Space charge dominated beam transport for THz studies at PITZ

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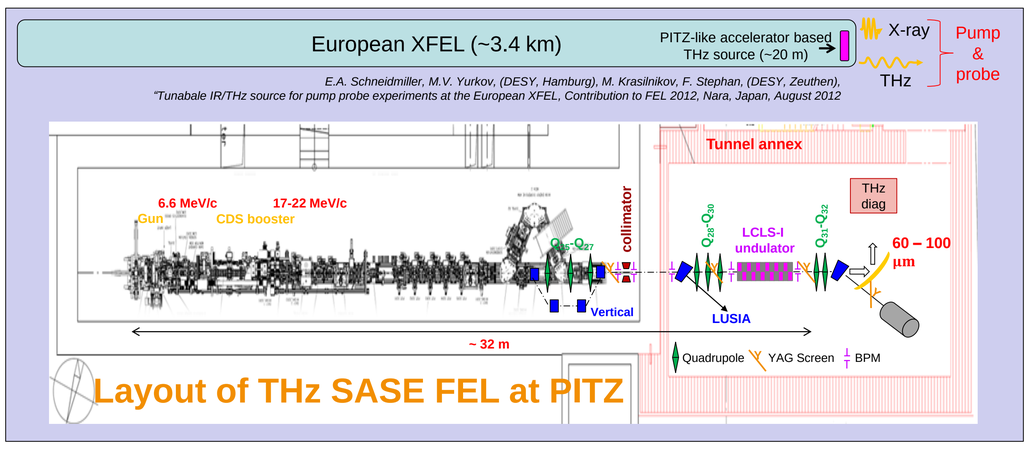
Background



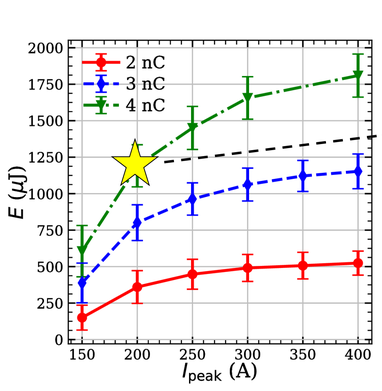
Layout of THz SASE FEL at PITZ

- **Advantages:**
  1) Identical pulse train structure as the X-rays with ~**mJ** level energy
  2) Low beam energy -> no need for large beam dump, therefore is close to XFEL user hall and can support all XFEL end stations
- **Challenges:**
  - Generation, transport and matching of space charge dominated beam with proper beam quality (peak current, emittance, etc.)

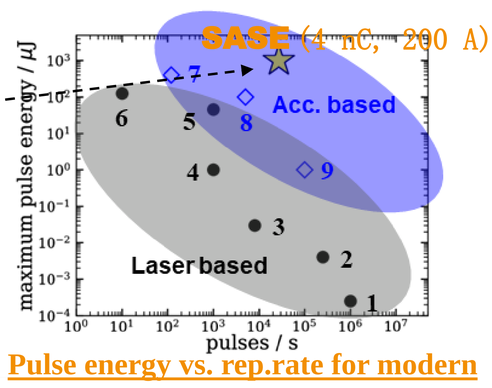
Parameter study towards mJ energy

- **Genesis 1.3 simulation**
  - LCLS-I undulator module
  - Flattop electron beam
  - Transverse emittance: 4 μm
  - Radiation wavelength: 100 μm

#	Mechanism
1,3,5,6	Optical rectification [1]
2	Photoconductive antenna [1]
4	Two-color Laser filamentation [2]
7	CTR (LCLS/FACET) [3]
8	UR (FLASH) [4]
9	UR (TELBE) [5]



Radiation energy vs peak current

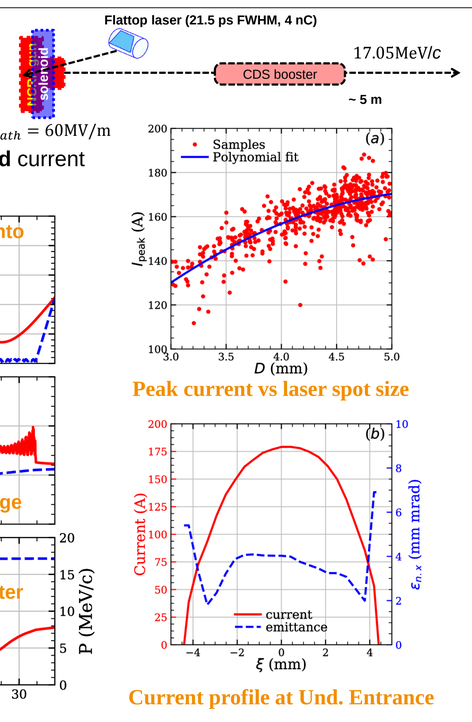


Pulse energy vs. rep.rate for modern THz sources

Start-to-End simulation

- **Beam dynamics by Astra**

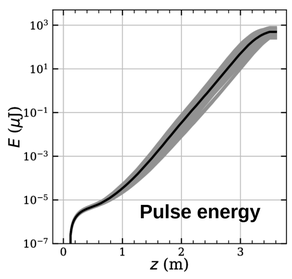
⇨ **Laser** spot, **gun** and **booster** phases, **solenoid** current **quadrupole** gradients tuned



Peak current vs laser spot size

Current profile at Und. Entrance

- **Genesis 1.3 simulation**



Parameter	Value	Unit
Pulse energy	**493.1±108.8**	μJ
Peak power	52.7±11.8	MW
Centre wavelength	**101.8±0.7**	μm
Spectrum width	2.0±0.4	μm
Arrival time jitter	1.45	ps

Beam transport in the undulator

- **Difficulties**
  - Strong vertical focusing: K=3.59
  - Small vacuum chamber: 5x11 mm

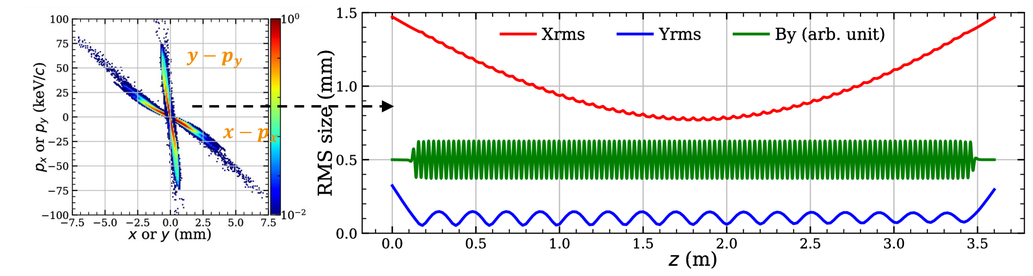
LCLS-I undulator:

$N_u = 113, \lambda_u = 30$ mm

$K = 3.59$

Goal function:

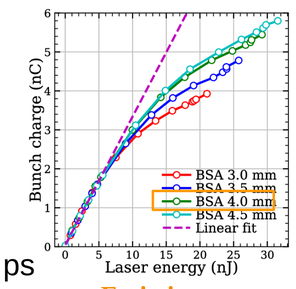
$$F = \frac{|\sigma_x^1 - \sigma_x^0|}{11} + \frac{|\sigma_y^1 - \sigma_y^0|}{5} + \frac{|\langle xx' \rangle^1 + \langle xx' \rangle^0|}{11} + \frac{|\langle yy' \rangle^1 + \langle yy' \rangle^0|}{5}$$



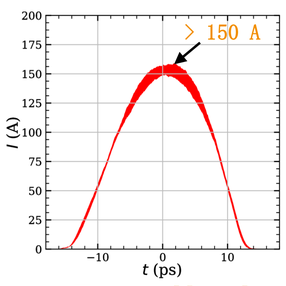
The transverse phase spaces are thus defined to well transport the beam in the vacuum chamber of the undulator

High peak current beam experiment

- **Challenges**
  1) High charge generation
  2) Proper beam quality
  3) Transport and matching

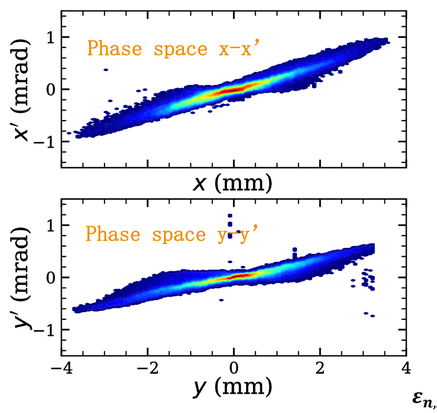


Emission curve



Temporal bunch profile

- **Experimental setup**
  - Gaussian laser FWHM~6 ps
  - Near saturation emission
  - Reducing bunch charge: 2.5 nC



Transverse phase spaces

Comparison of measured and simulated beam parameters

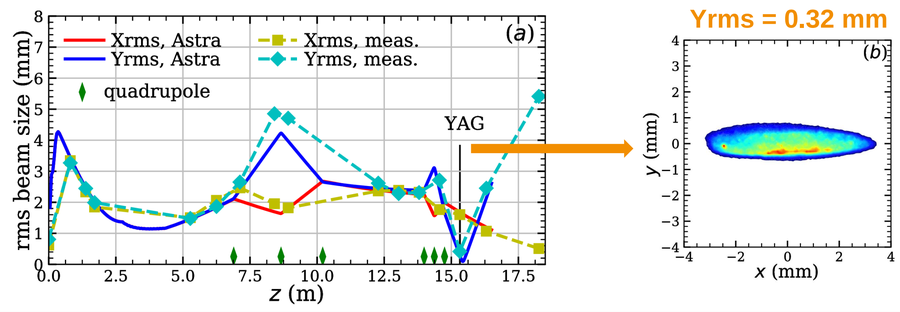
Parameter	Meas.	Simul.	Unit
Laser FWHM	6.2	6	ps
BSA	4	4	mm
Bunch charge	2.53±0.05	2.5	nC
Momentum	17.0	17	MeV/c
Peak current	153±0.5	156	A
xy emittance	3.90	4.14	mm mr

$\varepsilon_{n,x}$=(3.99 +/- 0.01) mm mrad
$\varepsilon_{n,y}$=(3.82 +/- 0.13) mm mrad
$\varepsilon_{n,xy}$=(3.90 +/- 0.07) mm mrad

Transport & matching of the beam to the "undulator"

- Using two sets of triplets
- Good agreement with simulation

Xrms = 1.54 mm
Yrms = 0.32 mm



Summary

- The prototype THz SASE FEL is under-going construction at PITZ as a proof-of-principle experiment for pump-probe experiments at EuXFEL
- With the ideal flattop laser, start-to-end simulations with space charge dominated beams have yielded THz pulse energy of 0.5 mJ at 100 um
- Experimental studies on the generation, characterization and matching of beams of a few nC have been carried out in the existing PITZ beamline with a Gaussian laser. Next, beam transport will be carried out with even more bunch charge induced by a longer flattop laser

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PITZ Photo Injector Test Facility Zeuthen

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

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