Scientific Synergies and Opportunities

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FIAS Frankfurt Institute for Advanced Studies

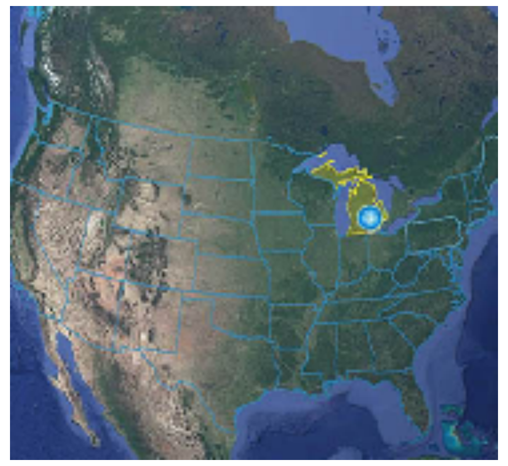
EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

Second Annual Meeting of Euro-Labs, 9.-11.10.2023

Euro-Labs Network

- Embracing
  - Nuclear Physics
  - Accelerators for HEP
  - Detectors for HEP
- Network of 33 research and academic institutions from 18 countries
  - 25 beneficiaries and
  - 8 associated partners
- 47 Research Infrastructures

includes associated partners in Japan and US



Participating Institutes

Beneficiaries

European Accelerator based science

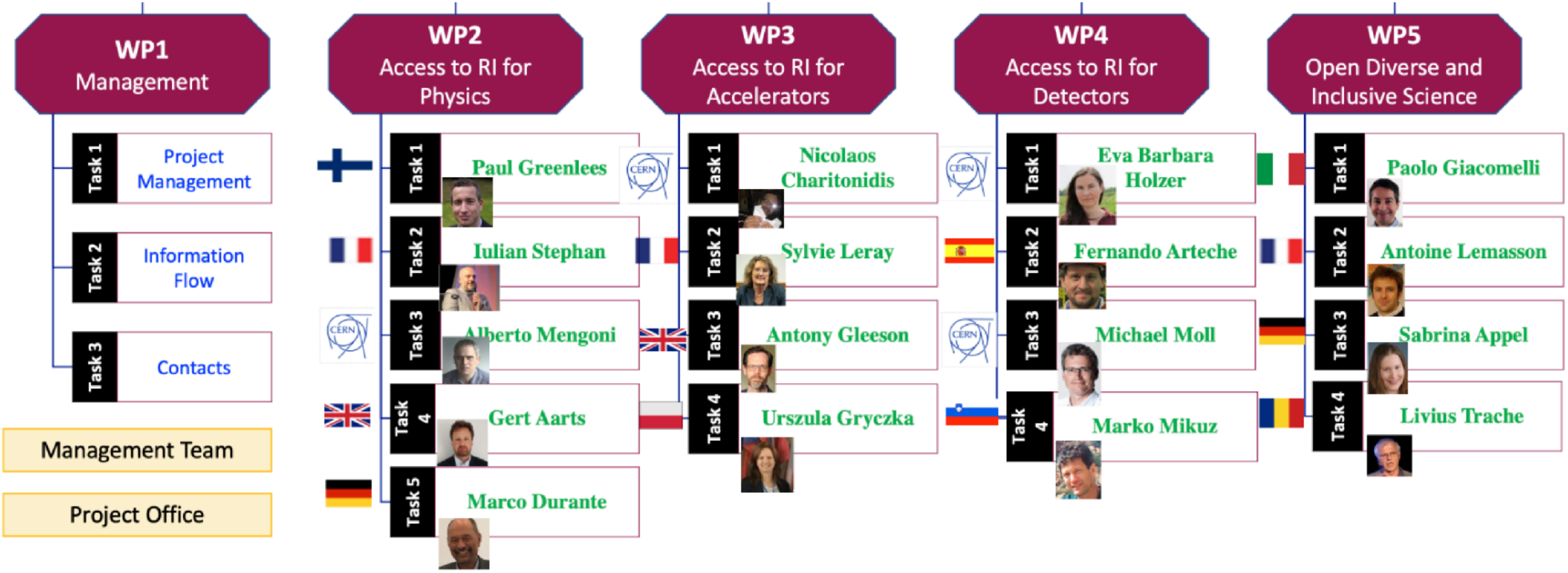
Associated Partners

Transnational Access

The European Who is Who in Particle and Nuclear Physics

Organisation

Organigramme



Why a network?

- RI centres often are requested to operate with high availability for users
  - Superb engineering and scientific expertise required and available
  - No resources and time to advance innovative ideas – that are in conflict with the continuous operation of the infrastructure
- Universities offer the ideas and talents for fresh approaches. They need access to the RIs – hence, the need for networks

Compare to shareholder companies who have outsourced their innovation to start-ups

What is the need?

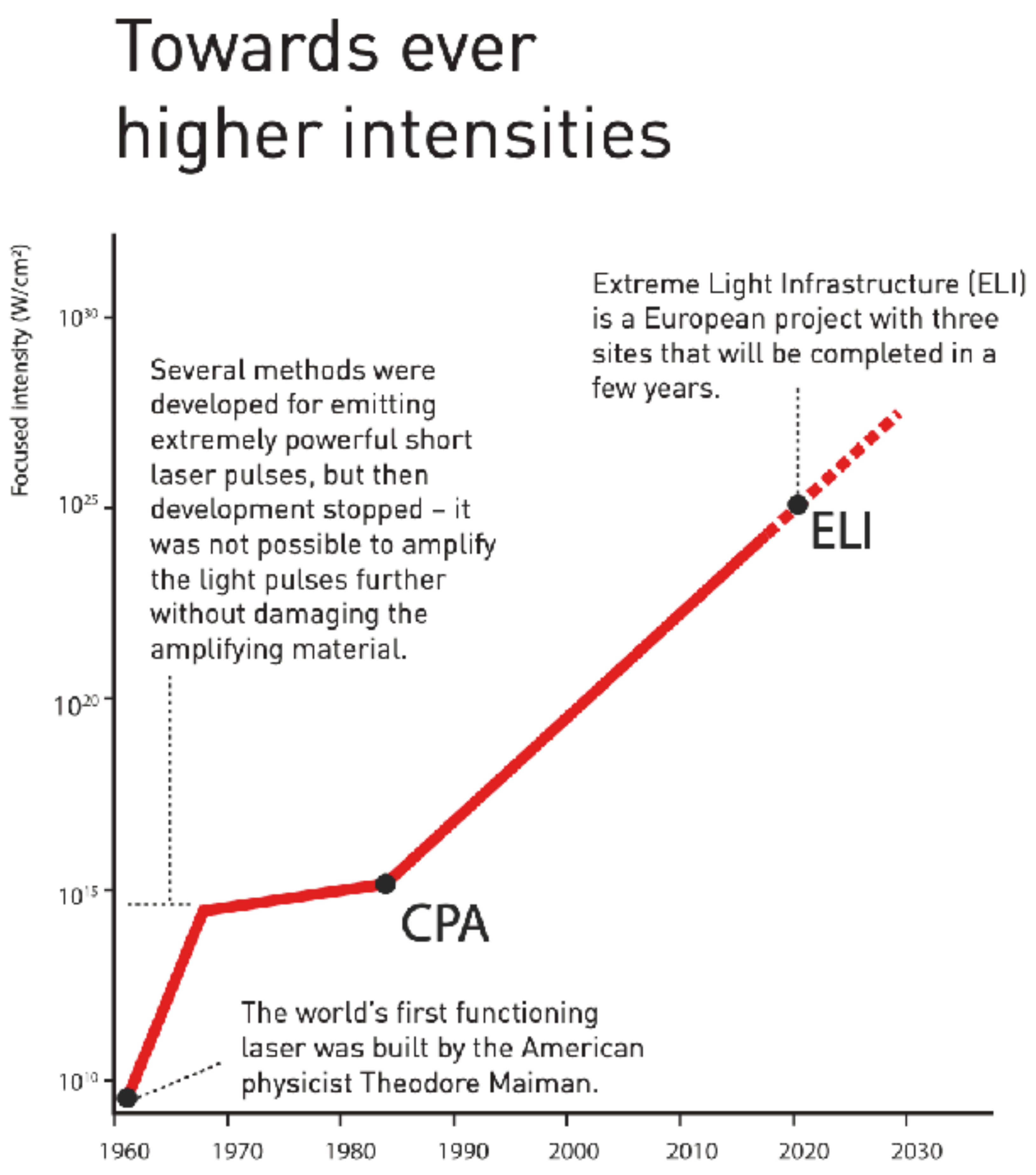
- European Particle Physics Strategy Update (EPPSU) 2020 instigated…
  - ECFA Detector R&D Roadmap
    - Comprehensive list of detector and sensor needs for particle and nuclear physics
      - led to DRDC groups that are under scrutiny of CERN committees
  - LDG Accelerator R&D Roadmap
    - Compilation of ongoing activities in the laboratories

Lasers

Laser Properties

- coherence
- Power
- wavelength
- duration

Powerful tool to manipulate charged particles



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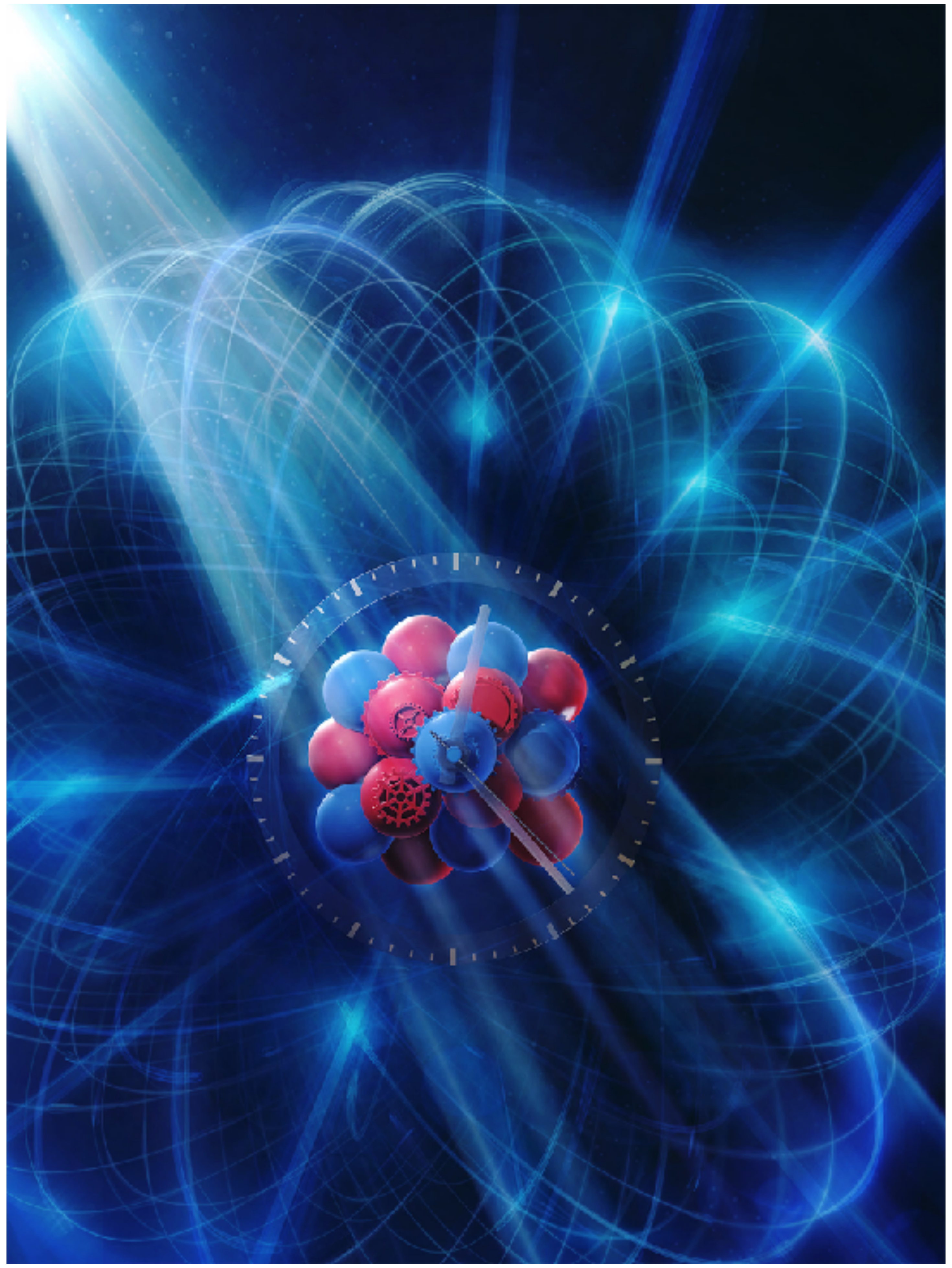
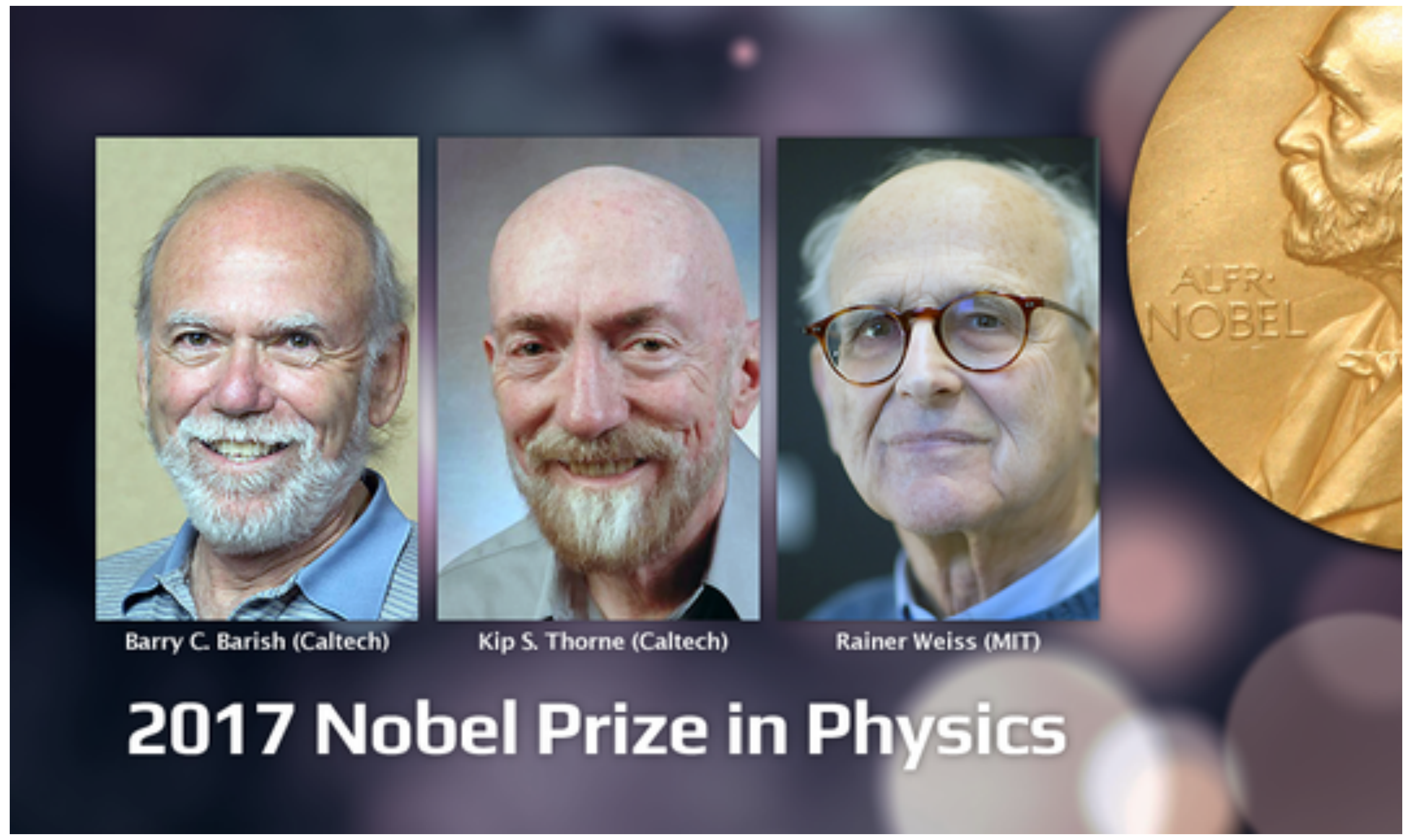
Laser Metrology

- Nuclear clock
  - Sc excited by 12.4 keV xray
  - Width 1.4 feV,
    - precision of 10^{-19}



GW Detectors

- Laser Interferometers
  - powerful lasers
  - longterm stability
  - continuous operation



LIGO Livingston

Squeezed light and squeezed vacuum

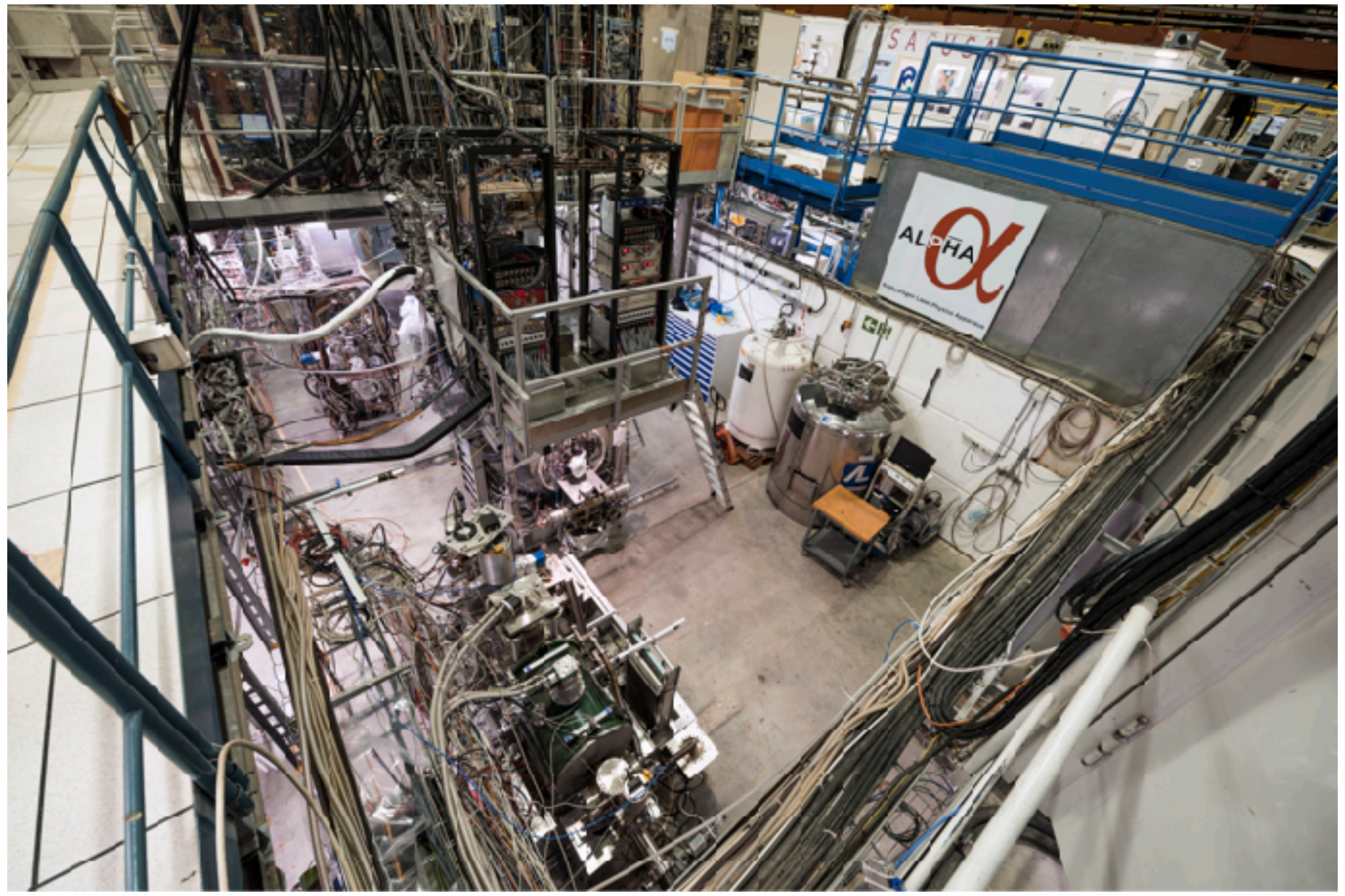
Rendering of future LIGO installation in Maharastra

Laser cooling – of anti-hydrogen

- Laser cooling exploits (anti-)atoms excitations in a slightly de-tuned laser beam

  - resulting inhomogeneous recoil, hence cooling

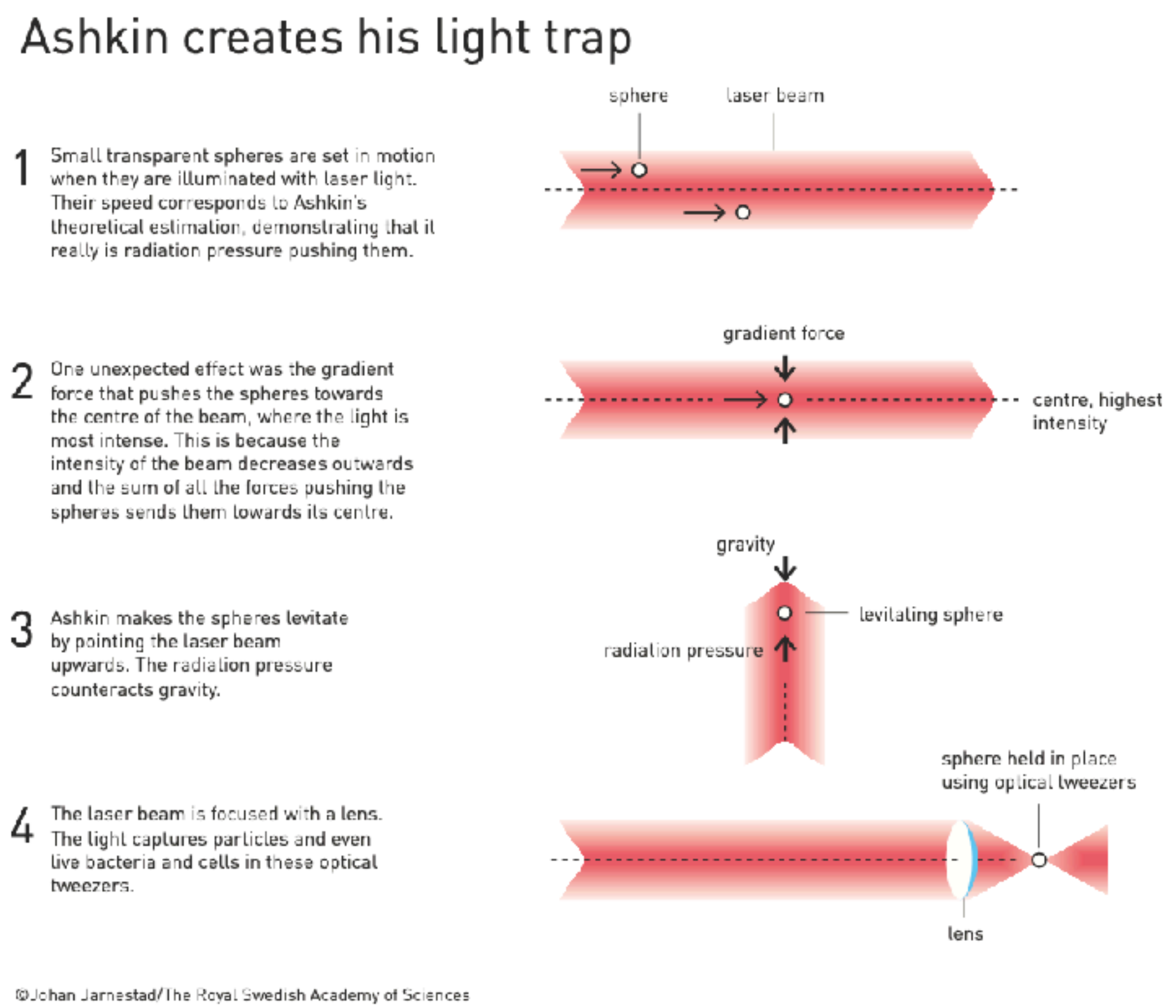
Free-Fall experiments

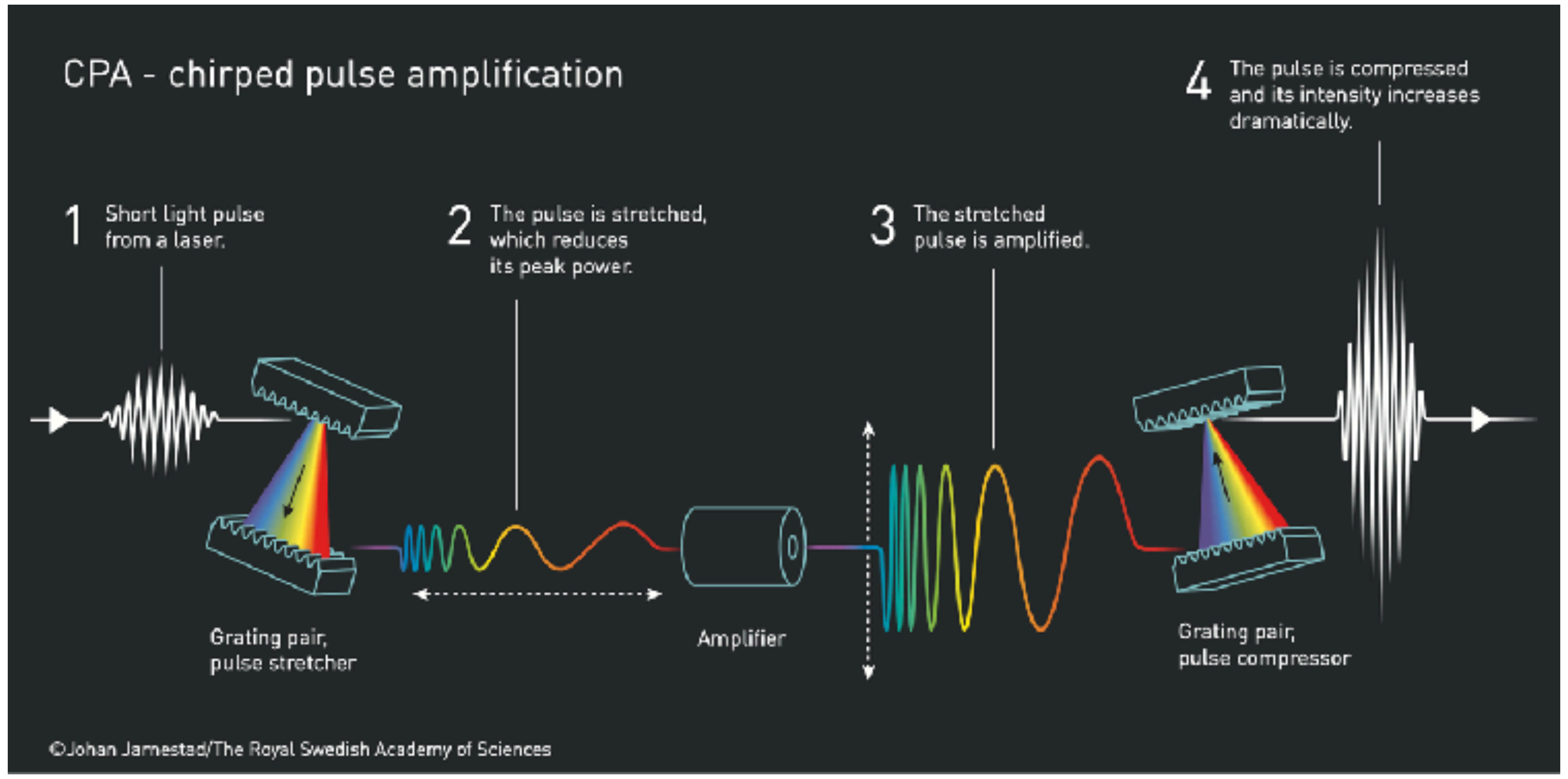


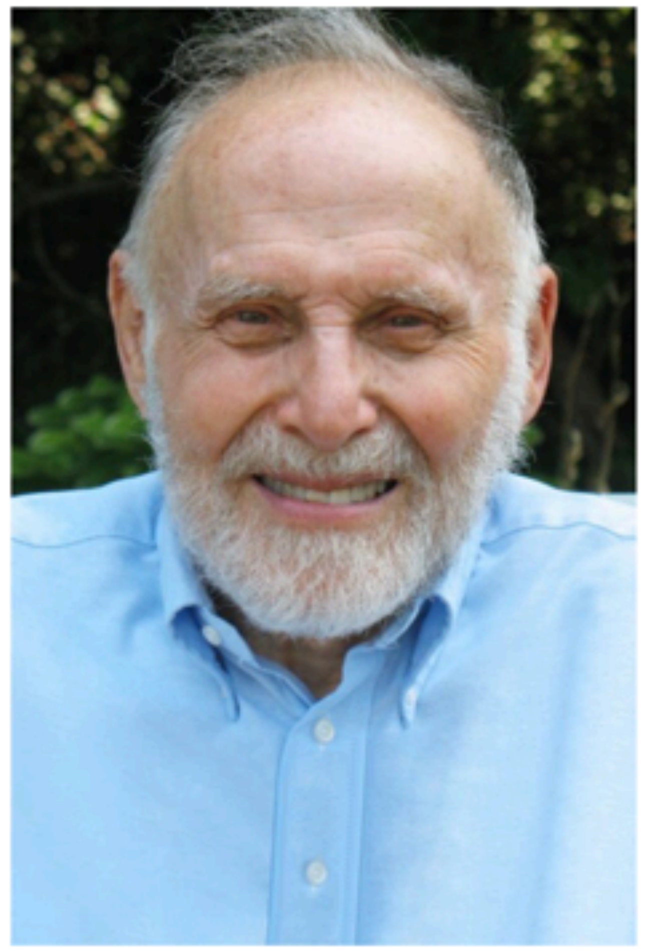
ALPHA-g

…Generating high-intensity, ultra-short optical pulses

- Optical tweezer and chirped light amplification







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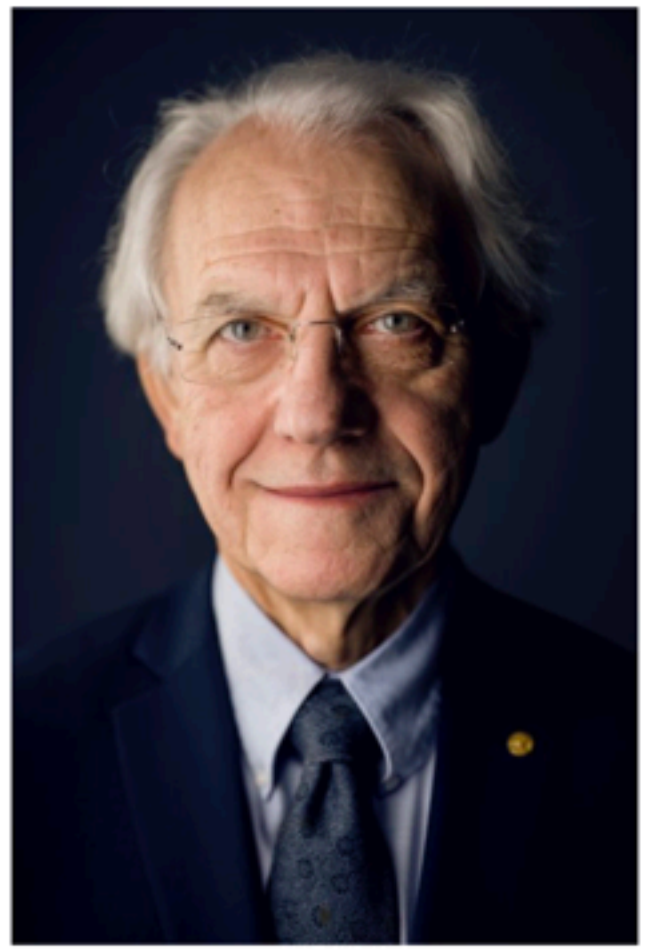

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Gérard Mourou

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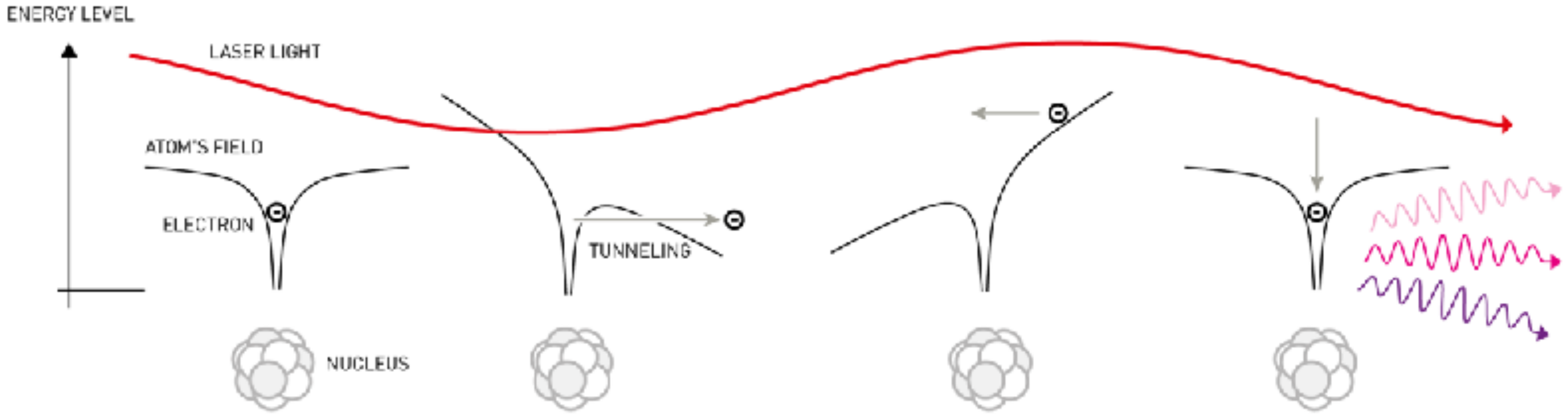
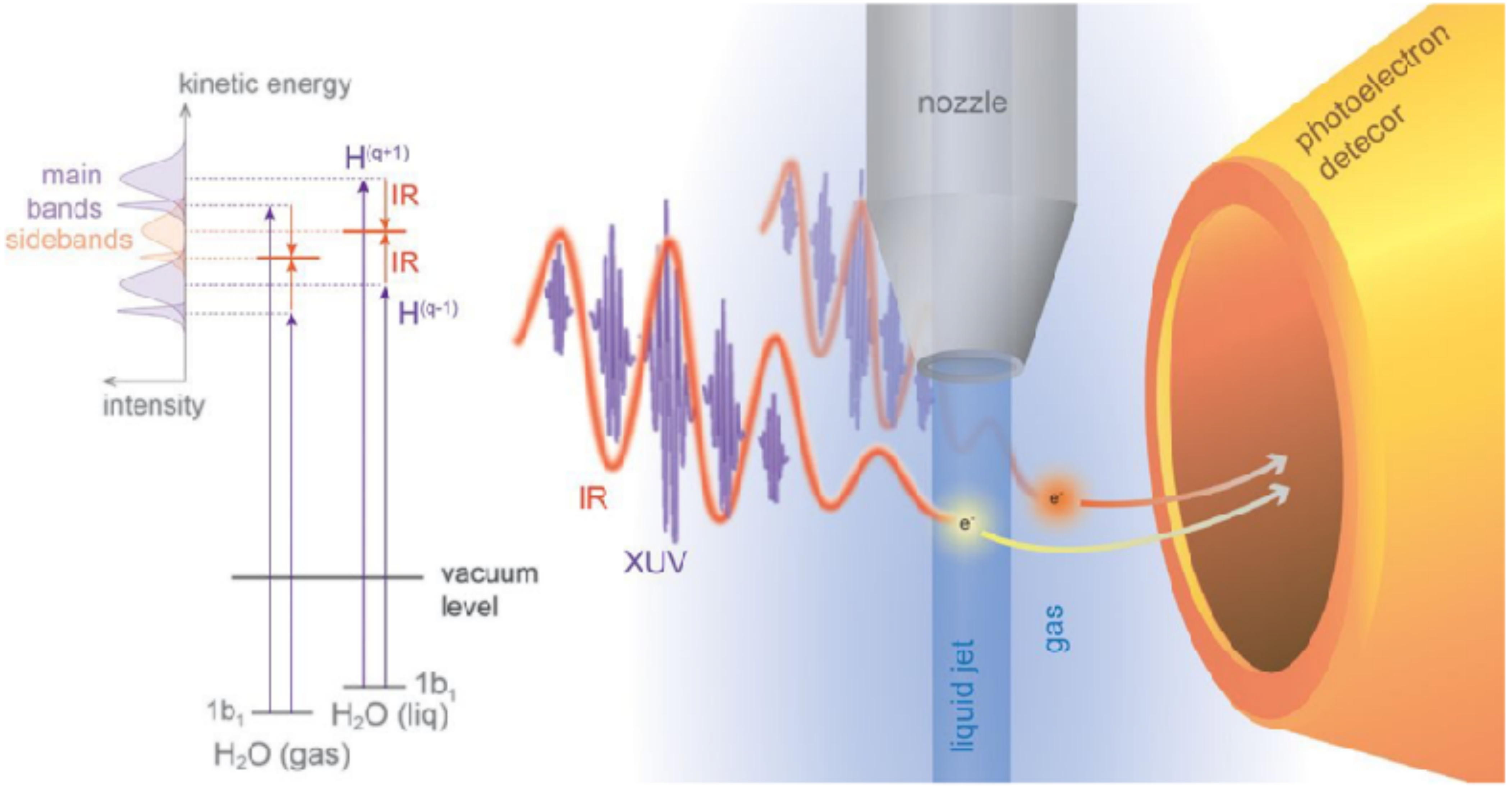
Donna Strickland

Laser based atomic physics

- High Harmonic Generation (HHG)

- 2023 Nobel prize for *Experimental Methods that generate attosecond pulses of light for the study of electrons dynamics in matter*

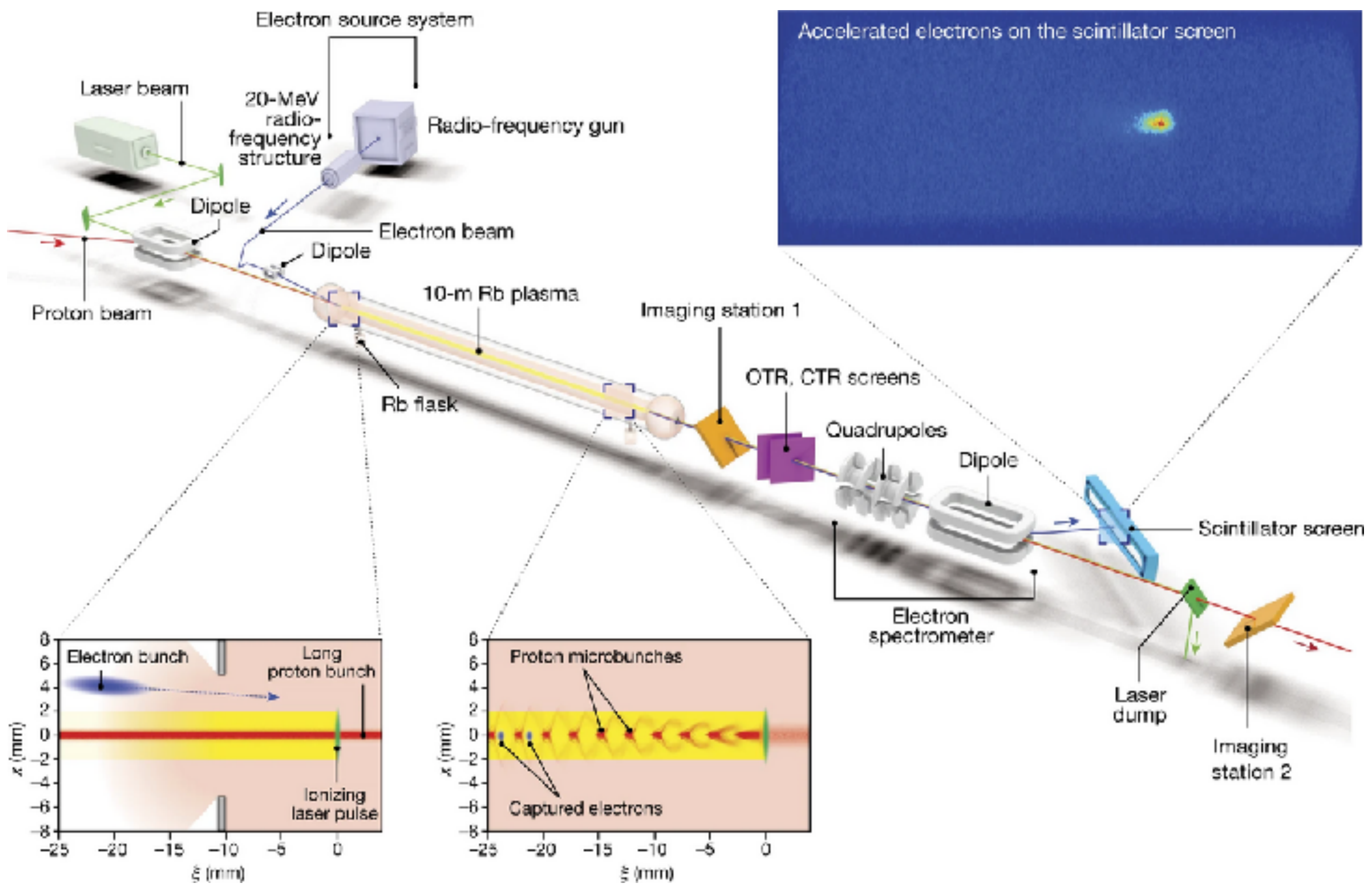




Plasma Wakefield Acceleration

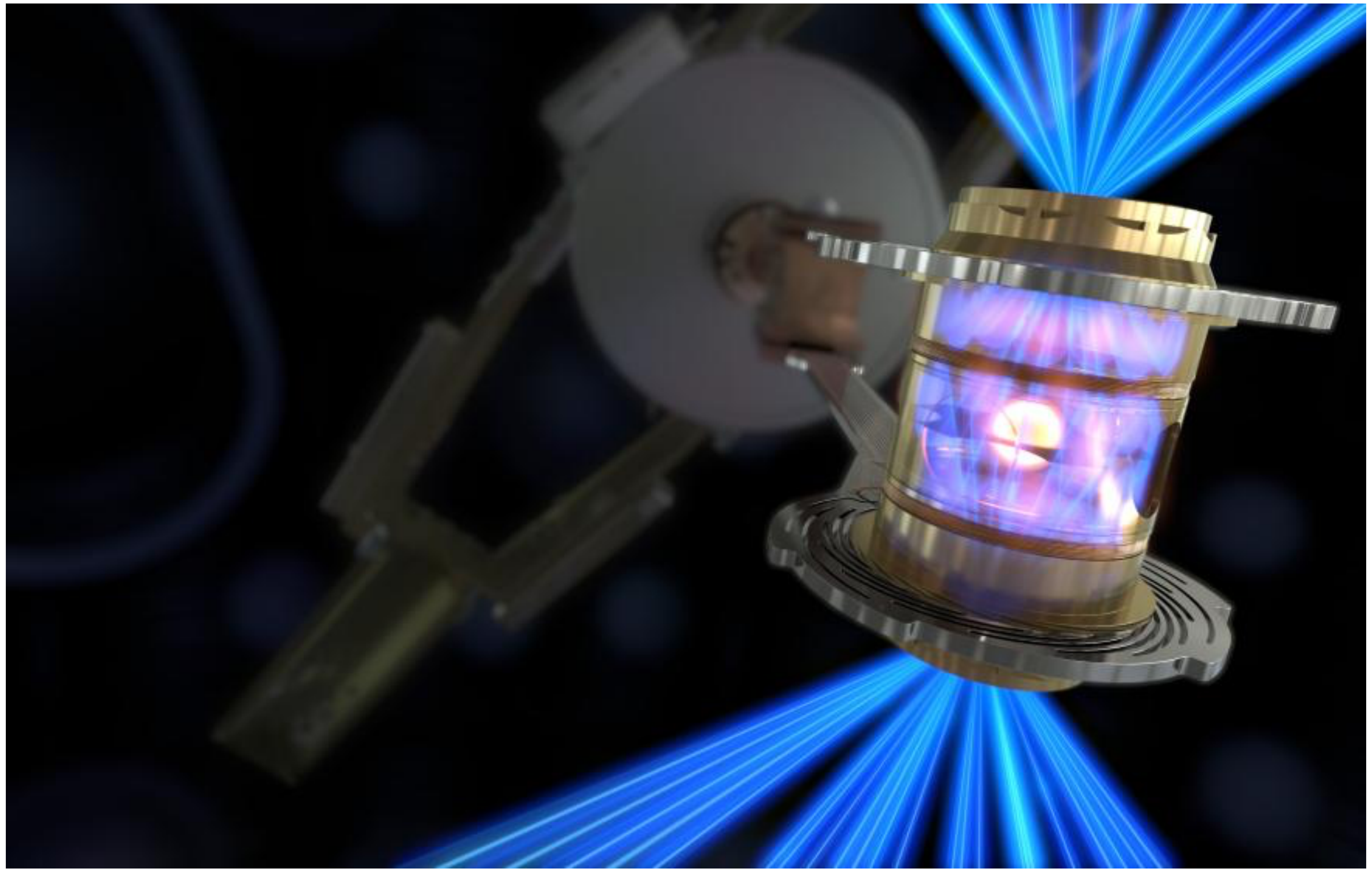
- Laser driven
  - Plasma generation directly by laser LPWA or
- Beam driven
  - Plasma preparation by priming laser
  - beam excitation
  - charge release in 2-component gas, i.e 2 ionisation potentials

AWAKE @ CERN



Inertial Confinement Fusion

- Break-even energy release reached in 2022
  - assembly of 192 individual lasers
- Generates a surge in Spin-off companies worldwide
  - together with magnetic inclusion (Wendelstein, ITER, etc.)



Target cell of LLNL

Laser Lithography

- EUV light (13 nm) generation
  - starting with a CO_2 laser
  - X-rays from pre-prepared, flattened droplets of Sn-plasma

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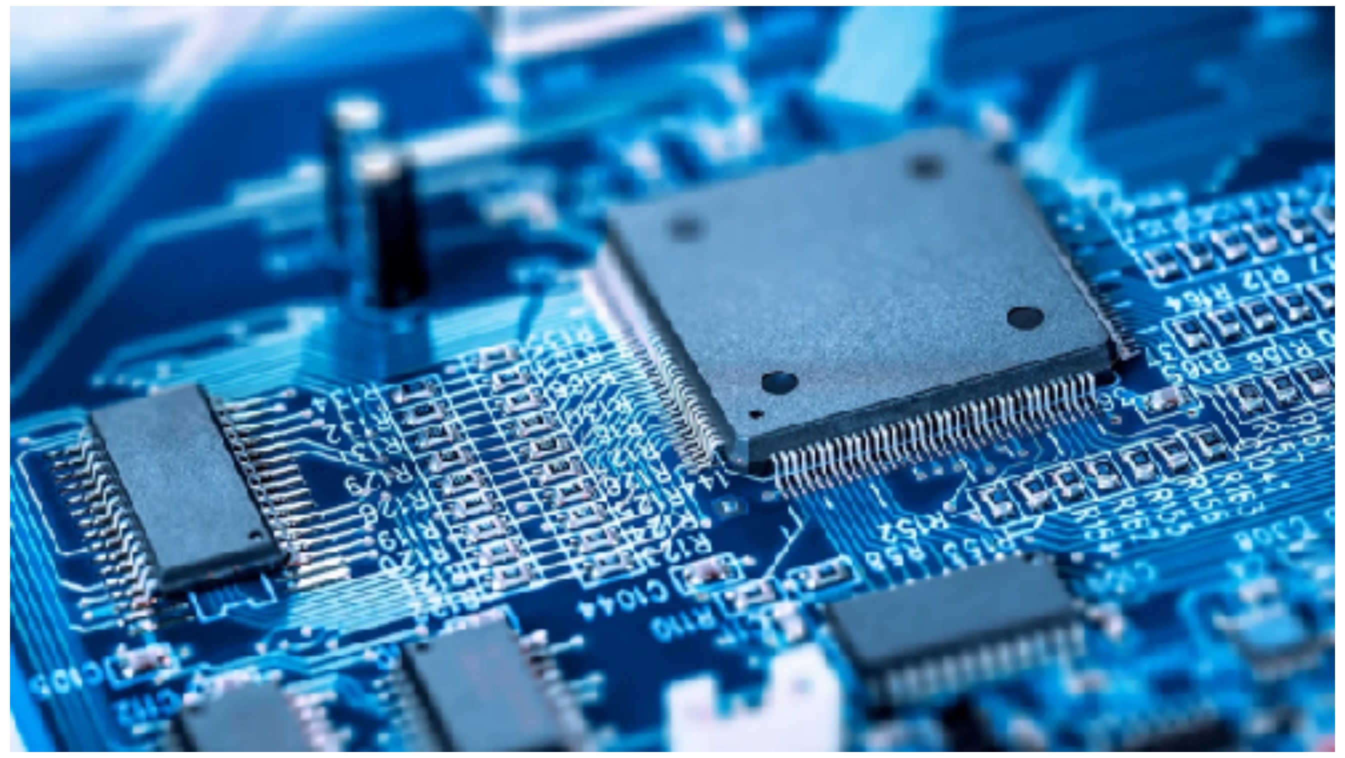

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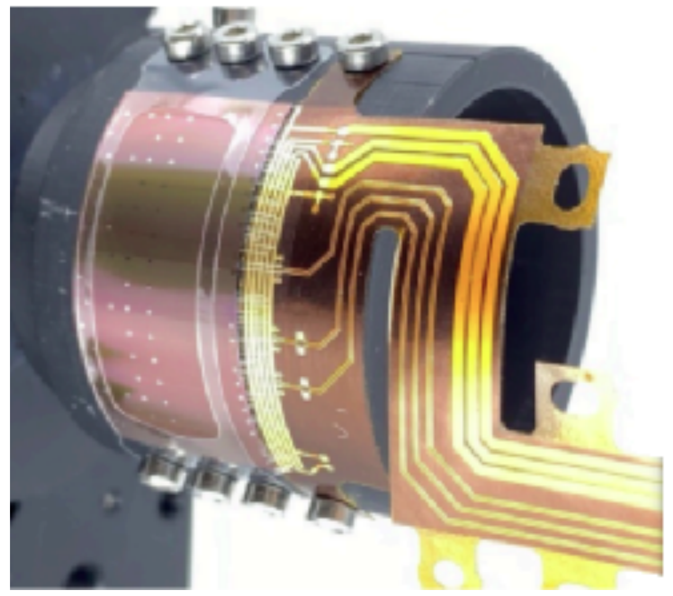
Detectors and Sensors

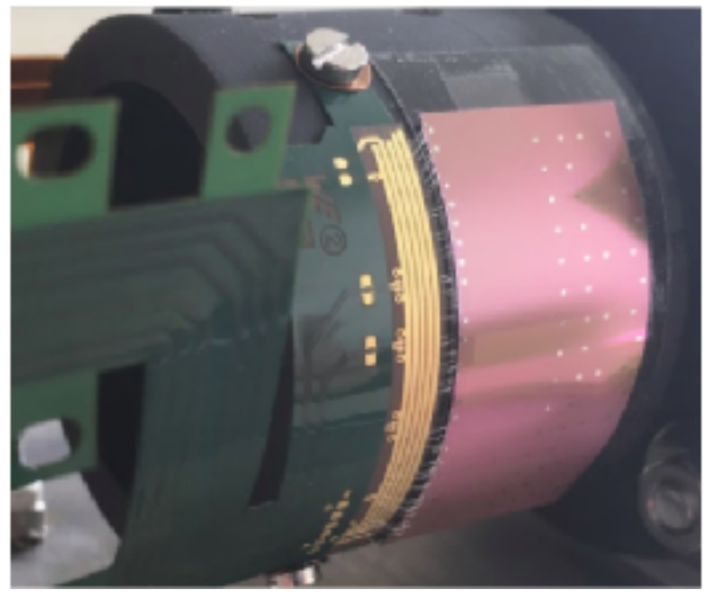
Topics

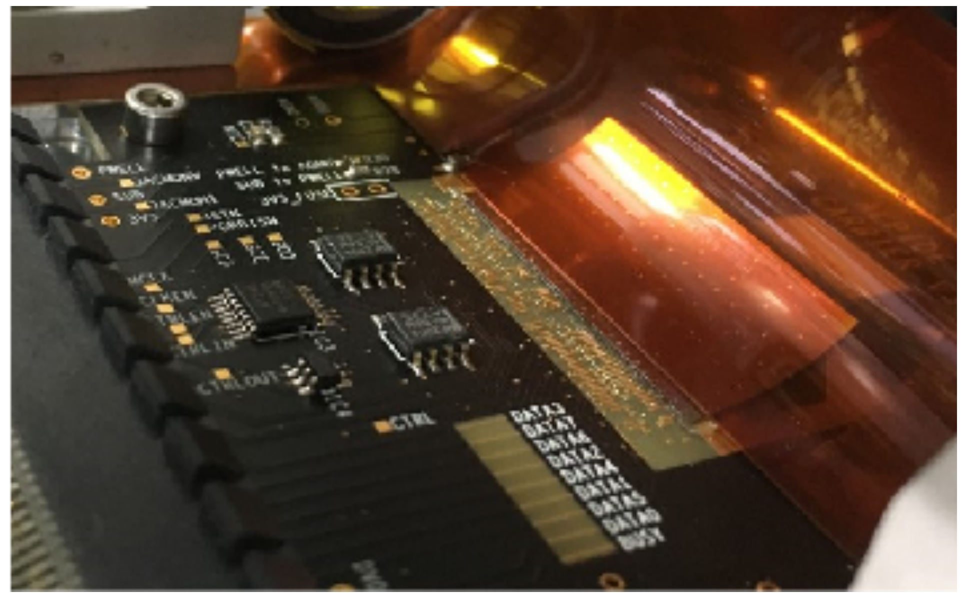
- Gaseous detectors
- Liquid detectors
- Solid state detectors
- Particle identification and photon detectors
- Quantum and Emerging Technologies Detectors
- Calorimetry
- Electronics and Data Processing
- Integration

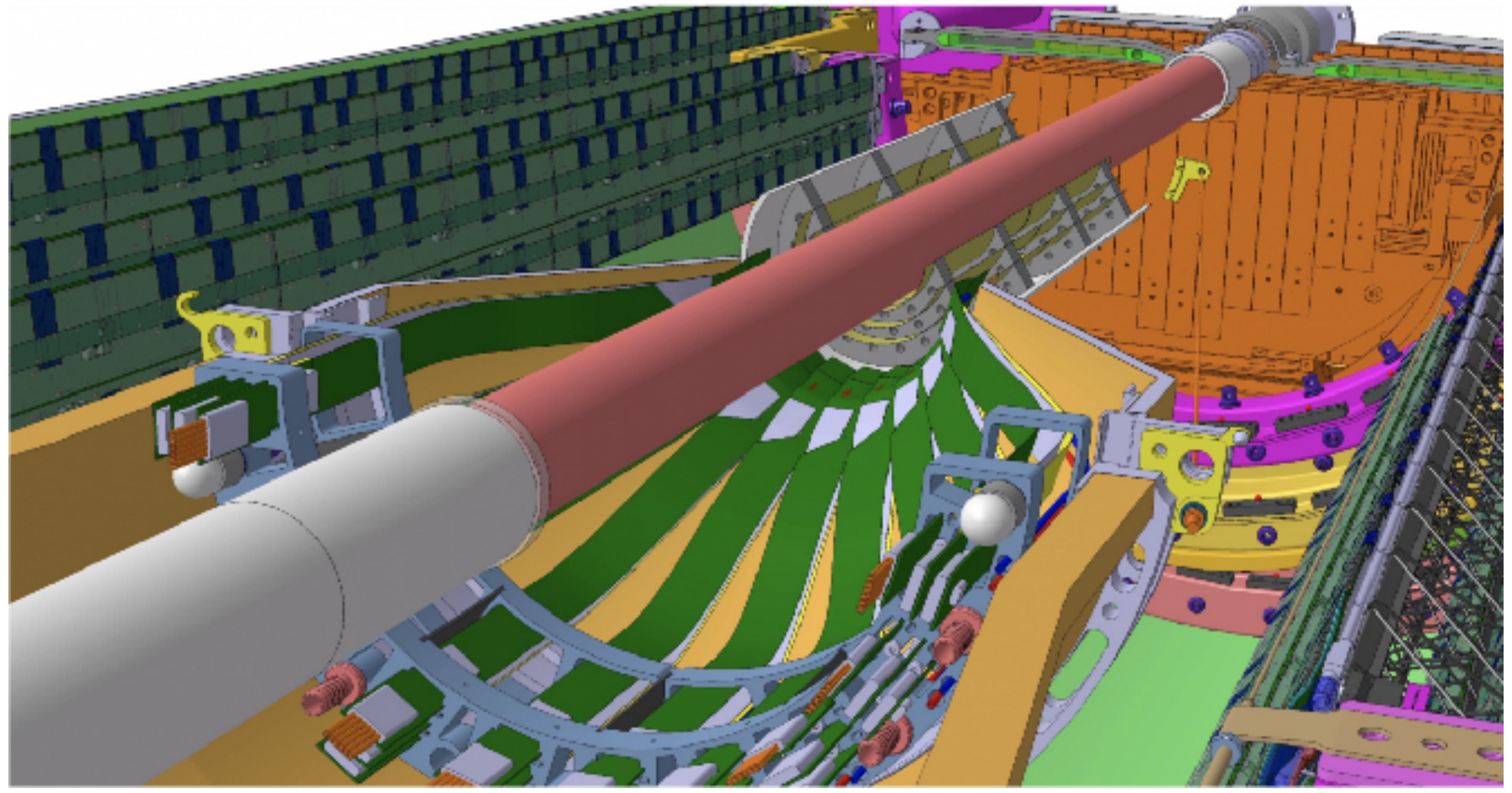
Si-sensors

- Profit from industry developments
- CMOS now widely adopted
- Active pixel readout allows thin sensors; flexible detectors
    - eventually in arbitrary shape









Semiconductor Sensors

- State of the art in industrial production is now at 3 nm
- Particle physics requirements
  - 50 – 250 nm commensurate with the size of the ionisation
  - often large area detectors are needed
- Need to invest in production capability across science fields or learn to live with smaller feature size.

Gaseous detectors

- Affordable solution for large area detectors
  - Timing requirements often can be implemented
  - Choice of gas
    - Carbon footprint
    - non-fluoride gases
- Industrial support is required for large area systems and quality control

Accelerator

Topics

- High-field magnets
- high gradient acceleration
  - metallic structures
  - plasma
  - dielectrics
- Bright muon beams and colliders

Sustainability

Sustainable beam facilities

- Facility design and layout
  - Construction is a major impact of the GHG footprint (concrete)
  - Heat recovery were possible; introduce heat pumps where adequate
- Target the physics
  - Hadron colliders leave considerable footprint in QCD background (mb-cross sections; physics at the fb-scale)
  - (radioactive) ion storage rings offset some wasteful production and have other benefits
  - μ-colliders need to overcome inefficient production process (focussing in target)
  - e-colliders
    - storage rings use entire stored beam to produce luminosity; however suffer heavily from synchrotron radiation losses
    - linear colliders allow for lower currents and ERL to be implemented

Limit in focussing?

Education & Outreach

Inauguration of the Science Gateway at CERN, 7.10.2023

Conclusion

- New physics and technological opportunities arise that must be exploited to advance science and reduce ecological footprint
  - Roadmaps exist everywhere
    - With the long lead times in many large projects we need to be courageous and adventurous in adopting new technologies
- EURO-Labs is a genuine network to foster such developments and to train young researchers