Update on THz studies at PITZ

*Tunable IR/THz source based on PITZ-like accelerator for pump probe experiments at the European XFEL*

Mikhail Krasilnikov and Prach Boonpornprasert (DESY) for the PITZ Team
H2020 LUSIA project meeting, 27.11.2017, Szentágothai Research Centre, Pécs, Hungary

Outline:
- PITZ Introduction
- PITZ based THz source for p&p experiments
  - CTR/CDR (+recent experiments)
  - SASE FEL
  - Other options (seeding, single cycle)
- Conclusions and outlook
PITZ focuses on the development, test and optimization of high brightness e-sources for SC linac driven FELs:

⇒ test-bed for FEL injectors: FLASH, the European XFEL (conditioning and characterization of gun cavities and photo injector subsystems, e.g. photocathode laser)

⇒ high brightness → small $\varepsilon_{tr}$ (projected and slice)

⇒ further studies → e.g. cathodes: dark current, photoemission, QE, thermal emittance, …

⇒ currently highest priority at PITZ → participate in the solution of the remaining problems of the RF gun for EXFEL (long term reliability and stability, RF windows, cathode RF contact spring)
PITZ “engine”: RF-Gun and Photocathode (PC) Laser

RF gun
- L-band (1.3 GHz) 1.6-cell copper cavity
- Ecath $>\sim$60MV/m $\rightarrow$ 7MeV/c e-beams
- 650us x 10Hz $\rightarrow$ up to 45 kW av. RF power
- Cs$_2$Te PC (QE $\sim$5-10%) $\rightarrow$ up to 5nC/bunch
- LLRF control for amp&phase stability
- Solenoid for emittance compensation

Pulse Train Time Structure:
PITZ and EXFEL trains with up to 600 (2700) laser pulses

Photocathode laser(s) (UV)

Default PC laser system
(Max-Born-Institute, Berlin)

Gaussian:
- FWHM $\sim$ 2 ps
- FWHM $\sim$ 7 ps
- FWHM $\sim$ 11 ps
- FWHM $\sim$ 17 ps

Multicrystal birefringent pulse shaper containing 13 crystals

Simulated pulse-stacker
- FWHM $\sim$ 20 ps
- FWHM $\sim$ 24 ps
- FWHM $\sim$ 24 ps

Flattop

Cathode laser pulse: temporal profile

3D (ellipsoidal) pulse shaper:
- SLM based
- Upgrade with VBG

Oscillator upgrade – Pharos-20W-1MHz frontend
Pulse length 0.25-10ps+

Different lasers
- various THz options
- possibility of simultaneous usage

New PC laser ELLA

Institute of Applied Physics of the Russian Academy of Sciences

Institute of Applied Physics of the Russian Academy of Sciences
### PITZ evolution 2000-2017

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</tr>
</thead>
<tbody>
<tr>
<td>cavity</td>
<td>gun-2</td>
<td>gun-1</td>
<td>gun-3.1</td>
<td>g-3.2</td>
<td>gun-4.2</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Ez,MV/m</td>
<td>35</td>
<td>37</td>
<td>42--&gt;60</td>
<td>43</td>
<td>60</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td></td>
</tr>
<tr>
<td>Ebeam</td>
<td>~4MeV</td>
<td>4.3MeV---&gt;6MeV</td>
<td>4.5MeV</td>
<td>~6.5MeV</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
</tbody>
</table>

**Highlights:**
- Increasing the brightness (decreasing the emittance)
- Improving gun stability and reliability
- Extending beam diagnostics
- Use high brightness beam capability
Motivation for accelerator based tunable IR/THz source for pump probe experiments at the European XFEL

### Requirements to the pump source

**General:**
- **Time structure** of IR/THz source → time structure of x-ray pulses
- IR/THz source should have wide **tunability** range
- IR/THz source → wide possibilities for generation of different temporal and spectral patterns, **polarization**. (i.e. strong single-cycle pulses, narrow band radiation)
- Many applications require high peak power (field strength) or **high pulse energy**.
- **Time jitter** of pump and probe pulses should be small enough for resolving time-dependent phenomena

### Specific for the European XFEL:

- EXFEL → burst mode: 10Hz x 0.6 ms x 4.5 MHz = 27000 pulses per sec
- Current **range** of interest:

<table>
<thead>
<tr>
<th>λ, μm</th>
<th>from</th>
<th>to</th>
</tr>
</thead>
<tbody>
<tr>
<td>f, THz</td>
<td>50 - 15</td>
<td>3 - 0.3</td>
</tr>
<tr>
<td>hν, meV</td>
<td>207 - 62</td>
<td>12.4 - 1.24</td>
</tr>
</tbody>
</table>

- **Pulse energy spans** a lot: μJ → hundreds of μJ → mJ
- **Time jitter**: 2 types of experiments:
  - **field** driven dynamics where temporal resolution ~few fs → **CEP stability**
  - "intensity" driven dynamics where temporal resolution ~longest pulse duration (e.g. if THz pulse is 3 ps than the timing only need to be 3 ps).

### Generation of IR/THz radiation by relativistic electron beams

**Attractive features are:**
- clean in-vacuum radiation production
- **tunability** of radiation with e.g. electron beam manipulation
- potential to provide **high power** (high field)
- **polarization** control

**Methods of generation:**
- radiation in a **bend** magnet
- **undulator** radiation
- **transition** radiation (i.e., crossing metallic foil)
- **diffraction** radiation (i.e. passing through an aperture)
- …
Accelerator based tunable IR/THz source: PITZ as a prototype?

- Accelerator based IR/THz source meets all requirements for pump-probe experiments
- Construction of a radiation shielded annex (like present PITZ facility) is possible close to user experiments at the European XFEL
- Prototype of the accelerator already exists – it is PITZ facility at DESY in Zeuthen
- Can be excellent investment of efforts of accelerator consortium after finishing construction and commissioning phases of the European XFEL

PITZ can serve as prototype for such a development
Case studies of THz radiation generation produced by the PITZ electron beam

► Coherent Transition Radiation (CTR) for $\lambda_{rad} \geq 100 \mu m \ (f \leq 3 \ THz)$

PITZ beamline layout including extension for simulation studies

PITZ Highlights:
• Pulse train structure
• High charge feasibility (4 nC)
• Advanced PC laser shaping
• E-beam diagnostics
• Available tunnel annex
• ...

Current PITZ “boundary conditions”:
• 22-25 MeV/c max
• No bunch compressor
• ...

PST.Scr2 will be modified to be a CTR/CDR station

Proposal extension for: SASE FEL

► SASE FEL for $\lambda_{rad} \leq 100 \mu m \ (f \geq 3 \ THz)$
Experimental tests with electron beams for CTR option at PITZ

\[ \frac{d^2U_{\text{bunch}}}{d\omega d\Omega} \propto N^2 |F_{\text{long}}(\omega)|^2; \quad F_{\text{long}}(\omega) = \int_{-\infty}^{+\infty} \rho_{\text{long}}(t)e^{-i\omega t} dt \Rightarrow T_{\text{bunch}} \ll 1/f \Rightarrow \text{short bunches for CTR!} \]

### CTR Calculations from simulated Velocity Bunching at PITZ

- **ASTRA simulations with short Gaussian photocathode laser and CDS booster -60deg off-crest**
- **Total CTR radiation energy, \(I_{\text{peak}}\) and \(P_{z,\text{rms}}\) vs bunch charge**
- **Form factors of the compressed bunch at the CTR station (z=16m)**

#### Experiments on velocity bunching with short Gaussian PC laser pulses

- **Measured electron bunch length**
  - BSA=beam shaping aperture (laser Ø)
- **Measured bunch current profiles**
- **Calculated form-factors**

*P. Boonpornprasert*
Experimental tests with electron beams for CTR option at PITZ

Experimental Optimization of Comb-beams

Examples of measured comb-beam profiles with various bunch charges and booster phases

![Graph showing measured beam profiles with various charges and phases.](image)

Corresponding form factors

![Graph showing form factors for different charges.](image)

Design of CTR/CDR Station

- PST.Scr2 → CTR station
- THz radiation diagnostics system → tunnel
- The system will be used to measure THz radiation:
  - energy/power
  - spatial profile
  - polarization
  - spectrum (Michaelson interferometer)
- The detectors are pyroelectric detector and THz camera with minimum response speed of 10 Hz
- 1st experiments → Autumn 2017

P. Boonpornprasert
Measurements of THz Coherent Transition Radiation (CTR)

- PST.Scr2 was modified to be a CTR station.
  - The radiator is an Al-sheet with dimensions of 27mm x 55 mm x 1 mm.
  - The vacuum window is made of Z-cut crystal quartz.

- The radiation measurement system was set up beside the CTR station to measure the “backward” transition radiation in normal room environment.
  - A THz pyroelectric detector was used for radiation pulse energy measurement.
  - The spectral distributions were measured by the setup of a Michelson interferometer.
### Examples of THz CTR Measurement Results

<table>
<thead>
<tr>
<th>photocathode laser shape</th>
<th>Short Gaussian</th>
<th>Comb with 4 uniform peaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser $t_{\text{FWHM}}$</td>
<td>~ 2.5 ps</td>
<td>?</td>
</tr>
<tr>
<td>Bunch charge</td>
<td>1 nC</td>
<td>1 nC</td>
</tr>
<tr>
<td>Bunch compression</td>
<td>$\Phi_{\text{booster}}$ off-crest for -80°</td>
<td>-</td>
</tr>
<tr>
<td>Average CTR pulse energy</td>
<td>1.972 µJ</td>
<td>0.164 µJ</td>
</tr>
</tbody>
</table>

**Interferograms obtained from the Michelson interferometer**

**Beam current profiles measured by TDS**

- Resolution ~3.4 ps
- Resolution ~5.8 ps

**Spectral distributions obtained from the Michelson interferometer**

*P. Boonpornprasert*
IR/THz Options at PITZ (High-gain FEL and CTR)

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

► Coherent Transition Radiation (CTR) for $\lambda_{\text{rad}} \geq 100 \, \mu\text{m} \ (f \leq 3 \, \text{THz})$

► SASE FEL for $\lambda_{\text{rad}} \leq 100 \, \mu\text{m} \ (f \geq 3 \, \text{THz})$

PITZ Highlights:
- Pulse train structure
- High charge feasibility (4 nC)
- Advanced PC laser shaping
- E-beam diagnostics
- Available tunnel annex
- ...

Current PITZ “boundary conditions”:
- 22-25 MeV/c max
- No bunch compressor
- ...
THz SASE FEL at PITZ: Undulator and beam parameter space

APPLE- II Undulator*

Radiation wavelength

\[ \lambda_{\text{rad}} = \frac{\lambda_u}{2y^2} \left( 1 + \frac{K^2}{2} \right) \]

\[ K = 0.934 \cdot B_0[\text{T}] \cdot \lambda_u[\text{cm}] \]

\[ B_0 = 1.54e^{-4.46(\frac{\text{cm}}{\lambda_u})+0.43(\frac{\text{cm}}{\lambda_u})^2} \]

Conditions:
- \( \lambda_{\text{rad}} \) of 20 – 100 µm
- Max \( P_z \sim 22 \text{ MeV/c} \)
- gap \( g \geq 10 \text{ mm} \)

Selections:
- \( \lambda_u \) of 40 mm
  - \( 22 \text{ MeV/c} \) for 20 µm
  - \( 15 \text{ MeV/c} \) for 100 µm

FEL Parameter Space with FAST code (\( \lambda = 100 \mu\text{m} \))

SASE FEL simulations assuming:
- Helical undulator with period length of 40 mm
- Electron beam with 15 MeV/c momentum, 4 nC bunch charge, ~2 mm rms bunch length

Preliminary conclusions:
- Transverse normalized emittance \( \varepsilon_n \) has almost no impact on saturation power
- Higher \( \varepsilon_n \) → lower saturation length
- Beam peak current (charge) → most impact

*Conceptual Design Report ST/F-TN-07/12, Fermi@Elettra, 2007

Courtesy M. Yurkov


Also LCLS (old) undulator under consideration…
Simulation Tools:

- **ASTRA code** → goals of the beam transport (0→22.5m):
  - \(\langle P_z \rangle \sim 15\) MeV/c at the undulator entrance
  - Symmetric transverse beam sizes and emittances at the undulator entrance
  - Bunch charge 4 nC
  - PC laser: \(\varnothing 5\)mm, flattop 2/20\(\mu\)s
  - Gun and booster phases and main solenoid optimized for high \(I_{\text{peak}}\) and small \(\delta E\)

- **GENESIS 1.3 code (Version 2) for SASE FEL:**
  - Time-dependent mode, space-charge calculation included.
  - Helical undulator with \(\lambda_u=40\) mm
  - SASE FEL, \(\lambda_{\text{rad}}\sim100\) \(\mu\)m (3 THz)

- **Power and energy in the radiation pulse as a function of undulator length**

- **Temporal profile of radiation pulse**
  - \(I_{\text{peak}}\sim200\) A
  - \(E_{\text{pulse}}\sim3\) mJ
  - \(L_{\text{und}}\sim5\) m
  - BW\sim5-10\%

- **Spectral profile of radiation pulse**

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**P. Boonpornprasert**
Experimental Characterization of 4 nC Beams for THz SASE FEL Option

Calculation of SASE FEL for measured profiles

- Calculation of SASE FEL for measured profiles
- \( \lambda_{rad} = 100 \mu m \)

<table>
<thead>
<tr>
<th>#</th>
<th>Photocathode laser pulse</th>
<th>Procedure</th>
<th>THz pulse energy (z=5m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Start-to-End (S2E) simulations (ASTRA→GENESIS)</td>
<td>2.6 mJ</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ASTRA→GENESIS</td>
<td>0.9 mJ</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Measured (not optimized) electron beam → GENESIS</td>
<td>0.5 mJ</td>
<td></td>
</tr>
</tbody>
</table>
Options to improve THz radiation stability

> Pre-bunching → “Seeding”

- Photocathode laser pulse temporal modulation
- Using IR laser, modulator and BC for E or δE modulations
- Exchange transverse to longitudinal modulation
- Using CDR from short seeding bunch?
- Using corrugated structures
- Using Dielectric Lined Waveguides - DLW (first experiments)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe radius $a$, mm</td>
<td>2</td>
</tr>
<tr>
<td>Pipe length $l$, m</td>
<td>0.5-2</td>
</tr>
<tr>
<td>Corrugation depth $d$, mm</td>
<td>0.05</td>
</tr>
<tr>
<td>Corrugation period $p$, mm</td>
<td>0.04</td>
</tr>
<tr>
<td>Corrugation gap $g$, mm</td>
<td>0.02</td>
</tr>
<tr>
<td>Gaussian bunch rms $\sigma$, mm</td>
<td>0.1-0.3(*8)</td>
</tr>
</tbody>
</table>

$E_0 = 8$ MeV, $f \approx 0.33$ THz

$E_0 = 20$ MeV, $f \approx 0.3$ THz

I. Zagorodnov
First Experiments with DLW at PITZ

In collaboration with CFEL (F. Lemery) and APC FNAL (P. Piot)

F. Lemery et al., Experimental demonstration of ballistic bunching with dielectric-lined waveguides at PITZ, IPAC 2017, WEPAB122
Options to improve THz radiation stability

> Pre-bunching → “Seeding”

- Photocathode laser pulse temporal modulation
- Using IR laser, modulator and BC for $E$ or $\delta E$ modulations
- Exchange transverse to longitudinal modulation
- Using CDR from short seeding bunch?
- Using corrugated structures
- Using Dielectric Lined Waveguides - DLW (first experiments)
- ...

> Single cycle schemes (discussions with Uppsala and KEK ongoing)

- **Manipulated undulator radiation** (idea of Takashi Tanaka)
  
  
  coherent emission from a *chirped* microbunched beam passing through a strongly *tapered* undulator

- **With short IR laser**
  
  → Pécs University group (Hungary) simulations

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<table>
<thead>
<tr>
<th>Pipe radius $a$, mm</th>
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<tbody>
<tr>
<td>Pipe length $l$, m</td>
<td>0.5-3</td>
</tr>
<tr>
<td>Corrugation depth $d$, mm</td>
<td>0.05</td>
</tr>
<tr>
<td>Corrugation period $p$, mm</td>
<td>0.04</td>
</tr>
<tr>
<td>Corrugation gap $g$, mm</td>
<td>0.02</td>
</tr>
<tr>
<td>Gaussian bunch rms $\sigma$, mm</td>
<td>0.1-0.3(%)</td>
</tr>
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</table>
Idea: Accelerator based THz (1) & electron diffraction source (2) for XFEL users

Basic PITZ parameters:
- bunch length: sub ps to 22 ps
- bunch charge: sub pC to > 5 nC
- max Pz ~ 24 MeV/c
- pulse train structure similar to XFEL

(1) Linac based THz source
Attractive features:
- provides high power (high field)

(2) Femtosecond e⁻ diffraction
v.s. X-ray:
- sub-pm wavelength, good spatial resolution
- ~10⁶ higher scattering cross section, good for thin or low density sample

v.s. other MeV electron diffraction source:
- higher rep. rate & higher flux;
- trade flux for higher transverse coherence;

new methodology:
- XFEL pump, electron probe;

Possible options:
- Undulator → SASE THz FEL
- Other, e.g. transition, diffraction, synchrotron, edge radiation

Challenges:
- Phase locking (CEP stability) for field driven dynamics
- Short bunches (bunch compression) for single-cycle radiation

Current status:
- First electron beam measurements for SASE THz FEL option were done
- CTR experiment station is under realization
- Seeding options under study

H. Qian
Conclusions

> The Photo Injector Test facility at DESY in Zeuthen (PITZ) develops high brightness electron sources for SASE FELs:
  - specs for the European XFEL (nominal and startup) have been demonstrated and surpassed
  - beam emittance has also been optimized for a wide range of bunch charge (pC→nC)
  - now main focus → stability and reliability (high duty factor performance)

> PITZ highlights:
  - Pulse train structure → EXFEL
  - Advanced PC laser systems
  - High bunch charge (several nC) attainable
  - High stability achieved
  - Extensive beam diagnostics

> THz activities at PITZ (since 2012) → Tunable linac based IR/THz source
  - CTR/CDR with short/pre-bunched using velocity bunching (short Gaussian PC laser pulses + comb-like):
    → Estimations – E-beam measurements – calculations
    → CTR station installed
    → First measurements (pulse energy, interferograms, polarization)
  - THz SASE FEL with 4nC bunches:
    → Estimations → s2e simulations (3mJ@100um) → E-beam measurements → simulations
  - Other options:
    Seeding (PC laser modulation, DLW- first tests, corrugated pipe, etc) → under studies
    Single cycle THz production → under discussion in collaboration with Uppsala, KEK, Pécs University group
    Femtosecond e-diffraction

> Outlook
Outlook: Possible “PITHz” Layout

- “all options” included
- reduction in size and costs possible

Supplementary Systems and Infrastructure

- General: Radiation protection and personal IL
- Control system and DAQ

Water Cooling System

- Laser(s)
- UED
- CTR
- CDS-1
- CDS-2
- Matching
- Modulator
- BC
- TDS
- Undulator
- S-band Klystron
- Vacuum components supplies
- Magnets power supplies
- Electronics: e-beam diagnostics
- Electronics: THz diagnostics

Supplementary Systems and Infrastructure

Hardware costs: VERY rough estimations

Σ~15M€
Outlook: PITZ tunnel(s)
Single cycle schemes by seed (preliminary simulations from University of Pécs)

Assumed parameters of the two Seeds and Modulator

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Seed 1</th>
<th>Seed 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>λ₁</td>
<td>1000 um</td>
<td></td>
</tr>
<tr>
<td>f₁</td>
<td>0.3 THz</td>
<td></td>
</tr>
<tr>
<td>Waist (w₀)</td>
<td>2000 um</td>
<td></td>
</tr>
<tr>
<td>Rayleigh length</td>
<td>1.26 cm</td>
<td></td>
</tr>
<tr>
<td>Electric field</td>
<td>1 MV/cm</td>
<td>0.4 MV/cm</td>
</tr>
<tr>
<td>Power</td>
<td>83 MW</td>
<td>13.3 MW</td>
</tr>
<tr>
<td>(c₀ε₀E²πw₀²) / 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulse duration</td>
<td>~3.3 ps</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>~0.3 mJ</td>
<td>~0.04 mJ</td>
</tr>
<tr>
<td>K</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>λ₂</td>
<td>8.65 cm</td>
<td></td>
</tr>
<tr>
<td>L/λ₂</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Assumed parameters of the Radiator

<table>
<thead>
<tr>
<th>Radiation wavelength</th>
<th>100 um (3 THz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undulator parameter (K)</td>
<td>0.5</td>
</tr>
<tr>
<td>Radiator period length</td>
<td>39.27 cm</td>
</tr>
</tbody>
</table>

Results (calculated 8 m after the radiator undulator)

<table>
<thead>
<tr>
<th>Seed 1</th>
<th>Seed 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (1&lt;sup&gt;st&lt;/sup&gt; method):</td>
<td>73.4 nJ</td>
</tr>
<tr>
<td>Energy (2&lt;sup&gt;nd&lt;/sup&gt; method):</td>
<td>113.4 nJ</td>
</tr>
</tbody>
</table>

Courtesy Zoltan Tibai, University of Pécs, Hungary

Mikhail Krasilnikov (DESY) | Update on THz studies at PITZ | 27.11.2017 | Page 24
Experimental Characterization of 4 nC Beams for THz SASE FEL Option

<table>
<thead>
<tr>
<th>X-X'</th>
<th>~22 MeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.26 mm mrad</td>
<td></td>
</tr>
</tbody>
</table>

| Y-Y' |
| 6.86 mm mrad |

| t-P_z |
| 23 |
| 22.5 |
| 22 |
| 21.5 |

Slice Emittance

Slice Momentum Spread

Calculation of SASE FEL for measured profiles

\[ \lambda_{rad} = 20 \, \mu m \]

<table>
<thead>
<tr>
<th>#</th>
<th>Photocathode laser pulse</th>
<th>Procedure</th>
<th>THz pulse energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>11 ps, 7.7 mm</td>
<td>ASTRA → GENESIS</td>
<td>0.6 mJ</td>
</tr>
<tr>
<td>6</td>
<td>Measured electron beam → GENESIS</td>
<td>0.5 mJ</td>
<td></td>
</tr>
</tbody>
</table>
### Properties

<table>
<thead>
<tr>
<th>Details</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td><strong>FIXED gap planar hybrid undulators (NeFeB permanent magnets)</strong></td>
</tr>
<tr>
<td>Nominal gap</td>
<td>6.8 mm</td>
</tr>
<tr>
<td>K-value</td>
<td>3.51-3.47 (can be reduced to 2.25 by tuning in the magnet lab)</td>
</tr>
<tr>
<td>Support diameter</td>
<td>30 cm</td>
</tr>
<tr>
<td>Vacuum chamber size</td>
<td>X = 5 mm, y = 11 mm</td>
</tr>
<tr>
<td>Period length</td>
<td>30 mm</td>
</tr>
<tr>
<td>Poles</td>
<td>226 poles (= 113 periods?)</td>
</tr>
<tr>
<td>Total weight without vacuum chamber</td>
<td>1000 kg</td>
</tr>
</tbody>
</table>

### Input Parameters for GENESIS

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>U period length</td>
<td>30 mm</td>
</tr>
<tr>
<td>Number of periods</td>
<td>114<em>2 (for total length of 3.42</em>2 m)</td>
</tr>
<tr>
<td>K</td>
<td>3.49</td>
</tr>
</tbody>
</table>
| Radiation wavelength
  | 123.3 μm                     | 100 μm                     | 57.35 μm                     |
| Beam momentum                   | 15 MeV/c                   | 16.85 MeV/c                | 22 MeV/c                    |
| GAMMA                           | 29.37                      | 32.8                       | 43.06                       |
| DELGAM                          | 0.5%                       |
| Xrms                            | 0.5 mm                     |
| γrms                            | ~0.71 mm (BetaX ~)         |
| Nor. EmitX                      | 2.10e-6 m                  | 2.33e-6 m                  | 3.08e-6 m                   |
| Nor. EmitY                      | 2.10e-6 m                  | 2.33e-6 m                  | 3.08e-6 m                   |
| AlphaX                          | -1                         |
| AlphaY                          | 1                          |
| Zrms                            | 2.34 mm                    |
| Ipeak                           | 200 A                      |

### Diagrams

- Peak power vs. Z (m)
- Pulse Energy vs. Z (m)
- Power vs. Time (μs)
- Normalized Intensity vs. λ (μm)