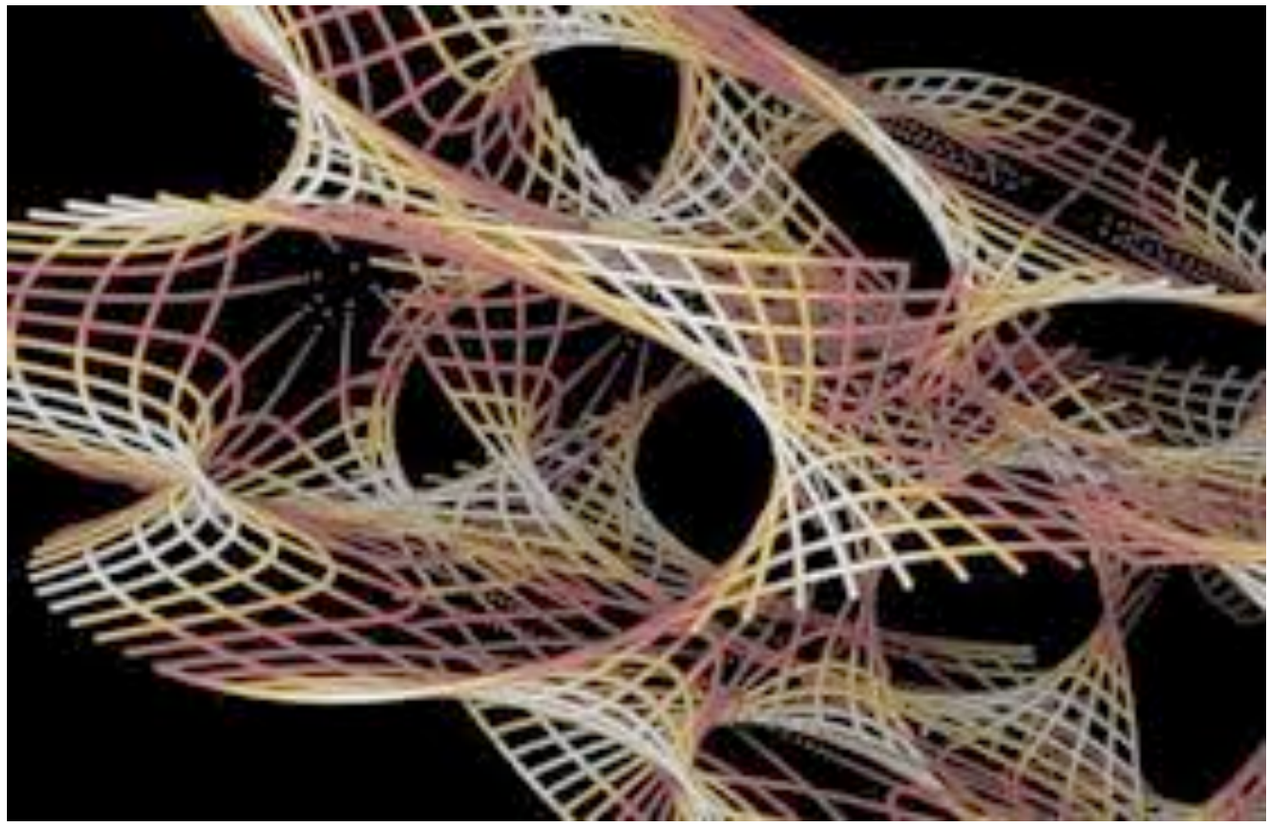
The Quantum Universe



Exploring the most fundamental secrets of nature within the Hamburg Science Centre

Georg Weiglein

For the research fields Particle Physics, Astro Physics and Mathematical Physics at Hamburg

WA Meeting,
DESY, Hamburg, 03 / 2015

The Quantum Universe: who

- More than 300 scientists, more than 100 graduate students

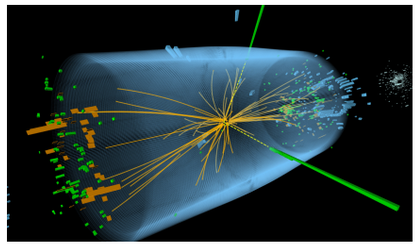
- Interdisciplinary: particle physics, astronomy, cosmology, mathematics; experiment & theory

- Internationally highly visible, well connected

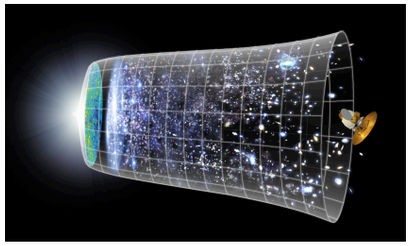
- High esteem (peer reviews, coordinating roles, ...), research grants (SFB676, DFG Graduate Schools, EU RTN networks, Humboldt Professorship, Helmholtz Recruitment Initiative, ERC Grants, HGF Young Investigator Groups, Emmy Noether Groups, Humboldt Awards & Fellows, ...)

- Role of DESY as a national laboratory

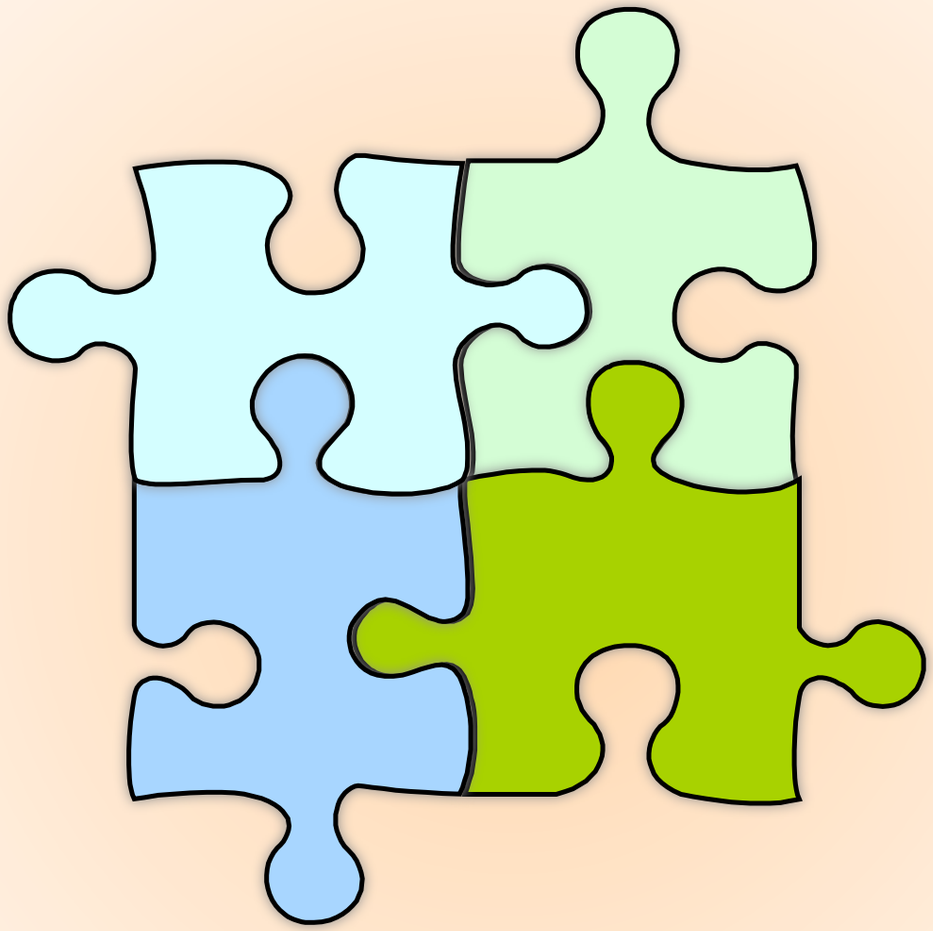
The Quantum Universe: what



Particle Physics Experiments Accelerators Underground



Astronomy Experiments Telescopes Satellites



Quantum Field Theory (Standard Model)

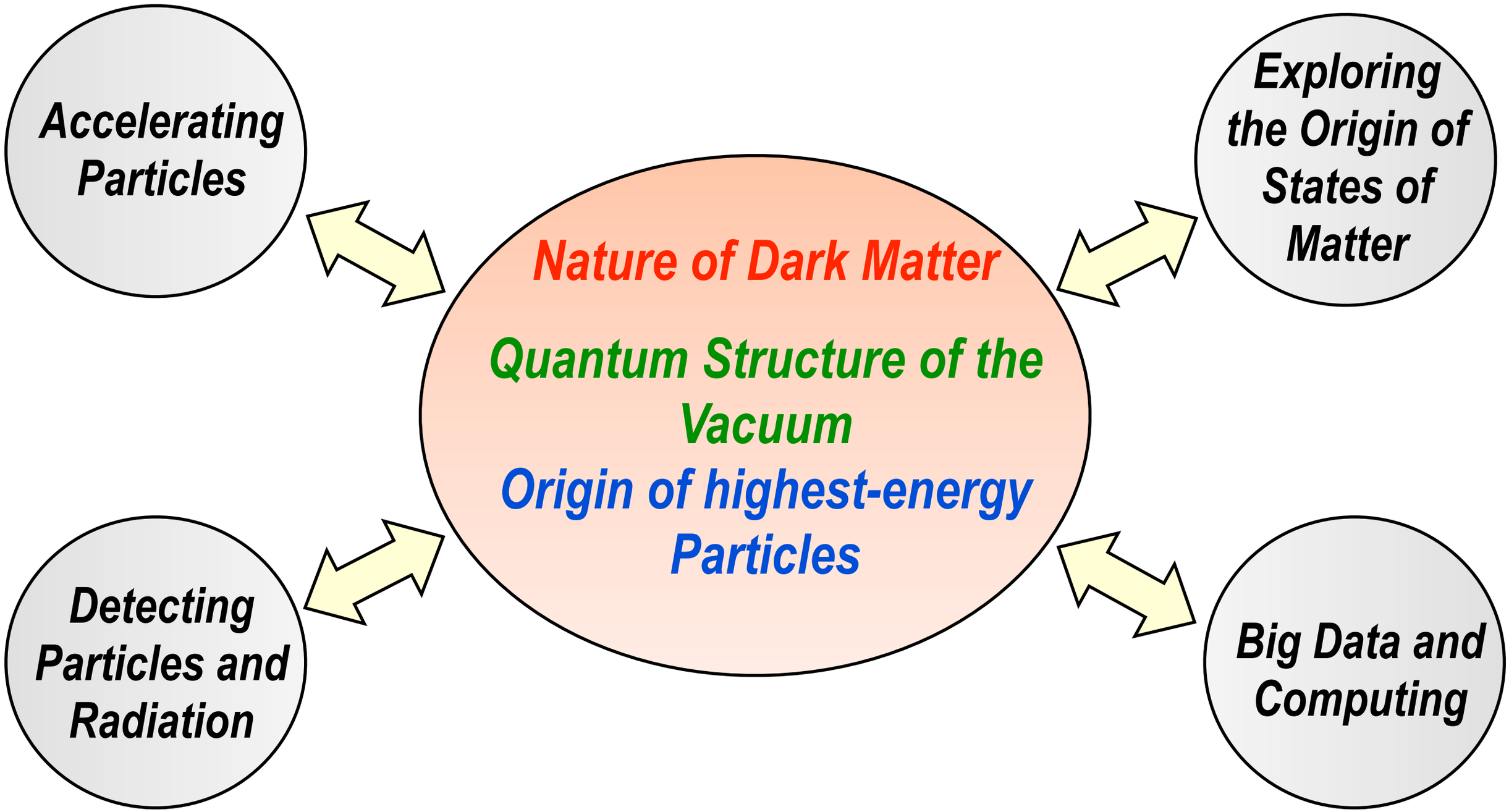
Standard Cosmology Model

10^{-18} m

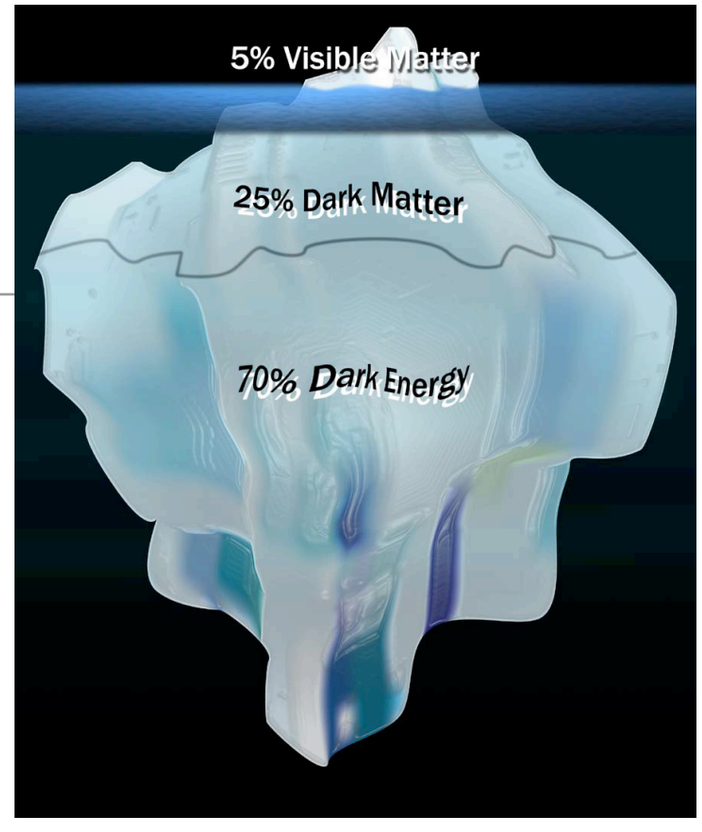
10^{26} m

⇒ Fundamental physics: coherent approach from the smallest to the largest scales

The Quantum Universe: what



What is the nature of dark matter?



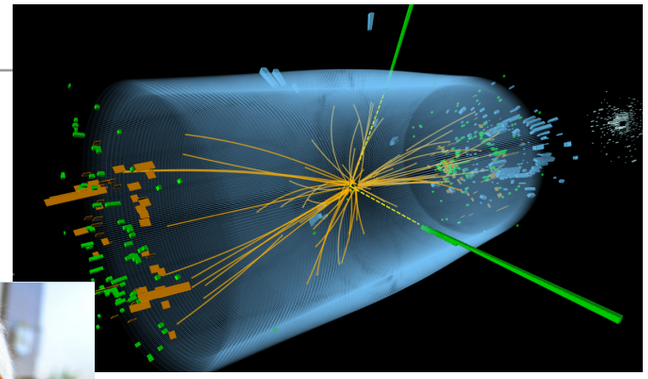
- There is overwhelming evidence for its existence, we don't know what it is

- The discovery of dark matter and the determination of its nature would be a scientific revolution

- Particle accelerators can provide us with the unique opportunity to produce dark matter in the laboratory; results from astronomy and cosmology can clarify its role within the universe

- The exploration of the properties of this completely new form of matter would open a new branch of science, with potentially far-reaching implications

What is the quantum structure of the vacuum?



- The recent discovery of a Higgs boson hints at a non-trivial structure of the vacuum, i.e. of the lowest-energy state in our universe

- The discovered particle provides access to studying the quantum structure of the vacuum!

- How can a Higgs boson be as light as 125 GeV?
  - A new symmetry of nature ⟶ Supersymmetry?
  - A new fundamental interaction of nature ⟶ composite Higgs?
  - Extra dimensions of space ⟶ impact on gravity on small scales?
  - Multiverses ⟶ anthropic principle?

The Quantum Universe: how

- Coherent scientific approach, tackles the big questions of fundamental physics

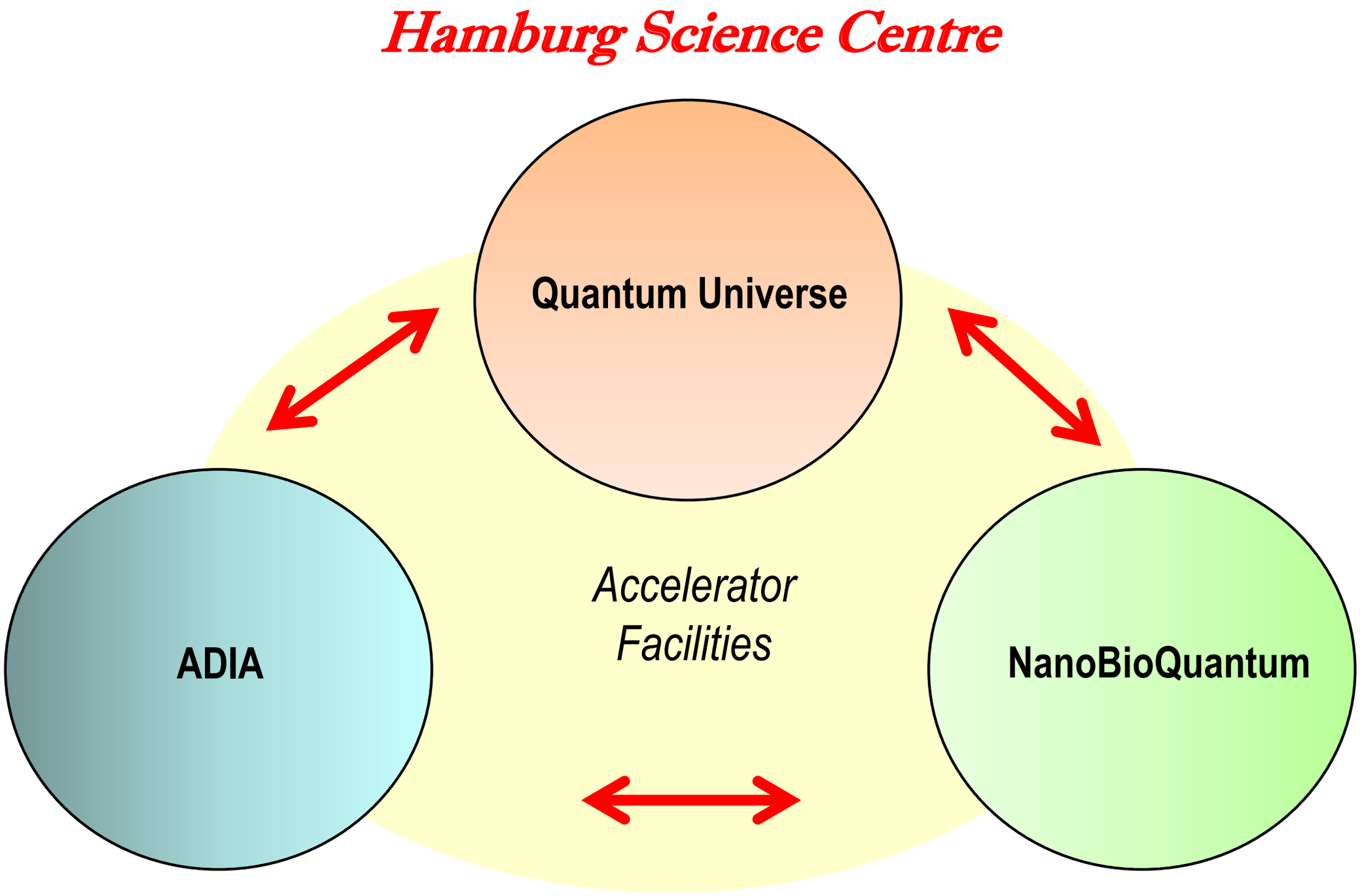
- Exploration of the research questions requires cutting-edge technologies and theoretical and mathematical methods

- This research field has been and will continue to be technology driver for many other sciences and beyond

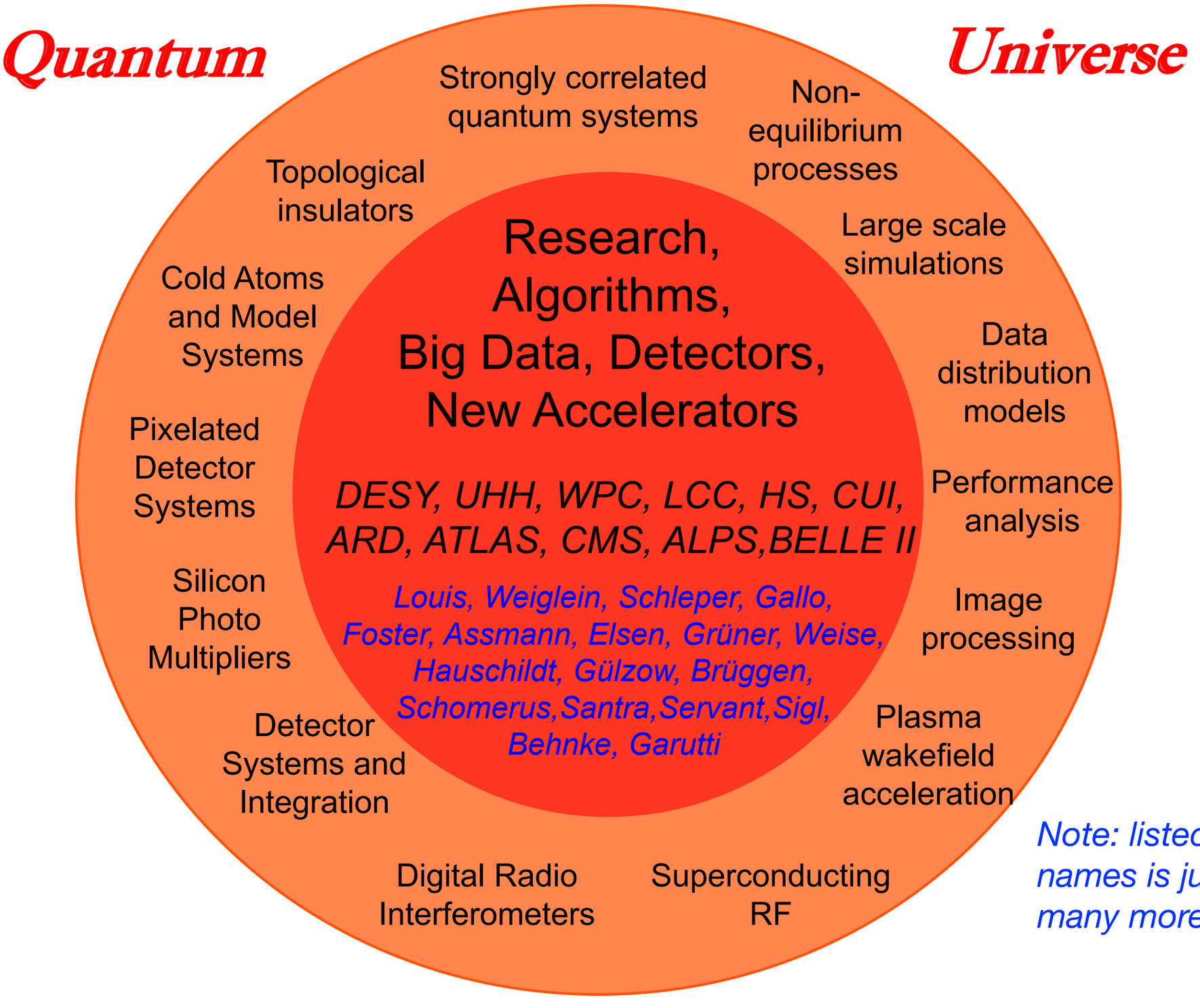
- It raises large interest in society and attracts many of the best young talents to science: fascinating topics with high impact on educational and outreach programmes

- Strong interdisciplinary links with the other research activities within the Hamburg Science Centre, builds on more than 50 years of successful cooperation between UHH and DESY

The Quantum Universe in the context of the Hamburg Science Centre



Links and synergies with other activities within the Hamburg Science Centre



Note: listed subset of names is just for indication; many more contributors

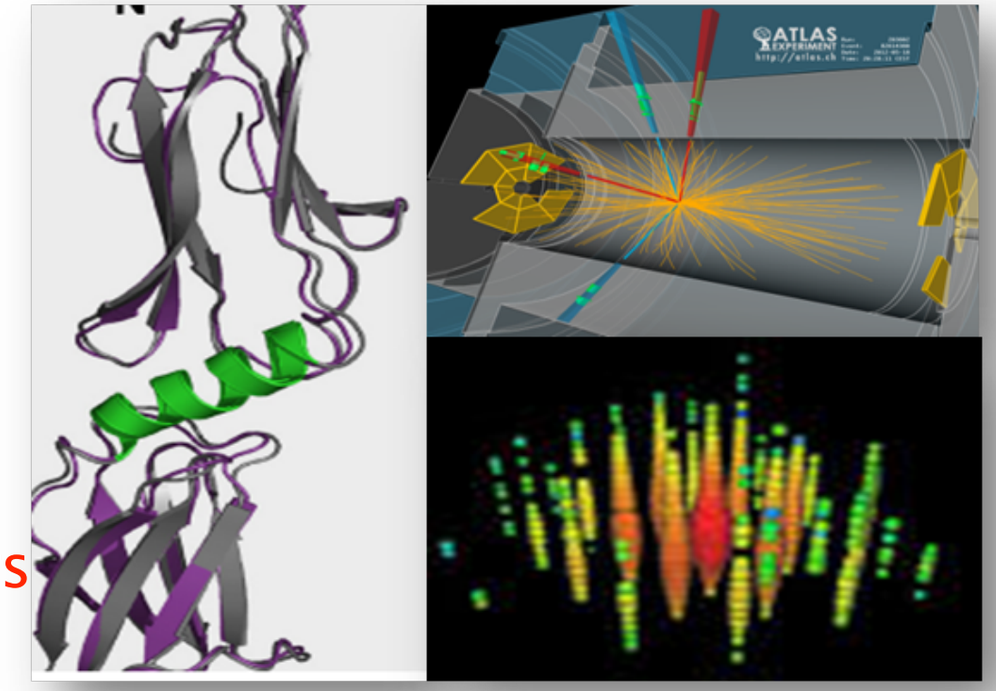
Examples of interactions with other activities

- Detector development
- Advanced computing
- Accelerator research
- Theoretical and mathematical physics

Detector development

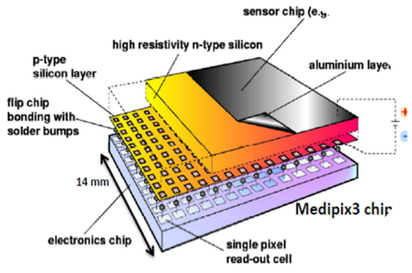
Main challenge: Development of imaging systems with unprecedented

- Granularity
- Data volume



Strong reliance on cutting edge technologies as a common basis for a broad range of science projects

Medical imaging: spin-off from particle detectors



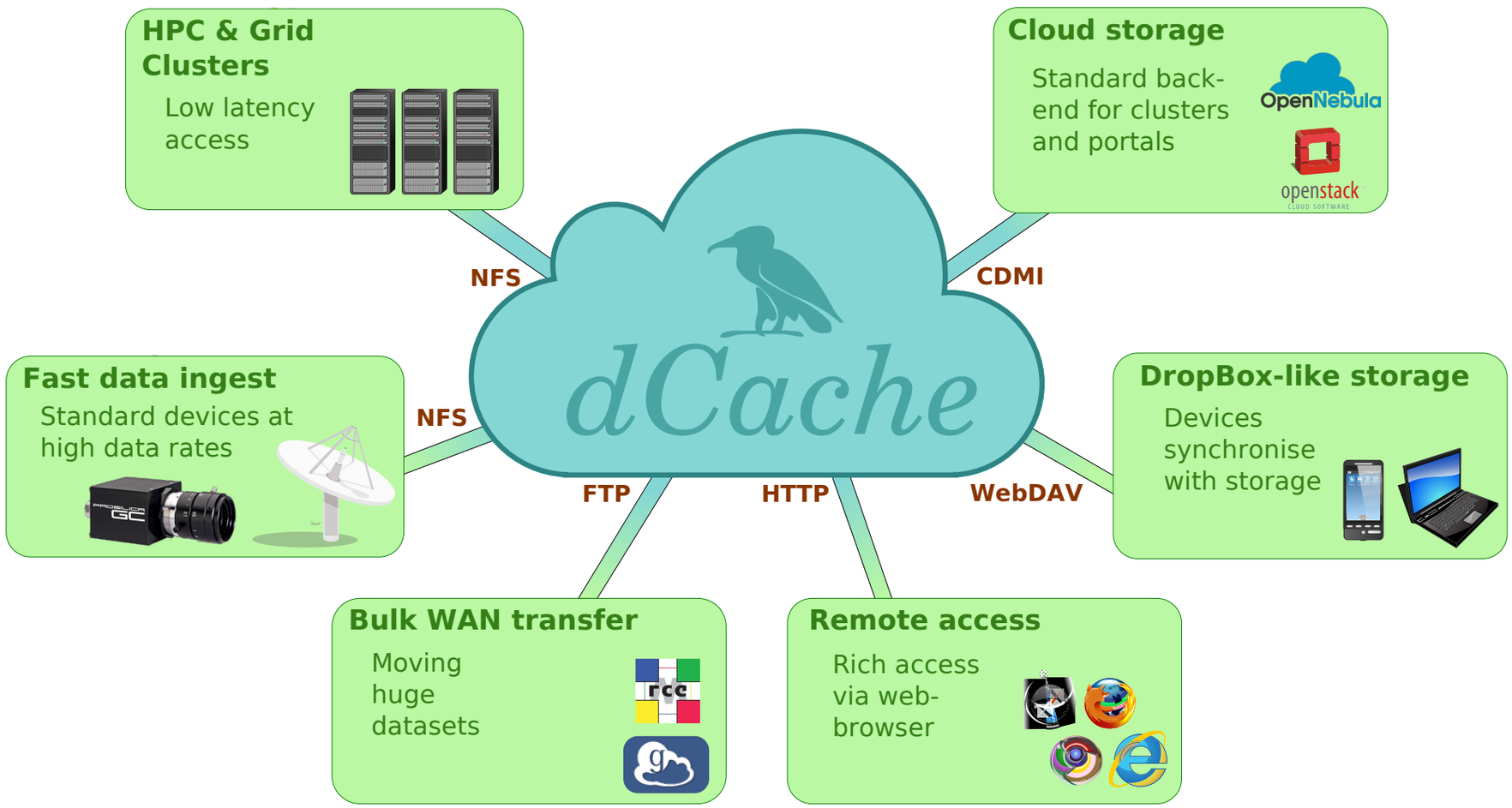
Pixelated readout electronics

Small, flexible imaging system for medical applications (EU funded)

Imaging of structures ranging from sub-atomic level, to molecules, to km scales (air shower)

Advanced computing

Storage Vision



Storage developed for handling of Big Data from the LHC
Applications in photon science

Accelerator research

- High gradients
- Ultra-low emmittance
- Highest currents
- Cost effectiveness

⇒ Strong links with ADIA research area

Theoretical and mathematical physics

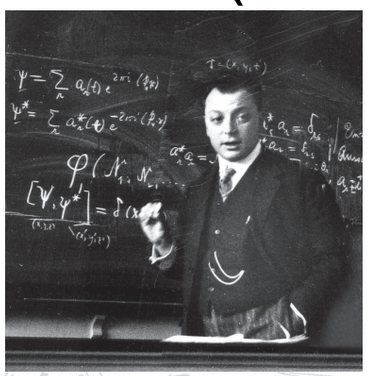
- Historic example: Higgs physics vs. superconductivity
- New strongly correlated (critical) phases of matter in Quantum Chromodynamics and Condensed Matter cold atoms systems
- Emerging research interaction with novel techniques, e.g. holographic dualities / string theory

- Wolfgang Pauli Centre (WPC)

Collaboration of the various theory groups in Hamburg

I.+II. Institute for Theoretical Physics
Sternwarte Hamburg
DESY Theory group
Center for Free-Electron Laser Science
The Institute of Laser Physics

WOLFGANG-PAULI-CENTRE
A COMPETENCE FIELD OF PIER



The Wolfgang Pauli Centre (WPC) unites the various theory groups of Hamburg University and DESY in the areas of particle physics, astrophysics and cosmology, mathematical physics, condensed matter, quantum optics and chemical physics. (Photos: Pauli Archives CERN)

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Eine Partnerschaft der Universität Hamburg und DESY

particle physics	**condensed matter**
astrophysics and cosmology	**quantum optics**
mathematical physics	**chemical physics**

- Centre for Mathematical Physics (ZMP)