Developing the Electron Source for the European X-ray Free Electron Laser Project

Frank Stephan
(Photoinjector Test Facility at DESY, Zeuthen site, PITZ)

Content:
- the European XFEL
- the PITZ facility and important results from the last years
- recent high brightness beam measurements at PITZ
- summary and outlook
2001 – **TESLA Proposal** and Science Council Eval.

Oct. 2002 – **X-ray FEL** with 20 GeV superconducting accelerator (TESLA-technology)

Feb. 2003 - **Approval** by Federal Government as European project

Nine countries signed **MoU for the Preparatory Phase** of the XFEL in January 2005

July 2006 – **Technical Design Report**

July 2006: **Plan Approval Process** completed

2009: groundbreaking started
The European XFEL GmbH is founded. Research institutes of the different countries will be shareholders. Construction and operation of the XFEL are entrusted to this company.

Partner countries contributing to European XFEL

FR: ~3%  DE: ~55%  IT: ~3%  RU: ~24%  GB: ~3%

= contribution to start version of XFEL (total 1050 M€, preliminary)
European XFEL project organisation

- Accelerator Consortium
  Coordinator: DESY
  Institutes from F, I, PL, RU, E, CH, etc.

- Other In-kind Contributors…

Europe XFEL GmbH
Management Board
2 Managing Directors:
Chairman, Admin. Director
3 Science Directors

XFEL Council

ADVISORY COMMITTEES
- Machine
- Science
- Finance

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European XFEL - a next generation light source

The XFEL will deliver:

- wavelength down to 0.1 nm ➔ atomic-scale resolution
- ultra-short pulses (≤ 100 fs) ➔ ultra-fast dynamics, “molecular movies”
- ultra-high peak brilliance ➔ investigations of matter under extreme conditions (Xe$^{21+}$)
- transverse spatial coherence ➔ imaging of single nanoscale objects, possibly down to individual macromolecules (no crystallisation needed!!)
The European XFEL in the International Context

**LINAC COHERENT LIGHT SOURCE (LCLS)**
- 2009 - 120 p/s

**SPring-8 Compact SASE Source (SCSS)**
- 2011-60 p/s

**European XFEL Facility (XFEL)**
- 2014 - 30 000 p/s
## Comparison of X-ray FEL Projects

<table>
<thead>
<tr>
<th></th>
<th>LCLS (USA)</th>
<th>SCSS (JAPAN)</th>
<th>EUROPEAN XFEL (SASE1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minimum Wavelength</strong></td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>(nm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Peak Brilliance</strong></td>
<td>8.5 $10^{32}$</td>
<td>5 $10^{33}$</td>
<td>5 $10^{33}$</td>
</tr>
<tr>
<td>(phot/s/mm²/mrad²/0.1%BW)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average Brilliance</strong></td>
<td>2.4 $10^{22}$</td>
<td>1.5 $10^{23}$</td>
<td>1.6 $10^{25}$</td>
</tr>
<tr>
<td><strong>Pulses/s</strong></td>
<td>120</td>
<td>60</td>
<td>30 000</td>
</tr>
<tr>
<td><strong>Pulse Duration (fs)</strong></td>
<td>100 and below</td>
<td>500</td>
<td>100 and below</td>
</tr>
<tr>
<td><strong>First Beam</strong></td>
<td>2009</td>
<td>2011</td>
<td>2014</td>
</tr>
</tbody>
</table>
Advantages of Superconducting RF Technology for FEL’s

- Possibility to inject thousands of bunches per RF pulse;
- Small wakefields: large iris even at high gradients (design value: 24 MV/m; tested up to 35 MV/m);
- High stability, intra bunch-train feedback for high quality beam;
- Operational flexibility of time structure and energy
Electron bunch trains (with up to 3000 bunches of 1nC each)

\[ \Delta t = 200 \text{ ns} \]

\[ 600 \mu \text{s} \]

\[ 100 \text{ ms} \]

\[ 188 \text{ fs} \]

\[ 100 \text{ fs} \] Photon pulses

FEL process
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Overall layout of the European XFEL

3.4km

The European X-ray laser project XFEL
Planning status October, 2003

XFEL site ± 50 m
Options for expansion

1000 m

Schenefeld
(Pinneberg district)

Schleswig-Holstein

Hamburg

Osdoerfe Born

Iserbrook

Deutsches Elektronen-Synchrotron

PETRA

HERA

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European XFEL – beam dynamic components

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Undulator and photon tunnels layout

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>SASE 1</th>
<th>SASE 2</th>
<th>SASE 3</th>
<th>SASE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron energy</td>
<td>GeV</td>
<td>17.5</td>
<td>17.5</td>
<td>17.5</td>
<td>17.5</td>
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<tr>
<td>Wavelength</td>
<td>nm</td>
<td>0.1</td>
<td>0.1</td>
<td>0.4</td>
<td>0.4</td>
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<tr>
<td>Photon energy</td>
<td>keV</td>
<td>12.4</td>
<td>12.4</td>
<td>3.1</td>
<td>3.1</td>
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<tr>
<td>Peak power</td>
<td>GW</td>
<td>20</td>
<td>20</td>
<td>80</td>
<td>80</td>
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<tr>
<td>Average power*</td>
<td>W</td>
<td>65</td>
<td>65</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>Photon beam size (FWHM)</td>
<td>µm</td>
<td>70</td>
<td>85</td>
<td>55</td>
<td>60</td>
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<tr>
<td>Photon beam divergence (FWHM)</td>
<td>µrad</td>
<td>1</td>
<td>0.84</td>
<td>3.4</td>
<td>3.4</td>
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<tr>
<td>Coherence time</td>
<td>fs</td>
<td>0.2</td>
<td>0.22</td>
<td>0.38</td>
<td>0.34</td>
</tr>
<tr>
<td>Spectral bandwidth</td>
<td>%</td>
<td>0.08</td>
<td>0.08</td>
<td>0.18</td>
<td>0.2</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>fs</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Photons per pulse</td>
<td>#</td>
<td>(10^{12})</td>
<td>(10^{12})</td>
<td>(1.6 \times 10^{13})</td>
<td>(1.6 \times 10^{13})</td>
</tr>
<tr>
<td>Average flux</td>
<td>#/s</td>
<td>(3.3 \times 10^{16})</td>
<td>(3.3 \times 10^{16})</td>
<td>(5.2 \times 10^{17})</td>
<td>(5.2 \times 10^{17})</td>
</tr>
<tr>
<td>Peak brilliance</td>
<td>B</td>
<td>(5.0 \times 10^{33})</td>
<td>(5.0 \times 10^{33})</td>
<td>(2.2 \times 10^{33})</td>
<td>(2.0 \times 10^{33})</td>
</tr>
<tr>
<td>Average brilliance*</td>
<td>B</td>
<td>(1.6 \times 10^{25})</td>
<td>(1.6 \times 10^{25})</td>
<td>(7.1 \times 10^{24})</td>
<td>(6.4 \times 10^{24})</td>
</tr>
</tbody>
</table>
Construction of the underground buildings started!

- Contracts signed December 12, 2008
- Construction started in early January
Why electron injector is so important .... ???

Any linac based short wavelength, high brilliance light source (e.g. SASE-FELs) contains the following main components:

- **electron source**
- **accelerating sections** \(\rightarrow\) e.g. wakefields, coupler kicks
  - in between: **bunch compressor(s)** \(\rightarrow\) e.g. coherent synchrotron radiation (CSR)
- **undulator** to produce FEL radiation
- **electron beam dump**
- **photon beamline(s)** for the users

**Example: FLASH**

- RF gun
- Diagnostics
- Accelerating Structures
- Collimator
- Undulators
- Bunch Compressor
- Bunch Compressor
- Bypass
- FEL Experiments

**property of linacs: beam quality will DEGRATE during acceleration in linac**

\(\rightarrow\) **electron source has to produce lowest possible emittance !!!**
What is Emittance?

long.: $\mathcal{E}_z \sim (e^\text{-} \text{bunch length}) \bullet (\text{energy spread of } e^- \text{bunch})$

trans.: $\mathcal{E}_{x,y} \sim (e^- \text{ beam size}) \bullet (e^- \text{ beam angular divergence})$

$\mathcal{E} = 6 \text{ dimensional phase space volume occupied by given } \# \text{ of particles}$

effect of acceleration on transverse emittance (adiabatic damping):

\[ \text{before: } \begin{align*}
\vec{p}_1 & \uparrow \\
\theta_1 & \uparrow \\
p_{1z} & \uparrow \\
p_{1x} & \\
\theta_1 & \\
p_{2x} = p_{1x} \\
\theta_2 & < \theta_1 \\
p_{2z} & \downarrow \\
\text{⇒ angular divergence is reduced } & \Rightarrow \beta \cdot \gamma \cdot \sqrt{\sigma_x^2} \\
\end{align*} \]

⇒ normalized RMS transverse emittance:

\[ \mathcal{E}_{x}^n = \beta \cdot \gamma \cdot \sqrt{\sigma_x^2 \cdot \sigma_{x'}^2 - \text{COV}^2(x, x')} \; ; \; \beta = \frac{v}{c}, \; \gamma = \frac{1}{\sqrt{1 - \beta^2}}, \; x' = \frac{dx}{ds} \]
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• Why emittance must be small ...

**FLASH**

- $\varepsilon_n = 1$ mm mrad
- $\varepsilon_n = 2$ mm mrad
- $\varepsilon_n = 4$ mm mrad

- $Q = 1$ nC
- Path length in the undulator (m)

**XFEL**

- $\varepsilon_n = 1$ mm mrad
- $\varepsilon_n = 2$ mm mrad
- $\varepsilon_n = 3$ mm mrad

- Peak current: 5 kA
- Energy spread: 2.5 MeV

- Path length in the undulator (m)

**XFEL goal:**

- $0.9$ mm mrad@injector $= 1.4$ mm mrad@undulator

- If even smaller emittance $\Rightarrow$ new horizons:
  - Shorter wavelength, higher repetition rate

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Most prominent solution: Photo Cathode RF Gun

Example: PITZ gun

(Photo Injector Test facility at DESY, Zeuthen site)

Main properties of PITZ gun:

- 1.3 GHz cavity, coaxial RF coupler (flexible solenoid position)
- Capable of high average power → long electron bunch trains (SC linac)
- Very low normalized transverse emittance
Colleagues actively participating in measurements / new design:

- **DESY, Zeuthen site:**

- **DESY, Hamburg site:**
  K. Flöttmann, S. Lederer, S. Schreiber

- **BESSY Berlin:**
  R. Ovsyannikov, D. Richter, A. Vollmer

- **CCLRC Daresbury:**
  B. Militsyn

- **INRNE Sofia:**
  G. Asova, K. Boyanov, L. Staykov, I. Tsakov

- **INR Troitsk:**
  A.N. Naboka, V. Paramonov, A.K. Skassyrskaja, A. Zavadsev

- **LAL Orsay:**
  M. Jore, A. Variola

- **LASA Milano:**
  P. Michelato, L. Monaco, D. Sertore

- **LNF Frascati:**
  D. Alesini, L. Piccadenti

- **MBI Berlin:**
  G. Klemz, I. Will

- **TU Darmstadt:**
  E. Arevalo, W. Müller

- **Uni Hamburg:**
  J. Rönsch

- **YERPHI Yerevan:**
  L. Hakobyan

* on leave from BINP, Novosibirsk, Russia
** on leave from INR, Dubna, Russia
*** on leave from UCLA, USA
**** on leave from MEPHI, Moscow, Russia


The work had partly been supported by the European Community, contract numbers RII3-CT-2004-506008 and 011935, and by the 'Impuls- und Vernetzungsfonds' of the Helmholtz Association, contract number VH-FZ-005.
Short history of PITZ

- September 1999: DESY directorate decision to build PITZ
- 2000: civil construction
- 2001: installation of infrastructure and first setup
- 13.1.2002: first photo electrons
- November 2003: fully characterized RF gun is sent to TTF2-FEL (FLASH)
- Upgrade of PITZ is continuously ongoing, periods for beam measurements in between
- 2005: first operation with booster cavity
- 2006: provide spare RF gun for FLASH
- 2007: first demonstration of XFEL requirements
PITZ experimental highlights in 2007/2008

Schematics of PITZ setup in 2007:

- RF gun + solenoids
- Booster
- Cs₂Te cathode
- Bucking Coil
- Main Solenoid
- Low energy part (~6.5 MeV/c)
- High energy part (~15 MeV/c)

1) transverse projected emittance
2) dark current
Projected Emittance Measurements: \( \rightarrow \) Slit Scan Technique

2007 analysis:  
\[
E_{x,n} = \beta \gamma \cdot X_{\text{rms}} \cdot X'_\text{rms}
\]

- \( X_{\text{rms}} \): RMS size of full beam at EMSY station (e.g. \( z = 4.3 \text{m} \))
- \( X'_{\text{rms}} = \frac{1}{L} \sum w_i \left( X_{\text{beamlet}} \right)^2 / \sum w_i \): uncorrelated local divergence
- \( X_{\text{beamlet}} \): RMS size of the beamlet image
- \( L \): distance from slit location to screen for beamlets

- **Standard procedure in 2007:**
  - take 11 equidistant beamlets over the full beam size (with statistics)
  - use 10 µm slit opening
  - ultimate resolution: \( \rightarrow 36 \mu \text{m x 15.4 } \mu \text{rad} \)
  - use camera with 12 bit signal depth for beamlet measurements
Transverse Projected Emittance Measurements

- Emittance (x)
- Emittance (y)
- SQRT(E_x * E_y)

Cathode: # 90.1
Gun gradient: ~60 MV/m
Gun phase: Φ_{gun} = Φ_{ref}
Momentum from gun: ~6.44 MeV/c

Booster phase: Φ_{booster} = Φ_{booster}
Total beam momentum: 14.5 MeV/c

With a 10 % charge cut in the tails of the phase space distribution (~ remove non-lasing electrons)
→ normalized projected emittance = ~0.9 mm mrad

→ first demonstration of the beam quality required for the European XFEL !!!

For ~60 MV/m we obtained
ε_{x,n} = 1.25 ± 0.19 mm mrad
ε_{y,n} = 1.27 ± 0.18 mm mrad

for 100 % RMS emittance !!
Surface Cleaning ↔ Dark Current, High Average Power

- **Surface cleaning techniques:**
  - HPWR: high-pressure water rinsing
  - CO₂: dry-ice cleaning

- **Major reduction of dark current by CO₂ snow cleaning**

- **zoom:**
  - Demonstrated operation with 50 kW average RF power
    - fulfill XFEL average RF power specs!
  - Allows high brightness, high average current operation:
    - 1–5 mA in 700 µs,
    - 7–35 µA long term average
Panorama of the PITZ setup in 2009

new dipole spectrometer

gun prototype 4.2
Machine stability problems – RF gun phase

- FPGA phase, reconstructed from virtual ADC probes

Phase slope within an RF pulse ~5deg/40us

Fluctuations:
- 10..15deg (p-p)
- 2..4 deg (rms)

“10”-MW klystron is working close to the saturation, no LLRF regulation!

Measurement #

FPGA phase (chanel[40])
e-beam size fluctuations at EMSY1

FPGA phase: 14deg(p-p)

XYrms: 7% (rms), 38%(p-p)

variation in rms beam size at EMSY1

impact on emittance measurements
RF gun phase fluctuation -> simulations of the effect

Fluctuations 10..15deg (p-p)
Slope (pulse train) ~5deg/40us

Emittance increase due to RF gun phase jitter

possible explanation why measured emittance for gun at +6deg off-crest is better than on-crest?
RF gun phase fluctuations: summary

One of the most critical problem up to now!!!

- FPGA phase fluctuations (+slope) have been observed
- These fluctuations are correlated with beam momentum and beam size variations in time → results in measured emittance increase: shot-to-shot and within pulse train
- The stabilization tool does not improve the stability

Planned Upgrade for current shutdown

Hope that unique 10MW in-vacuum directional coupler will work → then HH colleagues could install FLASH LLRF gun control at PITZ
Emittance measurements

- Measurement procedure improvements
- Nominal 1nC beam
- Various bunch charges
- Various laser temporal flat-top modulations
- Different rise/fall time
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Emittance measurements: procedure improvement

The main procedure – the single slit scan– has been accelerated:

Fast (slit) scan = beamlet image taking during continuous slit movement:

- Comparison to old standard method:
  * time: ~20 sec. (fast) vs. ~30 min (standard);
  * emittance value: the same trend (optimum), absolute values deviate (RF instability ?!!!);
  * transverse phase spaces are similar

- Usually quote 2D scaled emittance:
  \[ \varepsilon_n = \beta_y \frac{\sigma_x}{\sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2}}; \quad \frac{\sigma_x}{\sqrt{\langle x^2 \rangle}} (> 1) \]

- More accurate criteria for the beamlet image quality

Statistics of several fast scans

Check on saturation directly after fast scan data are taken!
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Nominal (1nC) measurements (21.08.2009M)

2D emittance for BSA=1.5mm, 1nC, gun: 6deg off-crest, booster: on-crest

- $\varepsilon_x = 0.76$ mm mrad
- $\varepsilon_y = 1.26$ mm mrad

$\varepsilon_{xy}(388A) = 0.98$ mm mrad

(100% RMS emittance data !)

Preliminary results
Now with charge cut:

![Graph showing 2D scaled emittance](image)
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Nominal (1nC) measurements (22.08.2009M)

- Q=1nC
- I_{main}=387A
- Gun: +6deg off-crest
- Booster: on-crest
- Laser temp.: 2.1/23.1/2.4ps
- Laser BSA=1.5mm

\[ \varepsilon_x = (0.721 \pm 0.013) \text{ mm mrad} \]

Preliminary results

X-X’ phase space
Nominal (1nC) measurements (22.08.2009M)

Y-Y’ phase space

$\varepsilon_y = (1.089 \pm 0.020) \text{mm mrad}$

- $Q=1\text{nC}$
- $I_{\text{main}}=387\text{A}$
- Gun: +6$^\circ$ off-crest
- Booster: on-crest
- Laser temp.: 2.1/23.1/2.4ps
- Laser BSA = 1.5mm

Preliminary results
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Nominal (1nC) measurements (22.08.2009)

beam @ EMSY1

- $Q=1nC$
- $I_{\text{main}}=387A$
- Gun: +6deg off-crest
- Booster: on-crest
- Laser temp.: 2.1/23.1/2.4ps
- Laser BSA=1.5mm

But! It was not possible to reproduce it in next shifts!

$E_{xy} = \left( 0.886 \pm 0.011 \right) \text{mm mrad}$

(100% RMS emittance)

25th, 2009, Frank Stephan (DESY)
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Emittance statistics of several fast scans

Short term (~3 hours): ~4.7% (stdev)

Long term (~4 days): ~6.85% (stdev)
~16.21% (peak-to-peak)*

Beam size and emittance at EMSY1 for BSA 1.5 mm
Charge of 1 nC, gun phase = -6 degree off-crest
laser 20 ps FWHM, 2 ps r/ft, Imain 384 A

Emittance

- \( \varepsilon_x = (1.046 \pm 0.075) \text{ mm mrad} \)
- \( \varepsilon_y = (1.330 \pm 0.058) \text{ mm mrad} \)
- \( \varepsilon_{xy} = (1.179 \pm 0.052) \text{ mm mrad} \)
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Emittance vs. bunch charge

Study of emittance vs. BSA size and charge

gun of +6 deg off-crest, booster on-crest

preliminary results

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Emittance vs. bunch charge: now with charge cut

2D scaled emittance

- XYemit (0.1nC)
- XYemit (0.25nC)
- XYemit (0.5nC)
- XYemit (1nC)
- XYemit (1nC, meas1-4)

Charge cut, % vs. Emittance (mm mrad)

Preliminary results
Various laser temporal flat-top modulations

Simulations

• higher modulation frequency ➔ larger emittance growth rate
• reliable simulations for modulations with >5 peaks are difficult

Simulated optimum emittance vs.
modulation depth

- 2 peaks
- 3 peaks
- 4 peaks
- 5 peaks

Simulations with
gun on-crest,
other parameters
optimized

preliminary results
Experimental temporal laser profiles

Experimental results compared to simulations

- not possible to measure the effect with the current machine stability
Check effect on rise/fall time

- Q=1nC
- I_{main} optimized
- Gun: +6 deg off-crest
- Booster: on-crest
- Laser: temp FWHM~20ps, BSA=1.5mm

\[ \text{not possible to measure the effect with current machine stability} \]
Longitudinal momentum modulations and cathode laser temporal shaping

Pz-modulation for various:
- bunch charges
- rf gun and booster phases
- Lyot filters (laser pulse bandwidth, pulse length, rise/fall time and flat-top ripple manipulation)

FWHM: 23.3ps rise: 1.86ps fall: 1.86ps FTmod: 3.88%
measured: 27.4.09 morning shift (8:52)

no Lyot

FWHM: 24.0ps rise: 1.79ps fall: 1.78ps FTmod: 2.79%
measured: 28.4.09 late shift (16:56)

thin filter (2mm)

FWHM: 22.3ps rise: 3.22ps fall: 3.13ps FTmod: 2.79%
measured: 27.4.09 morning shift (9:34)

medium filter (4mm)

FWHM: 20.7ps rise: 4.16ps fall: 4.00ps FTmod: 2.34%
measured: 29.4.09 late shift (11:46)

thick filter (8mm)
Longitudinal momentum modulations: meas. setup

- BSA 1.5mm
- solenoid focusing for best momentum resolution in LEDA (appr. 460A)
- solenoid setting for HEDA measurements 390 A (good transport), focusing by quads
### Longitudinal momentum modulations and cathode laser temporal shaping

<table>
<thead>
<tr>
<th>Gun phase</th>
<th>Booster phase</th>
<th>DA / # pulses</th>
<th>Q=1nC</th>
<th>Q=0.25nC</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>phase of maximum momentum gain -10deg (SPP)</td>
<td>no booster</td>
<td>LEDA / 30 pulses</td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td>Pz-modulations observed after RF-gun</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>higher bunch charge and thicker Lyot filter smear out the modulations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>nomial rf-gun phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>although no modulations after RF-gun, off-crest booster phase reveals Pz-modulations</td>
</tr>
</tbody>
</table>

**Preliminary results**
Another approach → **detuning** of an aligned pulse shaper, i.e. by purpose introducing modulations on the flat-top of the temporal laser distribution and measuring momentum distribution in HEDA.

**Machine conditions:**
- gun: on-crest
- booster: +10deg off-crest
- bunch charge: 500pC

---

**Electron beam longitudinal momentum distribution**

- (5 laser pulses used)
- Statistics (n = 10):
  - $p_{\text{mean}} = (14.684 \pm 0.003) \text{ MeV}/c$
  - $p_{\text{rms}} = (114.121 \pm 3.022) \text{ keV}/c$

- **preliminary results**

- (1 laser pulse used)
- Statistics (n = 10):
  - $p_{\text{mean}} = (14.600 \pm 0.004) \text{ MeV}/c$
  - $p_{\text{rms}} = (144.142 \pm 1.852) \text{ keV}/c$
Long pulse train operation: 700 pulses x 1nC, 7 MW in gun
(23.01.2009A)

Laser scope

Bunch charge: LOW.ICT1

Beam position: LOW.BPM1

Long pulse operation (aver. current 7.8 μA) has been demonstrated, BUT laser pulse train envelope still to be improved

preliminary results
**Summary and Outlook (1)**

- **European X-ray Free Electron Laser (XFEL)**
  - will allow unprecedented experiments with atomic resolution on femtosecond time scales with ultra-high peak and average brilliance photon beams of transverse spatial coherence → construction has started

- **Photo Injector Test facility at DESY, Zeuthen site (PITZ):**
  - develops electron source for XFEL
  - very low emittance and high average power operation were demonstrated:
    - nominal 1nC, several consequent measurements (22.08.2009M) delivered:
      \[
      \varepsilon_{xy} (100\%) = \left(0.886 \pm 0.011\right) \text{mm mrad} \\
      \varepsilon_{xy} (90\%) = \left(0.681 \pm 0.010\right) \text{mm mrad}
      \]
      but not reproducible in next shifts → av. of 10 measurements (13.09.`09):
      \[
      \varepsilon_{xy} (100\%) = \left(1.176 \pm 0.012\right) \text{mm mrad} \\
      \varepsilon_{xy} (90\%) = \left(0.878 \pm 0.040\right) \text{mm mrad}
      \]
    - for lower bunch charges, e.g.:
      \[
      \varepsilon_{xy} (Q = 0.25nC, BSA = 0.8mm, 100\%) = 0.47 \text{ mm mrad} \\
      \varepsilon_{xy} (Q = 0.1nC, BSA = 0.5mm, 100\%) = 0.34 \text{ mm mrad} \\
      \varepsilon_{xy} (Q = 0.25nC, 90\%) = 0.37 \text{ mm mrad} \\
      \varepsilon_{xy} (Q = 0.1nC, 90\%) = 0.26 \text{ mm mrad}
      \]
R&D at PITZ is ongoing → further improvements of facility, → new operation modes, → new research fields

- Major problem: rf gun phase instability → emittance fluctuations up to 10% (rms) and 20%(peak-to-peak).
  → hope that unique 10MW in-vacuum directional coupler will solve problem (if it works → FLASH LLRF to be installed at PITZ).
- Laser transport to cathode is critical issue (e.g. vacuum mirror)
- PITZ shutdown has started on 19.10.2009:
  → RF-Gun exchange (current one to FLASH, new one: CO₂ cleaned, LLRF)
  → new booster cavity (more stable and reliable, known field profile)
  → new tomography module (better characterization of trans. phase space)
  → diagnostics maintenance (burned screens, slit masks improvement)
- More intensively study low charge operation modes, incl. single spike lasing
- Interested in new research fields, e.g.:
  → CW electron source for XFEL with lowest possible emittance
  → acceleration of low emittance e-beams with laser plasmas → beam quality?
Developing the Electron Source for the European XFEL

Planning next steps

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<th>November</th>
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Seminar at Berkeley, USA, November 12th, 2009, Frank Stephan (DESY)
Developing the Electron Source for the European XFEL

PITZ beamline: Status and Future

Since 2009: new laser system
  → pulse length: 2-24 ps (FWHM)
  → temporal and transverse laser shaping

2009/2010: TESLA booster to be replaced by CDS booster

2009/2010: RF gun exchange

2010/2011: RF deflector (TDC)

2009/2010: Tomography module

2010/2011: HEDA2
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M. Krasilnikov,
M. Altarelli, R. Brinkmann, S. Schreiber

the whole PITZ collaboration
and the whole European XFEL Project Team