Motivation of emission studies at PITZ

PITZ activities to understand the discrepancies between measurements and simulations in:

- Transverse phase space
- Optimum machine parameters
- Auxiliary measurements

Ideas → how to explain the discrepancies:

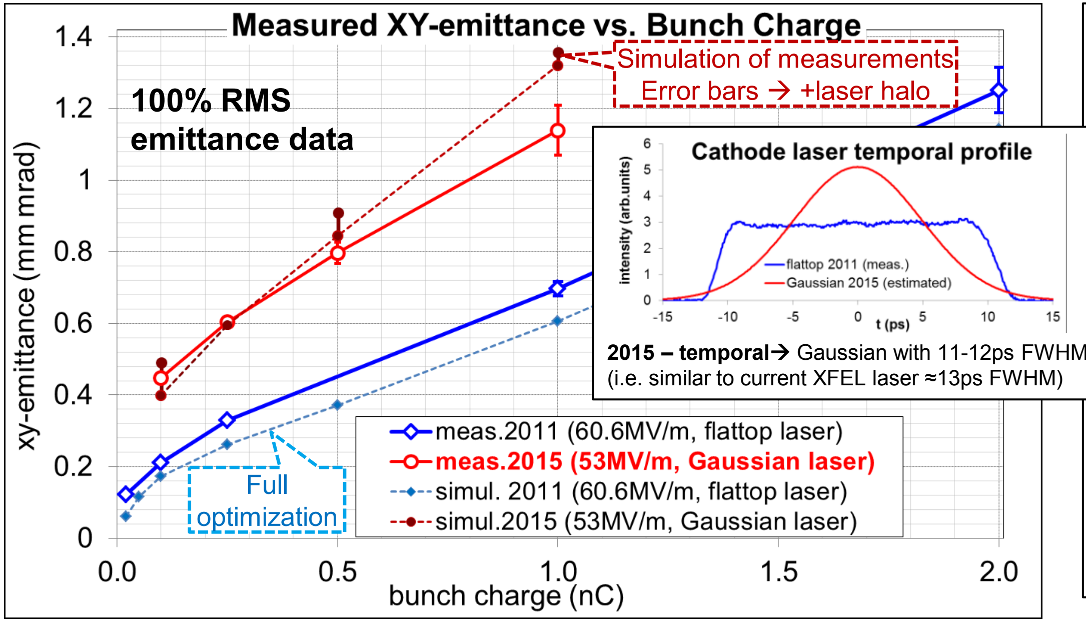
- Errors in measurements
- Extracted charge → emission modeling
- Imperfections (e.g. cathode laser halo)
- Sources of e-beam X-Y asymmetry/coupling (coaxial coupler, VM, solenoid…)

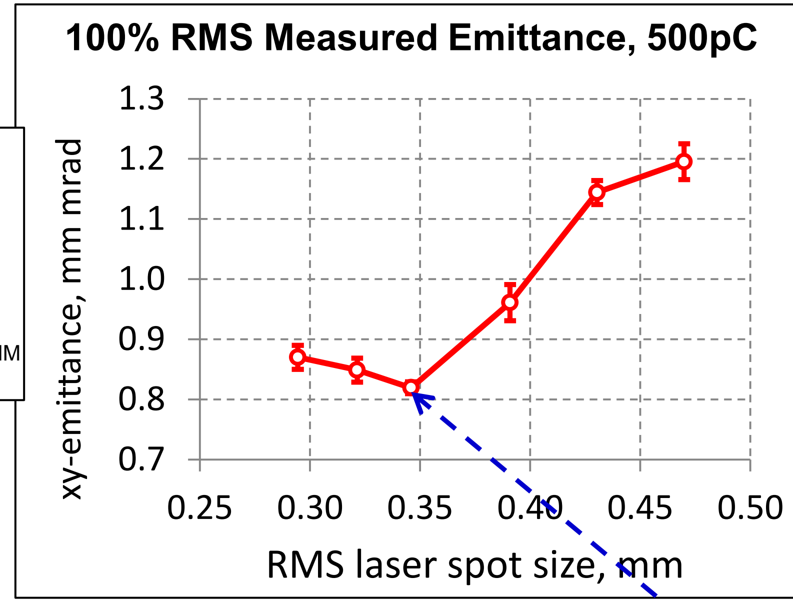
M. Krasilnikov
DESY-TEMF Meeting
Hamburg, 15 June 2015

HELMHOLTZ | ASSOCIATION

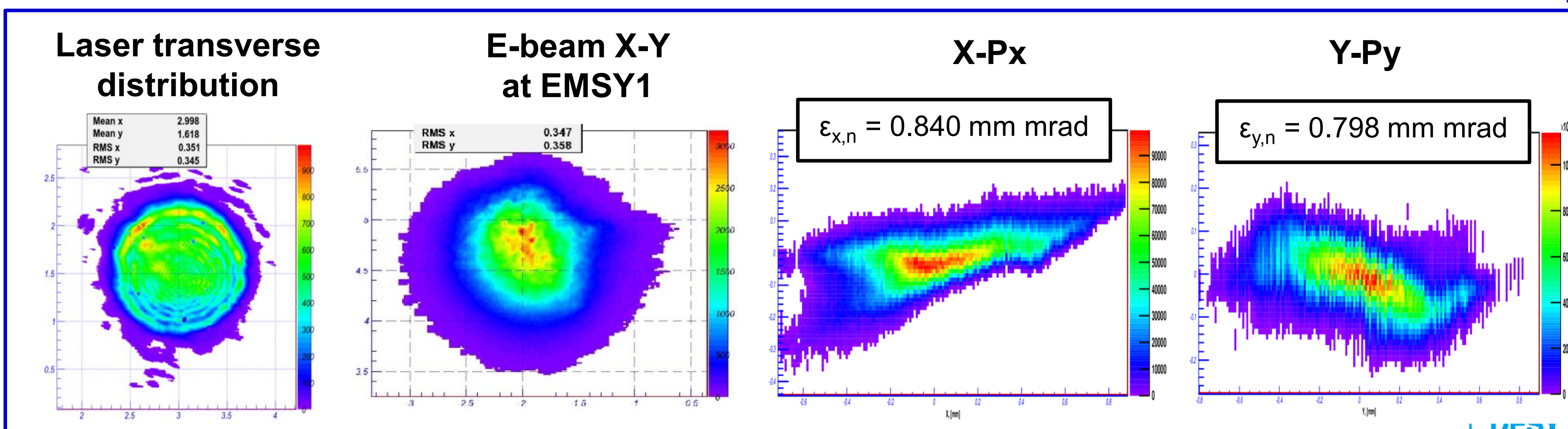
DESY

Emittance measurements in 2015 (vs. 2011): Gun at 53 MV/m, Cathode laser → temporal Gaussian



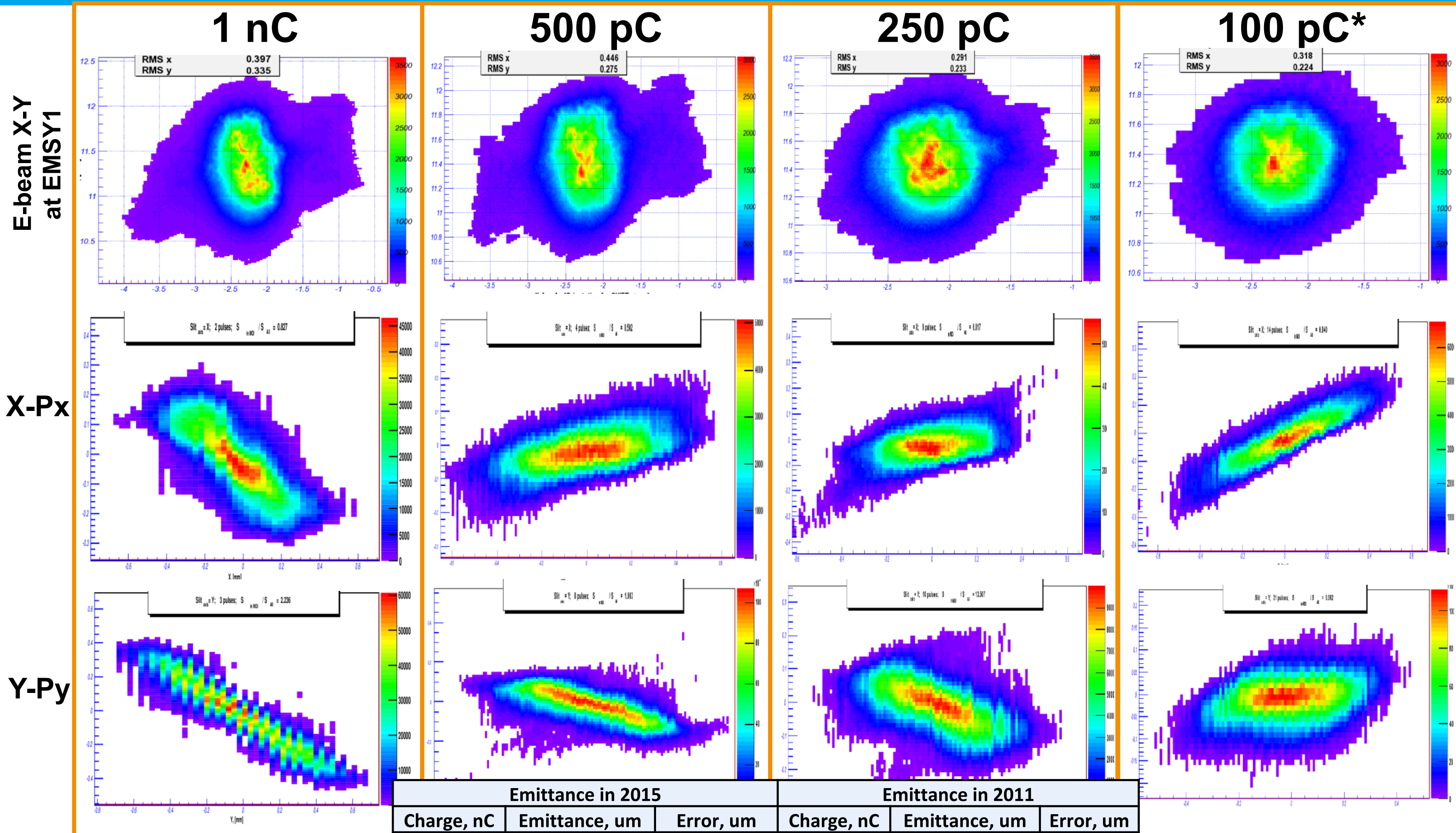


Requirement for XFEL injector commissioning: 1 mm mrad at 500pC ➔ **fulfilled !**



2015: Measured Phase Spaces

*Emittance measurements for 100 pC bunch charge are not completed: to be continued

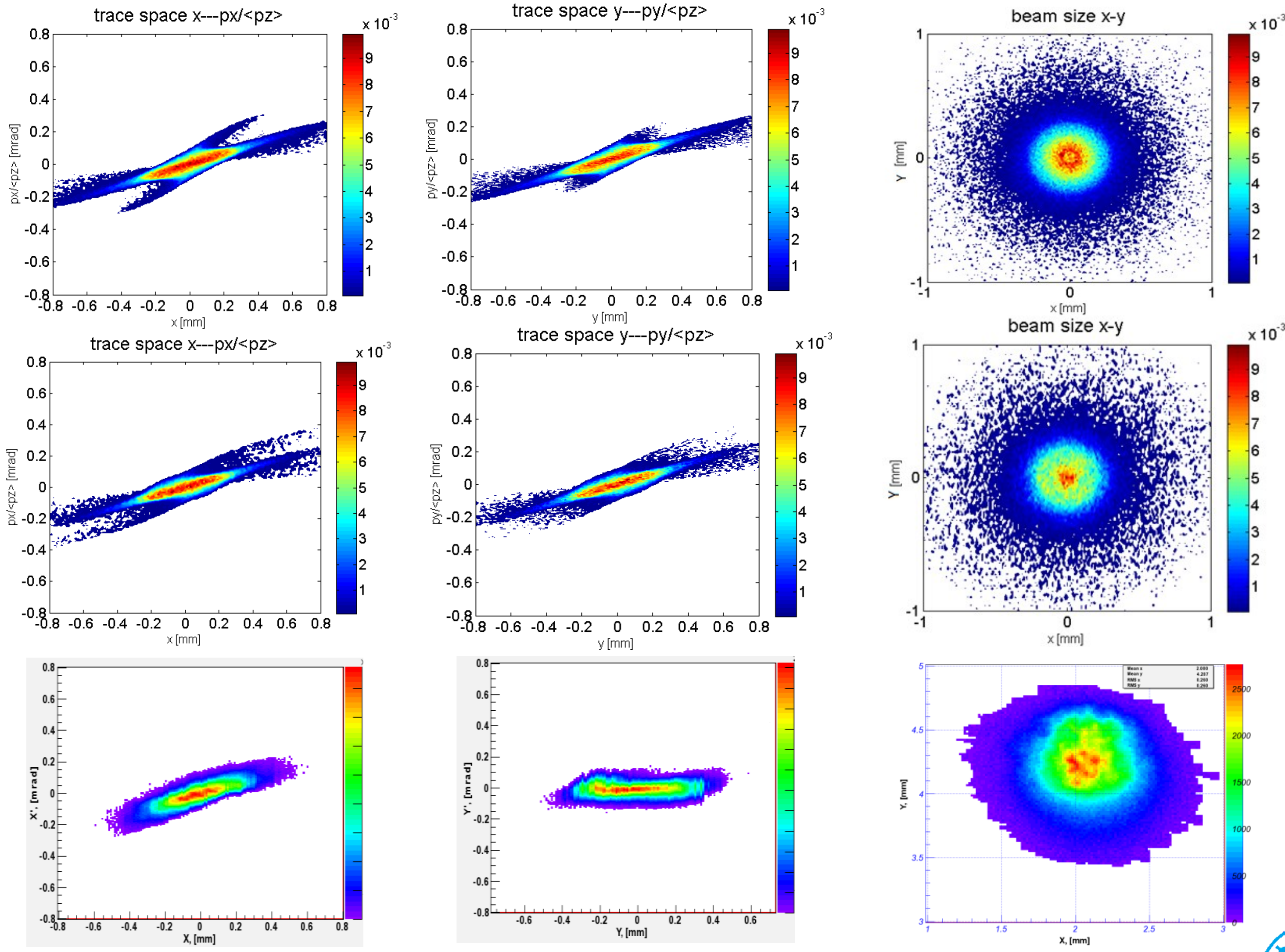


Emittance in 2015			Emittance in 2011		
Charge, nC	Emittance, um	Error, um	Charge, nC	Emittance, um	Error, um
			2	1.251	0.06
1	1.139	0.07	1	0.661	0.05
0.5	0.797	0.03			
0.25	0.603	0.01	0.25	0.328	0.01
0.1	0.448*	0.01	0.1	0.212	0.01
			0.02	0.121	0.01

G. Vashchenko

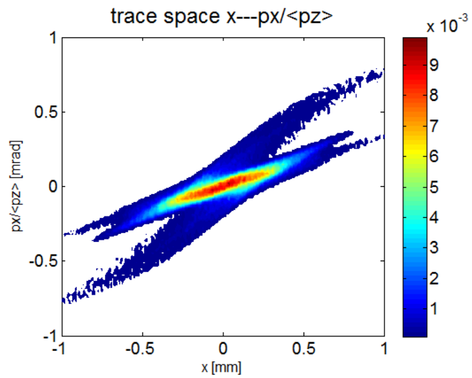
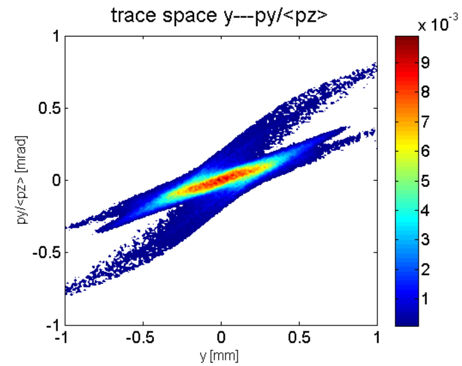
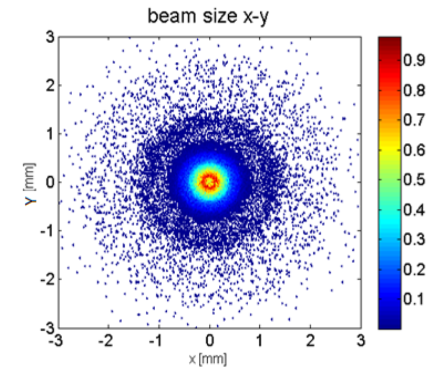
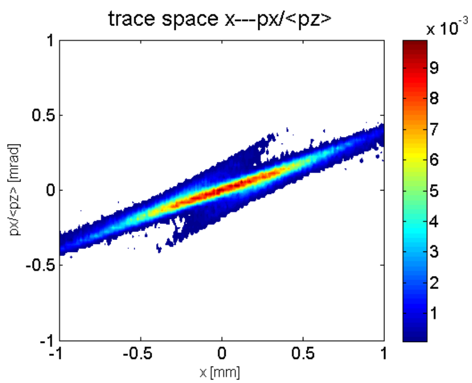
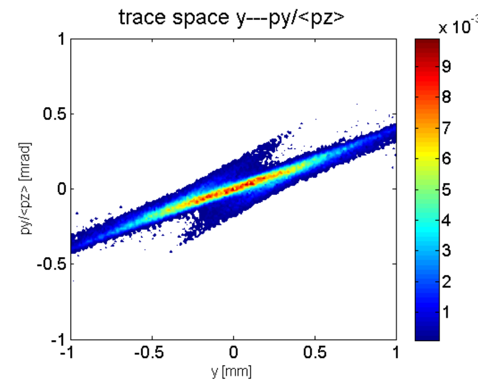
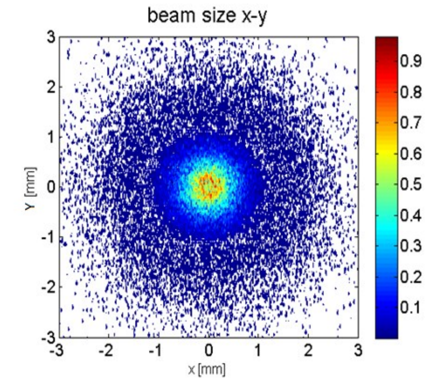
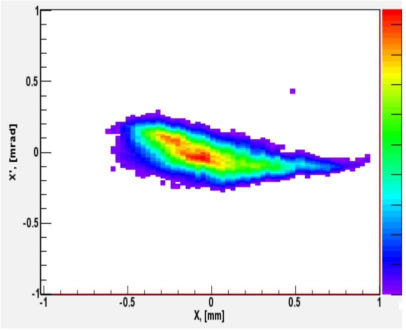
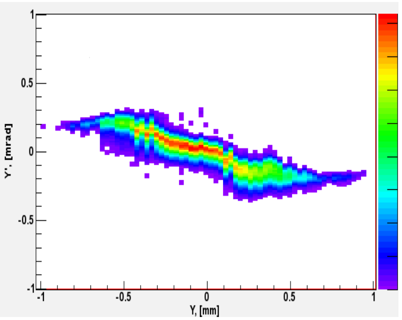
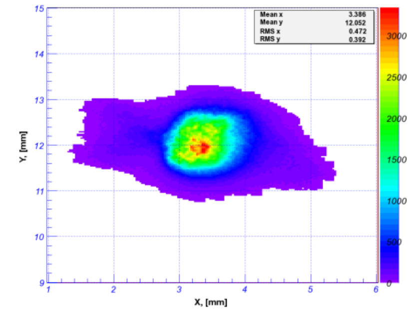
Phase space BSA = 0.9 mm, 100 pC, at EMSY1

	X Phase space	Y Phase space	X-Y Beam size
Uniform			
Core+ halo			
Experiment			



Q. Zhao

Phase space BSA = 1.6 mm, 1 nC, at EMSY1

	X Phase space	Y Phase space	X-Y Beam size
Uniform			
Core+halo			
Experiment			

Q. Zhao

Measurements vs. Simulations

<table>
<tr><th></th><th>2011</th><th>2015</th></tr>
<tr><td>Gun gradient, Ecath</td><td>60.6MV/m</td><td>53MV/m</td></tr>
<tr><td>Cathode laser, temporal</td><td>Flattop (2/21.5\2ps)</td><td>Gaussian (11-12ps fwhm)</td></tr>
<tr><td>CDS booster</td><td></td><td>Z-position → -0.4m</td></tr>
<tr><td>Optimum phase space</td><td colspan="2">•Even signs of <XPx>, <YPy> are opposite for high charge
•Rather good agreement for low charges (≤100pC)
•Larger charges (≥500pC) → larger discrepancies
•Strong X-Y asymmetry/coupling, tails in e-beam transverse distributions
•Strong dependence on e-beam trajectory</td></tr>
<tr><td rowspan="3">Optimum machine parameters
• Laser rms spot size
• Main solenoid current
• RF gun phase</td><td>• Simulated > Measured (e.g. for 0.25nC →+26%; 1nC →+35%; 2nC→59%)</td><td>• Implemented core+halo in transverse laser distribution reduces the discrepancy</td></tr>
<tr><td colspan="2">• Imain: Simulated-Measured →-4…-6A</td></tr>
<tr><td>• Simulated → ~MMMG
• Experiment → MMMG+6deg</td><td>• Simulated ≈ Measured → ~MMMG</td></tr>
<tr><td>Auxiliary measurements:
•Bunch charge vs. gun phase
•Bunch charge vs. laser pulse energy</td><td>Underestimated extracted bunch charge in ASTRA simulations:
• Gun phase scans
• LT scans</td><td>Implemented core+halo in transverse laser distribution → better coincidence between ASTRA simulations and experimental data (studies of Carlos Hernandez-Garcia), BUT still large discrepancies in phase space for 1nC</td></tr>
</table>

How to explain the discrepancies

> ?Measurement errors:

- Bunch charge: → cross-check using LOW.FC1,2, LOW.ICT1, HIGH.ICT1 ➔ OK
- Laser spot size at VC2
- Electron beam/beamlet size at YAG screens ➔ checked several times (grid based calibration)
- Gradient in the gun and CDS booster ➔ cross-checked with beam momentum scans
- Emittance measurements using single slit scan ➔ methodical studies were performed (e.g. transverse halo cut, etc.)
- Cathode laser pulse length (streak camera, OSS)

> Simulations of the charge extraction in RF-gun ➔ RF field + space charge at the cathode:

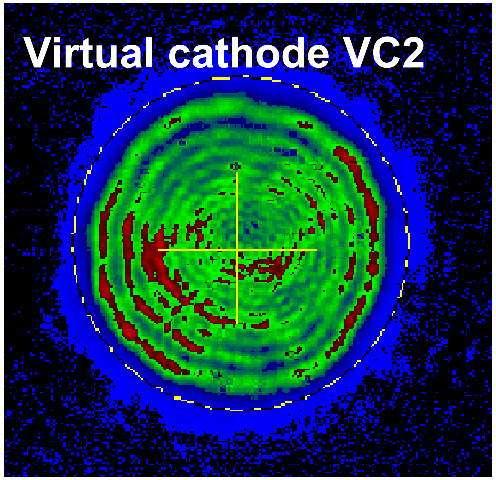
- Impact onto amount of extracted particles
- Impact onto beam dynamics ("initial" kick onto transverse and longitudinal phase spaces: correlation and intrinsic emittance?)
- Laser imperfections ➔ core+halo
- Additional motivation: 3D quasi-ellipsoidal laser pulses for the production of (ellipsoidal) electron bunches with extremely low emittance

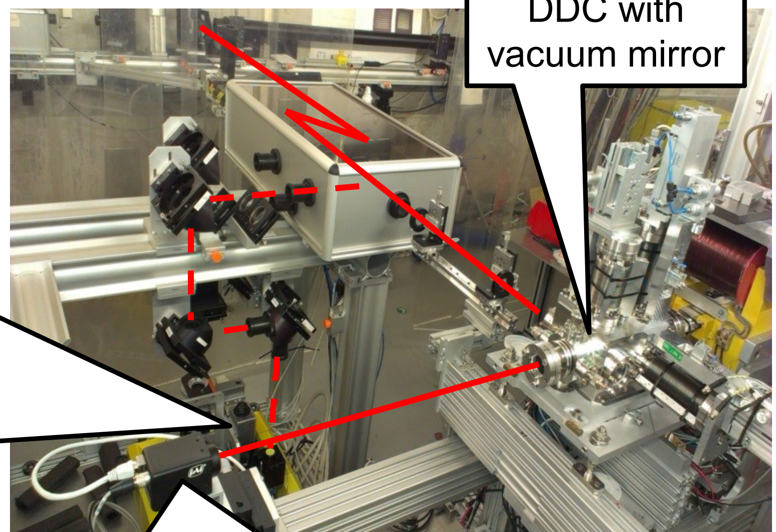
> Origin of X-Y asymmetry/coupling:

- ?RF-gun coaxial coupler kick (e-beam is large there + solenoid center)
- ??Vacuum mirror
- ???Other imperfections: wake field-like (image charge) effects of the beam line, solenoid, magnetic components

Cross-check of the VC2 (Virtual Cathode 2) measurements on 12.03.2013

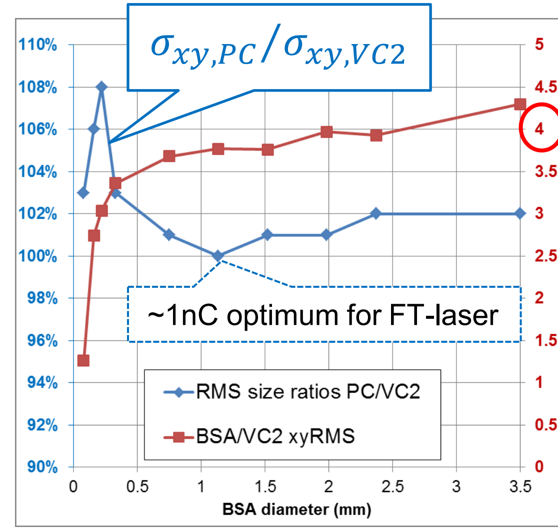
VC2 camera at laser trolley



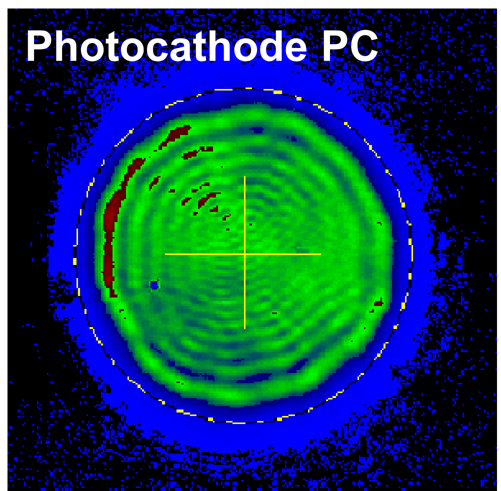


DDC with vacuum mirror

Laser beam a little bit bigger on photocathode (≤2%)



Cathode camera at gun location
(CCD=Cs_2Te cathode location at the gun back plane)



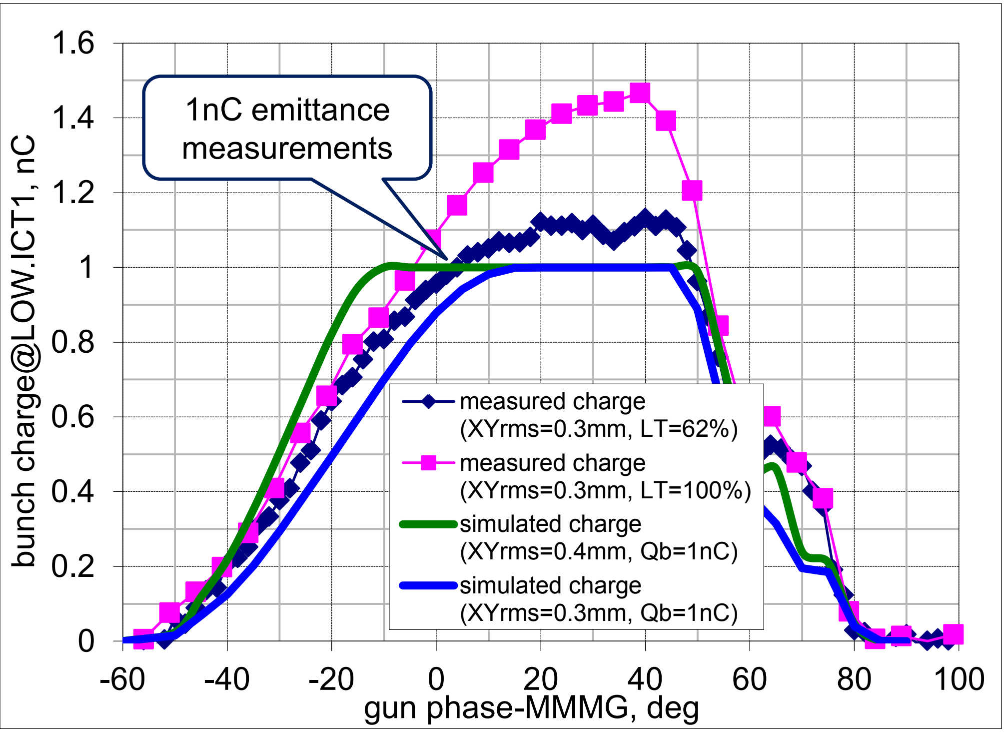
Quality (intensity) similar, the difference → due to different number of mirrors and view ports in the path:
- PC: viewport-VM-viewport
- VC2: 4x mirrors

Direct imaging onto CCD chip (pixel size 4.65um)

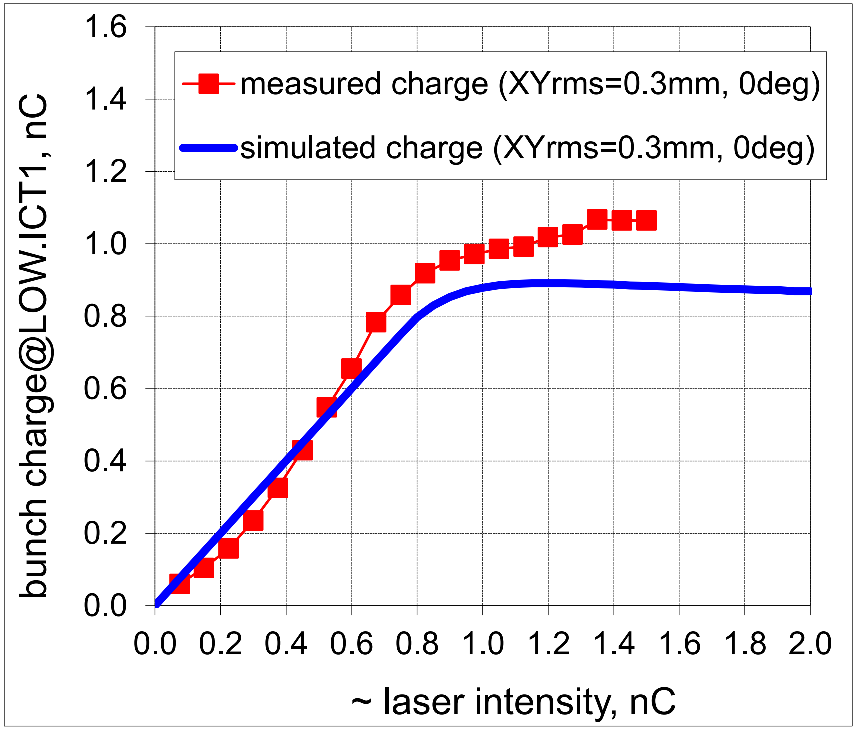
M. Gross

2011: 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)

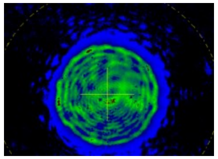
- Laser intensity (LT) scan at the MMMG phase (red curve with markers) shows higher saturation level, whereas the simulated charge even goes slightly down while the laser intensity (Qbunch) increases

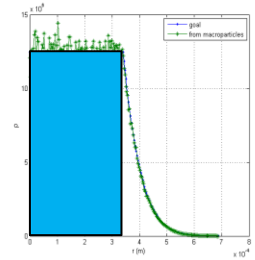
Possible reasons:
- Field enhancement of the photo emission should be taken into account
- Laser imperfections (transverse **halo** and temporal **tails**) could contribute at high charge densities

2015: Core+halo modeling applied to new measurements using cathode laser pulses with Gaussian temporal profile

If a uniform distribution is used instead, the charge saturates

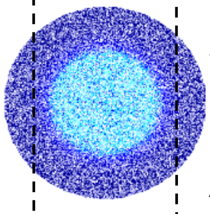
Laser radial distribution image





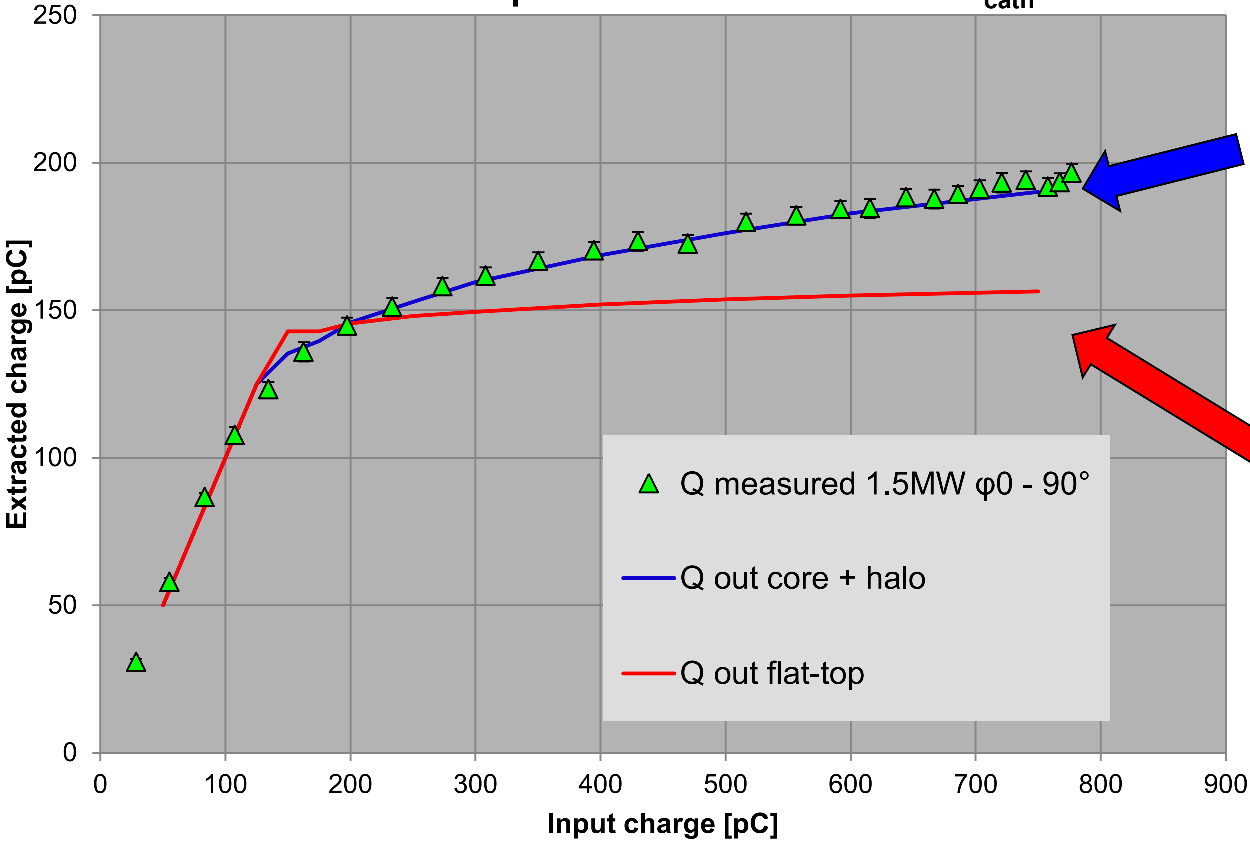
Transverse radial profile core + halo

0.68 mm

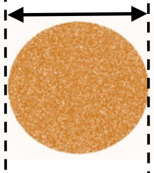


Generated ASTRA input distribution core + halo

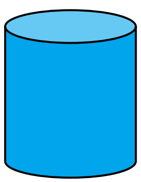
Extracted charge vs laser pulse energy for temporal Gaussian σ_t=1.5 ps BSA=0.8mm Gun Power = 1.5MW and Gun Phase φ0 - 90° set for maximum E_{cath}



0.80 mm



Nominal ASTRA input uniform distribution



Nominal transverse uniform radial profile

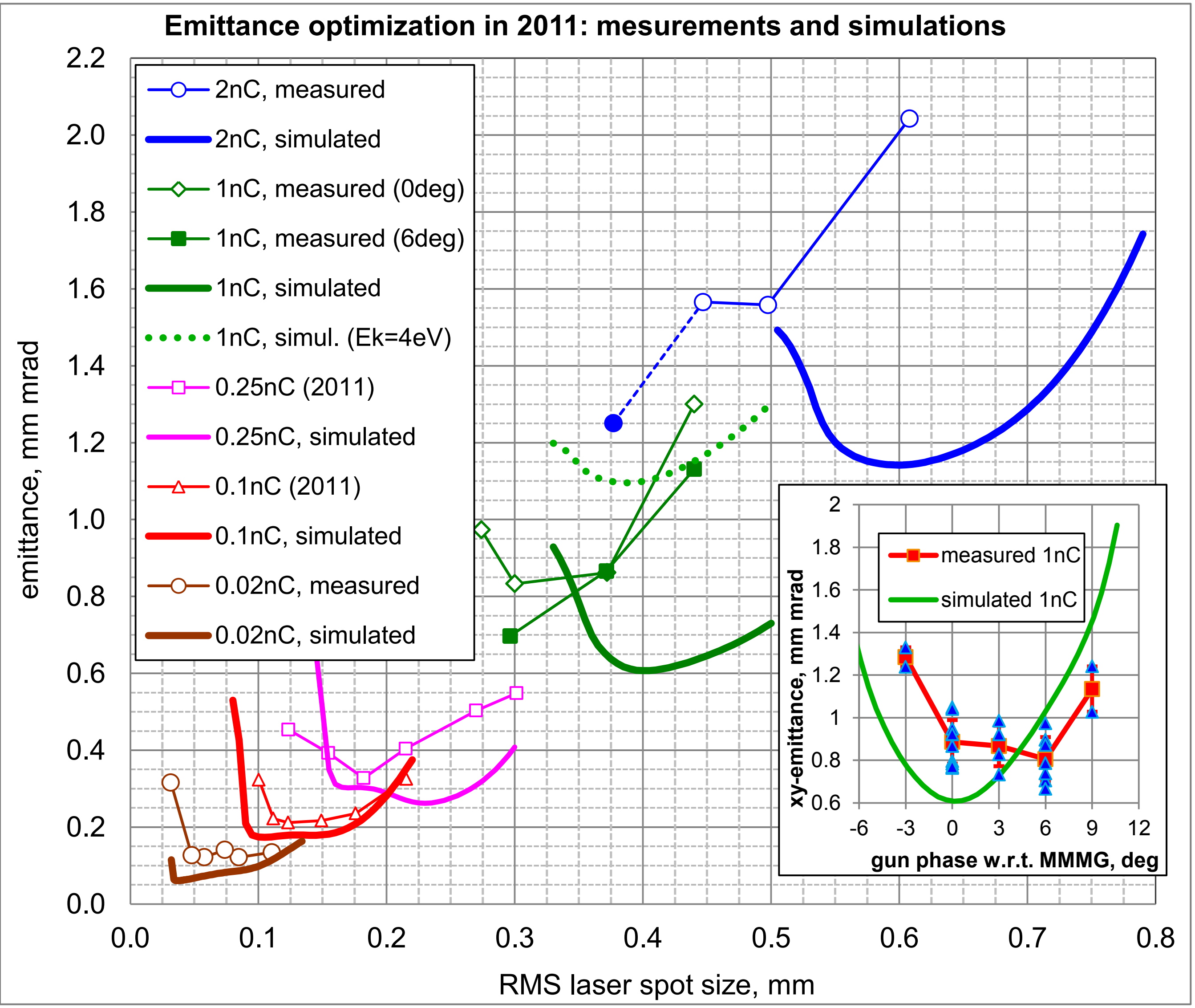
C. Hernandez-Garcia

Measurements vs. Simulations at PITZ: Summary

- PITZ ➔ 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
  - Laser spot size → less in 2015 by applying core+halo model
  - Main solenoid current
  - RF-Gun launch phase → more consistent in 2015 for Gaussian laser pulses
- Simulated and measured ***phase space***:
  - Rather good agreement for <0.1 nC
  - Large deviation for higher charges >500pC
  - Correlations have different signs for higher charges
- Photoemission studies (Talk of C. Hernandez-Garcia for more details):
  - New experimental benchmark (measurements for various RF and SC fields)
  - Implementation of the core+halo model ➔ better understanding of the emission curves, BUT still transverse phase spaces for higher bunch charges are not explained
- X-Y asymmetry/coupling – under study
- Outlook:
  - TDS for LPS (bunch length) measurements
  - More precise charge measurements (less jitter, LOW.FC2 up to now → best s2n)
  - Coaxial coupler kick measurements (repeat)?

BACKUP SLIDES

Emittance vs. Laser Spot size for various charges

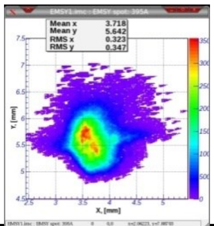
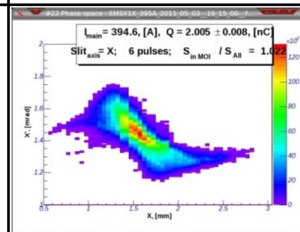
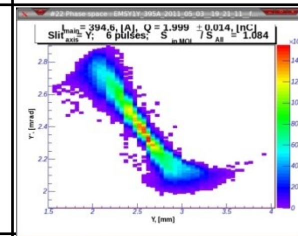
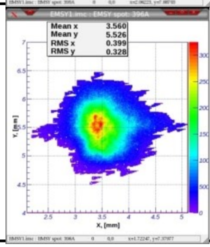
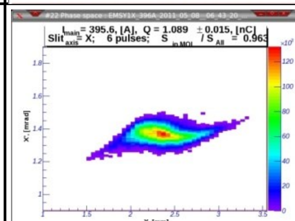
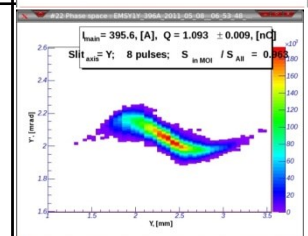
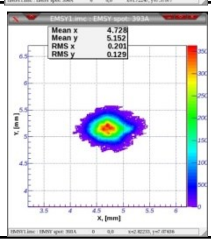
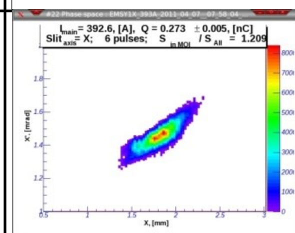
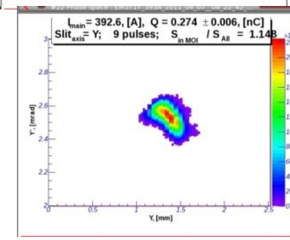
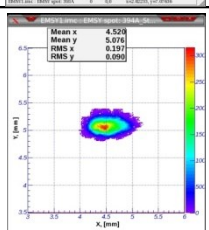
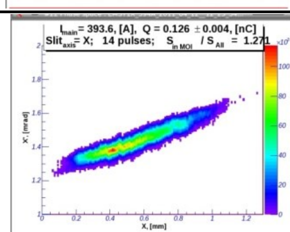
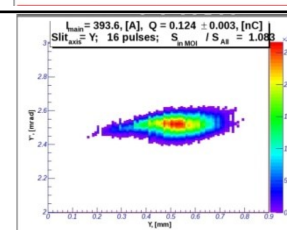
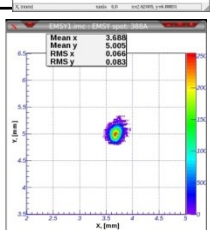
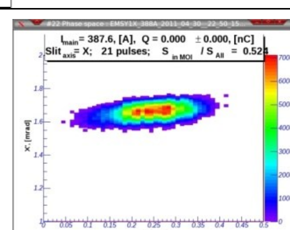
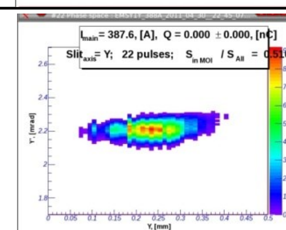


Minimum emittance

Charge, nC	Meas., mm mrad	Simul., mm mrad
2	1.25	1.14
1	0.70	0.61
0.25	0.33	0.26
0.1	0.21	0.17
0.02	0.12	0.06

- 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

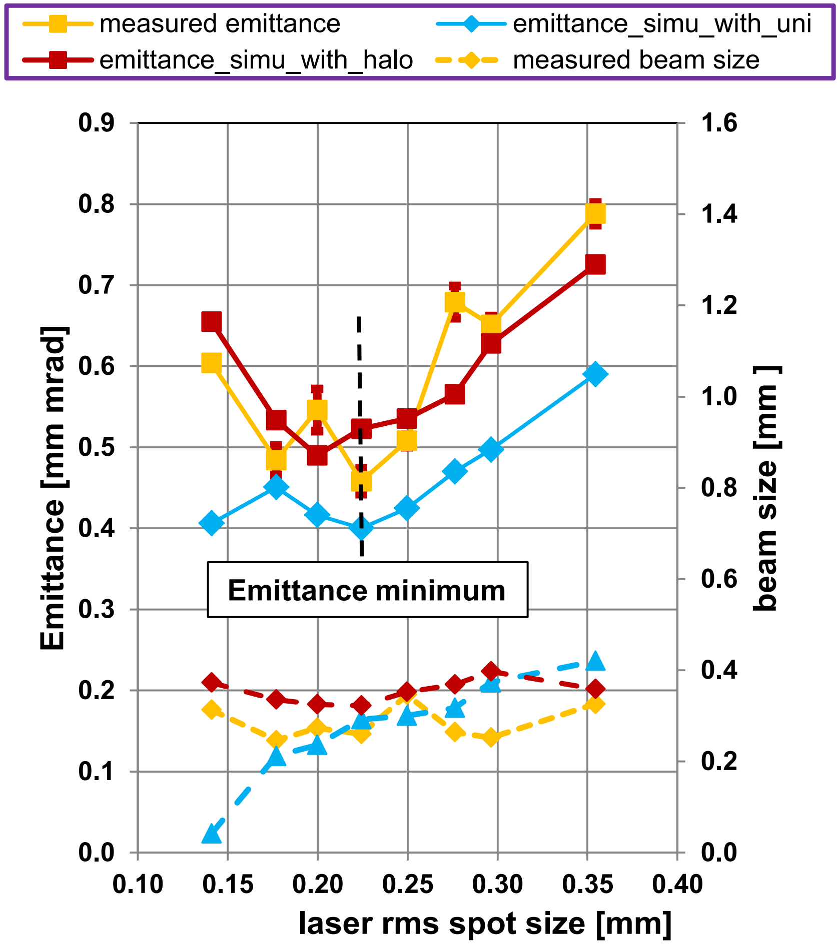
Measured Phase Spaces for various bunch charges

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

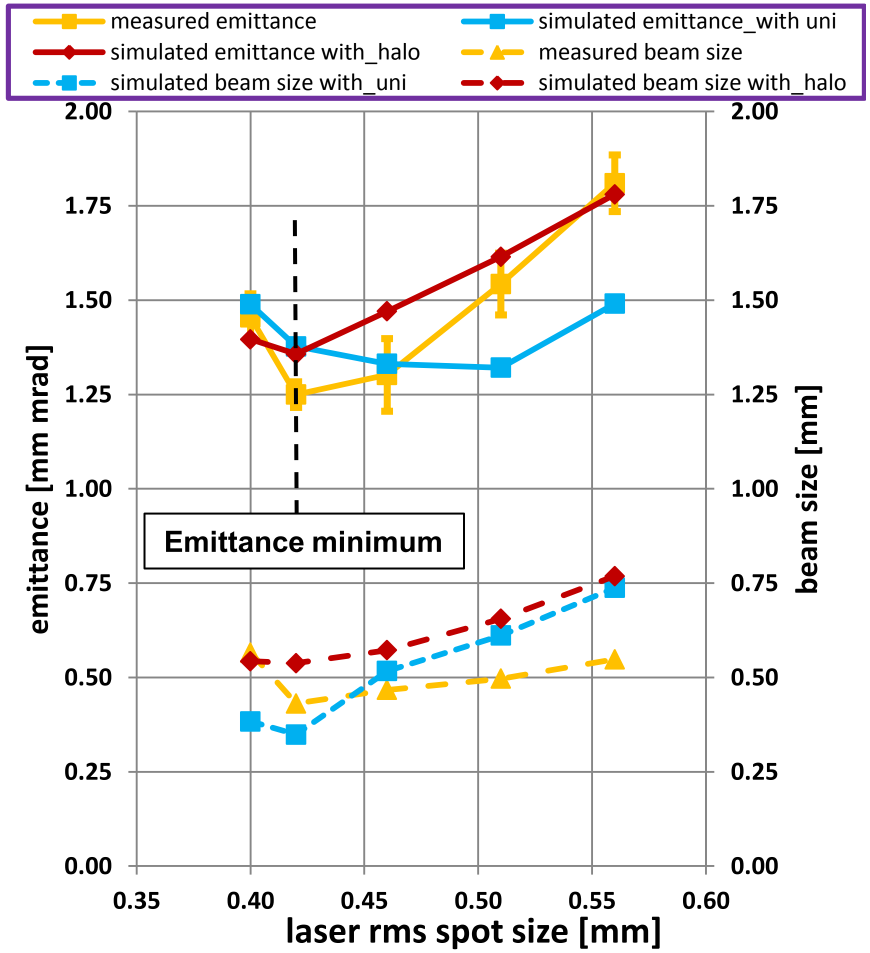
zoomed

Using core+halo input distributions in ASTRA renders closer agreement with emittance measurements than just using uniform core input distributions*

0.1 nC bunch charge



1 nC bunch charge



*ASTRA simulations by Q. Zhao (PITZ)

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
…	