ESS Instrument Suite and Future Science

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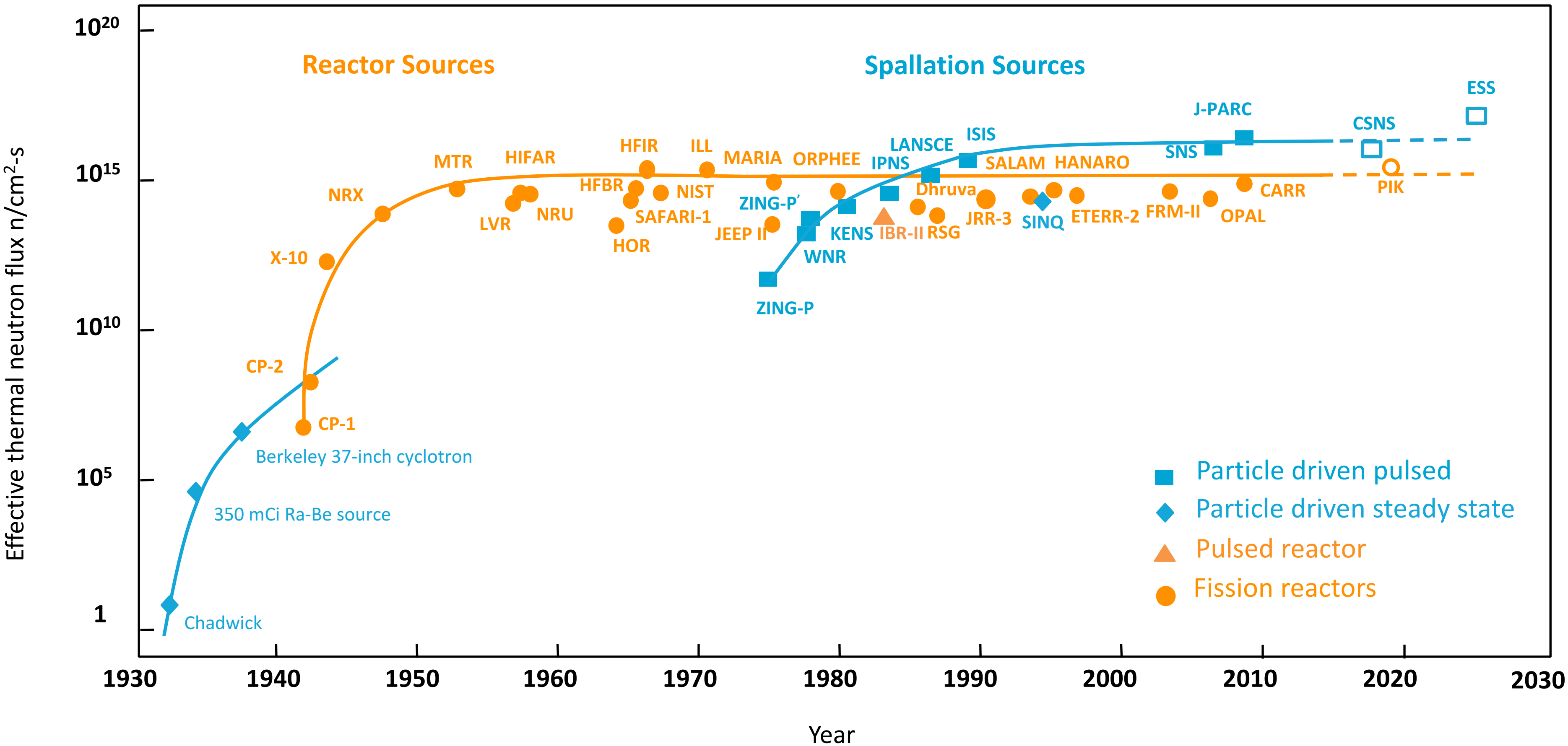
European Spallation Source

www.europeanspallationsource.se
14.9.2017

Neutron facilities – reactors and particle driven



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

Neutrons are special

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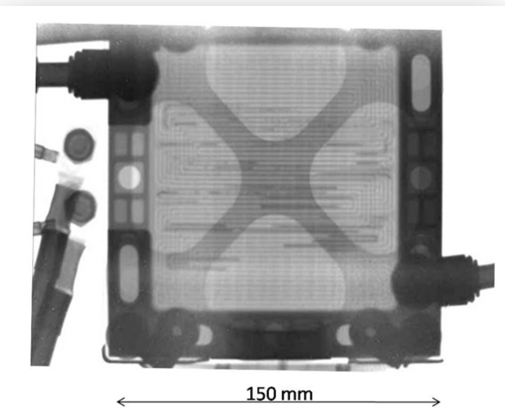
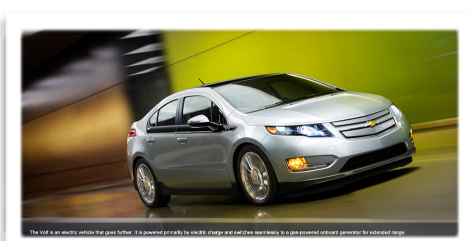
Charge neutral
Deeply penetrating

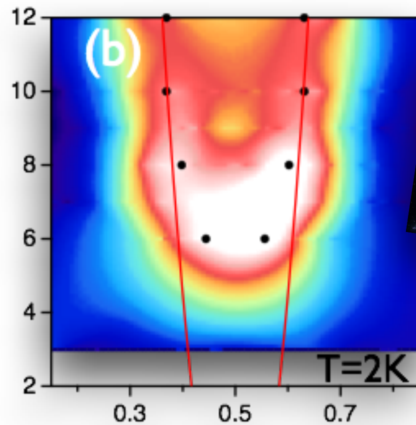


Li motion in fuel cells



Help build electric cars

S=1/2 spin
probe directly magnetism

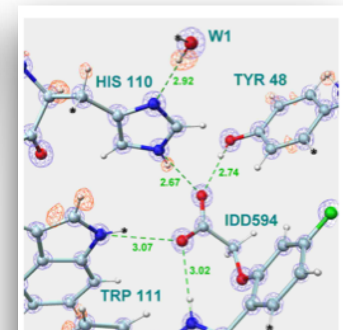


Test AdS/CFT correspondence

Solve the puzzle of High-Tc superconductivity

Efficient high speed trains

Nuclear scattering
Sensitive to light elements and isotopes



Active-site region of hAR

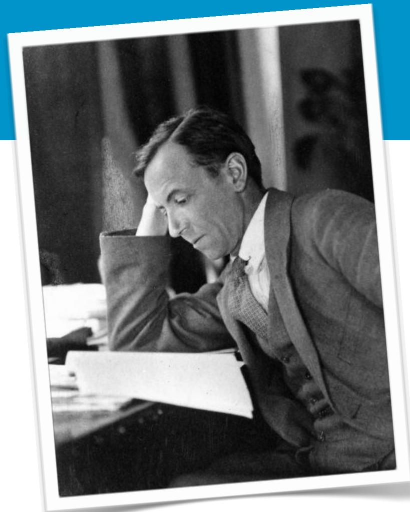
Actives sites in proteins

Tertiary structure of hAR

Better drugs

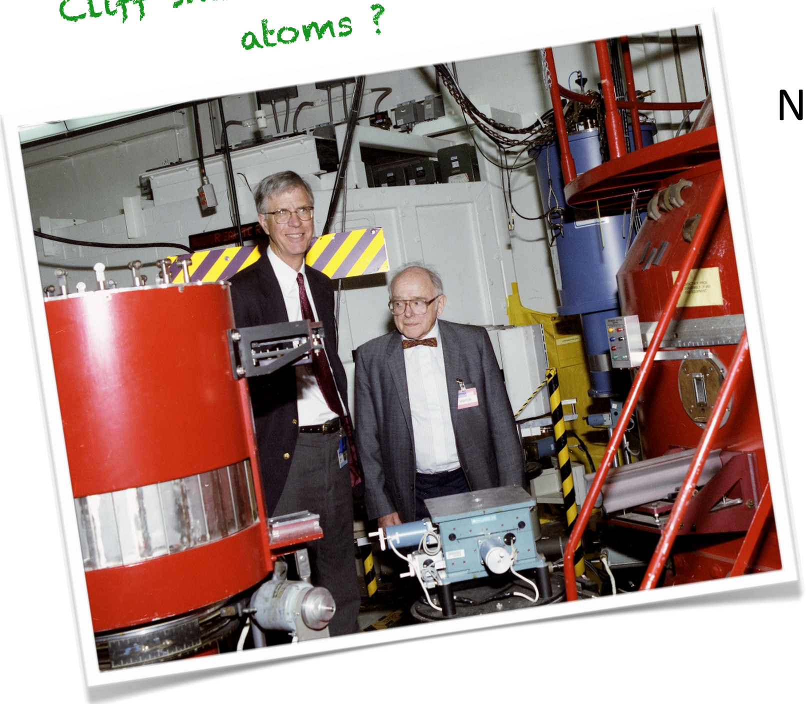
Neutrons and Nobel Prizes

Nobel prize 1935



1932: Chadwick discovers "a radiation with the most peculiar properties", the neutron.

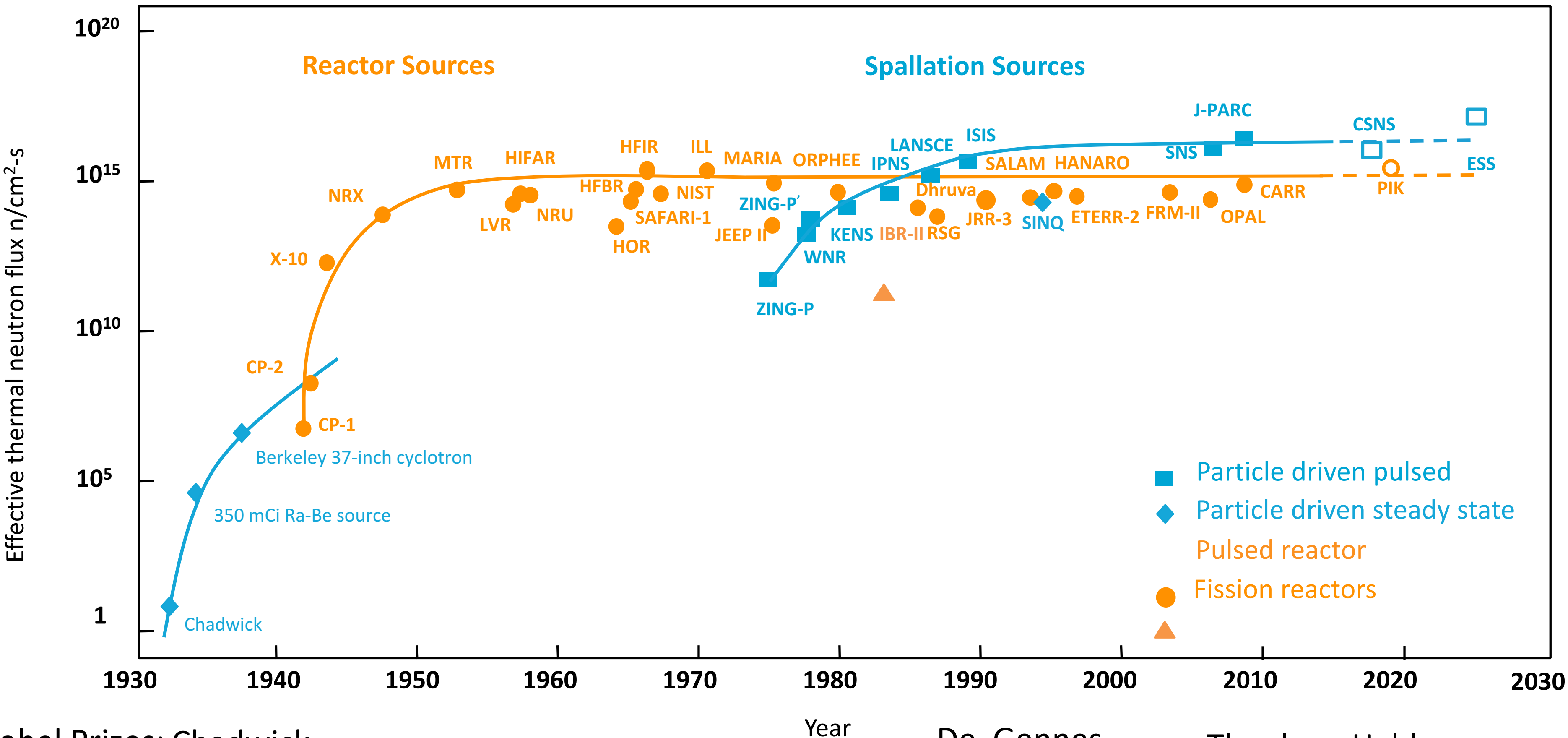
Cliff Shull: where are the atoms ?



Nobel prize 1994

Bert Brockhouse: what do they do ?

Neutron facilities – reactors and particle driven



Nobel Prizes: Chadwick

De Gennes

Brockhouse and Shull

Thouless, Haldane, Kosterlitz 2016

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

Nobel prize 2016

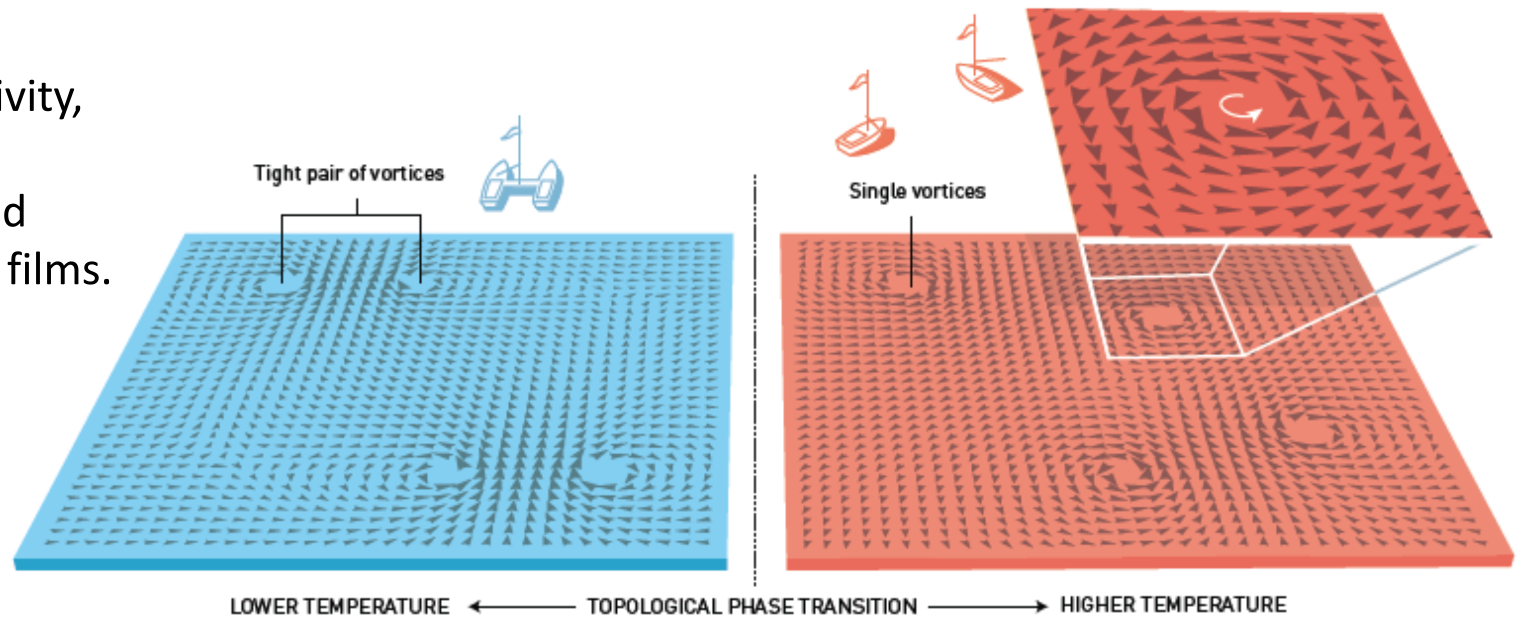
David J. Thouless, F. Duncan M. Haldane, and J. Michael Kosterlitz for

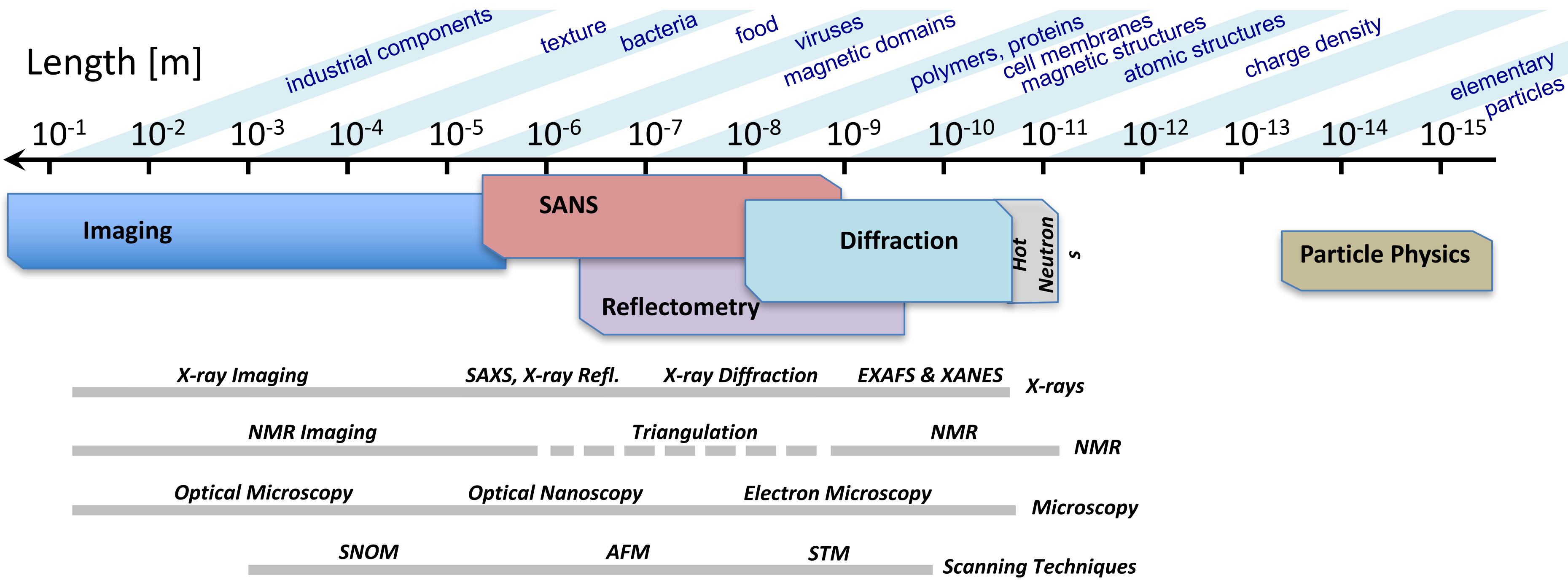
'theoretical discoveries of topological phase transitions and topological phases of matter'

Validated by neutron scattering experiments at ILL (FR), ISIS (UK), Chalk River (CDN), SNS (US), …

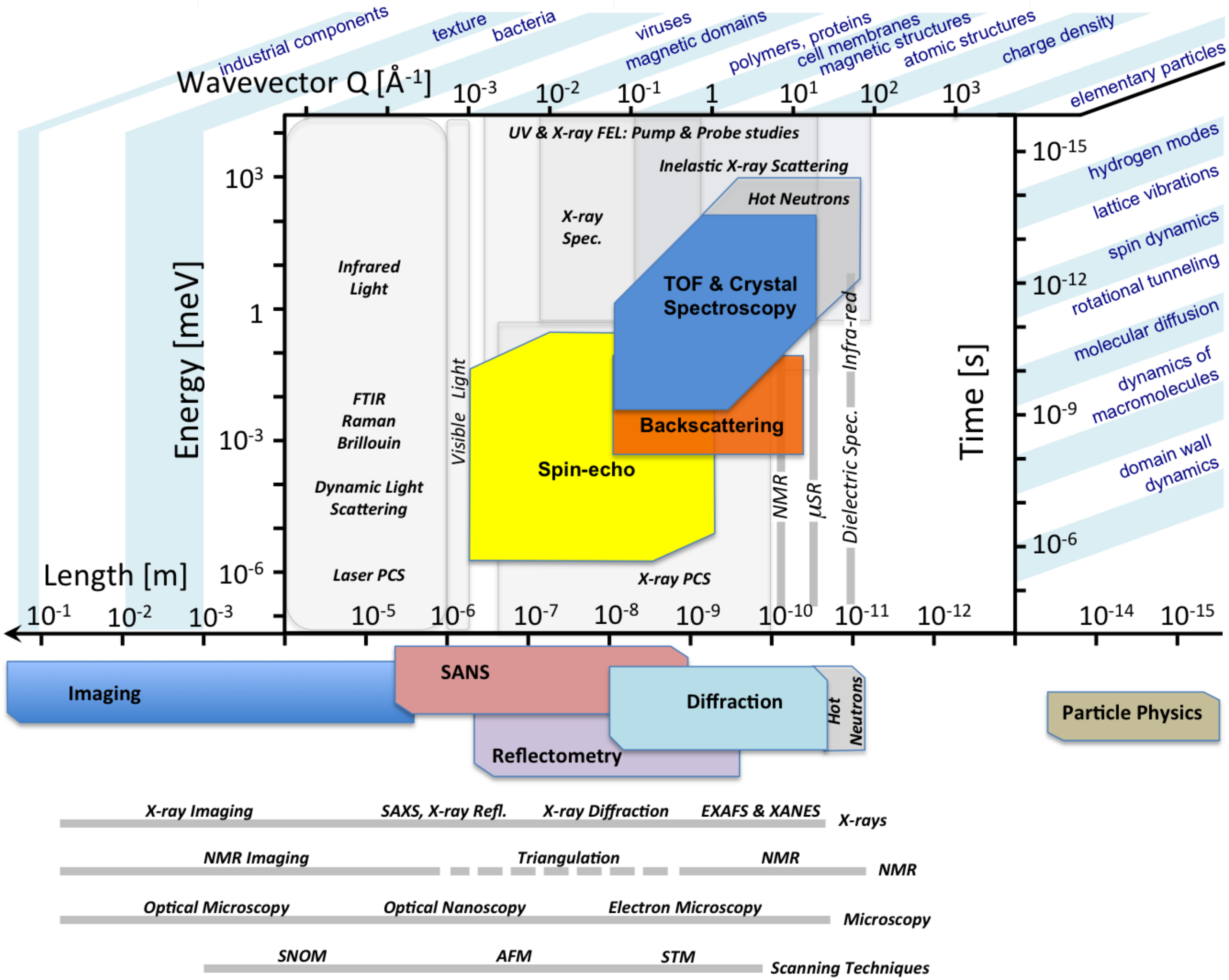
Haldane was postdoc at the ILL

occurs in superconductivity, lasers, superfluids and thin magnetic films.

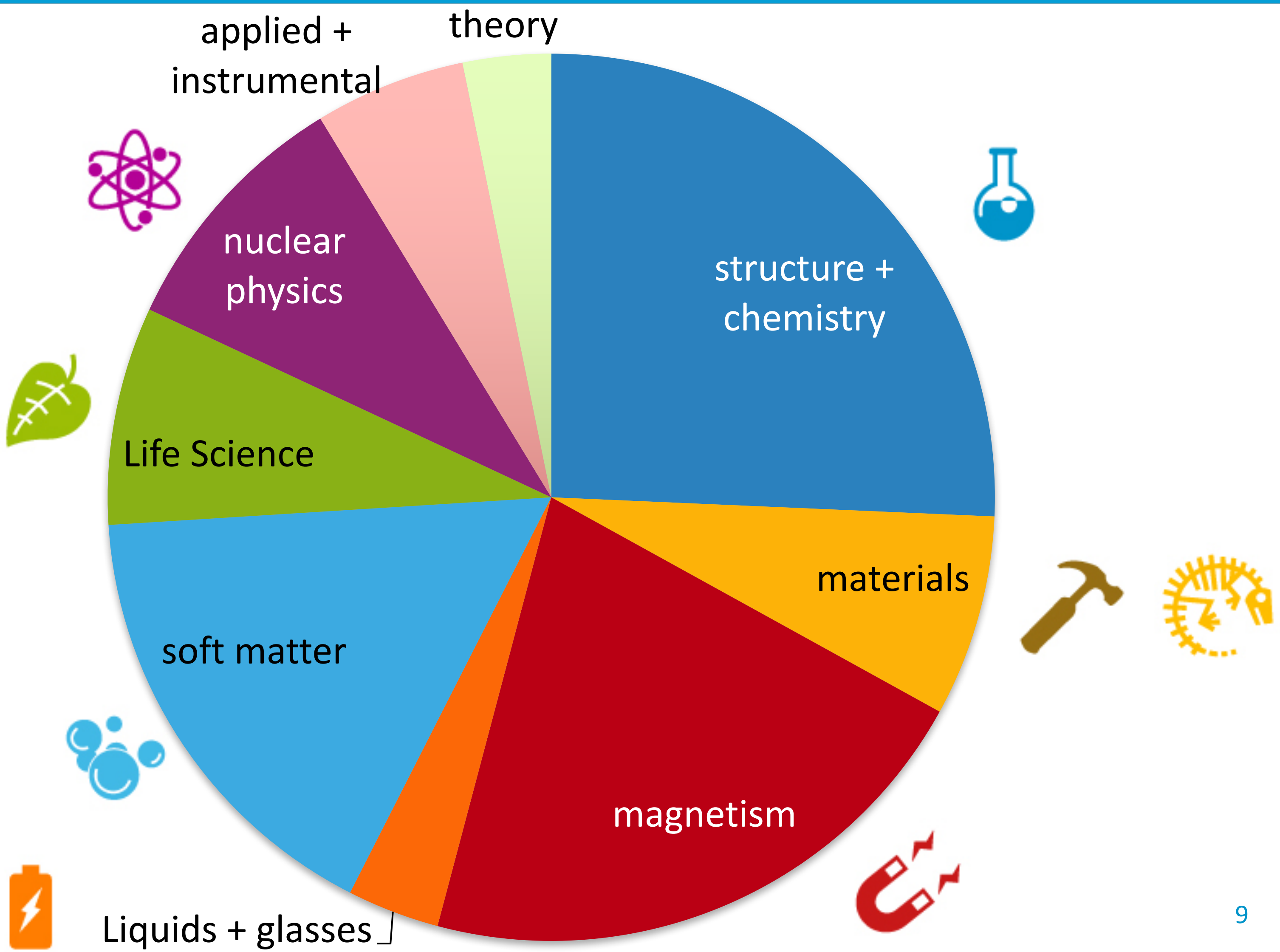



Length [m]
industrial components
texture
bacteria
food
viruses
magnetic domains
polymers, proteins
cell membranes
magnetic structures
atomic structures
charge density
elementary particles
10-1
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
10-10
10-11
10-12
10-13
10-14
10-15
Imaging
SANS
Reflectometry
Diffraction
Hot Neutrons
Particle Physics
X-ray Imaging
SAXS, X-ray Refl.
X-ray Diffraction
EXAFS & XANES
X-rays
NMR Imaging
Triangulation
NMR
NMR
Optical Microscopy
Optical Nanoscopy
Electron Microscopy
Microscopy
SNOM
AFM
STM
Scanning Techniques

Length and Energy Scales



Neutron use per science topic



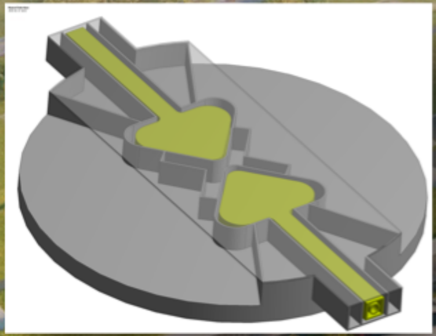
data: ILL

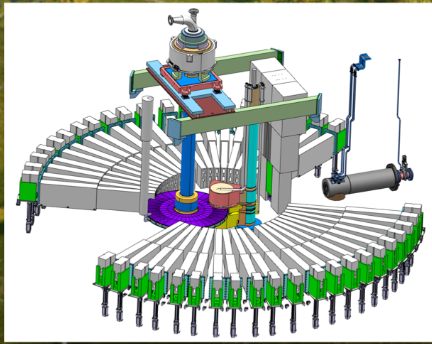
Journey to deliver the world's leading facility for research using neutrons

The European Spallation Source

High Power Accelerator means more neutrons

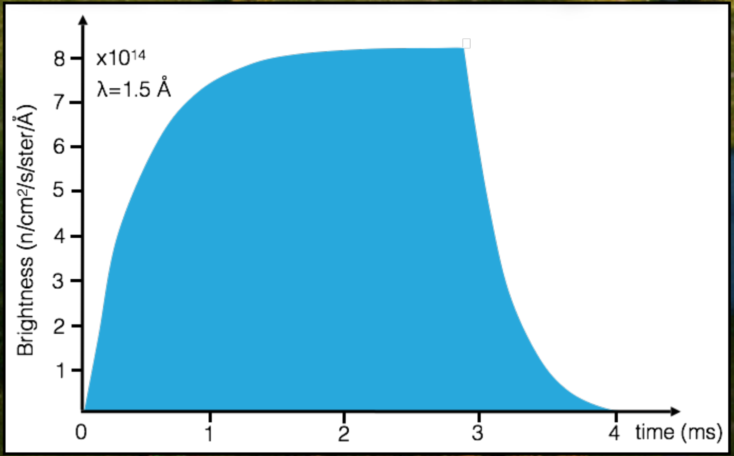
Flat moderator delivering smaller and brighter neutron beams



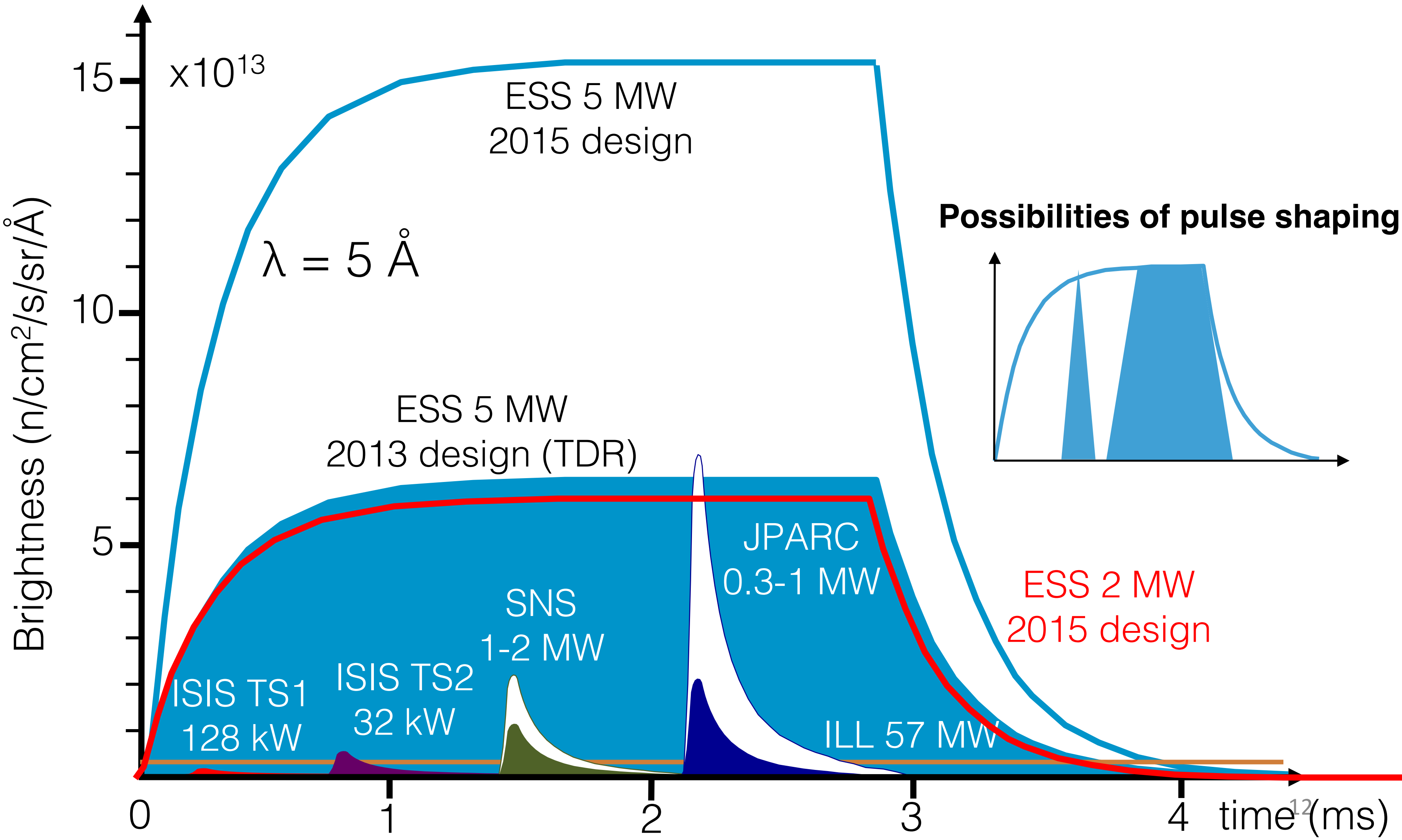


An Innovative Target Station that can host >30 instruments

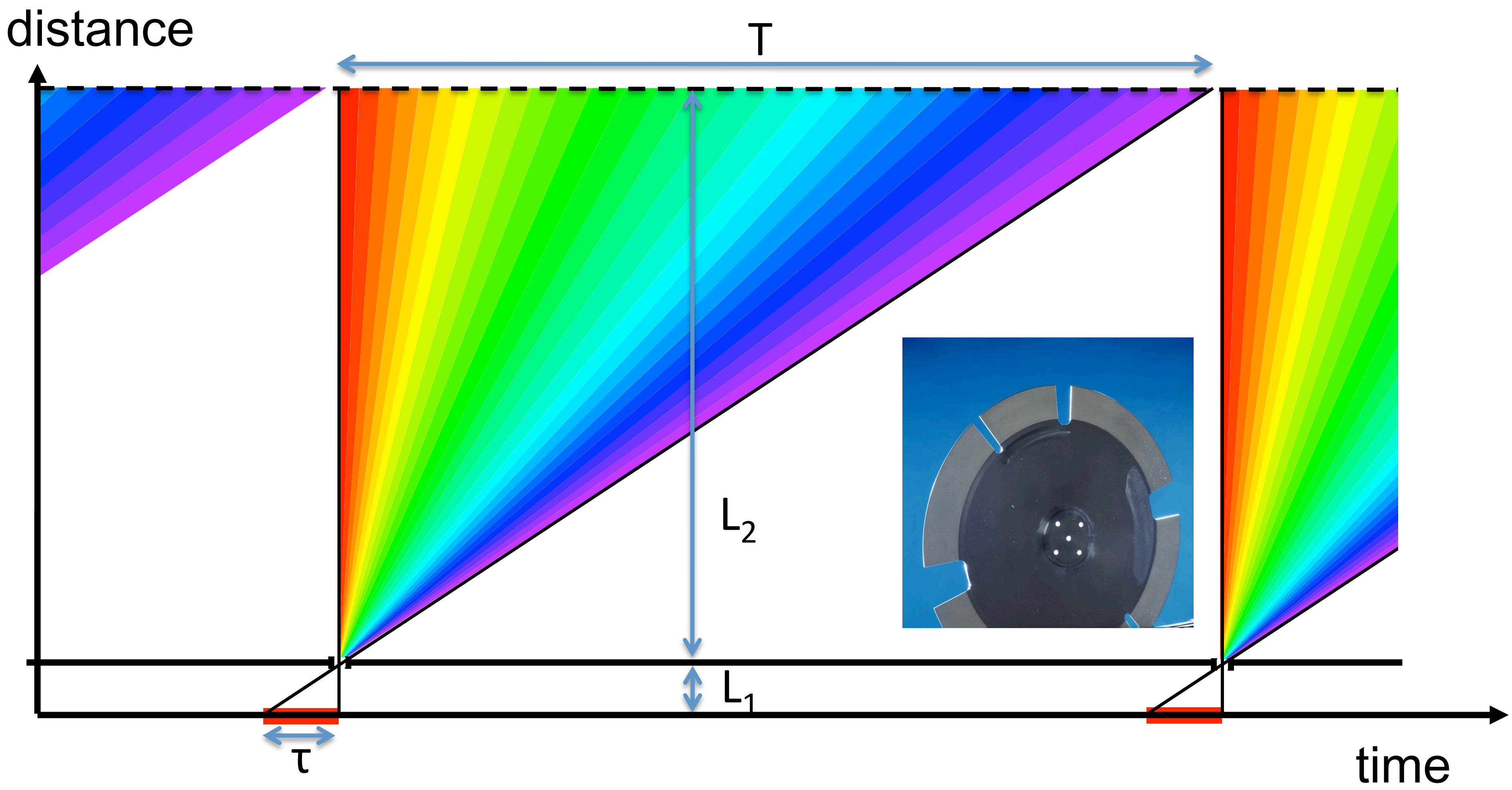
High brightness and tuneable resolution makes new measurements possible



Long-pulse performance



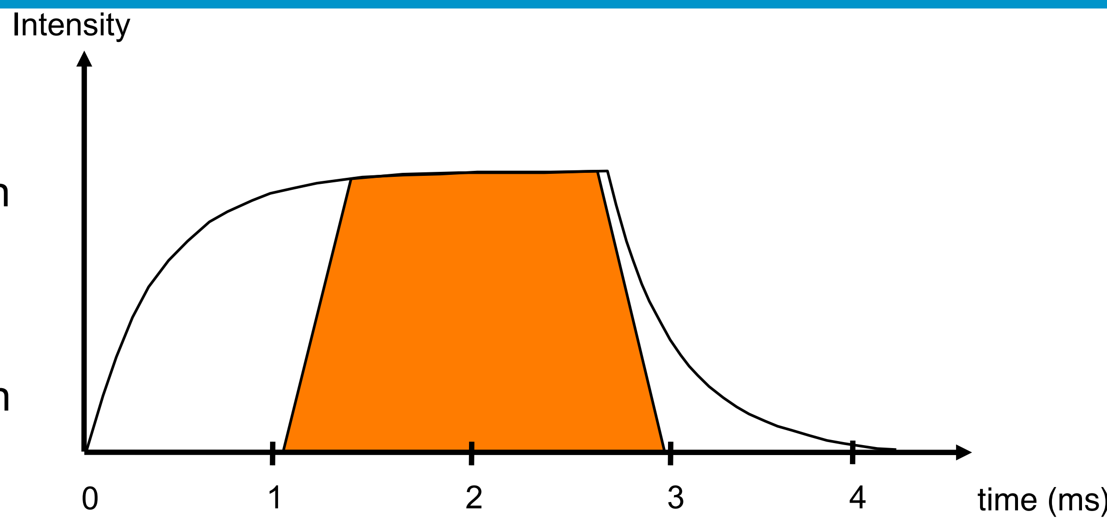
Pulsed Neutron Souces:
Neutron energy measurement via its time of flight



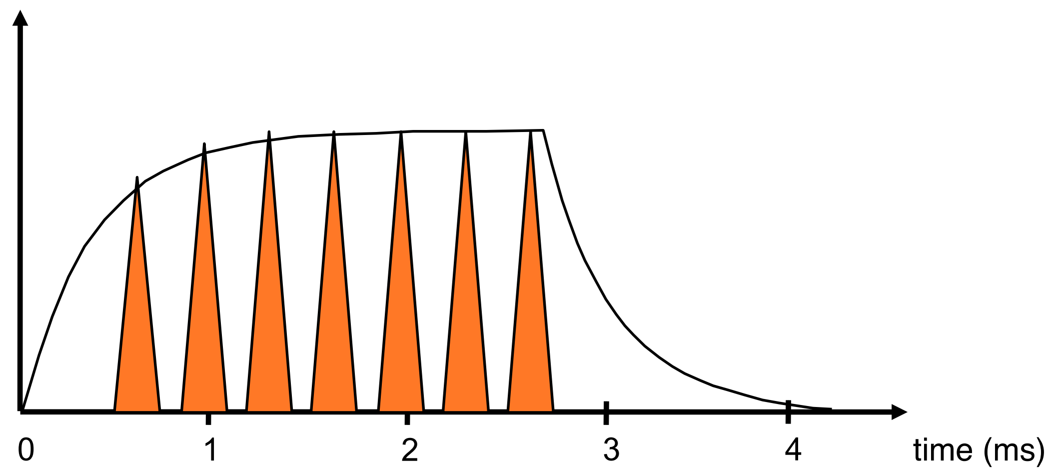
Time distance diagram of white beam instrument with Pulse Shaping Chopper

Two strategies for neutron instrumentation at ESS

Use as much as possible of the whole pulse:
Good for low wavelength resolution instruments.
SANS, Reflectometry, single crystal diffraction.
Estimated gains **10-100 times** than currently available.



Cut the long pulse into smaller pulses:
Good for higher wavelength resolution instruments
Diffraction, cold/thermal spectrometers.
Long Instruments (80-100 m)
Estimated gains **10-30 times** than currently available.
Thermal gains lower.



ESS Opens New Capabilities to Science

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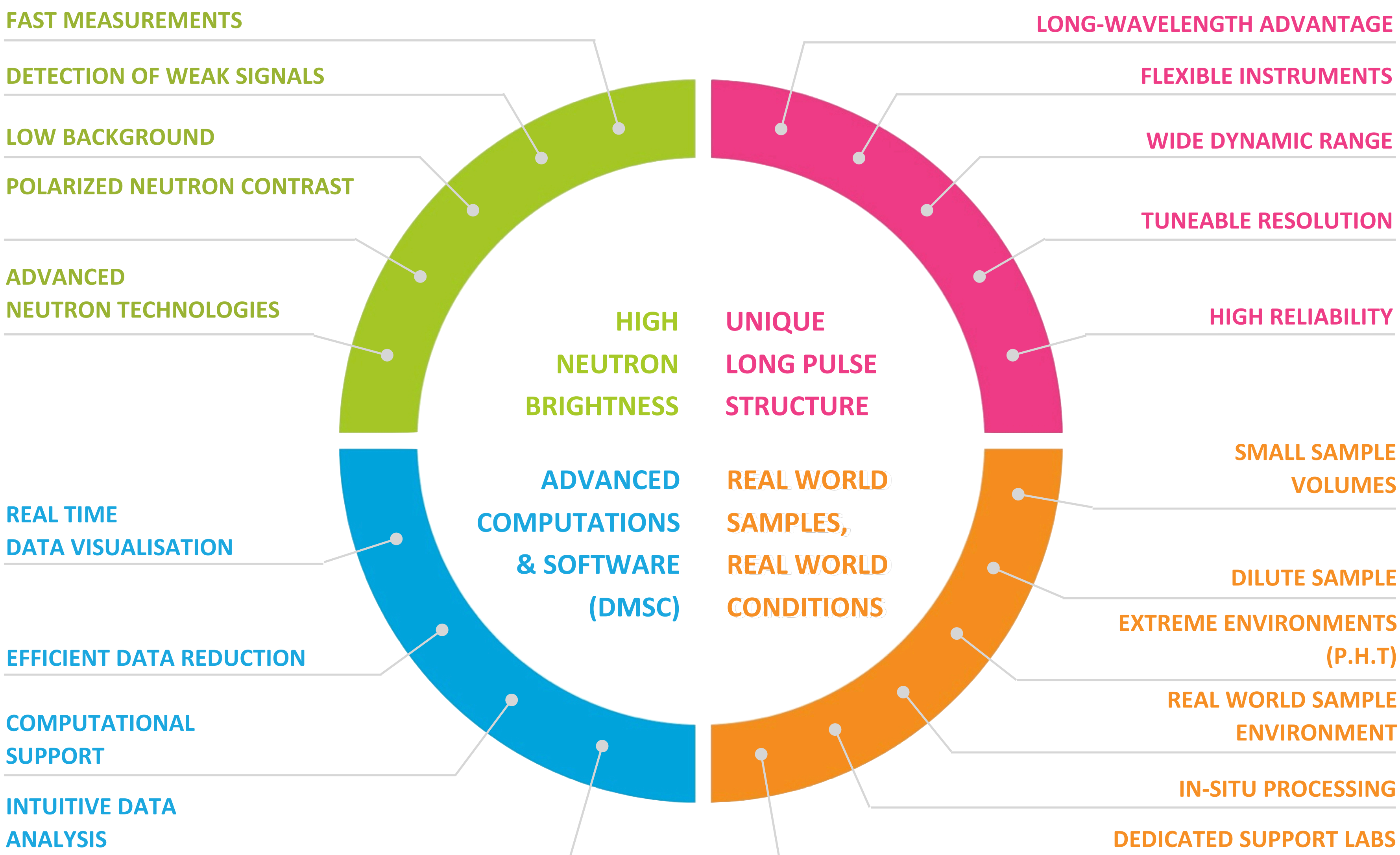
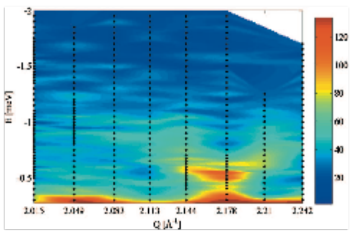
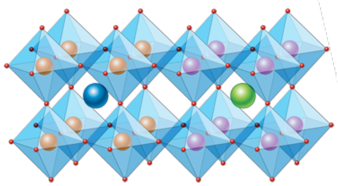


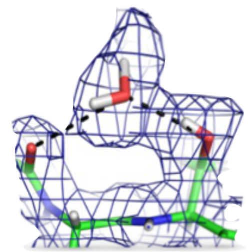
ESS Opens New Capabilities to Science

Complex Interfaces

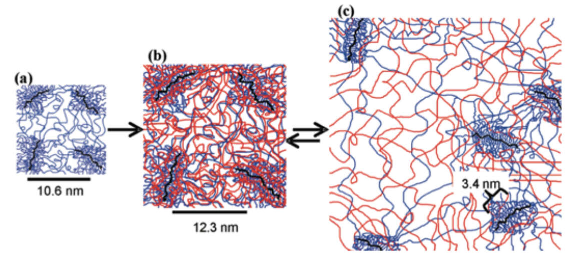



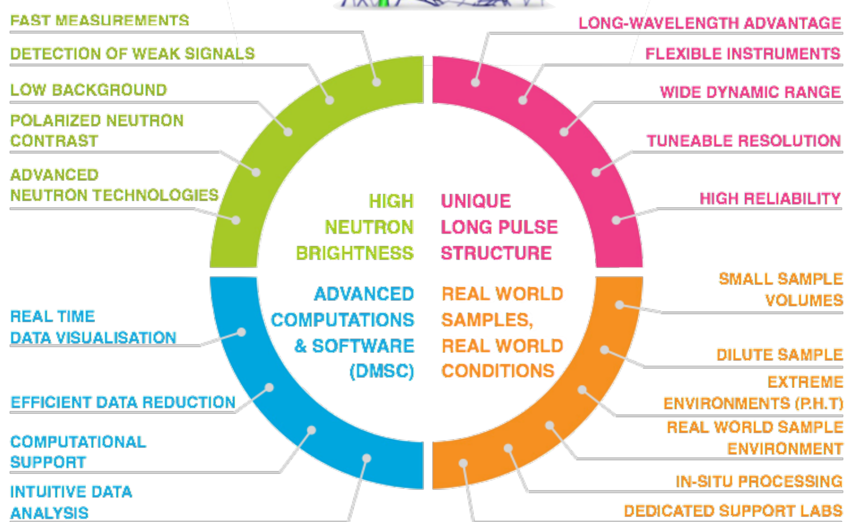
Quantum Enzymology

Protein Dynamics

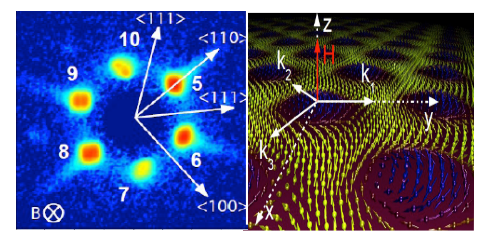


Multi-scale structure and dynamics

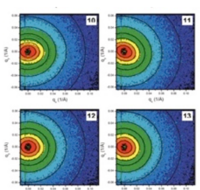
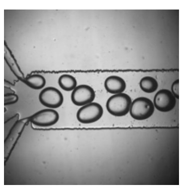




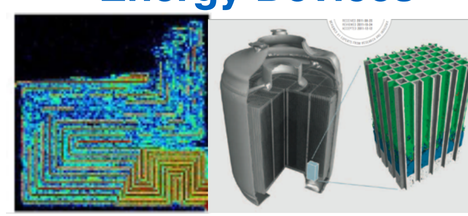
Charge and Spin Transport in Novel Materials



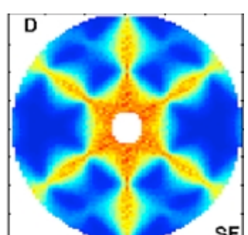
Kinetics of Complex micro-fluids

In Operandi Advanced Energy Devices

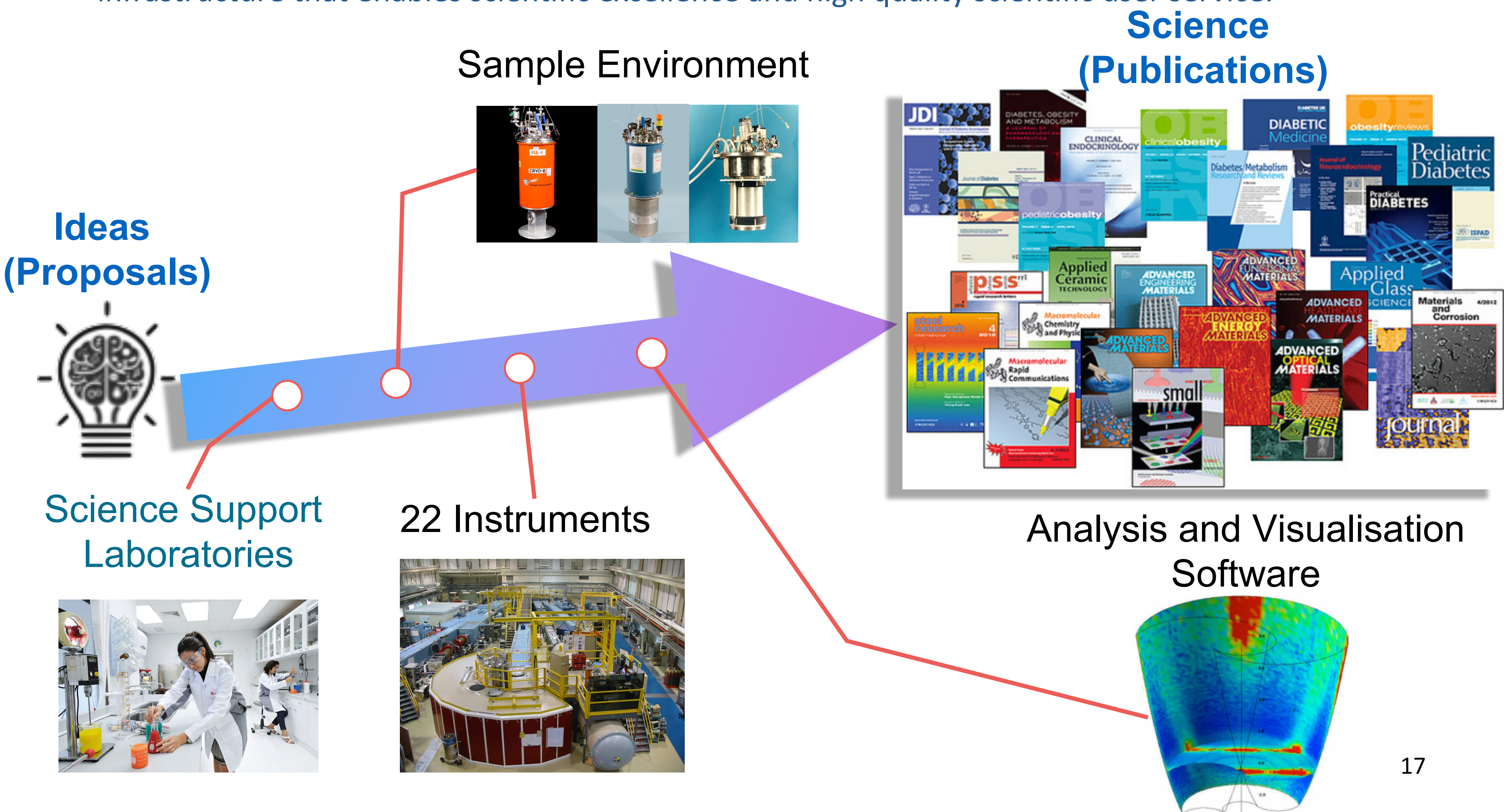


New States of Matter

ESS Project Scope on Instruments (Neutron Scattering Systems, NSS)

NSS Scope: 22 **public** instruments by 2028 together with a technical and scientific support infrastructure that enables scientific excellence and high quality scientific user service.



Council.07.14.a

The NSS Project Instruments
All are funded to be world leading in 2023

Instrument Class	Instrument	Costbook (M€)	Upgrade (M€)	Performance target at Cost book value (@ 2MW)
Large Scale Structures	LOKI (Broad band SANS)	12.19	3.0	5 x D22 & 20 x SANS2D
	SKADI (General Purpose SANS) *(+SONDE funds)*	11.50	3.0	4 x D22
	ESTIA (Focusing Reflectometer)	11.80	4.6	• Conventional mode: ~ 100 x D17 • High intensity mode: $1 cm^2$ samples = seconds
	FREIA (Liquids Reflectometer)	13.20	5.0	30 x FIGARO, INTER
Diffraction	DREAM (Bispectral powder diffractometer)	13.66	5.1	> 10 x POWGEN or WISH
	HEIMDAL (Hybrid diffractometer)	13.55	3.7	~ 50 x GEM, ~ 8 x new POLARIS
	MAGIC (magnetism single crystal diffractometer)	13.10	1.9	• Cold: > 100 x worlds best, • Thermal: $1 mm^3$ crystals = 10 min
	NMX (Macromolecular crystallography)	11.67	2.5	> 10 x LADI & Biodiff
Engineering & Industrial	BEER (Engineering diffractometer)	14.99	9.3	world leading in strain scanning, unique flexibility
	ODIN (multi-purpose imaging)	11.60	5.8	world leading for high resolution, > 10 x best for TOF methods
Spectroscopy	BIFROST (extreme environment spectrometer)	13.45	2.4	> 10 x THALES & MACS
	C-SPEC (cold chopper spectrometer)	16.50	2.4	2 - 6 x IN5
	T-REX (bispectral chopper spectrometer)	16.85	3.1	3 x 4-SEASONS, 3 x IN5
	VESPA (vibrational spectroscopy)	12.00	2.9	10 x VISION (ΔE = 130 meV)
	MIRACLES (backscattering spectrometer)	13.53	1.7	2 x BASIS and DNA
	Total cost book value	199.59	56.4	

The NSS Project Instruments
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EUROPEAN SPALLATION SOURCE

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Excellent oportunities for science at 2 W
Instrument upgrades add another factor 2-3
Going from 2 MW to 5 MW adds factor 2,5
=> Factor 6

15 Instruments selected so far
8 to be in user operation by 2023

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Large-Scale Structures

- ODIN imaging
- SKADI GP-SANS
- LOKI Broadband SANS
- Surface Scattering
- FREIA Hor. Refl.
- ESTIA Ver. Refl.

Diffraction

- HEIMDAL Pow. Diffr.
- DREAM Pow. Diffr.
- Monochromatic Powder Diffractometer
- BEER Eng. Diffr.
- Extreme Conditions Diffractometer
- MAGIC Magn. Diffr.
- NMX Macromol. Diffr.

Spectroscopy

- CSPEC ColdChopSp
- VOR BroadbandSp
- T-REX ThChopSpec
- BIFROST Xana Spec
- VESPA Vibr.Spec.
- MIRACLES BckScatt
- High-Resolution Spin-Echo
- Wide-Angle Spin-Echo
- Fundamental & Particle Physics

life sciences
soft condensed matter
chemistry of materials
energy research
magnetism & superconductivity
engineering & geo-sciences
archeology & heritage conservation
fundamental & particle physics

C.09.14.

Internal* Neutron Beam Instrument Schedule

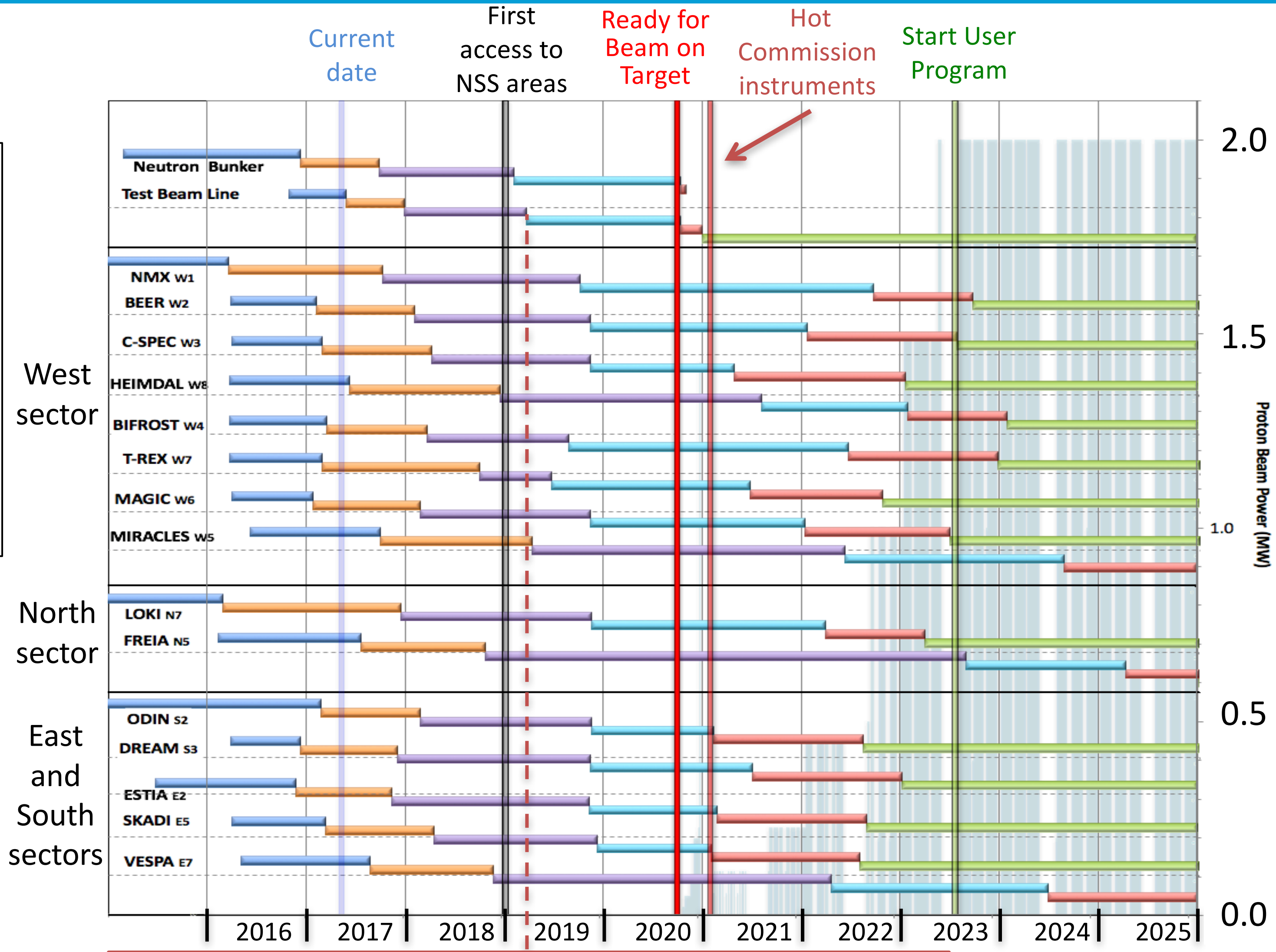
DRAFT FOR DISCUSSION V3.2, 9th May 2017

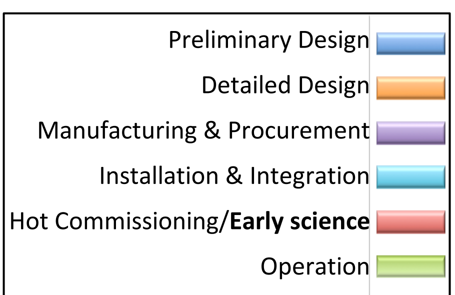
EUROPEAN SPALLATION SOURCE

* still under discussion with ESS-ERIC Council

NOTES:

- Assumes 2MW maximum power until end 2025
- Phases aligned with TG2 reviews on 1st 9 NBIs
- TG4 (Installation & Integration) not yet aligned with on-site resource plan





Installation for most instruments begins in Q2/2019 with in-monolith optics
Access to other "instrument construction areas" will be later

C.09.14.

Internal* Neutron Beam Instrument Schedule

DRAFT FOR DISCUSSION

V3.2, 9th May 2017

EUROPEAN SPALLATION SOURCE

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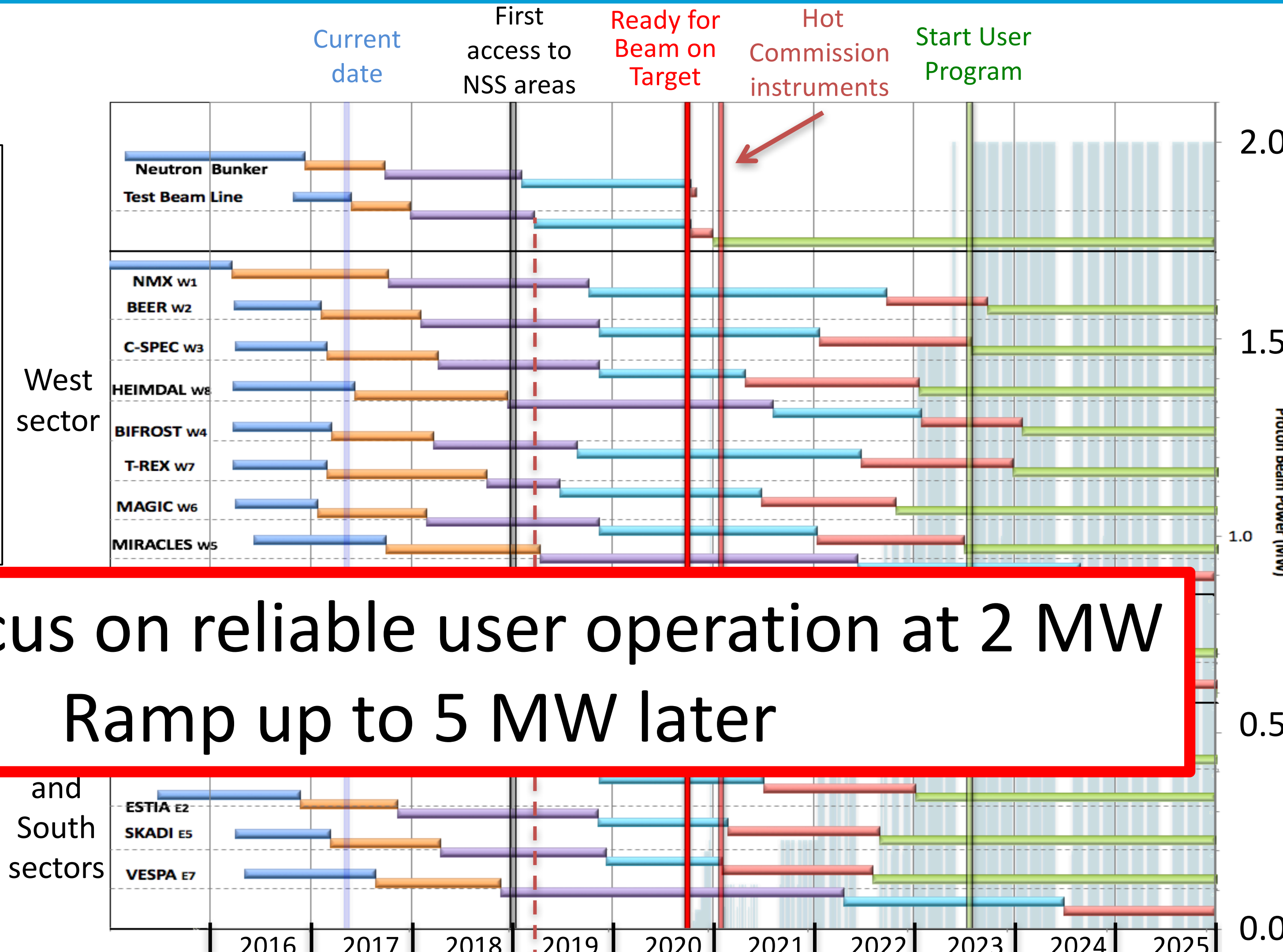

Initially focus on reliable user operation at 2 MW
Ramp up to 5 MW later

Preliminary Design
Detailed Design
Manufacturing & Procurement
Installation & Integration
Hot Commissioning/**Early science**
Operation

Installation for most instruments begins in Q2/2019 with in-monolith optics
Access to other "instrument construction areas" will be later

ESS will be a user facility

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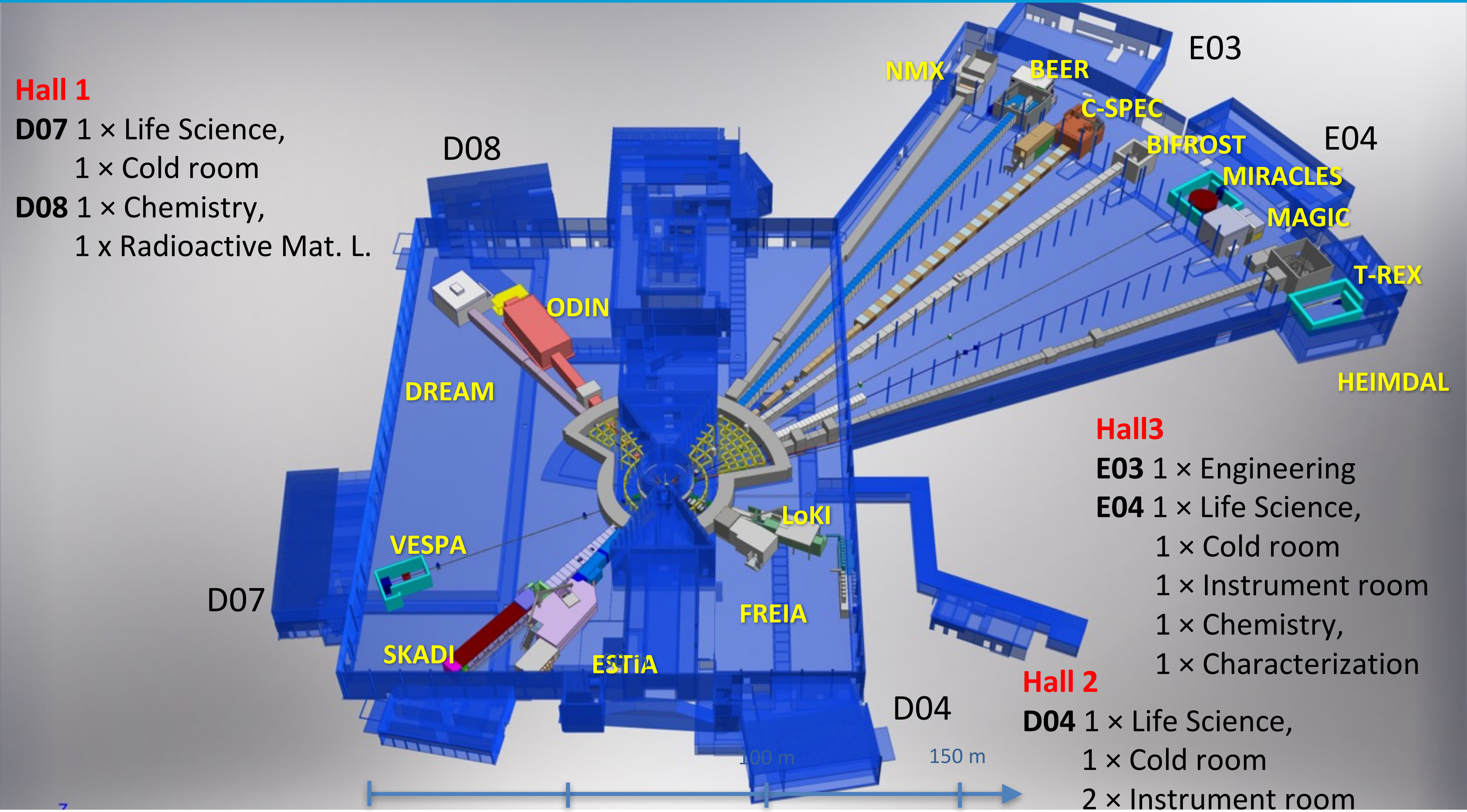
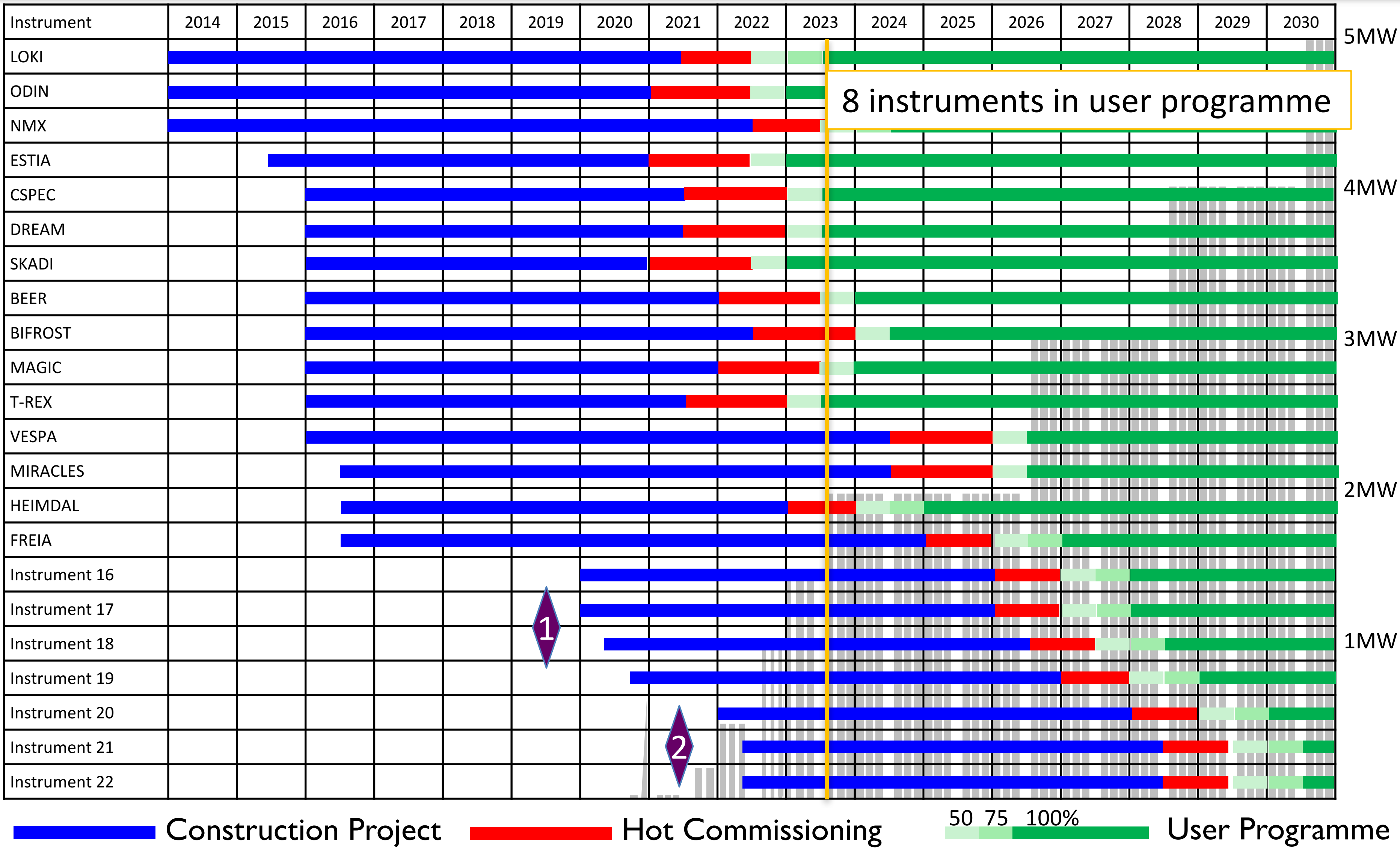
- For researchers who need neutron beams for their experiments.
- From universities, institutes, industry.
- We provide tools & support; they bring their projects and perform the experiments. Selection of experiments via proposal scheme by scientific excellence
- 2000-3000 visiting users/year. A stay can be days or weeks.
- Many different disciplines: materials research, physics, chemistry, life science…

ESS Neutron Instruments 1-15 and Support Infrastructure

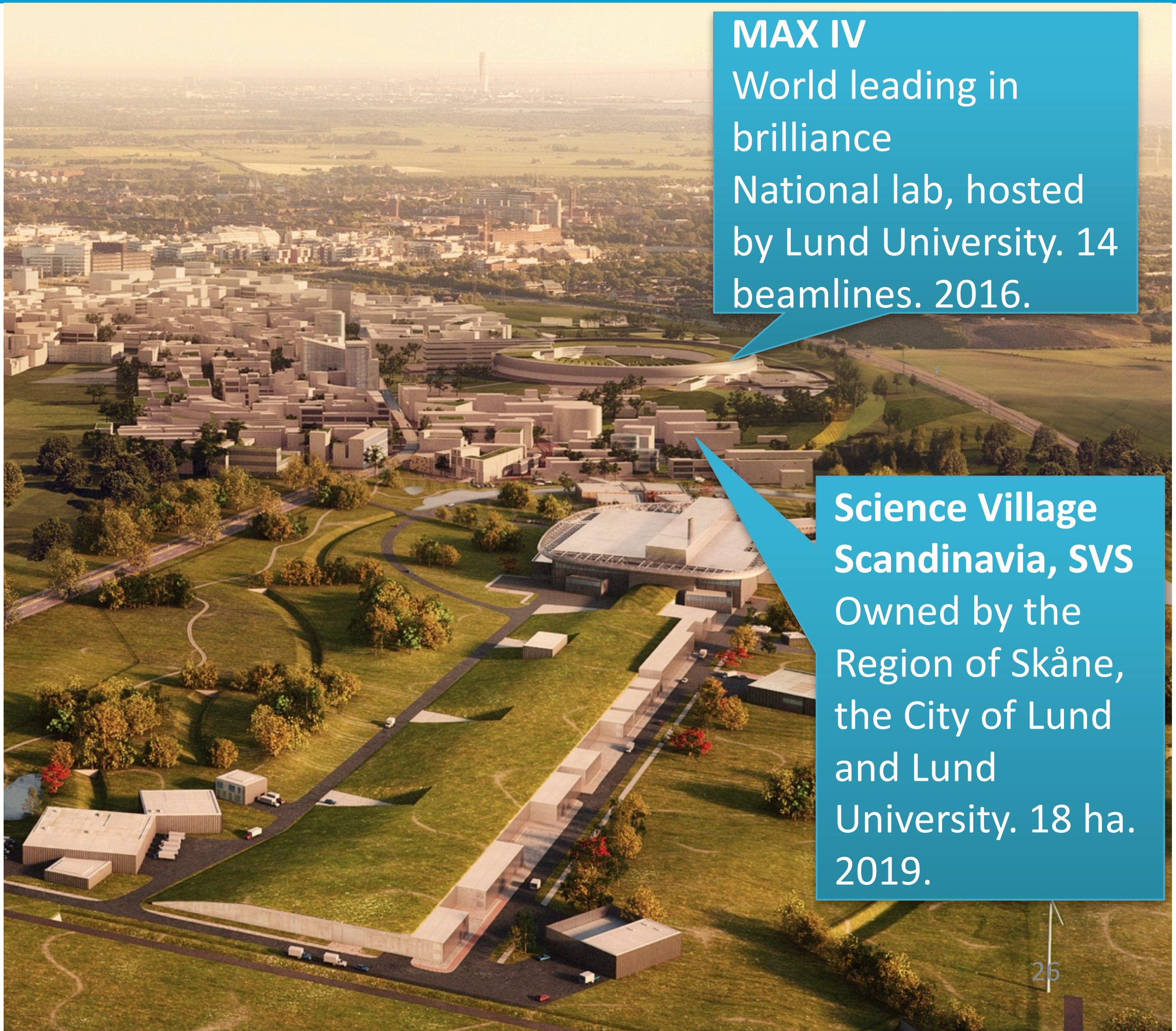


Tentative Instrument Ramp-up

based on Instrument Construction Working Schedule V3.1, 25/4/2017



ESS, MAX IV and Science Village Scandinavia



Conventional Facilities Schedule (preliminary)

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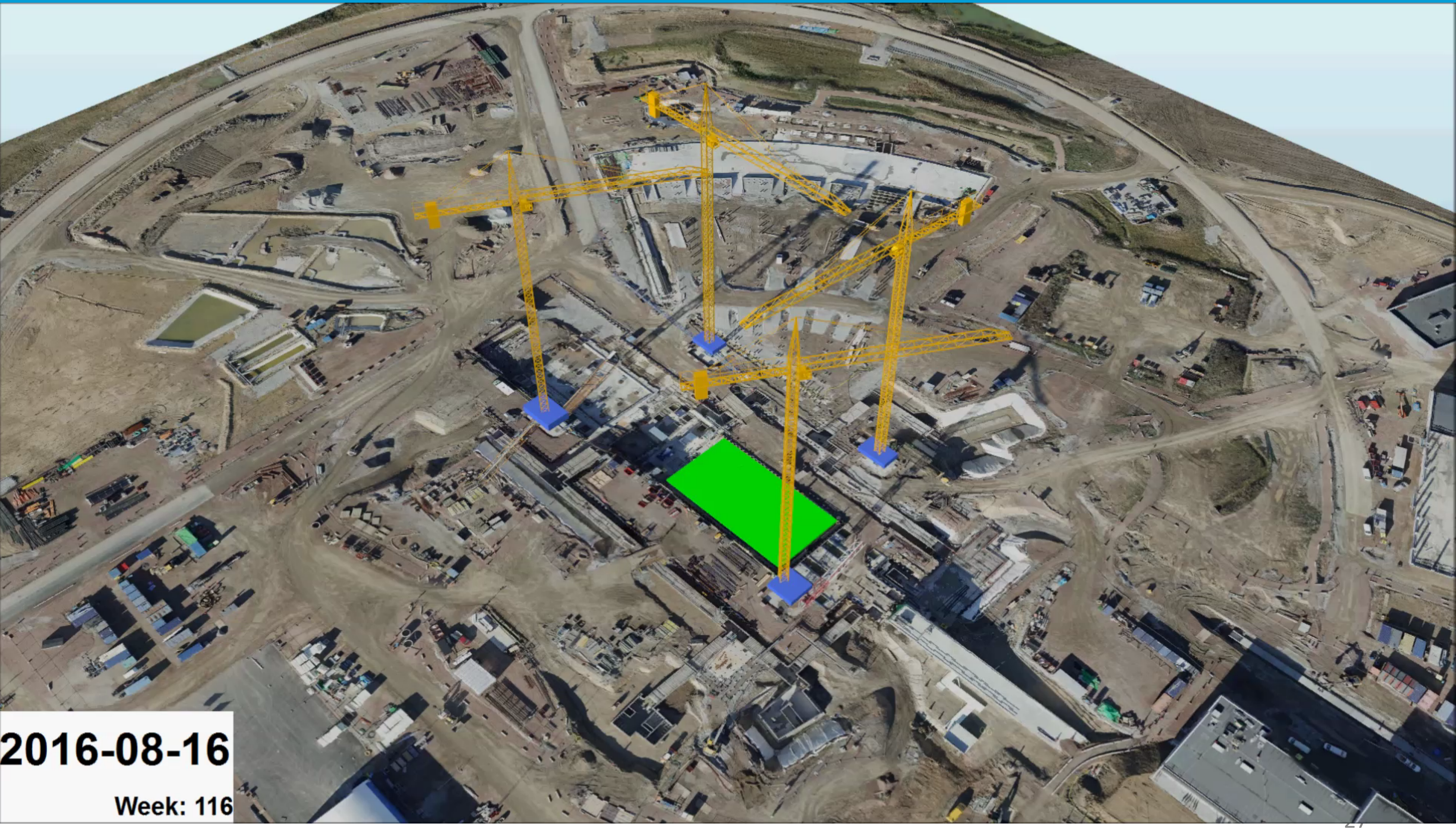


Summary

- ESS will be the worlds most intense neutron source
- ESS will provide world leading new research opportunities for research with neutrons in a wide range of science and technology
- User operation with 8 instruments is planned for 2023
- ESS is looking for further members

FUTURE SCENARIOS OUTLINED IN THE 2016 ESFRI REPORT

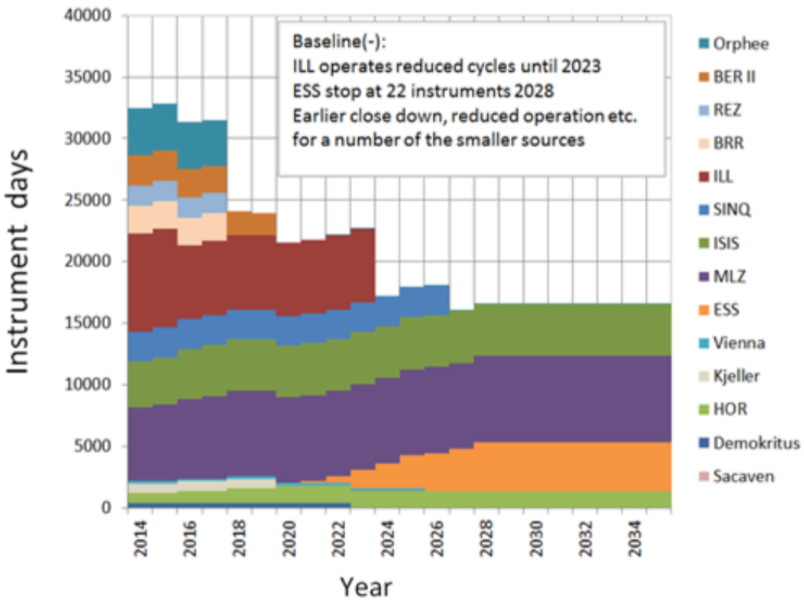


***Figure 11.** The predicted delivery of instrument beam-days in the Degraded Baseline Scenario.*

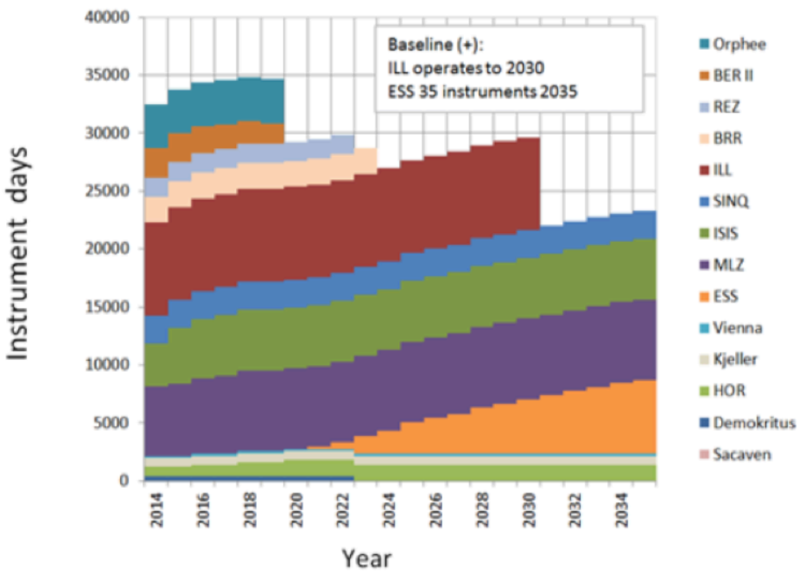


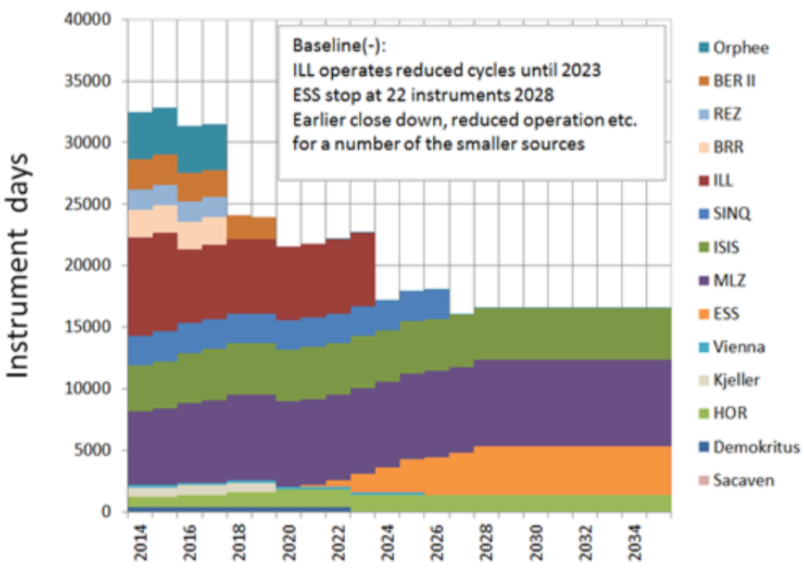
***Figure 12.** The predicted delivery of instrument beam days in the Enhanced Baseline Scenario*

Pessimistic scenario: ILL operates at reduced output until 2023, ESS with 22 instruments beyond 2028. Earlier closer and/reduced operations for a number of medium power sources

Optimistic scenario: ILL operates until 2030, ESS with **35** instruments beyond 2035.

FUTURE SCENARIOS OUTLINED IN THE 2016 ESFRI REPORT

EUROPEAN SPALLATION SOURCE



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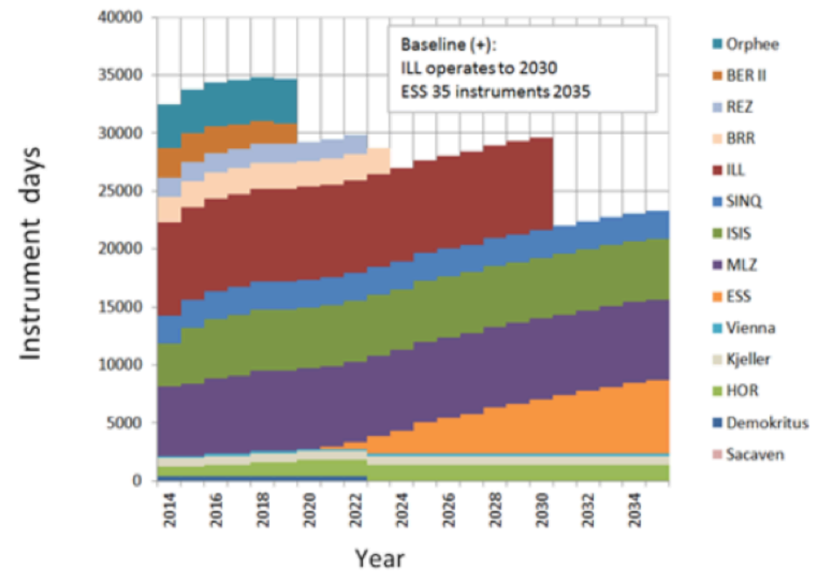


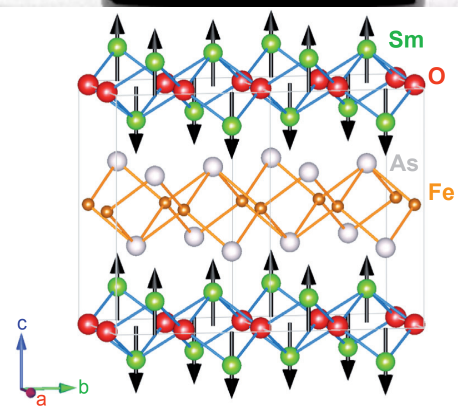
***Figure 12.** The predicted delivery of instrument beam days in the Enhanced Baseline Scenario*

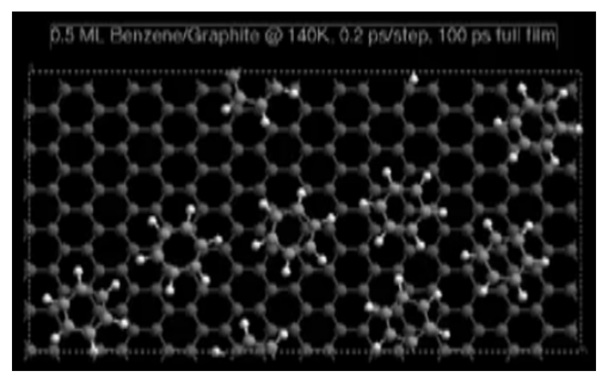
Pessimistic … 2030, ESS
until 2023, …
Earlier clos…
of medium…

ESS needs to build up its research capacity as soon as at all possible

Neutrons are special

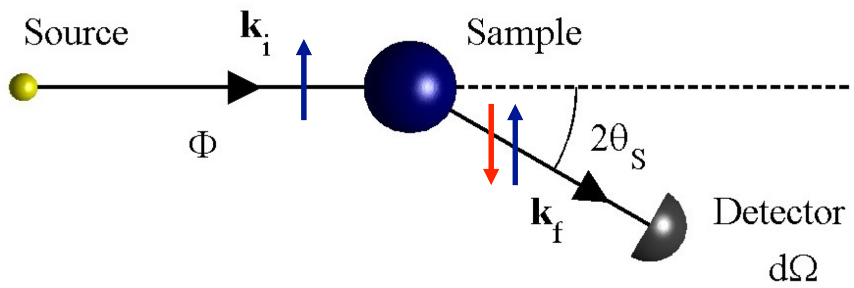
- **charge neutral:** deeply pene-trating ... except for some isotopes
- **nuclear interaction:** cross section depending on isotope (not Z), sensitive to light elements.
- **spin S = 1/2**: probing magnetism
- **unstable** $n \rightarrow p + e + \underline{\nu}_e$ with life time $\tau \sim 900s$, $I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



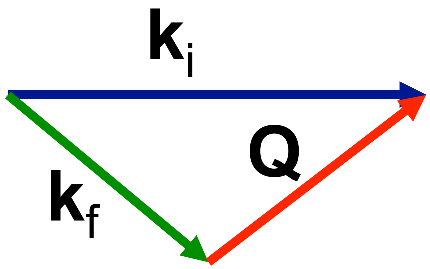


WHERE ARE THE ATOMS AND WHAT DO THEY DO?

Scattering based on Momentum and Energy conservation



scattering triangle



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

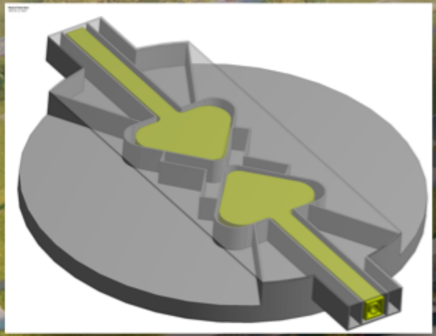
energy conservation $\hbar\omega = E_i - E_f$

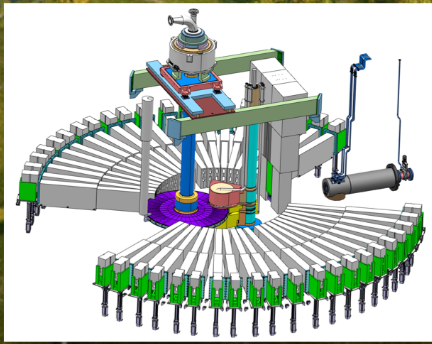
spin conservation: Polarisation analysis

The European Spallation Source

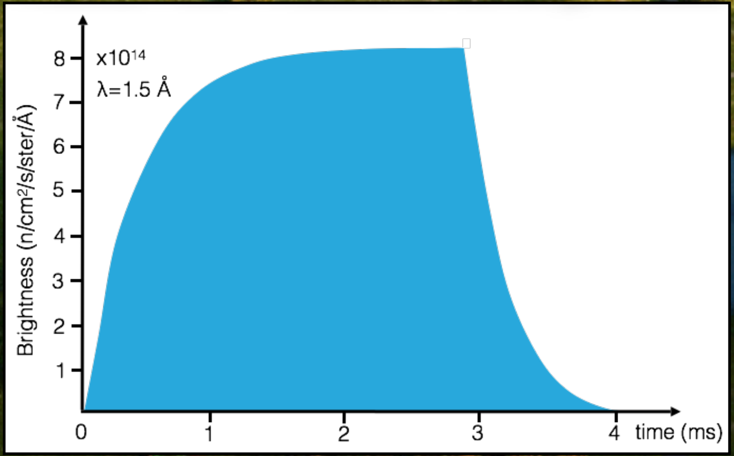
High Power Accelerator means more neutrons

Flat moderator delivering smaller and brighter neutron beams





High brightness and tuneable resolution makes new measurements possible



An Innovative Target Station that can host >30 instruments