New Measurement Techniques Using a Novel X-band Transverse Deflecting Structure with Variable Polarization

Daniel Marx,
R Assmann, P Craievich, U Dorda,
A Grudiev, B Marchetti
25 September 2017

daniel.marx@desy.de

With thanks to collaborators and colleagues (listed at end)
Outline

> Introduction
  - Technology
  - The collaboration
  - The SINBAD-ARES linac

> Planned measurements at SINBAD
  - Overview
  - 3D charge density reconstruction
  - Bunch energy measurement
  - Applications
Novel X-band TDS with variable polarization

Variable Polarization Circular TE11 Mode Launcher

This new design allows for changing the streaking direction of the TDS.

Collaboration to build and test the first prototype

At DESY, also FLASHForward, FLASH2 and potentially XFEL involved

Planned measurements

- Bunch Length
- 3D charge density profile using tomographic reconstruction (real space)
- Slice emittance measurement (transverse phase space)
- Slice energy measurement using dipole (longitudinal phase space)

6D phase space characterization
Tomographic reconstruction

- Aim: to reconstruct the 3D charge density distribution
- Relies on streaking at multiple angles => completely new measurement
- Principle:
  - Streak beam at different angles and measure intensity at screen
  - Slice profiles in time
  - Combine 1D profiles from different streaking directions to form a 2D transverse profile for each temporal slice
  - Stack slices together to form complete 3D charge profile reconstruction
Tomographic reconstruction

Magnetic chicane  Deflecting cavity  Deflecting cavity

0.8 m  0.8 m

Screen

B
P
M

$L \approx 5.8 \, m$

Not to scale
Magnet & screen positions not yet fixed

~20 MV per cavity = 40 MV max kick
Tomographic reconstruction

Beam parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [MeV]</td>
<td>84.2</td>
</tr>
<tr>
<td>Charge [pC]</td>
<td>3</td>
</tr>
<tr>
<td>$\sigma_t$ [fs]</td>
<td>5.15</td>
</tr>
<tr>
<td>$\sigma_{x/y}$ [\mu m]</td>
<td>87.9 / 96.8</td>
</tr>
<tr>
<td>$\epsilon_{x/y}$ [mm mrad]</td>
<td>0.224 / 0.190</td>
</tr>
<tr>
<td>$\beta_{x/y}$ [m]</td>
<td>5.69 / 8.14</td>
</tr>
<tr>
<td>$\alpha_{x/y}$</td>
<td>-0.377 / 0.258</td>
</tr>
</tbody>
</table>

Lattice: TDS (two 0.8-metre cavities) + 5-metre drift

Simulations in elegant

Tomographic reconstruction in Python

16 streaking angles

No space charge
No jitter
No misalignments
Tomographic reconstruction

Input beam used for test simulations at the TDS

Example of correlation x-z that we wish to detect

Input beam production simulated by J. Zhu
Tomographic reconstruction

16 xy screen profiles [2D]

- Convert y to t and divide into slices (0.85 fs) [2D]

- For each slice, take projection on x axis [1D] and combine using tomographic reconstruction (SART algorithm) [2D]

- Stack slices [3D]
Tomographic reconstruction

Actual distribution at screen with TDS off

Reconstruction

Simulations in *elegant*

D Marx *et al* 2017 *J. Phys.: Conf. Ser.* 874 012077
Slice energy measurement

> Combine TDS with dipole

[Diagram showing magnetic chicane, deflecting cavity, and dipole with quadrupoles and screen.]

Not to scale

Max field = 1.4 T
Bending angle = 1.331 rad = 76.3°
Induced energy spread

> Panofsky-Wenzel Theorem:
  - Transverse deflection only possible if there is a transverse gradient of the longitudinal electric field present

\[ \nabla_{\perp} E_z \neq 0 \quad \Rightarrow \quad E_z \text{ present} \]

> Relative momentum gain: uncorrelated + correlated

\[
\sigma_\delta = \frac{eV_0k}{pc} \cdot \sigma_y = K \cdot \sigma_y
\]

\[
\frac{d}{dz} \delta = \frac{1}{6}K^2L
\]

> Fundamental resolution limitation

\[
\sigma_\delta \cdot \sigma_\zeta > \frac{e_y}{\sin(\Delta \Phi)}
\]

C Behrens and C Gerth, *Proc. DIPAC09*, paper TUPB44
C Behrens and C Gerth, *Proc. DIPAC11*, paper TUPD31
Slice energy measurement

Simulations in *elegant*

2 MV kick per cavity = 4 MV total

Preliminary results for 10.3 fs rms generated beam
No space charge
Applications

- SINBAD will provide short bunches for use as a witness beam in LWFA experiments and for testing dielectric structures
- TDS will allow characterization of input beam
- Dielectric structures
  - Inject asymmetric beams
  - Characterizing beam important for matching & aperture considerations
- LWFA experiments
  - Plasma fields (and matching conditions) have longitudinal dependence in certain regimes
  - Accelerating fields also influenced by beam offsets so charge profile can help, e.g. for beam loading

See W Kuropka & F Mayet posters tonight
Summary

- New X-band TDS being developed for use at DESY & PSI facilities
- Allows streaking of bunch at all angles
- Allows several different measurements of beam, which together provide a characterization of the beam
- Novel 3D charge density reconstruction and longitudinal phase space reconstruction techniques presented
- Induced momentum spread and longitudinal resolution make measurements at short bunch lengths a challenge
- Further studies needed, incl. collective effects
- Key applications for LWFA and dielectric experiments

Contact: daniel.marx@desy.de
Acknowledgements

Present team working on application of X-band technology at DESY:

In addition, we are supported by colleagues from CERN & PSI, including:
➢ A. Grudiev, W. Wuensch, N. Catalan Lasheras, G. Mcmonagle (CERN)
➢ P. Craievich, M. Bopp, M. Pedrozzi, R. Zennaro, H. Braun et al. (PSI)

Contact: daniel.marx@desy.de