Karlsruhe Institute of Technology

Beam Transport System from a Laser Wakefield Accelerator to a Transverse Gradient Undulator

Christina Widmann - 19 June 2014

Laboratory for Applications of Synchrotron Radiation / ANKA

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Outline

Basic Experimental Concept

Layout of the Beam Transport System
- Target Parameters at the Undulator
- Initial Parameters for the Transport System

Tracking Studies

Summary and Outlook

Properties of Laser Wakefield Accelerators

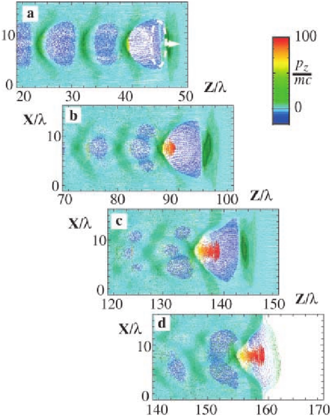

Fig.: Electron acceleration in a plasma wave.

- acceleration gradients $\sim 100\,\text{GV/m}$
- short acceleration length $< 1\,\text{cm}$
- electron energies up to 1 GeV
- bunch length $\sim 5\,\text{fs}$

but

- energy spread of some percent

A. Pukhov et al., Appl. Phys. B 74, 2002

Concept of Transverse Gradient Undulators

Idea: Matching of the electron energy to the magnetic field amplitude

$$\gamma \rightarrow \gamma(x)$$
$$B_{y_0} \rightarrow B_{y_0}(x)$$

undulator equation:

$$\lambda = \frac{\lambda_u}{2\gamma(x)^2}\left(1 + \frac{K(x)^2}{2}\right)$$

with $K = \frac{e}{2\pi m_0 c}\lambda_u B_{y_0}(x)$

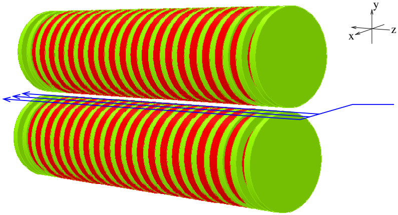

Fig.: Working principle of the TGU.

Compensation of the energy spread of the LWFA.

T.I. Smith et al., J. Appl. Phys 50, no. 3, 1979 *and* G. Fuchert et al., NIMA Vol.672, 2012

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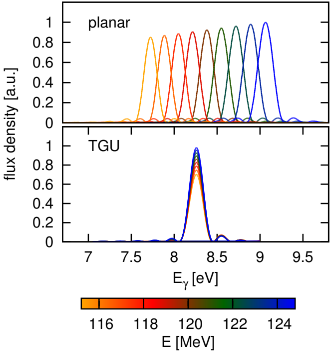

Fig.: Spectra of a planar undulator vs. TGU.

Compensation of the energy spread of the LWFA.

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Basic Experimental Concept

Aim: No increase of the undulator radiation bandwidth despite the energy spread of the LWFA.

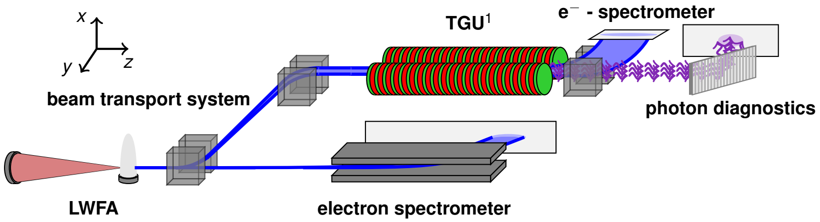


Fig.: Sketch of the setup planned at the LWFA in Jena.

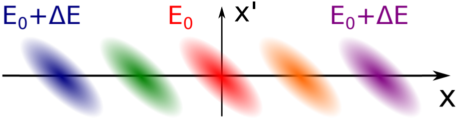
Design assumptions

- central electron energy $E_0 = 120\,\mathrm{MeV}$
- energy acceptance of the undulator $\Delta E / E = \pm 10\,\%$

[1] V. Afonso Rodriguez et al., IEEE, vol. 23, no. 3, 2012 and WEPRO036, these proceedings

Target Parameters at the Undulator

Considering monoenergetic beamlets



for each beamlet

- $\langle x \rangle_b$ - average position of beamlet
  $\rightarrow$ wavelength of the radiation
- $\langle x' \rangle_b < 0.1\,\text{mrad}$
  $\rightarrow$ parallel beamlets

$\Rightarrow$ linear target parameters:
$D = \text{-}0.02\,\text{m}$ and $D' = 0$

- small beam size in x
  $\rightarrow$ bandwidth of the spectrum

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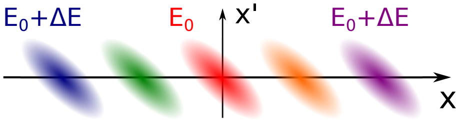

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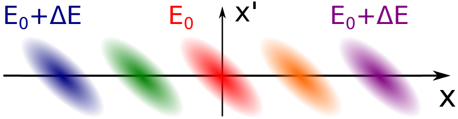

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Optimum beta functions

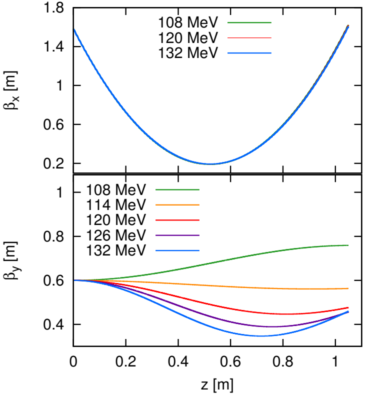

Fig.: Beta functions along the undulator.

Initial Parameters for the Transport System

measured at

the LWFA in Jena:

bunch size σ_{x_p} inside the plasma

- $\sigma_{x_p} = 0.7\,\mu$m
  measured via betatron radiation
- $\sigma_{x'_0} = 2.5$ mrad

M. Schnell et *al.*, Phys. Rev. Lett. 108, 2012

the ALPHA-X beamline (UK):

emittance measurements
using the pepperpot method

- average geometrical emittance
  $\varepsilon = 8.8$ nm rad
- $\sigma_{x'_0} = 2$-4 mrad
- estimated source size $\sigma_{x_0} = 3\mu$m

E. Brunetti et *al.*, Phys. Rev. Lett. 105, 2010

For this study:

initial parameters

σ_{x_0,y_0}	$4\,\mu$m
$\sigma_{x'_0,y'_0}$	2.5 mrad
ε_{x_0,y_0}	10 nm rad

- with beam waist
  at the exit of the LWFA
- same parameters in both planes

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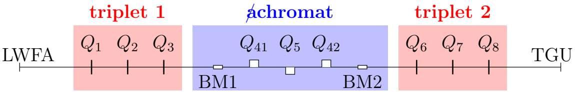
Linear Layout of the Transport System



- initial divergence
  → large beta functions
- high quadrupole strengths required
- longitudinal phase space not considered

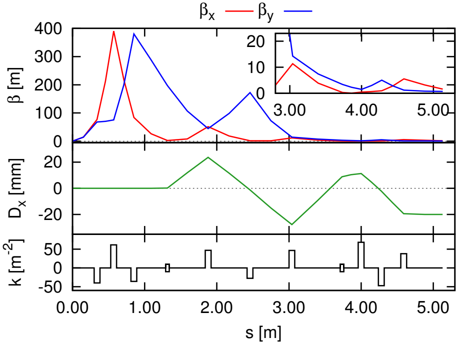


Fig.: Linear beam functions calculated with MAD-X.

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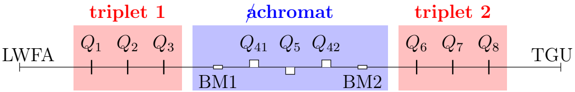

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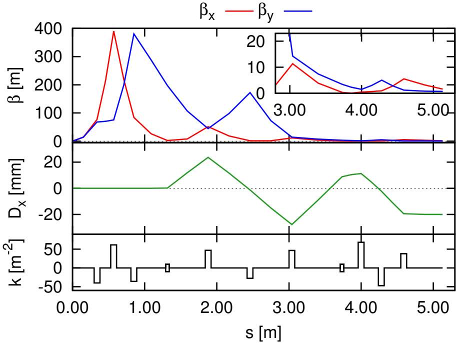

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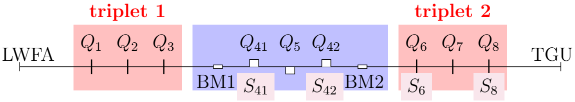
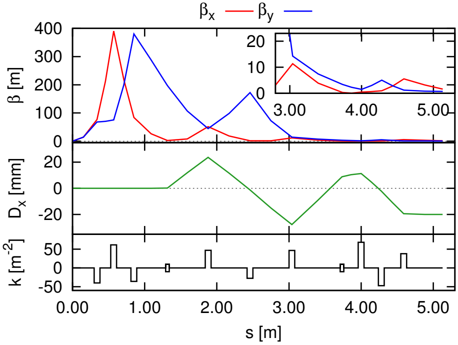
Chromatic Correction of the Transport System



Chromatic correction with combined quadrupole-sextupoles

$\Rightarrow$ requires $D \neq 0$

- S_{41} and S_{42}: large $\beta_{x,y}$ $\rightarrow$ strong distortion
- correction mainly at S_6 and S_8 preferable



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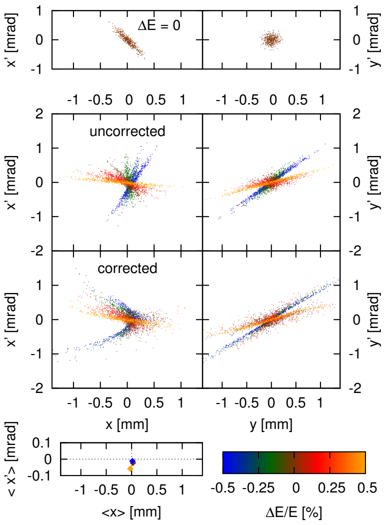
Phase Space Distribution with Correction



Phase space distributions calculated with PTC.

7 monoenergetic beamlets

- $\frac{\Delta E}{E} = \pm 0.5\,\%$
- $\sigma_{x_0} = 4\,\mu\text{m}$
- $E_0 = 120\,\text{MeV}$
- $\sigma_{x'_0} = 2.5\,\text{mrad}$

- $\langle x' \rangle$ in required range
- strong distortion in (x, x')
- increase of nonlinearities, but no improvement on correction with higher sextupole strengths

Reasons for that?

- strong quadrupoles $\rightarrow$ large chromatic abberation
- emittance too large

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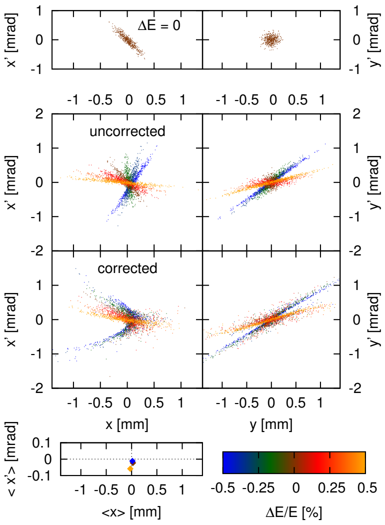

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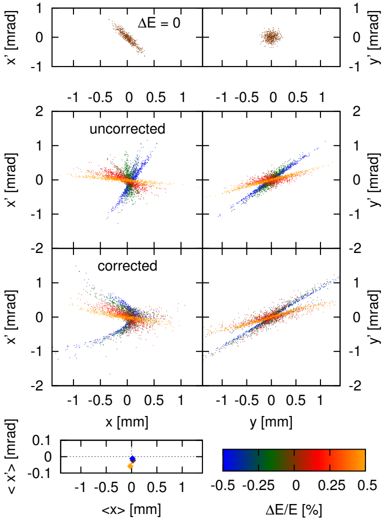

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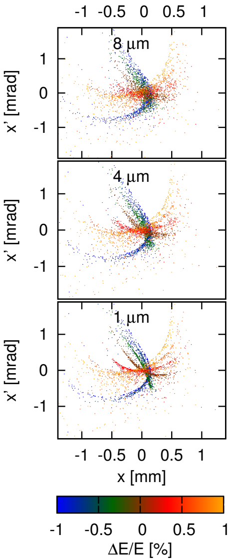
Variation of Source Size and Initial Divergence



$\Delta E / E = \pm 1.0\,\%$

Source size σ_{x_0}

increase to 8 μm

decrease to 1 μm

- slight increase of divergence with increasing σ_{x_0}

Initial divergence $\sigma_{x'_0}$

decrease to 2 mrad and 1 mrad

- reduction of beam size
- less distortion of phase space distribution

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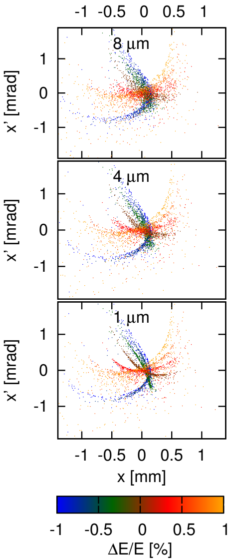

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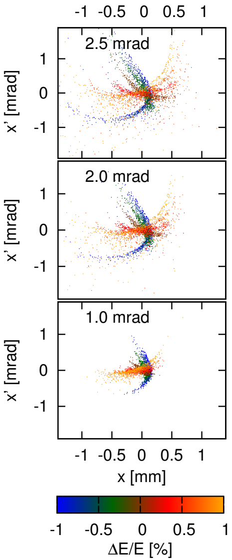
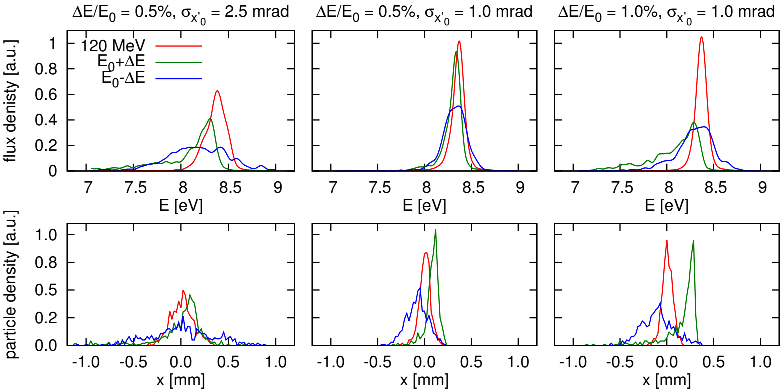


Radiation Spectra with Reduces Divergence

- simulation of the radiation spectra with *WAVE*[1]

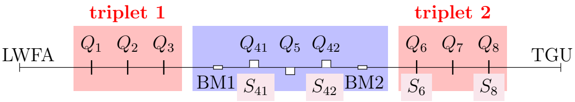


⇒ reducing the divergence leads to significantly improved results

[1] M. Scheer, ICAP'12, TUACC2 (2012)

Summary and Outlook

Layout of the beam transport system with combined function magnets:



- high quadrupole strengths required up to $k = 70/\mathrm{m}^2$
- chromatic correction causes strong nonlinearities
- emittance and divergence of the source
  are the limiting parameters for the chromatic correction

next steps

- iterative co-optimization of undulator and beam parameters
- investigation of higher order multipole correction schemes
- improvement of source parameters is essential

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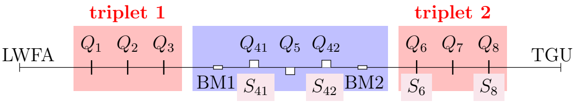

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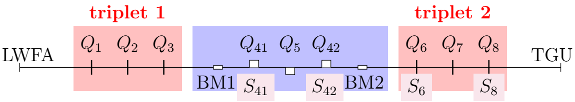

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