

# DESY

# The decoding of Matter

## Introduction to the Deutsches Elektronen-Synchrotron (DESY)

Antoine Laudrain (he/him)

Thanks to Thomas Schörner-Sadenius for the slides

*Beamline for Schools 2024 — 23.02.2024*



**HELMHOLTZ**

[antoine.laudrain@desy.de](mailto:antoine.laudrain@desy.de)

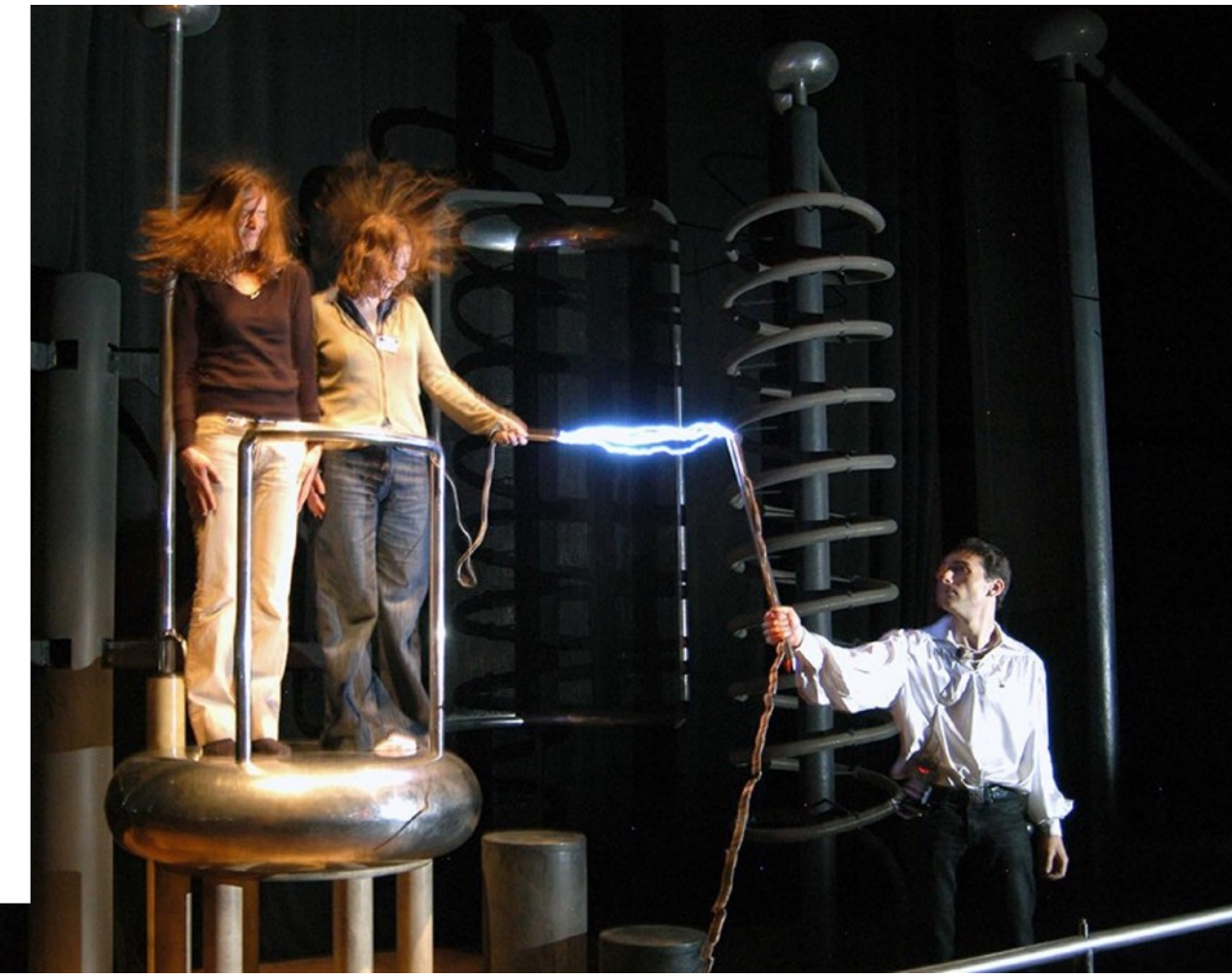
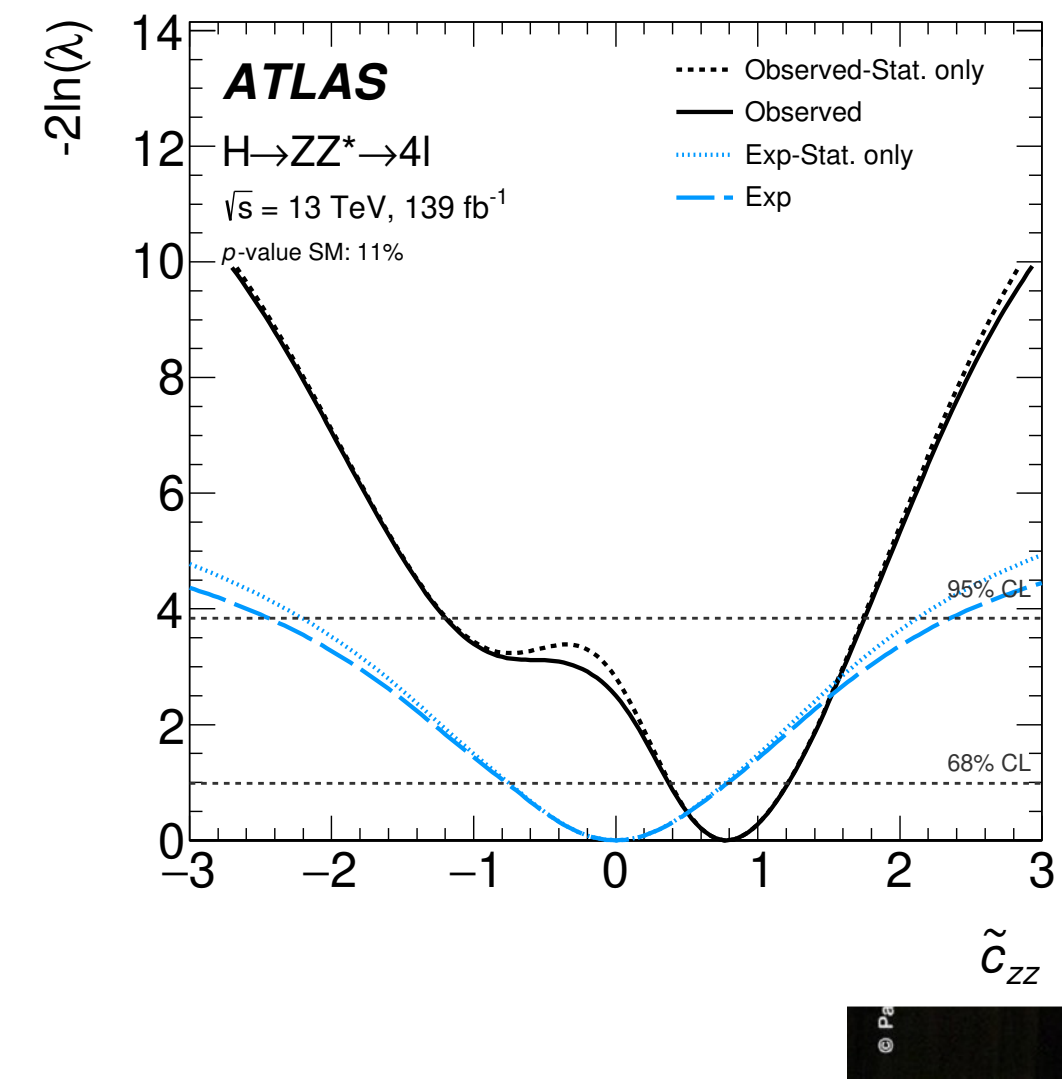


# About me!

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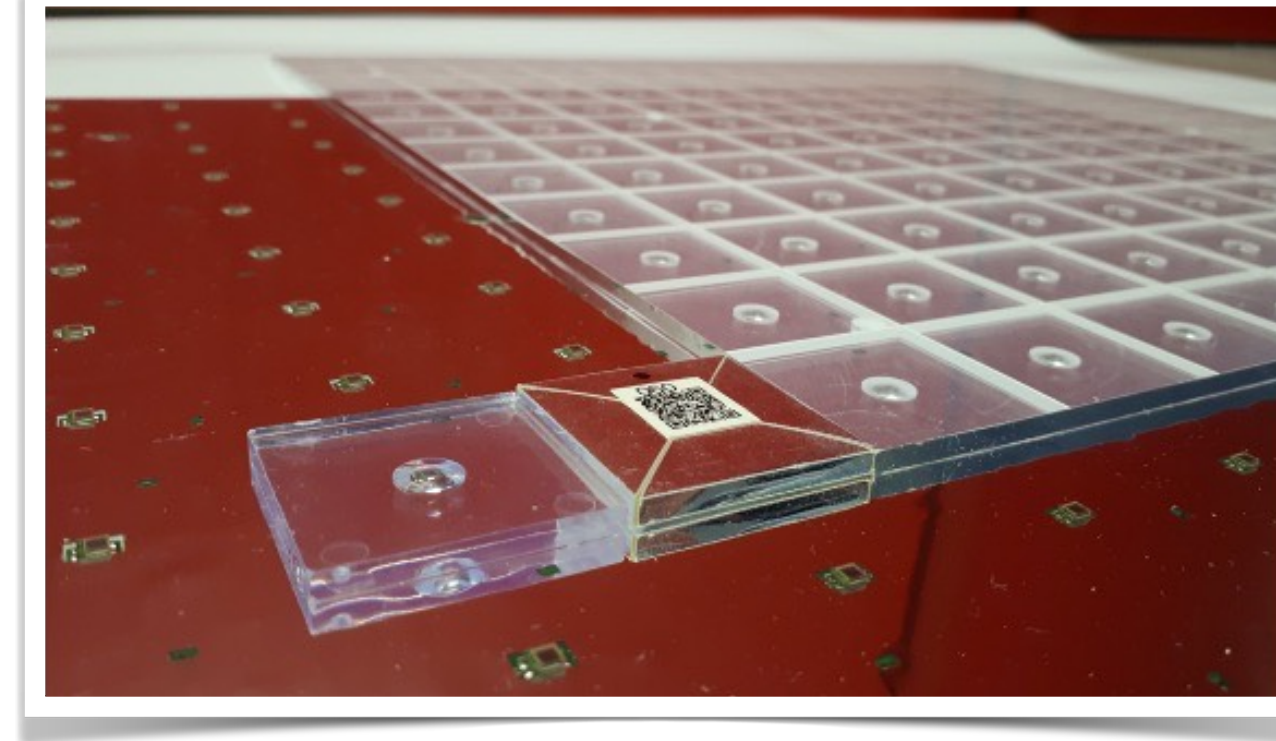
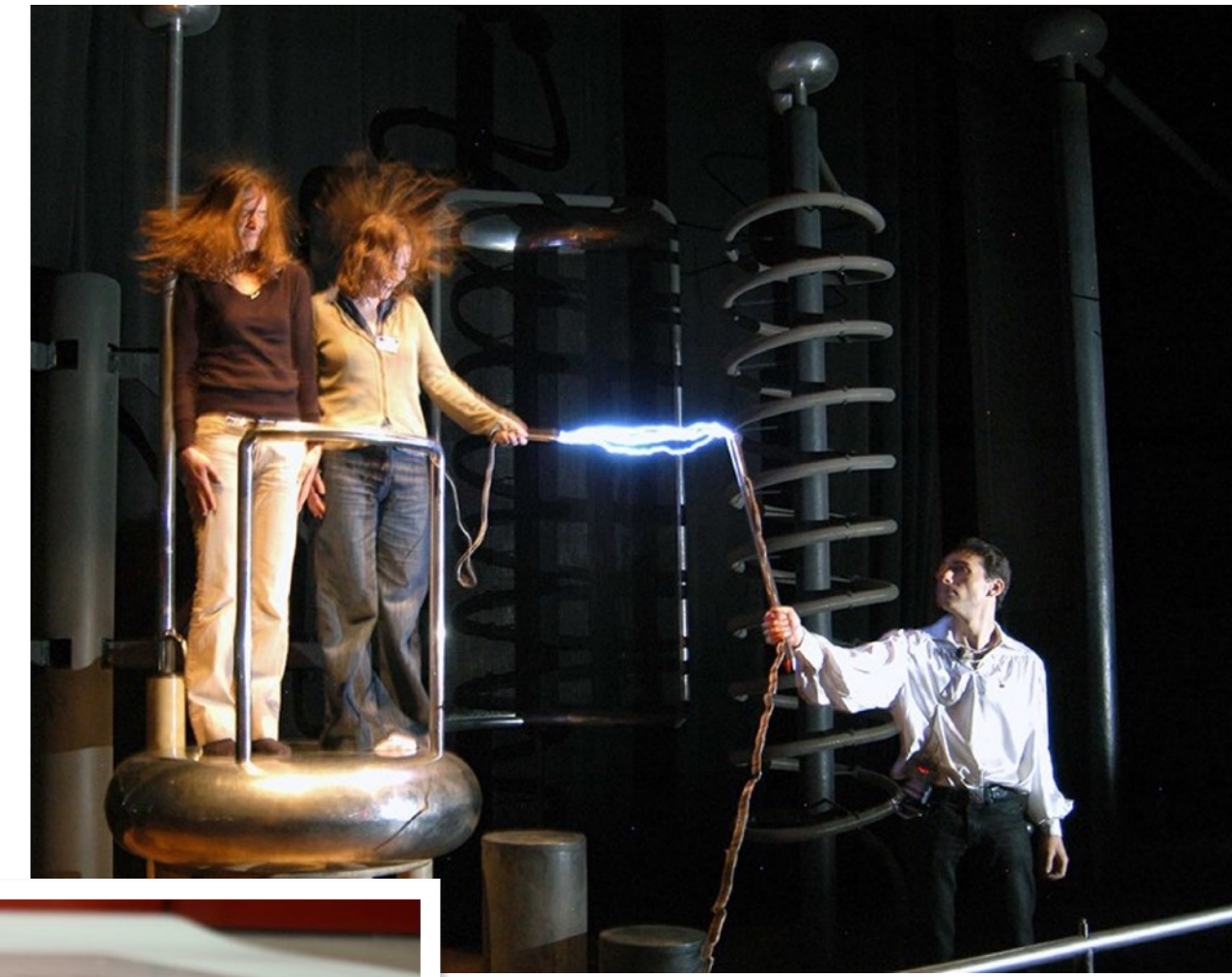
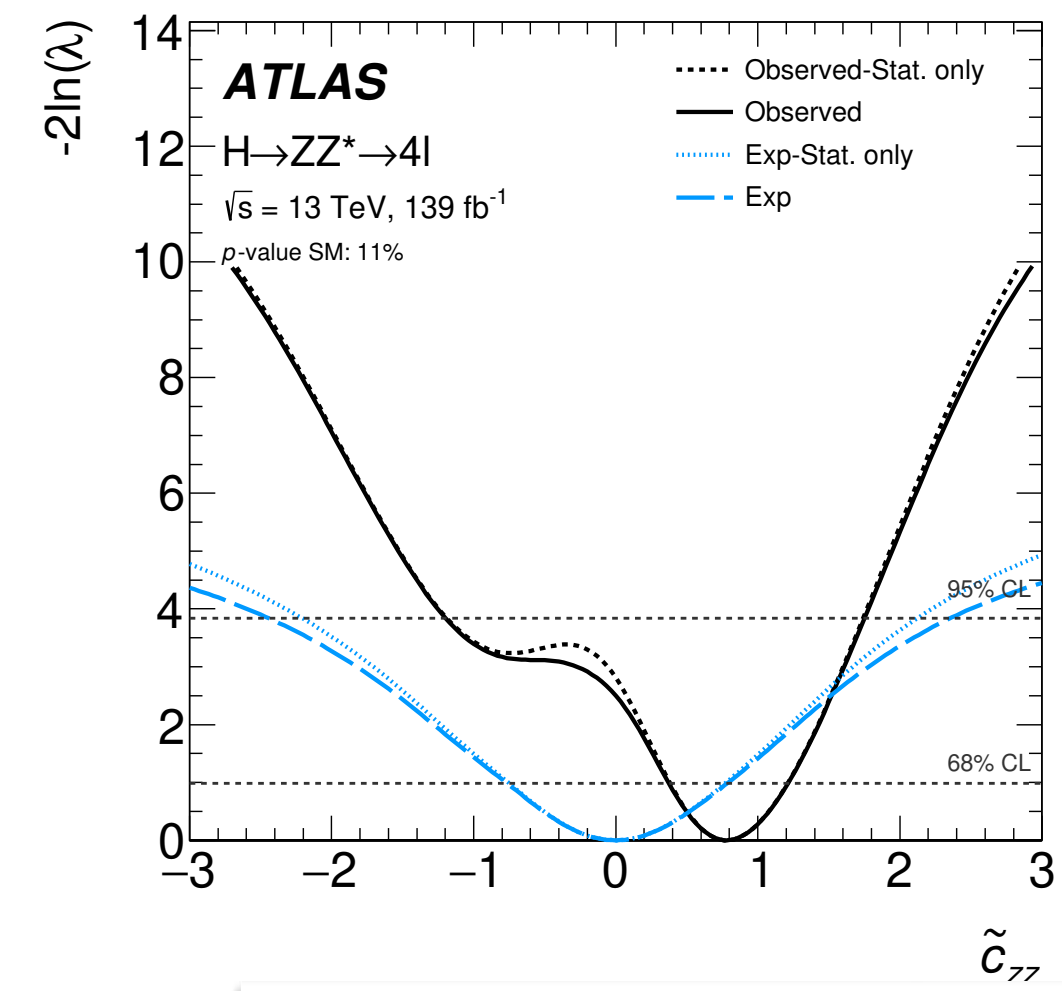
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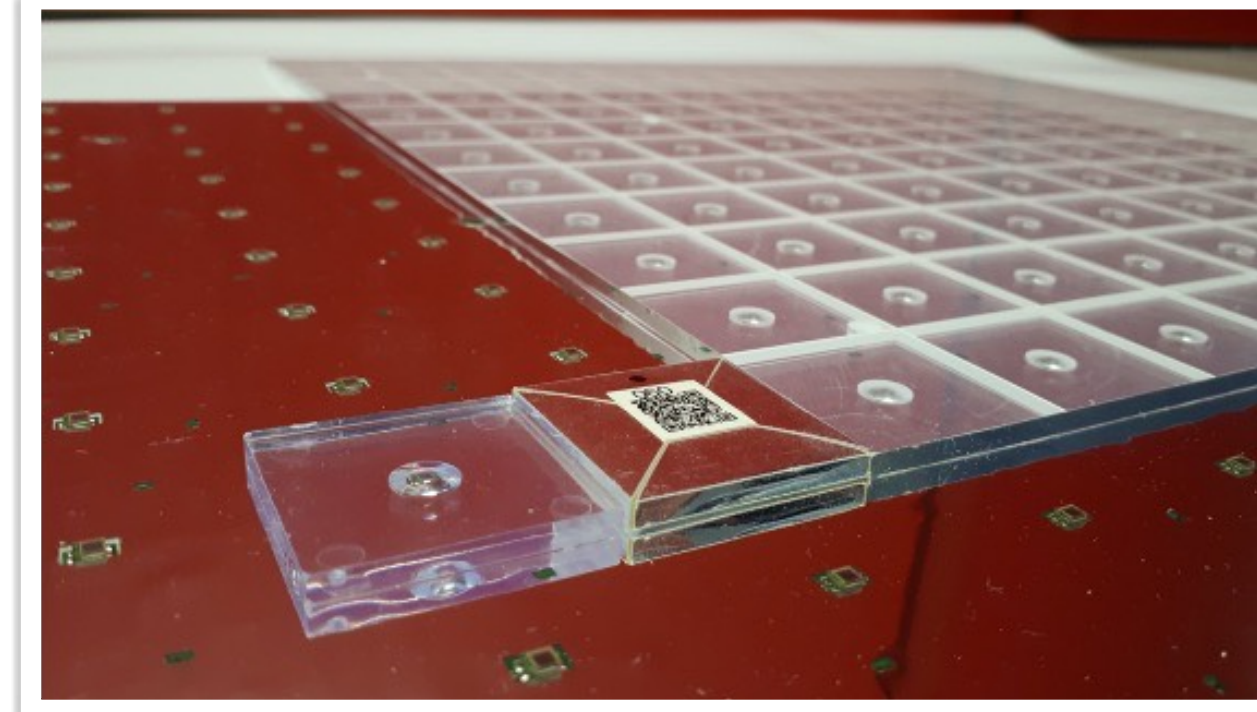
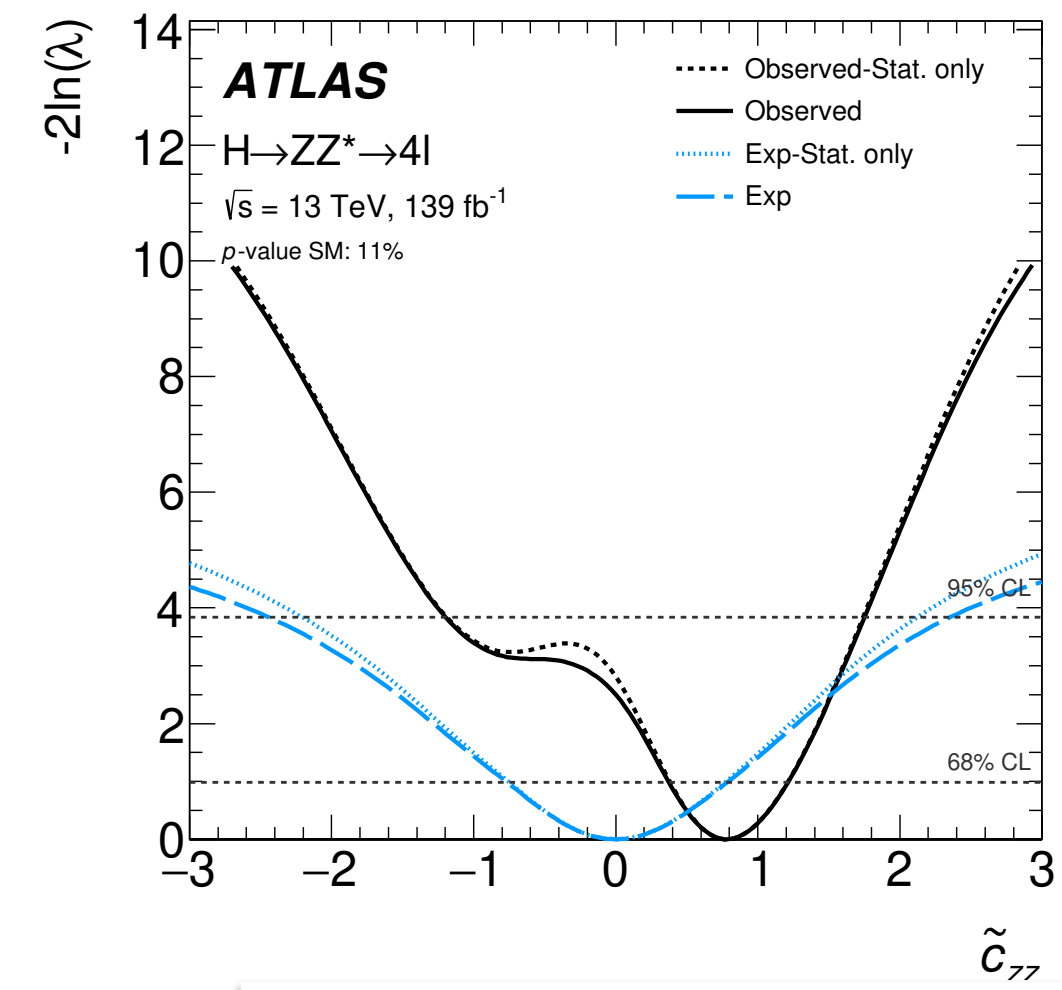
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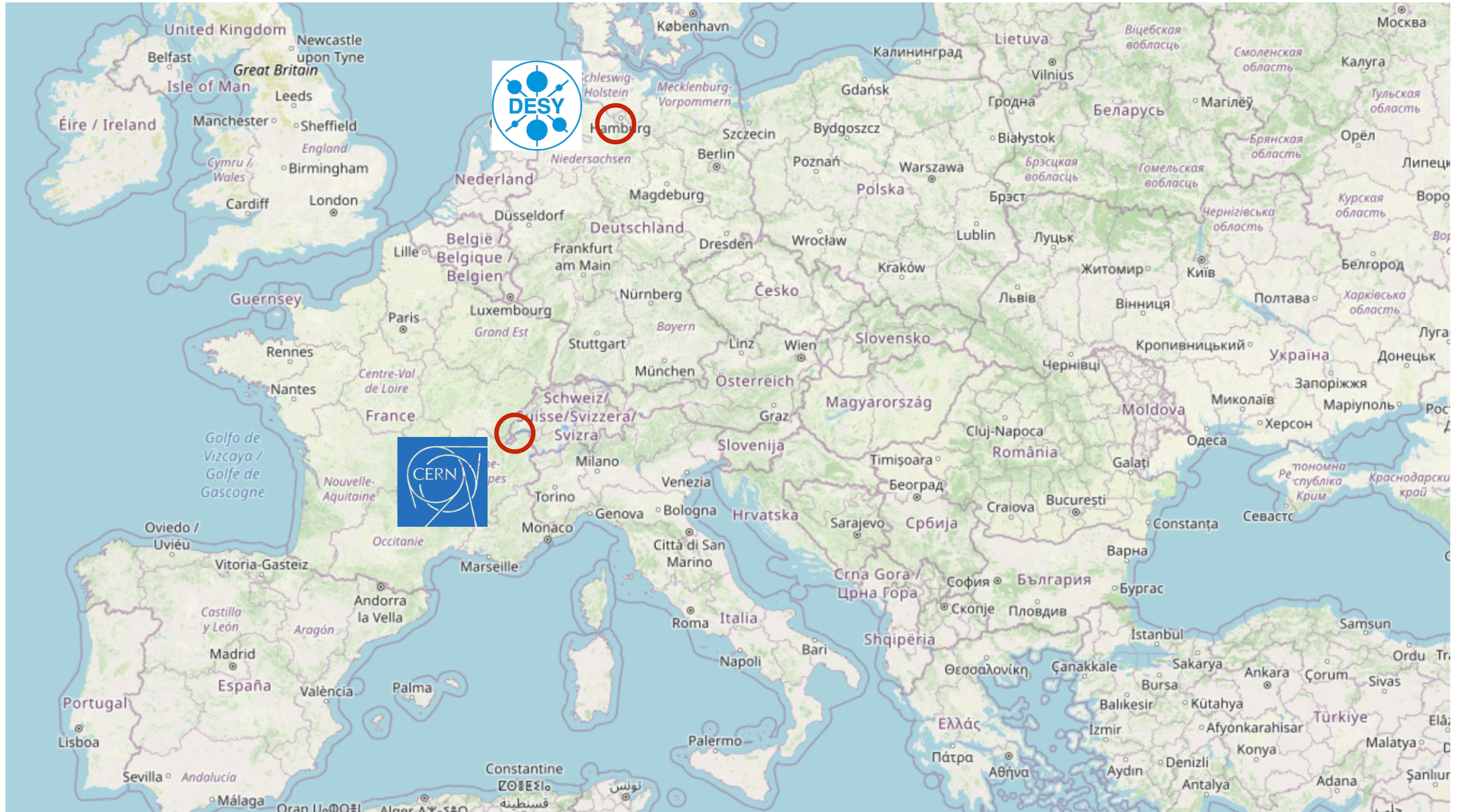
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- 2023-???: Post-doc in DESY
  - CMS calorimeter upgrade
  - Detectors for future colliders
  - Outreach: for YOU!



# DESY

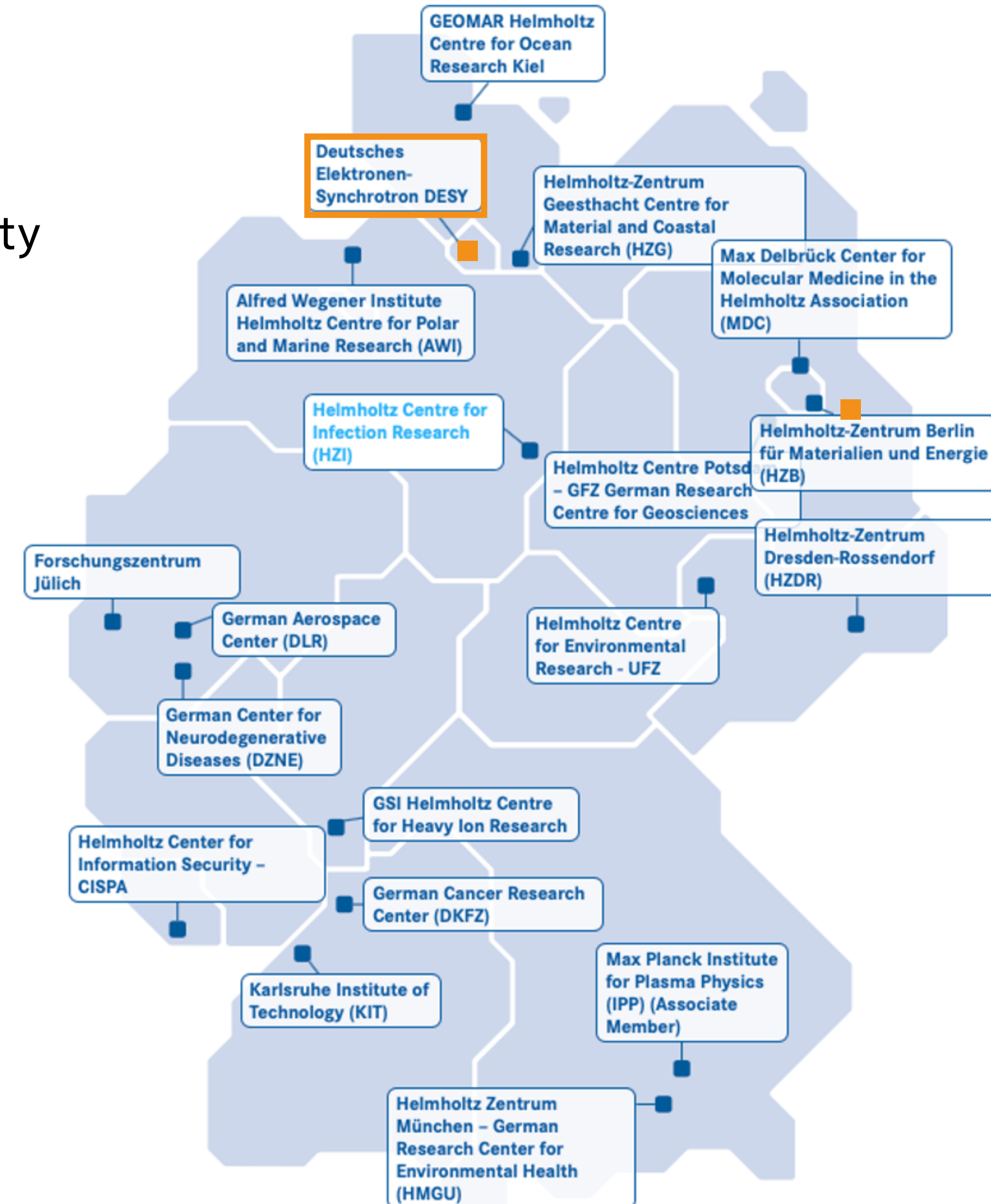
# Where am I?



# Helmholtz & DESY

## The Helmholtz association

- **Mission:** pursue the long-term research goals of state and society to maintain and improve the livelihoods of the population.
- **Top-level research** to identify and export the major challenges facing society, science and the economy.
- **In numbers:** 6 research fields, 18 centres, ~45'000 staff, ~6 B€ budget => largest science organisation in Germany.





# The Deutsches Elektronen-Synchrotron

## The German Electron Synchrotron

- Founded in 1959 as Germany's national accelerator laboratory in Hamburg
- DESY is the name of both
  - The centre
  - The first accelerator (still operating!)



# DESY today

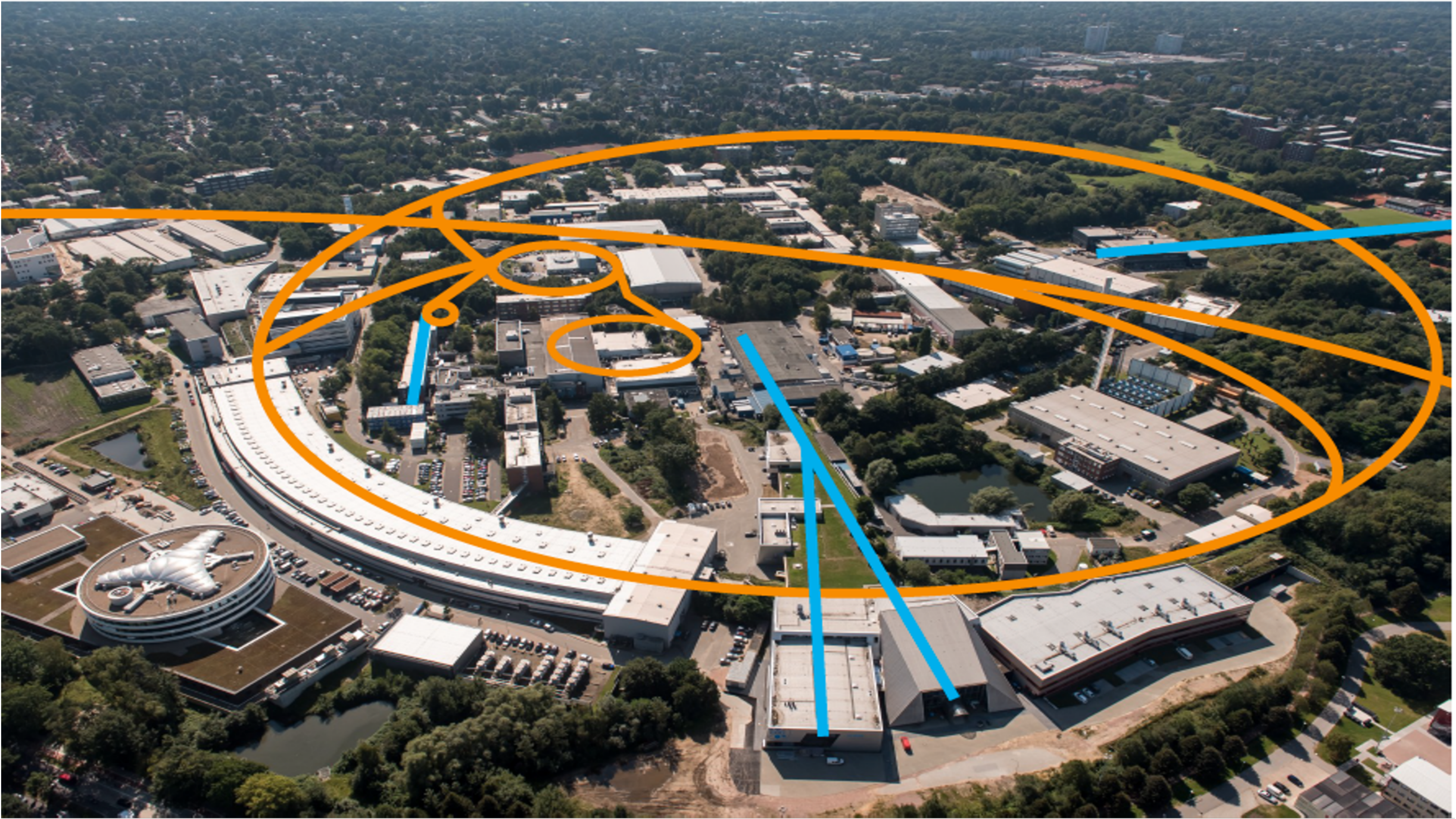
Zeuthen (near Berlin)



Hamburg



Currently ~2500 staff  
+ ~3000 visitors / year

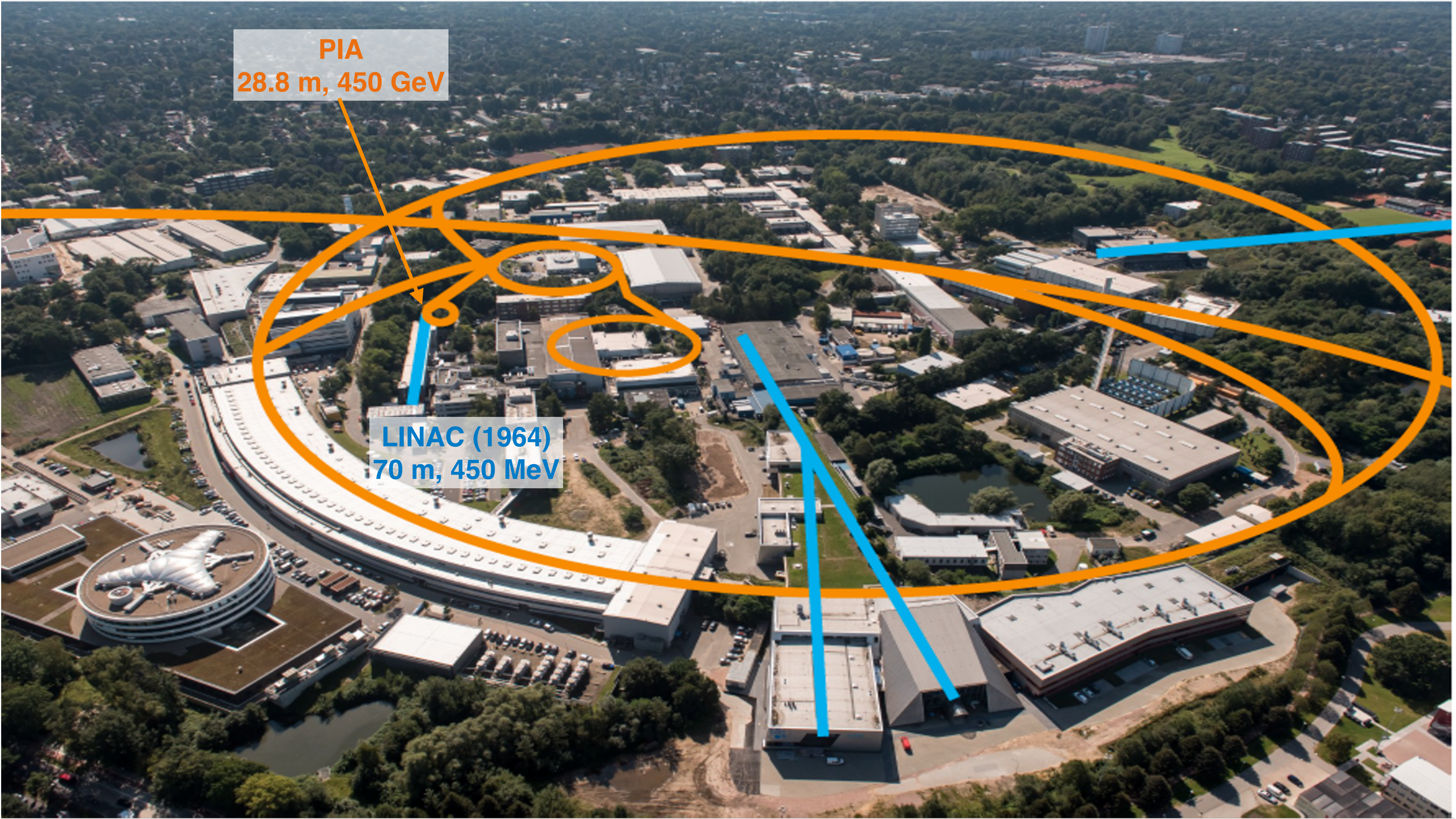




LINAC (1964)  
70 m, 450 MeV

**PIA**  
28.8 m, 450 GeV

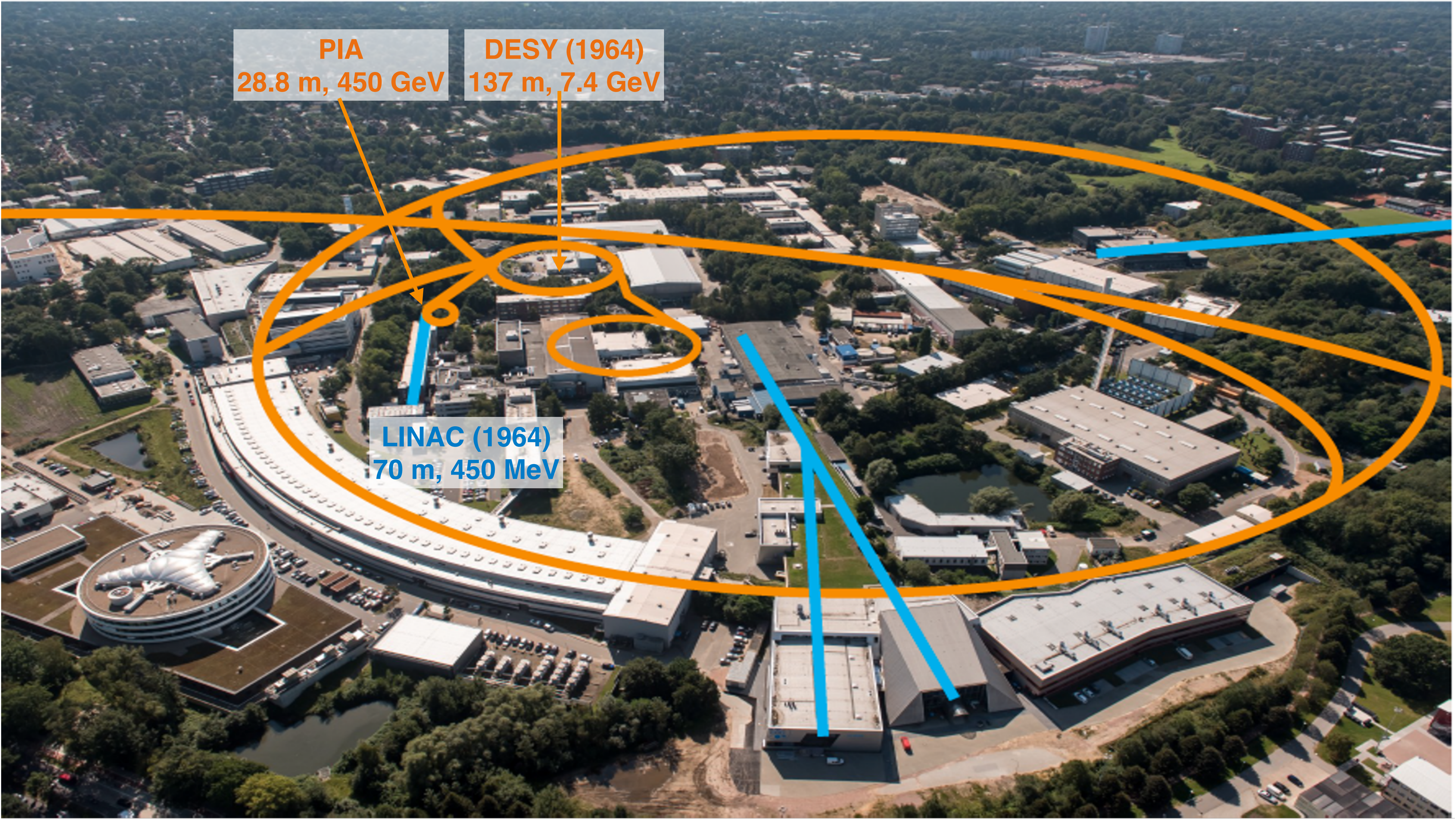
**LINAC (1964)**  
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**PIA**  
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**DESY (1964)**  
137 m, 7.4 GeV

**LINAC (1964)**  
70 m, 450 MeV

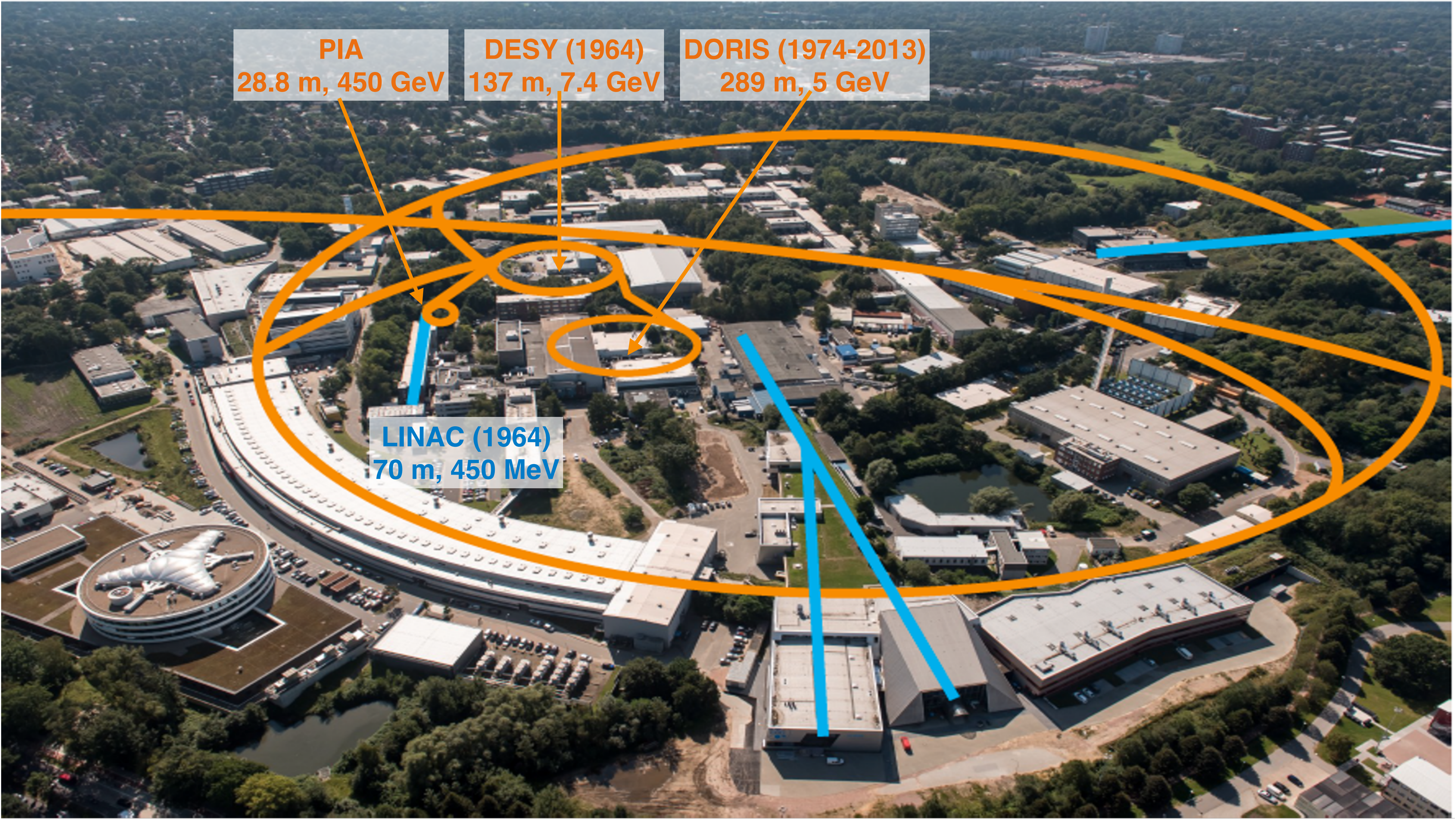


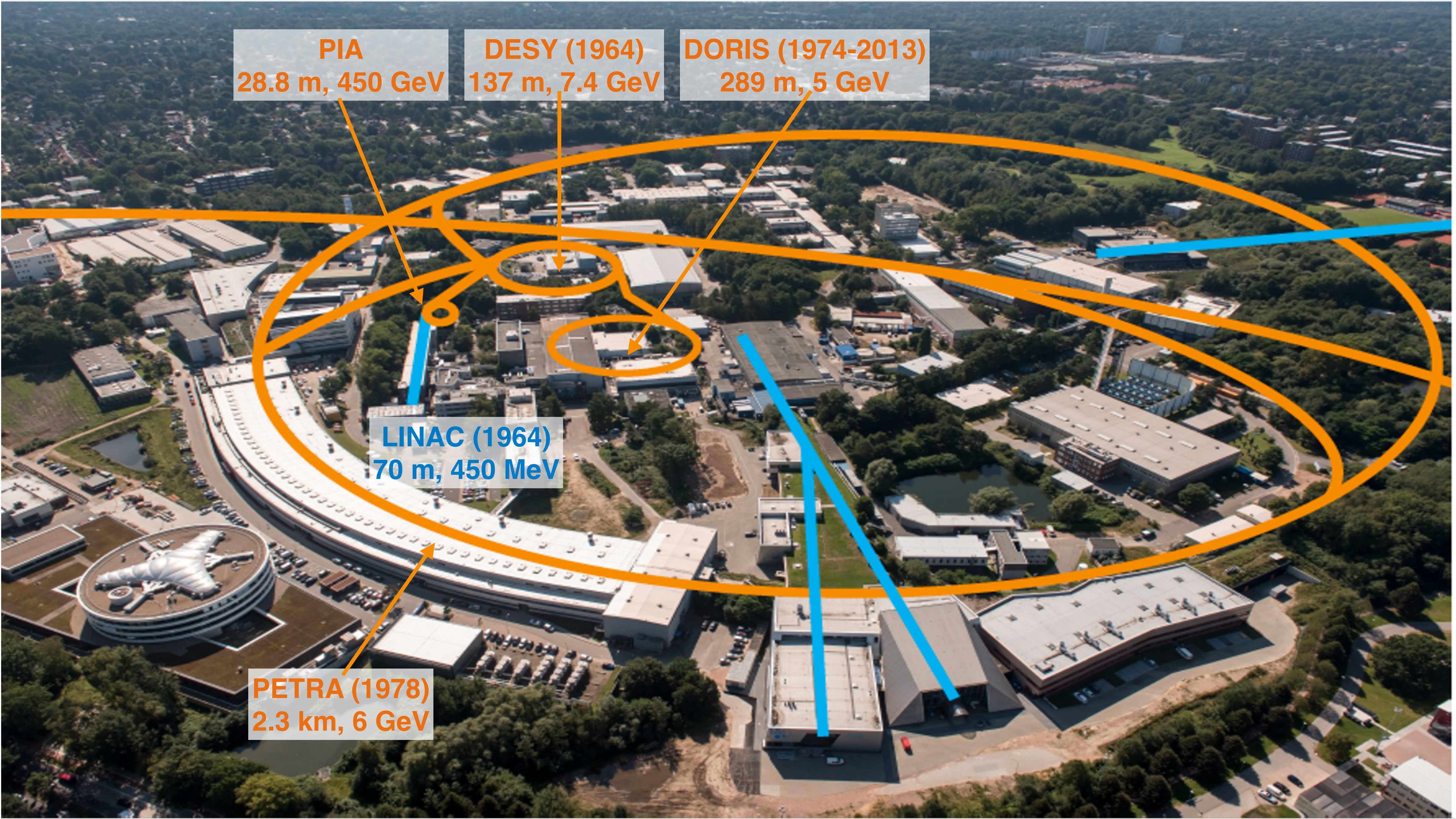
**PIA**  
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**DESY (1964)**  
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289 m, 5 GeV

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**PIA**  
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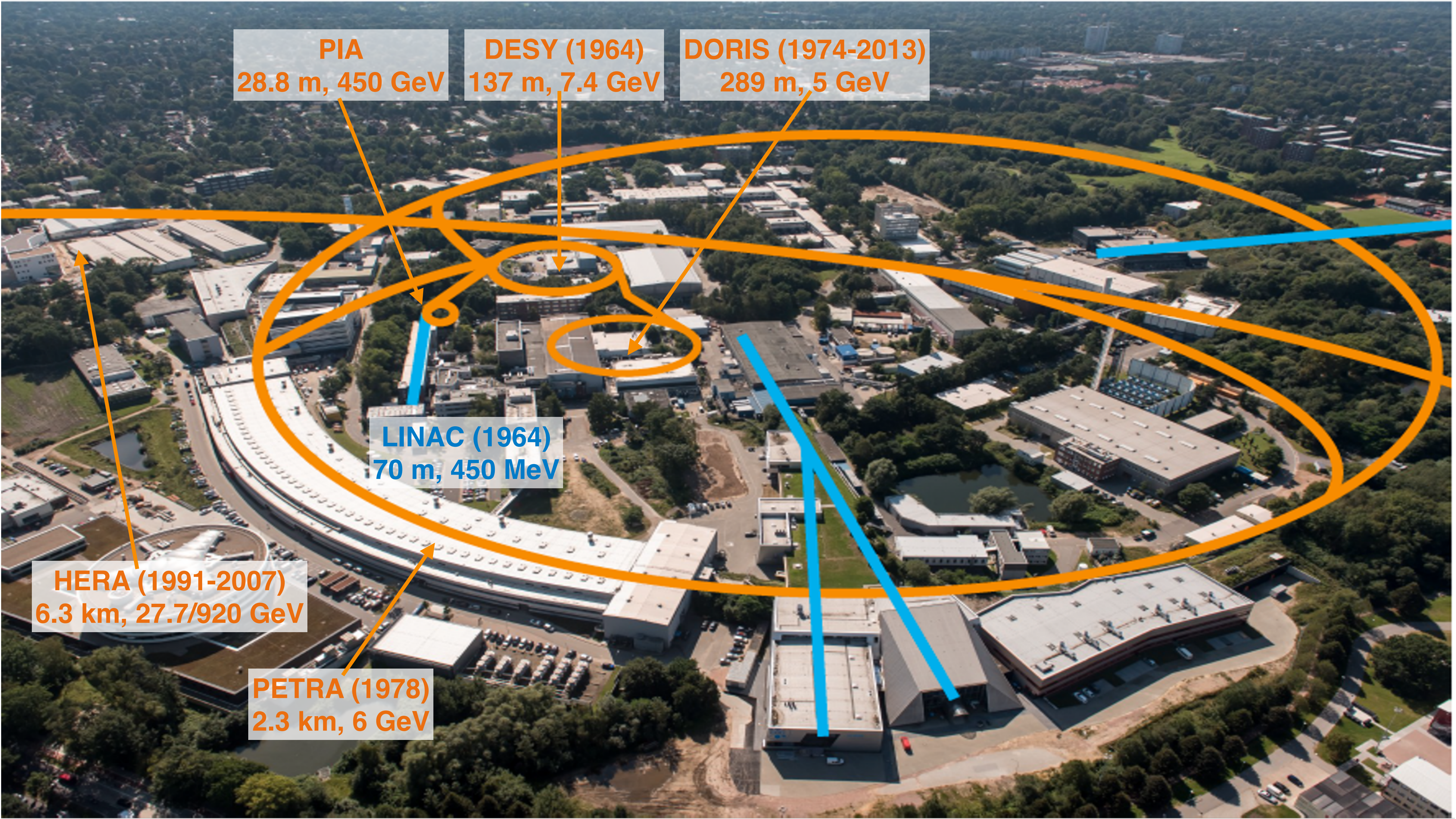
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**PETRA (1978)**  
2.3 km, 6 GeV





**PIA**  
28.8 m, 450 GeV

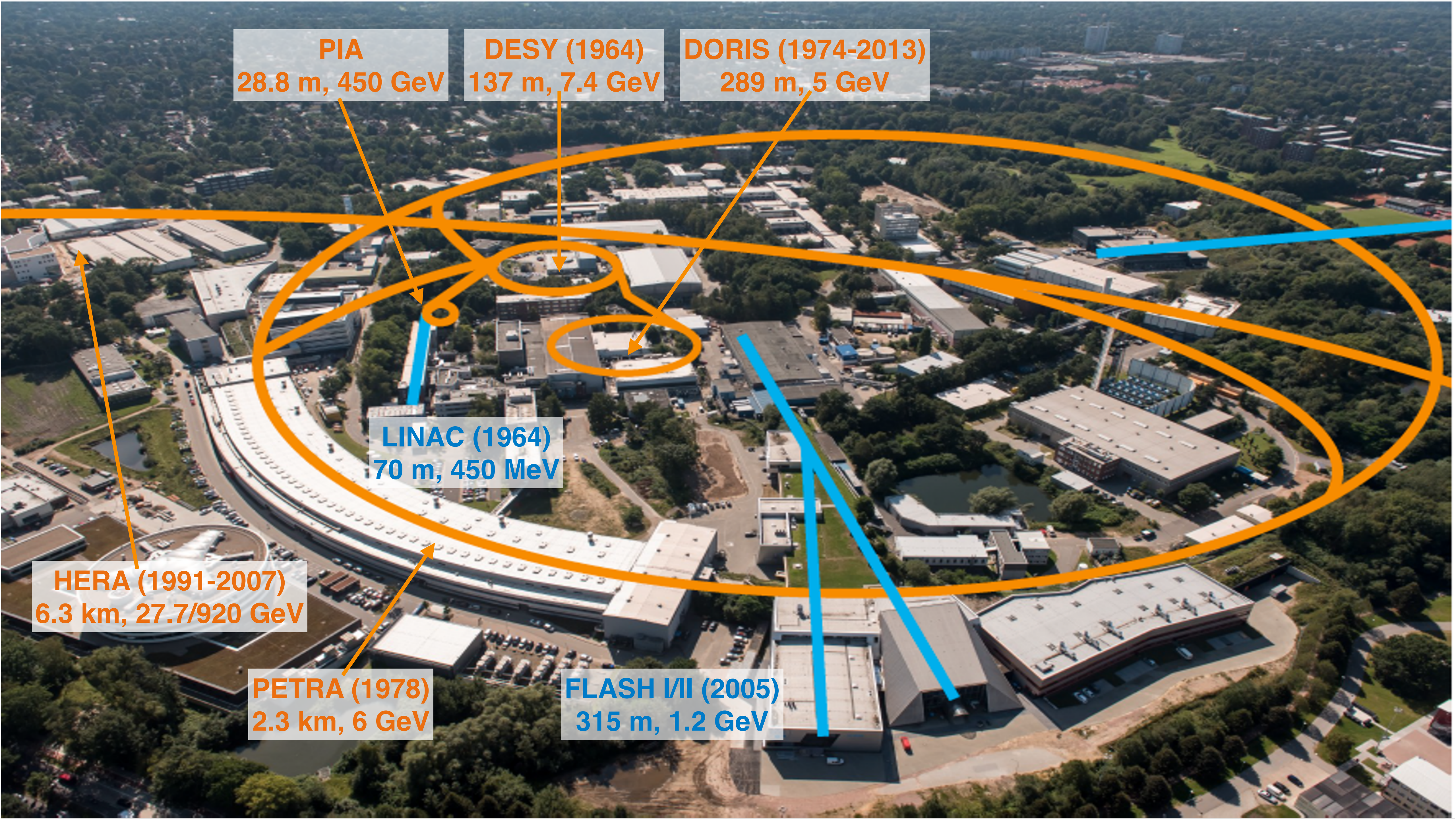
**DESY (1964)**  
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289 m, 5 GeV

**LINAC (1964)**  
70 m, 450 MeV

**HERA (1991-2007)**  
6.3 km, 27.7/920 GeV

**PETRA (1978)**  
2.3 km, 6 GeV



**PIA**  
28.8 m, 450 GeV

**DESY (1964)**  
137 m, 7.4 GeV

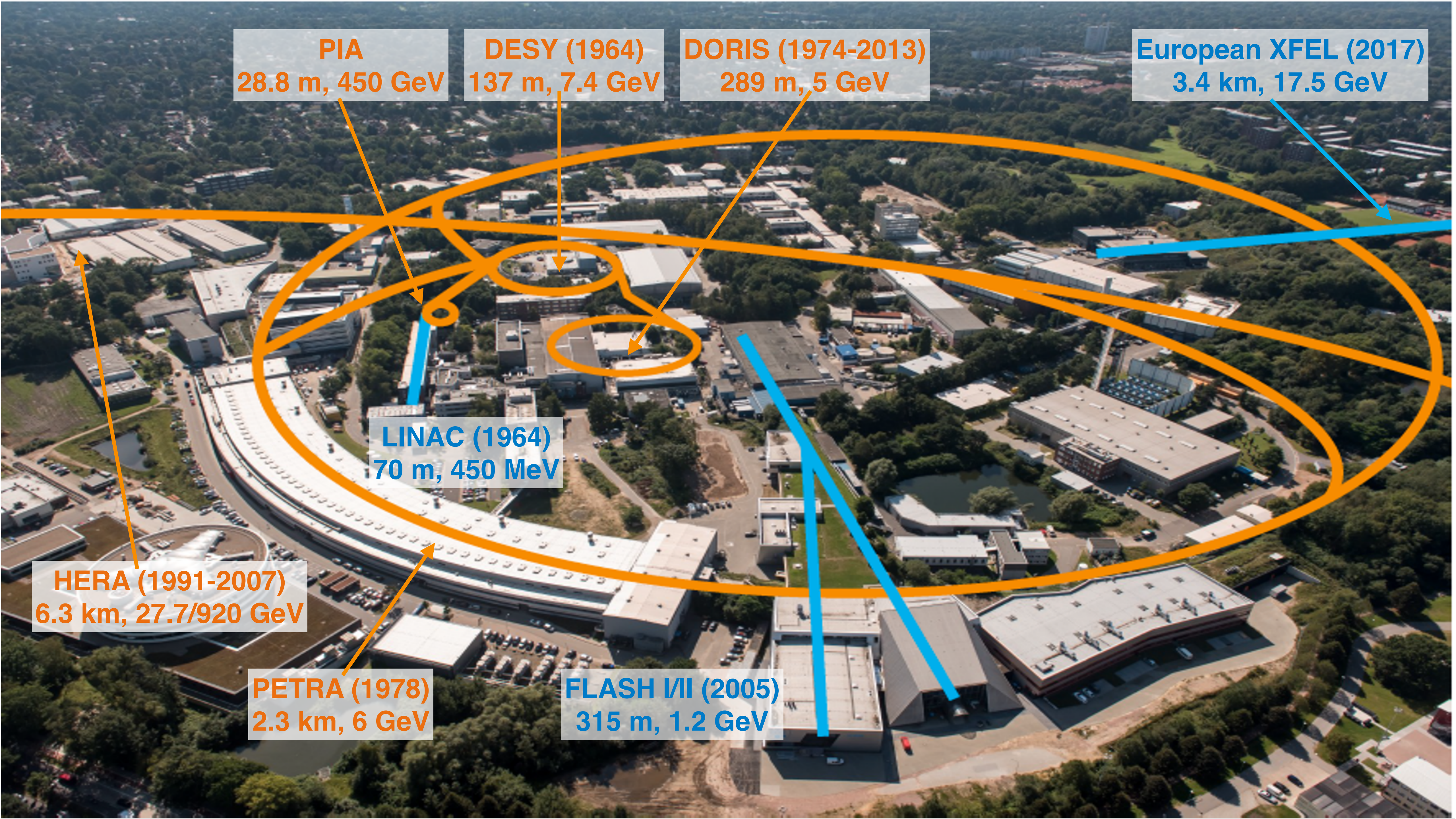
**DORIS (1974-2013)**  
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2.3 km, 6 GeV

**FLASH I/II (2005)**  
315 m, 1.2 GeV



**PIA**  
28.8 m, 450 GeV

**DESY (1964)**  
137 m, 7.4 GeV

**DORIS (1974-2013)**  
289 m, 5 GeV

**European XFEL (2017)**  
3.4 km, 17.5 GeV

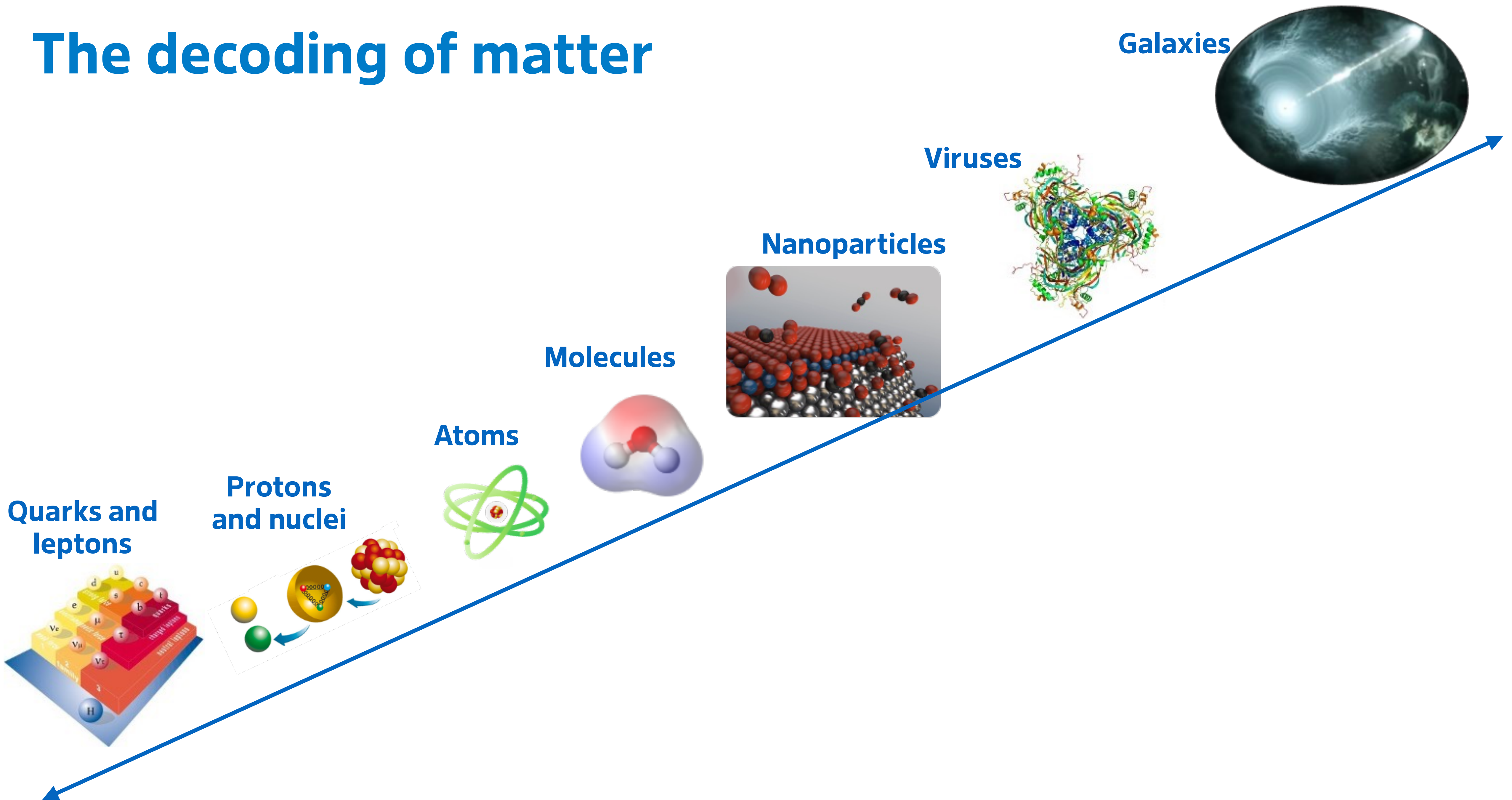
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# The decoding of matter

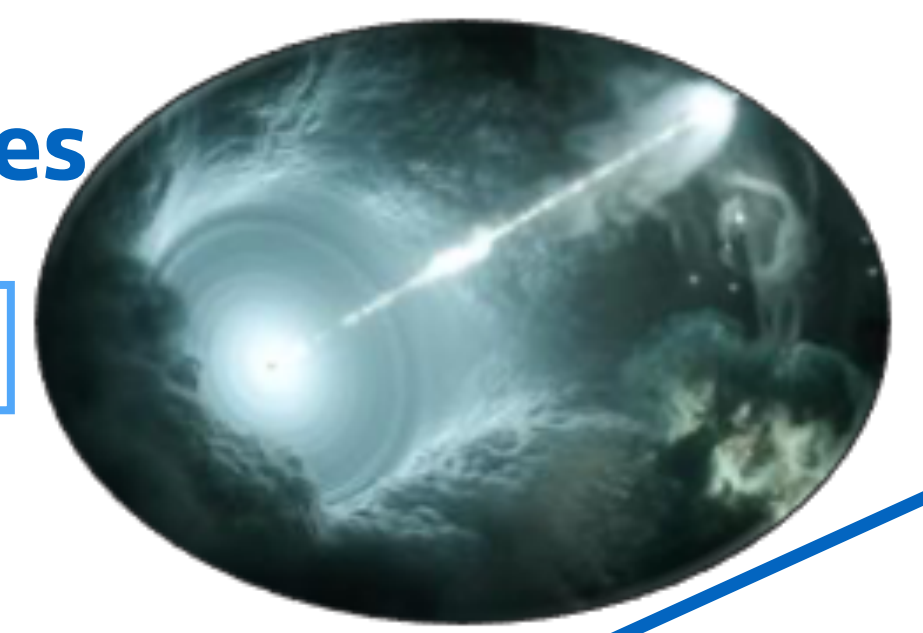


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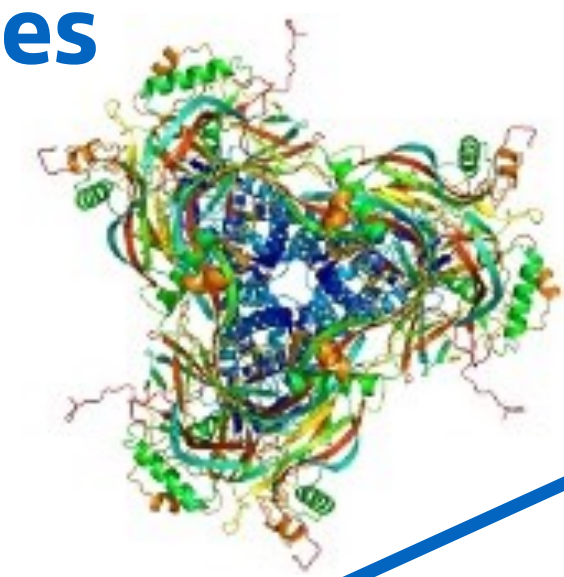
What is dark matter?

Galaxies

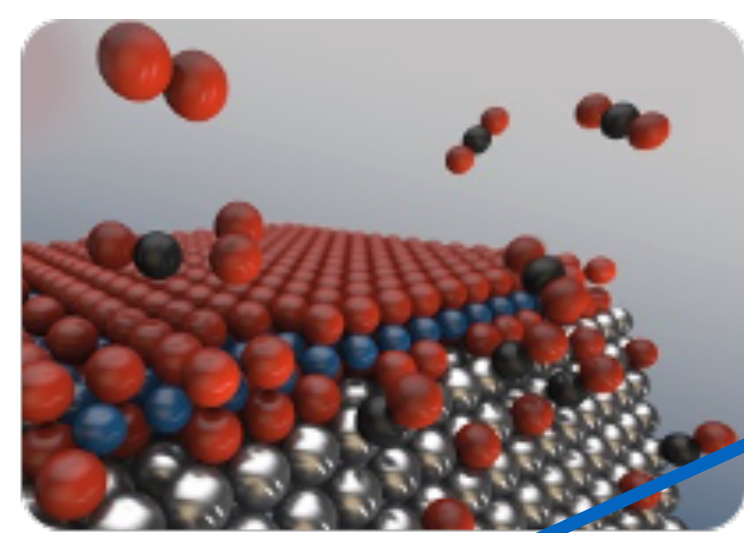
How do the large structure of the Universe form?



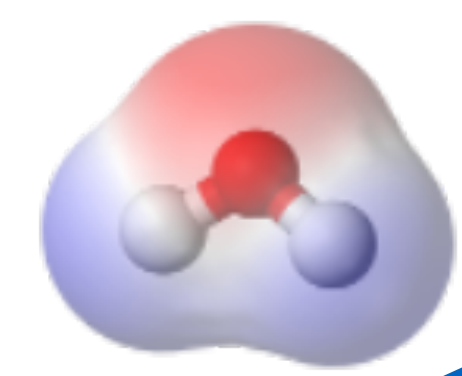
Viruses



Nanoparticles



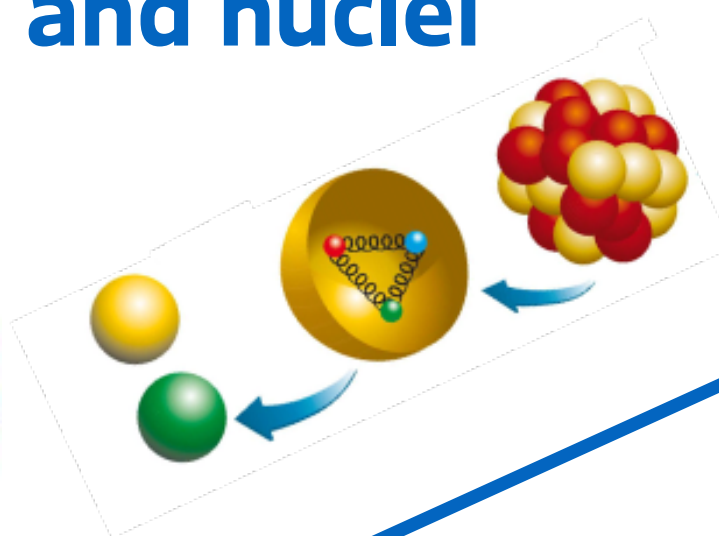
Molecules



Atoms



Protons and nuclei



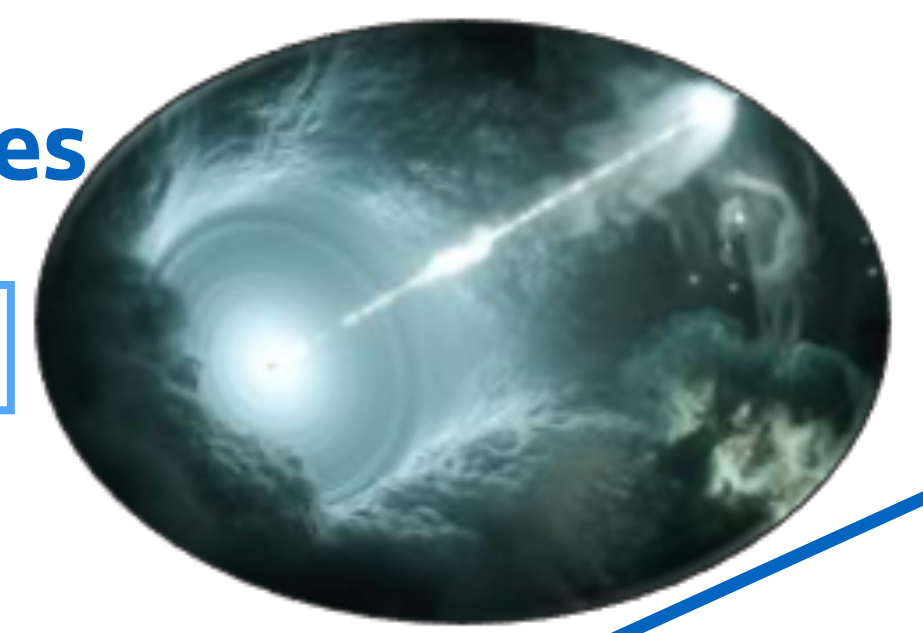
Quarks and leptons



# The decoding of matter

What is dark matter?

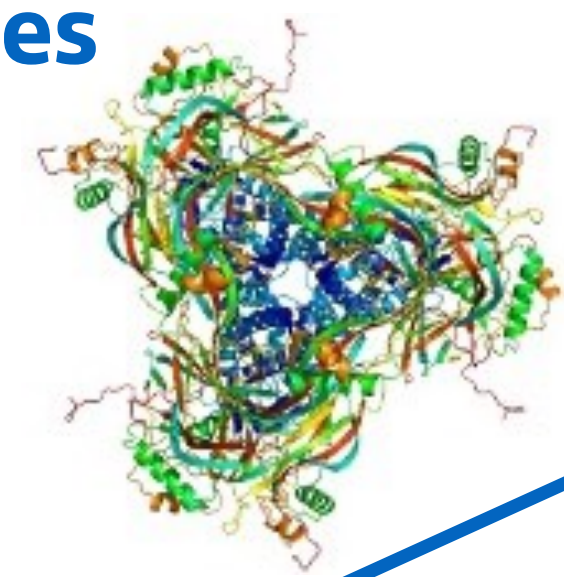
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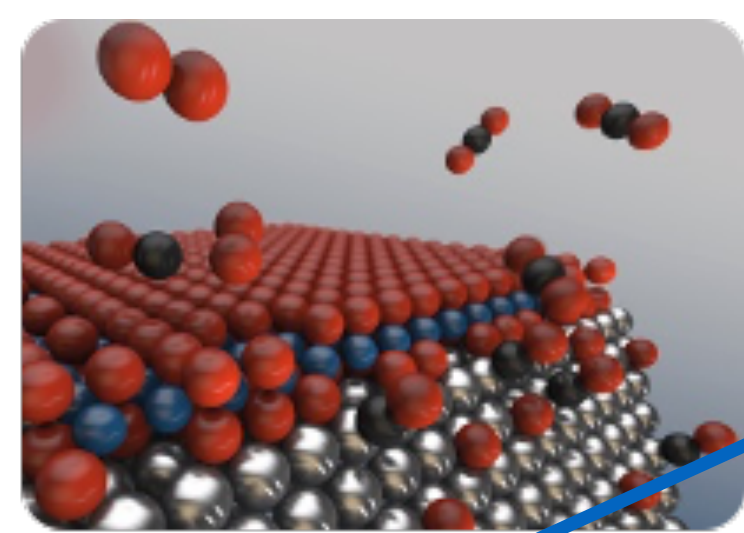
How do the large structure of the Universe form?

Can we understand infections at the molecular level?

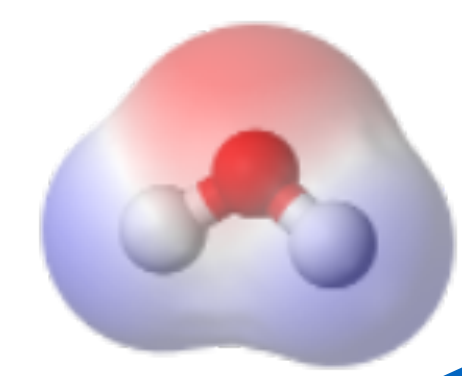
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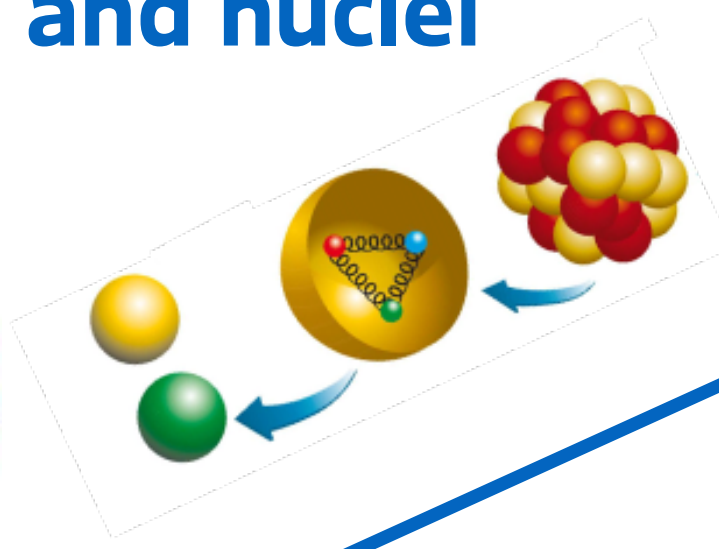
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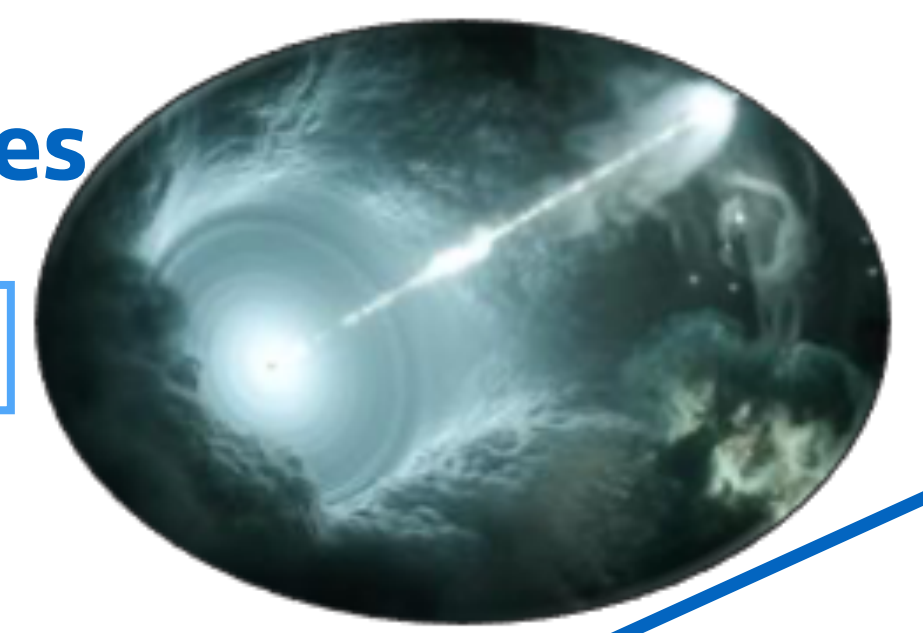
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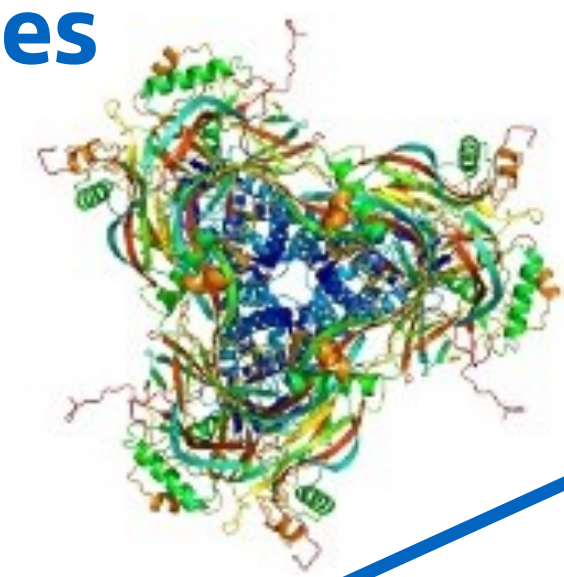
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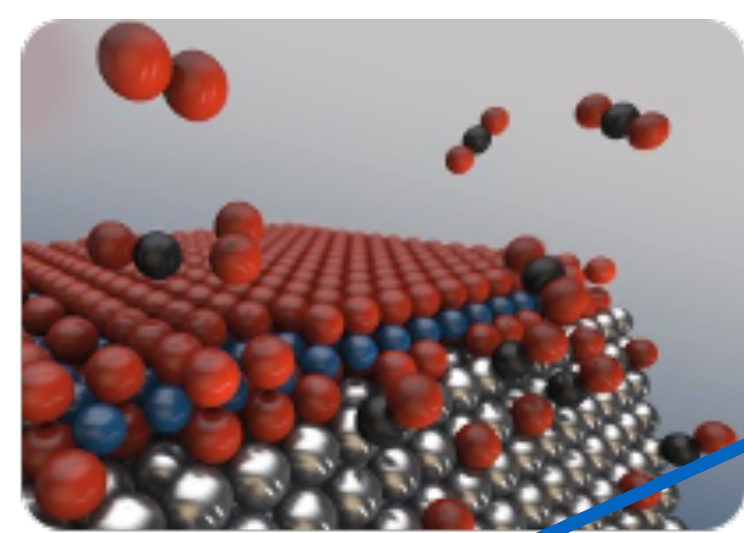
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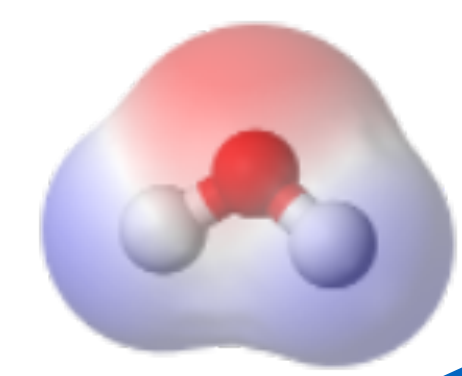


How to control the function of materials at the single electron and spin level?

Nanoparticles



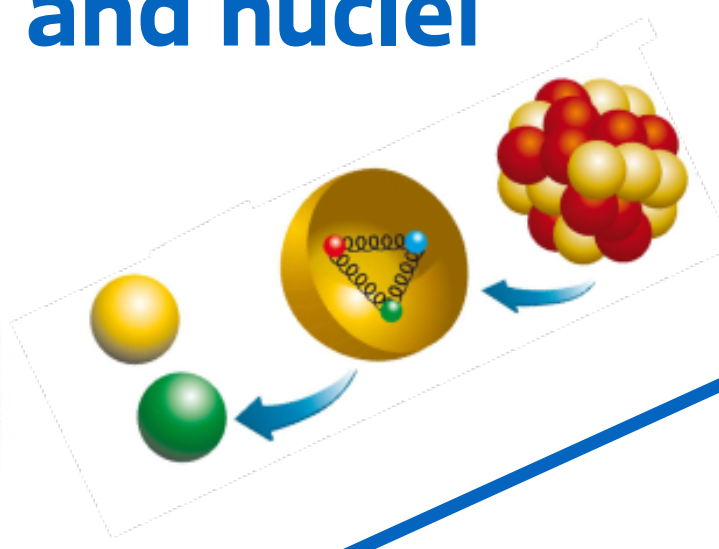
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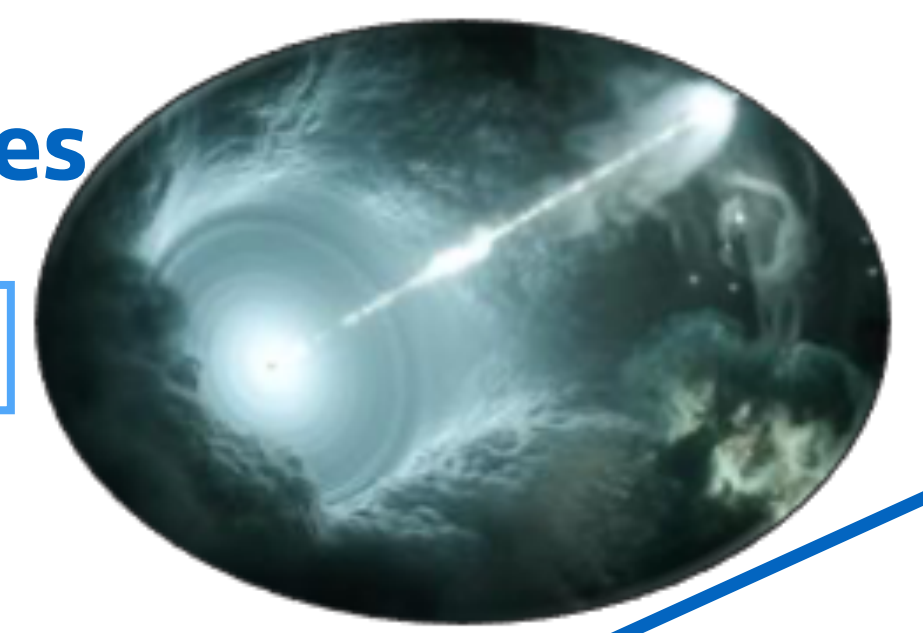
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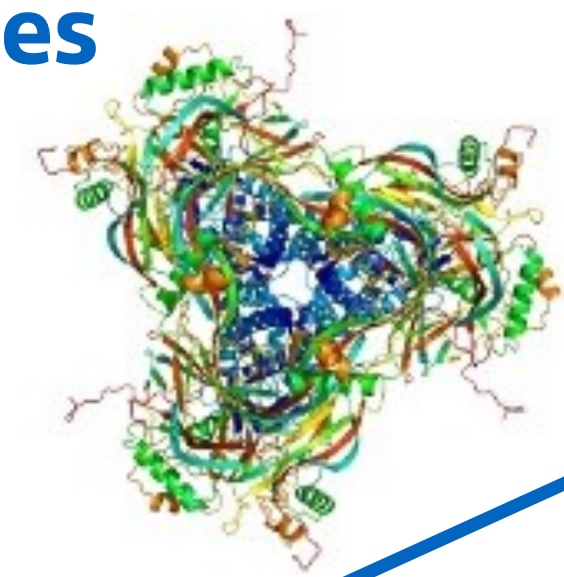
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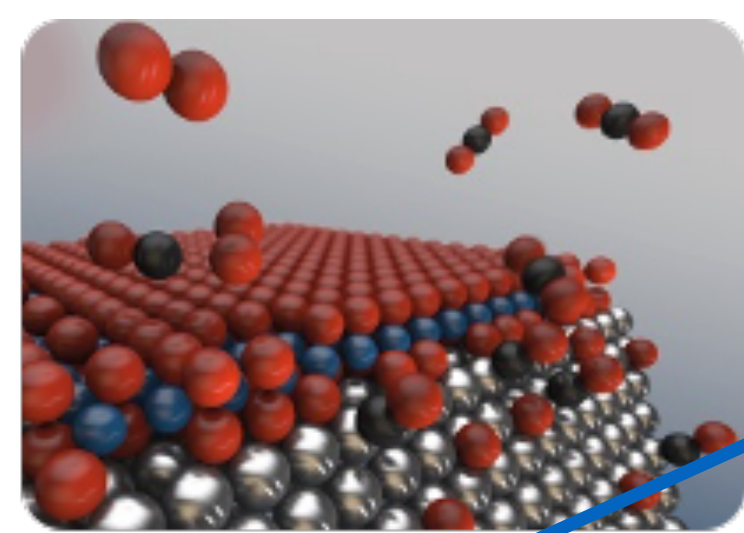
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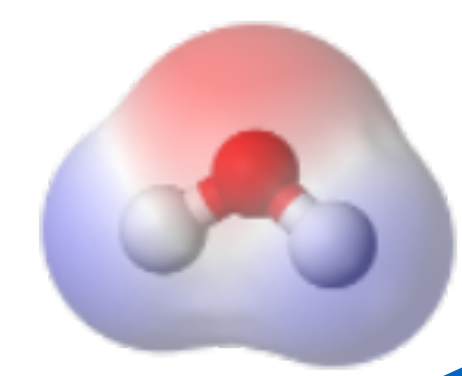
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Is there a common origin to all fundamental forces?

Molecules

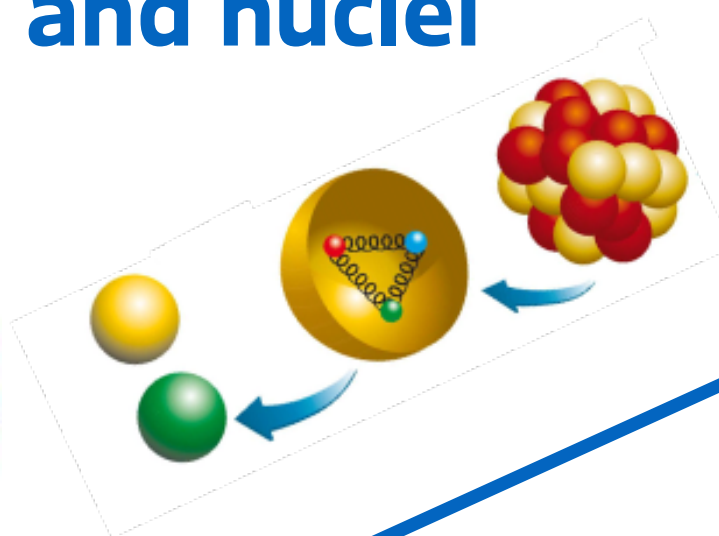


What is the mechanism that give particles their masses?

Atoms



Protons and nuclei



Quarks and leptons

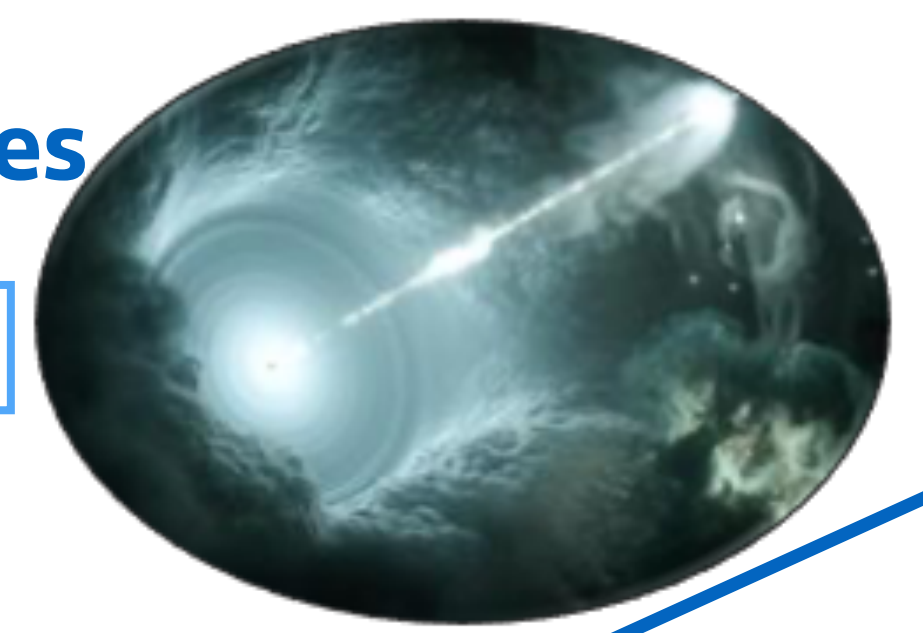




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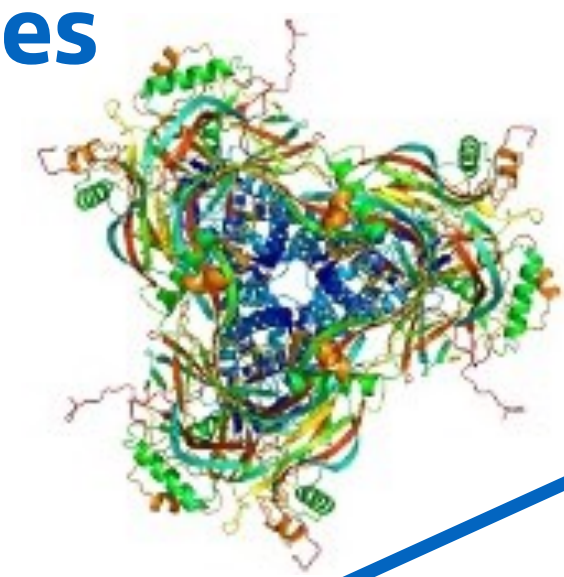
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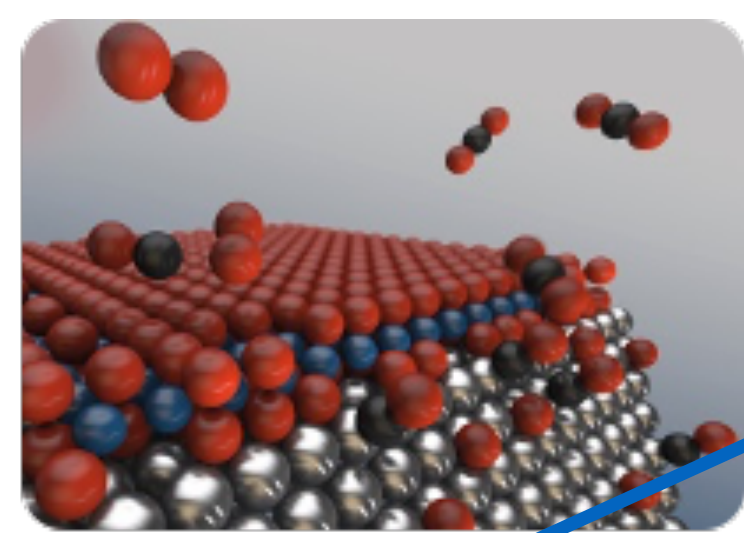
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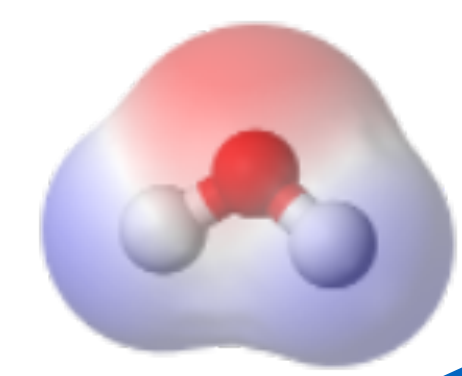
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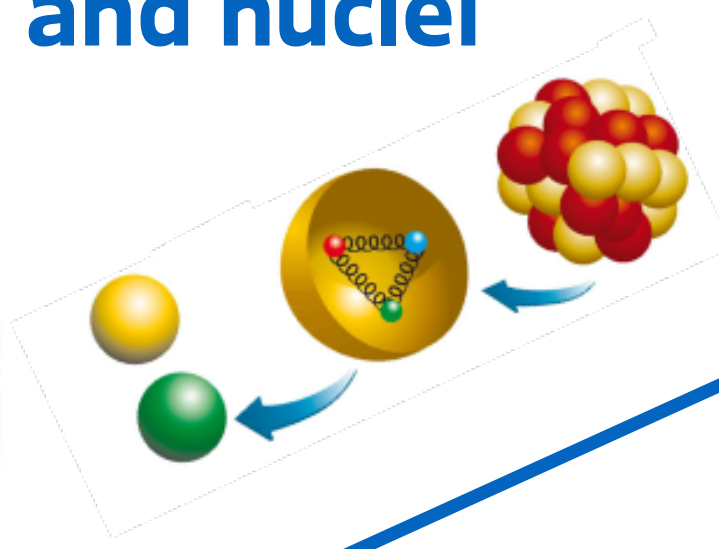


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Detectors



Accelerators

Computing

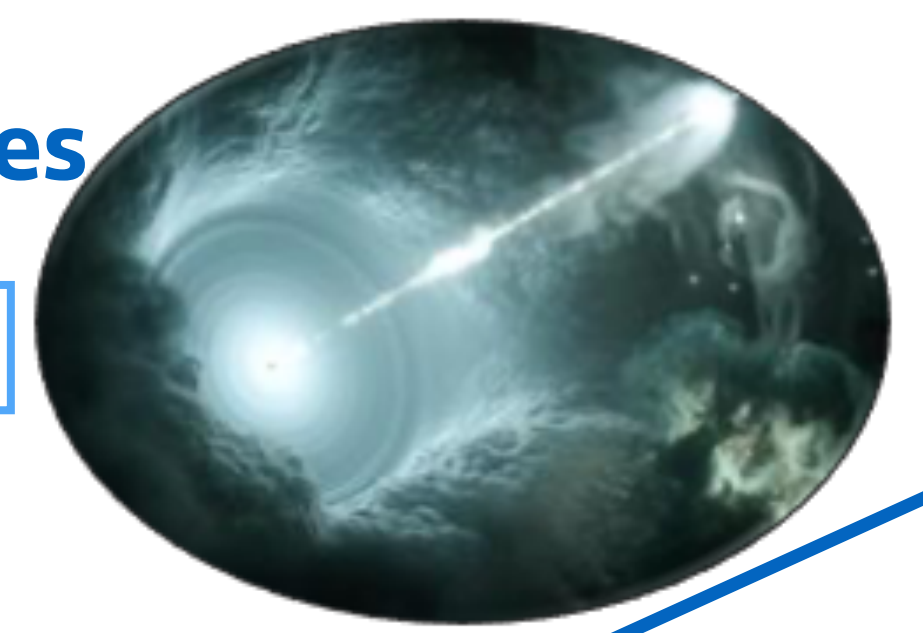
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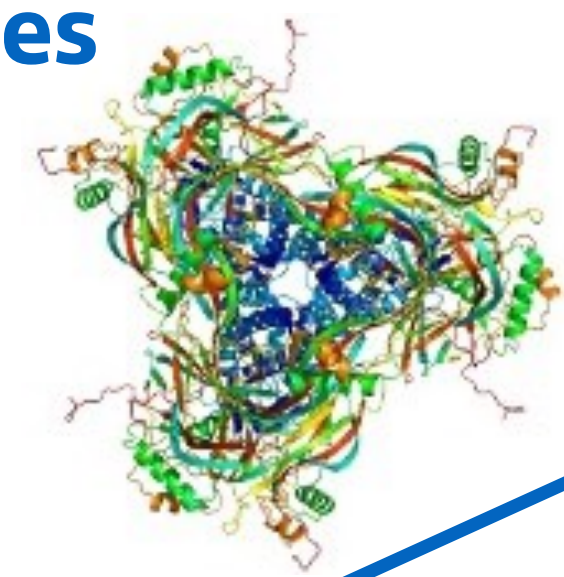
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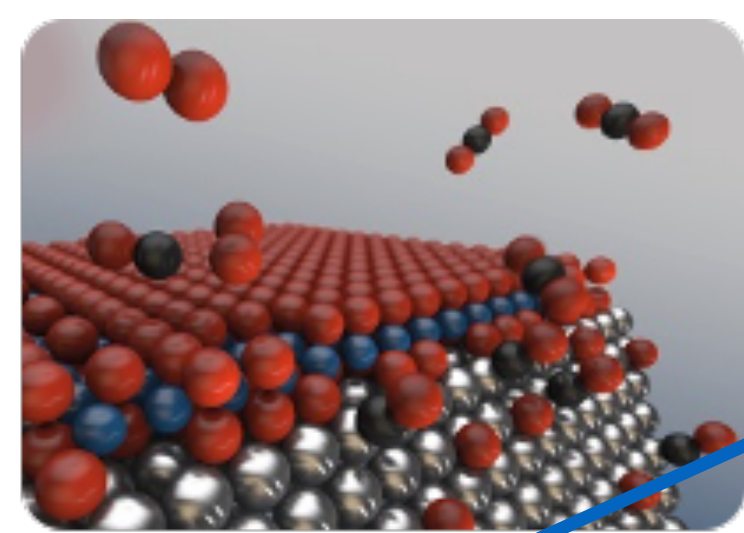
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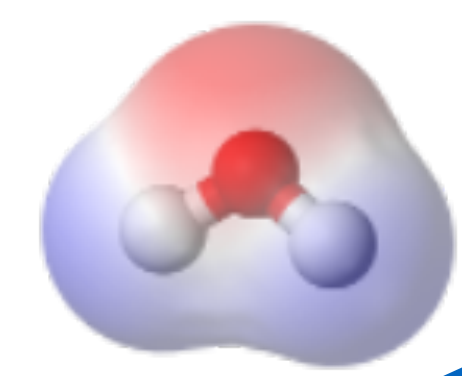
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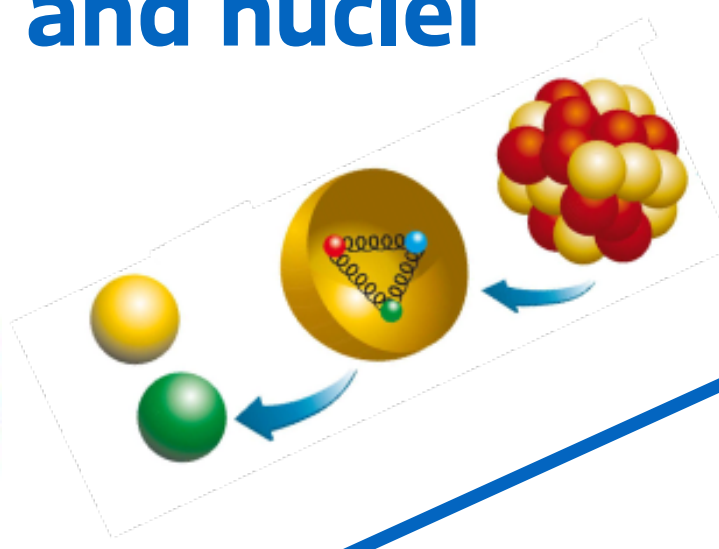


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Quarks and leptons



How to build compact accelerators?

Detectors



Accelerators

How to take millions of pictures / second?

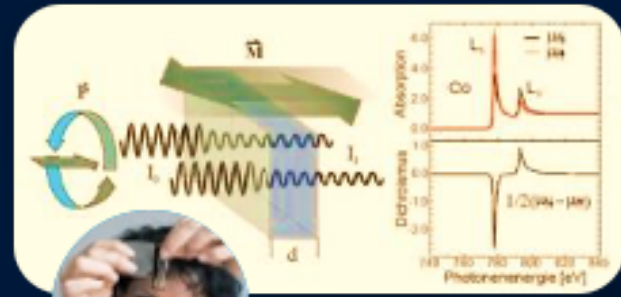
Computing

How to process all this data?

# 65 years "Decoding of matter"

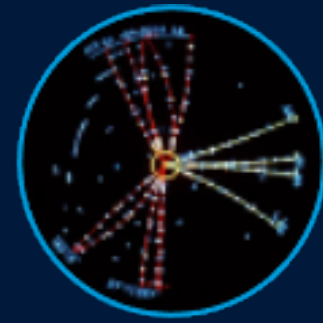


Werner Heisenberg

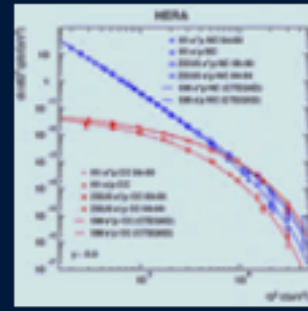


XMCD Effekt

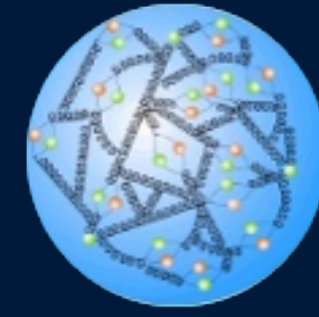
Schütz



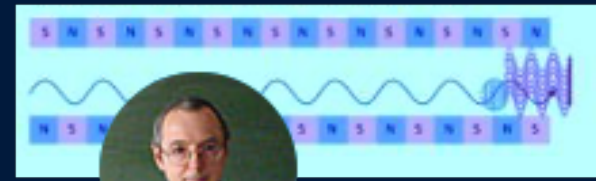
Gluon



Elektroschwache Vereinigung



Proton Struktur



Single-Path X-ray Laser

Saldin



Ribosom Struktur

Yonath



TESLA Technologie



XFEL LINAC



SFX

Chapman



Plasma-Beschleuniger

Leemans

DESY



1959

DORIS



1971

1974

PETRA



1981

DORIS-SR



HERA



1991 Zeuthen

1993

FLASH



2000

PETRA III-SR



2009

XFEL



2024



W. Jentschke



W. Paul



H. Schopper



V. Sörgel



B. Wiik



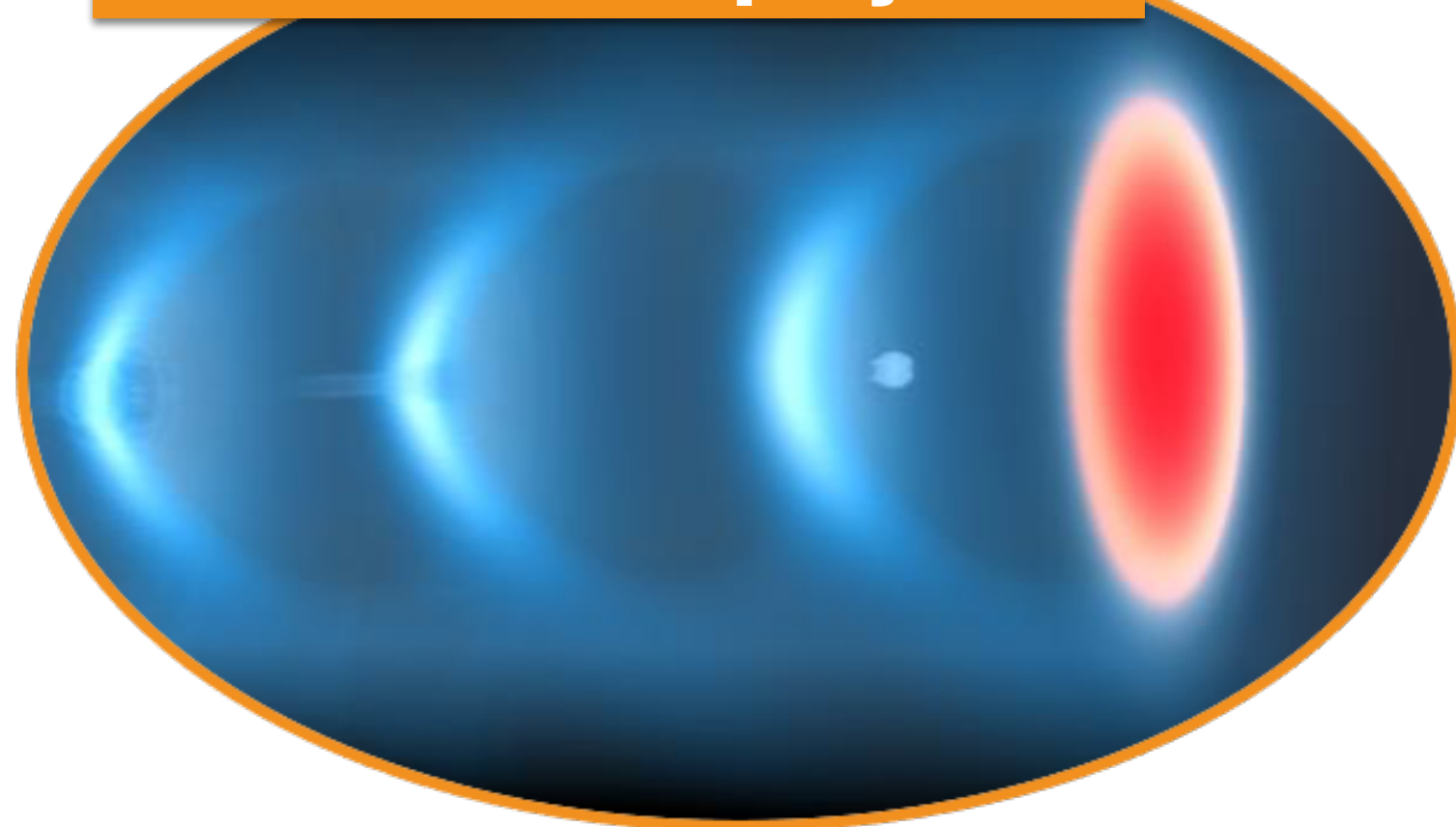
A. Wagner



H. Dosch

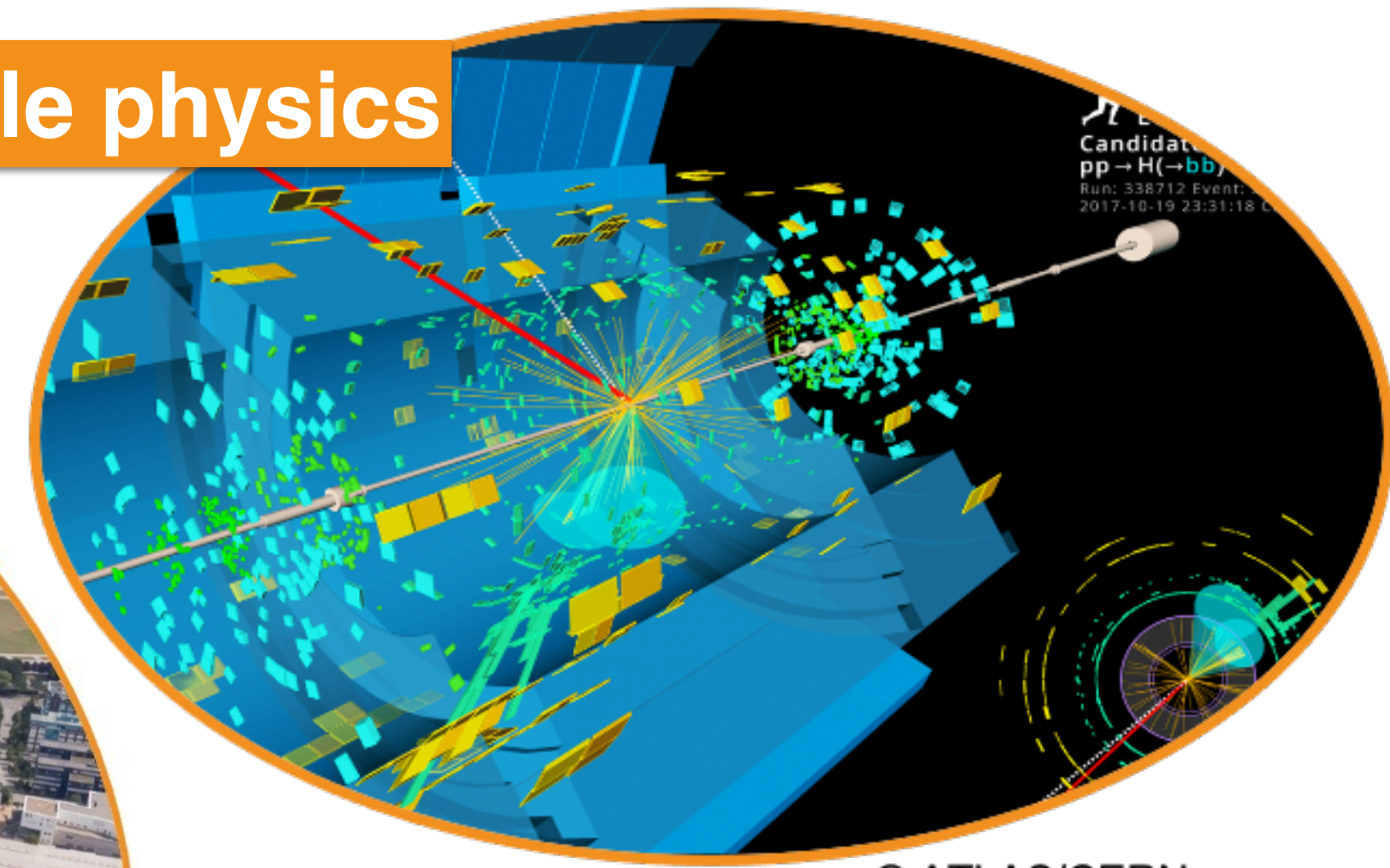
# DESY activities

## Accelerator physics



© DESY/UHH/A. Pousan

## Particle physics



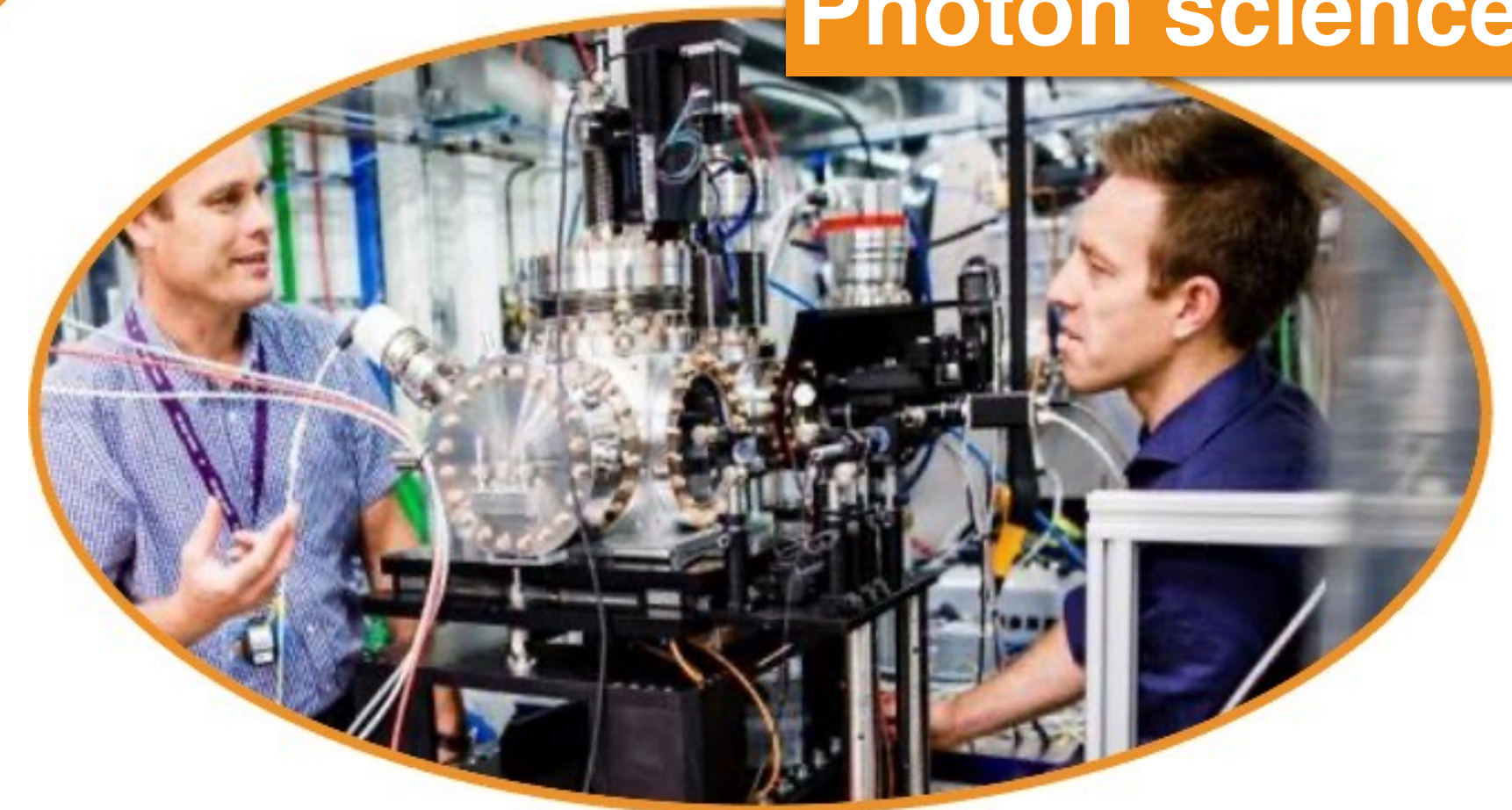
© ATLAS/CERN



## Astro-particle physics

© NASA/Swift/  
Dana Berry

## Photon science

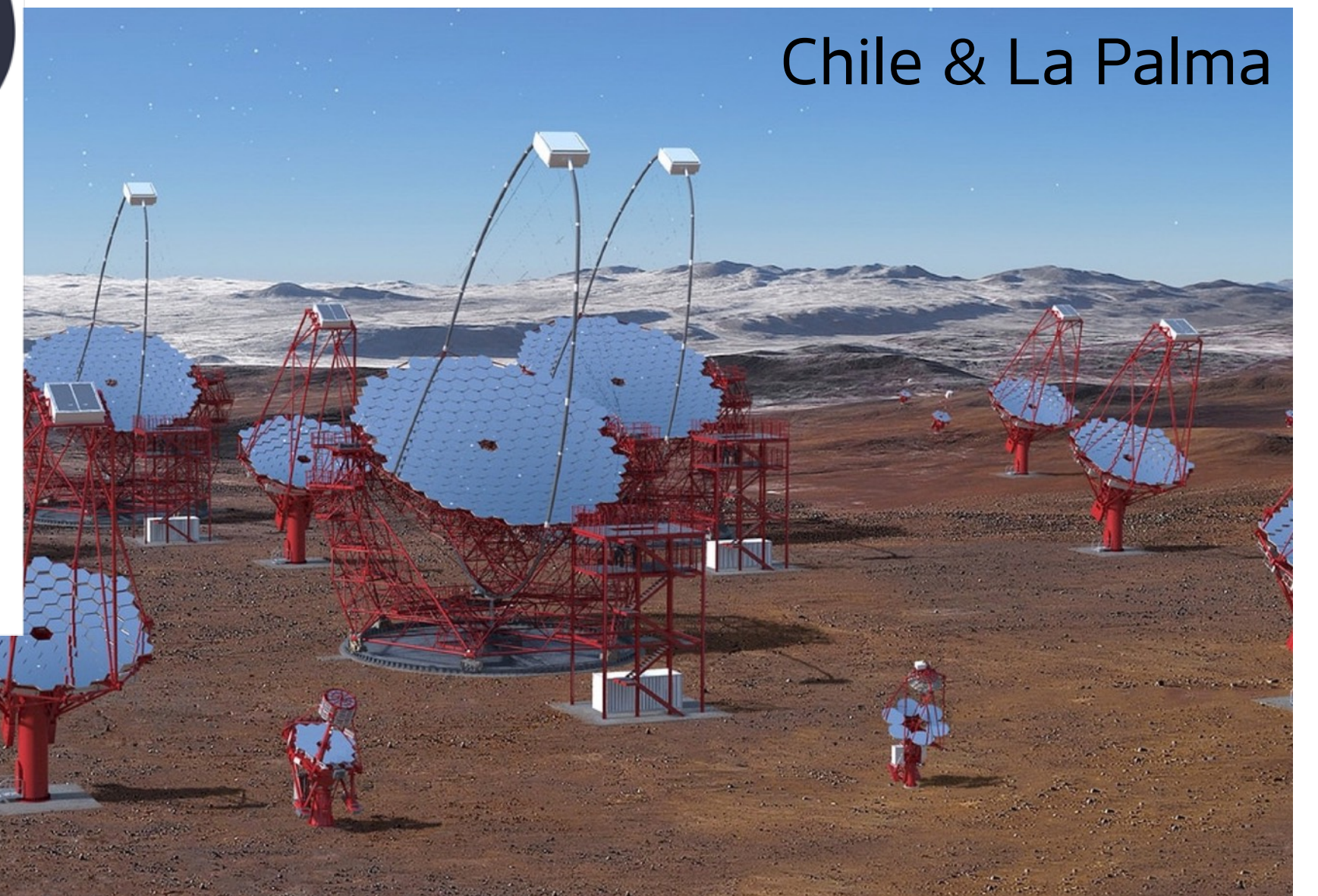
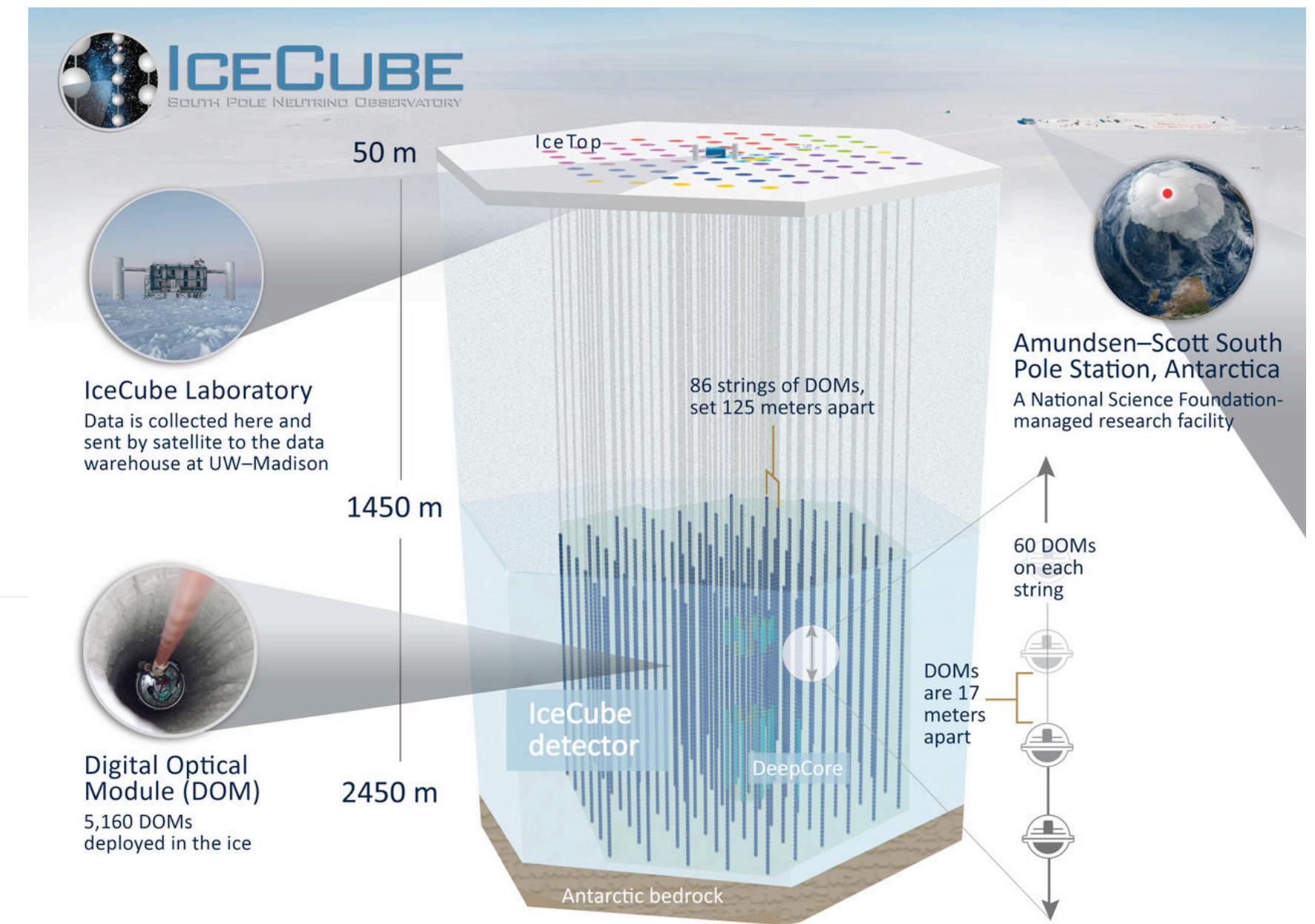
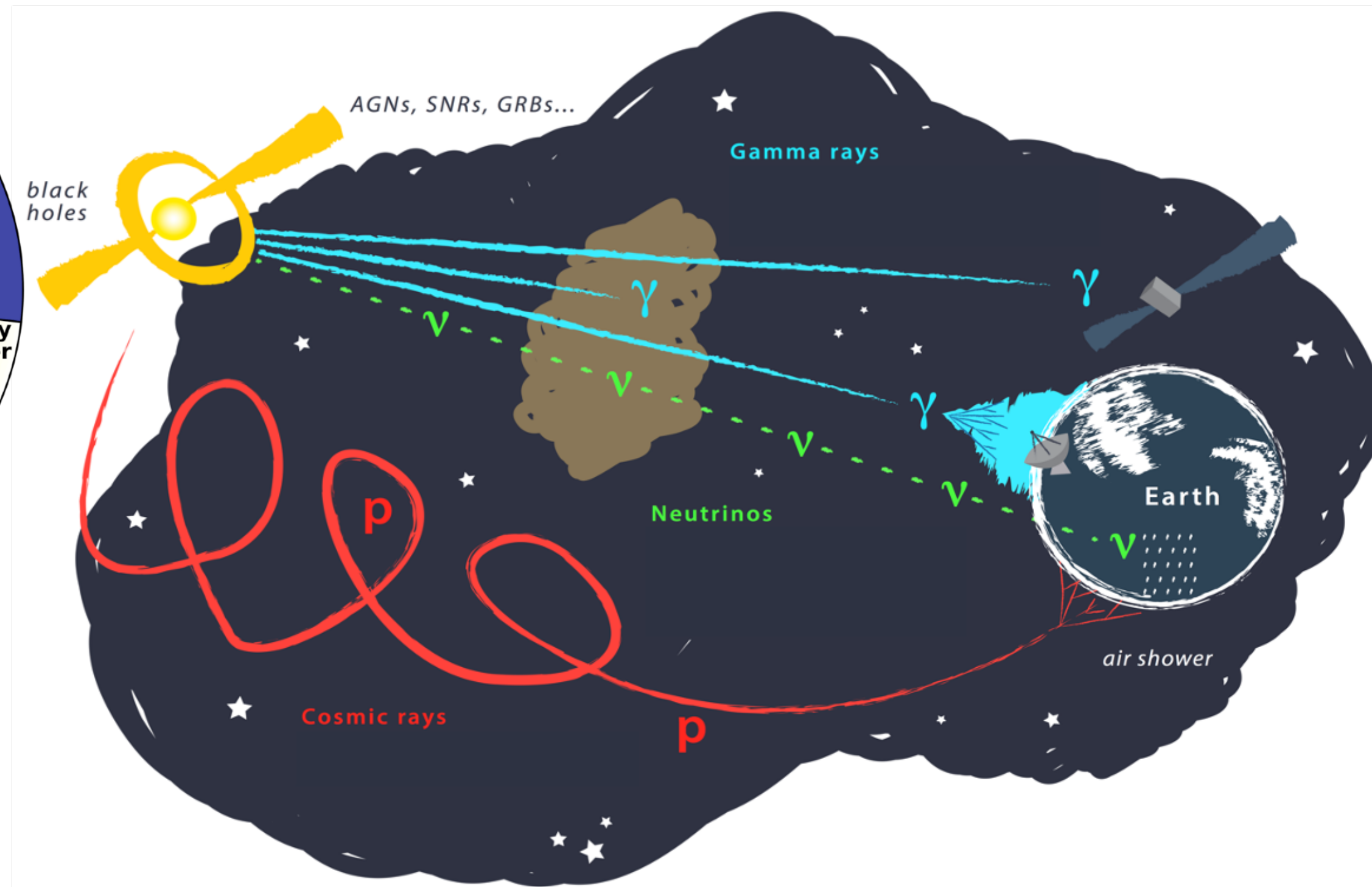
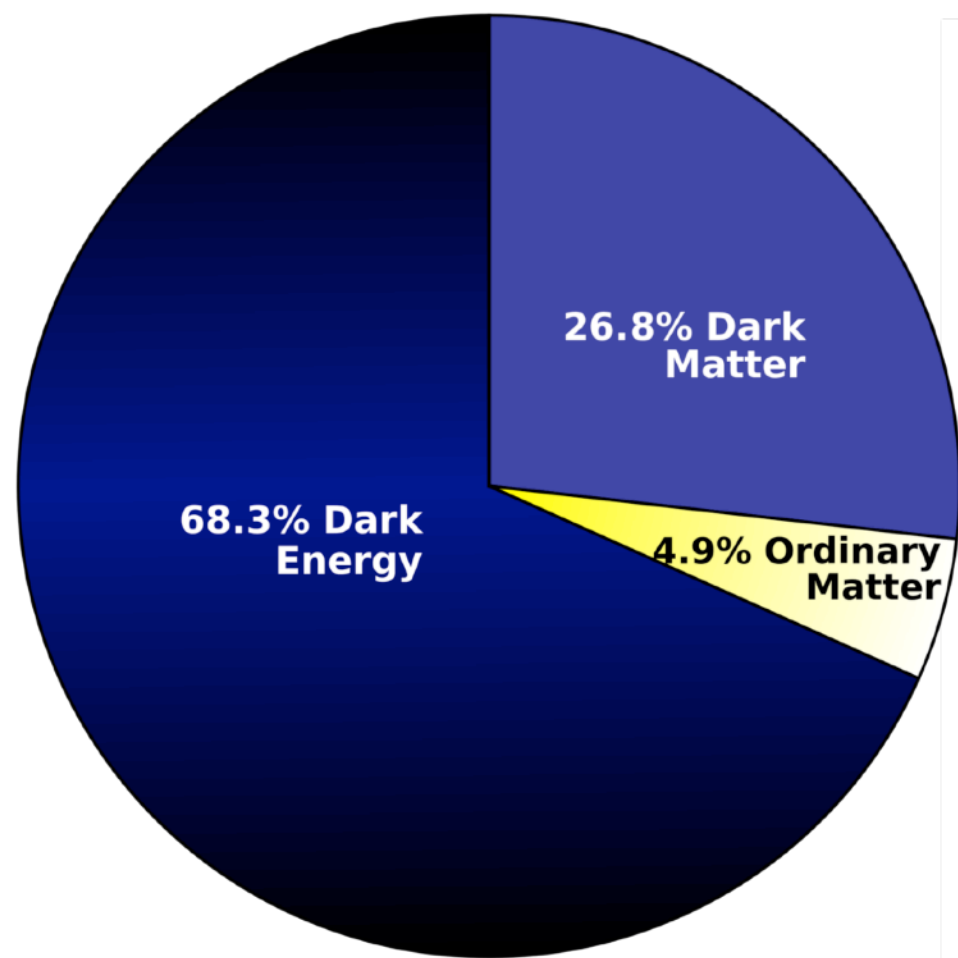


- + transverse activities:
  - Theory
  - mechanics
  - electronics

# Astro-particle physics

# Astro-particles

- How do the large structures in the Universe form?
- What is dark matter?



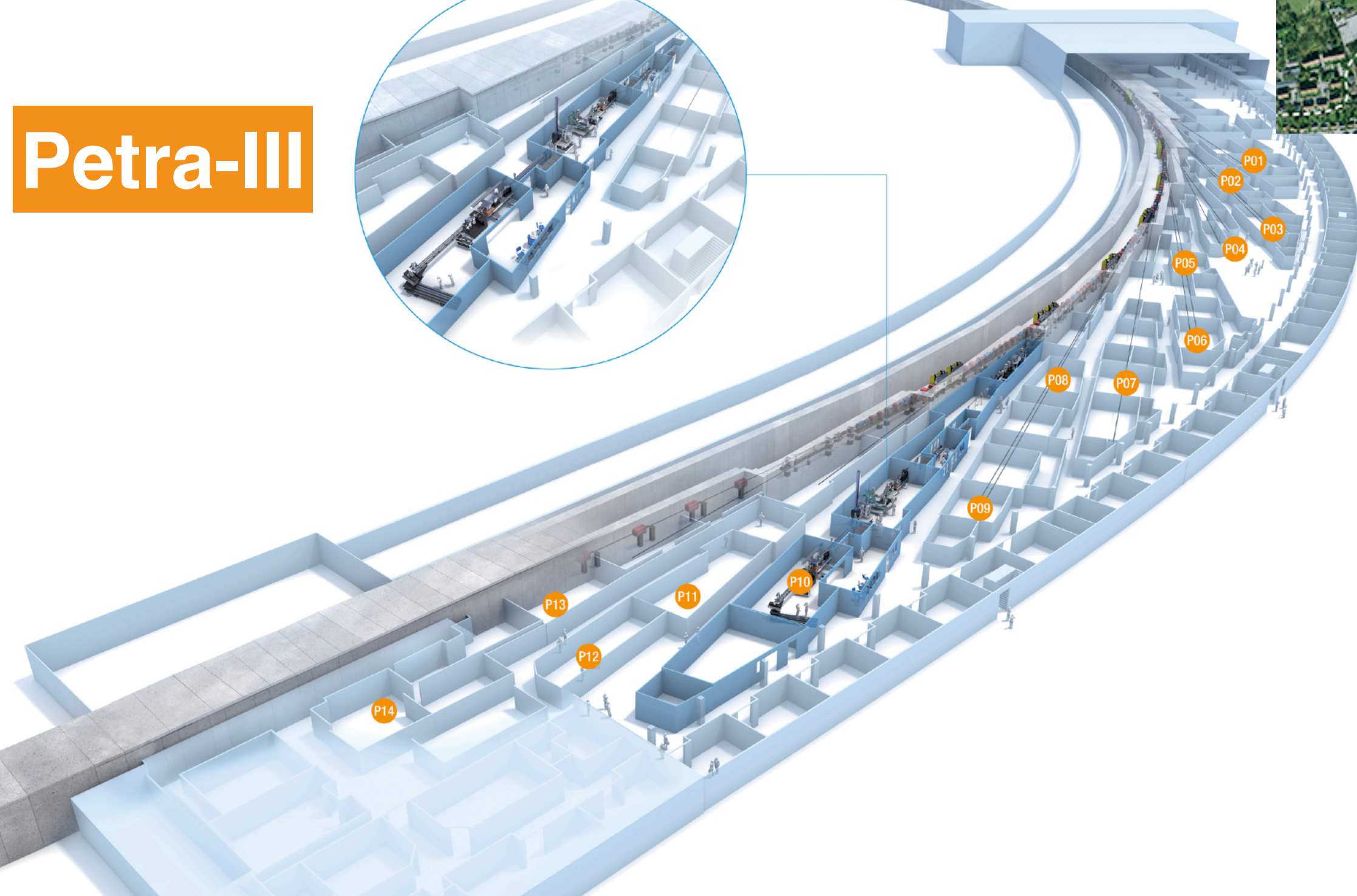
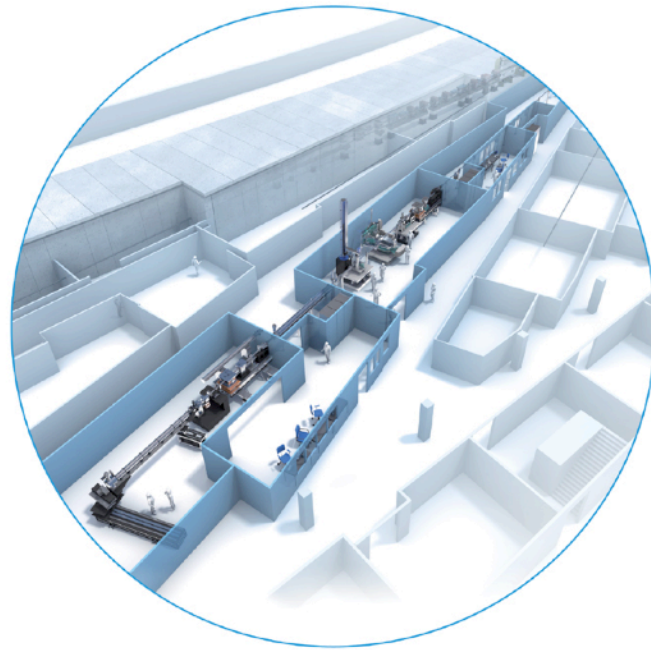
CTA: Europe's top priority in astro-particle physics

# Photon Science

# Photon science

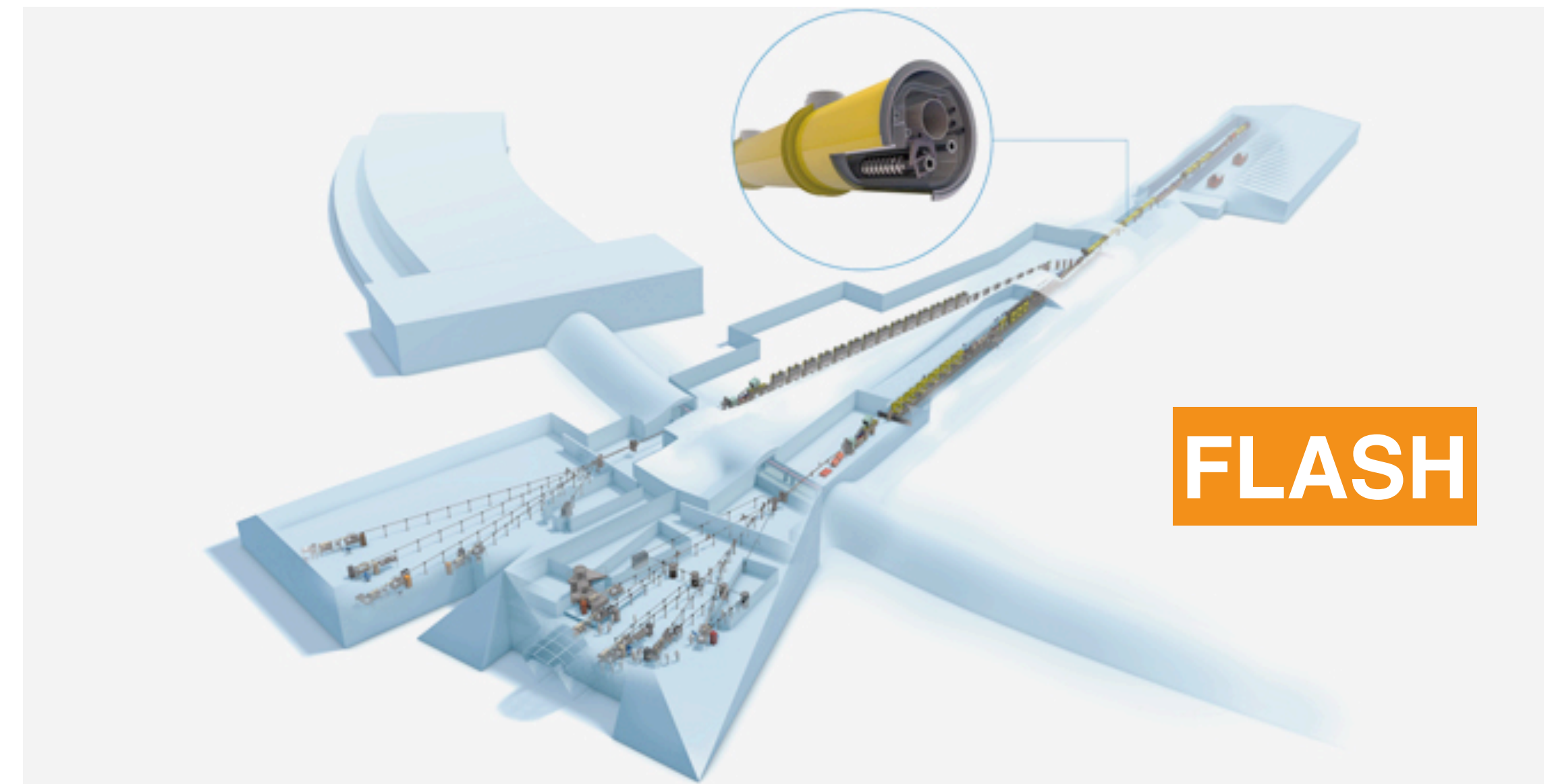


**Petra-III**



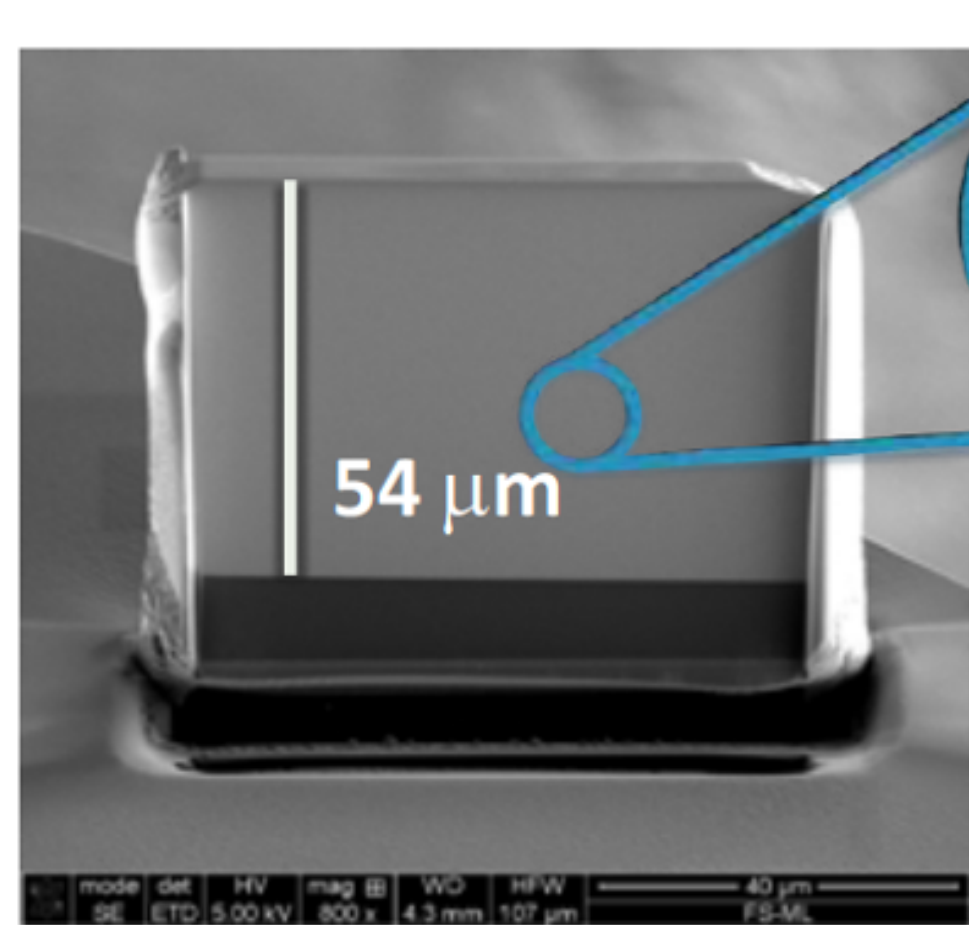
Among the world's brightest X-ray sources

One of the world's largest synchrotron light-source

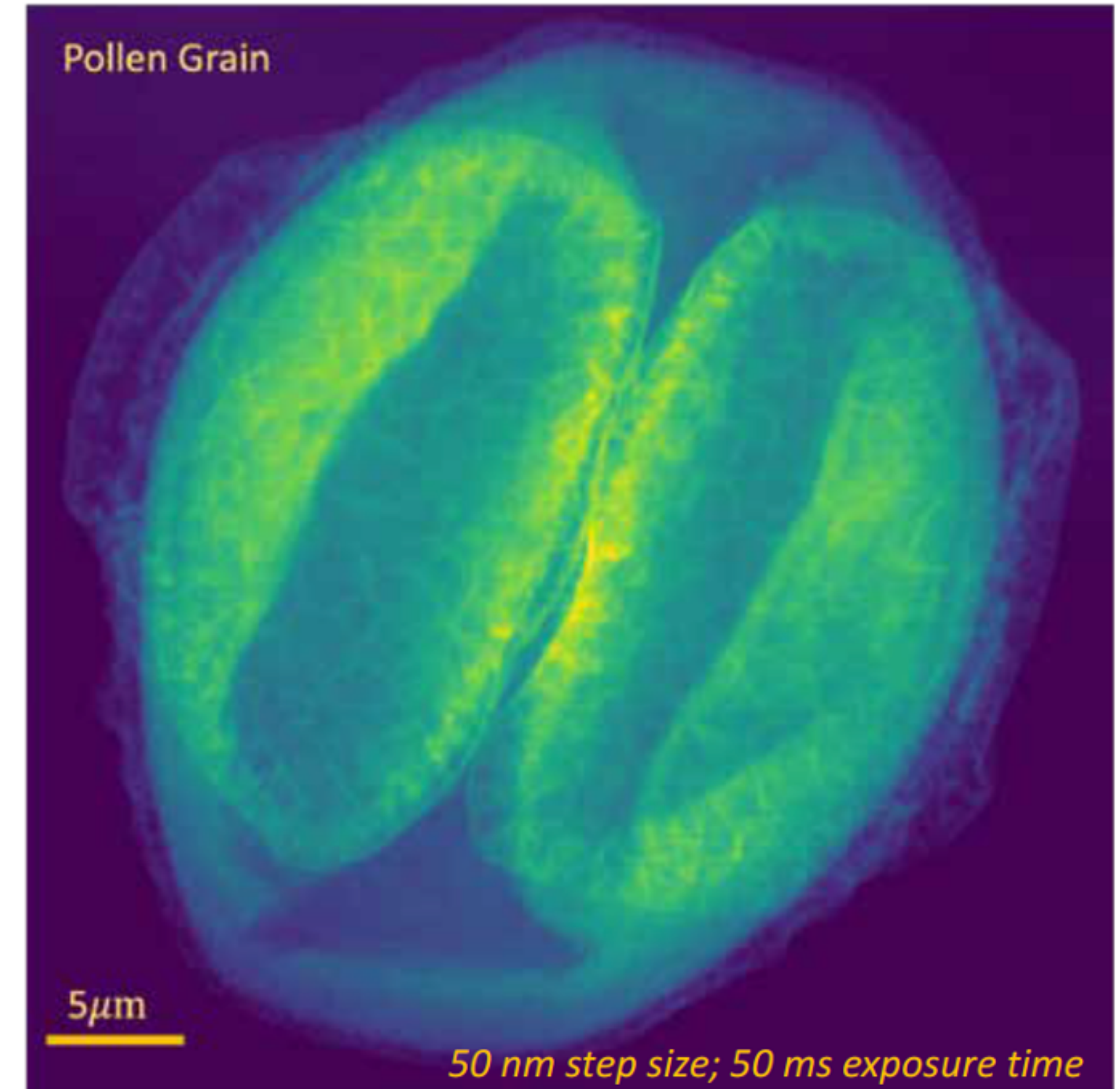




# Photon science



Multilayer Laue lens: <10 nm focus  
90% efficiency at 60 keV  
Saša Bajt, DESY/FS-ML



- fully hydrated pollen grain
- no visible sign of radiation damage after exposure

Courtesy: Sasa Bajt

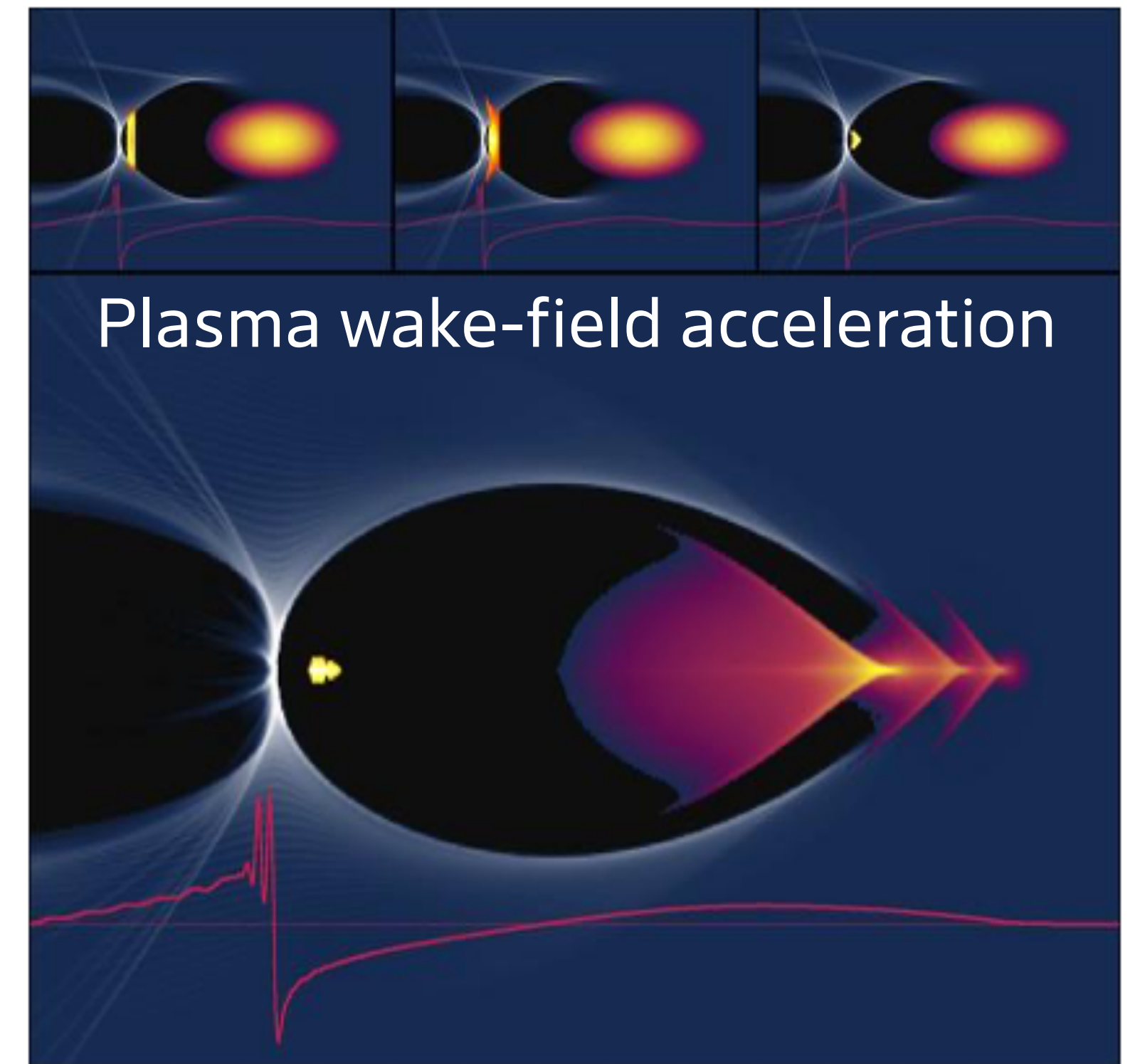
- Applications:
  - New materials
  - Study of Covid-19 infected tissue
  - Ultra-fast processes (snapshots how chemical reactions happen)

# Accelerator physics

# Accelerator physics



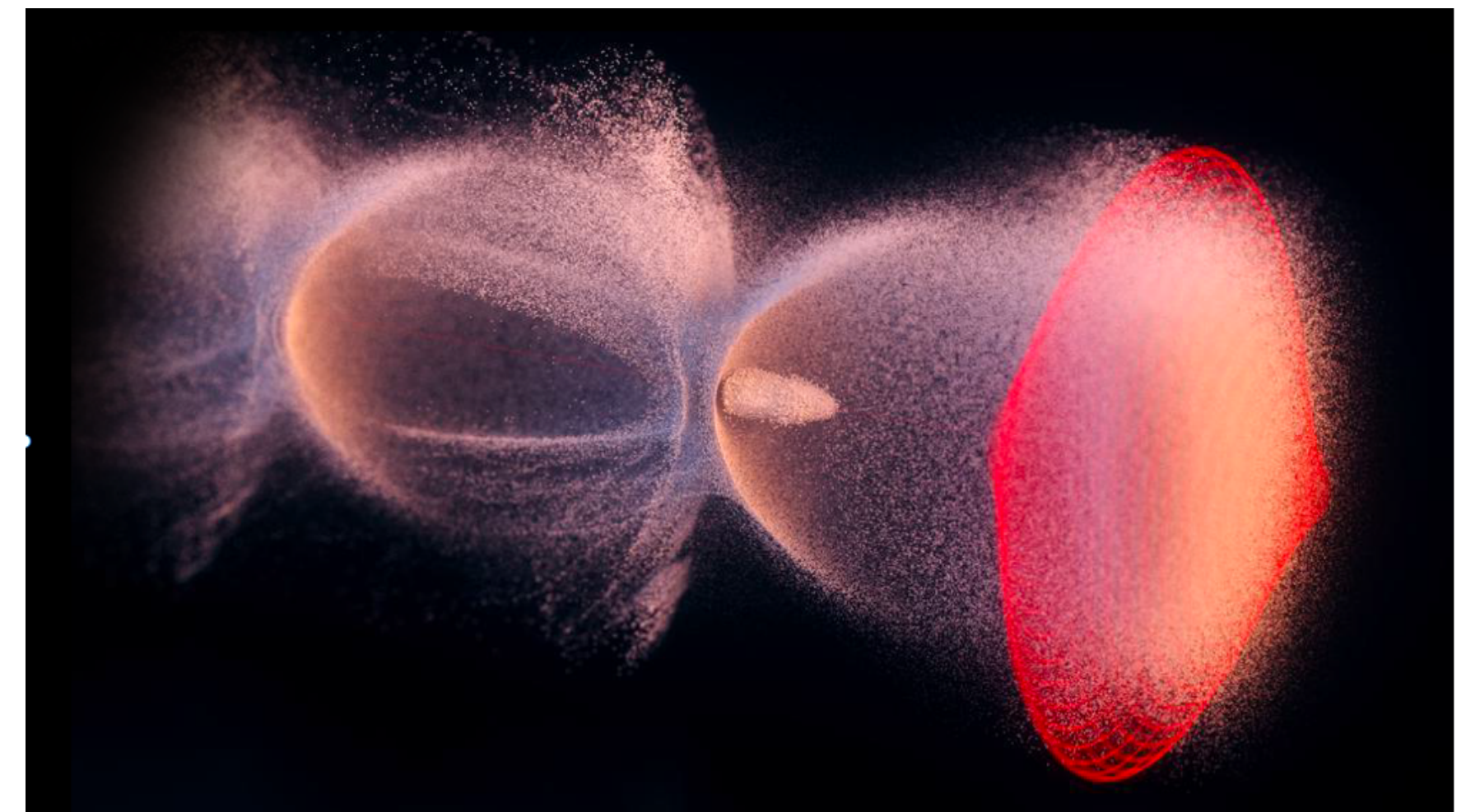
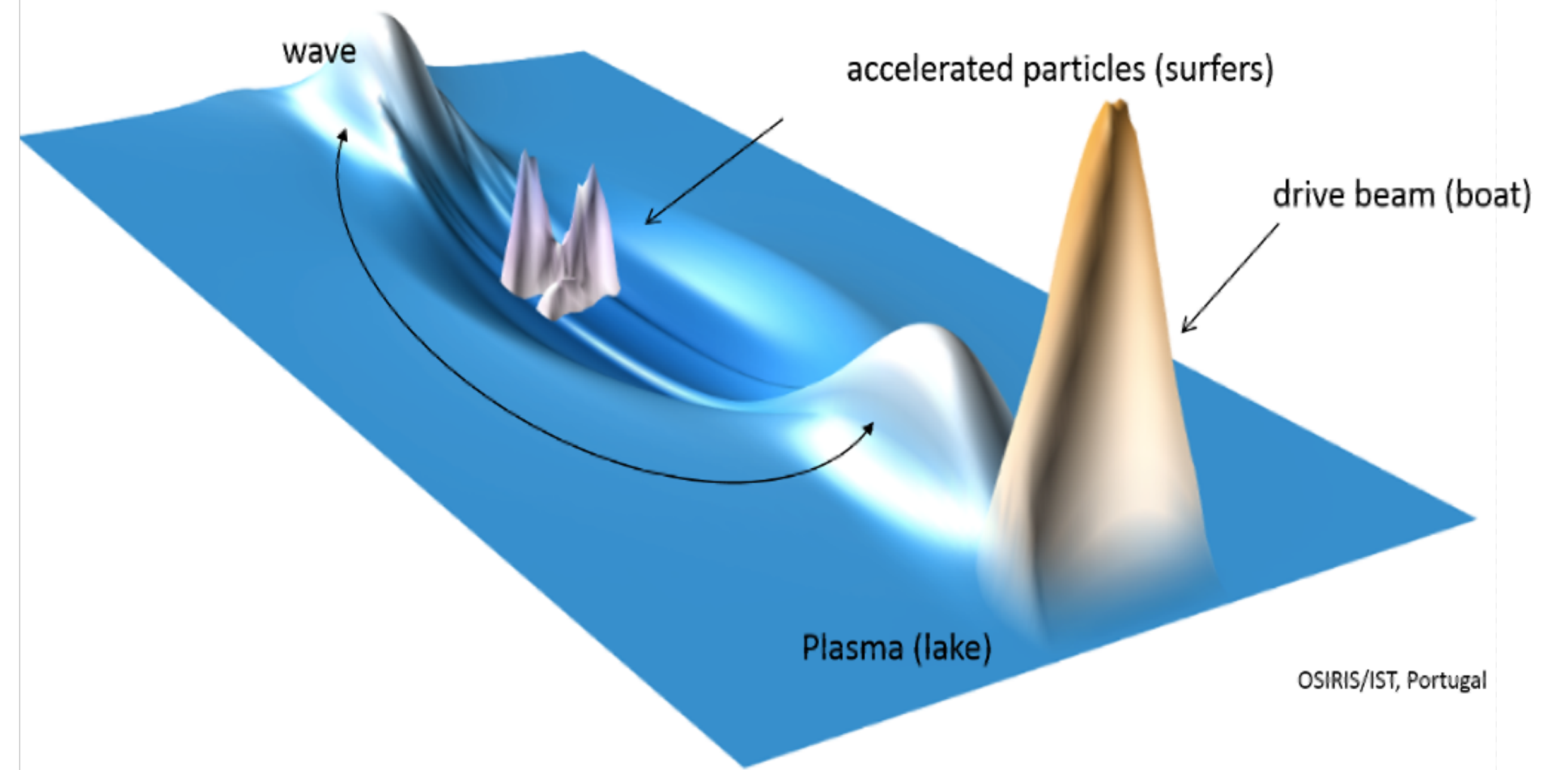
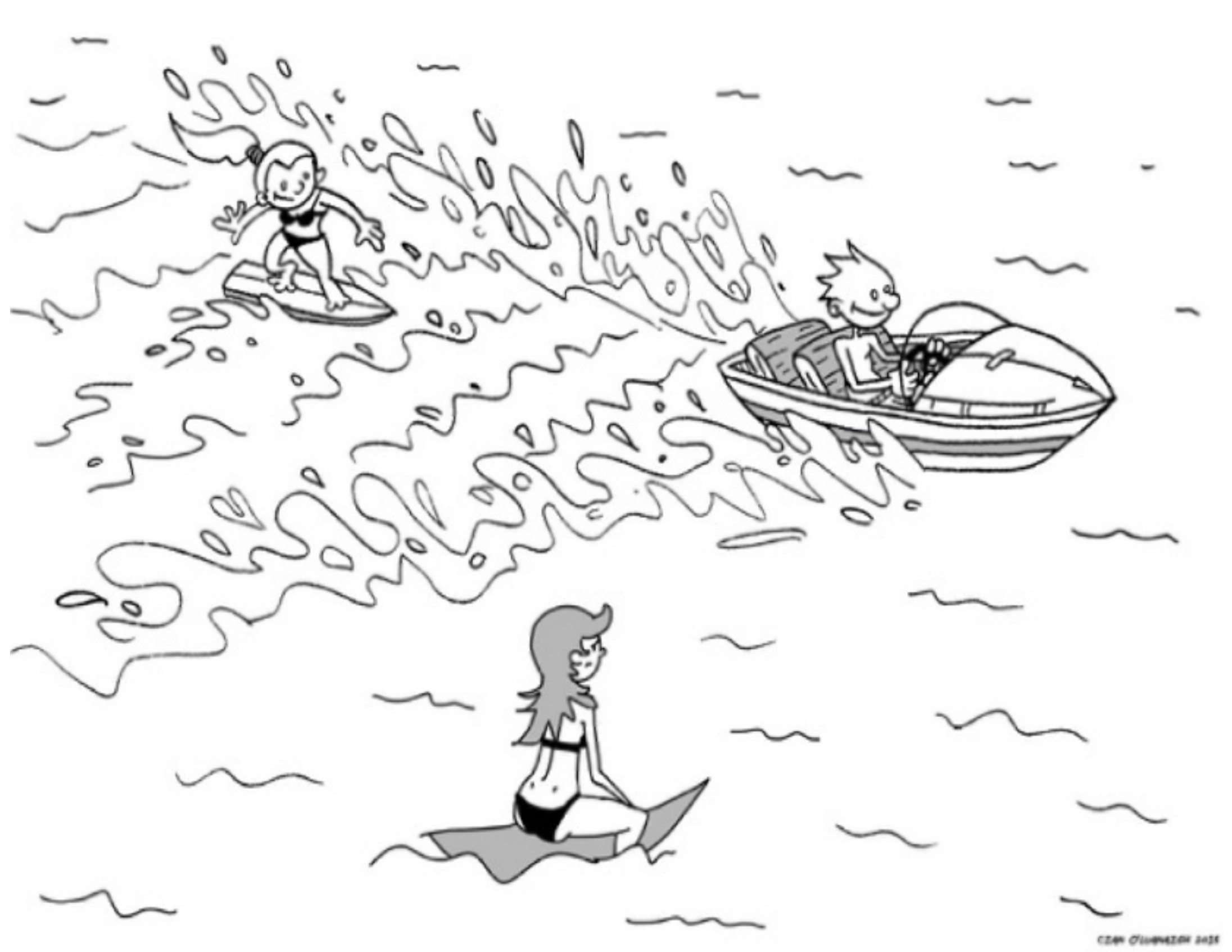
ILC accelerator cavity



Plasma wake-field acceleration

- Pioneering work in DESY facilities: FLASH and EU-XFEL
- Future accelerators get bigger and bigger, more expensive.
  - Can we make them shorter, less expensive?
- Research topics:
  - **Conventional accelerators** with higher gradients
  - **Plasma wake-field acceleration**
  - Muon colliders

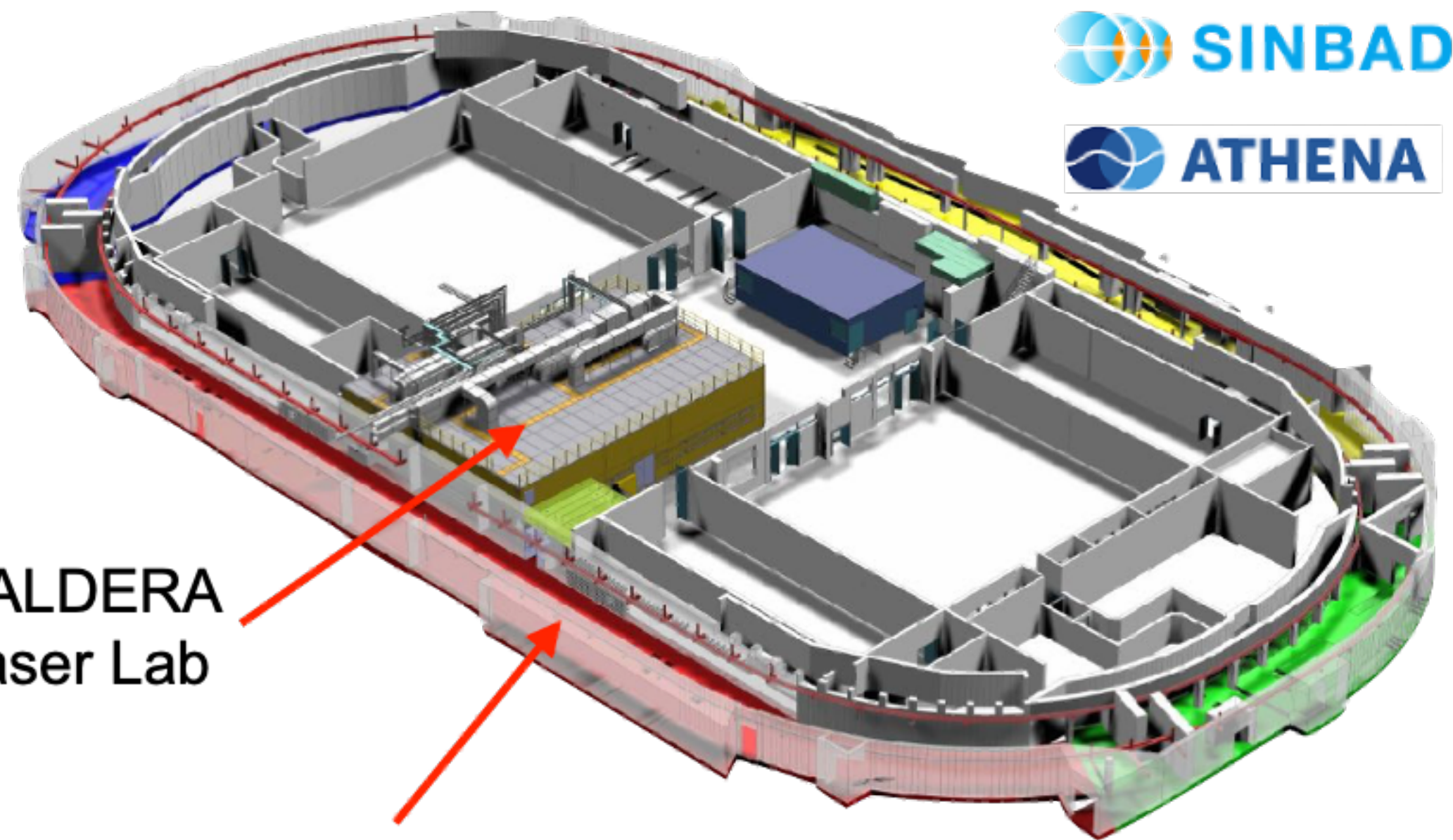
# Plasma wake-field acceleration



Particles surfing the plasma wave.  
Up to 1000x stronger acceleration "gradient"!

# Beam- and laser-driven acceleration

## KALDERA – kW, kHz laser driver



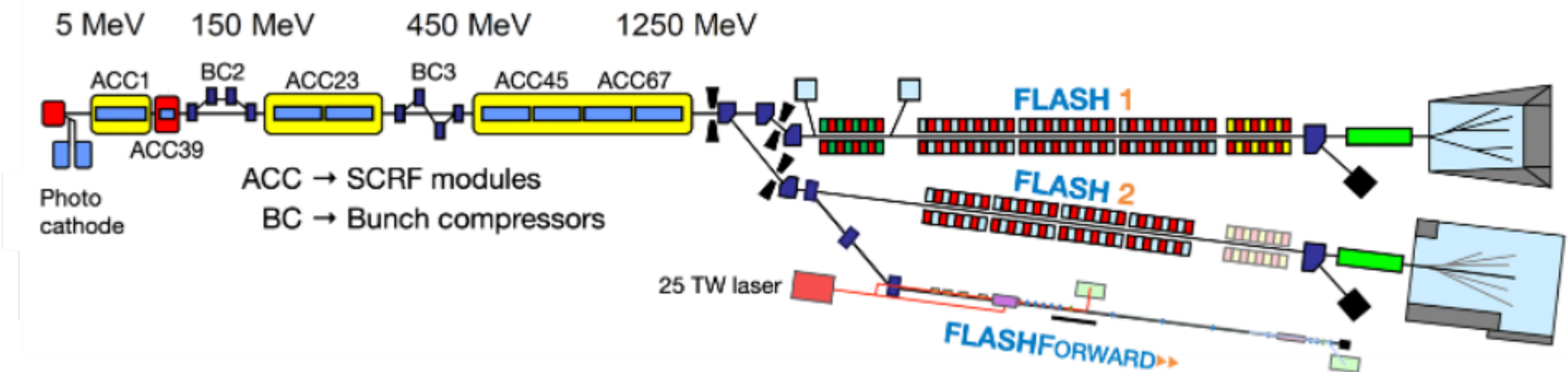
KALDERA  
Laser Lab

LUX II tunnel - kHz LPA

### Science case

- 100 TW-class laser @ kHz-level rep-rate
- active stabilization, feedback and ML/AI
- FEL-quality electron beams

## FLASHFORWARD – 10 kW beam driver



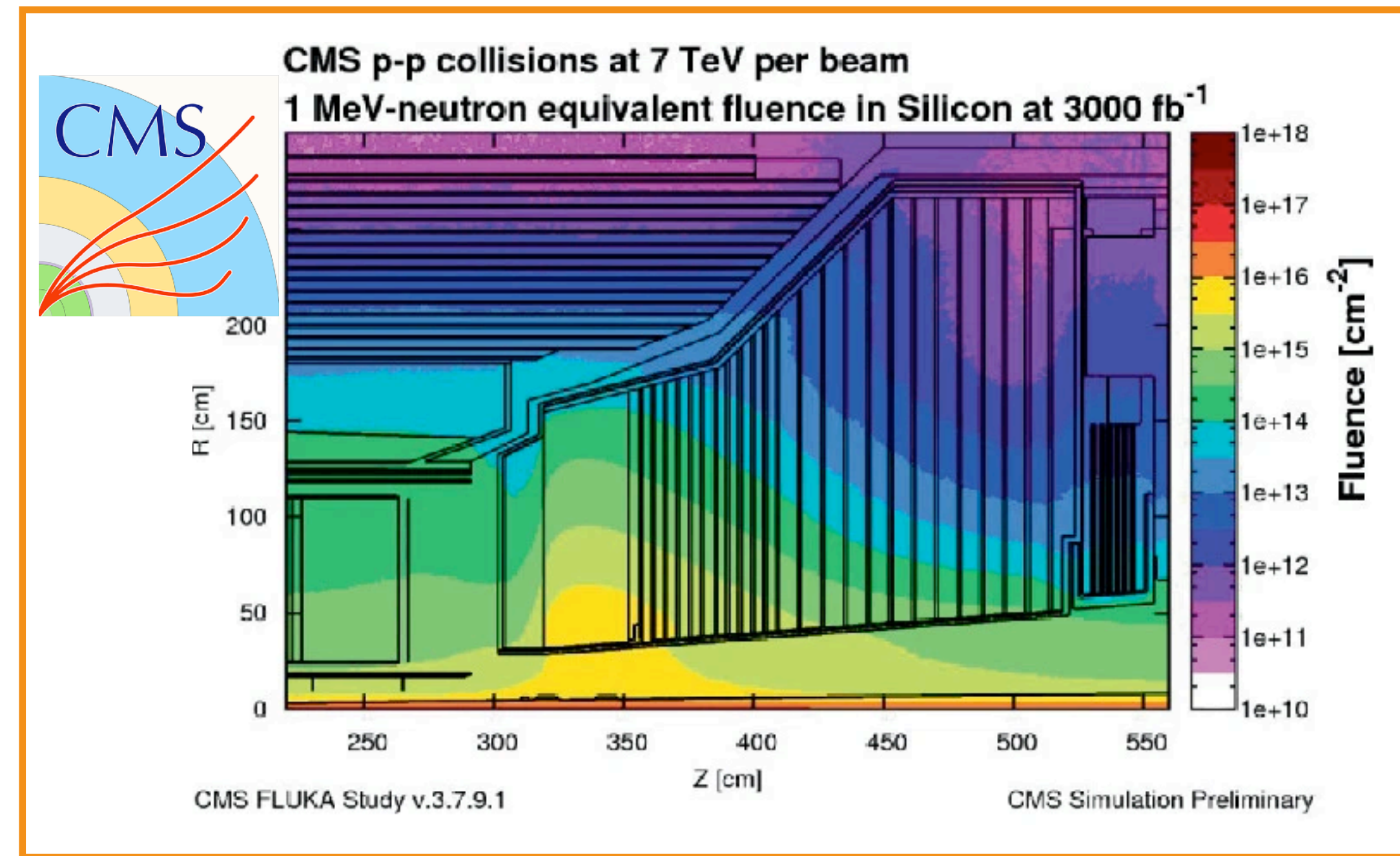
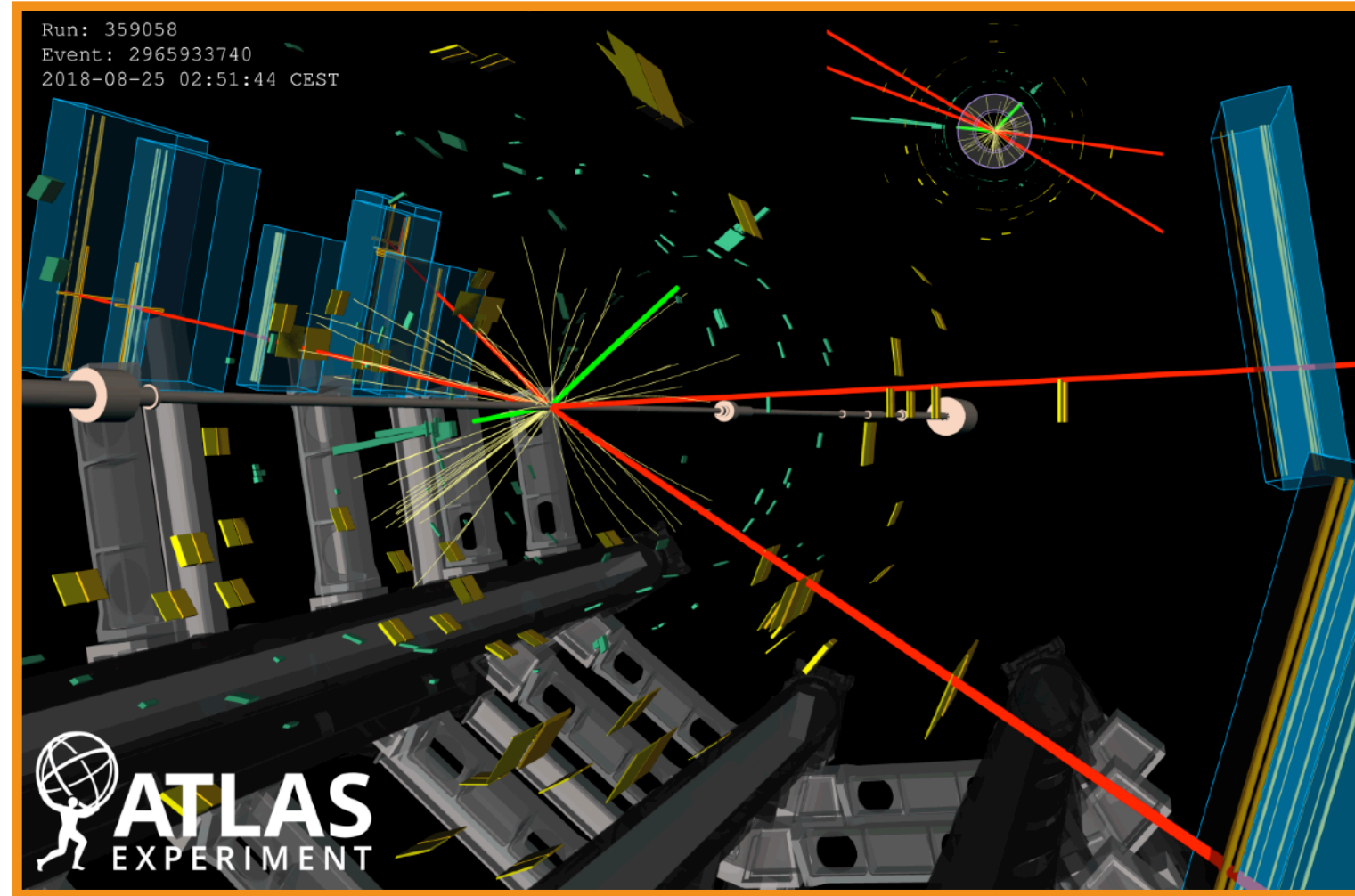
- ~10 kW avg. power, MHz rate acc. based on ILC/XFEL tech.
- Advanced FEL-user facility feedback and feedforward systems

**Goal:** demonstrate a self-consistent plasma accelerator stage with high efficiency, high quality, and high average power

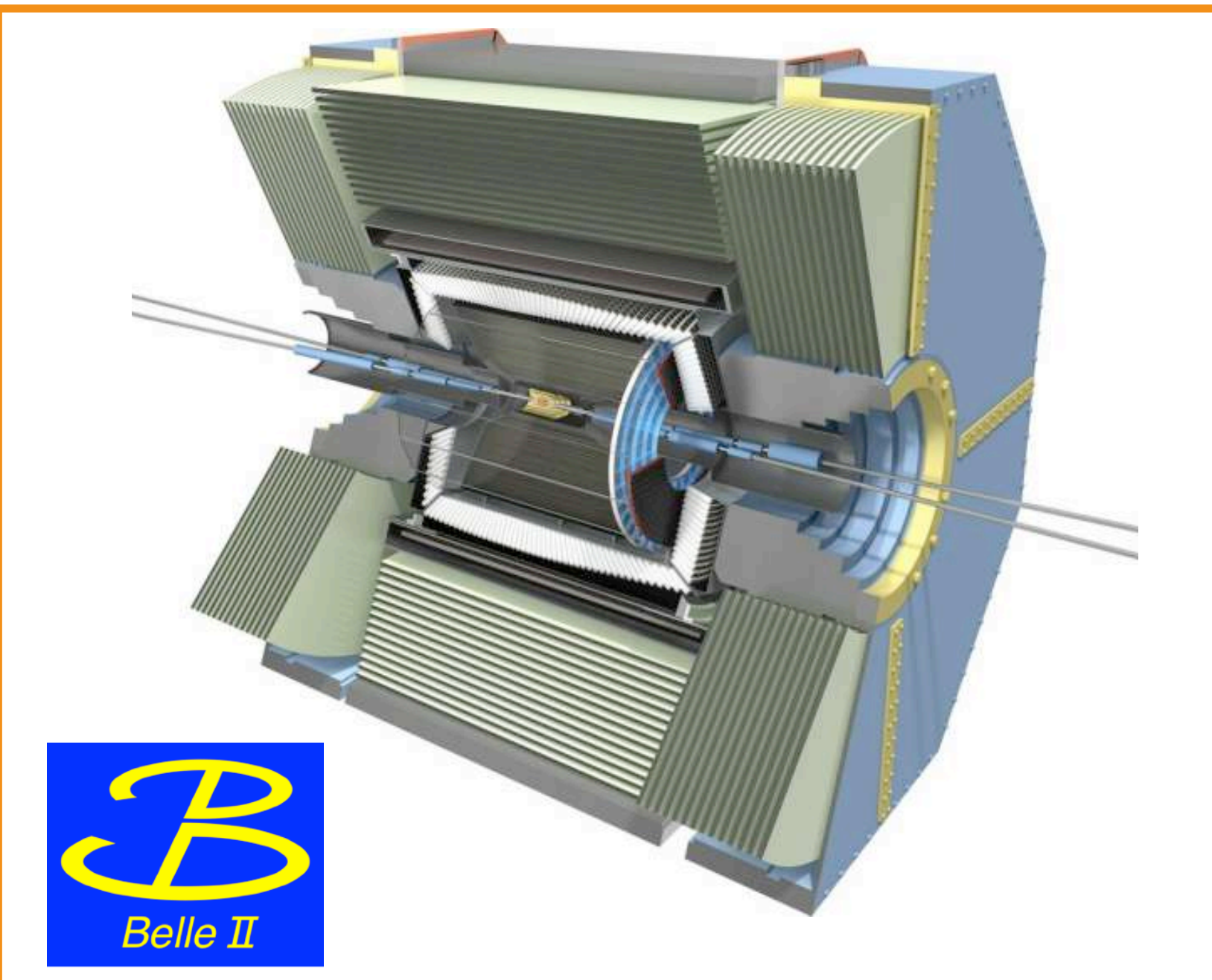


# Particle physics

# Particle physics

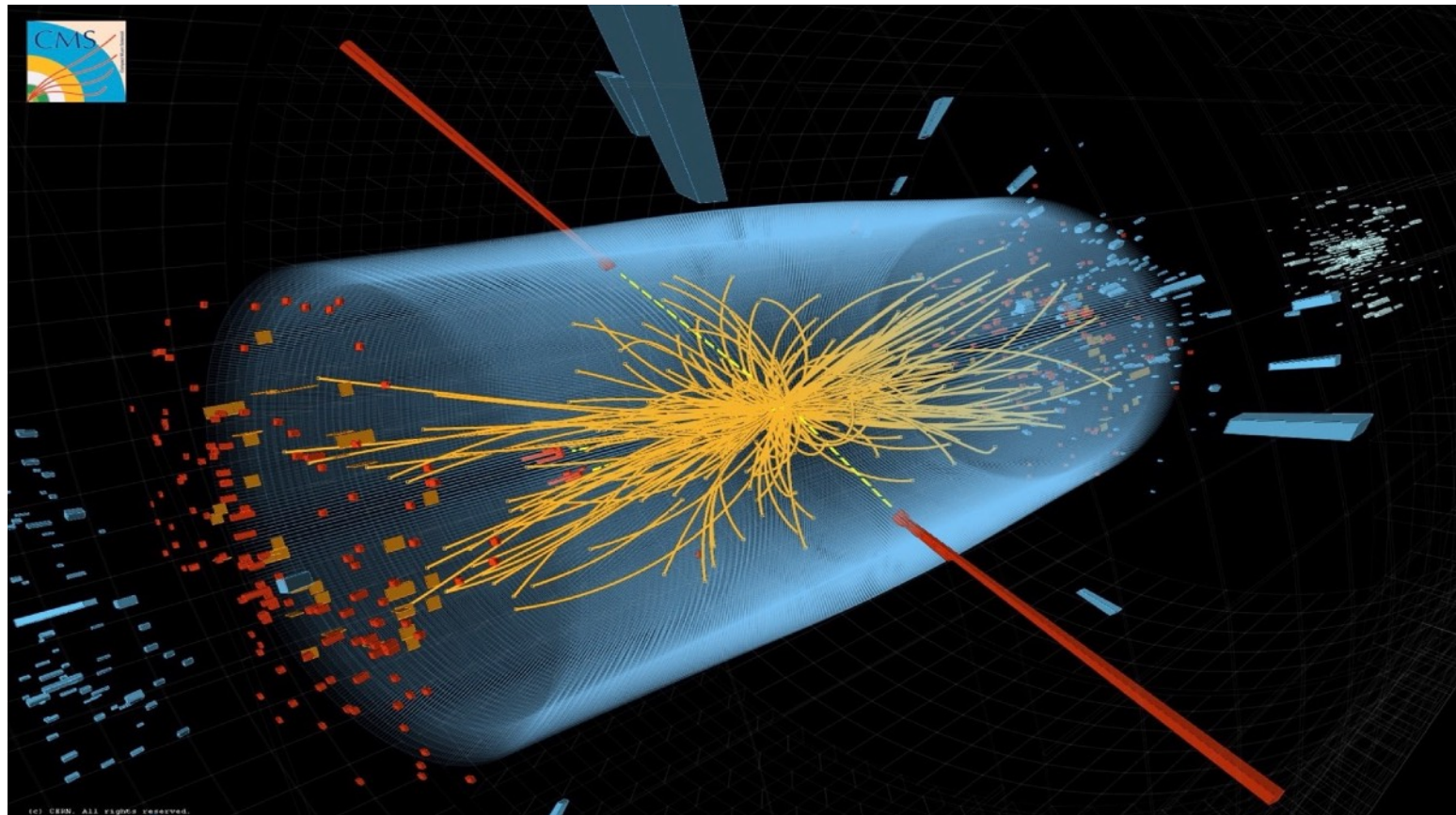


$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + h.c. + \chi_i Y_{ij} \chi_j \phi + h.c. + |D_m \phi|^2 - V(\phi)$$



# Particle physics at colliders: ATLAS, CMS, Belle2

- Discovery of the Higgs boson in 2012.
  - Now studying its properties:
    - Its own mass?
    - How strongly does it interact with other particles?

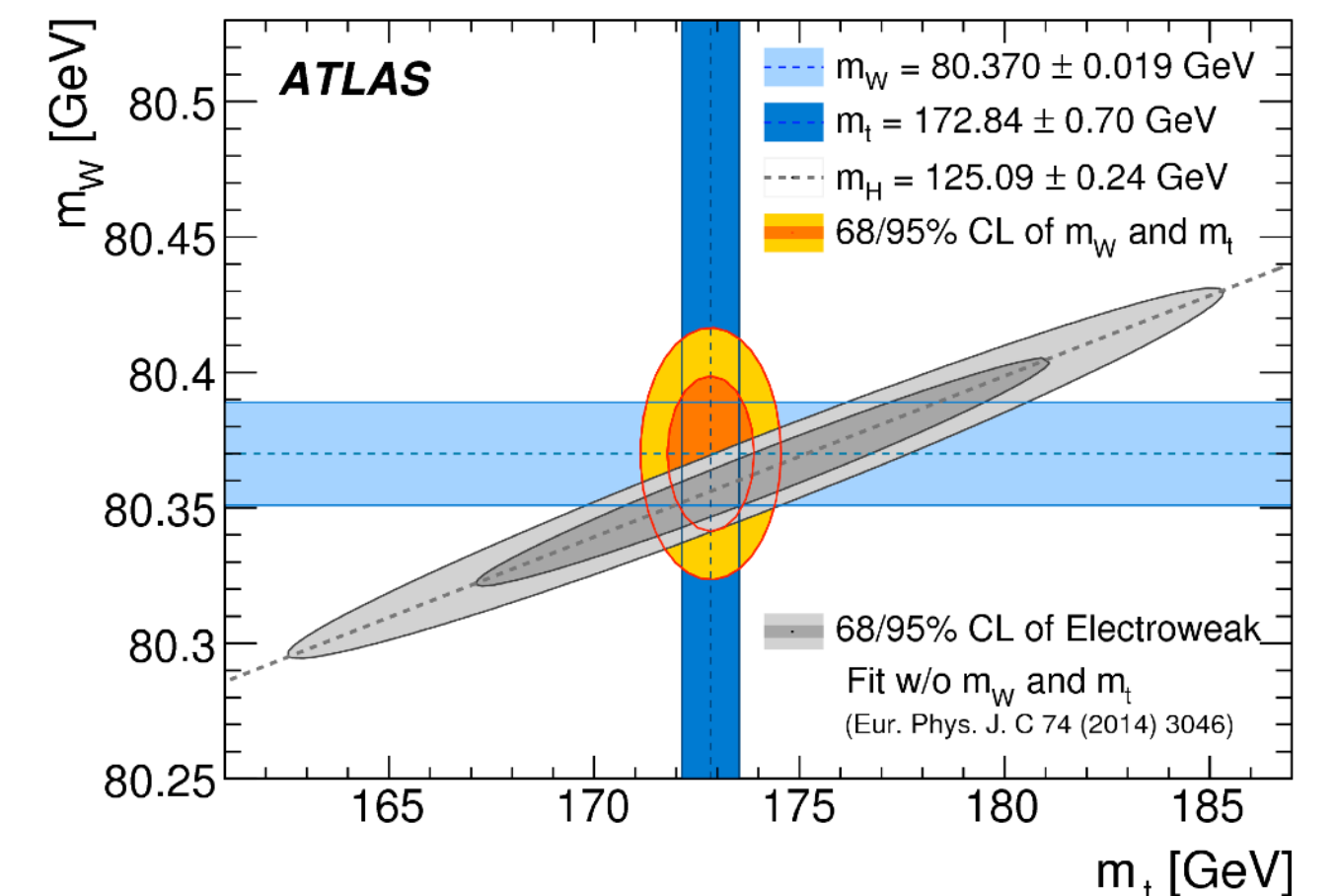
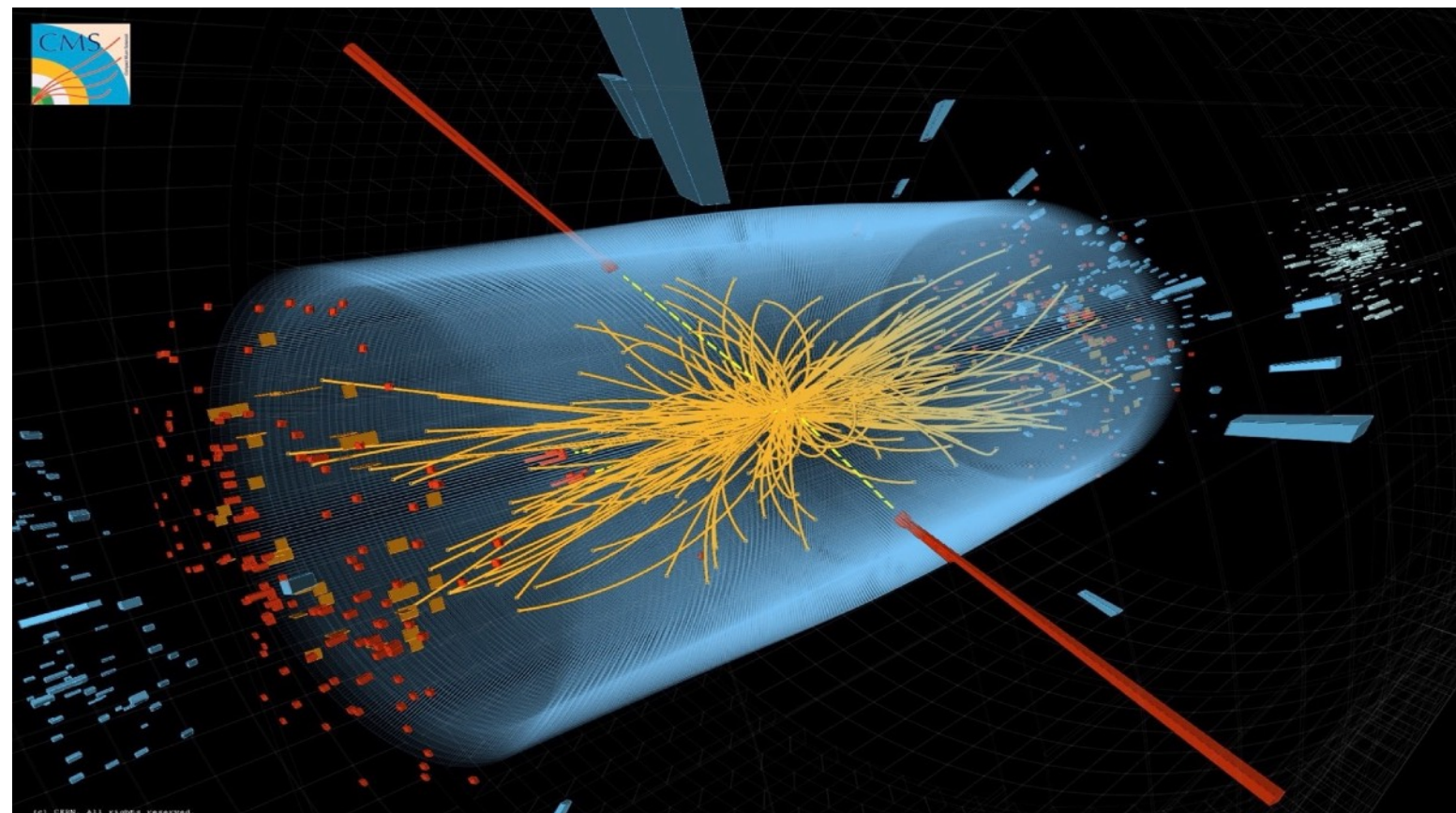
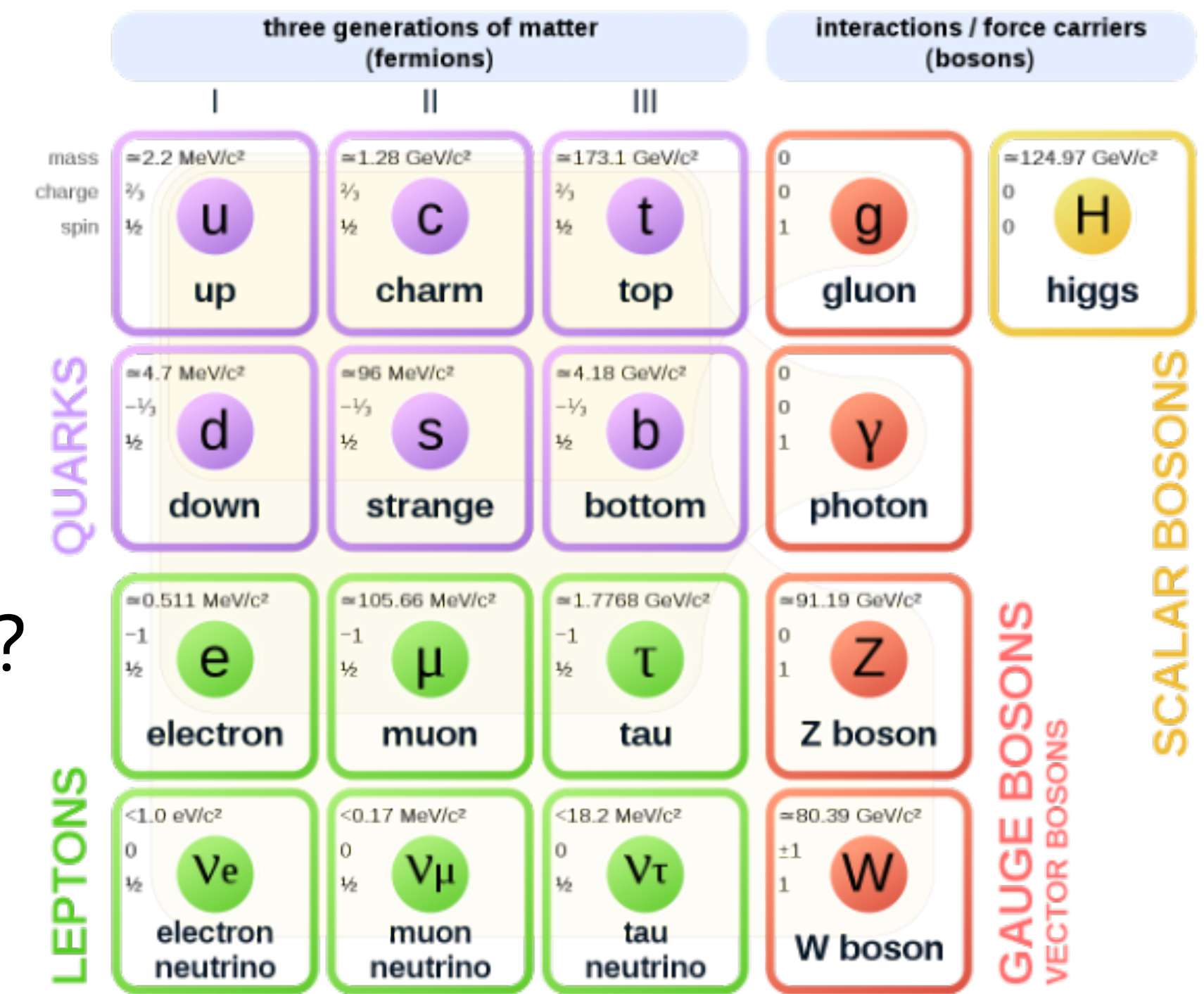




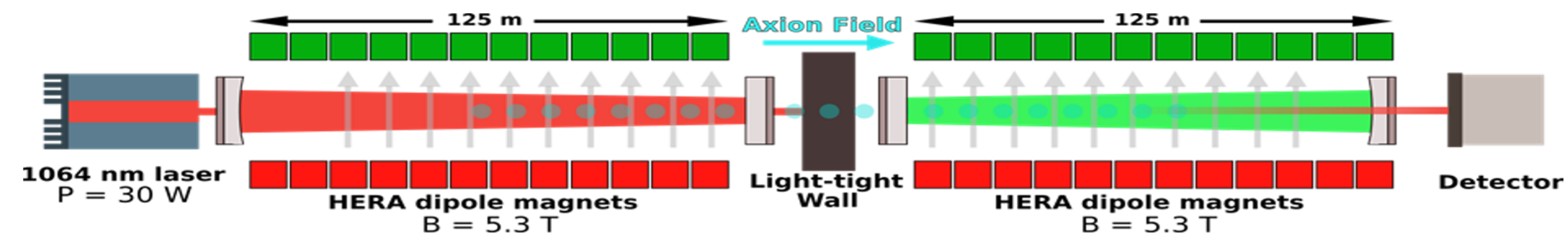
# Particle physics at colliders: ATLAS, CMS, Belle2

- Discovery of the Higgs boson in 2012.
  - Now studying its properties:
    - Its own mass?
    - How strongly does it interact with other particles?
- We know that the Standard Model has limitations.
  - Why is there more matter than anti-matter in the Universe?
  - Are there more than 3 families?
  - What is dark matter?
  - => Test all its predictions with higher level of precisions.

Standard Model of Elementary Particles



# Particle physics: ALPS

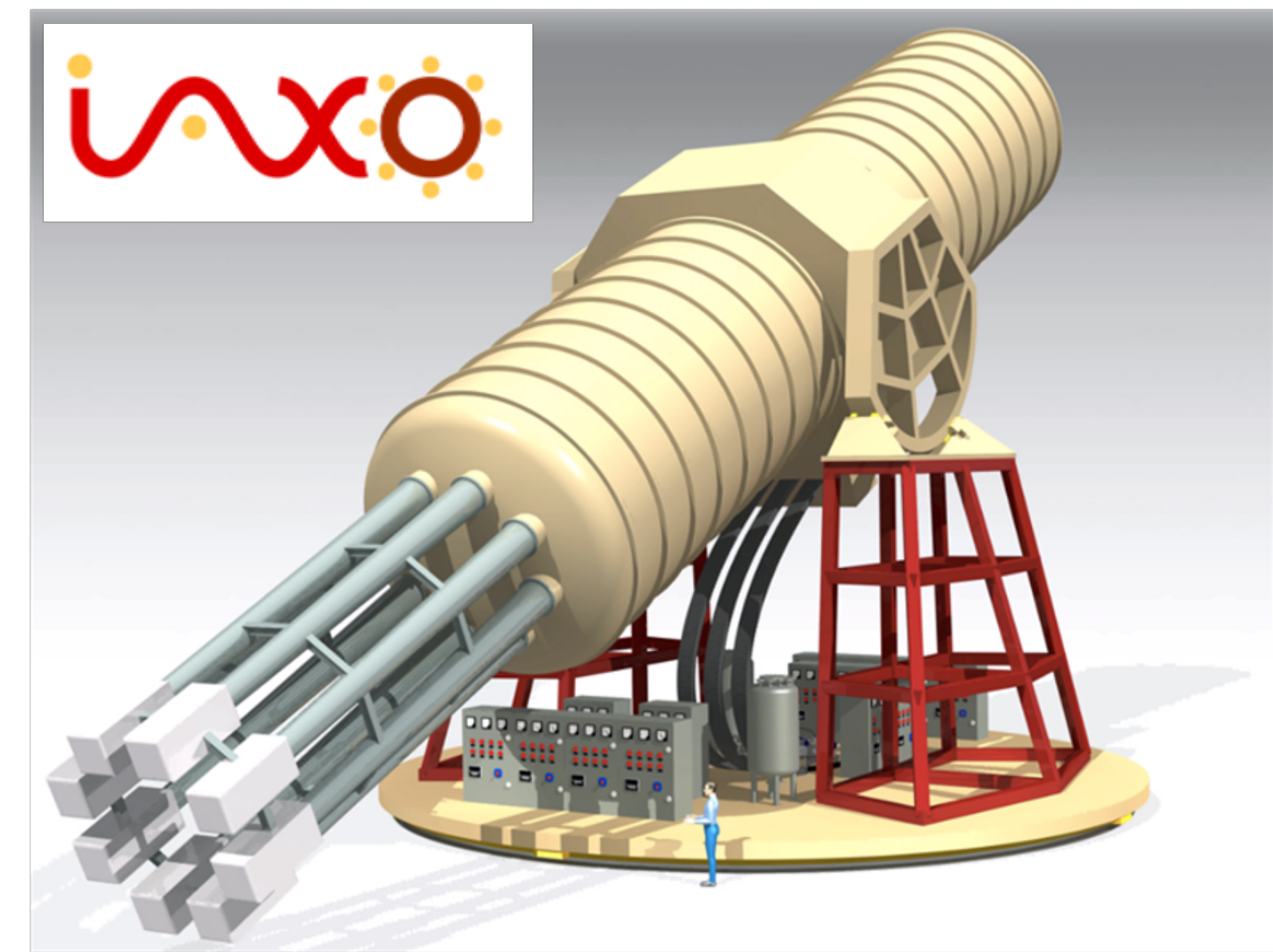
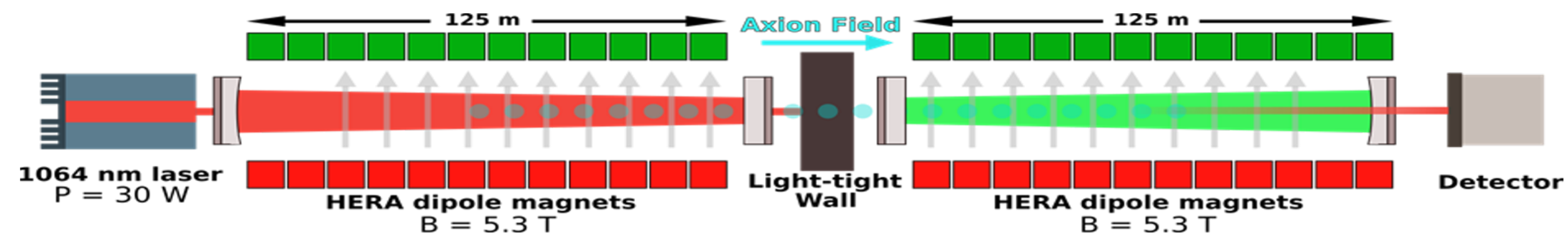


Search for axions: **"light shining through a wall"**

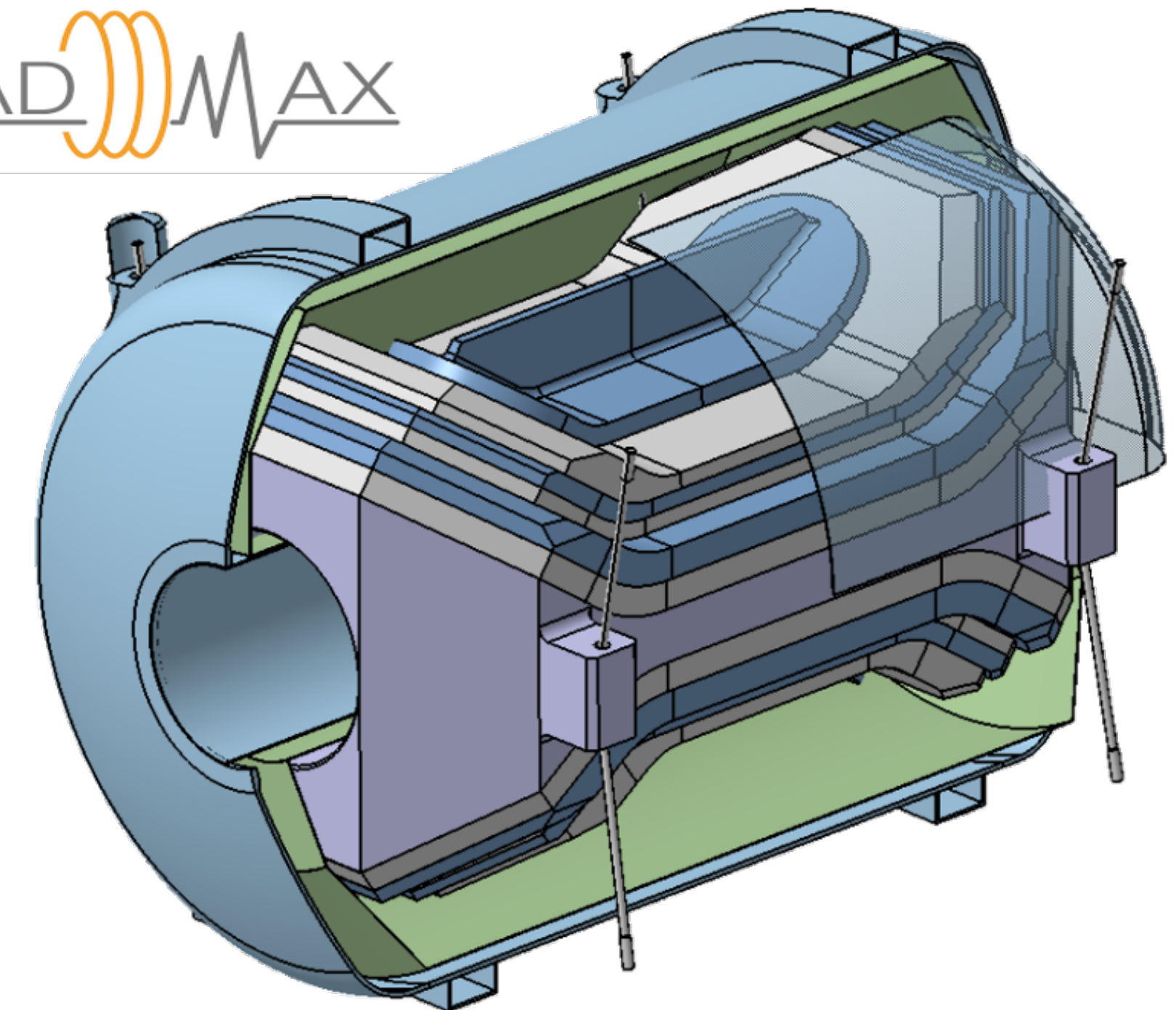
Reuse of the HERA tunnel and magnets.

Started taking data in 2023!

# Particle physics: ALPS



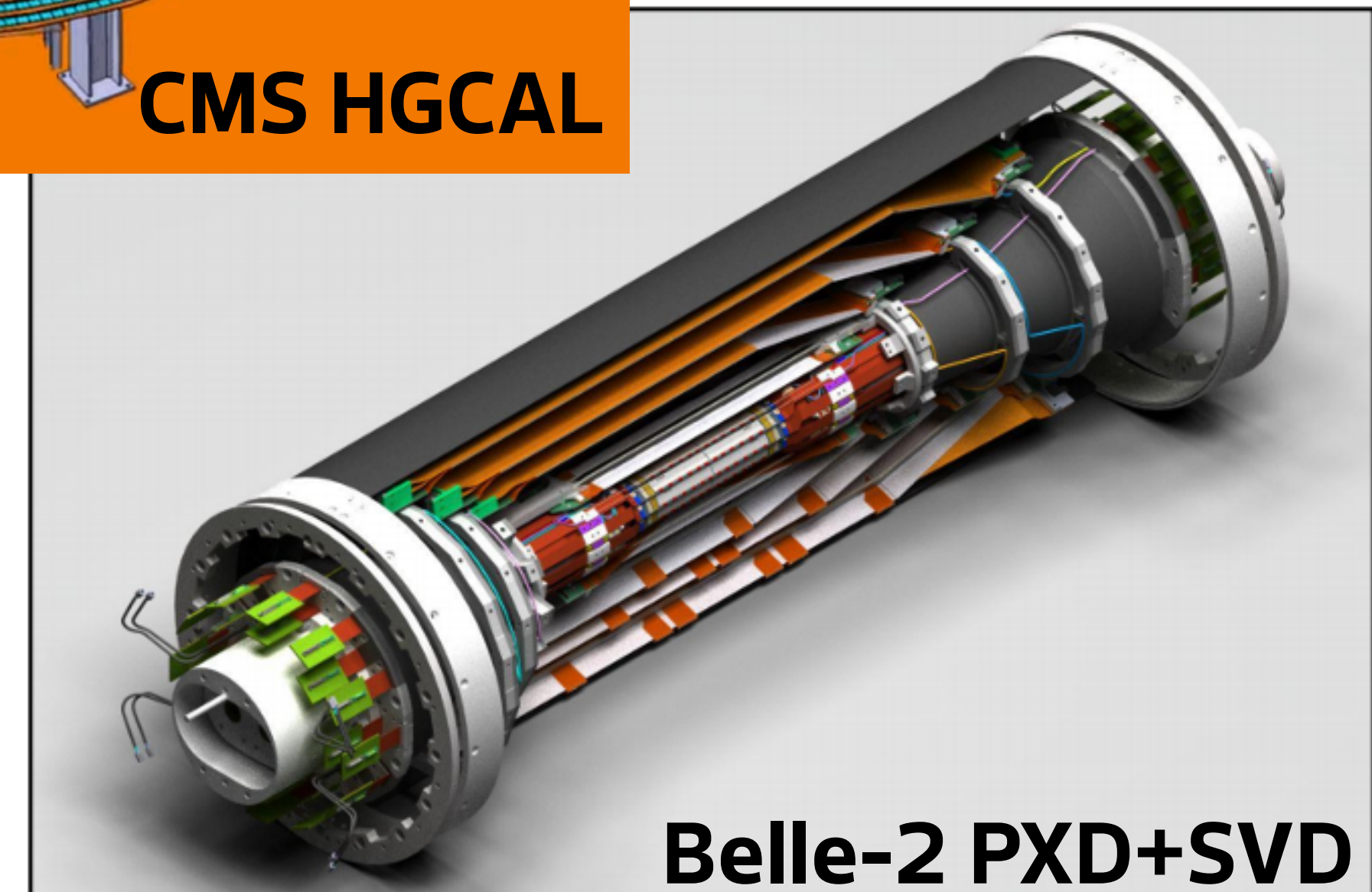
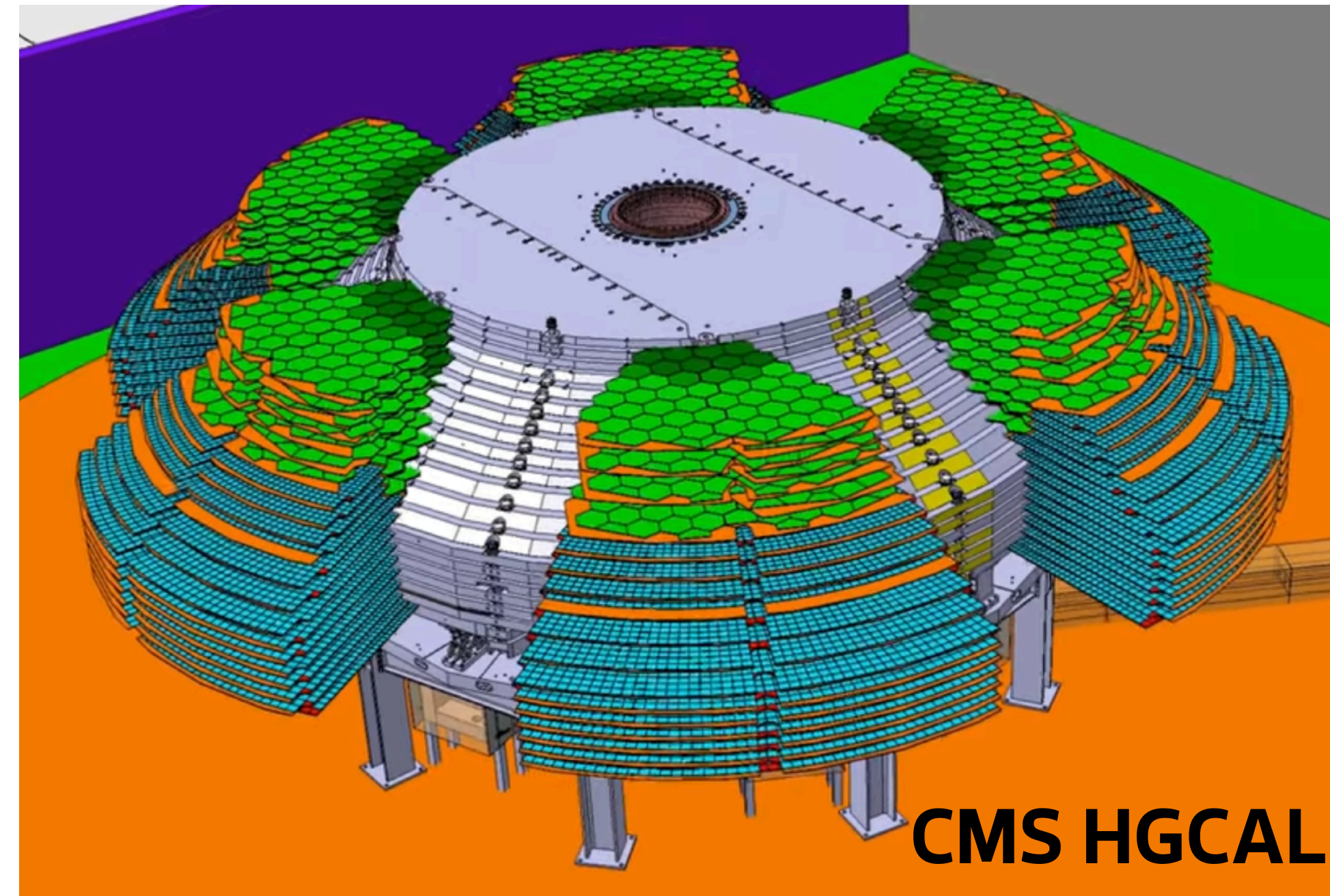
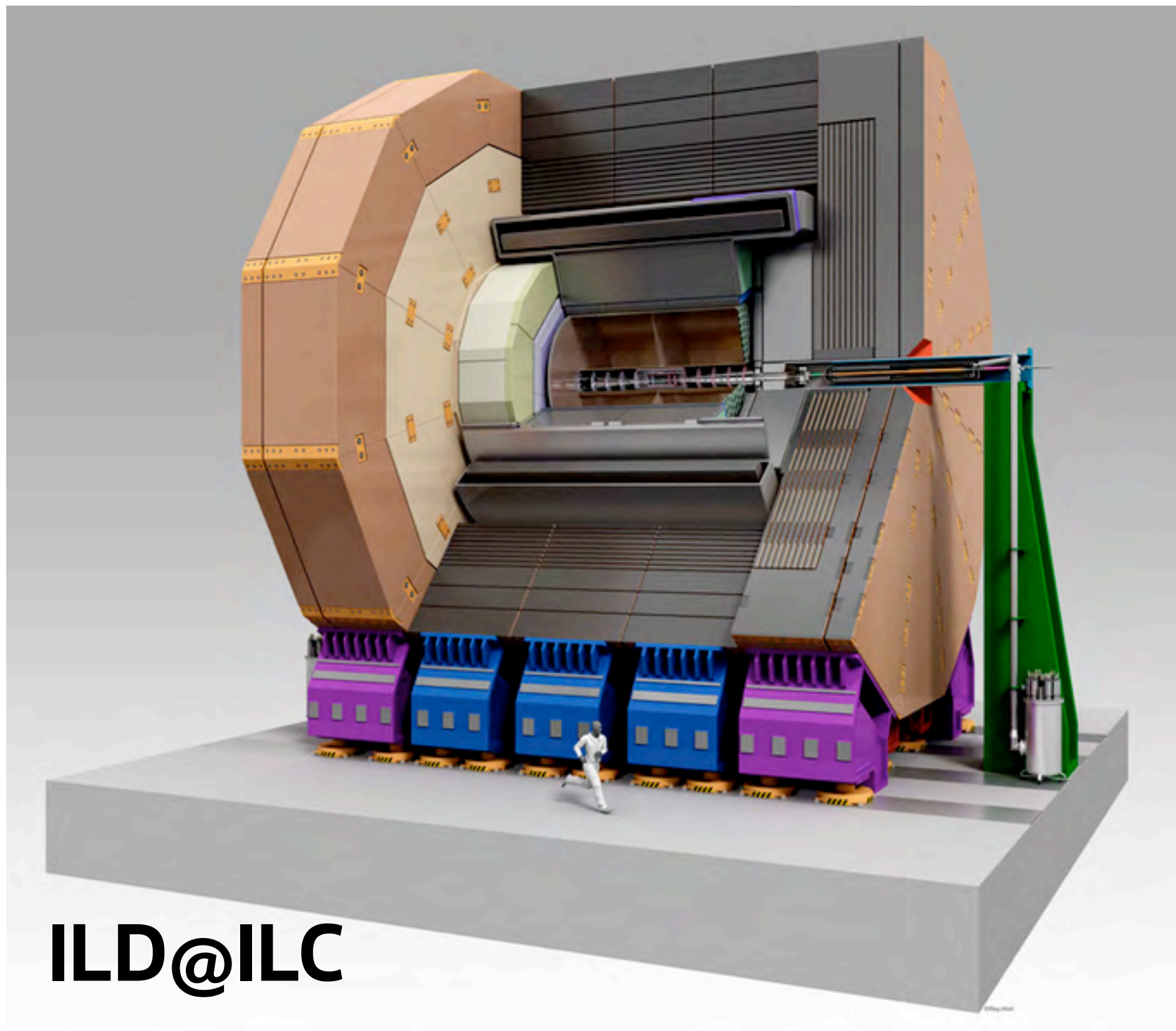
Search for axions: **"light shining through a wall"**  
Reuse of the HERA tunnel and magnets.  
Started taking data in 2023!



- Projects to be built at DESY, in the former HERA caverns
  - IAXO: helioscope for solar axions. BabyIAXO in the pipeline!
  - MadMax: axion dark-matter search.

# Particle physics: detector upgrades and future experiments

... and ATLAS ITk



# DESY in the future

# DESY in the future: Science City Bahrenfeld

- 
- 9500 researchers, technicians, administrative personnel
  - 3000 guests / year
  - 4000 students (physics, chemistry, biology)
  - Innovative ecosystem:
    - beam lines for the industry
    - innovation / technology centres
    - Start-ups, ...

# DESY in the future: accelerators

- **FLASH => FLASH 2020+**
  - Energy: 1.25 GeV => 1.35 GeV
  - Pulses: 10 fs => 1 fs
  - Circular polarisation
- **EU-XFEL**
  - second beam fan-out => new experiments
- **PETRA-IV**
  - New halls for new photon beamlines => more users and experiments
  - 50x more focused beam => better images
- Need accelerator chain upgrade...
  - **PIA-IV**
  - **DESY-IV**: better test-beam (studies ongoing)
    - Different operating mode (more data)?
    - More beamlines (more users)?

**Thanks for your attention!**

**Questions?**



# Backup