Construction of the BEAST II Undulator

FEL - Seminar

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CFEL SCIENCE

LAOLA. is a collaboration of

BEAST II TEAM

LUX Magnet <u>design</u>
-Geometry and fields of magnets and poles
-Order magnets

Florian Holy
Munich-Centre for Advanced Photonics

LUX undulator <u>construction</u>
-Order poles
-Design and build support structure
-Measure field

BEAST II TEAM

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I. Dornmair

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With great support from J. Bahrdt (HZB)

Outline

> LUX Overview

> Undulator Field and Trajectories

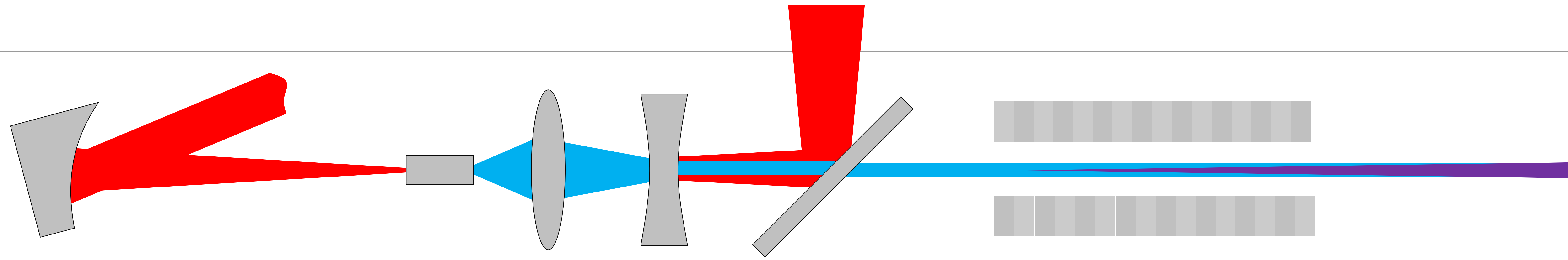
> Design parameters & error estimation

> Undulator Design & Construction

> Field Quality Measurement

> Conclusion & Outlook

Laser plasma driven undulator light source - LUX



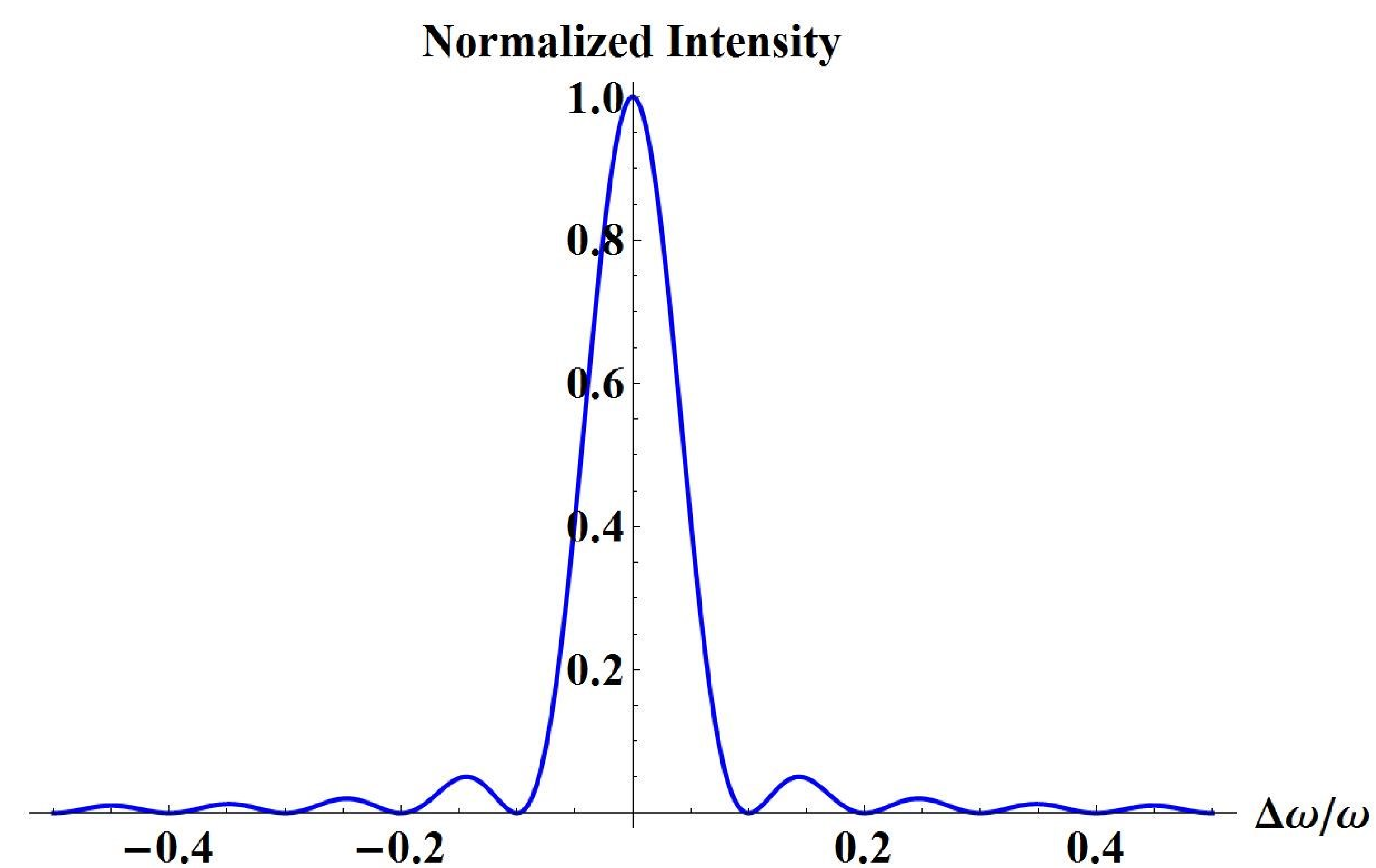
-High power laser (200 TW) focused into gas target

-creates plasma channel in which electron bunches are created & accelerated towards highly relativistic energies

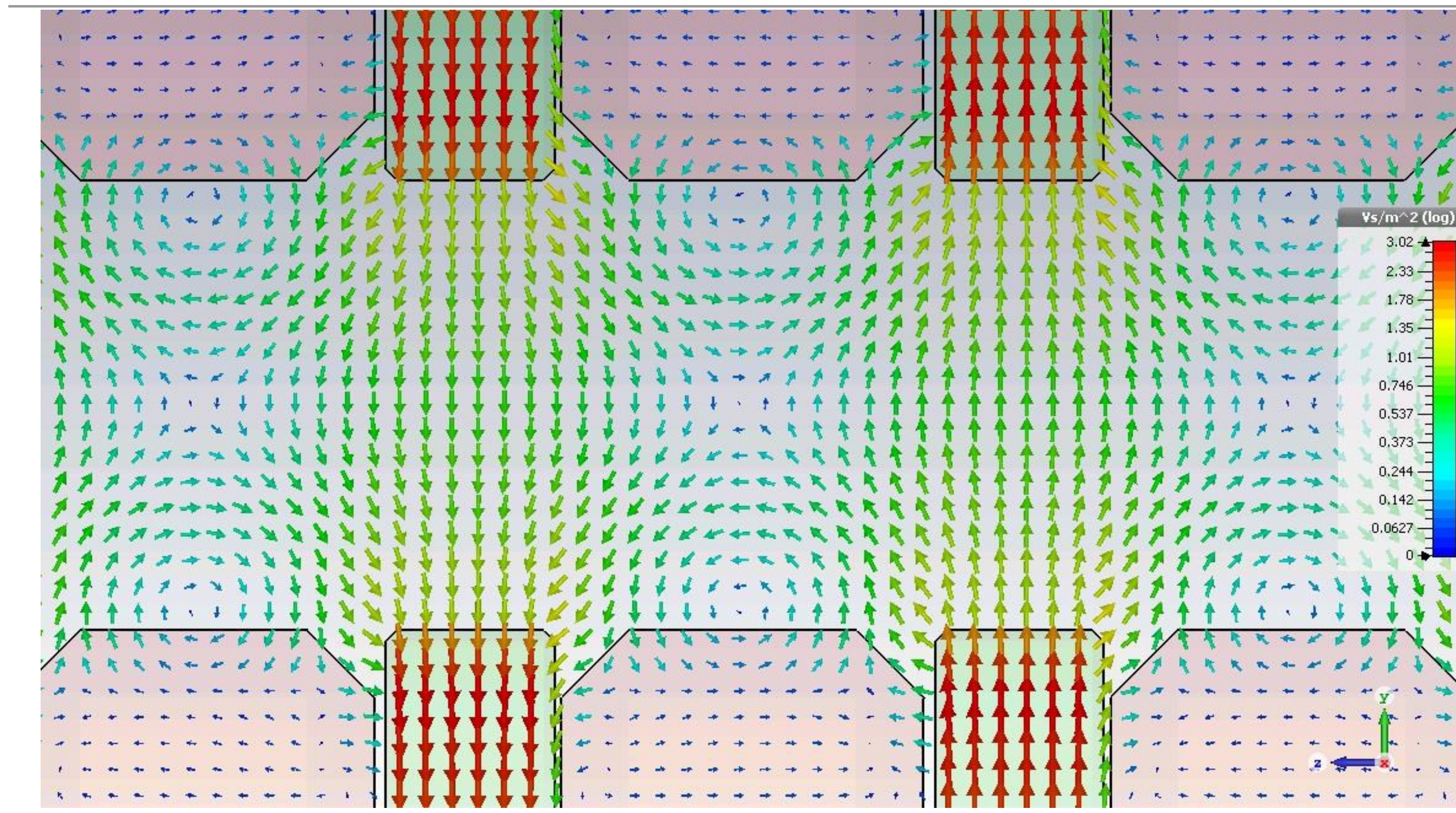
-Electrons captured with quadrupole magnets
Laser outcoupled to diagnostics

-Electrons focused into alternating dipole structure called undulator
Electrons wiggle around orbit and start to radiate

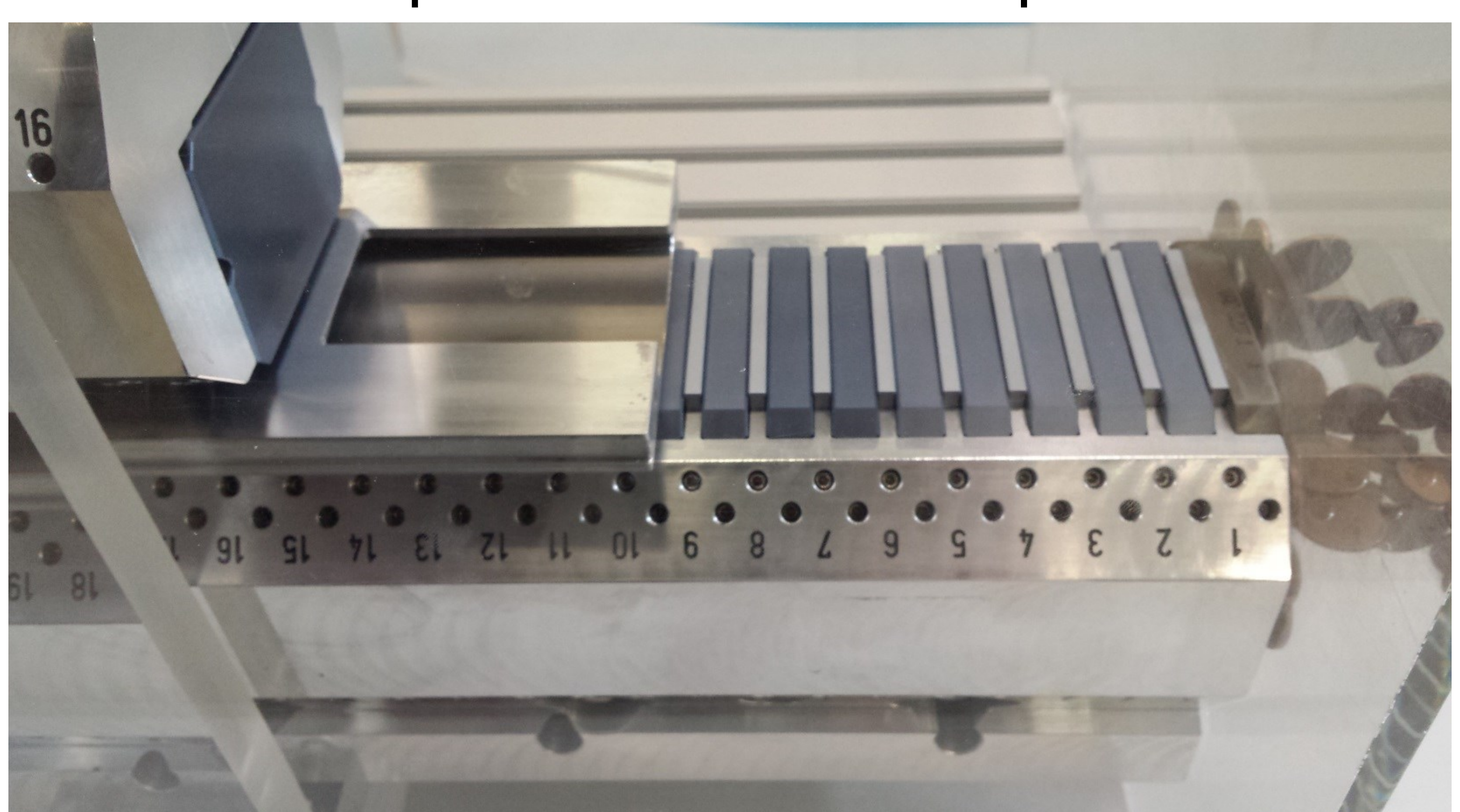
-Undulators produce tunable light pulses with high Intensity in a narrow bandwidth



Hybrid Undulator Field

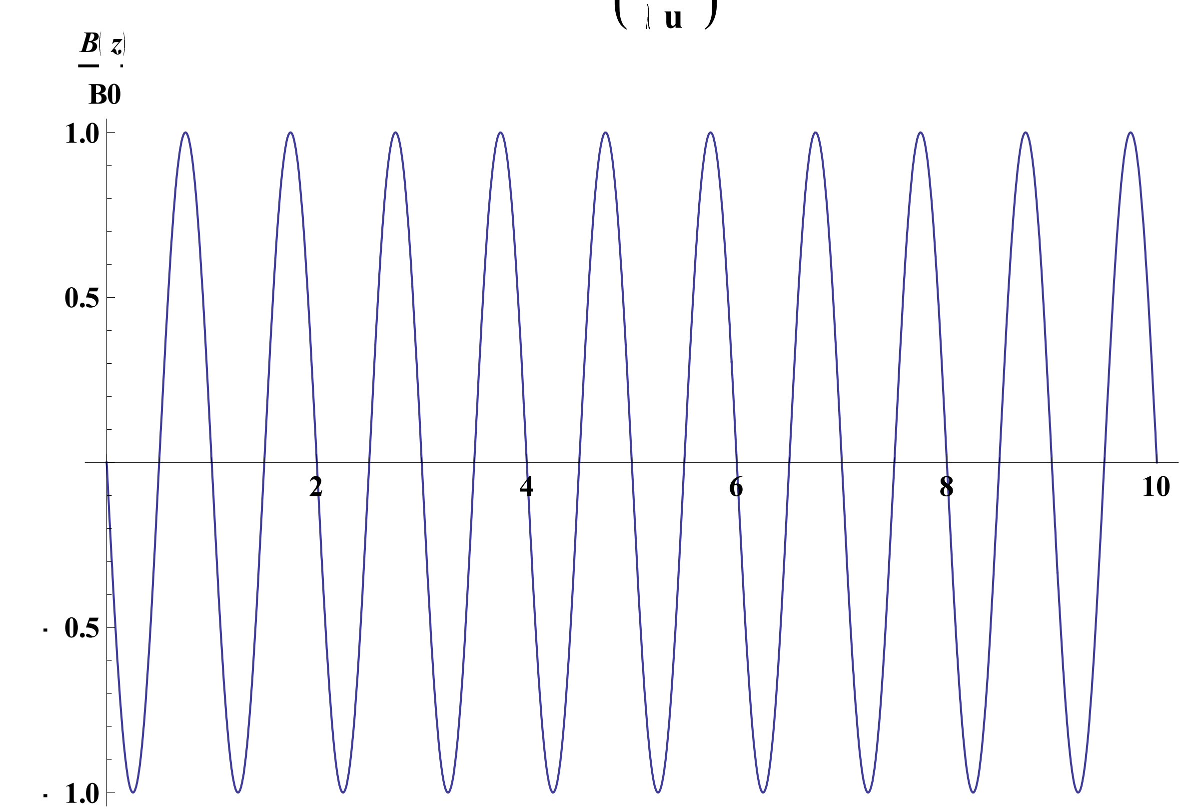


One period = λu = two dipole fields



Field on axis

$$B_y = -B_0 \sin\left(\frac{2\pi}{\lambda_u} z\right)$$

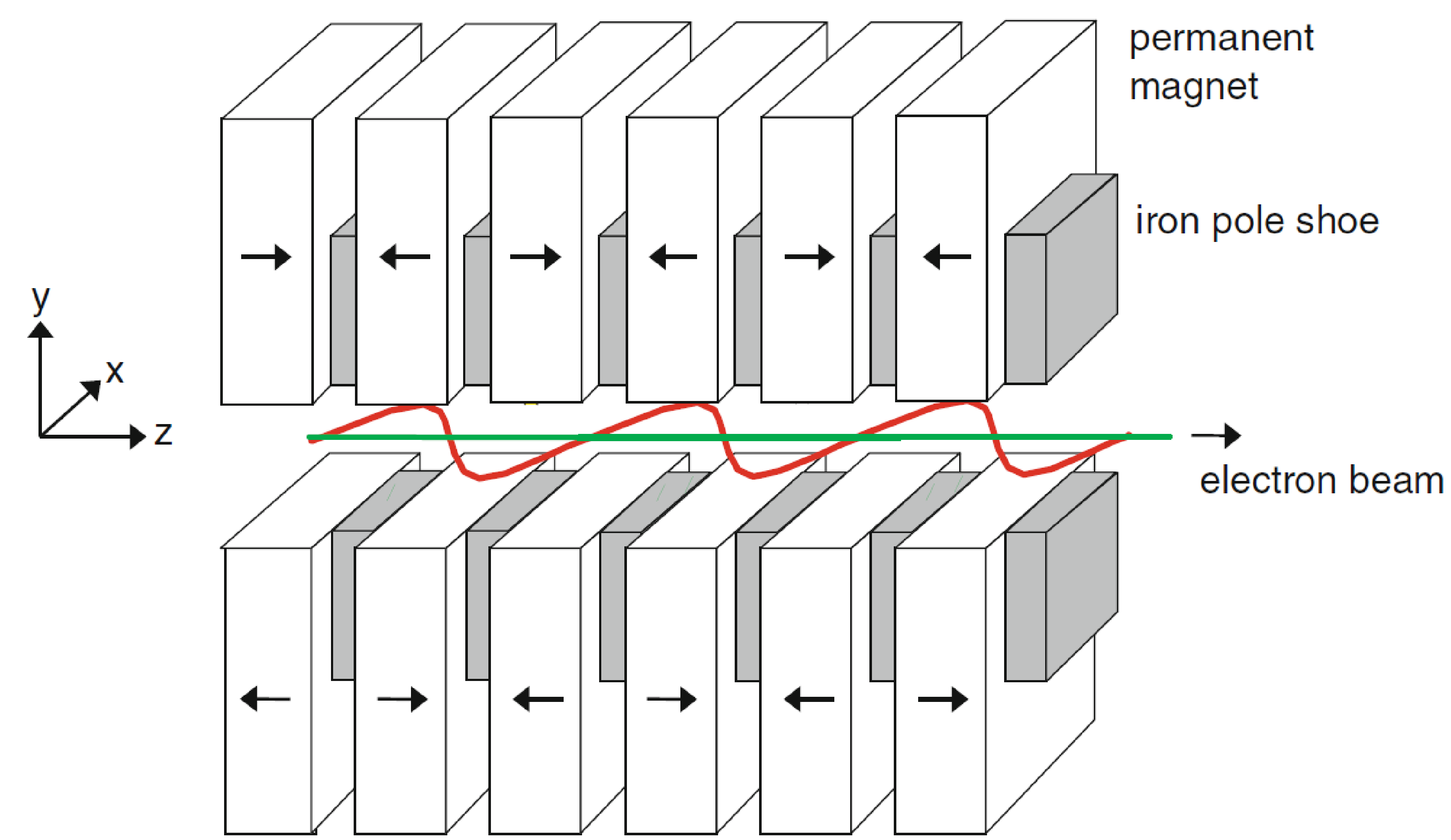


Undulator Trajectory - Physics

Field on axis
$B_y = -B_0 \sin(k_u z)$

$k_u = \frac{2\pi}{\lambda_u}$

Lorentz force:
$F = q(\vec{v} \times \vec{B})$



CR: Schmüser, Dohlus, Rossbach, Behrens – „Free-electron Laser in the Ultraviolet and X-Ray Regime“

Transverse velocity:
$\beta_x(z) = \frac{K}{\gamma} \cos(k_u z)$

Amplitude of deflection $K = \frac{\lambda_u e B_0}{2 \pi m c} = 0.934 B_0[T] \lambda_u[cm]$

Pure machine parameter!

Electrons oscillate, start to emit radiaton

Lorentz contraction and Doppler effect:

Central wavelength of radiation cone $\lambda_{obs} = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$

Interference effect:

Observed bandwidth shrinks with number of periods N : $\frac{\Delta\lambda}{\lambda} = \frac{1}{N}$

Undulator Trajectory - Engineering

Relevant for construction

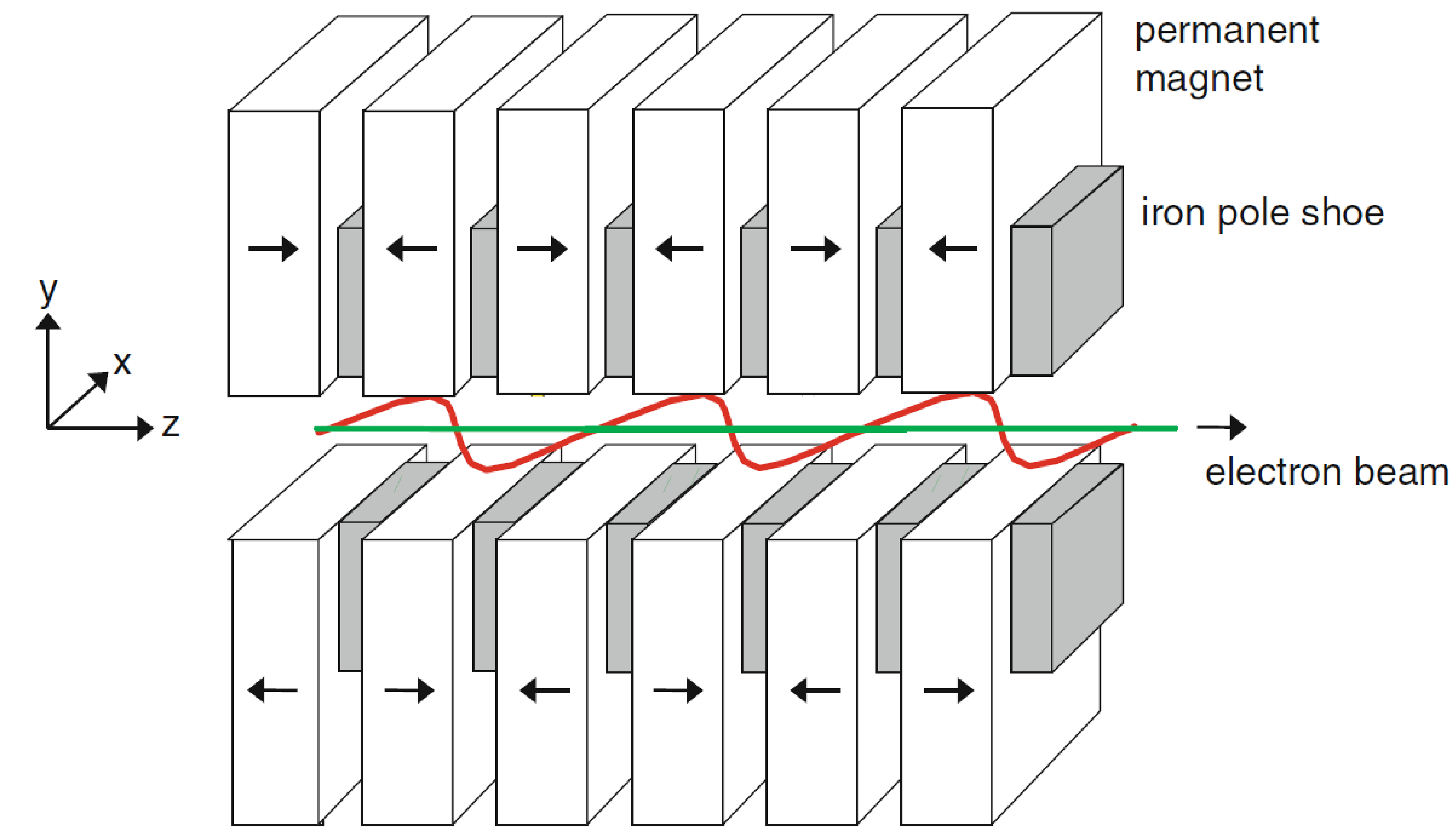
Keep fabricational errors as small as possible!

make magnetic field transparent over whole device

Field on axis: $\mathrm{B_y} = \mathbf{B_0} \sin\left(\frac{2\pi}{\lambda_u} z\right)$

Deflection: $\beta_x(z) \sim \int \mathrm{B_y}\, dz \coloneqq J_1 = 0$

Offset: $x(z) \sim \int \int \mathrm{B_y} dz dz' \coloneqq J_2 = 0$



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Influence of error sources should be smaller than bandwidth

BEAST II Design Parameters and Error Estimation

Design considerations:
In vacuum
Periods : 100
λ_u: 5 mm
Fixed gap 2 mm
Total length : 0.5 m
B_0 = 0.67 T
K = 0.3
γ = 800

λ=4.26 nm
E=291 eV
$\theta = 128$ µrad

$$\frac{\Delta\lambda}{\lambda} = 1\%$$

All other error sources should be in the range of 1%!

BEAST in a nutshell

Difference between global error and local errors
Local errors:
- errors in individual periods
- worsen performance

Global errors:
- Constant error in each period
- lead to different operation range of the whole machine

Pulsed Wire Measurement

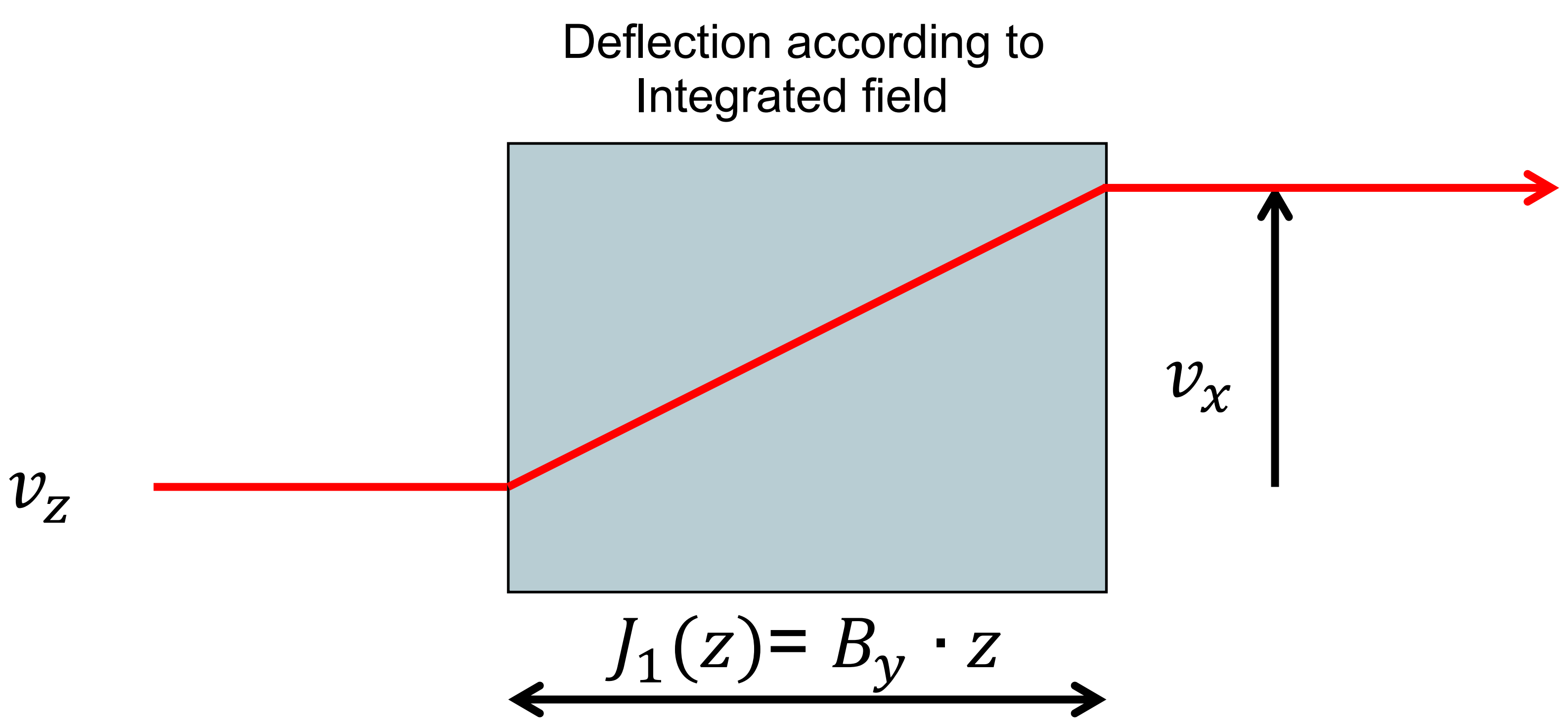
<u>Used to measure longitudinally resolved field integrals</u>

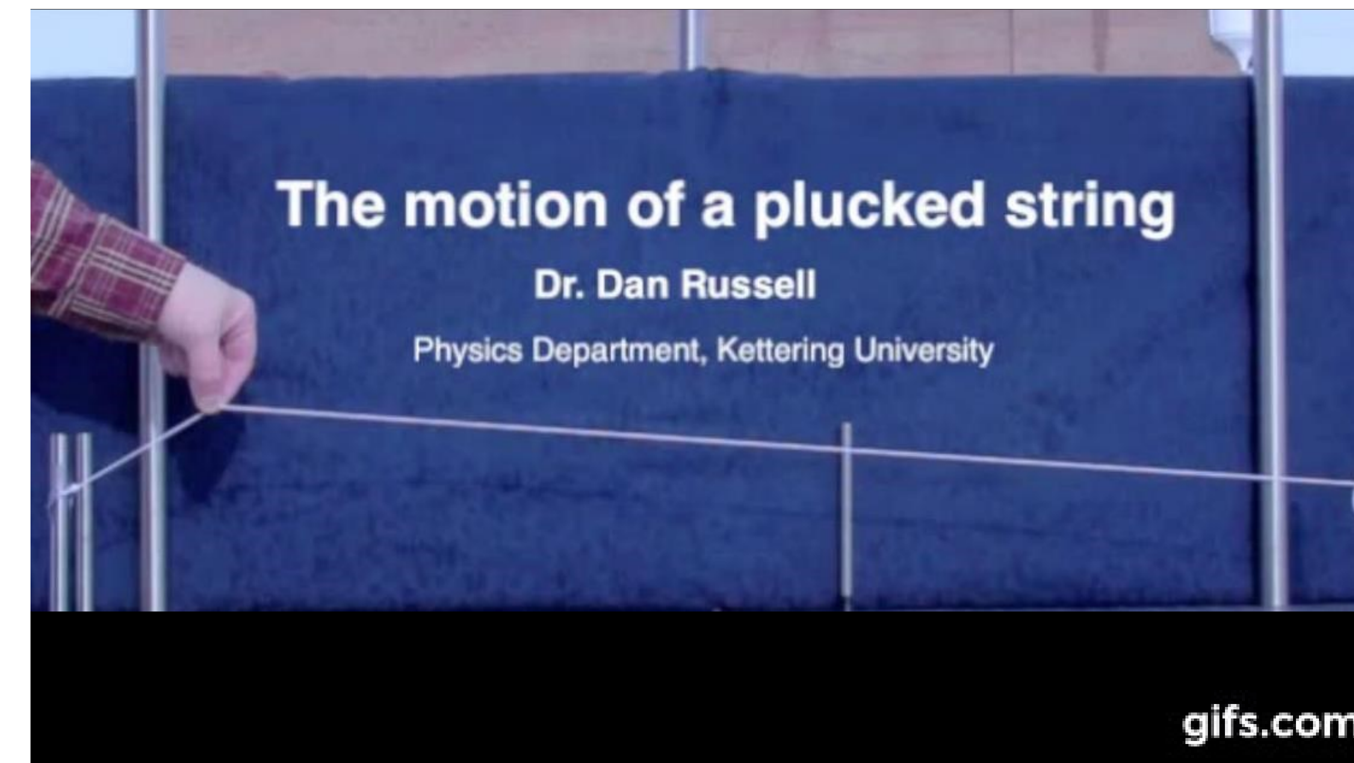
Field integrals represent transverse velocity/position change due to a force

Deflection: $v_x = \int \frac{F_{Lo}}{m}\, dt \sim \int B_y\, dz := J_1$

Field integral

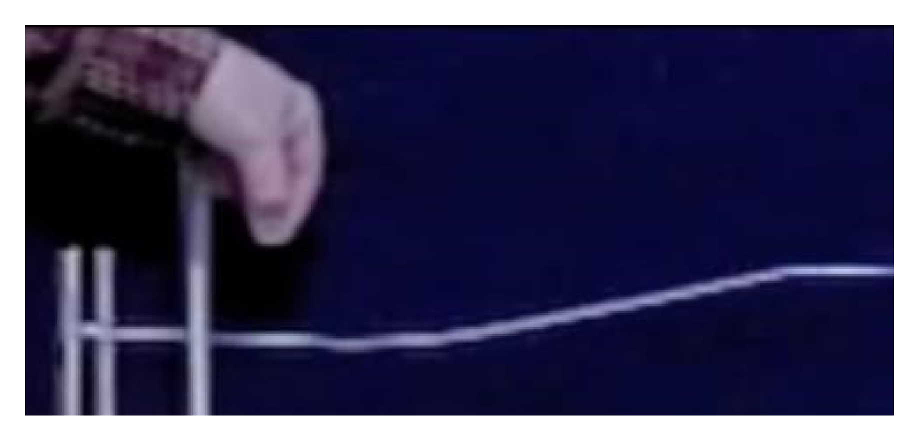
$$J_1(z) = \int_0^{v_z \cdot t} B_y(z) dz = B_y \cdot z$$





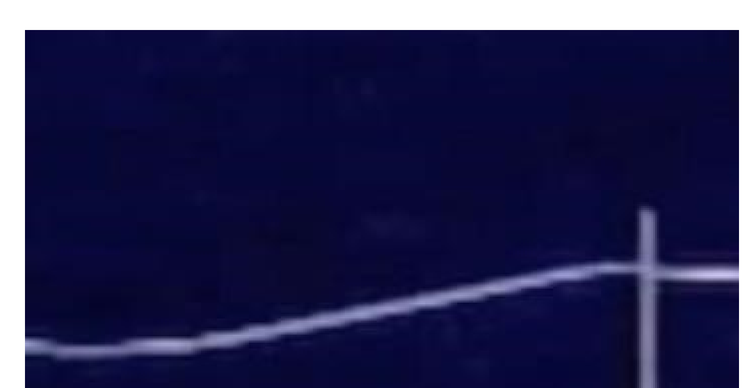
Release wire:
Short force effect $\delta\tau$

$$\frac{dx}{dt} = \frac{F\delta\tau}{m} \rightarrow dx = \frac{F\delta\tau}{m} dt$$



=>Kick travels along the wire and generates wavefront

$$dx = -\frac{F\,\delta\tau}{2\, v_w \cdot m}\, dz$$



At the detector:
wavefronts sum up
as a step function

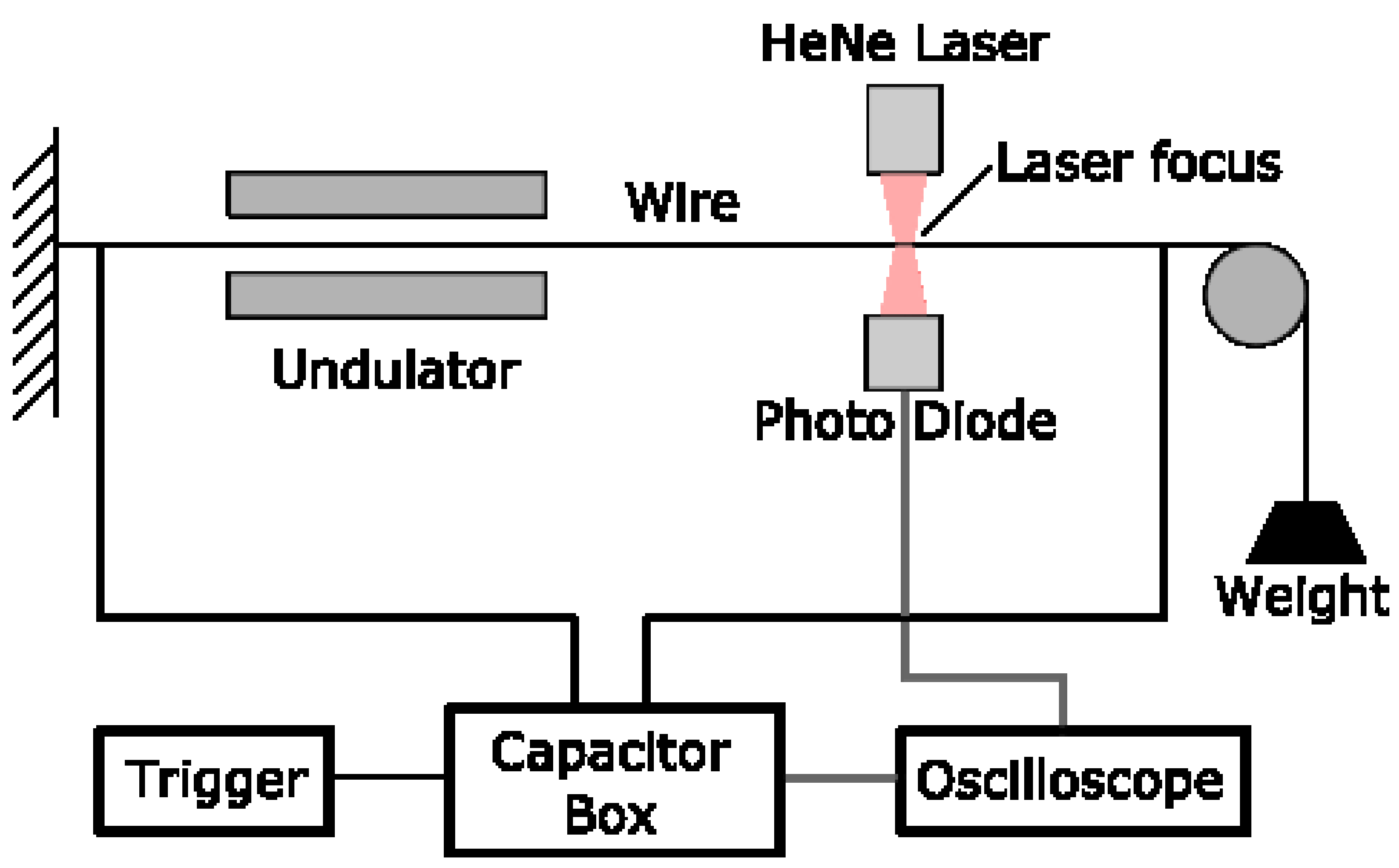
$$x(t) = -\frac{\delta\tau}{2\, v_w \cdot m} \int F\, dz$$

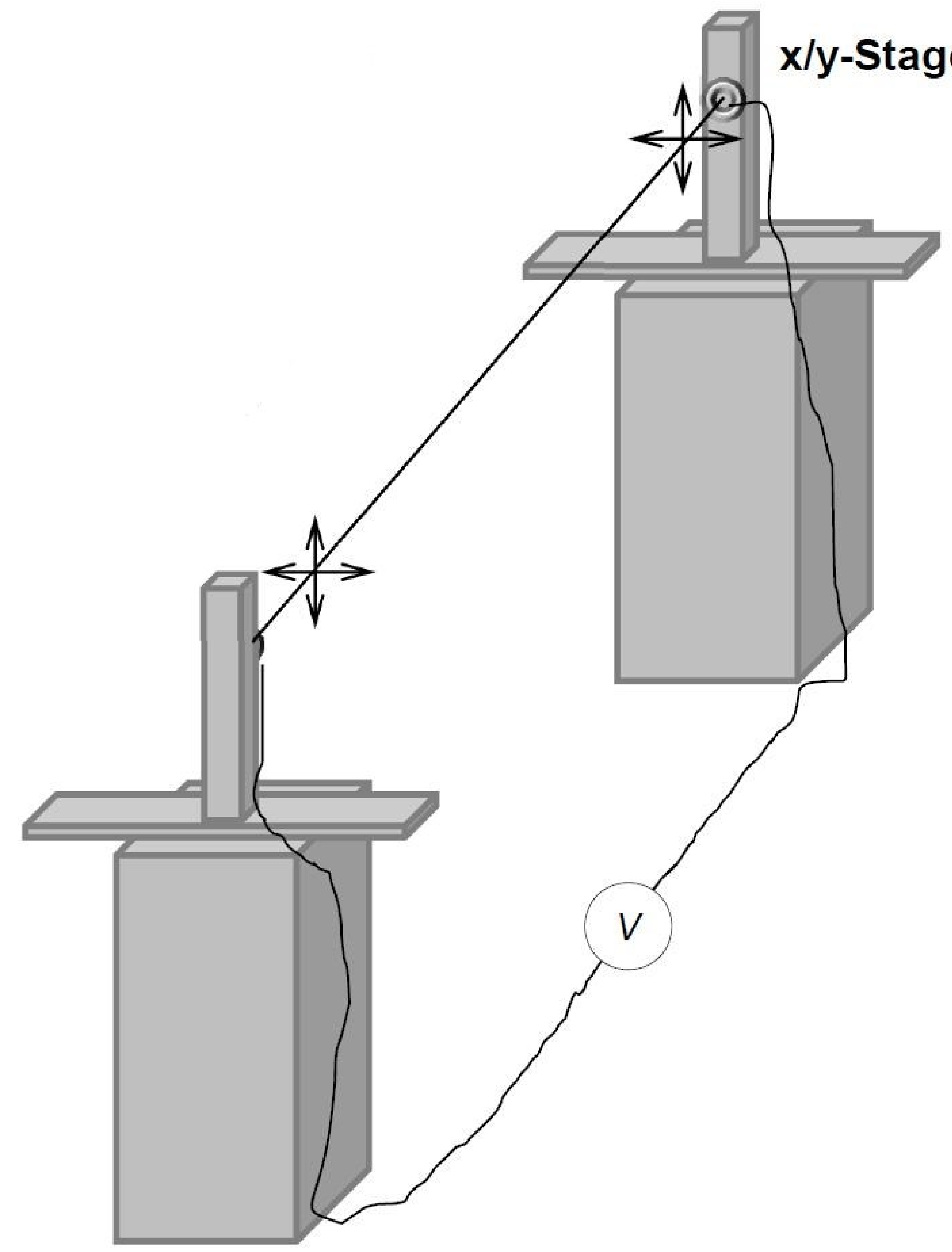
Pulsed Wire Measurement

Wire: curent circuit!

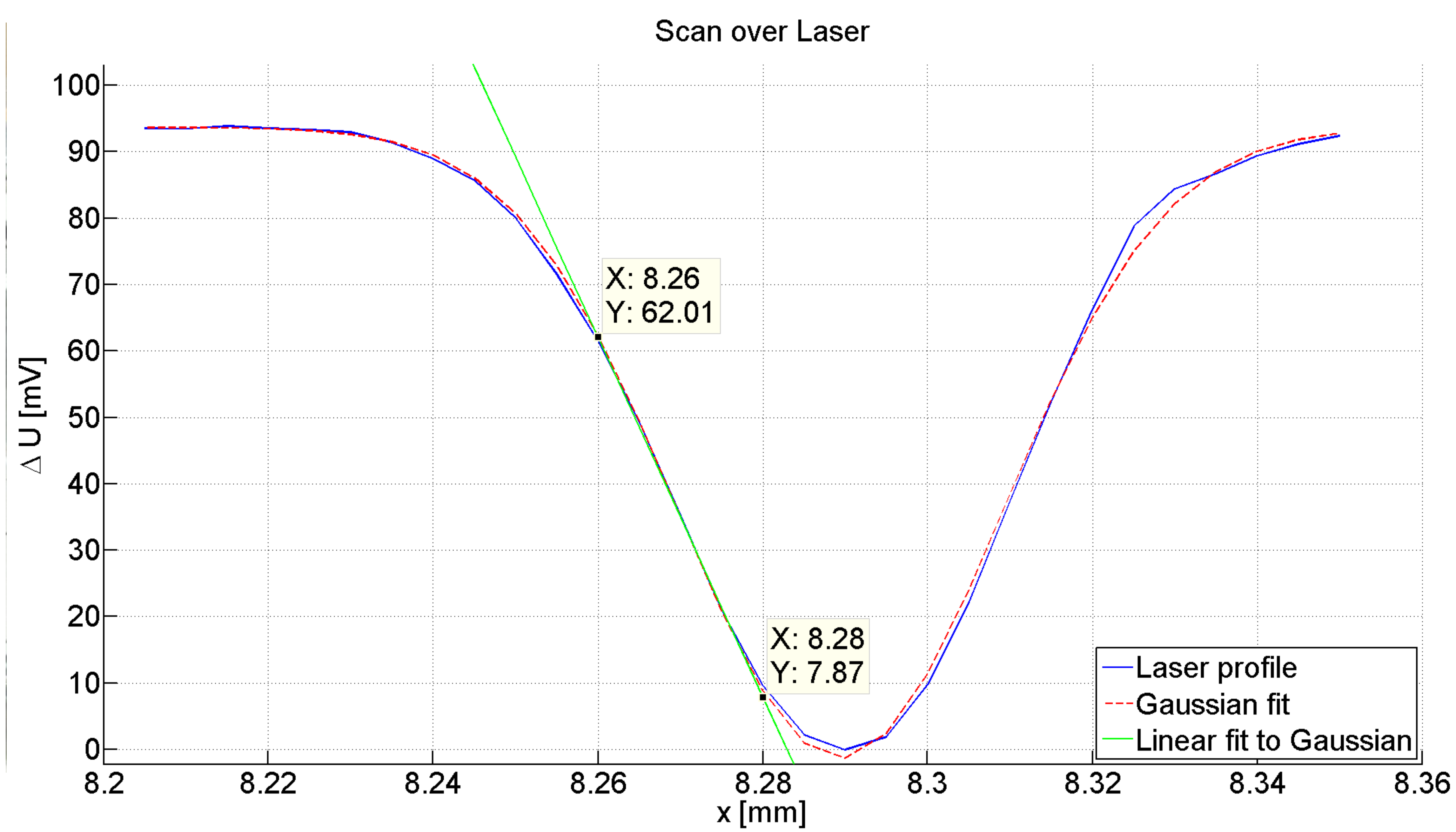
$F_{Lo} = I \cdot l \cdot B$

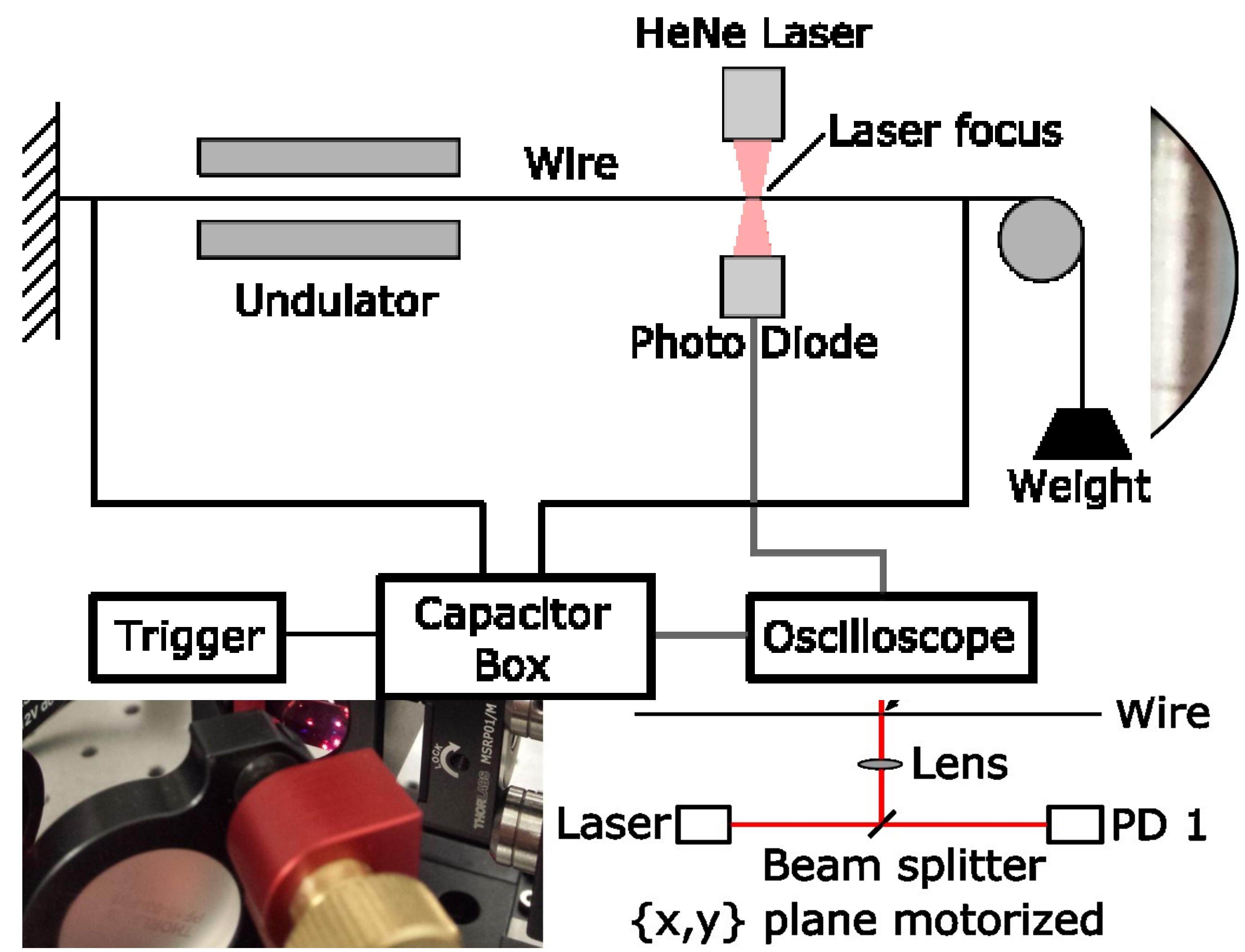
-) Current pulse I flows simultaniously
-) Magnetic fields act simultaniously
-) Wire gets deflected => acoustic waves!





Pulsed Wire Measurement – Setup





Calibration $c_{cal} = -2707\ \frac{V}{m}$

Linear regime: $\delta\ U_{cal} = \pm 26 mV$

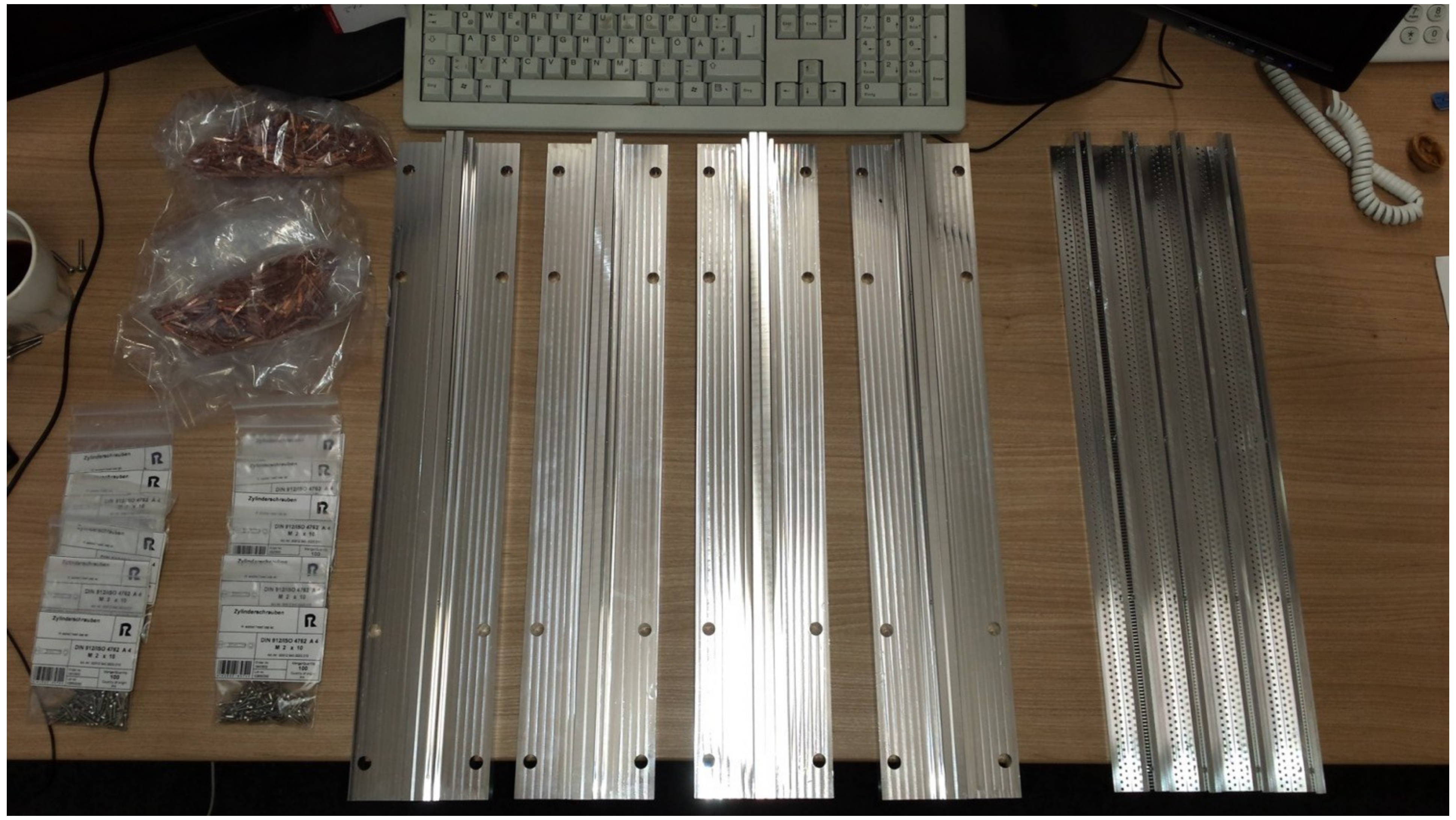
Conclusion - Manufacturing

<u>Challenge:</u>
Mass production of high precision elements!

Project was rejected by over 30 companies

Solution:
University Workshop!

Stephan Fleig (Master chief)
Christian Reimer (Wire erosion)
Jonas Hoelzer (CNC Milling)
Konstantin Herbst (CNC Milling)



Thank you for your attention!

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