Photo Injector Test facility at DESY, Zeuthen site

PITZ EXPERIENCE ON THE EXPERIMENTAL OPTIMIZATION OF THE RF PHOTO INJECTOR FOR THE EUROPEAN XFEL

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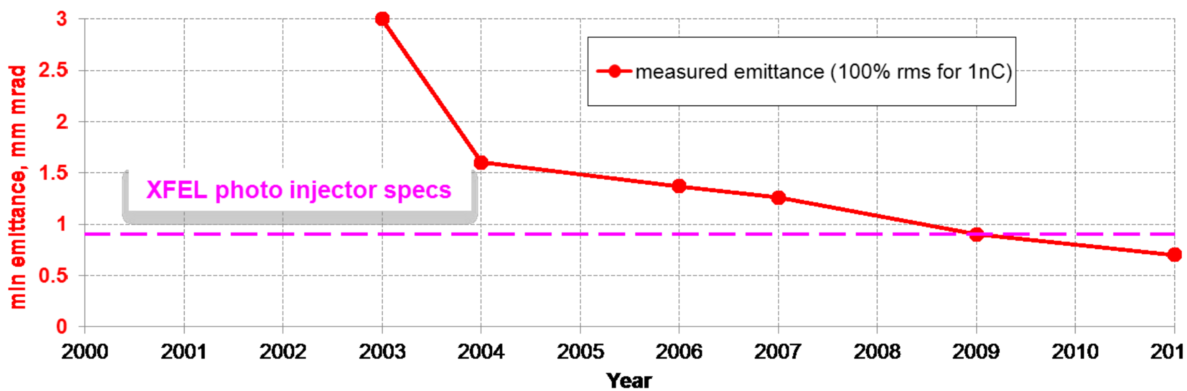
FEL 2013 conference, New York, USA, 27.08.2013

	Year-->	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
gun	cavity	gun-2		FLASH gun-1		gun-3.1	FLASH gun-3.2	gun-4.2		FLASH gun-4.1	
	Ez	35MV/m	37MV/m	42MV/m-->57MV/m		43MV/m	60MV/m				
	beam energy	~4MeV		4.3MeV-->6MeV		4.5MeV	~6MeV				
booster	cavity	no			TESLA at 2.5m		TESLA at 3.1m			CDS at 3m	
	beam energy				~13MeV					~25MeV	
laser	temporal	10ps	6/24\6ps	-->	-->	6/24\6ps		2/22\2ps	-->	-->	-->
emittance	EMSY1 at	z=1.618m			z=4.3m		z=5.74m				
	Ldrift	1.01m			2.334m		2.64m				
	methodics	center BL	3xBLs		e-meter	11xBLs			detailed scan		
	min ε_{xy} (1nC) mm mrad		3	1.5-1.7		1.37	1.26		0.9		0.7

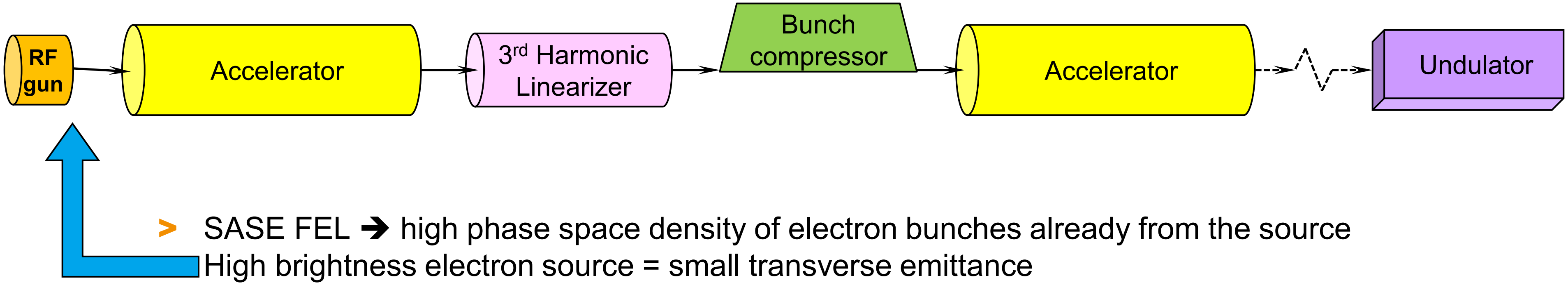


HELMHOLTZ ASSOCIATION

DESY

Motivation: High Brightness Photo Injector for SASE FEL

Linac based Free Electron Laser



- SASE FEL ➔ high phase space density of electron bunches already from the source
  High brightness electron source = small transverse emittance
- The Photo Injector Test facility at DESY in Zeuthen (PITZ) focuses on the development, test and optimization of high brightness electron sources for superconducting linac driven FELs (FLASH and the European XFEL)

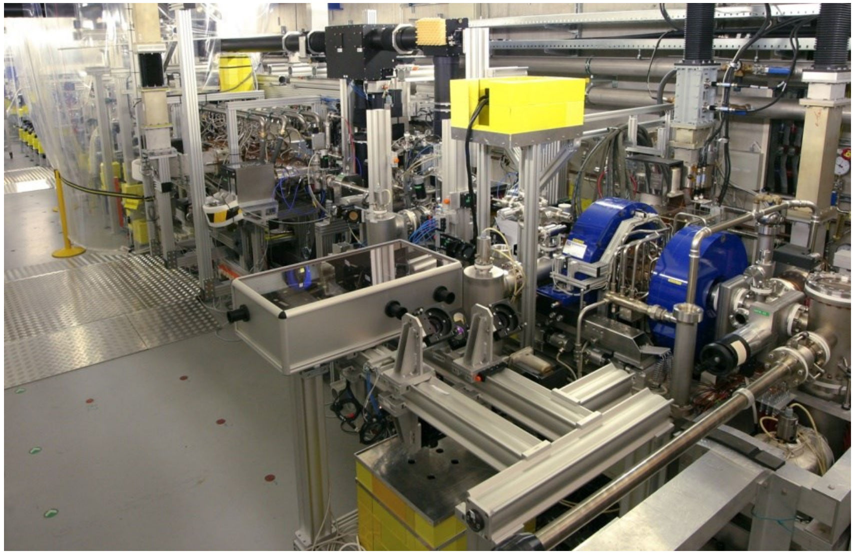


Photo Injector Test Facility at DESY in Zeuthen (PITZ)

> **RF gun**

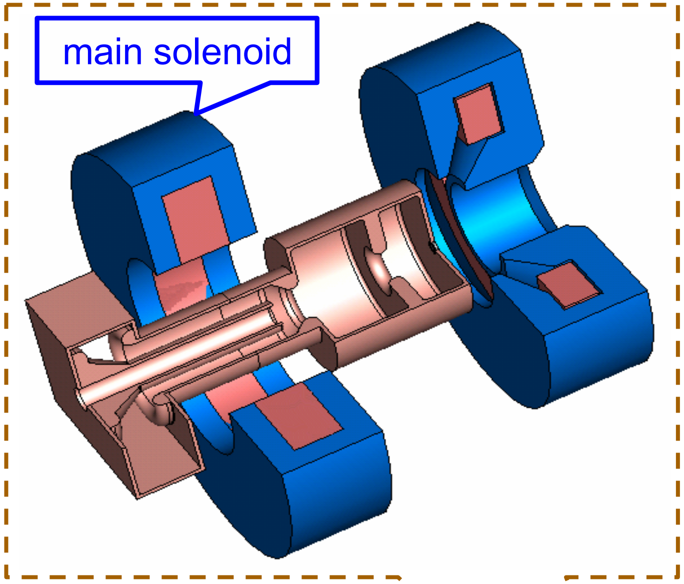
- L-band 1.6-cell copper cavity
- Dry ice cleaning → low dark current (<100uA@6MW)
- Cs_2Te photocathode (QE~5-10%)
- LLRF control for amplitude and phase stability
- Solenoid for emittance compensation

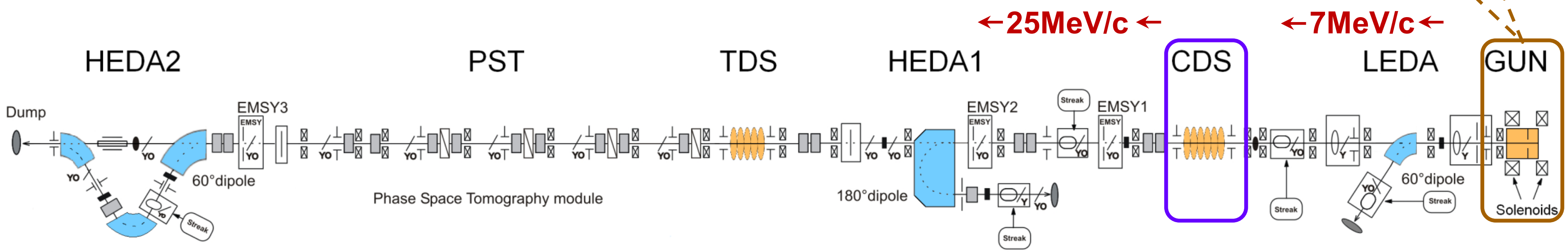
> Photocathode laser

- Pulse train structure
- Micropulse temporal shaping

> **CDS booster**

- L-band, 14-cell copper Cut-Disc-Structure
- Matching → emittance conservation



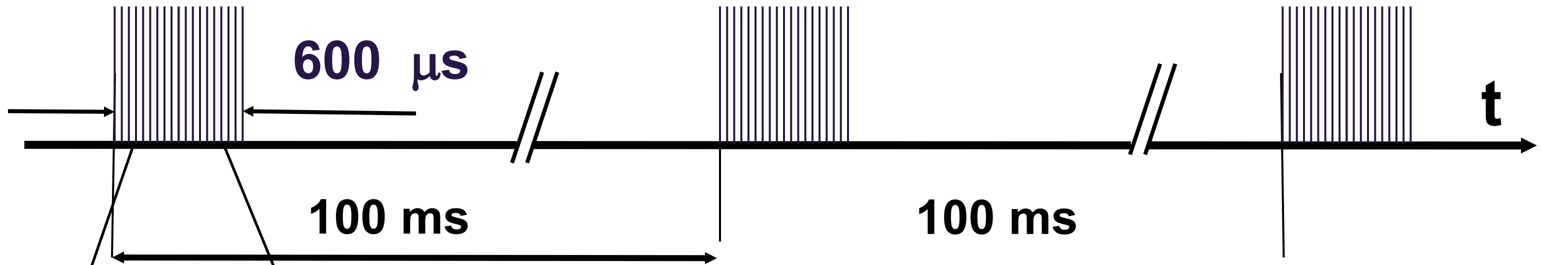


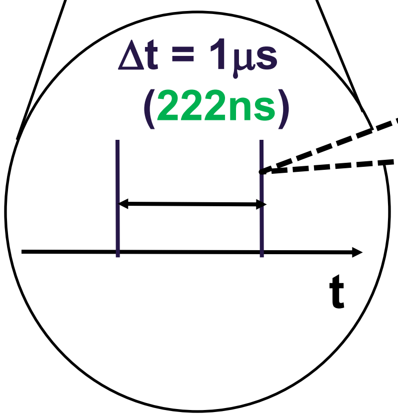
XFEL Photo Injector Performance Requirements → PITZ

subsystem	parameter	*value*	remarks
RF gun cavity	frequency	*1.3 GHz*	L-band 10MW MBK
	E-field at cathode	***60 MV/m***	dark current issue
	RF pulse duration	*650 us*	max
	Repetition rate	*10 Hz*	max
Cathode laser	Temporal –> flat top –> FWHM	***~20 ps***	**challenge** 
	Temporal –> flat top –> rise/fall time	***2 ps***	
	Transverse – rad.homogen.XYrms	*0.3-0.4 mm*	fine tuning -> **thermal emittance**
	Pulse train length	*600 us*	max
	Bunch spacing	*222 ns (4.5MHz)*	1us (1MHz) at PITZ now
	Repetition rate	*10 Hz*	max
Electron beam	Bunch charge	*1 nC*	**0.02-1nC (Post-TDR)**
	Projected emittance at injector	***0.9 mm mrad***	→ for 1 nC
	Bunch peak current	*5 kA*	after bunch compression (not at PITZ)
	Emittance (slice) at undulator	***1.4 mm mrad***	**0.4-1.0 mm mrad (Post-TDR)**

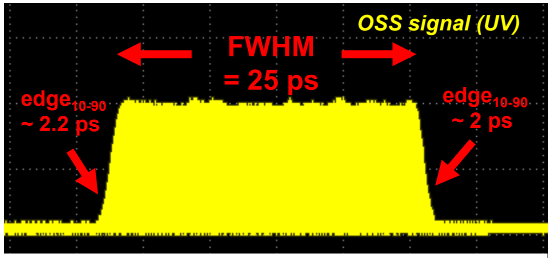
Pulse Train Time Structure: PITZ and European XFEL

Trains with up to 600 (2700) laser pulses → electron bunches of 1nC each





Cathode laser pulse: temporal profile



birefringent shaper: 13 crystals

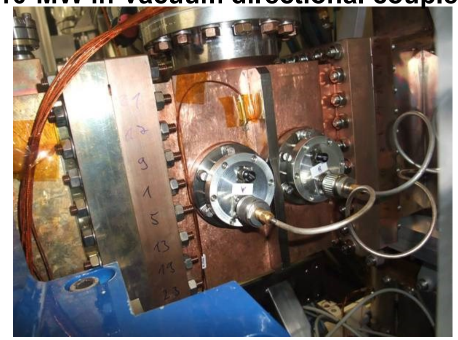
Max-Born-Institute →
→ Photocathode laser system with temporal pulse shaping

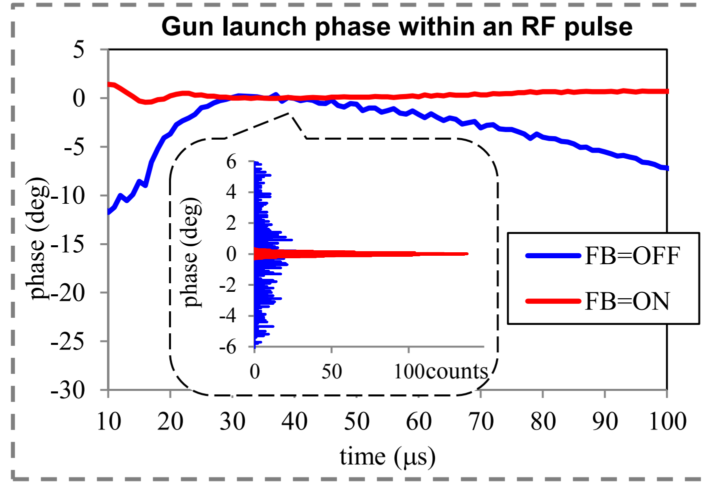
27000 electron bunches per second

How to achieve small emittance

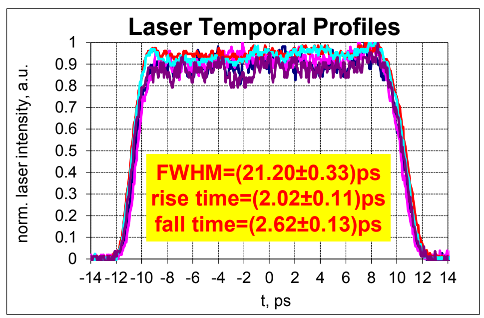
- High gradient at the cathode ~60MV/m (1.3GHz)
- Gun launch phase stability

10-MW in-vacuum directional coupler

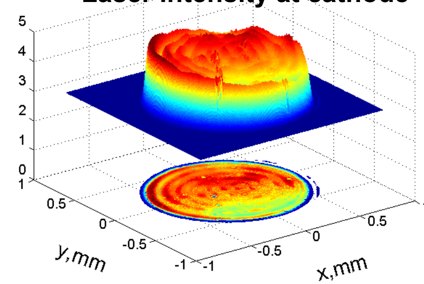




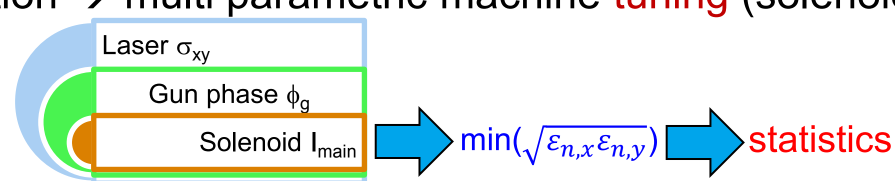
- Cathode laser pulse shaping



Laser intensity at cathode



- Beam based alignment, trajectory optimization
- Emittance compensation and conservation → multi parametric machine tuning (solenoid, laser spot size, gun phase, booster,…)

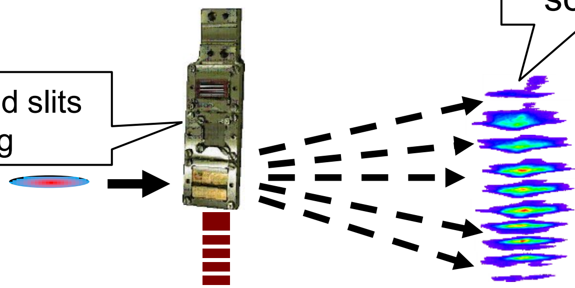


Slit Scan Technique for Emittance Measurements at PITZ

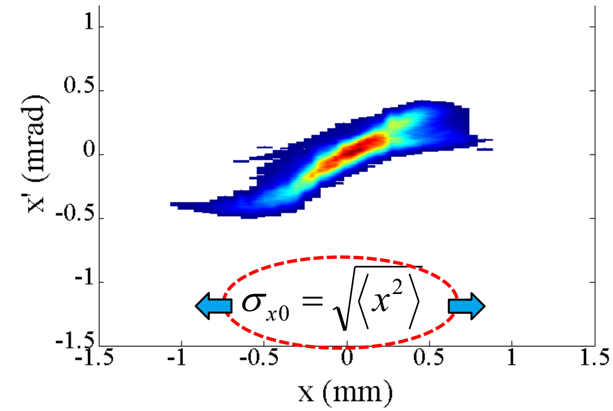
Emittance **M**easurement **SY**stem

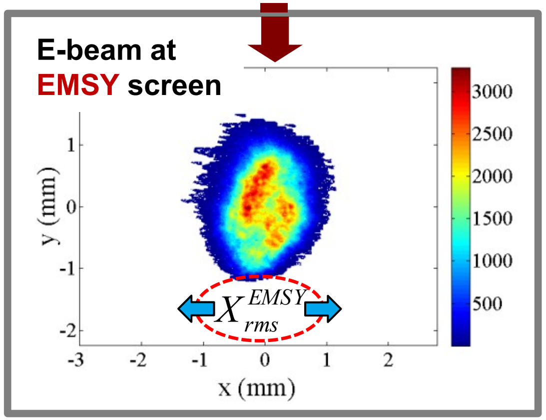
EMSY: screens and slits 10 (50) μm opening

Beamlet collector screen



measured transverse phase space





As conservative as possible!

$$\varepsilon_x = \beta\gamma \frac{X^{EMSY}_{rms}}{\sigma_{x0}} \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2}$$

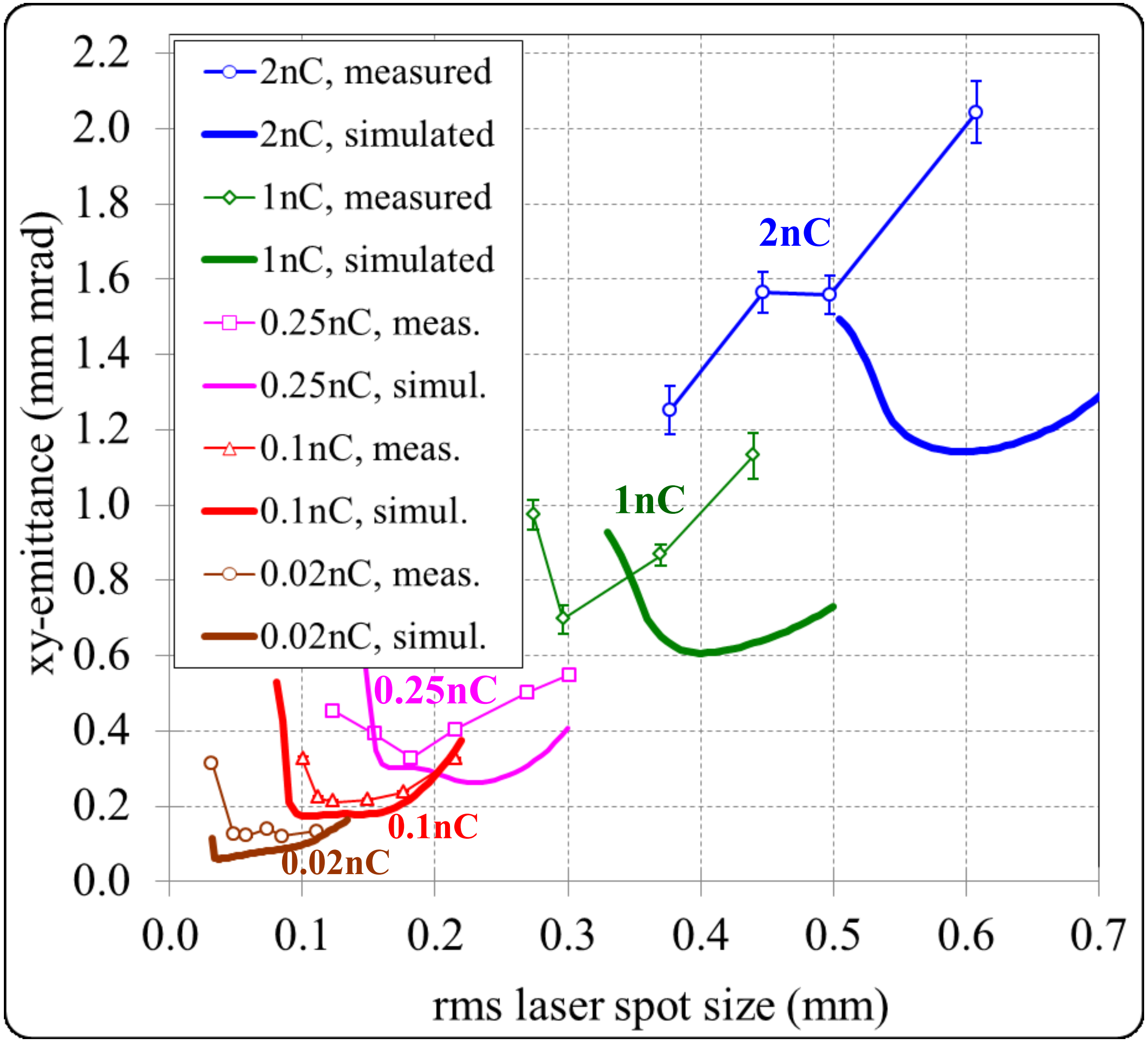
"100%" rms emittance

Correction factor introduced to correct for low intensity losses from beamlet measurements

"we are measuring more and more of less and less…"

Emittance versus Laser Spot Size for various Charges

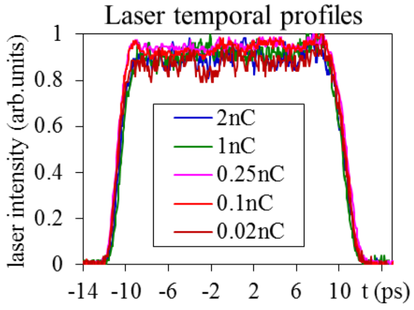
Measured (100%) rms normalized emittance vs. simulations



Minimum emittance ($\sqrt{\varepsilon_{n,x}\varepsilon_{n,y}}$)

Charge, nC	Measured, mm mrad	Simulated, mm mrad
2	1.25±0.06	1.14
1	0.70±0.02	0.61
0.25	0.33±0.01	0.26
0.1	0.21±0.01	0.17
0.02	0.121±0.001	0.06

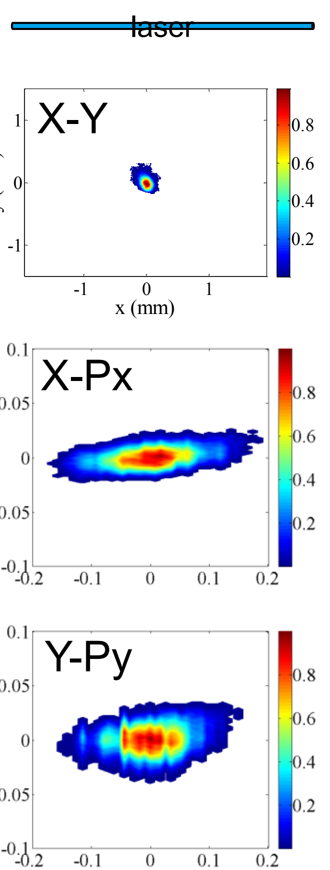
- Optimum machine parameters (laser spot size, gun phase):
  experiment ≠ simulations
- Difference in the optimum laser spot size is bigger for higher charges (~good agreement for 100pC)
- Simulations of the emission needs to be improved



Emittance and Brightness versus Bunch Charge

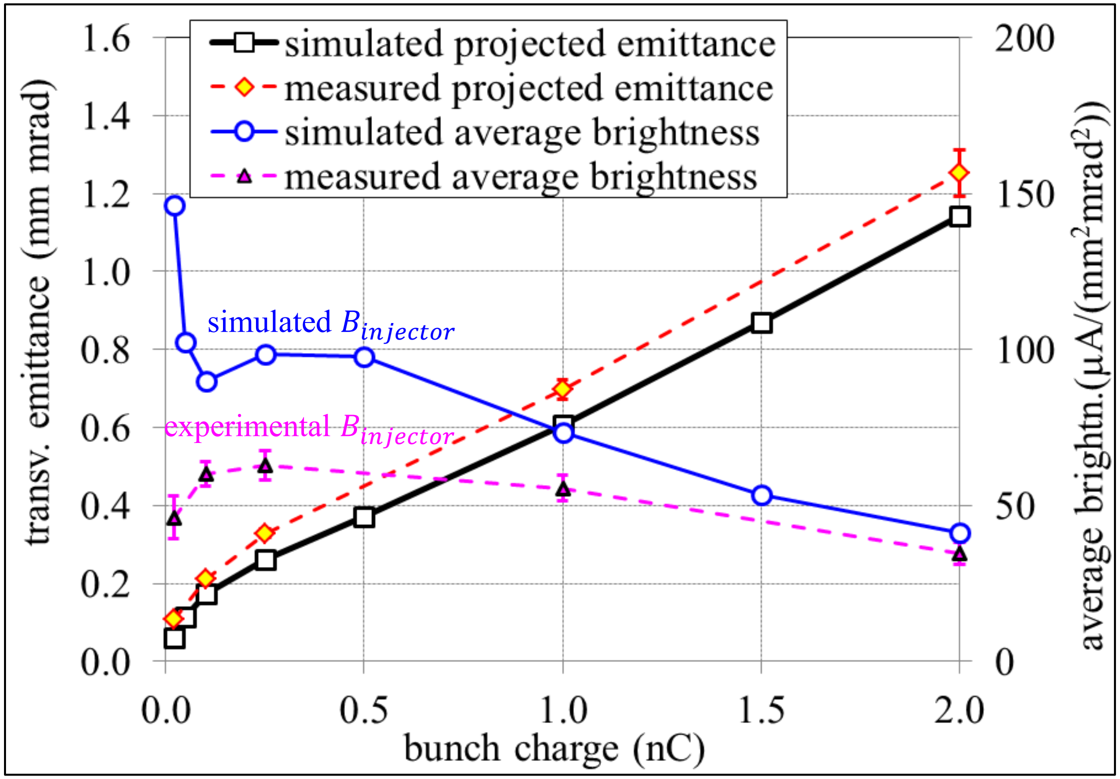
*Cathode laser pulse duration was **fixed at 21.5 ps (FWHM)** for all bunch charges!*

20pC measured

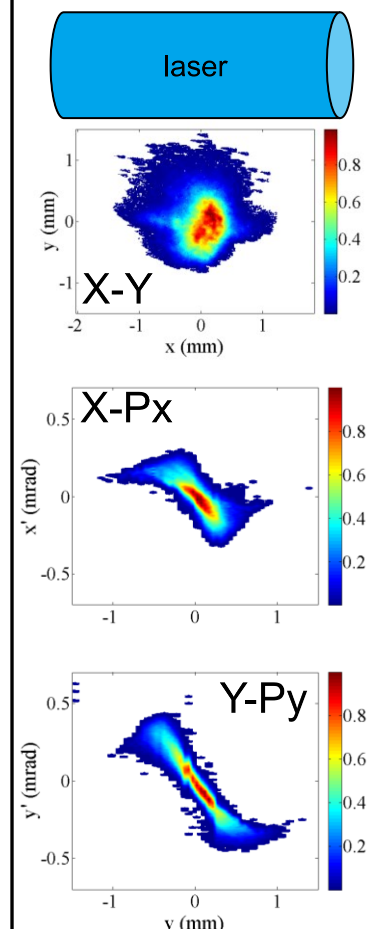


~linear SC

$$B_{injector} = \frac{I_{injector}}{\varepsilon_x \varepsilon_y} = \frac{Q \cdot NoP \cdot RR}{\varepsilon_x \varepsilon_y}$$



2nC measured



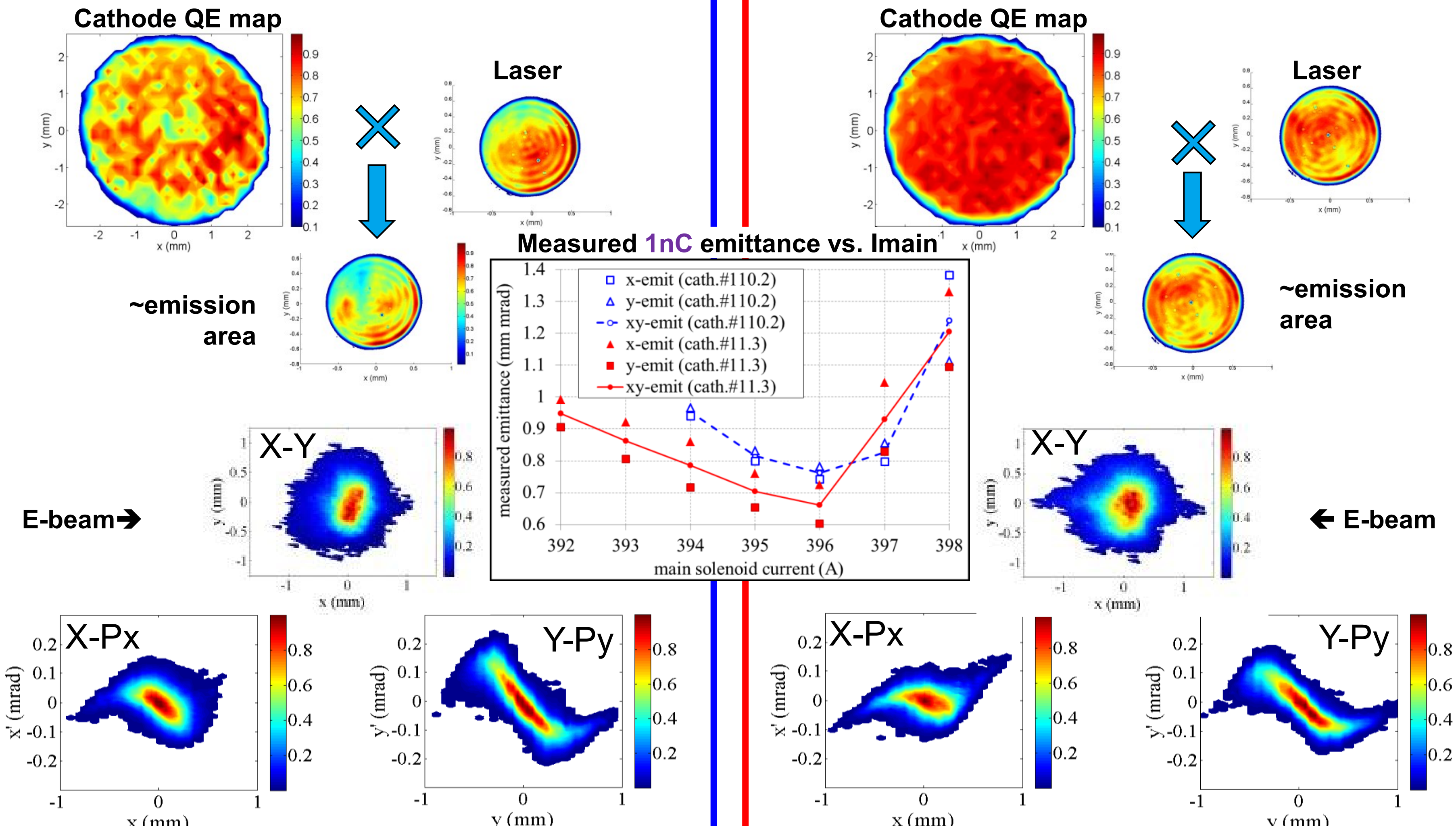
nonlinear SC

Bunch charge reduction at fixed cathode laser pulse duration → space charge (SC) modification

Emission Area Homogeneity

Cs2Te cathode#110.2

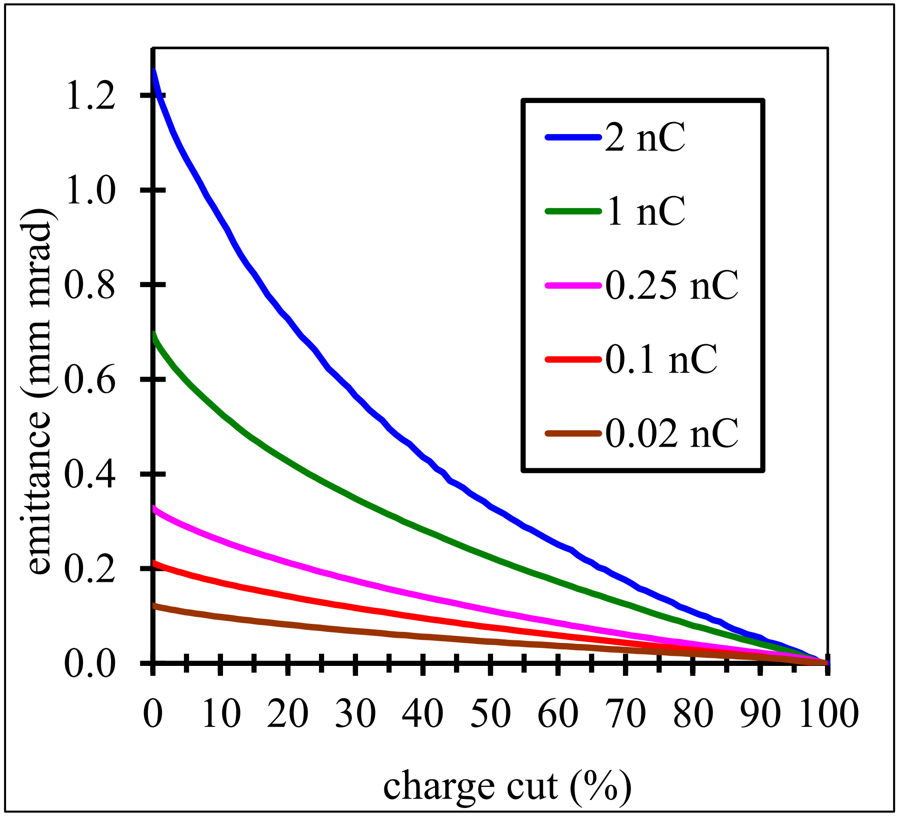
Cs2Te cathode#11.3



min($\sqrt{\varepsilon_{n,x}\varepsilon_{n,y}}$)=0.762±0.017 mm mrad

min($\sqrt{\varepsilon_{n,x}\varepsilon_{n,y}}$)=0.661±0.033 mm mrad

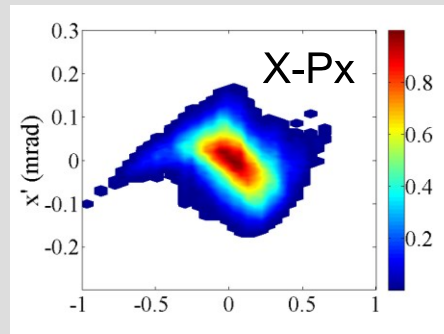
Core Emittance



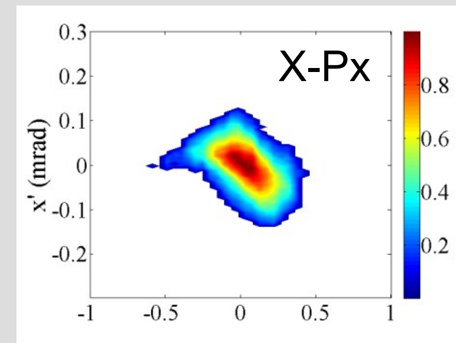
Raw phase space (100%) → intensity cut ➔ charge cut ➔ core emittance

Measured Transverse Phase Space (1nC)

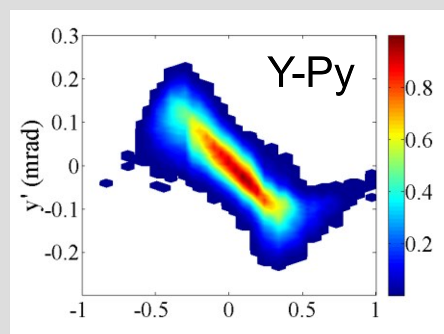
100% | 90%



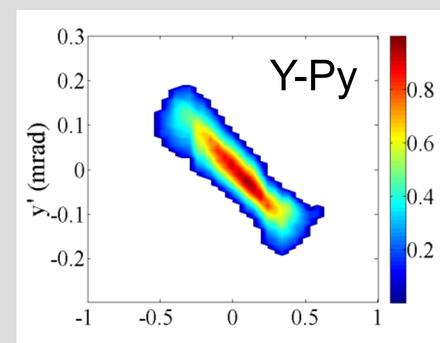
$\varepsilon_{n,x}(100\%)$=0.707mm mrad



$\varepsilon_{n,x}(90\%)$=0.543 mm mrad



$\varepsilon_{n,y}(100\%)$=0.685 mm mrad



$\varepsilon_{n,y}(90\%)$=0.515 mm mrad

Conclusions and Outlook

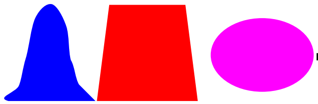
- The Photo Injector Test facility at DESY in Zeuthen (PITZ) develops high brightness electron sources for SASE FELs:
  - specs for the European XFEL have been demonstrated and surpassed (emittance <0.9 mm mrad at 1nC)
  - XFEL gun conditioned at PITZ (**TUPSO30**) → Hamburg in July 2013
  - beam emittance has also been optimized for a wide range of bunch charge (20pC…2nC)
  - optimized measured emittance:

Q	min($\sqrt{\varepsilon_{n,x}\varepsilon_{n,y}}$),100% mm mrad	min($\sqrt{\varepsilon_{n,x}\varepsilon_{n,y}}$),90% mm mrad
20 pC	0.12	0.10
100 pC	0.21	0.17
250 pC	0.33	0.26
1 nC	0.70	0.53
2 nC	1.25	0.94

- PITZ serves also as a benchmark for theoretical understanding of the photo injector physics (beam dynamics simulations vs. measurements)
  - rather good agreement on emittance minima between measurements and simulations
  - optimum machine parameters: simulations ≠ experiment
  - simulations of the emission needs to be improved

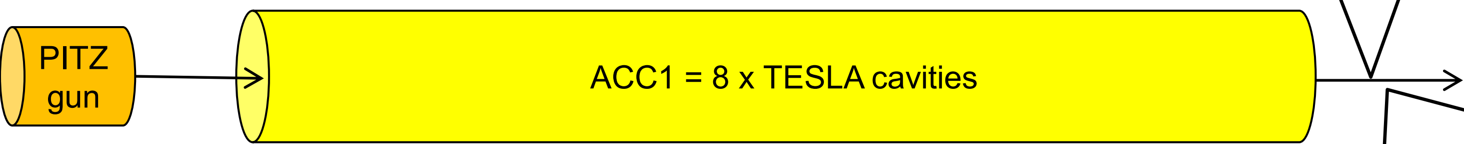
- Outlook:
  - slice diagnostics (RF deflector) → transverse emittance and longitudinal phase space
  - next step in optimization ➔ 3D ellipsoidal cathode laser pulses ➔ BMBF and HGF projects (collaboration DESY-IAP-JINR)

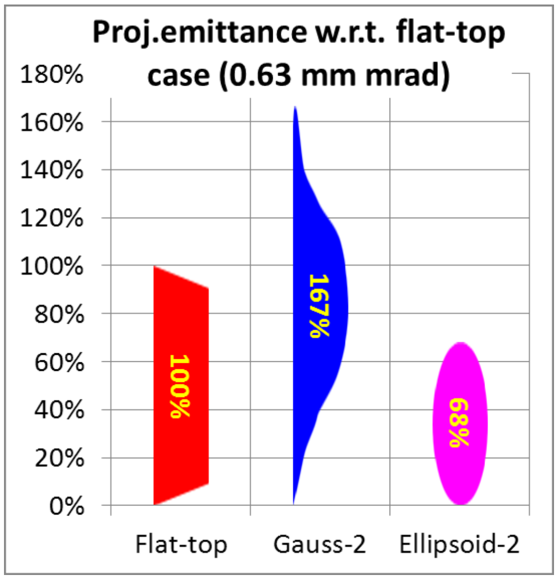
Outlook: Beam Dynamics Simulations: XFEL Photo Injector (1nC)

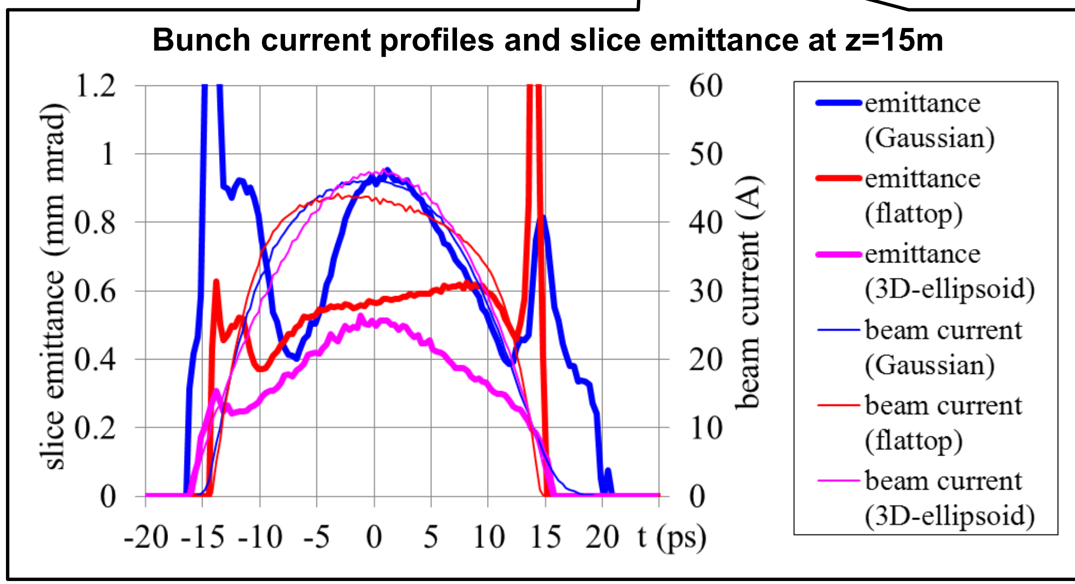


➔Various shapes of the photocathode laser pulse
(Gaussian and Flattop temporal profiles vs. 3D-ellipsoid)

z=15m
E_{beam}~150MeV
σ_t ~7ps







- **3D ellipsoidal cathode laser pulses** ➔ Major improvements on beam emittance
- Developments of the new laser system are on-going → more details → **TUPS036, TUPS039**

Acknowledgements

PITZ Team

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Thank you for your attention!