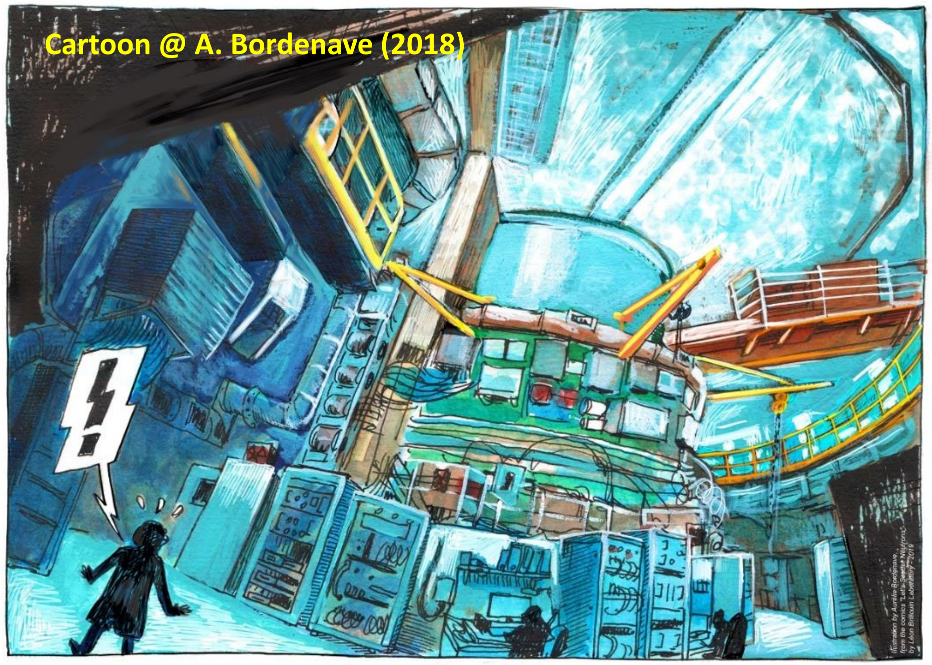
New high-power Beryllium target for a high intensity compact neutron source



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The Laboratoire Leon Brillouin (CEA – CNRS) and the Institute for Research into the Fundamental laws of the Universe (IRFU-CEA) are cooperating to realize the French CANS SONATE

New high-power Beryllium target for a high intensity compact neutron source

OUTLINE

- Context
- The project : on the road to « Sonate »
- Progress status -> focus on the Be target
- Conclusions

Context

European Neutron landscape : a large capacity, a large community but some risks

International facility : ILL Grenoble (France) -> ok until 2032
National facilities : ISIS (UK), PSI (CH), FRM2 (Germany), BNC (Hu), etc.
→ but closure of BER2 (Germany) and Orphée (France) in 2019

Coming up : ESS-Lund (Sweden)
Very large investment at the continental level
Absolute need to maintain/develop national sources

Need of new neutron sources to maintain a healthy user community (conclusion from all surveys)

HiCANS a versatile cost effective solution :

- Without fissile material
- From 20 M€ to 200 M€
- Upgradable
- Able to provide instruments with similar performances than the one on medium flux reactors

Context

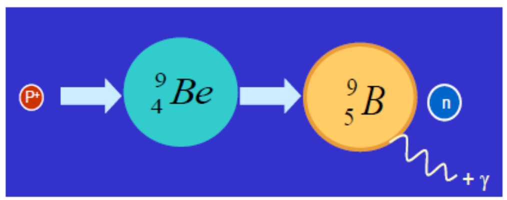
French Neutron landscape : a sharp decrease fo beam-time access since 2019

- Orphée was stopped in 2019
- RHF (ILL) will be stopped some day beyond 2032
- French participation to ESS will give limited access to users

~90% decrease of beam days available
Common understanding : Our current model of use of neutron scattering will change
How to make the best out of the ESS investment ?

We need a "good-value-for money" neutron source (~2-3k€ / beam day) proposing instruments with significant performances to nurture an ecosystem of neutron users.
This is the **Sonate project** based on a low-energy proton accelerator and a light-element target (Be)
→ "stripping process" for neutron production

Low energy protons (3 – 60 MeV) strip a neutron from a light element (ex. Be, Li):



The Project:
On the road to « Sonate »

HiCANS are becoming efficient because of rapid progress in :

- Neutron optics for neutron extraction
- Low dimension moderators (eg. ESS)
- Large detectors
- Large data sets treatment (eg. ESS, SNS, ISIS, J-Parc)
- High intensity accelerators (eg. ESS)

Current technological limitation : Target ageing able to sustain beam power for enough time

Various solutions :
Liquid target (Li, GaIn) : SARAF
Rotating Be targets : NFS, ANEM
Encapsulated Li : NUANS
Multilayer target : RANS, ARGITU
Metallic target at higher energies : HBS
High temperature target : Sonate

Sonate choices

Sonate
NEUTRONS FOR MATERIALS SCIENCE

Reduced operating costs
Multiple targets on a single accelerator
Fixed target easy to change -> high temperature Be target
Low energy operation for low activation (20 MeV max)

Optimized performances
Multi-moderator targets adapted to every instrument
Use of large area detectors and chopper beam shaping
Accept low resolution and statistical choppers
Advanced neutron optics

The Project:
On the road to « Sonate »

SONATE : THE FUTURE COMPACT NEUTRON SOURCE FACILITY IN FRANCE

"Neutrons for Materials Science" facility

Proton beam (100 mA peak current and E=20 MeV)

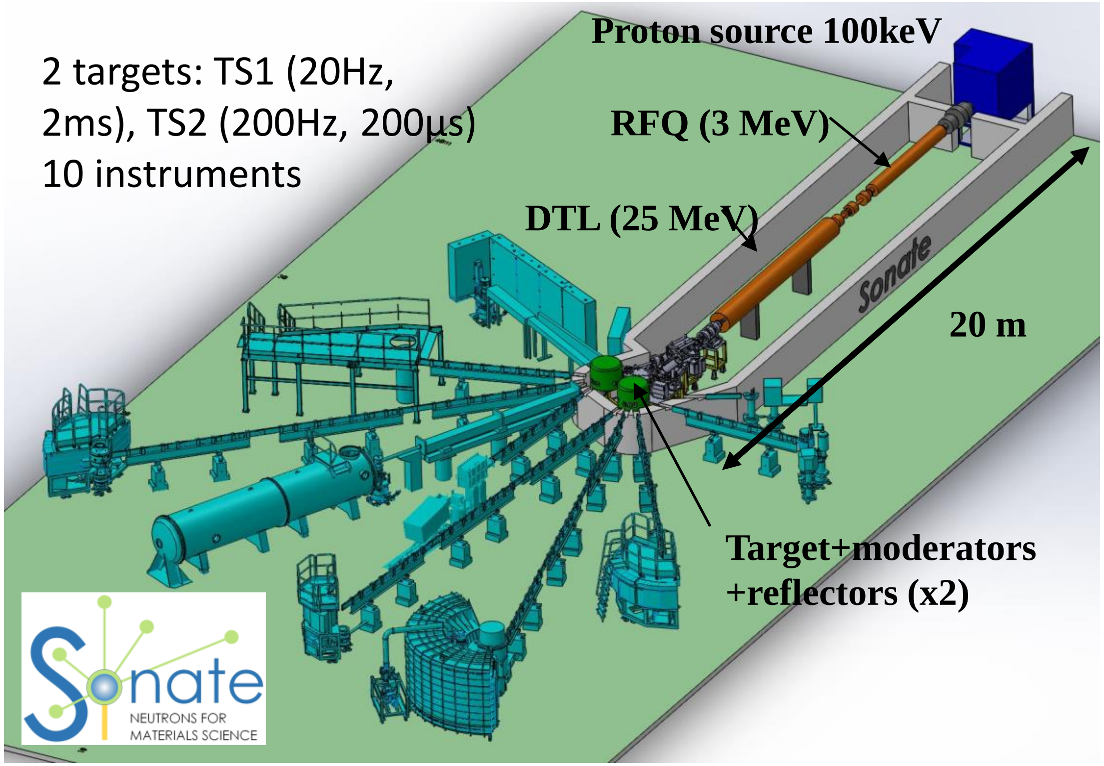
2 Be targets :

Long pulses, 4% duty cycle, 2 msec – 20 Hz, 80 kW, 5 10^8 $n_{th}/cm^2/s$ at target wall

Short pulses, 2% duty cycle, 200 msec – 100 Hz, 40 kW, 2.5 10^8 $n_{th}/cm^2/s$ at target wall

Up to 5 instruments per target (eg. powder diffraction, SANS, reflectometer, imaging, TOF spectroscopy, etc.)

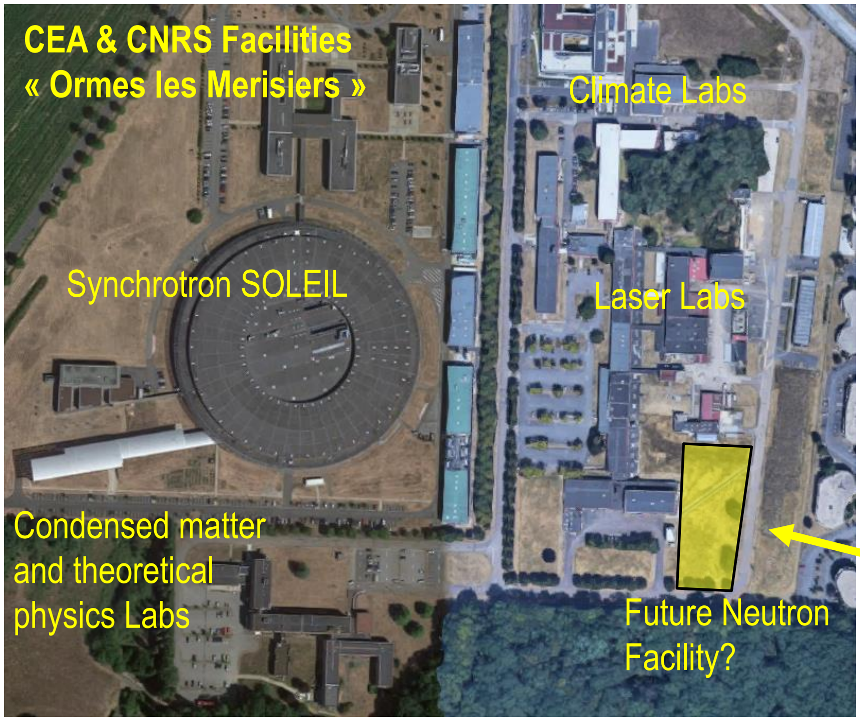
2 targets: TS1 (20Hz, 2ms), TS2 (200Hz, 200µs)
10 instruments

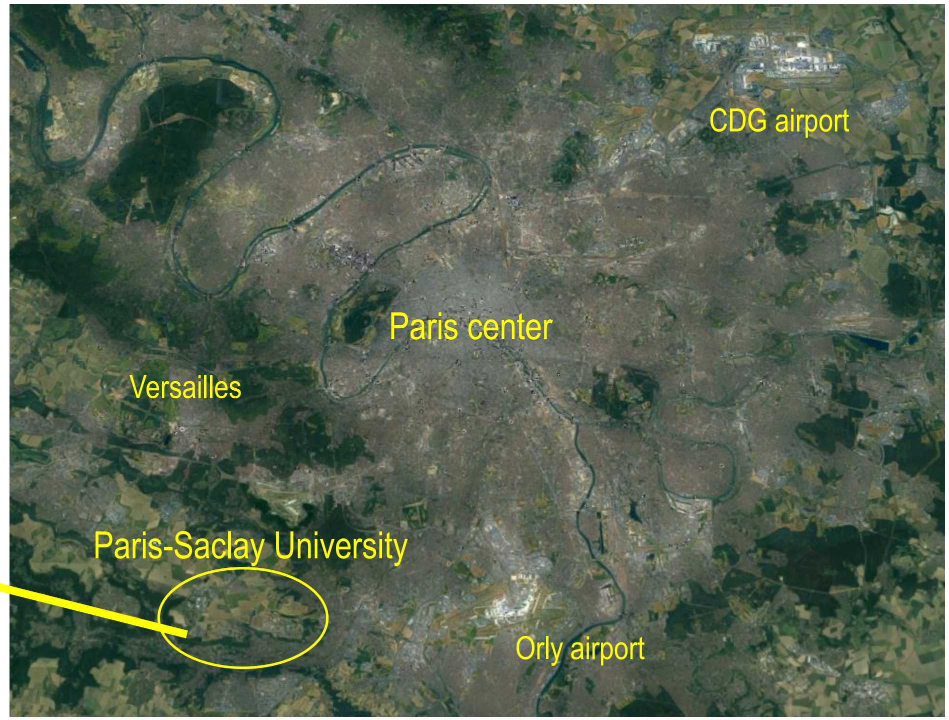


Anticipated performances are equivalent to a medium power nuclear reactor

The Project:
On the road to « Sonate »

A new French Neutron Source
in the Paris-Saclay vast ecosystem





université PARIS-SACLAY

13% of France's research potential with 275 labs and about 17000 staff

Progress Status :
Focus on the Be Target

Build a single target demonstrator

Ion source

RFQ (~3 MeV) + DTL (~20 MeV)

Light-element target

3 test instruments (powder, SANS, imaging)

Funding by:

îledeFrance

cea

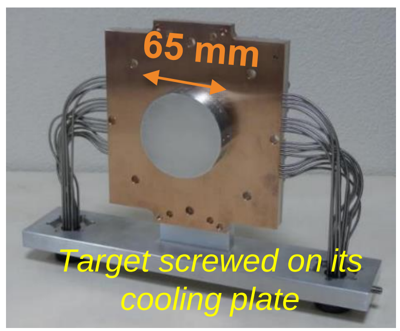
IPHI : the high-intensity proton injector

The IPHI accelerator in Saclay

Designed to sustain **0.5 kW**

2 inches Be wafer screwed on Cu block

Water cooled



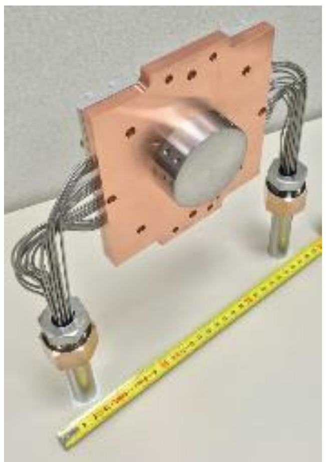
The small Be Target

Tested on IPHI in 2019 and 2020

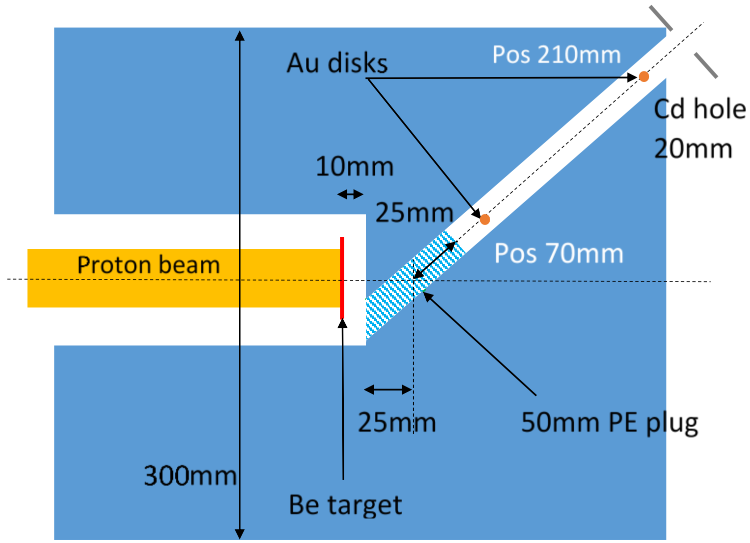
- Beam power ~ 3.5kW
- No significant evolution, stable neutron flux
- No Beryllium found in the beam line
- Validation of thermo-mechanics
- Blisters occur after a few hours

The polyethylene block around the Be target

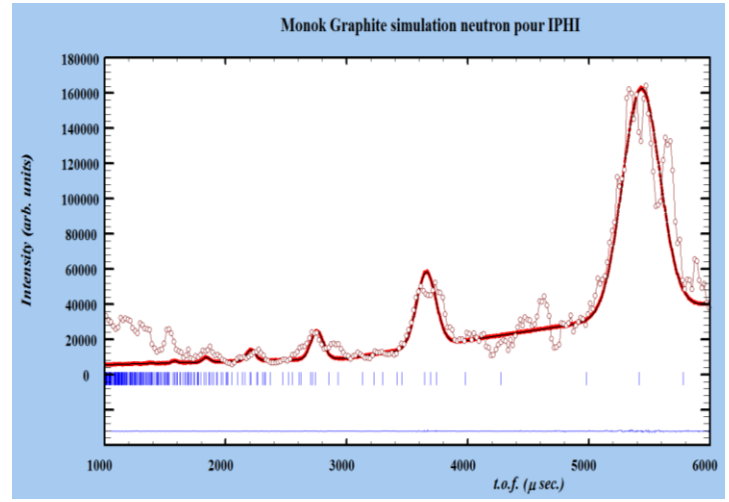
Progress Status :
Focus on the Be Target



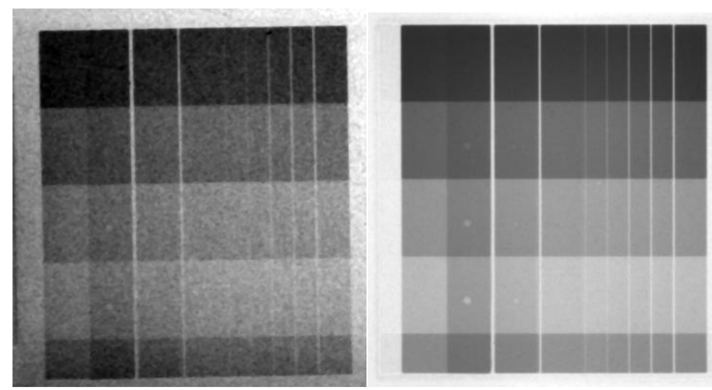
The small Be Target



Diffraction of Graphite



- **Verification of the flux calculation**
- **First neutron radiography done**
- **First diffraction measured**



Standard ASTM measured
on IPHI (left) and Orphée (right)

Progress Status :
Focus on the Be Target

A high power Beryllium target has been tested

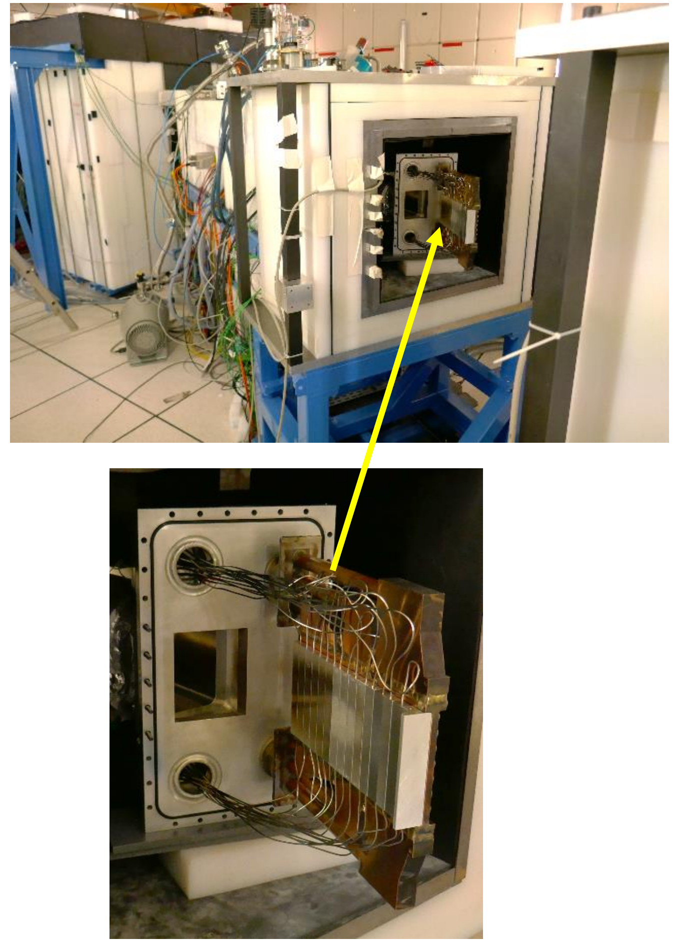
- Operation at 28kW for 107 hours (3200 Coulombs)
  - Operation with 2 shifts (2 x 8 hours/days) with 2 operators
  - One day of operation in 24/24 mode
- Total power can be upgraded to ~50 kW with a beam rastering system on the whole target.

Key features of the design

- Power density 0.5 kW/cm² ;
- Operation at T_{surf} ~ 500°C to minimize blistering
- Assembly of 15 sub-targets which can be easily removed and changed
  - The Cu cooling system is separated from the targets
    ➔ safe operation whatever happens to the target
  - Target at an angle of 20 degs wrt to the beam direction
  - Surface ~ 10x25 cm2
  - The Beryllium blocks are rather inexpensive (~5k€ per set)
  - Different materials can be used (Be, Ta, Al, V…)

To be mentionned

- The target handling operation was demonstrated after the 107 hours run. The central sub-targets were swapped for new ones.
- No Beryllium detected in the accelerator beam line
- Blistering of surface target due to proton implantation stabilized after a few hours

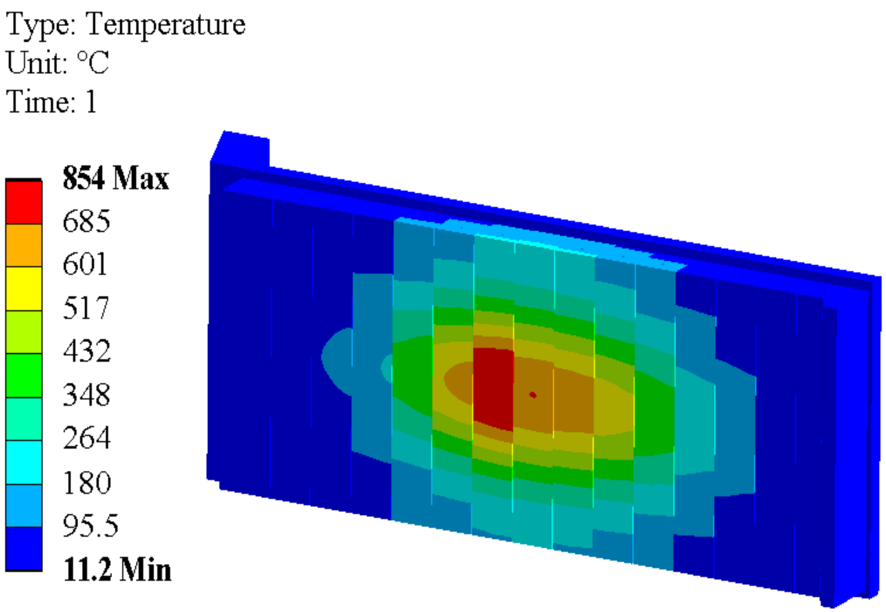


50kW Be Target installed at the end of the IPHI accelerator.

Progress Status :
Focus on the Be Target

New high power Beryllium target tested on IPHI (2022)

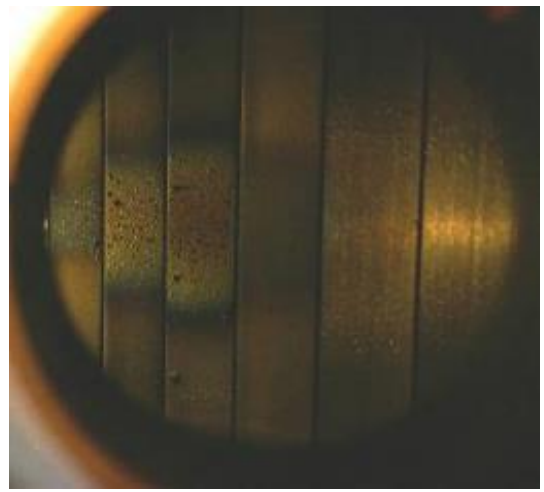
Calculated temps at the surface of the Be target (30 kW operation)



The degradation of Be sub-targets by the proton beam stabilized itself after a few hours of operations.

View of the surface of the target elements after the tests

Be target tested at more than 25 kW (~0,4 kW/cm^2) during 107 hours without important damages



Progress Status :
Focus on the Be Target

New high power Beryllium target tested on IPHI (2022)

Neutron flux measured through Au foil activation (preliminary)

Measurement:

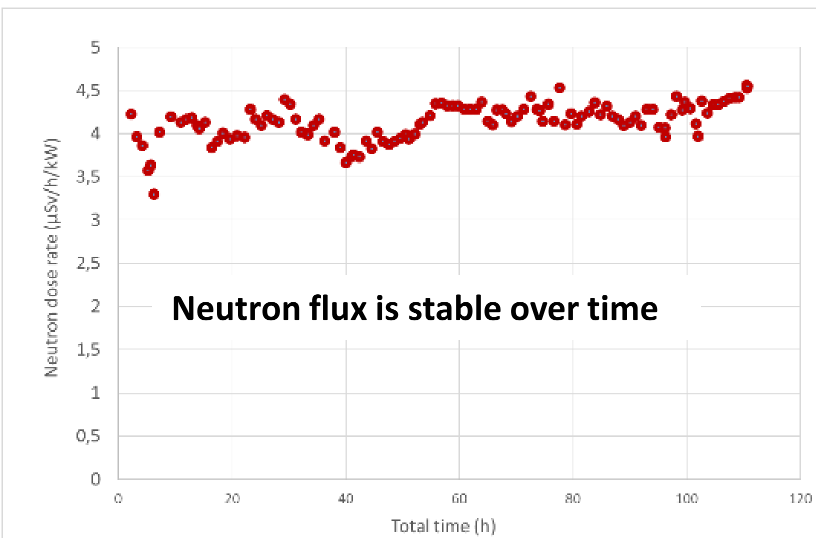
(1.85 ± 0.21) 10^4 n/cm²/s/kW

Uncertainty = neutron spectrum, power on target

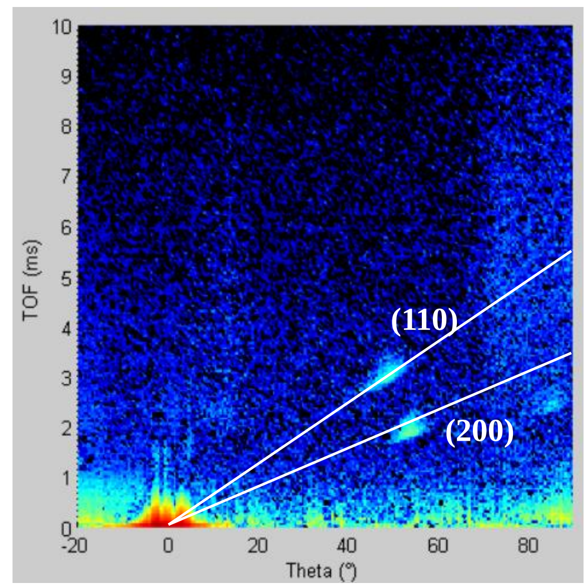
Simulation (Geant 4):

(2.16 ± 0.39) 10^4 n/cm²/s/kW

Uncertainty = statistics, geometry…



First neutron scattering of an iron extruded rod obtained in 10 minutes with a non optimized pulse width and repetition rate

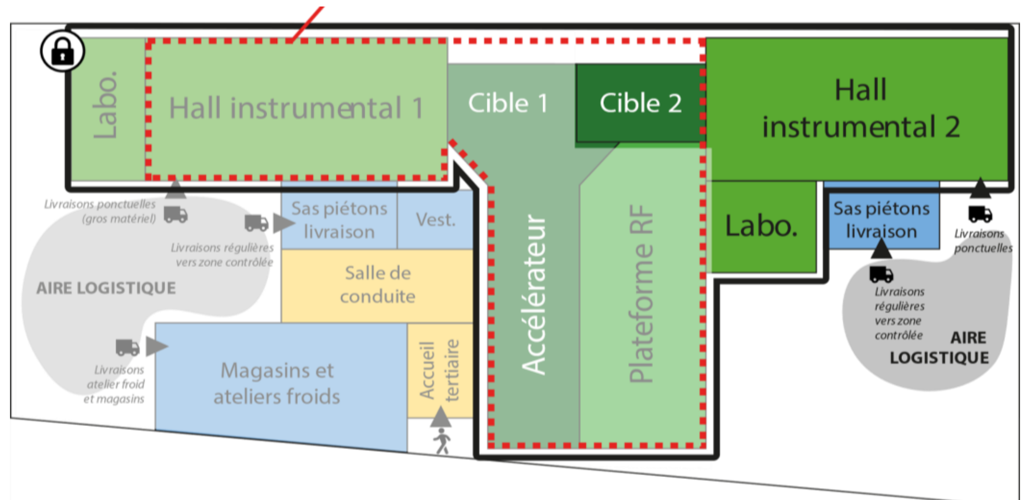


The Project:
On the road to « Sonate »

Still a long way forward

- *Instrument performance calculation : done*
- *Test of high power target : done*
- *Demonstration of target long term behavior : partly done (100 hours only)*
- Design and test of a cold moderator : started
- **Sonate -> Building and operation budgets**

A new site at the heart of University Paris-Saclay:
New building at Orme les Merisiers, Saclay
Building size : 3250 m^2
Estimated full cost : 25 M€
Time scale for construction : 5 years



Key steps for funding

- Consortium CEA/CNRS → governmental funding scheme (PEPR) by end of 2022
- We hope to be convincing enough to launch this project in 2023.

Conclusions

- Project Iphi-Neutron partly funded by “Région Ile de France” successfully finished (demonstration of neutron production with a Be target at 3 MeV and 50 kW)
- A high-power Be target has been developed and tested at 28kW and over 100 hours.
- Studies for the construction of a new building for Sonate are almost complete
- Design of a para-hydrogen cold moderator finished (Conemo project). Construction and tests are on the way.
- Collaboration with JCNS (Jülich, Germany) : transfer of the LLB-Hermes reflectometer to Big-Karl underway
- Full funding still under active work! We are looking for new funding opportunities