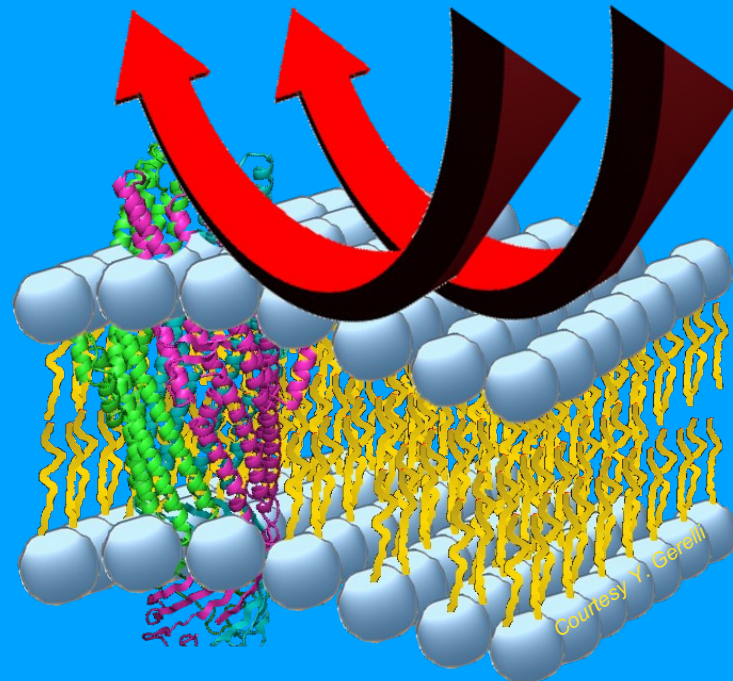
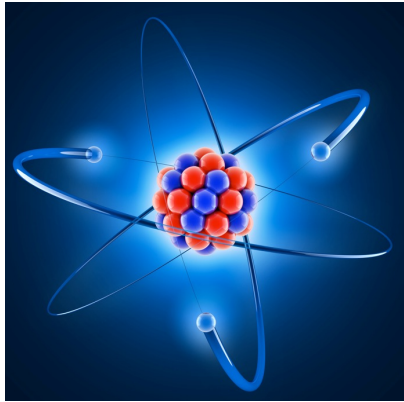


Neutron Scattering – Exploring Cell Membrane Mechanisms



Giovanna Fragneto
European Spallation Source ERIC





Neutrons

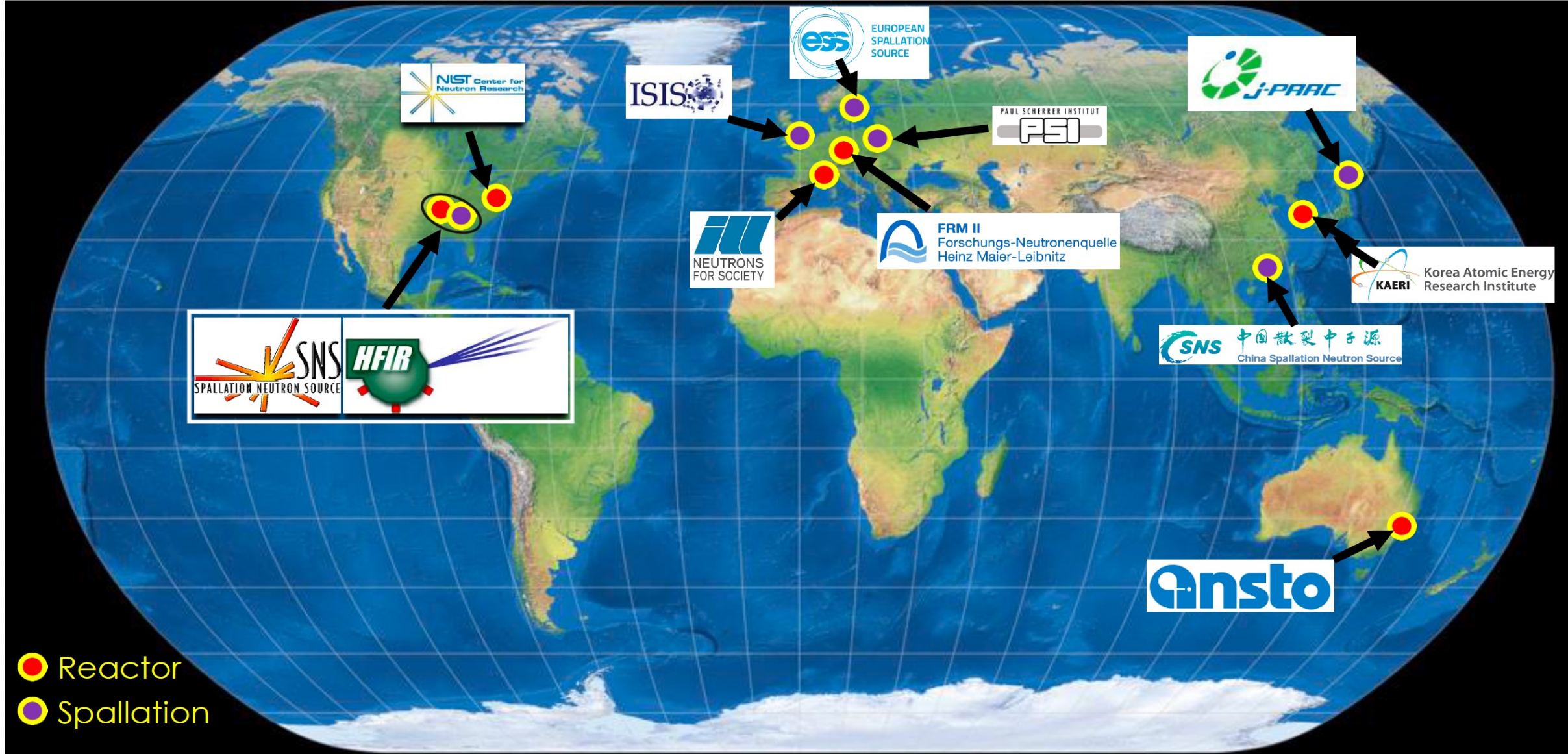


- Subatomic particles found in atomic nuclei
- Discovered in 1932 by Chadwick
- Mass slightly higher than that of protons ($\sim 1.67 \times 10^{-27} \text{ kg}$)
- Uncharged
- Lifetime ~ 15 mins
- Wave-particle duality ($v = 2.2 \text{ km/s at RT}$)
- Wavelength similar to atomic distances ($\lambda = 0.18 \text{ nm at RT}$)
- Energies similar to motion of molecules ($\sim 0.025 \text{ eV}$)
- Possess a spin

Generating neutrons

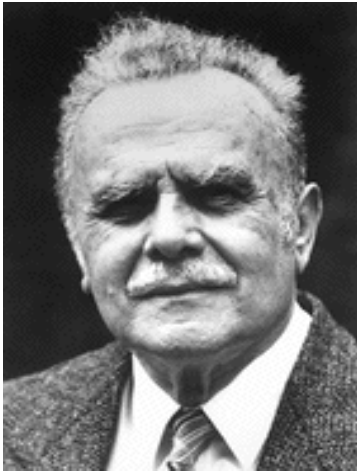


Neutron Sources around the world



Nobel Prize in Physics, 1994

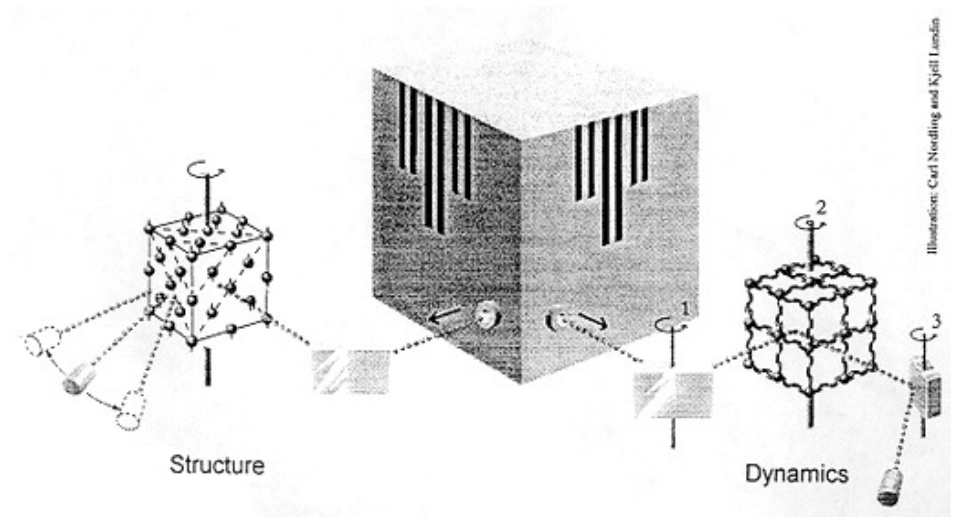
A unique probe of 'where atoms are and what atoms do' -
*to paraphrase the citation for the Nobel Prize in Physics
awarded to Brockhouse and Shull in 1994*



Bert Brockhouse
Dynamics
(Neutron Spectroscopy)



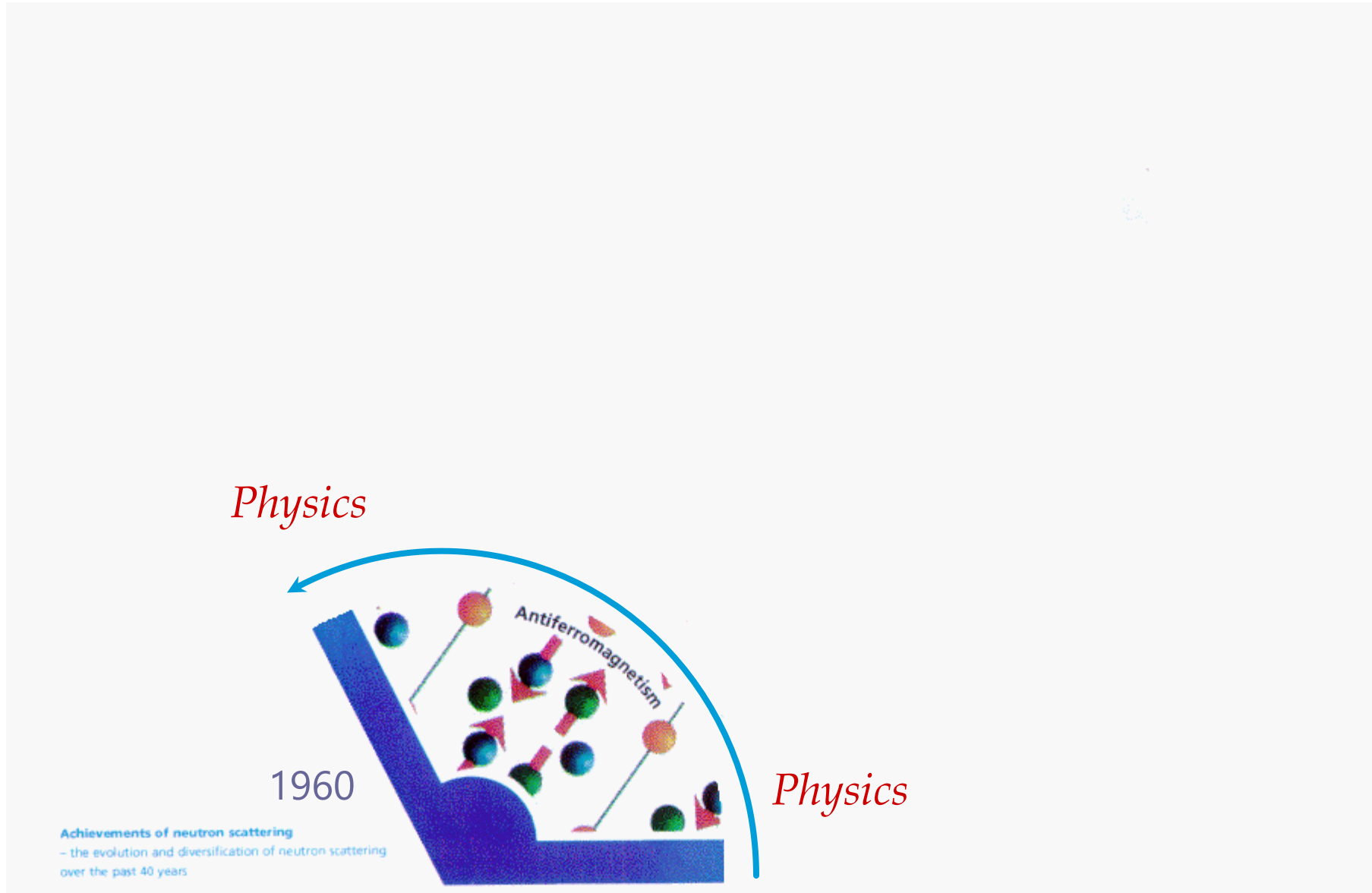
Cliff Shull
Structure
(Neutron Diffraction)



12 Oct 1994
Press Release

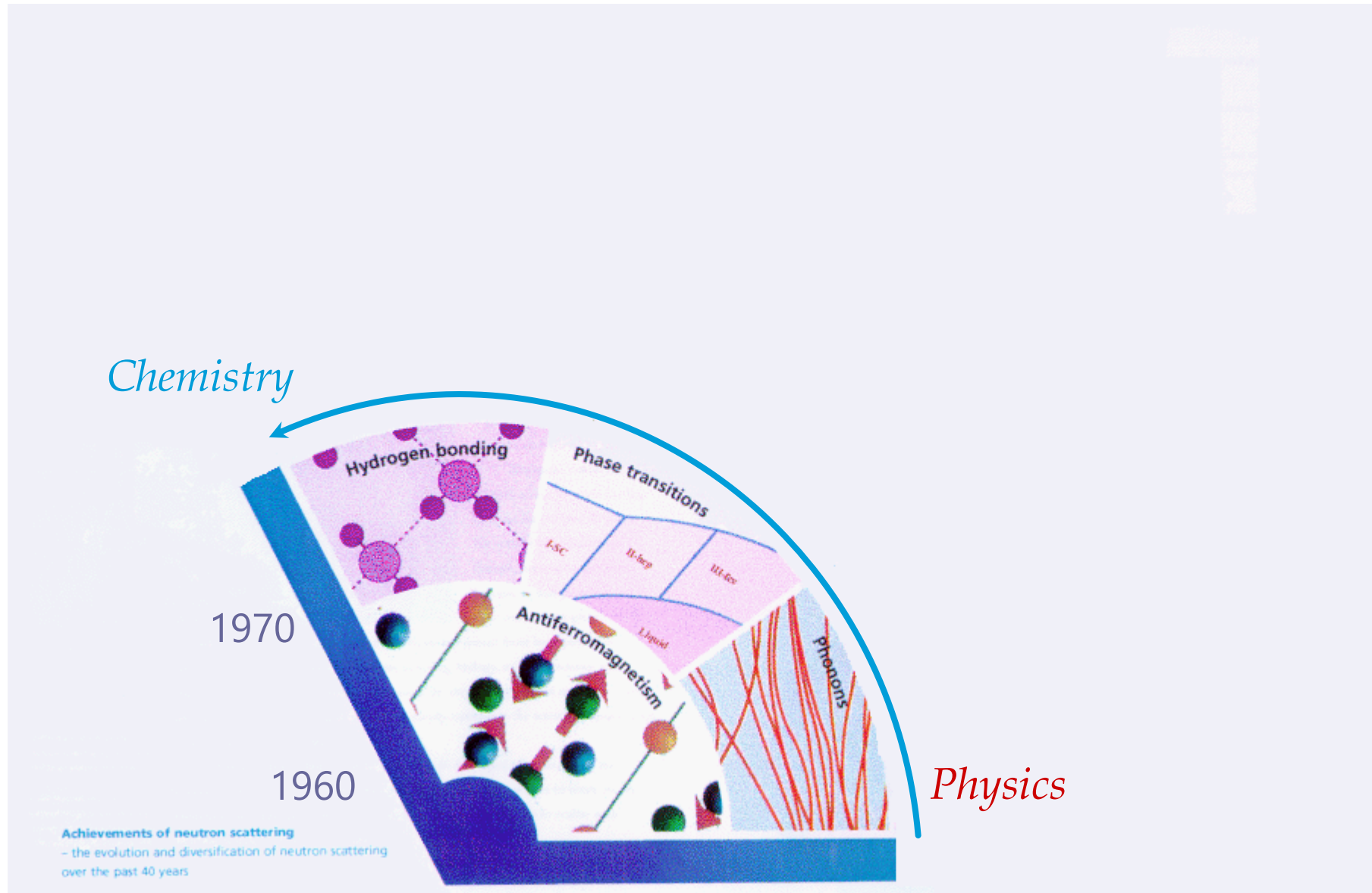
(...) Both methods are based on the use of neutrons flowing out from a nuclear reactor. When the neutrons bounce against (are scattered by) atoms in the sample being investigated, their *directions* change, depending on the atoms' relative positions. This shows how the atoms are arranged in relation to each other, that is, the structure of the sample. Changes in the neutrons' *velocity*, however, give information on the atoms' movements, e.g. their individual and collective oscillations, that is their dynamics.

Science with neutrons



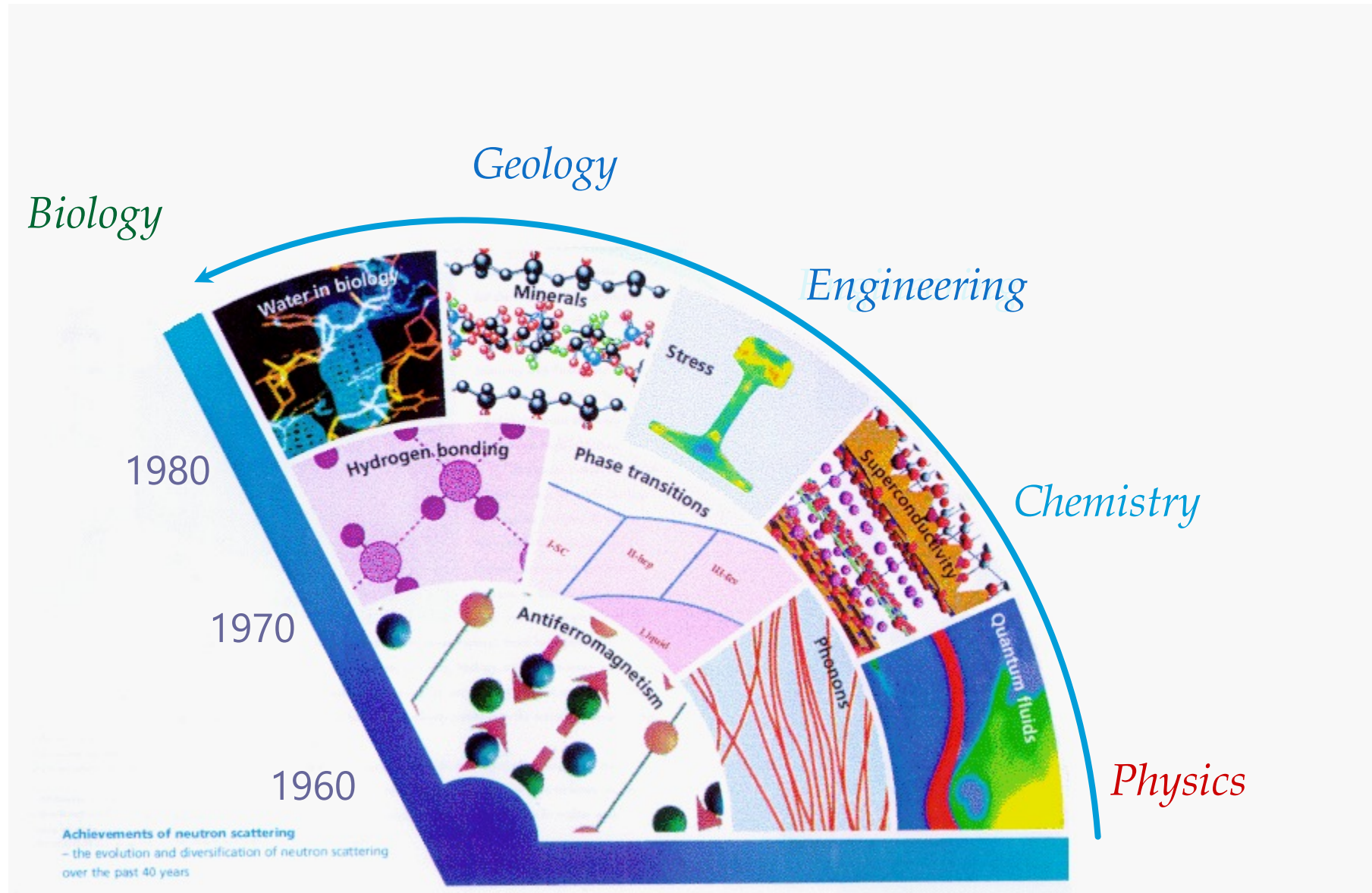
Courtesy of ISIS

Science with neutrons



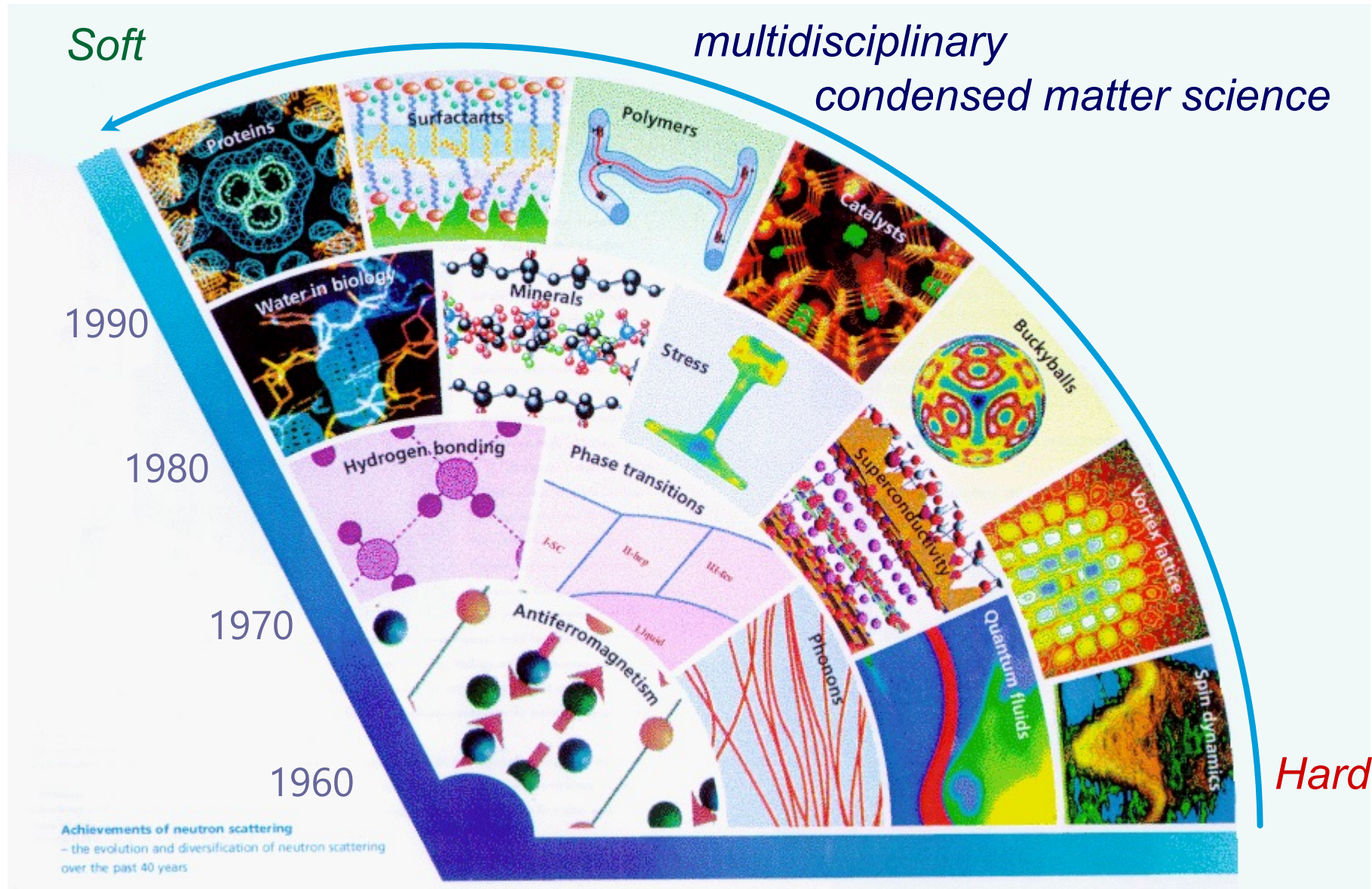
Courtesy of ISIS

Science with neutrons



Courtesy of ISIS

Science with neutrons



Present and Future:
Health
Energy
Environment
Fundamental science

1990

1980

1970

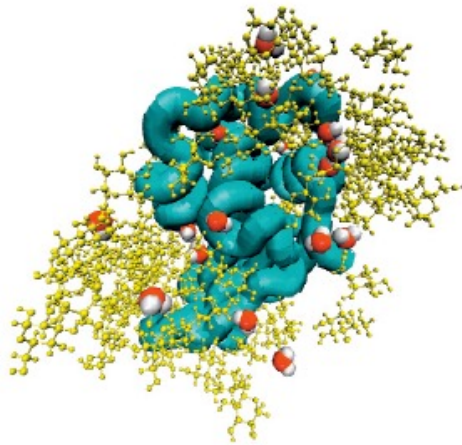
1960



Neutrons: An ideal probe at the atomic scale

- Like X-rays thermal neutrons possess the right wavelengths (structures $\text{\AA}$ to μm).
- They possess the ideal energies for spectroscopy of thermal fluctuations (dynamics ps to hr).

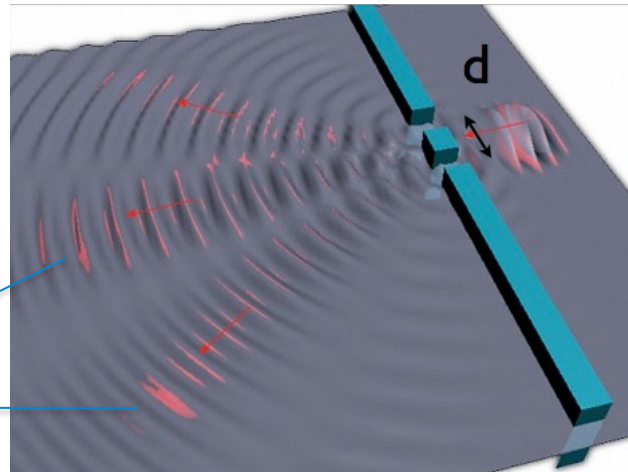
From 1000 nm



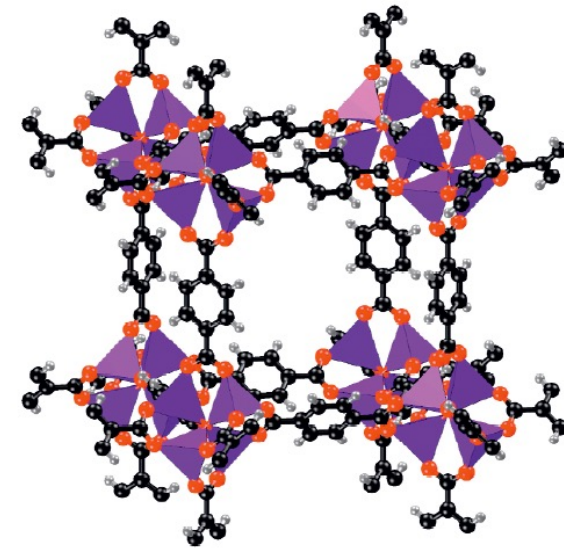
Cold Neutrons

$$\Delta\phi = \frac{\Delta y}{D} = \frac{\lambda}{d}$$

The information is encoded in the change of direction and speed of the neutrons as they path through the material.



Up to 0.001 nm



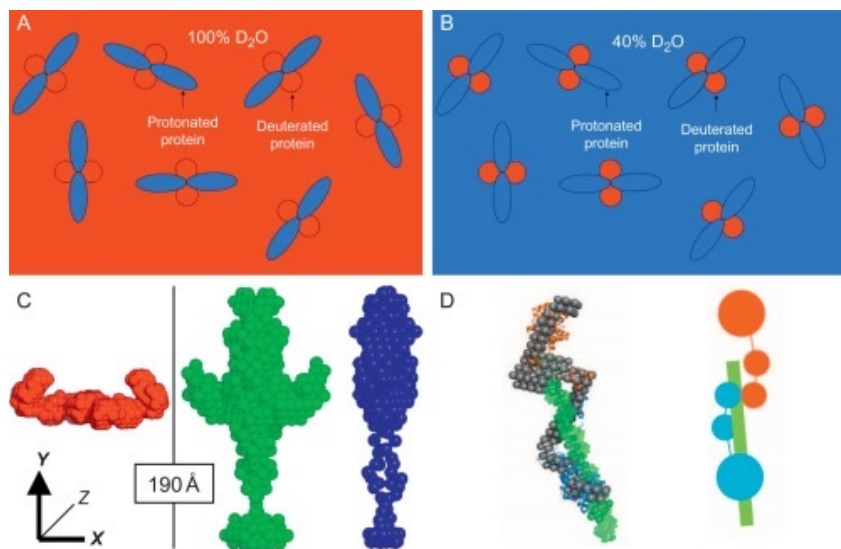
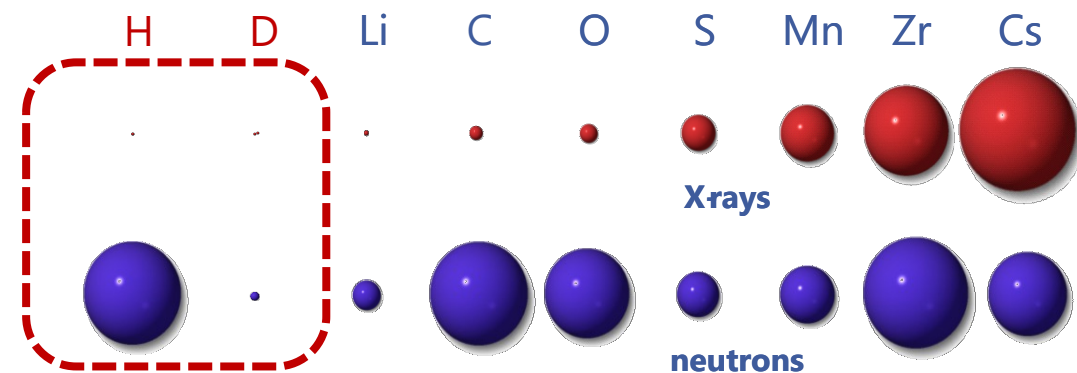
Hot Neutrons

Why use neutrons to study soft and biological material?

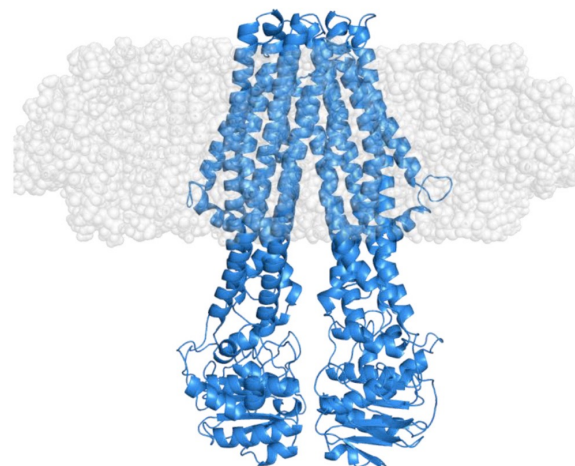


Neutrons interact with nuclei

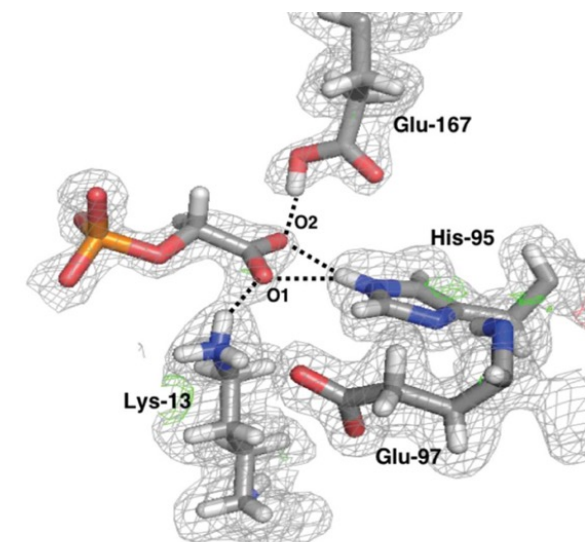
- are sensitive to light atoms, particularly hydrogen
- can exploit isotopic substitution, especially H/D
- 'see' materials differently to X-rays, complementary
- no markers



Haertlein et al. *Methods in Enzym.* 2016.



Josts et al. *Structure* 2018

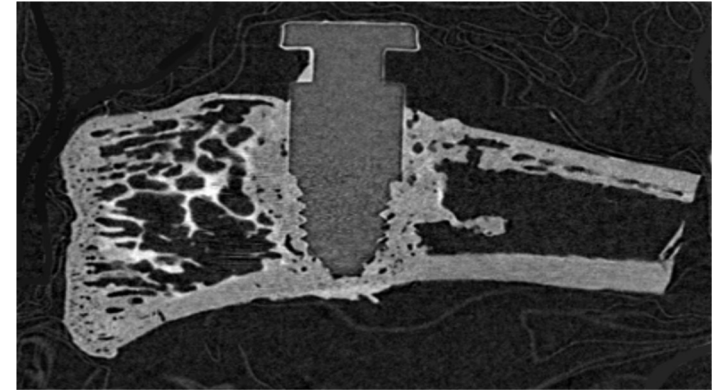
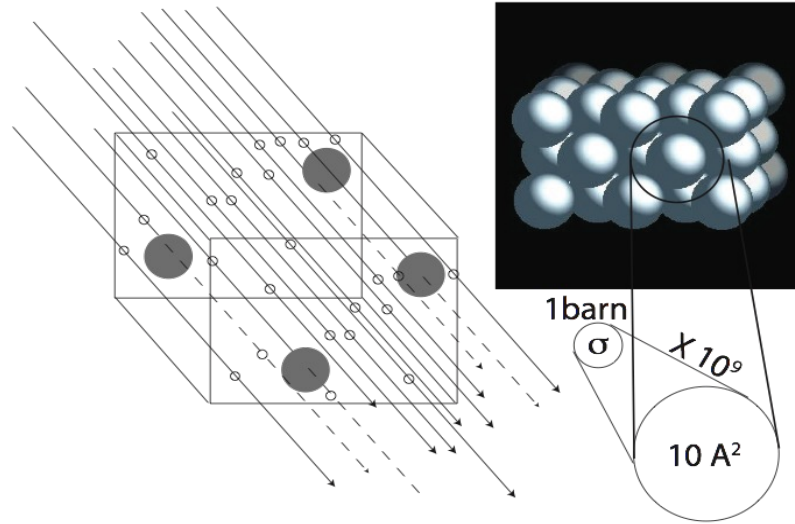
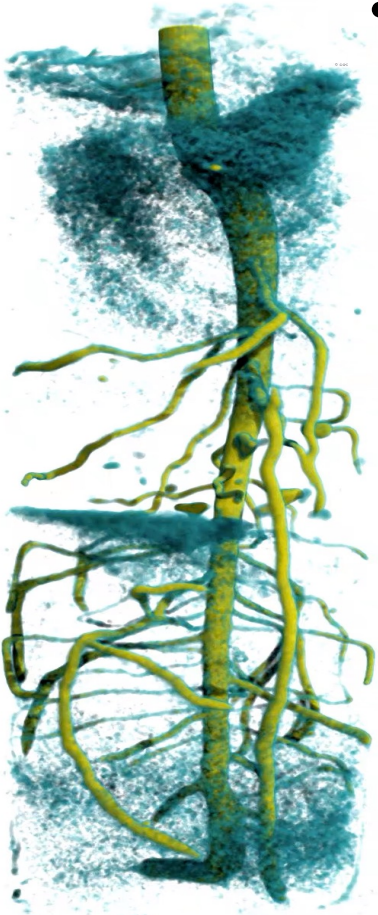


Kelpsas, V., Caldararu, O. et al.
(2021) *IUCr* 8 633-643

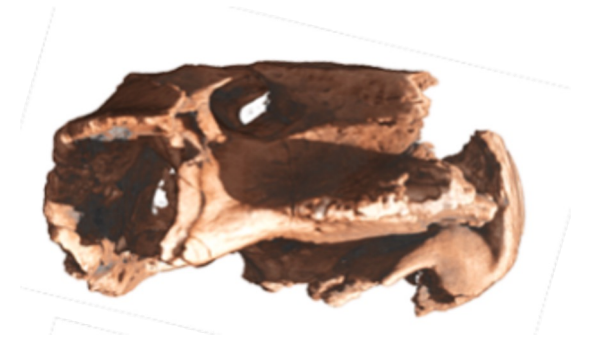
Neutrons are a neutral particle

0 sec

- are highly penetrating - imaging of light elements deeply buried in materials
- can be used as non-destructive probes

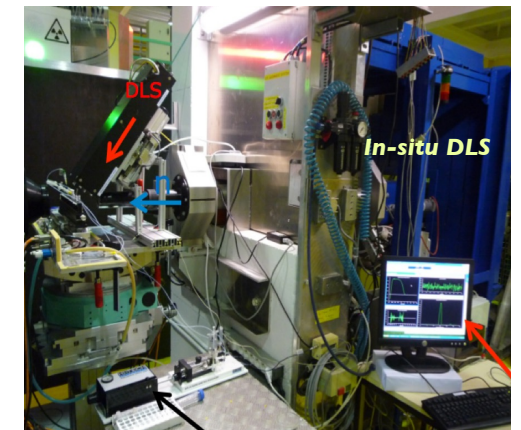
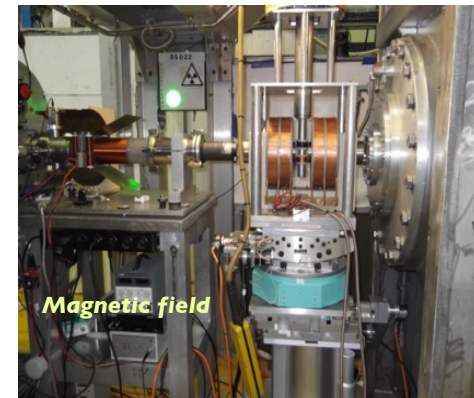
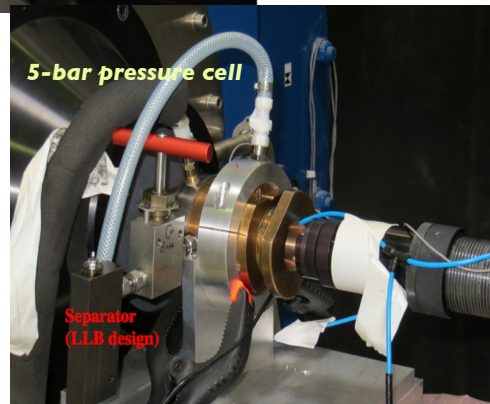
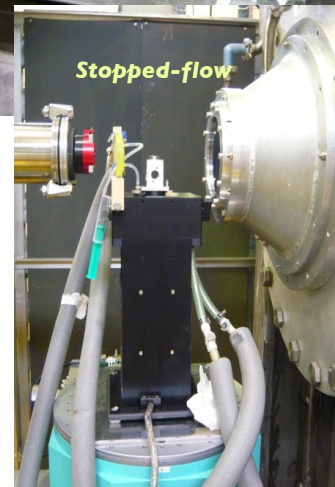
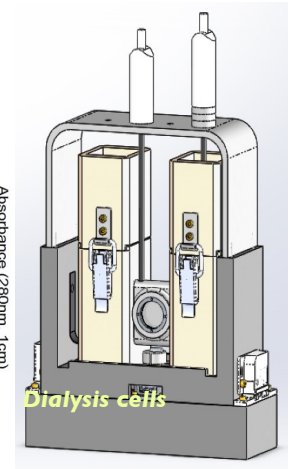
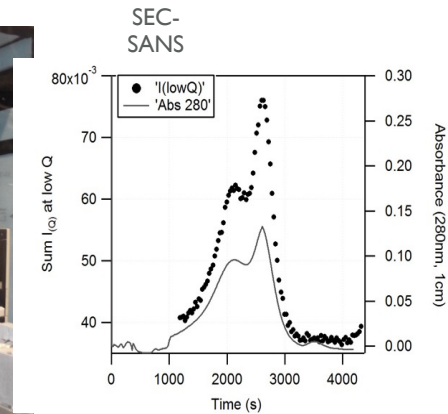
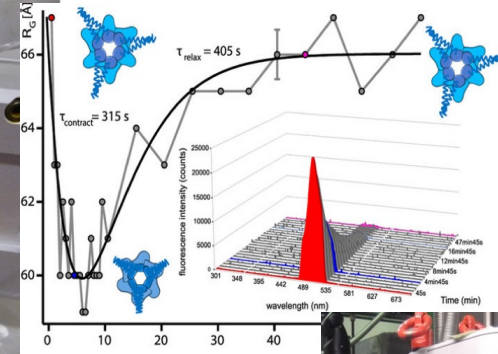
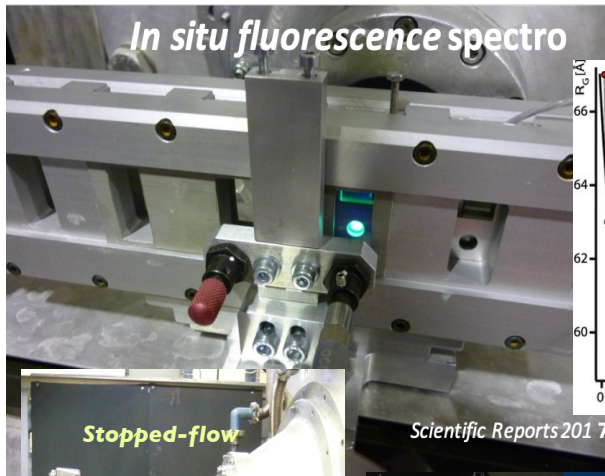


Bone Structures
+ implants



Neutrons are a neutral particle

- are highly penetrating → *buried interfaces*
- can be used to study samples in extreme environments and allow use of in-situ complementary techniques



Why use neutrons to study soft and biological material?

Non destructive

Possibility to work in physiological conditions



Neutrons

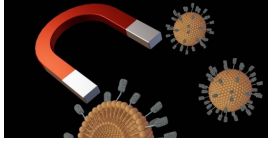
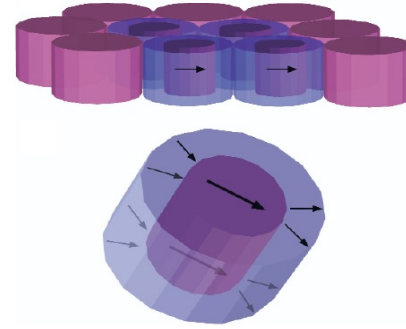
vs.



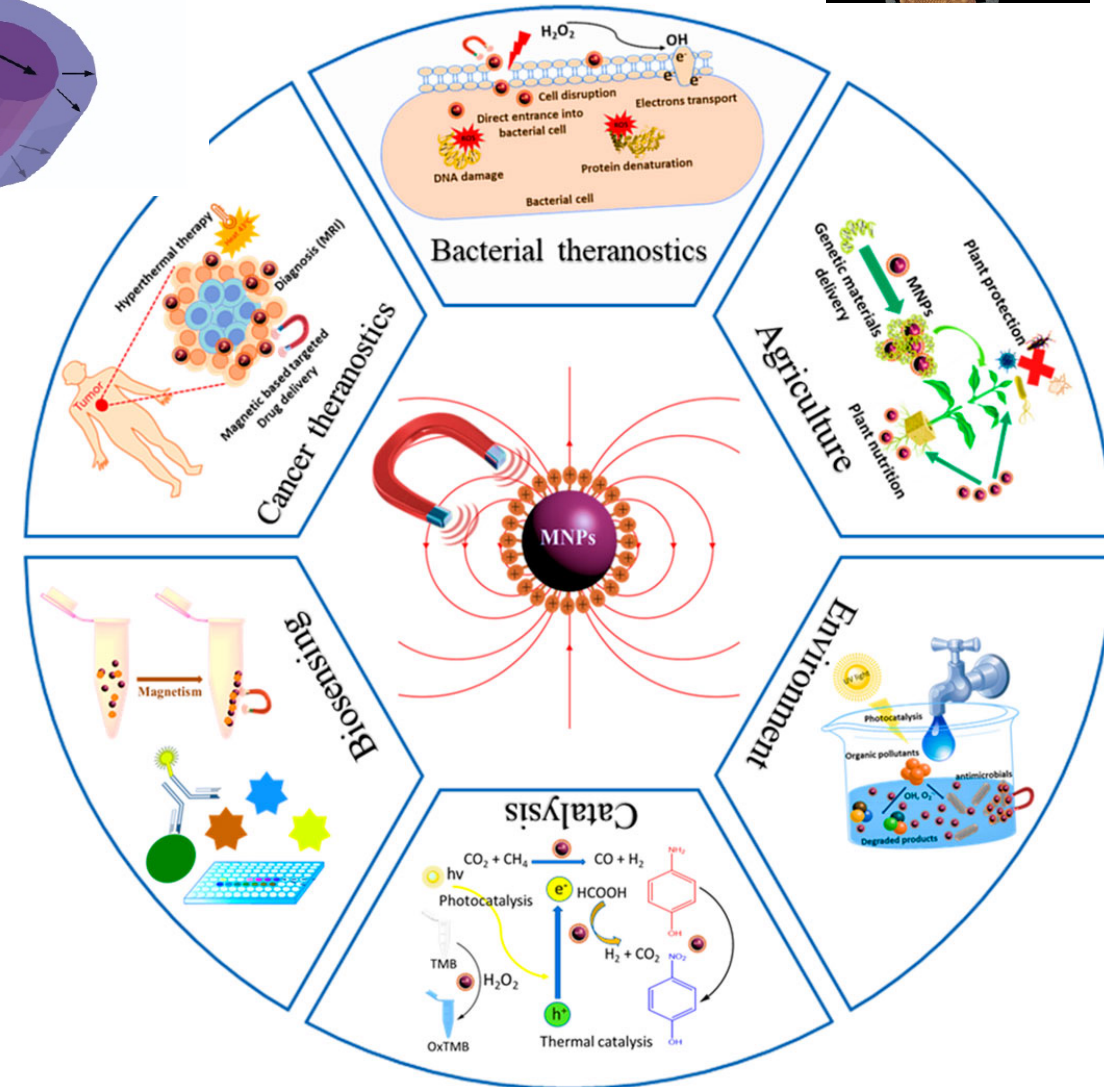
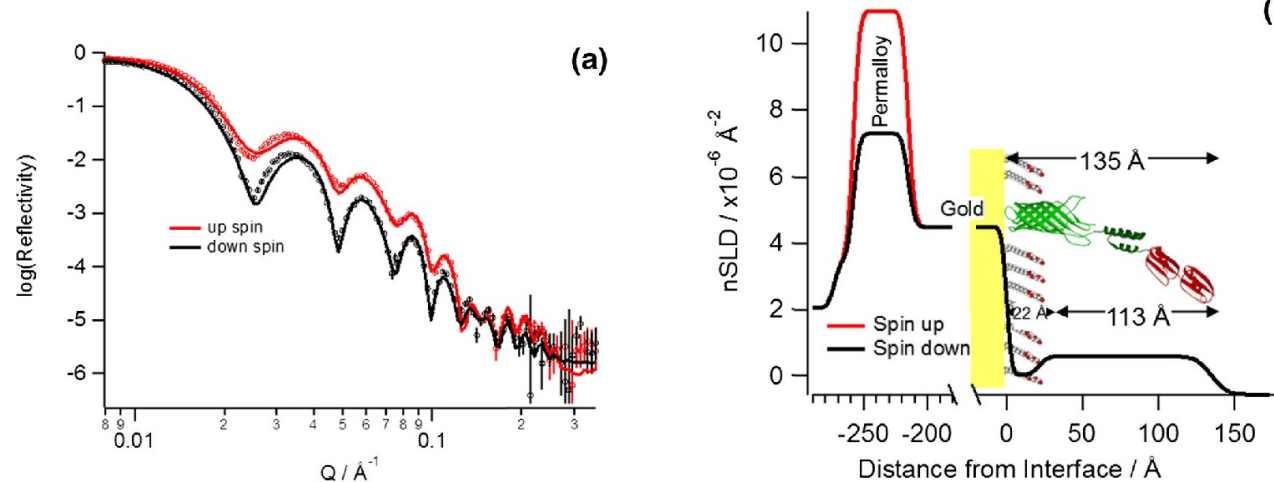
Some other methods

Neutrons have a magnetic moment and spin

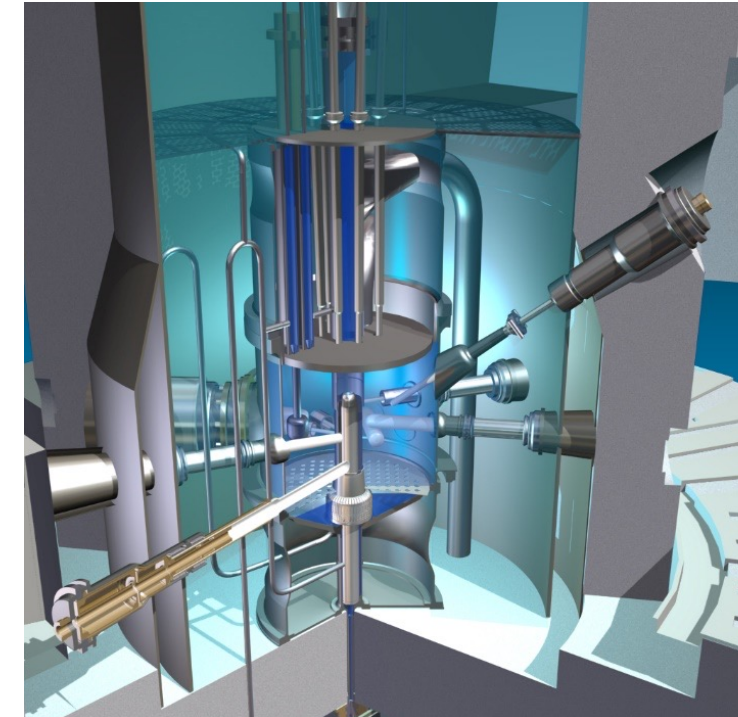
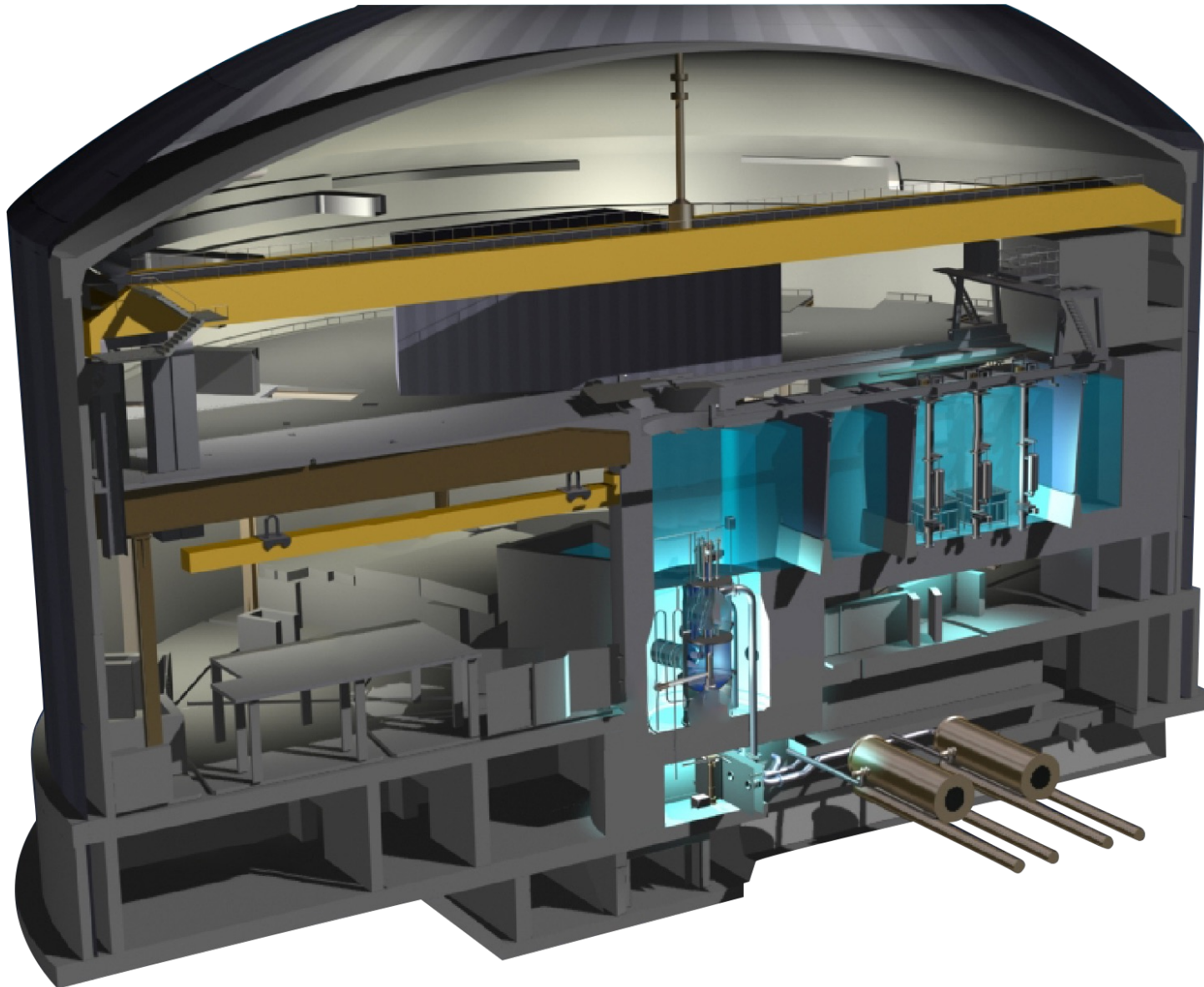
- study microscopic magnetic structures
- study magnetic fluctuations , and
- develop magnetic materials
- formed into polarised beams,
- study nuclear (atomic) orientation, and
- separate coherent from incoherent scattering



- *magnetic systems in soft matter (magnetic nanoparticles)*
- *magnetic contrast in reflectometry*

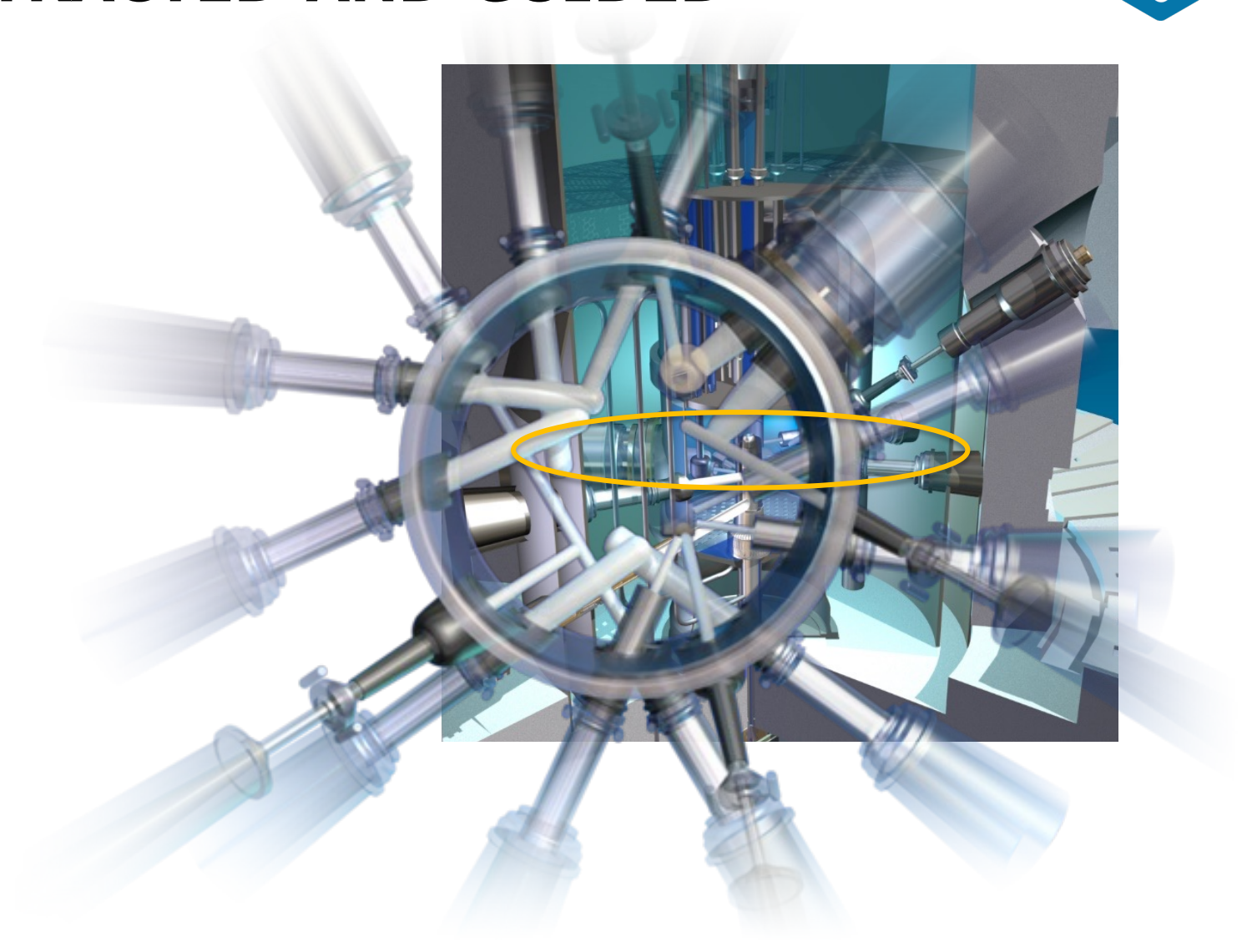


The ILL benefits from the world's most intense continuous neutron source operating since 1971

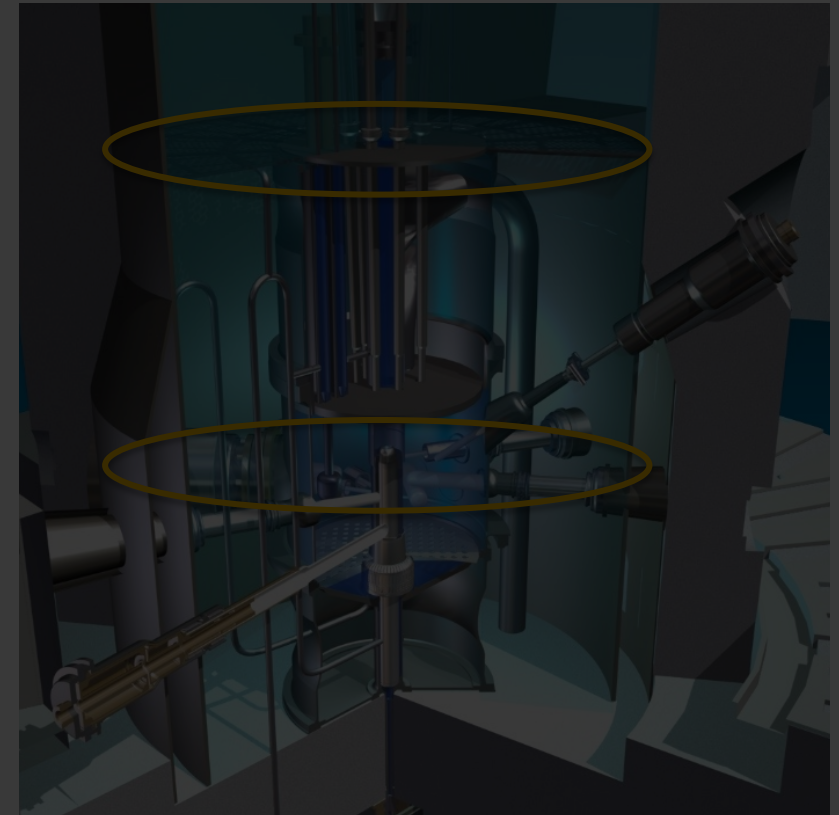
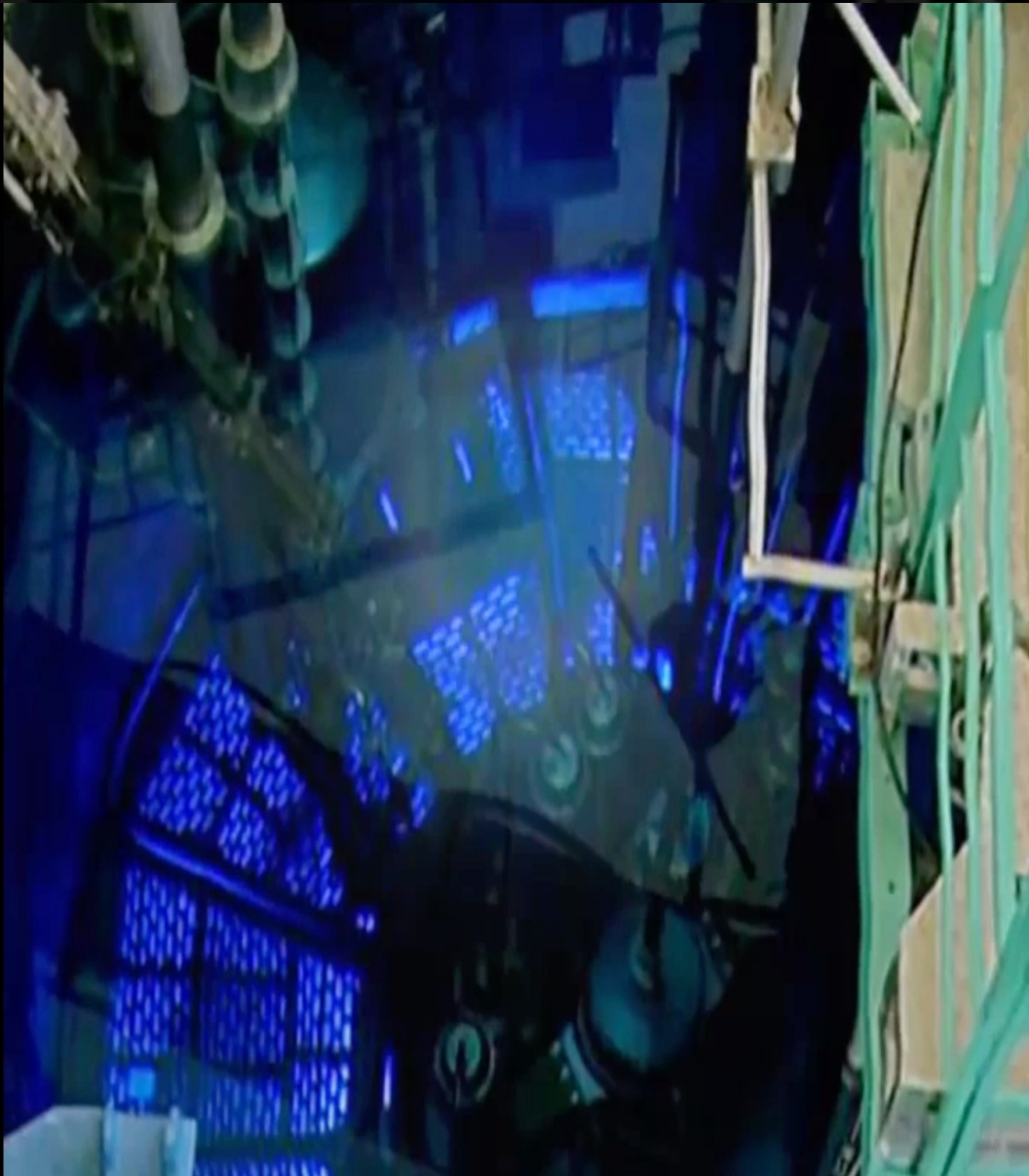


**A neutron source generating
 5×10^{18} fast neutrons/sec
at a max power of 58 MW**

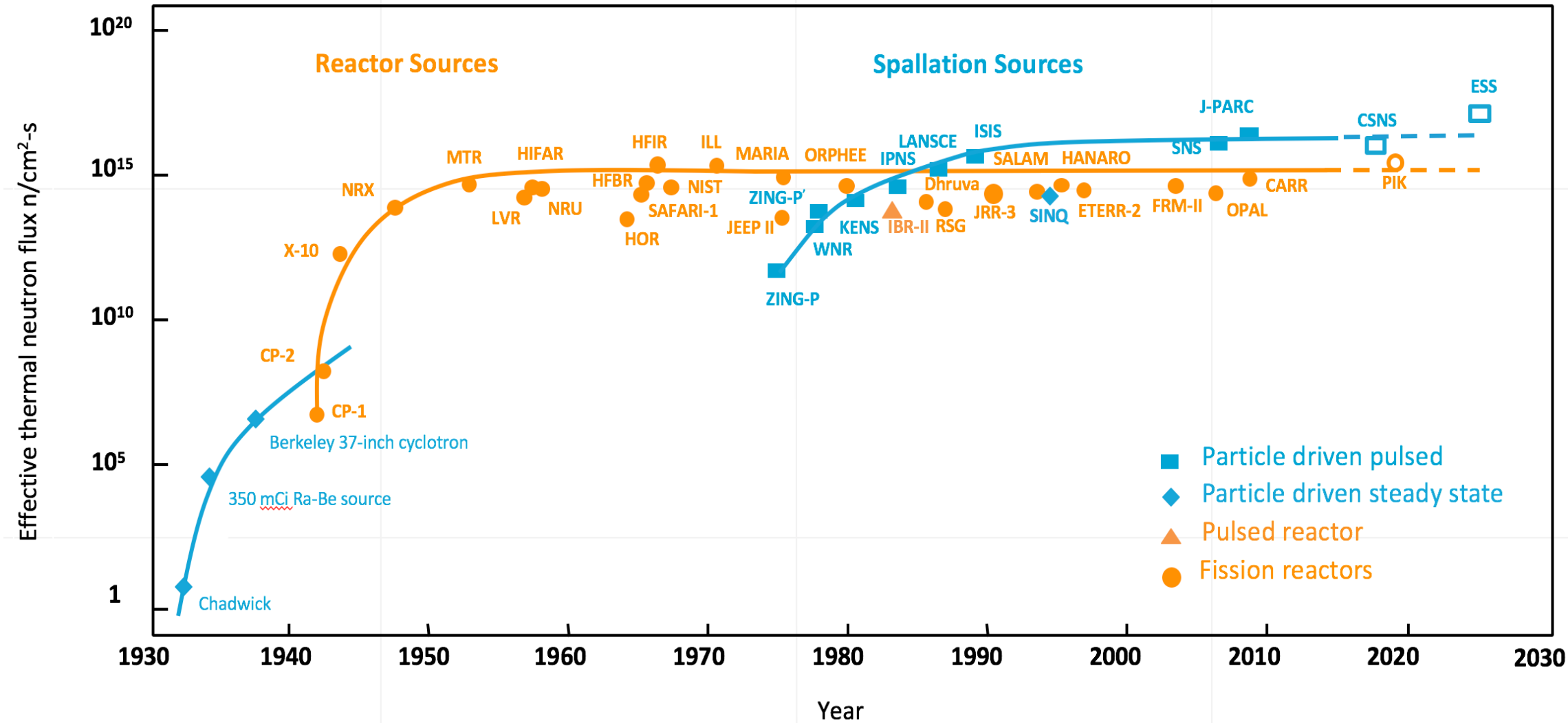
HOW NEUTRONS ARE EXTRACTED AND GUIDED



HOW NEUTRONS FEED THE INSTRUMENT SUITE



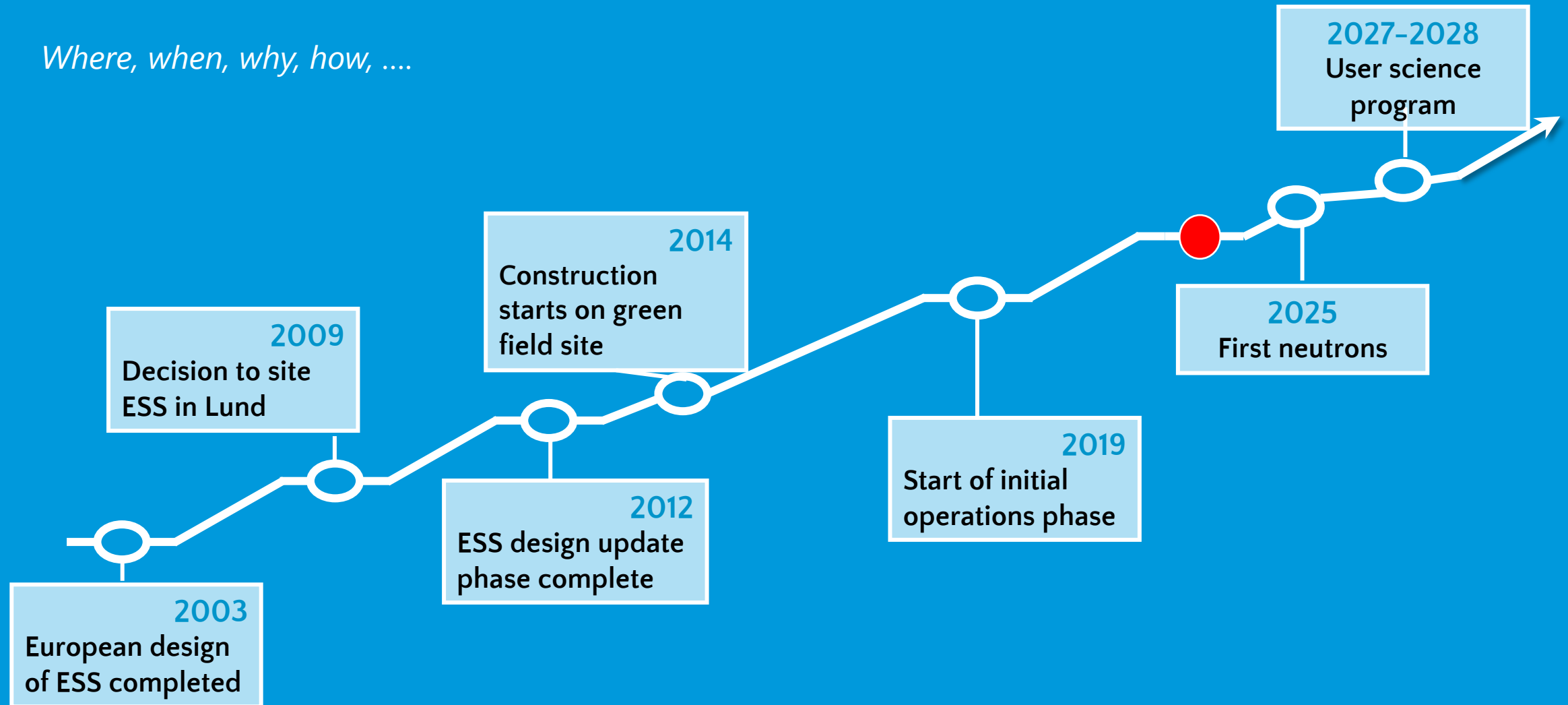
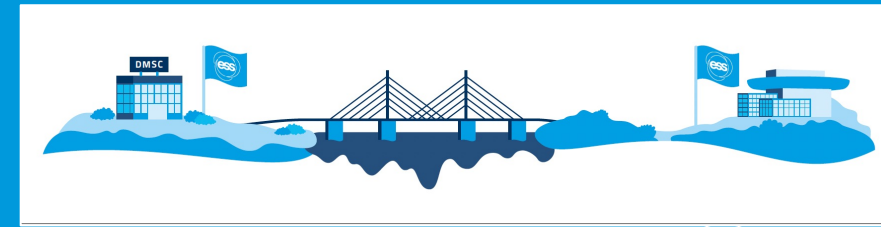
Neutron Source Brightness



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

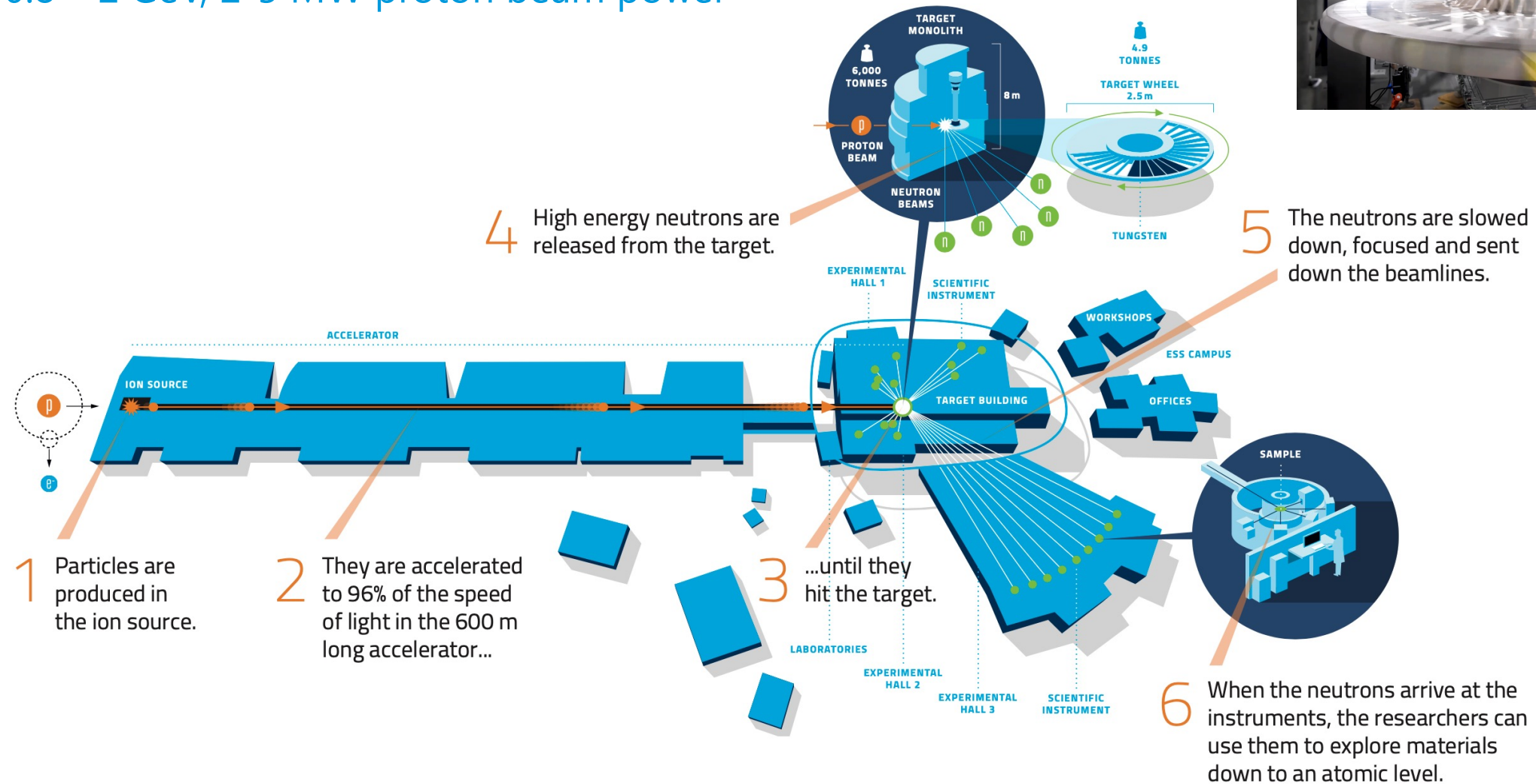
The European Spallation Source Project

Where, when, why, how,



Long-pulse driven by linear accelerator pulse length 2.86 milliseconds

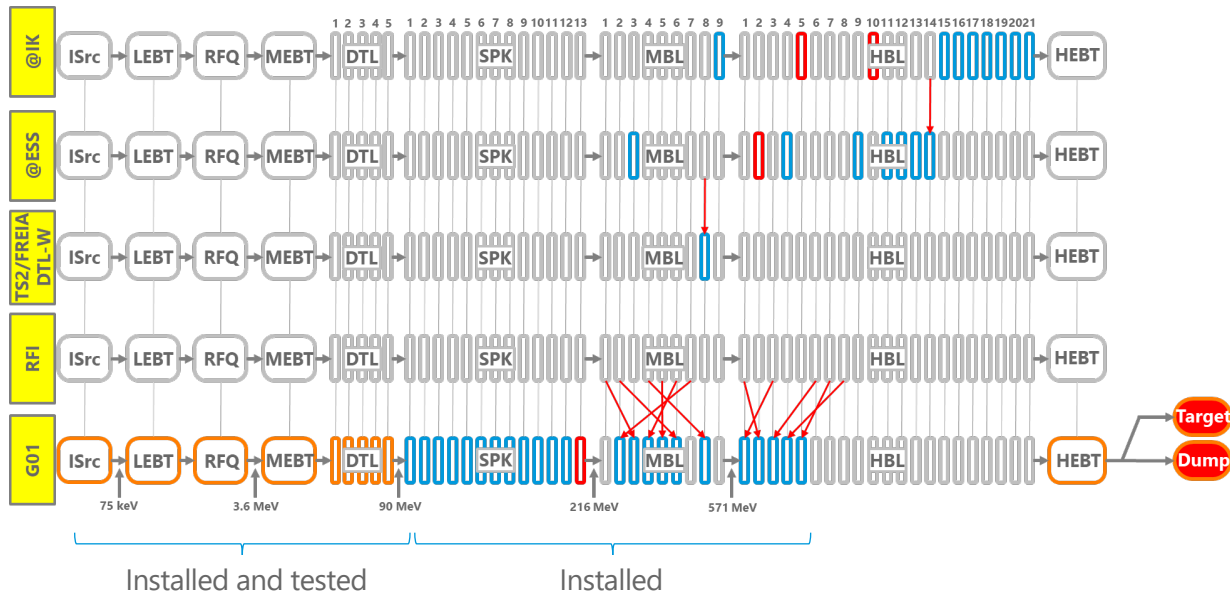
14 Hz, 0.8 – 2 GeV, 2-5 MW proton beam power



Accelerator

Installations progressing

- Almost a full compliment of CMs ready for BOD/BOT
- Gallery support systems are in good shape. All RF racks needed for BoT have been energized, now being soak tested.
- A2T region nearing completion



Week 5: The French state visit to the Accelerator tunnel celebrating the recent achievements leading up to beam operations at the end of 2024

Target

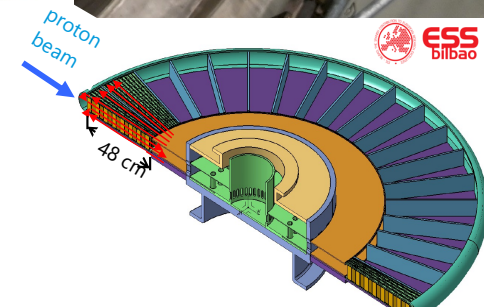
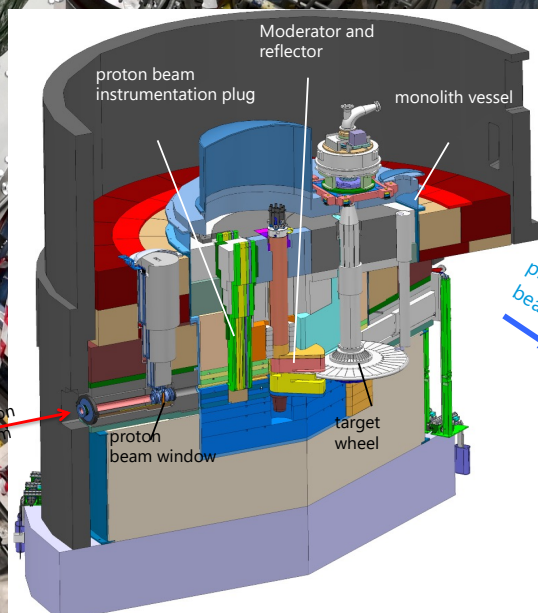
Monolith systems

The connection cell and monolith area has been a hive of activity.

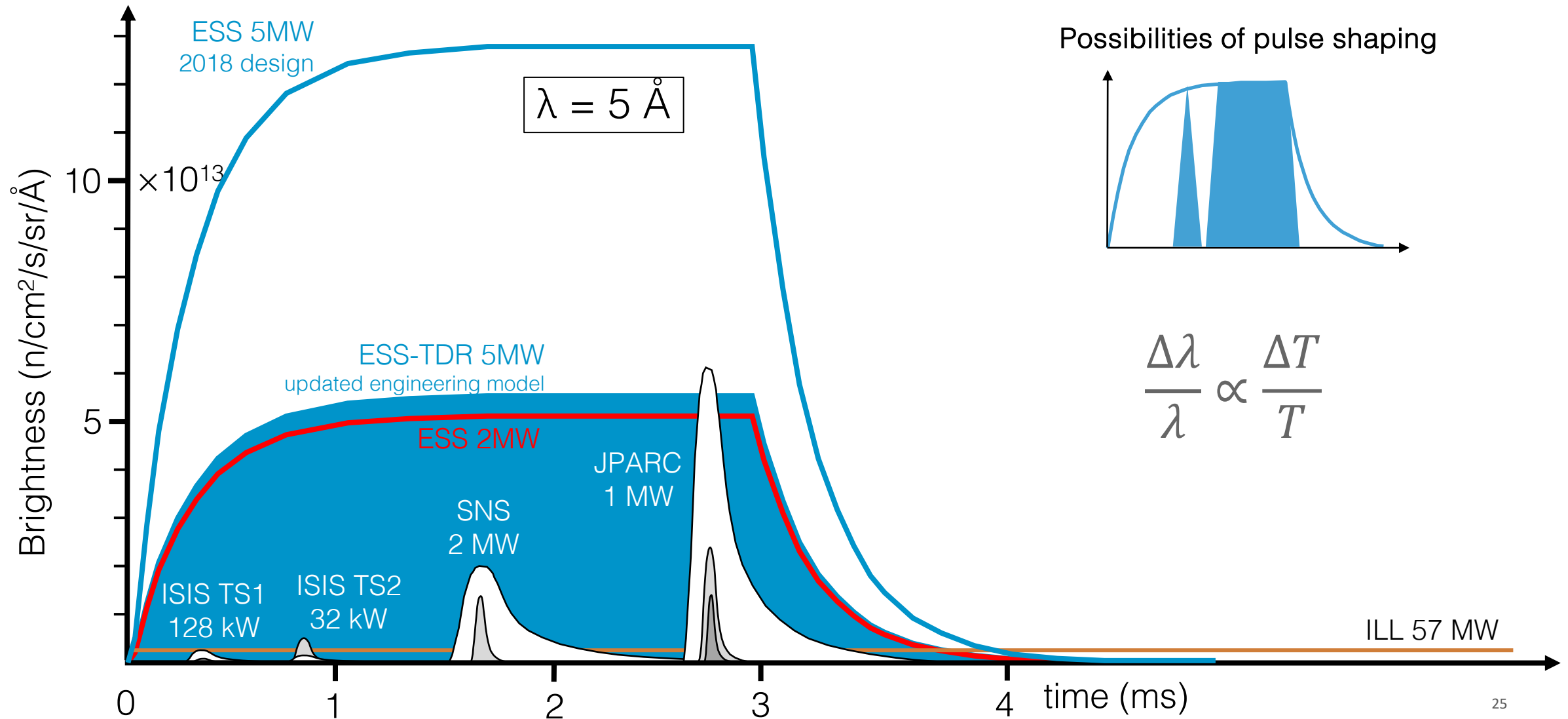
ess

Next step is to install the target wheel drive unit and continue with electrical/mechanical connections in the connection cell

Installation is rapidly turning to testing and commissioning leading up to TAR RBOT



Long-pulse Performance and Flexibility



Neutron Instruments

Andersen, K. H.; Argyriou, D. N.; Jackson, A. J. et al. The Instrument Suite of the European Spallation Source.

Nuclear Instruments and Methods in Physics Research Section A: **2020**, 957, 163402.

<https://doi.org/10.1016/j.nima.2020.163402>.

15 instruments + Test Beamline

Diffractometers (DREAM, MAGiC, HEIMDAL)

SANS (LoKI, SKADI)

Reflectometers (Estia, FREIA)

Imaging (ODIN)

Engineering Diffraction (BEER)

Macromolecular Crystallography (NMX)

Spectrometers (CSPEC, T-REX, BIFROST, MIRACLES, VESPA)

Novel detector technologies and geometries

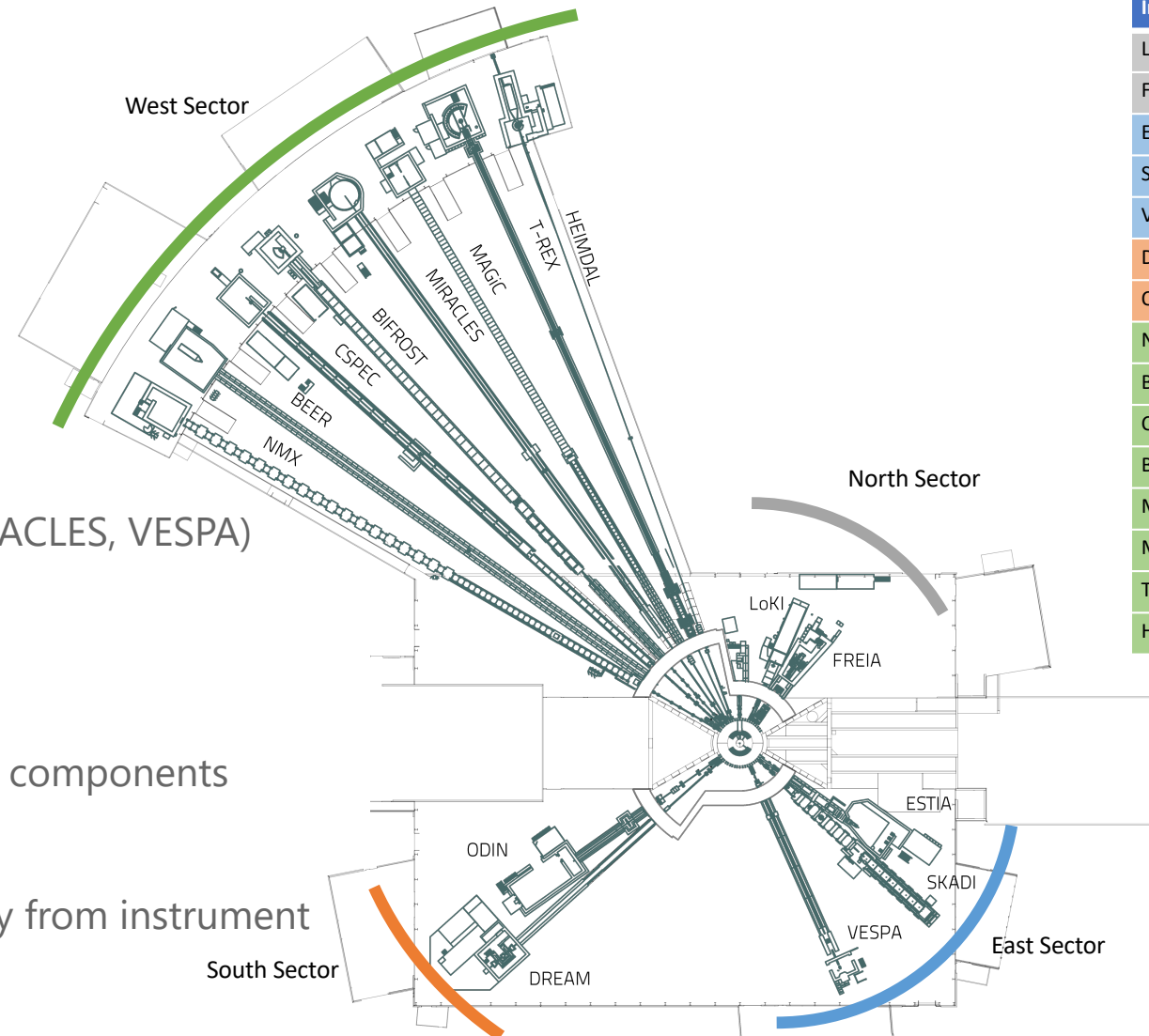
Complex pulse-shaping

Shared neutron bunker – common space for components

Common timing system for facility

Single controls infrastructure (EPICS)

Control and data recording running remotely from instrument



Instrument	Beamport
LoKI	N7
FREIA	N5
Estia	E2
SKADI	E3
VESPA	E7
DREAM	S3
ODIN	S2
NMX	W1
BEER	W2
CSPEC	W3
BIFROST	W4
MIRACLES	W5
MAGIC	W6
T-REX	W7
HEIMDAL	W8

Neutron Instruments for soft/bio science

Andersen, K. H.; Argyriou, D. N.; Jackson, A. J. et al. The Instrument Suite of the European Spallation Source.

Nuclear Instruments and Methods in Physics Research Section A: **2020**, 957, 163402.

<https://doi.org/10.1016/j.nima.2020.163402>.



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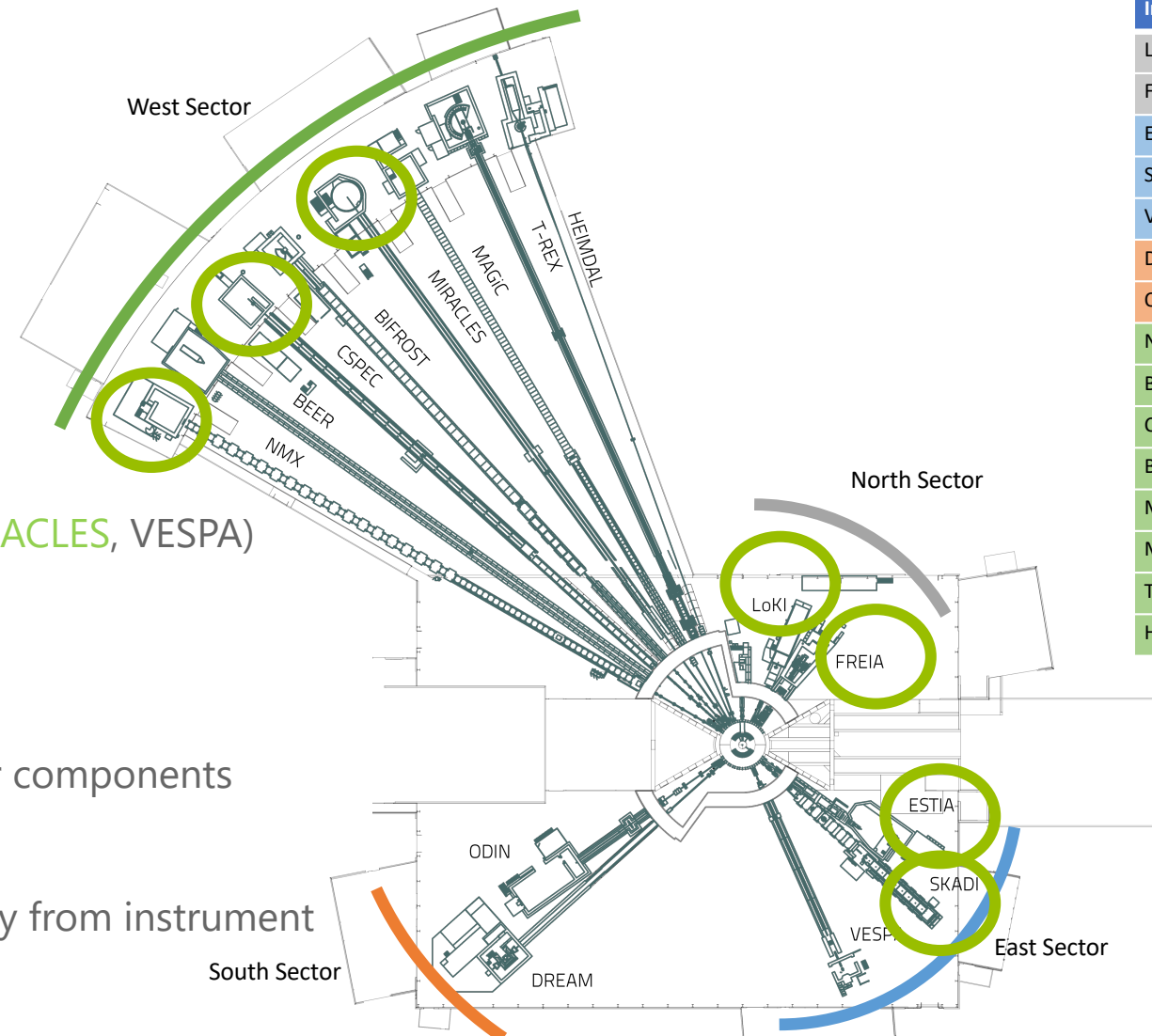
Complex pulse-shaping

Shared neutron bunker – common space for components

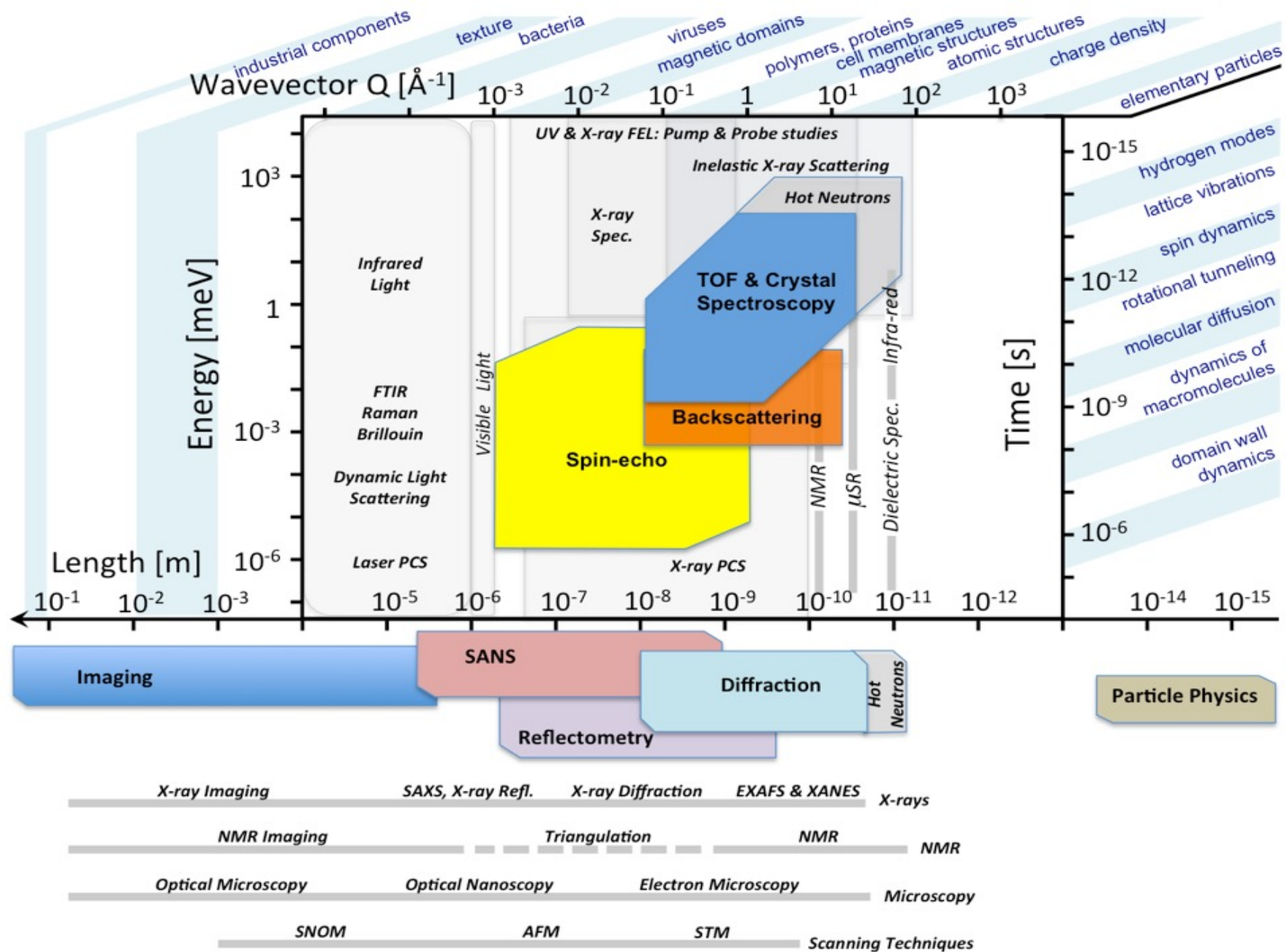
Common timing system for facility

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Instrument	Beamport
LoKI	N7
FREIA	N5
Estia	E2
SKADI	E3
VESPA	E7
DREAM	S3
ODIN	S2
NMX	W1
BEER	W2
CSPEC	W3
BIFROST	W4
MIRACLES	W5
MAGIC	W6
T-REX	W7
HEIMDAL	W8

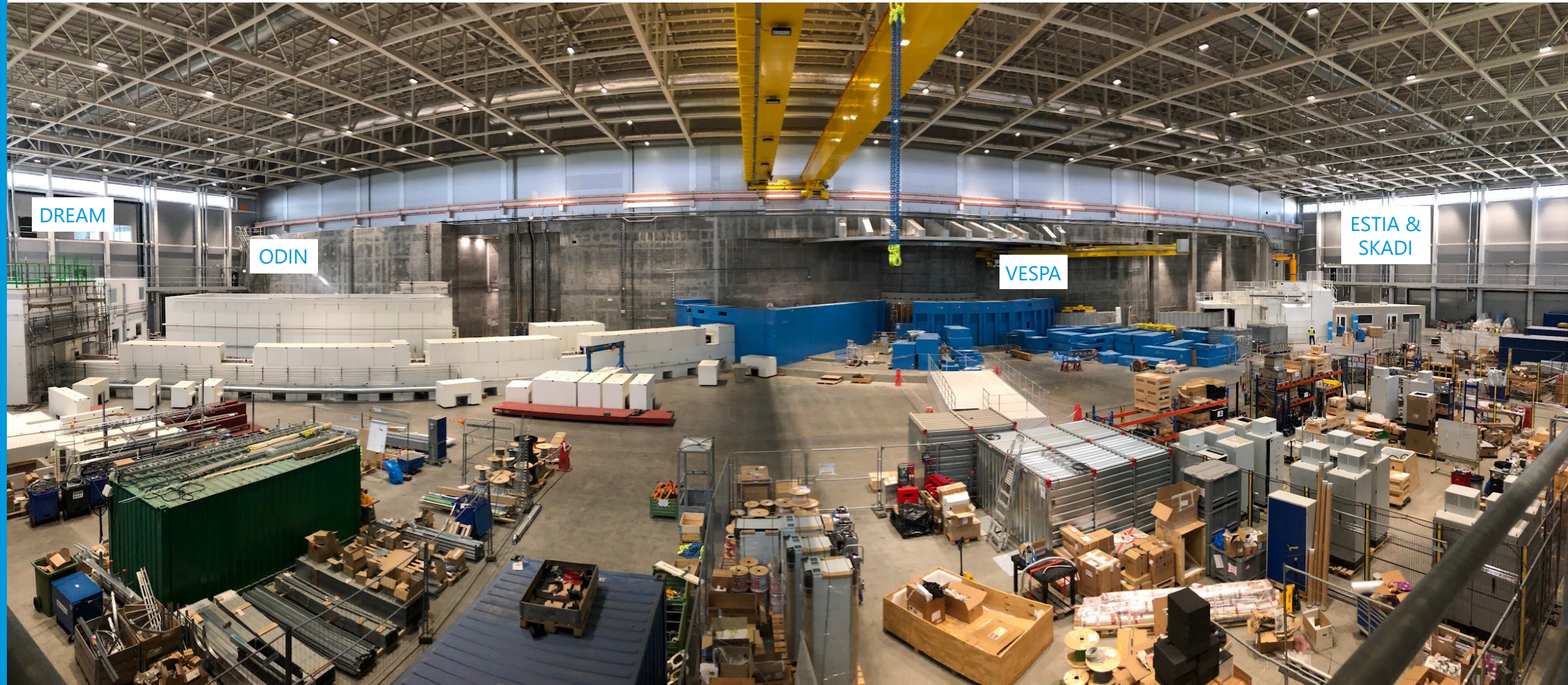


Instruments are optimised to access the desired length and time scales.

Neutron Instruments at ESS



D01 side



Neutron Instruments at ESS



D03 side



LOKI &
FREIA

TBL

NMX, BEER, CSPEC,
BIFROST, MIRACLES,
MAGIC, T-REX, HEIMDAL
(towards long hall)

Neutron Instruments at ESS



The current focus is getting LOKI, BIFROST, ODIN, DREAM, NMX and TBL ready for BOT

In bunker components for later instruments are also being prioritized to limit future bunker work

Cave installations for ESTIA, SKADI and MAGIC ongoing

Week 6: The in-bunker neutron guide section for LOKI is being assembled and aligned in an area next to the cave.

ODIN: Imaging instrument



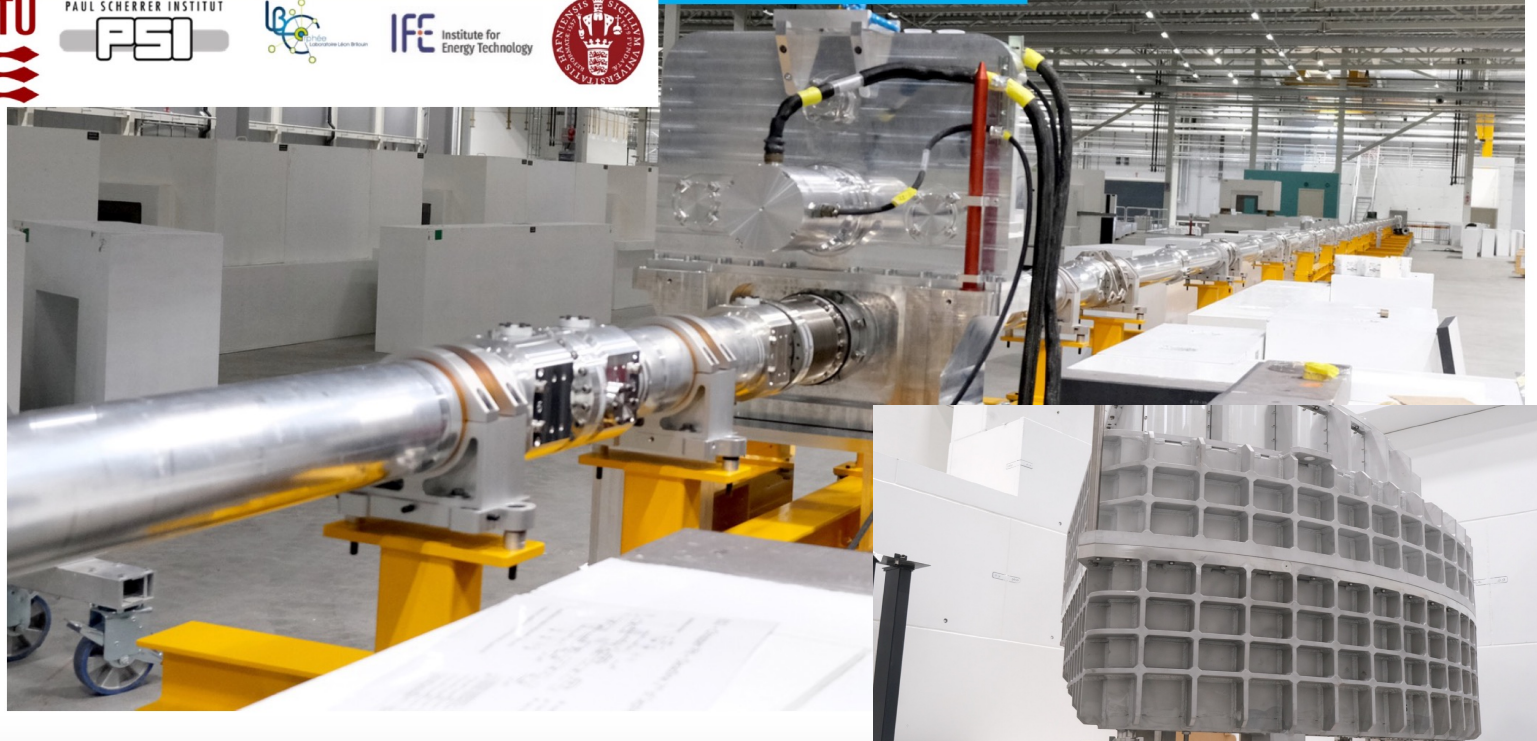
DREAM: Diffraction resolved by energy and angle resolved measurements



BIFROST: Extreme environment cold spectrometer

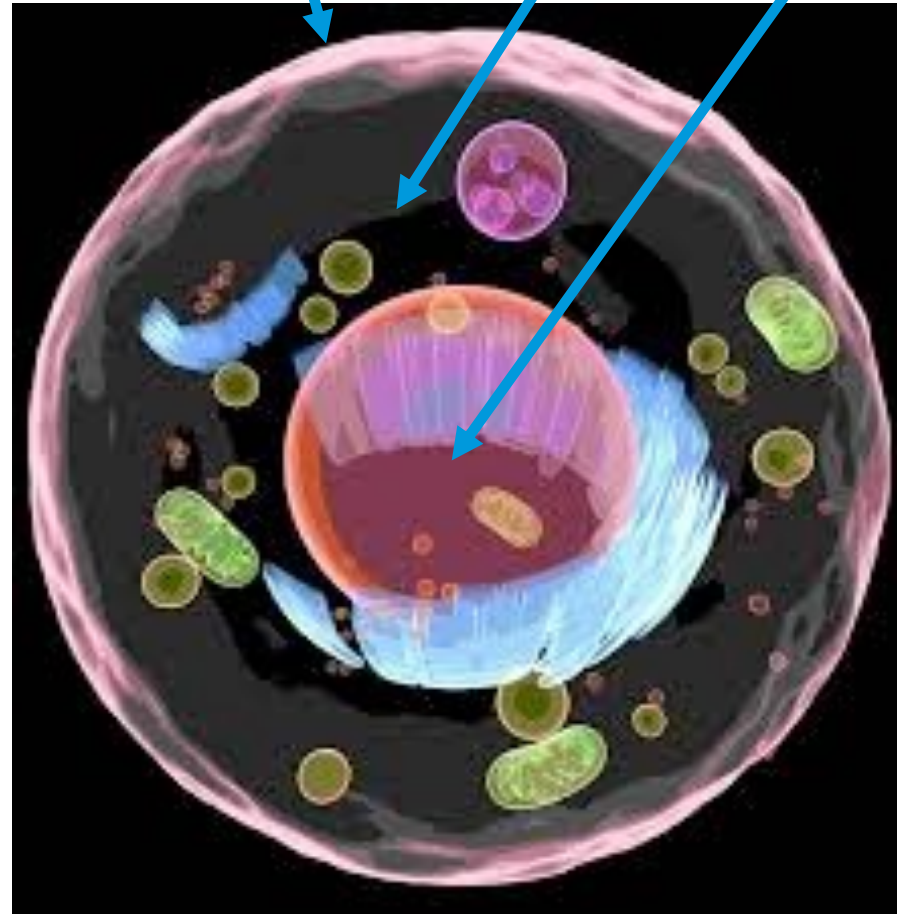
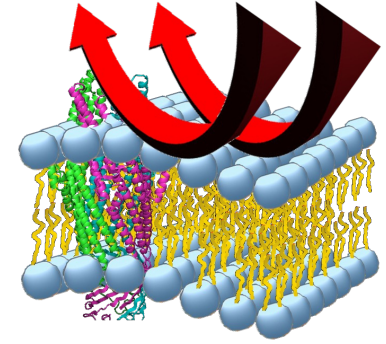


materials and bio-science



Mechanisms at cell membranes

Cells are the smallest living units of an organism
All cells have three things in common, no matter what type of cell they are:
a cell membrane, cytoplasm and DNA



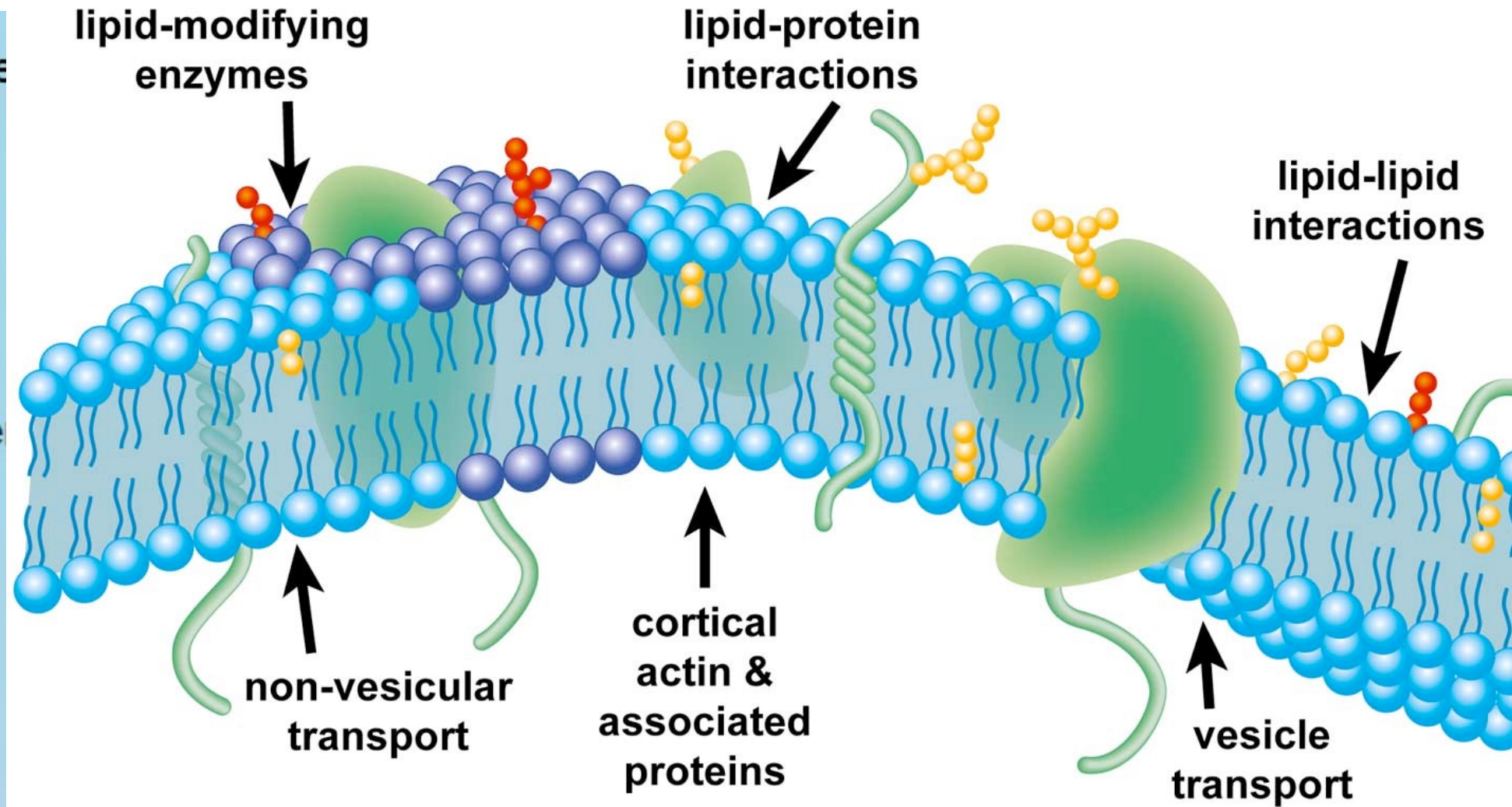
Mechanisms at cell membranes

Complex assembly
of lipids & proteins

Exhibit short range
but not long range
order

High degree of lateral
heterogeneity

Transversely
asymmetric



Lipid scaffold composed by a large variety of lipid species and levels of chain unsaturation, often difficult to synthesise chemically. Because of the complexity model membrane systems are used for fundamental studies.

Why so much interest for membranes and lipid bilayers

Total surface of membranes covers an area of 30,000 m² in our body

Function of membrane proteins : dependent on membrane composition, lipid-protein interaction, lipid mediated protein-protein interaction

Pharmacological interest : Drug transport through membranes (dependent on physico-chemical membrane properties), anti-microbial peptides

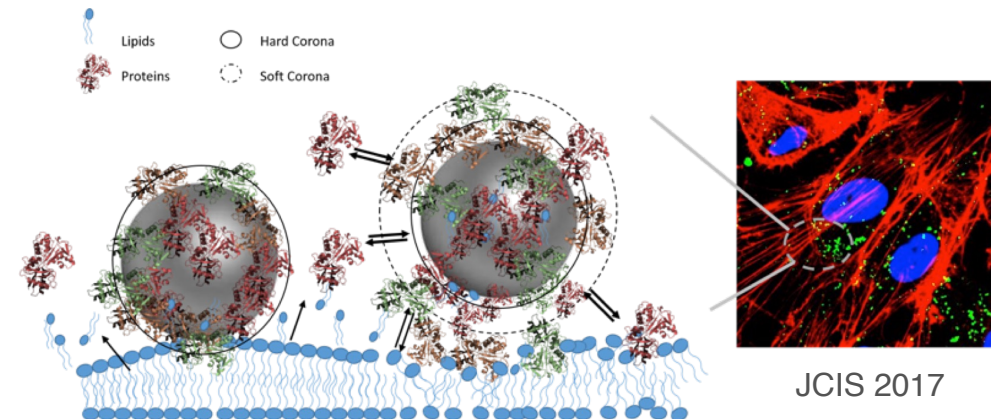
Membranes may play a *direct* role in **signal transduction**

Diseases associated with changes in lipid composition (diabetes, schizophrenia, Tay-Sachs syndrome, Alzheimer, Parkinson)

Cell adhesion

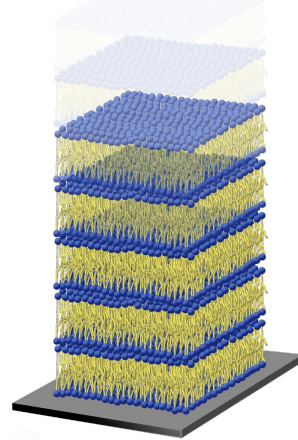
Nano-biotechnology applications (biosensors, bio-coatings)

and **fascinating chemistry and physics!**

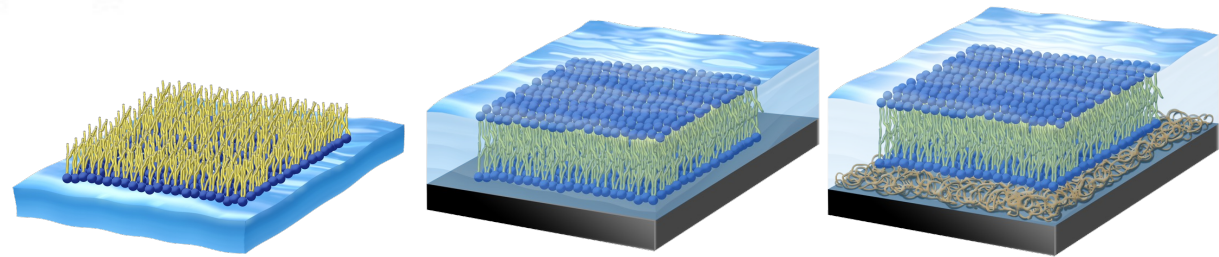
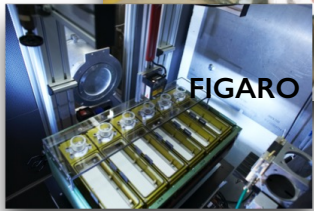
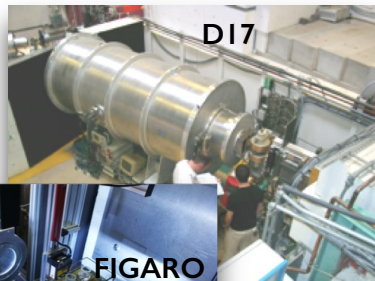


JCIS 2017

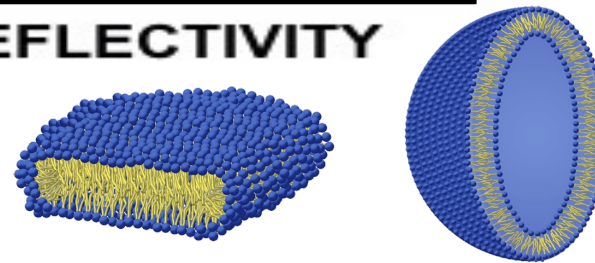
Model membranes and scattering techniques



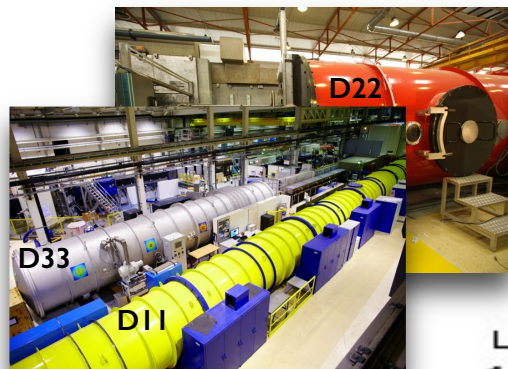
DIFFRACTION



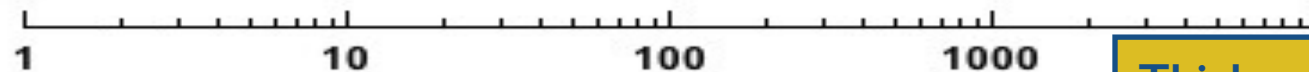
REFLECTIVITY



SANS

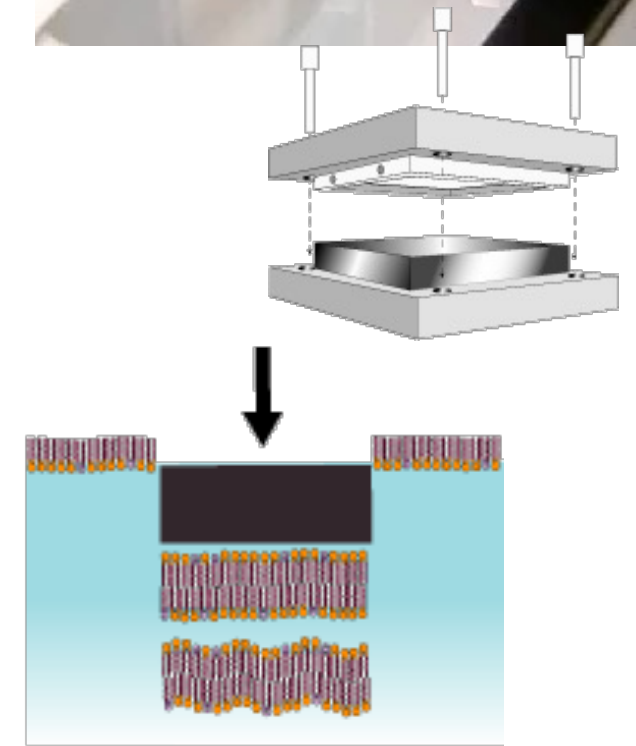
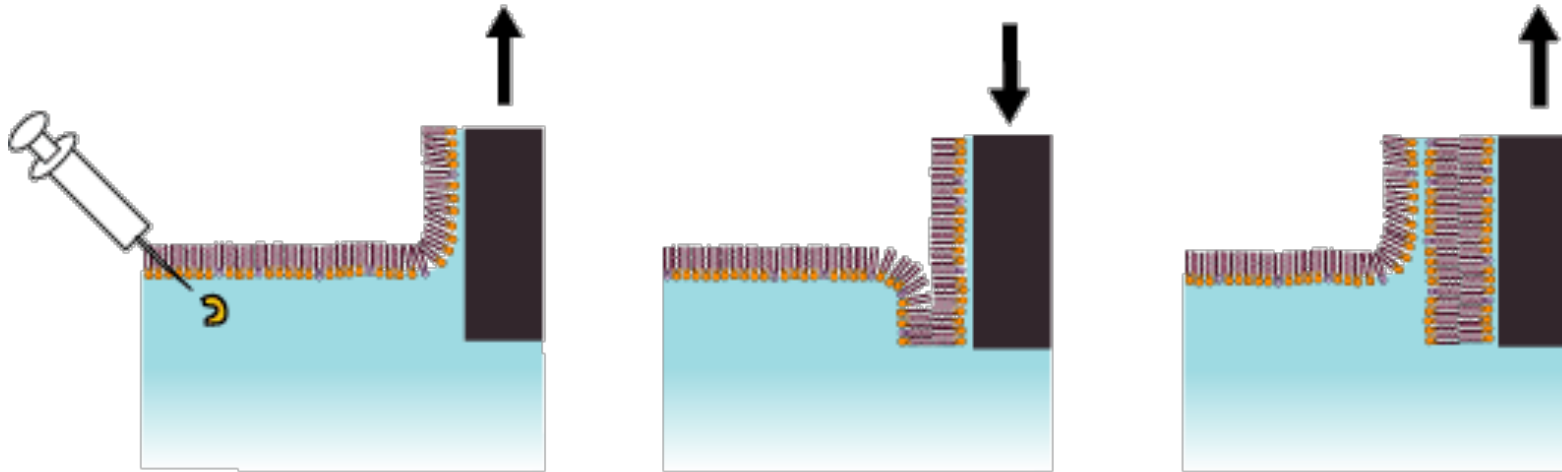
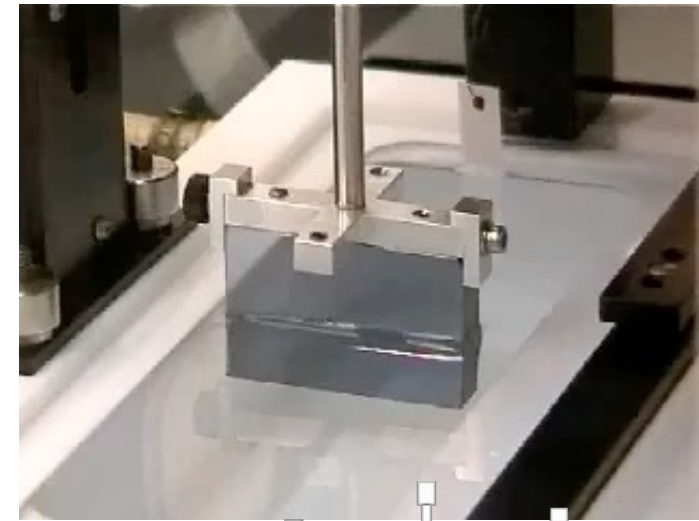


D11



Thickness Å

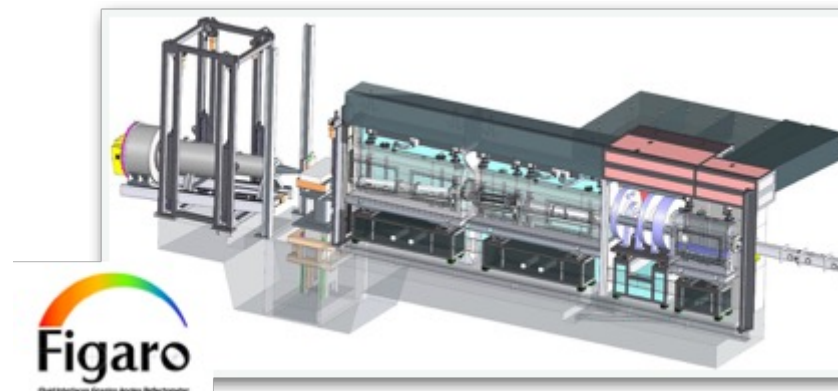
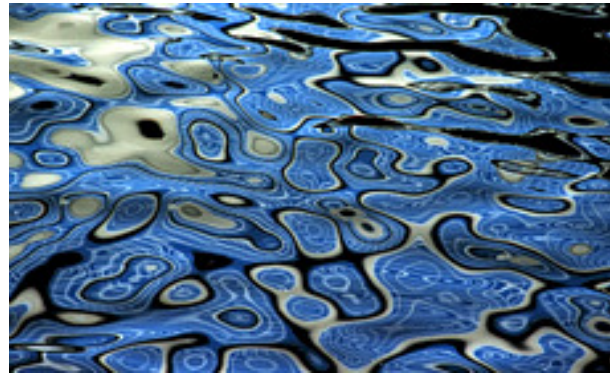
Floating bilayers prepared by Langmuir-Blodgett Langmuir-Schaefer techniques



EPJB 1999

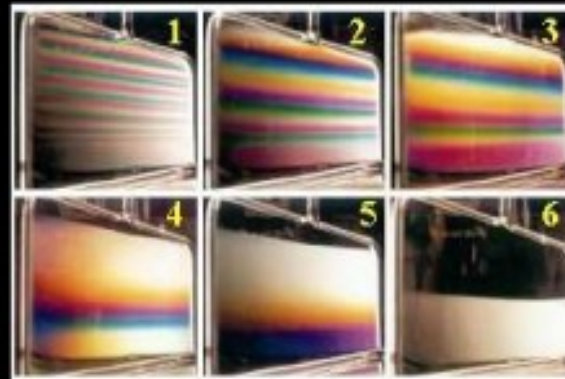
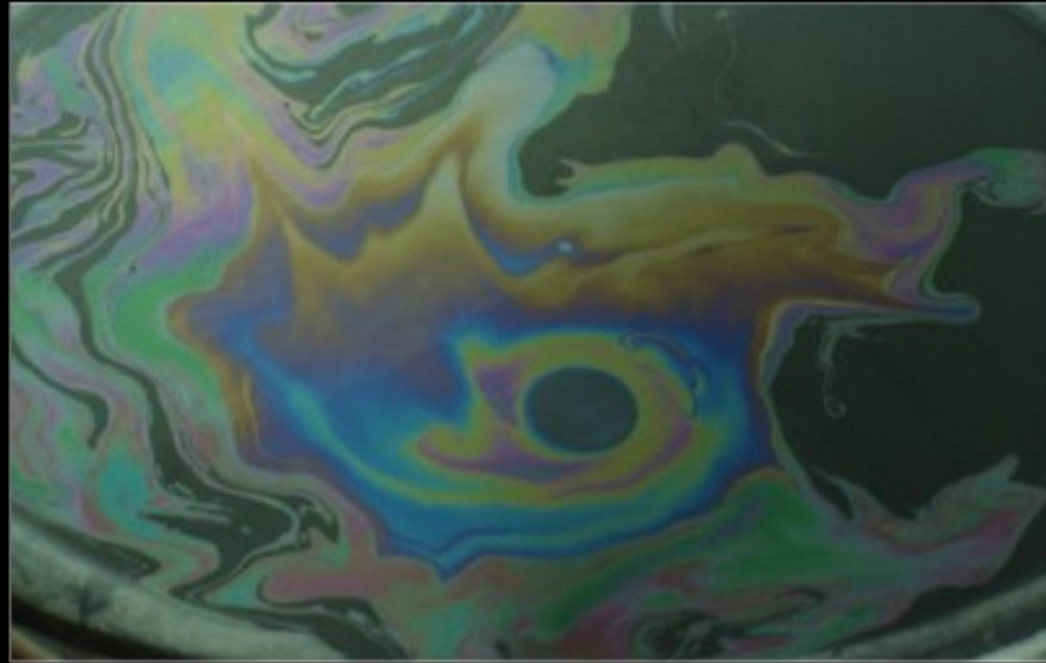
Looking at Surfaces with Neutron Reflectometry = Skipping Stones

“Skipping stones is the act of throwing a (usually) flat stone into a body of water in a manner such that the stone ricochets off the top layer of water, appearing to “skip” along the water’s surface.”



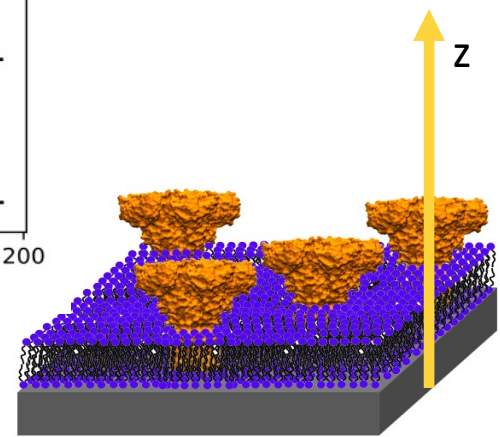
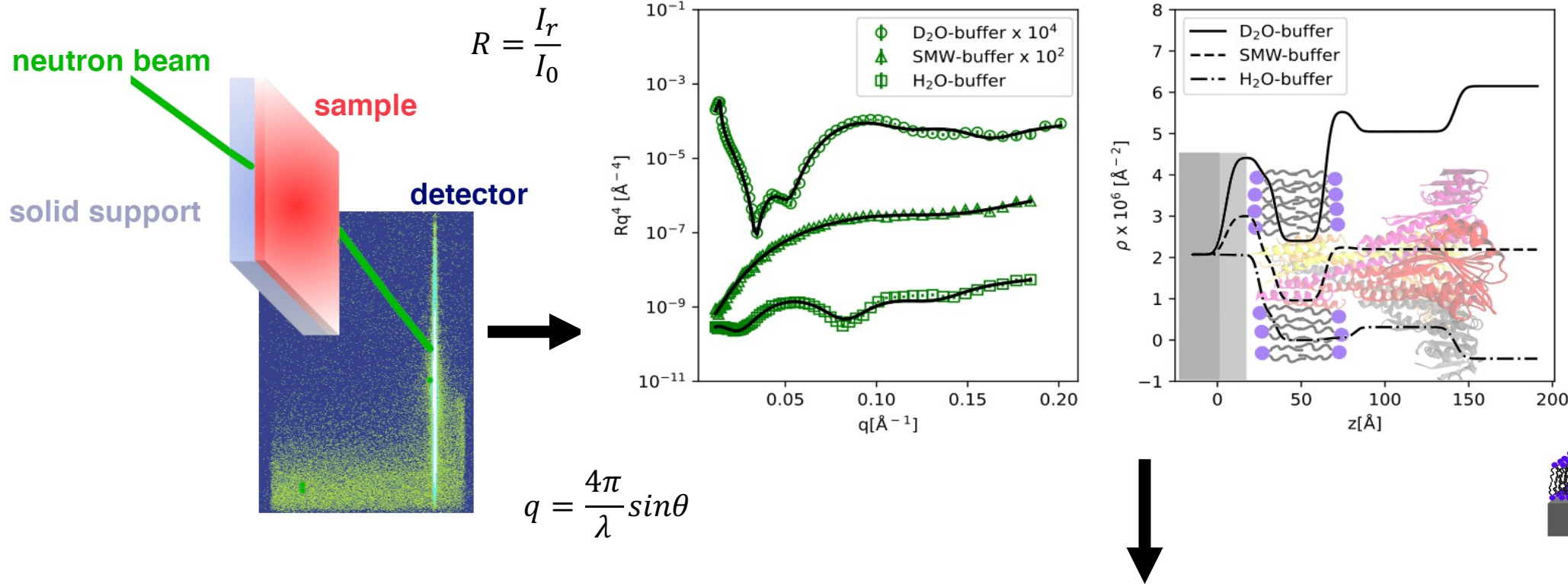
Two well known examples of light interference from thin films

Oxidized oil film on water

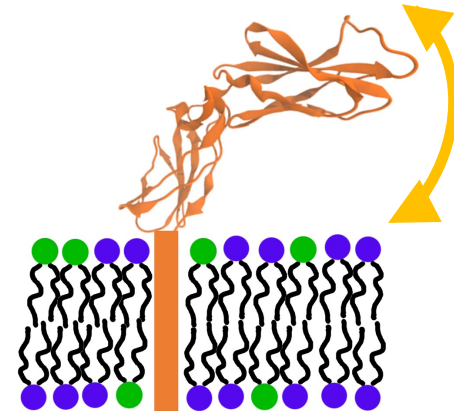


Drainage of soap film. Note the absence of reflection
in the top half of the film in 6.

Neutron Reflectometry and biological membranes



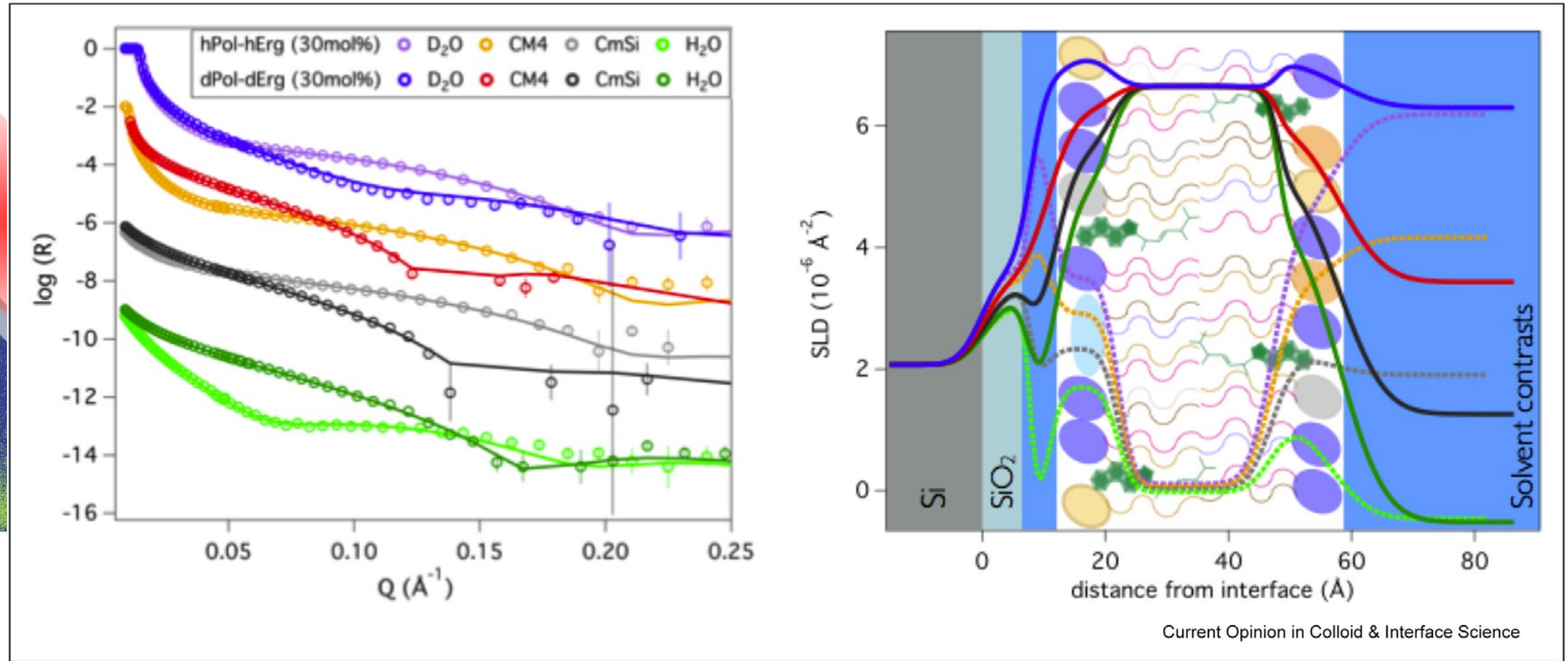
- Structural information along the direction (z) perpendicular to the membrane surface.
- relevant direction for investigating protein structure in a membrane and interactions at membrane surface



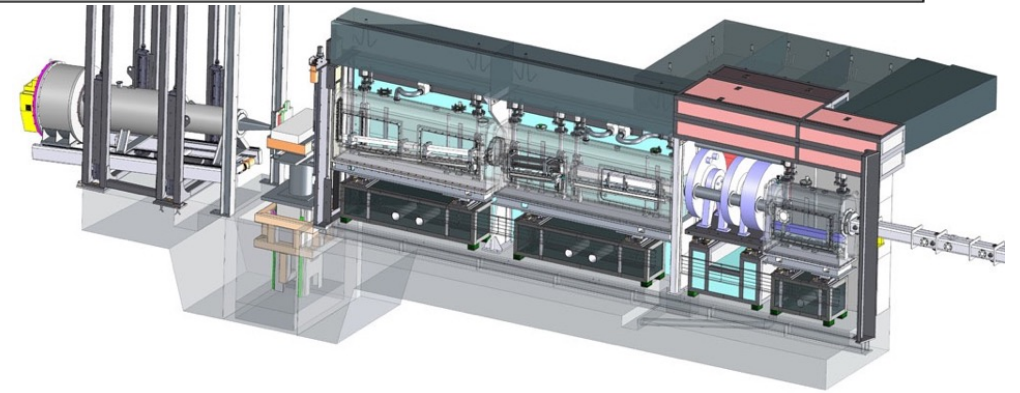
Specular reflectivity measurements

neutron beam

solid support

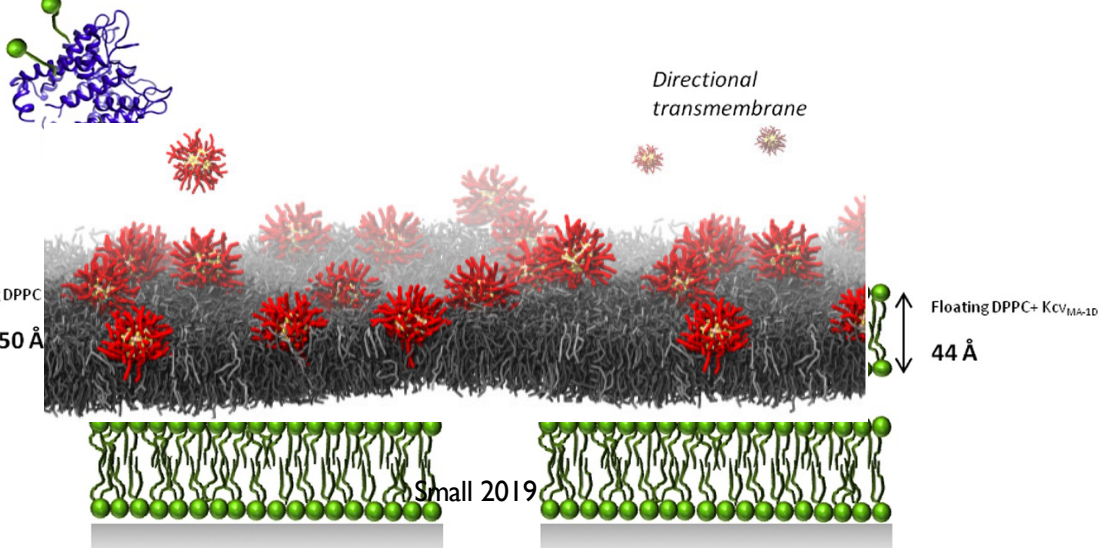


- Isotopic substitution and multiple contrast measurements used to improve resolution

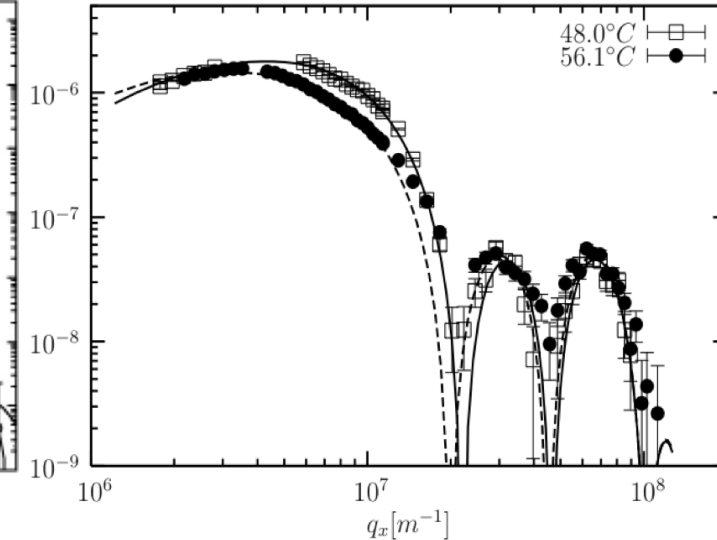
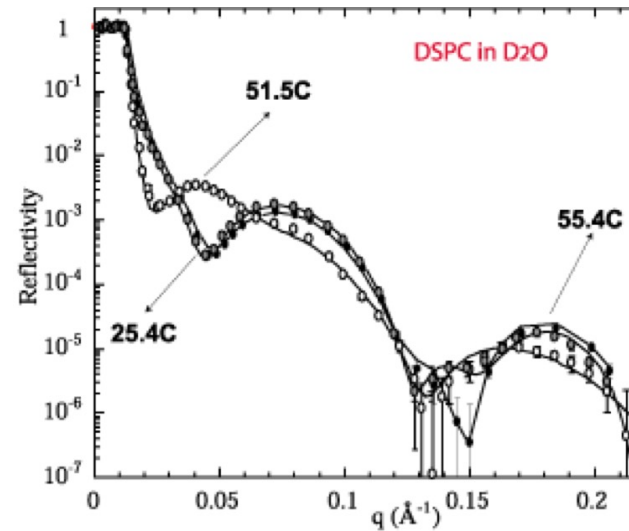
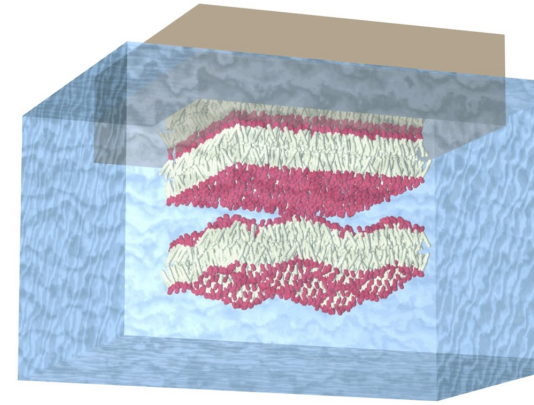


Neutron and synchrotron radiation studies of structure and fluctuations of floating bilayers

- Effect of temperature (giant swelling)
- Effect of charges
- Effect of AC current
- Interaction with gene delivery complexes
- Effect of domain forming molecules/asymmetry
- Lipid flip-flop
- Interaction with nano particles
- Transmembrane insertion



Mukhina et al., J. Chem. Phys. Lett. 2019



$$\langle z(q_{\parallel}) z(q_{\parallel}) \rangle = \frac{k_B T}{A + \gamma q_{\parallel}^2 + \kappa q_{\parallel}^4}$$

EPJB 1999
 EPL 2001
 Langmuir 2001
 Langmuir 2003
 Langmuir 2005
 Langmuir 2005
 PNAS 2005
 EPJE 2006
 Soft Matter 2007
 Langmuir 2009
 BBA 2012
 PNAS 2012
 Langmuir 2012
 EPJE 2013
 Soft Matter 2015
 PRL 2016
 BBA 2018
 Small 2019
 J Chem Phys Lett 2019
 J. Coll. Int. Sci. 2021



Contents lists available at [SciVerse ScienceDirect](http://www.sciencedirect.com)

Biochimica et Biophysica Acta

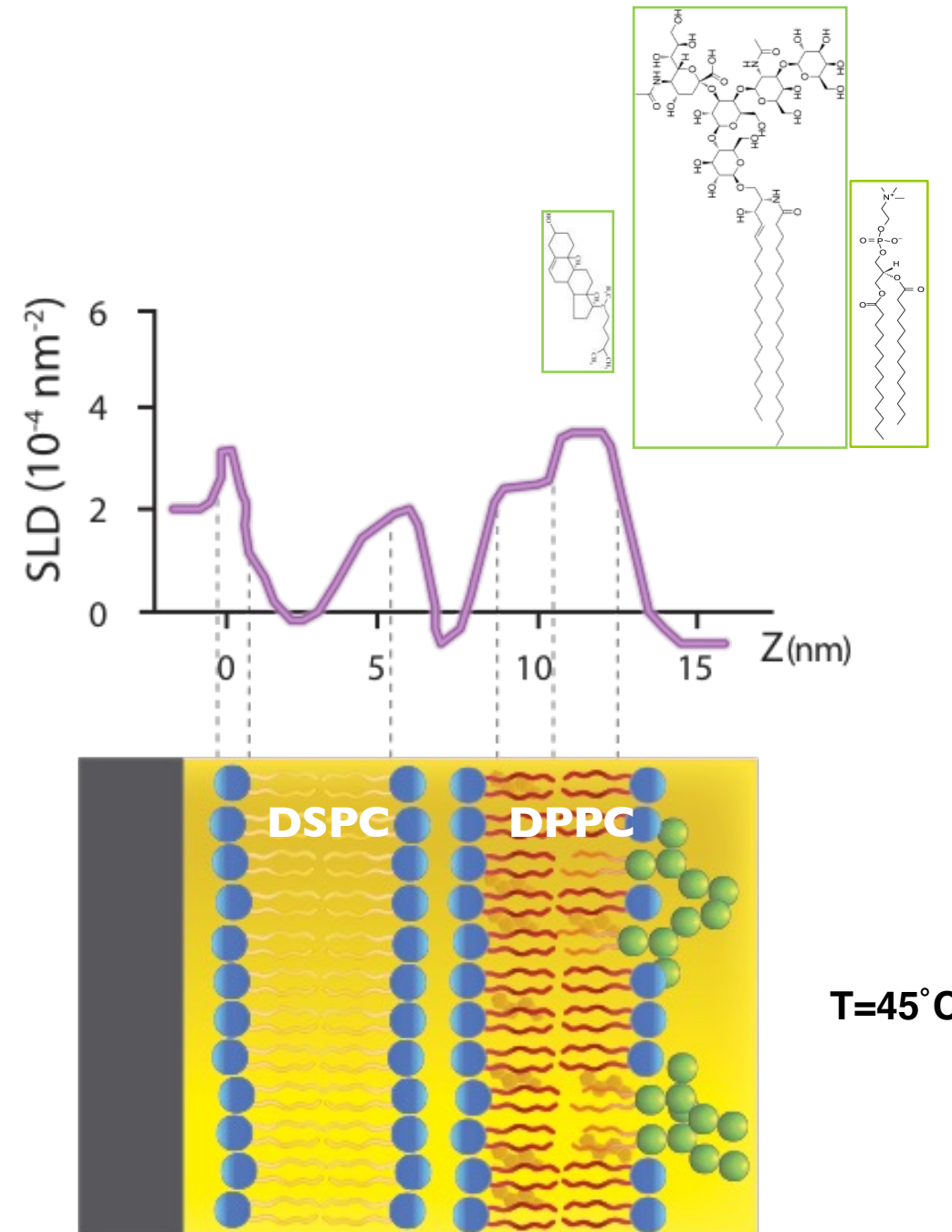
journal homepage: www.elsevier.com/locate/bbamem



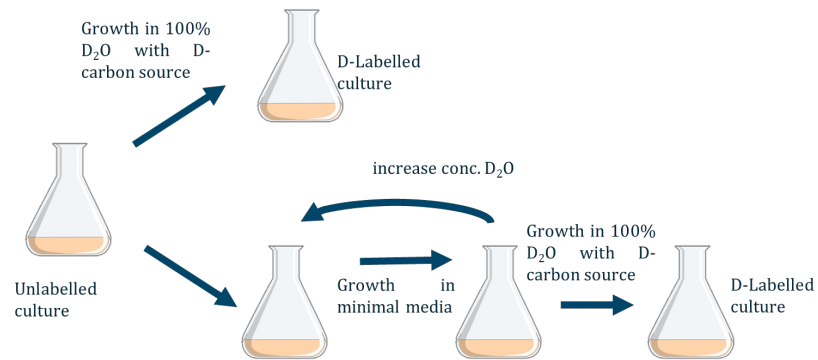
Ganglioside GM1 forces the redistribution of cholesterol in a biomimetic membrane

V. Rondelli ^a, G. Fragneto ^b, S. Motta ^a, E. Del Favero ^a, P. Brocca ^a, S. Sonnino ^a, L. Cantù ^{a,*}

- The presence of ganglioside **forces asymmetry** in cholesterol distribution, opposite to what happens for a ganglioside-free membrane where a full symmetrisation of cholesterol distribution is observed.
- A **preferential asymmetric distribution of ganglioside and cholesterol** is attained revealing that a **true coupling** between the two molecules occurs.



Moving towards complexity: deuterated (and non) lipid extraction and purification: better mimic of real membranes, easier deuteration

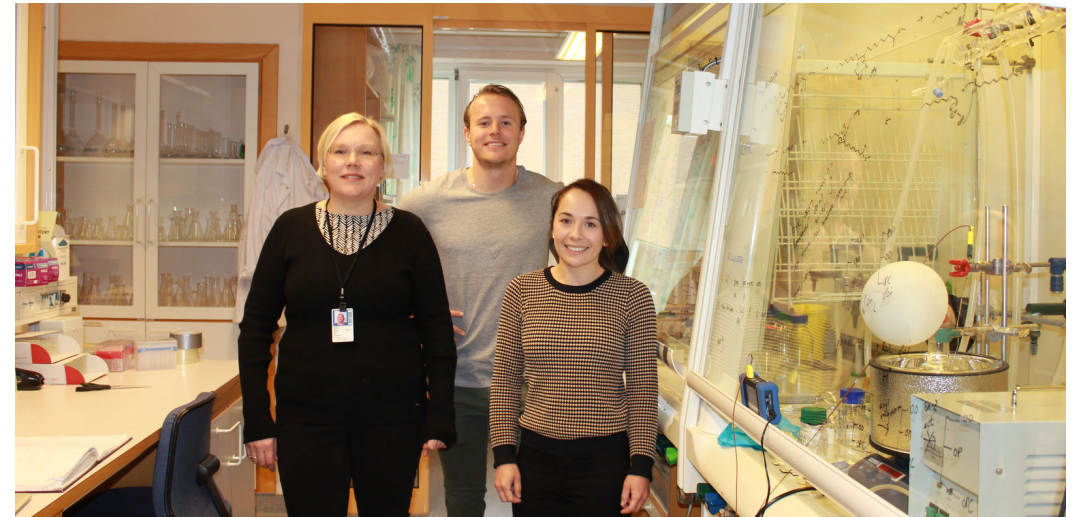


www.ill.eu/L-Lab



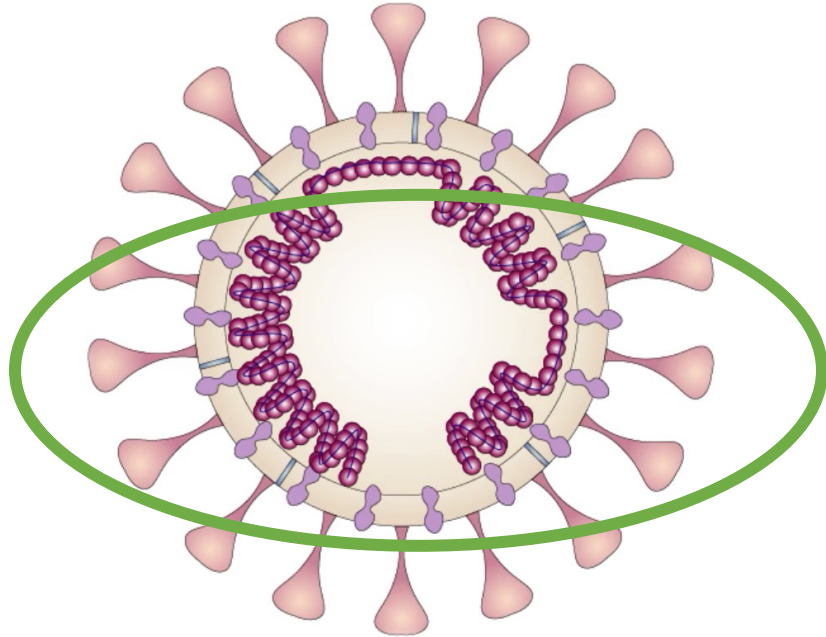
Yeast lipid production at DEMAX

The Deuteration and
Macromolecular Crystallisation
(DEMAX) platform supports life
science and soft matter research
users of neutron instruments.



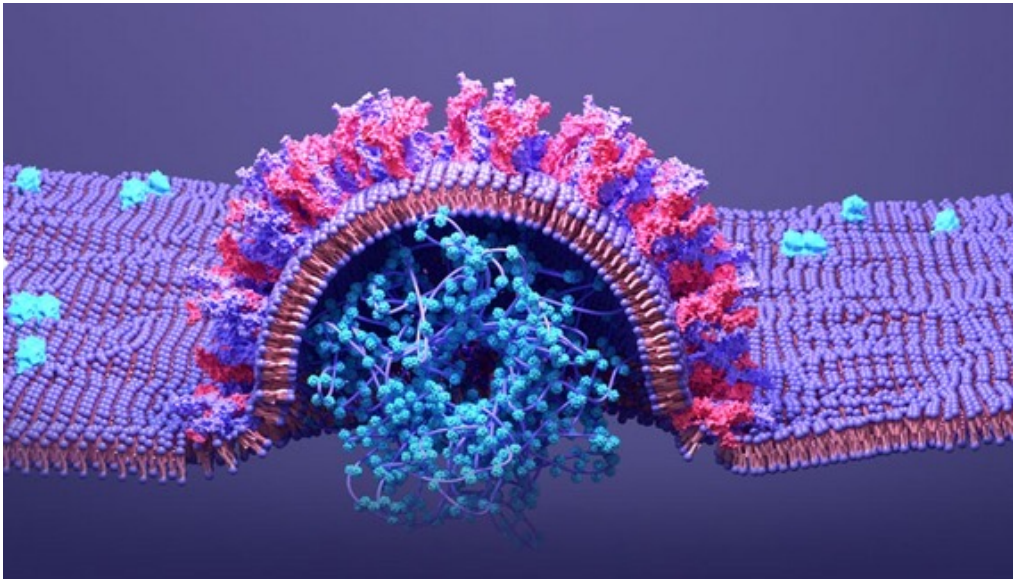
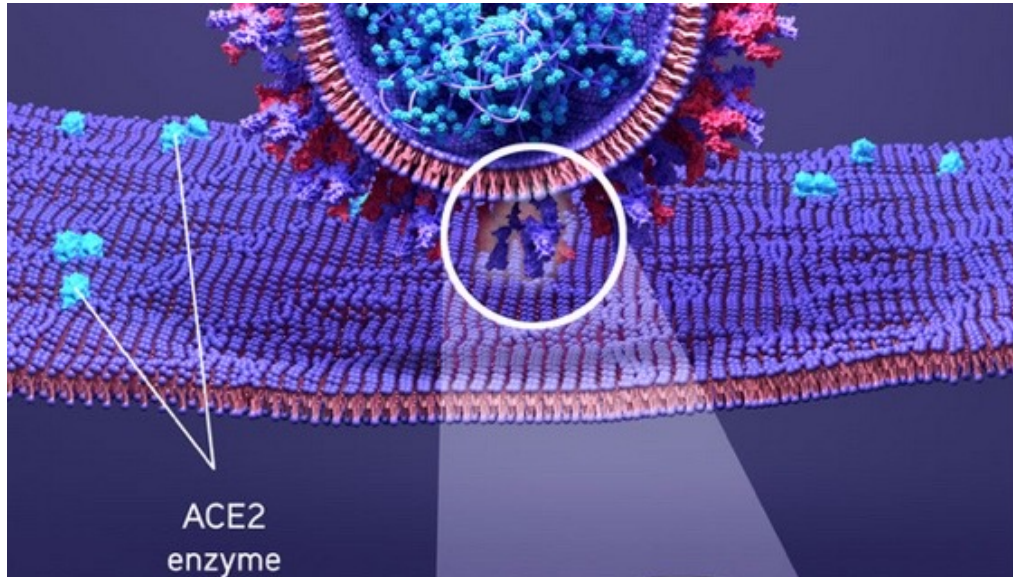
SARS-CoV-2 VIRAL FUSION MECHANISM

- Interaction of spike protein with ACE2 receptor containing membranes
- Interaction of spike fusion peptides with biological model membranes



*Schematic of the
membrane fusion
process*

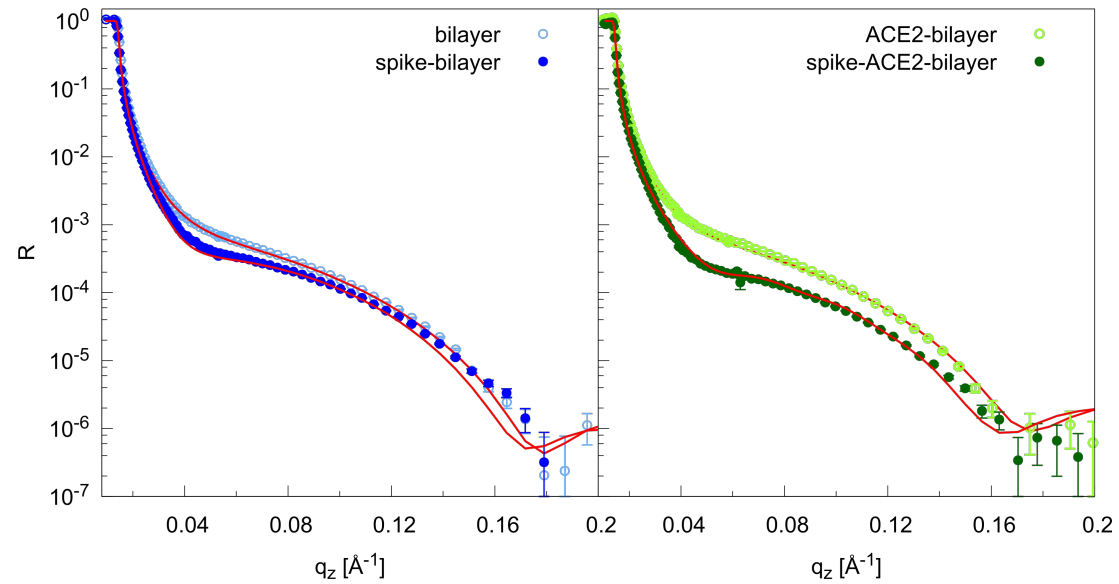
Viral infection and spike proteins



- SARS-CoV 2 is an enveloped virus
- The viral envelope contains a large fraction of glycoproteins, also known as Spike proteins
- The Spike proteins play a fundamental role in favouring the fusion between the virus envelope and the host cell
- Attachment of the virus to the host cell membrane can occur via binding of the Spike proteins to the ACE2 receptor

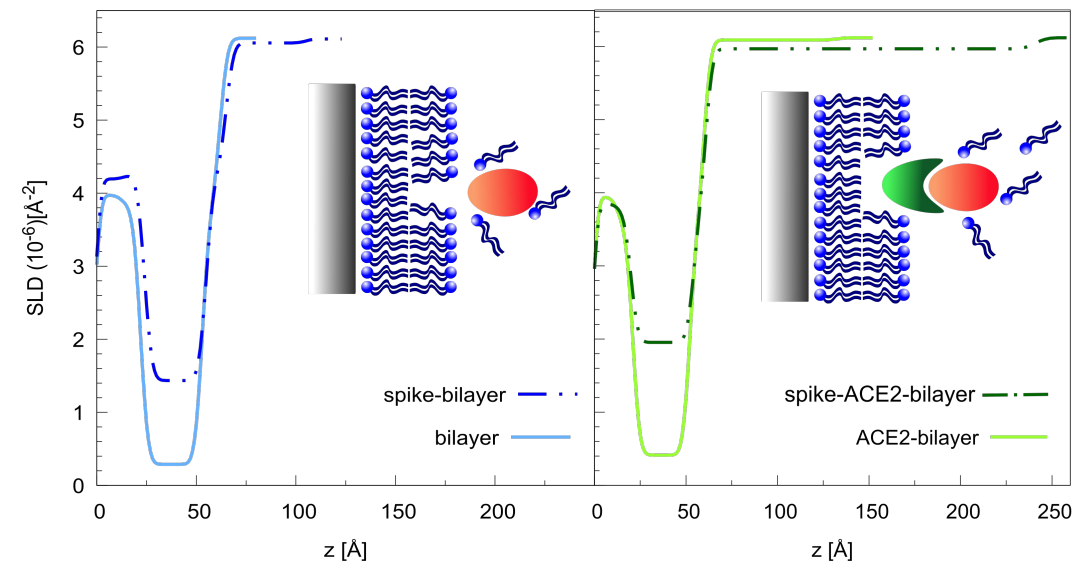
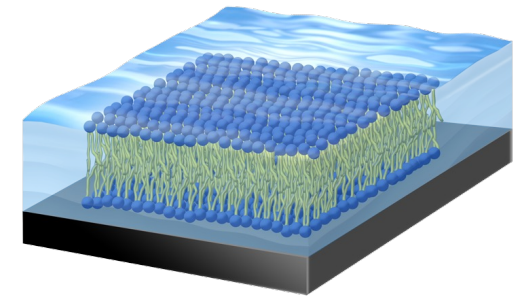
What is the interaction of the Spike proteins with the lipid membrane of the host cell?

Interaction of spike protein with ACE2 receptor containing membranes



spike protein
from IBS

*Bilayers formed from natural lipids in
presence and absence of ACE-2*



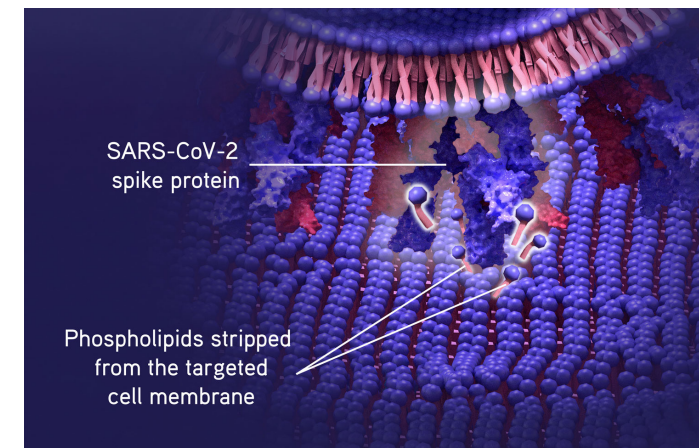
scientific reports

OPEN

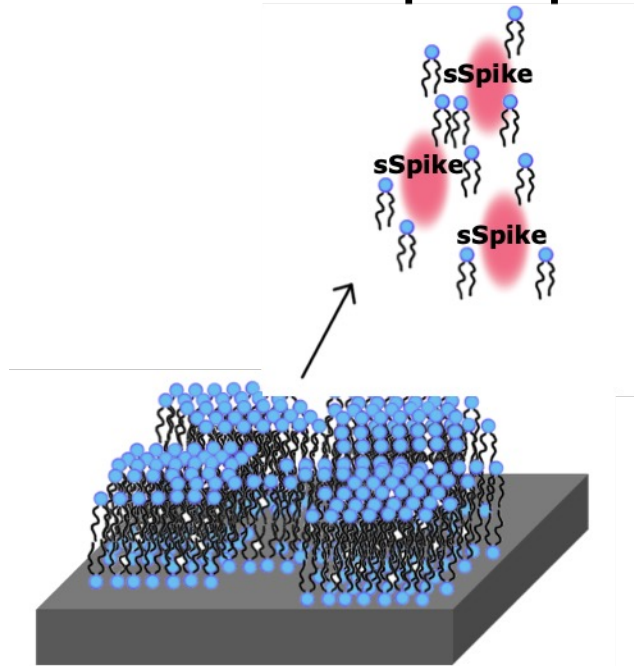
**Lipid bilayer degradation
induced by SARS-CoV-2 spike
protein as revealed by neutron
reflectometry**

Alessandra Luchini^{1,5}, Samantha Micciulla^{1,5}, Giacomo Corucci², Krishna Chaitanya Batchu²,
Andreas Santamaria³, Valerie Laux², Taimir Darwish¹, Robert A. Russell³, Michel Thepaut⁴,
Isabelle Bailly⁴, Franck Fieschi⁴ & Giovanna Fraaije^{1,5}

48



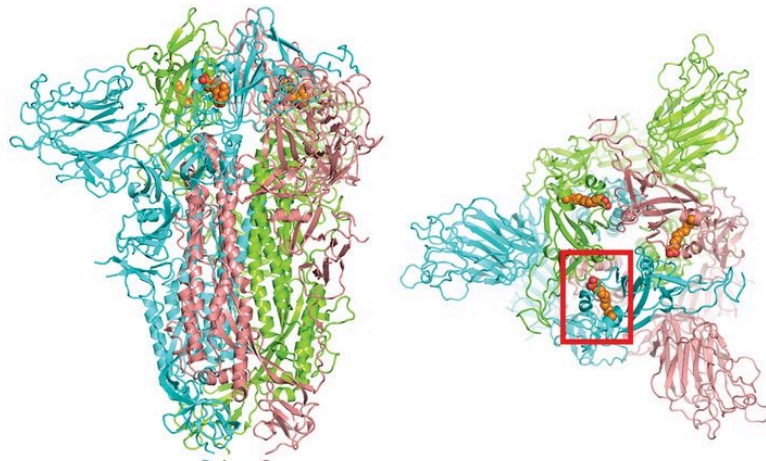
Interaction of spike protein with ACE2 receptor containing membranes



spike protein
from IBS

The spike protein interacts with model membranes either in presence or absence of ACE-2 receptor in the membrane.

In both cases it promotes lipid removal although to a bigger extent in presence of receptor where a very diluted layer of spike on the surface of the membrane can be resolved at Å level



Lipid pockets in the extramembrane domain of sSpike

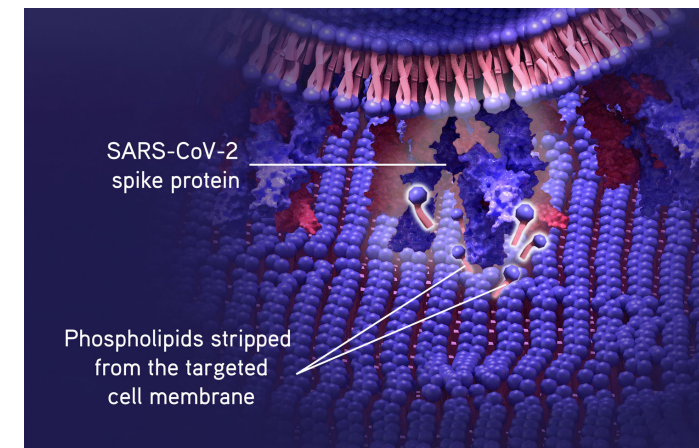
scientific reports

OPEN

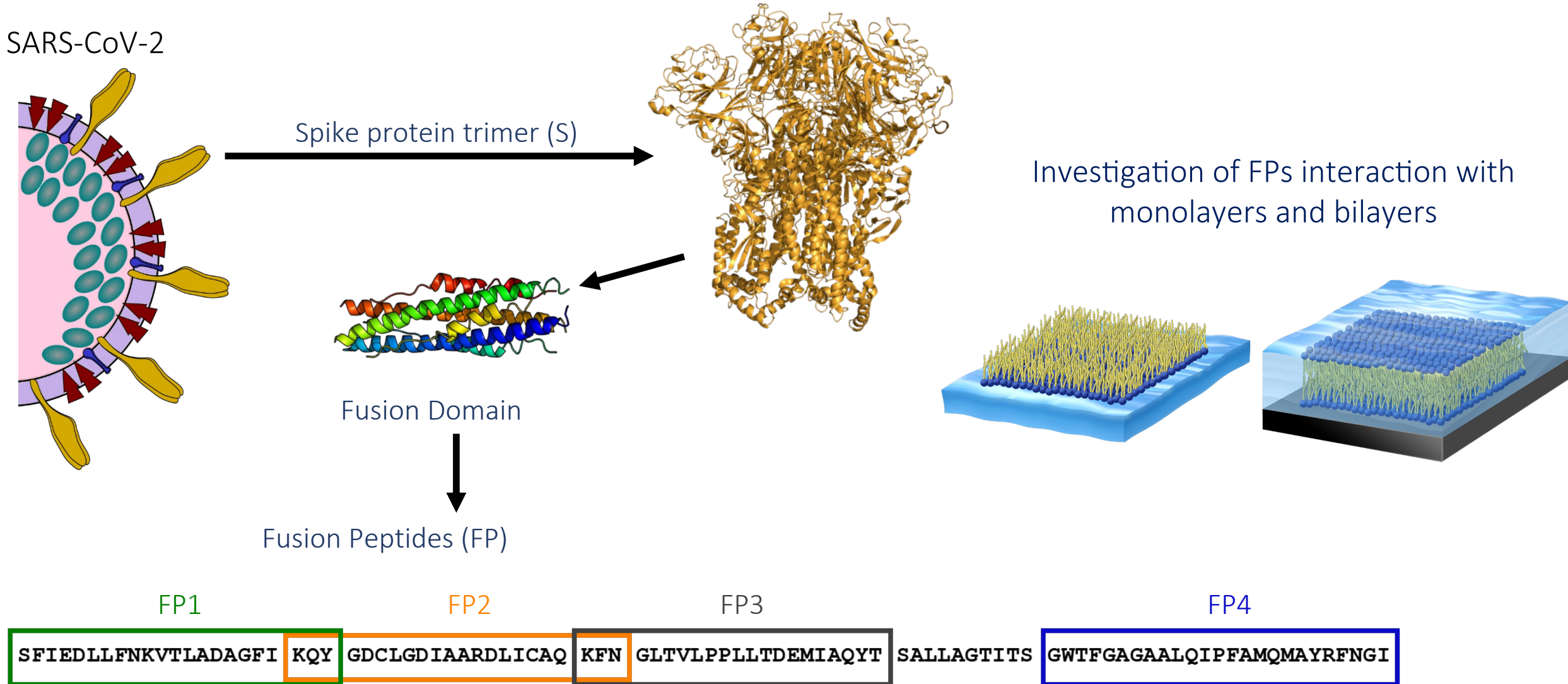
Lipid bilayer degradation induced by SARS-CoV-2 spike protein as revealed by neutron reflectometry

Alessandra Luchini^{1,5}, Samantha Micciulla^{2,5}, Giacomo Corucci³, Krishna Chaitanya Batchu², Andreas Santamaria², Valerie Laux², Taimir Darwish¹, Robert A. Russell³, Michel Thepaut¹, Isabelle Bailly⁴, Franck Fieschi⁴ & Giovanna Fraaije^{2,5}

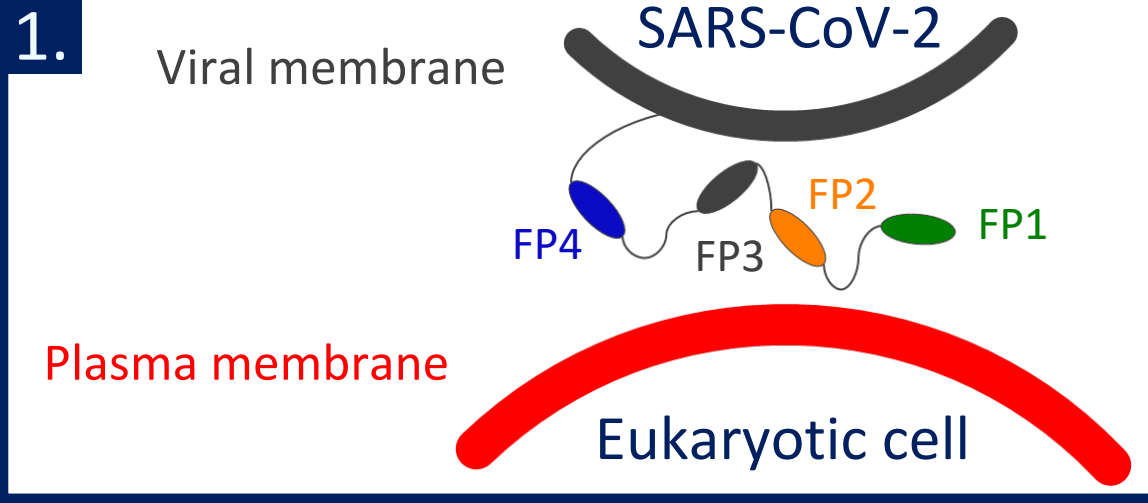
49



Interaction of spike protein fusion peptides with model membranes

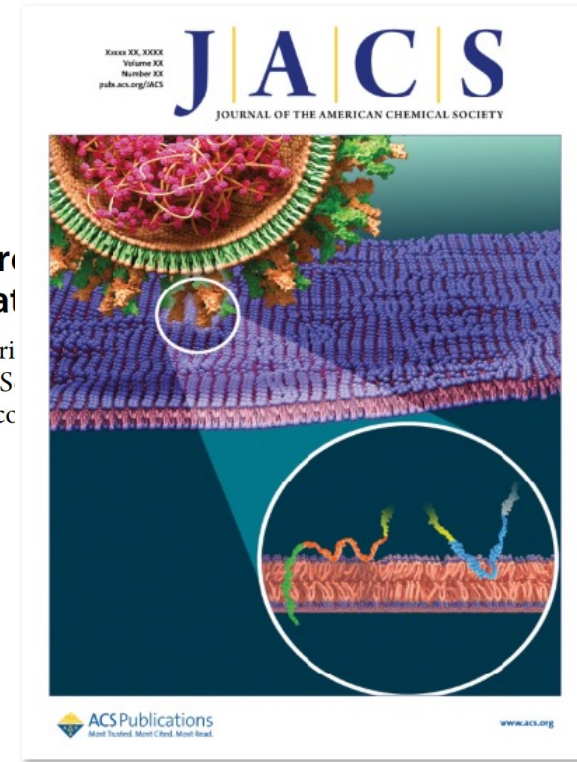


Model for fusion mechanism



Strikingly Different by Neutron Scattering

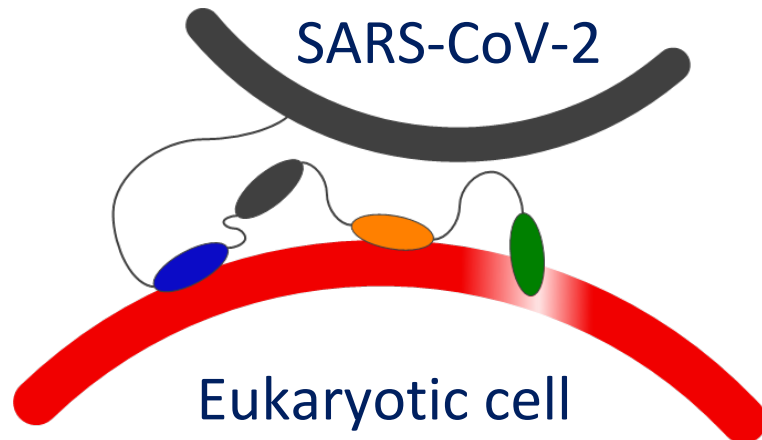
Andreas Santamaria, Kri
Francesca Natali, Tilo S
Robert A. Russell, Giacc



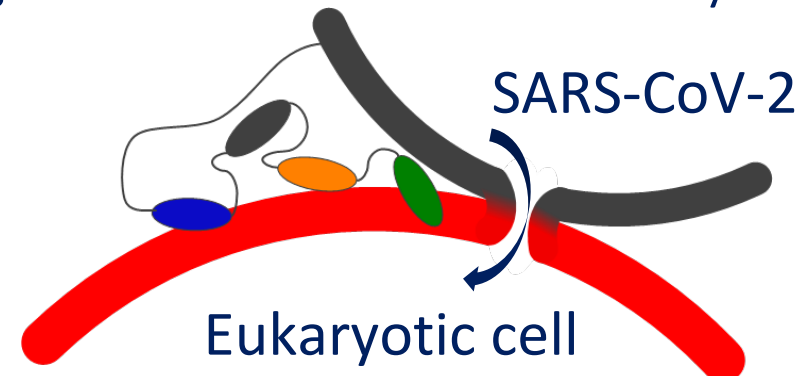
ptides Uncovered

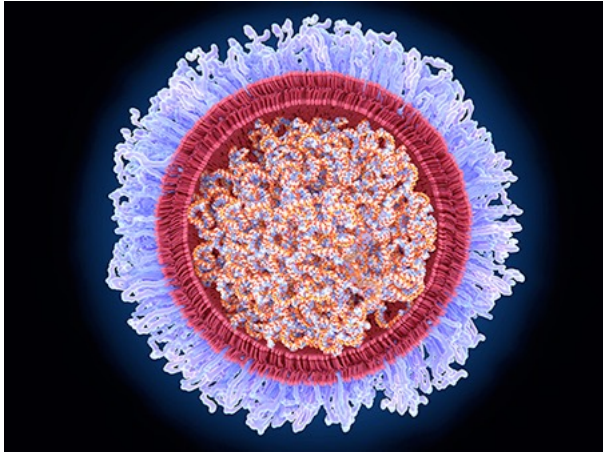
it, Daniela Russo,
ein, Tamim A. Darwish,
y,* and Nathan R. Zaccai*

- 2.
- FP2 and FP4 bind PM with high affinity bridging the two membranes
 - FP1 inserts in the PM, creating fusion points



- 3.
- Fusion of the membranes occurs and viral genetic material enters the eukaryotic cell

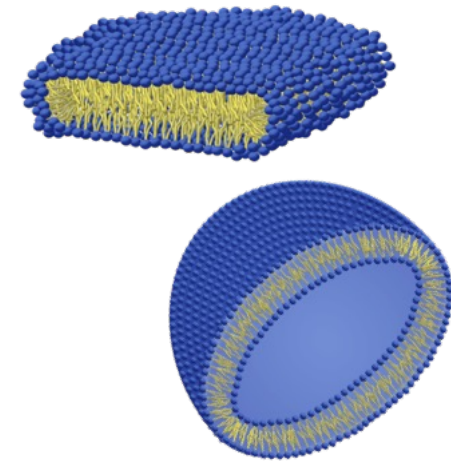
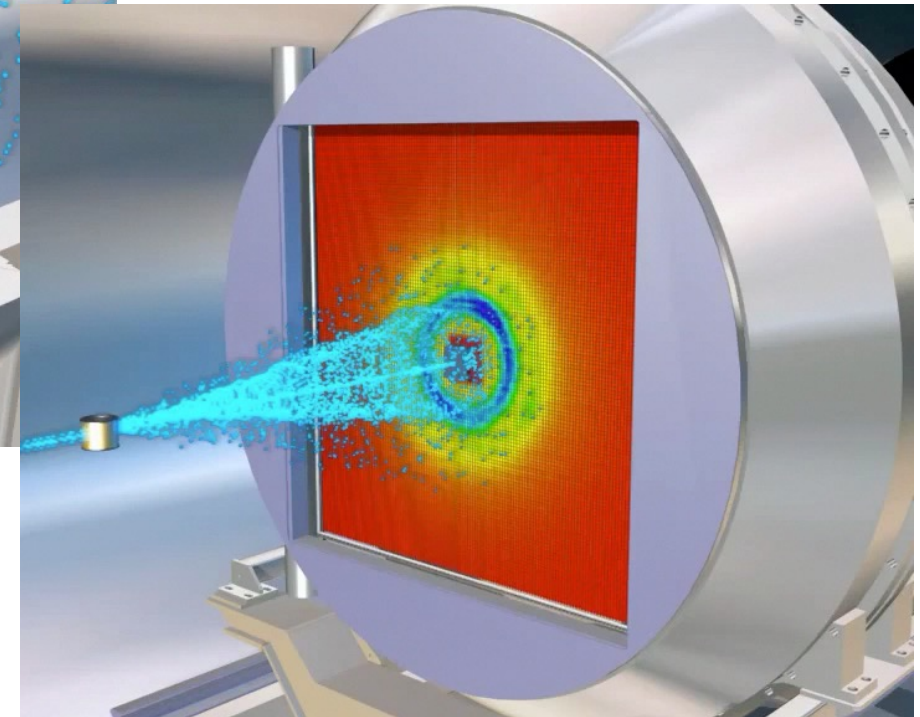
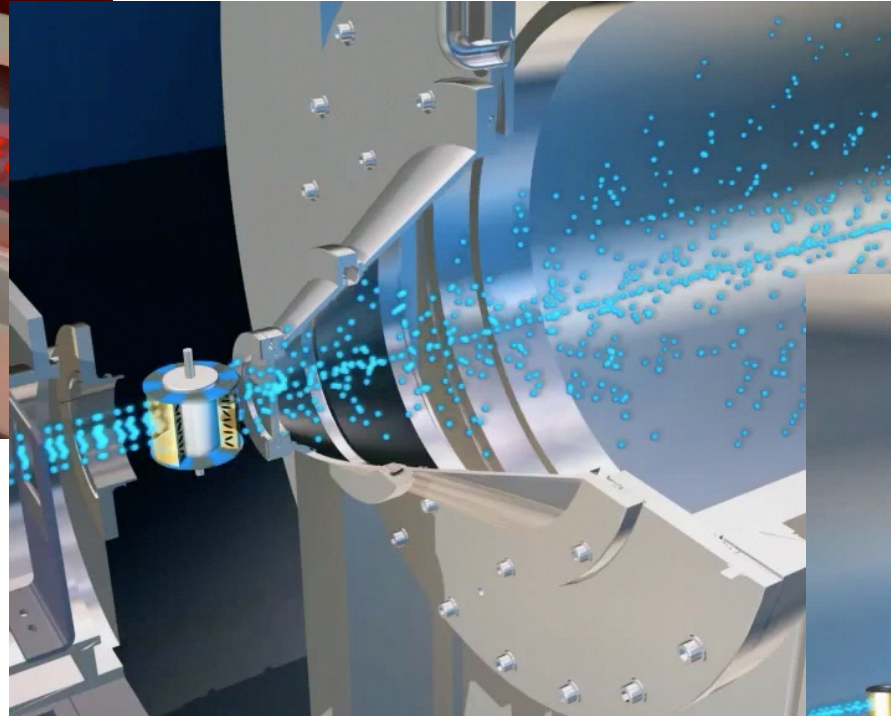
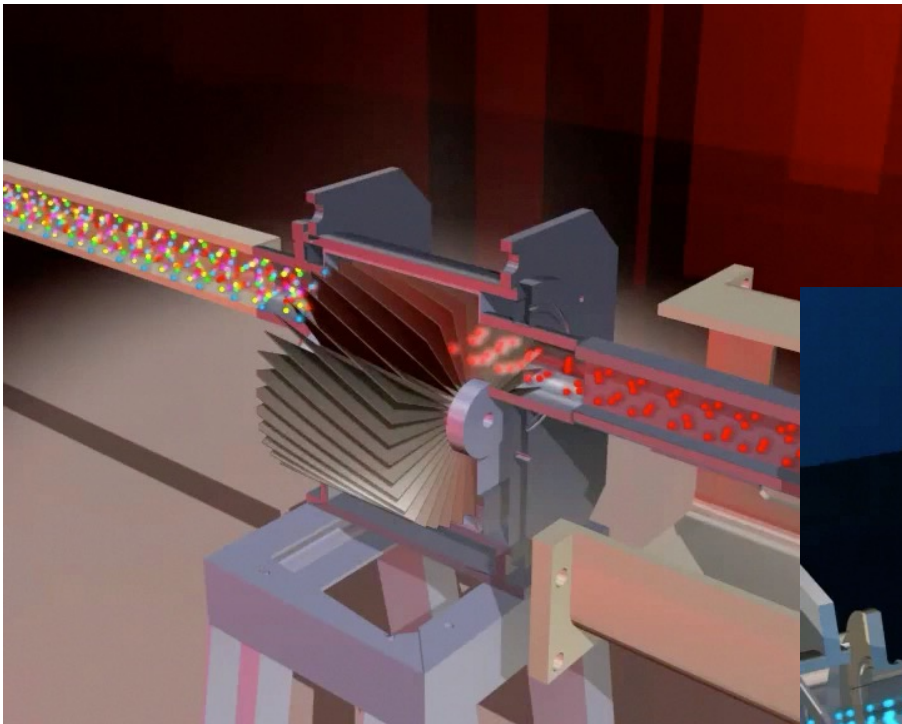




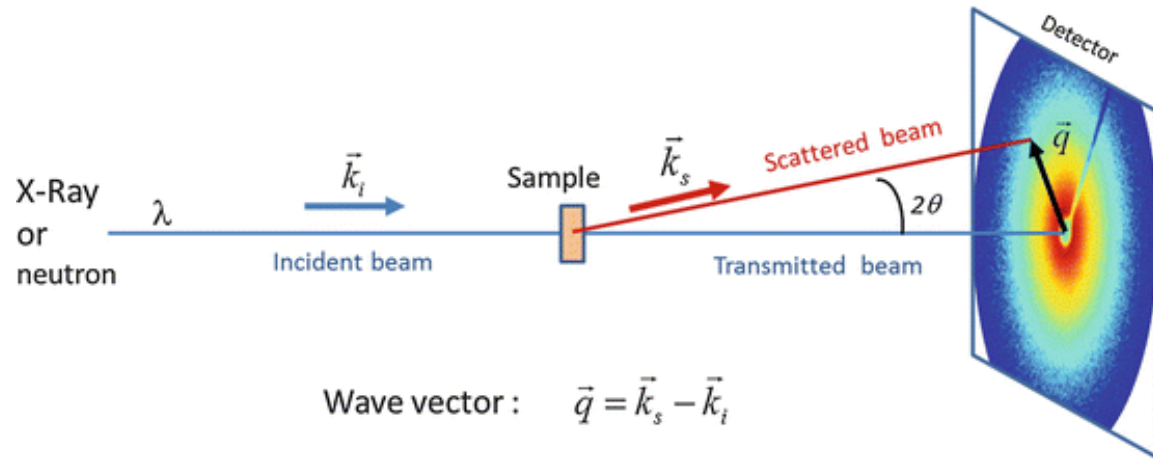
SANS for mRNA VACCINES



SMALL ANGLE NEUTRON SCATTERING



SANS & contrast variation



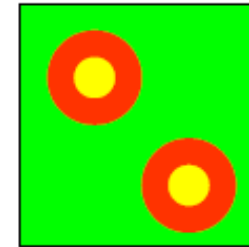
Idea of contrast variation



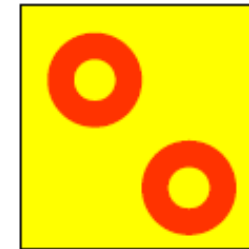
Vary scattering behaviour of (parts of) solutes with respect to solvent



- Contrast Matching
 - reduce the number of phases 'visible'

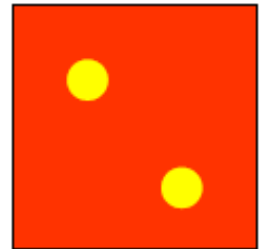


becomes...



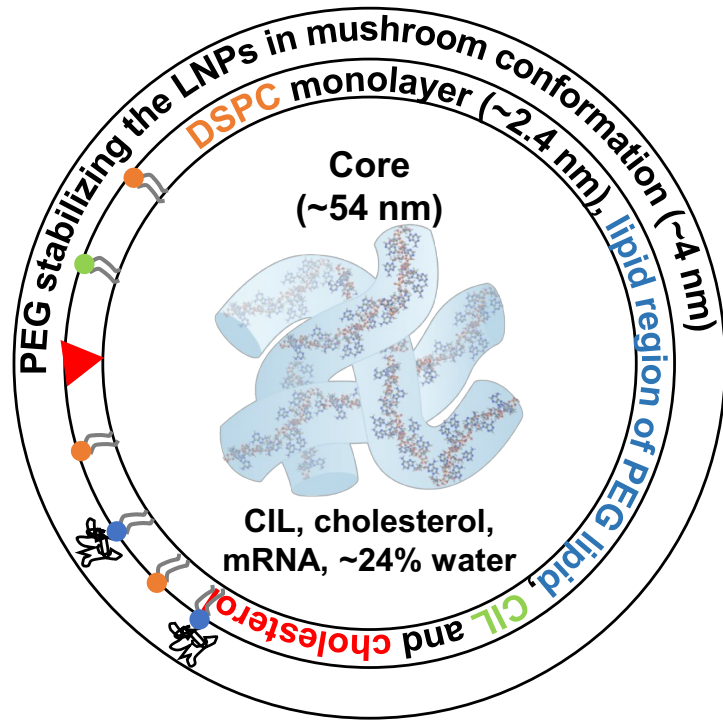
$\rho_{\text{solvent}} = \rho_{\text{core}}$
(shell visible)

or



$\rho_{\text{solvent}} = \rho_{\text{shell}}$
(core visible)

Samples



mRNA-LNP composition

CIL:DSPC:Chol:DMPE-PEG

50:10:38.5:1.5

CIL:nucleotide 3:1

*LNP – lipid nanoparticle
CIL - cationic ionizable lipid: a critical component that quickly concentrates in the liver upon intravenous LNP administration*

MCH prepared with matched out-cholesterol

→ **localise cholesterol**

MCHPC with a combination of matched out-cholesterol
and d-DSPC

→ **highlight the shell**

MMC with deuterated CIL

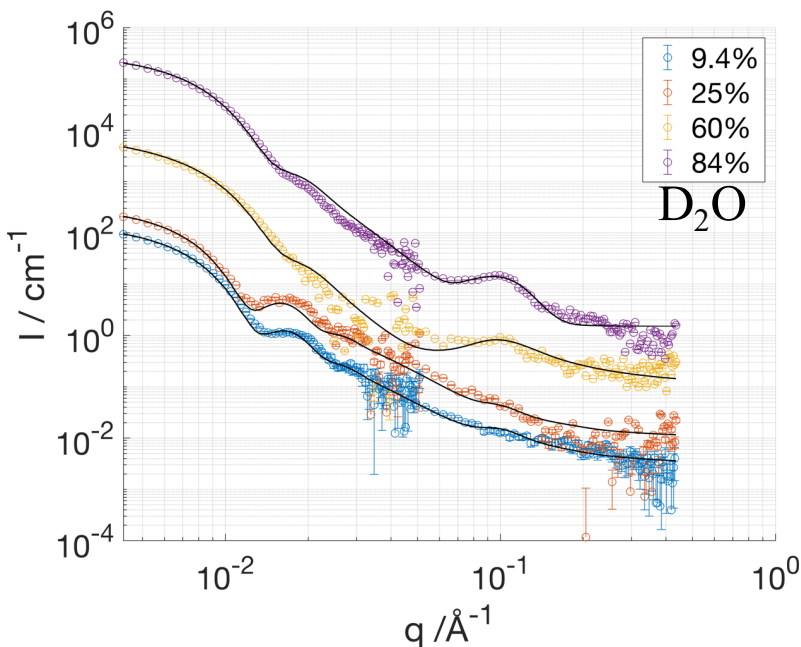
→ **localise CIL**

M. Yanez-Arteta *et al.* PNAS, **115**, E3351 (2018).

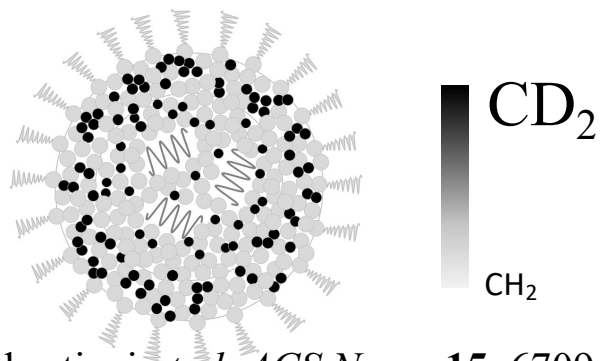
F. Sebastiani *et al.* ACS Nano, **15**, 6709 (2021).

Results

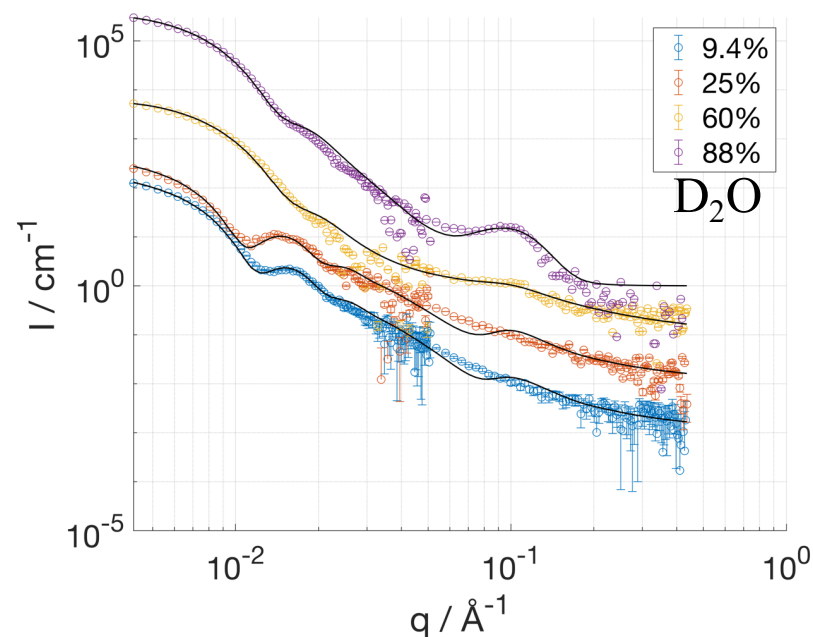
MCH



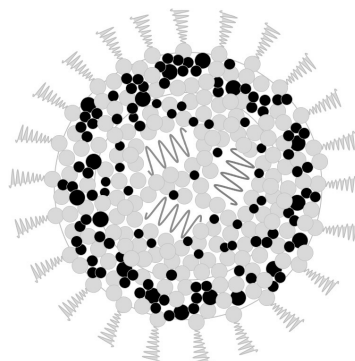
100 % mo-chol



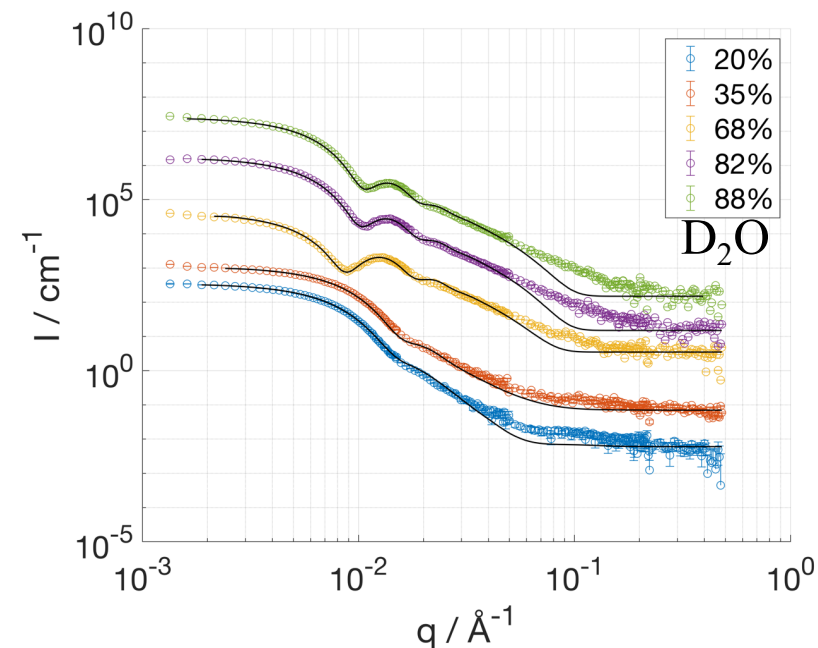
MCHPC



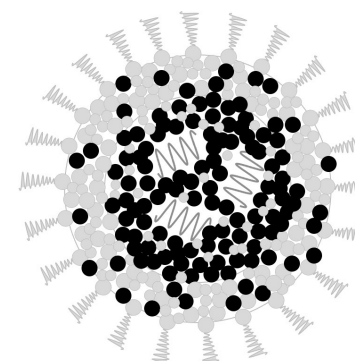
100% mo-chol 32% d-DSPC



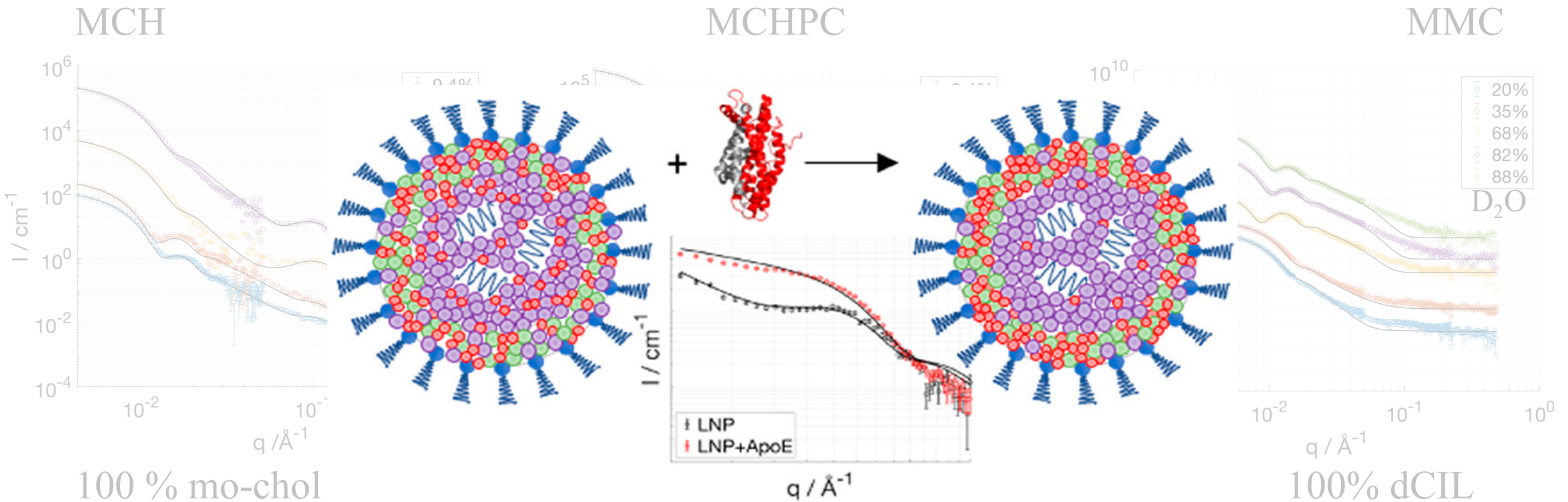
MMC



100% dCIL



Results

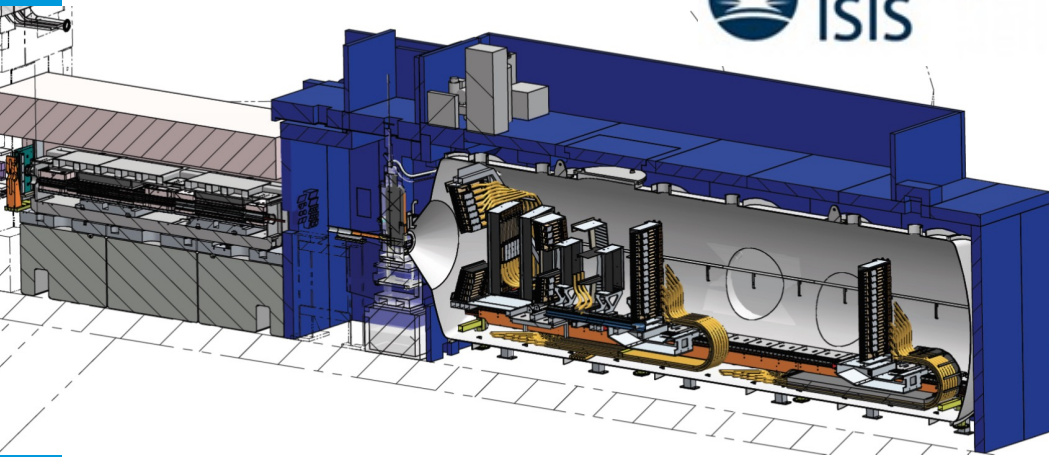


apolipoproteinE (ApoE), being responsible for fat transport in the body, plays a key role in the LNP's plasma circulation time.

Future opportunities at ESS

LoKI : Broad Band SANS

Science Case



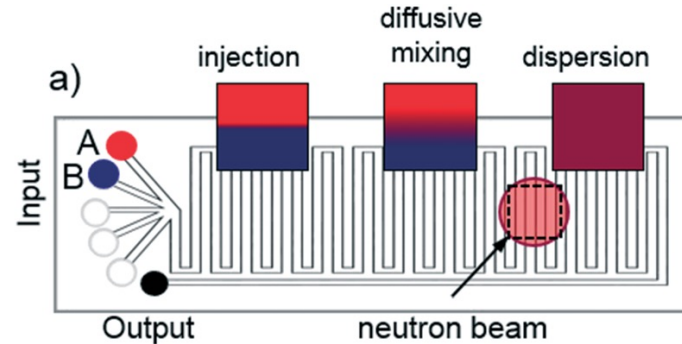
→ high flux, wide simultaneous size range, and a flexible sample area.

ABILITIES:

- Investigate multiple length scale systems (simultaneously 0.5-300 nm)
- Perform "single-shot" kinetic measurements on sub-second timescales.
- Perform experiments that use flow e.g. rheology & microfluidics with small beam sizes
- High throughput of regular SANS measurements

Microfluidic SANS:

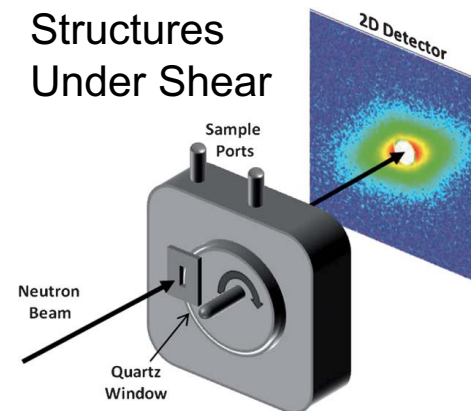
High Throughput Mixing & Tailored Flow Geometry



Lab Chip, 2017, **17**, 1559

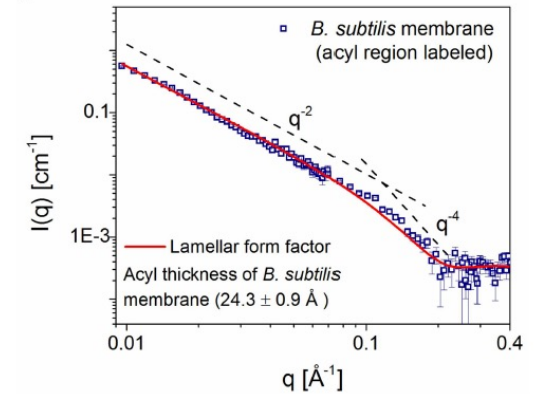
Rheo-SANS:

Structures Under Shear



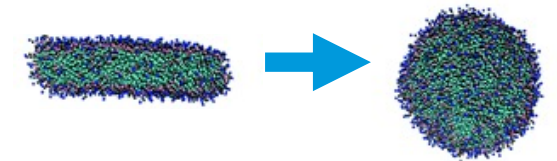
Soft Matter, 2011, **7**, 9992

Biological Samples: Weak Scatterers & Dilute Solutions



PLoS Bio, 2017, **15**, e2002214

Non-Equilibrium Studies: Self-Assembly & Kinetics

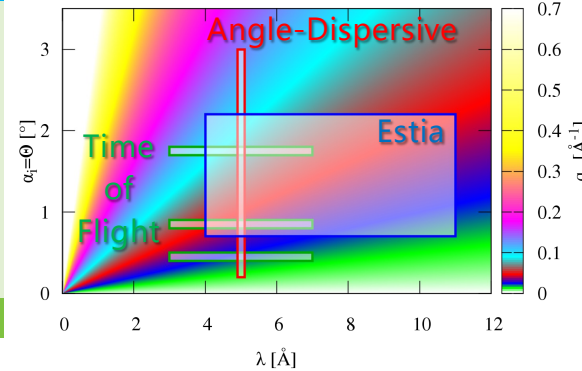
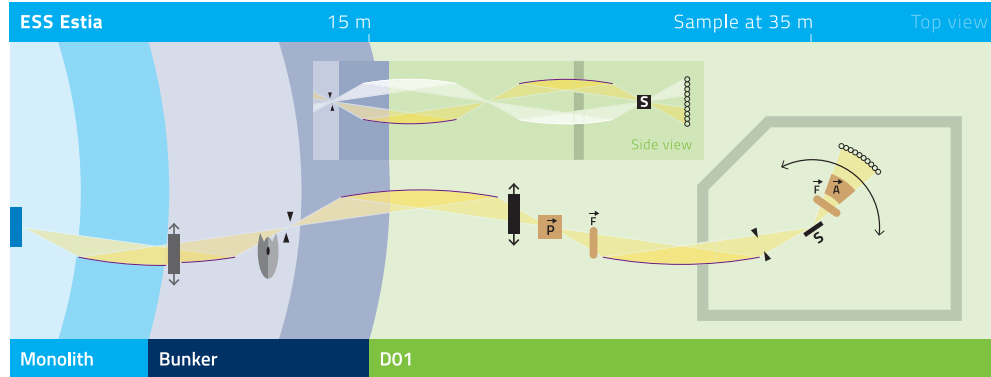


Colloid Polym Sci, 2010, **288**, 827



Estia

Focussing Polarised Reflectometer for Tiny Samples

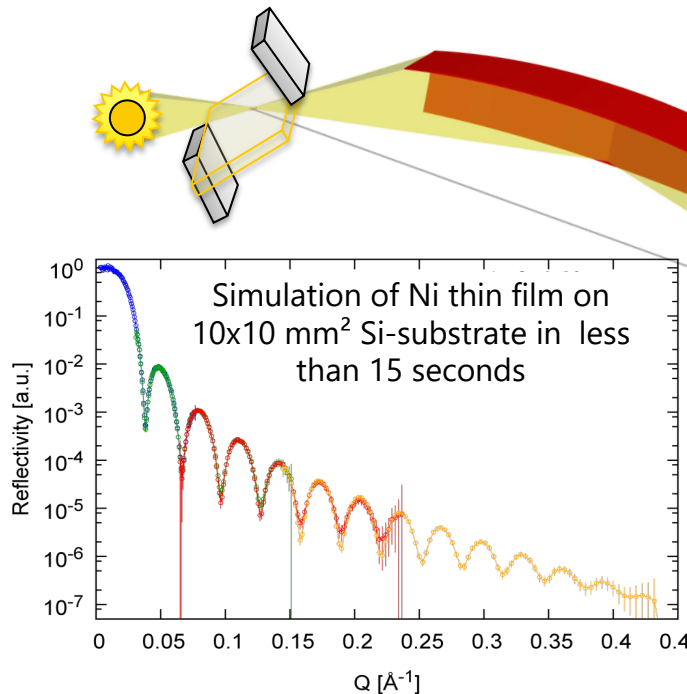


Estia Quick Facts.

Estia Quick Facts	
Instrument Class	Reflectometry
Moderator	Cold
Primary Flightpath	35 m
Secondary Flightpath	4 m
Wavelength Range	3.75–28 Å
Polarised Incident Beam	Optional
Polarisation Analysis	Optional
Sample Orientation	Vertical
Total Q-Range	0.001 to 3.15 Å ⁻¹ /–0.001 to –0.3 Å ⁻¹
Standard Mode (14 Hz)	
Bandwidth	7 Å
Flux at Sample at 2 MW ^a	6 × 10 ⁸ n s ⁻¹ cm ⁻²
Relative Q-Range	Q _{max} = 2.85 × Q _{min}
Q-Resolution ΔQ/Q	7.8%–3.0% over Q-range
2-Pulse Skipping Mode (4.7 Hz)	
Bandwidth	21 Å
Flux at Sample at 2 MW ^a	2 × 10 ⁸ n s ⁻¹ cm ⁻²
Relative Q-Range	Q _{max} = 6.6 × Q _{min}
Q-Resolution ΔQ/Q	7.8%–1.3% over Q-range

^aFull-divergence beam averaged over 5(H) × 10(V) mm².

- **Selene neutron guide** projects tiny beam from Virtual Source
- **Small samples:**
 - Large divergence (1.5°x1.5°)
 - Samples down to 1x1 mm²



PAUL SCHERRER INSTITUT



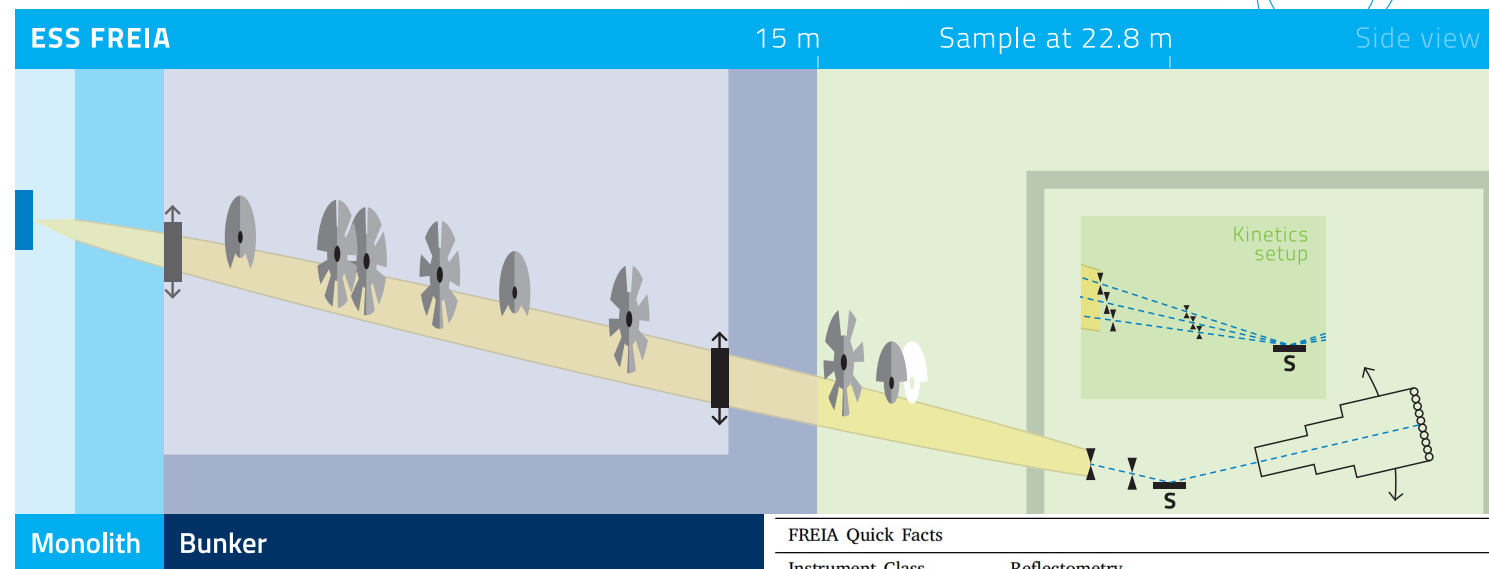
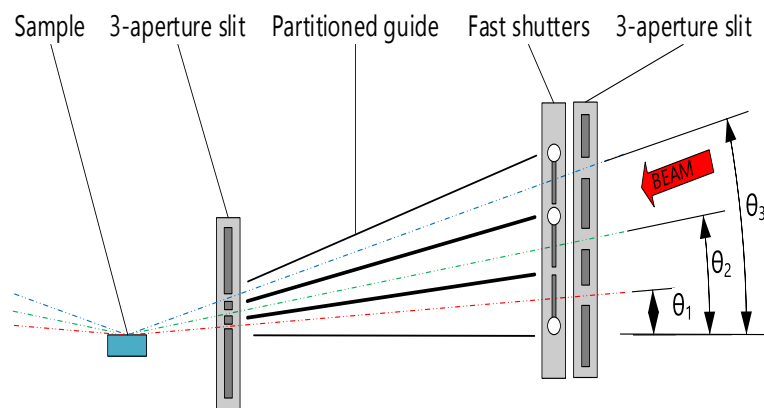
For the study of surfaces and interfaces including magnetic layers

FREIA Horizontal Reflectometer

FREIA is a flexible instrument optimised for **time-resolved** and high throughput studies:

- Wide vertical divergence; **extended simultaneous Q range** & avoids slow sample movements
- Downward orientation for **liquid interfaces**
- **Flexible** Collimation options
- High flux ($d\lambda/\lambda = 3\text{--}20\%$) or high resolution ($d\lambda/\lambda < 3\%$) modes

Wide ranging science case in **soft-matter and biosciences**



FREIA Quick Facts

Instrument Class	Reflectometry
Moderator	Cold
Primary Flightpath	22.8 m
Secondary Flightpath	3.0 m
Polarised Incident Beam	Available as a foreseen upgrade
Sample Orientation	Horizontal
Representative Incident Beam Angles	0.45°, 0.9°, 3.4° (full range 0.2°–3.7° depending on angular resolution)

Standard Mode (14 Hz)

Wavelength Range	2–10 Å
Flux at Sample at 2 MW	1 × 10 ⁵ , 5 × 10 ⁵ , 7 × 10 ⁶ n s ⁻¹ cm ⁻² [high res (WFM) mode] 1 × 10 ⁶ , 4 × 10 ⁶ , 6 × 10 ⁷ n s ⁻¹ cm ⁻² [high flux mode] 1 × 10 ⁸ n s ⁻¹ cm ⁻² [full divergence mode]
Q-Range	0–1 Å ⁻¹ (solid samples) 0.0045–0.38 Å ⁻¹ (free liquids)
Q-resolution	3%–3.5% [high res (WFM) mode] 5%–23% (across free-liquid Q-range) [high flux mode] 2%–6% [full divergence (WFM) mode]

Pulse Skipping Mode (7 Hz)

Wavelength Range	2–18 Å
Flux at Sample	5 × 10 ⁵ , 2 × 10 ⁶ , 3 × 10 ⁷ n s ⁻¹ cm ⁻² [high flux mode]
Q-Range	0–1 Å ⁻¹ (solid samples) 0.002–0.38 Å ⁻¹ (free liquids)
Q-resolution	3%–23% (across free-liquid Q-range) [high flux mode]

Fast Shutter development

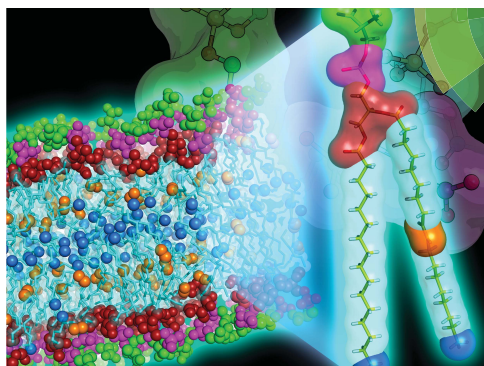
Rapidly change angles
without moving sample...
allows full Q-range
measurement with
collimated beam with sub-
second time resolution

FREIA

Science Case



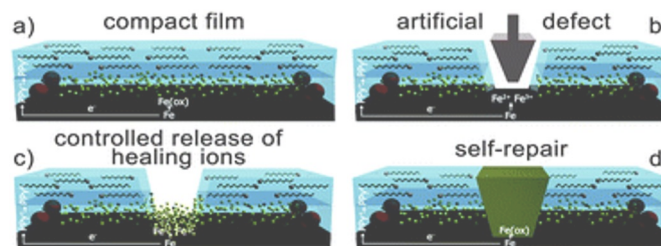
In-situ time-resolved reflectometry for soft condensed matter, life science and functional materials



Instrument characteristics to allow very fast measurements:

- Very high flux
- Horizontal sample geometry
- Flexible collimation
- Variable resolution
- Broad simultaneous Q
- No sample movement

Applications

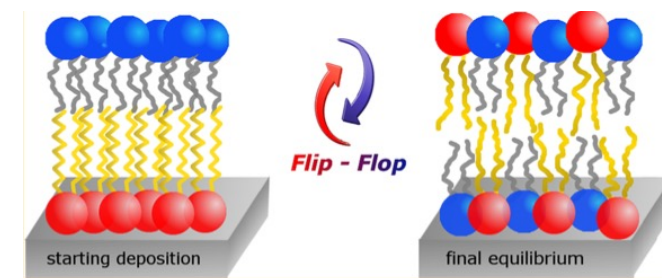


Design



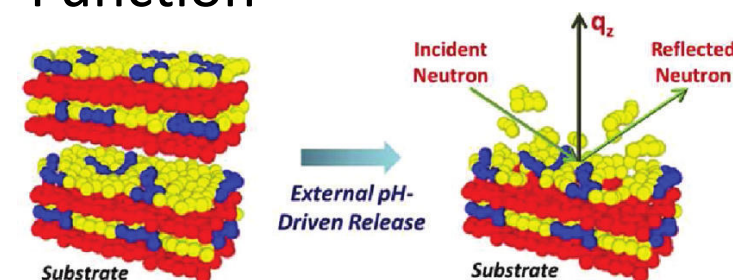
- response to external stimuli
- in situ and in operando
- complex sample environments

Dynamics



- deposition, structure and phase behavior
- adsorption, self-assembly and reactions
- gas/liquid/solid interfaces

Function



Consider using neutrons for your research!

Thank you!

