Photo injector optimization at PITZ, status 2011: measurements vs. simulations

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    - emittance vs. main solenoid detuning
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- Summary
- Simulation request for PITZ

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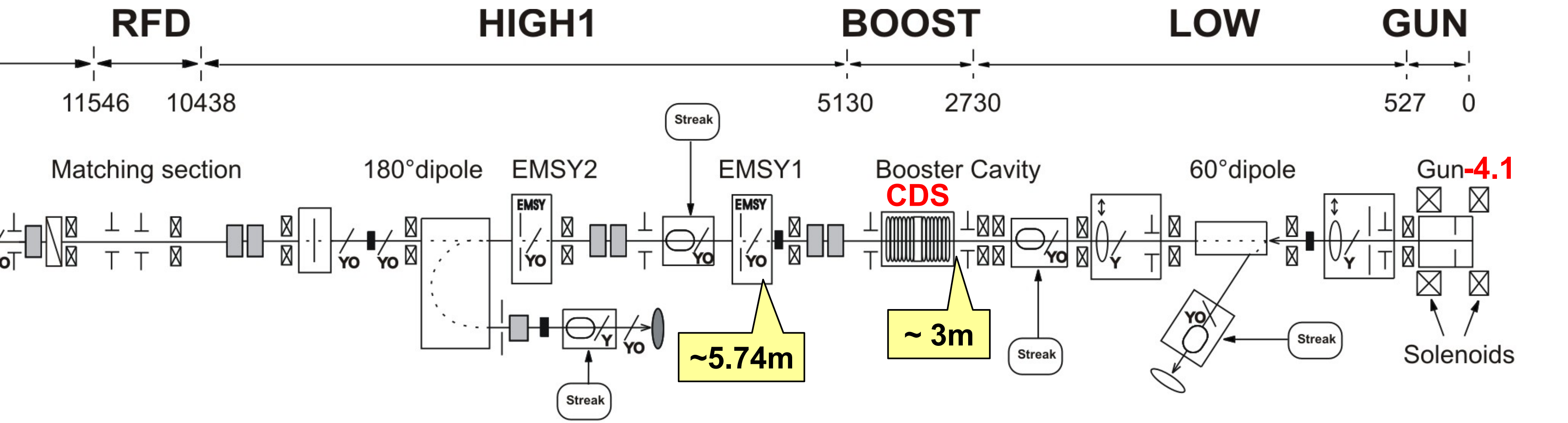
PITZ Photo Injector Test Facility Zeuthen

DESY

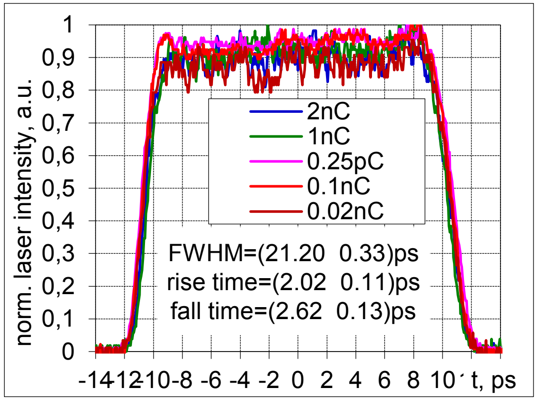
Beam Dynamics Simulations (ASTRA) for PITZ-1.8 Setup



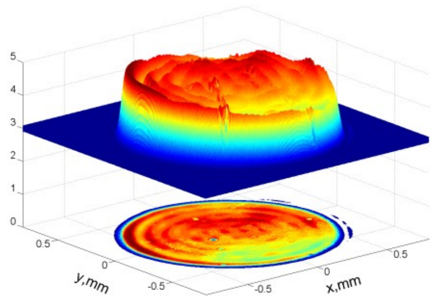
Cathode laser pulse profiles

Measured

Temporal profiles (OSS)

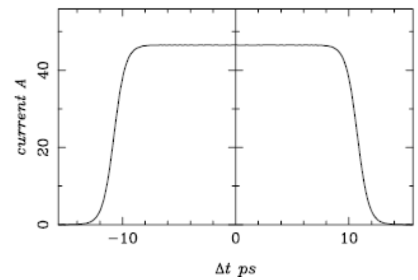


Transverse distribution (VC2)

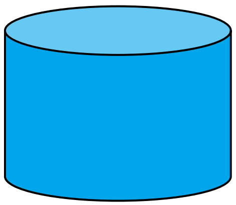


Used in beam dynamics simulations

Ideal temporal profile:
2ps/21.5ps\2ps

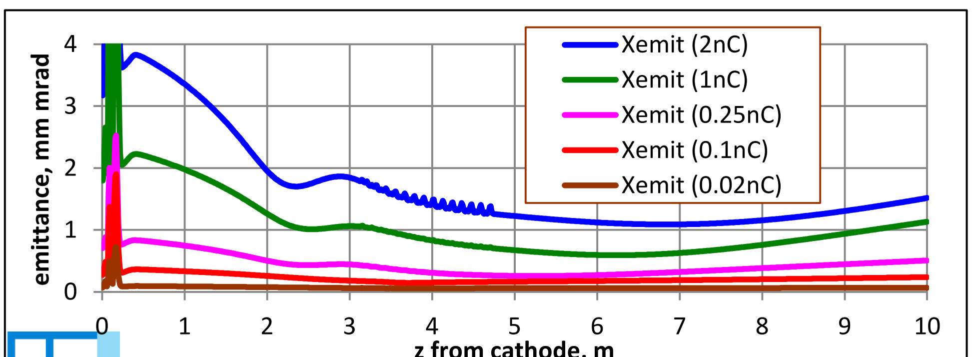


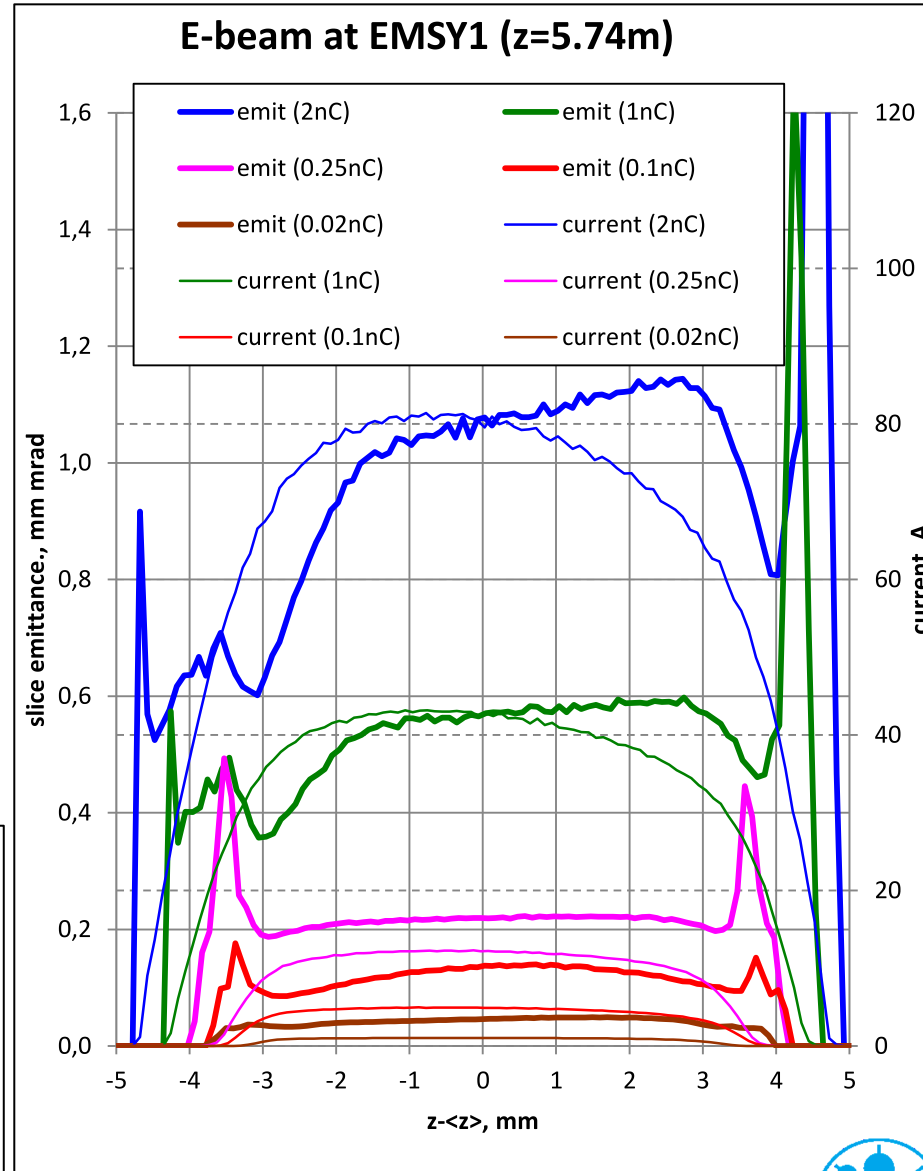
Transverse distribution
radial homogeneous



BD simulations (ASTRA) for various charges

	parameter	unit	20pC	100pC	250pC	1nC	2nC
cathode laser	temporal	profile	Flat-top				
	transverse	distribution	radial homogen.				
	rt/FWHM\ft	ps	**2/21.5\2**				
	Trms	ps	6.27				
	XYrms	mm	0.037	0.102	0.230	0.401	0.600
	Ek	eV	0.55				
	th.emit.	mm mrad	0.031	0.086	0.195	0.340	0.508
RF-gun	Ecath	MV/m	60.58				
	phase*	deg	1.43	1.24	1.01	-1.40	-2.63
	maxBz	T	-0.2243	-0.2270	-0.2272	-0.2279	-0.2284
CDS boost	**maxE**		20*	20*	20*	19.76	20*
	phase*	deg	0				
e-beam @EMSY1	charge	nC	0.02	0.1	0.25	1	2
	energy	MeV	23.6	23.6	23.6	23.41	23.6
	rms length	mm	1.74	1.85	1.86	2.16	2.31
	proj.emit.	mm mrad	**0.061**	**0.173**	**0.262**	**0.607**	**1.144**
	th./proj.em.	%	52%	50%	74%	56%	44%
	<sl.emit.>	mm mrad	0.044	0.121	0.219	0.538	0.978

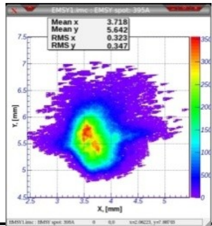
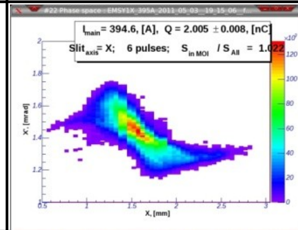
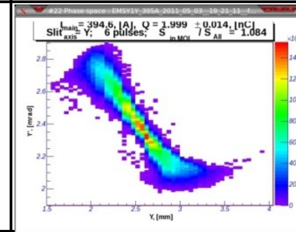
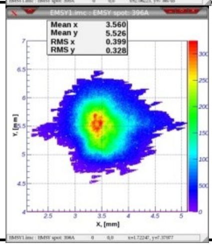
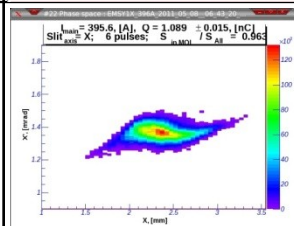
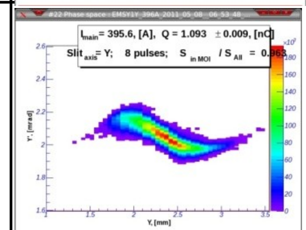
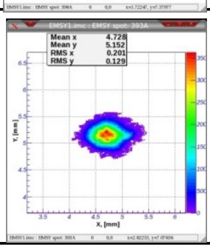
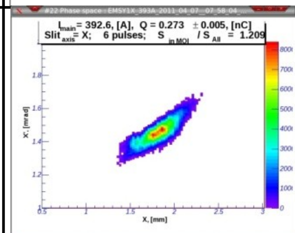
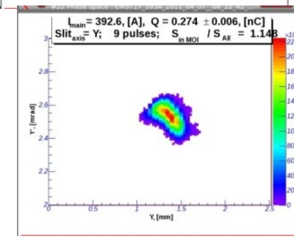
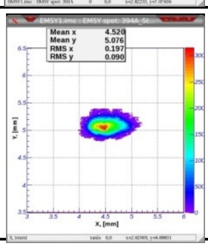
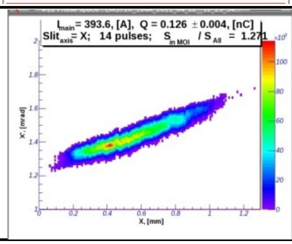
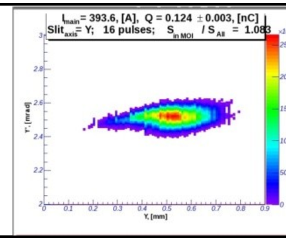
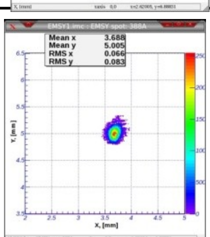
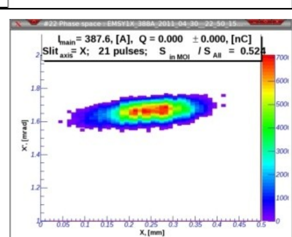
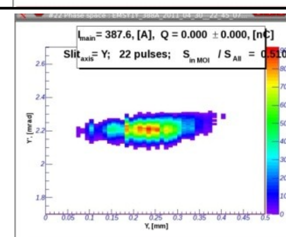




Emittance at PITZ-1.8:

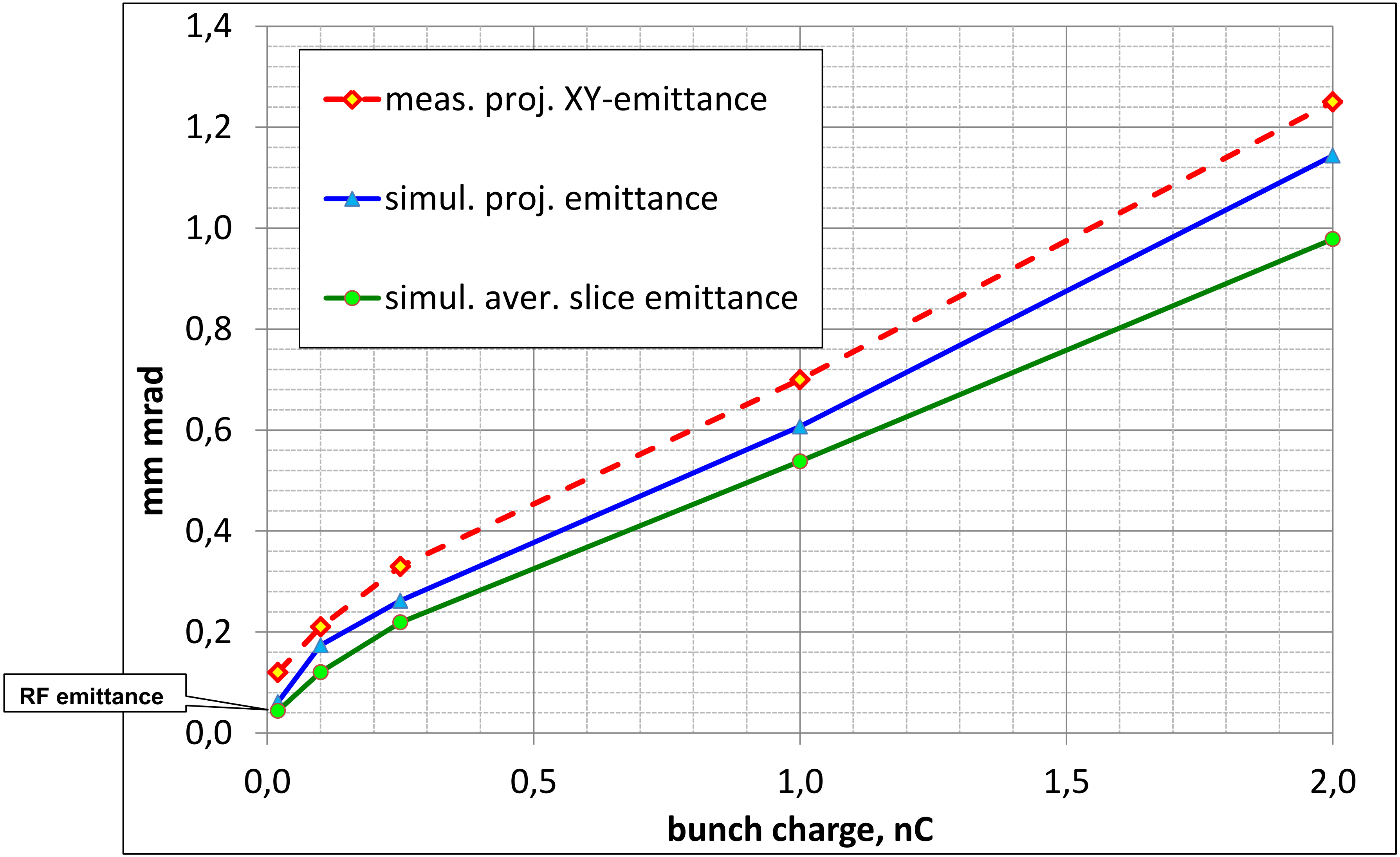
Measurements vs. Simulations

Measured Phase Spaces for various bunch charges

Qbunch / Las.XYrms	Beam at EMSY1: XY-Image	Beam at EMSY1: σ_x / σ_y	Horizontal phase space	ε_x	Vertical phase space	ε_y	ϕ_{gun}
2 nC / 0.38 mm		0.323mm 0.347mm		1.209 mm mrad		1.296 mm mrad	+6deg
1 nC / 0.30 mm		0.399mm 0.328mm		0.766 mm mrad		0.653 mm mrad	+6deg
0.25 nC / 0.18 mm		0.201mm 0.129mm		0.350 mm mrad		0.291 mm mrad	0deg
0.1 nC / 0.12 mm		0.197mm 0.090mm		0.282 mm mrad		0.157 mm mrad	0deg
0.02 nC / 0.08 mm		0.066mm 0.083mm		0.111 mm mrad		0.129 mm mrad	0deg

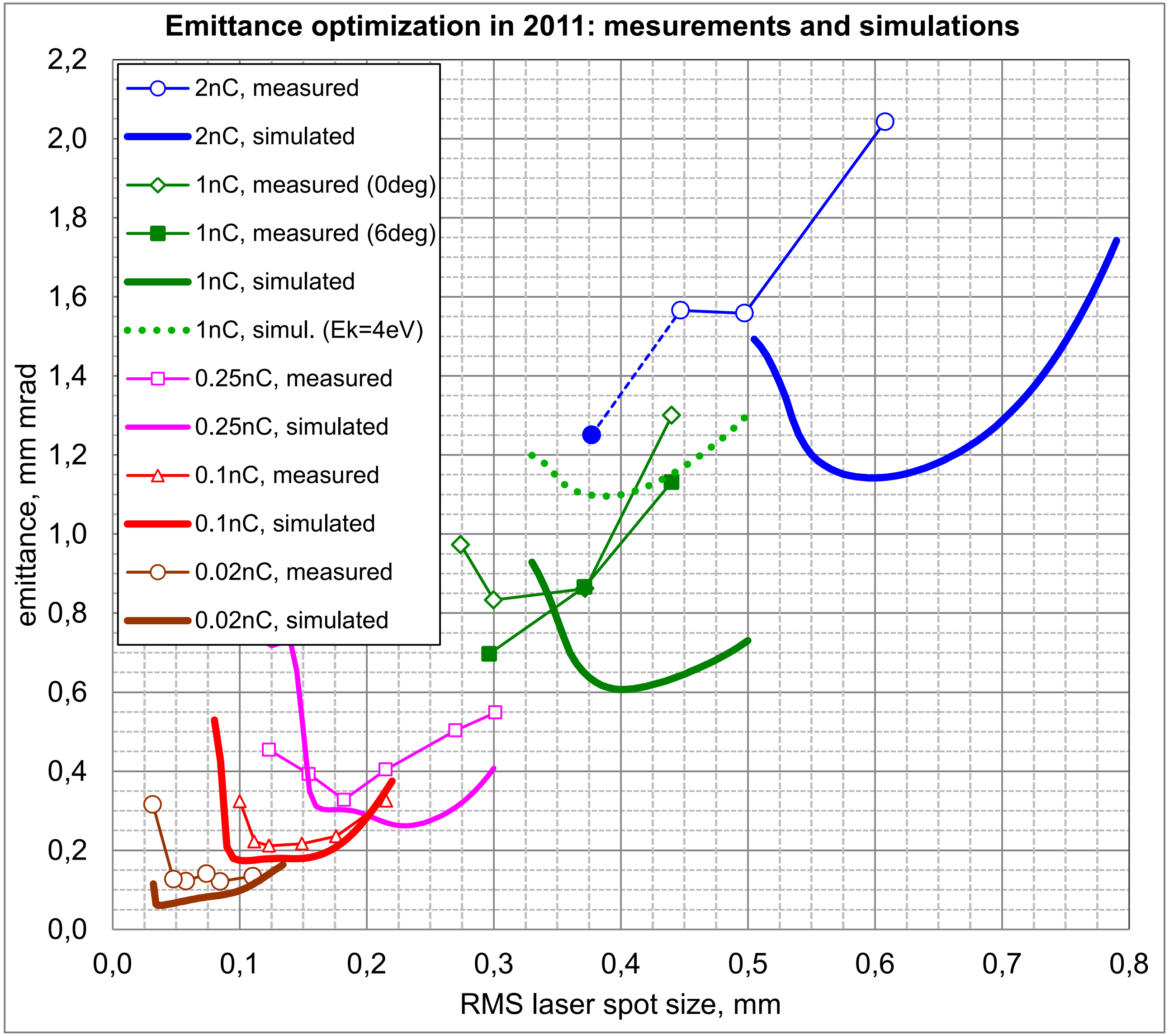
zoomed

Optimized Emittance vs. Bunch Charge



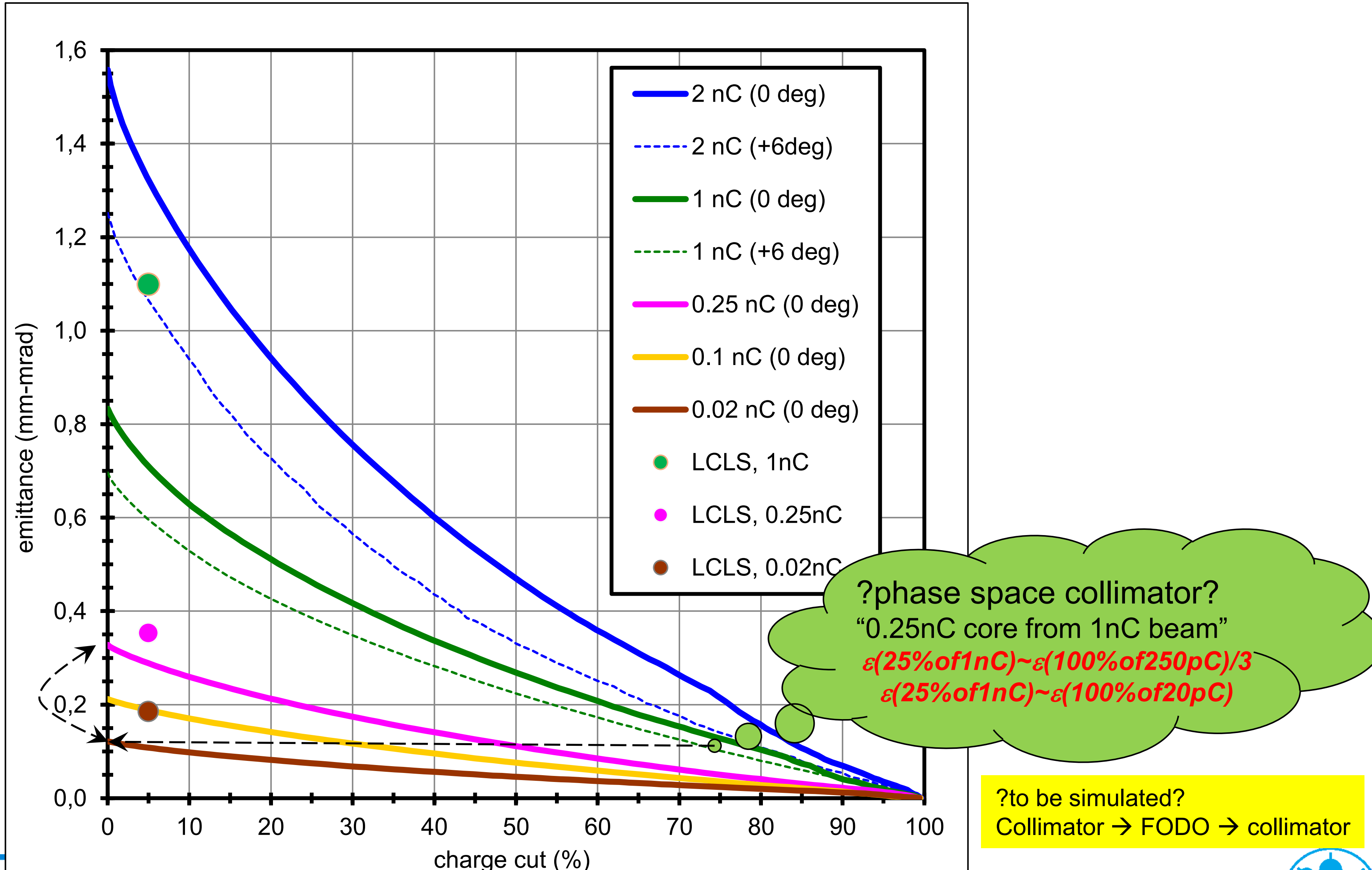
Rather good agreement on emittance values, but …

Emittance (Q, rms laser size): simulations vs. measurements



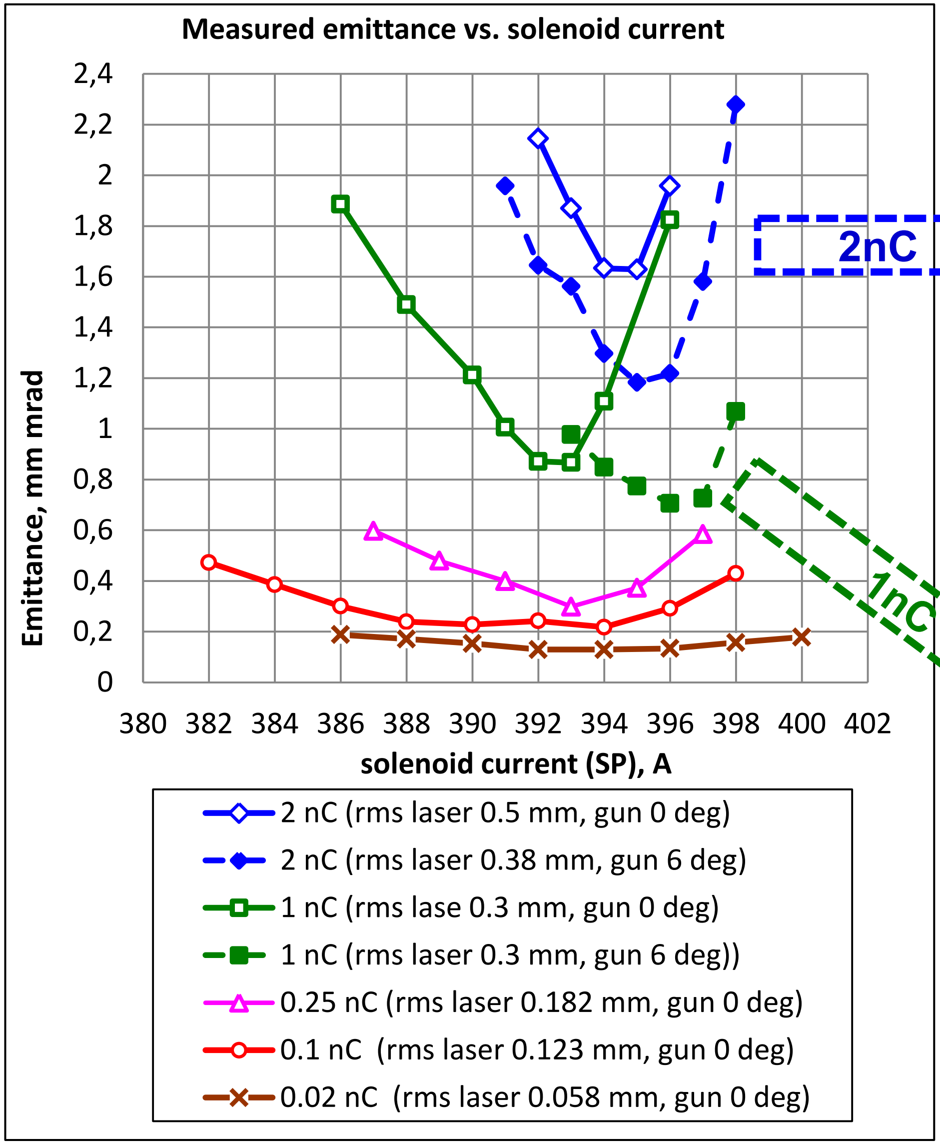
- Optimum machine parameters (laser spot size, gun phase): experiment ≠ simulations
- Difference in the optimum laser spot size is bigger for higher charges (~good agreement for 100pC)
- A radial homogeneous laser pulse distribution is used in simulations whereas the experimental transverse distribution is not perfect
- Artificial increase of the thermal kinetic energy at the cathode (from 0.55eV to 4eV) did not improve the understanding

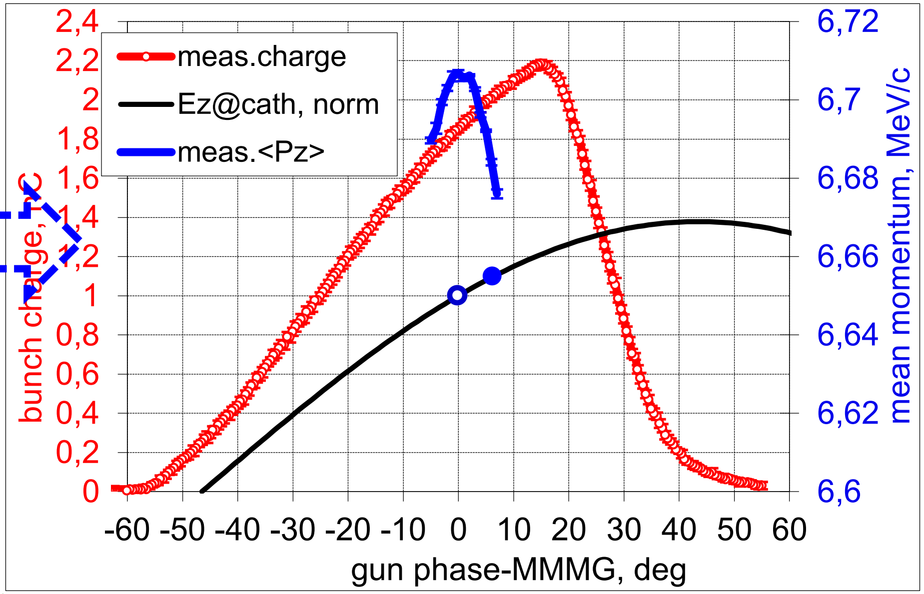
Core Emittance for various bunch charges

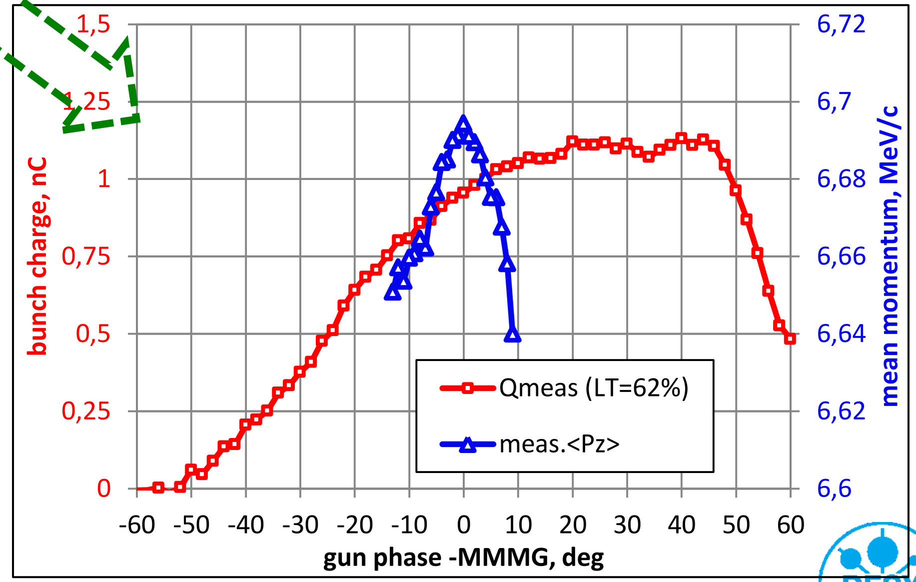


?to be simulated?
Collimator → FODO → collimator

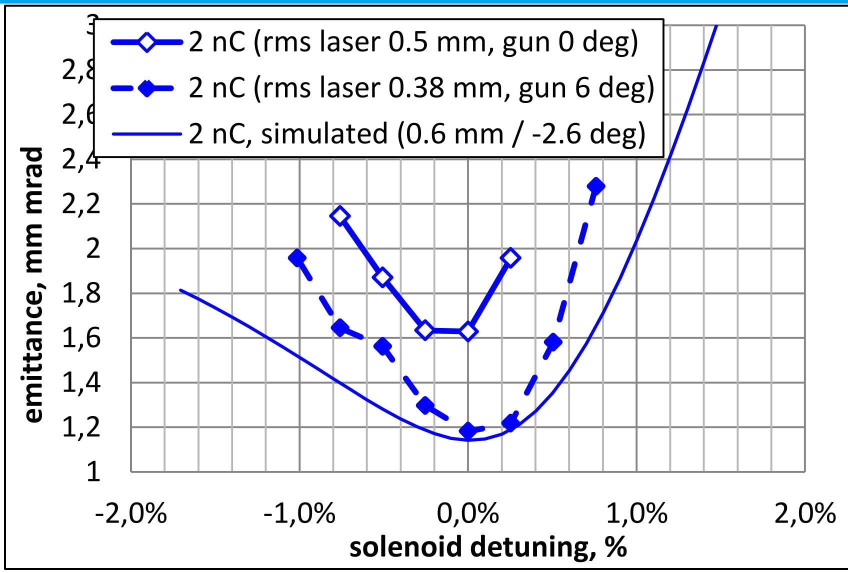
Emittance vs. Imain for various bunch charges

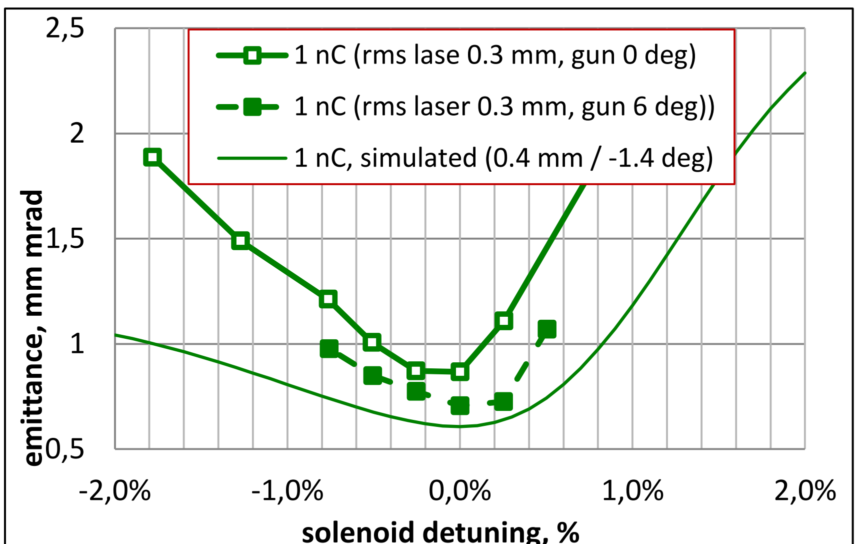


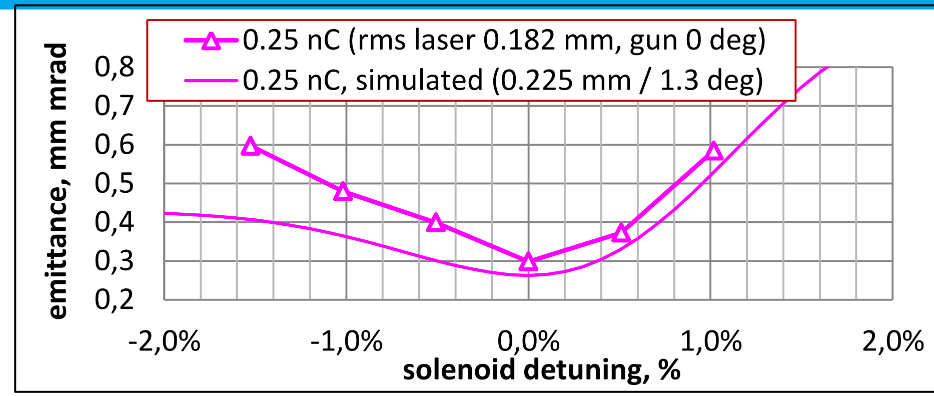


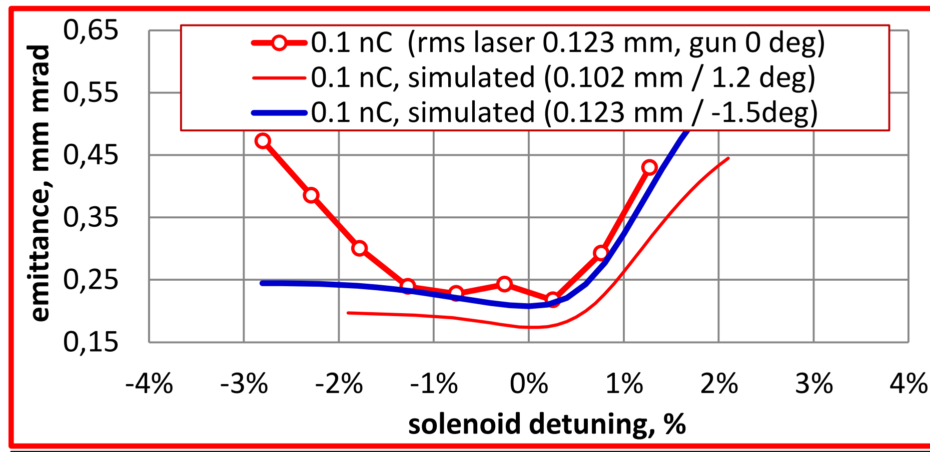


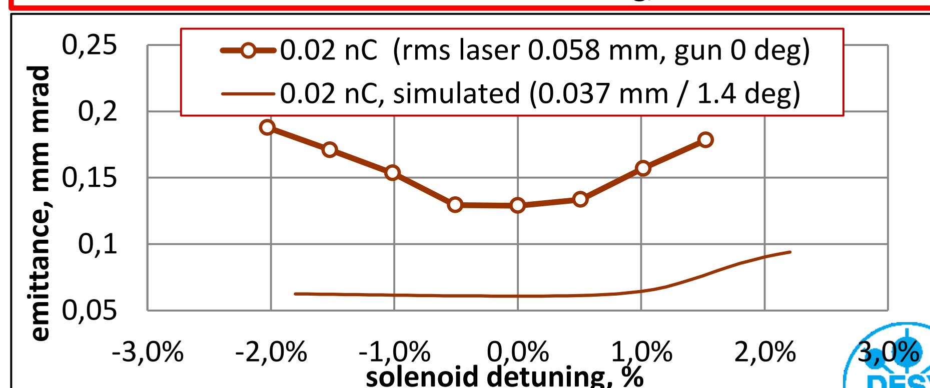
Emittance vs. (Imain/I*-1) for various bunch charges: M←→S



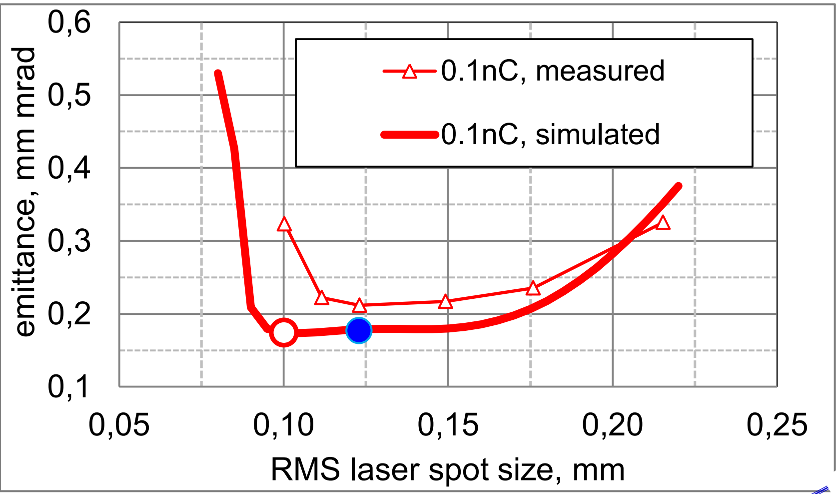


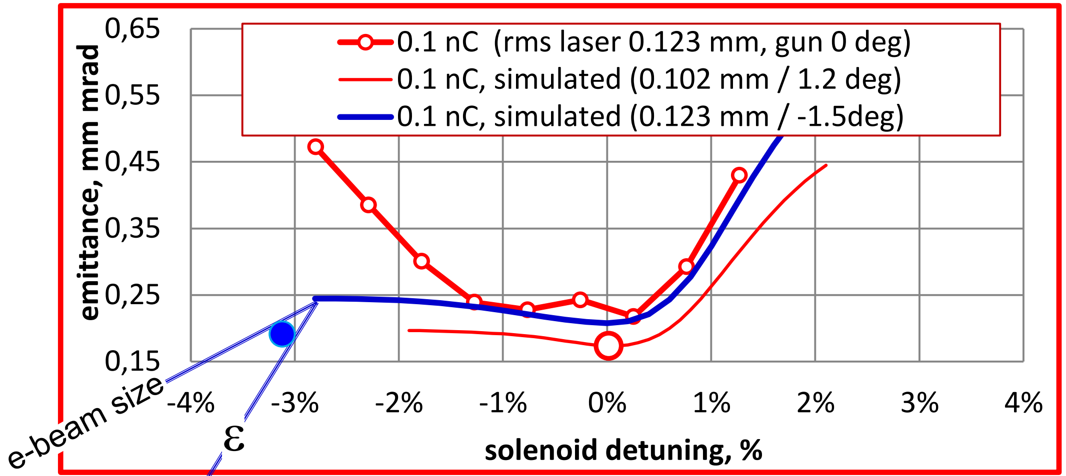


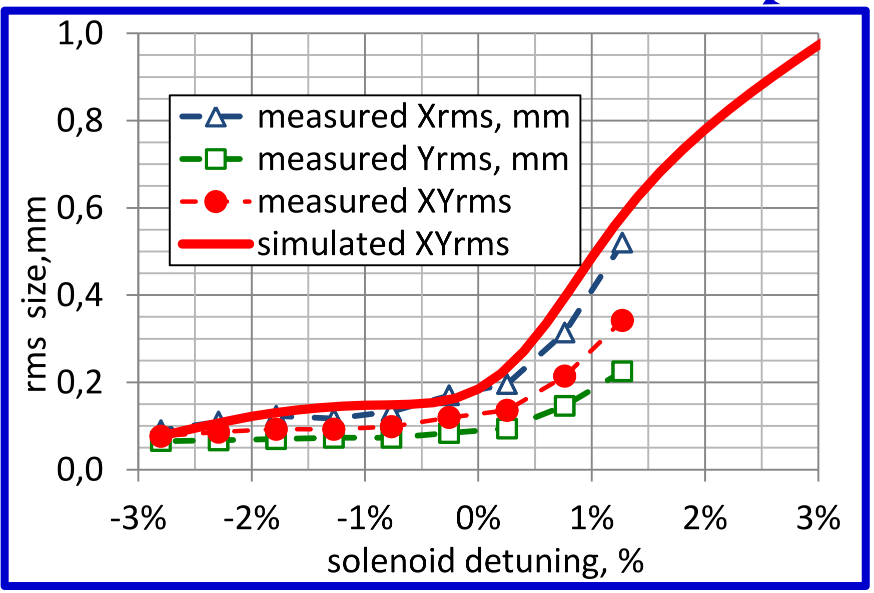


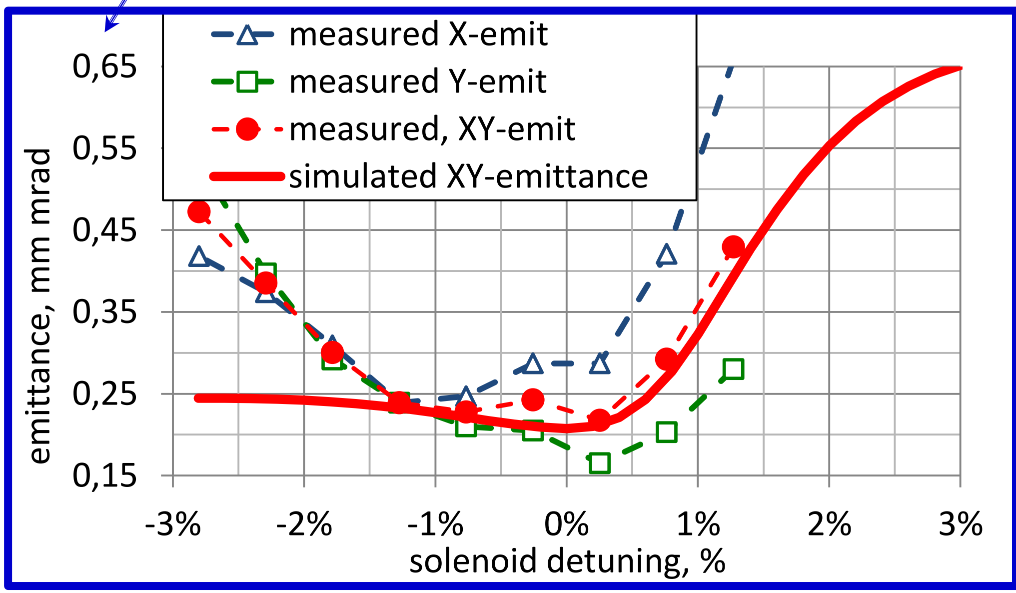


Measured and Simulated Emittance: 0.1nC





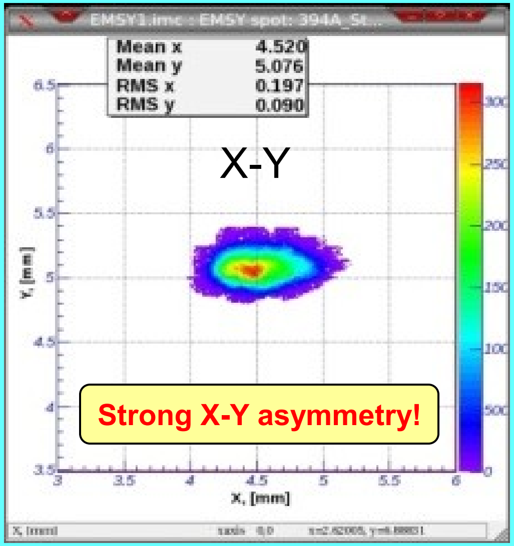


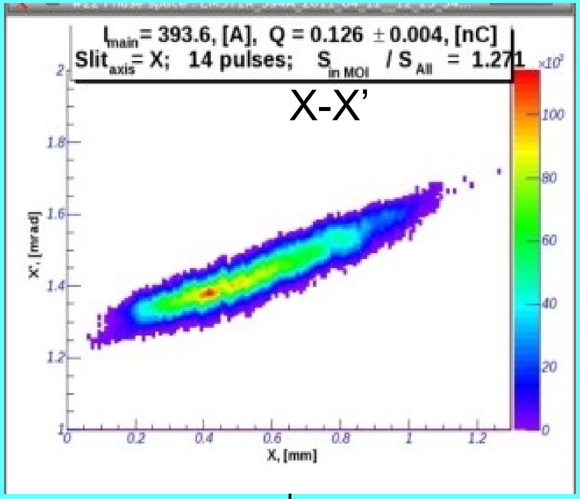


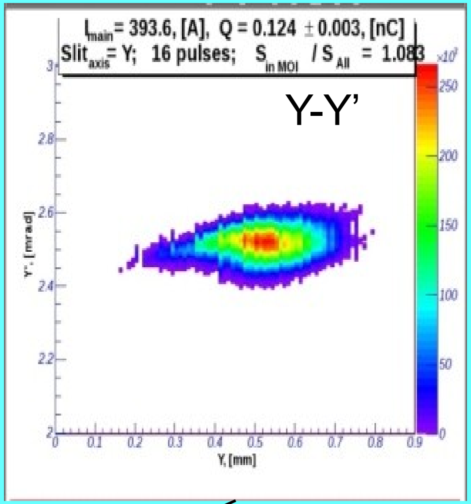
Rather good agreement in both beam rms size and emittance!

Measured and Simulated Phase Space at EMSY1: 0.1nC

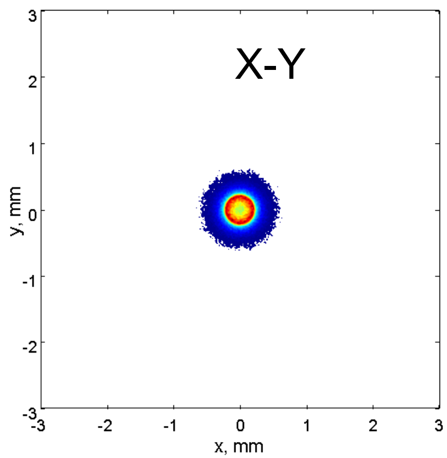
Measured

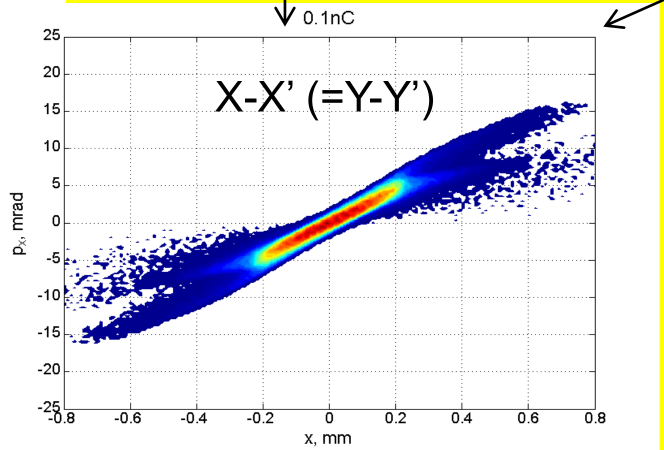


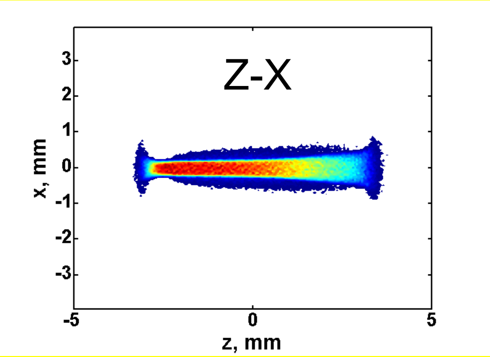




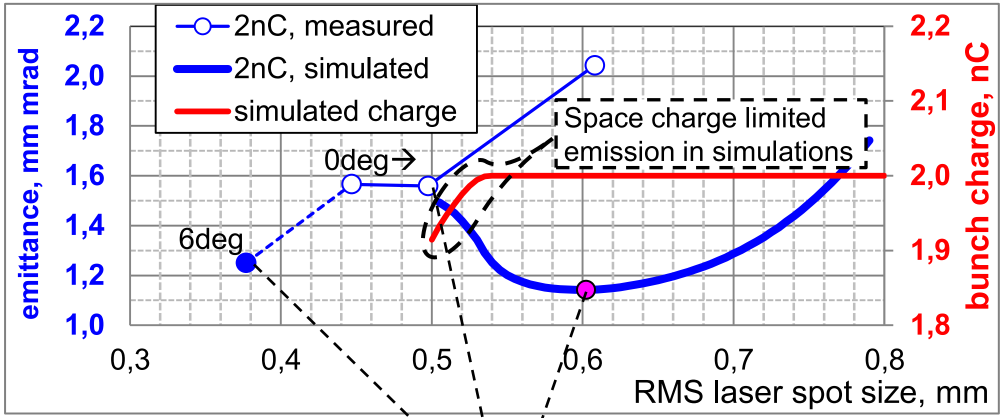
Simulated



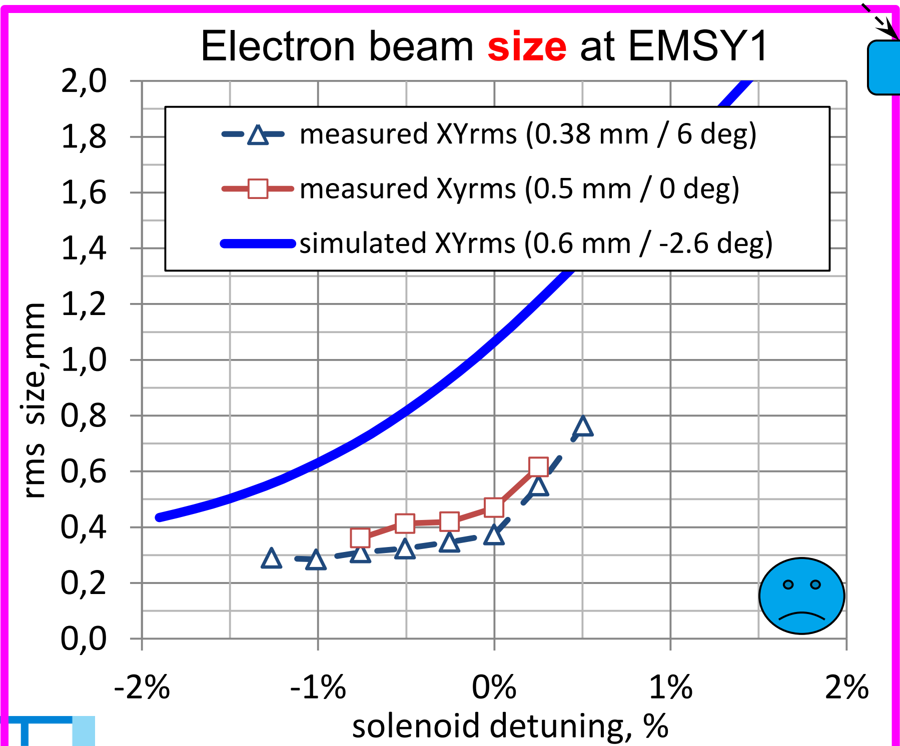


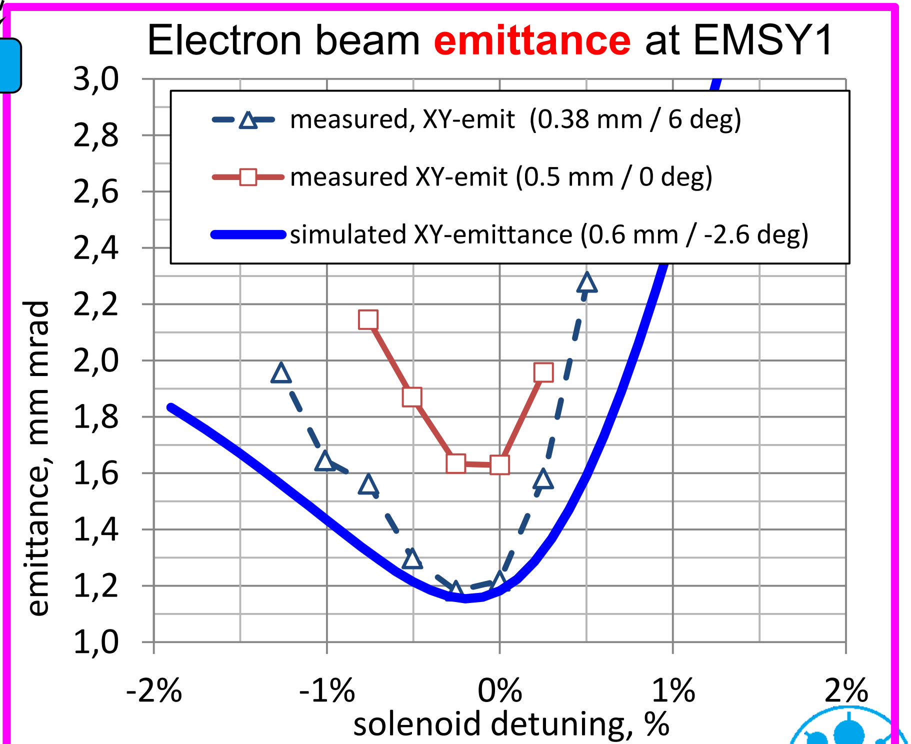


Measured and Simulated Emittance: 2nC



- Good agreement only on the minimum emittance **value**
- Strong disagreement in the optimum **laser spot size** (no 2nC simulated at 0.5 mm, but measured)
- Simulated **electron beam size** is much larger than the measured one

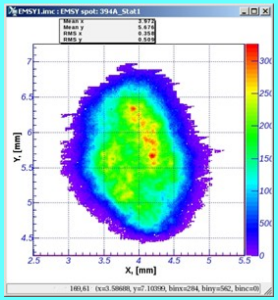


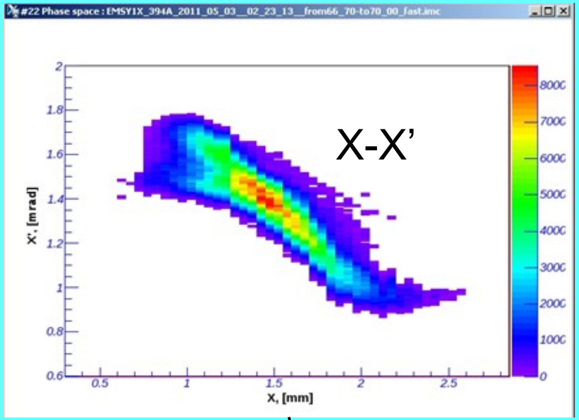


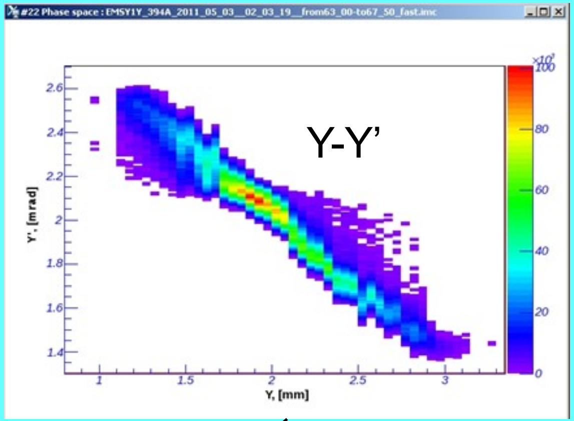
Measured and Simulated Phase Space at EMSY1: 2nC

Measured

X-Y



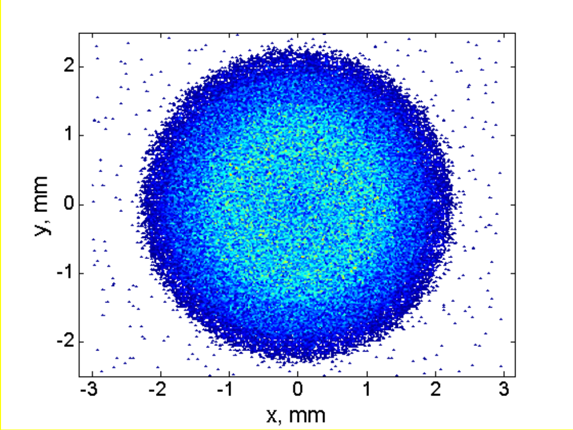


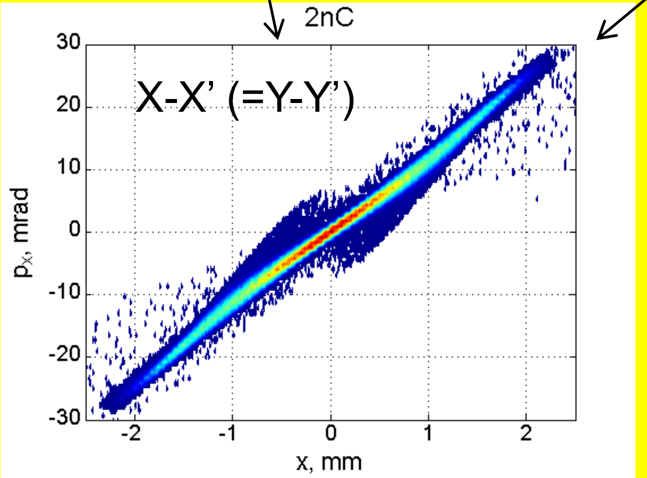


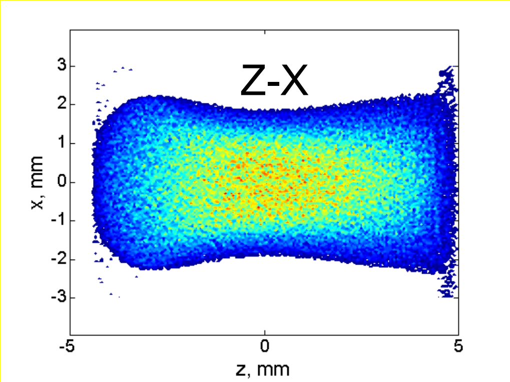
Sign of the X-X' (Y-Y') correlation ?

Simulated

X-Y

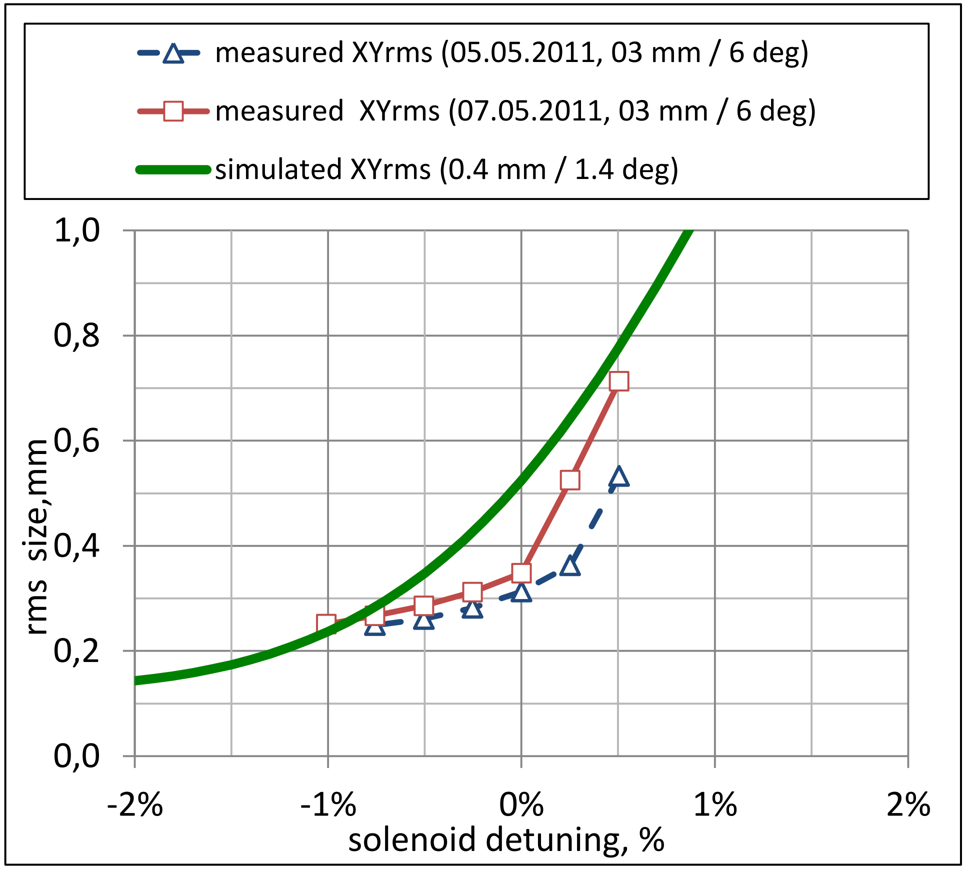




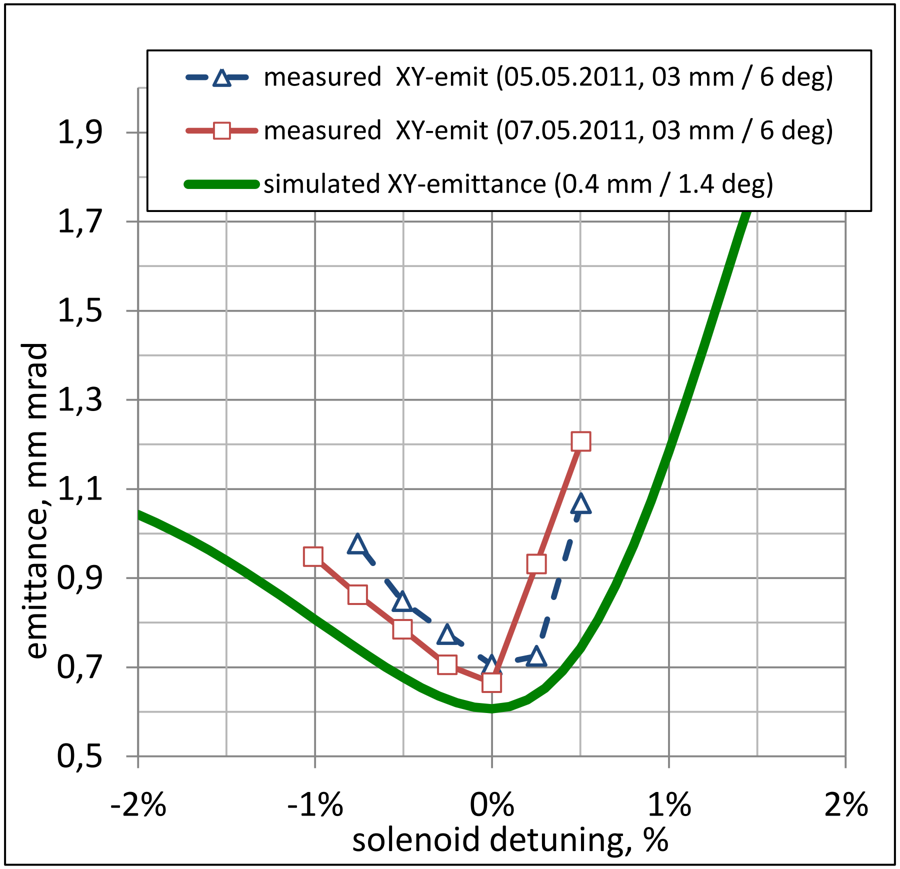


Measured and Simulated Emittance: 1nC

Electron beam **size** at EMSY1



Electron beam **emittance** at EMSY1

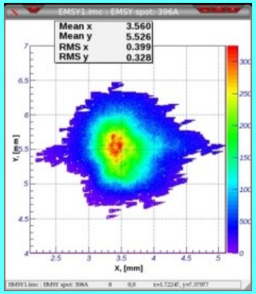


- Optimum laser rms spot sizes:
  - **Experimental** XYrms=0.30mm (BSA=1.2mm)
  - XYrms=0.4mm → from **simulations**
- Simulated electron beam size at EMSY1 is still larger than the measured one
- Applying 0.3 mm laser spot to the simulation – it is impossible to produce **1nC**!

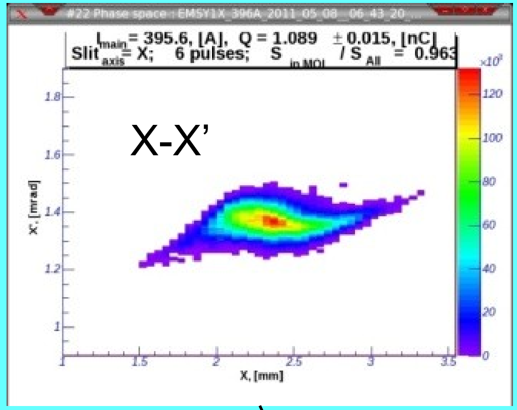
Measured and Simulated Phase Space at EMSY1: 1nC

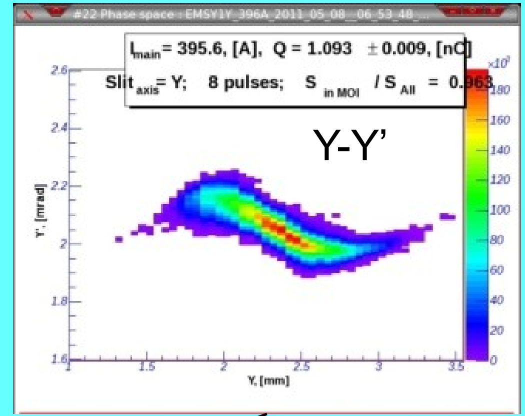
Measured

X-Y



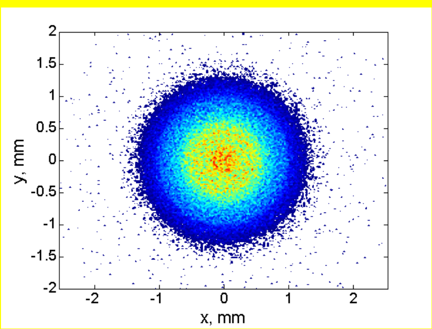
Tails (~horizontal) in the beam distribution!

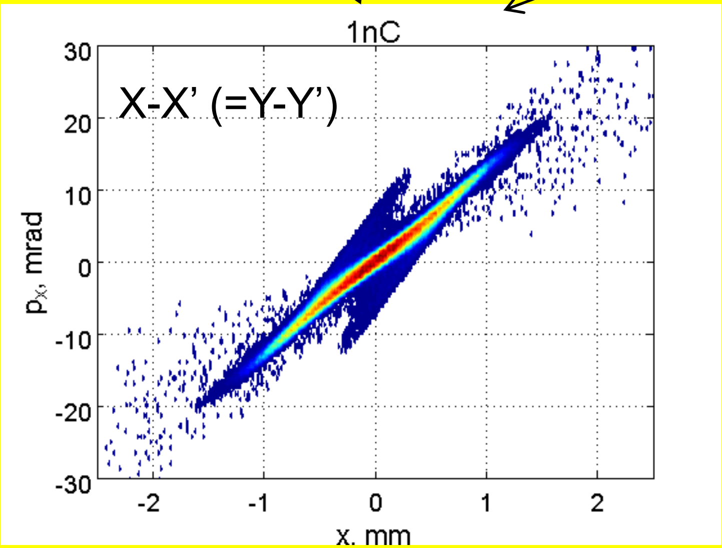


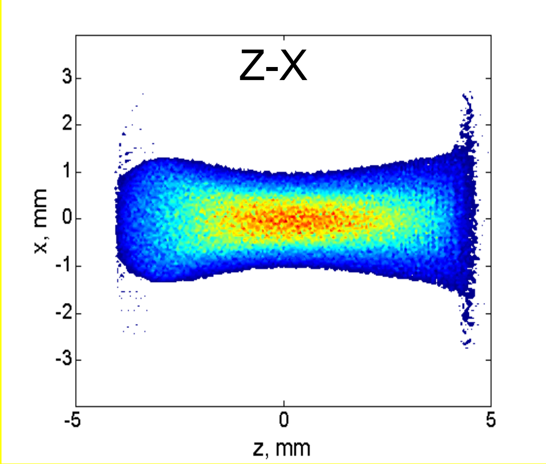


Simulated

X-Y

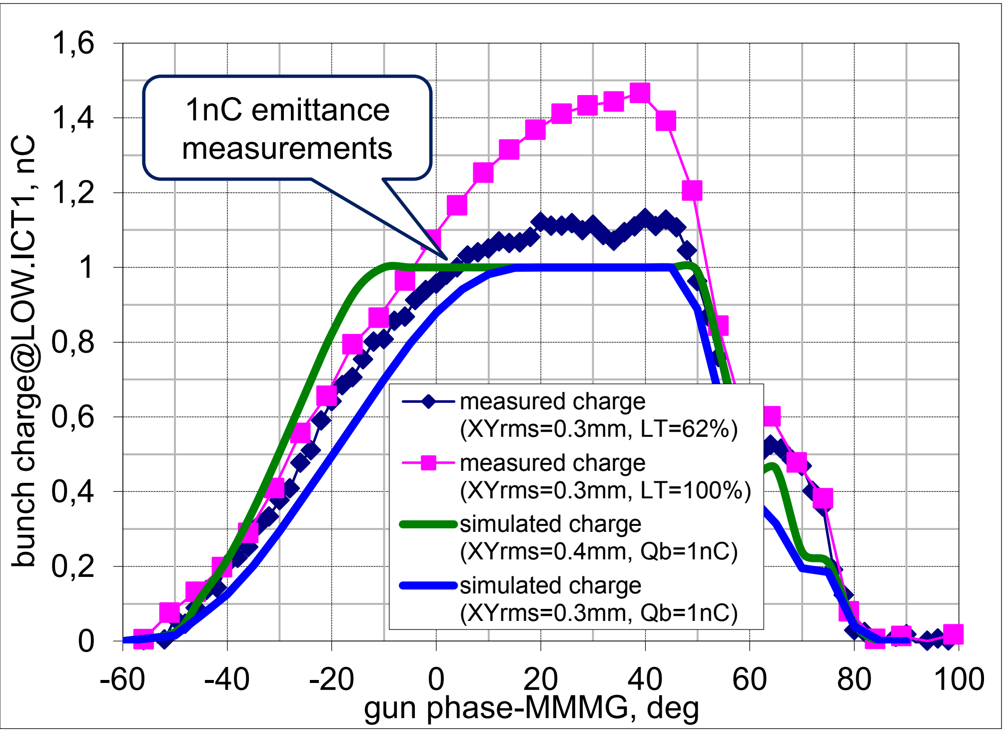




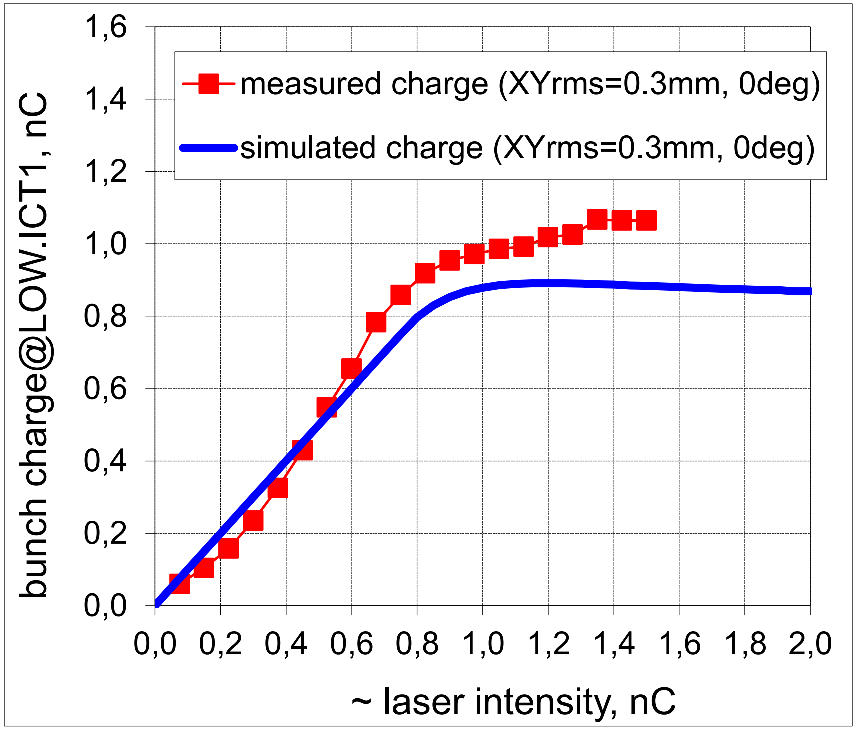


Reasons of discrepancy for high Q? → Emission from the cathode?

Measured and simulated Schottky scans (1nC)



Measured and simulated laser energy scan (1nC)



- Direct plug-un machine settings into ASTRA does not produce 1nC at the gun operation phase (+6deg), whereas 1nC and even higher charge (~1.2nC) are experimentally detected
- Simulated (ASTRA) phase scans w/o Schottky effects (solid thick lines) have different shapes than the experimentally measured (thin lines with markers)

- Laser intensity (LT) scan at the MMMG phase (red curve with markers) shows higher saturation level, whereas the simulated charge even goes slightly down while the laser intensity (Qbunch) increases

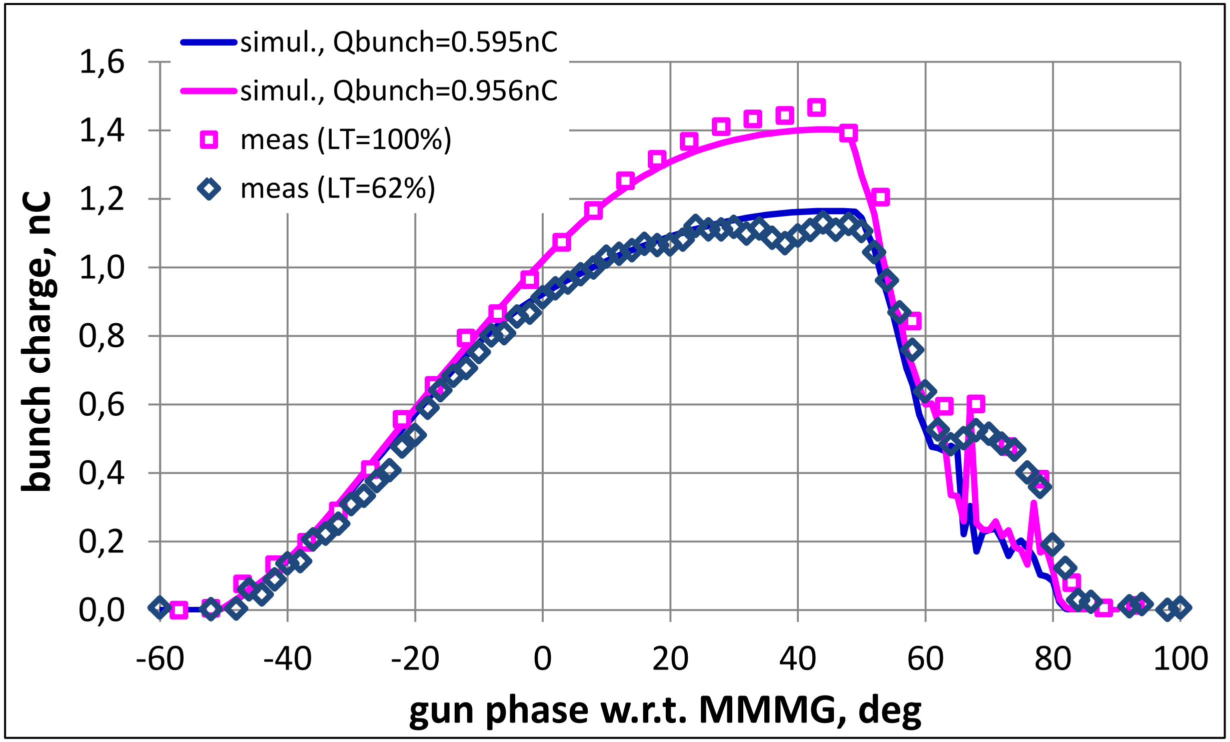
Possible reasons:

- Field enhancement of the photo emission (**Schottky-like effect**) should be taken into account
- Laser imperfections (transverse **halo** and temporal **tails**) could contribute at high charge densities

Simulated (ASTRA) bunch charge for XYrms=0.32 mm

√

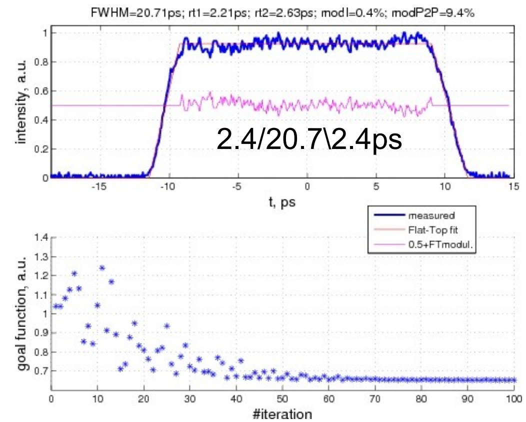
Using XYrms=0.30mm it was not possible to produce measured charges for any combination (*Q0;Srt_Q_Schottky;Q_Schottky*) ➔ light increase of laser spot size? (e.g. from 0.30 mm to 0.32 mm rms)

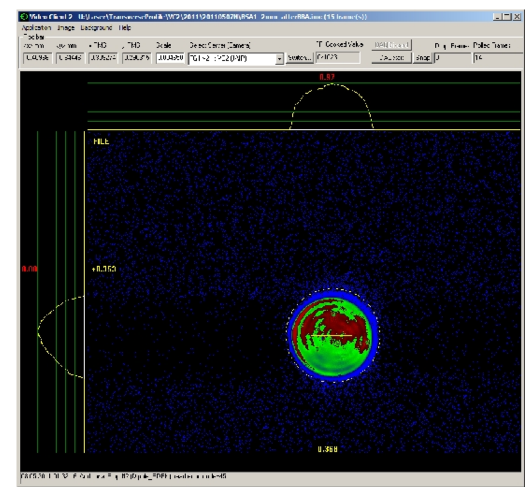


ASTRA simulations:

- Ecath=60.58MV/m
- Meas. Phase →+8 deg (not +6deg!)
- Laser XYrms=0.32mm (not 0.3mm!)
- Qbunch(62%)=0.595nC; Q_Schottky=0.01nC/(MV/m); SRT_Q_Schottky=0.05nC/(MV/m)$^{1/2}$

Another possible source of the discrepancy is the uncertainty of the cathode laser pulse measurements: transverse distribution (core-halo) and temporal profile imperfections.





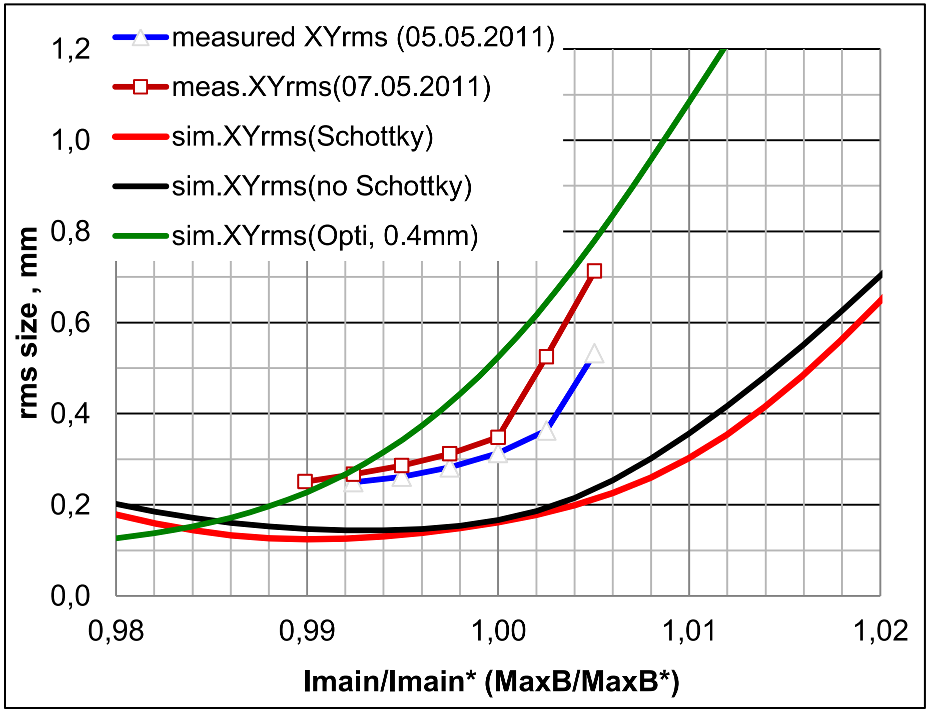
Corresponding beam emittance simulations

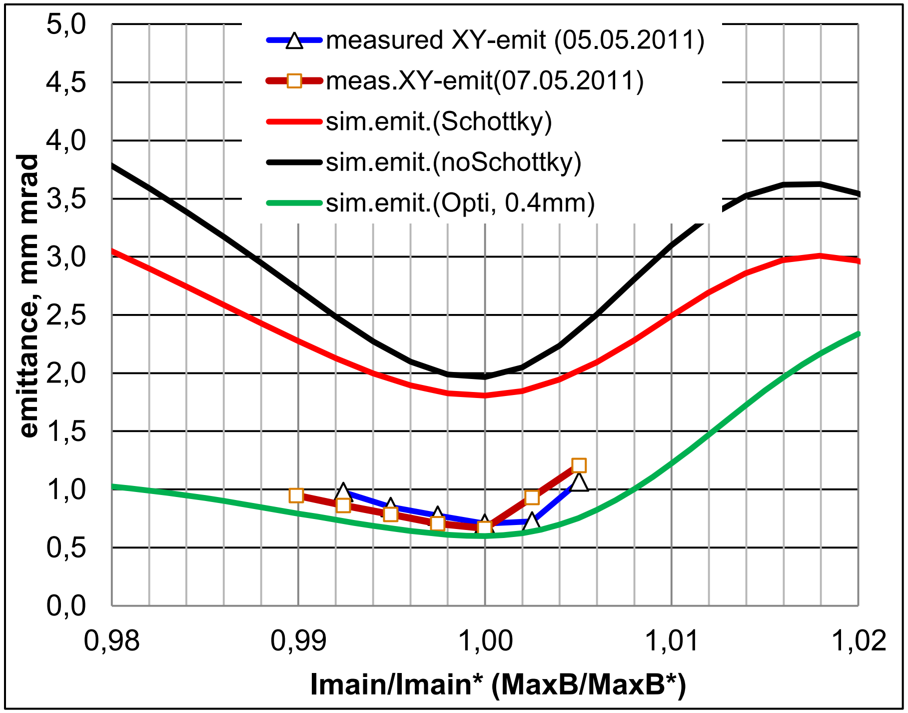
Opti (no Schottky)
XYrms=0.40mm
Qbunch=1nC;
Q_Schottky=0.0nC;
SRT_Q_Schottky=0.0nC
1nC e-beam, **optimized simul.**

No Schottky
XYrms=0.32mm
Qbunch=1nC;
Q_Schottky=0.0nC;
SRT_Q_Schottky=0.0nC
0.995nC e-beam

Schottky
XYrms=0.32mm
Qbunch(62%)=0.595nC;
Q_Schottky=0.01nC;
SRT_Q_Schottky=0.05nC
1nC e-beam

Imain*→ min(ε_{xy})

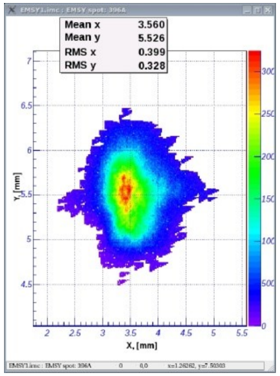


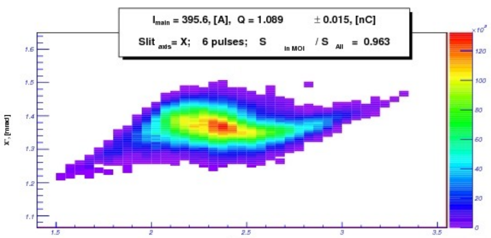


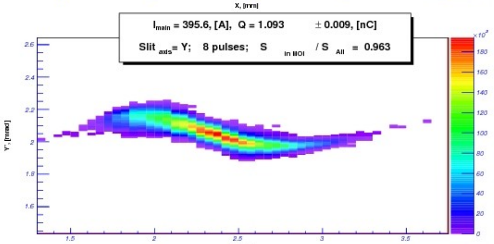
Measured and Simulated Phase Space at EMSY1: 1nC bunches

measured

laserXYrms=0.3mm







Results

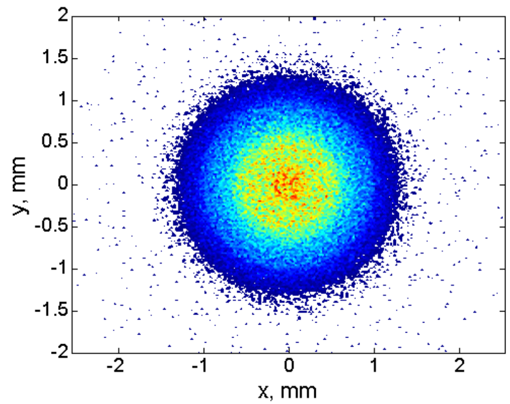
Plot system ver. Feb 17 2011 19:41:48

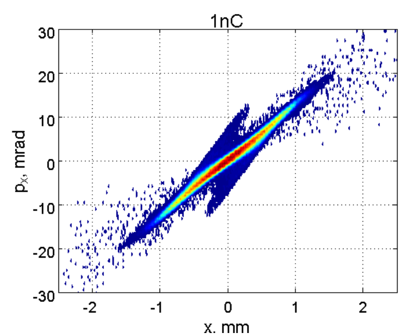
Laser:			
rms size	$\langle x^2\rangle_0$=0.30900,	$\langle y^2\rangle_0$=0.29000,	[mm]
Electron beam:			
Momentum gun:	6.67400	± 0.0402,	[MeV/c]
Momentum boo:	24.66900	± 0.0686,	[MeV/c]
σ_{yag}	0.32770		[mm]
σ_{scan}	0.29405		[mm]
divergence	0.07226		[mrad]
covariance	-0.01744		[mm mrad]
sheared div	0.01214		[mrad]
$\varepsilon^{scaled}_{sheared}$	0.522		[mm mrad]
$\varepsilon^{noscaled}_{2D}$	0.586		[mm mrad]
$\varepsilon^{scaled}_{2D}$	0.653		[mm mrad]

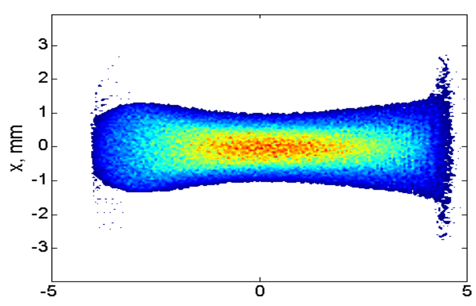
Comments: EMSY1Y_396A_2011_05_08__06_53_48__from63_00-to68_00Stat_fast

simulated, no Schottky

laserXYrms=0.32mm

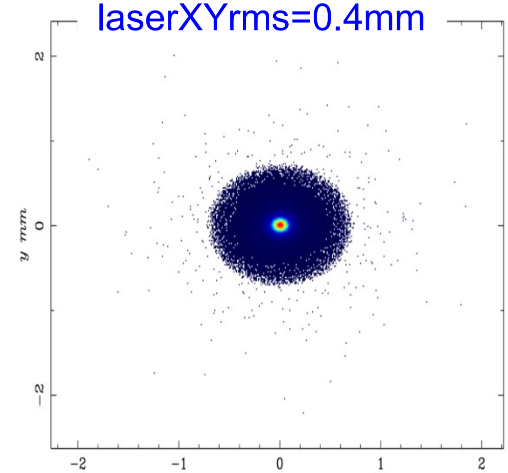


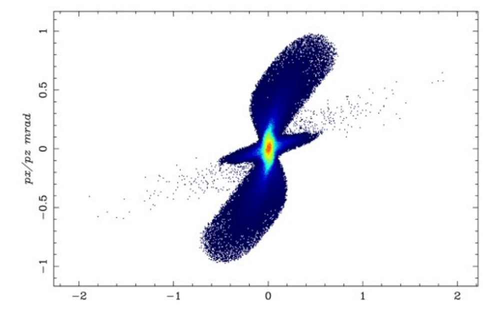


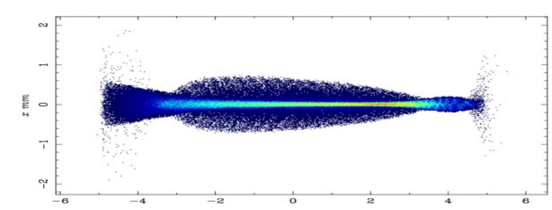


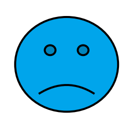
simulated+Schottky

laserXYrms=0.4mm



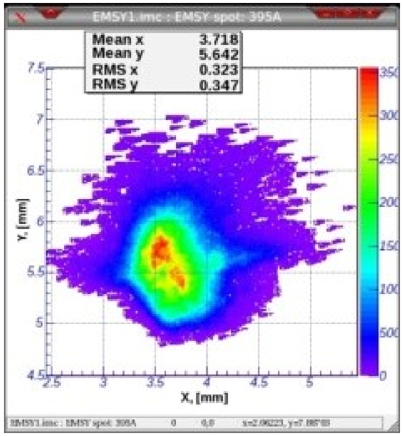


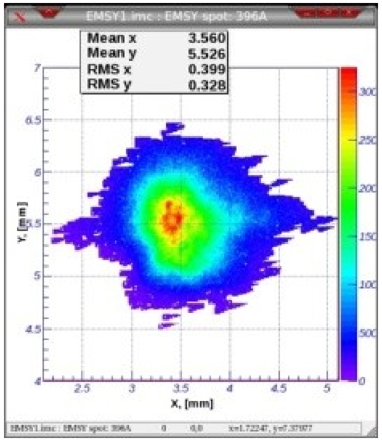




Problems

- Simulated optimum machine parameters (laser spot size and RF gun phase) ≠ to those obtained experimentally
- Photo emission (bunch charge) needs more detailed modeling in simulations
- Tails (~horizontal) in the beam distribution:
  - X-Y asymmetry
  - Large scaling factor (beamlets from tails are not detectable)





??Reasons:

- Remaining magnetizable components
- Vacuum mirror
- Solenoid imperfection
- Stray fields from IGPs
- …

Measurements vs. Simulations at PITZ-1.8: Summary

- PITZ serves also as a benchmark for theoretical understanding of the photo injector physics (beam dynamics simulations vs. measurements)
- BD simulations → to establish experimental optimization procedure
- Rather good agreement on emittance values between measurements and simulations
- Optimum machine parameters: simulations ≠ experiment
- Simulated and measured phase space:
  - Rather good agreement for 0.1 nC
  - Large deviation for higher charges
  - Correlations have different signs for higher charges
- Emission (charge production) from experiment is not easy reproducible by nominal simulations:
  - Schottky-like effect?
  - Imperfection in the laser distributions (t- and r- tails)
  - More detailed studies (benchmarking + other codes) are needed
- Tails in X-Y distributions especially for high space charge dominated beams – ?reasons:
  - Remaining magnetizable components
  - Vacuum mirror
  - Solenoid imperfection
  - Stray fields from IGPs
  - …

Simulation request for PITZ

Observation / problem / idea	? to be simulated
Core emittance	"Phase space collimator (beam scraper)" ?influence of image charges + wakes
Measured e-beam shape (asymmetry, tails), transverse phase space (emittance) depend on trajectory	•Magnetic components (active, passive), e.g. solenoid imperfections? •Wake field (like) effects (VM, DDC,…)
Charge production, influence of real laser transverse and temporal profiles (imperfections)	Beam dynamics simulations, especially in the cathode vicinity (emission), slice emittance formation
E-beam matching into the tomography section	Using V-code with space charge to find quad strength
Particle driven plasma wake field acceleration	Self modulation of the driver, etc
…	