The Effect of Space Charge along the Tomography Section at PITZ.

G. Kourkafas , M. Khojoyan, M. Krasilnikov, D. Malyutin, B. Marchetti, M. Otevrel, F. Stephan, G. Vashchenko, DESY, 15738 Zeuthen, Germany. G. Asova, INRNE-BAS, 1784 Sofia, Bulgaria

Introduction

The Photo-Injector Test Facility at DESY in Zeuthen (PITZ) focuses on the characterization and optimization of **high brightness electron sources** for free electron lasers. Currently it is able to deliver electron bunches of:

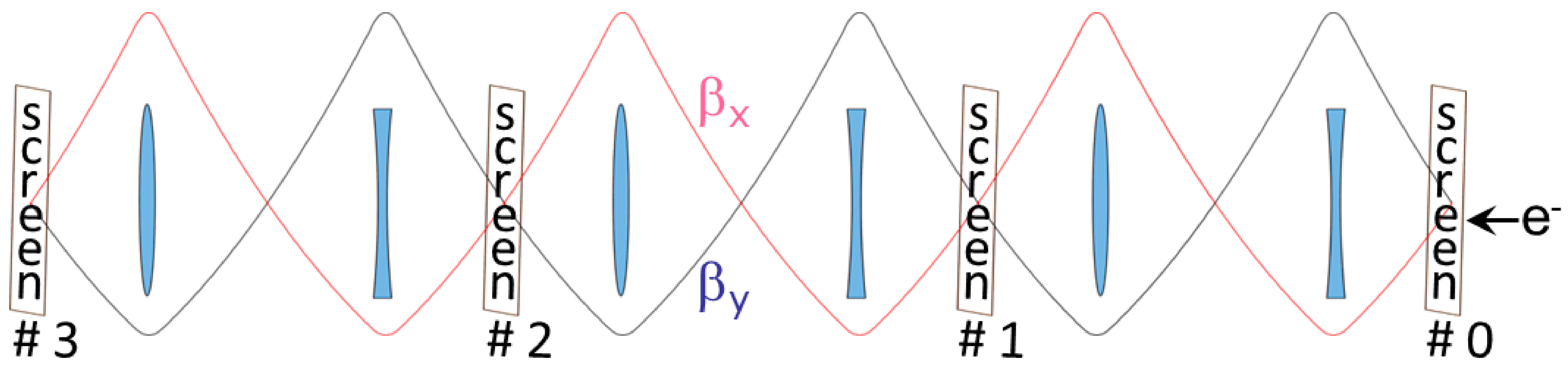
- 1 nC nominal charge
- < 25 MeV beam energies
- < 1 mm·mrad normalized rms emittance.

The tomography module is used to measure the **transverse phase-space distribution** of the beam. The current analysis does not take the **space-charge** force into account, introducing errors in the phase-space reconstruction. Simulations were carried out in order to quantify this effect.

Transverse phase space tomography at PITZ

- **3 FODO cells** oppose a 180° rotation in the normalized phase space
- **4 screens** capture the spatial projections of the beam profile at both transverse planes, ideally at equidistant phase advance values
- These **projections** are then used as input to a reconstruction algorithm, together with their corresponding **transfer matrices** w.r.t. the point of reconstruction (screen #0)

The **algorithm** implements the basic principle of tomography: reconstruction of a sample (phase-space distribution) from a set of projections (spatial profiles) of defined transformation (transfer matrix).

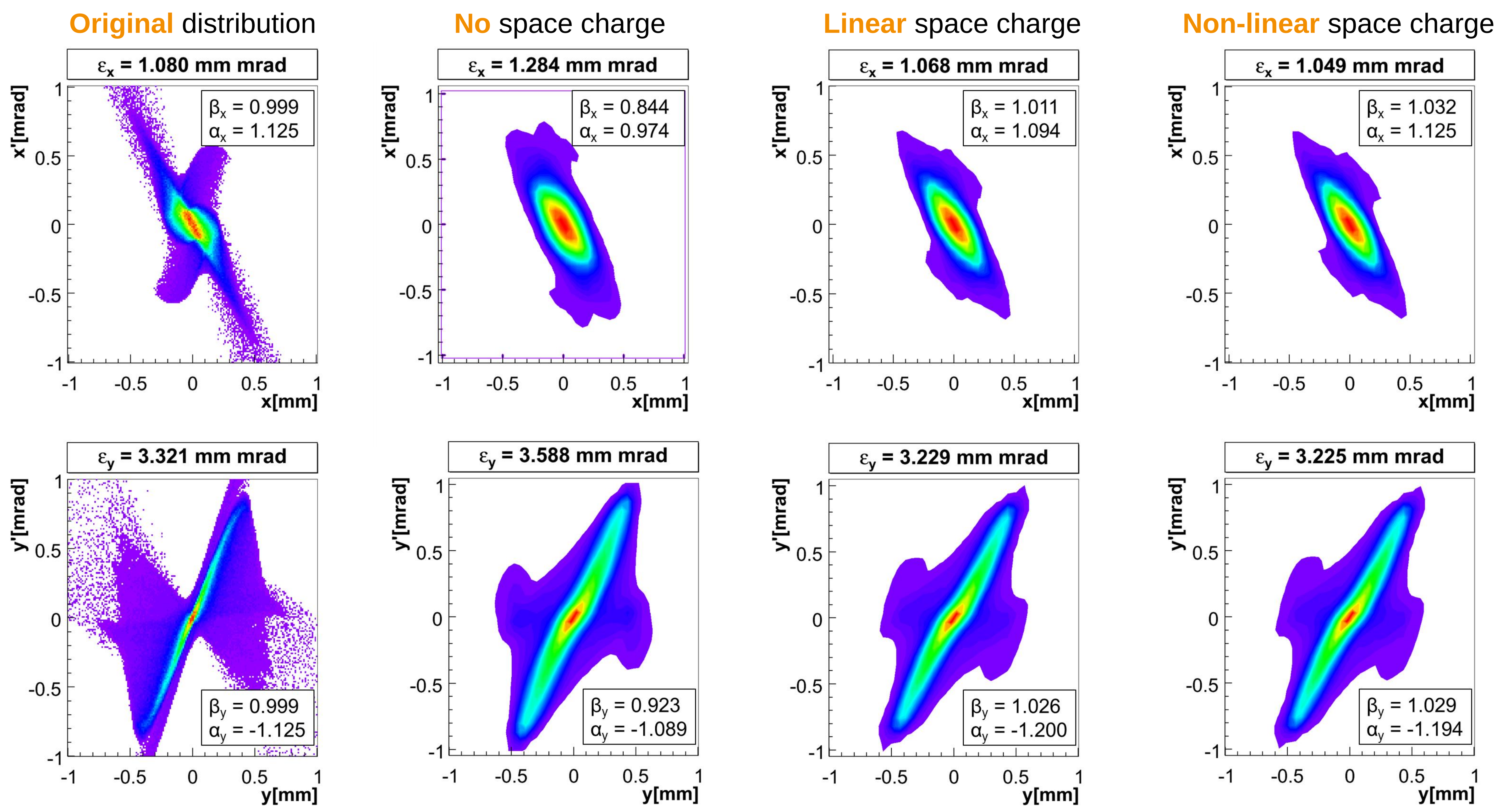


Simulation walk-through

1. Generate a characteristic photo-injector **input beam**:
   - Tune ASTRA to deliver a beam of **1 nC** charge, **24.7MeV/c** momentum and emittance equal to the result of a past slit-scan measurement
   - Adjust the Twiss parameters at screen #0 to the design values: $\beta_{x,y}$=0.999 , $\alpha_{x,y}$=±1.125
2. Produce the **projections** of the transverse planes at the tomography screens:
   - Tune the tomography quadrupoles so as to deliver 45° phase advance between each screen (matching solution from MAD, neglects space charge)
   - Track the input beam along the tomography lattice with ASTRA (3D space charge) and extract the X and Y profiles at the screens
3. Calculate the corresponding **transfer matrices** of each projection for different space-charge treatments:
   - **No** space charge
   - **Linear** space charge (V-Code)
   - **Non-linear** space charge (ASTRA)

   after simulating the beam transport along the tomography lattice for each tracking approach, using:

$$M_n = \begin{pmatrix} \sqrt{\frac{\beta_n}{\beta_0}}\,(cos\phi_n + \alpha_0 sin\phi_n) & \sqrt{\beta_n\beta_0}\,sin\phi_n \\ -\frac{1+\alpha_n\alpha_0}{\sqrt{\beta_n\beta_0}}\sin\phi_n + \frac{\alpha_0-\alpha_n}{\sqrt{\beta_n\beta_0}}\cos\phi_n & \sqrt{\frac{\beta_0}{\beta_n}}\,(cos\phi_n - \alpha_n sin\phi_n) \end{pmatrix}$$



Simulation results

Reconstructed emittance (X-plane):

- No space charge: **+18.9%**
- Linear space charge: **-1.1%**
- Non-linear space charge: **-2.9%**

Maximum phase advance mismatch: **25°**

Reconstructed emittance (Y-plane):

- No space charge: +8.0%
- Linear space charge: -2.8%
- Non-linear space charge: -2.9%

Maximum phase advance mismatch: 15°

When space-charge fields are neglected:

- Significant errors appear in the **emittance** value and **slope** of the reconstructed distribution
- The denser the **particle distribution** the stronger the effect

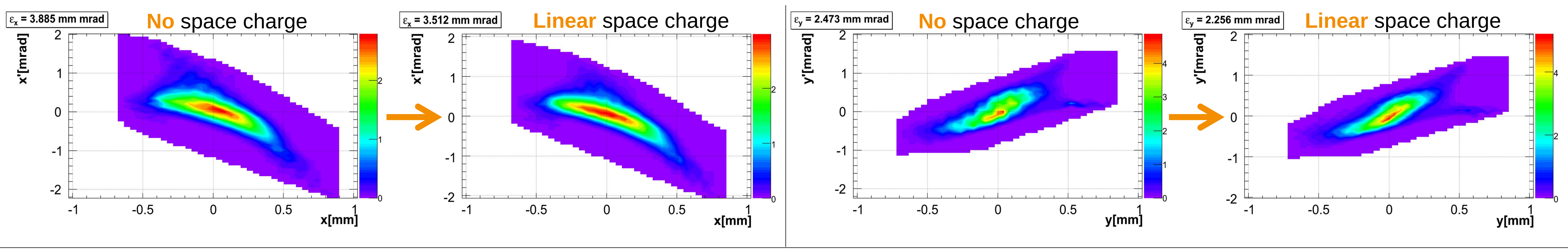
The emittance difference between the two space-charge implementations is less than 2%. The **linear** space-charge reconstruction gives better results than the general space-charge case, due to:

- Correlated emittance growth inside the quadrupoles in ASTRA
- Shorter achievable tracking step with V-Code
- Treatment of the low intensity tails by the reconstruction procedure

Application to experimental data

The strategy developed for the simulation was also applied to existing experimental data. Except from the measured projections and the quadrupole strengths during the measurement, the transverse and longitudinal **moments of the incoming beam** are needed for the transfer matrix calculations (available from other diagnostics or from simulation).

The space-charge reconstruction shows **smoother** lines and less pronounced artifacts. The resulting X and Y emittance drops by ~10%, in **agreement** with the simulation result for the vertical plane (→ similar rms beam size).



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