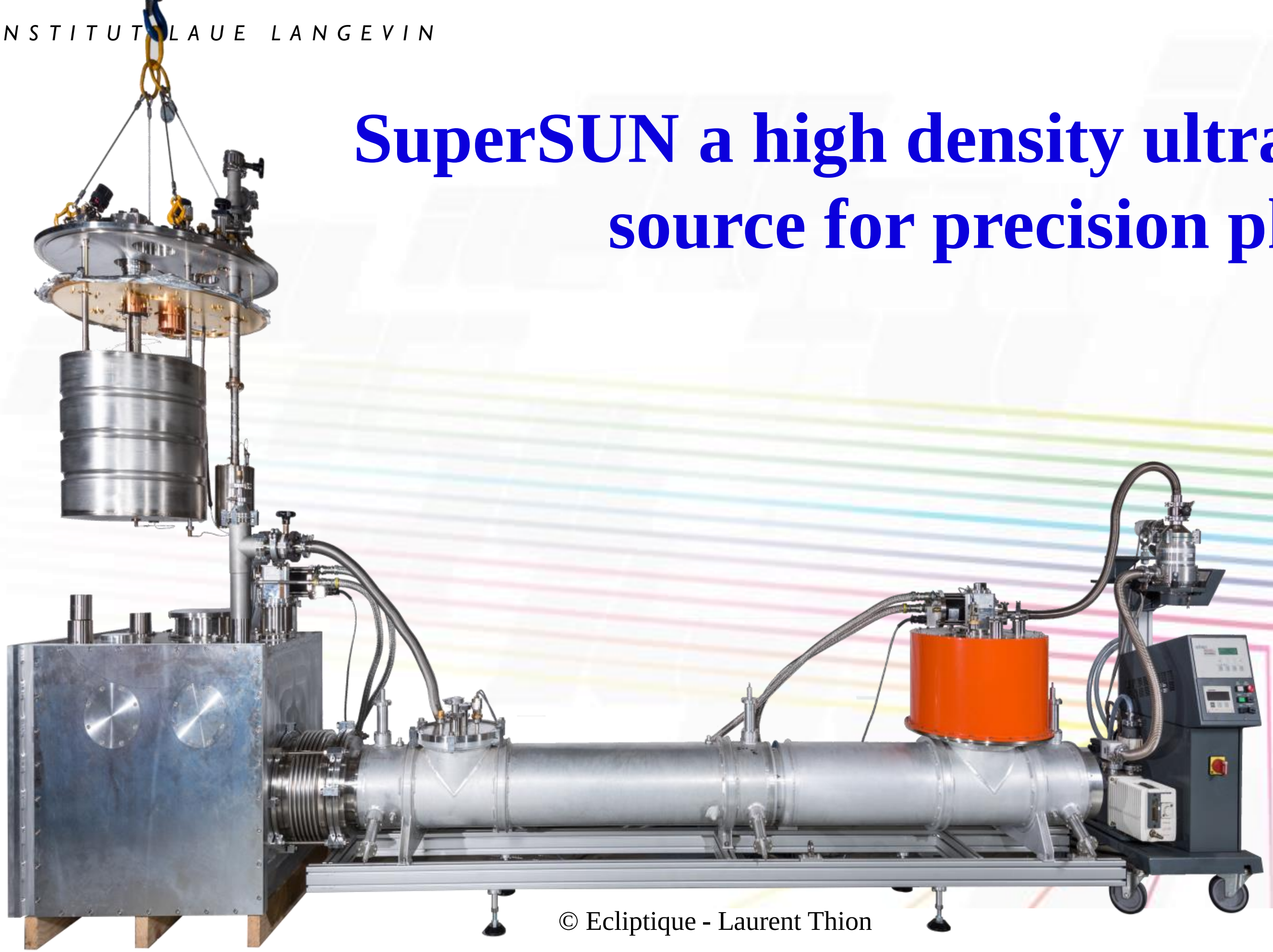
SuperSUN a high density ultra-cold neutron source for precision physics

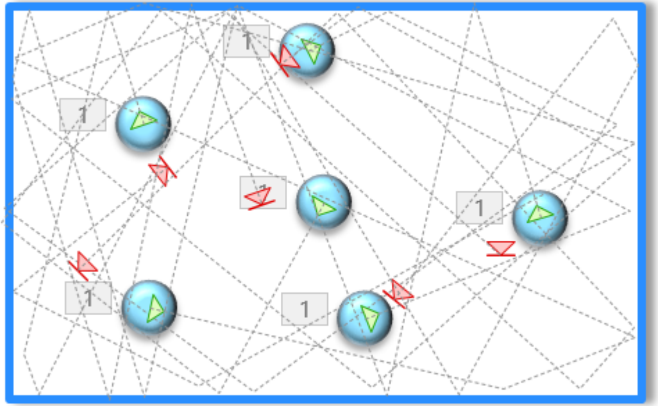


Ultra cold neutrons

Definition:

- free neutron that undergo reflection under any angle of incidence
- free neutron that can be stored in material containers

Materiaux	V_f (neV)	η (capture)
DLC	~300	$\sim 3 \times 10^{-7}$
Béryllium	250	5.4×10^{-7}
Inox 316	183	2×10^{-4}
Teflon	124	7×10^{-7}
Deutérium solide	107	4×10^{-8}
Graisse Fomblin	106	6.4×10^{-7}
Aluminium	54	3.7×10^{-5}
Superfluide 4He	18.8	0
Polyethylène	-9.2	/



Principle of an accumulation helium source

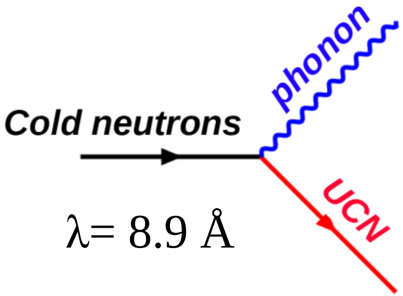
$$\rho_{UCN} = P\tau$$

P : (volumetric) production rate of UCN

τ : losses time constant

Production of UCN in superfluid ^{4}He

- Single scattering
- Non thermal equilibrium
- Resonance cross-section
- Vanishing loss cross-section



λ= 8.9 Å

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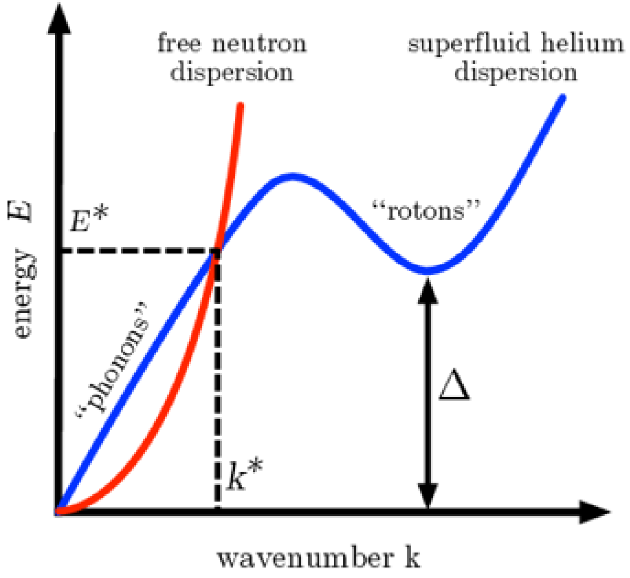

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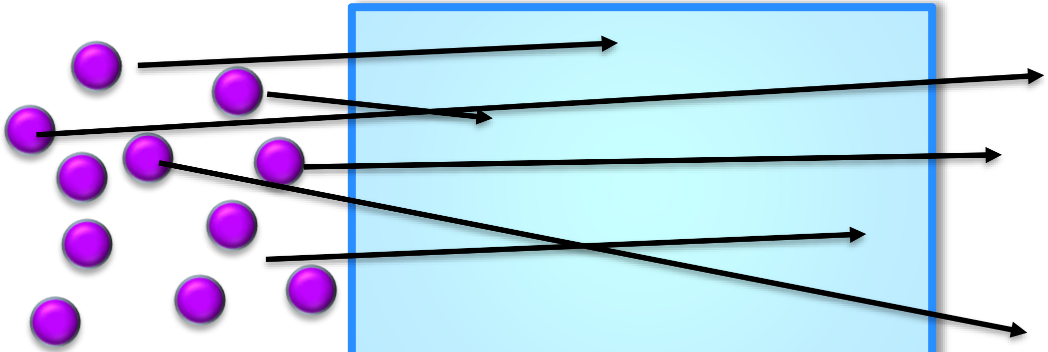

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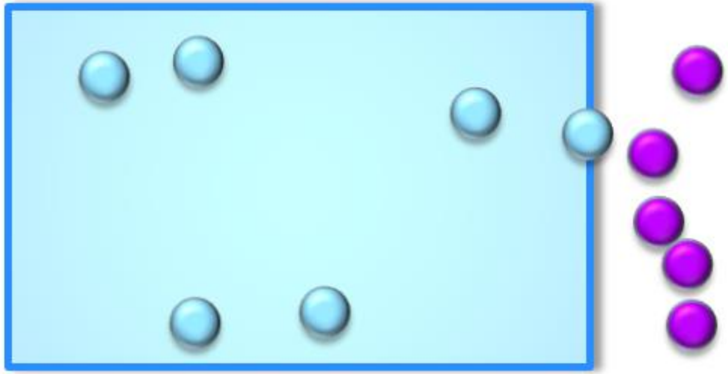
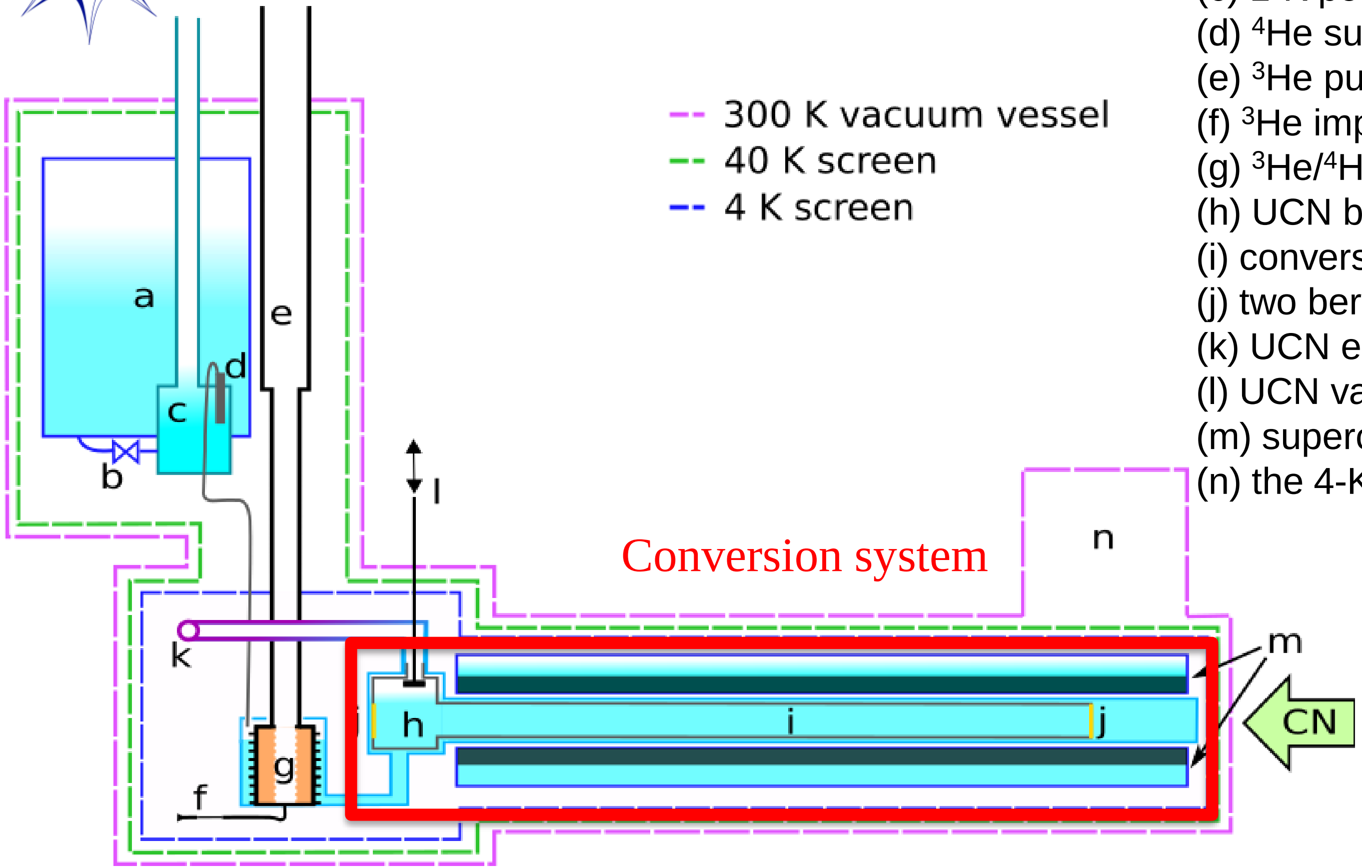
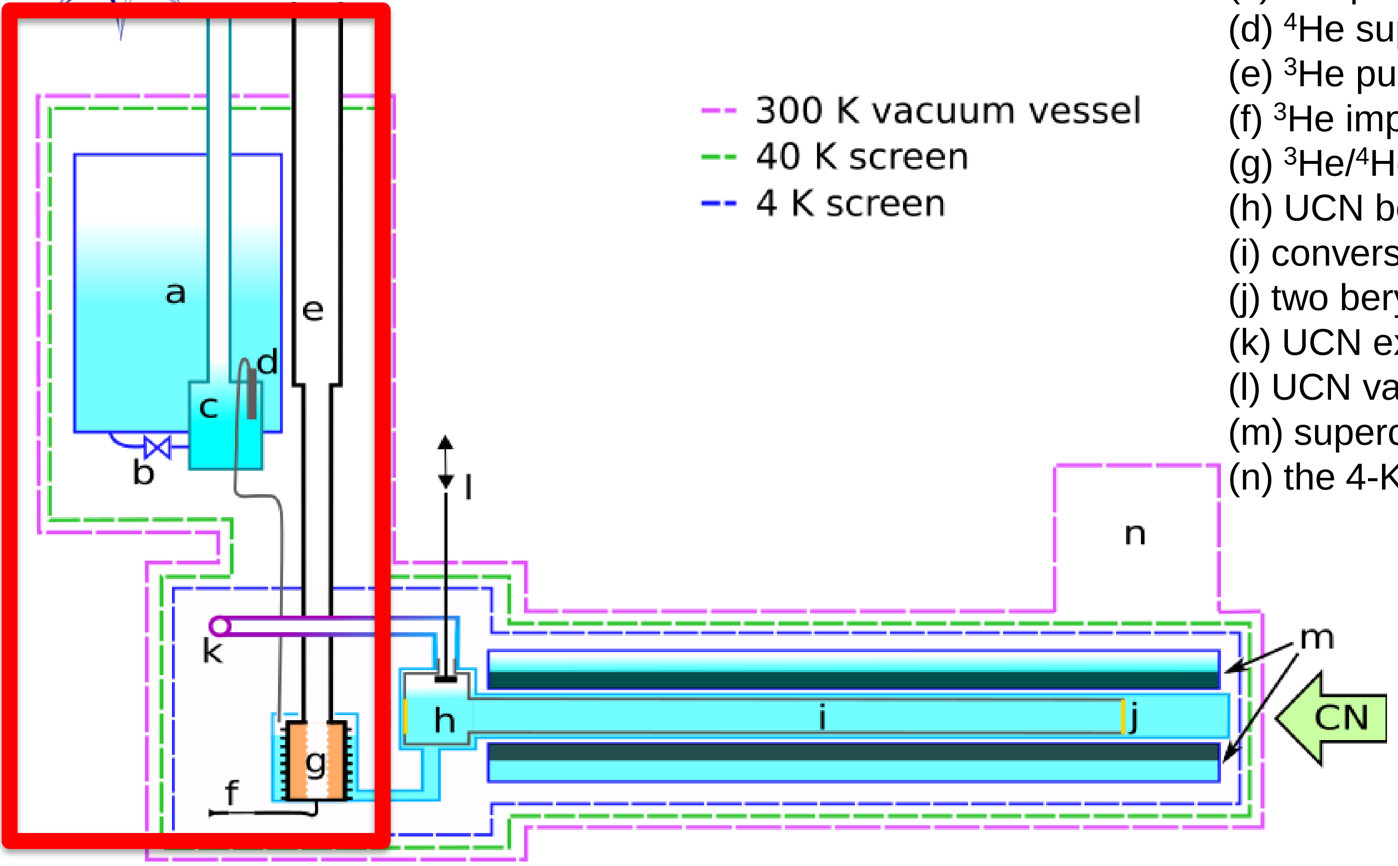




(a) 100-L liquid helium bath,
(b) needle valve,
(c) 1-K pot,
(d) ^{4}He superleak,
(e) ^{3}He pumping column,
(f) ^{3}He impedance,
(g) ^{3}He/^{4}He heat exchanger
(h) UCN box,
(i) conversion volume at 0.6 K,
(j) two beryllium windows,
(k) UCN extraction system,
(l) UCN valve,
(m) superconducting magnet for phase II
(n) the 4-K cryostat

E. Chanel et al. JNR, pre-press, pp. 1-11, 2022

Cryogenic system



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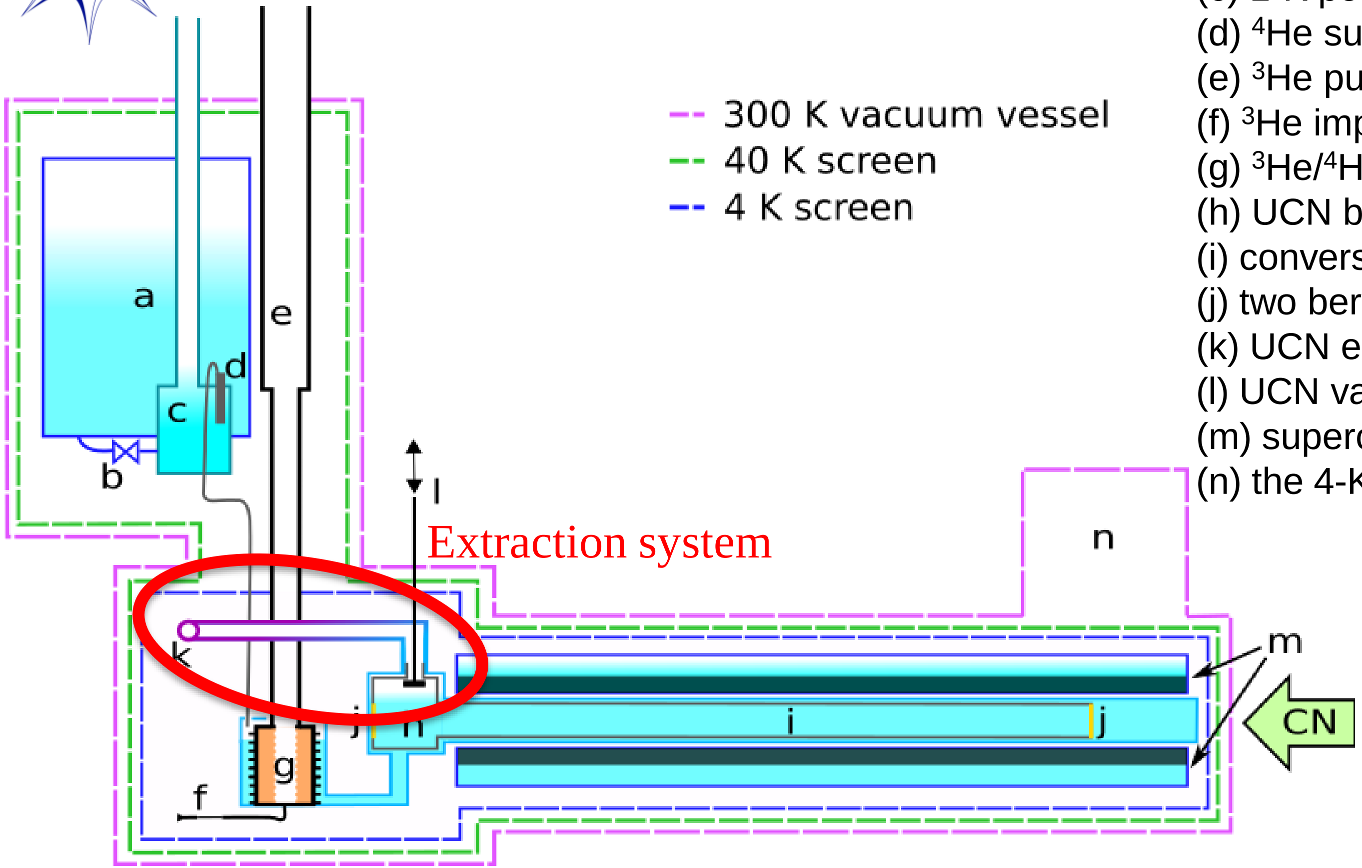

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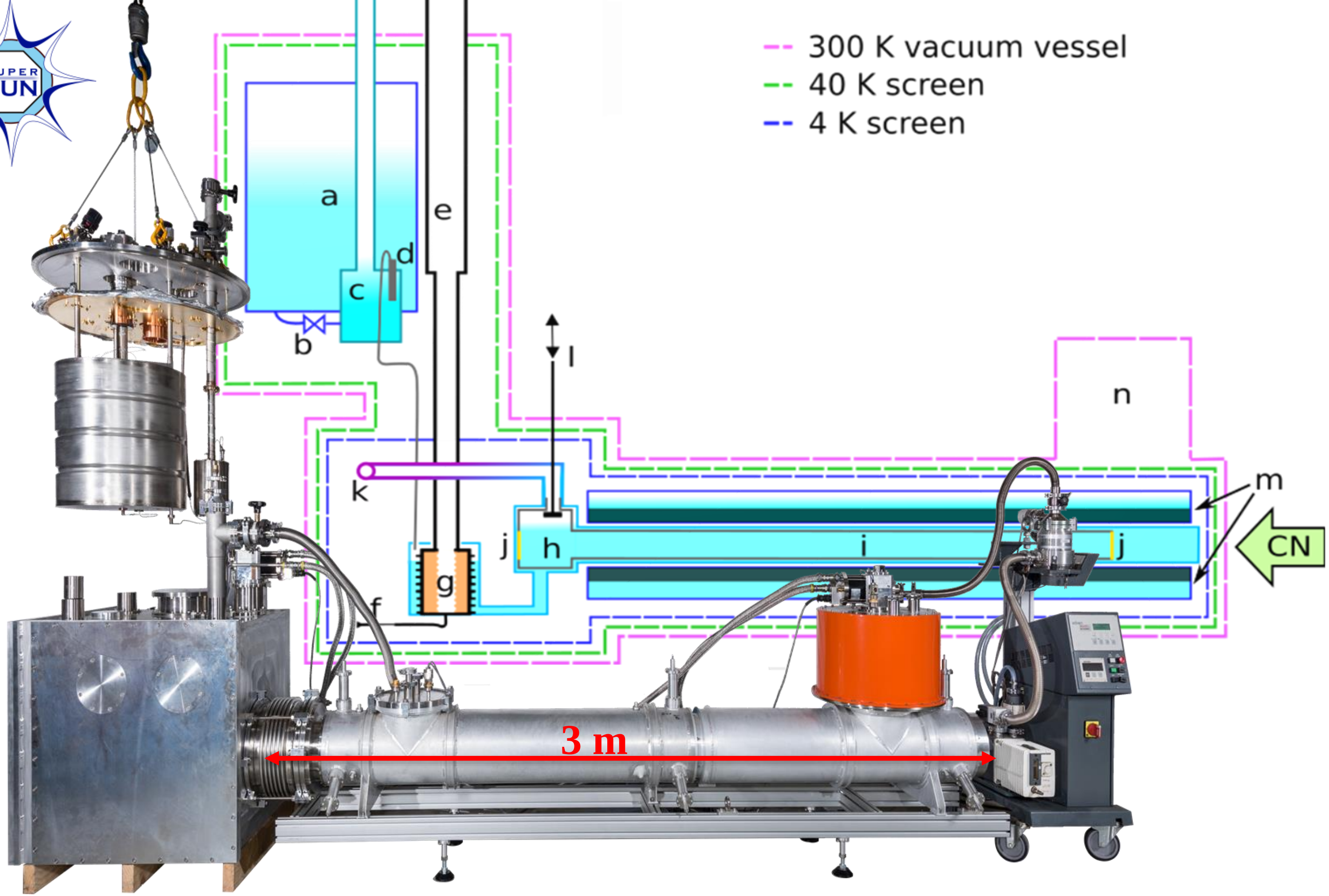


NEUTRONS FOR SOCIETY

Optimisation of SuperSUN

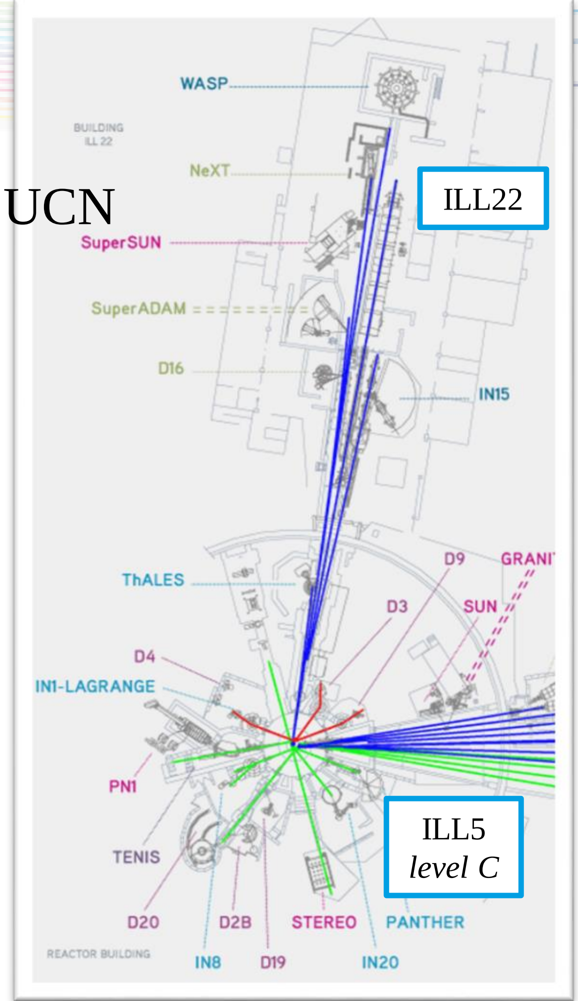
$$\rho_{UCN} = P\tau$$

P : (volumetric) production rate of UCN

τ : losses time constant

Optimizing the production UCNs

- Direct primary cold neutron beam
- Transition from rectangular to cylindrical
- Guiding cold neutrons inside conversion volume



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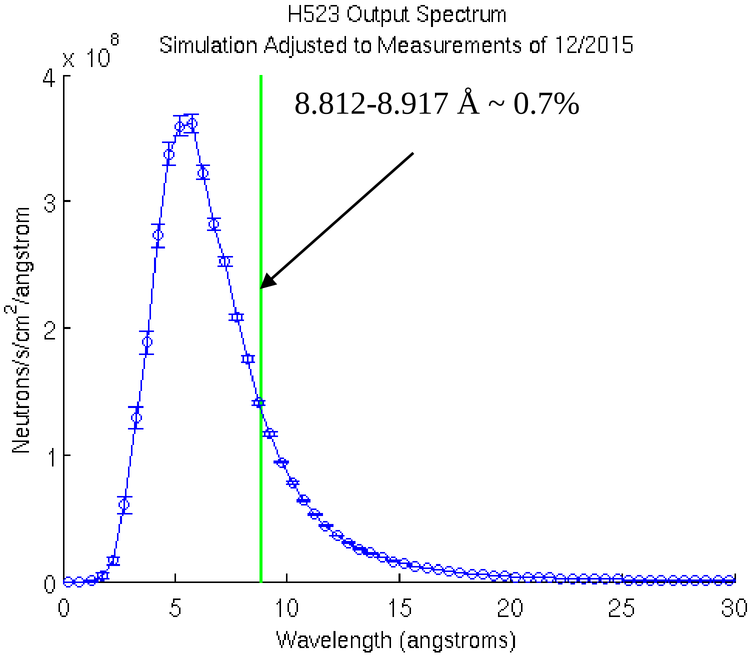
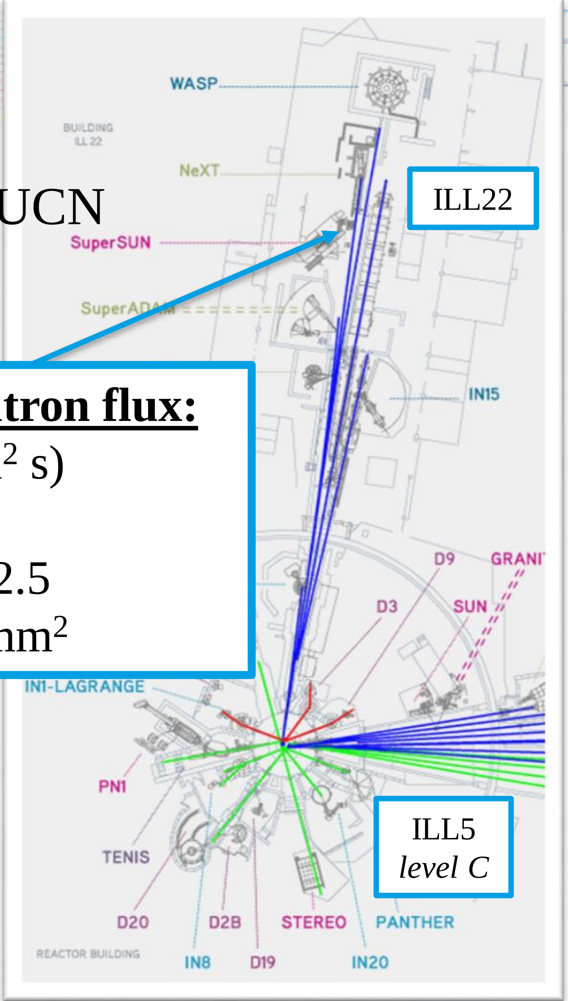


Incident cold neutron flux:

$\Phi \sim 2\times10^{10}$ n/(cm² s)

Guides

- m=1.2 and m=2.5
- XS: 60 × 120 mm²



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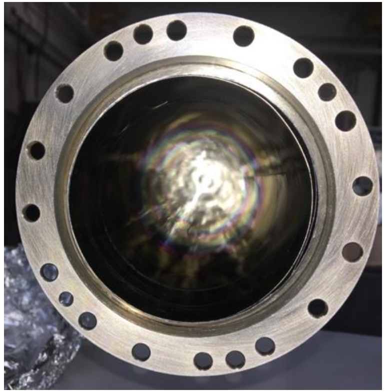
Optimizing the production UCNs

S-DH



S. Degenkolb, M. Kreuz, O. Zimmer, JNR 20(4) 117-122, 2018

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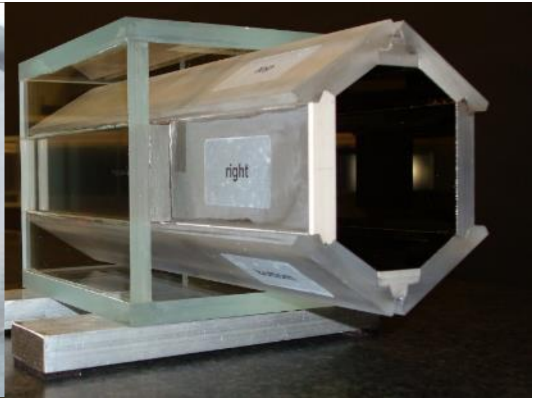

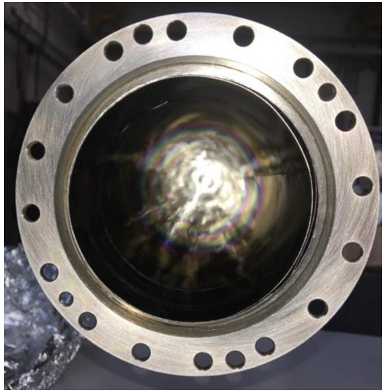

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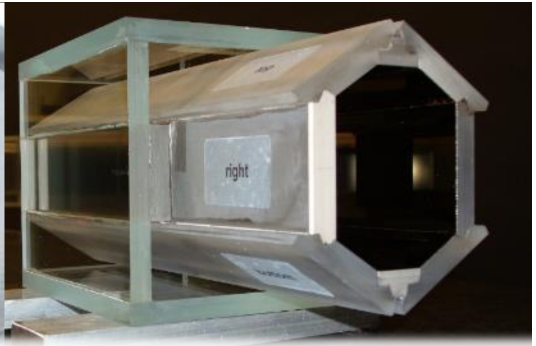

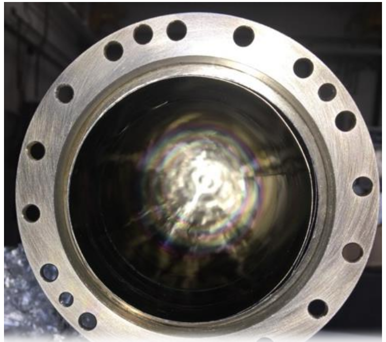

85% of the 8.9 Å can be delivered to SuperSUN

S. Degenkolb, M. Kreuz, O. Zimmer, JNR 20(4) 117-122, 2018

NEUTRONS FOR SOCIETY

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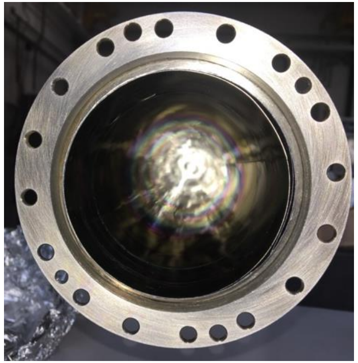

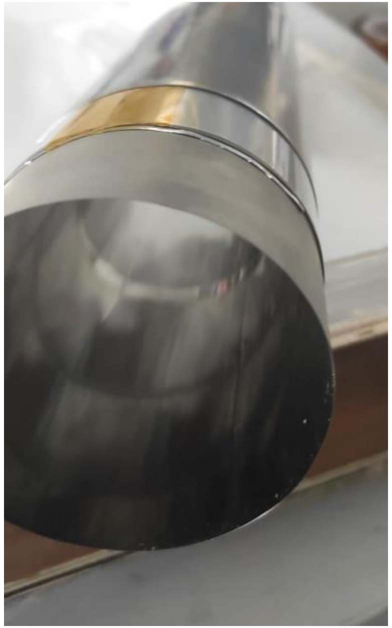

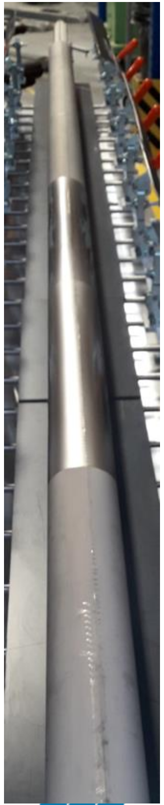

NEUTRONS FOR SOCIETY

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$$\rho_{UCN} = P\tau$$

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τ : losses time constant

Optimizing the losses time constant

$$\tau^{-1} = \tau^{-1}_{abs\ ^3He} + \tau^{-1}_{up} + \tau^{-1}_{wall} + \tau_{\beta}^{-1} + \cdots$$

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- $\tau^{-1}_{abs\ ^3He}$: use ultra-pure ^{4}He, for which σ_a=0 barn

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- τ^{-1}_{up} : at 0.6 K, $\tau^{-1}_{up} \approx \frac{(T[K])^7}{100\ [s]}$ = (3600 s)$^{-1} \ll \tau_{\beta}^{-1}$

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- τ^{-1}_{wall} : long storage time material (Cytop) and magnetic trap (Octupole)

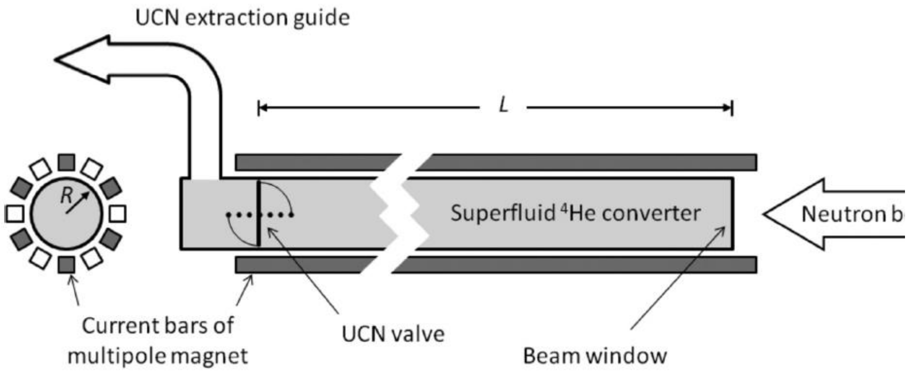
T. Neulinger, *et al. Eur. Phys. J. A* **58**, 141 (2022)

SuperSUN phase II

$\rho_{UCN} = P\tau$

P : (volumetric) production rate of UCN

τ : losses time constant



Storage:

2.1T gradient field

Adiabaticity:

50 mT field

PHYSICAL REVIEW C 92, 015501 (2015)

SuperSUN phase II

$$\rho_{UCN} = P\tau$$

P : (volumetric) production rate of UCN

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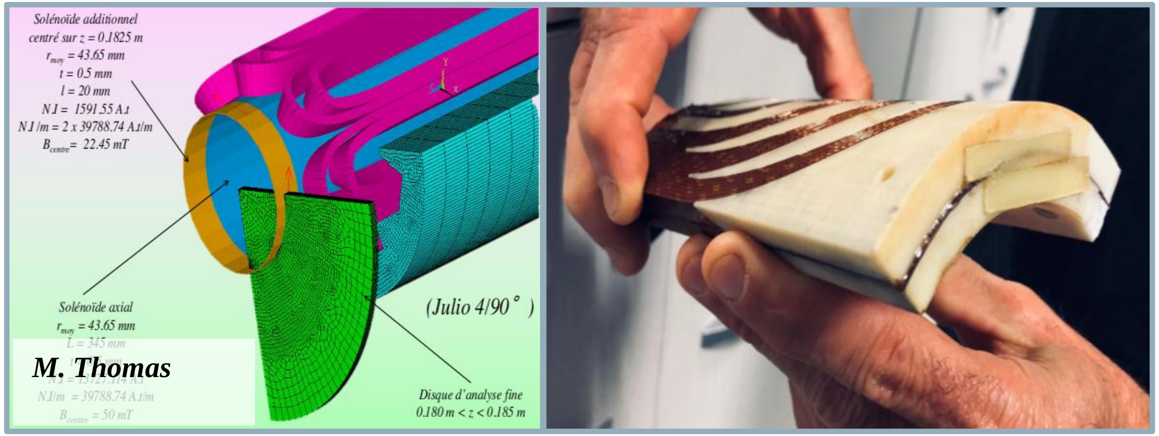

Storage:

2.1T gradient field

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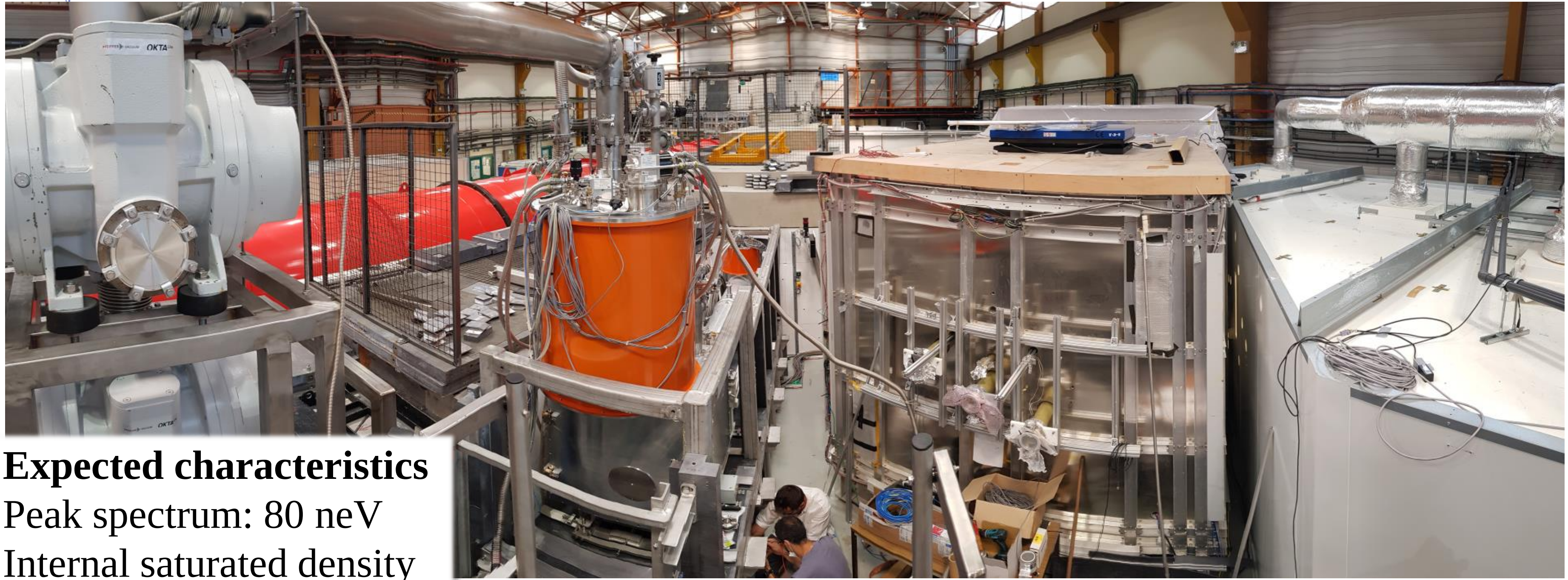
ELYTT ENERGY

PHYSICAL REVIEW C 92, 015501 (2015)

PanEDM: a neutron EDM experiment



Expected characteristics
Peak spectrum: 80 neV
Internal saturated density extrapolated from SUN2: 330 UCN/cm^3

SuperSUN

PanEDM MSR

PanEDM clean room

Neutron electric dipole moment

$$H = -\mu_n \vec{\sigma}\cdot\vec{B} - d_n \vec{\sigma}\cdot\vec{E}$$

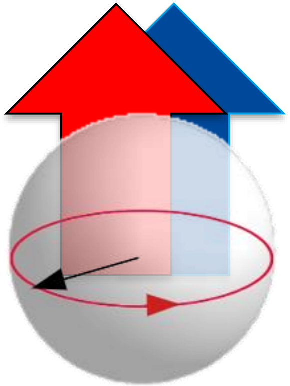
CP violation

Probing BSM and strong sector of SM

Measure the precession frequency in a known electric and magnetic field

Sensitivity equation

$$S_{d_n} = \frac{\hbar}{2\ \alpha T\ E\ \sqrt{N}}$$



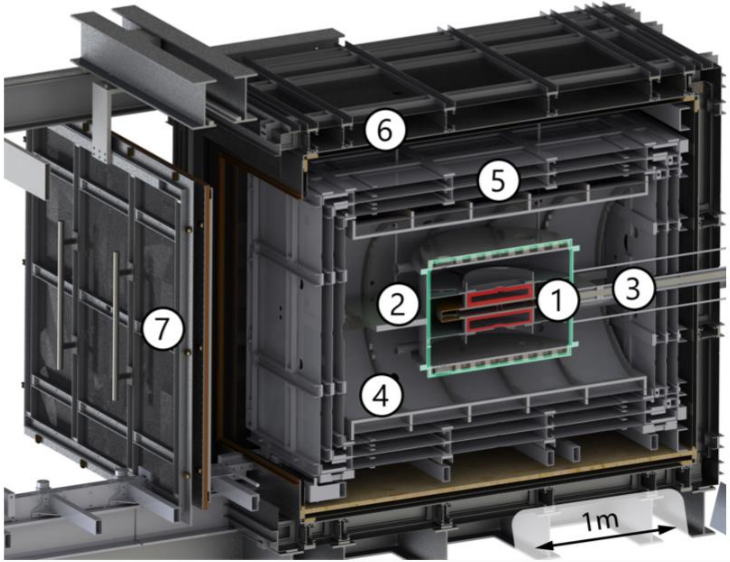
H:	Hamiltonian
μ_n:	magnetic dipole moment
B:	magnetic field
d_n:	electric dipole moment
E:	electric field
σ:	neutron spin

S_{d_n}:	statistical sensitivity
T:	interaction time
$\hbar$:	reduced Plank constant
α:	visibility
N:	number of UCN counted

PanEDM: a neutron EDM experiment

PanEDM Magnetic and RF Shielding

1: UCN cells
2: vacuum chamber
3: HV insertion
4: cylindrical shield
5: inner shields (3)
6: outer MSR (2+1)
7: MSR door



Statistical sensitivity:

SuperSUN	Phase I
Saturated source density [cm^{-3}]	330
Diluted density [cm^{-3}]	63
Density in cells [cm^{-3}]	3.9
PanEDM Sensitivity [1σ, e cm]	
Per run	5.5×10^{-25}
Per day	3.8×10^{-26}
Per 100 days	3.8×10^{-27}

extraction losses…

More details, including phase II:

EPJ Web of Conferences **219**, 02006 (2019)
https://doi.org/10.1051/epjconf/201921902006

Extrapolated from saturated density of SUN2

ACKNOWLEDGEMENTS

All what will be shown would not have been possible without huge engagement of people:

THANK YOU!!!

SuperSUN: E. Chanel, S. Baudoin, M.H. Baurand, N. Belkhier, E. Bourgeat-Lami, S. Degenkolb, M. van der Grinten ,M. Jentschel, V. Joyet, M. Kreuz, E. Lelièvre-Berna, J. Lucas, A. Quirk, M. Thomas, X. Tonon, O. Zimmer,…

PanEDM: D. Beck, T. Chupp, R. Combe-Colas, S. Degenkolb, P. Fierlinger, H. Filter, L. Hopf, F. Kuchler, V. Popescu, M. Rosner, P. Rößner, M. van der Grinten, M. Wojke, D. Wurm …

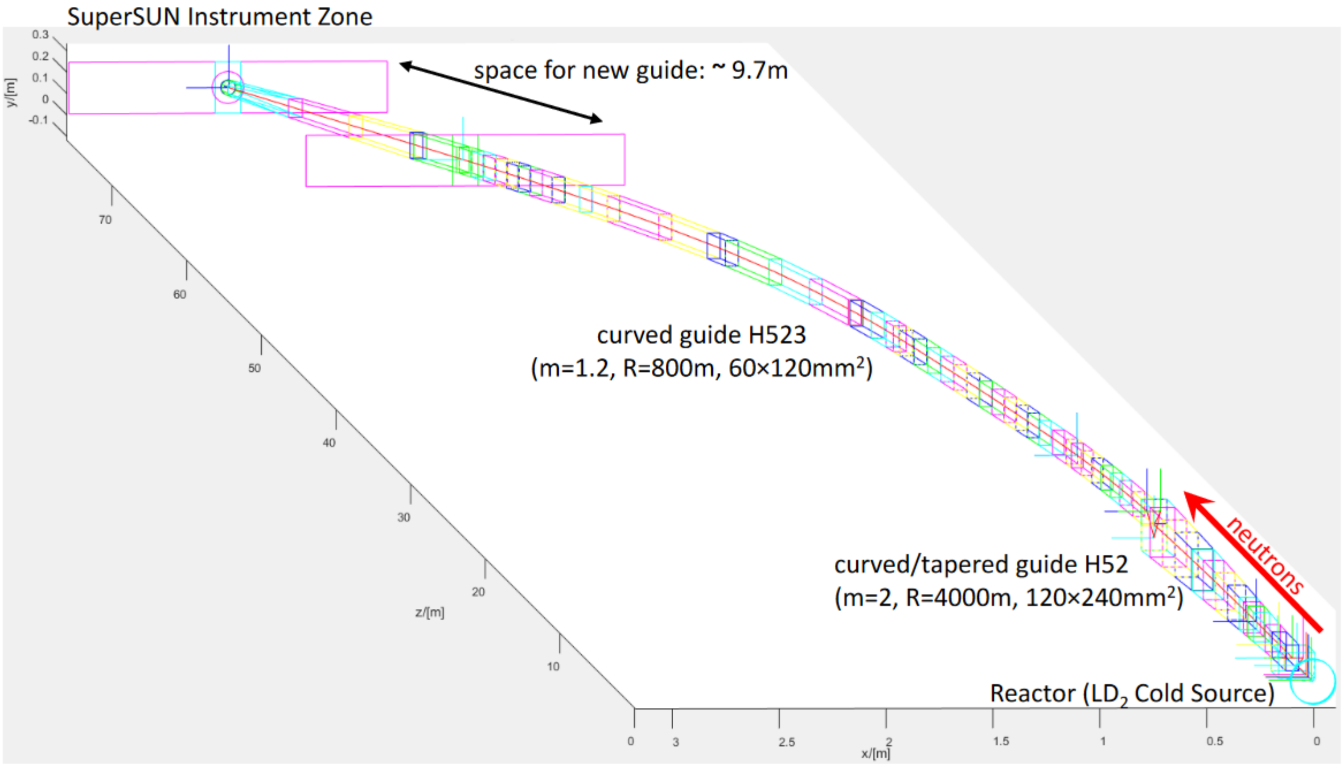
Support: D. Berruyier, J. Bonnevaux, P. Cogo, R. Gandelli, Y. Gibert, M. Kreuz, P. Lachaume, T. Mazili, C. Monon, C. Mounier , A. Robert, M. Thomas…

…and many, many others.

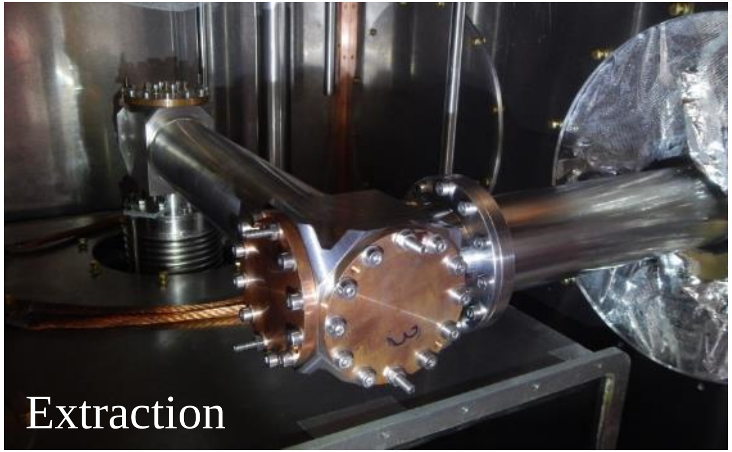
NEUTRONS FOR SOCIETY

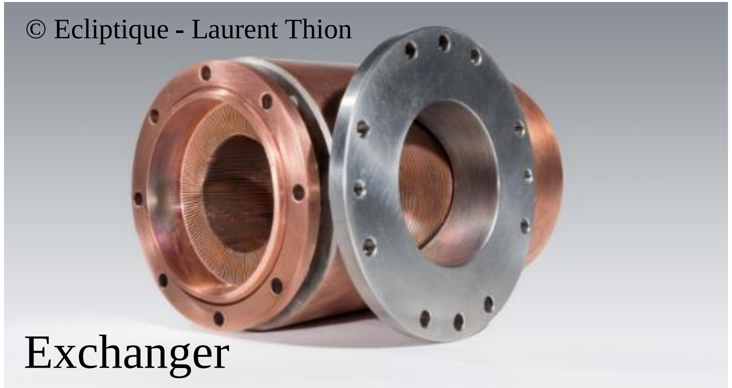
I N S T I T U T L A U E L A N G E V I N

H523 (as simulated using McStas)



Work and slide by S. Degenkolb

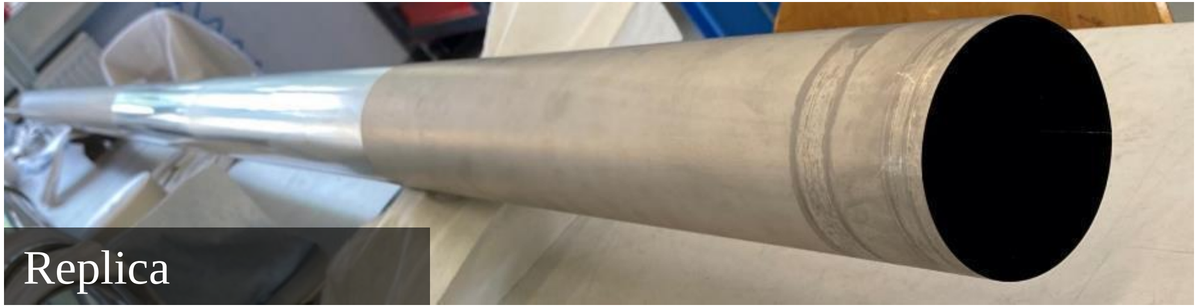

Extraction


© Ecliptique - Laurent Thion
Exchanger

Components


4K cryostat


Octagonal guide

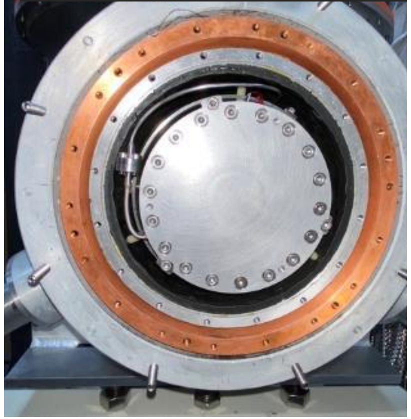

Replica


Convertor volume

More components

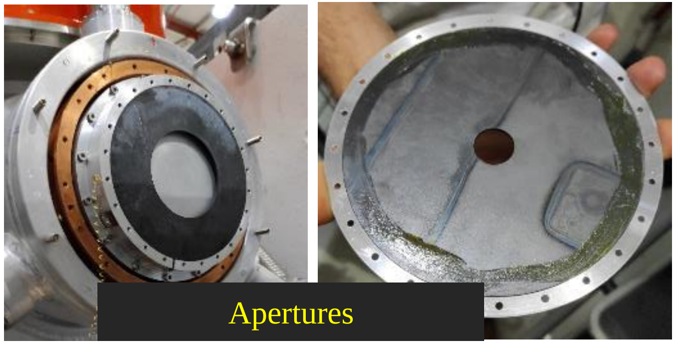
Octogone supermirror neutron guide

Conversion volume entry

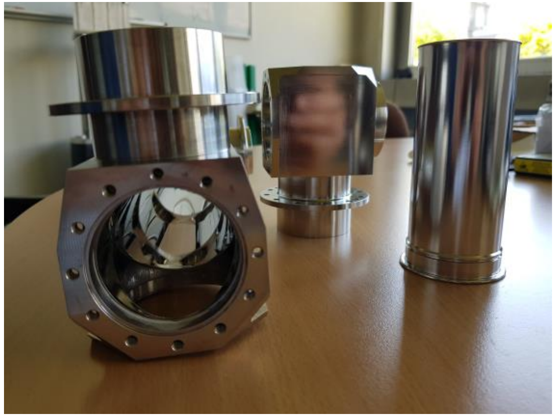


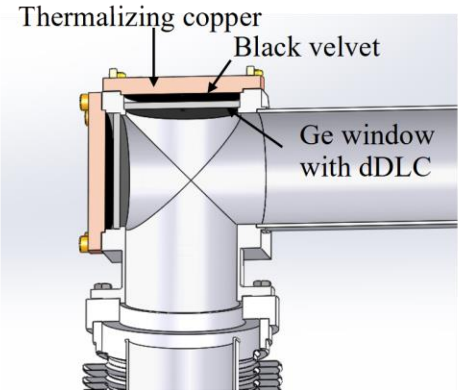

Beam stop

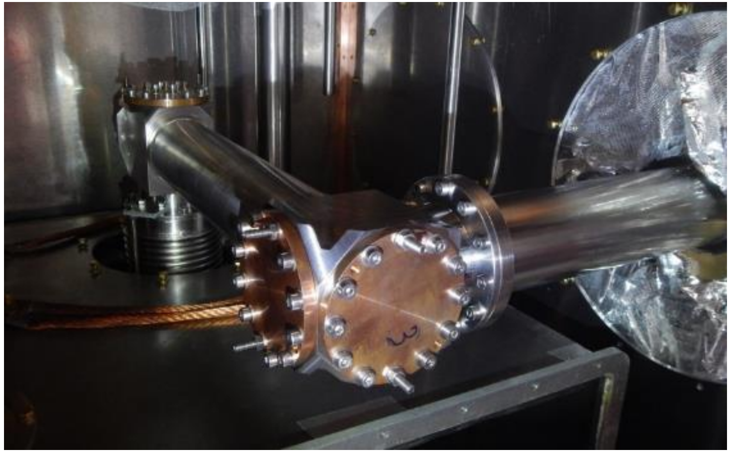

Beryllium window


Apertures

UCN extraction







Slide adapted from M. Jentschel

Publication Cytop

Eur. Phys. J. A (2022) 58:141
https://doi.org/10.1140/epja/s10050-022-00791-x

THE EUROPEAN PHYSICAL JOURNAL A

Special Article - New Tools and Techniques

Ultracold neutron storage in a bottle coated with the fluoropolymer CYTOP

Thomas Neulinger[1,2,a], Douglas Beck[2], Euan Connolly[1,3], Skyler Degenkolb[1,4], Peter Fierlinger[5], Hanno Filter[1,5], Jürgen Hingerl[1,5], Pontus Nordin[1], Thomas Saerbeck[1], Oliver Zimmer[1]

[1] Institut Laue-Langevin, Grenoble 38042, France
[2] University of Illinois Urbana-Champaign, Urbana, IL 61801, USA
[3] University of Bristol, Bristol BS8 1TL, UK
[4] Universität Heidelberg, Heidelberg 69120, Germany
[5] Technische Universität München, Garching 80805, Germany

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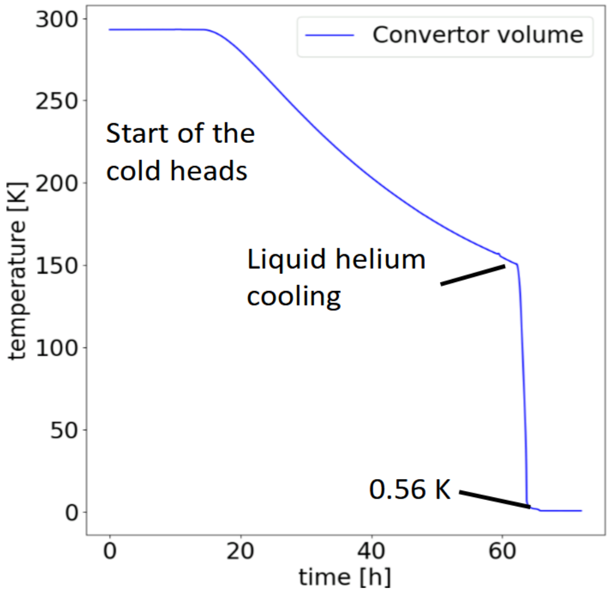
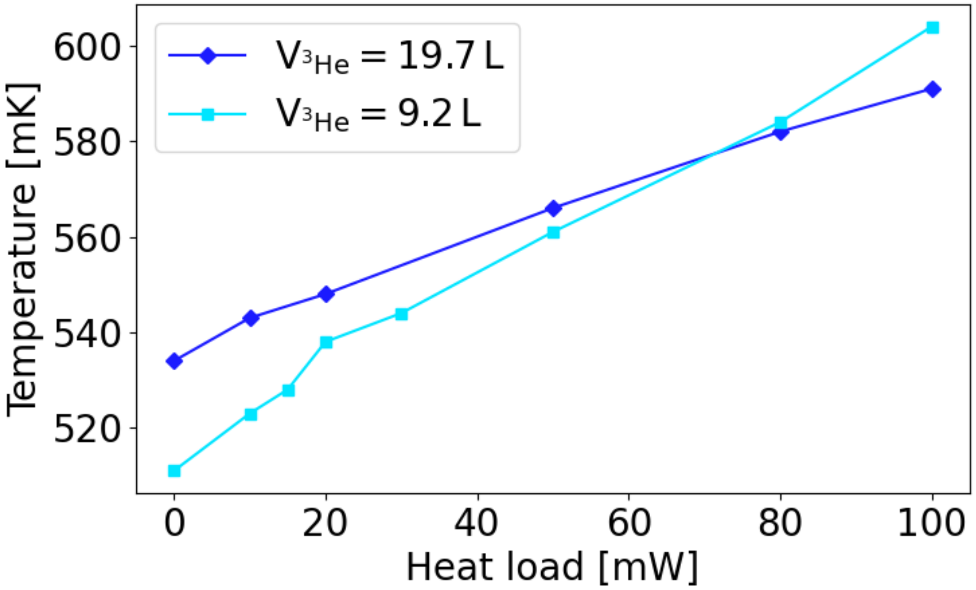
Communicated by Alexandre Obertelli

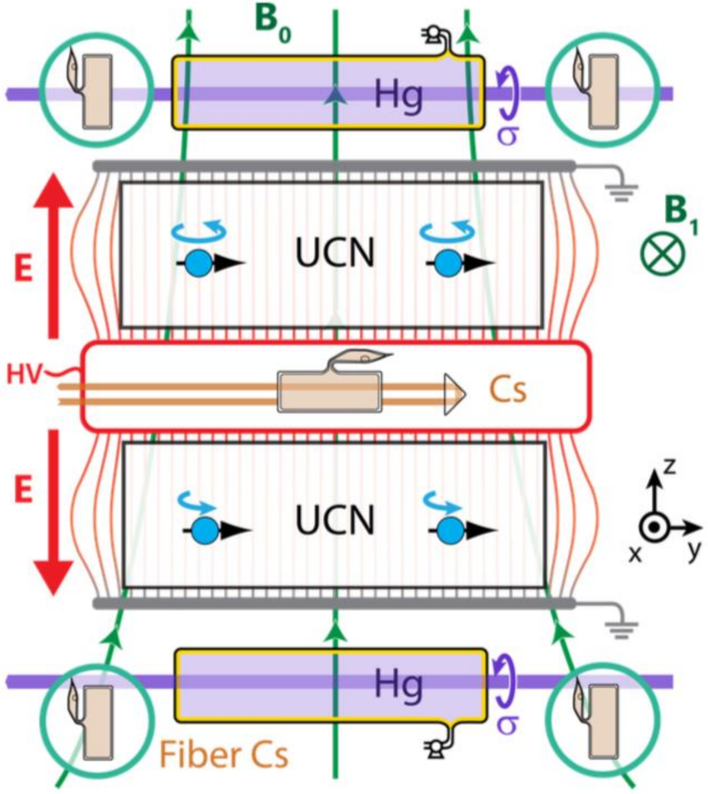
Abstract The fluoropolymer CYTOP was investigated in order to evaluate its suitability as a coating material for ultracold neutron (UCN) storage vessels. Using neutron reflectometry on CYTOP-coated silicon wafers, its neutron optical potential was measured to be 115.2(2) neV. UCN storage measurements were carried out in a 3.8 l CYTOP-coated aluminum bottle, in which the storage time constant was found to increase from 311(9) s at room temperature to 564(7) s slightly above 10 K. By combining experimental storage data with simulations of the UCN source, the neutron loss factor of CYTOP is estimated to decrease from $1.1(1)\times10^{-4}$ to $2.7(2)\times10^{-5}$ at these temperatures, respectively. These results are of particular importance to the next-generation superthermal UCN source SuperSUN, currently under construction at the Institut Laue-Langevin, for which CYTOP is a possible top-surface coating in the UCN production volume.

SuperSUN cryogenic test





PanEDM phase I



High voltages	
field	20 kV/cm
Magnetic field	
shielding factor at 1 mHz	6×10^6
magnetometers resolution	few-fT
$\lvert B_0 \rvert$	1.3 μT
Statistics	
polarization	0.8
double chambers with	3.9 UCN/cm^3
free precession time	250 s
Expected sensitivity (100 days)	3.8×10^{-27}

EPJ Web of Conferences **219**, 02006 (2019)
https://doi.org/10.1051/epjconf/201921902006