About Injector Characterization Program

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Why do we need simulations?

• To predict the electron and photon beams parameters which can be measured.
• To predict the electron and photon beams parameters which can not be measured.
• To optimize the setup of the real machine: “working points”.
• To model and study a special scenarios which are yet not possible in the real machine.

We need a physical/mathematical model which reproduces the electron/photon beam properties measured in the “real” machine.
What is a “good” simulation?

• One that predicts expected “good” beam properties? No.
• One that agrees with the measurements and reproduces different actuator – detector dependences.

What is a “good” measurement?

• Not one point but a whole actuator – detector dependence.
• We know what is measured: we know a detector response function to do a “deconvolution” or simulate the measurement.
• We know estimation of systematic and statistical errors of the detector/the measurement.
• We know the states of other parameters which impact the measurement and which depend on the actuator during the measurement.
• Reproducibility.
Motivation for the current injector studies

• To reproduce the measured beam properties in the simulations
• To create a computer model of electron beam with the measured properties before the injector dogleg

Approach

• To measure and to calibrate the “hardware” parameters used in the simulations
• To measure the beam properties vs scans of the calibrated hardware parameters
“Hardware” parameters

- Photocathode laser longitudinal and transverse profiles
- Gun solenoids fields
- Gun RF field
- Gun quadrupoles fields
- A1 module field
- AH1 module field
- TDS cavity field
- Quadrupole fields
- Laser heater fields
Beam parameters

• Beam charge vs laser pulse energy
• Beam charge vs gun phase
• Beam energy vs RF gun phase
• Beam size vs solenoid strength
• Beam size vs gun quad strength
• Longitudinal phase space, current and energy profiles vs RF parameters
• Projected and slice emittances
• Correlated and uncorrelated energy spreads
“Hardware” parameters

- Photocathode laser **transverse** distribution
  
  Laser 2, 29.10.19

- Photocathode laser **temporal** profile
  
  XFEL in October 2019 → measurements not available

- Laser 2 (last winter) from Frank Brinker

- Optical Sampling System
“Hardware” parameters

- Photocathode laser **longitudinal** and transverse profiles

Schottky scans: bunch charge vs. gun SP phase using BPMG.24.11 (BSA=1mm, PfwdSP=55.6)

We hope to estimate the longitudinal laser profile from these scans

\[
\phi = \text{SPPhase} - \Phi_0
\]

\[
Q_{fit}(\text{SPPhase}) = Q_{bkg} + A \cdot F_{\text{schottky}}(\phi) \cdot (1 - \text{Erf}(C \cdot \phi))
\]

\[
F_{\text{schottky}}(\phi) = \begin{cases} 
1 + S \cdot \sqrt{\sin \left(-\frac{\phi - \Phi_0}{180}\right)}, & \text{if } \phi \leq 0 \\
1, & \text{if } \phi > 0
\end{cases}
\]

Fit for the mean charge fit \( Q_{fit} \):

- \( \Phi_0 \) - zero crossing phase
- \( Q_{bkg} \) - background charge (dark current)
- \( A \) - scaling factor \( \to \) max bunch charge
- \( S \) - constant in Schottky factor \( F_{\text{schottky}}(\phi) \)
- \( C \) - scaling factor in the error function argument

\( \sigma \) - rms length (in deg) of the derived Gaussian

M. Krasilnikov, “Improved beam-based method for RF photo gun stability measurements”, ARD ST3 meeting, 2015
Beam parameters

• Beam charge vs laser pulse energy

Bunch charge vs. laser pulse energy (PfwdSP=55.6, SPPhase=MMMG=-45deg, BSA=1mm)

Working point: 0.07/0.32 → ~22% saturation!
Beam parameters

- Beam energy vs RF gun phase

Beam position (~momentum) in the low energy dispersive arm (PfwdSP=55.6)
## “Hardware” parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method</th>
<th>Parasitic</th>
<th>29/30.10.1019</th>
<th>Older</th>
<th>Wanted</th>
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<tbody>
<tr>
<td>Laser transverse profile</td>
<td>virtual cathode</td>
<td>yes/no</td>
<td>+</td>
<td>+</td>
<td>Realistic 2D distribution</td>
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<tr>
<td>Laser longitudinal profile</td>
<td>UV Cross-correlator, streak camera, low charge Schottky scan Q(gun phase)</td>
<td>no</td>
<td>+</td>
<td></td>
<td>UV cross-correlator with resolution &lt; 0.5ps</td>
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<tr>
<td>Gun solenoid field</td>
<td>E-beam size vs solenoid current</td>
<td>no</td>
<td>+</td>
<td>+</td>
<td>Calibration: strength vs current</td>
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<tr>
<td>Gun quad field</td>
<td>E-beam size vs quads currents</td>
<td>no</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RF gun field</td>
<td>Beam energy vs gun phase</td>
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<td>+</td>
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<tr>
<td></td>
<td>Beam energy vs gun gradient</td>
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<tr>
<td>A1 module field</td>
<td>Beam phase space with TDS</td>
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<td>+</td>
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<tr>
<td>AH1 module field</td>
<td>Beam phase space with TDS</td>
<td>no</td>
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<td>TDS cavity field</td>
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<td>Quadrupole fields</td>
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<tr>
<td>Laser heater fields</td>
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</table>
Measurements: PITZ Gun-4.6

Mean momentum and Maximum Mean Momentum Gain (MMMG) phase

\[ \langle P_z \rangle = \beta_z \gamma \cdot 0.511 \frac{MeV}{c} \]

\[
\beta_z = \frac{v_z}{c}
\]

\[
\gamma = \frac{1}{\sqrt{1 - \beta_z^2}}
\]

\[
\frac{1}{\beta_z} = \frac{1}{\sqrt{\gamma^2 - 1}}
\]

\[ P[MW] = 0.00176 \cdot (E_{cath}[MV/m])^2 \]
<table>
<thead>
<tr>
<th>Beam parameters</th>
<th>diagnostics</th>
<th>29/30.10.1019</th>
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<tr>
<td>Beam charge vs laser pulse energy</td>
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<tr>
<td>Beam charge vs gun phase</td>
<td>BPMG.24.I1</td>
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<tr>
<td>Beam energy vs RF gun phase</td>
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<td></td>
<td>Beam momentum (absolute) and momentum distribution</td>
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<tr>
<td>Beam size vs main solenoid strength/current</td>
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<tr>
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<td>Correlated and uncorrelated energy spreads</td>
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</table>
Horizontal orbit change during A1 phase scan with the “constant” beam energy (S. Tomin).
Vertical orbit change during A1 phase scan with the "constant" beam energy (S. Tomin).
Horizontal orbit change during AH1 phase scan with the “constant” beam energy (S. Tomin).
Vertical orbit change during AH1 phase scan with the “constant” beam energy (S. Tomin).