IPHI - Neutrons

www.cea.fr

HiCANS
High Current Accelerator-driven Neutron Sources

State of the art

Frédéric OTT
Laboratoire Léon Brillouin CEA/CNRS
IRFU, CEA
Université Paris-Saclay
CEA Saclay 91191 Gif-sur-Yvette France

REMINDER → COMPACT NEUTRON SOURCES = CANS

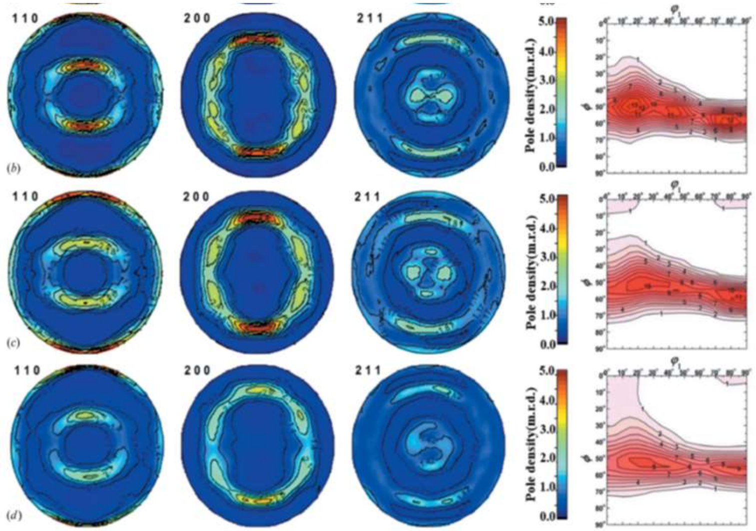
Compact Source Using a low energy (~ 10 MeV) proton accelerator

- Technologically, a new solution for neutron scattering
  - Use of a low energy accelerators (7-13MeV) (Vs 1-2 GeV for a spallation source)
  - Reduced investment costs (5 - 10 M€)
  - Reduced operation costs (0.5 - 1 M€)

RANS at RIKEN (Japon) (100W – 700W)

RANS@RIKEN

- E_p = 7MeV
- Use of 30µs pulses at f = 115Hz → Duty Cycle = 0.35% (100W)



RANS (**100W**)

TAKUMI@JPARC

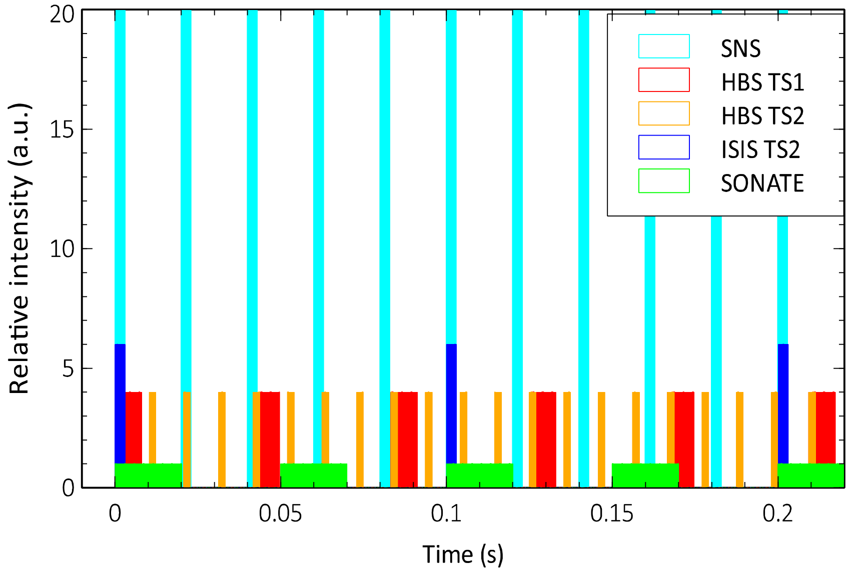
HIPPO@LANSCE

HOW FAR CAN WE PUSH THE PERFORMANCES ?

Existing CANS in operation : P_{target} < 1kW

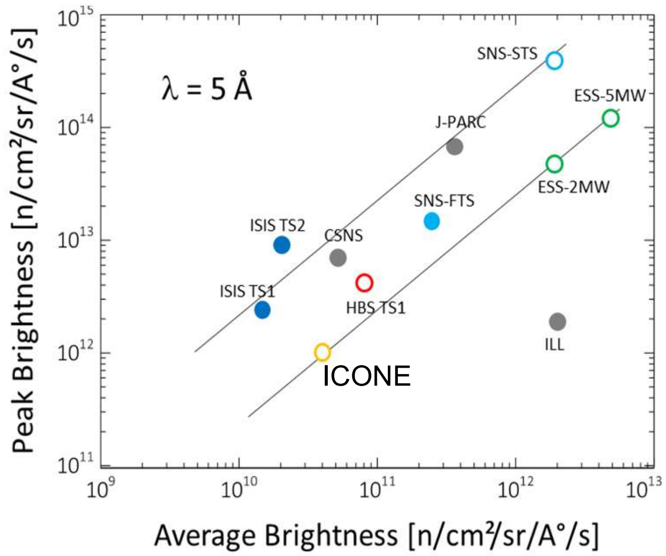
1°/ Increase the proton energy → 25 – 70 MeV (neutron yield increases)
2°/ Increase the proton current I_{peak} = 100 mA (I_{av}= 2mA, I_{RIKEN} = 0.01mA)

→ **HiCANS High Current Accelerator-driven Neutron source (20-100kW)**



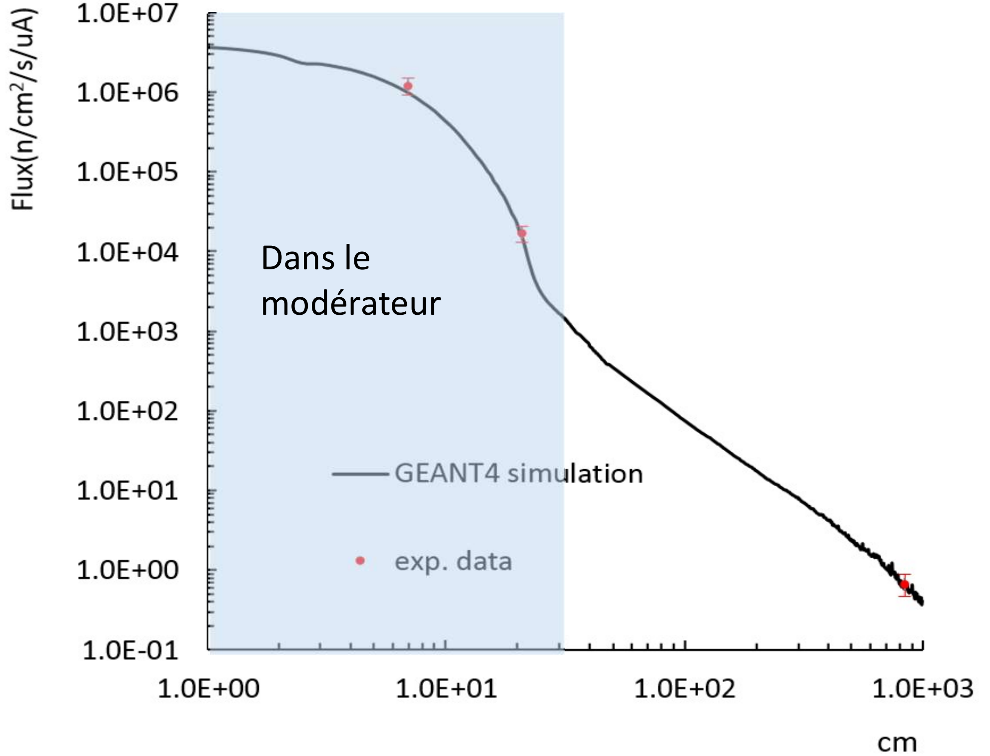
For legibility, the width of the pulses have been dilated by a factor 10.

ICONE: E_p = 25 MeV, I_{peak} = 80 mA, duty cycle = 4%, P = 80 kW
HBS: E_p = 70 MeV, I_{peak} = 100 mA, duty cycle = 1.5%, P =100 kW



Numerical simulations of the neutron production on a CANS / HiCANS

- MCNP and GEANT4 and TRIPOLI and OpenMC



IPHI measurements
Inside and outside
the moderator

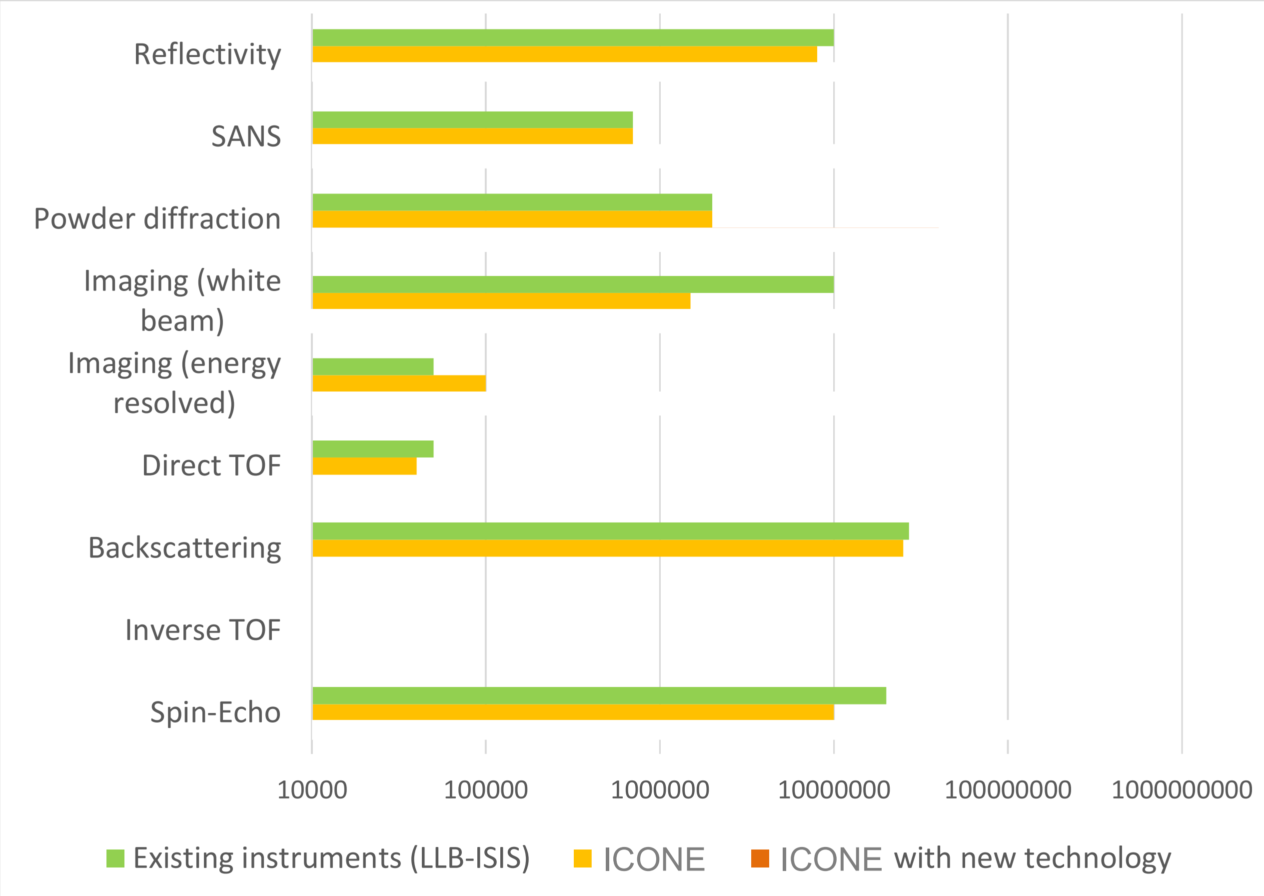
- These results can be fed into Monte-Carlo simulation of instruments (McStas)

INSTRUMENTS PERFORMANCES ON ICONE

ICONE
Neutrons for Materials Sciences

Reference design ICONE

E_p = 25 MeV, I_{peak} = 80 mA, duty cycle = 4%, P = 80 kW



Neutrons at sample position [n/cm²/s]

Motto: build the source for the instruments

HiCANS ingredients:

- High average current (3mA vs 0.3mA) (x10)
- Fort couplage cible – modérateur (x2)
- Modérateur directionnel (x3)
- Optimisation structure temporelle (x2)

Design HBS 70MeV

	Length [m]	Resolution	Bandwidth	Flux [cm^{-2} s^{-1}]	Frequency [Hz]
SANS	20.0	5% $\Delta\lambda/\lambda$	2.0-9.0 Å	9.4×10^7	24
Reflectometer	22.0	4% $\Delta\lambda/\lambda$	1.3-8.0 Å	1.7×10^7	24
Thermal powder diffr.	100.8	0.0061-0.014 $\Delta d/d$	0.75-2.4 Å	1.5×10^8	24
Cold neutron imaging I	6.0	2.0-10.0%	1.0-15.0 Å	3.0×10^8	96
Disordered material diffr.	61.0	0.016-0.028 $\Delta d/d$	0.5-1.2 Å	1.9×10^7	96
Macromolecular diffr.	12.5		2.0-4.0 Å	4.0×10^7	96
Cold chopper spectr.	18.5		1.6-10.0 Å	3.4×10^5	96
Backscattering spectr.	102.5	3.0-20.0 μeV	6.05-6.0 Å	7.0×10^6	96
Epithermal neutron imaging	37.0		25-80 meV	5.0×10^9	384
High energy chopper spectr.	28.5	4% ΔE/E	0.5-2.5 Å	9.0×10^4	384
PDGNAA-2	21.0	50%	0.6 eV - 10 MeV	2.7×10^7	384

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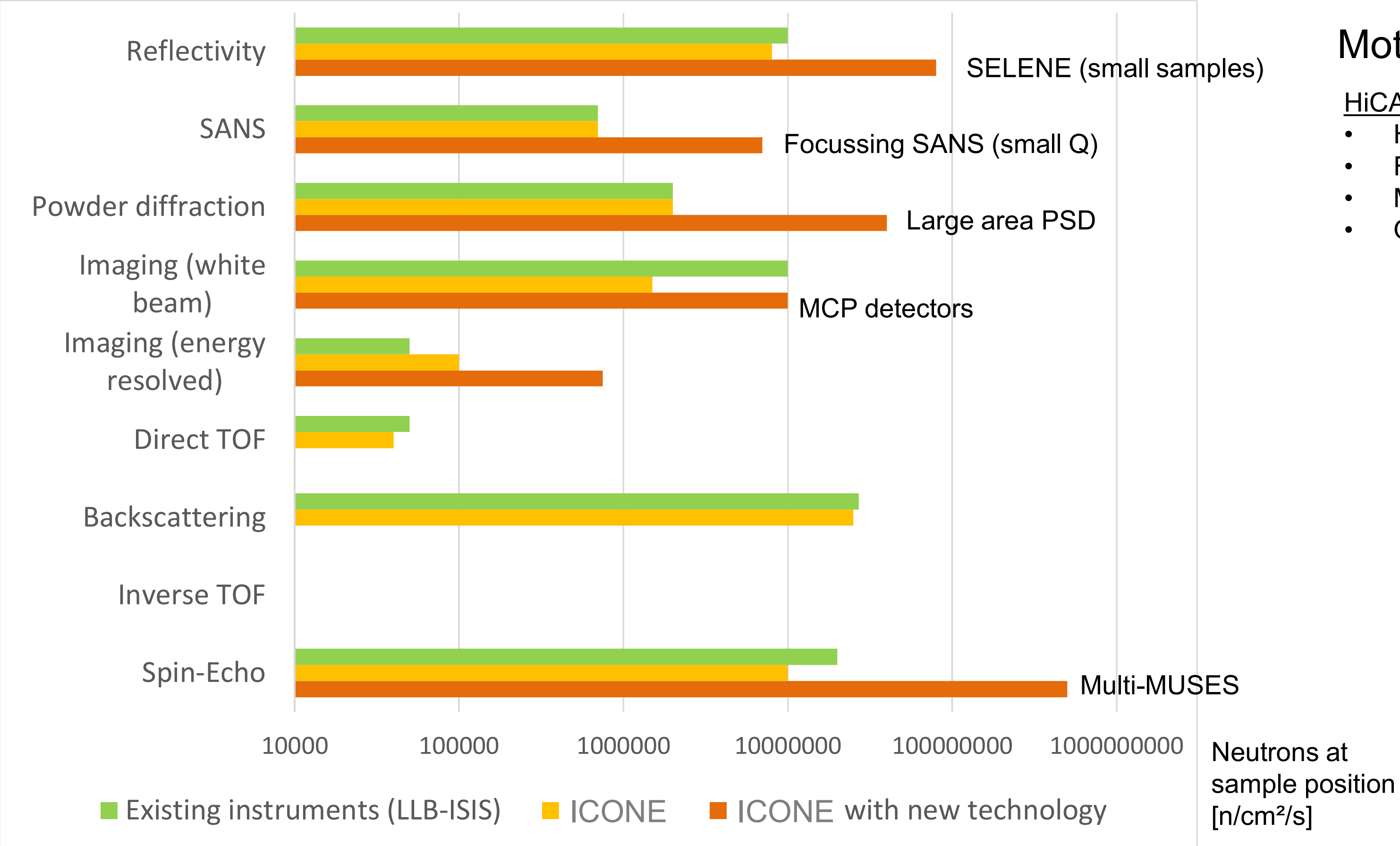

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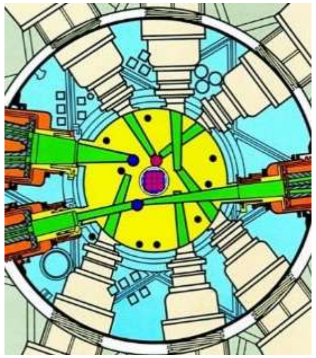
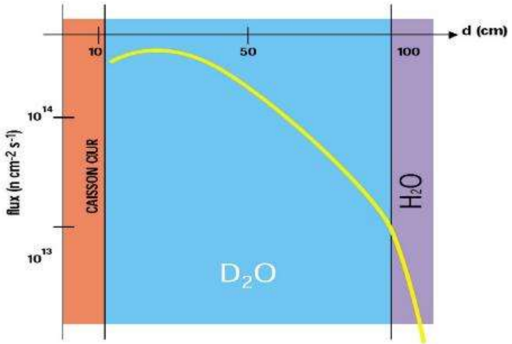
MAXIMISING THE BRILLANCE: STRONG COUPLING

Reactor

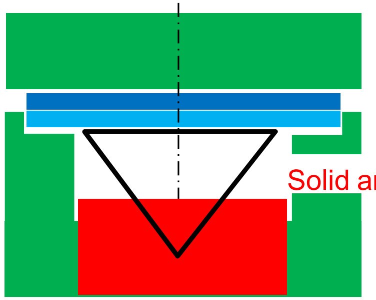
- Core = 0.1 m^3
- Moderator vessel D_2O ~ 1m^3

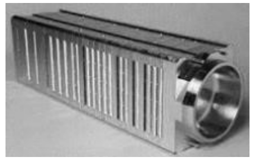




Spallation

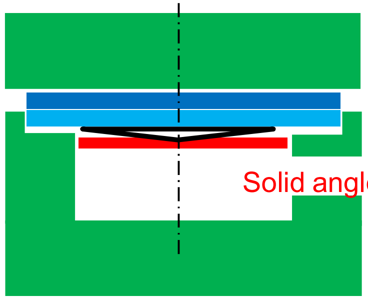
- target = 4 litres
- moderator ~ 1 litre (not too well coupled)

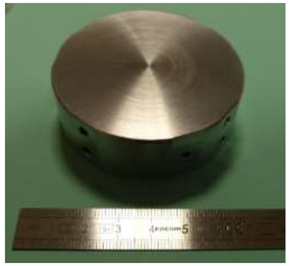




Low energy nuclear reactions

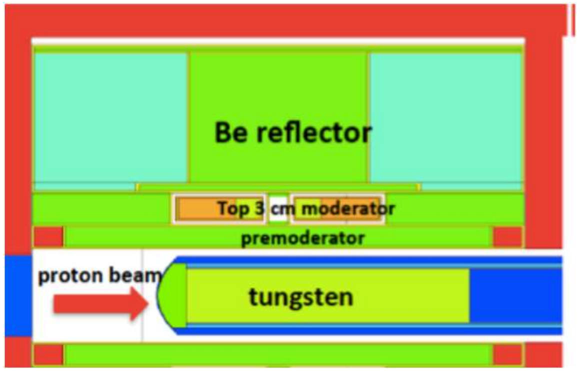
- Target = 0.05 litres
- moderator ~ 1 litre (coupling 90%)

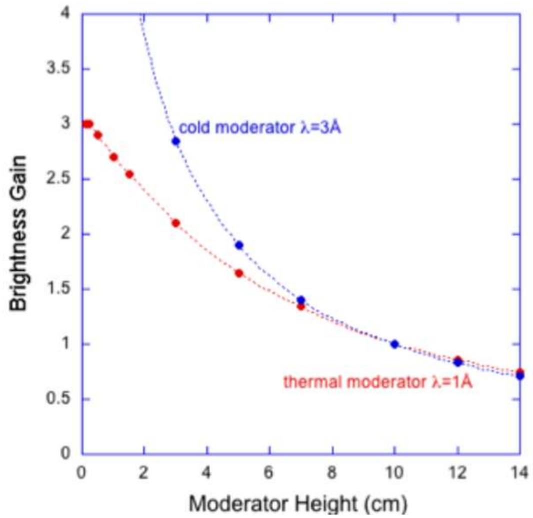


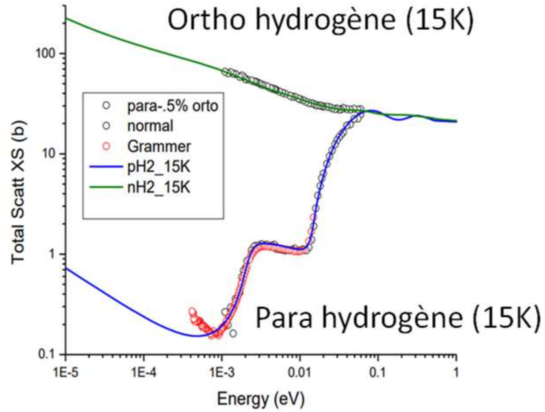


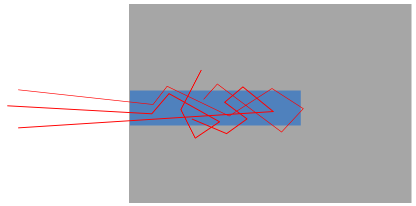
Reduced dimensionnality (disk - cylinder) to increase the brillance

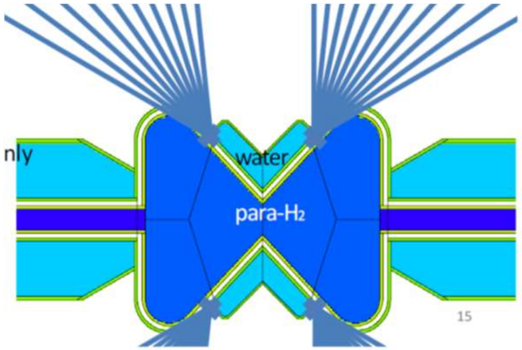
- Developed for ESS
- To be experimentally demonstrated







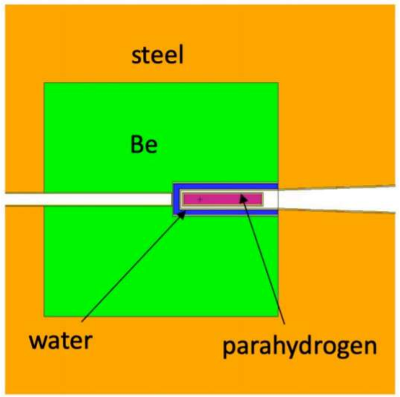




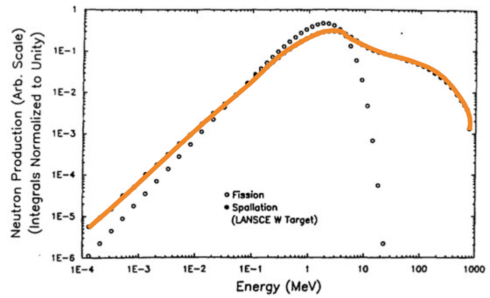
1D

Brillance (x7)

Zanini (2020)



HICANS VERSUS SPALLATION SOURCES



1°/ Accelerator (20 MeV à 70 MeV) Versus (800MeV @ ISIS)

- Construction and operation costs are reduced
- Reduced electrical consumption

2°/ Low proton energies ➔ Little production of energetic secondary particles (neutrons, gamma) E_n et $E\gamma < E_p$

➔ Reduced shielding : 20T Vs 6000 Tonnes
One can get closer to the source → important for time-of-flight instrumentation

➔ Lesser structures activation → reduction of the quantity of produced activated materials

➔ Background noise on the instruments is reduced or at least the lower limit is easier to achieve

➔ A lot less radiative heating
A few watts are deposited on the moderator compared to kW on a reactor

The technical concepts must be experimentally demonstrated

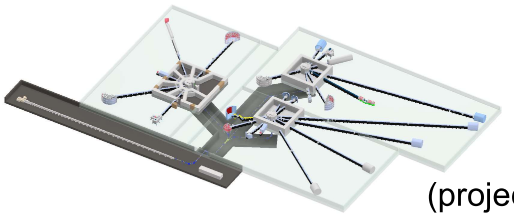
INITIATIVES ABROAD

ELENA
European Low Energy accelerator-driven Neutron facilities Association

LvB in Hungary
(MIRROTRON)

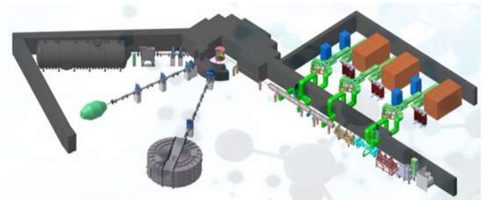
Commiss.
(2.5kW)

HBS in Germany
(FZJ / JCNS)

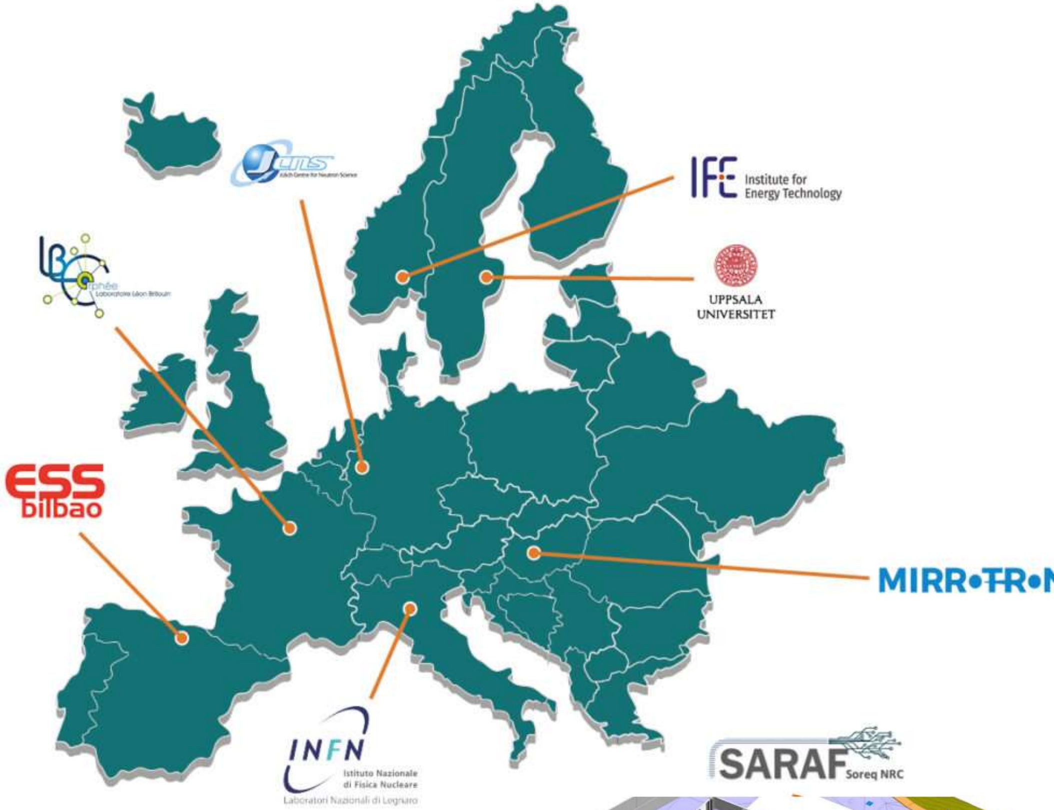


(project)

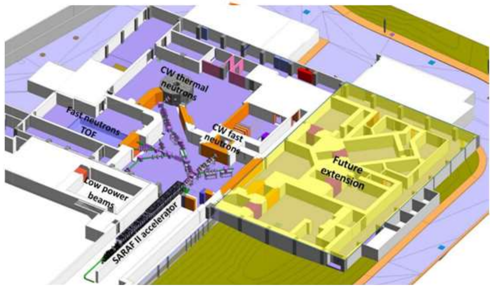
ARGITU in Spain
(ESS Bilbao)



(project)



Commiss.
(200kW, CW)



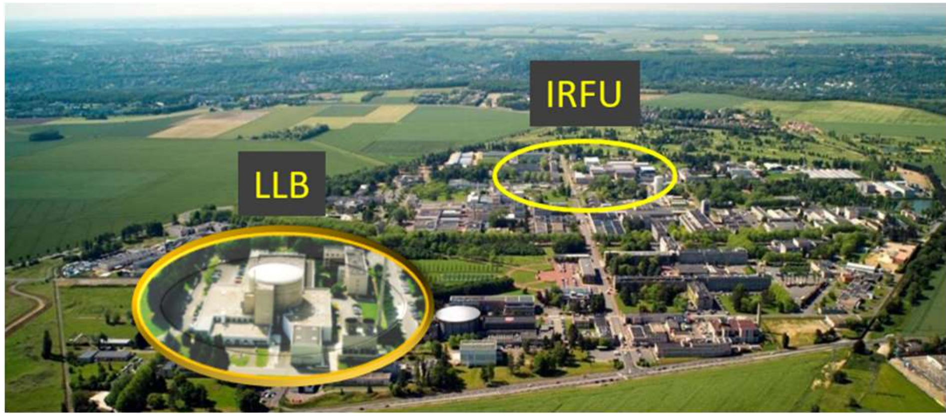
ACTIVITIES AT SACLAY

PHASE « 0 » : LE PROJET IPHI – NEUTRONS

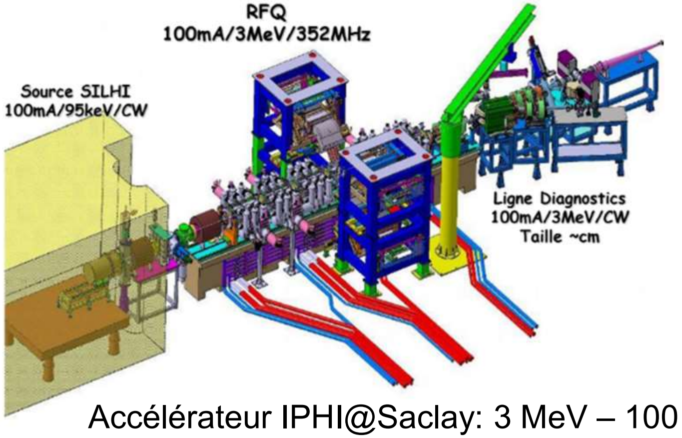
Projet SESAME (2017-2021) îledeFrance

<u>Objectives :</u>

- Develop a high power 50kW target
- Install a neutron scattering instrument

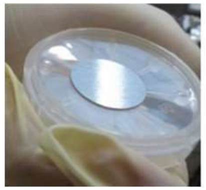


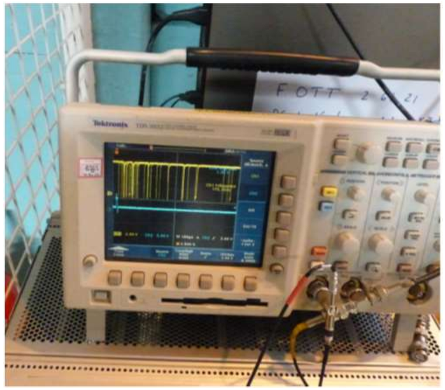
2016 La première expérience
IRFU – LLB, 13 juin - 6 juillet 2016
Puissance du faisceau = 10 W
sur un disque mince en Béryllium



Accélérateur IPHI@Saclay: 3 MeV – 100 mA pic

Neutron pulses
100 μs @ 1 Hz





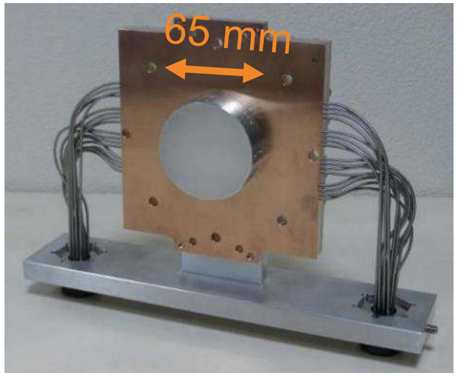
Activités **IRFU** + IRAMIS/LLB, période 2018 - 2022

IRAMIS/LLB
IRAMIS/NIMBE
IRFU/DACM
IRFU/DIS
IRFU/DEDIP
IRFU/DPhN
SPR

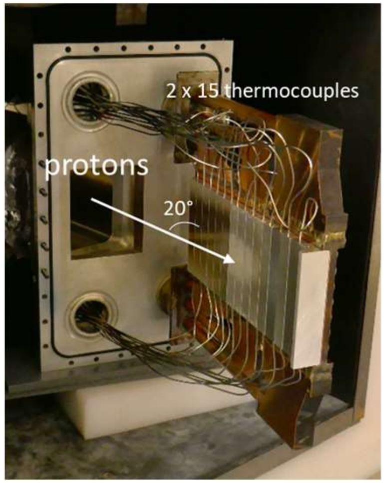
- Simulations neutroniques
- Calculs thermomécaniques
- Conception mécanique cible, modérateur, blindage
- Réalisation de deux versions de cibles
- Mécanique, diagnostiques
- Fiabilisation, optimisation et opération d'IPHI
- Radioprotection et sécurité Béryllium
- Réalisation de campagnes de tests
- Mesures flux de neutrons, imagerie, diffraction

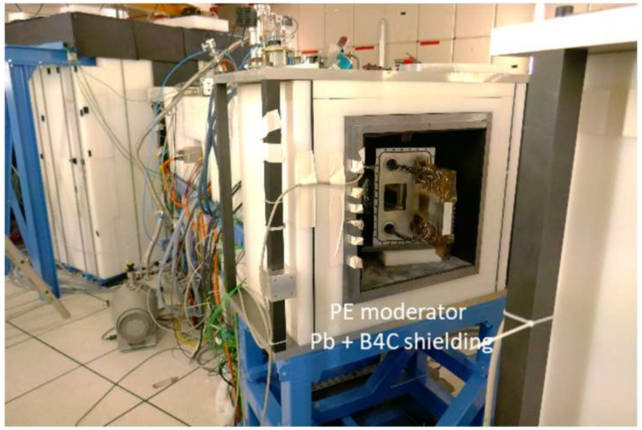
HIGH POWER TARGETS PROTOTYPES

2019 - 2020



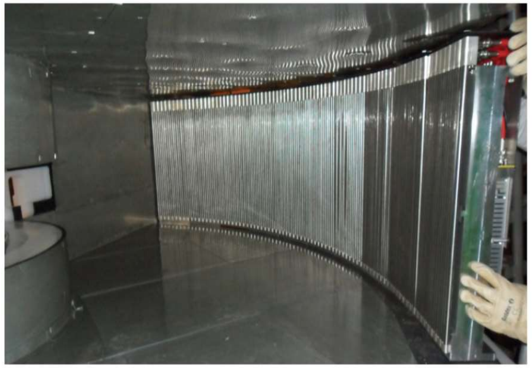
2021 - 2022





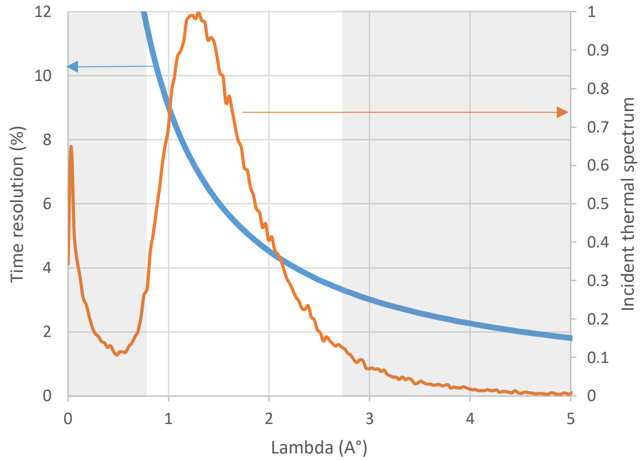
Long term operation of a 30 kW Beryllium target at IPHI.
J. Schwindling et al, Journal of Neutron Research, vol. **24**, no. 3-4, pp. 289-298, 2022.
DOI: 10.3233/JNR-220024

DIOGENE@ IPHI-NEUTRONS



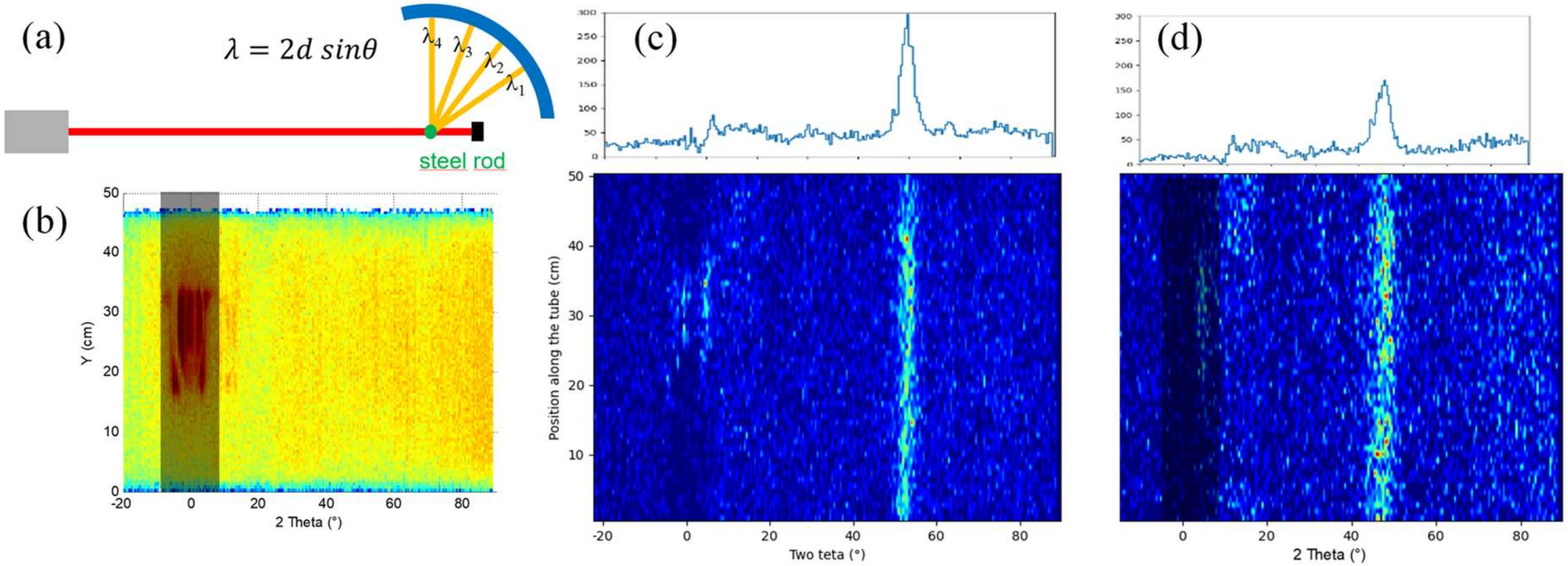
DIoGENE : Un diffractomètre de neutrons

- 256 tubes ^{3}He tubes
- Angle solide = 0.74 sr
- Event mode electronics (Mesytec)
- Shielding 10cm PE + Cd

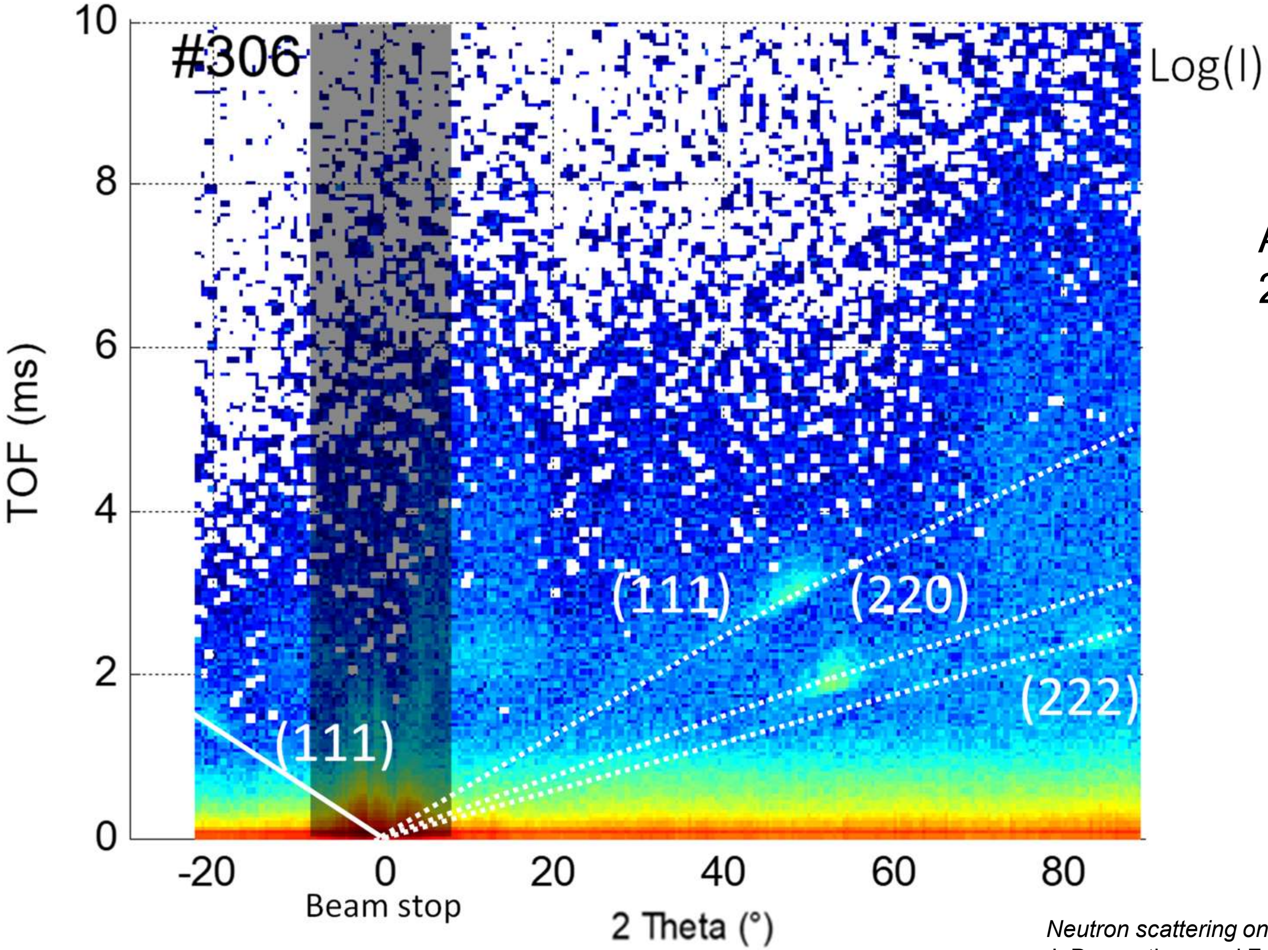


Une base de vol courte → 6.6m

POWDER DIFFRACTION



MESURE DE DIFFRACTION (2)

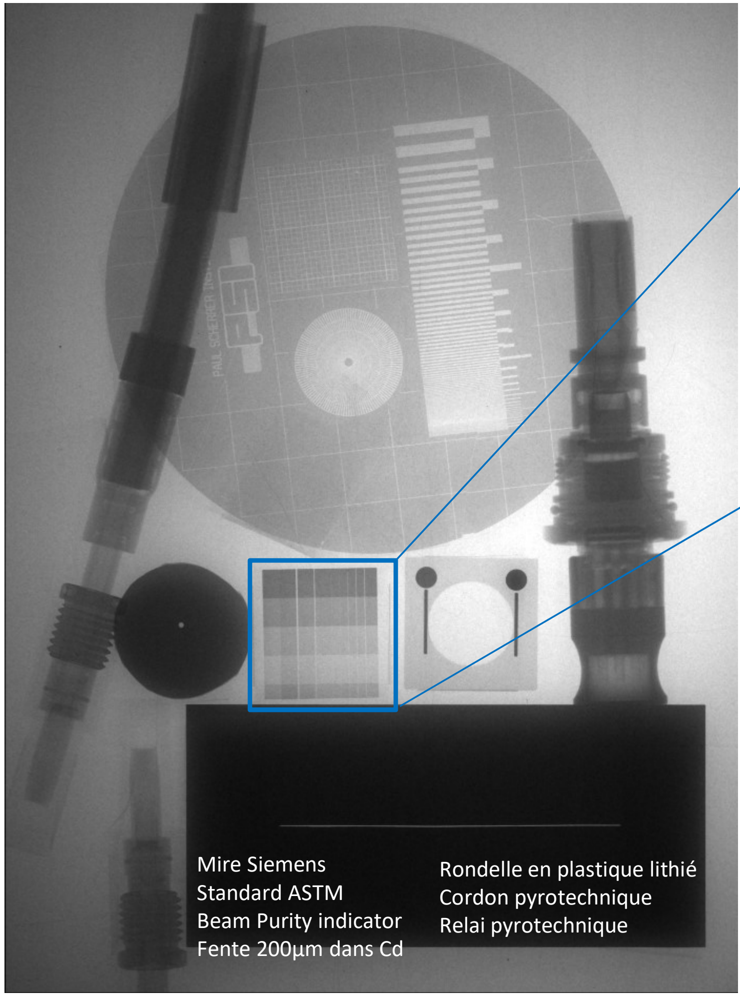


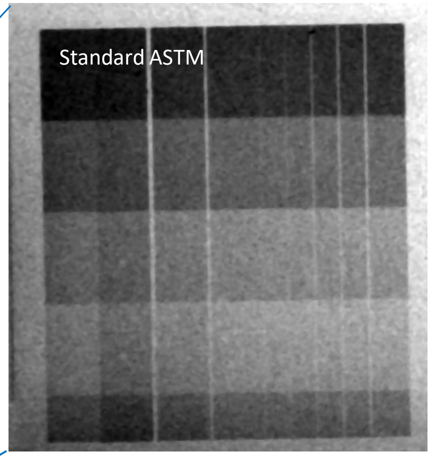
Austenite steel rod
200W, 1 hour

Neutron scattering on DIoGENE at IPHI–neutrons.
J. Darpentigny and F. Ott, Journal of Neutron Research **24** (2022) 385–393 385.
DOI 10.3233/JNR-220018

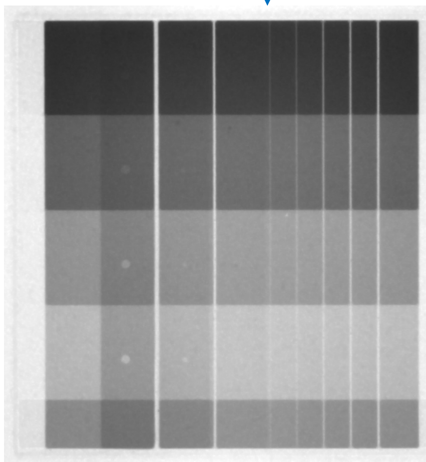
NEUTRON RADIOGRAPHY

IPHI 1hour at 3kW





Spacer 15µm



G45 « standard conditions » (P = 14MW)

DIOGENE : diffractometer at IPHI – Neutrons

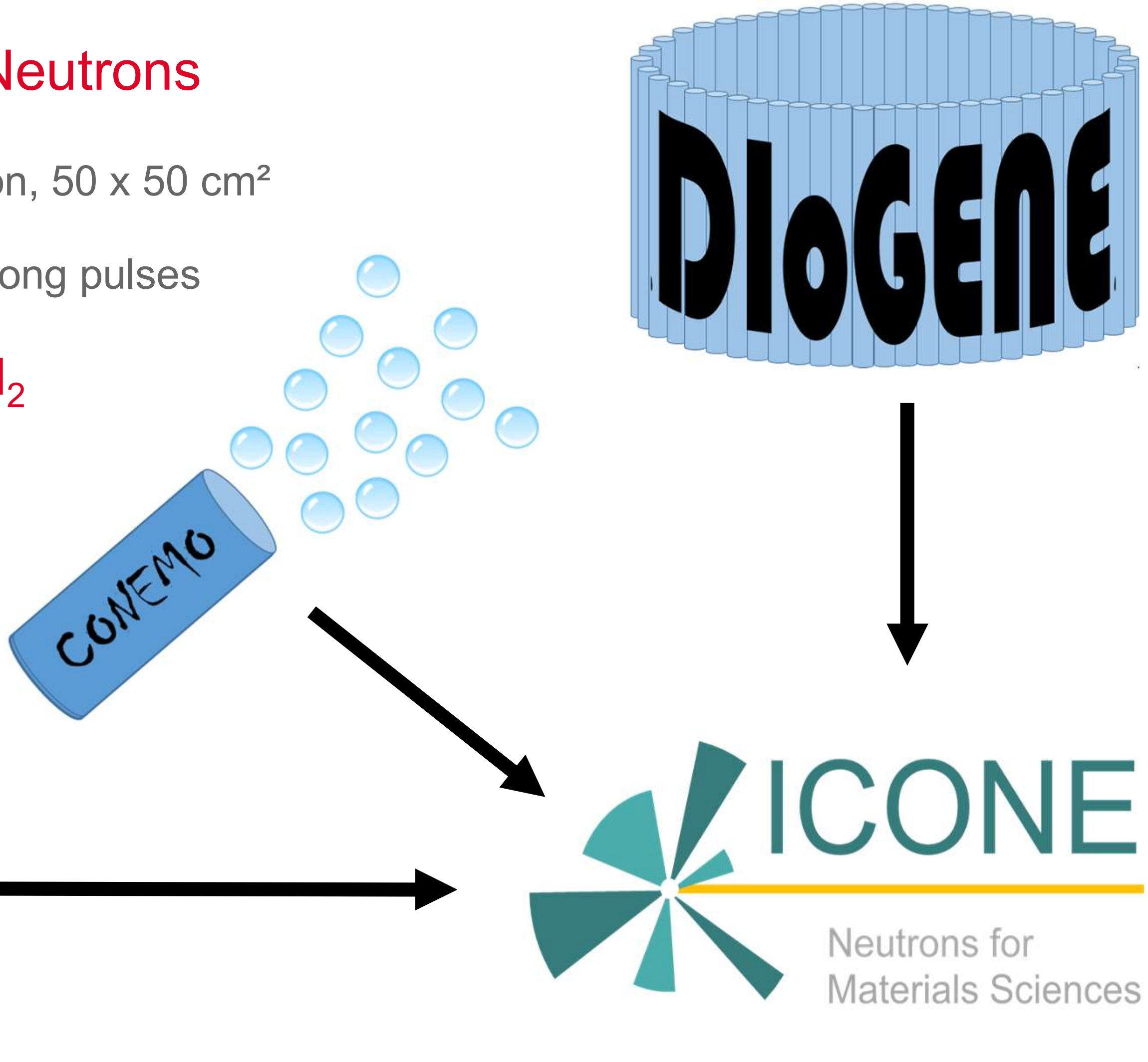
- Upgrade of 2 detectors banks
  → « SANS detector », 5mm spatial resolution, 50 x 50 cm²
- Reflectivity + SANS
- Statistical chopper → haute résolution with long pulses

CONEMO : cold moderator using para-H_2

- Financement PTC

RAEVEN

- Event mode radiography



CONCLUSIONS

The performances of a HiCANS are potentially equivalent to a medium power research reactor or spallation source

- The construction and operation costs are reduced

Technologies

- Accelerator OK
- Target → test on-going (+ other solutions under development)
- Moderator OK / can be updated
- Instruments OK

Possibility to benefit from the French ecosystem

- Scientific and technical expertise at Saclay and Grenoble
- Users
- Possibility to reuse R&D efforts from ESS
- Existing instrumentation

Objective : a new French neutron scattering facility