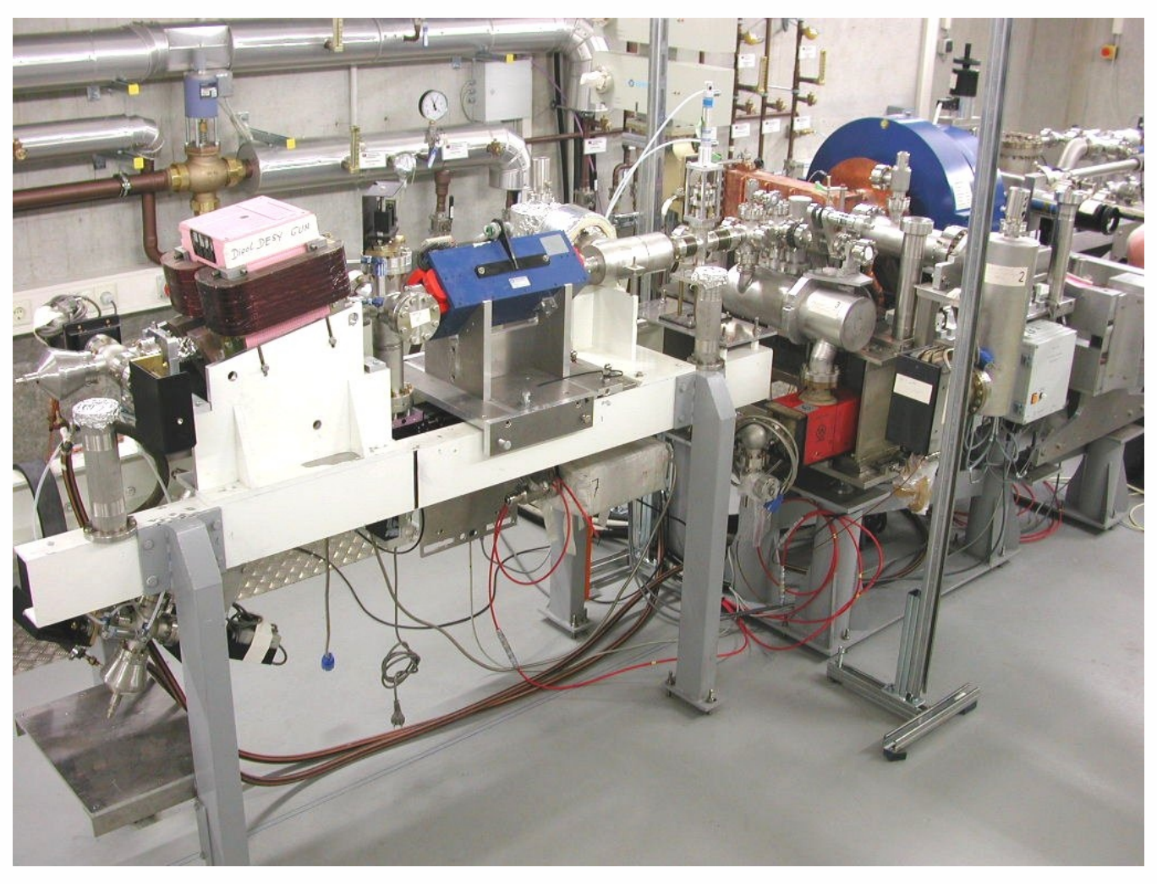
Photo Injector Test Facility at DESY Zeuthen
PITZ

Characterization of the Electron Source **at PITZ**

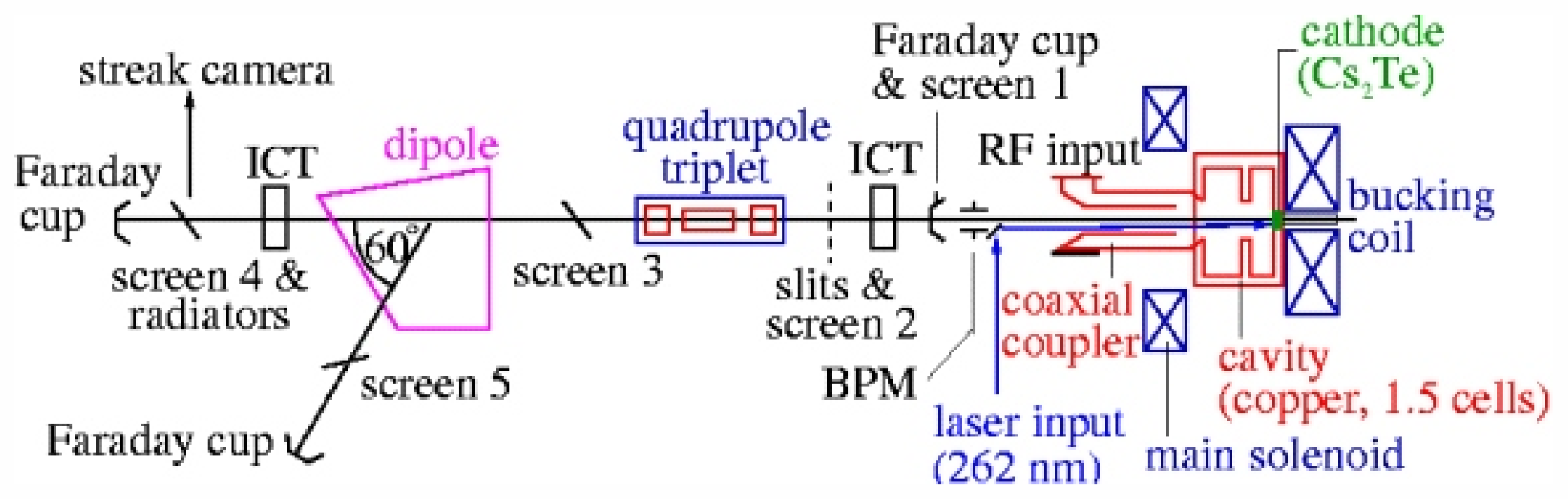
M.v. Hartrott, E. Jaeschke, D. Krämer, BESSY, 12489 Berlin, Germany
J.P. Carneiro, K. Flöttmann, J. Roßbach, S. Schreiber, DESY, 22603 Hamburg, Germany
K. Abrahamyan[&], J. Bähr, I. Bohnet, U. Gensch, H.J. Grabosch, J.H. Han, M. Krasilnikov, D. Lipka, V. Miltchev, A. Oppelt, B. Petrossyan[&], F. Stephan, DESY, 15738 Zeuthen, Germany
P. Michelato, C. Pagani, D. Sertore, INFN Milano, 20090 Segrate, Italy
L. Staykov, I. Tsakov, INRNE Sofia, 1784 Sofia, Bulgaria
W. Sandner, I. Will, Max-Born-Institute, 12489 Berlin, Germany
W. Ackermann, R. Cee, W.F.O. Müller, S. Setzer, T. Weiland, TU Darmstadt, 64289 Darmstadt, Germany



Abstract

The Photo Injector Test Facility at DESY Zeuthen (PITZ) was built to test and optimise electron sources for Free Electron Lasers and future linear colliders. The focus is on the production of intense electron beams with minimum transverse emittance and short bunch length as required for FEL operation. The experimental set-up includes a 1.5 cell L-band gun cavity with coaxial RF coupler, a solenoid for space charge compensation, a laser capable to generate long pulse trains with variable temporal and spatial pulse shape, an UHV photo cathode exchange system, and an extensive diagnostics section. This contribution will give an overview on the facility and will mainly discuss the measurements of the electron beam transverse phase space. This will include measurements of the transverse and longitudinal laser profile, beam charge as a function of RF phase, and transverse emittance as a function of different parameters. The corresponding measurements of momentum and momentum spread as well as the RF commissioning results will be summarized. As a first application of the PITZ electron source it will be installed at the TESLA Test Facility Free Electron Laser at DESY Hamburg in autumn 2003.

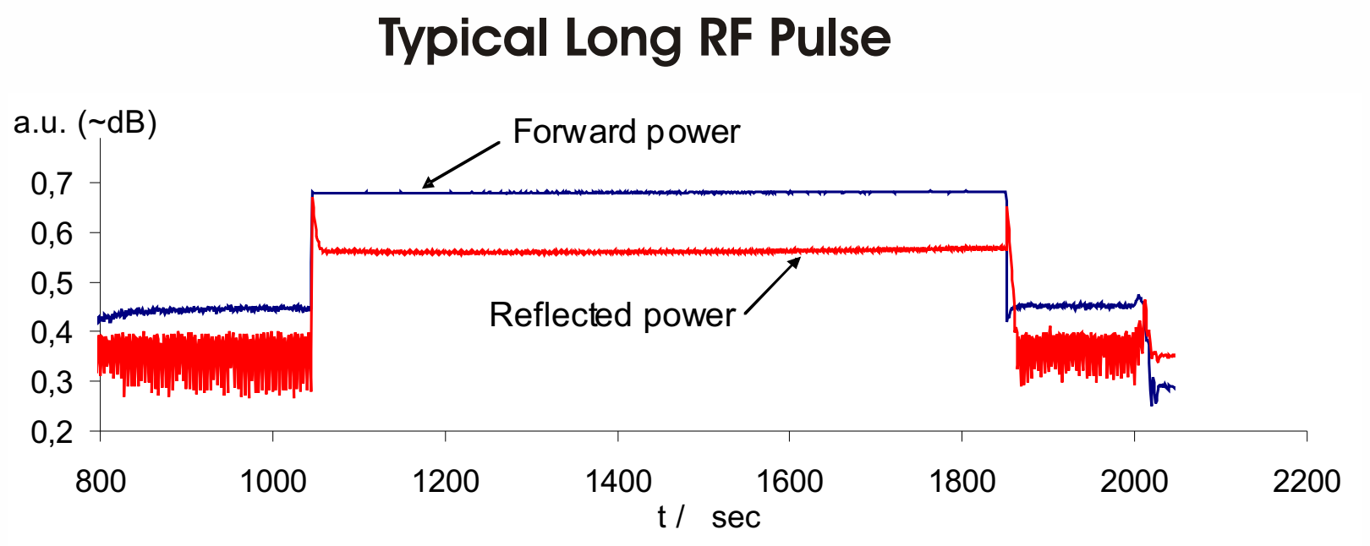
Photo Injector Set-up



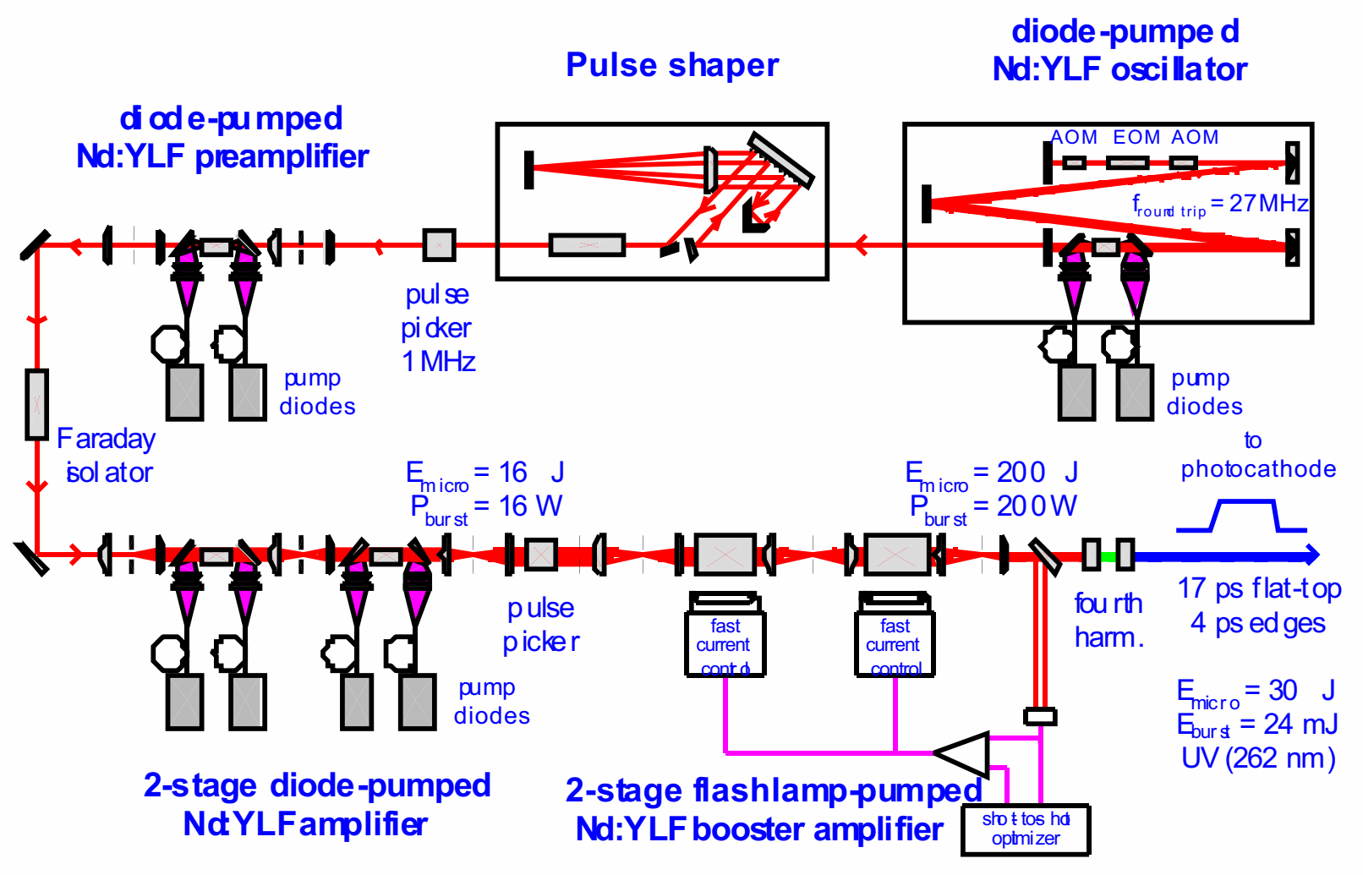
Achievements on RF Conditioning

RF frequency: 1.3 GHz
Maximal averaged RF power in the gun:
- RF pulse length: **900 sec**
- repetition rate **10 Hz**
- gradient at photocathode ~ **40 MV/m**
  duty cycle **0.9%**,
  averaged power in the cavity **27kW**

Typical Long RF Pulse



New Laser System

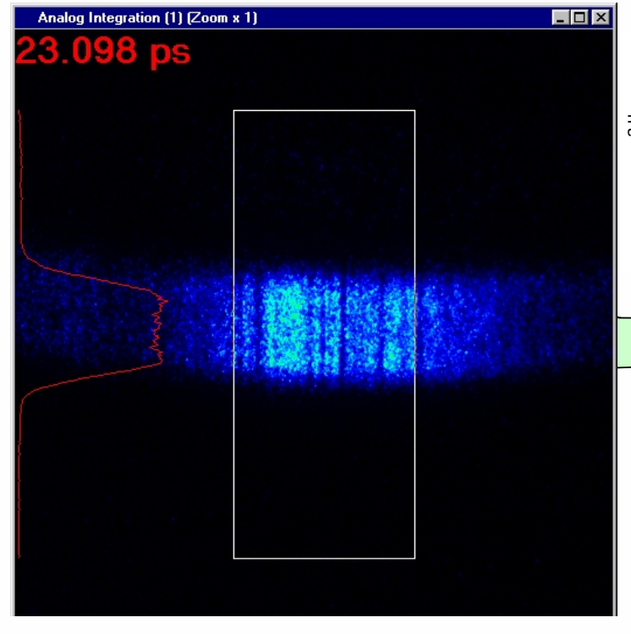


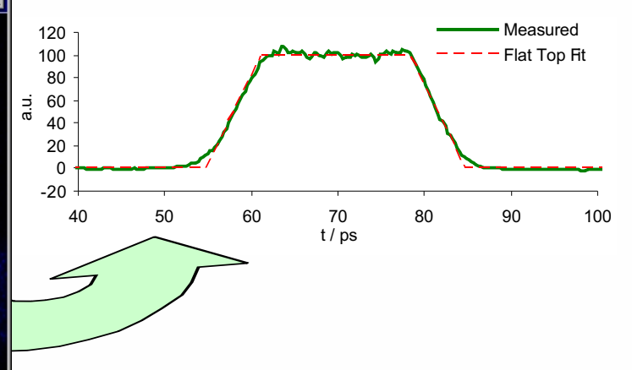
The main achievement of the cathode laser upgrade at PITZ is a stable production of long laser pulse trains where each micro pulse has a **flat top longitudinal profile.**

The laser is based on a diode-pumped pulsed oscillator synchronized with the RF. A diode-pumped amplifier chain and two flash-lamp-pumped booster amplifiers follow. A grating based pulse shaper allows for generation of temporal flat-top pulses. The laser material is Nd:YLF operated at a wavelength of 1047 nm. Since the photo cathode requires ultraviolet radiation, the infrared laser pulses are converted to the fourth harmonic (262 nm) by means of two nonlinear crystals. The rising edge of the flat top pulses after conversion to the UV is presently in the order of 4-6 ps.

The laser is able to generate trains of micro pulses of up to 800 μs length.

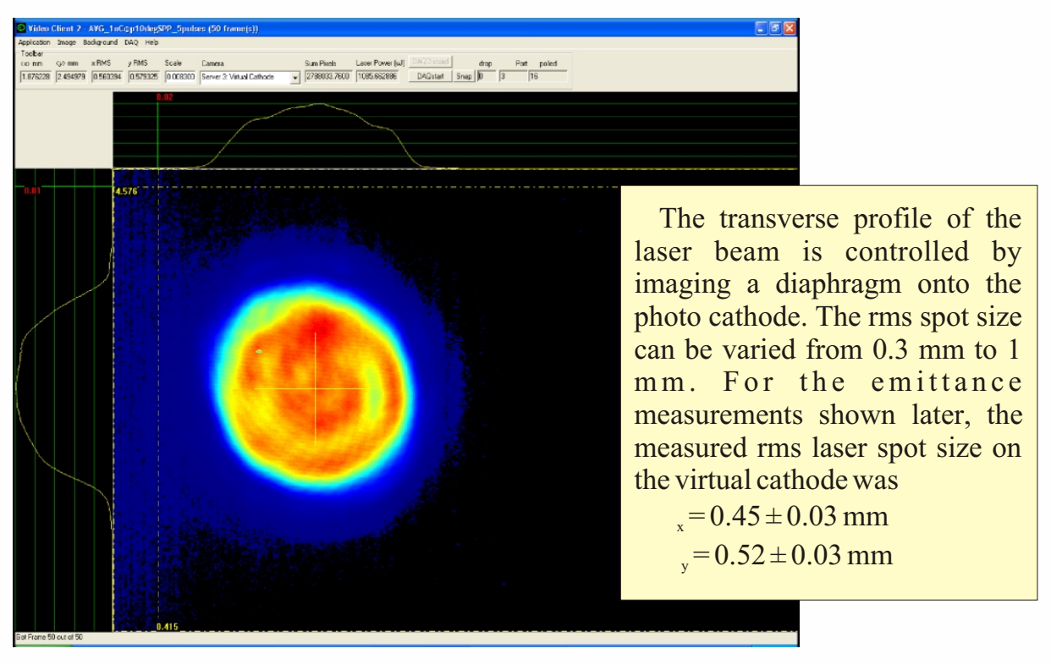
Temporal Laser Profile





Temporal profile of the laser micro pulse measured at a wavelength of 524 nm using a streak camera. 10 laser pulses have been integrated. The dashed line shows a flat top fit with ~ 24 ps FWHM and 6 ps rise/fall time.

Transverse Laser Intensity Distribution



The transverse profile of the laser beam is controlled by imaging a diaphragm onto the photo cathode. The rms spot size can be varied from 0.3 mm to 1 mm. For the emittance measurements shown later, the measured rms laser spot size on the virtual cathode was
$_x$ = 0.45 ± 0.03 mm
$_y$ = 0.52 ± 0.03 mm

Beam Charge Measuremenmts

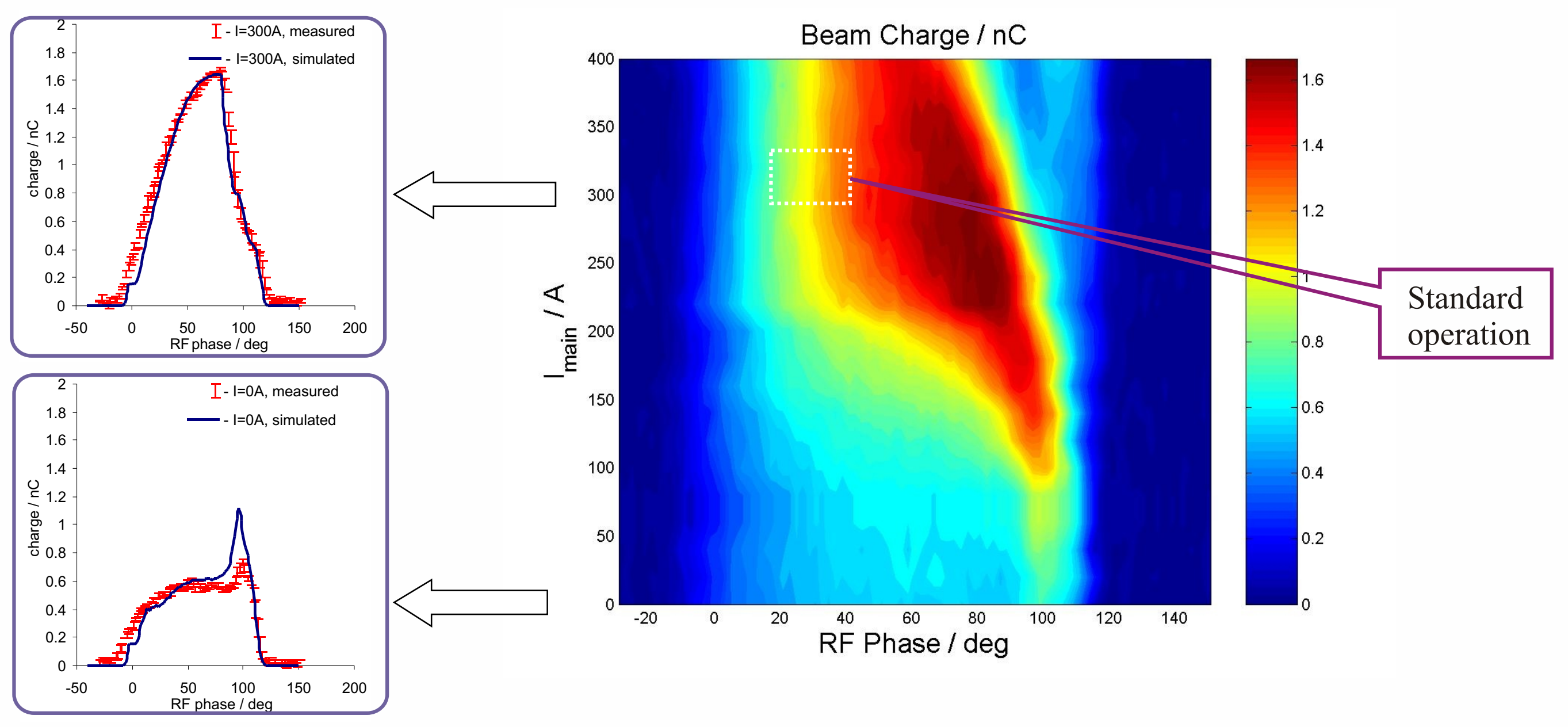
The charge of the electron beam is measured with Faraday Cups and integrating current transformers (ICT).
A basic measurement is the so called **phase scan**. The accelerated charge downstream of the RF gun measured as a function of launch phase, the relative phase of the laser pulses with respect to the RF.
The space charge effects on and near the cathode depending on the laser pulse shape, the solenoid position and strength, and the acceleration gradient at the cathode determine the shape of the phase scan.

Phase Scan

Beam charge measured at the first Faraday Cup as a function of RF phase
Gradient at the cathode ~40 MV/m, maximum charge ~ 1.6 nC

2D Phase Scan

Beam charge measured at the first Faraday Cup as a function of RF phase and main solenoid current
Gradient at the cathode ~40 MV/m, maximum charge ~ 1.6 nC

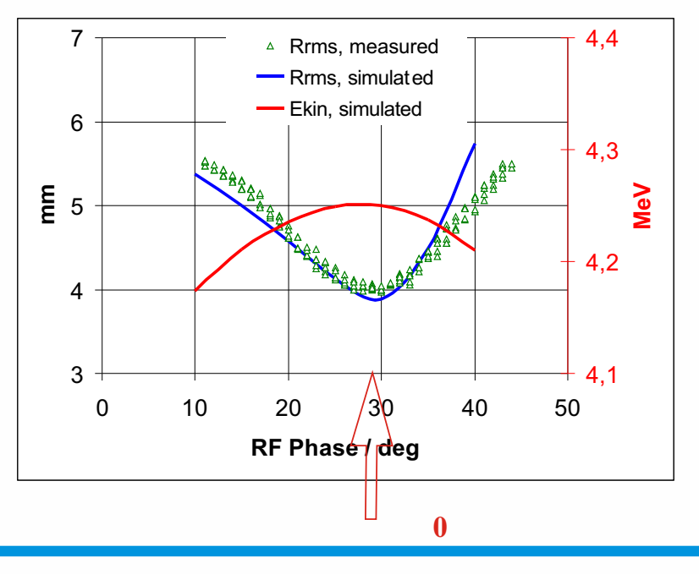


Reference RF Phase

In order to have a defined comparison between measurements and simulations a corresponding **reference RF phase** $_0$ has to be settled.

To not rely on details of the comparison between the measured and simulated phase scans, the reference RF phase is defined as the phase with **maximum mean energy gain**. This is easy and reliably obtained using a beam transverse size vs. RF phase measurement. The transverse beam size is to be measured at screen 3 as a function of the RF phase for slighly over focussing main solenoid current. The reference phase corresponds to the minumum of the beam size

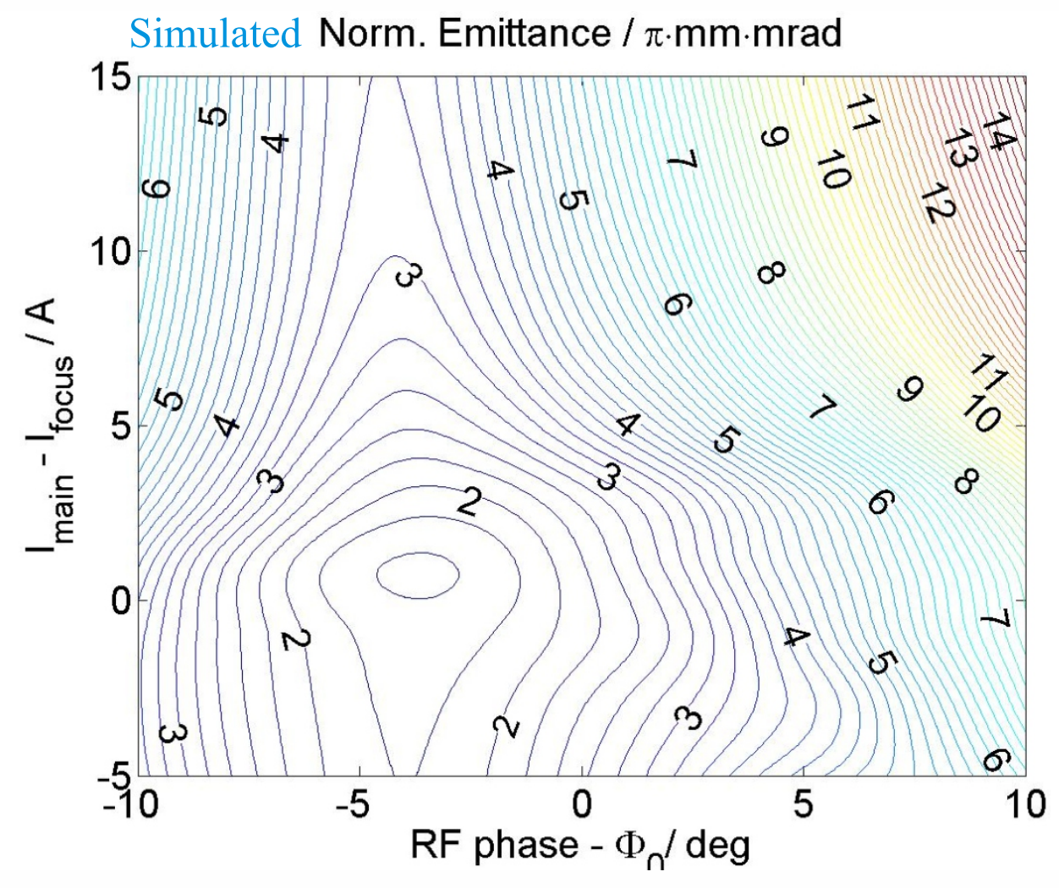
Transverse Beam Size at Screen 3 as a Function of RF Phase,
main solenoid current 300A



Beam Emittance Measurements

Preliminary Simulations

Before starting emittance measurements numerous beam dynamics simulations have been performed. The emittance has been simulated for a 1 nC beam with a laser longitudinal profile of 25 ps FWHM and 5 ps rise/fall time. A homogeneous transverse laser profile with $_{x,y}$ = 0.45 mm and an accelerating gradient at the cathode of 40 MV/m were assumed. Only changing the transverse laser shape to a Gaussian with the same $_{x,y}$ yields an emittance minimum of ~ 5 mm mrad.

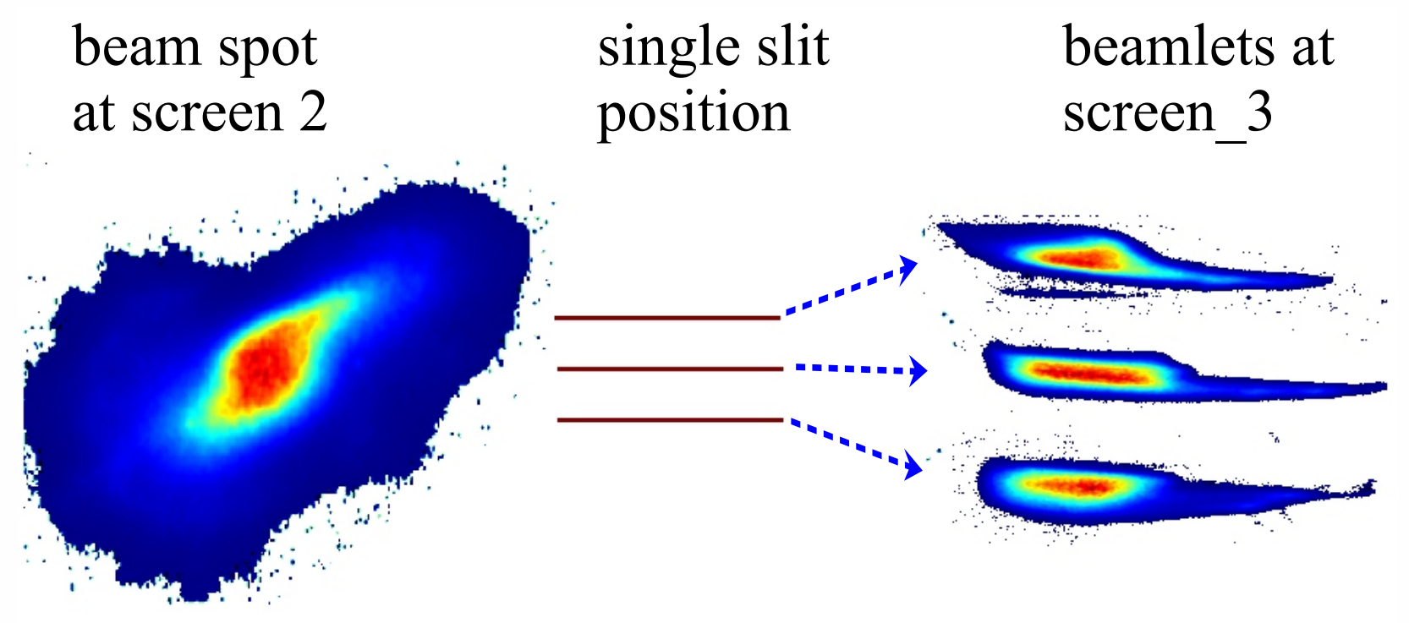


Contour plot of simulated transverse normalized beam emittance as a function of RF phase and main solenoid current. The reference solenoid current corresponds to the conditions of electron beam focusing at screen 2.

Emittance Measurements: Conditions and Method

Gradient at the cathode ~ 40 MV/m
Beam charge 1nC (laser power has been tuned for every RF phases)
RF Phase -10...+10deg
Main solenoid current 285A...315A
(300A->beam focus at screen 2)

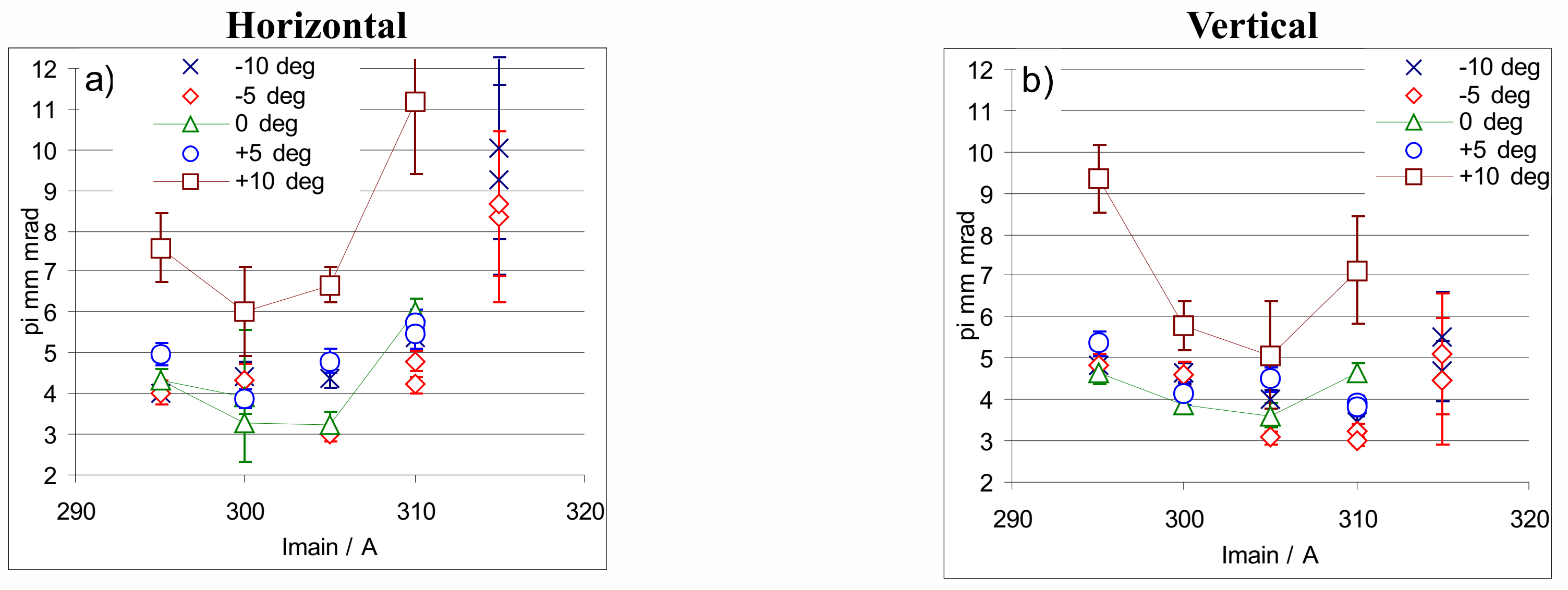
Measurements of the transverse emittance were performed using a single-slit scan technique. Beamlet profiles were observed 1010 mm downstream of a single-slit mask (z- position of screen 2; 1 mm thick tungsten plate, 50 μm slit opening) at screen 3.
Beamlets from three slit positions were taken into account for the emittance calculation y_n $\langle Y\rangle^{screen2}$ n 0.7 $_y^{screen2}$; n 1,0,1 .

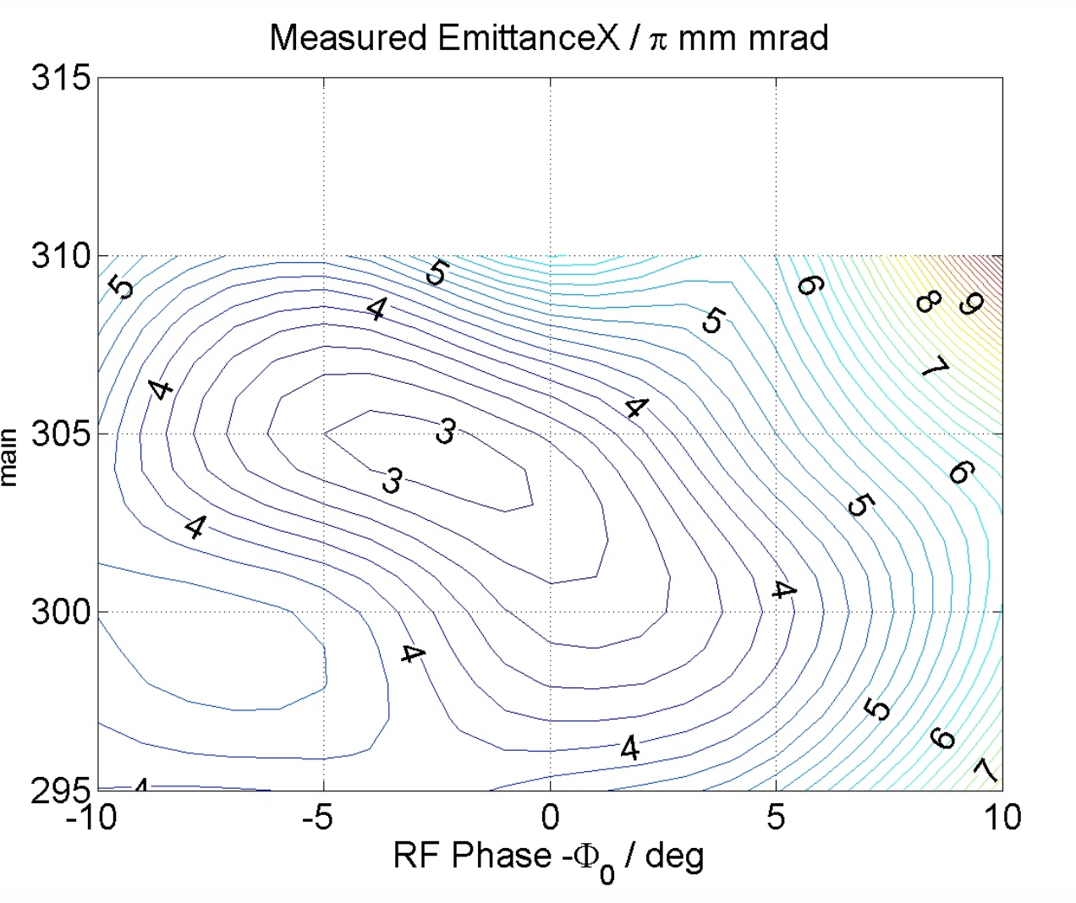


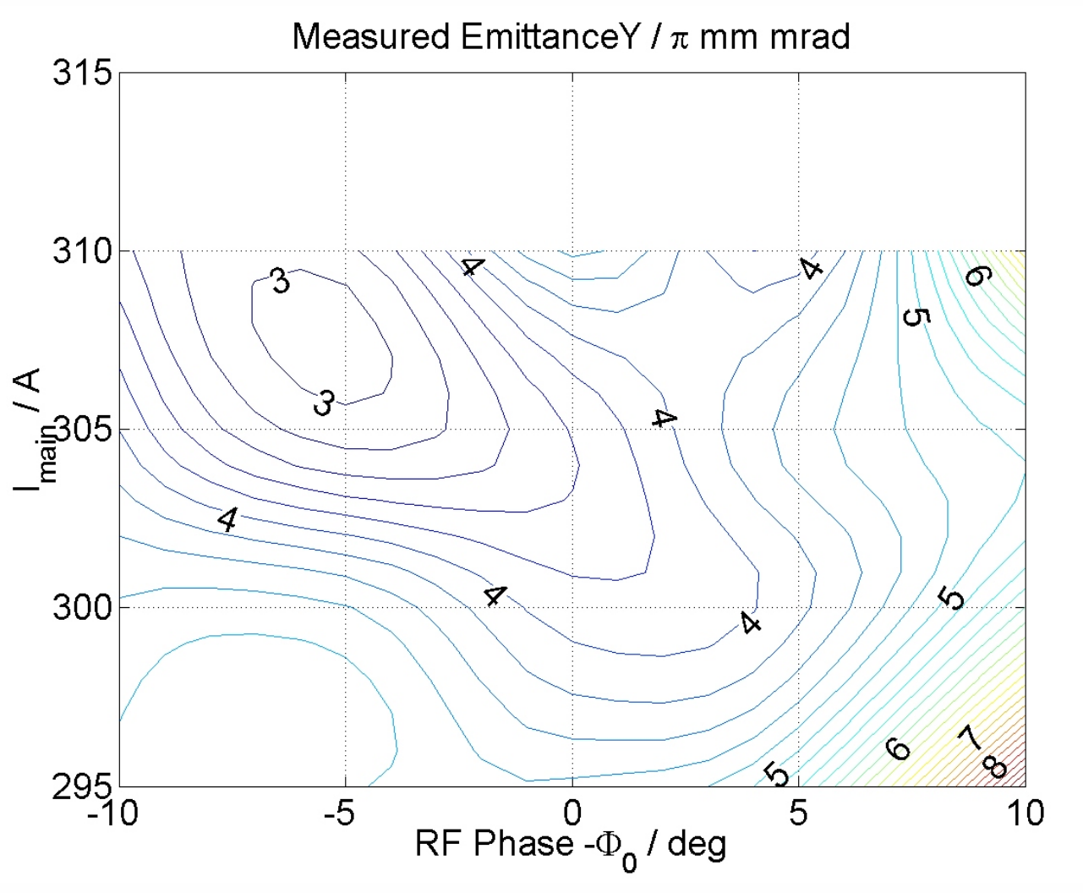
Measured Normalized Beam Emittance

Horizontal

Vertical





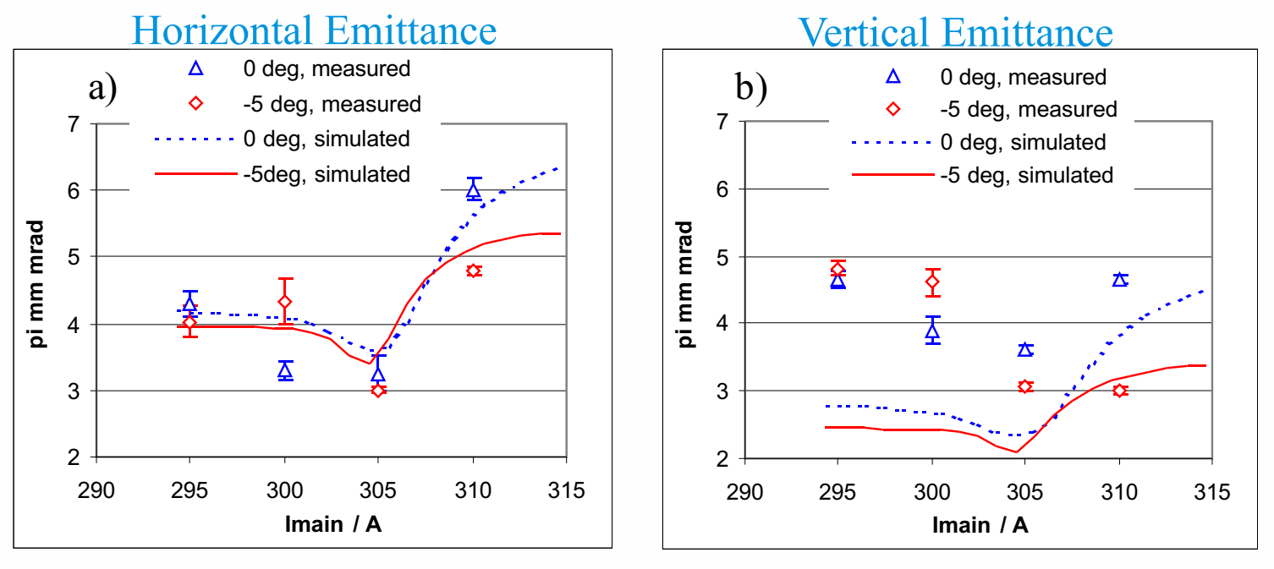


ASTRA Simulations

The normalized beam emittance has been simulated using ASTRA for injector parameters close to the ones observed during emittance measurements. This includes the modelling of the measured transverse and longitudinal laser profiles.

Horizontal Emittance

Vertical Emittance



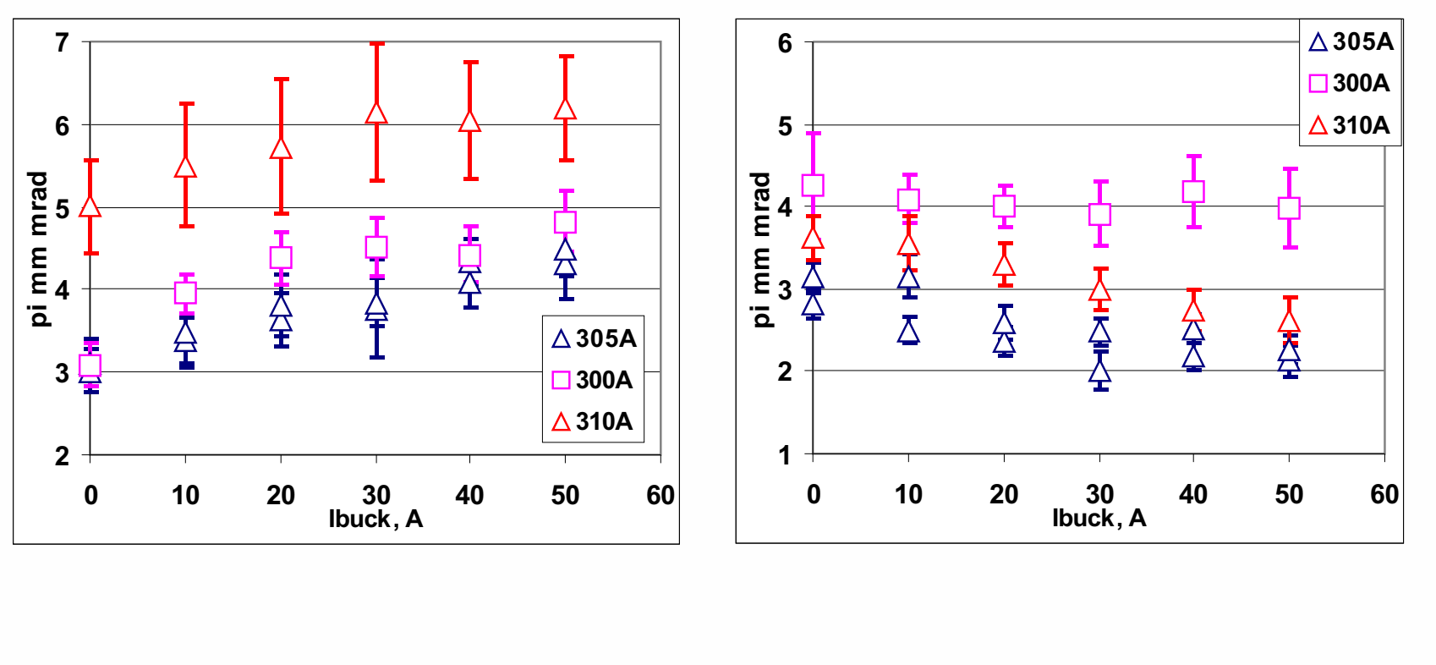
The coarse agreement between measurement and simulation (minimum emittances between 2 and 5 mm mrad for different transverse laser profiles) is good. In detail, the usage of the measured transverse laser distribution as an input for the simulations results in a rotational asymmetry. At least a part of the disagreement between simulated and measured emittances can be explained by the fact, that the space charge routine used in ASTRA is based on a cylinder symmetric beam model. Another probable explanation comes from possible imperfections in slit orientation, which causes X-Y coupling resulting in increased measured emittances.

Measured Normalized Transverse Beam Emittance as a Function of Bucking Coil Current

RF phase (-5deg) and main solenoid current (305-310A) corresspond to minimum emittance measured wit the bucking coil off

Horizontal Emittance

Vertical Emittance



Conclusions

The experimental optimisation and full characterization of the electron source at PITZ is ongoing. The current optimum machine parameters have been found.

A normalized transverse beam emittance of **3 mm mrad** for **1nC** electron beam is measured with high stability and reproducibility.

The simulations for the phase scan show reasonable agreement, while emittance simulations need further studies.