Time-resolved Measurements using the Transversely Deflecting RF-Structure LOLA at FLASH (DESY)

Michael Roehrs, Holger Schlarb, Christopher Gerth, Andy Bolzmann, Markus Huening, Bolko Beutner
Outline

• Principle of measurements with LOLA
• LOLA and its integration into the FLASH-Linac
• Recent / possible measurements :
  – Longitudinal density profile
  – Slice emittance
  – Energy-time correlation
  – Horizontal slice centroid shifts
  – 3-dimensional spatial particle distribution
Introduction

- Maximum streak at 500 MeV: ~6mm/ps
- Streak depends on optics downstream of LOLA:
  \[ \Delta y \approx R_{34} \cdot y' \]

Courtesy: H. Schlarb, M. Nagl, M. Ross et al.
Some facts about LOLA

- Originally used as a rf separator for secondary particles (1968)
- Named after its designers G. Löew, R. Larsen, O. Altenmueller
- Already used for beam diagnostics at SLAC
- Installation at DESY in 2003, in operation since 2005

Courtesy: M. Nagl
LOLA installation at FLASH

Some important issues:

• Klystron
• Modulator
• Water Cooling
• Synchronization
• Kicker
• Diagnostic screen

The installation team:

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<tr>
<th>Field of activity</th>
<th>Group</th>
<th>Contact</th>
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<tr>
<td>Coordination at SLAC</td>
<td></td>
<td>M. Ross</td>
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<td></td>
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<td>D. McCormick</td>
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<td></td>
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<td>T. Smith</td>
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<tr>
<td>Coordination at DESY</td>
<td>MIN</td>
<td>H. Weise</td>
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<td>M. Nagl</td>
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<td>K. Klose</td>
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<td>Installation of LOLA and the vacuum components in</td>
<td>MVP</td>
<td>K. Zapfe</td>
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<td>the TTF2 Beamline.</td>
<td>MPL</td>
<td>H. Remde</td>
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<td>G. Weichert</td>
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<td>Waveguide</td>
<td>MVA</td>
<td>D. Jagnow</td>
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<td>H. Remde</td>
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<td></td>
<td>MIN</td>
<td>J. Rothenburg</td>
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<td>Modulator, Klystron 5045, RF Components</td>
<td>MIN</td>
<td>M. Rakutt</td>
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<td>J. Hermann</td>
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<td>Water-cooling</td>
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<td>F.-R. Ulrich</td>
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<td>Klystron + Cavity</td>
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<td>Synchronisation</td>
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<td>S. Simrock</td>
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<td>M. Ross</td>
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<td>BIS + Interlock</td>
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<td>M. Staack</td>
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<td>DOOCS</td>
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<td>K. Rehlich</td>
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<td>Trigger</td>
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<td>Diagnostic Screens</td>
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<td>K. Honkavaara</td>
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<td>D. Noelle</td>
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Courtesy: M. Nagl
## Parameters of LOLA IV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Type of structure</td>
<td>Constant impedance structure</td>
</tr>
<tr>
<td>Mode type</td>
<td>TM 11 (Hybrid Mode)</td>
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<tr>
<td>Phase shift / cell</td>
<td>120° (2 Pi / 3)</td>
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<tr>
<td>Cell length</td>
<td>35 mm</td>
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<tr>
<td>Design wavelength</td>
<td>105 mm</td>
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<tr>
<td>Nominal operating frequency</td>
<td>2856 MHz</td>
</tr>
<tr>
<td>Nominal operating temperature</td>
<td>45 °C</td>
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<tr>
<td>Quality factor</td>
<td>12100</td>
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<tr>
<td>Relative group velocity</td>
<td>1.89 %</td>
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<tr>
<td>Filling time</td>
<td>0.645 µs</td>
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<tr>
<td>Attenuation</td>
<td>0.477 N = 4.14 dB</td>
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<tr>
<td>Transverse shunt impedance</td>
<td>16 Ω / m</td>
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<tr>
<td>Deflecting voltage</td>
<td>(V_\circ = 1.6 \text{MV} \cdot \text{L/m} \cdot (\text{P}_\circ / \text{MW})^{1/2})</td>
</tr>
<tr>
<td>Nominal deflecting voltage</td>
<td>26 MV at 20 MW</td>
</tr>
<tr>
<td>Maximum operating power</td>
<td>25 MW</td>
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<tr>
<td>Length of structure</td>
<td>3640 mm (about 12 feet)</td>
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<td>Disk thickness</td>
<td>5.84 mm</td>
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<tr>
<td>Iris aperture</td>
<td>44.88 mm</td>
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<tr>
<td>Cavity inner diameter</td>
<td>116.34 mm</td>
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<tr>
<td>Cavity outer diameter</td>
<td>137.59 mm</td>
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Courtesy: M. Nagl
LOLA in the FLASH beamline

Beam direction

UND6 ... UND1 Collimator LOLA ACC5 ACC4 BC3 ACC2 ACC3 BC2 ACC1 GUN

Q9ACC7 Q9/10ACC6 Q9/10ACC5 Q9/10ACC4

Off-axis screen

Horizontal Kicker

LOLA

Courtesy: H. Schlarb
Screen Calibration

- For fixed power: measurement of the vertical beam position for different phases $\phi$
  \[ \Delta y \approx \text{const} \cdot \phi, \quad \phi = \omega_{LOLA} \cdot \Delta t \]

- For arbitrary power:
  \[ \frac{\Delta y}{\Delta t} = \text{const} \cdot \sqrt{P_0} \]
Measurements with LOLA:
Longitudinal density profile

Δt [ps] norm. density
Δt_{spike} = 132.8 ± 8.3 fs (FWHM)
Q_{spike} = 0.230 ± 0.016 nC

LOLA off:

LOLA on:

→ Resolution depends on the vertical beam size at the screen

132 fs (FWHM);
0.23 nC (1nC bunch charge)
Measurements with LOLA:
Horizontal slice emittance

→ scan of quadrupole(s) upstream of LOLA
→ measurement of horizontal slice widths
→ both BCs on, 4.5 deg from maximum compression

Subdivision into slices:

→ emittance blow up in the head
→ gradually changing twiss parameters along the bunch
Measurements with LOLA:

Energy – time correlation

- Measurement on screen 5ECOL in a dispersive section

- Calibration of screen, measurement of horizontal dispersion \( \Delta E \) on x-axis and time on y-axis of the screen

\[
\frac{\Delta E}{E_o} \text{ on x-axis and y-axis of the screen}
\]

\[
\text{Dispersion at 5ECOL; reference current } I_0 \text{ of D1ECOL: 111.5 A}
\]

\[
\text{Fit: } D = -29386.4972 \text{ pixel} = -290.9263 \text{ mm}
\]
Energy-time correlation: Both BCs by-passed

Dispersion: $D = 290$ mm
Energy-time correlation: BC3 on, ACC23 off-crest

ACC23–phase: −32 deg.

LOLA off:

→ slice energy width
→ Calculation of the peak current?
→ Comparison with simulations

CSR/ longitudinal space charge forces
Scan of ACC23-phase

ACC23-phase: −32 deg.

ACC23-phase: −31 deg.

ACC23-phase: −30 deg.

ACC23-phase: −29 deg.

ACC23-phase: −27 deg.

ACC23-phase: −26 deg.

rms energy width for different ACC23 phases

rms bunch length for different ACC23 phases
Measurements with LOLA: Tomography

- Scanning the LOLA power allows to reconstruct the 3-dimensional spatial particle distribution
  → reconstruction of the vertical slice emittance?
  → combination with phase space tomography?
Measurements with LOLA:
Slice centroid shifts

• Energy-loss due to coherent synchrotron radiation in the dipoles of the bunch compressors lead to horizontal slice centroid shifts
• Comparison with simulations (Bolko Beutner)

Over-compressed beam with slice centroid shifts

BC2 off, BC3 on, overcompression
Summary and Outlook

LOLA is a very powerful device especially well-suited for measurements of bunch length and the spatial particle distribution, slice emittance, energy-time correlations and for studies of CSR- and space charge effects.

Future plans:

• Measurement of slice-emittance and energy-time correlation under SASE- conditions (planned for August 2006)
• Comparison with simulations
• Study of slice-centroid shifts (Bolko Beutner)
• Reconstruction of the complete spatial particle distribution by tomography
- LOLA IV transverse deflecting structure fabricated in 1968 for use in the End Station C secondary beam as an RF separator.

- It was called LOLA after its designers, Greg LOew, Rudy Larsen and Otto Altenmuller.

- The use of transverse RF for secondary beam separation, where secondary particles of different species are naturally phase shifted by their time of flight, was first proposed in the 1950’s.

- Twenty MW in the LOLA structure delivers a peak integrated deflecting field of 33 MV.

Courtesy: M. Ross