TRANSVERSE EMITTANCE MEASUREMENTS AT THE PHOTO INJECTOR TEST FACILITY AT ZEUTHEN

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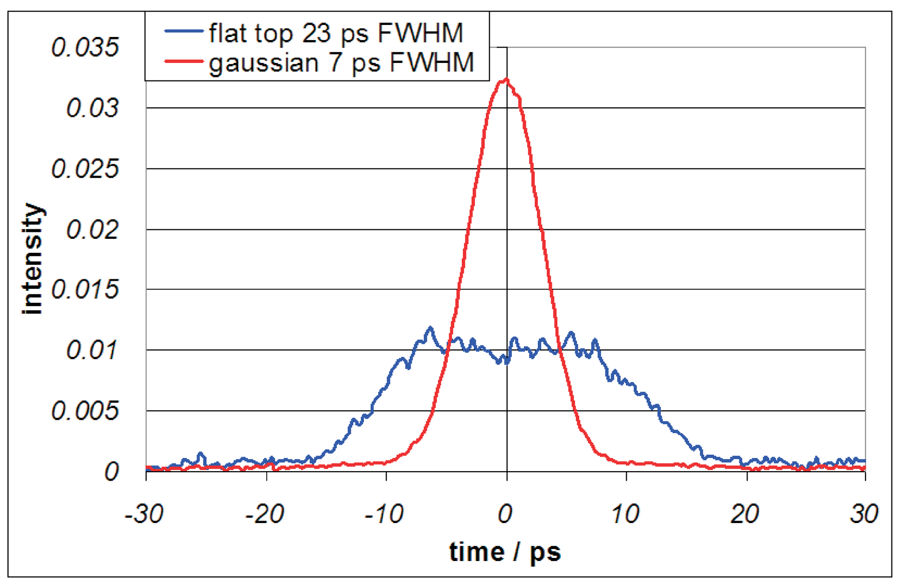
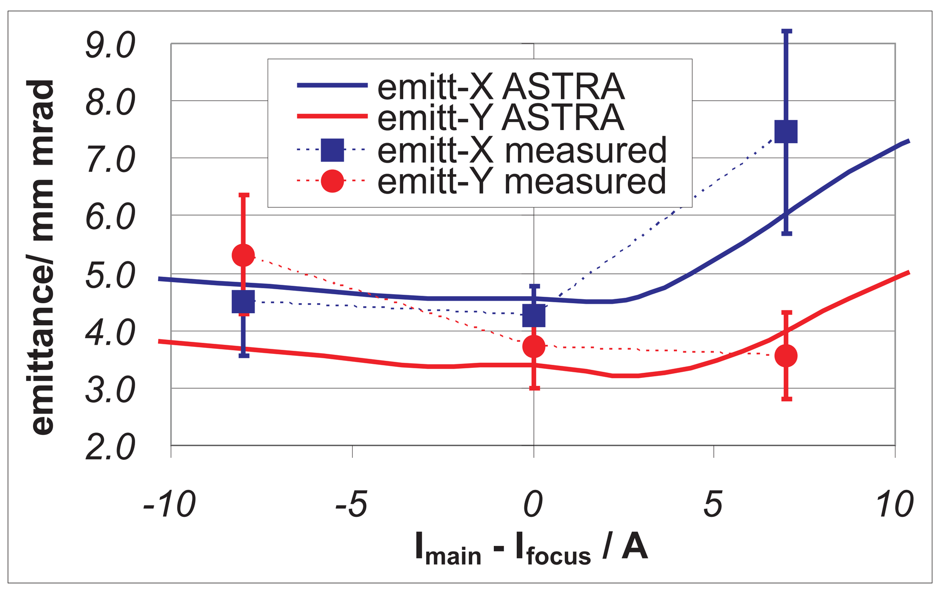
Measurements with various temporal profiles of the UV laser pulse

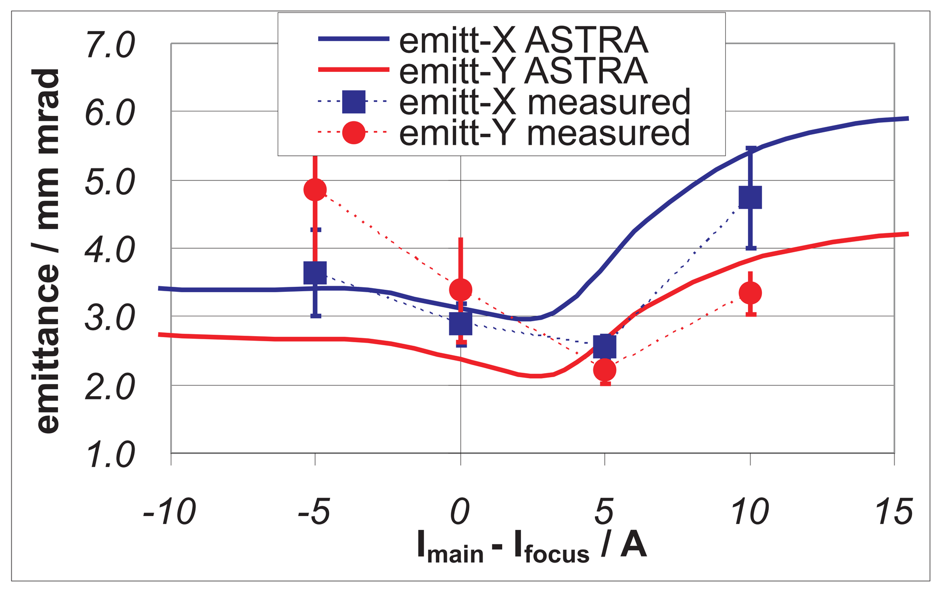
After an upgrade the PITZ laser system went over from the generation of gaussian to flat top temporal profile of the individual laser pulses. This change was motivated by the resulting significant reduction of the transverse emittance. It is shown that a longitudinal **flat top** laser pulse yields at 1 nC about two times smaller emittance than the **gaussian** profile at 0.5 nC. Since the emittance scales with the charge, we expect the emittance for the gaussian case at 1 nC to be even larger.



Longitudinal profiles of the laser pulse measured with a streak camera. Shown are two settings used in the experiments: a gaussian shaped and a flat top shaped profile



Projected normalized transverse emittance as a function of the main solenoid current I_{main} for a bunch charge of 0.5 nC and a **gaussian** laser pulse with a length of 6.3 ps FWHM. The minimal emittance is about 4 mm mrad

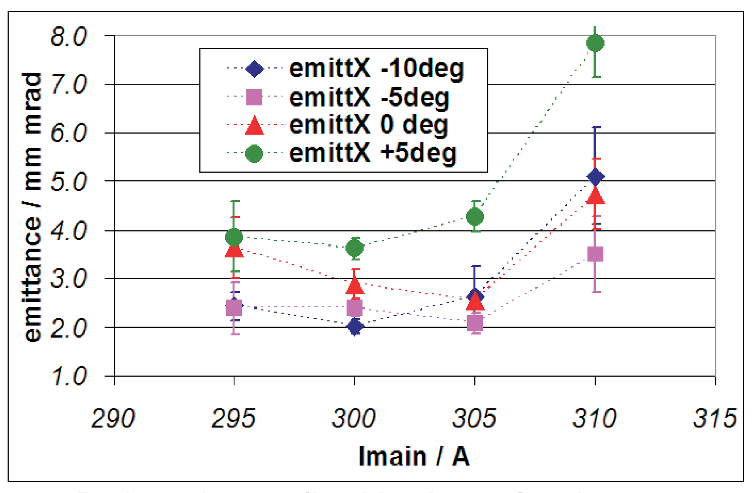


Projected normalized transverse emittance as a function of the main solenoid current I_{main} for a bunch charge of 1.0 nC and a **flat top** laser pulse with a length of 23 ps FWHM. The minimal emittance is about 2.3 mm mrad.

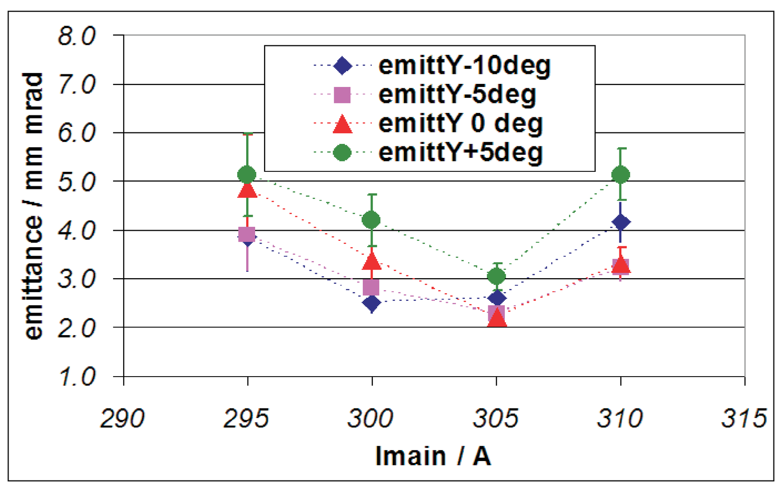
Emittance optimization of cavity prototype #2 towards the VUV-FEL requirements

For the case of the VUV-FEL in Hamburg, a normalized transverse projected emittance at the undulator entrance of about 3 mm mrad at 1.5 kA peak current is needed for saturation at about 30 nm and 2 mm mrad at 2.5 kA peak current is needed for saturation at 6 nm.

As a first optimization step, the transverse emittance for a bunch charge of 1 nC is measured as a function of the main solenoid current I_{main} for the rf phases $\Phi - \Phi_m = -10^\circ, -5^\circ, 0^\circ$ and $+5^\circ$ at a maximum accelerating gradient on the cathode of 42 MV/m. Here Φ_m denotes the pase with maximum energy gain.

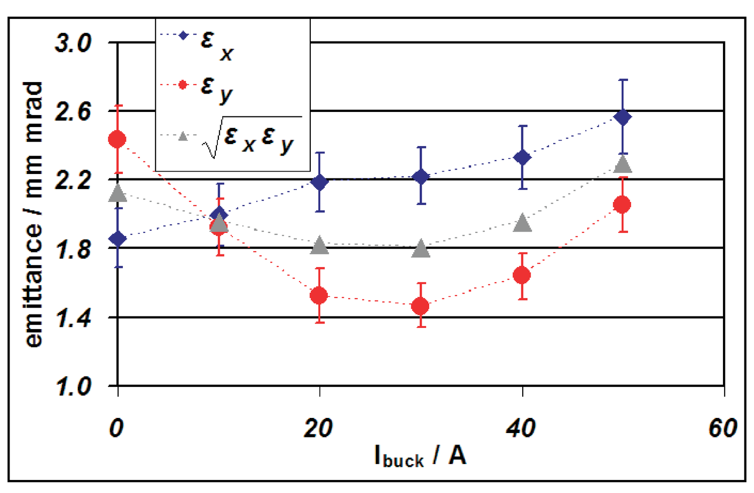


Projected normalized **horizontal** emittance for different main solenoid currents and gun phases $\Phi - \Phi_m = -10^\circ, -5^\circ, 0^\circ$ and $+5^\circ$. The bunch charge is 1.0 nC

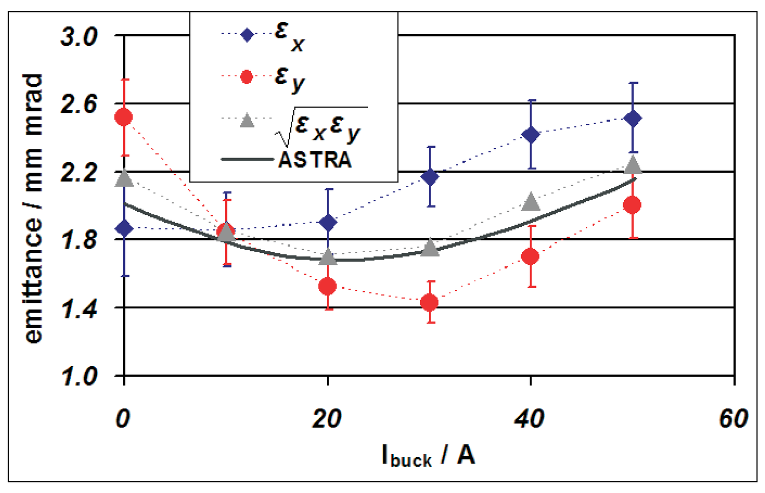


Projected normalized **vertical** emittance for different main solenoid currents and gun phases $\Phi - \Phi_m = -10^\circ, -5^\circ, 0^\circ$ and $+5^\circ$. The bunch charge is 1.0 nC

For the measurements plotted in the Figures above the residual magnetic field on the photo cathode has not been compensated. Therefore, additional scans with the compensating bucking solenoid were performed for the settings with the smallest emittance: {305 A, $\Phi - \Phi_m = 0^\circ$} and {305 A, $\Phi - \Phi_m = -5^\circ$}. The results are shown below.



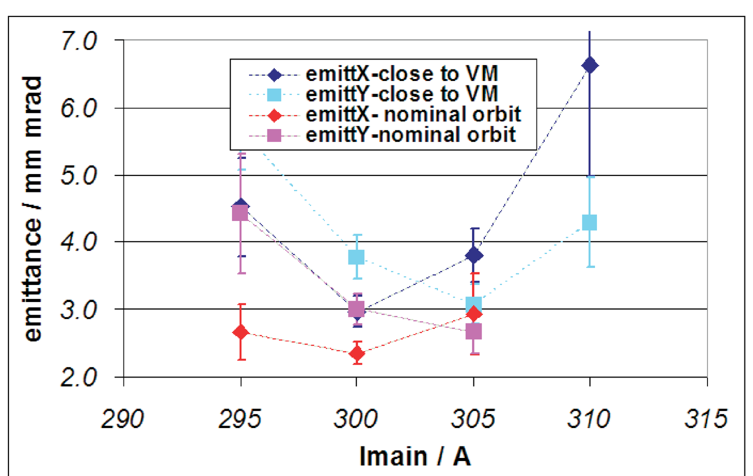
Projected normalized emittance for different bucking solenoid currents. The bunch charge is 1.0 nC, the main solenoid was set to 305 A and the gun phase $\Phi - \Phi_m = 0^\circ$.



Projected normalized emittance for different bucking solenoid currents. The bunch charge is 1.0 nC, the main solenoid was set to 305 A and the gun phase $\Phi - \Phi_m = -5^\circ$.

The smallest normalized projected emittance is measured with 1.5 mm mrad in the vertical plane. The smallest geometrical average emittance of both transverse planes is 1.7 mm mrad.

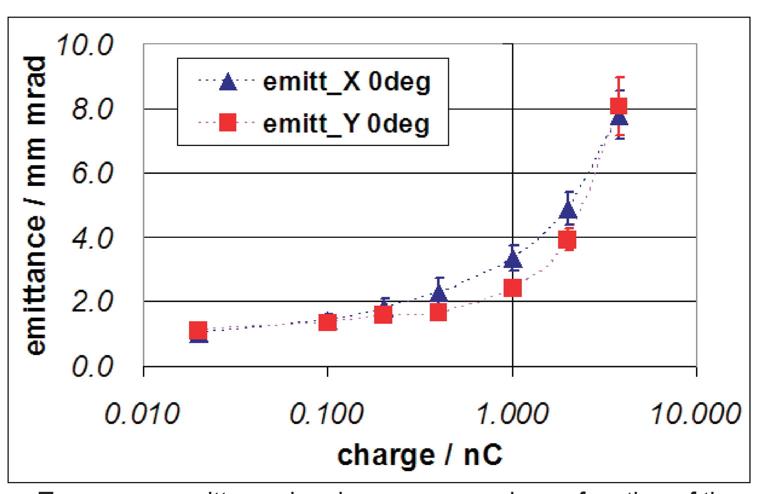
Impact of vacuum components



For the first of the two sets of measurements shown, the electron beam has been horizontally shifted with respect to its design orbit. The beam is steered 6 mm closer to the laser vacuum mirror (VM) then the nominal distance of 12 mm. This metallized glass mirror is being charged up by the beam and dark current and the resulting electrostatic field affects the beam quality. As it is shown in the second measurements set an emittance reduction of 0.5 to 1.0 mm mrad is achieved by steering the beam away from VM.

Emittance scaling with the charge

Measurement conditions not yet optimized for minimum emittance



Transverse emittance has been measured as a function of the bunch charge at rf phase $\Phi = \Phi_m$. The charge was varied in the range 0.02 to 3.80 nC and the main solenoid current set to focus the beam at the position of the slit mask for each emittance measurement

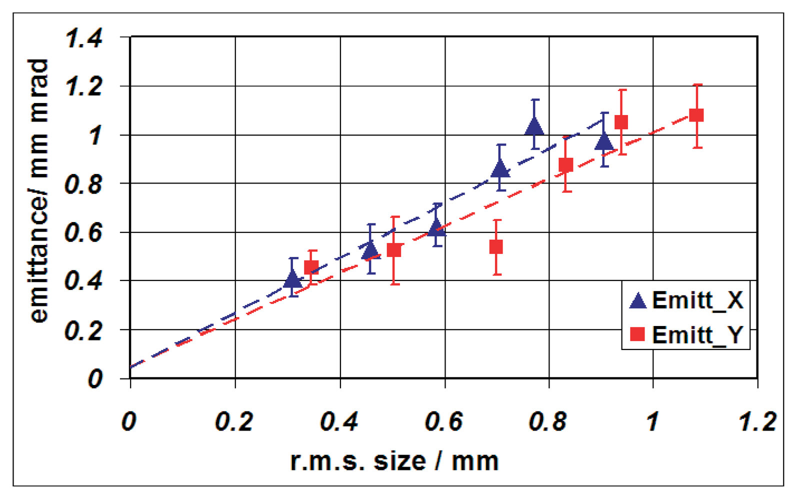
Thermal emittance measurements for Cs_2Te photo-cathode

The thermal emittance is limiting the emittance reach in photo-cathode rf guns. Therefore, its measurement is of high importance to understand the ultimate performance limit of rf gun based electron sources.

The thermal emittance measurements use a laser pulse with a gaussian temporal profile of 6 to 8 ps FWHM. Simulations with ASTRA show that for these short pulses the emittance growth due to the rf field should be negligible (less than 2%) compared to the expected thermal emittance ε_{th}. The final goal of the measurements is to estimate the average kinetic energy E_k of the electrons emitted from the Cs_2Te photo-cathode. An emission model is assumed, such that:

$$\varepsilon_{th} = \sigma\sqrt{\frac{2E_k}{3m_0c^2}} \Rightarrow E_k = 1.5m_0c^2\left(\frac{d\varepsilon_{th}}{d\sigma}\right)^2$$

Emittance scaling with the laser spot r.m.s. size

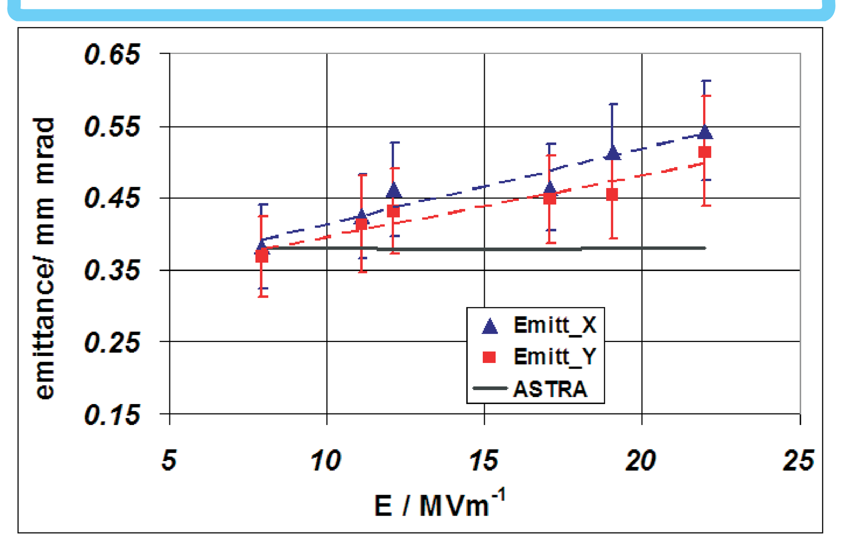


The Figure above shows the normalized emittance for different r.m.s. laser spot sizes measured with the single slit scanning method at a charge of about 3 pC and an accelerating gradient at the cathode of 32 MV/m. For these conditions simulations predict an emittance growth of less than 5 % due to space charge effects. From a straight line fit one obtains:

$$\frac{d\varepsilon}{d\sigma} = 1.0 \text{ to } 1.1 \text{ mrad}$$

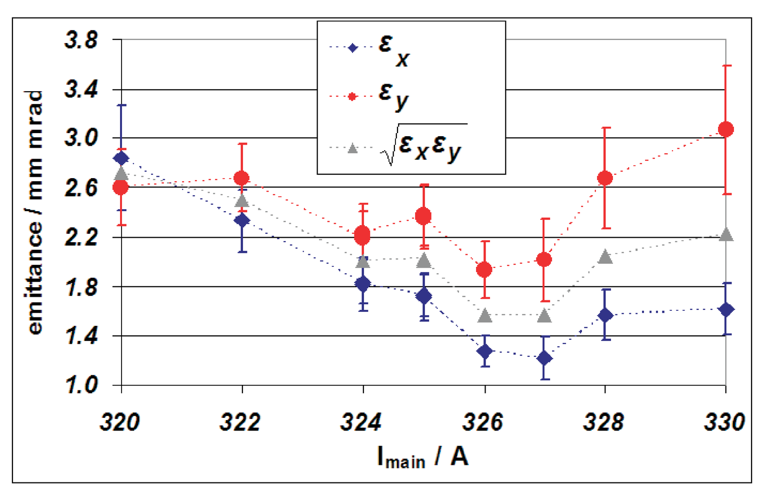
$$\Rightarrow E_k = 0.8 \pm 0.1 eV$$

Dependence of emittance on accelerating gradient



The transverse emittance was measured at a charge of 2 to 3 pC as a function of the accelerating field E at the cathode. The single slit scanning technique was used for this measurements. The electric field amplitude E_0 was varied in the range of 24 to 37 MV/m. The laser spot size was kept fixed. The solenoid current was adjusted such that the beam was focused on the position of the slit mask. The rf phase Φ was set to Φ_m for each measurement. In addition, before each measurement the charge was measured as a function of the rf phase. From the rising edge of the phase scan the zero crossing phase Φ_0 was determined. Finally the applied field at the cathode is calculated as $E=E_0 \sin(\Phi_m - \Phi_0)$. Presented results show an increasing transverse emittance with the accelerating field. The simulation predicts a constant emittance. It includes the beam dynamics in the rf gun, but does not scale the kinetic energy of the emitted electrons with the applied field at the cathode. The increasing emittance corresponds to a rising kinetic energy of the emitted electrons.

Recent measurements with cavity prototype #1



After cavity prototype #2 was fully characterized at PITZ and installed at TTF, cavity prototype #1 was put into operation at PITZ in the beginning of 2004 followed by the rf conditioning. The beam dynamics optimization is ongoing. The Figure above shows emittance measurements done for a bunch charge of 1 nC at the current stage of optimization.

Summary

The impact of the temporal laser pulse profile on the transverse emittance has been demonstrated. A longitudinal flat top laser pulse yields a significantly better transverse emittance than a gaussian shape. The characterization of the rf gun cavity for the VUV-FEL was presented. The smallest normalized projected emittance is measured with 1.5 mm mrad in the vertical plane. The smallest geometrical average emittance of both transverse planes is 1.7 mm mrad. Measurements to estimate the thermal emittance have been done using a very small bunch charge and moderate accelerating gradients. The average kinetic energy of the emitted photo electrons is estimated to be 0.8 eV. An increasing of the thermal emittance with the accelerating field on the cathode has been observed. The characterization of the next cavity at PITZ is ongoing and shows promising results.

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