Case Study of IR/THz source for Pump-Probe Experiment at the European XFEL

# Simulations of the IR/THz Options at PITZ (High-gain FEL and CTR)

## Outline

- Introduction
- Simulations of High-gain FEL (SASE)
- Simulation of CTR
- Summary & Outlook

Prach Boonpornprasert

$7^{th}$ Market of Accelerator Ideas
DESY, Hamburg
1.09.2015

HELMHOLTZ ASSOCIATION

PITZ Photo Injector Test Facility Zeuthen

DESY

**Photo Injector Test Facility at DESY, Zeuthen site (PITZ)**

Considering

**Development of "Intense and wide-wavelength-range" IR/THz source at PITZ**

Motivations & Goals

European - XFEL — X-ray

PITZ-like — IR/THz

Pump & Probe experiment

**PITZ is an ideal machine for development of the prototype IR/THz source**

(Reference: E.A.Schneidmiller et al., WEPD55, FEL2012 conf.)

- Photon diagnostics
- Radiation based e-bunch diagnostics
- Service for light users

**Case studies of radiation generation produced by the PITZ electron beam**

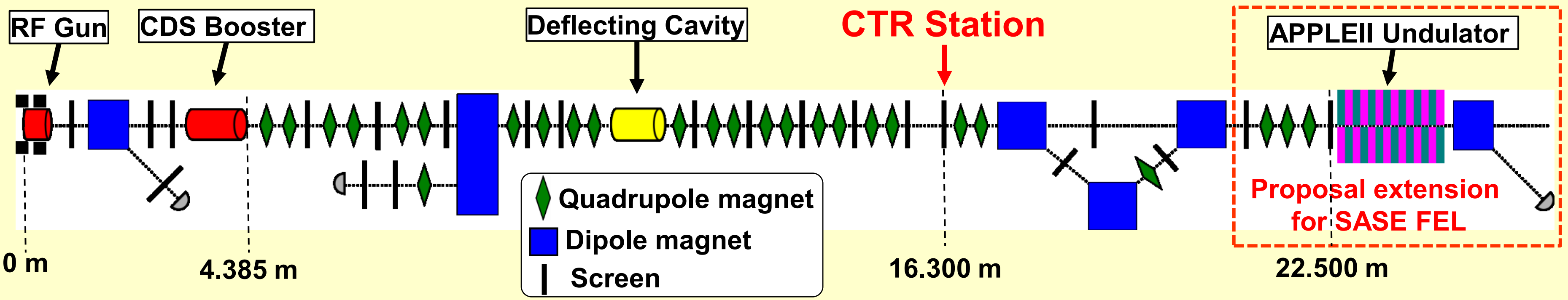
- SASE FEL
- Coherent Transition Radiation (CTR)

**Works in This Presentation**

Preliminary Start-to-End (S2E) simulations for SASE FEL and CTR

# PITZ Beamline Overview






PITZ Beamline layout including radiation stations for simulation studies

- Photocathode RF Gun
- Cut Disk Structure (CDS) Booster
- UV photocathode laser
  - Cylindrical pulse shape (Gaussian, flat-top).
  - 3D-ellipsoidal pulse shape
- Electron beam diagnostics stations
- **Radiation stations for simulations studies**
  - **CTR station**
  - **Extension for SASE FEL**

| Key Parameters | |
|---|---|
| **Laser temporal length** | **2 - 20 ps FWHM** |
| **Bunch charge** | **few pC … 4 nC** |
| **Maximum mean momentum $<P_z>$** | **~22 MeV/c** |

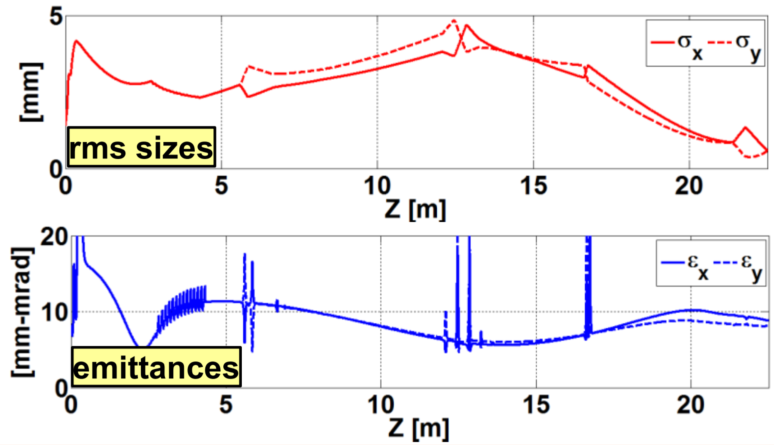
# SASE FEL: Beam Dynamics Simulations



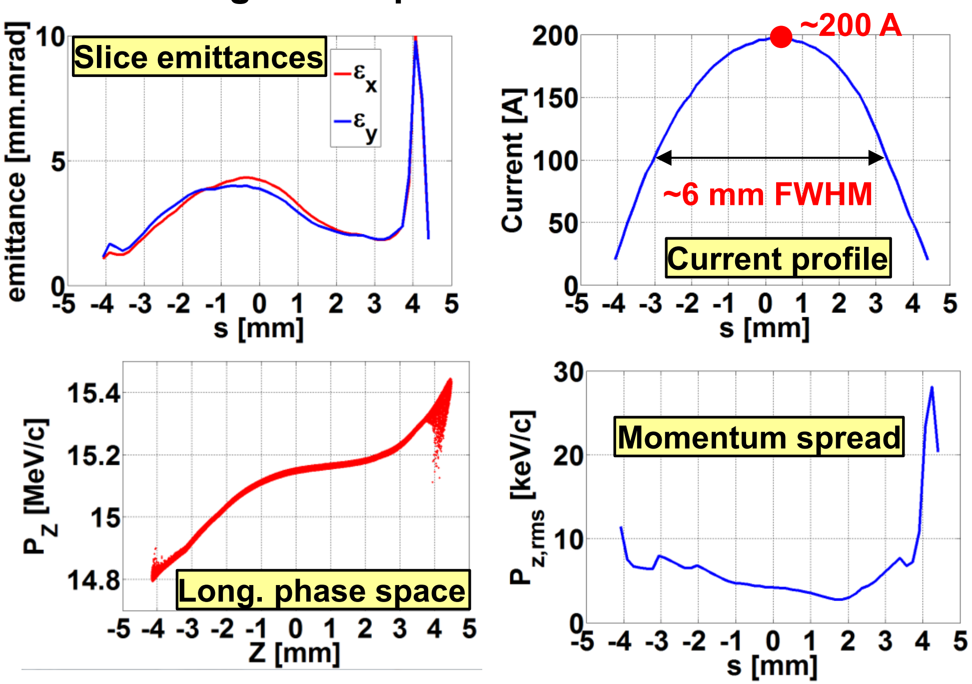
- **Simulation Tool: ASTRA code**
- **Goals of the beam transport:**
  - **$\langle P_z \rangle$ ~ 15 MeV/c** at the undulator entrance
  - Symmetric transverse beam sizes and emittances at the undulator entrance

| Input for ASTRA | |
|---|---|
| **Laser pulse shape** | Flattop |
| **Laser temporal length** | 20 ps FWHM |
| **Rms laser spot size** | 1.25 mm |
| **Bunch charge** | 4 nC |
| **$Z_{start}$ to $Z_{end}$** | 0 (cathode) to 22.500 m |
| **Gun peak E-field** | 60 MV/m |
| **Booster peak E-field** | 10 MV/m<br>**(for $\langle P_z \rangle$ ~ 15 MeV/c)** |
| **Gun phase** | Optimized for:<br>***High peak current***<br>***Low energy spread*** |
| **Booster phase** | |
| **Solenoid fields** | |

**Evolutions of transverse beam sizes and emittances**




**The longitudinal profiles at undulator entrance**

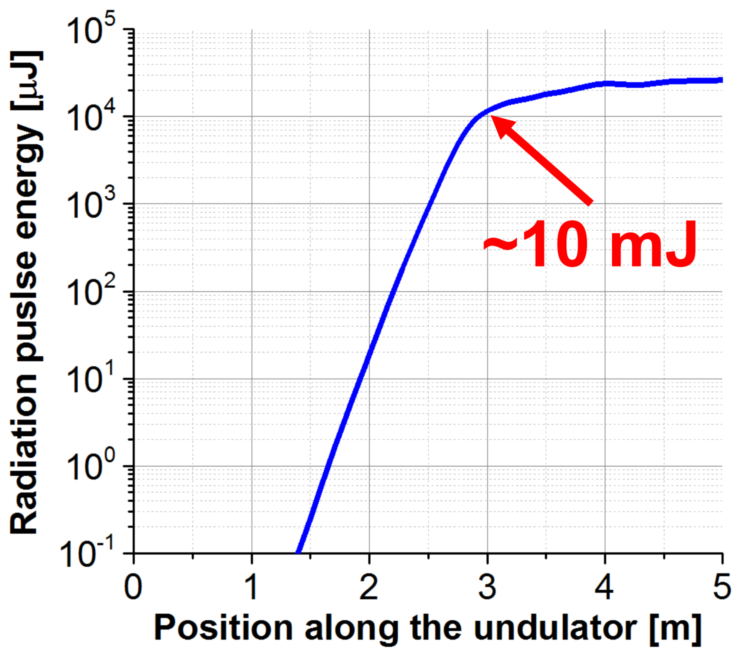


# SASE FEL: Radiation Calculations

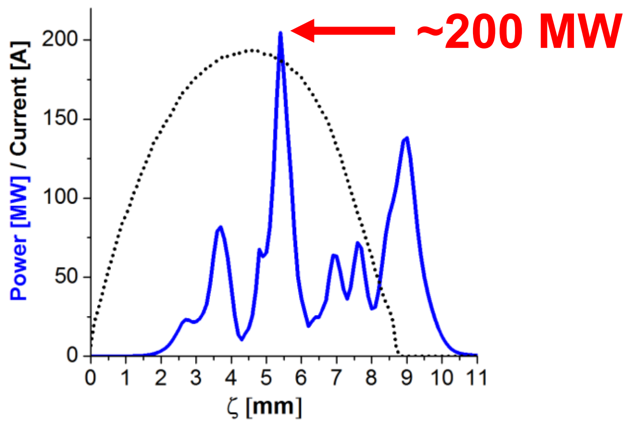


- **GENESIS 1.3 code (Version 2) was used for numerical calculations of SASE FEL**
- **Input for GENESIS:**
  - Time-dependent mode, space-charge effect included.
  - Helical undulator with **period length of 40 mm**
  - SASE FEL, **Radiation wavelength of 100 µm (3 THz)**

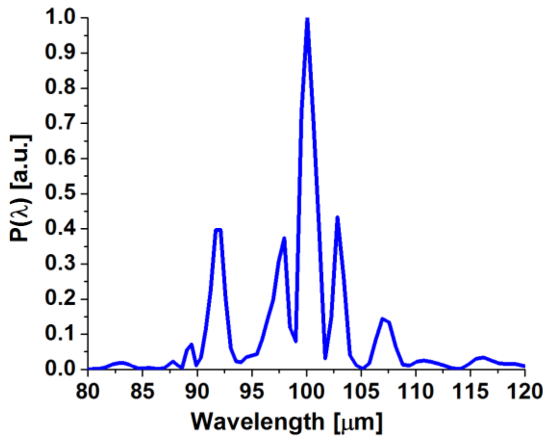
**Energy in the radiation pulse as a function of Undulator length**




**Temporal profile of radiation pulse at the saturation**




**Spectral profile of radiation pulse at the saturation**



# CTR: Beam Dynamics Simulations

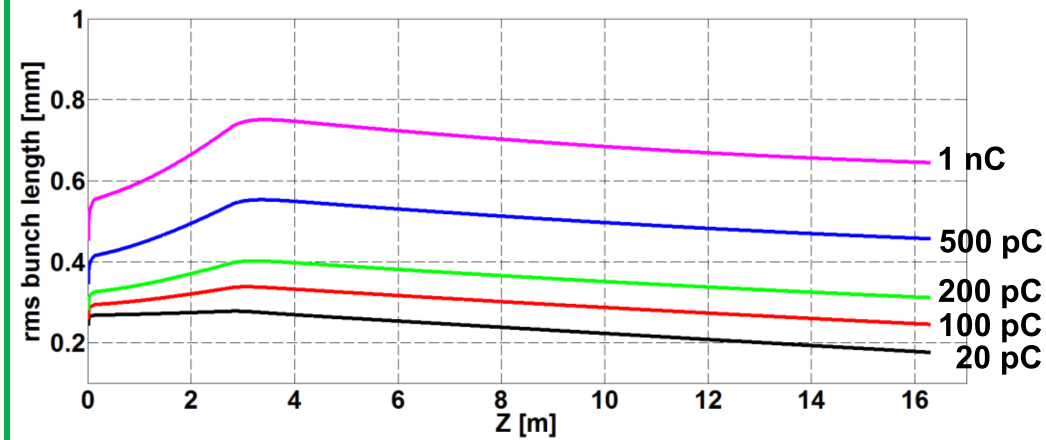


- **Simulation Tool: ASTRA code**
- **The bunch compressed by velocity bunching in the booster.**
- **Minimum <$P_z$> is limited to ~15 MeV/c to prevent too big emission angle (θ α 1/γ)**

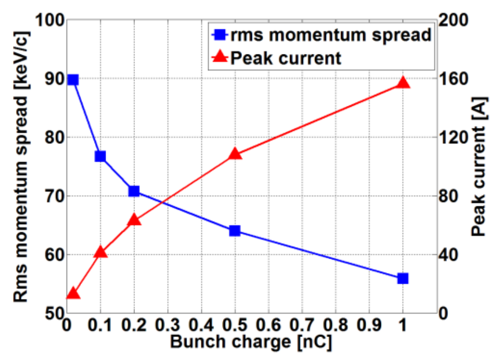
| Input Parameters for ASTRA | |
|---|---|
| Laser pulse shape | Gaussian |
| Laser temporal time | 2.43 ps (FWHM) |
| Rms laser spot size | 1 mm |
| Bunch charge | 20 pC to 1 nC |
| $Z_{start}$ to $Z_{end}$ | 0 (cathode) to 16.30 m |
| Gun peak field | 60 MV/m |
| Booster peak field | 18 MV/m |
| Gun phase* | 0° |
| Booster phase* | -60° |

*with respect to maximum momentum gain phase

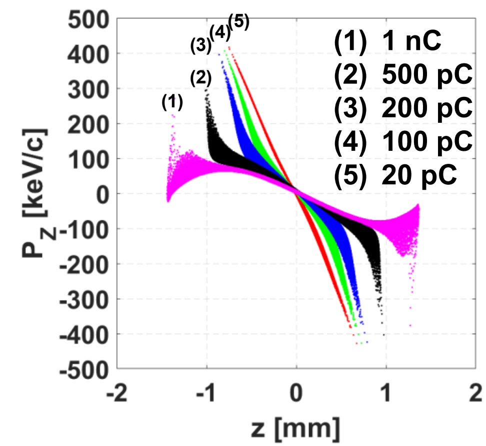
## Evolutions of simulated rms bunch length




## Rms momentum spread and peak current VS bunch charges at the CTR station




## Long. phase spaces at the CTR station

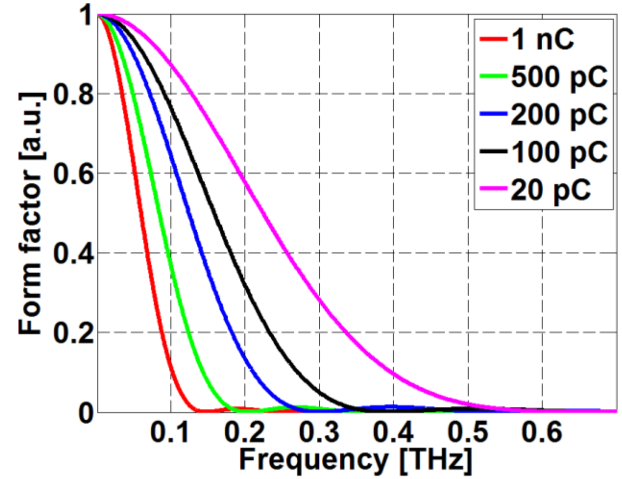


# CTR: Radiation Calculations

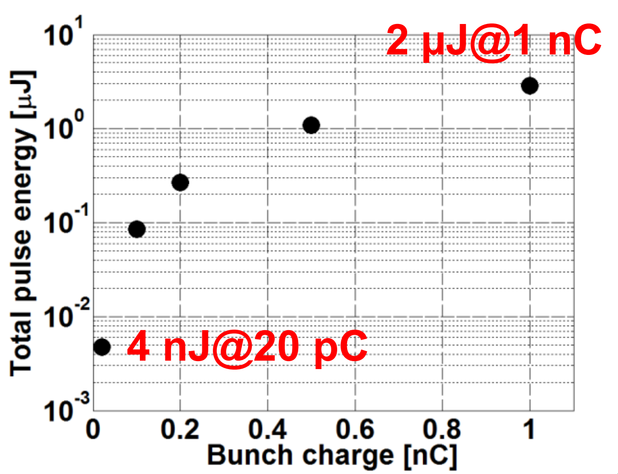


- **CTR calculations were performed by using Generalized Ginzburg-Frank Formula** [Casalbuoni et al., TESLA 2005-15].
- **Assumptions and input:**
  - Perfect conductor and **circular screen with radius of 15 mm.**
  - Backward radiation, far-field regime calculation
  - **E-beam with radius of 0.5 mm** is normal incident to the screen.

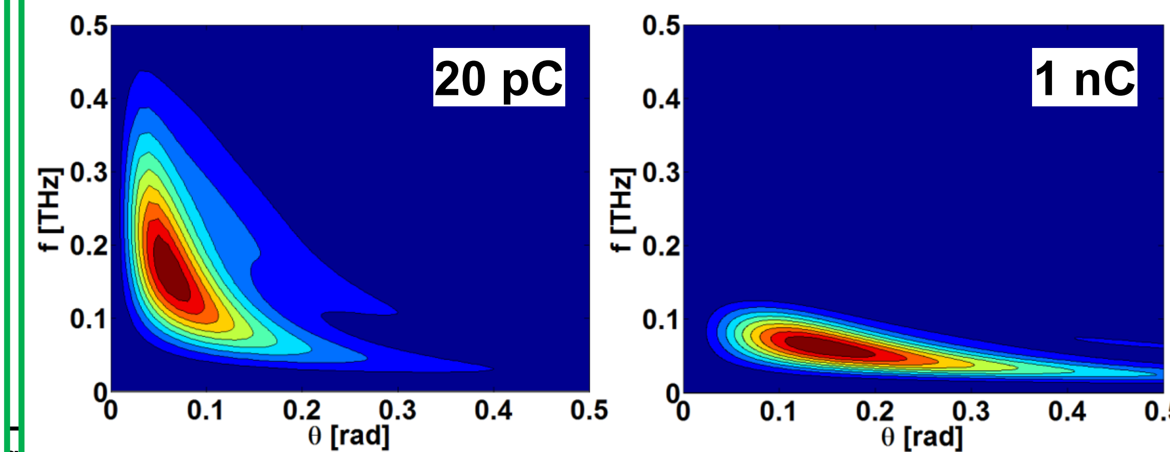
**Form factors of the compressed bunch at the CTR station**




**Total radiation energy VS bunch charge**




**Normalized radiation energy VS frequency (f) and the emission angle (θ)**



# Summary

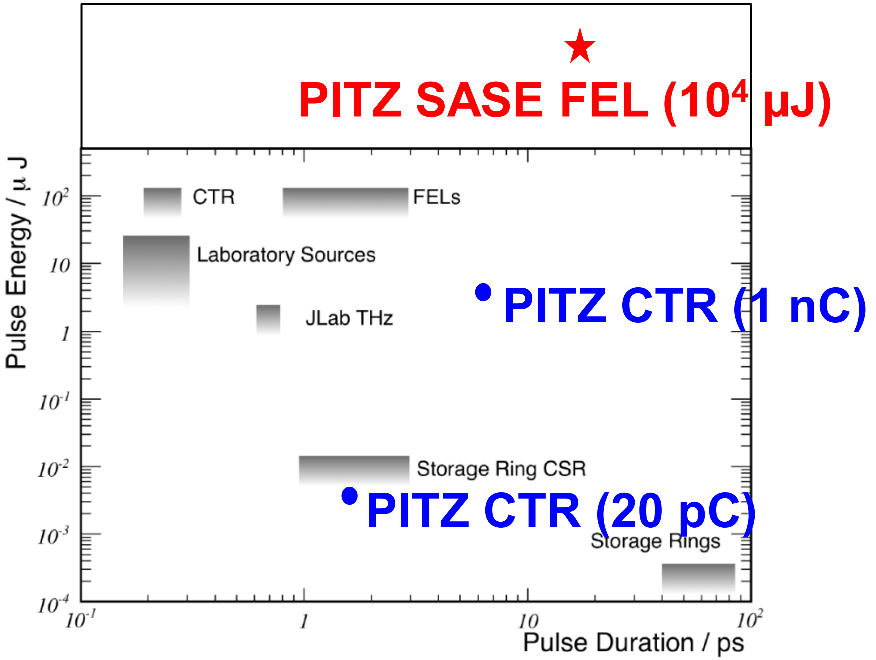


- Preliminary S2E simulations for the SASE FEL and the CTR using the PITZ accelerator were studied.

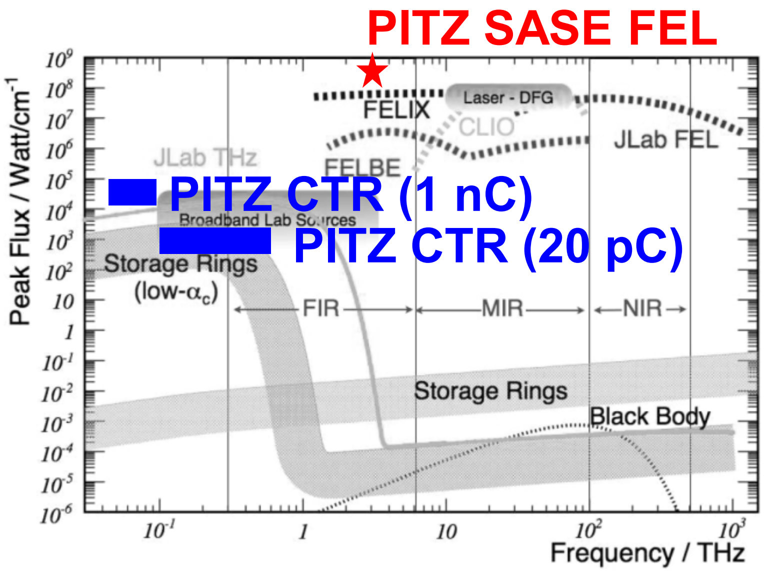
**Comparison to the other IR/THz sources**

**(the radiations from the PITZ source are just estimation)**

**Pulse energy VS FWHM of the generating bunch for the various sources**




**Spectral peak power density VS frequency**




**Reference: Anke-Susanne Müller, Rev. Accl. Sci. Tech., 03, 165 (2010)**

# Outlook



- **Tbe implemented in the simulations studies:**
  - **SASE FEL:** Planar undulator
  - **CTR:** an oblique screen, near-field regime
  - Bunch compression using the HEDA2 section
  - Radiation transport
- **The CTR experiment is foreseen to take place in 2016**
- **We are seeking for:**
  - Planar/helical undulator with period length of **~40 mm** and K **~ 1-2**
  - Bunch compressor

# Acknowledgement



## PITZ Team


- M. Yurkov, Y. Schneidmiller, B. Marchetti — **DESY, Hamburg**
- C. Thongbai, S. Rimjaem — **CMU, Thailand**

**Thank you for your attentions!**