Emittance measurements of the electron beam at PITZ for the commissioning phase of the European XFEL.

- PITZ gun and laser operated at E-XFEL conditions
- Simulations with realistic laser transverse shape
- Emittance for E-XFEL conditions
- Emittance for various beam charges
- Summary and outlook

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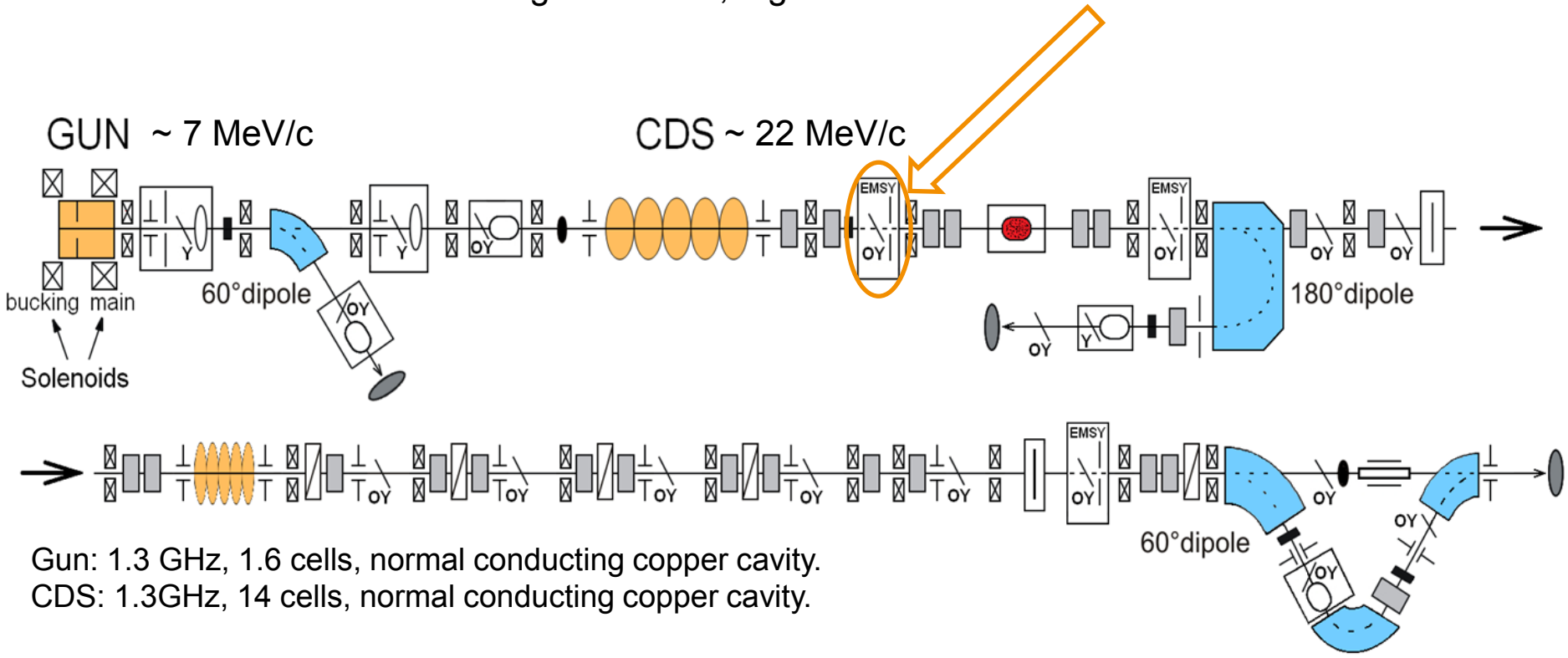
Dajeon, 24.08.2015

HELMHOLTZ GEMEINSCHAFT

DESY

PITZ: Photo Injector Test facility at DESY, Zeuthen site

- **Test bed for the FLASH and the European XFEL injectors, currently focused on:**
  - Solution of the remaining problems of the RF gun for XFEL (RF windows, RF spring, stability and long term reliability)
  - Conditioning and operation of the gun cavities
  - Characterization of the gun cavities, e.g. in terms of emittance of electron beam



Gun: 1.3 GHz, 1.6 cells, normal conducting copper cavity.
CDS: 1.3GHz, 14 cells, normal conducting copper cavity.

Gun and laser setup corresponding to E-XFEL commissioning parameters

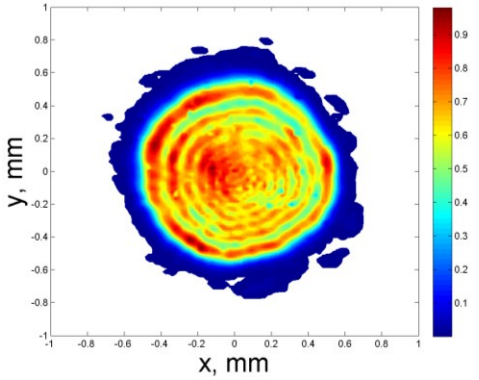
Parameter	XFEL injector, nominal	XFEL injector, startup
RF gun gradient (peak power)	E_{cath}=60MV/m (6.4MW)	E_{cath}=50…53MV/m (4.5…5.0MW)
RF pulse length	650us	650us
Repetition rate	10Hz	10Hz
RF gun phase stability (rms)	0.01deg	
RF gun amplitude stability (rms)	0.01%	
Cathode laser	Flattop (2/20\2ps)	Gaussian (~13ps FWHM)
Beam emittance (bunch charge)	< 0.9 mm mrad (1nC)	≤1 mm mrad (500pC)

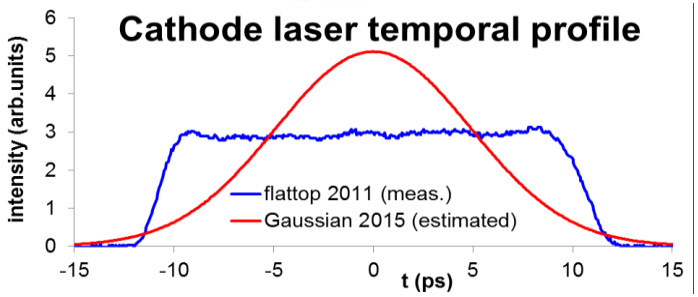
Gun setup:

- 640 us RF pulse length
- 53 MV/m on-axis peak field on the cathode ➔ P_z ~ 6.1 MeV/c

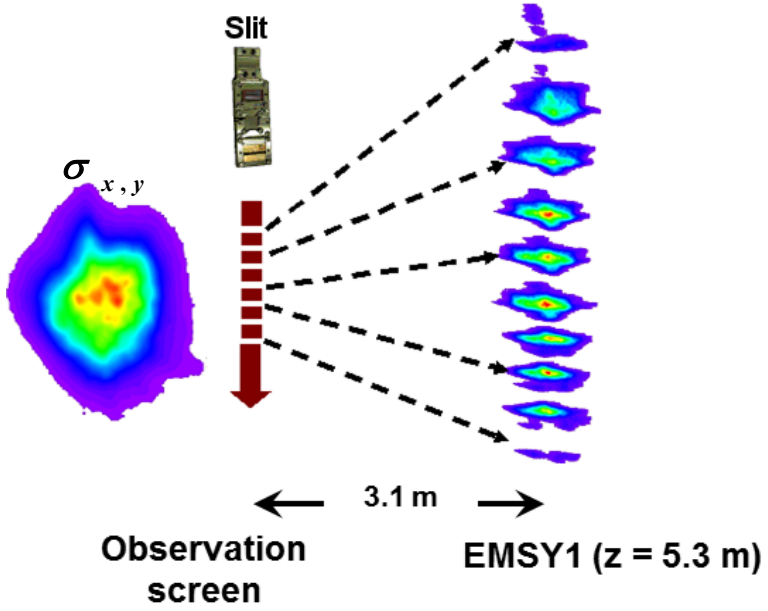
Laser setup:

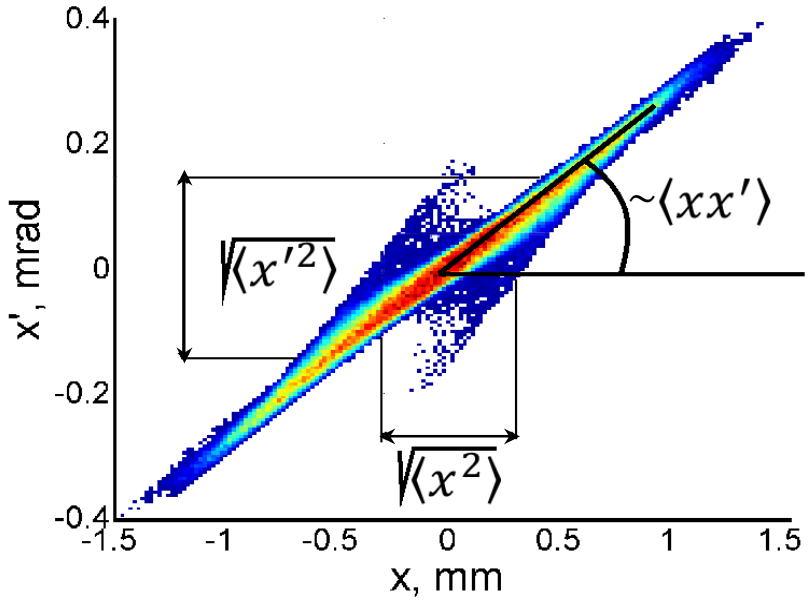
- Gaussian longitudinal pulse shape with FWHM of about 12 ps
- Quasi-uniform transverse profile





Emittance measurements setup





- Emittance vs. charge
  - Emittance vs. laser spot size
  - Emittance vs. gun phase
    - Emittance vs. main solenoid current

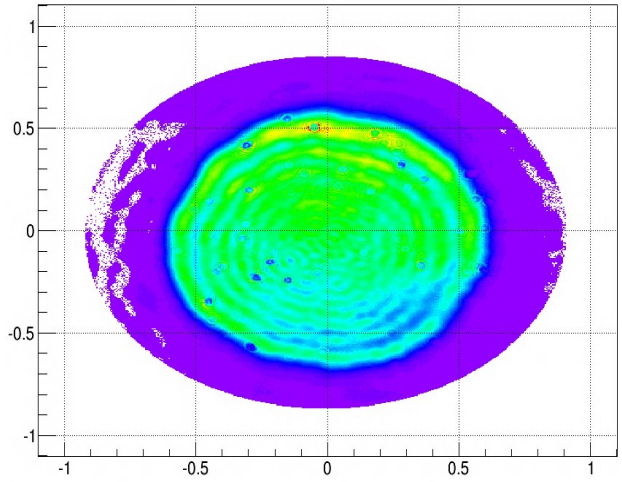
$$\varepsilon_n = \frac{\sigma_x}{\sqrt{\langle x^2 \rangle}} \beta\gamma \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2}$$

correction factor (>1) introduced to correct for low intensity losses from beamlet measurements => conservative estimation

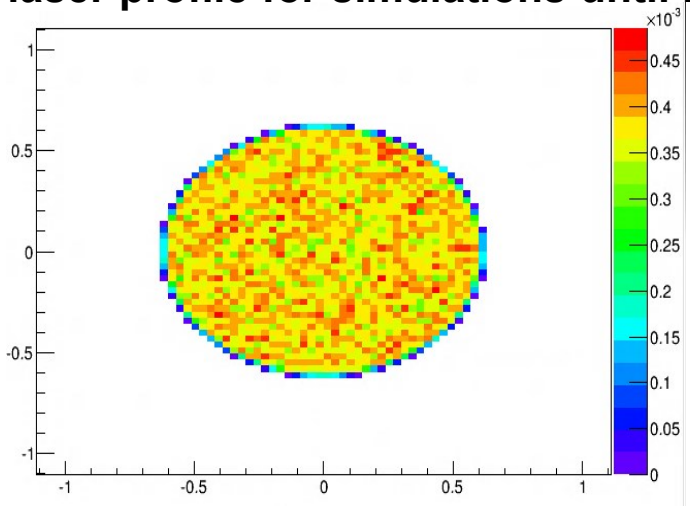
100% RMS emittance

Beam dynamics simulations with realistic transverse laser shape

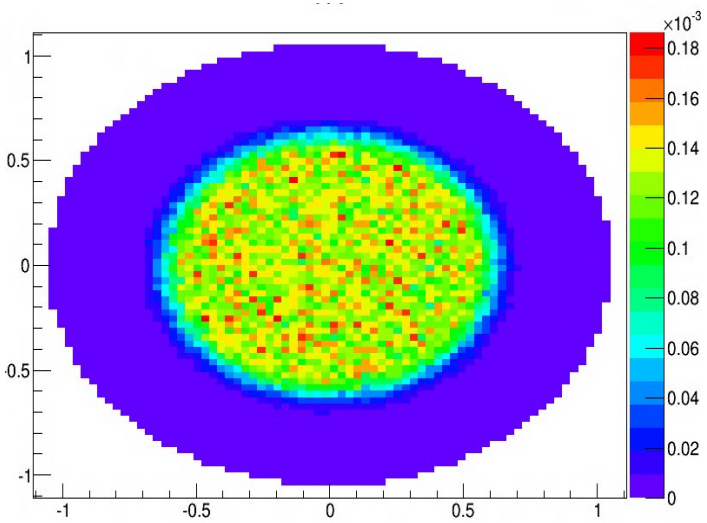
Measured laser transverse profile



Uniform laser profile for simulations until now

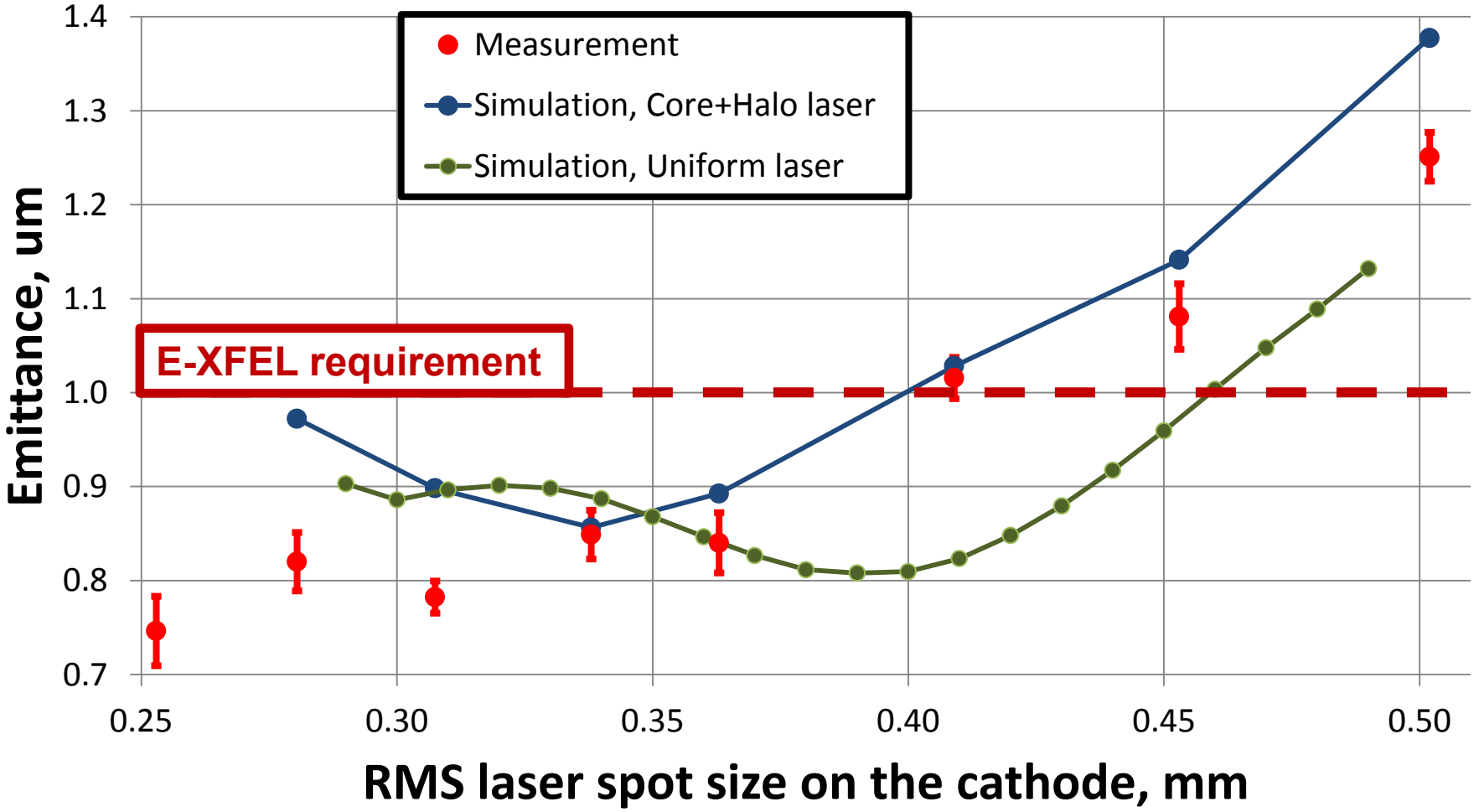


New approach: core + halo generation for simulations



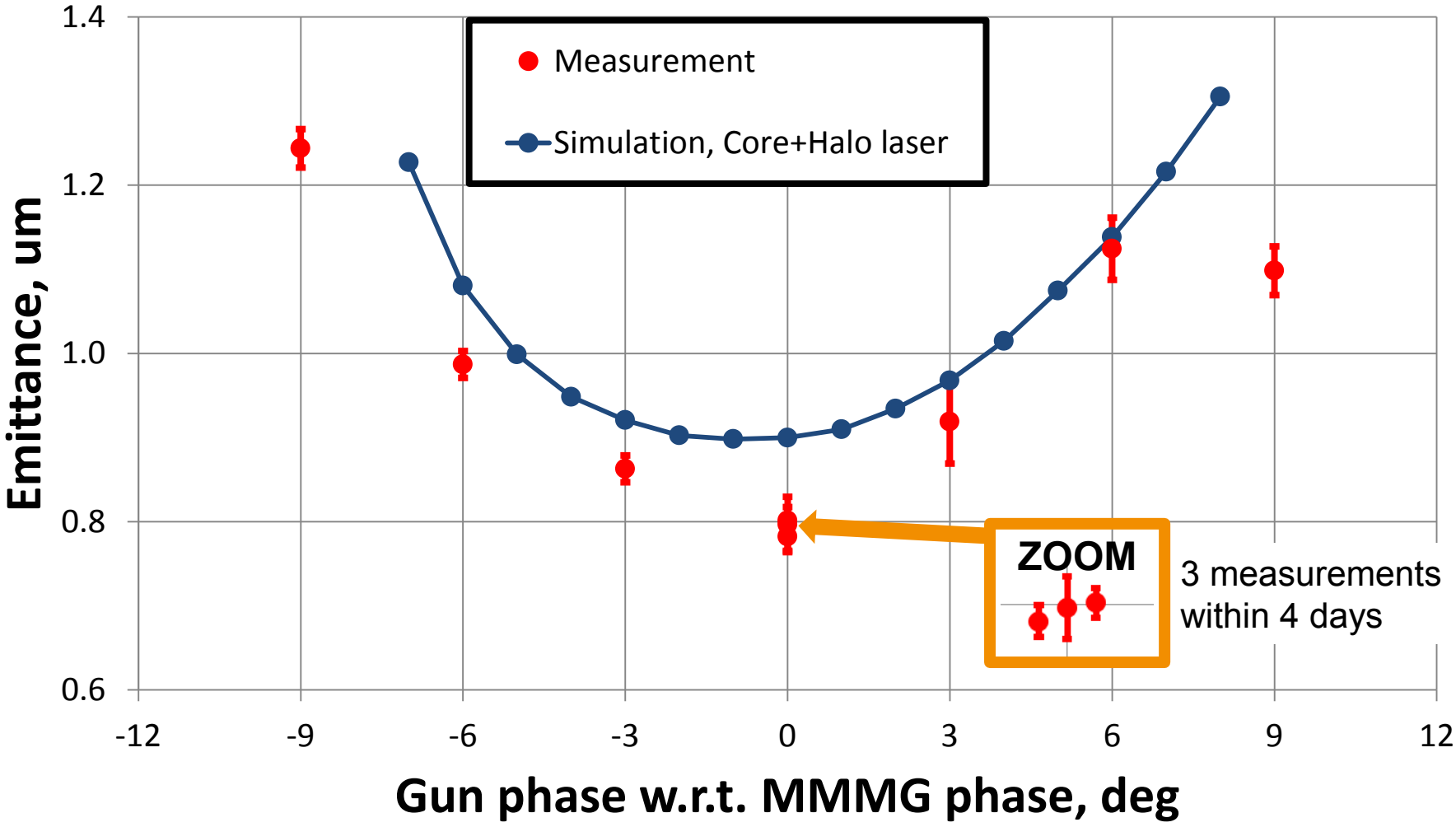
- Better modeling but keeping 2D symmetry as required by simulation tool
- Directly plug in measured transverse profile into simulations

Emittance measurements for 500 pC, 12 ps Gaussian temporal laser profile, 53 MV/m gun gradient



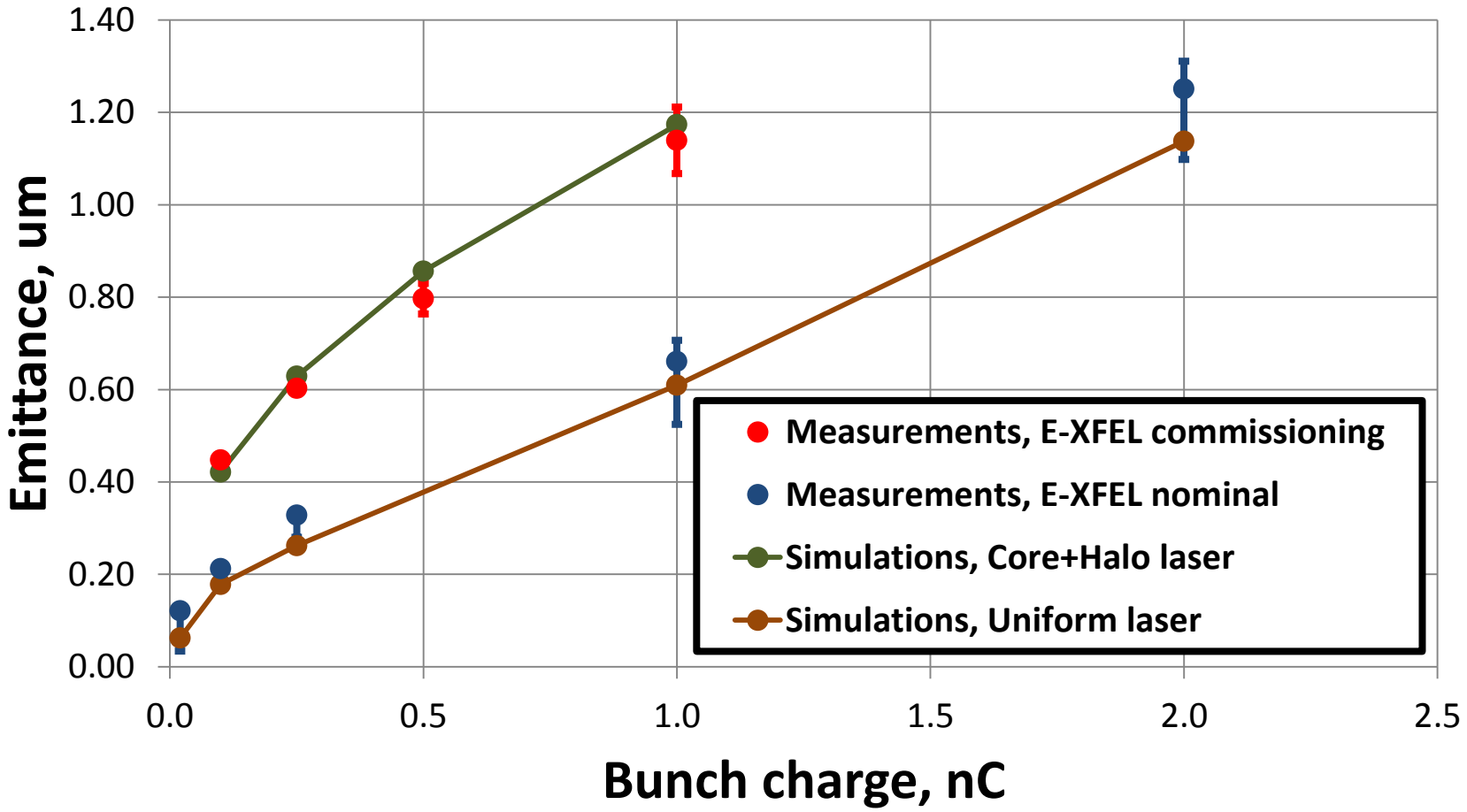
European XFEL commissioning phase requirement on emittance is fulfilled.

Emittance measurements for 500 pC, 12 ps Gaussian temporal laser profile, 53 MV/m gun gradient



*MMMG – Maximum Mean Momentum Gain

Emittance for different charges



Emittance measurements in 2011 were performed for the gun on-axis peak field of 60 MV/m (53MV/m in 2015) and flat-top laser pulse shape with FWHM of 21.5 ps (Gaussian with 11-12 ps FWHM in 2015)

Summary and outlook

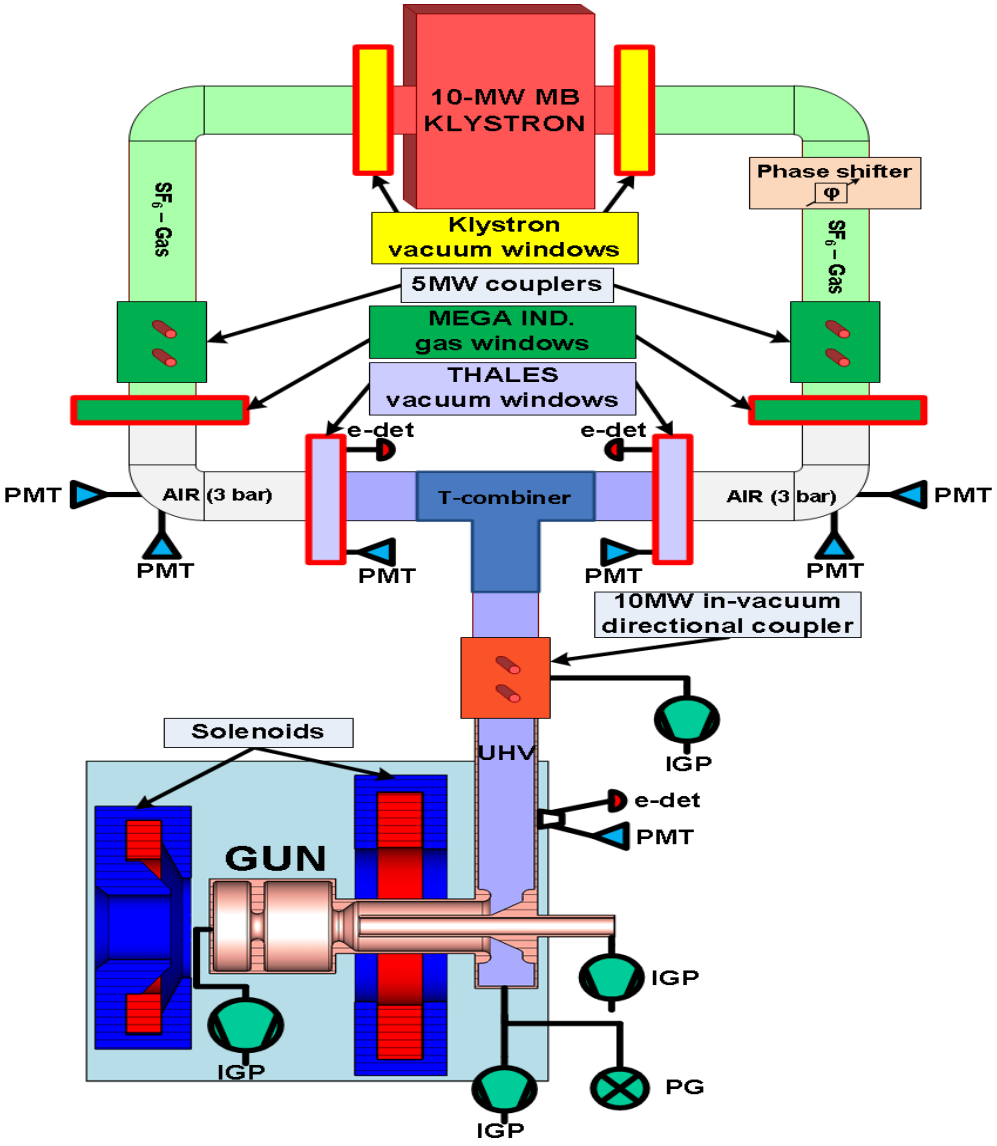
- **European XFEL commissioning phase requirement on emittance is fulfilled**
- Emittance for electron beam charges of 100, 250, 500 and 1 nC, gun operated at 53 MV/m on-axis peak field and Gaussian laser temporal profile with FWHM of 11-12 ps was measured.
- Beam dynamics simulations with improved modeling of the transverse laser distribution were performed and yield to better agreement between the simulated and measured data not only in terms of minimum achievable emittance but also in terms of obtained machine parameters.
- On the way to further improvement of the electron beam quality for FELs, PITZ is performing the commissioning of a state-of-art photocathode laser system which will be able to generate 3D-ellipsoidal laser pulses.

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

Thank you for attention!

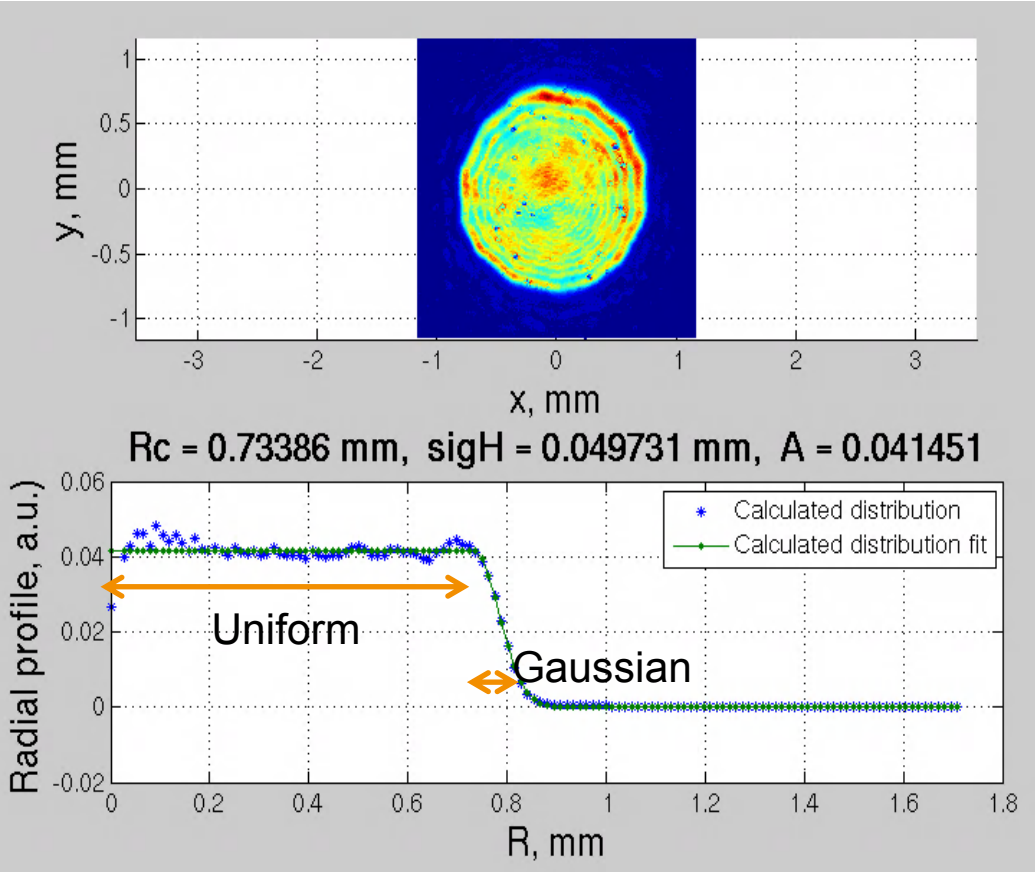
- H. Huck “First Results of Commissioning of the PITZ Transverse Deflecting Structure” MOP039
- P. Boonpornprasert “Numerical Simulations of a Sub-THz Coherent Transition Radiation Source at PITZ” MOP033
- J. Good
- M. Bakr “Beam Dynamics Simulation for the Upgraded PITZ Photo Injector Applying various Photocathode Laser Pulse Shapes” TUP065

PITZ gun setup

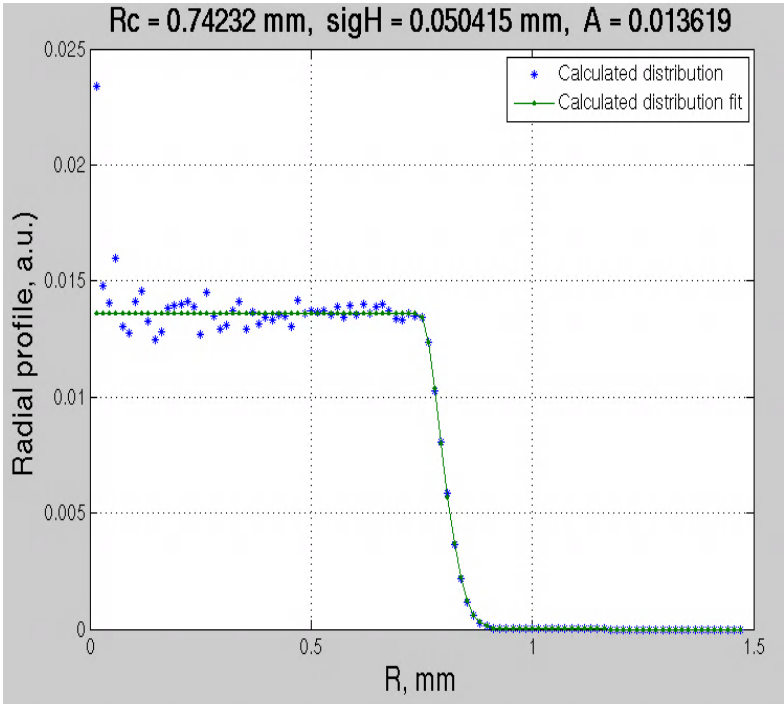


Beam dynamics simulations with realistic transverse laser shape

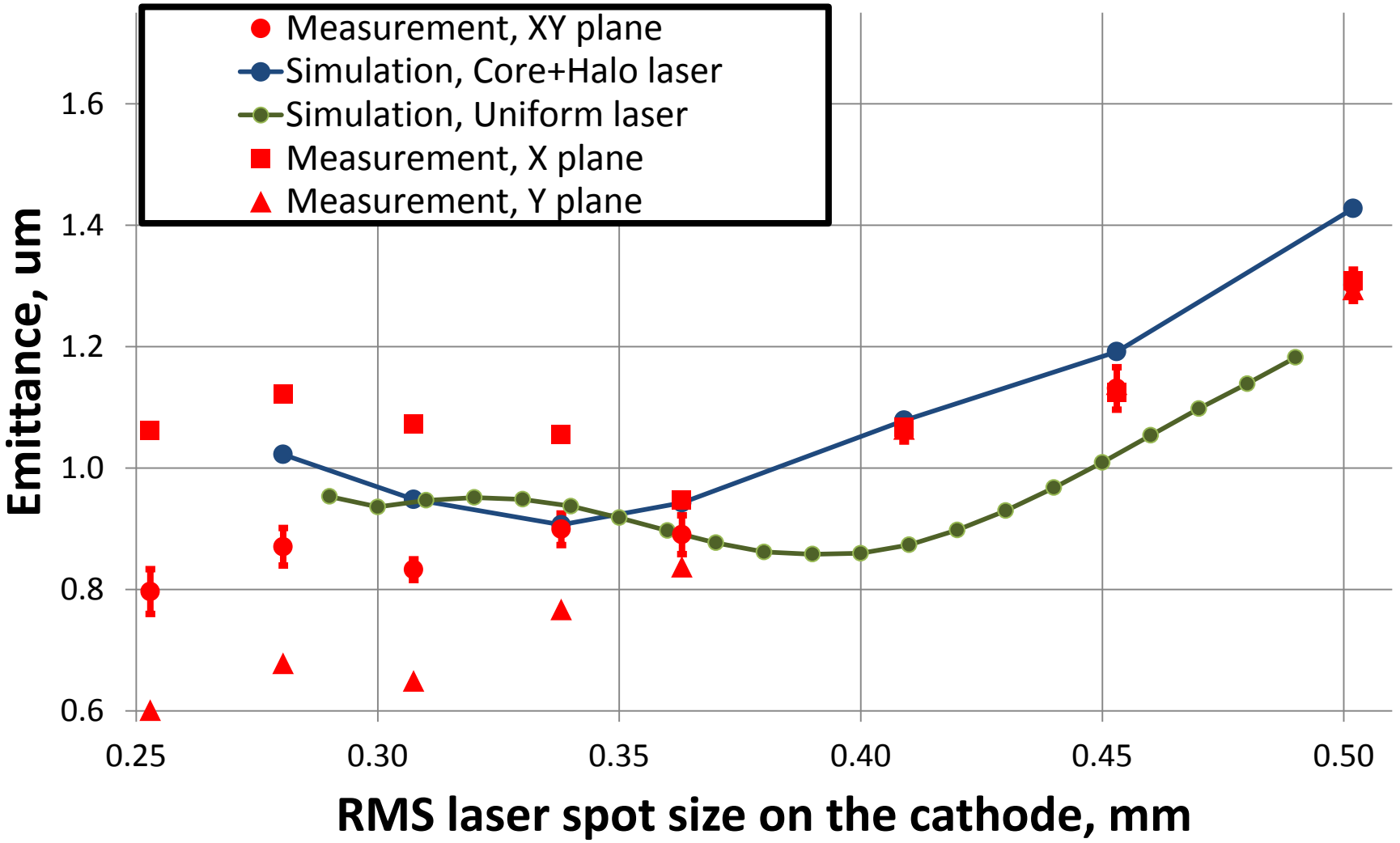
Real laser transverse profile



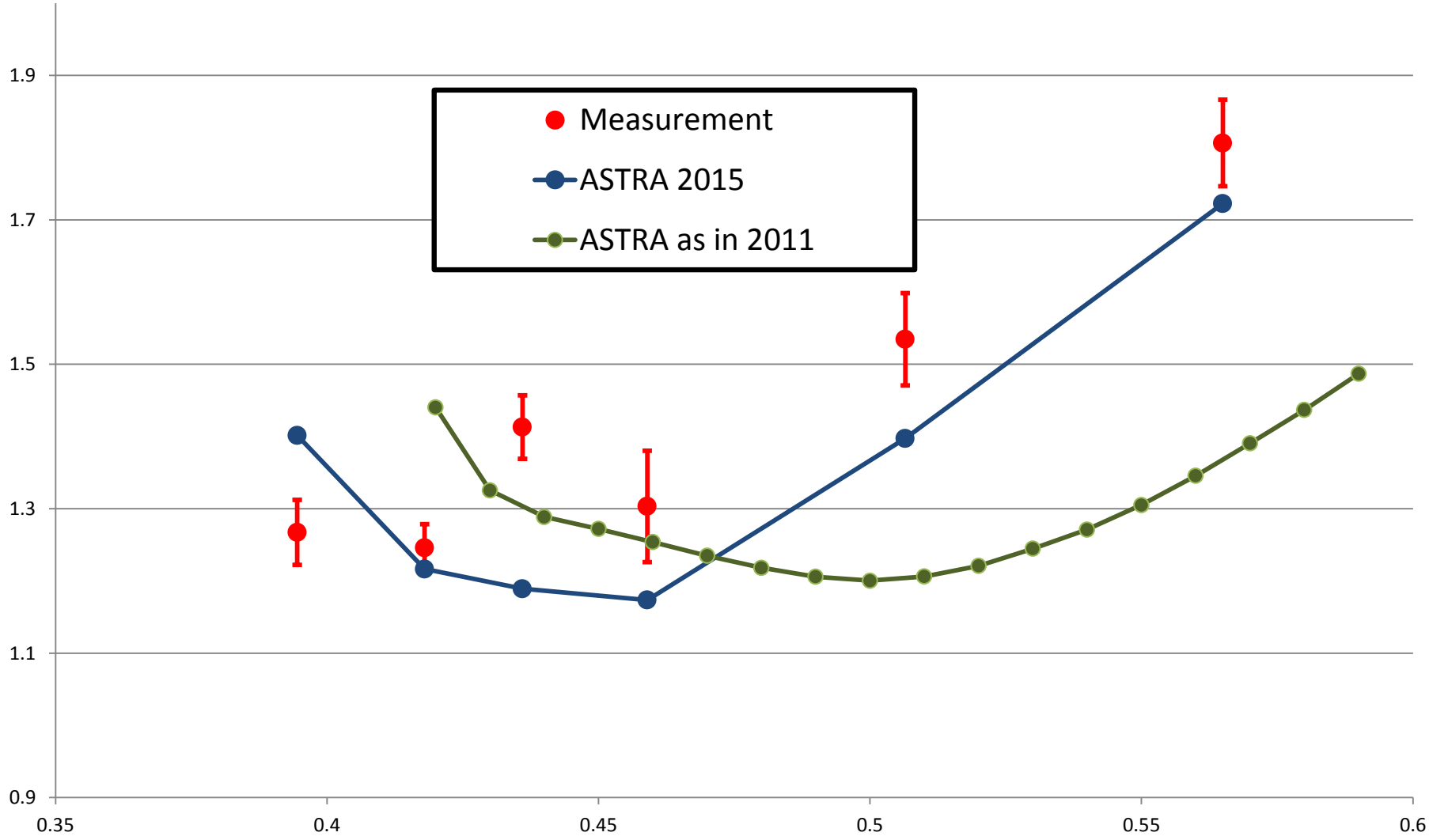
Generated laser profile with fit parameters for simulations



Emittance measurements for 500 pC, 12 ps Gaussian temporal laser profile, 53 MV/m gun gradient



Emittance measurements for 1 nC, 12 ps Gaussian temporal laser profile, 53 MV/m gun gradient



Emittance measurements for 250 pC, 12 ps Gaussian temporal laser profile, 53 MV/m gun gradient