Future Scientific Possibilities in Neutron Scattering at the European Spallation Source for Users from Academia and Industry

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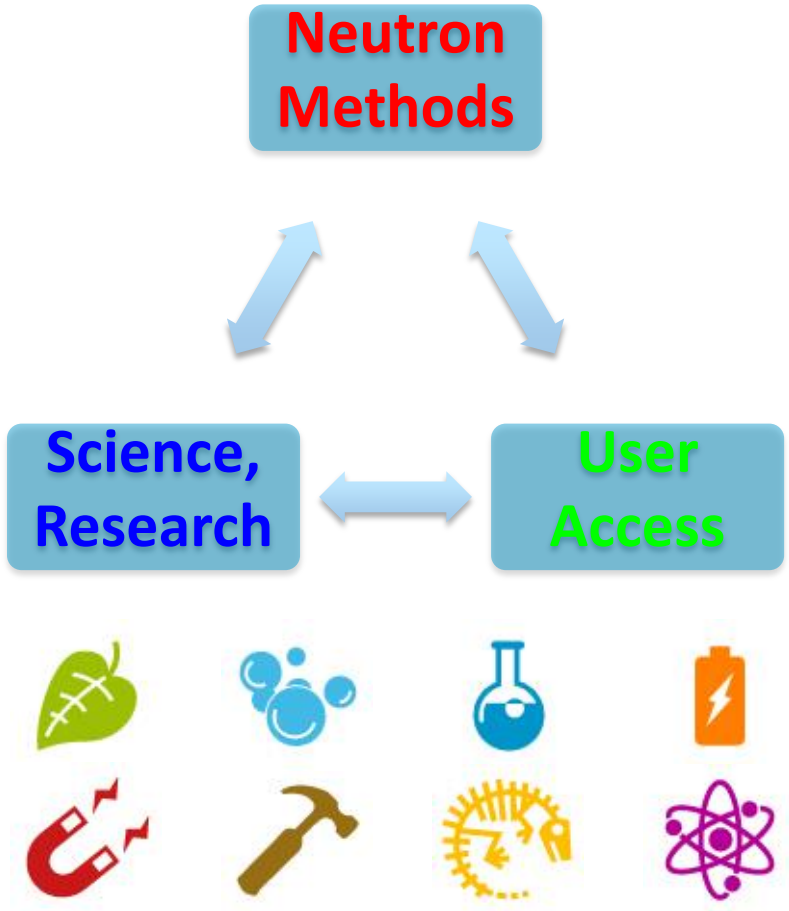
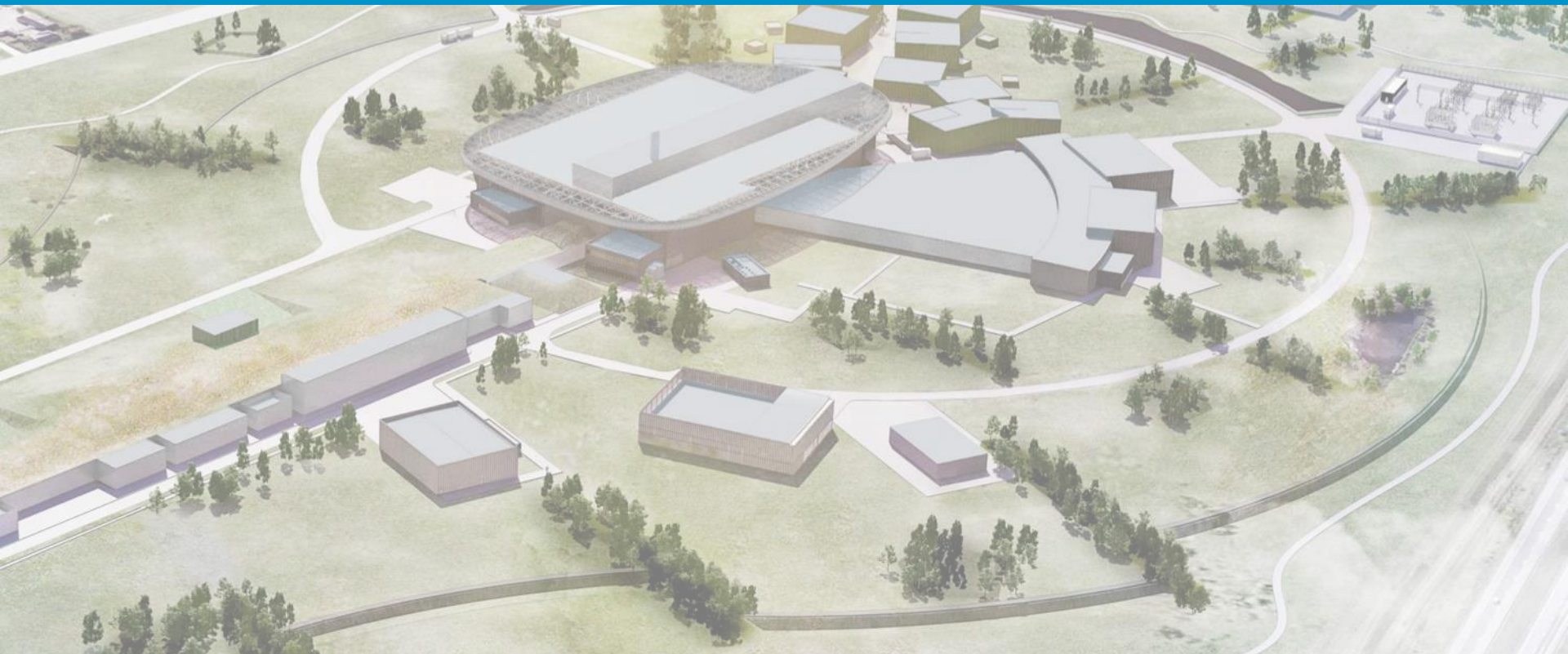
European Spallation Source - Scope



"A partnership of European Nations collectively building and operating the world's leading user facility for research using neutrons."

idea by user → proposal, sample, labs → experiment, sample env. → data, modeling → publication by user

The European Spallation Source ERIC Project Commitments



- ☑ 5 MW accelerator capability, 2.8ms long pulse, 14Hz
- ☑ Innovative instrument suite with initially 16 instruments
- ☑ Construction cost of 1,843 B€; Steady-State Ops at 140 M€/year

The road to realizing the world's leading facility for research using neutrons

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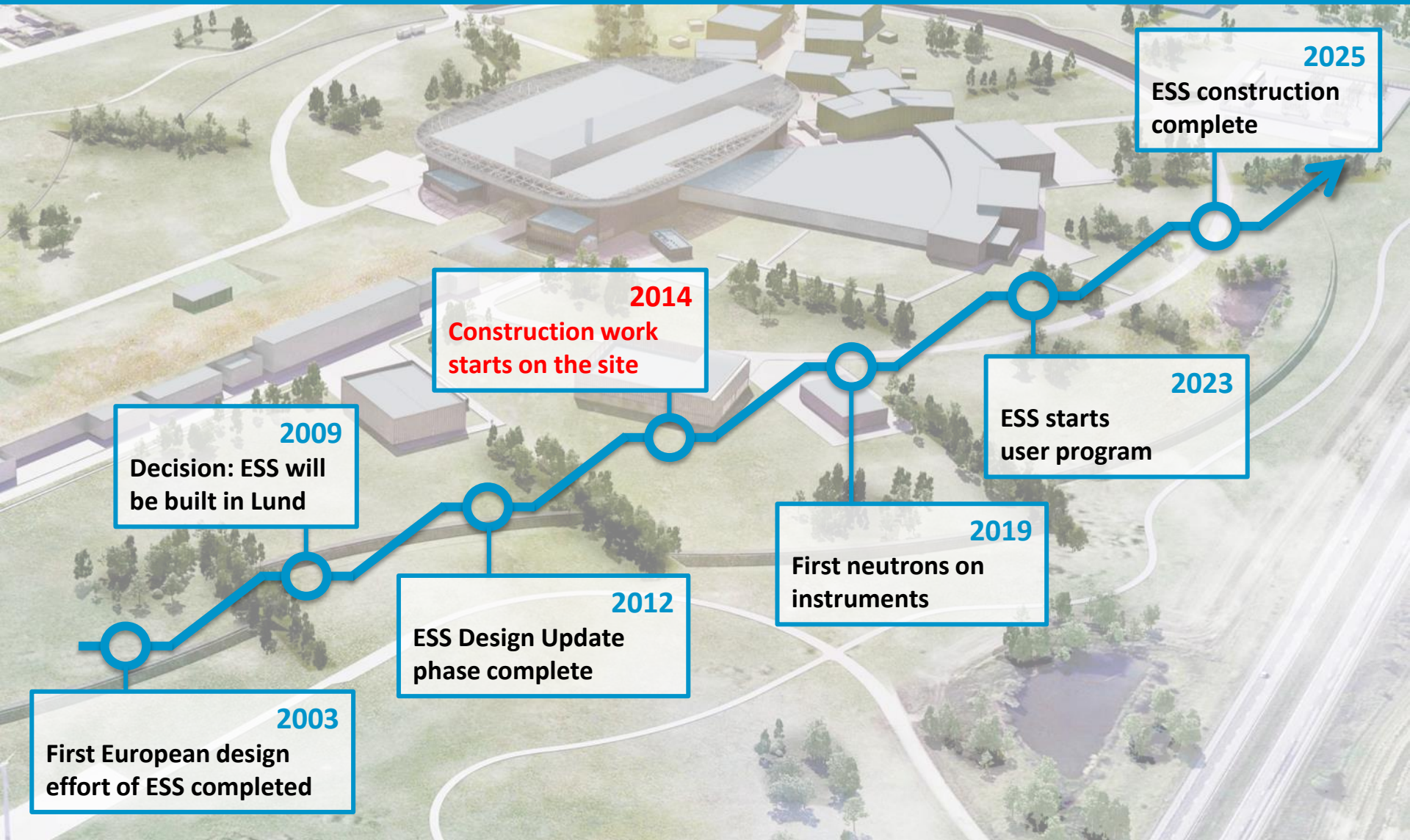
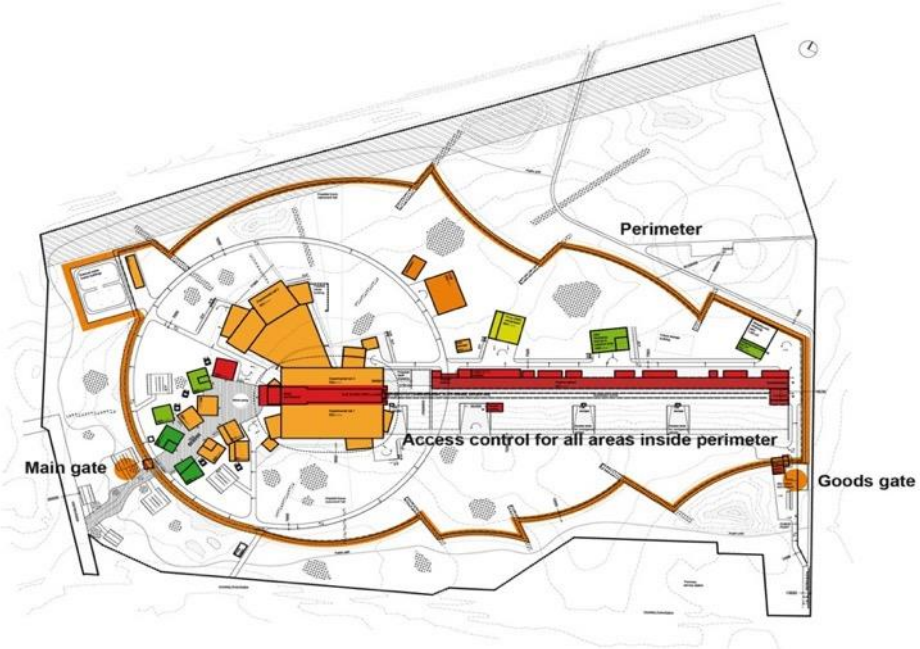


Construction ongoing

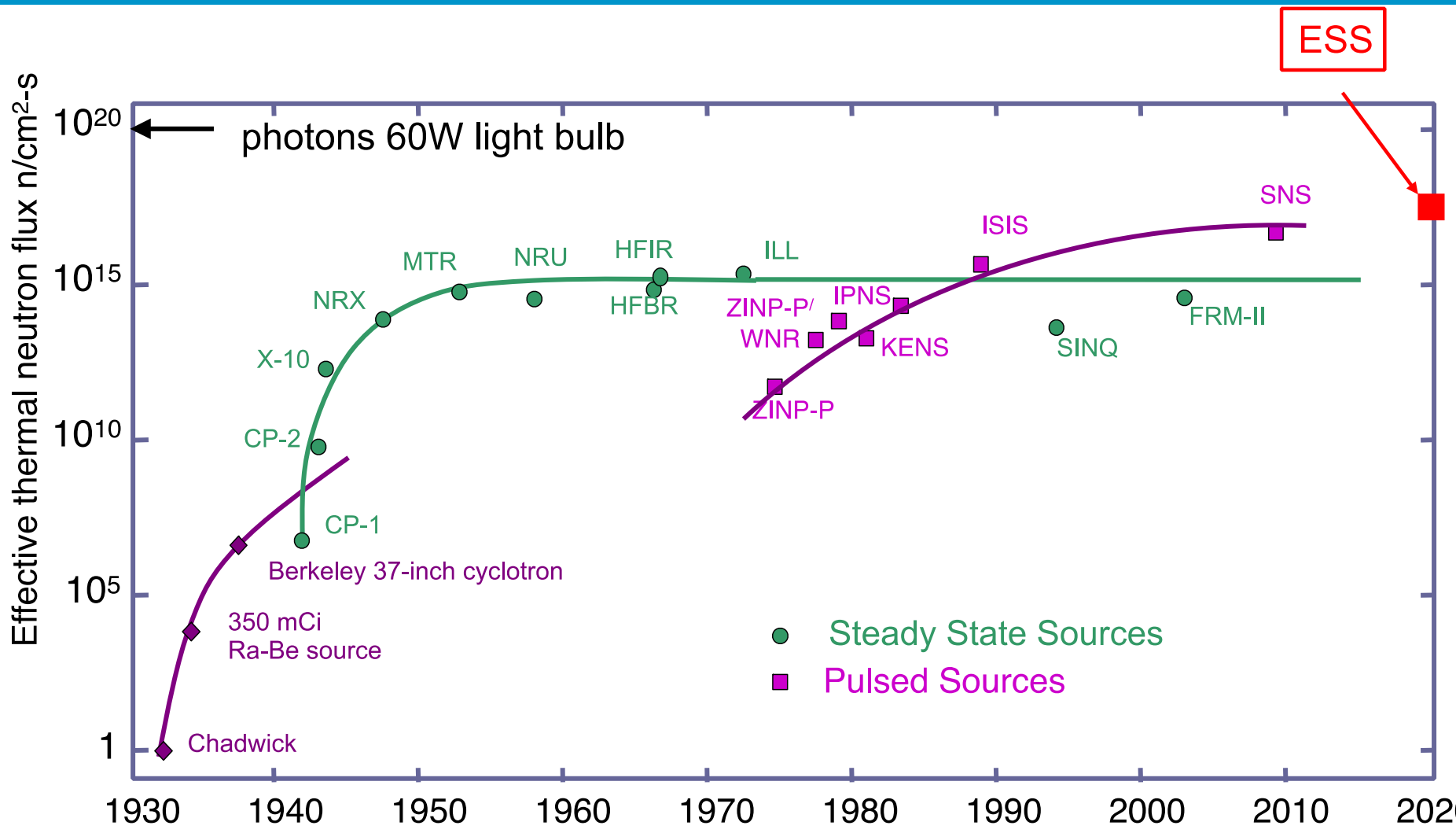


July 2014

Dec 2014

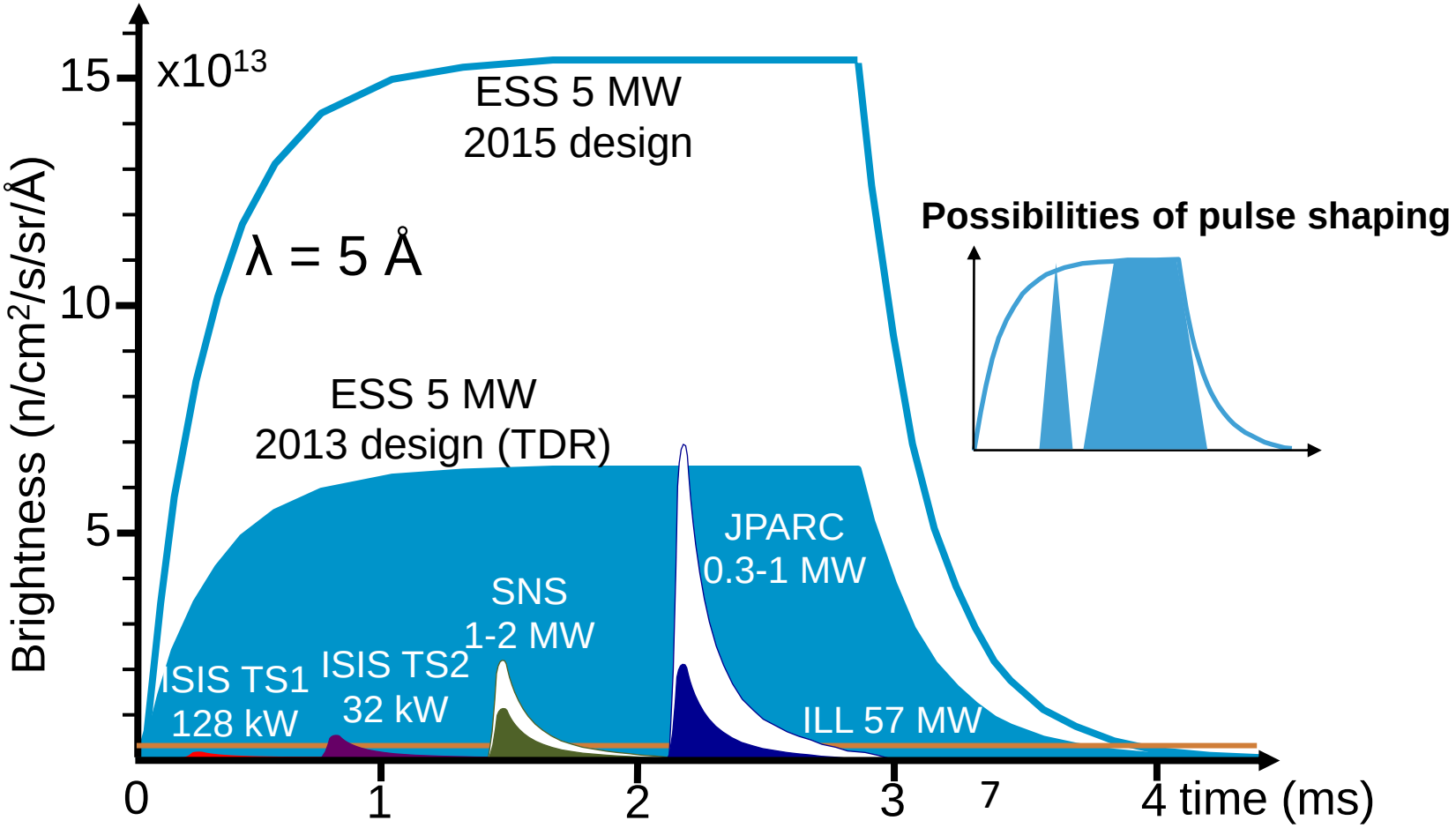
Dec 2015

Evolution of neutron sources



(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

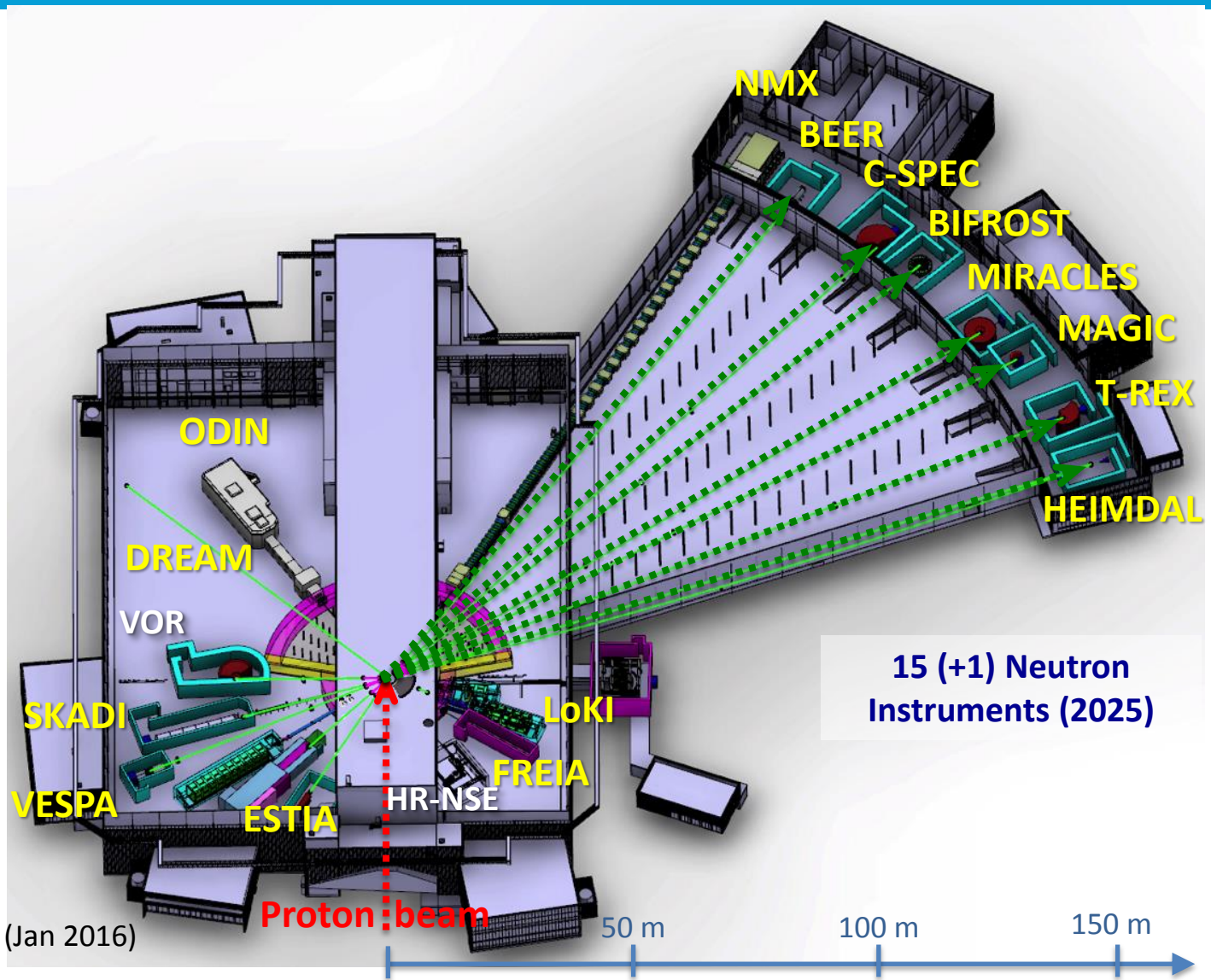
The unique ESS long pulse of cold neutrons (E = 2.5meV)



more cold neutrons per second than any steady state source …

… with higher brightness than any other spallation source

The ESS Neutron Instrument Suite



Instrument Layout (Jan 2016)

Science Drivers for the Reference Instrument Suite

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Large-Scale Structures

- **Multi-Purpose Imaging ODIN**
- **General-Purpose SANS SKADI**
- **Broadband SANS LOKI**
- Surface Scattering
- **Horizontal Reflectometer FREIA**
- **Vertical Reflectometer ESTIA**

Diffraction

- **Thermal Powder Diffractometer HEIMDAL**
- **Bispectral Powder Diffractometer DREAM**
- Monochromatic Powder Diffractometer
- **Materials Science Diffractometer BEER**
- Extreme Conditions Diffractometer
- **Single-Crystal Magnetism Diffractometer MAGICS**
- **Macromolecular Diffractometer NMX**

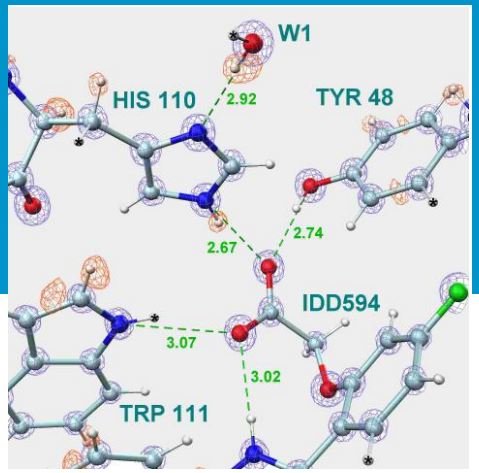
Spectroscopy

- **Cold Direct Geometry Spectrometer C-SPEC**
- **Wide Bandwidth Direct Geom. Spectrometer VOR**
- **Bispectral Direct Geometry Spectrometer TREX**
- **Cold Crystal-Analyser Spectrometer CAMEA**
- **Vibrational Spectrometer VESPA**
- **Backscattering Spectrometer MIRACLES**
- High-Resolution Spin-Echo
- Wide-Angle Spin-Echo
- Fundamental & Particle Physics

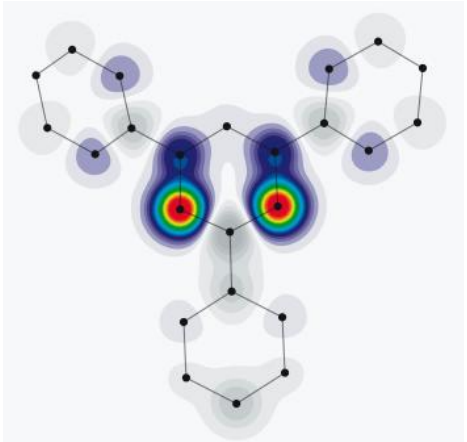
Outside ESS construction scope:

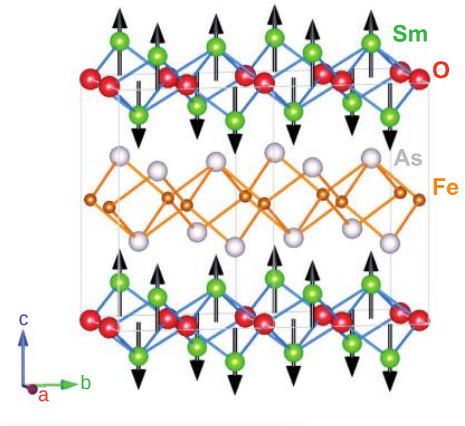
- Fast neutron application (BNCT, chipIR)
- neutron- antineutron oscilaations
- Isotope production, material irradiation
- μSR, neutrinos

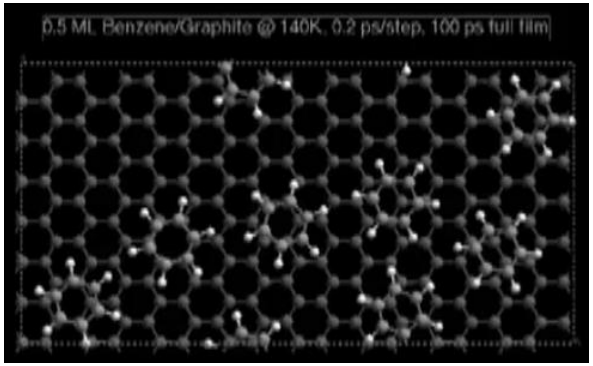
Neutrons are special



- charge neutral: deeply pene-trating ... except for some isotopes
- nuclear interaction: cross section depending on isotope (not Z), sensitive to light elements.
- spin S = 1/2: probing magnetism
- unstable $n \rightarrow p + e + \underline{\nu}_e$ with life time $\tau \sim 900s$, $I = I_0 \ e^{-t/\tau}$
- mass: n ~p; thermal energies result in non-relativistic velocities.
  E = 293 K = 25 meV,
  v = 2196 m/s , λ = 1.8 Å

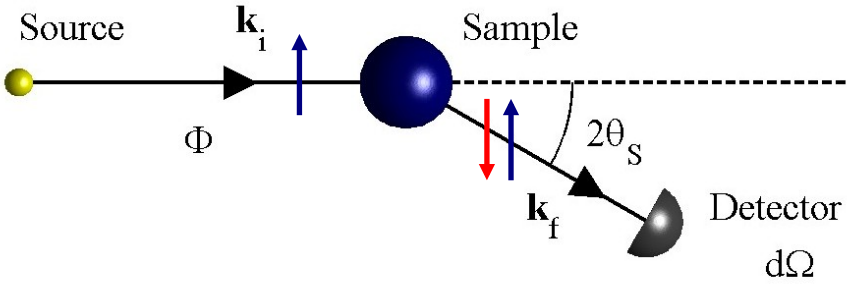




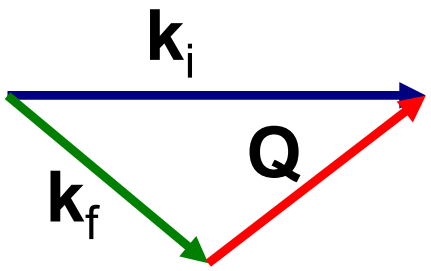


WHERE ARE THE ATOMS AND WHAT DO THEY DO?

Scattering based on Momentum and Energy conservation



scattering triangle



momentum conservation $\vec{Q} = \vec{k}_i - \vec{k}_f$

energy conservation $\hbar\omega = E_i - E_f$

spin conservation: Polarisation analysis

Length and Energy Scales

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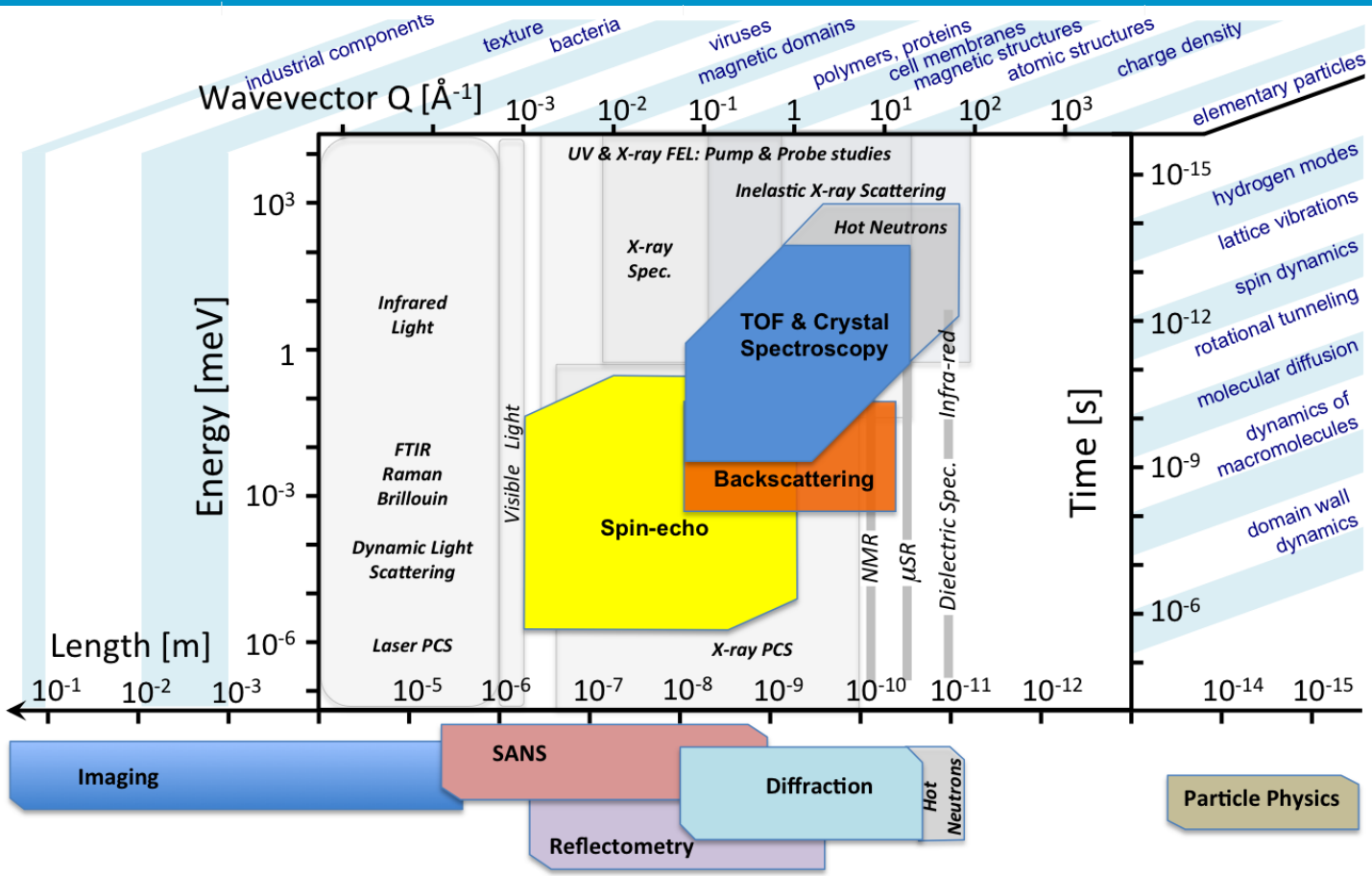
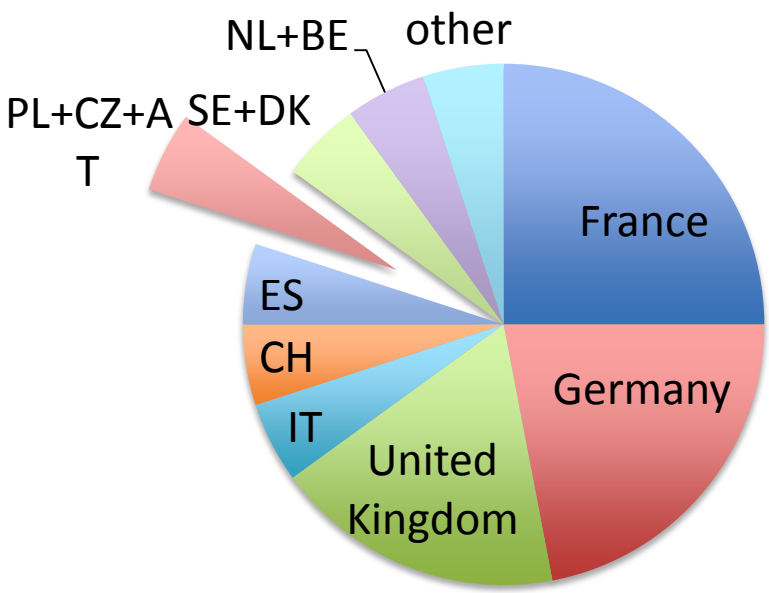
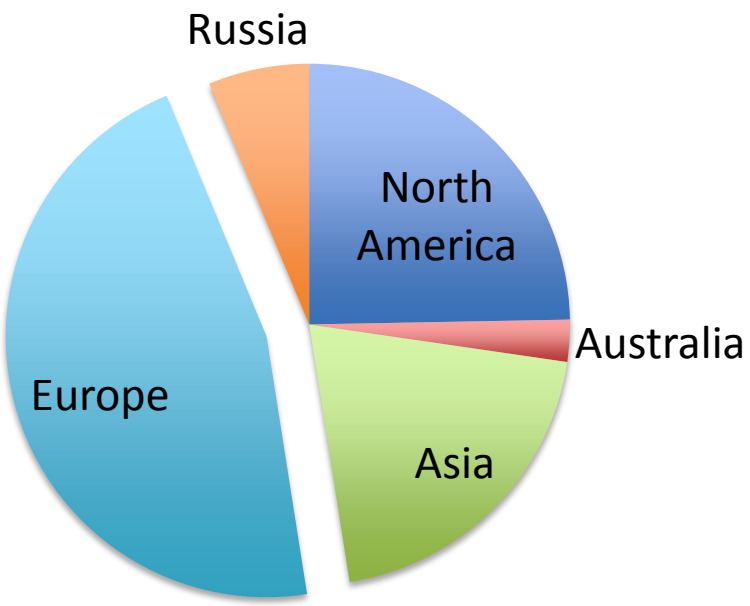


User Community based on publications





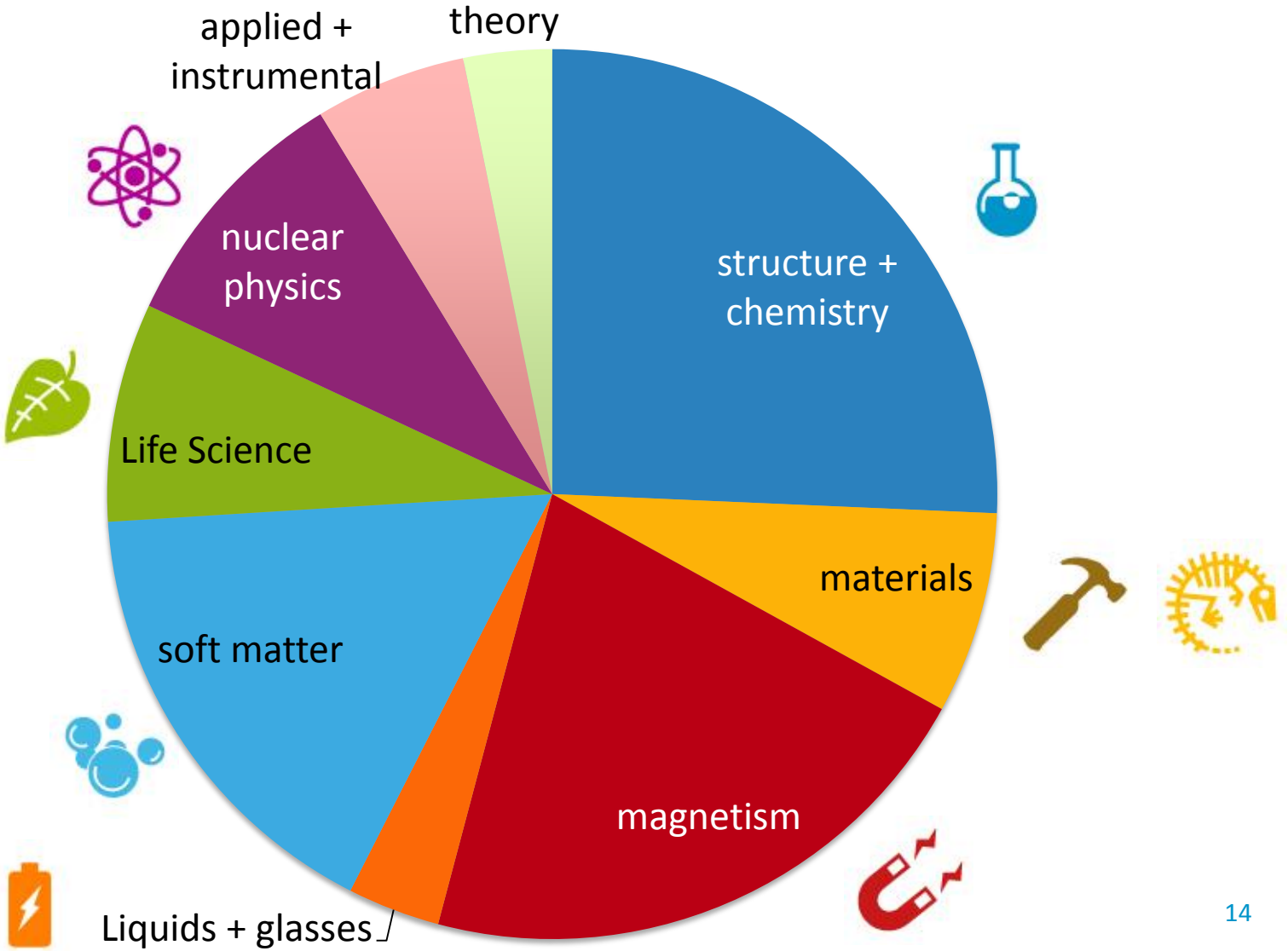
European Community

5000 - 6000 researchers

2000 publications per year

data: ESFRI, KFN

Neutron use per science topic



data: ILL

Formation of nano-MOF-5 in the presence of a modulator

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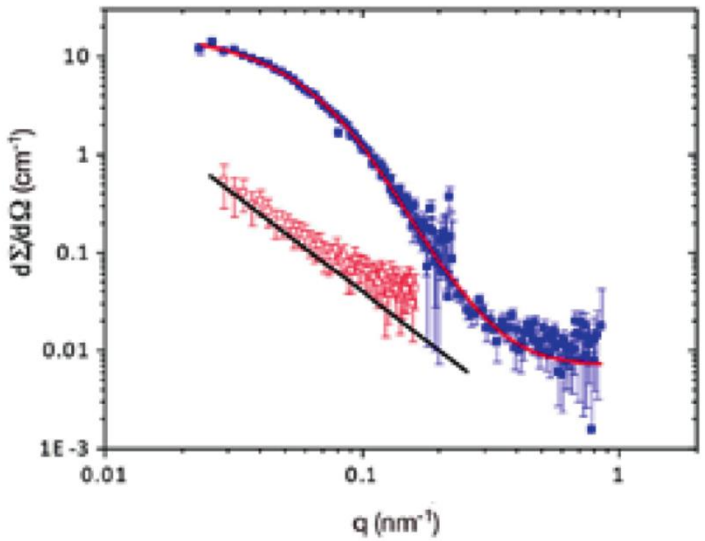
environment, energy

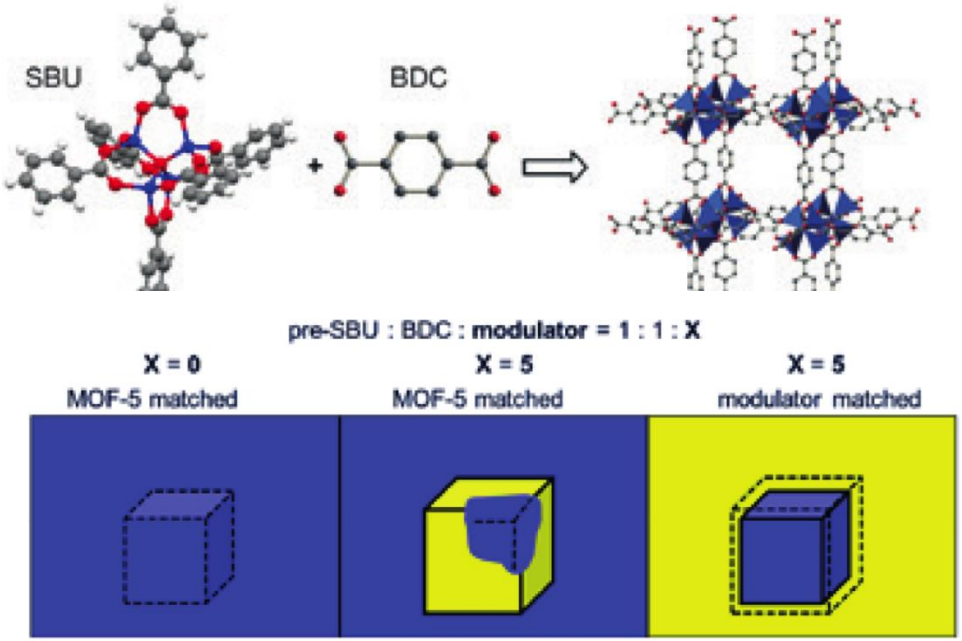
Metal organic frameworks (MOF): hybrid materials with organic and inorganic components

Large internal surfaces: promising candidates for gas storage, gas separation and catalysis.

Contrast matching using (partly) deuterated compounds reveals shell around the MOF

The modulator wraps around nanoparticle.





Zacher et al. (ILL 2014)

Neutrons for Energy Research

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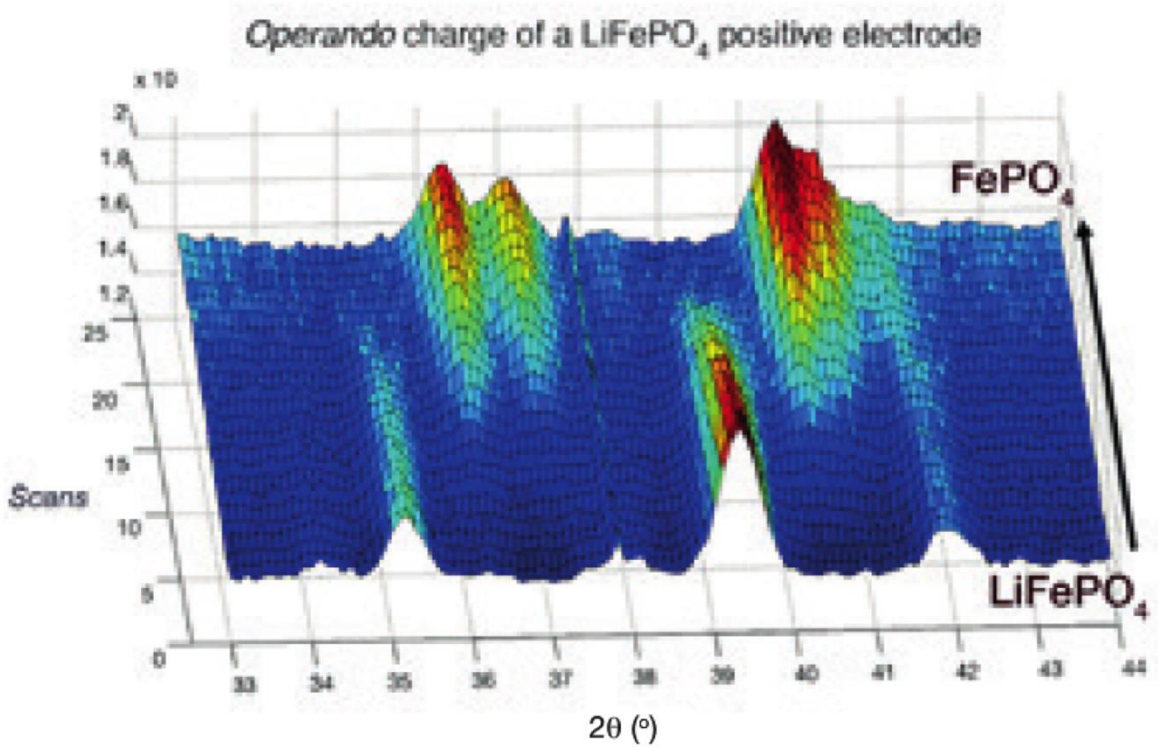
energy

Real-time neutron diffraction studies of electrode materials for Li-ion batteries.

Neutrons are sensitive to light elements light lithium.

High intensity powder diffraction reveals lithium extraction / insertion in electrode material.



Bianchini and Suard (ILL 2014)

Stress around fatigue cracks

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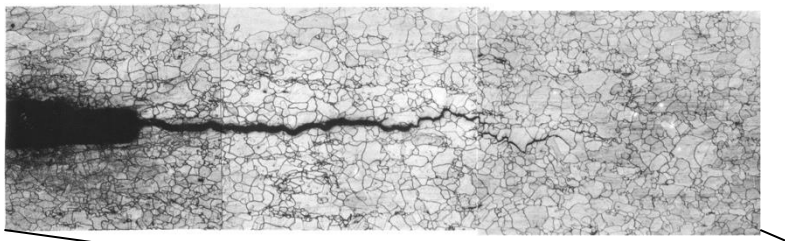
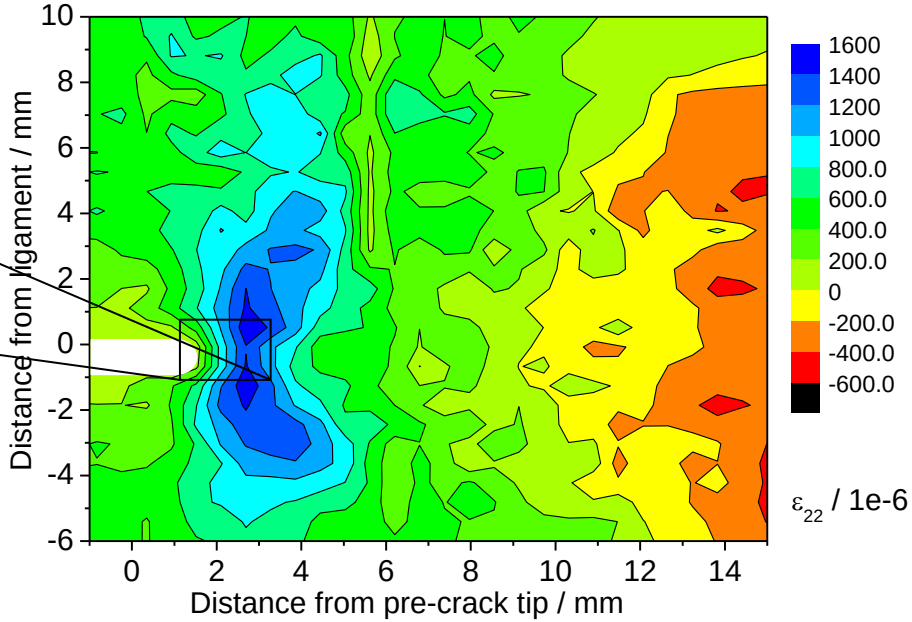
new materials, mobility

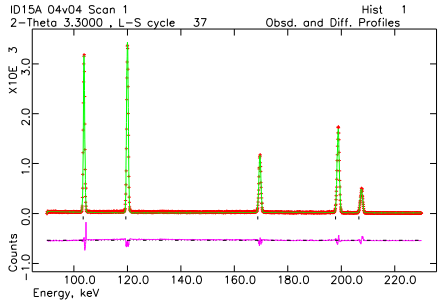
Fatigue + Creep Crack in **25mm** Austenitic steel

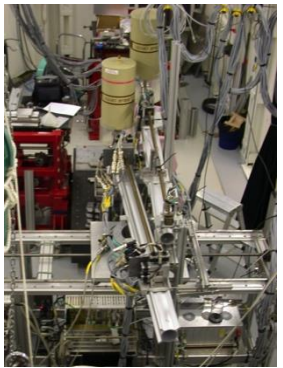




Exploring the boundaries of spatial resolution achievable in real materials engineering components.

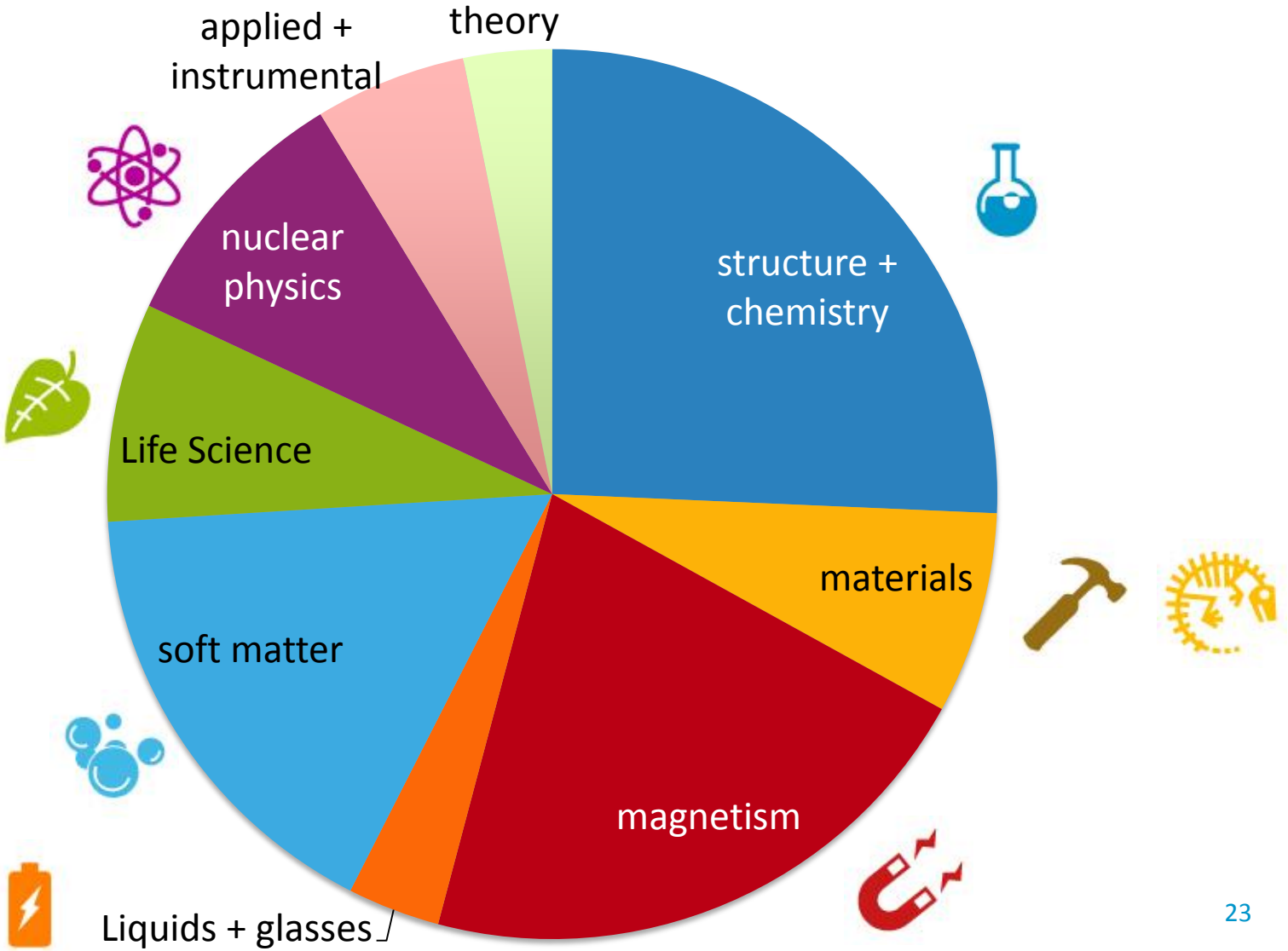
Using combinations of in-situ techniques: imaging & diffraction, in-situ loading, high-temperature…





A Steuwer et al, J Appl Crysts (2004)

Neutron use per science topic



data: ILL

Conclusions

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- Neutron scattering techniques are unique and complementary to lab methods and other scattering probes.
- Neutron scattering techniques have answered many questions in many science areas
  - … addressing the grand challenges of our society
  - … and the science case for neutrons is freshly written every day.
- Strong European Scientific Community is mobilized and ….
  - … we are building ESS together now to meet our needs.