



ESS Industrial Day MESR 7 février 2014

C. Alba-Simionesco
Laboratoire Léon Brillouin
CEA-CNRS, Saclay

la diffusion neutronique pour la recherche appliquée et fondamentale

The Nobel Prize in Physics 1994



Clifford G. Shull, MIT, Cambridge, Massachusetts, USA, winner one half of the 1994 Nobel Prize in Physics for development of the neutron diffraction technique.

Neutrons behave as particles and as waves

Neutrons reveal structure and dynamics

The Royal Swedish Academy of Sciences has awarded the 1994 Nobel Prize in Physics for pioneering contributions to the development of neutron scattering techniques for studies of condensed matter.

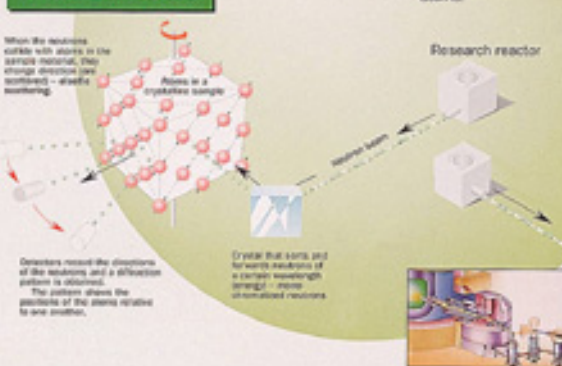
Berttram N. Brockhouse, McMaster University, Hamilton, Ontario, Canada, winner one half of the 1994 Nobel Prize in Physics for the development of neutron spectroscopy.

S Shull made use of elastic scattering i.e. of neutrons which change direction without losing energy when they collide with atoms.

Because of the wave nature of neutrons, a diffraction pattern can be recorded which indicates where in the sample the atoms are situated. Even the placing of light elements such as hydrogen in metallic hydrides, or hydrogen, carbon and oxygen in organic substances can be determined.

The pattern also shows how atomic dipoles are oriented in magnetic materials, since neutrons are affected by magnetic forces. Shull also made use of this phenomenon in his neutron diffraction technique.



Neutrons show where atoms are

When the neutrons collide with atoms in the sample material, they change direction (are scattered) - elastic scattering.

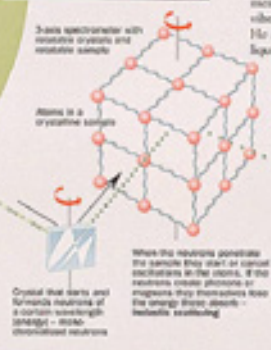
Atoms in a crystalline sample.

Crystal that sorts and diffracts neutrons of a certain wavelength (energy) - energy conservation.

Detectors record the directions of the neutrons and a diffraction pattern is obtained. The pattern shows the positions of the atoms relative to one another.

B Brockhouse made use of inelastic scattering i.e. of neutrons, which change both direction and energy when they collide with atoms. They then start or cancel atomic oscillations in crystals and record movements in liquids and solids. Neutrons can also interact with spin waves in magnets.

With his 3-axis spectrometer Brockhouse measured energies of phonons (atomic vibrations) and magnons (magnetic waves). He also studied how atomic structures in liquids change with time.

Neutrons show what atoms do

3-axis spectrometer with sensitive crystals and sensitive sample.

Atoms in a crystalline sample.

When the neutrons penetrate the sample they start or cancel oscillations in the atoms. If the neutrons create phonons or magnons they themselves lose the energy they've absorbed - inelastic scattering.

Changes in the energy of the neutrons are first analysed in an analyser crystal... and the neutrons then focused in a detector.

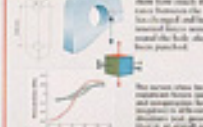
Neutrons see more than X-rays

X-rays are scattered by electrons (atoms) by atomic nuclei. With X-rays it is extremely rare to see the light elements. Neutrons, for example, which has only one electron is not so rare to see. With neutrons, all kinds of atoms are visible.



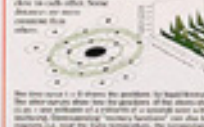
Neutrons reveal inner stresses

It tells the long-packed in an important small detail part. From the pattern of neutron diffraction we can learn how much the atoms have moved from their normal positions. The pattern shows the positions of the atoms relative to one another.



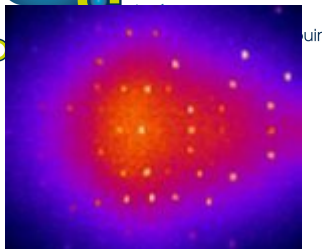
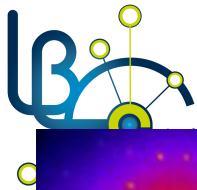
Neutrons show what atoms remember

Of their earlier position when they were randomly in solution or in a new polymer or a polymer with a certain local order. The most common many randomly close to each other. Some distances are more constant than others.



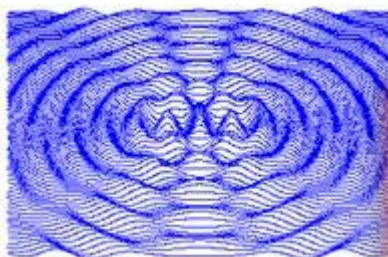
Further reading

- Clifford G. Shull, The Nobel Prize in Physics 1994, Stockholm, 1994, pp. 1-10, 11-12, 13-14, 15-16, 17-18, 19-20, 21-22, 23-24, 25-26, 27-28, 29-30, 31-32, 33-34, 35-36, 37-38, 39-40, 41-42, 43-44, 45-46, 47-48, 49-50, 51-52, 53-54, 55-56, 57-58, 59-60, 61-62, 63-64, 65-66, 67-68, 69-70, 71-72, 73-74, 75-76, 77-78, 79-80, 81-82, 83-84, 85-86, 87-88, 89-90, 91-92, 93-94, 95-96, 97-98, 99-100, 101-102, 103-104, 105-106, 107-108, 109-110, 111-112, 113-114, 115-116, 117-118, 119-120, 121-122, 123-124, 125-126, 127-128, 129-130, 131-132, 133-134, 135-136, 137-138, 139-140, 141-142, 143-144, 145-146, 147-148, 149-150, 151-152, 153-154, 155-156, 157-158, 159-160, 161-162, 163-164, 165-166, 167-168, 169-170, 171-172, 173-174, 175-176, 177-178, 179-180, 181-182, 183-184, 185-186, 187-188, 189-190, 191-192, 193-194, 195-196, 197-198, 199-200, 201-202, 203-204, 205-206, 207-208, 209-210, 211-212, 213-214, 215-216, 217-218, 219-220, 221-222, 223-224, 225-226, 227-228, 229-230, 231-232, 233-234, 235-236, 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Electriquement neutre, pénétrant et non destructif

Idéal pour les systèmes biologiques,
échantillons sous conditions extrêmes,
réactions chimiques in situ,
Engineering, héritage culturel ,objet de grand taille (voiture, moteurs...)
par imagerie



Plusieurs ordres de grandeur dans l'espace ET le temps

Un ensemble de techniques expérimentales

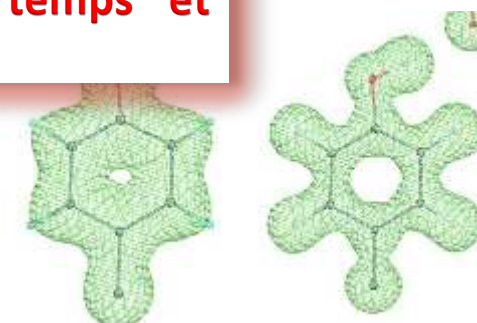
pour couvrir des grandes échelles de temps et d'espace simultanément

Sens

Distingue les atomes légers, les isotopes
Contraste isotopique dans les systèmes complexes
Cristallographie macromoléculaire
Hydratation, mécanisme enzymatique,
ligand binding, bio-ingénierie
Stockage de l'hydrogène, systèmes organiques

10^{-11}m à 10^{-6}m

magnons

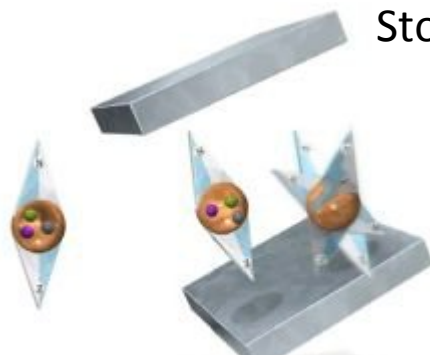
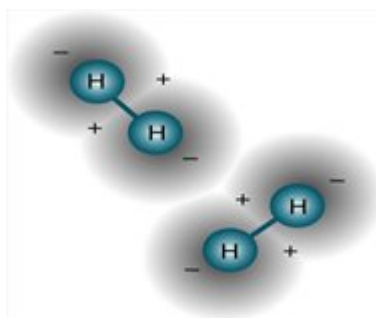


X-ray 1Å

Neutron(D) 1Å

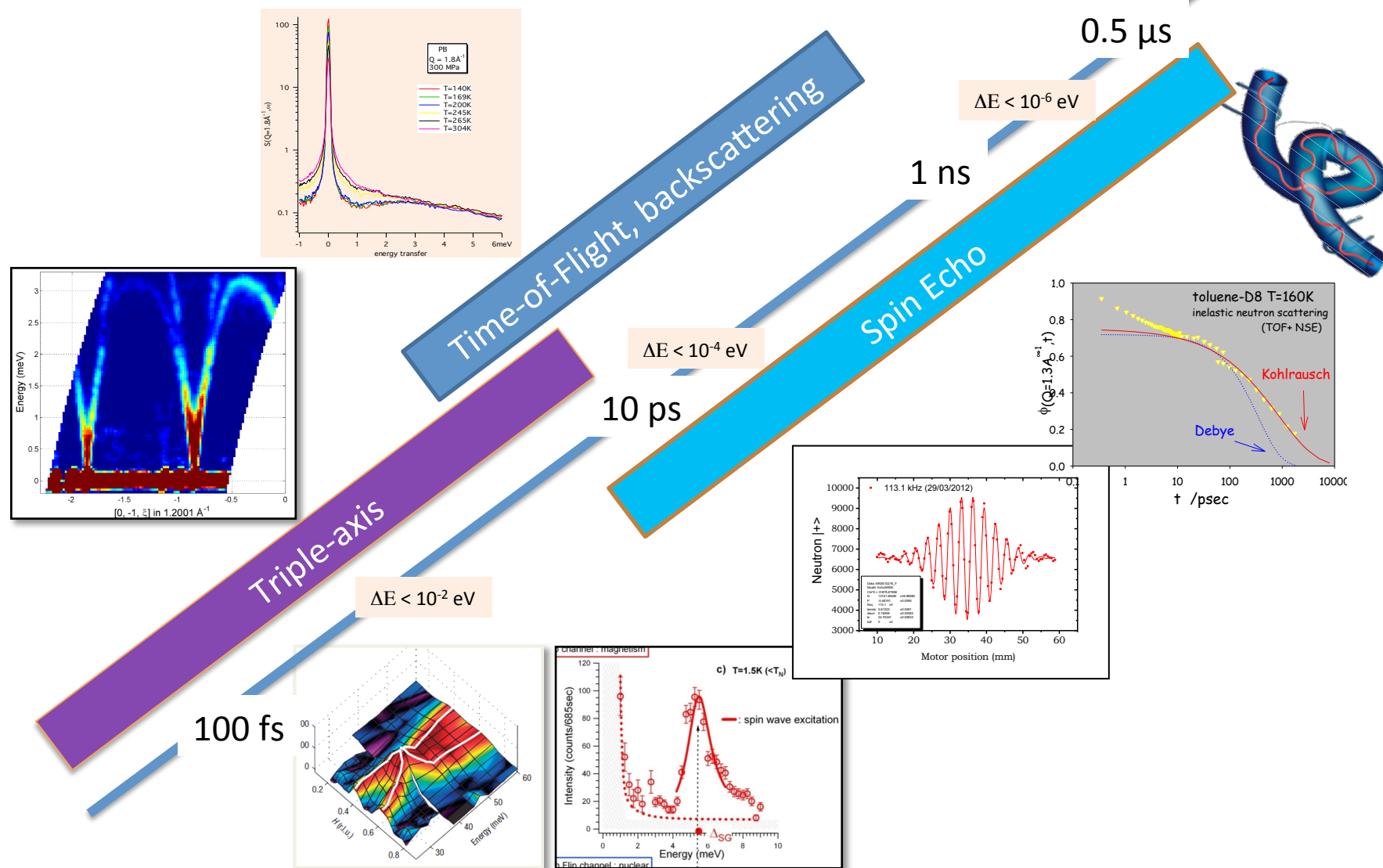
Magnétisme :

Petit aimant, sensible aux champs magnétiques généré par électrons non appariés; structures magnétiques, magnons, Spintronique, aimant moléculaire, supraconductivité



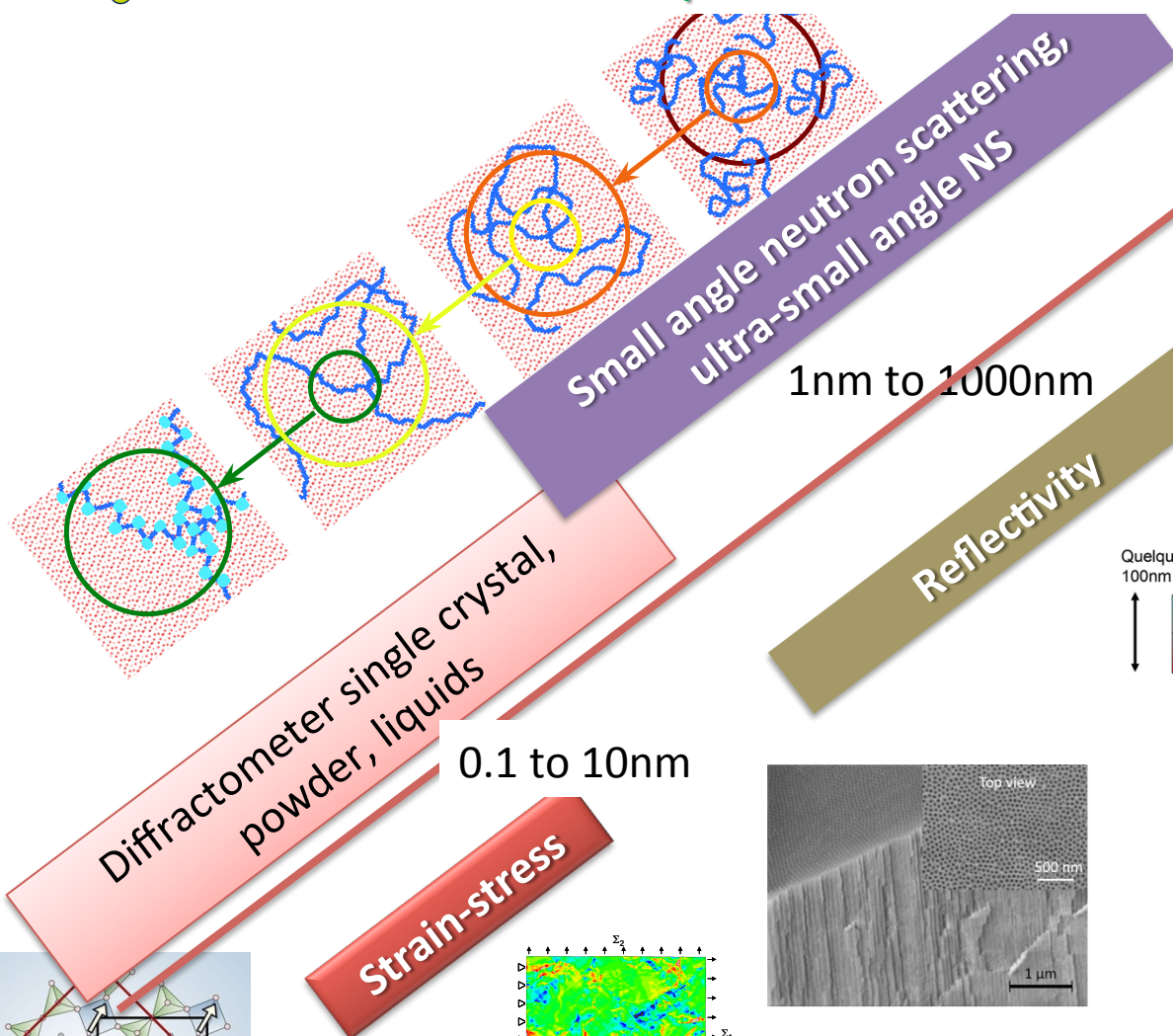
Temporal domain

Processus Dynamique $100\text{fs} < t < 0.5\text{ }\mu\text{s}$ et cinétique $t > \text{ms}$



spatial domain

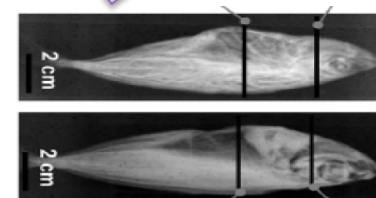
Échelles Atomique à nano- et micro-macro



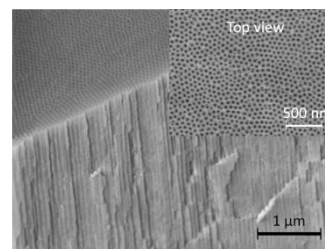
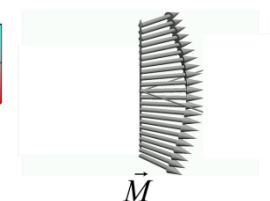
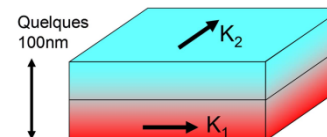
Radiography
tomography

Neutron imaging

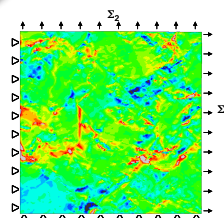
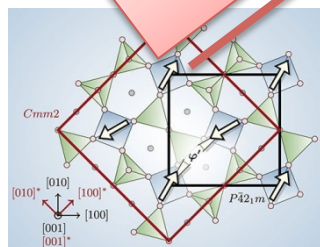
10 μ m to m



K. Tanoi et al 2009



[neutron activation analysis.](#)
[Particle and nuclear physics](#)



Sciences de la vie et médecine,
Diffraction imagerie, temps de vol
macromolécules
Structures hydrogel, implants,
Anticorps, drug delivery

Héritage Culturel
Tomographie et radiographie,
diffusion aux petits angles, réflectivité
Archéologie, peinture, sculpture, livres

technologies de l' Information
Diffraction monocristaux, poudres; réflectivité
diffusion inélastique (bispectral)
Stockage disque dur, de la chimie vers les
nouveaux calculateurs
Magnétorésistance géante, spintronique

Énergie et science de l'environnement
Diffusion petits angles, réflectivité,
imagerie, temps de vol
Stockage de l'hydrogène, piles à
combustible
batteries, Conducteurs ioniques,
clathrates, céramiques,
catalyse, décontamination
Géosciences, agriculture
Expériences in situ et in operando,

Nano science & engineering
Diffusion petits angles, diffraction,
réflectivité, imagerie, temps de vol
Matériaux fonctionnalisés, nouveaux alliages
Nanocomposites, Rhéologie, microfluidique
texture-contrainte alliages,
suivi de procédés agroalimentaires



Panorama des centres français

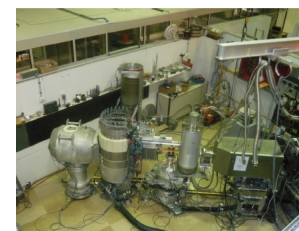
Un **centre international à Grenoble: l'Institut Laue Langevin**
(un réacteur 1^{ère} génération + 27 instruments + 9 CGR)
France-Allemagne- Royaume-Uni associés + partners



Un **centre national à Saclay** :
un réacteur Orphée 2^{ème} génération+ infrastructure
Laboratoire Léon Brillouin CEA-CNRS
Coordinateur des projets instrumentaux français



5 CRG (Collaborating Research Group) CEA-CNRS
installés à l'ILL en collaboration avec centre de Jülich

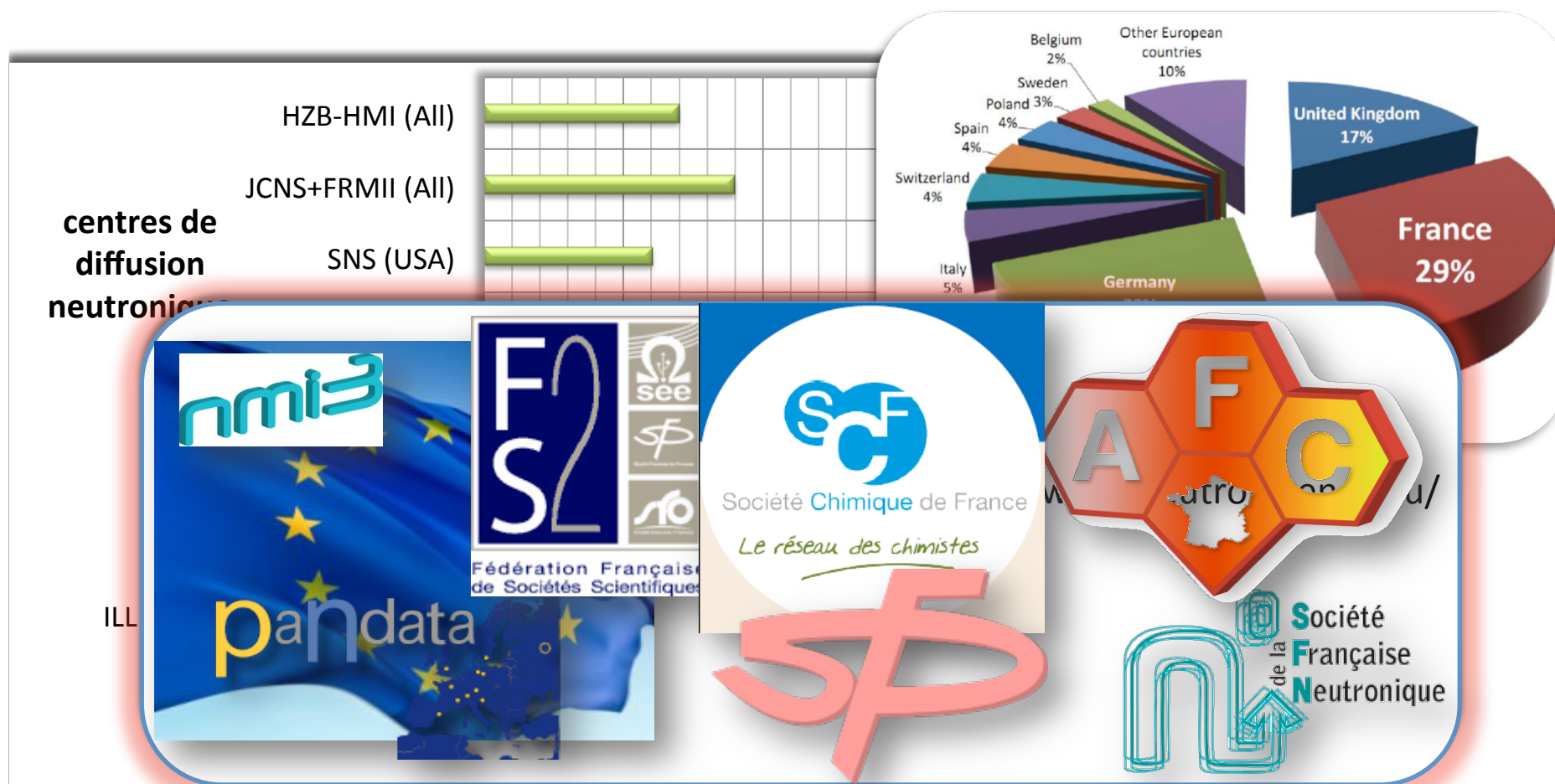


Un projet européen **ESS à Lund** Suède



UN LEADERSHIP EUROPÉEN

IMPORTANTE CONTRIBUTION FRANÇAISE EN TERME DE PUBLICATIONS





Bureau d'étude (études, mises en plans)
Design Office (studies, drawing)

Chaudronnerie (enceintes)
Sheet metal work,

Mécanique (enceintes), **precision machining**
Mécanique de précision (positionnements, fentes..)

Special grounds for displacement (marble, polishing, resins)
sols spéciaux pour déplacements d'instruments (marbre, béton poli, résines, ...)

Sample Environment (électro/cryo aimants, bobines, fours, refroidisseurs, ...)

Electronique (puissance, contrôle, baies, cartes, ...)
Electronics (racks, powder electronics, control..)

Radioprotection (bétons, concrete, lead, B4C, polyEthylene)

Prestations informatique (acquisition de données, traitements, backup, ...) **Software development**; Data acquisition, treatment

PROPOSAL FOR INSTRUMENT CONSTRUCTION @ ESS

Spectroscopie

Diffraction et magnétisme

Diffusion aux petits angles

Réflectivité

**Environnements échantillon
particuliers**

Contacts :
S. Désert, A. Menelle

French Users and labs ready to follow the construction phase

Utilisateurs Français intéressés dans le suivi de la construction

Research centers and Universities

Spectroscopie (Time-Of-Flight)

Diffraction (and Magnetism)

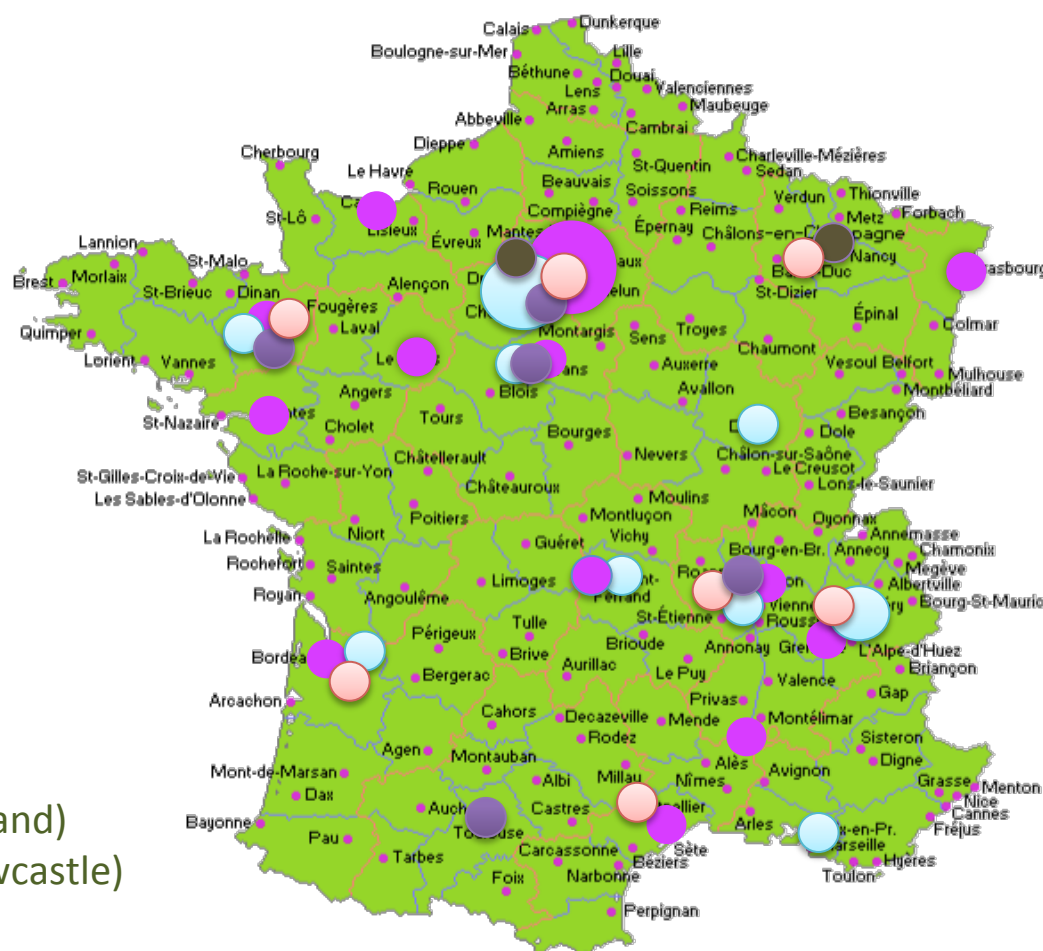
Diffusion aux petits angles (SANS)

Réflectivité (Reflectivity)

Environnements échantillon particuliers (sample environment)

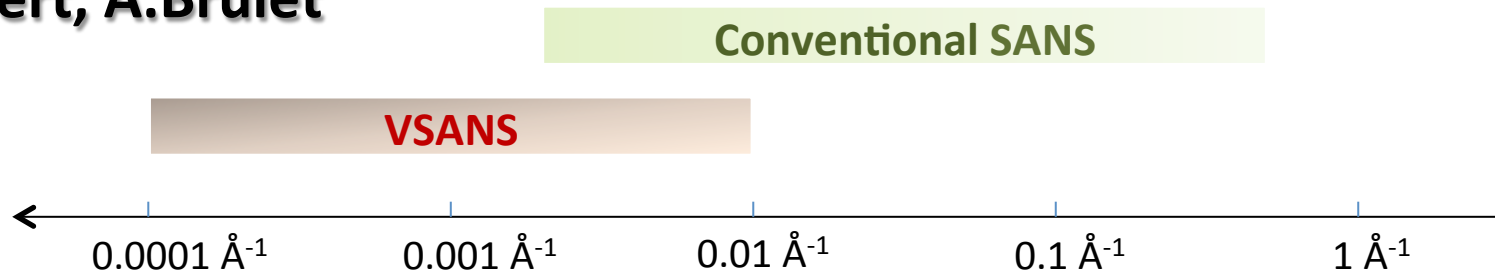
Industrial users:

L. Barré (**IFPEN**, Rueil-Malmaison)
M. Couty (**Michelin**, Clermont-Ferrand)
J. Gummel (**Procter & Gamble**, Newcastle)
J.Y. Delannoy (**Solvay**, Saint-Fons)
CEA



HIGH INTENSITY SANS AND FOCUSING SANS MULTI SLITS VSANS/GISANS SKADI (OCTOBER 2013)

Jacques Jestin,
S.Désert, A.Brulet



Probing larger scale distances (10 to 1000 nm) than conventional SANS (0.5 to 100 nm)
overlap white light scattering domain while benefiting from Neutron scattering advantages:
Contrast variation, dark and concentrated media...

SOFT MATTER: polymers, poly-electrolytes, micelles, gels, nanocomposites, copolymers, vesicles...

BIOLOGICAL SYSTEMS: proteins, membranes...

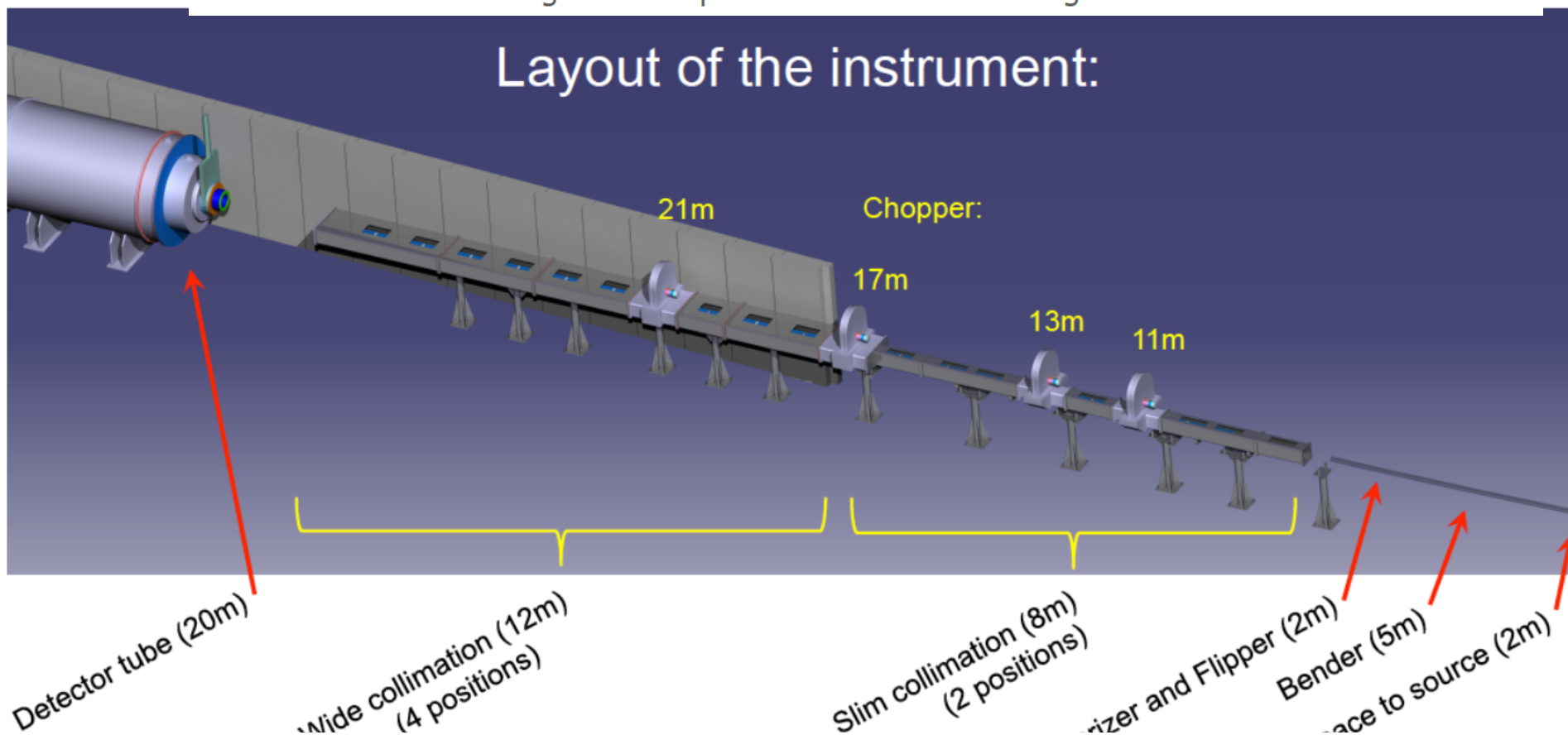
MATERIALS SCIENCE: chemical demixing, precipitates, porous materials, memory shape alloys...

MAGNETIC MATERIALS: critical magnetic fluctuations near transitions, vortices in superconductors
Nano-magnets, micro-phase separation in Manganites...

The **S**mall **K** Advanced **D**iffractometer SKADI is a SANS instrument, which will make use of samples of $1 \times 1 \text{ cm}^2$ size. Its general concept focuses on four main features:

- **Flexibility** (sample area is approx. $3 \times 3 \text{ m}^2$, and versatile collimation)
- **Very small Q** accessible through VSANS (using focusing elements)
- **High dynamic Q-range** (covering three orders of magnitude simultaneously)
- **Polarization** for magnetic samples and incoherent background subtraction

Layout of the instrument:



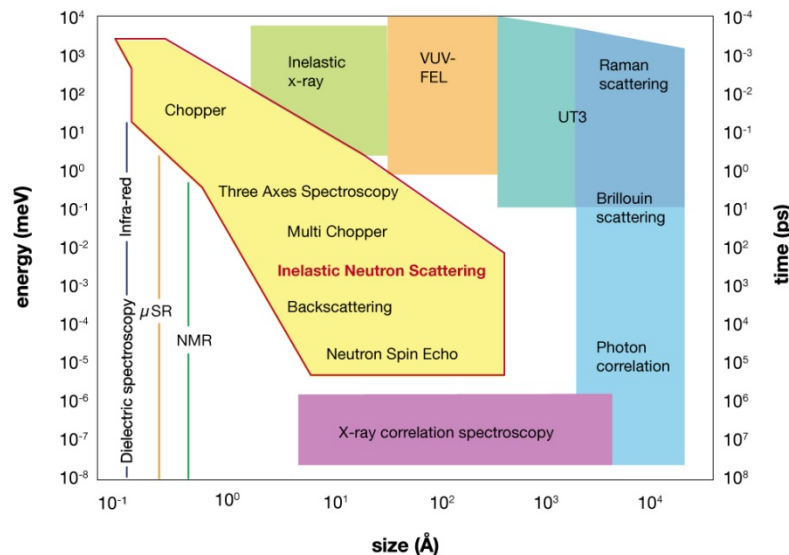
C-SPEC : a cold time-of-flight spectrometer

Join project between the Technische Universität München
and the Laboratoire Léon Brillouin

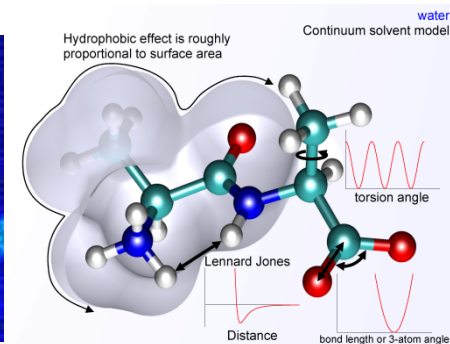
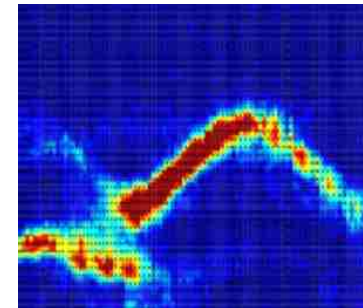
S.Longeville, JM Zanotti

Time-of-flight spectroscopy : atomic and molecular motions

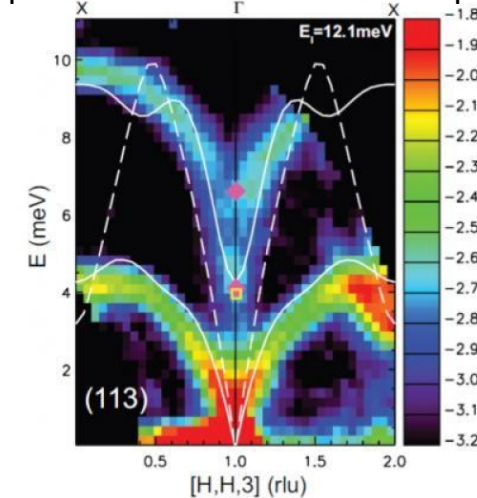
Application to solid state physics, chemistry, biophysics, food science, cultural heritage etc ..



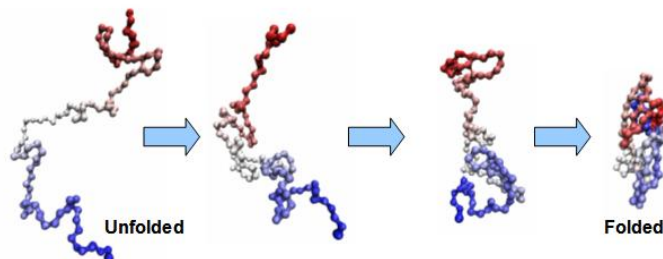
Understand molecular interactions



Dispersion curves for solid state physics



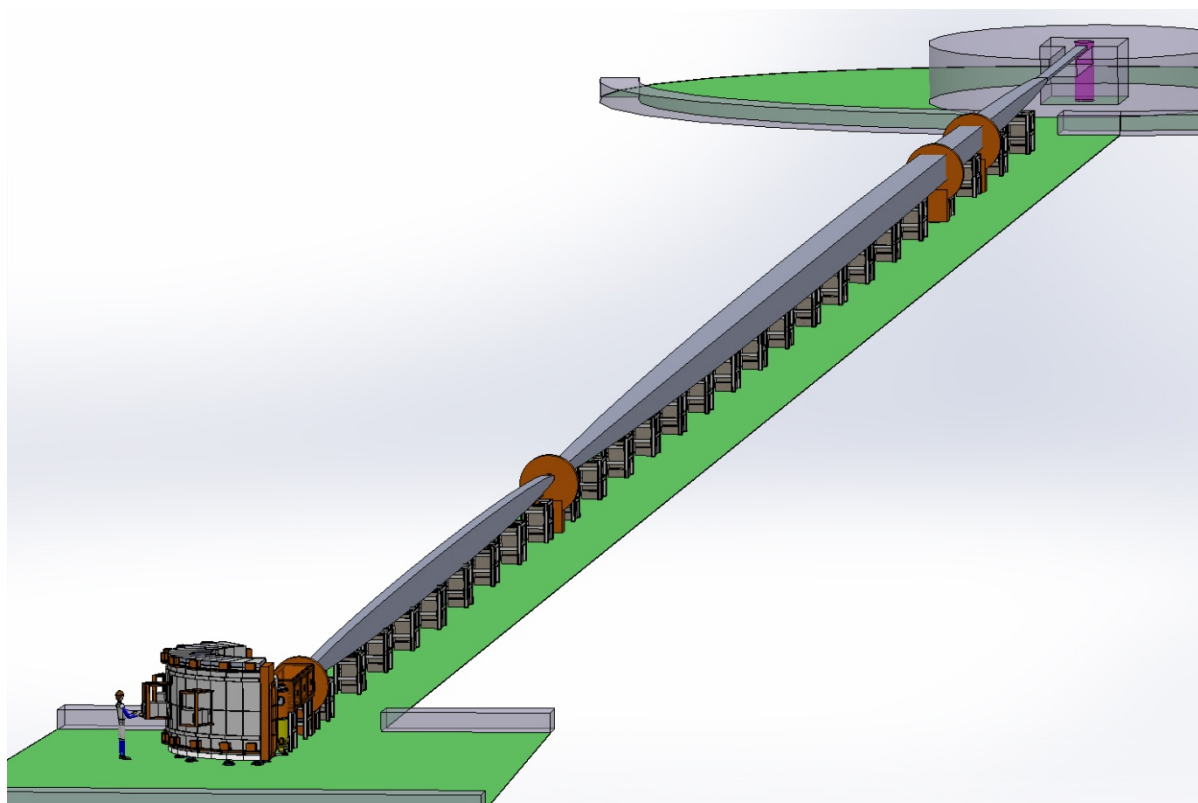
Understand macromolecular conformations changes



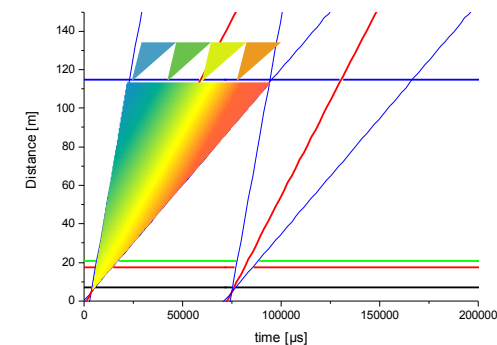
C-SPEC : a cold time-of-flight spectrometer October 2013

C-SPEC: A ToF-ToF concept for long pulse source

A 150 m long chopper spectrometer with multi-frame acquisition



Broad wavelength band :
 1 to 2 orders of magnitude better
 than the current state of the art
 spectrometer



The ESS single crystal magnetism diffractometer MagDif

A. Goukasov and W. Schweika

Join project ESS and Laboratoire Leon Brillouin, France, JCNS

The single crystal magnetism diffractometer profits largely from the ESS long pulse structure, its high flexibility and low background allowing to measure very small samples. Measurements by TOF Laue method efficiently cover the reciprocal space of interest by a single or a few sample settings only.

~2 orders of magnitude gain compared to best existing instruments

- Nuclear and magnetic structure
- Reciprocal space mapping
- Phase transitions in extreme conditions
- Polarized neutron +XYZ analysis

workshop MagDif est prévu pour 26-27 mai 2014

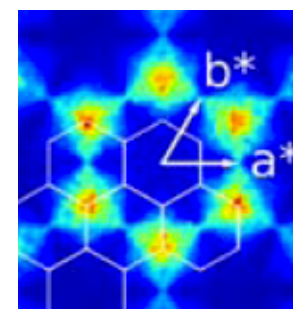
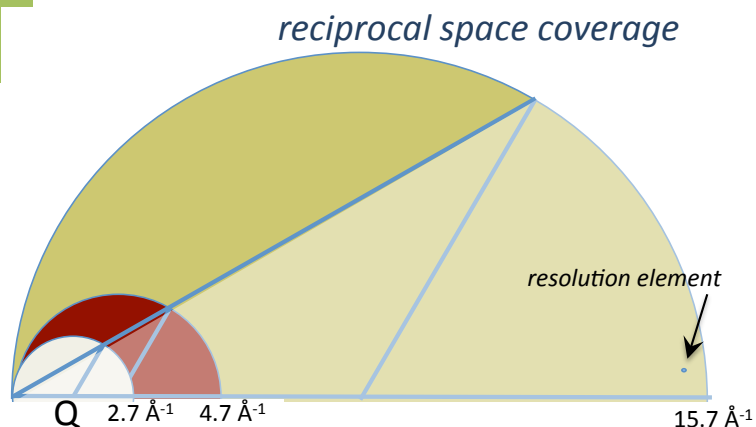
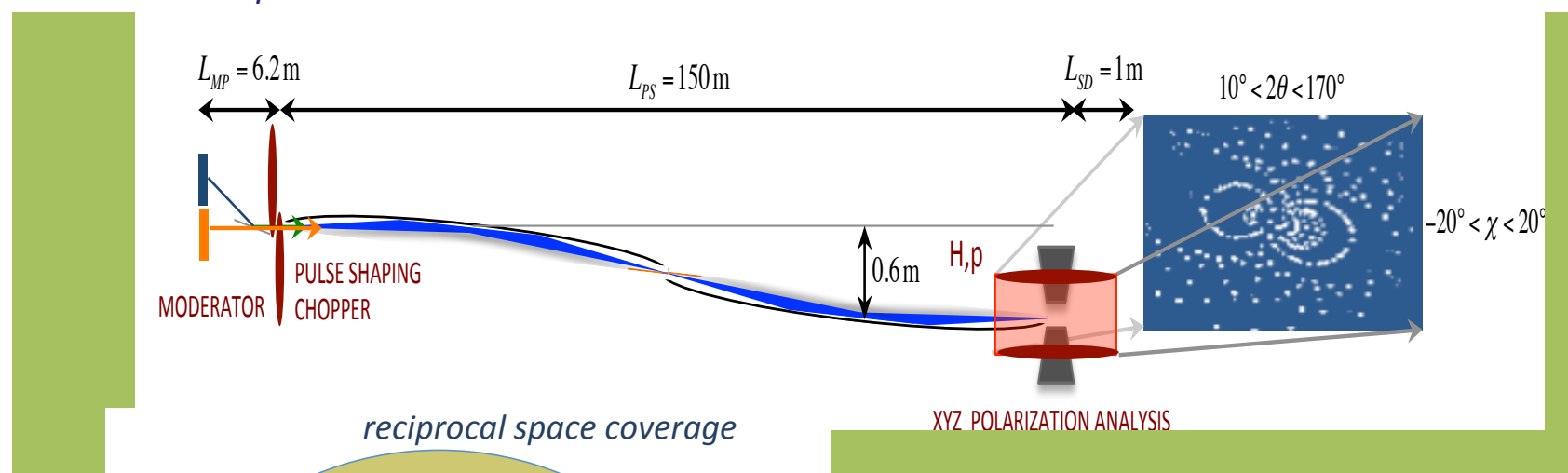
Principal layout of MagDif

thermal + polarization and field

*site susceptibilities
spin densities*

cold + polarization analysis

*magnetic structure determination
diffuse magnetic scattering*



$$\frac{\Delta t}{t} \leq 0.025$$

Reflectometer VERITAS

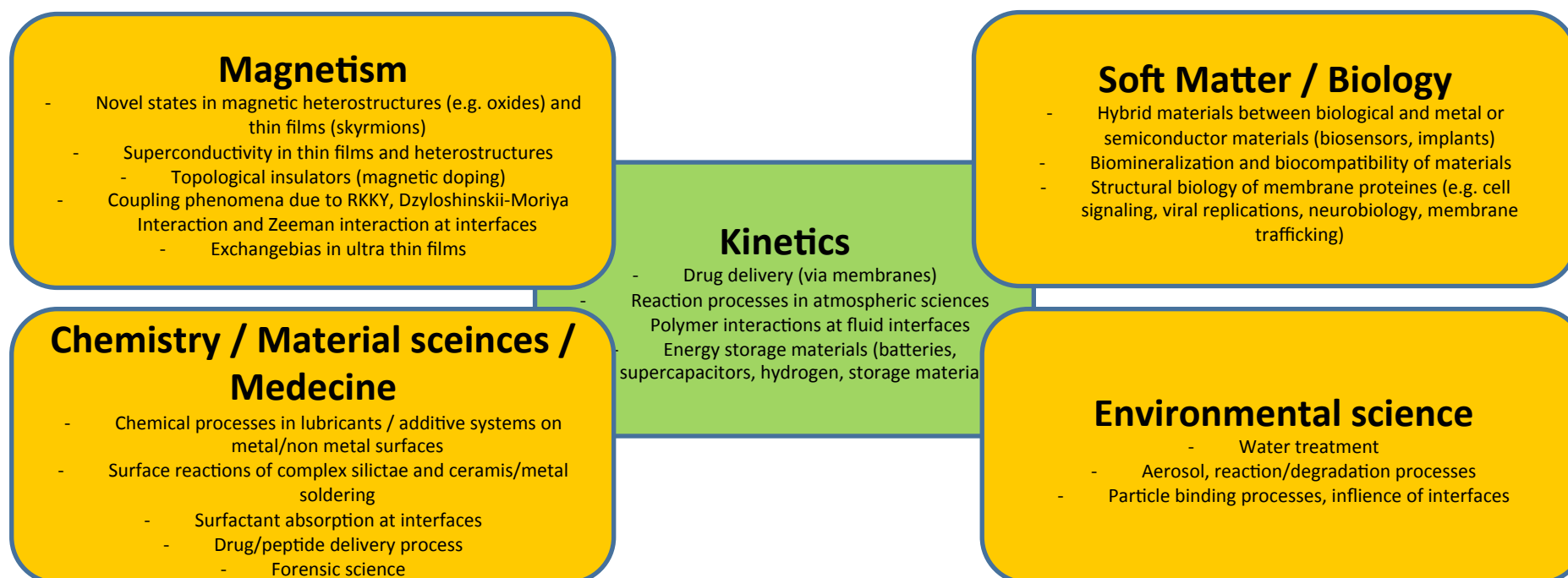
Consortium : JCNS Jülich Centre for Neutron Scattering, LLB Laboratoire Léon Brillouin, HZG Helmholtz Zentrum Geesthacht

F. Ott , A. Menelle

Goal

Very high flux; simple and low risk instrument able to start on Day 1

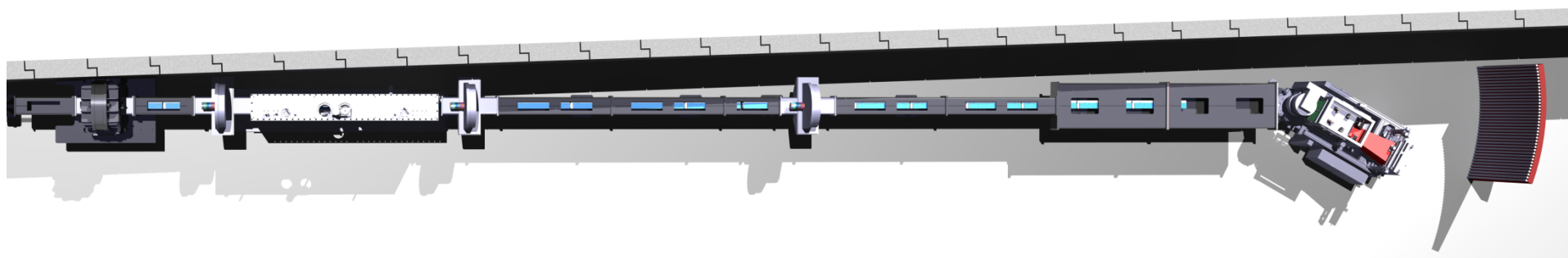
Scientific domains



Reflectometer VERITAS

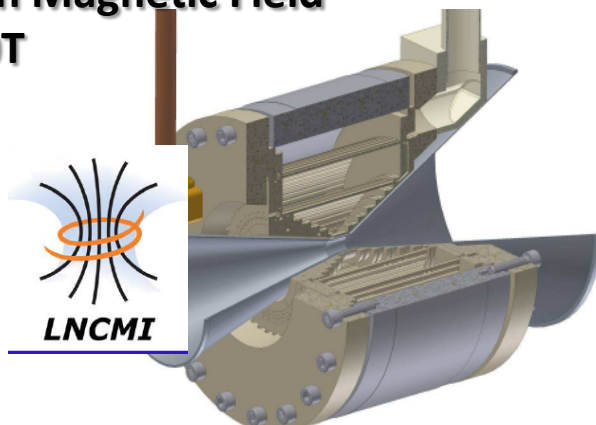
Design

- **Mode standard (high flux)**
 - Résolution $dQ/Q = 10\%$
 - Small samples sizes (1cm^2)
 - length 36m
- **Options (sans compromis sur les performances du mode standard)**
 - high resolution $dQ/Q = 1\%$
 - Focalisation on very small samples ($2\times 2\text{mm}^2$)
 - Kinetics Mode (@ 7Hz)
 - Option small angles scattering (en incidence rasante) (GISANS)



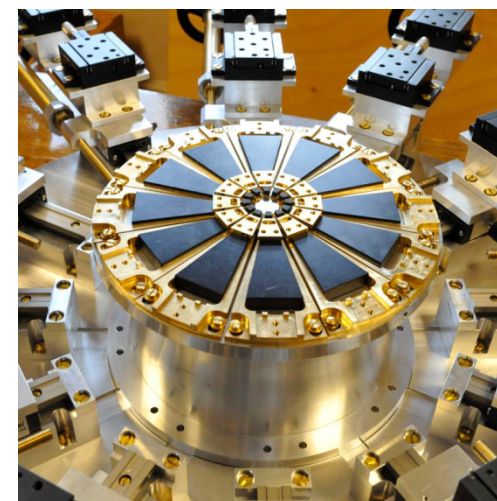
Specific Sample Environments and Extreme Conditions

Very high Magnetic Field
Up to 40T

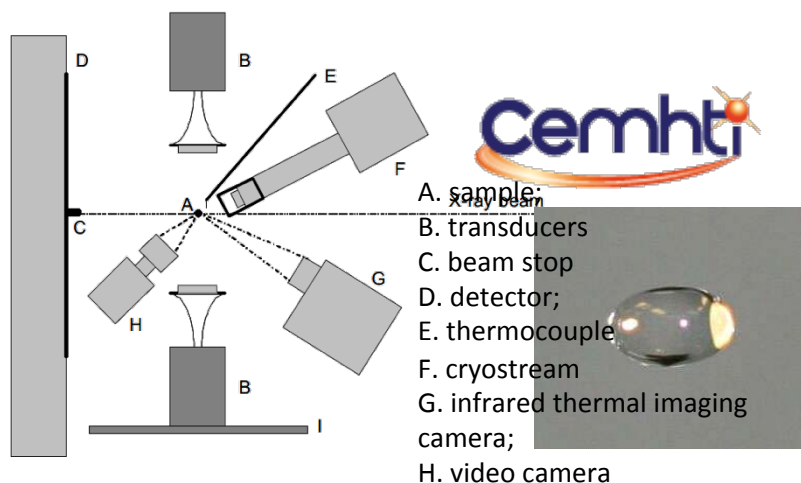


NMR in situ

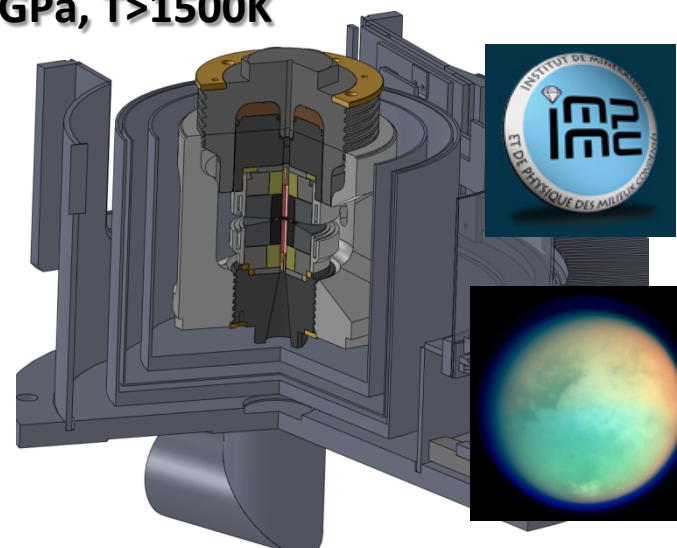
SIS2M /
LSDRM,

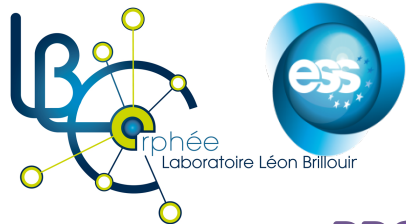


Levitation techniques
aérodynamique et acoustique



Very high Pressure and Temperature
P>15GPa, T>1500K





PROPOSAL FOR INSTRUMENT CONSTRUCTION ESS

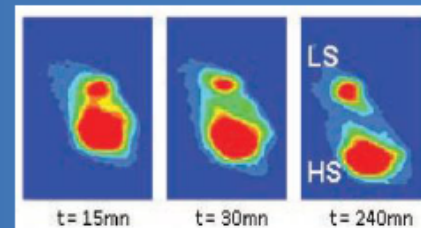
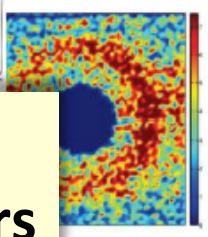
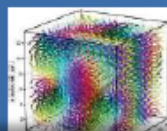
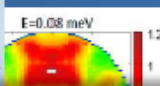
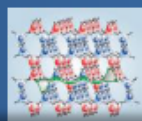
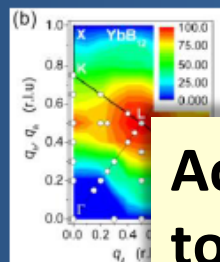
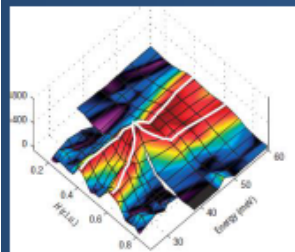
instrument	Date de dépôt	Porteur français LLB Contacts	co proposant
Sans SKADI	oct-13	J Jestin-A Brulet S Desert	JCNS Jülich
C-SPEC ToF	oct-13	S Longeville, JM Zanotti	TuM
Diffraction DIF MAG	oct-14	A. Goukassov	JCNS-ESS
Diffracto poudre POWHOW	oct-13	F Porcher	JCNS-ESS-HZB
Reflectometer VERITAS	oct-13	F Ott, A.Menelle	JCNS Jülich HZG eesthacht
envir /echant	oct-14	S Klimko, P Lavie, B Annighöfer	LNCMI, Univ, CNRS
R&D détecteurs	oct-14	A Menelle, M. Mur	CEA/IRFU

Actions de Formation pour les industriels

Contacts MH Mathon & A.Menelle

Ecoles de neutronique organisées au LLB chaque année





Acknowledgements to many LLB contributors

Sylvain Desert
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Arsen Goukassov
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Dimitrios Sakelleriou
Livia Bove
Louis Hennet
Alexandre Bataille

