Update on Beam Imperfections Studies at PITZ

- Motivation
- Electron beam asymmetry studies
- Electron beam imaging studies
- Photoemission studies
- Conclusions and outlook

M. Krasilnikov
DESY-TEMF-Meeting, 24.06.2016
Electron Beam Imperfections at PITZ: Observations

**Observed electron beam imperfections**

- **E-beam x-y asymmetry** (tails)
- Emittance vs. laser XYrms
- Emittance vs. Imain Bunch charge vs. laser energy
- Emittance vs. laser XYrms (tails)

**Optimum:** \( I_{\text{main}} \neq \text{MaxB} \)

- **E-beam dynamics w/o space charge**
- Main solenoid calibration check
- Beam imaging studies
- Photoemission studies

- Core+halo model
- Other mechanisms?

**Goals:**
1. Precise (quantitative) understanding of beam dynamics in a photo injector
2. Reveal a source of the asymmetry kick
3. Try to minimize the kick (?compensating coils?)

**Simulate measured x-y distributions and transverse phase space of electron beam and reproduce optimum machine setup**

**Originate and characterize the asymmetry kick**

Larmor angle experiment interpretation

**Photoemission studies space charge!**

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Electron beam asymmetry $\rightarrow$ Larmor angle experiment: ASTRA “tracking back” towards cathode

<table>
<thead>
<tr>
<th></th>
<th>Cathode</th>
<th>Z=0.18m</th>
<th>EMSY</th>
</tr>
</thead>
<tbody>
<tr>
<td>MaxB=0.208692T</td>
<td><img src="cathode.png" alt="Image" /></td>
<td><img src="z018_simulated.png" alt="Image" /></td>
<td><img src="emsy_measured.png" alt="Image" /></td>
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<tr>
<td>T (+361A) normal polarity</td>
<td><img src="cathode.png" alt="Image" /></td>
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<tr>
<td>(-361A) opposite polarity</td>
<td><img src="cathode.png" alt="Image" /></td>
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<td><img src="emsy_measured.png" alt="Image" /></td>
</tr>
</tbody>
</table>

The edge particles at EMSY coming from the edge of the laser distribution at the cathode

45° Kick at z~0.2 m $\rightarrow$ skew quadrupole?

Impact onto the laser BBA?

Currently: 2 kick sources:

- normal quad from solenoid (polarity dependent)
- skew quad from RF (solenoid polarity independent)
Main solenoid calibration: Electron beam imaging studies (Q. Zhao)

**Main idea:** beam dynamics w/o space charge to confirm RF gun + solenoid electron optics, e.g. the main solenoid calibration:

\[ B_{z,\text{main}}[T] = 5.889 \times 10^{-4} \times I_{\text{main}}[A] + 7.102 \times 10^{-5} \]

**Tools:** grid at the BSA location → to be imaged onto the cathode, then electron image at LOW.Scr1,2,3 for various RF peak power level \( E_{\text{cath}} \) by \( I_{\text{main}} \) tuning.

\[ P_{\text{gun}} = 3\text{MW} \rightarrow 4.84\text{MeV/c} \]

\[ P_{\text{gun}} = 5\text{MW} \rightarrow 6.07\text{MeV/c} \]
E-beam Imaging: Magnification factor and images analysis

Images resolution and contrast analysis

Example: 3MW, 390A, scr1

\[ MF = \frac{X_{image}}{X_{object}} \]

- Grid magnification factor from experiment were analyzed and simulated
- The images resolution and contrast from experiment are more precisely analyzed to explain Exp-Sim discrepancy

No symmetry distortion (from the kick) observed

Confirm that the solenoid calibration is correct:

\[ B_{z,main}[T] = 5.889 \times 10^{-4} \times I_{main}[A] + 7.102 \times 10^{-5} \]
Photo emission studies (October-November 2015)

Measurements (1.11.2015M-A):
- $P_{\text{gun}}=6\text{MW} (6.68\text{MeV/c max})$
- Launch phase 30; 49; 90 deg w.r.t. "0"
- Cathode laser:
  - Short Gaussian 2 ps FWHM (expected)
  - BSA=0.8mm (VC2)
- $I_{\text{main}}=460; 470; 460\text{A (tuned to focus e-beam)}$
- Charge measured using LOW.FC1 ($z=0.8\text{m}$)

Solid curves = mean (runs4,13,14,17,10)
Dashed curves = min and max (runs4,13,14,17,10)

ASTRA Simulations for uncertainty estimation

<table>
<thead>
<tr>
<th>Run</th>
<th>$\sigma_t$ (ps)</th>
<th>Ecath (MV/m)</th>
<th>$\Delta \Phi$ (deg) phase</th>
<th>Radial profile: XX-core + Gaussian halo</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.85</td>
<td>59.569</td>
<td>0</td>
<td>Flattop core</td>
</tr>
<tr>
<td>13</td>
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<td>59.569</td>
<td>-1</td>
<td>Average core</td>
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<tr>
<td>14</td>
<td>0.85</td>
<td>59.569</td>
<td>0</td>
<td>Average core ± $\sigma_\Phi$</td>
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<tr>
<td>17</td>
<td>0.85</td>
<td>59.569</td>
<td>-1</td>
<td>Flattop core</td>
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</tr>
</tbody>
</table>

Laser radial profiles
Update on photo emission studies: 90 deg phase

Measured charge for 90deg w.r.t zero-crossing phase (short 2ps FWHM Gaussian pulses, BSA=0.8mm):
- systematically lower than corresponding simulations (especially at QE→SC transition)
- systematically lower than the charge measured at lower phases (30, 49deg) with higher gradients ($E_{\text{cath}}$), but same $E_{\text{emission}}$

$E_{\text{emission}}=45\text{MV/m}\times\sin(90\text{deg})$, measured

$E_{\text{emission}}=30\text{MV/m}\times\sin(90\text{deg})$, measured
Update on photo emission studies: zero-crossing phase

Still not understood: Zero-crossing phase $\leftrightarrow$ MMMG phase $\Rightarrow$ 2-3 deg phase shift between measurements and simulations

Gun phase = 33.8 deg - SPPPhase
Measured MMMG = 46.8 deg
Simulated MMMG = 43.3 deg

<table>
<thead>
<tr>
<th>cathode laser $\sigma_1$ (ps)</th>
<th>fwhm (ps)</th>
<th>$E_{kin}$ (eV)</th>
<th>delta $\phi$</th>
<th>$dq/d\phi$ - Gauss fit</th>
<th>$\sigma_1$ / $\sigma_1$ fit</th>
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<tr>
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<td>1.67</td>
<td>1.96</td>
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</table>
δE-program at PITZ (new)

Idea: establish δE measurements (best resolution and flexibility) and measure δE for various conditions (temporal profiles, SC effect, etc.)

Motivation from DESY-HH:
- Initial δE for micro-bunching instability studies (M. Dohlus)

Motivation from PITZ:
- Measurements vs. simulations
- Improve measured σE (projected) understanding
- Detailed emission modeling (e.g. zero-crossing phase)

ASTRA simulations with “Pz-heater” at cathode

EMSY1 (5.27m)
Summary and Conclusions

> E-beam asymmetry:
  - The experiment on Larmor angle:
    - skew quad (→ RF) kick at z~0.18m
    - normal quad (→ solenoid) kick at z~0.34m

> Beam imaging studies:
  - Main solenoid calibration + RF field dynamics ~> seems to be OK, but still more investigations are to be done

> Photo emission:
  - Core+halo model of the laser transverse distribution → better agreement in bunch charge vs. laser pulse energy. But not much improved discrepancy in measured-to-simulated phase spaces and optimum machine setup
  - Still to be understood:
    - measured curves $Q(E_{\text{laser}})$ for 90 deg w.r.t. “0”
    - “0”-phase determination

> $\delta E$-program at PITZ
### Photo injector setups for emission studies

<table>
<thead>
<tr>
<th>Setup</th>
<th>BSA diameter (mm)</th>
<th>Laser temporal profile</th>
<th>Laser pulse length FWHM (ps)</th>
<th>Gun RF power (MW)</th>
<th>Gun RF Phase (deg)</th>
<th>$E_{\text{cathode}}$ at moment of emission (MV/m)</th>
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<tbody>
<tr>
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<td>Gaussian</td>
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<td>MMMG</td>
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**Studies on charge production from Cs$_2$Te photocathodes in the PITZ L-band normal conducting radio frequency photo injector**