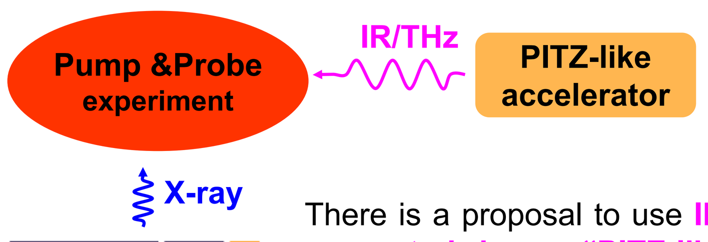
Experimental Optimization and Characterization of Electron Beams for Generating IR/THz SASE FEL Radiation with PITZ.

P. Boonpornprasert, G. Asova[1], Y. Chen, J. Good, H. Huck, I. Isaev, D. Kalantaryan, M.Krasilnikov, X. Li, O. Lishilin, G. Loisch, D. Melkumyan, A. Oppelt, H,Qian, Y. Renier, T. Rublack, F. Stephan, C. Saisa-ard[2] and Q.Zhao[3] (DESY, Zeuthen, Germany)
On leave from [1]INRNE, Sofia, Bulgaria, [2]Chiang Mai University, Chiang Mai, Thailand, [3]IMP/CAS, Lanzhou, China

Introduction



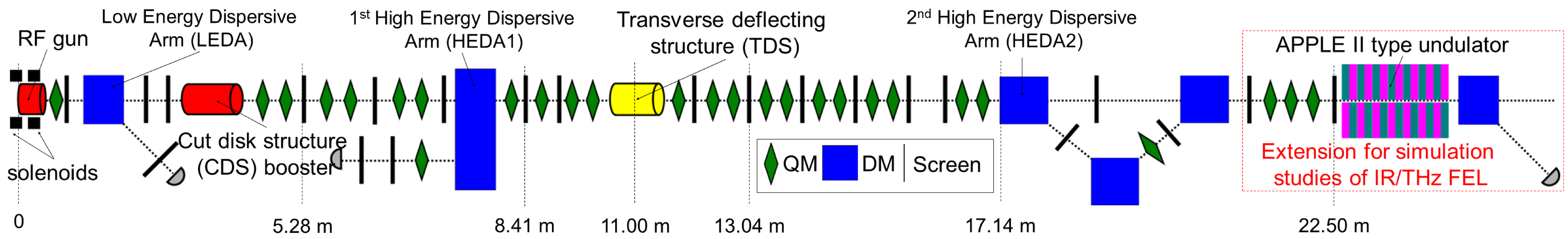
There is a proposal to use IR/THz radiation generated by a "PITZ-like" accelerator close to the user end-station together with X-rays from the European XFEL for pump-probe experiments.
[E.A.Schneidmiller et. al, WED55, FEL2012].

PITZ accelerator is an ideal machine for the development of a prototype of such IR/THz source.

- Over a decade of **experience** in high brightness photo injector research and development.
- PITZ has **same type of electron source** as EXFEL ➔ same time structure of radiation pulse ➔ merit for precise synchronization.
- The site of a PITZ-like setup is **small enough** to fit in the experimental hall for the EXFEL users. ➔ short IR/THz transport
- **Born to be a test facility**, the beam time and the accelerator are adaptable to new research ideas and proposals.

- **2 methods of radiation production have been studied at PITZ.**
  - Single-pass FEL ➔ SASE FEL for $\lambda_{rad} \leq$ **100 µm** (**f ≥ 3 THz**)
  - Coherent Transition Radiation(CTR) for $\lambda_{rad} \geq$ **100 µm** (**f ≤ 3 THz**)
- **Start-to-end (S2E) simulations of the THz SASE FEL from a PITZ-like accelerator were performed [MOP055, FEL2014].**
  - The radiator is an APPLE-II undulator with a period length of **40 mm**.
  - **4 nC** electron beams with momenta of **15 and 22 MeV/c** were used to generate radiation wavelengths of **100 µm and 20 µm**, respectively.
  - The results show that a radiation peak power of at least **90 MW** can be achieved within an undulator length of **6 m**.

In order to demonstrate that such electron beams with the required parameters for SASE FEL radiation can be obtained from the PITZ accelerator, experimental optimization and characterization of electron beams with bunch charges of 4 nC for such purpose were performed.



Layout of the PITZ beamline including extension for an IR/THz FEL for simulation studies. Here QM, DM and screen represent quadrupole magnets, dipole magnets and screen stations for monitoring of beam transverse profiles, respectively. The numbers represent the distance from the photocathode location (Z = 0).

Optimization and Characterization of 4 nC Electron Beams

Optimization of Transverse Projected Emittance

Machine and electron beam parameters

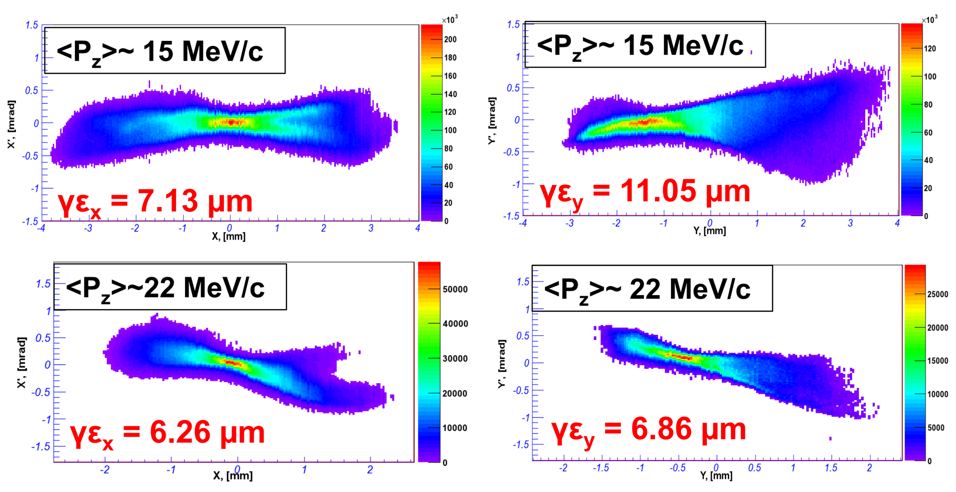
Parameters	Values
Photocathode laser pulse duration	11 ps FWHM (Gaussian shape)
Photocathode laser diameter on the cathode	3.7 mm
Peak E-field in the gun	60.5 MV/m
Peak E-field in the booster	9.8 and 17.2 MV/m
Bunch charge	4 nC
$\langle P_z \rangle$ after the gun	6.5 MeV/c
$\langle P_z \rangle$ after the booster	15 and 22 MeV/c

The transverse projected emittance is measured using **the single slit-scan technique**. Slit masks with an opening gap of 10 µm and a beamlet collecting screen locate at Z = 5.28 m and Z = 8.41 m, respectively.

Optimization procedure:
- *1st step*, measure emittance as a function of the main solenoid current. Then, fix it to the value that delivers the smallest emittance.
- *2nd step*, use the quadrupole magnets installed at the gun exit to symmetrize the optimized horizontal and vertical emittances from 1st step.

Optimized transverse normalized projected emittance of the 4 nC beams at Z = 5.28 m

	$\varepsilon_{n,x}$ [µm]	$\varepsilon_{n,y}$ [µm]
15 MeV/c ASTRA	4.92	4.92
15 MeV/c measurement	7.13	11.05
22 MeV/c ASTRA	4.44	4.44
22 MeV/c measurement	6.26	6.86

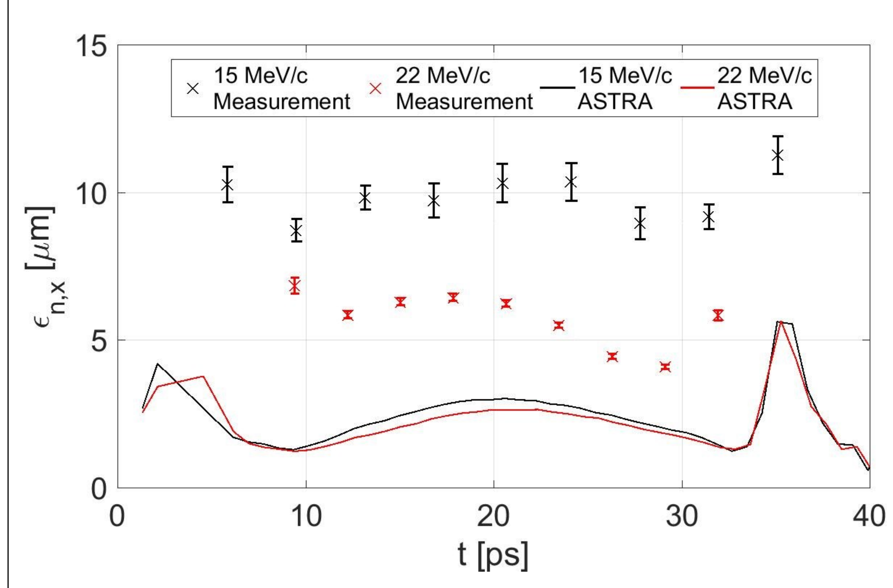


Measured optimized Horizontal phase spaces

Measured optimized Vertical phase spaces

Evaluation of Slice Emittance

Slice emittance is evaluated by using **the quadrupole scan technique**. The quadrupole doublet right before the TDS is used for the measurement. The experimental setup is similar to one used for the bunch current profile measurement. Linear transport matrix approach was applied to obtain slice emittance values. Note that space charge effects were not taken into account for the Twiss parameters determination.



Horizontal slice emittance of the optimized beams at Z = 5.28 m. The error bars only include statistical errors.

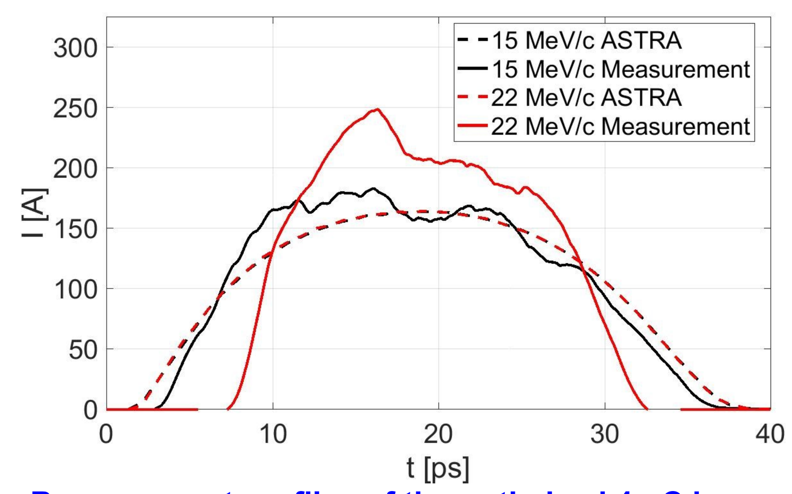
Causes of Uncertainty and Discrepancy

- **Space charge effects are neglected** in the slice emittance reconstruction from the quadrupole scan.
- **X-y coupling** in the experiments.
- **Mechanisms of the space charge dominated photoemission** are more complex than those implemented in the ASTRA code.
- **The asymmetry kick** in the gun region is not fully compensated by the gun quadrupole magnets.

Current Profile Measurement

The current profiles of the optimized beam are measured by using the TDS. The screen located at Z = 13.04 m is used for monitoring the streaked beam.

The measured current profiles and those from the ASTRA simulations are presented in figure on the right hand side. Both simulation profiles show peak current of about **160 A** and bunch duration of about **25 ps FWHM**. The measured profile of 15 MeV/c case is quite close to the one from the simulation while the measured profile of the 22 MeV/c case is a bit shorter than the others. The reason of this difference is still not fully understood and under investigation.



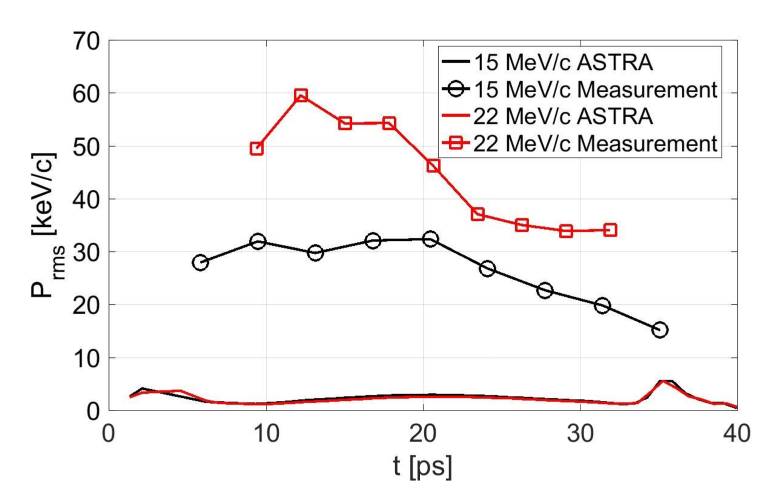
Beam current profiles of the optimized 4 nC beams. Note that the profiles from ASTRA are for the beams at Z = 5.28 m.

Evaluation of Slice Momentum Spread

The longitudinal phase space is measured by transporting the streaked beam from the TDS downstream to HEDA2. By using the TDS together with the first dipole magnet, the current profile and the momentum distribution of the beam can be shown simultaneously on the first monitoring screen in HEDA2. Then the slice momentum spread can be derived from the measured LPS.

Causes of Uncertainty and Discrepancy

- The values of beam projected emittance **limit transverse focusability** of the beams and therefore the minimum achievable measured momentum resolution.
- Imperfections of the beam transport could cause **beam dispersions** and spoil the beam momentum spread.
- **TDS induced energy spread** can also contribute to the discrepancy



Slice momentum spread profiles of the 4 nC beams. Note that the profiles from ASTRA are for the beams at Z = 5.28 m.

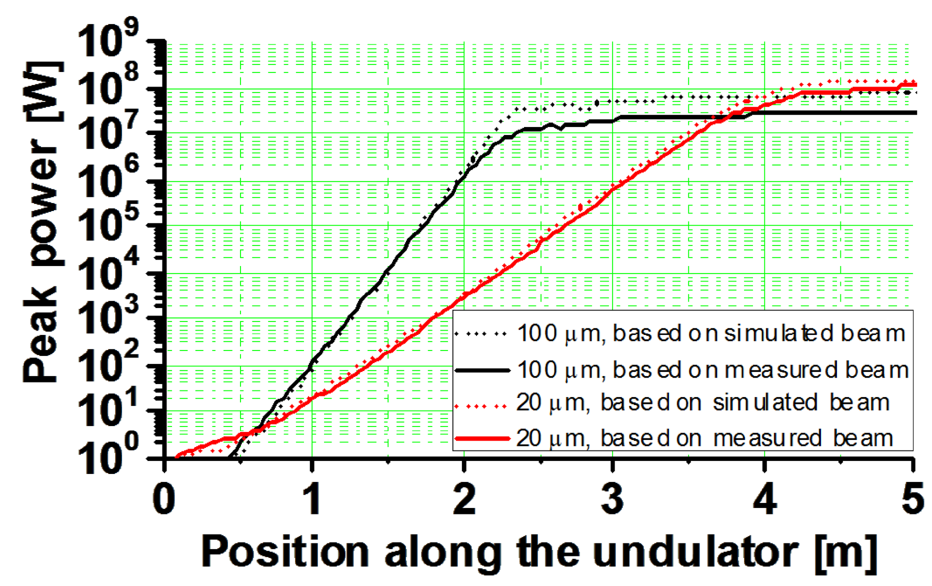
SASE FEL Calculation

The GENESIS 1.3 code is used for simulations of the SASE FEL radiation. An APPLE-II undulator in helical with period length of 40 mm is used as the radiator. The simulations were performed for two cases:
- 20 µm using 22 MeV/c beam
- 100 µm using 15 MeV/c beam

We assumed that the measured and simulated beam profiles from previous sections are those at the undulator entrance. The Twiss parameters of the beams were assumed to be matched for beam transport along the undulator.

Simulated FEL saturation power, saturation length and pulse energy

	P_{sat} [MW]	L_{sat} [m]	E_{sat} [µJ]
100 µm, based on Simulated beam	67	3.74	650
100 µm, based on measured beam	29	4.16	390
20 µm, based on Simulated beam	143	4.60	570
20 µm, based on Measured beam	101	4.92	480



Simulated FEL peak powers along the undulator axis.

prach.boonpornprasert@desy.de
mikhail.krasilnikov@desy.de
frank.stephan@desy.de