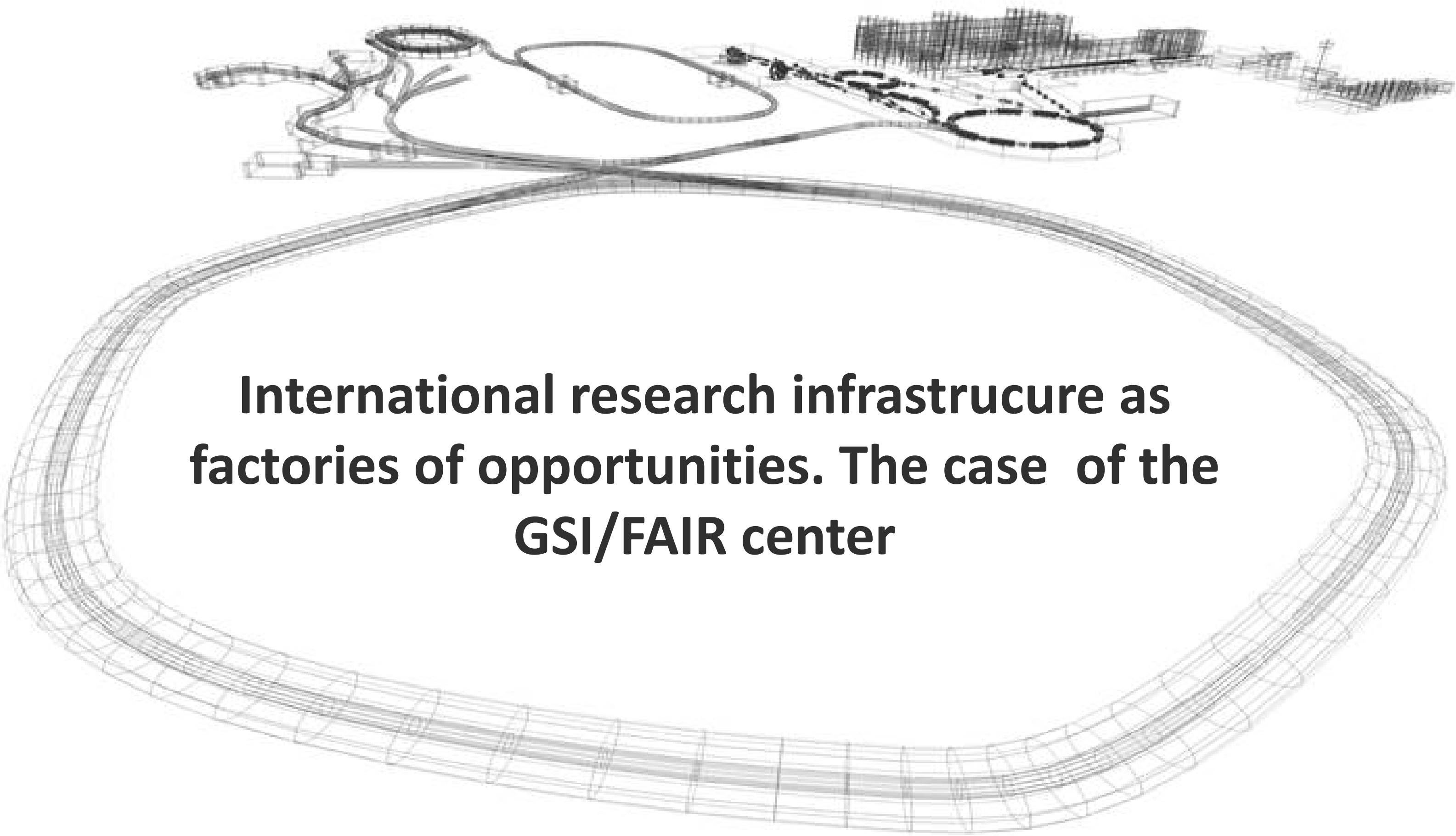


International research infrastrucure as factories of opportunities. The case of the GSI/FAIR center

Paolo Giubellino, FAIR and GSI

Why big science international projects ?

They are unique opportunities for world science.

- Addressing fascinating fundamental questions for human knowledge

They produce advanced technologies of enormous societal impact

- advances in medical instrumentation, IT, ...

They are a unique tool to grow the next generations of talented scientists and engineers

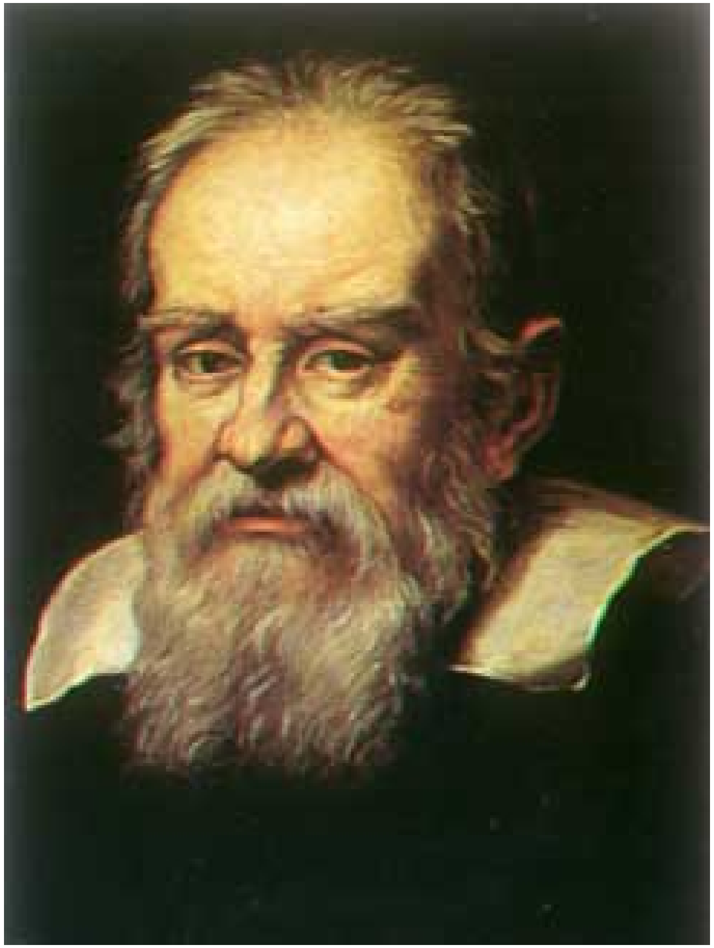
- proven tools of talent growth, capable of successfully competing at the global level

International cooperation is a must

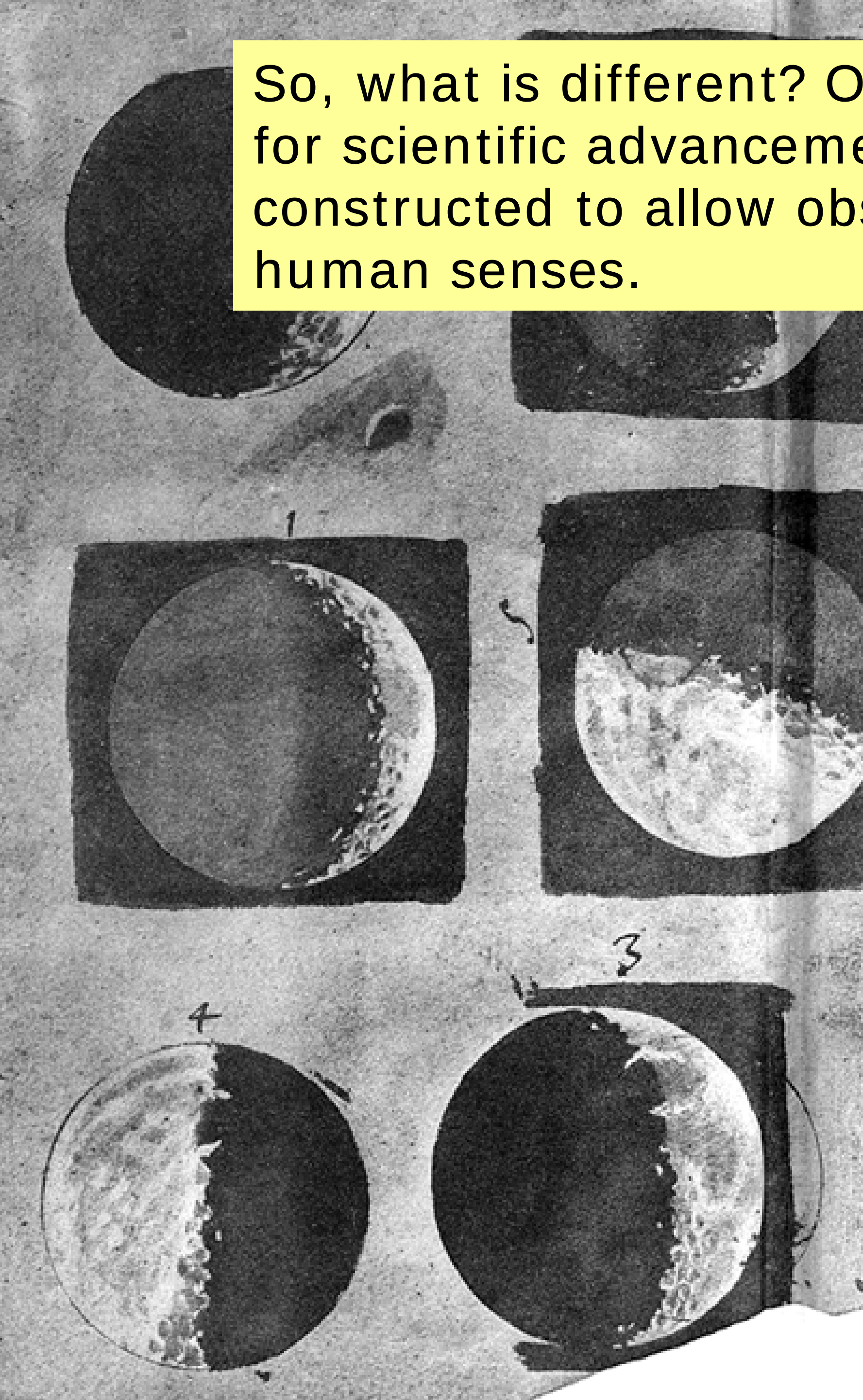
- convergent collaboration from many countries is indispensable to realize these projects, not just for the financial resources, but even more for the human capital needed.

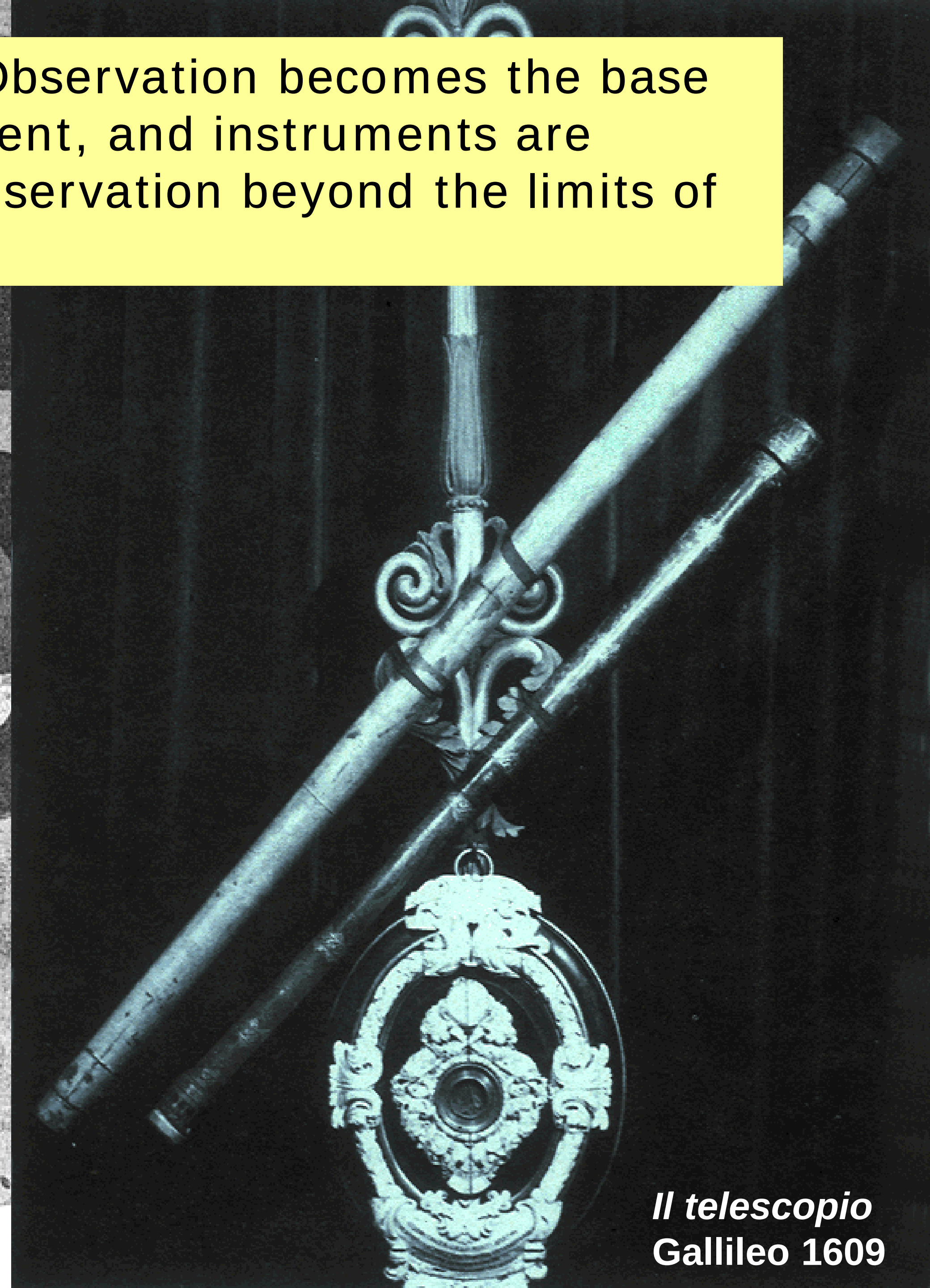
The scientific revolution

- Between the ancient vision of the world and the one reached in our times there is an immense difference.
- This difference is mostly a matter of **method**. The scientific method introduced by Galileo Galilei (1564-1642)... Not without paying a personal price!



So, what is different? Observation becomes the base for scientific advancement, and instruments are constructed to allow observation beyond the limits of human senses.

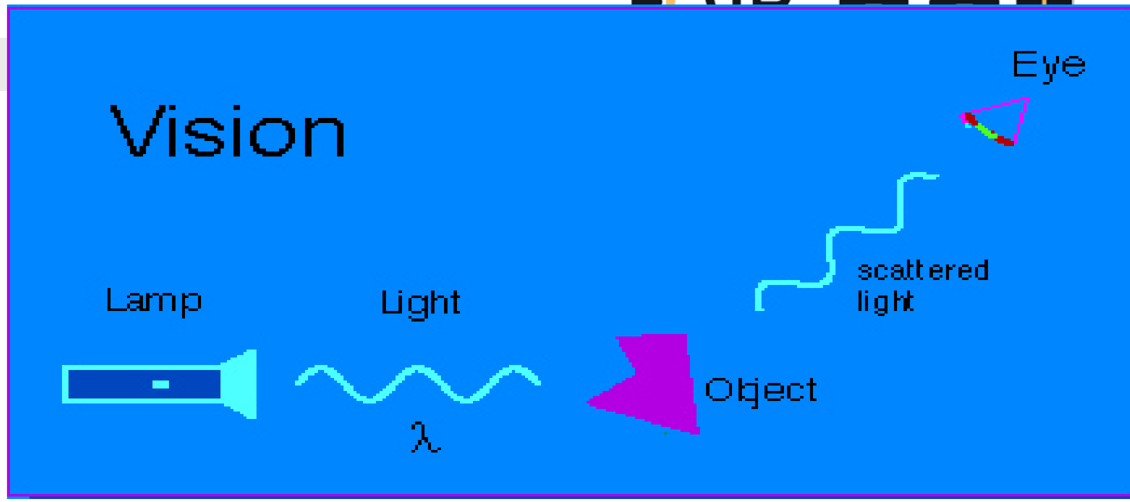




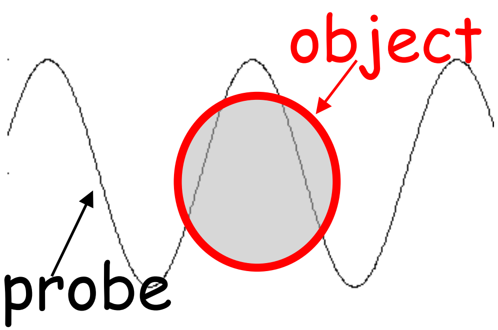
Il telescopio
Gallileo 1609

"LOOKING" at smaller and smaller details

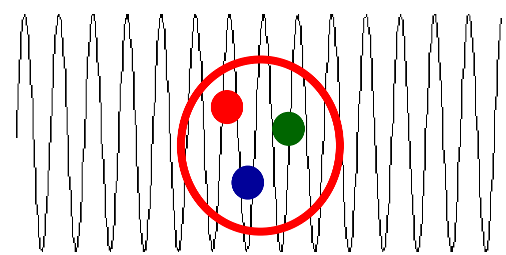
With our bare eye we can see down to ~10^{-2} cm



- In order to probe finer and finer scales
  - in quantum physics, each particle is associated with a wave
  - the associated wavelength decreases with increasing energy
  - as the energy is increased finer details can be resolved



low energy

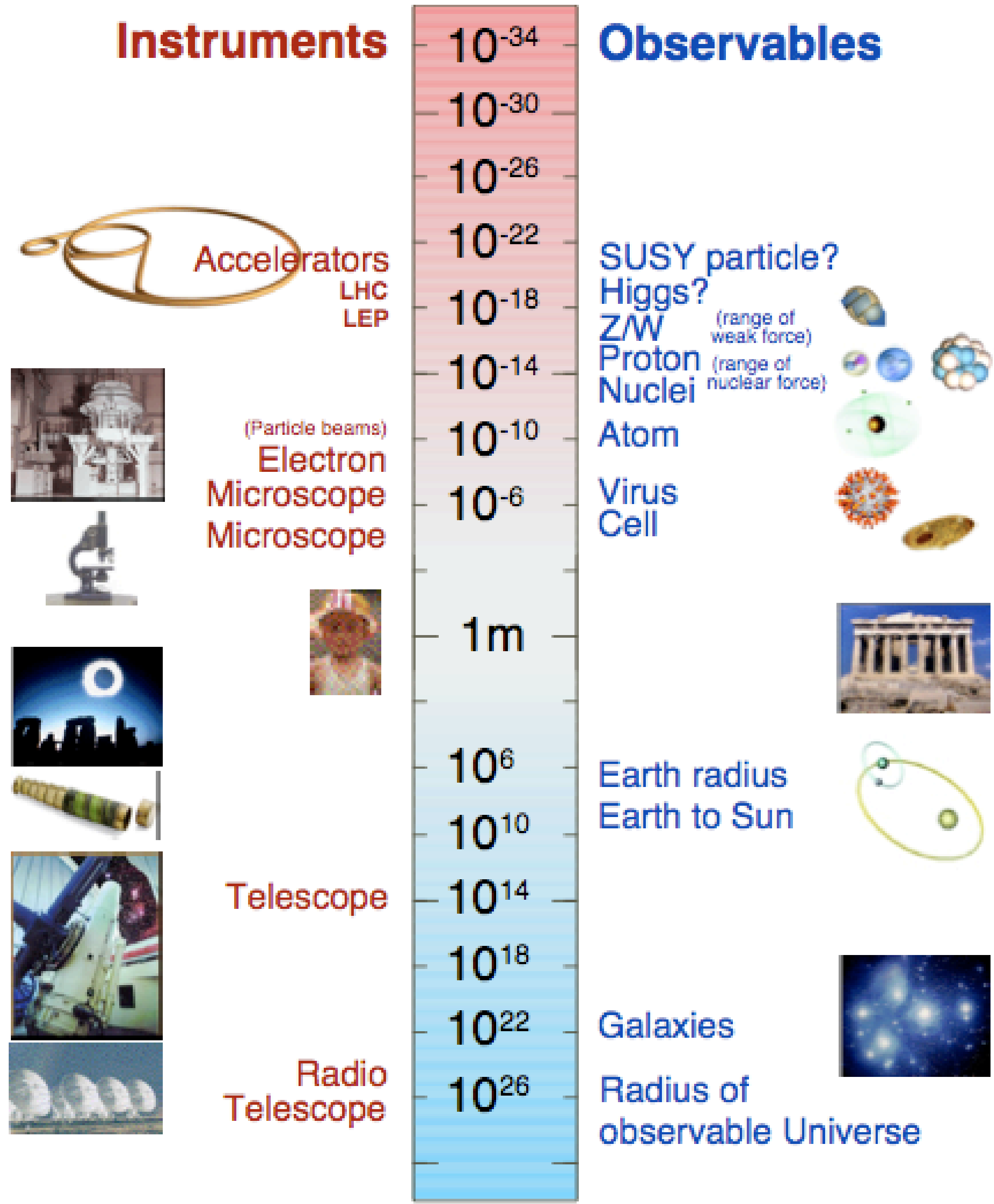


high energy

Electron microscopes can explore down to ~10^{-6} cm – structures like the DNA

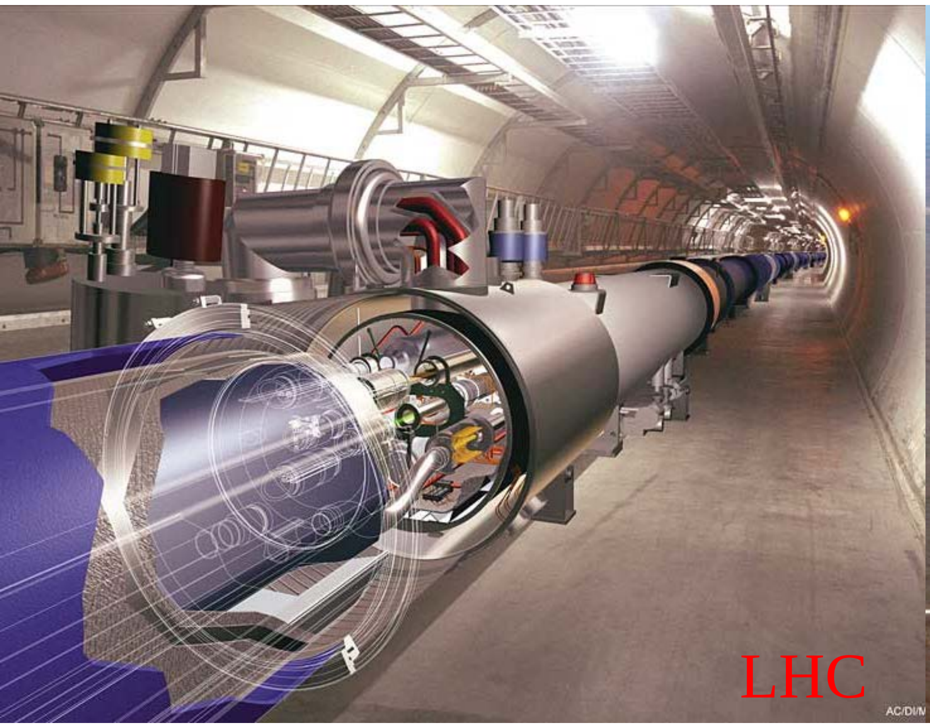
Since that moment, instruments of ever increasing power

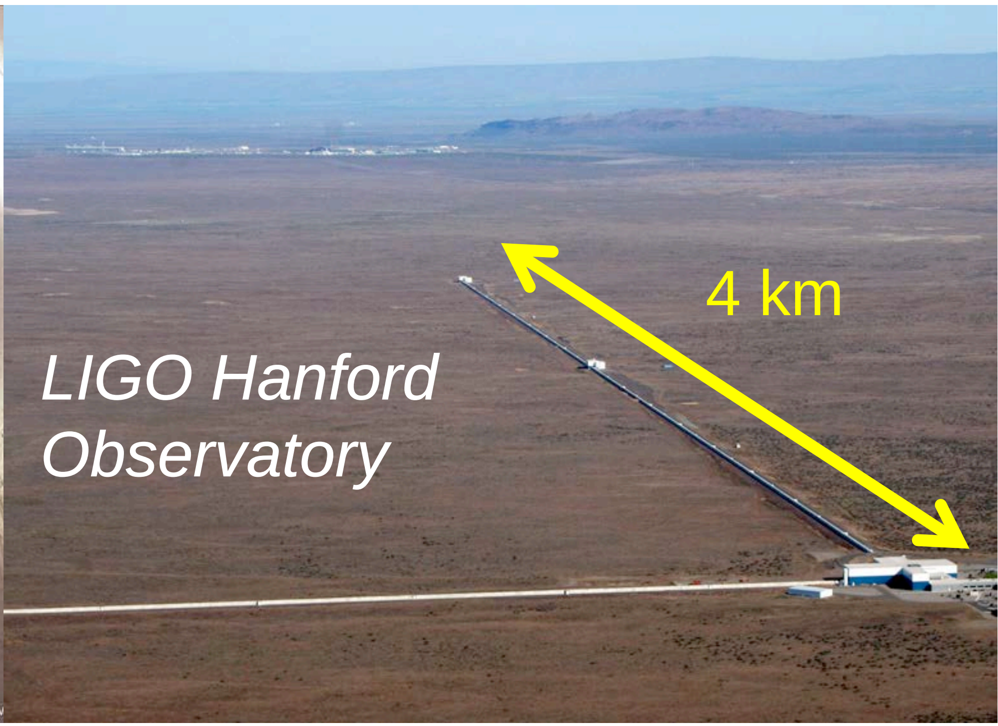
- The instrument to be used depends on the size of the system to be studied
- To observe small details, higher energy probes are necessary



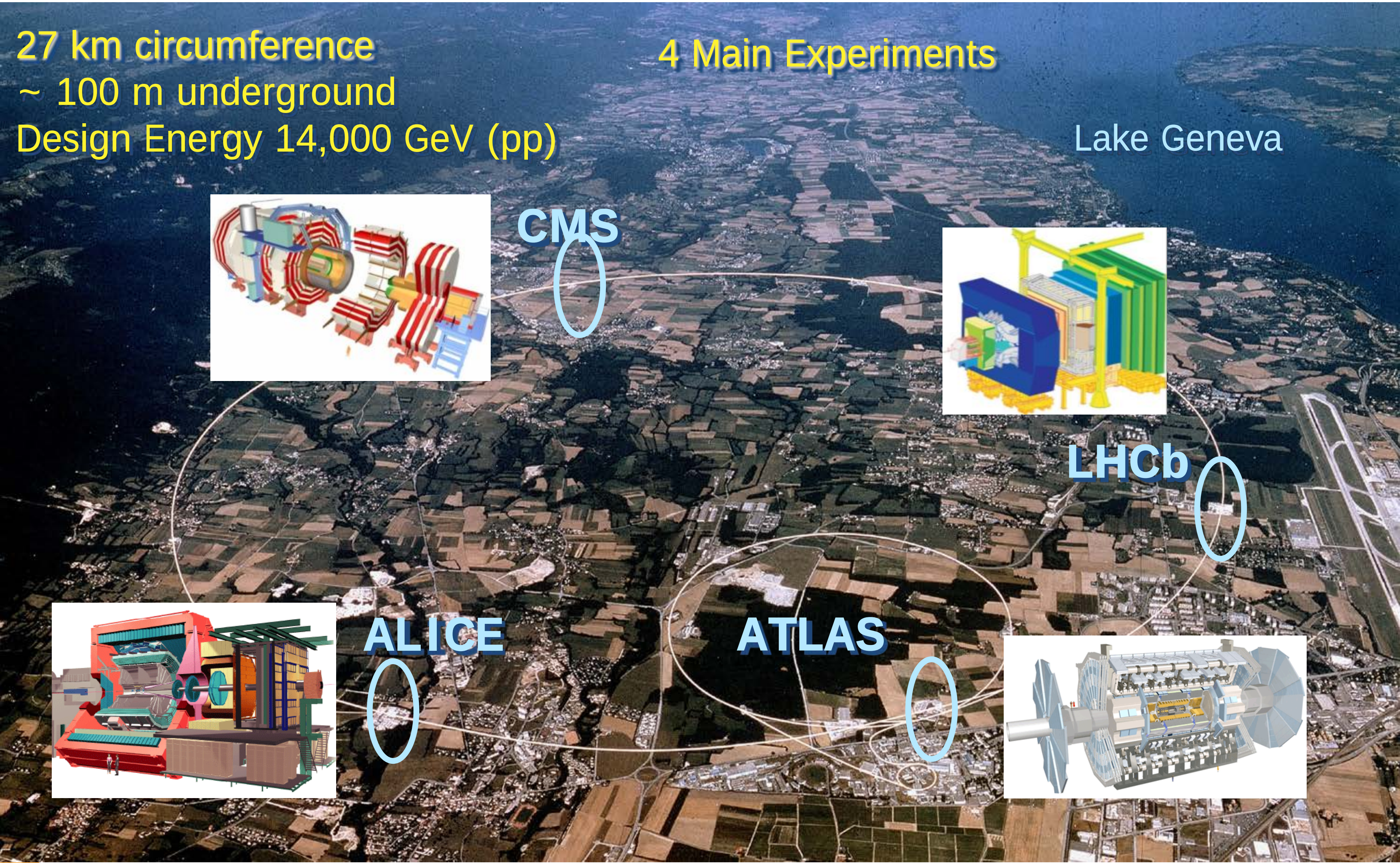
Extreme Instruments

"telescopes" with which science explores the Universe

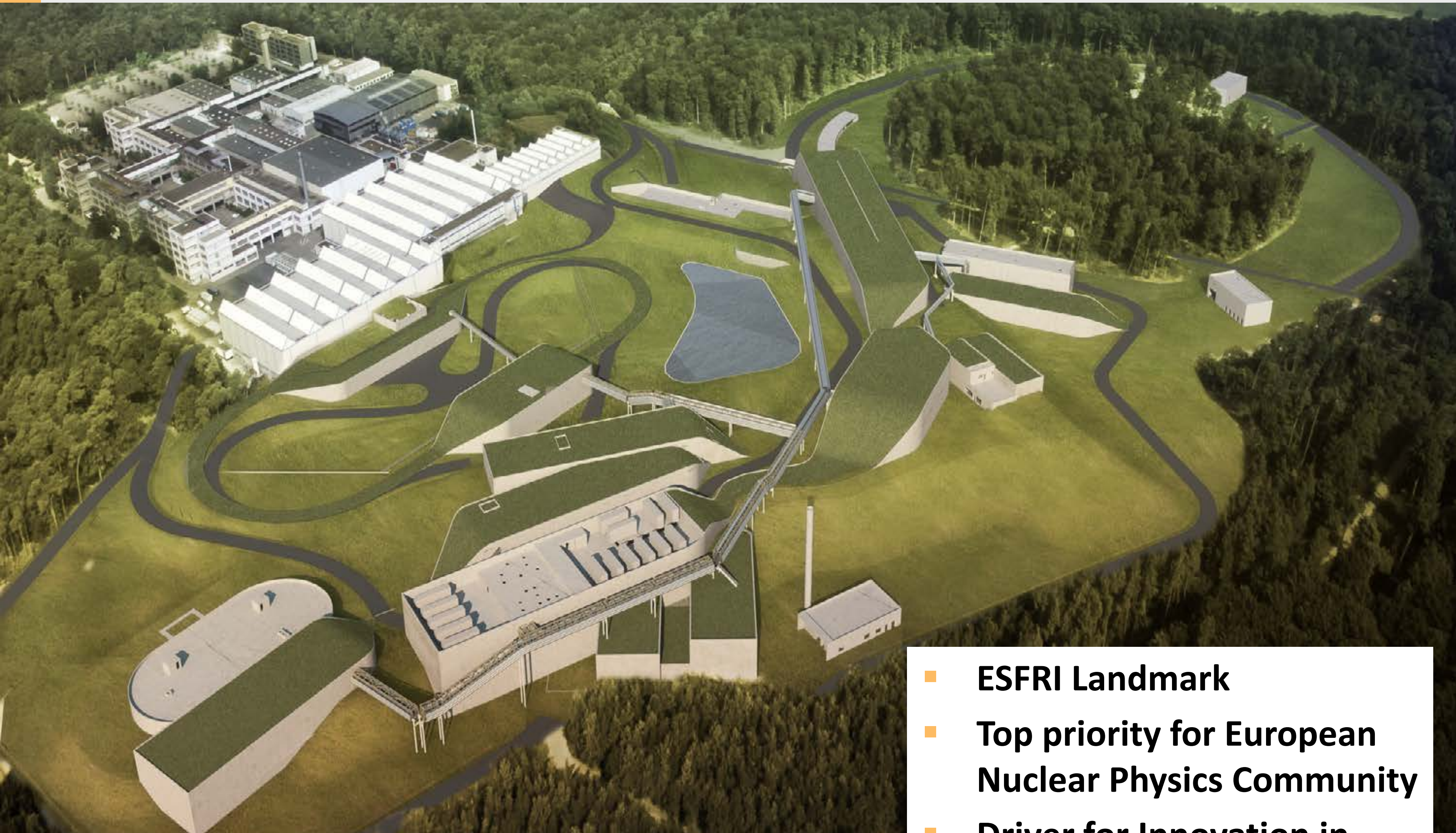




And need very large and complex infrastructure, like the Large Hadron Collider LHC, at CERN



... or the FAIR complex of accelerators: Each facility is optimized for different parameters

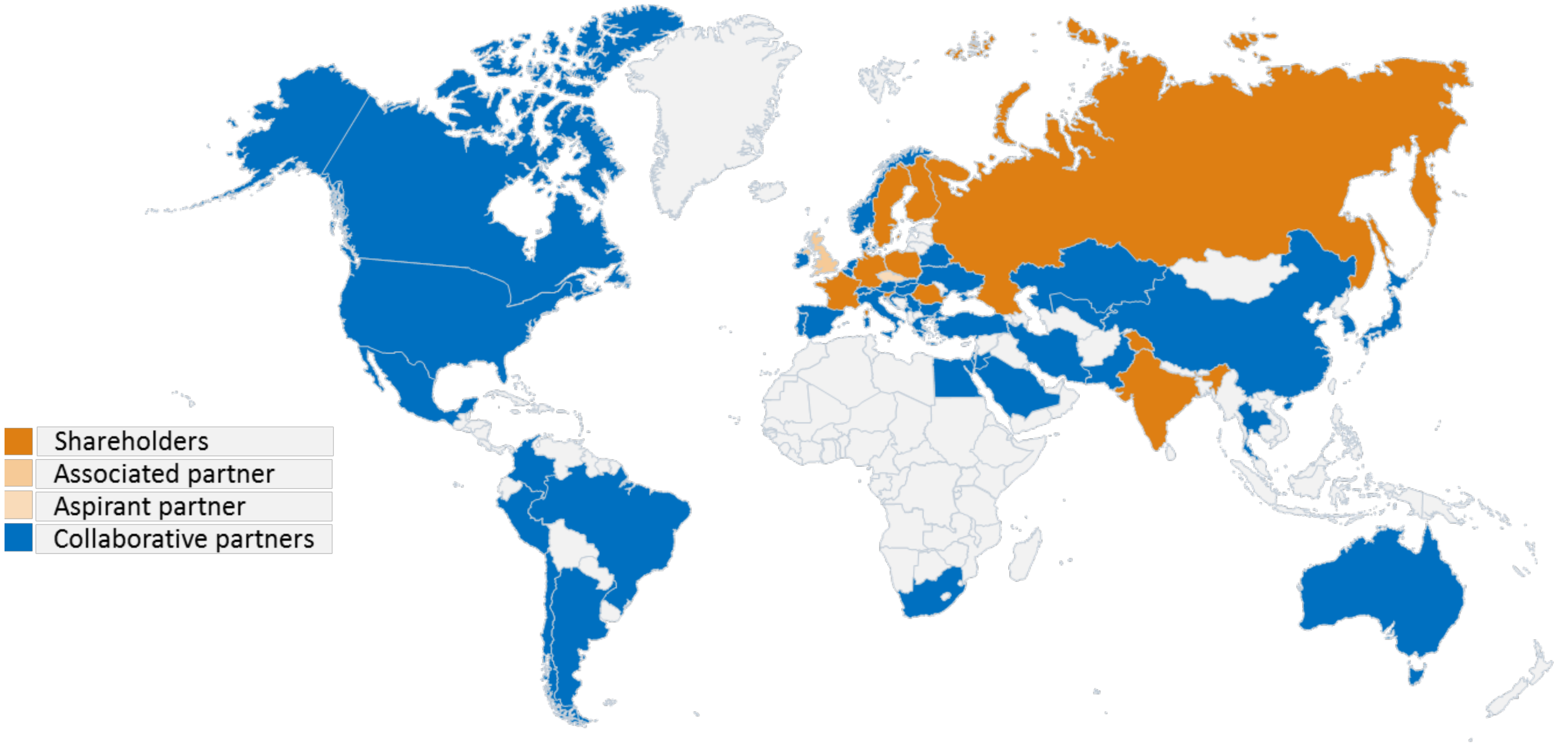


- ESFRI Landmark
- Top priority for European Nuclear Physics Community
- Driver for Innovation in Science and Technology

FAIR was born on 04.10.2010

FAIR GmbH formed (convention signed) on 4th October 2010 by the Shareholders in Wiesbaden Germany

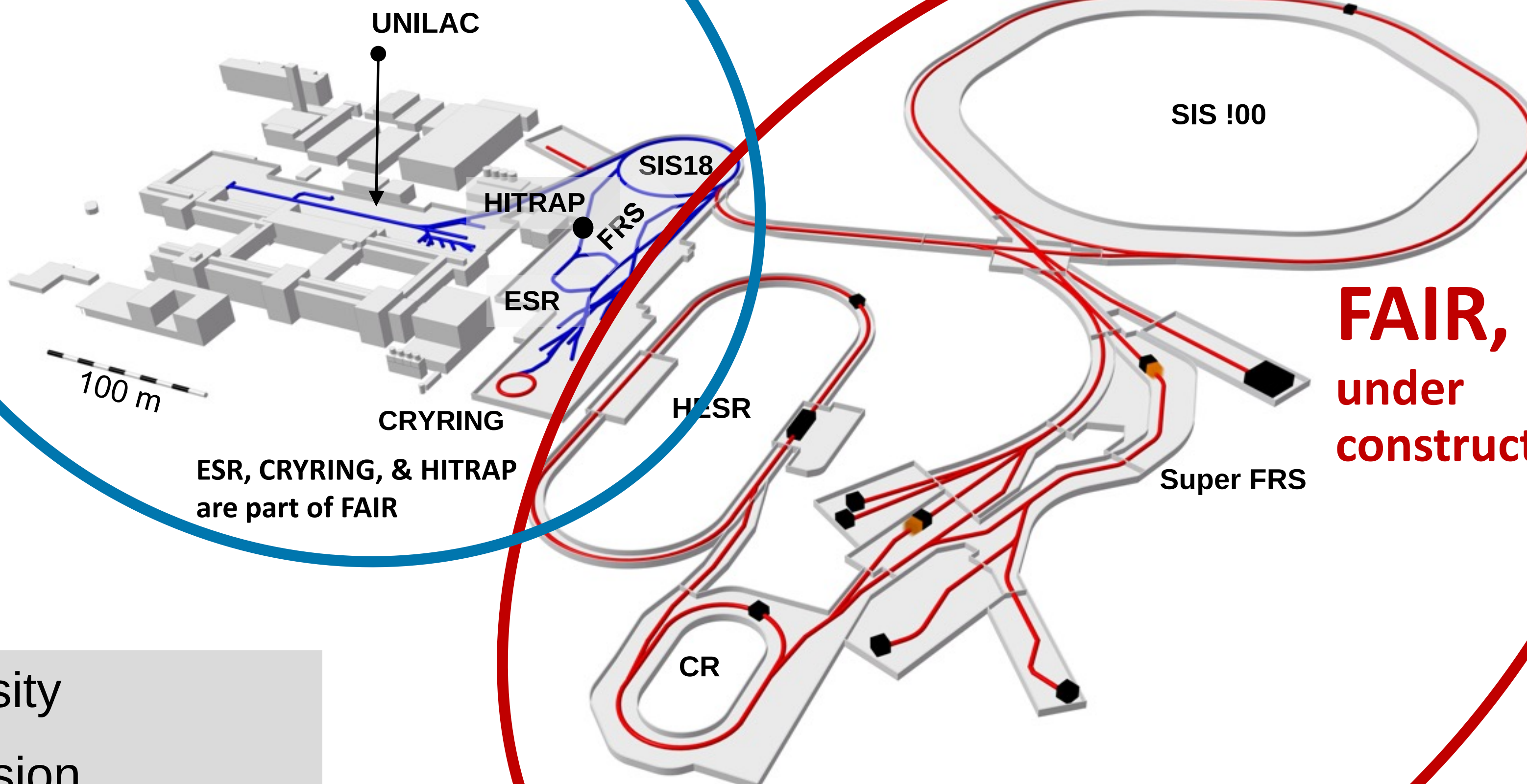
And they are realized as international efforts, at the level of the laboratories...



- **9 international FAIR Shareholders**
- 1 Associated Partner (United Kingdom)
- 1 Aspirant Partner Czech Republic (Since 2018)
- Participation of **3.000 scientists from all continents**

GSI and FAIR – The Facility

GSI, existing (upgraded to integrate with FAIR)



ESR, CRYRING, & HITRAP are part of FAIR

FAIR, under construction

- Intensity
- Precision
- Storage rings
- Antiproton beams

Construction volumes

2 million m³

of earth

to be moved

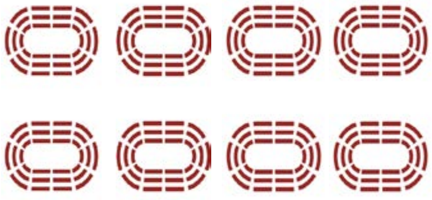
As much as for 5,000 single-family homes

600,000 m³

of concrete

to be used

As much as eight Frankfurt soccer stadiums

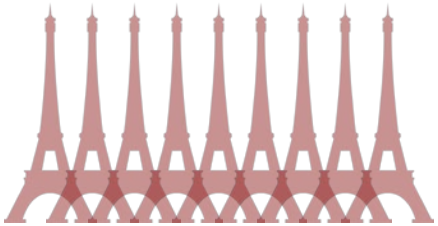


65,000 tons

of steel

to be utilized

As much as nine Eiffel Towers



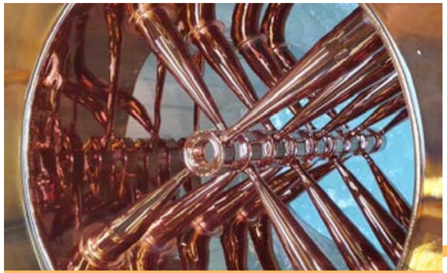
FAIR Civil Construction: Site View

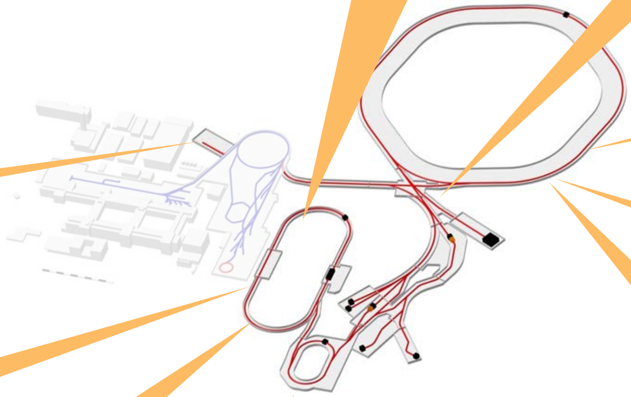
FAIR total facility - Worldwide production and delivery of accelerator components and experiments


HEBT: Dipole magnets


Power Supply Units whole facility

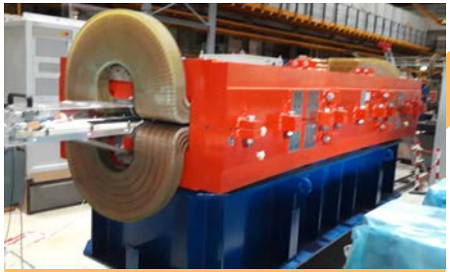

SIS100: Quadrupole-Magnets


p-Linac: RFQ-Development




SIS100: Vacuum Chambers


HESR: Quadrupole-Magnets


HESR: Dipol-Magnet


CR: Dipol-Magnet


SFRS: Multiplett-Magnet @ test bench


SIS100: Dipole Magnets

FAIR Accelerator components – Storage Area Weiterstadt

- Storage area: approx. 9.900 m²
- 4.195 objects (Components, assemblies, boxes, etc.)
- 08/2021 - Commissioning of a warehouse frame with approx. 1000 pallet spaces
- 50% of SIS100 components stored

Contributions “in kind”

- Many partners prefer to contribute components instead of money
- From the component list, each piece of the facility has a value (“cost book value”) agreed upon by the Scientific and Technical Issues Working Group.
- For providing a given component, this value is credited.
- In principle, no discussion about actual cost of production.
  - First definition of costs in 2005
  - In 2009 cost review: the costbook values were defined for the Convention

- Model followed by XFEL, ESS, CTA (and possibly others)

A specific example: Slovenia in FAIR

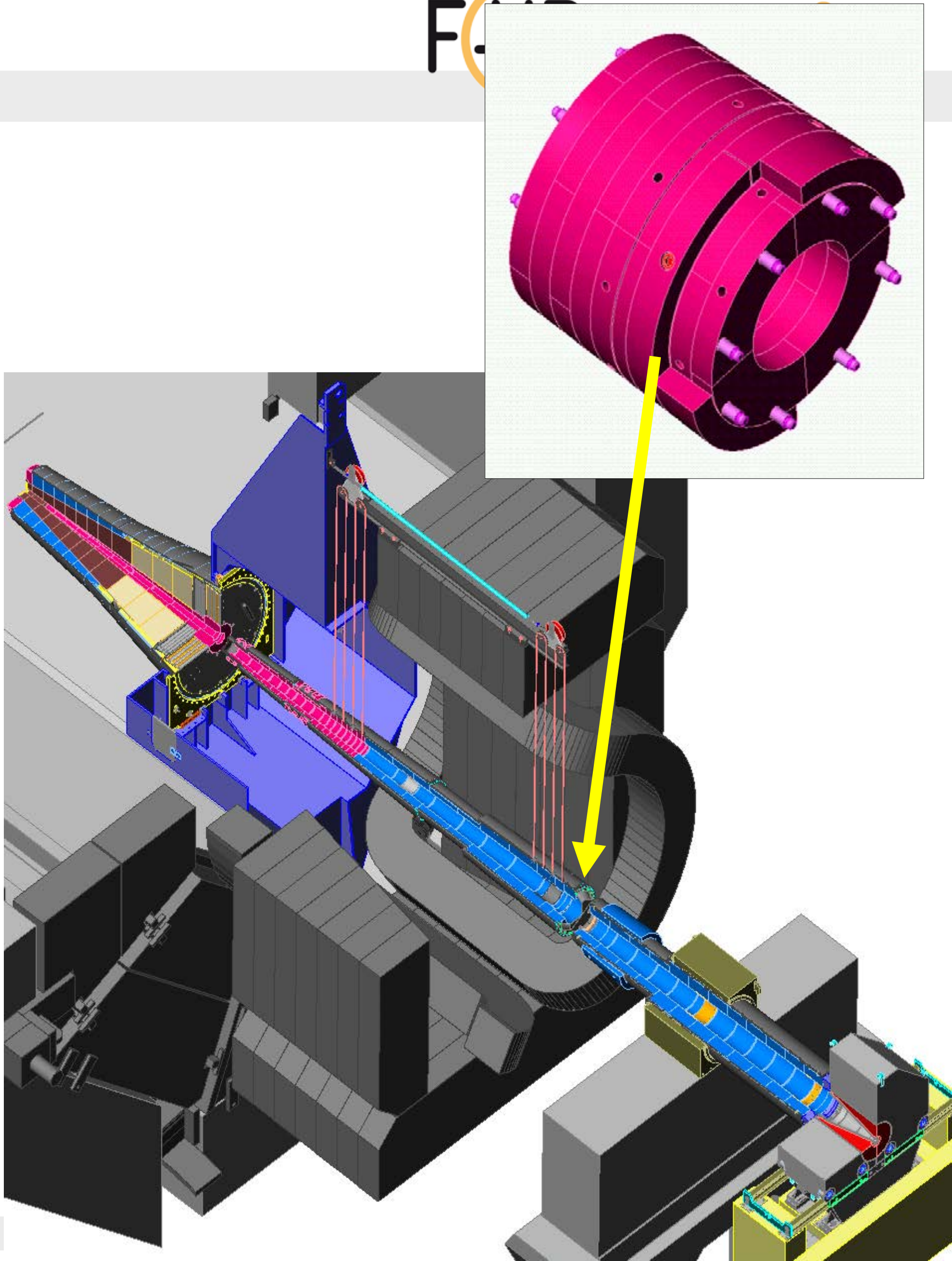
- BDP growth
  - Developments of products for FAIR by Tehnodrom will result in **200 Mio EUR** of taxable income in the next 10 years.
- ROI through taxes
  - During the period of working for FAIR, Cosylab and Instrumentation technologies alone contributed about **45 Mio EUR in taxes**
- Slovenia got new high tech jobs
  - The consortium increased the number of employees by **more than 300** – many of which would have relocated abroad otherwise

International cooperation

- Science needs and fosters international cooperation, mutual understanding, and promotes growths for all partners
- Science is a vehicle of dialogue and peace
- “Big Science” projects share many of their technologies and benefit from important synergies and collaborations

Even the “simplest” element requires the know-how and contributions from all over the world Example: the ALICE Muon Absorber

- complex mechanical piece ~ 100 tons ~ 18 m
  - optimized material content W, Pb, Fe, graphite, Boron, plastic, concrete,..
  - carefully chosen geometry
- minimize cost via design by factor 2!
  - and by worldwide bargain hunting

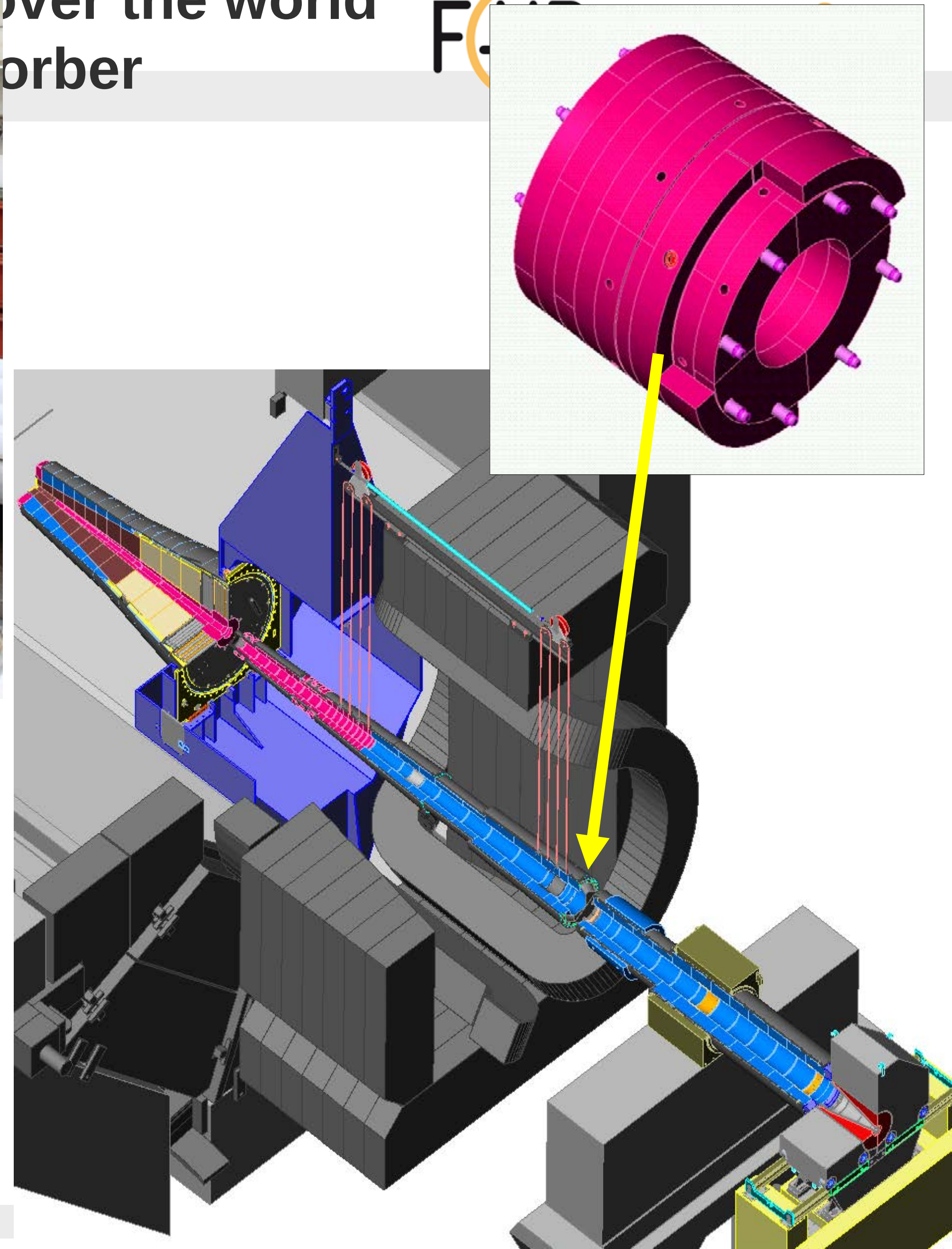


Even the “simplest” element requires the know-

…over the world

…orber

hunting



Even the “simplest” element requi

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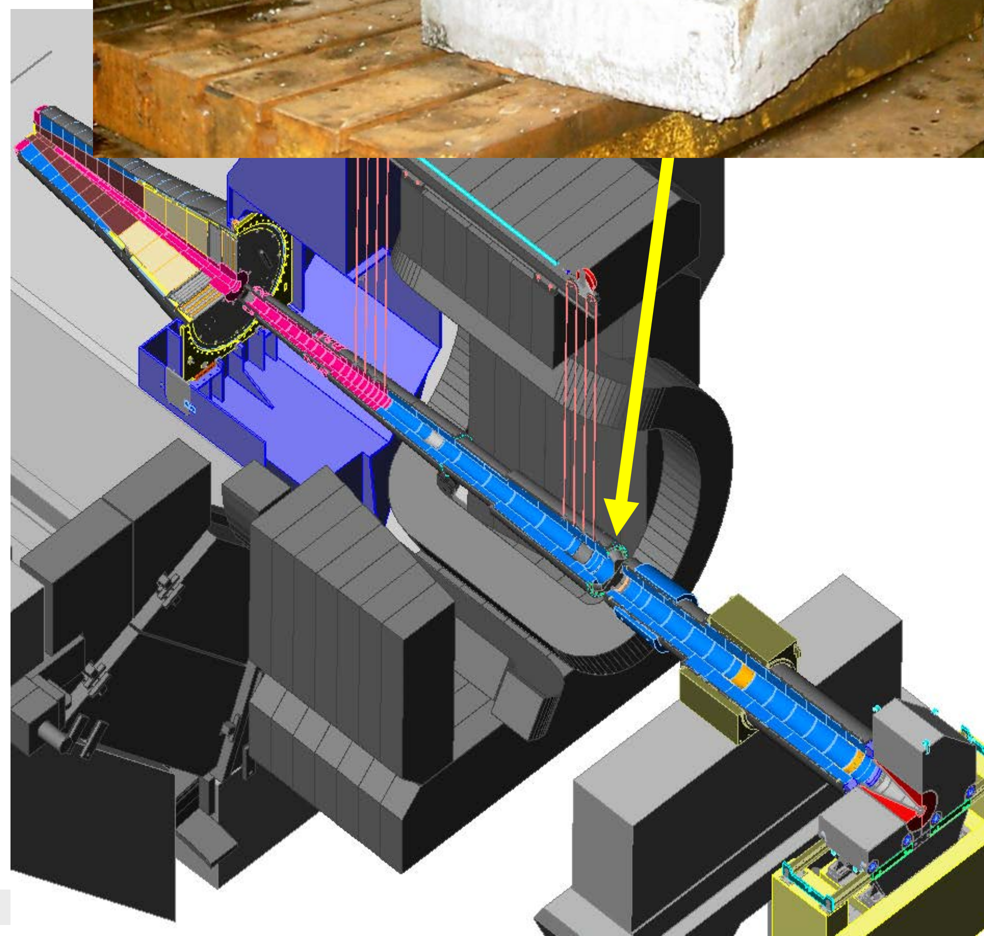

hunting

Even the “simplest” element requi

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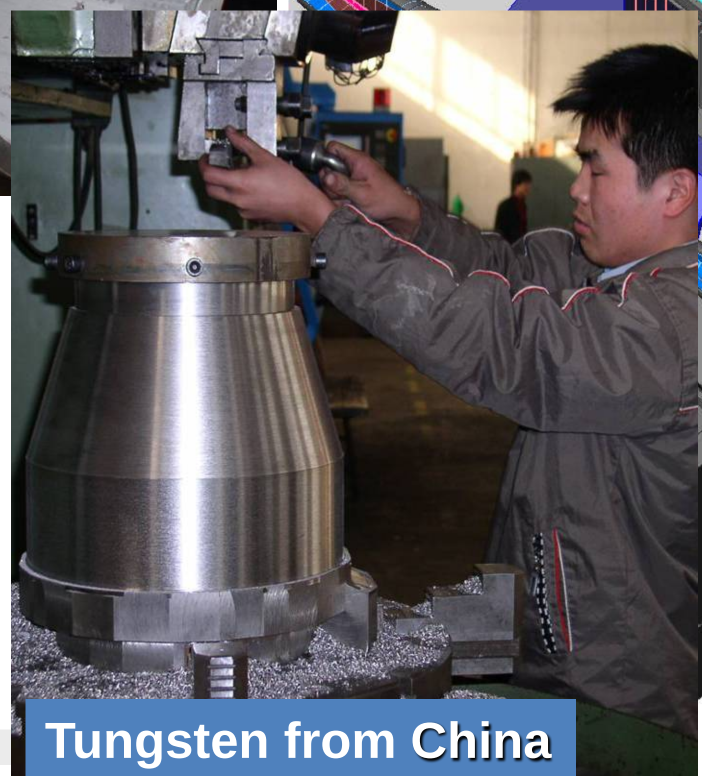

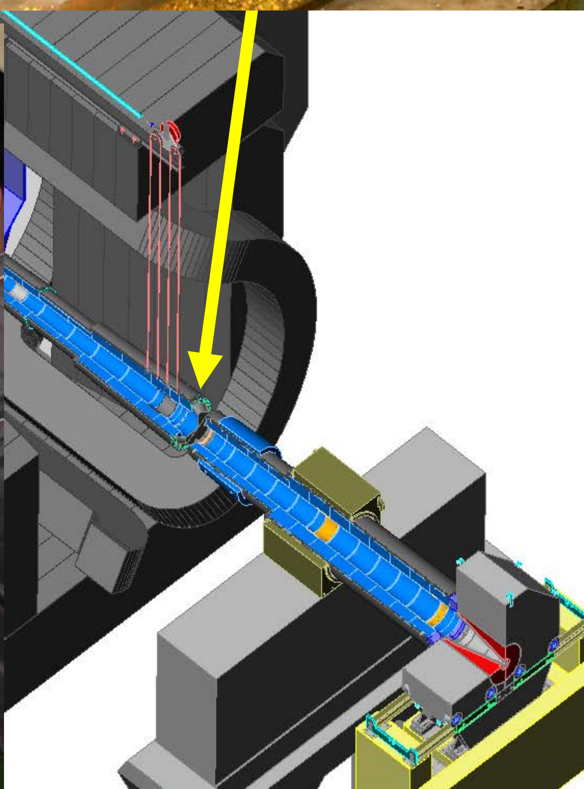

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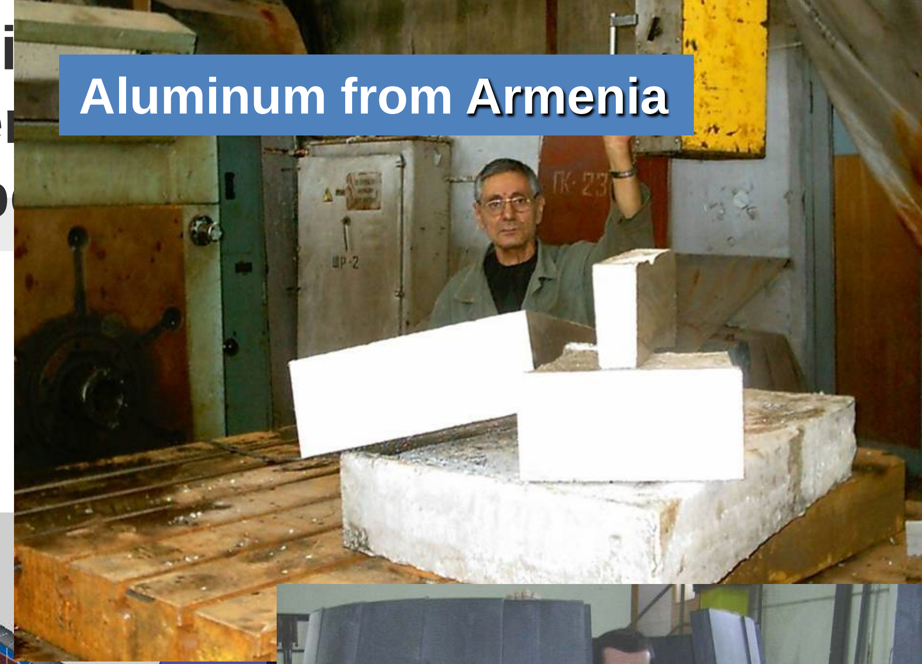


Even the “simplest” element requi

Even the “simplest” element requi

Even the “simplest” element requi

A TRUE "GLOCAL" SYSTEM

- Most of the FAIR accelerator and detector components are contributed by the member countries as in-kind contributions, namely they are designed and built by the participating institutions, in collaboration with local Industry.
- This effort implies also the development of innovative technologies
- The components are designed and built "at home", in the individual participating institutions, which bring in their know-how, scientific and technical skills, the local industry… but with a continuous exchange with the others, which makes it possible for all the individual elements to fit together.
- The groups who have developed a specific element follow it up in the test, commissioning and integration in the experiment, and later in its operation
- The data collected are spread worldwide for processing and final analysis, which is carried again in the home institutions, although the analysis groups meet typically on a weekly basis (via internet)
- within the experimental collaborations, all decisions on the technical choices, on operations and on the analysis are taken collectively by the collaboration

What motivates such efforts?

- **Thousands of scientists and engineers from all over the world work together for decades, having to fight for resources and support**
- Cultural differences, workstyles and organizational issues can be huge
- but in spite of the fact that most of the scientists could at any moment decide to do something else, they do abide to their commitments

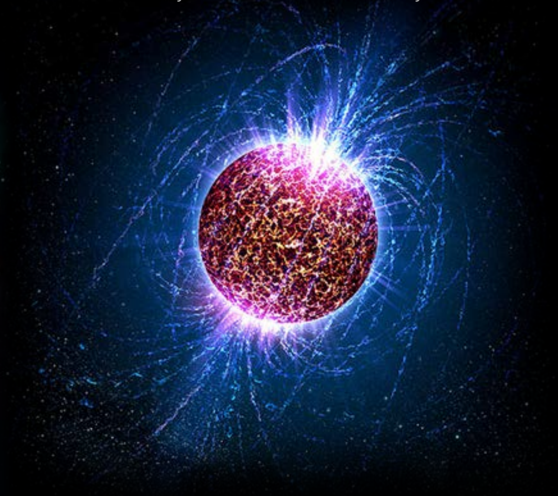
- **So.... Why?**
- **Guided by passion, they aim at answering key questions about the world around us, about the Universe, at solving fundamental issues for the future of humanity**

The secrets of the Universe

Creating extreme conditions existing in the universe with heavy ion accelerators

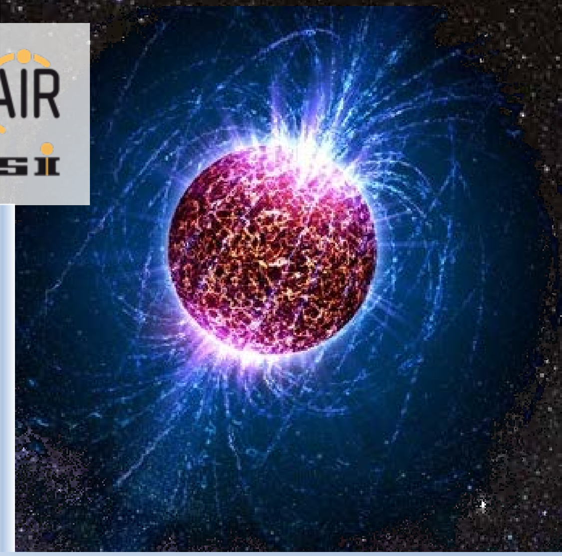
NASA, ESA, J. Hester and A. Loll (Arizona State University)

Casey Reed - Penn State University



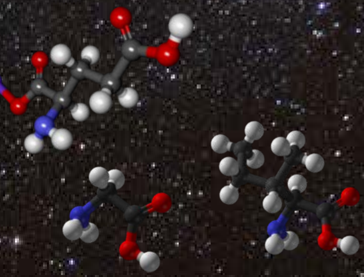
We bring the Universe to the lab

Where are heavy elements created?



What is in the interior of a neutron star?

What happens to human cells on the way to Mars?

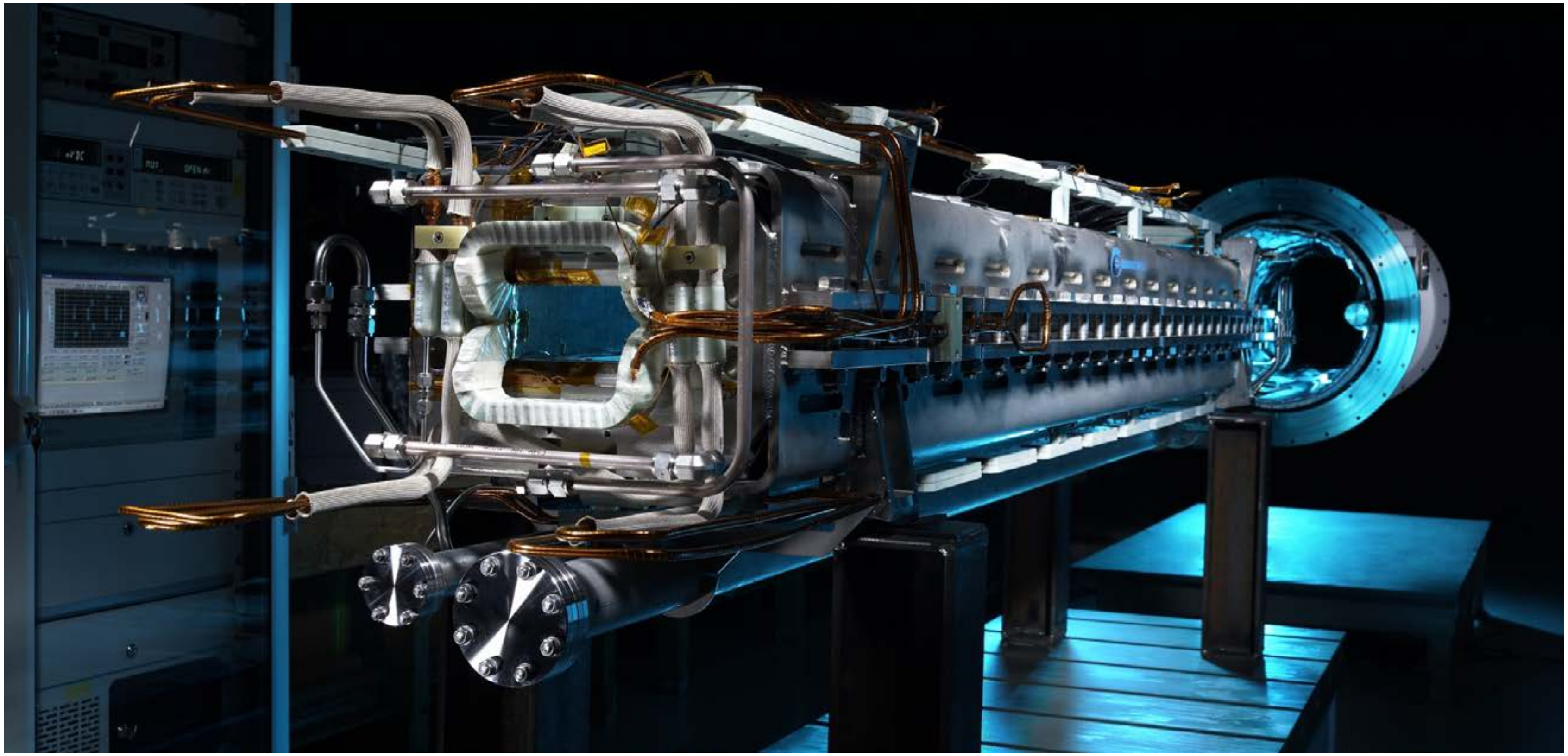


How are complex molecules created?

How do materials behave under high pressure?

Fotos: Uranus, Jupiter, Erde Quelle: http://de.wikipedia.org

But also ... Forefront Technologies



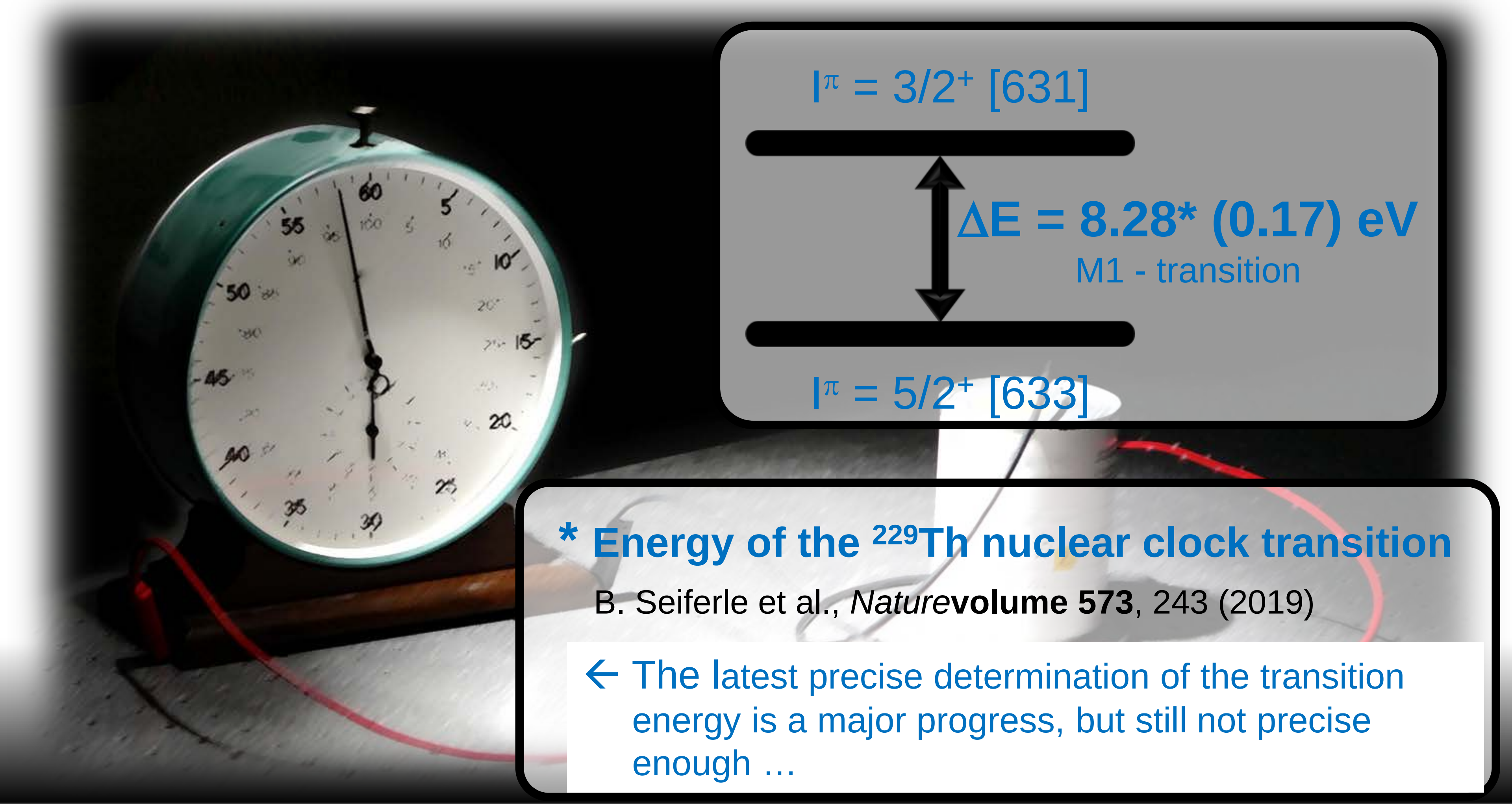
- Applications in accelerator science, detector instrumentation, materials research, radiation biology, therapy, computing
- Accelrator applications require **constant development** and **qualified, specialized personnel** => basics science accelerator labas are the factories for these

Green IT at FAIR

- Technological advancements in high-performance & scientific computing, Big Data, Green IT

More applications: $^{229(m)}$Th: A Unique Candidate for an Extreme Stable Nuclear Optical Frequency Standard

Concept: E. Peik and C. Tamm, Europhys. Lett. **61**, 181 (2003)



$I^{\pi} = 3/2^{+}$ [631]

ΔE = 8.28* (0.17) eV

M1 - transition

$I^{\pi} = 5/2^{+}$ [633]

*** Energy of the ^{229}Th nuclear clock transition**

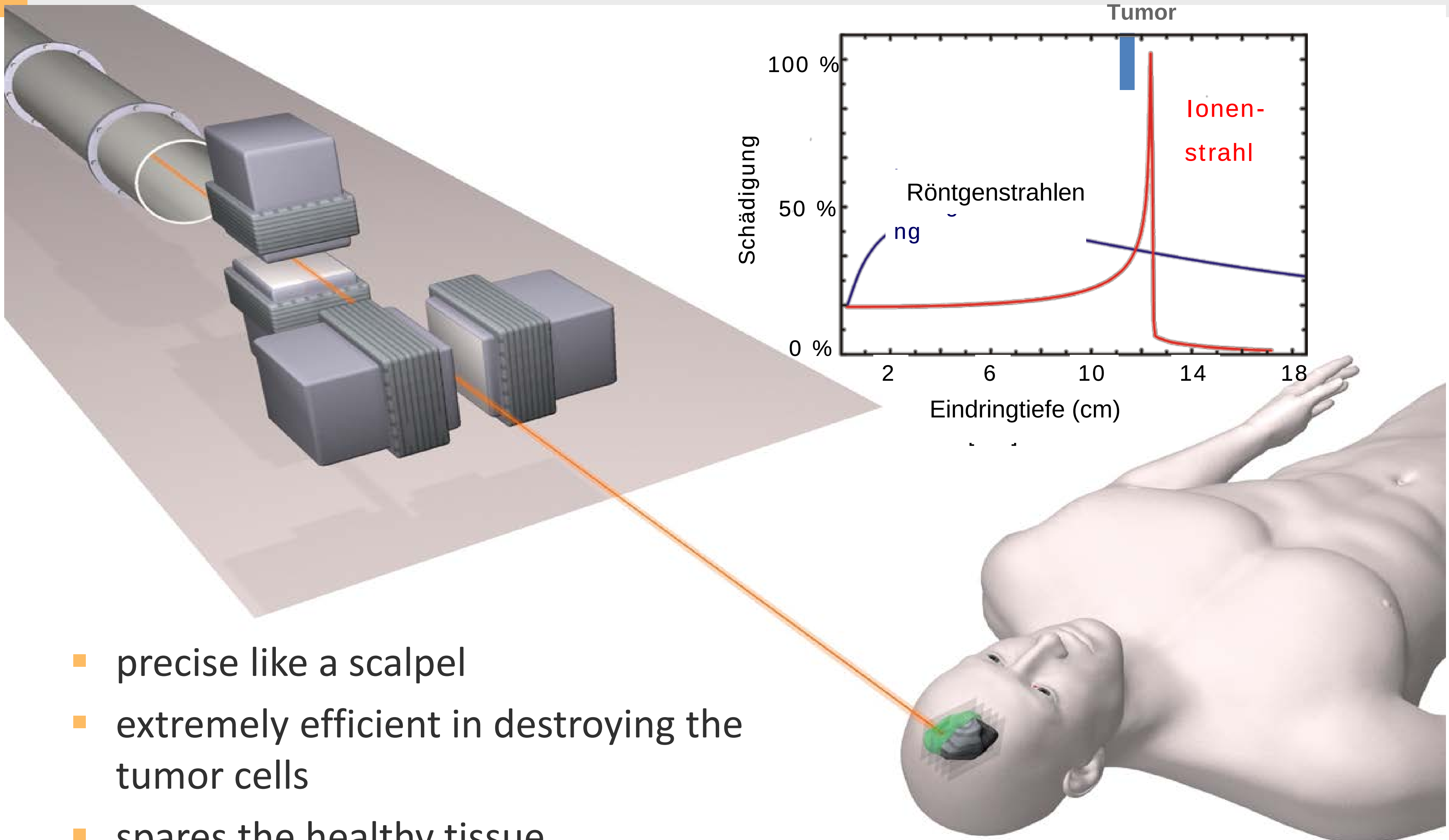
B. Seiferle et al., *Nature* **volume 573**, 243 (2019)

← The latest precise determination of the transition energy is a major progress, but still not precise enough …

GSI/FAIR: Innovation in cancer therapy

- Therapy with nuclear beam, pioneered at GSI
- Over 400 patients treated on site, now established clinical protocol

Ion Beam Therapy at GSI/FAIR

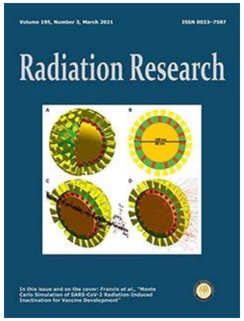


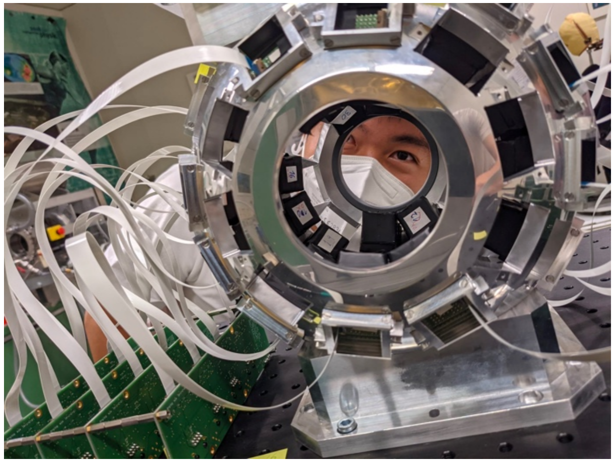
- precise like a scalpel
- extremely efficient in destroying the tumor cells
- spares the healthy tissue

Continuous progress…

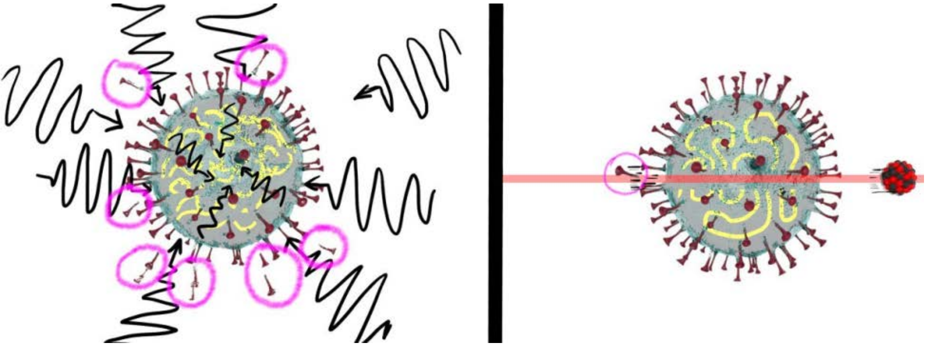
FLASH – new method for ultrafast, high dose treatment of cancer with carbon ion beams

FAIR Phase 0 Research Program





Hybrid γ-PET detectors for RIB

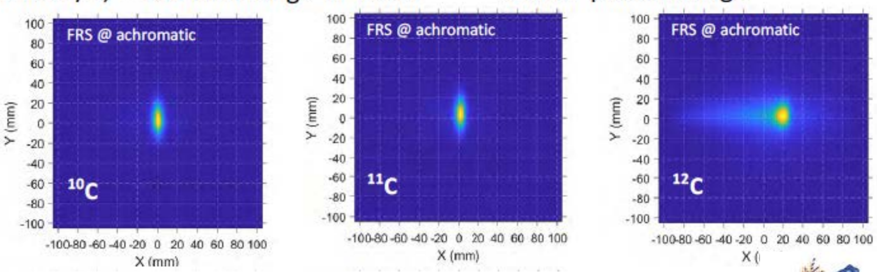


Research on COVID-19 vaccines production with heavy ion beams in cooperation with HZI-Braunschweig

BARB (ERC Grant) – Cancer Therapy with radioactive isotopes for simultaneous treatment and PET

~270 MeV/u, ~120 mm range in water

3D PET planar image



www.gsi.de/BARB

Materials…

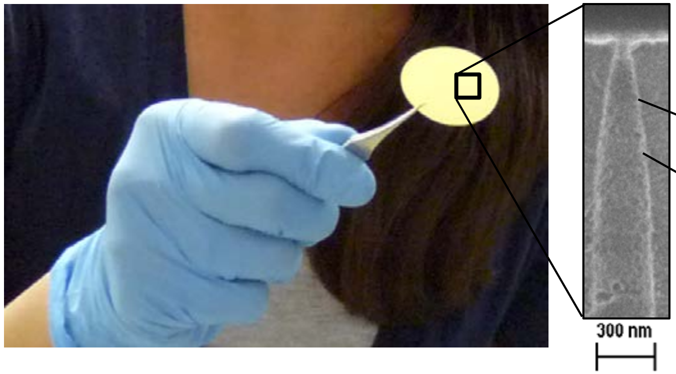
- New sensor for SARS-CoV-2 and other viruses based on GSI/FAIR nanotechnology
  - better and faster virus detection with single nanopore membranes
  - detection of SARS-CoV-2 in saliva, serum or wastewater without sample pretreatment
  - same sensitivity as a qPCR test, result in 2 hours
  - sensor distinguishes infectious from non-infectious corona viruses

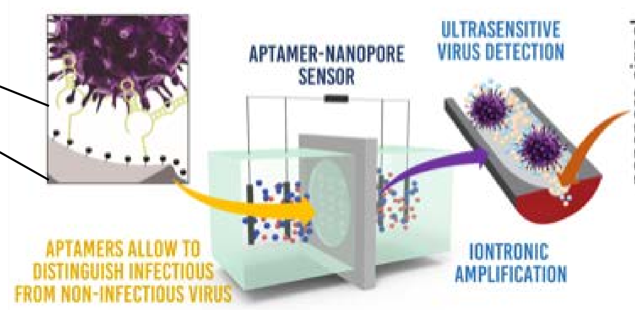
FAIR Phase 0 Research Program

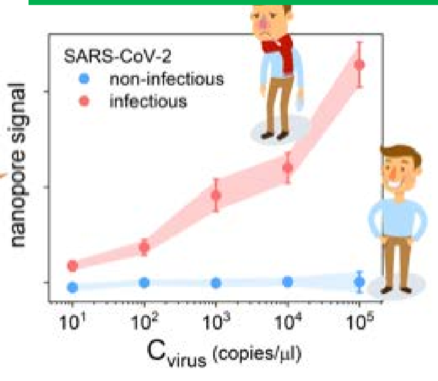
Highly sensitive nanopore by Ion-track nanotechnology

High selectivity by coating nanopore with selective aptamers that bind specific virus (tested with SARS-CoV-2 and adenovirus)

Transport measurements through coated nanopore indicate infectious state of tested virus







The third pillar: talent development.
example: Talent Factories

A unique capability to attract and create talent and know-how.

Training and education of the next generation of scientists, engineers and computing experts from all over the world:

- Fair Example:
  - Graduate Schools with currently more than 300 doctoral students from all over the world
  - International Postdoc Programs
  - Multiple training programs for students
  - Bilateral Agreements with several countries for training and education of young scientists and engineers

Responsibility

- Our **economic responsibility** has become imperative since the birth of "Big Science". Fundamental scientific questions need ever more complex and expensive equipment to be addressed (e.g. particle accelerators); no single university or state can carry the cost.[1] FAIR costs the public money, and the public expects a return on that. The SSC in Texas was cancelled also because of its perceived lack of economic return.[2]
- We have **political responsibility**, too. Science is expected to address the so-called "grand societal challenges" such as climate, energy, food and health. Society looks to science for the deep tech innovations expected to help us here.[3]

[1] G. F. Giudice, Phys. Perspect. 2012
[2] S. Weinberg, *The Crisis of Big Science*, 2012
[3] EU Horizon 2020 programme

Models for socioeconomic impact at the institutional level

The Technopolis model gives the following categories of impact:[1]

- Scientific added value from the research itself: knowledge
- Creation of networks and human capital
- Economic added value – including innovation
- Added value for society

[1] Technopolis, *The Role and Added Value of Large Scale Research Facilities*, 2011

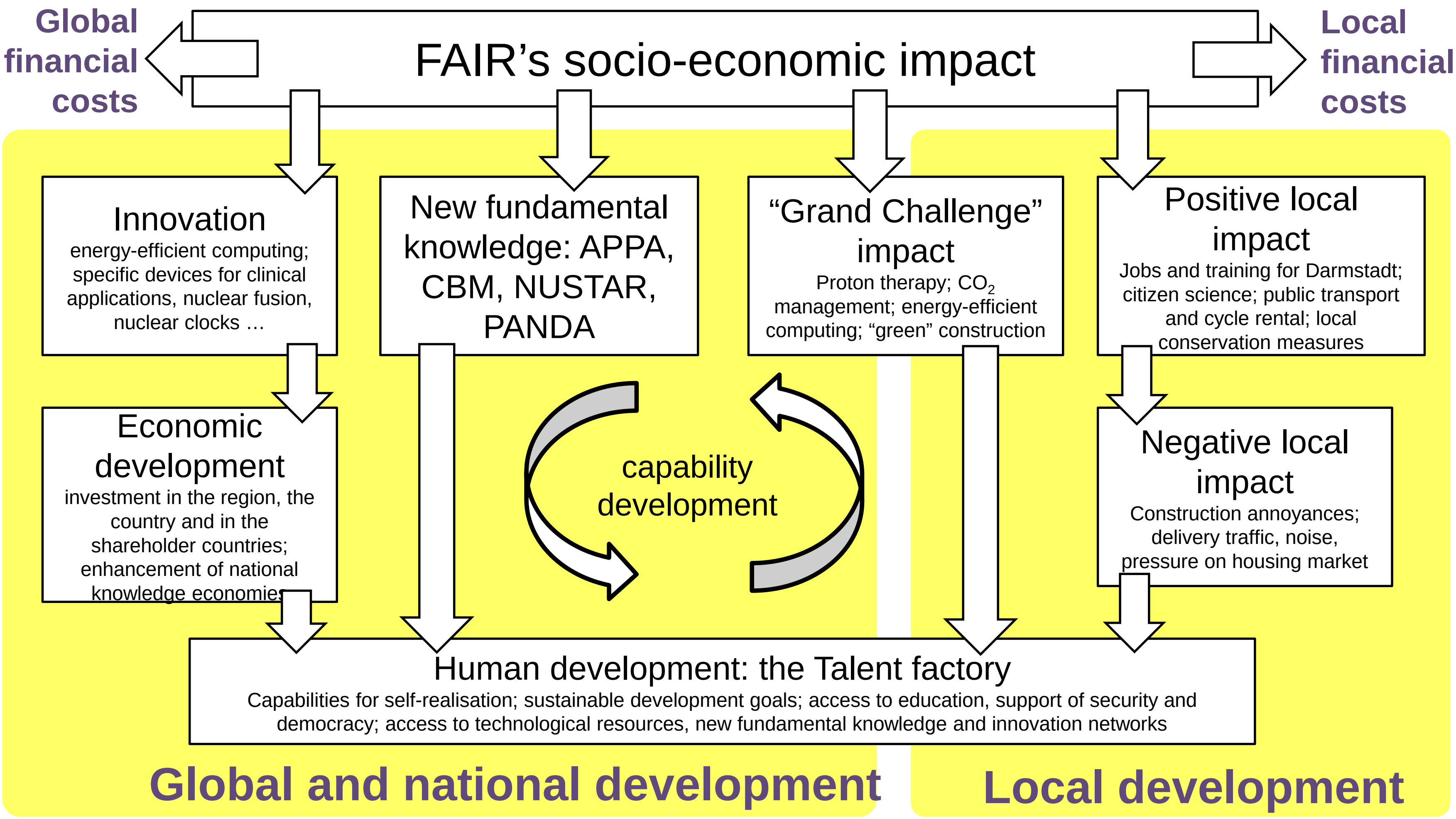


Figure adapted from M. Gastrow and T. Oppelt, *The Square Kilometer Array and Local Development Mandates in the Karoo, 2019*

Knowledge spillover as a development goal

- Academic and trades knowledge transfer: FAIR and its parent, GSI, have an educational mandate to educate and train scientists, engineers and tradespeople. Our lead scientists teach in many universities: Darmstadt, Frankfurt, Mainz, Jena, Heidelberg, Tübingen, Gießen, Bochum and several more, including outside Germany
- Public knowledge transfer: outreach and citizen science. FAIR and GSI offer tours, school visits, girls' day activities, masterclasses, public lectures.
- Downstream innovation – technology push: research and instrument development made at FAIR can be applied to other problems. Examples at FAIR: the digital open lab and RosEn. This is the "classic" technology transfer, including spin-off, licencing and incubators.[1]
- Upstream innovation– demand pull: FAIR needs technologies at the frontier of technology – or even beyond that frontier. FAIR's needs act as a motor of innovation. Upstream innovation is managed through the tools of in-kind collaboration, procurement and industrial liaison. It is notoriously hard to measure.[2]

[1] Geschka and Geschka, *Innovation Strategies*, 2018
[2] E. Autio, *Innovation from Big Science: Enhancing Big Science Impact Agenda*, 2014

Downstream innovation at FAIR

- Digital open lab for developing, testing and upscaling energy-efficient high-performance computing to the scale of industrial demonstrators. Joint development around the topics of HPC, Big Data and ultra-fast data acquisition
- Covid 19: membranes for filter masks; virus detection membranes; ion radiation for vaccine development; proton therapy for lung damage caused by SARS-Cov 2.
- Passive neutron dosimeter for environmental monitoring
- RosEn method for the time-dependent processing of 4-dimensional CT, MRI and X-ray images, such as the continuously changing surface of a breathing lung.
- Double Threshold Discriminator Chip for high speed signal processing

Sustainability: the cost side

- big science, big costs
- responsible use of resources imposes innovation
- accelerator energy consumption
  - smart use involving AI
  - expanded use of supercondutors
  - new acceleration technologies
- computing energy consumption
  - major breakthrough on cooling, yet still many opportunities
- patient exam of many smaller aspects
  - „culture of sustainability“

Why big science international projects ?

They are unique opportunities for world science.

- Addressing fascinating fundamental questions for human knowledge

They produce advanced technologies of enormous societal impact

- advances in medical instrumentation, IT, ...

They are a unique tool to grow the next generations of talented scientists and engineers

- proven tools of talent growth, capable of competing successufully at the global level

International cooperation is a must

- convergent collaboration from many countries is indispensable to realize these projects, not just for the financial resources, but even more for the human capital needed.


Big Science = > Unique Opportunities
Thank You!

Backup

Measuring impact: the what and the how

- What impacts so we have the time and resources to measure?
- How shall we measure them?

At FAIR, we are concentrating on long-term knowledge and innovation impact using the following ingredients:

- Case study
- Innovation ecosystem theory
- Upstream innovation using the methodology of Florio et al.[1]
- Knowledge mapping of Boisot and Nordberg.[2]

[1] M. Florio, *Industrial and Corporate Change, Vol 27, no. 5*, 2018
[2] M. Boisot and M. Nordberg in *Collisions and Collaboration*, 2011

The “magic ingredient” of innovation

Since the invention of the internet at CERN, policy makers have been looking for the “magic ingredient” that made it happen.

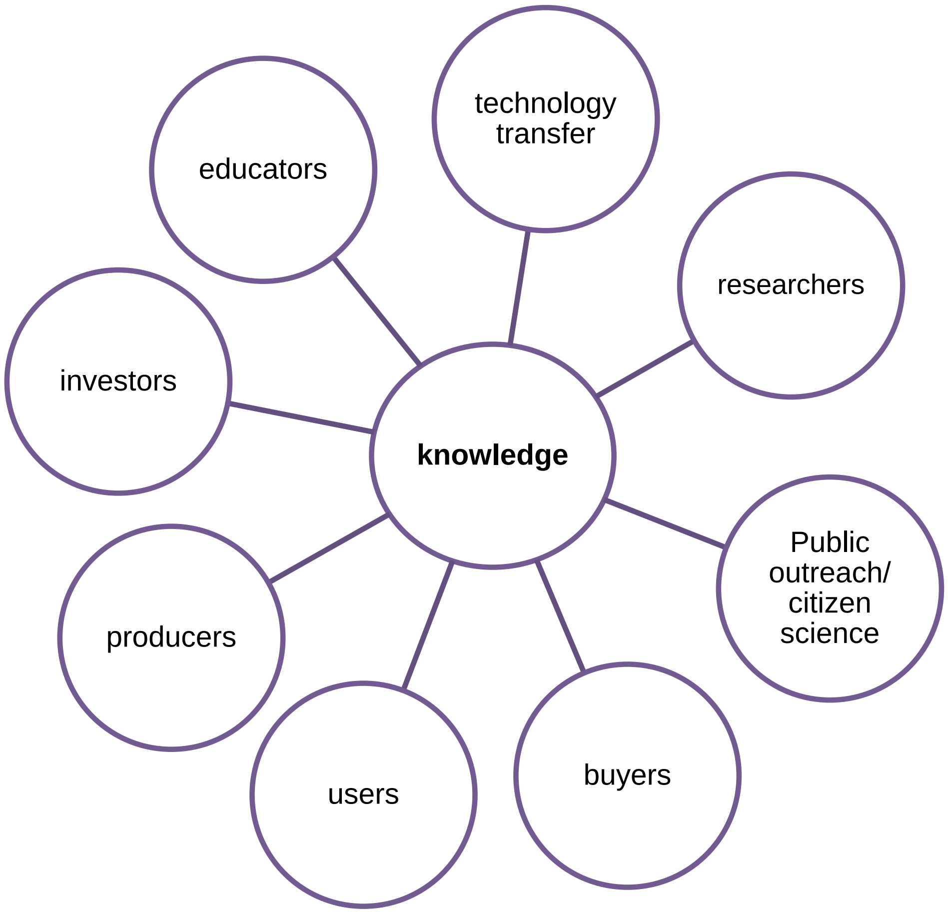
- The ingredients of classical innovation theory (culture, creativity, diversity, academic freedom, risk mitigation etc.) are a given for any Big Science centre, FAIR included.
- What role do interventions such as incubators play?
- The role of business plan and governance in making FAIR a cradle of innovation.[1]
- Mapping the innovation ecosystem at FAIR
- Who has knowledge, and when?

[1] H. Chesbrough, *Business Model Innovation: Opportunities and Barriers*, Long Range Planning 43, 2010

The FAIR knowledge ecosystem

knowledge nodes

knowledge type



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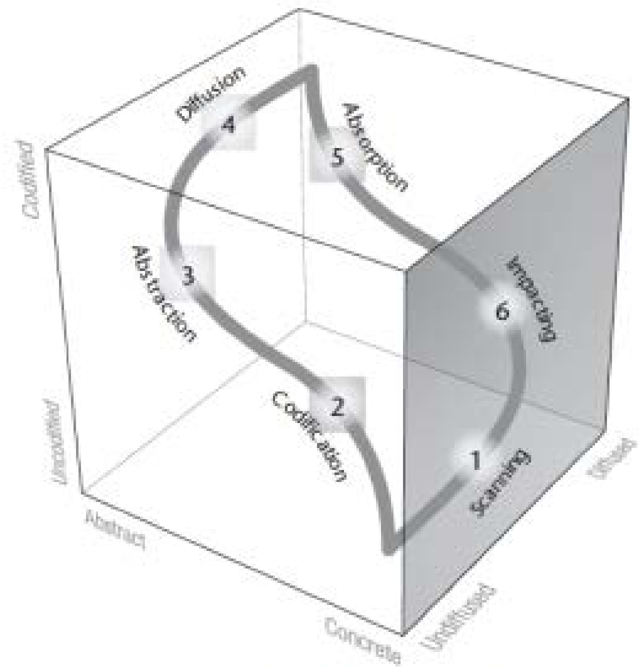

Image taken from M. Boisot and M. Nordberg in *Collisions and Collaboration*, 2011

FAIR's commitment

- To identify and measure our impact, especially knowledge spillover
- To improve positive impact through innovation and education
- To reduce negative impact
- To establish impact benchmarks