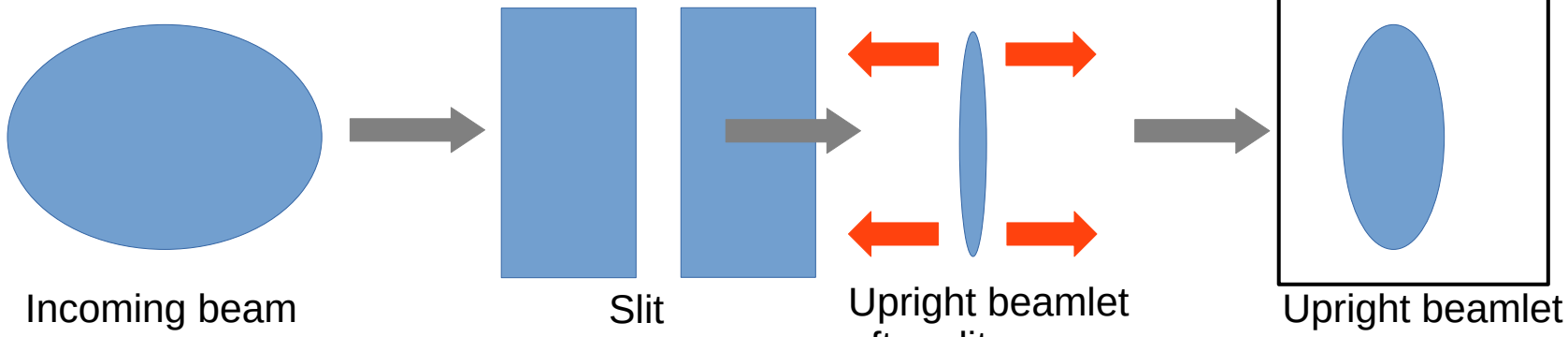


Tilted beamlets

Many measurements have tilted beamlets → 4D coupling

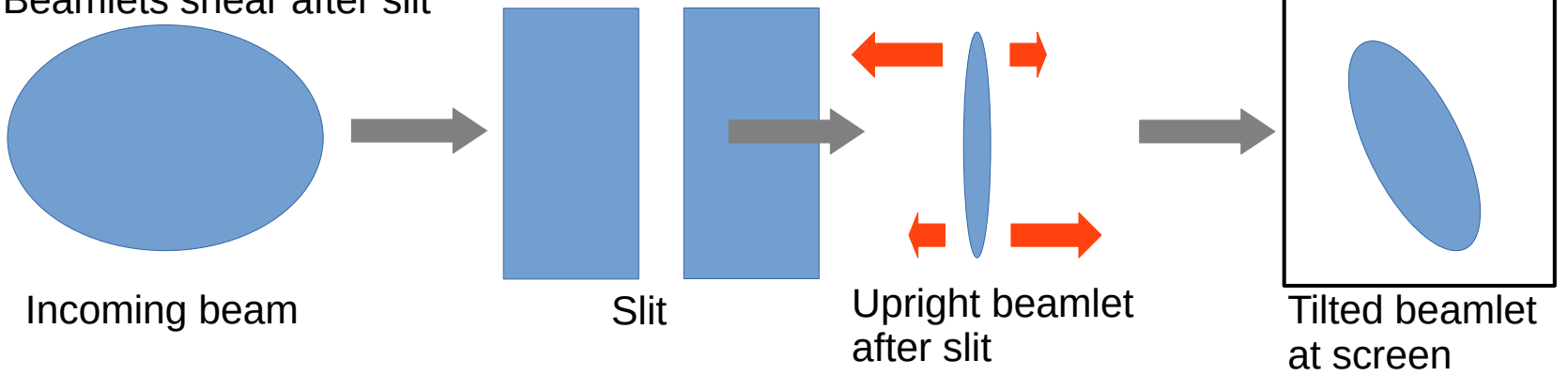
Uncoupled beam

- X angle is independent of Y (and vise versa)
- Beamlets expand uniformly after slit → stays vertical/horizontal

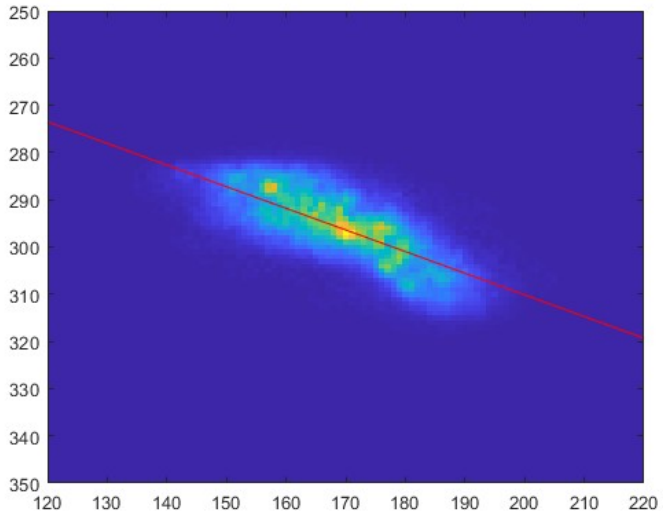


Coupled beam

- X angle is dependent on Y (and vise versa)
- Beamlets shear after slit



Measured beamlet

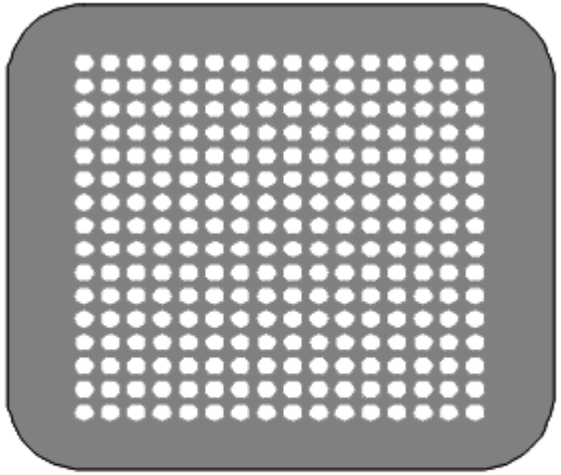


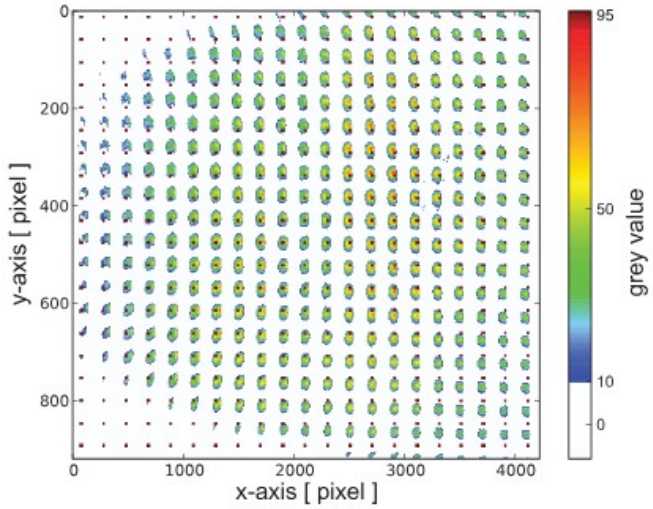
4D emittance measurements

Method of VPP

Pepper Pot

- Insert mask with grid of holes into the beam
- Measure beamlet positions on a downstream screen
- Calculate X and Y angle of each beamlet by comparing the beamlet position to the hole position

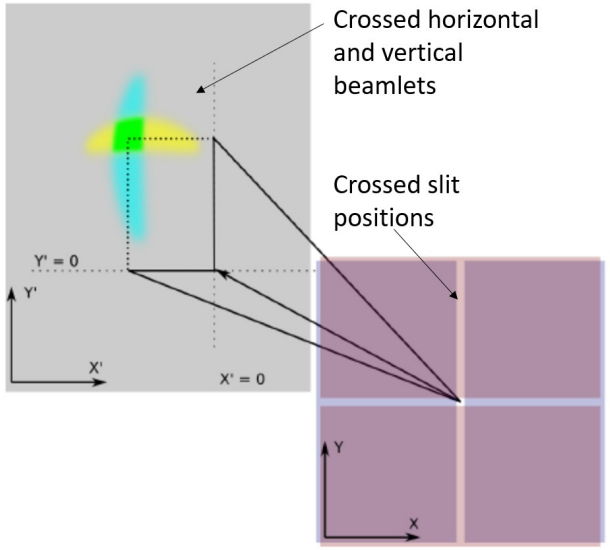


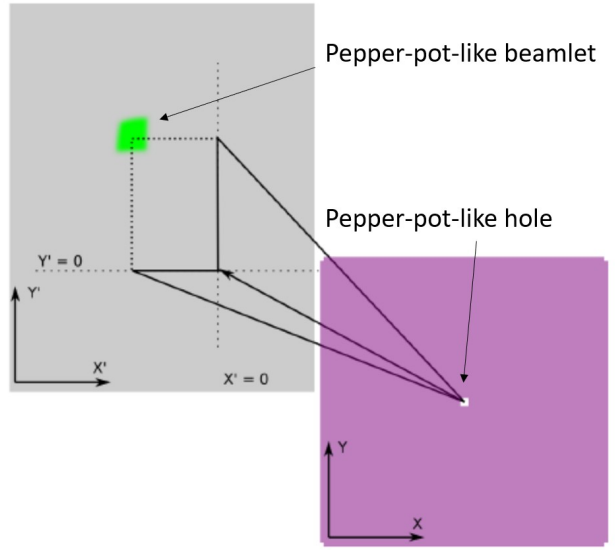


Grid

Virtual Pepper Pot (VPP)

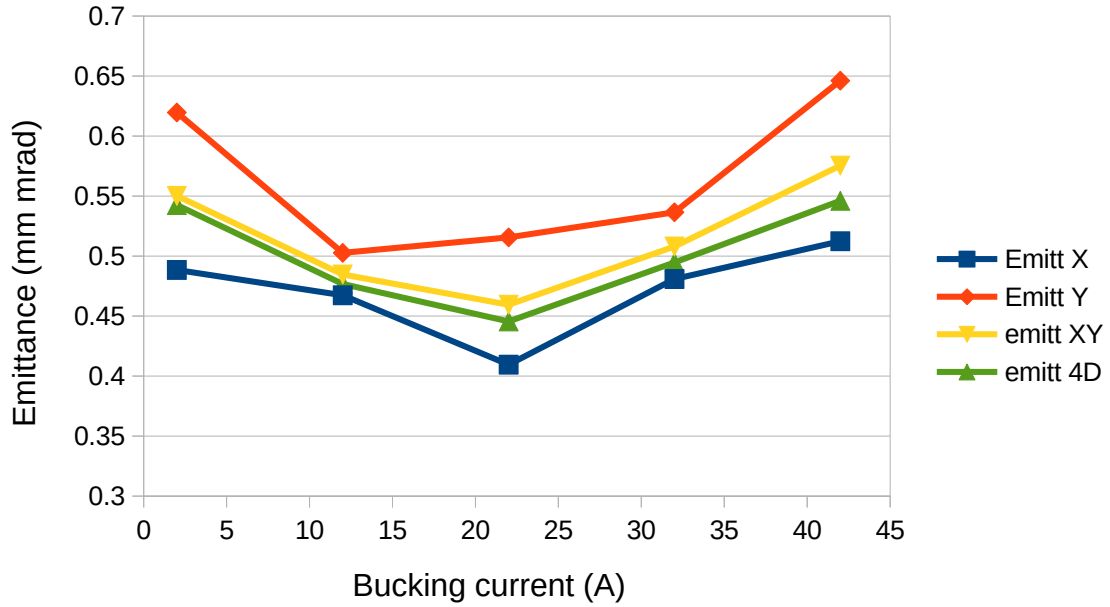
- Cannot instert X and Y slits at the same time to form a hole → Do virtual crossing of slit position
- Cross beamlet images to create a virtual pepper pot mask/image
- Use this to reconstruct the 4D phase space

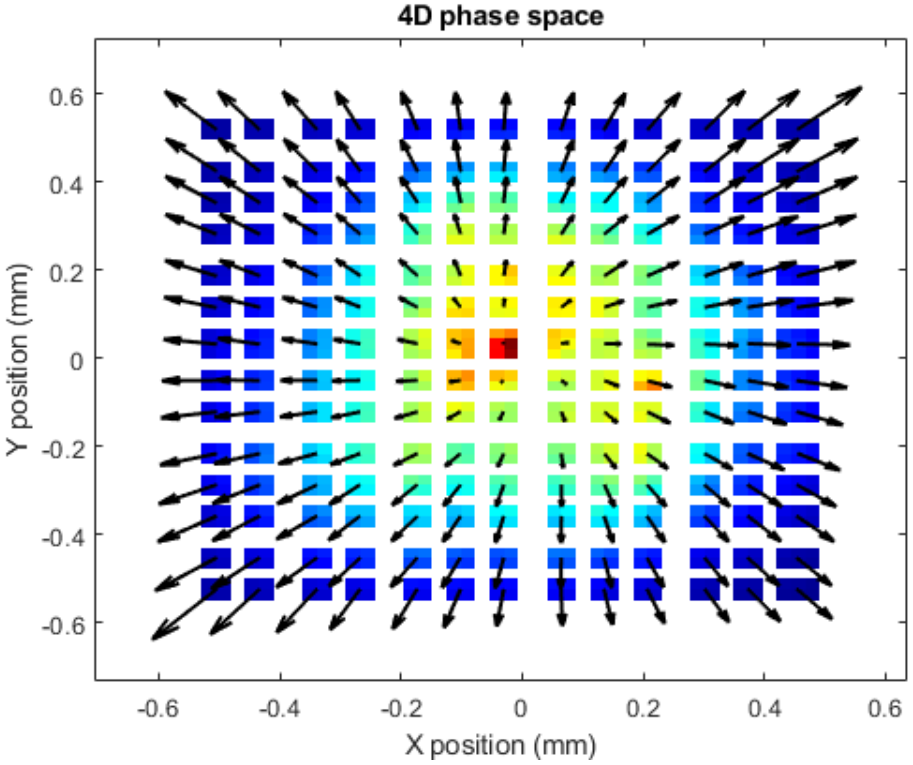


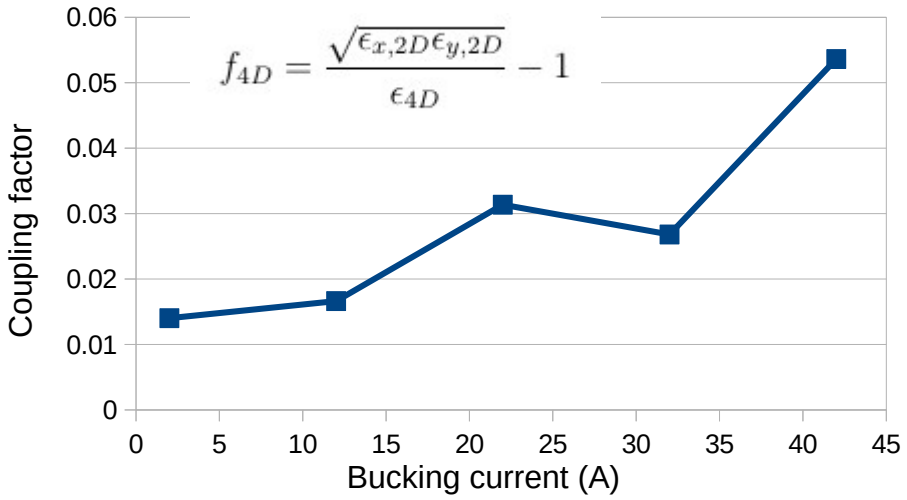


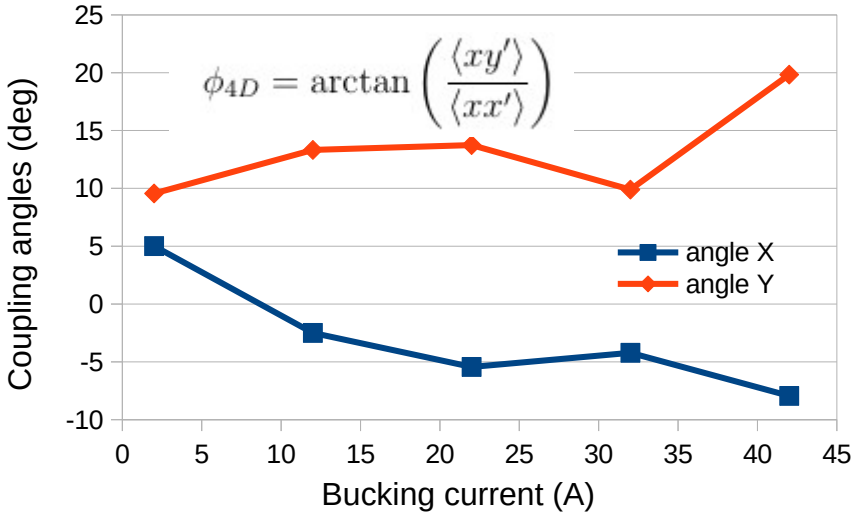
Developed by N. Aftab

Results of VPP analysis



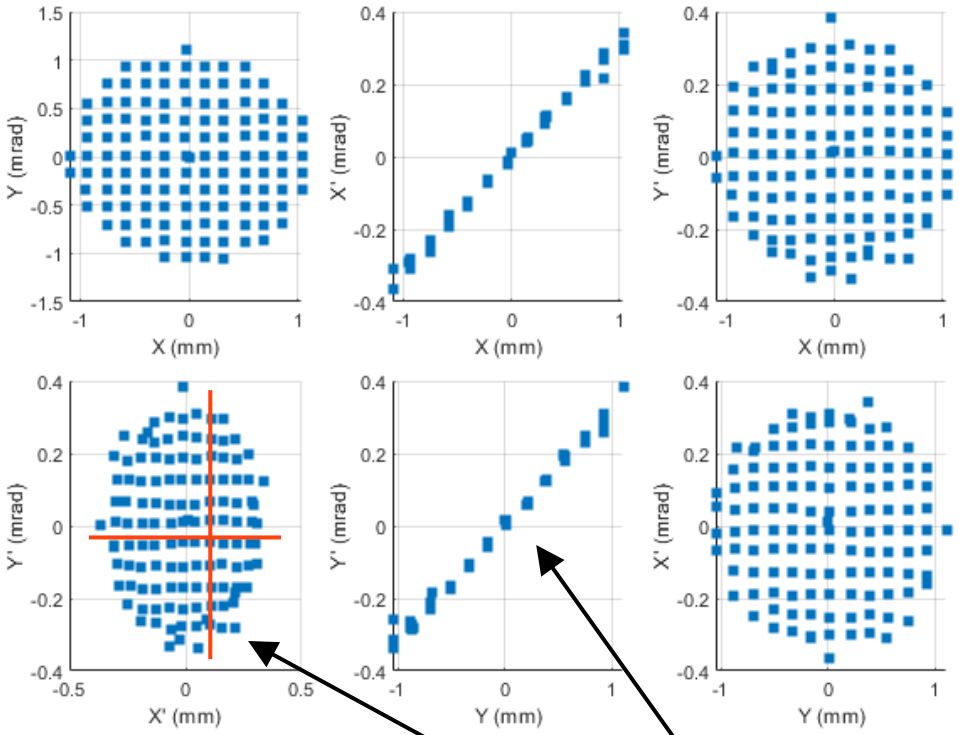


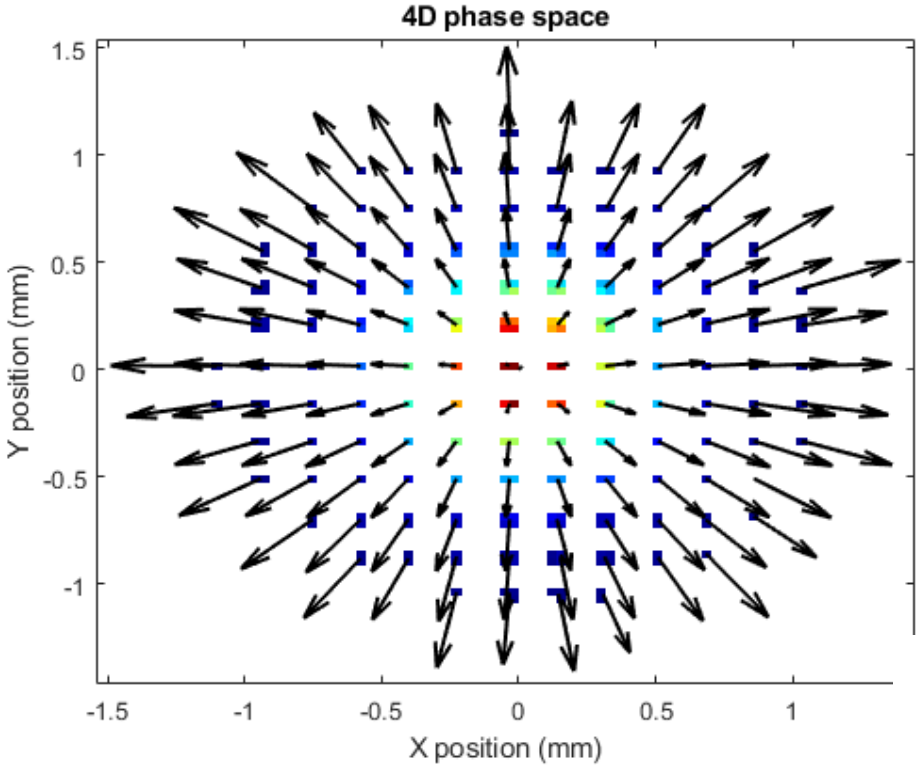


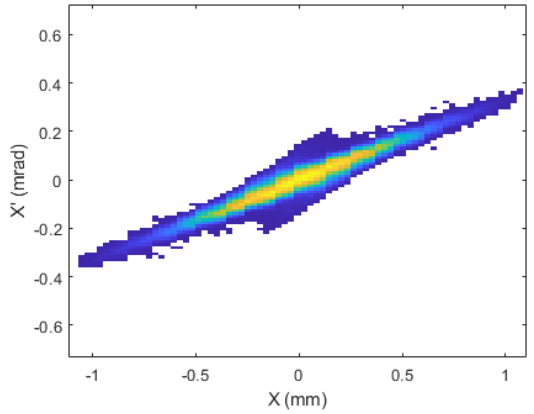


Examples from simulations – Uncoupled beam

Example from simulation of PITZ beamlet to the 1st emittance measurement station





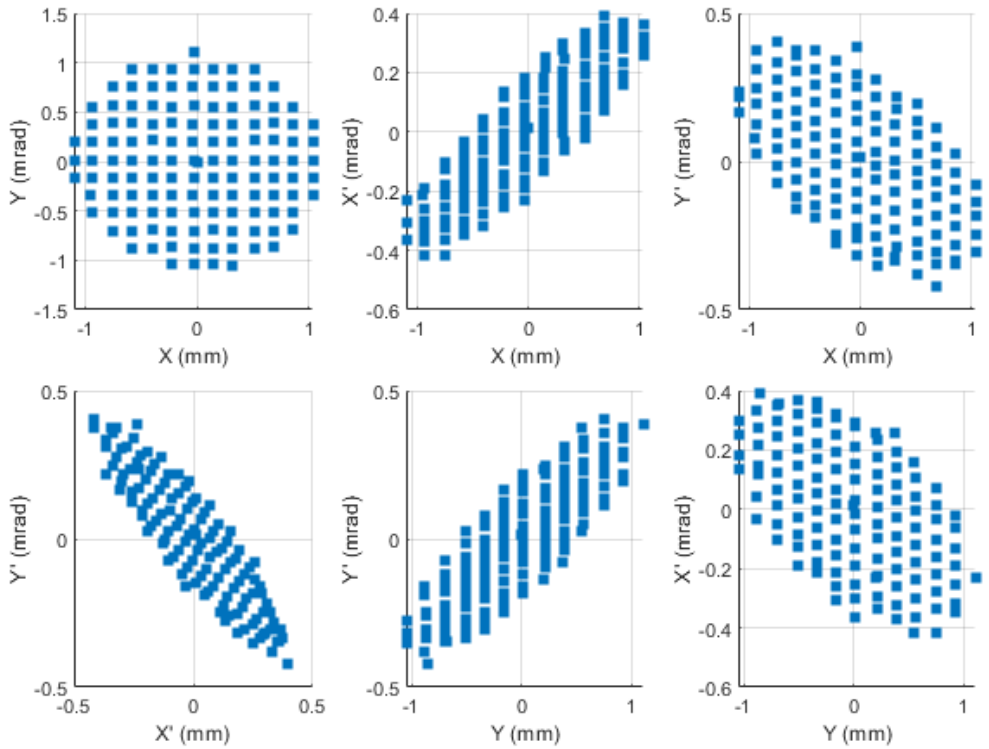


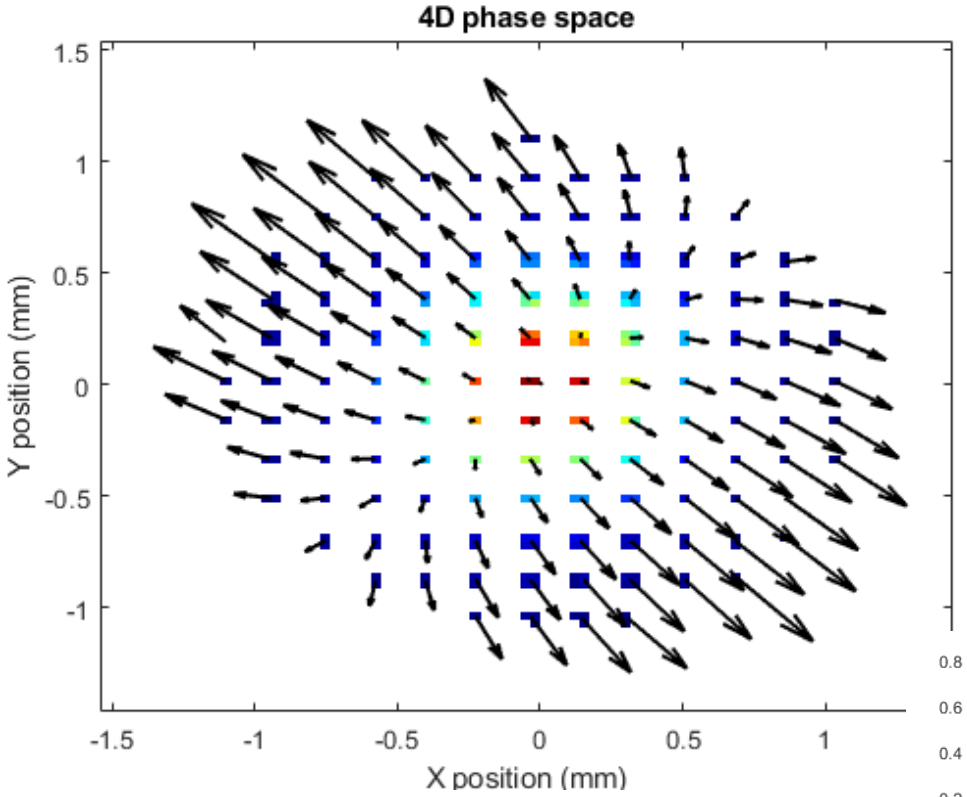
Uncoupled beam signatures

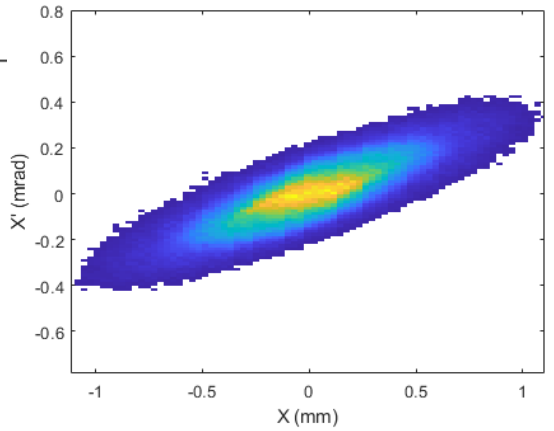
- 2D phase spaces are lines
- X' and Y' values lay on horizontal and vertical lines

Examples from simulations – coupled beam

Same simulation as previous slide, but added a skew quad directly before the slit





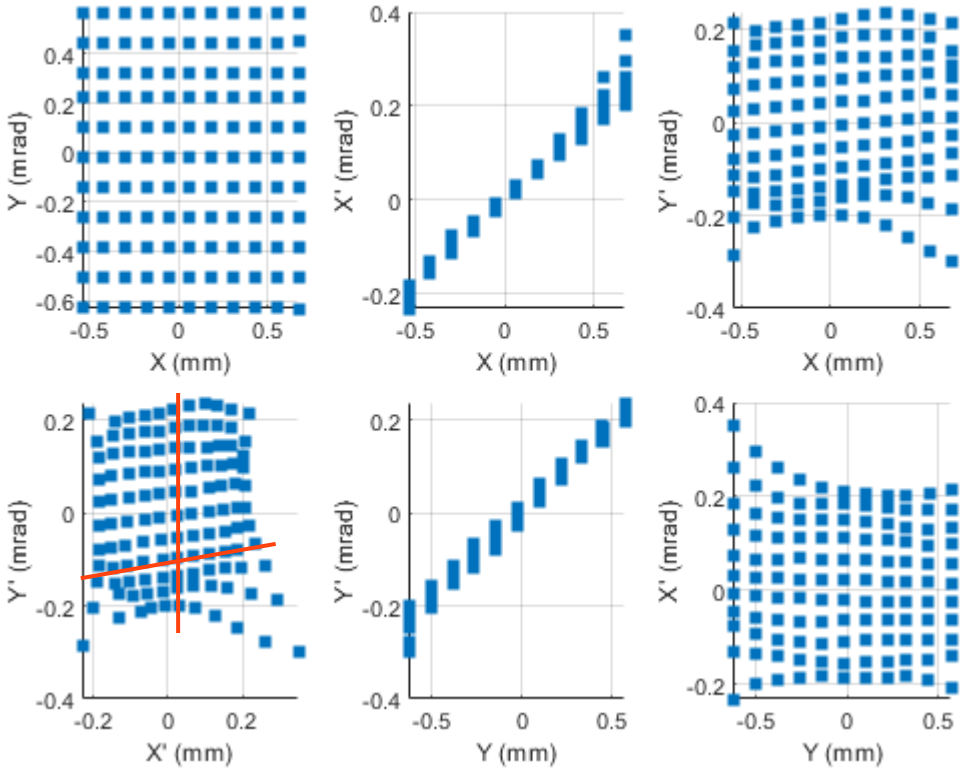


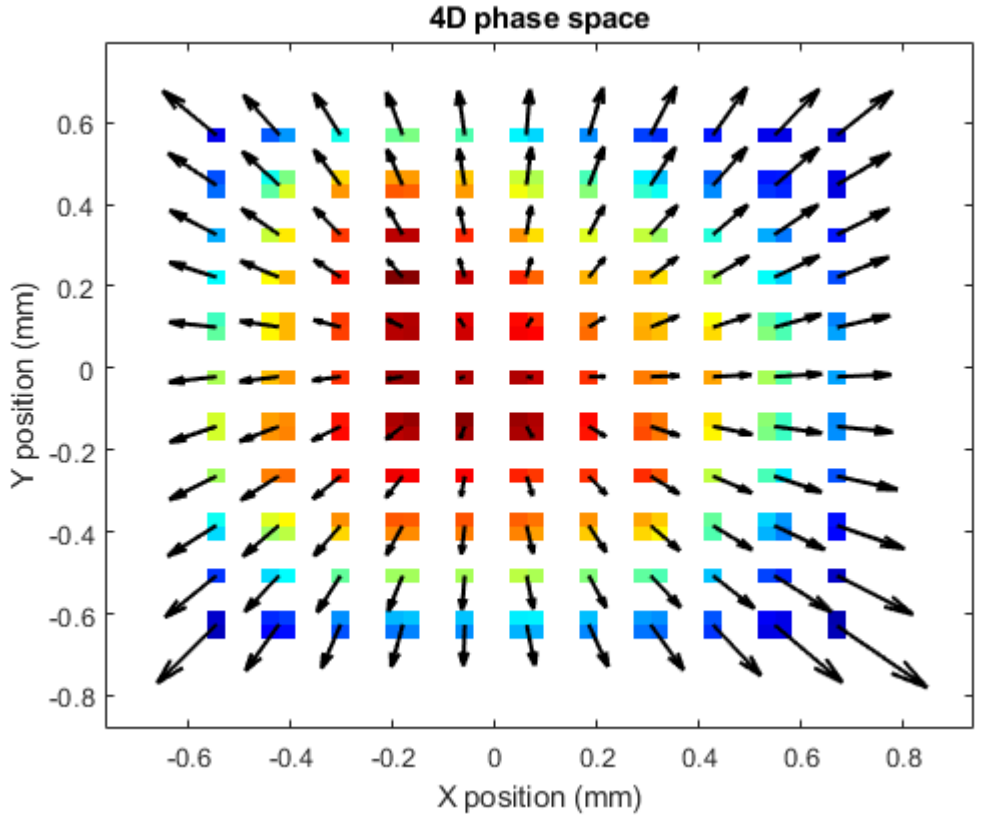
Coupled beam signatures

- Broad 2D phase spaces
- X’ and Y’ values lay on slanted lines

VPP of initial measurements of gun 5.1

With gun quad optimization

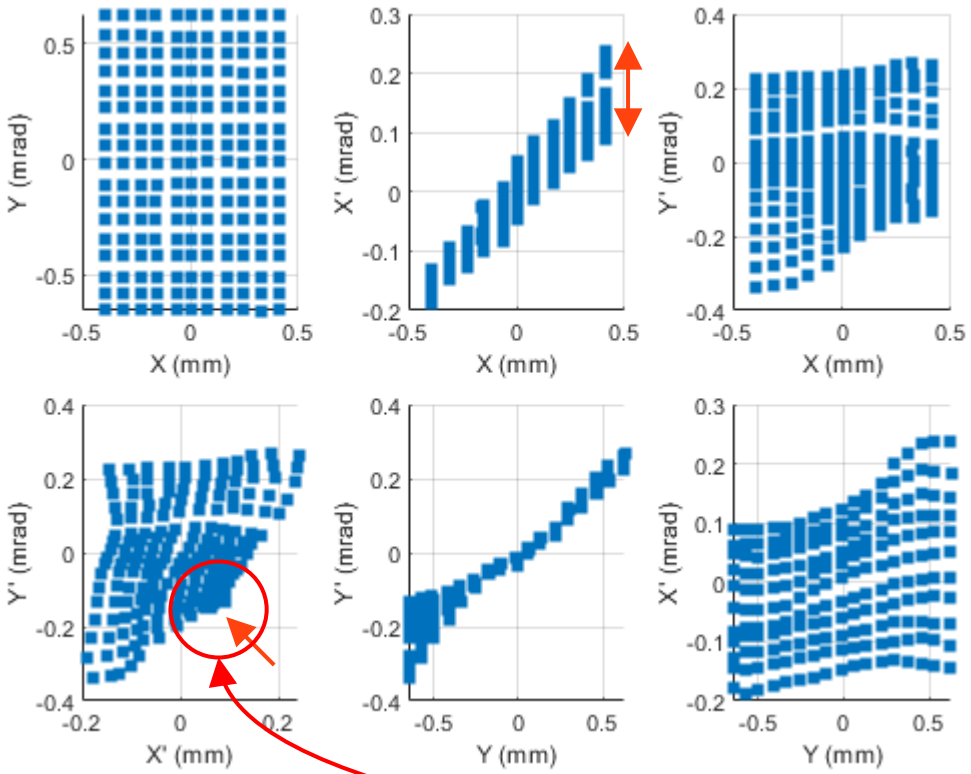


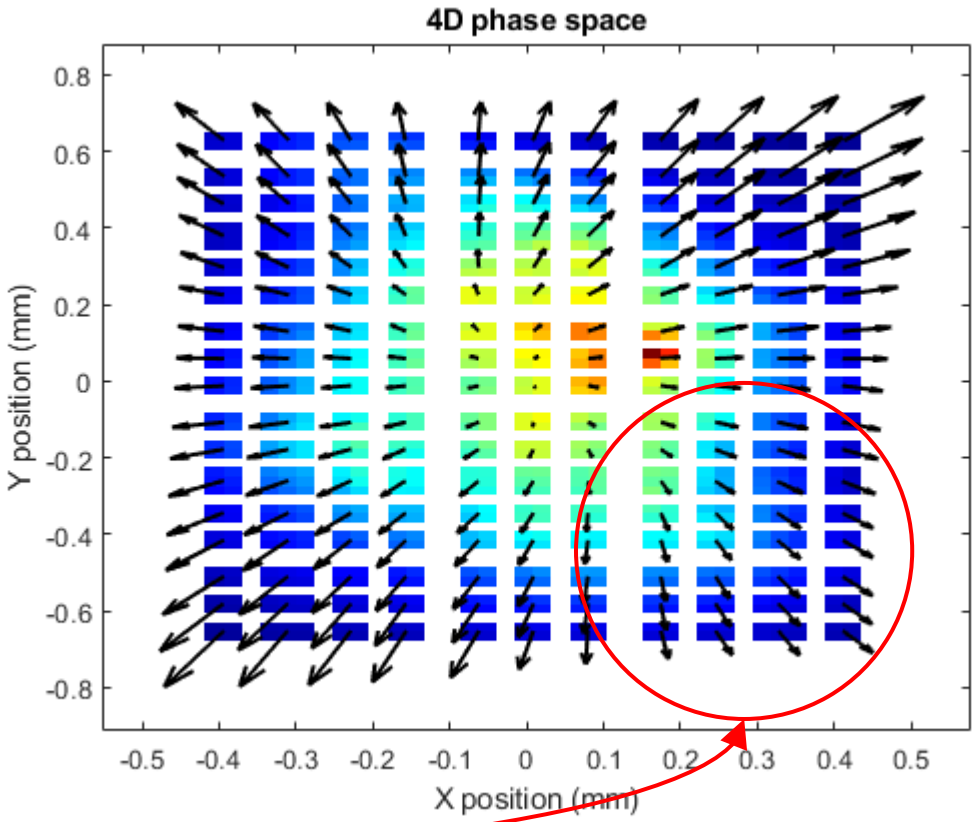


VPP of initial measurements of gun 5.2 [1]

No gun quad or bucking optimization

Asymmetric phase space: Angles in one corner of the beam are “shoved” in



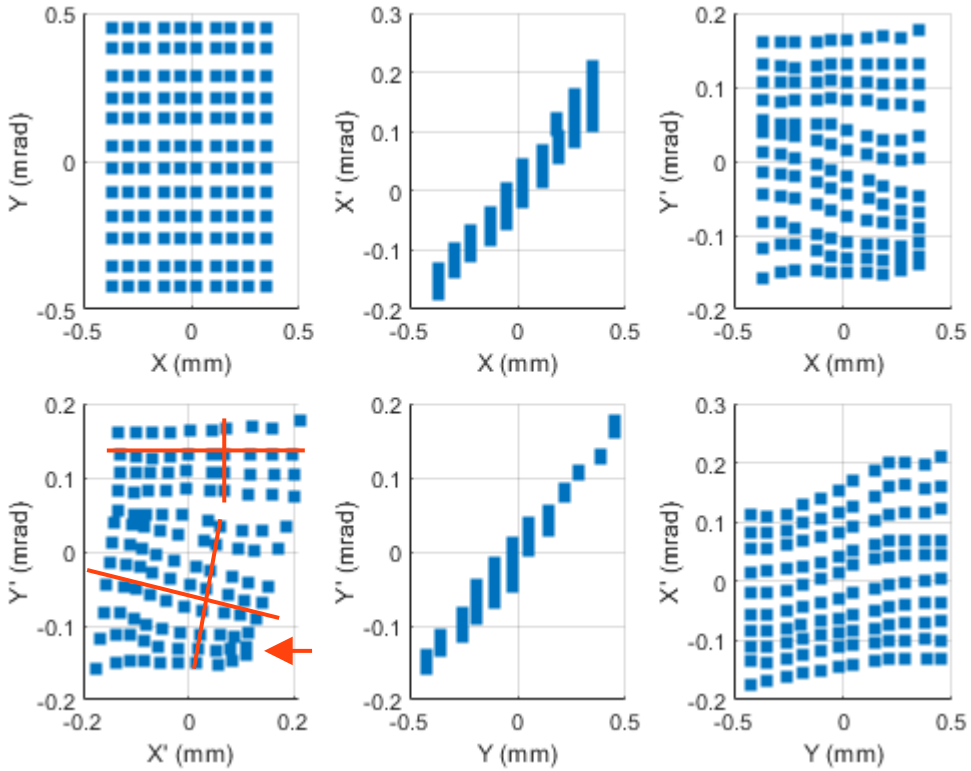


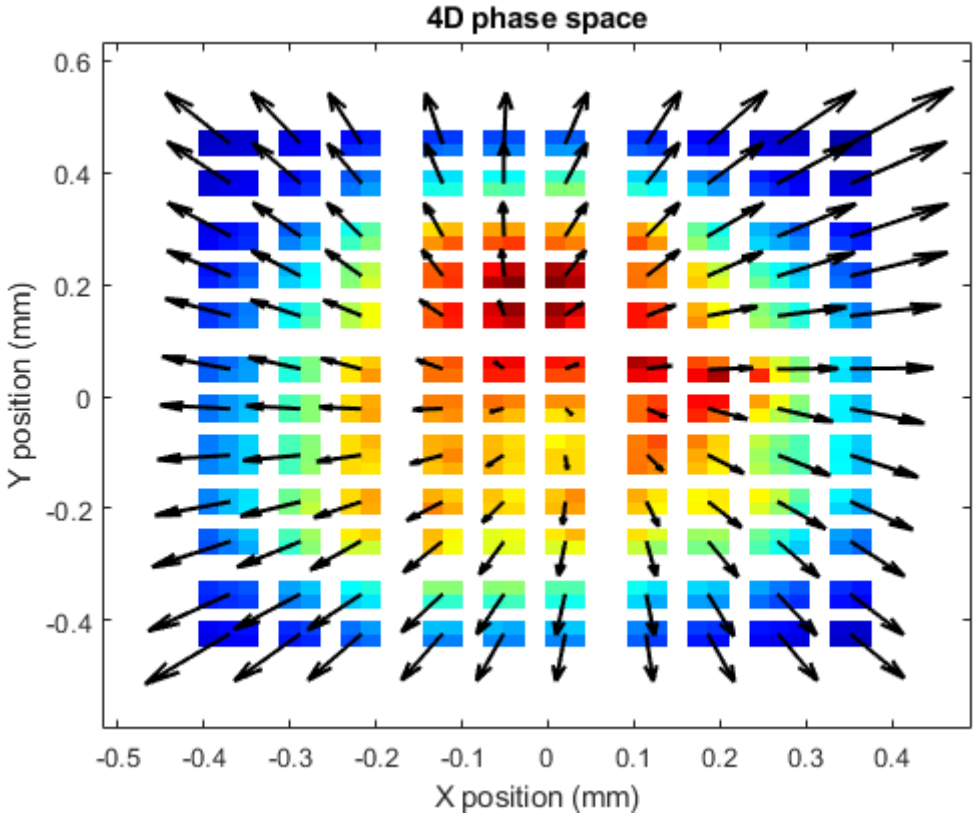
Effect is primarily in lower right corner of the beam

Changes with gun quad symmetrization

Overall improvement

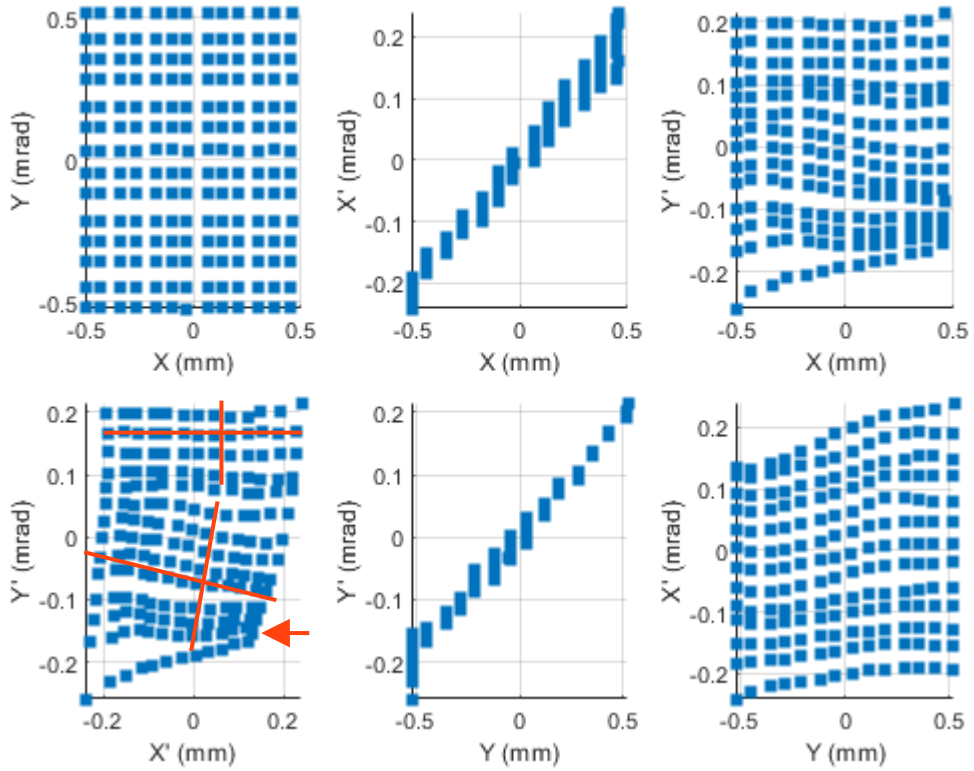
But still see coupling in lower right corner

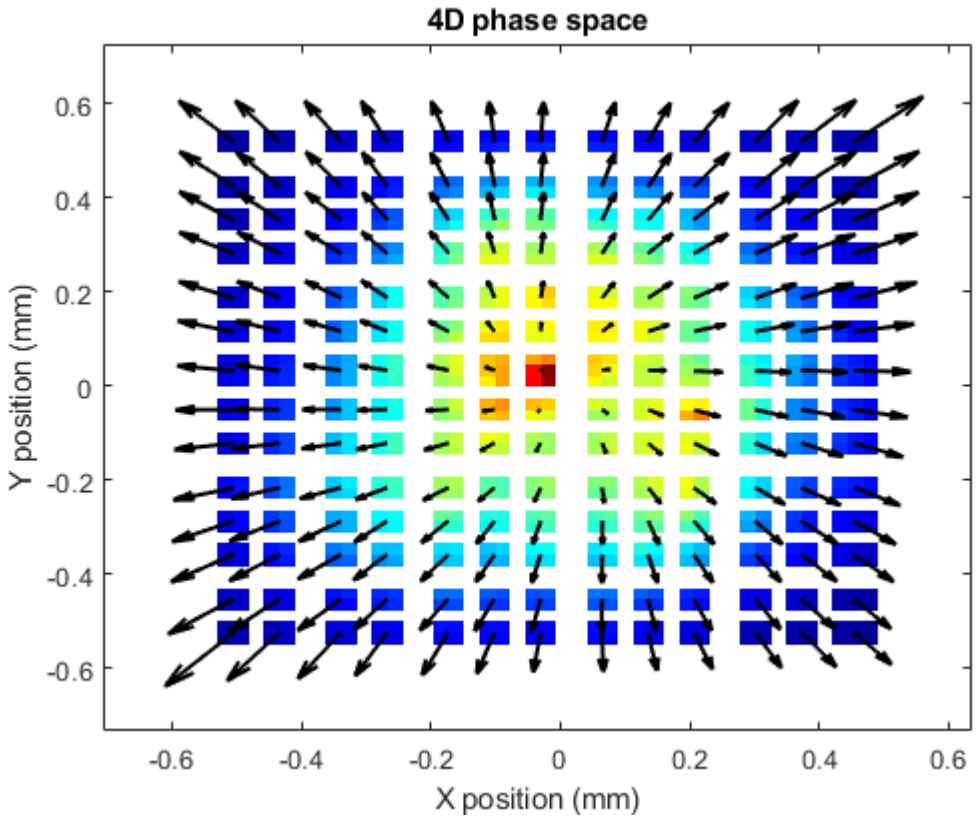




Optimized bucking coil current and gun quads

Not much improvement from only using gun quads





Summary

Assymetric 4D phase spaces measured with gun 5.2 → further investigations ongoing

Measured 0.5 mm mrad X-Y emittance

But have large X-Y emittance diparity

Assymmetric 4D phase spaces measured

Causes large 2D emittances and X-Y disparity

Emittance can be improved by symmetrizing the beam with normal and skew quad near the gun and optimizing bucking coil current. But X-Y disparity remains

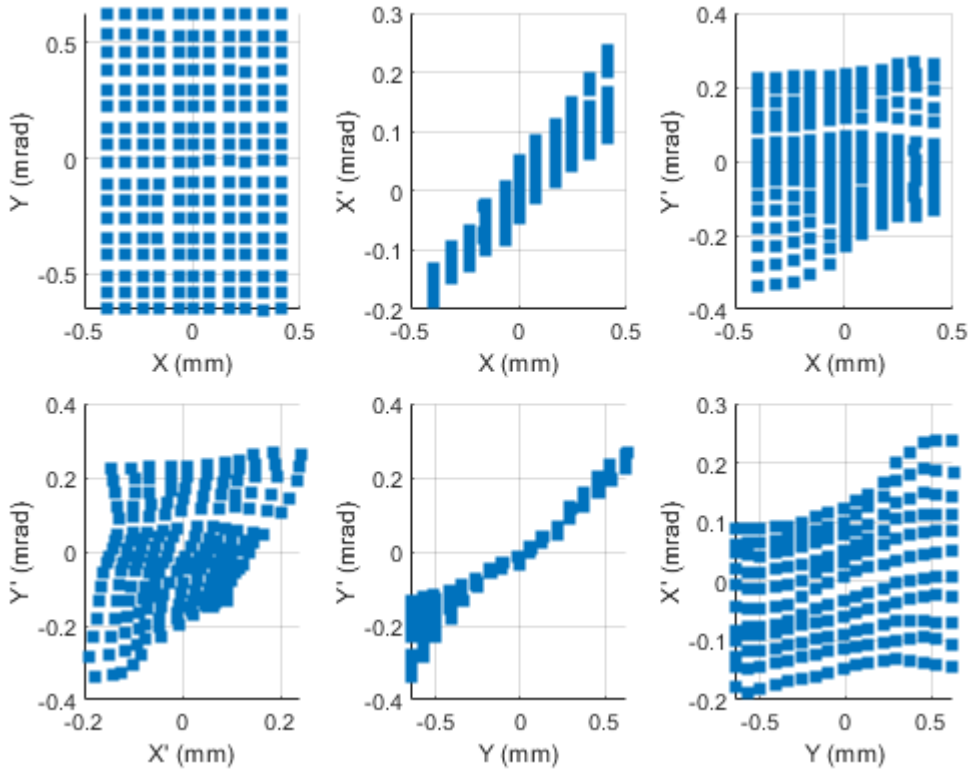
Most significant effect is on lower right corner of the beam

Possible source: laser vacuum mirror

Located on +x side of beamline

The beam could excite wakefields if passing too close.

Previously had a steerer between the gun and mirror to steer away → removed because of space constraints with symmetric coupler



Vielen Dank

Thanks to the PITZ group, especially the shift crews

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