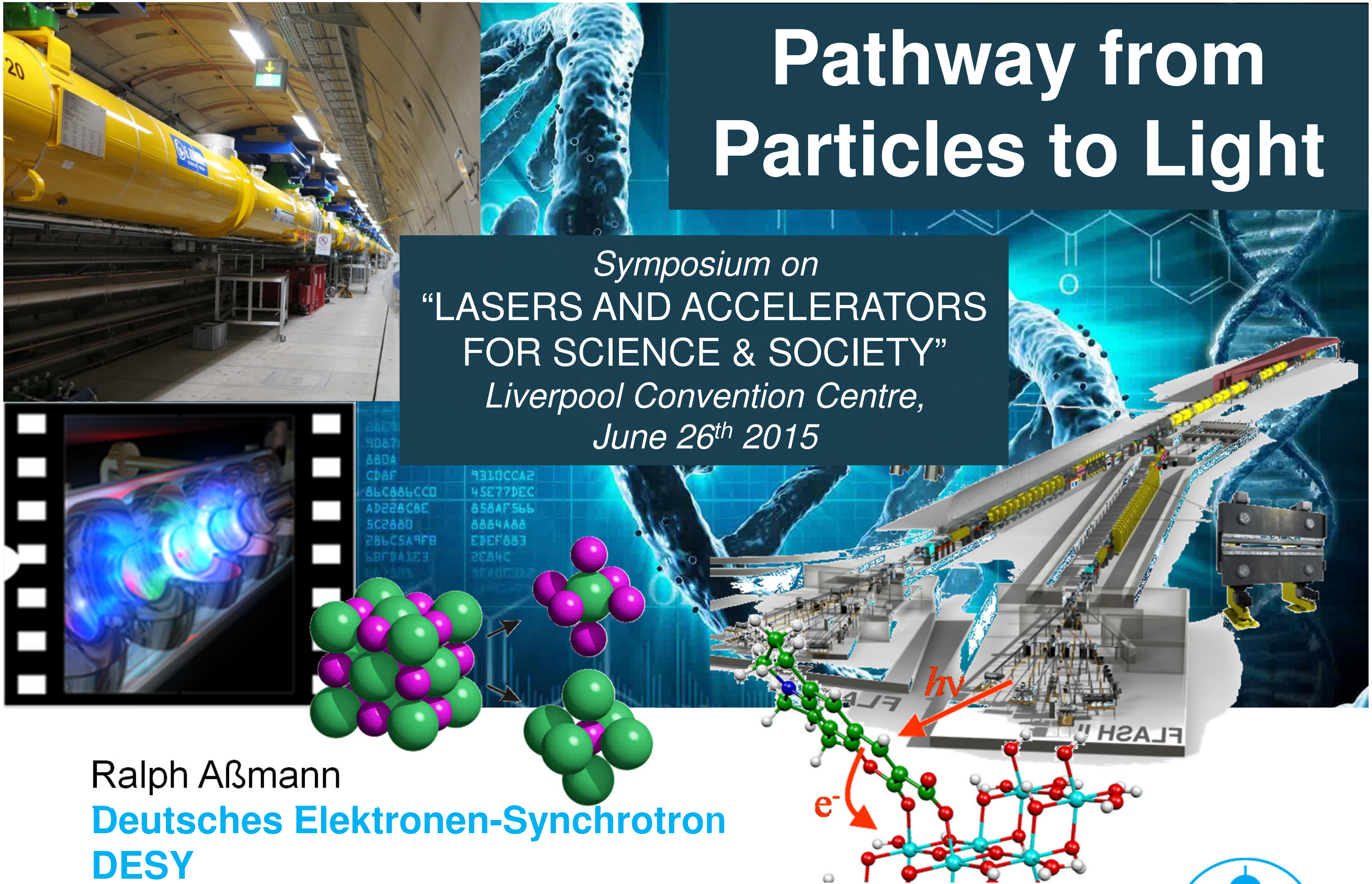
Pathway from Particles to Light

Symposium on
"LASERS AND ACCELERATORS FOR SCIENCE & SOCIETY"
Liverpool Convention Centre,
June 26th 2015



Ralph Aßmann
Deutsches Elektronen-Synchrotron DESY

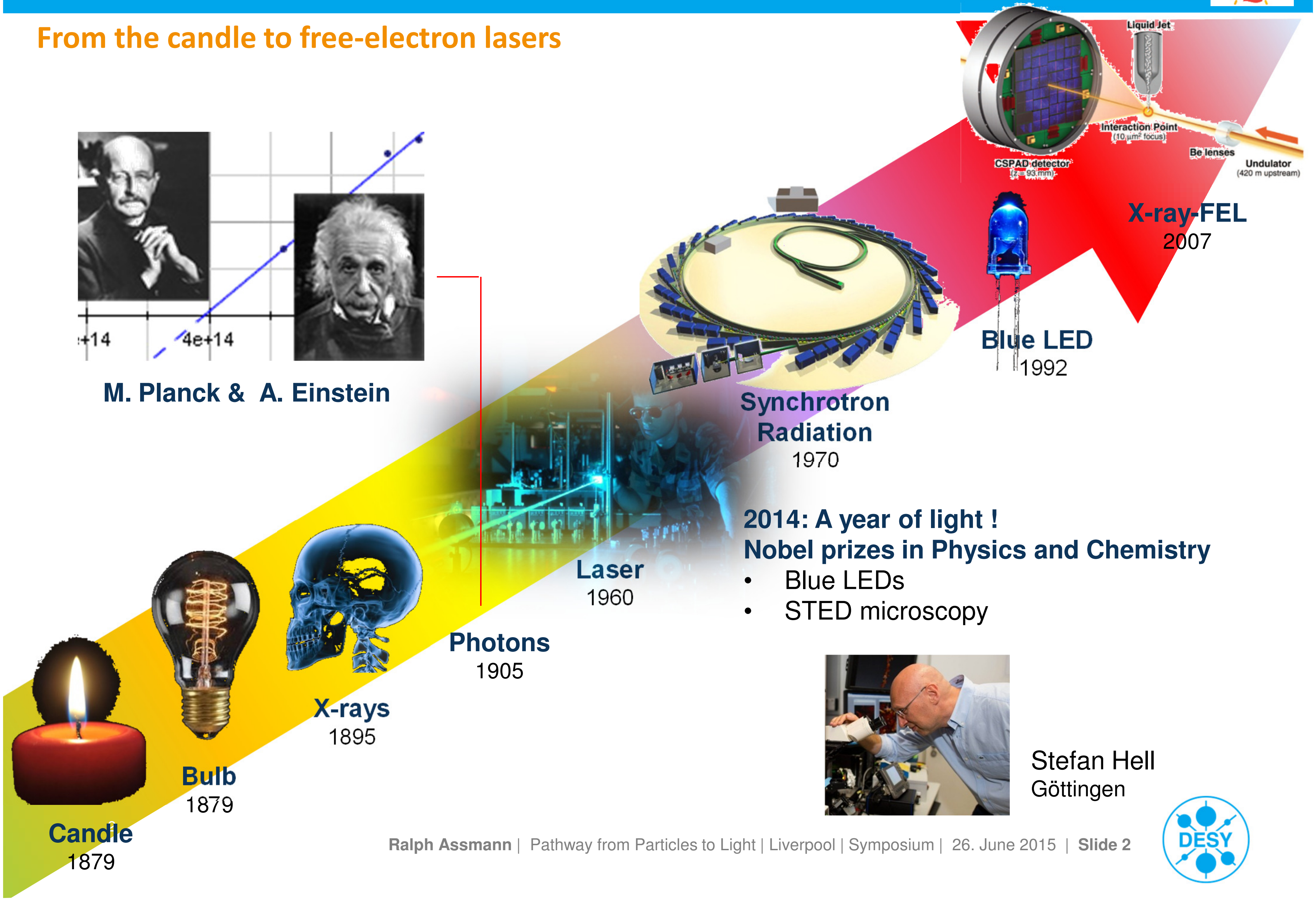
HELMHOLTZ GEMEINSCHAFT

Acknowledgements: J. Boedewadt, R. Brinkmann, H. Dosch, U. Dorda, C. Hahn, F. Lehner, B. Marchetti, H. Weise

2015. UNESCO „International Year of Light“

From the candle to free-electron lasers

M. Planck & A. Einstein



2014: A year of light !
Nobel prizes in Physics and Chemistry

- Blue LEDs
- STED microscopy

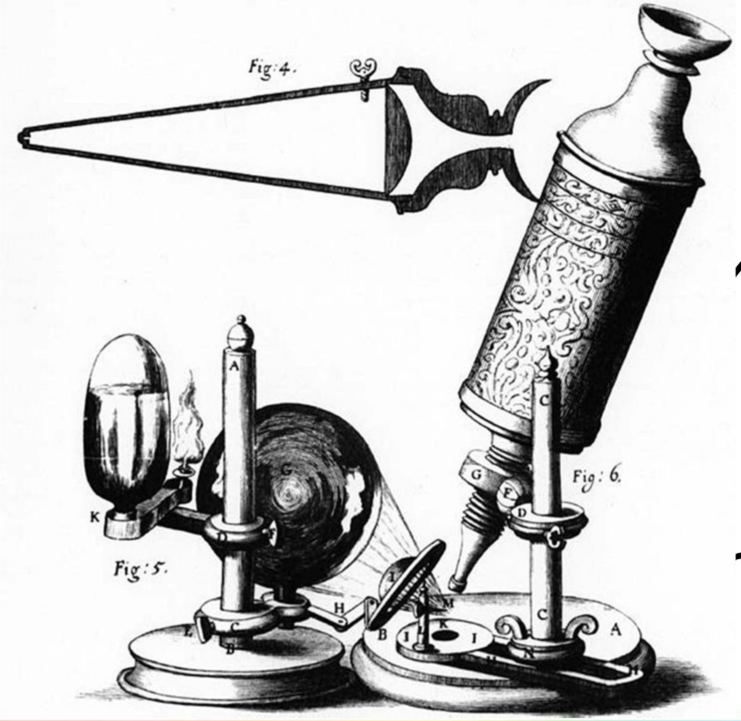
Stefan Hell
Göttingen

DESY

Dream of Mankind: Make invisible Things visble

17th Century: Birth of optical microscopy

Galileo Galilei
Christian Huygens
Robert Hooke

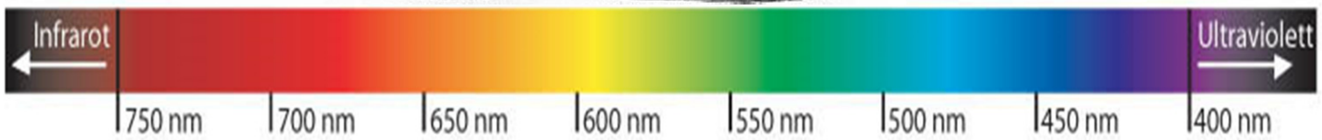


Spatial resolution
(Ernst Abbe, 1873)

1676 Antoni van Leeuwenhoek discovers bacteria

Image depends on

- quality of lenses
- Amount of light through optical aperture



DESY | 1nm

Dream of Mankind: Make invisible Things visible

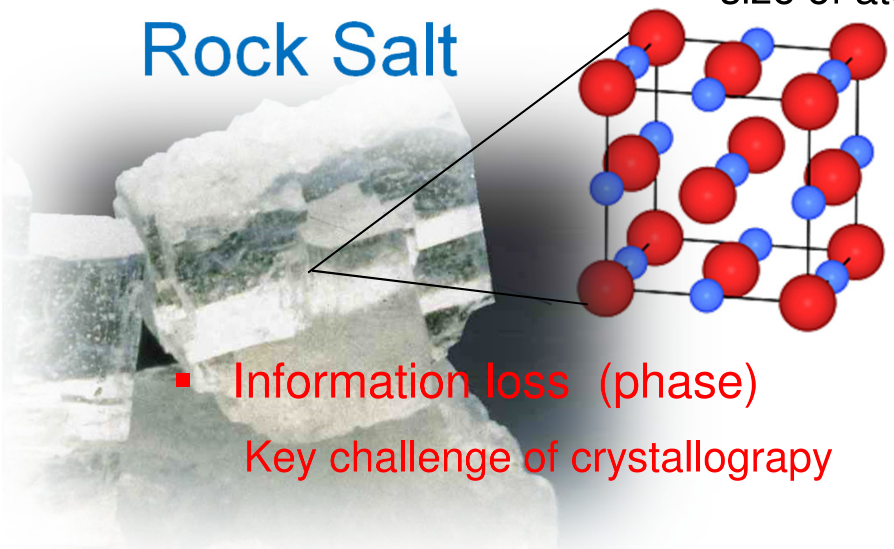
20th Century: Birth of x-ray diffraction „Lenseless microscopy“

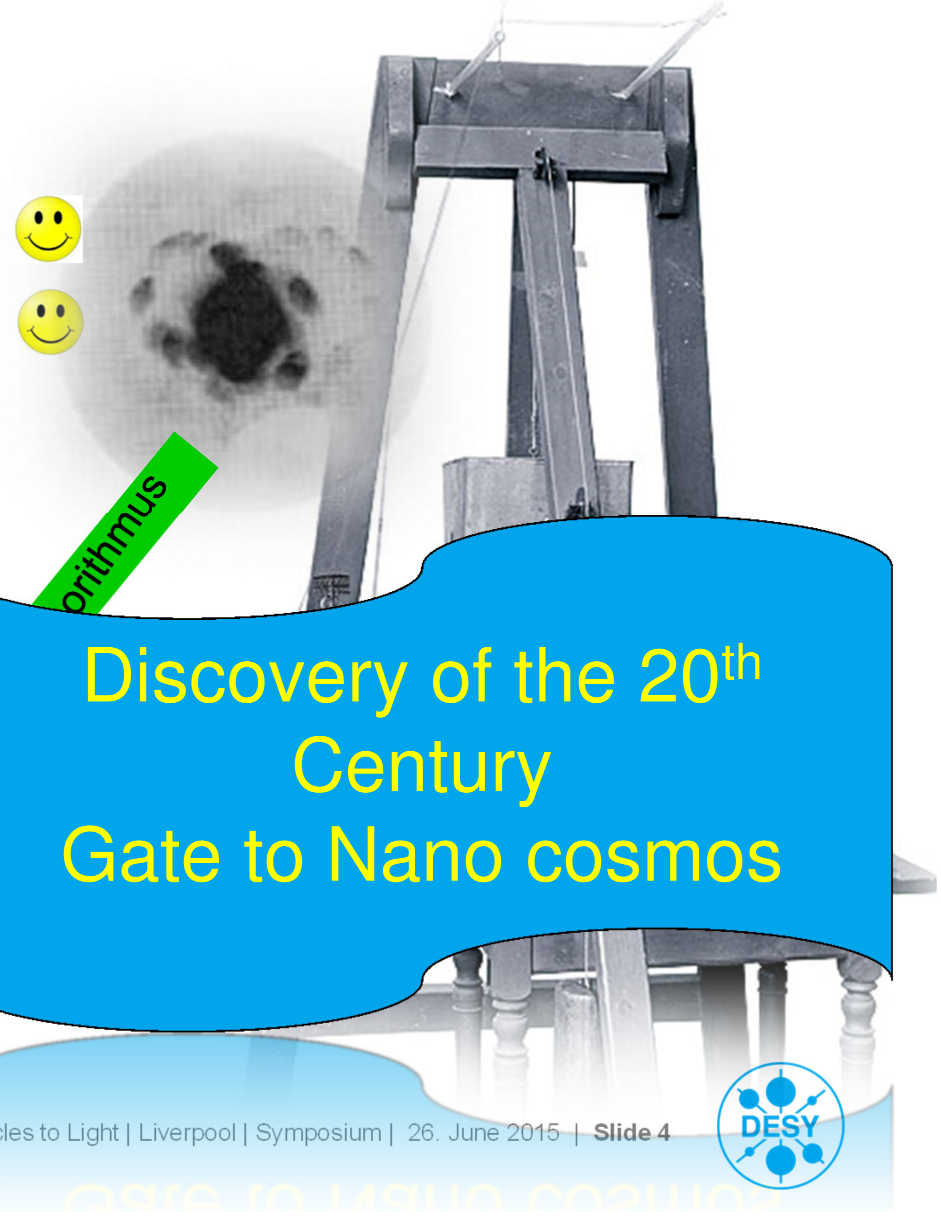
Max von Laue, Paul-Peter Ewald
W.L. Bragg

- Image does not depend on lenses
- **Access to molecular structure**

as
x-rays: λ = 0,1 nm
= size of atoms

Rock Salt



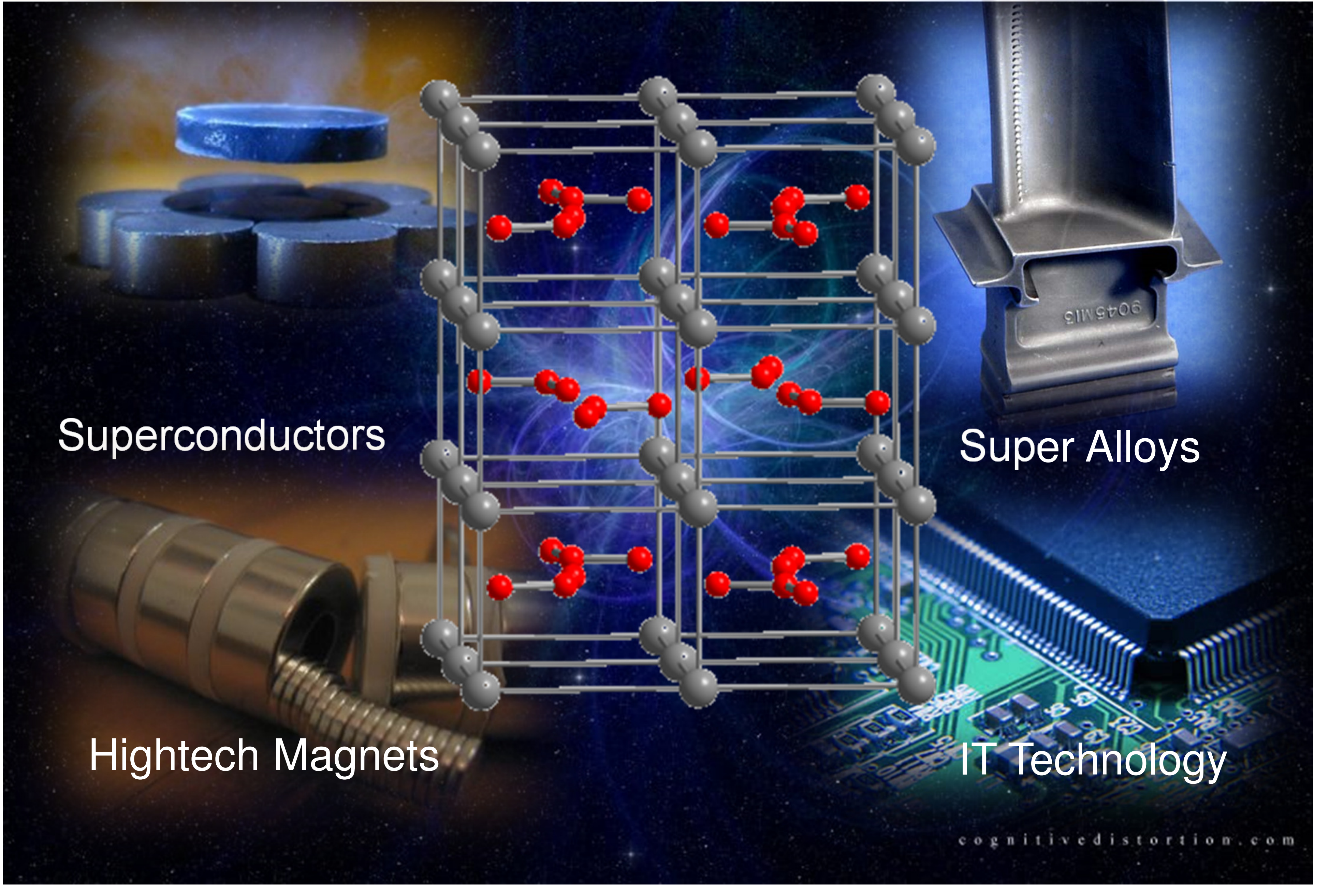


Discovery of the 20th Century
Gate to Nano cosmos

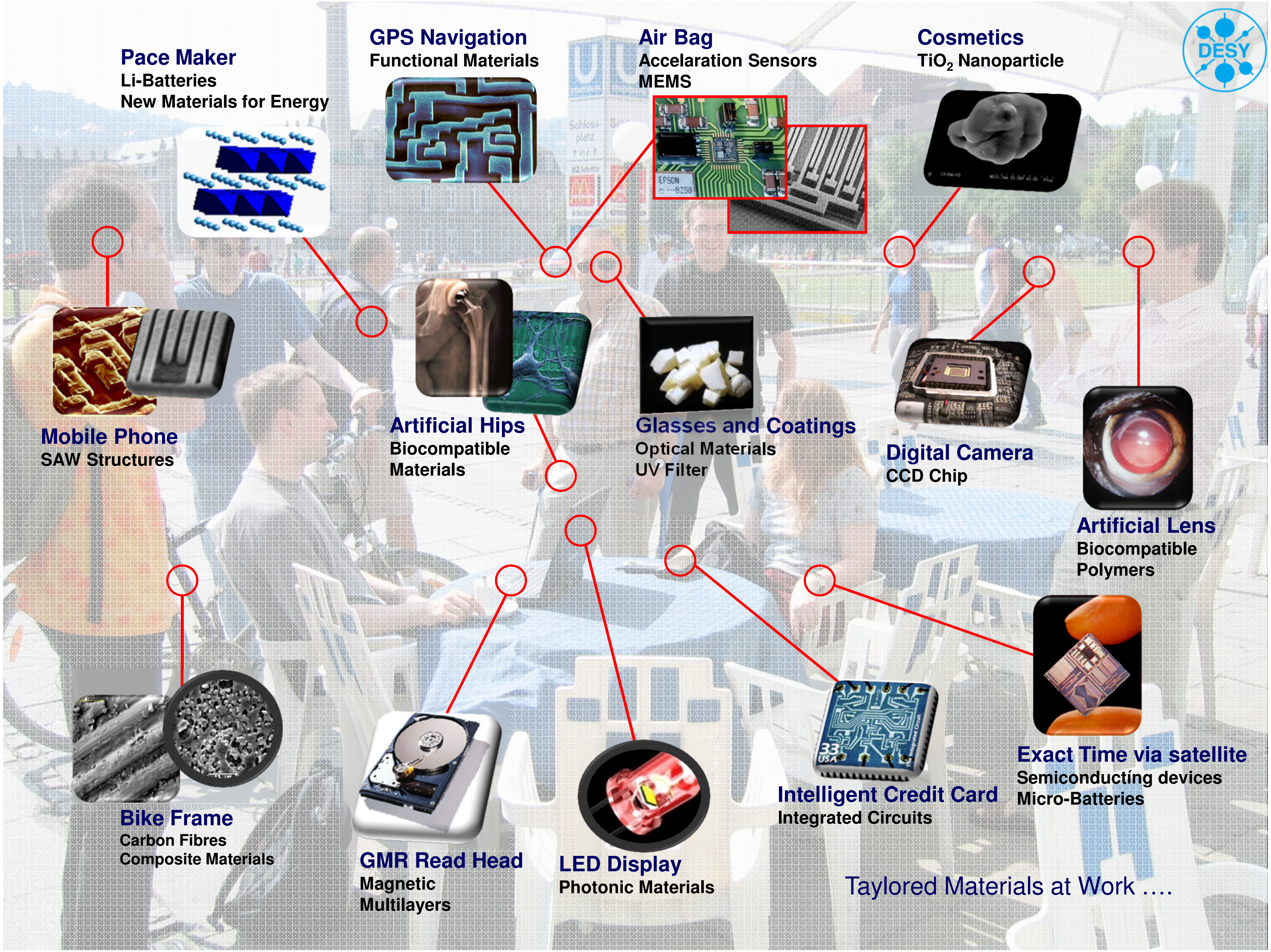
- Information loss (phase)

Key challenge of crystallograpy

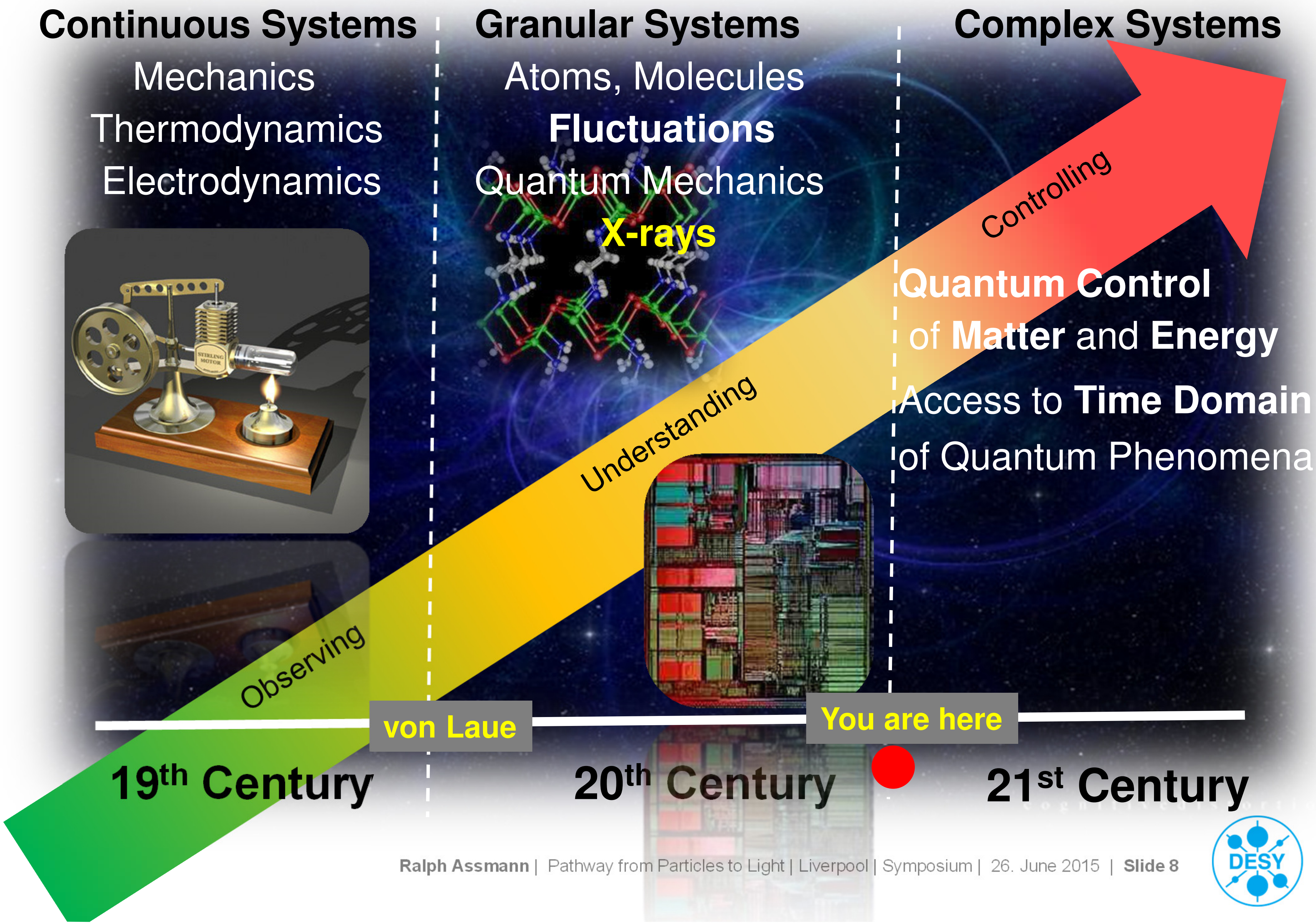
1912-2012. „Century of Crystals“



Germany 2015.

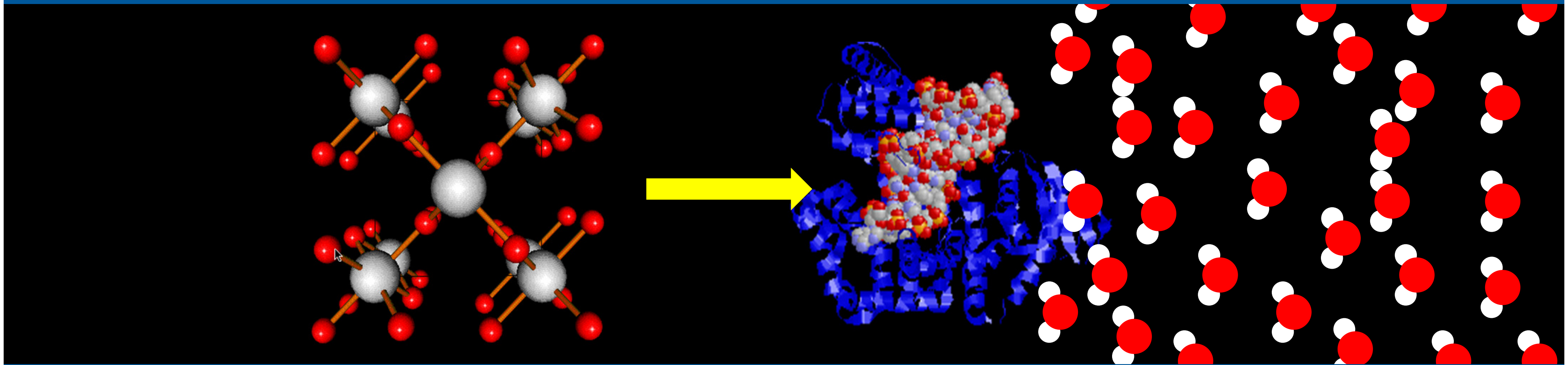

Pace Maker
Li-Batteries
New Materials for Energy
GPS Navigation
Functional Materials
Air Bag
Accelaration Sensors
MEMS
Cosmetics
TiO_2 Nanoparticle
DESY
Mobile Phone
SAW Structures
Artificial Hips
Biocompatible
Materials
Glasses and Coatings
Optical Materials
UV Filter
Digital Camera
CCD Chip
Artificial Lens
Biocompatible
Polymers
Exact Time via satellite
Semiconducting devices
Micro-Batteries
Bike Frame
Carbon Fibres
Composite Materials
GMR Read Head
Magnetic
Multilayers
LED Display
Photonic Materials
Intelligent Credit Card
Integrated Circuits
Taylored Materials at Work ….

The new Challenge.



X-Ray Challenge of the 21st Century.

„When the going get‘s tough“



1900 | 2000 | future

Era of Crystalline Matter

Ordered Structures
Equilibrium Phenomena
Phase Diagrams

you are here

Era of Complex Matter

Locally Ordered Structures
Nonequilibrium Phenomena
Transient States

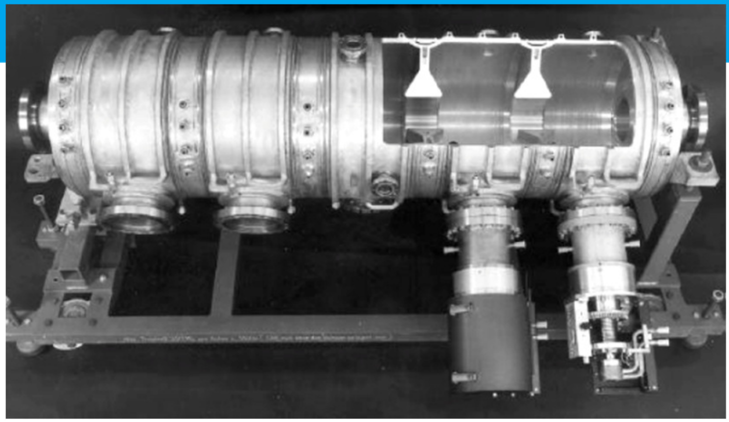
State of the art accelerators for the best light possible

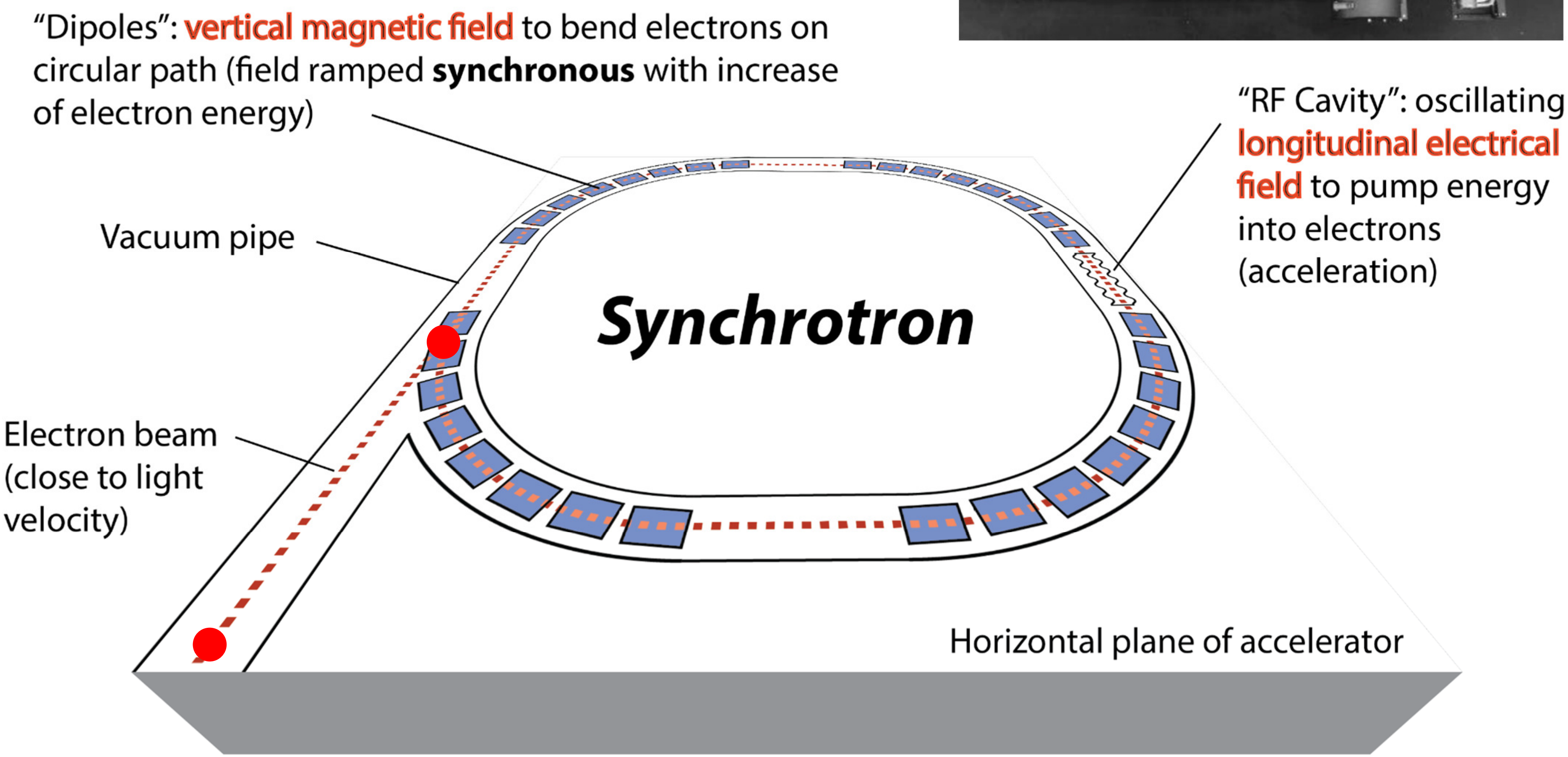
Synchrotron radiation | X-Ray Lasers + High Brilliance SR

The Synchrotron Accelerator

Remember the field B required for bending a particle (charge e) of momentum p into circle of radius R?

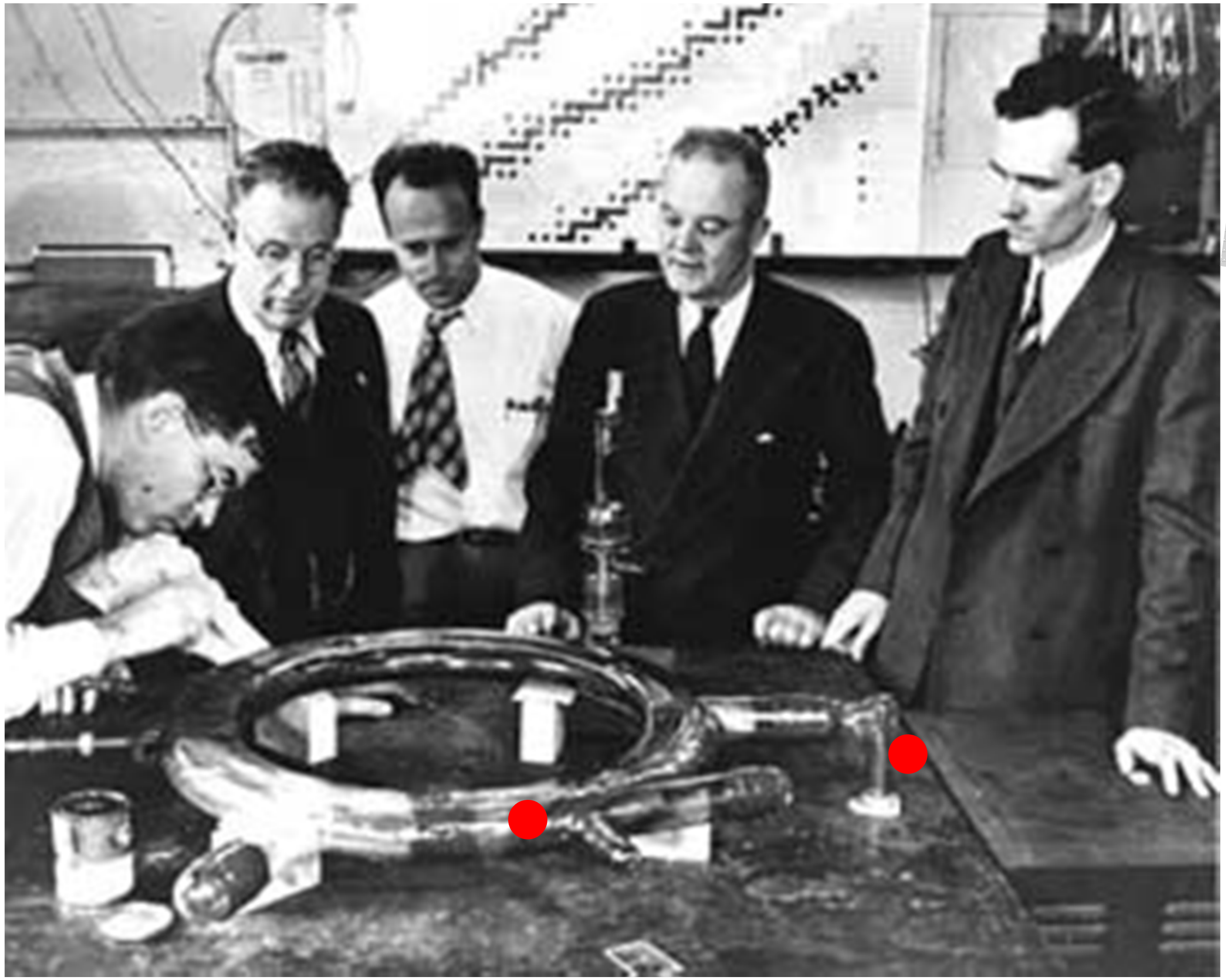
$$p \sim R \cdot e \cdot B$$





Quadrupoles and sextupoles not shown here but required

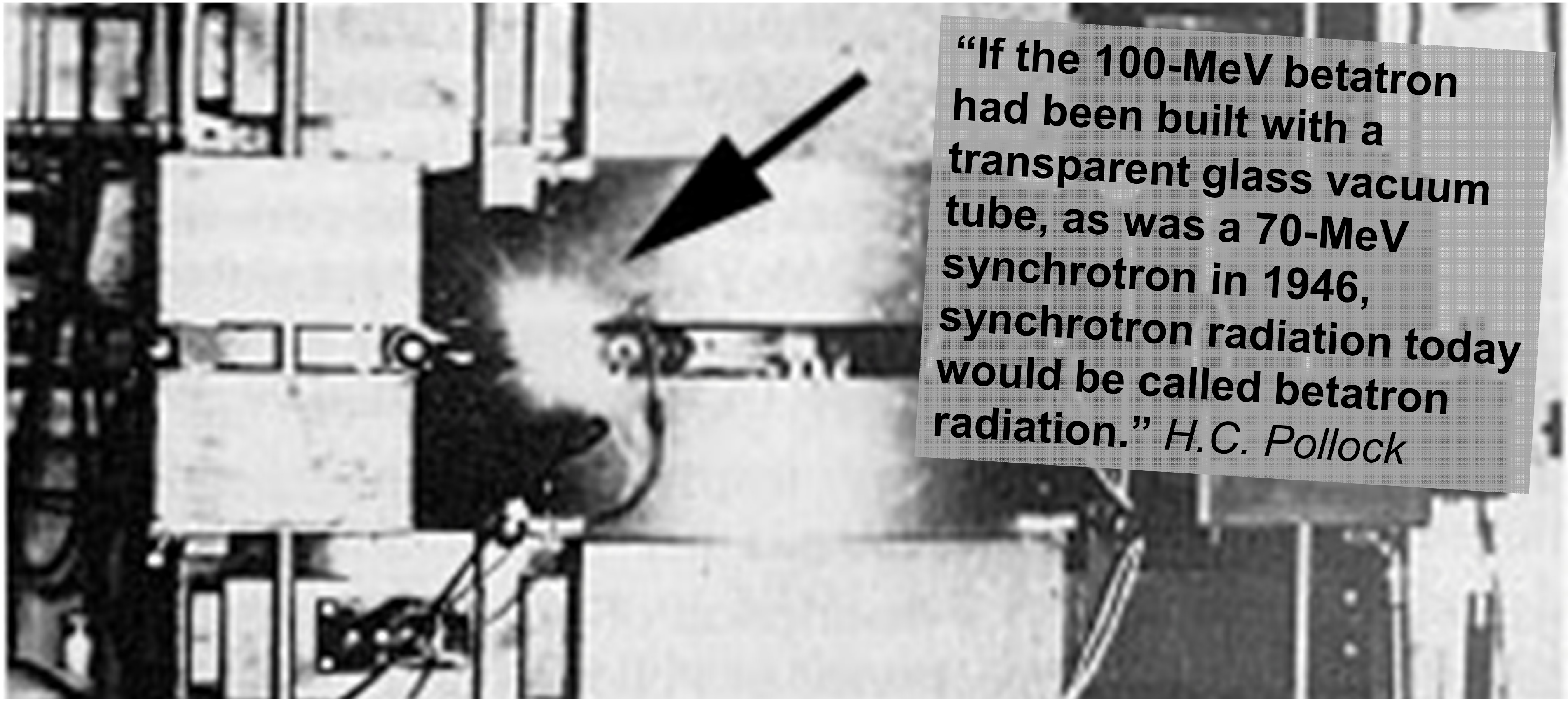
The Situation in 1946…



Glass vacuum chamber of the 1947 General Electric Synchrotron Accelerator (70 MeV). Courtesy BNL and ESRF.

A synchrotron can store a charged particle beam for many hours or even days ("storage ring").

General Electric Synchrotron Accelerator 1946



"We had some sparking from one of the pulse transformers.

When Haber looked around the comer of the wall he noticed a very bright spot of light coming from the tube on the left hand side."

Herbert C. Pollock's Notebook from 1946

Nobel Prize Winners, a Spy and an Actor/Politician…

The discovery of synchrotron radiation

Herbert C. Pollock

2147 Union Street, Schenectady, New York 12309

(Received 12 April 1982; accepted for publication 29 April 1982)

"From the **academic community** there were many visitors between 1947 and 1949.

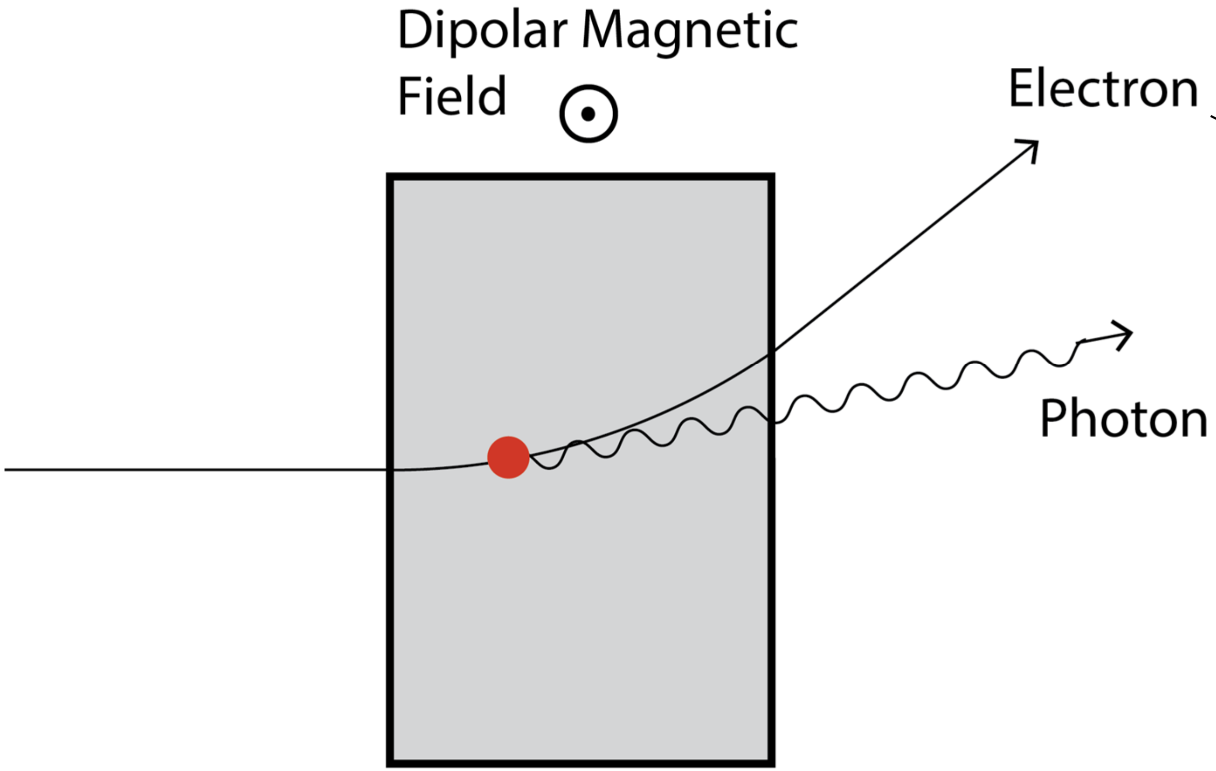
Among them we can count **six Nobel prize winners**.

With other visitors came Klaus Fuchs, the famous **Russian spy**, clearly capable since none of us in the synchrotron room could remember his visit until it was documented beyond question by the FBI.

Another visitor for 20 minutes was **Ronald Reagan**…"

Big impact on society obviously immediately expected.

Light from Accelerated Electrons



Energy Conservation

$$E_{\text{out}} = E_0 - E_{\text{photon}}$$

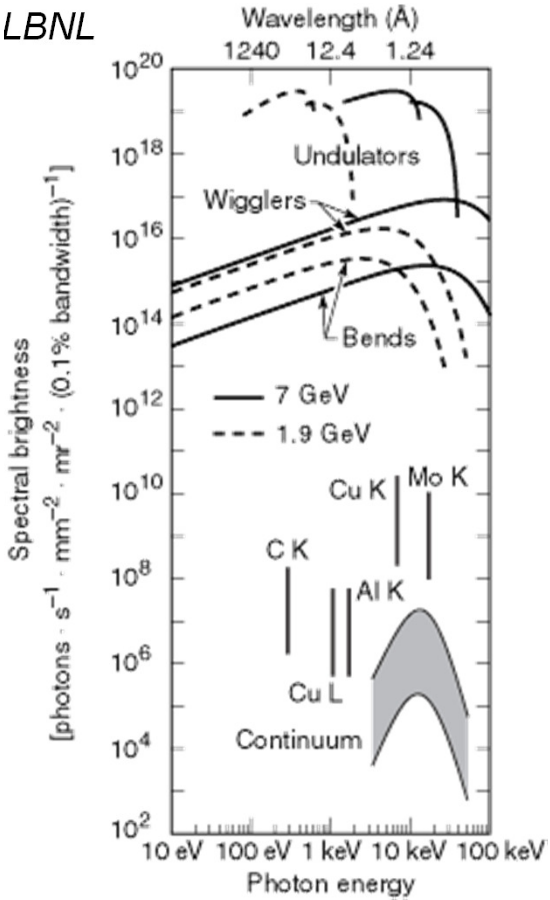
$$E_{\text{photon}} = \hbar\omega$$

Synchrotron Radiation **Converts energy of electrons into photons**

Relativistic Electrons **Forward cone of photons**

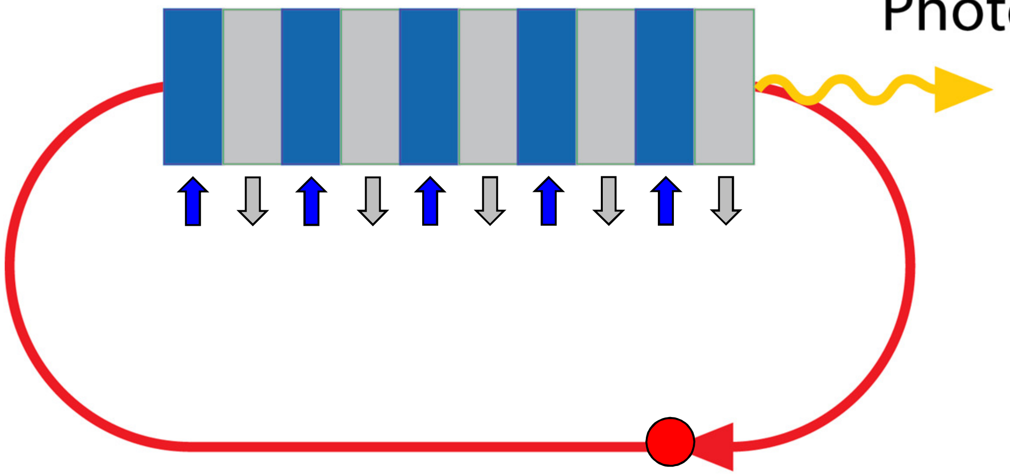
Undulators & Spectral Brightness of Synchr. Radiation

LBNL



Storage ring undulator

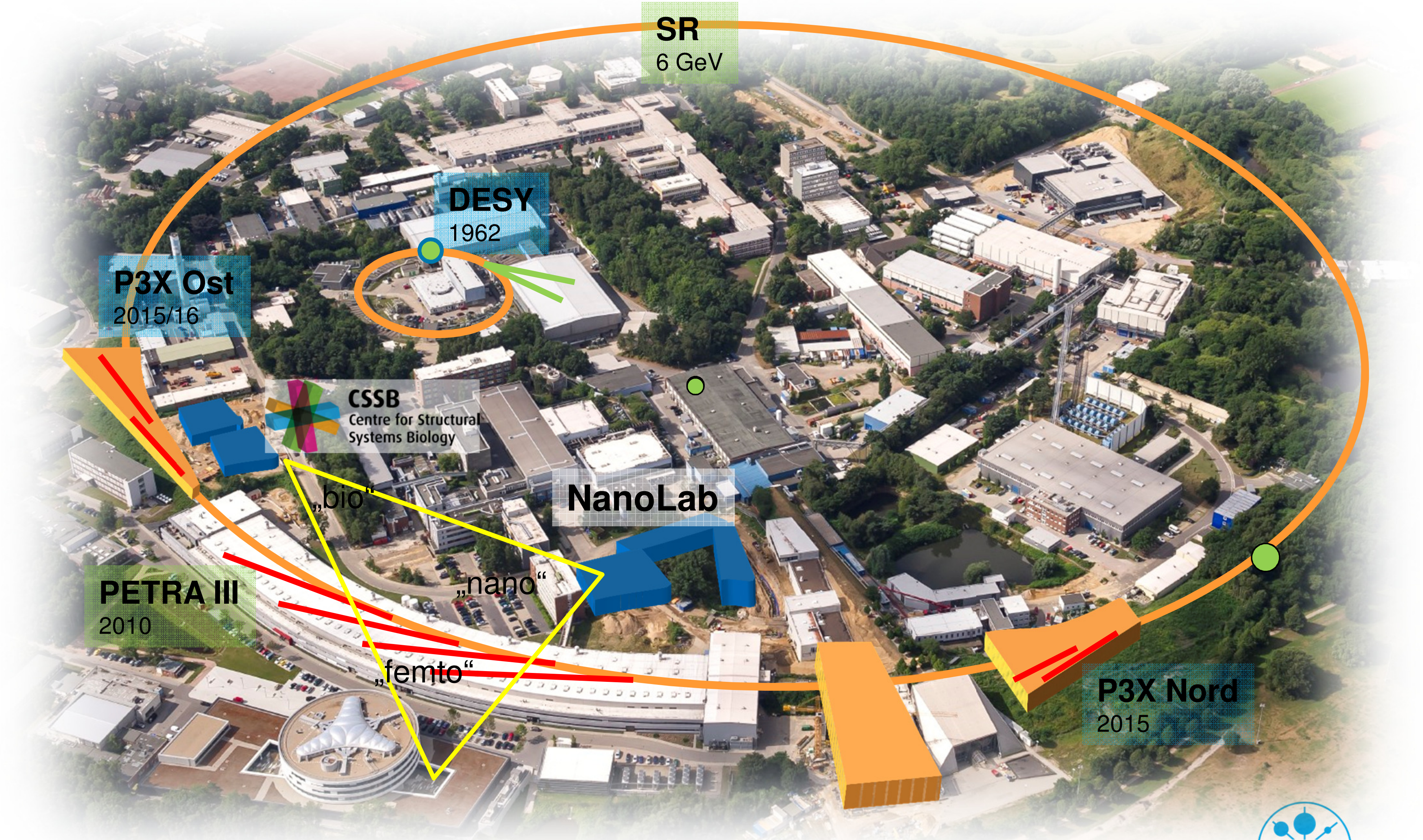
(DORIS, DESY)



Undulators create locally high bending fields for relativistic electrons:

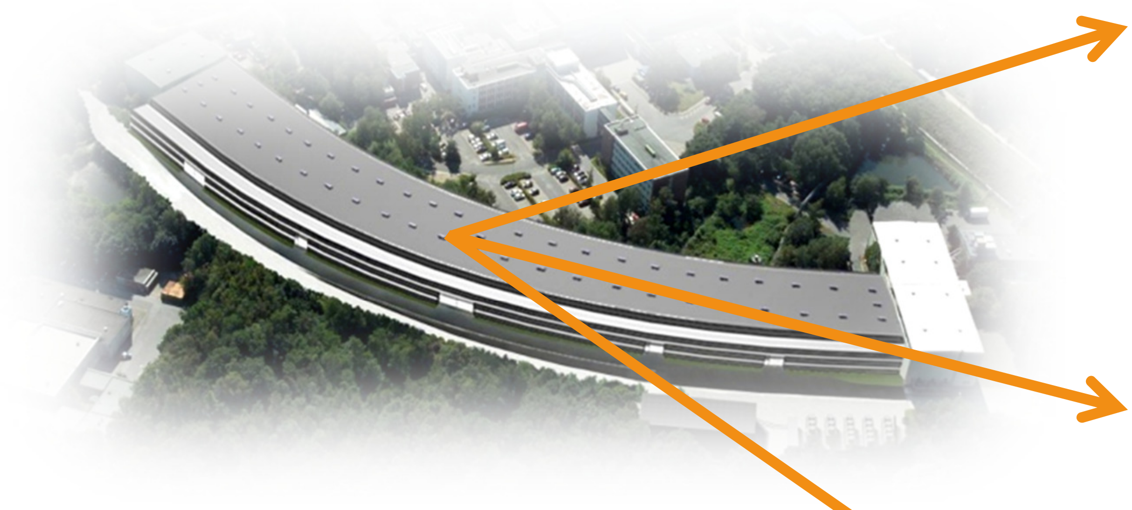
- More photons
- Localized emission areas
- Well-defined photon

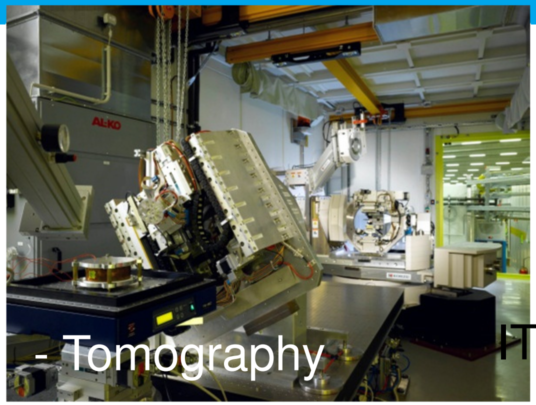
Modern X-Ray Facilites at DESY. *Synchrotron Radiation*

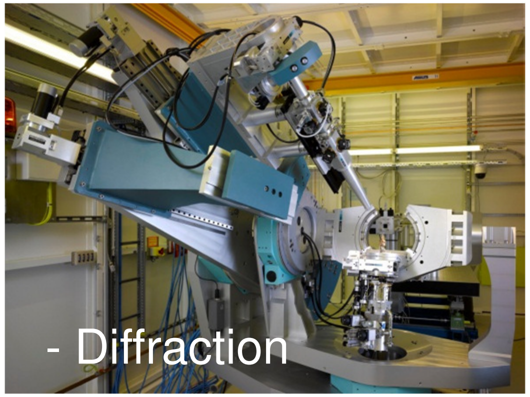


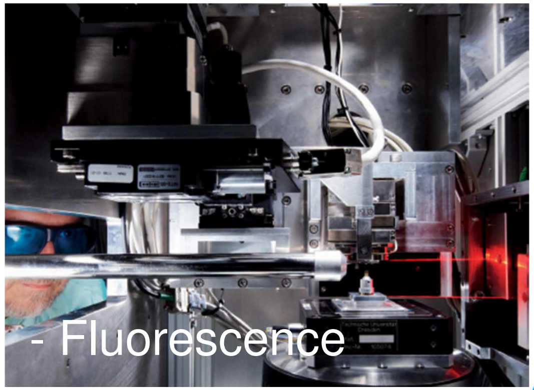
PETRA III.

Modern X-Ray Technology



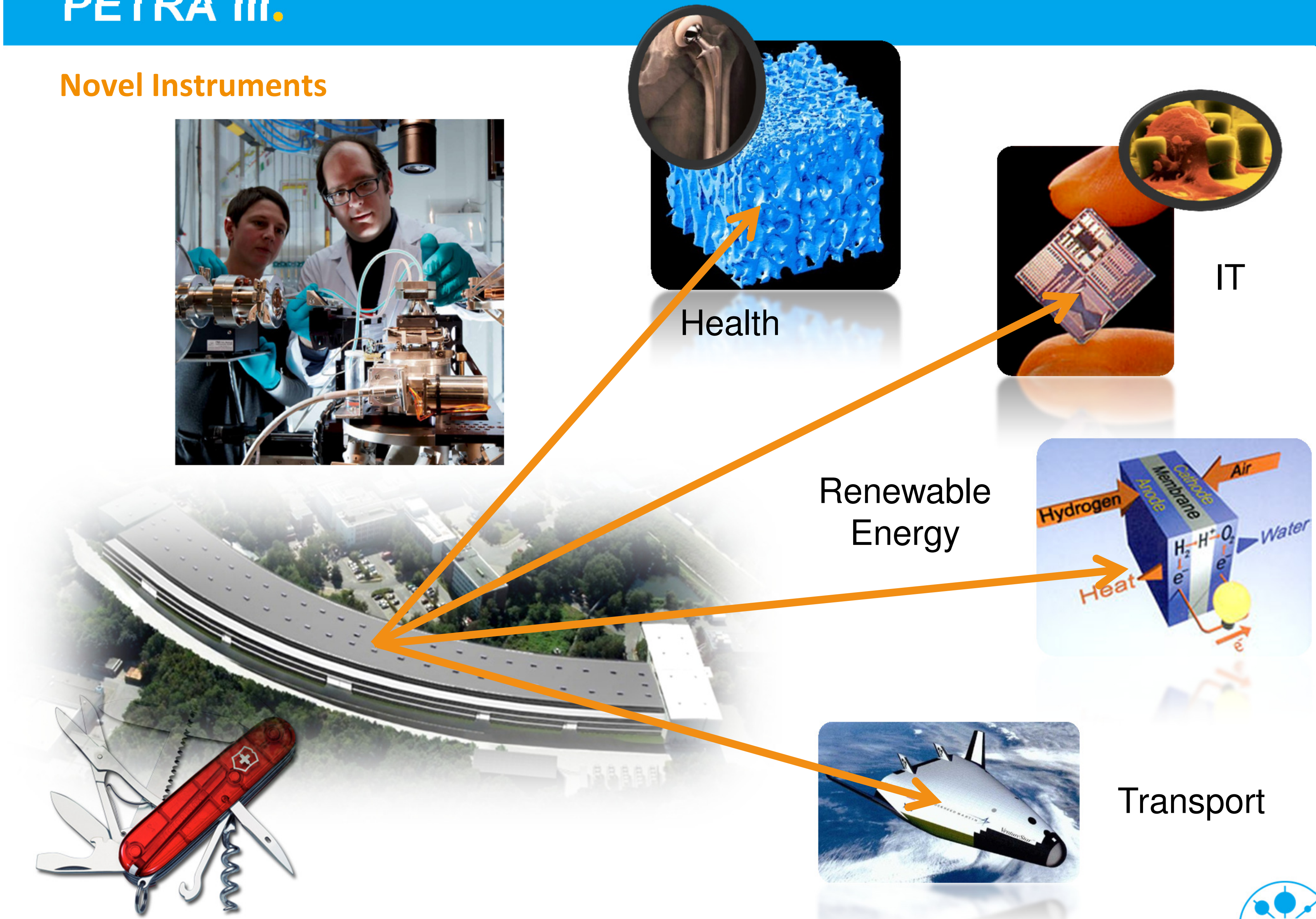




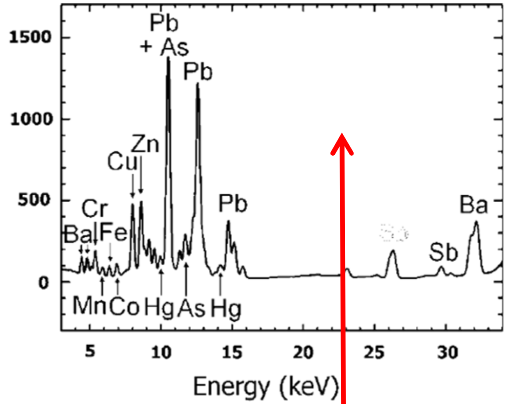


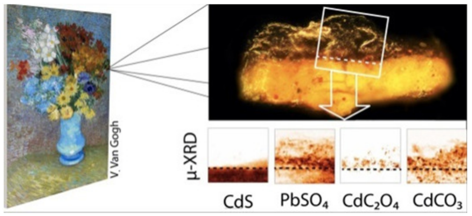
PETRA III.

Novel Instruments

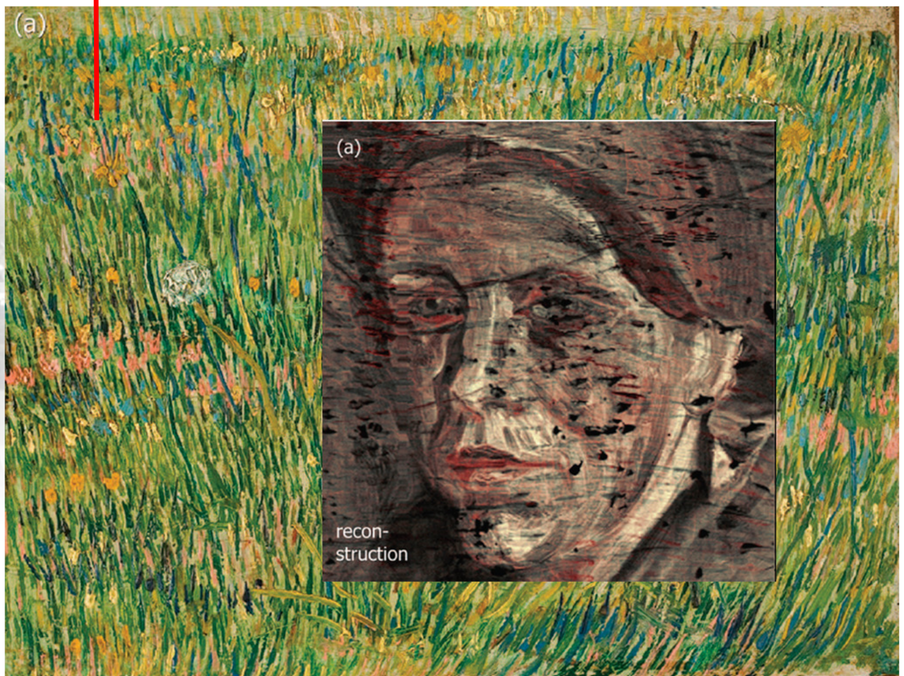


X-ray Micro-Fluorescence Analysis discovers hidden van Gogh



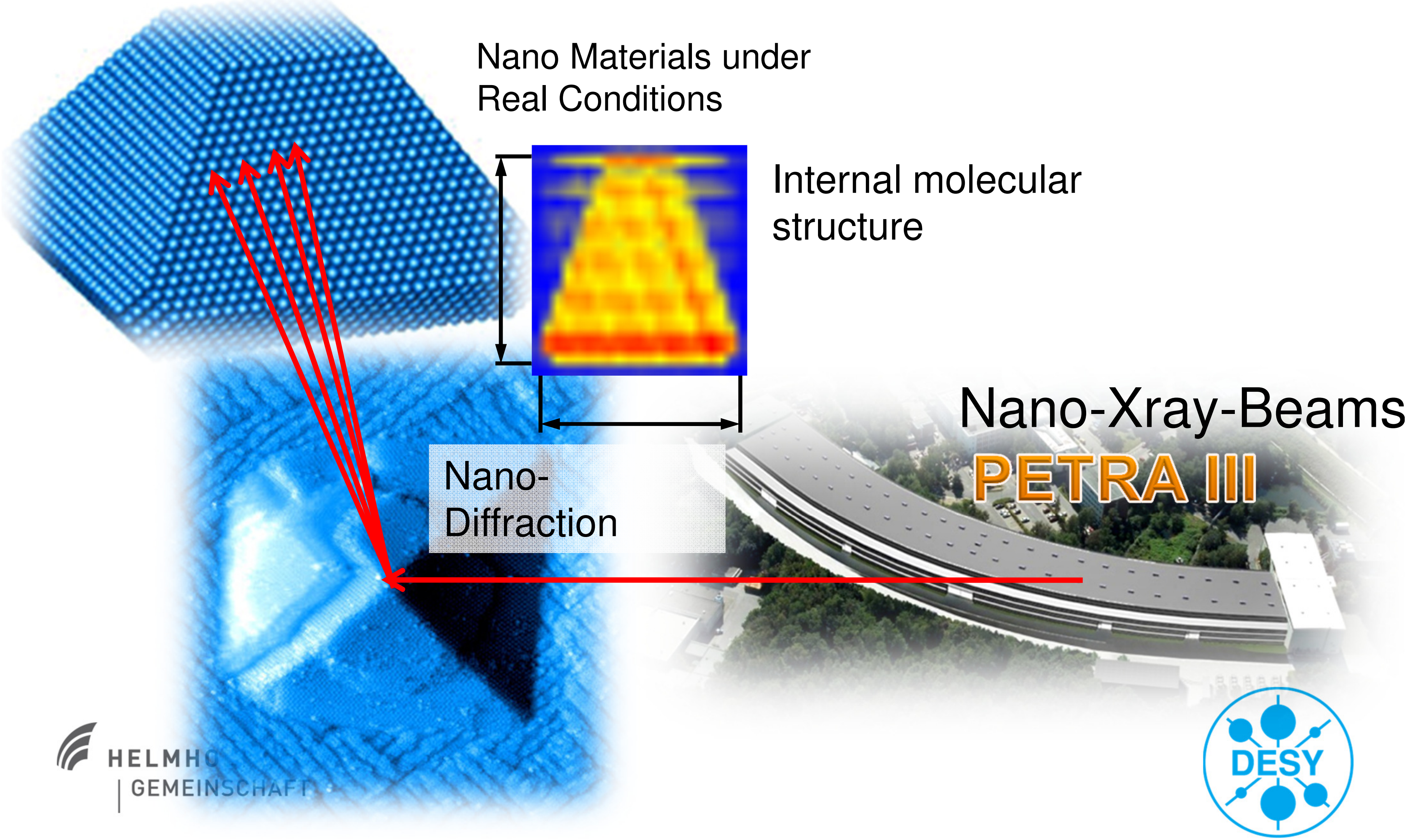


Van Gogh, Grasgrond 1887



Expedition into Nano World

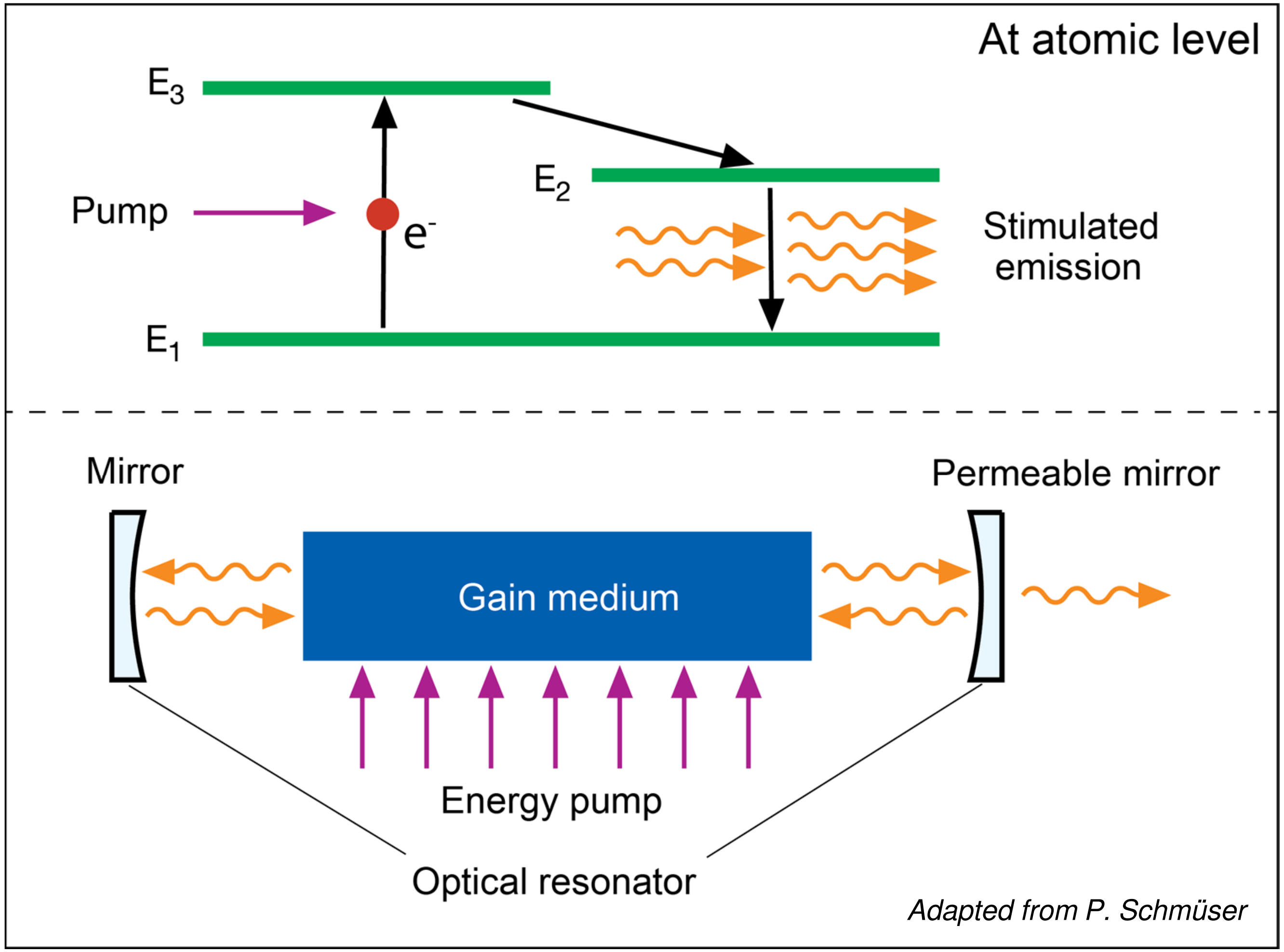
Design of taylored Nanostructures



What about a Free-Electron Laser?

- Free electrons = here **beam** of electrons (bunch = packet of e^-)

- Reminder: **Laser** (light from orbital electrons in an atom)

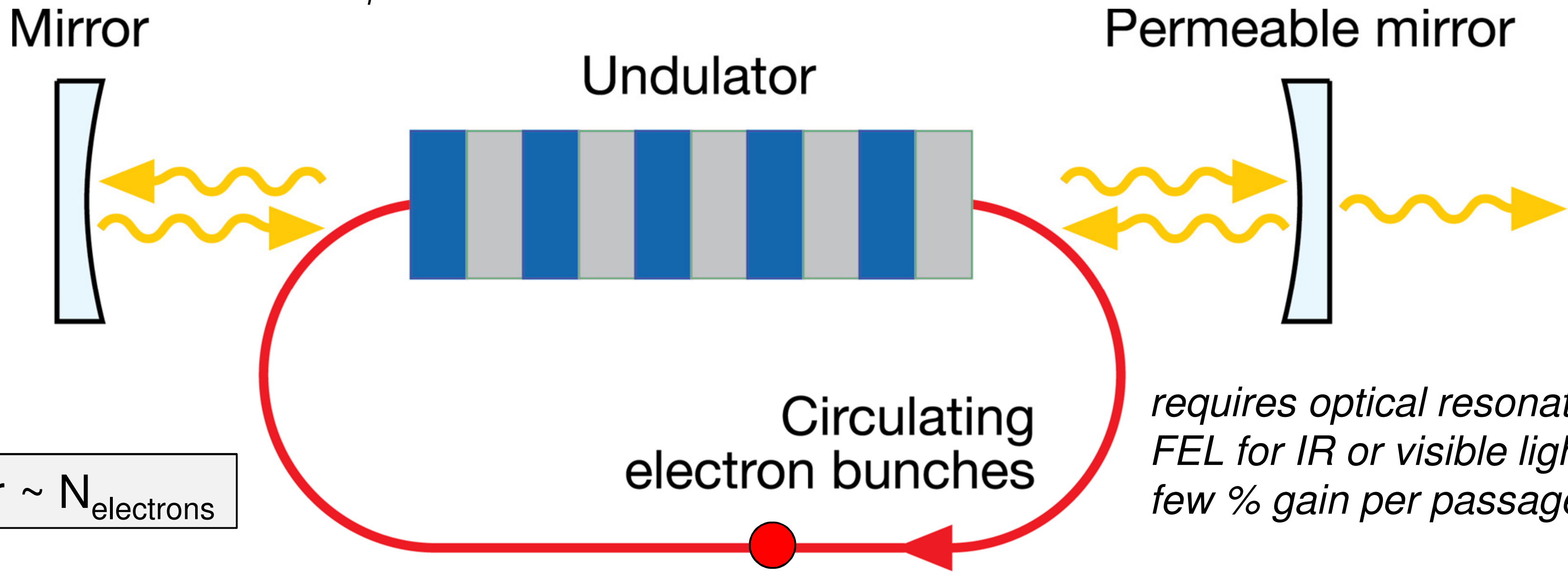


LASER

"Light Amplification by Stimulated Emission of Radiation"

Low Gain Free Electron Laser with a Synchrotron

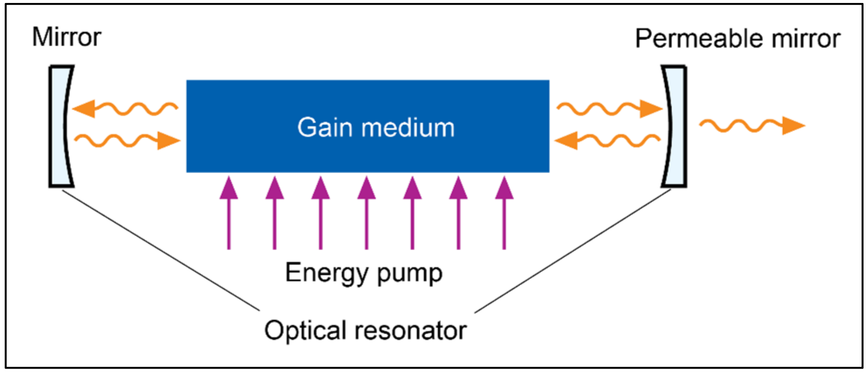
Adapted from P. Schmüser



Power ~ $N_{electrons}$

requires optical resonator
FEL for IR or visible light
few % gain per passage

Reminder: The Laser principle



High Gain Free Electron Laser with a Linear Accelerator

Electron beam moves through undulator (only once)

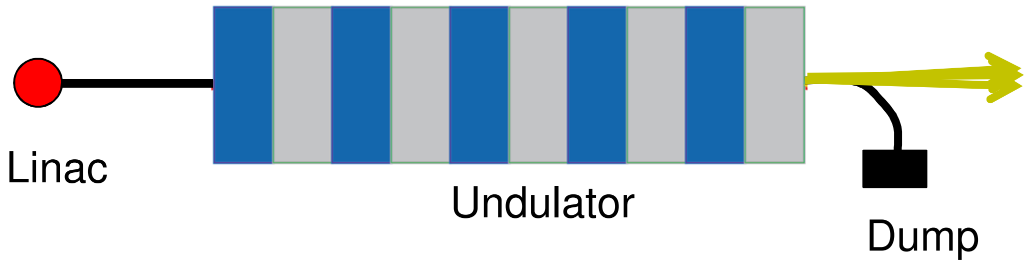
Each electron radiates a electromagnetic field

The fields act on other electrons, establishing a collective interaction

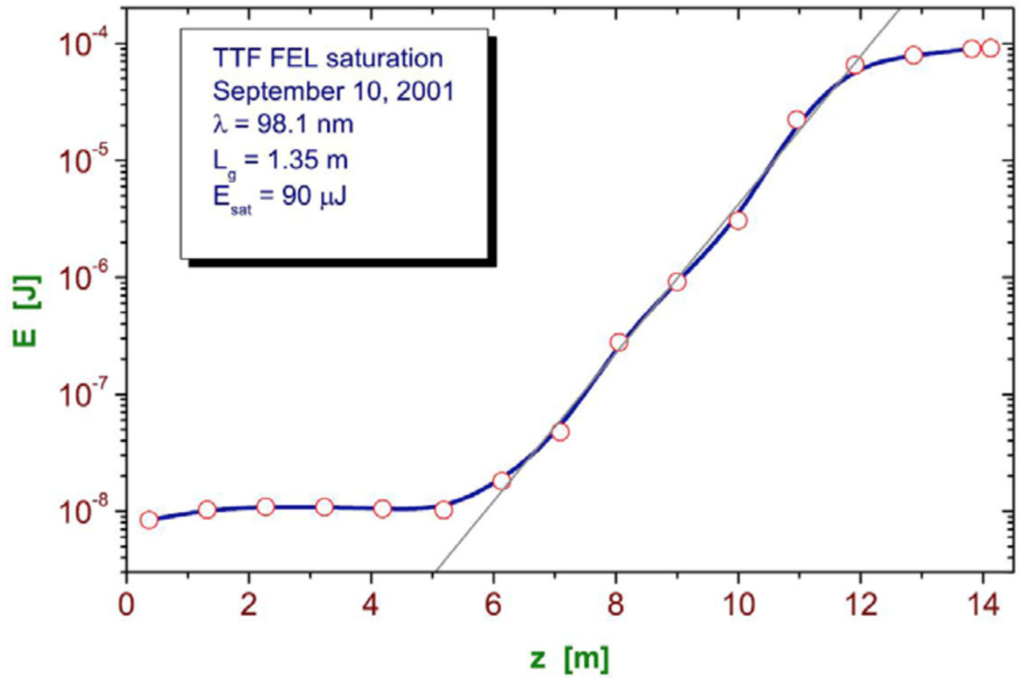
If several conditions are met (energy spread, emittance)

Beam forms micro-bunches separated by the radiation wavelength

Radiation is coherent and has larger intensity



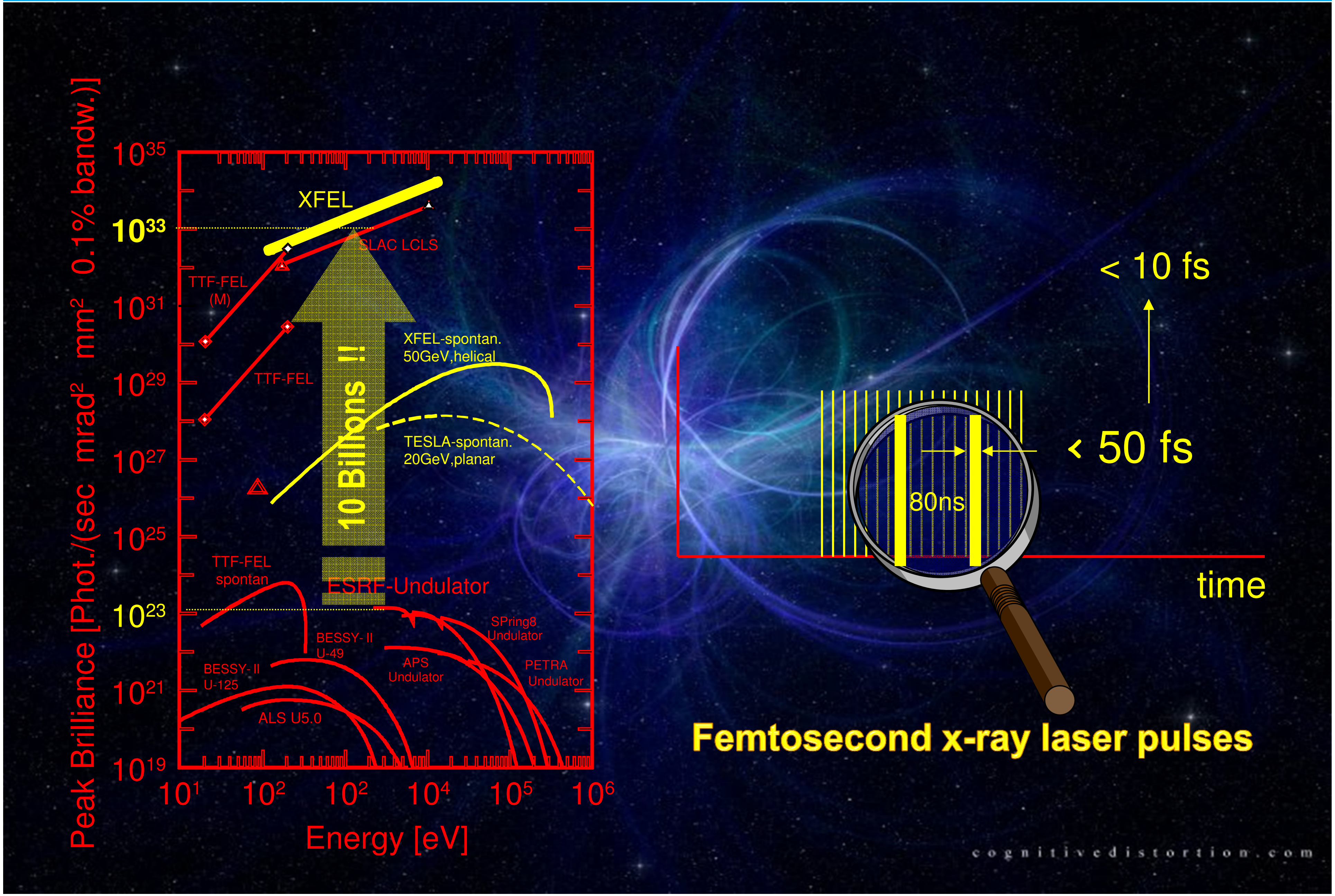
Power ~ $(N_{electrons})^2$



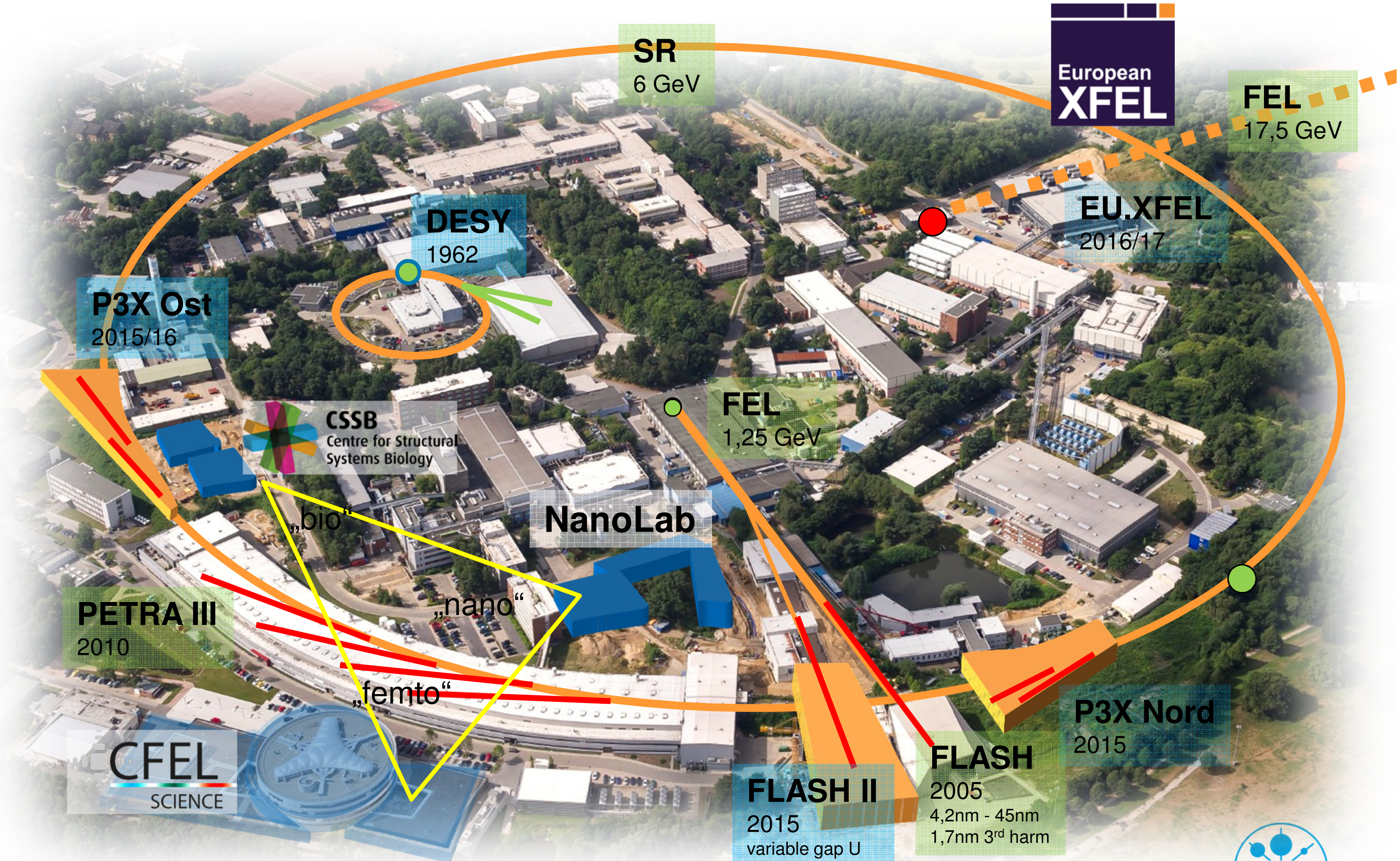
The Power of Coherence

Adapted from P. Schmüser

Impact of Free-Electron Lasers.

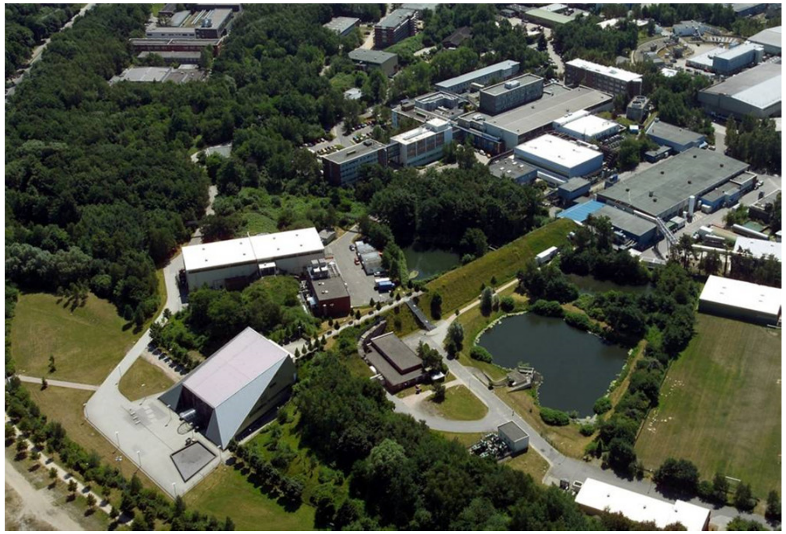


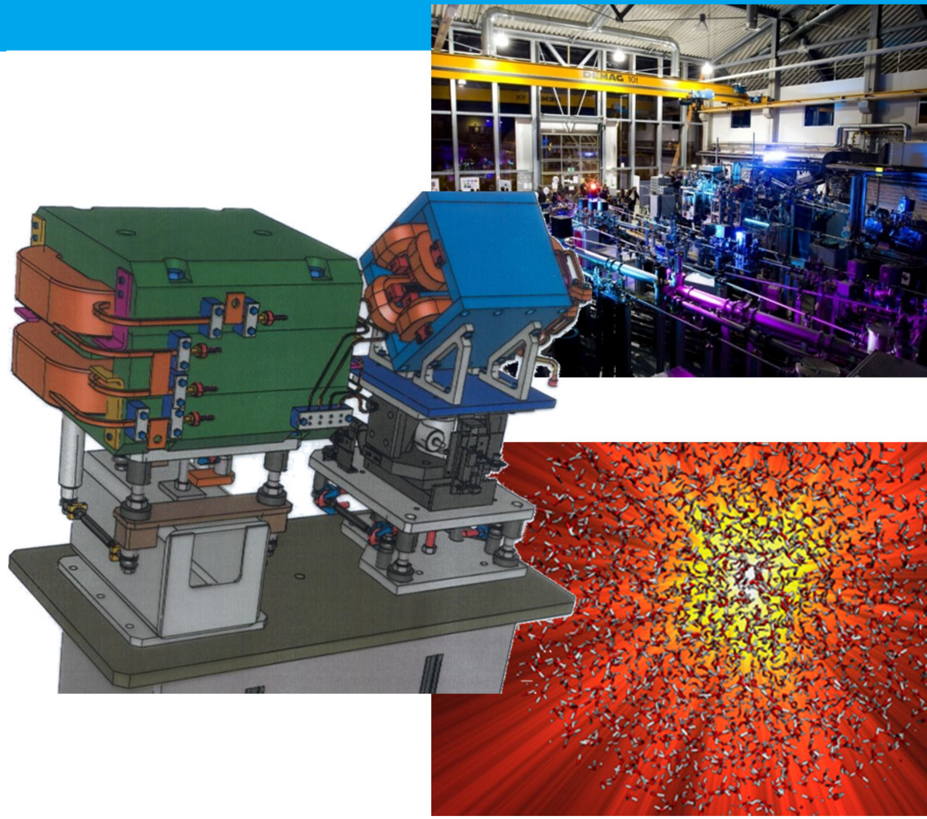
X-Ray Facilites at DESY.



FLASH.

„X-FEL Big Bang"





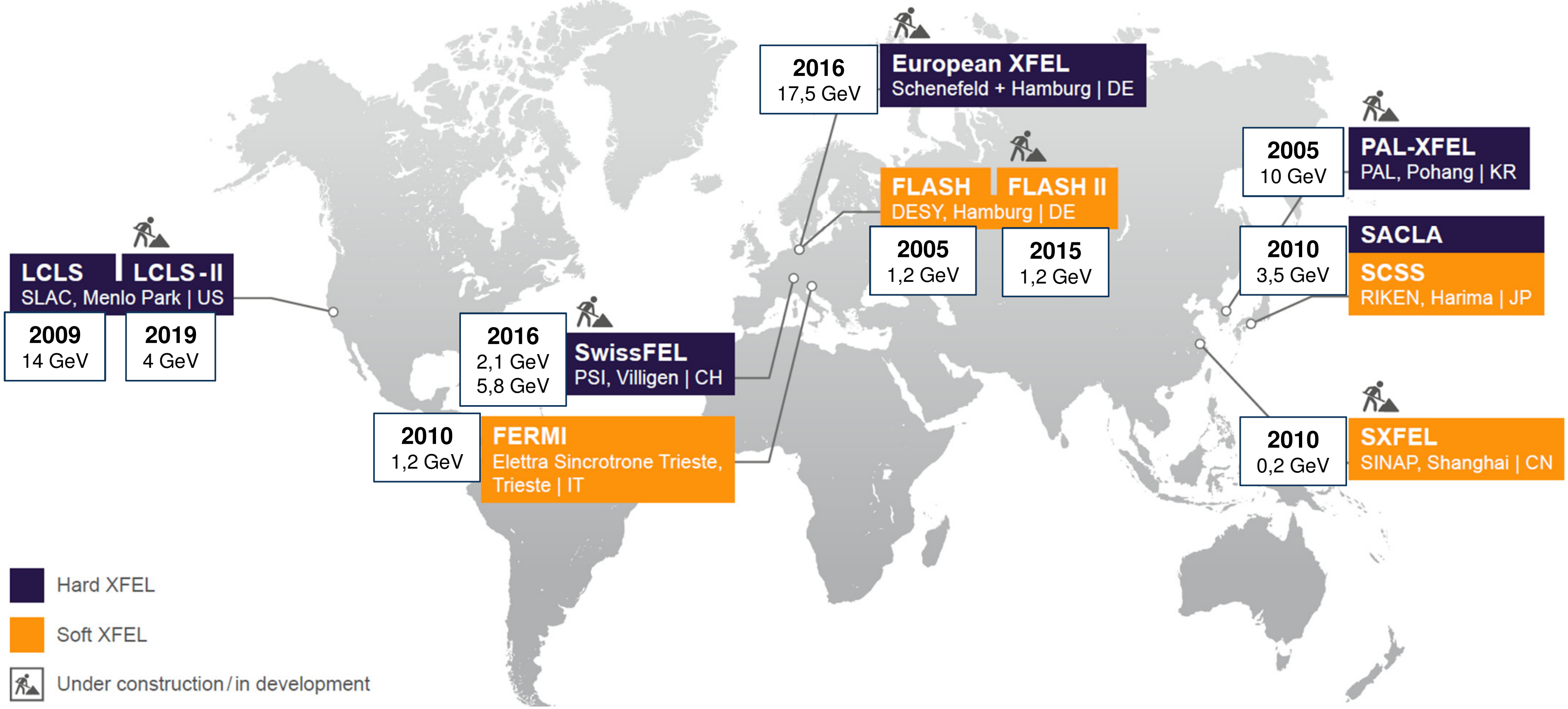
• Jan 2005	first lasing at 32 nm
• Energy range	~0.3 - 1 GeV
	~6.5 - 60 nm
• Pulse energy	5 - 100 µJ
• Pulse duration	~10 - 50 fs
• Peak power	1 - 10 GW
• Bandwidth $\Delta\lambda/\lambda$	~0.7 - 1 %

First FEL X-ray Laser

Critical tests of

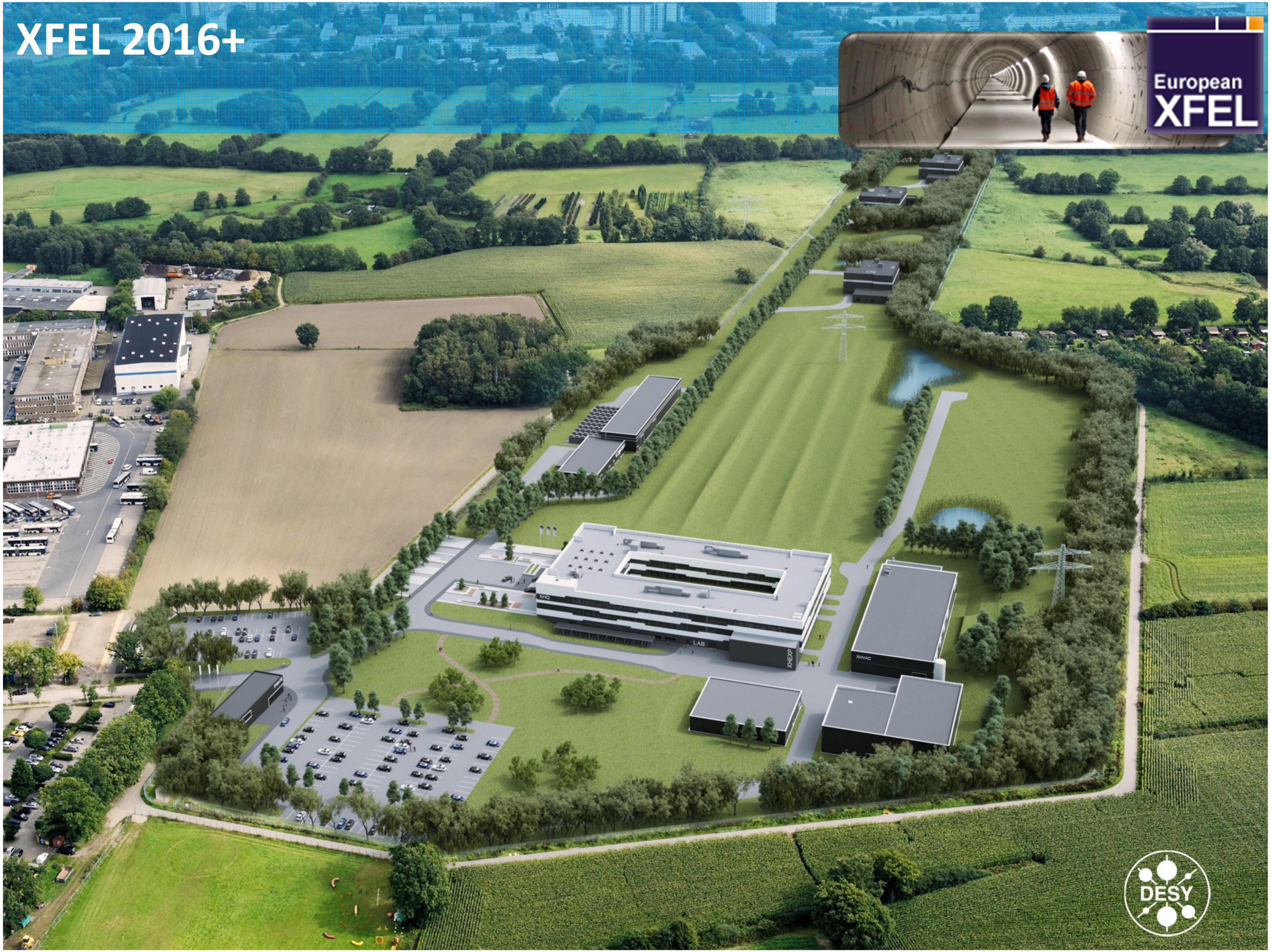
- SASE principle
- Scientific case
- User operation
- Multi user potential (FLASH II)

X-RAY FEL Map of the World.

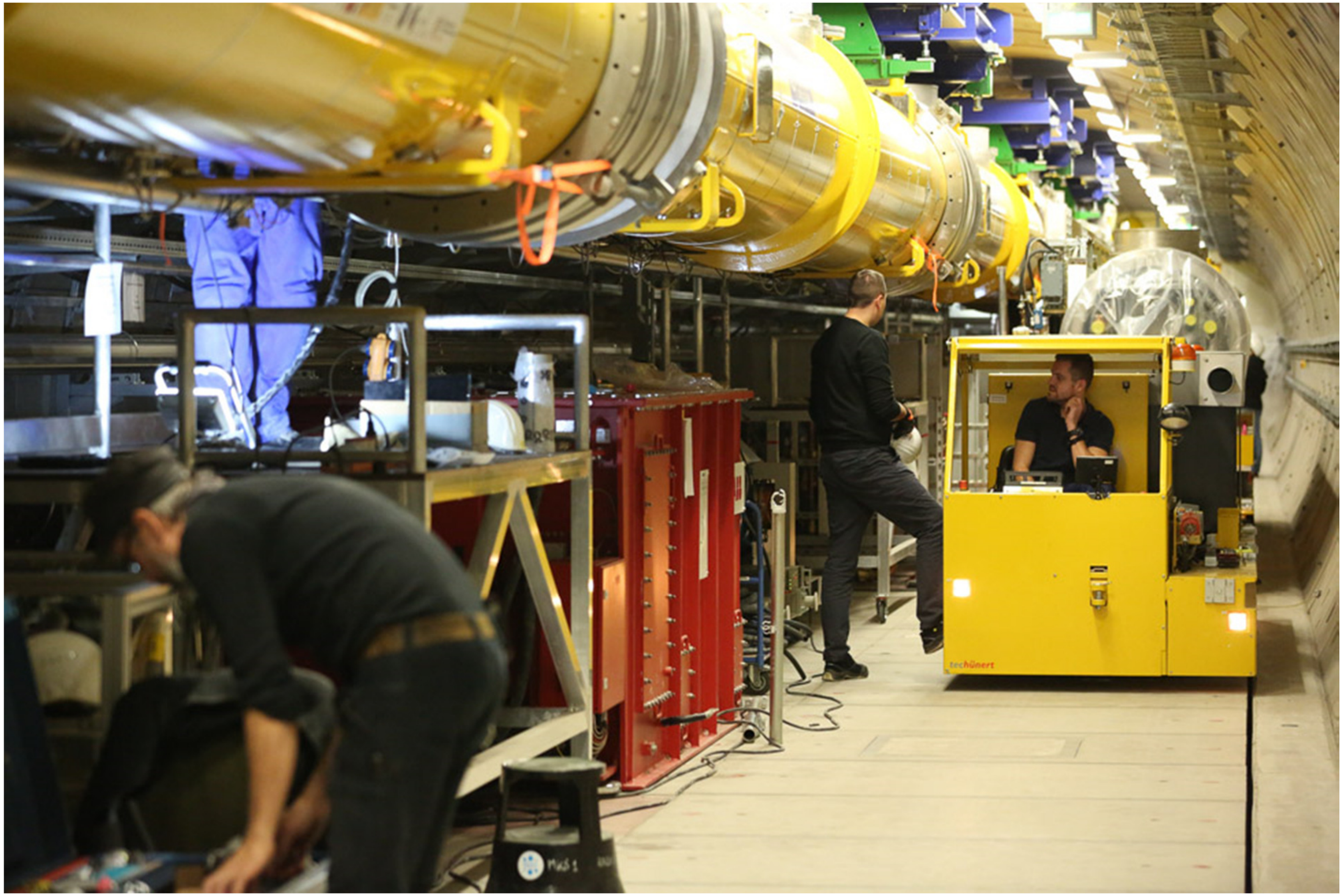


DESY

XFEL 2016+



Installation Work in the XTL Main Linac Section

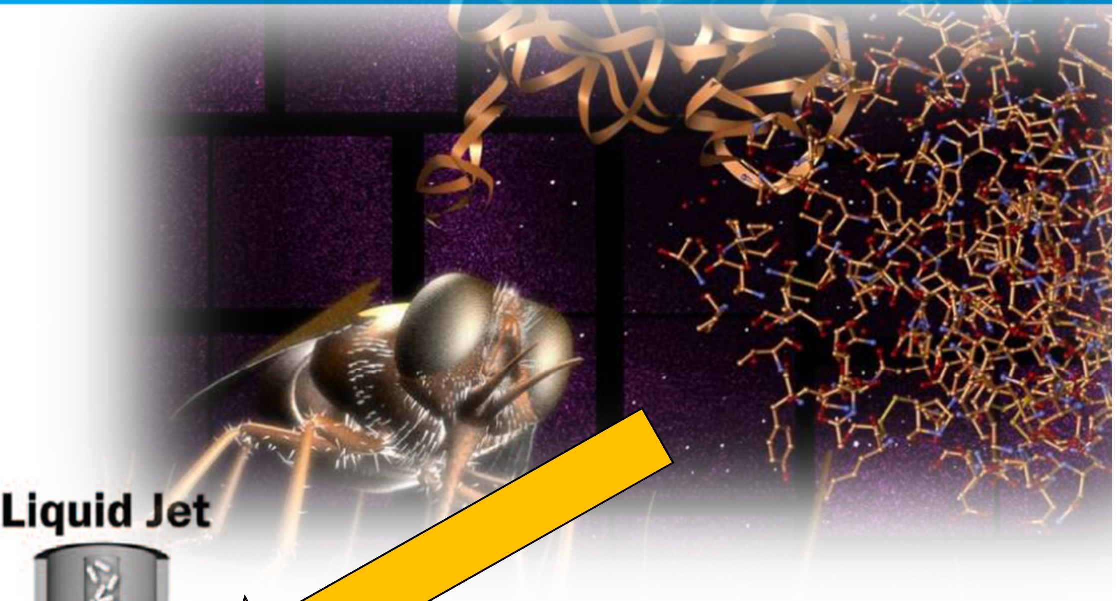


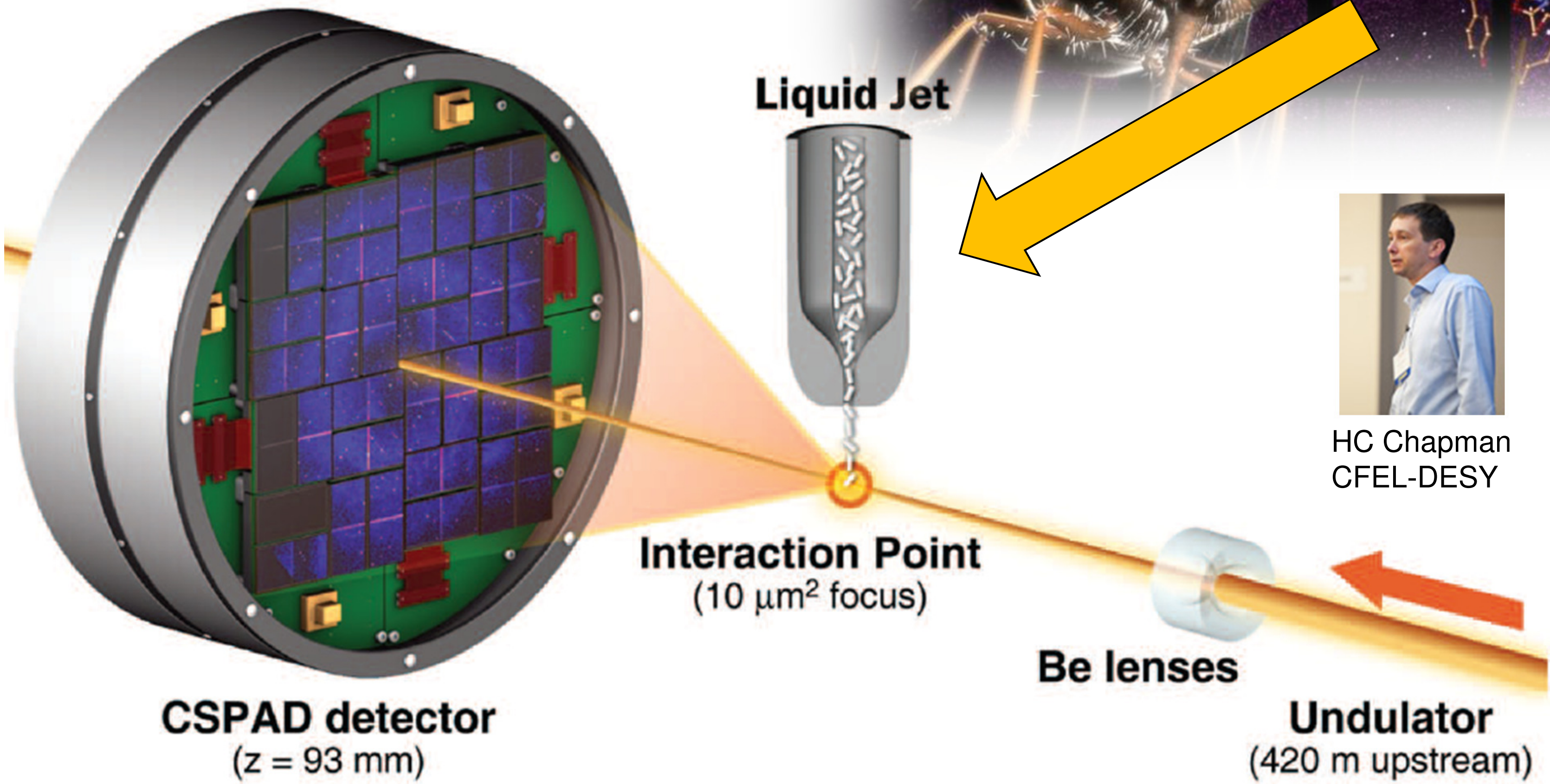
12 Module String in L3 Linac Section

XFEL Killer-App. Femtosecond Nanocrystallography

XFEL discloses structure of enzyme related to sleeping seekness

Single shot
10 fsec images

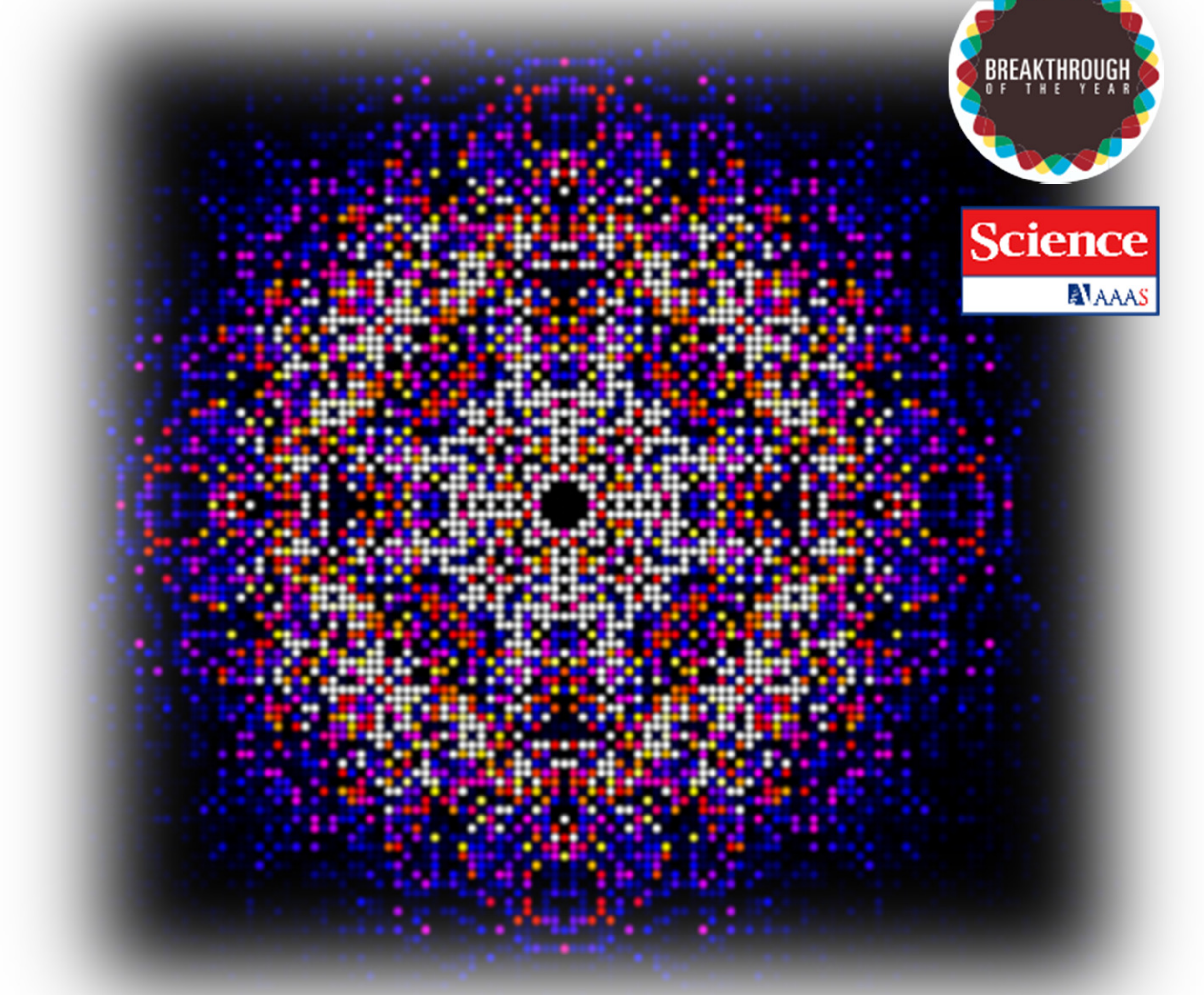




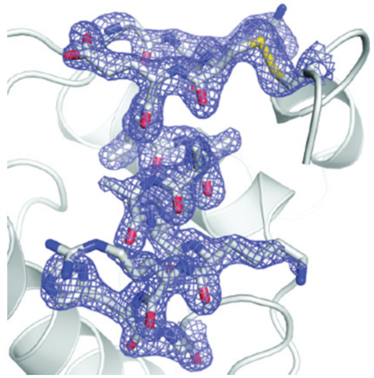
HC Chapman
CFEL-DESY

XFEL Killer-App. Femtosecond Nanocrystallography

XFEL discloses structure of enzyme related to sleeping seekness



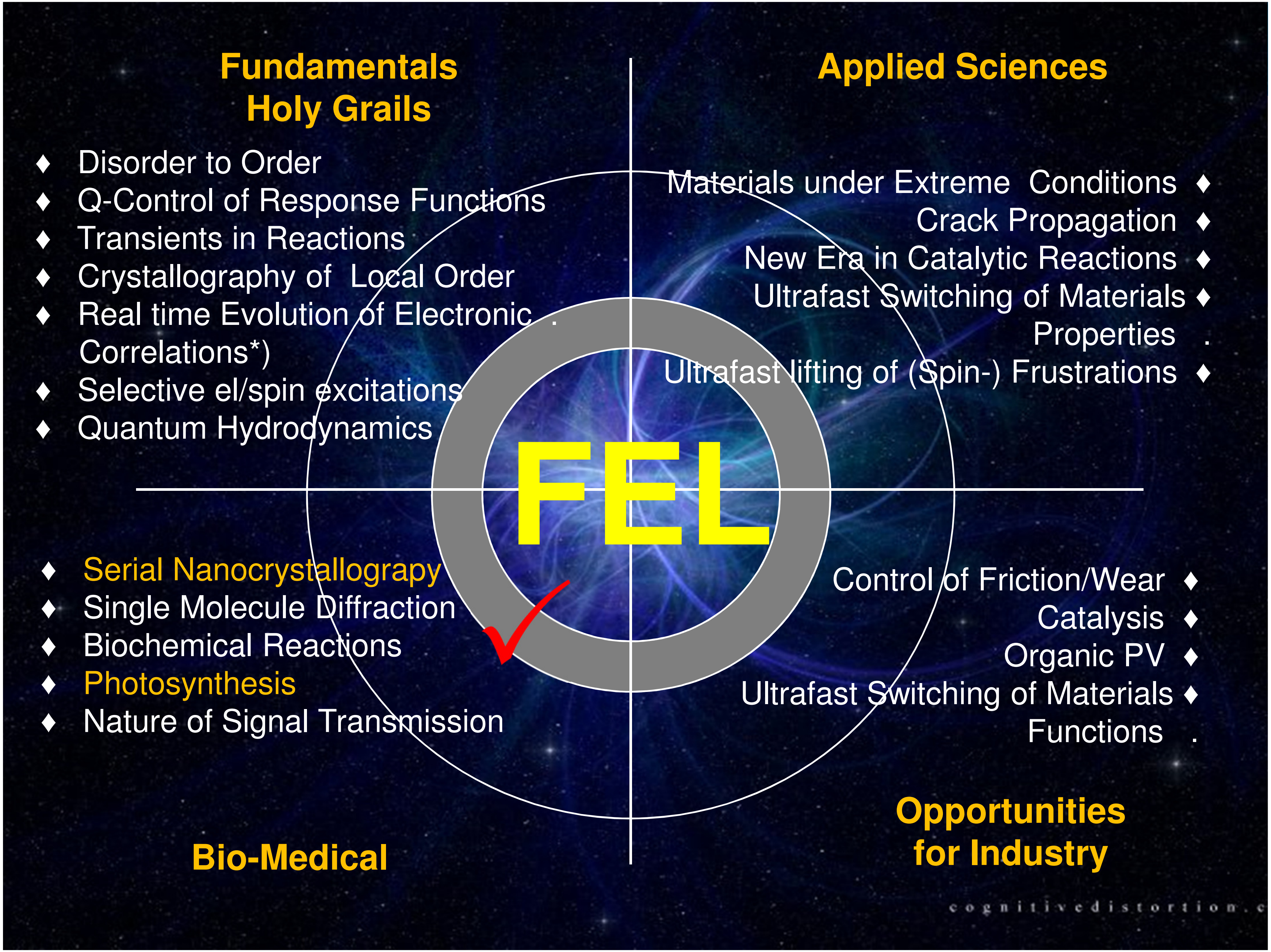
Merged structure factors from 175,000 single-shot patterns



Trypanosoma brucei cathepsin B

Science TOP 10
2012

Redecke, Nass et al. Science (2013)


Fundamentals
Holy Grails
♦ Disorder to Order
♦ Q-Control of Response Functions
♦ Transients in Reactions
♦ Crystallography of Local Order
♦ Real time Evolution of Electronic Correlations*)
♦ Selective el/spin excitations
♦ Quantum Hydrodynamics
Applied Sciences
Materials under Extreme Conditions ♦
Crack Propagation ♦
New Era in Catalytic Reactions ♦
Ultrafast Switching of Materials Properties ♦
Ultrafast lifting of (Spin-) Frustrations ♦
FEL
♦ Serial Nanocrystallograpy
♦ Single Molecule Diffraction
♦ Biochemical Reactions
♦ Photosynthesis
♦ Nature of Signal Transmission
Bio-Medical
Control of Friction/Wear ♦
Catalysis ♦
Organic PV ♦
Ultrafast Switching of Materials Functions ♦
Opportunities
for Industry
cognitivedistortion.c

2015+ Accelerator-Based Gate to the Quantum Cinema.

The End

Thanks to J. Boedewadt, R. Brinkmann, H. Dosch, U. Dorda, C. Hahn, F. Lehner, B. Marchetti, H. Weise.