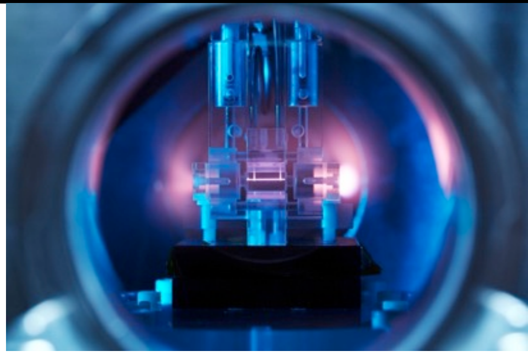
Smaller, Cheaper, Simpler – Accelerators for the Future

EuPRAXIA

International Science Journalism School

What's Next: Challenges and Opportunities for Tomorrow's Fundamental Physics

Erice (Italy), June 24th-29th, 2018



Ralph W. Assmann (DESY)
Coordinator EuPRAXIA, Lead Scientist Accelerator R&D

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

MT ARD DESY.

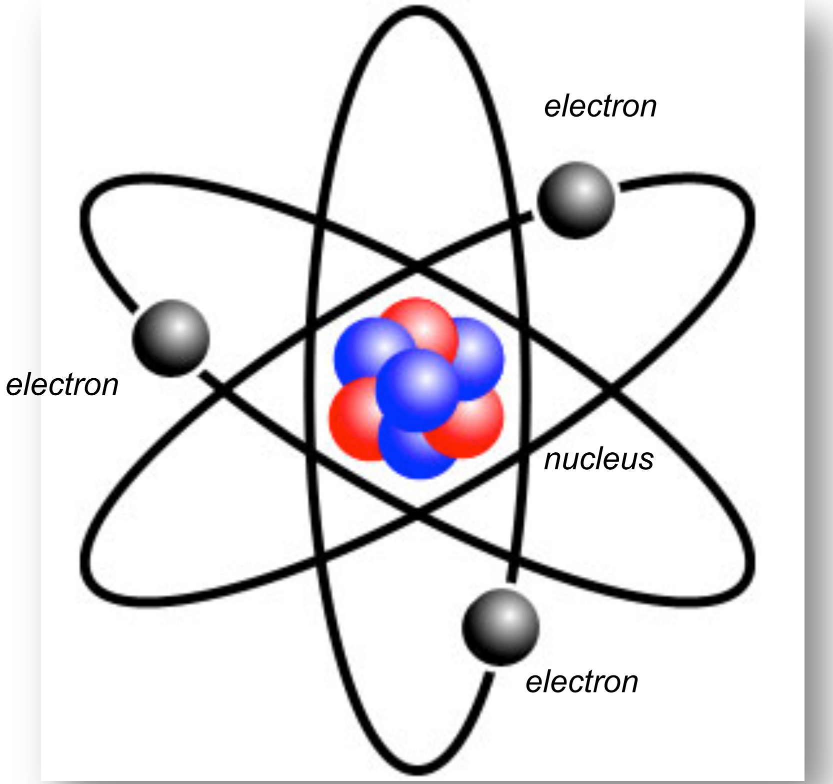
Introduction

Particle Accelerators

Hands-On Experience with Electrons

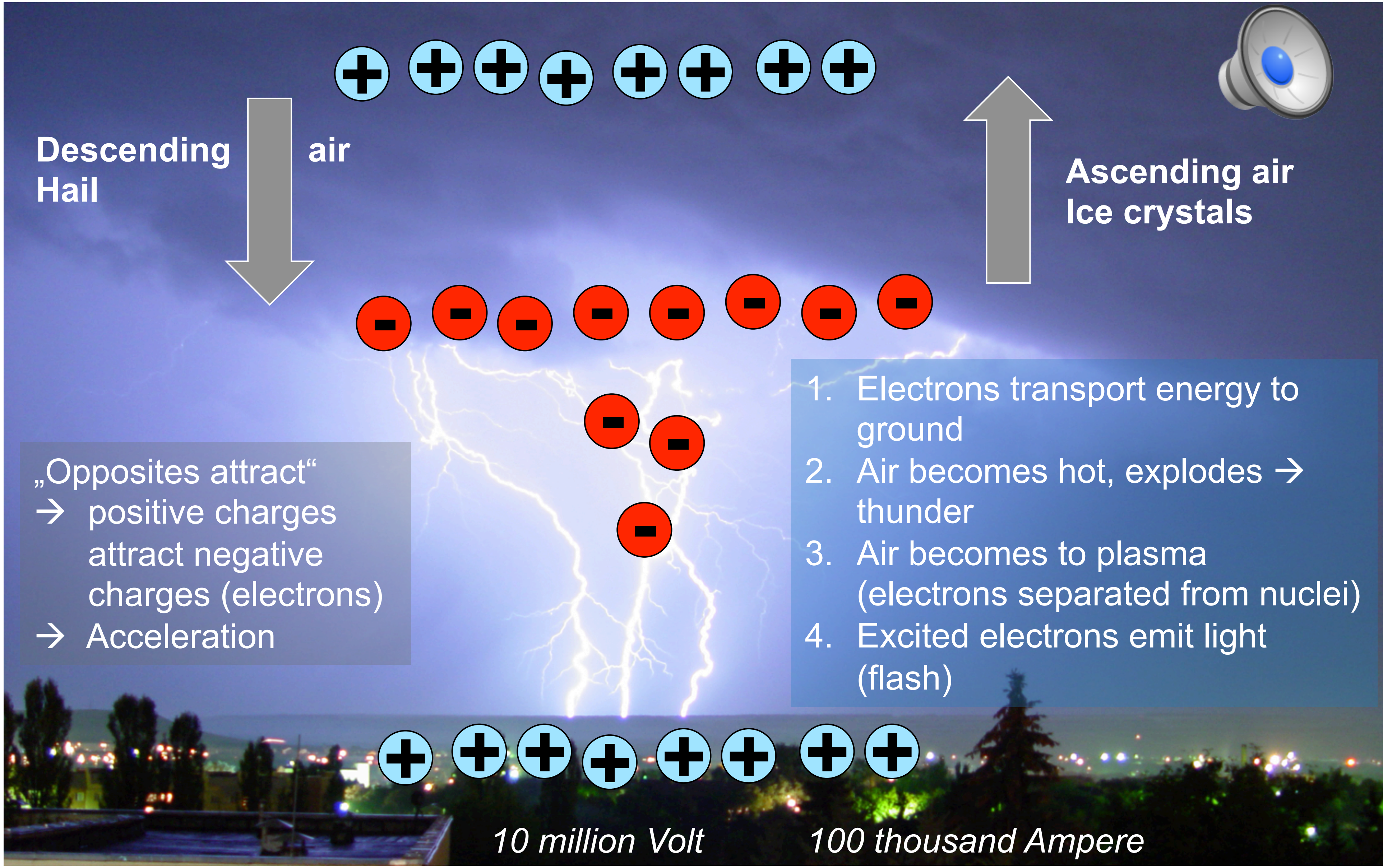
The particle that we all know first hand

- **Electrons** are **negatively charged**, have a very low weight and are very mobile
- In the atoms the electrons circle the **positive nuclei** (protons and neutrons) which are quite heavy and less mobile
- **Electrons can be released from the atoms** through friction:
  - When your shoes rub on the carpet, we are collecting electrons, which then can be passed on through our hands to a door knob
  - We receive a small electrical shock, which we can feel
- Electrons are **carriers of electricity and transport electrical current**, the driver of our technical civilization.
- Without electrons no telephone, no x ray, no electrical light, ...



Electrons and Plasma in Everyday Life...

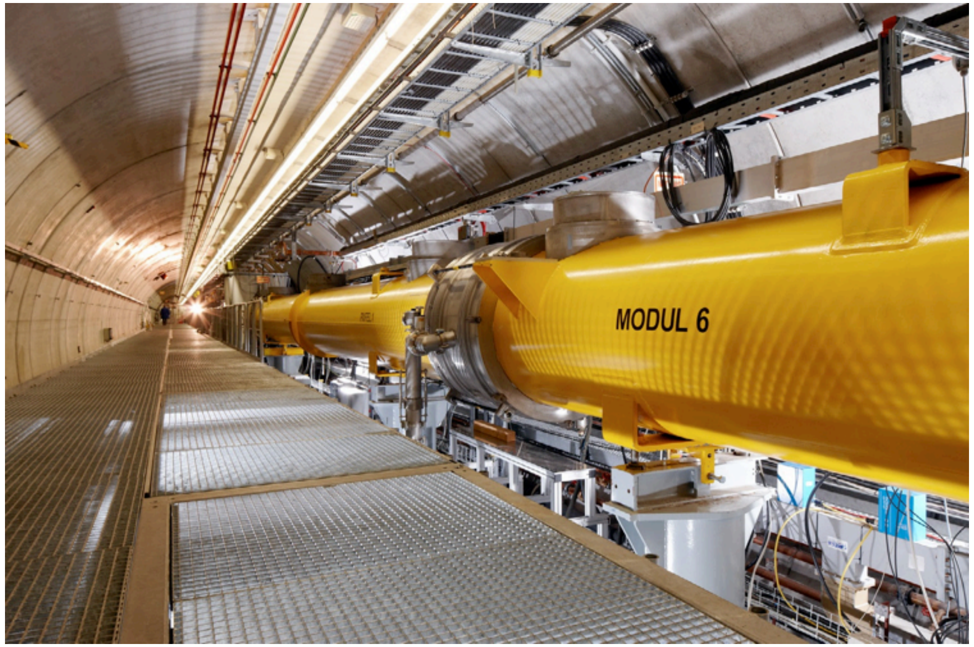
Nature is accelerating electrons, creating plasmas and is generating light



Triumph of Science

Mankind mastering nature's laws and forces

- In ancient times thunderstorms were considered as the work of gods ("Thor the God of Thunder").
- **Today we understand** how electrons produce flash and thunder.
- Thunderstorms are pretty impressive, but they are uncontrolled and can generate significant damage.
- The human tries to **control and use the forces of nature and their carriers** (here electrons) since thousands of years.
- Today we can **bundle electrons, control them, accelerate them, guide them, make them emit light** → particle accelerators
- Particles and particle beams can be used as extremely useful tools today, helping humans.

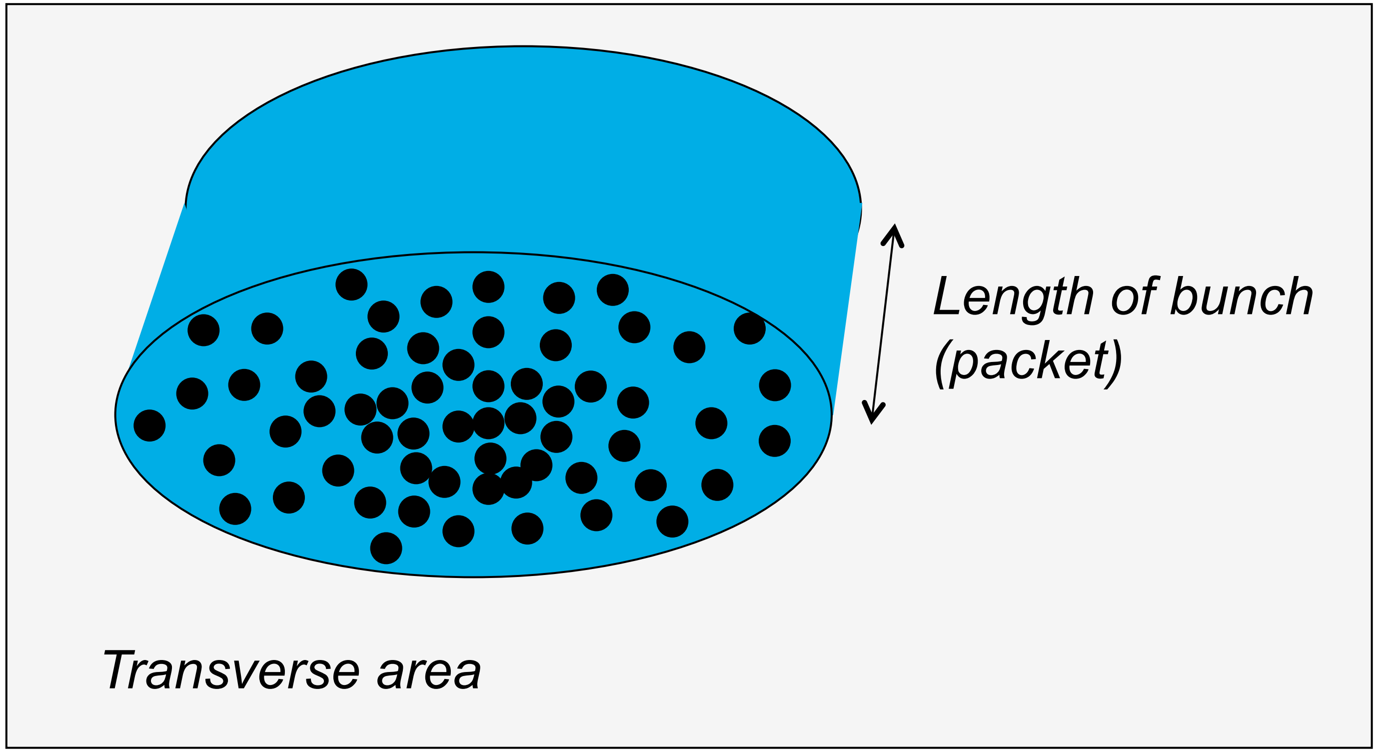


Particle Accelerators

90 Years of Success

Frontier Electron Beams and Directions for New Beams

Towards ultra-dense, highest brightness electron beams

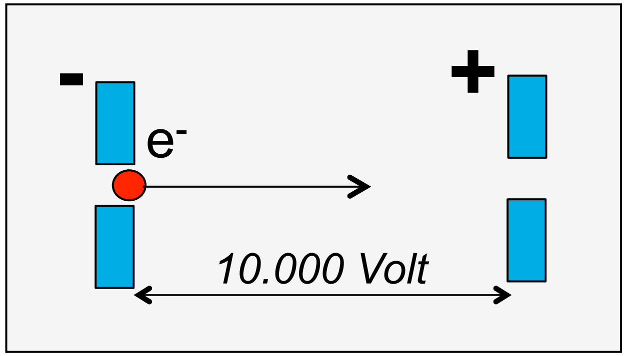


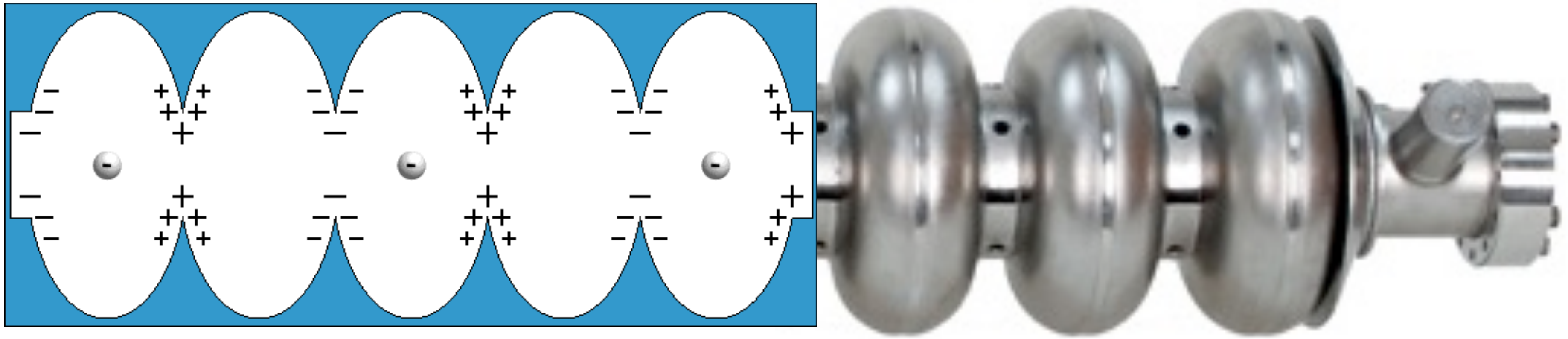
- **Increase kinetic energy** of particles (MeV − GeV − *TeV*)
- **More particles** per bunch (1 million − *100 billion*)
- **Smaller transverse area** (*1 nm* − 1 mm smallest diameter)
- **Shorter bunches** for access to ultra-fast science (*100 nm* – 100 μm)
- **More bunches** (1 – 1000)

RF Acceleration in Metallic Structures

From 10 thousand to 100 million Volts per meter of acceleration

- Areas with positive and negative charge; free electrons in between.
- Free electron (e^-) is attracted to the positively charged area (anode) and accelerated towards it ("**opposites attract each other**")
- For a voltage of 10 thousand Volt the electrons gain 10.000 **electron-volts (eV)**
- Higher energies with **alternating voltage ("RF")**:





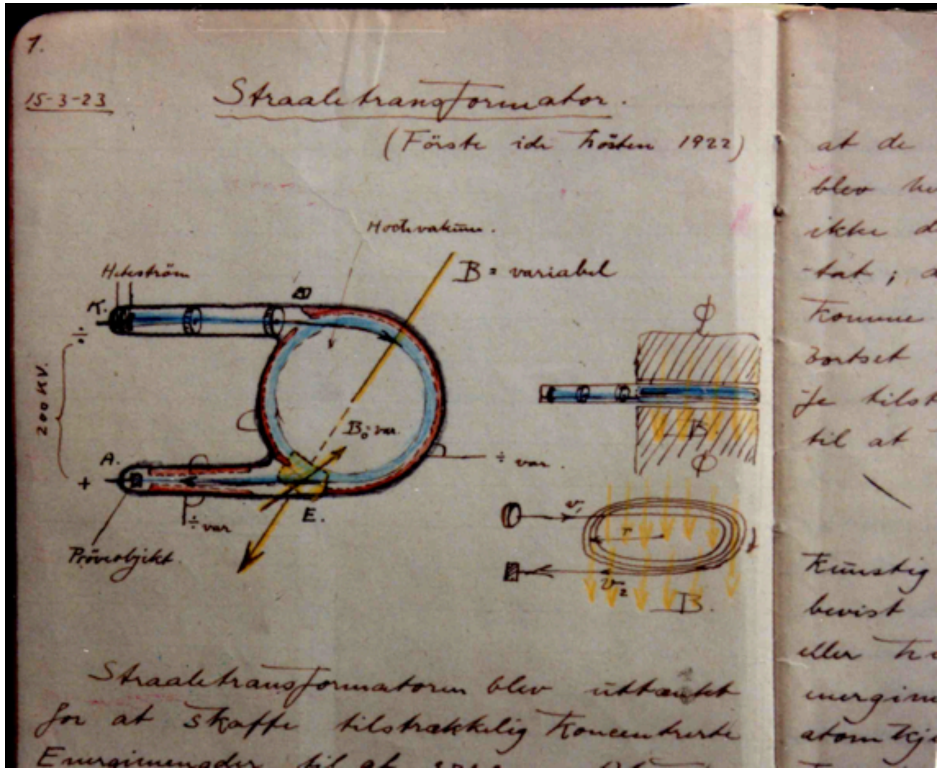
Sketch Padamse, Tigner

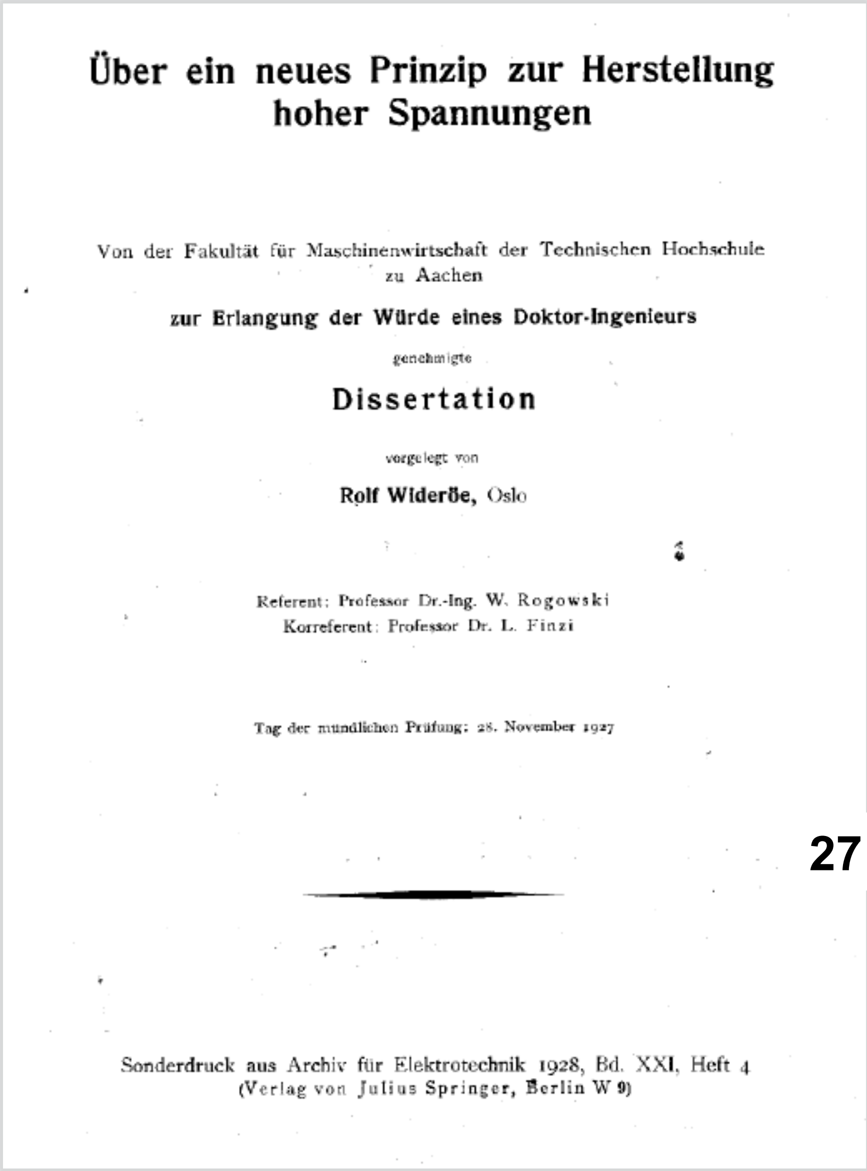
"Runzelröhre"

20 million Volt per meter

First RF Linac Setup: PhD Wideröe 1927 in Aachen

Where RF accelerators started in practice





Über ein neues Prinzip zur Herstellung hoher Spannungen

Von der Fakultät für Maschinenwirtschaft der Technischen Hochschule zu Aachen

zur Erlangung der Würde eines Doktor-Ingenieurs

genehmigte

Dissertation

vorgelegt von

Rolf Wideröe, Oslo

Referent: Professor Dr.-Ing. W. Rogowski
Korreferent: Professor Dr. L. Finzi

Tag der mündlichen Prüfung: 28. November 1927

Sonderdruck aus Archiv für Elektrotechnik 1928, Bd. XXI, Heft 4
(Verlag von Julius Springer, Berlin W 9)

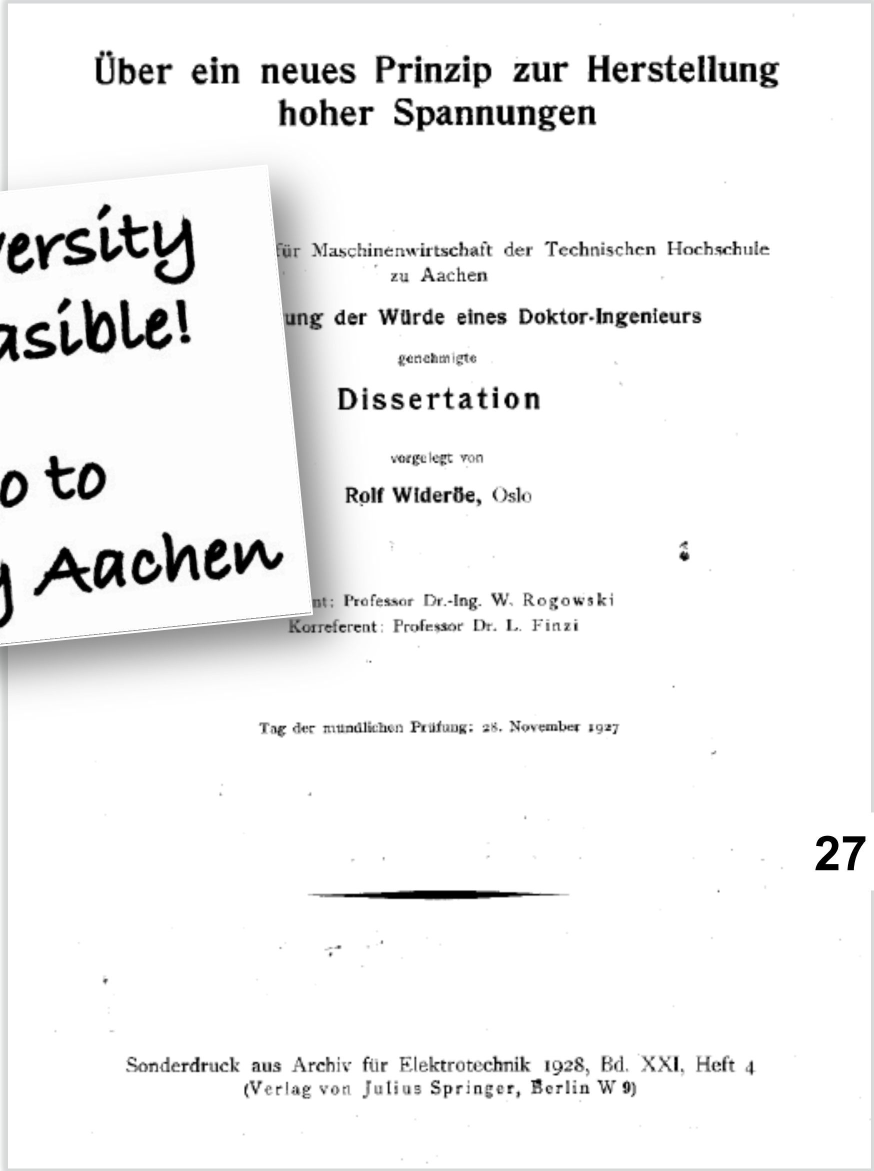
27 pages

First RF Linac Setup: PhD Wideröe 1927 in Aachen

Where RF accelerators started in practice

First refused at university Karlsruhe as not feasible!

Wideröe had to go to Technical University Aachen



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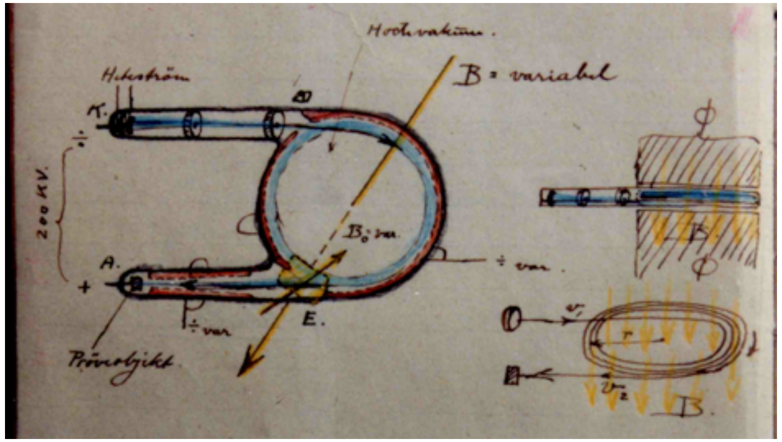
The Situation in 1946

20 years after Wideröe's sketch

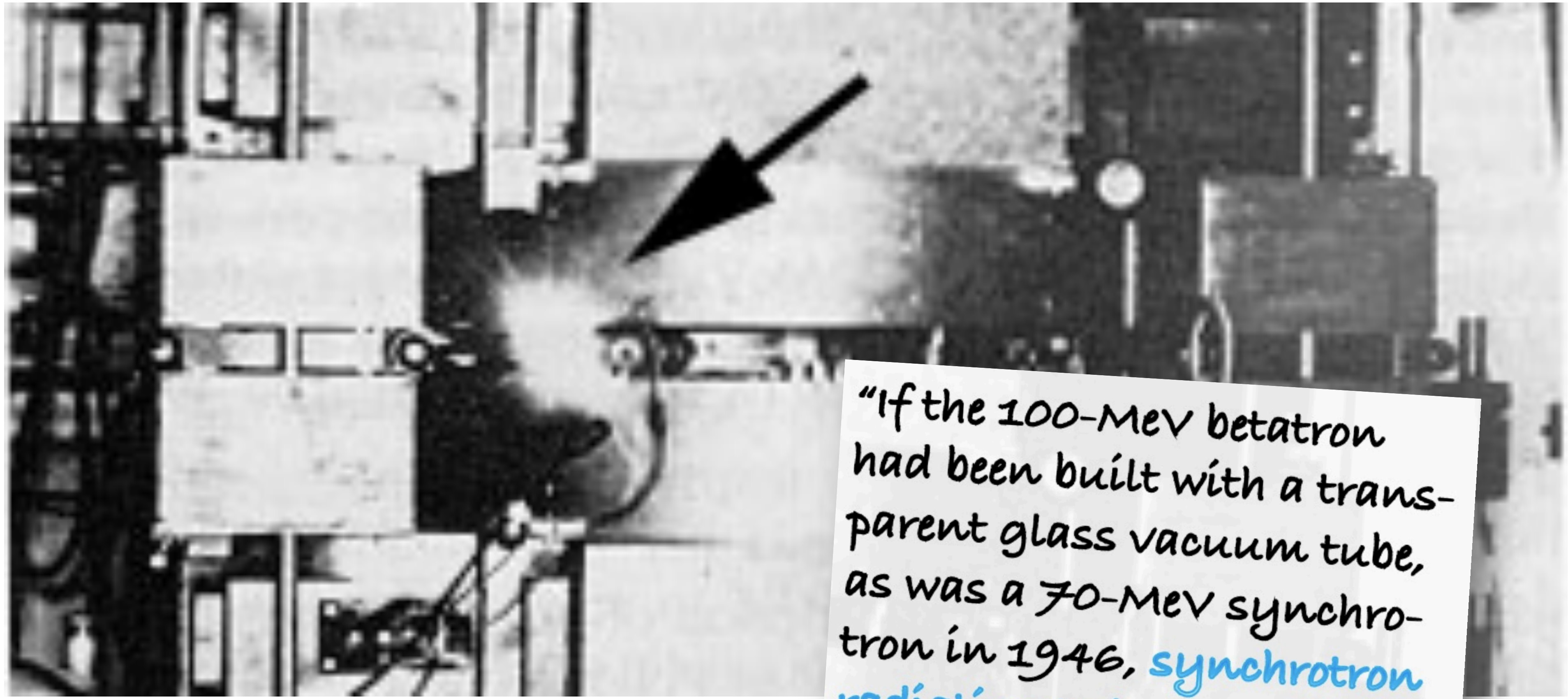


A synchrotron can store a charged particle beam for many hours or even days ("storage ring")

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

Discovery of Synchrotron radiation in 1946

General Electric Synchrotron Accelerator



70 million electron Volt (70 MeV)

"If the 100-MeV betatron had been built with a transparent glass vacuum tube, as was a 70-MeV synchrotron in 1946, synchrotron radiation today would be called betatron radiation."
H.C. Pollock

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

When **Haber looked around the corner** 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

The Story of Science and Espionage

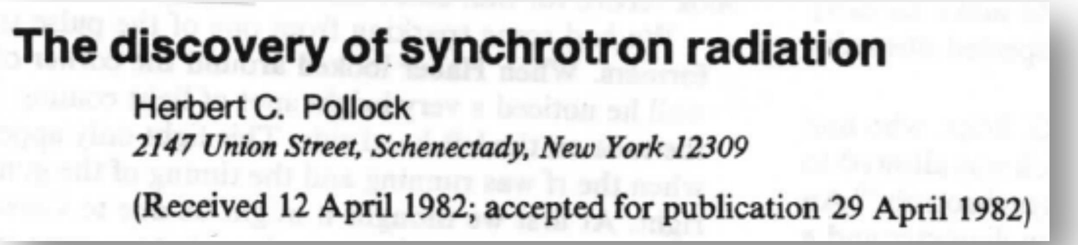
1946 at the General Electric Synchrotron

“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**…”


The discovery of synchrotron radiation

Herbert C. Pollock

2147 Union Street, Schenectady, New York 12309

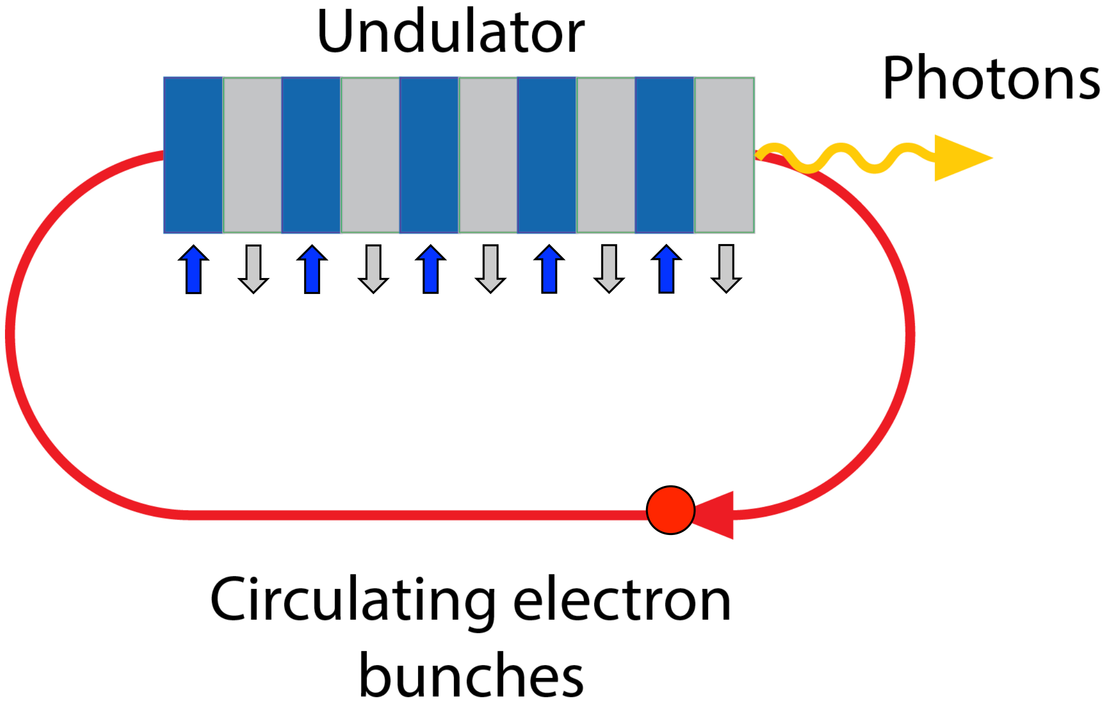
(Received 12 April 1982; accepted for publication 29 April 1982)

Big impact on society obviously immediately expected

Synchrotron Radiation

Deflected electrons emit photons

- If skiers would be invisible: We would recognize them in each curve through the stirred up snow
- **Skiers create in each curve a small storm of snow particles**
- **Electrons create in each curve a small pghoton storm**
- Electron emits photons ("Particles of Light")
- Generally: "Bremsstrahlung". Or more precise: "Synchrotron Radiation"



Today: Discovery Machines and Innovation Drivers

For Science, Industry and Society

- Today: world-wide operate about **30,000 particle accelerators** for science, medicine and industry
- Most accelerators are used for **industrial** applications
- Accelerators produced **data for dozens of discoveries that were rewarded with nobel prizes**.
- Accelerators help saving lifes and **curing people**.

Physics: Cyclotron

Physics: Stochastic Cooling

Physics: Higgs particle

Chemistry: ribosoms

Probing for New Particles and Forces

Fundamental Research Particle Physics

Higgs Seminar 4.7. 2012

THE TIMES

Higgs celebrates 'God particle' discovery

Tom Whipple, Science Correspondent, and Giles Whittell at Cern

Updated 35 minutes ago

Professor Peter Higgs has said he is chilling the champagne, and Geneva's bars are preparing to celebrate the scientific achievement of the decade, after Cern announced the discovery of a new "Higgs-like" boson, believed to be the fundamental particle known as the...

- How it unfolded
- Video blunder
- Bill Bryson at LHC
- Award for Higgs
- 5 Comments

LHC at CERN as a **Masterpiece of Accelerator Science**

Protons at ***6 thousand billion electron Volt*** → ***27 km***

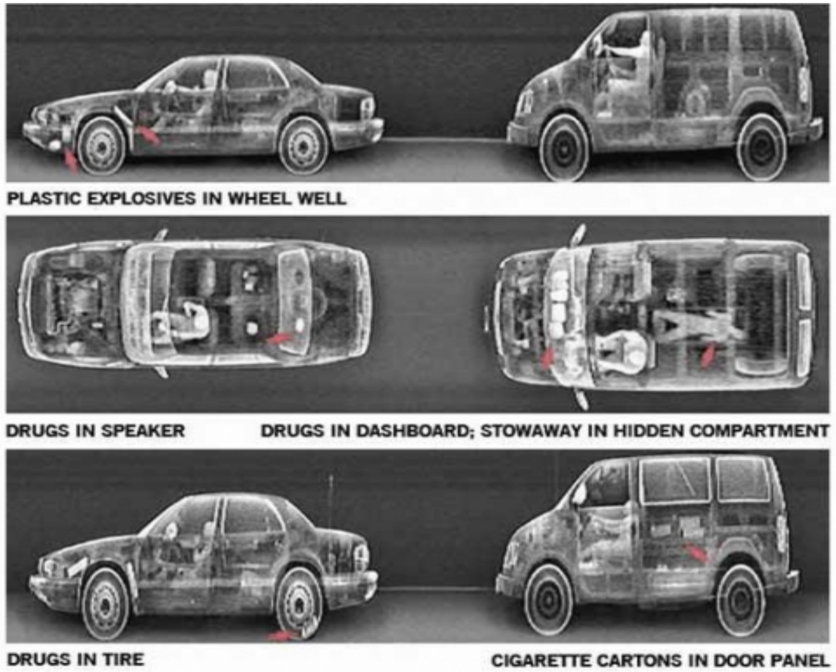
Understanding fundamental laws

Producing X Rays for Inspection

Industry and Security

Nuctech (China)

Varian (USA)



X-Ray radiography – Cargo inspection with a **compact 6 MeV linear electron accelerator**

Electrons at 6 million Electron Volt

Protecting people

Irradiating and Destroying Tumor Cells

Medicine and Health

Heidelberg Ion-Beam Therapy Center (HIT)

Proton therapy

Varian TrueBeam STx Linac with BrailLab ExacTrac system at University Hospital Düsseldorf.

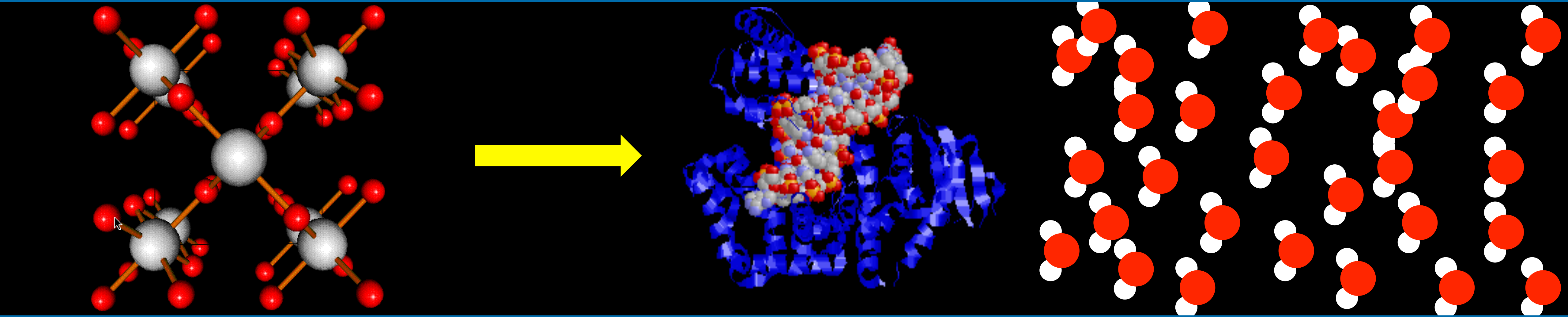
Electron therapy

up to 12 million electron Volt

Curing people

Producing Light and Filming Molecular Movies

Fundamental Research Physics, Structural Biology, Chemistry, Material Science



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 from accelerators

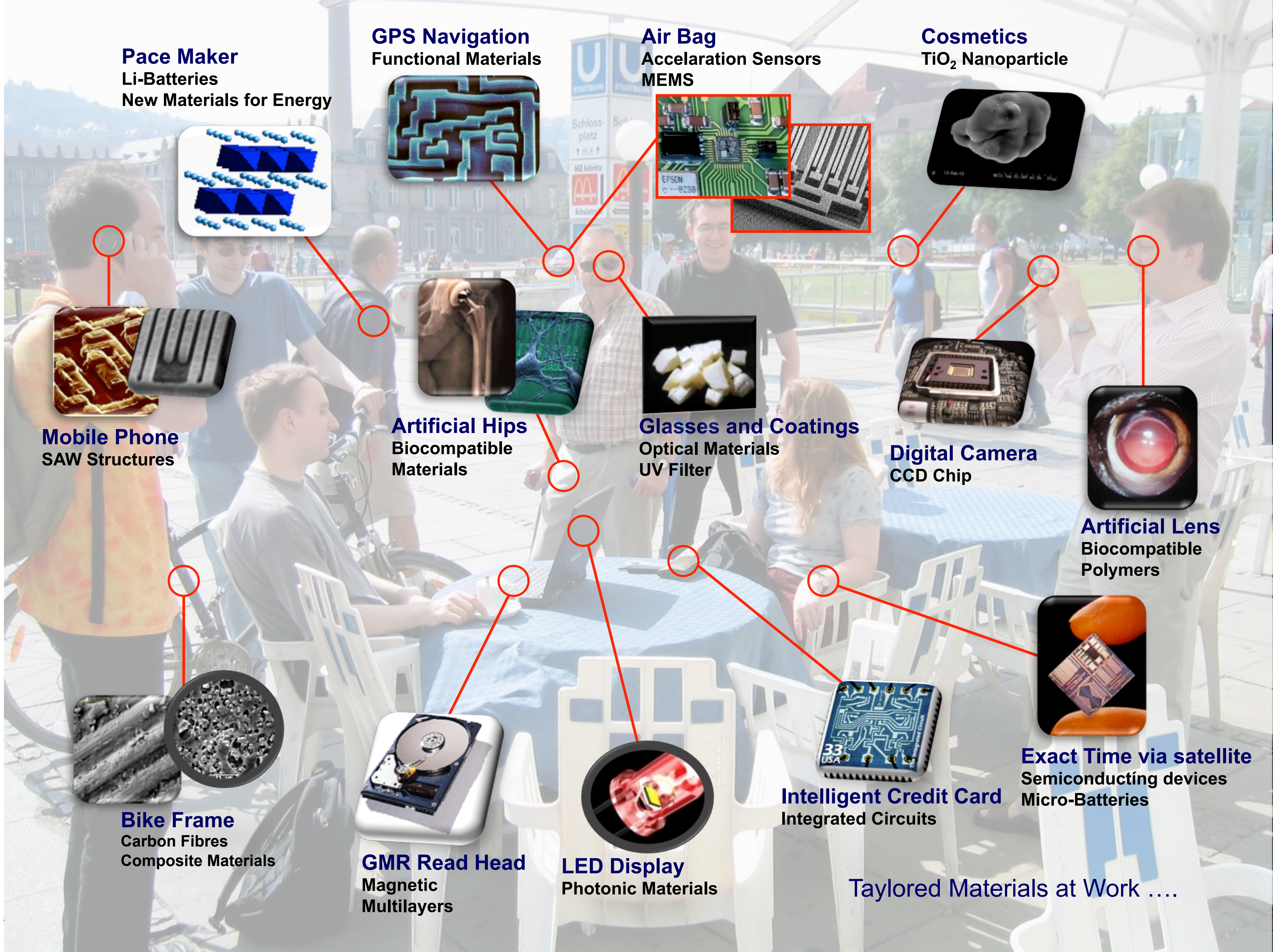
X-Ray Laser accelerators
+ High Brilliance SR accelerators

Germany Today

Accelerator-Based Photon Science Research Affecting Everyday Life

Germany Today

Accelerator-Based Photon Science Research Affecting Everyday Life



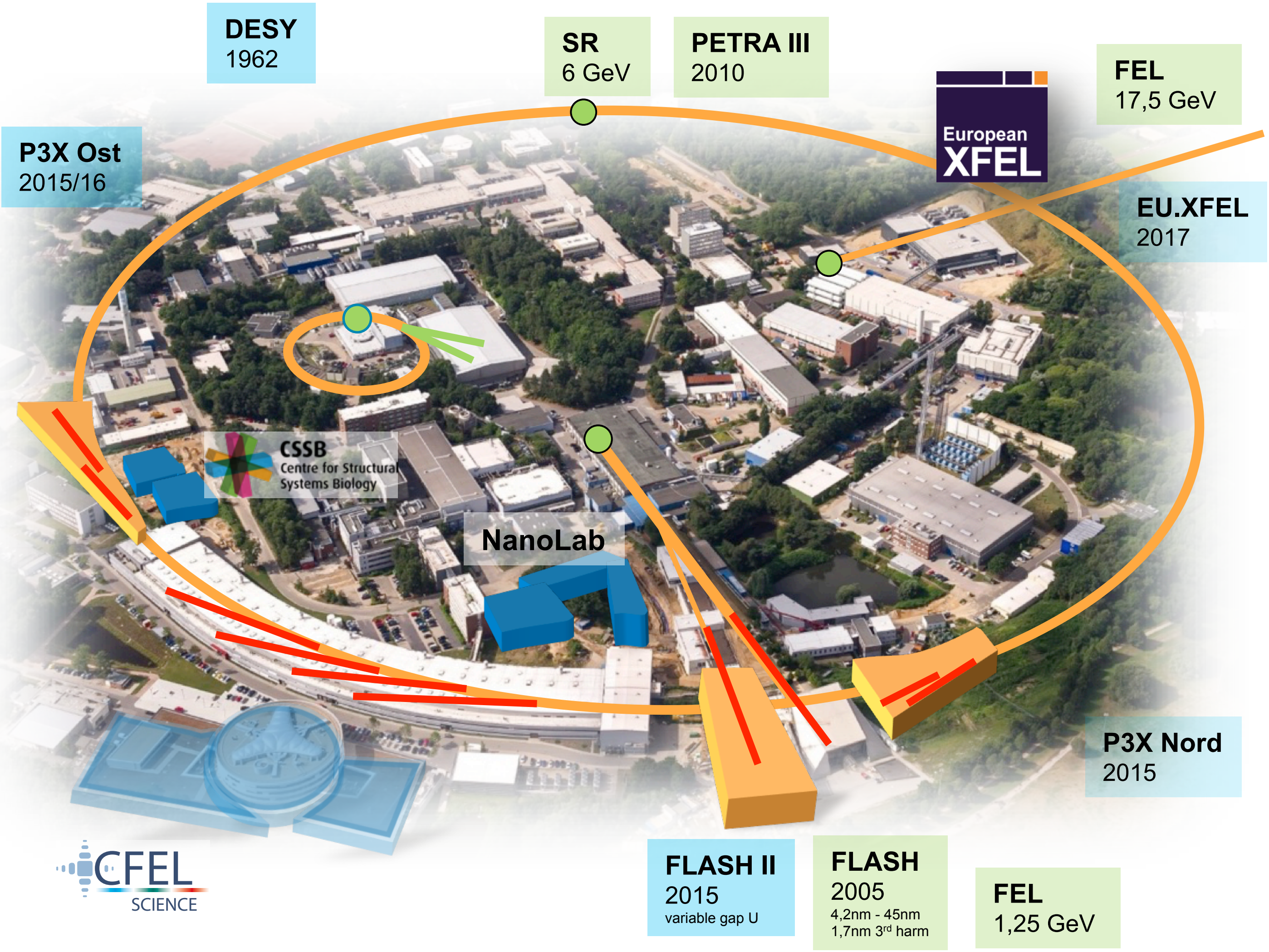
Particle Accelerators at DESY – Excellence in Photon Science

From 50 years ago to today…

- DESY started as a particle physics laboratory
- Several flagship projects in the international race to discover new forces and particles.

Particle Accelerators at DESY – Excellence in Photon Science

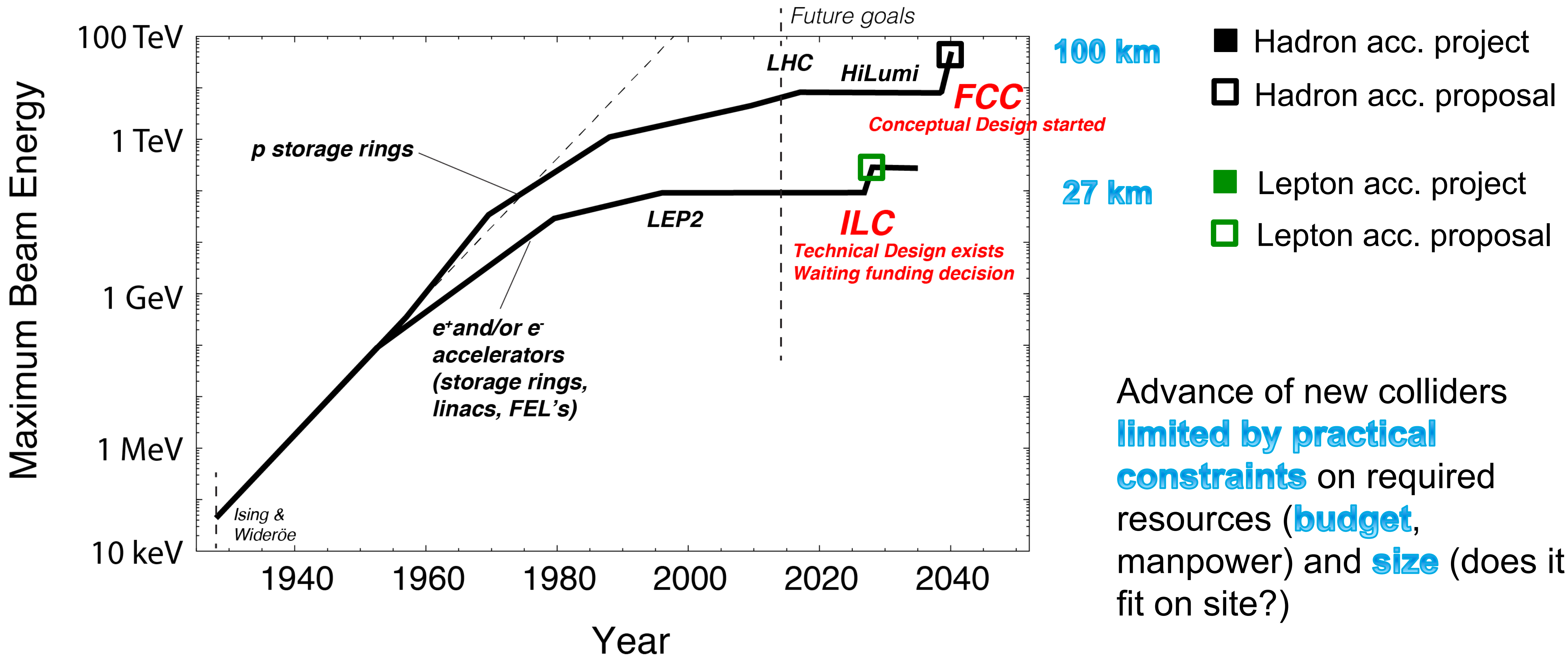
From 50 years ago to today (electrons up to 17 billion electron Volt)…



BUT:
Progress in Hamburg-based colliders **limited by practical considerations on size and cost**.

Slow-down in Energy Increase of Frontier Accelerators

Livingston plot leveling off – here our version, giving beam energy versus time



Advance of new colliders **limited by practical constraints** on required resources (**budget**, manpower) and **size** (does it fit on site?)

Thinking about the Future

Can we overcome the limits in size and cost?

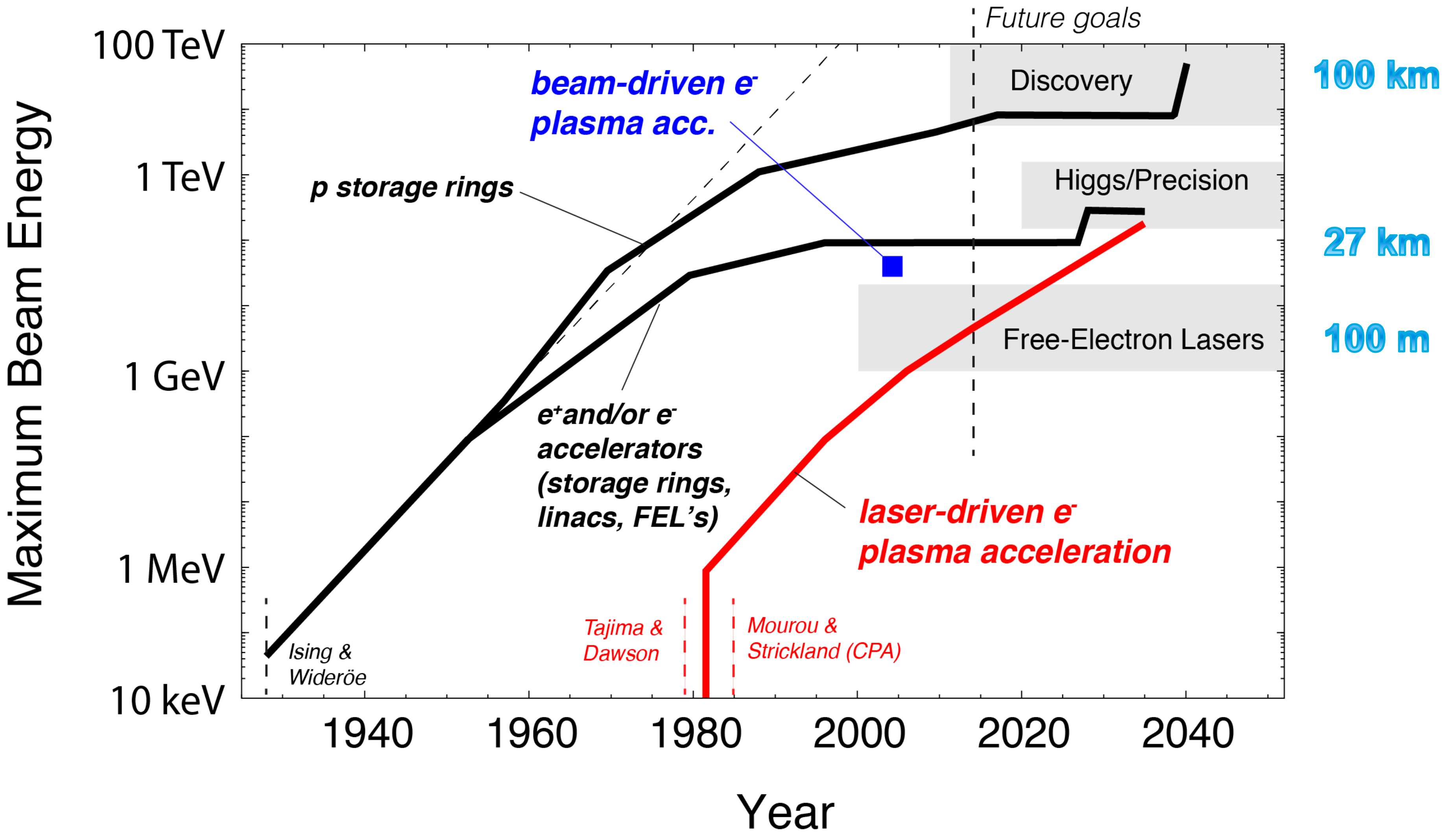
Wouldn‘t it be great to build particle accelerators much smaller (and more cost-effective)?

- New discovery machine at the energy frontier
- Free electron lasers in the basement of universities
- Cost-effective e- irradiation therapy facilities
- Accelerators small enough to be implanted into human bodies for in-situ e- irradiation
- Accelerators in outer space and on other planets
- Compact irradiation facilities for diagnostics and inspection in medicine and industry

Plasma Accelerators
The Promise for the Future

A New Technology Has Been Invented

Plasma Accelerators



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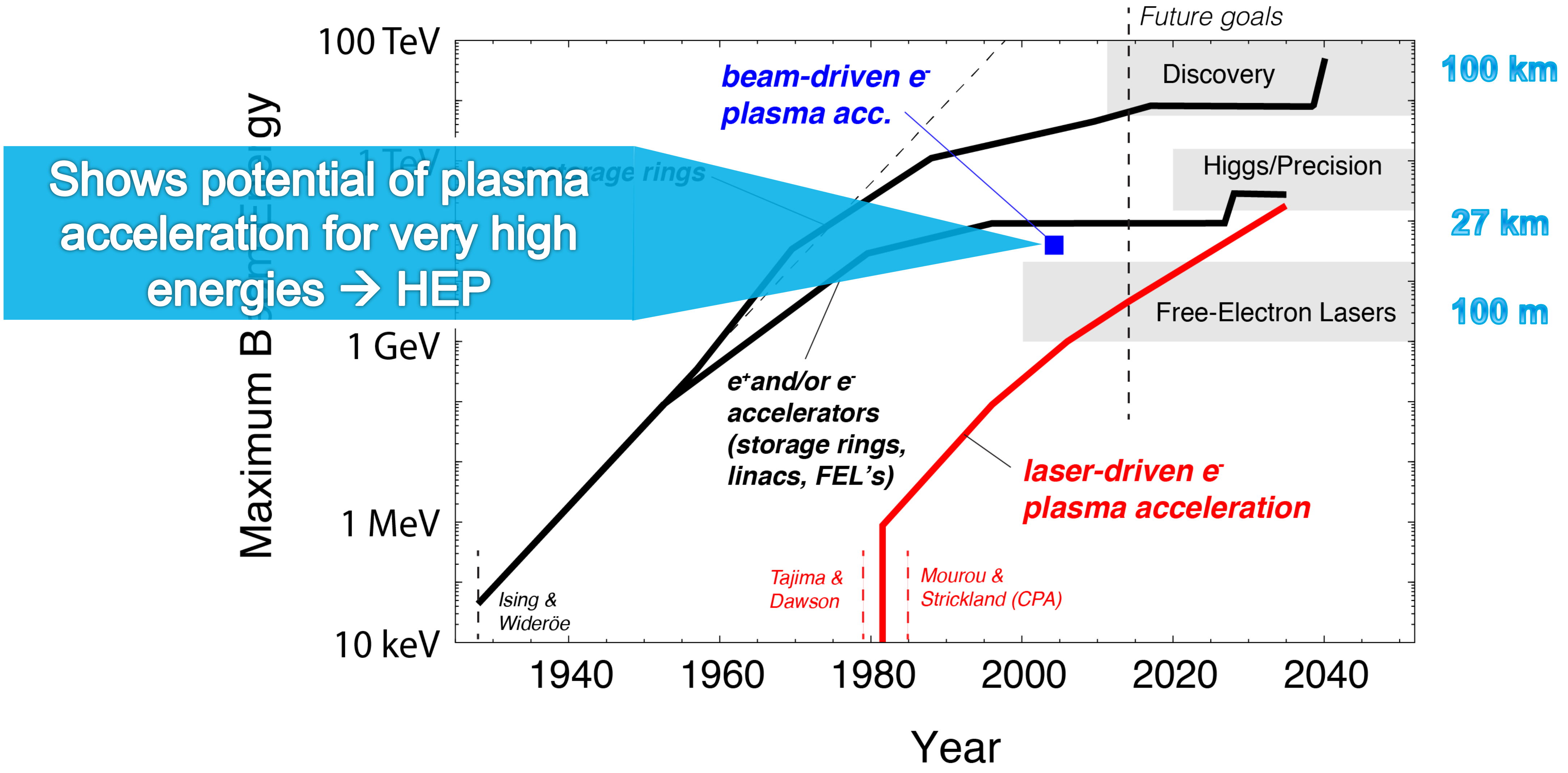

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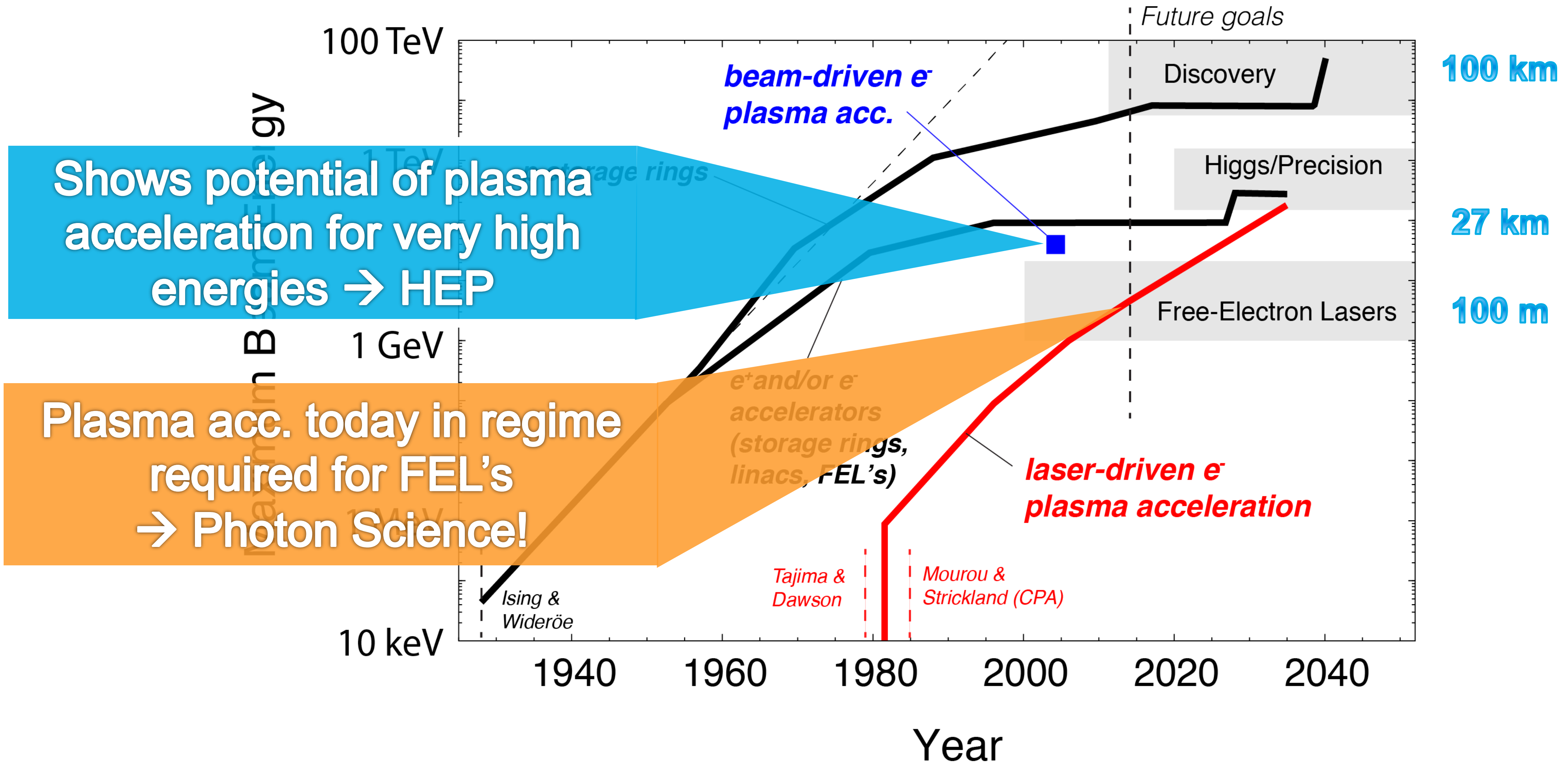
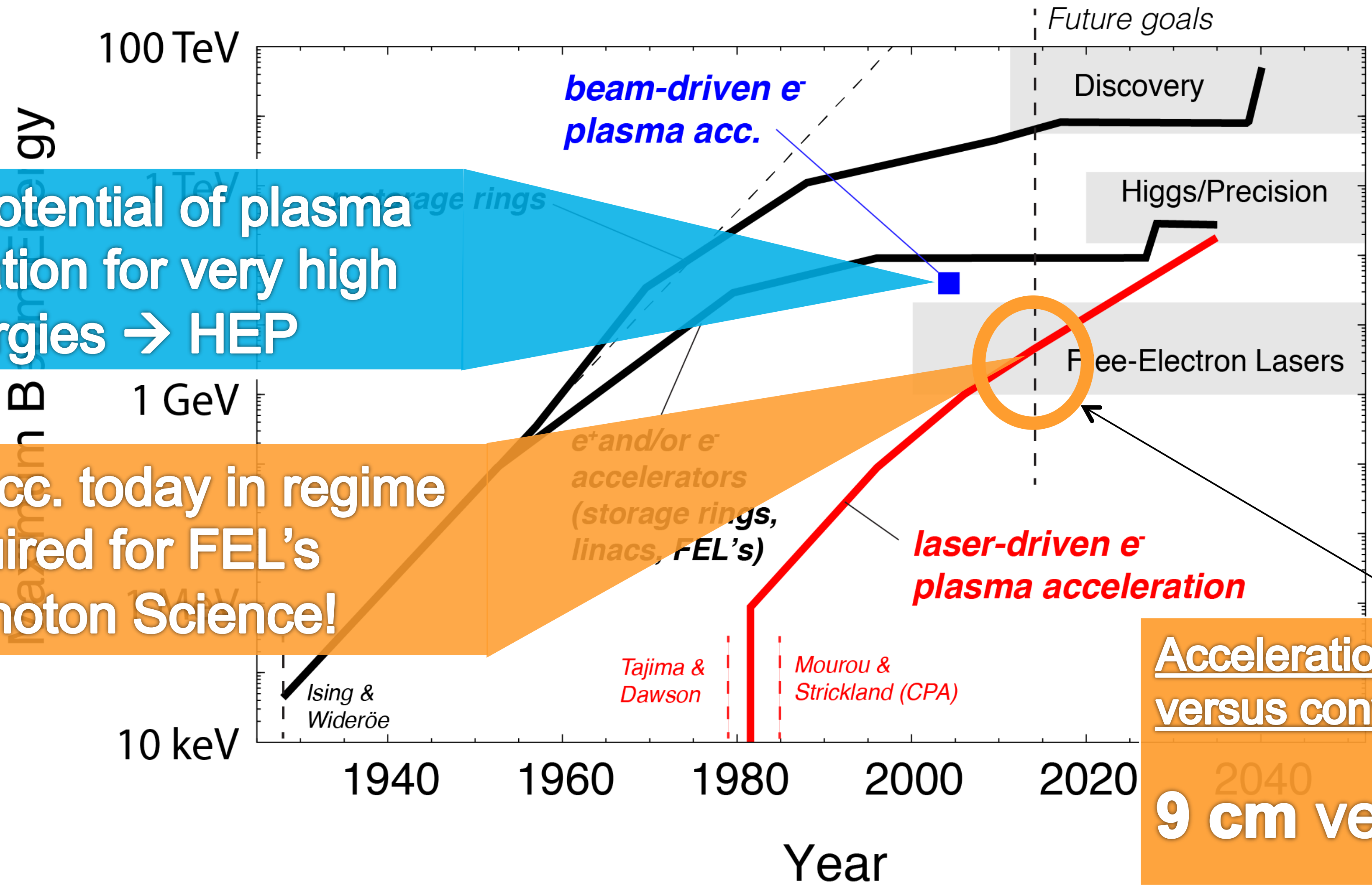


A New Technology Has Been Invented

Plasma Accelerators



100 km

27 km

100 m → 9 cm

Shows potential of plasma acceleration for very high energies → HEP

Plasma acc. today in regime required for FEL's → Photon Science!

Acceleration length (new versus conventional):

9 cm versus 100 m

How Does it Work?

How to get higher accelerating voltage?

Surfer gain velocity and energy by riding the water wave!

Charged particles gain energy by riding the electromagnetic wave!

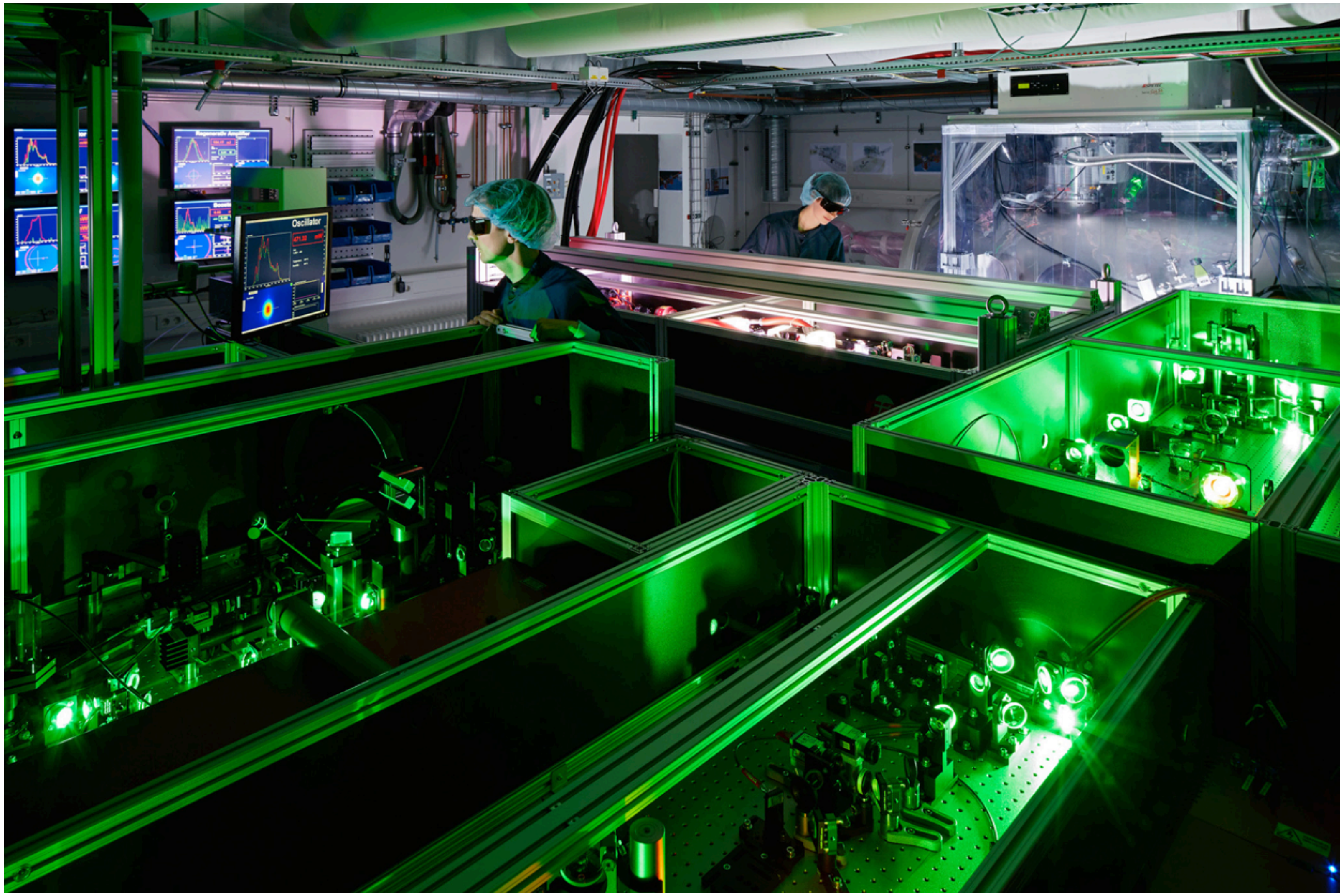
Modern lasers generate light pulses with very large transverse fields:

Many 1.000 billion volt per meter

Plasma or metallic structures couple fields to our particles!

ANGUS Laser Laboratory for Accelerator R&D

200 TW Ti-Sa laser, DESY & University Hamburg



The Laser Promise: Transverse Electrical Field

We can produce every day very high transverse electrical fields

$$E_0 = \sqrt{2 \cdot \frac{I_0}{c\,\epsilon_0}}$$
$$\epsilon_0 = \text{Dielectric constant}$$
$$c = \text{Light velocity}$$

$$P = 100\,\mathrm{TW}$$
$$r_0 = 10\,\mu\mathrm{m}$$
$$I_0 = 6.4 \cdot 10^{19}\,\mathrm{W/cm^2}$$

$$E_0 = 22\,\mathrm{TV/m}$$

22 thousand billion Volt per meter
("LHC energy in 30 cm instead of 27 km")

This is what we need!

Scientists wonder: Can we use the strong transverse electrical fields to accelerate our beam?

The Plasma Accelerator Concept

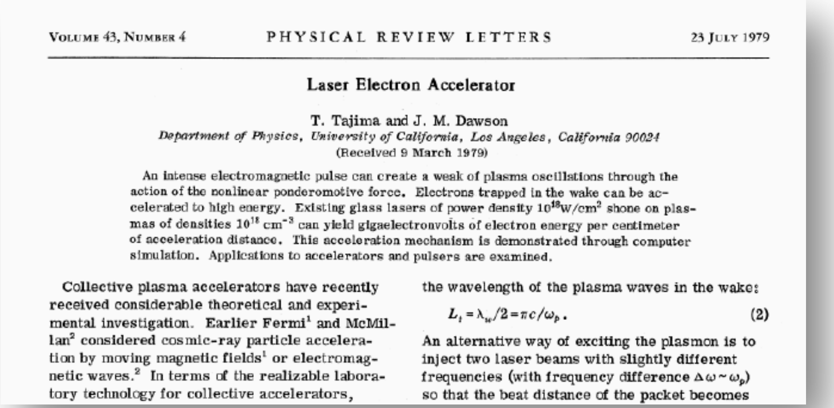
Overcome high-field limitations of metallic walls with dynamic plasma structures (undestructible)

New **idea in 1979 by Tajima and Dawson**: Wakefields inside a homogenous plasma can convert

transverse forces into **longitudinal accelerating fields**

Pondero-motive force of a laser **or** Space charge force of a charged particle bunch (e-, p+) → transverse forces

longitudinal accelerating fields → Accelerating gradients of 10 GeV/m to 1,000 GeV/m



VOLUME 43, NUMBER 4 — PHYSICAL REVIEW LETTERS — 23 JULY 1979

Laser Electron Accelerator

T. Tajima and J. M. Dawson
Department of Physics, University of California, Los Angeles, California 90024
(Received 9 March 1979)

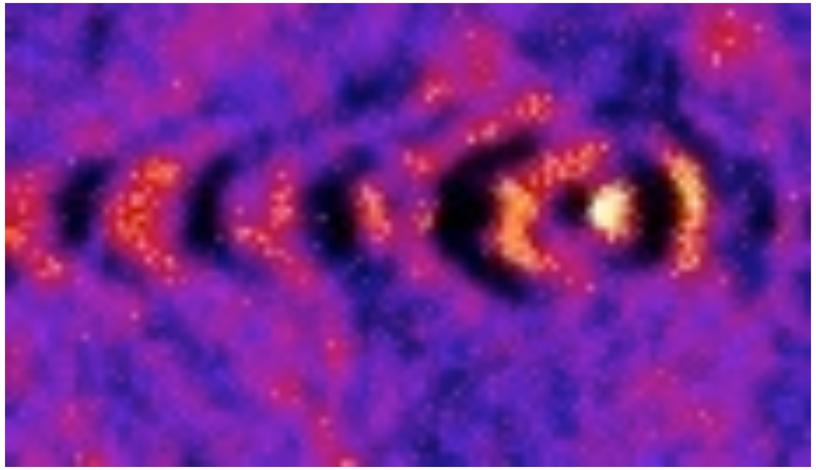
An intense electromagnetic pulse can create a weak of plasma oscillations through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density 10^{18}W/cm^2 shone on plasmas of densities 10^{18} cm^{-3} can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.

Collective plasma accelerators have recently received considerable theoretical and experimental investigation. Earlier Fermi[1] and McMillan[2] considered cosmic-ray particle acceleration by moving magnetic fields[1] or electromagnetic waves.[2] In terms of the realizable laboratory technology for collective accelerators,

the wavelength of the plasma waves in the wake:

$$L_t = \lambda_w/2 = \pi c/\omega_p . \quad (2)$$

An alternative way of exciting the plasmon is to inject two laser beams with slightly different frequencies (with frequency difference $\Delta\omega \sim \omega_p$) so that the beat distance of the packet becomes



Courtesy M. Kaluza

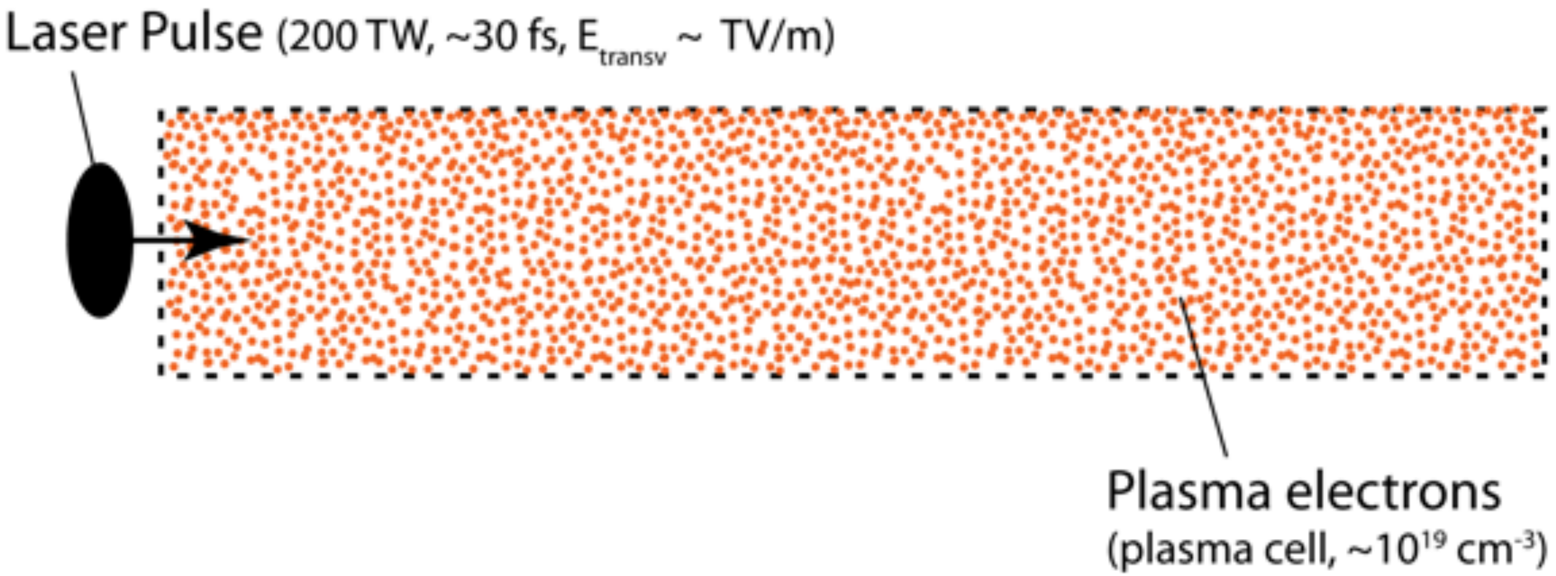
Options for driving wakefields:

- **Lasers**: Industrially available, steep progress, path to low cost
  Limited energy per drive pulse (up to **50 J**)
- **Electron bunch**: Short bunches (need μm) available, need long RF accelerator
  More energy per drive pulse (up to **500 J**)
- **Proton bunch**: Only long (inefficient) bunches, need very long RF accelerator
  Maximum energy per drive pulse (up to **100,000 J**)

Plasma Acceleration

Internal injection

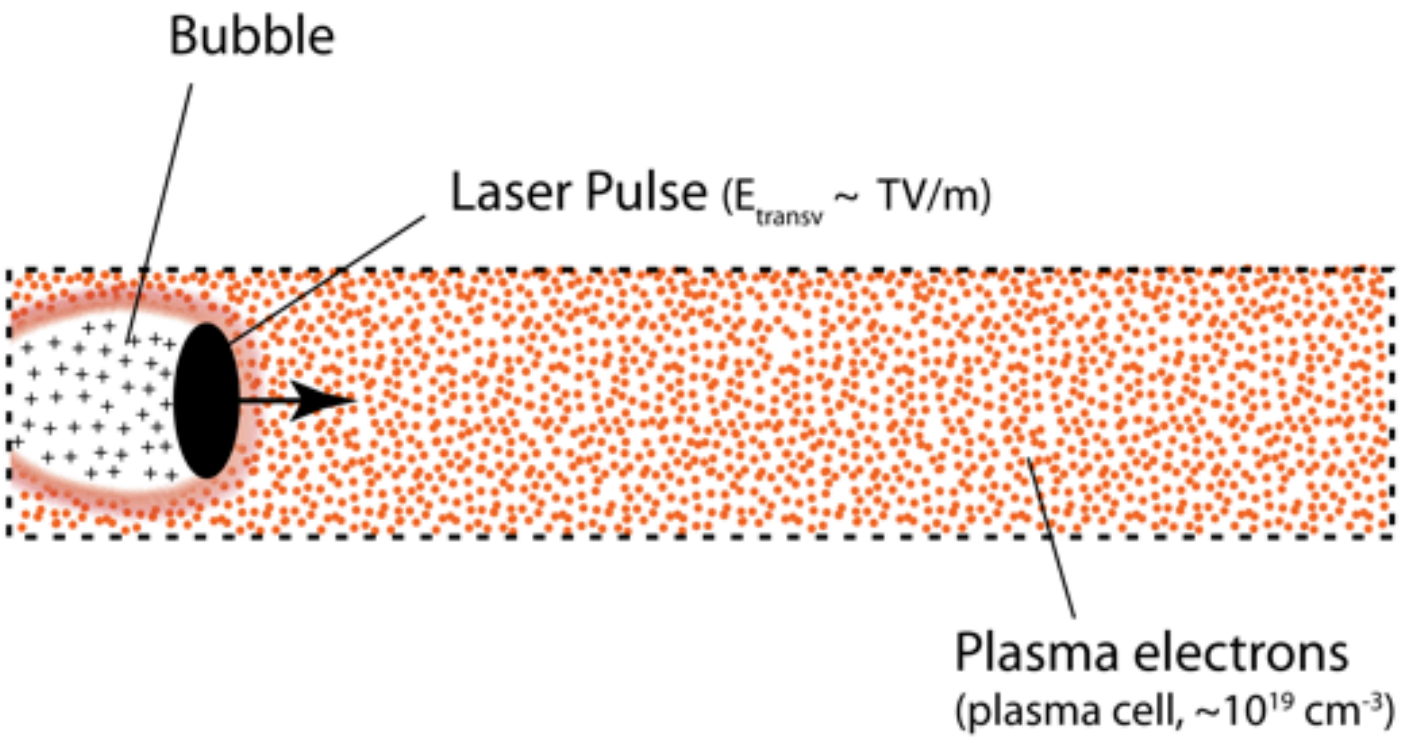
Works the same way with an **electron beam as wakefield driver**. But then usually lower plasma density. Ponderomotive force of laser is then replaced with space charge force of electrons on plasma electrons (repelling).



Like wakes left behind by a boat in water

Plasma Acceleration

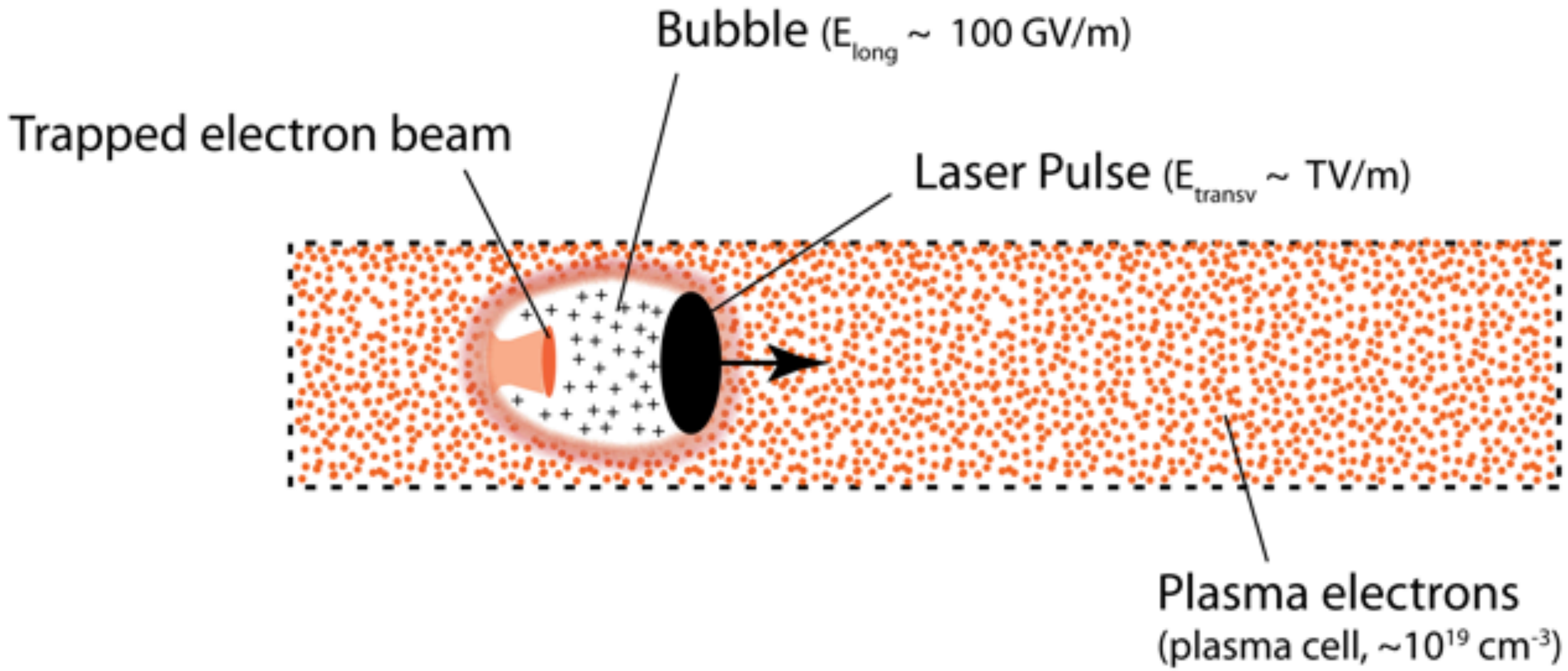
Internal injection



Like wakes left behind by a boat in water

Plasma Acceleration

Internal injection → strong fields in the bubble suck in plasma electrons to form the electron beam

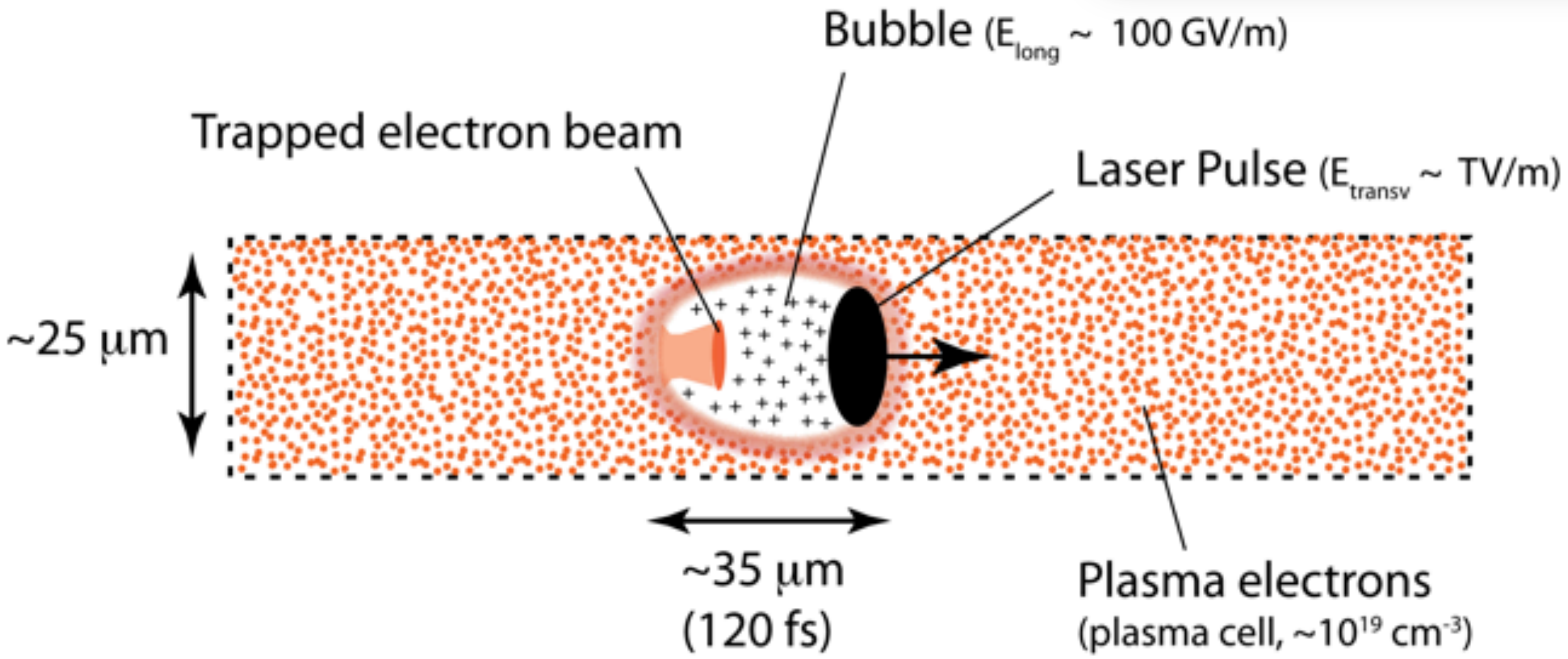


Like wakes left behind by a boat in water

Plasma Acceleration

Internal injection ("bubble regime")

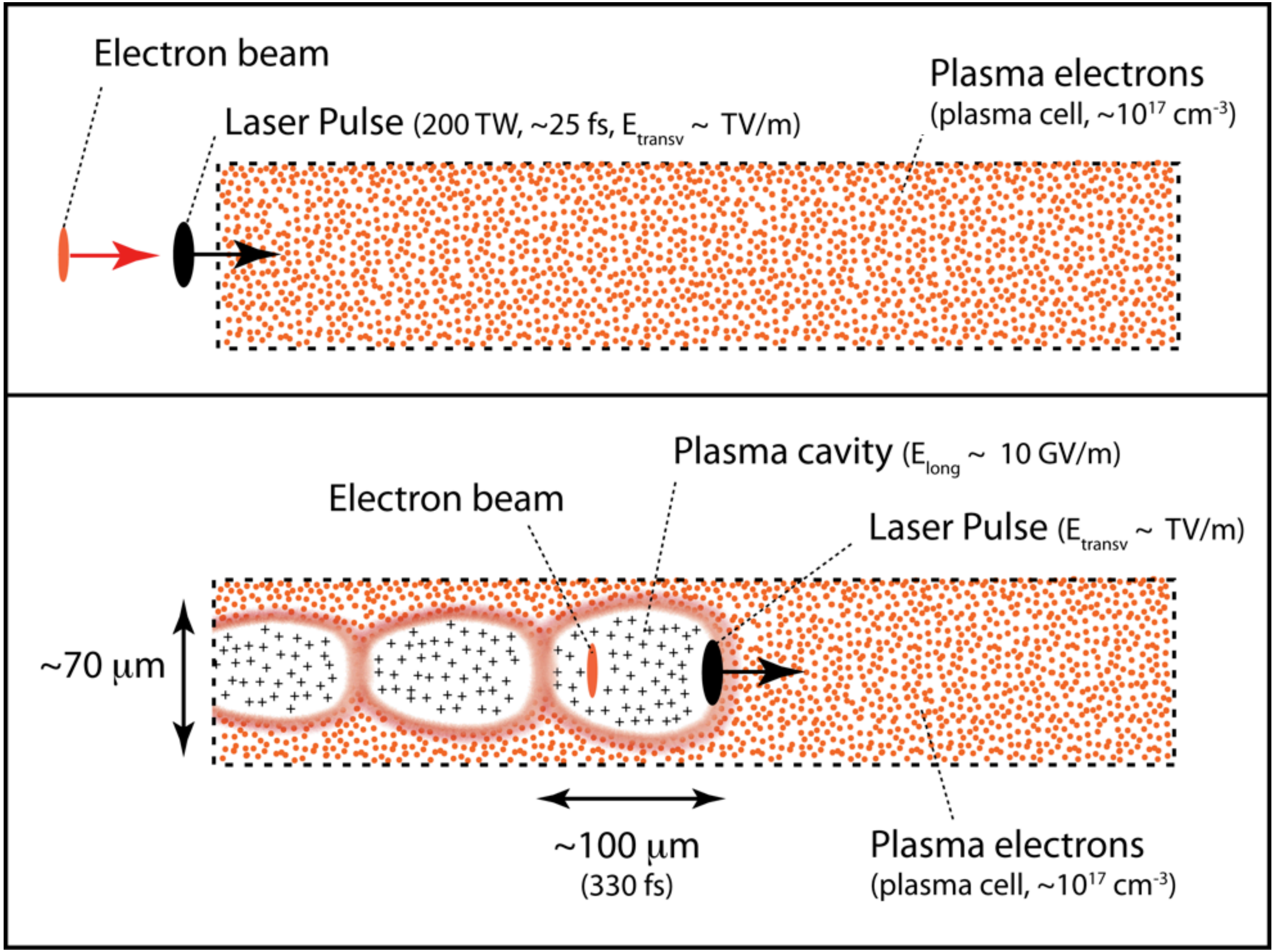
This accelerator fits into a human hair



Like wakes left behind by a boat in water

Plasma Acceleration

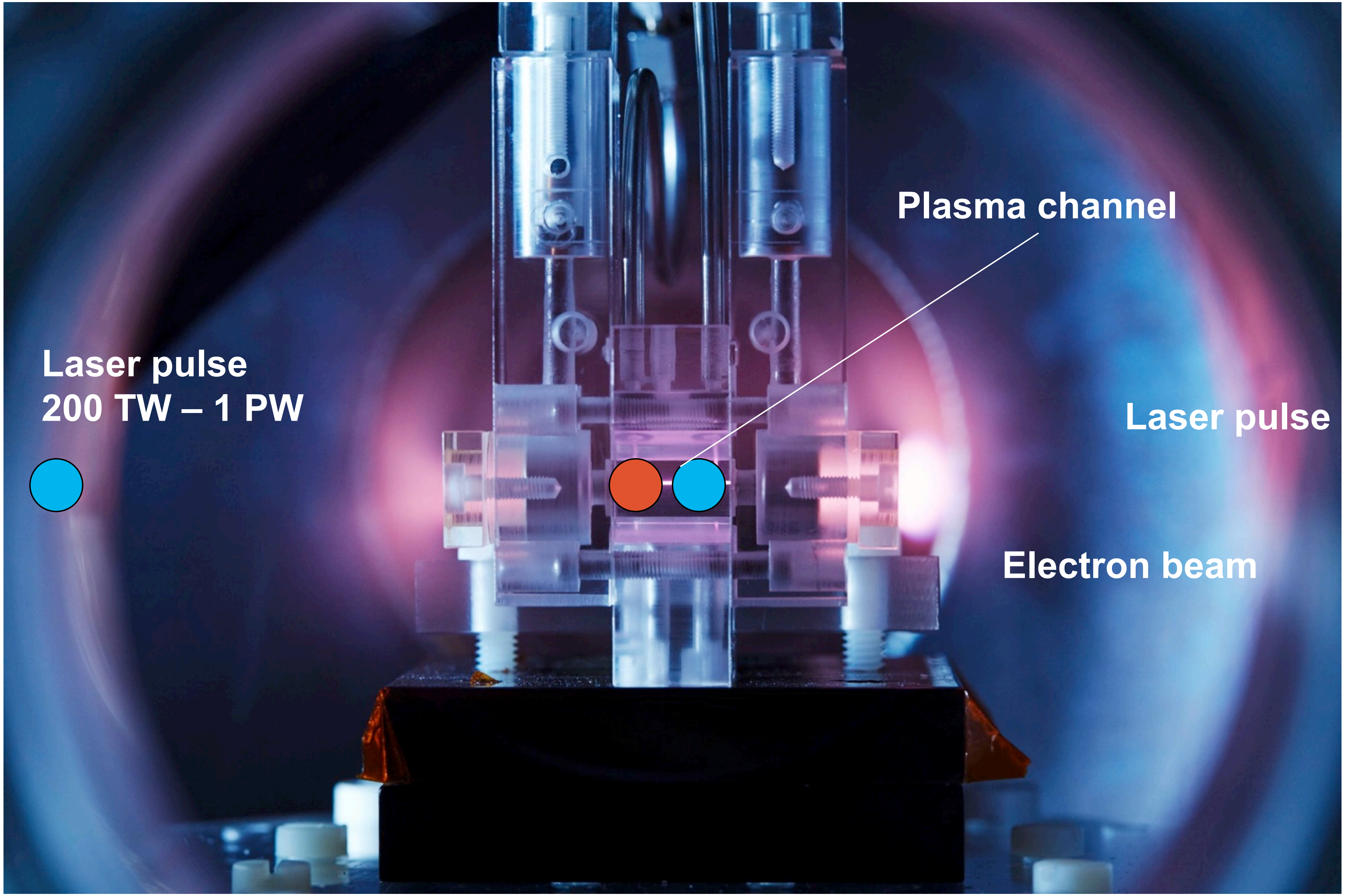
External injection



Like wakes left behind by a boat in water

Laser Plasma Accelerator for Electron Beams

"Bubble regime", invented in Europe



...and it is really much smaller!

A few cm's of plasma create as much energy as the 100 m long S.C. FLASH linac

Accelerator size becomes almost negligible!

Do not forget the **size of the laser**, which is the dominant size here:

Fit a **10 billion electron Volt accelerator in 300 square-meter** laboratory instead of 500 meter long accelerator tunnel!

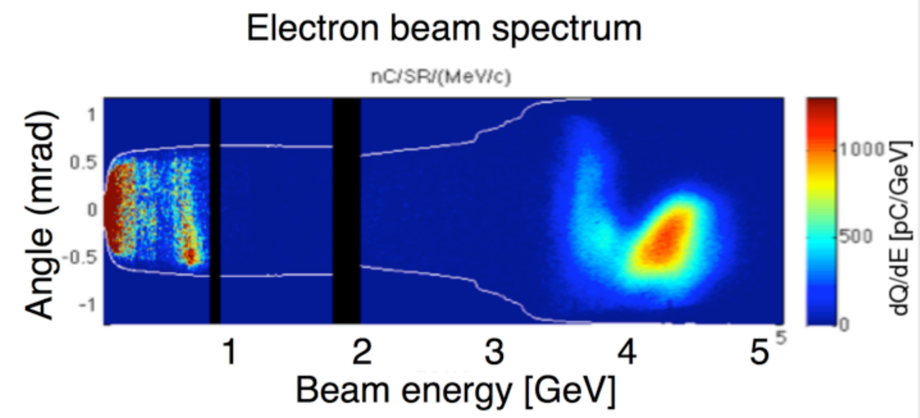
€ $ ¥ £

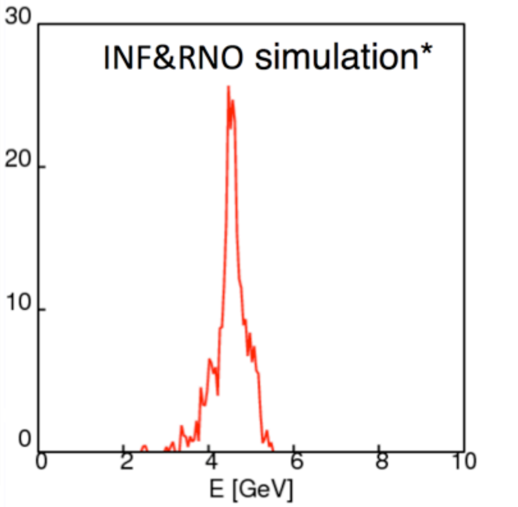
LBNL: 4.25 GeV beams have been obtained

from 9 cm plasma channel powered by 310 TW laser pulses (15 J)

4.25 GeV beams have been obtained from 9 cm plasma channel powered by 310 TW laser pulses (15 J)

*C. Benedetti et al., proceedings of AAC2010, proceedings of ICAP2012



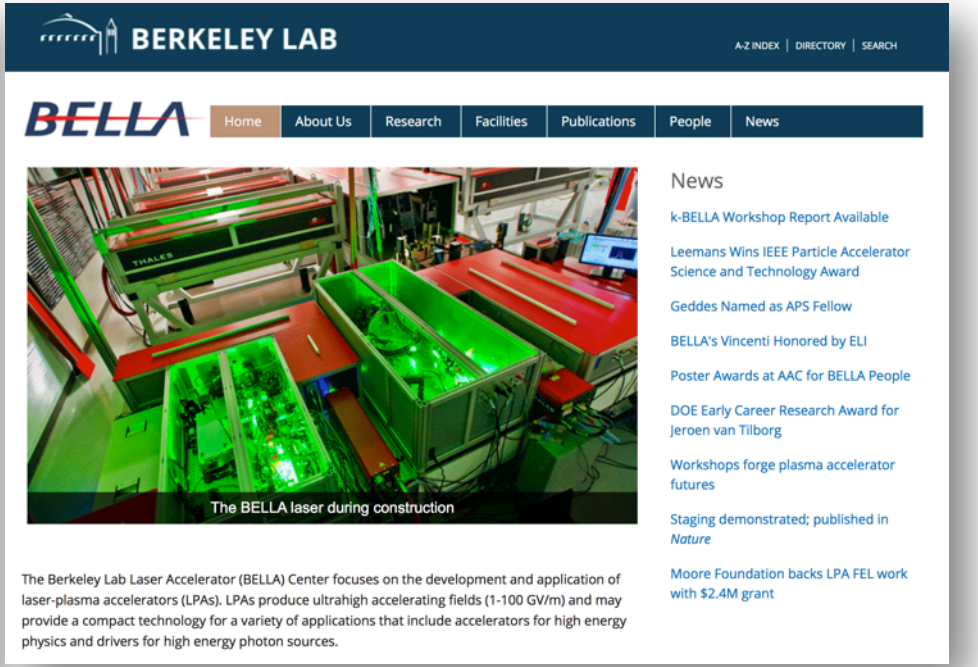


Slide: W. Leemans

- **Laser** (E=15 J):
  - Measured longitudinal profile (T_0= 40 fs)
  - Measured far field mode (w_0=53 µm)
- **Plasma:** parabolic plasma channel (**length 9 cm, n_0~$6x10^{17}$ cm^{-3}**)

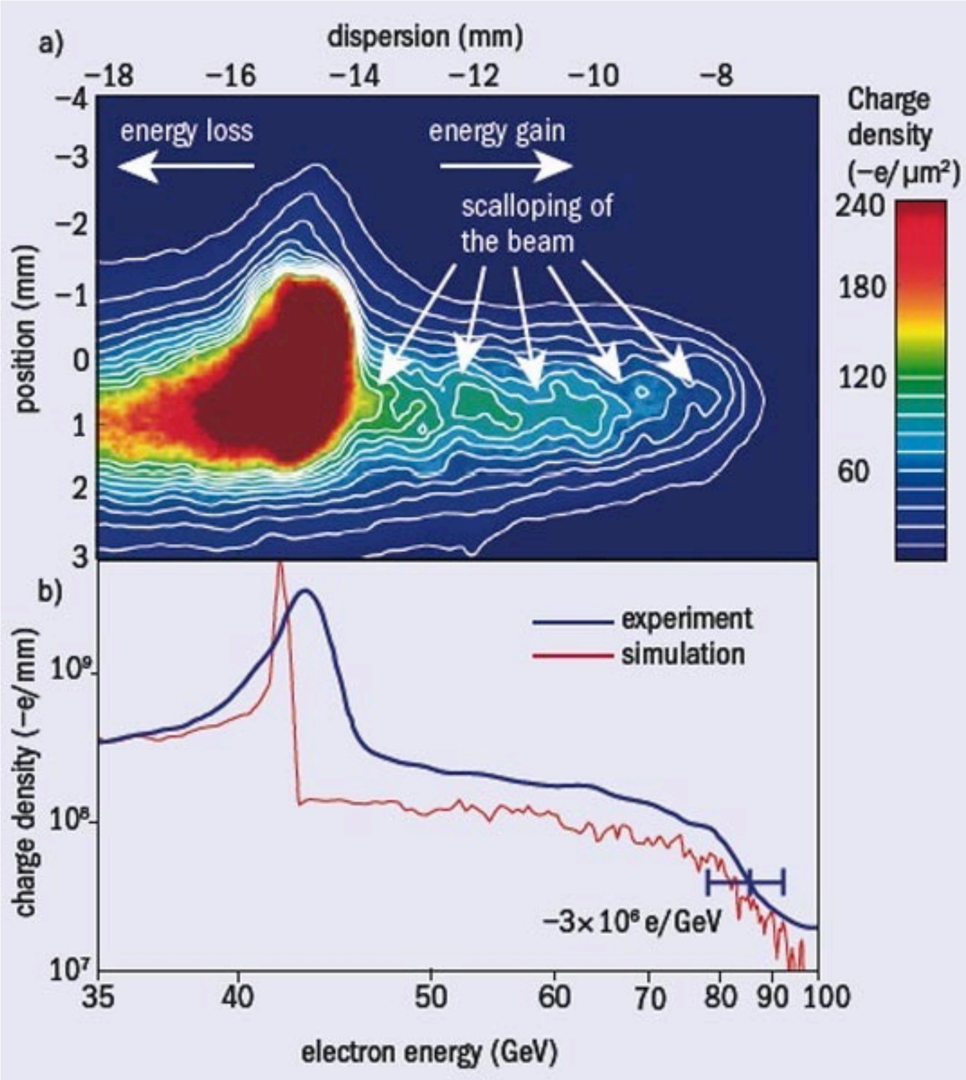
W.P. Leemans et al., PRL 2014

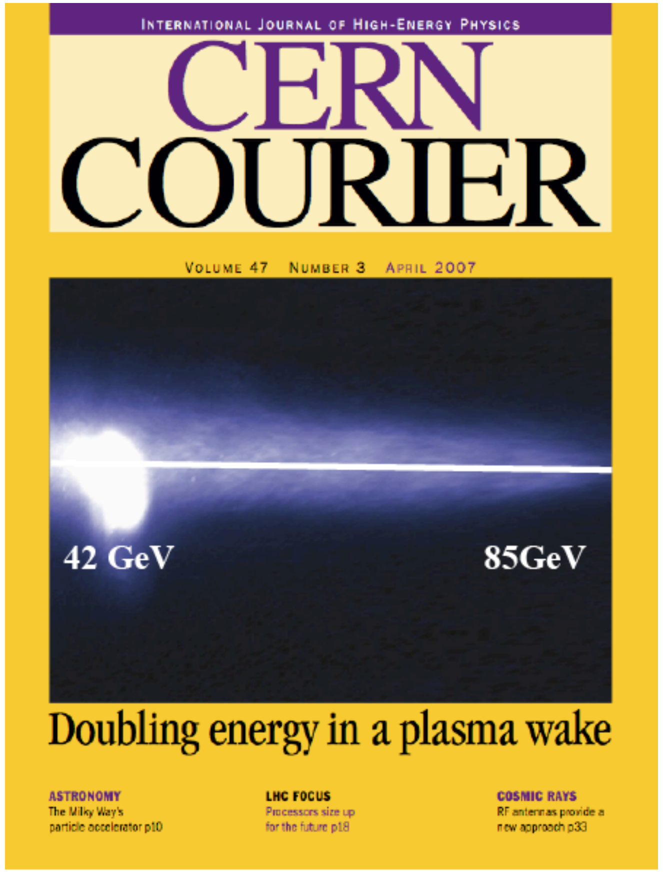
	Exp.	Sim.
Energy	**4.25 GeV**	4.5 GeV
ΔE/E	5%	3.2%
Charge	~20 pC	23 pC



SLAC: 42 GeV acceleration has been shown

85 cm plasma driven by a 42 GeV electron beam, tail of bunch accelerated





Bob Siemann, SLAC

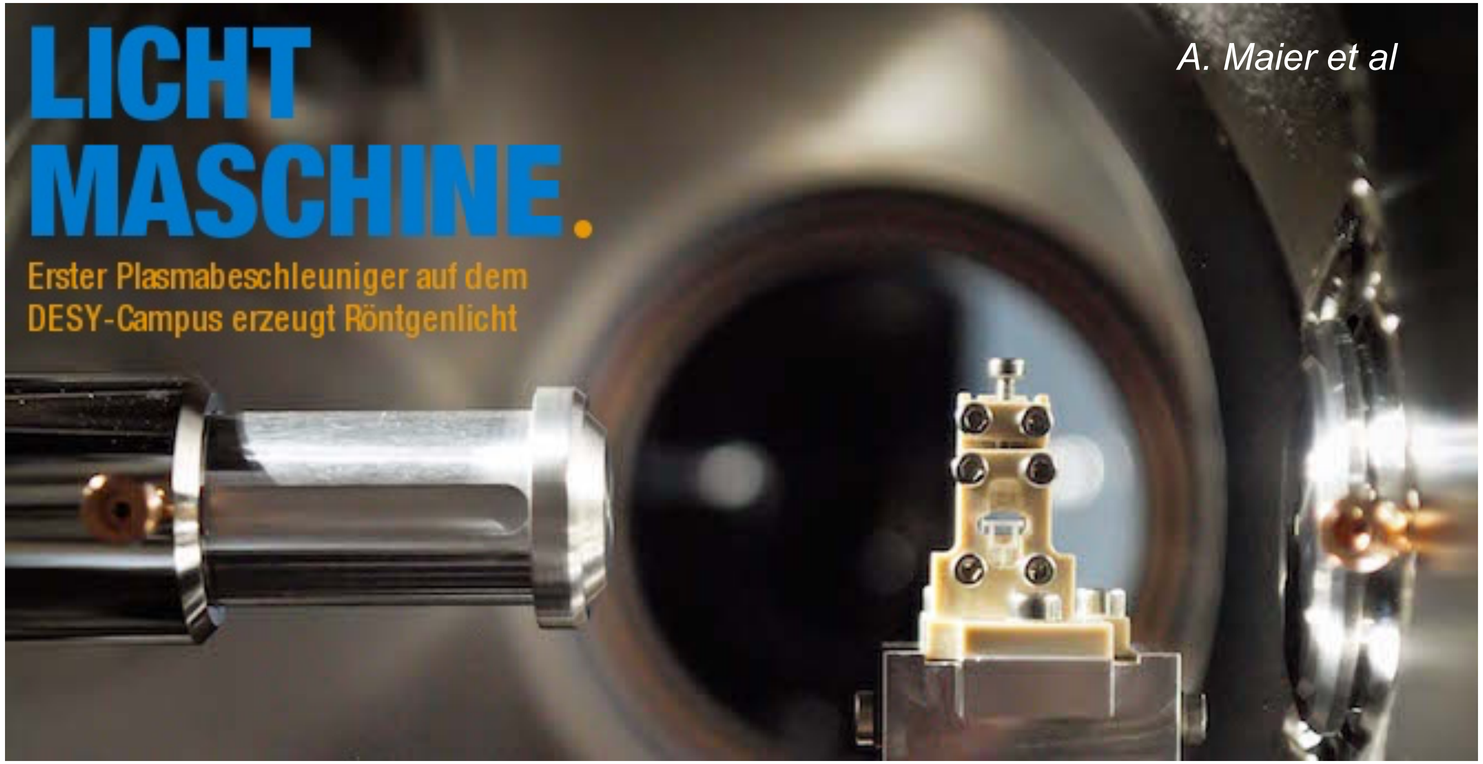
E167 collaboration
SLAC, UCLA, USC

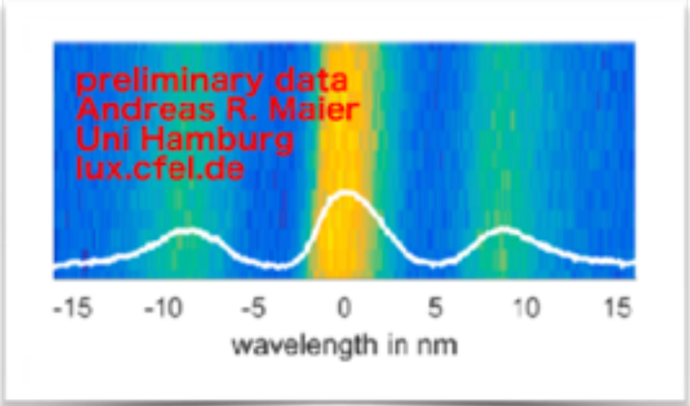
I. Blumenfeld et al, Nature 445, p. 741 (2007)

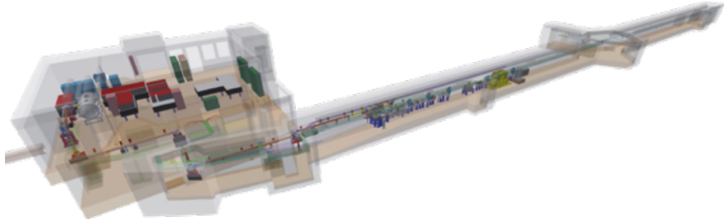
University Hamburg / DESY: LUX (A. Maier et al)

An laser-driven plasma R&D approach → towards FEL applications

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG







About **400 MeV electrons** from plasma accelerator, guide beam out of plasma, transport to undulator, generate X rays in undulator, dump electron beam, measure **X rays (8 nm)**, first **24h operation**. Latest: 1 GeV electron beam.

Next steps: towards harder X rays, lasing (saturation not possible in available length of undulator)

Would It Not Be Reasonable to Reap the Benefits of Innovative Laser, Plasma and Accelerator Technology also in Europe for our Science, Industry and Society?

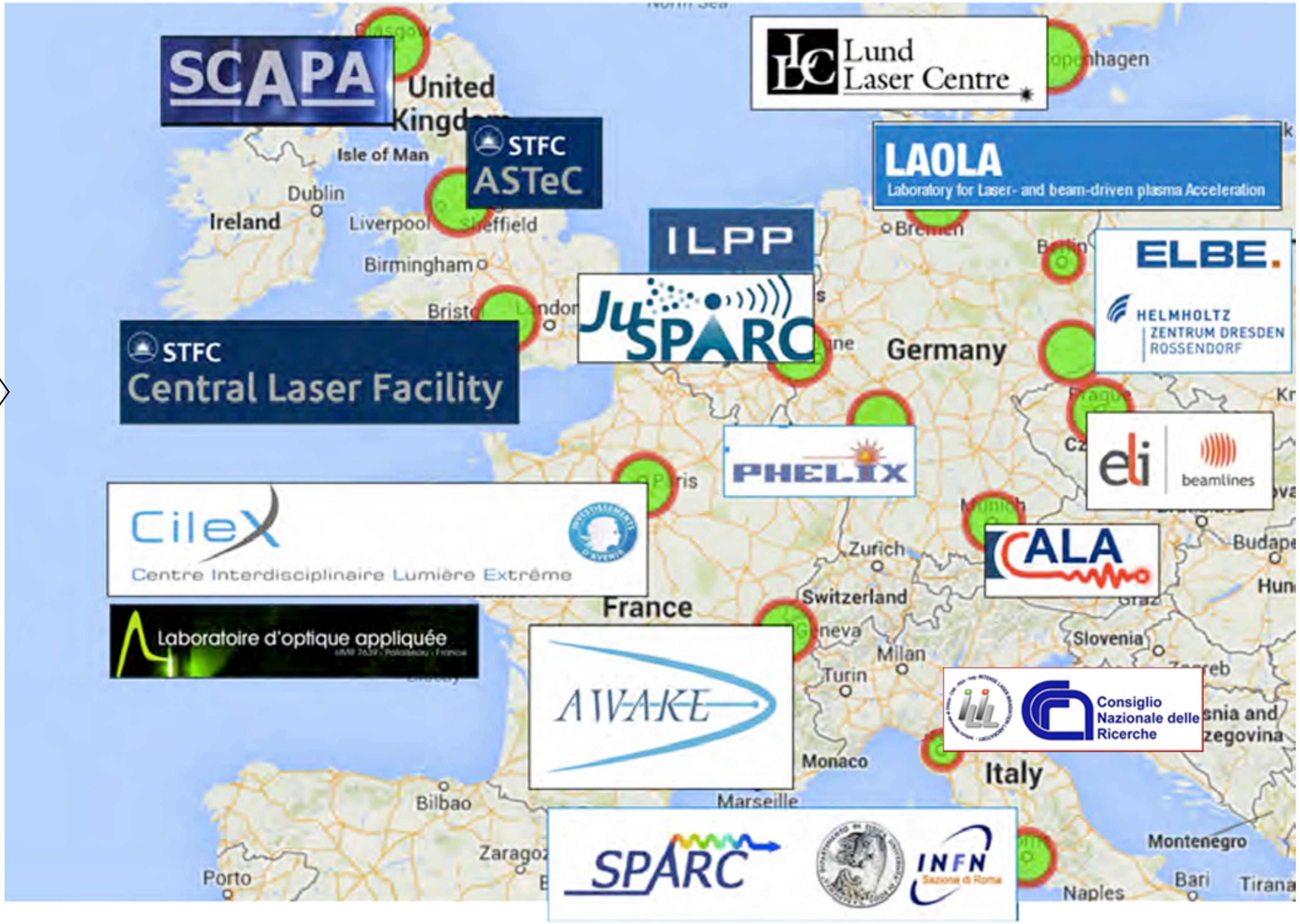
High Tech leadership creates well paid jobs for our young people!

The European Opportunity

Europe is Very Well Placed in Race to Make it Work

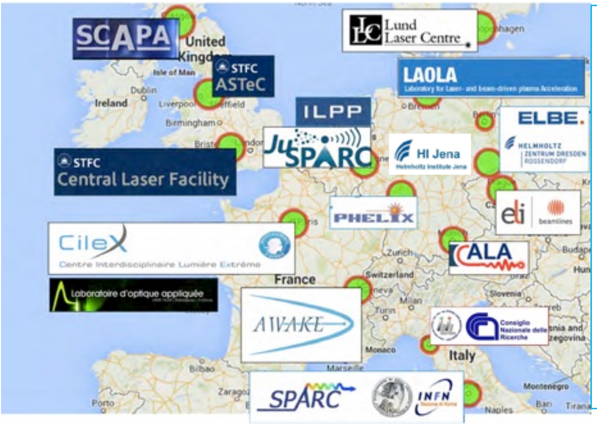
Let's compete and win

- Europe has **highly competitive plasma accelerator R&D** (invention bubble regime, radiation generation)
- European **R&D facilities**: e.g. laser plasma beams produce photons in FEL-type undulators
- Europe has **excellent accelerators, FEL's and HEP colliders**
- Europe has the **world-leading high power laser industry**, building the lasers used for this R&D around the globe



Novel Acceleration R&D in Europe

How can we develop plasma accelerators towards usability?



Independent national projects*, funded by national states. About 16 major facilities for novel plasma acceleration R&D.

European Network EuroNNAc for Novel Accelerators

European novel accelerator projects with international involvement

AWAKE

CERN experiment collaboration under leadership of MPI (A. Caldwell): proton driven

AXSIS

ERC Synergy Grant

EuPRAXIA

Funded by EU Horizon2020 as EU Design Study: laser & electron driven

** See note on ELI*

EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

EuPRAXIA

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

PARTICIPANTS

DESY, Germany

INFN, Italy

CNR, Italy

CNRS, France

University of Strathclyde, UK

IST-ID, Portugal

STFC, UK

SOLEIL, France

University of Manchester, UK

University of Liverpool, UK

ENEA, Italy

CEA, France

Sapienza Universita di Roma, Italy

Universität Hansestadt Hamburg, Germany

Imperial College London, UK

University of Oxford, UK

CONTACT US:

Project Coordination
Dr. Ralph Assmann,
DESY (Coordinator)

Dr. Arnd Specka,
CNRS/IN2P3 (Deputy)

Primary Coordinator Contact
Mrs. Ruth Mundt, DESY
eupraxia-admin@desy.de

Media Enquiries
Prof. Dr. Carsten P. Welsch,
Cockcroft Institute/University of Liverpool
carsten.welsch@cockcroft.ac.uk

www.eupraxia-project.eu

ACCELERATOR INNOVATION FOR NEW HORIZONS IN SCIENCE

SMALLER SIZE AND IMPROVED COST-EFFICIENCY

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 653782. The information herein reflects only the views of its authors and the Research Executive Agency is not responsible for any use that may be made of the information contained.

EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

EuPRAXIA

DESIGNING THE FUTURE

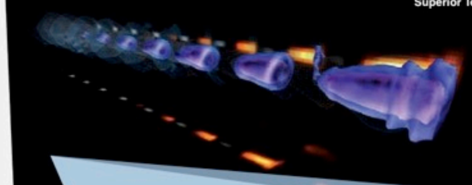
© DESY, Heiner Müller-Elsner

The EuPRAXIA Consortium is preparing a conceptual design for the world's first multi-GeV plasma-based accelerator with industrial beam quality and dedicated user areas.

INTERNATIONAL COLLABORATION

EuPRAXIA brings together a consortium of 16 laboratories and universities from 5 EU member states. The project, coordinated by DESY, is funded by the EU's Horizon 2020 programme. The consortium has been joined by 18 associated partners to make additional in-kind contributions.

The consortium holds open international events to strengthen collaborations, to connect to interested users from FEL's, high-energy physics, medicine and industry, and to assess the development of the project.



Computer simulation of a laser wakefield

© Dr Jorge Vieira, Instituto Superior Tecnico, Lisbon

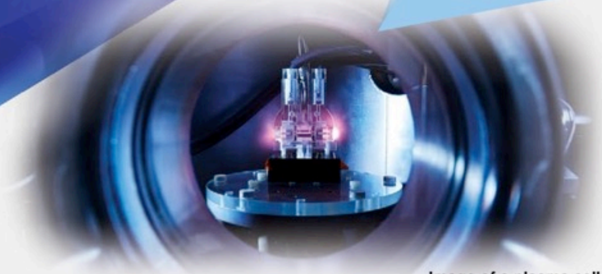


Image of a plasma cell.

© DESY, Heiner Müller-Elsner

Particle accelerators have become powerful and widely used tools for industry, medicine and science. Today there are some 30,000 particle accelerators worldwide, all of them relying on well-established technologies.

The achievable energy of particles is often limited by practical boundaries on size and cost, for example, in hospitals and university laboratories, or available funding for very large scientific instruments at the energy frontier.

A new type of accelerator that uses plasma wakefields promises accelerating gradients as much as 1,000 times higher than conventional accelerators! This would allow much smaller machines for fundamental and applied research.

The goal of this project is to produce a conceptual design for the world's first multi-GeV plasma-based accelerator that can provide industrial beam quality into dedicated user areas.

ADVANCED TECHNOLOGIES

The project is structured into 14 working groups dealing with simulations of high gradient laser plasma accelerator structures, design and optimization of lasers and electron beams, research into alternative and hybrid techniques, Free Electron Lasers (FEL), high-energy physics, and radiation source applications.

EuPRAXIA joins novel acceleration schemes with modern lasers, the latest correction technologies and large-scale user areas. The consortium offers unique training opportunities for researchers in a multidisciplinary field.

OPENING NEW HORIZONS

The project will bridge the gap between successful proof-of-principle experiments and ground-breaking, ultra-compact accelerators.

With a smaller size and improved efficiency, plasma-based technologies have the potential to revolutionize the world of particle accelerators multiplying their applications to medicine, industry and fundamental science.

Participants in the EuPRAXIA Steering Committee Meeting. Paris, February 2016

© Sylvaine Pieyre, LLR

EuPRAXIA

EuPRAXIA Horizon2020 Design Study

European Plasma Accelerator Infrastructure with Pilot Users

- **Collaboration** brings together:
  - Big science labs: photon science, particle physics
  - Laser laboratories: high power lasers
  - International laboratories: CERN, ELI (associated)
  - Universities: accelerator research, plasma, laser
- **125 scientists** in our work list

Start: 1 Nov 2015
End: 31 Oct 2019

Deliverable: Conceptual Design Report

www.eupraxia-project.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Collaboration of 40 institutes

From Europe, Asia and United States

16 EU laboratories are beneficiaries. **24 associated partners** from EU, Europe, Asia and US contribute in-kind.

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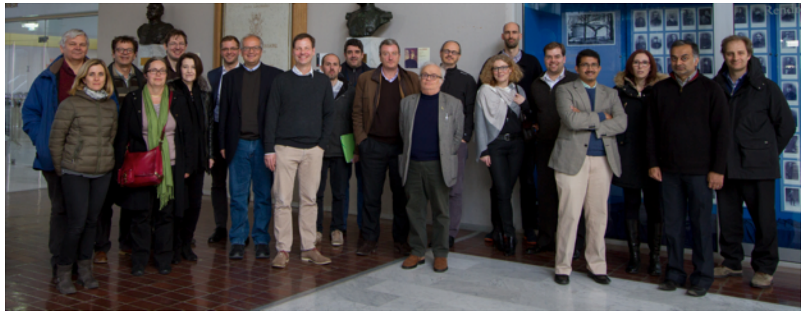
Management Structure

Heads of Project and of Supervisory Boards

Collaboration board
Scientific advisory board
Project coordinator
Management support team
Steering committee
WP1: Project management and technical coordination
WP2: Physics and simulation
WP3: High-gradient laser-plasma accelerating structures
WP4: Laser design and optimization
WP5: Electron beam design and optimization
WP6: FEL pilot application
WP7: High-energy physics and other pilot applications
WP8: Outreach and liaison
WP9: Alternative e-beam driven plasma structures
WP10: Use of other novel technologies
WP11: FEL application prototyping
WP12: Accel. prototyping and experiments at test facilities
WP13: Alternative radiation generation
WP14: Hybrid laser-electron-beam driven acceleration

Steering Committee



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A European Strategy for Accelerator Innovation

Required intermediate step between proof of principle and production facility
One accelerator unit!

PRESENT EXPERIMENTS

Demonstrating **100 GV/m** routinely

Demonstrating **GeV** electron beams

Demonstrating basic **quality**

EuPRAXIA INFRASTRUCTURE

Engineering a high quality, compact plasma accelerator

5 GeV electron beam for the 2020's

Demonstrating user readiness

Pilot users from FEL, HEP, medicine, ...

PRODUCTION FACILITIES

Plasma-based **linear collider** in 2040's

Plasma-based **FEL** in 2030's

Medical, industrial applications soon

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EuPRAXIA Objectives

EuPRAXIA is a conceptual design study for a 5 GeV electron plasma accelerator

1. Address **quality**. Show **plasma accelerator technology is usable**

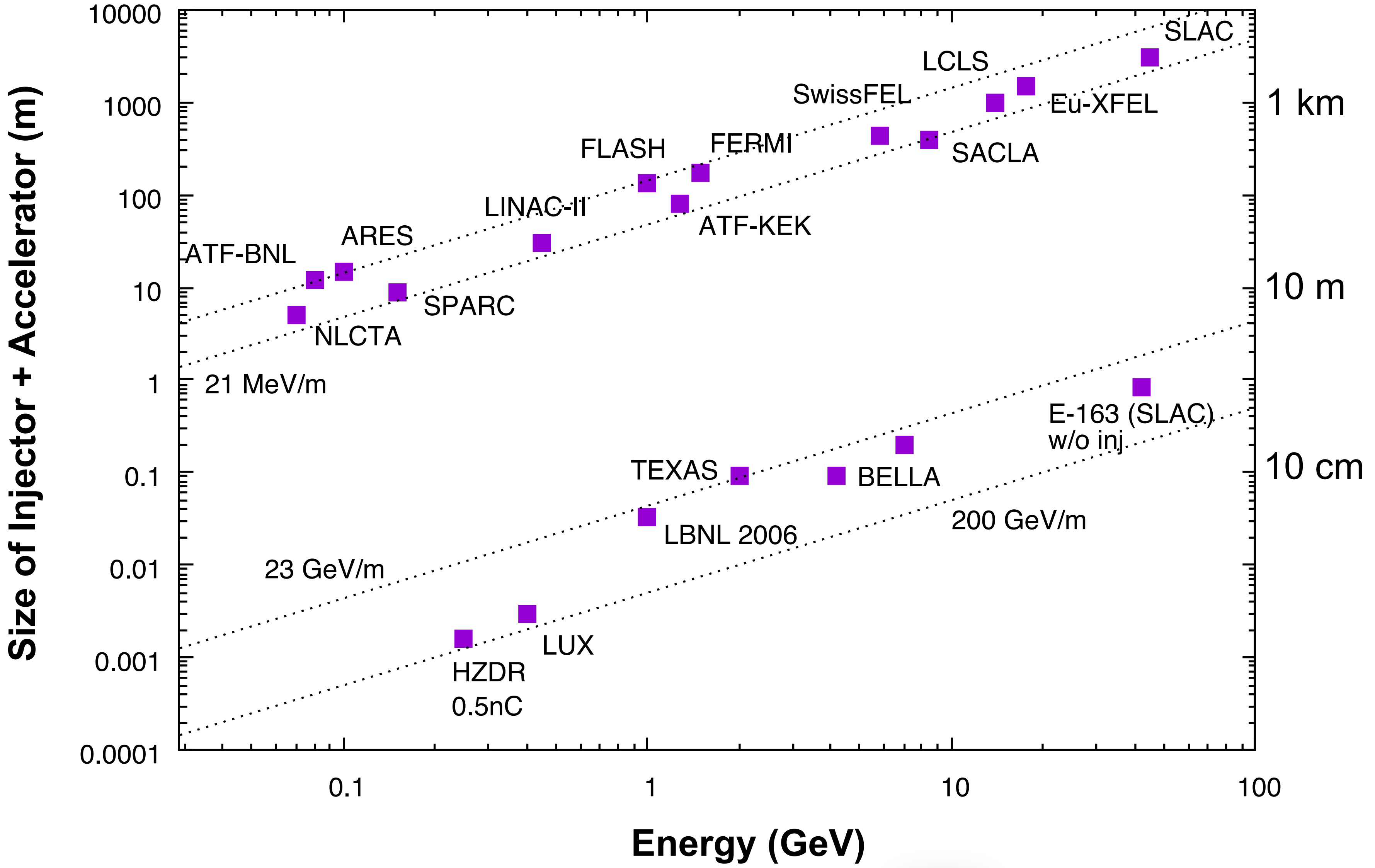
2. Show **benefit in size and cost** versus established RF technology

Note: EuPRAXIA will initially be **low power** and **low wall-plug power efficiency**

- Baseline (10 Hz): 10s of Watt with ~ 1 mJ/photon pulse energy
- Efforts with **industry and laser institutes** to improve rep. rate & efficiency (incorporate fiber-based lasers with 30 % efficiency)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Accelerator Size versus Energy



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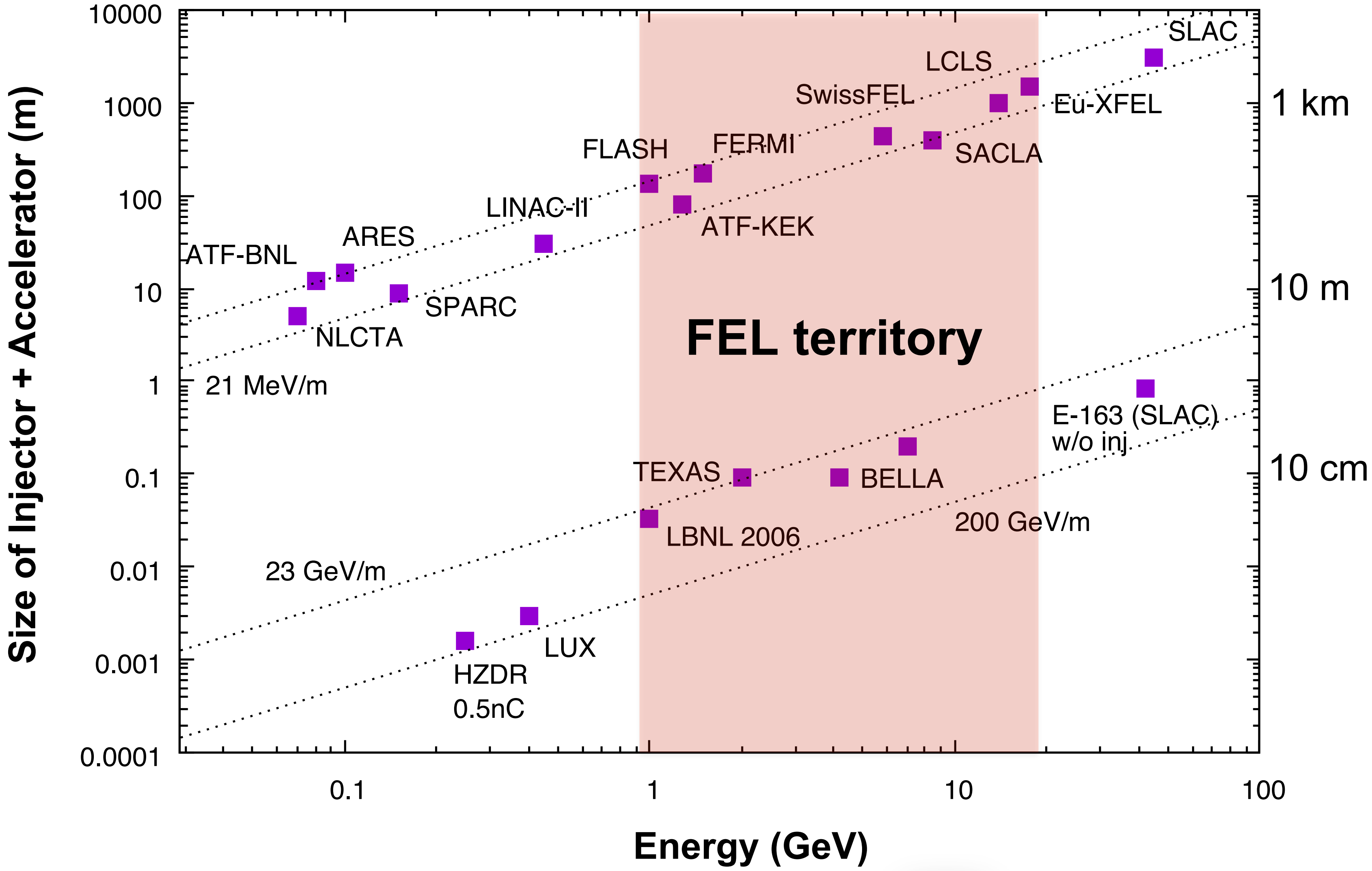
Accelerator Size versus Energy



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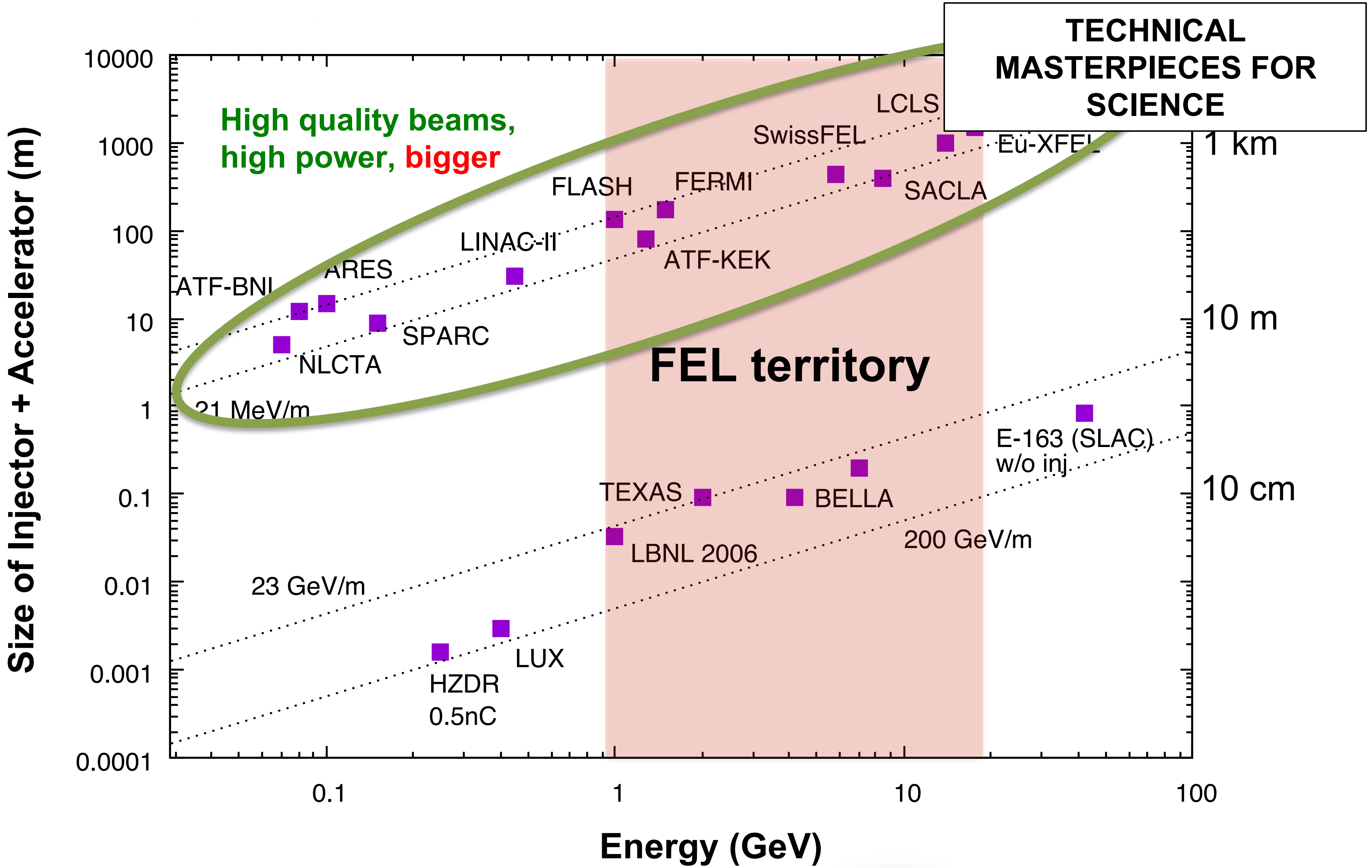
Accelerator Size versus Energy



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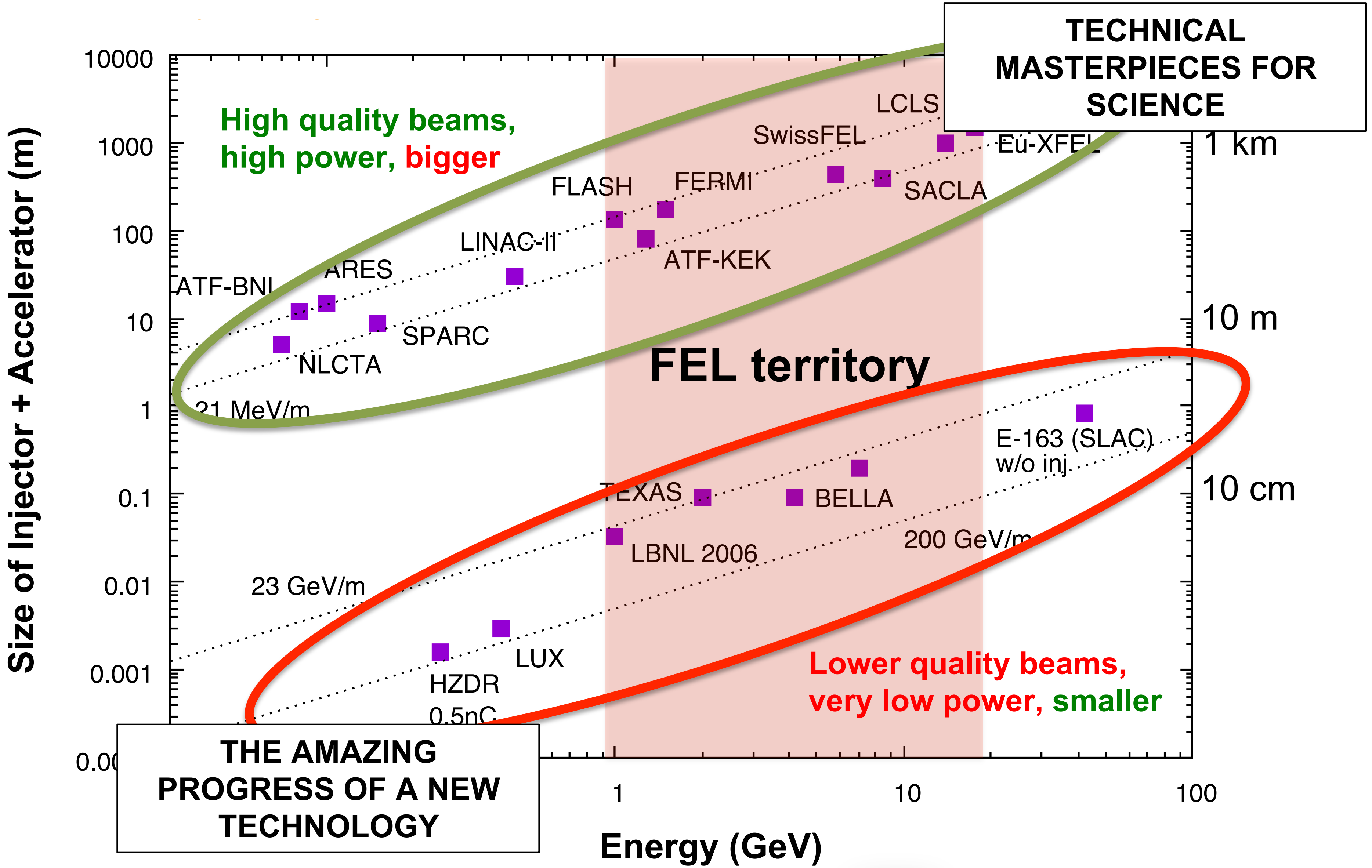
Accelerator Size versus Energy



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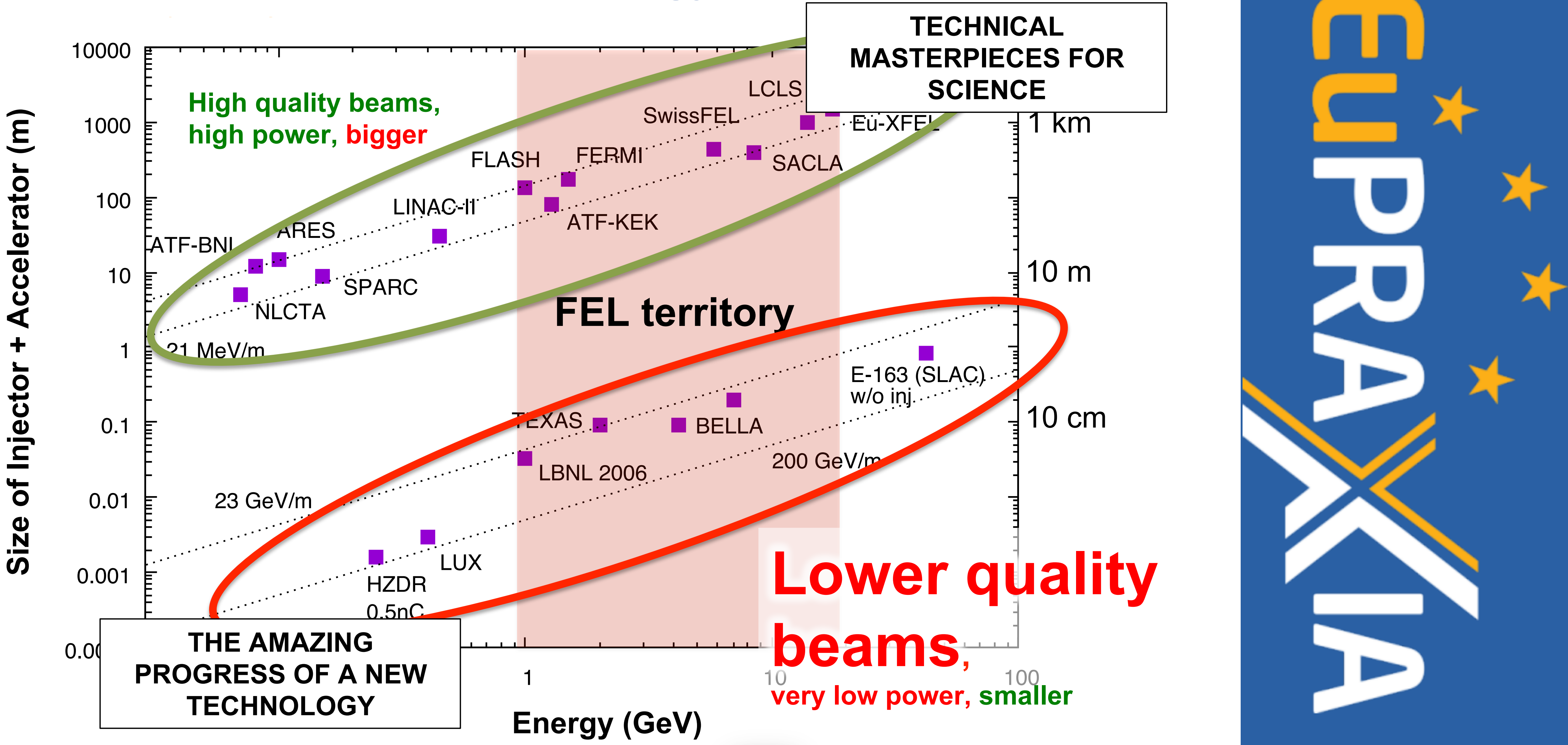
Accelerator Size versus Energy



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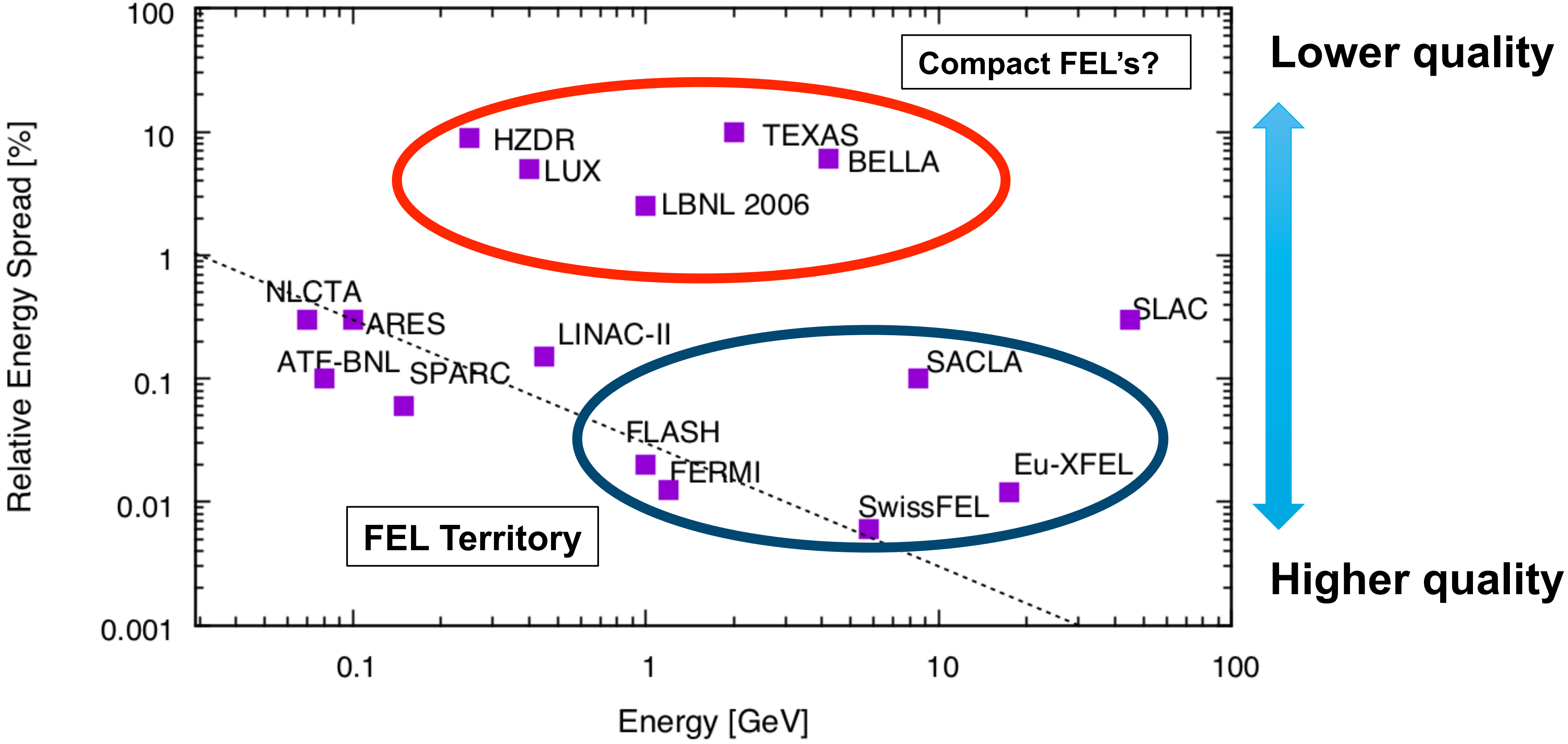
Do All Electrons Have the Same Energy?

Energy Spread – Variation of Beam Energy between Electrons in the Beam



EuPRAXIA aims at **addressing the quality problem**.

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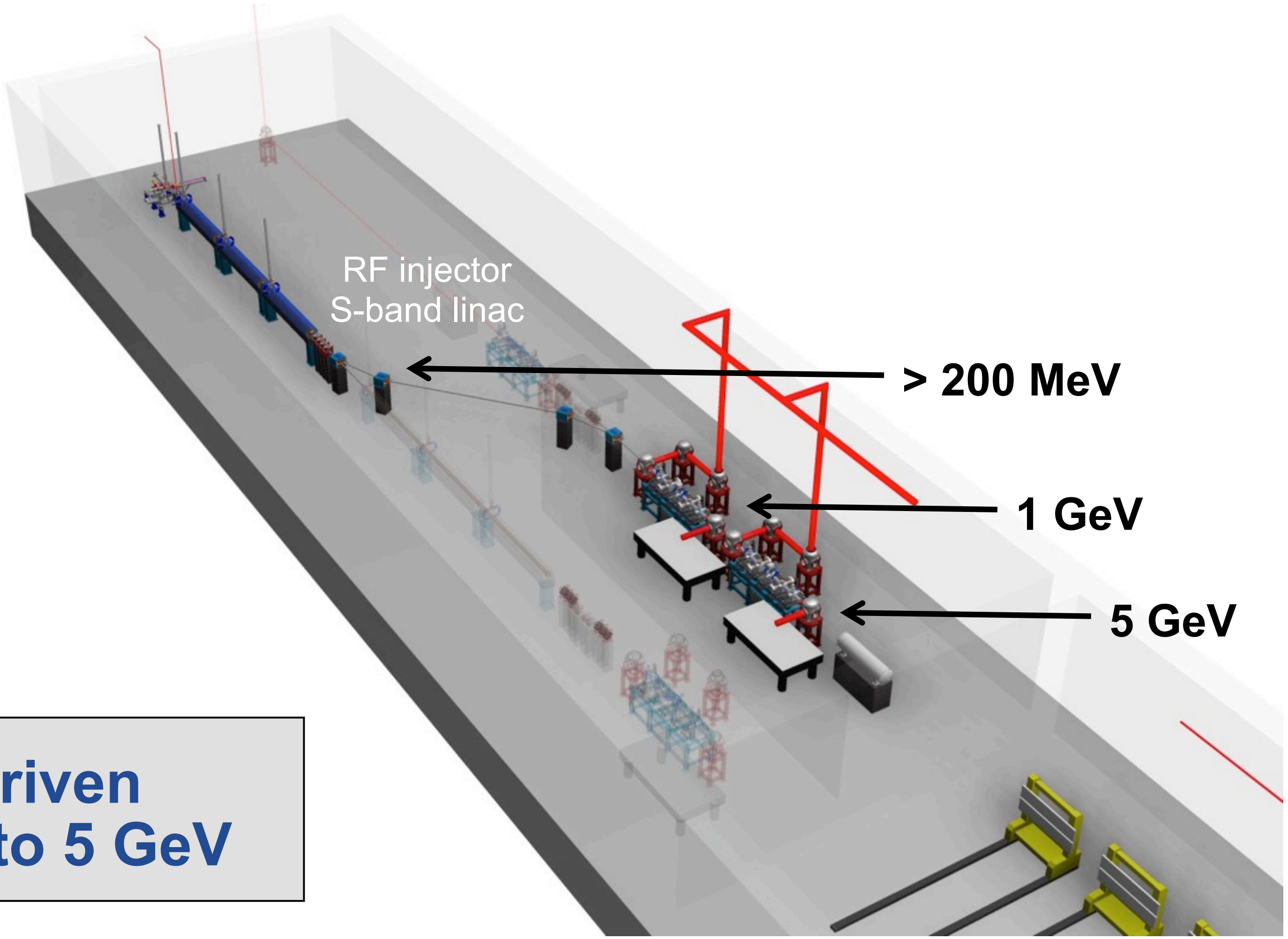
The 50 Billion Volt per Meter Linear Accelerator



A Laser-Driven Stages to 5 GeV

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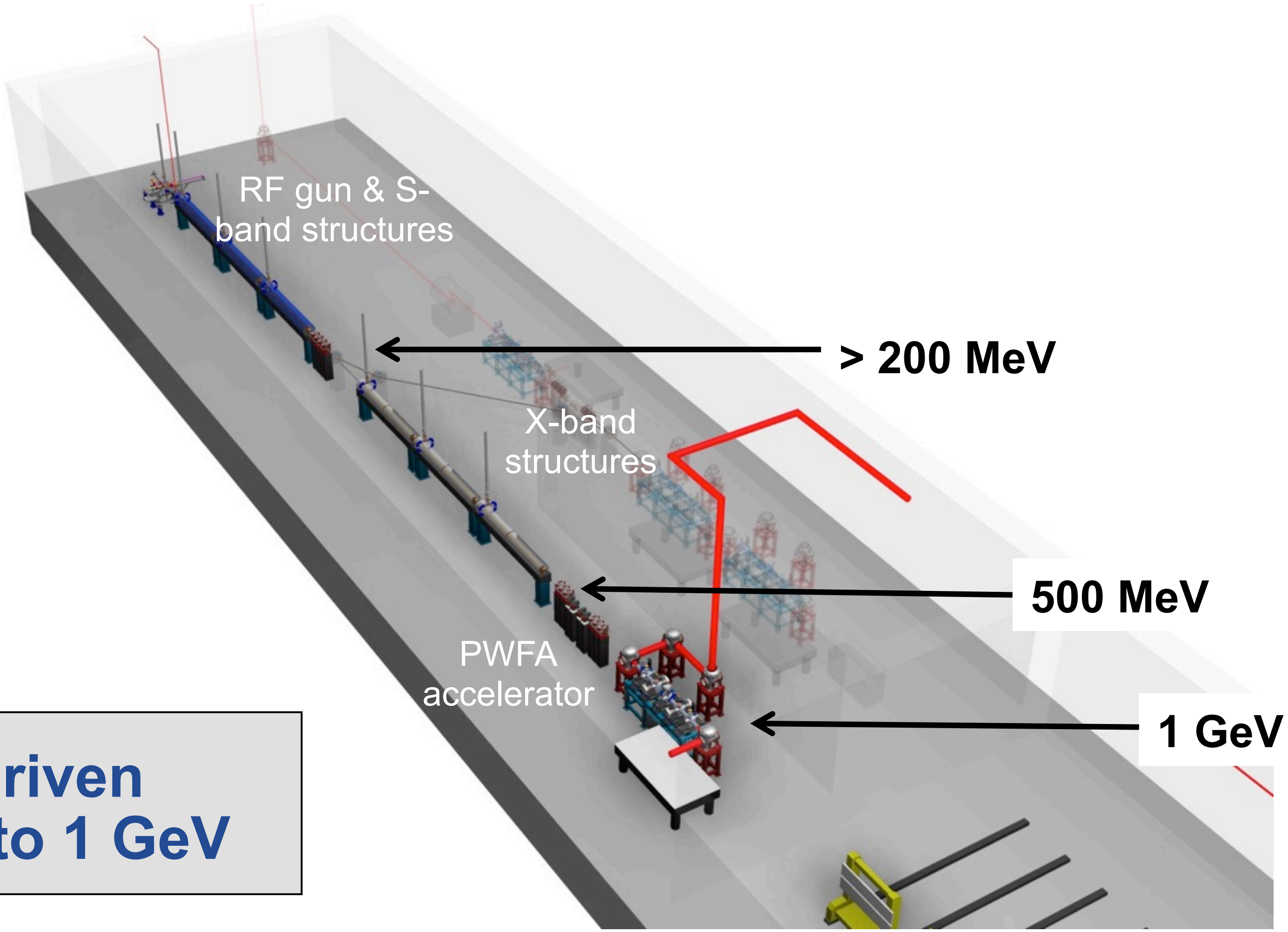
EuPRAXIA

The 50 Billion Volt per Meter Linear Accelerator



B **Beam-Driven Stages to 1 GeV**

EuPRAXIA

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Targets in Facility Parameters

Overview of EuPRAXIA technical goals. Not self-consistent cases. Detailed and self-consistent parameter tables are available upon request.

High-energy, ultrashort electron beams		
Energy	[GeV]	1 – 5
Energy spread	[%]	0.1 – 5
Beam duration	[fs]	3 – 20
Beam charge / no. of electrons	[pC / -]	5 – 50 / $3x10^7$ – $3x10^8$
Typical transverse beam size*	[µm]	2 – 100
Repetition rate	[Hz]	1 – 100
Ultrashort Free-Electron Laser radiation pulses		
Wavelength	[nm]	0.05 – 10
No. of photons per pulse	[-]	10^{10} – 10^{12}
Pulse duration	[fs]	3 – 35
Bandwidth	[%]	0.1 – 0.5
Three main high power laser systems		
Wavelength	[nm]	800
Energy on target	[J]	5 – 100
Pulse duration	[fs]	20 – 60
Repetition rate	[Hz]	20 – 100

* *with a normalised transverse beam emittance of 0.5 – 1.5 µm*

EuPRAXIA

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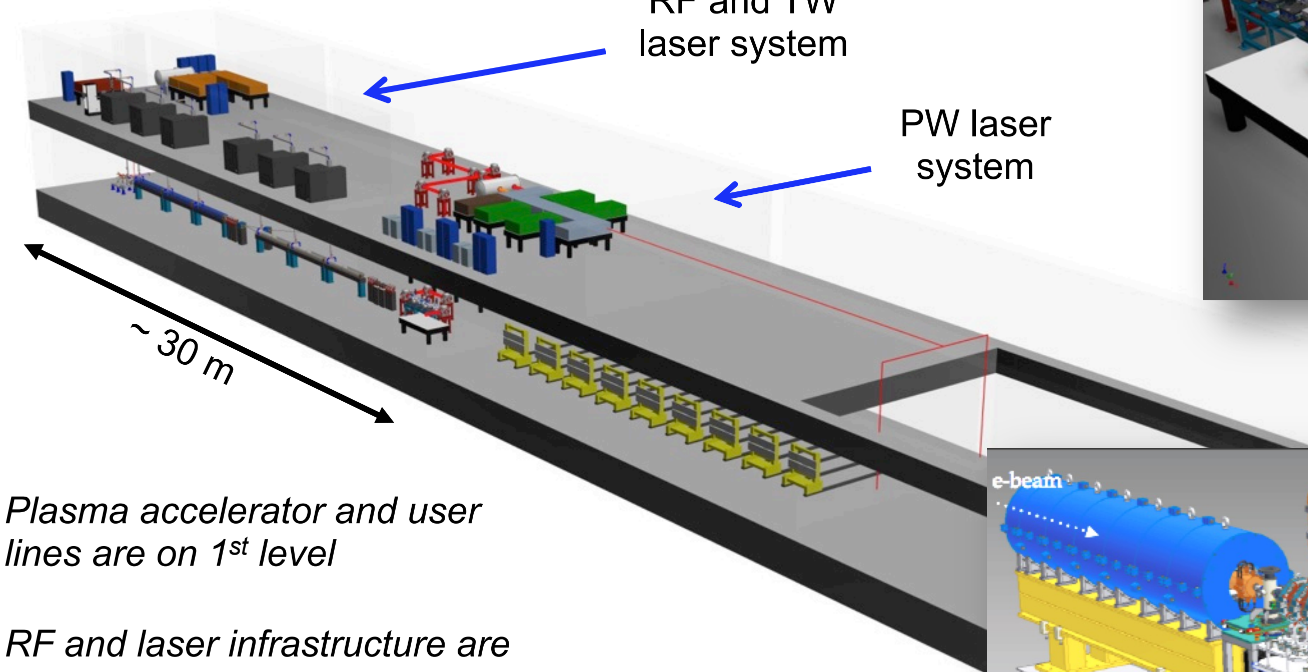
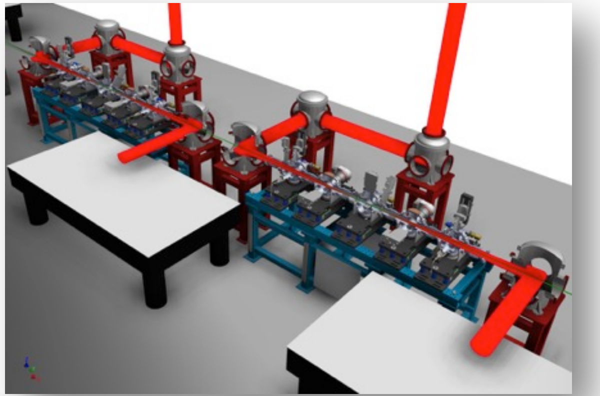
The EuPRAXIA Facility (Under Design)

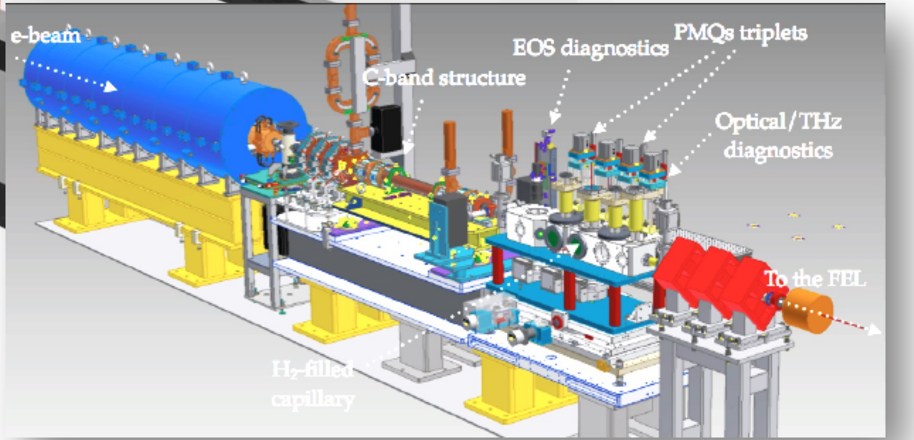


RF and TW laser system

PW laser system

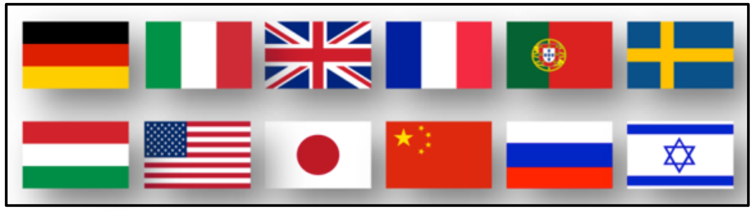
~ 30 m





Plasma accelerator and user lines are on 1st level

RF and laser infrastructure are on 2nd level



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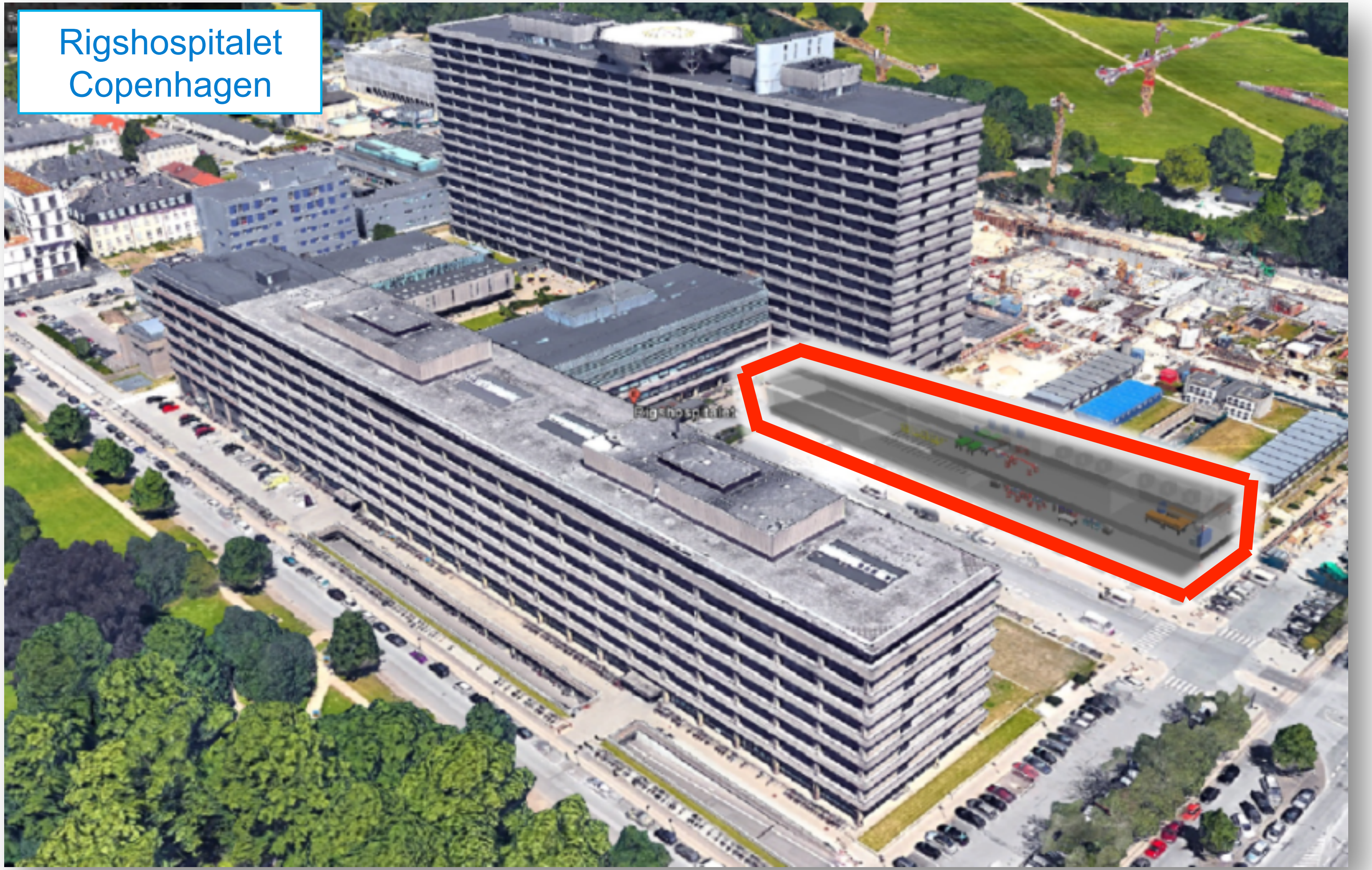
EuPRAXIA

Fits on the Parking Lot of the Hospital Copenhagen



Illustrative example prepared for IPAC17 talk in Copenhagen

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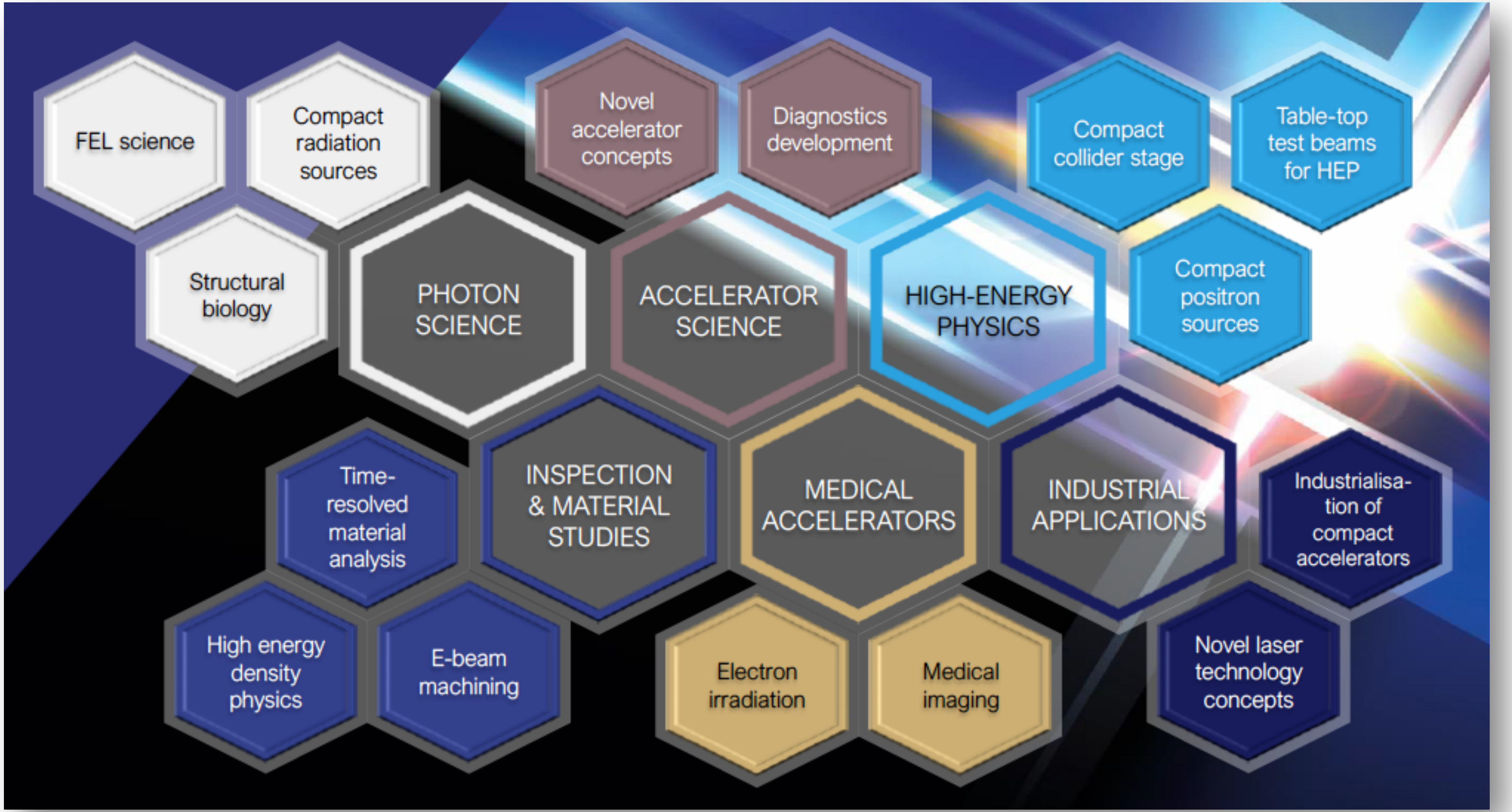
Versatile – Designed for Multiple Applications

High Energy – Accelerator R&D – Photon Science – Material – Medical – Industrial



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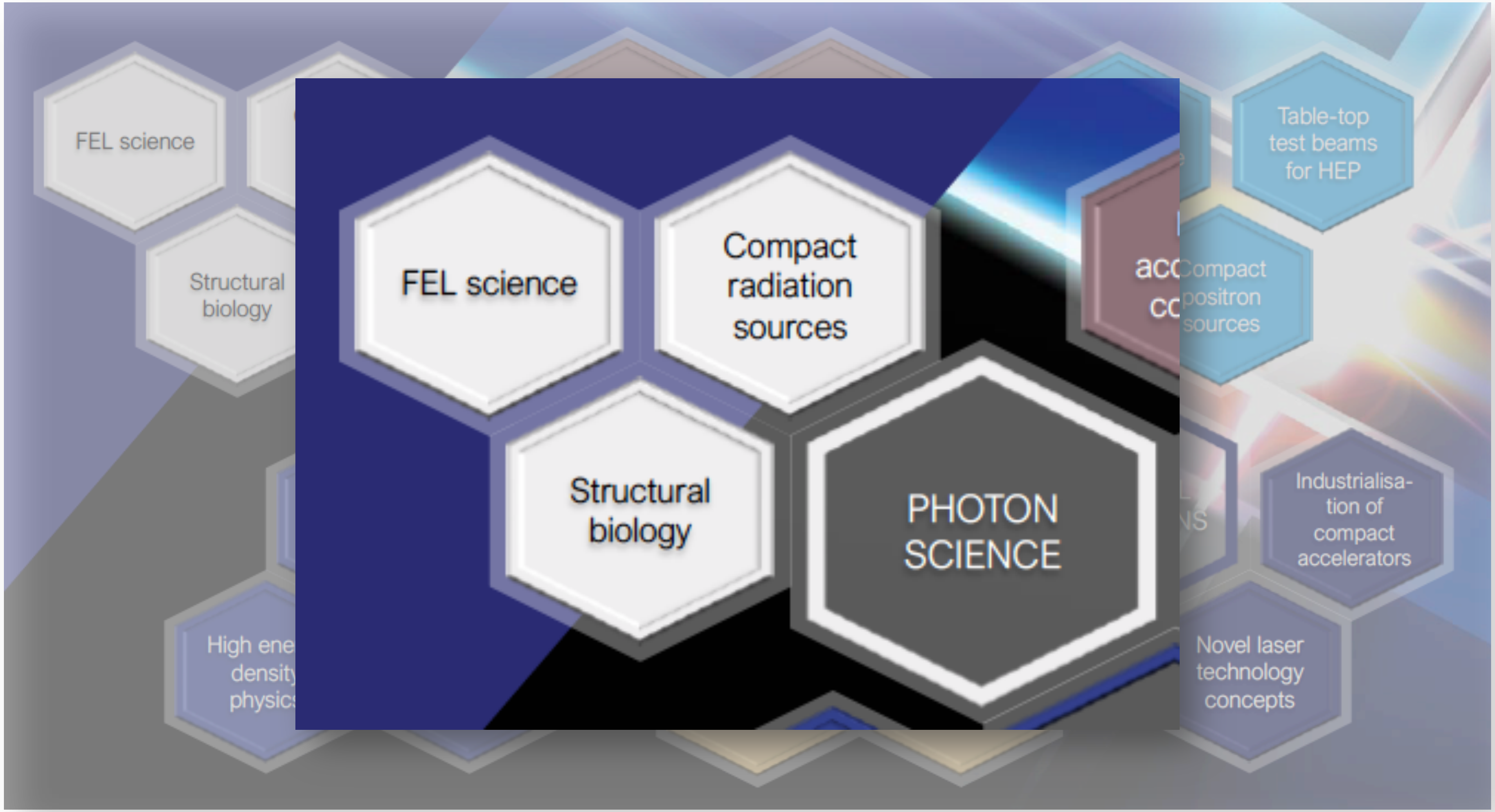

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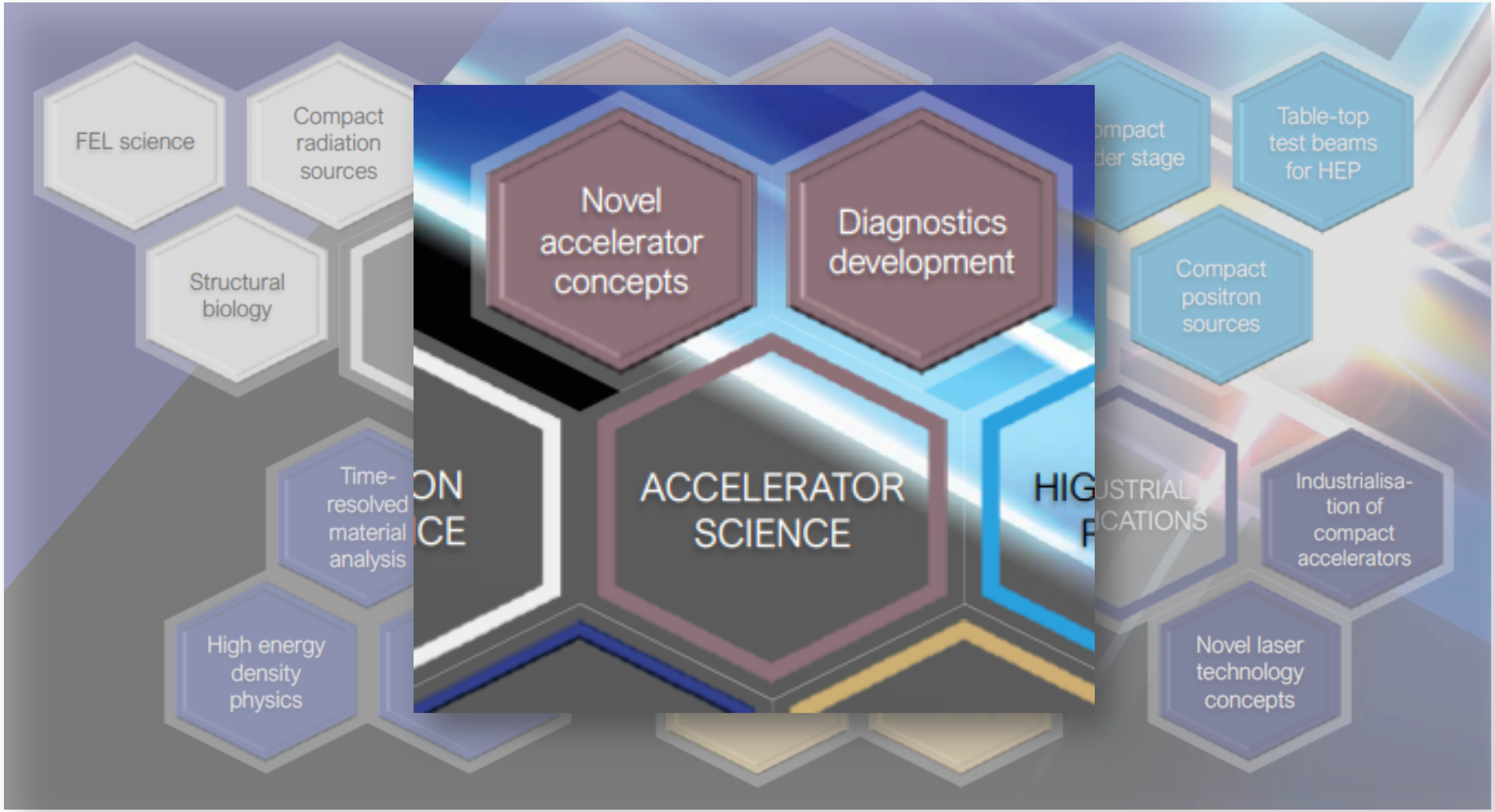

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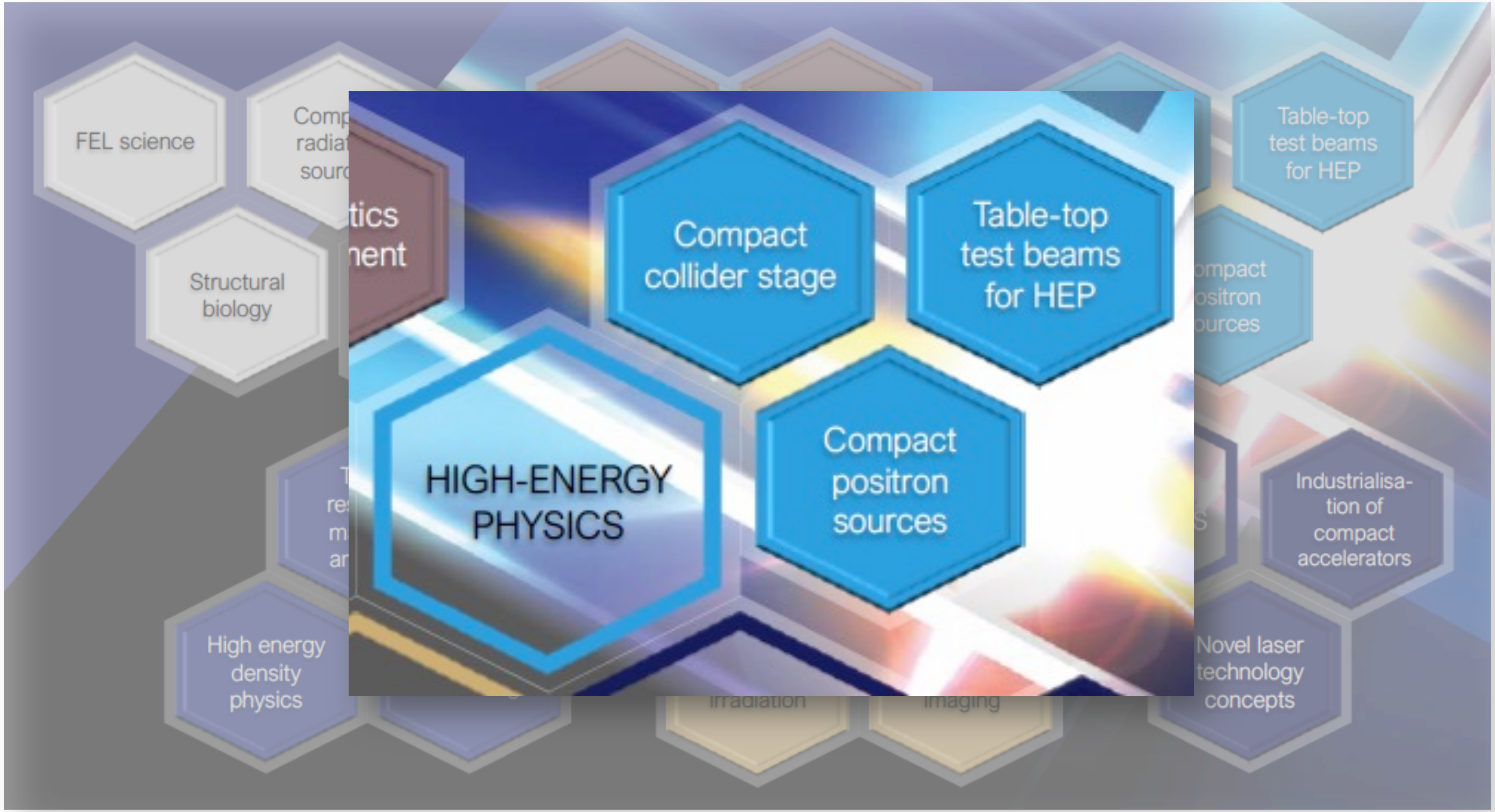

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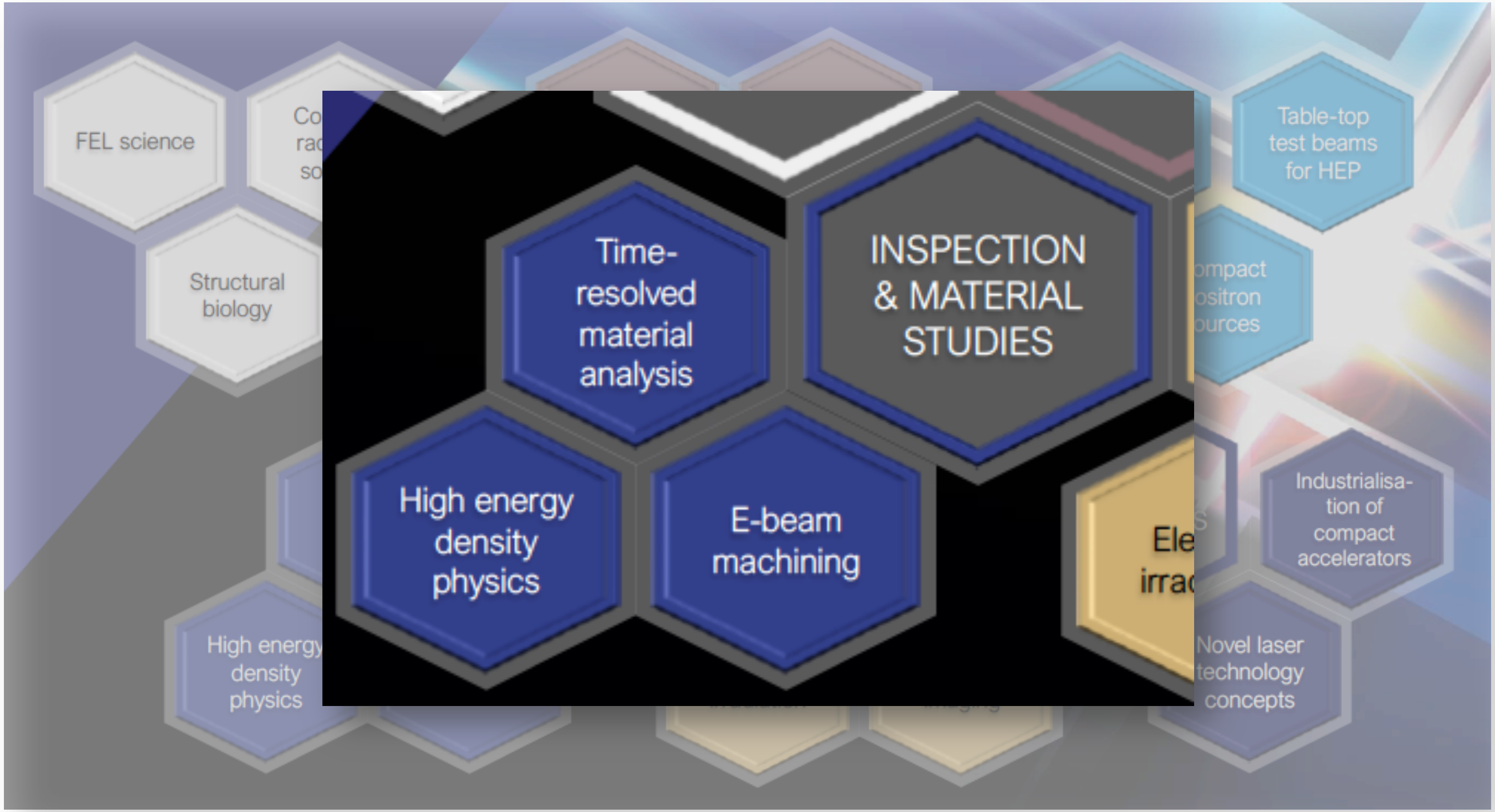

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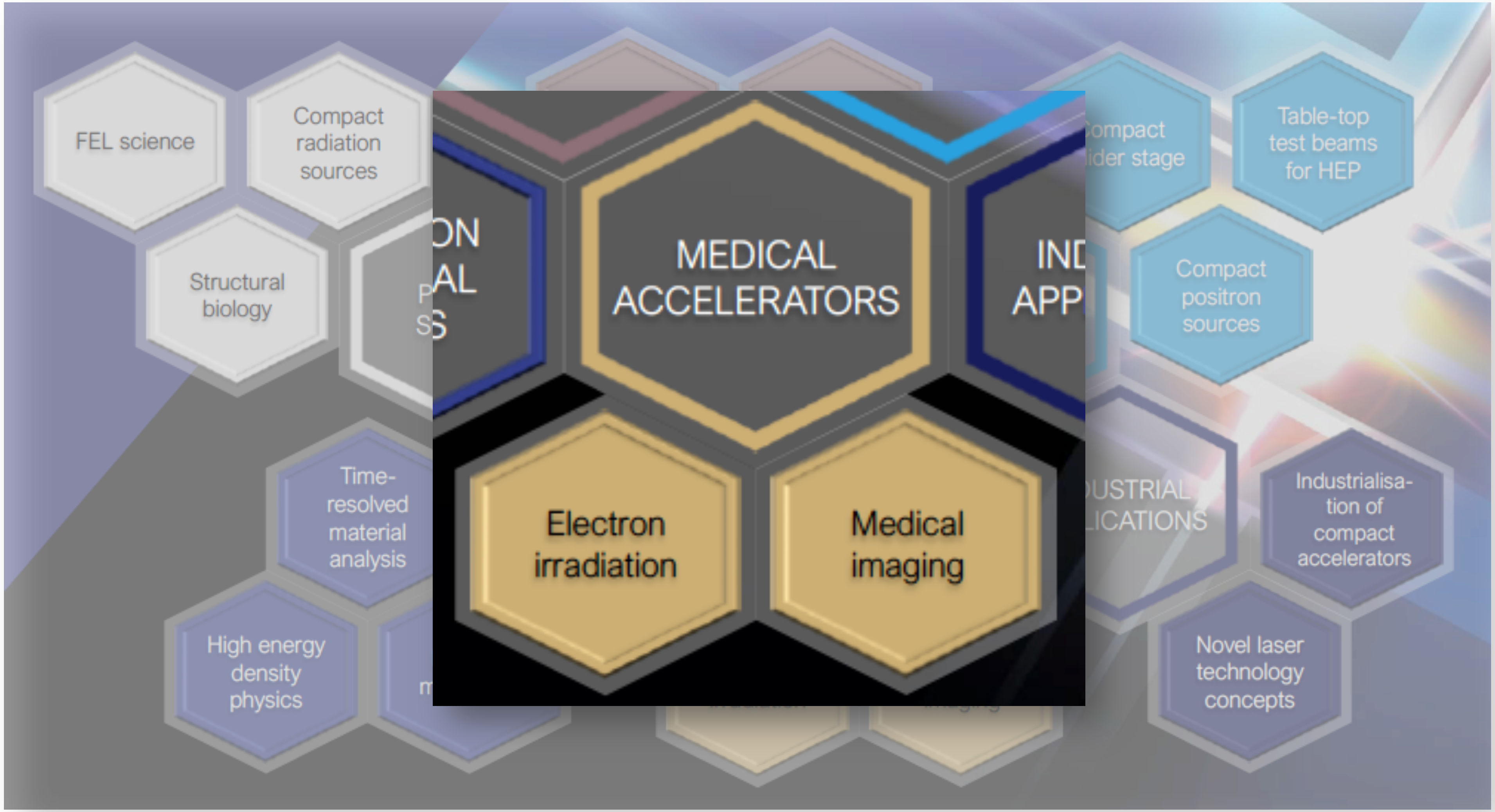

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Medical Imaging with Plasma Accelerators

Some Unique Advantages – Already Working Today – Too Slow at the Moment

2015 publication from J.M. Cole et al., John-Adams-Institute, UK: "Laser-wakefield accelerators as hard x-ray sources for 3D medical imaging of human bone". Nature Scientific Reports 5, 13244 (2015)

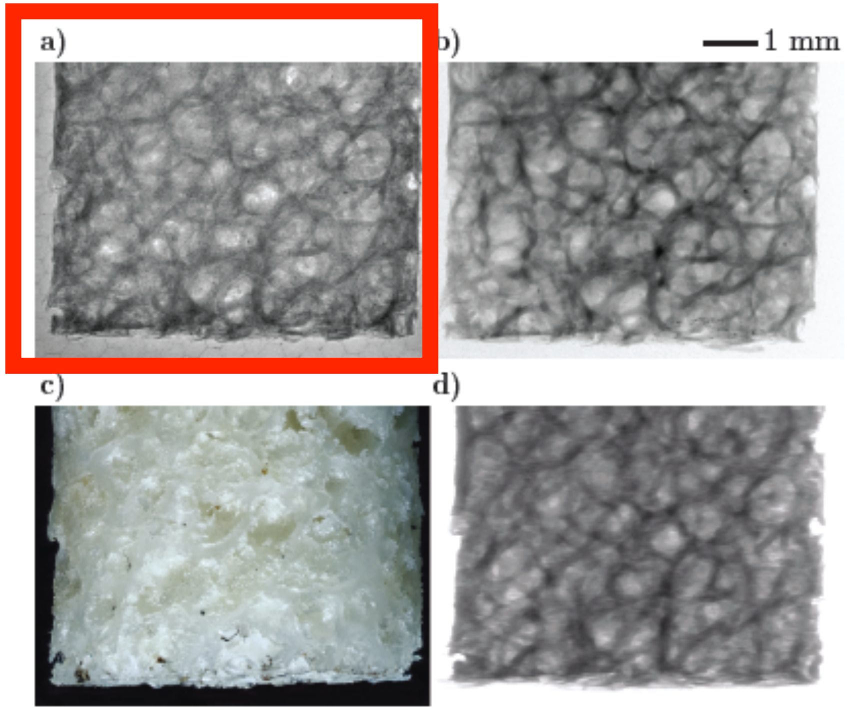
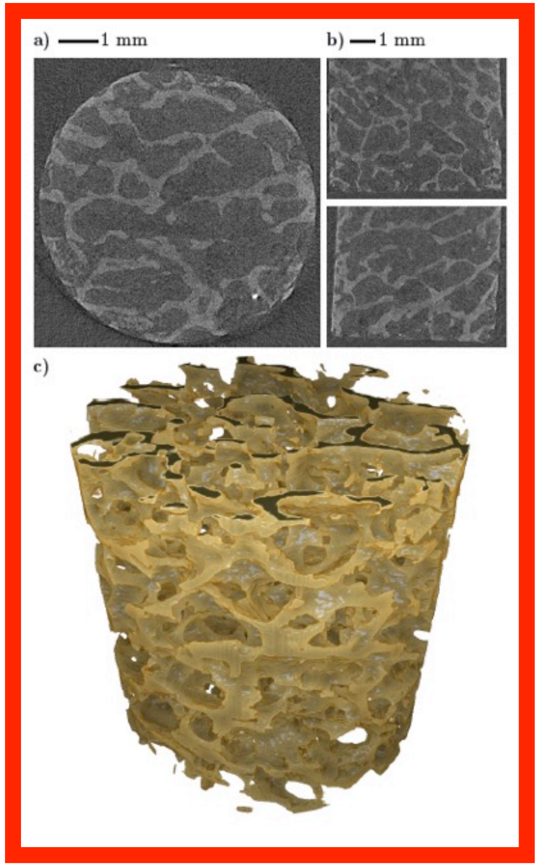
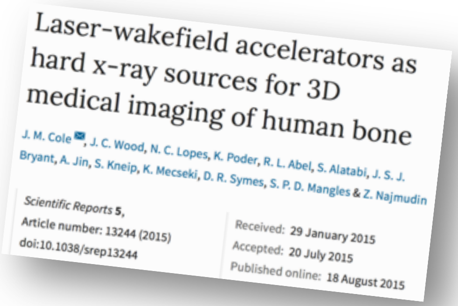


Figure 3. Images of the bone sample recorded with a) the betatron x-ray source b) conventional μCT scanning c) composite macro photography d) virtual illumination of the 3D reconstruction by a source of $E_{crit} = 33\,\mathrm{keV}$.




Laser-wakefield accelerators as hard x-ray sources for 3D medical imaging of human bone

J. M. Cole, J. C. Wood, N. C. Lopes, K. Poder, R. L. Abel, S. Alatabi, J. S. J. Bryant, A. Jin, S. Kneip, K. Mecseki, D. R. Symes, S. P. D. Mangles & Z. Najmudin

Scientific Reports 5, Article number: 13244 (2015) doi:10.1038/srep13244

Received: 29 January 2015 Accepted: 20 July 2015 Published online: 18 August 2015

Laser plasma based betatron X ray source

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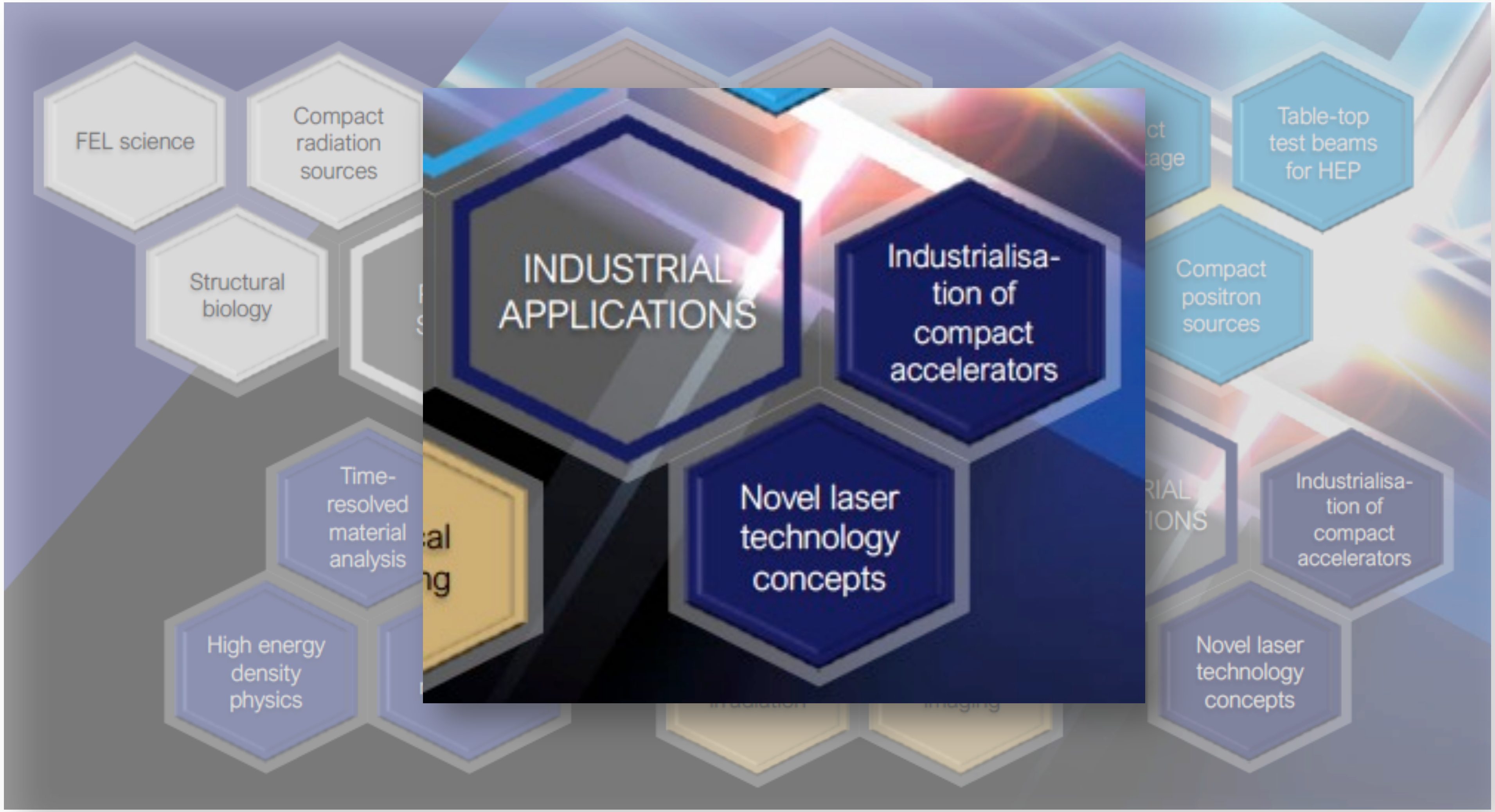
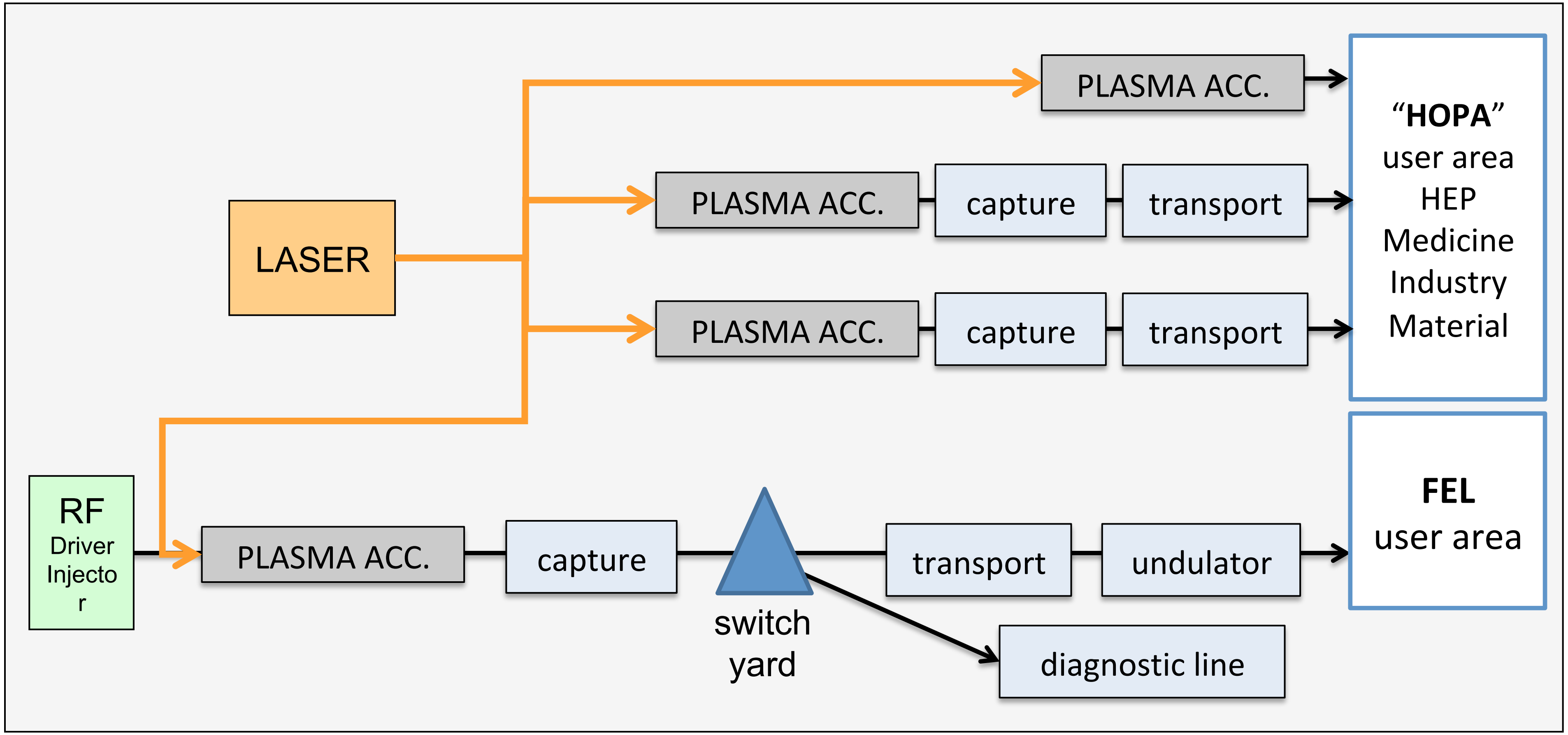
High Energy – Accelerator R&D – Photon Science – Material – Medical – Industrial



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Can the Facility REALLY Do ALL of This?

Another Advantage of Plasma Accelerators



Laser pulses distributed to "small" plasma accelerators to drive many applications!

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How and where to build it?

We must deliver what we promised to EU

- EuPRAXIA: proposal for **site independent conceptual design study** for a European Research Infrastructure that
  - (a) can produce **high quality electron beams** from plasma accelerators
  - (b) advance several **applications for pilot users**.
- **Deliverables** in CDR:
  - (a) Technical concept(s) and major components of EuPRAXIA facility
  - (b) Cost
  - (c) Schedule
  - (d) Concept of usage
  - (e) Governance model
  - (f) Site studies

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

How and where to build it?

Distributed construction of central infrastructure

- EuPRAXIA: **Build EuPRAXIA similar to a particle physics detector – many labs together build a central infrastructure**
- We need to collect interests and proposals. For example:
  - Who does prototyping, testing and building of EuPRAXIA laser(s)?
  - Who does prototyping, testing and building of RF injector/linac?
  - Who does prototyping, testing and building of plasma accelerator(s)?
  - Who does prototyping, testing and building of undulators?
  - Who does prototyping, testing and building of instrumentation?
  - Who does project management?
- **Can and should be consortia of labs, using their local expertise and infrastructure**! Budget follows from responsibility!

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How and where to build it?

Site wishes

- **Possible sites** for EuPRAXIA research infrastructure being pushed strongly and clear site studies:
  - **Frascati, Italy** (first few M€, aiming for 50 M€ Italian project)
  - **DESY, Germany** (electron site for ATHENA a 30M€ invest laser plasma project)
- **Other possible sites** which have been discussed:
  - **CILEX, France** (political support not yet clear)
  - **CLF, UK** (impact from BREXIT unclear)
  - **ELI** (laser infrastructure with important milestones ahead – happy to connect to EuPRAXIA without being the EuPRAXIA site)
  - ... (?)
- In this situation, have been thinking about best way forward...

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How and where to build it?

Working and building together

- Consortia address the relevant topics in design, construction and commissioning. Budget defined by responsibility...

Laser
Pisa, CNRS, CLF, ELI, FBI, ...

RF Tech
DESY, INFN, CERN, Daresbury, ...

FEL
SOLEIL, Roma, DESY, Daresbury, ...

Applica-tions
Oxford, CNRS, UB, Strathclyde, ...

Plasma
U. Paris, DESY, Oxford, ...

Theory/ Sim
CEA, IST, DESY, INFN, HZDR, ...

Instrumen-tation
INFN, KIT, SOLEIL, DESY, ...

xxx
...

Not complete, just examples...

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Construct as a Collaboration

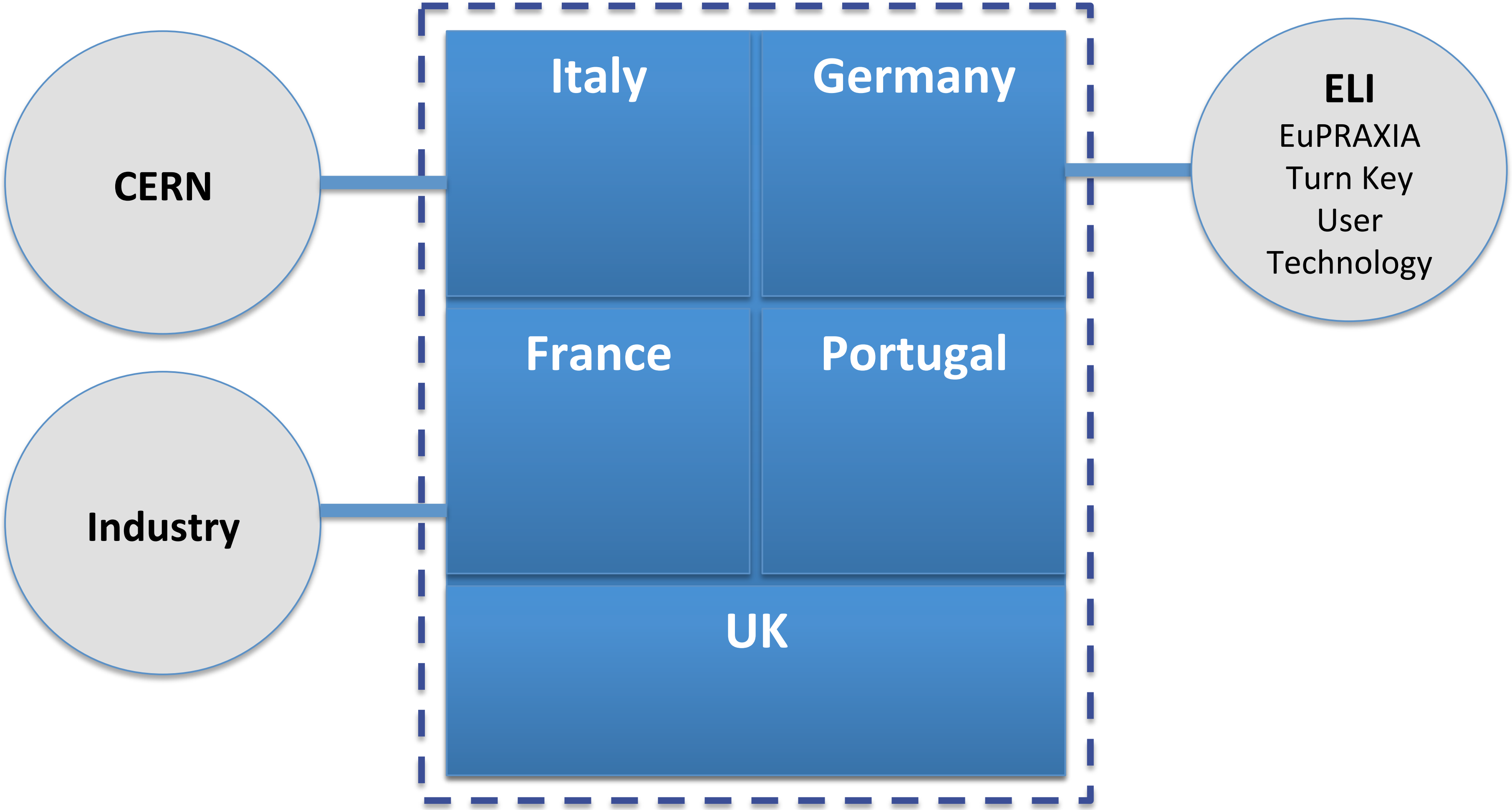
EuPRAXIA aiming at HEP Collaboration Model

- We will also need to define a governance model of EuPRAXIA
- Proposal: **Model after high energy physics collaborations for constructing a big detector**.
- Have one of the agreements as model. For example:
  - Collaboration board as top executive body.
  - Agreements on part deliveries, responsibilities.
  - Publication policy.
  - Spokesperson elected.
  - ...
- Comments and suggestions welcome. Volunteers to help are welcome.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

EuPRAXIA Concept: Alternative Site View?

Countries get their shares



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EuPRAXIA Concept: Alternative Site View?

Countries get their shares

CERN
X Band RF Technology (Compact Driver)

Industry
European laser and accelerator Industry

Italy
EuPRAXIA Site for beam-driven plasma acc.

Germany
EuPRAXIA Site for laser-driven plasma acc.

France
EuPRAXIA Center for Technology

Portugal
EuPRAXIA Center for Theory & Plasma Simulation

UK
EuPRAXIA Center for Industrial Applications

ELI
EuPRAXIA Turn Key User Technology

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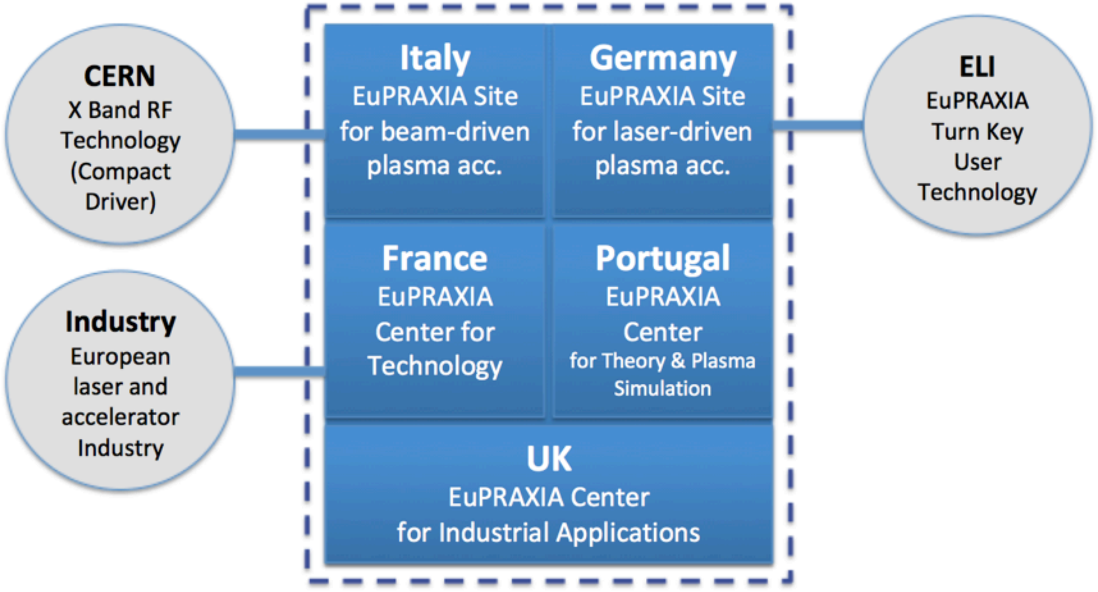
How and where to build it?

Project considerations

- Reflects ambitions known to us but integrates all into a common project.
- **Two sites reflect two driver technologies** – minimal duplications due to common project work!
- **Use of existing sites** use pre-invest and make sure OP costs are covered.
- Very visible roles to France, Portugal and UK without the need to propose a site.
- Connects to European industry, ELI and CERN.



- Simplifies discussion of radiation protection, safety, ...: labs take care of it through existing structures.
- Easy to explain to people not interested in technical details.

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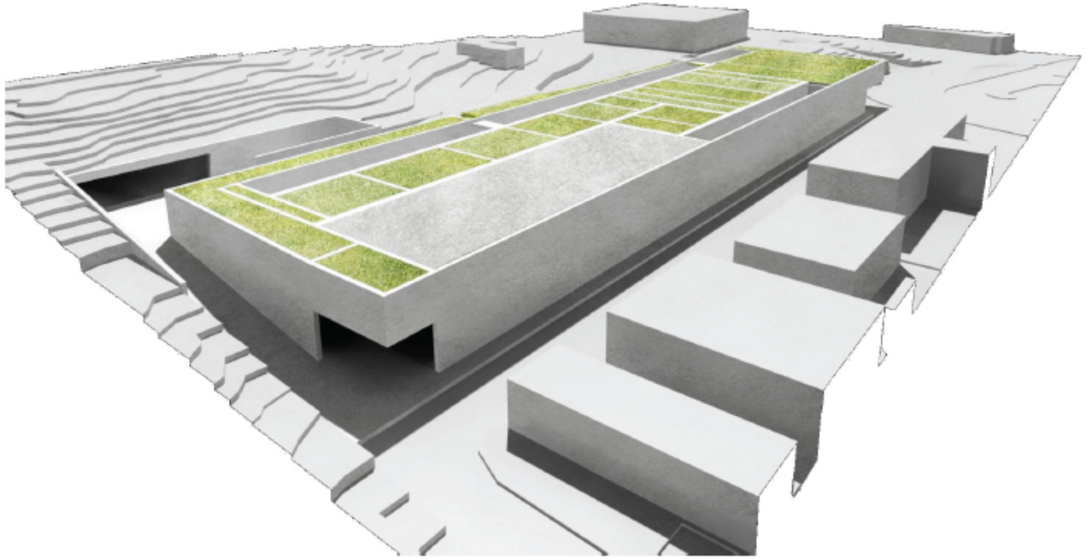
EuPRAXIA at SPARClab in Frascati




INFN
Istituto Nazionale di Fisica Nucleare

CDR-1, April 2018

EuPRAXIA@SPARC_LAB

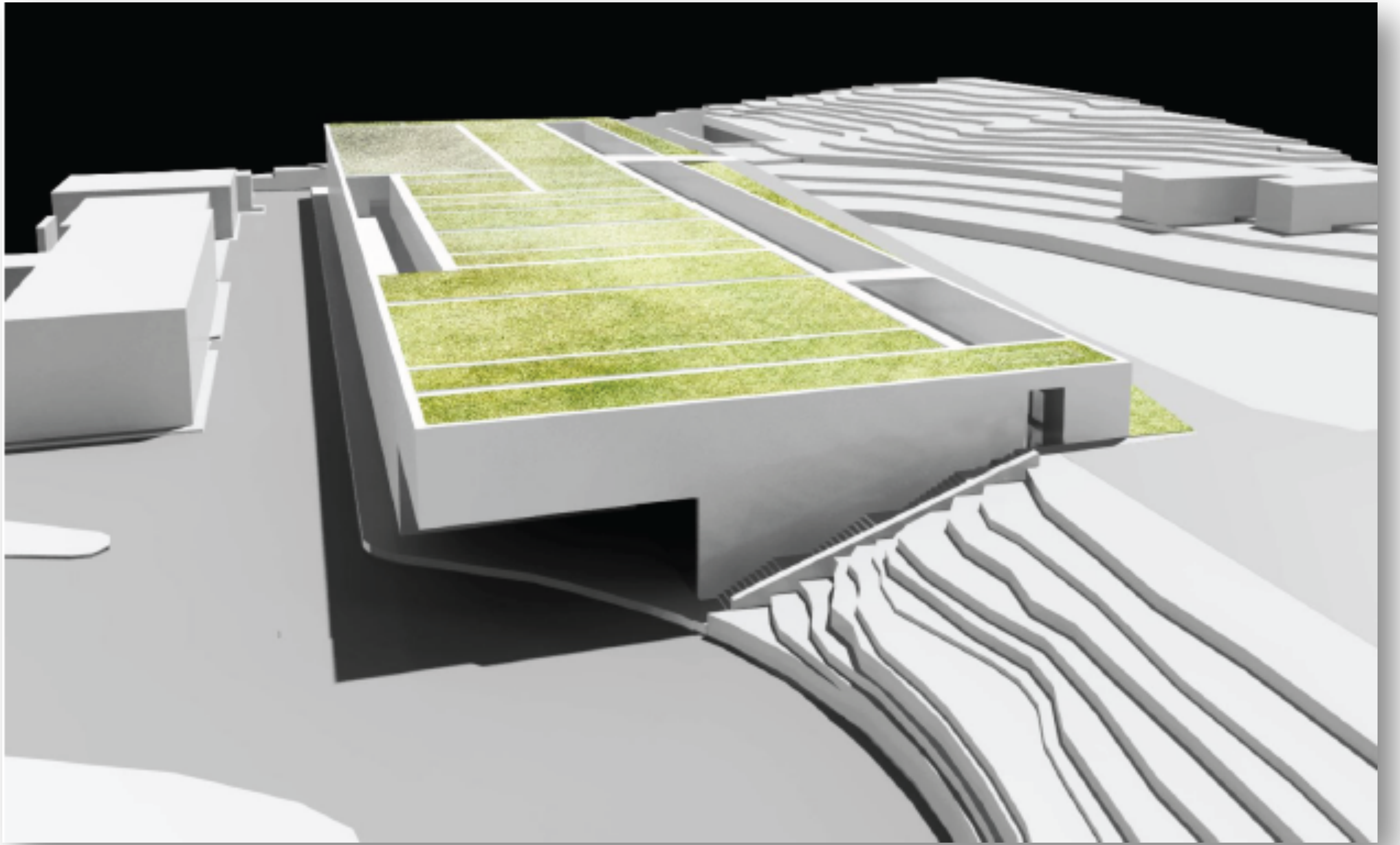
Conceptual Design Report

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Layout of EuPRAXIA@SPARC_LAB at LNF

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Impression of EuPRAXIA@SPARC_LAB at LNF



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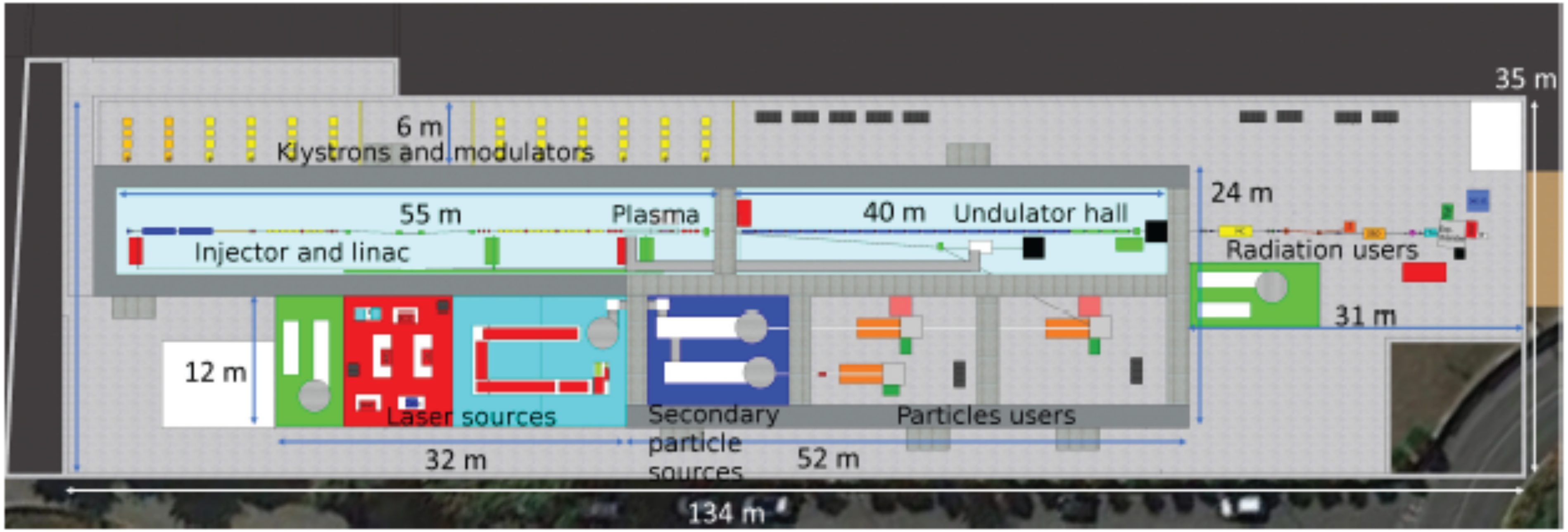
Top View of EuPRAXIA@SPARC_LAB at LNF

RF beam driver in X band with CERN



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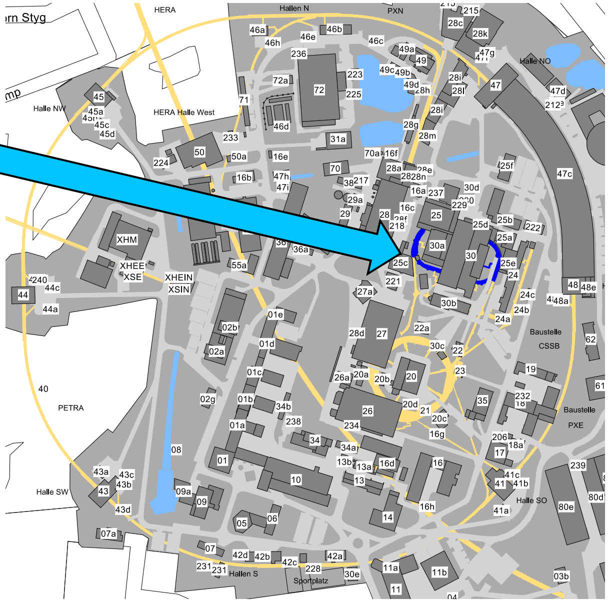
Hamburg Infrastructure – SINBAD

Under construction – will house laser-driven novel accelerators at DESY → ATHENA$_e$ project at DESY

SINBAD

Ex-DORIS



Helmholtz Support for Compact Accelerators (Germany)

In this context this does not include muon collider R&D but is focused on plasma accelerators

HELMHOLTZ
GEMEINSCHAFT

Stand: 26. September 2016

AGENDA des Präsidenten der Helmholtz-Gemeinschaft

Zu den inhaltlichen Herausforderungen zählen aus heutiger Sicht:

From today's perspective the following challenges are identified

- Energiesysteme der Zukunft — ***energy systems***
- Information und Data Science — ***information and data science***
- Integrierte Erforschung des Erdsystems — ***research earth system***
- Neuartige Materialien und Wirkstoffe — ***new materials and agents***
- Entwicklung neuer Mobilitätskonzepte — ***new mobility concepts***
- Psychische Erkrankungen und Translation für eine individualisierte Medizin — ***psych. disease indiv. medicine***
- Neue Generationen von kompakten Beschleunigersystemen. — ***New generations of compact accelerators.***

In den nächsten Jahren werden wir diese und andere Themen auf vielfältige Weise unterstützen.

Support programs:

Accelerator R&D
ARD research topic in Matter&Technology (MT)

Independent **research activity**: same hierarchical level as HEP and photon science

IuVF funding
"Plasma Accelerator"

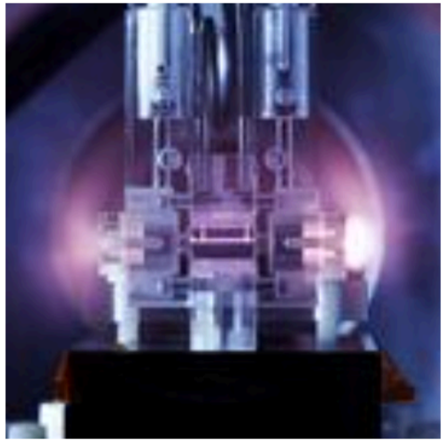
Strategic investment
30M€ ATHENA soon? (same funding pot as Helmholtz LHC detector lab)


DESY.
ACCELERATORS | PHOTON SCIENCE | PARTICLE PHYSICS
Deutsches Elektronen-Synchrotron
A Research Centre of the Helmholtz Association
Google™ Custom Search
DESY HOME | RESEARCH | NEWS | ABOUT DESY | CAREER | CONTACT
INFOS & SERVICES
» PRESS
» WORKING AT DESY
» JOB OFFERS
» OFFERS FOR PUPILS
» SERVICES FOR INDUSTRY
» DESY USER
» ACCELERATORS
» PHOTON SCIENCE
» PARTICLE PHYSICS
PROJECT FUTURE.
ATHENA platform develops novel particle accelerators
1 2 3 4

Accelerator R&D Program of Helmholtz Association I

Accelerator science as independent research

Latest press releases



18/06/14 · Press-Release

Helmholtz Association supports ATHENA with 29.99m euro grant

ATHENA ("Accelerator Technology HElmholtz iNfrAstructure") is a new research and development platform focusing on accelerator technologies and drawing on the resources of all six Helmholtz accelerator...

The work on ATHENA is closely embedded in the wider context of European research through the EU-sponsored design study EuPRAXIA, with its 40 partner institutes, which is also coordinated by DESY. Hence the top German research project ATHENA has had a clear European perspective and orientation right from the start.

- Latest news: ATHENA project approved for 29.99 M€ investment.
- Funded by Helmholtz strategic funding and BMBF "Pakt für Forschung"

ATHENA Helmholtz Project

(final approval June 12)

Accelerator Technology HElmholtz iNfrAstructure

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES · DESY. · HZDR · HZB Helmholtz Zentrum Berlin · JÜLICH FORSCHUNGSZENTRUM · KIT Karlsruhe Institute of Technology · GSI · HI Jena Helmholtz Institute Jena

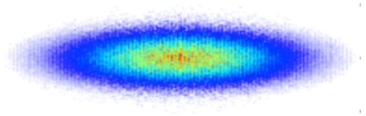
30 M€ Strategic Investment into ARD Infrastructure for Helmholtz Development of Laser-Driven Plasma Accelerators – funded by Helmholtz and BMBF (Pakt für Forschung)

1 **50 GV/m electron accelerator with usable beam quality**
Flagship at DESY, build infrastructure for developing 1 GeV pilot FEL, < 100 MeV injector, medical imaging applications

2 **Compact p/ion accelerator towards higher average flux**
Flagship at HZDR, build infrastructure for developing applications in medical, plasma and material areas

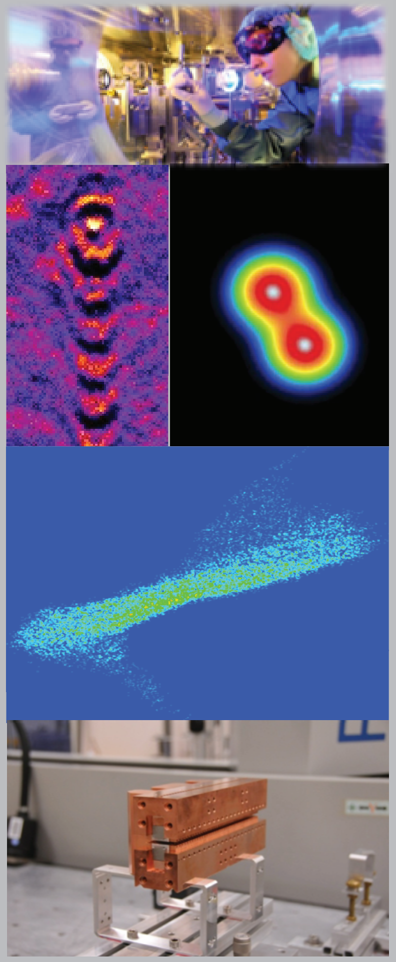
Two common flagship projects

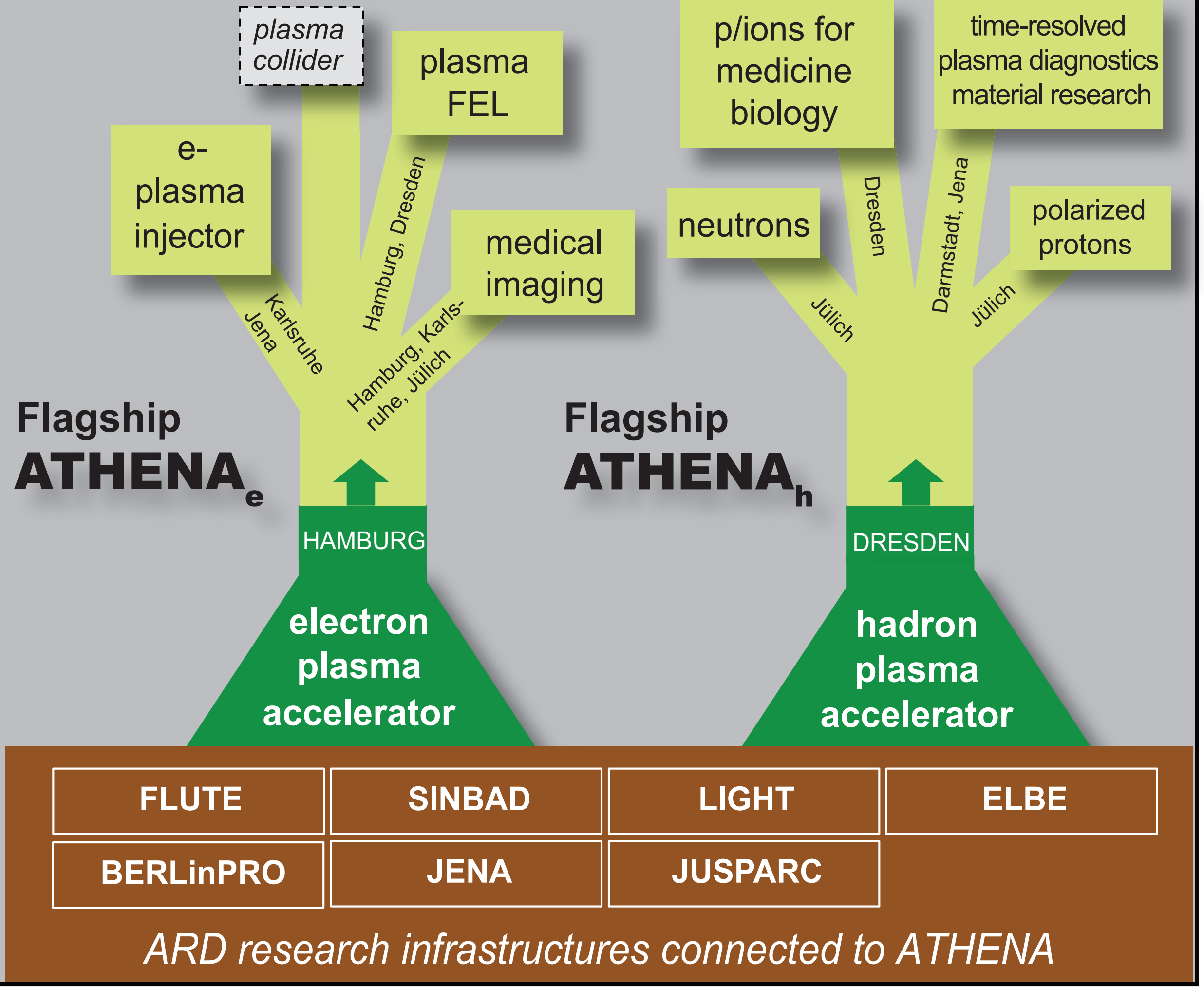
→ R&D infrastructure in and applications for all centers

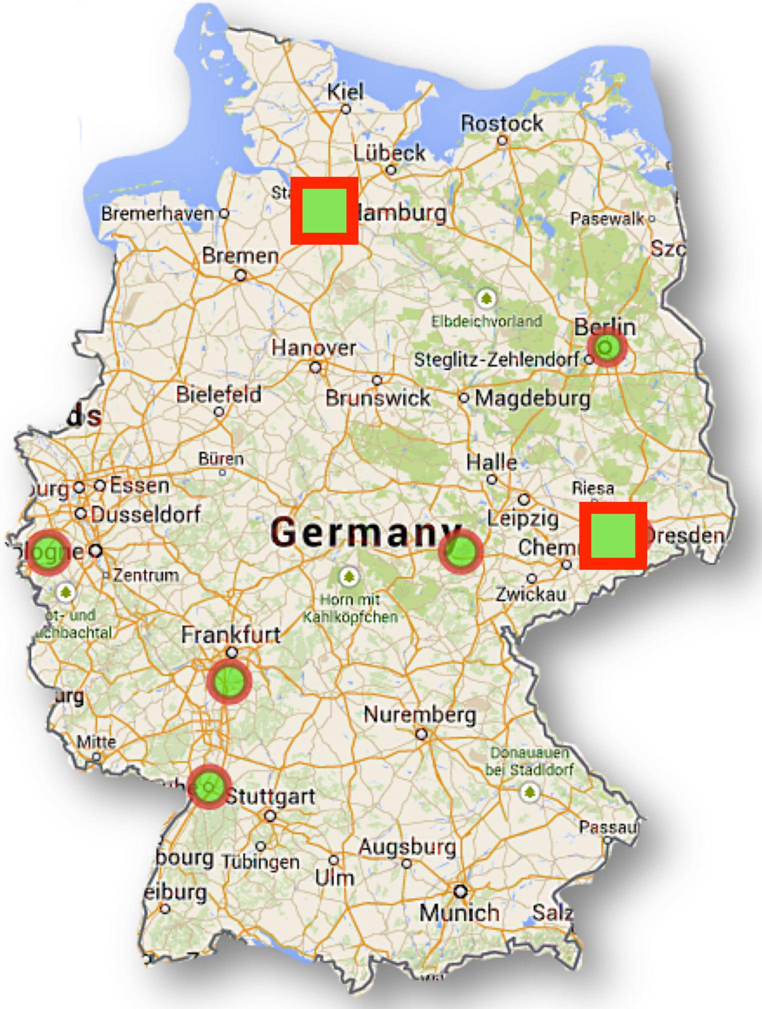


ATHENA: Advancing Laser Plasma Accelerators

The Helmholtz accelerator centers collaborating on developing new technology towards user readiness

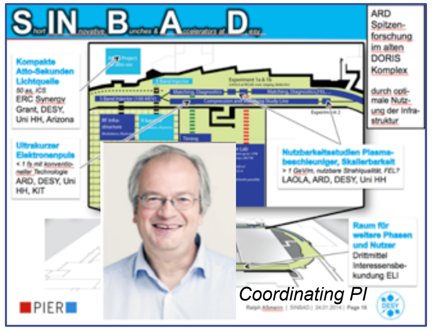


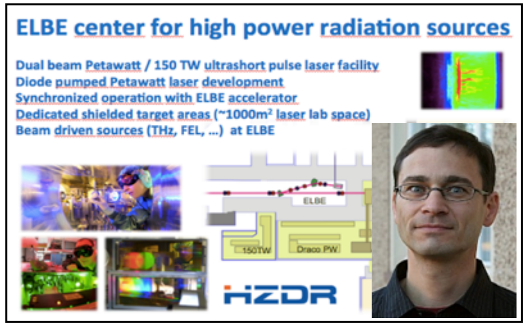


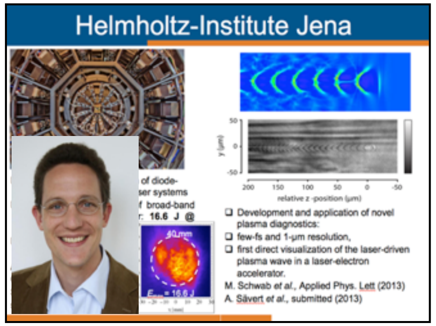


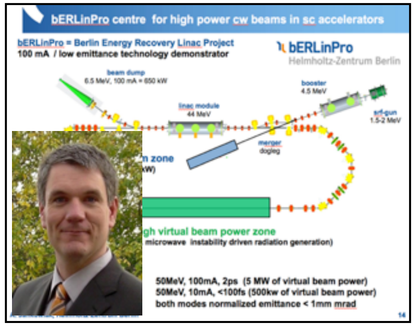
PI’s and Timeline

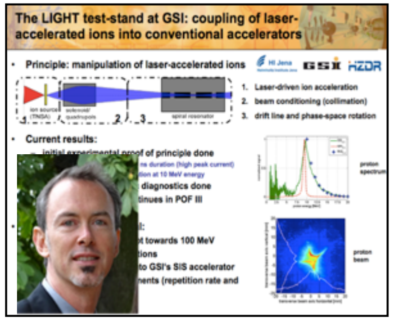
Plus local universities as key partners and University Strathclyde in UK











ATHENA Project Timeline

2015 Project proposal

2018 Project start

2021 Project completion

2022 Start of operation

Press and Public Understand the Huge Potential

Examples from Germany


DIE WELT

SAMSTAG, 28. MÄRZ 2015

Bremse für Superbeschleuniger

Größer, schneller, teurer geht's nicht mehr. Bis zu sechs Milliarden Dollar kosten die Teilchenschleudern in Genf oder anderswo. Materieforscher müssen sich etwas einfallen lassen

“Bigger, faster, more expensive: no way!”


DER SPIEGEL

DER SPIEGEL 11/2015

Im Bann von Waxahachie

Physik Forscher bauen immer gewaltigere Teilchenbeschleuniger, um die Geheimnisse des Universums zu enträtseln. Geht es auch eine Nummer kleiner?

Unter den Feldern von Texas erstreckt sich ein verlassener Tunnel, knapp 23 Kilometer lang. Die Zugänge sind verschüttet, in der Röhre sammelt sich Wasser.

Die Ruine nahe dem Städtchen Waxahachie steht für das Trauma der Teilchenphysik: Hier baute die stolze Zunft einst

“Can we have smaller machines?”

“Yes, we can!”


Hamburger Abendblatt

WISSEN

Der Mini-Teilchenbeschleuniger

“The tiny particle accelerator”

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 653782.

Conclusions

Europe developing new high tech and compact accelerators

- The **long-term future is bright**: there will be plenty of opportunities as technology advances!
- **EuPRAXIA Goals on 10-15 year time-scale:**
  - Demonstrate the generation of plasma-wakefield accelerated multi-GeV-scale electron beams with stability and quality sufficient for first pilot user experiments
  - Contribute to the conception of new European accelerator facility
- A long-term future with novel accelerators does not come by itself: **We must be serious and need support.**
- Your advise and help is very welcome...

Plasma Comic

By Zach Weiner

Thank you for your attention..

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