Beam dynamics simulations for the European XFEL photo injector

Cathode laser pulse shape influence

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“Nominal” XFEL Photo Injector (PI) setup for BD simulations

- RF gun:
  - **Gun-4.1** field profile (FB=1.08) and Ecath=60.58MV/m*
  - Main solenoid centered at z=0.276m, bucking at compensation

- Cathode laser:
  - Temporal: flat-top 2ps/21.5ps\2ps*
  - Transverse: radial homogeneous

- Booster: ACC1=8xTESLA cavities:
  - 1\textsuperscript{st} cavity is centered at z~4.04m from the cathode
    (1\textsuperscript{st} iris of the 1\textsuperscript{st} TESLA cavity \(\rightarrow\) z=3.637m \(\leftrightarrow\) CDS at PITZ z=3.24m)
  - Epeak=33.5MV/m
  - Phase \(\rightarrow\) on-crest

- ASTRA optimization
  - 200k particles
  - Minimized transverse projected transverse **emittance** at z=15m
  - Tuned parameters: laser rms spot size, main solenoid peak field, gun launch phase, rms bunch length**

** used for the Gaussian and 3D ellipsoidal laser pulse optimization for the second comparison option

To be compared with Gaussian temporal profile and 3D ellipsoidal pulses

To be compared with Gaussian temporal profile and 3D ellipsoidal pulses
Different cathode laser pulse shapes: strategy of comparison

same $\sigma_t^{\text{laser}}$

- Gauss
- Flat-top
- Ellipsoid

$\Rightarrow$ comparison-1 (various $\sigma_z^{e-bunch}$)

same $\sigma_t^{e-bunch}$

- Gauss-2
- Ellipsoid-2

$\Rightarrow$ $\sigma_z^{\text{laser}}$ to be tuned

comparison-2

Graph:

- Zrms (Flat-top)
- Zrms (Gauss)
- Zrms (Ellipsoid)
- Zrms (Gauss-2)
- Zrms (Ellipsoid-2)

$rms \text{ bunch length (mm)}$

$0 \quad 2 \quad 4 \quad 6 \quad 8 \quad 10 \quad 12$

$z \text{ from cathode (m)}$

Mikhail Krasilnikov  |  Beam dynamics simulations for the European XFEL photo injector | 11.06.2013  |  Page 3
Different cathode laser pulse shapes: strategy of comparison

same $\sigma_t^{laser}$

Gauss

Flat-top

Ellipsoid

$\Rightarrow$ comparison-1

(Various $\sigma_z^{e\text{-bunch}}$)

same $\sigma_t^{e\text{-bunch}}$

Gauss-2

Ellipsoid-2

$\Rightarrow \sigma_z^{laser}$ to be tuned

comparison-2

Smaller $\varepsilon_z \Rightarrow$ better compressible beam

$\varepsilon_z$

$\sigma_t$

comparison

Zemit(Flat-top)

Zemit(Gauss)

Zemit(Ellipsoid)

Zemit(Gauss-2)

Zemit(Ellipsoid-2)

NB $\rightarrow$ in this talk:

• only results of comparison-2

• 3D ellipsoids $\rightarrow$ preliminary results
### Comparison-2: Optimized machine parameters

<table>
<thead>
<tr>
<th></th>
<th>Temporal profile/shape</th>
<th>PITZ-1.8 (M.Khojoyan)</th>
<th>European XFEL photo injector*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>cylindrical 3D ellipsoidal</td>
<td>cylindrical 3D ellipsoidal</td>
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<td></td>
<td></td>
<td>Gaussian Flat-top PRSTAB-2012 3D homogeneous</td>
<td>Gaussian Flat-top [PITZ gun+laser] 3D homogeneous</td>
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<tr>
<td>Cathode Laser</td>
<td>Transverse distribution</td>
<td>radial homogeneous 3D homogeneous</td>
<td>radial homogeneous 3D homogeneous</td>
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<td>Trms</td>
<td>ps</td>
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<td></td>
<td>XYrms</td>
<td>mm</td>
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<td>Th. emit.</td>
<td>mm mrad</td>
<td>0.326</td>
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<tr>
<td></td>
<td>Ecath.</td>
<td>MV/m</td>
<td>60.58</td>
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<tr>
<td></td>
<td>Phase</td>
<td>deg</td>
<td>~ on-crest</td>
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<tr>
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<td>MaxBz</td>
<td>T</td>
<td>0.2275</td>
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<tr>
<td>Booster</td>
<td>MaxE</td>
<td>MV/m</td>
<td>19.76</td>
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<td>Electron beam</td>
<td>Charge</td>
<td>nC</td>
<td>1</td>
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<tr>
<td></td>
<td>Momentum</td>
<td>MeV/c</td>
<td>23.96</td>
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<td></td>
<td>Proj. emittance</td>
<td>mm mrad</td>
<td>1.08</td>
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<td>Th. / proj.</td>
<td>%</td>
<td>30</td>
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<tr>
<td></td>
<td>&lt;Sl. emit.&gt;</td>
<td>mm mrad</td>
<td>0.778</td>
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<td>Rms bunch length</td>
<td>mm</td>
<td>2.163</td>
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<td>Peak current</td>
<td>A</td>
<td>45.4</td>
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<td>Long. emittance</td>
<td>mm keV</td>
<td>107</td>
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</table>
Projected along the beam line and $\varepsilon_{\text{slice}}(z = 15m)$

<table>
<thead>
<tr>
<th>Cathode pulse</th>
<th>$\varepsilon_{\text{proj}}$</th>
<th>$\langle \varepsilon_{\text{slice}} \rangle$</th>
<th>$\langle B_I \rangle$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat-top</td>
<td>0.63</td>
<td>0.55</td>
<td>135</td>
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<tr>
<td>Gauss-2</td>
<td>1.05</td>
<td>0.72</td>
<td>90</td>
</tr>
<tr>
<td>Ellipsoid-2</td>
<td>0.43</td>
<td>0.40</td>
<td>240</td>
</tr>
</tbody>
</table>

"Local brightness"

$$B_l = \frac{I(z)}{\varepsilon_{\text{sl,x}} \cdot \varepsilon_{\text{sl,y}}}$$
Conclusions

Beam dynamics simulations for the European XFEL photo injector have been performed:

- Gun and laser input → from PITZ-1.8 experimental data, comparing the PITZ-1.8 setup (E_{cath}=60.6MV/m)
- ACC1 as a booster + further acceleration (∼150MeV)
- Solenoid and booster positions were not varied

3 cathode laser pulse shapes were simulated to reach the smallest projected emittance after the injector:

- Flat-top (2/21.5\(\mu\)s), Gaussian and 3D ellipsoid (preliminary)
- Comparison-2 option discussed → tuning Gaussian and ellipsoid laser duration to yield the same rms electron bunch length