

Wissenschaftliches Rechnen als Anleitung zum wissenschaftlichen Arbeiten

Laser in der Krebstherapie

Michael Bussmann, Computergestützte Strahlenphysik

HZDR



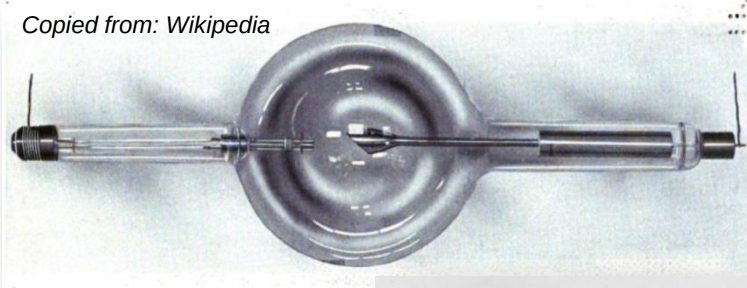
HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

Teilchen- beschleuniger

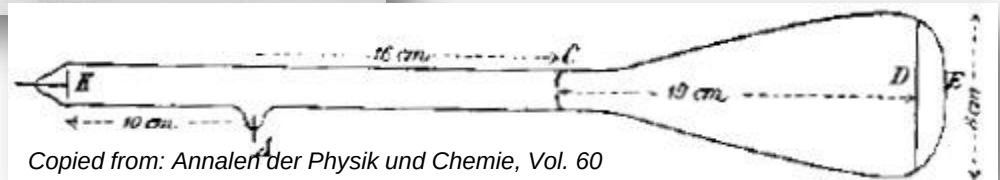


100 Jahre Beschleunigerforschung

Copied from: Wikipedia



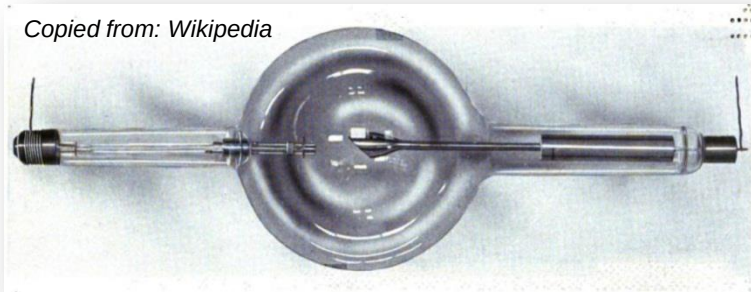
Copied from: GE Flickr foto stream



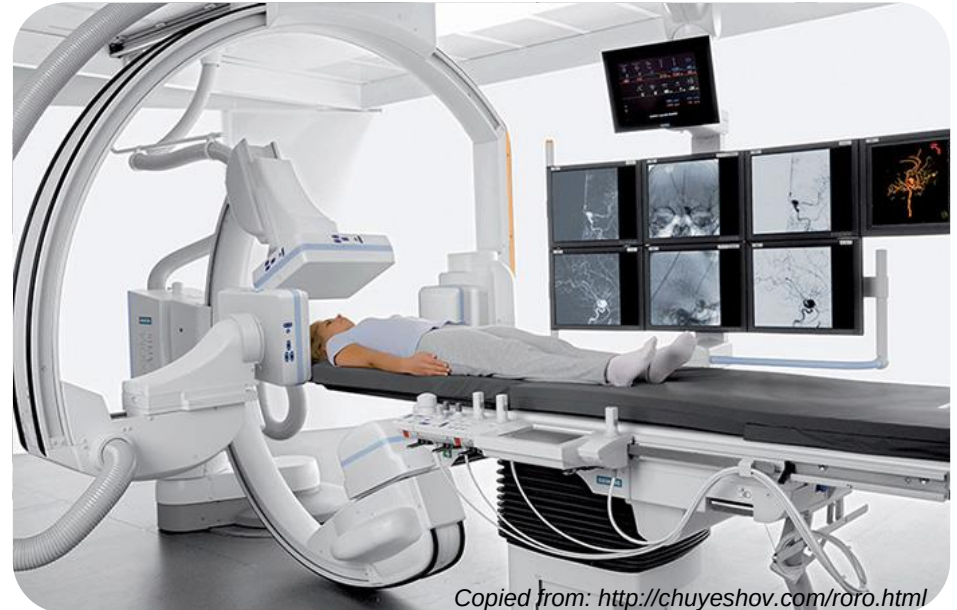
Copied from: Annalen der Physik und Chemie, Vol. 60

Elektronenröhren vom Beginn des 20. Jahrhunderts

Medizinische Anwendungen



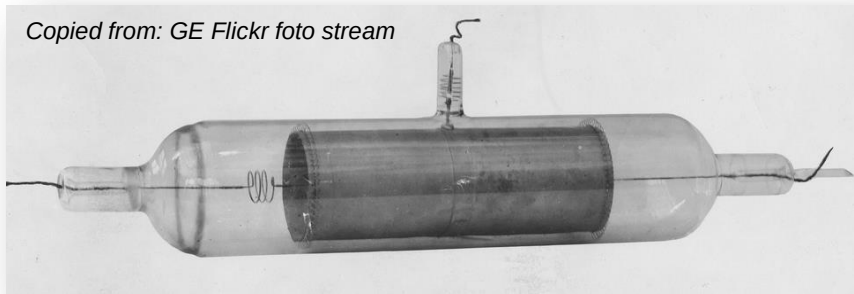
Coolidge X-Ray Tube



Copied from: <http://chuyeshov.com/roro.html>

Siemens Axiom Artis dBA

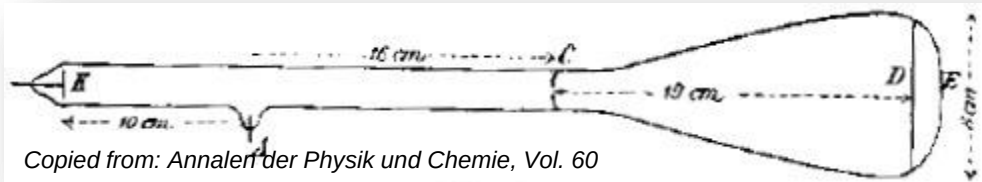
Haushaltsgeräte



Hull Magnetron



Microwave



Braun Tube



TV Cathode Ray Tube

Große Laser für die gute Sache





Laser- Teilchenbeschleunigung

Laserintensität

100 TW Laser

$$I = 10^{20} \text{ W/cm}^2$$

$$E_0 = 10^{12} \text{ V/m}$$

3 J in 30 fs

0.1 mm²

$$I = 10^{20} \text{ W/cm}^2$$

Laser charakterisieren

Pulsdauer

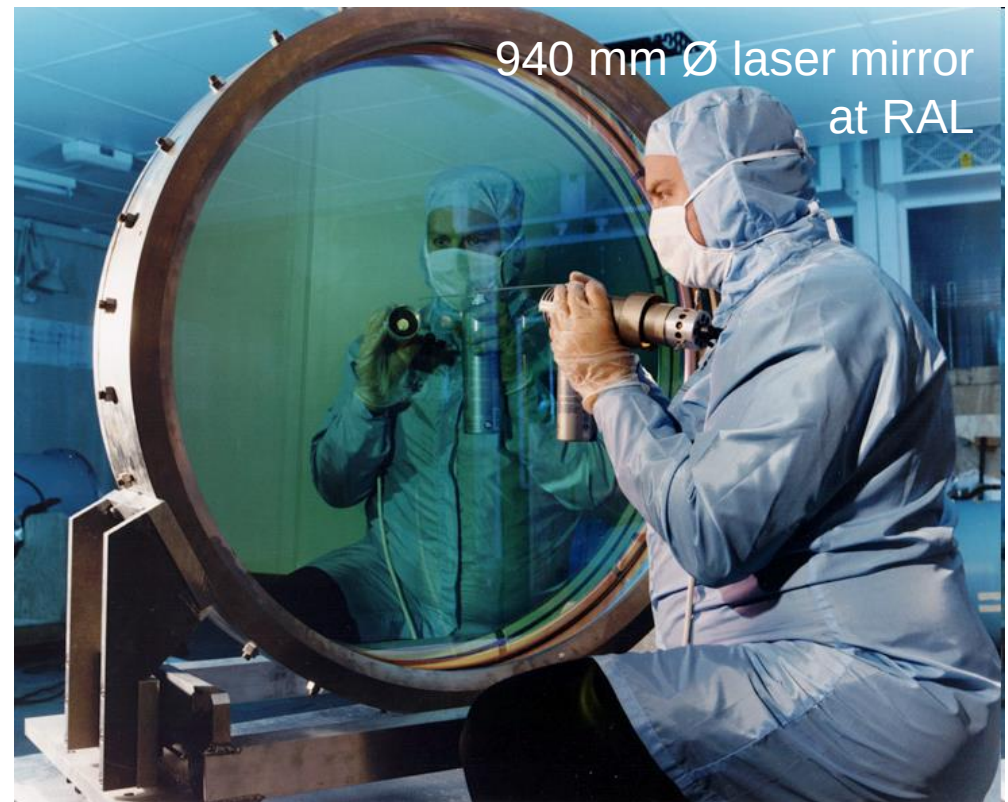
- Ultrakurz (10 fs – 1 fs)
- Kurz (ps - 100 fs)
- Lang (ns)

Energie im Puls

- mJ
- J
- kJ bis MJ

Wiederholrate

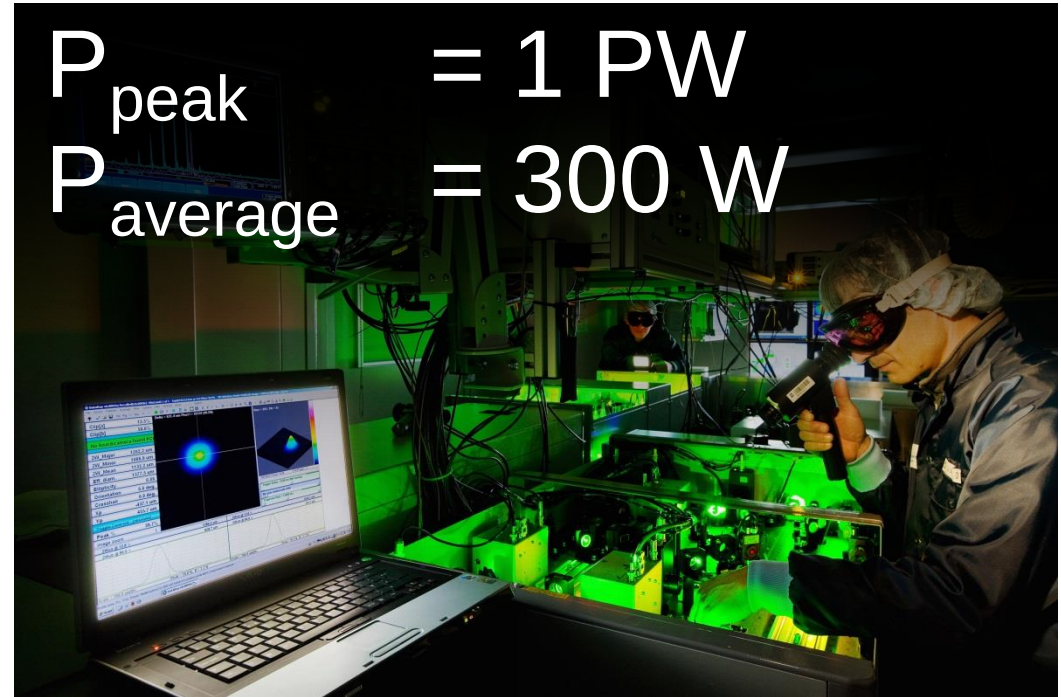
- kHz to MHz
- Hz
- 1/h bis 1/Tag



Spitzenleistung und Durchschnittsleistung

$$P_{\text{peak}} = \frac{E_{\text{pulse}}}{\tau_{\text{pulse}}}$$

$$P_{\text{average}} = E_{\text{pulse}} f_{\text{repetition}}$$



DRACO Laser am HZDR

- Wiederholrate
- Pulsenergie
- Pulsdauer

$$f_{\text{repetition}} = 10 \text{ Hz}$$

$$E_{\text{pulse}} = 30 \text{ J}$$

$$\tau_{\text{pulse}} = 30 \text{ fs}$$



Laserparameter a_0 — Relativistische Intensitäten

$$a_0 = \frac{eE_0 \lambda_{\text{Laser}}}{2\pi m_e c^2} = 0.85 \times 10^{-9} \times \sqrt{I_{\text{laser}} [\text{W} / \text{cm}^2]} \times \lambda_{\text{laser}} [\mu\text{m}]$$

$$a_0 = 1 \Rightarrow \underbrace{eE_0 \lambda_{\text{laser}}}_{\sim \text{kinetische Energie im Laserfeld}} \approx \underbrace{m_e c^2}_{\text{Ruheenergie eines Elektrons}} \xRightarrow{\lambda_{\text{laser}} = 1 \mu\text{m}} I_0 \approx 1.38 \times 10^{18} \text{ W} / \text{cm}^2 \quad \underbrace{\hspace{1cm}}_{\text{Intensität, bei der Elektronen relativistisch werden}}$$

$$a_{0,\text{ion}} = \frac{m_{\text{ion}}}{m_{\text{electron}}} a_{0,\text{electron}}$$

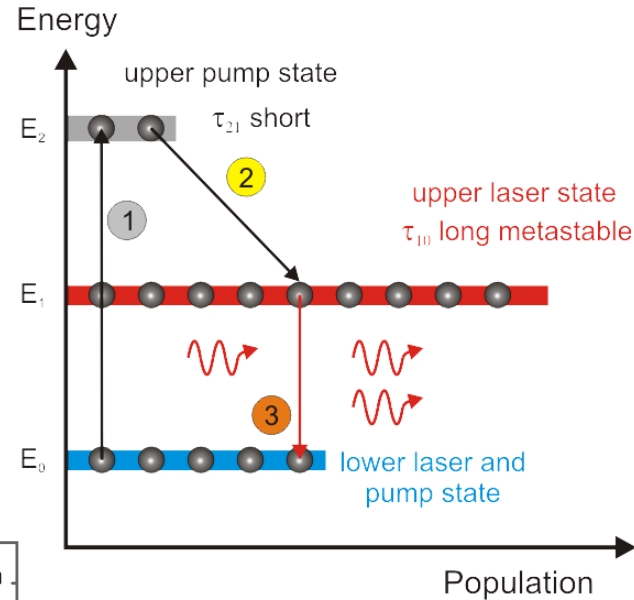
$$\lambda_{\text{laser}} \approx 1 \mu\text{m}$$

$$I_{\text{DRACO}} = 10^{18} \text{ W} / \text{cm}^2 \dots 10^{21} \text{ W} / \text{cm}^2$$

Laserverstärkung

Dreilevelsystem

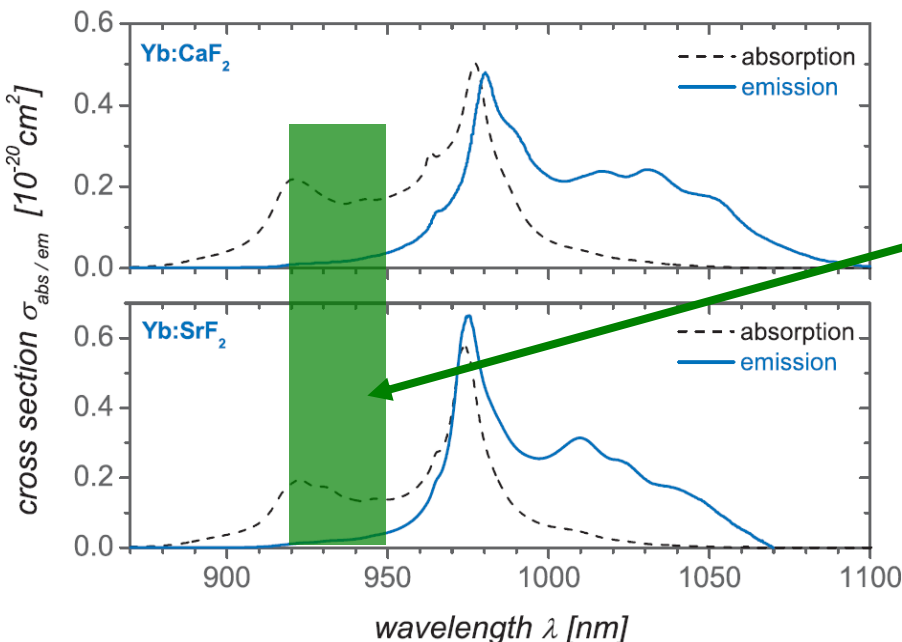
- Pumpwellenlänge (grün)
- Schneller Zerfall in langlebigen Zustand
- Populationsinversion
- Stimulierte Emission (Lasing)



Pumpwellenlänge

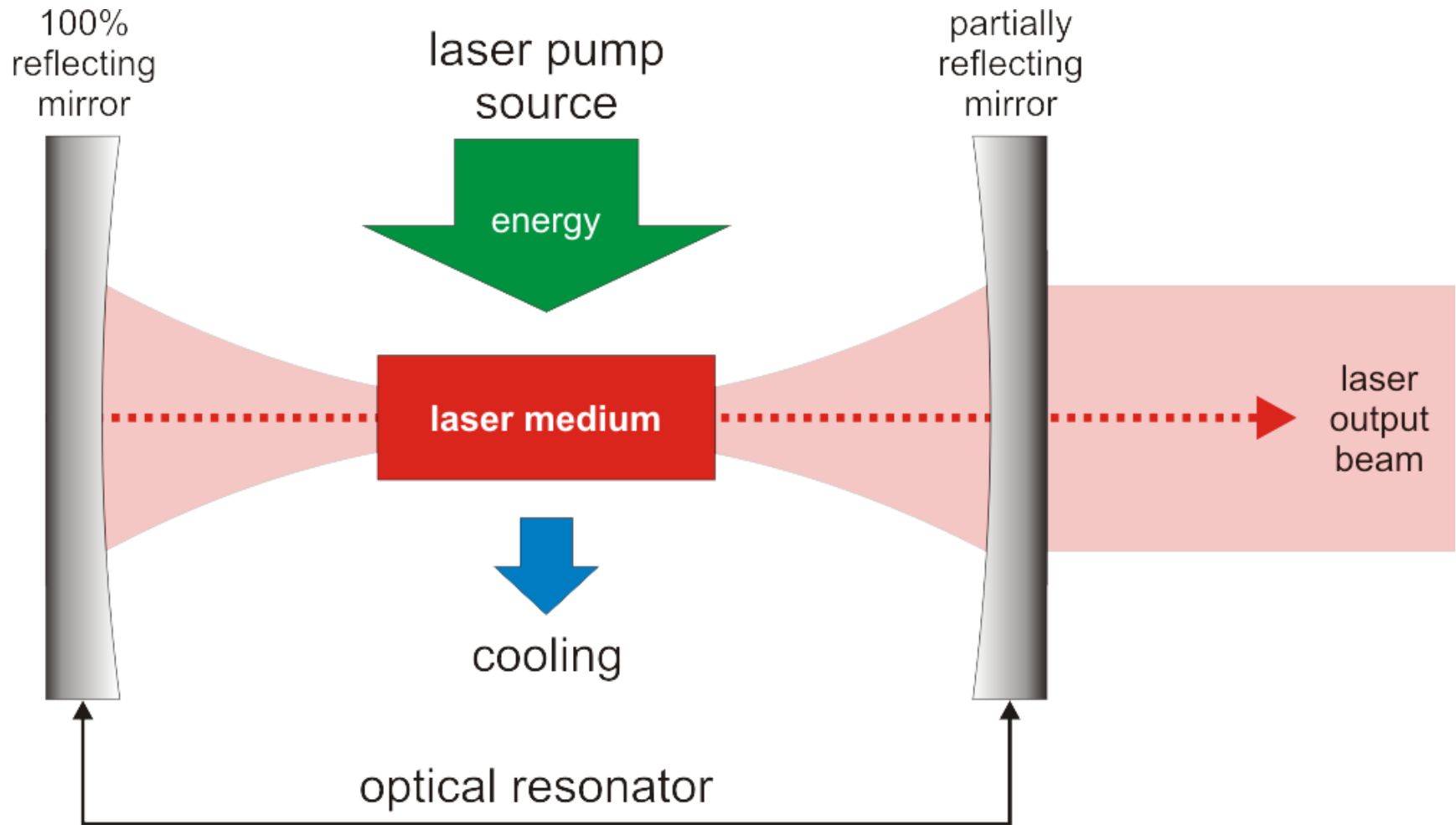


Pumplaserdioden
(gestapelt)

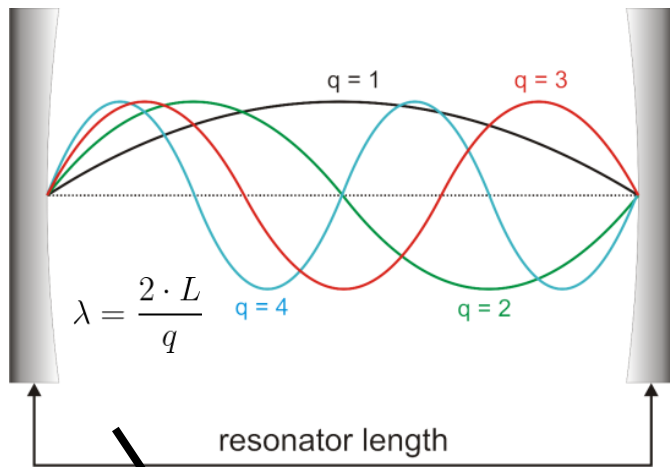


V. Petit et al., Appl.Phys.B **78**, p.681, (2004).
M. Siebold et. al., Opt.Lett. **32** p.1818 (2007).

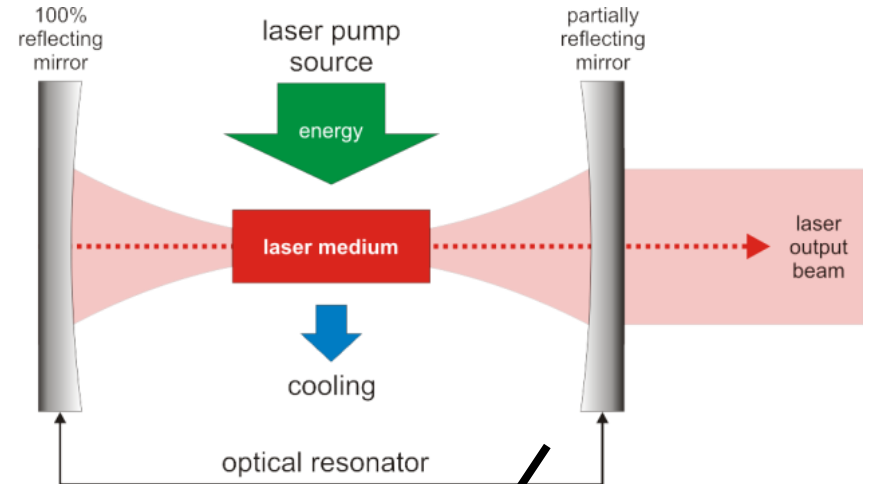
Laserberstärkung



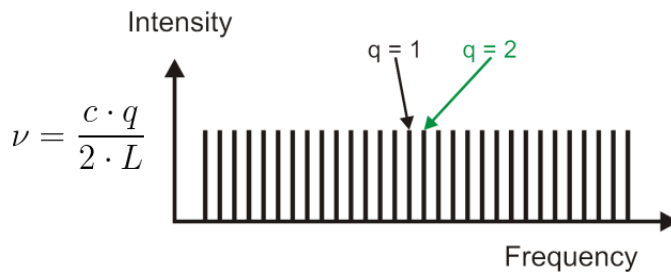
Kurzpulserzeugung durch Interferenz in Resonator



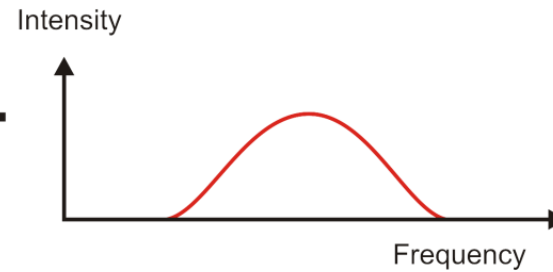
Resonator modes



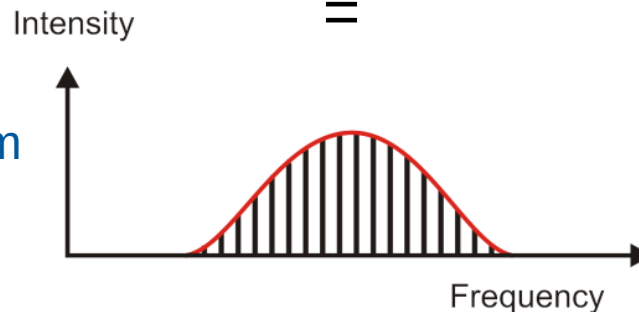
Gain spectrum



+



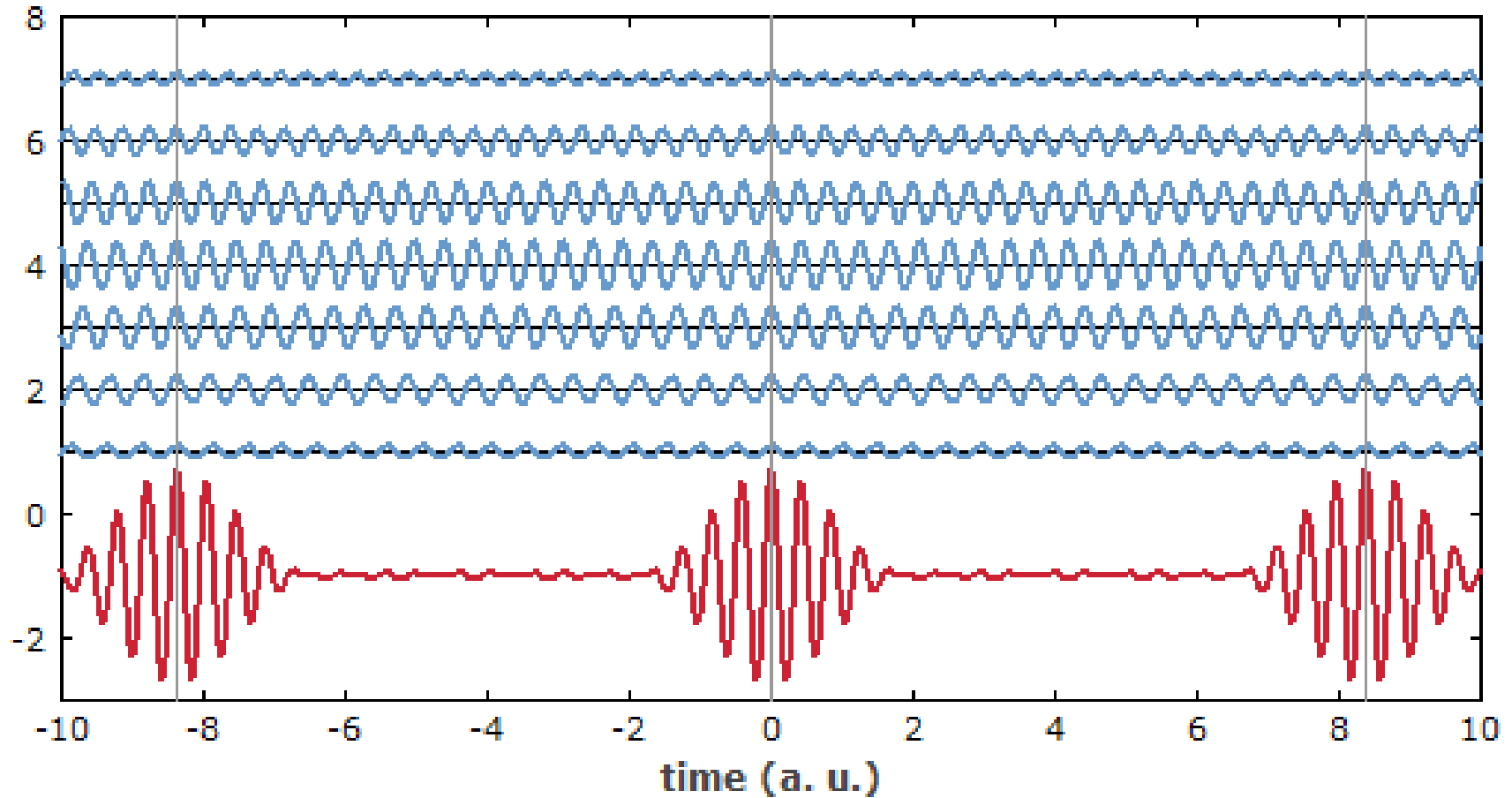
=



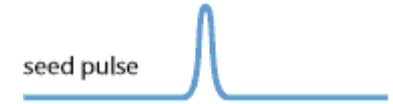
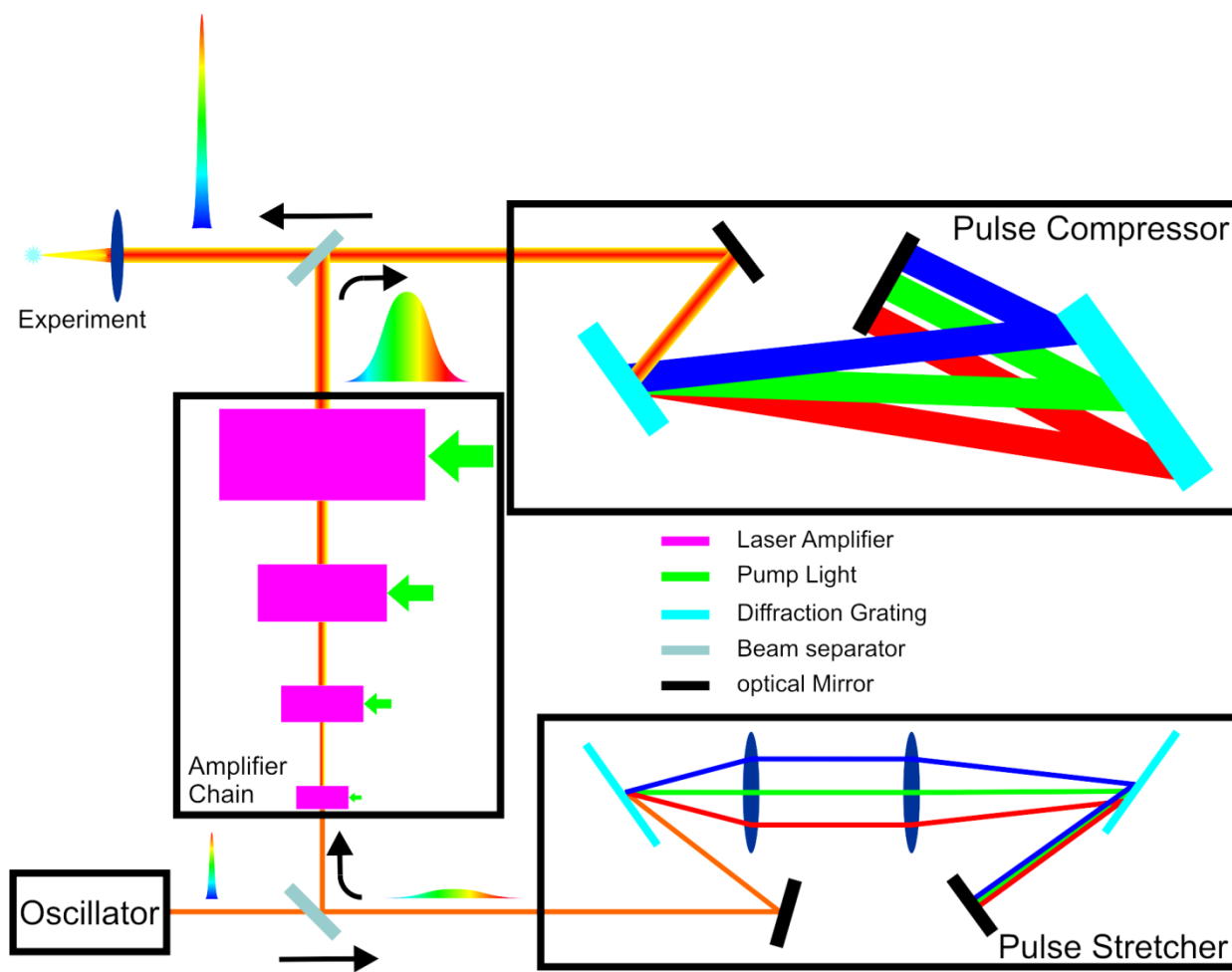
the broader the spectrum
the shorter the pulse

c speed of light
 ν frequency
 λ wavelength
 q mode number
 L resonator length

Kurzpulserzeugung durch phasenrichtige Addition



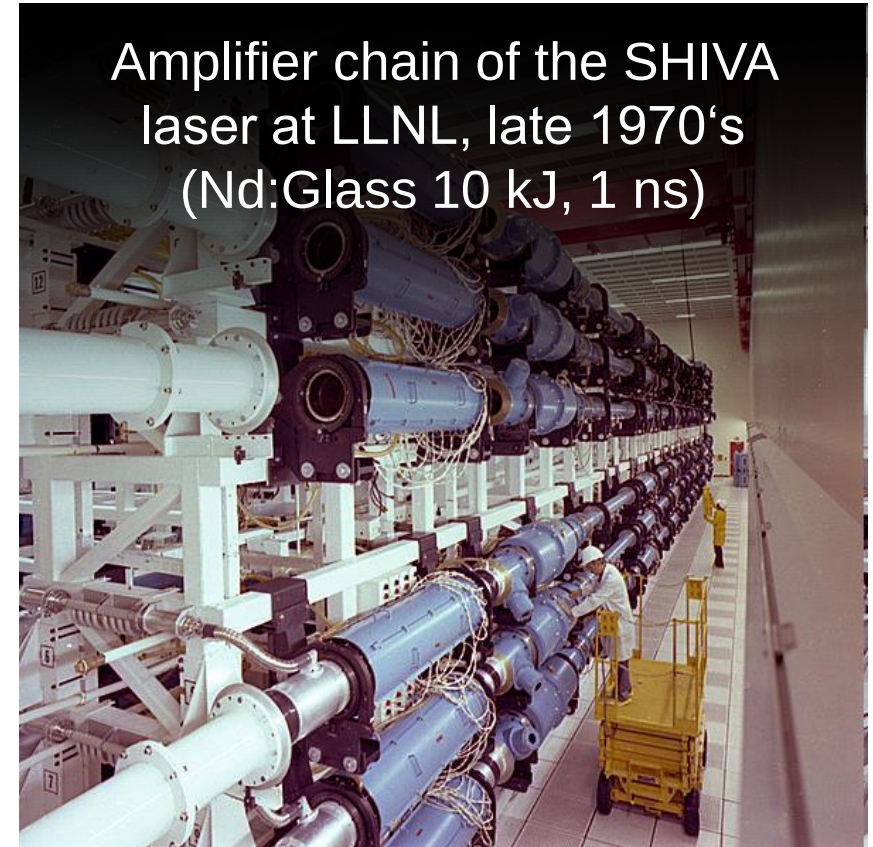
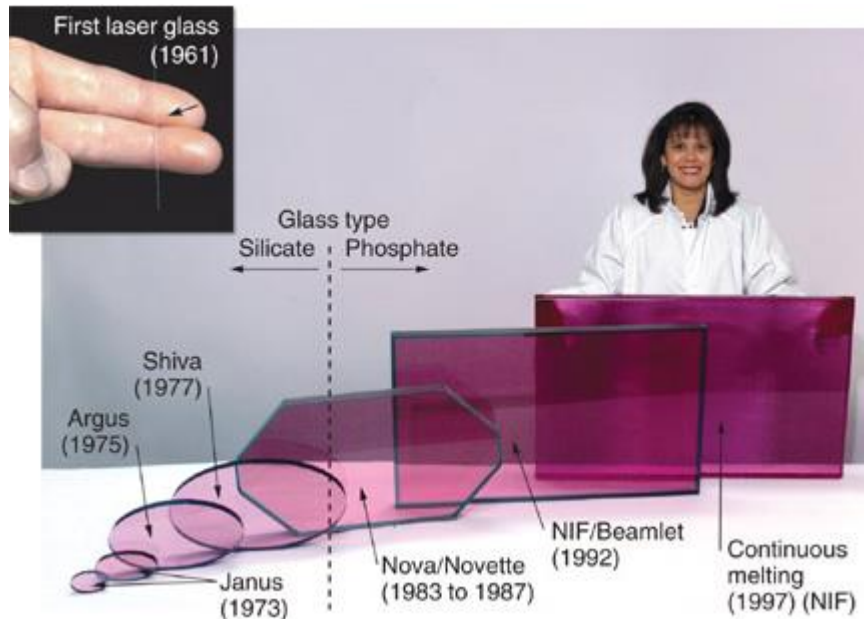
Chirped Pulse Amplification (CPA)



Todessternlaser: kJ, ns, wenige Schüsse pro Tag

Dotiertes Glas als Lasermedium

- isotrop
- Geringe Wärmeleitfähigkeit
- Breites Emissionsspektrum

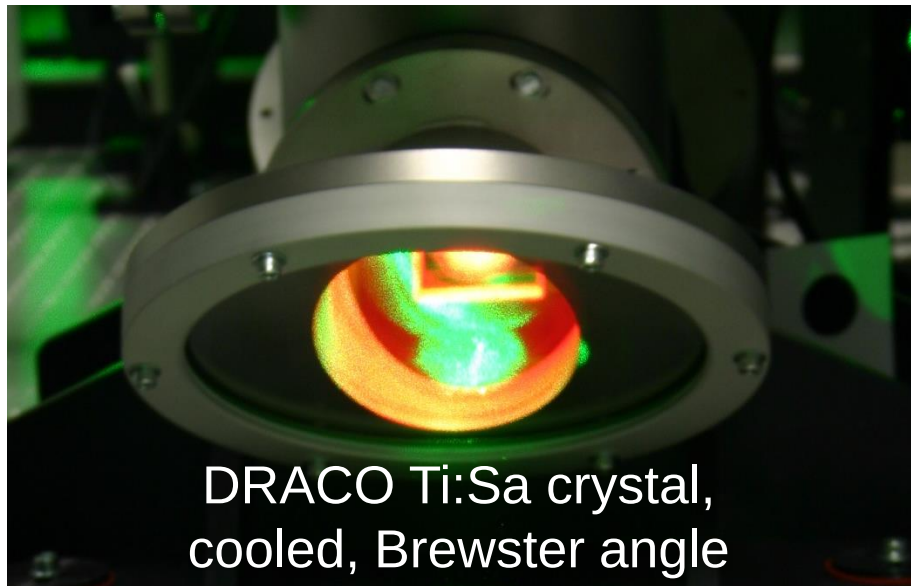


Amplifier chain of the SHIVA laser at LLNL, late 1970's (Nd:Glass 10 kJ, 1 ns)

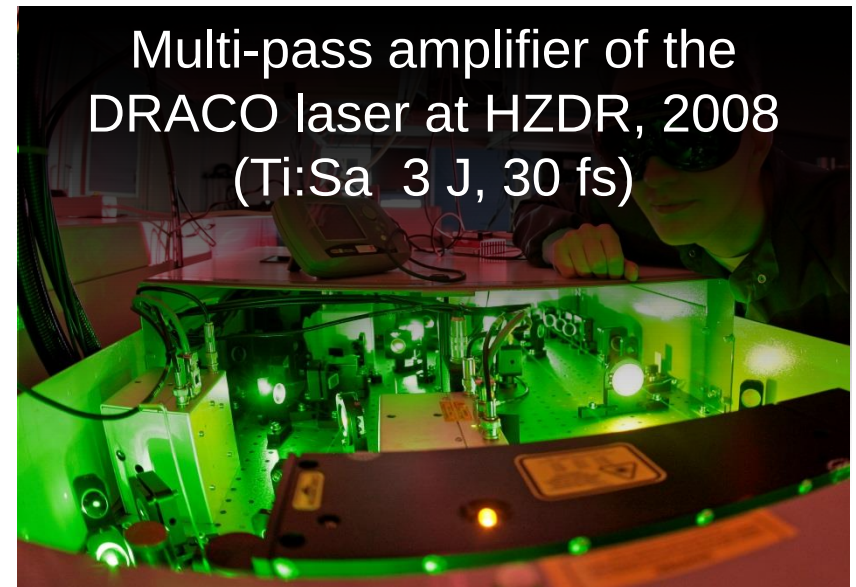
Ultrakurzpulslaser — mJ to J, fs, Hz to kHz

Dotierte Kristalle als Lasermedium

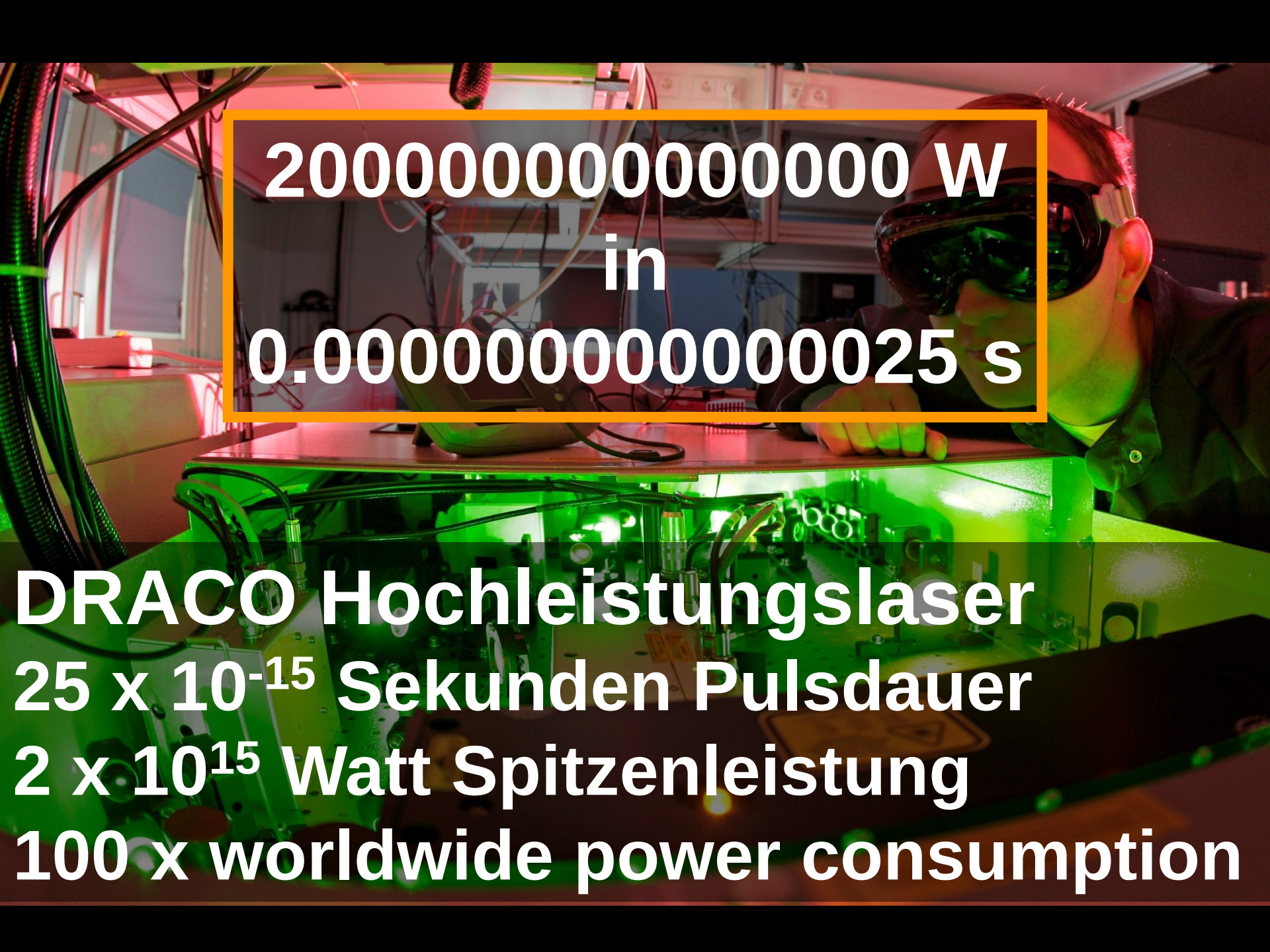
- Hohe Verstärkung
- Hohe Wärmeleitfähigkeit
- Geringe optische Qualität



DRACO Ti:Sa crystal,
cooled, Brewster angle



Multi-pass amplifier of the
DRACO laser at HZDR, 2008
(Ti:Sa 3 J, 30 fs)



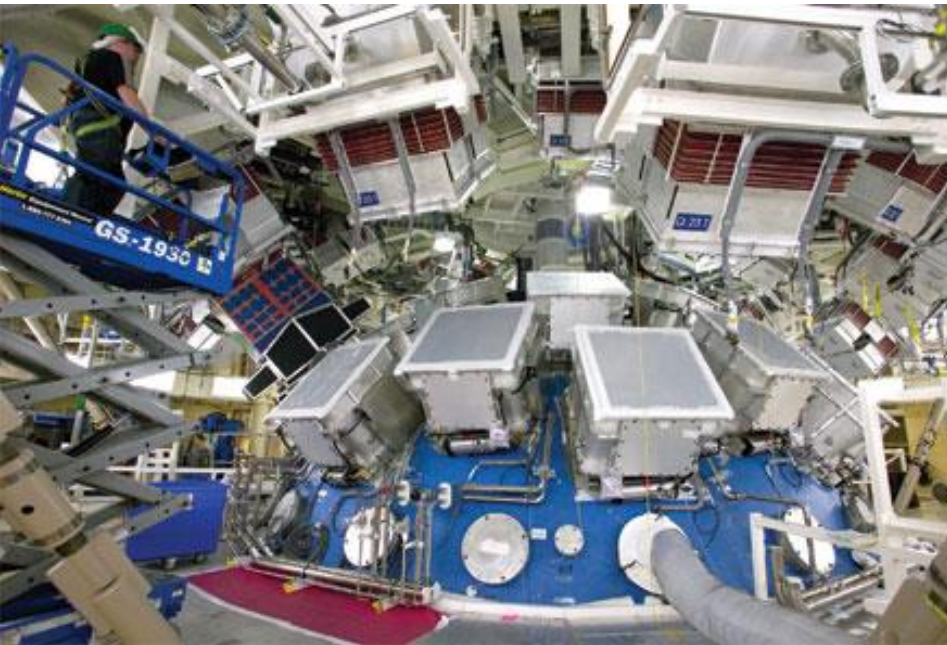
2000000000000000 W
in
0.0000000000000025 s

DRACO Hochleistungslaser
 25×10^{-15} Sekunden Pulsdauer
 2×10^{15} Watt Spitzenleistung
100 x worldwide power consumption

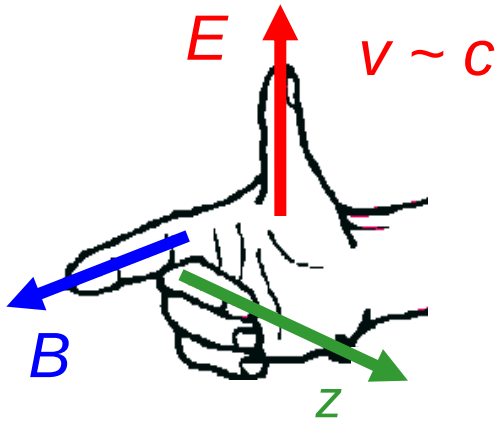


Laser und Plasmen

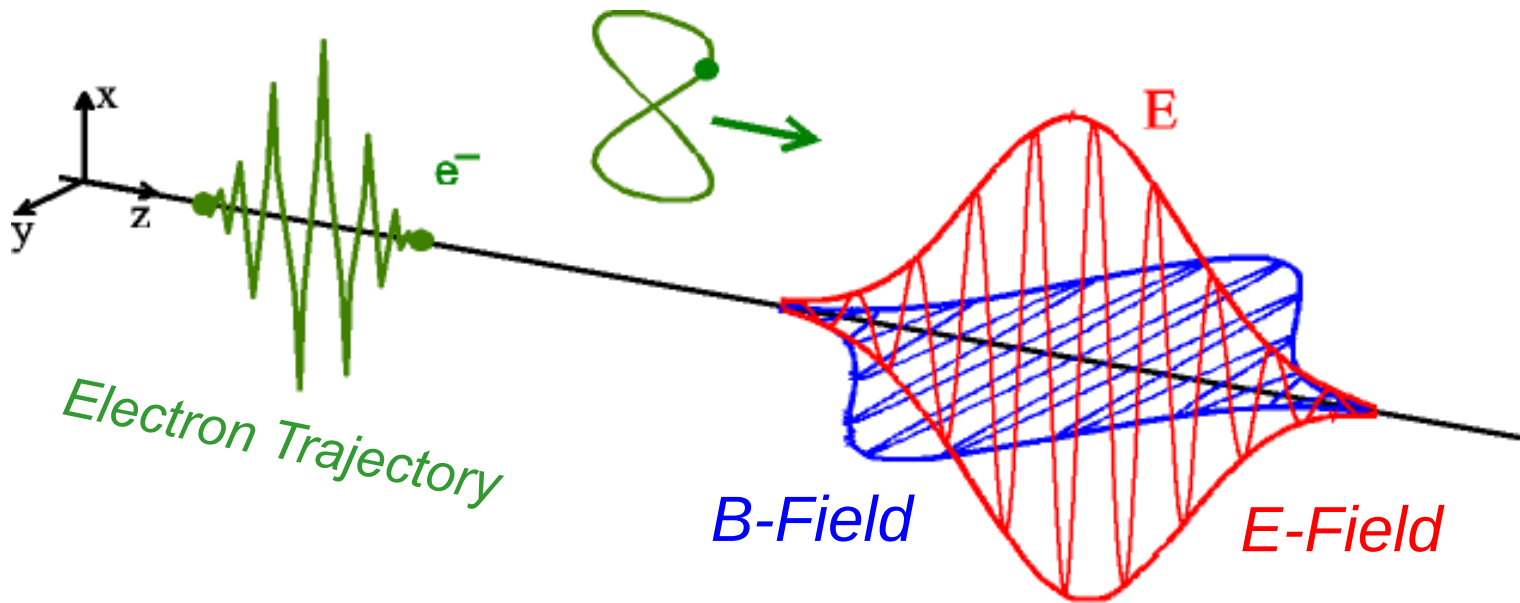
Star Trek Into Darkness vs. National Ignition Facility



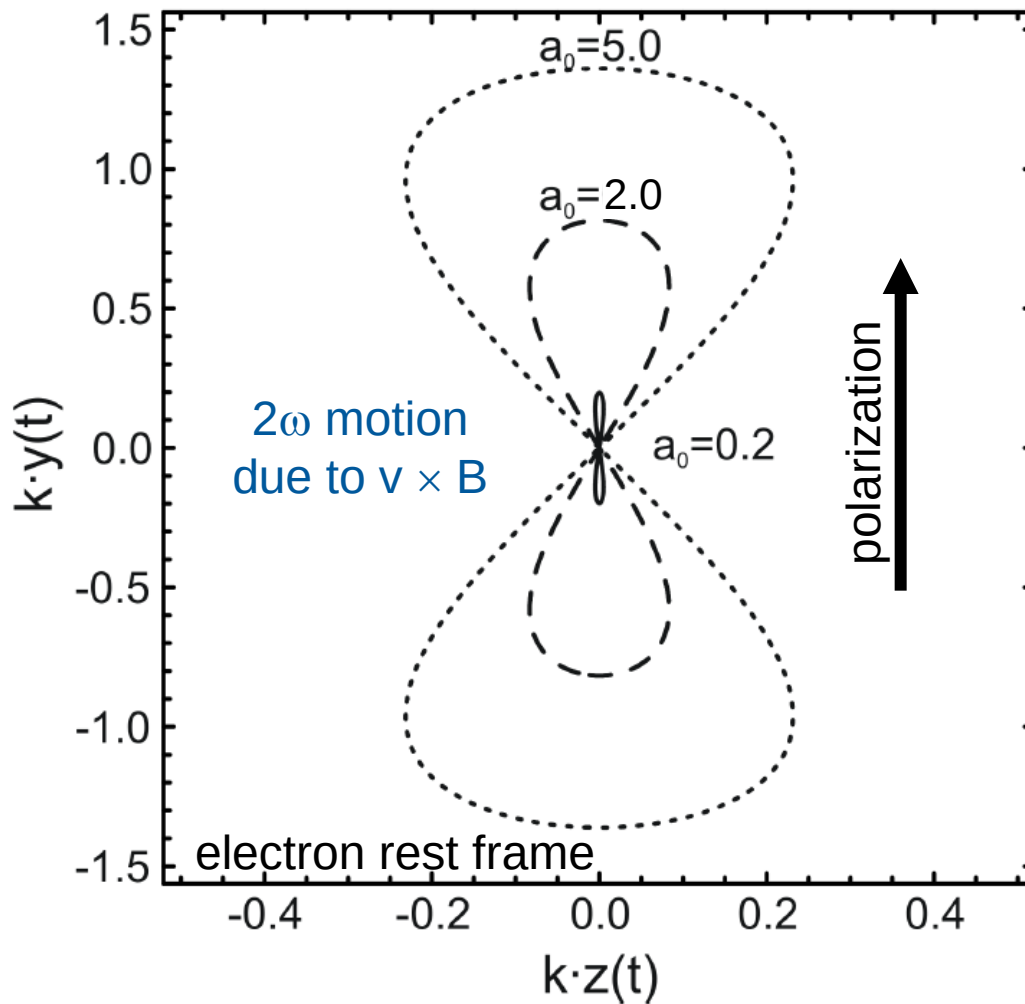
Die Lorentzkraft



$$\vec{F}_{\text{Lorentz}} = e(\vec{E} + \vec{v} \times \vec{B}) \quad (B_0 = E_0/c)$$



Bei hohen Feldstärken wird das Magnetfeld wichtig



$$\vec{E} = E_0 \sin(\omega t - kz) \vec{e}_y$$

$$\frac{d}{dt} \vec{p} = -e (\vec{E} + \vec{v} \times \vec{B})$$

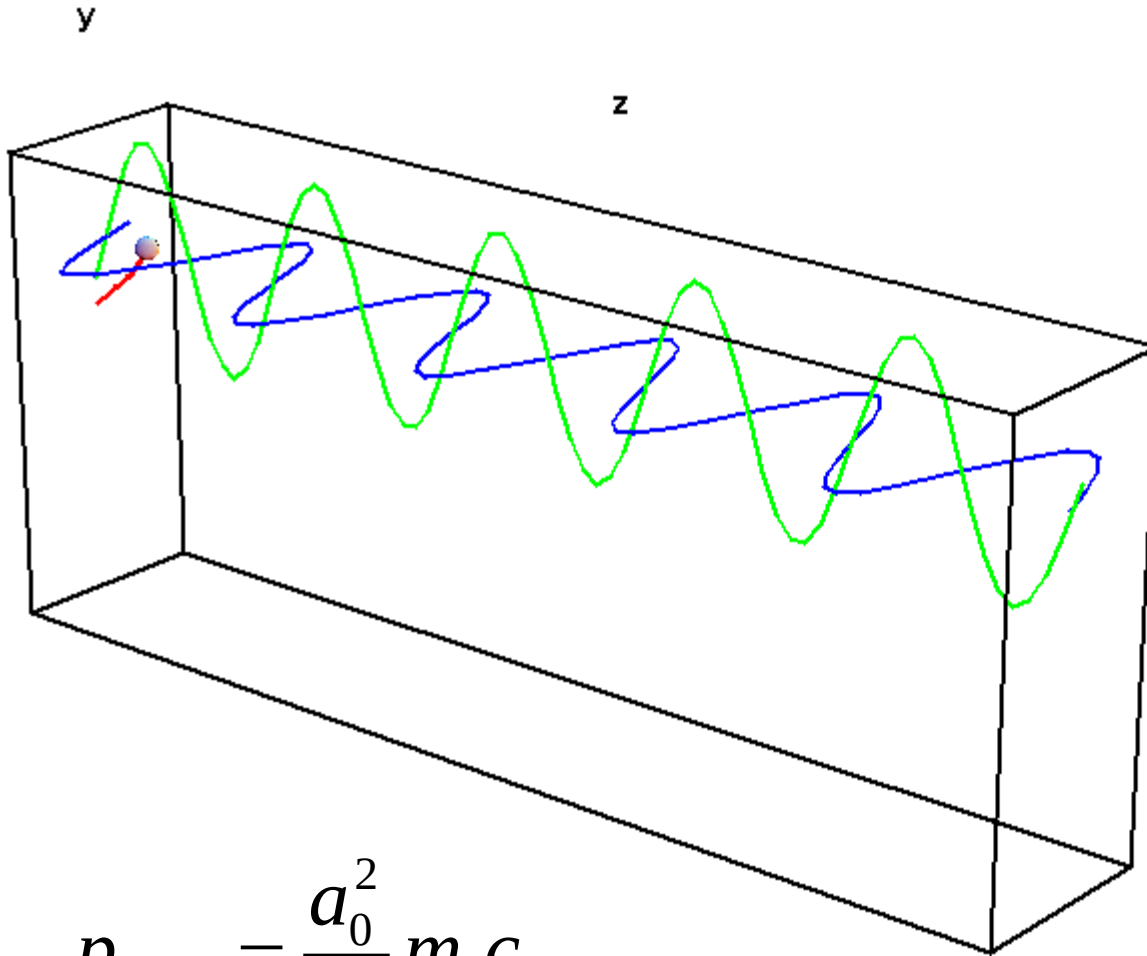
$$k \cdot y(t) = a_0 \sin(\varphi(z, t))$$

$$k \cdot z(t) = \frac{a_0^2}{4} \left[\varphi(z, t) + \frac{1}{2} \cos(2\varphi(z, t)) \right]$$

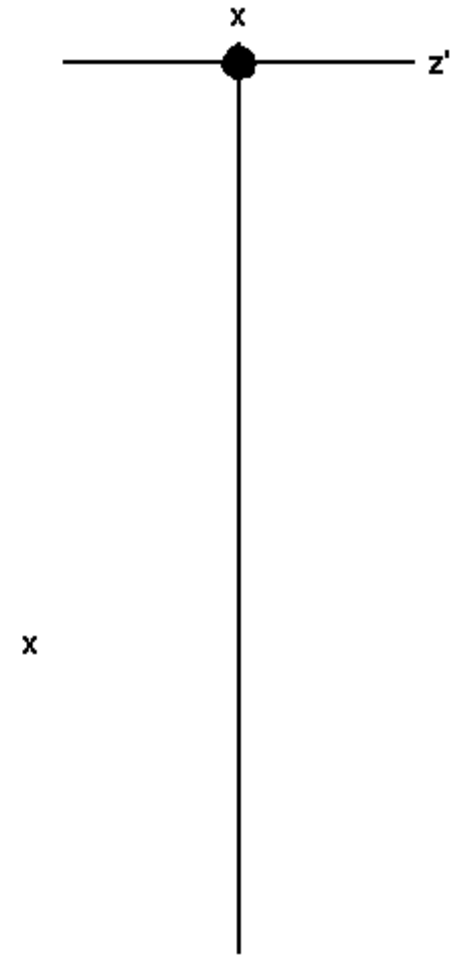
$$\varphi(z, t) = \omega t - kz(t)$$

Relativistische Bewegung

Labor

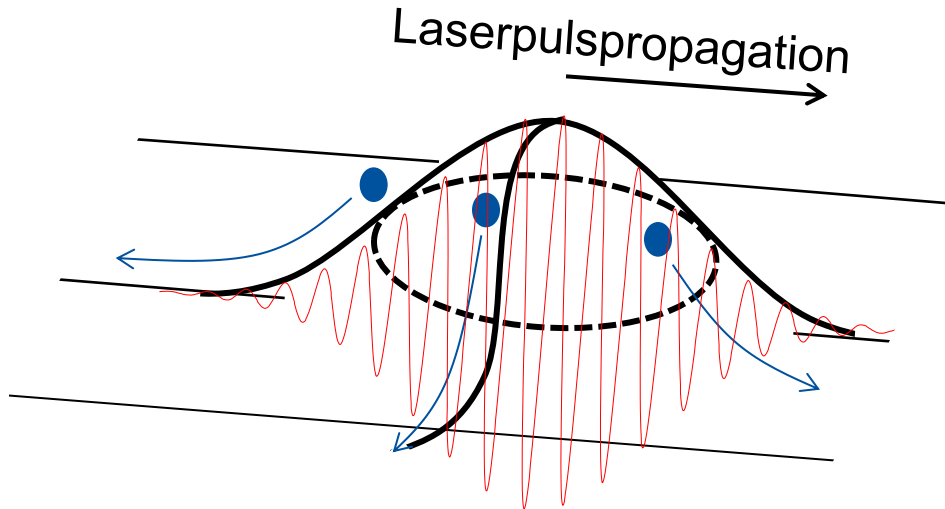


Ruhesystem des Elektrons



$$p_{Drift} = \frac{a_0^2}{4} m_e c$$

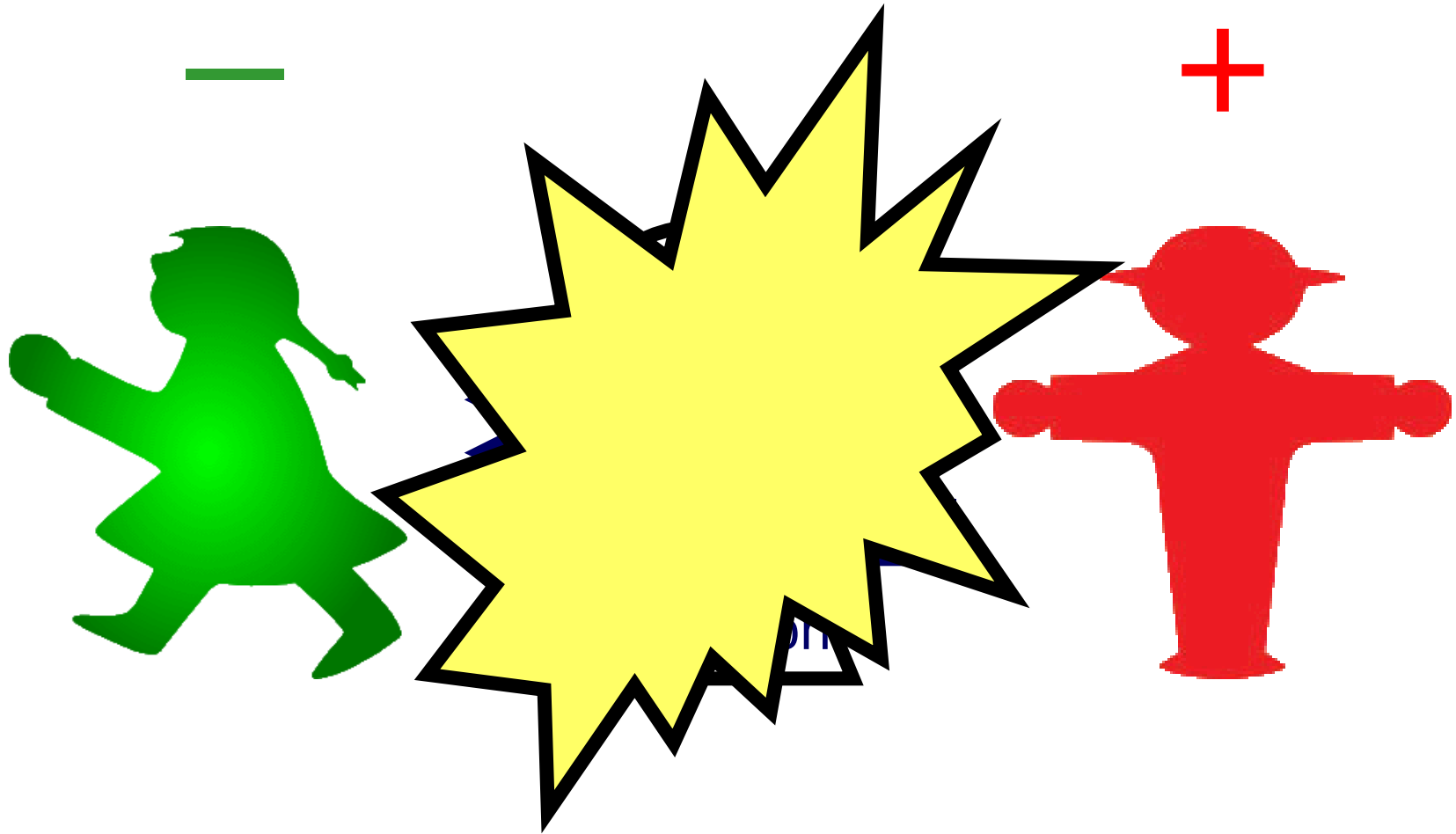
Ponderomotive (zeitgemittelte) Kräfte



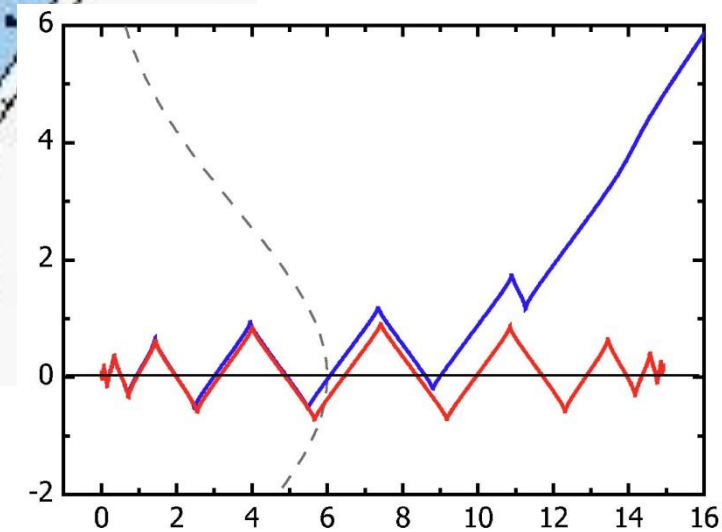
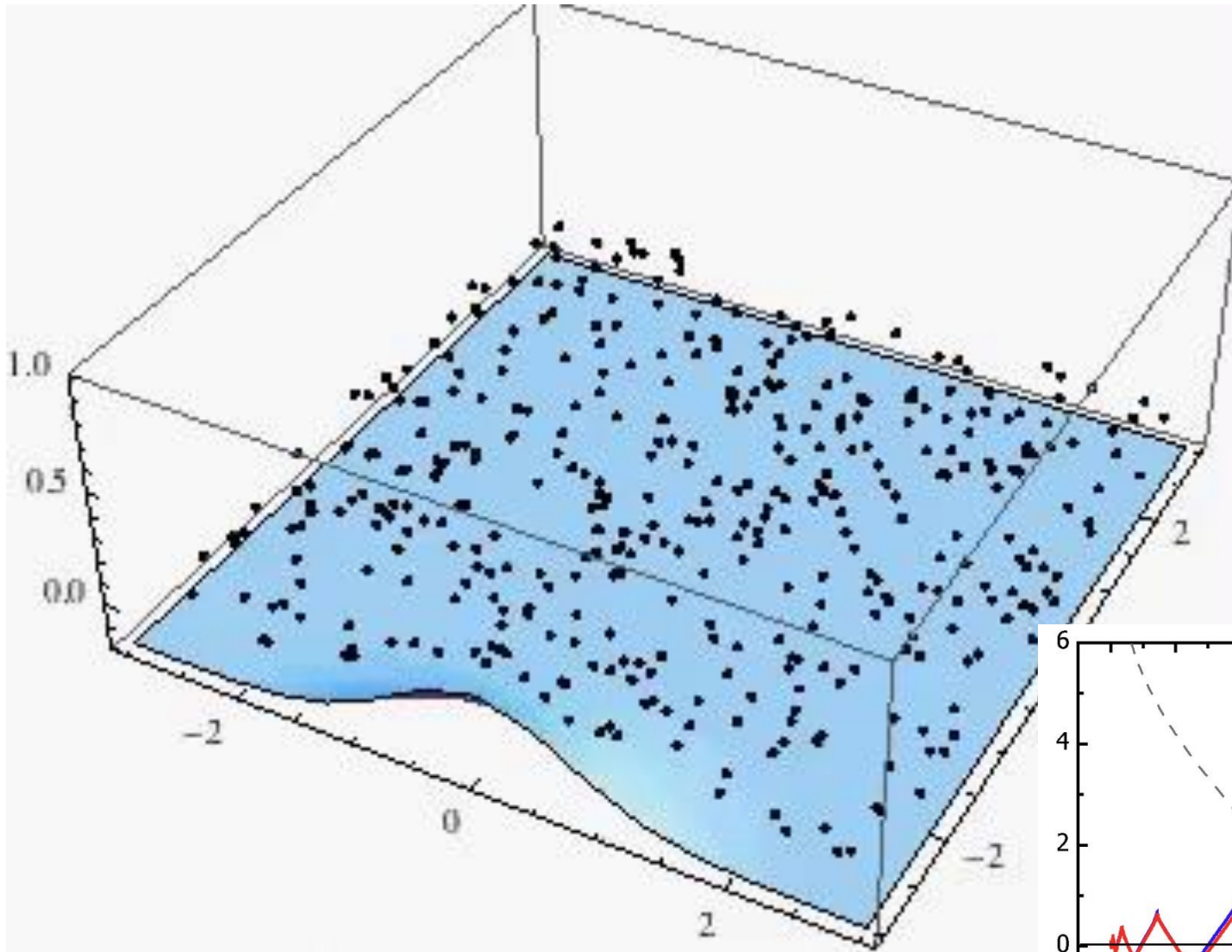
$$\vec{F}_{\text{Ponderomotive}} = \frac{d\langle \vec{p} \rangle_{\text{phase, focus}}}{dt} \begin{cases} \xrightarrow{a_0 \rightarrow 0} -\frac{m_e c^2}{4} \nabla \langle a_0 \rangle_{\text{phase, focus}}^2 \\ \xrightarrow{a_0 \rightarrow \infty} -\frac{m_e c^2}{\sqrt{2}} \nabla |\langle a_0 \rangle_{\text{phase, focus}}| \end{cases}$$

Elektronenenergie ~ MeV

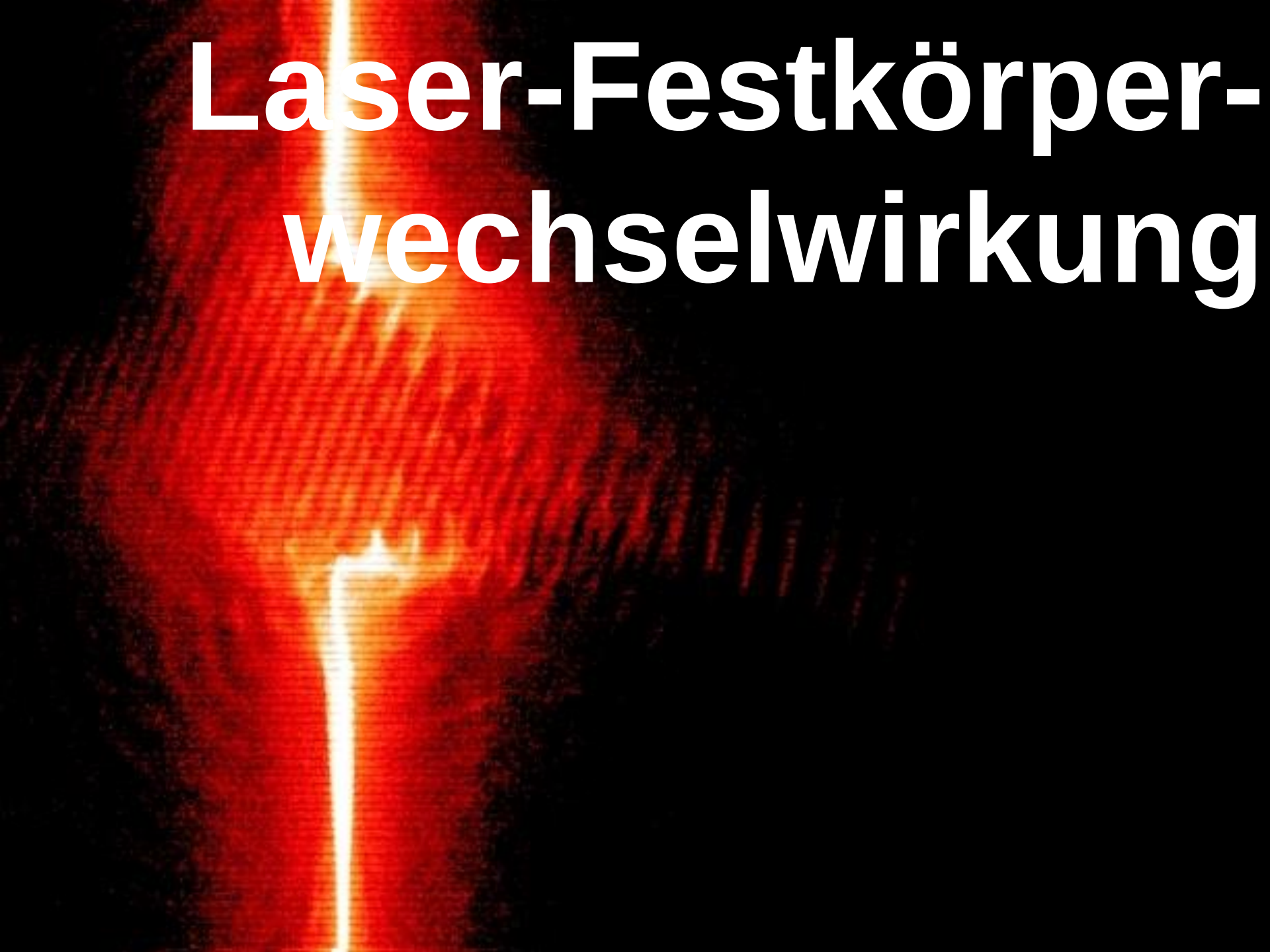
Plasmen

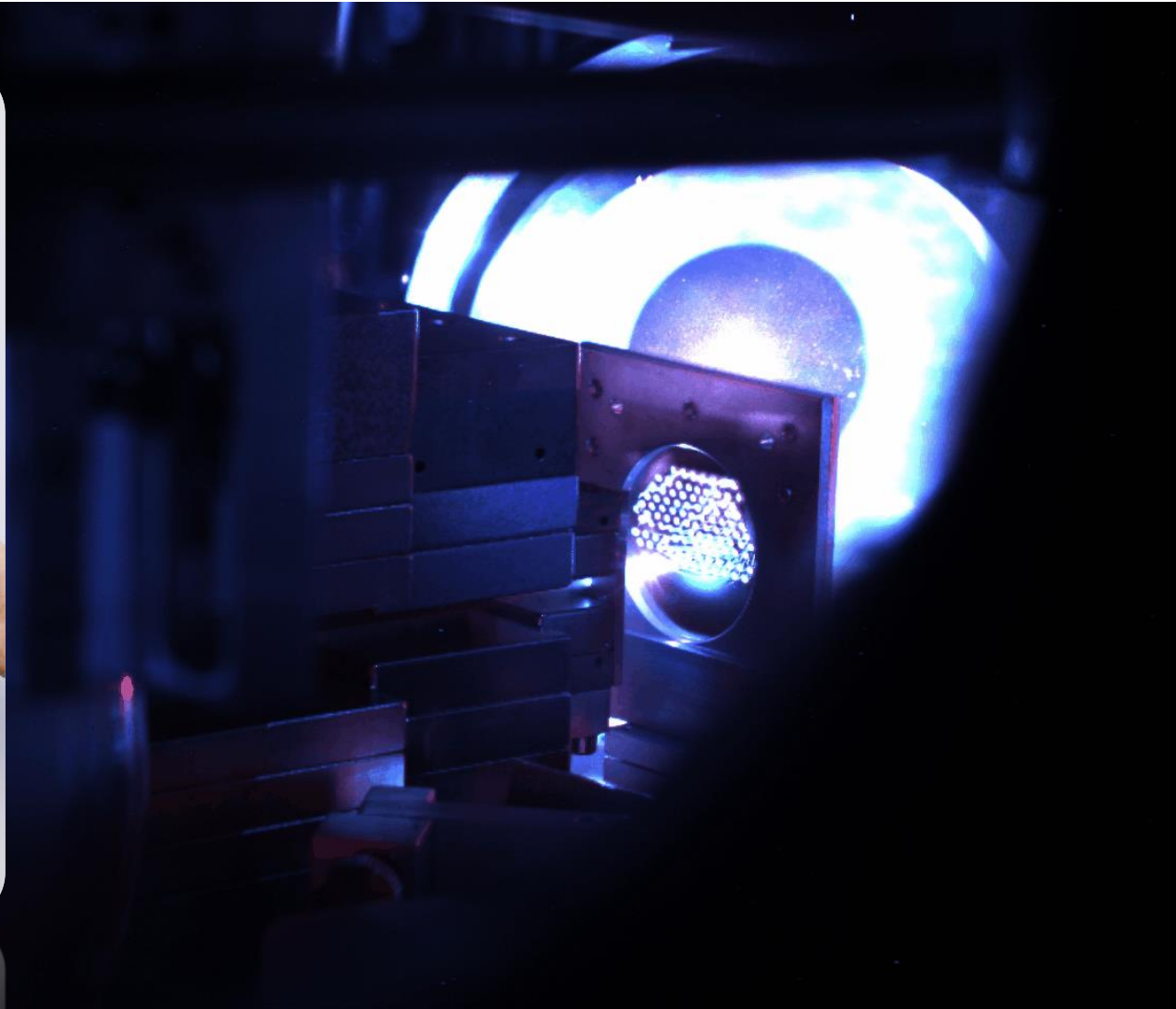


Ponderomotive Kraft im Plasma

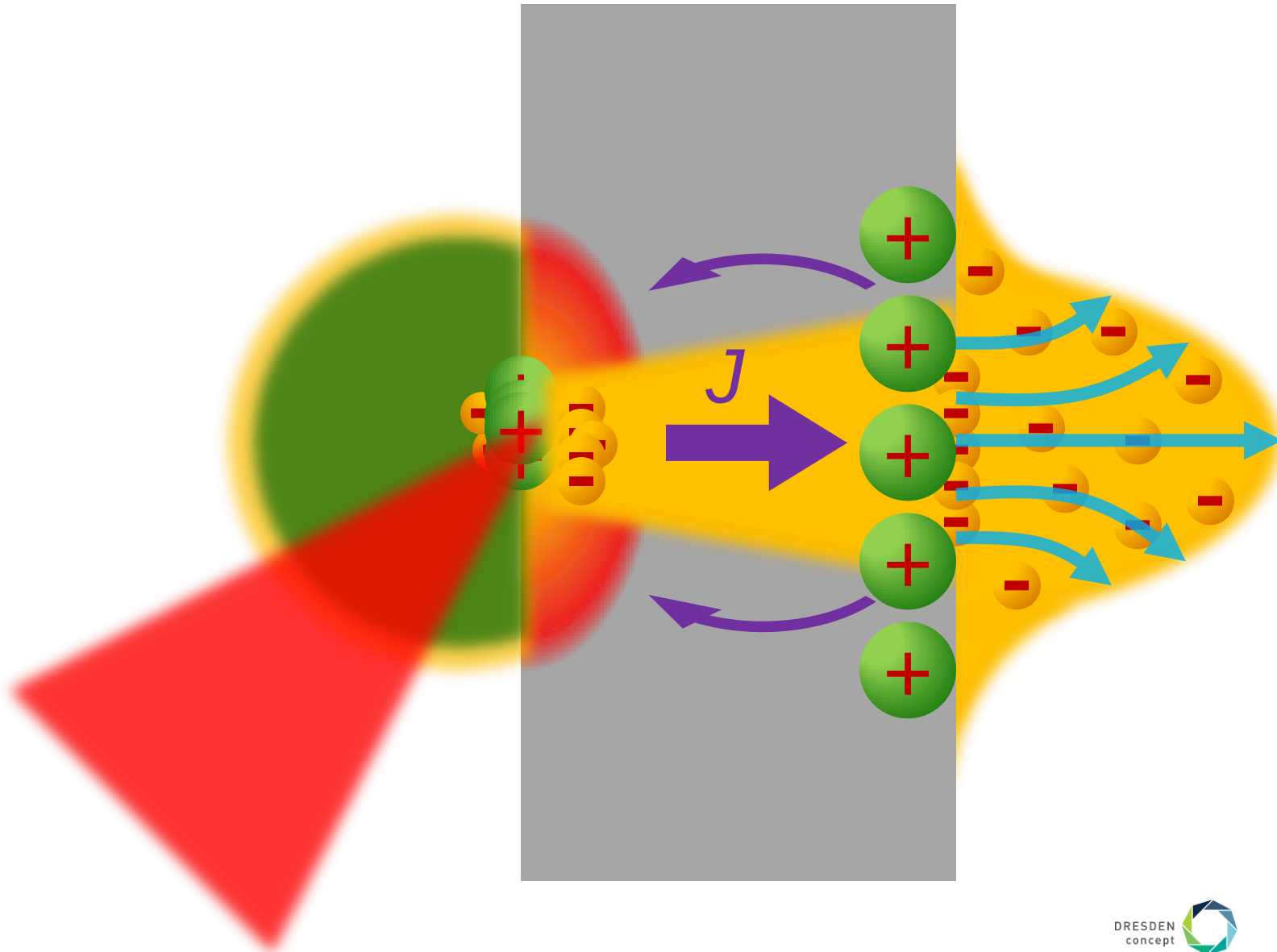


Laser-Festkörper- wechselwirkung

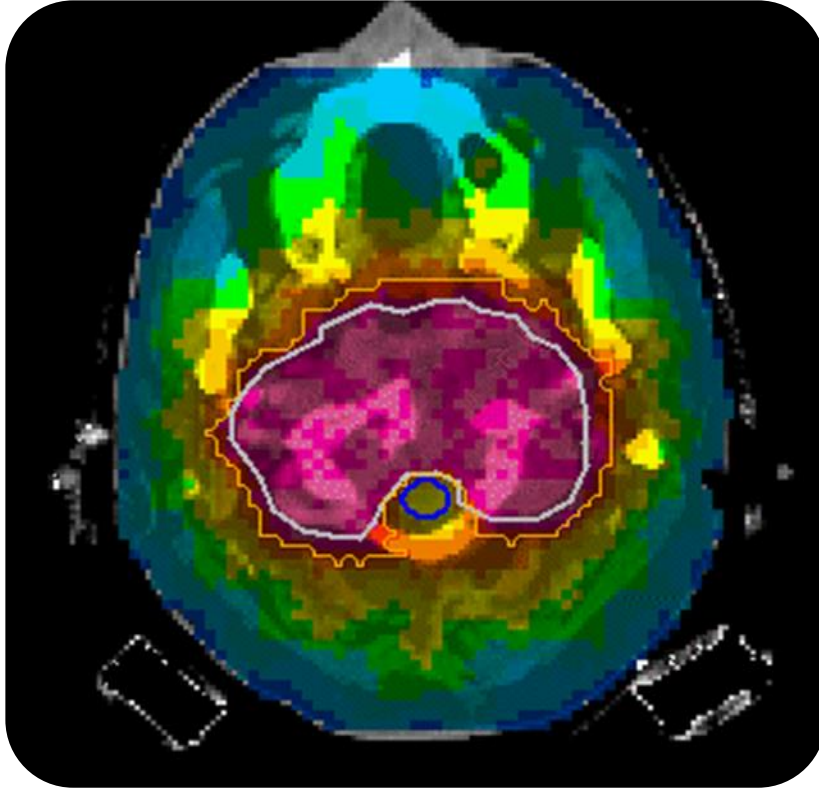




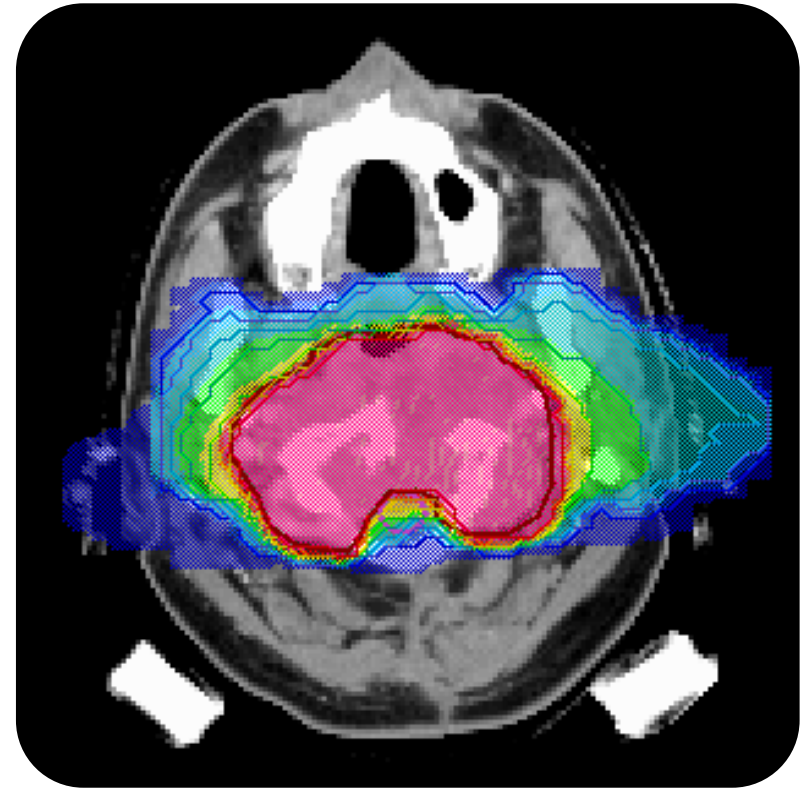
Target-normal sheath acceleration (TNSA)



Protonentherapie von Krebs

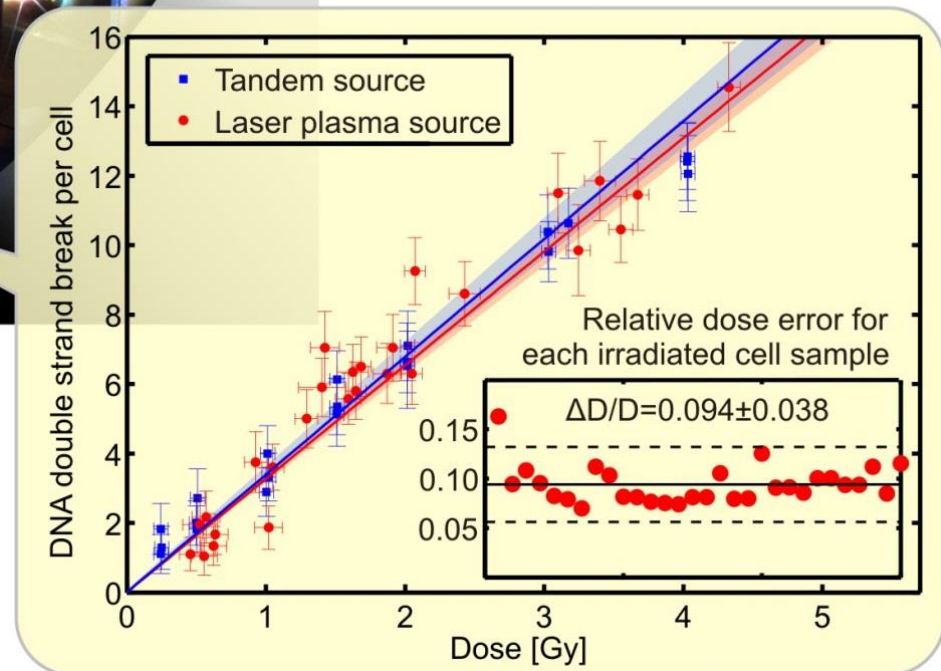
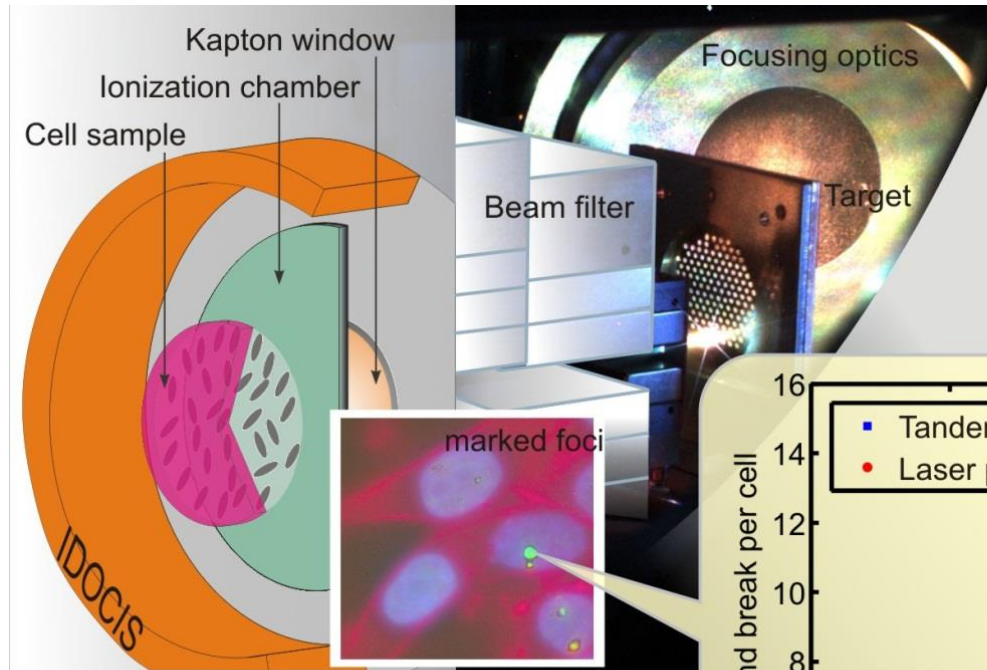


8 Röntgenstrahlen

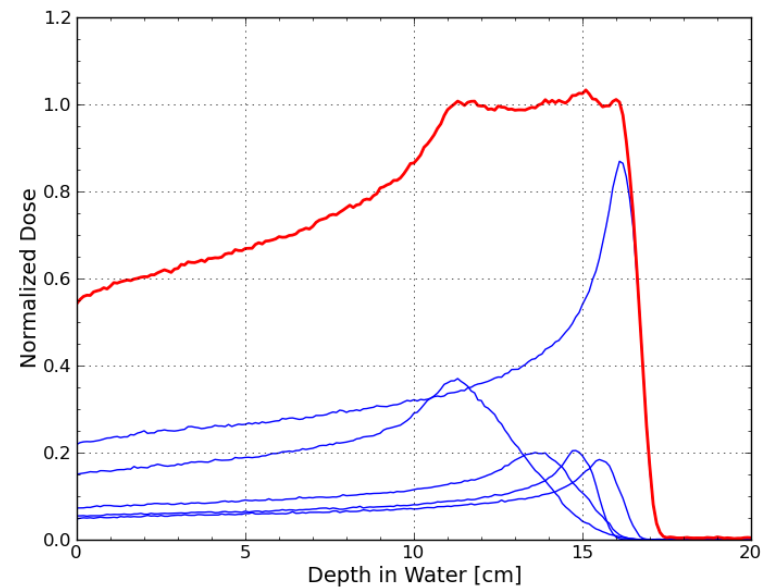
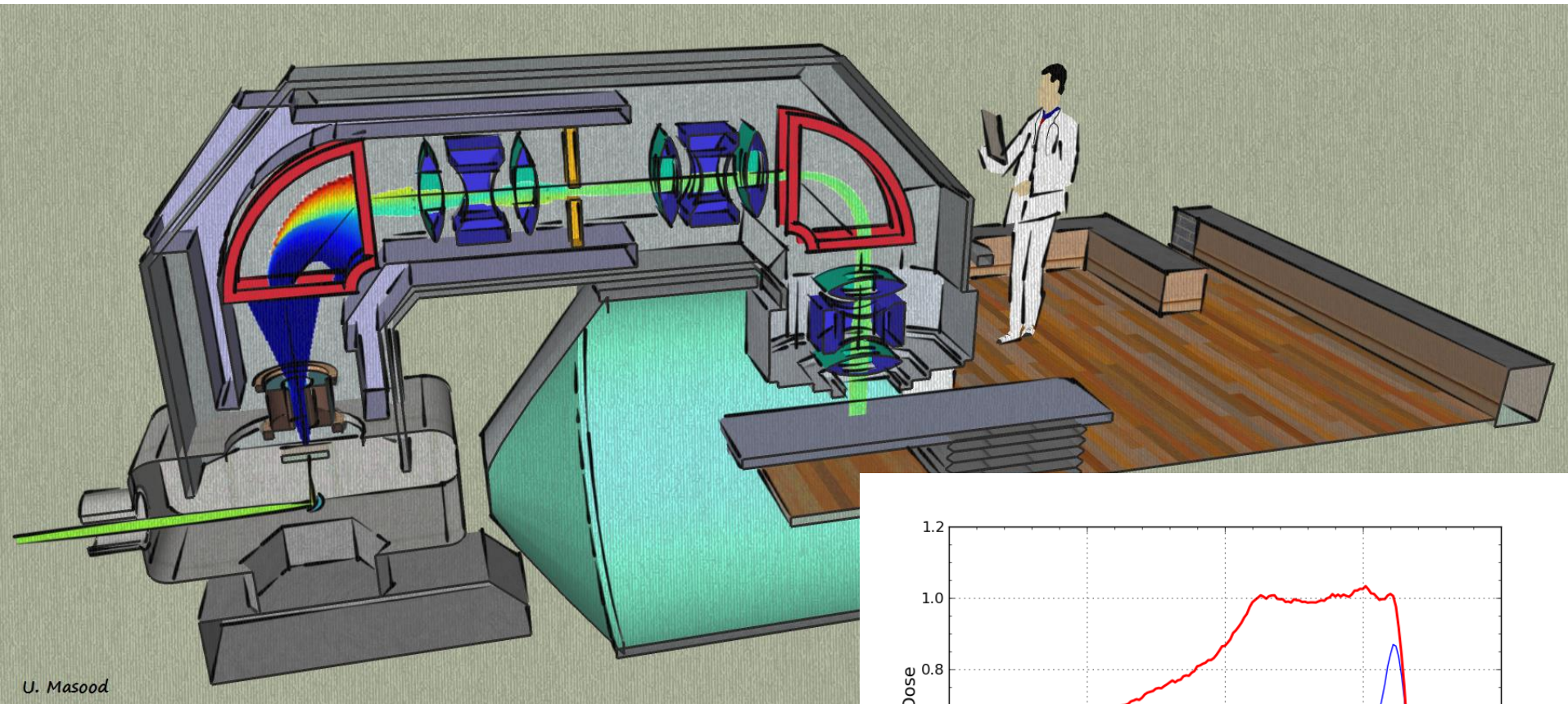


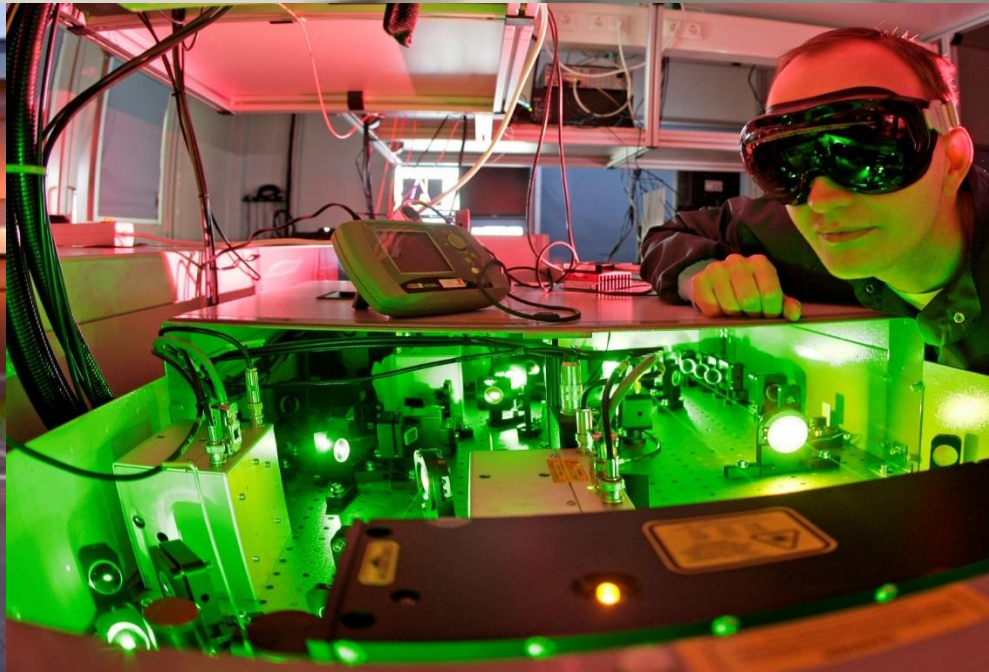
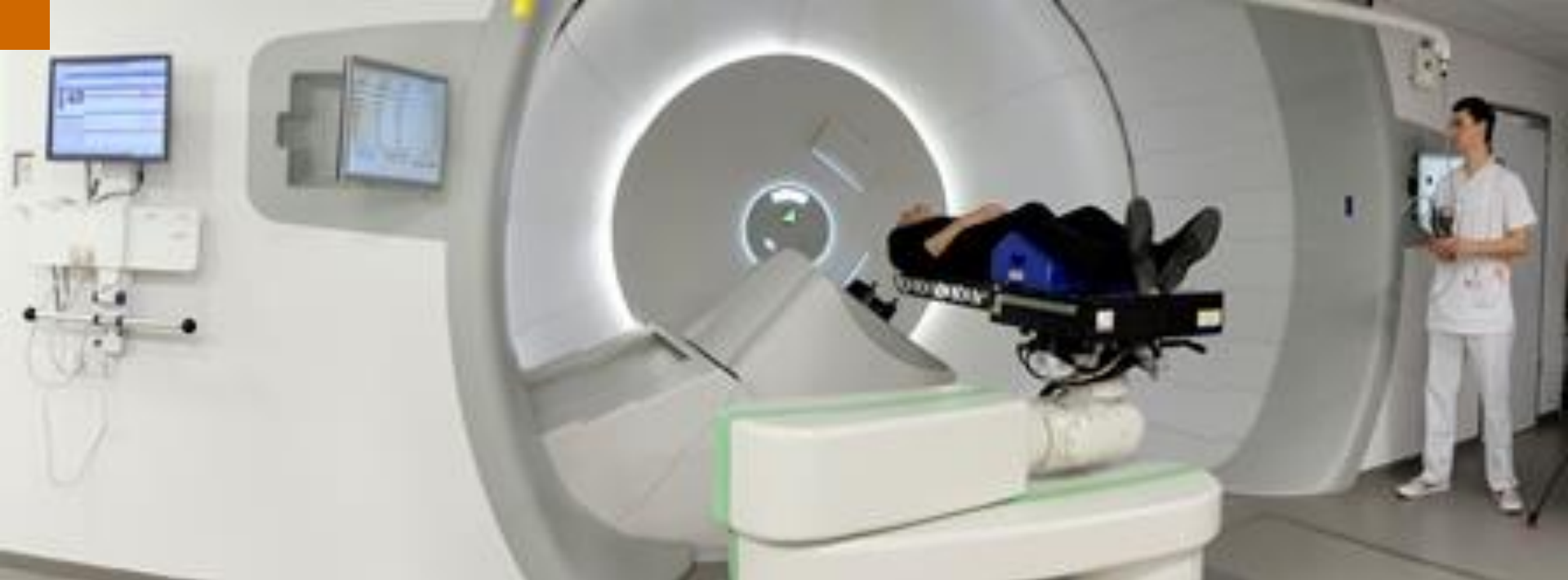
2 Ionenstrahlen

Damaging living Cells by laser-driven Proton Beams



Kompakt = Preiswerter

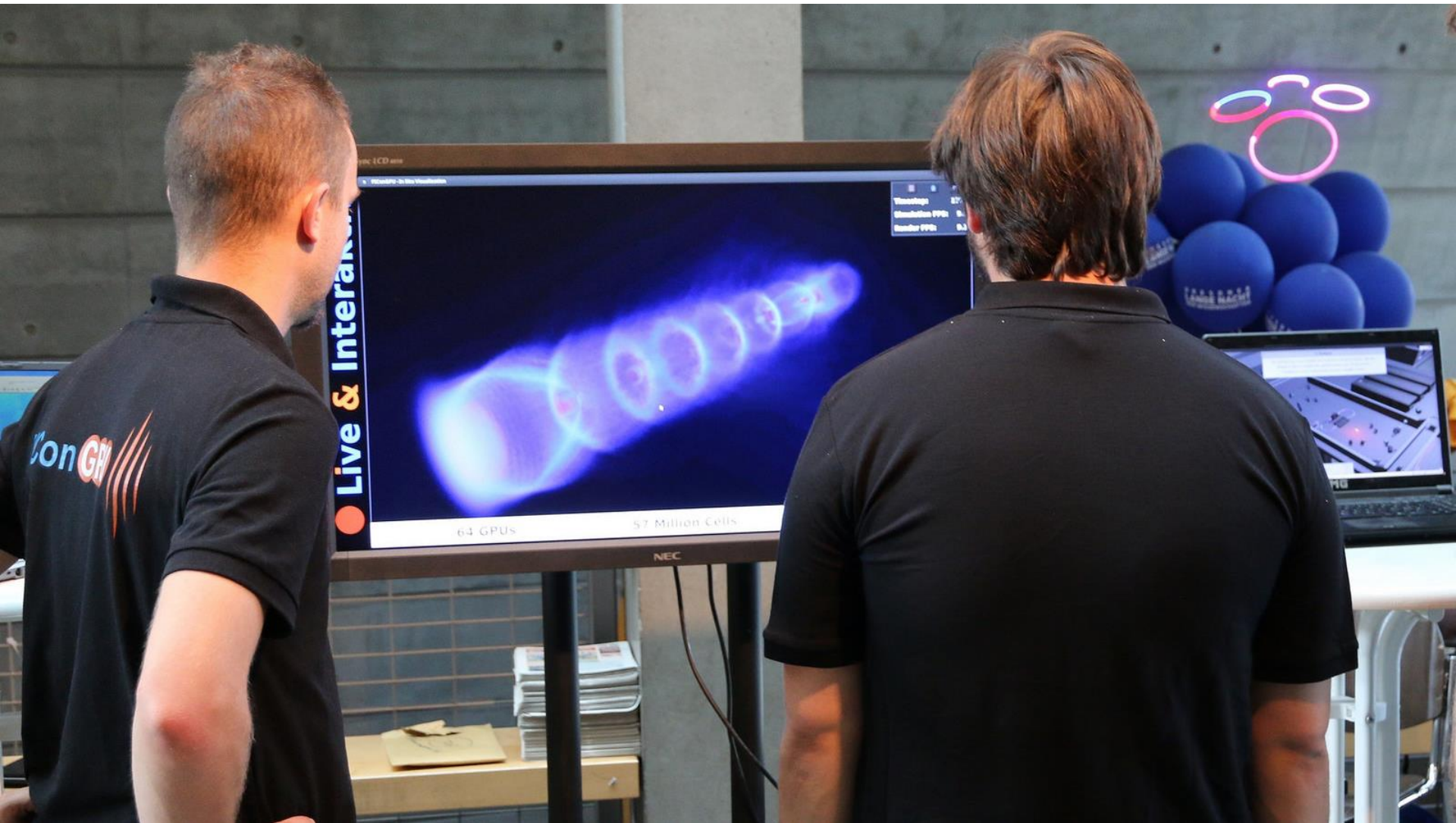


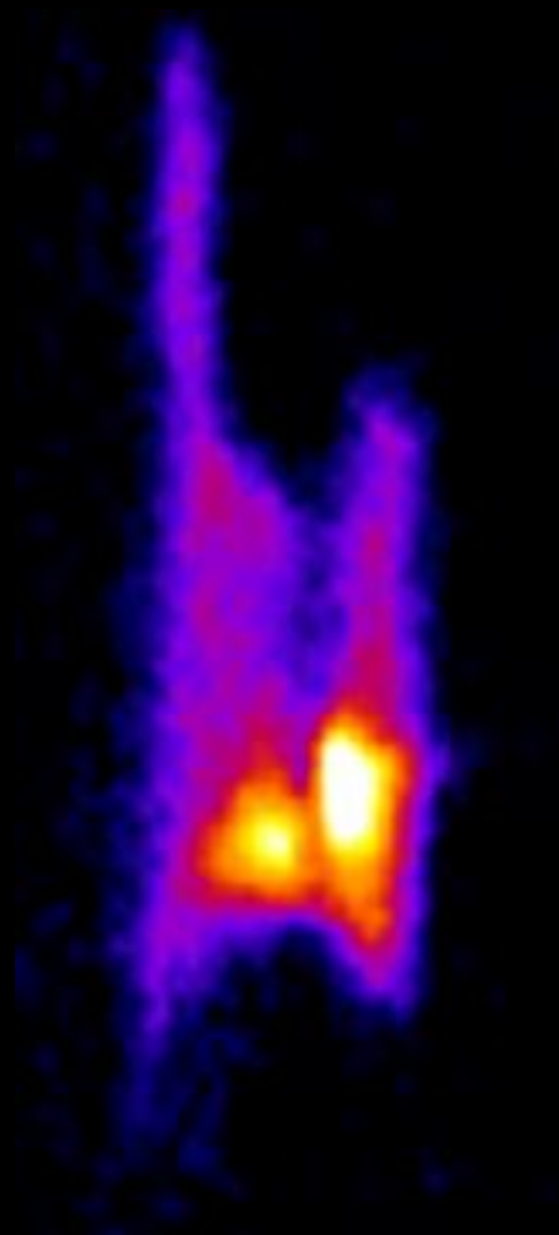


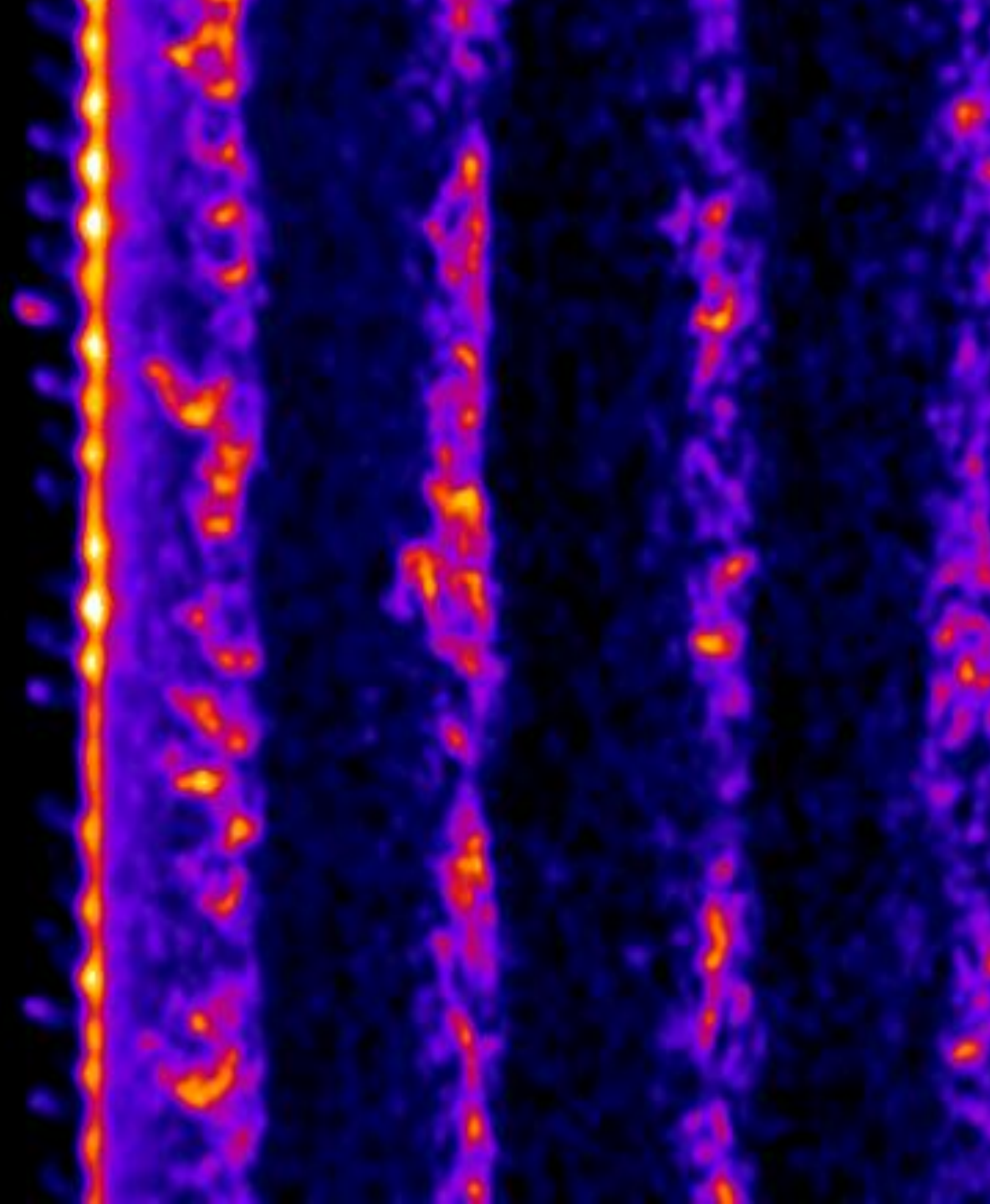


Simulationen

Dresdner Nacht der Wissenschaften





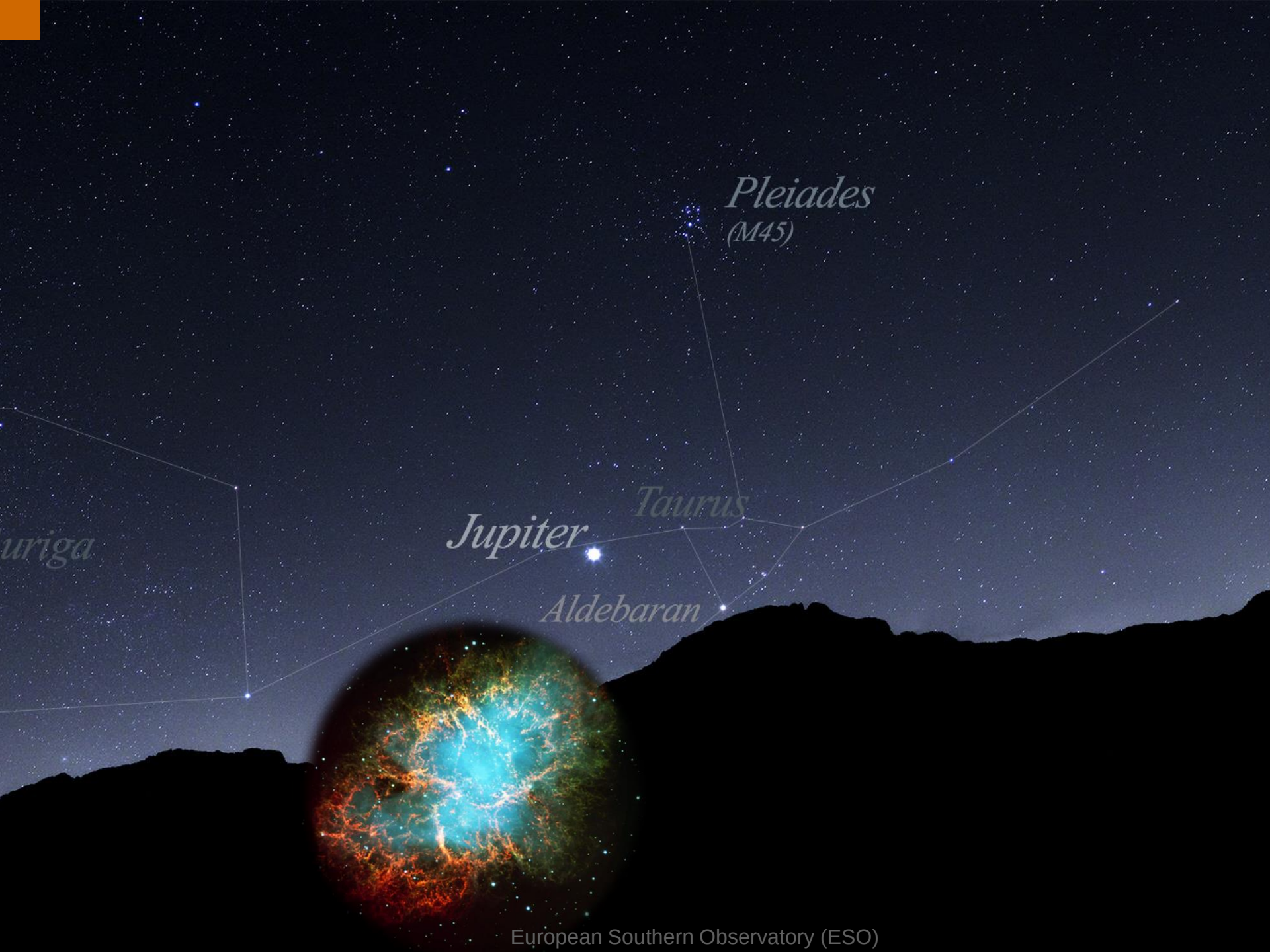


A night sky photograph with a starry background and a dark mountain silhouette at the bottom. The sky is filled with numerous stars of varying brightness. A prominent bright star is visible in the center-left. The mountain silhouette is dark and jagged, spanning the bottom of the frame. The title "Astrophysik mit Computern" is overlaid in white text at the top.

Astrophysik mit Computern

Wir sehen nur das Licht der Sterne





Pleiades
(M45)

Taurus

Jupiter

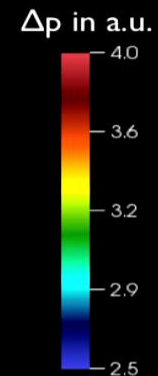
Aldebaran

uriga

Aber unsere Teleskope werden immer besser

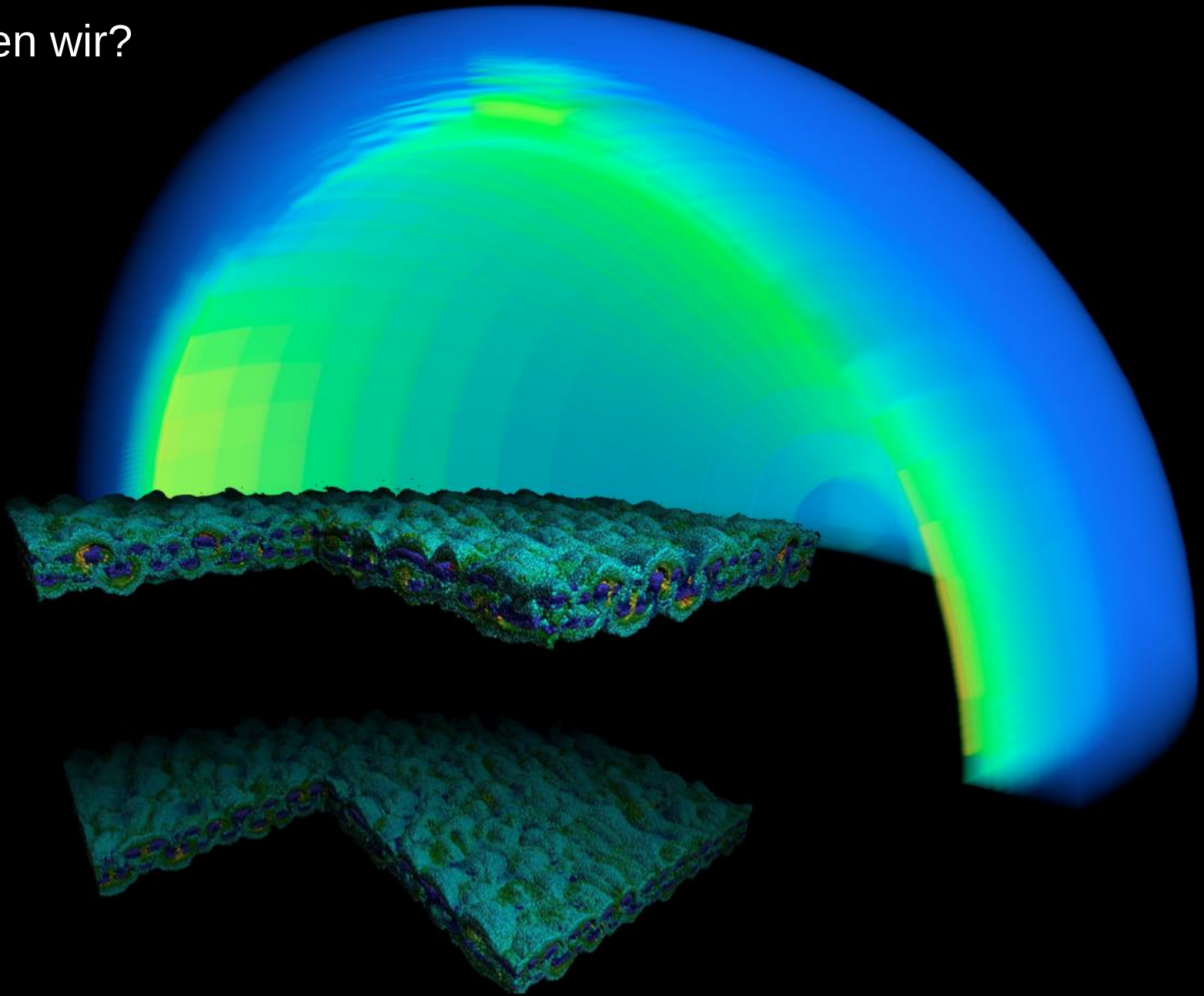


Time: $21 \omega_{pe}^{-1}$



75 Milliarden Teilchen

Was sehen wir?



Freie Software



GPL Open Source Entwicklung (picongpu.hzdr.de)

[This page](#) | Search | [Full request](#) | Icons | RSS

ComputationalRadiationPhysics / picongpu

PICongPU - A particle-in-cell code for GPGPUs <http://picongpu.hdf.de> — Edit

	12M commits	3 branches	0 releases	12 contributors
Search release 5.1.1 • picongpu +				
Refresh repository Watch Fork Star				
Code Issues Pull requests Wiki				
Settings About				

Repository	Last commit	Created on	Updated
picongpu-HPC	Usage pull request #1122 from asell/picongpu@11	17 days ago	2 months ago
PICsystemCompatibility	Update Modules and CMakeLists	2 months ago	2 months ago
PICsim	Remove redundant "include" tag	2 months ago	2 months ago
PICexamples	Fix LUTS Example: Hydrogen	2 months ago	2 months ago
PICsim	Usage pull request #1122 from asell/picongpu@11	2 months ago	2 months ago
gpgpuacc	Add entry to file extensions: "gpgpuacc"	2 months ago	2 months ago
CHANGINGLOG.md	Changing to 5.1.1 Release	2 months ago	2 months ago
CMakeLists.txt	Rearrange UseModules macro call in CMakeLists	2 months ago	2 months ago
CONTRIBUTING.md	Pin Type, fix gpgpuacc issue #11	11 months ago	2 months ago
COPYING	add doc	2 years ago	2 years ago
COPYING.LESSER	add doc	2 years ago	2 years ago
LICENSE.md	LICENSE and new path of copyright	2 years ago	2 years ago
README.md	Developers: Add Source Center	2 months ago	2 months ago
REFERENCE.md	Citation Language and Bibtex	2 years ago	2 years ago
script	Remove Reme to plain text in all remaining files	2 years ago	2 years ago
testlog	Check if the dir for "testlog" exists	2 years ago	2 years ago
test/testParticleSet	Call "make" instead of "ls" in log	2 years ago	2 years ago

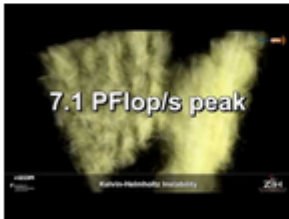
PICongPU and

PICongGPU - A Many GPGPU PIC Code

Open Alpha

Please note that this is an Open Alpha release for developers and power users only.

Users should wait for our Open Beta release!



7.1 PFlop/s peak

Karlsruhe Institute of Technology

PICongGPU

New

Introduction

PICongGPU is a fully relativistic, many GPGPU, 3D-V particle-in-cell (PIC) code. The Particle-In-Cell algorithm is a central tool in plasma physics. It describes the dynamics of plasma by computing the motion of electrons and ions in the plasma based on Maxwell's equations.

PICongGPU implements various numerical schemes to solve the PIC cycle. Its features include:

- a Yee-lattice like grid structure
- particle pushers that solve the equation of motion for charged particles, e.g. the Boris- and the Vay-Pusher
- Maxwell field solvers, e.g. Yeik's and Lehel's scheme
- rigorously charge conserving current deposition schemes, proposed by Villardier-Gillot and Gombosi
- macro-particle form factors ranging from NGP (Oh order), CIC (1st), TSC (2nd) to PSQ (3rd)

ComputationalRadiationPhysics / **picongpu**

Unwatch 41 Unstar 130 Fork 73

Issues Pull requests Labels Milestones Filters is:open is:issue New issue

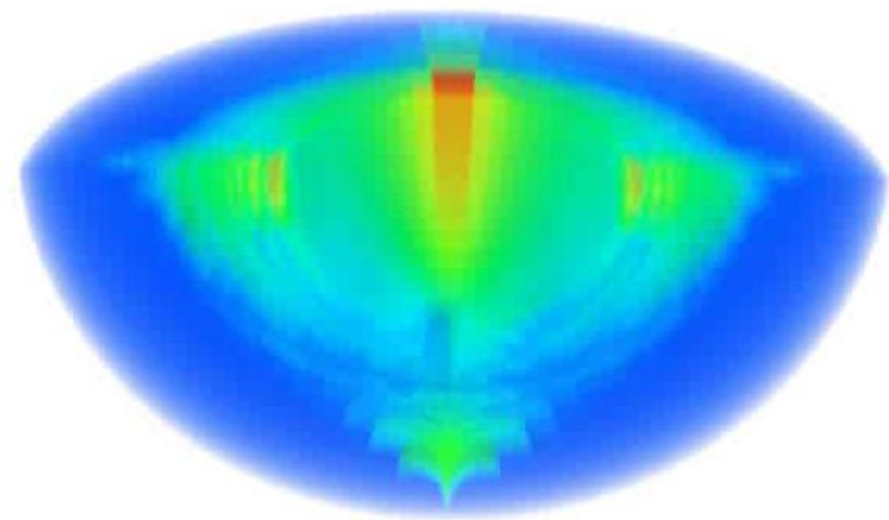
X Clear current search query, filters, and sorts

	178 Open	✓ 212 Closed	Author ▾	Labels ▾	Milestones ▾	Assignee ▾	Sort ▾
	cuSTL gather assumes same size buffers on all ranks	#1195 opened 2 days ago by Flamefire					0
	[cuSTL] Assignment of Buffers ignores sizes/pitches...	#1194 opened 2 days ago by Flamefire					0
	cuSTI not throw exception on cuda errors libPMacros	#1192 opened 5 days ago by psychocoderHPC Open Beta					0
	Make getEmptyFrame return a pointer libPMacros refactoring	#1191 opened 6 days ago by Flamefire Open Beta					1
	Any reason for choosing the cudaEvent_t pool to be of size 300? question	#1189 opened 7 days ago by anshumang Open Beta					1
	Magnetic field strength - SingleParticleTest examples question	#1186 opened 7 days ago by PrometheusPi Open Beta					0
	Is sm_20 as the default in cmakeFlags of KHI necessary?	#1185 opened 8 days ago by anshumang					2
	C++11: Remove own Limits trait C++11 feature	#1183 opened 8 days ago by Flamefire Future					0

Physiker und Informatiker arbeiten zusammen

Alexander Debus	Postdoc
Thomas Kluge	Postdoc
Jan Vorberger	Postdoc
Axel Hübl	PHD Student
Marco Garten	PHD Student
Richard Pausch	PHD Student
Klaus Steiniger	PHD Student
Erik Zenker	PHD Student
Heiko Burau	Master Student
Carlchristian Eckert	Master Student
Alexander Grund	Master Student
Alexander Matthes	Master Student

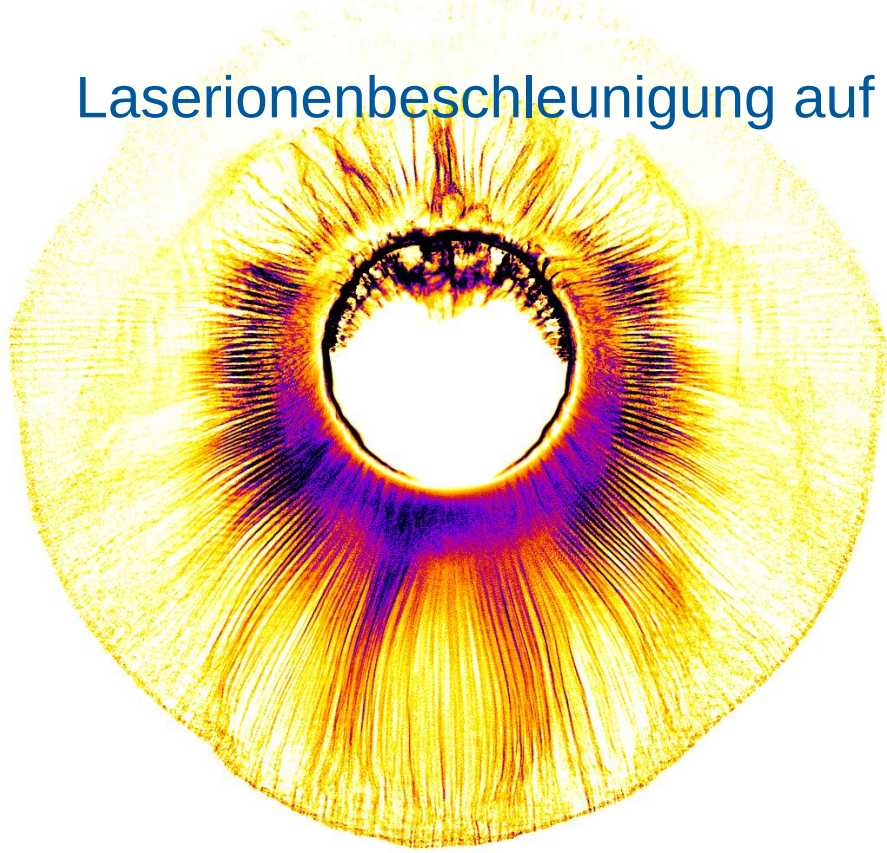
René Widera	Programmer
Sven Brieden	Bachelor Student
Maximilian Böhme	Student Intern
Daniel Gräveling	Student Intern
Fabian Jung	Student Intern
Malte Zacharias	Student Intern



Wenn Menschen zusammenarbeiten

Reading Log...

Laserionenbeschleunigung auf Supercomputern



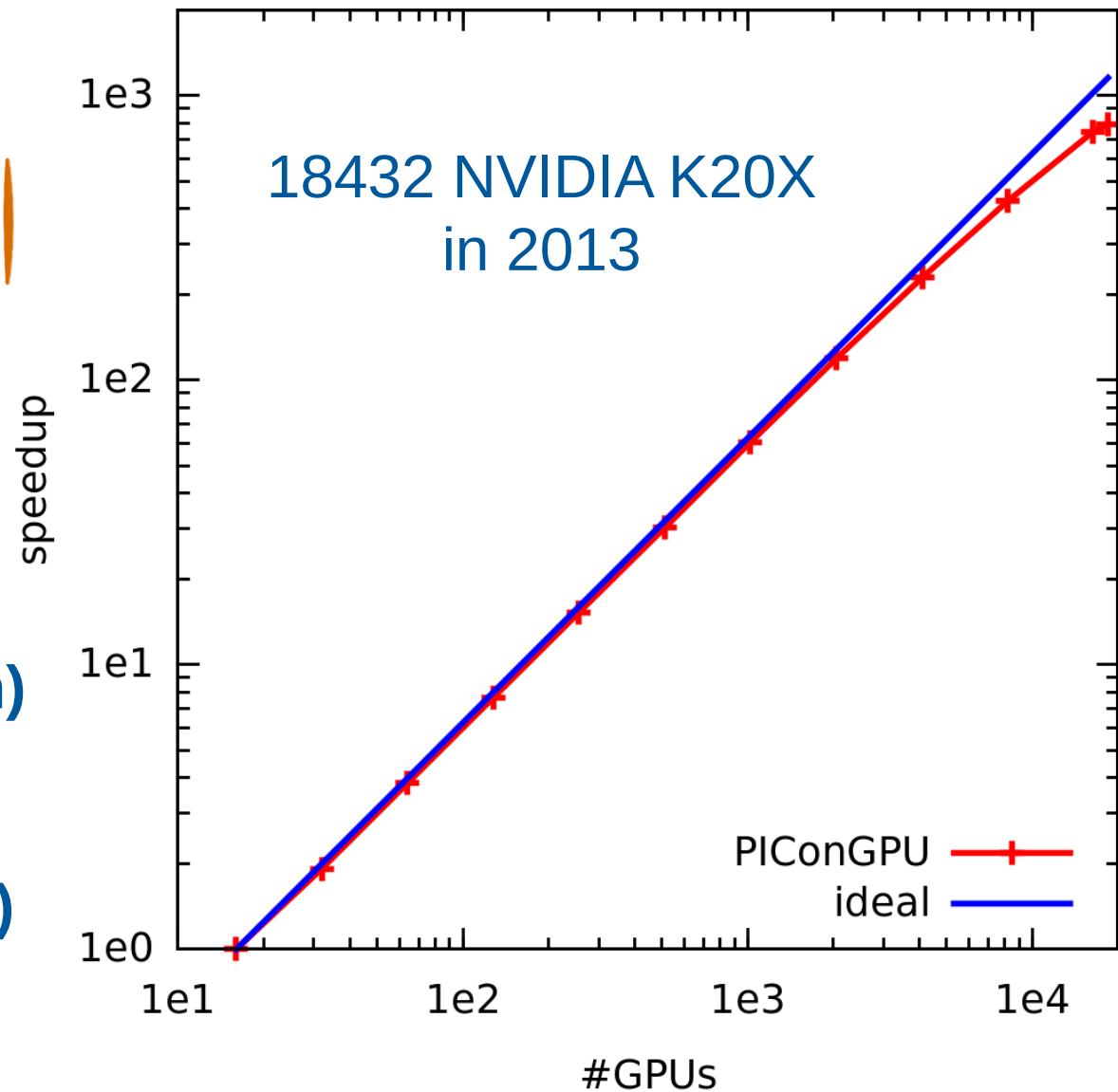
- Fünf 3D Simulationen
- $100 n_c$, λ_{plasma} Auflösung
- 1 ps Dauer @ as Auflösung

60 MCPU/h auf TITAN

Parallele Skalierung



**7.176 PFLOPs/s
(double-precision)
plus
1.449 PFLOPs/s
(single-precision)**



Dateien schreiben und lesen wird zum Problem

