Accelerators for Physics with Neutrons

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16 February, 2017

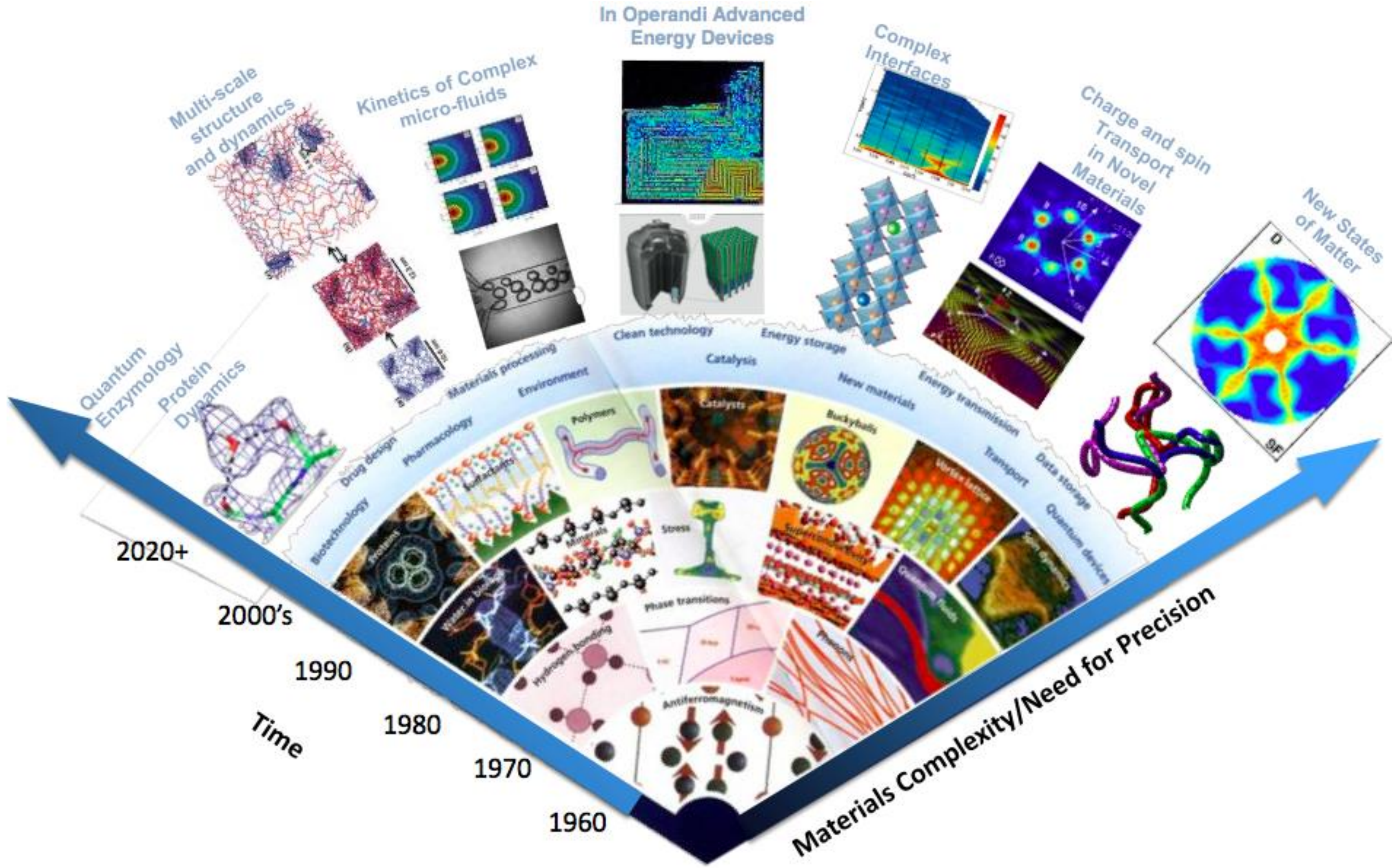
Outline

- Applications of neutrons
  - Science (incl. physics) using neutrons
- Current status of neutron sources
  - In Europe
- Potential of the sources
- ESS and its role
  - Where we are now
  - Challenges and prospects
- Conclusions
  - Stating perhaps the obvious, but still…

Applications of neutrons

- Multi-disciplinary science applications
  - Next slides
- Transmutation of radioactive (waste) material
  - Accelerator-driven Systems
- Industrial applications: materials analysis and non-destructive testing tools in many industries, including oilfield operations, heavy mechanical production, art conservancy, detective work, and medicine.
- Coming from a spallation source, with a light source background, I concentrate on the first bullet

Science at ESS



Physics with Neutrons

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- Or rather: science with neutrons
  - **life sciences**: For structural investigations of biological macromolecules such as proteins or nucleic acids at the atomic level by crystallography the key advantage of neutrons is that they allow the hydrogen atoms to be visualized.
  - **soft condensed matter research**: Many soft materials have commercial or medical applications. Designing and predicting the complex behavior of these materials requires understanding the roles of individual components, for which neutron scattering techniques exploiting non-invasive deuterium labeling are an ideal tool.
  - **chemistry of materials** Neutrons and X-rays are the most basic tools for characterizing these new materials. While X-rays often provide highly accurate information on complex symmetry, neutrons are best suited for accurately finding the position of atoms.
  - **energy research** the high penetration depth of the neutron can be used to probe complex systems and assemblies under working conditions. In many cases, the presence of light atoms such as oxygen, lithium and hydrogen require neutron-based techniques to elucidate structure and to determine mechanistic pathways.

Physics with Neutrons

- **magnetic and electronic phenomena**: Neutrons investigate electronic properties via the interaction of its spin with the electronic state of condensed matter.
- **engineering materials and geosciences**: The penetration ability of neutrons allows scientists to investigate non-destructively the properties of bulk materials, complex assemblies such as multi-component devices, and to investigate inner structure and processes with high precision and sensitivity.
- **archaeology and heritage conservation**: Simultaneous diffraction/SANS/imaging studies are invaluable for sensitive samples of historical and cultural value. Neutrons can penetrate through coatings and layers of corrosion, and there is generally very little need for cleaning or sample preparation.
- **fundamental and particle physics**: The higher intensity and the pulse structure of ESS provide new possibilities for fundamental neutron physics experiments. Ultracold neutrons are available at other sources (UCN@PSI for example)

Science with neutrons

- Observation: the previous list contains almost the same topics as the list for science with synchrotron sources
- Methods are not rivals but complementary
- Communities are however traditionally very different
  - This may be changing, slowly but surely
- Could the synergy be better utilized?
  - Certainly!
- Some sites have the potential
  - PSI (SINQ,SLS,SwissFEL), RAL(Diamond Light Source, ISIS), HZB (BESSY-II, BER-II)
  - And Lund, with ESS and MAX-IV

Operating neutron sources in Europe

- Accelerator-based (2)
  - ISIS-Rutherford-Appleton Laboratories, United Kingdom
  - SINQ, Paul Scherrer Institut (PSI), Switzerland
  - (ESS in preparation)
- Reactor-based
  - Institut Laue-Langevin, Grenoble, France (25% funded by Germany)
  - Leon Brillouin Laboratory, Saclay, France
  - **Berlin Neutron Scattering Center, Germany**
  - **GEMS at Helmholtz-Zentrum Geesthacht, Germany**
  - **FRM-II, Munich, Germany**
  - Budapest Neutron Centre, Hungary
  - RID, Delft, The Netherlands
  - Frank Laboratory of Neutron Physics, Dubna, Russia
  - St. Petersburg Neutron Physics Institute, Gatchina, Russia

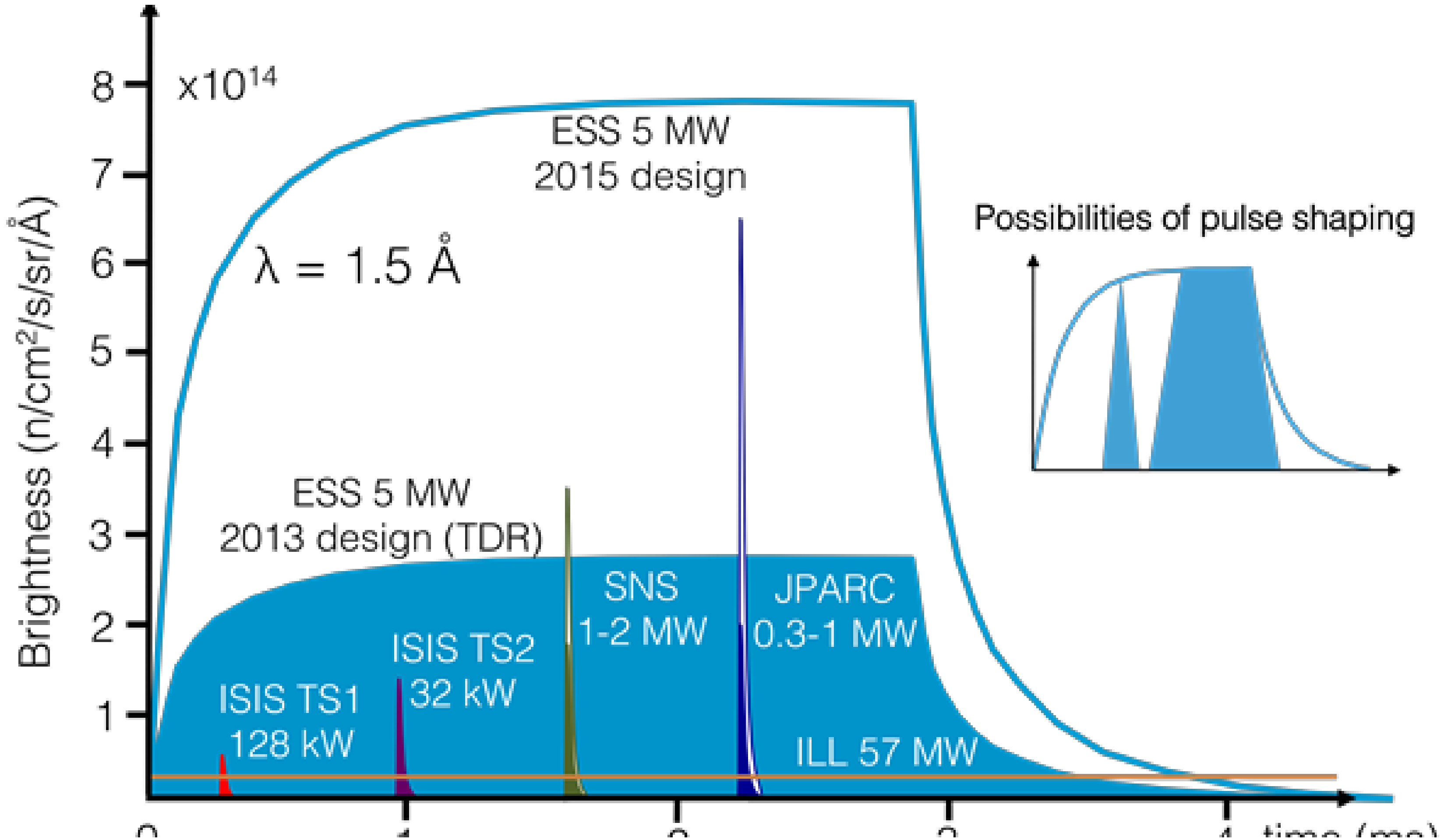
Neutron Science in Europe

- Reactors
  - most of neutron science is done at reactor-based facilities today
  - In the long run, reactors will be shut down. Not easy to build new ones
- Accelerators
  - In Europe: ISIS (pulsed), PSI (continuous) and ESS (long pulsed, in construction)
  - There is a clear need for more accelerator-based sources (if neutron science is to prosper)

Key properties of a user facility

- Reliability and availability
  - Hard to beat a reactor with an accelerator
  - But we should try to be very close
- Performance: brightness, flux
  - Spallation sources have a clear advantage
- Flexibility to accommodate user’s needs
  - Accelerator-based sources have an advantage
- User-friendliness
  - Regardless of source type, I think there is work to be done

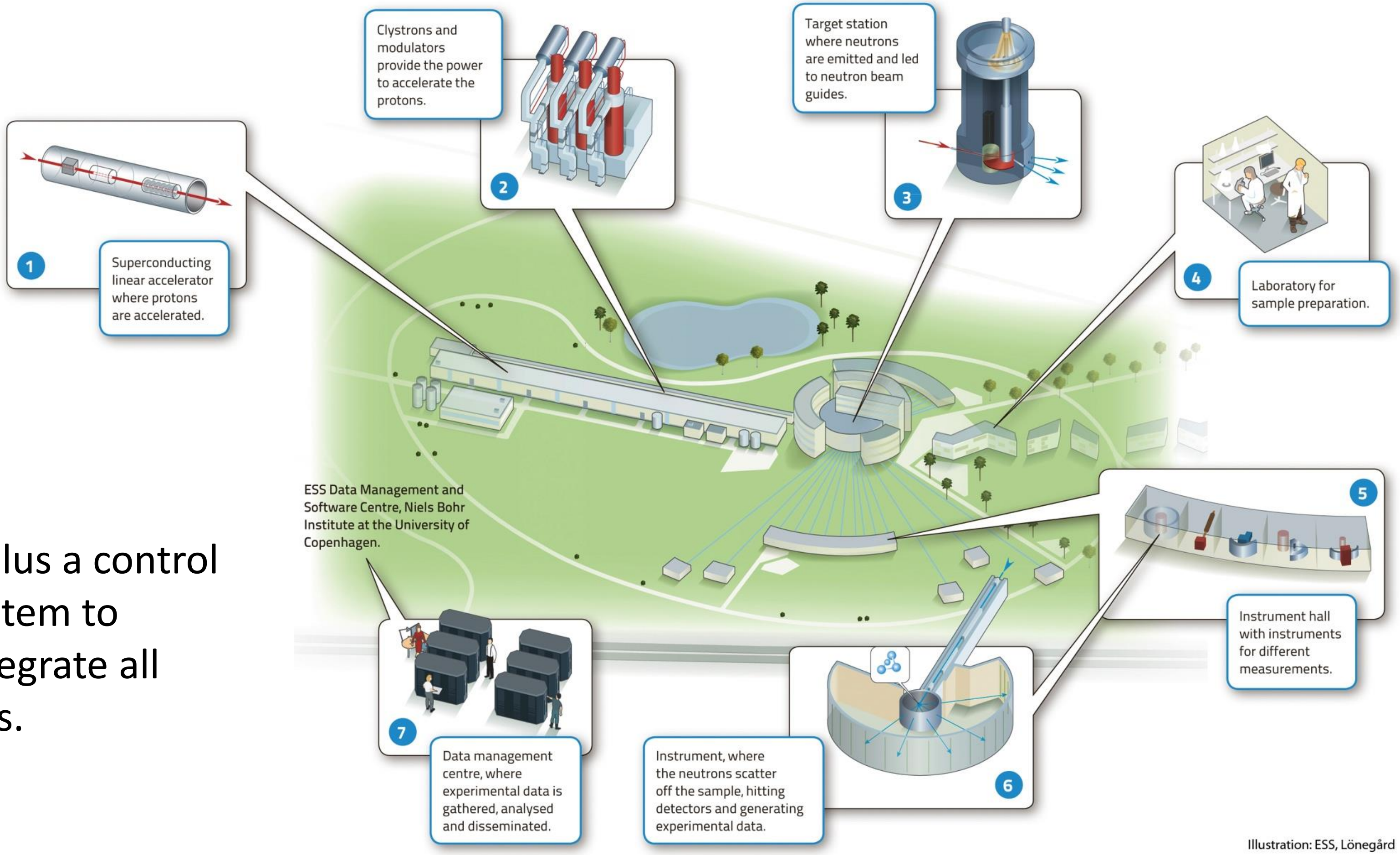
Comparison of brightness potential



The European Spallation Source

- To be the world’s most powerful neutron source
- High power linac (5 MW average, 125 MW peak)
  - Has also a “technology demonstrator” function
- Complex facility to build
  - Learning to run the machine efficiently will take quite some time
- Also the surrounding organization (laboratory) has to be built at the same time
  - Needed to become a real user facility!
- A lot of work to do to before the whole infrastructure is in place!

ESS components

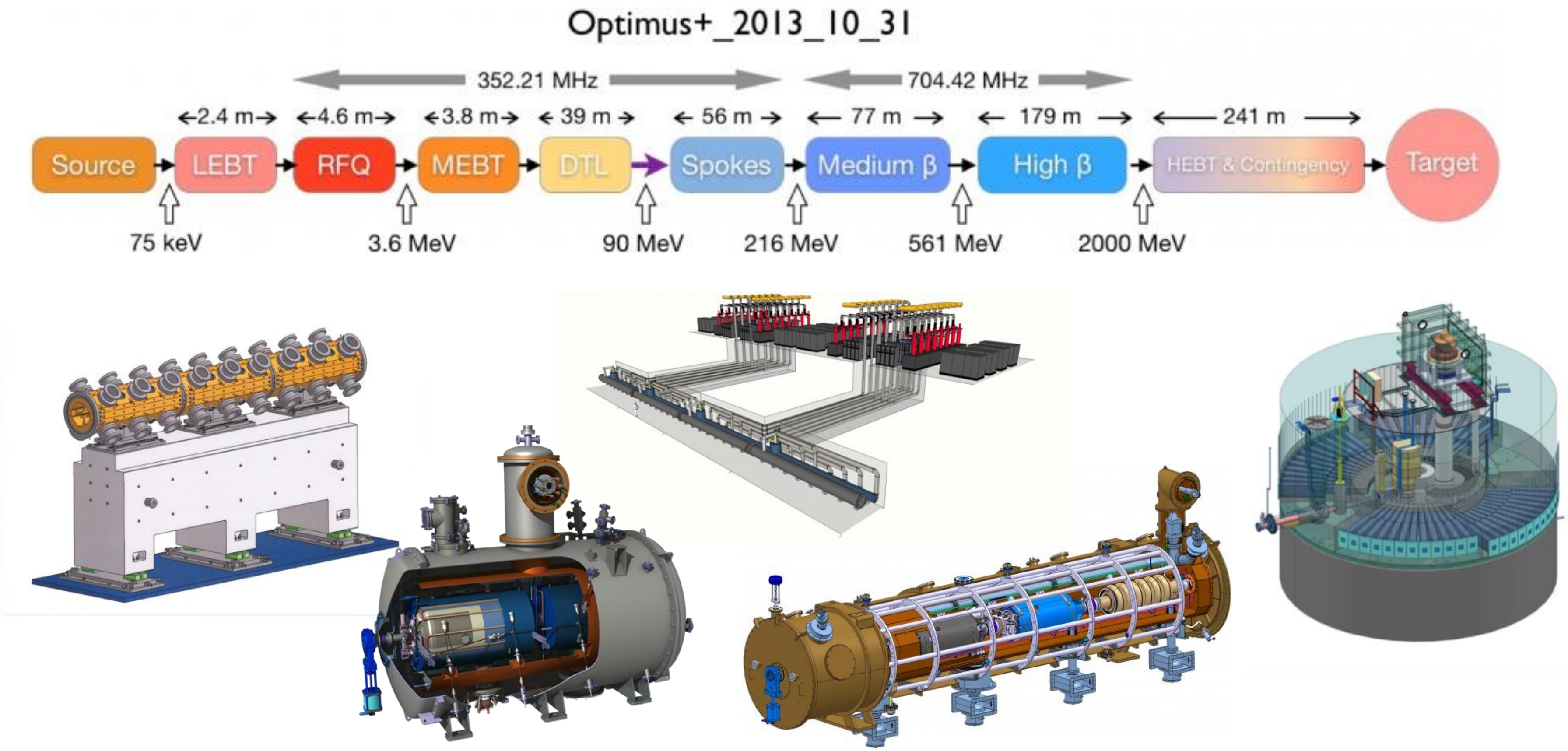


…plus a control system to integrate all this.

ESS facility (accelerator and target)

- Source
  - The Microwave Discharge Ion Source (MDIS), 75 keV protons
  - The Low Energy Beam Transport (LEBT)
- Warm linac
  - The Radio-Frequency Quadrupole (RFQ), 75 keV to 3.62 MeV, 352.21 MHz
  - The Medium Energy Beam Transport (MEBT)
  - The Drift Tube Linac (DTL), 3.62 MeV to 90 MeV, 4 tanks of 8 m each
- Cold linac
  - Spoke linac, 90 MeV to 216 MeV, 352.21 MHz
  - Elliptical linac, 216 MeV to 2.0 GeV, medium-beta and high-beta cavities at 704.41 MHz
- High Energy Beam Transport
  - Rastering system spreads heat load over a larger area on the target
    - Seems to affect the neutron flux at the instruments
- Target
  - Rotating tungsten target, with 36 sectors
  - two liquid-hydrogen moderators

ESS Linac & target components



ESS Construction progress (Feb-2017)

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The site starts to take shape
-accelerator tunnel and klystron gallery are close to completion
-first control systems are in operation (conventional facilities)

Target monolith is under busy construction, but still a lot of work is ahead.

Challenges of a high-end facility

- High-current accelerators like ESS require new levels of control of beam losses and instabilities
    - advanced beam diagnostics and analysis methods,
    - reliable computer models and verification tools, and
    - novel beam distribution control and feedback systems.
- Machine protection is critical
    - Protect the machine but do not block (i.e., "protect the beam")
- Control system performance and user-friendliness
    - Transport, storage and management of high volume, high complexity data – even in the accelerator (not only instruments)
        - Estimated 1.5 million "process variables"
    - Flexible methods of data handling
        - Storage, retrieval, indexing
- Availability expectations are high (>95%)
    - Compared against reactors and synchrotron light sources

Role of ESS as I see it

- ESS is a frontier facility
  - Important but probably unique, for a good while
  - Not sufficient alone to foster neutron science
  - Pushes the limits of achievable
- Serves a crucial role, but access is limited
  - High competition for beam time
  - Will take time to mature
- Should be complemented with other facilities
  - within reach of national institutes or universities

Scales of facilities

- Large-scale facilities, intensity frontier
  - Time-consuming to build
  - Only a few are feasible world-wide
  - Intensity frontier, discovery machines
    - Explore and extend the limits of possibilities
    - High competition to access
- Medium-scale
  - Feasible within one (major) institute or university
  - Easier to access for a scientist
    - Different path to discoveries – shorter cycle
- Small-scale (do they exist?)
  - Even commercially available
  - Spin-offs from larger facilities
  - Multitude of applications

Conclusions

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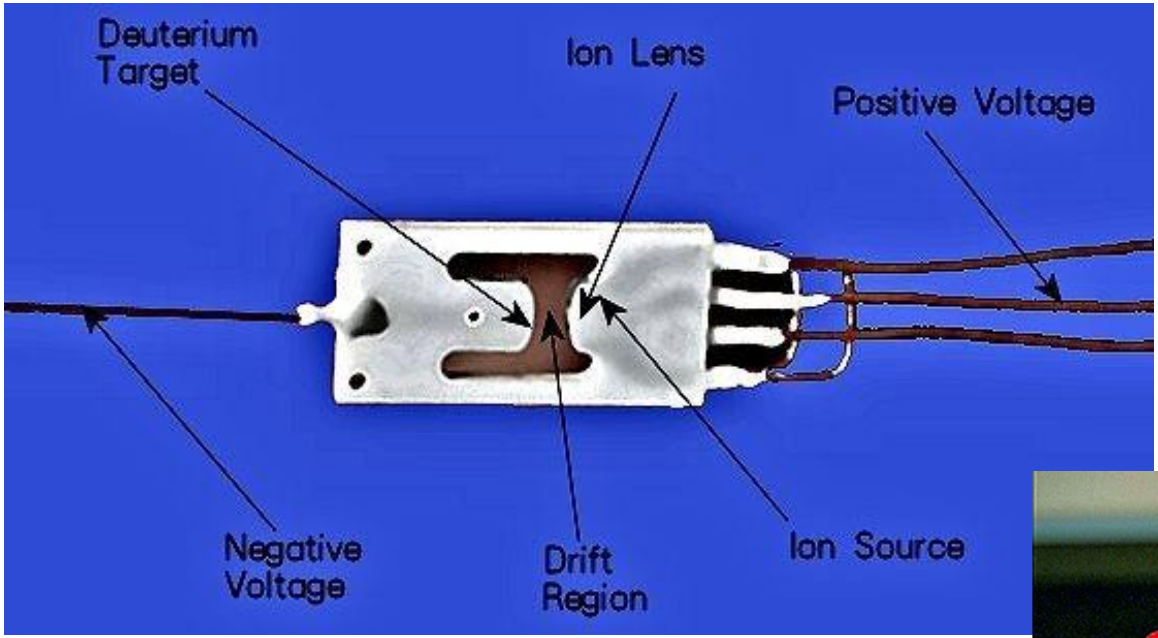
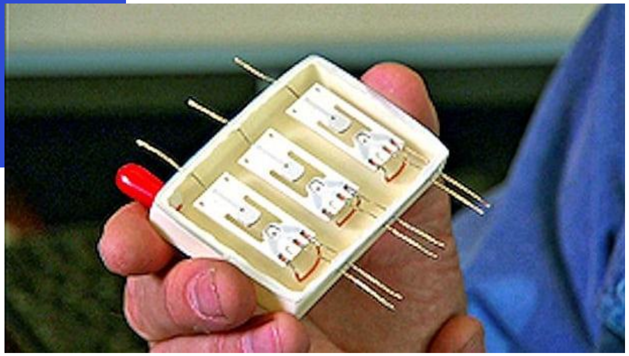
- ESS will be the frontier (accelerator-based) facility for neutron science in Europe for the next 10-20 years
  - Hard to see that a second facility of that scale could be funded and built any time soon.
- ESS cannot by far satisfy the need for neutron sources in Europe
  - Compact sources would be important to foster the field
  - Compact: affordable by a single institute or university
    - In the spirit of light sources
  - Building new reactor-based facilities does not look promising
- Complementary features of neutron scattering and synchrotron radiation should be better exploited
  - Could open up totally new perspectives
- Accelerator technology has to be complemented by powerful control systems and data handling capabilities
  - "big" data is coming to the accelerator world

Other end of the size spectrum

Smallest neutron source I could find – the Sandia Labs "Neutristor"





Compact Neutron Source RANS in Japan

RANS is aimed for application manufacturing sites that deal with metal materials and light elements that are most suitable for utilization of neutron beams.
The size of RANS is approximately 15m in length 2m in width.