Photo Injector Test Facility at DESY, Location Zeuthen (PITZ)
Ye Chen for the PITZ team, Würzburg, Germany, 19.03.2018
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An apology to the colleagues who are not included in this photo!

This talk is based on contributions from all members of the PITZ Group.
Photo Injector Test facility at DESY, Zeuthen site (PITZ)

- The Photo Injector Test facility at DESY in Zeuthen (PITZ) focuses on the development, test and optimization of high brightness electron sources for superconducting linac driven SASE FELs:

  - test-bed for FEL injectors: FLASH, the European XFEL
  - high brightness $\rightarrow$ small $\epsilon_r$ $\rightarrow$ emittance optimization
  - fundamental research in photo injector physics $\rightarrow$ cathode, photoemission, thermal emittance, etc.
  - applications of high brightness beam $\rightarrow$ high repetition rate THz source, beam-driven plasma acceleration, etc.

Detailed description of the PITZ facility and research activities:

The PITZ RF Gun and Photocathode (UV) Laser

- L-band (1.3 GHz) 1.6-cell copper cavity
- $E_{\text{cat}} \sim 60$ MV/m
- $650 \mu$s $\times$ 10Hz
- Cs$_2$Te photocathode (QE~5-10%) $\rightarrow$ up to 5nC/bunch
- LLRF control for amplitude & phase stability
- Solenoid for emittance compensation
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Trains with up to 600 (2700) laser pulses

Flattop

Gaussian:

Cathode laser pulse: temporal profile

Default PC laser system (Max-Born-Institute, Berlin)
The PITZ RF Gun and Photocathode (UV) Laser

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Collaboration with MBI
### PITZ Evolution 2000-2017

**Highlights of the Evolution:**
- Increasing the brightness (decreasing the emittance)
- Improving gun stability and reliability
- Extending beam diagnostics
- Use high brightness beam capability
Improving Projected Transverse Emittance and Slice Emittance by cathode laser pulse (quasi-ellipsoidal) shaping

\[ \varepsilon_n = \sqrt{\varepsilon_{th}^2 + \varepsilon_{sc}^2 + \varepsilon_{rf}^2 + \varepsilon_{mp}^2 + \varepsilon_{Bz}^2 + 2\eta \varepsilon_{sc} \varepsilon_{rf}} \]

→Optimization of the cathode laser pulse shape in order to minimize the impact of the space charge on the transverse emittance

\( \varepsilon_{th} \): thermal, \( \varepsilon_{sc} \): space charge, \( \varepsilon_{rf} \): RF, 
\( \varepsilon_{mp} \): multipole, \( \varepsilon_{Bz} \): solenoid, \( \eta \): coupling
Improving Projected Transverse Emittance and Slice Emittance (cont'd)

by cathode laser pulse (quasi-ellipsoidal) shaping

Transverse phase spaces at z=5.74m

- Gaussian
- Flat-top
- 3D Ellipsoid

Spatial Light Modulator (SLM) shaper
Collaboration with IAP, JINR

Laser shaping simulation

IR cross correlation measurements

- ~no beam halo $\rightarrow$ better signal/noise, reduced radiation damage
- ~pure sinusoidal longitudinal phase space $+3^{rd}$ harm. $\rightarrow$ simplify/allow required compression
- less sensitive to machine settings $\rightarrow$ higher stability
Beam Asymmetry Compensation

For improving transverse beam profile and phase space

- Demonstration for a 500 pC bunch of 22 MeV/c

Guan quadrupoles off

Guan quadrupoles on

- Gun quads compensate rotational asymmetry of gun RF field and solenoid field, improve both beam symmetry and emittance.
- Three copies are installed at PITZ, XFEL, FLASH

On RF coupler: Proc. FEL 2017, WEP005
On gun quads: Proc. FEL 2017, WEP007
On quadrupole field error: Proc. FEL 2017, WEP010
Photoemission Modeling

For cathode brightness optimization and slice emittance formation modeling

- Photoemission beyond linear region is not well simulated.
- Short Gaussian laser case is improved using Core + Halo model.
- For long laser pulses more relevant to FELs (e.g. Flattop), agreement is worse work needed.

3D photoemission modeling using full EM Lienard-Wiechert approach.
- Cathode surface barrier correction due to Schottky effect and laser potential.
- Cathode physics model determines 3D QE distribution.
- Modeling of penetrating field effects

NIM A 889 (2018) 129–137
NIM A 871 (2017) 97–104

Best beam emittance located in transition region, needs more accurate photoemission modeling.

Würzburg, Germany, 19.03.2018
High Repetition Rate THz Source Development
For XFEL pump-probe experiments

Laser based THz pulse energy is limited at high repetition rate, while most IR/THz driven dynamics needs pulse energy above 1 μJ.

PITZ like high repetition rate compact accelerator can produce ~mJ THz pulses matching timing structure of XFEL X-ray pulse.
High Repetition Rate THz Source Development (cont'd)

For XFEL pump-probe experiments

- Compact accelerator based THz source is proposed for **XFEL pump & probe experiment**.
- PITZ like accelerator can be placed close to the XFEL end station.
- **Preliminary THz studies** were started at PITZ.

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

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

Proc. IPAC 2017, WEPAB033
Proc. FEL 2017, WEP004
Proc. FEL 2015, MOP033
Proc. FEL 2014, MOP055
High Repetition Rate THz Source Development (cont'd)

THz CTR

- Preliminary measurements of THz CTR

Interferograms obtained from the Michelson interferometer

Spectral distributions obtained from the Michelson interferometer

Measured comb-beam profiles with various bunch charges and booster phases

Graph showing measured beam current over time for different bunch charges.
High Repetition Rate THz Source Development (cont'd)

THz SASE FEL

- 4nC beam characterization for THz SASE FEL

\[ \lambda_{\text{rad}} = 100 \, \mu\text{m} \]

<table>
<thead>
<tr>
<th>#</th>
<th>Photocathode</th>
<th>Procedure</th>
<th>THz pulse energy (z=5m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>laser pulse</td>
<td>Start-to-End (S2E) simulations (ASTRA→GENESIS)</td>
<td>2.6 mJ</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>ASTRA→GENESIS</td>
<td>0.9 mJ</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Measured (not optimized) electron beam (\rightarrow) GENESIS</td>
<td>0.5 mJ</td>
</tr>
</tbody>
</table>
Micro Bunching by DLW (dielectric lined waveguides)

For improving THz radiation stability

Beam micro bunching induced by DLW wakefield and ballistic bunching

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

DLW withstands ~1 nC beam and 200 pulses per train at PITZ.

Proc. IPAC 2017, WEPAB122
Proc. EAAC 2017
Summary

- PITZ-E-XFEL-FLASH
- Gun-Emittance
- Advanced photocathode laser shaping for improved emittance
- Gun quads for phase space improvements
- IR/THz source for potential pump-probe experiments at E-XFEL
- Photoemission modeling
- Micro-bunching by DLW

Know PITZ from recent publications:

- **Facility overview**

- **Beam driven plasma acceleration activities**
  - Self-modulation experiments on PRL 2018

- **Advanced photocathode laser shaping**
  - Physics Uspekhi 60 (10) 1039 -1050 (2017)
  - Proc. FEL 2017, WEP006

- **Photoemission modeling**
  - NIM A 889 (2018) 129–137
  - NIM A 871 (2017) 97–104

- **Beam asymmetry compensation**
  - Proc. FEL 2017, WEP005
  - Proc. FEL 2017, WEP007
  - Proc. FEL 2017, WEP010

- **Gun system development**
  - NIM A 854 (2017) 113–126
  - Proc. IPAC 2017, TUPIK051

- **High repetition rate THz source development**
  - Proc. IPAC 2017, WEPAB033
  - Proc. FEL 2017, WEP004

- **Micro bunching by DLW**
  - Proc. IPAC 2017, WEPAB122
  - Proc. EAAC 2017

Thank you very much for your attention!
Gun System Development

Gun 4.6 Summary and Gun 5 Development

- PITZ high gradient RF guns drives superconducting linac in long pulse mode (e.g. 650 μs × 10 Hz).
- State of the art electron beam emittance has been demonstrated with PITZ gun in bunch train mode.
- Further improvement of gun stability and reliability requires new gun design (Gun 5).

Gun 4.6

- Ecath = 53 MV/m (XFEL startup)
- 60 MV/m (XFEL nominal), for better slice emittance, operated with up to 98.9% up time
- Improved cathode spring holder design
- Double RF windows with optimized location
- In-vacuum directional coupler enabled RF stability improvements to ~2e-4 (amplitude) and ~0.06° (phase).

Collaboration with INR

Gun 5

- Cavity RF pickup added: enable fine control of RF stability and allows symmetric RF coupler
- Improved cell geometry: reduced RF heating
- Improved water cooling + reduced gun deformation
- More reliable operation at high duty cycle